

Searching For The Pentaquark at HERMES

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for HERMES Collaboration

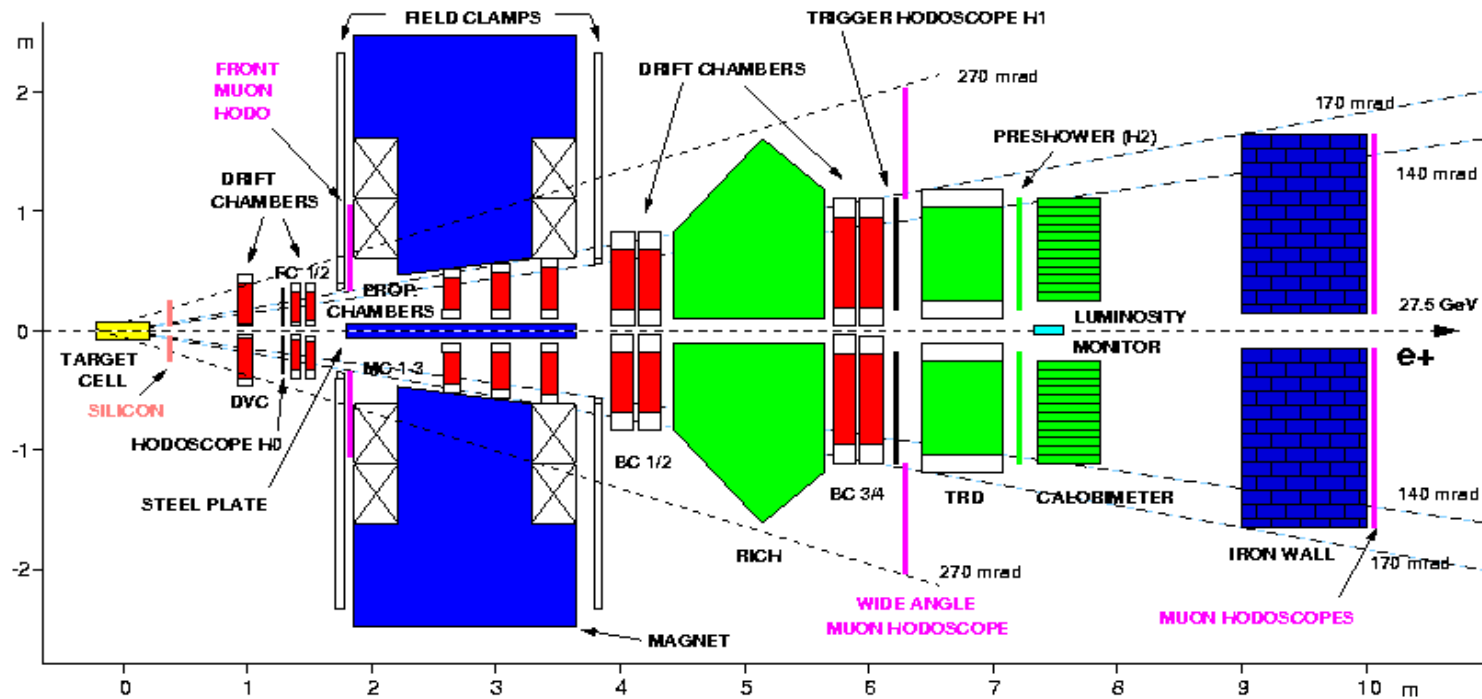
Feb. 18, 2004

- **Introduction**
- **HERMES Spectrometer**
- **Event topology**
- **Particle identification**
- **Background understanding**
- **Isospin, width, cross-section?**
- **Summary**

Introduction

- Quasi-real photo production, from 27.5GeV e^+ scattering off a deuterium target, with decay mode: $\Theta^+ \rightarrow p K_s^0 \rightarrow p \pi^+ \pi^-$
- First evidence at HERMES seen in May, 2003
- Preliminary results released on Sept. 24, 2003
- Shown at the EINN 2003 conference in Santorini (Oct 7-12), and JLab workshop (Nov 7, 2003)
- Submitted to PLB & hep-ex (hep-ex/0312044) on Dec. 16, 2003
- Accepted by PLB on Jan. 29, 2004

