

Pentaquark searches at ZEUS

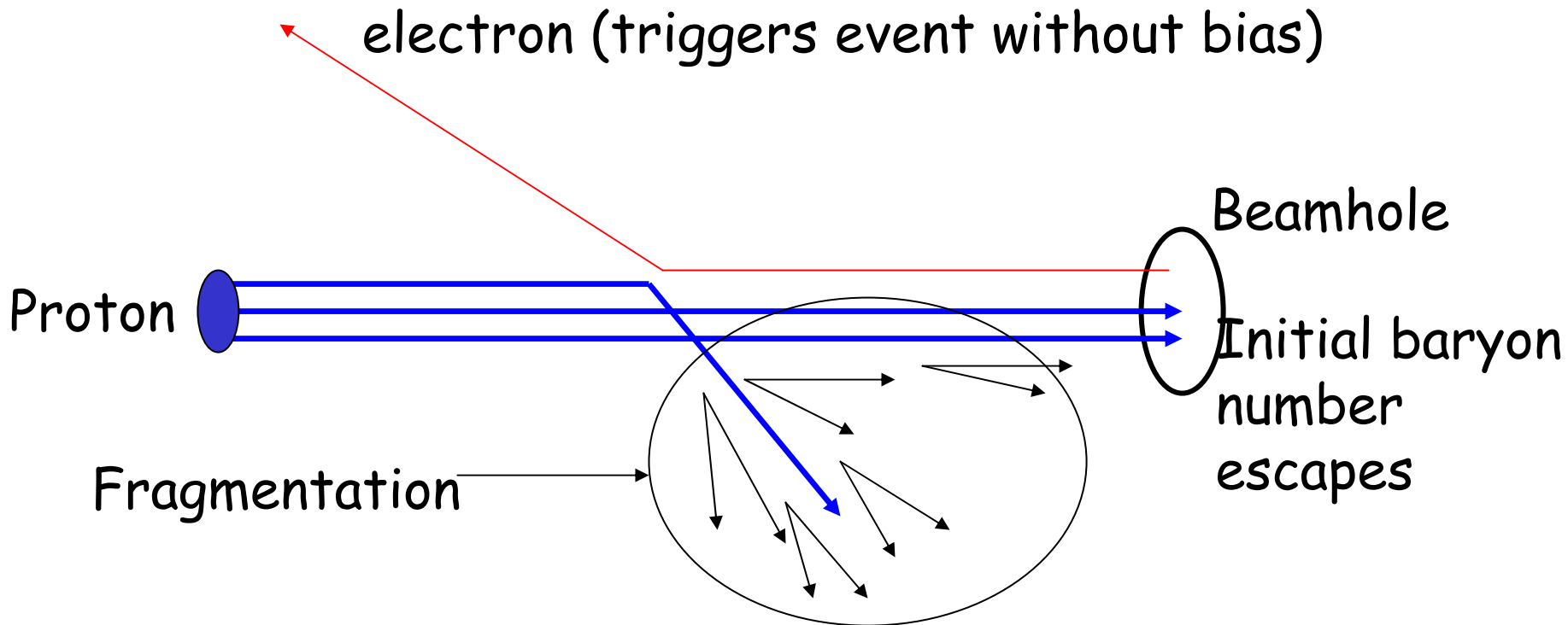
1. $\Theta \rightarrow K_S p$: Many fixed target experiments report $\Theta^+ \rightarrow K^+ n$ (and $K_S p$) at ~ 1530 MeV
2. $\Xi_{3/2}^- \rightarrow \Xi^- \pi$: NA49 reports exotic $\Xi_{3/2}^-$ at ~ 1860 MeV
3. $\Theta_c \rightarrow D^* p$: H1 reports $\Theta_c \rightarrow D^* p$ at 3099 MeV

$$\Theta \rightarrow K_S p$$

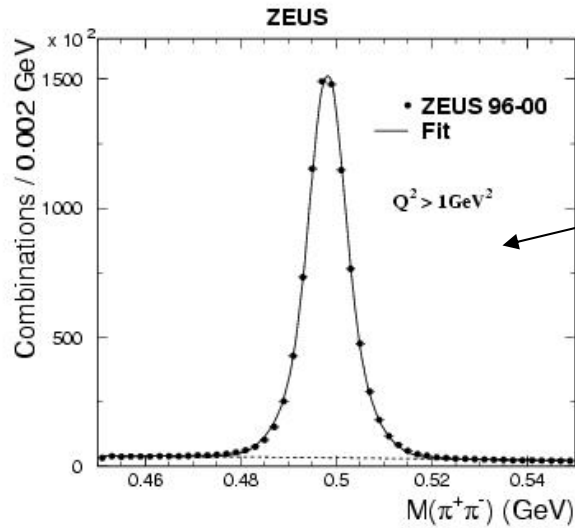
- $\Theta^+ \rightarrow K^+ n$ is a manifestly exotic state ($uudd\bar{s}$). Observed mass $\sim 1530 \text{ MeV}$.
- $\Theta \rightarrow K_S p$ is not manifestly exotic. Can be interpreted as a Σ^* ($uudds$).
- $K_S p$ spectrum has many reported " Σ bumps" (observed by experiments at low significance). 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 $K_S p$ would be consistent with the exotic Θ^+ .

$$\Theta \rightarrow K_{sp}$$

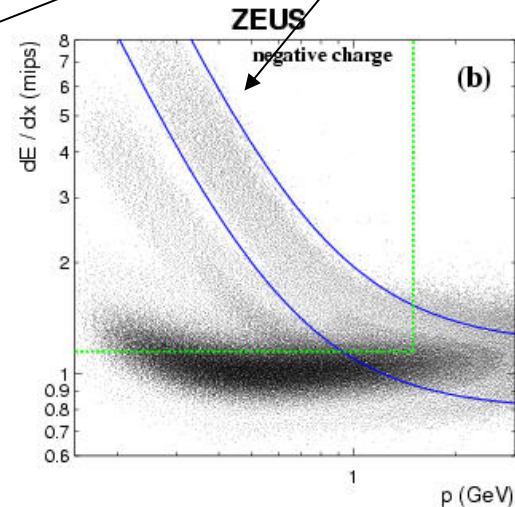
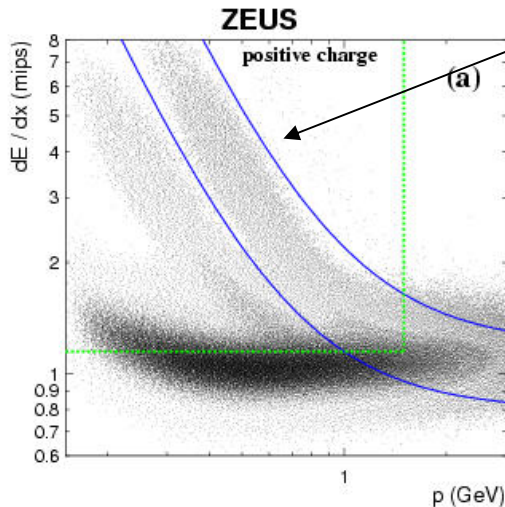
The search is made in Deep Inelastic Scattering
sample: $\sim 121 \text{ pb}^{-1}$, the entire HERA I sample.



