Discovery of the Pentaquark: Experimental Status

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Pentaquark Forum
DESY
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- Introduction
- Experimental results (chronologically):
  - SPRING-8
  - DIANA
  - CLAS
  - SAPHIR
  - ITEP-2
  - Search for $\Theta^+ \rightarrow pK_s$ at HERMES
  - ... continued
- New weird Ξ^{--} from NA49
- Summary and Outlook

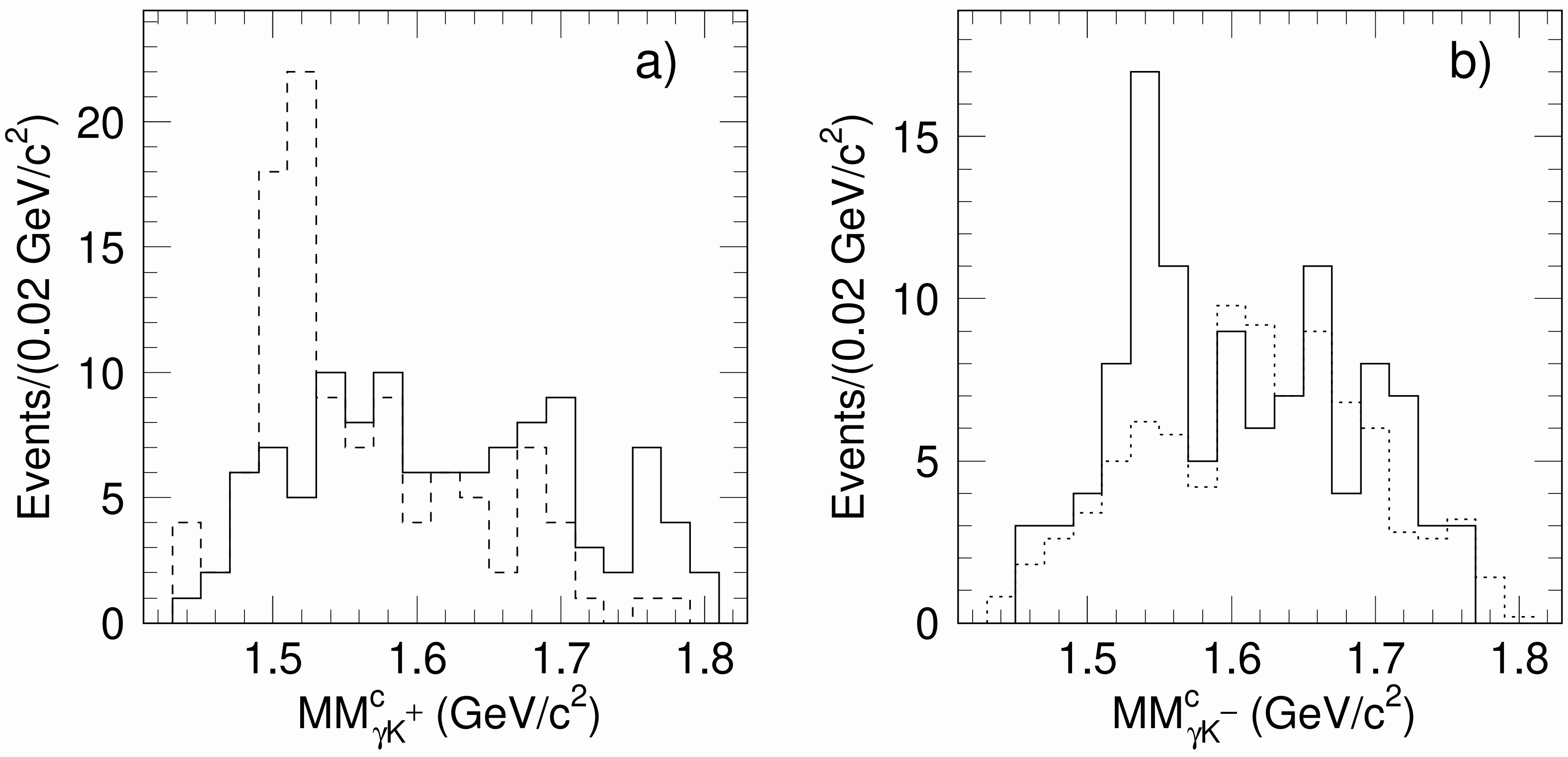
Historical Lesson on S = +1 Baryon System

- PDG 1986; Phys. Lett. B170, 289 wrote:
  The evidence for strangeness +1 baryon resonance 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 P_{13} and perhaps other waves resonate.
- and then continued:
  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.

Experimental Evidence from LEPS at SPRING-8

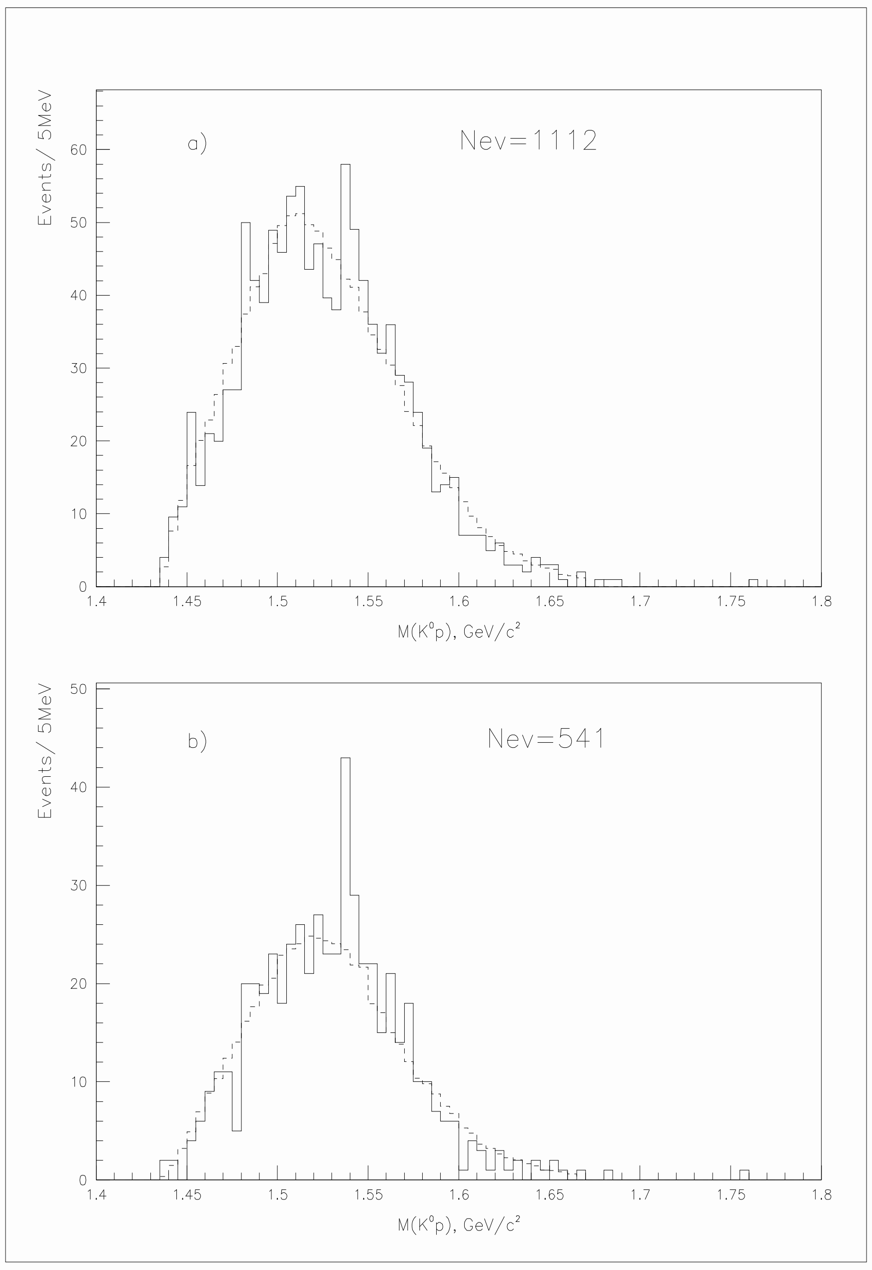
- LEPS Collaboration at SPRING-8:
  (T.Nakano et al.,PRL 91,012002(2003))
- Tagged photons → energy range (1.5– 2.4) GeV, (σ = 15 MeV) :
  (Compton back-scattering from 8 GeV electrons)
- Targets:
  0.5 cm thick plastic scintillator(SC) (C:H $\simeq 1:1)$
  5 cm thick liquid-hydrogen (LH_2) 9.5 cm upstream of (SC) target
- Particle Identification: Time-of-Flight
- Search for resonance $\Theta^+ \rightarrow K^+$n in exclusive reaction:
  $\gamma n(^{12}C) \rightarrow K^+K^-n$

