Pentaquark Search at HERMES

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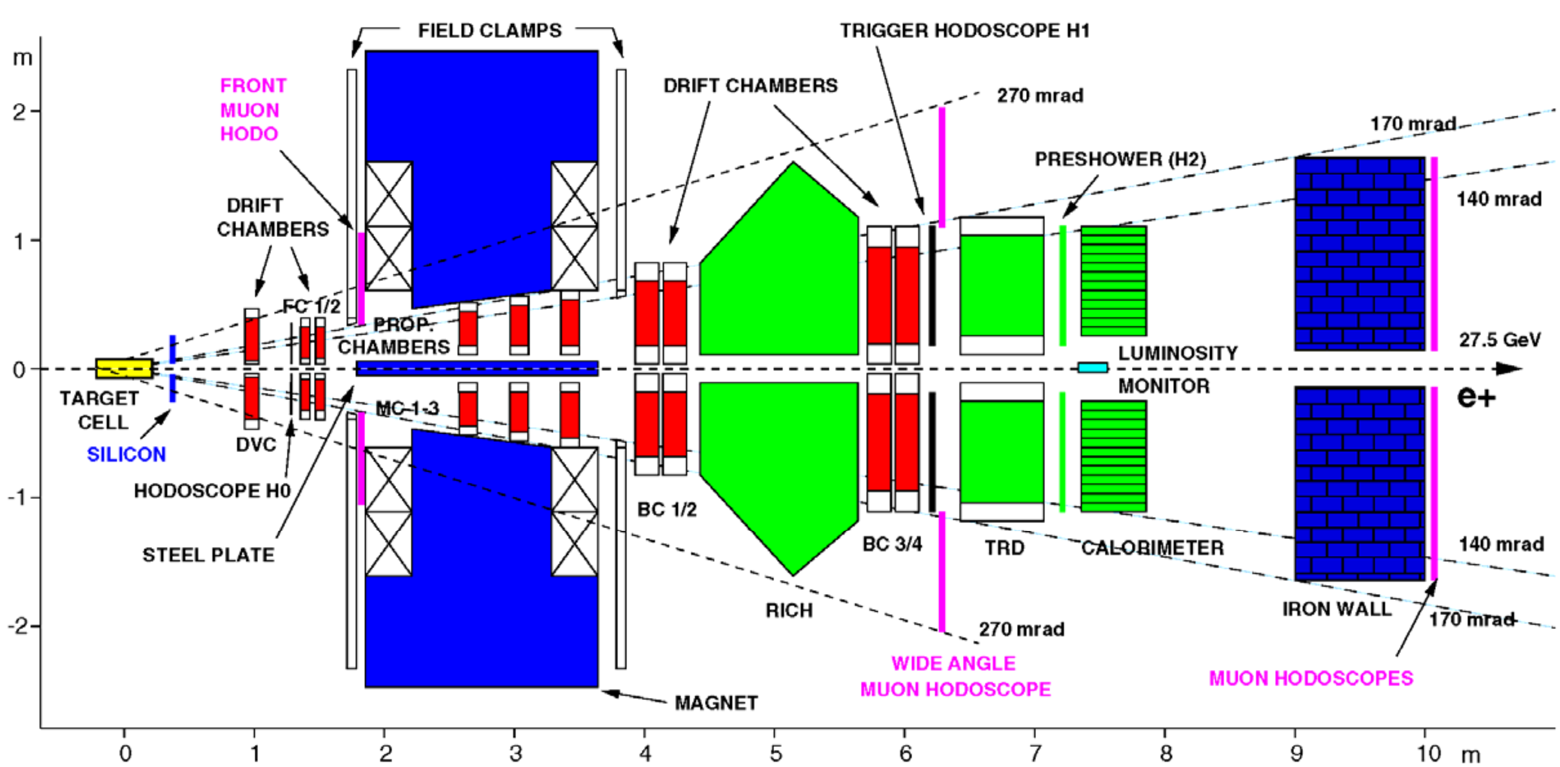
for the HERMES Collaboration

- Particle ID
- Search for pK_s resonances
- Systematic Studies
- Summary and Conclusions

PENTAQUARK04, 20-23 July 2004

The HERMES Spectrometer



Beam: 27.6 GeV e^+/e^- from HERA accelerator

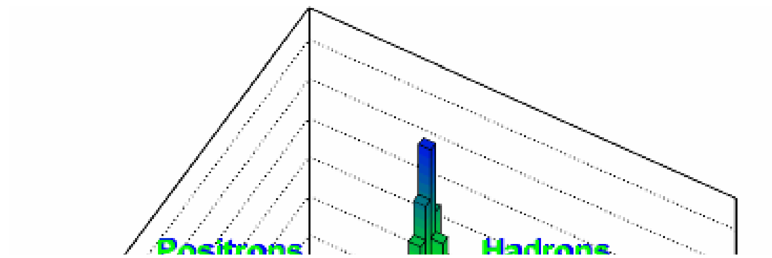
Track reconstruction: $\Delta p/p < 2\%$, $\Delta\theta < 0.6$ mrad

Particle ID: TRD, Preshower, Calorimeter (hadron/lepton sep.)
dual radiator RICH (π, **K**, **p** separation)