$\ominus \rightarrow K_S^0$



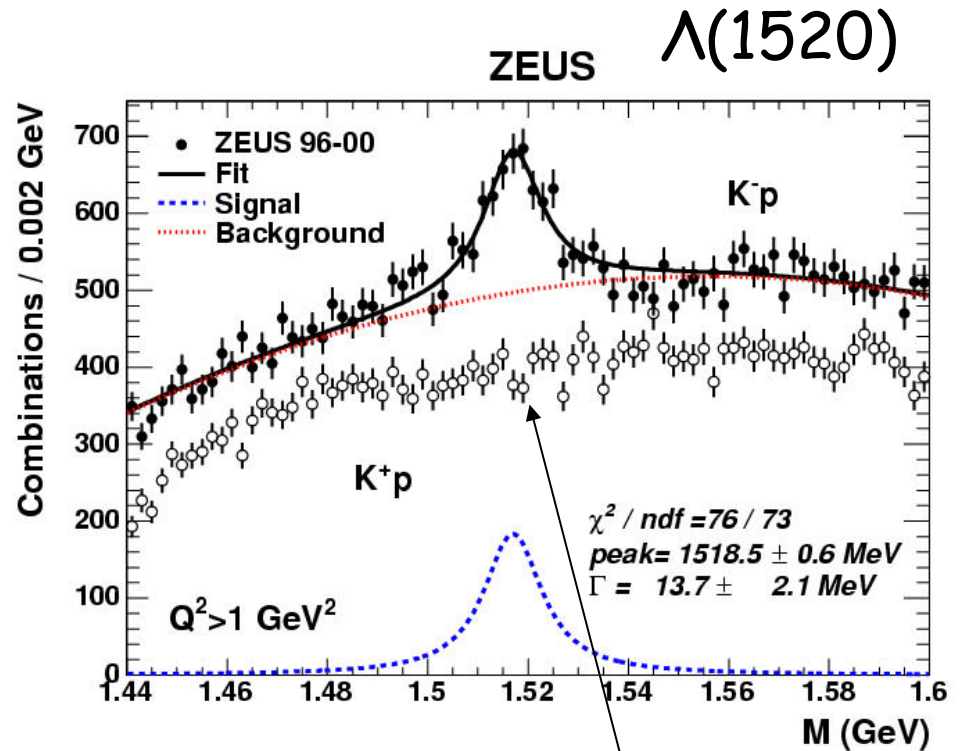
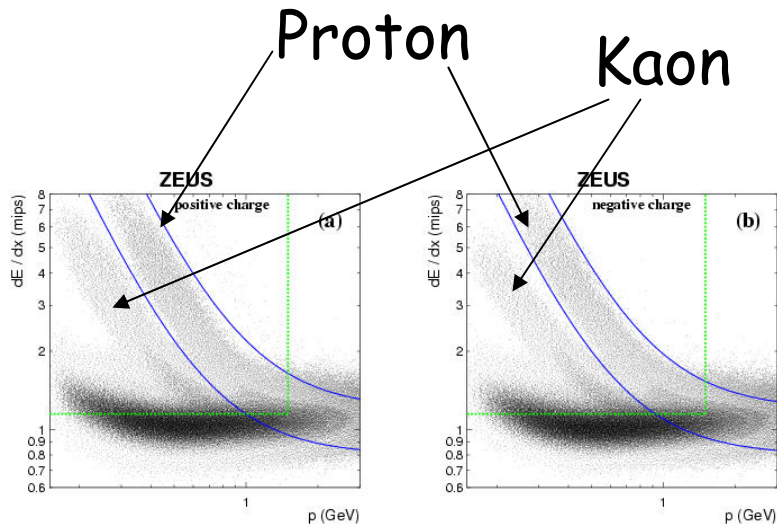
870k Ks reconstructed



(anti)Proton candidates from dE/dx in the central tracking chamber (CTD).

$\Theta \rightarrow K_S p$

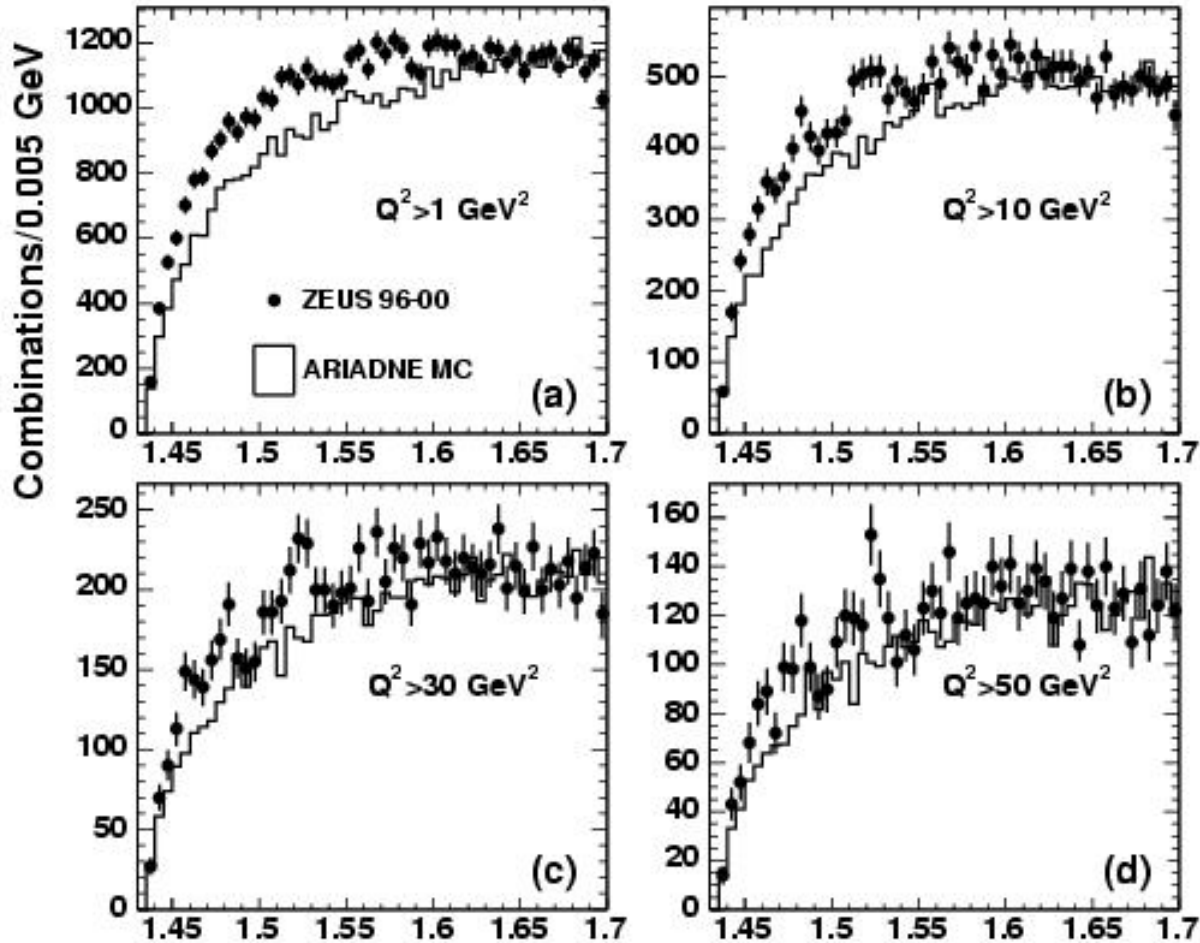
Looking for known states using same sample and dE/dx



No Θ^{++}

$$\Theta \rightarrow K_{sp}$$

Spectrum in bins of Q^2 .



