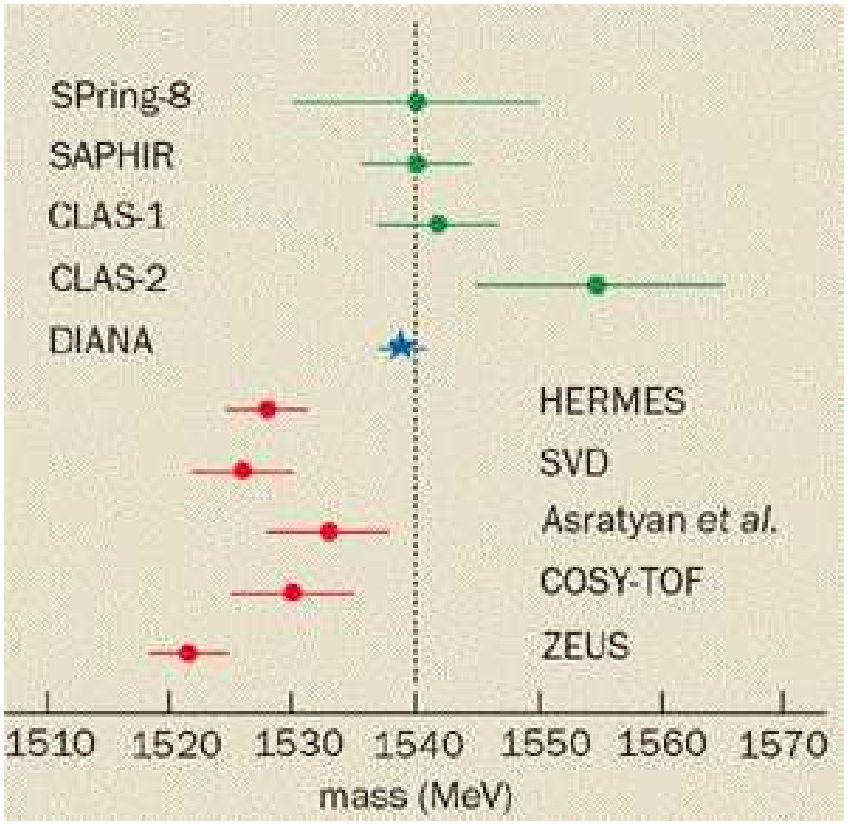
Pentaquarks searches at HERA

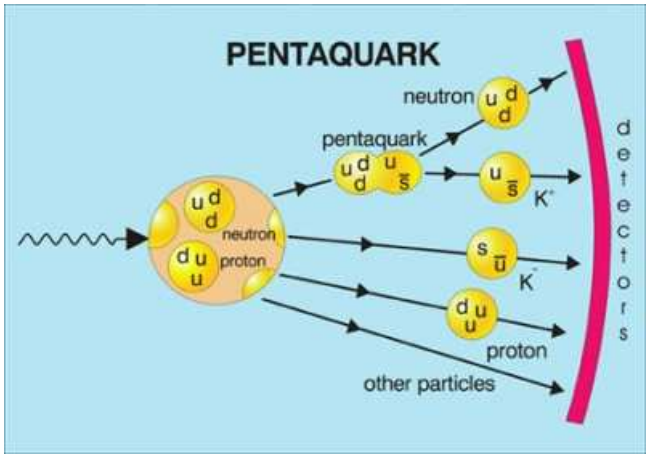
Amita Raval - Penn State University

QCD05 - Montpellier, July 2005

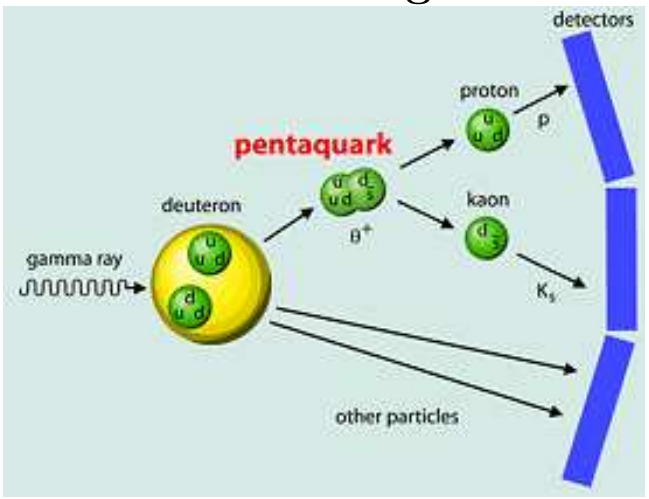
- Introduction
- Strange pentaquarks: Θ^{+}, Ξ^{--}
- Charmed pentaquark: Θ_c
- Summary

Evidence for pentaquarks





$\Theta^+ \rightarrow nK^+ \Rightarrow$ higher mass



$\Theta^+ \rightarrow pK^0_S \Rightarrow$ lower mass

Very recent Θ^+ results:

CLAS (γp): negative

LEPS (γn(d)): positive

Also evidence for:

NA49: Ξ^{--} (ddss$\bar{u}$)

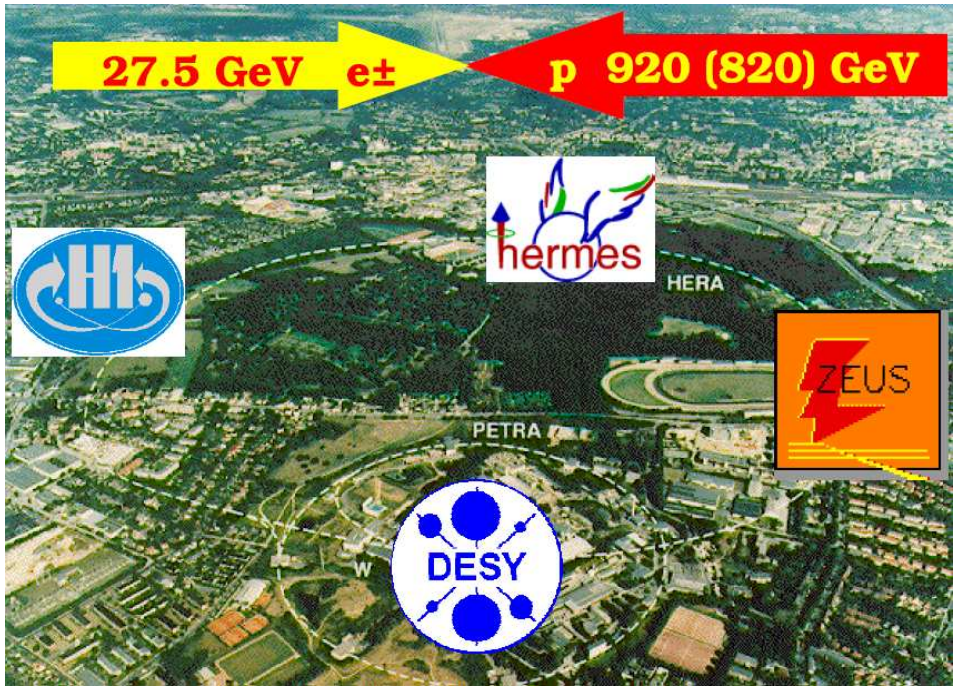
H1: Θ_c (uudd$\bar{c}$)

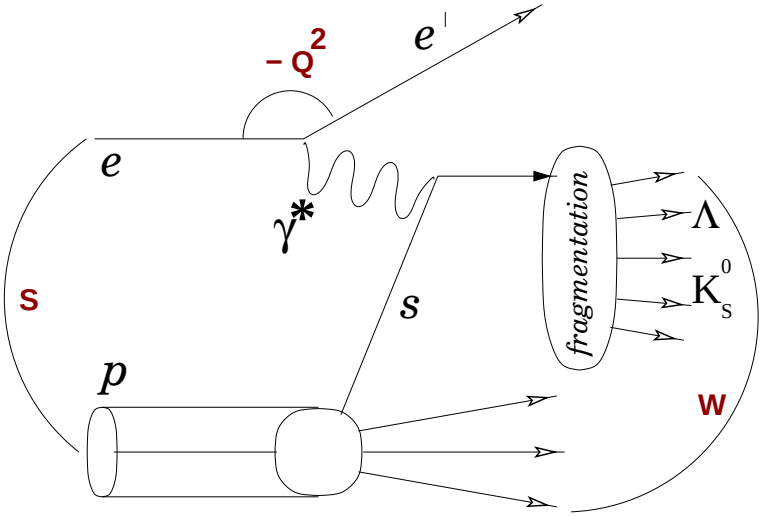
Fixed target: pq's use valence quarks

High energy: pq's via fragmentation

HERA and high energy collisions

$$\frac{\text{HERA: } e^{\pm}p \rightarrow e'X}{\sqrt{s} = 300\ (318)\ \text{GeV}}$$





