Search for a new baryonic state decaying to pK^0_S

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History of the subject

Early 2000's: several experiments reported "exotic" objects apparently consisting of more than 2 – 3 quarks.

Results were not consistent.

ZEUS: evidence for a peak in pK^0_S (+ c.c.) that would correspond to a $uudd\bar{s}$ state (pentaquark, PQ) at 1.53 GeV from 1996-2000 data (HERA-1)

Recently, LHCb have announced discovery of two pentaquark states at 4.38, 4.45 GeV, corresponding to $uudc\bar{c}$. The subject is topical again!

Here we report on a new ZEUS search for the previous pK^0_S state, using considerably increased statistics from HERA-2 (2003-2007)

The HERA-1 Results

ZEUS Phys. Lett. B 591 (2004) 7

121 pb^{-1}

Peak at 1.521.5 GeV,
consistent with Θ state reported by other experiments.

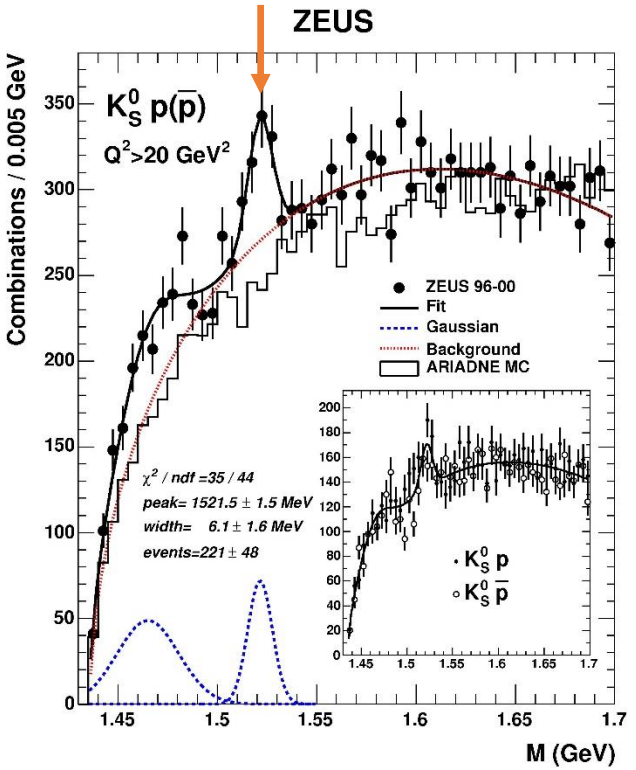
H1 Phys. Lett B 639 (2006) 202

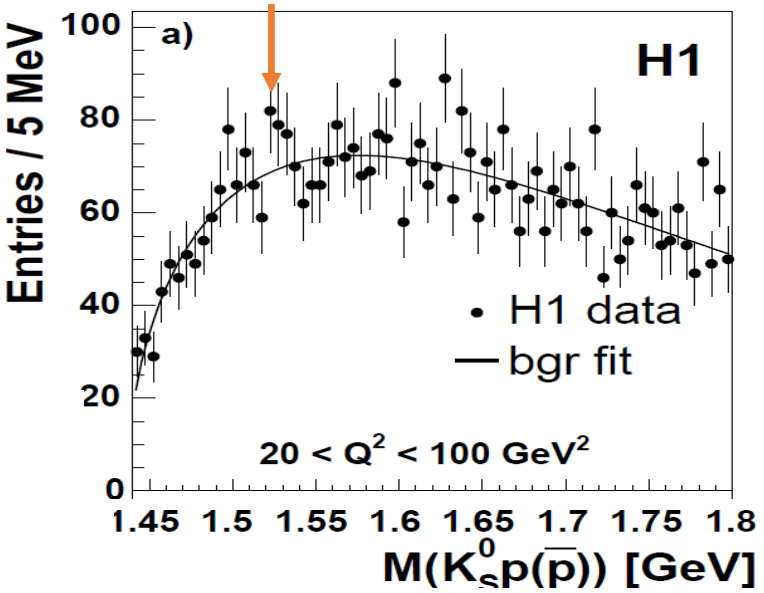
No significant signal seen.

