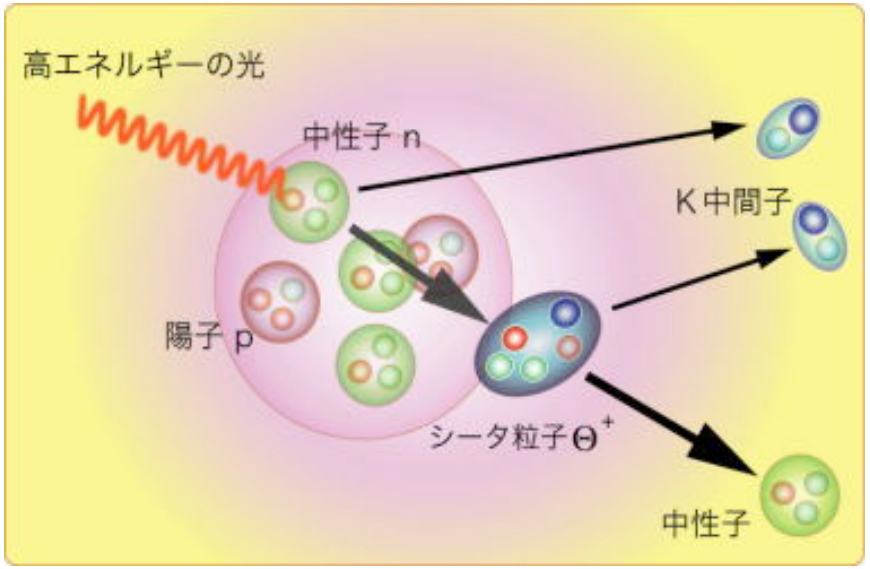
Evidence for Narrow S=+1 Baryon Resonance at LEPS/SPring-8

T. Nakano (RCNP, Osaka Univ)

- **Introduction**
- **Experiment**
- **Evidence for Θ+**
- **Results from other labs**
- **Conclusion & Outlook**



KEK Seminar

August 5, 2003 @ KEK

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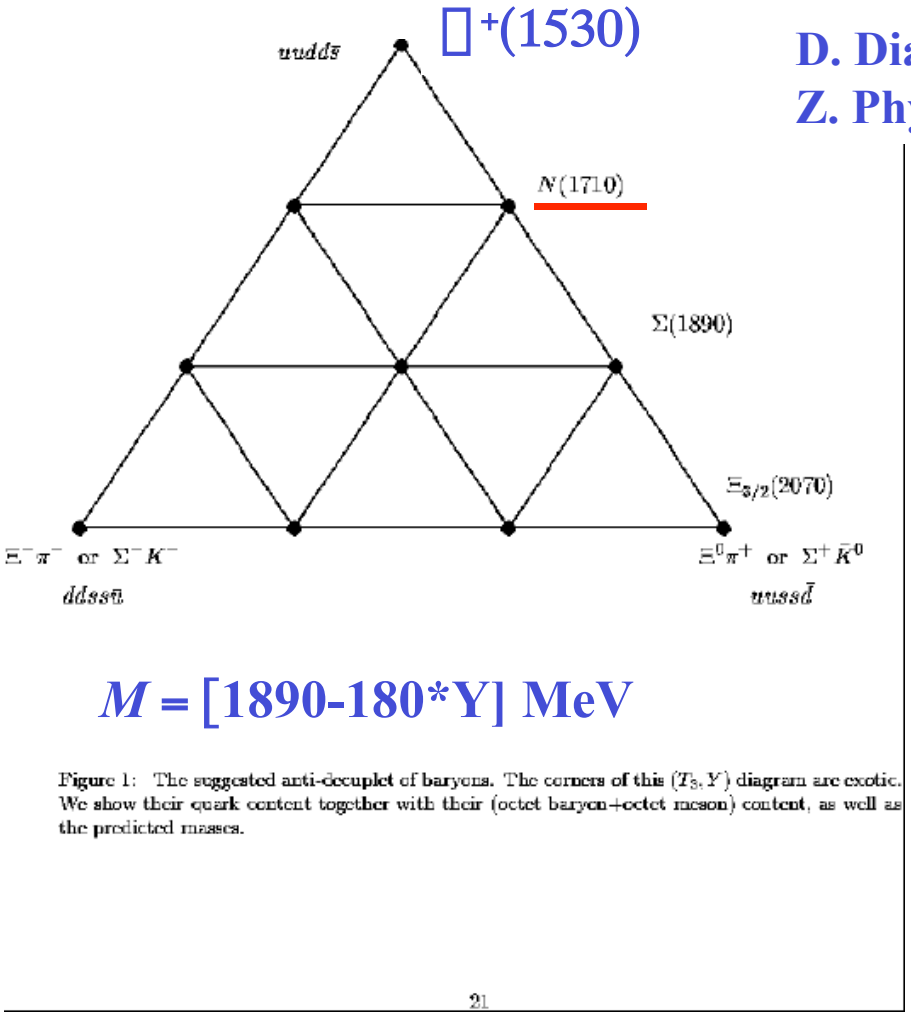
# of collaborators/# of institute = 3

□⁺(Z⁺) Baryon



D. Diakonov, V. Petrov, and M. Polyakov, Z. Phys. A 359 (1997) 305.

- **Exotic: S=+1**
- **Low mass: 1530 MeV**
- **Narrow width: < 15 MeV**
- **$J^P=1/2^+$**

Exotic S=+1 Baryon

NOTE ON THE S = + 1 BARYON SYSTEM

(PDG 1986; Phys. Lett. B170, 289)

The evidence for strangeness +1 baryon resonances was reviewed in our 1976 edition,[1] and more recently by Kelly[2] and by Oades.[3] Two new partial-wave analyses[4] have appeared since our 1984 edition. Both claim that the P_{13} and perhaps other waves resonate.

However, the results permit no definite conclusion- the same story heard for 15 years. The standards of proof must simply be much more severe here than in a channel in which many resonances are already known to exist. The general prejudice against baryons not made of three quarks and the lack of any experimental activity in this area make it likely that it will be another 15 years before the issue is decided.

References

•1. Particle Data Group, Rev. Mod. Phys. 48, SI88 (1976).

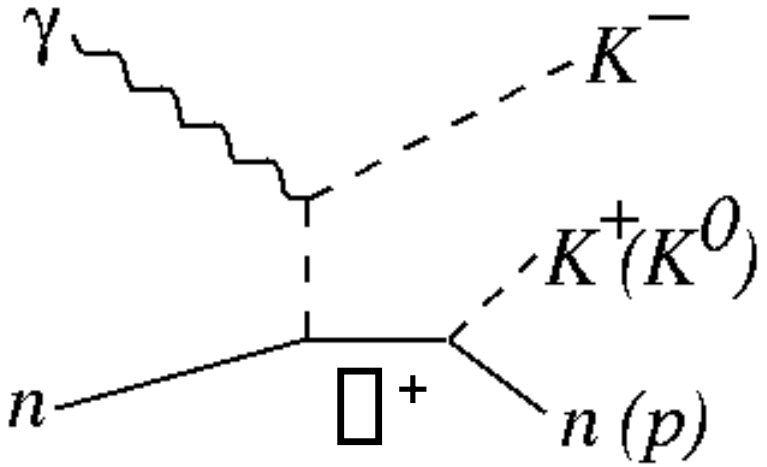
•2. R.L. Kelly, in Proceedings of the Meeting on Exotic Resonances (Hiroshima, 1978), ed. I. Endo et al.

•3. G.C. Oades, in Low and Intermediate Energy Kaon-Nucleon Physics (1981), ed. E. Ferrari and G. Violini.

