NP04

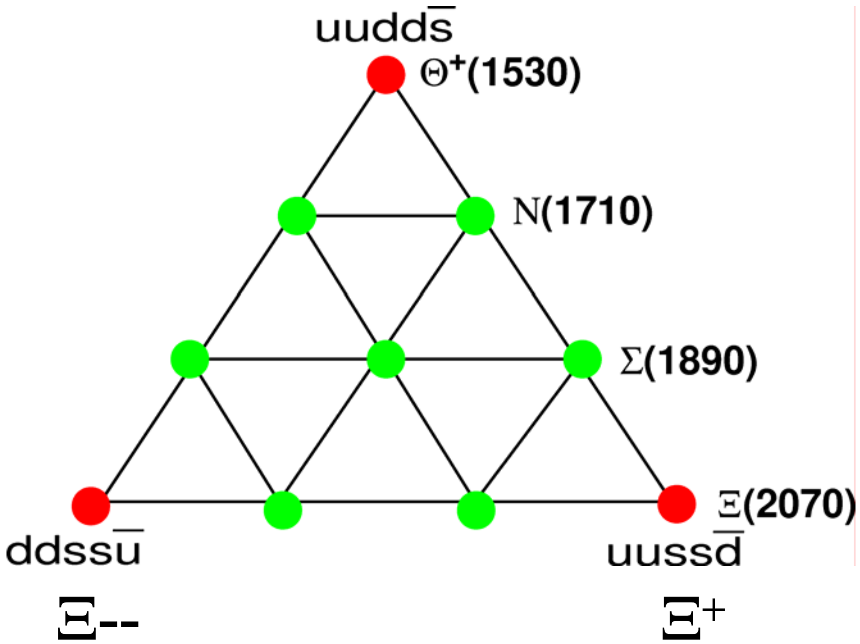
2004/8/3 (Tokai)

Penta-quark and perspective

K. Imai (Kyoto)

- Introduction
- Brief review of Penta04 at SPring8
- Width of Θ+
- E559 at KEK-PS
- Perspectives of exotics at JPARC
- Summary

$\Theta^+(Z^+)$ 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**
- **$J^p=1/2^+$**

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

M = [1890-180*Y] MeV

Discovery of Pentaquark Θ^+

SPring-8 LEPS

- **γ +n -> K$^-$ +K$^+$+n,**
  Θ^+ -> K$^+$ n

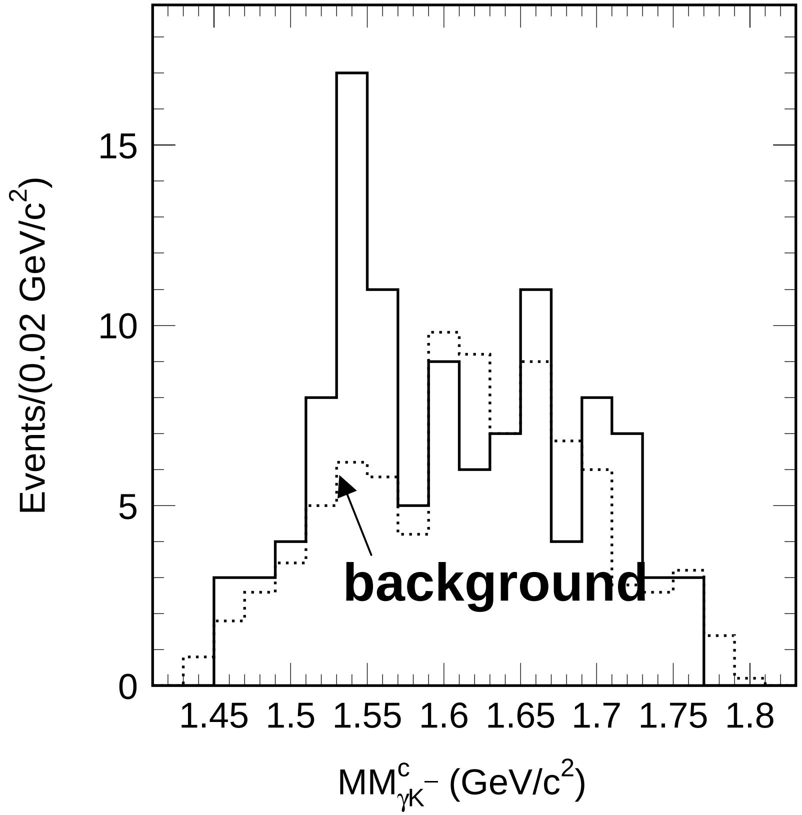
Θ^+: uudd s-bar

T. Nakano et al.,

Phys.Rev.Lett. 91 (2003) 012002

hep-ex/0301020

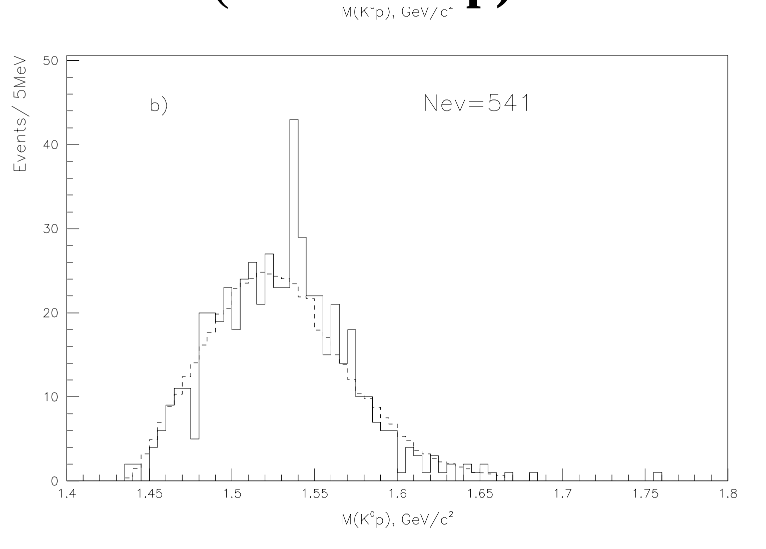
M = 1540±10 MeV
Γ < 25 MeV
Gaussian significance 4.6σ



Confirmation from US and Russia

DIANA/ITEP

K^+ Xe → K^0 p X
(K^+ n→ K^0 p)