The Θ^+ resonance from LEPS



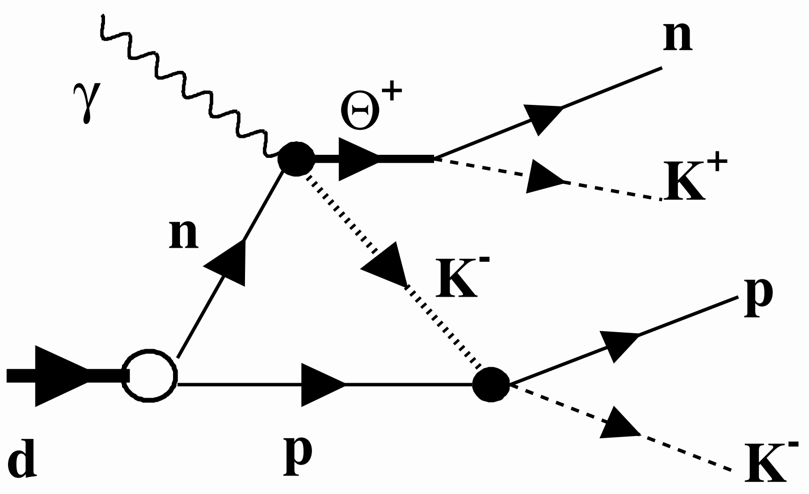
- a) solid histogram: K^-n missing mass (no res. expected)
  dashed histogram: K^-p missing mass ($\Lambda(1520)$ expected)
- b) solid histogram: K^+n missing mass (Θ^+ expected ?)
  dashed histogram: LH_2 spectrum of K^+p (no res. expected)
- Conclusion: M=1540 $\pm$ 10 MeV, Γ <25 MeV, $\sigma = \frac{N_s}{\sqrt{N_b}}$ = 4.6 ± 1.

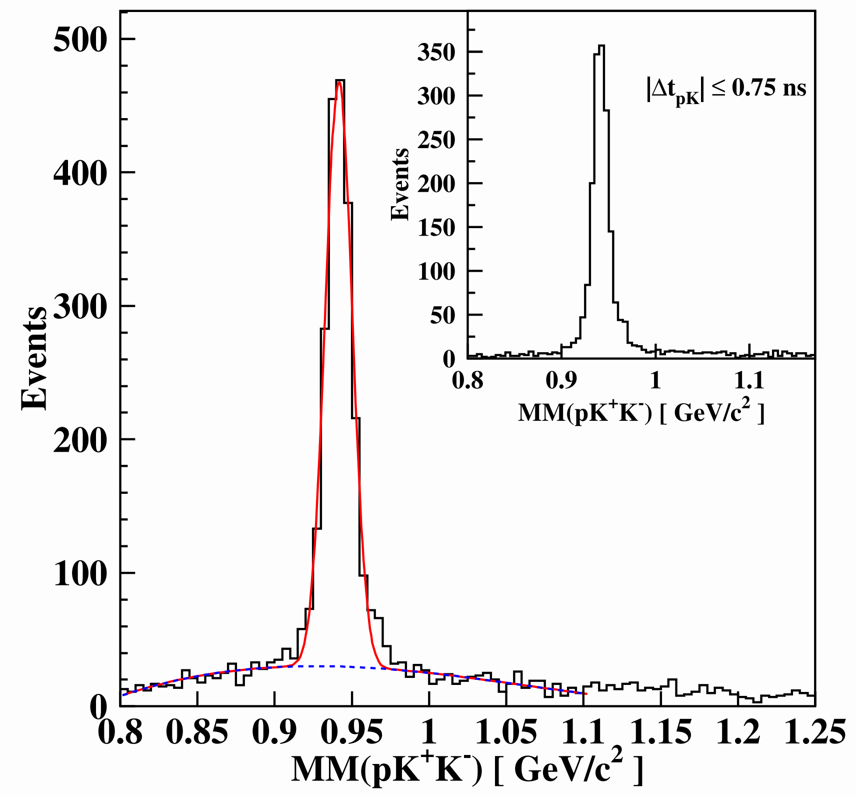
Experimental Evidence from DIANA at ITEP



- DIANA collaboration at ITEP: Xenon bubble chamber
- $K^+Xe \rightarrow K^0_s pX$ ($P_{k+} \sim 480MeV$) (Quasi-free $K^+n \rightarrow K^0p$)
- PID via ionization and momenta from ranges (no magnet)
- a) solid histgram: K^0p invariant mass without cuts
  dashed histogram: background due to charge-exchange $K^+Xe \rightarrow K^0Xe$
- b) solid histogram: K^0p spectrum with cuts imposed:K^0 and p going forward and back-to-back
  Conclusion: (hep-ex/0303040)
  M = 1539±2 MeV, $\Gamma \leq 9$ MeV, σ=4.4

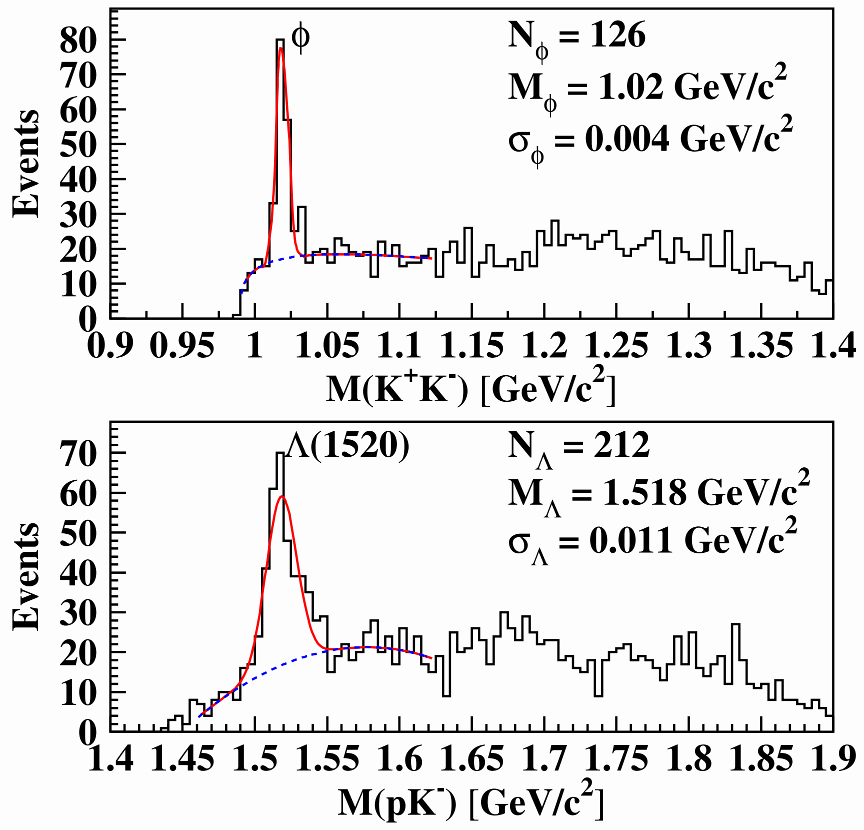
Experimental Evidence from CLAS at JLAB



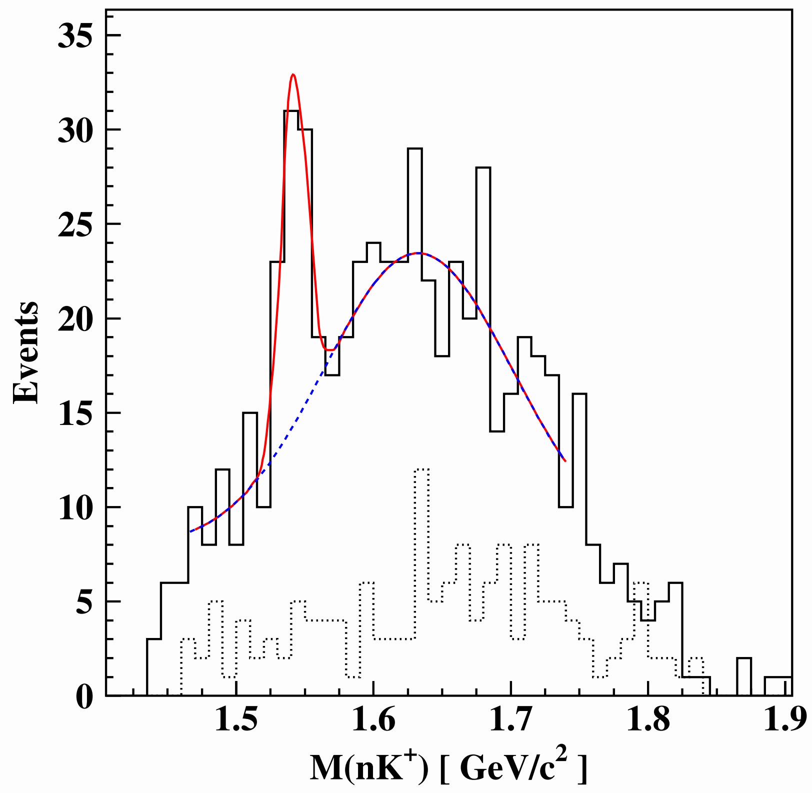


- exclusive $\gamma d \rightarrow pK^+K^-n$
  CLAS Collaboration (S.Stepanyan et al., hep-ex/0307018)
- Tagged photon beam from E_e = (2.5–3.1) GeV, with ΔE_γ = (3–5) MeV
- Particle Identification with TOF

The Θ^+ resonance from CLAS



- Production of ϕ and $\Lambda(1520)$ in the reaction $\gamma d \rightarrow pK^+K^-n$
  They are removed in the analysis.