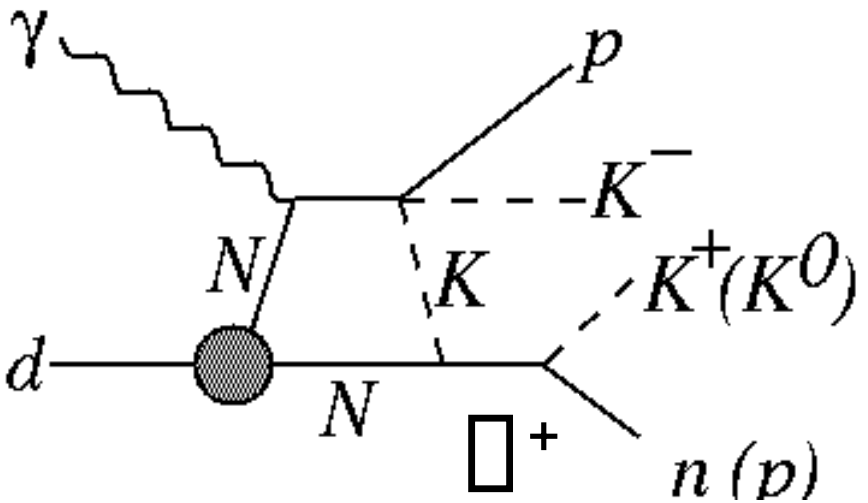
•4. K. Hashimoto, Phys. Rev. C29, 1377 (1984); and R.A. Arndt and L.D. Roper, Phys. Rev. D31, 2230 (1985).