The HERMES Spectrometer

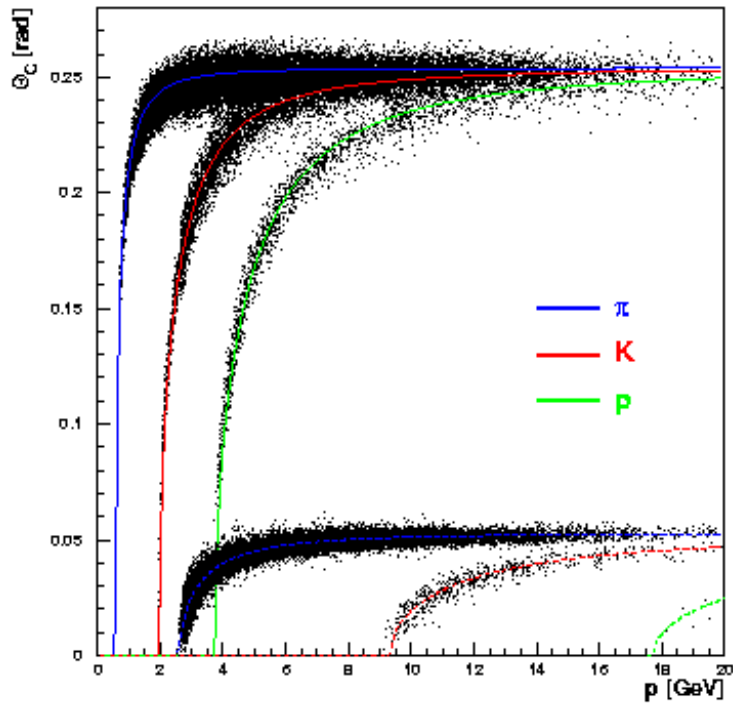


- Resolution: $\delta p/p = 1.4 \dots 2.5\%$, $\delta\Theta \lesssim 1$ mrad
- Particle Identification: TRD, Preshower, Calorimeter, RICH (dual radiator)

Trigger: coincidence between hodoscope, preshower, calorimeter

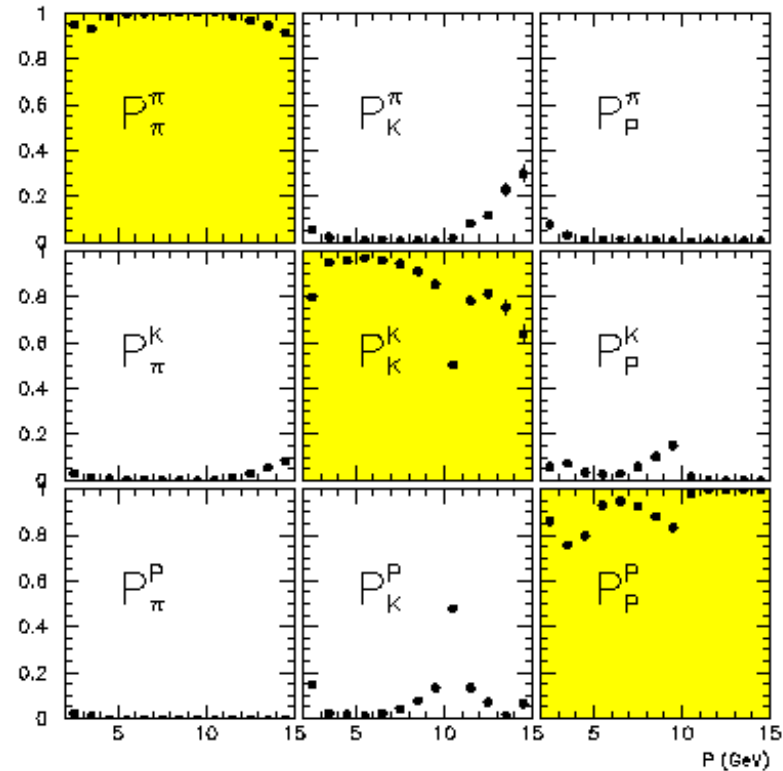
Events: at least $\pi^+\pi^-$ pair in coincidence with a p

