Pentaquark Searches in ZEUS

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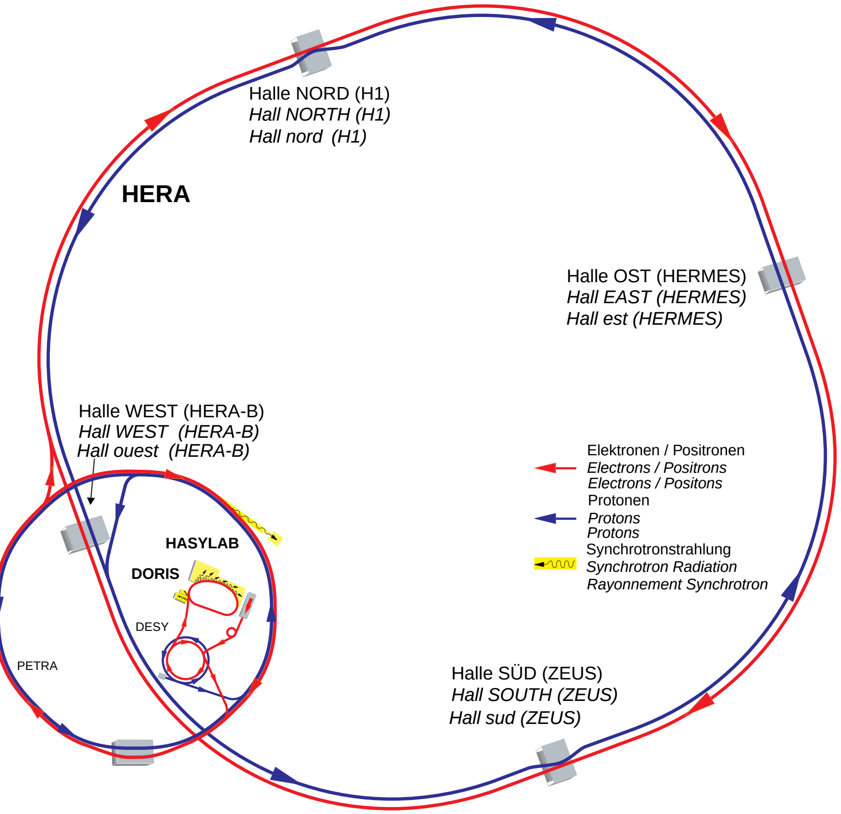
- The ZEUS $\Theta^{+}(1530)$ Signal
- Production of baryons decaying to strange particles
- Search for the $\Xi\pi$ Pentaquark
- Search for the $\Theta_c^0(3100)$ Pentaquark
- Summary

Introduction - HERA and ZEUS at DESY

H E R A



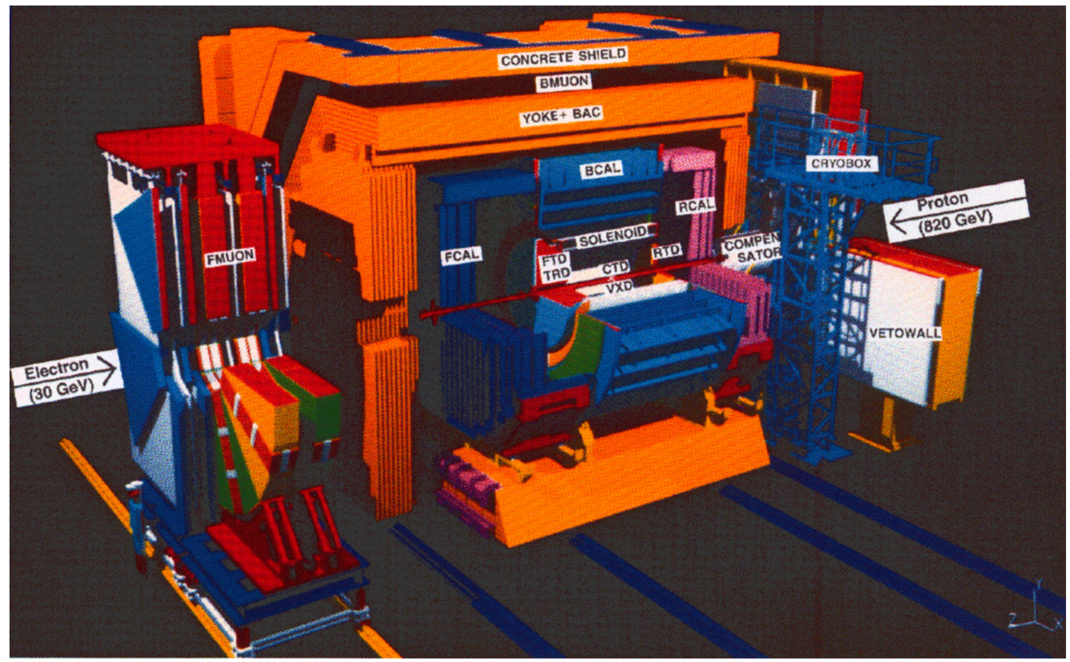
$e \Rightarrow$ $\Leftarrow p$

$27.6\ GeV$ $820 - 920\ GeV$

$\sqrt{s} \approx 300 - 319$ **GeV**

Experiments: H1, ZEUS, HERMES

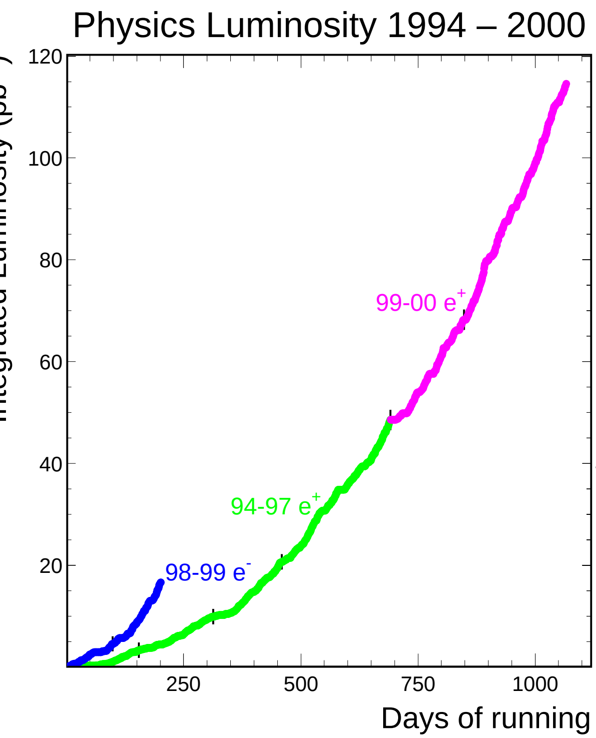
Z E U S

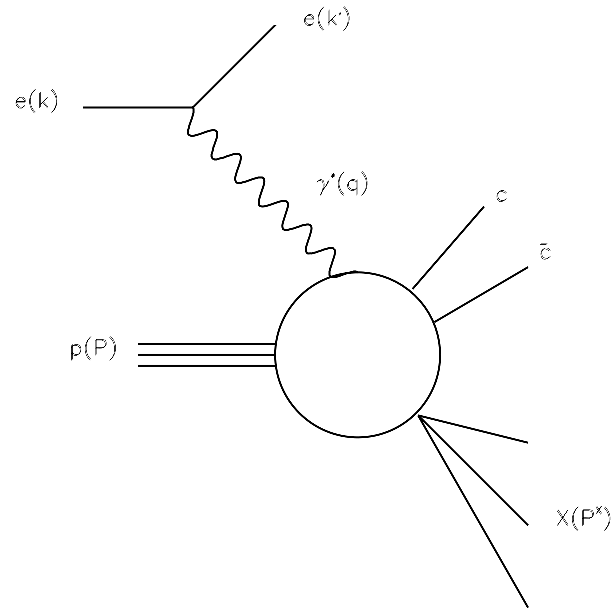


Tracking $\Rightarrow$ vertex finding, momentum measurement, particle ID

Calorimetry $\Rightarrow$ energy measurement

Introduction - HERA I: Luminosity, Kinematic variables





Kinematic Variables

(Four-momentum transfer)^2 : $Q^2 = -q^2 = -(k - k')^2$

Bjorken-x scaling variable: $x = \frac{Q^2}{2\ P \cdot q}$

Fraction of energy transfer: $y = \frac{P \cdot q}{P \cdot k}$

(γ p CMS energy)^2 : $W_{\gamma p}^2 = (P + q)^2 \cong 4\ E_e\ E_p\ y$

Two kinematic regimes:

Deep Inelastic Scattering (DIS) $Q^2 > 1 GeV^2$

Scattered e visible in main detector

Photoproduction (PHP) $Q^2 < 1 GeV^2$; $< Q^2 > \approx 3 \cdot 10^{-4}$

No scattered e in main detector $\Rightarrow$ **quasi-real photon**

The ZEUS $\Theta^+(1530) \to K^0_S p(\bar{p})$ signal

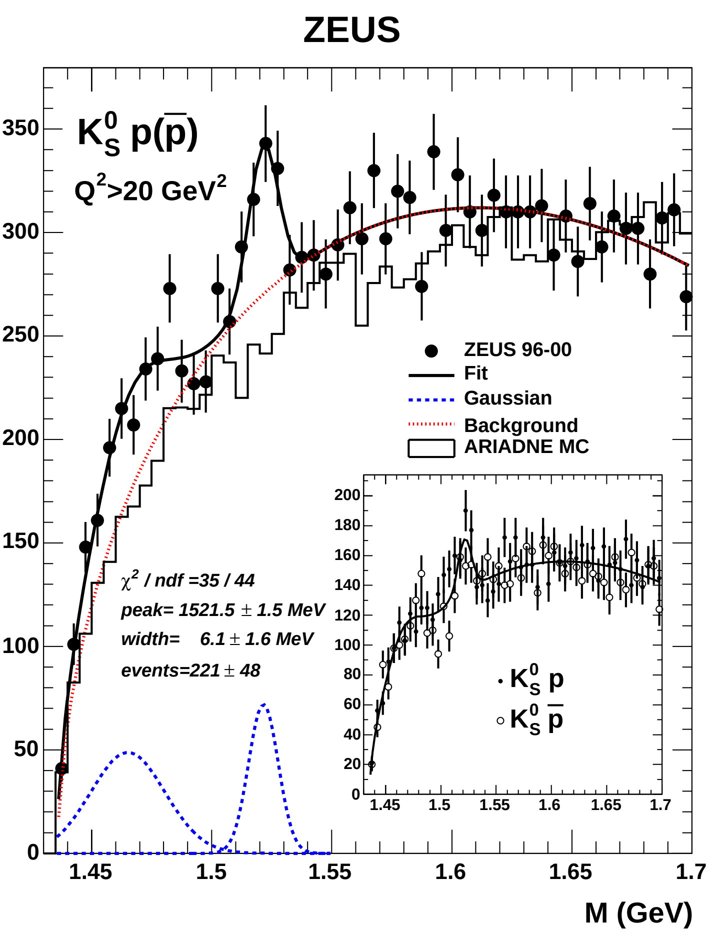
EUS HERA-I DIS data (121 $\mathbf{pb^{-1}}$) Phys. Lett. B 591 (2004) 7

$\approx 867,000$ K^0_S **candidates with** $\approx 6\%$ **background**

rotons identified by ionization energy loss dE/dx

Fit the $M(K^0_S p)$ distribution with $Q^2 > 20$ GeV^2 to two Gaussians
+ threshold background function $\Rightarrow \chi^2/ndf = 35/44$

First Gaussian consistent with a PDG Σ bump at 1480 MeV



$M(\Theta^+) = 1521.5 \pm 1.5(stat.)^{+2.8}_{-1.7}(syst.)$ **MeV**

Gaussian width=$6.1 \pm 1.6(stat.)$ **MeV**

Resolution=2.0 ± 0.5 **MeV**

$\Rightarrow \Gamma(BW) = 8 \pm 4(stat.)$ **MeV**

221 ± 48 **events** ≈ 4.6 **s.d.**

Single Gaussian fit

$\longrightarrow$ **worse** χ^2/ndf**, peak robust**

Signal seen in both charges (inset)

$K^0_S \bar{p}$ **fit:** 96 ± 34 **(2.8 s.d.)**

If real - evidence for antipentaquark Θ^-

Θ^+ cross section (prel.)

Determine Θ^+ cross section at measured kinematic region:

$Q^2 > 20$ **GeV**^{2}, $0.04 < y < 0.95$, $p_T(\Theta^+) > 0.5$ **GeV**, $|\eta(\Theta^+)| < 1.5$

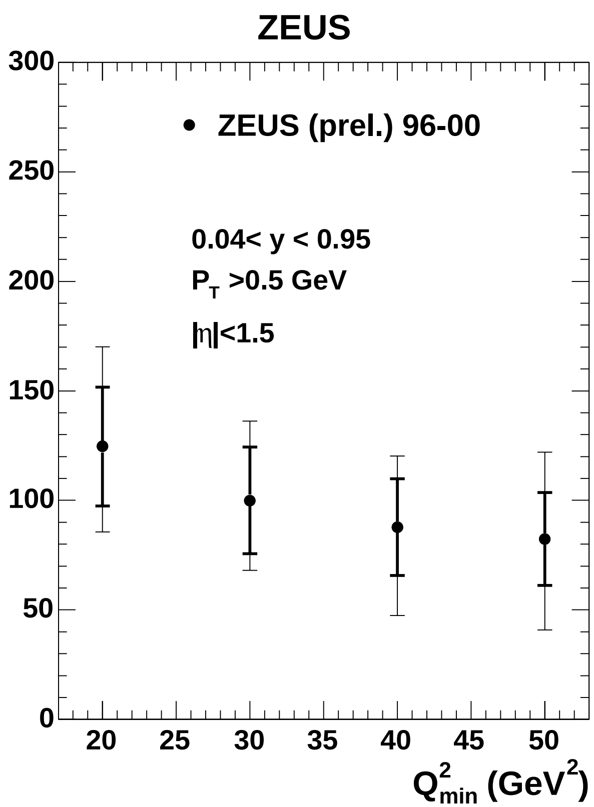
$\sigma(ep \to e\Theta^+X \to e^\pm K^0pX) = 125 \pm 27(stat.)^{+36}_{-28}(syst.)pb$

