Study of narrow baryonic pentaquark candidates with the ZEUS detector at HERA

Uri Karshon
Weizmann Institute of Science
Israel

on behalf of the ZEUS Collaboration

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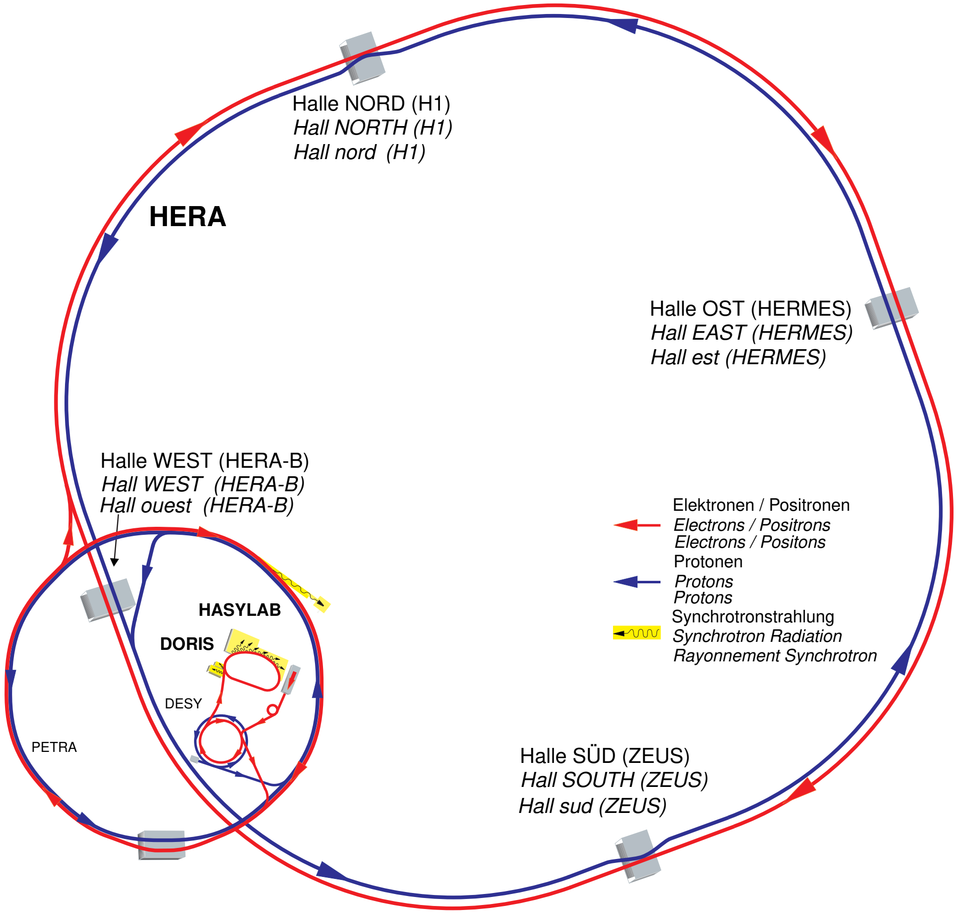
OUTLINE

- Introduction
- Evidence for the Strange Pentaquark Θ^+
- Search for Pentaquark Baryons in the $\Xi\pi$ channels
- Search for a Charm Pentaquark decaying to $D^{*\pm}p^{\mp}$
- Summary

Introduction - HERA at DESY



$e \Rightarrow \qquad \Leftarrow p$

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

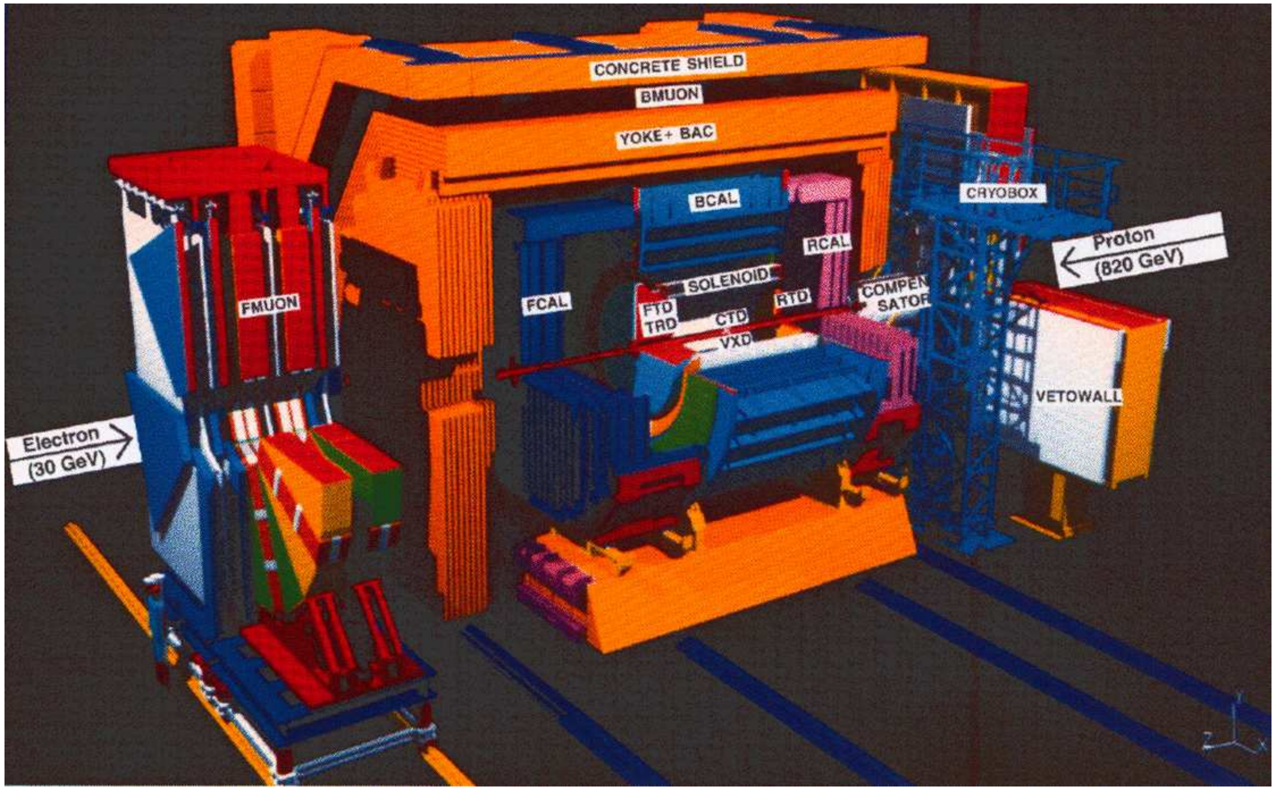
$\sqrt{s} \approx 300 - 319$ **GeV**

Two separate magnet systems guide the e and p beams around a 6.3 km long ring.

DESY and PETRA serve as injectors

4 Experiments: H1, ZEUS, HERMES, HERA-B

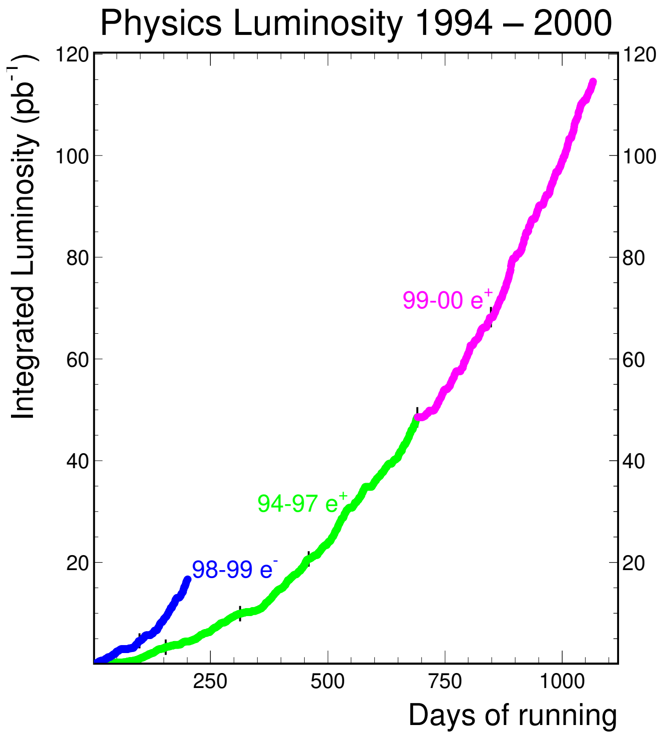
Introduction - The ZEUS detector

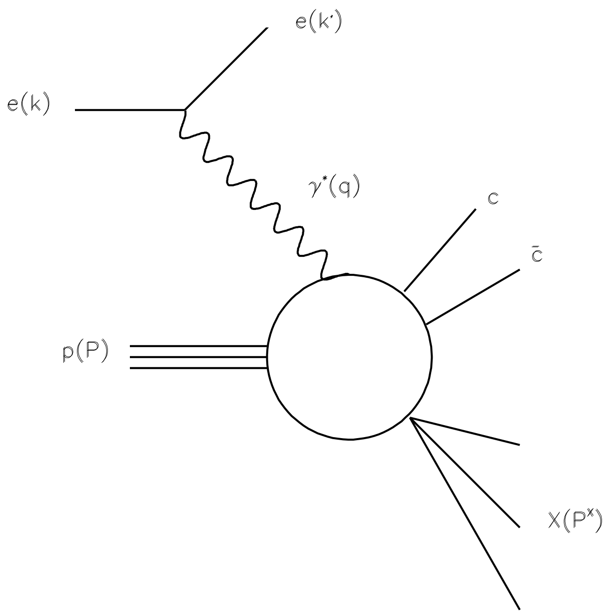


Overall dimensions: $\approx 10 \times 12 \times 20 m^3$

CTD 72 drift chamber layers covering polar angles $15^\circ < \theta < 164^\circ$
Thin superconducting SOLENOID: provides 1.43 T magnetic field
Full length track resolution: $\sigma_{p_\perp}/p_\perp = 0.0058\, p_\perp \oplus 0.0065 \oplus 0.0014/p_\perp$ **(**$p_\perp$ **in GeV)**
CAL uranium-scintillator sampling hermetic calorimeter
Inner EM and outer HAD sections
FCAL, BCAL, RCAL forward, barrel, rear CAL
Resolution: $0.18/\sqrt{E}$ **(**E **in GeV) for electrons**
$0.35/\sqrt{E}$ **for hadrons**
FMUON, BMUON forward, barrel μ **chambers**

Introduction - 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 : $W^2_{\gamma p} = (P + q)^2 \cong 4\ E_e\ E_p\ y$

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**

Search for $\Theta^+ \to K^0_S p$ in DIS

Fixed-target low-energy experiments saw a narrow exotic $S = +1$ baryon $\Theta^+ \to K^+ n$ around 1.53 GeV, as predicted by Diakonov et al. at the top of a $SU(3)$ anti-decuplet of baryons

Narrow peaks at a similar mass were also seen in $K^0_S p$ (not necessarily exotic) $\Rightarrow$ Attributed to Θ^+

It is interesting to search for Θ^+ in high-energy colliding experiments

- Look at central rapidity region, dominated by fragmentation $\to$ Little sensitivity to the proton remnant
- Can pentaquarks be created in the fragmentation region with no net baryon number?