MC studies:
(produce Θ in
the same way
as baryons in
fragmentation)

At $Q^2 \approx 10 \text{ GeV}^2$
or larger,

$\Theta/\text{event} \approx \text{const}$

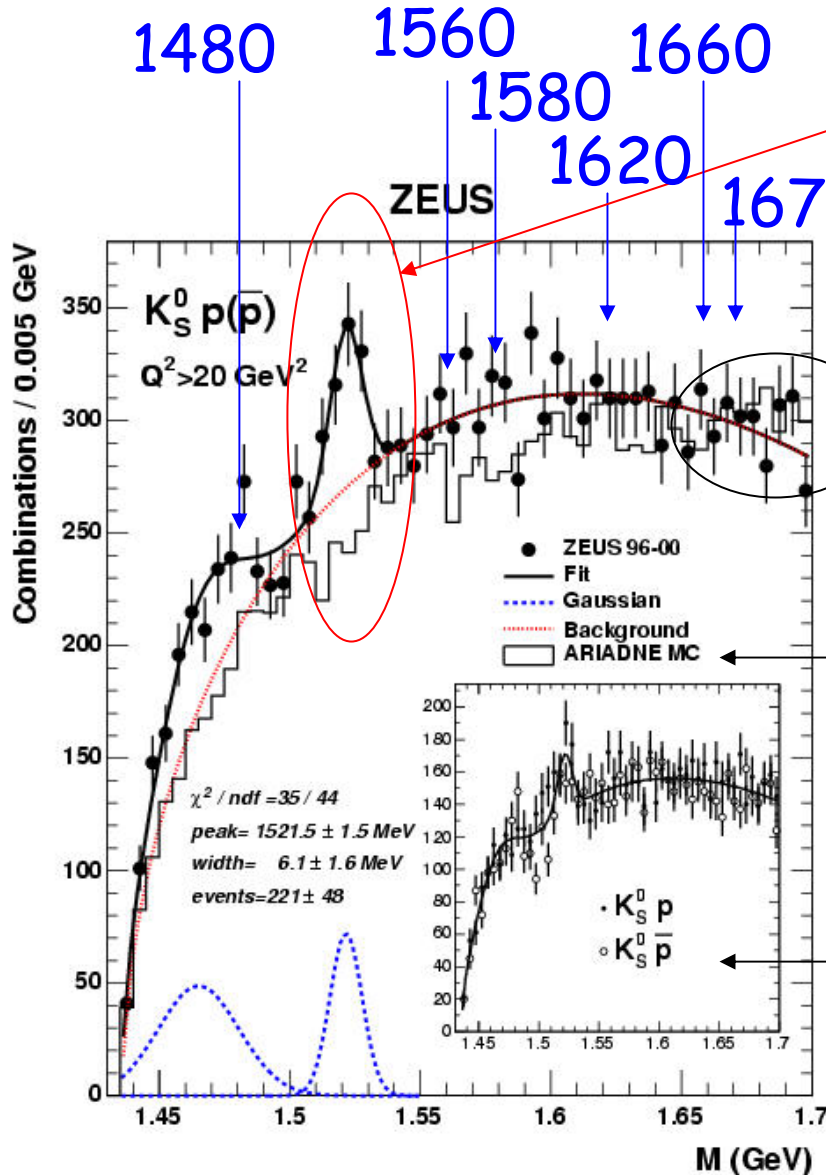
$\Theta/\text{bgd} \approx \text{const}$

As $Q^2 \rightarrow 0$

$\Theta/\text{event} \downarrow$

$\Theta/\text{bgd} \downarrow$

$$\Theta \rightarrow K_S p$$



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

Monte Carlo normalized here

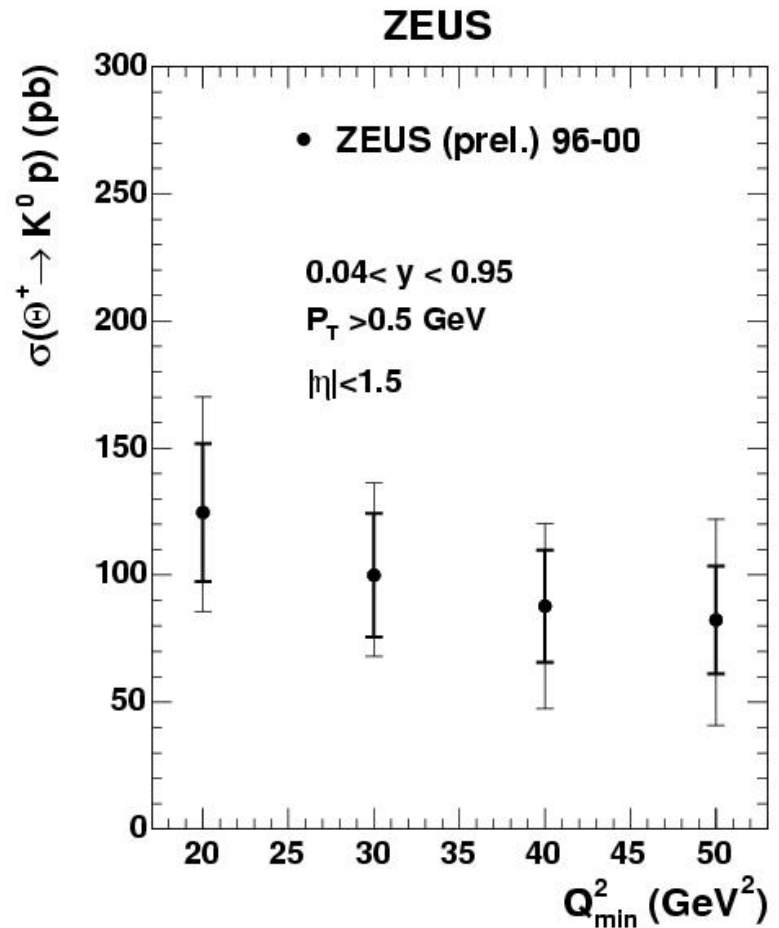
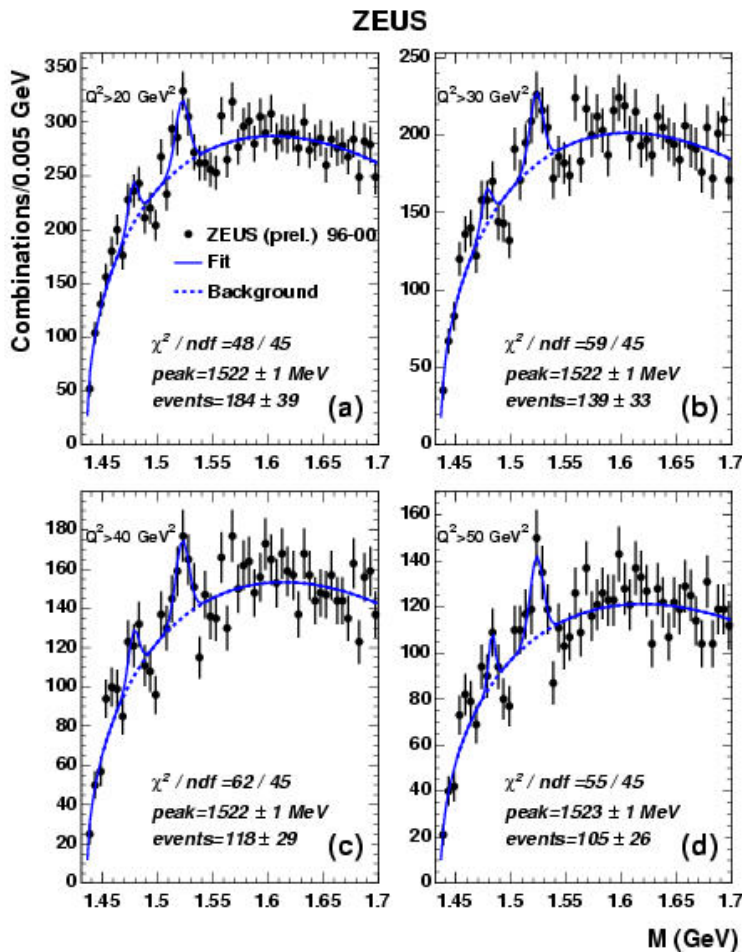
Monte Carlo has no knowledge of "Σ bumps"