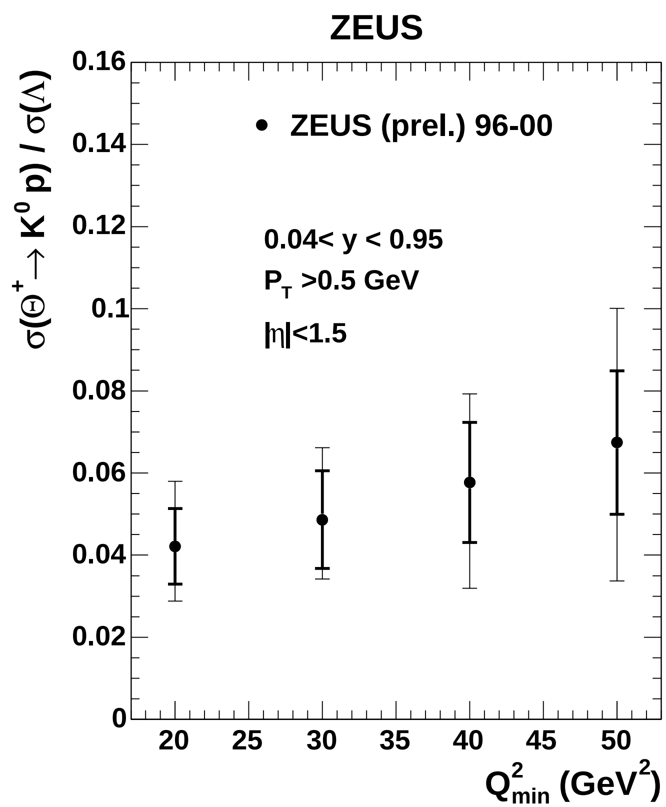
Compare to well-known baryon Λ:

$\sigma(\Theta^+)$ **and** $\sigma(\Theta^+)/\sigma(\Lambda)$ **as a function of** Q^2_{min}

Λ **measured in the same kinematic region**

rotons from Λ selected by dE/dx with same cuts as for Θ^+





Acceptance $A(\Theta^+)$, $A(\Lambda)$ **calculated using RAPGAP/ARIADNE MC**

For $A(\Theta^+)$ **used** $\Sigma^\pm$ **with** $M = 1522$ **MeV and** 100% **decay to** $K^0_Sp(\bar{p})$

$A(\Theta^+) \approx 4\%$; $A(\Lambda) \approx 10\%$

For $Q^2 > 20$ **GeV**^{2} **:**

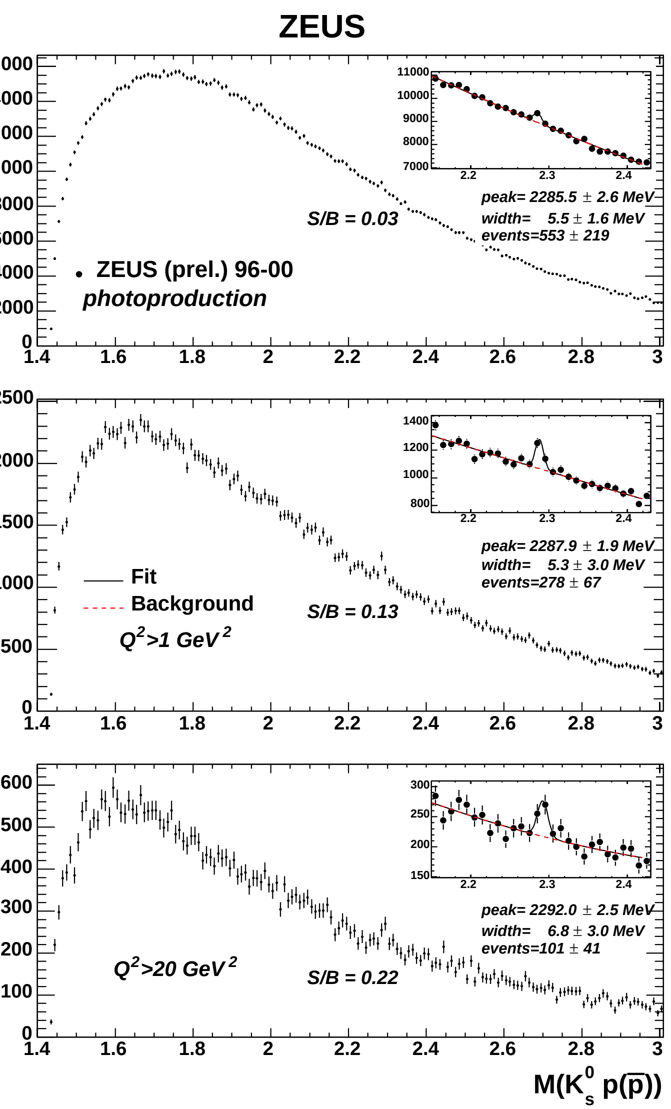
$\sigma(\Theta^+ \to K^0p)/\sigma(\Lambda) = (4.2 \pm 0.9^{+1.2}_{-0.9})\%$

Production of baryons decaying to strange particles (prel.)

EUS is the only high-energy experiment that sees the $\Theta^+(1530)$

it a statistical fluctuation or a peculiar production mechanism?

ompare Θ^+ production to known baryons with similar decay channels



$M(K_S^0 p(\bar{p}))$ **for 3 data samples:**
PHP; $Q^2 > 1$ **GeV**^{2}**;** $Q^2 > 20$ **GeV**^{2}

See Θ^+ **peak at high** Q^2
Λ_c **signal for all 3 samples**

Strong increase of S/B **for** Λ_c **vs.** Q^2
$S/B =$ **0.03 (PHP)**
0.13 (DIS low Q^2**)**
0.22 (DIS high Q^2**)**

PHP events enriched by K_S^0 **and** $p(\bar{p})$
from light-q fragmentation

Θ^+ **not seen in PHP (and low** Q^2**)**
perhaps due to low S/B **(large combinatorial background and particle multiplicity)**

Λ_c production properties

$_c$ $Q^2 > 1$ GeV^2 peak studied in forward vs. rear pesudorapidity region separately for p's and $\bar{p}$'s

Low statistics $\Rightarrow$ mass and width fixed from overall $Q^2 > 1$ GeV^2 fit

omparable number of Λ_c for all 4 spectra: $N(\Lambda_c) = 131 \pm 40$; $\eta > 0$

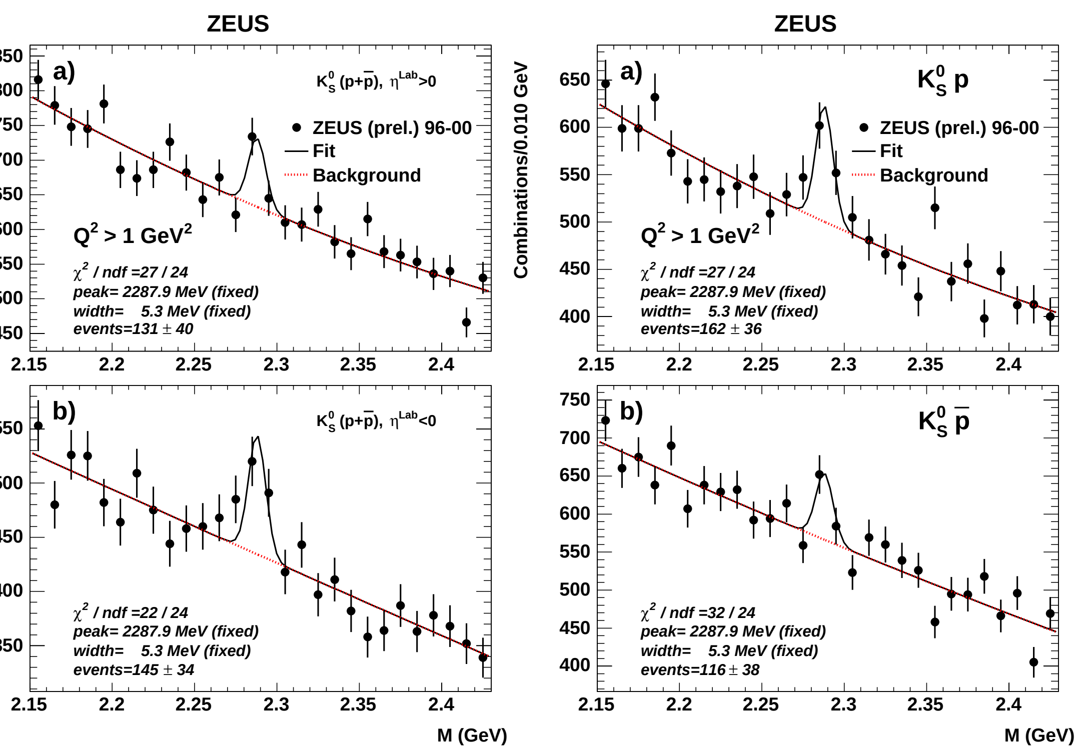
145 ± 34; $\eta < 0$

162 ± 36; p

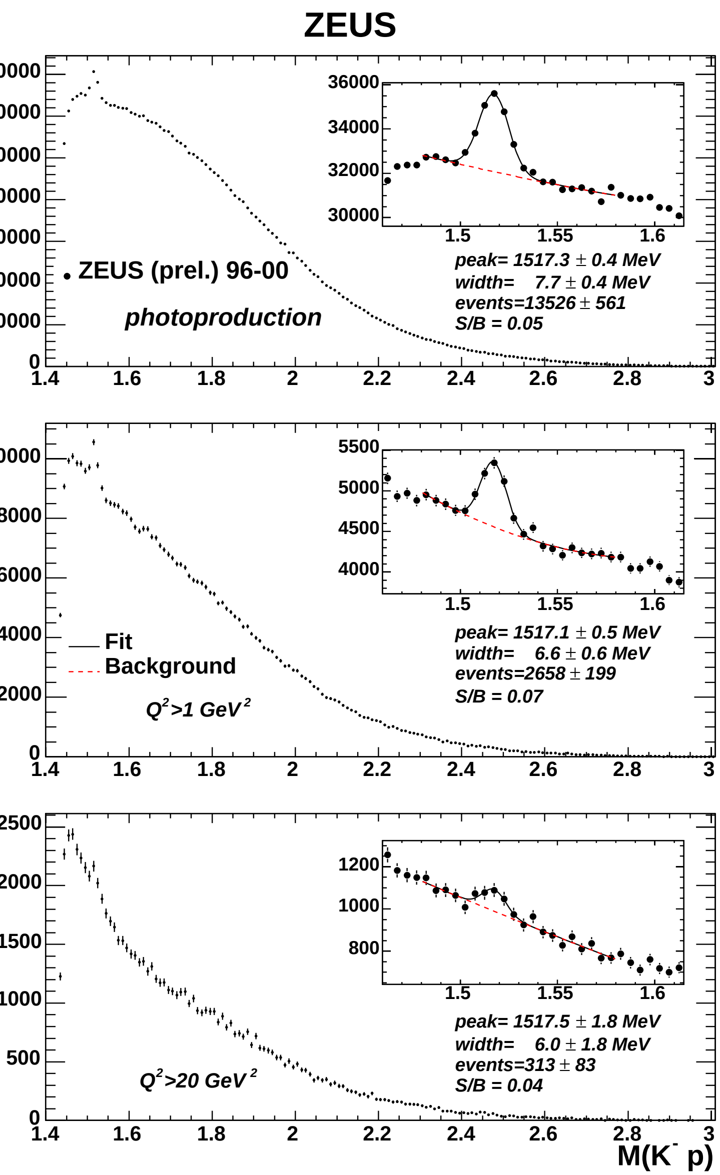
116 ± 38; $\bar{p}$

$\Rightarrow$ Λ_c produced in parton fragmentation region

as expected for c fragmentation via BGF $\gamma^* g \to c\bar{c}$



Production properties of baryons decaying into $K^- p(K^+ \bar{p})$



$M(K^- p(K^+ \bar{p}))$ **for 3 data samples:**
PHP; $Q^2 > 1$ **GeV^2;** $Q^2 > 20$ **GeV^2**

Reconstruct significant numbers of $\Lambda(1520)$ for all 3 samples

$N(\Lambda(1520)) = 13526 \pm 561$ **PHP**
2658 ± 199 $Q^2 > 1$ **GeV^2**
313 ± 83 $Q^2 > 20$ **GeV^2**

Unlike Λ_c, S/B similar for PHP and DIS
S/B **= 0.05 (PHP)**
0.07 (DIS low Q^2)
0.04 (DIS high Q^2)

Possible if $\Lambda(1520)$ production rate proportional to $< n_{ch} >$

Indicates light-quark fragmentation origin, not partons from hard interaction as for Λ_c

$\Lambda(1520)$ production properties

(1520) $Q^2 > 1$ **GeV**^{2} **peak studied in** $\eta > 0$ **and** $\eta < 0$ **regions separately for** p**'s and** $\bar{p}$**'s**

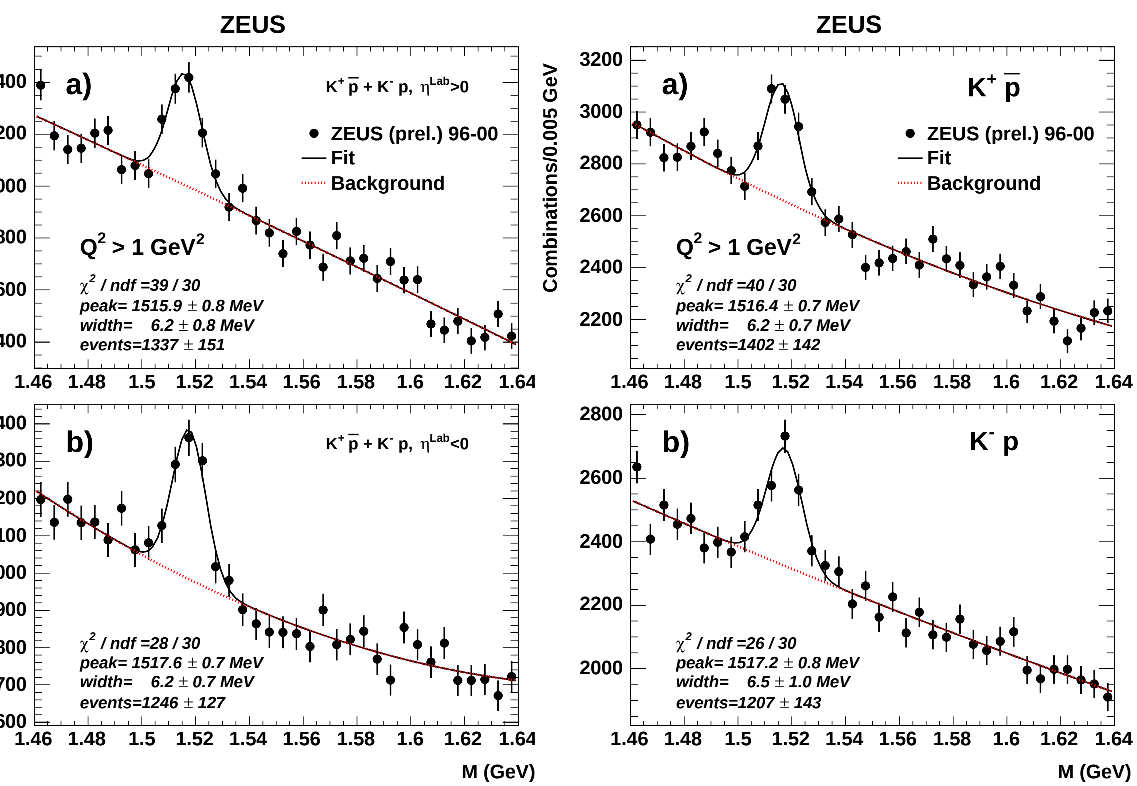
omparable number for all 4 spectra: $N(\Lambda(1520)) = 1337 \pm 151;\ \eta > 0$