Search in $K^0_S p$ mode complicated due to PDG (unestablished) Σ bumps e.g. $\Sigma(1480)$, $\Sigma(1560)$

No Σ bumps reported around Θ^+ mass range

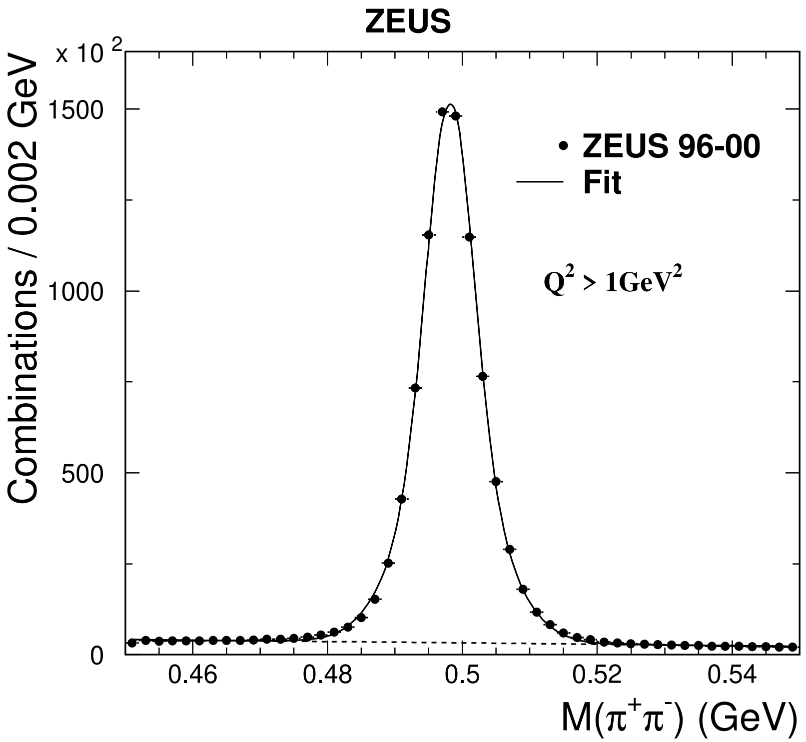
ZEUS Θ^+ observation: Phys. Lett. B 591 (2004) 7

Event selection

- **All ZEUS HERA-I data** $(\mathbf{121\ pb^{-1}})$
- e^+p, e^-p **collisions at CM energy** $300 - 318$ **GeV**
- $Q^2 > 1$ $\mathbf{GeV^2}$

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

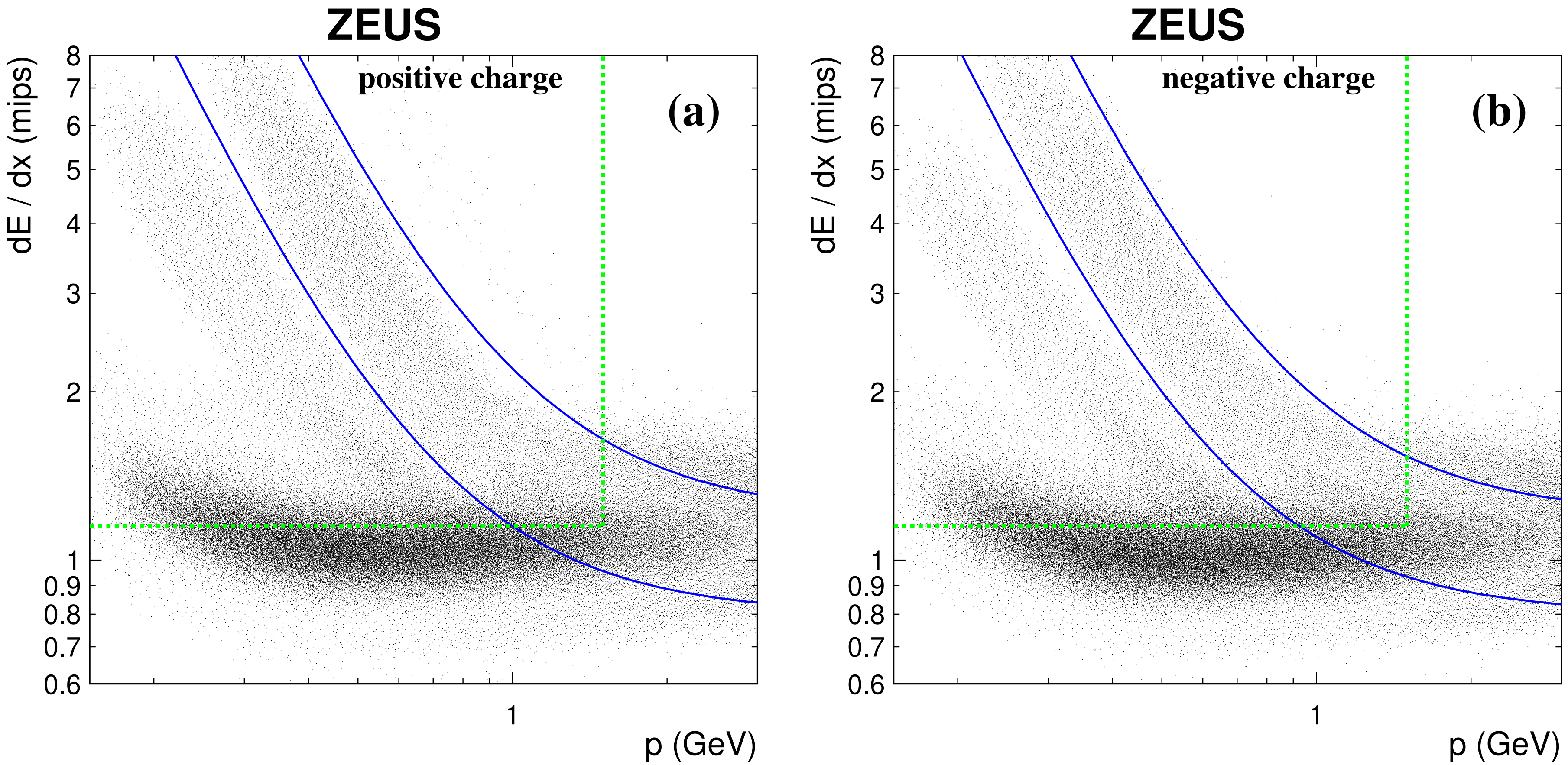
- **CTD tracks** $p_T > 0.15$ **GeV**, $|\eta| < 1.75$
- K^0_S **reconstructed from secondary-vertex tracks**
- **Remove photon conversions** $M(e^+e^-) < 50$ **MeV** **and** Λ**'s** $M(\pi p) < 1.121$ **GeV**
- $p_T(K^0) > 0.3$ **GeV**, $|\eta(K^0)| < 1.5$
- $0.483 < M(\pi^+\pi^-) < 0.513$ **GeV**



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

proton selection

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



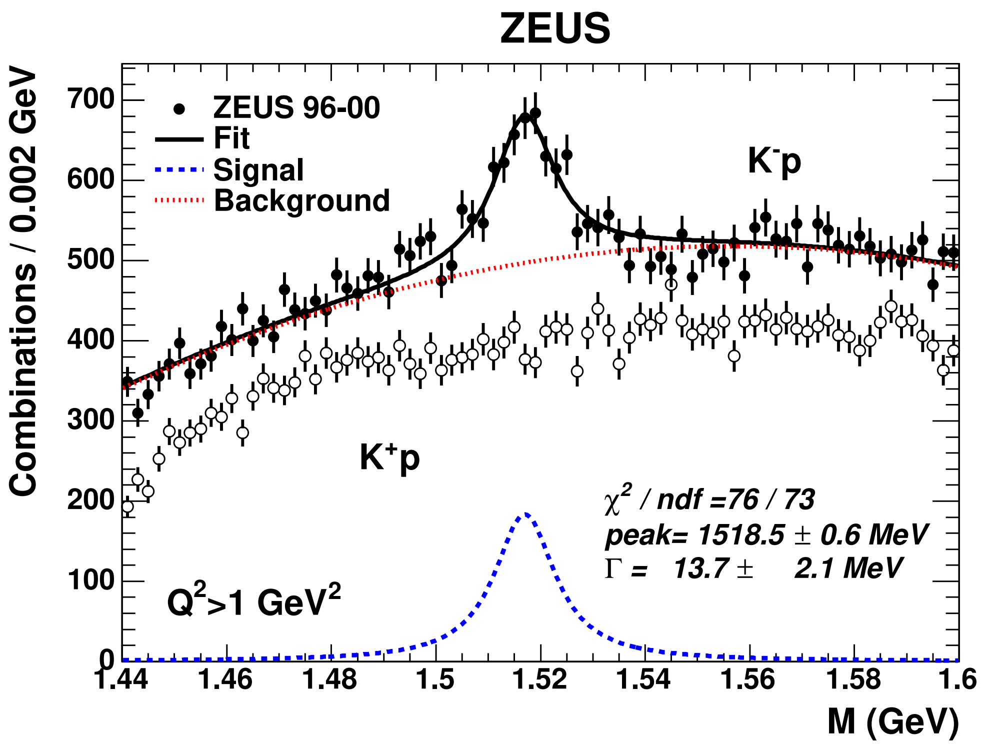
$dE/dx > 1.15$ **mips,** $P(p, \bar{p}) < 1.5$ **GeV**

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

Results: $K^{\pm}p(\bar{p})$

Look first as a check on $M(K^{\pm}p)$

Select protons and kaons using dE/dx



See a clean $\Lambda(1520) \rightarrow K^{-}p$ **with mass and width consistent with PDG**

$N(\Lambda) \approx N(\bar{\Lambda}) \Rightarrow$ **Main source - Fragmentation**