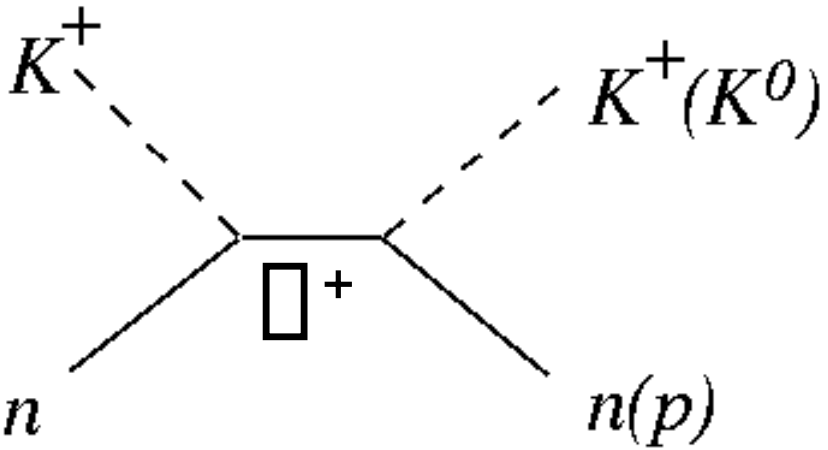
Possible Θ+ Production Reactions

LEPS/SPring-8

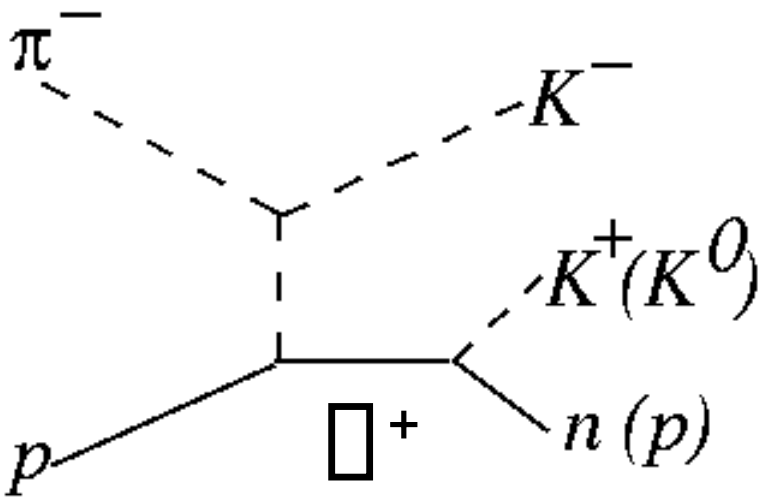


CLAS/JLAB





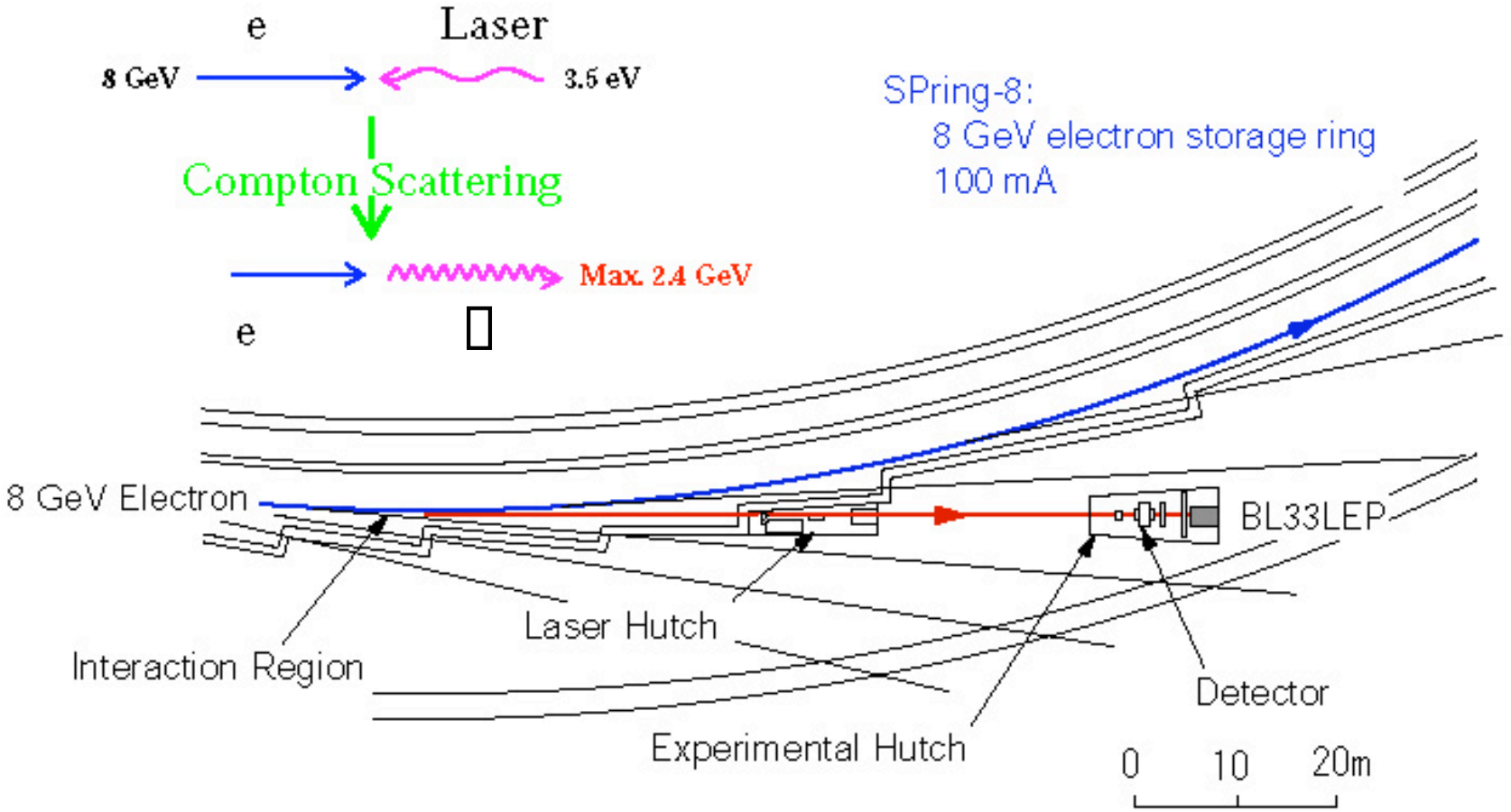
DIANA/ITEP



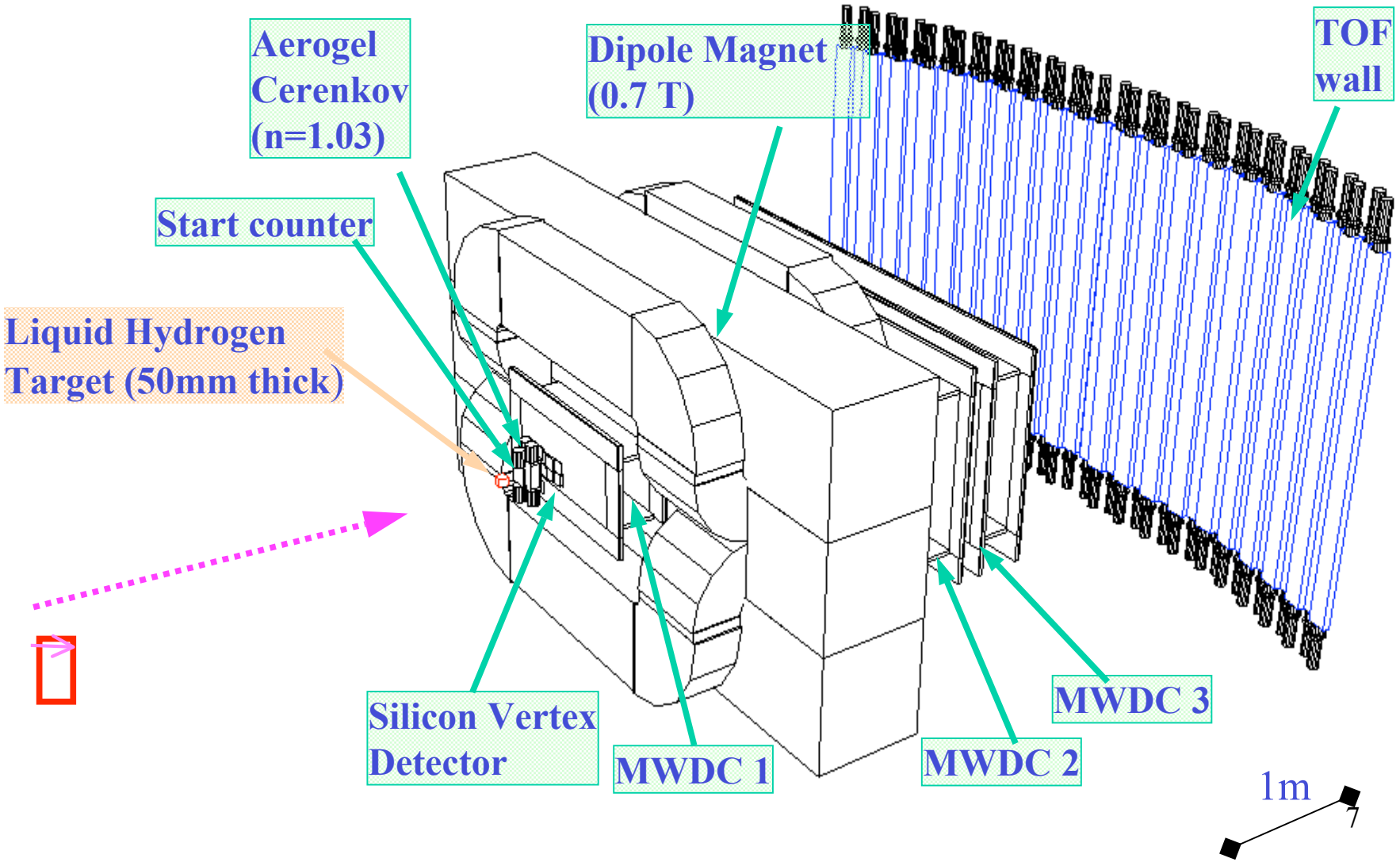
KEK-PS/E522

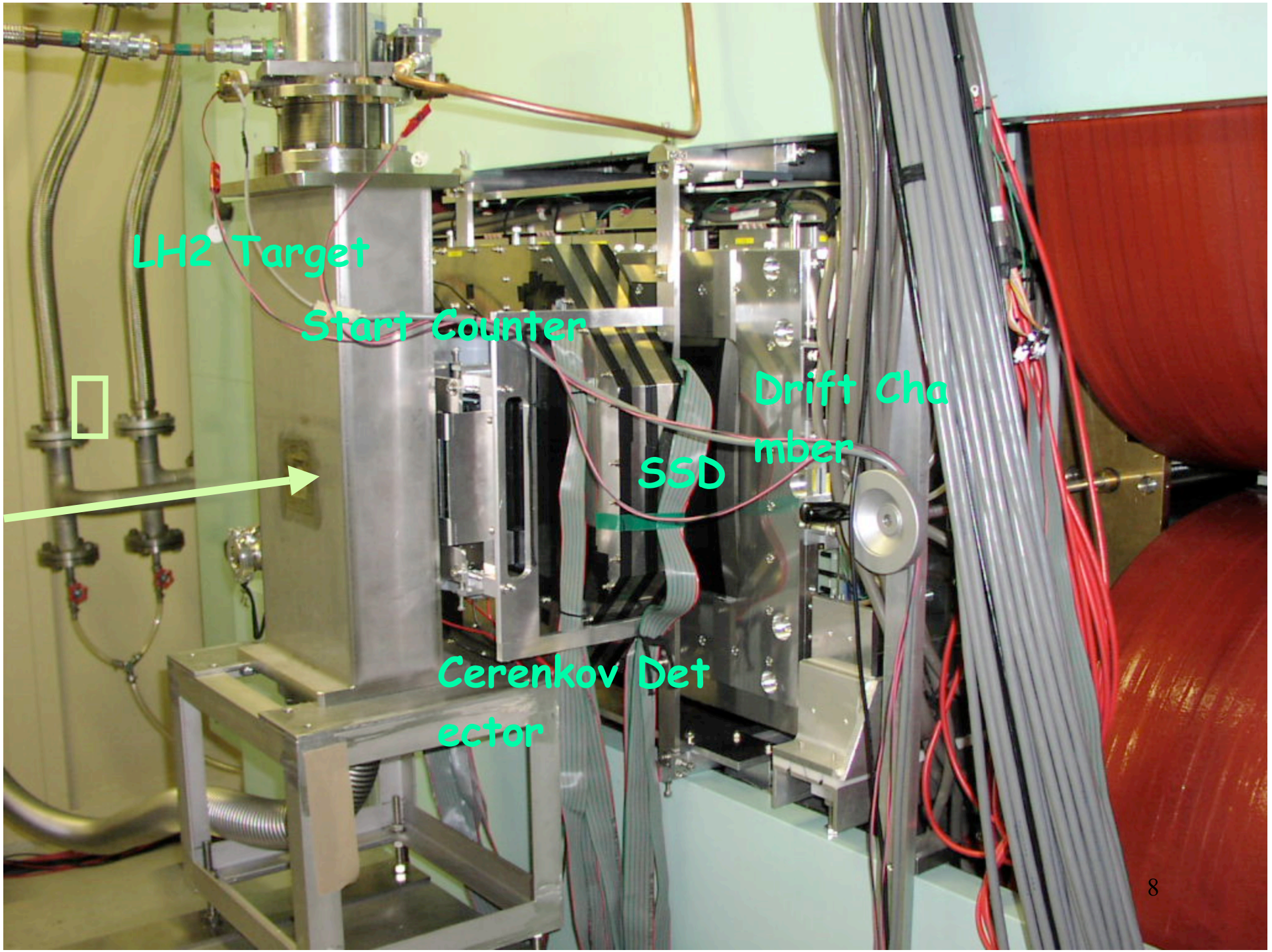
Laser Electron Photon facility at SPring-8

