Penta-quarks at J-PARC

K. Imai (Kyoto)

- Introduction
- Width and spin-parity of Θ^+ and E559 at KEK-PS
- Exotic hadron spectroscopy at J-PARC
- Summary

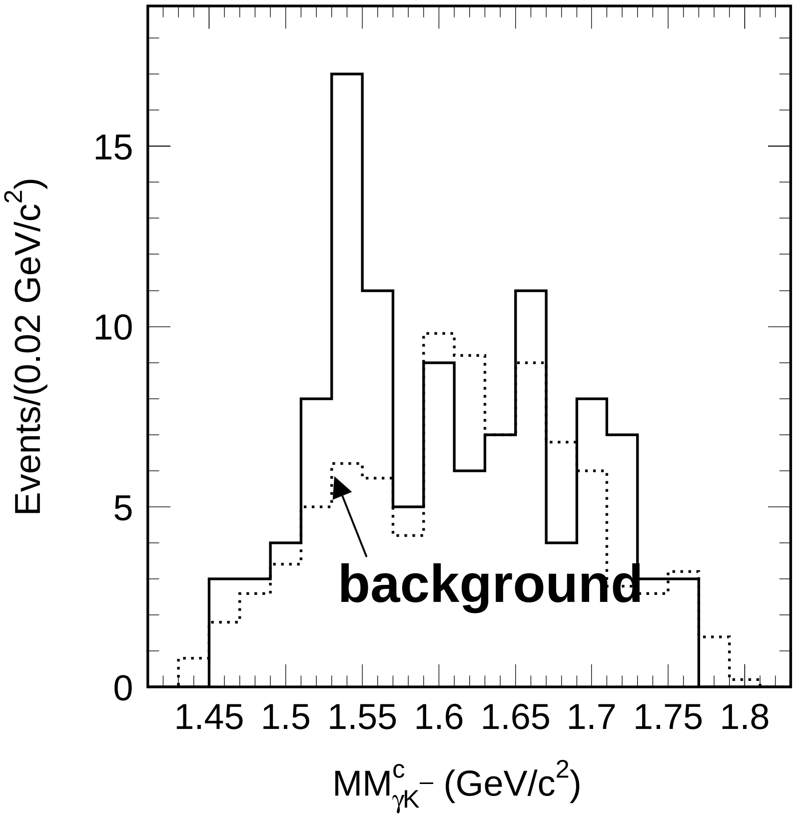
Discovery of Pentaquark Θ^+

$M = 1540 \pm 10$ MeV
$\Gamma < 25$ MeV
Gaussian significance 4.6σ

SPring-8 LEPS

- $\gamma + n \rightarrow K^- + K^+ + n$,
  $\Theta^+ \rightarrow K^+ n$

Θ^+: uudd s-bar

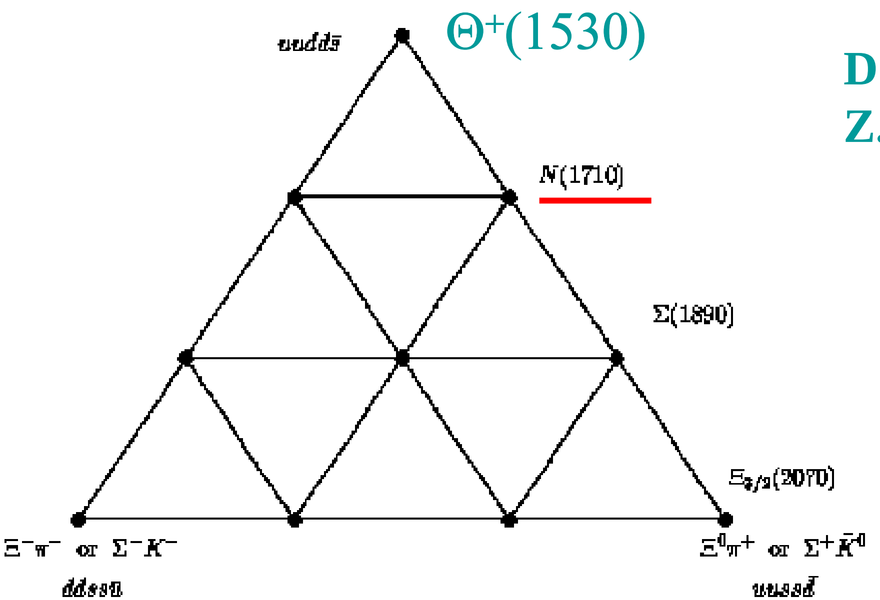


T. Nakano et al.,

Phys.Rev.Lett. 91 (2003) 012002

hep-ex/0301020

$\Theta^+(Z^+)$ prediction of anti-decuplet



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

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

Figure 1: The suggested anti-decuplet of baryons. The corners of this (T_3, Y) diagram are exotic. We show their quark content together with their (octet baryon+octet meson) content, as well as the predicted masses.

Jaffe & Wilzcek
Diquark model predict also Anti-decouplet pentaquark $J^p=1/2+$ (N(1440))

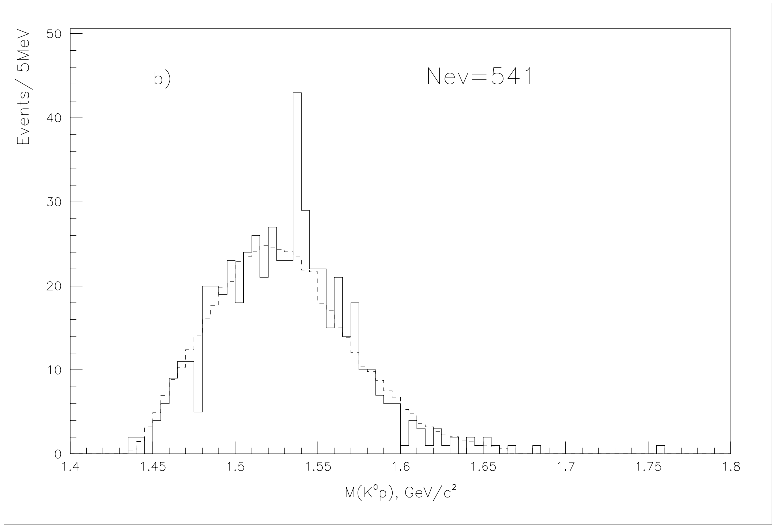
M = [1890-180*Y] MeV

21

Confirmation from US and Russia

DIANA/ITEP

K^+ Xe → K^0 p X
(K^+ n→ K^0 p)