HERA-2 ZEUS improvements:

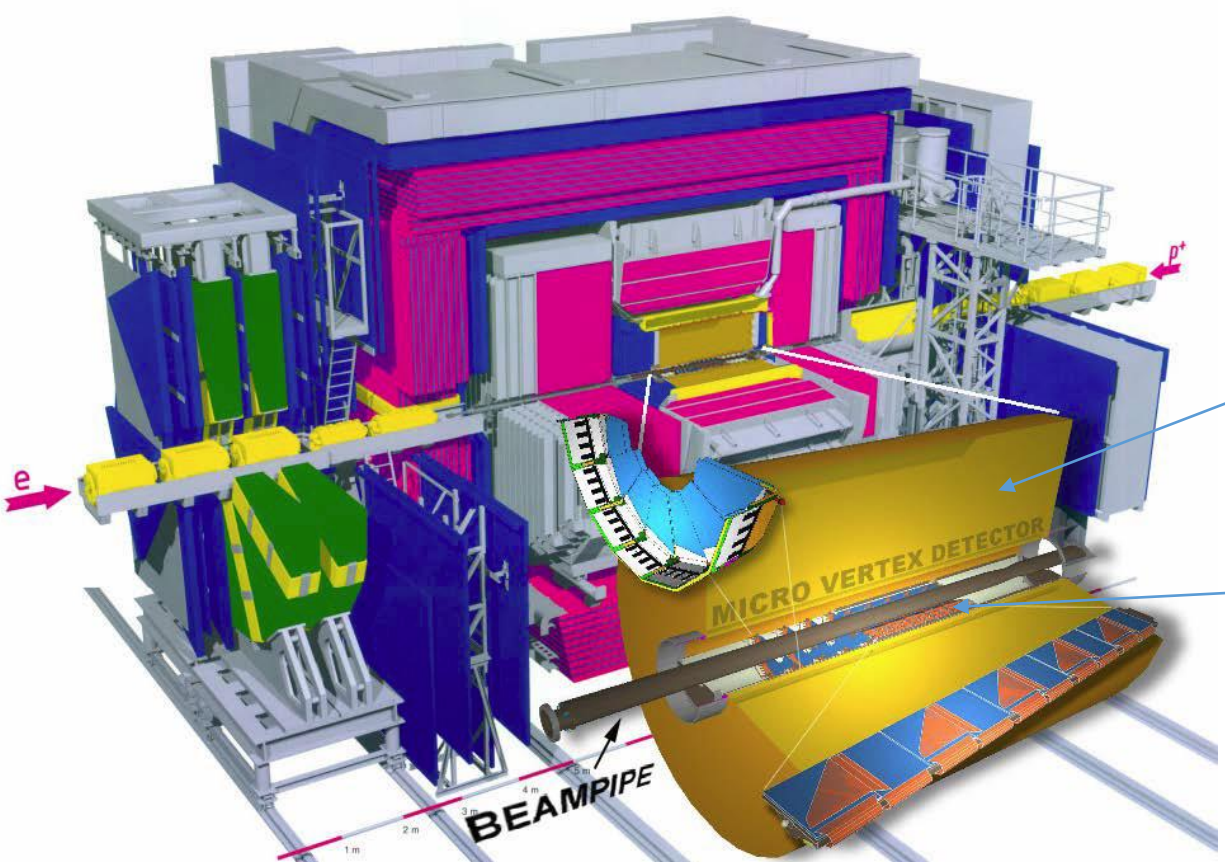
3x luminosity: 358 pb^{-1}

Upgraded tracking system.





ZEUS in HERA-2



Central Tracking Detector (CTD)

Micro Vertex Detector (MVD)

Both the CTD and the MVD provided dE/dx information that was critical in helping to identify the (anti)proton in the possible pK^0 state

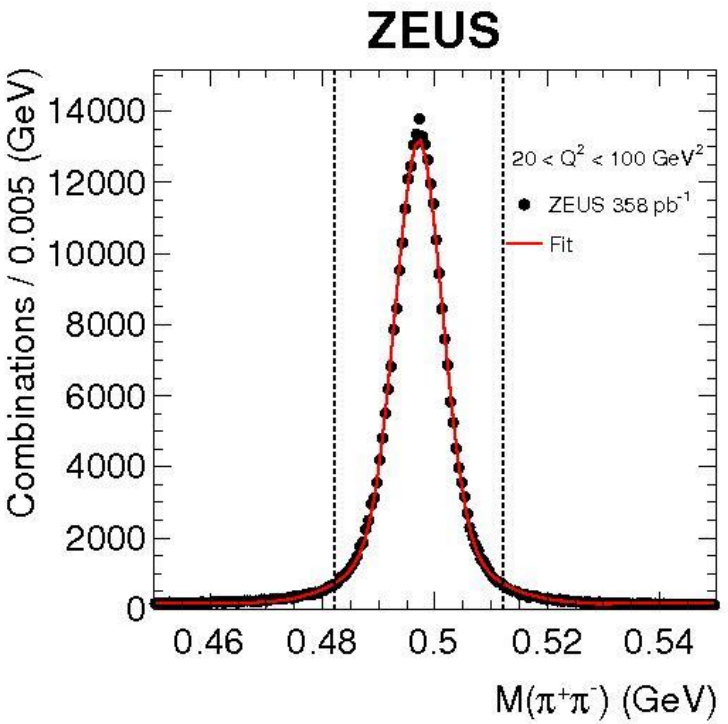
DIS event selection

E_p = 920 GeV, E_e = 27.5 GeV (electron or positron beam)

