

The  $\Theta^+$

# Pentaquark

Search at HERMES

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Collaboration

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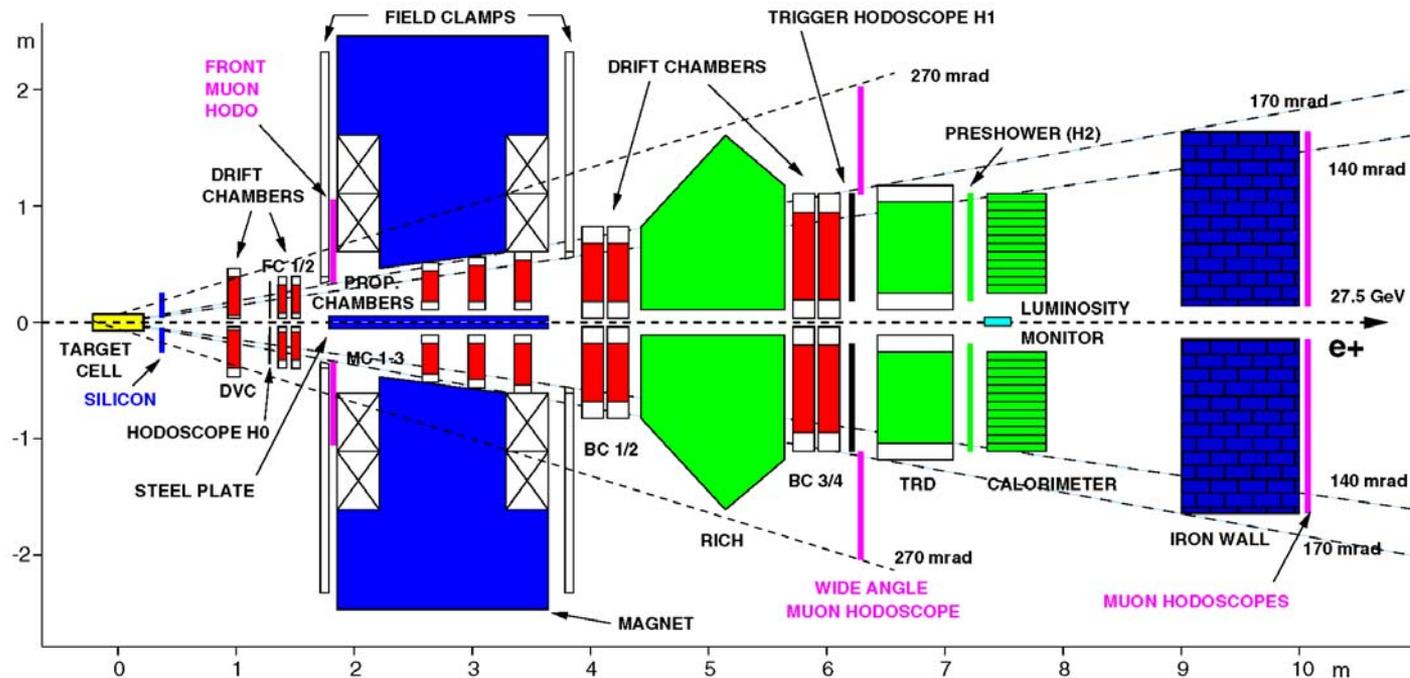
# Introduction

- HERMES is 6<sup>th</sup> group to **report evidence** for the  $\Theta^+$  pentaquark
  - quasi-real photo production at high energy on deuterium target in inclusive  $p K_s X$
- **Features of analysis:**
  - **new RICH P-matrices** (effic., contam.) derived using MC (Pythia)
  - MC (Pythia) **simulation of background** (very time consuming)
  - $\Theta^+$  **"toy Monte Carlo"** (gives instrumental resolution and acceptance)
  - various systematic studies
  - provide more **concise information** related to its **mass** and **isospin** (wait for publication)

# Experimental Evidence from HERMES

quasi-real photo production on deuterium target with decay mode:

$$\Theta^+ \rightarrow p K_s^0 \rightarrow p \pi^+ \pi^-$$

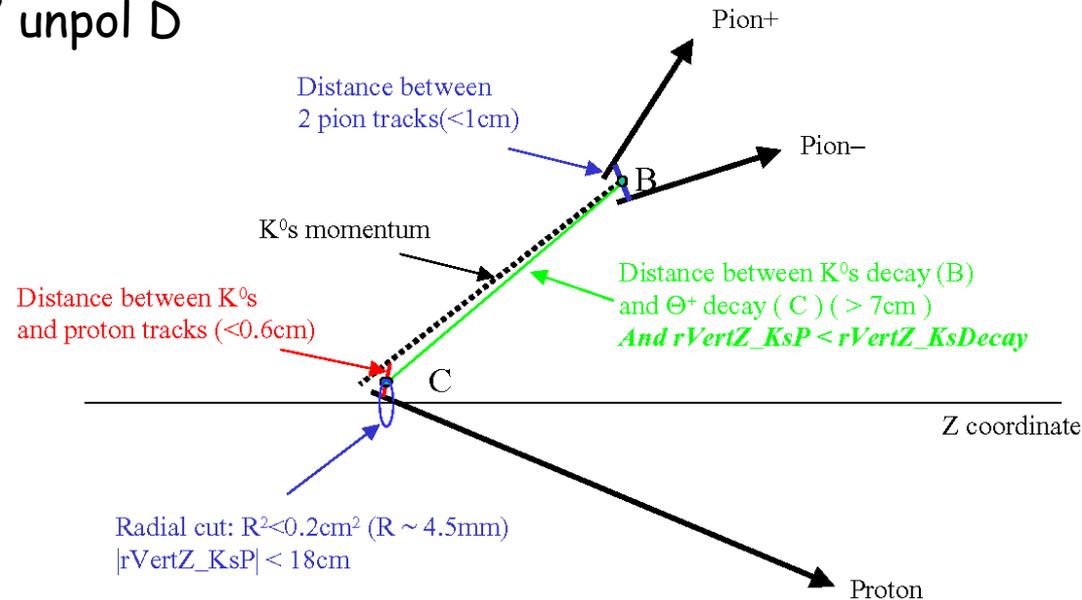


**Trigger:** coincidence between hodoscope, preshower, calorimeter

**Events:** at least  $\pi^+ \pi^-$  pair in coincidence with a proton

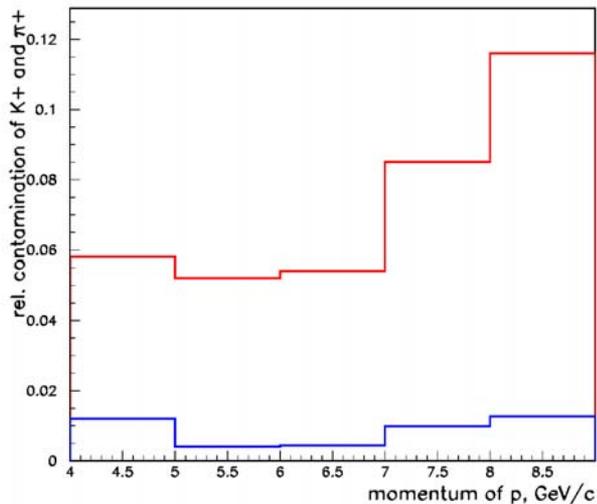
# Data Set, Event Reconstruction, Cuts

- $E_{\text{beam}} = 27.6 \text{ GeV}$ , Target: pol/ unpol D
- Reaction:  $eD \rightarrow p K_s X$
- Data set used: 1998-2000
- RICH identification of  $p$  and  $\pi$
- Momentum range:  
 $\pi$  (1-15 GeV)  $p$  (4-9 GeV)
- Cuts: data quality, distance between two  $\pi$ ,  $K_s$ ,  $p$ ,  $\Theta^+$  beam
- $K_s$ : decay length  $> 7 \text{ cm}$ ,  
 $485 < K_s \text{ mass} < 509 \text{ MeV}$
- Target vertex, fiducial volume cuts on all tracks
- $\Lambda(1116)$  excluded: reject event if  $M(\pi^- p)$  within  $1\sigma$  of nominal  $\Lambda$  mass