in operation since 2000

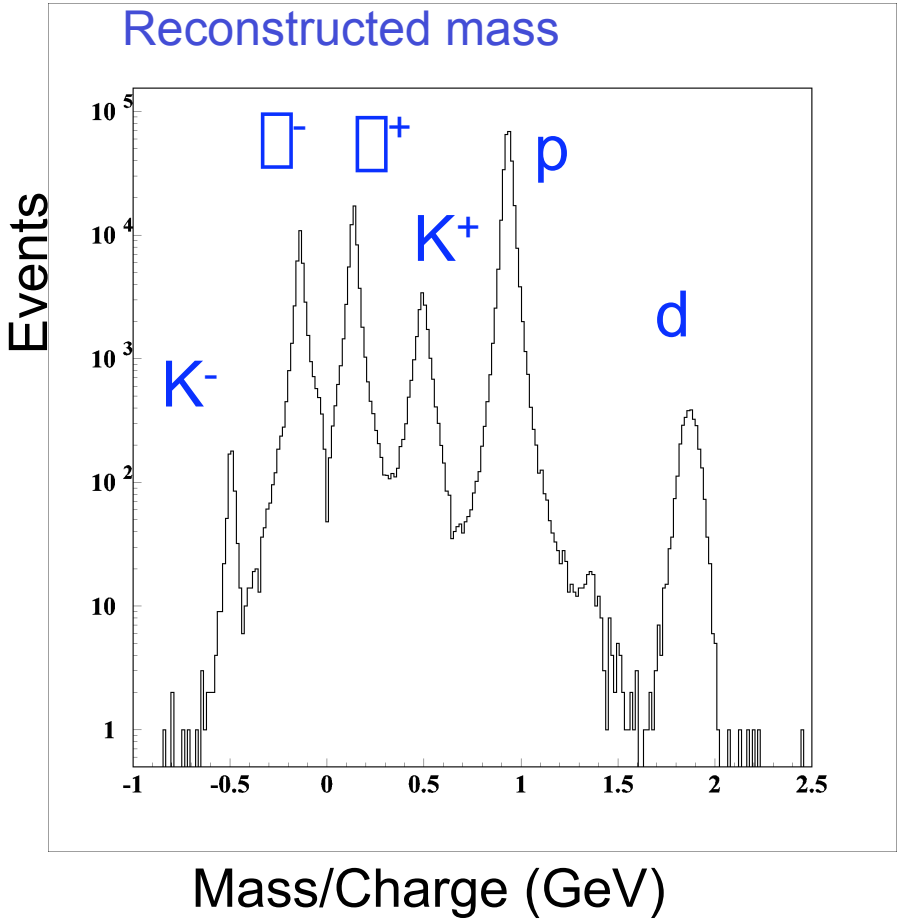


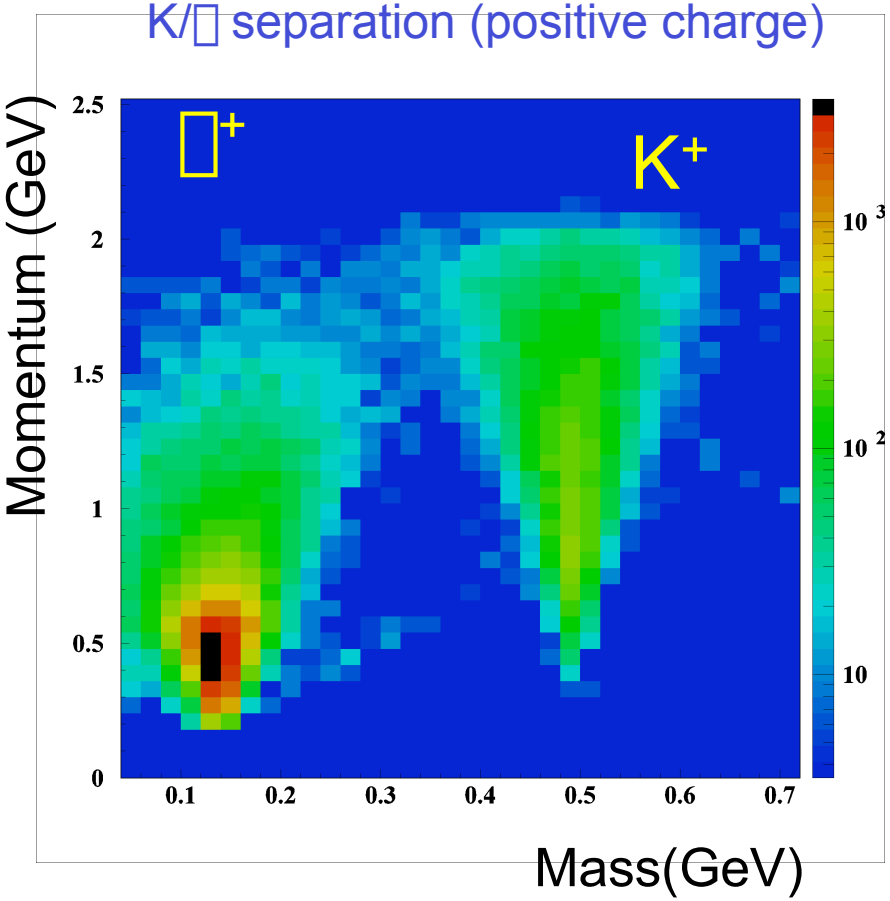
LEPS detector




LH2 Target
Start Counter
Drift Cha
mber
SSD
Cerenkov Det
ector

Charged particle identification Photon beam asymmetries for K^+ photoproduction

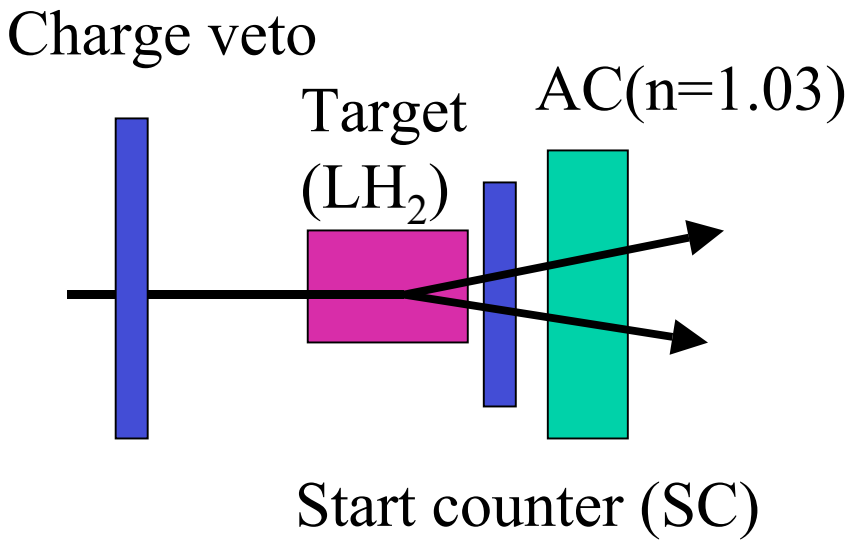




(mass) = 30 MeV(typ.) for 1 GeV/c Kaon

Summary of data taking

30 Hz for 800 kHz@tagger



- Total number of trigger
  $1.83*10^8$ trigger

Dec, 2000 to Jun, 2001

- Number of events with reconstructed charged tracks
  $4.37*10^7$ events

- About a half of events were produced in SC

Optimized for $\gamma p \rightarrow \phi p \rightarrow K^+ K^- p$

Small distance between LH_2 and SC

High index of AC

~~$\gamma p \rightarrow K^0 \Sigma^+ \rightarrow \pi^+ \pi^- K^+ n$~~

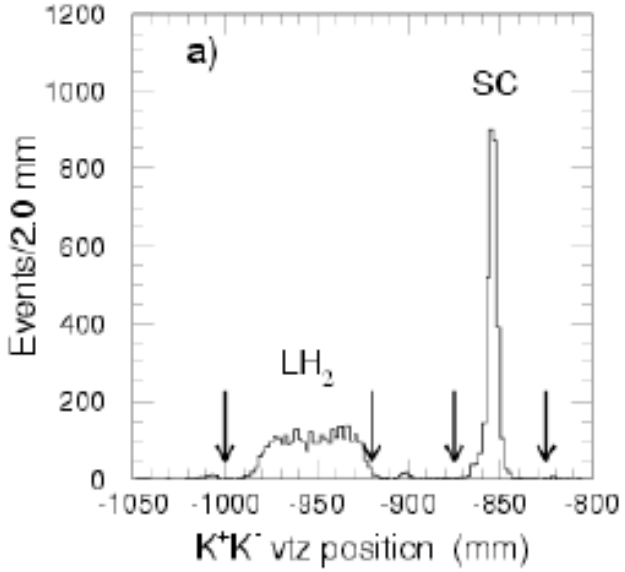
Identification of □⁺

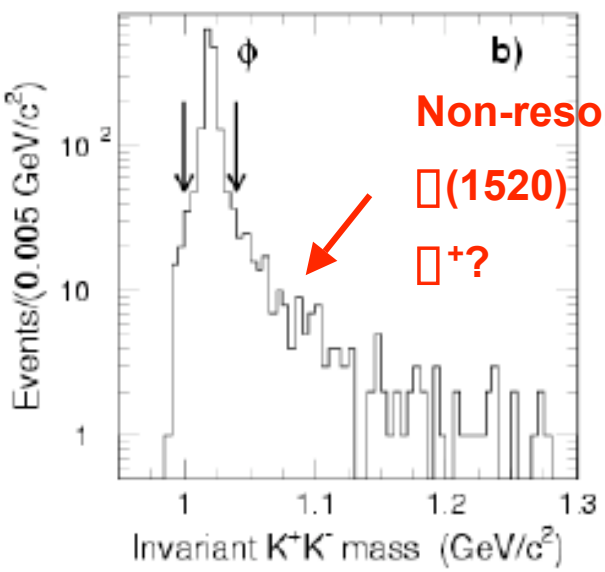
□n → K⁻ □⁺ → K⁻ K⁺ n

- K⁻ missing mass gives □⁺ mass
- K⁺K⁻ missing mass gives n

Problems:

- no neutron target
  - CH start counter (n is part of C!)
- "background"
  - □□ K⁺K⁻ (produced from n & p)





Non-resonant KK

□(1520)

□⁺?