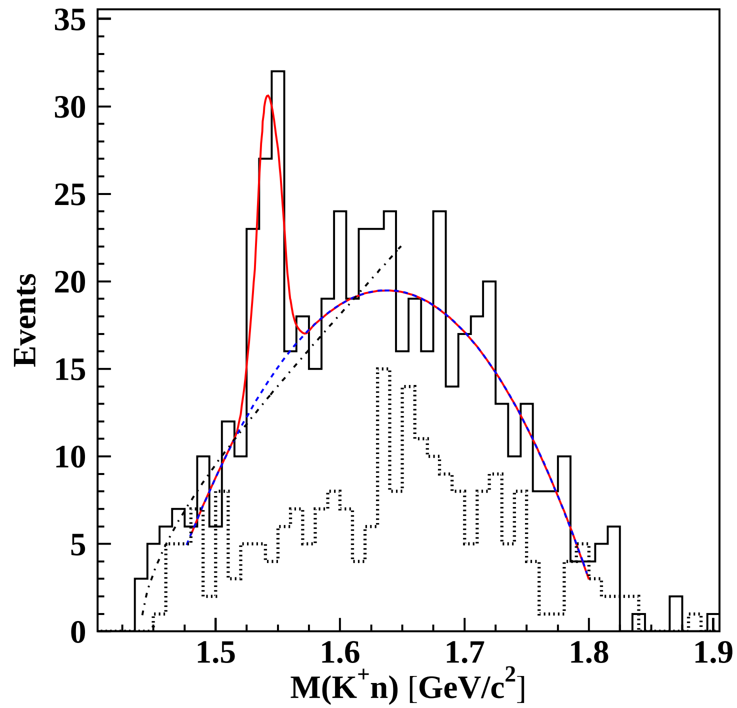


M = 1539±2 MeV
Γ < 9 MeV

hep-ex/0304040

CLAS/JLAB

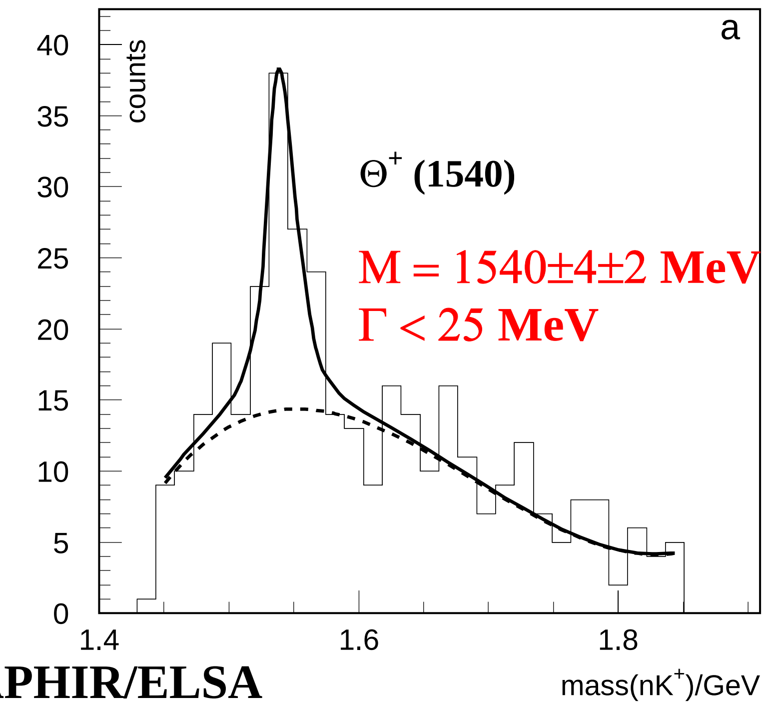
γ d → p K^+ K^- n

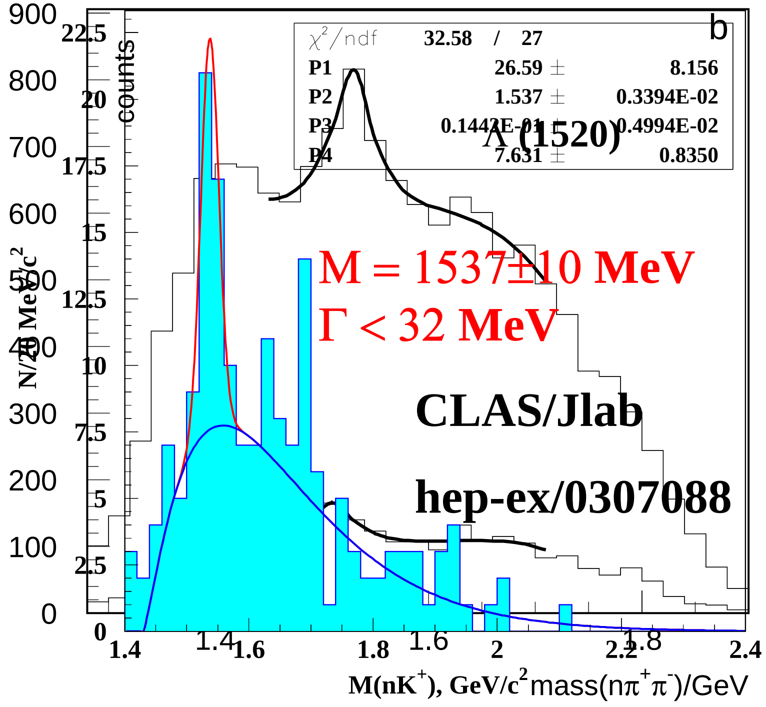


M = 1542±5 MeV
Γ < 21 MeV

hep-ex/0307018

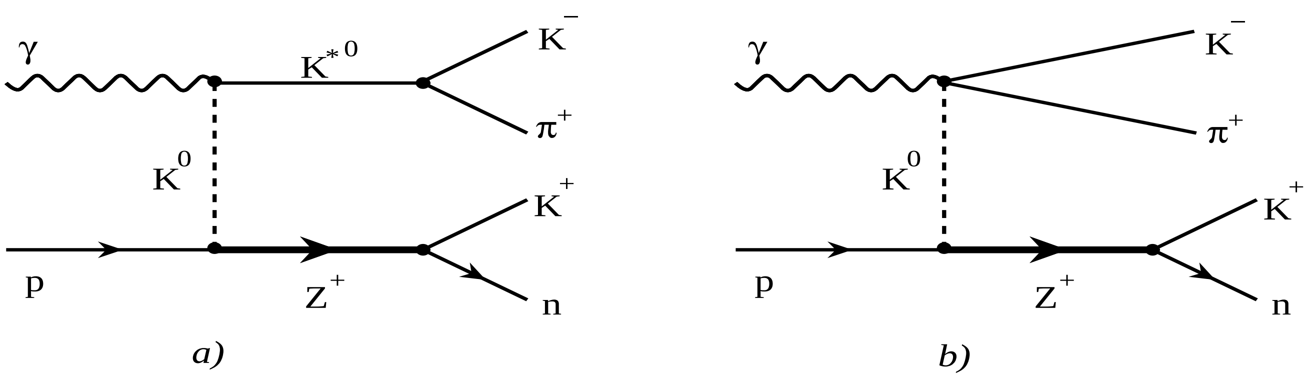
Further confirmation with proton target





SAPHIR/ELSA

hep-ex/0307083



Excitement

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

R.Jaffe (2003.8)

Renaissance of Hadron Spectroscopy ! (K.I)

S=-2 Penta-quark Ξ^{--}

M=1862 MeV Γ<18 MeV

NA49 collaboration

hep-ex/0310014

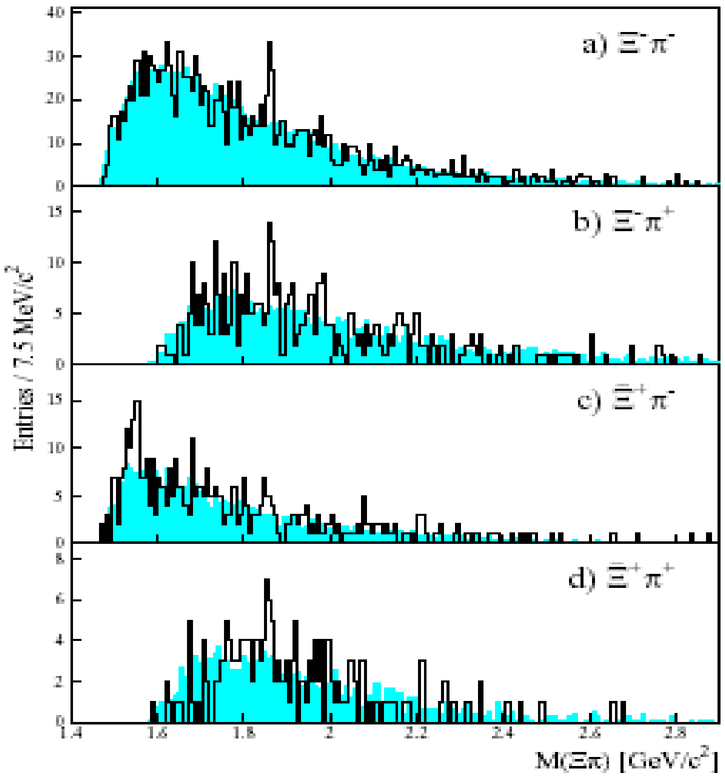


FIG. 2: (Color online) Invariant mass spectra after selection cuts for $\Xi^-\pi^-$ (a), $\Xi^-\pi^+$ (b), $\bar{\Xi}^+\pi^-$ (note that the $\bar{\Xi}(1530)^0$ state is also visible) (c), and $\bar{\Xi}^+\pi^+$ (d). The shaded histograms are the normalised mixed-event backgrounds.

