The experimental search for CHARM pentaquarks (ZEUS)

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DIS 2005
Madison, Wisconsin

27 April 2005

OUTLINE

• I: Introduction: Narrow pentaquarks
• II: The ZEUS D* Data
• III: Zeus search for Charm pentaquark
• IV: Conclusions
Many high statistics experiments searched but did NOT see the $\Theta^0_{1530}$.

* Sept. 2004: ZEUS published the NO observation of $\Theta^0_{1530}$.

* Observation of this resonance reported.

* ZEUS reported no $\Theta^0_{1530}$ at 3.1 GeV (update: previous talk).

* H1 reported in March 2004 the observation of a narrow charm pentaquark.

* Many other experiments have searched but have NOT seen the $\Theta^0_{1530}$.

* Some QCD does not forbid 5-quark hadronic states.

* Such pentaquarks do not exist in the naive quark model, but QCD cannot be made of 5 quarks.

* $\Theta^0_{1530}$ also reported observing $\Theta^0_{1530}$ (update: previous talk).

* See also report of the CLAS collaboration at this conference.

* In this conference, a narrow exotic baryon state $\Theta^0_{1530}$ has been observed.

* Many experiments, mainly fixed target, at low energy, observe lower than quark model expectations.

* Babar, CLEO, Belle: New $D^*$ mesons $D^*(2317)$ and $D^*(2457)$ with masses.

* The significance was always between 3-7$\sigma$. Some examples:

* Observations of narrow states were recently reported.

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**Exotic Hadronic Pentaquarks**
\[ H \approx W \text{ GeV} \approx \frac{7}{3} \Xi \text{ GeV} \]

anti-decuplet members are predicted to have \( S = -2 \),

the \( S = 1 \) member is predicted to have \( W \text{ GeV} \).
The \( S = 0 \) member of the anti-decuplet, \( \Xi \text{ GeV} \),

ASSUMING the \( N(1710) \) to be \( S = 0 \) member of the \( S \Xi \) decuplet (as in the \( S \Xi \) decuplet) and

with linear \( \Sigma(3) \) breaking in \( \Sigma(3) \) breaking in

\[ \Sigma \text{ Physics, 1992, 1994, 1996} \]

various anti-decuplet of baryons

\( 0 = I \) and was predicted by Diakonov et al.

\[ +2/1 = \frac{1}{2} \]

A narrow \( (1 \text{ MeV}) \) exotic state with strangeness \( S = +1 \),

The Skyrme model prediction
\[ + \text{c.c.} \] in the spectra, where \( D^* \) signals \( \Theta^0 \) and \( ZEUVS \) at HERA searched for. HI

\[ \Delta \rightarrow D^* \Theta^0 \]

\( \Delta \rightarrow D^* \Theta^0 \) can decay to \( \Theta^0 \) and \( ZEUVS \) at HERA searched for. HI

\[ \Delta \rightarrow D^* \Theta^0 \] and not seen \( u_0 \) or \( D^- \) dominates in decay. Not seen \( u_0 \) or \( D^- \) dominates in decay.

Chen et al. hep-ph/0308176: \( \Delta \rightarrow D^* \Theta^0 \)

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Several theoretical predictions:

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Charm Pentagluarks:

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Charm Pentagluarks:
Signal also seen in photoproduction sample with same ratio to $D^*$

Roughly 1% of the total $D^*$ production rate (1.46 ± 0.32)%

The signal consists of \( 3.6 \pm 1.2 \) events (see previous talk)

The quoted mass resolution (in talks) was about 7 MeV.

The measured Gaussian width \( 12 \pm 3 \) (stat.) MeV


at a mass of \( M = 3.999 \pm 0.003 \) (stat.) \( \pm 0.007 \) (sys.) MeV

in the decay mode \( D_0^- \rightarrow K^+ \pi^- \). (c.c.) in the \( D_0^+ \) reported observation of a narrow resonance

In a DIS sample of 34000 \( D^* \) events, \( H_1 \) reported observation of a narrow resonance

\( M(D^*_p) \) [GeV]

<table>
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<th>Entries per 10 MeV</th>
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<td>0</td>
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<td>10</td>
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<td>20</td>
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<td>30</td>
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The HI Charm Pentaguk
For channels (1, 2) respectively: \( 0.144 \text{ GeV} > M_{\pi^\phi \gamma} > M_{\eta^* \rho} > 0.145 \text{ GeV} > 0.147 \text{ GeV} > M_{\eta^* \rho} > M_{\eta^*} > \eta^* W > 1.885 \text{ GeV} \)

Mass windows for the \( D^0 \) selection:

Kine metric \( D^* \) region: \(-1.6 < (M_{D^*})^l < 1.6 \), \( D^0 \) region: \(-1.6 < (M_D)^l < 1.6 \), \( D^+ \) region: \(-1.6 < (M_{D^+})^l < 1.6 \).