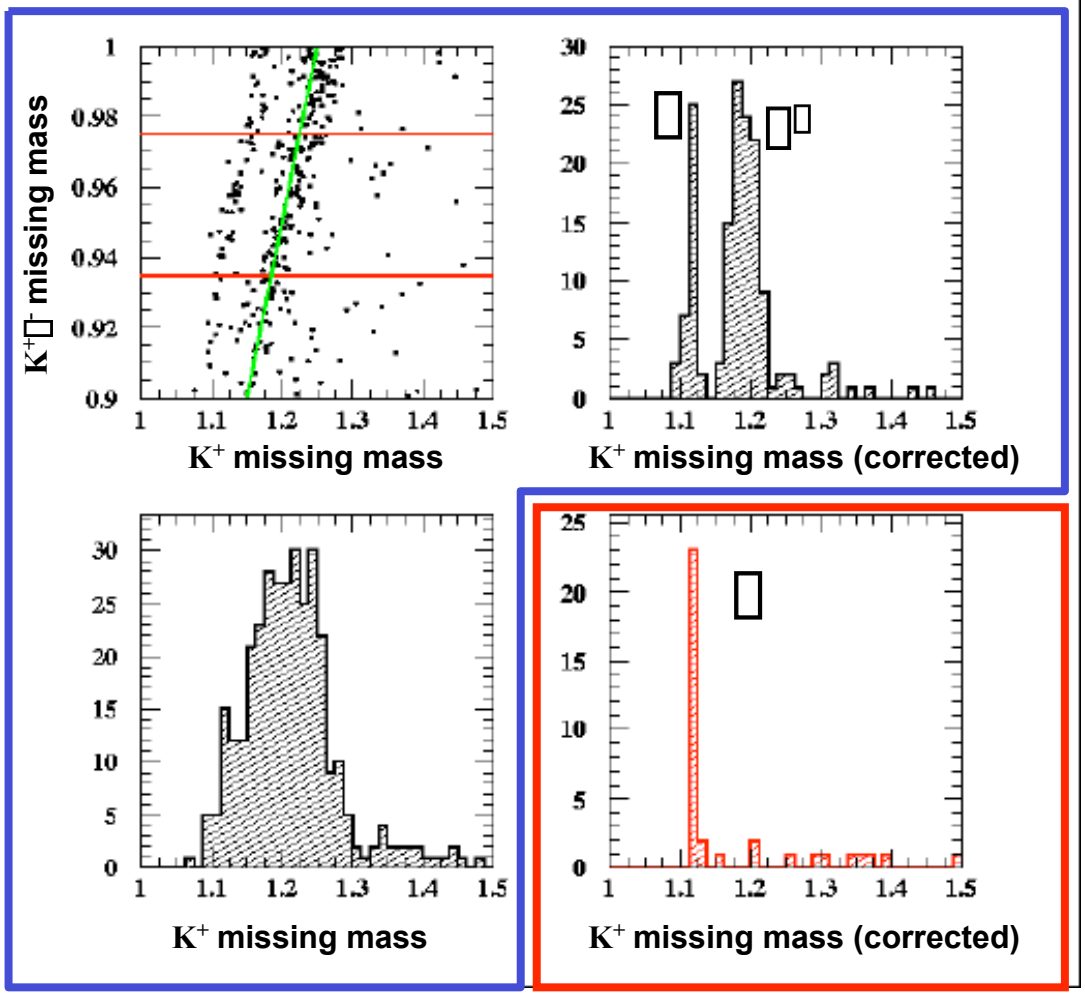
Fermi motion correction

Test-case:

$\gamma n \rightarrow K^+ \Sigma^- \rightarrow K^+ \pi^- n$

$\gamma p \rightarrow K^+ \Sigma^0 \rightarrow K^+ \pi^- p$

Correction works better when $p_n \approx p_K$ is small.

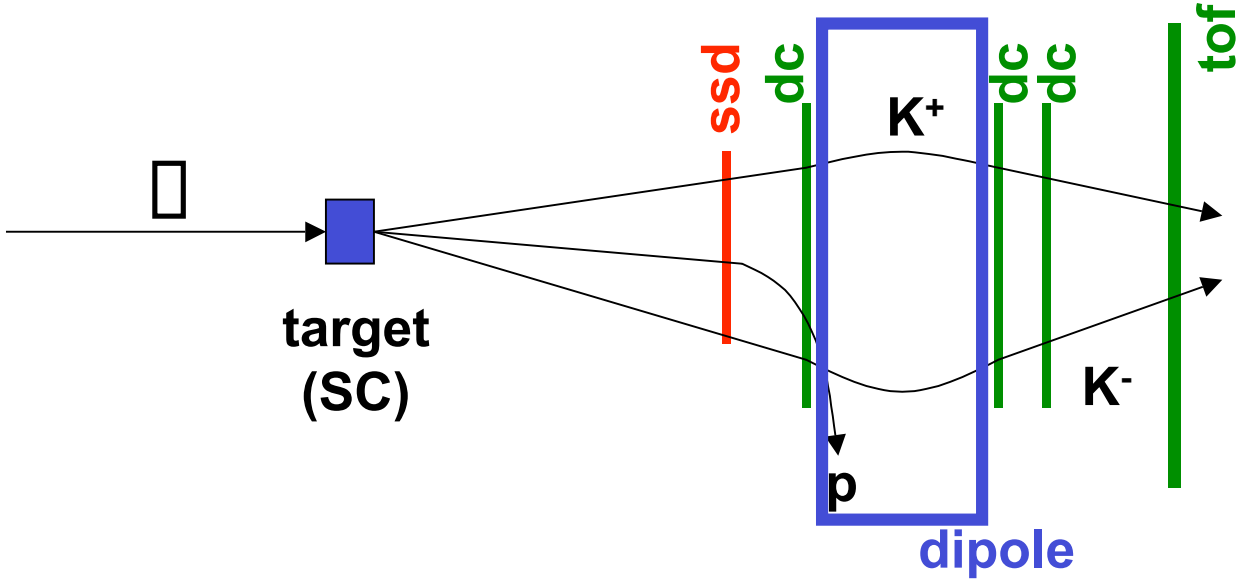


Correction: MM_{K^+} (corrected) = MM_{K^+} - $MM_{K^+\pi^-}$ + M_n

Proton-recoil cut

- □n□ K^+K^-n no recoil proton (proton is a spectator)
- □p□ K^+K^-p slow recoil proton is present

□ proton is too slow to be seen in full detector, but might be seen in SSD vertex detector.



Remove all events for which proton is detected in SSD, or for which predicted proton track does not hit SSD.

