The high baryon density CBM experiment and other QCD related research activities at the future FAIR facility in Germany

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CBM collaboration

Outline

• overview on **FAIR**: facility, research programs

→ main QCD related research activities:

• radioactive ion beams: nuclear structure, astrophysics

NUSTAR: motivation, facility, experiments

• antiproton beams: hadron physics

PANDA: main topics, experiment

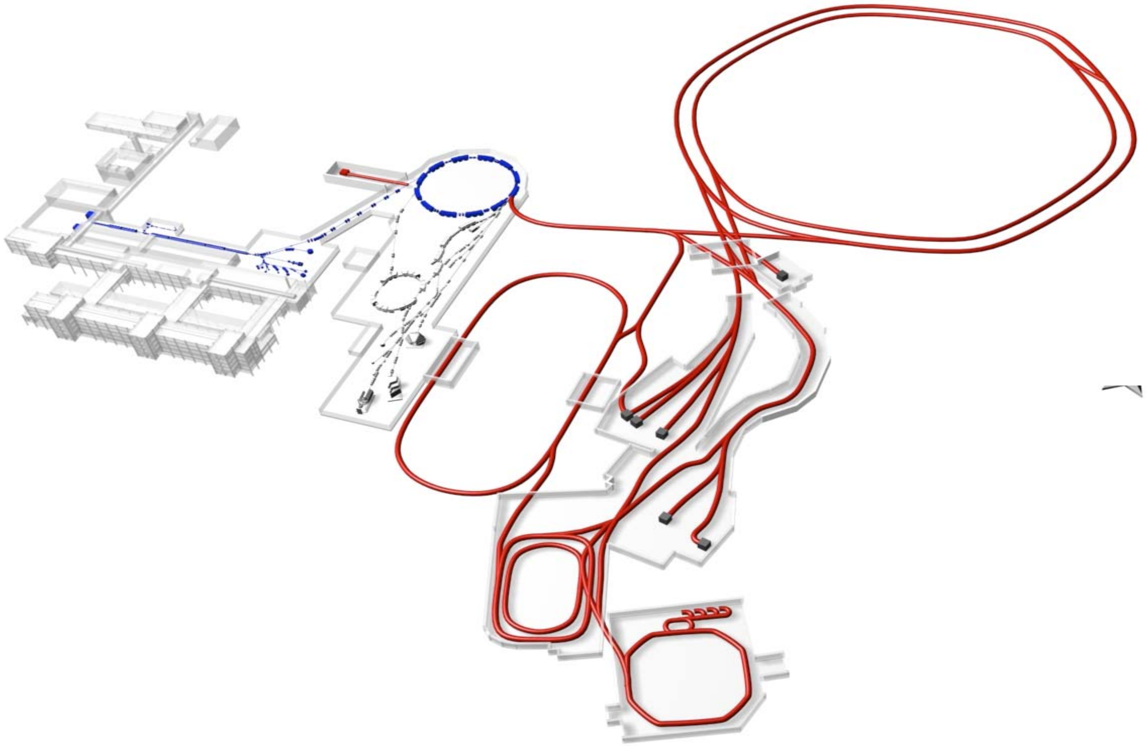
• heavy ion collisions: physics of dense baryonic matter

- **CBM**
- motivation
- observables
- experiment
- feasibility studies

FAIR

- **F**acility for **A**ntiproton and **I**on **R**esearch
- international accelerator facility planned at GSI, Darmstadt, Germany
- multifaceted, multidisciplinary research program
    - focus: QCD related research studies
    - up to 5 research programs will run in parallel
- cost of the FAIR project: 1 Billion € (25% from foreign partners)
  German federal government assigned construction budget over 10 years
  start of civil construction: end of 2007
- 3 stages planned, completion until 2015
    - stage 1 (2007-2011) → upgrade SIS 18, RIBs
    - stage 2 (2011-2013) → SIS 100, antiprotons
    - stage 3 (2013-2015) → SIS 300, CBM

FAIR II



primary beams

- 10^{12}/s; 1.5-2 GeV/u; $^{238}U^{28+}$
- factor 100-1000 increased intensity
- $2x10^{13}$/s 90 GeV protons
- 10^{10}/s $^{238}U^{92+}$ 35 GeV/u (Ni 45 GeV/u)

secondary beams

- radioactive beams 0 – 1.5 (2) GeV/u
- rare isotopes 1.5 - 2 GeV/u; factor 10 000 increased intensity
- antiprotons (0) 3 - 15 GeV

storage and cooler rings

- beams of rare isotopes
- e – A Collider (proposal: antiproton - A)
- 10^{11} stored and cooled antiprotons 0.8 - 14.5 GeV

accelerator technical challenges

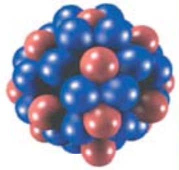
- rapidly cycling superconducting magnets
- high energy electron cooling
- beam losses

FAIR III

... former layout, but still gives an impression of our plans

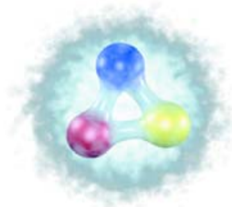
Research programs at FAIR

Rare isotope beams; nuclear structure and nuclear astrophysics



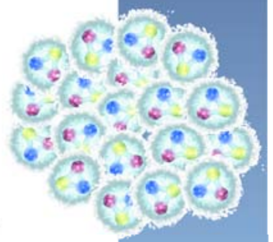
- nuclear structure far off stability
- nucleosynthesis in stars and supernovae

Beams of antiprotons: hadron physics



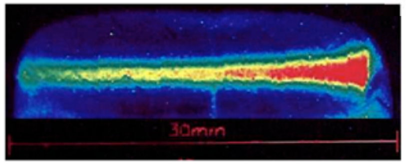
- quark-confinement potential
- search for gluonic matter and hybrids
- hypernuclei

high-energy nucleus-nucleus collisions: compressed baryonic matter



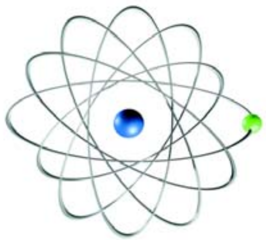
- baryonic matter at highest densities (neutron stars)
- phase transitions and critical endpoint
- in-medium properties of hadrons

short-pulse heavy ion beams: plasma physics



- matter at high pressure, densities, and temperature
- fundamentals of nuclear fusion

atomic physics and applied research



- highly charged atoms
- low energy antiprotons (anti-hydrogen)
- radiobiology
- materials research

accelerator physics

- high intensive heavy ion beams (vacuum!)
- rapidly cycling superconducting magnets
- high energy electron cooling

Research programs at FAIR II

• recently a nice overview over the full physics potential appeared as a special issue of "Nuclear Physics News", Vol.16.1 (2006)

http://www.nupecc.org/npn/npn161.pdf

(not latest version, but still...)

Nuclear Physics News

Volume 16/No. 1

Contents

• further information in LOIs, Technical Proposals/ Status Reports

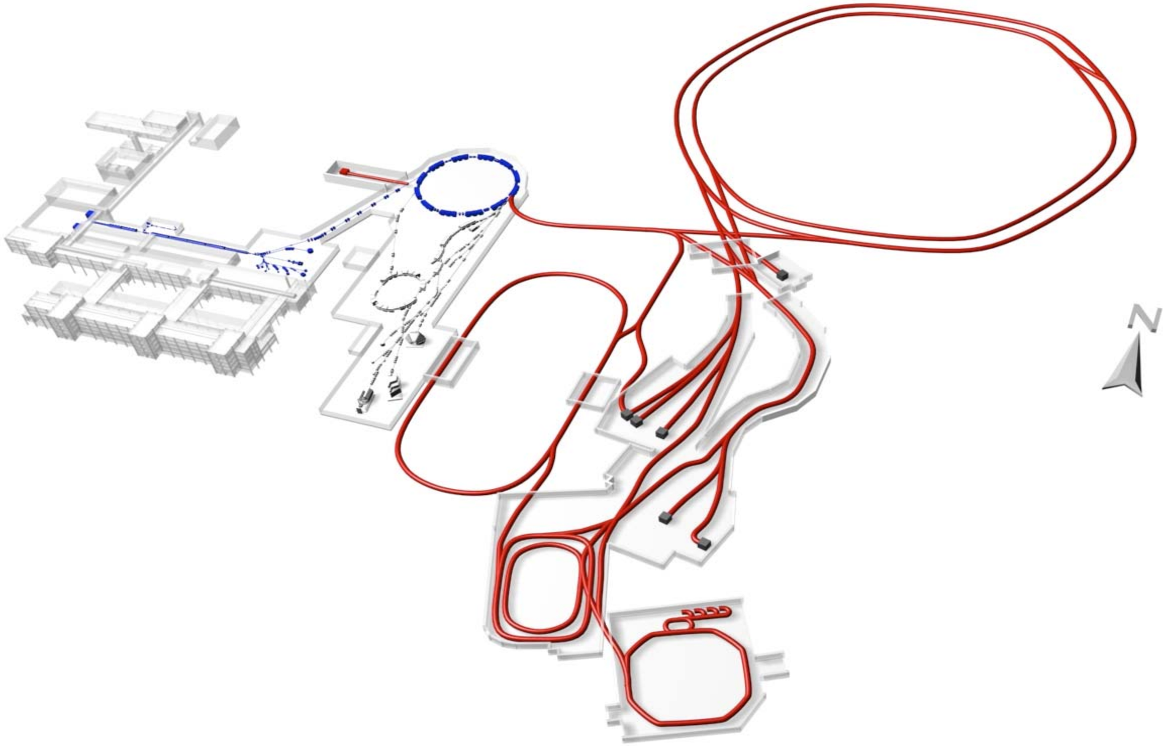
Status Signatures Memorandum of Understanding for the FAIR project (November 24, 2005)

Country	Signatory	Date
Finland	Prof. Dr. D. Riska	22.09.2004
France	Dr. E. Giacobino	08.12.2004
Germany	Dr. H. Schunck	13.09.2004
Greece	Prof. Dr. C. Fotakis	11.11.2004
Italy	Dr. L. Criscuoli	06.12.2004
Poland	Prof. Dr. R. Kulessa	18.01.2005
Russian Federation	Dr. S. Mazurenko	11.11.2004
Spain	Dr. S. Ordónez Delgado	06.10.2004
Sweden	Dr. P. Omling	21.09.2004
United Kingdom	Prof. Dr. J. Wood	13.09.2004
China	Meng Shuguan / Ma Yanhe	24.11.2005
India	Dr. Y.P. Kumar	17.11. 2005

Observers: EU, USA, Hungary, Austria, Romania

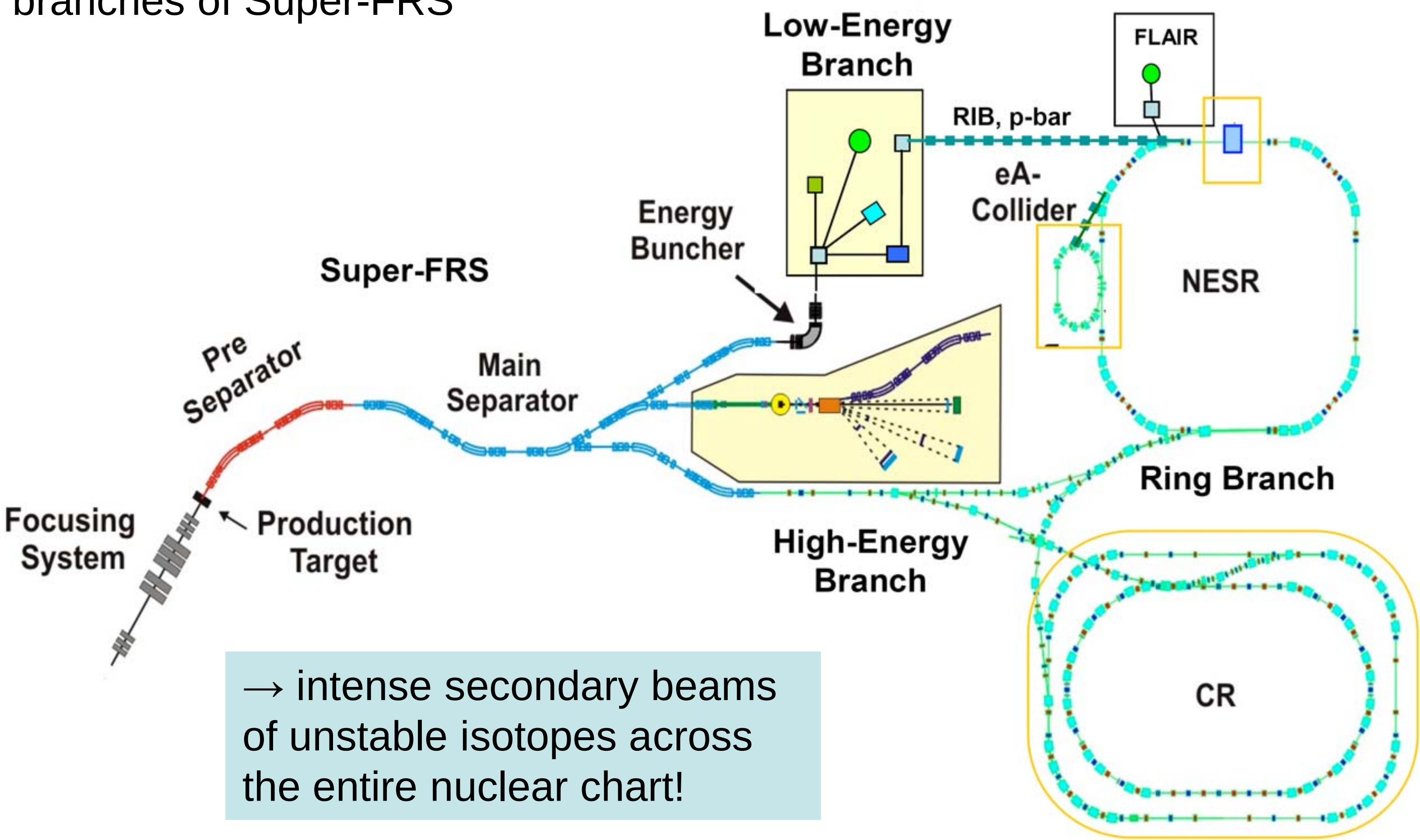
Summary FAIR

- exiting new facility for a wide range of physics will become available within the next 10 years!
- since decided new LOIs are coming in, e.g. on experiments with polarized antiprotons...
- in particular broad spectrum of QCD related studies will open up with unprecedented possibilities



NUSTAR

- **Nu**clear **St**ructure, **A**strophysics, and **R**eactions
- FAIR radioactive ion / rare-isotope beam community (~ 600 members)
- 8 experiments currently planned, one more proposed
- 3 branches of Super-FRS



→ intense secondary beams of unstable isotopes across the entire nuclear chart!

NUSTAR – physics case

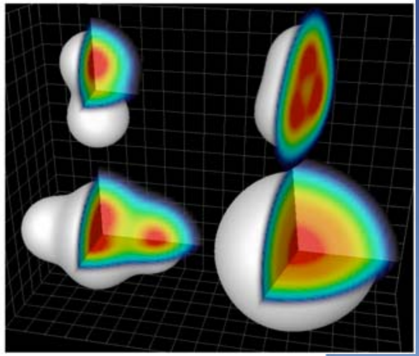
• **nuclear structure**

• atomic nucleus as exceedingly interesting many-body system

• underlying QCD structure → complex nucleon-nucleon force

• exiting new aspects from study of exotic short lived nuclei (proton/ neutron skins or halos, new magic numbers...)

→ pave way for theoretical framework with predictive power for nuclei beyond experimental reach



• **astrophysics**

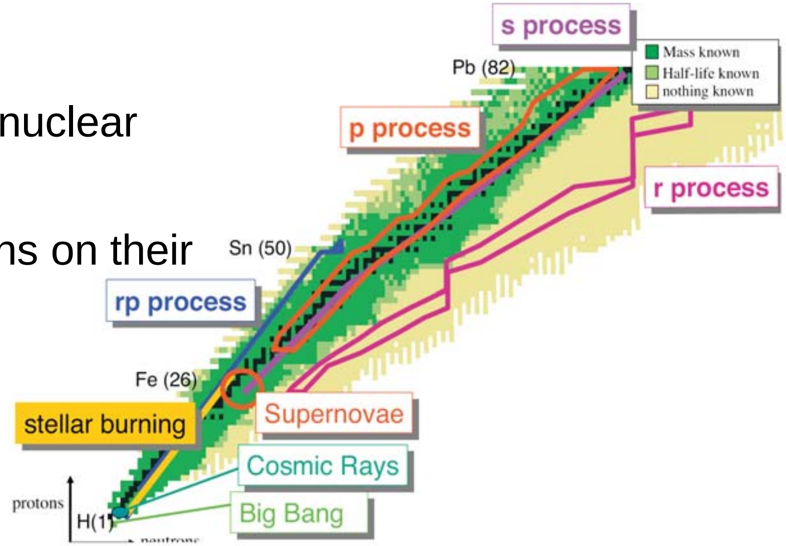
• interactions between nuclei, halflives... play decisive role

• origin of the heavy elements

• physics of stellar explosions (core-collapse, thermonuclear supernovae)

• understanding of compact objects and the explosions on their surfaces (x-ray bursts)

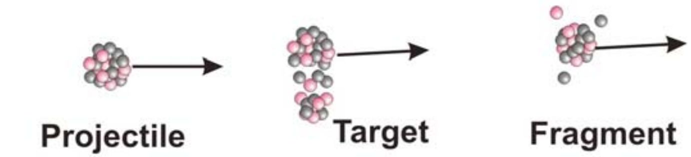
• simultanously: exiting new data will come in from the next generation of astronomical observatories!



