Search for exotic baryons at HERMES

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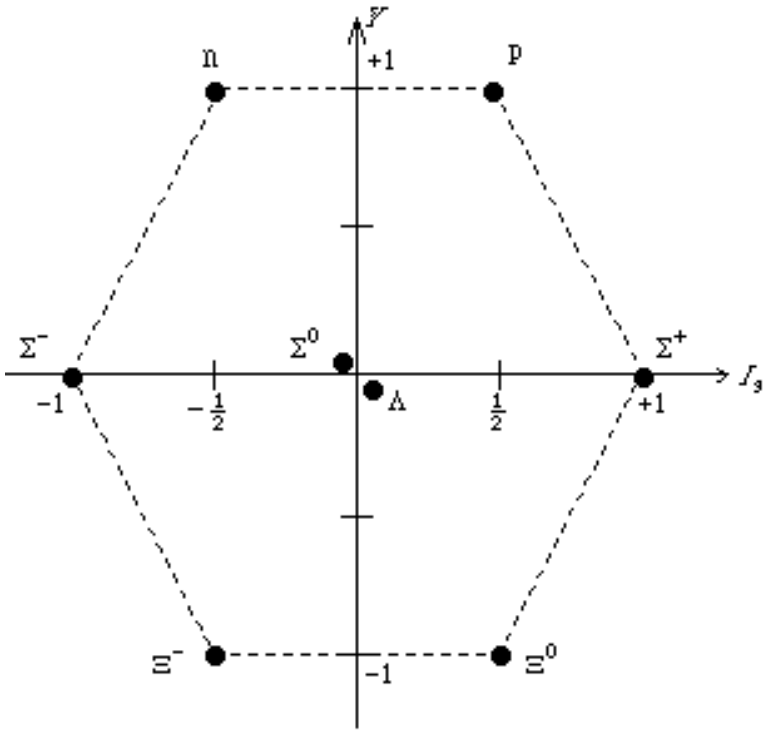
Overview

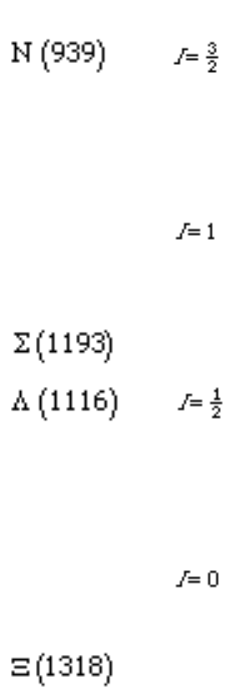
- Introduction
- HERA and the HERMES Experiment
- Exotics analysis at HERMES
  - $\Theta(1540)$ analysis
  - Additional $\Theta(1540)$ studies
  - Related $\Lambda(1520)$ studies
- Conclusions

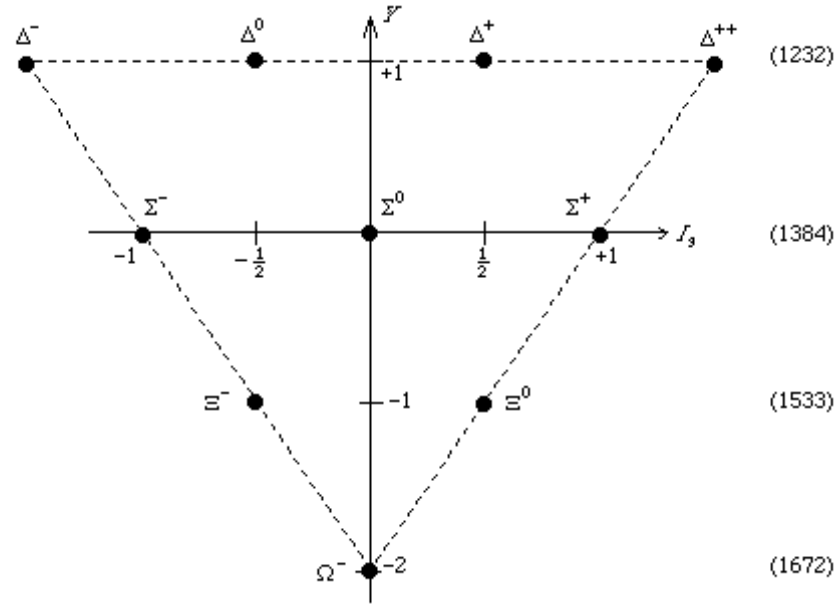
QCD with light quarks (u, d, s)

Multiplets of hadronic states

- Light mesons ($q\overline{q}$) $\rightarrow \mathbf{3}_f \times \overline{\mathbf{3}}_f = \mathbf{1} + \mathbf{8}$
- Light baryons (qqq) $\rightarrow \mathbf{3}_f \times \mathbf{3}_f \times \mathbf{3}_f = \mathbf{1} + \mathbf{8} + \overline{\mathbf{8}} + \mathbf{10}$







QCD with light quarks (u, d, s)

More than 3 quarks

- *Exotic mesons* ($qq\overline{q}\overline{q}$) have ≥ 4 quarks, integer spin
- *Exotic baryons* ($qqqq\overline{q}$) have ≥ 5 quarks, half-integer spin

Quark sea

This happens all the time in the quark sea!
A proton can also be $uud + s\overline{s}$ (*crypto-exotic*), but mixes with uud.

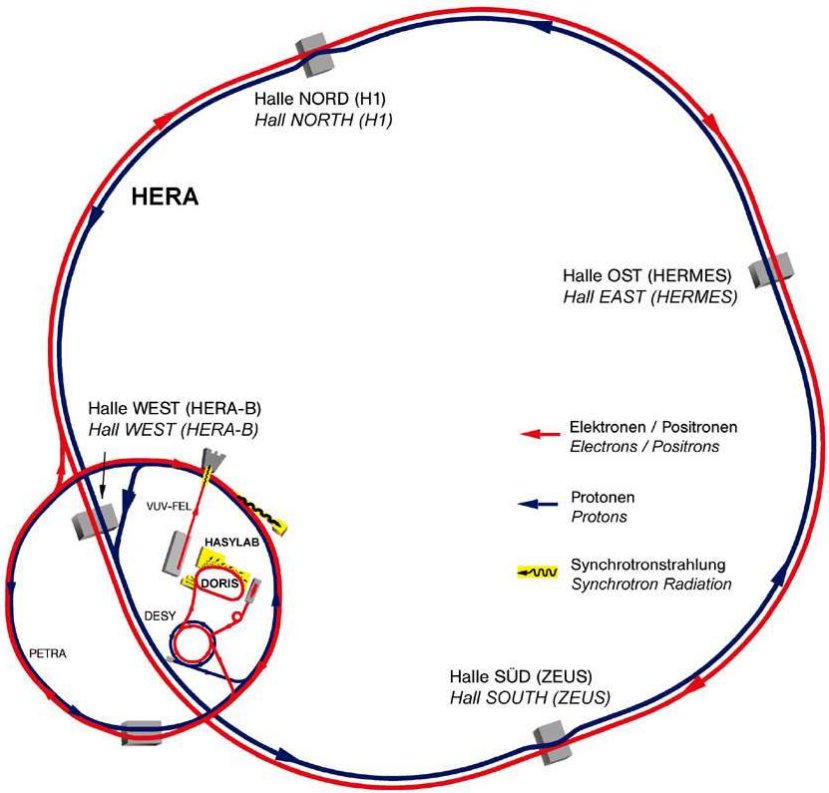
Manifestly exotic baryons (pentaquarks)