- A good scattered electron/positron in the sensitive area of the calorimeters.
- Electron probability > 0.9
- $20 < Q^2 < 100\ \text{GeV}^2$
- $E_e' > 10$ GeV
- $y_e < 0.95$, $y_{JB} > 0.04$
- $38 < E - p_Z < 60$ GeV

K^0_S selection

- Two central ($|\eta| < 1.75$) tracks with opposite charge
  $|\eta|$ of combination < 1.6
- > 2 barrel MVD hits, > 2 inner CTD hits for each track.
- p_T (track) > 0.15, pT (combination) > 0.25 GeV/c
- Common vertex fit with $\chi^2 < 5$
  and decay length $L_{XY} > 0.5$ cm.
- Collinearity angle of fitted combination direction with vector from primary vertex < 0.06 in XY plane, 0.15 in 3-D.
- To eliminate contaminations,
  assign track masses and require
  - $m(e^+e^-) > 0.07$ GeV (γ conversions)
  - $m(\pi p) > 1.121$ GeV (Λ)



→ 0.31 M K^0 events, 0.482 < $m(\pi^+\pi^-)$ < 0.512 GeV

Proton identification (PID)

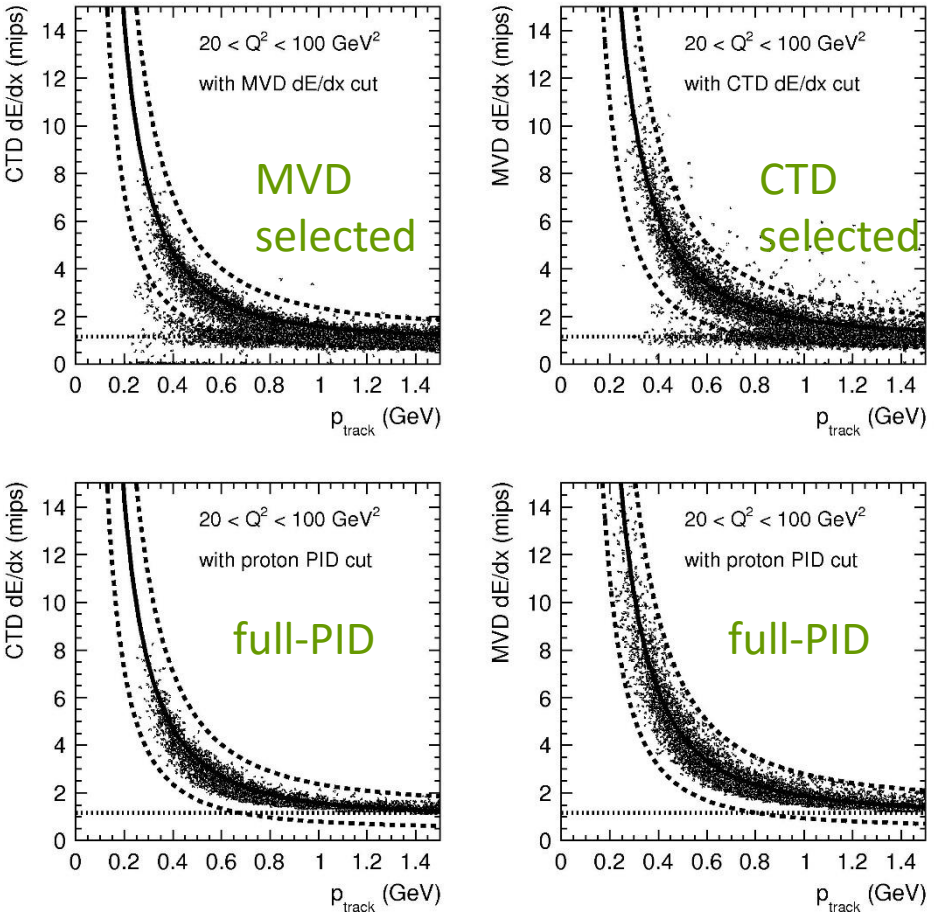
- Track not used in K^0_s
- $0.2 < p_p < 1.5$ GeV/c
- passes though CTD layer 1 and at least to layer 3.
- PID in both CTD and MVD

- Up to 70 CTD hits available
- Up to 6 MVD hits available

In each detector, selection based on distance from Bethe-Bloch function and likelihood of e, π, p hypotheses.

Both selections used for full PID when available.