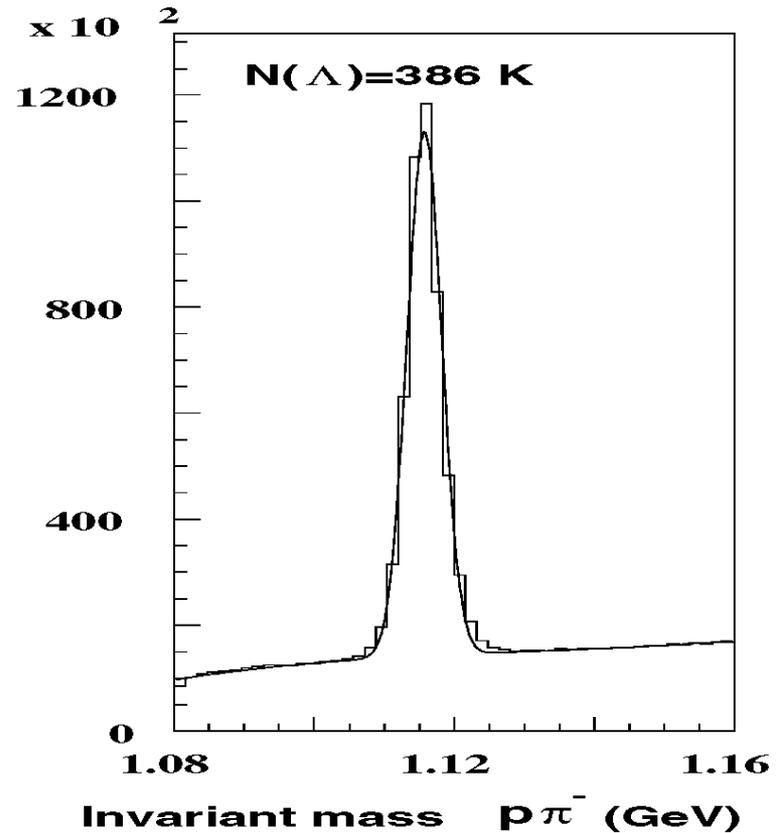


# Proton Identification

- rely heavily on RICH
- RICH performance sensitive to event topology
  - > determine PID efficiencies and cross contaminations
  - > use Pythia MC



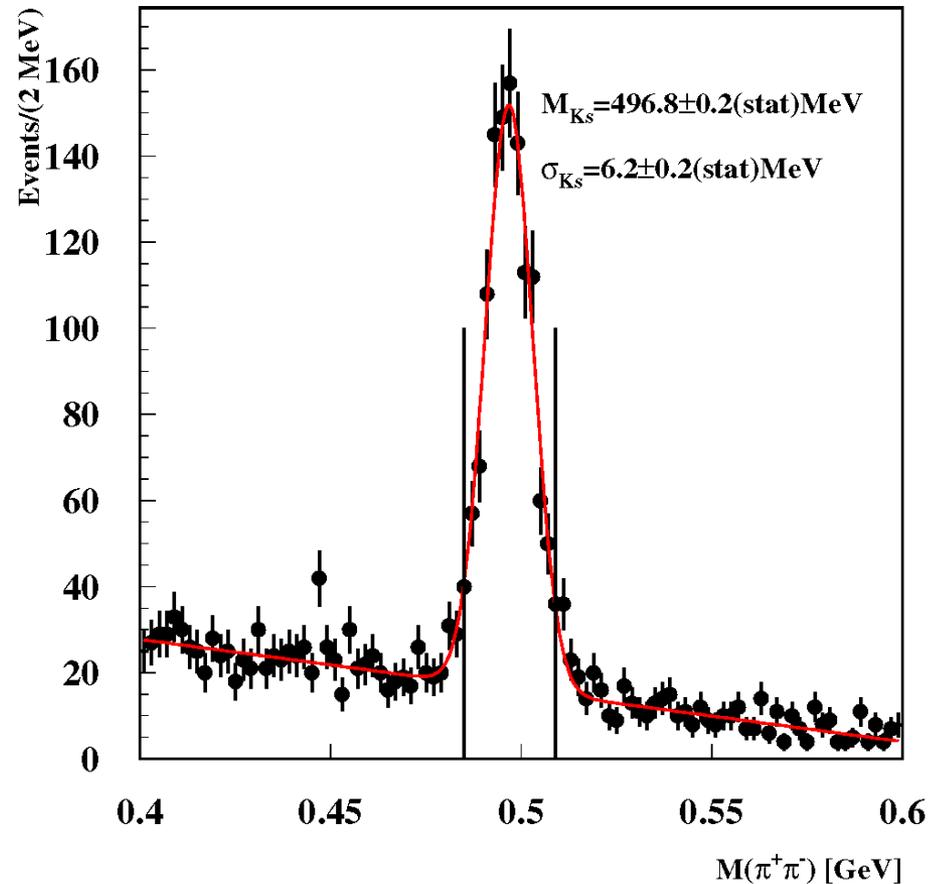
$K^+$  and  $\pi^+$  contamination negligible  
for  $4 < P_p < 9 \text{ GeV}$



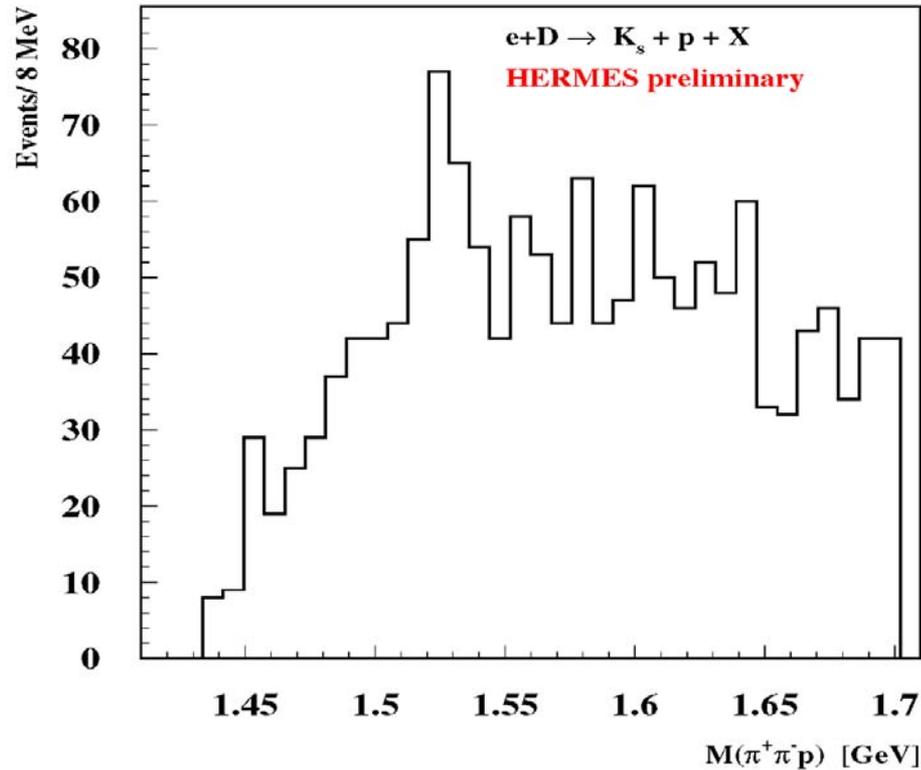
Lambda is well identified =>  
protons are cleanly identified