$1246 \pm 127;\ \eta < 0$

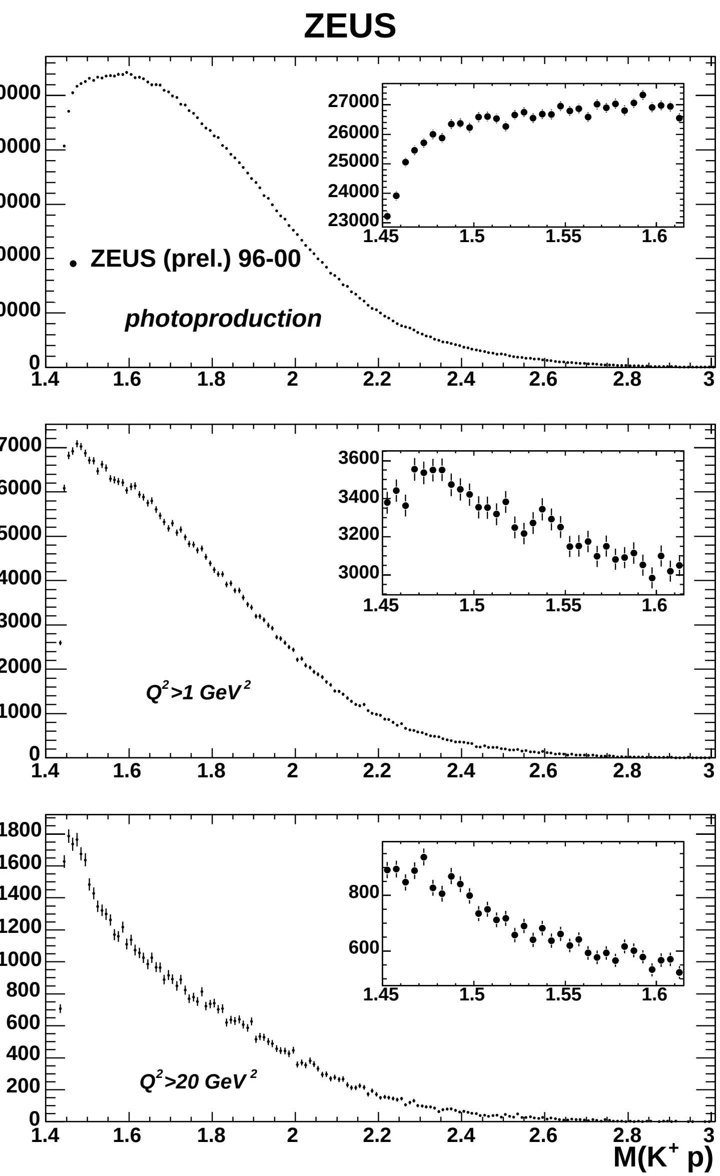
$1207 \pm 143;\ p$

$1402 \pm 142;\ \bar{p}$

$\Rightarrow$ **Dominant production mechanism of** $\Lambda(1520)$ **is pure fragmentation**



Search in the $K^+p(K^-\bar{p})$ mass spectra



$M(K^+p(K^-\bar{p}))$ **for 3 data samples:**

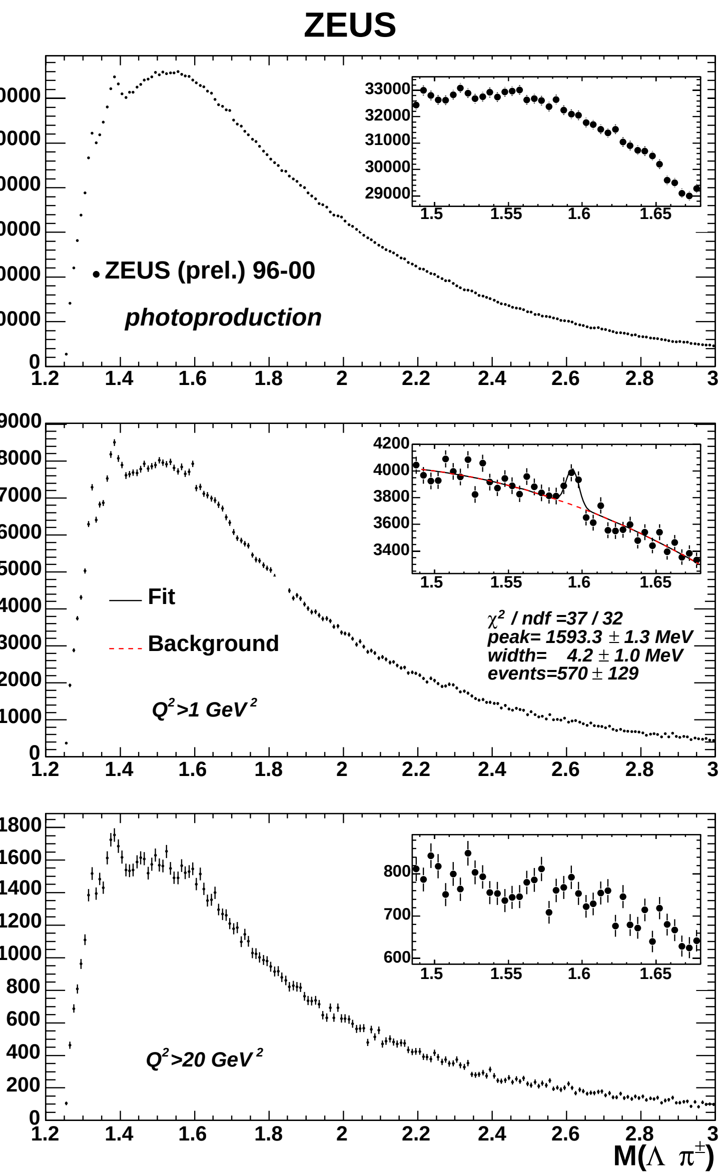
PHP; $Q^2 > 1$ **GeV**^{2}**;** $Q^2 > 20$ **GeV**^{2}

No statistically significant Θ^{++} **state found**

Some peak at ≈ 1.54 **GeV for** $Q^2 > 1$ **GeV**^{2}

STAR at RHIC see Θ^{++} **candidate**
at $M \approx 1.53$ **GeV in d-Au and Au-Au**

Search in the $\Lambda\pi^{\pm}$ mass spectra



If $\Theta^+(1530) \to K^0_S p$ peak is a new Σ state, the decay $\Theta^+(1530) \to \Lambda\pi^+$ is also allowed

$M(\Lambda\pi^{\pm})$ for 3 data samples:
PHP; $Q^2 > 1$ GeV^2; $Q^2 > 20$ GeV^2

Peaks due to known baryons $\Xi(1320)$, $\Sigma(1385)$ are clearly seen

No statistically significant peak near 1530 GeV

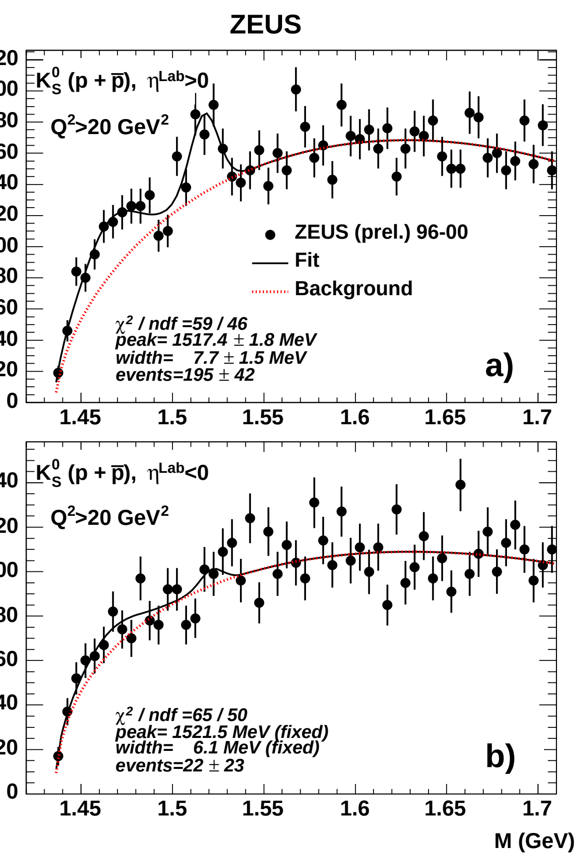
For $Q^2 > 1$ GeV^2, a peak with 4.4σ is seen near 1600 MeV consistent with the not-well established PDG states $\Sigma(1580)$ or $\Sigma(1620)$

$\Theta^+(1530)$ production properties

on-observation of $\Theta^+(1530)$ in e^+e^- collisions may indicate that the ZEUS
is related to proton fragmentation. In this case: S.Chekanov, hep-ph/0502098

- High-Q^2 events are more favorable
- $\Theta(1530)$ is produced mainly in the forward region ($\eta > 0$)
- Θ^+ rate is larger than Θ^-

(1530) $Q^2 > 20$ GeV^2 peak studied in $\eta > 0$ and $\eta < 0$ regions



If $\Theta^+(1530)$ produced by pure fragmentation as $\Lambda(1520)$
$\Rightarrow$ signal should be seen for both $\eta > 0$ and $\eta < 0$

A two Gaussian fit yields:

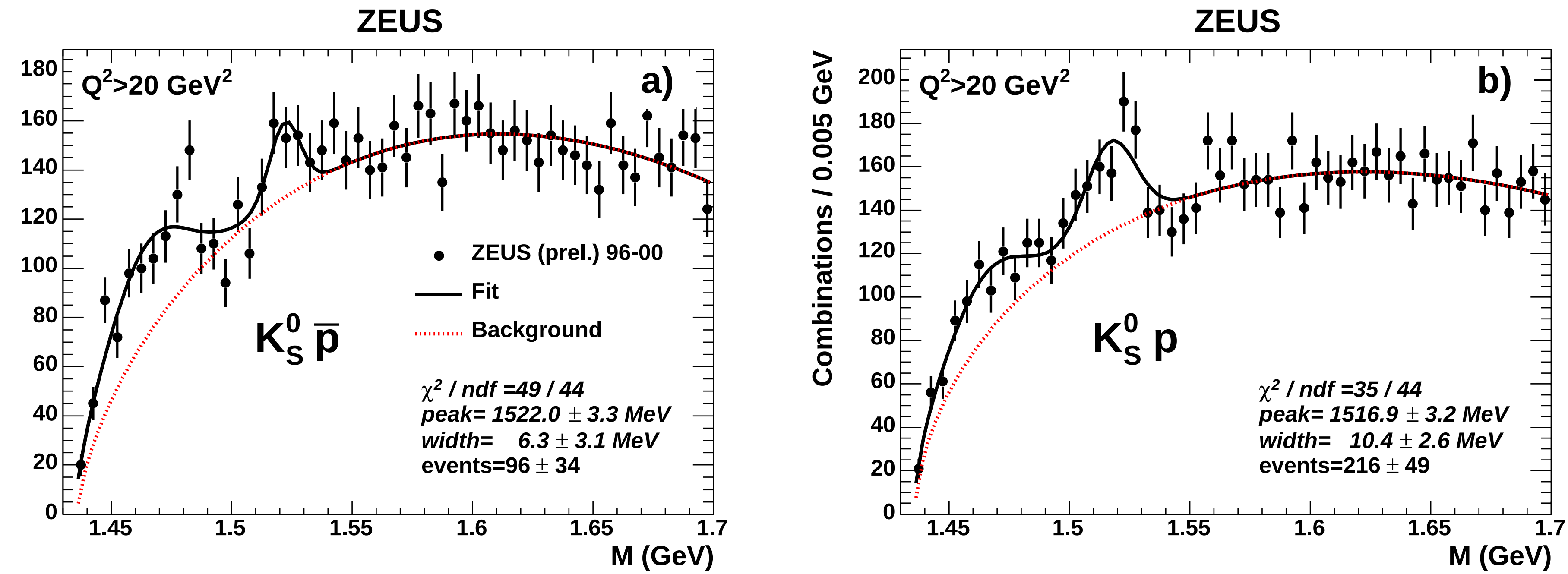
$N(\Theta(1530)) = 195 \pm 42$; $\eta > 0$

22 ± 23; $\eta < 0$

$\Rightarrow$ $\Theta(1530)$ production related to proton remnant ?

$\Theta^+(1530)$ production properties

(1530) $Q^2 > 20$ GeV^2 peak studied separately for p's and $\bar{p}$'s



A two Gaussian fit yields: $N(\Theta(1530)) = 216 \pm 49$; p

96 ± 34; $\bar{p}$

Number of $K^0_S p$ events larger than for $K^0_S \bar{p}$

o strong conclusion possible due to complicated background
r $K^0_S \bar{p}$ near 1480 MeV region

$\Theta^+(1530)$ production properties

plit the $\Theta(1530)$ signal to $K^0_S p$ and $K^0_S \bar{p}$ combinations for $\eta > 0$:

eft plots: Two Gaussian fit; one free parameter for the overall normalization

ther parameters fixed from sum of the two distributions

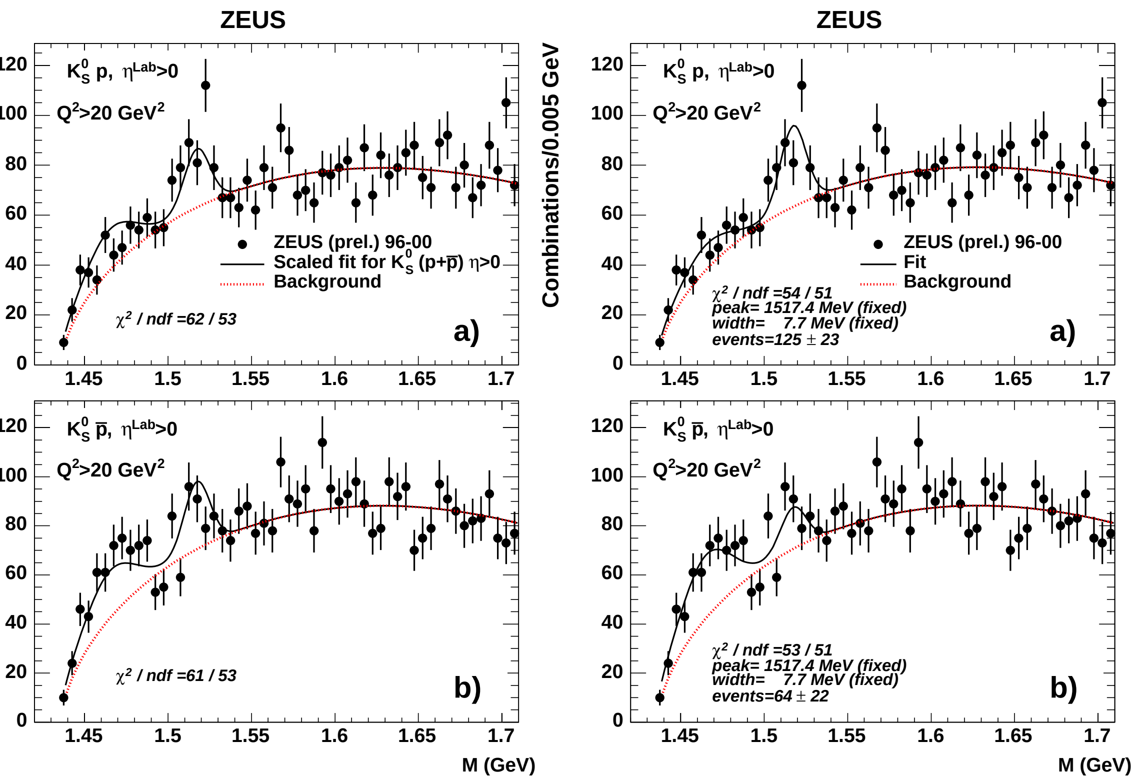
t not inconsistent with sum of the two distributions

ght plots: Two Gaussian fit with 3 free parameters:

o for number of events in peaks; one for background normalization

eaks and widths fixed to the sum of the two distributions

t has better χ^2/ndf and yields 5.4σ statistical significance for the p channel



Search for the $\Xi\pi$ pentaquark

A49: Found narrow peaks in all $\Xi\pi$ combinations ($M \approx 1862$ **MeV, width** < 18 **MeV)**

