Pentaquark searches with ZEUS

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On behalf of the ZEUS collaboration

Summary:

- Observation of $\Theta^+ \to K^0_S p$
- Search for $\Xi^{--} \to \Xi^- \pi^-$
- Search for $\Theta^0_c \to D^* p$
- Conclusions

Θ^+

- **Low energy γA experiments (LEPS, CLAS, SAPHIR) saw a new exotic $S = +1$ baryon $\Theta^+ \to K^+ n$**
  $M \sim 1540$ MeV, $\Gamma < 20$ MeV
  $uudd\bar{s}$ **pentaquark ?**

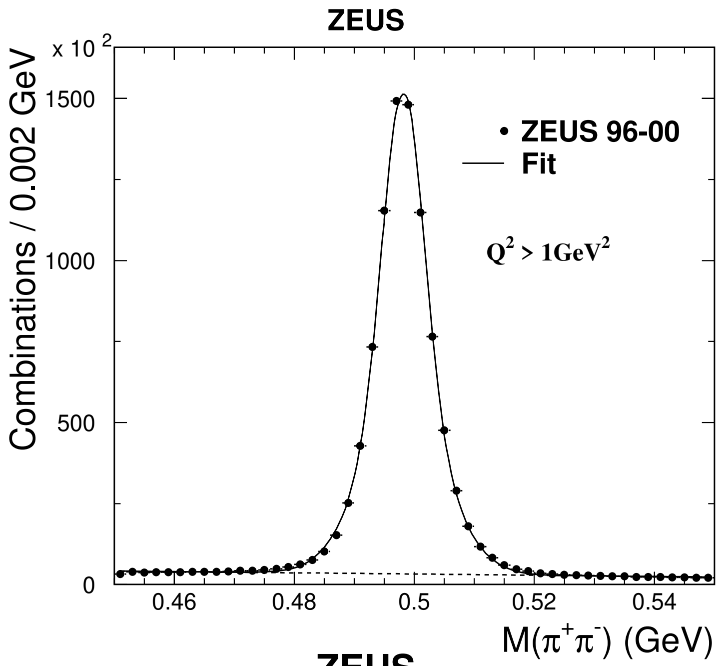
- **non exotic decay mode $\Theta^+ \to K^0_S p$ seen by other fixed target experiments (DIANA, HERMES, COSY-TOF, SVD, ...)**

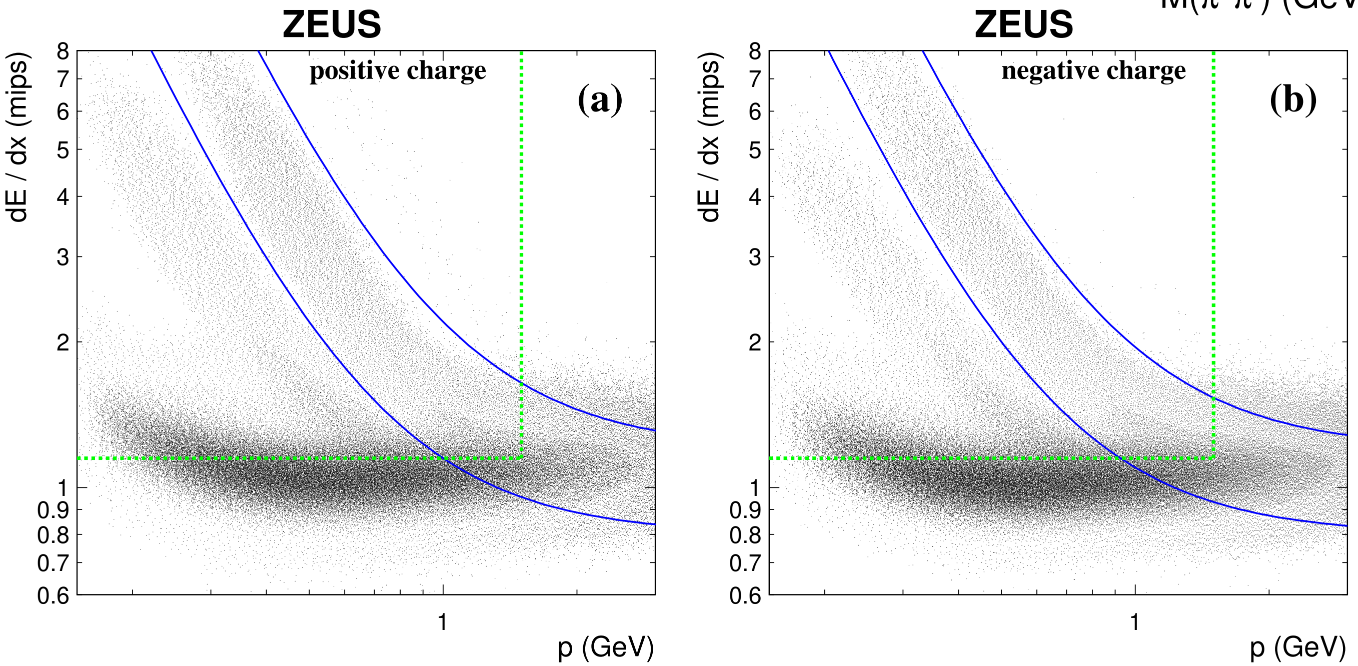
- **negative results from low-energy e^+e^- (BES, BaBar, BELLE)**

- **is it produced by fragmentation in high-energy collisions ?**
  - **negative results (HERA-b, CDF, ALEPH, DELPHI, L3)**
  - **observation by ZEUS (Phys. Lett. B 591 (2004) 7) ...**

K^0 and p reconstruction

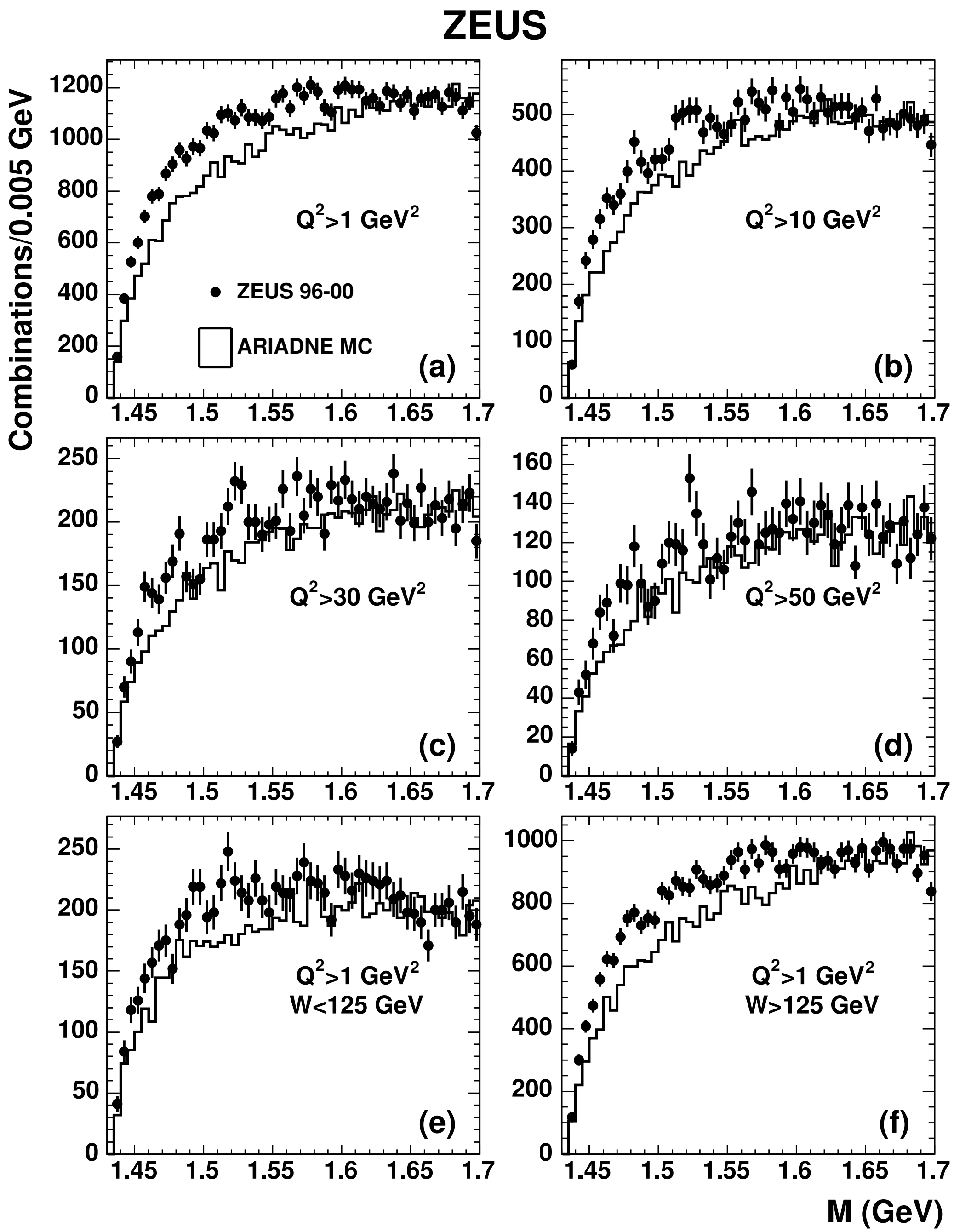
- Search for $\Theta^+ \to pK^0_S$
- $\mathcal{L} = 121$ pb^{-1}
- DIS sample $Q^2 > 1$ GeV^2
- 870 000 $K^0_S \to \pi^+\pi^-$ from sec. vertex
  $p_T(K^0) > 0.3$ GeV, $|\eta(K^0)| \leq 1.5$
- p selected from dE/dx band and
  $dE/dx > 1.15$ mips, $P < 1.5$ GeV
  $p_T > 0.15$ GeV, $|\eta| < 1.75$
  60% proton purity