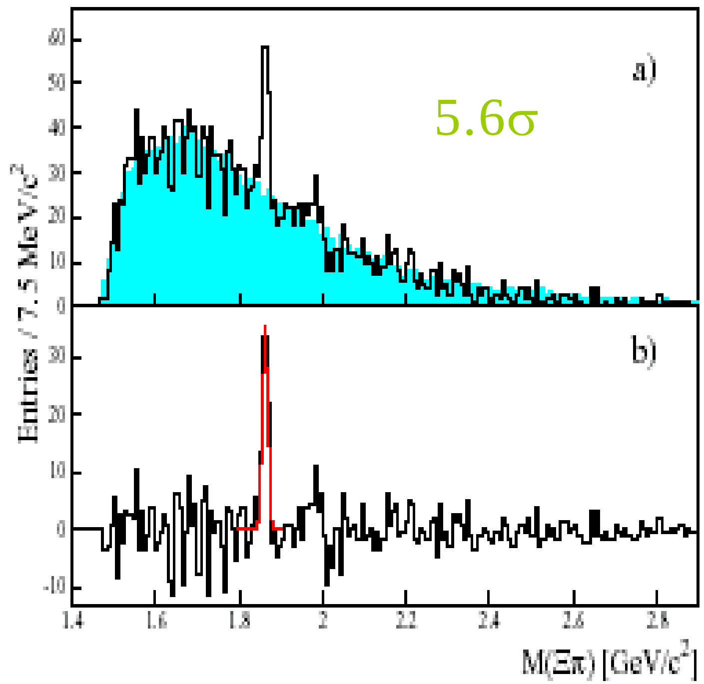
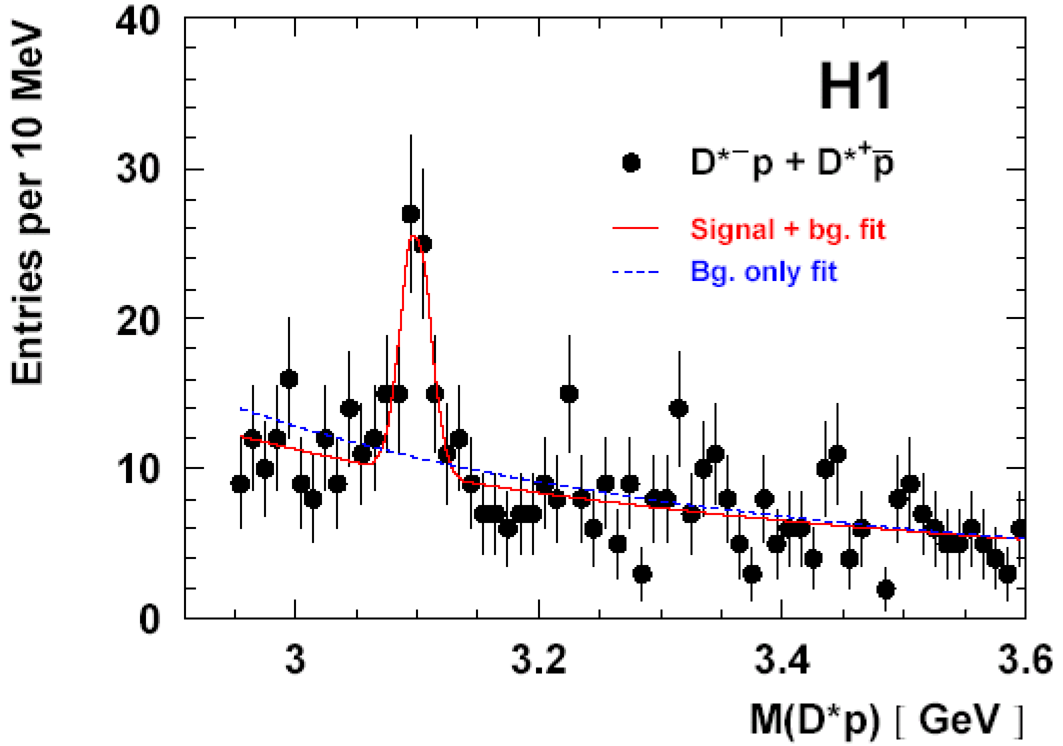


FIG. 3: (Color online) (a) The sum of the $\Xi^-\pi^-$, $\Xi^-\pi^+$, $\bar{\Xi}^+\pi^-$ and $\bar{\Xi}^+\pi^+$ invariant mass spectra. The shaded histogram shows the normalised mixed-event background. (b) Background subtracted spectrum with the Gaussian fit to the peak.

Charmed pentaquark **HERA-H1**



M=3099 MeV   Γ=12 MeV

Summary of positive results on Θ+

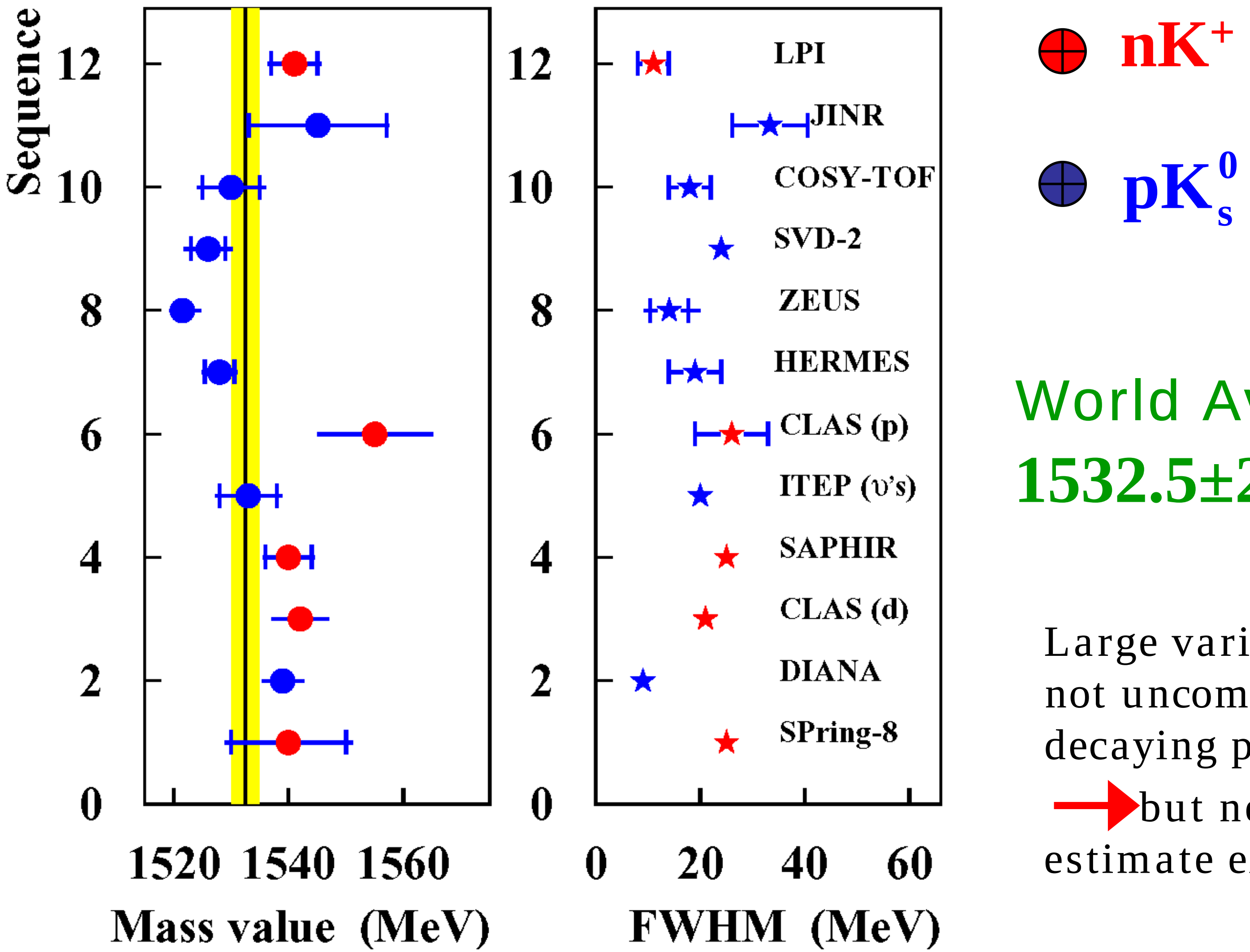
(Exotics04 04/02 Kyoto)