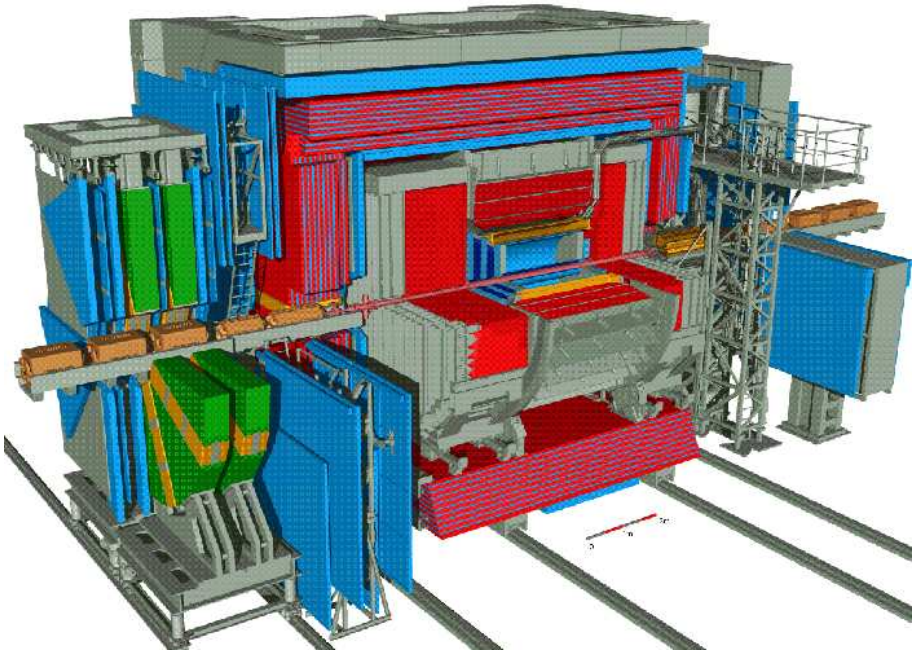
$Q^2 = -q^2$: photon virtuality

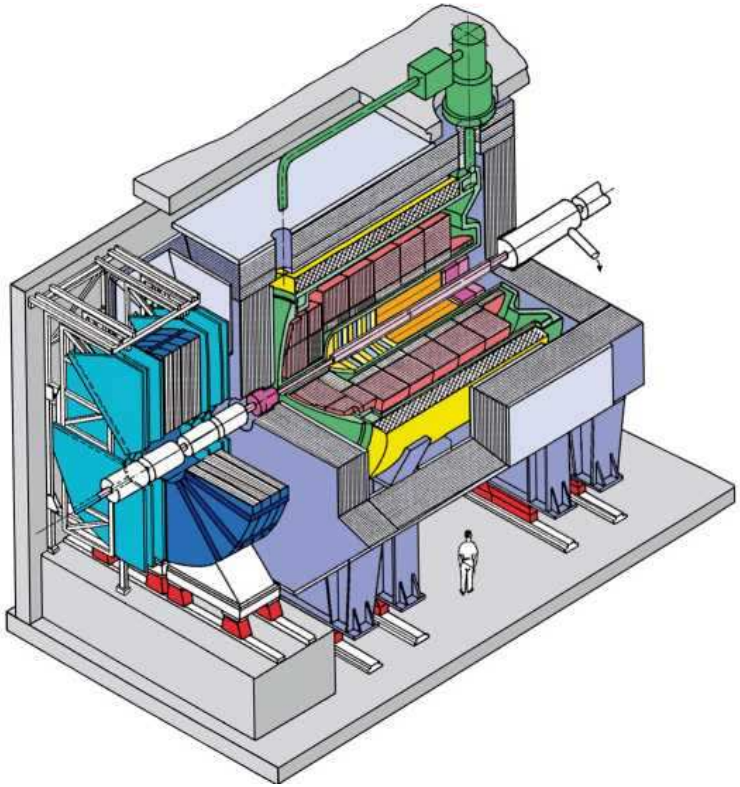
- $Q^2 > 1\ \text{GeV}^2$: DIS
  - require scattered electron
- $Q^2 < 1\ \text{GeV}^2$: γ-production

$W = \gamma * p$ energy

Baryons via fragmentation

ZEUS and H1 detectors



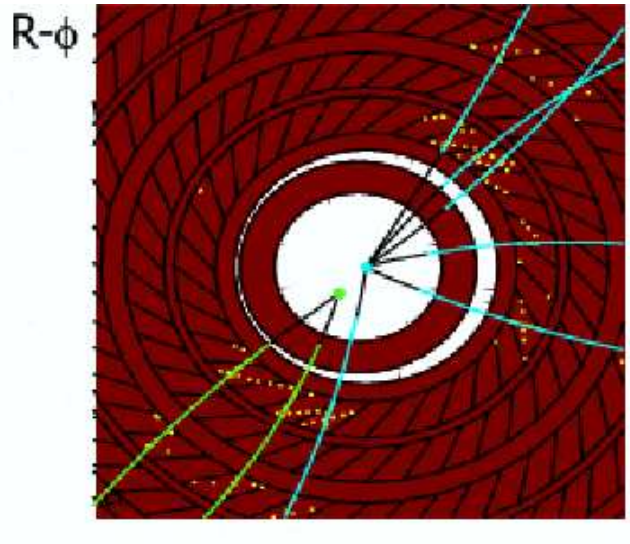


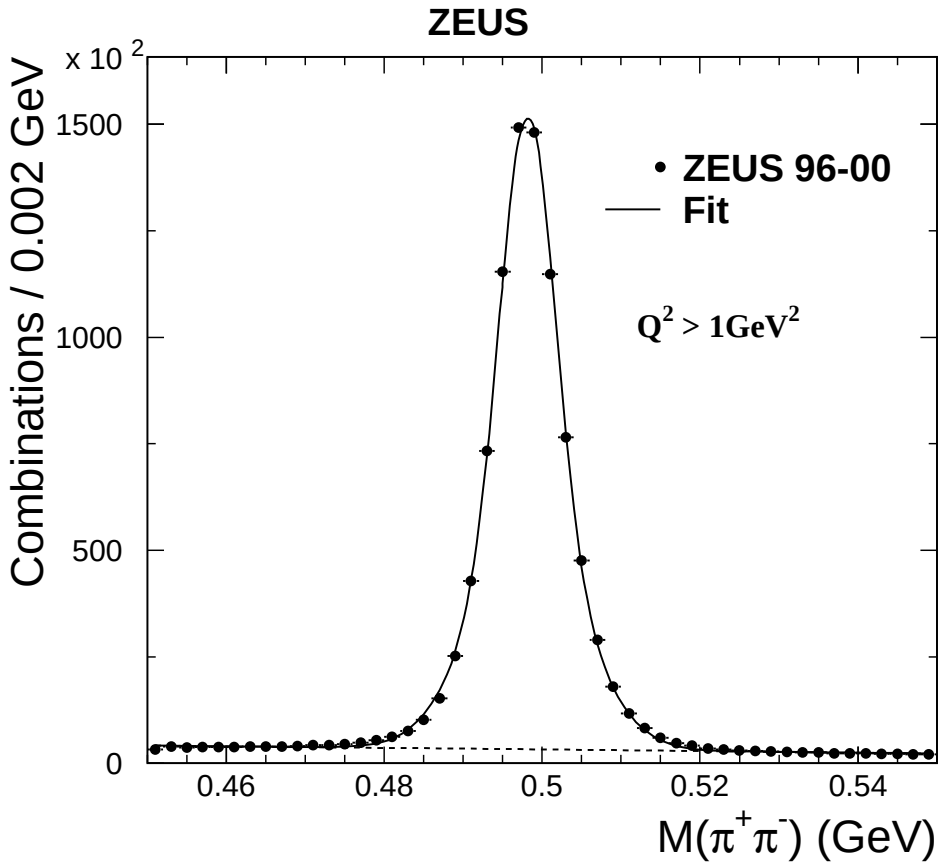
ZEUS **H1**

- Tracking ⇒ vertex finding, momentum measurement, particle ID
- Calorimetry ⇒ energy measurement

Θ^+ search with ZEUS: K^0_S, proton selection

- **HERA I (96-00) $\Rightarrow$ 121 pb^{-1}, $Q^2 > 1$ GeV^2**
- **$\Theta^+ \rightarrow K^0_S p$ $(\bar{\Theta}^- \rightarrow K^0_S \bar{p})$**
- **K^0_S Selection**
  - **$p_T(K^0_S) > 0.3$ GeV, $|\eta(K^0_S)| < 1.5$**