$K^0_S p$ invariant mass

- $K^0_S p$ (+ c.c.) invariant mass
- no signal at ~ 1530 MeV for $Q^2 > 1\text{GeV}^2$
- bump at ~ 1520 MeV for $Q^2 > 10$ GeV^2
- seen also for $Q^2 > 1$ GeV^2 and $W < 125$ GeV
- other bump at ~ 1465 MeV at high Q^2?
- Ariadne (Jetset) MC (normalised in the high-mass region) does not reproduce the shape of the data. Due to unestablished PDG Σ bumps $\Sigma(1480)$, $\Sigma(1560)$?



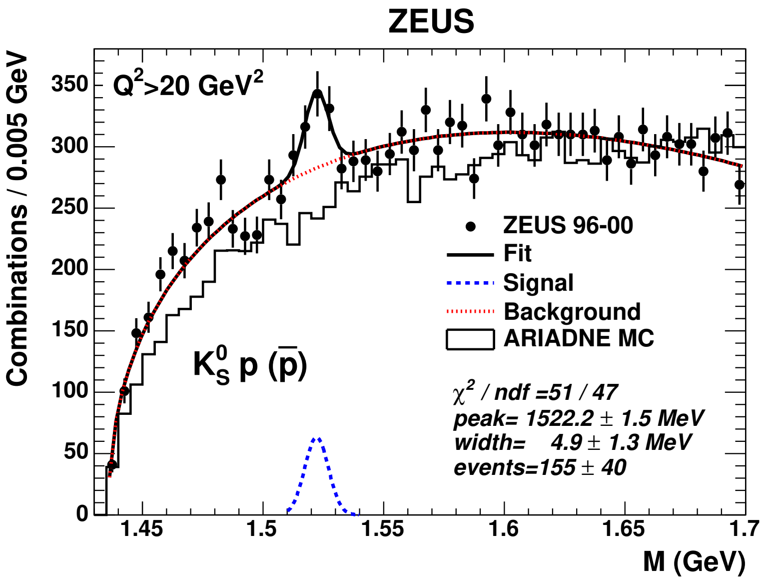
Signal for $Q^2 > 20\mathbf{GeV}^2$

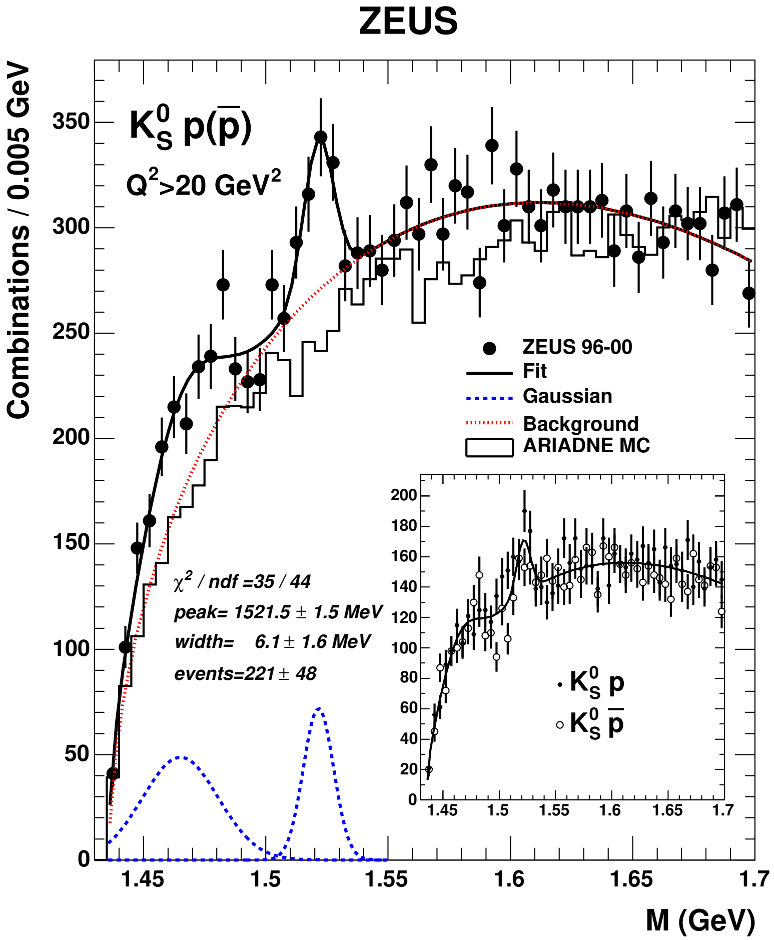
- **Bump seen best for** $Q^2 > 20$ GeV^2

- **Fit with Gaussian + background (3 par.)**
  $M = 1522$ MeV
  $N = 155 \pm 40$ **events (3.9 s.d.)**
  intrinsic width compatible with zero

- **Fit with two Gaussians + bkg**
  (one Gaussian for bump at 1465 MeV)
  $M = 1521 \pm 1.5(\mathrm{stat.})^{+2.8}_{-1.7}(\mathrm{syst.})$ MeV
  $N = 221 \pm 48$ **events (4.6 s.d.)**
  intrinsic width $\Gamma = 8 \pm 4(\mathrm{stat.})$ MeV,
  compatible with zero

- **Signal seen in both charges:**
  anti-pentaquark θ^-





Θ^+ rate (new)

- Acceptance $\sim 4\%$ from Ariadne (Jetset) MC with Θ^+ treated as a Σ^+ baryon
- Θ^+ cross section in the visible kinematic range:
  $Q^2 > 20\ \text{GeV}^2$, $0.04 < y < 0.95$, $p_T > 0.5\ \text{GeV}$, $|\eta| < 1.5$

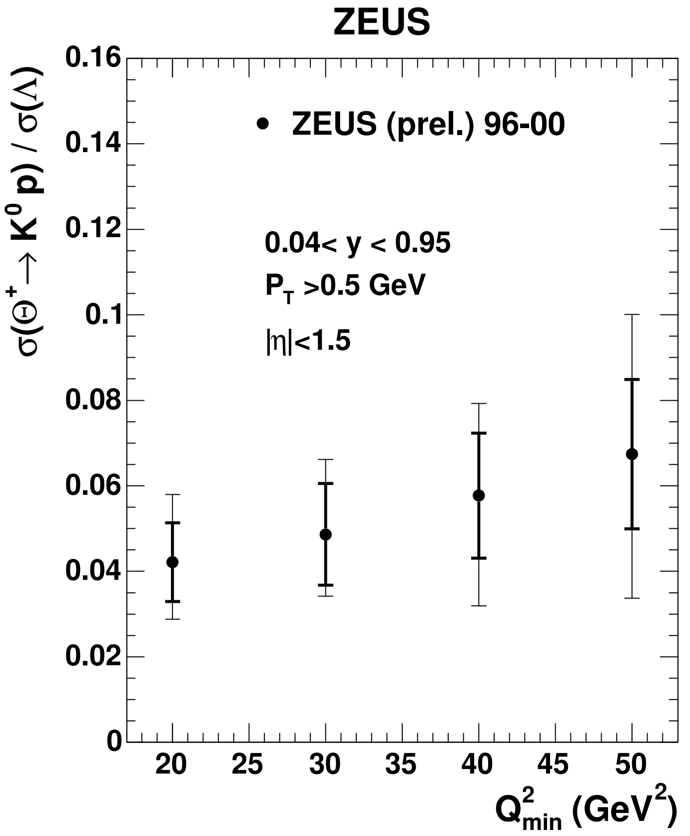
$$\sigma(ep \to e\Theta^+ X \to eK^0 pX(+\text{c.c.})) = 125 \pm 27(\text{stat.})^{+36}_{-28}(\text{syst.})\text{pb}$$