# $K_S$ Identification

- event selection: constraints on event topology to optimized yield of  $K_S$  peak in  $M(\pi^+\pi^-)$  while minimizing bkg
- NO constraints optimized to increase significance of signal in final  $M(p \pi^+\pi^-)$  -> standard statistical tests can be applied
- subject to all cuts that also appear in  $M(p \pi^+\pi^-)$  spectrum
- $K_S$  after applying all described cuts => well identified  
PDG value:  $497.7 \pm 0.03$  MeV

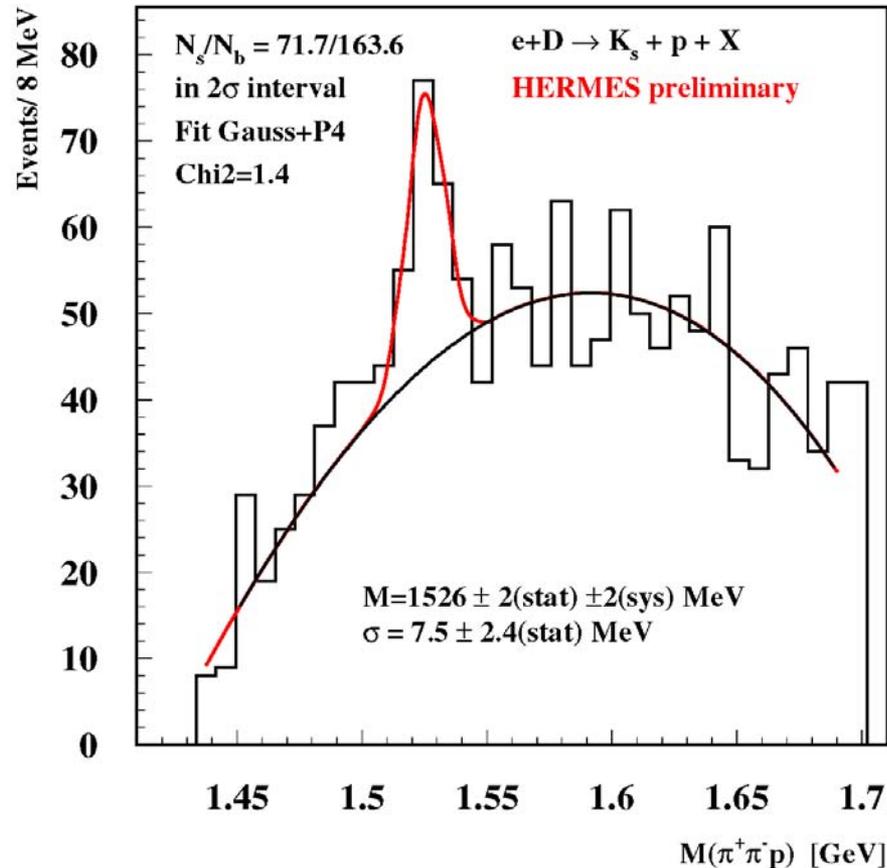


# $M(\rho \pi^+ \pi^-)$ Spectrum



- Excess at 1526 MeV
- Width of  $\sigma=7.5$  MeV dominated by detector resolution