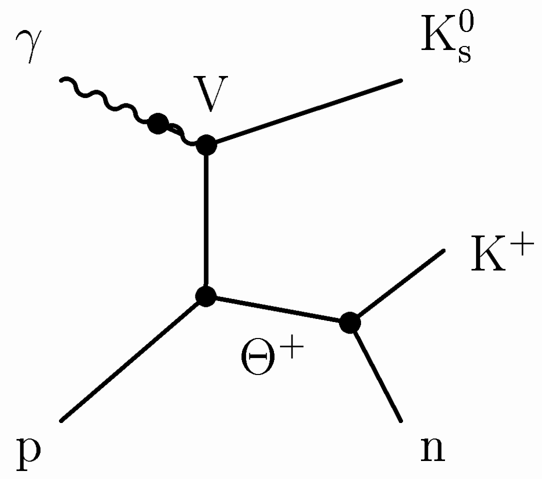


- solid histogram: final M(nK^+)
  solid line: arbitrary fit + bkgd
  dashed histogram: $\Lambda(1520)$ events

- Conclusion: M=1542±5 MeV, FWHM=21 Mev, σ=5.3±0.5

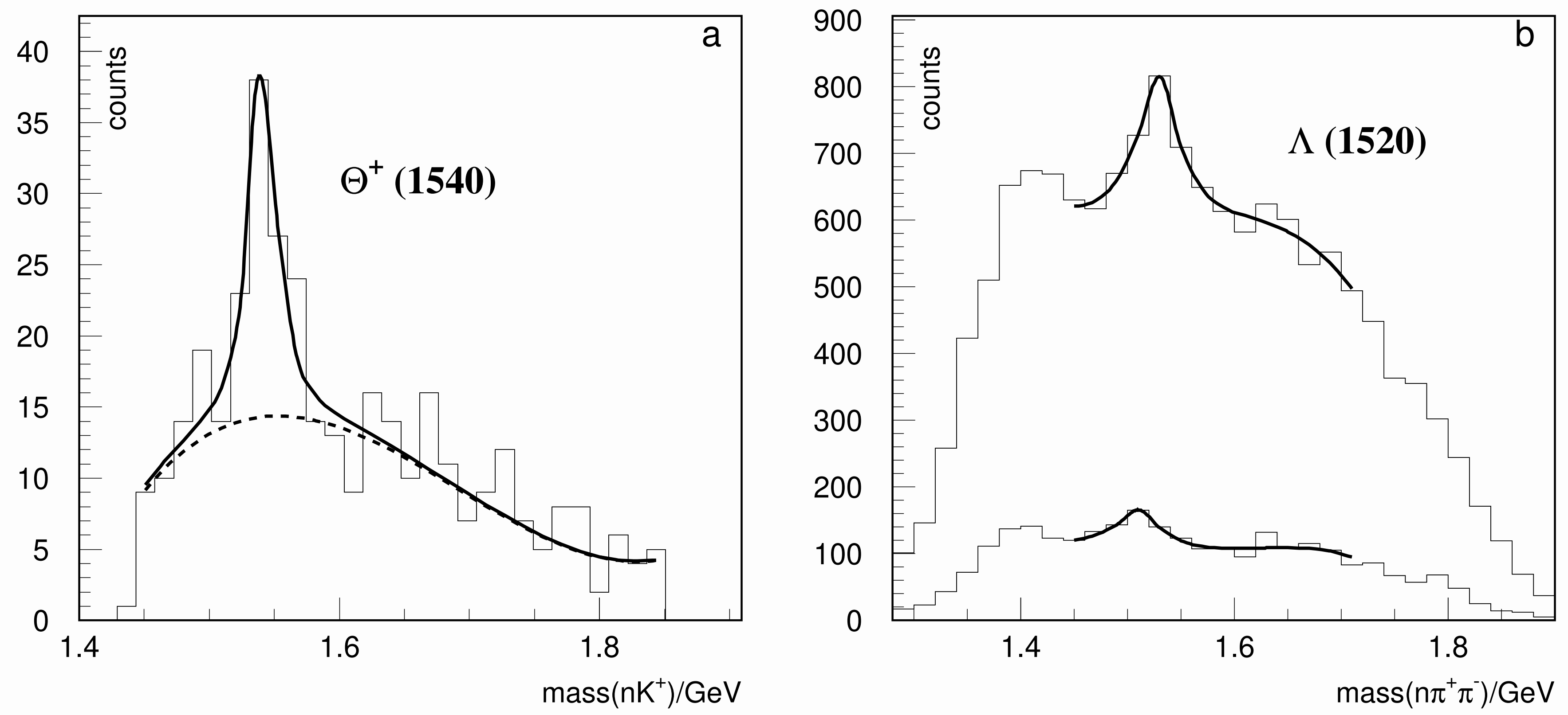
Experimental Evidence from SAPHIR at ELSA

- SAPHIR detector at ELSA : 1.–2.7 GeV tagged photon beam
- π^+, π^-, K^+ identified with TOF
- Exclusive $\gamma p \to \bar{K}^0\Theta^+ \to \bar{K}^0 K^+ n \to \pi^+\pi^- K^+ n$



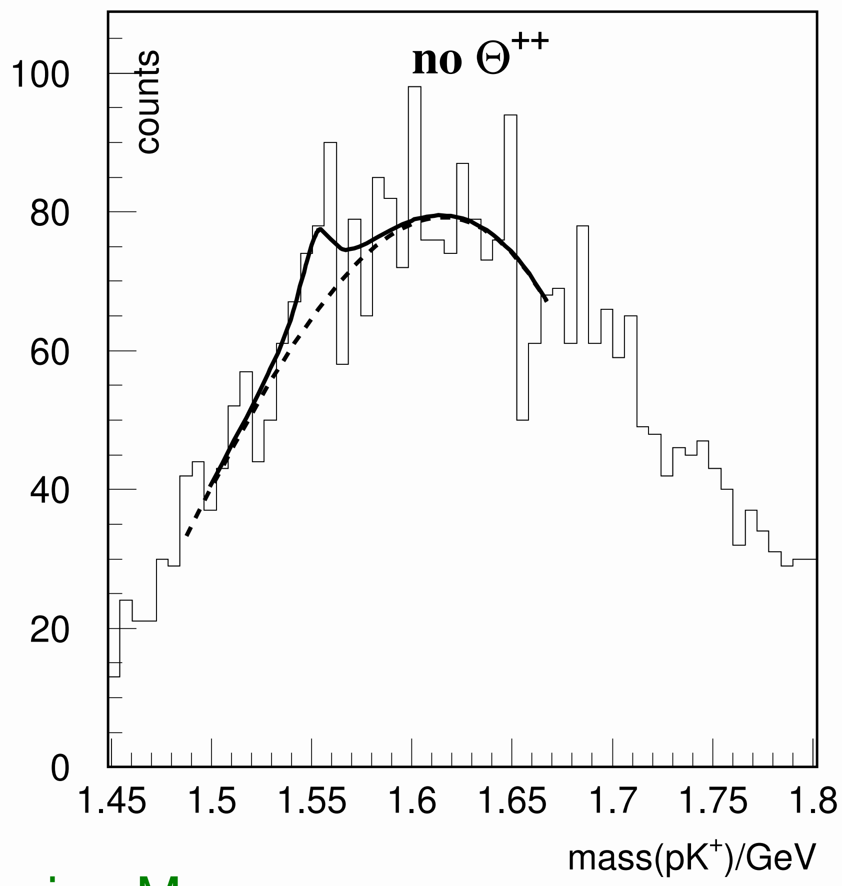
- detect $\bar{K}^0 K^+ \to$ reconstruct $K^+ n$ Missing Mass (hep-ex/0307083)