- Minimum quark content: 4 q and 1 $\overline{q}$
- $\overline{q}$ has a different flavor!
- Quantum numbers can only be obtained with five or more quarks (*e.g.* $uudd\overline{s}$ has strangeness $+1$)


В. ПОЛЯКОВ
МИР

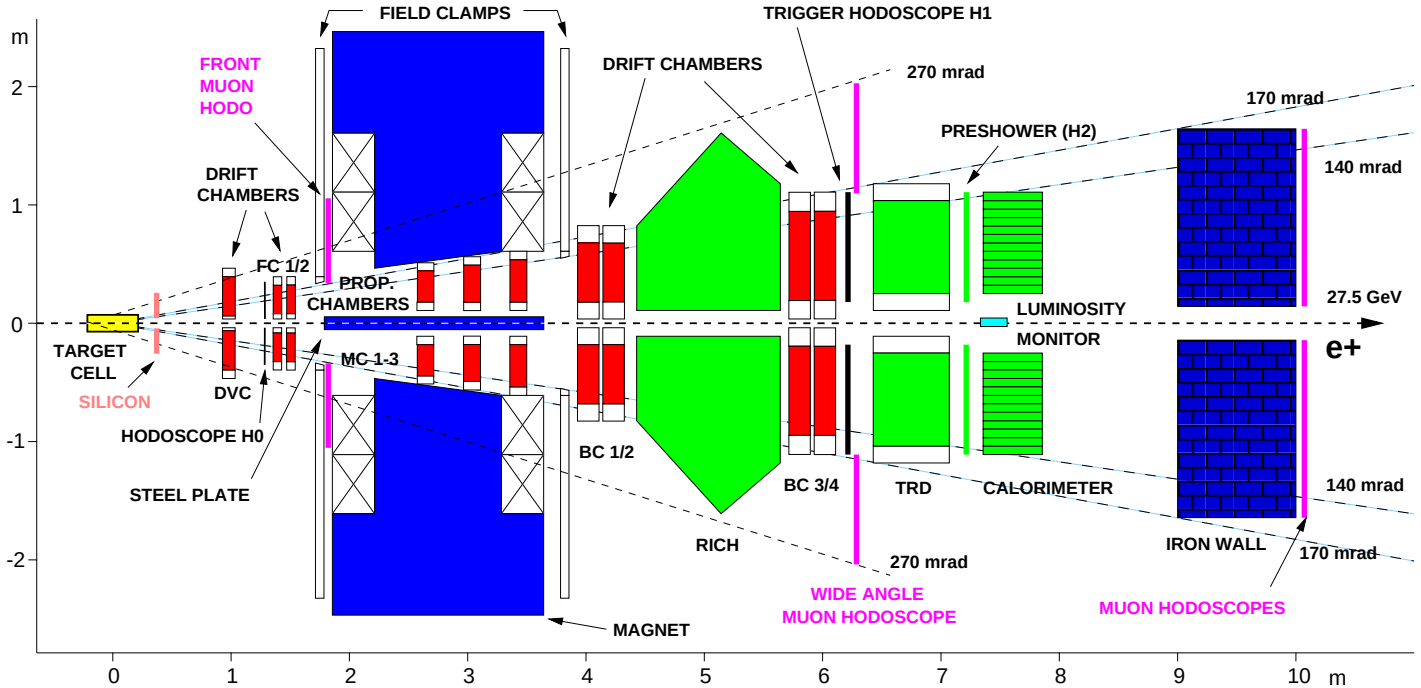
The HERA Accelerator

The HERA Accelerator



- Particle/nuclear physics
  - H1, ZEUS: 27.5 GeV e on 920 GeV p
  - HERMES: 27.5 GeV e on A
  - HERA-B: 920 GeV p on A
- Synchrotron radiation
  - HASYLAB
  - VUV-FEL
  - XFEL (ready: 2013)

The HERMES Spectrometer



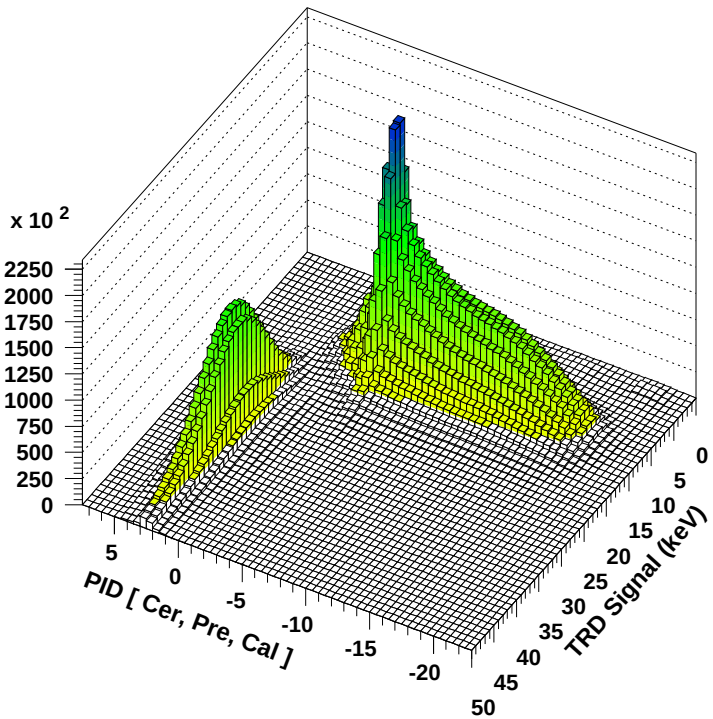
- 27.6 GeV $e^{\pm}$ HERA beam on $\overrightarrow{H}$, $\overrightarrow{He}$, $\overrightarrow{D}$ or H_2, D_2, He,...
- Resolution: $\frac{\Delta p}{p}$ = 1.4 – 2.5%, $\Delta\vartheta \lesssim 0.6$ mrad
- TRD, Calorimeter and Preshower: hadron/lepton separation
- RICH: hadron identification (p, π, K)

The HERMES Spectrometer

Hadron/lepton separation:

combination of

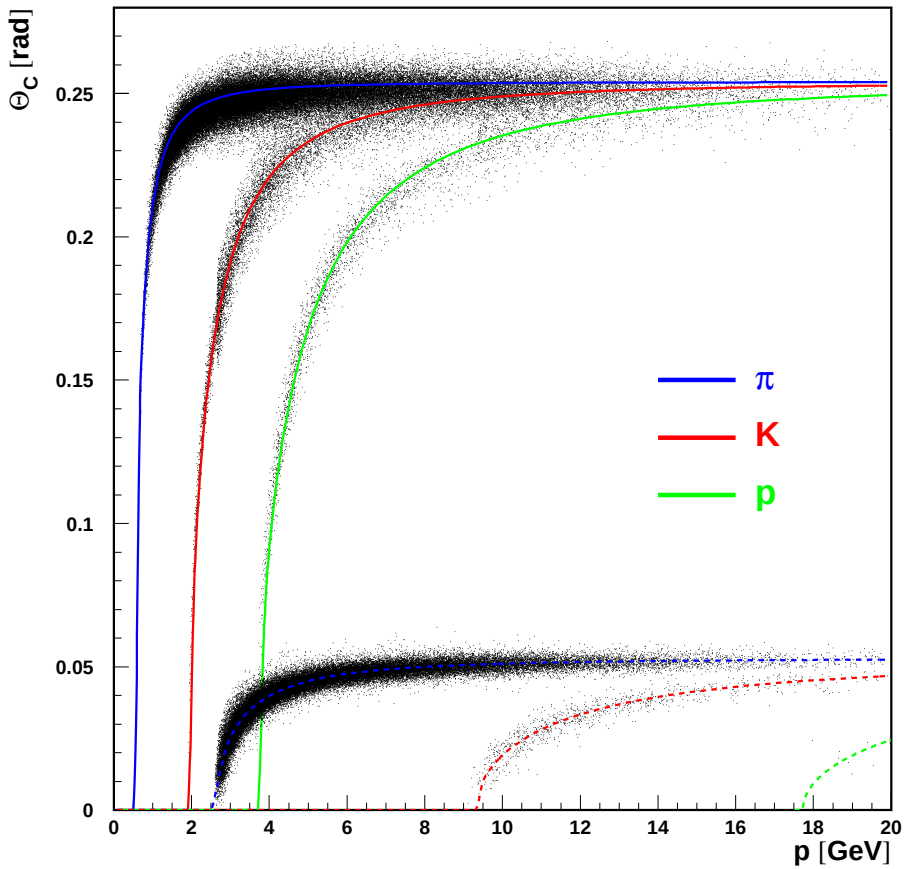
- TRD
- Calorimeter
- Preshower
- RICH



Hadron identification:

dual radiator RICH ($\cos\theta_c = \frac{1}{n}$)

- aerogel: $n = 1.03$
- C_4F_{10} gas: $n = 1.0014$

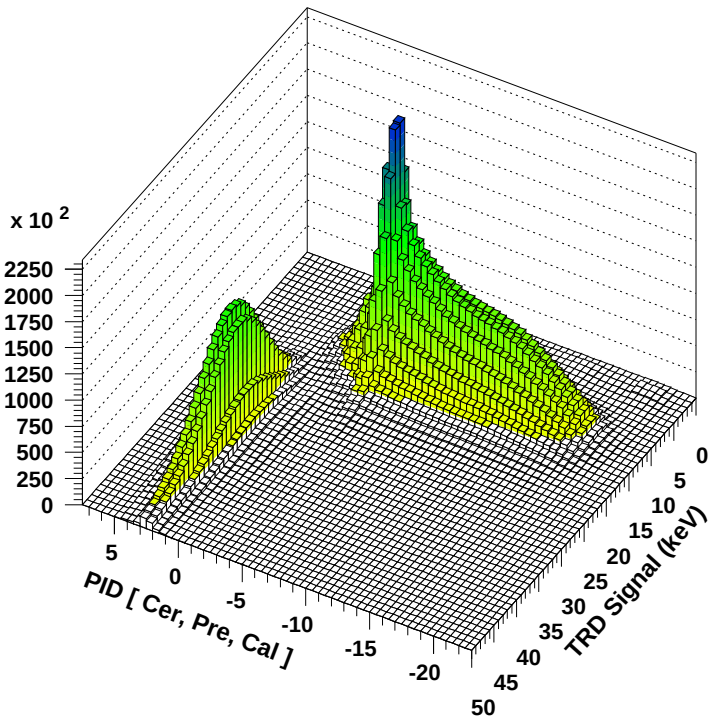


The HERMES Spectrometer

Hadron/lepton separation:

combination of

- TRD
- Calorimeter
- Preshower
- RICH



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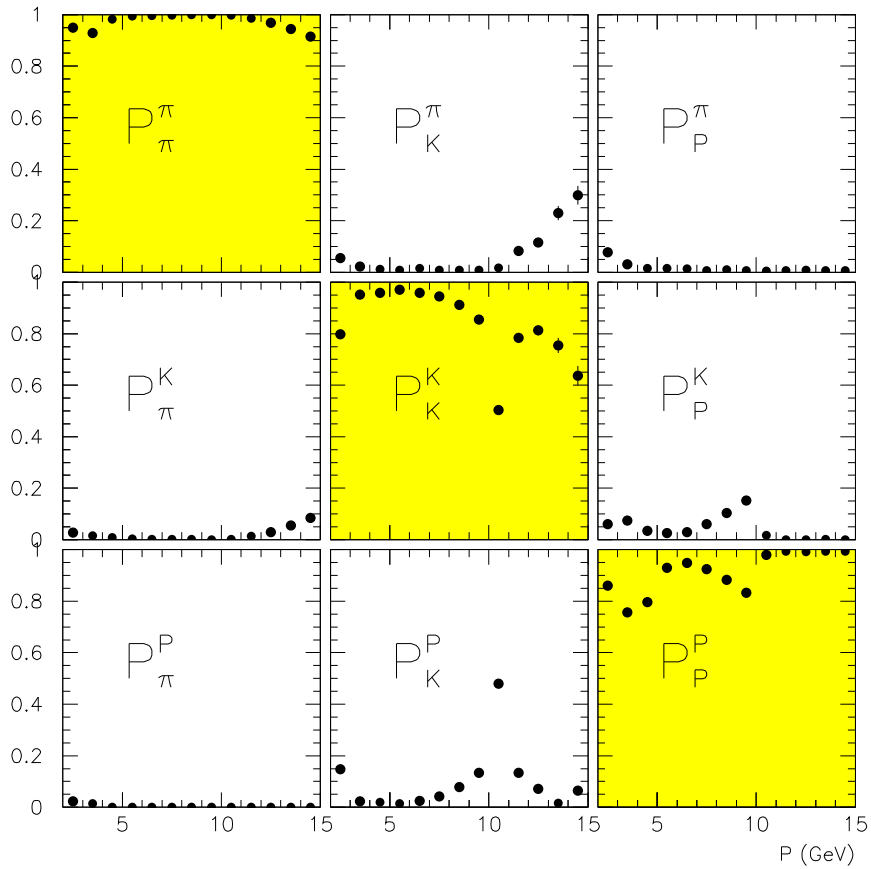
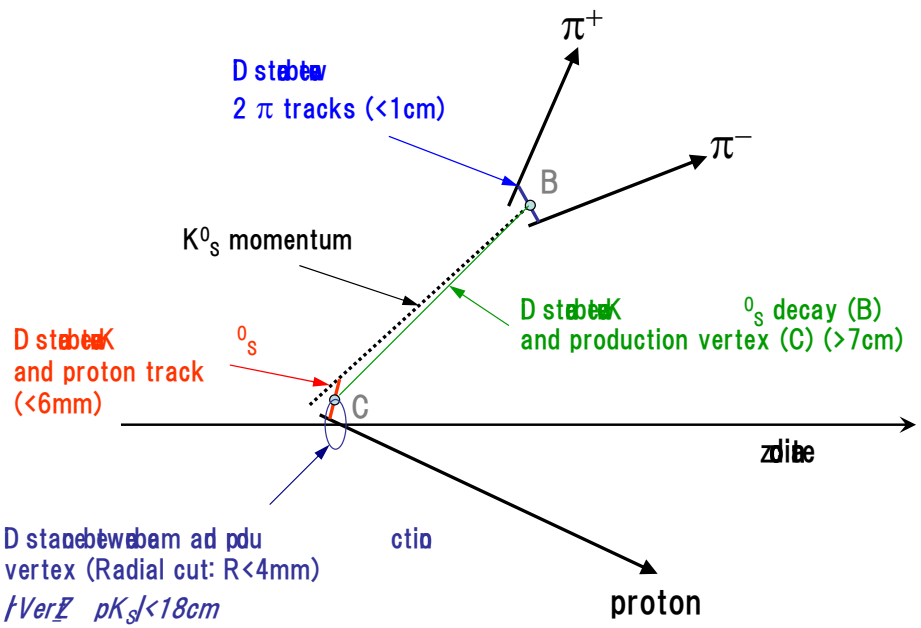