- production rate compared to Λ:

$$\mathcal{R} = \frac{\sigma(\Theta^+ \to K^0 p(+\text{c.c.}))}{\sigma(\Lambda + \bar{\Lambda})} = 4.2 \pm 0.9(\text{stat.})^{+1.2}_{-0.9}(\text{syst.})\%$$

  for Λ in the same kinematic range

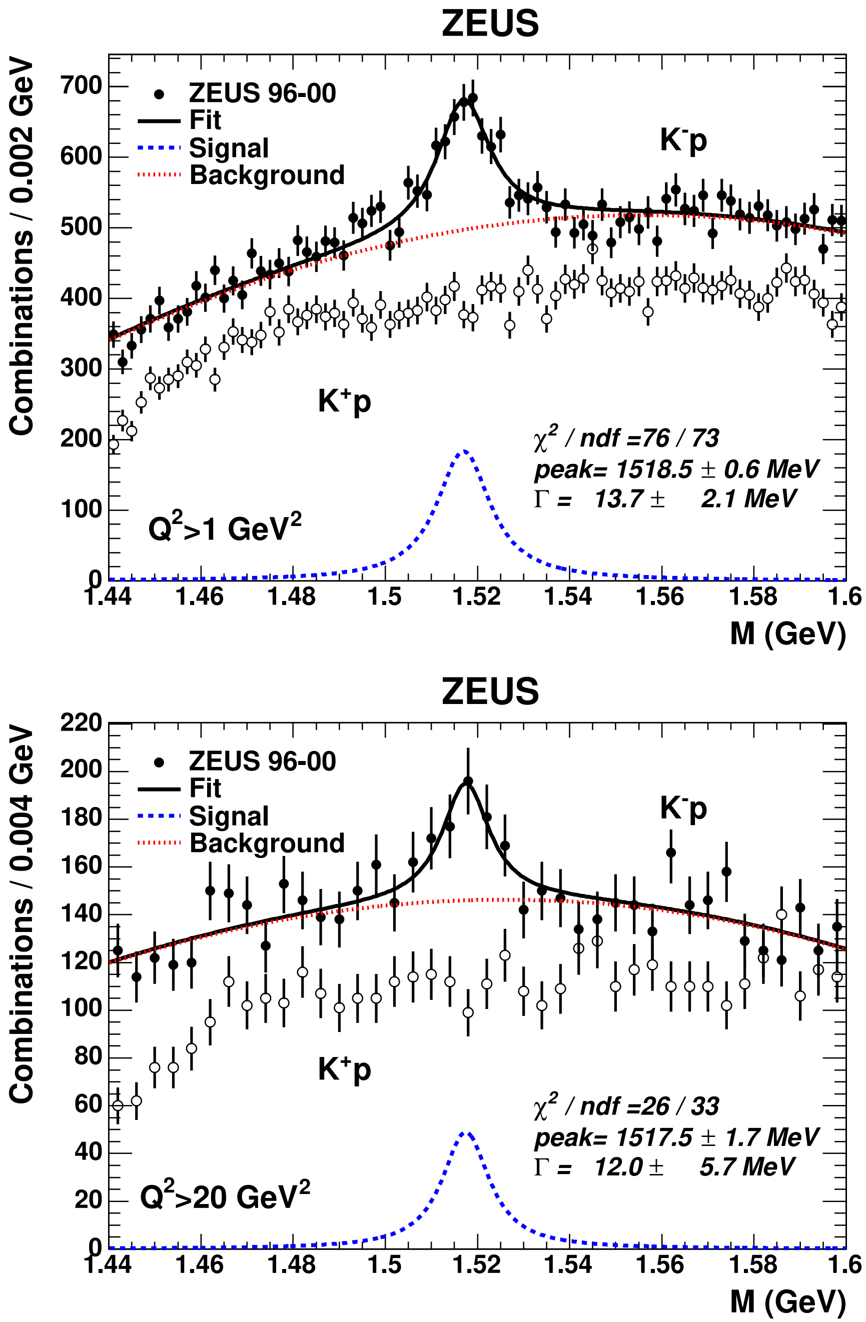
- no dependence on minimum Q^2 cut
- MC studies suggest that the absence of the signal at low Q^2 may be due to acceptance effects



- Not compatible with limits from other high-energy experiments:
  HERA-b: $R(\Theta^+/\Lambda) < 0.92\%$ for $B_{\Theta^+ \to K^0_S p} = \frac{1}{4}$ $\Longrightarrow \mathcal{R} < 0.46\%$,
  ALEPH: $R(\Theta/Z) < 0.29\%$ for $B_{\Theta^+ \to K^0_S p} = \frac{1}{4}$, $R(\Lambda/Z) = 39\%$ $\Longrightarrow \mathcal{R} < 0.2\%$
  dependence on process or phase space ?

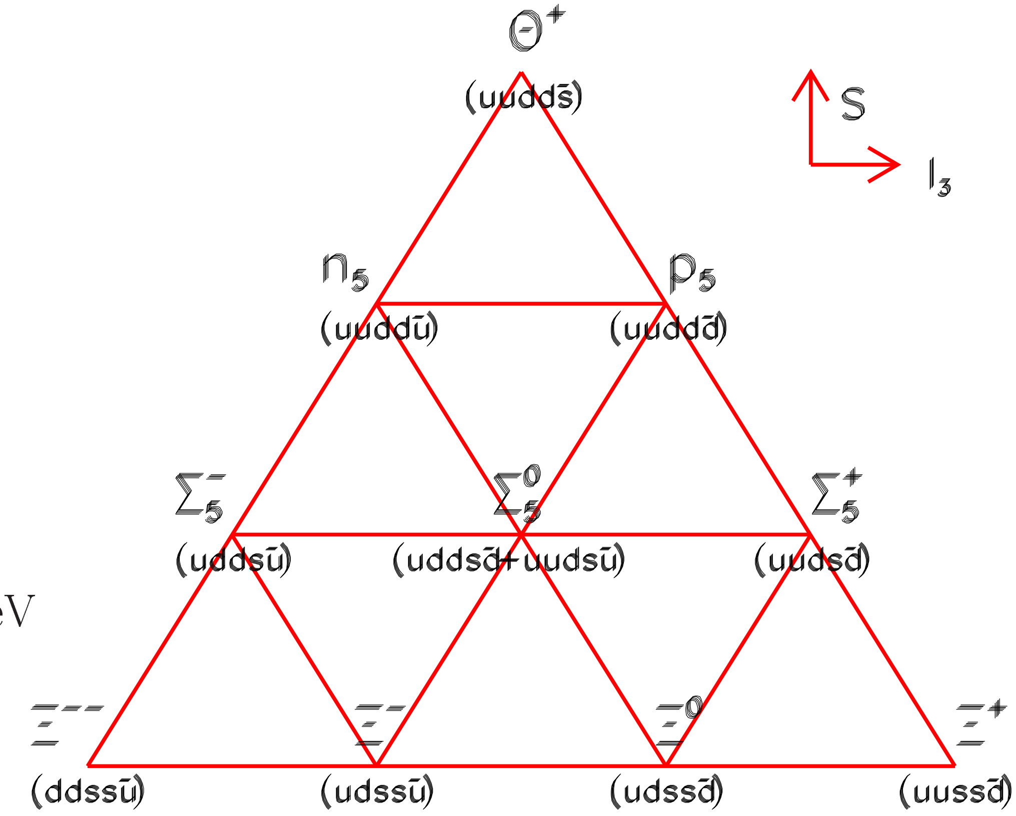
Charged Kp mass sepctrum

- **Is Θ^+ member of a $I = 1$ triplet: Θ^0, Θ^+, Θ^{++} ?**
- **Search for $\Theta^{++} \to K^+p$ (+c.c.)**
- **K and p selected using dE/dx**
- **no signal seen at 1520 MeV**
- **known $\Lambda(1520)$ seen in K^-p (+c.c.)**
- **no signal for $Q^2 > 20$ GeV^2**