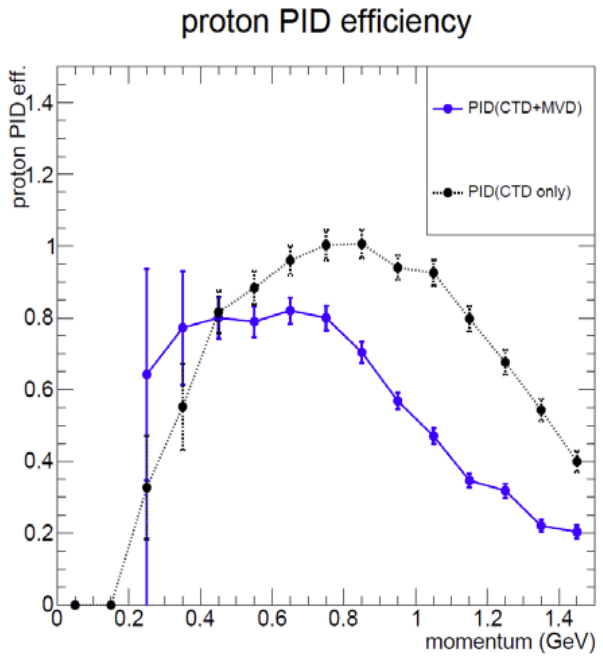
CTD dE/dx **MVD dE/dx**



If no valid CTD dE/dx, just use MVD. ZEUS Hera-1 analysis had only CTD.

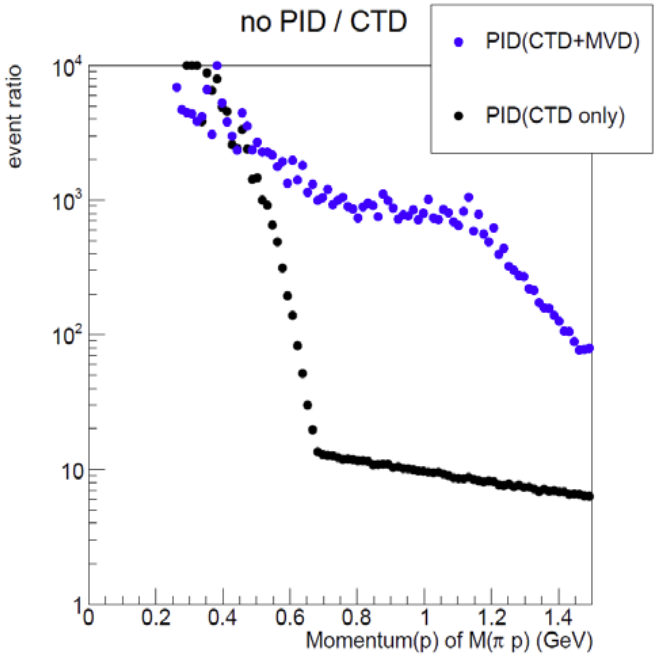
PID efficiency

- Evaluated using a selected sample of Λ baryons
- Estimated using **CTD-only** method (HERA-1) and **CTD+MVD** method (HERA-2, tighter CTD cuts)

