Search for exotic Baryons at HERMES

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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 ($\pi, K, p$ separation)
Particle Identification

hadron/lepton separation
Combination of:
- TRD
- calorimeter
- preshower
- RICH

hadron identification
Dual radiator RICH
- aerogel: n=1.03
- $C_4F_{10}$ gas: n=1.0014

\[
\cos \Theta = \frac{1}{n}
\]
Event Reconstruction

\[ e^+ + D \rightarrow \Theta^+ + X \rightarrow pK_S^0 + X \]

Hadron identification: RICH

- \( \pi^- \): 1.7–15 GeV
- \( p \): 4–9 GeV

Direct reconstruction: detection of each decay particle, invariant mass reconstruction

Suppress contamination from \( \Lambda(1116) \rightarrow p\pi^- \)
Invariant Mass Distribution of $p\pi^+\pi^-$

- Events selected in a $\pm 2\sigma$ window about $K_S$ peak
- Peak is observed at $1528 \pm 2.6\,\text{(stat)} \pm 2.1\,\text{(syst)}$ MeV in $pK_S$ invariant mass distribution
- Width, $\sigma = 8$ MeV, is observably larger than experimental resolution
- No known positively charged strange baryon in this mass region
- Statistical significance is $3–5\sigma$
- Three models of background were studied
**PYTHIA6 and mixed-event backgrounds**

- **Filled histogram**: PYTHIA6 MC (lumi normalized): No resonance structure from reflections of known mesonic or baryonic resonances
- **Green histogram**: mixed event background normalized to PYTHIA6: reproduces the shape of PYTHIA6 simulation
- Excited Σ* hyperons not included in PYTHIA6 lie below 1500 MeV and above 1550 MeV
- **Mass**: $1527 \pm 2.3$ MeV
- **σ**: $9.2 \pm 2$ MeV
- **Significance**: $4.3\sigma$

\[
\begin{align*}
M & = 1527 \pm 2.3\text{ (stat) MeV} \\
\sigma & = 9.2 \pm 2\text{ (stat) MeV}
\end{align*}
\]
Θ⁺ or Σ⁺⁺?

- Is our peak a previously missing Σ⁺⁺ or a pentaquark state?
- If peak is Σ⁺⁺ ⇒ also see a peak in M(Λπ⁺)

![Graphs showing distributions of Σ⁻ and Σ⁺⁺](image)

No peak in Λπ⁺ spectrum near 1530 MeV

but no Σ⁺⁺s (1480, 1560, 1580, 1620) too!!!! should we say all bumps in pKₛ spectrum are pentaquarks?
Further background suppression - additional $\pi$

- signal/background: 1:3
- signal/background: 2:1
- same kinematic cuts
What is the Isospin of the $\Theta^+$?

In the decay channels:
- $pK^-$: clear $\Lambda(1520)$ peak at 1522.7 MeV
- $pK^+$: no peak, zero counts at 91% C.L.

Not isotensor

→ probably isosinglet
Width of Peak

- $\Theta^+$ Monte Carlo with complete detector simulation
- generated peak: 
  $M=1540$ MeV, $\sigma=2$ MeV
- reconstructed peak: 
  $M=1539.5$ MeV, $\sigma=6.2$ MeV
  $\Delta_{\text{detect.}}(\text{FWHM}) = 10$–14.6 MeV
- $\text{FWHM}_{\text{meas.}} = 19$–24 MeV

\textbf{Intrinsic width:} $\Gamma = 17 \pm 9 \pm 3$ MeV
Invariants Mass Distribution of $\bar{p}\pi^+\pi^-$

- **Goal**: compare cross section ratio of $\Theta^-$ to $\Theta^+$ production with ratio of $\bar{\Lambda}(1520)$ to $\Lambda(1520)$ production ($\sim 1:5$) or $\Xi^0(1530)$ to $\Xi^0(1530)$ production ($1:4$)
  - shed light on production mechanism
- same event selection and kinematic constraints as for $p\pi^+\pi^-$
- Gaussian plus $3^{rd}$ order polynomial, width of Gaussian fixed
- no peak is observed
  - hint that in HERMES kinematics target-remnant plays an important role different to ZEUS, which has basically the same number of $\Theta^+$ and $\Theta^-$.  