The mass difference of the \( D^* \) mesons were identical using the two decay channels

\begin{align}
\text{(2)} & \quad \delta_0 = \delta^p_D - \delta^p_{D^*} \\
\text{(1)} & \quad \delta_0 = \delta^p_D - \delta^p_{D^*}
\end{align}

The \( D_{*}^{\pm} \text{ HERA I data was examined (126.5 pb}^{-1}) \) ZEUS search for the \( \Theta \) selection
(1) All Protons. 3 methods of p usage:

1. \( \text{d} p_{\text{T}} \)

2. \( \text{d} p_{\text{T}} \) applied for protons

3. High \( \text{d} p_{\text{T}} \) band:

\[ d(xp/\text{d} \phi) : d \text{d} p_{\text{T}} \]

4. Low \( \text{d} p_{\text{T}} \) band:

\[ d(xp/\text{d} \phi) : d \text{d} p_{\text{T}} \]

Proton selection: \( \text{d} p_{\text{T}} \) for the DIS sub-sample

\( N_{\text{D}^*} > 1.3, 900 \) for the DIS sub-sample

For the DIS sub-sample

\( N_{\text{D}^*} > 62,000 \)

Yellow bands searched for with \( \text{D}^* \) 's from \( \Theta^0 \) decay modes

\( \text{D}^* \) signals in \( \text{D}^*_{\Theta^0} \) decay modes

\( w^\mu \sim (0D)(0D)w = (\text{D}^*_0 \text{D}^*_0)W = W \nabla \)


ZEUS search for the \( \Theta^0 \)
(c.c.)

$D^0_0 \leftrightarrow K^- \nu + \nu^- \nu^+ \nu^0 + (c.c.)$

$D^0_0 \leftrightarrow K^- \nu + (c.c.)$

$D^0_0$ decay modes

well at low momentum for both $p$, $K$, and $\nu$ bands separated.

To ensure good $x_F$ resolution

Plots of $dE/dx$ for $W > 3.6 \text{GeV}$

ZEUS 1995-2000

ZEUS search for the $\Theta^o_0$
After the cut \( \xi > 0.15 \), it becomes \( d_\perp < 0.15 \). The acceptance of the protons before the cut \( d_\perp \) was, using the \( \Theta \) MC, 89\% and the acceptance of the protons towards the \( \Theta \) background: \( d_\perp < 0.15 \). The distribution of the proton candidates shows a sharp peak at and \( 0 \sim d_\perp \) for larger \( d_\perp \) values. The resolution was parameterized empirically as 

\[
\frac{\chi^2}{\nu} = \frac{(xp/IP)^{\mu\nu}}{\nu - (xp/IP)^{\mu\nu}}
\]

and \( \chi^2 \) was calculated as:

\[
xp/IP \text{ value that estimates the deviation of the measured }\]

For each particle, \( \chi^2 \) is the value that estimates the deviation of the measured.
No evidence for a signal at 3.1 GeV. Similar cuts to H1 no signal.

Histograms are like-sign combinations. Mass resolution from MC: 4 MeV.

\( \text{ZEUS} \) 1995-2000, \( Q^2 > 1 \text{ GeV}^2 \)

\( \text{ZEUS} \) 1995-2000, \( Q^2 > 2 \text{ GeV}^2 \)

\( \text{ZEUS} \) 1995-2000, \( Q^2 > 1 \text{ GeV}^2 \)

**DIS sample**

\[ (d_s^+ D) W + (s_{\mu \nu}) W - (d_s^+ W) W = (d_s^+ D) W \]
No evidence for $\Theta_0^-$ also in the $D_0^-$ $K_{-}^{0}$$\nu^{+}\nu^{-}$$\nu^{+}\nu^{-}$ channel.
No evidence for opposite H1 and D_0 \rightarrow K^{-} \pi^{+} \nu cuts. ZEUS rate relative to H1 is proportional to relative D_0 MC.