The Θ^+ resonance from SAPHIR



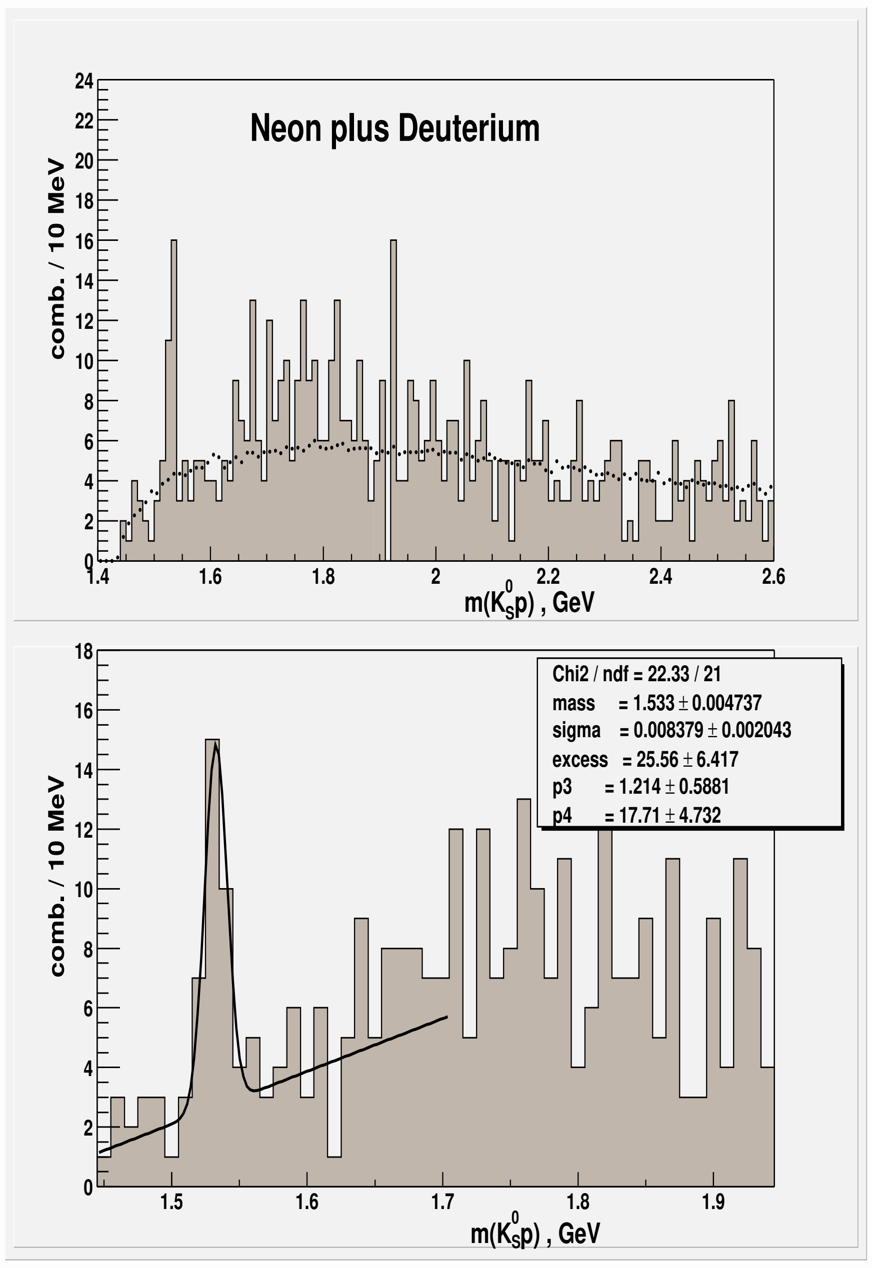
- a) K^+n Missing Mass with the cut $\Theta^{cm}_{K_s} > 0.5$
- b) $\pi^+\pi^-n$ Missing Mass with (lower histogram) without (upper histogram) $\Theta^{cm}_{K_s} > 0.5$ cut
- Conclusion: M=1540$\pm 4 \pm 2$MeV, $\Gamma < 25$MeV, σ=4.8

The Θ^+ Isospin from SAPHIR



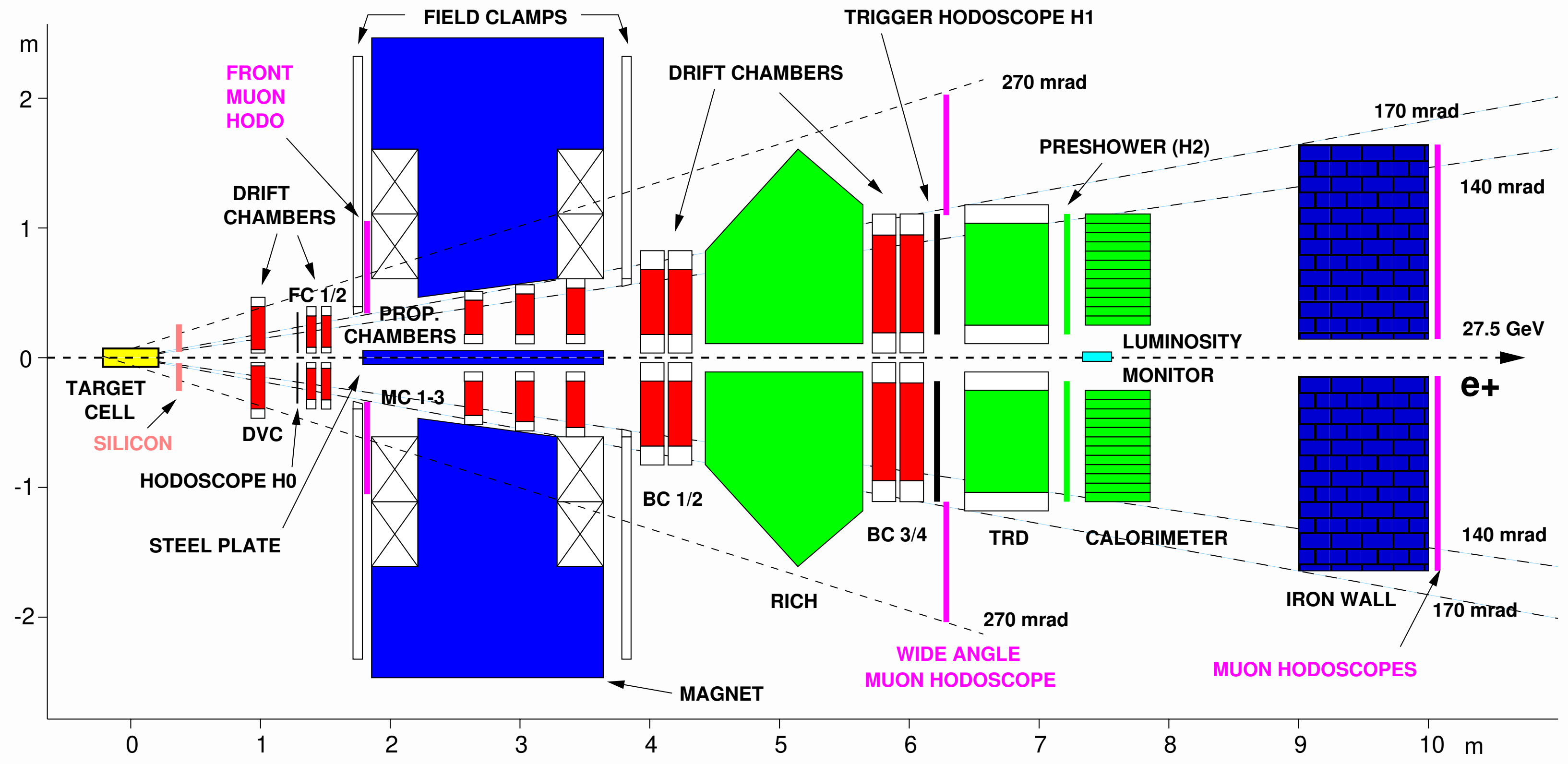
- K^+p Missing Mass
- from Clebsh-Gordan and acceptance: expected 5000 Θ^{++}
  $\rightarrow$ far above experimental value
- Conclusion: Θ^+ is an isoscalar