$S = -2$ pentaquarks

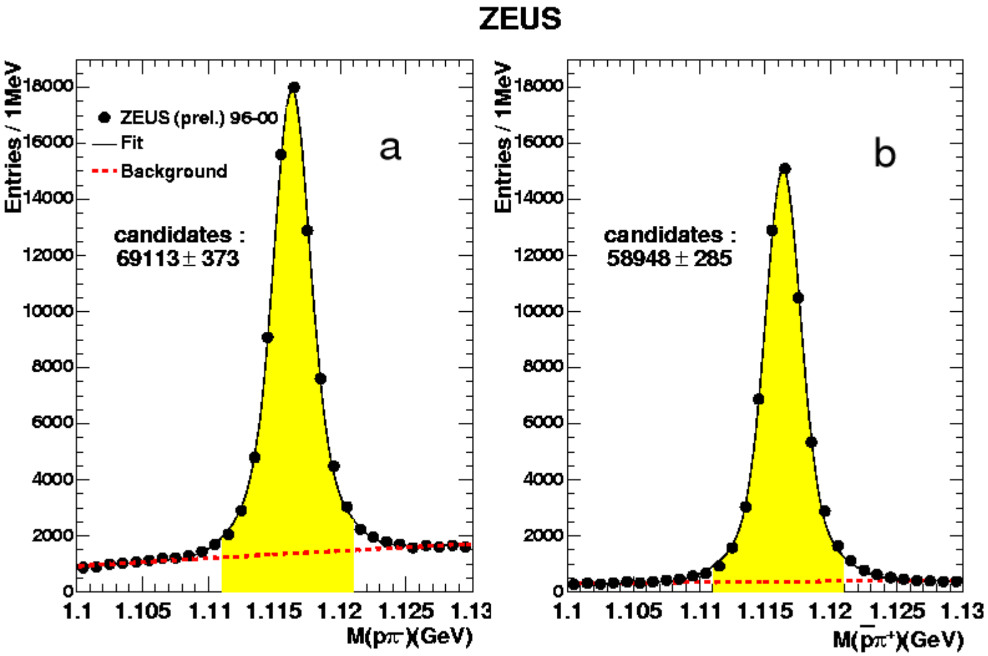
- $q^4\bar{q}$:
  $3 \otimes 3 \otimes 3 \otimes 3 \otimes \bar{3} = 1 \oplus 8 \oplus 10 \oplus \bar{10} \oplus 27 \oplus 35$
  $\bar{10}$ **is the lowest exotic multiplet**
- $\Theta^+(uudd\bar{s})$, Ξ^{--} $(ddss\bar{u})$ **and** Ξ^+ $(uuss\bar{d})$
  at the corners of the anti-decuplet
  are manifestly exotic baryons



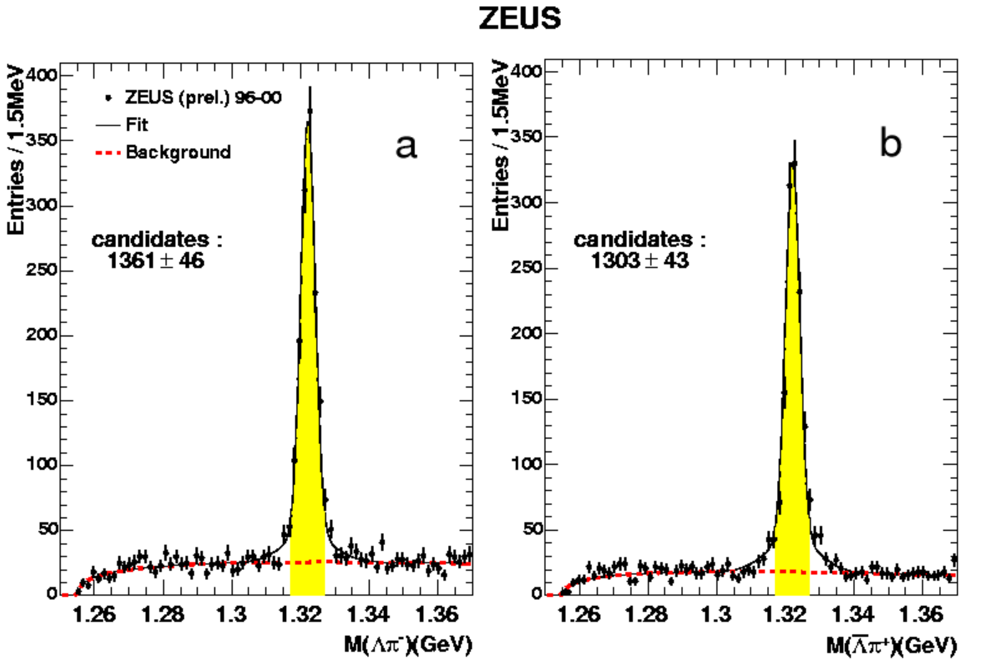
- **NA49 (pp at** $\sqrt{s} = 17$ **GeV)**
  observes peaks in all the $\Xi^{\pm}\pi^{\pm,\mp}$
  at $M = 1862 \pm 2$ MeV **with width** < 18 MeV
  compatible with
  $\Xi^{--} \rightarrow \Xi^-\pi^-$ **+ c.c. (exotic)**
  $\Xi^0 \rightarrow \Xi^-\pi^+$ **+ c.c. (non-exotic)**
- **no evidence from WA89, CDF and HERA-b**

S=-2 pentaquark search in ZEUS

- $\mathcal{L} = 105$ **pb**$^{-1}$
- **DIS sample** $Q^2 > 1\ \mathrm{GeV}^2$
- **use tracks with** $p_T > 150$ MeV**,** $|\eta| < 1.75$



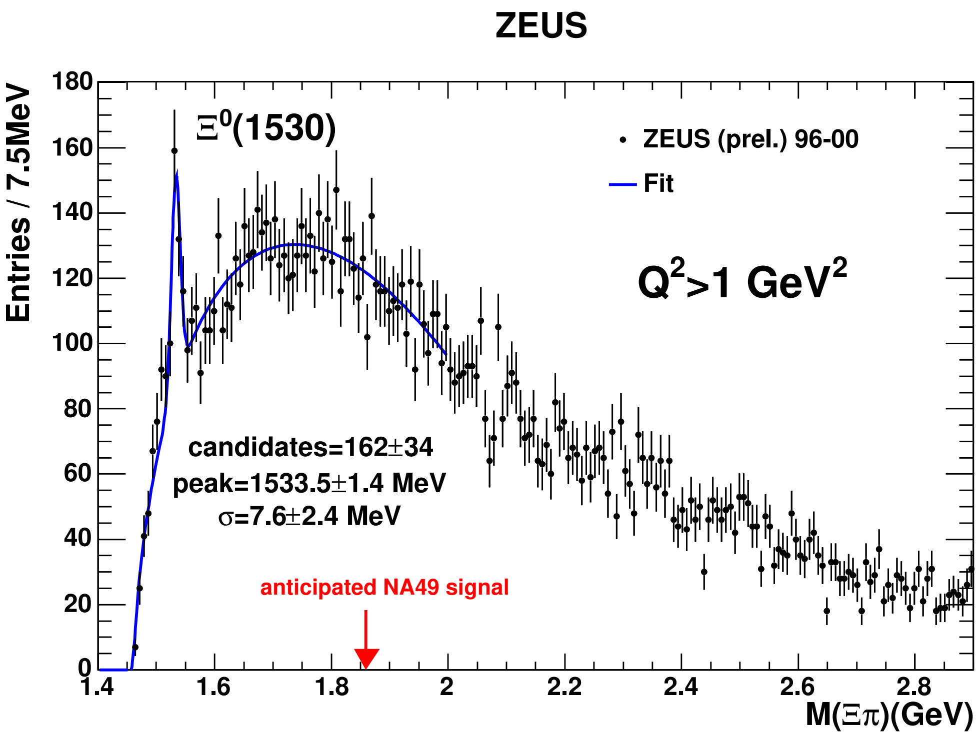
- $\Lambda \to p\pi^-$ **(+c.c.)** ~ 130000 **candidates**