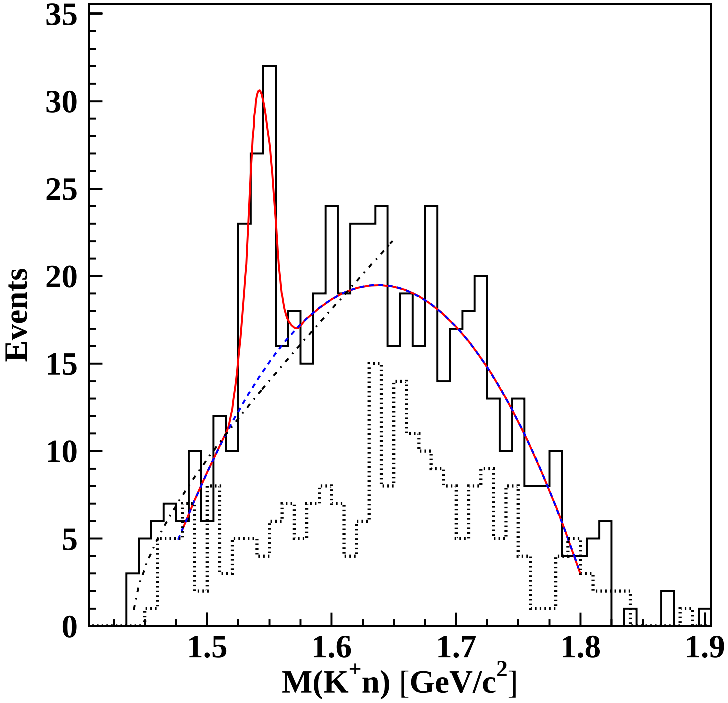


M = 1539±2 **MeV**
Γ < 9 **MeV**

hep-ex/0304040

CLAS/JLAB

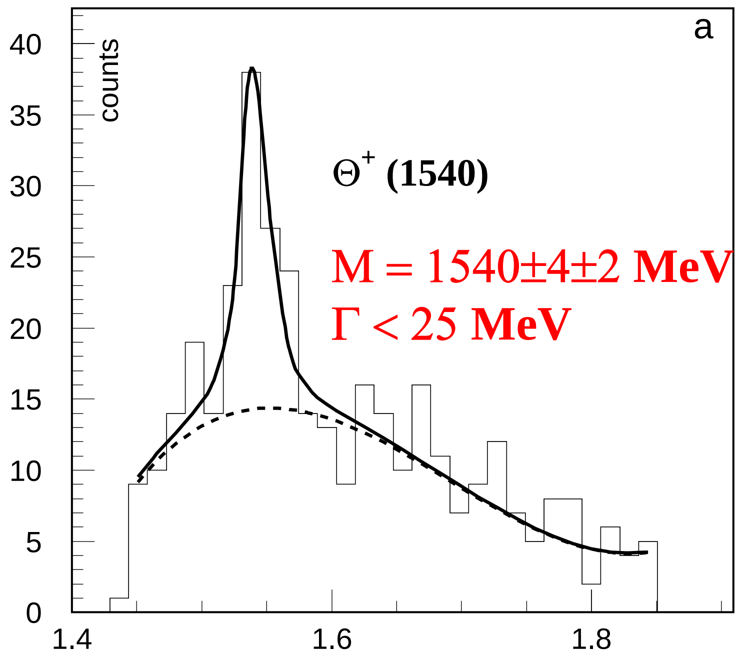
γ d → p K^+ K^- n



M = 1542±5 **MeV**
Γ < 21 **MeV**

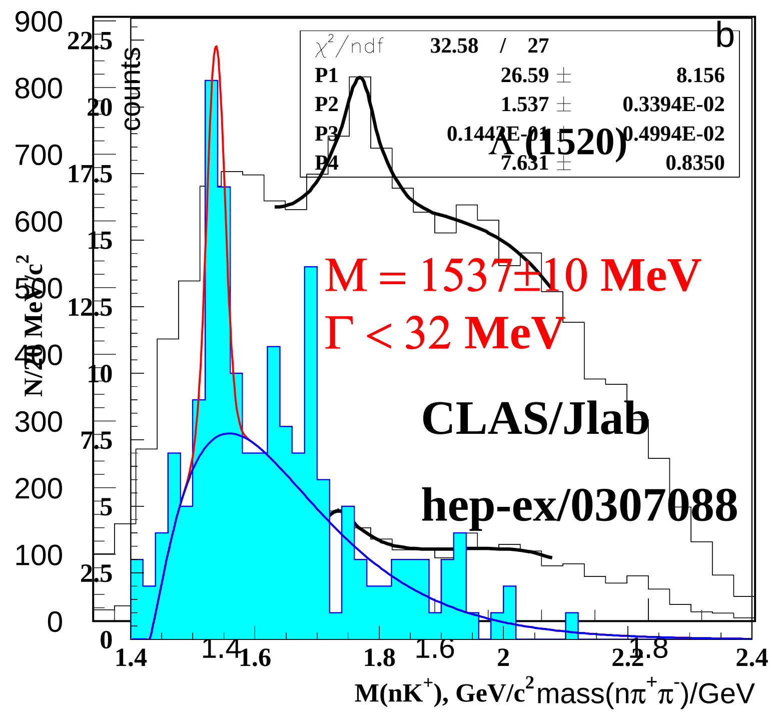
hep-ex/0307018

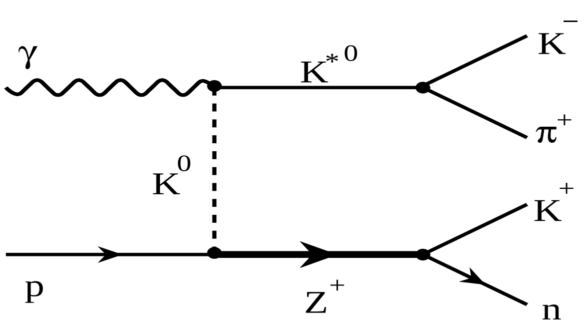
Further confirmation with proton target



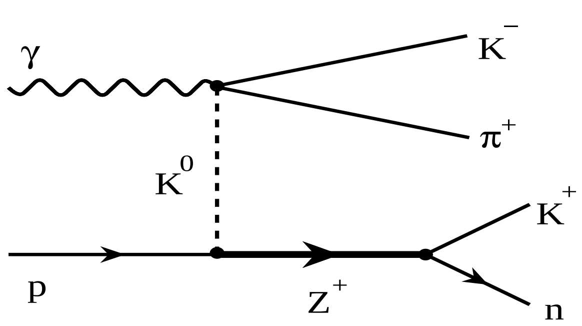
SAPHIR/ELSA

hep-ex/0307083





a)



b)

Neutrino scattering

Reanalysis of bubble chamber experiments from WA21, WA25, WA59, E180, E632

A.Asratyan,A.Dolgolenko, M.Kubantsev
hep-ex/0309042

M = 1533± 5 MeV

Γ < 20 MeV

M(K_sp) spectrum

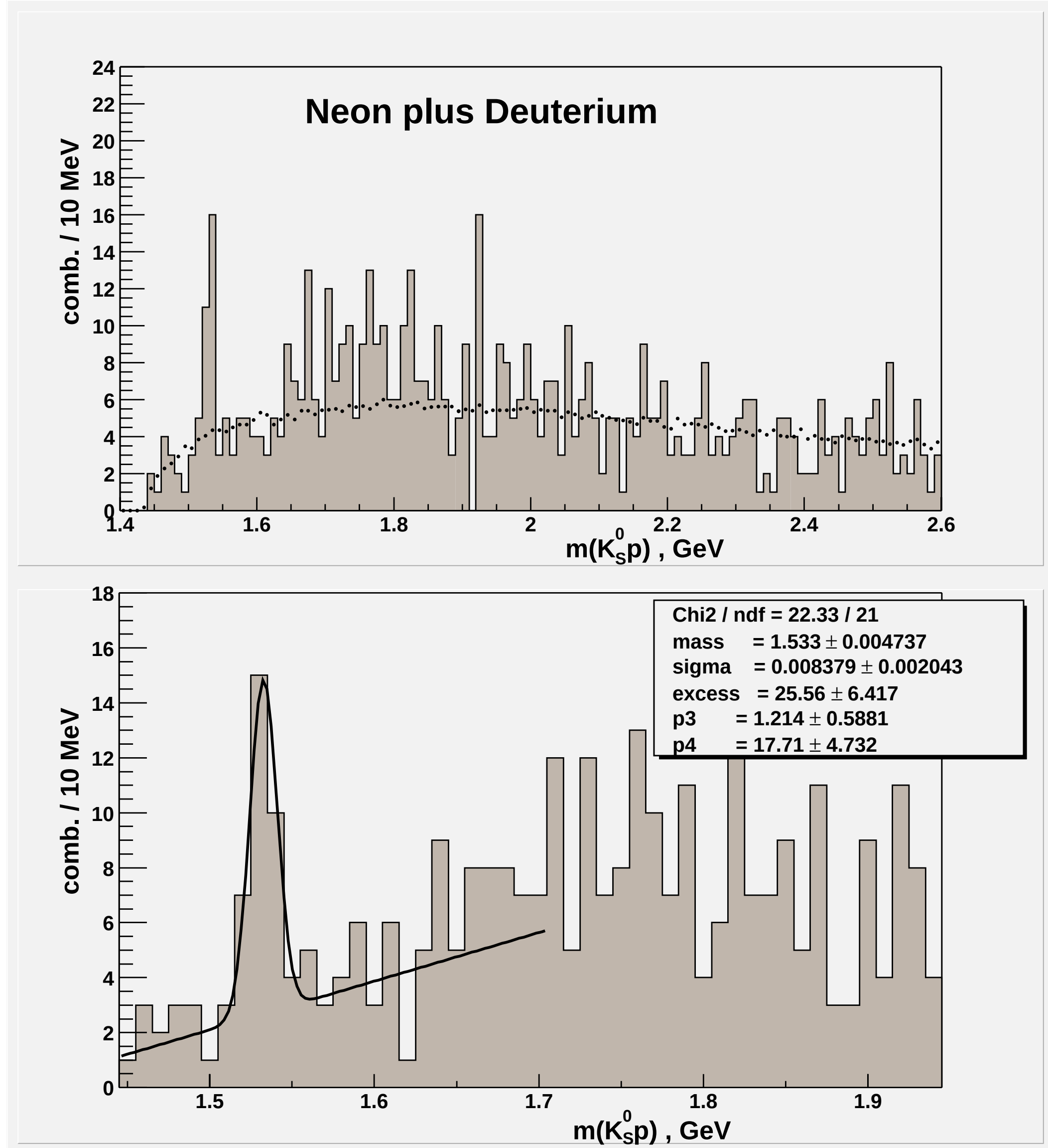


Figure 4: Invariant mass of the $K^0_S p$ system for Neon and Deuterium combined (top panel). The dots depict the random-star background. A fit of the same $m(K^0_S p)$ distribution fitted is shown in the panel.