▷ Candidates: $\sim$ 870K Background: $< 6\%$ Peak: 498.12 ± 0.01 MeV

- **Protons identified by ionization energy loss**

Θ^+ search with ZEUS: $K^0_S p(\bar{p})$ invariant mass

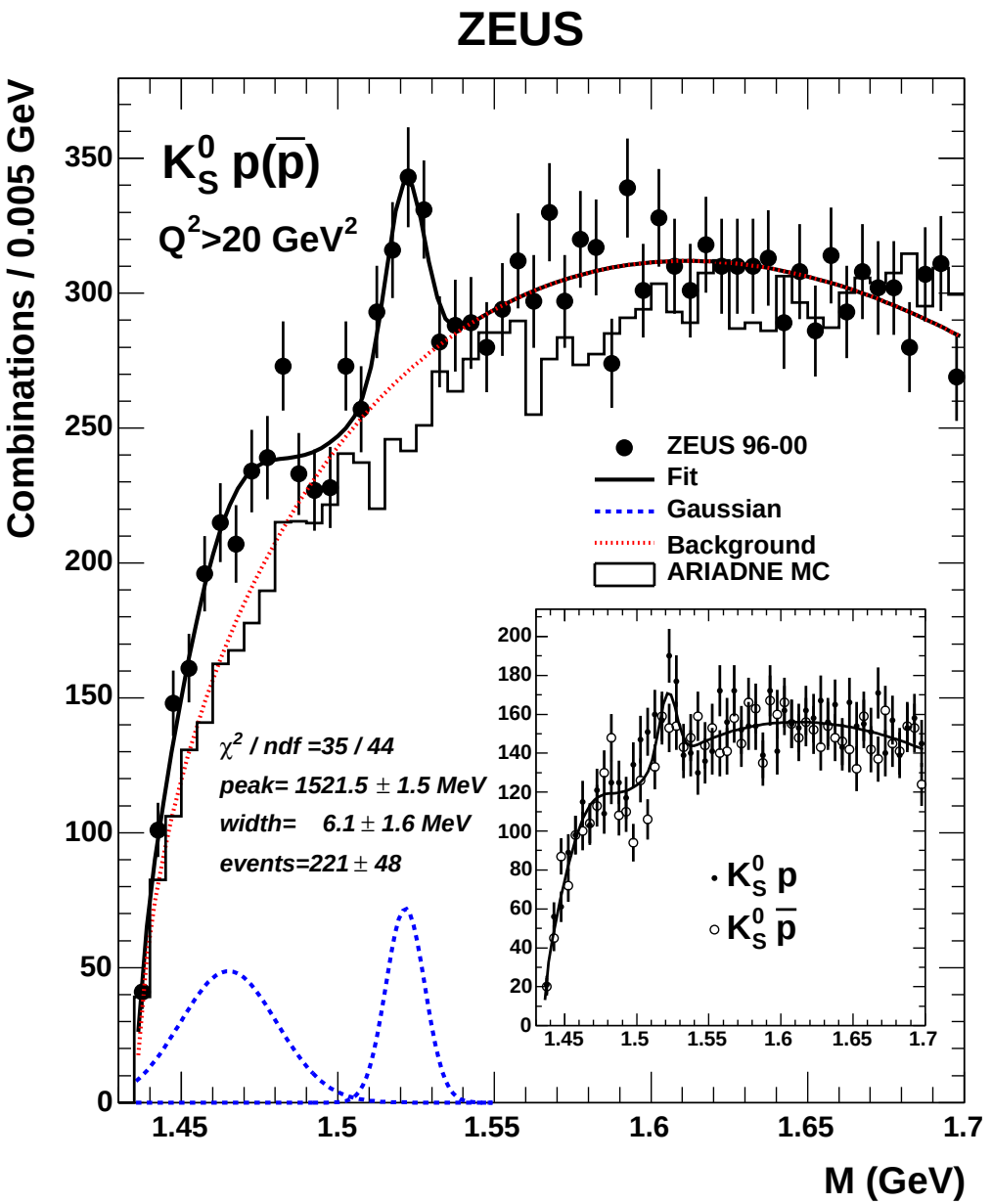
$p_T(\Theta^+) > 0.5$ GeV , $|\eta(\Theta^+)| < 1.5$

- Θ^+ Signal $\Rightarrow$ $Q^2 > 20$ GeV^2

- $M : 1521.5 \pm 1.5(\mathrm{st})^{+2.8}_{-1.7}(\mathrm{sy})$ MeV
- $\sigma : 6.1 \pm 1.5$ MeV
  $\Gamma = 8 \pm 4$ MeV

- Fit: 3P background + 2 G signal
  - $\sim 4.6\ \sigma$
  - $\chi^2/\mathrm{ndf} = 35/44$
  - single Gaussian fit $\Rightarrow$ worse χ^2/ndf, peak robust

- $\bar{\Theta}^-$: 96 ± 34 events $\Rightarrow 2.8\ \sigma$
  - if $K^0_S p$ interpreted as Θ^+ then $K^0_S \bar{p} \Rightarrow \bar{\Theta}^-$(antipentaquark)?

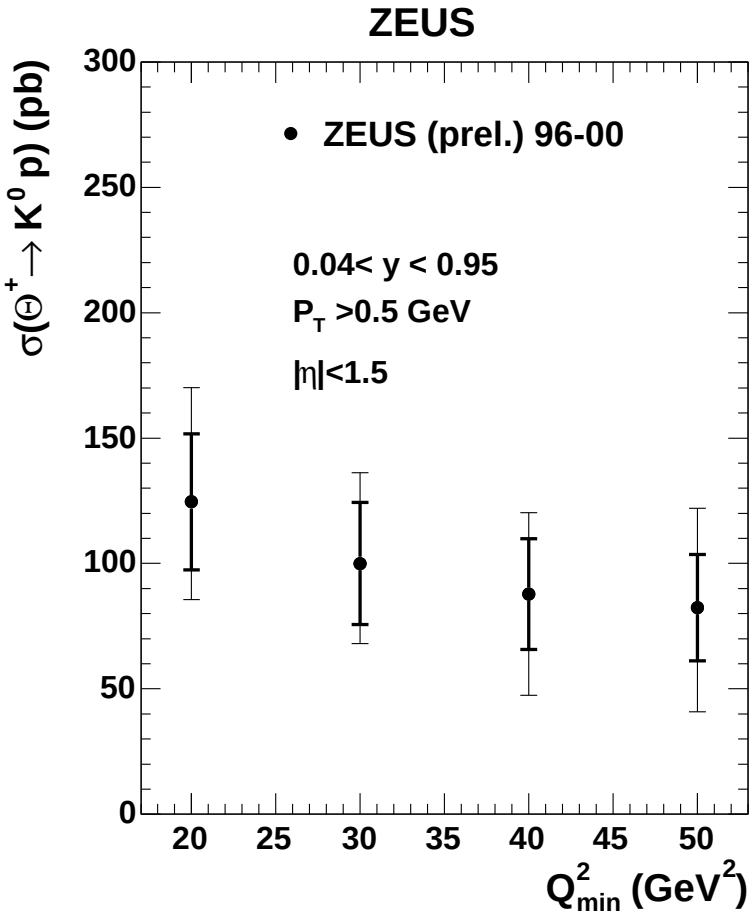


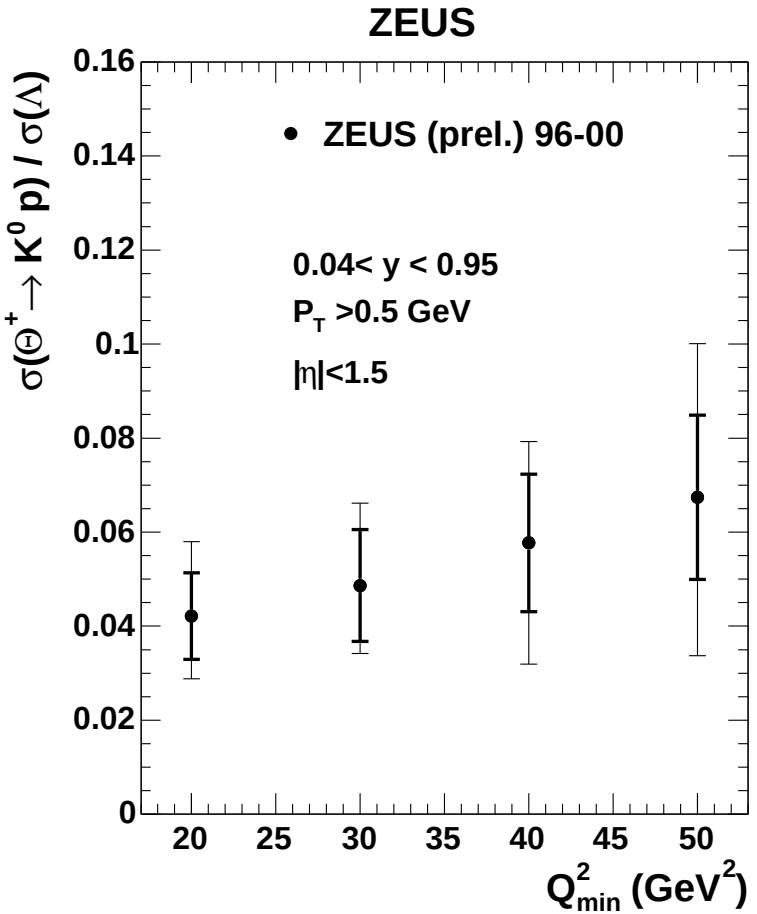
Θ^+ search with ZEUS: Θ^+ cross section

- Determine cross section using MC $\Rightarrow$ Σ forced to be Θ^+

  $\Longrightarrow \sigma(ep \to e\Theta^+X \to K^0pX) = 125 \pm 27(sy)^{+36}_{-28}(st)$ pb