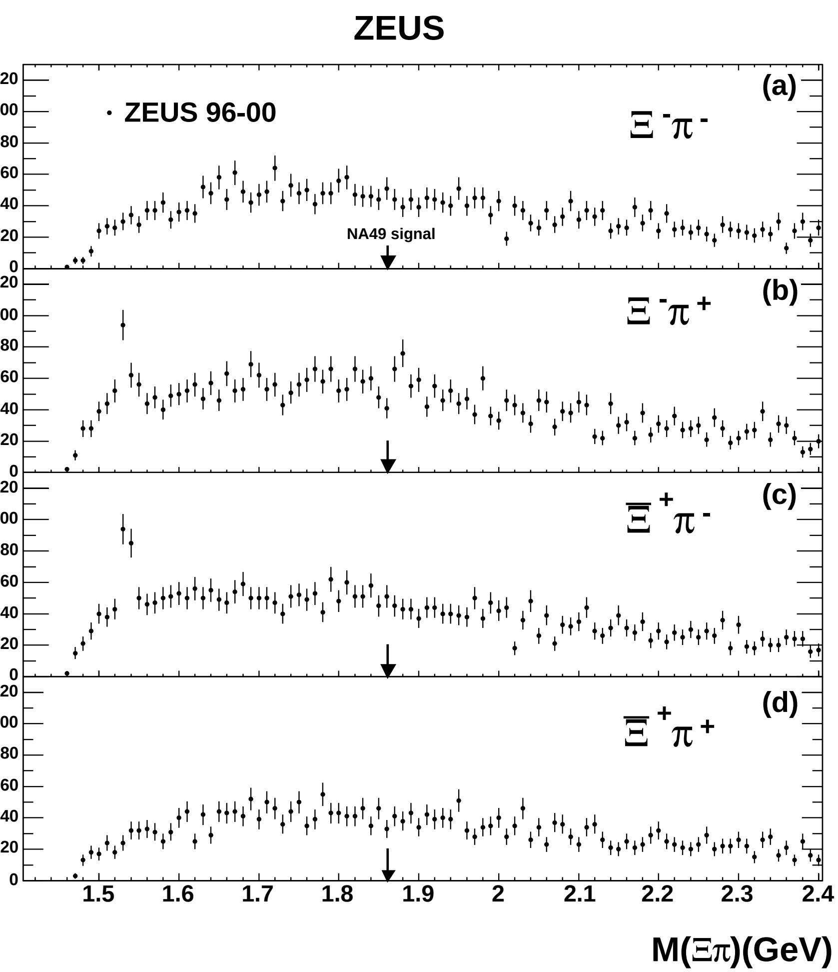
EUS HERA-I DIS data (121 pb^{-1}) Phys. Lett. B 610 (2005) 212

econstruct $\Lambda \to p\pi^-$; $\bar{\Lambda} \to \bar{p}\pi^+$; $\Xi^- \to \Lambda\pi^-$; $\bar{\Xi}^+ \to \bar{\Lambda}\pi^+$ from secondary vertices

rotons identified by ionization energy loss dE/dx

EUS Λ,Ξ signals: higher statistics; smaller background

$M(\Xi\pi)$ for $Q^2 > 1$ GeV^2 for each decay channel separately



See a clean signal of $\Xi^0(1530) \to \Xi^-\pi^+$ (+c.c.)

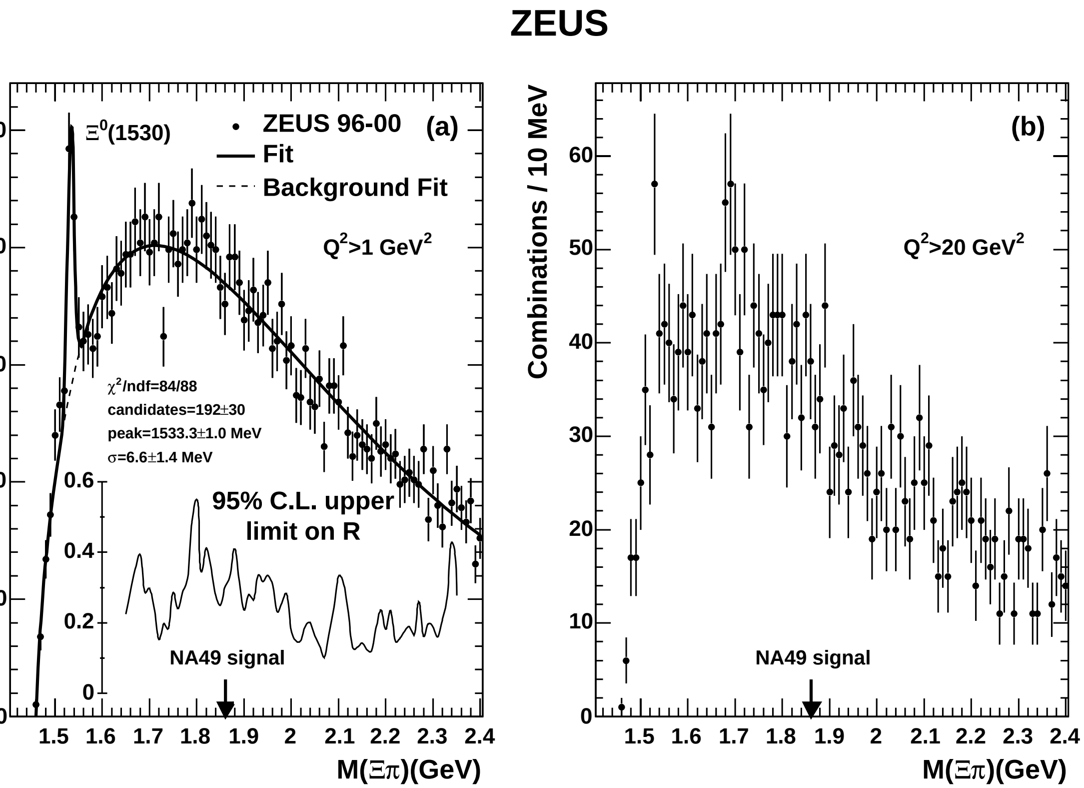
No evidence for a signal at 1862 MeV

NA49 (fixed target) has good acceptance in forward region

$\Rightarrow$ Non-observation in ZEUS at central fragmentation region -
no contradiction if NA49 signal mainly in forward direction

Search for the $\Xi\pi$ pentaquark

$M(\Xi\pi)$ **for** $Q^2 > 1$ **and** $Q^2 > 20$ **GeV**^{2} **(all** $\Xi\pi$ **charge combinations)**



See a $\Xi^0(1530) \to \Xi^-\pi^+$ **(+c.c.) signal**

$\Xi^0(1530)$ **fitted to Gaussian**
+ threshold background function

Right plot: Peak at ≈ 1690 **MeV (?)**

Can be due to PDG $\Xi(1690)$ ***

Fit yields:

$M = 1687.5 \pm 4.0$ **(stat.) MeV**
width=9.5 ± 3.7**(stat.)MeV**
Significance 2.5σ

(1530) **fit yields:** $M = 1533.3 \pm 1.0$ **(stat.) MeV ; width =** 6.6 ± 1.4 **(stat.) MeV**
192 ± 30 **events**

$1530)$ **signal much bigger than NA49**

o evidence for the NA49 1862 **signal**

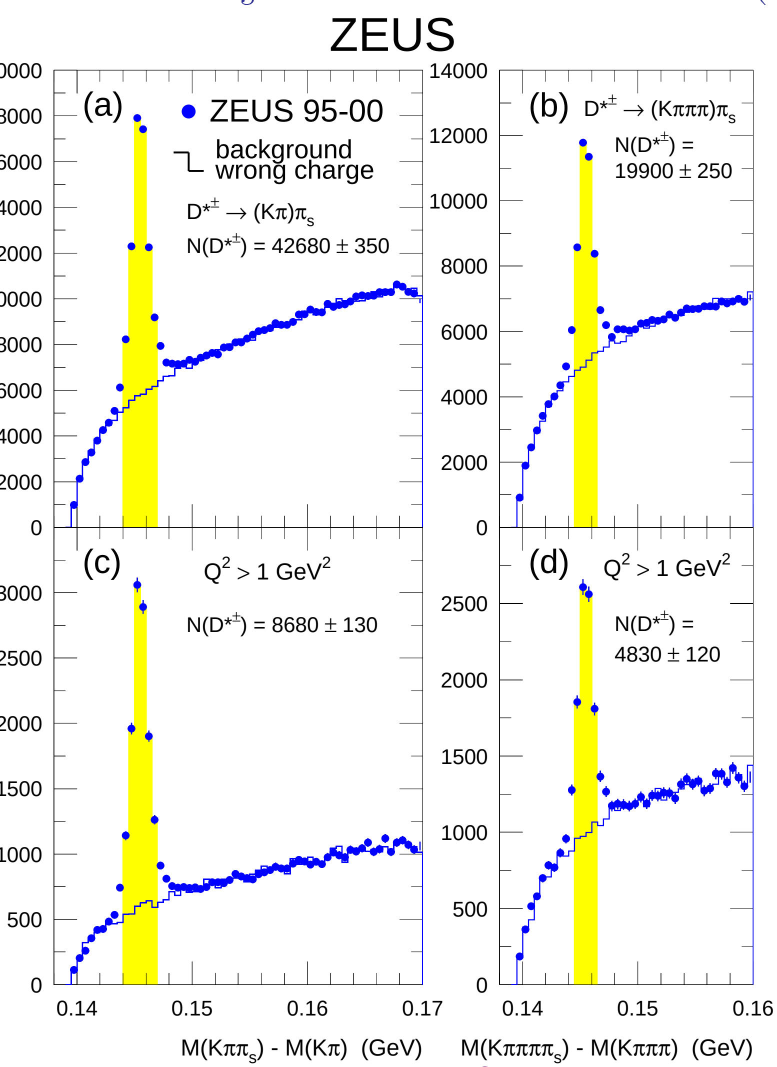
urly curve is 95% **C.L. upper limit ratio** $R = \Xi^{--}_{3/2}(\Xi^0_{3/2})/\Xi^0(1530)$
function of $M(\Xi\pi)$ **in the range** $1650 - 2350$ **MeV** $(R \approx 0.1 - 0.5)$

Search for the $\Theta_c^0(3100)$ Pentaquark

1 saw a narrow D^*p resonance at ≈ 3.1 GeV   Phys. Lett. B 588 (2004) 17

EUS HERA-I data (126.5 pb^{-1}) Eur. Phys. J. C38 (2004) 29

$^{*\pm} \to D^0\pi_s^\pm$ $\Delta M = M(D^{*\pm}) - M(D^0) \sim m_\pi$



$P_T(D^{*\pm}) > 1.35$ **GeV**, $|\eta(D^{*\pm})| < 1.6$

Clean D^* signals in 2 D^0 decay modes

$D^0 \to K^-\pi^+$; $D^0 \to K^-\pi^+\pi^+\pi^-$ **(+ c.c.)**

Θ_c^0 **searched for with D^*'s from**

yellow bands $N(D^{*\pm}) \approx 62,600$

For the DIS sub-sample $Q^2 > 1$ **GeV**^{2}

$N(D^{*\pm}) \approx 13,500$ **(x 4 of H1 sample)**

dE/dx calibrated with tagged $p(\bar{p})$ from Λ's

$$\chi^2 = \frac{(ln(dE/dx) - ln(dE/dx)_{expected})^2}{\sigma^2_{ln(dE/dx)}}$$

$p(\bar{p})$ **candidates with** $P_T > 0.15$ **GeV selected by**

$Prob(\chi^2)_p > 0.15$; $A(Prob(\chi^2)_p > 0.15) = 85.0 \pm 0.1\%$

Two strategies for p-selection:

1) **Low-P_p :** $Prob(\chi^2)_p > 0.15$; $P < 1.35$ **GeV**; $dE/dx > 1.3$ **(Clean p's from dE/dx)**

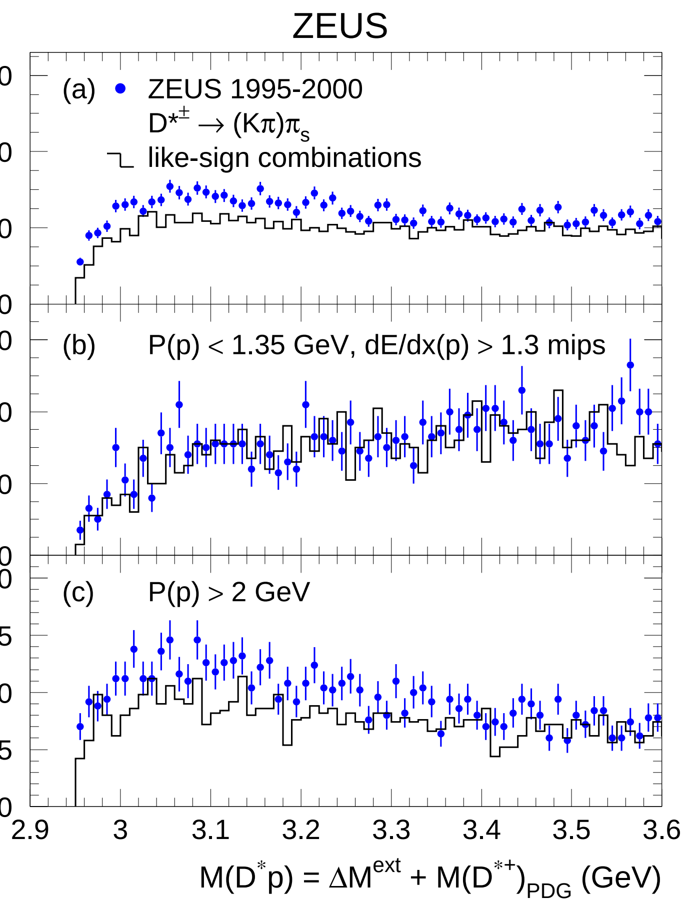
2) **High-P_p :** $Prob(\chi^2)_p > 0.15$; $P > 2$ **GeV** **(Nicer H1 signal without dE/dx cut)**