Particle Identification

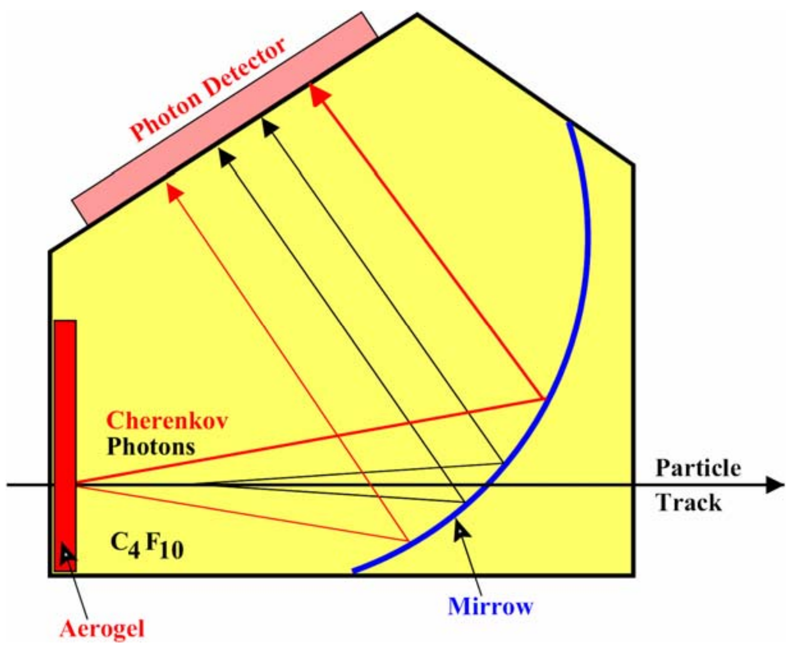
hadron / positron separation

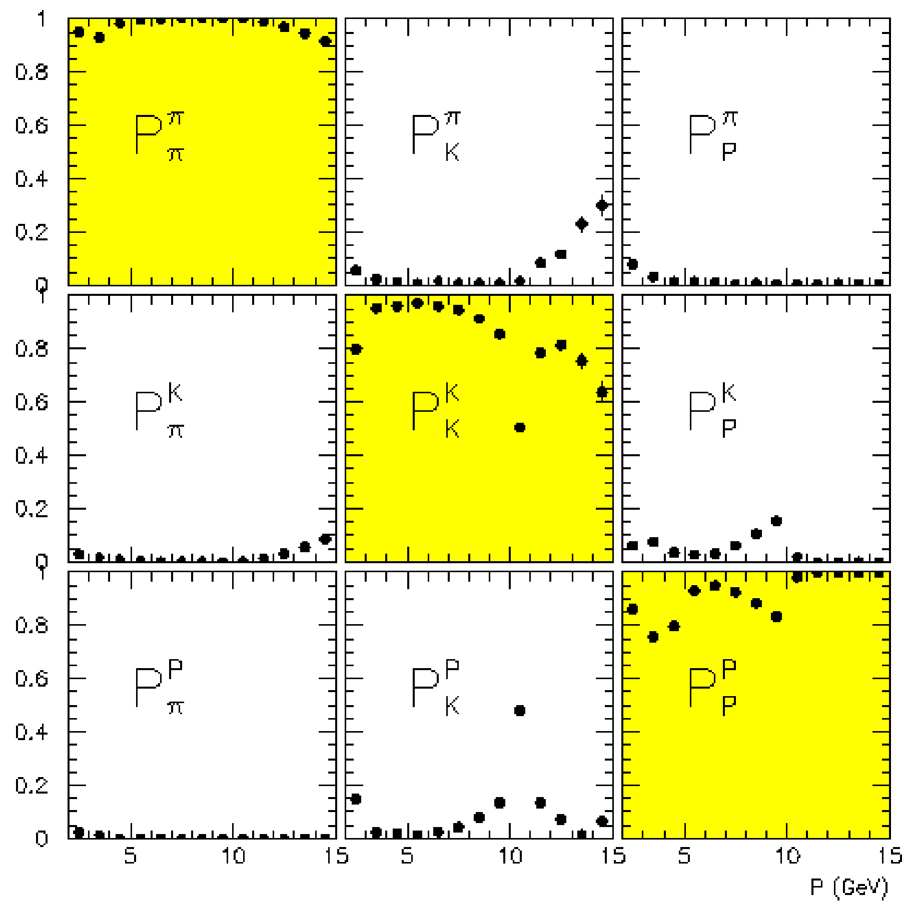
combining signals from:
TRD, calorimeter, preshower, RICH



hadron separation

Dual radiator RICH for π, **K**, **p**





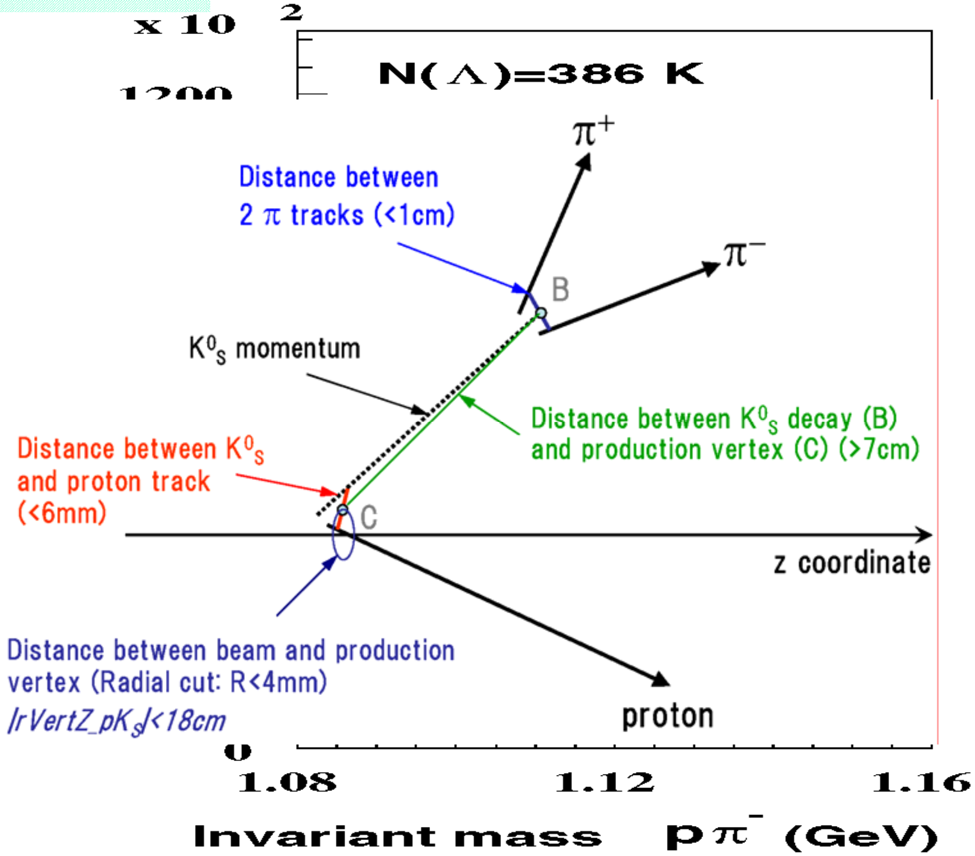
Event Reconstruction

$$e^+ + D \rightarrow \Theta^+ + X \rightarrow pK^0_S + X$$

- Hadron identification: RICH

  π: 1 - 15 GeV   **p:** 4 – 9 GeV

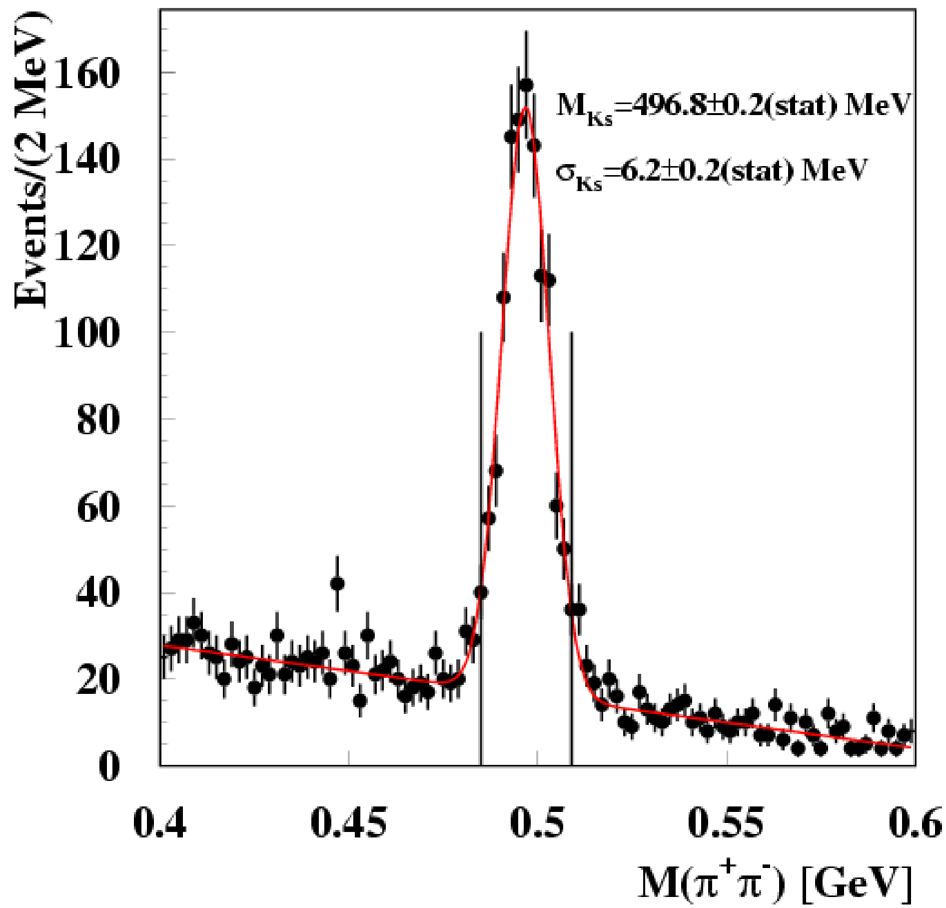
- Reject events from $\Lambda(1116) \rightarrow p\pi^-$ within $\pm 2\sigma$ of M_Λ
- Define appropriate event topology
- invariant mass calibration ± 2MeV



⇒ **direct reconstruction:** **detection of each decay particle, invariant mass reconstruction**

K_S^0 Identification

- after all constraints on event topology
- proton present in event sample
- only events with $M(\pi^+\pi^-)$ within $\pm 2\sigma$ of $M(K_S)$