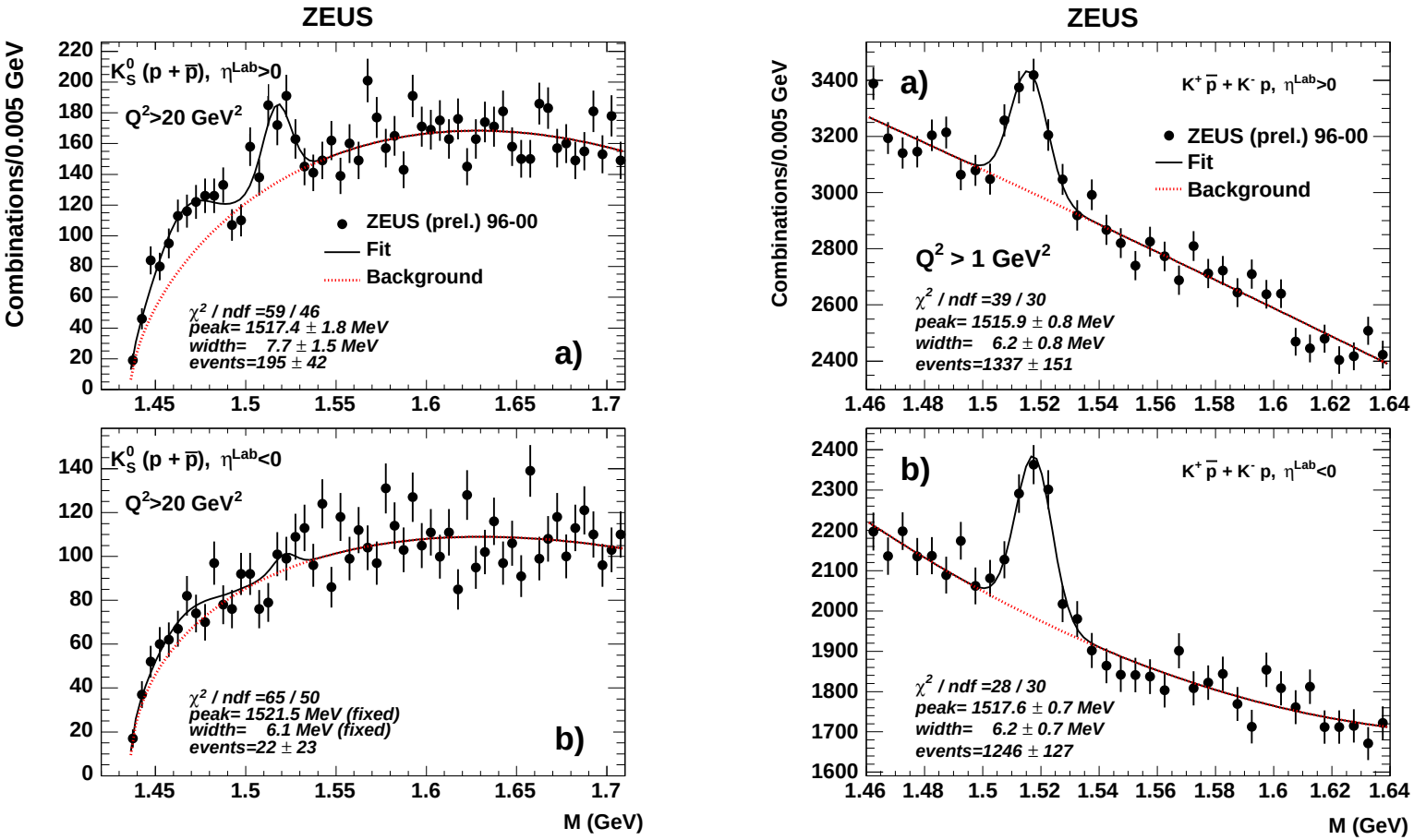
- $\Theta^+/\ \Lambda(1116)$ cross-section ratio $= 4.2 \pm 0.9(sy)^{+1.2}_{-0.9}(st)$ %





Θ^+ search with ZEUS: Θ^+ compared to $\Lambda(1520)$

- Investigate Θ^+ in different regions of detector (η)
- Compare Θ^+ properties to that of $\Lambda(1520)$

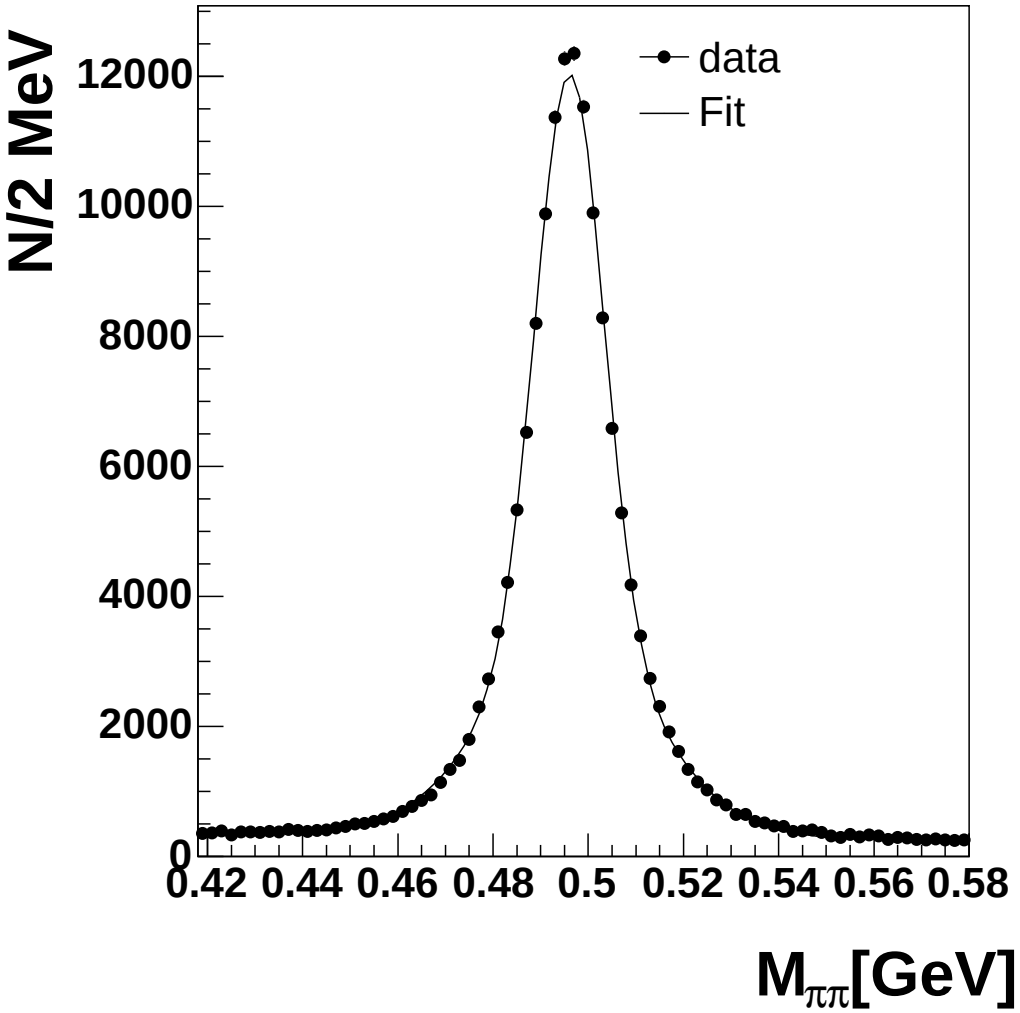


Message: Θ^+ produced in forward region of detector!

Asymmetry not seen for $\Lambda(1520)$ $\Rightarrow$ does Θ^+ production need proton remnant?

Θ^+ search with H1: K^0_S, proton selection

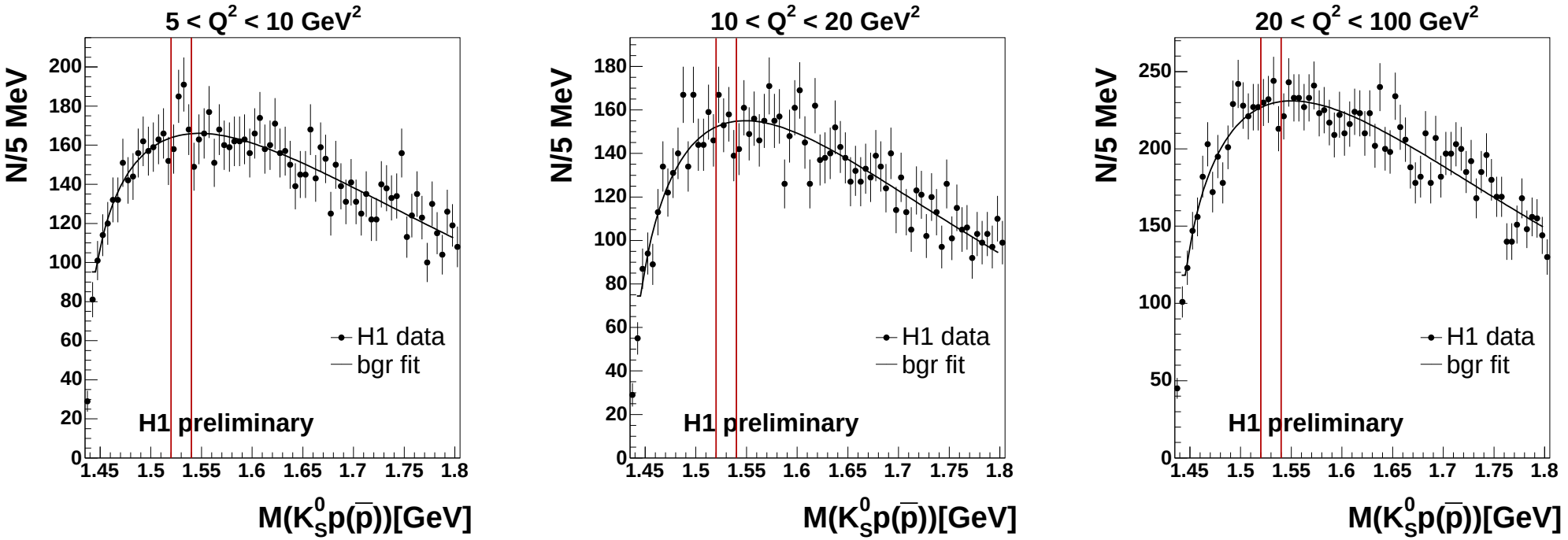
- HERA I (96-00) $\Rightarrow$ 75 pb^{-1}
  - $5 < Q^2 < 100$ GeV^2
- K^0_S selection
  - $p_T(K^0_S) > 0.3$ GeV
  - $1.5 < \eta(K^0_S) < 1.5$
  - K^0_S candidates: 140K