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

Penta04 at SPring8 (7/20-23)

- *Null results (mostly preliminary) from high energy experiments.*
- *The Θ peak was confirmed by new SPring8 data of D-target (preliminary).*
- *JLab high statistics experiments will provide results in the end of this year.*
- *Many interesting theory talks. (~20papers/month)*

Summary of Positive Results (W.Lorenzon)



World Average:

1532.5±2.4 MeV

Large variation in mass not uncommon for new, decaying particles

→ but need to better estimate exp. uncertainties

Summary of Null Results (W.Lorenzon)

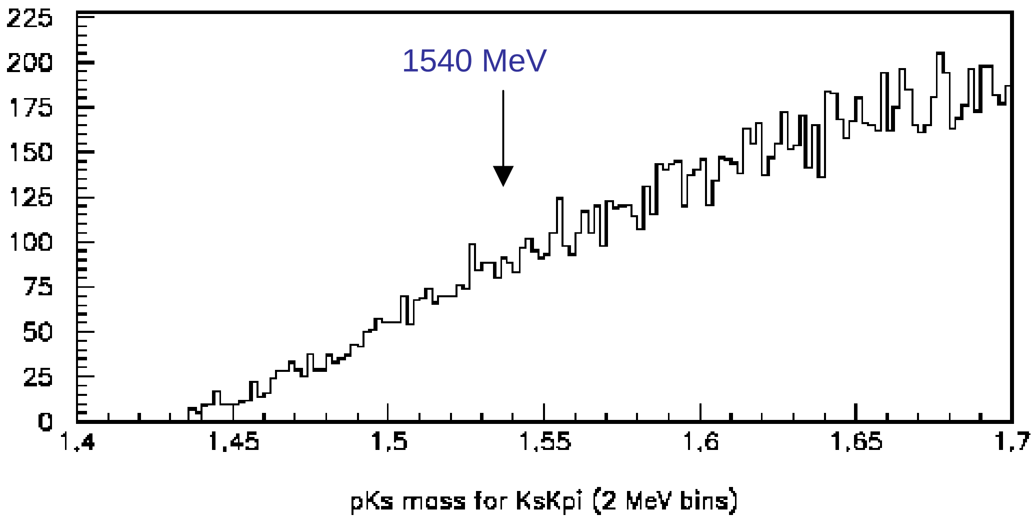
Experiment	$\Theta^+(1540)$ $(uudd\bar{s})$	$\Xi^{--}(1862)$ $(ddss\bar{s})$	$D^{*-}p(3100)$ $(uudd\bar{c})$	Reaction
HERA-B	NO	NO		$pA \to \Theta^+ X,\ \Xi^{--} X$
E690	NO	NO		$pp \to \Theta^+ X,\ \Xi^{--} X$
CDF	NO	NO	NO	$p\bar{p} \to \Theta^+ X,\ \Xi^{--} X,\ \Theta^c X$
HyperCP	NO			$\pi, K, p \to \Theta^+ X$
BaBar	NO	NO		$e^+e^- \to \Theta^+ X,\ \Xi^{--} X$
ZEUS	yes	NO	NO	$ep \to \Theta^+ X,\ \Xi^{--} X,\ \Theta^c X$
ALEPH	NO	NO	NO	$e^+e^- \to \Theta^+ X$
DELPHI	NO			$e^+e^- \to \Sigma^+ K^0 p$
PHENIX	NO			$AuAu \to \Theta^+ X$
FOCUS			NO	$\gamma A \to \Theta^c X$
BES	NO			$e^+e^- \to J/\Psi \to \Theta^+ \overline{\Theta^-}$

0 null results published, only 3 on arXiv so far (7-18-04)

⇒ need null results to be published

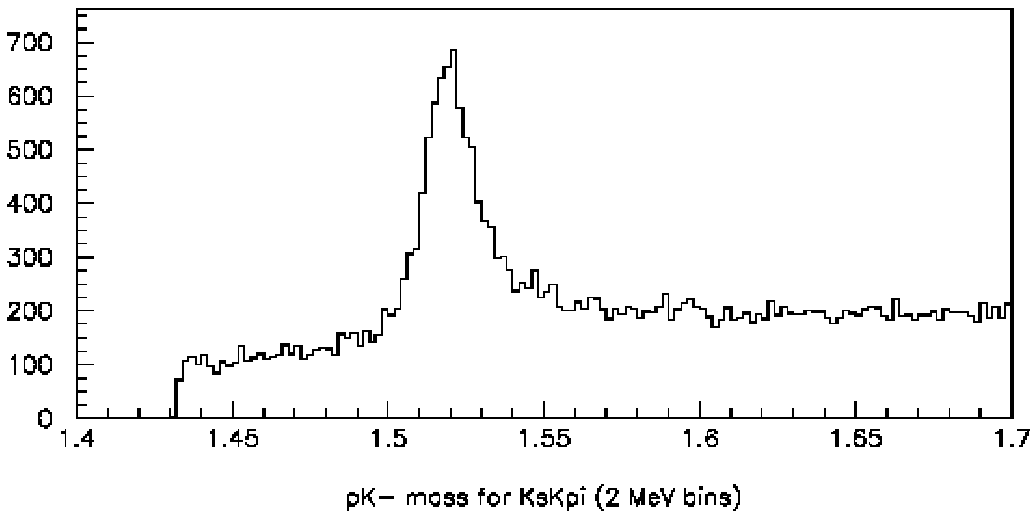
pK_s and pK^- (E960 Preliminary)

Monte Carlo pK_s mass resolution (σ) at 1540 MeV is 1.5 MeV.