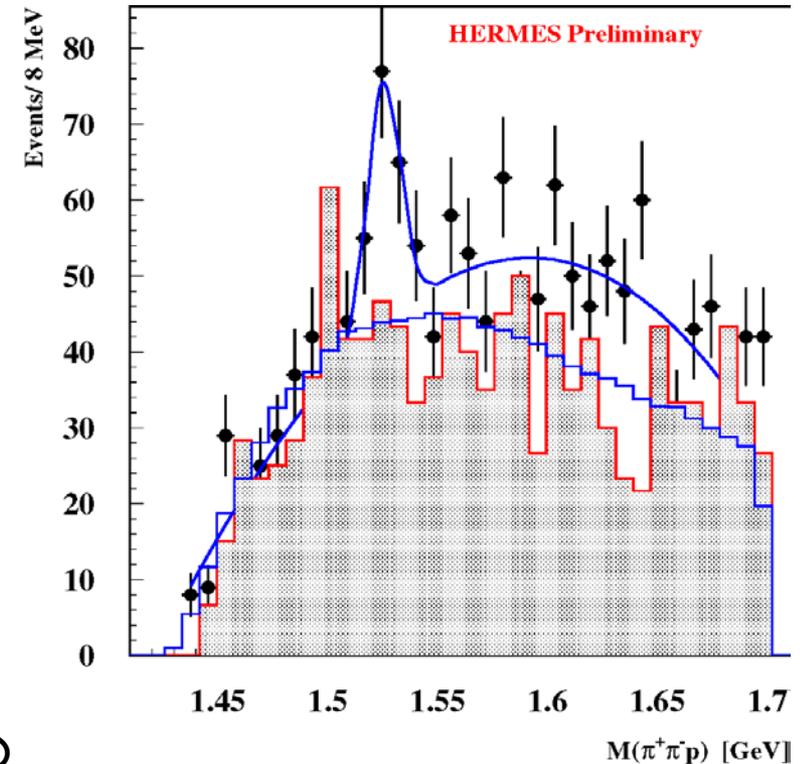
# $M(\rho \pi^+ \pi^-)$ Spectrum with naïve Background Model



- Background approximated by 4<sup>th</sup>-order polynomial
- No known **positive** charged strangeness-containing **baryon** in this mass region to **account** for observed **peak**

# Various (motivated) Background Models

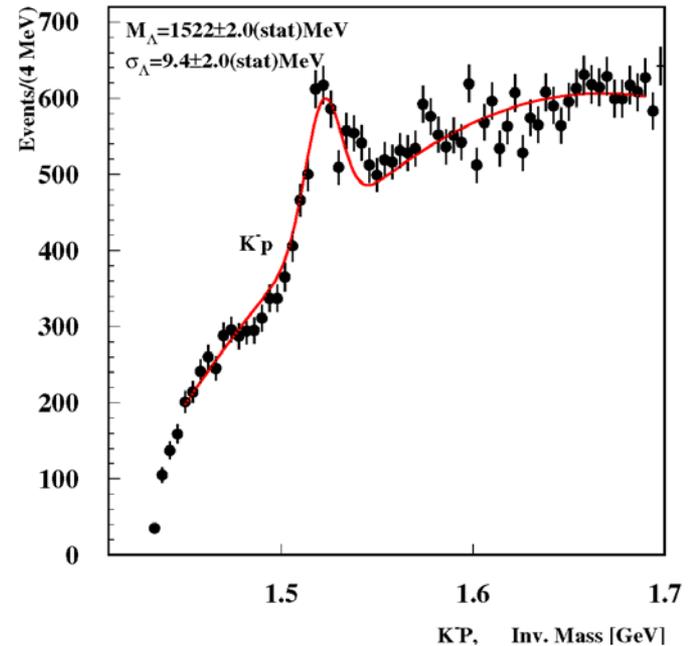
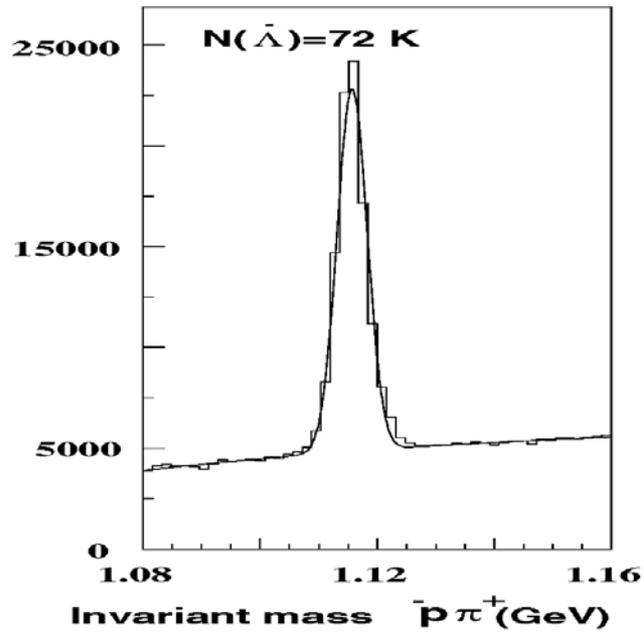
- Polynomial background:
  - appropriate degree determined by using orthonorm. Chebyshev polynomials of various degree
- Pythia6 code tuned for HERMES kinematics:
  - contains no resonances ( $\Theta^+$  or  $\Sigma^{*+}$ ) in mass range 1.4 - 1.7 GeV
    - > remaining strength due to known broad resonances plus new structure
  - MC for  $p$  not  $D$ :  $n$  still produced
    - > realistic mixing for  $D$
- Mixed-event background:
  - non-resonant bkg involves large enough multiplicity so that 4-momenta of  $K_S$  and  $p$  are largely uncorrelated
    - > combine  $K$  and  $p$  from different events
  - contribution of resonances suppressed (only visible because of high correlation between their decay particles)