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Search for reported $\Xi^{--}(1862)$ Exotic

- **Channel:** $\Xi^{--} \rightarrow \Xi^{-}\pi^{-} \rightarrow \Lambda\pi^{-}\pi^{-}$

- **Topology:**
  - Distance between $\Lambda$ track and pion track ($< 1.0$ cm)
  - Distance between $\Xi^{-}$ track and pion track ($< 2.5$ cm)
  - Distance between $\Xi^{-}$ decay vertex and production vertex ($> 10.0$ cm)

- $M(p\pi^{-})$ with $\Lambda$

- $M(p\pi^{-}\pi^{-})$ with $\Xi^{-}$

- Selected $\Lambda$ events ($2\sigma$ window)
- Selected $\Xi^{-}$ events ($2\sigma$ window)
\( \Xi^{--}(1862) \) search (II)

- \( M(p\pi^-\pi^-\pi^-) \) spectrum
- \( M(p\pi^+\pi^-\pi^-) \) spectrum

- mixed-event background
- No \( \Xi \) peaks around 1860 MeV
- \( \Xi^0(1530) \) seen, as expected

- upper limit \( \sigma(\Xi^{--}) \): 1.0–2.1 nb
- upper limit \( \sigma(\Xi^0) \): 1.2–2.5 nb
- \( \sigma(\Xi^0(1530)) = 8.8–24 \text{ nb} \)
Production Cross Sections

- Integrated luminosity: 290 pb\(^{-1}\)
- all measurements done in quasi-real photoproduction (Q\(^2\ll 1\text{GeV}^2\))
- Acceptances from Monte Carlo:
  \(\Lambda(1520)\): 1.5%
  \(\Theta^+\): 0.05%
  \(\Xi^0(1530)\): 0.036-0.1%
  \(\Xi^0(1860)\): 0.065%
  \(\Xi^{--}(1860)\): 0.031%

\[\sigma(\Theta^+) = 100-220 \text{ nb} \pm 25\% (\text{stat})\]  (add. x2 from prod. kinematics)

\[\sigma(\Lambda(1520)) = 62 \pm 11 \text{ nb}\]

\[\sigma(\Xi^0(1530)) = 8.8-24 \text{ nb}\]
Production process at HERMES?

- Can additional pion come from exclusive processes?
  \[ \gamma p \rightarrow \overline{K}^0 K^0 p \rightarrow \overline{K}^0 \Theta^+ \]
  \[ \pi^+ \pi^- \rightarrow K_S^0 p \rightarrow \pi^+ \pi^- p \]
  \[ \gamma n \rightarrow K^- K^0 p \rightarrow K^- \Theta^+ \]
  \[ K_S^0 p \rightarrow \pi^+ \pi^- p \]

- Associated \( K^- \) or \( K_S \) from exclusive processes goes backward
  - Even decay pions from \( K_S \) are inaccessible
  - PID threshold requires \( p(\Theta^+) > 7 \text{ GeV/c} \)

- Tagged pions events cannot come from these exclusive processes
  \[ \rightarrow \text{production process has to be at least partially inclusive} \]
  - Inclusive processes increase with higher energy
  - Exclusive processes decrease with higher energy
Comparison with World Data

Decay channel: $nK^+$ $pK_s^0$

World Average: $1531.1 \pm 2.1$ MeV

Observation of peak in two decay channels in same experiment would be convincing!
Summary – HERMES results on 5q exotics

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Conclusions and Outlook

- Direct reconstruction of $pK_s$ invariant mass
  $$eD \rightarrow \Theta^+ + X \rightarrow pK^0_s + X$$

- Mass: $M = 1528.2 \pm 2.6({\text{stat}}) \pm 2.1({\text{syst}})$ MeV
  - Intrinsic Width: $\Gamma_{\Theta^+} = 17 \pm 9 \pm 3$ MeV
  - Significance: $\sim 4\sigma$

- $\Theta^+$ is probably an isosinglet

- Additional $\pi$ improves signal/background,
  $\rightarrow$ eliminates $K_S$ contamination from various processes

- Production process is at least partially inclusive

- No evidence observed for $\Xi^-$ or $\Xi^0$ near 1860 MeV

- Anticipate x5 higher statistics by summer 2007