COSY-ToF pp -> Σ^+K^op

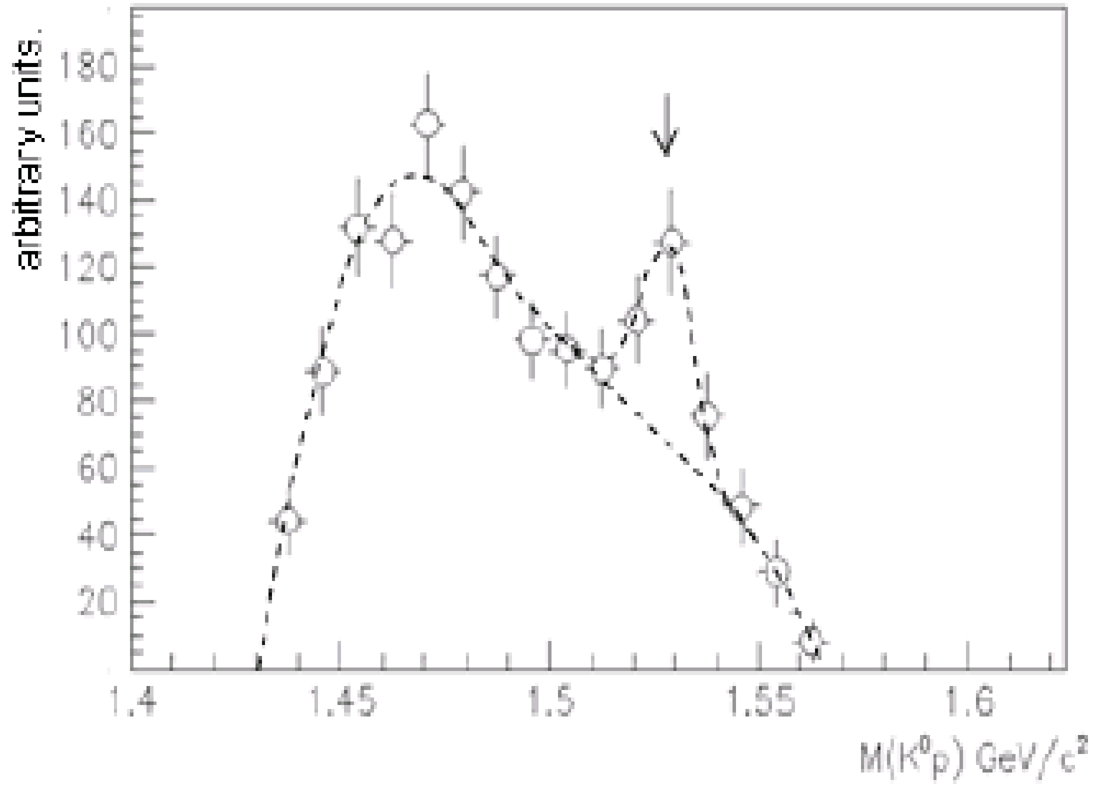
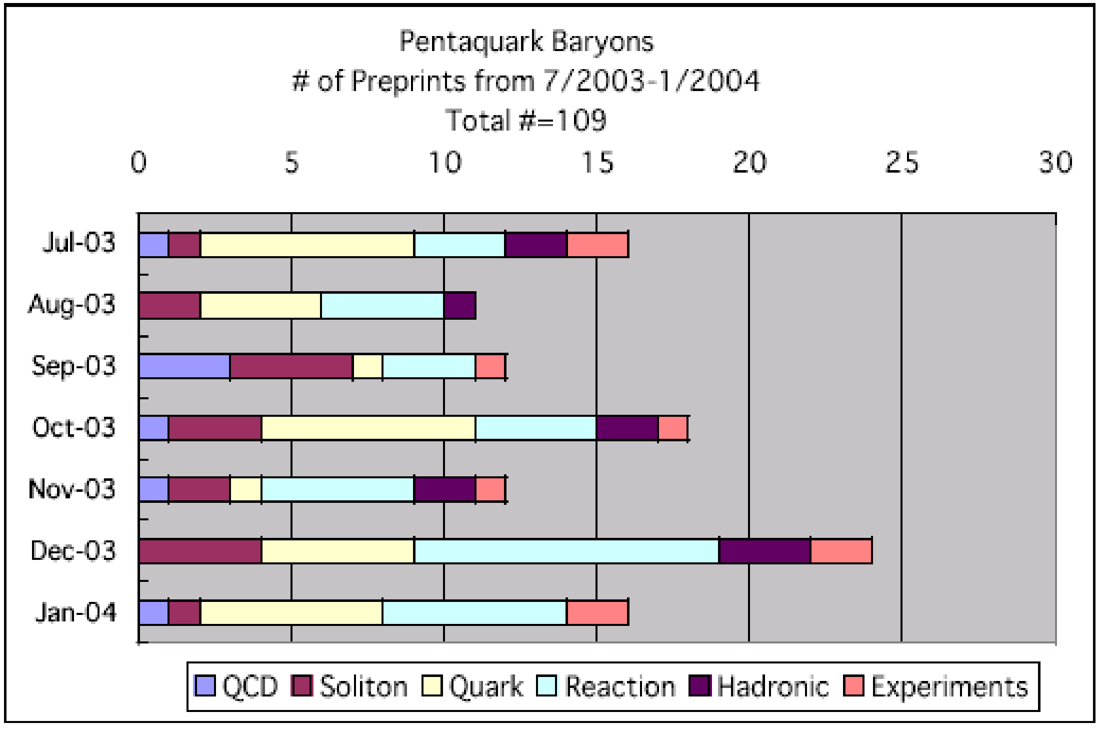


Figure 7: Efficiency corrected invariant mass spectrum of the K^0p subsystem obtained from the full sample.

Summary of positive results

Experiment	Θ^+ Mass (MeV)	Γ (MeV)
LEPS/SPring-8	: $1540 \pm 10 \pm 5$	: 25
DIANA	: $1539 \pm 2 \pm$ few	: 9
CLAS(d)	: $1542 \pm 2 \pm 5$	: 21
SAPHIR	: $1540 \pm 4 \pm 2$	: 25
ITEP(ν)	: 1533 ± 5	: 20
CLAS(p)	: $1555 \pm 1 \pm 10$	: 26 ± 7
HERMES	: $1528 \pm 2.6 \pm 2.1$	: $19 \pm 5 \pm 2$
ITEP(p)	: $1526 \pm 3 \pm 3$	: 24
ZEUS	: 1527+ 2	: 23
COSY	: 1530+ 5	: 18

Increasing number of papers



First Manifestly Exotic Hadron in 40 Years

- The discovery of the $\Theta^+(1540)$ this year marks the beginning of a new and rich spectroscopy in QCD….

R.Jaffe

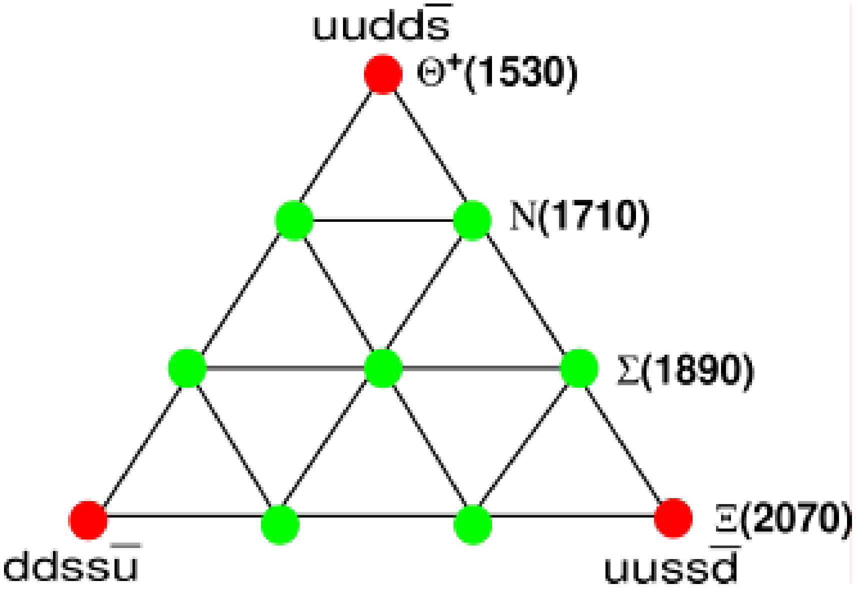
Renaissance of Hadron Spectroscopy !