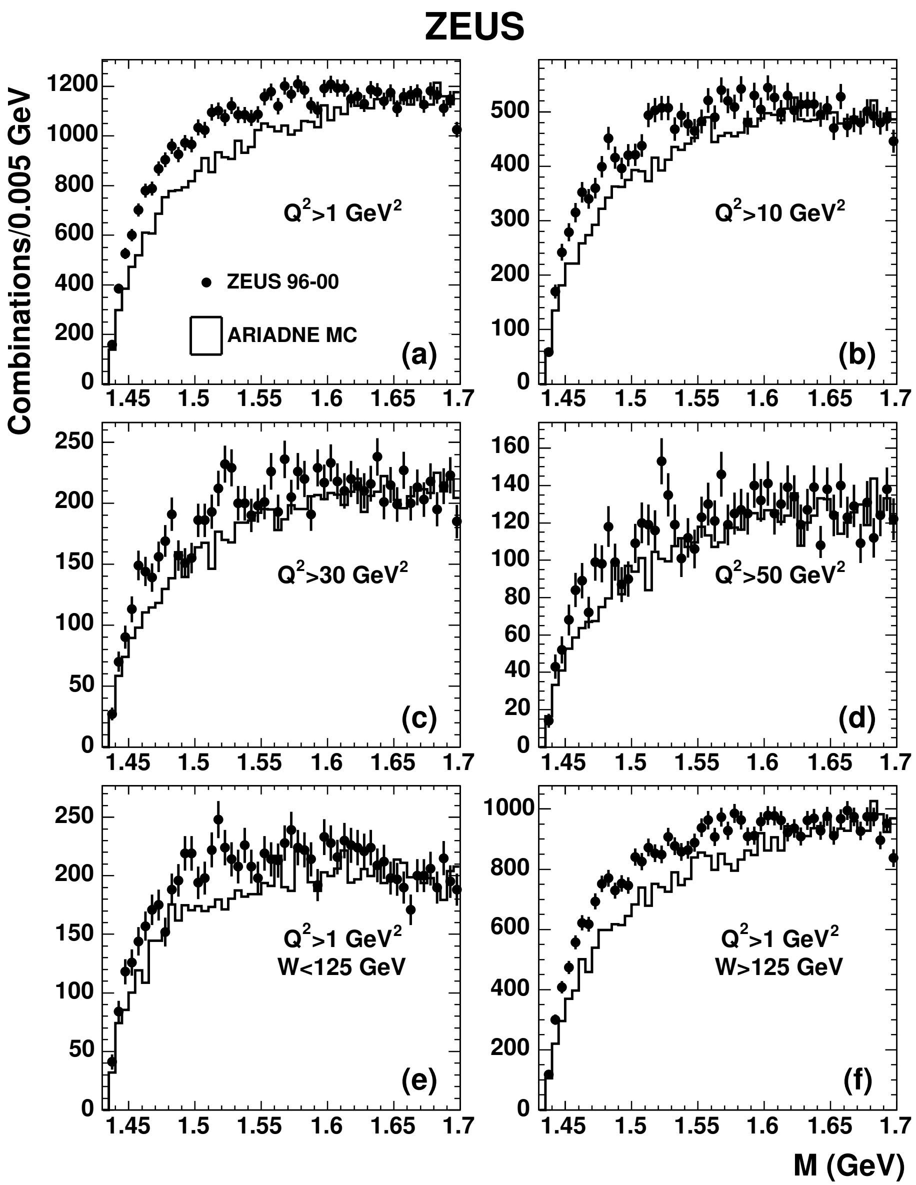
If Θ **is a** NK **bound state, both** $I = 0, 1$ **are possible**

$I = 1$ **would lead to 3 states:** Θ^{0}, Θ^{+}, Θ^{++}

No evidence for $I = 1$ **hypothetical** $\Theta^{++} \rightarrow K^{+}p$ **(+c.c.)**

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

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

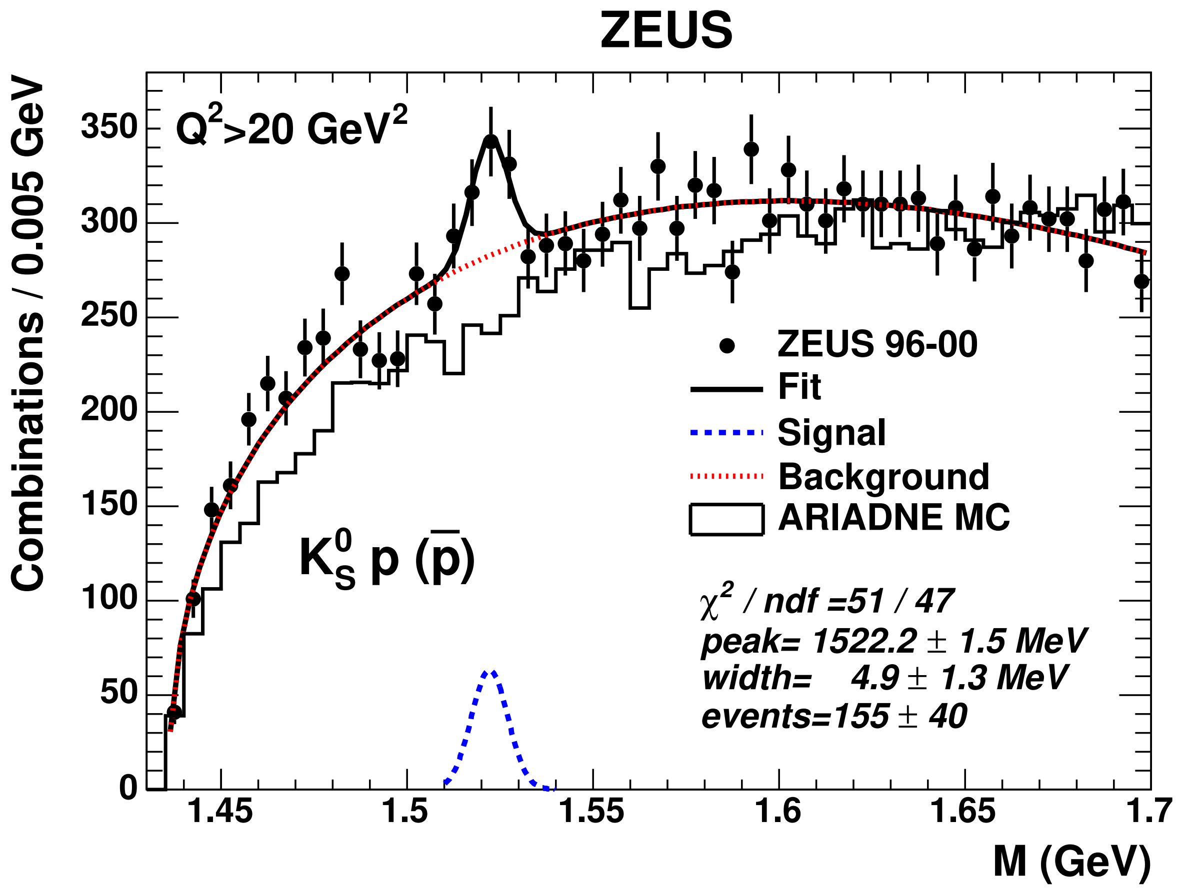
Signal at 1.52 GeV
increases with Q^2
decreases with W

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

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

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

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



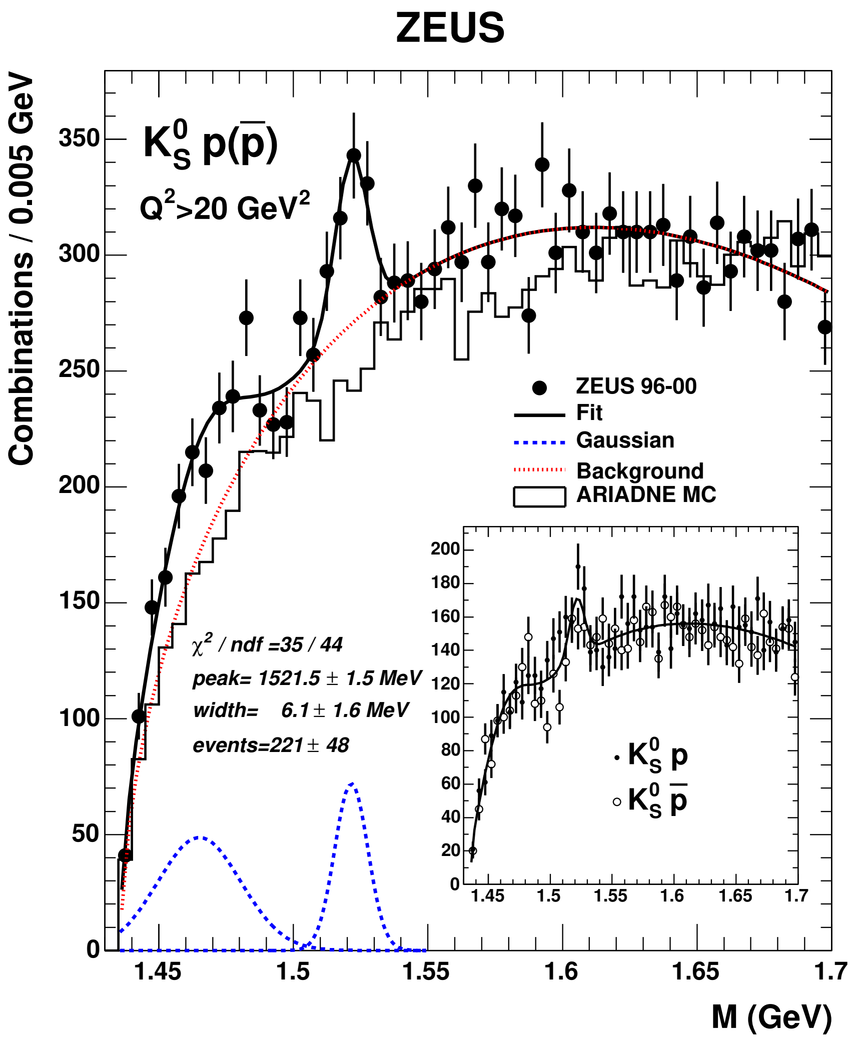
$M(\Theta^+) = 1522.2 \pm 1.5$ **MeV**

Significance ≈ 3.9 **s.d.**

Width consistent with resolution $(\approx 2$ **MeV**$)$

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

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



$M(\Theta^+) = 1521.5 \pm 1.5(stat.)^{+2.8}_{-1.7}(syst.)$ **MeV**
$Width = 6.1 \pm 1.6(stat.)^{+2.0}_{-1.4}(syst.)$ **MeV**
above but compatible
with resolution
221 ± 48 **events** ≈ 4.6 **s.d.**
Probability of background fluctuating into signal in the range $1.5 - 1.56$ **GeV is below** $6 \cdot 10^{-5}$
Signal seen in both charges (inset)
$K^0_S\bar{p}$ **fit:** 96 ± 34 **(2.8 s.d.)**
If real - evidence for antipentaquark Θ^-

NEW!! Θ^+ cross section

Estimate production rate of Θ^+ (+c.c.)

$\Rightarrow$ Calculate cross section at measured kinematic region:

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

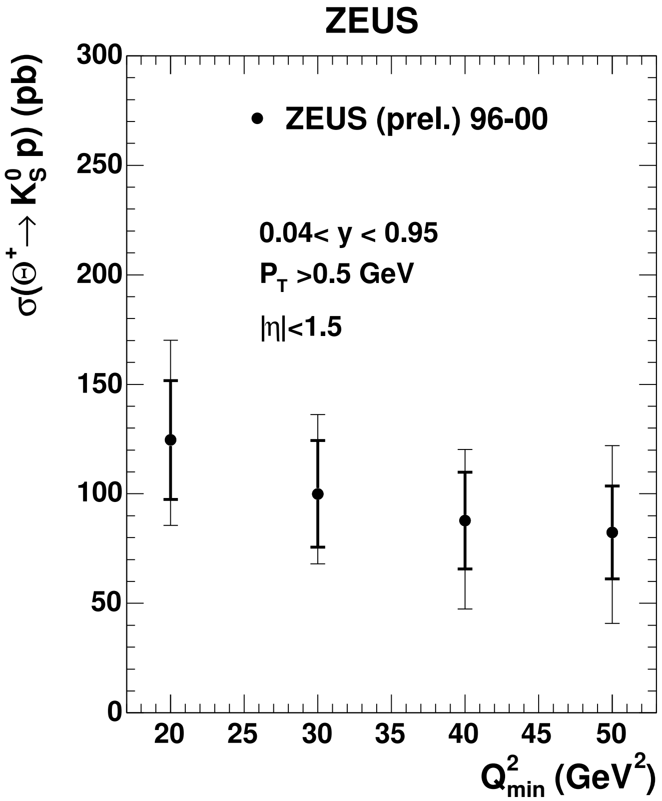
$$\sigma(e^{\pm}p \to e^{\pm}\Theta^+X \to e^{\pm}K^0_S pX) = 125 \pm 27(stat.)^{+36}_{-28}(syst.)pb$$