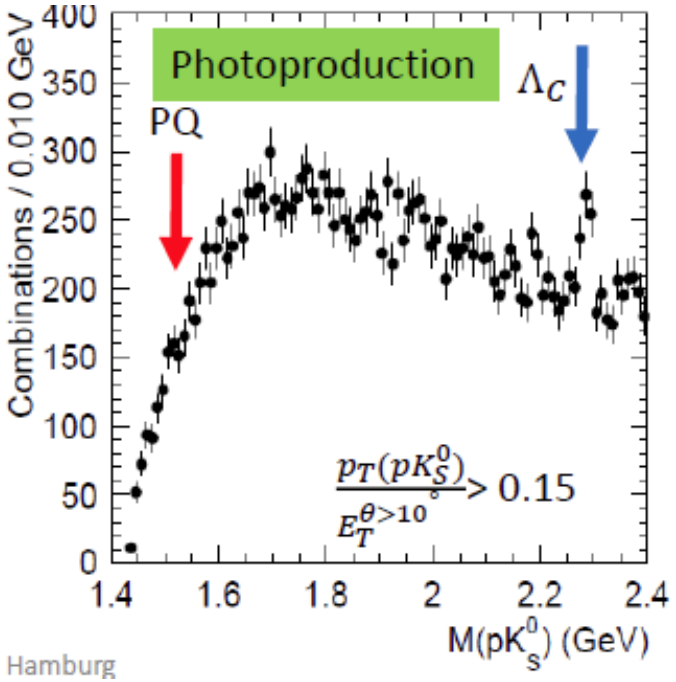


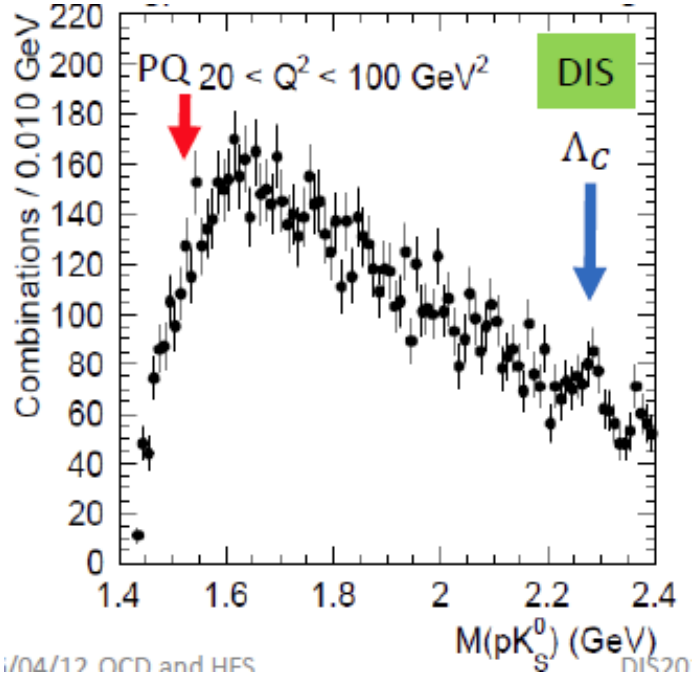
Pion rejection

- Evaluated using a selected K^0_S sample
- Typically 10-100 times better using present method.



Can we see any resonance at all? Check for Λ_c^+ (2286)





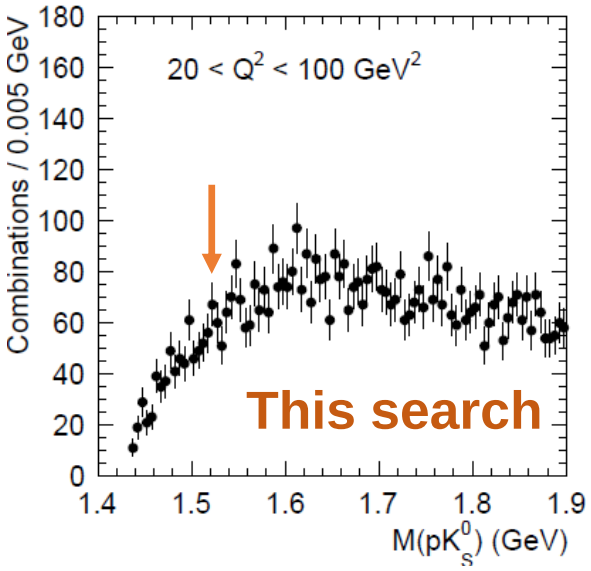
Select a photoproduction sample as well as the present DIS sample and plot pK^0_S mass. Use present optimised CTD+MVD proton PID.

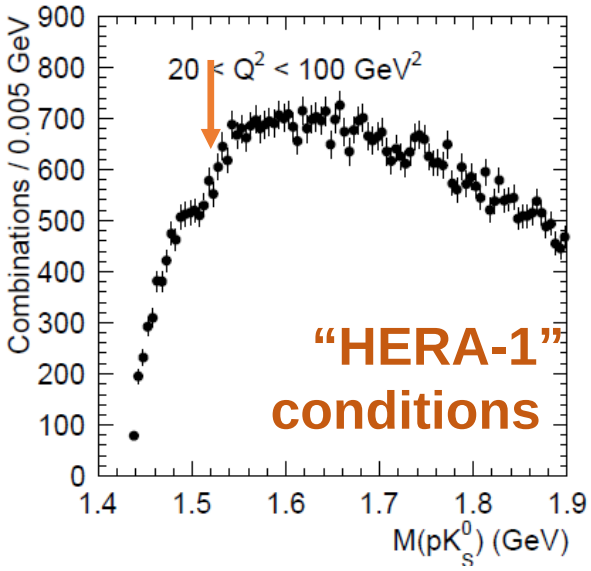
- The Λ_c^+ is clearly seen in the photoproduction sample, and evident with lower statistics in the DIS sample.