- Proton ID by ionization energy loss

Θ^+ search with H1: $K^0_S p(\bar{p})$ invariant mass

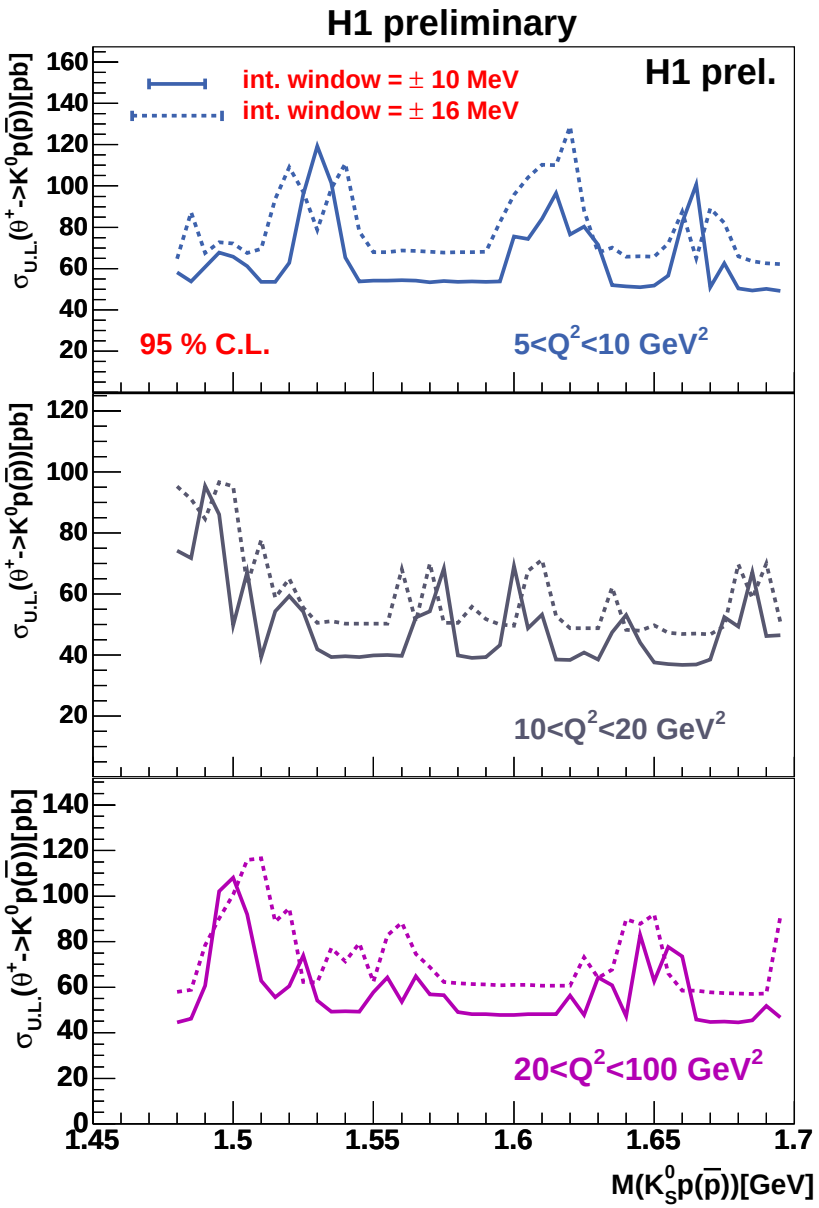
- $p_T(K^0_S) > 0.3$ GeV $\quad \eta|(K^0_S)| < 1.5$



- No significant signal in region of interest: 1.52 - 1.54 GeV

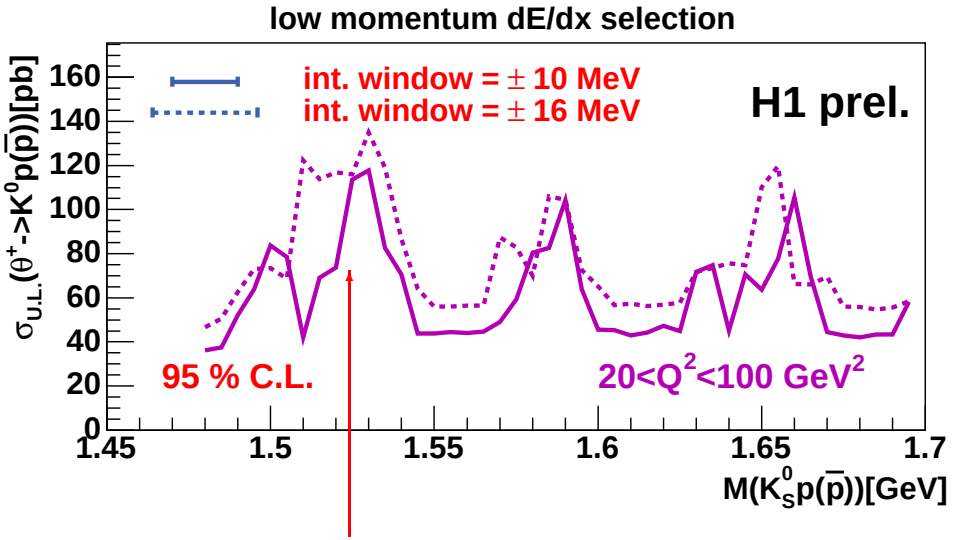
Θ^+ search with H1: Θ^+ cross-section limits

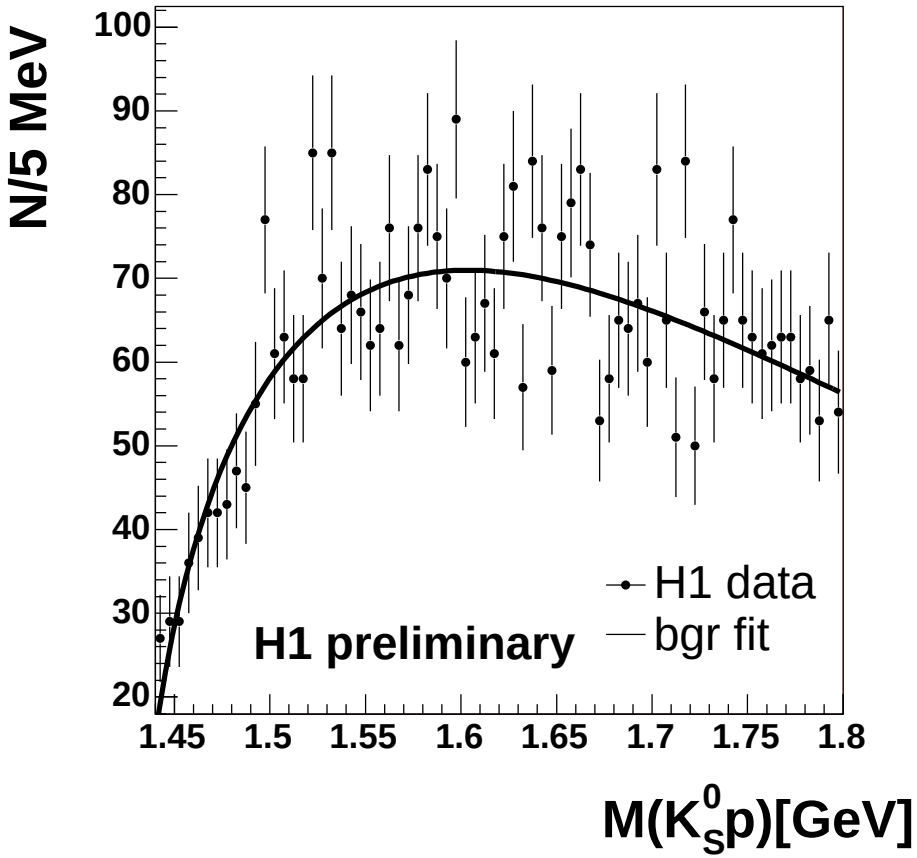
- $\sigma_{\text{u.l}}(\Theta^+ \rightarrow K^0 p) = \frac{N_{\text{u.l.}}(\Theta^+ \rightarrow K^0_S p)}{BR * A * L}$
- different fluctuations in Q^2 bins at different masses ...
- $\sigma_{\text{u.l}}(ep \rightarrow e\Theta^+ X \rightarrow K^0 p(\bar{p}) X)$ $\sim$ 40 - 120 pb
- searched in $K^0_S p$ & $K^0_S \bar{p}$ channels $\Rightarrow$ conclusion same!



Θ^+ search with H1: ZEUS selection

- Similar selection to ZEUS
  - kinematics: $20 < Q^2 < 100\ \mathrm{GeV}^2$
  - proton ID $\Rightarrow$ low p protons
- At $M = 1.522$ GeV
  - $\sigma_{\mathrm{U.L}}(ep \to e\Theta^+X \to K^0pX)$ $\sim$ 100 pb
- Not in contradiction with ZEUS!