Experimental Evidence from Neutrinos



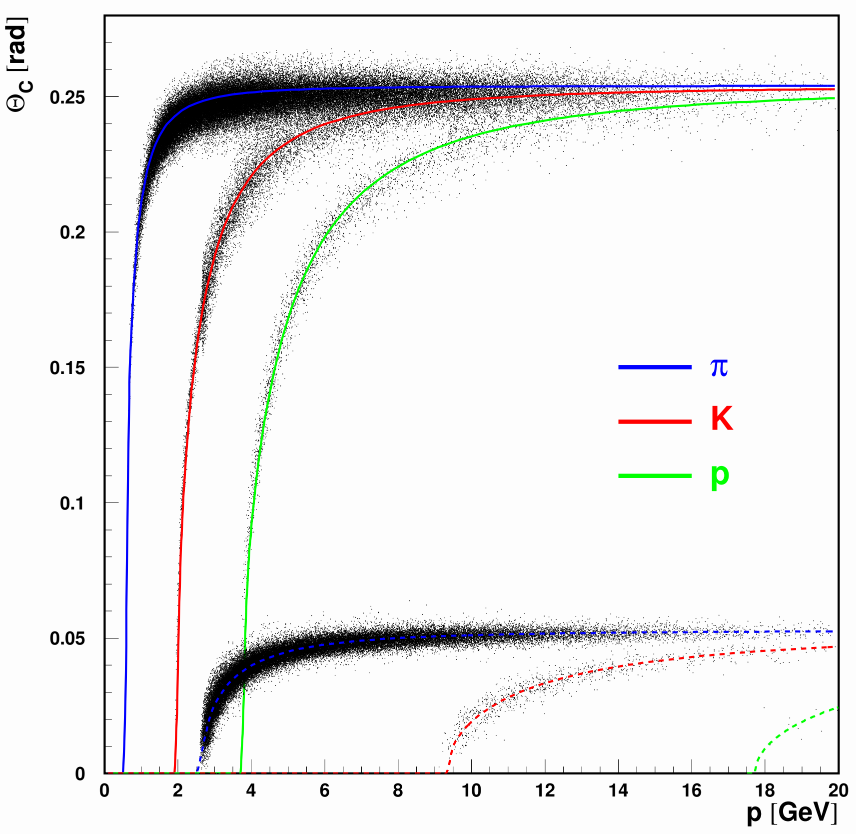
- Reanalysis of existing bubble chamber data from CERN, FNAL
- Inclusive $K^0 p$ production by high energy ν and $\bar{\nu}$, $E_{\nu,\bar{\nu}} \simeq$ (40–140) GeV, Neon plus Deuterium
- Upper panel: dots depict random star background
- Lower panel curve : Gaussian plus linear, width consistent with resolution
- Conclusion (A.E.Asratyan et al., hep-ex/0309042): M = 1533±5MeV, $\Gamma < 20$MeV, σ=6.7

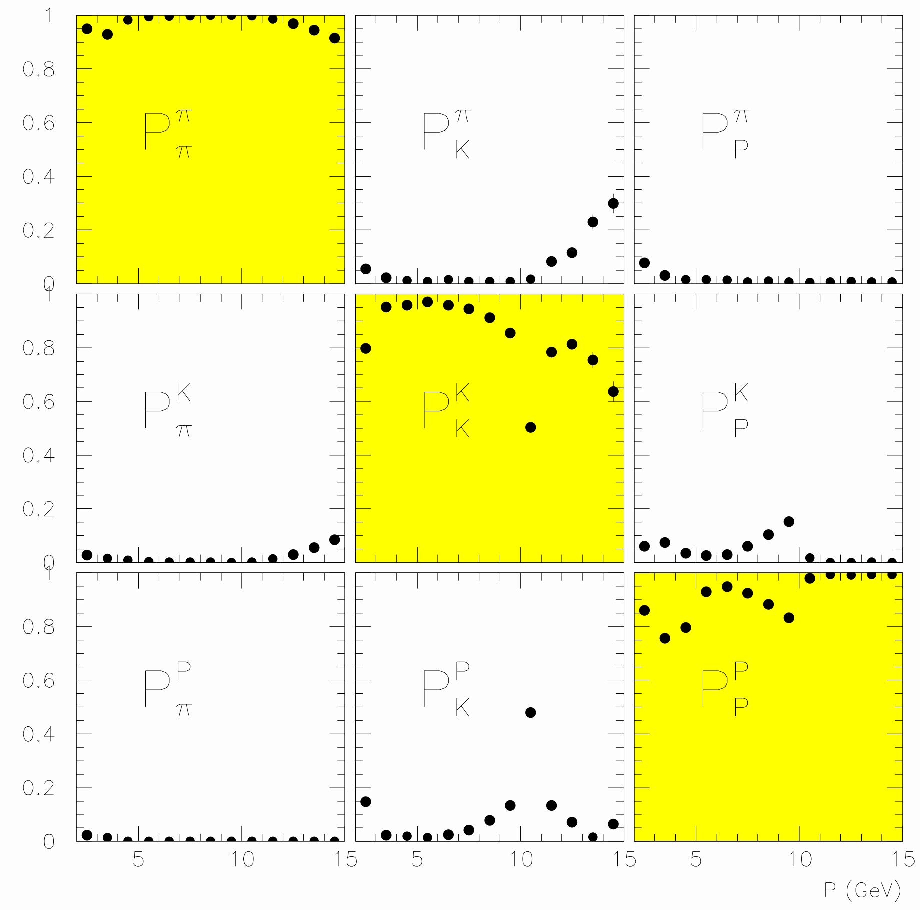
The HERMES Spectrometer



- Resolution: $\delta p/p = 1.4 \ldots 2.5\%$, $\delta\Theta \lesssim 1$ mrad
- Particle Identification: TRD, Preshower, Calorimeter, RICH (dual radiator)

The HERMES RICH



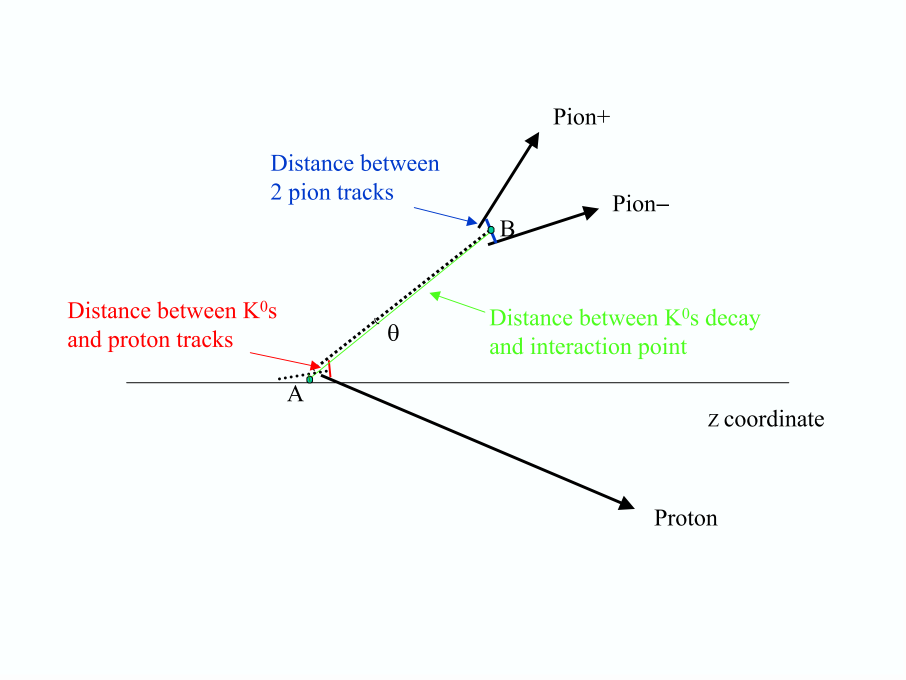


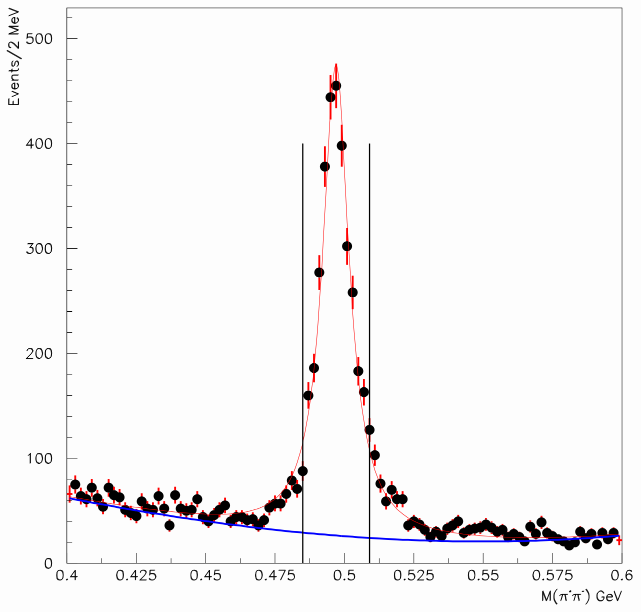
- Particle Identification:
  $\cos\Theta = \frac{1}{n}$