- No sign of previously claimed pentaquark (PQ)

Results of search

$20 < Q^2 < 100$ GeV^2
$0.5 < pT(pK^0_S) < 3.0$ GeV/c
$|\eta(pK^0_S)| < 1.5$



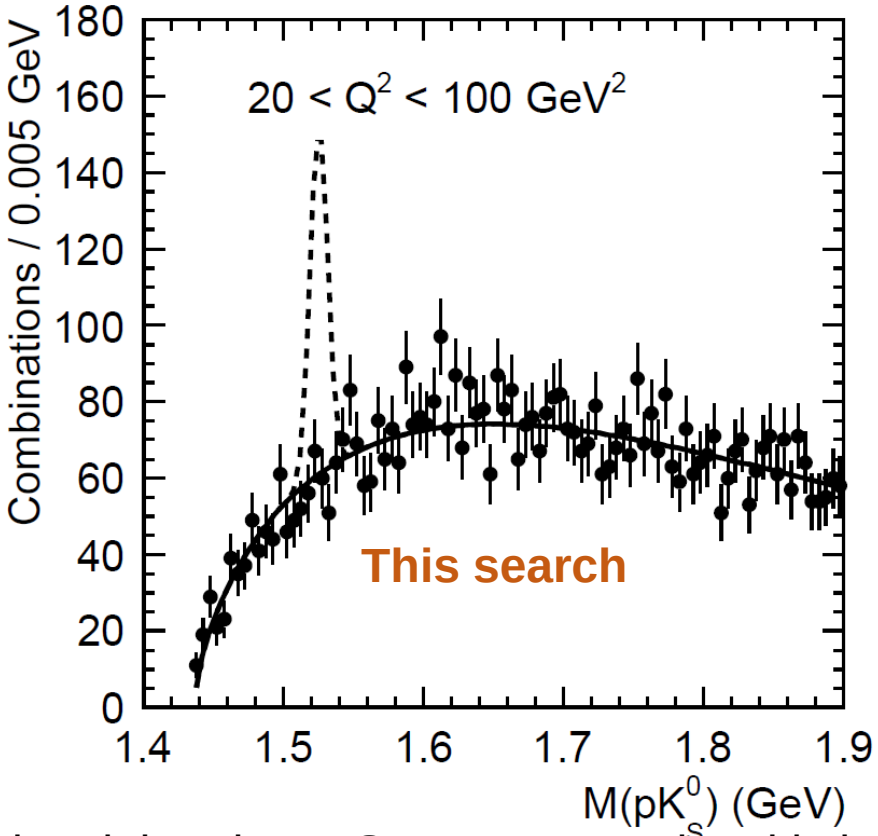


$m(pK^0_S)$

No pentaquark-like peak seen in present search.
Using conditions resembling HERA-1 search (only CTD dE/dx, different cuts) on present data sample, again **no peak seen.**

5% pion contamination in present search, >50% in HERA-1 like search, which had looser proton dE/dX selection.

Comparison to HERA-1 analysis



The expectation from the claimed ZEUS HERA-1 Θ^+ signal is indicated as a dashed peak (286 events). Clearly not confirmed.

So we calculate production limits from the present analysis.

Limit calculation – general method

- Use RAPGAP 3.1030 to simulate production cross section of a pentaquark (PQ) state.

- Model PQ by replacing $\Sigma^+(1189)$ in the particle table with PQ, isotropically decaying to $p + K^0$.
  Generate PQs for:
  mass values (1.45,1.5,1.522,1.54,1.56,1.6,1.65 GeV),
  $Q^2 > 1$GeV
  at least one PQ in event with rapidity $|y| < 2.5$
  BR ($K \rightarrow K^0_S$), BR($K^0_s \rightarrow \pi^+\pi^-$) = 0.5 and 0.6895 respectively.

- Pass generated events through the GEANT 3.21-based ZEUS detector + trigger simulation program.

- Fit data to background (see next page) + generated signal

- Define particle-level kinematic region:
  $20 < Q^2 < 100$ GeV2, $0.5 < p_T(PQ) < 3.0$ GeV/c, $|\eta(PQ)| < 1.5$
  Calculate acceptances relative to this region.

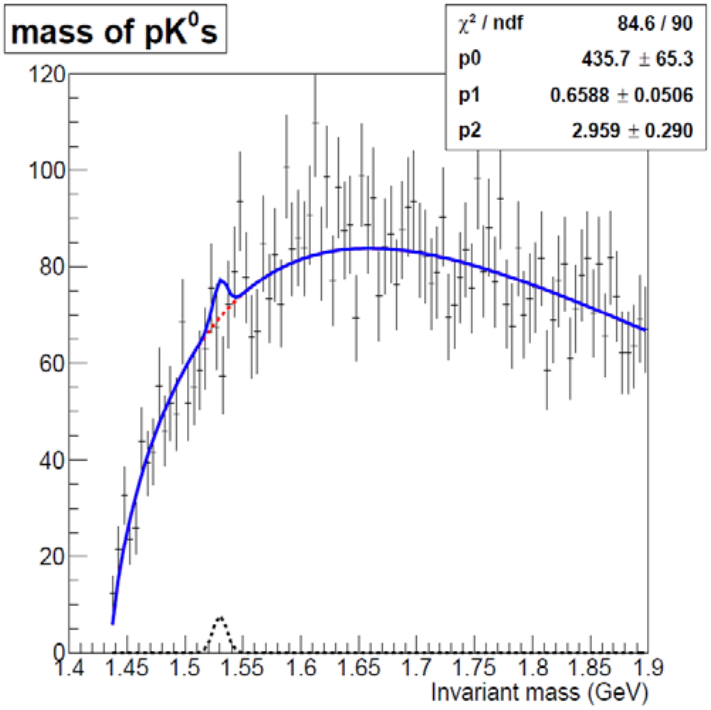
Limit calculation – Fitting method.