Production of unstable nuclei

Production of Exotic Nuclei at relativistic Energies

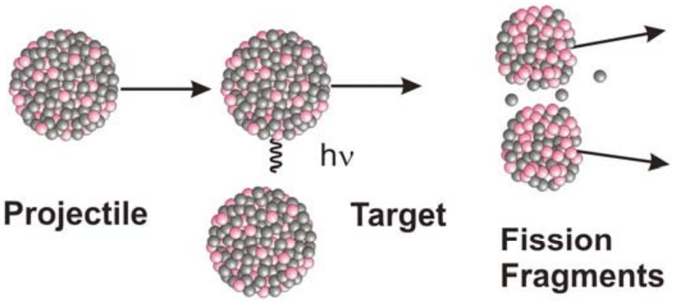
Projectile Fragmentation



Nucleon-nucleon collisions, abrasion, ablation

$$\vec{V}_f \approx \vec{V}_p$$

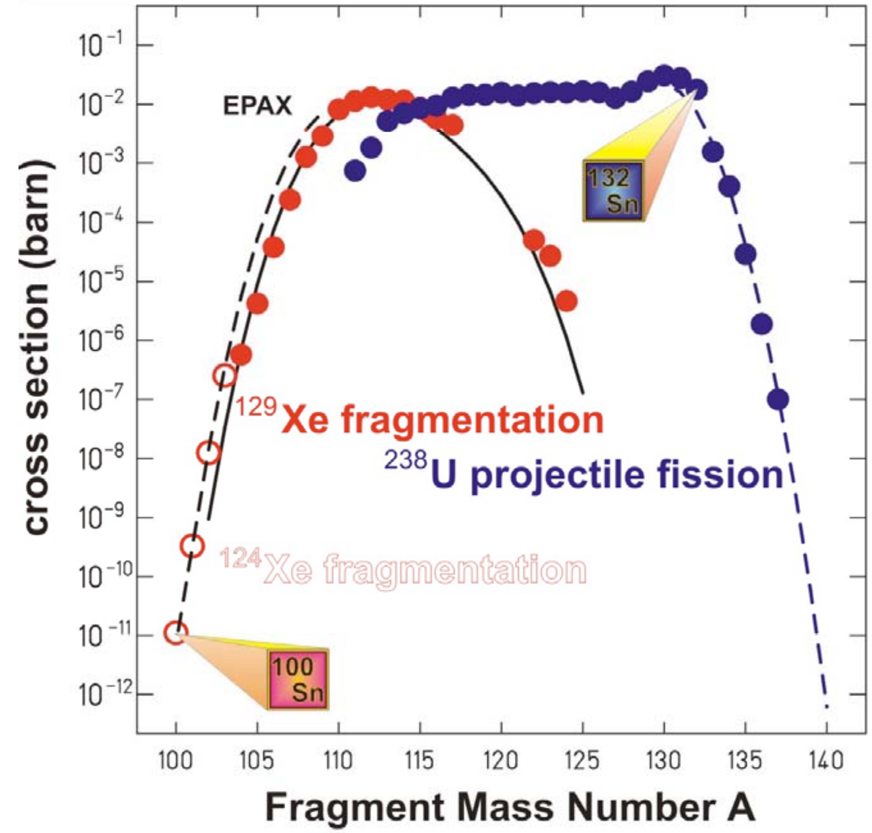
Projectile Fission



Electromagnetic excitation, fission in flight

$$\vec{V}_f \approx \vec{V}_p + \vec{V}_{fission}$$

Sn isotopes from projectile fragmentation and projectile fission

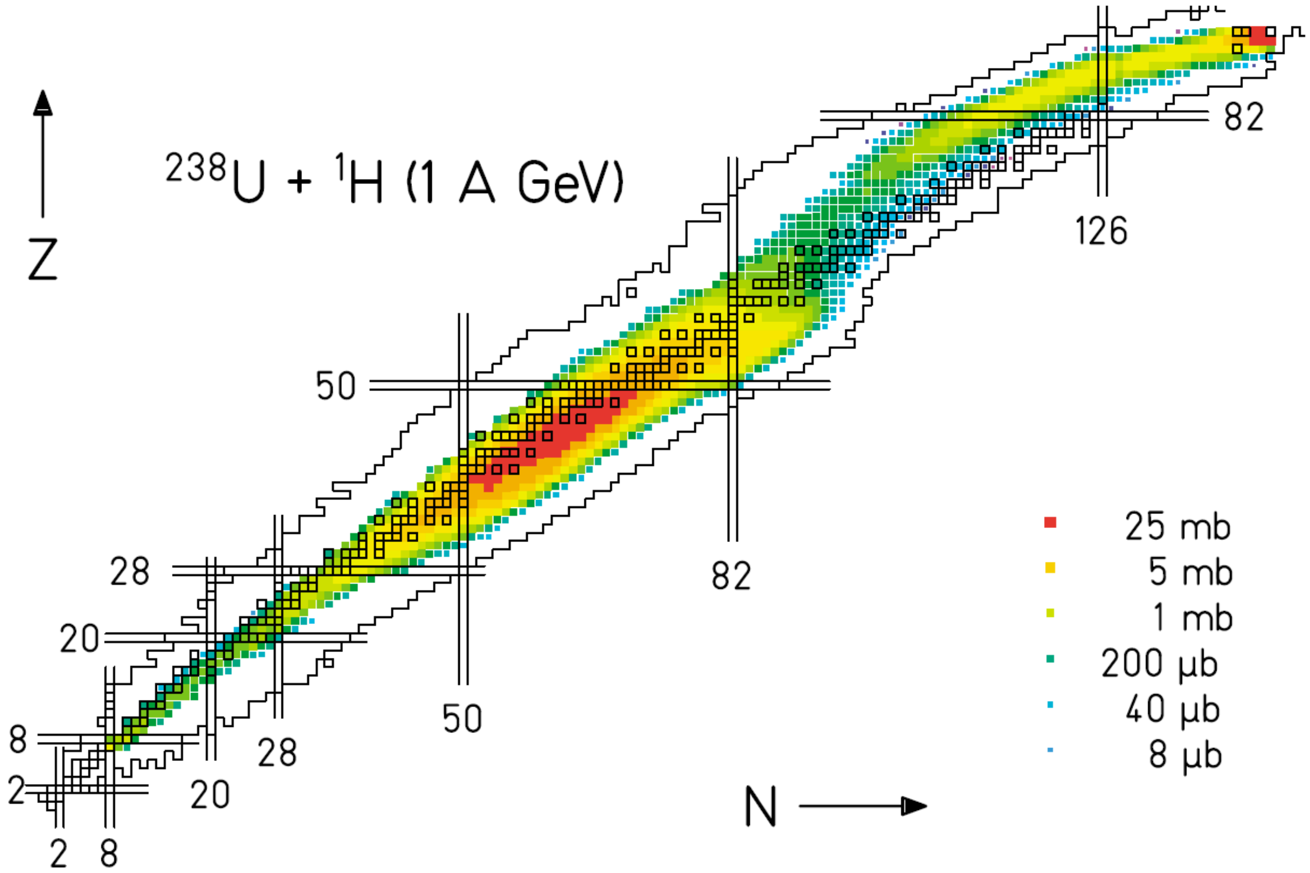


K.Sümmerer

FRS

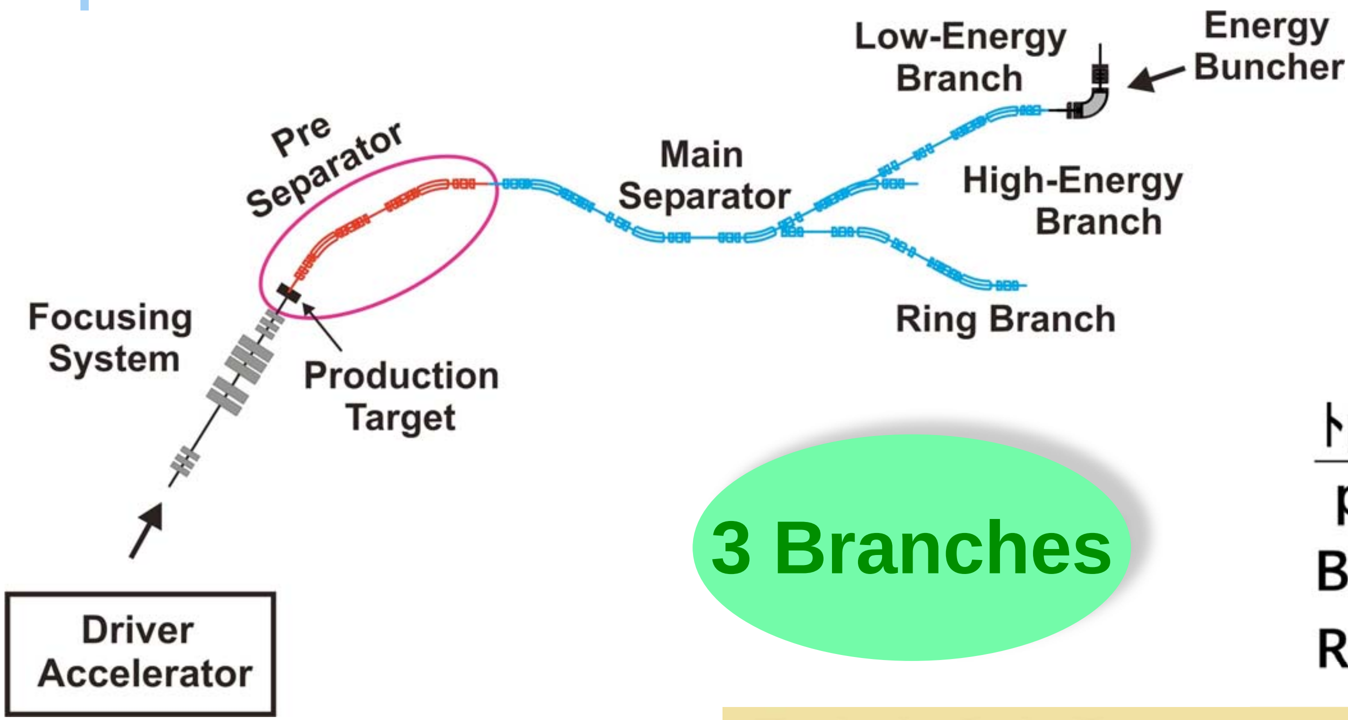
- identified nuclides (logarithmic color scale) from spallation of 1 *A*GeV ^{238}U with protons

[P. Armbuster et al., PRL 93 (2004) 212701]



The RIB Facility at FAIR

- **Super** – conducting **FR**agment **S**eparator
- large phase space acceptance (~100% for fragmentation products, 30-80% for fission products) → > factor 10 gain in transmission of fission products!
- selectivity and sensitivity (ion-by-ion identification in A and Z): fully ionized fragments + multiple separation stages (pre-separator!)



$_x = {}_y = 40$ mm mrad

$_x = 40$ mrad,

$_y = 20$ mrad

$\frac{p}{p} = 2.5\%$

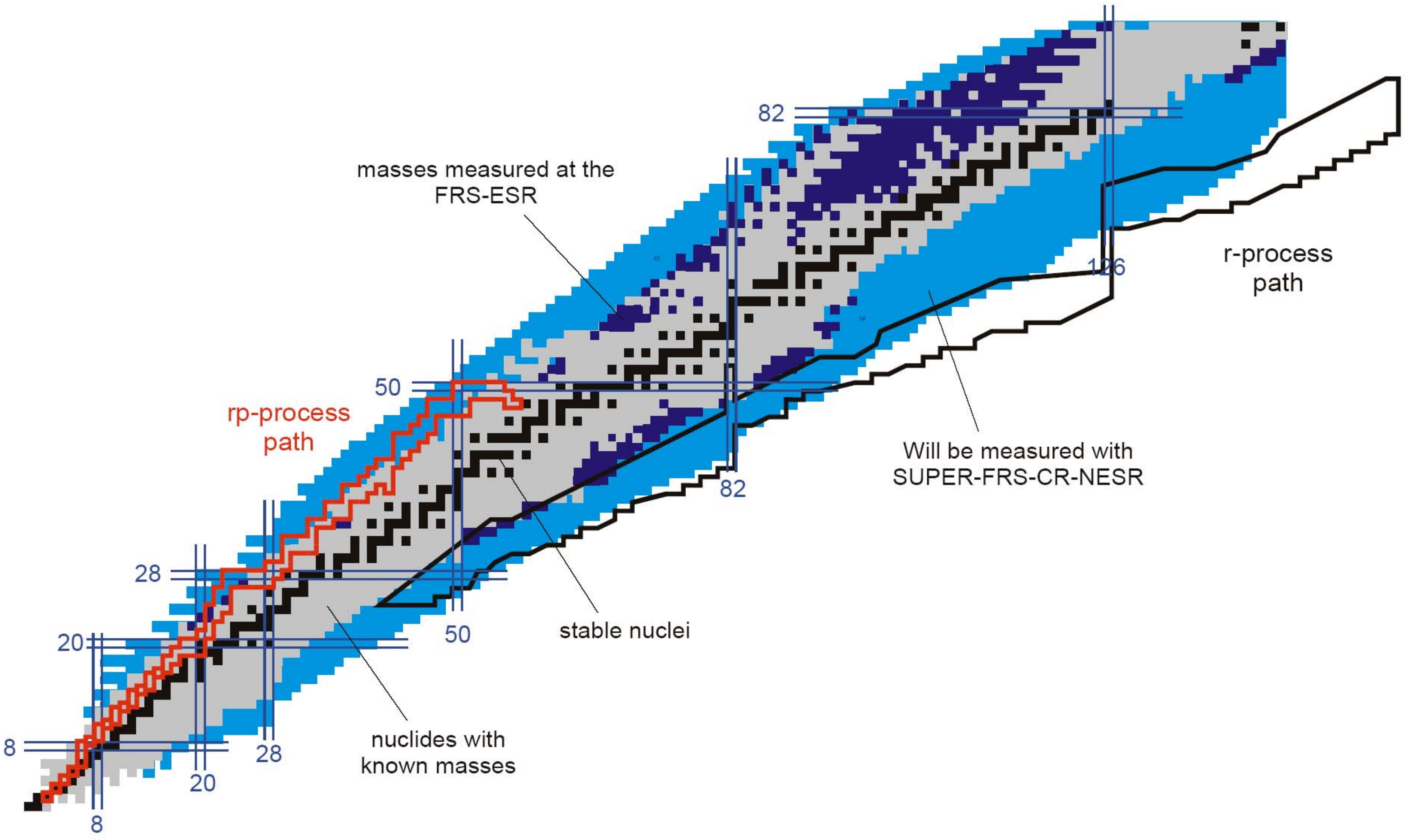
$B_{max} = 20$ Tm

$R_{ion} = 1500$

3 Branches

Technical challenges: target, beam dump, and Pre-Separator

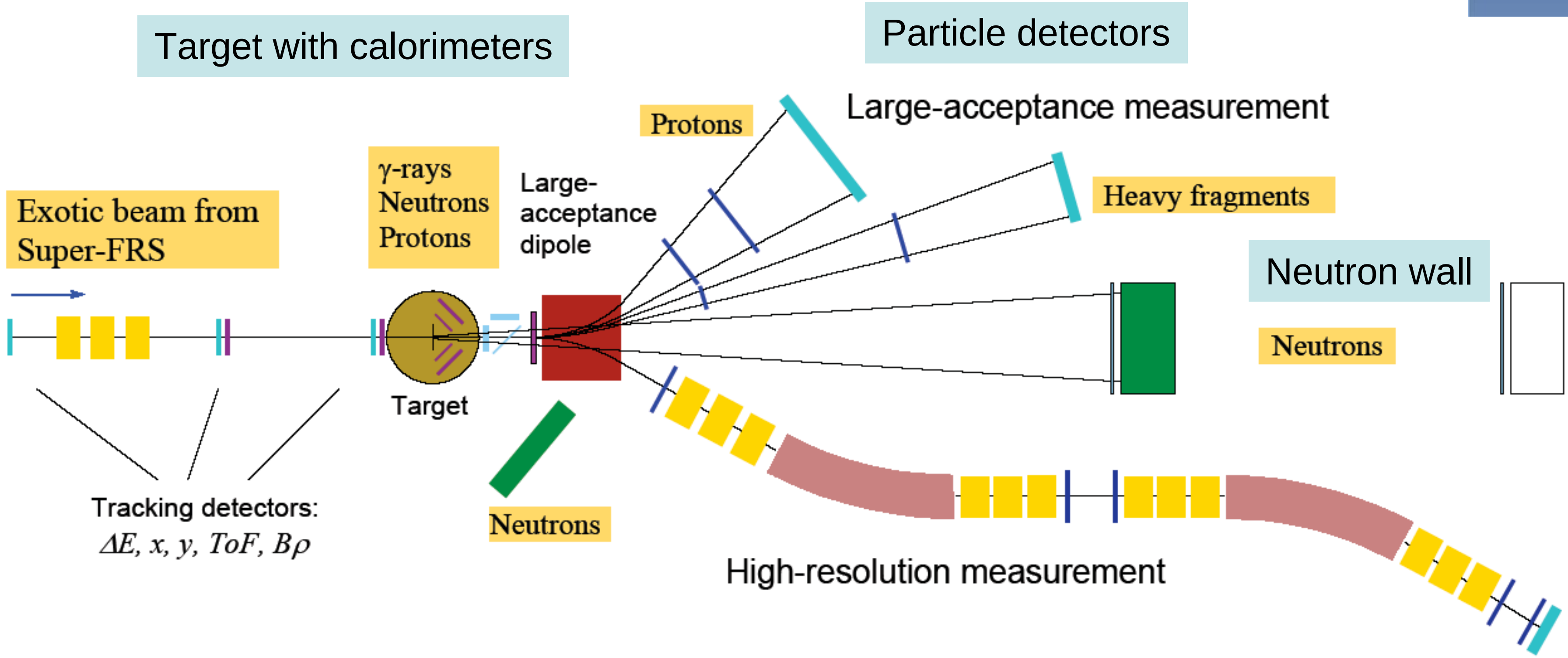
Super – FRS



82
masses measured at the FRS-ESR
50
rp-process path
28
20
8
8
20
28
50
82
126
r-process path
Will be measured with SUPER-FRS-CR-NESR
stable nuclei
nuclides with known masses

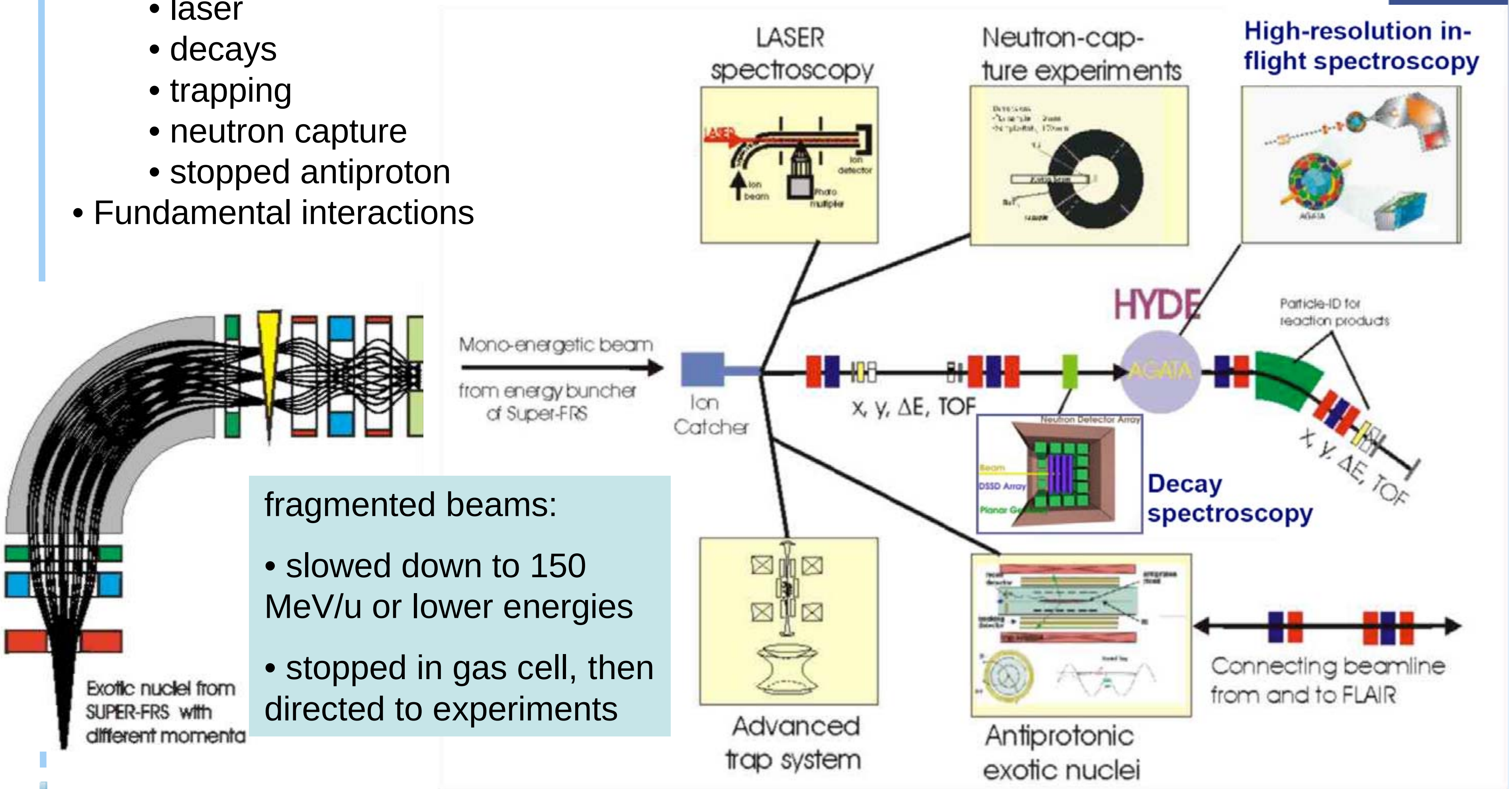
High energy branch

- **R**eactions with **R**elativistic, **R**adioactive **B**eams (R^3B)
- kinematical complete measurements of reactions with RIBs for nuclear structure investigations
- study of most exotic nuclei (beam intensities down to 1 ion/s)
- wide range of scattering experiments → radii, nuclear structure,...



Low energy branch

- Spectroscopy → information on lifetimes, moments, spins, radii.....
  - in –beam
  - laser
  - decays
  - trapping
  - neutron capture
  - stopped antiproton
- Fundamental interactions



fragmented beams:

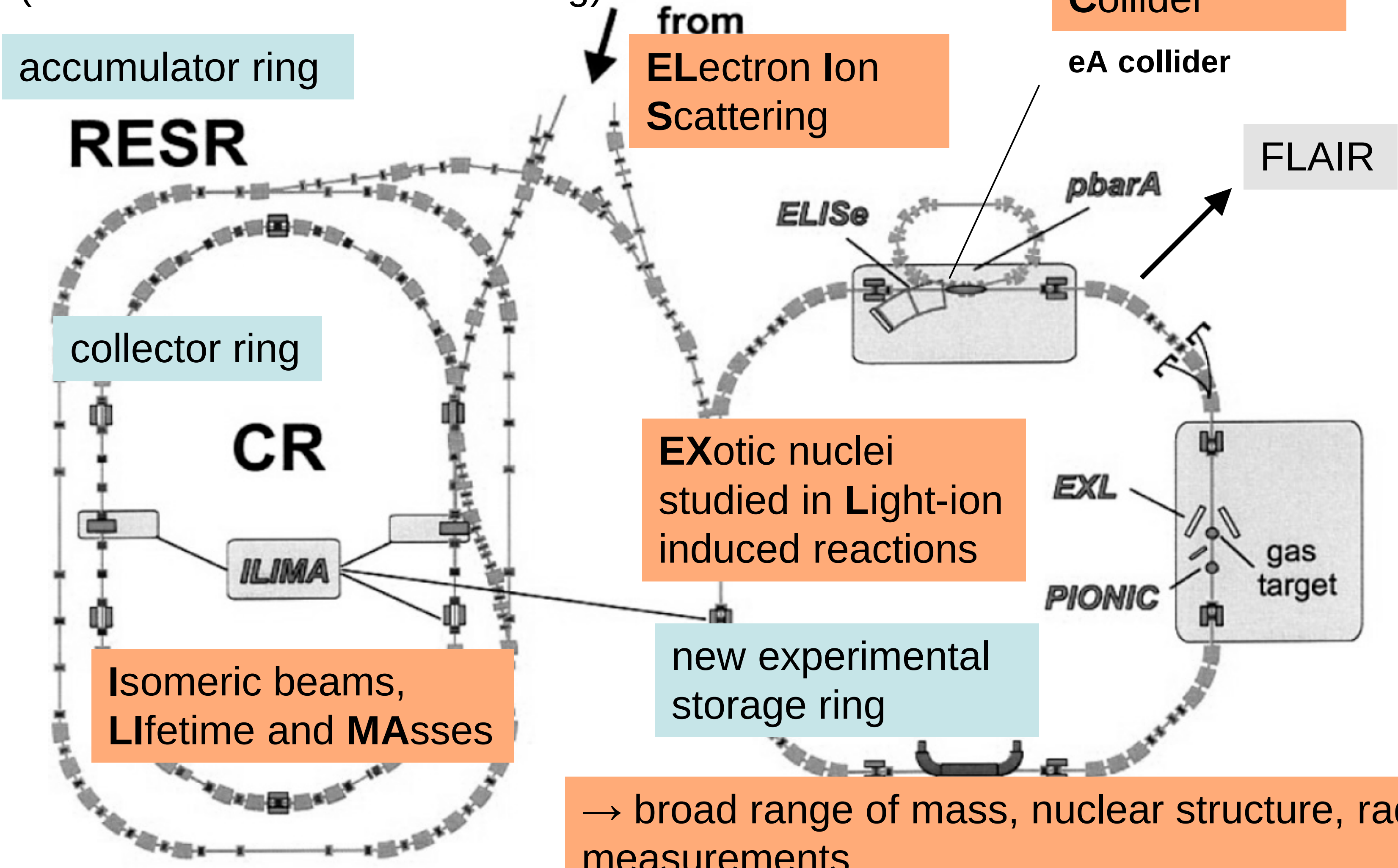
- slowed down to 150 MeV/u or lower energies
- stopped in gas cell, then directed to experiments

energy buncher → energy focussed secondary beams of all elements!

Ring branch

→ high luminosity for in-ring reaction experiments for an unprecedented variety of particle beams within cooling periods of < 1s!

(electron and stochastic cooling)



→ broad range of mass, nuclear structure, radii .... measurements

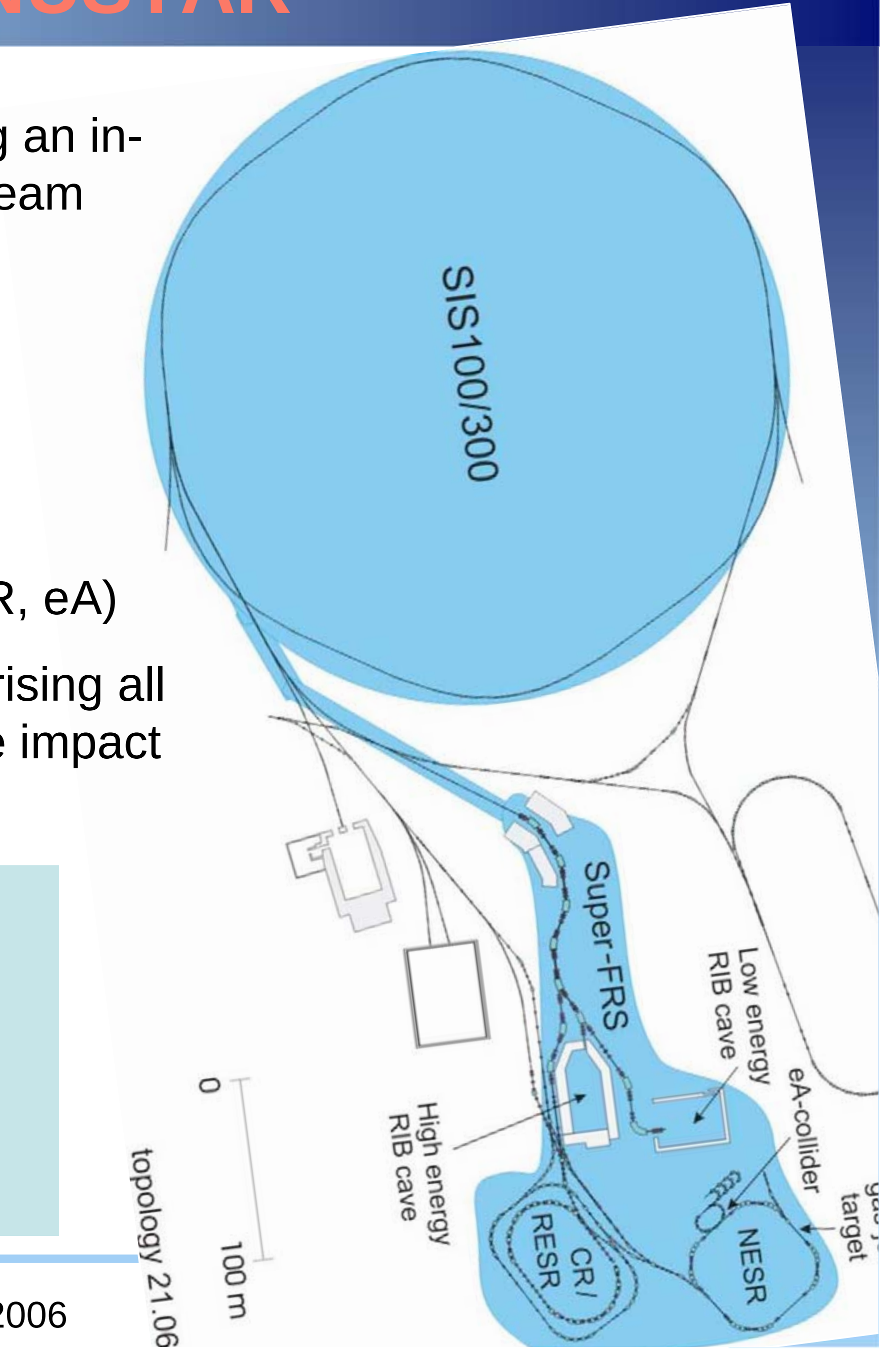
Summary – NUSTAR

• SIS 100/300 in high-intensity mode drivíng an in-flight (fragmentation/ fission) rare-isotope beam facility:

- Super-FRS
- High energy reaction setup
- energy-bunched stopped beams
- multi-storage rings (CR, RESR, NESR, eA)

• enormously broad physics program comprising all kinds of nuclear structure physics with large impact nuclear theory, astrophysics,...