(Birth of Exotic Hadron Spectroscopy)

What is Θ^+? Theorest's answer

- Chiral Soliton ½+
- Quark model
  - conventional ½ -
  - correlated diquark ½+
- Hadronic bound state
- Others

Lattice QCD ½- ?



Questions about Θ^+

Spin-parity: $J^\pi = \frac{1}{2}^+$ or $\frac{1}{2}^-$ or 3/2

-> selection of models

s-wave or p-wave ?

K+n -> K+n phase shift analysis

pol.γ N -> K- Θ+ decay distribution of Θ+

angular dependence

-> SPring-8 TPC project

pp -> Σ+Θ+ (COSY) Hosaka

Questions about width

- upper limit from direct measurement: 9 (20) MeV
-
  - S.Nussinov (hep-ph/0307357) based on K^+d scattering data $\Gamma(\Theta+)<6$MeV
  - Arndt,Strakovski & Workman (nucl-th/0308012) based on existing K+N elastic scattering data $\Gamma(\Theta+)$ as small as 1 MeV

K+p -> $\pi+$ $\Theta+$ KEK-SKS spectrometer (ΔE~1.3 MeV)

High resolution spectroscopy of pentaquark Θ^+ (E559 at KEK-PS)

- **K.Imai, K.Miwa, M.Hayata, M.Miyabe, N.Muramatsu, M.Niiyama, N.Saito, M.Wagner, M.Yosoi (Kyoto U.)**
- **T.Nagae, M.Ieiri, N.Noumi, Y.Sato, S.Sawada, M.Sekimoto, H.Takahashi, T.Takahashi, A.Toyoda (KEK)**
- **H.Fujioka, T.Maruta (U. Tokyo)**
- **T.Fukuda, P.K.Saha (Osaka ECU)**
- **T.Nakano (RCNP)**
- **K.Hicks (Ohio)**

- K+ p ->π+ Θ+ reaction with SKS spectrometer at KEK K6 beam line
- excellent mass resolution ΔE=1.0 MeV
- Decay angular distribution for spin determination

Objective of the experiment

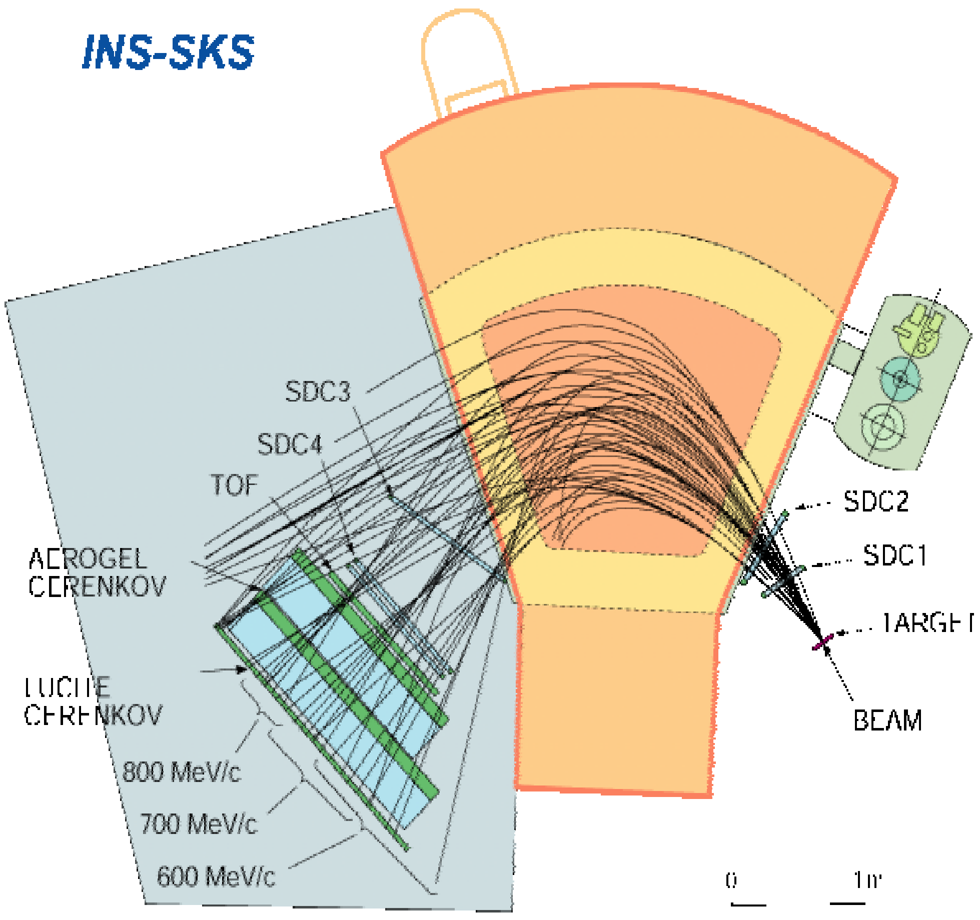
- To confirm Θ+ with high statistics and in hadron reaction
- -> 1500 events

- To determine width (lifetime) of Θ+
- -> 1.3MeV resolution

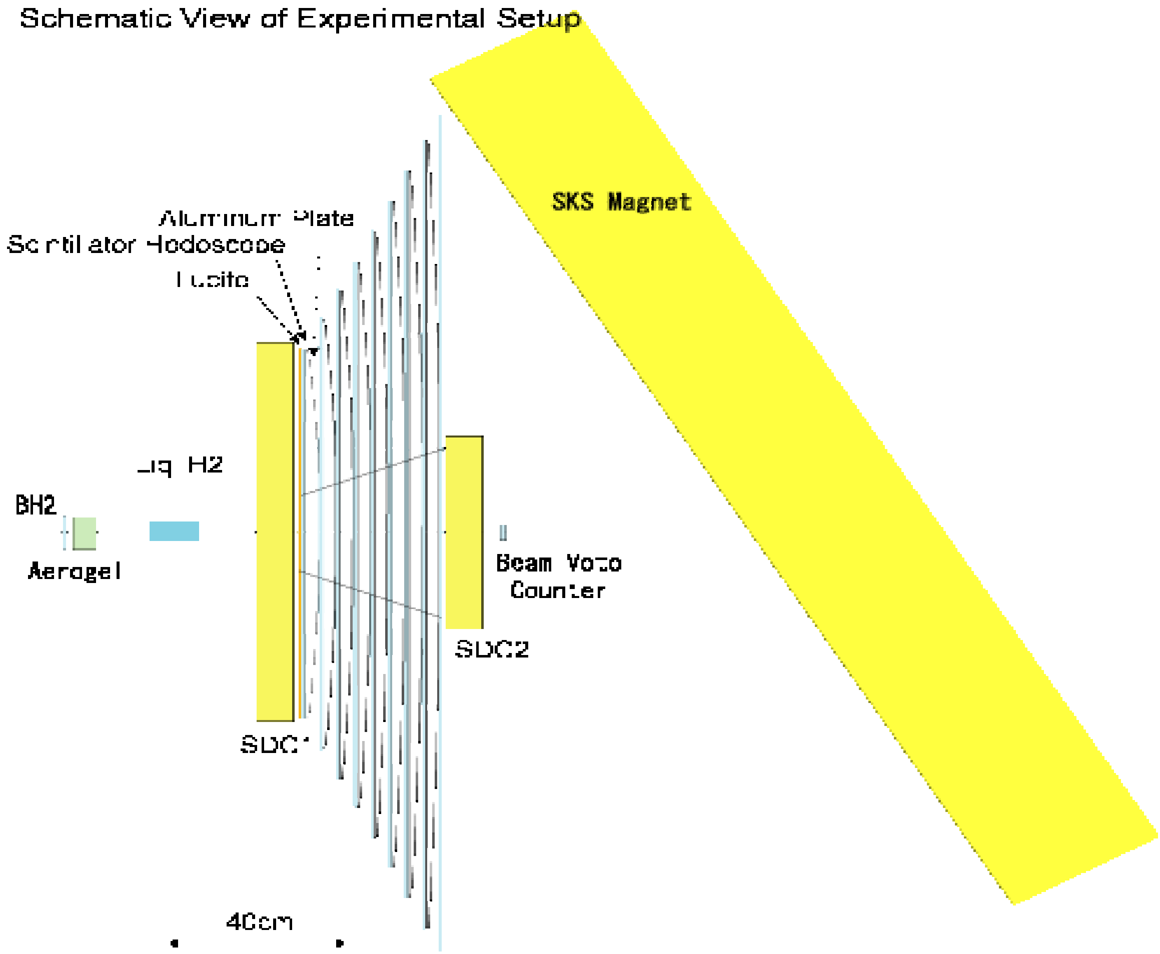
- To determine spin of Θ+

  -> decay distribution (Θ+->K+n)