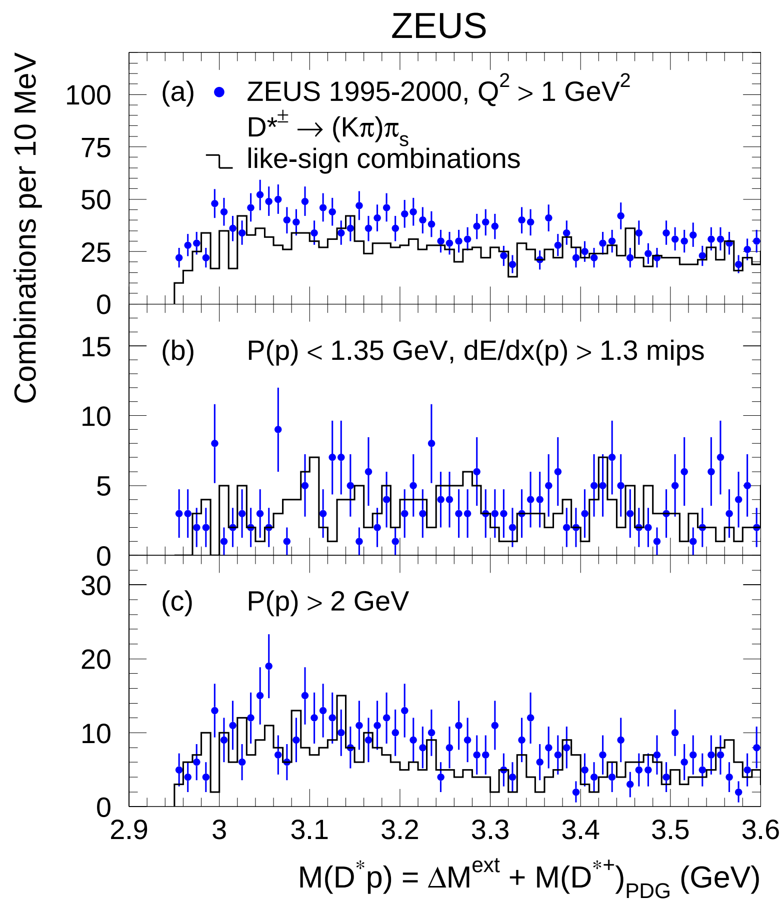
ZEUS $M(D^*p)$ spectra for the $D^0 \to K^-\pi^+$ channel

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

$M(D^*p)$ **resolution at** ≈ 3.1 **GeV is** ≈ 4 **MeV**

full sample **DIS sample**





All protons

Low-P_p

High-P_p

stograms are $M(D^{*\pm}p^{\pm})$ **like-sign combinations**

No evidence for a signal at 3.1 **GeV** **(also in the** $D^0 \to K^-\pi^+\pi^+\pi^-$ **mode)**

$\to K^-\pi^+$ **analysis repeated with very similar cuts to H1** $\Rightarrow$ **no signal**

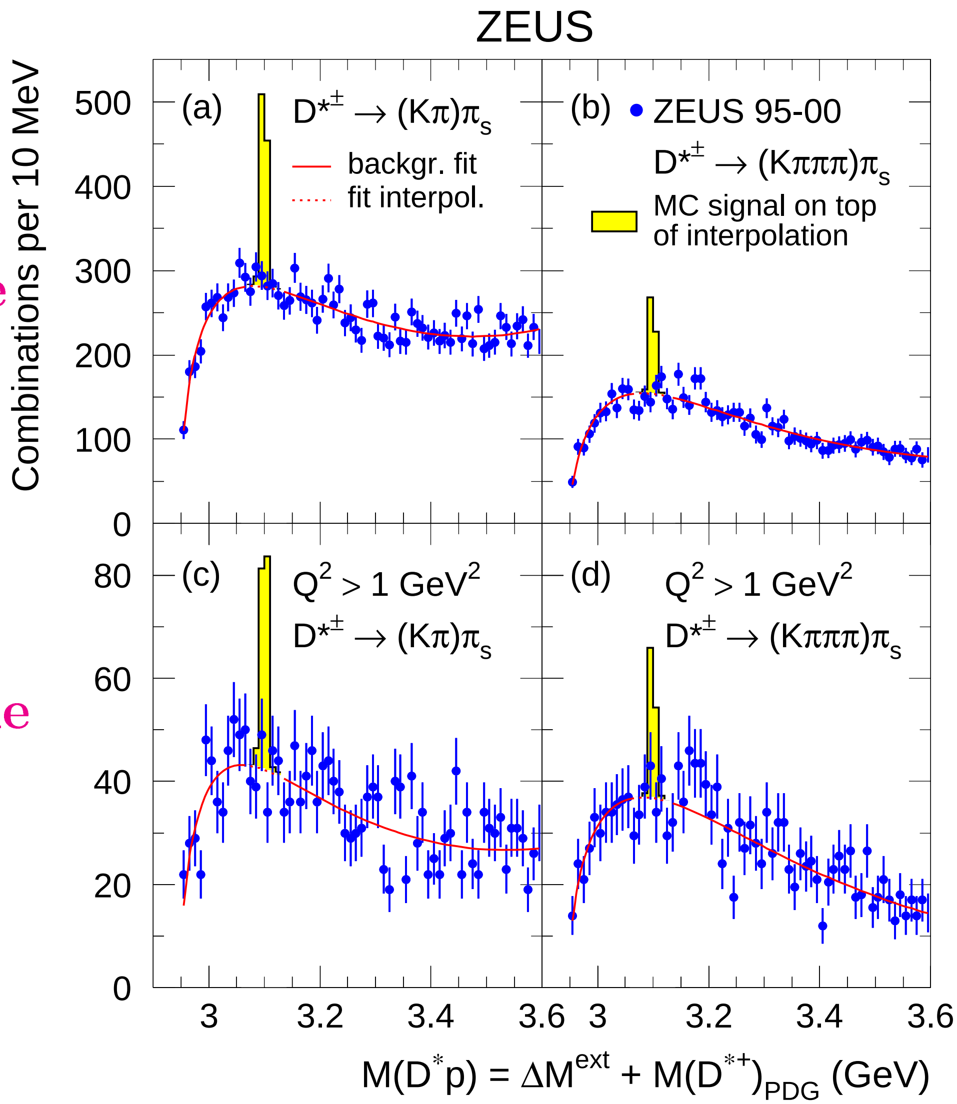
ZEUS upper limits for Θ_c^0 production

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

$$D^0 \to K^-\pi^+ \qquad D^0 \to K^-\pi^+\pi^+\pi^-$$

ll sample

IS sample



Yellow histograms are MC Θ_c^0 signals normalized to $\Theta_c^0/D^* = 1\%$ after H1 on top of a background fit (solid curves)

95% C.L. upper limits on $R(\Theta_c^0 \to D^*p/D^*)$ calculated in D^*p window 3.07-3.13GeV. A visible rate of $R = 1\%$ is excluded by 9 s.d. (5 s.d) for the full (DIS) sample. $R < 0.23\%$ $(< 0.35\%)$ for full (DIS) sample.

ccepted-corrected limits: $< 0.37\% (< 0.51\%)$ for full (DIS) sample.

$c \to \Theta_c^0) \cdot B_{\Theta_c^0 \to D^*p} < 0.16\%$ $(< 0.19\%)$ for the full (DIS) combined sample

Summary

sing all HERA-I high-energy data ($\approx 120\,\mathrm{pb}^{-1}$) in the ZEUS detector:

In inclusive ep DIS, a narrow peak is seen in $M(K^0_S p)$ ($M(K^0_S \bar{p})$)

For $Q^2 > 20$ GeV^2: fitted signal has 221 ± 48 events (4.6 s.d.)

$M = 1521.5 \pm 1.5(stat.)^{+2.8}_{-1.7}(syst.)$ **MeV;** $\Gamma(BW) = 8 \pm 4(stat.)$ **MeV**

For $Q^2 > 20$ GeV^2: $\sigma(\Theta^+ \to K^0 p) = 125 \pm 27(stat.)^{+36}_{-28}(syst.)$ **pb**

$$\sigma(\Theta^+ \to K^0 p)/\sigma(\Lambda) = (4.2 \pm 0.9^{+1.2}_{-0.9})\%$$

Unlike Λ_c and $\Lambda(1520)$: Θ^+ produced mainly in the forward (proton) region

$$N(\Theta^+ \to K^0_S p) > N(\Theta^- \to K^0_S \bar{p})$$

$\Rightarrow$ p-remnant effect (?)

$\Lambda(1520)$ **cannot be "reference" state for Θ^+ production**

may explain non-observation in other experiments?

Summary

No evidence for the NA49 $\Xi\pi$ signal at 1862 MeV in inclusive ep DIS

$R(\Xi(1862)/\Xi^0(1530)) < 0.29$ $(95\%$ $C.L.)$ **(Different kinematic region ?)**

No resonance structure seen in $M(D^{*\pm}p^{\mp})$ around 3.1 GeV from 62,600 D^*

At 95% C.L. $R((\Theta_c^0 \rightarrow D^*p)/D^*) < 0.23\%$;
for DIS ($Q^2 > 1$ GeV^2) $R < 0.35\%$

After acceptance correction: $R^{cor} < 0.37\%$;
$R^{cor}(H1) = (1.59 \pm 0.33^{+0.33}_{-0.45})\%$

$\Rightarrow$ **ZEUS limits are not compatible with the H1 Θ_c^0 signal**

Results from HERA-II are crucial to clarify the pentaquarks status at HERA

Backup: Θ^+ Event selection

All ZEUS HERA-I data $(121\ \mathbf{pb}^{-1})$

e^+p, e^-p **collisions at CM energy** $300 - 318$ **GeV**

$Q^2 > 1$ **GeV**^{2}

$K^0_S \to \pi^+\pi^-$ selection

CTD tracks $p_T > 0.15$ **GeV**, $|\eta| < 1.75$

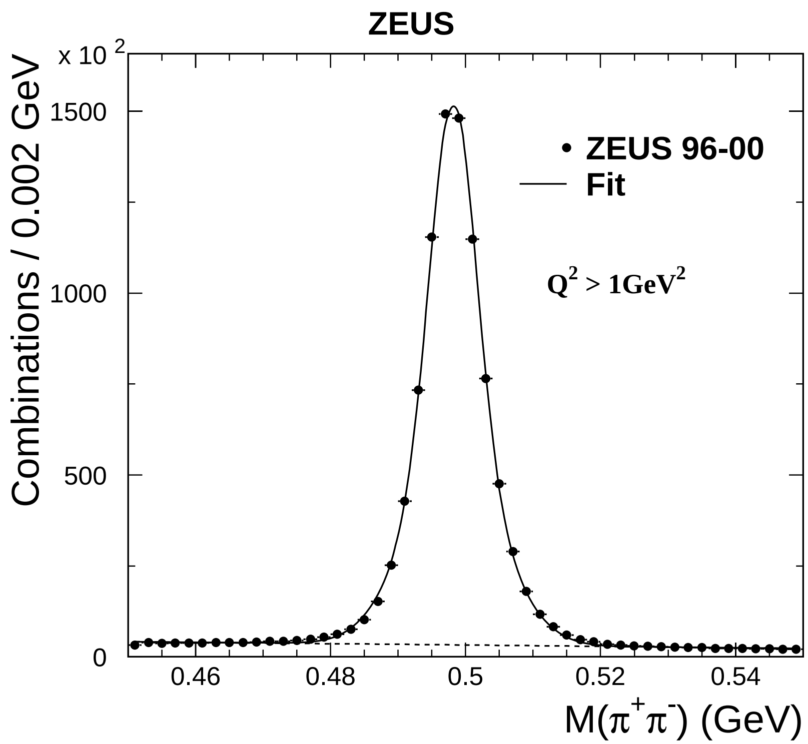
K^0_S **reconstructed from secondary-vertex tracks**