Key characteristics :
- all elements, H to U
- intensity > 10^{12} ions/sec.
- high energy, 1.5 GeV/u
- pulsed and CW beams



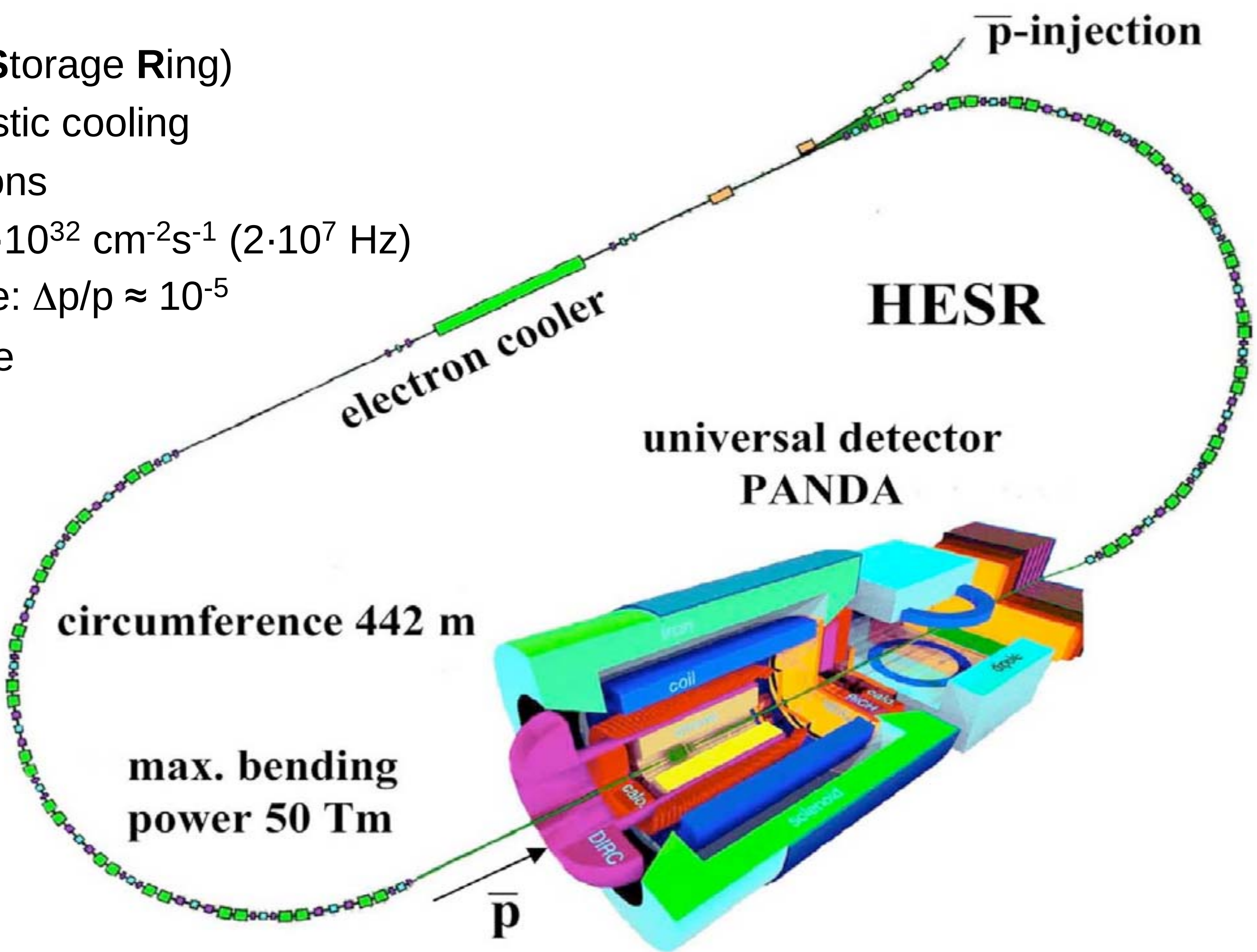
PANDA

antiProton ANnihilation at DArmstadt

→ nuclear and hadron physics with antiprotons

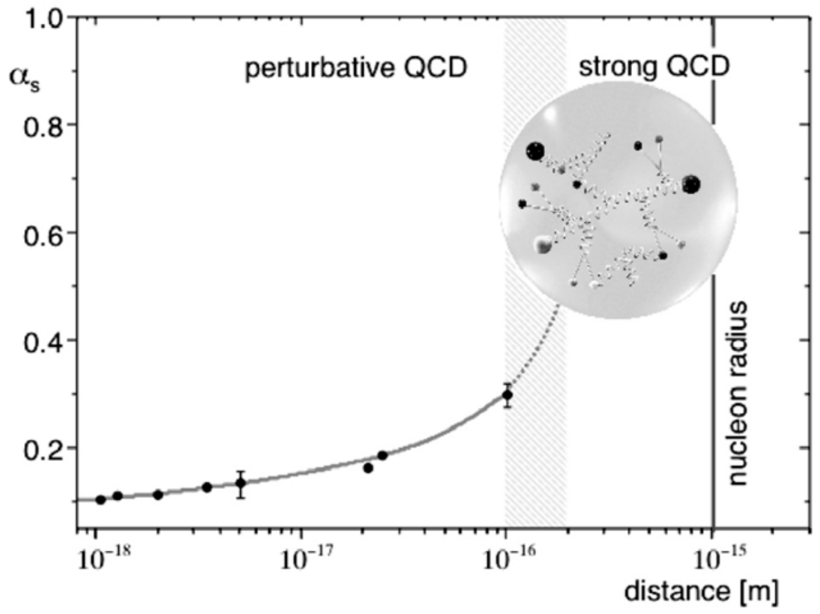
HESR (**H**igh **E**nergy **S**torage **R**ing)

- electron and stochastic cooling
- 10^{11} stored antiprotons
- design luminosity: $2 \cdot 10^{32}$ cm^{-2}s^{-1} ($2 \cdot 10^{7}$ Hz)
- high resolution mode: $\Delta p/p \approx 10^{-5}$
- high luminosity mode



PANDA – physics case

- **non-perturbative regime of QCD**
  - quark confinement
  - hadron masses » Σ quark masses
  - self interaction among gluons



→ **research program**

- hadron physics: charmonium spectroscopy
  gluonic excitations: glueballs, hybrids
- nuclear physics: open and hidden charm in nuclear matter
  hypernuclei

Experimental approach

- HESR energy range: pbar 1.5 – 15 GeV/c, ($\Delta p/p \approx 10^{-5}$)
- hadron (conventional and exotic) production by hadron annihilation processes

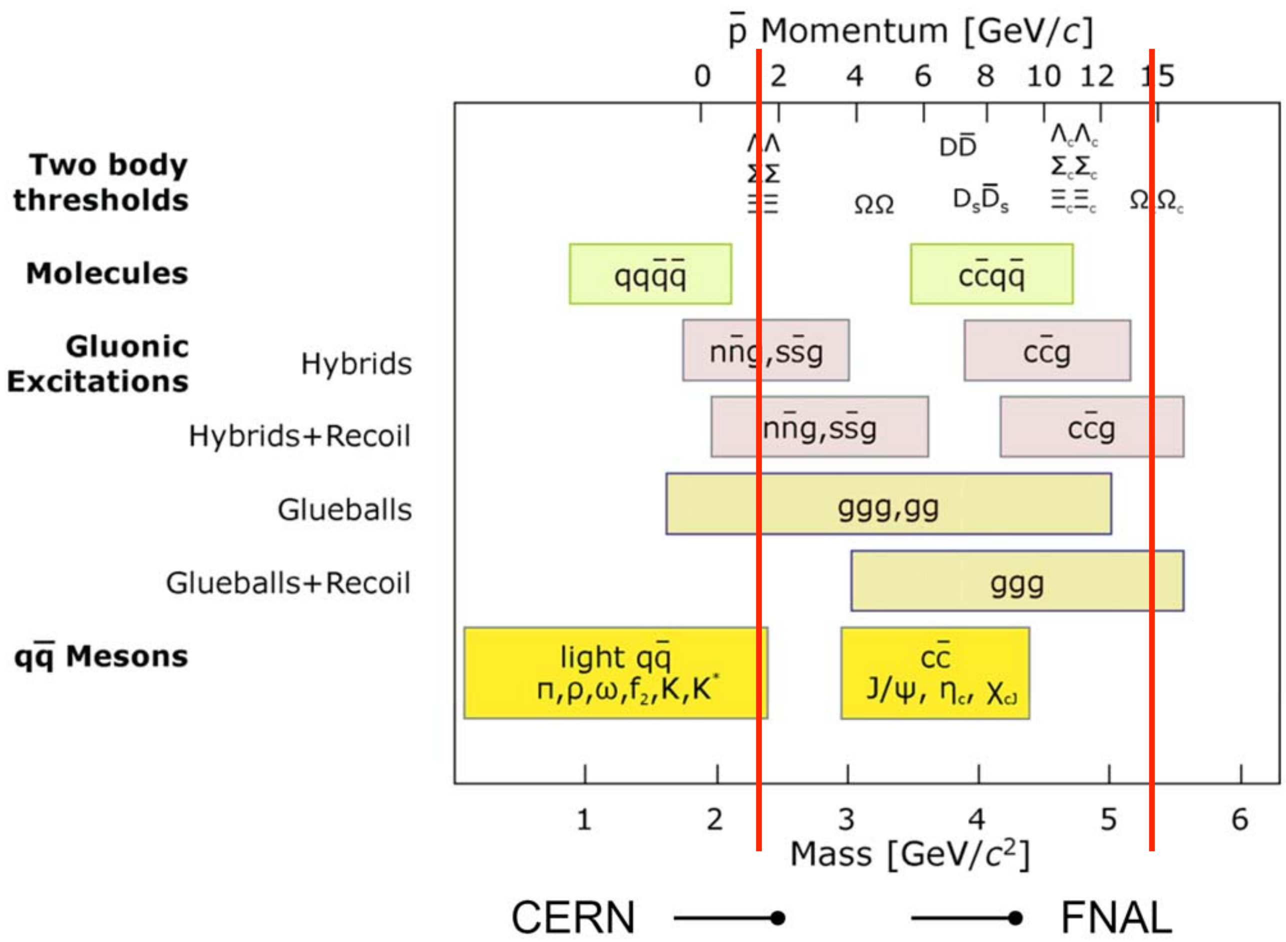
→ gluon-rich environment!

→ formation experiments of all states with non-exotic quantum numbers

→ high precision scan of narrow resonances

→ exotic systems in production experiments

→ high statistics!



Resolution!

Crystal Ball, SLAC

e^+e^- → J / → 朓 $_{1,2}$ → 聽 J / → 聽 e^+e^-

E835, Fermilab

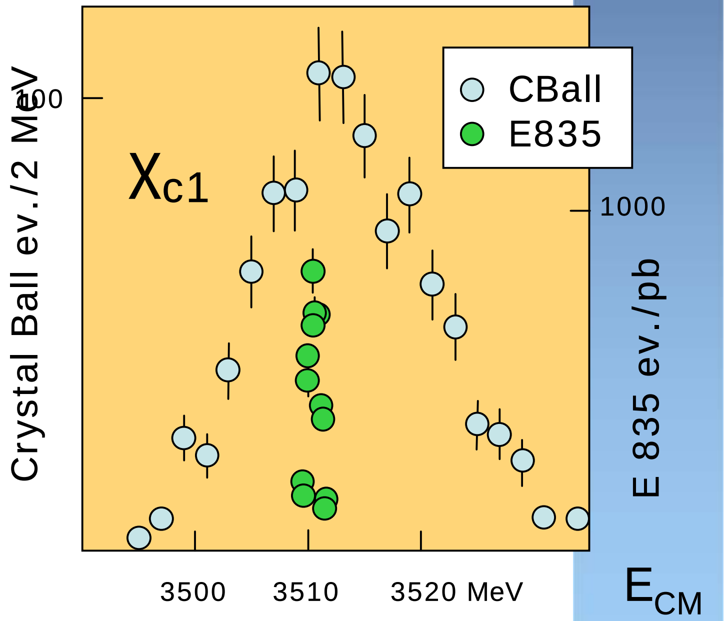
$p\bar{p}$ → $_{1,2}$ → 腟 / → e^+e^-

e^+e^- interactions:

– Only 1^{--} states are formed
– Other states only by secondary decays (moderate mass resolution)

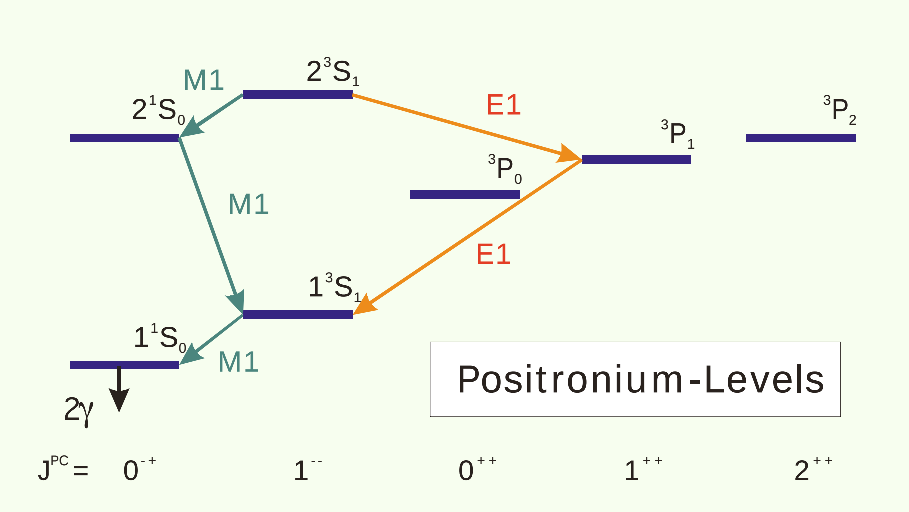
$p\bar{p}$ reactions:

– All states directly formed (very good mass resolution)

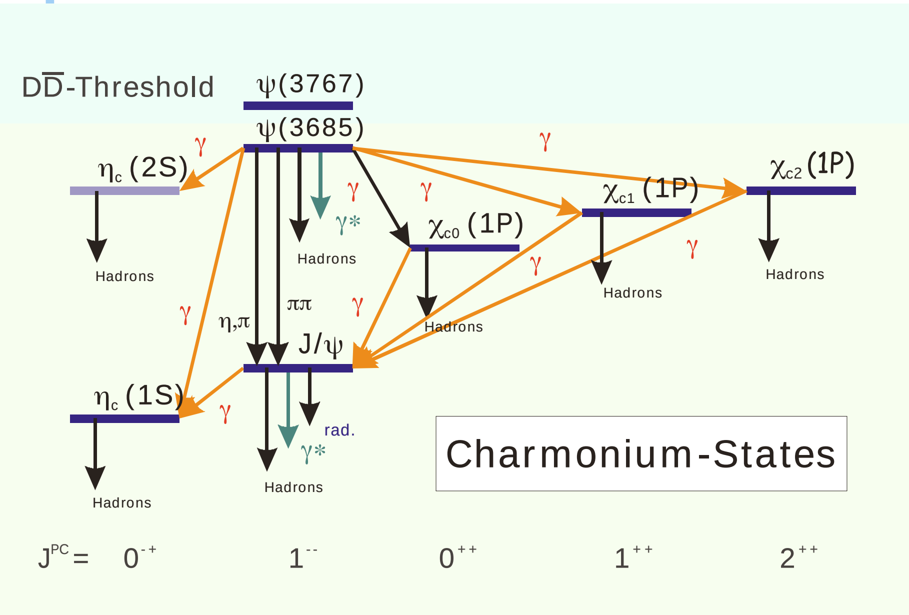


in addition: beam quality, high resolution detector, redundancy

Charmonium spectroscopy



- study strong interaction in bound system (similarly to QED and positronium)
- due to heavy charm mass this system allows to study the transition region between the perturbative and non-perturbative regime of QCD

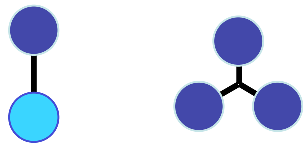


- systematic study of the complete spectrum (high precision, high statistics)
- states above D$\bar{D}$ threshold
- several questionable/ unsure states (e.g. h_c), partially poor agreement between measurements from past

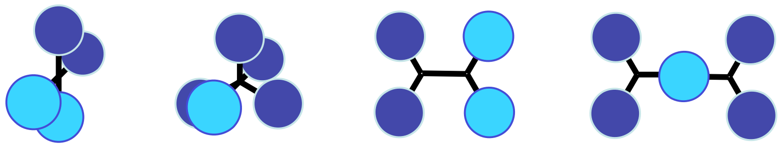
(Exotic) Objects of interest

Quark AntiQuark

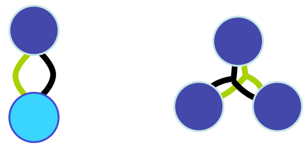
Mesons/ Baryons



Molecules/ Multiquarks



Hybrids



Glueballs

- rich spectrum of gluonic excitations predicted but poorly proven/ understood so far (experiments at BNL, LEAR, problem: mixing with "normal" states!)
- glueballs: look for states with spin-exotic quantum numbers!
- PANDA: charmed hybrids → narrow states if below $D\bar{D}$ threshold

  some with exotic quantum numbers

hadrons in cold nuclear matter

• medium modifications of hadron masses → partial restoration of chiral symmetry in nuclear matter?

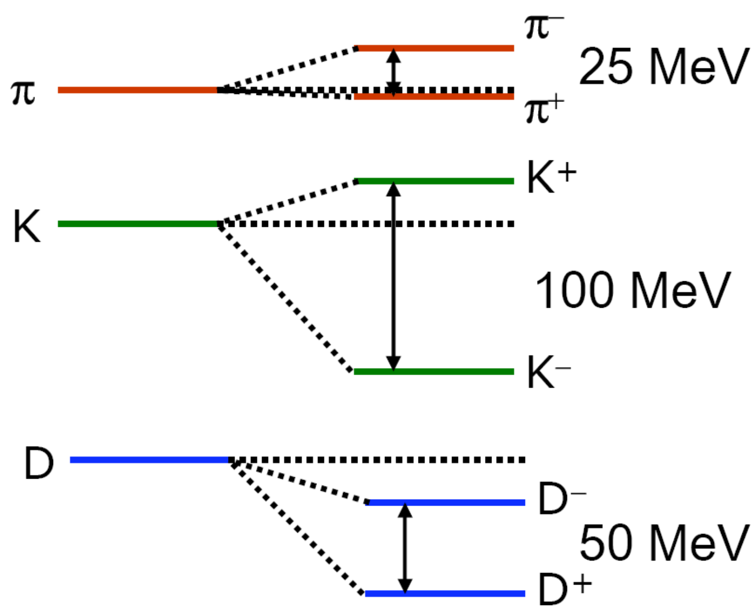
• origin of hadron masses?

• deeply bound pionic states

• ρ,ω,ϕ in-medium modifications in A+A collisions

• K production in A+A collisions at threshold

→ extend program to charm sector!