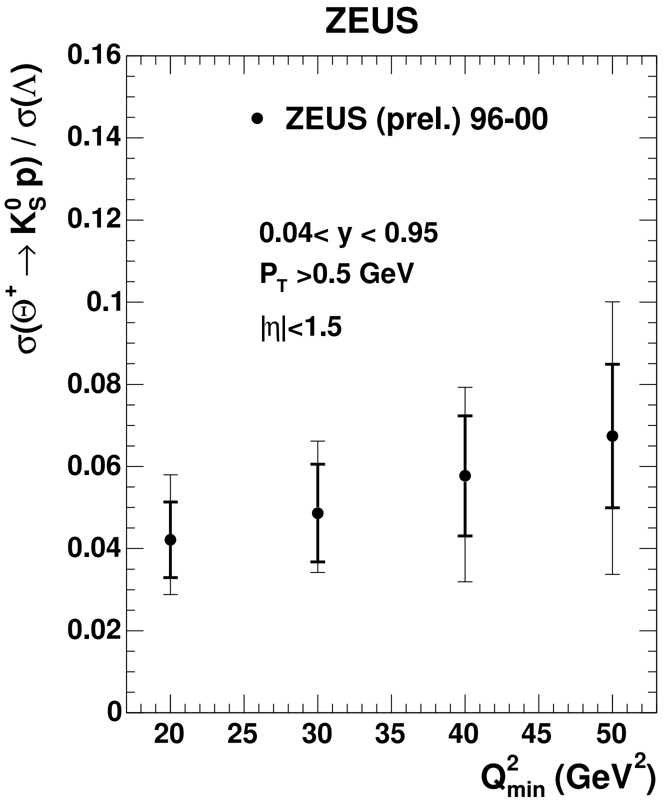
Compare to well-known baryon Λ:

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

Λ **measured at the same kinematic region**

Protons 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** $K^0_S p(\bar{p})$

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

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

Comparison with e^+e^-

Λ **multiplicity per Z^0 decay $=$ 0.37**

e.g. OPAL has 4.3M hadronic events
$\Rightarrow$ 1.6M events with Λ

LEP reconstruction efficiency: $\approx 20\%$ **for** K_S^0
$\approx 60\%$ **for proton**

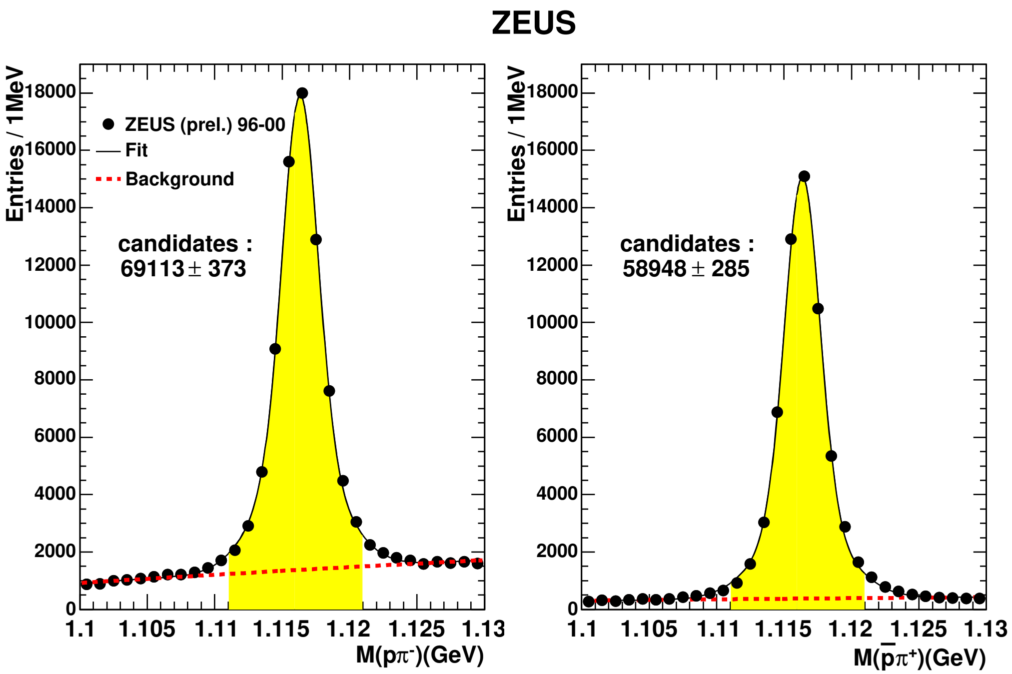
Assuming

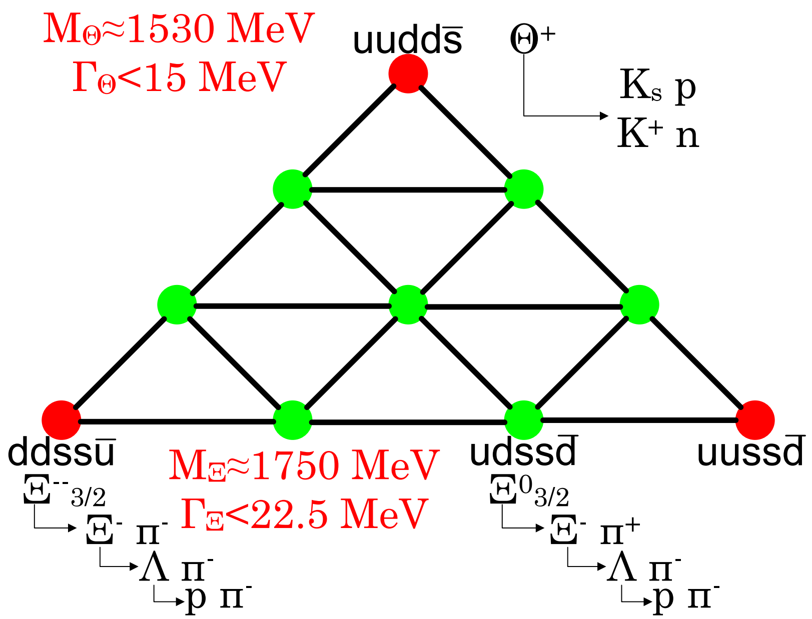
- **ratio of Θ^+/Λ at LEP as in ZEUS ($\approx 4\%$)**
- **Θ^+ and Λ produced in the fragmentation region**

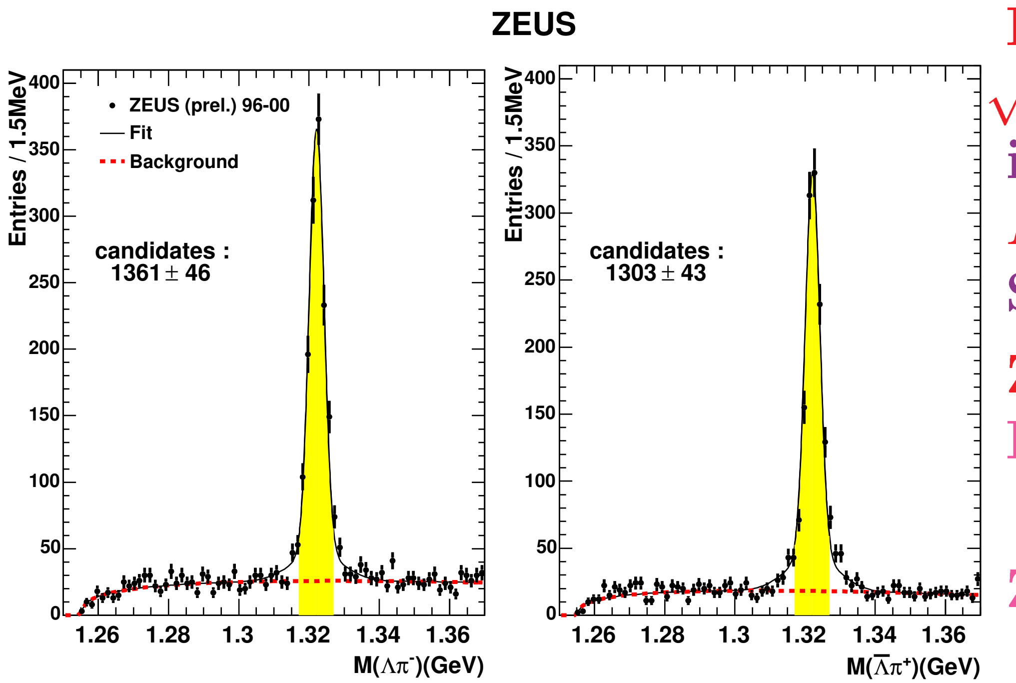
$\Rightarrow$ LEP experiments should have $\approx$64,000 pentaquarks
should reconstruct $\approx$ 8000 pentaquarks

Until now no LEP experiment reported Θ^+ signal

Search for the NA49 $\Xi\pi$ signal







NA49: fixed-target pp experiment $\sqrt{s} = 17.2$ **GeV.** Found narrow peaks in all $\Xi\pi$ combinations at $M \approx 1862$ **MeV, width** < 18 **MeV.** Sum of 4 $\Xi\pi$ channels $\Rightarrow 5.8$ **s.d.**

ZEUS DIS data: Similar analysis

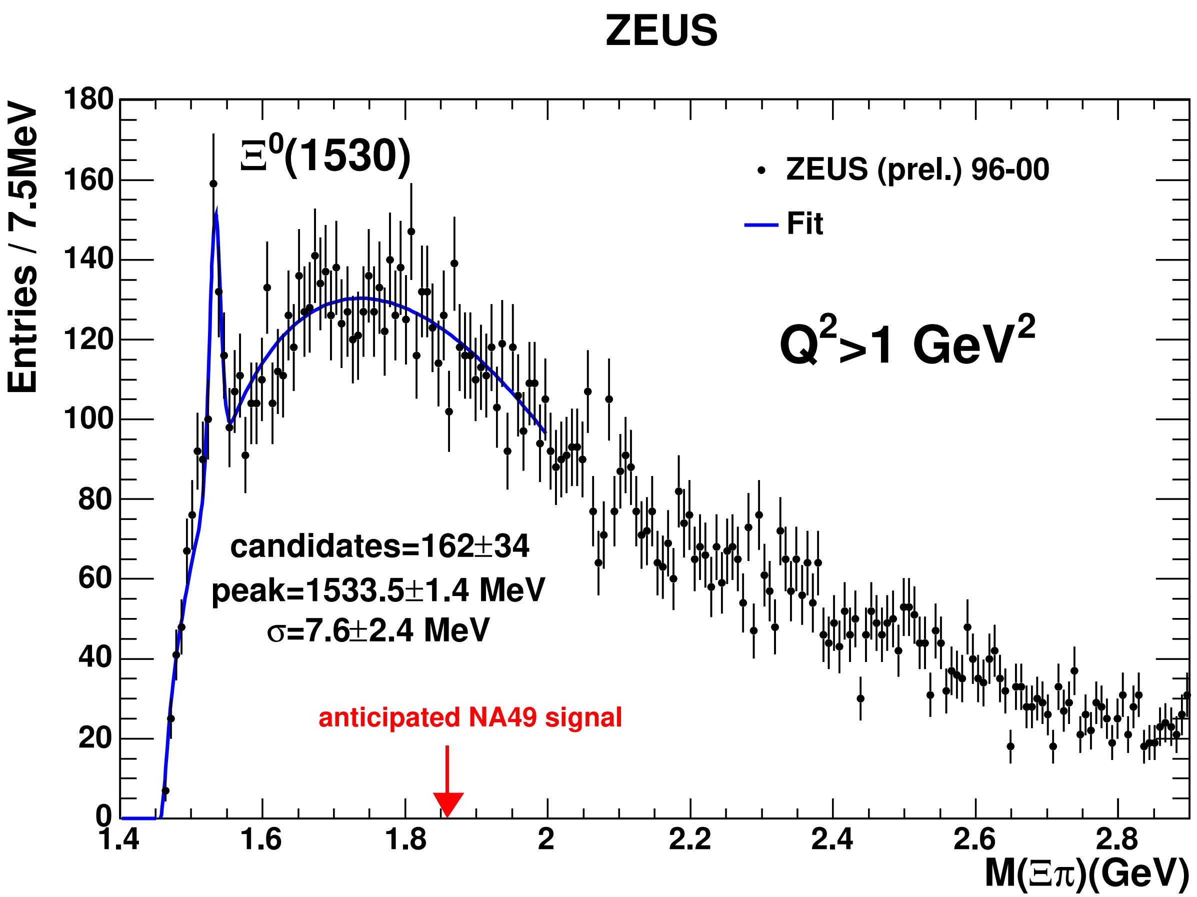
Reconstruct $\Lambda \to p\pi^-$; $\bar{\Lambda} \to \bar{p}\pi^+$