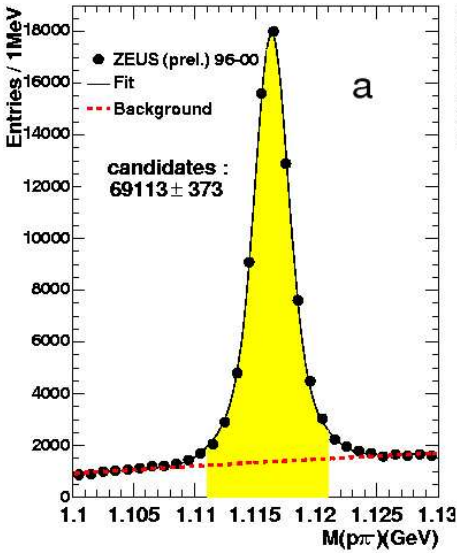


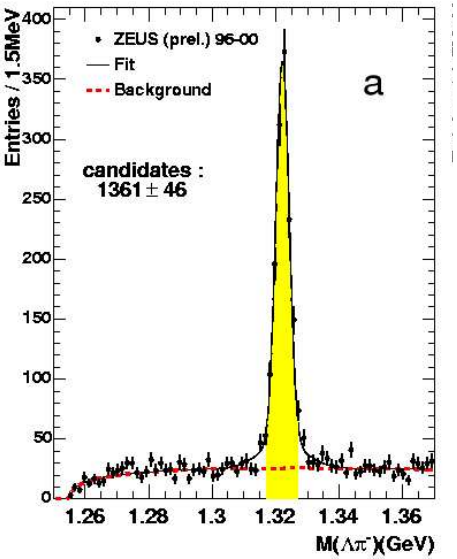


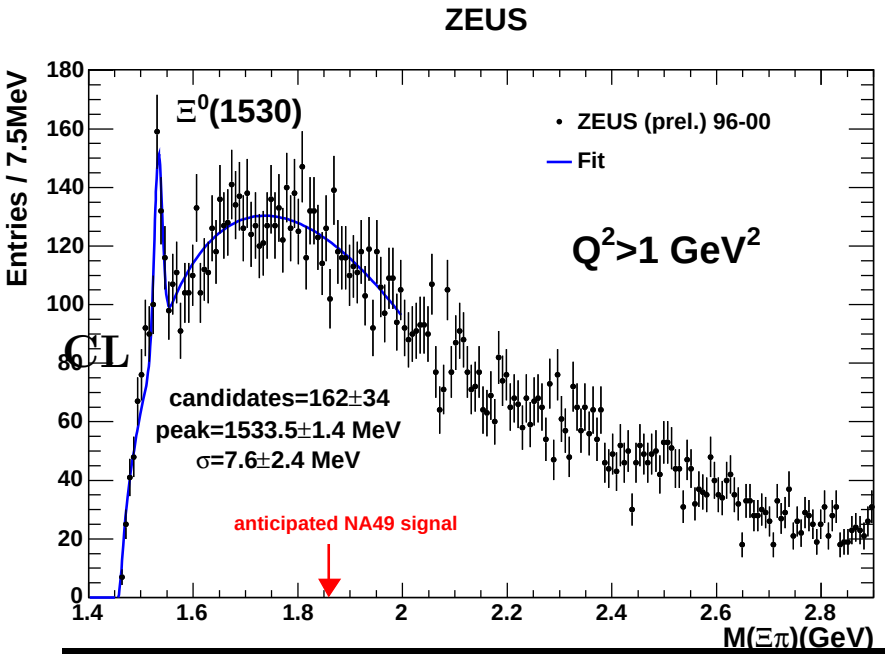
Search for Ξ^{--} with ZEUS

NA49 analysis repeated

- 96-00 data $\Rightarrow$ 105 pb^{-1}
- $\Xi^{--} \longrightarrow \Xi^{-}\pi^{-}$
  $\longrightarrow \Lambda^{0}\pi^{-}\pi^{-} \longrightarrow p\pi^{-}\pi^{-}\pi^{-}$
- high statistics, low bground







- NO Ξ^{--} signal!
- Clean $\Xi^{0}_{3/2}(1530)$ signal
  $\Longrightarrow$ $N(\Xi^{--})/N(\Xi^{0}_{3/2}(1530)) < 0.29$ at 95% CL
- Looking at different kinematic regions ...

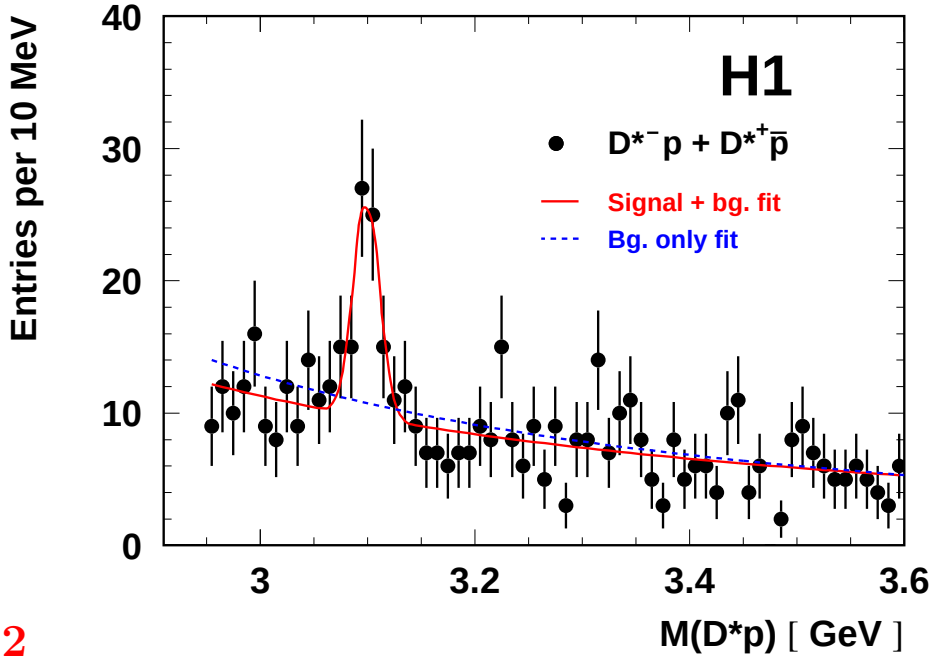
Search for Θ_c with H1

$$\Theta_c \rightarrow D^* p \rightarrow K^{\mp}\pi^{\pm}\pi_s^{\pm} p$$

- 96-00 data $\Longrightarrow$ 75 pb^{-1}
  - $1 < Q^2 < 100\ GeV^2$

- D^*: $\Delta m(D^*) = m(K\pi\pi_s) - m(K\pi)$
  - ▷ 3400 D^* events

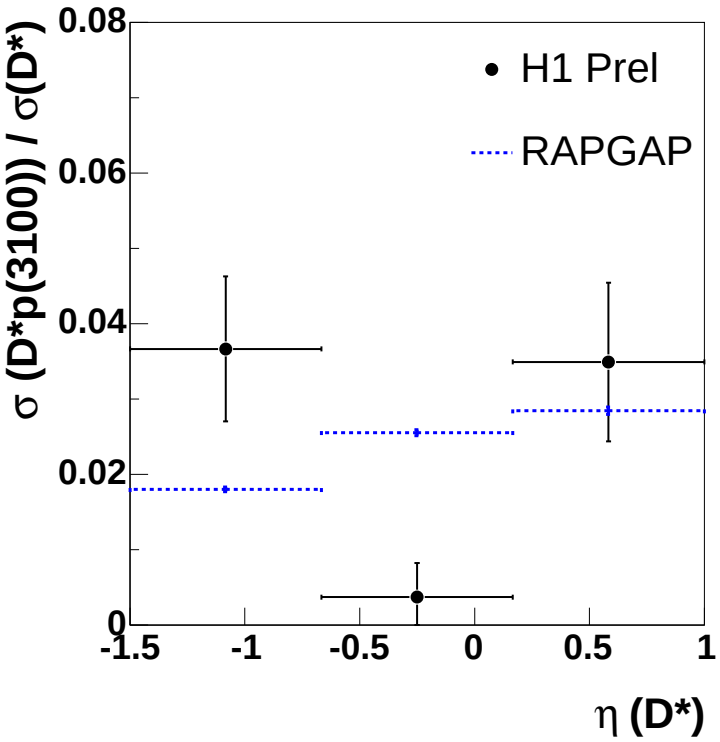
- Θ_c: $m(D^* p) = m(K\pi\pi_s p) - m(K\pi\pi_s) + M_{PDG}(D^*)$
  - Signal + Bground fit:
    - ▷ M=3099 $\pm$3(sy) $\pm$5(st) MeV
    - ▷ σ=12 $\pm$3 MeV
    - ▷ N_b= 45.0 $\pm$ 2.8, N_s= 50.6 $\pm$ 11.2

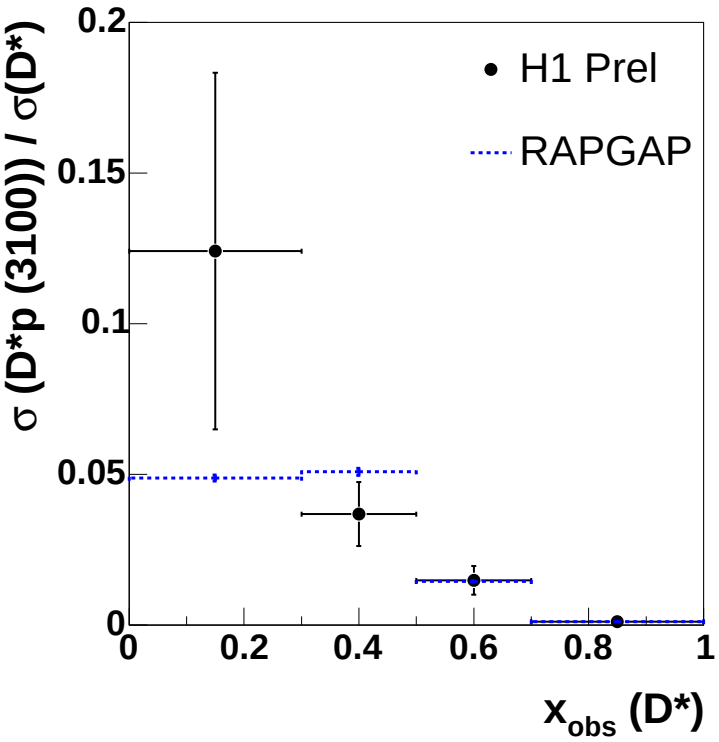


- $R_{cor}(D^* p/D^*) = 1.59 \pm 0.33(st)^{+0.33}_{-0.45}(sy)\%$
  - ▷ $p_T(D^* p) > 1.5\ GeV,\ -1.5 < \eta(D^* p) < 1.0$
  - ▷ $p_T(D^*) > 1.5\ GeV,\ -1.5 < \eta(D^*) < 1.0,\ z(D^*) > 0.2$