Remove photon conversions $M(e^+e^-) < 50$ **MeV**

and Λ**'s** $M(\pi p) < 1.121$ **GeV**

$p_T(K^0) > 0.3$ **GeV**, $|\eta(K^0)| < 1.5$

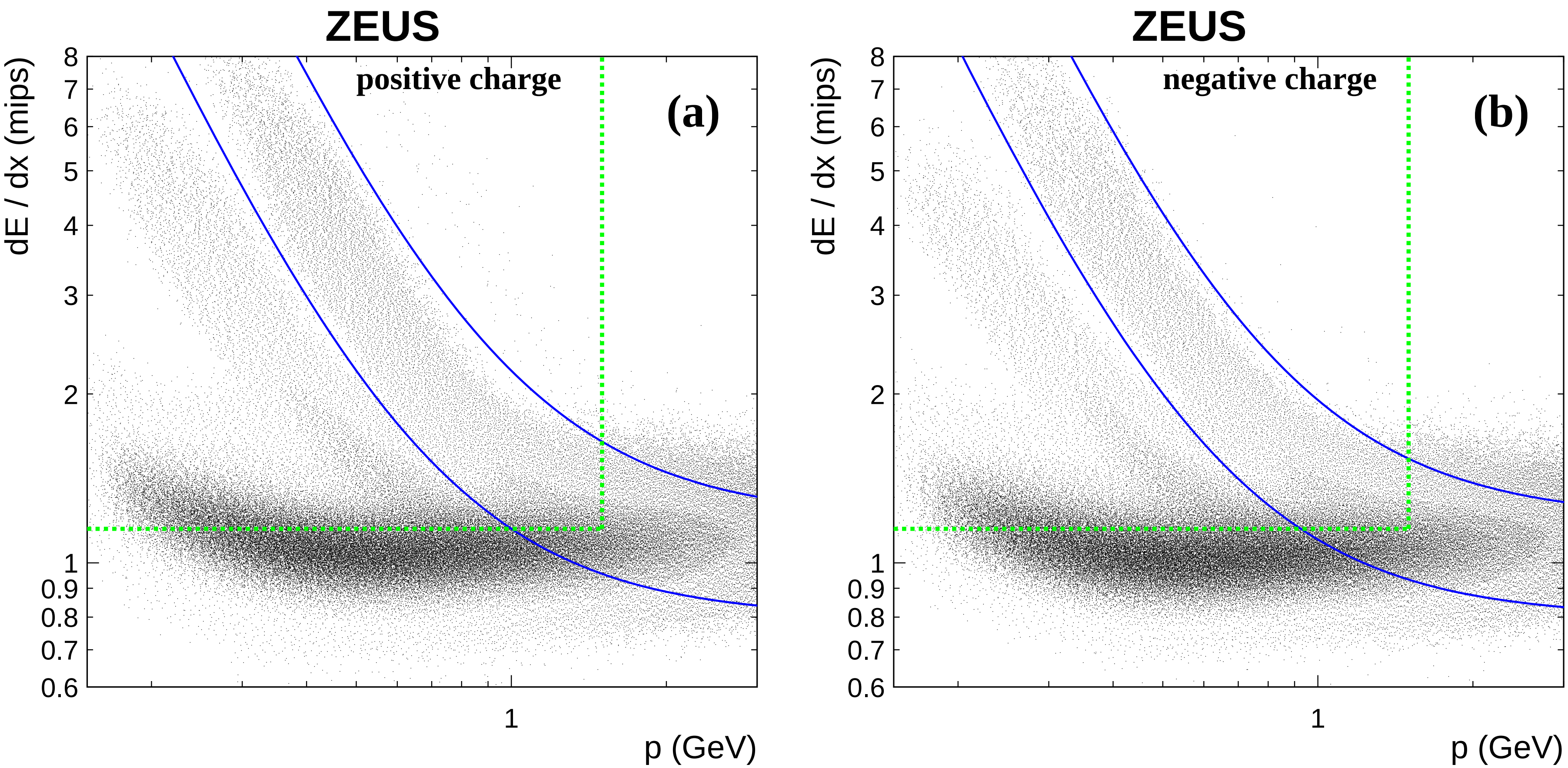
$0.483 < M(\pi^+\pi^-) < 0.513$ **GeV**



$\approx 867,000$ K^0_S **candidates with** $\approx 6\%$ **background**

Backup: Proton selection for Θ^+

Select protons from primary tracks: define ionization dE/dx bands



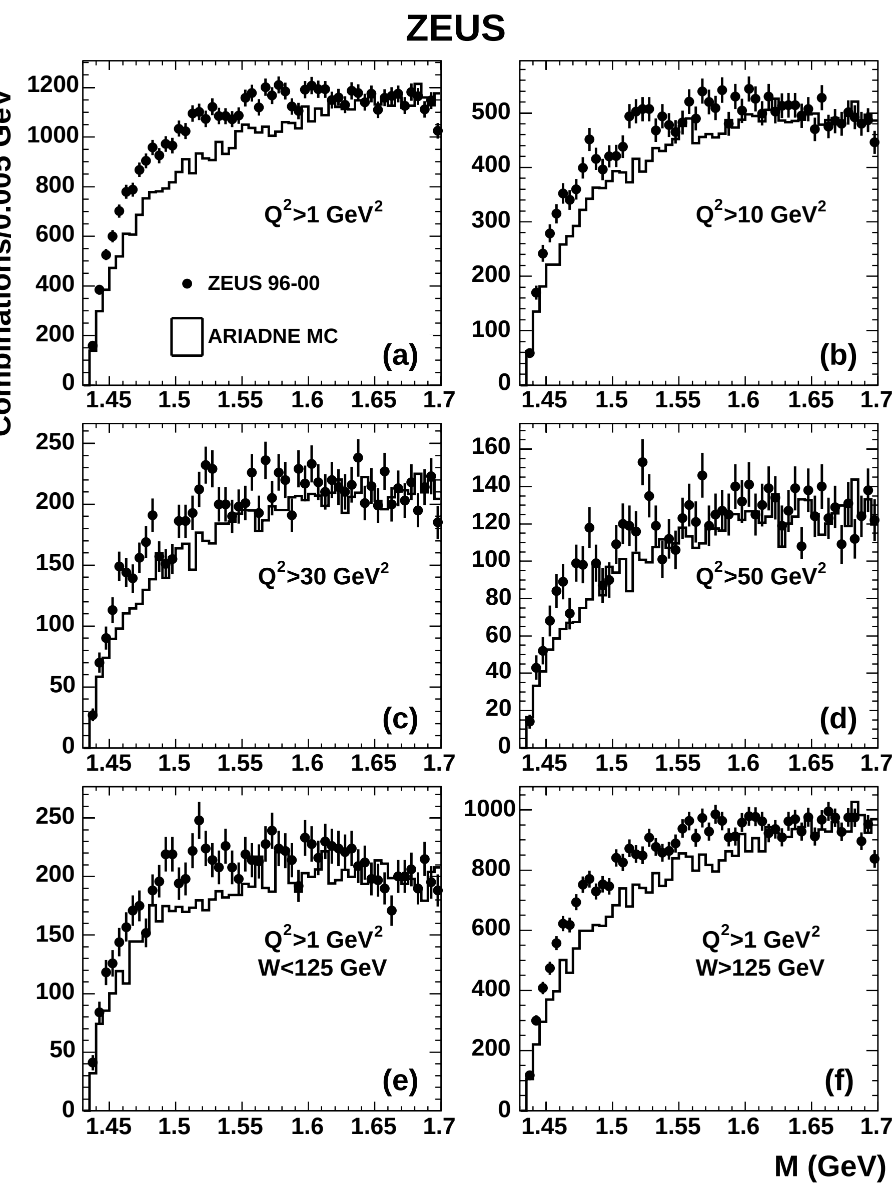
dE/dx resolution for full-length tracks: $\approx 9\%$

$dE/dx > 1.15$ **mips,** $P(p,\bar{p}) < 1.5$ **GeV**

$\Rightarrow \approx 60\%$ **proton purity**

Backup: $K^0_S p(\bar{p})$ results I

Search for Θ^+ in $M(K^0_S p)$ for $Q^2 > 1, 10, 30, 50$ GeV^2
$W < 125, \quad > 125$ GeV



See structures near
1.52 GeV and below

Signal at 1.52 GeV
increases with Q^2
decreases with W

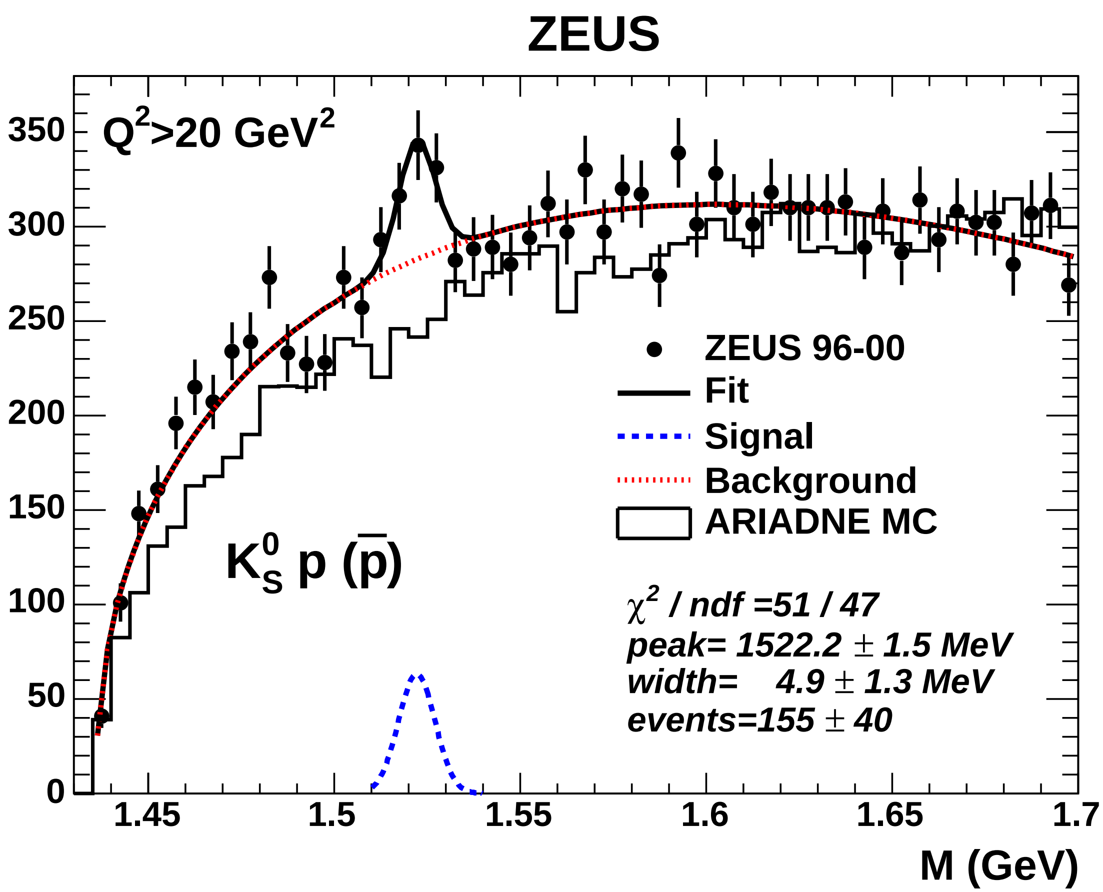
Histograms are ARIADNE MC simulation
normalised to data above 1.65 GeV
(Σ bumps not included in the MC)

Backup: $K^0_S p(\bar{p})$ results II

Fit the $M(K^0_S p)$ distribution with $Q^2 > 20$ GeV^2 to single Gaussian + threshold background function $P_1(M-m)^{P_2}(1+P_3(M-m))$

$m = m_K + m_p$; $P_{1,2,3}$ = **free parameters**

$\chi^2/ndf = 51/47$



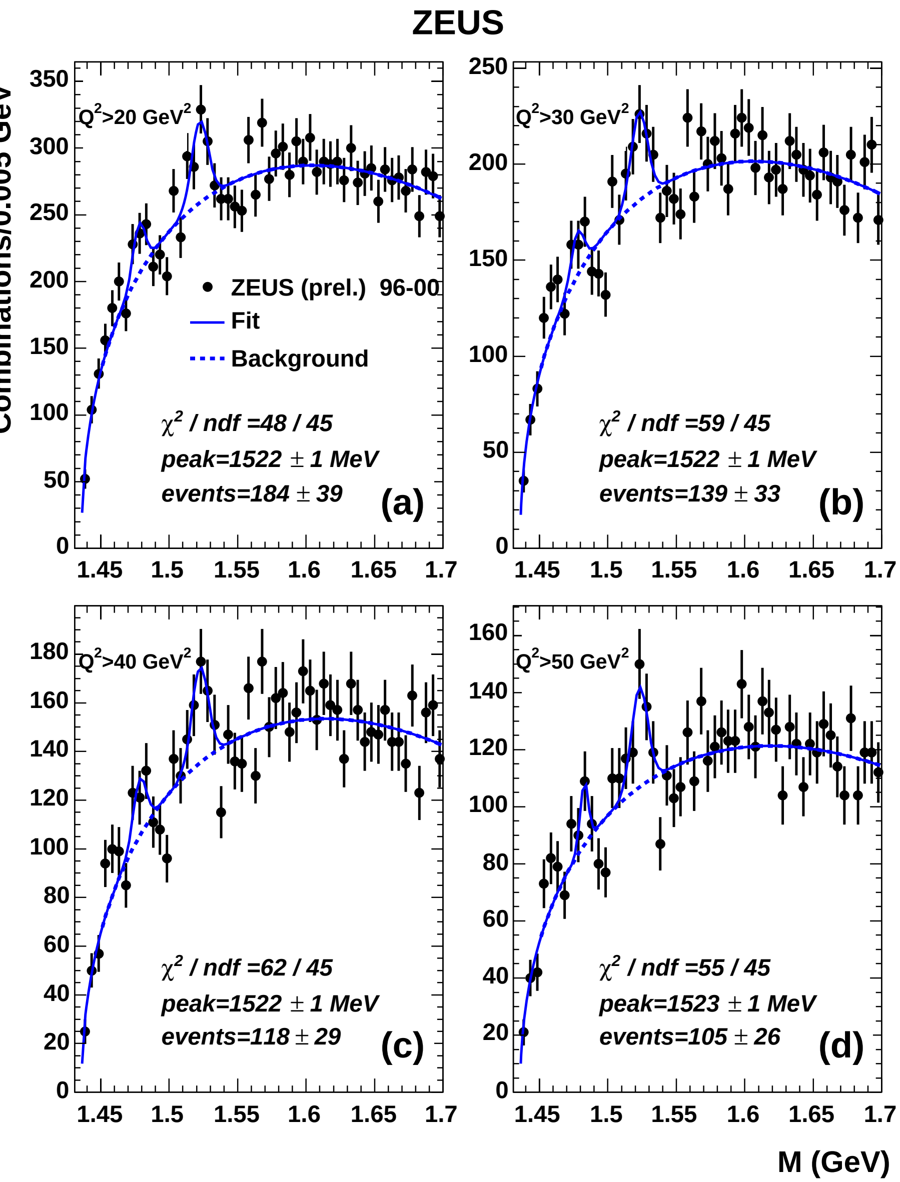
$M(\Theta^+) = 1522.2 \pm 1.5$ **MeV**

Significance ≈ 3.9 **s.d.**

Width consistent with resolution (≈ 2 MeV)

Backup: results $K^0_S p(\bar{p})$

Search for $\Theta(1530)$ in $M(K^0_S p)$ for $Q^2 > 20, 30, 40, 50$ GeV^2



Backup: Fit results for $Q^2 > 20$ GeV^2

Fit		Gaussian+Bkg.	2 Gaussians + Bkg.
χ^2/ndf	$M \leq 1700$ MeV	51/47	35/44
Peak 1	mass (MeV)	-	1465.1 ± 2.9
	width (MeV)	-	15.5 ± 3.4
	events	-	368 ± 121
Peak 2	mass (MeV)	1522.2 ± 1.5	1521.5 ± 1.5
	width (MeV)	4.9 ± 1.3	6.1 ± 1.6
	events	155 ± 40	221 ± 48

Backup: trigger selection

First level trigger:

- CAL-FLT: regional energy sums
- CTD-FLT: “tracks” looking to the nominal interaction point
  - DIS : scattered electron (and CTD-FLT)
  - Untagged PhP : CTD-CAL and CTD-FLT
  - Tagged PhP : 44m and 35m taggers, CTD-CAL and CTD-FLT

Second level trigger:

- DIS : scattered electron and CAL energies
- Untagged PhP : CAL energies and SLT tracks (high-W)
- Tagged PhP : 44/35m taggers, CAL energies and SLT tracks

Third level trigger:

- Inclusive DIS : almost offline selection
- $D^{*\pm}$ in DIS : reconstructed $D^{*\pm}$ in DIS events (low Q^2)
- Inclusive PhP : dijet events
- $D^{*\pm}$ in PhP : reconstructed $D^{*\pm}$ in tagged/untagged PhP events

Backup: Main systematic studies for Θ_c^0

selecting of DIS with $Q^2 > 15\,\mathbf{GeV}^2$

varying dE/dx **requirements for low-**P **selection**

no dE/dx **requirements for high-**P **selection**

require $\cos\theta^*(p) > -0.7$**, where** $\theta^*(p)$ **is the angle between** p **direction in** $5q$ **r.f. and** $5q$ **direction in the lab**