$\Xi^- \to \Lambda\pi^-$; $\bar{\Xi} \to \bar{\Lambda}\pi^+$

ZEUS Λ,Ξ signals: higher statistics smaller background

Search for the NA49 $\Xi\pi$ signal

$M(\Xi\pi)$ for $Q^2 > 1$ GeV^2 (all $\Xi\pi$ charge combinations)



See a clean $\Xi^0(1530) \to \Xi^-\pi^+$ (+c.c.) signal of ≈ 4.8 s.d.

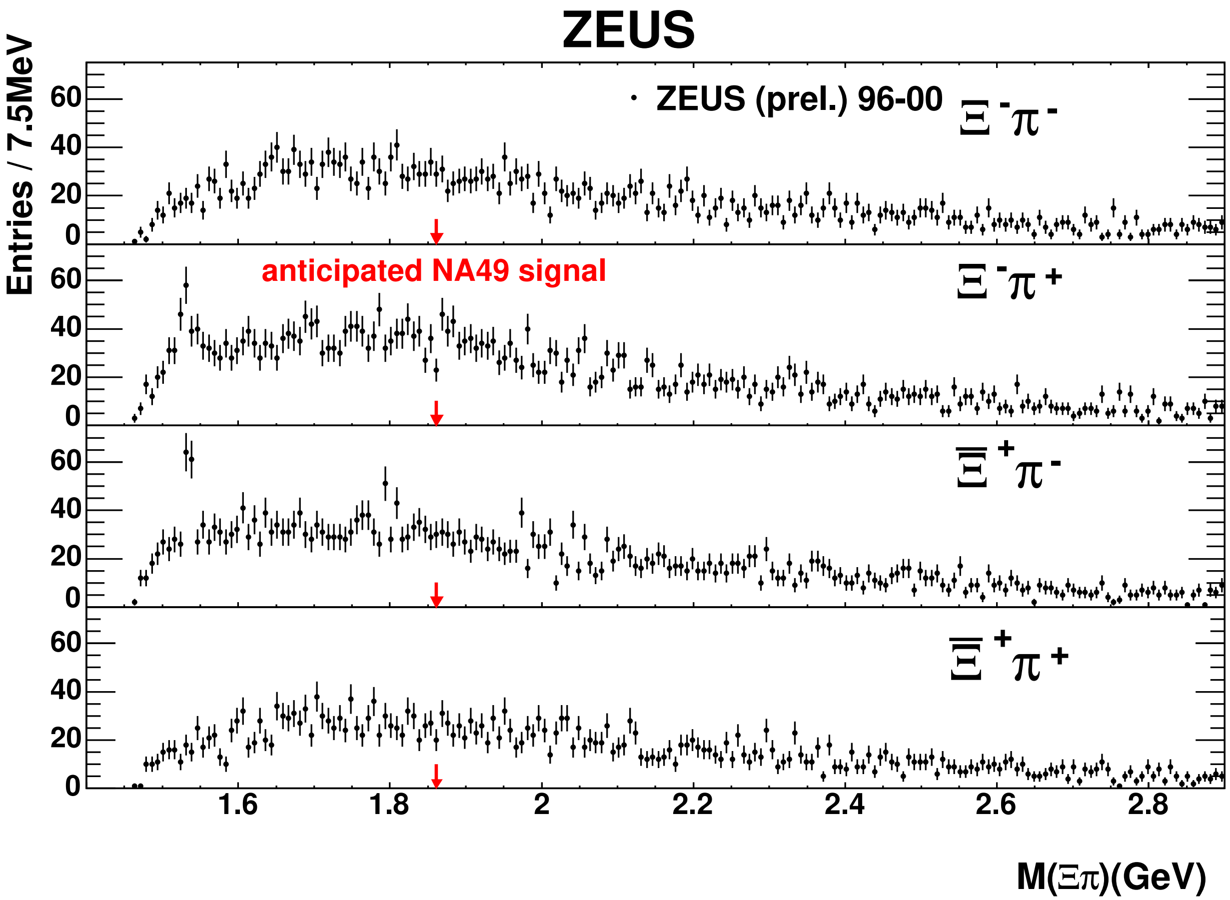
$\Xi(1530)$ signal much bigger than NA49 one

No evidence for the NA49 1862 signal for $Q^2 > 1$ GeV^2

also for $Q^2 > 20$ GeV^2

Search for the NA49 $\Xi\pi$ signal

$M(\Xi\pi)$ 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

Assuming same production mechanism and acceptance:

If $\Xi(1862)/\Xi(1530)$ is as big as in NA49, ZEUS cannot miss it !

Absence of signal in ZEUS data may indicate that $\Xi(1862)$ is mainly produced in forward region, where NA49 has good acceptance

Charm Pentaquarks

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

Predictions:

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

can decay weakly to $\Theta^+\pi^-$

Karliner-Lipkin (hep-ph/0307343):

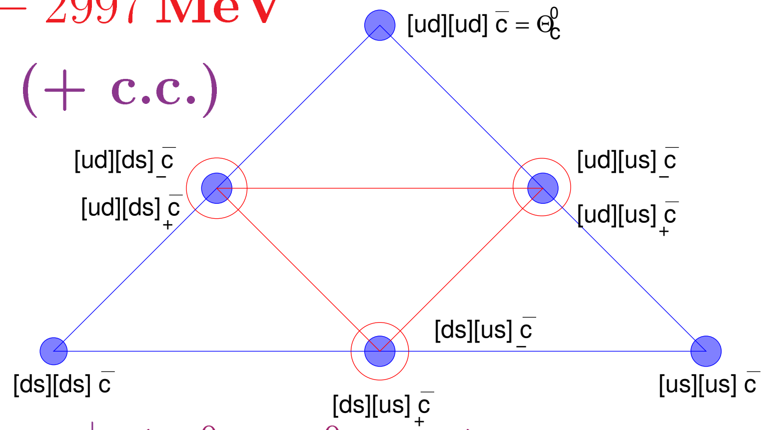
$$M(\Theta_c^0) = 2985 \pm 50\,\mathbf{MeV}\ ;\ \Gamma(\Theta_c^0) \sim 21\,\mathbf{MeV}$$

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** $D^{*\pm}p$

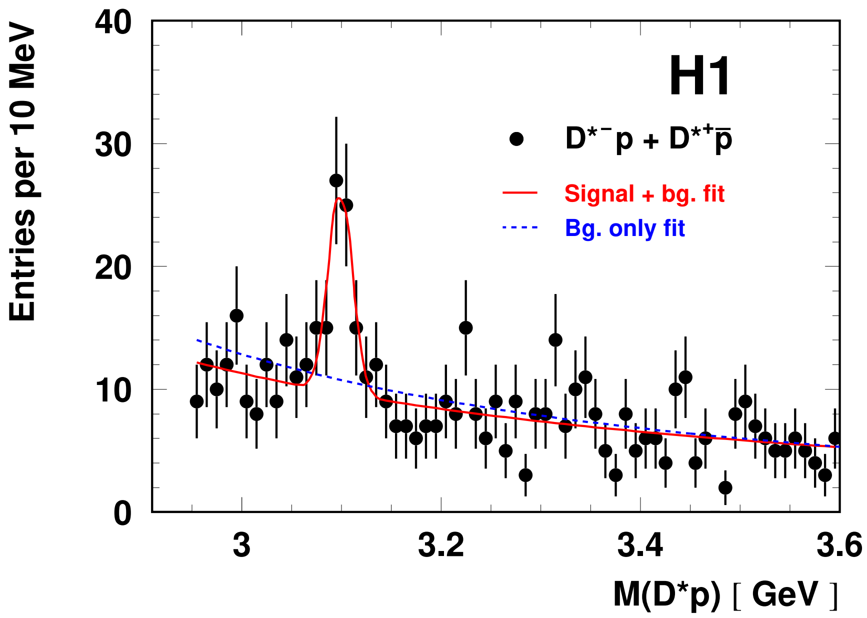


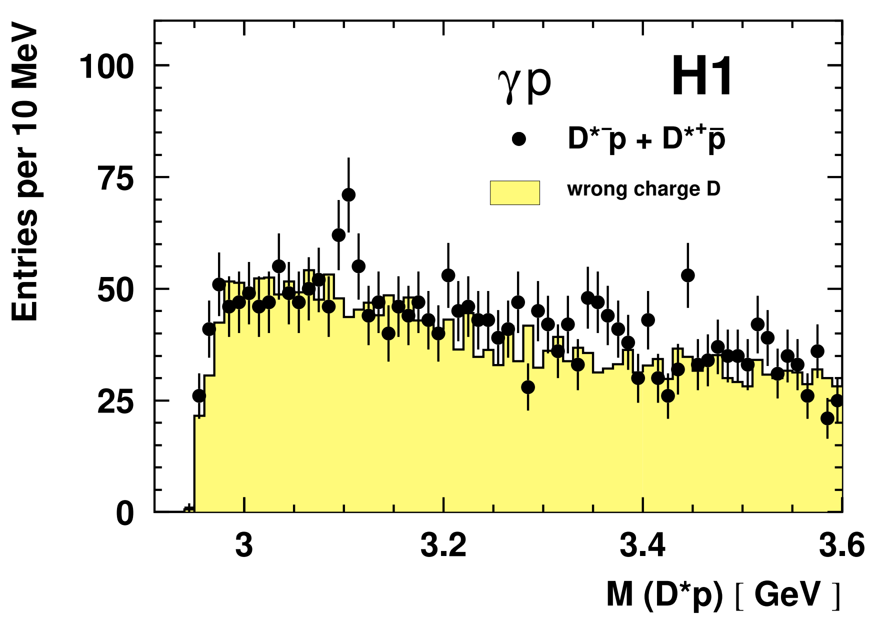
ZEUS is sensitive to resonances decaying to $D^{*\pm}$ $(D_1^0,\ D_2^{*0},\ D_{s1})$