Effectiveness of proton recoil cut

□p(n)□ K^+K^-p(n)

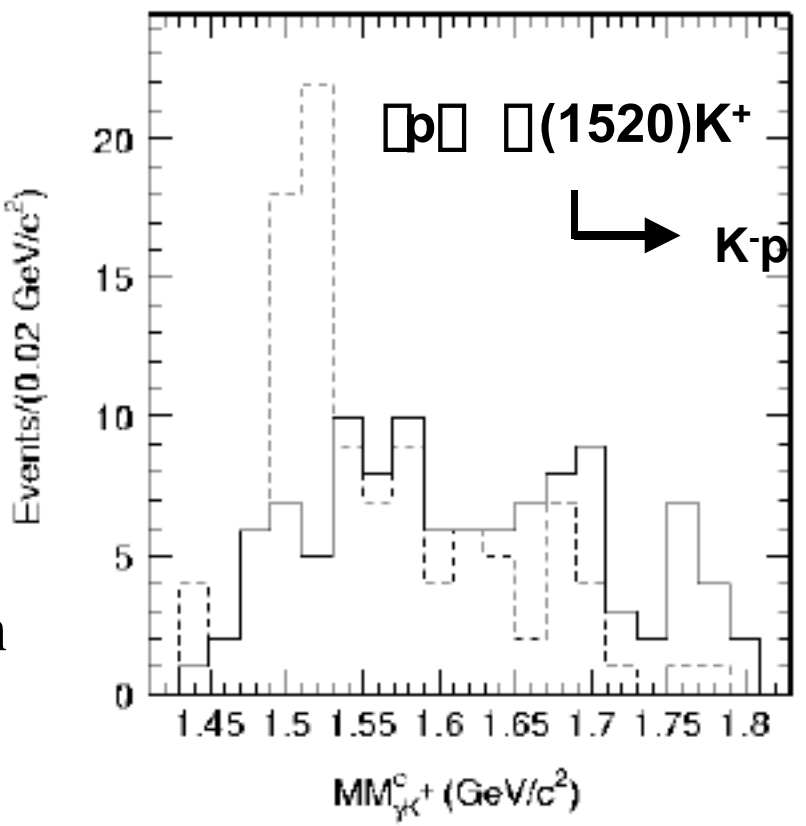
- select KK events from startcounter
- construct K^+ missing mass (corrected) plot
  - apply p-recoil cut

  - reverse p-recoil cut

- - - - - - - -

(proton is present)

$MM^c_{\square\square+} = MM_{\square\square+} - MM_{\square\square+\square\square} + M_n$



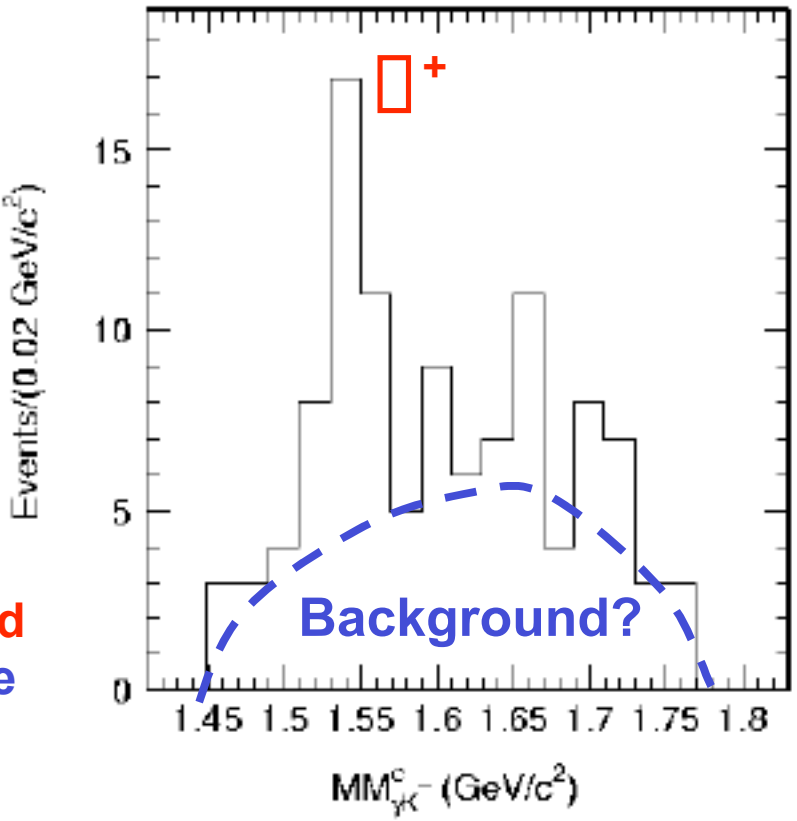
□□□(1520) peak in events with a spectator proton.

The cut enhances □n□ K^+K^-n

n(□,□⁻) missing mass

□n → K⁻ □⁺ → K⁻ K⁺ n

- **select KK events from SC**
- **apply KK invariant mass cut (□)**
- **apply KK missing mass cut (0.9<MM_{kk}<0.98)**
- **apply proton recoil cut**
- **construct K^- missing mass plot**



Background shape can be determined from events from LH_2 target using the same cuts except for:

- **Proton-recoil cut is removed**
- **□(1520) events are removed (only from p)**

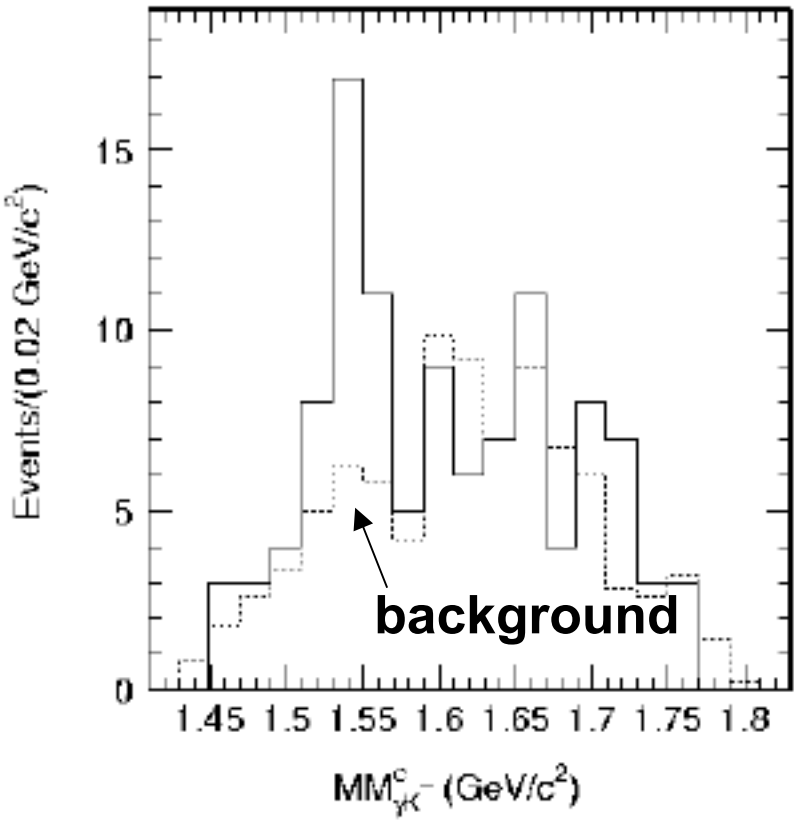
Θ^+ identification

Θ = 1.54±0.01 MeV
Θ < 25 MeV
Gaussian significance 4.6σ

Background level is estimated by a fit in a mass region above 1.59 GeV.

Assumption:

- Background is from non-resonant K^+K^- production off the neutron/nucleus
- … is nearly identical to non-resonant K^+K^- production off the proton