Particle and antiparticle

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

$$\Theta \rightarrow K_S p$$

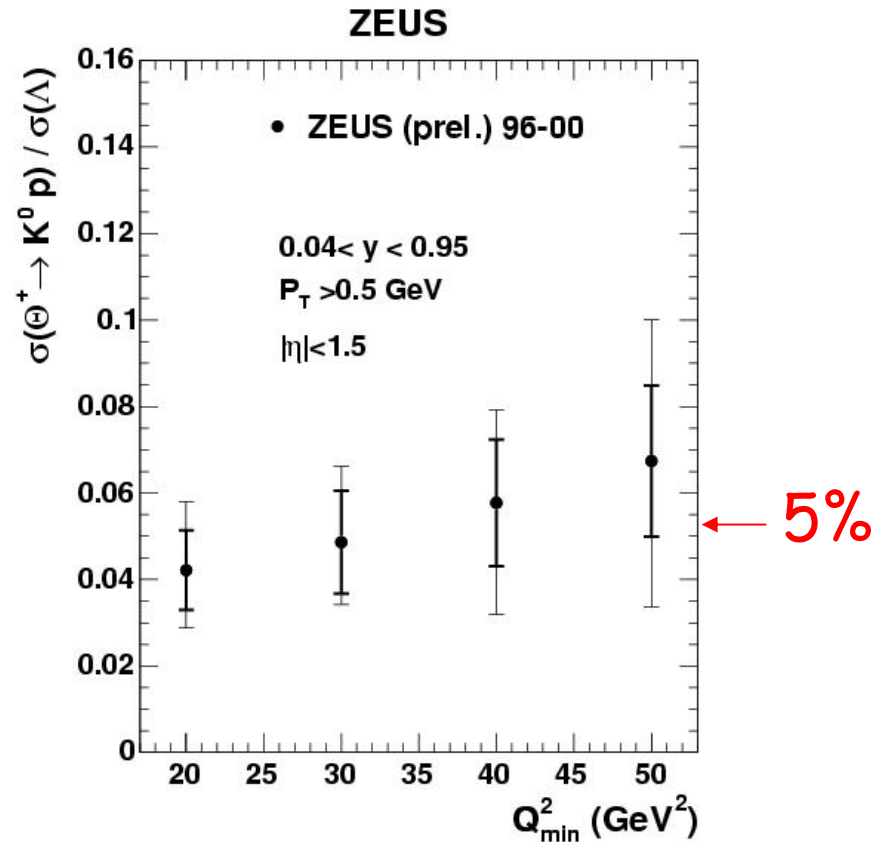
Determine cross-section using MC (Σ^+ forced to be Θ^+)



$$\Theta \rightarrow K_S p$$

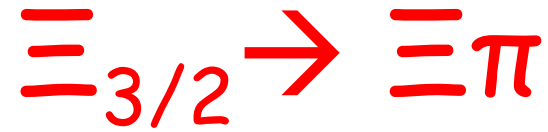
Cross-section ratio to the $\Lambda(1116)$ determined using $\Lambda \rightarrow p\pi$ mode.

$\Lambda(1520) \rightarrow K^+ p$ has very different kinematic selections due to the use of dE/dx for both K and p.



$$\Theta \rightarrow K_S p$$

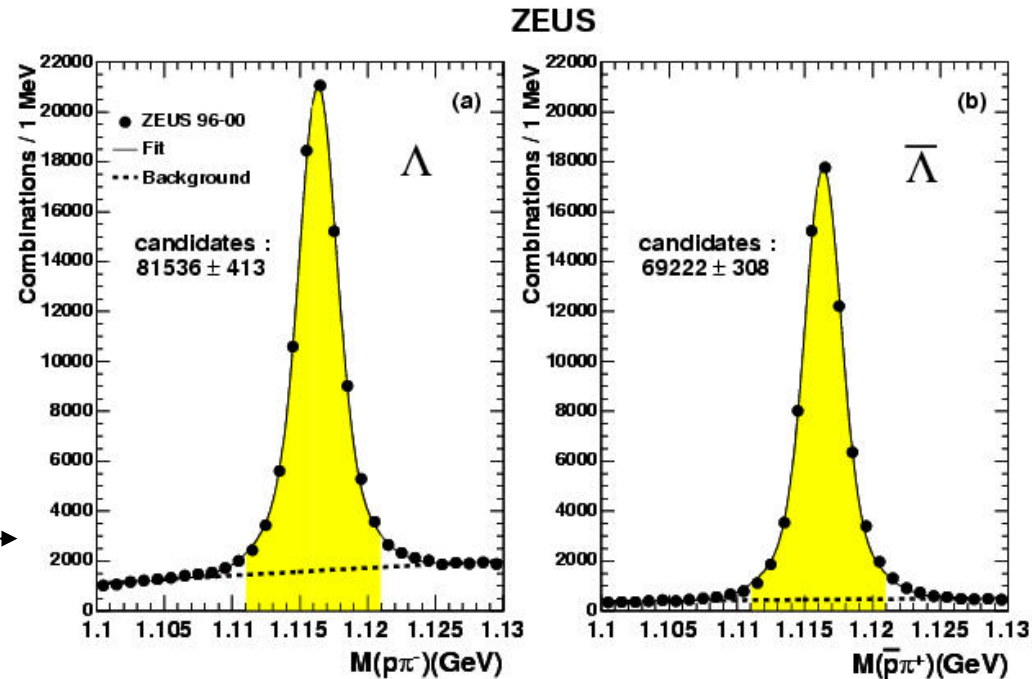
- A state at $1521.5 \pm 1.5 \text{ MeV}$ and width $\Gamma = 8 \pm 4 \text{ MeV}$ observed in 121 pb^{-1} of DIS sample in the $K_S p$ spectrum at $Q^2 > 20 \text{ GeV}^2$.
- The significance is $3.9\text{-}4.6\sigma$ (exact number cannot be determined due to the unknown background shape.)
- Interpretation:
 - Same state as Θ^+ pentaquark observed elsewhere. Then:
 - First observation in fragmentation
 - First observation of the anti-pentaquark
 - A so-far-unobserved Σ^* .
 - Structure due to some interference. (Reflections from known states were checked and ruled out)