SKS Spectrometer



Experimental setup around target and Range counter



Yield estimation

- ~1500 events/ 60shifts

  - K^+ beam: 14000/spill (2× 10^{12} proton/spill)
  - 10cm H_2 Target: 4.2×10^{23} /cm^2
  - Total cross section: 80 μbarn
  - Acceptance: 2.0 %
  - Detection Efficiency: 0.6
  - Probability of only two hit on SDC0 : 0.6
    (for Θ^+ production against K^+ 3-body decays)

$K^+p \to \pi^+\Theta^+$ reaction

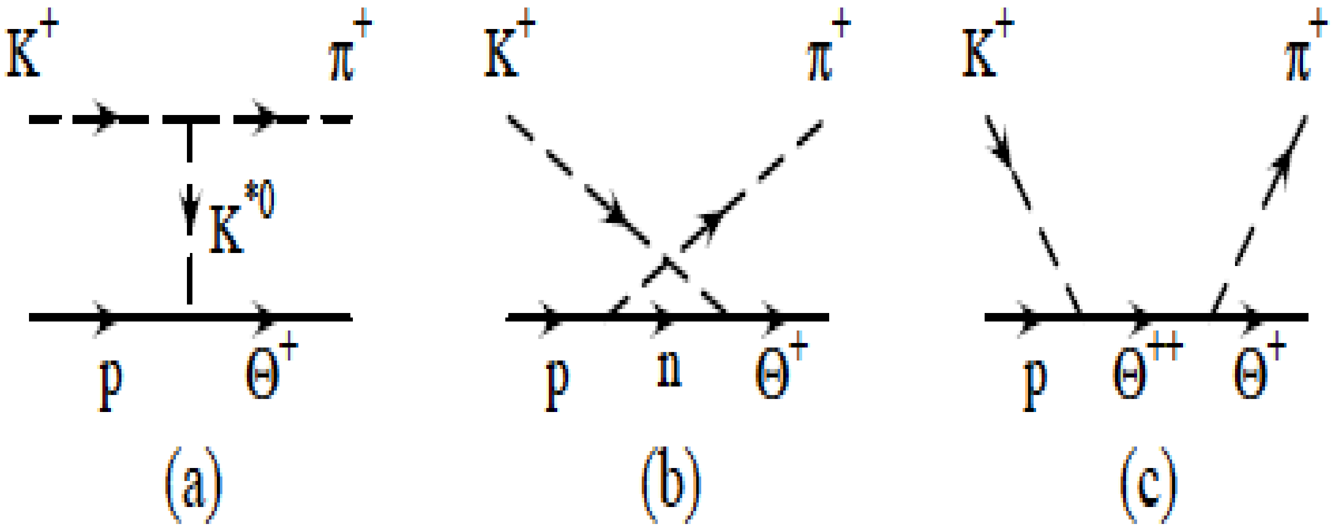


FIG. 1: Tree diagrams for $K^+p \to \pi^+\Theta^+$ reaction.

Total cross section for K+p->π+Θ+

Y.Oh et al., hep-ph/0311054

Γ(Θ+)~1MeV

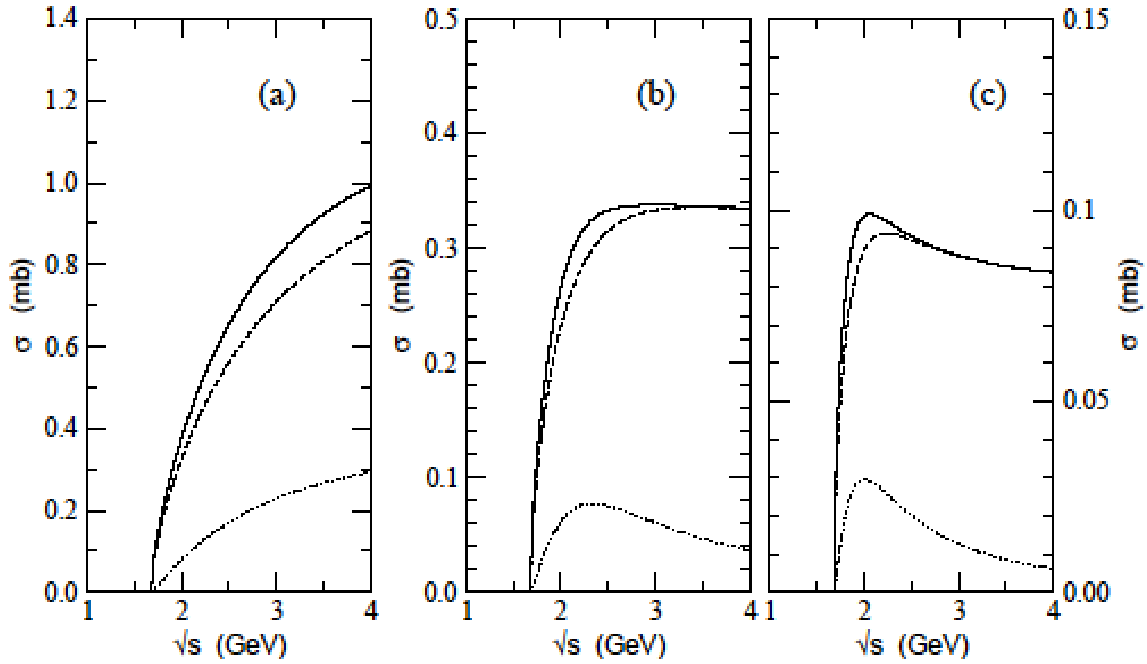
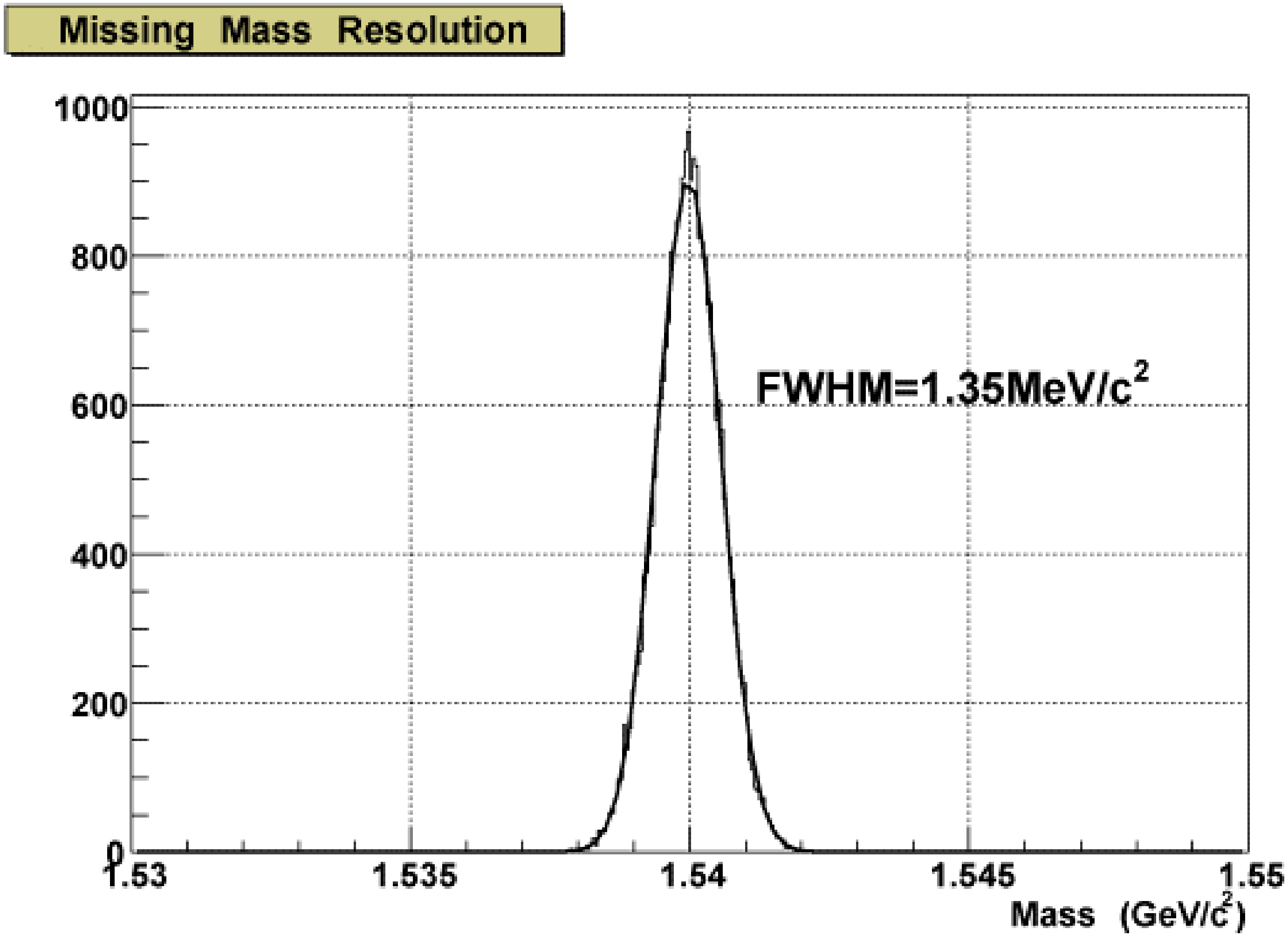