Phys.Rev.Lett. 91 (2003) 012002

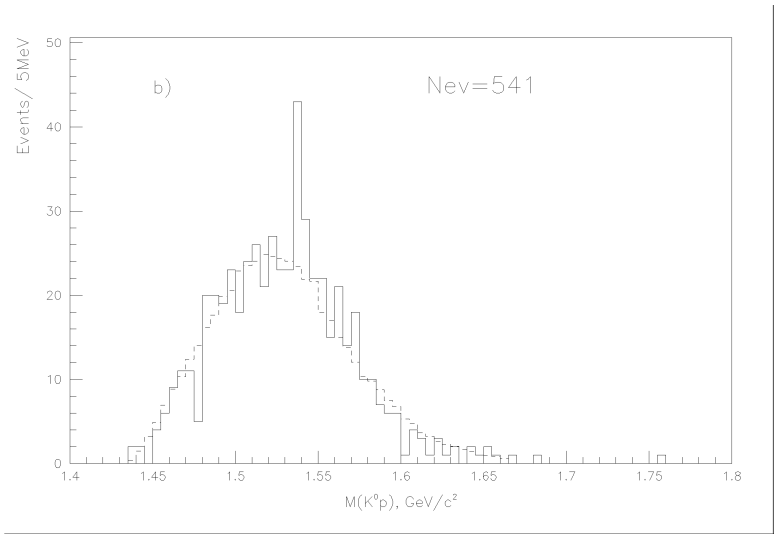
hep-ex/0301020

Confirmation from other labs

DIANA/ITEP

$K^+ Xe \rightarrow \Theta^0 p X$

$(\Theta^+ n \rightarrow K^0 p)$



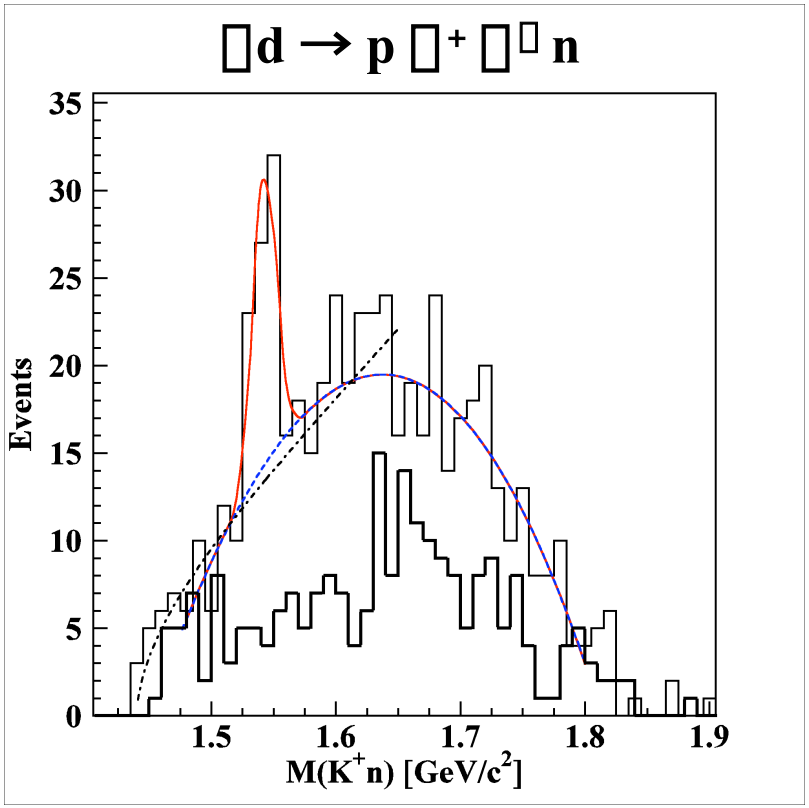
$M_{\Theta} = 1539 \pm 2$ MeV

$\Gamma_{\Theta} < 9$ MeV

hep-ex/0304040

CLAS/JLAB

$\gamma d \rightarrow p K^+ K^- n$



$M_{\Theta} = 1542 \pm 5$ MeV

$\Gamma_{\Theta} < 21$ MeV

hep-ex/0307018

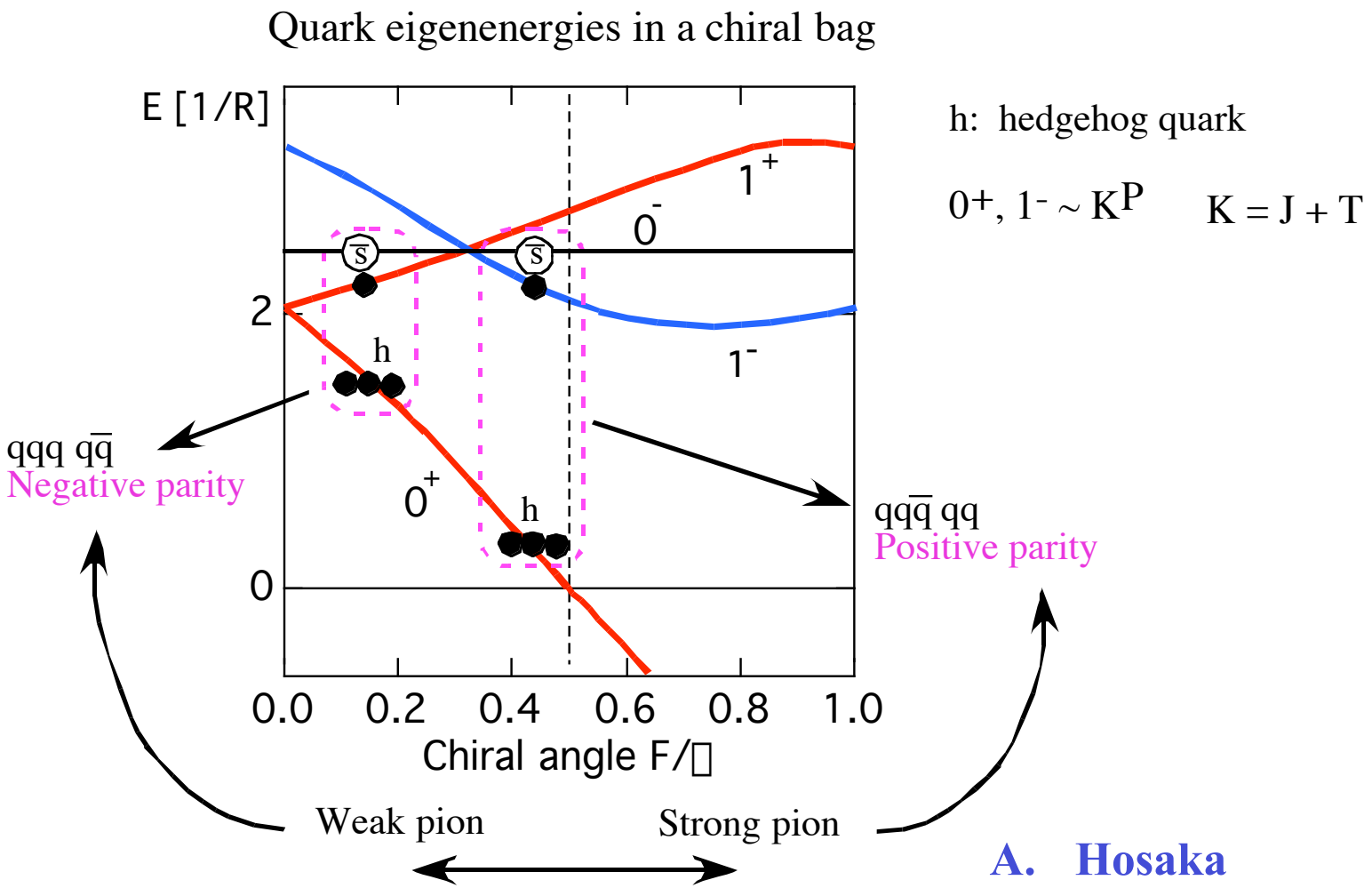
Mysteries

- Why is it so light?
- Why is the width so narrow?
- Pentaquark or KN molecule?
- Excited S=+1 states?
- Is this really an Θ^+, $J^p=1/2^+$ state?

Theoretical activities

- **Exotic baryon states in topological soliton models**
  Walliser, H ; Kopeliovich, V B, hep-ph/0304058
- **Interpretation of the Theta+ as an isotensor resonance with weakly decaying partners**
  Capstick, Page, Roberts, hep-ph/0307019
- **Stable $uudd\bar s$ pentaquarks in the constituent quark model**
  Stancu, Fl ; Riska, D O, hep-ph/0307010
- **The Constituent Quark Model Revisited - Quark Masses, New Predictions for Hadron Masses and KN Pentaquark**
  Karliner, Marek; Lipkin, Harry J, hep-ph/0307243
- **Pentaquark states in a chiral potential**
  Hosaka, Atsushi hep-ph/0307232
- **Group theory and the Pentaquark**
  Wybourne, B G, hep-ph/0307170
- **Diquarks and Exotic Spectroscopy**
  Jaffe, R L ; Wilczek, F, hep-ph/0307341
- **Understanding Pentaquark States in QCD**
  Zhu, Shi-Lin, hep-ph/0307345
- **The anticharmed exotic baryon Theta_c and its relatives**
  Karliner, Marek; Lipkin, Harry J hep-ph/0307343
- **Determining the Θ^+ quantum numbers through the $K^+p\to \pi^+K^+n$ reaction**
  Hyodo, T ; Hosaka, A ; Oset, E nucl-th/0307105