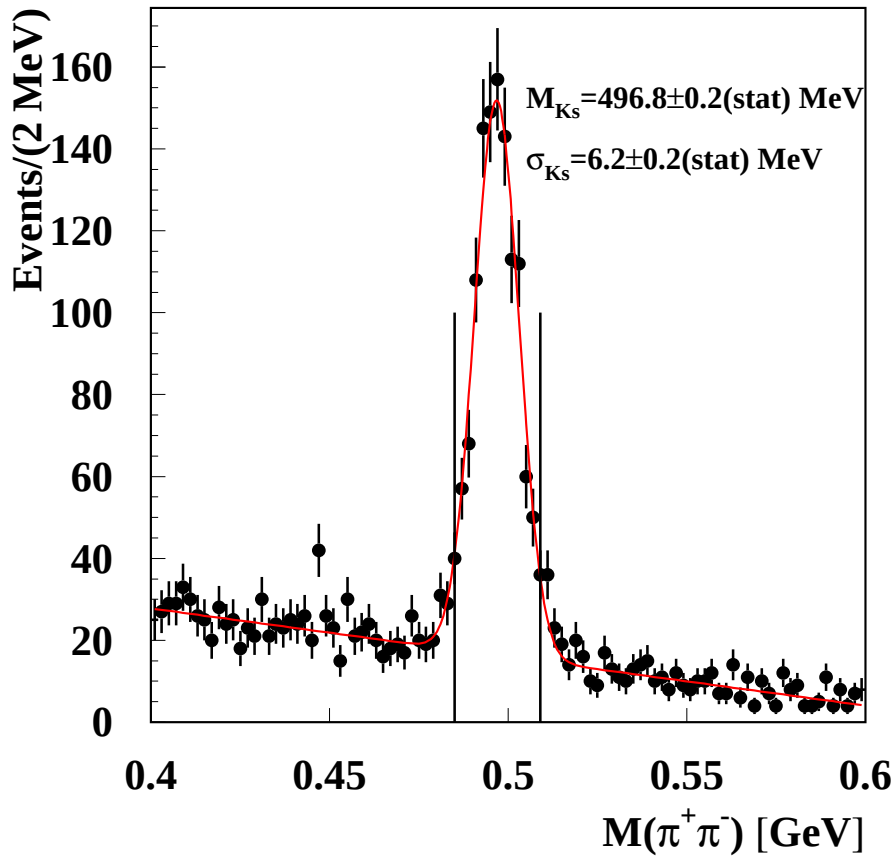
Θ^+ analysis: event selection

- Channel: $\Theta^+ \rightarrow pK^0_S \rightarrow p\pi^+\pi^-$
- Topology:



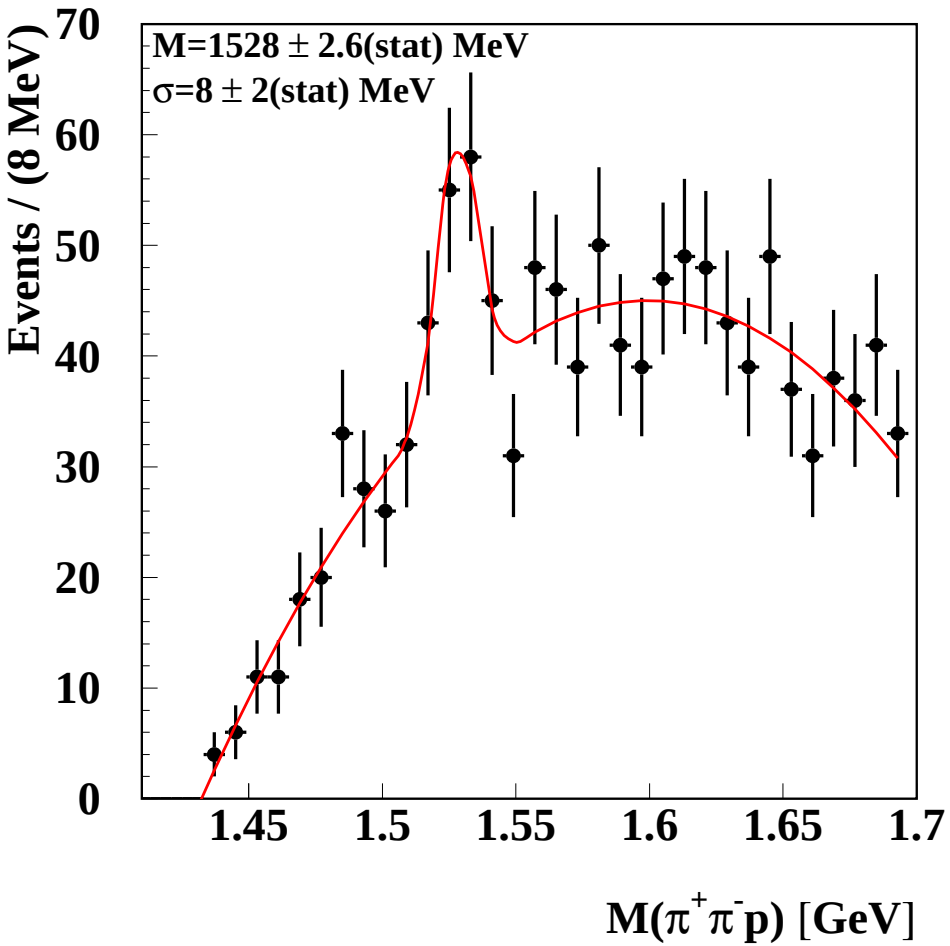
- Select K^0_S events ($2\,\sigma$ window)
- Remove Λ events ($3\,\sigma$ window)