FIG. 2: Total cross sections for $K^+p \to \pi^+\Theta^+$ (a) without form factor, (b) with form factor (9) and $\Lambda = 1.8$ GeV, (c) with $\Lambda = 1.2$ GeV. The solid lines are obtained with $g_{K^*N\Theta} = +g_{KN\Theta}$, the dotted lines are with $g_{K^*N\Theta} = 0$, and the dashed lines are with $g_{K^*N\Theta} = -g_{KN\Theta}$.

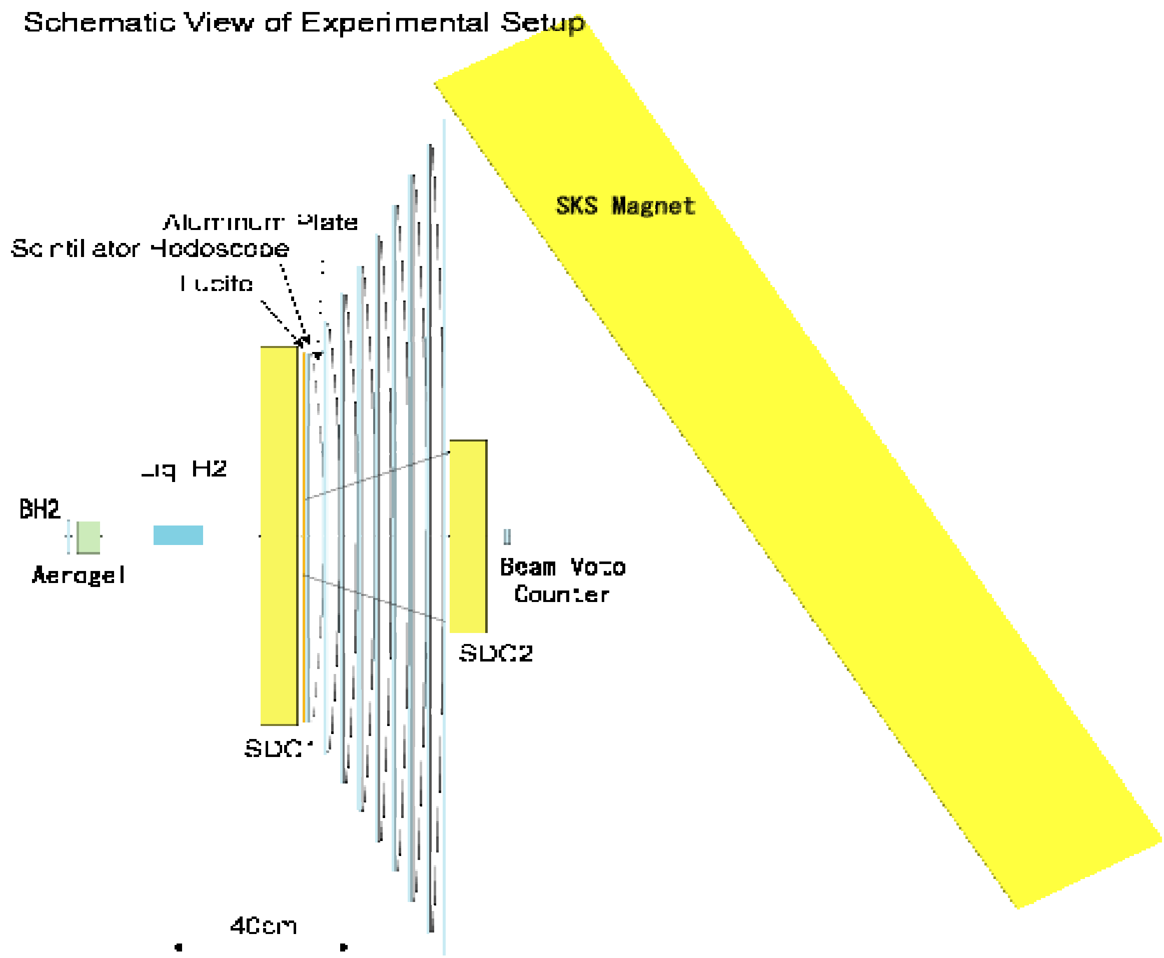
Expected mass resolution of Θ^+



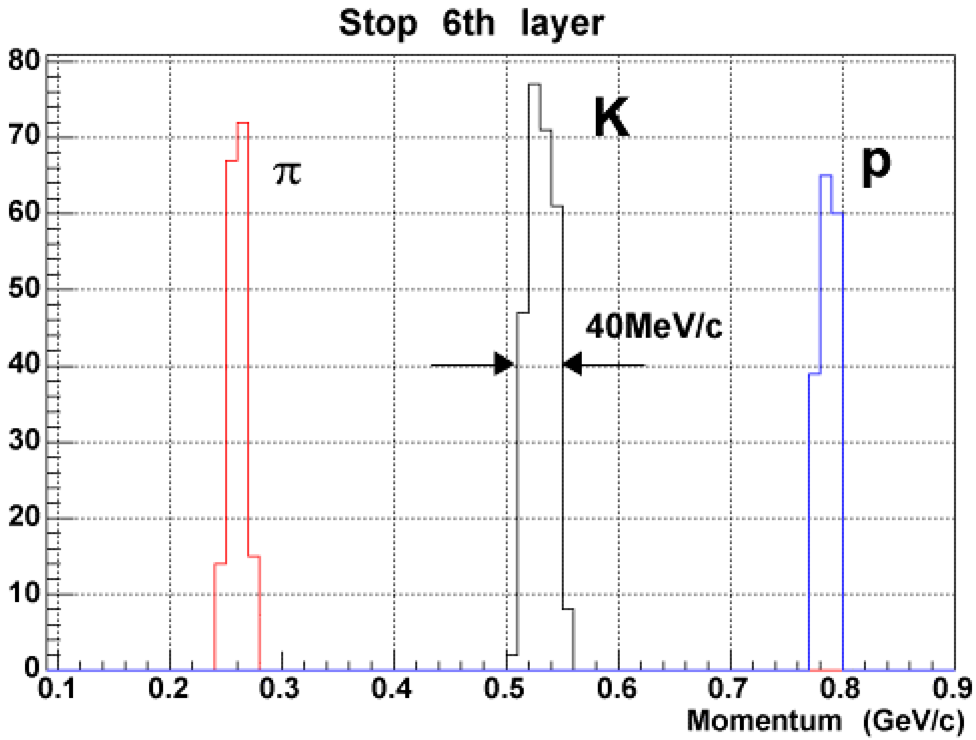
Background reactions for simulation

Reaction		Cross Section(mb) [18]
Δ production	$K^+p \to K^0\pi^+p$	3.43 ± 0.32
	$K^+p \to K^+\pi^+n$	0.32 ± 0.06
K^* production	$K^+p \to K^0\pi^+p$	1.06 ± 0.20
Phase Space	$K^+p \to K^0\pi^+p$	0.25 ± 0.30
	$K^+p \to K^+\pi^+n$	0.24 ± 0.06

