大型シミュレーション研究

外部評価報告書

２００３年２月
高エネルギー加速器研究機構
大型シミュレーション研究外部評価委員会

Picture 1. Fujitsu VPP500/80 system(～Dec. 1999)

Picture 2.Hitachi SR8000 system (jan. 2000～)

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for the KEK Large Scale Simulation Program

About the Review Committee

In order to support large scale simulations in high energy physics and related fields in Japan, the High Energy Accelerator Research Organization (KEK) started the "Large Scale Simulation Program" in April 1996. Under the program, KEK calls for proposals of projects to be performed employing the supercomputer at KEK. The proposals are reviewed by the Program Advisory Committee, which decides approval and computer time allocation. Since 1996, 77 projects have been accepted in total, and many results have been reported by the research groups. To review these achievements and identify possible problems, and to gain insight into possible future directions of the program, the Director General of KEK asked the Committee to review the Large Scale Simulation Program for the period starting in April 1996 and ending in March 2002.

The charge to the Committee covers the following items:

- To review the scientific research activities performed under the program.
- To review the effectiveness of the program.
- To review whether the computing resources and support available for the program were appropriate.

For each of the items, recommendations for future directions are also appreciated.

The members of the Committee are

Paul B. Mackenzie	*Fermi National Accelerator Laboratory, USA*
Toshihide Maskawa	*Yukawa Institute for Theoretical Physics, Kyoto University*
Denis Perret-Gallix	*French National Center for Scientific Research (CNRS), France*
Ichiro Sanda (Chairman)	*Nagoya University*
Toshikazu Takada	*Fundamental Research Laboratories, NEC Corporation*
Akira Ukawa	*Center for Computational Physics, University of Tsukuba*
Koichi Yazaki	*Tokyo Woman's Christian University*

The Committee met on December 12 and 13, 2002 at the Computing Research Center at KEK.

1 Purpose of the Large Scale Simulation Program

KEK (High Energy Accelerator Research Organization) is a research institution for carrying out accelerator-related scientific studies. The major task of KEK is particle and nuclear physics research. For this purpose, KEK has maintained and operated accelerators and detectors for high energy physics experiments. KEK has also maintained the computational capacity required for particle and nuclear physics research. The supercomputer system is an integral part of this system.

The usage of the supercomputer system is governed by the Large Scale Simulation Program. It calls for collaborative research proposals in high energy physics and related areas using the supercomputer of KEK. Applications can be made by researchers at all universities as well as those of governmental research organizations in Japan, or by those that the Director-General of KEK considers appropriate.

It is the opinion of the Review Committee (Committee for short below) that computational research is an indispensable component of particle physics research and an integral part of the KEK research program in a number of ways. The simulation of the Standard Model, and in particular of the QCD non-perturbative sector, is an indispensable major part of the entire B physics program to extract meaningful physical quantities from experimental results at the B Factory. Computational research is also crucial in nuclear physics and in related fields such as astrophysics and others.

The Committee understands that the computational resources necessary to carry out leading edge research in these fields are very high. Since it is extremely difficult for individual research groups to develop the required computing environment, the entire physics community appreciates the KEK effort.

2 Scientific achievements

Modern large scale computing has enabled unprecedented advances in many areas of physics. The KEK Large Scale Simulation Program has enabled significant advances in several of these areas. The Committee heard from seven groups currently working under the program. The great diversity in the physics enabled by large scale supercomputing is well represented by these groups. For example, computers have enabled the well established techniques of perturbative quantum field theory to be pushed to new heights. The scminami group has developed a method for the automatic computer generation of Feynman amplitudes that is widely used at LEP and in particle searches for future colliders. Very different calculational techniques have been used to make advances in nuclear physics. The scnucl/scsokaku group has used the KEK supercomputer to understand areas relevant to strangeness nuclear physics and possible heavy ion experiments at J-PARC.

In nonperturbative quantum field theory especially, large scale numerical simulations have made possible the solution of previously intractable strongly coupled theories. In addition to being a significant intellectual achievement, this has an urgent practical importance to the experimental programs of KEK and the world. Tens of billions of yen are being spent at KEK and around the world on B physics experiments that cannot be completely analyzed theoretically without calculations from QCD, a strongly coupled field theory that cannot be solved without large scale simulation. These experiments are required, for example, to determine the elements of the Cabibbo-Kobayashi-Maskawa matrix. These fundamental parameters of the Standard Model are essential clues to further understanding of beyond the standard model physics, and are central targets of current particle physics experiments. The Large Scale Simulation Program has enabled the scqcd group to be world leaders in these calculations. Even larger computations are still required to complete calculations required by experiments at KEK and around the world, so there is a need for continued leadership in this field.

2.1 Study of lattice QCD with large scale numerical simulation (scqcd group)

With the VPP-500 computer, this group has computed B_K, $m_{u,d}$, f_π, proton decay matrix elements, f_B, B_B, and $a_{\pi\pi}$ using the quenched approximation. These calculations involved controlling the chiral behavior. For B_K this required solving the operator mixing problem, using chiral Ward identities. Their result on B_K has been used as a standard value by the Particle Data Group, which indicates that the number is widely used by the high energy physics community. The Committee notes that the B physics computations are essential to the completion of the analysis of the Belle experiments.

As the SR8000 computer became available in 2000, they started unquenched calculations including dynamical up and down quarks. Their results on f_B, B_B and the SU(3) symmetry breaking ratio $(f_{B_s}\sqrt{B_{B_s}})/(f_B\sqrt{B_B})$ are leading the worldwide competition, and show that the quenched approximation introduces significant error of about 10%. They have stated that all above computations should be repeated with a dynamical strange quark. It is noted that 90% of all the available time from the Supercomputer System has been used by this collaboration. The Committee congratulates the group for achieving these world leading results.

The Committee recognizes that these results are of vital importance, not only to the experimental program of KEK, but also to the world wide high energy physics community. Full unquenched results of the same quality (which need more computing power) are required for the completion of this calculational program. There is therefore a substantial opportunity for continued accomplishment of essential results, if sufficient computing resources are available. The Committee also heard that there will be strong competition from US and European groups within a year. It strongly urges KEK to take all necessary steps for the collaboration to stay at the top.

2.2 Monte Carlo study of the color confinement mechanism and monopoles in QCD (scknzw group)

This group attempts to prove the conjecture made by t'Hooft that monopole condensation in QCD is crucial in understanding the confinement mechanism. They have observed, using dynamical fermions, (1) Abelian and (2) monopole dominance. Among other results of interest is a pictorial description of the color flux distribution between the quark and anti-quark in a meson.

The results of this group represent considerable progress in conceptual understanding of the confinement mechanism. The group, however, has not achieved its goal of deriving useful effective theory which can be used to understand hadron dynamics at low energy.

It is noted that appreciable time allocated for the collaboration has not been used.

2.3 Automatic Feynman amplitude computation and application to HEP (scminami group)

The group has developed an automatic generator of helicity amplitudes (GRACE) for 1 or 2-body $\longrightarrow$ n-body scattering at tree level in the standard model and the minimal supersymmetric standard model. It is, actually, a generator of "event generators". This package has been extensively used at LEP. A new package is in final testing for one-loop diagrams (n=2 and some n=3). Higher loop corrections are being studied. In most cases the limitation comes from computer system performance (CPU, memory and disk size). Quadruple precision is essential for these calculations. This package will be widely used in hunting for SUSY particles at the LHC and future linear colliders.

As the effort along this direction is essential for understanding experimental data from high energy physics detectors, several groups around the globe are now developing similar packages In order to keep the leading position, it is important that this original effort continue to be supported by the appropriate computing system.

The Committee congratulates the group for achieving world leading results for many important reactions.

2.4 QCD at finite temperature and density (sctaro group)

This group studies hadron masses at finite temperature and density with anisotropic lattices. Extrapolation to the chiral limit has been examined. Pole and screening masses as functions of T have been obtained for pseudoscalar, vector, scalar, and axial-vector masses. First attempts to study hadron masses at finite density have been made and the chiral order parameter $\langle\bar{\psi}\psi\rangle$ has been calculated for finite chemical potentials.

It is noted that appreciable time recently allocated for the group has not been fully used.

The program is relevant to p-A (and possible A-A') experiments at J-PARC.

2.5 Spectral analysis of nucleon excited states in lattice QCD using the maximum entropy method (scmelqcd group)

This group studies nucleon excited states by extracting spectral functions from nucleon operator correlators using the maximum entropy method they proposed previously. A parity projection has been made to identify the $N'(1440)$ and $N^*(1535)$ in the spectral functions. Finite volume effects have been found to be important for light quark masses and the long-standing puzzle of the level ordering between the two excited states has been resolved in the infinite volume limit.

The program started recently and is not time consuming. It is important in hadron spectroscopy which is one of the subjects of J-PARC.

2.6 Nuclear structure and heavy ion reaction studies with microscopic computational approaches (scnucl/scsokaku group)

Three subjects are being pursued by this group: (1) the structure of hypernuclei, (2) the structure of stable/unstable nuclei, and (3) heavy ion collisions at intermediate energy. For subject (1), they use the Gaussian basis to study light hypernuclei and extract information on Y-N and Y-Y interactions. Λ-Σ coupling has been found to be essential for a unified description of the light hypernuclei. Subjects (2) and (3) use anti-symmetrized molecular dynamics as a microscopic approach to nuclear many-body systems. The exotic structure of neutron rich nuclei and the observed features of multi-fragmentation in heavy-ion collisions have been nicely explained.

It is noted that appreciable time has been allocated and mostly used, implying that program tuning has been well taken care of.

The subjects are frontier topics in nuclear physics and are closely related to strangeness nuclear physics and possible heavy ion experiments at J-PARC.

2.7 Numerical astrophysics (scastro)

This group consists of two subgroups: a supernova subgroup and a numerical relativity subgroup. The supernova (SN) subgroup has developed SN simulation codes (sophisticated 1-dimensional and simplified 2- and 3-dimensional codes), obtained r-process heavy element abundances in qualitative agreement with the observed ones, and reanalyzed the neutrino events from SN1987a considering the possibility of neutrino oscillation. The numerical relativity subgroup has studied coalescing binary neutron stars and resulting gravitational radiation. Four-dimensional Einstein equations and general relativistic hydrodynamical equations have been numerically solved.

Ample time has been allocated but has not been fully used. Better tuning for the supercomputer may be necessary. The program is important not only in astrophysics but also in particle and nuclear physics and is relevant to neutrino physics at J-PARC.

3 Computational resources and user environment

The supercomputer hardware was well chosen to be the most cost-effective possible at the time of its selection. It is well-suited to the main application of the computer, the large scale simulation of lattice QCD. The hardware has been used very effectively for its main purposes. It has been the most powerful computer used for lattice QCD for the last several years.

At the time of its installation in 2000, it was the ninth most powerful computer in the entire world according to the Top500 List of Supercomputers. Its position has dropped to number 53 in 2002, and will continue to drop rapidly in the coming years. An upgrade will become urgent if KEK is to maintain its top position in lattice gauge theory and other major large scale simulation programs. The six year rental period of the present contract is too long to ensure a system that stays at the forefront of the competition. It would be preferable for future rental contracts to be shorter.

Supporting hardware infrastructure is important for optimal use of the supercomputer. The planned upgrade of networking to remote sites to gigabit ethernet will improve the ability of remote users to use the supercomputer and to collaborate effectively. Increased disk storage is desirable as disks become increasingly cheap. Support for computing for which the supercomputer is not optimal may be desirable. Inexpensive PC farms may provide an effective solution for some of the computing tasks of users of the supercomputer. The effectiveness of various types of hardware for different types of computing tasks should be considered carefully in future plans for upgrading the system.

Sufficient support staff to help optimize the use of the supercomputer is essential to its effective use. It is particularly important that recently vacated staff position for lattice QCD be filled in a timely way. Workshops on the use of the supercomputer may facilitate the work of outside users.

4 On the reviewing system

The Large Scale Simulation Program Advisory Committee has been in charge of reviewing and selecting the proposals to be run on the supercomputer facility.

As stated in section 2, the Committee has been satisfied by the quality of the research conducted using the supercomputer facility. Therefore it concludes that the reviewing and program selection process has been performed smoothly.

4.1 On the selection of the projects

The Committee finds that some of the applications could have been run on more appropriate computer architectures like PC clusters. Moreover some of the requested and allocated CPU time budgets have been only partially consumed by the users, although thanks to the bi-annual reviewing system, the free time has been reallocated to other users ending up in a full use of the resources.

The Committee therefore recommends that a broader scope of CPU resources available in the computer center should be opened to the Program Advisory Committee in order to redirect applications to other facilities, if appropriate.

For large CPU time requests, the application should be first tested and validated in order to be approved. Small amounts of test time should be made available on request to users for this purpose.

4.2 On the post evaluation of the projects

The Committee understands that all research results are reviewed by the Large Scale Simulation Program Advisory Committee. It is recommended that the laboratory make this evaluation more rigorous and transparent. The Committee finds the official reports of the fiscal year from 1997 to 2001 inadequate to evaluate the research efforts. Neither the motivation nor the usefulness of the results is very clear. It is recommended that each report should be written in such a way that researcher in other fields can understand it.

It is also noted that there are only three written reports for fiscal Year 2000. This is clearly unacceptable. It is this type of attitude that destroys public confidence towards the computational laboratory, which was earned over many years of hard work.

It is recommended that a critical review by experts in the field be made for each project at the end of its proposed period. The Committee also recommends that a summary of activities that can be understood by the general public be posted on a web page.

5 Organization of the program

5.1 Committee structure

Currently, the operation of the KEK supercomputer system is under the supervision of the Supercomputer System Operation Committee appointed by the head of the Computing Research Center, while the approval of projects and resource allocation in the Large Scale Simulation Program are determined by the Program Advisory Committee.

Since the research program and computer operation are closely related to each other, they should be organized in an unified manner so that the scientific program and the computer operation are consistent with each other. This is especially important when the future direction of the supercomputer research programs is to be decided.

The Committee therefore suggests that establishing a single committee under the Director General of KEK, whose function covers both the the organization of the Large Scale Simulation Program and the operation of the supercomputer system, will further enhance the scientific effectiveness of the KEK supercomputer facility. The future direction of the supercomputer program is also to be discussed by the new committee.

5.2 A suggestion for a long term strategy

Although the task of the present committee is to review the supercomputer system of the laboratory, it felt it necessary to emphasize the importance of a solid and well structured computing environment for the future endeavors of the particle and nuclear physics community in Japan as well as in Asia.

It, therefore, suggests that KEK evaluate the general needs of community and the role that the KEK computing center could play as a major node in the global network of particle and nuclear physics computing activities.

6 Summary

Particle and nuclear physics research is, nowadays, highly demanding of high precision, massive computation. New projects cannot be carried out successfully without the support of powerful computing systems in an well structured framework. The efficiency and competitiveness of Japanese research is at stake.

Although some improvements have been proposed by the Committee, in general, it is the opinion of the Committee that the Large Scale Simulation Program has provided an excellent framework for achieving the research goals of its community. The program has provided the high performance computing resources that are essential not only to members of KEK, but also to researchers outside of KEK. In this way, the program has encouraged the collaborative effort of communities of physicists to attack many interesting problems. The Committee finds this system to be very effective, and hence should be continued and strongly supported to benefit the entire physics community.

The research quality has been very high in general; in non-perturbative QCD, in particular, they have been leading the world in calculating a number of quantities indispensable for B physics. The Committee strongly urges KEK to continue full support of the supercomputer facility and its collaborative use by researchers through the Large Scale Simulation Program.

The problem of the reviewing system is universal in all research projects supported by the Ministry of Education and Science. The system should be overhauled. The Committee hopes that by pointing out the problem at all possible occasions, a change can be triggered. It also hopes that the KEK Large Scale Simulation Program will take the first step along this direction.

Finally, the Committee hopes that further discussions will occur to enhance the role and activity of the Computing Research Center in wider areas of computer science in Japan and abroad, including Asian countries.

Part II

KEK 大型シミュレーション研究外部評価委員会報告（日本語訳）

KEK 大型シミュレーション研究
外部評価委員会報告（日本語訳）

KEK 大型シミュレーション研究外部評価委員会

外部評価委員会について

高エネルギー加速器研究機構 (KEK) は、1996 年4 月、日本での高エネルギー物理学およびその関連分野の大規模シミュレーションをサポートするために、公募型研究制度「大型シミュレーション研究」を開始した。この制度により、KEK はスーパーコンピュータを使って実施する研究プロジェクトを公募し、申請は「大型シミュレーション研究審査委員会」で審査され、採否と計算時間の割り当てが決定される。1996 年からこれまでに、のべ 77 の研究プロジェクトの申請が採択され、多くの研究成果がそれぞれの研究グループから発表された。これらの成果を評価し、問題点があるならばそれをあげ、ひいてはこの制度の将来の方向性について知見を得るために、KEK 機構長はこの委員会に、1996 年4 月から 2002 年3 月までに実施された「大型シミュレーション研究」に関する評価を依頼した。

この委員会に与えられた任務は以下の通りである。

- この制度の下で行われた研究に関する評価。
- この制度の効果に関する評価。
- この制度のための計算機資源とサポートが適切であるどうかを評価。

これらの点について、将来の方向性についての勧告も期待されている。

この委員会の委員は以下の通りである。

Paul B. Mackenzie	米国、フェルミ国立加速器研究所
益川敏英	京都大学基礎物理学研究所
Denis Perret-Gallix	フランス国立科学研究センター (CNRS)
三田一郎 (委員長)	名古屋大学
高田俊和	日本電気 基礎研究所
宇川彰	筑波大学計算物理学研究センター
矢崎紘一	東京女子大学

2002 年12 月12 および13 日に KEK 計算科学センターにおいて、この委員会の会合を開いた。

1 大型シミュレーション研究の目的

高エネルギー加速器研究機構 (KEK) は加速器科学およびその関連分野の研究を行う機関であり、素粒子原子核物理の研究はその主要な課題である。このために、KEK は高エネルギー物理実験のための加速器や検出器を保有し、運転している。また、KEK は素粒子原子核物理の研究に必要な計算機資源も整備しており、スーパーコンピュータシステムはその重要な一部をなしている。

スーパーコンピュータシステムは、大型シミュレーション研究を通じて使用されている。大型シミュレーション研究では、KEK のスーパーコンピュータを使う、高エネルギー物理および関連分野の共同研究を公募し、日本の大学および国公立研究機関の研究者、あるいは機構長が適切と認めた者がこれに応募できる。

本外部評価委員会 (以下では本委員会) は基本的に、計算機による研究は素粒子物理の研究に不可欠であり、KEK の研究計画の様々な点において重要であると考える。標準模型のシミュレーション、その中でも特にQCD の非摂動効果のシミュレーションは、B の物理全体の中でもB ファクトリー実験の実験結果から意味のある物理量を引き出すための欠かすことのできない主要な部分となっている。また、原子核物理および宇宙物理などの関係分野においても計算機による研究は本質的に重要である。

これらの分野で最先端の研究を行うには、非常に大きな計算機資源が必要である。個々の研究グループがこうした計算機環境を用意することは非常に困難であり、この面でのKEK の努力は物理学のコミュニティー全体が評価するところである。

2 研究成果

現在の大規模計算は、物理学の多くの分野で過去に例のないほどの進歩を可能にした。KEK の大型シミュレーション研究も、これらのいくつかの分野に重要な進展をもたらしてきた。本委員会は、このプログラムのもとで研究を進めている7 つの研究グループから、大規模な数値シミュレーションによって可能になった多様な物理の研究について報告を受けた。例えば、摂動的場の量子論においてすでに確立した手法も、計算機を使うことでさらに高いレベルに到達することができる。scminami グループは、ファインマン振幅を計算機を使って自動的に計算する手法を開発し、この手法はLEP 実験や将来の加速器実験の研究に幅広く使われている。原子核物理学の進展おいても、非常に異なる計算手法が使われている。scnucl/scsokaku グループは、KEK のスーパーコンピュータを使ってストレンジネス核物理やJ-PARC における重イオン衝突実験に関係する研究を行っている。

特に非摂動的な場の量子論においては、大規模な数値シミュレーションは過去には得られなかった強結合理論の解を求めることを可能にした。このことは著しい学問上の成果であると同時に、KEK や世界中で行われている実験計画にとって緊急の実際的な重要性がある。KEK やその他の実験では、数百億円を費やしてB 中間子の物理の実験を進めているが、その解析はQCD の計算なしには理論的に完全にはなりえない。そして、QCD は大規模数値シミュレーションなしには解くことのできない強結合場の理論なのである。これらの実験は、例えばカビボ-小林-益川行列の要素を決定するために必要になるものである。このような標準模型の基本パラメタは、標準模型を越える物理の理解を進めるうえで本質的な手がかりを与えるもので、現在の素粒子実験の中心的な目的になっている。大型シミュレーション研究のサポートによって、scqcd グループはこれらの計算で世界をリードしてきている。しかしながら、KEK や世界の実験で必要とされる計算を完成させるためには、さらに大きな計算が必要であり、従ってこの分野を引

続きリードしていく必要がある。

2.1 大規模数値シミュレーションによる格子QCD の研究(scqcd グループ)

このグループは、スーパーコンピュータVPP-500 を使って、B_K、$m_{u,d}$、f_π、陽子崩壊行列要素, f_B、B_B、および$a_{\pi\pi}$ をクェンチ近似の範囲内で計算した。これらの計算ではカイラル対称性による振る舞いを制御することが必要であり、B_K の場合には演算子混合の問題をカイラル・ワード・高橋恒等式を使うことで解決した。彼らのB_K の結果はParticle Data Group に標準的な値として採用されており、このことはその数値が高エネルギー物理学のコミュニティで広く使われていることを示している。また、本委員会は彼らのB の物理の計算がBelle 実験の解析を完成するために本質的であることを指摘しておきたい。

2000 年にスーパーコンピュータSR8000 が導入されたのにともない、このグループは動的なアップおよびダウンクォークを含んだクェンチ近似によらない計算を開始した。これにより得られたf_B、B_B、およびSU(3) の破れを表す比 $(f_{B_s}\sqrt{B_{B_s}})/(f_B\sqrt{B_B})$ の結果は世界の競争をリードするもので、クェンチ近似が10%程度の無視できない誤差を生むことを示した。彼らは、上であげたすべての計算をストレンジクォークの動的効果も取り入れて行うべきだと主張している。このグループは、スーパーコンピュータシステムの計算時間のうちの90%を使用している。本委員会は、このグループが世界をリードする成果を挙げていることについて祝意を表する。

これらの結果はKEK の実験計画だけでなく、世界中の高エネルギー物理のコミュニティにとって、極めて重要なものである。この研究を完成させるには、完全にクェンチ近似によらない同じ精度の計算が必要になる。(それにはより強力な計算機が必要である。) したがって、もし充分な計算資源が得られるならば、引き続いて本質的な成果をあげることが期待できる。今後一年のうちにアメリカおよびヨーロッパのグループが強力な競争相手になると予想される。本委員会は、この共同研究が最高水準を保つため、KEK が必要なすべての措置をとるよう強く勧告する。

2.2 QCD における色荷閉じ込め機構とモノポールのモンテカルロによる研究(scknza グループ)

このグループは、モノポール凝縮がQCD の閉じ込め機構において本質的であるというトフーフトの予想を証明しようと試みている。動的フェルミオンを含む計算によって、彼らは(1) アーベリアン、および(2) モノポールが支配的な役割を果たしていることを見い出した。特に、中間子の中のクォーク–反クォーク間の色荷流の分布を目に見えるように示したことは興味深い。

このグループの研究結果は、閉じ込め機構の概念的な理解にかなりの進歩をもたらした。しかしながら、低エネルギーでのハドロンの力学を理解するために使える有効理論を導くという目標までは果たしていない。

また、このグループに割り当てられた時間のうちかなりの部分が使われていないことも記しておきたい。

2.3 ファインマン振幅の自動計算と高エネルギー物理への応用(scminami グループ)

このグループは、1 体あるいは2 体からn 体への散乱のヘリシティ振幅を自動的に生成するプログラム(GRACE) を開発した。これは、標準模型あるいは超対称標

準模型の最低次の計算に用いられる。実際、これはイベントジェネレータのジェネレータとでも呼ぶべきものであり、LEP 実験において広く使われている。1 ループのダイアグラム (n=2 および n=3 のいくつか) の計算につかえるパッケージも最終テストの段階にあり、高次ループ補正も研究されている。ほとんどの場合、計算の制限は CPU やメモリー、ディスク容量といった計算機システムの性能によって与えられる。また、4 倍精度演算もこれらの計算には本質的である。このパッケージは、LHC や将来の線形加速器における超対称粒子の探索に広く使われることになるだろう。

こうした方向での研究は、高エネルギー物理の検出器で得られた実験データを理解する上で本質的であり、世界中でいくつかのグループが同様のパッケージを開発中である。今後も世界をリードする研究を続けるためには、この研究を今後も適切な計算機システムによりサポートすることが重要である。

本委員会は、このグループが多くの重要な反応において世界をリードする成果をあげていることに祝意を表したい。

2.4 有限温度および密度におけるQCD (sctaro グループ)