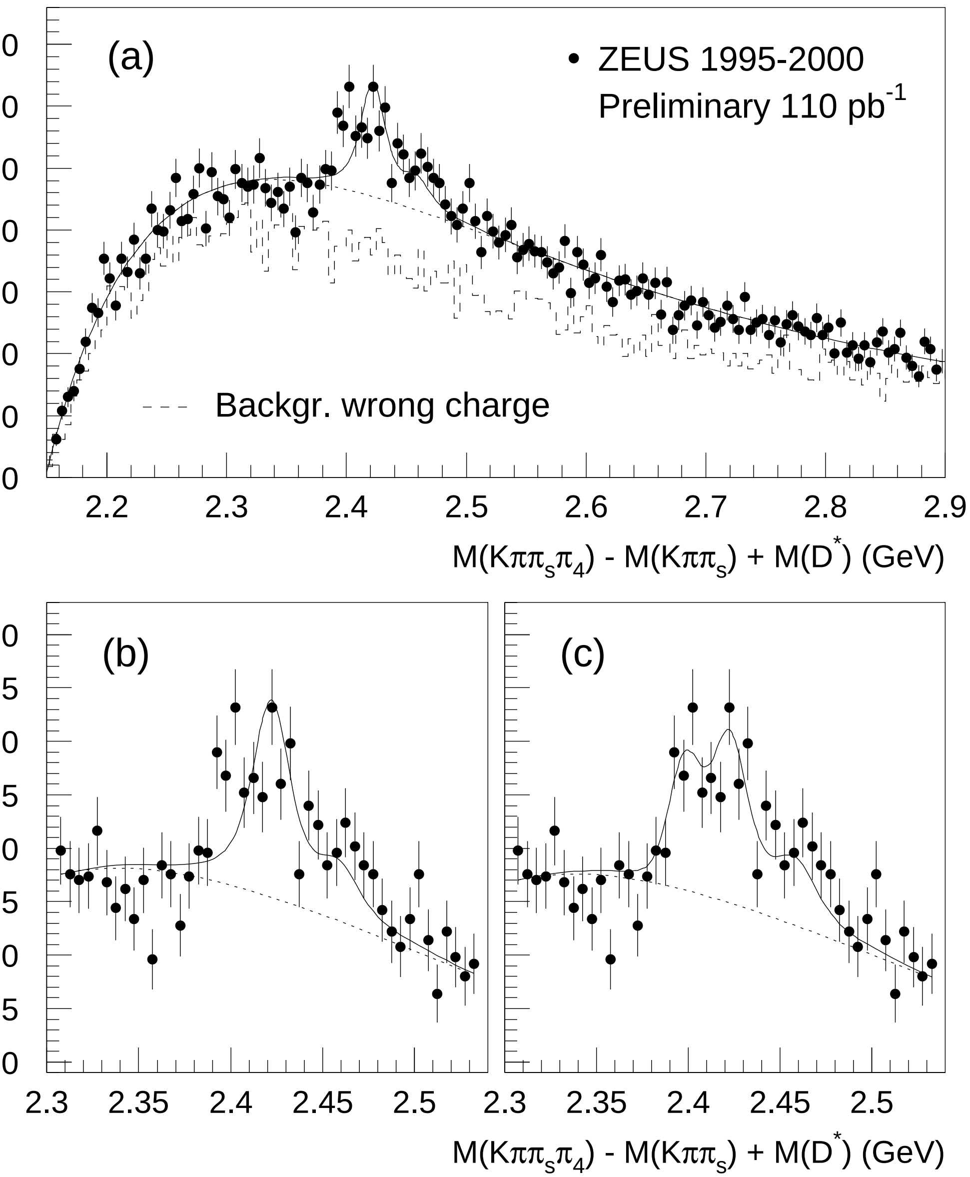
studying/removing reflections from $D_1^0, D_2^{*0} \to D^{*\pm}\pi^\mp$

removing the cut on $P_T(D^{*\pm})/E_T^{\mathrm{out}\,10^\circ}$**; using** $z(D^{*\pm}) > 0.2$ **instead**

making all cuts as close as possible to H1 selection

$\Rightarrow$ **No signal**

Backup: Orbitally excited P-wave D mesons



$D_1^0(2420), D_2^{*0}(2460) \to D^{*\pm}\pi^{\mp}$

$\Delta M^{ext} = M(K\pi\pi_S\pi_4) - M(K\pi\pi_s)$

2-dimensional fit with fixed M, Γ, resolution and helicity distribution:

$\frac{dN}{d\cos\alpha} \propto 1 + 3\cos^2\alpha \qquad (1^+, L+s=3/2)$

$\frac{dN}{d\cos\alpha} \propto 1 - \cos^2\alpha \qquad (2^+, L+s=3/2)$

helicity angle α : between π_4 and π_s in $D^{*\pm}$ rest frame

$N(D_1^0) = 526 \pm 65$

$N(D_2^{*0}) = 203 \pm 60$

Additional narrow bump ?

$N = 211 \pm 49$

$M = 2398.1 \pm 2.1(\text{stat.})^{+1.6}_{-0.8}(\text{syst.})$ **MeV**

New D meson ? Interference ?

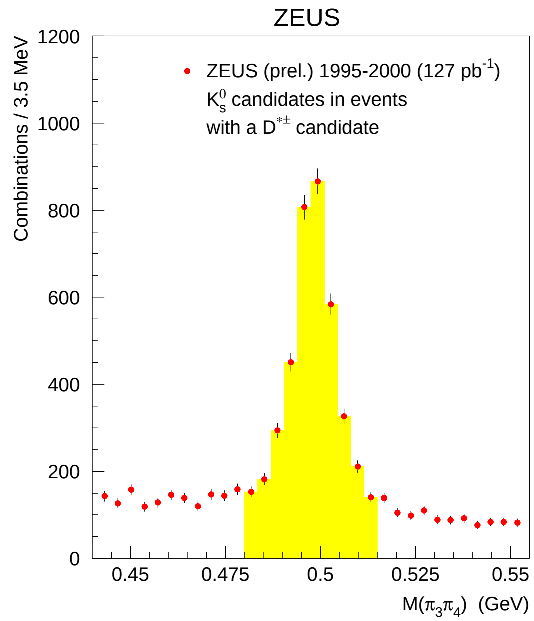
Backup: Charm-strange $D_{s1}^{\pm}(2536)$ meson

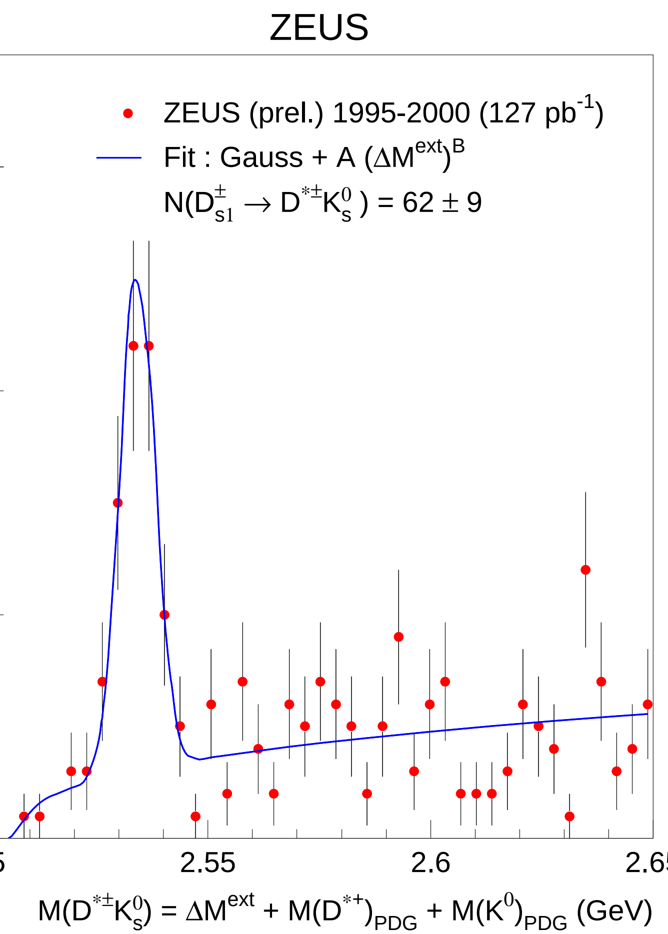
$D_{s1}^{\pm}(2536) \to D^{*\pm} K_s^0 \,, \quad K_s^0 \to \pi^+\pi^-$

$\Delta M^{ext} = M(K\pi\pi_S\pi_3\pi_4) - M(K\pi\pi_s) - M(\pi_3\pi_4)$

$N(D_{s1}) = 62.3 \pm 9.3$

$M(D_{s1}) = 2534.2 \pm 0.6 \pm 0.5\,\mathbf{MeV} \quad (\sim M_{\rm PDG})$





Helicity angle α : between K_S^0 and π_s in $D^{*\pm}$ r.f.

Fit to a form : $1 + R\cos^2\alpha$

$R = -0.53 \pm 0.32(\text{stat.})^{+0.05}_{-0.14}(\text{syst.})$ **(ZEUS prel.)**

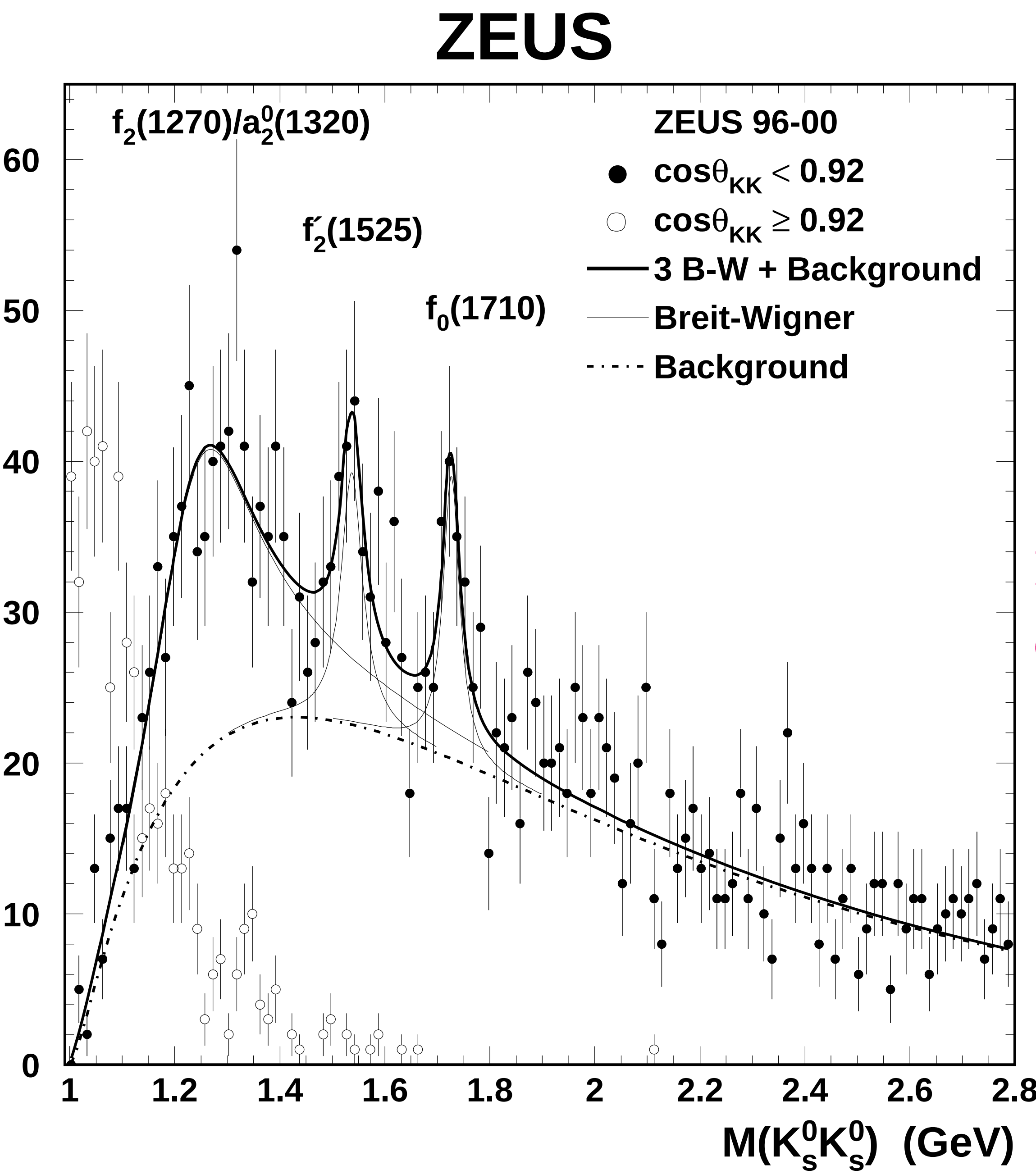
CLEO $(D_{s1}^{+} \to D^{*0}K^{+})$ **:** $R = -0.23^{+0.40}_{-0.32}$

ZEUS : consistent with $R = 0$, i.e. $J^P = 1^+$

does not contradict $R = -1$

expected for $J^P = 1^-,\ 2^+$

Backup: $K^0_S K^0_S$ Resonances in DIS



Several resonances observed

Produced in gluon-rich environment

$f_0(1710)$ = glueball candidate ??