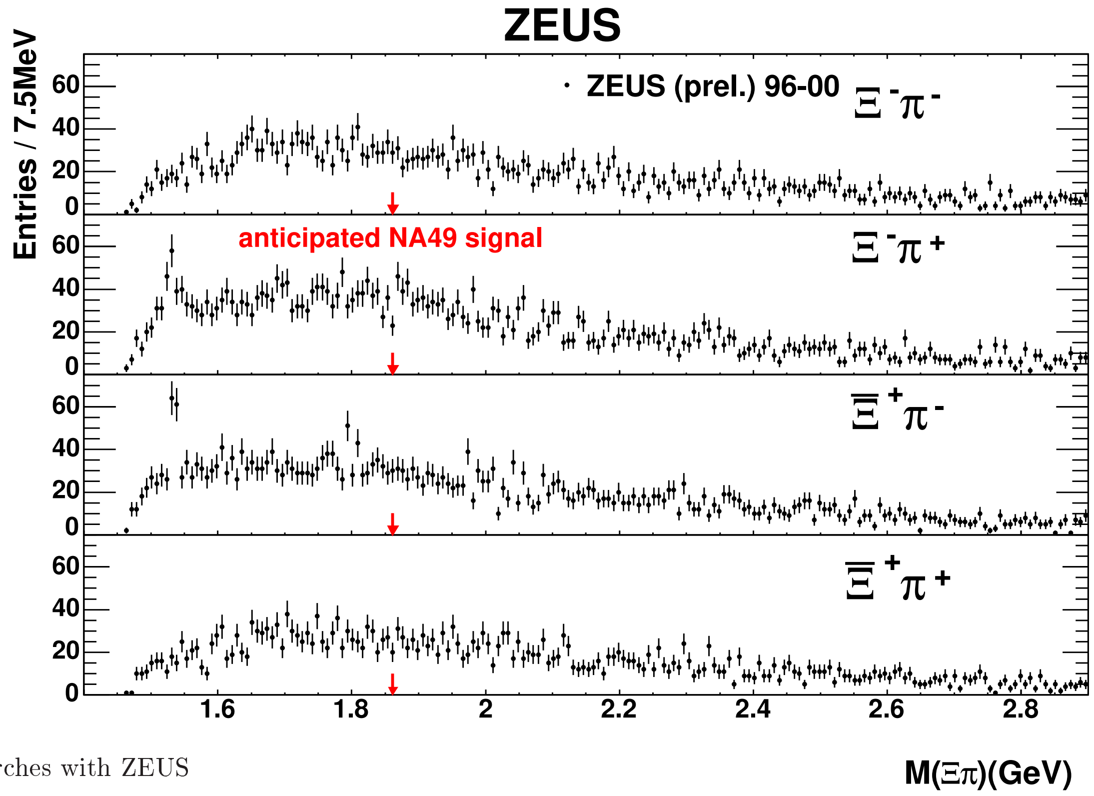


- $\Xi^- \to \Lambda\pi^-$ **(+c.c.)** ~ 2600 **candidates**

$\Xi\pi$ spectrum

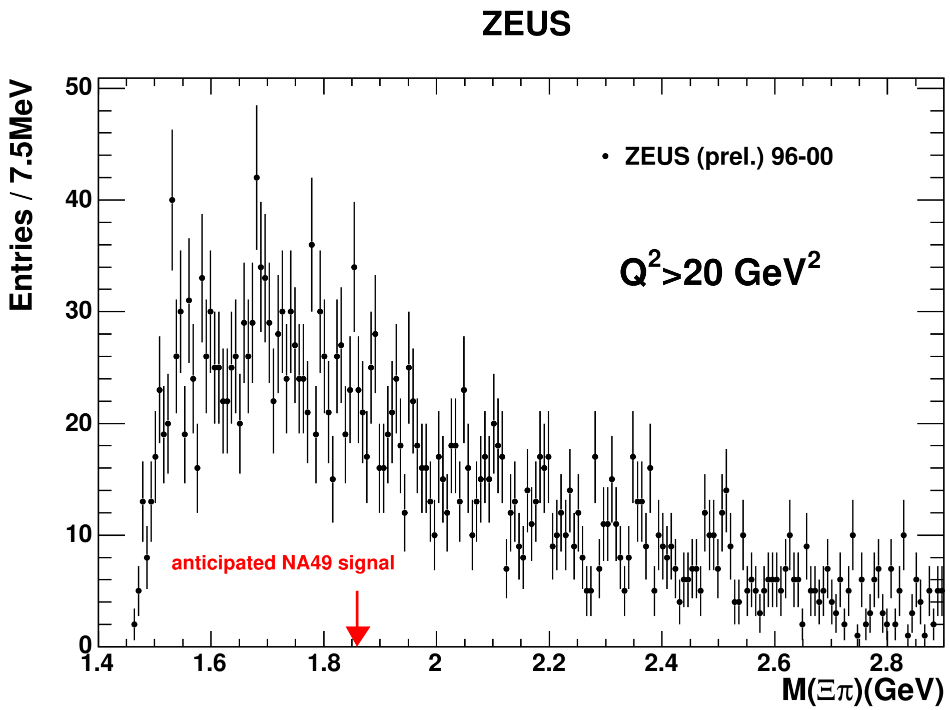
- $\Xi\pi$ invariant mass spectrum
- No signal around 1860 MeV
- Known non-exotic state $\Xi^0(1530)$ well visible
- No signal in the 4 possible charge combinations





Conclusion on Ξ^{--}, Ξ^0

- similar statisical sensitivity to NA49 (similar $\Xi^0(1530)$ signal)
- try same cuts on momentum and $\Xi\pi$ angle as NA49, no signal
- No signal for $Q^2 > 20$ GeV^2 (where Θ^+ is seen best)
- Anyway not incompatible: different reaction/phase space: ZEUS = central rapidity NA49 = also forward rapidities



Charmed pentaquark

- **if Θ^+ exist then charmed Θ_c^0 $(uudd\bar{c})$ should also exist**

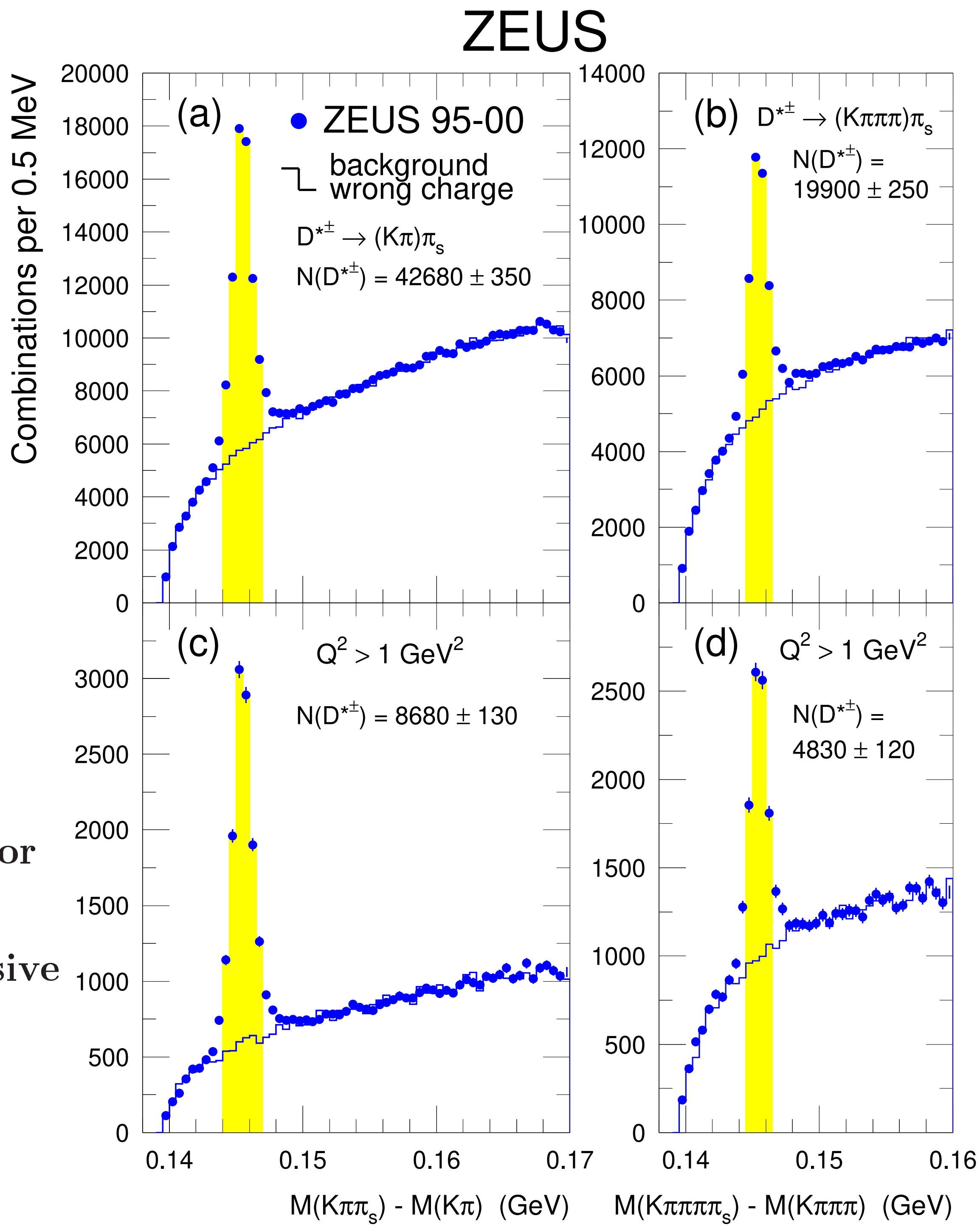
- **decay modes:**
  if $M(\Theta_c^0) < M(D^-) + M(p) = 2807$**MeV decays weakly** $\Theta_c^0 \to \Theta^+\pi^-$
  if $M(\Theta_c^0) > 2807$ **decays mainly to** D^-p **or** D^0n
  if $M(\Theta_c^0) > 2948$ **it may decay into** D^*p