このグループは、有限温度および密度でのハドロン質量の研究を非等方格子を使ってすすめている。カイラル極限への外挿が研究され、極および遮蔽質量が、擬スカラー、ベクター、スカラー、および軸ベクター粒子について温度の関数として得られている。また、有限密度でのハドロン質量の研究の最初の試みがなされ、カイラル秩序パラメタ $\langle\bar{\psi}\psi\rangle$ が、有限の化学ポテンシャルのもとで計算された。

なお、最近このグループに割り当てられた時間のうちかなりの部分が使われていないことも記しておきたい。

この研究計画は、J-PARC での p-A (あるいは A-A') 衝突実験に関係している。

2.5 格子QCD における核子励起状態の最大エントロピー法を用いたスペクトル解析 (scmelqcd グループ)

このグループは、彼らが以前提案した最大エントロピー法を用いて核子演算子の相関関数からスペクトル関数を抜き出すことで、核子の励起状態を研究している。スペクトル関数において $N'(1440)$ と $N^*(1535)$ 粒子を同定するために、パリティ射影がなされた。クォーク質量が軽いときには有限体積効果が重要になり、長年の疑問であった励起状態の間の準位の順序の問題は、無限体積の極限では解決されることが明らかになった。

この研究計画は最近始まったばかりで、計算時間は多くはない。また、この研究はJ-PARC における研究課題の一つであるハドロン分光学にとって重要である。

2.6 微視的計算法による核子構造と重イオン衝突の研究 (scnucl/scsokaku グループ)

このグループは3 つの課題を研究している。(1) ハイパー核の構造、(2) 安定および不安定核の構造、(3) 中間エネルギーでの重イオン衝突。(1) に対して、彼らは軽いハイパー核の研究にガウス基底を用いて、Y-N およびY-Y 相互作用に関する情報を引き出した。また、Λ-Σ 結合がハイパー核の統一的な理解に本質的であることを発見した。(2) と(3) に関しては、原子核多体系の微視的な扱いとして、反対称化分子動力学法を用い、中性子過剰核の奇妙な構造や重イオン衝突での多重破砕の様子を説明することに成功した。

彼らの研究にはかなりの計算時間が割り当てられ、そのほとんどを使いきっている。このことは、プログラムの最適化がよくなされていることを示している。

彼らの研究対象は核物理の最先端であり、J-PARC におけるストレンジネス核物理や重イオン衝突実験と密接に関連している。

2.7 数値的宇宙物理 (scastro グループ)

このグループは、超新星サブグループと数値相対論サブグループの２つからなっている。超新星サブグループは、超新星爆発のシミュレーションコード (洗練された１次元コードと単純化された２及び３次元コード) を開発し、観測されている r 過程での重粒子過剰を定性的に説明した。また、SN1987a からのニュートリノ事象を、ニュートリノ振動の可能性も考慮して再解析した。数値相対論サブグループは、融合する二連中性子星とその放出する重力波を、4 次元アインシュタイン方程式と一般相対論的流体方程式を数値的に解くことで研究した。

このグループには豊富な計算時間が割り当てられたが、すべては使われていない。スーパーコンピュータへのさらなる最適化が必要なのかもしれない。この研究は、宇宙物理においてだけではなく素粒子原子核物理においても重要であり、J-PARC で行われるニュートリノ物理にも関係している。

3 計算機資源とユーザ環境

スーパーコンピュータの機種は、導入時にもっとも価格性能比が高くなるよう、適切に選択されている。この計算機は、主要な応用分野である格子 QCD の大規模シミュレーションに適したものであり、非常に効果的に使用されている。過去数年の間は、格子 QCD の分野に使われた計算機としてはもっとも強力なものであった。

スーパーコンピュータの TOP500 リストによれば、2000 年の導入時には世界で 9 番目に高速であったが、2002 年には 53 位にまで順位を落としており、今後も急速に落ちていくと予想される。KEK が格子ゲージ理論とその他の大規模シミュレーションの分野でトップの地位を保つためには、計算機の更新が緊急の課題となる。現在の 6 年間のレンタル契約期間は、世界的な競争の先頭に立ち続けるシステムを保証するには長すぎる。今後のレンタル契約は、より短期のものにするべきである。

計算機をサポートする周辺環境は、スーパーコンピュータを最大限に使うために重要である。ギガビットイーサネットで遠隔地と接続するネットワークの増強計画は、遠隔地のユーザのスーパーコンピュータ利用環境を改善し、効果的な共同研究をもたらすであろう。近年のディスクの価格の下落を考えると、ディスク容量を増強することも望まれる。また、スーパーコンピュータが最適でないような計算需要に対してもサポートしていくことも重要であろう。安価な PC ファームは、スーパーコンピュータのユーザのある種の計算には効率的な解になりうる。将来のシステムの更新計画を練る際には、異なる計算需要に対してさまざまなタイプの計算機の効率性を、注意深く検討することが必要である。

スーパーコンピュータ利用の最適化を助けるために充分なサポートスタッフを擁することは、効率的な利用のためには本質的な重要性をもつ。最近空席となった格子 QCD のポジションを時機を逸することなく補充することは、特に重要である。スーパーコンピュータの使用に関するワークショップは、外部ユーザの仕事を促進するのに役にたつであろう。

4 審査システムについて

大型シミュレーション研究審査委員会は、スーパーコンピュータの設備を使って行う研究課題の提案について、審査し採択する役割を負っている。

第 2 章でも述べた通り、本委員会はスーパーコンピュータを使って行われた研究を高く評価している。したがって、審査と課題採択は問題なく行われていると考える。

4.1 研究課題の採択について

本委員会の見るところ、いくつかの計算は、例えば PC クラスターなど、より適した計算機アーキテクチャーで走らせることもできる。しかも、グループによっては申請され配分された計算時間のうち部分的にしか使用していない。ただし、年に 2 回の見直しが行われているため、余った時間は他のユーザに割り当てられ、全体ではすべての計算機資源が使われている。

したがって本委員会は、計算科学センターにあるより広範な計算機資源を審査委員会で扱えるようにし、計算の種類によっては、適切ならば他の計算機で実行できるようにすることを勧告する。

大規模な計算時間の申請に関しては、採択する前にまず計算をテストして有効であることを確認すべきである。この目的のために、テストのための小規模の計算時間については、要求に応じて認めるべきである。

4.2 研究プロジェクトの事後評価について

本委員会の理解するところでは、すべての研究結果は大型シミュレーション研究審査委員会で評価されることになっているが、我々はこの評価をより厳密に透明なやり方で実施することを勧告する。1997 年度から 2001 年度までの公式な成果報告書は、研究活動を評価するには不十分である。研究の動機や結果の有効性はどちらも明確に書かれていない。それぞれの研究報告は、他分野の研究者が理解できるように書くべきである。

さらに 2000 年度に関しては、3 グループの報告書しか掲載されておらず、これは明らかに受け入れがたい。このような態度は、長年にわたる努力によって得られた計算機の研究所に対する一般の信頼を損なうものである。

本委員会は、申請年度の終りには各分野の専門家による評価を行うことを勧告する。また、一般にも理解できるような研究活動のまとめをウェブページで公開することもすすめる。

5 組織

5.1 委員会の構成

現在は、KEK スーパーコンピュータシステムの運用は計算科学センター長に任命されるスーパーコンピュータシステム運用委員会の下で行われている。一方、研究計画の採択と計算時間の配分は大型シミュレーション研究審査委員会が決定する。

研究計画と計算機の運用とは互いに密接に関係しているので、両者が互いに矛盾しないよう統一的に組織されるべきである。このことは、特に将来のスーパーコンピュータによる研究計画を決定するときには重要になる。

したがって本委員会は、KEK 機構長の下に、大型シミュレーション研究の運営とスーパーコンピュータシステムの運用の両方を包含する委員会を設けること

を提案する。これによって、KEK のスーパーコンピュータの設備は、さらに効果的に科学に貢献できるようになるであろう。スーパーコンピュータによる研究計画の将来の方向性も、この新しい委員会で議論されることになろう。

5.2 長期的戦略に関する提案

本委員会の任務は、研究所のスーパーコンピュータに対する評価であるが、将来の日本およびアジアの素粒子原子核物理学のための、確固とした適切な構成の計算機環境の重要性を強調しておくことが必要であると考える。

したがって本委員会は、KEK がコミュニティ全般の需要を考慮し、素粒子原子核物理における計算機関係の研究活動のグローバルなネットワークの中で、計算科学センターが主要な核として果たしうる役割を評価することを提案する。

6 まとめ

現在の素粒子原子核物理の研究では、高精度かつ大規模な計算が強く要求される。適切に設計された強力な計算機システムなしには、新しい研究プロジェクトの成功はおぼつかない。日本の研究の効率性と競争力が問題になっているのである。

いくつかの改善点を指摘したが、全体としては、大型シミュレーション研究はコミュニティの研究目標を達成するためのすばらしい仕組みを提供しているというのが本委員会の考えである。この制度は、KEK 所員だけでなく所外の研究者にも高性能の計算資源を提供してきており、これによって、物理コミュニティの研究者が、共同して多くの興味深い問題に取り組む努力を後押ししてきた。本委員会は、この制度が非常に有効なものであると認めるとともに、物理コミュニティ全体のために、今後もこれを継続し、強くサポートすべきであると考える。

研究の水準は総じて非常に高い。特に非摂動QCD においては、B の物理に不可欠な数多くの物理量の計算で世界をリードしている。本委員会は、スーパーコンピュータの施設と大型シミュレーション研究を通じた研究者による共同利用のサポートを、KEK が継続することを強く勧める。

評価制度の問題は、文部科学省のサポートを受けたすべての研究プロジェクトに共通のものであり、正して行かなければならない。本委員会は、あらゆる機会にこの問題を指摘していくことで変化の契機になることを期待している。また、KEK 大型シミュレーション研究がこの方向への第一歩を踏み出すことを期待する。

最後に、日本とアジアの国々を含む諸外国での計算機科学のより幅広い領域で、計算科学センターの役割と研究活動を促進していくためのさらなる議論がすすめられることを、本委員会は期待している。

Part III

KEK Large Scale Simulation Program

KEK Large Scale Simulation Program

Report for the Large Scale Simulation Program
Review Committee

Chapter 1

KEK Large Scale Simulation Program

1.1 Description of the program

In the theoretical research of particle and nuclear physics, the role of computing has become indispensable to numerically solve nonlinear problems, which could not be treated solely by analytic methods. In particle physics, the Quantum Chromodynamics (QCD) — the elementary theory to describe the strong interaction — is one of such nonlinear problems, as its interaction becomes strong at low energies where it is relevant to the dynamics of hadrons (low energy bound state of quarks and gluons). Another important application where the numerical method is essential is the theoretical study of nuclei, which is essentially many-body system and hence its dynamics is quite nonlinear.

For these applications the numerical simulation provides a powerful tool, but their computing demand is extremely severe, and the state-of-the-art simulations have been performed on fastest supercomputer available at that period of time.

At KEK the first supercomputer was installed in 1985 to satisfy the increasing requirement of computing power. Since then, the supercomputer system has been replaced about every five years as listed below.

year/month	machine	peak performance
1985/06	Hitachi S810/10	350 MFlops
1989/01	Hitachi S820/80	3 GFlops
1995/01	Fujitsu VPP500/80	128 GFlops
2000/01	Hitachi SR8000/F1/100	1.2 TFlops

These machines have been mainly used for the large scale numerical simulations in particle and nuclear physics, accelerator science and astrophysics. In particular, a large portion of the CPU time has been spent on the simulations of Quantum Chromodynamics (QCD).

Until March 1996, these supercomputers were used for the research programs of KEK staffs and their collaborators. However, in April 1996, KEK started the *"Large Scale Simulation Program."* through which the dominant part of the supercomputer resources was opened to research projects in high energy physics and related fields in Japan, in order to promote the large scale simulations with supercomputers. [1] The projects under the *"Large Scale Simulation Program."* are reviewd and approved by the *"Program Advisory Committee"* formed by the Director General of KEK.

Under the program, KEK calls for proposals of project to be performed employing the supercomputer at KEK. Usually the formal announcement of the call for proposals for next fiscal year (stating in April) is sent to universities in November or December, and the proposals are accepted by late January. Then, the Program Advisory Committee holds a committee meeting usually in March to decide the approval and computer time allocation. The meeting consists of an open session to hear from each research group and of a closed session of the committee members to discuss on the approval.

The supercomputer is operated by the *Computing Research Center* under the supervision of the *Supercomputer System Operation Committee*, which consists of KEK staffs and members from institutions outside of KEK. The Computing Research Center also supports users in the technical problems on the supercomputer system.

The subject of the present review is the *Large Scale Simulation Program* and the research activities under this program in the period April 1996 – March 2001.

1.2 Program Advisory Committee

The *Program Advisory Committee* consists of both KEK staff members and members from other institutions. They are appointed by the Director General of KEK. The members of the committee are listed in the following tables.

Higashijima, Kiyoshi*	Osaka Univ.
Hirose, Tachishige	Tokyo Metropolitan Univ.
Kobayashi, Makoto	KEK, IPNS
Muta, Taizo	Hiroshima Univ.
Ohara, Ken-ichi	Niigata Univ.
Shimizu, Yoshimitsu	KEK, IPNS
Watase, Yoshiyuki	KEK, Computing Research Center
Yokoya, Kaoru	KEK, Accelerator Lab.

Table 1.1: Program Advisory Committee: FY1996–1998 (* : chairperson)

The Program Advisory Committee reviews the research projects proposed by each group and evaluate their scientific significance to decide the approval of the proposals. Each proposal includes the detailed estimate of computer time needed for the project, and the Program Advisory Committee decide the machine time to be used by the project.

The high-end supercomputers as used for the *Large Scale Simulation Program* show their best performance only when the computer program is tuned for the architecture of the machines; otherwise, there is no significant difference between the supercomputer and ordinary computers, and hence one may waste

[1] A small amount of computer time, say less than 10%, has been allocated for small sized projects being performed by KEK scientists.

Higashijima, Kiyoshi*	Osaka Univ.
Horiuchi, Hisashi	Kyoto Univ.
Kobayashi, Makoto	KEK, IPNS
Ohara, Ken-ichi	Niigata Univ.
Shimizu, Yoshimitsu	KEK, IPNS
Uematsu, Tsuneo	Kyoto Univ.
Watanabe, Yasushi	Tokyo Inst. of Tech.
Watase, Yoshiyuki	KEK, Computing Research Center
Yokoya, Kaoru	KEK, Accelerator Lab.

Table 1.2: Program Advisory Committee: FY1999–2002 (* : chairperson)

the machine power. Therefore, the performance of the simulation program written by the research groups is a subject of review by the committee, in addition to the significance of their scientific research.[2]

Three months before the end of fiscal year, the budgets (machine time) for the projects are adjusted to avoid the situation that the machine is left unused by any groups for the reason of the limitation of the budget. Thus, the used CPU time by a project may exceed the originally approved value.

1.3 Research Projects

The applied projects and their allocated and used CPU time are listed in the tables in the subsequent pages for each fiscal year. The value of CPU time in the tables is multiplied by the number of machine nodes (80 for VPP500; 100 for SR8000) since they can run in parallel.

In January 2000, Fujitsu VPP500 was replaced by the new machine Hitachi SR8000. The difference in the architecture of two machines is so large that the effort of tuning of the programs was required. Therefore, the period March–July 2000 was assigned for the program tuning and the budget was not enforced.

[2] The groups that do not have enough experience with the architecture of the KEK supercomputer may apply for the *Large Scale Simulation Program* as a test project. Those applications are usually accepted with computer time of 300 hours.

Table 1.3: List of projects in FY 1996 (April 1996 – March 1997).

no.	group	users	title
1	scqcd	15	Study of QCD by numerical method
2	scknzw	14	Monte-Carlo study of quark confinement mechanism
3,14	scosaka	3	Supersymmetry on a Lattice
4	scjuhyo	5	Transport coefficients of Quark Gluon Plasma
5	scseries	1	Series Expansion for Lattice Gauge Systems and spin systems by the Finite Lattice Method
6	scastro	11	Numerical Astrophysics
7	scchaos	5	Simulation of string theories
8	sctaro	3	Study of Perfect Lattice Action
9	scminami	2	Feynman amplitudes automatic calculation of and its application to High Energy Physics
10	scgauge	3	Numerical Study of Dynamics of Chiral Gauge Theory
11	scqed	1	Study on Energy Spectrum of QED bound systems muonium hyperfine structure
12	scgrav	3	Simulation of Quantum Gravity and its Renormalization-Group Analysis
13	sccpnl	3	Monte Carlo Simulations of Field Theories with Topological terms

Table 1.4: List of approved budgets and their usage in FY 1996.

no.	group	spokesperson		CPU (hours)		
				requested	accepted	used
1	scqcd	M. Okawa	KEK, IPNS	336,000	336,000	524,439
2	scknzw	T. Suzuki	Kanazawa Univ.	10,040	10,040	3,633
3, 14	scosaka	Y. Yoshida	Osaka Univ.	1200	1200	649
4	scjuhyo	S. Sakai	Yamagata Univ.	1,000	1,000	3,604
5	scseries	H. Arisue	Osaka Prefectual College of Tech.	50	50	0
6	scastro	H. Suzuki	KEK, IPNS	38,400	38,400	1,552
7	scchaos	T. Yukawa	The Graduate Univ. for Advanced Studies	52,000	1,000	891
8	sctaro	O. Miyamura	Hiroshima Univ.	3,300	3,300	77
9	scminami	K. Kato	Kogakuin Univ.	43,000	43,000	2,251
10	scgauge	Y. Kikukawa	Kyoto Univ.	1,210	1,210	659
11	scqed	M. Nio	Nara Women's Univ.	4,200	4,200	6,196
12	scgrav	J. Nishimura	Nagoya Univ.	20	20	72
13	sccpnl	H. Yoneyama	Saga Univ.		test	6

Table 1.5: List of projects in FY 1997 (April 1997 – March 1998).

no.	group	users	title
15	scqcd	18	Study of lattice QCD by large scale numerical simulation
16	scgauge	2	Numerical study of dynamics of chiral gauge theories
17	scknzw	15	Monte Carlo study of quark confinement mechanism
18	scgrav	2	Simulation of Quantum Gravity and its Renormalization-Group Analysis
19	scqed	1	Radiative corrections of QED bound systems
20	scseries	1	Series Expansion for spin systems by the finite-lattice method
21	scchaos	1	Numerical Simulation of String theory
22	scastro	8	Numerical Astrophysics
23, 29	sclngvn	2	Applications of the Langevin method to the lattice QCD
24	sctaro	7	Study of perfect lattice actions
25	scibac	4	Simulating galaxy formation
26	sccpnl	1	Monte Carlo Simulation of Field Theories with Topological Terms
27	scjuhyo	8	Study of Gluon Propagator at finite temperature and transport coefficients of Quark Gluon Plasma with Improved Action
28	scminami	2	Feynman amplitudes automatic calculation of and its application to High Energy Physics
30	scnucll	2	Theoretical study of nuclear physics with numerical simulations

Table 1.6: List of approved budgets and their usage in FY 1997.

no.	group	spokesperson		CPU (hours)		
				requested	accepted	used
15	scqcd	M. Okawa	KEK, IPNS	417,000	417,000	477,474
16	scgauge	Y. Kikukawa	Kyoto Univ.	990	990	0
17	scknzw	T. Suzuki	Kanazawa Univ.	9,400	9,400	8,055
18	scgrav	J. Nishimura	Nagoya Univ.	1,000	1,000	1,315
19	scqed	M. Nio	Nara Women's Univ.	18,000	18,000	17,879
20	scseries	H. Arisue	Osaka Prefectual College of Tech.	50	50	0
21	scchaos	T. Yukawa	The Graduate Univ. for Advanced Studies	1,200	1,200	12
22	scastro	H. Suzuki	KEK, IPNS	12,800	12,800	659
23, 29	sclngvn	H. Nakajima	Utsunomiya Univ.	3,200	3,200	260
24	sctaro	O. Miyamura	Hiroshima Univ.	800	800	1,347
25	scibac	M. Yokozawa	Ibaraki Univ.	test	test	1
26	sccpnl	H. Yoneyama	Saga Univ.	test	test	0
27	scjuhyo	S. Sakai	Yamagata Univ.	4,200	4,200	2,797
28	scminami	K. Kato	Kogakuin Univ.	17,800	17,800	6,858
30	scnucll	Y. Enyo	KEK, IPNS	22,774	22,774	22,226

Table 1.7: List of projects in FY 1998 (April 1998 – March 1999).

no.	group	users	title
31	scqed	1	Radiative corrections of QED bound system
32	scqcd	17	Study of lattice QCD by large scale numerical simulation
33	scknzw	18	Monte Carlo study of quark confinement mechanism
34	sclngvn	2	The Lattice QCD Simulations in Landau Gauge
35	scastro	8	Numerical Astrophysics
36	sctaro	9	Study of perfect lattice actions
37	scminami	10	Feynman amplitudes automatic calculation of and its application to High Energy Physics
38	scgrav	4	Numerical Simulation of Quantum Gravity and Renormalization Group Analysis
39	scnucll	3	Theoretical study on nuclear physics with numerical simulations
40	scchaos	5	Numerical Simulation of String theory
41	scocha	3	Phase Transition on a Lattice
42	scjuhyo	3	Analysis of calculation of transport coefficients of quark gluon plasma and simulation on anisotropic lattices.
43	scgauge	2	Restoration of local gauge invariance in lattice chiral gauge models and BRST invariance
44	scstring	4	Non-perturbative formulation of string theory

Table 1.8: List of approved budgets and their usage in FY 1998.

no.	group	spokesperson		CPU (hours)		
				requested	accepted	used
31	scqed	M. Nio	Nara Women's Univ.	18,000	18,000	16
32	scqcd	M. Okawa	KEK, IPNS	433,000	394,600	468,722
33	scknzw	T. Suzuki	Kanazawa Univ.	45,700	41,860	32,813
34	sclngvn	H. Nakajima	Utsunomiya Univ.	3,660	1,900	1,910
35	scastro	H. Suzuki	KEK, IPNS	17,400	17,400	7,930
36	sctaro	O. Miyamura	Hiroshima Univ.	3,000	3,000	1,912
37	scminami	K. Kato	Kogakuin Univ.	4,600	4,600	5,645
38	scgrav	J. Nishimura	Nagoya Univ.	5,000	5,000	1,490
39	scnucll	Y. Enyo	KEK, IPNS	50,500	50,500	39,716
40	scchaos	T. Yukawa	The Graduate Univ. for Advanced Studies	1,000	300	1
41	scocha	A. Sugamoto	Ochanomizu Univ.	4,600	4,600	1
42	scjuhyo	S. Sakai	Yamagata Univ.	200	200	1
43	scgauge	Y. Kikukawa	Kyoto Univ.	990	990	0
44	scstring	H. Kawai	KEK, IPNS	2,500	2,500	27

Table 1.9: List of projects in FY 1999 (April 1999 – December 1999).

no.	group	users	title
45	scqcd	18	Study of lattice QCD by large scale numerical simulation
46	sclngvn	2	The lattice Landau gauge QCD simulation
47	scknzw	17	Monte Carlo study of quark confinement mechanism
48	scnucll	3	Theoretical study of nuclear physics with numerical simulations
49	scminami	10	Feynman amplitudes automatic calculation of and its application to High Energy Physics
50	sctaro	9	Study of QCD Thermo-Dynamics by Improved Actions
51	scjuhyo	4	Preliminary Simulation on Improved Anisotropic Lattice
52	scastro	8	Numerical Astrophysics
53	scgrav	3	Numerical Simulation of Matrix Models

Table 1.10: List of approved budgets and their usage in FY 1999.

no.	group	spokesperson		CPU (hours)		
				requested	accepted	used
45	scqcd	M. Okawa	KEK, IPNS	287,000	287,000	341,692
46	sclngvn	H. Nakajima	Utsunomiya Univ.	3,320	3,320	4,634
47	scknzw	T. Suzuki	Kanazawa Univ.	34,180	34,180	1,640
48	scnucll	Y. Enyo	KEK, IPNS	17,620	17,620	16,488
49	scminami	K. Kato	Kogakuin Univ.	4,600	4,600	3,566
50	sctaro	O. Miyamura	Hiroshima Univ.	2,600	2,600	4,657
51	scjuhyo	S. Sakai	Yamagata Univ.	280	280	0
52	scastro	H. Suzuki	KEK, IPNS	20,800	20,800	22,091
53	scgrav	J. Nishimura	Nagoya Univ.	3,000	3,000	237

Table 1.11: List of projects in FY 2000 (August 2000 – March 2001).

no.	group	users	title
54	scqcd	17	Study of Hadronic matrix elements by large scale numerical simulation of Lattice QCD with effects of dynamic quarks
55	scminami	10	Feynman amplitudes automatic calculation of and its application to High Energy Physics
56	scgrav	-	Numerical simulation of matrix model
57	sclngvn	3	The lattice Landau gauge QCD simulation
58	scsokaku	3	Nuclear structure and heavy ion reaction studies with microscopic simulation
59	scknzw	15	Monte Carlo study of quark confinement mechanism
60	scmelqcd	4	Analysis of spectral function in quantum mechanics of finite temperature with maximum entropy method
61	scjuhyo	2	Study of hadrons with heavy quarks on an anisotropic lattice
62	scrabbit	10	Study of non-perturbative vacuum and properties of hadrons by simulation of lattice QCD
63	scastro	8	Numerical Astrophysics
64	sctaro	11	Study of hadron spectrum of finite temperature in lattice QCD
65	scconfig	1	London penetration depth as a confinement order parameter