Backup: Charm Pentaquarks

Since $\Theta^+ = udd\bar{s}$ exists, heavy pentaquarks, such as
$^0_c = uudd\bar{c}$ should also exist

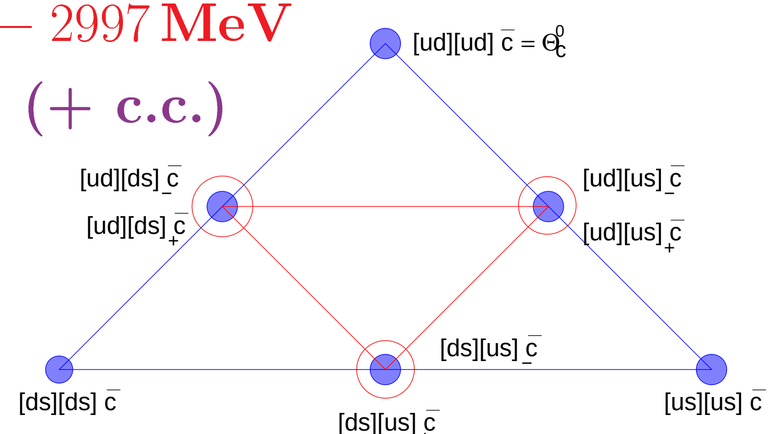
Predictions:

Jaffe-Wilczek (hep-ph/0307341); Wu-Ma (hep-ph/0402244):
$(\Theta_c^0) \approx 2700$ **MeV** $\Rightarrow$ **too light to decay to** D **mesons**
can decay weakly to $\Theta^+\pi^-$

Karliner-Lipkin (hep-ph/0307343):
$M(\Theta_c^0) = 2985 \pm 50\,\mathbf{MeV}$; $\Gamma(\Theta_c^0) \sim 21\,\mathbf{MeV}$

Cheung (hep-ph/0308176): $M(\Theta_c^0) = 2938 - 2997\,\mathbf{MeV}$
decays dominantly to D^-p^+ **or** $D^0 n$ **(+ c.c.)**

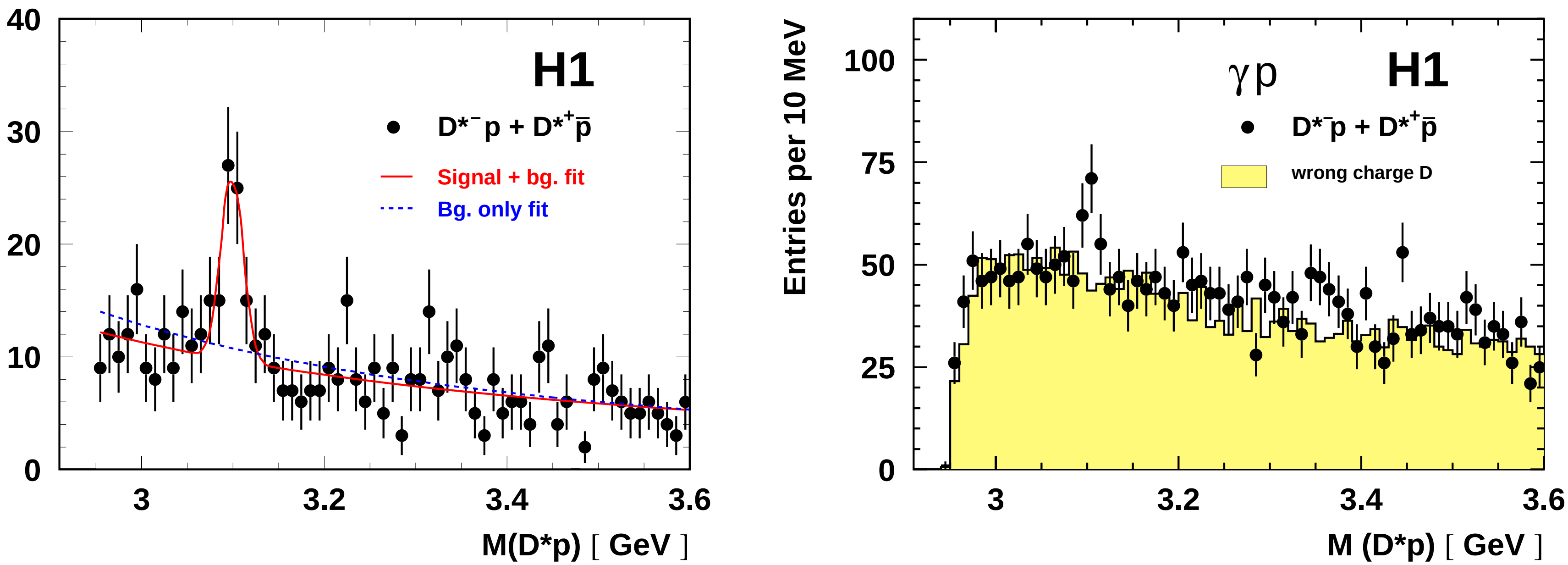
If $M(\Theta_c^0) > M(D^{*\pm}) + M(p) = 2948\,\mathbf{MeV}$,
Θ_c^0 **can decay to** $D^{*\pm}p$



EUS is sensitive to resonances decaying to $D^{*\pm}$ $(D_1^0,\ D_2^{*0},\ D_{s1})$
very narrow resonances $(\Theta^+,\ f_2'(1525),\ f_0(1710))$

$\Rightarrow$ Search for Θ_c^0 signal in $M(D^{*-}p)$ (+ c.c.) spectra

Backup: H1 observation



a DIS sample of $\approx 3400\ D^{*\pm}$ H1 sees a narrow resonance in $(D^{*-}p)$ and $M(D^{*+}\bar{p})$ with $M = 3099 \pm 3(stat.) \pm 5(syst.)$ **MeV**

Atkas et al., Phys. Lett. B 588, 17 (2004)

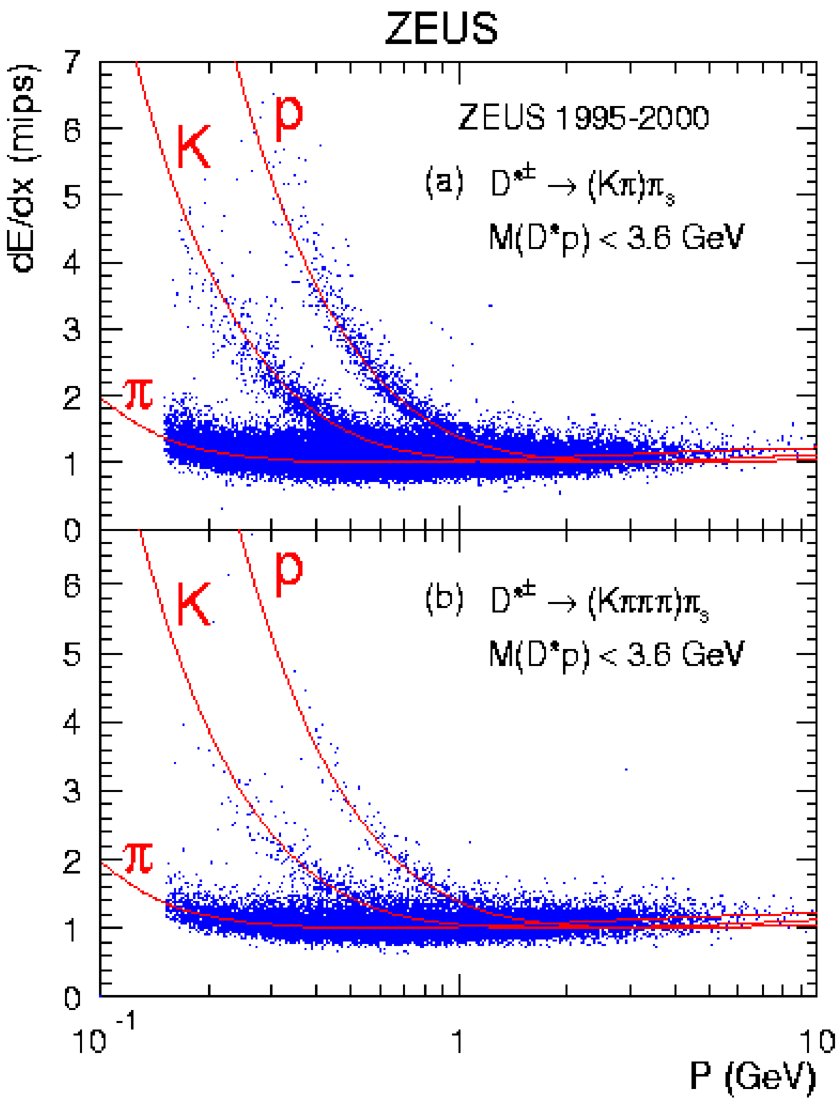
ne measured Gaussian width $12 \pm 3(stat.)$ **MeV** compatible with experimental resolution

ne signal consists of 50.6 ± 11.2 events

oughly 1% of the total D^* production rate"

gnal (with large background) also seen in a photoproduction mple with $\approx$ same ratio to D^*

Backup: dE/dx for the Θ_c analysis



More careful dE/dx calibration w.r.t. Θ^+ analysis

Parameters tuned using

- tagged $p(\bar{p})$ from Λ^0 decays
- tagged π's from K^0_S decays

To select $p(\bar{p})$ candidates:

$$\chi^2 = \frac{(ln(dE/dx) - ln(dE/dx)_{expected})^2}{\sigma^2_{ln(dE/dx)}}$$

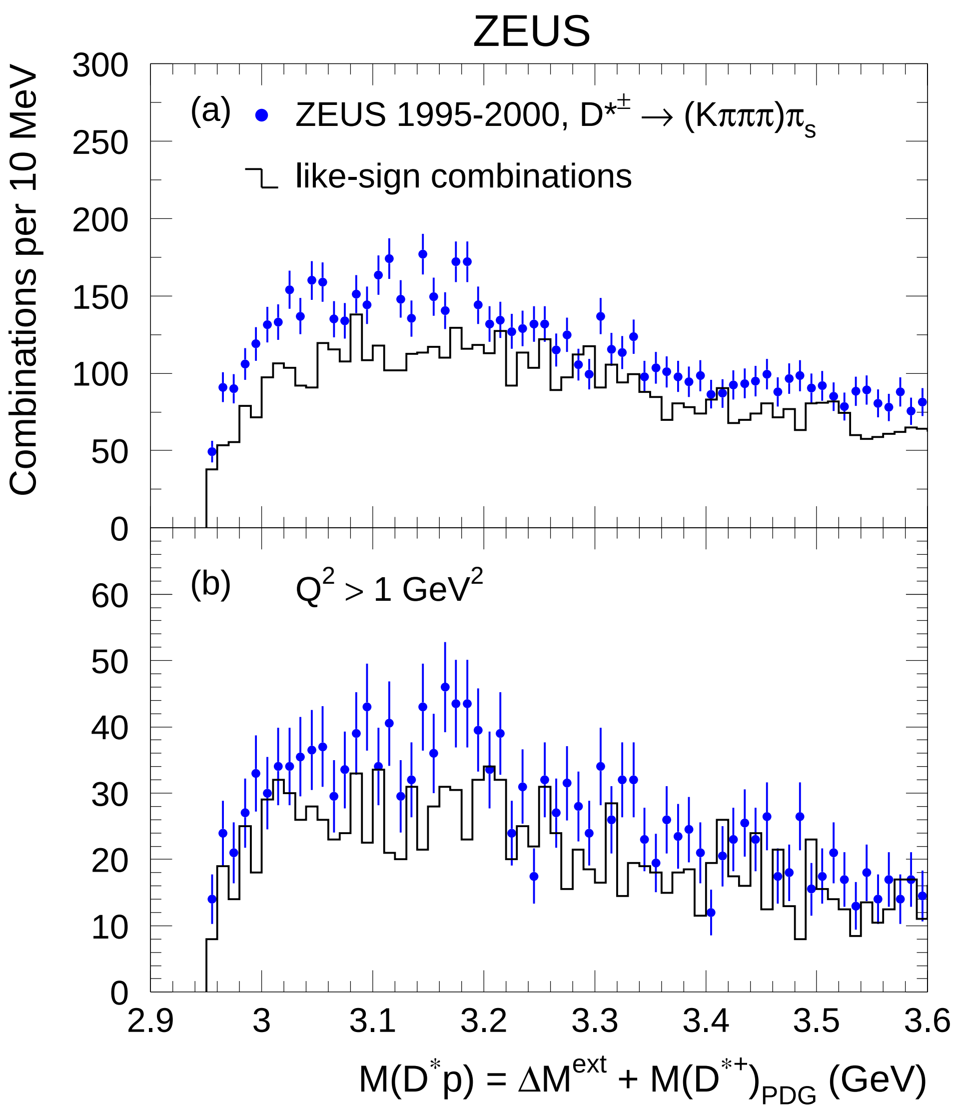
$$\sigma_{ln(dE/dx)} = a/\sqrt{n}$$

n=no.of hits used for dE/dx measurement

$Prob(\chi^2)_p > 0.15$

$A(Prob(\chi^2)_p > 0.15) = 85.0 \pm 0.1\%$

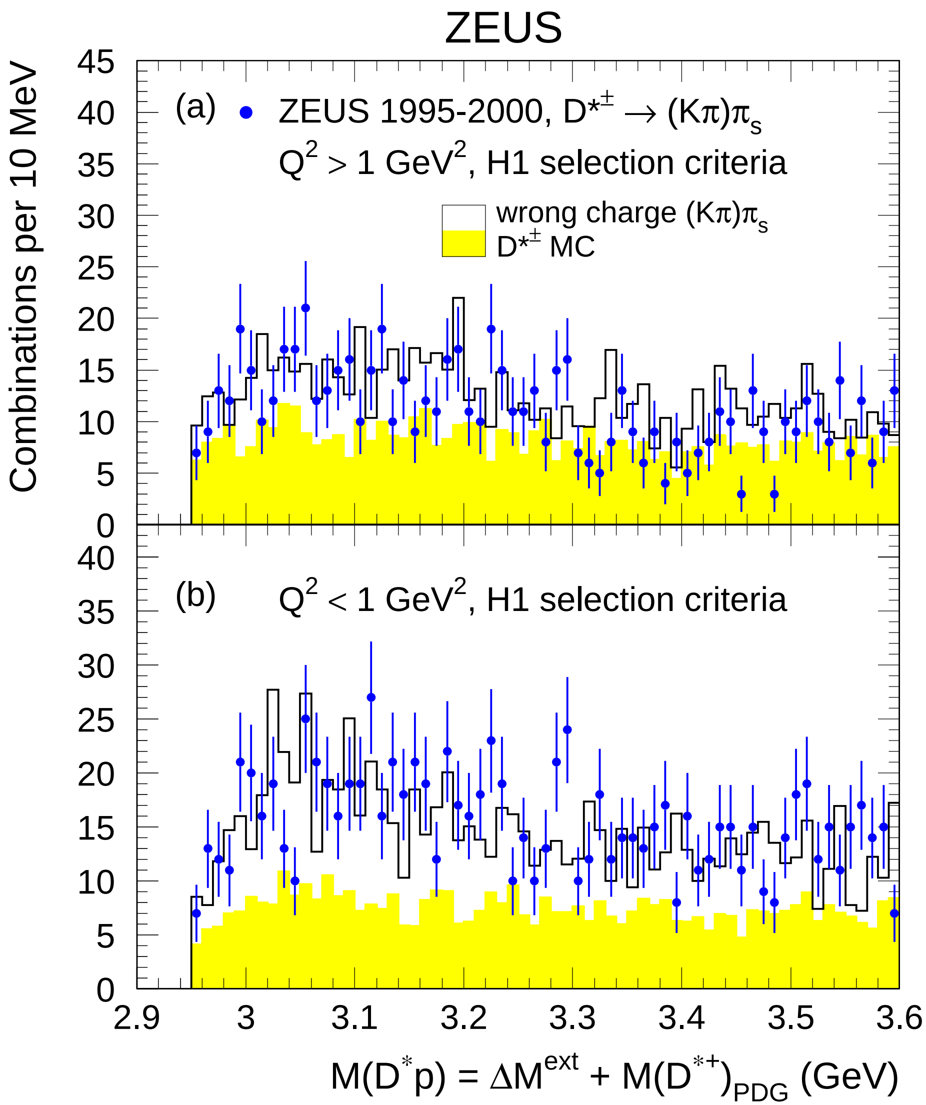
Backup: $M(D^*p)$ for $K\pi\pi\pi$



No evidence for a signal at 3.1 GeV in the $D^0 \to K^-\pi^+\pi^+\pi^-$ mode

Backup: $M(D^*p)$ with H1-like cuts

$^0 \to K^-\pi^+$ analysis repeated with cuts very similar to H1



o evidence for a signal at 3.1 GeV

Backup -

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	
$R(\Theta_c^0 \to D^*p/D^*)$	$< 0.41\%$	$< 0.69\%$	$< 0.35\%$
$R^{cor}(\Theta_c^0 \to D^*p/D^*)$	$< 0.59\%$	$< 1.06\%$	$< 0.51\%$
$f(c \to \Theta_c^0) \cdot B_{\Theta_c^0 \to D^*p}$	$< 0.20\%$	$< 0.56\%$	$< 0.19\%$