- For the proposed signal choose a Gaussian function with 3 possible widths:
  - 6.1 MeV as reported in ZEUS HERA I analysis.
  - 1× and 2× the detector mass resolution ($0.009591MM$- 0.01111 GeV)

- Background: an empirical function
  - $\alpha\,(M\text{-}M_0)\,\beta \times (\,1 + \gamma(M - M)\,)$
  - $M = (pK^0_S)$ mass
  - M_0 = sum of p + K^0_S masses
  - α, β, γ are free parameters

- Vary signal strength for each mass, calculate minimum $\chi^2 = \chi^2_0$ and signal strength giving
  - $\chi^2 = \chi^2_0 + 2.71$ (95% CL)

(example: M = 1.53 and width=6.1 MeV)

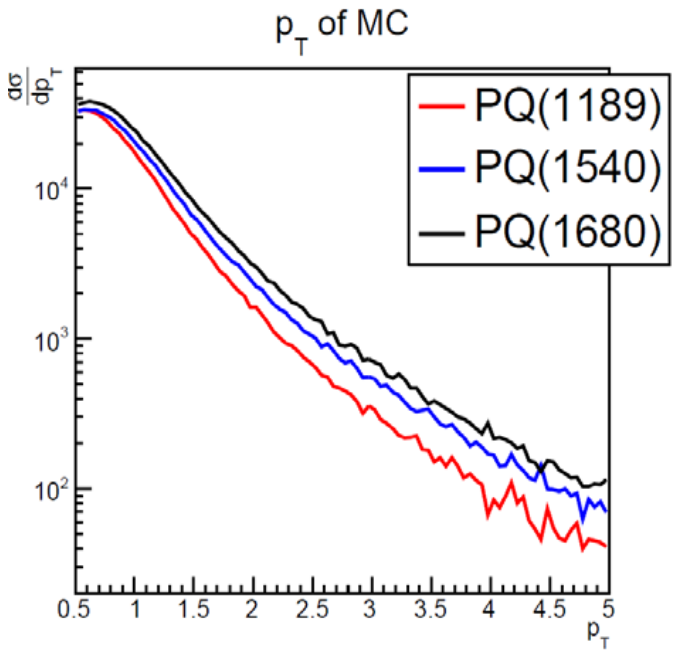


Limit calculation – systematic uncertainties

Systematic uncertainties were estimated for the following items.
10% effect on upper limits.

- DIS event selection
- PID
- Acceptance for (pK^0_S) system
- p_T distribution of (pK^0_S) system
- Luminosity

(Largest effect was with reweighting the p_T distribution to make it independent of M(PQ).)