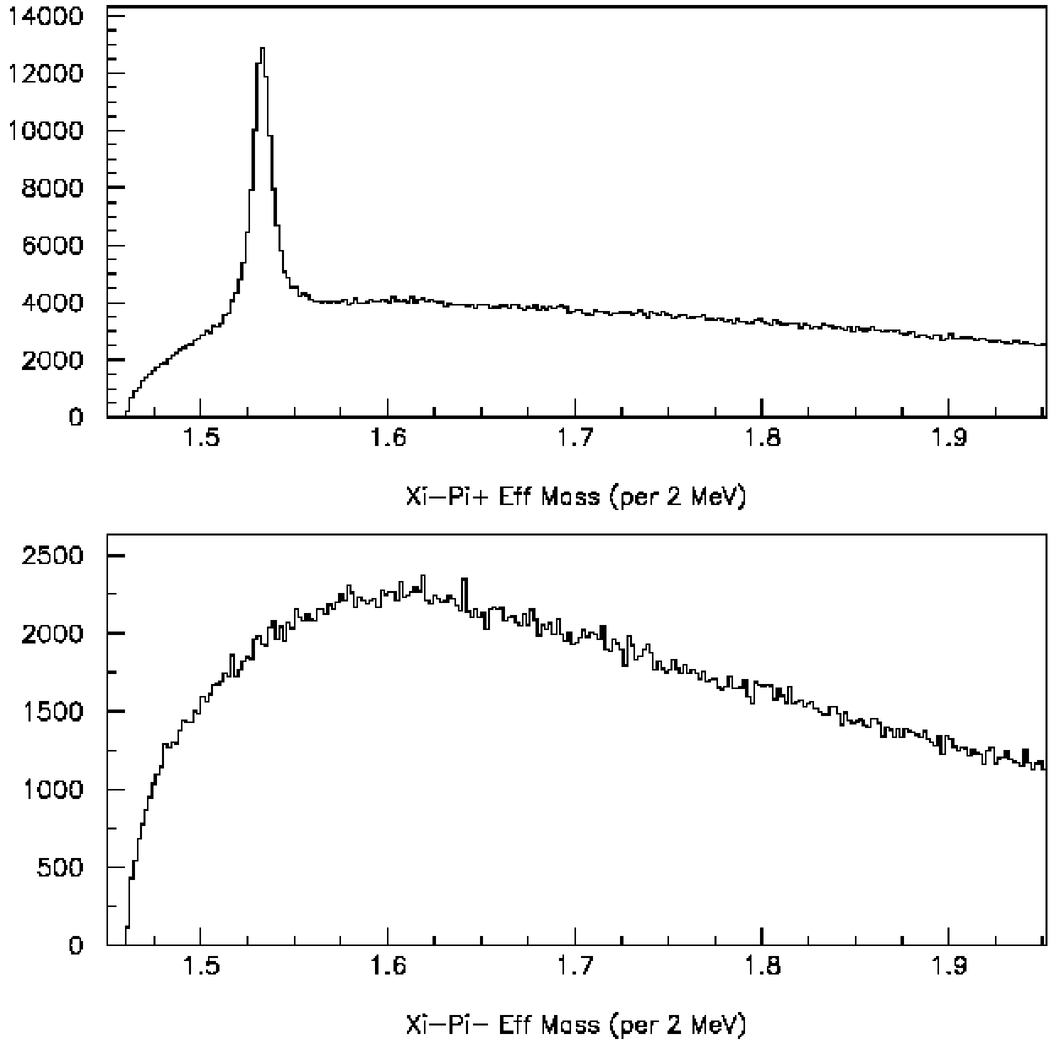


Yield of narrow (pK_s) at 1540 MeV is less than 25 events (95% CL).

~5000 Λ(1520) above background; FWHM ~ 14 MeV



$\Xi^{-}\pi^{+}$ and $\Xi^{-}\pi^{-}$ (E960 Preliminary)

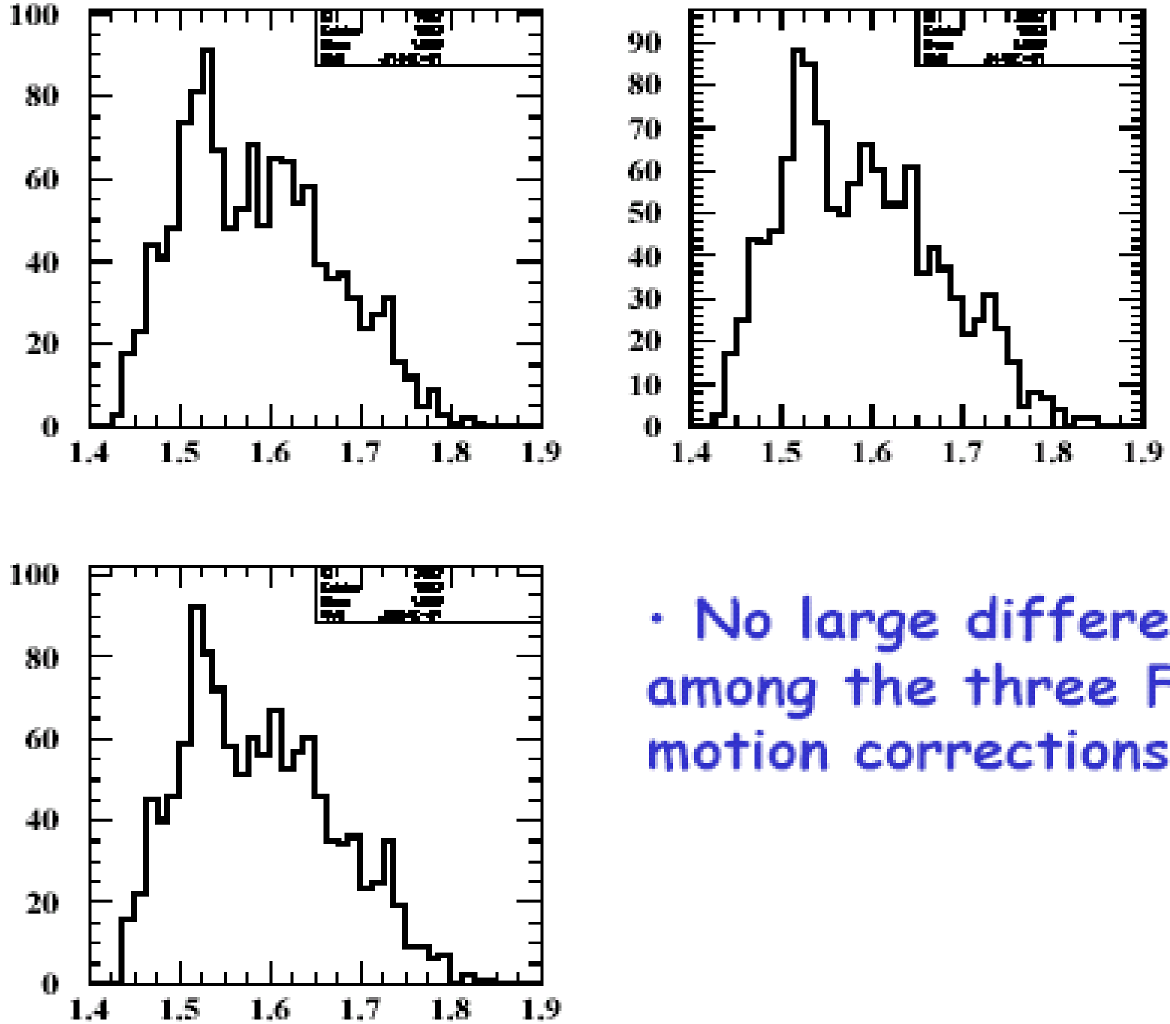


~70,000 Ξ(1530) above background;

FWHM ~ 14 MeV.