- detection efficiencies

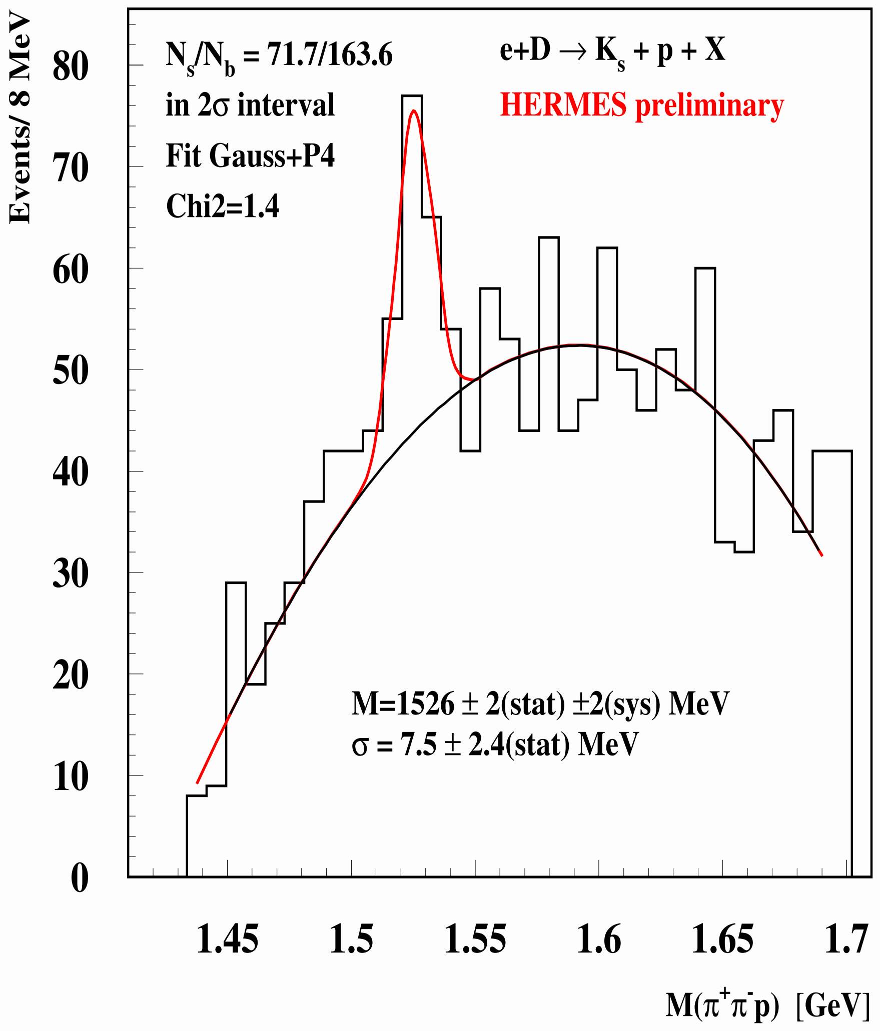
The Θ^+ Pentaquark Search at HERA-HERMES

- $e + D \rightarrow \Theta^+ + X \rightarrow K_s p + X$ (E_{e^+}=27.5 GeV)
- Protons and pions identified with RICH
- K_s reconstructed using decay length
- $p\pi^-$ events from $\Lambda(1116) \pm \sigma$ range excluded



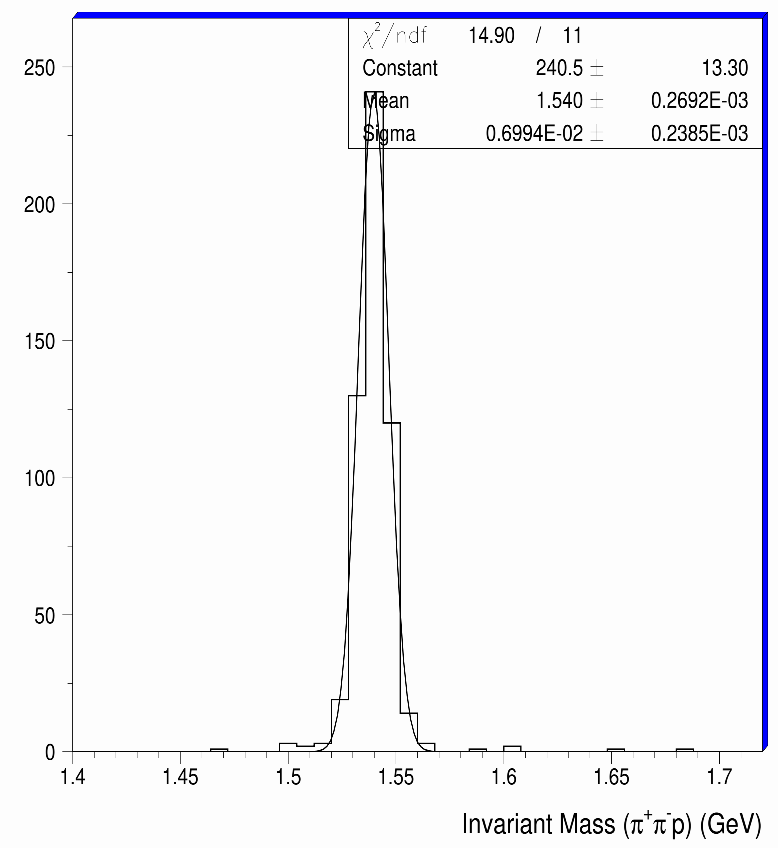


The Θ^+ from HERMES: Penta or not Penta ?



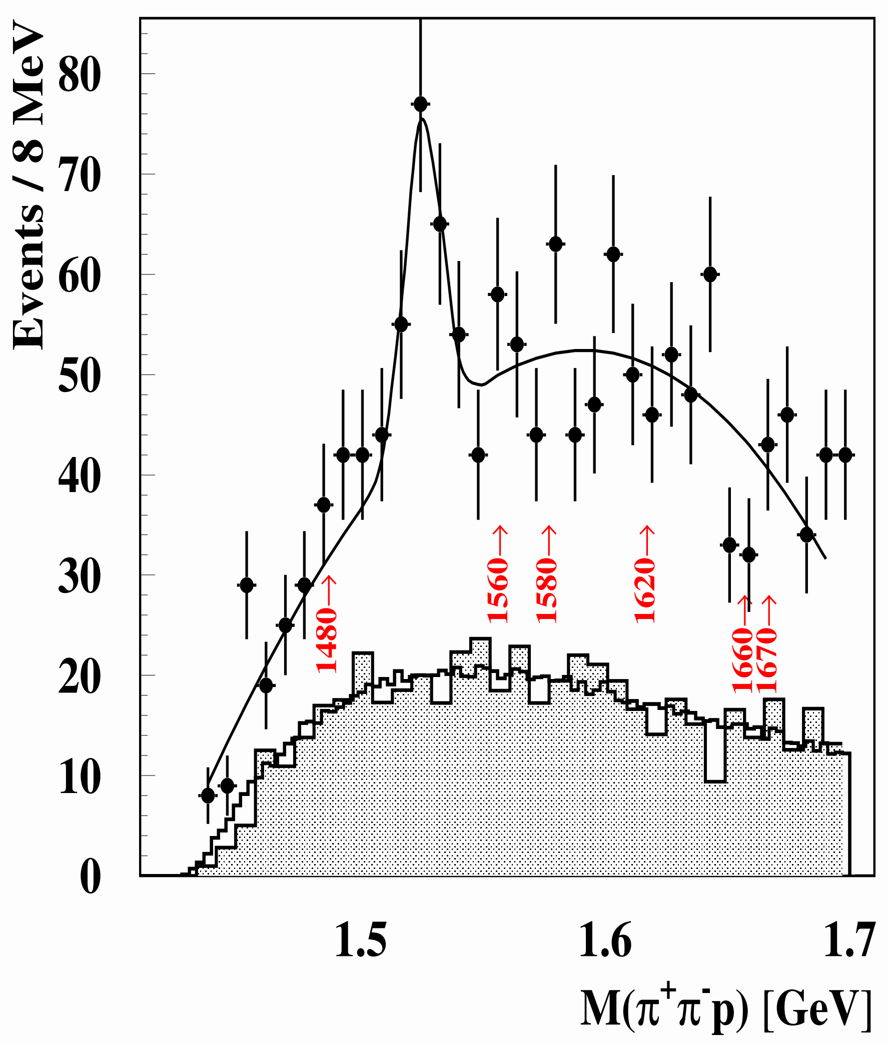
- Resonance is observed at $1526 \pm 2(stat.) \pm 2(syst.)$MeV in K_sp invariant mass distribution
- the width: σ = $7.5 \pm 2.4(stat.)$ MeV dominated by experimental resolution