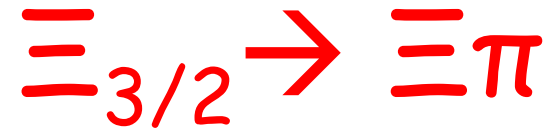


NA49 has reported the observation of doubly charged decuplet partner of the Θ , the $\Xi_{3/2}^-$ as well as the $\Xi_{3/2}^0$.

ZEUS has searched for this state in the same 121 pb⁻¹ DIS sample as for the Θ search.

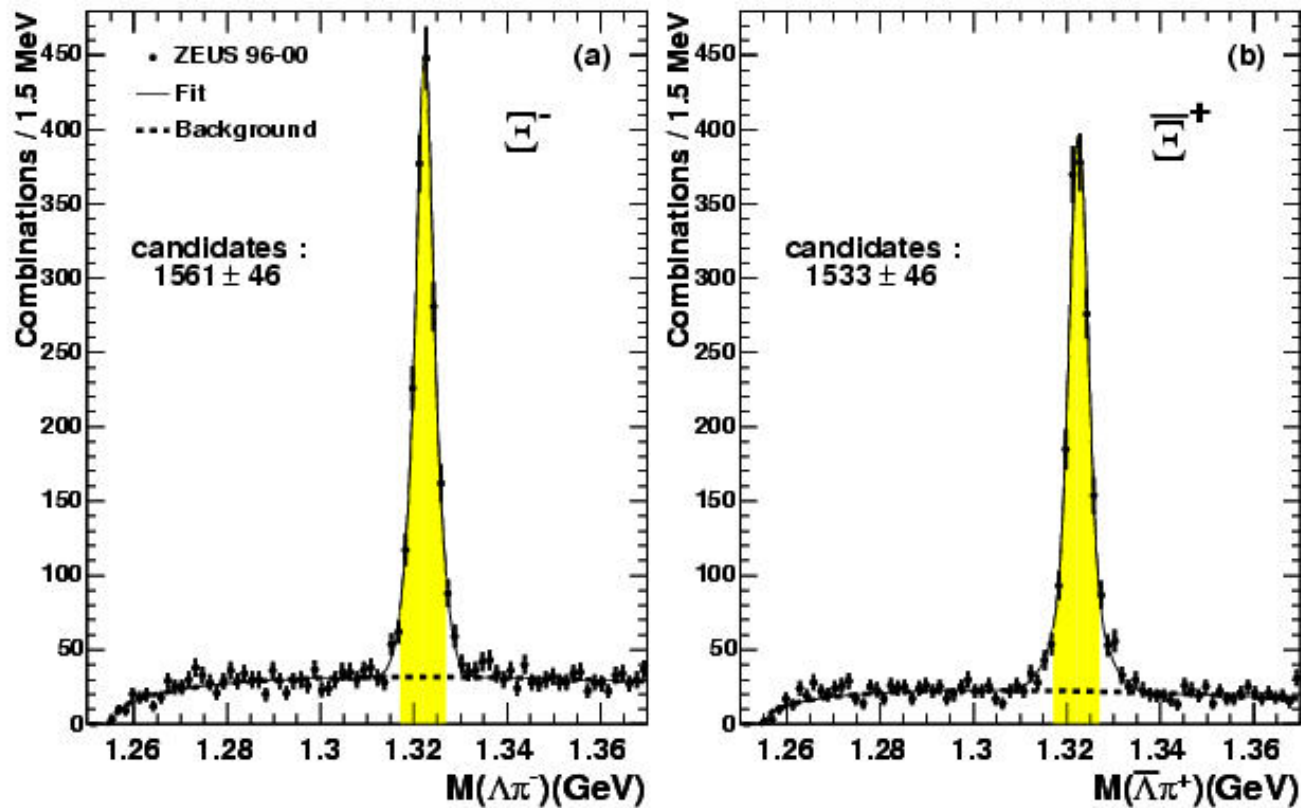
First reconstruct Λ using dE/dx to ID protons.