The HERMES RICH



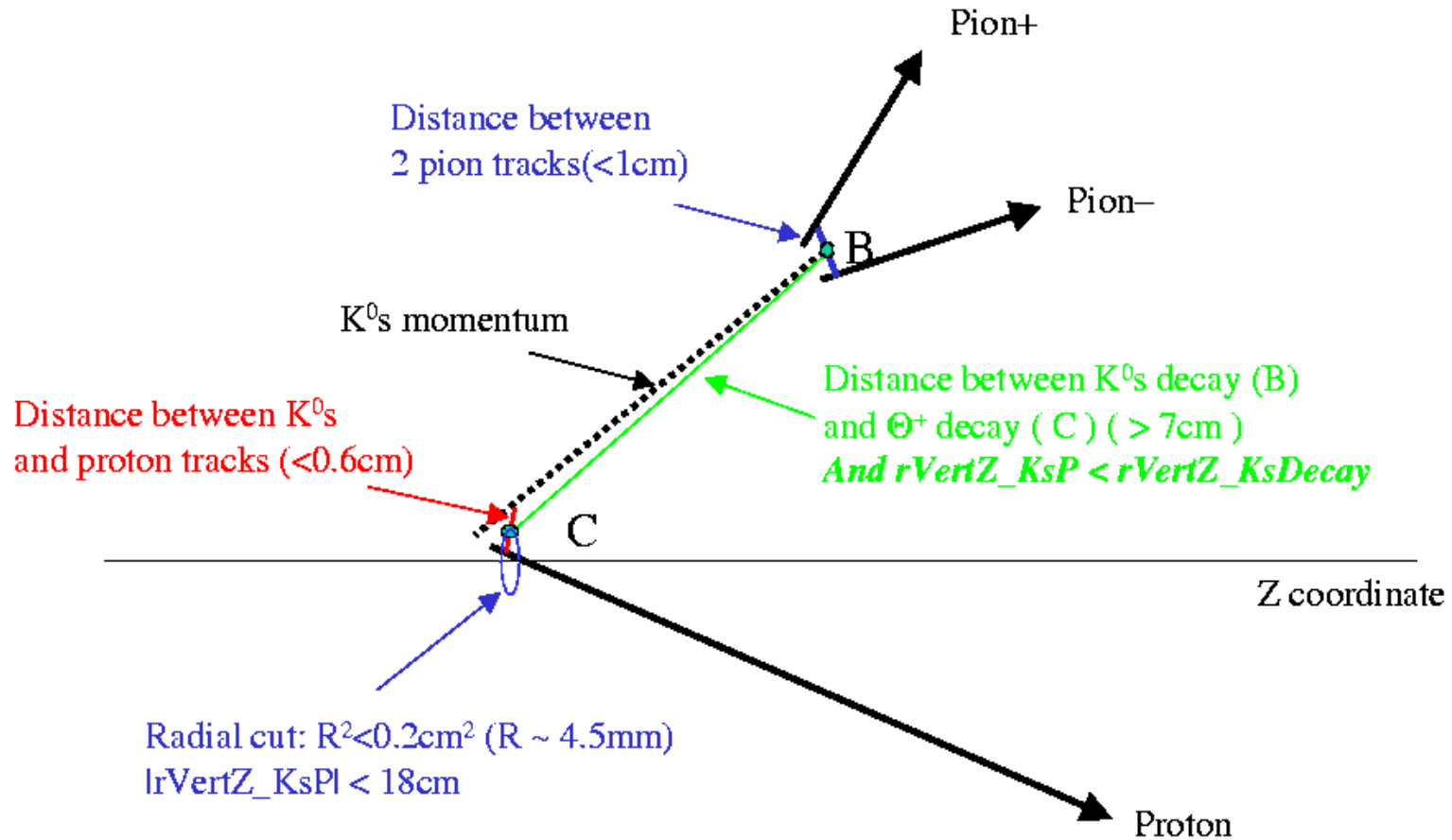
● Particle Identification:

$$\cos\Theta = \frac{1}{n}$$

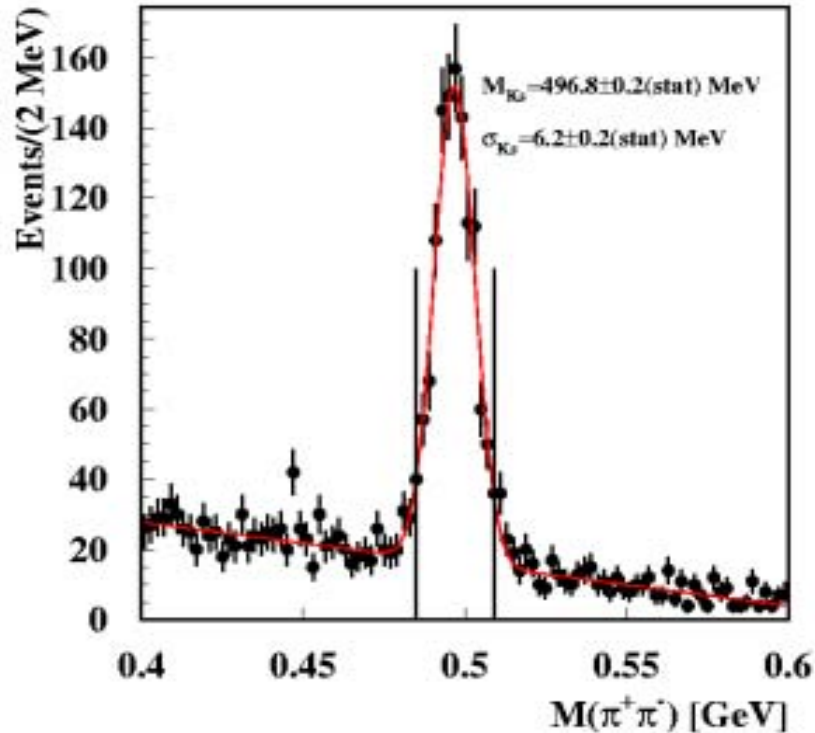


● detection efficiencies

Reconstruction of Θ^+ At HERMES



K_s^0 Identification

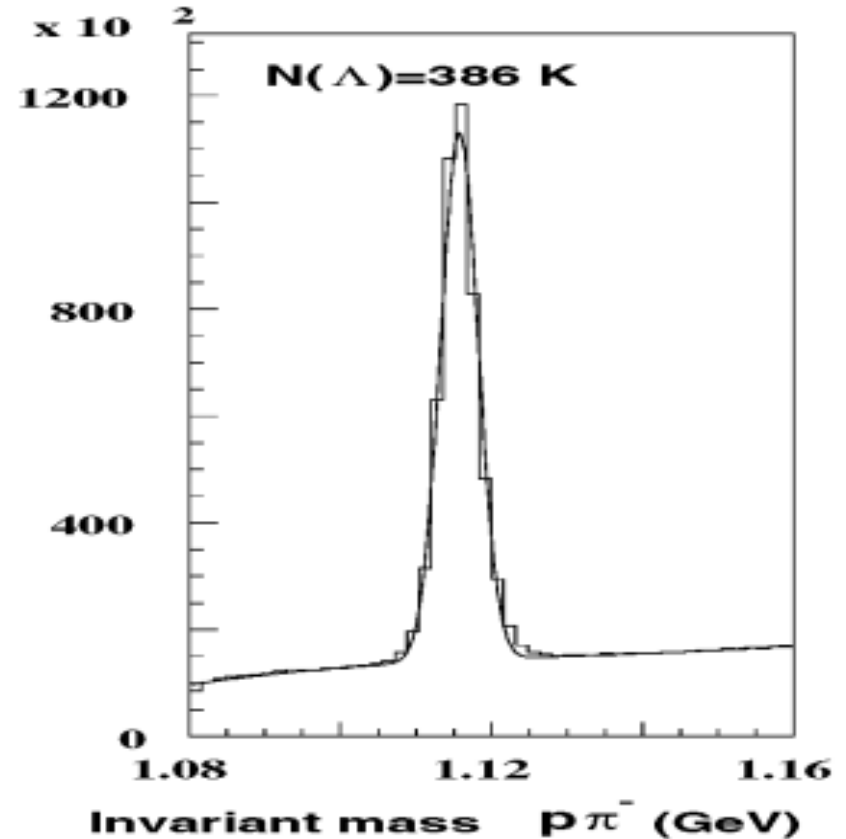
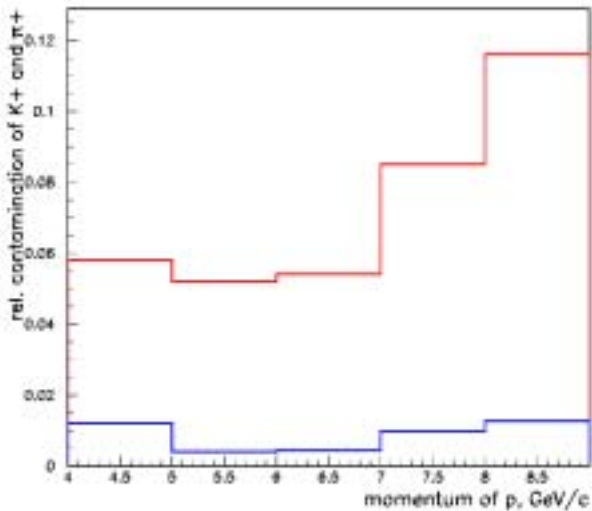


- Pions identified by RICH
- 2-pion distance checked with MC
- 7cm decay length
- $\pm 2\sigma$ mass window