- **H1 finds a narrow signal in the** D^*p **invariant mass at** $M = 3100$ **MeV**
  "roughly 1% of the visible D^* **rate"**
  better seen in DIS, also seen in Photoproduction
  (see H1 talk)

- **ZEUS: similar to H1, collected large** D^* **sample**
  should be able to see it as well ...

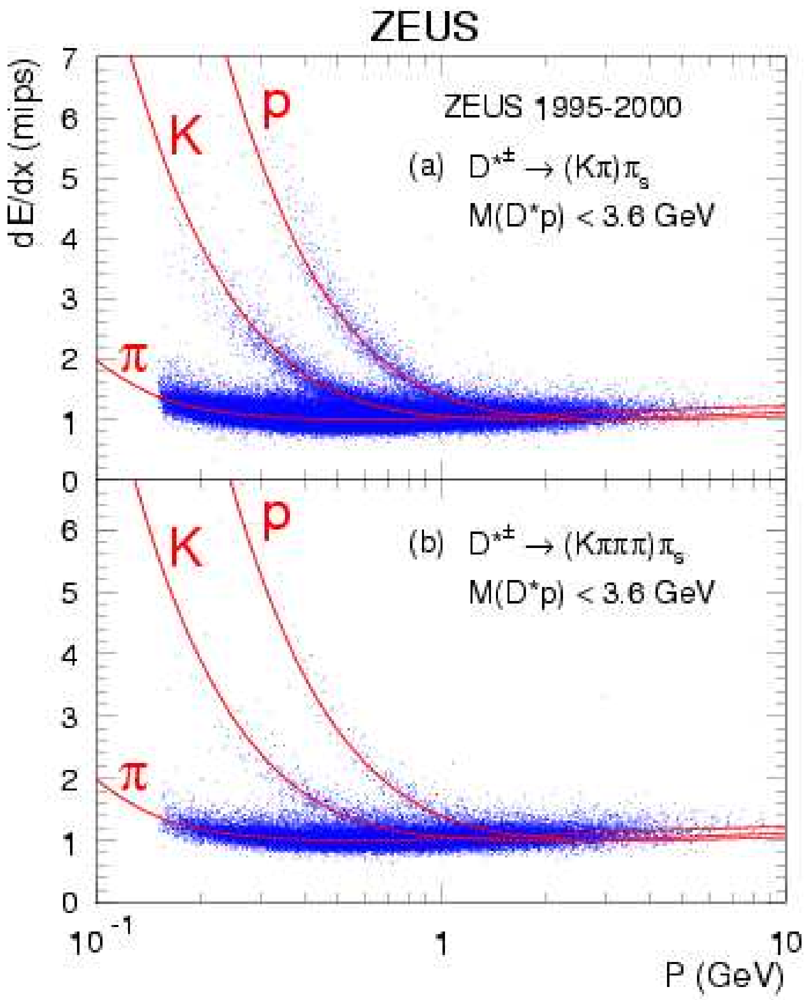
D^* selection

- $\mathcal{L} = 126$ **pb**$^{-1}$
- D^* **reconstructed in two channels:**
  $D^{*+} \to D^0\pi_s^+ \to (K^-\pi^+)\pi_s^+$
  $D^{*+} \to D^0\pi_s^+ \to (K^-\pi^+\pi^+\pi^-)\pi_s^+$
  (+ c.c.)
- D^* **Kinematic range:**
  $p_T(D^*) > 1.35$ GeV **for** $(K\pi)\pi_s$
  $p_T(D^*) > 2.80$ GeV **for** $(K\pi\pi\pi)\pi_s$
  $|\eta(D^*)| < 1.6$ **(both channels)**
- **total** ~ 62000 D^***s,**
- ~ 13000 **have a DIS** e **in the detector corresponding to** $Q^2 > 1$ **GeV**^{2}
- **larger sample than H1 both inclusive and DIS**



