Observation of the $\Theta^+$ Pentaquark at HERMES

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On behalf of the HERMES Collaboration
Introduction

Hadrons: baryons \((qqq)\) and mesons \((q\bar{q})\)
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“The general prejudice against baryons not made of three quarks and the lack of any experimental activity in this area make it likely that it will be another 15 years before this issue is decided.” (PDG 1986)
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1997: Prediction by Diakonov, Petrov and Polyakov, based on the Chiral Quark Soliton Model. Lightest pentaquark is \(\Theta^+\)

- Mass \(\approx 1530\) MeV - Width \(\approx\) a few MeV (longliving)
- \(uudd\bar{s}\)
- Decays in \(K^+ + n\) or \(K_s + p\) \((K_s \rightarrow \pi^+ + \pi^-)\)
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- 2003: Evidence for a \(S = +1\) Pentaquark from LEPS (Spring 8), DIANA (ITEP), CLAS (JLAB), SAPHIR (ELSA), ITEP2, HERMES (DESY), SVD-2 (IHEP)
The HERMES spectrometer
27.5 GeV $e^+$ beam from HERA accelerator
The HERMES spectrometer

Tracking Chambers + Magnet \[\Rightarrow \delta p/p = 1.4 \ldots 2.5\%\]
\[\delta \theta \leq 1\ \text{mrad}\]
Hadron/lepton separation: TRD, Preshower, Calorimeter
The HERMES spectrometer

Hadron identification ($\pi, K, p$): RICH
Hunting for the $\Theta^+$ Pentaquark at HERMES

Reaction of interest: $e + D \rightarrow \Theta^+ + X$

$\rightarrow p + K_s + X$

$\rightarrow p + \pi^- + \pi^+ + X$
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Distance between two pion tracks
Distance between $K_s^0$ decay and interaction point

Events/(2 MeV)

$M(K_s) = 496.8 \pm 0.2\,\text{(stat)}\,\text{MeV}$
$\sigma_{K_s} = 6.2 \pm 0.2\,\text{(stat)}\,\text{MeV}$

Brecht Hommez, Lake Louise Winter Institute 2004
Observation of the $\Theta^+$ Pentaquark at HERMES

$M = 1528 \pm 2.6\,\text{(stat)} \,\text{MeV}$

$\sigma = 8 \pm 2\,\text{(stat)} \,\text{MeV}$
Observation of the $\Theta^+$ Pentaquark at HERMES

- Resonance is observed at $1528 \pm 2.6 \text{ (stat)} \pm 2.1\text{ (syst)} \text{ MeV}$ in $K_s p$ invariant mass distribution.
- Width is dominated by experimental resolution.
Understanding the background

PYTHIA 6 simulation
Understanding the background

Events / (8 MeV)

M(π⁺π⁻p) [GeV]

mixed event background

PYTHIA 6 simulation

Brecht Hommez, Lake Louise Winter Institute 2004
Understanding the background

$M = 1527 \pm 2.3\text{(stat)} \text{ MeV}$

$\sigma = 9.2 \pm 2\text{(stat)} \text{ MeV}$

$M(\pi^+\pi^-p)$ [GeV]

Events / (8 MeV)

0 10 20 30 40 50 60 70

1.45 1.5 1.55 1.6 1.65 1.7

6 known $\Sigma^{*+}$ resonances + narrow Gaussian for expected peak

mixed event background

PYTHIA 6 simulation
Isospin of $\Theta^+$

- $M_\Lambda = 1522.7 \pm 1.2 \text{(stat)} \text{ MeV}$
- $pK^- \rightarrow pK^+ \rightarrow M(pK^-)$, $M(pK^+)$

- if no $\Theta^{++} \Rightarrow$
- $\Theta^+$ probably isoscalar
- Clear peak for $\Lambda(1520) \rightarrow pK^-$
- No peak for $\Theta^{++} \rightarrow pK^+$
Comparison with other experiments

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Mass value [MeV]</th>
<th>FWHM [MeV]</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>1520</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1540</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>1560</td>
<td>40</td>
</tr>
</tbody>
</table>

- HERMES
- CLAS (p)
- ITEP (ν’s)
- SAPHIR
- CLAS (d)
- DIANA
- SPring-8
Conclusions

HERMES found evidence for a narrow baryon resonance in the $pK_s$ spectrum

- Quasi-real photoproduction
- $e + D \rightarrow pK_s + X$
- Produced in a fragmentation process, far from threshold
- $1528 \pm 2.6$ (stat) $\pm 2.1$ (syst) MeV
- Width: dominated by experimental resolution
- Significance: 4-6 standard deviations
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- $\Theta^+$ is probably an isosinglet

- Precise (and different) pentaquark mass is quite relevant:
  - *hep-ph/0402008: A Mass Inequality for the $\Xi^*$ and $\Theta^+$ Pentaquarks (M. Karliner, H. J. Lipkin)*