Table 1.12: List of approved budgets and their usage in FY 2000.

no.	group	spokesperson		CPU (hours)		
				requested	accepted	used
54	scqcd	M. Okawa	KEK, IPNS	450,000	450,000	469,950
55	scminami	T. Kaneko	Meiji-Gakuin Univ.	9,000	9,000	233
56	scgrav	J. Nishimura	Nagoya Univ.		rejected	
57	sclngvn	H. Nakajima	Utsunomiya Univ.	1,400	1,400	1,115
58	scsokaku	Y. Enyo	KEK, IPNS	13,400	13,400	10,653
59	scknzw	T. Suzuki	Kanazawa Univ.	13,400	13,400	685
60	scmelqcd	M. Asakawa	Nagoya Univ.	2,660	2,660	0
61	scjuhyo	S. Sakai	Yamagata Univ.	1,980	1,980	0
62	scrabbit	H. Suganuma	Tokyo Inst. of Technology	9,500	9,500	1,615
63	scastro	H. Suzuki	KEK, IPNS	49,600	49,600	1,511
64	sctaro	O. Miyamura	Hiroshima Univ.	10,800	10,800	5,918
65	scconfig	T. Matsuki	Tokyo-kasei Univ.	300	300	1

Table 1.13: List of projects in FY 2001 (April 2001 – March 2002).

no.	group	users	title
66	scqcd	16	Study of Hadronic matrix elements by large scale numerical simulation of Lattice QCD with effects of dynamic quarks
67	scminami	8	Feynman amplitudes automatic calculation of and its application to High Energy Physics
68	scalar	7	Study of sigma meson in lattice QCD
69	sclngvn	2	The lattice Landau gauge QCD simulation
70	scsokaku	3	Nuclear structure and heavy ion reaction studies with microscopic simulation
71	scknzw	15	Monte Carlo study of quark confinement mechanism
72	scmelqcd	4	Study of nucleon excited states in numerical simulation of lattice QCD with maximum entropy method
73	scjuhyo	3	Study of heavy quarks on an anisotropic lattice
74	scrabbit	5	Study of non-perturbative vacuum and properties of hadrons by simulation of lattice QCD
75	scastro	8	Numerical Astrophysics
76	sctaro	7	Study of hadron spectrum of finite temperature in lattice QCD
77	scconfig	1	London penetration depth as a confinement order parameter
78	schyper	2	Development of strangeness nuclear physics

Table 1.14: List of approved budgets and their usage in FY 2001.

no.	group	spokesperson		CPU (hours)		
				requested	accepted	used
66	scqcd	M. Okawa	KEK, IPNS	644,000	644,000	674,545
67	scminami	M. Kuroda	Meiji-Gakuin Univ.	6,900	6,900	2
68	scalar	M. Sekiguchi	Kokushikan Univ.	5,950	5,950	5,336
69	sclngvn	H. Nakajima	Utsunomiya Univ.	10,500	10,500	4,339
70	scsokaku	Y. Enyo	KEK, IPNS	23,520	23,523	14,844
71	scknzw	T. Suzuki	Kanazawa Univ.	23,520	23,523	10,393
72	scmelqcd	S. Sasaki	Tokyo Univ.	8,950	8,950	5,179
73	scjuhyo	S. Sakai	Yamagata Univ.	300	300	0
74	scrabbit	H. Suganuma	Tokyo Inst. of Technology	29,000	29,000	1,843
75	scastro	H. Suzuki	Tokyo Univ. of Science	48,400	48,400	2,394
76	sctaro	O. Miyamura	Hiroshima Univ.	51,000	51,000	21,008
77	scconfig	T. Matsuki	Tokyo-kasei Univ.	300	300	6
78	schyper	Y. Akaishi	KEK, IPNS	4,400	4,400	1,435

Chapter 2

Supercomputer systems at KEK

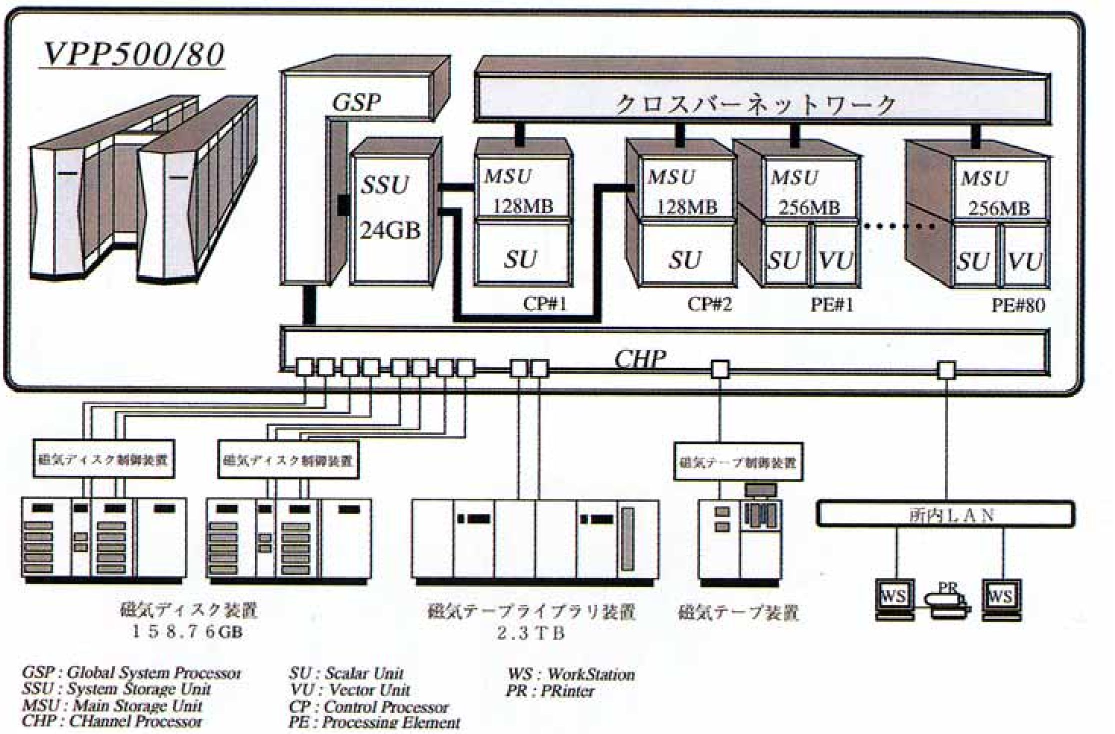
Fujitsu VPP500/80 was installed in January 1995. The structure of the system is shown in Fig. 1. The system comprises 80 processor elements, each of which is a vector processor with an accompanying scalar processor and a distributed memory of 256 MB. The I/O performance has been improved by using the large buffer memory in the front-end processor.

In March 2000, the Fujitsu VPP500 was replaced by Hitachi SR8000/F1. Hitachi SR8000 Model F1 is a supercomputer consists of 100 nodes connected by a fast dedicated network.

Each node has 9 processors, one of which is for the operating system and the other 8 processors are used for numerical calculations. These 8 processors in a single node work in parallel, which is called "element parallel" operations. The Fortran and C compilers analyze the logical structure of users' source codes to find calculations, which can be carried out in parallel, and generate object codes automatically. The parallel processing of multi-node can be written as usual using message passing library, such as the Message Passing Interface (MPI). Thus, the machine has a hierarchical parallelism within a node and among nodes. The peak performance of each node is 12 GFlops. In total, the peak performance is 1200 GFlops with 448 GB main memory. The structure of the computer system is shown in Fig. 2.

Thirty nodes out of one hundred serve also as I/O nodes, which are connected to disk array with 71.5 GB for each and the total storage size is 2,145 GB. Tape library Sony DMS-K140L is connected to the system which can store up to 138 volume of 200GB magnetic tapes.

The system is equipped with Hitachi H9000V/L1000 server, which works as a front-end processor. In order to keep the security of the system, the system can only be accessed from registered hosts with `ssh`(secure shell) command through front-end machine.



スーパーコンピュータシステム構成図

Fig.1 Fujitsu VPP500/80 system

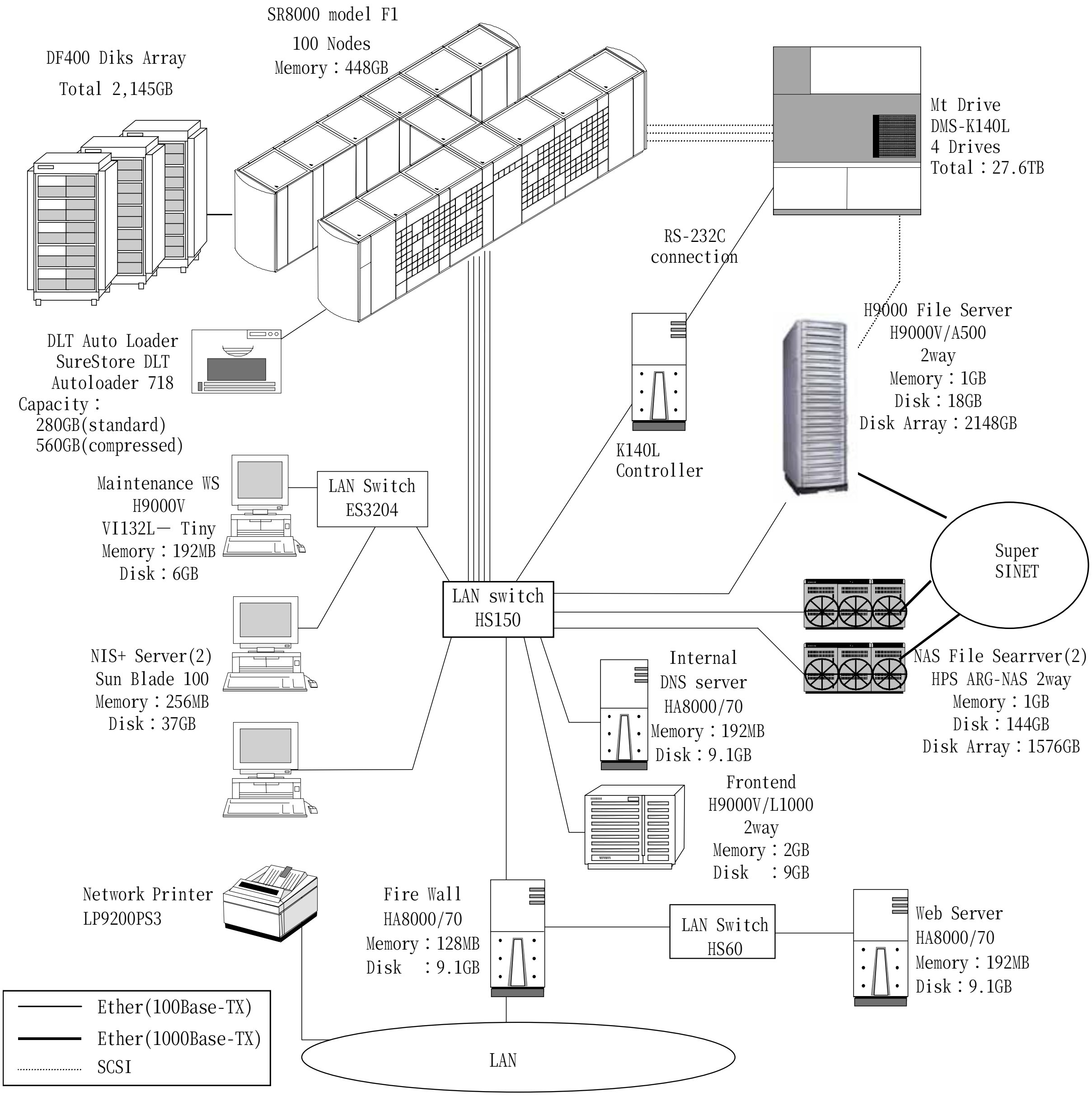
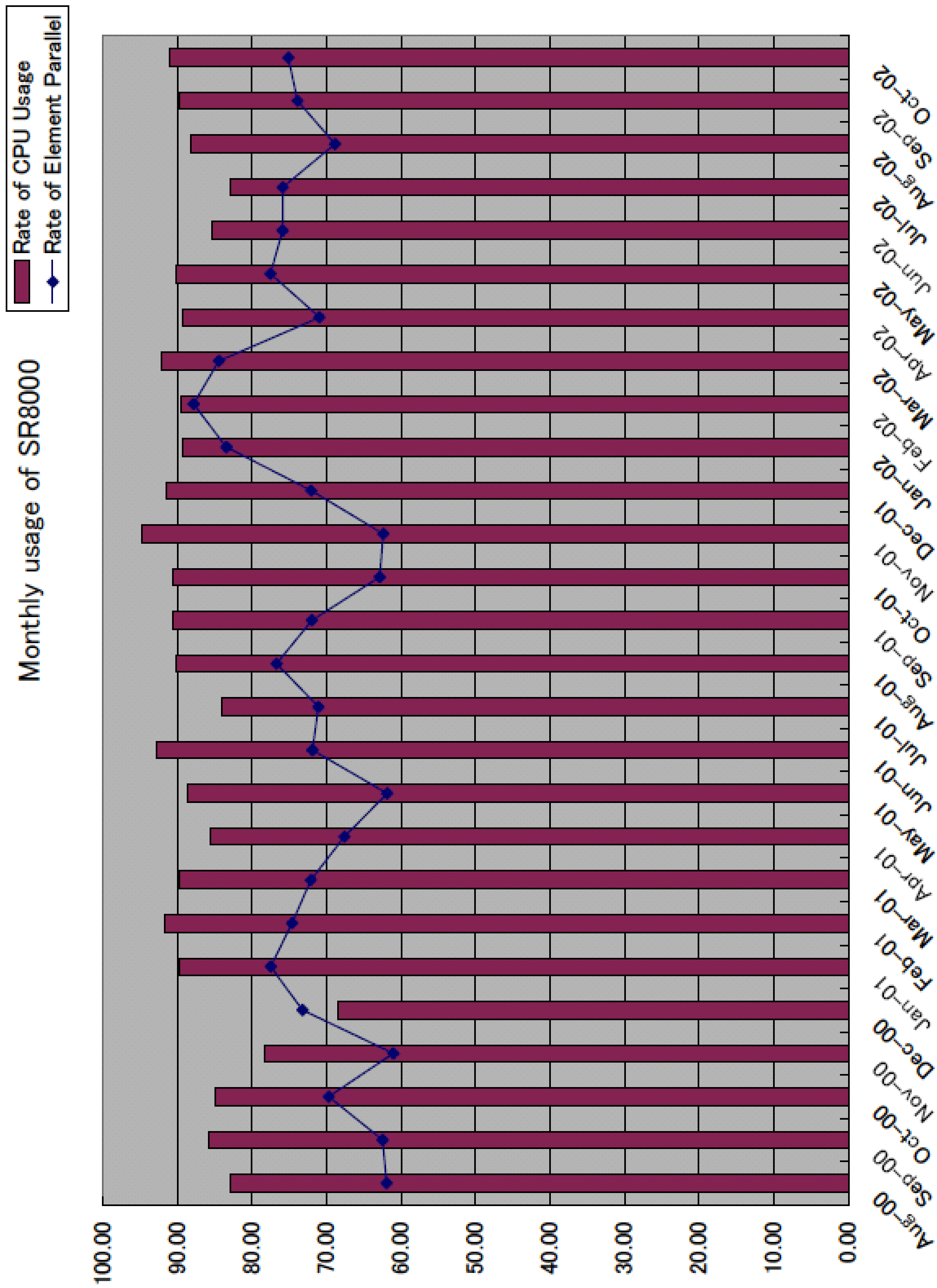


Fig.2 Hitachi SR8000 system

2.1 Usage of the machine

Monthly usage of SR8000 is shown in Fig. 3, which shows the ratio of used time to the service time and the ratio of time used for element parallel operations in the CPU time. More detailed monthly usage is shown in Table 1.

The usage of each project is shown in the subsequent tables.


Monthly usage of SR8000
Rate of CPU Usage
Rate of Element Parallel
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Aug-00
Sep-00
Oct-00
Nov-00
Dec-00
Jan-01
Feb-01
Mar-01
Apr-01
May-01
Jun-01
Jul-01
Aug-01
Sep-01
Oct-01
Nov-01
Dec-01
Jan-02
Feb-02
Mar-02
Apr-02
May-02
Jun-02
Jul-02
Aug-02
Sep-02
Oct-02

Monthly Usage of SR8000

Month	Operation (h)	Service (h)	Jobs	CPU (h)	Scalar (h)	EP (h)	EP total (h)	EP (%)	Performance GFLops/node	Op(%)	Used(%)
Aug-00	59,100.00	58,146.60	2451	398,503.20	48,243.85	29,872.37	257,335.95	61.92	2.92	98.39	82.97
Sep-00	71,023.77	70,464.70	4405	503,920.26	60,394.22	37,726.20	324,462.07	62.47	2.95	99.21	85.71
Oct-00	74,062.00	73,945.67	9624	534,146.33	62,788.61	43,760.82	369,118.14	69.70	3.26	99.84	84.91
Nov-00	72,000.00	70,483.69	10339	498,714.59	55,157.88	33,656.16	290,569.74	61.02	2.69	97.89	78.26
Dec-00	66,400.00	66,206.63	7969	438,398.22	45,308.91	33,174.81	277,517.27	73.22	2.56	99.71	68.44
Jan-01	66,300.00	62,998.73	5523	428,417.48	50,881.32	39,433.20	326,863.63	77.50	3.71	95.02	89.72
Feb-01	67,200.00	67,177.73	5223	445,030.63	53,244.86	39,730.47	331,156.26	74.62	3.66	99.97	91.67
Mar-01	74,400.00	74,261.77	5624	473,175.77	53,964.64	38,909.43	326,317.11	72.10	3.64	99.81	89.69
Apr-01	72,000.00	70,114.33	5199	450,938.83	48,400.97	32,720.99	277,444.79	67.60	3.22	97.38	85.53
May-01	74,400.00	71,437.00	3982	467,893.49	52,071.76	32,203.96	277,494.83	61.85	2.82	96.02	88.52
Jun-01	72,000.00	71,934.84	6420	511,471.14	61,244.38	44,029.51	369,456.00	71.89	3.56	99.91	92.81
Jul-01	74,400.00	72,657.07	5005	475,910.13	57,509.96	40,878.17	343,659.13	71.08	3.60	97.66	84.11
Aug-01	67,900.00	60,343.20	3608	428,239.84	51,486.61	39,492.95	327,939.51	76.71	4.01	88.87	90.10
Sep-01	72,000.00	71,999.67	6375	492,948.98	57,154.67	41,129.04	344,964.55	71.96	3.72	100.00	90.55
Oct-01	74,400.00	72,688.66	3504	486,878.82	54,202.44	34,076.02	292,561.23	62.87	2.99	97.70	90.59
Nov-01	72,000.00	71,944.98	6501	505,753.22	56,383.20	35,163.53	302,405.02	62.37	2.76	99.92	94.84
Dec-01	63,100.00	63,100.00	5303	410,935.51	48,368.05	34,859.36	292,261.60	72.07	3.39	100.00	91.48
Jan-02	66,200.00	65,950.00	4218	370,388.23	44,637.60	37,234.19	305,246.00	83.41	3.84	99.62	89.21
Feb-02	67,200.00	67,200.00	2233	404,055.18	48,992.87	43,019.40	350,109.41	87.81	4.10	100.00	89.40
Mar-02	74,400.00	74,400.00	4150	464,752.64	55,903.07	47,169.13	386,053.06	84.38	3.99	100.00	92.19
Apr-02	72,000.00	66,361.67	4188	438,567.06	52,252.71	37,080.40	311,773.09	70.96	3.33	92.17	89.19
May-02	74,400.00	74,400.00	4765	496,973.03	59,078.09	45,811.93	379,732.90	77.54	3.60	100.00	90.16
Jun-02	72,000.00	71,926.20	3078	437,889.11	52,368.78	39,750.04	330,614.19	75.90	3.53	99.90	85.30
Jul-02	69,600.00	66,295.00	3105	405,813.58	48,928.65	37,125.37	308,805.08	75.88	3.53	95.25	82.89
Aug-02	74,184.23	74,184.23	3220	444,864.35	52,650.24	36,253.41	306,426.03	68.86	3.38	100.00	88.08
Sep-02	72,000.00	71,674.87	5652	467,150.36	55,835.38	41,249.85	344,568.65	73.88	3.57	99.55	89.75
Oct-02	74,400.00	71,171.67	4518	430,694.98	51,462.77	38,668.70	322,127.50	75.14	3.54	95.66	91.08

Operation : operation time
Service : service time of NQS
Jobs : the number of sumitted jobs.
CPU : used CPU time summed over nodes
Scalar : used time of scalar processor.
EP : used time of element parallel operations
EP total : total time of element parallel operations (EP x 7 + Scalar)
EP (%) : ratio of element parallel operations (EP/Scalar)
Performance : average perfromance in GFlops/Node
Op(%): Operation/Service
Used(%) : CPU/Operation

Usage of supercomputer (CPU & VU time)
From Apr. 1996 to Mar. 1997

Queue	q1a		q1b		q1c		q1d		q4	
Group	cpu	vu	cpu	vu	cpu	vu	cpu	vu	cpu	vu
scqcd	57.1	30.3	114.8	24.6	623.0	564.4	233.2	215.0	692.8	437.8
scknzw	27.5	18.8	127.7	98.5	621.8	543.5	478.3	499.1	20.8	7.0
scosaka	1.4	1.3	1.2	1.0	158.0	152.5	182.6	181.9	0.4	0.1
scjuhyo	1.8	1.7	27.2	26.8	1000.1	992.1	2575.4	2534.1	0.0	0.0
scseries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
scastro	9.6	8.3	30.9	28.4	608.7	583.1	889.2	873.2	13.6	5.0
scchaos	14.2	7.1	37.8	20.8	435.9	180.0	402.6	188.4	0.0	0.0
sctaro	4.6	3.8	0.0	0.0	70.7	67.3	0.4	0.1	1.6	0.3
scminami	24.3	12.3	46.5	30.6	47.3	33.6	32.4	25.0	113.2	59.8
scgauge	5.4	3.5	55.0	46.3	360.5	349.7	229.7	217.8	8.0	7.9
scqed	1.2	1.2	6.2	5.8	866.4	856.9	908.8	902.4	13.6	13.2
scgrav	49.7	37.4	14.8	10.2	5.4	5.0	2.1	2.0	0.0	0.0
sccpnl	0.5	0.0	2.7	0.5	2.7	0.5	0.0	0.0	0.0	0.0
Total	197.3	125.7	463.8	293.5	4800.5	4328.6	5934.7	5639.0	864.0	531.2

Queue	q4l		q8		q64		Total	
Group	cpu	vu	cpu	vu	cpu	vu	cpu	vu
scqcd	6086.8	4668.6	55819.2	42646.9	460812.8	349756.9	524439.7	398343.5
scknzw	0.0	0.0	2356.8	2097.6	0.0	0.0	3632.9	3264.5
scosaka	0.0	0.0	304.8	294.4	0.0	0.0	648.1	631.3
scjuhyo	0.0	0.0	0.0	0.0	0.0	0.0	3604.5	3554.7
scseries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
scastro	0.0	0.0	0.0	0.0	0.0	0.0	1552.0	1498.0
scchaos	0.0	0.0	0.0	0.0	0.0	0.0	890.5	396.3
sctaro	0.0	0.0	0.0	0.0	0.0	0.0	77.3	71.5
scminami	194.8	113.0	1014.4	667.5	780.8	533.3	2252.7	1475.0
scgauge	0.0	0.0	0.0	0.0	0.0	0.0	658.6	625.2
scqed	1913.6	1896.4	2485.6	2460.7	0.0	0.0	6195.4	6136.6
scgrav	0.0	0.0	0.0	0.0	0.0	0.0	72.0	54.6
sccpnl	0.0	0.0	0.0	0.0	0.0	0.0	5.9	1.0
Total	8195.2	6677.9	61980.8	48166.1	461593.6	350290.2	544029.6	416052.3