# Significance

- Naive estimator:  $\sigma = N_s / \sqrt{N_b} = 72 / \sqrt{164} = 5.6$ 
  - neglects uncertainty in background -> overestimates sign. of peak
  - statistics books:  $\sigma = N_s / \sqrt{N_b + \text{var}(N_b)}$  stress 2<sup>nd</sup> factor
- Second estimator:  $\sigma = N_s / \sqrt{N_b + N_s} = 72 / \sqrt{236} = 4.7$ 
  - gives somewhat lower value
  - ??
- "Realistic" estimator:  $\sigma = N_s / \delta N_s = 72 / 17.4 = 4.1$ 
  - $N_s$  area of peak from fitting function,  $\delta N_s$  its fully correlated uncertainty
  - measures how far peak is away from zero in units of its own stand. dev.
  - all correlated uncertainties, incl. of bkg parameters, are accounted for

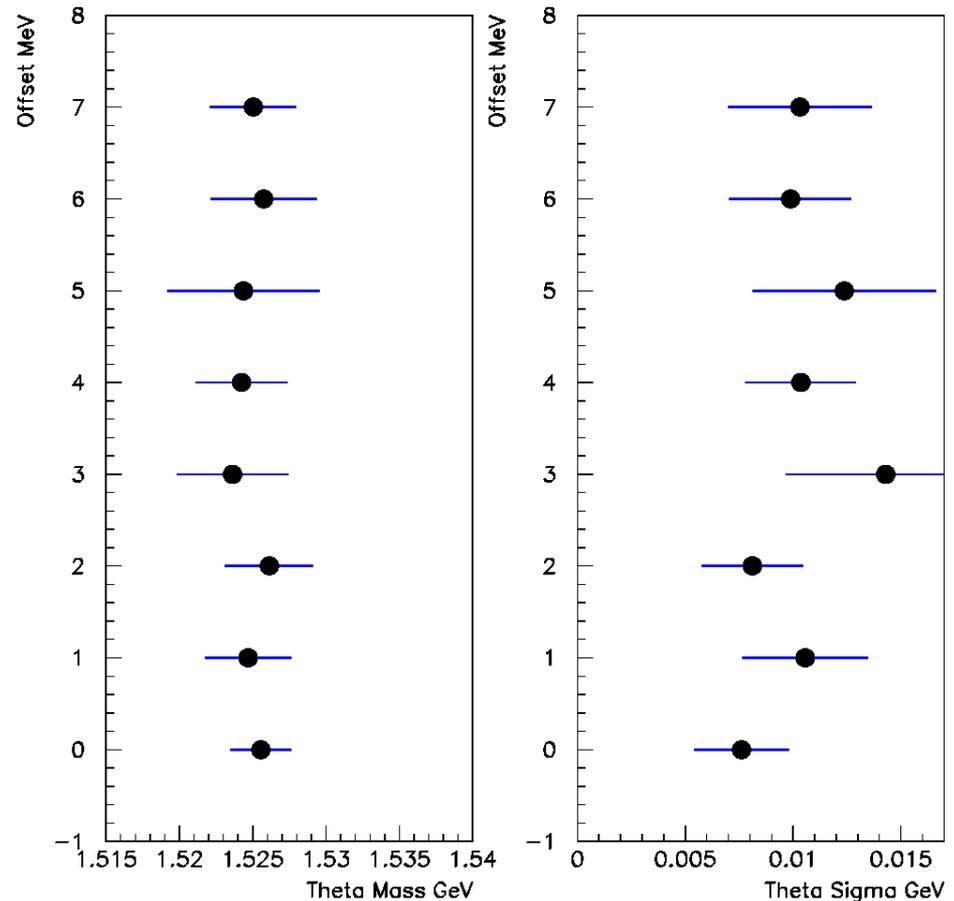
