Pentaquark searches at ZEUS

1. $\Theta \rightarrow K_S p$ : Many fixed target experiments report $\Theta^+ \rightarrow K^+ n$ (and $K_S p$) at $\sim 1530$ MeV

2. $\Xi_{3/2} \rightarrow \Xi \pi$ : NA49 reports exotic $\Xi_{3/2}$ at $\sim 1860$ MeV

3. $\Theta_c \rightarrow D^{*} p$ : H1 reports $\Theta_c \rightarrow D^{*} p$ at 3099 MeV
\[ \Theta \rightarrow K_{Sp} \]

- \( \Theta^+ \rightarrow K^+n \) is a manifestly exotic state (uudd\overline{s}). Observed mass \( \sim 1530 \text{ MeV} \).
- \( \Theta \rightarrow K_{Sp} \) is not manifestly exotic. Can be interpreted as a \( \Sigma^* \) (uudd\overline{s}).
- \( K_{Sp} \) spectrum has many reported "\( \Sigma \) bumps" (observed by experiments at low significance). 1480 MeV (near threshold), 1560 MeV, 1580 MeV,…
- A "window" exists \( 1500 \rightarrow 1550 \text{ MeV} \) where no states are reported.
- A narrow state at \( \sim 1530 \text{ MeV} \) in \( K_{SP} \) would be consistent with the exotic \( \Theta^+ \).
The search is made in Deep Inelastic Scattering sample: \( \sim 121 \text{ pb}^{-1} \), the entire HERA I sample.
\[ \Theta \rightarrow K_{Sp} \]

870k Ks reconstructed

(anti)Proton candidates from \( \text{d}E/\text{d}x \) in the central tracking chamber (CTD).
Looking for known states using same sample and dE/dx

\[ \Theta \rightarrow K_{sp} \]
$\Theta \rightarrow K_{Sp}$

**MC studies:** (produce $\Theta$ in the same way as baryons in fragmentation)

At $Q^2 \approx 10 GeV^2$ or larger,
$\Theta/\text{event} \approx \text{const}$
$\Theta/\text{bgd} \approx \text{const}$

As $Q^2 \rightarrow 0$
$\Theta/\text{event} \downarrow$
$\Theta/\text{bgd} \downarrow$

**Spectrum in bins of $Q^2$.**
\[ \Theta \rightarrow K_S p \]

Monte Carlo has no knowledge of "\( \Sigma \) bumps"

\[ M = 1521.5 \pm 1.5 \text{ MeV} \]
\[ \Gamma = 8 \pm 4 \text{ MeV} \]

Particle and antiparticle

(Results same for \( Q^2 > 15-30 \text{ GeV}^2 \))
$\Theta \rightarrow K_S p$

Determine cross-section using MC ($\Sigma^+$ forced to be $\Theta^+$)
Cross-section ratio to the Λ (1116) determined using \( \Lambda \rightarrow p\pi \) mode.

\( \Lambda (1520) \rightarrow K^+p \) has very different kinematic selections due to the use of \( dE/dx \) for both \( K \) and \( p \).
A state at $1521.5 \pm 1.5$ MeV and width $\Gamma = 8 \pm 4$ MeV observed in 121 pb$^{-1}$ of DIS sample in the $K_{sp}$ spectrum at $Q^2 > 20$ GeV$^2$.

The significance is 3.9-4.6$\sigma$ (exact number cannot be determined due to the unknown background shape.)

Interpretation:
- Same state as $\Theta^+$ pentaquark observed elsewhere. Then:
  - First observation in fragmentation
  - First observation of the anti-pentaquark
- A so-far-unobserved $\Sigma^*$.
- Structure due to some interference. (Reflections from known states were checked and ruled out)
\[ \Xi_{3/2} \to \Xi \pi \]

NA49 has reported the observation of doubly charged decuplet partner of the \( \Theta \), the \( \Xi_{3/2} \) as well as the \( \Xi^0 \).

ZEUS has searched for this state in the same 121 pb\(^{-1}\) DIS sample as for the \( \Theta \) search.

First reconstruct \( \Lambda \) using dE/dx to ID protons.
\[ \Xi_{3/2} \rightarrow \Xi \pi \]

Combine \( \Lambda \) with \( \pi \) to reconstruct \( \Xi \)

ZEUS
$\Xi_{3/2} \rightarrow \Xi\pi$

NA49

ZEUS

$\Xi(1690)$?