CPU : Scalar + Vector CPU
VU : vector CPU

Usage of supercomputer (CPU & VU time)
From Apr. 1997 to Mar. 1998

Queue	q1a		q1b		q1c		q1d		q4	
Group	cpu	vu	cpu	vu	cpu	vu	cpu	vu	cpu	vu
scqcd	101.2	63.3	307.9	259.0	218.1	146.0	67.9	41.7	189.3	102.2
scgauge	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
scknzw	61.8	51.2	301.0	259.7	904.9	859.2	447.3	426.8	14.9	3.0
scgrav	84.4	69.1	151.5	124.2	723.0	559.4	356.4	286.3	0.0	0.0
scqed	1.8	1.7	1.2	1.2	40.0	39.4	1858.0	1847.0	8.4	8.2
scseries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
scqchaos	0.0	0.0	0.0	0.0	11.7	11.3	0.0	0.0	0.0	0.0
scastro	4.7	4.1	17.2	16.5	109.1	105.6	14.6	14.2	28.4	22.9
scdngvn	6.1	3.0	61.7	43.2	106.2	59.0	0.0	0.0	9.0	0.6
sctaro	10.5	8.6	313.0	264.9	259.3	226.7	764.1	674.0	0.0	0.0
scibac	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sccpnl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
scjuhyo	0.7	0.6	1.7	1.4	1548.4	1540.0	1245.8	1239.3	0.7	0.2
scminami	23.7	10.3	84.4	53.3	67.5	54.9	722.0	700.2	13.8	4.3
scnucll	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	3.0	2.6
Total	295.4	212.1	1239.6	1023.4	3988.2	3601.5	5476.1	5229.5	267.5	144.0

Queue	q4l		q8		q64		Total	
Group	cpu	vu	cpu	vu	cpu	vu	cpu	vu
scqcd	8994.2	6878.3	39616.1	28504.8	427979.5	339721.1	477474.2	375716.4
scgauge	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
scknzw	107.7	69.4	6217.3	4340.6	0.0	0.0	8054.9	6009.9
scgrav	0.0	0.0	0.0	0.0	0.0	0.0	1315.3	1039.0
scqed	13108.8	13037.4	2861.7	2827.0	0.0	0.0	17879.9	17761.9
scseries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
scqchaos	0.0	0.0	0.0	0.0	0.0	0.0	11.7	11.3
scastro	42.9	36.8	441.9	367.4	0.0	0.0	658.8	567.5
scdngvn	77.4	5.0	0.0	0.0	0.0	0.0	260.4	110.8
sctaro	0.0	0.0	0.0	0.0	0.0	0.0	1346.9	1174.2
scibac	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
sccpnl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
scjuhyo	0.3	0.1	0.0	0.0	0.0	0.0	2797.6	2781.6
scminami	463.1	300.9	1580.9	1279.3	3902.8	2829.4	6858.2	5232.6
scnucll	7.0	5.7	15.6	15.3	22200.5	19565.1	22226.3	19588.9
scqmdrel	0.0	0.0	0.0	0.0	0.0	0.0	11266.8	10210.5
Total	22801.4	20333.6	50733.5	37334.4	454082.8	362115.6	538884.5	429994.1

CPU : Scalar + Vector CPU
VU : vector CPU

Usage of supercomputer (CPU & VU time)
From Apr. 1998 to Mar. 1999

Queue	q1a		q1b		q1c		q1d		q4		q4l		q8	
Group	cpu	vu	cpu	vu	cpu	vu	cpu	vu	cpu	vu	cpu	vu	cpu	vu
scqed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	15.8	15.7	0.0	0.0
scqcd	40.3	8.8	43.7	18.3	47.2	14.5	353.8	318.6	64.3	34.4	22317.5	17408.3	49133.6	38275.7
scknzw	140.2	119.3	649.8	586.9	907.8	854.1	769.8	720.6	43.2	28.2	687.4	587.5	1716.5	1368.9
sdngvn	0.8	0.1	0.4	0.2	133.0	66.5	0.0	0.0	26.0	3.4	386.1	60.1	1364.0	101.5
scastro	0.4	0.1	0.0	0.0	0.0	0.0	7.4	7.2	50.5	36.3	184.8	162.8	1917.5	1558.4
sctaro	1.9	1.6	30.8	29.1	187.4	176.9	188.1	178.9	26.4	8.1	1477.6	1065.9	0.0	0.0
scminami	6.6	3.1	9.3	7.2	3542.6	3467.6	2086.8	2041.5	0.0	0.0	0.0	0.0	0.0	0.0
scgrav	14.3	8.8	56.0	38.7	715.6	465.8	702.8	533.4	1.4	0.0	0.0	0.0	0.0	0.0
scnucll	1.5	1.4	4.2	2.0	9.7	1.6	68.1	64.9	1.8	1.6	543.8	509.5	1695.3	1612.4
scqchaos	0.2	0.0	1.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
scocha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0
scjuhyo	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
scgauge	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
scstring	1.3	0.7	0.5	0.1	25.0	20.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	340.2	234.3	1084.6	902.0	6012.3	5399.2	4455.4	4120.0	224.7	117.0	25614.3	19811.0	57549.3	44392.3

Queue	q16a		q16b		q16c		q16d		q64		Total	
Group	cpu	vu	cpu	vu	cpu	vu	cpu	vu	cpu	vu	cpu	vu
scqed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.9	15.8
scqcd	9170.0	7204.0	9192.1	7226.1	9188.1	7207.8	9030.5	7092.8	360141.2	262897.6	468722.3	347706.9
scknzw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27898.4	22662.1	32813.1	26927.6
sdngvn	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1910.3	231.8
scastro	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5769.5	3145.9	7930.1	4910.7
sctaro	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1912.2	1460.5
scminami	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5645.3	5519.4
scgrav	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1490.1	1046.7
scnucll	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	37391.6	33440.7	39716.0	35634.1
scqchaos	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.2
scocha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0
scjuhyo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
scgauge	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
scstring	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.8	21.6
Total	9170.0	7204.0	9192.1	7226.1	9188.1	7207.8	9030.5	7092.8	431200.7	322146.3	560168.4	423459.7

CPU : Scalar + Vector CPU
VU : Vector CPU

Usage of supercomputer (CPU & VU time)
From Apr. 1999 to Dec. 1999

Queue	q1a		q1b		q1c		q1d		q4		q4l		q8	
Group	cpu	vu	cpu	vu	cpu	vu	cpu	vu	cpu	vu	cpu	vu	cpu	vu
scqcd	21.8	14.9	60.4	46.3	37.6	19.9	0.0	0.0	54.4	42.6	2650.0	2257.1	32463.3	21426.6
sdngvn	0.2	0.0	1.4	0.0	10.7	0.2	0.0	0.0	4.4	0.3	2194.8	240.1	2422.3	101.4
scknzw	73.4	60.6	317.6	288.2	961.9	901.5	286.8	278.2	0.0	0.0	0.0	0.0	0.0	0.0
scnucll	0.0	0.0	0.2	0.2	2.1	2.1	0.7	0.7	1.0	1.0	120.3	115.8	65.4	60.4
scminami	2.2	0.6	1.0	0.2	1453.8	1426.3	2018.8	1982.7	2.9	1.0	9.0	1.9	78.3	36.6
sctaro	0.4	0.3	0.5	0.5	36.9	29.2	1.0	1.0	6.2	4.1	4612.2	3565.0	0.0	0.0
scjuhyo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
scastro	0.6	0.1	0.0	0.0	63.3	61.5	0.0	0.0	10.3	4.3	64.7	56.3	1472.1	1250.8
scgrav	5.7	4.7	442.6	384.7	1084.6	1022.0	2687.7	2612.7	0.9	0.5	6710.5	5204.6	45.1	42.9
Total	104.3	81.2	823.7	720.1	3650.9	3462.7	4995.0	4875.3	80.1	53.8	16361.5	11440.8	36536.5	22918.7

Queue	q16a		q16b		q16c		q16d		q64		Total	
Group	cpu	vu	cpu	vu	cpu	vu	cpu	vu	cpu	vu	cpu	vu
scqcd	17858.8	8243.3	17937.0	8252.2	17452.4	8083.3	17796.7	8229.0	235369.6	175088.1	341692.0	231703.3
sdngvn	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4633.8	342.0
scknzw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1639.7	1528.5
scnucll	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16298.0	14493.7	16487.7	14673.9
scminami	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3566.0	3449.3
sctaro	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4657.2	3600.1
scjuhyo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
scastro	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20479.9	12013.2	22090.9	13386.2
scgrav	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10977.1	9272.1
Total	17858.8	8243.3	17937.0	8252.2	17452.4	8083.3	17796.7	8229.0	272147.5	201595.0	405744.4	277955.4

CPU : Scalar + Vector CPU
VU : vector CPU

Usage of Supercomputer
From Aug.2000 to Mar.2001

Queue	1node			4node	8node			16node			32node(2)		
Group	Budget(h)	Used(h)	Ratio(%)	Used(h)	Budget(h)	Used(h)	Ratio(%)	Budget(h)	Used(h)	Ratio(%)	Budget(h)	Used(h)	Ratio(%)
scqcd	16000	12181.3	76.1	2435	4800	4318.8	90	5300	5035.2	95	11000	10403.6	94.6
scminami	1000	106.5	10.7	15.8	400	7.9	2	100	0	0	100	0	0
scdngvn	1000	756.5	75.7	89.5	50	0	0	0	0	0	0	0	0
scsokaku	800	179.0	22.4	16.7	550	317.7	57.8	250	248.6	99.4	125	121.5	97.2
scknzw	700	436.2	62.3	5.8	200	0	0	0	0	0	0	0	0
scmelqcd	200	0.0	0.0	0	200	0	0	0	0	0	0	0	0
scjuhyo	60	0.0	0.0	0	30	0	0	0	0	0	0	0	0
scrabbit	1500	1178.3	78.5	4.3	200	52.4	26.2	0	0	0	0	0	0
scastro	5600	1510.9	27.0	0	900	0	0	300	0	0	1000	0	0
sctaro	4400	2993.8	68.0	50.5	500	251.3	50.3	400	44.5	11.1	0	0	0
scconfn	300	1.2	0.4	0	0	0	0	0	0	0	0	0	0
schyper	1000	885.1	88.5	0	0	0	0	0	0	0	0	0	0
Total	32560	20228.8		2617.6	7830	4948.1		6350	5328.3		12225	10525.1	

Available time for users is 5447 hours.

Usage of Supercomputer
From Apr. 2001 to Mar. 2002

Queue	1node			4node	8node			16node			32node(2)		
Group	Budget(h)	Used(h)	Ratio(%)	Used(h)	Budget(h)	Used(h)	Ratio(%)	Budget(h)	Used(h)	Ratio(%)	Budget(h)	Used(h)	Ratio(%)
scqcd	20000	10060.6	50.3	2859.2	6000	5167.7	86.1	7000	6389.2	91.3	16500	15921.2	96.5
scminami	500	1.2	0.2	0.5	200	0	0	100	0	0	100	0	0
scalar	350	342.4	97.8	13.1	200	112.1	56.1	250	252.8	101.1	0	0	0
scdngvn	900	37.0	4.1	333.4	1200	371	30.9	0	0	0	0	0	0
scsokaku	1600	1139.5	71.2	52	604	276.3	45.7	550	189.6	34.5	260	257.9	99.2
scknzw	1550	1406.2	90.7	187.2	600	598.6	99.8	300	215.6	71.9	0	0	0
scmelqcd	1000	85.8	8.6	22.8	500	36.2	7.2	400	294.5	73.6	0	0	0
scjuhyo	300	0.0	0.0	0	0	0	0	0	0	0	0	0	0
scrabbit	5000	77.8	1.6	12	1000	214.7	21.5	1000	0	0	0	0	0
scastro	3600	2393.8	66.5	0	1100	0	0	300	0	0	1000	0	0
sctaro	3000	2151.9	71.7	9.7	2000	1046.3	52.3	2000	653.4	32.7	0	0	0
scconfn	300	5.5	1.8	0	0	0	0	0	0	0	0	0	0
schyper	2000	1435.3	71.8	0	300	0	0	0	0	0	0	0	0
Total	40100	19137.0	47.7	3489.9	13704	7821.9	57.1	11900	7995.1	67.2	17860	16179.1	90.6

Available time for users was 8337 hours

Part IV

Research activities under the KEK Large Scale Simulation Program

Research activities under the KEK Large Scale Simulation Program

Report for the Large Scale Simulation Program
Review Committee

Chapter 1

scqcd group

Study of Lattice Quantum Chromodynamics with Large Scale Numerical Simulations

1.1 Members

The **scqcd** group is officially known as the *JLQCD* collaboration. The group leader is Masanori Okawa (KEK till 2001; moved to Hiroshima University early 2002). The current members of the JLQCD collaboration are the following.

Shoji Hashimoto, Takashi Kaneko, Yoshinobu Kuramashi,
Shinichi Tominaga, Naoto Tsutsui, Norikazu Yamada
High Energy Accelerator Research Organization (KEK),
Tsukuba 305-0031, Japan

Sinya Aoki, Yoichi Iwasaki
Institute of Physics, University of Tsukuba,
Tsukuba 305-8571.

Ken-Ichi Ishikawa, Naruhito Ishizuka, Kazuyuki Kanaya, Akira Ukawa,
Tomoteru Yoshié
Institute of Physics, University of Tsukuba,
Tsukuba 305-8571.
and
Center for Computational Physics, University of Tsukuba,
Tsukuba 305-8577.

Masataka Fukugita
Institute for Cosmic Ray Research, University of Tokyo,
Kashiwa 277-8582.

Tetsuya Onogi
Yukawa Institute for Theoretical Physics, Kyoto University,
Kyoto 606-8502.

Masanori Okawa
Department of Physics, Hiroshima University,
Higashi-Hiroshima 739-8526.

1.2 Research overview

The prime goal of the JLQCD collaboration is to calculate a range of physical quantities relevant to hadron phenomenology starting from the first principles of the strong interaction, *i.e.* Quantum Chromodynamics (QCD). The quantities of interest include hadron masses, quark masses, weak interaction matrix elements.

In particular, the calculation of the weak matrix elements is a necessary step to extract fundamental parameters of the Standard Model from experimental data, and the lattice QCD simulation provides an unique possibility to calculate them without employing some model assumptions. The kaon B parameter, the B meson decay constant and B parameter, and the B meson semileptonic decay form factors are among the most important physical quantities in this respect.

The collaboration started in 1995 when the Supercomputer project of KEK was launched. The members have enough experiences on the lattice gauge theory and its numerical simulations, so that we could quickly write effective computer program for the parallel vector supercomputer Fujitsu VPP-500/80, which was the most powerful machine used on this field. The works described in Section 1.3 had been done on VPP-500.

In 2000 the Fujitsu machine was replaced by a 10 times faster machine Hitachi SR8000-F1/100. Then, we decided to use the increased machine power to eliminate the quenched approximation in the previous lattice calculations. This project is still underway and its status is reported in Section 1.4.

1.3 Works done on VPP-500

1.3.1 Kaon B parameter

The precise calculation of kaon B parameter B_K is crucial for the determination of a Kobayashi-Maskawa matrix element Im V_{td}, which describes the magnitude of CP violation in the Standard Model.

In the lattice calculation of B_K the chiral symmetry plays an important role as it forbid a mixing of the relevant $\Delta S{=}2$ operator $(\bar{s}d)_L(\bar{s}d)_L$ with other operators carrying different chirality. Unless the mixing is forbidden, the matrix element calculated on the lattice contains unwanted pieces which may diverge in the limit of physical quark masses. The perturbation theory was originally used to eliminate the mixed operators, but it turned out the the accuracy is not enough to obtain B_K reliably.

To avoid this problem we developed a method to subtract the mixed operators nonperturbatively [15, 10]. We use a set of chiral Ward identities as a renormalization condition to determine the mixing parameters for the Wilson fermion, which explicitly breaks the chiral symmetry at finite lattice spacing a. As a result we found that the result for B_K is stable against the change of lattice spacing albeit with a large error bar.

Another possible solution to the above problem is to use a lattice fermion action which maintains the chiral symmetry. The staggered fermion is one of the candidates of those lattice fermions. One of the problems in this case is a large scaling violation, which is probably a property of the (unimproved) staggered fermion. In order to control the large scaling violation, we adopt a brute-force strategy: namely we performed several sets of lattice simulations changing lattice spacing a from 0.24 fm to 0.04 fm, which corresponds to lattice size from 12 3×24 to $56^3\times96$ [13]. Then, we extrapolate the data with a theoretically expected $O(a^2)$ form including some higher order terms. The extrapolation is plotted in Figure 1.1.

The result of this work is currently considered as a standard input for CKM matrix elements fitting, and is even treated as a "benchmark" result for B_K. It means that it is used to test other modern formulation of lattice fermions which preserves chiral symmetry.

1.3.2 Light quark mass

The quark masses are fundamental parameters of the Standard Model, and hence their precise determination is important to gain insight into the mechanism of mass generation in nature.

The accuracy of the lattice calculation of light quark masses was limited by the large perturbative coefficients in the matching of the continuum operator

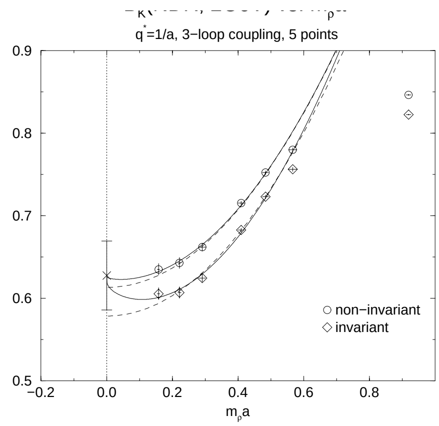


Figure 1.1: B_K with the staggered fermion. The results are plotted as a function of lattice spacing. Two symbols represent different lattice operators which should eventually lead to the same continuum limit.

onto its lattice counterpart. Therefore, an essential step to obtain reliable estimate for the quark masses is to calculate the matching in a nonperturbative way. We performed such a nonperturbative matching for the staggered fermion action using the Regularization Independent (RI) scheme, and calculated the light quark masses extrapolated in the continuum limit as shown in Figure 1.2 [9].

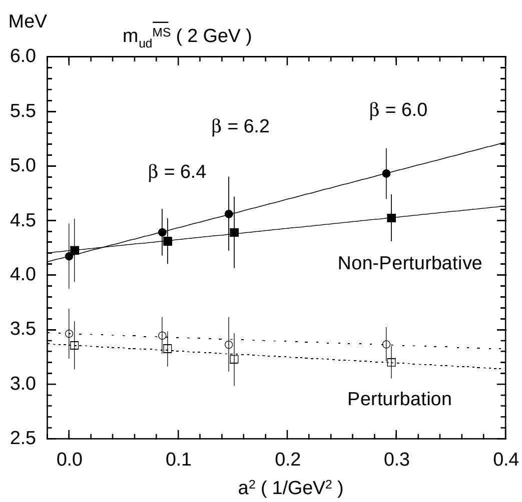


Figure 1.2: Light quark mass with the staggered fermion. The results are plotted as a function of lattice spacing squared.

1.3.3 Pion decay constant

For the staggered fermion which preserves chiral symmetry in a flavor-mixed direction, the partially conserved axial current may be defined and the problem of the perturbative matching is absent. We calculated the pion decay constant with and without the partially conserved axial current and investigated the effect of the (non-)perturbative matching [6].

1.3.4 Proton decay matrix element

The proton decay is an unique prediction of the Grand Unified Theory (GUT) models, and its experimental search is one of the most interesting frontiers in particle physics. In order to make an accurate prediction on the decay rate from a certain model, however, one needs a nonperturbative calculation of the hadron matrix element, in which a GUT operator is sandwiched by the proton state and a final state meson. The lattice QCD is the only possibility to calculate such matrix element in a model independent manner.

We studied the proton decay matrix element in some detail and found that the matrix element seems to be larger than the estimate of the chiral lagrangian by a factor 3–5 [7] which gives stronger constraints on the model parameters of GUT theories.

1.3.5 B meson decay constant and B parameter

The B meson decay constant f_B and B parameter B_B control the magnitude of the neutral B meson (B^0–$\bar{B}^0$) mixing, and thus they are needed to extract the Kobayashi-Maskawa matrix element $|V_{td}|$, which is crucial in the test of the unitarity of the Kobayashi-Maskawa matrix. The lattice calculation of these parameters is one of the main goals of our collaboration.

The lattice simulation of heavy quarks such as the b quark requires a dedicated treatment, since their mass is too large to simply simulate on a lattice with currently available lattice spacings.

We first attempted to calculate f_B using the conventional Wilson fermion and its $O(a)$-improved version, which requires a reinterpretation of mass parameters when used for heavy quarks (El-Khadra, Kronfeld, Mackenzie, 1993). We performed an investigation of its lattice spacing effect and found that f_B is already insensitive to the lattice spacing around $a \simeq 0.1$ fm, and then we obtained the results in the continuum limit as presented in Figure 1.3 [11].

We also carried out a calculation of f_B using the lattice NRQCD, an effective theory valid for heavy quarks. We studied the systematic errors associated with the effective theory using lattice data at several lattice spacings and found that they are controlled at 10–15% level [8]. The result is totally consistent with the other approach, and hence it makes the lattice calculation of f_B more confident.

More recently, we have carried out a calculation of the B meson B parameter B_B using the same NRQCD formulation for heavy quark and published the most complete calculation of this quantity [2].

1.3.6 B meson semileptonic decays

The $B \to \pi l \nu$ semileptonic decay may be used to extract the Kobayashi-Maskawa matrix element $|V_{ub}|$. The basic strategy to calculate the form factor

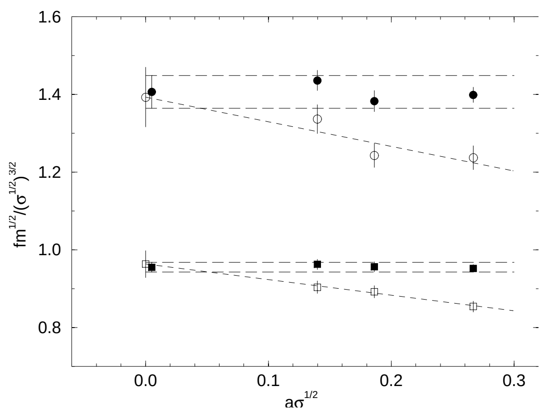


Figure 1.3: Heavy-light decay constants normalized as $f_P\sqrt{M_P}$ with physical scale given by the string tension. Circles denote $f_B\sqrt{m_B}$ while squares are $f_D\sqrt{m_D}$. Continuum extrapolation is shown for both Wilson (open) and $O(a)$-improved (filled symbols) fermions.

for this decay mode is the same as those used for f_B and B_B, but it is computationally more demanding as it requires the simulation of mesons with finite spatial momenta. Also, the heavy quark scaling is less simple due to the q^2 dependence of the form factor, where q is the momentum transfer to the final state lepton pair.

We calculated the necessary form factors $f^+(q^2)$ and $f^0(q^2)$ through their another definition $f_1(v \cdot k)$ and $f_2(v \cdot k)$ motivated by the Heavy Quark Effective Theory (HQET). The advantage of the HQET motivated form factors is that their heavy quark scaling is manifest, and therefore it is easy to interpolate/extrapolate as a function of $1/m_Q$. The lattice calculation was performed using the NRQCD action as applied to f_B and B_B in our previous works. We investigated the heavy and light quark mass dependences in detail, and obtained a physical prediction for partial decay rate integrated over a certain kinematical region [5].

1.3.7 $\pi\pi$ scattering

One of the most challenging problems in the low energy hadron physics is the understanding of the $\Delta I = \frac{1}{2}$ enhancement and the quantitative estimate of the direct CP violation ϵ'/ϵ. As a first step toward this goal, we investigated the $\pi\pi$ scattering in the lattice simulation. For the $I = 2$ channel, which is the simplest channel among the $\pi\pi$ interaction precesses, we have successfully obtained the scattering length by actually calculating the four-point correlation function and the energy shift relative to the free two-pion state [3]

1.3.8 QCD thermodynamics

The dynamical properties of QCD at zero temperature are the confinement and spontaneous breakdown of chiral symmetry. Both of these properties disappear through a phase transition at finite temperature. It is very important to make a nonperturbative study of the phase transition by lattice QCD, since its prediction can be tested by heavy ion experiments and gives information on the evolution of the early universe.

To understand the nature of the phase transition, systematic finite size scaling studies are necessary. Including the effect of dynamical quarks with the staggered fermion, we performed a scaling analysis of susceptibilities as a function of the quark mass and found an indication that the second order phase transition locates at the zero quark mass limit and disappears for non-zero quark masses [14].

1.4 Works being done on SR8000: Dynamical QCD simulations

Due to the limitation of computational resources, most of the studies described in the previous sections employed the so-called quenched approximation, with which one neglects the effect of dynamical creation and annihilation of quark and anti-quark pairs. It induces an uncontrollable source of systematic errors, and should eventually be eliminated by performing unquenched simulations, which include the dynamical quark effects.

Therefore, we shifted our main project to the dynamical quark simulations in 2000 when the supercomputer served for the KEK Supercomputer project was updated to a over-tera-flops machine Hitachi SR8000, which was the most powerful machine at that time available for the study of lattice gauge theory.

Since the projects are ongoing, most of the works presented in this section have not yet published as journal papers, but some preliminary results have been reported at some conferences (mainly at the annual lattice conferences).

1.4.1 Two-flavor QCD simulations

We started dynamical QCD simulations using the $O(a)$-improved Wilson fermion with a nonperturbatively determined improvement coefficient c_{SW} (Jansen, Sommer, 1998). The first several months were devoted to develop efficient simulation program working on the new machine, and also some improvements in the dynamical fermion simulation were pursued. Some of the results are presented in [4].