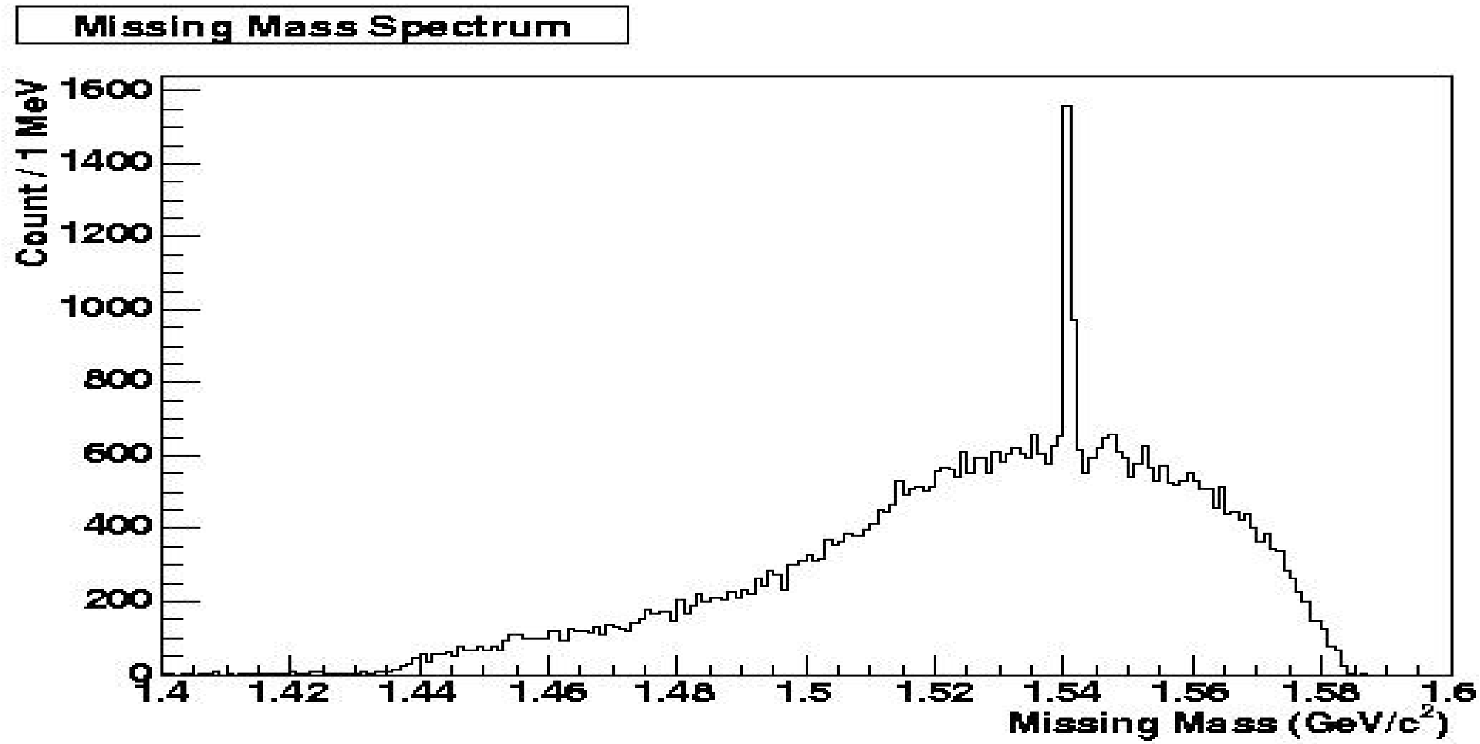
Experimental setup around target and Range counter



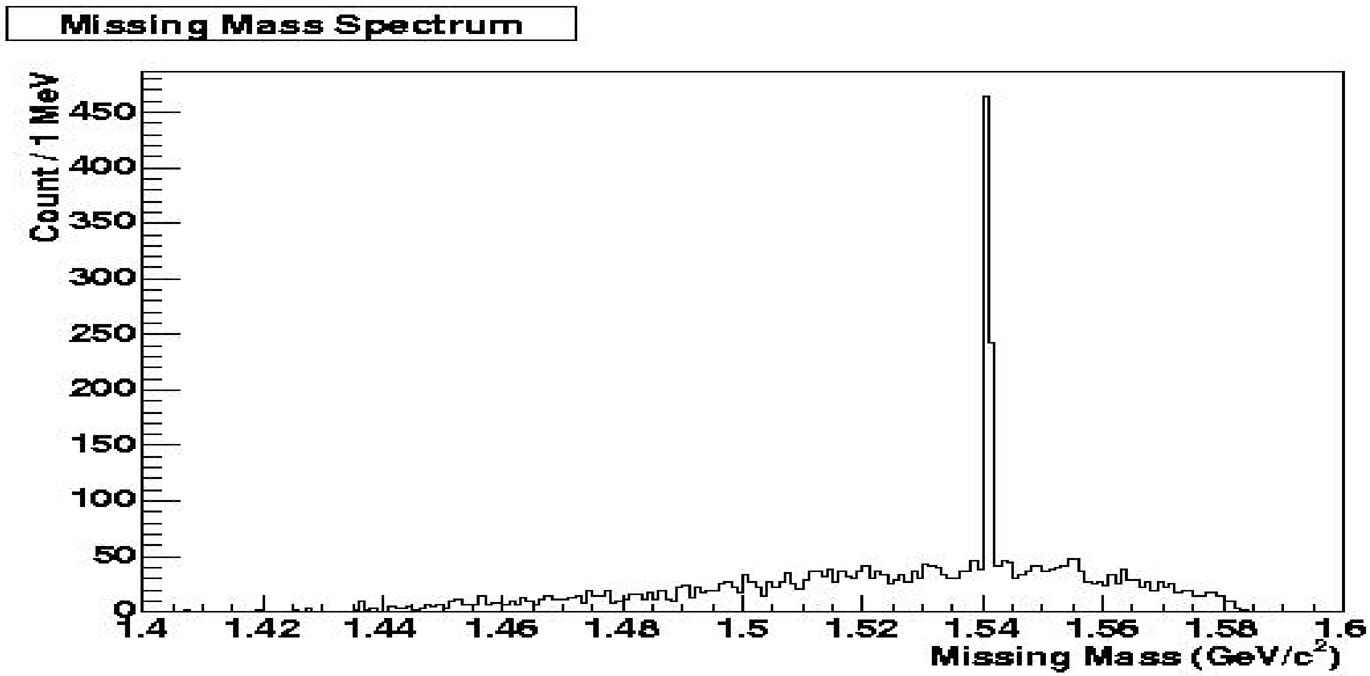
Momentum resolution of range counter



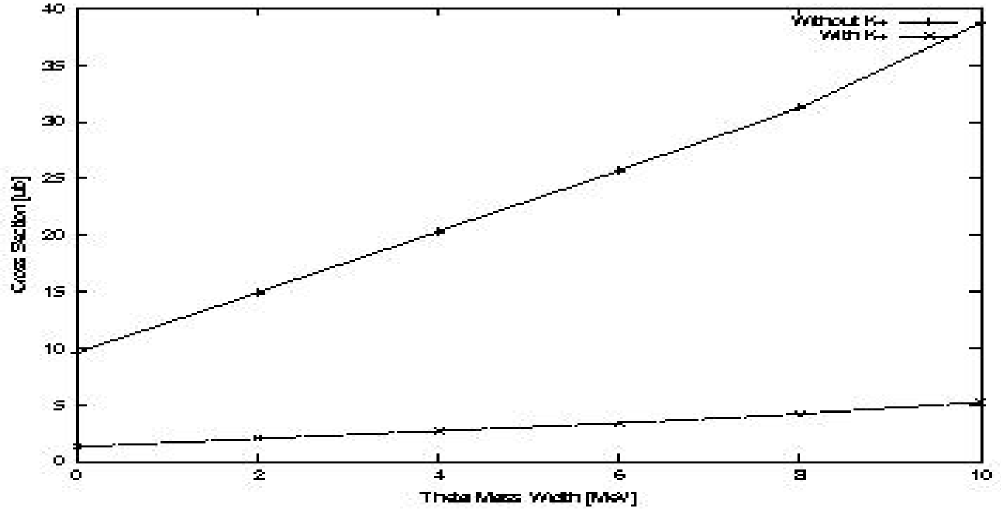
Missing Mass Spectrum
(without K+ detection)



Missing Mass Spectrum (with K+ detection)



Cross section to observe Θ+ as 5σ peak vs width



Without K+ detection

With K+ detection

To establish anti-decuplet

- Ξ^{--}

  n K^- -> K^+ Ξ^{--} , p K^- -> K^+ π^+ Ξ^{--}
- Ξ^+

  p K^- -> K^0 π^- Ξ^+

	S=-2	**S=0**
Diakonov	2070	1710 MeV
Jaffe, Wilczek	1750	1440 MeV

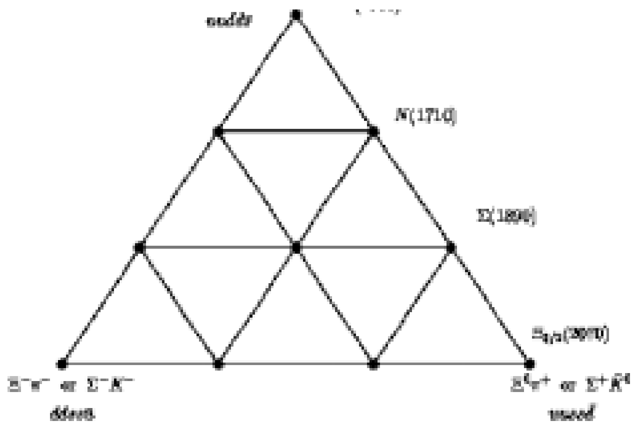


Figure 1: The suggested anti-decuplet of baryons. The corners of this (T_3, Y) diagram are exotic. We show their quark content together with their (octet baryon+octet meson) contents, as well as the predicted masses.