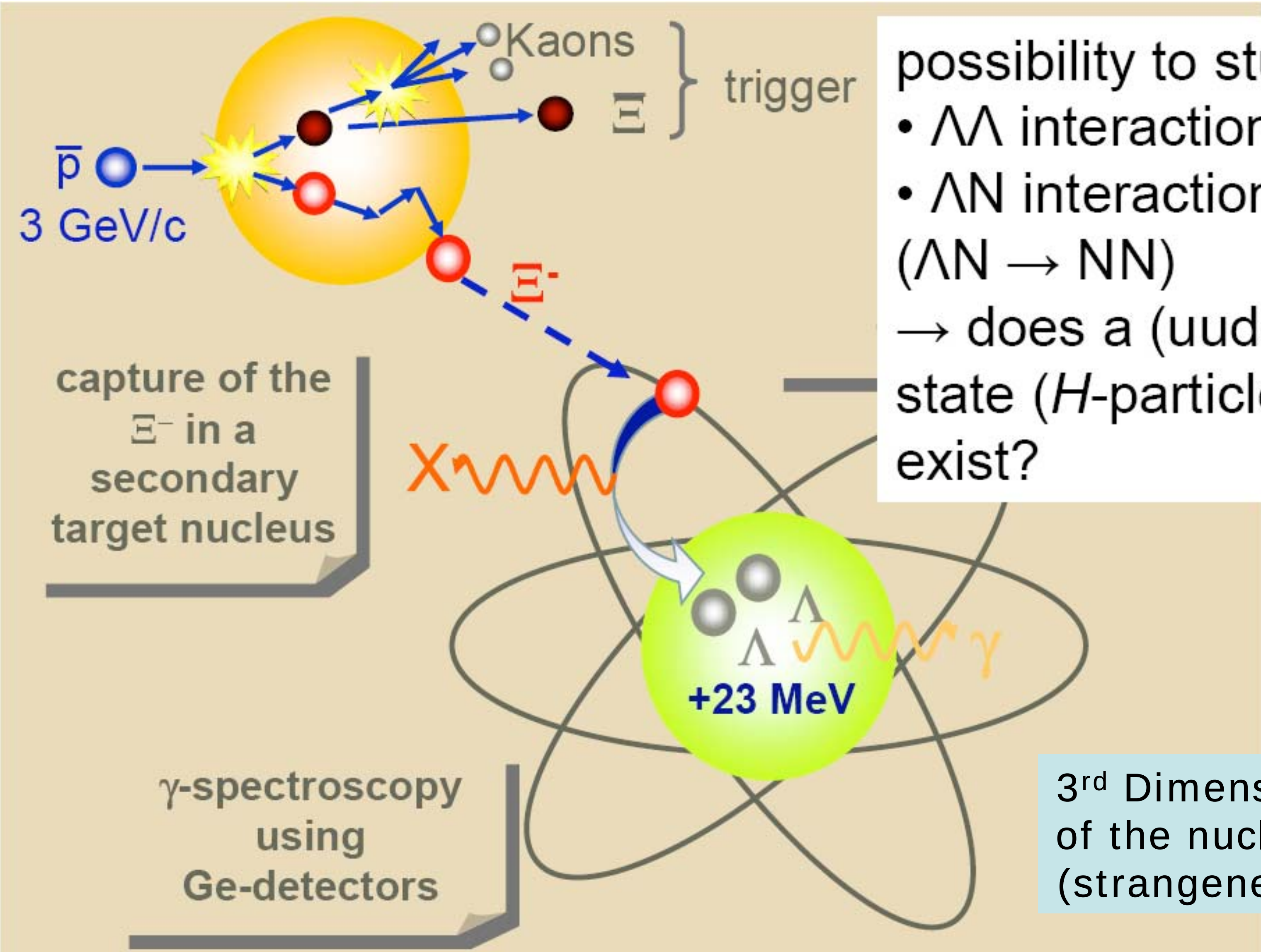


A. Hayashigaki, PLB 487 (2000) 96

• charmonium: mass determined by charm → sensitive to gluon condensate

• open charm: heavy + light quark ("QCD hydrogen") → more sensitive to quark condensate

Hypernuclei



possibility to study
- ΛΛ interaction
- ΛN interaction

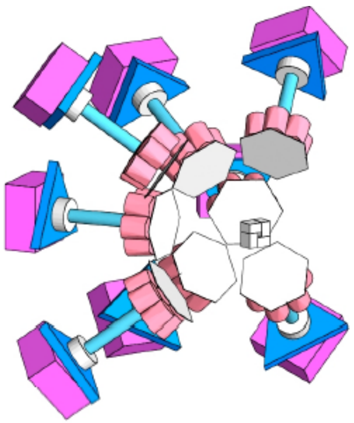
(ΛN → NN)

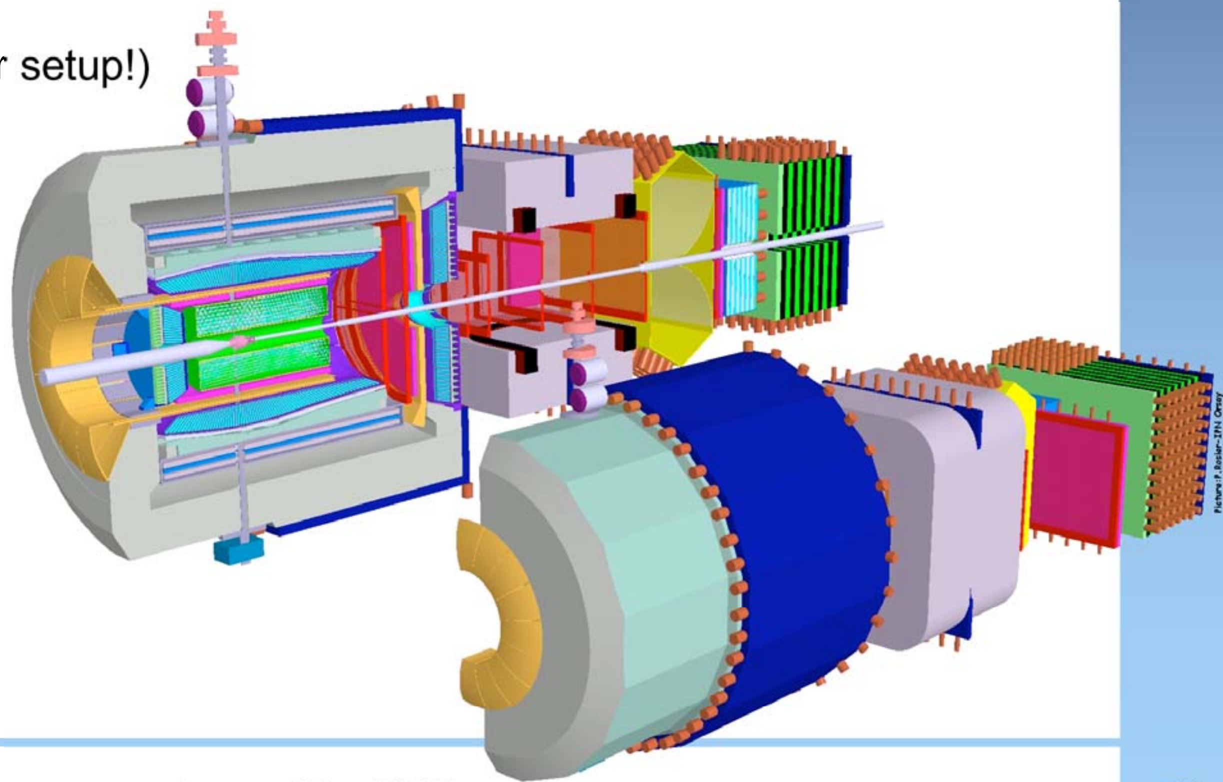
→ does a (uuddss) state (*H*-particle) exist?

3rd Dimension of the nuclear chart (strangeness)

Detector requirements

- full angular acceptance and angular resolution for charged particles and g, π^0
- particle identification (p, K , p, e, μ) in the range up to ~ 8 GeV/c
- resolution of secondary vertices (open charm!)
- forward capabilities
- high momentum resolution in a wide energy range
- high rate capabilities, especially in interaction point region and forward detector : expected interaction rate ~ 10^7 /s
- sophisticated trigger
- modularity (hypernuclear setup!)





PANDA - Summary

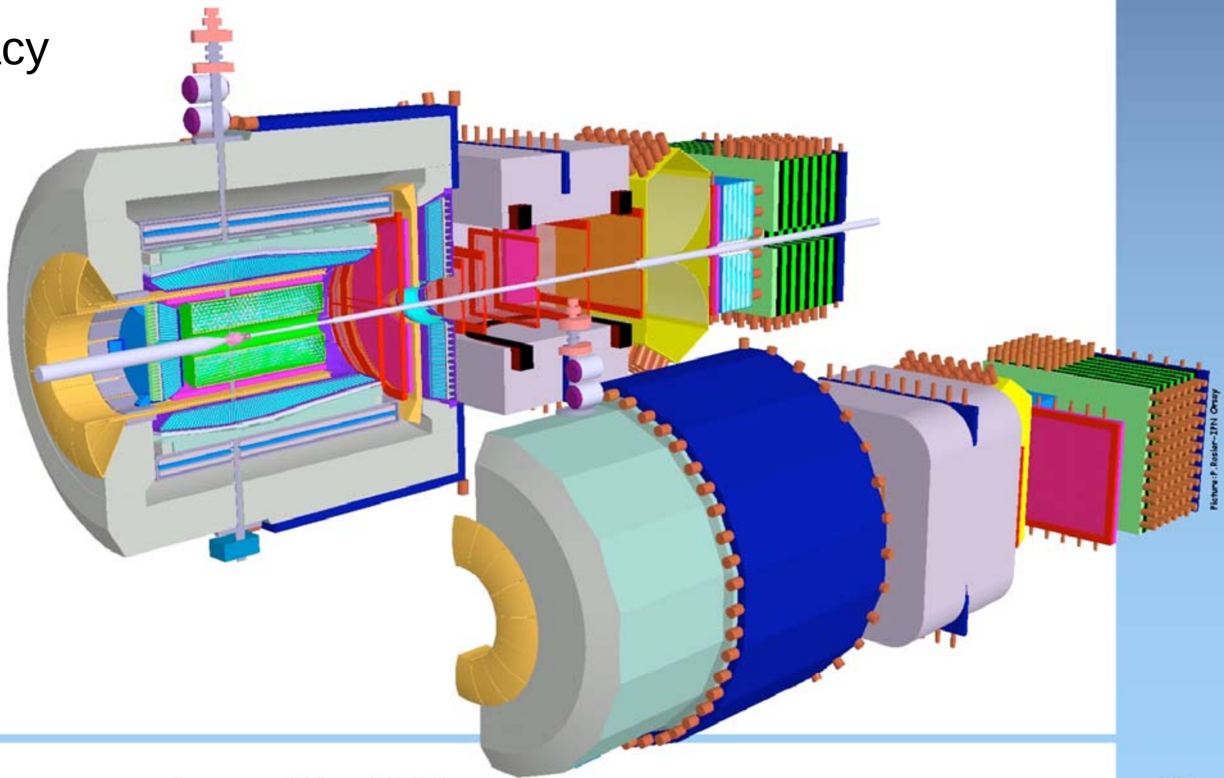
• broad physics spectrum studying hadron and nuclear physics in the non perturbative region of QCD

• key features:

  • high luminosity, high beam quality

  • $p\bar{p}$ formation experiment for states with non-excotic quantum numbers

→ unprecedented accuracy



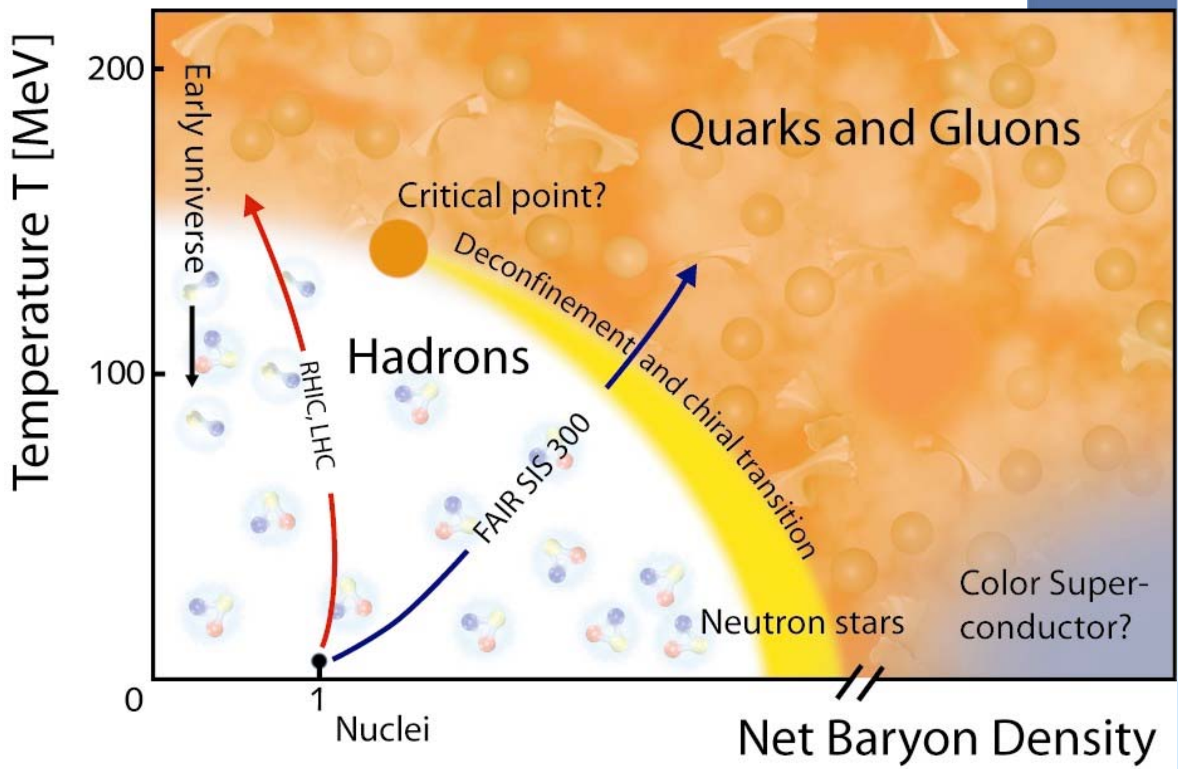
CBM

- **C**ompressed **B**aryonic **M**atter experiment
- SIS 300 → U^{92+} 15-35 GeV/nucleon with beam intensities up to 10^9/s

  Z/A = 0.5 nuclei up to 45 GeV/nucleon

→ exploration of the QCD phase diagram with heavy-ion collisions!

→ investigation of nuclear matter at highest baryon densities but still moderate temperatures in A+A collisions



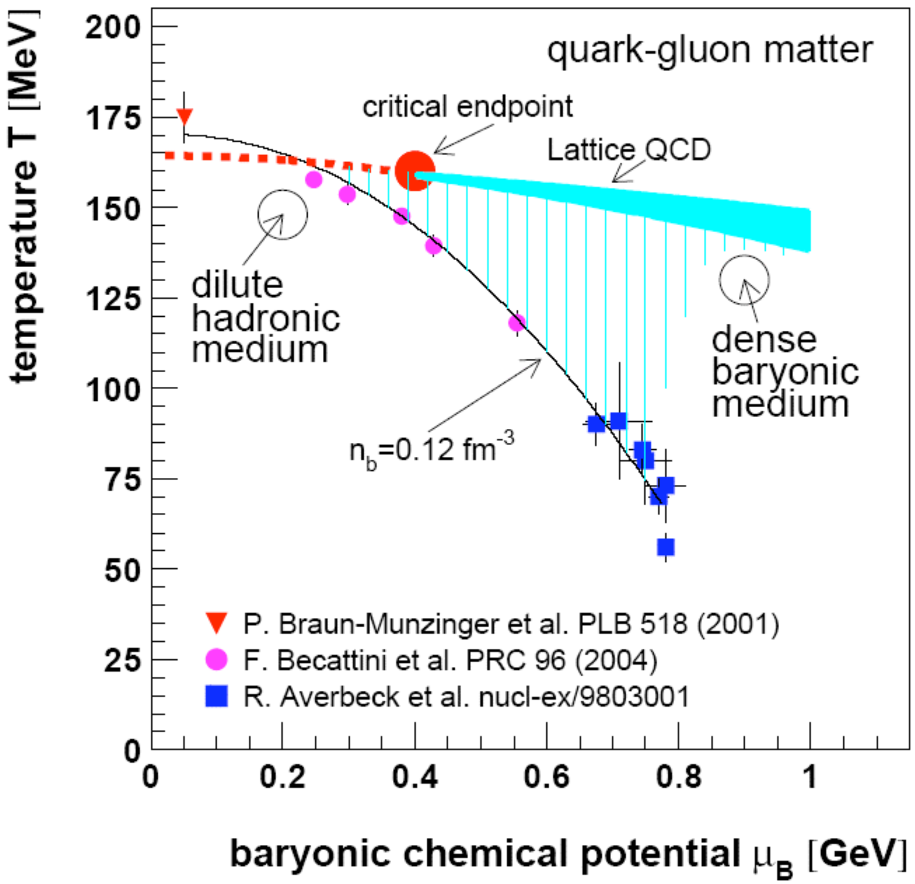
CBM – physics case

• **milestone** in mapping the QCD phase diagram would be the (unambiguous) discovery of either the critical point or the 1st order phase transition

• top SPS, RHIC, LHC :
high T, low μ_B region –
most probably **crossover**

• **high μ_B region !**
onset of deconfinement?
1st order phase transition?
critical point?
high baryon density!
in medium modifications of hadrons

• lower SPS, AGS:
limited in observables, statistics

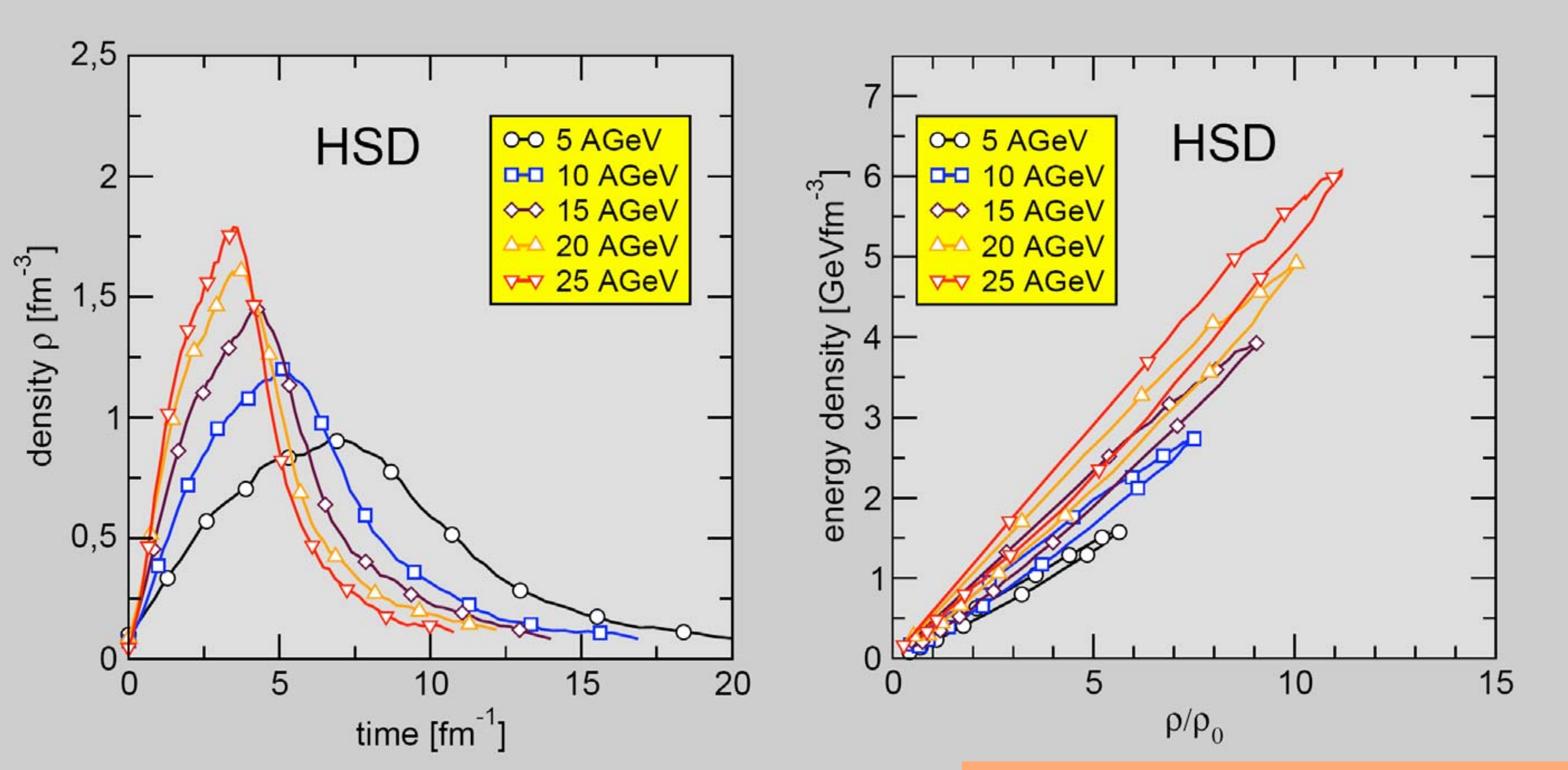


critical endpoint:
[Z.Fodor, S.Katz, JHEP 0404:050 (2004)]
[S.Ejiri et al., hep-lat/0312006]

→ **SIS 300 @ FAIR**
2nd generation experiment! → **charm, dileptons, fluctuations, correlations**

Dense baryonic matter

- baryon density in central cell (Au+Au, b=0 fm) in transport calculations HSD (mean field, hadrons + resonances + strings), QGSM similar results
- enormous energy and baryon densities reached! ($\varepsilon > \varepsilon_{crit}$)



[CBM physics group, C. Fuchs priv. com.]

Phase diagram

- UrQMD calculation of T, μ_B as function of reaction time

(open symbols – nonequilibrium,

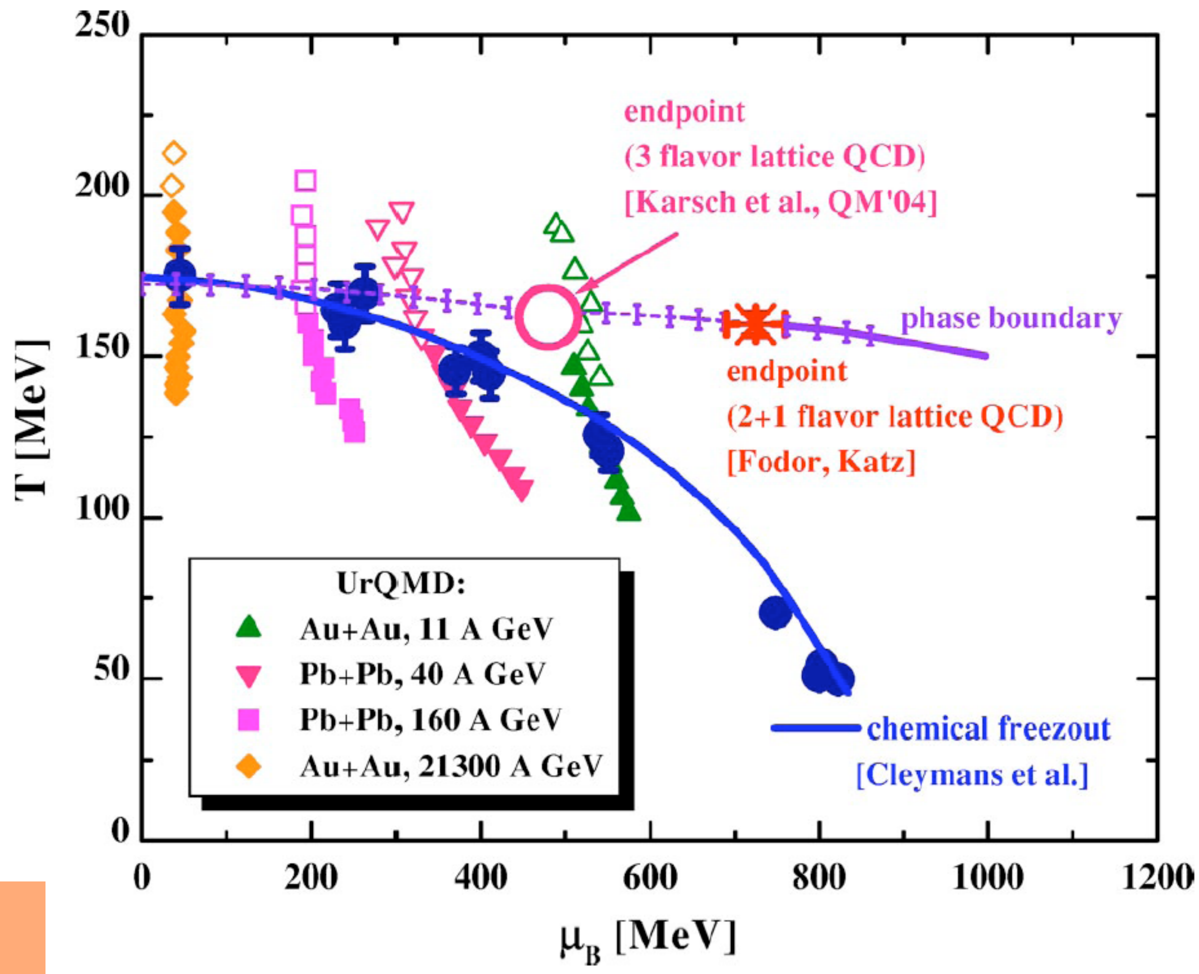
full symbols – appr. pressure equilibrium)

- phase border crossed already at rather low energies

(see also results from 3-fluid hydrodynamics)

- critical point in reach?