The Θ^+ Monte Carlo



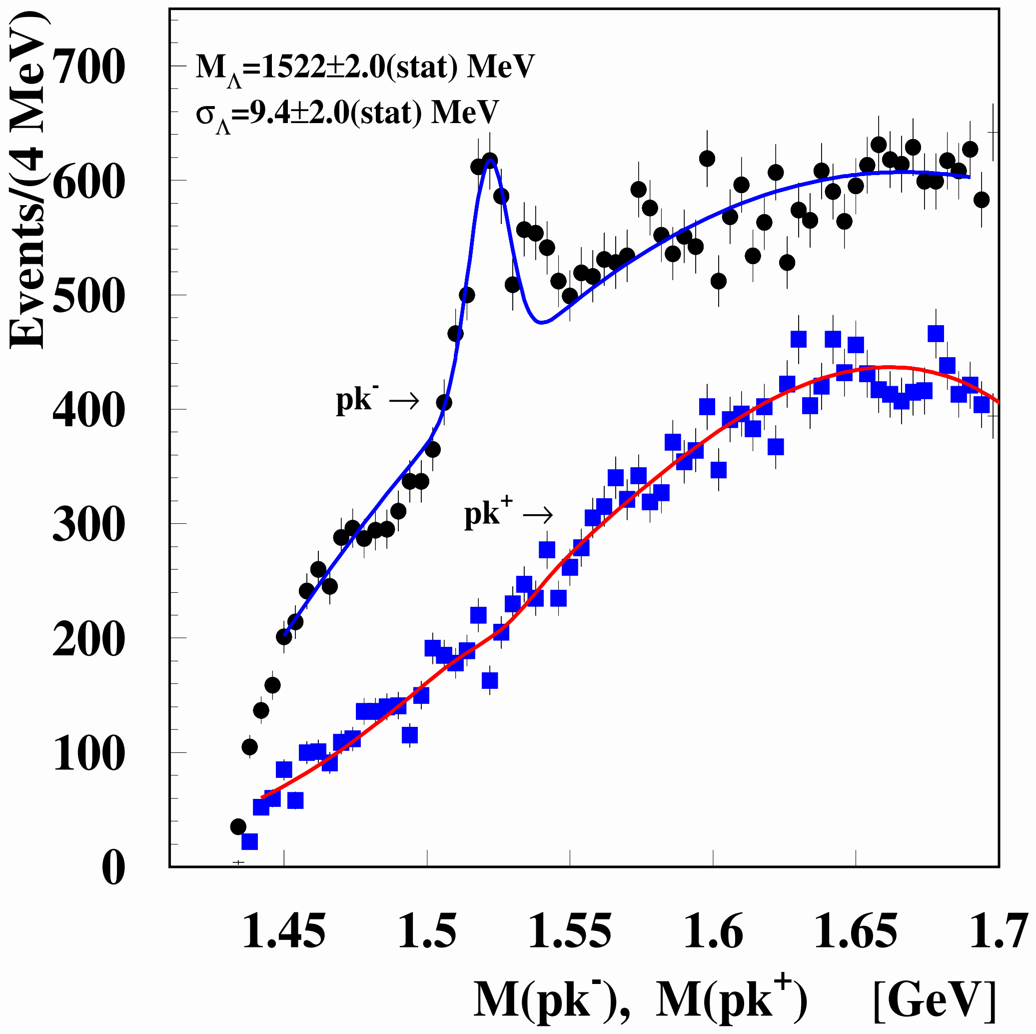
- The Θ^+ generated with:
  M=1540MeV and σ = 2MeV
- Reconstructed values:
  M=1540MeV and σ = 7MeV
  (due to resolution)

PYTHIA6 and Mixed Event Background



- Hatched histogram – PYTHIA6 MC simulation (lumi normalized): No resonance structure from reflections of known mesonic or baryonic resonances
- Solid histogram — mixed event background normalized to PYTHIA6: well reproduces the shape of PYTHIA6 simulation
- Excited Σ^* hyperons not included in PYTHIA6 lie below 1500MeV and above 1550MeV

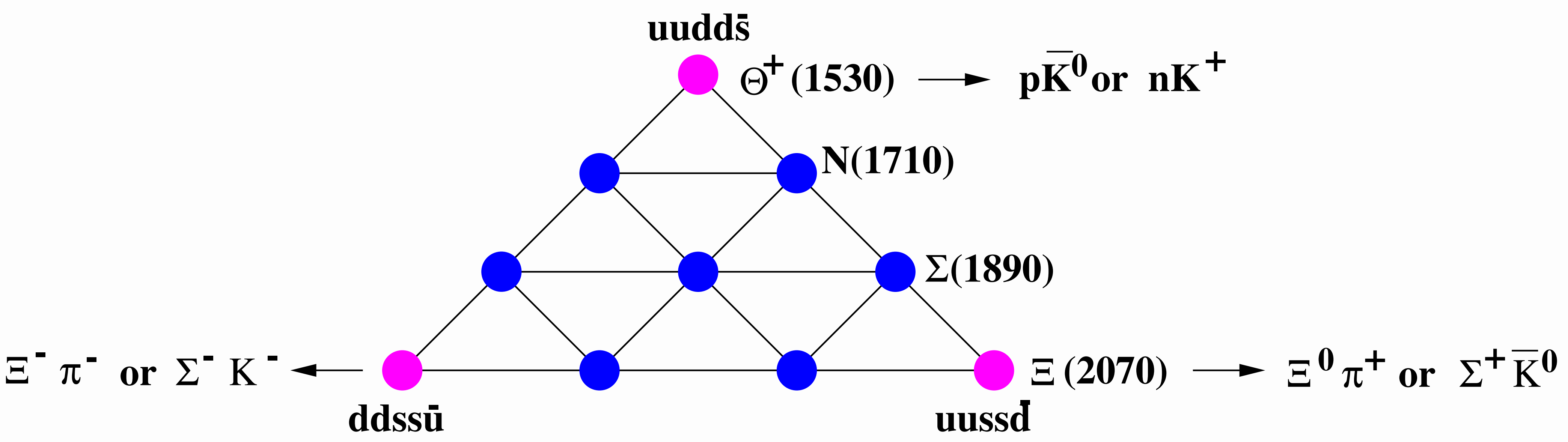
Θ^+ *Isospin from HERMES (prelim.)*



- Clear signal for $\Lambda(1520)$
- No peak structure in pK^+
- Gell-Mann-Nishidjima relation: Q = I_3 + Y/2, where Y=B+S
- if no Θ^{++} then:
- $\rightarrow \Theta^+$ is an isosinglet