Since we aimed to calculate hadron matrix elements as described in Section 1.3, we chose the lattice spacing relatively small, $a \simeq 0.1$ fm, to control the systematic errors associated with the finite lattice spacing. The price to pay is the limited physical volume. We, therefore, first studied the finite size effect in some detail performing simulations on $12^3{\times}48$, $16^3{\times}48$, and $20^3{\times}48$ lattices. We found that the finite size effect can be kept small on our largest lattice for mesons, while it is more problematic for baryons [28, 19].

Our first observation in our dynamical quark simulation was the sea quark effect in the light meson hyperfine splitting. In the quenched approximation, it was known that the K^* mass is much lower than the experimental value when the strange quark mass is determined by the K meson mass as input. In our dynamical simulation we found that this disagreement becomes smaller as the sea quark mass decreases, which is a clear indication of the sea quark effect [21, 19].

The most recent topic in the unquenched simulations is the search for the chiral logarithm in the lattice observables. Since the unquenched QCD is a consistent theory, we expect to find the pion loop effect predicted by the chiral perturbation theory, as far as the sea quark is light enough. We have not found, however, the characteristic behavior known as the chiral logarithm in our lattice data, which suggests that the sea quark mass may not be small enough. We therefore need sensible method to obtain chiral limit of many physical quantities [21, 17].

We have also started a calculation of the B meson decay constant and B parameter on the unquenched lattice. Our preliminary results are presented in [25].

1.4.2 Toward three-flavor QCD simulation

Although the number of light quark flavors which affect the dynamics of low energy QCD is three (up, down and strange quarks) in the nature, most of the unquenched simulations have been done with two-flavor of dynamical quarks. The main reason is the lack of efficient algorithm to simulate odd number of dynamical flavors for the Wilson-type lattice fermions[1]. Therefore, we developed an algorithm to treat odd number of dynamical quarks by modifying the usual Hybrid Monte Carlo algorithm (Duane *et al.*, 1987) with a polynomial approximation of inverse square-root of the fermion matrix. Performing a test of the algorithm on a lattice of realistic volume, we found that it works efficiently for the sea quark mass around the physical strange quark mass [4].

Our first attempt of the three-flavor dynamical QCD simulation was done with the $O(a)$-improved Wilson fermion and the standard (plaquette) gauge action. Surprisingly, we found a first-order phase transition as the sea quark mass decreases. It occurs even at zero temperature, and we suspect that the phase transition is induced by a lattice artifact. In fact, if we use a RG (renormalization group) improved gauge action (*à la* Iwasaki) in a similar parameter region we do not find it [24]. For this reason, the three-flavor QCD simulation with the usual standard plaquette gauge action combined with the $O(a)$-improved Wilson fermion is unrealistic.

Before starting large scale simulations in three-flavor QCD using the RG-improved gauge action, we have to determine the $O(a)$-improvement parameter $c_{\rm SW}$ nonperturbatively using the Shrödinger functional technique in order to reduce the lattice spacing effect as much as possible. This work is currently in its final stage.

1.5 Future directions

Since a set of simulations of two-flavor QCD has been completed, we are shifting our main project to the three-flavor QCD. As soon as the nonperturbative calculation of the $O(a)$-improvement parameter, which is itself a time-consuming dynamical simulations, we are going to start an exploratory simulation of three-flavor QCD. Its first physics target will be the light hadron spectroscopy. In

[1]The R algorithm (Gottlieb *et al.*, 1987) may be used for any number of flavors, and actually used for simulations with the staggered fermions. It contains, however, a source of systematic error at finite molecular dynamics step size.

particular, the effect of third flavor on the K–K^* meson mass splitting is interesting.

The data set of gauge configurations generated with two flavors of dynamical quarks may open a wide range of applications to the hadron matrix elements. The B meson decay constant and B parameter have already been calculated, and a calculation of the Grinstein ratio of the heavy-light decay constant is underway. In addition, we are planning to calculate the K_{l3} decay form factors, $B \to D^{(*)} l\nu$ form factors at zero recoil, $B \to \pi(\rho) l\nu$ form factors, and the proton decay matrix elements, on our unquenched gauge configurations. The kaon B parameter is also an important quantity, for which the unquenched calculation is to be done, but its calculation with the Wilson-type fermion is rather hard. Therefore, we are going to investigate a possibility to use other fermion formulations for valence quarks.

We also consider to make our unquenched gauge configurations available for other groups in the KEK Supercomputer project. The global network HEPnet-J/sc is being constructed to enhance data sharing among major laboratories of particle and nuclear physics laboratories in Japan. We believe that the study of lattice QCD in Japan is significantly accelerated by sharing unquenched configurations in the near future.

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Number of citations = 1.

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Number of citations = 10.

[67] S. Hashimoto, "Summary Of Lattice Results For Decay Constants, Mixing, etc," invited talk at 8th International Symposium On Heavy Flavor Physics (Heavy Flavors 8), 25-29 Jul 1999, Southampton, England.

[68] S. Hashimoto, "B decays on the lattice," plenary talk at 17th International Symposium on Lattice Field Theory (LATTICE 99), Pisa, Italy, 29 Jun -

3 Jul 1999; Nucl. Phys. Proc. Suppl. **83**, 3 (2000) [arXiv:hep-lat/9909136].
Number of citations = 40.

[69] Y. Kuramashi, "Light hadron weak matrix elements," plenary talk at 17th International Symposium on Lattice Field Theory (LATTICE 99), Pisa, Italy, 29 Jun - 3 Jul 1999; Nucl. Phys. Proc. Suppl. **83**, 24 (2000) [arXiv:hep-lat/9910032].
Number of citations = 10.

[70] T. Yoshie, "Light hadron spectroscopy," plenary talk at Lattice 97: 15th International Symposium on Lattice Field Theory, Edinburgh, Scotland, 22-26 Jul 1997; Nucl. Phys. Proc. Suppl. **63**, 3 (1998) [arXiv:hep-lat/9711017].
Number of citations = 22.

[71] T. Onogi, "Semileptonic form factors," plenary talk at Lattice 97: 15th International Symposium on Lattice Field Theory, Edinburgh, Scotland, 22-26 Jul 1997; Nucl. Phys. Proc. Suppl. **63**, 59 (1998) [arXiv:hep-lat/9802027].
Number of citations = 8.

[72] A. Ukawa, "Finite-temperature QCD on the lattice," plenary talk at Lattice 96: 14th International Symposium on Lattice Field Theory, St. Louis, MO, 4-8 Jun 1996; Nucl. Phys. Proc. Suppl. **53**, 106 (1997) [arXiv:hep-lat/9612011].
Number of citations = 60.

Chapter 2

scknzw group

Monte Carlo Study of Color Confinement Mechanism and Monopole in QCD

2.1 Present staff member

Suzuki, Tsuneo, *Kanazawa University*, Professor
Koma, Yoshiaki, *Max Planck Institute*, PD
Ichie, Hiroko, *Kanazawa University*, PD
Kitahara, Shun-ichi, *Jumonji Junior College*, Lecturer
Yazawa, Tateaki, *Kinjo Junior College*, Lecturer
Vitaly Bornyakov, *IHEP & Kanazawa University*
Maxim Chernodub, *ITEP & Kanazawa University*

DESY-ITEP-KANAZAWA collaboration in full QCD study

DESY group (G.Schierholz, T.Streuer(PD),H.Stueben)
ITEP group (M.Polikarpov, S.Veselov, F.Gubarev)
KANAZAWA group

2.2 Research Overview

The purpose of this study is to clarify what is the confinement mechanism in QCD (quench and full), making use of large-scale Monte Carlo simulations. Our standpoint is based on 'tHooft's idea of monopole condensation after abelian projection of QCD. Block-spin transformation of monopoles on the dual lattice and an inverse Monte Carlo method are our unique way of deriving an infrared effective abelian action in the continuum limit.

2.3 Results in pure QCD study 1990-2000 — mainly using vector machine such as VPP500

From the last 12 years' studies, we have found important evidence for 'tHooft conjecture. That is, color confinement is due to monopole condensation.

2.3.1 Discovery of abelian dominance

Performing abelian projection in the maximally abelian gauge (MA), we found the ablian degree of freedom can reproduce the essential features of confinement in QCD. (Ref: Suzuki and Yotsuyanagi, 1990; Hioki *et al.*, 1991)

2.3.2 Discovery of monopole dominance

In MA gauge, we can extract monopole currents from abelian link variables. It is found that the monopole degree of freedom among abelian variables alone is responsible for the confinement problem. (Ref: Shiba and Suzuki, 1994; Ejiri *et al.*, 1997)

2.3.3 Derivation of an effective monopole action

Extending the Swendsen inverse Monte Carlo method, we successfully derived an effective monopole action. (Ref: Shiba and Suzuki, 1995)

2.3.4 Block-spin transformation and the quantum perfect monopole action $SU(2)$ and $SU(3)$

Performing a block spin transformation of monopole currents, we studied a renormalization flow. Finally we found a quantum perfect monopole action showing the scaling in the continuum limit. Energy-entropy balance showed the occurence of monopole condensation at least in pure QCD similarly as found in compact QED. The monopole action can be transformed into that of lattice string model. A quantum perfect operator for the static potential was also developed with which the rotational invariant static potential was obtained theoretically using the derived string model [9, 11].

2.3.5 Detailed study of the dual Meissner effect in the meson case

The detailed analyses of the flux distribution around static quark-antiquark pair was made numerically [36]

2.3.6 $T \neq 0$ QCD and monopole

Monopoles are shown to play important role also in the confinement-deconfinement phase transition. Even in the high teperature phase, there remains a non-perturbative effect. It can be understood in terms of a Coulomb gas of static monopoles and they tend to 'tHooft-Polyakov instantons in the high temperature limit [4]. (Ref: Kitahara, Matsubara and Suzuki, 1995)

2.4 Results in full QCD study: 2001~ — mainly using parallel maschine SR8000

We are making simulations of full QCD using $N_f = 2$ non-perturbatively $O(a)$ improved clover fermion on $16^3 \times 8$ and $24^3 \times 8$. We are also using $T = 0$ configurations on $16^3 \times 32$ and $24^3 \times 48$ taken QCDSF group at DESY Zeuthen and $16^3 \times 8$ data taken by ITEP group. The purpose of this particular study is to understand the mechanism of phase transition and the relation between chiral breaking and confinement in terms of abelian and monopole degrees of freedom.

2.4.1 Observation of abelian and monopole dominance

Abelian and monopole dominances are seen also in full QCD. But the density of monopoles is twice larger than that in the quenched QCD. This is due to the effect from dynamical charged quarks [43].

2.4.2 Screening and confinement. flattening of the static potential

Screening, the flattening of the static potential was observed from the Polyakov loop correlators. How the screening is understood in the framework of effective abelian theories was clarified. Why the screening is observed more easily in the Polyakov-loop correlators than in the Wilson loop was also shown [2, 1].

2.4.3 The dual Meissner effect in the meson and the baryon cases

The dual Meissner effect is observed clearly also in the meson case and in the baryon case [19].

2.5 On-going project using SR8000

We are studying the following subjects using $N_f = 2$ non-perturbatively $O(a)$ improved clover fermion on $16^3 \times 8$ and $24^3 \times 8$ and $24^3 \times 10$ lattices.

1. To fix the critical T_c in the chiral and the continuum limit combining the data of $16^3 \times (6, 8)$ and $24^3 \times (8, 10)$.
2. To determine an effective action including the effects from a dynamical charge like quarks.
3. To understand the mechanism of the phase transition in terms of monopoles.
4. To understand the gauge problem of monopole dynamics.
5. To measure directly the entropy and the energy of monopole loops.
6. The detailed study of the flux-tube profile in the baryon case and the vacuum state.

2.6 Computers used

We are using VPP700 maschine at RIKEN and SX5 at RCNP for the purpose of analyses and measurements in full QCD and in pure QCD. We use KEK SR8000 only for generation of configurations. Since April 2002, we use

1. SR8000F1 at KEK
   1200h (8 node), 450h (16 node), 300h (32 node) for generating configuration (lattice size:$24^3 \times 8$).
2. SX-5 at Research Center for Nuclear Physics (RCNP), Osaka U.
   3000h (1 node) for analysis and gauge fixing.
3. VPP700 at RIKEN
   1500h(1node) for quenched QCD study.

2.7 Comment on the Supercomputer project at KEK

The most important is to update the maschine into 10FP one. This is urgent to perform a full QCD simulations on larger lattice. We are happy if the capacity of hard disk will be increased.

Journal papers

[1] V. Bornyakov *et al.*, "Thermodynamics and heavy quark potential in N(f) = 2 dynamical QCD," arXiv:hep-lat/0209157.
Number of citations = 0.

[2] T. Suzuki and M. N. Chernodub, "Screening and confinement in U(1)**(N-1) Abelian effective theories," arXiv:hep-lat/0207018.
Number of citations = 2.

[3] M. N. Chernodub, K. Ishiguro and T. Suzuki, "Blocking of lattice monopoles from the continuum in hot lattice gluodynamics," arXiv:hep-lat/0204003.
Number of citations = 1.

[4] K. Ishiguro, T. Suzuki and T. Yazawa, "Effective monopole action at finite temperature in SU(2) gluodynamics," JHEP **0201**, 038 (2002) [arXiv:hep-lat/0112022].
Number of citations = 2.

[5] V. G. Bornyakov, M. N. Chernodub, F. V. Gubarev, M. I. Polikarpov, T. Suzuki, A. I. Veselov and V. I. Zakharov, "Anatomy of the lattice magnetic monopoles," Phys. Lett. B **537**, 291 (2002) [arXiv:hep-lat/0103032].
Number of citations = 14.

[6] Y. Koma, E. M. Ilgenfritz, H. Toki and T. Suzuki, "Casimir scaling in a dual superconducting scenario of confinement," Phys. Rev. D **64**, 011501 (2001) [arXiv:hep-ph/0103162].
Number of citations = 6.

[7] Y. Koma, E. M. Ilgenfritz, T. Suzuki and H. Toki, "Weyl symmetric representation of hadronic flux tubes in the dual Ginzburg-Landau theory," Phys. Rev. D **64**, 014015 (2001) [arXiv:hep-ph/0011165].
Number of citations = 9.

[8] K. Yamagishi, T. Suzuki and S. i. Kitahara, "Lattice monopole action in pure SU(3) QCD," JHEP **0002**, 012 (2000) [arXiv:hep-lat/0002011].
Number of citations = 3.

[9] M. N. Chernodub, S. Fujimoto, S. Kato, M. Murata, M. I. Polikarpov and T. Suzuki, "An almost perfect quantum lattice action for low-energy SU(2) gluodynamics," Phys. Rev. D **62**, 094506 (2000) [arXiv:hep-lat/0006025].
Number of citations = 16.

[10] F. Shoji, T. Suzuki, H. Kodama and A. Nakamura, "A new gauge fixing method for Abelian projection," Phys. Lett. B **476**, 199 (2000) [arXiv:hep-lat/9910042].
Number of citations = 7.

[11] S. Fujimoto, S. Kato and T. Suzuki, "A quantum perfect lattice action for monopoles and strings," Phys. Lett. B **476**, 437 (2000) [arXiv:hep-lat/0002006].
Number of citations = 11.

[12] F. V. Gubarev, E. M. Ilgenfritz, M. I. Polikarpov and T. Suzuki, "The lattice SU(2) confining string as an Abrikosov vortex," Phys. Lett. B **468**, 134 (1999) [arXiv:hep-lat/9909099].
Number of citations = 18.

[13] M. N. Chernodub, S. Kato, N. Nakamura, M. I. Polikarpov and T. Suzuki, "Various representations of infrared effective lattice SU(2) gluodynamics," arXiv:hep-lat/9902013.
Number of citations = 16.

[14] S. Kitahara, O. Miyamura, T. Okude, F. Shoji and T. Suzuki, "Monopoles and hadron spectrum in quenched QCD," Nucl. Phys. B **533**, 576 (1998) [arXiv:hep-lat/9803020].
Number of citations = 4.

[15] S. Kato, N. Nakamura, T. Suzuki and S. Kitahara, "Perfect Monopole Action For Infrared SU(2) QCD," Nucl. Phys. B **520** (1998) 323.
Number of citations = 23.

[16] H. Kodama, Y. Matsubara, S. Ohno and T. Suzuki, "Inter-meson potentials in dual Ginzburg-Landau theory," Prog. Theor. Phys. **98**, 1345 (1997) [arXiv:hep-ph/9704340].
Number of citations = 0.

[17] K. Ishiguro, Y. Nakatani and T. Suzuki, "Finite Temperature Phase Transition And Monopole Action In SU(2) QCD," Prog. Theor. Phys. Suppl. **138**, 34 (2000).
Number of citations = 0.

[18] T. Yazawa and T. Suzuki, "Lattice instanton action from 3D SU(2) Georgi-Glashow model," JHEP **0104**, 026 (2001) [arXiv:hep-lat/0101004].
Number of citations = 3.

Conference talks

[19] V. Bornyakov, H. Ichie, Y. Koma, Y. Mori, Y.Nakamura, M. Polikarpov, G. Schierholz, T.Streuer, T. Suzuki, "The profile of the broken string in the confined and deconfined phase in full QCD," to appear in Nucl Phys. B (Proc. Suppl.) (2002).

[20] M. N. Chernodub, K. Ishiguro and T. Suzuki, "Lattice monopoles in hot SU(2) gluodynamics as blocked continuum defects," invited talk at the NATO Advanced Research Workshop "Confinement, Topology, and other Non-Perturbative Aspects of QCD", Stara Lesna, Slovakia, 21-27 Jan 2002; arXiv:hep-lat/0202020.
Number of citations = 0.

[21] Y. Koma, "Casimir scaling and hadronic flux tube in a dual superconducting vacuum of QCD," invited talk at ECT* Workshop on the Physics of colour confinement, ECT*, Trento, Italy, 12–21 September, 2001.

[22] Y. Koma, M. Koma, D. Ebert and H. Toki, "Towards the string representation of the dual Abelian Higgs model beyond the London limit," invited talk at Tübingen Workshop on Quarks and Hadrons in Continuum Strong QCD, Tübingen, Germany, 3–6 September, 2001; JHEP **0208**, 047 (2002) [arXiv:hep-th/0108138].
Number of citations = 2.

[23] T. Suzuki, "An almost perfect lattice action for infrared QCD," invited talk at the International Workshop on Non-Perturbative Methods and Lattice QCD, Guangzhou, China, 15-21 May 2000; arXiv:hep-lat/0007036.
Number of citations = 0.

[24] T. Suzuki, "An (Almost) Perfect Lattice Action for SU(2) and SU(3) Gluodynamics," Proceedings of the International Workshop 'Confinement 2000', Osaka.

[25] S. Kato, "Search for a quantum perfect lattice action for infrared QCD," talk at Japan-Germany Seminar, Kanazawa, 1999.

[26] T. Suzuki, "Search for perfect monopole action in QCD," invited talk at 8th Workshop on lattice field theory (VIELAT98), Vienna, 1998.

[27] T. Suzuki, "Low-Energy Effective Theories From QCD," Prepared for 8th Yukawa International Seminar on Non-Perturbative QCD: Structure of the QCD Vacuum (YKIS 97), Kyoto, Japan, 2-12 Dec 1997; Prog. Theor.

Phys. Suppl. **131**, 633 (1998).
Number of citations = 4.

[28] T. Suzuki, S. Kato, N. Nakamura, M. N. Chernodub, M. I. Polikarpov and S. Kitahara, "Dual lattice blockspin transformation and perfect monopole action for SU(2) gauge theory," Prepared for NATO Advanced Study Institute on Confinement, Duality and Nonperturbative Aspects of QCD, Cambridge, England, 23 Jun - 4 Jul 1997.

[29] Y. Mori, Y. Nakamura, V. Bornyakov, M. Chernodub, Y. Koma, M. Polikarpov, G. Schierholz, H. Stueben, T. Suzuki, "Finite temperature phase transition in lattice QCD with $N_f = 2$ nonperturbatively improved Wilson fermions at $N_t = 8$," presented at XVI Particles and Nuclei International Conference September 30 - October 4, 2002, Osaka, Japan.

[30] S. Ito, S. Kitahara, T. W. Park and T Suzuki, "Gauge Problem of Monopole Dynamics in SU(2) Lattice Gauge Theory," presented at XVI Particles and Nuclei International Conference September 30 - October 4, 2002, Osaka, Japan.

[31] T. Suzuki and M.N. Chernodub, "String breaking and monopoles in QCD," presented at XVI Particles and Nuclei International Conference September 30 - October 4, 2002, Osaka, Japan.

[32] "Heavy quark potential in $N_f = 2$ lattice QCD with nonperturbatively improved Wilson fermions below and above the finite temperature phase transition," presented at XVI Particles and Nuclei International Conference September 30 - October 4, 2002, Osaka, Japan.

[33] Y. Koma, M. Koma, T. Suzuki, E.-M. Ilgenfritz, "Electric magnetic duality of the confining flux tube in Abelian-projected gluodynamic," Proceedings of 5th International Conference on Quark Confinement and the Hadron Spectrum V, Gargnano, Garda Lake, 10–14 September 2002.

[34] T. Suzuki and M.N. Chernodub, "String breaking and monopoles," 5th International Conference "Quark confinement and the hadron spectrum," Gargnano (Brescia), Italy, September 10-14, 2002,

[35] "Heavy quark potential in lattice QCD at finite temperature," 5th International Conference "Quark confinement and the hadron spectrum," Gargnano (Brescia), Italy, September 10-14, 2002,

[36] Y. Koma, M. Koma, T. Suzuki, E. M. Ilgenfritz and M. I. Polikarpov, "A fresh look on the flux tube in Abelian-projected SU(2) gluodynamics," Contributed to 20th International Symposium on Lattice Field Theory (LATTICE 2002), Boston, Massachusetts, 24-29 Jun 2002; arXiv:hep-lat/0210014.
Number of citations = 0.

[37] Y. Koma, "The structure of confining flux tube in AP-SU(2) lattice gauge theory," INTAS meeting, Moscow, Russia, 25–28 February 2002.

[38] M.N. Chernodub (speaker), T. Suzuki, K. Ishiguro, "Properties of monopoles in high temperature SU(2) gluodynamics," International Meeting "Hadron Physics and Vacuum Structure from Lattice QCD," Moscow Region, Russia, Feb. 25-28, 2002,

[39] M.N. Chernodub, V.I. Zakharov, "Fermionic signatures of Lattice monopoles," International Meeting "Hadron Physics and Vacuum Structure from Lattice QCD," Moscow Region, Russia, Feb. 25-28, 2002,

[40] "Finite Temperature Lattice QCD with $N_f = 2$ Nonperturbatively Improved Clover Fermion Action," International Meeting "Hadron Physics and Vacuum Structure from Lattice QCD," Moscow Region, Russia, Feb. 25-28, 2002,

[41] "Heavy quark potential at finite temperature with two flavors of nonperturbatively O(a) improved Wilson fermions," Contributed to 20th International Symposium on Lattice Field Theory (LATTICE 2002), Boston, Massachusetts, 24-29 Jun 2002.

[42] T. Suzuki, Y. Koma, S. Ito, E. M. Ilgenfritz, T. W. Park, M. I. Polikarpov and T. Yazawa, "Topics of monopole dynamics in gluodynamics," Contributed to 19th International Symposium on Lattice Field Theory (Lattice 2001), Berlin, Germany, 19-24 Aug 2001; Nucl. Phys. Proc. Suppl. **106**, 631 (2002) [arXiv:hep-lat/0110059].
Number of citations = 2.

[43] V. Bornyakov *et al.*, "On the dynamics of color magnetic monopoles in full QCD," Talk given at 19th International Symposium on Lattice Field Theory (Lattice 2001), Berlin, Germany, 19-24 Aug 2001; Nucl. Phys. Proc. Suppl. **106**, 634 (2002) [arXiv:hep-lat/0111042].
Number of citations = 5.

[44] S. Fujimoto, S. Kato, M. Murata and T. Suzuki, "String tension and glueball masses of SU(2) QCD from perfect action for monopoles and strings," Presented at 17th International Symposium on Lattice Field Theory (LATTICE 99), Pisa, Italy, 29 Jun - 3 Jul 1999; Nucl. Phys. Proc. Suppl. **83**, 494 (2000) [Prog. Theor. Phys. Suppl. **138**, 38 (2000)] [arXiv:hep-lat/9909103].
Number of citations = 1.

[45] T. Suzuki *et al.*, "Recent topics of infrared effective lattice QCD," presented at 17th International Symposium on Lattice Field Theory (LATTICE 99), Pisa, Italy, 29 Jun - 3 Jul 1999; Nucl. Phys. Proc. Suppl. **83**, 550 (2000) [arXiv:hep-lat/9909104].
Number of citations = 2.

[46] S. Fujimoto, S. Kato and T. Suzuki, "A perfect monopole action for SU(2) QCD," Presented at 17th International Symposium on Lattice Field Theory (LATTICE 99), Pisa, Italy, 29 Jun - 3 Jul 1999; Nucl. Phys. Proc. Suppl. **83**, 455 (2000) [arXiv:hep-lat/9909102].
Number of citations = 0.