- $M(\pi^+\pi^-)$ mass spectrum
  K^0_S peak at 496.8 MeV



Θ^+ analysis: final spectrum

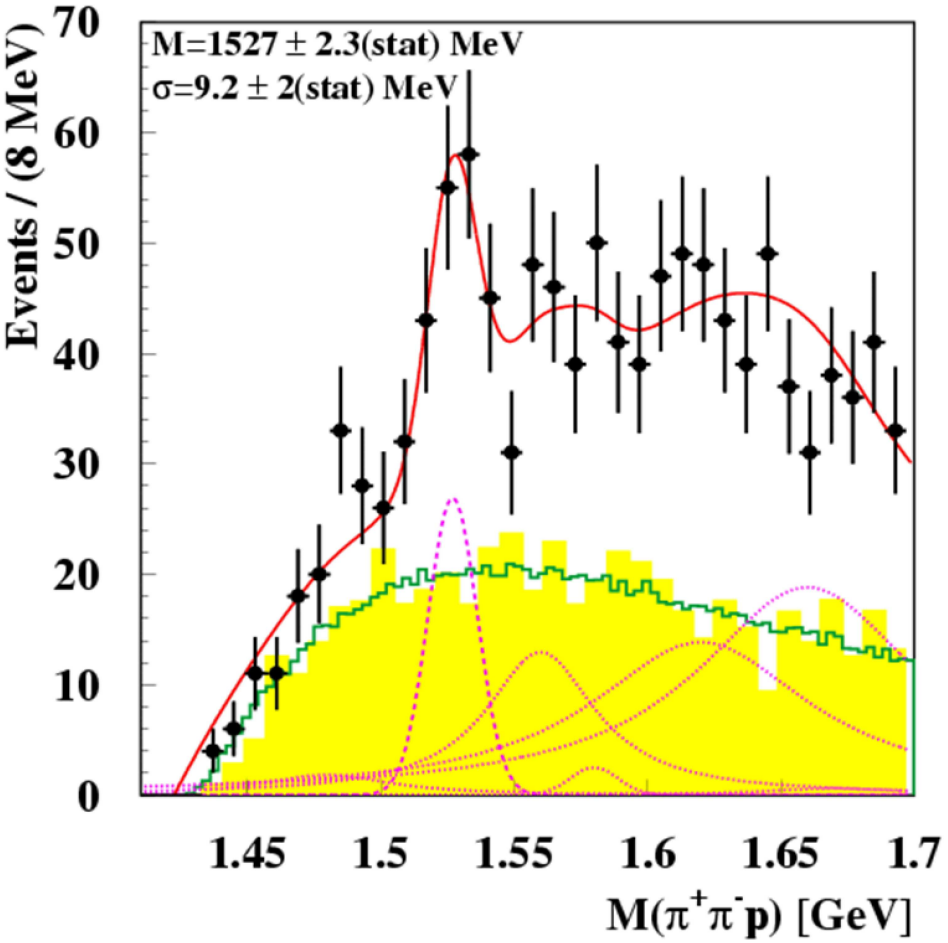
- Spectrum with polynomial fit



- Unbinned fit with 3rd order polynomial and Gaussian
- Θ^+ peak:
  - M = 1528 ± 2.6 MeV
  - σ = 8 ± 2 MeV
- Significance 3.7 σ

Θ^+ analysis: understanding the background

- Spectrum with MC background



- Mixed-event background
  - p from one event
  - K^0_S from other event
- PYTHIA6 Monte Carlo
  - No Σ^{*+} resonances
  - Added by hand (*cfr.* PDG)
- Θ^+ peak:
  - M = 1527 ± 2.3 MeV
  - σ = 9.2 ± 2 MeV
- Significance 4.3 σ

Additional Θ^+ studies: isospin

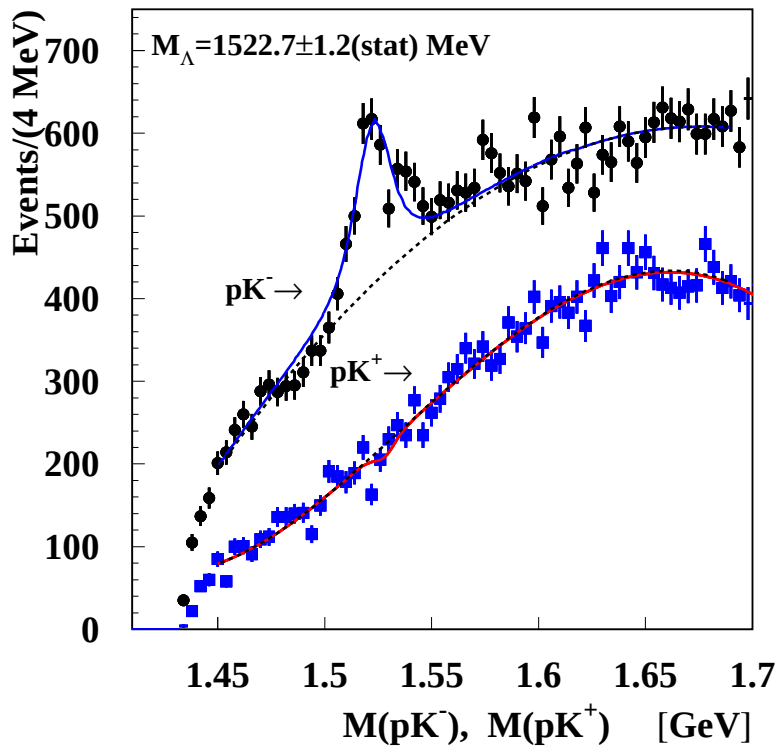
If Θ isotensor:

- Θ^{++} should exist!
- With same mass, width,...
- Decay: $\Theta^{++} \rightarrow pK^+$

At HERMES, in decay channel

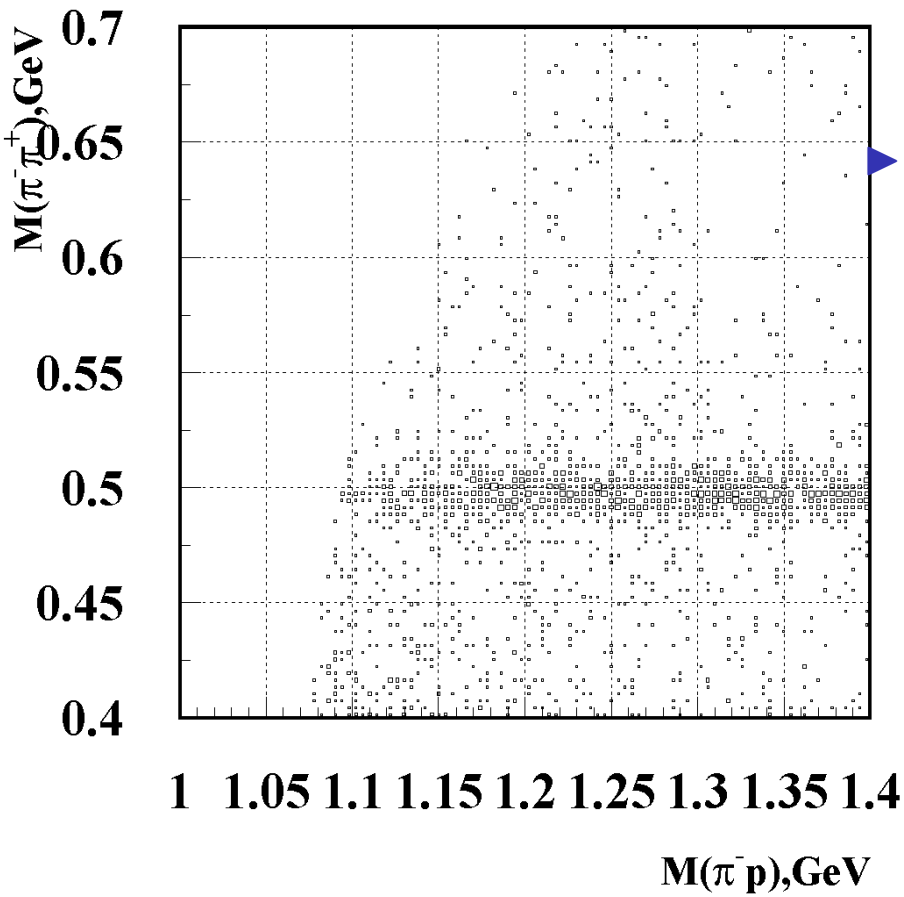
- pK^-: Clear Λ peak at 1522.7 MeV
- pK^+: no peak, no counts (91% C.L.)