very narrow resonances $(\Theta^+,\ f_2'(1525),\ f_0(1710))$

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

H1 observation





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

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

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

The signal consists of 50.6 ± 11.2 events

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

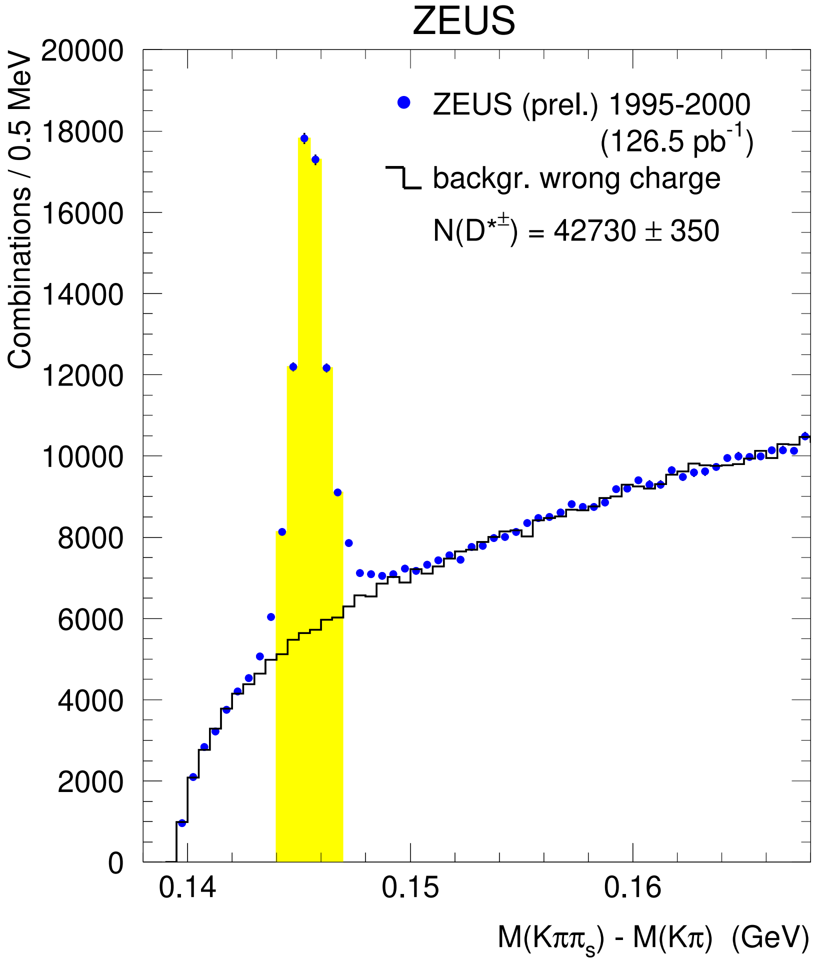
Signal (with large background) also seen in a photoproduction sample with $\approx$ same ratio to D^*

ZEUS $D^{*\pm}$ and proton tagging

DATA 1995-2000 (126.5 pb^{-1})

$D^{*+} \to D^0\pi_s^+ \to (K^-\pi^+)\pi_s^+$ **(+ c.c.)**; $f(c \to D^{*+}) \approx 24\%$, $BR = 2.6\%$

$\Delta M = M(D^{*+}) - M(D^0) \sim m_\pi$; $P_T(D^{*\pm}) > 1.35\,\mathbf{GeV}$, $|\eta(D^{*\pm})| < 1.6$



Candidates with $144 < \Delta M < 147\,\mathbf{MeV}$ (yellow band) were used. In this range after background subtraction:

$$N(D^{*\pm}) = 42730 \pm 350$$

better than 1% stat. precision

PROTON SELECTION:

$P_T(p) > 0.15$ **GeV**

Wide dE/dx p-band as in the Θ^+ analysis:

$f < dE/dx < F$, **where**

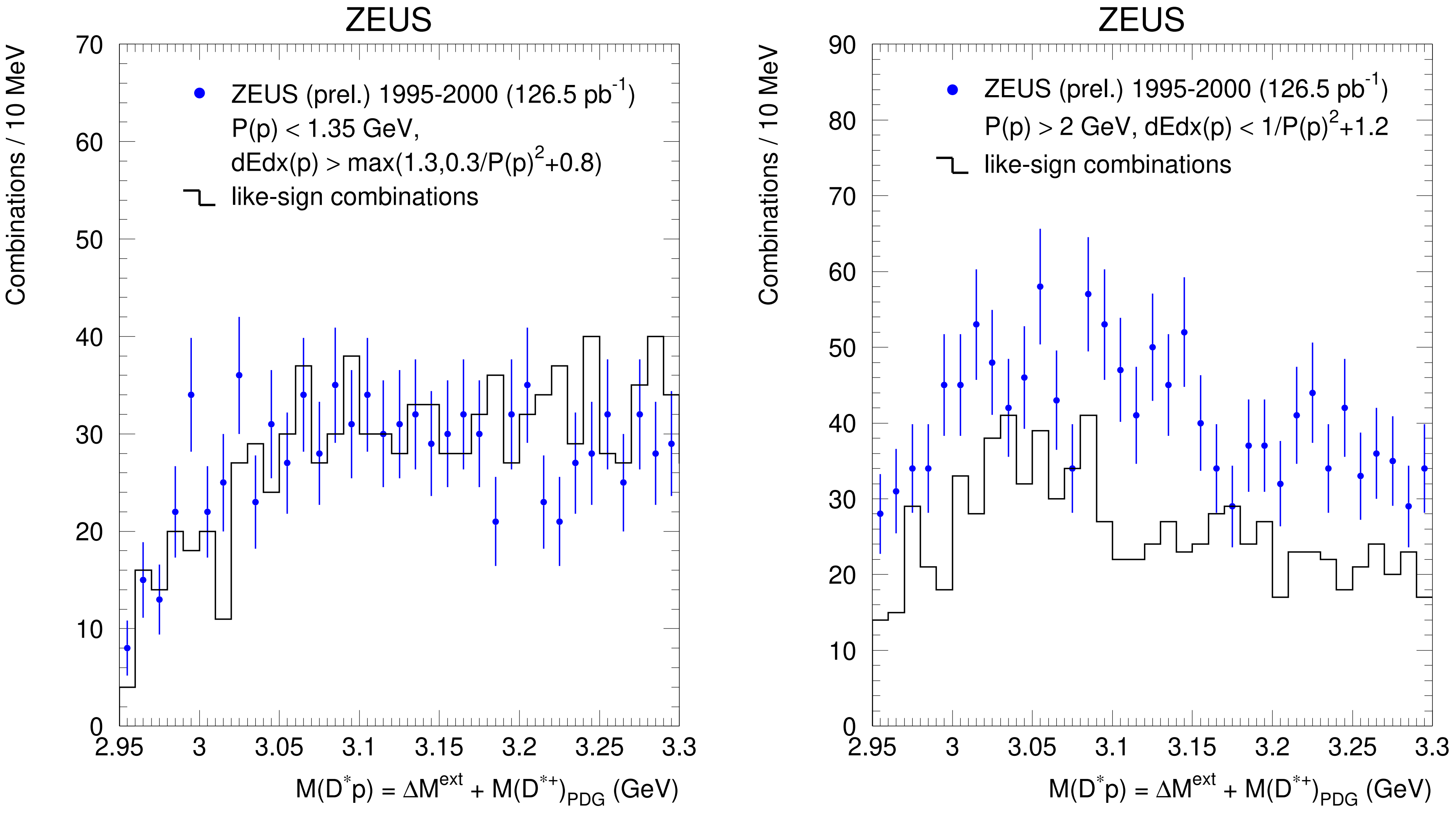
$f = 0.3/P^2 + 0.8$, $F = 1.0/P^2 + 1.2$

Two strategies for p-selection:

1) Low-P_p : $(dE/dx)_p$ **band;** $P < 1.35\,\mathbf{GeV}$; $dE/dx > 1.3$ **(Clean p's from dE/dx)**

2) High-P_p : $(dE/dx)_p$ **band;** $P > 2\,\mathbf{GeV}$ **(Nicer H1 signal without dE/dx cut)**