➔ clean K_s^0 samples
signal/background ~ 8:1

Proton Identification

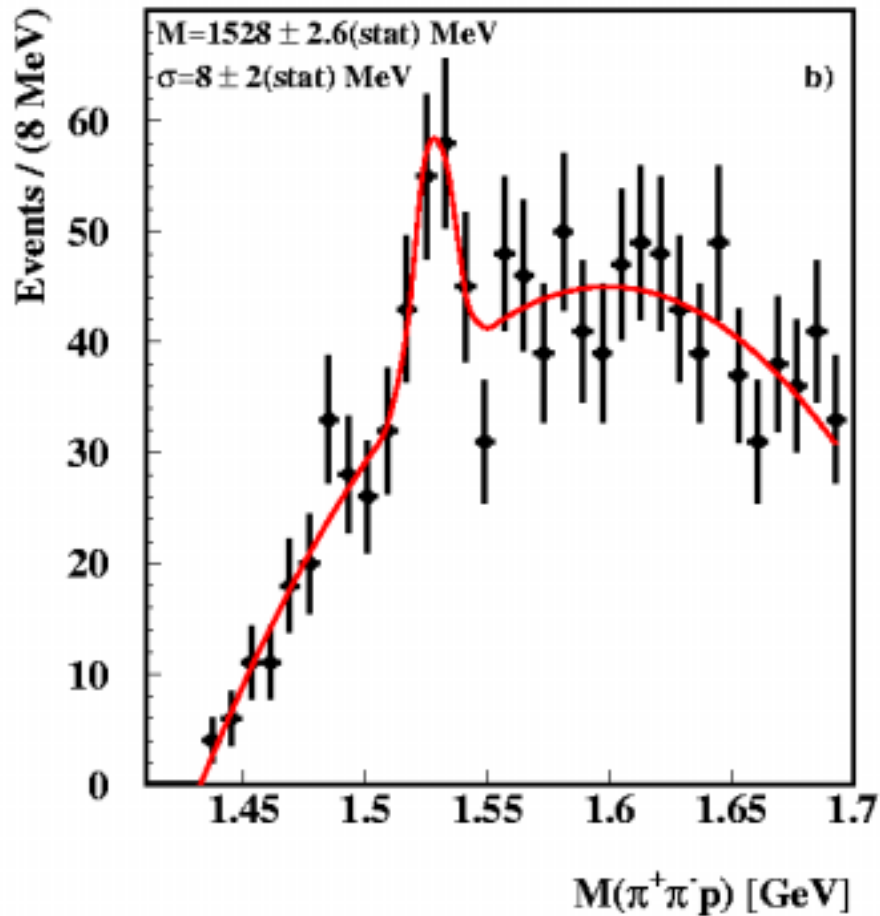
- Rely heavily on RICH
- RICH performance sensitive to event topology
 - ➔ determine PID efficiencies and cross contaminations
 - ➔ use Pythia MC