Not isotensor, probably isosinglet



Additional Θ^+ studies: Tracking or PID problems

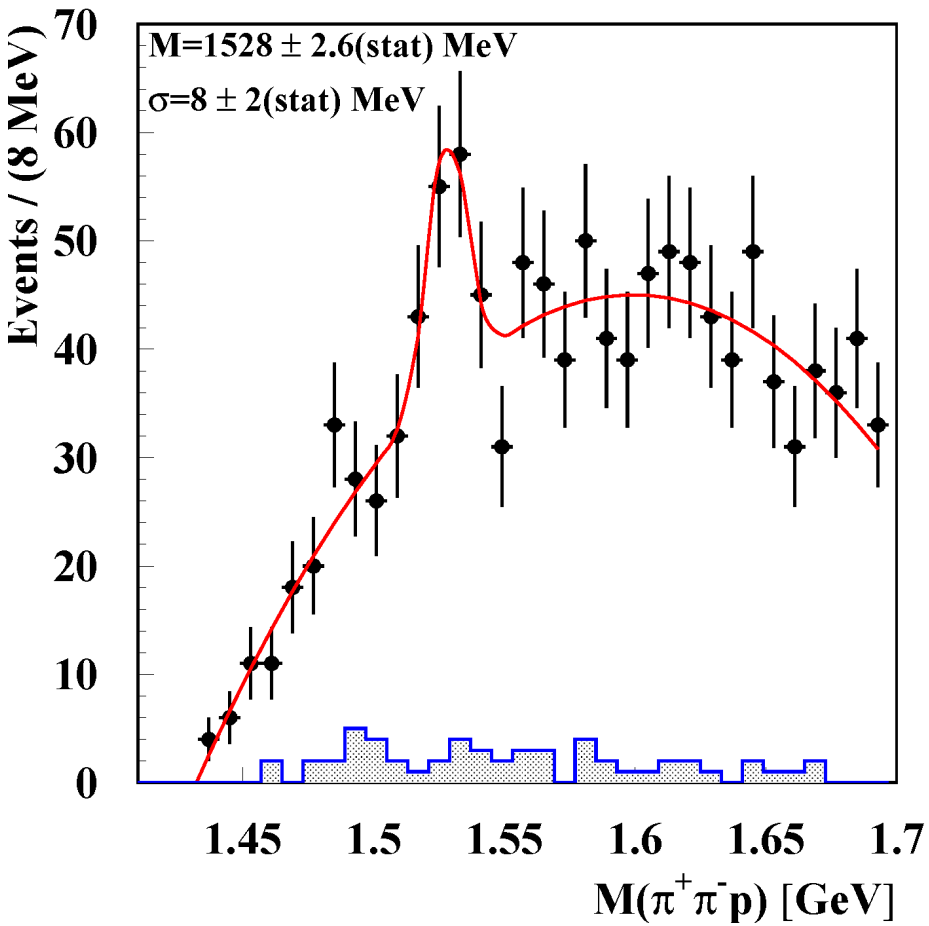
- Correlation $M_{\pi\pi}$ vs. $M_{p\pi}$



- Ghost tracks
  - No correlations
  - Examined data files
  - No ghost tracks!
- PID leaks
  - π^+ is actually p (mis-ID)
  - K_S combination is a Λ
  - Λ peak at $M_\Lambda = 1116\,\text{MeV}$ not seen
  - No significant mis-ID of p tracks as π^+!

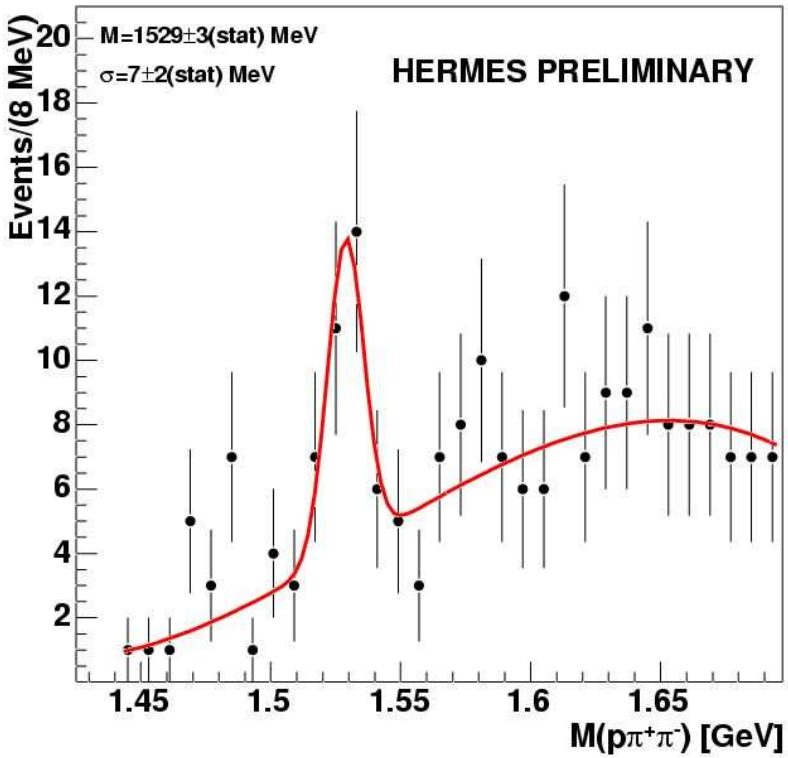
Additional Θ^+ studies: Tracking or PID problems

- $\Lambda(1116)$ contribution



- Ghost tracks
  - No correlations
  - Examined data files
  - No ghost tracks!
- PID leaks
  - π^+ is actually p (mis-ID)
  - K_S combination is a Λ
  - Λ events are cut out from spectrum
  - Inefficient Λ cut not reason for peak!