$M(D^*p)$ spectra



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

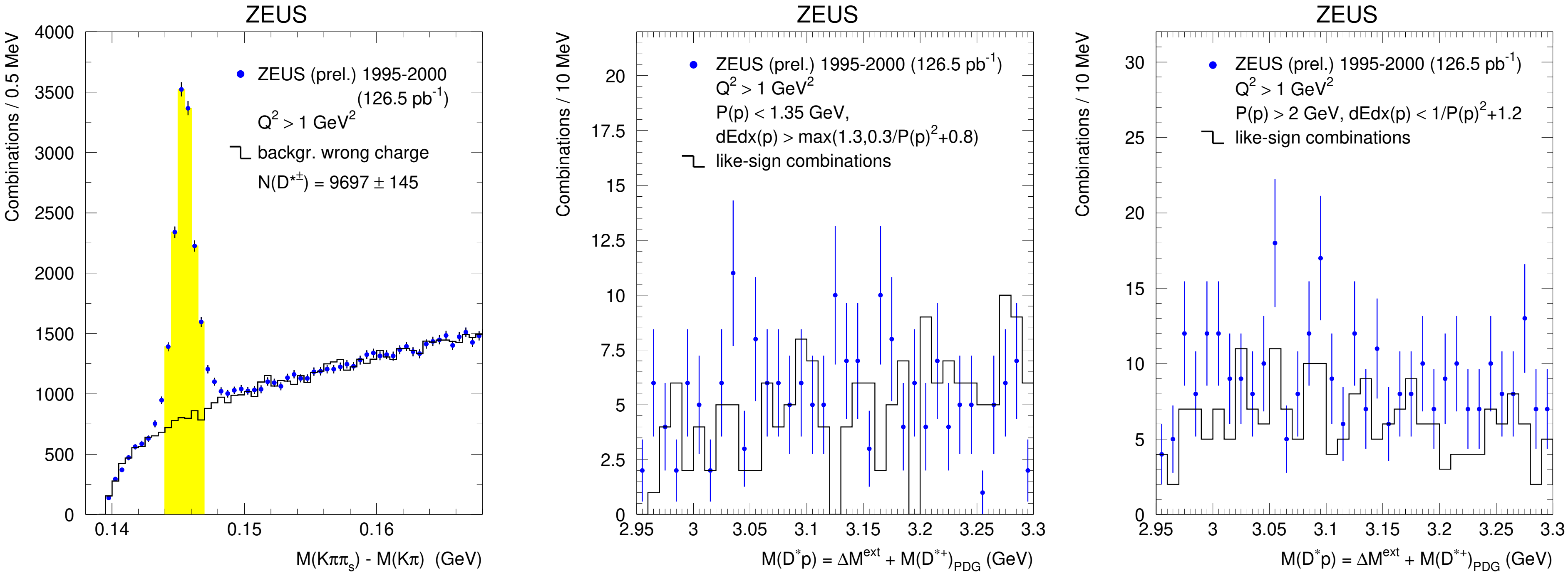
No evidence for a signal at 3.1 GeV

$M(D^*p)$ spectra in DIS

$D^{*\pm}$ in DIS with $Q^2 > 1\,\text{GeV}^2$

D^* signal is cleaner but ~ 4.5 times smaller than inclusive case

$$N(D^{*\pm}) = 9697 \pm 145$$



No evidence for a signal at 3.1 GeV

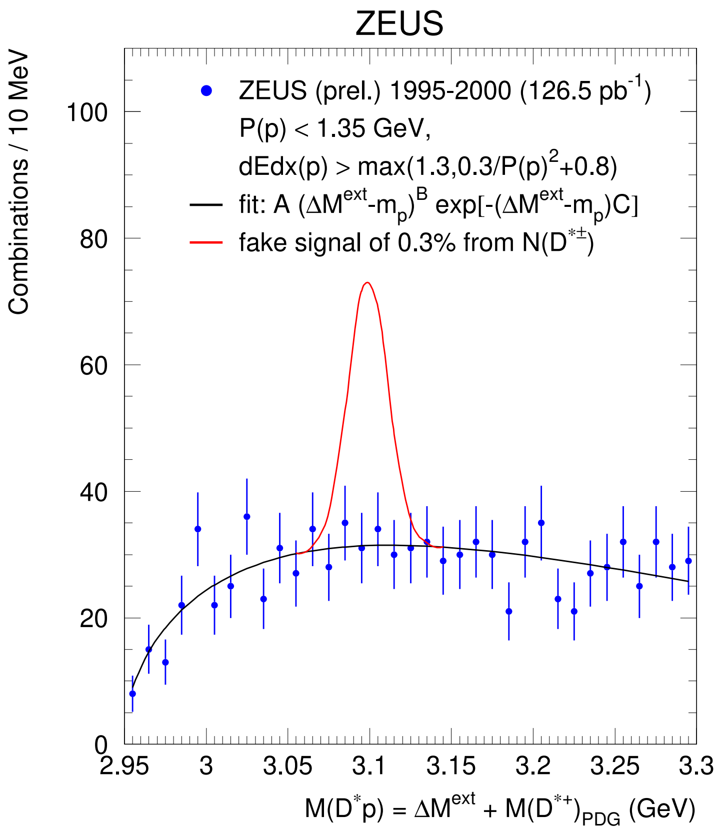
Estimated signal expectation

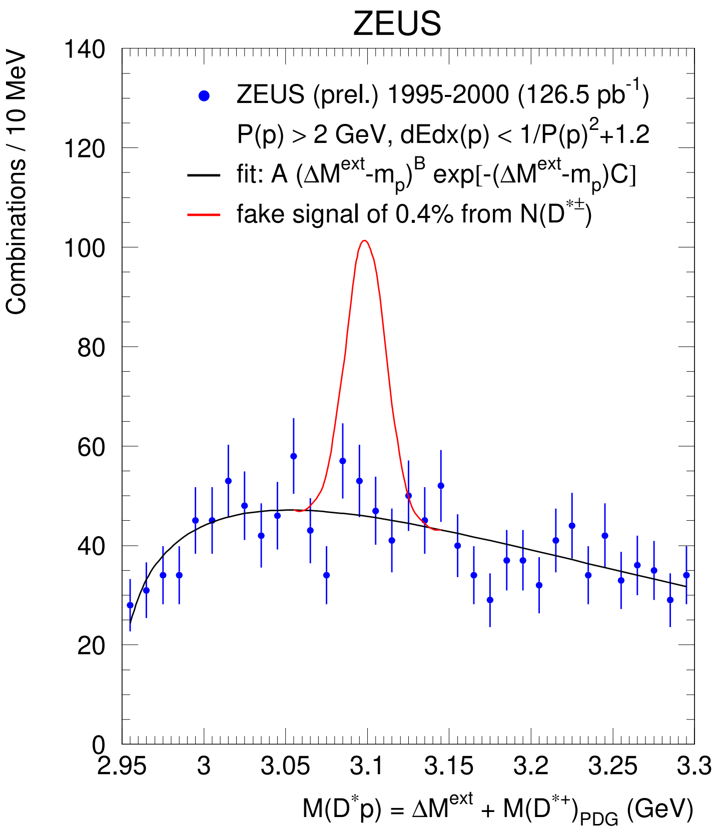
Estimation of expected signals (inspired by H1 observation):

$$\frac{N^{\rm rec}(\Theta_c^0 \to D^{*-}p + c.c.)}{N^{\rm rec}(D^{*\pm})} \sim 1\%$$

$$\frac{N^{\rm rec}(P(p)<1.35\,{\rm GeV}, dE/dx(p)>1.3)}{N^{\rm rec}(\text{all } p)} \sim 30\%$$ $\Rightarrow$**low-P selection : 0.3% from $N(D^{*\pm})$**

$$\frac{N^{\rm rec}(P(p)>2\,{\rm GeV})}{N^{\rm rec}(\text{all } p)} \sim 40\%$$ $\Rightarrow$ **high-P selection : 0.4% from $N(D^{*\pm})$**





Large signals are excluded

In DIS with $Q^2 > 1$ GeV^2 smaller sensitivity; still no large signal

$\Rightarrow$ H1 observation of a Θ_c^0 baryon at 3.1 GeV contributing $\approx 1\%$ of the total D^* production rate is not confirmed by ZEUS

Summary

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

- **In inclusive ep DIS, a peak is seen in $M(K^0_S p)$, $M(K^0_S \bar{p})$ consistent with the strange (anti)pentaquark $\Theta^{\pm}$**
- **For $Q^2 > 20$ GeV^2: fitted signal has 221 ± 48 events; $M = 1521.5 \pm 1.5(stat.)^{+2.8}_{-1.7}(syst.)$ MeV; width consistent with resolution**
- **If due to $\Theta^{\pm}$:**
  - $K^0_S \bar{p}$ **signal is first evidence for antipentaquark** $\Theta^- = \bar{u}\bar{u}\bar{d}\bar{d}s$
  - **First evidence for production in kinematic region dominated by fragmentation**
  - **For $Q^2 > 20$ GeV^2** $\sigma(\Theta^+ \to K^0_S p)/\sigma(\Lambda) = (4.2 \pm 0.9^{+1.2}_{-0.9})\%$
  - **If same production dynamics in ep and ee**
    $\Rightarrow$ LEP-I experiments should reconstruct thousands of $\Theta^{\pm}$
- **No evidence for the NA49 $\Xi\pi$ signal at 1862 MeV in inclusive ep DIS**
- **If same production, acceptance, ratio to $\Xi(1530)$ $\Rightarrow$ ZEUS should see it**
- **No resonance structure seen in $M(D^*p)$ around 3.1 GeV**
- **ZEUS data constrain the uncorrected fraction of $D^{*\pm}$ mesons originating from Θ^0_c decays to be well below 1%**

Summary of Pentaquark searches at HERA

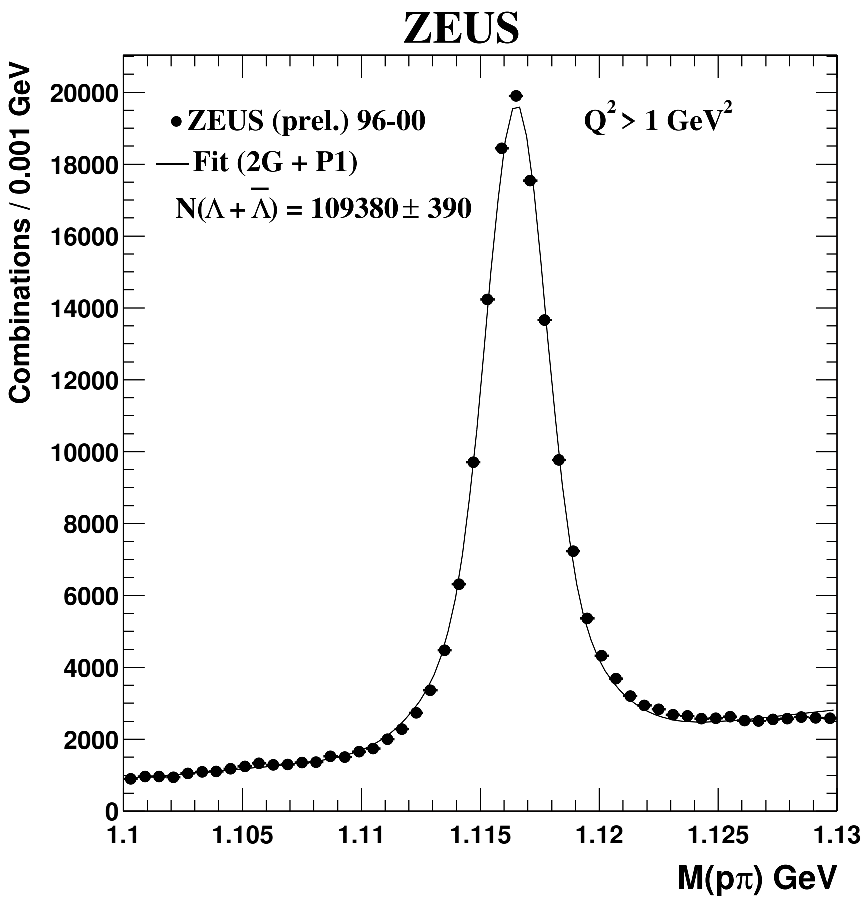
Experiment	Interaction	$\sqrt(s)$ GeV	No. of K_S^0	No. of Θ^+	No. of Ξ^-	No. of Ξ^{--}	No. of $D^{*\pm}$	No. of Θ_c^0
HERMES	$e-d$	10	$\approx 1,000$	78 ± 18		?		?
HERA-B	$p-A$	41.6	$\approx 3,400,000$	NO	$\approx 19,000$	NO		?
ZEUS DIS	$e-p$	300-319	$867,000$	221 ± 48	$2,664$	NO	$\approx 9,000$	NO
H1 DIS	$e-p$	300-319	?	?		?	$\approx 3,400$	50.6 ± 11.2
ZEUS PHP	$\gamma-p$		?	?		?	$\approx 33,000$	NO
H1 PHP	$\gamma-p$		?	?		?	$\approx 4,900$	43 ± 14