CBM energy range:
15 - 35 AGeV for Au+Au



[Bratkovskaya et al., PRC 69 (2004) 054907]

Physics of CBM

physics topics

deconfinement at high ρ_B ?

softening of EOS ?

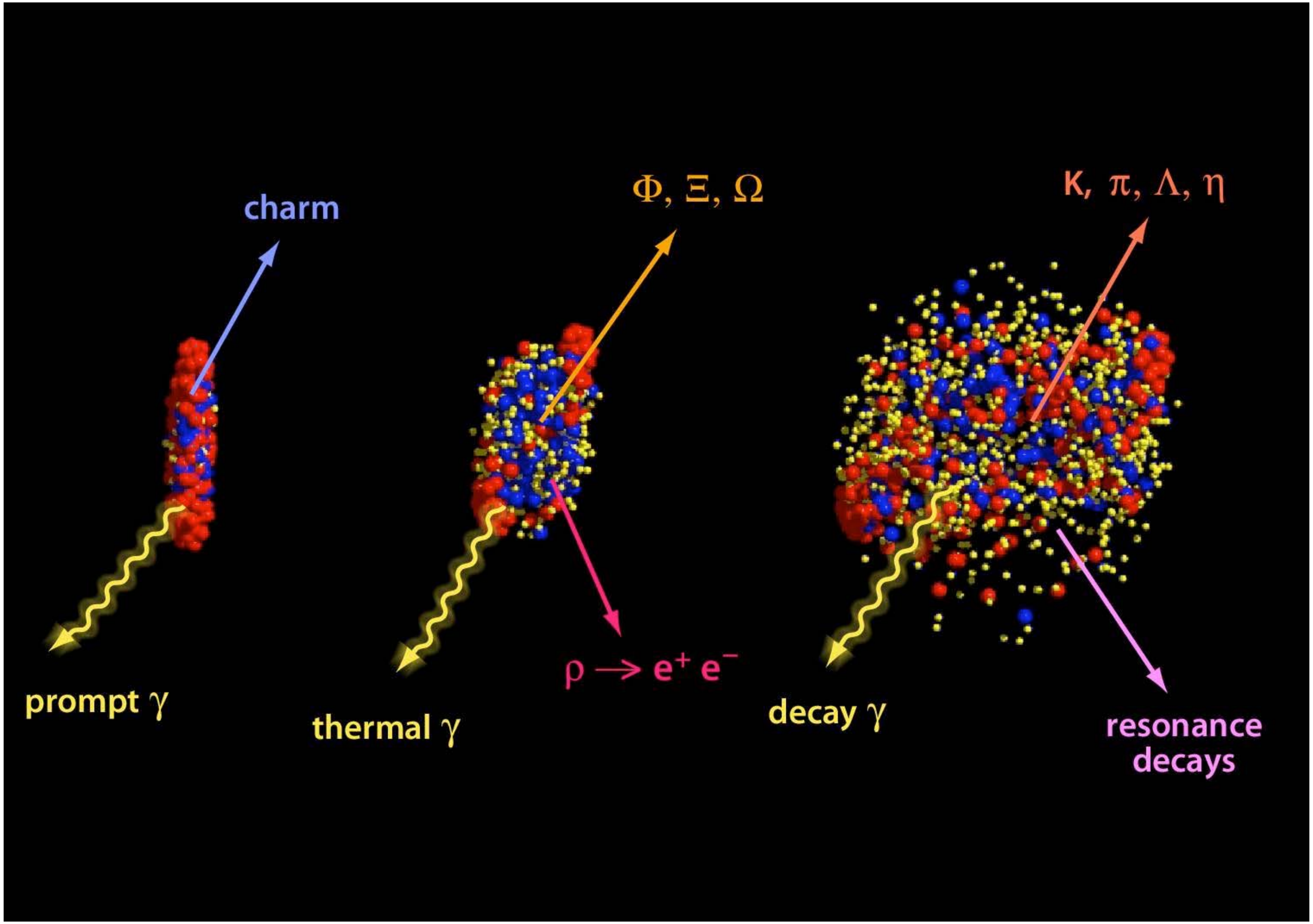
order of phase transition ?

in-medium properties of hadrons

$\rightarrow$ onset of chiral symmetry restoration at high ρ_B

Critical point ?

Diagnostic probes



Physics of CBM

physics topics

observables

deconfinement at high ρ_B ?
softening of EOS ?
order of phase transition ?

→

strangeness production: K, Λ, Σ, Ξ, Ω
charm production: J/ψ, D
flow excitation function

in-medium properties of hadrons
→ onset of chiral symmetry restoration at high ρ_B

→

ρ, ω, $\phi \to e^+e^-$
open charm

Critical point ?

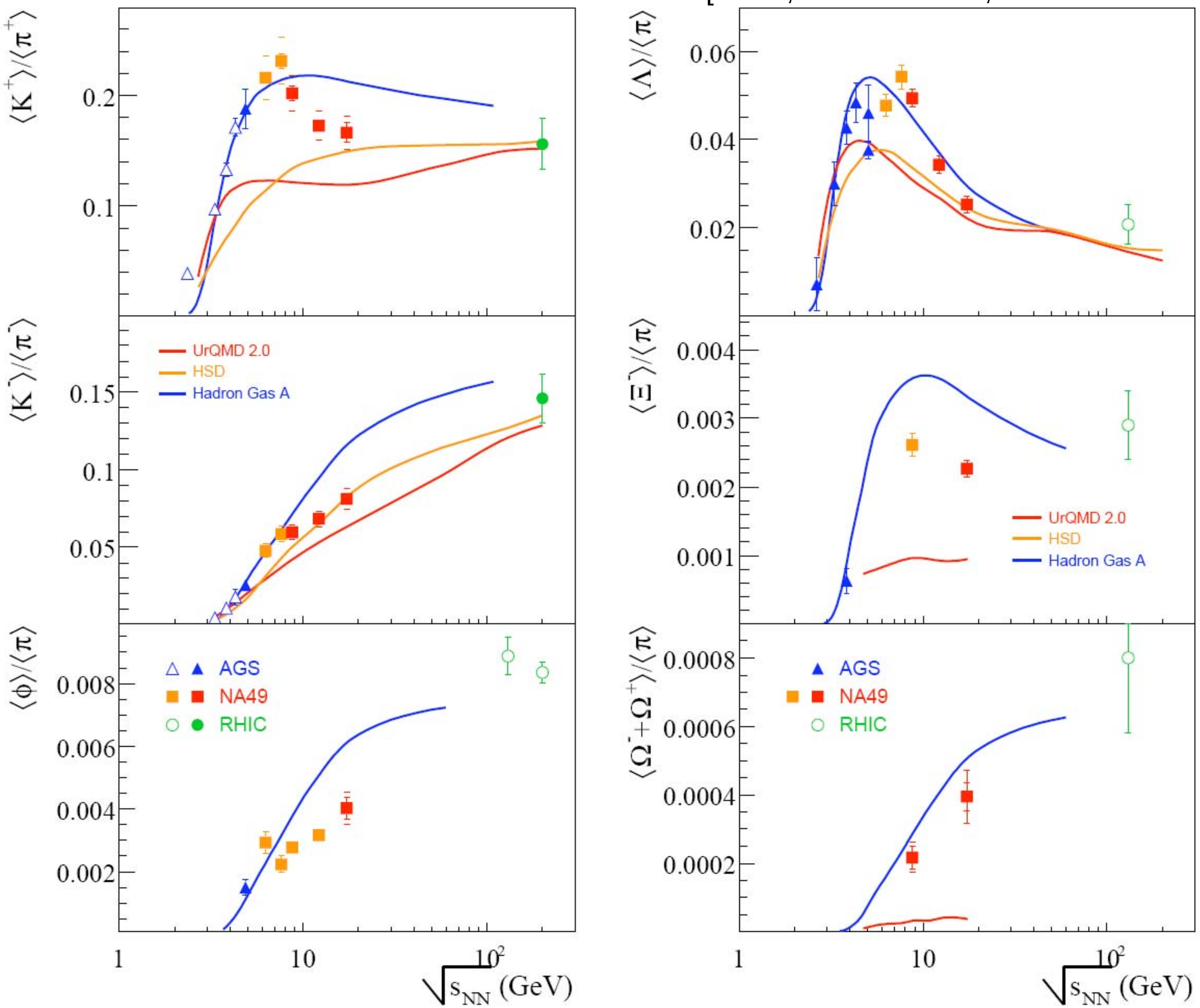
→

event-by-event fluctuations

CBM: rare probes → high interaction rates!

Strangeness production

[NA49, C.Blume et al., nucl-ex/0409008]



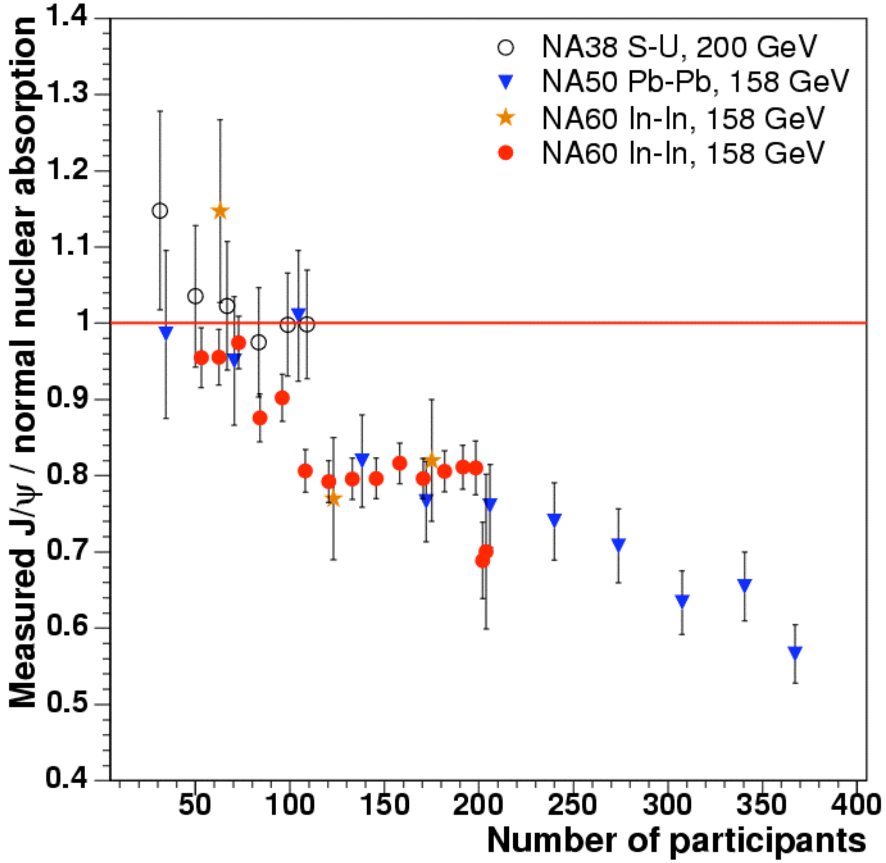
- s-production mechanism different in hadronic / partonic scenario
- maximum of strangeness production at 30 AGeV

→ change from hadronic to partonic phase?

- CBM energy range: 15 – 35/45 AGeV (depending on A)
- verify and extend energy dependence!

J/ψ suppression

[E. Scomparin for NA 60, QM05]



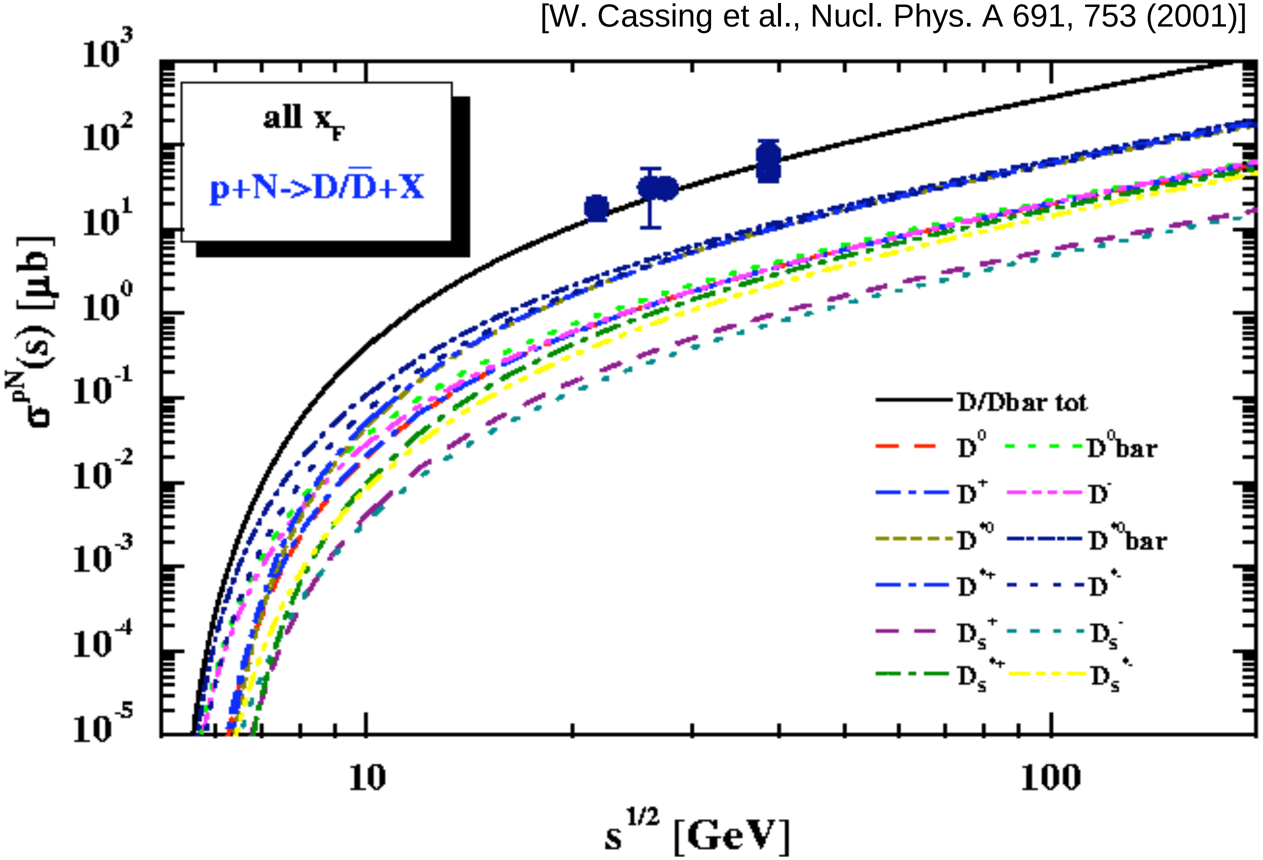
- screening of $c\bar{c}$ pairs in partonic phase
- anomalous J/ψ suppression observed at top-SPS and RHIC energies
- signal of deconfinement?
- energy dependence?!

charm production

Charm production (and propagation in A+A collisions) at threshold?
- not much known
- important constraints for models!

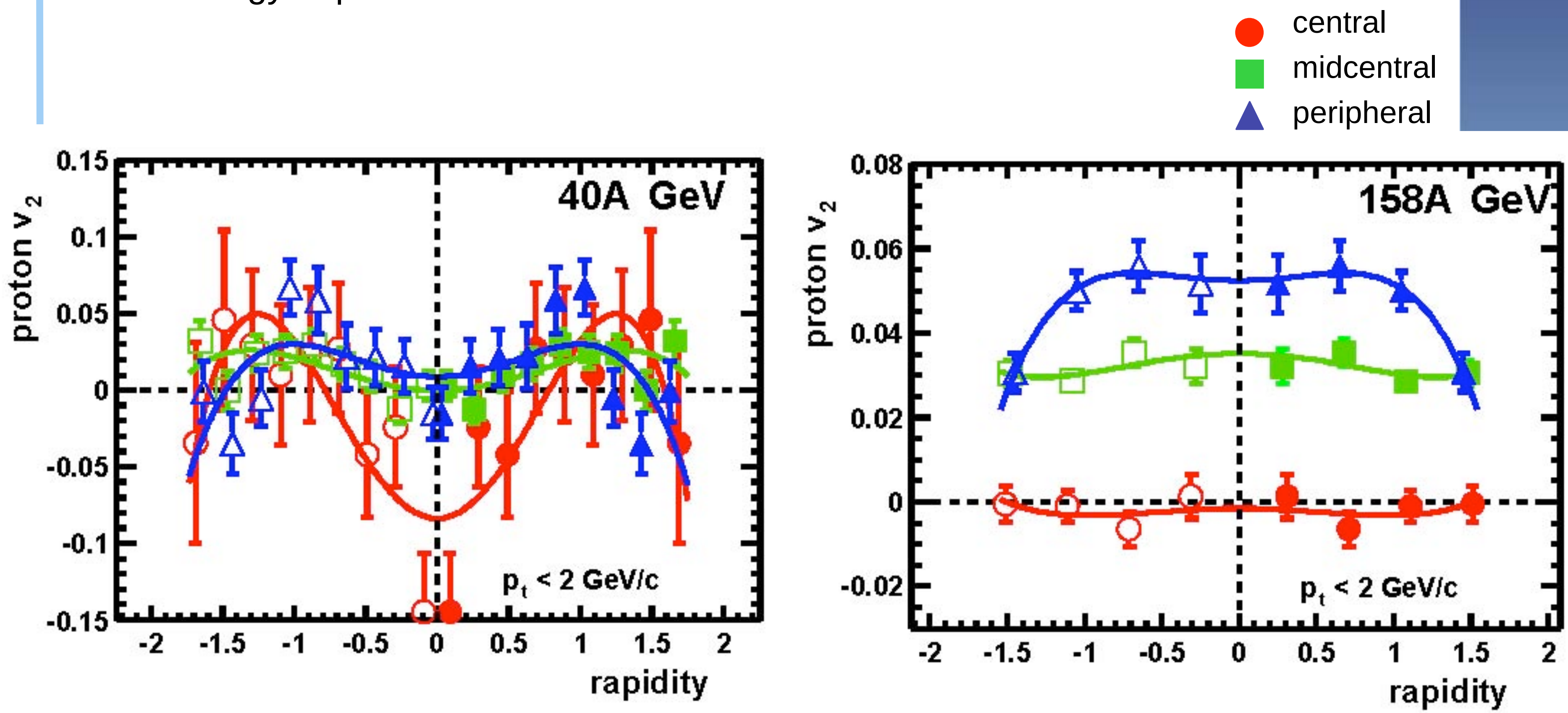
→ D-meson, J/ψ

[W. Cassing et al., Nucl. Phys. A 691, 753 (2001)]



collective flow

- collapse elliptic flow of protons at lower energies signal for first order phase transition?! [e.g. Stoecker, NPA 750 (2005) 121, E. Shuryak, hep-ph/0504048]
- full energy dependence needed!

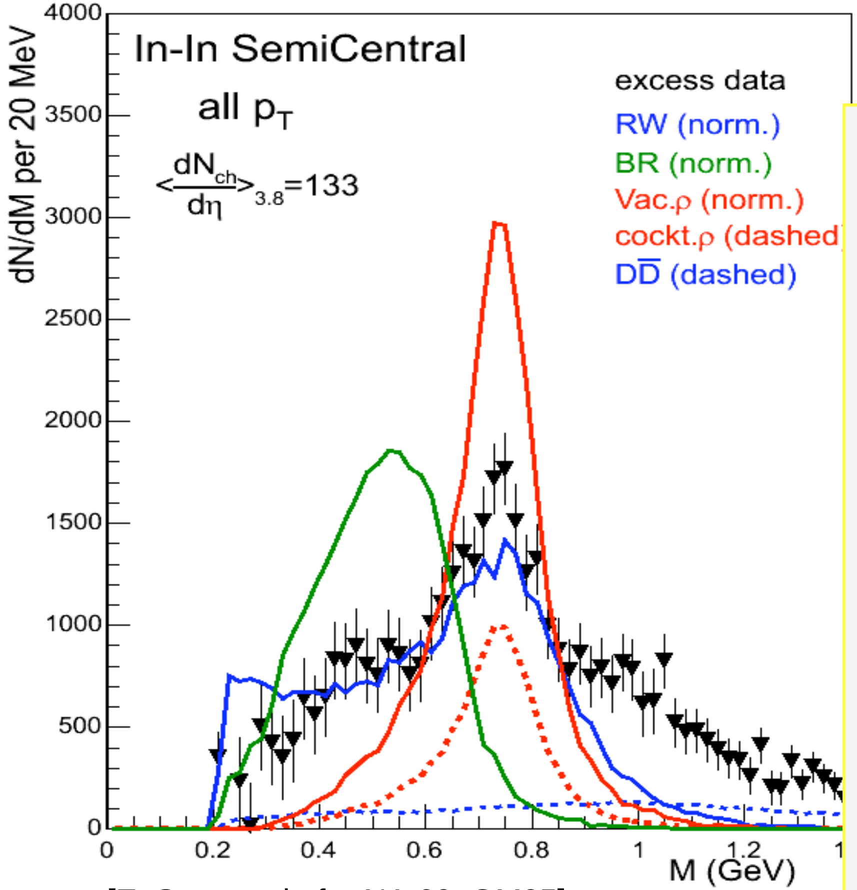


[NA49, PRC68, 034903 (2003)]

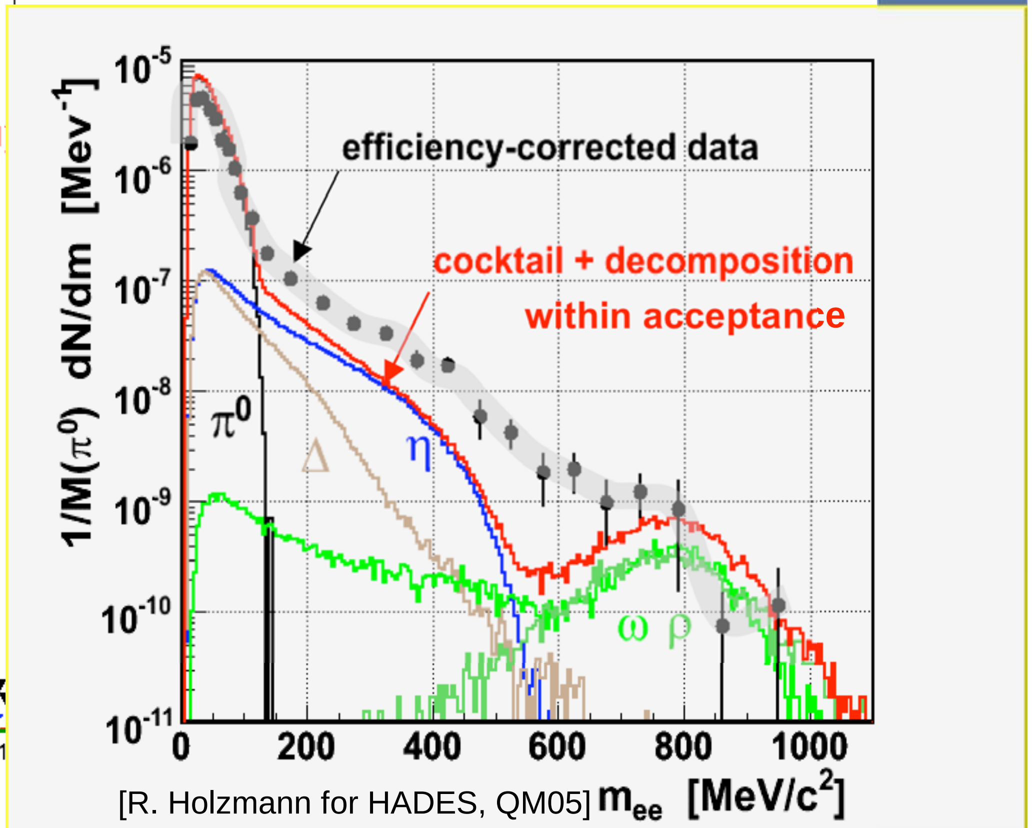
In medium modifications $\rho\ \omega\ \phi \rightarrow l^+l^-$

• high quality data at low and high energies now coming in from NA60 (SPS, 158 AGeV, In+In) and HADES (SIS, 2 AGeV, C+C)

• enhancement of low-mass dilepton pairs!