Θ^+ Level



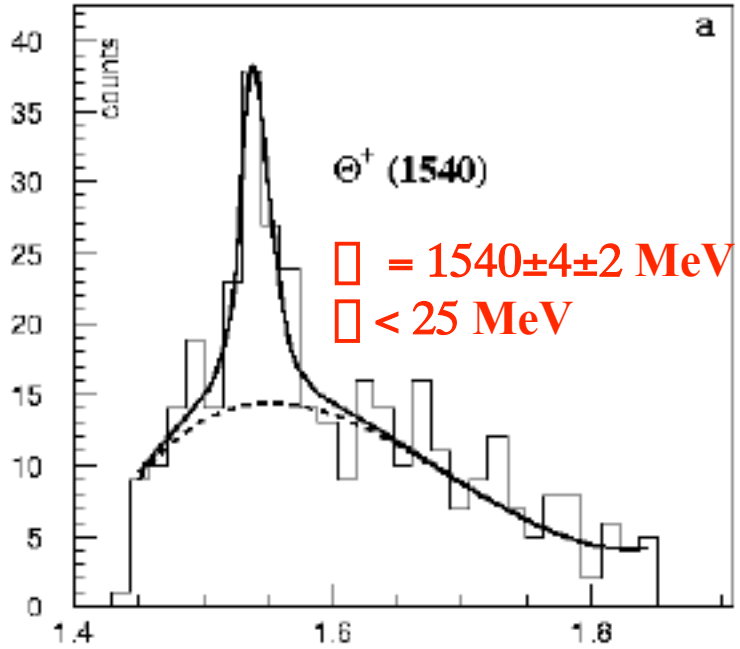
h: hedgehog quark

$0^+, 1^- \sim K^P$ $K = J + T$

A. Hosaka

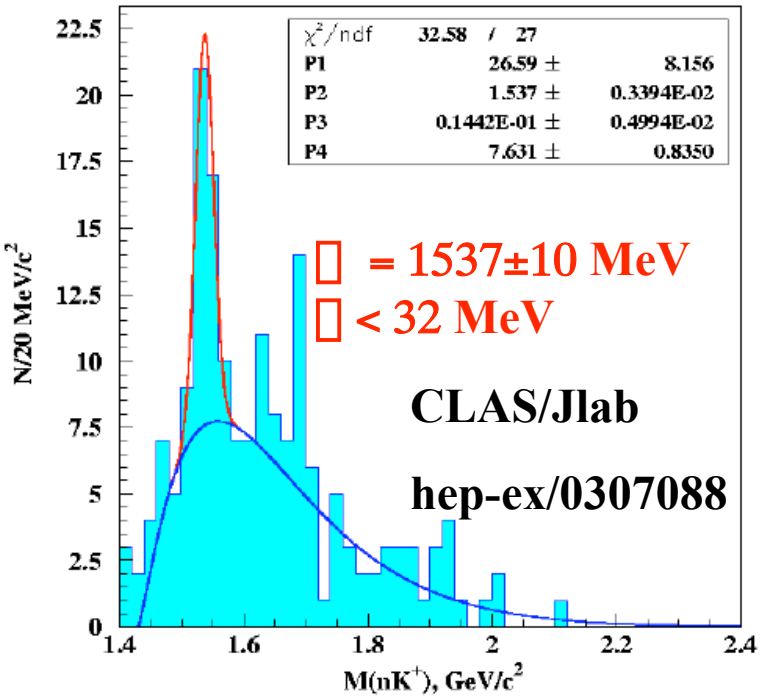
hep-ph/0307232

Very recent results with proton target

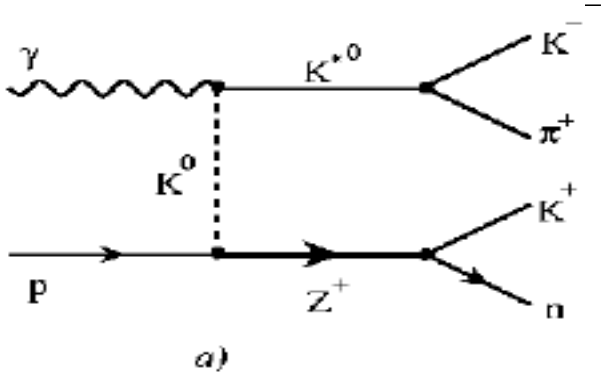


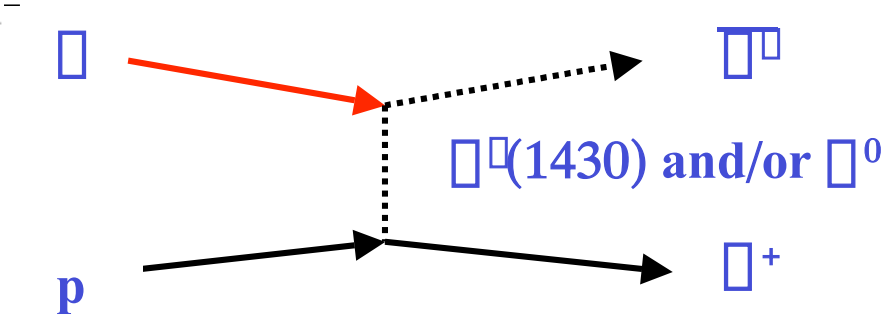
SAPHIR/ELSA

hep-ex/0307083



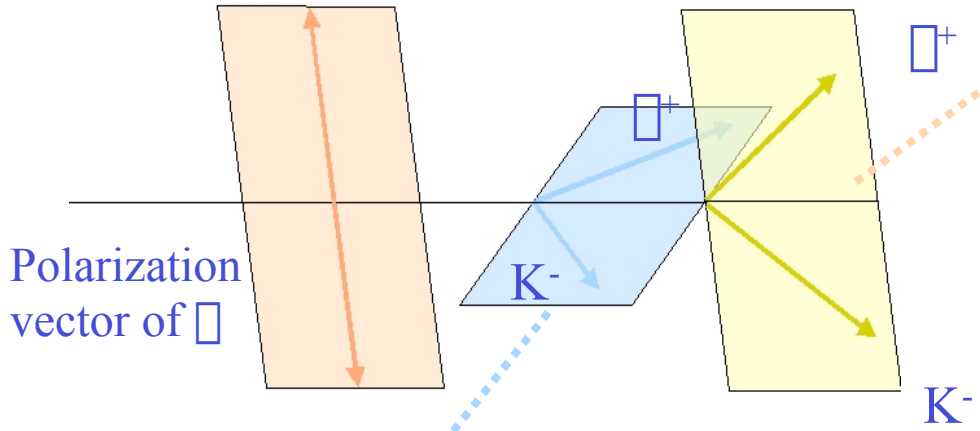
Require cos θ_K^* > 0.5





Photoproducion by linearly polarized photon

In □□ rest frame (Helicity frame)



Decay Plane // □

if natural parity exchange $(-1)^J$

Decay Plane ⊥ □

if unnatural parity exchange $-(-1)^J$ (Pseudoscaler mesons)

Decay Angular distribution of □□

Decomposition of
- natural parity exchange
- unnatural parity exchange

□p → K*□+ E_{th} = 2.65 GeV

4□ detector TPC

To determine Spin and Parity

- Polarize Λ^+ and measure the K+ direction and the neutron spin.
- Double or triple polarization experiment?

Polarized target

Conclusion & Outlook

- **Observation of Nariirow Peak in Missing Mass of □ n → K^- X.**
  - **Evidence for Narrow S=+1 baryon at LEPS at 1.54 GeV with a narrow width.**
  - **Confirmation from other facilities (CLAS(d)/Jlab, DIANA/ITEP, CLAS(p)/Jlab, SAPHIR/ELSA).**
  - **Narrow S=+1 baryon state at 1.54 GeV is well established.**
  - **Further data taking with LD_2 target finished at LEPS and scheduled at CLAS.**
- **Next things to do.**
  - **Determination of Spin and Parity. Is this really □$^+$?**
  - **Other pentaquark resonances ? (S=+1 or not)**
  - **More theoretical works including lattice are needed.**

Conclusion & Outlook (cont.)

- **For further experimental study**
  - **4□ Coverage . → A new TPC (Readout system will be ready in a few month.)**
  - **Photon energy upgrade (Max. 3 GeV) to study □ (and □(1405)) in K*(892) photo-production. (Use linearly polarized photons as a parity filter.)**
  - **Measurement of a recoiled nucleon polarization OR a Polarized target. (Technically the latter is easier.)**

A new competition has just started.

Let's work together!