Results

Peak at:

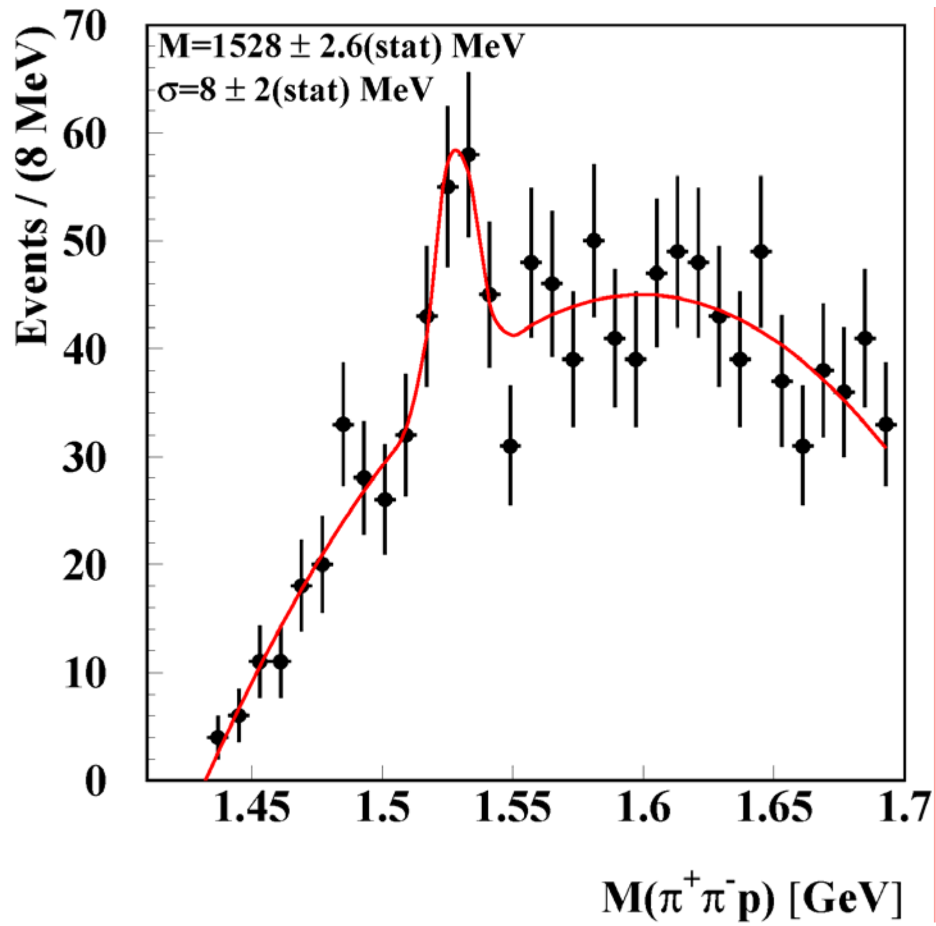
M= 1528 ± 2.6 MeV

σ= 8 ± 2 MeV

Significance:

$$N_s^{2\sigma} / \sqrt{N_b^{2\sigma}} = 4.7$$ (naïve)

$$N_s / \delta N_s = 3.7$$ (realistic)



Unbinned fit is used: ***result independent of bin size and starting point***

The Signal Width

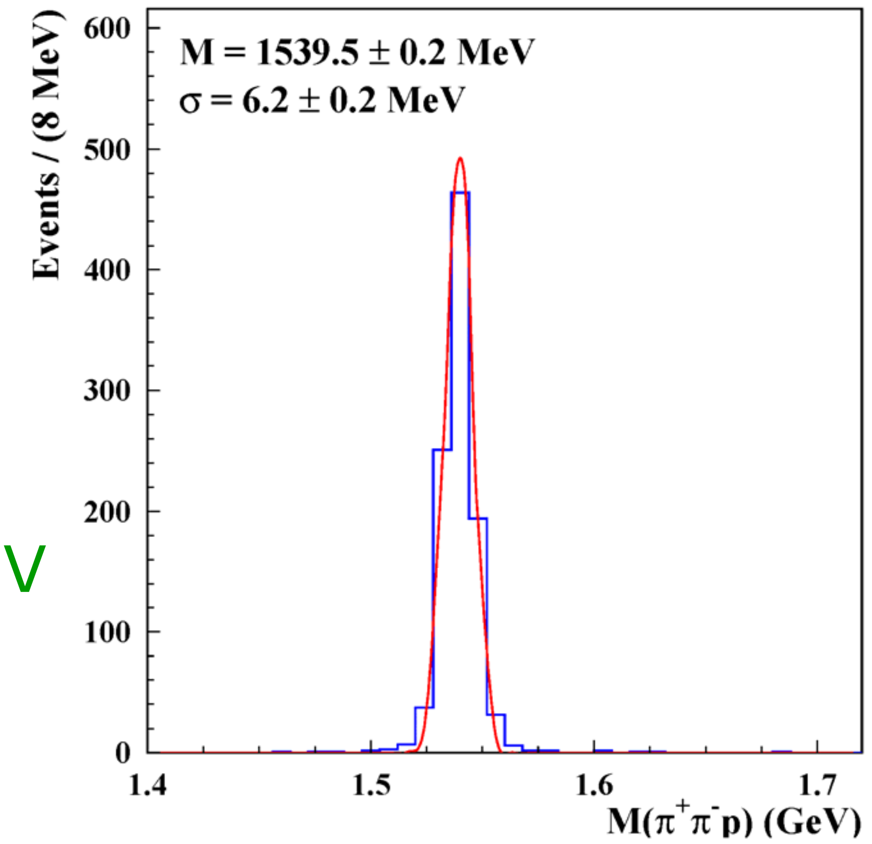
Θ^+ Monte Carlo with complete detector simulation

- generated:
  M=1540 MeV , σ=2 MeV

- reconstructed:
  M=1539.5 MeV , σ=6.2 MeV

Production kinematics are those observed for Λ**(1116)**

- p_z monotonically falling
- p_t gaussian



The Signal and its Background

Peak at:

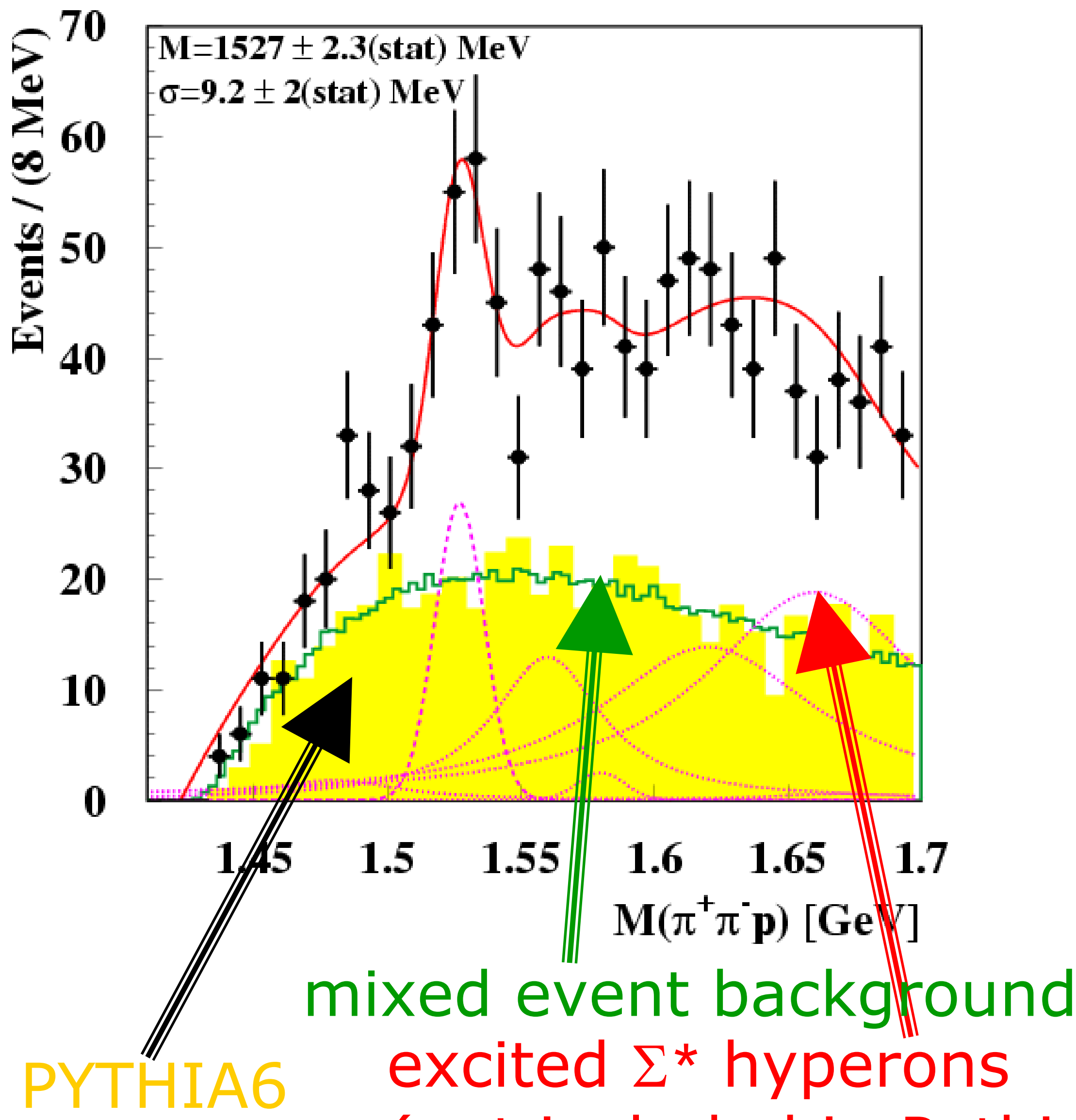
M= 1527 ± 2.3 MeV

σ= 9.2 ± 2 MeV

Significance:

$N_s^{2\sigma} / \sqrt{N_b^{2\sigma}} = 6.1$ (naïve)

$N_s / \delta N_s = 4.3$ (realistic)



A Non-Zero Width for Θ^+?

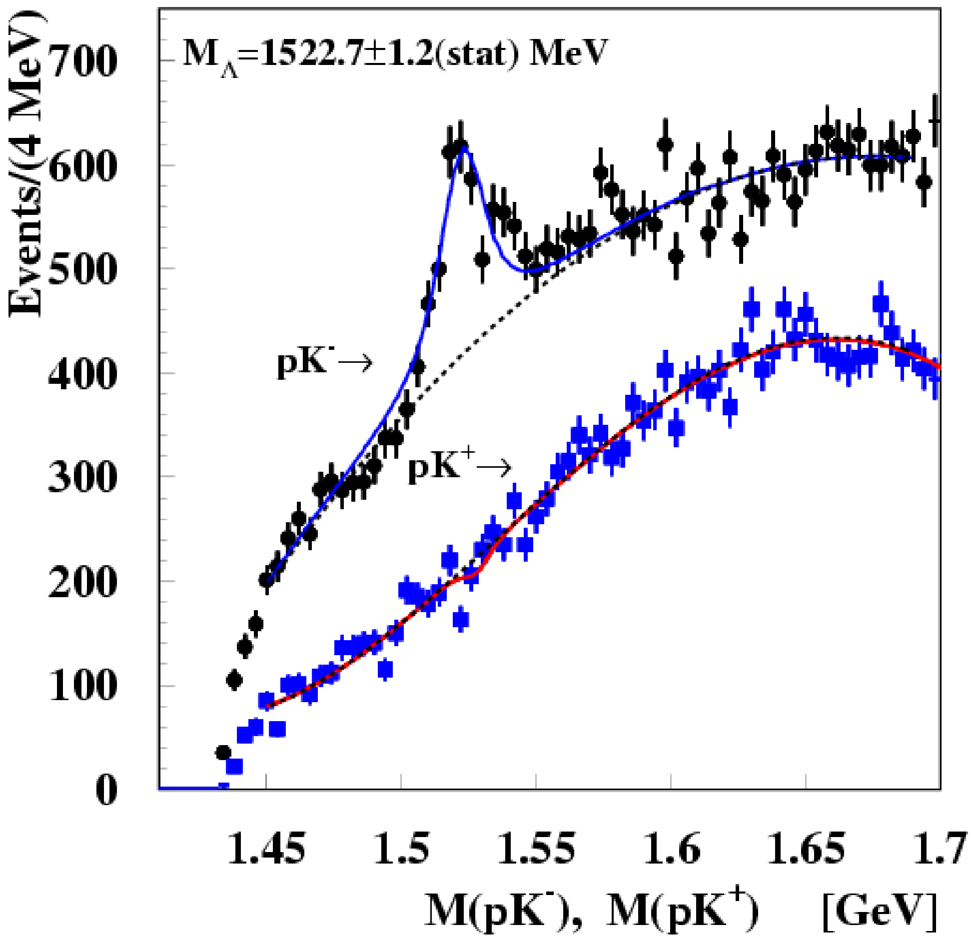
- Observed width FWHM: **19 – 24** MeV

- Detector resolution (from MC)
  FWHM: **10 – 14.6** MeV

- re-fit spectra with Breit-Wigner convolved with a Gaussian (fixed by MC)

→ *HERMES intrinsic width:* Γ = **17** ± **9** ± **3** MeV

Θ^+ Isospin



- Well established $\Lambda(1520) \to pK^-$ with acceptance:1.5%
- No peak structure for $\Theta^{++} \to pK^+$ zero counts at 91% CL

Θ^+ not isotensor

→ probably **isoscalar**

Production Cross Section

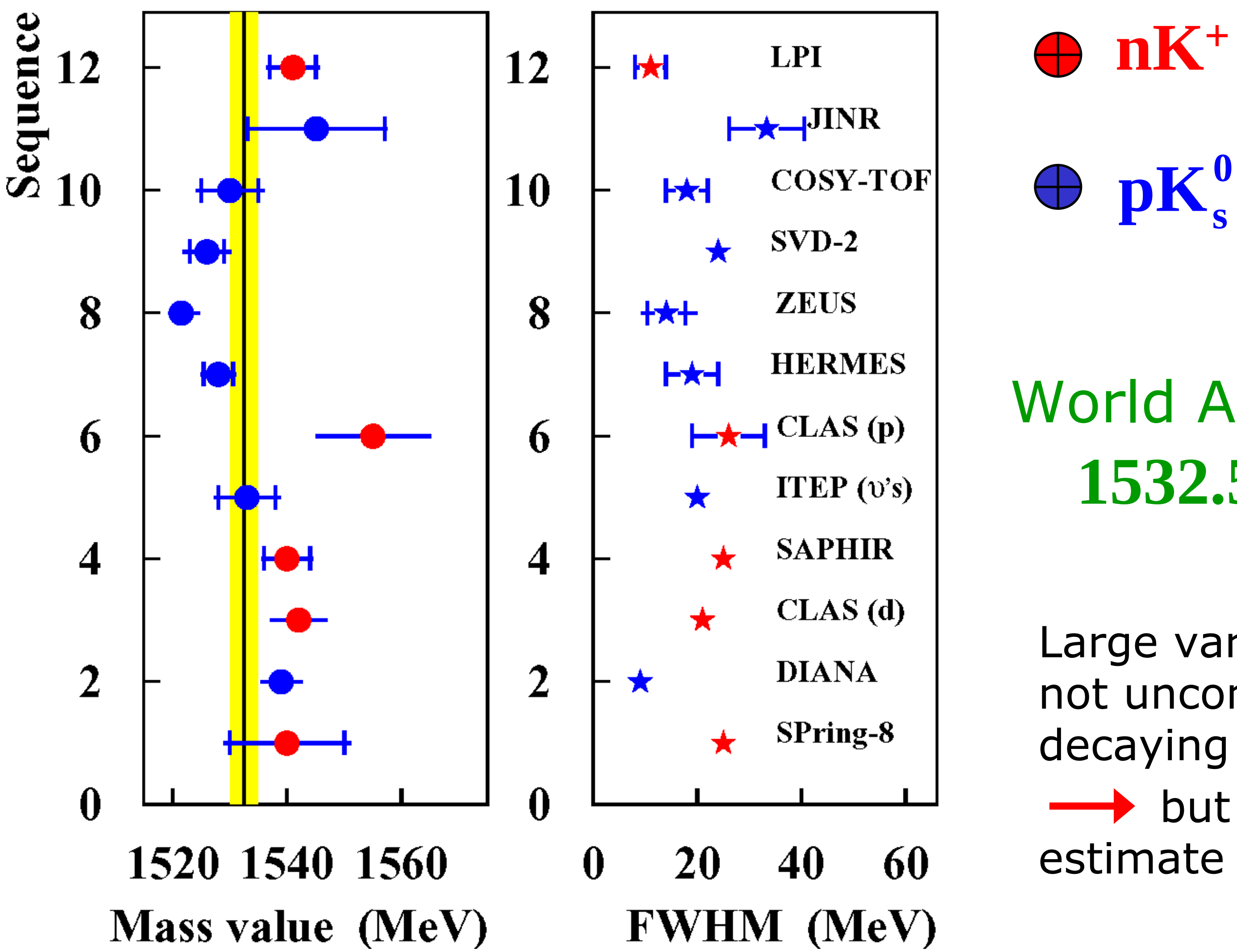
- Integrated luminosity: **250** pb^{-1}
- Acceptance from MC:
  - 1.5% for Λ**(1520)**
  - 0.05% for Θ^+
- branching ratio to pK^0_s: ¼