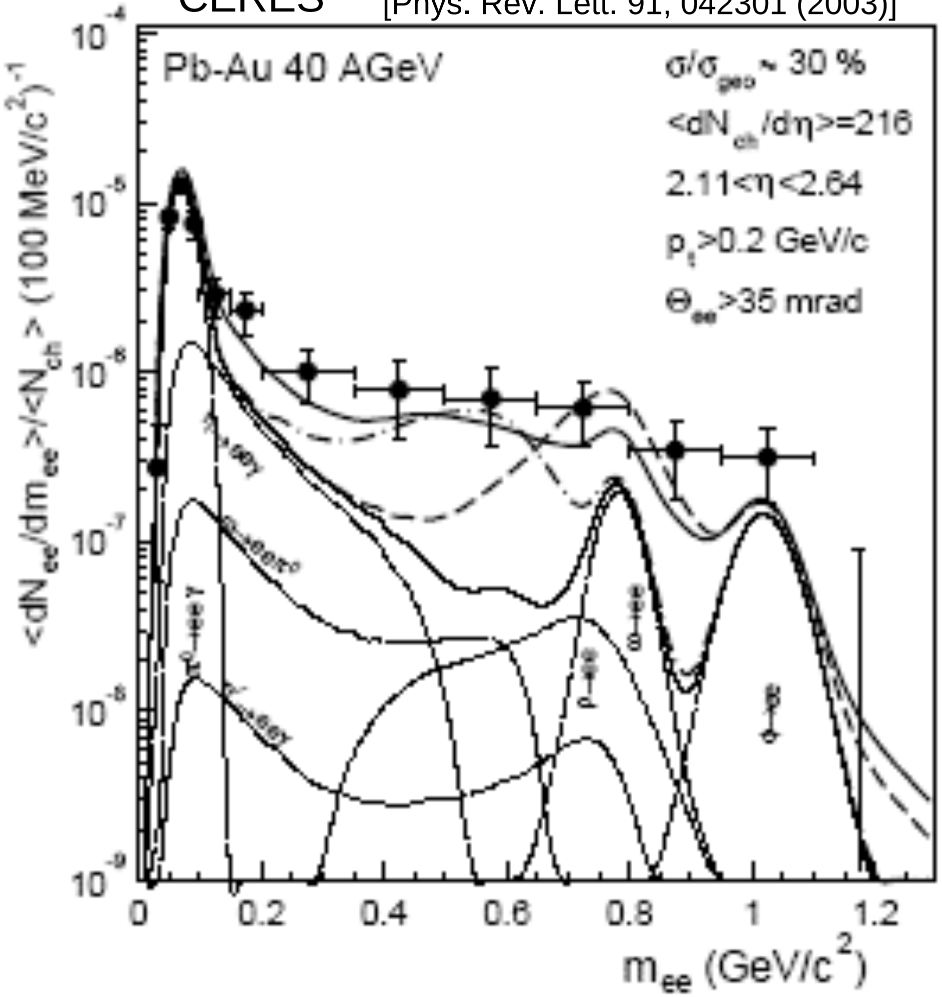
[E. Scomparin for NA 60, QM05]



[R. Holzmann for HADES, QM05]

In medium modifications $\rho\ \omega\ \phi \rightarrow e^+e^-$

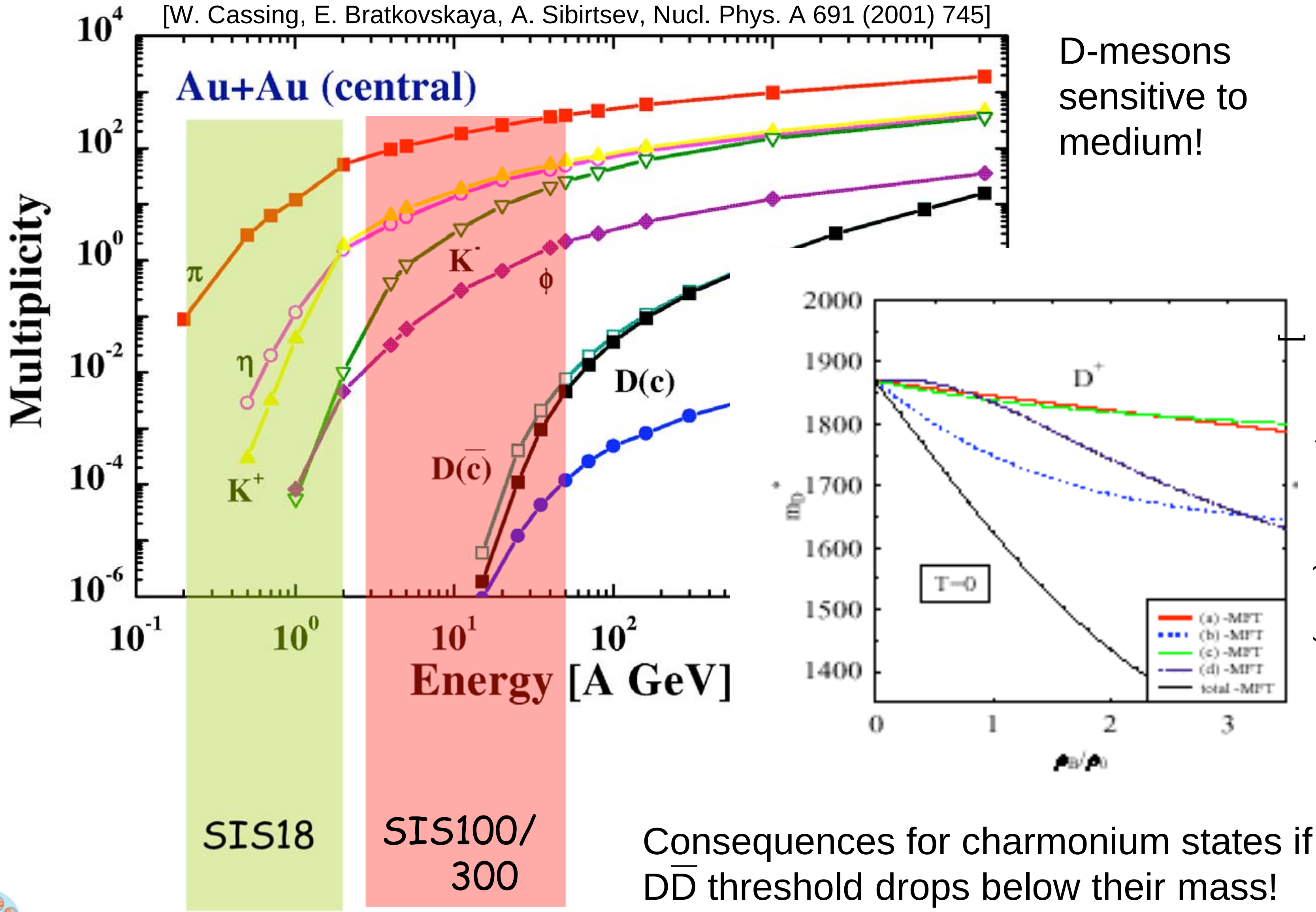
CERES [Phys. Rev. Lett. 91, 042301 (2003)]



- intermediate energies with highest baryon densities?
- pioneering measurement of CERES
- study full energy dependence!

D-mesons

[W. Cassing, E. Bratkovskaya, A. Sibirtsev, Nucl. Phys. A 691 (2001) 745]



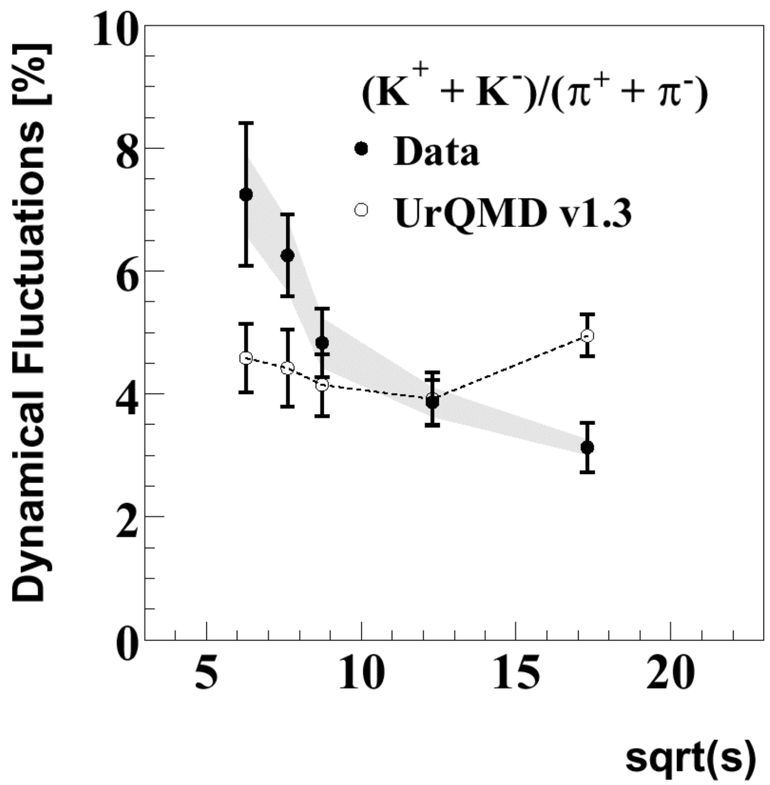
D-mesons sensitive to medium!

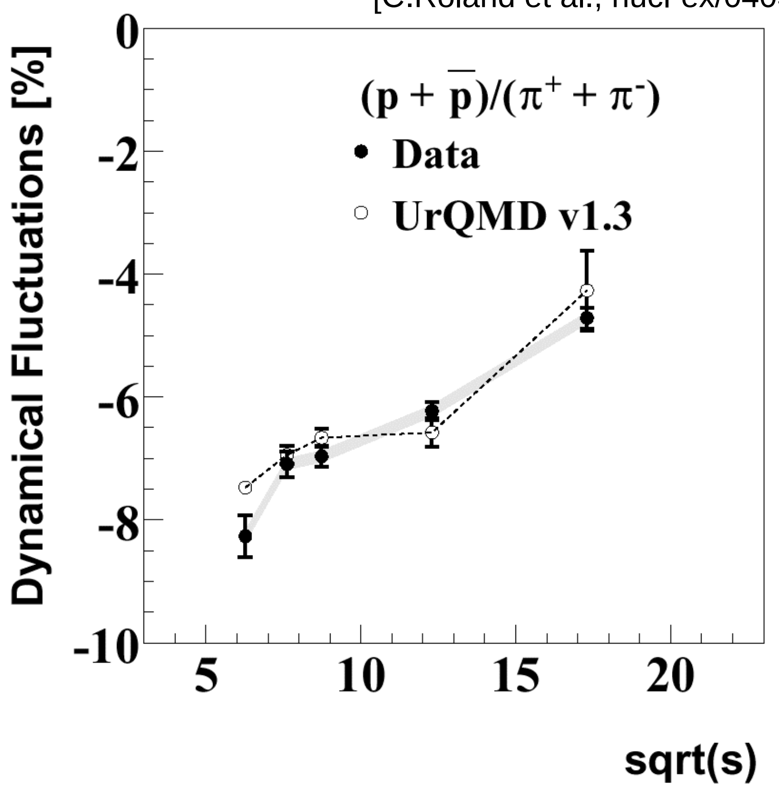
[Mishra et al., PRC 69, 015202 (2004)]

Consequences for charmonium states if $D\overline{D}$ threshold drops below their mass!

Critical point fluctuations

[C.Roland et al., nucl-ex/0403035]





- dynamical fluctuations of the K/π ratio increasing towards lower energies
- p/π due to resonance decays, reproduced by UrQMD
- continuous rise? maximum at lower SPS energies? (acceptance effects?)

→ Energy dependence needed for larger range!

detector requirements

observables

strangeness production: K, Λ, Σ, Ξ, Ω

charm production: J/ψ, D

flow excitation function

rare signals!

ρ, ω, ϕ $\rightarrow$ e^+e^-

open charm

event-by-event fluctuations

detector requirements & challenges

tracking in high track density environment (~ 1000)

hadron ID

lepton ID

myons, photons

secondary vertex reconstruction

(resolution $\leq$ 50 μm)

large statistics: large integrated luminosity:

high beam intensity (10^9 ions/sec.) and duty cycle

beam available for several months per year

high interaction rates (10 MHz)

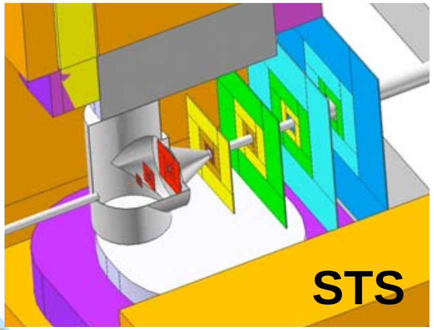
fast, radiation hard detector

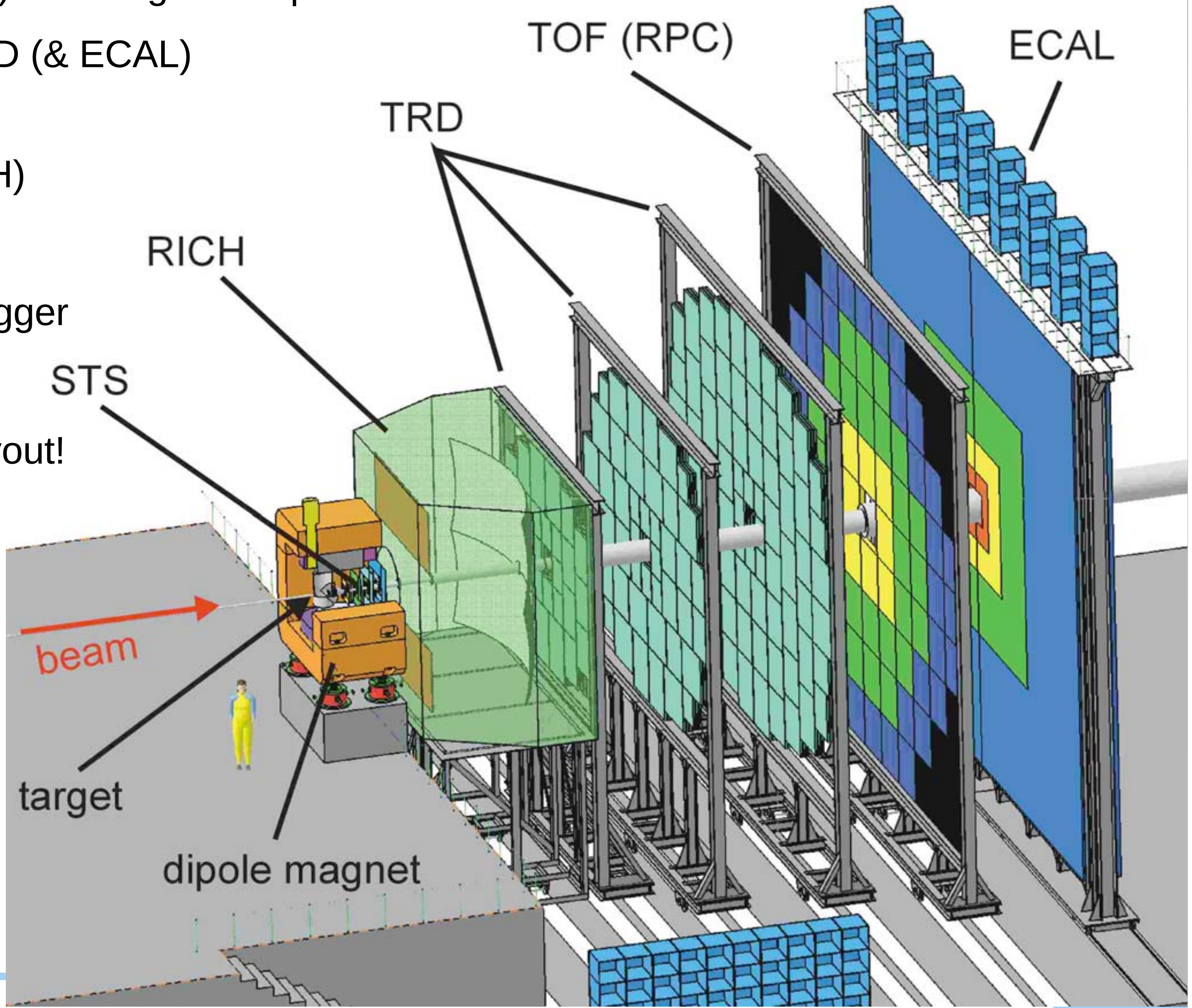
efficient trigger

Systematic investigations:
A+A collisions from 8 to 45 (35) AGeV, Z/A=0.5 (0.4) (up to 8 AGeV: HADES)
p+A and p+p collisions from 8 to 90 GeV

The CBM experiment

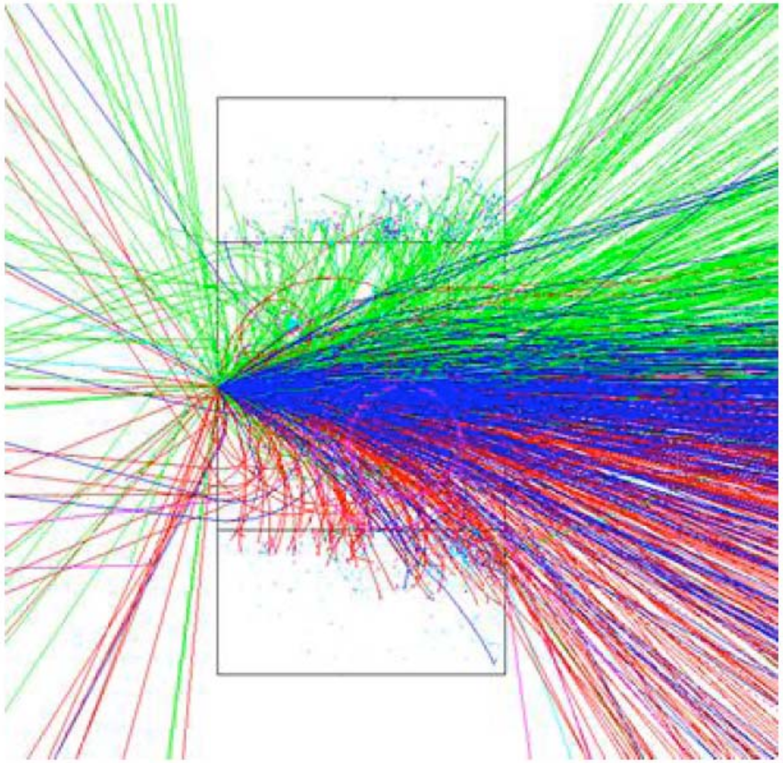
- tracking, momentum determination, vertex reconstruction: radiation hard silicon pixel/strip detectors (STS) in a magnetic dipole field
- electron ID: RICH & TRD (& ECAL)
  $\rightarrow \pi$ suppression $\geq 10^4$
- hadron ID: TOF (& RICH)
- photons, π^0, μ: ECAL
- high speed DAQ and trigger
- not necessarily fixed layout!
- more like „facility“





STS tracking

Challenge: high track density
≈ 600 charged particles in ± 25°

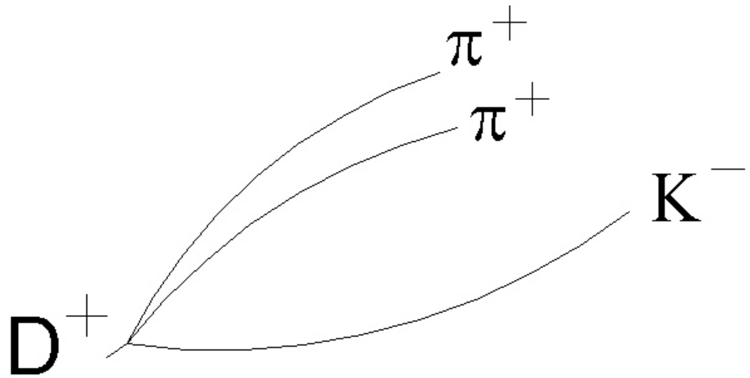


$D^+ \rightarrow \pi^+\pi^+K^-$ ($c\tau$ = 317 μm)

$D^0 \rightarrow K^-\pi^+$ ($c\tau$ = 124 μm)

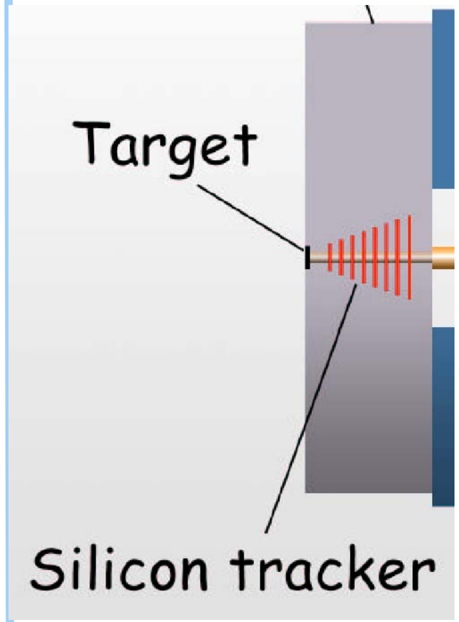
task

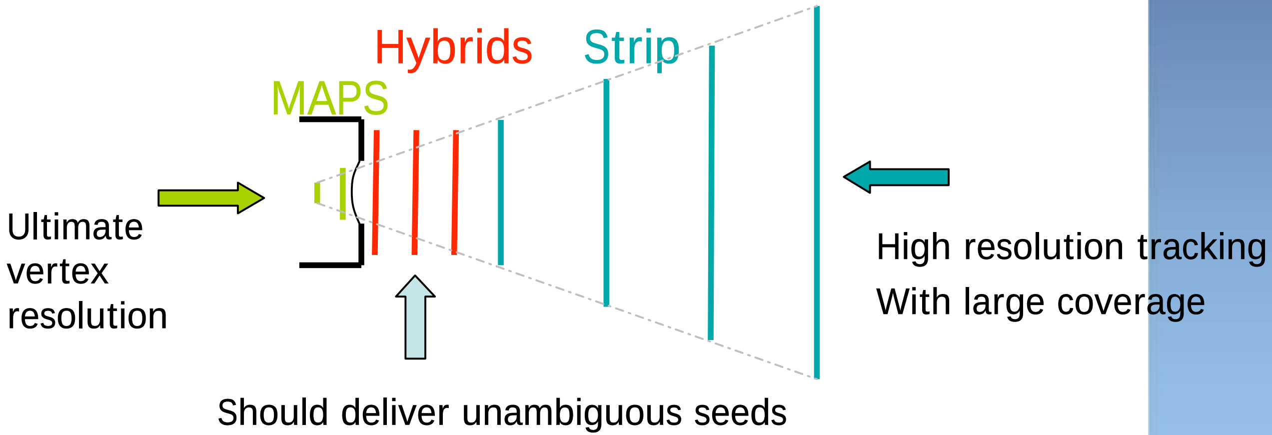
- track reconstruction for tracks with 0.1 GeV/c < p ≤ 10-12 GeV/c and with a momentum resolution of order 1% at 1 GeV/c
- primary and secondary vertex reconstruction (resolution ≤ 50 μm)
- V_0 track pattern recognition (hyperons, e^+e^- pairs from γ-conversion)