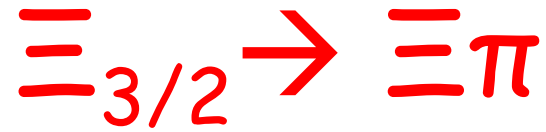




Combine Λ with π to reconstruct Ξ

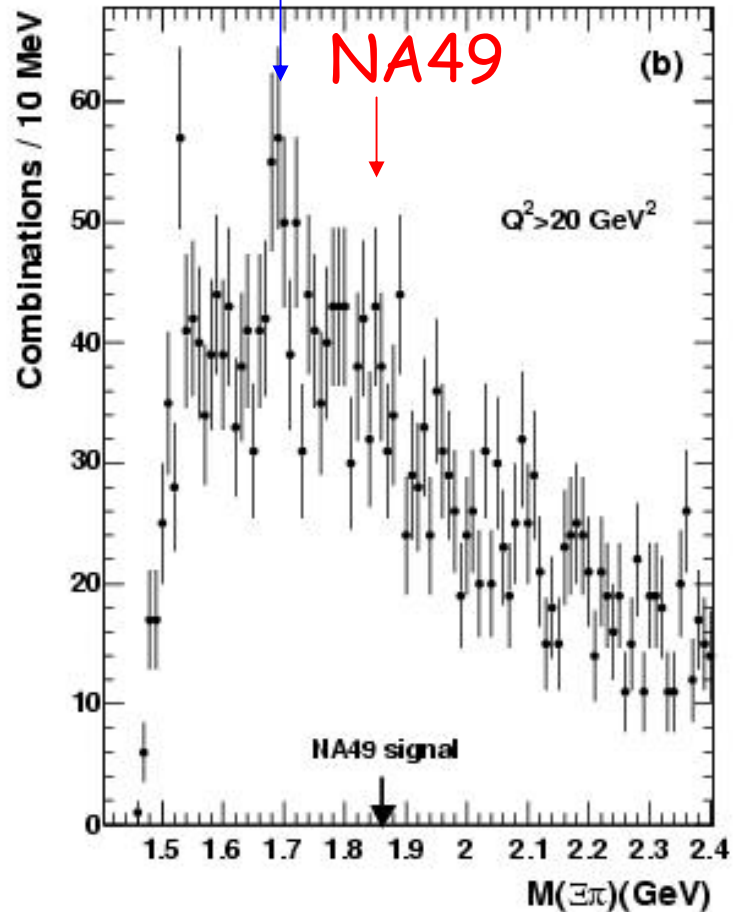
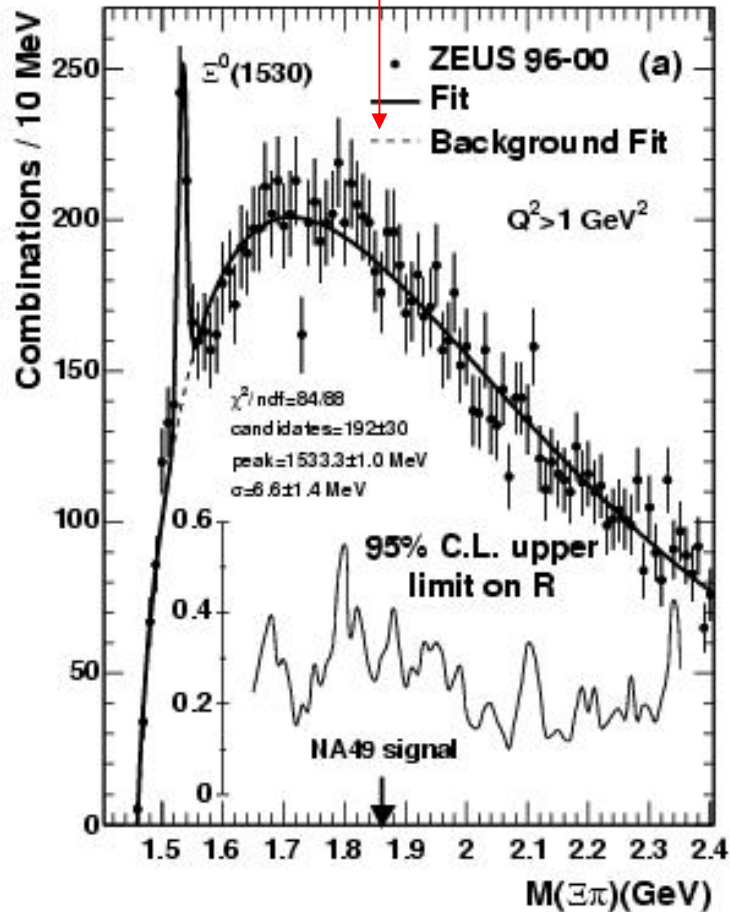
ZEUS

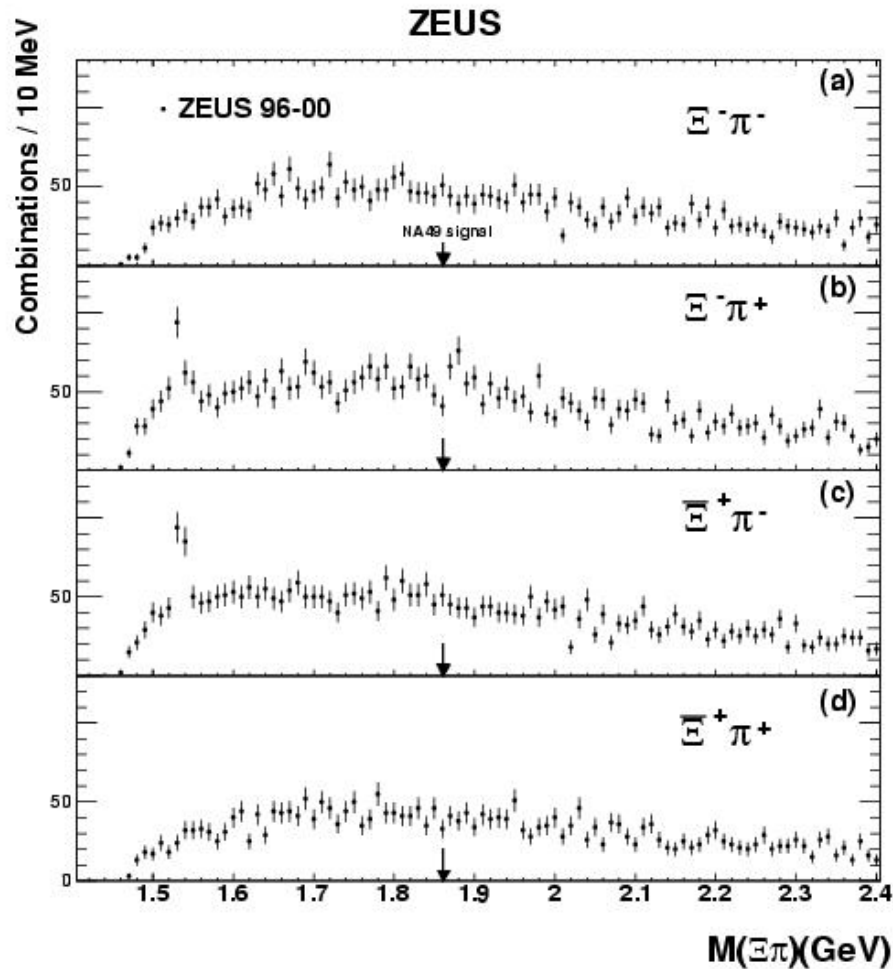
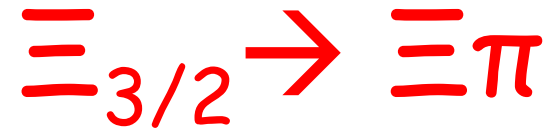




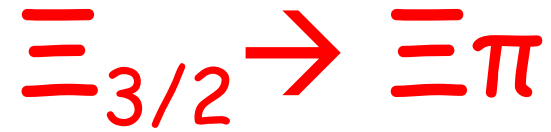
NA49

ZEUS $\Xi(1690)?$





No peaks observed
in any of the
combinations.