→ *HERMES estimate:* $\sigma(\Lambda(1520)) = \mathbf{62 \pm 11}$ nb

$\sigma(\Theta)=$ **100-220** nb ± 25% (stat)

(additional factor 2 from production kinematics)

Comparison with other experiments



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

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

Open Questions

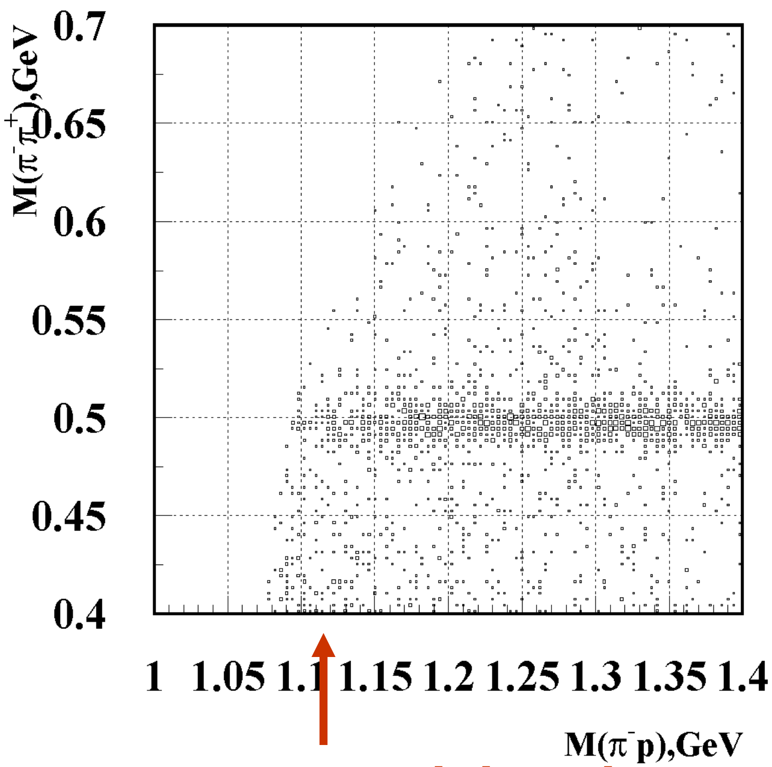
- How real are positive results?
  - check if peaks are generated by
    “kinematic reflections”(?)
    ghost tracks
    acceptance or cuts
- How real are negative results?
  - need to published
    scrutinized as hard as positive results
- Mass?
- Width?
- Spin and Parity
- etc.

How real is the Peak?

- check for
  - fake peaks ("kinematic reflections")
  - detector acceptance and cuts (PYTHIA6 MC / Toy MC)
- Θ^+ vs Σ^{*+}
  - is Θ^+ a pentaquark or a previously unobserved Σ^{*+}?
- add a fourth hadron
  - is the peak still there?
  - can we guess the production process for the Θ^+?
  - can we suppress background?

Fake Peaks?

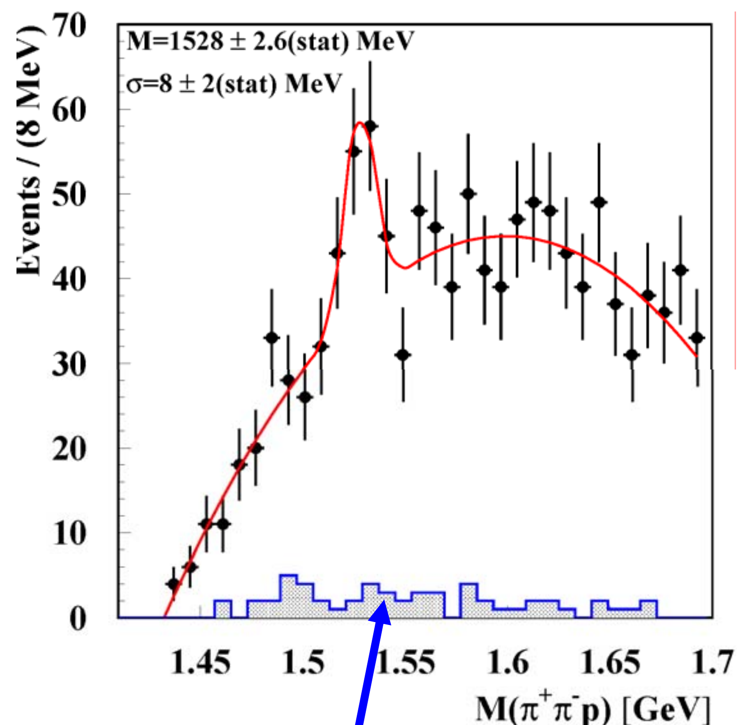
- particle miss-assignment
  - ghost tracks
  - PID “leaks”



expect peak in M(π^-p)