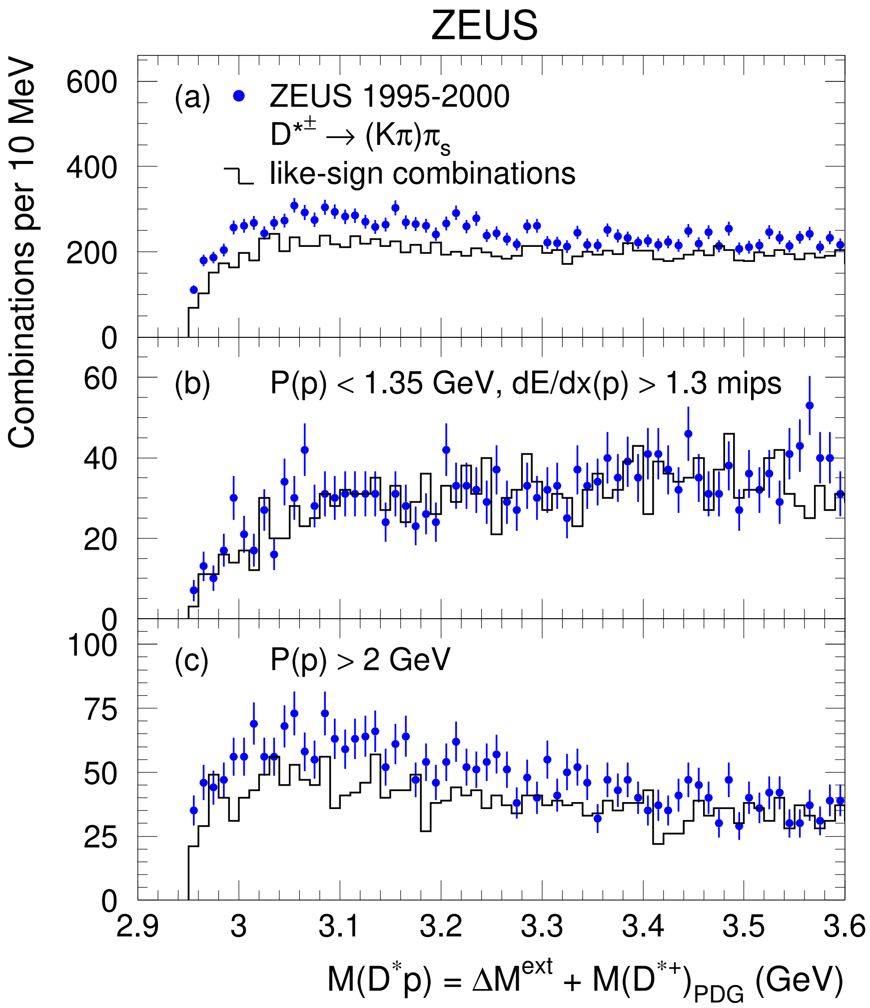
proton selection

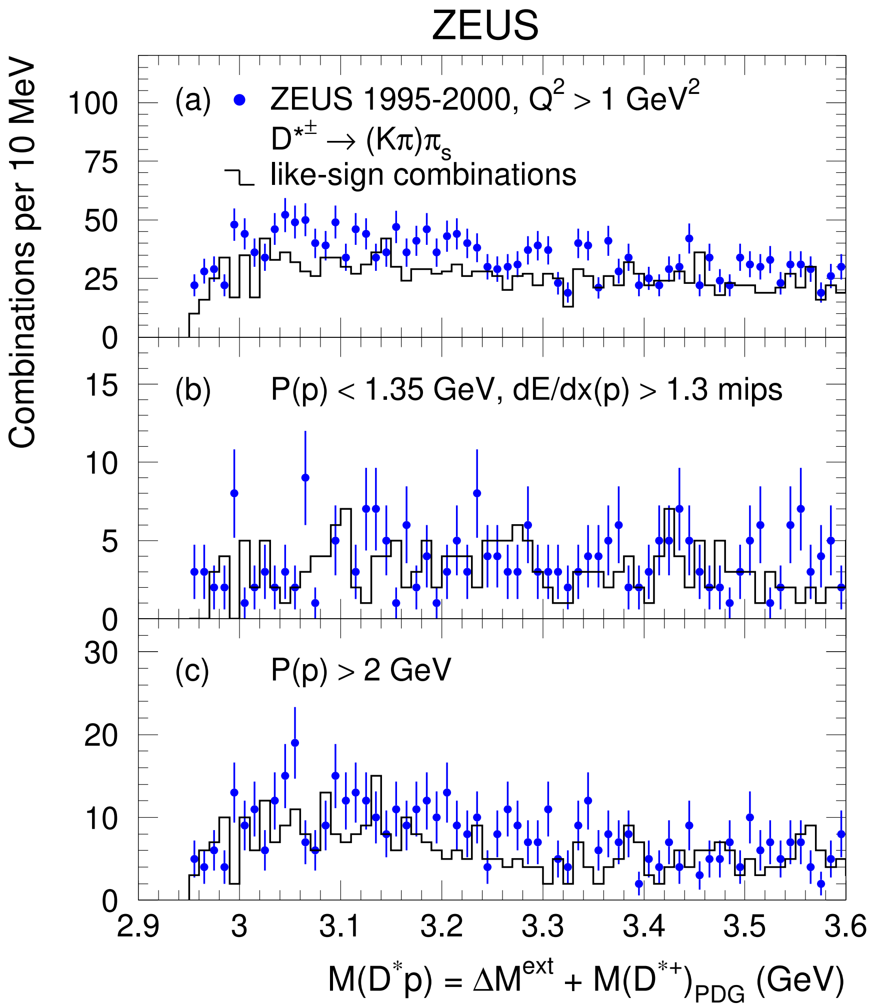
- **proton ID refined wrt Θ^+ search**
- dE/dx **resolution** $\sim 9\%$ **for full-length tracks (similar to H1)**
- **require** χ^2 **probability for** p **hypothesis** > 0.15
- $p_T > 0.15$ GeV



D^*p mass spectrum, $(K\pi)\pi_s$ mode

- $M(D^*p) = M(K\pi\pi_s p) - M(K\pi\pi_s) + M(D^*)_{\mathrm{PDG}}$ **resolution (from MC)** ~ 4 **MeV**
- **No signal in full sample (left)**
- **No signal in DIS (right)**
- **(b)** $P(p) < 1.35$ GeV, $dE/dx > 1.3$mips **to improve proton purity**
- **(c)** $P(p) > 2$ GeV **where H1 signal is more visible**
- **no signal**



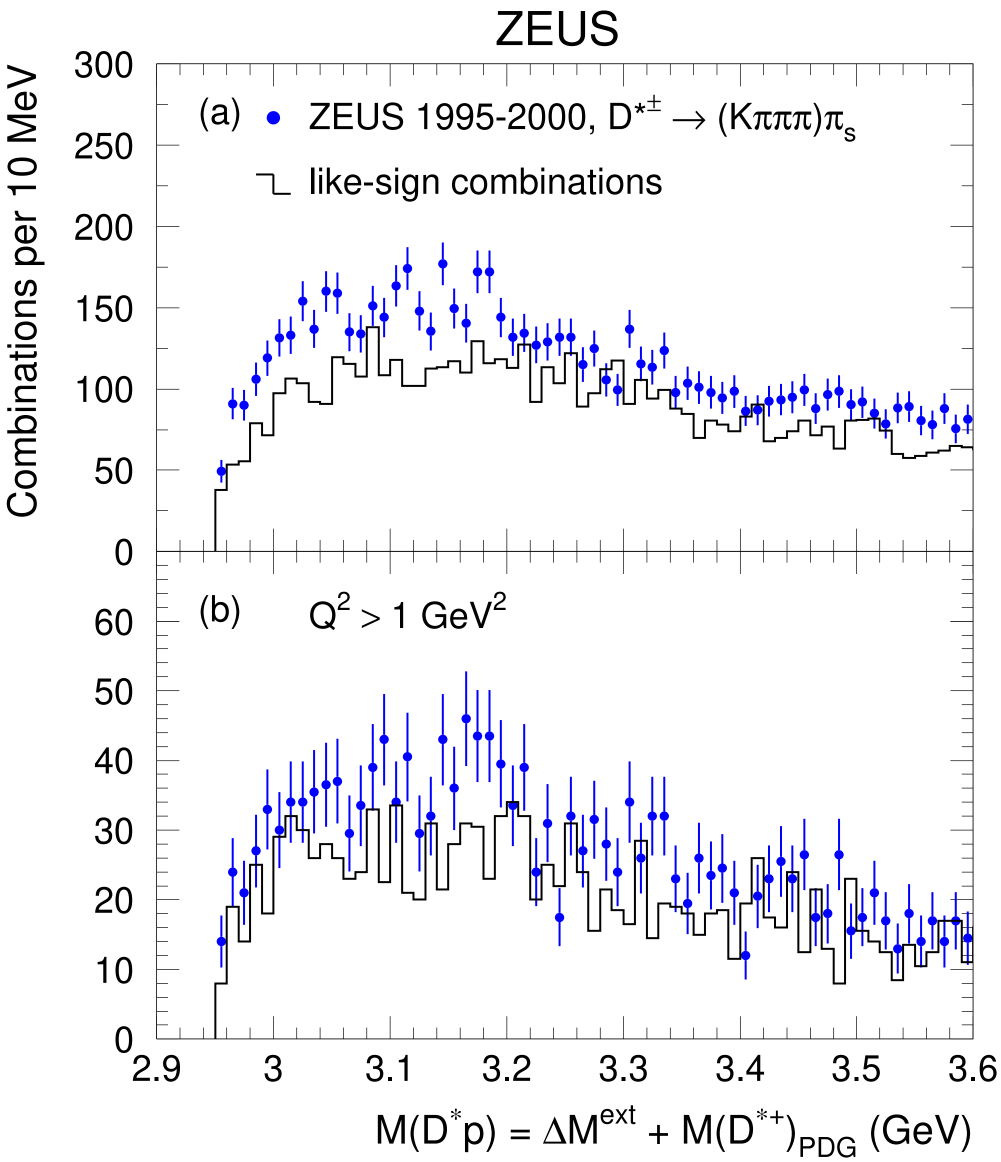


D^*p mass spectrum $(K\pi\pi\pi)\pi_s$

- $M(D^*p) =$
  $M(K\pi\pi\pi\pi_s p) - M(K\pi\pi\pi\pi_s) + M(D^*)_{\text{PDG}}$