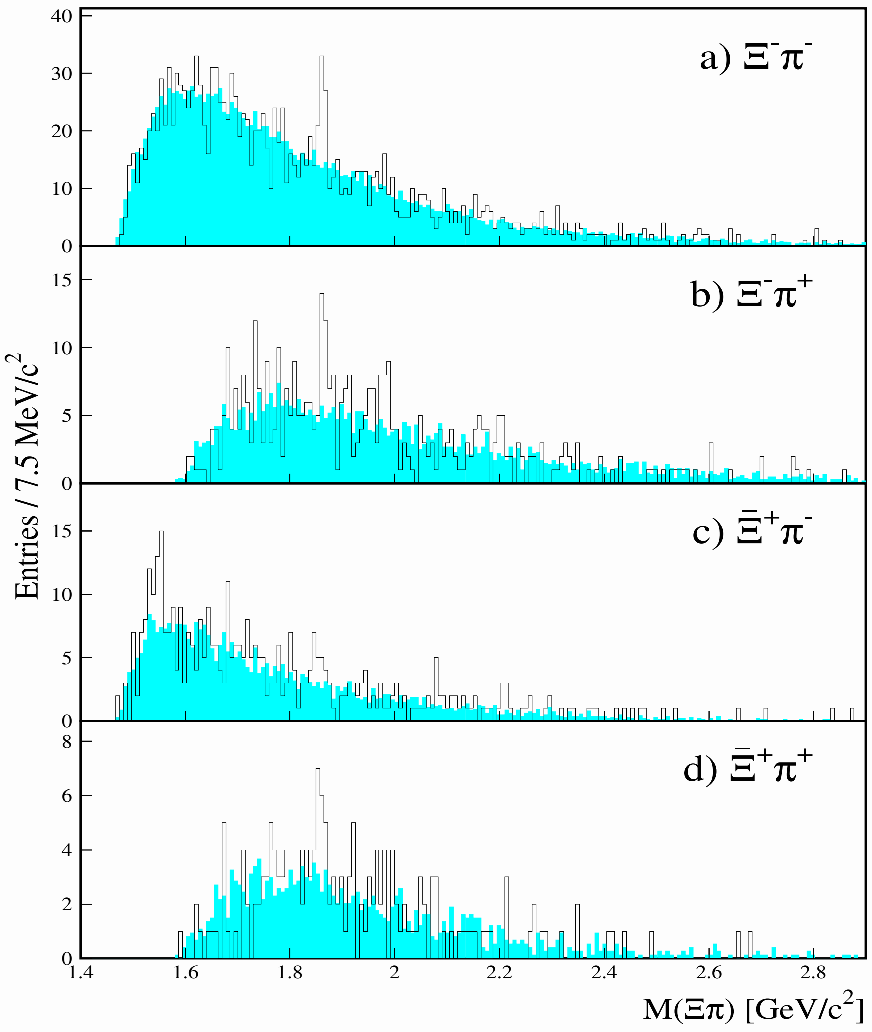
Hunting Other Members

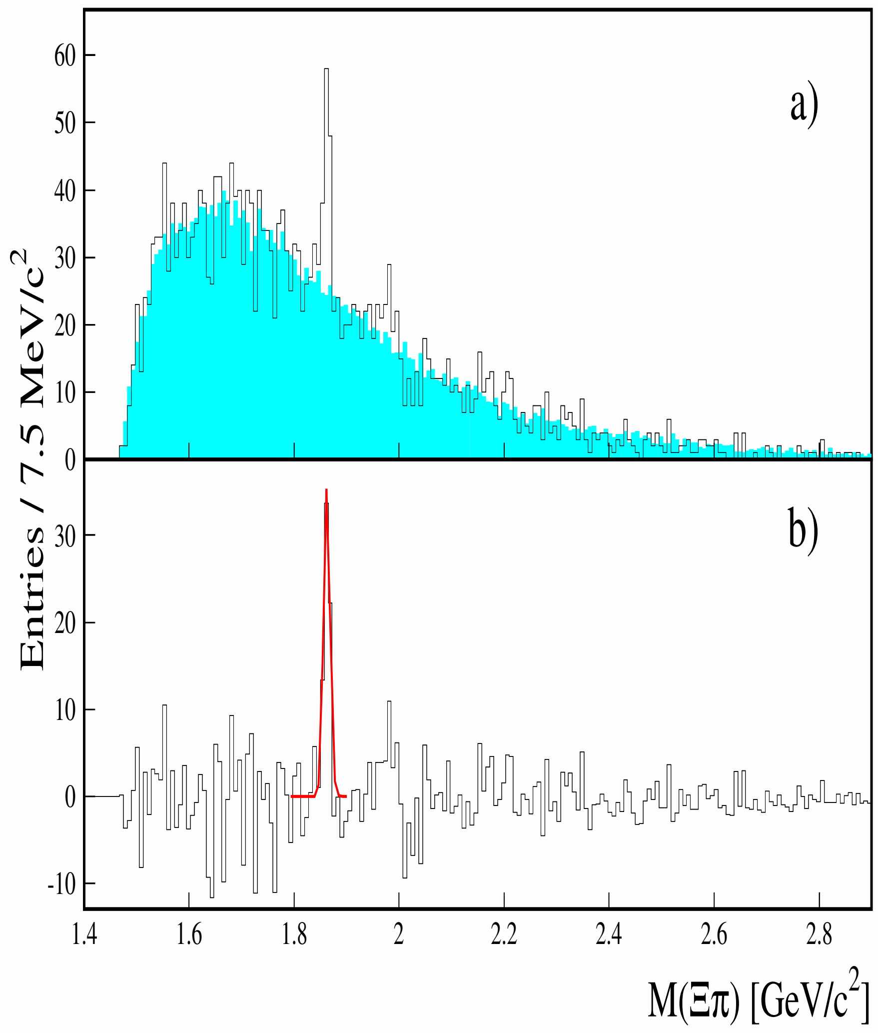
- PENTAQUARKS: hiding in the corners



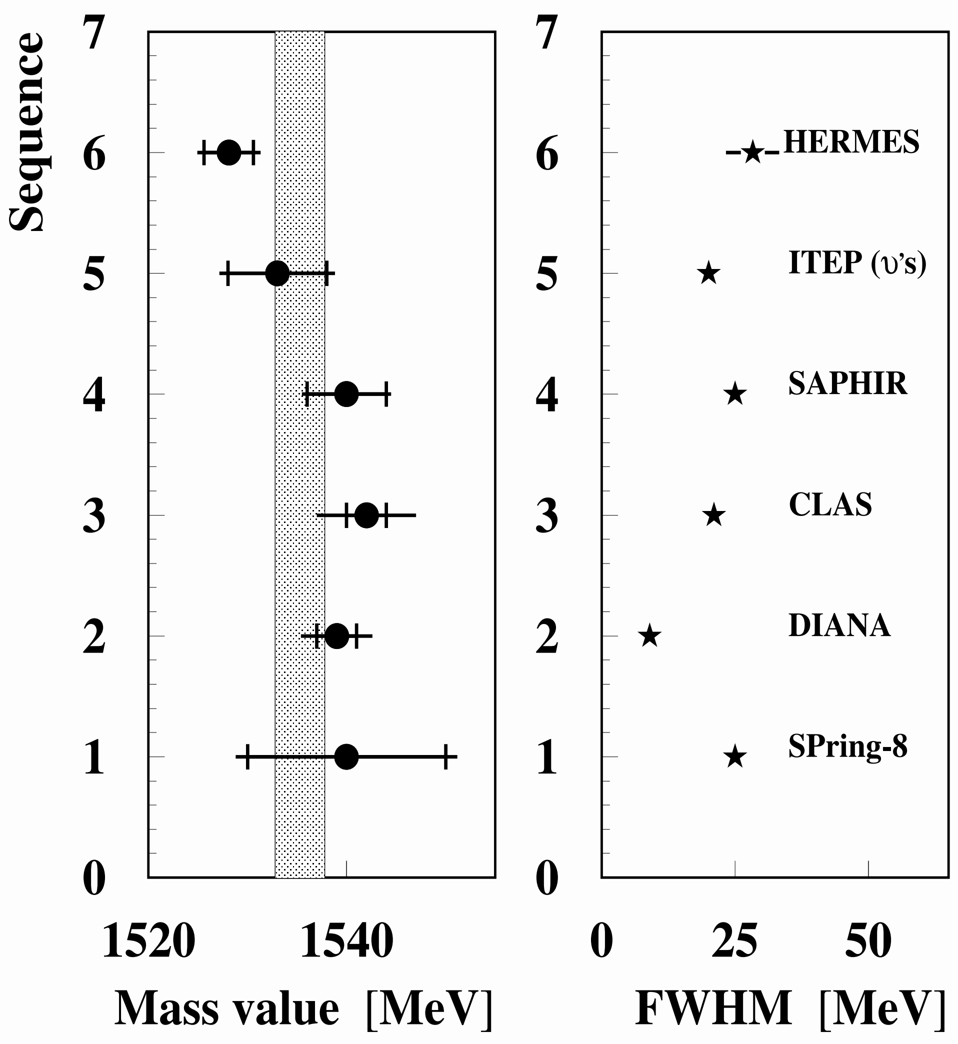
Exotic Ξ^{--} from NA49 at CERN

- NA49 Coll.: evidence for exotic $\Xi^{--}(dsds\bar{u})$ in pp at $\sqrt{s}$=17 GeV
  $S = -2$ and $I = 3/2$ with $M = 1862 \pm 2$MeV and width < 18 MeV





Masses Values and Experimenta Widths of Θ^+



- Left panel: measured masses The weighted average of all experiments: M=1535±2.5MeV (hatched band)
- reduced χ^2 a la PDG corresponds to confidence level of 0.1
- Right panel: measured widths
- ZEUS →Welcome on Board
- HERA-B: strong controversy or affordable result?

Summary

- Exotic baryon resonance Θ^+ is observed in different experiments with very narrow width and $\underline{PENTAQUARK}$ structure
- Quantum numbers are undefined except of isospin $\rightarrow \Theta^+$ is an $\underline{ISOSINGLET}$
- New member of anti-decuplet Ξ^{--} is observed at NA49 (needs confirmation)
- Further theoretical and experimental work is needed to establish quantum numbers like $SPIN$ and $PARITY$ of observed resonances
- Pentaquarks open $\underline{NEW}$ window for our understanding of quarks and hadrons in the extreme conditions and possibly also in the stellar objects
- HERA experiments contribute to the world efforts on this subject