if π^+ is **p** and K_S is Λ**(1116)**

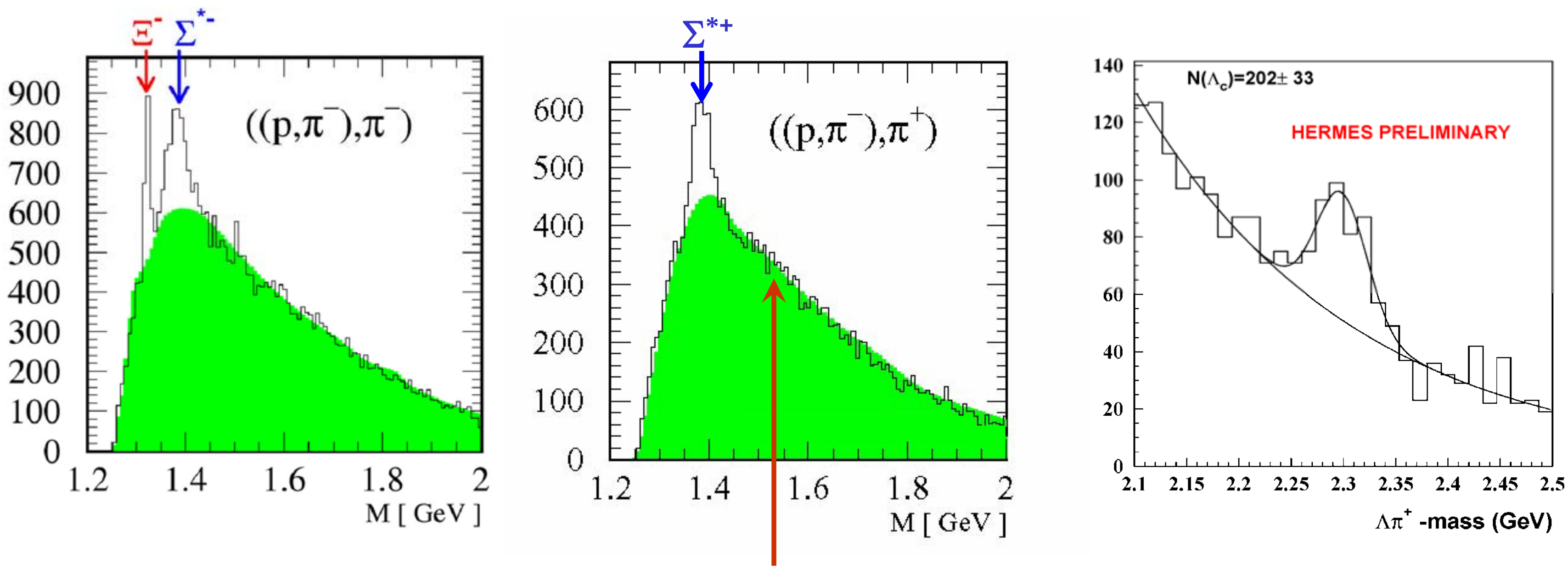
- remove Λ**(1116)** contribution



Spectrum of events associated with Λ**(1116)**

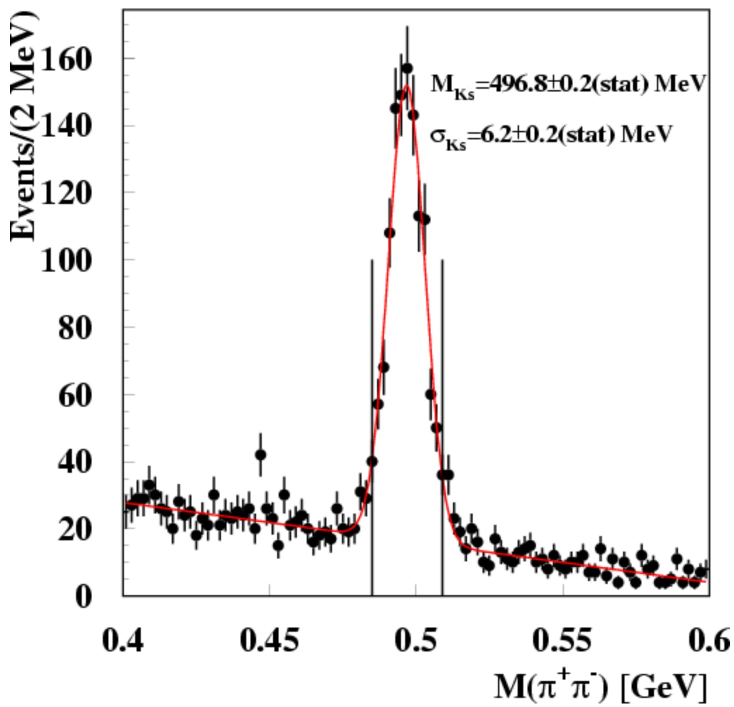
Θ^+ vs Σ^{*+}

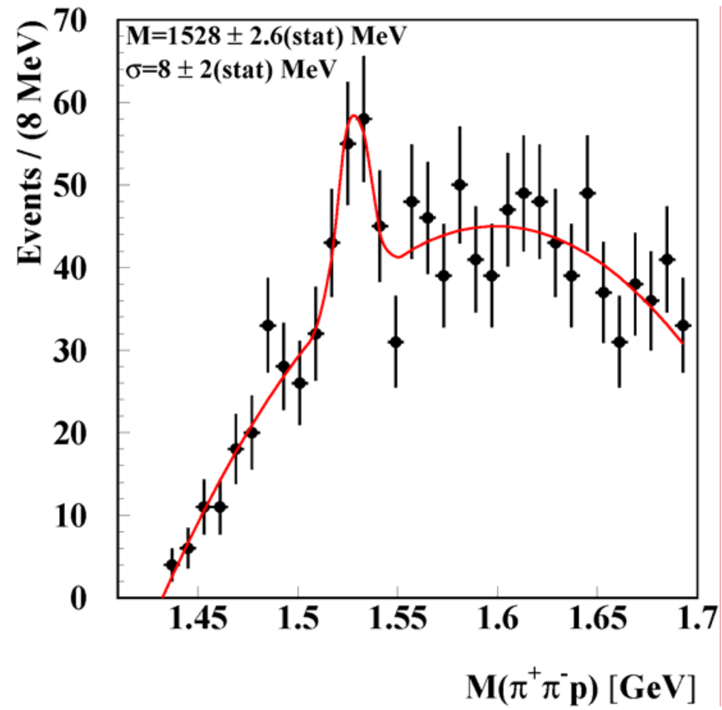
- Is peak a new Σ^{*+} or a pentaquark state?
- If peak is Σ^{*+} ⇒ also see a peak in $M(\Lambda\pi^+)$
  - — if member of baryon octect: b.r.$(\Lambda\pi^+)/(pK_s) \gtrsim 3/2$
  - — if member of decuplet: ~ 3/2 (M. Polyakov)