STS tracking (II)

- set of silicon tracking stations inside magnetic field („heart of CBM“)
  - 2-3 vertex detectors with high resolution, minimum thickness (e.g. MAPS)
  - outer stations: Si-strip, (hybrid pixel detectors in addition?)
- challenge: readout speed (10 MHz interaction rate), radiation hardness (10^9 ions/s), material budget, resolution





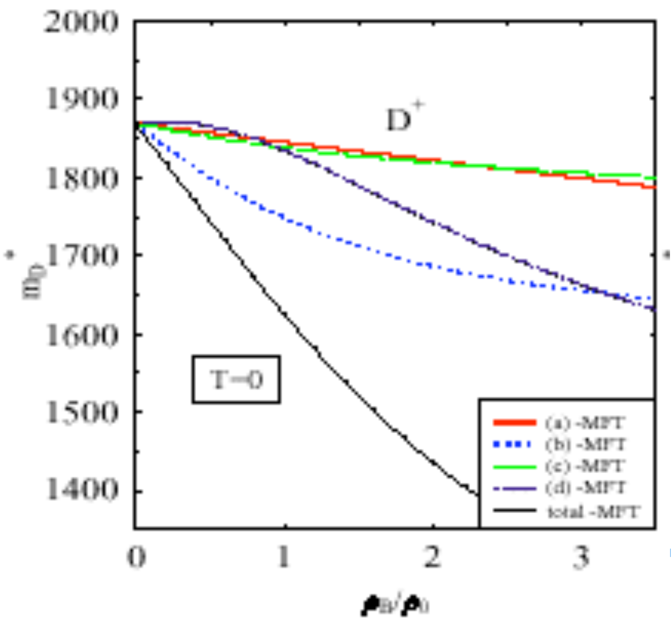
so far: simple standard layout with 7 stations (3 + 4) in use

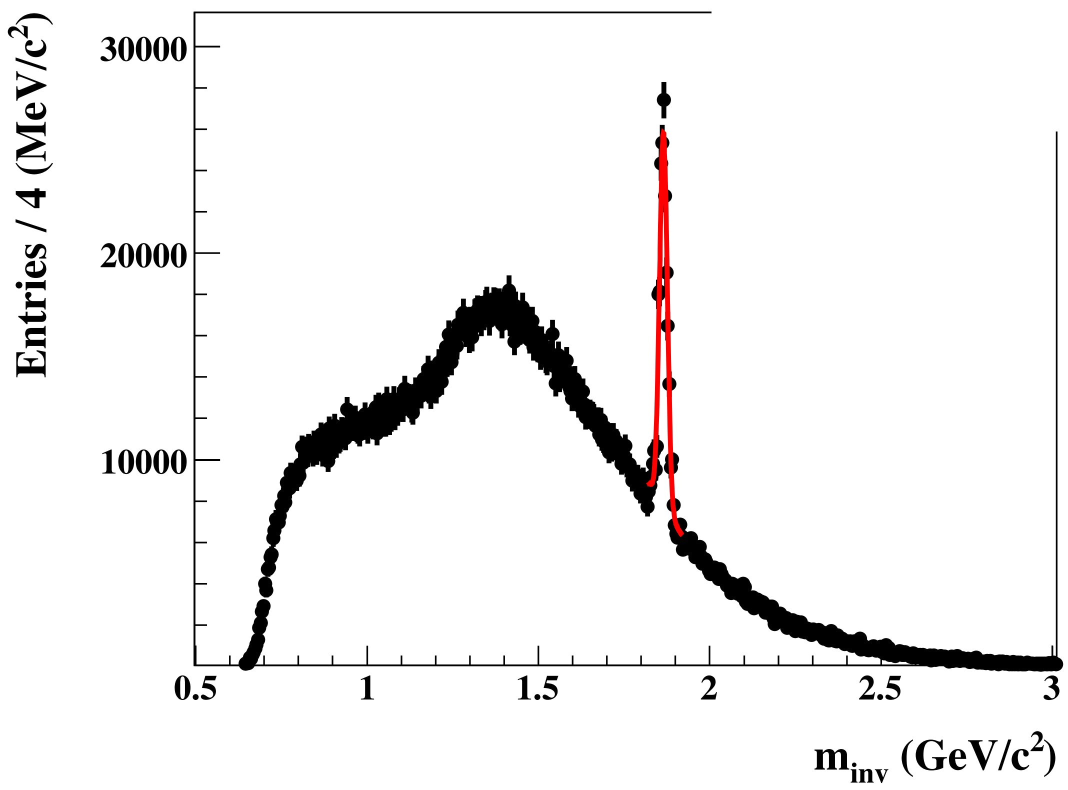
optimization of layout started

tracking!!

open charm production

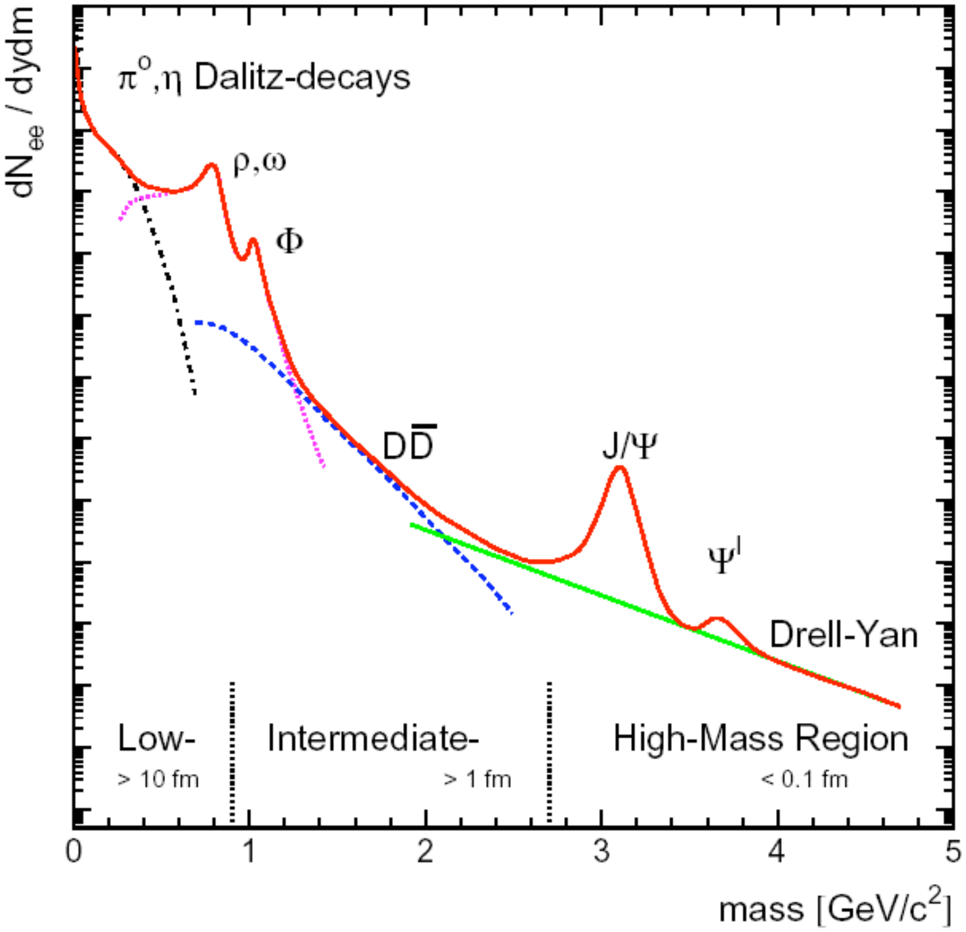
- $D^0 \rightarrow K^-\pi^+$ ($c\tau$ = 124 μm), minimum bias Au+Au collisions at 25 AGeV
- $\langle D^0 \rangle = 4 \cdot 10^{-5}$
- ~50 μm secondary vertex resolution
- proton identification via TOF
- even better signal for
  $D^+ \rightarrow K^-\pi^+\pi^+$
  (3-particle 2nd vertex)





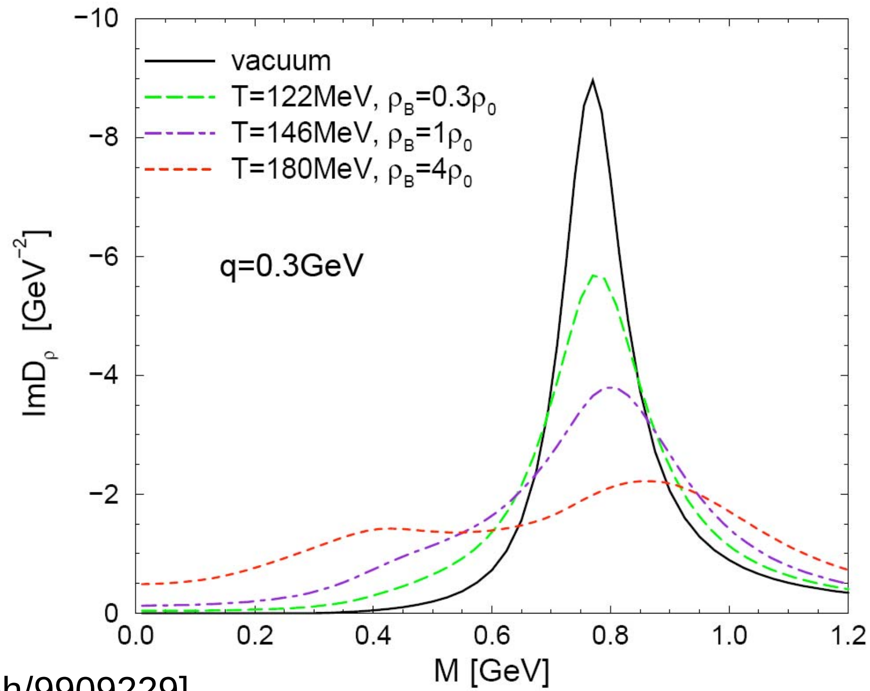
[Mishra et al ., Phys. Rev. C 69, 015202 (2004)]

Dileptons



- dileptons are penetrating probes!
- modifications in hot and dense matter expected –

see CERES, NA50, NA60, HADES



best way to measure? $e^+e^- \leftrightarrow \mu^+\mu^-$

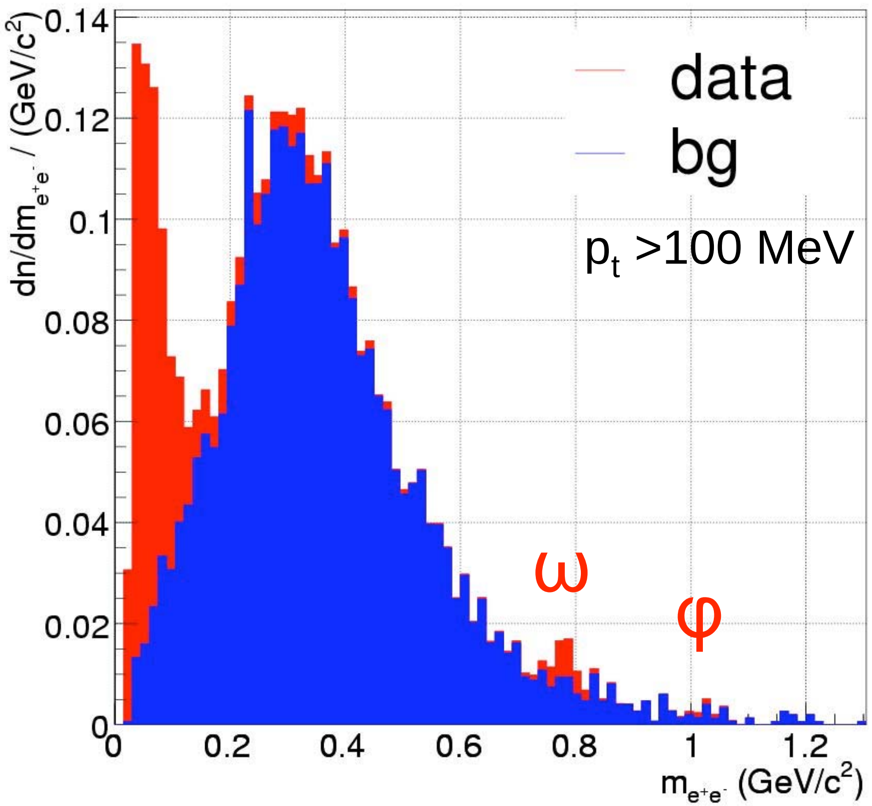
[Rapp, Wambach, Adv. Nucl. Phys. 25 (2000) 1, hep-ph/9909229]

dileptons - electrons

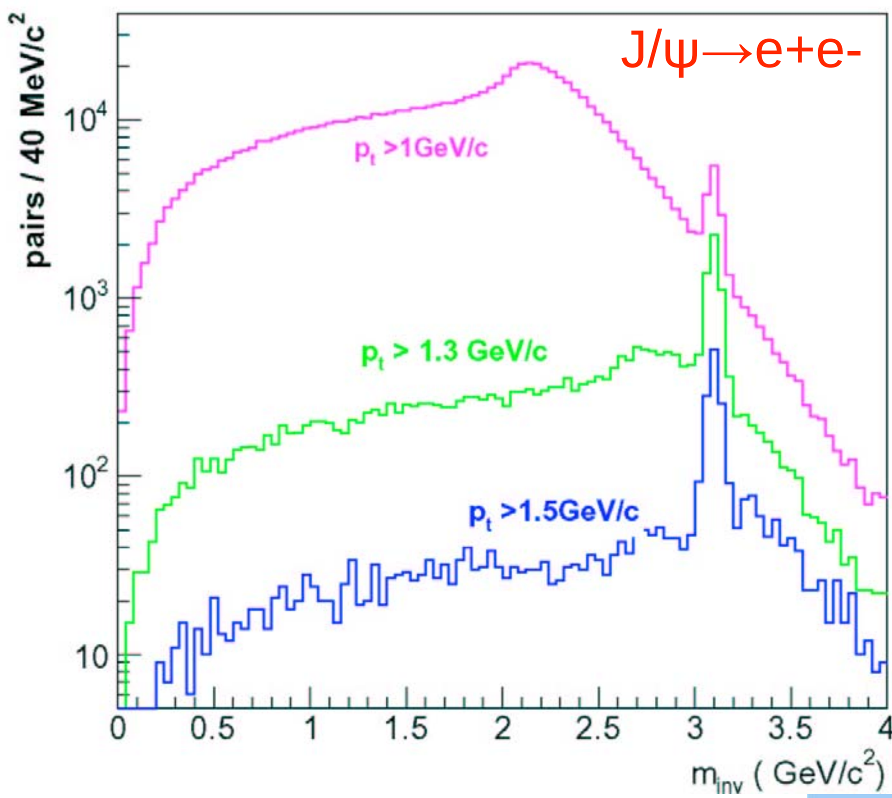
- low-mass vector mesons: develop sophisticated cut strategy

→ (so far) signal quality mainly limited by ability of background rejection

- J/ψ: cut on p_t (1GeV) seems sufficient
- so far no track reconstruction, PID included



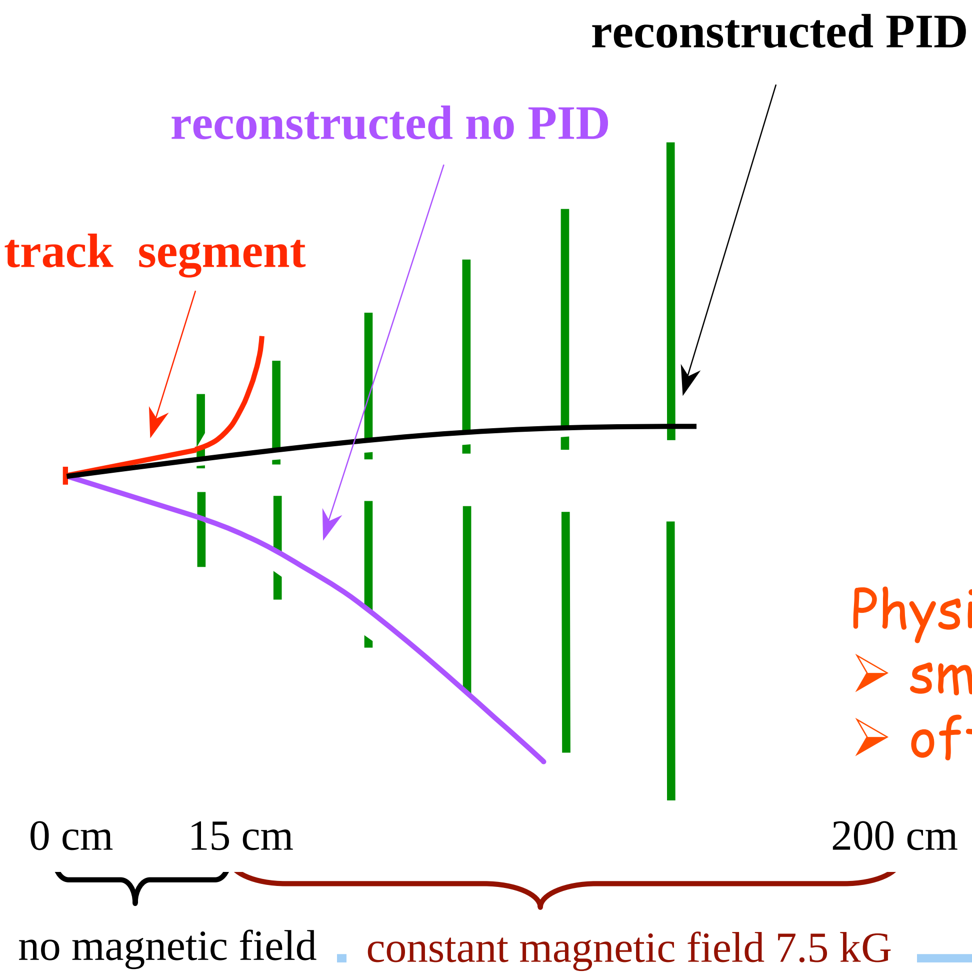
central Au+Au, 25 AGeV



low-mass dileptons - electrons

Conceptional studies: MC tracks, ideal particle ID

Major background sources: $\pi^0 \rightarrow \gamma\, e^+e^-$, $\gamma \rightarrow e^+e^-$

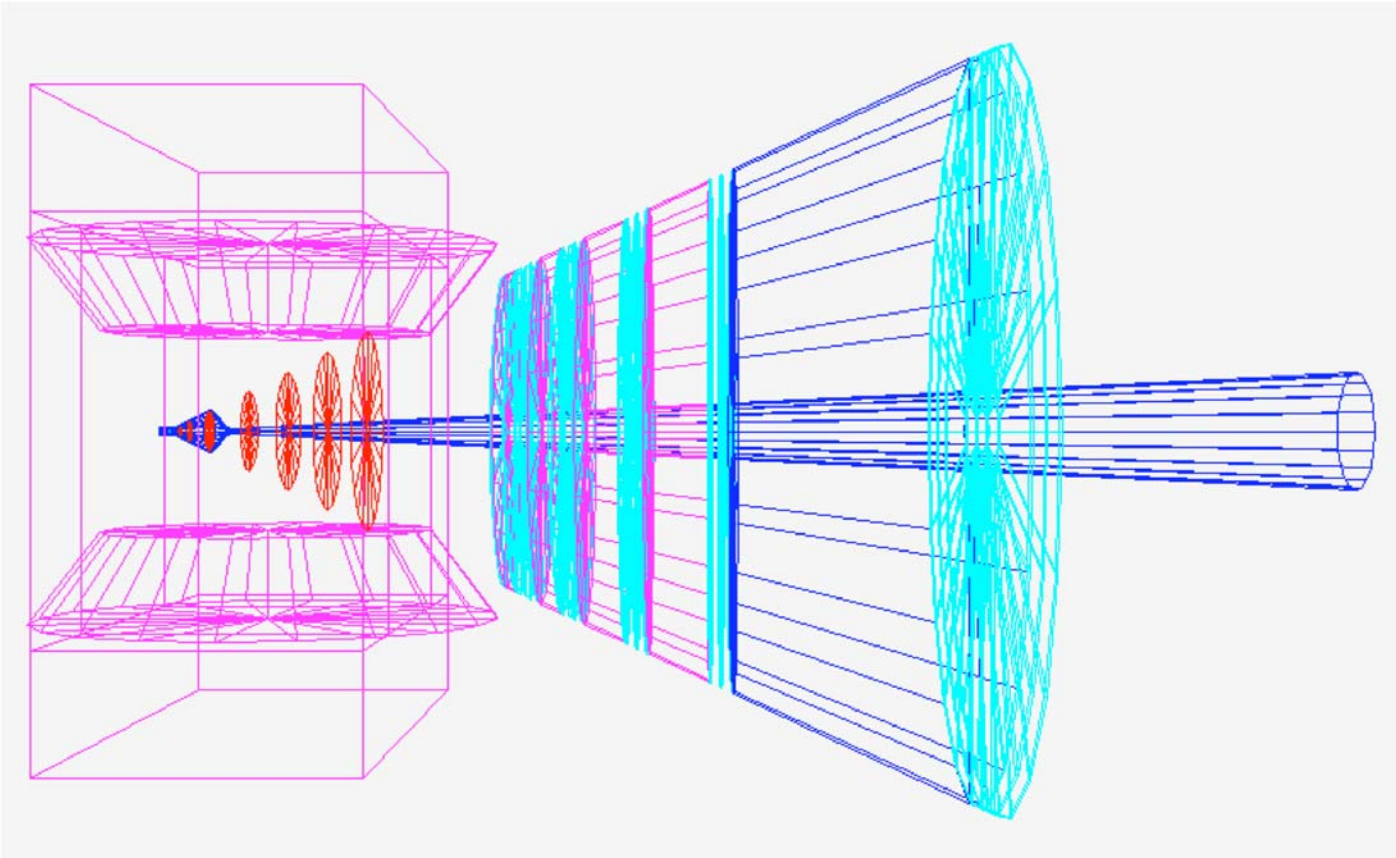


N/event		Decay	BR
η	36	$\rightarrow e^+ e^- \gamma$	$5.\times10^{-3}$
ω	38	$\rightarrow e^+ e^- \pi^0$ $\rightarrow e^+ e^-$	5.9×10^{-4} 7.07×10^{-5}
ϕ	1.28	$\rightarrow e^+ e^-$	3.1×10^{-4}
ρ^0	28	$\rightarrow e^+ e^-$	4.44×10^{-5}