Additional Θ^+ studies: require extra hadron



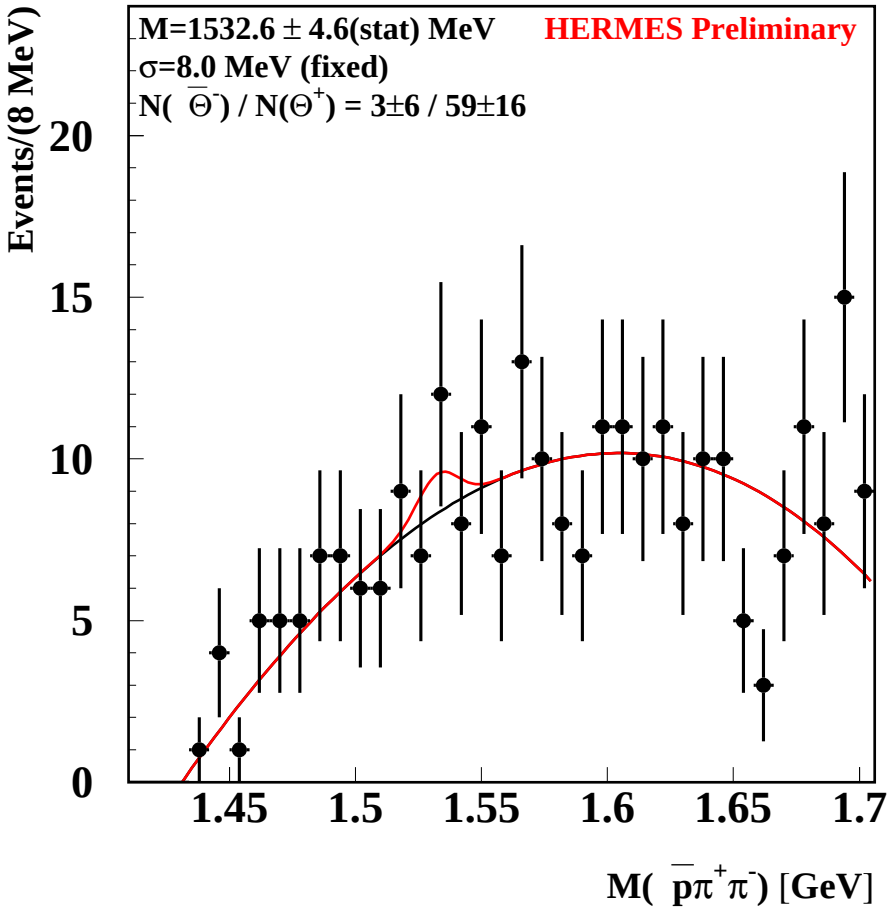
Require $\Theta^+ \to pK^0_S + h$

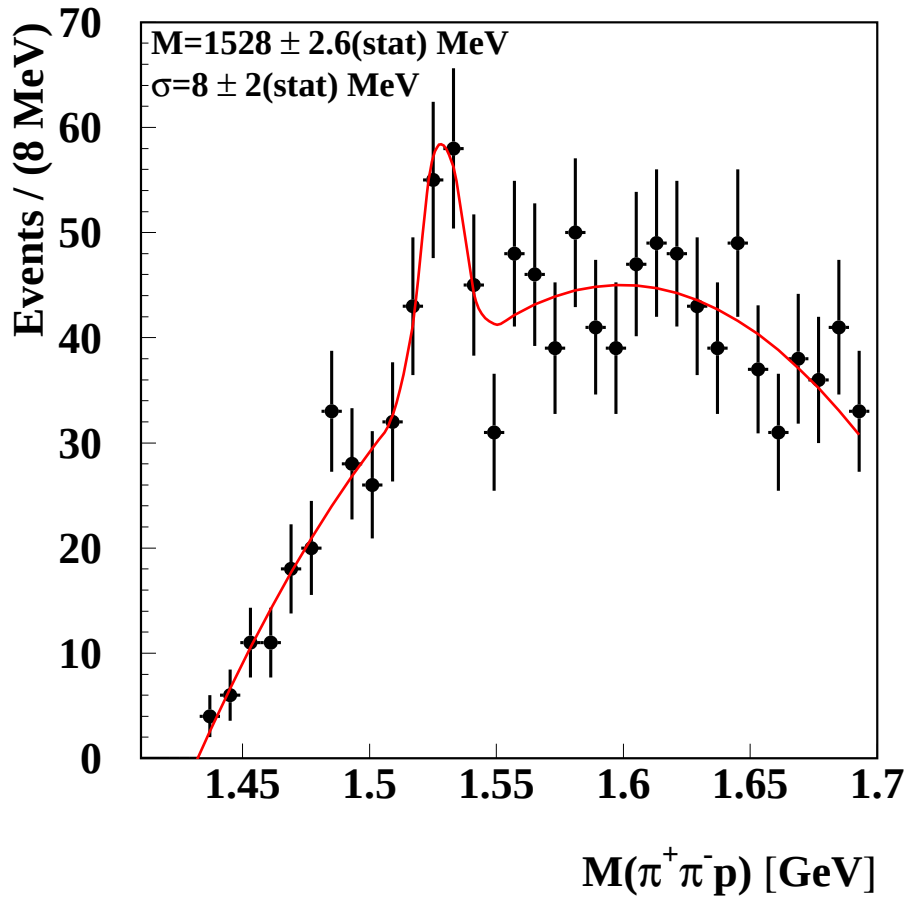
- h can be π, K, p
- $h = K, p$: low statistics
- $h = \pi$: peak stays

Extra hadron h is π

- Background goes down
- Signal stays there
- Signal/background improves!

Additional Θ^+ studies: anti-particle $\bar{\Theta}(1540)$





- No clear $\bar{\Theta}(1540)$ structure visible
- Ratio $\bar{\Theta}/\Theta$ determined

$\Lambda(1520)$ analysis: event selection

$209.2\,\mathrm{pb}^{-1}$ of deuterium data

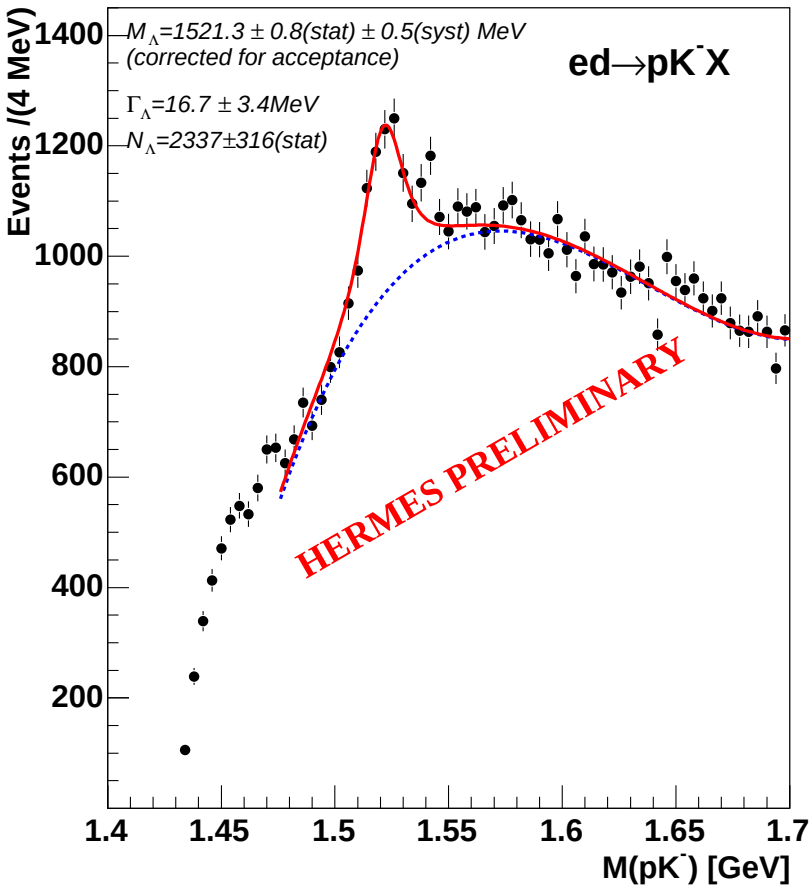
- $e^+D \rightarrow \Lambda(1520)X \rightarrow pK^-X$
- $e^+D \rightarrow \bar{\Lambda}(1520)X \rightarrow \bar{p}K^+X$

Event topology (checked in Monte Carlo)

- p and K tracks closer than $0.6\,\mathrm{cm}$
- $\Lambda(1520)$ decayed inside target
  - $R < 0.4\,\mathrm{cm}$
  - $|z| < 18\,\mathrm{cm}$
- $\Lambda(1520)$ decay length $< 5\,\mathrm{cm}$ (motivated by resolution)

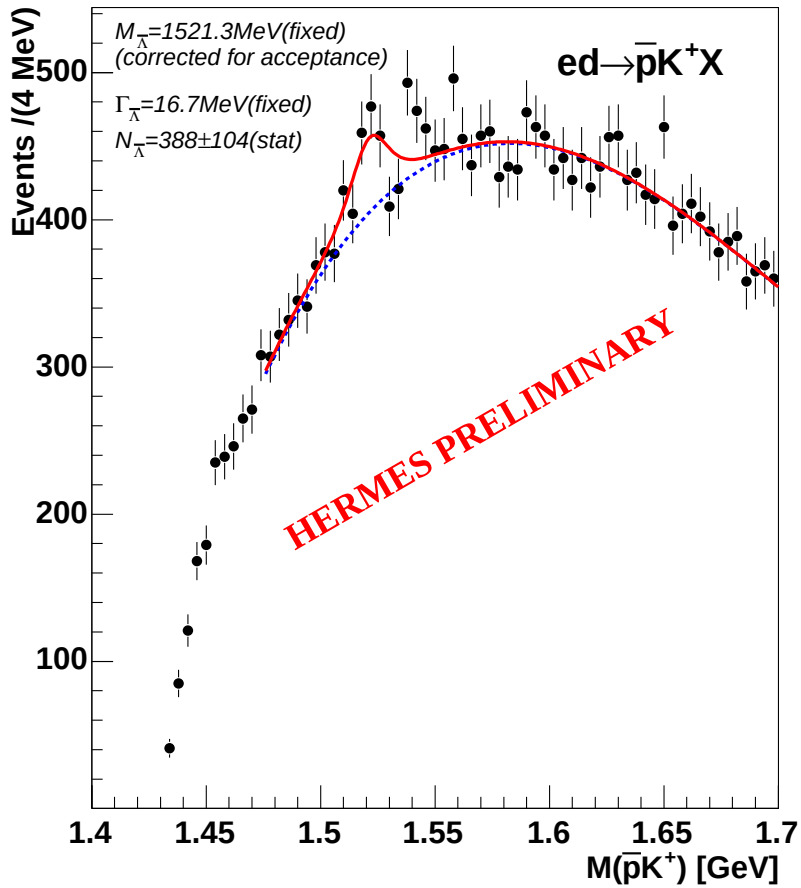
Λ(1520) analysis: invariant mass spectra