No peak in $\Lambda\pi^+$ spectrum near 1530 MeV

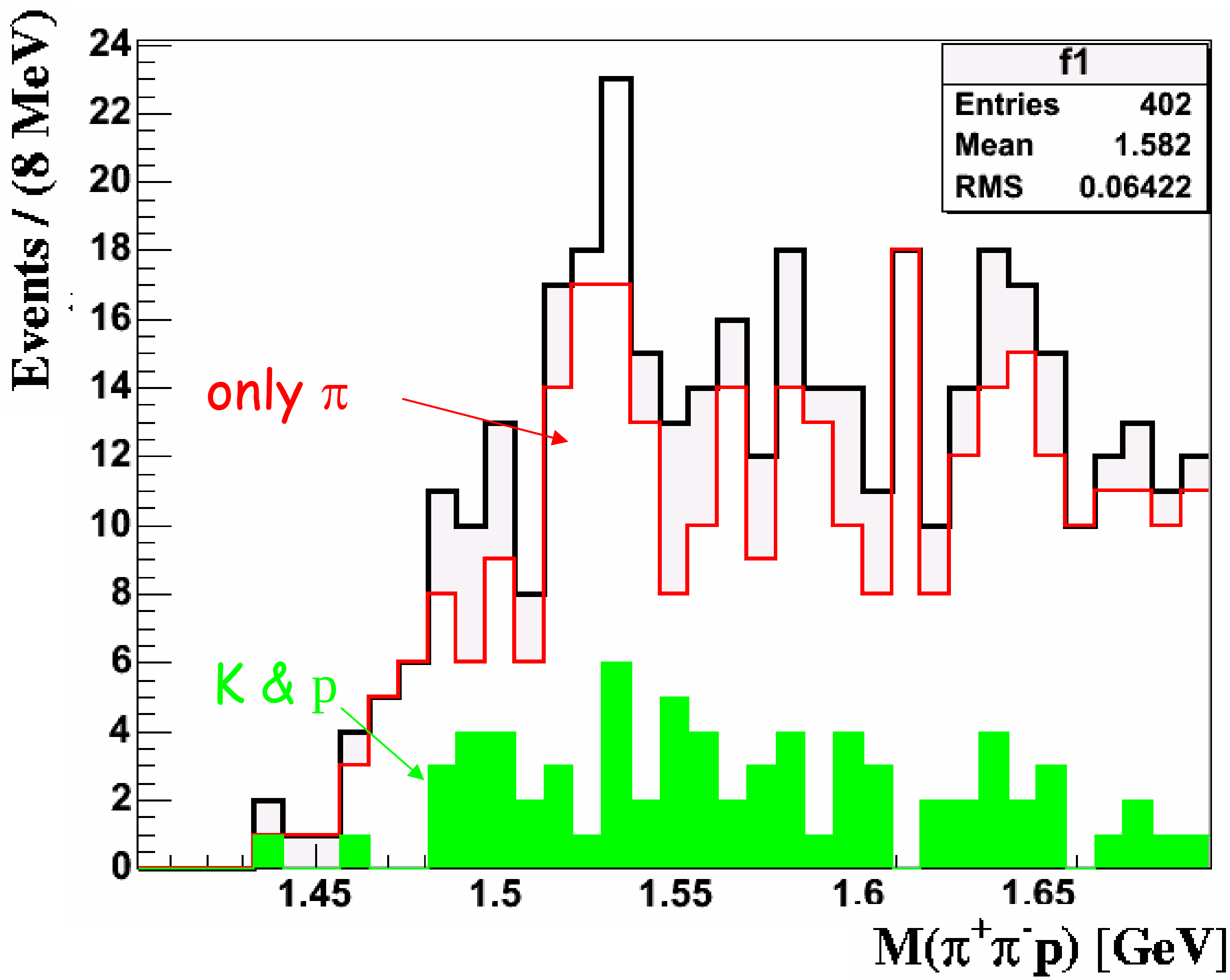
The Mass Spectrum





- relatively large BG, although good PID for proton and K_S
- what if we require one additional hadron?
- could additional hadron help remove K_S from other process?

Mass Spectrum after requiring 4^{th} hadron as π



Black requires 4^{th} hadron (all species)

Red specifies 4^{th} hadron as π

Green specifies 4^{th} hadron as *not* π

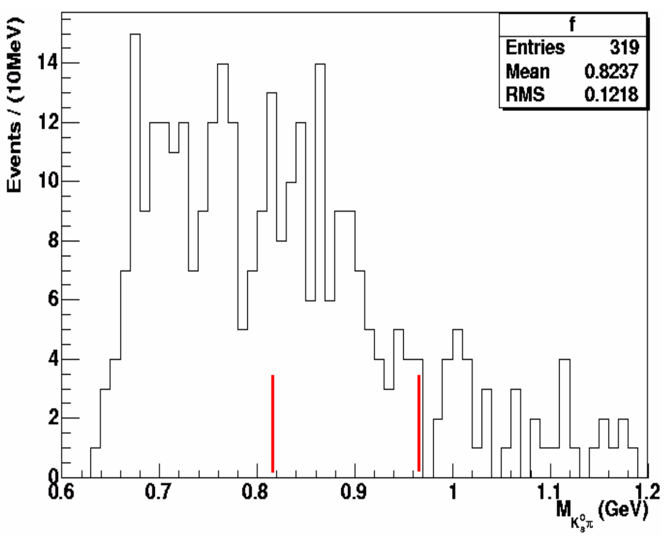
Why does additional π help?

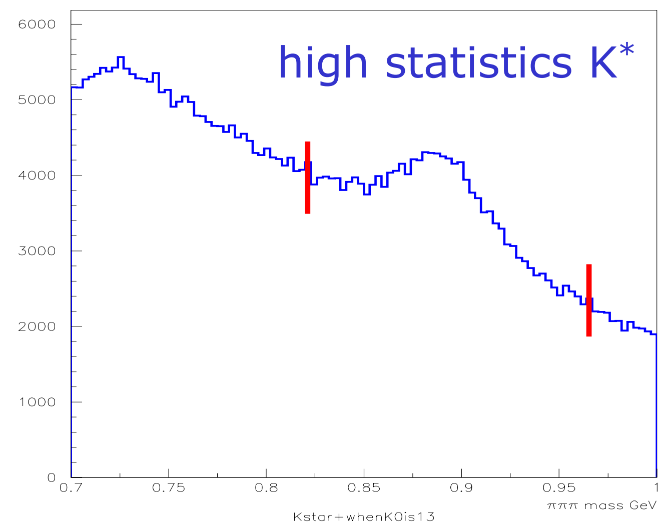
- remove $\gamma p \to \phi p \to K_L^0 K_S^0 p$

  $K_S^0 p \to \pi^+ \pi^- p$

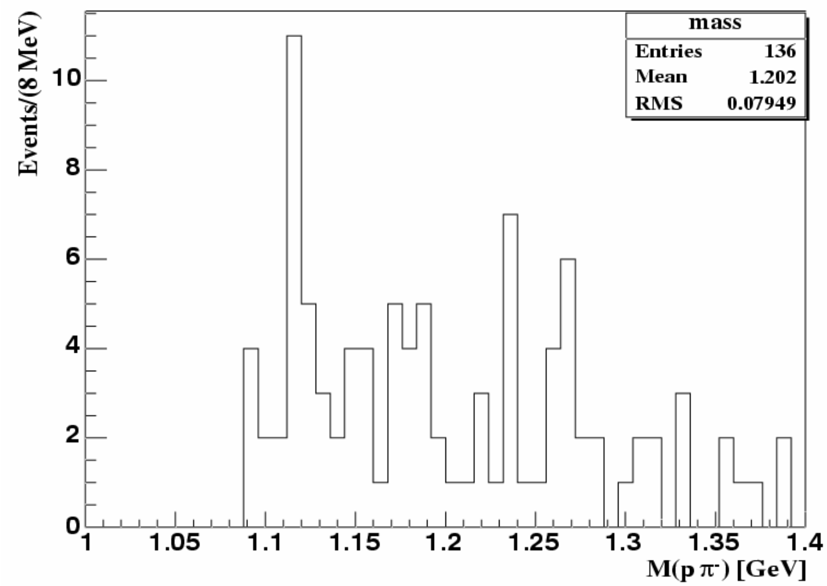
- remove $p(K^*)^\pm \to p K_S^0 \pi^\pm$