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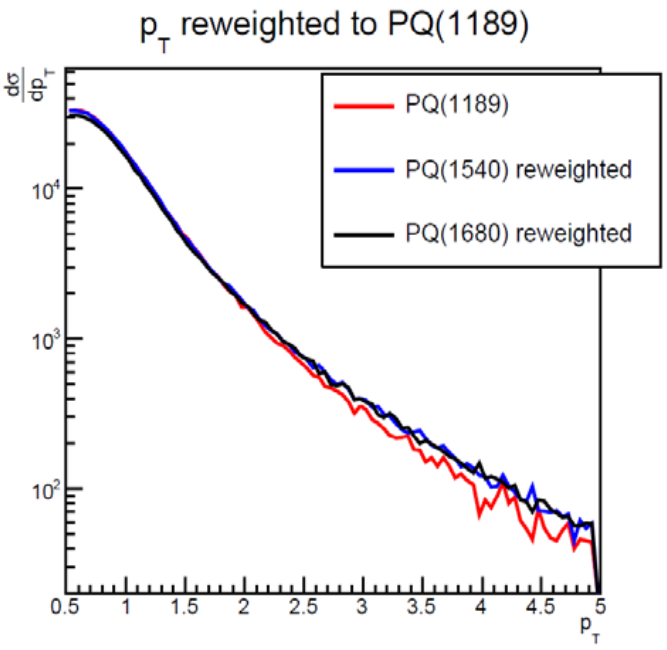
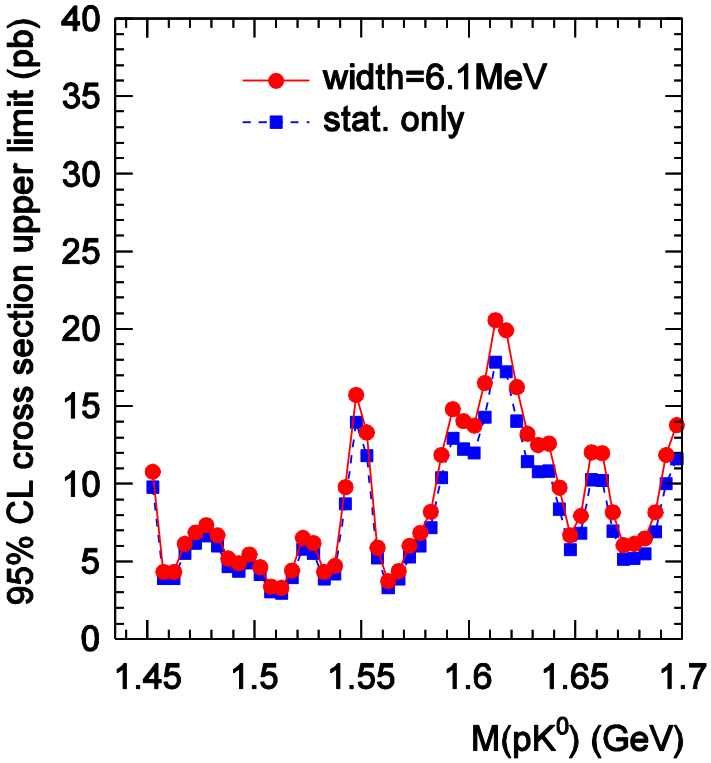
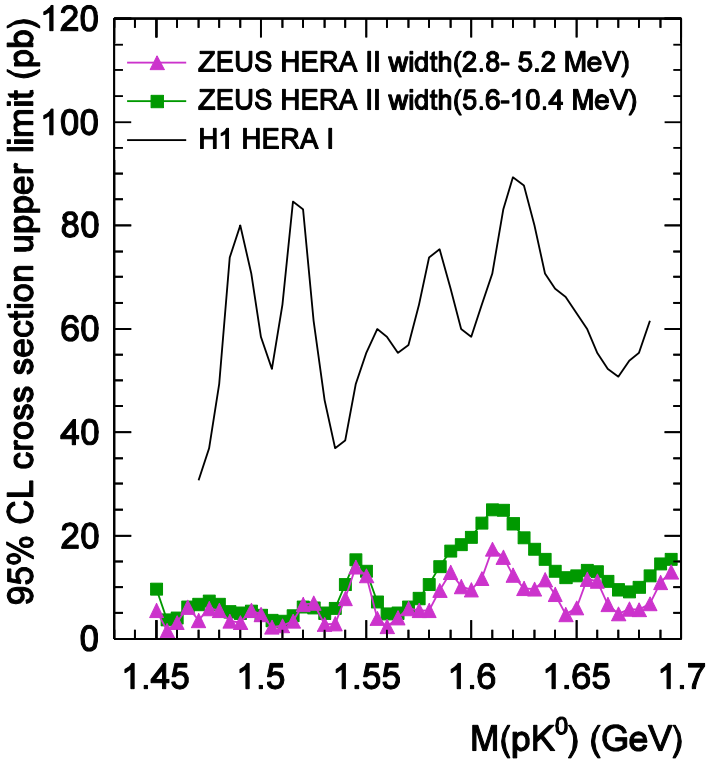


reweighted

Limit calculation – results and comparisons





- 95% CL upper limits for PQ × BR(PQ $\rightarrow pK^{0}$) production cross section are shown for 6.1 MeV width (left) and detector resolution width models (right).

- The broader detector resolution most resembles H1 (also shown)

SUMMARY

- ZEUS have searched for a pentaquark-like resonance in the (pK^0_S) system using the full HERA-2 DIS data sample, updating an earlier claim for evidence for a $\Theta^+(1520)$ state based on HERA-1 data.

- Improvements in tracking, particle identification and integrated luminosity produce a much improved result.

- The previously claimed state is not confirmed.

- Limits for production cross section of such a state are presented, as a function of mass, for the kinematic region
  $20 < Q^2 < 100\ \text{GeV}^2$, $0.5 < p_T(PQ) < 3.0\ \text{GeV/c}$, $|y| < 1.6$,