[47] S. Kato, S. Fujimoto, M. Murata and T. Suzuki, "On the perfect lattice actions of abelian-projected SU(2) QCD," Presented at 16th International Symposium on Lattice Field Theory (LATTICE 98), Boulder, CO, 13-18 Jul 1998; Nucl. Phys. Proc. Suppl. **73**, 533 (1999) [arXiv:hep-lat/9902006]. Number of citations = 2.

[48] S. Kato, M. N. Chernodub, S. Kitahara, N. Nakamura, M. I. Polikarpov and T. Suzuki, "Various representations of infrared effective lattice QCD," Nucl. Phys. Proc. Suppl. **63**, 471 (1998) [arXiv:hep-lat/9709092]. Number of citations = 6.

Chapter 3

sctaro group

Report from QCD-TARO collaboration

3.1 QCD-TARO Collaboration (SC-TARO)

Ph. de Forcrand[a], M. García Pérez[b], T. Hashimoto[c], S. Hioki[d], Y. Liu[f], H. Matsufuru[e], O. Miyamura[f], A. Nakamura[g], I.-O. Stamatescu[hi], T. Takaishi[j], and T. Umeda[f]

[a]ETH-Zürich, CH-8092 Zürich, Switzerland
[b]Dept. Física Teórica, Universidad Autónoma de Madrid, E-28049 Madrid, Spain
[c]Dept. of Appl. Phys., Fac. of Engineering, Fukui Univ., Fukui 910-8507, Japan
[d]Dept. of Physics, Tezukayama Univ.,Nara 631-8501, Japan
[e]Research Center for Nuclear Physics, Osaka Univ., Ibaraki 567-0047, Japan
[f]Dept. of Physics, Hiroshima Univ., Higashi-Hiroshima 739-8526, Japan
[g]RIISE, Hiroshima Univ., Higashi-Hiroshima 739-8521, Japan
[h]Institut für Theoretische Physik, Univ. Heidelberg, D-69120 Heidelberg, Germany
[i]FEST, Schmeilweg 5, D-69118 Heidelberg, Germany
[j]Hiroshima University of Economics, Hiroshima 731-01, Japan

QCD-TARO[1] is an international collaboration, i.e., Japan, Germany and Switzerland, whose physical interest is to study the hadronic world at finite density and density by the lattice QCD. For this purpose, we are also interested in improving our tools in numerical simulations and study the anisotropic lattice and the renormalization improved gauge actions. In this report, we describe three works by QCD-TARO, *i.e.*, (i) the Monte Carlo renormalization group analysis to find an approximate renomaled trajectory, (ii) pole and screening hadron masses at finite temperature, and (iii) the responce of hadrons to the chemical potential.

3.2 Renormalization Group analysis and DBW2 action

We studied renormalization effects by means of a blocking transformation which changes the lattice cut-off but leaves the long range contents of the system invariant. New blocked actions S' as a function of blocked link variables V's are constructed from the original $S(U)$ as

$$e^{-S'(V)} = \int e^{-S(U)}\delta(V - P(U))DU, \tag{3.1}$$

where P defines the blocking transformation. The action S' includes the renormalization effect induced by blocking. In the space of coupling constants, the blocking transformation makes a transition from a point corresponding to S to a new one of S'. Repeating the blocking transformation we obtain trajectories in coupling space which define the so called renormalization group flow.

There is a special trajectory, i.e. renormalized trajectory (RT), which starts at the ultra-violet fixed point. On the RT, the long range information corre-

[1] QCD on Thousand-cell ARray processor. The group started its activity to use AP1000 by Fujitsu, which has 1000 array processors called cell.

sponding to continuum physics is preserved. Therefore if we find a RT corresponding to a blocking transformation, it provides an action which gives accurate results in the continuum limit. Even if it is an approximate one, it may serve as a well-improved action.

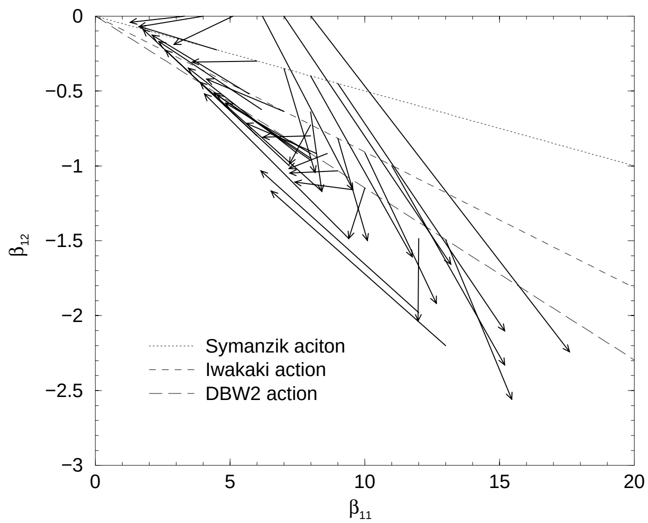

Figure 3.1: Renormalization group flow for QCD in two coupling space. The line to which these arrows converge is the renormalized trajectory.

In this work, we made a numerical analysis of the RG flow in two coupling space, (β_{11}, β_{12}), corresponding to 1×1 and 1×2 loops respectively, of SU(3) lattice gauge theory and clarify the structure of the renormalization group flow. The resulting renormalization group flow runs quickly towards an attractive stream which has an approximate line shape.

3.3 Pole and screening masses of hadrons at finite temperature

When we increase the temperature, hadronic correlators are expected to change their nature drastically. At the critical temperature, the deconfinement of color degrees of freedom and the restoration of the chiral symmetry are expected to occur simultaneously.

We analyze *temporal* and *spatial* meson correlators in quenched lattice QCD at $T \geq 0$ using the anisotropic lattices.

In this analysis the changes of the meson properties with temperature appear to be small below T_c. Above T_c we observed apparently opposing features: On the one hand, the behavior of the t-propagators, in particular the change in the ordering of the mass splittings could be accounted for by contributions from free quark propagation in the mesonic channels, which would also explain the variation of $m_{eff}^{(\tau)}(t)$ both with t and with the source. On the other hand, the behavior of the wave functions obtained from the 4-point correlators sug-

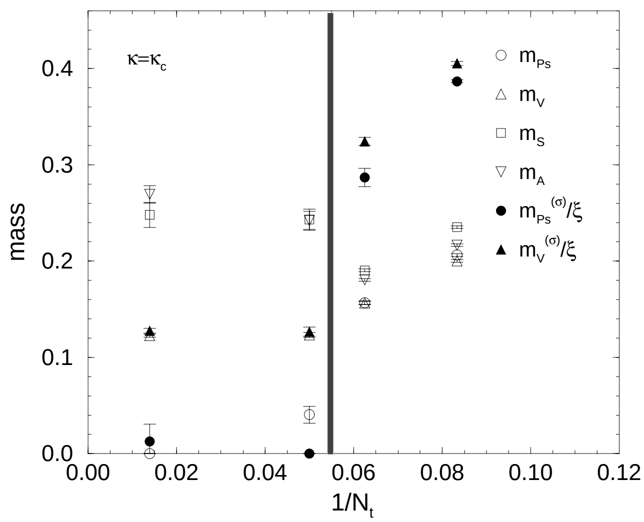

Figure 3.2: Temperature dependence of masses (in a_τ^{-1}) in the chiral limit (bottom). Full (open) symbols correspond to spatial (temporal) masses. The grey vertical line roughly represents T_c.

gests that there can be low energy excitations in the mesonic channels above T_c appearing as metastable bound states which replace the low temperature mesons.

3.4 Chemical potential responce of hadrons

It is well known that studying finite density QCD through lattice simulations is a very hard problem. The fermionic determinant at finite chemical potential is complex, and gives an oscillating behavior in quantum averages which makes simulations very inefficient. Since the naive quenched approximation at finite chemical potential leads to an essentially different world, the use of dynamical fermions would be essential to extract the relevant physics. In spite of these difficulties, the study of hadrons in a finite baryonic environment is quite important in view of recent experimental developments and of the theoretical interest in the phase structure of QCD.

We constructed a framework to compute the responses of hadron masses to the chemical potential in lattice QCD simulations at $\mu = 0$. There is in fact much interesting physical information which can be extracted from the behavior of a system at small chemical potential. Our strategy is to expand the hadronic quantities, such as masses and the quark condensation, in the vicinity of zero chemical potential at finite temperature, and explore their changes through the response to the chemical potential at $\mu = 0$. This allows to perform the numerical simulations with standard methods.

As a first trial, the screening mass of the pseudoscalar meson and its first and second responses are evaluated. We present results on a $16 \times 8^2 \times 4$ lattice with two flavors of staggered quarks below and above T_c. The responses to both the

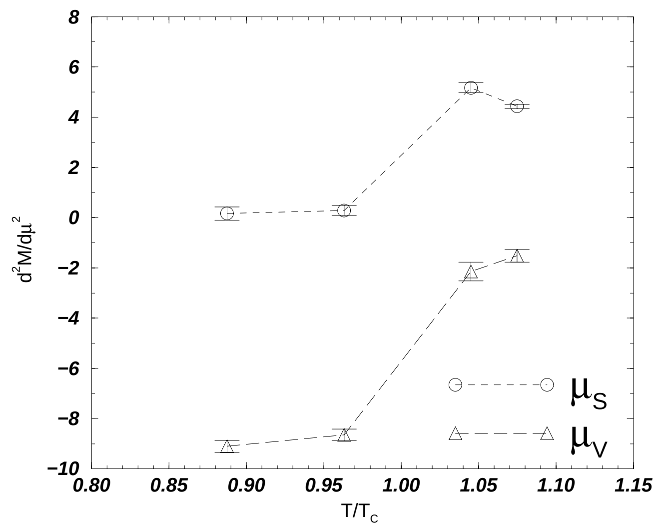

Figure 3.3: Second responses $d^2\hat{M}/d\hat{\mu}_S^2$ and $d^2\hat{M}/d\hat{\mu}_V^2$ of the PS meson mass at $ma = 0.025$.

isoscalar and isovector chemical potentials are obtained. They show different behavior in the low and the high temperature phases, which may be explained as a consequence of chiral symmetry breaking and restoration, respectively.

3.5 Use of machines at other institutions

We have used also SX5 at RCNP, and RS8000 at Hiroshima University computer center. Approximate CPU time spent on KEK, RCNP and Hiroshima university is 6:3:1.

3.6 Comment on the KEK Supercomputer project

Computational resources provided by KEK is essential for our group. We hope that KEK will continue the system, i.e., to introduce the best performance machine and to provide big computational resources to computational high energy physics groups.

Journal papers

[1] O. Miyamura, S. Choe, Y. Liu, T. Takaishi and A. Nakamura, “Responses of quark condensates to the chemical potential,” Phys. Rev. D **66**, 077502 (2002) [arXiv:hep-lat/0204013].
Number of citations: 1.

[2] S. Choe *et al.* [QCD-TARO Collaboration], “Responses of hadrons to chemical potential at finite temperature,” Nucl. Phys. A **698**, 395 (2002) [arXiv:hep-lat/0107002].
Number of citations: 7.

[3] P. de Forcrand *et al.* [QCD-TARO Collaboration], “Meson correlators in finite temperature lattice QCD,” Phys. Rev. D **63**, 054501 (2001) [arXiv:hep-lat/0008005].
Number of citations: 22.

[4] S. Choe *et al.*, “Responses of hadrons to the chemical potential at finite temperature,” Phys. Rev. D **65**, 054501 (2002).
Number of citations: 7.

[5] P. de Forcrand *et al.* [QCD-TARO Collaboration], “Renormalization group flow of SU(3) lattice gauge theory: Numerical studies in a two coupling space,” Nucl. Phys. B **577**, 263 (2000) [arXiv:hep-lat/9911033].
Number of citations: 17.

Conference presentations

[1] S. Choe *et al.* [QCD-TARO Collaboration], "Quenched charmonium near the continuum limit," Contributed to 19th International Symposium on Lattice Field Theory (Lattice 2001), Berlin, Germany, 19-24 Aug 2001; Nucl. Phys. Proc. Suppl. **106**, 361 (2002) [arXiv:hep-lat/0110104].
Number of citations: 2.

[2] S. Choe *et al.* [QCD-TARO Collaboration], "Screening mass responses to chemical potential at finite temperature," Contributed to 19th International Symposium on Lattice Field Theory (Lattice 2001), Berlin, Germany, 19-24 Aug 2001; Nucl. Phys. Proc. Suppl. **106**, 462 (2002) [arXiv:hep-lat/0110223].
Number of citations: 2.

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Number of citations: 4.

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[6] Y. Liu, O. Miyamura, A. Nakamura and T. Takaishi, "Simulation of SU(2) dynamical fermion at finite chemical potential and at finite temperature," To be published in the proceedings of International Workshop on Non-Perturbative Methods and Lattice QCD, Guangzhou, China, 15-21 May 2000; arXiv:hep-lat/0009009.
Number of citations: 16.

[7] P. de Forcrand *et al.* [QCD-TARO Collaboration], "Finite temperature QCD on anisotropic lattices," Talk given at 16th International Symposium on Lattice Field Theory (LATTICE 98), Boulder, CO, 13-18 Jul 1998; Nucl. Phys. Proc. Suppl. **73**, 420 (1999) [arXiv:hep-lat/9809173].
Number of citations: 4.

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Number of citations: 6.

[9] T. Umeda *et al.* [QCD-TARO Collaboration], "Scaling analysis of improved actions for pure SU(3) gauge theory," Talk given at 16th International Symposium on Lattice Field Theory (LATTICE 98), Boulder, CO, 13-18 Jul 1998; Nucl. Phys. Proc. Suppl. **73**, 924 (1999) [arXiv:hep-lat/9809086].
Number of citations: 3.

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Number of citations: 6.

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Number of citations: 5.

[12] M. Fujisaki *et al.* [QCD-TARO Collaboration], "Finite temperature gauge theory on anisotropic lattices," Presented at Lattice 96: 14th International Symposium on Lattice Field Theory, St. Louis, MO, 4-8 Jun 1996; Nucl. Phys. Proc. Suppl. **53**, 426 (1997) [arXiv:hep-lat9609021].
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Number of citations: 9.

Chapter 4

scmelqcd group

Spectral analysis of the nucleon excited state in lattice QCD using the maximum entropy method

4.1 scmelqcd group

The group leader is S. Sasaki (Univ. of Tokyo). Other members are

T. Hatsuda, K. Sasaki (Univ. of Tokyo),
M. Asakawa (Kyoto Univ.)

4.2 Research progress

We are aiming to explore hadron spectroscopy, which includes *the excited states* as well as the ground states, in lattice QCD Monte Carlo simulations. The spectral functions (SPFs) of the two-point correlation function is expected to expose rich physical information for excited states. Nevertheless, the reconstruction of SPF, $A(\omega)$ from given Monte Carlo data of the Euclidian time correlator: $G(t) = \int d\omega A(\omega)\exp(-\omega t)$ is a typical ill-posed problem. The maximum entropy method (MEM) is a useful method to circumvent such ill-posed problem by making a statistical inference of the most probable image of $A(\omega)$ based on Bayesian statistics.

Recently the MEM analysis is widely employed on various problems in lattice simulations after the first success in our research area. (Y. Nakahara, M. Asakawa and T. Hatsuda, Phys. Rev. D60 (1999) 091503; M. Asakawa, T. Hatsuda and Y. Nakahara, Prog. Part. Nucl. Phys. 46 (2001) 459.) As for the light hadron spectroscopy, the CP-PACS collaboration analyzed their own high-precision quenched lattice QCD data using the MEM. They show the reliability of the MEM through checking consistency between the standard analysis and the MEM analysis after the continuum extrapolation. (CP-PACS Collaboration, Phys. Rev. D65 (2002) 014501.) However above applications were carried out *only for mesonic hadrons*. In this project, we apply the MEM analysis to lattice QCD data for **both spin-1/2 and spin-3/2 baryons** in order to study the excited state spectrum of baryons.

We are interested in a long standing puzzle regarding the excited state spectrum of the nucleon, namely, the level order of the positive-parity excited nucleon $N'(1440)$ and the negative-parity nucleon $N^*(1535)$. The pattern of the level order between positive and negative-parity excited states can be found universally in the Δ, Σ and flavor-octet Λ channels. Recent quenched lattice QCD studies show that the wrong ordering between N' and N^* actually happens in the relatively *heavy-quark* mass region. (S. Sasaki, T. Blum and S. Ohta, Phys. Rev. D65 (2002) 074503.) Thus, we address a serious question whether or not the level switching between N' and N^* would occur in the *light-quark* mass region. Finding of this possibility might be directly connected to the understanding of the mysterious Roper resonance $N'(1440)$.

We remark that the simulation for the light-quark mass requires large lattice size since the "wave function" of the bound state enlarges as the quark mass decreases. Once the "wave function" is squeezed due to the small volume, the kinetic energy of internal quarks raises and thus the total energy of the bound state should be pushed up. This is an intuitive picture for the finite size effect on the mass spectrum. Such effect is expected to become serious for the (radial) excited state rather than the ground state. Indeed, the above paper reported that the N' mass in the light-quark region is significantly heavier than the mass extrapolated from the heavy quark region.

To study the finite size effect, numerical simulations are performed on two lattice sizes $16^3 \times 32$ and $24^3 \times 32$. We generate quenched QCD configurations with the standard single-plaquette action at $\beta = 6.0$ ($a^{-1} \approx 1.9$GeV). The quark propagators are computed using the Wilson fermion action at four values of the hopping parameter κ, which cover the range $M_\pi/M_\rho \approx 0.69 - 0.92$. Our preliminary results are analyzed on 352 configurations for the smaller lattice ($L \approx 1.5$fm) and 300 configurations for the larger lattice ($L \approx 2.2$fm).

We apply the maximum entropy method to lattice QCD data for both spin-1/2 and spin-3/2 baryons to study the positive-parity excited state spectrum. We succeed in extracting SPFs for baryons as well as mesons. Based on the systematic analysis utilizing two lattice sizes, we confirmed the large finite size effect on the first excited nucleon state in the light quark mass region originally pointed out in Sasaki *et al.*. Our results may be compared with the previously published results for the N^* at the same lattice spacing (QCDSF-UKQCD-LHPC Collaboration, Phys. Lett. B532 (2002) 63). We find that the level spacing between N^* and N' reduces significantly in the chiral limit. However the level switching between them might not happen in lattice simulations with $L \lesssim 2.2$fm.

We are now doing the additive simulations on the further large lattice size ($L \sim 3.0$fm) and also at different lattice spacing. The former simulation is for finding the possibility of the level switching between N^* and N' in the infinite volume limit. The latter is to confirm the existence of unphysical bound states of a physical quark and two doublers, which have been found in the mesonic case [3].

Conference presentations

[1] S. Sasaki, K. Sasaki, T. Hatsuda and M. Asakawa, "Bayesian approach to the first excited nucleon state in lattice QCD," presented at 20th International Symposium on Lattice Field Theory (LATTICE 2002), Boston, Massachusetts, 24-29 Jun 2002. arXiv:hep-lat/0209059.

[2] M. Asakawa, T. Hatsuda, K. Sasaki, S. Sasaki, "Excited nucleon spectrum from lattice QCD with maximum entropy method," presented by K. Sasaki at The XVI International Conference on Particles and Nuclei, Sep 30 – Oct 4, 2002, Osaka, Japan.

Chapter 5

scrabbit group

Study of noperturbative vacuum and hadron properties using lattice QCD simulation

5.1 scrabbit group

Group leader:

Hideo Suganuma *Faculty of Science, Tokyo Institute of Technology*

We have used the KEK-supercomputer, HITACHI-SR8000, for the lattice QCD Monte Carlo simulation as a numerical simulation project at KEK from April 2000. We briefly report our activities with the supercomputer in this period of the two and a half years.

5.2 Heavy Quark Action on Anisotropic Lattices

We propose to use anisotropic lattices for precise computation of heavy-light matrix elements. For this purpose, a systematic improvement program must be applied in the heavy quark region. We numerically examined the relativity relation of heavy-light mesons and found that the quark mass dependence of the anisotropy parameter is sufficiently small up to $m_q a_\tau \simeq 0.3$. This result suggests that improvement at the massless limit, such as the nonperturbative improvement program, suffices for a heavy quark whose mass is sufficiently less than the temporal lattice cutoff a_τ.

5.3 Study of $O(a)$ Improved Wilson Quark Action on Anisotropic Lattice

We developed O(a) improved quark action on anisotropic lattice, which is particularly useful for example for precise computation of heavy-light matrix elements and studies of hadronic correlators at finite temperature. This paper numerically tunes the parameter in the action on quenched lattices and applies the action to light hadron spectroscopy for verifying that the systematic uncertainties are kept under control.

5.4 Three Quark Potential in SU(3) Lattice QCD

The static three-quark (3Q) potential is studied in detail using SU(3) lattice QCD with $12^3 \times 24$ at $\beta = 5.7$ and $16^3 \times 32$ at $\beta = 5.8$, 6.0 at the quenched level. For more than 300 different patterns of the 3Q systems, we perform the accurate measurement of the 3Q Wilson loop with the smearing method, which reduces excited-state contaminations, and present the lattice QCD data of the 3Q ground-state potential $V_{3\mathrm{Q}}$. We perform the detailed fit analysis on $V_{3\mathrm{Q}}$ in terms of the Y-ansatz both with the continuum Coulomb potential and with the lattice Coulomb potential, and find that the lattice QCD data of the 3Q potential $V_{3\mathrm{Q}}$ are well reproduced within a few deviation by the sum of a constant, the two-body Coulomb term and the three-body linear confinement term $\sigma_{3\mathrm{Q}} L_{\mathrm{min}}$, with L_{min} the minimal value of the total length of color flux tubes linking the three quarks. From the comparison with the Q-$\bar{\mathrm{Q}}$ potential, we find a universality of the string tension as $\sigma_{3Q} \simeq \sigma_{Q\bar{Q}}$ and the one-gluon-exchange result for the Coulomb coefficients as $A_{3Q} \simeq \frac{1}{2}A_{Q\bar{Q}}$. We investigate also the several fit analyses with the various ansätze: the Y-ansatz with the Yukawa potential, the Δ-ansatz and a more general ansatz including the Y and the Δ ansätze in some limits. All these fit analyses support the Y-ansatz on the confinement part in the 3Q potential V_{3Q}, although V_{3Q} seems to be approximated by the Δ-ansatz with $\sigma_\Delta \simeq 0.53\sigma$.

5.5 The Flavor-Singlet Negative-Parity Baryon and $\Lambda(1405)$

Using lattice QCD, we study mass spectra of positive-parity and negative-parity baryons in the octet, the decuplet and the singlet representations of the SU(3) flavor. In particular, we consider the lightest negative-parity baryon, the $\Lambda(1405)$, which can be an exotic hadron as the $N\bar{K}$ molecular state or the flavor-singlet three-quark state. We investigate the negative-parity flavor-singlet three-quark state in lattice QCD using the quenched approximation, where the dynamical quark-anitiquark pair creation is absent and no mixing occurs between the three-quark and the five-quark states. Our lattice QCD analysis suggests that the flavor-singlet three-quark state Is so heavy that the $\Lambda(1405)$ cannot be identified as the three-quark state, which supports the possibility of the molecular-state picture of the Λ(1405).

5.6 Glueball Properties at Finite Temperature in SU(3) Anisotropic Lattice QCD

The thermal properties of the glueballs are studied using SU(3) anisotropic lattice QCD with β=6.25, the renormalized anisotropy $\xi = a_s/a_t$=4 over the lattice of the size $20^3 \times N_t$ with N_t = 24, 26, 28, 30, 33, 34, 35, 36, 37, 38, 40, 43, 45, 50, 72 at the quenched level. To construct a suitable operator on the lattice, we adopt the smearing method, and consider its physical meaning in terms of the operator size. First, we construct the temporal correlators $G(t)$ for the 0^{++} and 2^{++} glueballs, using more than 5,500 gauge configurations at each temperature. We then measure the pole-mass of the thermal glueballs from $G(t)$. For the lowest 0^{++} glueball, we observe a significant pole-mass reduction of about 300 MeV near T_c or $m_G(T \simeq T_c) \simeq 0.8 m_G(T \sim 0)$, while its size remains almost unchanged as $\rho(T) \simeq$ 0.4fm. Finally, for completeness, as an attempt to take into account the effect of thermal width $\Gamma(T)$ at finite temperature, we perform a more general new analysis of $G(t)$ based on its spectral representation. By adopting the Breit-Wigner form for the spectral function $\rho(\omega)$, we perform the best-fit analysis as a straightforward extension to the standard pole-mass analysis. The result indicates a significant broadening of the peak as $\Gamma(T) \sim$ 300 MeV as well as rather modest reduction of the peak center of about 100 MeV near T_c for the lowest 0^{++} glueball. The temporal correlators of the color-singlet modes corresponding to these glueballs above T_c are also investigated.

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Number of citations: 3.

[2] J. Harada, H. Matsufuru, T. Onogi and A. Sugita, "Heavy quark action on the anisotropic lattice," Phys. Rev. D **66**, 014509 (2002) [arXiv:hep-lat/0203025].
Number of citations: 2.