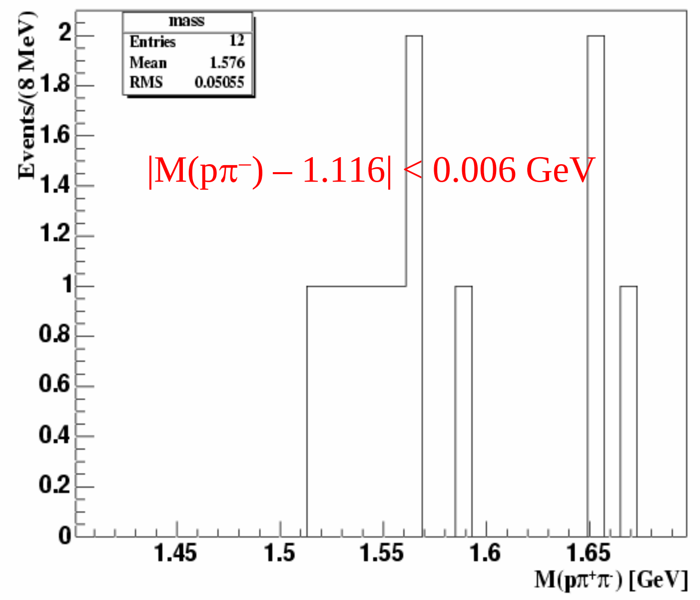
  add new cut: |M($K_S\pi$)-892|<75 MeV





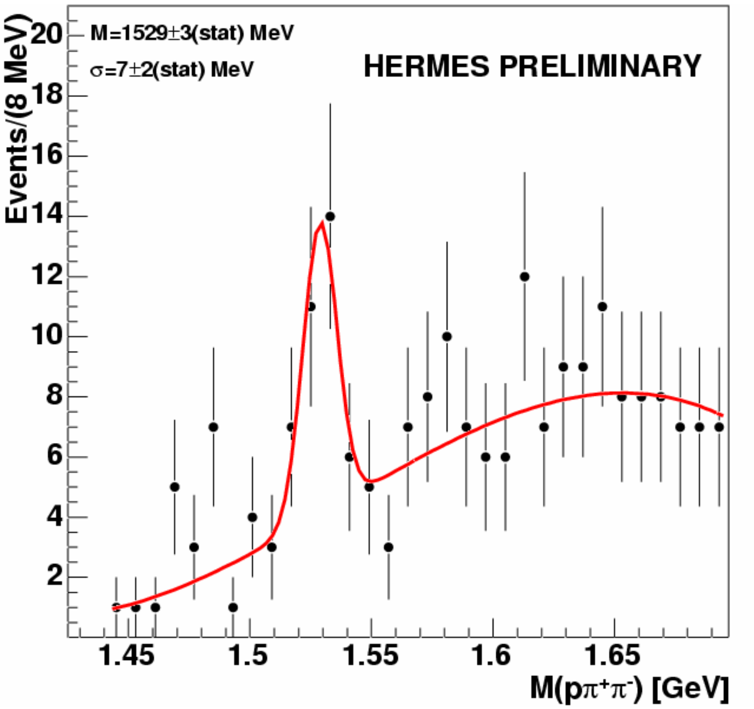
The Mass of $p\pi^-_{4th}$ (K* removed)

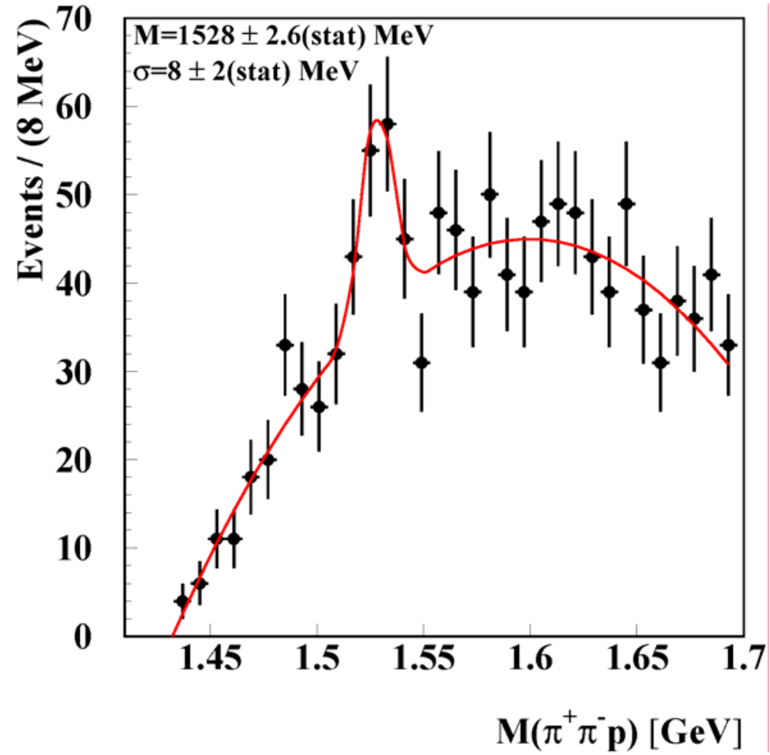




- there is a Λ**(1116)** peak from $p\pi^-_{4th}$
- it only contributes 3 events under the Θ^+ peak
- add Λ veto as a new cut

Θ^+ Mass spectrum with additional π





- standard cuts applied + K^* and Λ veto
- signal/background: 2:1

- signal/background: 1:3

Production process at HERMES

- can 4th hadron come from exclusive processes?

$$\gamma\, p \rightarrow \overline{K}^0 K^0 p \rightarrow \overline{K}^0 \Theta^+$$

$$\overline{K}^0 \rightarrow \pi^+ \pi^- \qquad \Theta^+ \rightarrow K^0_S\, p \rightarrow \pi^+ \pi^- p$$

$$\gamma\ n \rightarrow K^- K^0 p \rightarrow K^- \Theta^+$$

$$\Theta^+ \rightarrow K^0_S\, p \rightarrow \pi^+ \pi^- p$$

- associated K^- or K_S from exclusive processes goes backward
  - — even decay pions from K_S are inaccessible
  - — PID threshold requires $p(\Theta^+) > 7$ GeV
- tagged pions events cannot come from these exclusive processes
  - $\Rightarrow$ production process has to be at least partially inclusive
    - inclusive processes increase with higher energy
    - exclusive processes decrease with higher energy

Conclusions and Outlook

- Direct reconstruction of Θ^+ invariant mass

$$\mathbf{eD \rightarrow \Theta^+ + X \rightarrow K_s^0 p + X}$$

- Mass: $\mathbf{M} = 1528 \pm 2.6(stat) \pm 2.1(syst)\ \mathbf{MeV}$

  Intrinsic Width: $\Gamma_{\Theta^+} = 17 \pm 9 \pm 3\ \mathbf{MeV}$

  Significance: ~ 4 σ

- Θ^+ is probably an isosinglet
- Requiring additional π improves signal/background, it eliminates K_S contamination from various processes
- Production process is at least partially inclusive
- Anticipate doubling statistics by end of this summer
- Will soon report on Ξ^{--} search and Θ^+ from TOF (low p)

Detector Mass Calibration

	$K_s^0 p \to \pi^+\pi^-$	$\Lambda(1116) \to p\pi^-$	$\Lambda(1520) \to pK^-$	$\Xi^-(1321) \to p\pi^-\pi^-$
HERMES Mass[MeV]	**496.8±0.2**	**1115.70±0.01**	**1522.7±1.9**	**1321.5 ±0.3**
PDG Mass[MeV]	**497.67**	**1115.68**	**1519.5±1.0**	**1321.31±0.13**
σ width (data)[MeV]	**6.2±0.2**	**2.6±0.1**	**4.4±3.7**	**3.1 ±0.3**
σ width (MC)[MeV]	**5.4**	**2.1**	**3.5**	**2.5**
Decay Pcm[MeV/c]	**206**	**101**	**244**	**139($\Lambda\pi^-$)**

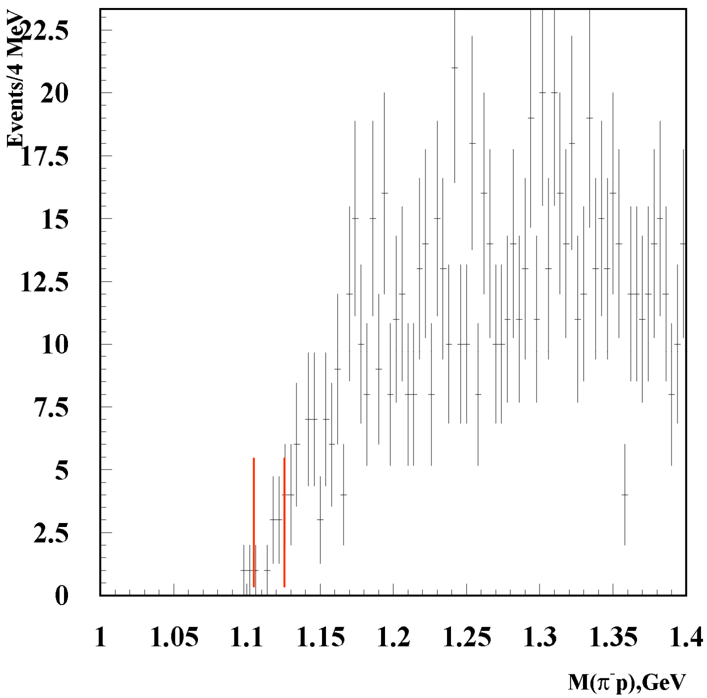
→ **invariant mass reconstruction of known particles**

→ **full MC simulation reproduces data well**

→ **±2MeV systematics**

Fake Peaks?

- particle miss-assignment
  - ghost tracks
  - PID "leaks"



- cut of $\pm 2\sigma$ on $M(K_s)$
- <10 events within $\pm 3\sigma$ of M_Λ