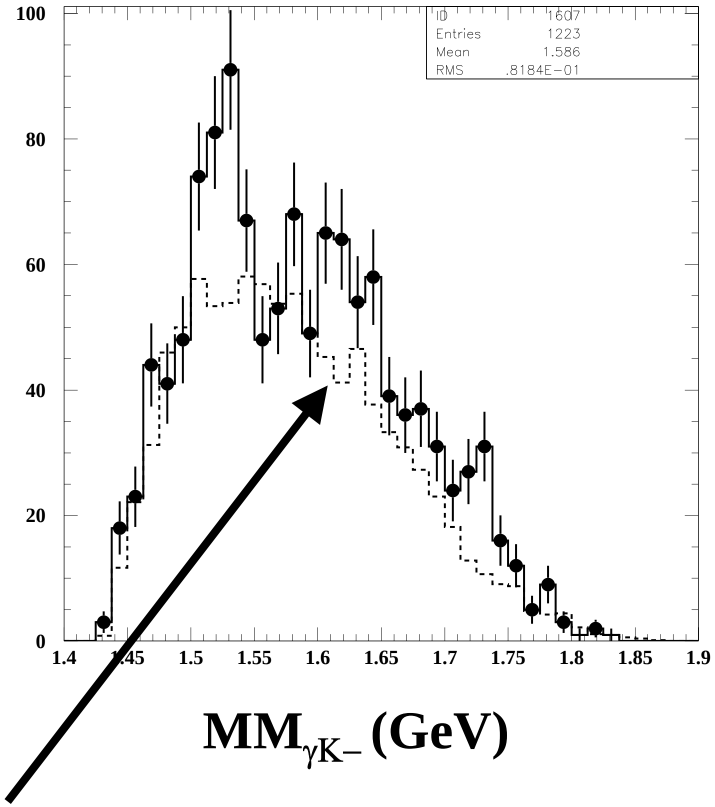
Yield of narrow ($\Xi\pi$) at 1862 MeV
is less than 200 events (95% CL).

Θ^+ (D_2 target) at SP8 (Preliminary)



- No large difference among the three Fermi motion corrections.

LEPS: Θ^+ spectrum (Preliminary)



Background estimate from LH_2 target mixed-event analysis.

The peak was not due to statistical fluctuation

- **The excess above the BG level is ~90 events.**
- **The peak position, width, significance strongly depends on the BG shape.**

Narrow width ?

- R.Cahn & G.Trilling hep-ph/0311245
- R.Arndt, Strakovsky, Workman, P.R C68 (03) 042201

$K{+}n \rightarrow K{+}n$, $K{+}n \rightarrow K^{o}p$

- Resonant cross section (Breit-Wigner formula)

  $\sigma(m)=B_iB_f\sigma_o\,(\Gamma^2/4)/\{(m-m_o)^2+\Gamma^2/4\}$

  $\sigma_o=4\pi(2J+1)/k^2(2s_1+1)(2s_2+1)=(68mb)$

  $\Theta^+ \rightarrow K^+n$, K^op (Br=1:1) J=1/2 m_o=1540MeV

  integral of $\sigma(m)$ gives total resonant cross section
- Width (Γ) < – > Cross Section (σ)

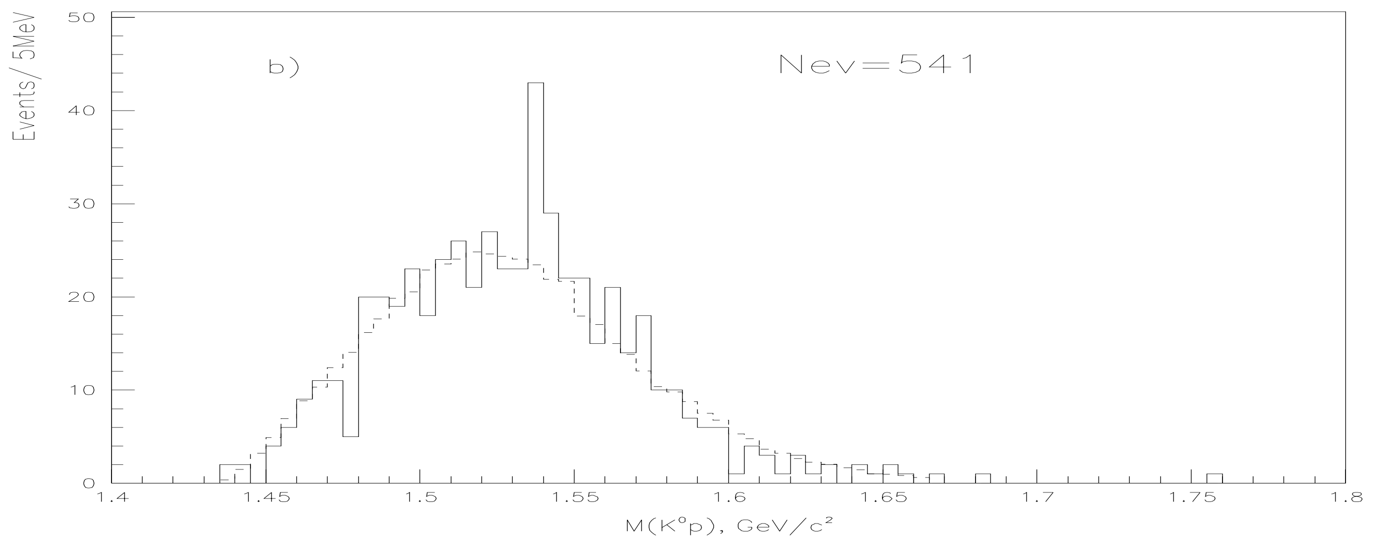
DIANA Experiment

- $K^+(n) \to K^o + p$ in Xenon Bubble Ch. (Fermi motion)
  Θ^+ resonance at P(K+)=440MeV/c

- assume all background reaction is charge exchange
  $K^+ d \to K^o pp$ 4.1+0.3 mb (from old BC data)
- From DIANA data (resonance/charge exchange),
  -> resonant cross section = 24 mb MeV
  -> Γ= 0.9+-0.3 MeV
  (rescattering in nuclei is neglected)
-

DIANA Data

$K^+ Xe \rightarrow K^0 p X \quad (K^+ n \rightarrow K^0 p)$



hep-ex/0304040

M = 1539±2 MeV
Γ < 9 MeV

Old data (K+d CEX)

- P(K+) = 376 MeV/c σ(cex) = 3.1+-0.4 mb
- 434 4.0+-0.15
- 530 6.5+-0.6

- Fermi smeared cross section near resonance deduced from neutron momentum distribution in deuteron

  $\sigma(\sim m(\Theta))$= 3.6mb/MeV $B_i B_f \Gamma$

  -> 1mb possible excess -> 1.1 MeV for width

Old data (K+d σ(tot))