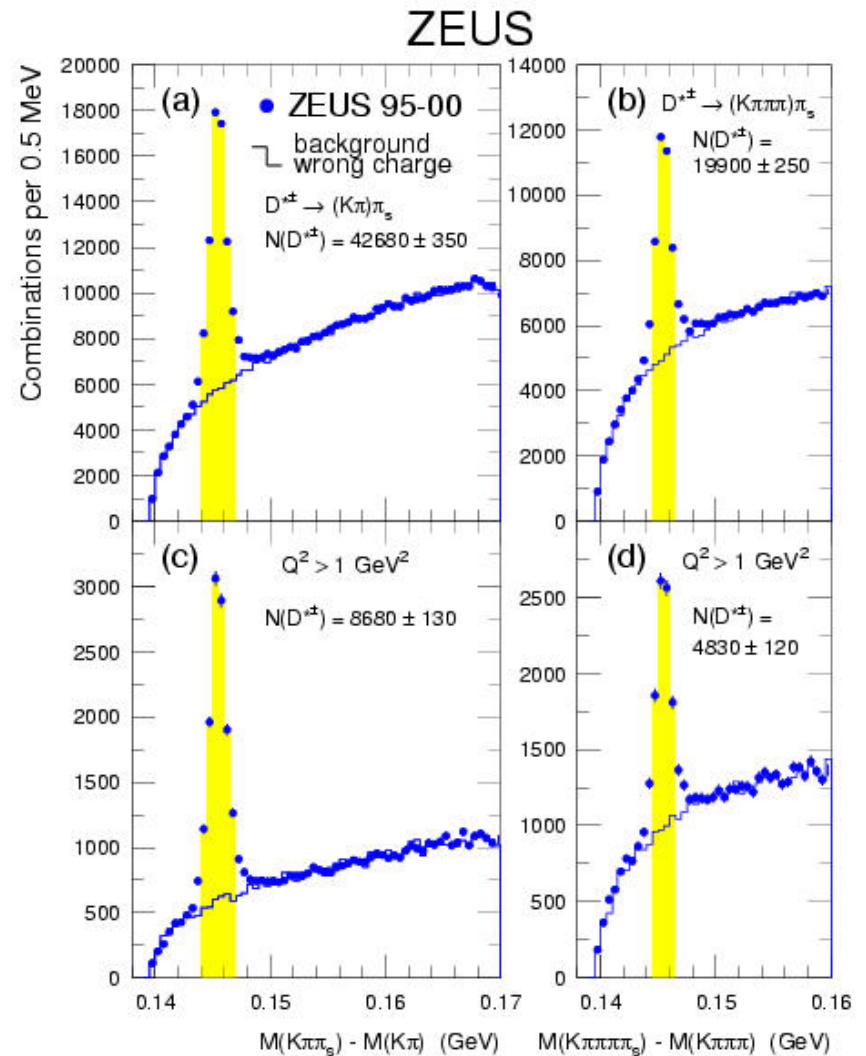
- No $\Xi_{3/2}$ state was observed.
- The number of $\Xi(1530)$ observed in this study is about the same as for the NA49 study.
- The ratio $R=N(\Xi_{3/2})/N(\Xi(1530))$ around 1860 MeV is <0.29 at 95% C.L.
- Since this is a search in the fragmentation region—does not necessarily contradict the NA 49 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 ($51 \pm 11 \Theta_c s$ observed)
- H1 also reports a compatible state observed in photoproduction ($Q^2 \approx 0$).

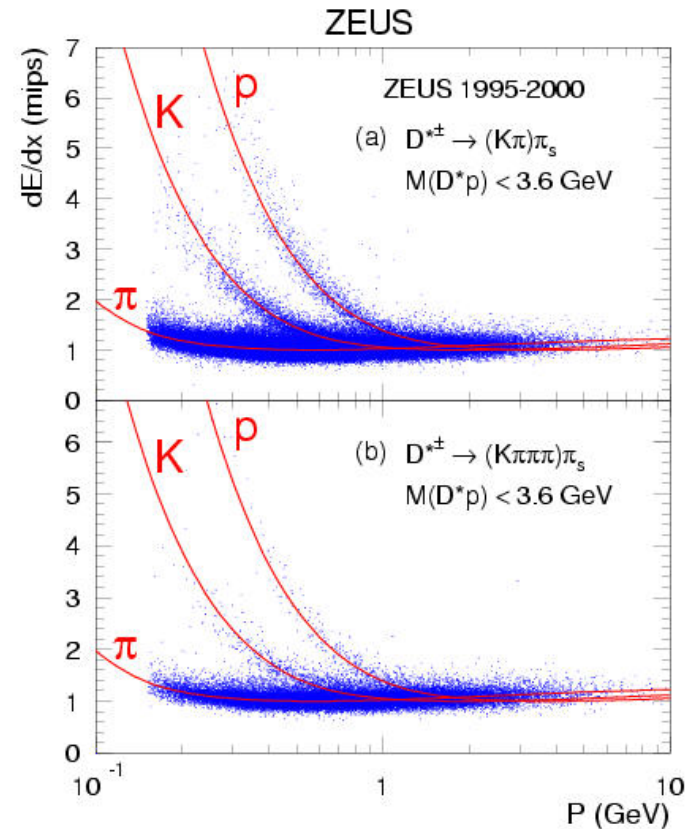
$$\Theta_c \rightarrow D^* p$$

- ZEUS has made a search in 126 pb⁻¹ of DIS and photoproduction data.
- Both K2π and K4π decay modes of D* were used. (H1 uses K2π only).
- Altogether, 62600 D*s are found. 13500 in DIS alone. If 1% of D*s came from Θ_c - expect **>600 Θ_c s.**



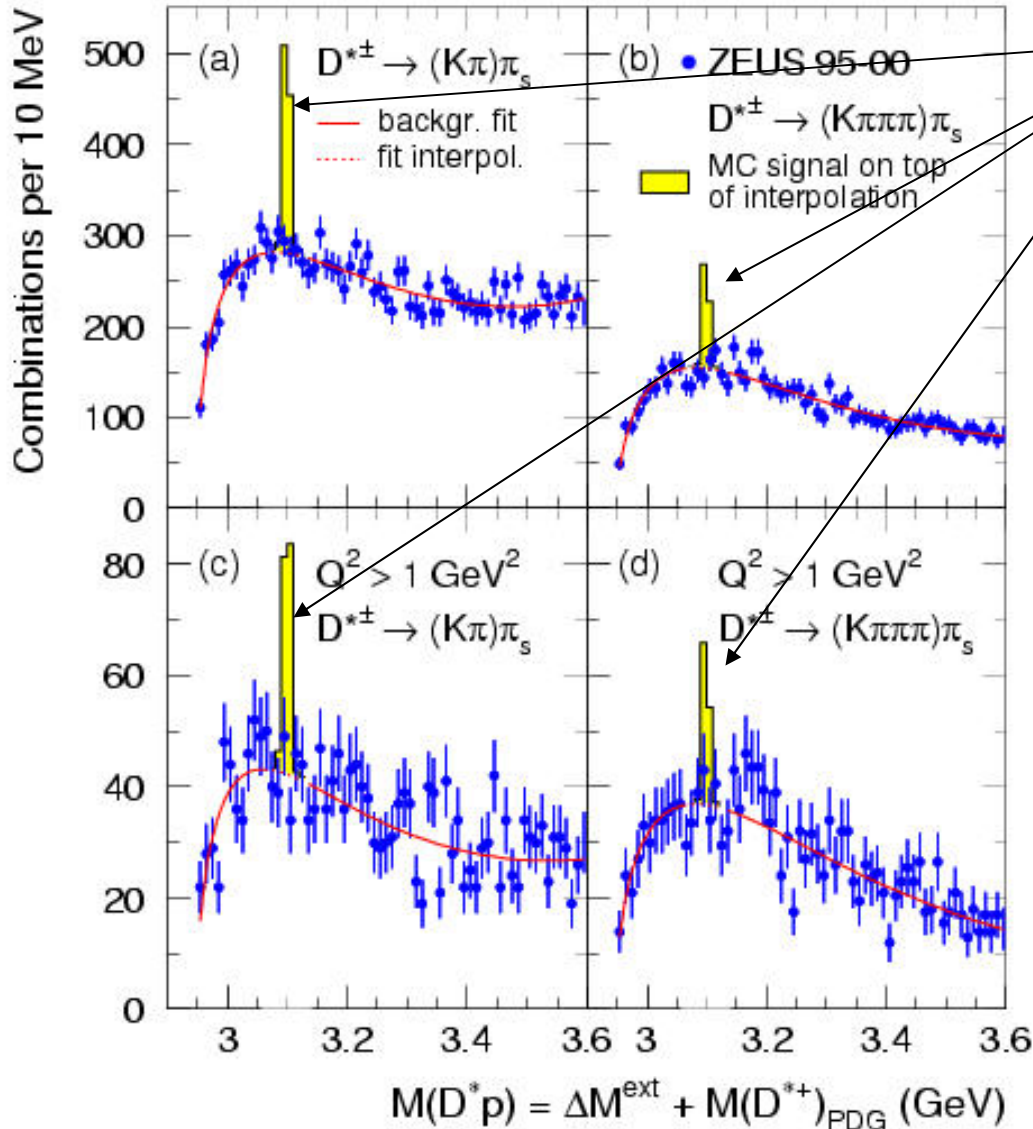
$$\Theta_c \rightarrow D^* p$$

- dE/dx was again used to identify protons.
- Procedure was somewhat refined—use χ^2 probability of a proton hypothesis rather than a simple cut.



$$\Theta_C \rightarrow D^* p$$

ZEUS



MC simulation of Θ_C at 1% of observed D^*s .