ZEUS spectra (d* \rightarrow K^{+} \pi^{-})_{\nu} \rightarrow H1 selection criteria.
the $0^+\Theta$ decays $0^+\Theta$ to reconstruct the fraction of $\Theta^*$ mesons originating from any number of candidates in the window. This number was divided by the number of reconstructed $\Theta^*$ mesons, yielding the fraction of $\Theta^*$ mesons originating from the observed background function. The number of reconstructed $\Theta^*$ mesons was estimated by subtracting the range (see following figures) distributions reasonably well in the whole

The fitted curves describe the distributions $d_{\Sigma}W$ and:

$$(s_{\Sigma} - d_{\Sigma})W = \int_{\Xi} W \nabla \left( \frac{s_{\Sigma}}{d_{\Sigma}} \right) W = \int_{\Xi} W \nabla$$

where $s_{\Sigma} = \int_{\Xi} W \nabla x$ for the proton mass and:

$$(s_{\Sigma} - d_{\Sigma})W = \int_{\Xi} W \nabla (x^c + x^q - d_{\Sigma})W = \int_{\Xi} W \nabla$$

The fitted distribution was shifted outside the signal window to the functional form $d_{\Sigma}W - \int_{\Xi} W \nabla = x$ where $x$ is the proton mass.

Each distribution was obtained with $\Theta^*$ reconstructed in channels (1) and (2) and $\Theta^*$ full $\pi^+\pi^-\eta\pi^0\Theta$ samples.

Obtained with $\Theta^*$ reconstructed in channels (1) and (2). The upper limits were calculated for the full measurement taking into account the uncertainties of the measured mass $0^+\Theta$ and width. The upper limits were calculated for the full $\pi^+\pi^-\eta\pi^0\Theta$ samples.

Upper limits on the fraction of $\Theta^*$ mesons originating from the $0^+\Theta$ decays were calculated.

\[ \text{ZEUS upper limits for production} \]
the detailed results of both channels are given in the following table:

A plot of such expected number of events is shown in the following figures and
exclusion is about 5.0.

For our DIS (\(Z < 1\) GeV) sample the
statistical fluctuations larger than 0.9. Ground events could produce 62% events in the signal window only in cases
Assuming Gaussian statistics, a 1% signal with the expected number of back-
samples of both decay channels.

where

\[
\frac{d_0}{d_{\star 0}} \text{ events} \times \frac{\text{with our number of } \star \text{ mesons in our kinemati region and assuming a 1% signal}}{\text{production rate for } \star \text{ mesons originating from the decay of } \Theta_0^{\prime}}
\]

\(d_{\star 0} \text{ events} \times \frac{\text{with our number of } \star \text{ mesons in our kinemati region and assuming a 1% signal}}{\text{production rate for } \star \text{ mesons originating from the decay of } \Theta_0^{\prime}}
\]

\[
R = \frac{(d_{\star 0})_{\text{mess}} \times (d_{\star 0})_{\text{orig}}}{(d_{\star 0})_{\text{orig}}}
\]

To correct the fraction of \(\star\) mesons originating from the decay of \(\Theta_0^{\prime}\) we also calculated the relative acceptance of the above ratio R:

The combined upper limit for DIS with \(\Theta_0^{\prime}\), based on BDT, D57, 3873(1998), (1) and (2), respectively. The combined upper limit for both channels is 0.23%.

The 95% C.L. upper limits on \(\theta(D\bar{D}/d_{\star 0} \text{ events} \times \frac{\text{with our number of } \star \text{ mesons in our kinemati region and assuming a 1% signal}}{\text{production rate for } \star \text{ mesons originating from the decay of } \Theta_0^{\prime}})
\]

\text{sign probability function (Freiman and Cousins, PR.D57, 3873(1998)).
for the full (DIS) combined sample.

Full (DIS) sample

For the full (DIS) sample, excluded by 9 s.d. (5 s.d.)

A visible rate of $R = 1\%$ is calculated

(95% C.L. upper limits on the (solid curves)

on top of a background

1% after HI

MC signals normalized

Yellow histograms are

$\mu^+\mu^- \leftrightarrow 0\mu^+\mu^- \leftrightarrow 0\nu^+\nu^-$

$D^{\pm}(+D)^W + (s\nu\nu Y)W - (d^s\nu\nu Y)W = (d^s\nu\nu Y)W$

ZEUS upper limits for production

$\theta$
The results are shown for the full data sample for DIS with $Q > 1$ GeV and for production with $Q > 1$ GeV. The decay to $D^* B$ results are shown for the full data sample, for DIS with $Q > 1$ GeV and for production with $Q > 1$ GeV.