- P(K+)=366MeV/c σ(tot)=21.41+-0.30mb
- 440 23.46+-0.24
- 506 24.16+-0.23

- Linear interpolation -> excess of 0.60+-0.30mb at 440MeV/c

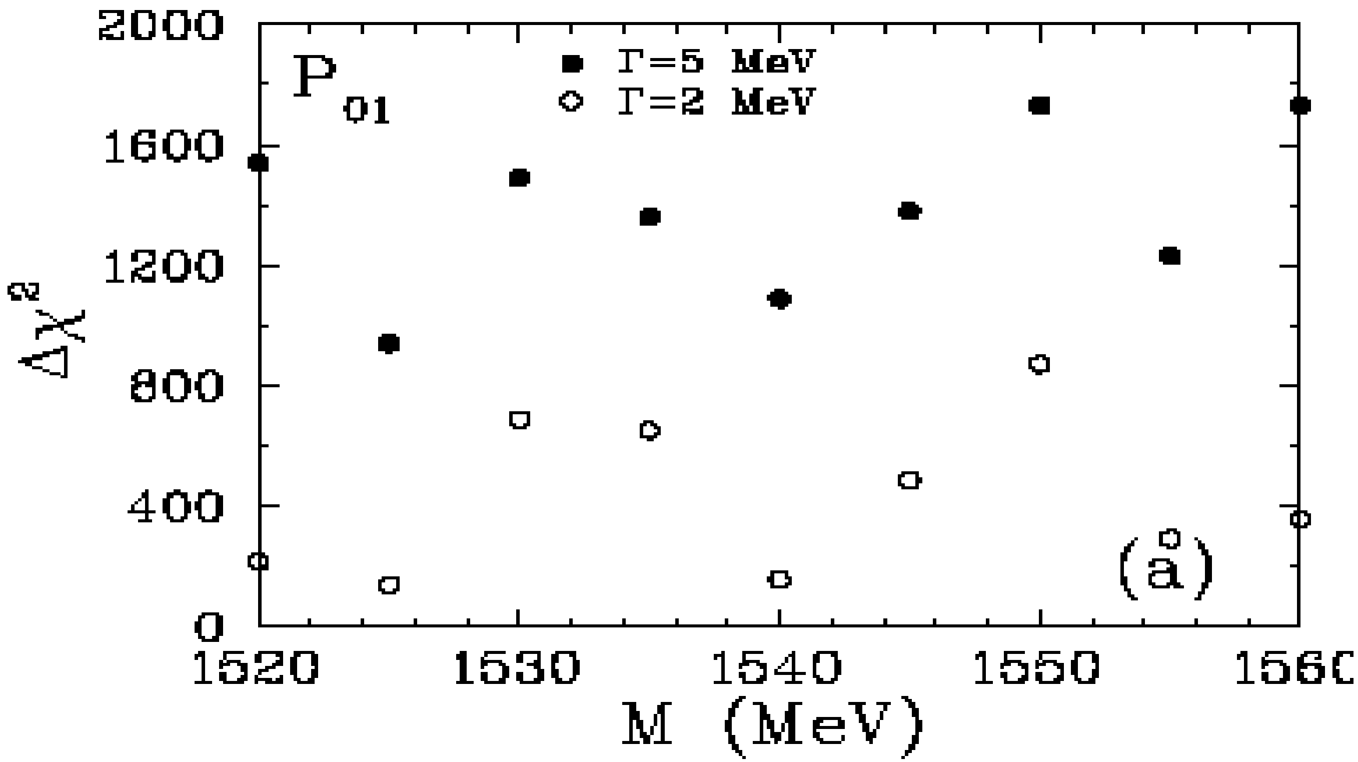
  -> Γ=0.8MeV (Cahn & Trilling)

- More conservative limit -> 6 MeV

  (Nussinov hep-ph/0307357)

Increase of chi-square in K+N Phase shift analysis (for P01) (Arndt et al,)

→ should be less than 1MeV



Comparison with Λ(1520)

Λ(1520) mass is almost same as Θ+ (1540)

- Γ=15.6 MeV
- Br(K-p)=0.45 Br(Σπ)=0.45 Br(Λππ)=0.1
- In old BC data Λ(1520) was clearly observed via

  π-p -> K^o K-p

  while π-p -> K- Θ+ (K+n, K^op) was not observed.

  (Next talk by K.Miwa)
- With γ beam (SP-8)

  γd-> K-K+pn yield of Λ(1520)>>Θ(1540)

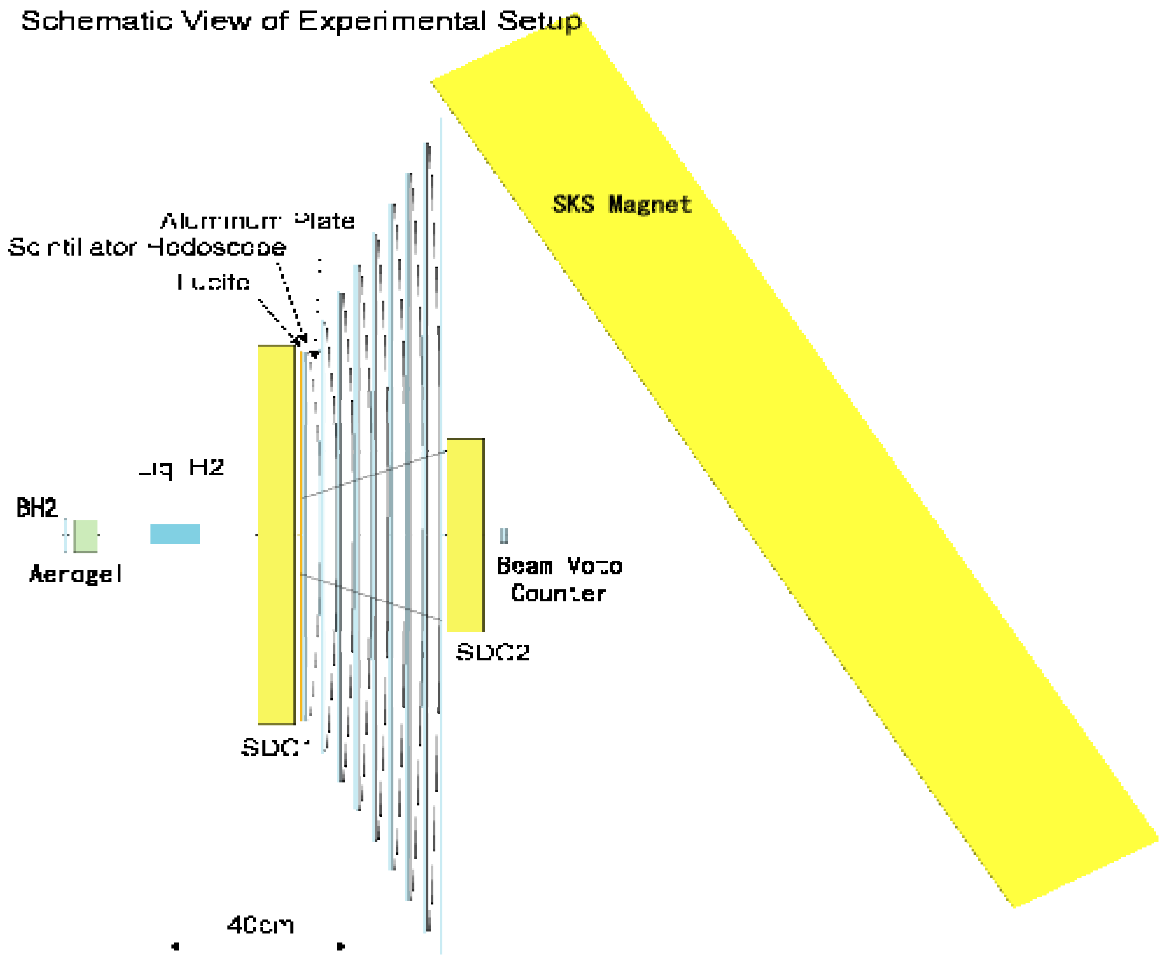
- -> Width of Θ+ is ~ 1/10 of that of Λ(1520)