Θ_c search with H1: Θ_c properties

- Investigate Θ_c in different regions of detector (η)
- Investigate Θ_c in terms of momentum fraction from parent charm quark (x_{obs})



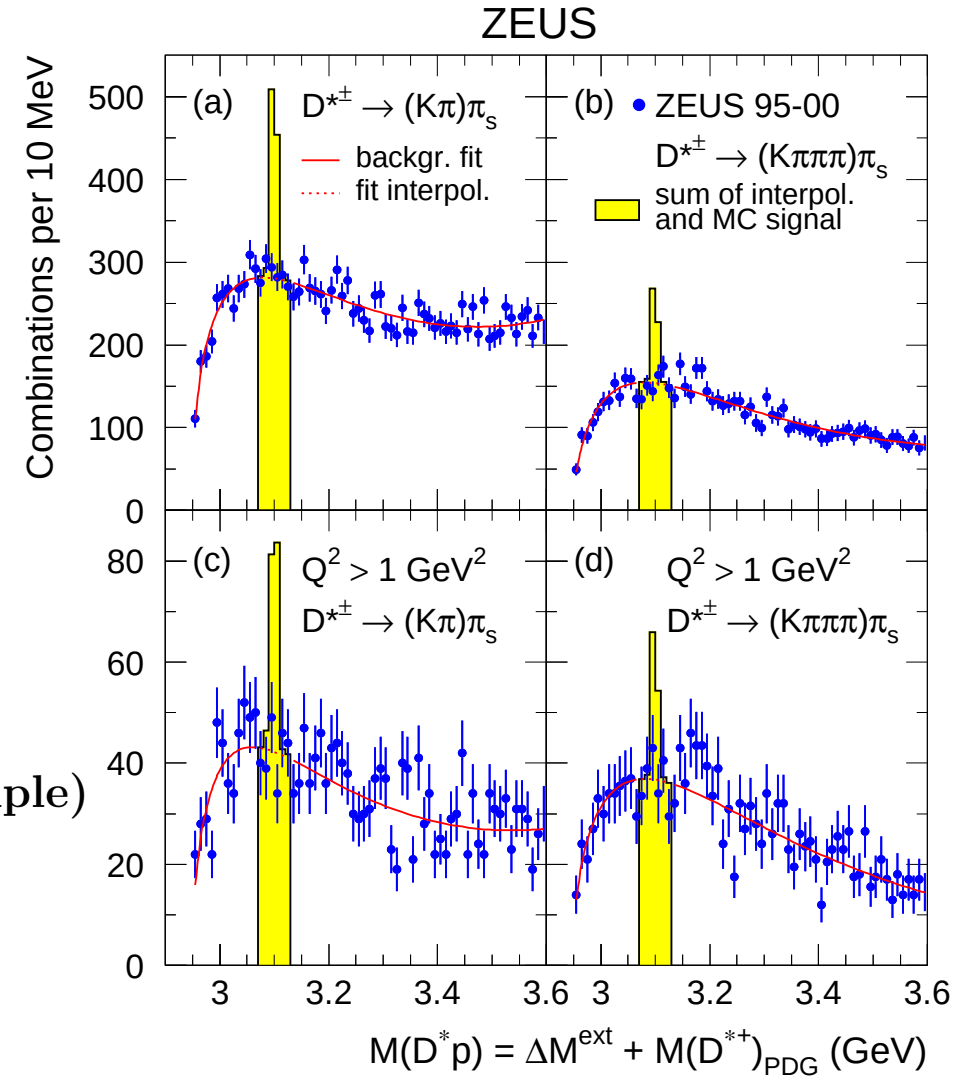


Message: D*p production is different from charm production
D*'s from D*p production are different from inclusive D*'s!

Search for Θ_c with ZEUS

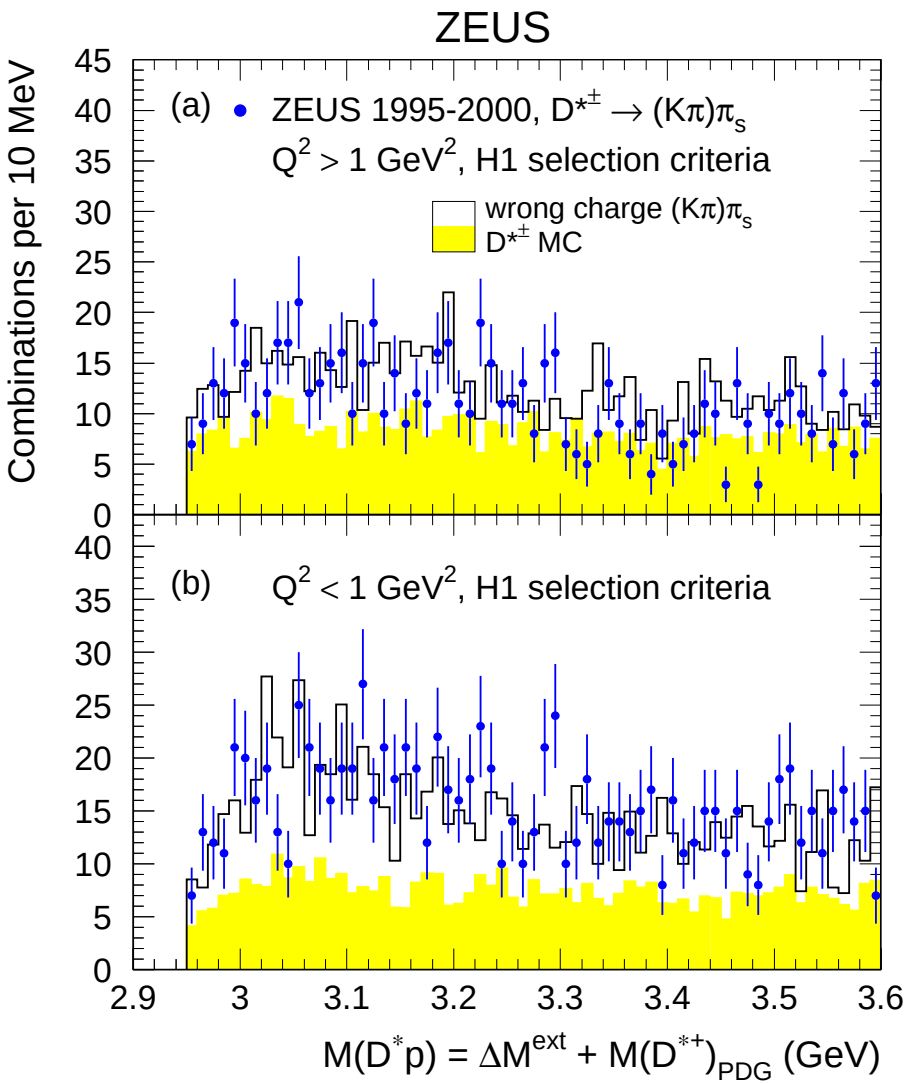
$$\Theta_c \to D^* p \to K\pi\pi_s p \quad \text{and} \quad \Theta_c \to D^* p \to K\pi\pi\pi\pi_s p$$

- 95-00 data $\Longrightarrow$ 126 pb^{-1}
  - Photoproduction and DIS
- D^*: mass difference method
  - ▷ 62,600 D^*'s (13,500 in DIS alone)
  - ▷ if 1% D^*'s from $\Theta_c \Rightarrow$ 626 Θ_c's!
- Θ_c: NO SIGNAL!
  - 1% signal ruled out!
- Upper limit at 95% CL:
  - ▷ $R_{cor} < 0.59\%$ ($K2\pi$, DIS sample)
  - ▷ $R_{cor} < 0.37\%$ ($K2\pi$ & $K4\pi$, full sample)
- Incompatible with H1 result ...



Search for Θ_c with ZEUS: H1 selection

- Default selection
  - K2π and K4π
  - $-1.6 < \eta(D^*) < 1.6$
  - $p_T(D^*) > 1.35$ GeV (for K2π)
  - electron inelasticity: $y < 0.95$
- "H1 selection" $\Rightarrow$ all cuts tighter
  - K2π only
  - $-1.5 < \eta(D^*) < 1.0$
  - For DIS
    - $p_T(D^*) > 1.5$ GeV
    - $0.05 < y < 0.7$
  - For Photoproduction
    - $p_T(D^*) > 2.0$ GeV
    - $0.2 < y < 0.8$
  - ... other minor changes



NO SIGNAL!

Summary

- $\Theta^+ \rightarrow K^0_S p$
  - ZEUS sees a narrow state at ~ 1522 MeV for $Q^2 > 20$ GeV^2
  - Θ^+ seems to be produced in the forward region of detector
  - Θ^+ / Λ cross-section ratio $\Rightarrow 4.2 \pm 0.9(\mathrm{sy})^{+1.2}_{-0.9}(\mathrm{st})\%$
  - H1 does not observe a signal but ...
    $\Rightarrow$ UL on cross section is not in contradiction with ZEUS result!