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

Lambda is well identified => protons are cleanly identified

Fitting With A Polynomial Background



Resonance is observed at

$$1528 \pm 2.6 \pm 2.1 \text{ MeV}$$

Width is

$$\text{FWHM} = 19 \pm 5 \pm 2 \text{ MeV}$$

Naïve significance $\frac{N_s}{\sqrt{N_b}}$ in $\pm 2\sigma$

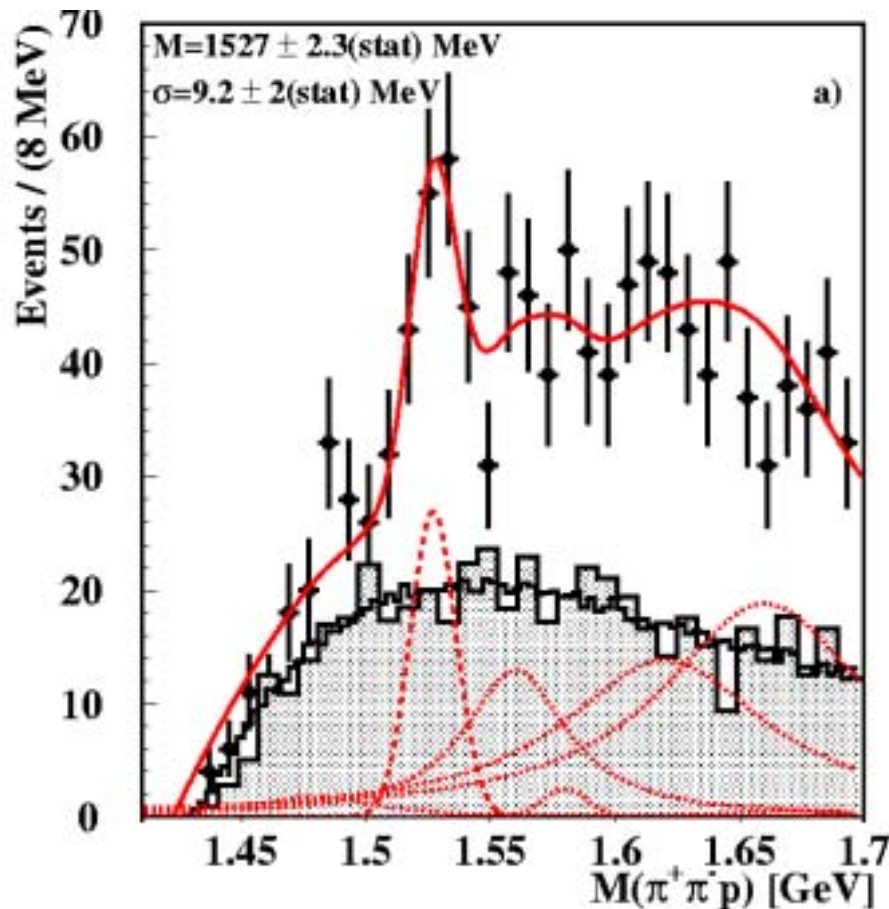
$$56 / \sqrt{144} \sim 4.7\sigma$$

True significance $\frac{N_s}{\delta N_s}$

$$59/16 \sim 3.7\sigma$$

Unbinned fit is used: *result doesn't depend on bin size and starting point*

Efforts To Reproduce Background



Non-resonance BG

(PYTHIA MC, confirmed by
Event Mixing Technique)

+ Existing Σ^*s ?

Resonance is observed at

$$1527 \pm 2.3 \pm 2.1 \text{ MeV}$$

Width is

$$\text{FWHM} = 22 \pm 5 \pm 2 \text{ MeV}$$

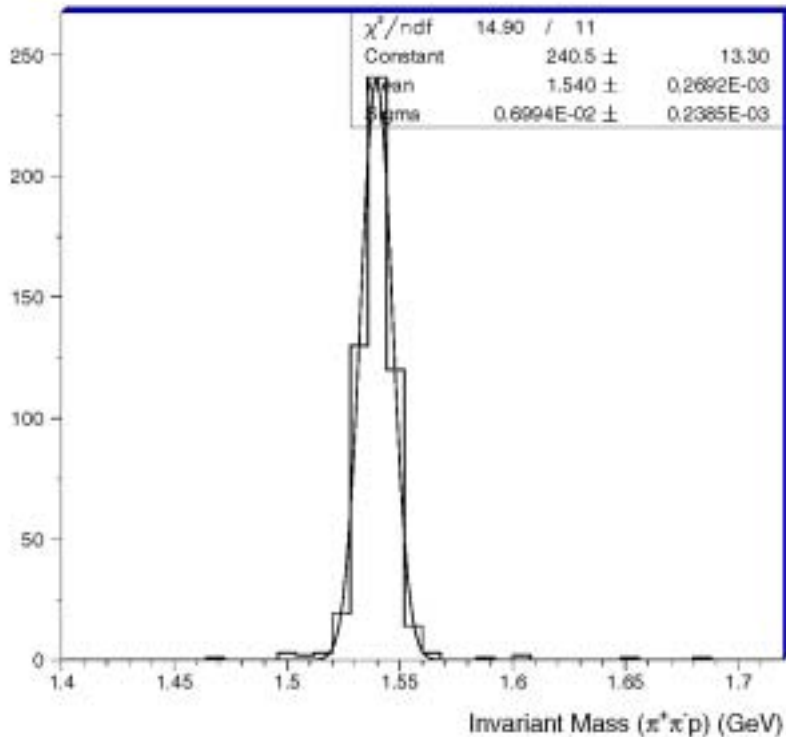
Naïve significance

$$74/\sqrt{145} \sim 6.1\sigma$$

True significance

$$78/18 \sim 4.3\sigma$$

What A Toy Θ^+ MC Can Tell



$M(\pi^+\pi^-p)$: $M=1540 \pm 0.3$ MeV $\sigma=6.2 \pm 0.3$

$M(K_s^0 p)$: $M=1540 \pm 0.3$ MeV $\sigma=4.3 \pm 0.3$ MeV

- Assuming $M(\Theta^+) = 1540$ MeV
 $\Gamma(\Theta^+) = 2$ MeV
 p_z : monotonic fall, p_t : gaussian
- Full detector simulation
- Apply same set of cuts as on data, also analyze with same code
 - ➔ to understand each cut, especially acceptance cuts
 - ➔ to study acceptance
 - ➔ to compare $M(\pi^+\pi^-p)$ and $M(K_s^0 p)$ spectra.