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

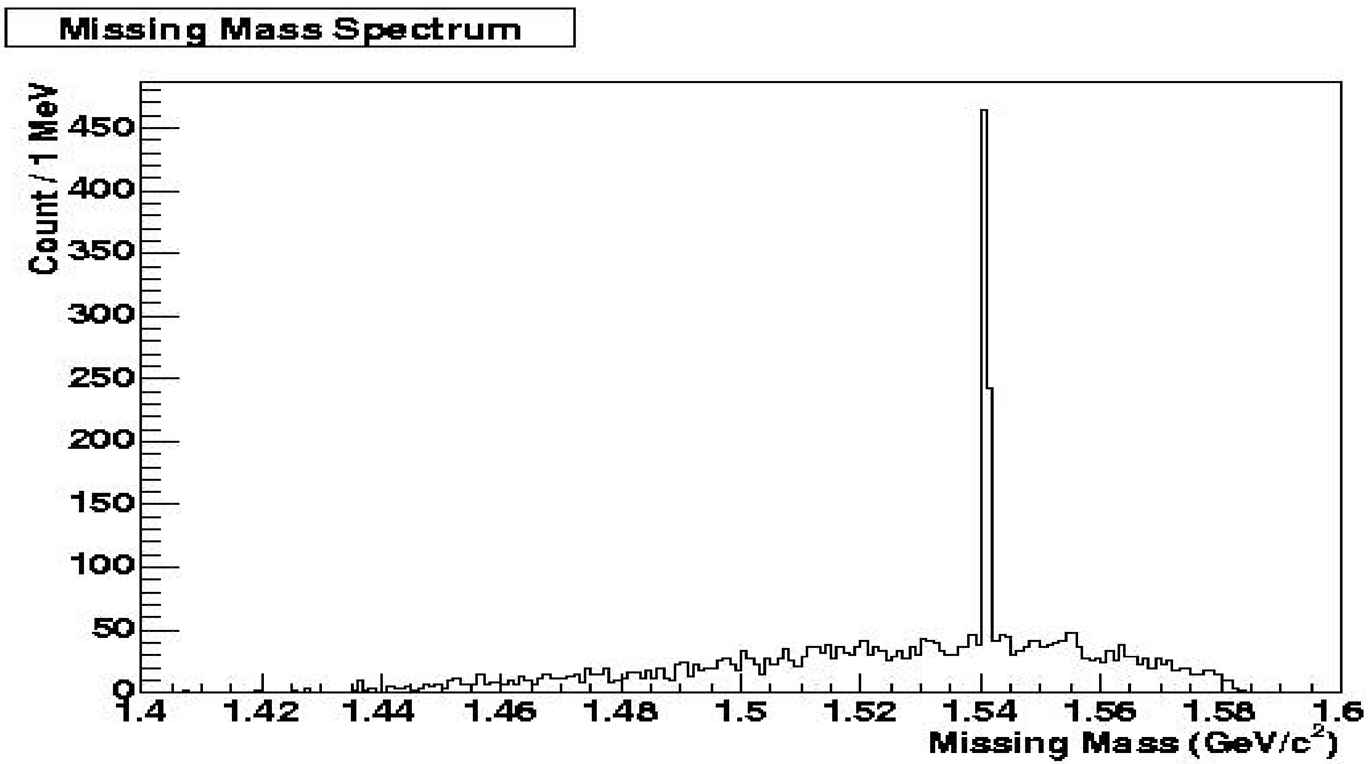
- **K.Imai, K.Miwa, M.Hayata, M.Miyabe, N.Muramatsu, M.Niiyama, N.Saito, M.Wagner, M.Yosoi (Kyoto U.)**
- **T.Nagae, M.Ieiri, S.Ishimoto, N.Noumi, Y.Sato, S.Sawada, M.Sekimoto, H.Takahashi, T.Takahashi, A.Toyoda (KEK)**
- **H.Fujioka, T.Maruta (U. Tokyo)**
- **T.Fukuda, P.K.Saha (Osaka ECU)**
- **K.Ajimura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

- K+ p -> π+ Θ+ reaction with SKS spectrometer at KEK K6 beam line
- excellent mass resolution ΔE=1.3 MeV
- Decay angular distribution for spin determination

Experimental setup around target and Range counter (for K+ detection)



Expected Missing Mass Spectrum (with K+ detection)



Perspective at JPARC

- Θ+ width, spin-parity,

  (determined before JPARC ?)

- Θ+ nuclei (Hyponuclei)

  (K+,π+) spectroscopy at P_{K+}~1GeV/c

- Other penta-quarks

  Anti-decuplet N*, Σ*, Ξ*(Ξ--,Ξ+)

  Charmed pentaquark

Spin-Parity of Θ^+

Spin-parity: J^π= $\frac{1}{2}^+$ 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+

-> JLab high statistics data

-> SPring-8 TPC project

K+p -> π+Θ+, Θ^+ ->K+n (E559)

pp -> Σ+Θ+ (COSY) Hosaka

Beam line requirements for pentaquark

pentaquark Θ

K+ beam ~500 MeV/c for $K^+n \to K^+n$, K^0p

K+ beam ~1 GeV/c for Θ^+-nuclear physics

- other anti-decuplet pentaquark

K- and π beams up to 2.5 GeV/c (for Ξ--?)

- charmed pentaquark Lipkin

5 GeV(on-axis) neutrino-beam for bound Θ_c

Summary

- *Pentaquark, which was not known at NP02 and LOI submission period, is now a very hot topic in hadron physics and QCD.*
- *We have to prepare for this physics at JPARC, although we can not predict how things develop untill 2008.*
- *Low momentum (0.5~1.0 GeV/c) K+ beam of high resolution will be useful for Θ+ and Θ-nuclear physics.*
- *JPARC can be a major playground for the exotic hadron spectroscopy.*

- *Neutrino beam may be useful for charmed pentaquark search and also other hadron physics.*

COSY-ToF pp -> $\Sigma^+ K^o p$

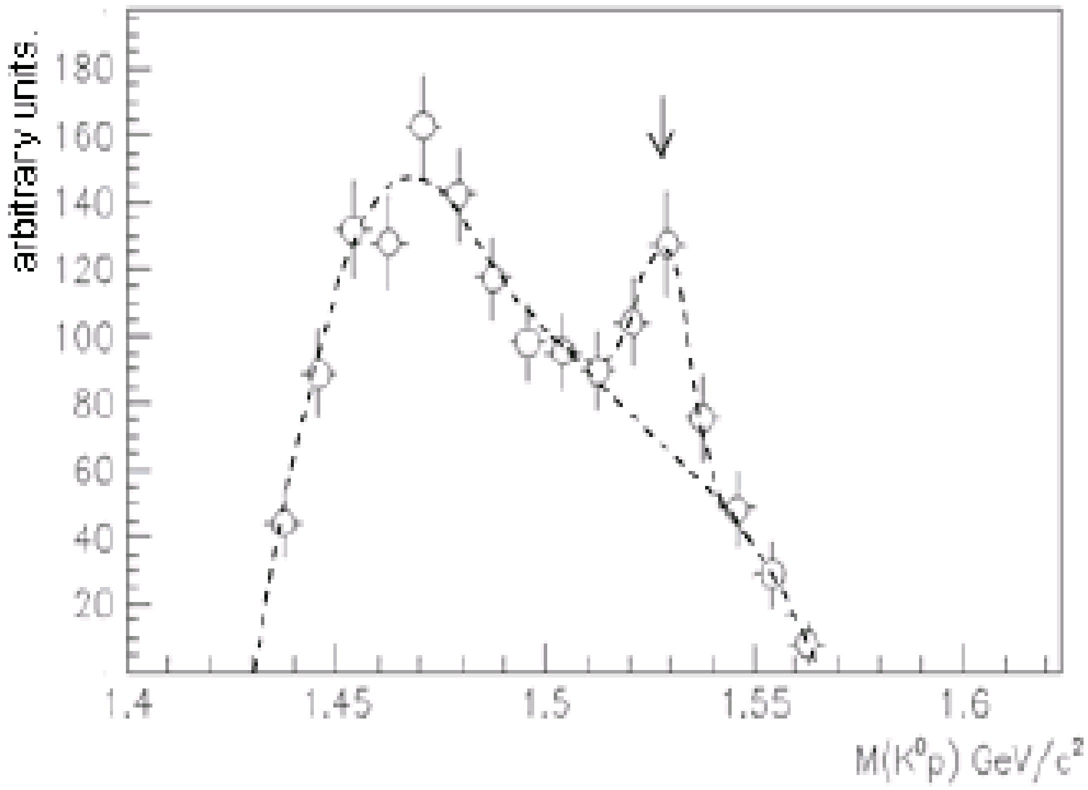


Figure 7: Efficiency corrected invariant mass spectrum of the K^0p subsystem obtained from the full sample.