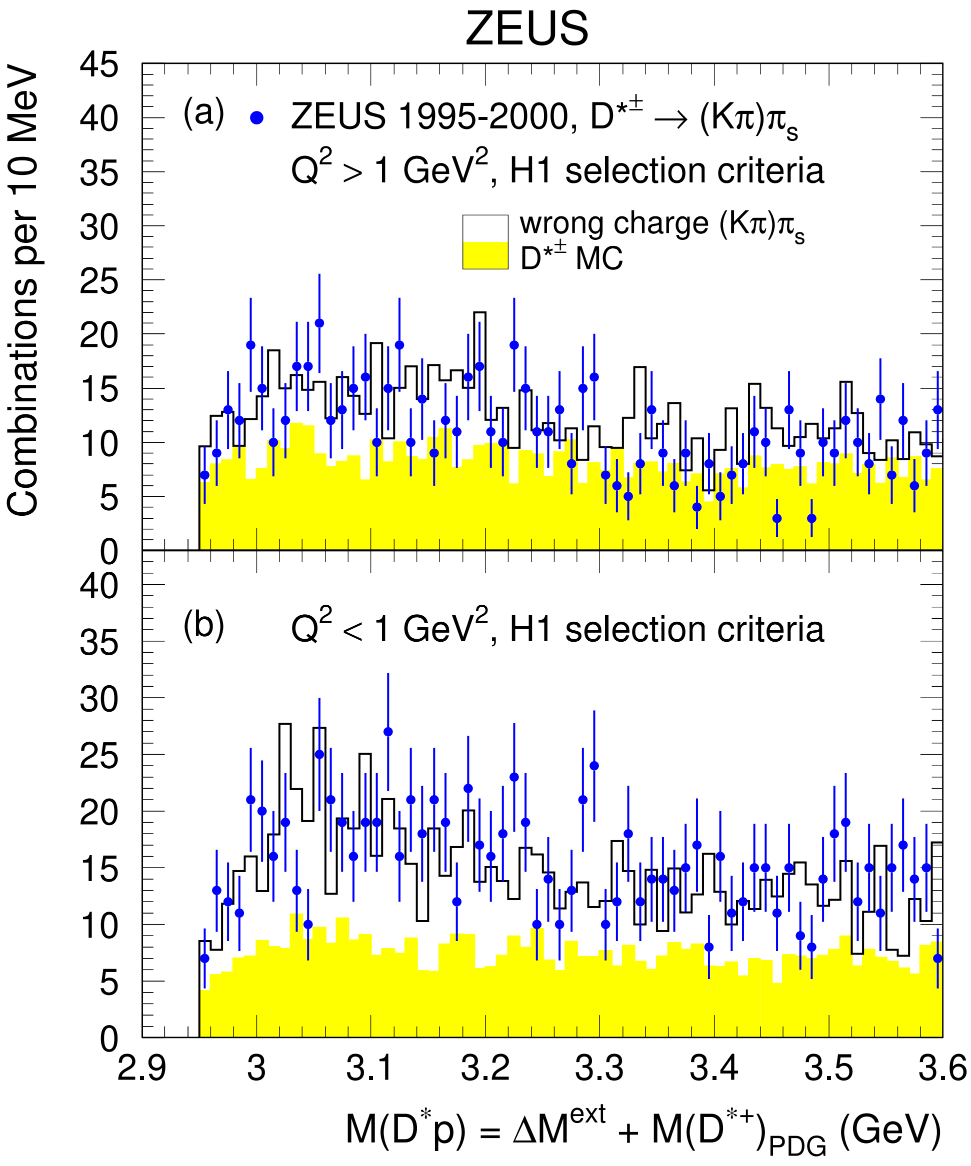
- **No signal in full sample**

- **No signal in DIS**



Selection a la H1

- **Try to reproduce H1 analysis (see H1 talk for details)**
- **same cuts as H1**
- **use "probability ratio" for p ID**
- **No signal seen**

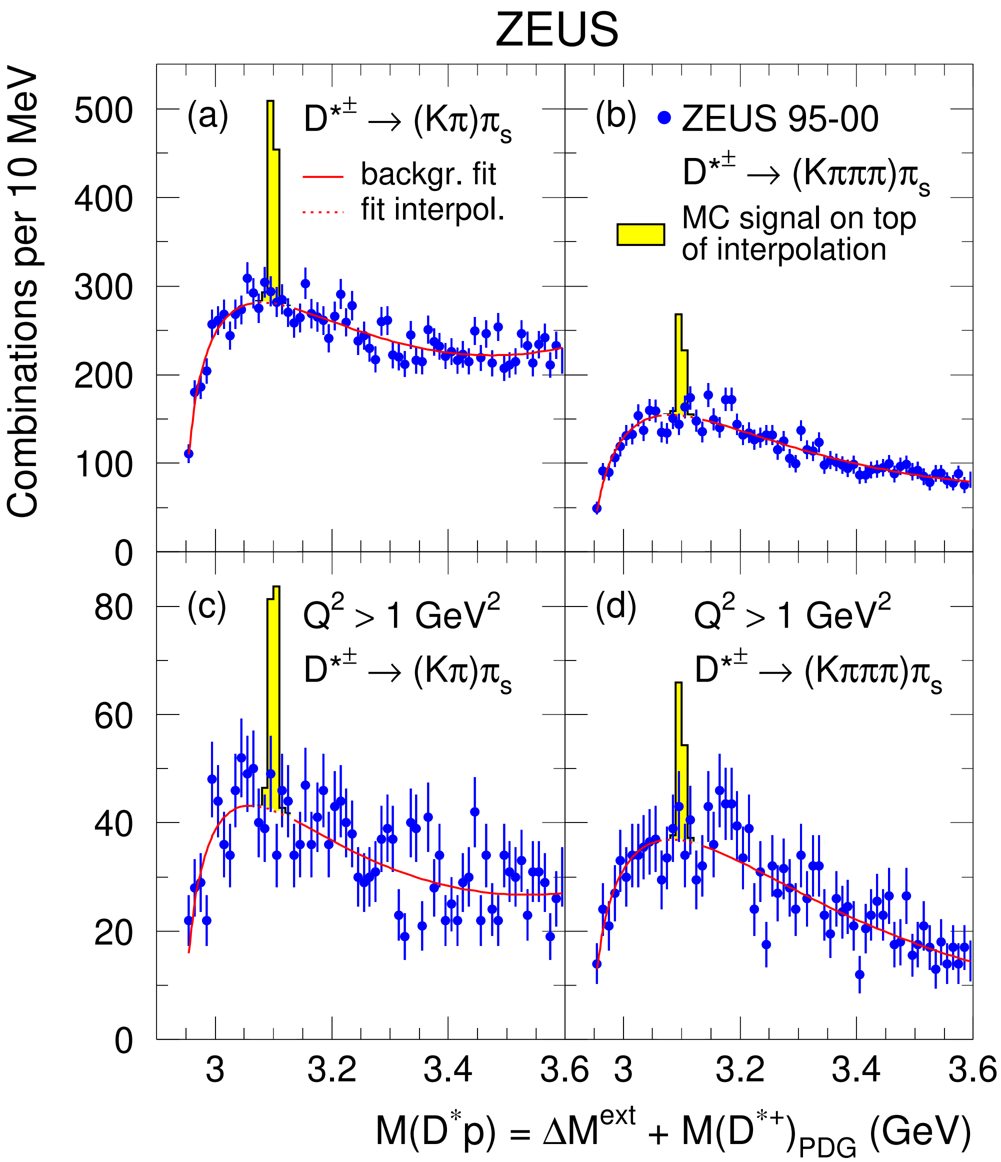


Limits on Θ_c^+ rate

- signal MC normalized to 1% of observed D^*
- such rate excluded at 9 s.d.
- Combined $(95\%\mathrm{CL})$ limits on the fraction of D^* coming from Θ_c^0:
  - Visible: $R < 0.23\%$
  - Acceptance corrected: $R^{\mathrm{corr}} < 0.37\%$
- For $Q^2 > 1$ GeV^2: $R < 0.35\%$
- Limit on fraction of charm quarks fragmenting to Θ_c^0:

$$f(c \to \Theta_c^0) \times B(\Theta_c^0 \to D^* p) < 0.16\%$$

(assuming universality of charm fragmentation function)



Conclusions

- $\Theta^+ \rightarrow K^0_S p$
  - ~ 4 **sigma bump at** ~ 1520 **MeV**
  - **only visible at** $Q^2 > 10$ GeV^2
  - $R(\Theta^+/\Lambda)$ **larger than limits from ALEPH, HERA-b: dependence on reaction or phase-space ?**
- $\Xi^{--} \rightarrow \Xi^- \pi^-$, $\Xi^0 \rightarrow \Xi^+ \pi^-$
  - **similar sensitivity to NA49**
  - **not seen**
- $\Theta^0_c \rightarrow D^* p$
  - **a rate of** 1% **of visible** D^* **excluded at 9 sigma**
  - **acceptance corrected rate** $R^{\mathrm{corr}} < 0.37\%$
  - **need** R^{corr} **from H1 for full comparison**

Backup: details of D^* selection

- $(K\pi)\pi_s$:
  $p_T(K) > 0.45, p_T(\pi) > 0.45, p_T(\pi_s) > 0.1$ **GeV**
  $p_T(D^*)/E_T^{\theta>10^o} > 0.12(0.2)$
  where $E_T^{\theta>10^o} = E_T$ **outside a** 10^o **forward cone**
- $(K\pi\pi\pi)\pi_s$:
  $p_T(K) > 0.5, p_T(\pi) > 0.2, p_T(\pi_s) > 0.15$ **GeV**
  $p_T(D^*)/E_T^{\theta>10^o} > 0.2$

Backup: Θ^+ mass

- **ZEUS:**
  $M(\Theta^+) = 1521 \pm 1.5(\text{stat.})^{+2.8}_{-1.7}(\text{syst.})$**MeV**
- **Somehow lower than results from K^+n (CLAS, Spring-8, SAPHIR)**
- **Compatible with other results from K^0p (HERMES, SVD, COSY-TOF)**
- **Systematic uncertainty not reported by DIANA**