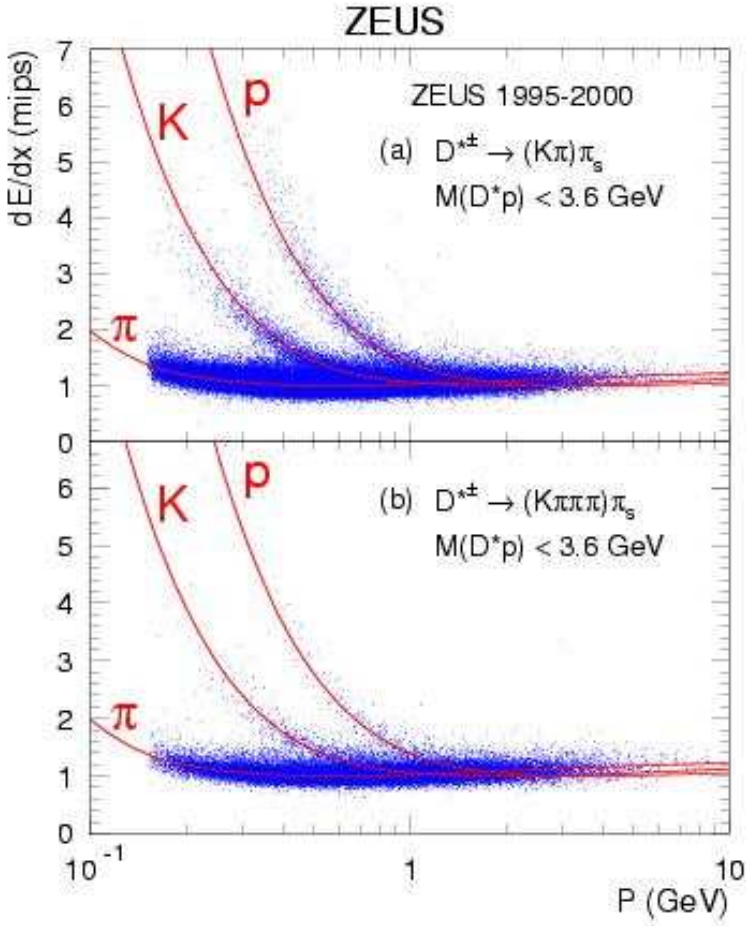
- $\Xi^{--} \rightarrow \Xi\pi$
  - Zeus does not see a signal but ...
  - probing a different kinematic region to NA49

- $\Theta_c \rightarrow D^* p$
  - H1 observes a narrow state at ~ 3099 MeV
  - $R_{cor}(D^* p / D^*) = 1.59 \pm 0.33(\mathrm{st})^{+0.33}_{-0.45}(\mathrm{sy})\%$
  - ZEUS does not confirm this signal $\Rightarrow R_{cor} < 0.37\%$

- In general, the pentaquark situation is unclear ...
  $\Rightarrow$ We are already looking into HERA II data!

Backup ZEUS: proton identification

(anti)proton selection $\Longrightarrow$ define ionization band in dE/dx

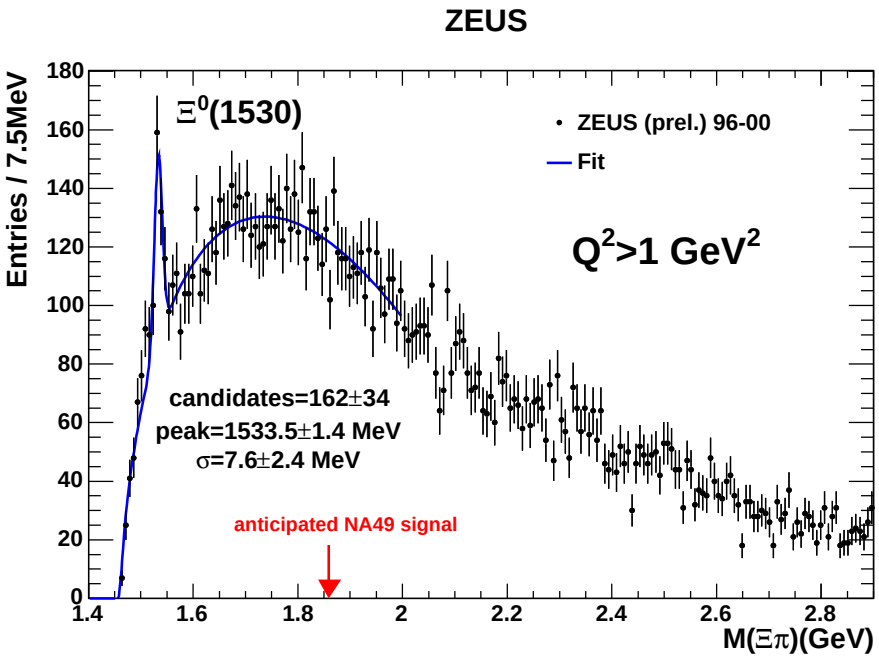


- resolution for minimum ionizing particles: $\sim 9\%$
- Strange pentaquark
  dE/dx > 1.15 mips
  P(p) < 1.5 GeV
  $\sim 60\%$ proton purity
- Charmed pentaquark
  use χ^2 probability of proton
  $l_p > 0.15 \Rightarrow$
  $A(l_p > 0.15) = 85.0 \pm 0.1\%$

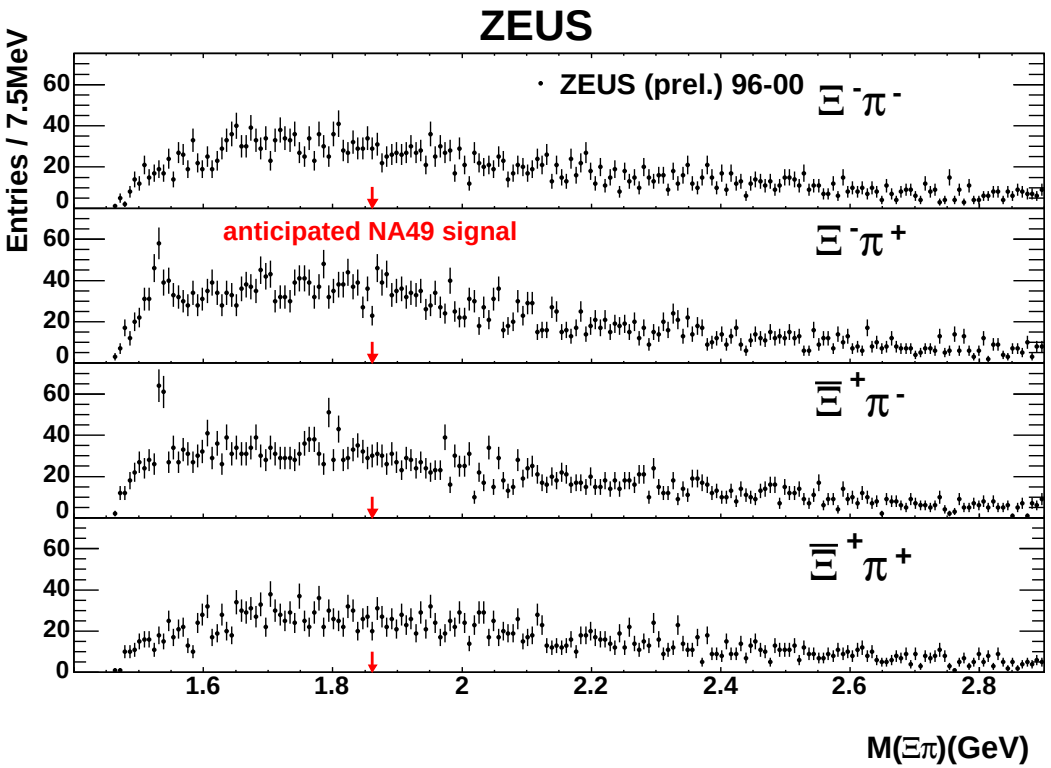
Search for Ξ^{--} with ZEUS

- NO Ξ^{--} signal!
- Clean $\Xi^0_{3/2}(1530)$ signal $\Longrightarrow$ $N(\Xi^{--})/N(\Xi^0_{3/2}(1530)) < 0.29$ at 95% CL

4 channels combined



4 channels separated



Ξ^{--} produced in forward region?

Backup - Θ_c

D^* decay channel	$(K\pi)\pi_s$	$(K\pi\pi\pi)\pi_s$	Both channels
Full data sample			
N_{window}	1710	914	
N_{backgr}	1678 ± 23	919 ± 19	
$N(D^*)$	42680 ± 350	19900 ± 250	
$R(\Theta_c^0 \to D^*p/D^*)$	$< 0.29\%$	$< 0.33\%$	$< 0.23\%$
$R^{cor}(\Theta_c^0 \to D^*p/D^*)$	$< 0.47\%$	$< 0.50\%$	$< 0.37\%$
$f(c \to \Theta_c^0) \cdot B_{\Theta_c^0 \to D^*p}$	$< 0.18\%$	$< 0.33\%$	$< 0.16\%$
DIS with $Q^2 > 1$ GeV^2			
N_{window}	252	220	
N_{backgr}	252.8 ± 9.2	219.8 ± 8.8	
$N(D^*)$	8680 ± 130	4830 ± 120	
$R(\Theta_c^0 \to D^*p/D^*)$	$< 0.41\%$	$< 0.69\%$	$< 0.35\%$
$R^{cor}(\Theta_c^0 \to D^*p/D^*)$	$< 0.59\%$	$< 1.06\%$	$< 0.51\%$
$f(c \to \Theta_c^0) \cdot B_{\Theta_c^0 \to D^*p}$	$< 0.20\%$	$< 0.56\%$	$< 0.19\%$