$\Lambda(1520) \rightarrow pK^-$



- $M = 1521.3 \pm 0.8(\text{stat}) \pm 0.5(\text{syst})$ MeV
- $\Gamma = 16.7 \pm 3.4$ MeV

$\bar{\Lambda}(1520) \rightarrow \bar{p}K^+$



- $M_{PDG} = 1519.5 \pm 1.0$ MeV
- $\Gamma_{PDG} = 15.6 \pm 1.0$ MeV

Λ(1520) analysis: partial cross sections

Method of calculation (total cross section)

$$\sigma_{\gamma^* D \to \Lambda(1520)X} = \frac{N_{observed}^{eD \to \Lambda(1520)X}}{\Phi \cdot Br \cdot \mathcal{L} \cdot \epsilon} \quad (1)$$

- photon flux $\Phi = 0.02\,\mathrm{GeV}^{-3}$
- branching ratio $Br = 22.5\%$
- integrated luminosity $\mathcal{L} = 209.2\,\mathrm{pb}^{-1}$
- efficiency and acceptance ϵ (in full momentum range)

Efficiency and acceptance ϵ

- Determine ϵ using Monte Carlo simulation
- PYTHIA Monte Carlo: no Λ(1520) state available...
- Model for decay momentum distribution of Λ(1520) necessary

$\Lambda(1520)$ analysis: partial cross sections

$P_z > 6\,\mathrm{GeV}$

- Motivated by HERMES acceptance for $\Lambda(1520)$

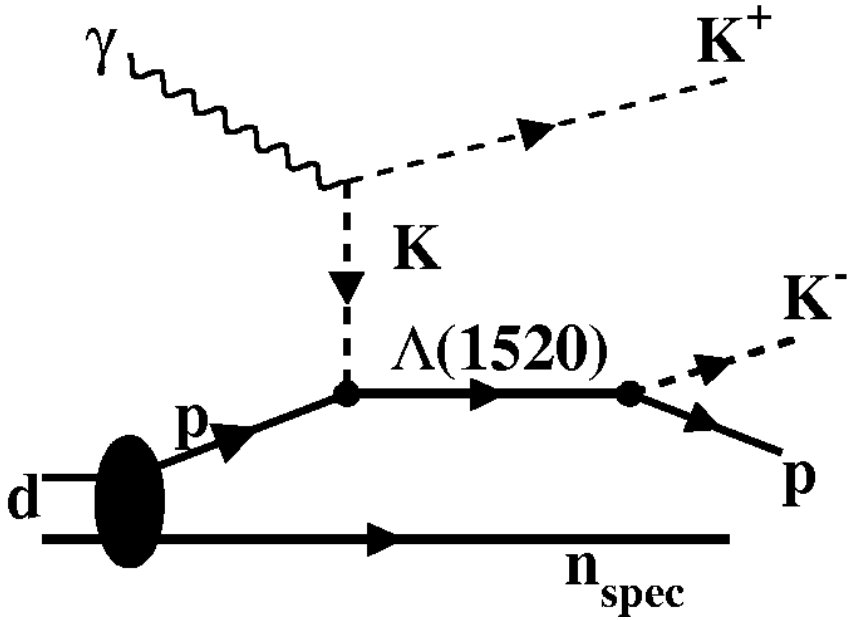
Photo-production cross sections

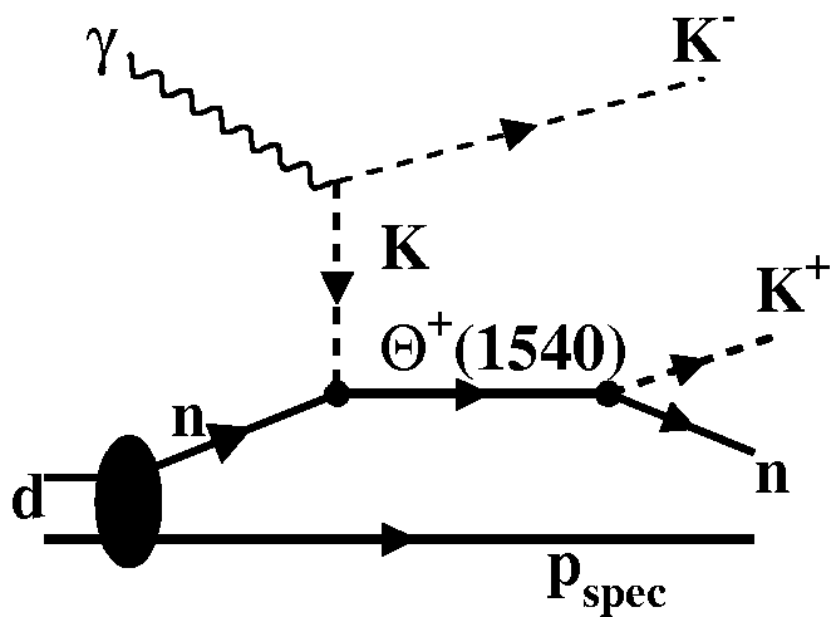
- $\sigma_{\gamma^* D \to \Lambda(1520) X} = 65.3 \pm 8.8(\mathrm{stat}) \pm 6.9(\mathrm{syst})\,\mathrm{nb}$
- $\sigma_{\gamma^* D \to \bar{\Lambda}(1520) X} = 9.8 \pm 2.6(\mathrm{stat}) \pm 0.9(\mathrm{syst})\,\mathrm{nb}$

Cross section ratio $\bar{\Lambda}(1520)$ over $\Lambda(1520)$

- $R_{\bar{\Lambda}/\Lambda} = 0.15 \pm 0.05(\mathrm{stat}) \pm 0.02(\mathrm{syst})$

$\Lambda(1520)$ analysis: extrapolation to $\bar{\Theta}(1540)$





Expected number of $\bar{\Theta}(1540)$

- 59 ± 16 $\Theta(1540)$ observed
- 10 ± 4 $\bar{\Theta}(1540)$ are expected when $R_{\bar{\Theta}/\Theta} = R_{\bar{\Lambda}/\Lambda}$
- 3 ± 6 $\bar{\Theta}(1540)$ were observed

Conclusions

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Conclusions

Overview of HERMES contributions

- Θ^+ observed at 1528 MeV, but with low statistics
- Lots of systematic studies on result: peak is robust
- No Θ^{++} observed $\rightarrow$ isosinglet
- No Ξ^{--} observed (not in this talk)
- No $\bar{\Theta}$ observed, but from the $\Lambda(1520)$ we don't expect to see it

Plans

- Data taking on hydrogen and deuterium is continuing
- Analysis of hydrogen data ongoing
- Finally create some clarity in this field!

History of the pentaquark?

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