Comparison of Results For $M(K_s^0 p)$ And $M(\pi^+ \pi^- p)$ Spectra

	Θ^+ Mass [MeV]	FWHM [MeV]	N_s in $\pm 2\sigma$	N_b in $\pm 2\sigma$	Naïve signif.	Total $N_s \pm \delta N_s$	Signif.
a)	$1527.0 \pm 2.3 \pm 2.1$	$22 \pm 5 \pm 2$	74	145	6.1σ	78 ± 18	4.3σ
a')	$1527.0 \pm 2.5 \pm 2.1$	$24 \pm 5 \pm 2$	79	158	6.3σ	83 ± 20	4.2σ
b)	$1528.0 \pm 2.6 \pm 2.1$	$19 \pm 5 \pm 2$	56	144	4.7σ	59 ± 16	3.7σ
b')	$1527.8 \pm 3.0 \pm 2.1$	$20 \pm 5 \pm 2$	52	155	4.2σ	54 ± 16	3.4σ

without ', Results from $M(\pi^+ \pi^- p)$ spectrum

With ', Result from $M(K_s^0 p)$ spectrum

a), a') are for the background model of MC BG+ Σ^* resonances

b), b') are for the background model of 3rd order of polynomial

Known Particles As References

	$K_s^0 p \rightarrow \pi^+ \pi^-$	$\Lambda(1116) \rightarrow p \pi^-$	$\Lambda(1520) \rightarrow p K^-$	$\Sigma^-(1321) \rightarrow p \pi^- \pi^-$
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($\Lambda \pi^-$)

- ➔ **HERMES can precisely measure the above known particles**
- ➔ **The MC well reproduce the data**
- ➔ **The systematic error estimated is about 1.9MeV**

A Non-Zero Width For Θ^+ ?

- Observed width FWHM $\sim 19 - 24\text{MeV}$
- Detector resolution (from MC)
FWHM $\sim 10-14.6\text{MeV}$ ($\sigma = 4.3-6.2\text{MeV}$)

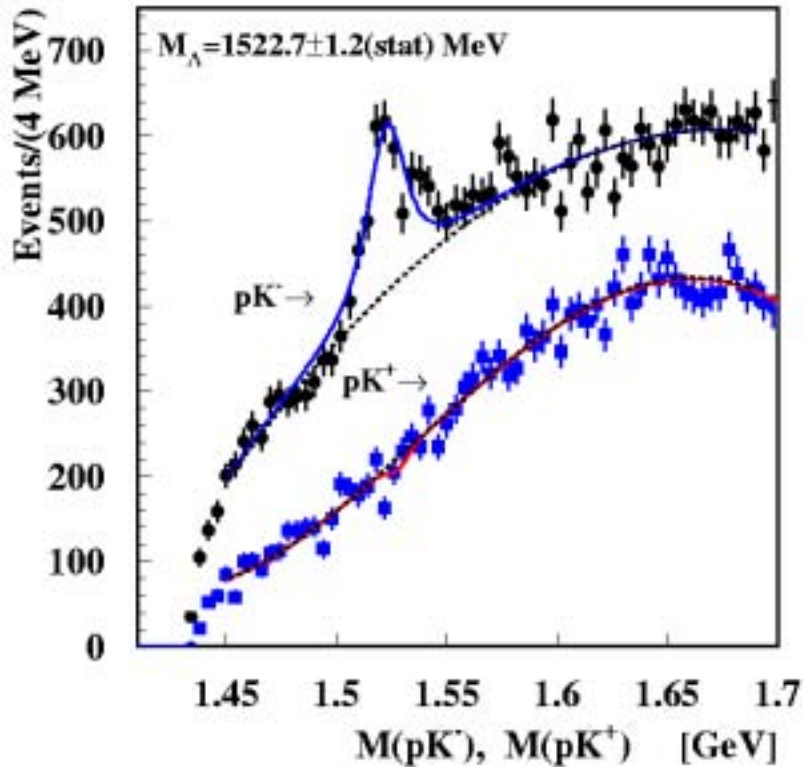
➔ *Re-fit the spectra with Breit-Wigner convoluted with a gaussian*

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- | | | | |
|------|----|---------------------------------------|---|
| a) | BW | $\Gamma = 12 \pm 9 \pm 3\text{MeV}$, | fixed gaussian $\sigma = 6.2\text{MeV}$ |
| a ') | BW | $\Gamma = 20 \pm 8 \pm 3\text{MeV}$, | fixed gaussian $\sigma = 4.3\text{MeV}$ |
| b) | BW | $\Gamma = 8 \pm 8 \pm 3\text{MeV}$, | fixed gaussian $\sigma = 6.2\text{MeV}$ |
| b ') | BW | $\Gamma = 13 \pm 9 \pm 3\text{MeV}$, | fixed gaussian $\sigma = 4.3\text{MeV}$ |
-