<table>
<thead>
<tr>
<th>Production with $Q &gt; 1$ GeV</th>
<th>34000 ± 330</th>
<th>15070 ± 720</th>
<th>694 ± 16</th>
<th>458</th>
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</thead>
<tbody>
<tr>
<td>DIS with $Q &gt; 1$ GeV</td>
<td>252 ± 8.8</td>
<td>26 ± 2</td>
<td>918 ± 19</td>
<td>619</td>
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Table 1: Numbers of the $W$ channels. The signal window $N_{\text{signal}}$ is the background and estimation's number of reconstructed $D$ mesons.
DATA MAY RESOLVE THE ZEUS/HERA $^3_0 \Theta$ DISCREPANCY

FUTURE RESULTS FROM HIGH STATISTICS HERA II

rate.

duction in DIS and photoproduction, with a rate, in DIS, of roughly 1% of the $D^*$ production

CONCLUSION: the ZEUS data are not compatible with the H1 report of $^0_0 \Theta$ hadron pro-

the limits become 0.37% and 0.51% respectively.

DIS with $q^2 > 1$ GeV^2 is 0.35% (95% C.T.) Thus the corrected ratio, $\rho_{cor}$, $^0_0 \Theta$ mesons originating from $\Theta$ decays is 0.23% (95% C.T.). The upper limit for $^0_0 \Theta$ mesons. The upper limit on the fraction of $D^*$ spectrum from more than 6000 reconstructed $D^*$ mesons were used to identify $D^*$ mesons.

No resonance structure was observed in the $\lambda_{+} \rightarrow 0D^*$ spectrum from $D^*$ mesons.

$D^*$ mesons were searched for as resonances in the invariant-mass spectrum at HERA using an integrated luminosity of 126 pb$^{-1}$. The decay channels $D^* \rightarrow D \pi$ have been investigated.

$^3_0 \Theta$ DISCREPANCY

SUMMARY OF ZEUS SEARCH FOR $^3_0 \Theta$ IN $d^3 \rightarrow e^+ \nu_\tau \bar{\nu}_\tau \Theta$ AT HERA
No Θ

\[
\theta \left( \sum \right)
\]

seen in the ZEUS data with the HL cuts.

No Θ

\[
\theta \left( \sum \right)
\]

seen in the ZEUS data with the HL cuts.

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\theta \left( \sum \right)
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seen in the ZEUS data with the HL cuts.
Also no evidence for $\Theta_{+}(1530)$ at DELPHI and OPAL

\[ \frac{d_{-}D_{0}}{(c_{0\Theta})N} \frac{d_{+}D_{0}}{(c_{0\Theta})N} \]

ALPHE 97% C.L. Limits:

No evidence for $\Theta_{+}(1530)$, $\Xi_{--}(1862)$, $\Theta_{0}(3099)$

Other pentaquark searches: LEP-1 $e^+e^-\text{ annihilations}$. 
CDF 90% C.L. limits:

\[
\begin{align*}
\frac{d}{d_\theta} B R (\Theta) N & > 3.9 \cdot 10^{-5} \\
\frac{d}{d_\theta} B R (\Theta) N & > (1.530)N/(1.862)\Xi N: \Xi - \Xi \rightarrow N + K \\
\frac{d}{d_\theta} B R (\Theta) N & > 0.06 \\
\frac{d}{d_\theta} B R (\Theta) N & > 0.0034
\end{align*}
\]

No evidence for \( (\Xi^{0})^{0} (1862), \Theta^{3099} \)

CDF Run II at the Tevatron \( (220 \text{ pb}^{-1} ) \)

Other pentauquark searches: CDF, in \( pp \) collisions at \( \sqrt{s} = 1.96 \text{ GeV} \)
No evidence for $\Theta^{+}(1530)$

$84,000 \Delta \approx 60,000 \Xi(1530) \Xi(1560) \Xi(1680)$

Sample: 63 million $\Lambda_0^*$

$\Theta^{+}(1530)$ and $\Theta^{0}(1530)$

Search for $\Theta^{+}(1562)$ and $\Theta^{0}(1582)$

Photon beam from 300 GeV $\gamma$ beam on BeO targets

FOCUS: Fixed-target Fermilab experiment

Other pentagurk searches: FOCUS