[3] N. Ishii, H. Suganuma and H. Matsufuru, "Glueball properties at finite temperature in SU(3) anisotropic lattice QCD," to appear in Phys. Rev. D, arXiv:hep-lat/0206020.
Number of citations: 3.

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Number of citations: 6.

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Number of citations: 9.

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Number of citations: 23.

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[1] H. Suganuma, K. Amemiya, H. Ichie, N. Ishii, H. Matsufuru, N. Nakajima, Y. Nemoto, M. Oka and T.T. Takahashi, "Hadron Physics and Confinement Physics in Lattice QCD," invited talk at Int. Symp. on "Hadrons and Nuclei", Seoul, Korea, February 20-22, 2001, AIP Conference Proceedings **CP594** (2001) 376-386.

[2] H. Suganuma, K. Amemiya, H. Ichie, H. Matsufuru, Y. Nemoto and T. T. Takahashi, "Quark Confinement Physics from Lattice QCD," invited talk at Int. Symp. on "Quantum Chromodynamics and Color Confinement (CONFINEMENT 2000)", Osaka, March 7-10, 2000 (World Scientific, 2001) 103-119.

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Number of citations: 0.

[5] N. Ishii, H. Suganuma and H. Matsufuru, "The thermal width of the glueball at non-zero temperature," Contributed to 20th International Symposium on Lattice Field Theory (LATTICE 2002), Boston, Massachusetts, 24-29 Jun 2002; arXiv:hep-lat/0208043.
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Number of citations: 0.

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Number of citations: 2.

[11] H. Matsufuru, Y. Nemoto, H. Suganuma, T. T. Takahashi and T. Umeda, "Static three quark potential in the quenched lattice QCD," talk given at 18th International Symposium on Lattice Field Theory (Lattice 2000), Bangalore, India, 17-22 Aug 2000; Nucl. Phys. Proc. Suppl. **94**, 554 (2001) [arXiv:hep-lat/0010071].
Number of citations: 2.

[12] N. Nakajima, H. Matsufuru, Y. Nemoto and H. Suganuma, "SU(3) Lattice QCD Study for Octet and Decuplet Baryon Spectra," presented at Int. Symp. on "Hadrons and Nuclei", Seoul, Korea, February 20-22, 2001; AIP Conference Proceedings **CP594** (2001) 349-356.

[13] T. T. Takahashi, H. Suganuma, H. Matsufuru and Y. Nemoto, "SU(3) Lattice QCD Study for Static Three-Quark Potential," presented at Int. Symp. on "Hadrons and Nuclei", Seoul, Korea, February 20-22, 2001; AIP Conference Proceedings **CP594** (2001) 341-348.
Number of citations: 2.

[14] H. Matsufuru, O. Miyamura, H. Suganuma and T. Umeda, "J/Ψ at Finite Temperature – Lattice QCD Result and Potential Model Analysis," presented at Int. Symp. on "Hadrons and Nuclei", Seoul, Korea, February 20-22, 2001; AIP Conference Proceedings **CP594** (2001) 258-265.

[15] N. Ishii, H. Suganuma and H. Matsufuru, "Glueball properties in anisotropic SU(3) lattice QCD with improved action," talk given at Workshop on Lepton Scattering, Hadrons and QCD, Adelaide, Australia, 26 Mar - 6 Apr 2001; arXiv:hep-lat/0106004.

[16] T. T. Takahashi, H. Matsufuru, Y. Nemoto and H. Suganuma, "Static Three Quark Potential in SU(3) Lattice QCD Monte Carlo Simulation," presented at TMU-Yale Symp. on "Dynamics of Gauge Fields", TMU, Tokyo, Dec. 13-15, 1999; (Universal Academy Press, 2000) 179-180.

Chapter 6

scminami group

Automatic Feynman Amplitudes computations and its application to High Energy Physics

6.1 Members

J. Fujimoto[a)] T. Ishikawa[a)], M. Jimbo[b)], T. Kaneko[a)], K. Kato[c)],
S. Kawabata[a)], K. Kon[d)], M. Kuroda[e)], Y. Kurihara[a)], T. Munehisa[g)],
N. Nakazawa[c)], Y. Shimizu[a)], H. Tanaka[f)], K. Tobimatsu[c)], F. Yuasa[a)]

a) KEK, Oho, Tsukuba, Ibaraki 305-0801 Japan
b) Tokyo Management Collage, Ichikawa, Chiba 272-0001, Japan
c) Kogakuin University, Nishi-Shinjuku, Tokyo 163-8677, Japan
d) Seikei University, Musashino, Tokyo 180-8633, Japan
e) Meijigakuin University, Totsuka, Yokohama 244-8539, Japan
g) Yamanashi University, Kofu, Yamanashi, Japan
g) Rikkyo University, Nishi-Ikebukuro, Tokyo 171-8501, Japan

6.2 Introduction

Field theory is considered the most reliable framework in the present particle physics. Observations in experiments in the High Energy physics are compared with the theoretical predictions in models build in this framework. These predictions are obtained with perturbative or non-perturbative calculations. Perturbative method is widely applied to the theories where coupling constants are small enough, such as Quantum Electro-magnetic theory (QED), Electro-Weak theory and Quantum Chromo-dynamics (QCD) with large momentum transfer. These perturbative method of calculation is established with rigorous procedure of the calculation with Feynman diagrams.

On the other hand progress of accelerator science and experimental High Energy physics requires more and more theoretical calculations. Higher energy avaialbes in the experiments requires the predictions of more physical processes with more final states. The more accurate results of experiments requires the more accurate calculations with higher order calculations in the perturbation. When the final states increases, the contribution of the number of process should be increased in which the more Feynman diagrams appear. The amount of calculations necessary for the theoretical prediction of these processes exceeds one which can be performed by theoreticians by hand. It should be a structural improvement of the procedure of getting the theoretical predictions.

One possible way of the improvement is to utilization of computers. Since a large part of the perturbative calculation is defined as mechanical methods, it is possible to construct a computer software to reduce the human labor.

Such software systems was first developed for QED by our group[38]. It is extended to Standard and supersymmetric models and perturbative QCD in tree calculation and for loop corrections by several authors[4, 39], [40], [41], [42] and [43]. These systems are now indispensable for the large perturbative calculations required for the analysis of the experimental data.

6.3 `GRACE` system

We have developing **`GRACE`**[39] system for this purpose. The input to the system is Feynman rules and the specification of a process to be calculated. It first generates necessary and sufficient set of Feynman graphs[44], which can be drawn on a graphic device. From the generated Feynman graphs, GRACE produces programming code of Feynman amplitudes. For a tree process, a set of FORTRAN codes of numerical calculation of differential cross section and interfaces to BASES/SPRING[45]. BASES is a numerical integration package used to integrate the differential cross section phase space. SPRING generates simulated events based on the result of BASES. Since the cross section is calculated by a spinor technique through CHANEL[46] library, it is possible to calculate polarized processes. For a one-loop process, GRACE generates REDUCE or FORM code which produce FORTRAN code after completing dimensional regularization. Loop integration and counter terms are prepared as in a library.

Although an automatic calculating system produces numerical results for a given process, which may include over several thousand Feynman graphs, how can we rely on the validity of the results? There may be a bug in the system which does not appear when the processes are of small sizes. Even if the calculation method and the generated codes are logically correct, it is possible that the numerical calculation is not stable because of the errors included in the computer arithmetics. So the most important feature of an automatic system is which systematic checking methods of the results are provided by the the system itself.

6.4 Electro-weak theory

6.4.1 Tree processes

For tree processes of elector-weak theory, GRACE produces FORTRAN code which calculates the helicity amplitudes using CHANEL library which keeps all particle masses. As CHANEL leaves covariant gauge parameters free, we can confirm explicitly the gauge invariance of the cross section by changing the values of gauge parameters.

With commands "grc[44]"(graph generation) and "grcfort"(FORTRAN code generation), this system generates all necessary subroutines, Makefiles and interfaces to numerical integration and event generation package BASES/SPRING. It is sufficient for a user just to type "make" and "integ" to obtain the total cross section.

With this system, we have constructed sets of event generators grc4f[57] and GRC$\nu\overline{\nu}\gamma$ [3]. The former includes 76 processes of the processes of $e^+e^- \to 4$ fermions. The latter includes $e^+e^- \to \nu\overline{\nu}\gamma$ and $e^+e^- \to \nu\overline{\nu}\gamma\gamma$ with anomalous coupling of W^3 and W^4 vertices. Both of them include all possible Feynman graphs keeping particle masses. Initial and final state radiations are produced by QEDPS[2, 5, 6, 60, 61] parton shower package.

6.4.2 One-loop processes

In contrast to the tree cases, GRACE system calculates squares of amplitudes in the case of one-loop, corresponding to the expression

$$T_{loop} \times (\sum_{tree} T^{\dagger}_{tree}). \tag{6.1}$$

Since this expression contains n-dimensional calculation in T_{loop} for the regularization of ultra-violet divergences, GRACE system generates Reduce[47] or

Form[48] codes, which process integration over loop momenta and then produces FORTRAN code including Feynman parameters. Integration over Feynman parameters are calculated by a numerical integration package[64, 65] developed separately. This library can be replaced by FF[49] package for the comparison of the results. Counter terms and two-point functions are also prepared in the library.

The results of the calculations are tested in terms of (1) cancellation of ultra-violet divergences, (2) cancellation of infrared divergences and (3) gauge invariance.

The resultant code keeps a parameter expressing the ultra-violet divergences

$$C_{UV} = \frac{1}{\epsilon} - \gamma + \ln(4\pi).$$

By varying the value of this parameter, we can confirm the cancellation of ultra-violet divergences.

The system introduces fictitious photon mass in order to regularize the infrared divergences. They should be cancel out when soft photon contributions are added to the one loop-corrections. It can be confirmed explicitly by changing the value of the fictitious photon mass.

As in the tree processes, we can confirm the gauge invariance of the results by varying gauge parameters. In contrast with tree processes, covariant gauge introduces a difficulty in the loop integration since the propagators of gauge bosons have a term of higher powers of momenta. However, in non-linear gauge fixing procedure[50] we can take free gauge parameters keeping the same form of the denominators of the propagators. Thus we can check gauge invariance directly without changing loop integration package.

The gauge fixing term is taken as:

$$\begin{aligned}\mathcal{L}_{\rm GF} = \quad & -\frac{1}{\xi_W}\left|(\partial_\mu - ie\tilde{\alpha}A_\mu - ig\cos\theta_W\tilde{\beta}Z_\mu)W^{+\mu}\right. \\ & \left. \qquad +\xi_W\frac{g}{2}(v+\tilde{\delta}H+i\tilde{\kappa}\chi_3)\chi^+\right|^2 \\ & -\frac{1}{2\xi_Z}\left(\partial_\mu Z^\mu + \xi_Z\frac{g}{2\cos\theta_W}(v+\tilde{\epsilon}H)\chi_3\right)^2 \\ & -\frac{1}{2\xi_A}(\partial_\mu A^\mu)^2.\end{aligned}$$

In fixing parameters $\xi_W = \xi_Z = \xi_A = 1$, we can keep the same structure of the propagators of the gauge bosons as in 'tHooft-Feynman gauge. We can check the independence of the results in terms of other gauge parameters $\tilde{\alpha}$, $\tilde{\beta}$, $\tilde{\delta}$, $\tilde{\kappa}$ and $\tilde{\epsilon}$.

Table 1 shows the calculated loop processes confirmed with this checking procedure[26]

6.5 MSSM

6.5.1 Tree processes

Tree processes in the minimum super symmetric model (MSSM) are automatically calculated as same as in the case of the standard model. GRACE system

Process	Feynman graphs	
	Tree	1 Loop
$W^+W^- \longrightarrow W^+W^-$	7	925
$W^+W^+ \longrightarrow W^+W^+$	7	925
$W^+W^- \longrightarrow HH$	6	827
$ZZ \longrightarrow ZZ$	3	657
$ZZ \longrightarrow W^+W^-$	6	840
$ZZ \longrightarrow HH$	6	830
$\gamma\gamma \longrightarrow W^+W^-$	5	619
$W^+\gamma \longrightarrow t\overline{b}$	4	239
$W^+Z \longrightarrow t\overline{b}$	4	284
$W^+H \longrightarrow t\overline{b}$	4	285
$HH \longrightarrow HH$	4	805
$e^+e^- \longrightarrow W^+W^-$	4	334

Table 6.1: One loop processes in Standard model calculated with **GRACE**

Model	particles	vertices
Standard model	24	139
MSSM	55	3553

Table 6.2: the number of particles and vertices in the standard model and MSSM

generate helicity amplitude in the form of **FORTRAN** code. All particle masses is included and gauge parameters are handled as free parameters which enables to check gauge invariance of the result numerically.

In MSSM there appear Majorana particles and vertices in which Fermion number is not conserved. In order to handle these particles and vertices, **CHANEL** library is extended[63] so as to include additional factor of the charge conjugation operator.

Another differences of these two models are that more particles and vertices appear in MSSM. We show the numbers of particles and vertices in two models in Table 2.

Since there are more than three thousand vertices, a systematic method is needed to check the coupling constants of each vertices. We have checked the gauge invariance explicitly of all 582,102 processes with 6 external particles, which total number of graphs is 264,027,310. Each cross section includes many terms which magnitudes of contributions to the result will alter in different energy regions and in different phase space points. In stead of checking with extensive parameter scan, we have required high precision agreement for different value of gauge parameters at one phase space point. We have confirmed that the all differential cross section agree more than 30 digits in quadruple precision. This shows that they are consistent to gauge invariance up to terms of small contribution, which may become large in different energy region or in other phase space points.

Process	Tree	1-loop
$H^+ \longrightarrow t\bar{b}$	1	74
$e^-e^+ \longrightarrow W^-W^+$	5	1,871

Table 6.3: One-loop processes of MSSM calculated with GRACE .

6.5.2 One-loop processes

We calculated one-loop processes in MSSM shown in table 3. We have applied the same checking procedures for the cancellation of ultraviolet and infrared divergences. However, the gauge invariance of the result not checked in this case. It is necessary to introduce non-linear gauge as in the case of the standard model.

6.6 Hadronic processes

For hadronic processes, interfaces are prepared for the parton distribution function and decay functions (PYTHIA).

An event generator grape[51] is constructed for the process $e^-P \to e^-l\bar{l}N$ with GRACE system. This generator afford calculations for all energy scales combining elastic, intermediate and deep inelastic region.

Another event generator called gr@ppa[52] is been preparing for the process $\overline{P}P \to b\bar{b}b\bar{b}$, which includes all subprocess (initial $q\overline{q}$ and gg). This generator includes all calculation of $O(\mathrm{QCD}^4)$, $O(\mathrm{QCD}^2 \times \mathrm{ELWK}^2)$ and $O(\mathrm{ELWK}^4)$.

6.7 Tools and acceleration

For a large scale calculations of Feynman amplitudes, we have prepared several tools.

Graph drawing package gracefig provide an utility to give a high quality drawn graphs. Graph selection tool grcsel[21] enables to select graphs with combining section conditions. One can also pickup a set of graphs between 1-loop and real photon processes which cancel IR divergence among them. Job submitting tools are prepared for executing large scale jobs with systematic checking tools of the validity of the calculation. For accelerating the calculations, we have also tools to make code efficient on vector or parallel computers[62, 53]

6.8 Numerical integration

GRACE has used a multi-dimensional integration package BASES as mentioned in Sect. 2, to calculate the cross section. BASES relies on a stratified and importance ampling method, which can even integrate a singular function unless the singuralities locate around a diagonal line in the integral volume. For such a diagonal singularity, we have to find an appropriate variable transformation to have efficient sample points around the singular region. In the calculation of the real physics process, as the number of the final state particles increases or the order of the perturbation increase, the singular behavior of the integrand becomes too complex to fund a good set of integration variables for the phase space integral. At the same time, we may face a practical problem that the CPU time required becomes longer due to a huge number of sample points to make the integration converge.

Therefore, in order to proceed the automatization of the calculation further, it is indispensable to develop the multi-dimensional numerical integration with a new algorism to handle the various singuralities of integrand. As a solution for this request, `DICE` has been developed. The first version of `DICE` was reported in 1992[54] and successively in 1998 the vectorised version was reported[55]. Recently the parallel computing version with MPI library exists now. `DICE` has worked well for several example integrations which have a singurality of 'diagonal', and results show good agreement to the analytical values.

`DICE` should be applied to more concrete problem of the physics and simultaneously, other algorithms are also studied more.

6.9 International collaboration

Since it has been world-widely recognized that the study on the automatic calculations and its application to the collider experiments are rather important and desired, the collaboration among Japan, France and Russia has been proceeded. The colleague from Moscow University have developed the automatic calculation system `CompHEP`[40] for the tree leve. `GRACE` evaluates the helicity amplitude numerically. On the other hand, their system calculates the amplitude squared with the symbolic system. Therefore, complete independent checks are possible between two systems[66]. Phenomenological studies such as QCD[20], SUSY[27] and non-linear gauge fixing model[50, 26] have been collaborated with LAPTH group in France. Two workshop, CPP1998[41-45] and CPP2001[25-29], were held in Japan based on the above triangle collaboration.

A lot of program packages for event generators were written by the `GRACE` system and those have been used by experimentalists. In order to make precision check of these packages, the collaboration with Cracow INP in Poland has also been proceeded[13]. As one of the results of this collaboration, their event generator programs `KoralW`[56] for W-pair physics equips with the full set of amplitudes of the 4-fermion final states in e^+e^- collision generated by `GRACE` system.

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Chapter 7

scnucll/scsokaku group

Nuclear Structure and Heavy Ion Reaction studies with microscopic methods

7.1 scnucll/scsokaku group

Group members:

Emiko Hiyama, Yoshiko Kanada-En'yo and Akira Ono*

Institute of Particle and Nuclear Studies,
High Energy Accelerator Research Organization,
1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan
* *Department of Physics, Tohoku University, Sendai 980-8578, Japan*

This research project consists of three subjects on the nuclear structure and reaction studies with microscopic methods.

1. Structure study of hyper nuclei with three-body and four-body calculations.

2. Structure study of unstable and stable nuclei with a method of antisymmetrized molecular dynamics.

3. Heavy-ion reaction study with methods of antisymmetrized molecular dynamics.

The reports of the researches on these subjects are shown below.

7.2 Structure study of hyper nuclei

One of the goals of our study is to understand the hyperon-nucleon(YN) and hyperon-hyperon(YY) interactions from the hypernuclear structure study. The second purpose of our study is to study new dynamics of many body systems consisting of nucleons and hyperons. Along this line, the following studies have been done so far.

7.2.1 Shrinkage effect in ${}^{7}_{\Lambda}$Li due to the addition of Λ hyperon

In order to see a dynamical contraction of the core nucleus, taking ${}^{5}_{\Lambda}\mathrm{He} + n + p$ three-body model, we predicted $B(E2; 5/2^+ \to 1/2^+)$ in ${}^{7}_{\Lambda}$Li to be 2.42 e^{2}fm^4 and that core nuclear size by addition of Λ particle was reduced by 25 %. The recent high-resolution γ-ray experiment KEK-E419 was in good agreement with our prediction. Then, it was confirmed the shrinkage of the nuclear size induced by the Λ particle for the first time.

7.2.2 Spin-orbit force in ${}^{9}_{\Lambda}$Be and ${}^{13}_{\Lambda}$C

For the study of YN spin-orbit force, high-resolution γ-ray experiments, BNL-E930 and BNL-E929, to measure the spin-orbit splitting energies of ${}^{9}_{\Lambda}$Be and ${}^{13}_{\Lambda}$C have been done. Before measurements, we predicted energy splittings of these hypernuclei using two-types YN spin-orbit forces, meson-theory-based YN interaction and quark-model-based YN interaction. Recent experiments, BNL-E929 and E930, have supported our predictions using the quark-mode-based spin-orbit interaction.

7.2.3 $\Lambda N - \Sigma N$ coupling in ${}^4_\Lambda$H and ${}^4_\Lambda$He

For the study of $\Lambda N - \Sigma N$ coupling, it is considered that four-body calculation of ${}^4_\Lambda$H and ${}^4_\Lambda$He taking $3N + \Lambda$ and $3N + \Sigma$ channel explicitly is suitable. We performed this coupled four-body calculation and found that $3N + \Sigma$ channel is essentially important to make ${}^4_\Lambda$H and ${}^4_\Lambda$He bound.

7.3 Structure study of unstable nuclei

We systematically studied structures of the ground and excited states of various nuclei ranging from stable and unstable nuclear region. we applied a method of antisymmetrized molecular dynamics (AMD), which has been proved to be a powerful microscopic approach to explain exotic shapes due to clustering in the ground and excited states.

The theoretical results predicted molecular states in light unstable nuclei such as ^{10}Be, ^{11}Be, ^{12}Be, ^{14}Be and ^{15}B. Owing to the progress of experimental technique, the predicted molecular states were measured by break-up reactions. The molecular structures are considered to be new phenomena in neutron-rich nuclei, and the search is one of the hot subjects now.

In the theoretical study on *sd*-shell nuclei(Mg, Si, Ar and Ca), it is suggested that a variety of exotic shapes may develop in the excited states due to clustering aspects. For example, the super deformations in ^{32}S and ^{40}Ca are suggested to exist in the states with cluster cores. It is a long-standing problem in the theoretical and experimental research whether or not clustering features are found in such heavy *sd*-shell nuclei. In the present work, possible cluster features and molecular resonances are found without assuming the existence of any clusters for the first time. These theoretical results imply that clustering aspect is one of the general features in the excited states of heavy nuclei as well as light nuclei.

It should be pointed out that, except for our AMD calculations, there are few microscopic calculations with which one can systematically describe such properties of ground and excited states as exotic shapes and clustering aspects in these nuclear region (*sd*-shell and heavier nuclei). The large dimensional calculations are required because of the treatment of many-nucleon degrees, the spin-parity projections, and the superpositions of wave functions.

7.4 Heavy-ion reaction study

Antisymmetrized molecular dynamics (AMD) with quantum branching was applied to collisions of heavy nuclei such as ^{197}Au+^{197}Au. For the central collisions at 150 and 250 MeV/nucleon, the experimental data of the mass and charge distribution of the fragments produced from strongly expanding system are well reproduced by AMD with Gogny force that corresponds to a soft equation of state of nuclear matter. The sensitively to the equation of state (EOS) of nuclear matter has been studied. The proton neutron ratio in the compressed region at the early reaction stage was found to be sensitive to the density dependence of the symmetry energy, which can result in the neutron proton differential flow and the energy difference between ^{3}H and ^{3}He fragments.

Similar isospin effects were also found in the AMD calculation for lighter systems with lower energies, by comparing ^{60}Ca + ^{60}Ca and ^{40}Ca + ^{40}Ca at 35 MeV/nucleon, for example. We have obtained a clear 'isoscaling' relation for the ratio of the fragment yields. The sensitivity to the EOS of asymmetric nuclear matter has been found in the neutron proton ratio of produced fragments, the slope parameter of the isoscaling, and so on.

An extension in the quantum branching process of AMD has been introduced so that it can incorporate an advantage of the mean field approach, by taking account of the coherence among branched wave packets for some duration τ. When a slowly expanding big system is formed in collisions of heavy nuclei with relatively low energy (Xe+Sn at 50 MeV/nucleon, for example), the usual AMD ($\tau = 0$) predicts too rapid expansion that results in the production of too many and too small fragments. On the other hand, by taking a finite coherence time τ, the expansion is slower and the data of the fragment yield has been reproduced very well.

7.5 Used computer facilities other than KEK supercomputer

The computational calculations were partially done by using following supercomputers.

1. NEC SX4, SX5 in RCNP, Osaka Univ. (30 %).

2. Fujitsu VPP700 in RIKEN (7 %).

3. Fujitsu VPP5000 in Kyushu Univ. and JAERI (3 %).

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[2] E. Hiyama, M. Kamimura, T. Motoba, T. Yamada and Y. Yamamoto, "Lambda Sigma conversion in (Lambda)He-4 and (Lambda)H-4 based on four-body calculation," Phys. Rev. C **65**, 011301 (2002) [arXiv:nucl-th/0106070].
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[3] H. Kamada *et al.*, "Benchmark Test Calculation of a Four-Nucleon Bound State," Phys. Rev. C **64**, 044001 (2001) [arXiv:nucl-th/0104057].
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[4] E. Hiyama, M. Kamimura, T. Motoba, T. Yamada and Y. Yamamoto, "Three- And Four-Body Structure Of Light Lambda Hypernuclei," prepared for HYP2000: 7th International Conference on Hypernuclear and Strange Particle Physics, Torino, Italy, 23-27 Oct 2000; Nucl. Phys. A **691**, 107 (2001).
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[5] E. Hiyama, M. Kamimura, T. Motoba, T. Yamada and Y. Yamamoto, "Three- And Four-Body Structure Of Light Hypernuclei," prepared for 16th International Conference on Few-Body Problems in Physics (FB 16), Taipei, Taiwan, China, 6-10 Mar 2000; Nucl. Phys. A **684**, 227 (2001).
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[6] E. Hiyama, M. Kamimura, T. Motoba, T. Yamada and Y. Yamamoto, "Lambda N Spin-Orbit Splittings In (Lambda)Be-9 And (Lambda)C-13 Studied With One-Boson-Exchange Lambda N Interactions," Phys. Rev. Lett. **85**, 270 (2000).
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alistic Lambda N Interactions," Nucl. Phys. A **639**, 169 (1998).
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[10] A. Dote, H. Horiuchi, Y. Kanada-Enyo, "Antisymmetrized Molecular Dynamics Plus Hartree-Fock Model and Its Application to Be Isotopes," Phys. Rev. **C56**, 1844 (1997).
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[11] H. Horiuchi, Y. Kanada-Enyo, "Structure of Light Exotic Nuclei Studied with AMD Model," Nucl. Phys. **A616**, 394c (1997).
Number of citations: 1.