Took average of a ') & b ') for the better resolution

➔ **HERMES width: $\Gamma = 17 \pm 9 \pm 3\text{MeV}$**

Θ^+ Isospin From HERMES



- Clear $\Lambda(1520)$ is observed in pK^- spectrum
- No peak structure in pK^+ mass spectrum, gaussian+polyn. fitting shows 0 counts with 91% C.L.

isotensor, rule out
isovector, unlikely

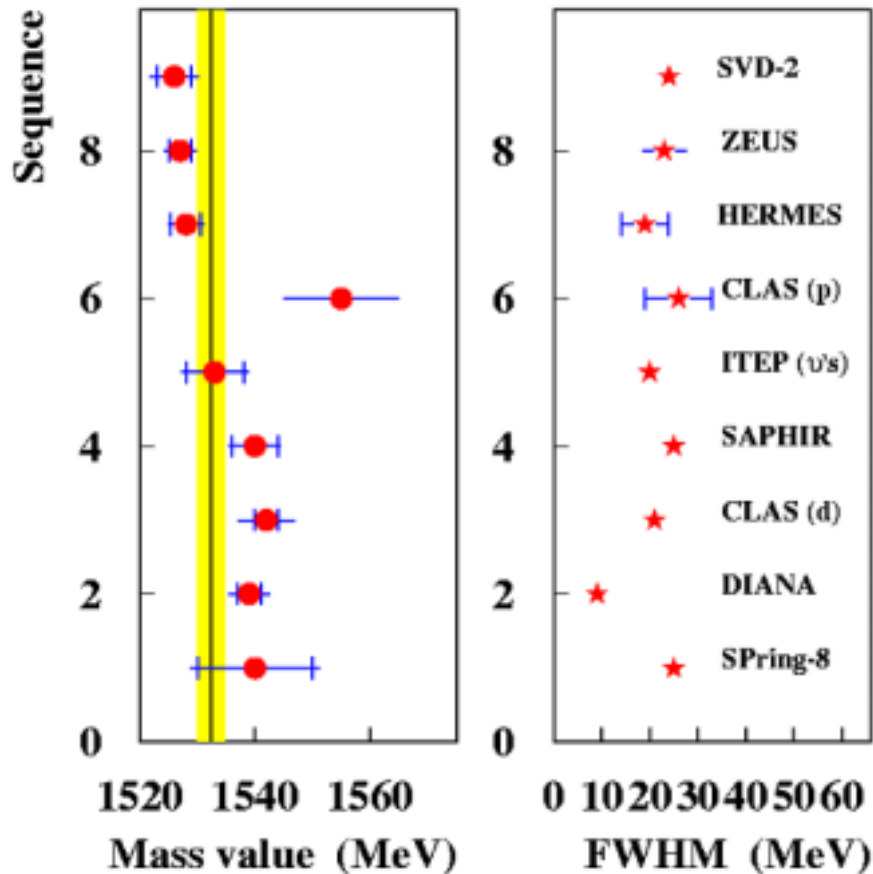
➔ **isosinglet, very likely**

Production Cross-Section?

- Integrated luminosity: 250pb^{-1}
- Acceptance from MC: 1.5% for $\Lambda(1520)$, 0.05% for Θ^+
- Branch ratio to final state
- Flux factor
- Observed signals

➔ *HERMES estimate:* $\sigma(\Lambda) = 62 \pm 11 \text{ nb}$
 $\sigma(\Theta) = (100-220\text{nb}) \pm 25\%(\text{stat.})$

Comparison With Other Experiments



- For a better comparison, take result from simply BG fitting
- Left panel: mass average = $1532 \pm 2.4 \text{ MeV}$ (take $\pm 3 \text{ MeV}$ of syst. error for ITEP, DIANA)
- Right panel: width FWHM (include detector resolution)

Summary

- A narrow exotic resonance is observed at $1528 \pm 2.6 \pm 2.1$ MeV in quasi-real photo-production via $eD \rightarrow K_s^0 pX$ reaction at HERMES
- **The resonance is stable** against event topologies, 2 or 3 body mass calculation and no special cut is required
- The mass calibration with known particles shows HERMES can provide **a precise mass measurement**
- A width of the resonance, $\Gamma = 17 \pm 9 \pm 3$ MeV, is extracted
- **Isosinglet is preferred** due to lack in peak structure in pK^+ mass spectrum
- A production **cross-section, (100-220nb) $\pm 25\%$ (stat.)**, is estimated