Physical background:
- small pair opening angle
- often: one hard, one soft electron

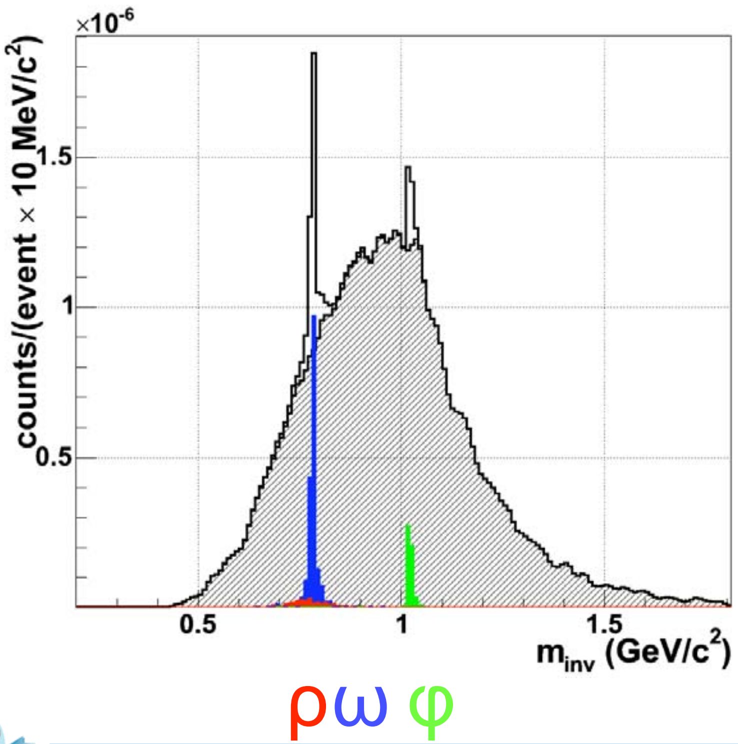
dileptons - muons

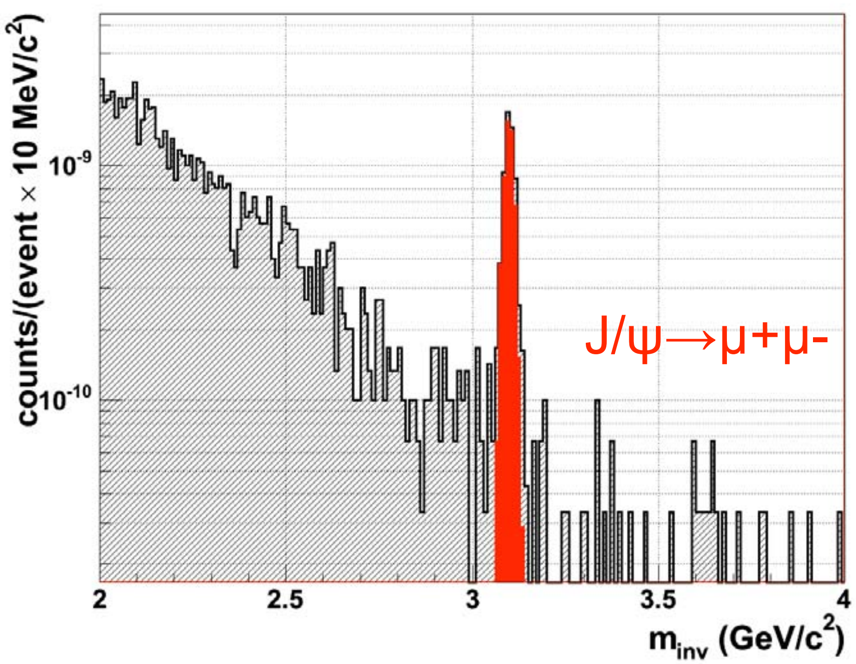
- study alternative CBM setup with active muon absorbers (Fe + C + detector layers)
- problems:
  - low efficiency for soft muons!
  - challenging muon detector (high particle densities!)



dileptons - muons

- minimum bias Au+Au, 25 AGeV
- low efficiency for soft muons → early cutoff in invariant mass spectrum of low-mass vector mesons
- phantastic J/ψ, even ψ' should be accessible



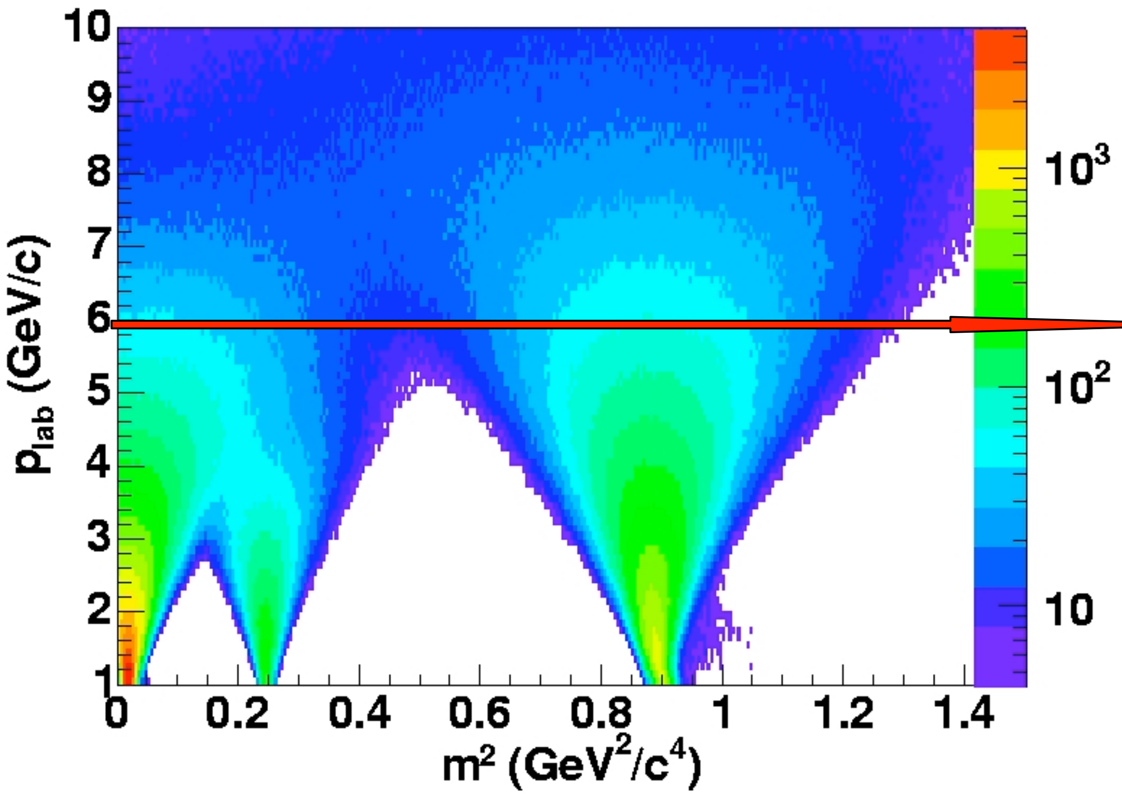


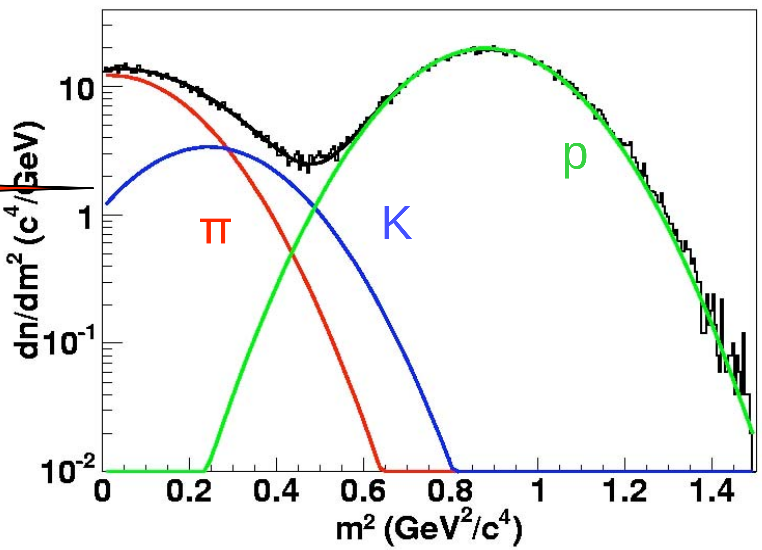
hadron identification – TOF (RPC)

- challenge: counting rate, large area, sufficient position resolution, time resolution < 80ps
- simulations: central Au+Au at 25 AGeV, UrQMD
  time resolution 80ps, TOF wall in 10m distance to target
  no track reconstruction and mismatch yet!

Squared mass measured with TOF

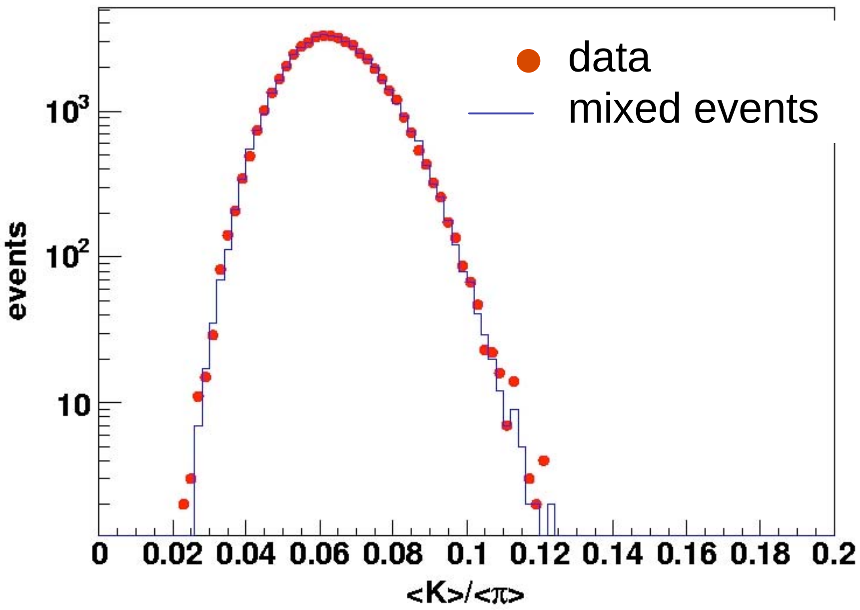
Mass² distribution for p = 6 GeV/c

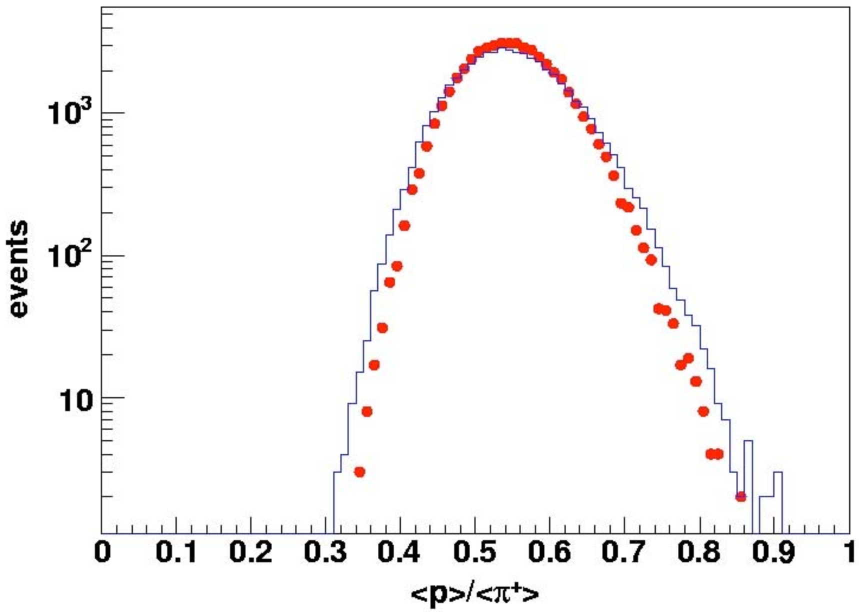




dynamical fluctuations

- UrQMD: central Au+Au collisions at 25 AGeV, no track reconstruction





	4 π acceptance	identified particles
K/ π	3.2 ± 0.3	2.6 ± 0.6
p/ π	-5.3 ± 0.07	-5.9 ± 0.1

- resonance contribution?
- little influence of limited detector acceptance
- lower detectable limit of dyn. fluctuations?

$$\sigma_{dyn} = \sqrt{\sigma_{data}^2 - \sigma_{mixed}^2}$$

CBM – summary

• CBM offers a very interesting physics program studying the QCD phase-diagram

• unique features expected in CBM energy range: first order phase transition, critical point

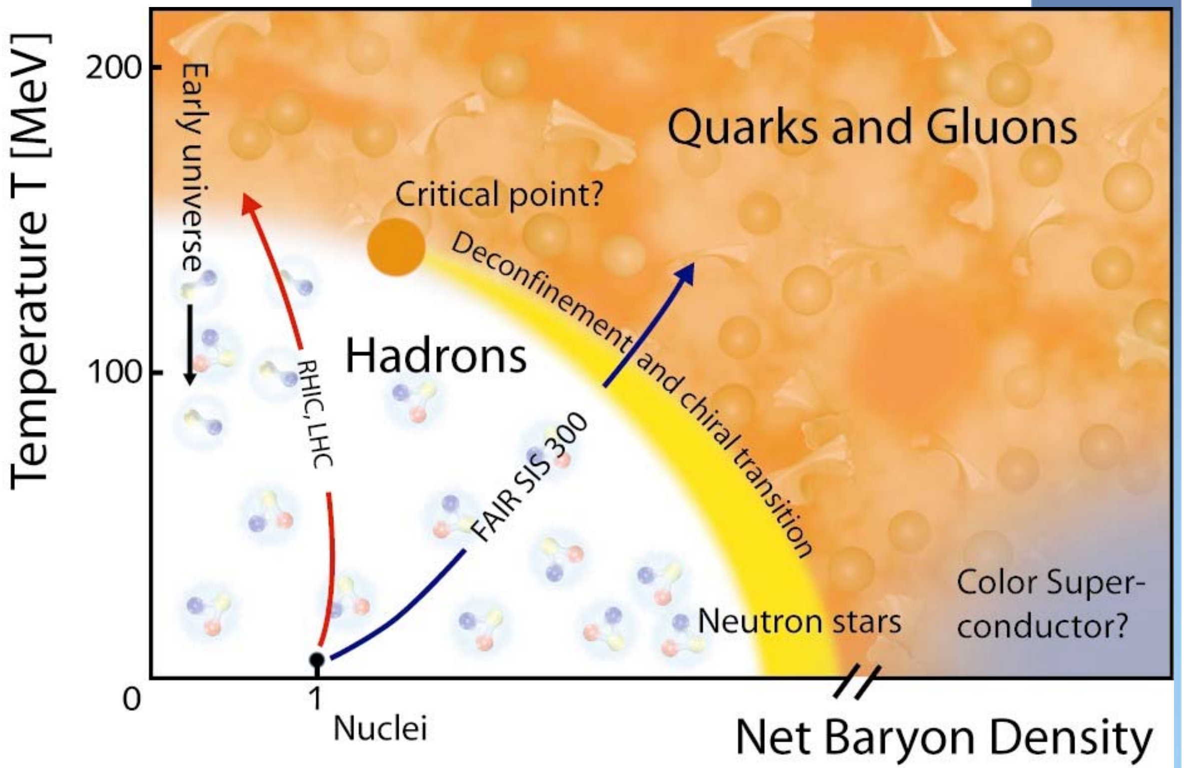
• CBM as 2nd generation experiment will be able to study rare probes, fluctuations and correlations!

• detector development under way

• increasingly realistic feasibility studies are performed

• Technical proposal due in 2007

• open for new collaborators!



CBM collaboration

CBM Collaboration : 40 institutions, > 350 Members

Croatia:
RBI, Zagreb

China:
Wuhan Univ.
Hefei Univ.

Cyprus:
Nikosia Univ.

Czech Republic:
CAS, Rez
Techn. Univ. Prague

France:
IReS Strasbourg

Hungaria:
KFKI Budapest
Eötvös Univ. Budapest

India:
VECC Kolkata

Korea:
Korea Univ. Seoul
Pusan National Univ.

Norway:
Univ. Bergen

Germany:
Univ. Heidelberg, Phys. Inst.
Univ. HD, Kirchhoff Inst.
Univ. Frankfurt
Univ. Kaiserslautern
Univ. Mannheim
Univ. Münster
FZ Rossendorf
GSI Darmstadt

Poland:
Krakow Univ.
Warsaw Univ.
Silesia Univ. Katowice

Portugal:
LIP Coimbra

Romania:
NIPNE Bucharest

Russia:
IHEP Protvino
INR Troitzk
ITEP Moscow
KRI, St. Petersburg
Kurchatov Inst., Moscow
LHE, JINR Dubna
LPP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
Obninsk State Univ.
PNPI Gatchina
SINP, Moscow State Univ.
St. Petersburg Polytec. U.

Ukraine:
Shevshenko Univ. , Kiev

special thanks for help on NUSTAR and PANDA to Hans Emling and Olaf Hartmann

supported by EU/FP6 HadronPhysics, INTAS

Hot topic!

• at BNL low energy runs are strongly pushed forward

• recent focus article in Science, Vol 312 from 14 April 2006

The critical point is "*the* landmark on the phase diagram," ... "If it's not there then we don't have even a qualitative understanding of the diagram," ...

"Others say the discovery of the critical point would merit a Nobel Price."

treats the lattice structure as an integral part of the model. It would be difficult to change from a square to an irregular grid without altering the entire program. The connectivity in lattices can affect a number of conditions—the shape of the cell, which chemical signals it is exposed to, how much light it gets—altering development.

Gunawardena's group has created a model of embryonic development but made the lattice a flexible module. In Little b, it can be altered or replaced without reprogramming any other part, allowing the same experiment to be run on a wide array of cell-lattice patterns.

Little b can also be used to model complete organisms. There's a *Drosophila melanogaster* living in silico on a laptop at Harvard Medical School, designed completely by Gunawardena's group in Little b. Many research groups are modeling entire organisms and might well make use of a modular approach.

Although it doesn't aim to model whole organisms, the integrative cancer biology program of the National Cancer Institute (NCI) in Bethesda, Maryland, is considering a modular approach to modeling. "It's the Holy Grail to take all these individual modeling components, plug them together, and get a comprehensive view of what's going on," says Daniel Gallahan, the associate director of NCI's division of cancer biology.

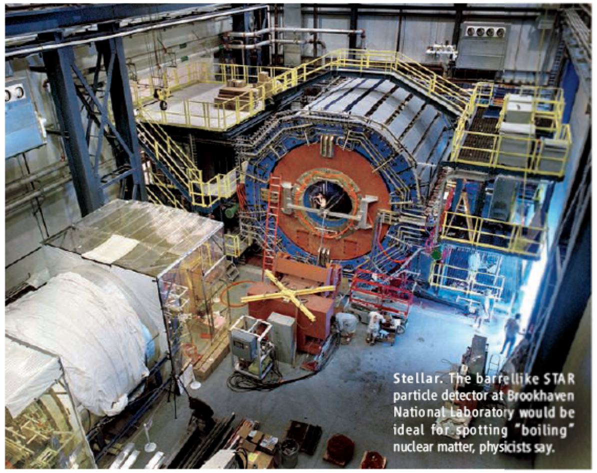
Other researchers agree that modularity is necessary if computational biology is to advance. Sauro, for one, decries the "huge waste of grant money" in the "chronic reinvention" of computer tools that employ one-off models. The redundancy is amazing, he says. For example, the BioModels Database has tens of models just of the MAP kinase cascade, a signal pathway in mammalian cells. And no matter how many MAP kinase cascade models there are available, or how well curated they may be, without modularity they're next to useless to a researcher who wants one ready-made to integrate into a larger model. There's simply no way to plug it in.

Whether Little b succeeds will depend in part on how it evolves and how widely it is accepted. Not everyone is enchanted with it, because it's based on an abstract language called LISP originally devised for artificial intelligence applications. Sauro suggests that the best way to get biologists to adopt a modeling language like this would be to give it a friendly graphical interface. No one has started a project like that, to his knowledge. Several computational biologists also say Little b's developers have not shared much information about their efforts thus far. Without input from the biology community, they ask, how can it satisfy everyone's needs?

Gunawardena says his group plans to begin teaching Little b to students at Harvard soon; he's preparing a paper that he hopes to publish this year. Then the test of community acceptance will begin in earnest.

–KIM KRIEGER

Kim Krieger is a writer in Washington, D.C.



Stellar. The barrellike STAR particle detector at Brookhaven National Laboratory would be ideal for spotting "boiling" nuclear matter, physicists say.

NUCLEAR PHYSICS

Scheme for Boiling Nuclear Matter Gathers Steam at Accelerator Lab

Physicists hope to glimpse that violent transformation by running a gargantuan particle collider in lowest gear

UPTON, NEW YORK—Coiling through the woods and buried beneath meters of sandy Long Island loam, a vast atom smasher here at Brookhaven National Laboratory (BNL) has transported physicists back to the big bang. Since 2000, researchers have used the 4-kilometer-long Relativistic Heavy Ion Collider (RHIC) to produce a superhot, ultrathin soup of fundamental particles called quarks and gluons (*Science*, 22 April 2005, p. 479). The observation of the quark-gluon plasma sheds light on the type of matter that filled the infant universe and has opened a new frontier in nuclear physics. To explore it, though, researchers need a landmark—and they hope to find it by boiling nuclei like water in a kettle.

Imagine a map of nuclear matter with temperature increasing to the north and density increasing to the east. Ordinary nuclei fill a spot on the chilly southern edge, and RHIC has explored the low-density, high-temperature western border (see diagram, p. 191). Most theorists believe that somewhere to the north and east in the "phase diagram" lies a special point beyond which the transformation from ordinary nuclear matter to free-flying quarks and gluons becomes violent, like the boiling of water. RHIC might be able to reach that "critical point," and in March, more than 50 physicists gathered here to consider whether to try.

The critical point is "*the* landmark on the phase diagram," says Krishna Rajagopal, a theorist at the Massachusetts Institute of Technology in Cambridge and Lawrence Berkeley National Laboratory in California. "If it's not there, then we don't have even a qualitative understanding of the diagram," which also predicts an exotic "color superconductor" state of nuclear matter in neutron stars. Others say the discovery of the critical point would merit a Nobel Prize.

Searching for the critical point may be tricky, however. Pressing eastward on the phase diagram means producing higher density nuclear matter. That requires ratcheting RHIC's energy *down* to as little as 1/40 of its normal level—a challenge akin to driving a Formula 1 race car at jogging pace without stalling. And nobody knows exactly where the critical point should be or how experimenters will recognize it.

Still, previous experiments may have spotted hints of it, and researchers here are eager for

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