[12] Y. Kanada-Enyo, H. Horiuchi, "Opposite Deformations between Protons and Neutrons in Proton-Rich C Isotopes," Phys. Rev. **C55**, 2860 (1997).
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[13] Y. Kanada-Enyo, H. Horiuchi, A. Doté,
"Structure of Excited States of Unstable Nuclei Studied with Antisymmetrized Molecular Dynamics," J. Phys. (London) **G24**, 1499 (1998).

[14] Y. Kanada-En'yo, "Variation After Angular Momentum Projection For The Study Of Excited States Based On Antisymmetrized Molecular Dynamics," Phys. Rev. Lett. **81**, 5291 (1998) [arXiv:nucl-th/0204039].
Number of citations: 10.

[15] Y. Kanada-En'yo, H. Horiuchi and A. Dote, "Structure of Excited States of 10Be studied with Antisymmetrized Molecular Dynamics," Phys. Rev. C **60**, 064304 (1999) [arXiv:nucl-th/9905048].
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[16] Y. Kanada-En'yo, H. Horiuchi and A. Dote, "Structures And Transitions In Light Unstable Nuclei," Nucl. Phys. A **687**, 146 (2001) [arXiv:nucl-th/0204038].
Number of citations: 0.

[17] Y. Kanada-En'yo and H. Horiuchi, "Structure of Light Unstable Nuclei Studied with Antisymmetrized Molecular Dynamics," Prog. Theor. Phys. Suppl. **142**, 205 (2001) [arXiv:nucl-th/0107044].
Number of citations: 0.

[18] Y. Kanada-En'yo, "Exotic clusters in the excited states of Be-12, Be-14 and B-15," Phys. Rev. C **66**, 011303 (2002) [arXiv:nucl-th/0204063].
Number of citations: 1.

[19] Y. Kanada-En'yo and H. Horiuchi, "Structure of excited states of Be-11 studied with Antisymmetrized Molecular Dynamics," Phys. Rev. C **66**, 024305 (2002) [arXiv:nucl-th/0204041].
Number of citations: 0.

[20] A. Ono, "Antisymmetrized molecular dynamics with quantum branching processes for collisions of heavy nuclei," Phys. Rev. C **59**, 853 (1999) [arXiv:nucl-th/9809029].
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[21] A. Ono, "Antisymmetrized Molecular Dynamics Approach to Multifragmentation," Prog. Theor. Phys. Supp. **140** (2000) 134.

[22] A. Ono, S. Hudan, A. Chbihi and J. D. Frankland, "Compatibility of localized wave packets and unrestricted single particle dynamics for cluster formation in nuclear collisions," Phys. Rev. C **66**, 014603 (2002) [arXiv:nucl-th/0204005].
Number of citations: 0.

Conference presentations

[23] E. Hiyama, "New understanding in hypernuclear physics generated by solving four-body problem," invited talk at the Symposium on topics in the field of light nuclei, Cracow, Poland, Jun 1999.

[24] E. Hiyama, "Three- and four-body structure of light hypernuclei," invited talk at International workshop on "Hypernuclear physics with electromagnetic probes" Greesboro, USA, Dec 1999.

[25] E. Hiyama, "Three- and four-body structure of light hypernuclei," invited talk at 16th International conference on few-body problems in physics, Taipei, Taiwan, Mar 2000.

[26] E. Hiyama, "Few-body hypernuclear systems and hyperon-nucleon interactions," invited talk at the first APS-JPS Joint DNP Fall Meeting, Hawaii, USA, Oct 2001.

[27] E. Hiyama, "Comments from theorists," invited talk at International Workshop on Nuclear and Particles Physics at 50 GeV PS, NP01, KEK, Tsukuba, Dec 2001.

[28] E. Hiyama, "Three- and four-body structures of light double-Lambda hypernuclei," invited talk at Czech-Japan Joint Workshop on Selected Topics in Hypernuclear Physics, Prague, Chech Republic, Jan 2002.

[29] E. Hiyama, "Few-body aspects of hypernuclear physics," invited talk at the Second Asia-Pacific Conference on Few-Body Problems in Physics, Shanghai, China, Aug 2002.

[30] E. Hiyama, "Few-body aspects of hypernuclear physics," invited talk at 18th European conference on few-body problem in physics, Bled, Slovenia, Sep 2002.

[31] E. Hiyama, "Theoretical Overview," invited talk at International Workshop on Nuclear and Particles Physics at 50 GeV PS, NP02, Kyoto, Japan, Sep 2002.

[32] E. Hiyama, "Four-body calculation of ${}^4_\Lambda$H and ${}^4_\Lambda$He with realistic YN and NN interactions," the 7th Conferece on Meson and Light Nuclei '98, Prague, Czech Republic, Aug 1998.

[33] E. Hiyama, "Four-body calculation of ${}^4_\Lambda$H and ${}^4_\Lambda$He with realistic YN and NN interactions," the KEK-Tanashi International Symposium on PHYSICS OF HADORONS AND NUCLEI, Tokyo, Dec 1998.

[34] E. Hiyama, "Four-body calculation of ${}^4_\Lambda$H and ${}^4_\Lambda$He with realistic YN and NN interactions," the APCP Workshop on Strangeness Nuclear Physics Seoul, Korea, Feb 1999.

[35] E. Hiyama, "Four-body calculation of ${}^4_\Lambda$H and ${}^4_\Lambda$He with $\Lambda N - \Sigma N$ conversion," the First Asia-Pacific Conference on Few-Body Problems in Physics, Noda/Kashiwa, Chiba, Aug 1999.

[36] E. Hiyama, "Four-body calculation of ${}^4_\Lambda$H and ${}^4_\Lambda$He with $\Lambda N - \Sigma N$ conversion,"
International Symposium on Hadrons and Nuclei Seoul, Korea, February, 2001.

[37] E. Hiyama, "Four-body calculation of ${}^4_\Lambda$H and ${}^4_\Lambda$He with the realistic YN and NN interactions," the 8th Conferece on Meson and Light Nuclei '01, Prague, Czech Republic, Jul 2001.

[38] Y. Kanada-En'yo, H. Horiuchi and A. Doté. "Structure of Excited states of Unstable Nuclei studied with Antisymmetrized Molecular Dynamics," presented at International Workshop in Physics with Radioactive Nuclear Beams, Puri, India, 12-17 Jan 1998.

[39] Y. Kanada-En'yo. "Structure of Light Unstable Nuclei," invited talk at International Workshop on JHF Science, Tsukuba, Japan, 4-7 Mar 1998.

[40] Y. Kanada-En'yo, H. Horiuchi, A. Doté. "Structures and Transitions in Light Unstable Nuclei," invited talk at *INTERNATIONAL CONFERENCE ON GIANT RESONANCES*, Osaka, Japan, Jun 2000.

[41] Y. Kanada-En'yo, H. Horiuchi. "Structures of excited states of Be isotope," presented at *The International Symposium on Perspectives in Physics with Radioactive Isotope Beams 2000*, Hayama, Kanagawa, Japan, Nov 2000.

[42] Y. Kanada-En'yo, H. Horiuchi. "Structures of the excited states of Be isotopes," presented at *3RD INTERNATIONAL CONFERENCE ON EXOTIC NUCLEI AND ATOMIC MASSES*, Hameenlinna, Finland, Jul. 2001.

[43] Y. Kanada-En'yo. "Molecular Structure with Exotic Clusters in light Neutron-rich Nuclei," invited talk at *Yukawa International Seminar 2001 (YKIS01) Physics of Unstable Nuclei*, Kyoto, Japan, Nov 2001.

[44] Y. Kanada-En'yo, M. Kimura and H. Horiuchi, "Exotic shapes in ^{40}Ca and ^{36}Ar studied with Antisymmetrized Molecular Dynamics," invited talk at *4th Catania Relativistic Ion Studies(CRIS2002) Exotic clustering*, Catania, Italy, 10-14 Jun. 2002.

[45] A. Ono and H. Horiuchi, "Antisymmetrized Molecular Dynamics Calculation of Collisions of Heavy Nuclei," invited talk at *XVII RCNP International Symposium on Innovative Computational Methods in Nuclear Many-Body Problems*, Osaka, November 10–15, 1997.

[46] A. Ono and H. Horiuchi, "AMD Study of Multifragmentation," presented at *International Workshop XXVII on Gross Properties of Nuclei and Nuclear Excitations*, Hirschegg, Kleinwalsertal, Jan 17–23, 1999.

[47] A. Ono, "Cluster Formation Dynamics in Medium Energy Nuclear Collisions," invited talk at *7th International Conference on Clustering Aspects of Nuclear Structure and Dynamics*, Rab, Croatia, June 14–19, 1999.

[48] A. Ono, "Antisymmetrized Molecular Dynamics Approach to Multifragmentation," invited talk at *14th Nishinomiya Yukawa Memorial Symposium: Frontiers of Nuclear Collision Dynamics*, Nishinomiya, November 18–19, 1999.

[49] A. Ono, "AMD Study of the Dynamics of Multifragmentation," presented at *Gordon Conference 2000 on Nuclear Chemistry*, Colby Sawyer College, New London, New Hampshire, June 18–22, 2000.

[50] A. Ono, "Molecular dynamics approach with quantum branching to multifragmentation," presented at *The Fourth Japan-China Joint Nuclear Physics Symposium*, Lanzhou, July 31 – August 2, 2000.

[51] A. Ono, "AMD Study of the EOS of Asymmetric Nuclear Matter in Nuclear Collisions", invited talk at *Yukawa International Seminar 2001, Physics of Unstable Nuclei*, Kyoto, Nov. 5 – 10, 2001.

[52] A. Ono, S. Hudan, A. Chbihi, J. D. Frankland, "Compatibility of the Localized Wave Packets and the Unrestricted Single Particle Dynamics for the Cluster Formation in Nuclear Collisions," presented at *International Symposium on Clustering Aspects of Quantum Many-Body Systems*, Kyoto, Nov. 12 – 14, 2001.

[53] A. Ono "AMD study of the EOS in nuclear collisions," invited talk at *Gordon Conference 2002 on Nuclear Chemistry*, Colby Sawyer College, New London, New Hampshire, June 16–21, 2002.

[54] A. Ono, "AMD Study of Nuclear Collisions with High Isospin Asymmetry," presented at *Institute for Nuclear Theory Workshop 02-26W, Reaction Theory for Nuclei Far From Stability*, Sep 16–20, 2002.

Chapter 8

scastro group

Numerical Astrophysics

8.1 scastro group

Group members:

H. Suzuki, *Tokyo University of Science*
K. Sumiyoshi, *Numazu College of Technology*
S. Yamada, *Waseda University*
Y. Suto, *University of Tokyo*
K. Yoshikawa, *Kyoto University*

Using numerical simulations on supercomputers, we have performed researches concerning supernova neutrinos, nucleosynthesis at the core-collapse-driven supernova explosions and cosmological hydrodynamics.

8.2 Supernova

As for collapse-driven supernova explosions, whereas it has been pointed out that aspherical natures such as convection might be essential for the explosion, it gets more important to study neutrino transfer and neutrino opacity in the supernova cores in detail. We have discussed the latter points using sophisticated numerical simulations of spherical models as follows. We developed a numerical code to solve the spherical Boltzmann equation for the neutrino distribution function with an implicit hydrodynamics code. The code is fully general relativistic and adopts variable angular mesh which is optimised for various stages and for various regions taking aim at better angular resolution. In addition, we compared solutions with three different numerical methods: Monte Carlo method, Multigroup Flux Limited Diffusion (MGFLD) method and the Boltzmann solver, for the same static background models and clarified advantages and problems of the use of the Boltzmann solver.

Meanwhile, since the existing equation of states (EOS) for the high density matter have some troubles in numerical supernova simulations, we asked a nuclear physics group mainly in RCNP, Osaka University to make numerical data tables of a new EOS for the high density matter with finite temperature. The EOS is based on the relativistic mean field theory, and the parameters in its Lagrangian have been chosen to reproduce the experimental properties of both stable and unstable nuclei. With this new EOS and our general relativistic hydrodynamics code, we investigated the adiabatic collapse of stellar cores both of Nomoto's group and of Woosley's group. It was confirmed even with the new EOS that, while adiabatic prompt explosions could occur for small cores, massive cores could not explode in the prompt way. Furthermore we have done dynamical simulations of neutrino wind models in which the surface layers of protoneutron stars are blown away by strong neutrino flux. Compared with steady models so far, it was found that more realistic boundary conditions, energy spectra and time profiles of neutrino flux are necessary. Based on these dynamical models, calculation of heavy nuclei nucleosynthesis in ejecta of prompt explosion and of the neutrino wind have been done in collaboration with Terasawa and the results showed that the observed r-process elements could be produced in our models.

For observational points of view concerning supernova neutrinos, numerical simulations of protoneutron star cooling have been performed with the the new numerical EOS table. We note that the numerical table covers such a wide range of thermodynamical quantities (temperature, 0 $\sim$100MeV; electron fraction, 0 $\sim$ 0.56; density, $10^{5.1} \sim 10^{15.4}$g/cc) that cooling simulations even for 50 seconds could be done without troubles. The quasistatic evolution of protoneutron stars was investigated in detail with a numerical code including neutrino transfer (MGFLD scheme). Even with revised subroutines concerning neutrino emission rates due to nucleon bremsstrahlung and with the new EOS, mean energy differences between electron-type anti-neutrinos and non-electron-type anti-neutrinos at the second half of supernova neutrino burst were found to be rather small as in our previous studies. In the case with neutrino oscillations which the atmospheric and solar neutrino experiments indicate, energy spectra of the supernova neutrinos should be also affected. We calculated the neutrino flavour conversion probabilities for the three generation models and both for normal mass hierarchy and for inverted hierarchy cases taking into account the matter effects of stellar envelope. Although it has been pointed out that there are possible inconsistencies between the observed SN1987A neutrino data and large mixing angle solutions for the solar neutrino problem, our numerical results are consistent with observed SN1987A data both in the cases with and without neutrino oscillation because our original neutrino spectra have similar and rather low mean energies of electron-type and non-electron-type anti-neutrinos. Note that, however, our simulations correspond only to the second half of supernova neutrinos, therefore simulations corresponding to the whole stage of supernova neutrinos starting from the onset of core collapse to the protoneutron star cooling phase are strongly required. Such simulations are now on trial with implicit Boltzmann solver and hydrodynamics code.

8.3 Cosmological hydrodynamics

We also investigated cosmological problems such as clustering of Lyman-break galaxies at $z \sim 3$. Recently Steidel et al. (1998) reported a discovery of a highly significant concentration of galaxies on the basis of the distribution of 78 spectroscopic redshifts in the range $2 \leq z \leq 3.4$ for photometrically selected "Lyman break" objects. We examine the theoretical impact of their discovery in much greater detail using a large number of mock samples from N-body simulations. We identify halos of galaxies using the Friend-Of-Friend (FOF) algorithm with a bonding length 0.2 times the mean particle separation, and assume that each halo corresponds to one Lyman break galaxy. Thus our analysis properly takes account of several important and realistic effects including (i) the survey volume geometry, (ii) redshift-space distortion, (iii) selection function of the objects, (iv) fully nonlinear evolution of dark halos, and (v) finite sampling effect.

We studied the volume-averaged two-point correlation functions in real space of the halos and found that over the scales of interest the correlation functions of halos are enhanced approximately by a constant factor relative to those of the dark matter. Comparing the mean number density of halos with observed number density of Lyman break galaxies, we found that while the clustering of objects is naturally biased with respect to dark matter, the predicted bias $1.5 \sim 3$ is not large enough to be reconciled with such a strong concentration of galaxies at $z \sim 3$ *if one similar structure is found per one field on average*. We predict one similar concentration approximately per ten fields in SCDM and per six fields in LCDM and OCDM. Therefore future spectroscopic surveys in a dozen fields (Pettini et al. 1997) are quite important in constraining the cosmological models, and may challenge all the existing cosmological models *a posteriori* fitted to the $z = 0$ universe.

8.4 Use of machine other than KEK supercomputer

These works were done with use of several computers:

- KEK supercomputers $\sim 30\%$,
- RIKEN supercomputers $\sim 30\%$,
- NAO supercomputers $\sim 20\%$,
- workstations at host institutes $\sim 20\%$.

Journal papers

[1] S. Yamada, "An Implicit Lagrangean Code for Spherically Symmetric General Relativistic Hydrodynamics with an Approximate Riemann Solver," Astrophys. J. **475** (1997) 720 [arXiv:astro-ph/9601042].
Number of citations: 1.

[2] K. Sumiyoshi, S. Yamada, H. Suzuki and W. Hillebrandt, "The fate of a neutron star just below the minimum mass: Does it explode?," Astron. Astrophys. **334** (1998) 159 [arXiv:astro-ph/9707230].
Number of citations: 7.

[3] K. Sumiyoshi and T. Ebisuzaki, "Performance of parallel solution of a block-tridiagonal linear system on Fujitsu VPP500," Parallel Computing **24** (1998) 287.

[4] S. Yamada, H. T. Janka and H. Suzuki, "Neutrino transport in type II supernovae Boltzmann solver vs. Monte Carlo method," 8th Marcel Grossmann Meeting on Recent Developments in Theoretical and Experimental General Relativity, Gravitation and Relativistic Field Theories (MG 8), Jerusalem, Israel, 22-27 Jun 1997; Astron. Astrophys. **344** (1998) 533 [arXiv:astro-ph/9809009].
Number of citations: 3.

[5] K. Sumiyoshi, H. Suzuki, K. Otsuki, M. Terasawa and S. Yamada, "Hydrodynamical study of neutrino-driven wind as an r-process site," Publ. Astron. Soc. Jap. **52**, 601 (2000) [arXiv:astro-ph/9912156].
Number of citations: 9.

[6] K. Sumiyoshi, M. Terasawa, G. J. Mathews, T. Kajino, S. Yamada and H. Suzuki, "R-Process in Prompt Supernova Explosions Revisited," Astrophys. J. **562** (2001) 880 [arXiv:astro-ph/0106407].

[7] M. Terasawa, K. Sumiyoshi, S. Yamada, H. Suzuki and T. Kajino, "r-process nucleosynthesis in neutrino-driven winds from a typical neutron star with M = 1.4-M(solar)," Astrophys. J. Lett. **578** (2002) 137 [arXiv:astro-ph/0206322].

[8] Y. P. Jing and Y. Suto, "Confronting cold dark matter cosmologies with strong clustering of Lyman break galaxies at $z \sim 3$," Astrophys. J. **494**, L5 (1998) [arXiv:astro-ph/9710090].
Number of citations: 37.

[9] K. Yoshikawa and Y. Suto, "Reconstructing the radial profiles of gas density and temperature in clusters of galaxies from high-resolution X-ray and radio observations," Astrophys. J. **513** (1999) 549 [arXiv:astro-ph/9810247].
Number of citations: 1.

[10] Y. P. Jing and Y. Suto, "Density Profiles of Dark Matter Halo are not Universal," Astrophys. J. Lett. **529** (2000) 69 [arXiv:astro-ph/9909478].

[11] K. Yoshikawa, Y.P. Jing and Y. Suto, "Cosmological Smoothed Particle Hydrodynamic Simulations with Four Million Particles: Statistical Properties of X-Ray Clusters in a Low-Density Universe," Astrophys. J. **535** (2000) 593.
Number of citations: 1.

[12] K. Yoshikawa, A. Taruya, Y. P. Jing and Y. Suto, "Nonlinear Stochastic Biasing of Galaxies and Dark Halos in Cosmological Hydrodynamic Simulations," Astrophys. J. **558** (2001) 520 [arXiv:astro-ph/0104361].
Number of citations: 2.

[13] Nonlinear Stochastic Biasing of Galaxies and Dark Halos in Cosmological Hydrodynamic Simulations',
K. Yoshikawa, A. Taruya, Y. P. Jing and Y. Suto, Astrophys. J. **558** (2001) 520.
SPIRES citation 2

Conference presentations

[14] S. Yamada, "Physics of Collapse-driven Supernovae," invited talk at Int. Conf. on The Origin of Matter and Evolution of Galaxies, Tanashi, Tokyo, Japan, 2000.

[15] S. Yamada, "Collapse-driven Supernovae," invited talk at Int. Symposium on Numerical Simulations in Astronomy, Tokyo, Japan, Jul 2002.

[16] K. Sumiyoshi, "R-process nucleosynthesis in supernova explosions: from unstable nuclei to observation of stars," invited talk at Yukawa International Seminar 2001 (YKIS01), "Physics of Unstable Nuclei," Kyoto, Japan, Nov 2001.

[17] K. Sumiyoshi, H. Shen, K. Oyamatsu, Y. Sugahara, M. Terasawa, K. Otsuki, H. Suzuki, S. Yamada, T. Kajino, H. Toki and I. Tanihata, "Unstable nuclei and EOS table for supernova explosion and r-process in relativistic many body approach," presented at International Symposium on Models and Theories of the Nuclear Mass, RIKEN, Wako, Japan, Jul 1999.

[18] K. Sumiyoshi, S. Yamada, H. Suzuki and W. Hillebrandt, "Explosion of a neutron star just below the minimum mass: a possible site for r-process nucleosynthesis," presented at International Symposium on Origin of Matter and Evolution of Galaxies '97, Atami, Japan, Nov 1997.

[19] K. Sumiyoshi, S. Yamada, H. Suzuki and W. Hillebrandt, "The fate of a neutron star just below the minimum mass: does it explode?," presented at International Symposium on Neutron Stars and Pulsars, Rikkyo University, Tokyo, Japan, Nov 1997.

[20] H. Suzuki, S. Yamada and H.-T. Janka, "Comparison of neutrino transfer methods for 1D supernova simulations," presented at International Symposium on Neutron Stars and Pulsars, Rikkyo University, Tokyo, Japan, Nov 1997

[21] H. Suzuki, "MGFLD Code for Cooling Simulations of Protoneutron Stars," presented at International Symposium on Numerical Astrophysics, National Olympic Memorial Youth Center, Tokyo, Japan, Mar 1998.

[22] S. Yamada, H. -Th. Janka and H. Suzuki, "Neutrino Transport in Type II Supernovae: Boltzmann Solver vs Monte Carlo Method," Eighth Marcel Grossman Meeting on General Relativity, Jerusalem, Israel, 1998.

[23] S. Yamada, H. -Th. Janka and H. Suzuki, "Neutrino Transport in Type II Supernovae: Boltzmann Solver vs Monte Carlo Method," presented at 23rd IAU general assembly, Kyoto, Japan, Aug 1998.

[24] K. Sumiyoshi, H. Shen, K. Oyamatsu, Y. Sugahara, M. Terasawa, K. Otsuki, H. Suzuki, S. Yamada, T. Kajino, H. Toki and I. Tanihata, "Unstable nuclei and EOS for supernova and r-process," presented at the RCNP-TMU Symposium on Spins in Nuclear and Hadronic Reactions, Tokyo Metropolitan University, Tokyo, Japan, Oct 1999.

[25] K. Sumiyoshi, "Unstable Nuclei and an EOS Table for Supernovae and the r-Process in a Relativistic Many-Body Approach," presented at International Symposium on Origin of Matter and Evolution of Galaxies 2000, CNS, Tokyo, Japan, Jan 2000.

[26] K. Sumiyoshi, "Collapse-driven supernovae and the r-process with new data of unstable nuclei," Tours 2000 Symposium on Nuclear Physics IV, Tours, France, Sep 2000.

[27] K. Sumiyoshi, "Relativistic EOS table for supernova and r-process," presented at the Institute for Nuclear Theory program INT-01-2 "Neutron Stars", Seattle, USA, Aug 2001.

[28] K. Sumiyoshi, "Patterns of r-process in collapse-driven supernovae: delayed or prompt mechanism?," presented at The 7th International Symposium on Nuclei in the Cosmos, Fuji-Yoshida, Japan, Jul 2002.

[29] H. Suzuki, H. Kogure, F. Tomioka, K. Sumiyoshi, S. Yamada and H. Shen, "Protoneutron Star Cooling with A New Equation of State," presented at The 7th International Symposium on Nuclei in the Cosmos, Fuji-Yoshida, Japan, Jul 2002.

[30] K. Sumiyoshi, "Pattern of r-process nucleosynthesis and mechanism of supernova explosion," presented at Astrophysics Summer Institute 2002 on "The Origin of the Elements", Sophia University, Tokyo, Japan, Jul 2002.

[31] K. Sumiyoshi, "R-process in prompt & delayed supernova explosions," XVI International Conference on Particles and Nuclei, Osaka, Japan, Sep 2002.