- If M(Ξ^{--}) ~ 1750 MeV
  (Jaffe & Wilczek, hep-ph/0307341)

->2GeV/c K- beam (BNL or KEK or (J-PARC)) !

S=-2 Penta-quark Ξ^{--}

M=1862 MeV Γ<18 MeV

NA49 collaboration

hep-ex/0310014

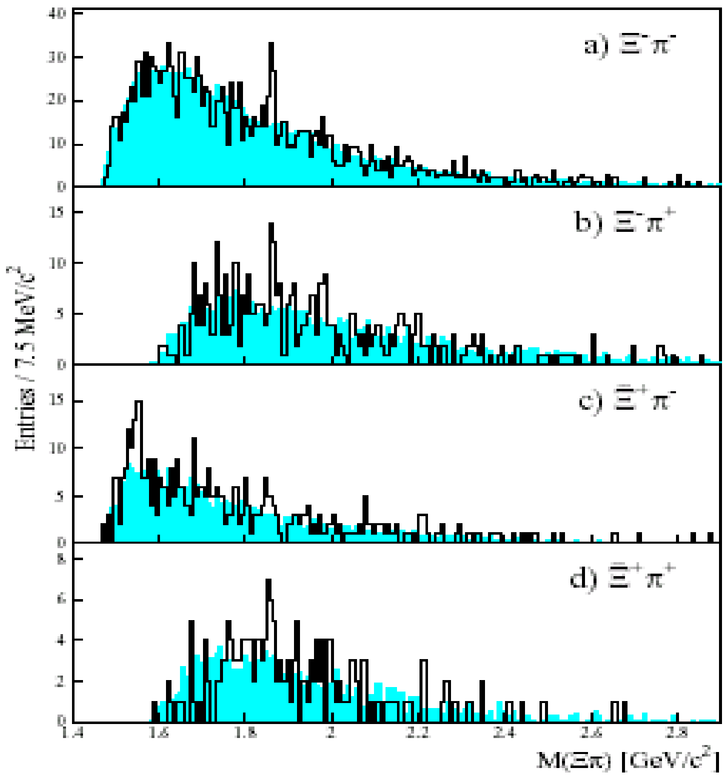


FIG. 2: (Color online) Invariant mass spectra after selection cuts for $\Xi^-\pi^-$ (a), $\Xi^-\pi^+$ (b), $\overline{\Xi}^+\pi^-$ (note that the $\overline{\Xi}(1530)^0$ state is also visible) (c), and $\overline{\Xi}^+\pi^+$ (d). The shaded histograms are the normalised mixed-event backgrounds.

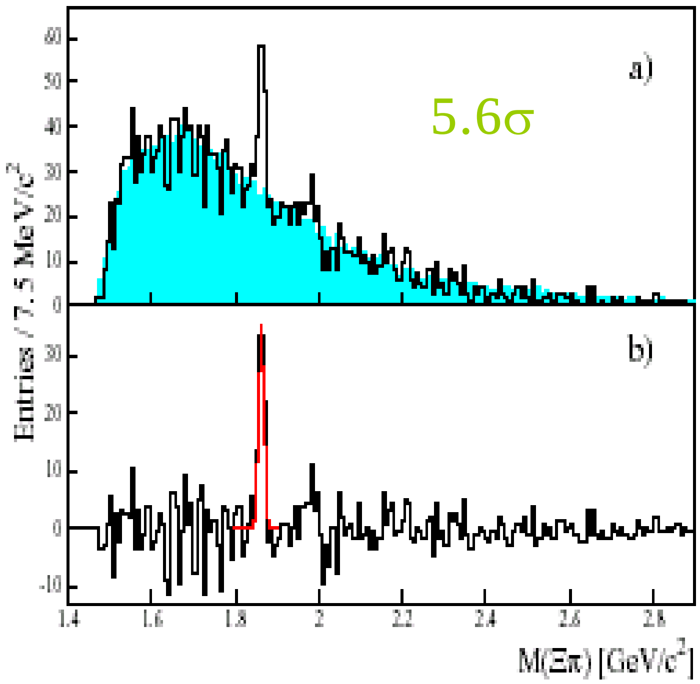
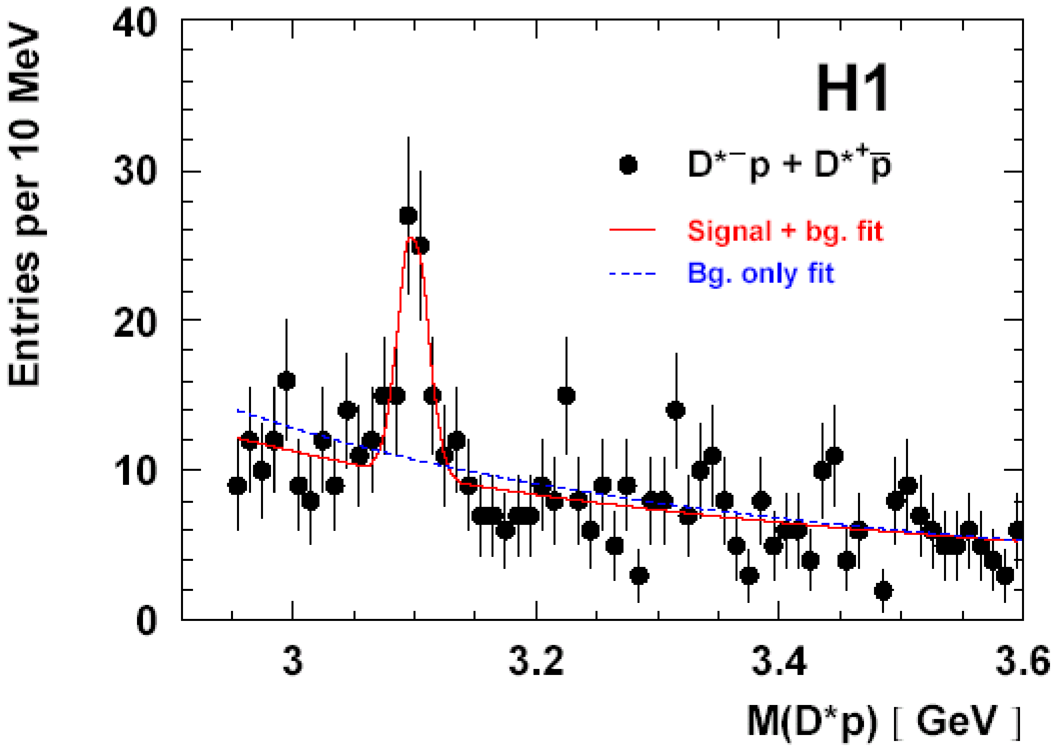


FIG. 3: (Color online) (a) The sum of the $\Xi^-\pi^-$, $\Xi^-\pi^+$, $\overline{\Xi}^+\pi^-$ and $\overline{\Xi}^+\pi^+$ invariant mass spectra. The shaded histogram shows the normalised mixed-event background. (b) Background subtracted spectrum with the Gaussian fit to the peak.

Charmed pentaquark **HERA-H1**



M=3099 MeV Γ=12 MeV

Pentaquarks at J-PARC

- Precision study of Θ^+ (Θ^+ Factory)

  π-p -> K-Θ^+, K^+p -> $\pi^+\Theta^+$, K^+n->K^+n

  2 GeV/c π- 1GeV/c K+ 0.5 GeV/c K+

  Ξ--, Ξ^+

  K-n -> $K^+\Xi$--

  K-p -> π-$K^0\Xi^+$ 2.5 GeV/c K- beam or high energy beam

- Charmed pentaquark

  ν+emulsion -> bound state ->K$\pi\pi$p

Summary

- We need Θ+ "factory" to determine its spin-parity and structure.

  -> Intense K+ and π- beam (K1.1&K1.8)

- We have to establish other members

  Ξ--, Ξ+ and others by K+(>2.5GeV/c) or

  high energy hadron beams

- Charmed pentaquark!

  ν beam for hadron physics