NA49

\[ \chi^2_{\text{ndf}} = 84.88 \]
\[ \text{candidates} = 192 \pm 30 \]
\[ \text{peak} = 1333.3 \pm 1.0 \text{ MeV} \]
\[ \sigma = 6.8 \pm 1.4 \text{ MeV} \]

95% C.L. upper limit on $R$

NA49 signal

$M(\Xi\pi)$(GeV)

$\chi^2 > 1 \text{ GeV}^2$

$\chi^2 > 20 \text{ GeV}^2$

$M(\Xi\pi)$(GeV)
No peaks observed in any of the combinations.
\[ \Xi_{3/2} \rightarrow \Xi \pi \]

- No \( \Xi_{3/2} \) state was observed.
- The number of \( \Xi(1530) \) observed in this study is about the same as for the NA49 study.
- The ratio \( R = \frac{N(\Xi_{3/2})}{N(\Xi(1530))} \) around 1860 MeV is <0.29 at 95% C.L.
- Since this is a search in the fragmentation region—does not necessarily contradict the NA49 result.
$\Theta_c \rightarrow D^*p$

- H1 collaboration has reported an observation of a narrow state $\Theta_c \rightarrow D^*p$ at 3099 MeV in DIS.
- The signal corresponds to $\sim$1% of the observed number of $D^*$s ($51\pm11$ $\Theta_c$s observed)
- H1 also reports a compatible state observed in photoproduction ($Q^2\approx0$).
\[ \Theta_C \rightarrow D^* p \]

- ZEUS has made a search in 126 pb\(^{-1}\) of DIS and photoproduction data.

- Both \(K^2\pi\) and \(K^4\pi\) decay modes of \(D^*\) were used. (H1 uses \(K^2\pi\) only).

- Altogether, 62600 \(D^*\)s are found. 13500 in DIS alone. If 1\% of \(D^*\)s came from \(\Theta_C\), expect >600 \(\Theta_C\)s.
$\Theta_c \rightarrow D^*p$

- $dE/dx$ was again used to identify protons.
- Procedure was somewhat refined—use $\chi^2$ probability of a proton hypothesis rather than a simple cut.
\[ \Theta_C \rightarrow D^*p \]

MC simulation of \( \Theta_C \) at 1% of observed \( D^* \)s.

- “1%” signal is ruled out for the whole sample at 9\( \sigma \)
- ruled out for DIS alone at 5\( \sigma \)
$\Theta_c \to D^* p$

**Default selection**
- $K^2\pi$ and $K^4\pi$
- $-1.6 < \eta(D^*) < 1.6$
- $P_T(D^*) > 1.35$ GeV (for $K^2\pi$)
- $y < 0.95$

**“H1” selection**
- $K^2\pi$ only
- $-1.5 < \eta(D^*) < 1.0$
- For DIS
  - $0.05 > y > 0.7$
  - $P_T(D^*) > 1.5$ GeV
- For Photoprod.
  - $0.2 > y > 0.8$
  - $P_T(D^*) > 2.0$ GeV
- ..other minor changes

Note all cuts are tighter for the “H1” selection.
H1 selection

\[ \Theta_C \rightarrow D^*p \]

(a) ZEUS 1995-2000, \( D^{*+} \rightarrow (K\pi)\pi_s \)
\[ Q^2 > 1 \text{ GeV}^2, \text{ H1 selection criteria} \]
- Combinations per 10 MeV
  - \( \sim 5900 \text{ } D^*s \)

(b) \( Q^2 < 1 \text{ GeV}^2, \text{ H1 selection criteria} \)
\[ \sim 11500 \text{ } D^*s \]

\[ M(D^*p) = \Delta M^{ext} + M(D^{*+})_{PDG} \text{ (GeV)} \]
$\Theta_C \rightarrow D^* p$

- No resonance structure observed from >60k $D^*$s.
- “1%” signal is ruled out at 9$\sigma$ for all and 5$\sigma$ for DIS only.
- (Also checked $Q^2$>20 GeV$^2$—nothing was found)
- The upper limit of observed $D^*$s originating from $\Theta_C$ is 0.23% (95% C.L.)
- After acceptance correction: (assuming $P_T(\Theta_C)$ and $\eta(\Theta_C)$ same as those of $D^*$): the upper limit of $D^*$s, in the measured kinematic region, originating from $\Theta_C$ is 0.16% (95% C.L.)
- These results are incompatible with the H1 result.
Summary

1. $\Theta \rightarrow K_S p$ : A narrow state observed at 1520 MeV at $Q^2>20$ GeV$^2$. Maybe the $\Theta^+$ pentaquark.

2. $\Xi_{3/2} \rightarrow \Xi \pi$ : No state is observed. May still be compatible with NA49 result—fragmentation region probed.

3. $\Theta_c \rightarrow D^* p$ : No state is observed. A production at 1% of the $D^*$ rate is ruled out. Not compatible with H1 result.