# Detector Mass Calibrations



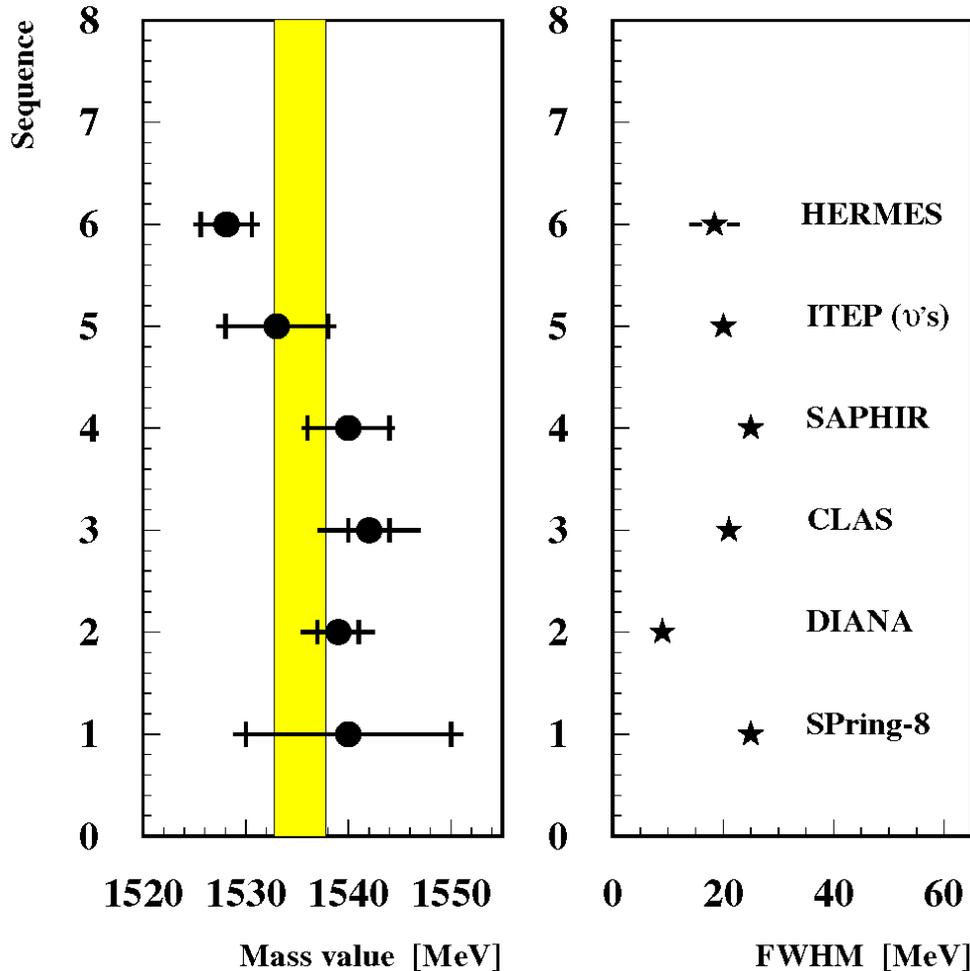
Reconstructed  $\bar{\Lambda}(1116)$ ,  $\Lambda^*(1520)$  in agreement with PDG  $\pm 2 \text{ MeV}$

# $\Theta^+$ Mass

- $\Theta^+$  Mass:  $1526 \pm 2.0 \pm 2.5$  MeV
- syst. uncertainty contributions:
  - various reconstruction algorithms
  - different bkg descriptions
  - reproduction of known particles
    - discrepancy from PDG
    - stat precision of fits
- used unbinned max likelihood fits to original event distributions
  - results of fitting histograms can be sensitive to
    - choice of bin size
    - starting offset



# Comparison with other Experiments



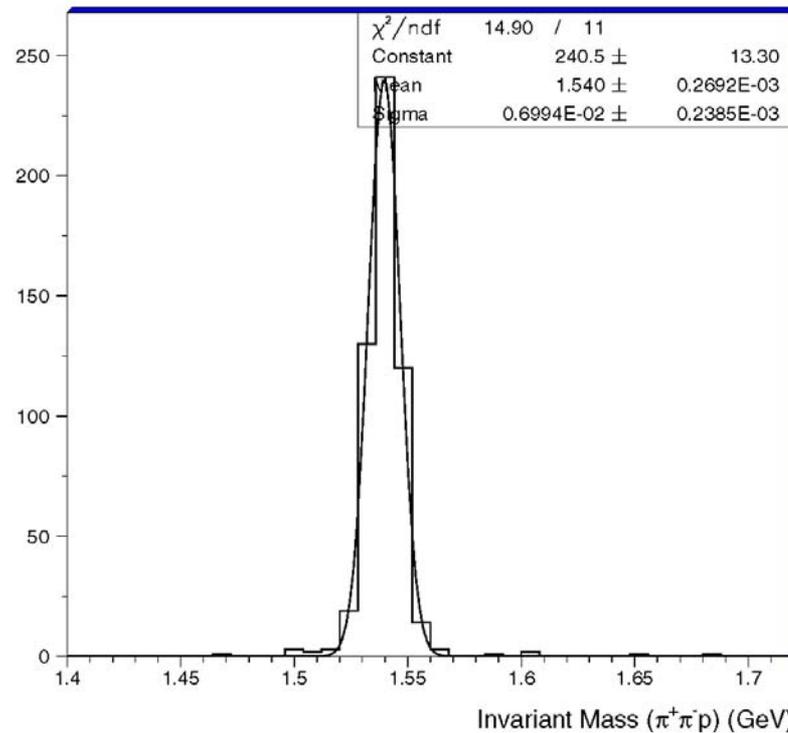
World average:

$\rho^+$  Mass:  $1535 \pm 2.9$  MeV

(taken syst. uncertainty for DIANA and ITEP:  $\pm 3$  MeV)

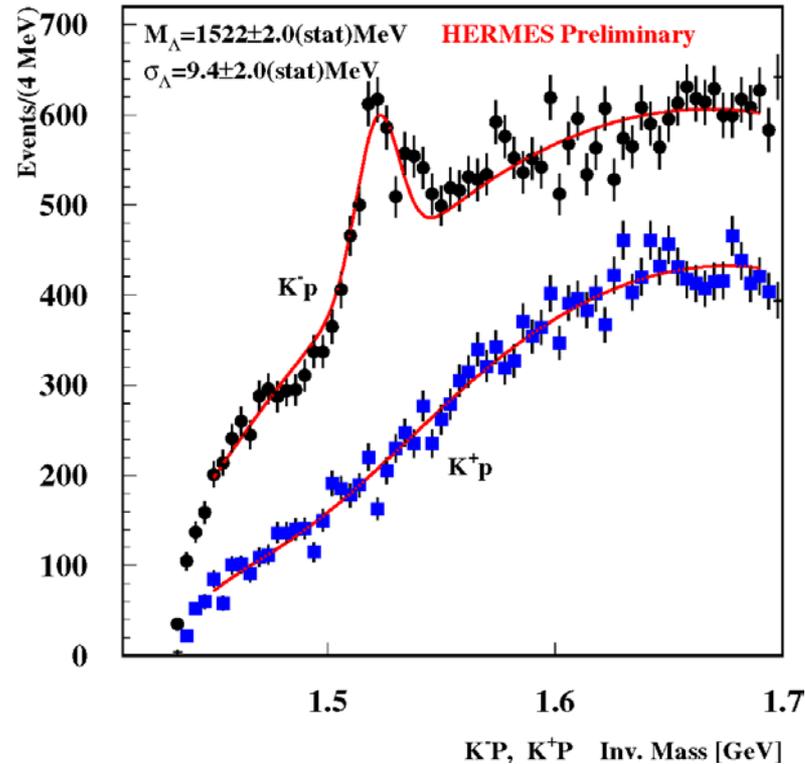
HERMES (prelim.) differs by  $2.1\sigma$  from world average

# Monte Carlo Simulation



- Simulate resonance at 1540 MeV with  $\Gamma = 2$  MeV decaying to  $pK_S$ 
  - study constraints imposed on decay products by kinematics and accept.
- Full detector simulation
- Results: Mass:  $1540 \pm 0.3$  MeV      Width:  $\sigma = 7.0 \pm 0.3$  MeV

# $\Theta^+$ Isospin (prelim.)



- No evidence for  $\Theta^{++}$  peak in  $pK^+$  inv. mass distribution
- HERMES acceptance is 30x larger for  $pK^+$  (and  $pK^-$ ) than for  $pK_S$
- since production cross section unknown  $\rightarrow$  rel. production cross sections for members in multiplet unknown
- If about same  $\rightarrow$  strong evidence that  $\Theta^+$  is **isosinglet**

## Conclusions

- Search for narrow exotic baryon resonance was performed
  - **Target:** Deuterium
  - **Kinematics:** quasi-real photo-production
  - **Reaction:**  $eD \rightarrow pK_S X$
  - **Mass:**  $1526 \pm 2$  (stat)  $\pm 2.5$  (sys) MeV
- Observed **width** of  $\sigma=7.5$  MeV: dominated entirely by exp. resolution
  - $\Gamma < 20$  MeV at 90% c.l.
- **Isospin** constrained by  $pK^+$  invariant mass spectrum
- More details in paper coming soon

# Experimental Evidence for $\Theta^+$

After failing to find any convincing evidence for exotic states for over 30 years:

Experiments	Results				
	Mass (MeV)		Width (MeV)		Significance ( $\sigma$ )
LEPS	$1540 \pm 10 \pm 5$		$\Gamma < 25$		$4.6 \pm 1$
DIANA	$1539 \pm 2 \pm \text{"few"}$		$\Gamma < 8$		4.4
CLAS	$1542 \pm 2 \pm 5$		FWHM $< 21$		$5.3 \pm 0.5$
SAPHIR	$1540 \pm 4 \pm 2$		$\Gamma < 25$		4.8
ITEP ( $\nu$ 's)	$1533 \pm 5$		$\Gamma < 29$		6.7
HERMES	$1526 \pm 2 \pm 2.5$		$\Gamma < 20$		5.6
<b>World Average</b>	<b><math>1535 \pm 2.5</math></b>				
Prediction	<b>1530</b>	<b><math>\Gamma &lt; 15</math></b>	<b>I=0</b>	<b>S=+1</b>	<b><math>J^P = \frac{1}{2}^+</math></b>