- "1%" signal is ruled out for the whole sample at 9σ
- ruled out for DIS alone at 5σ

$$\Theta_c \rightarrow D^* p$$

Default selection

- $K2\pi$ and $K4\pi$
- $-1.6 < \eta(D^*) < 1.6$
- $P_T(D^*) > 1.35 \text{ GeV}$ (for $K2\pi$)
- $\gamma < 0.95$

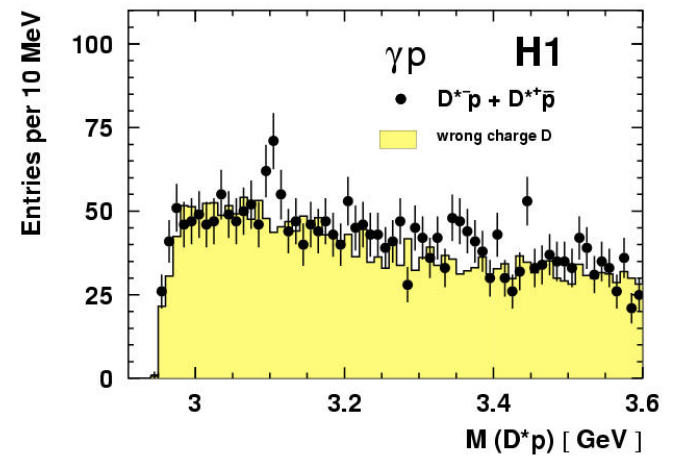
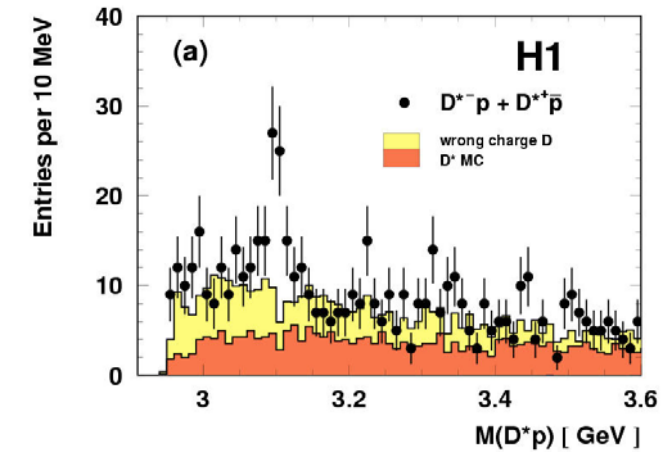
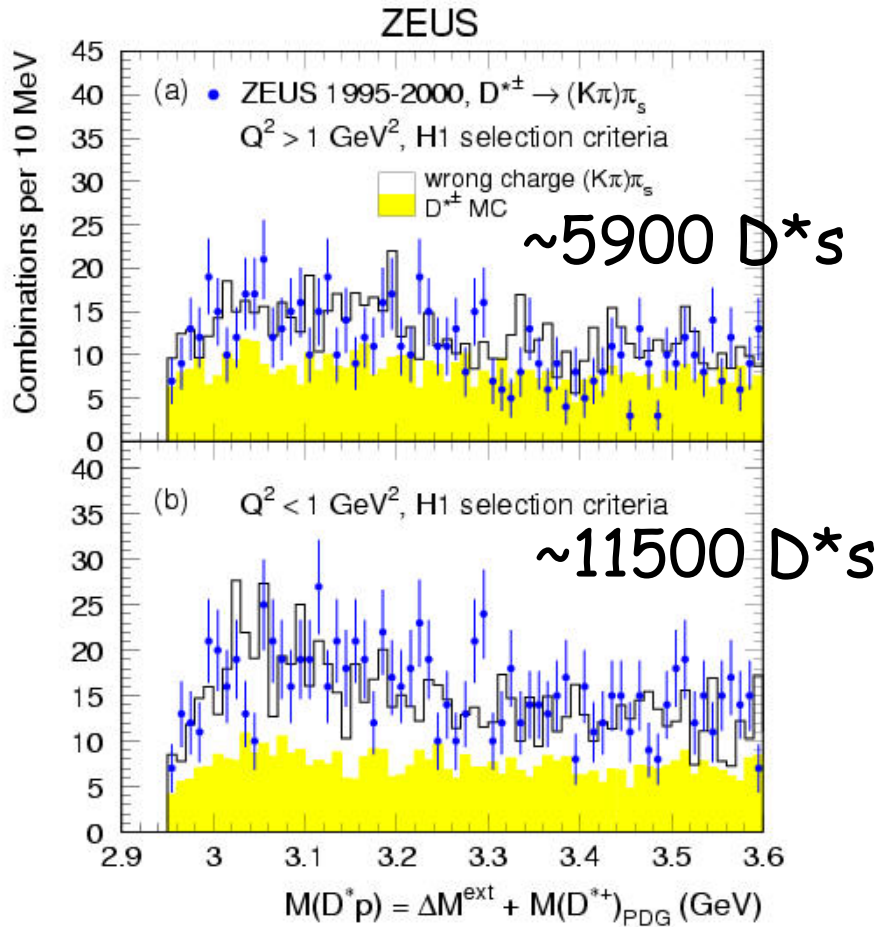
Note all cuts are tighter for the "H1" selection.

"H1" selection

- $K2\pi$ only
- $-1.5 < \eta(D^*) < 1.0$
- For DIS
 - $0.05 > \gamma > 0.7$
 - $P_T(D^*) > 1.5 \text{ GeV}$
- For Photoprod.
 - $0.2 > \gamma > 0.8$
 - $P_T(D^*) > 2.0 \text{ GeV}$
- ..other minor changes

$$\Theta_c \rightarrow D^* p$$

H1 selection



$$\Theta_c \rightarrow D^* p$$

- No resonance structure observed from >60k D^* s.
- "1%" signal is ruled out at 9σ for all and 5σ for DIS only.
- (Also checked $Q^2 > 20 \text{ GeV}^2$ —nothing was found)
- The upper limit of observed D^* s originating from Θ_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 Θ_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 $Q^2 > 20 \text{ GeV}^2$. Maybe the Θ^+ 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.