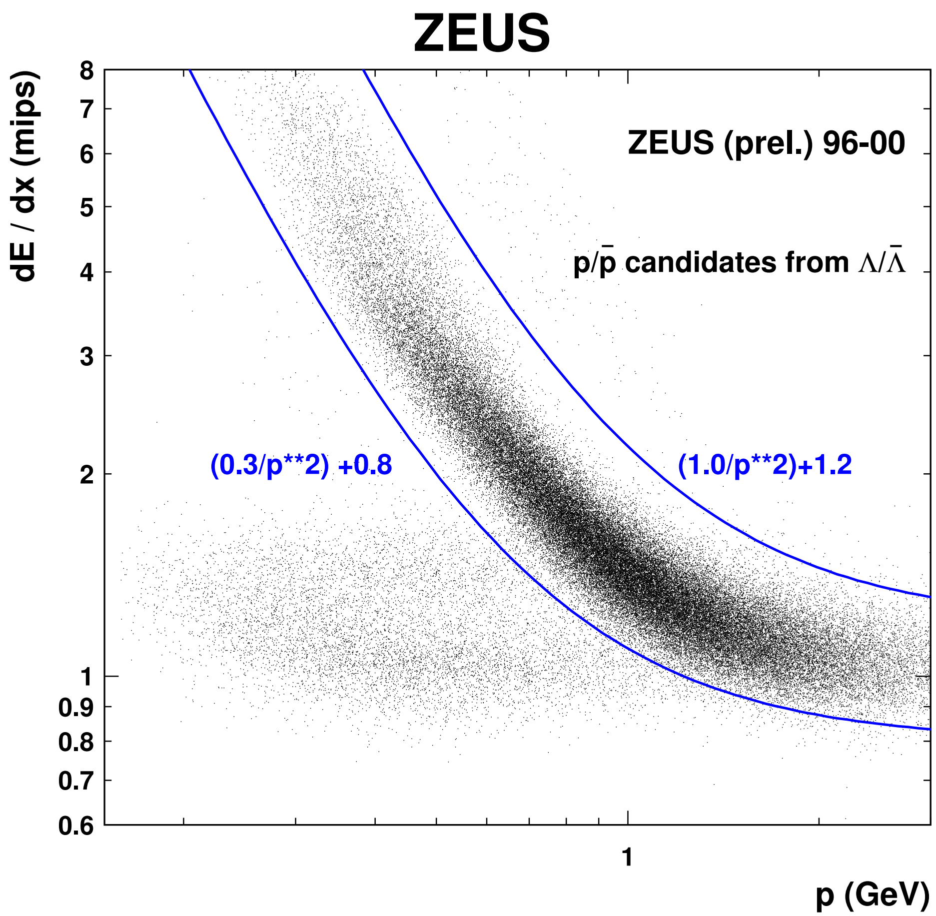
Θ^+ : 2 positive, 1 negative

Ξ^{--} : 2 negative

Θ_c^0 : 1 positive, 1 negative

Backup: Proton dE/dx band





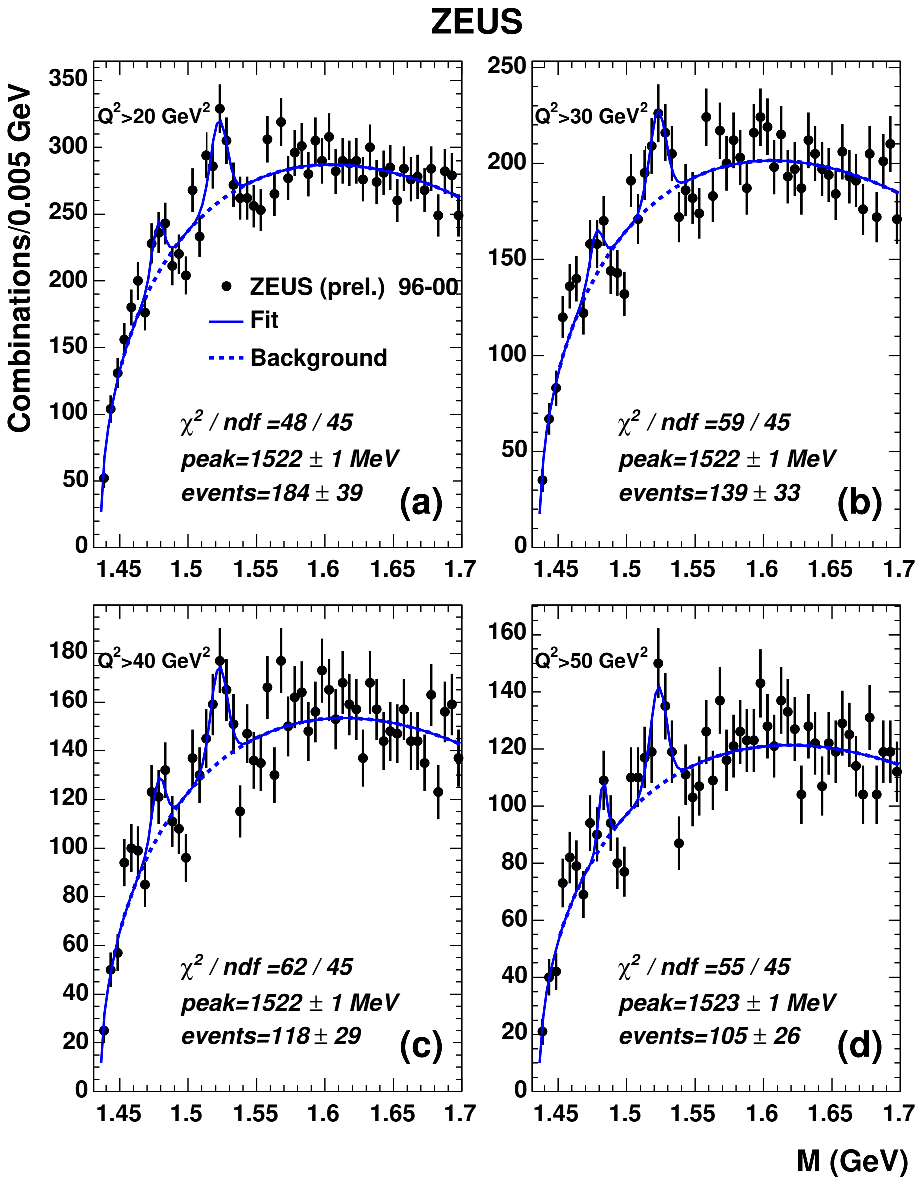
$\Lambda^0 \to p\pi$ **from sec.vert.**

dE/dx **for** $p/\bar{p}$ **candidates**

$$0.3/P^2 + 0.8 < dEdx < 1.0/P^2 + 1.2$$

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

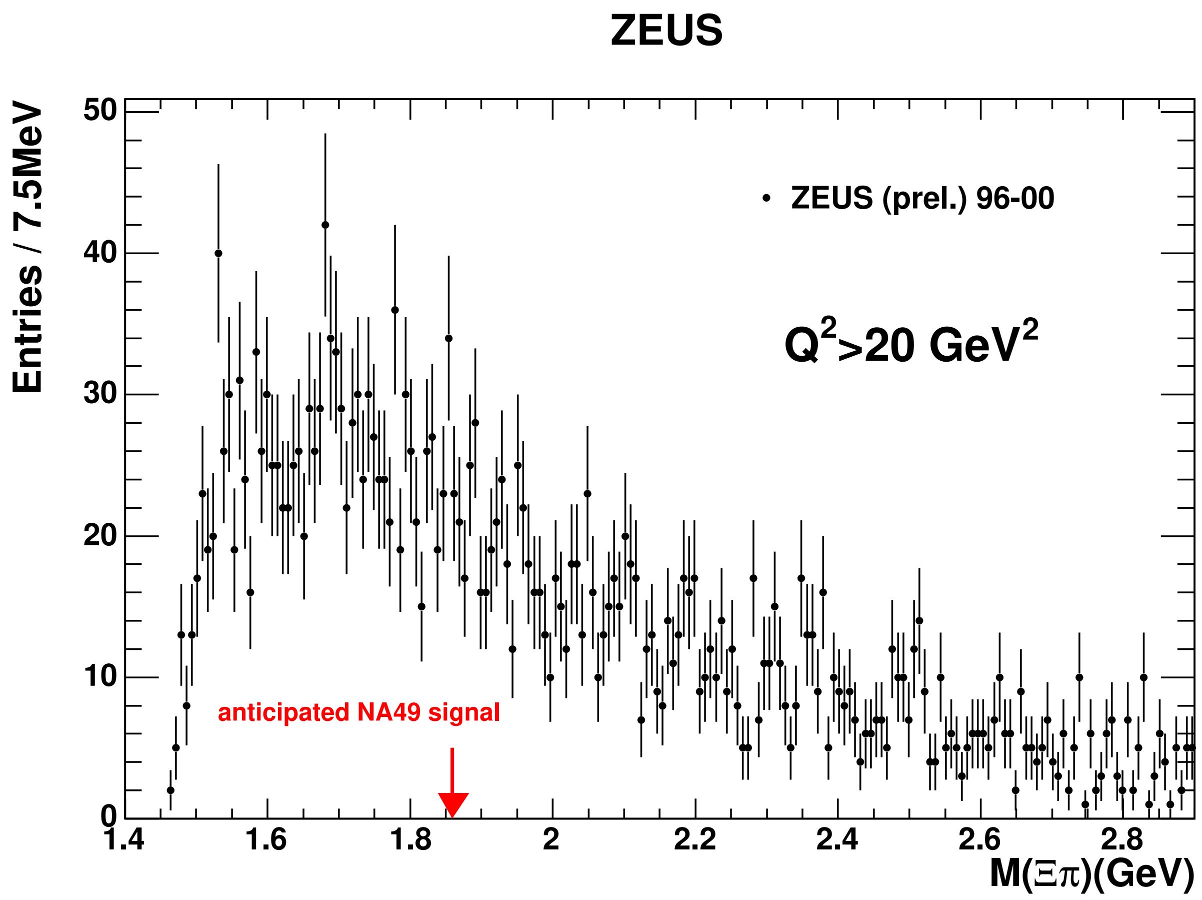


Backup: Fit results for $Q^2 > 20$ GeV^2

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: Search for the NA49 $\Xi\pi$ signal

$M(\Xi\pi)$ for $Q^2 > 20$ GeV^2 (all $\Xi\pi$ charge combinations)



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

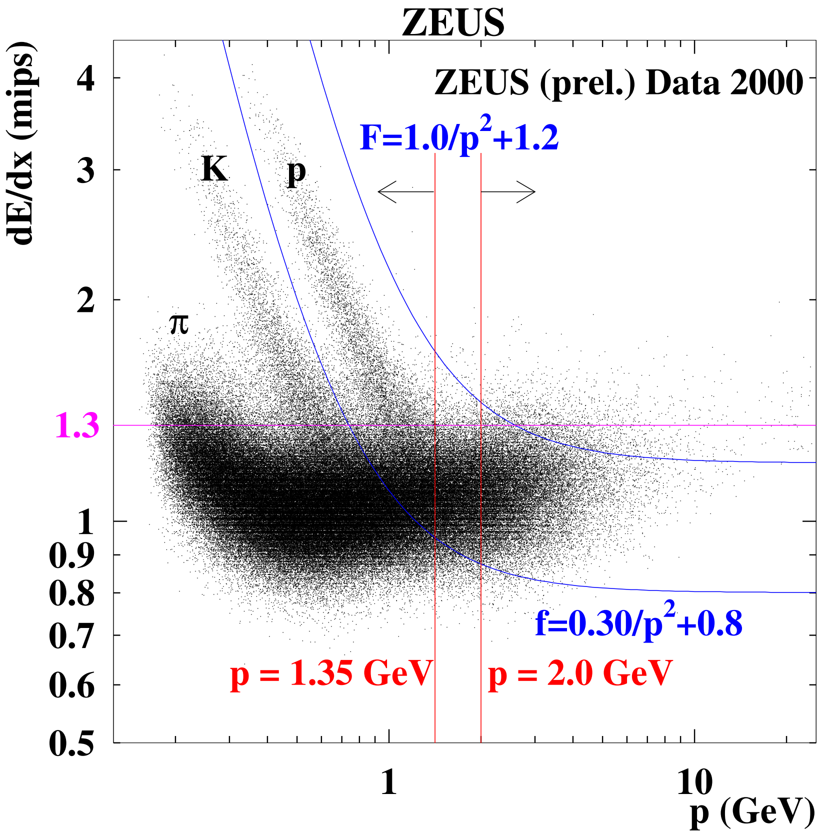
$D^{*\pm}$ in PhP : reconstructed $D^{*\pm}$ in tagged/untagged PhP events

Backup: Selection of p candidates

$P_T(p) > 0.15$ **GeV**

Define wide dE/dx p-band: $f < dE/dx < F$**, where**

$$f = 0.3/P^2 + 0.8 \;,\; F = 1.0/P^2 + 1.2$$



Scatter plot: subset of 2000 data for illustration

dE/dx **proton selection effective mainly for low-**P

Protons from $5q$ **decays can have higher momentum than the bulk of pions and kaons**

two strategies for p-selection:

1) $(dE/dx)_p$ **band with** $P < 1.35\,$**GeV and** $dE/dx > 1.3$

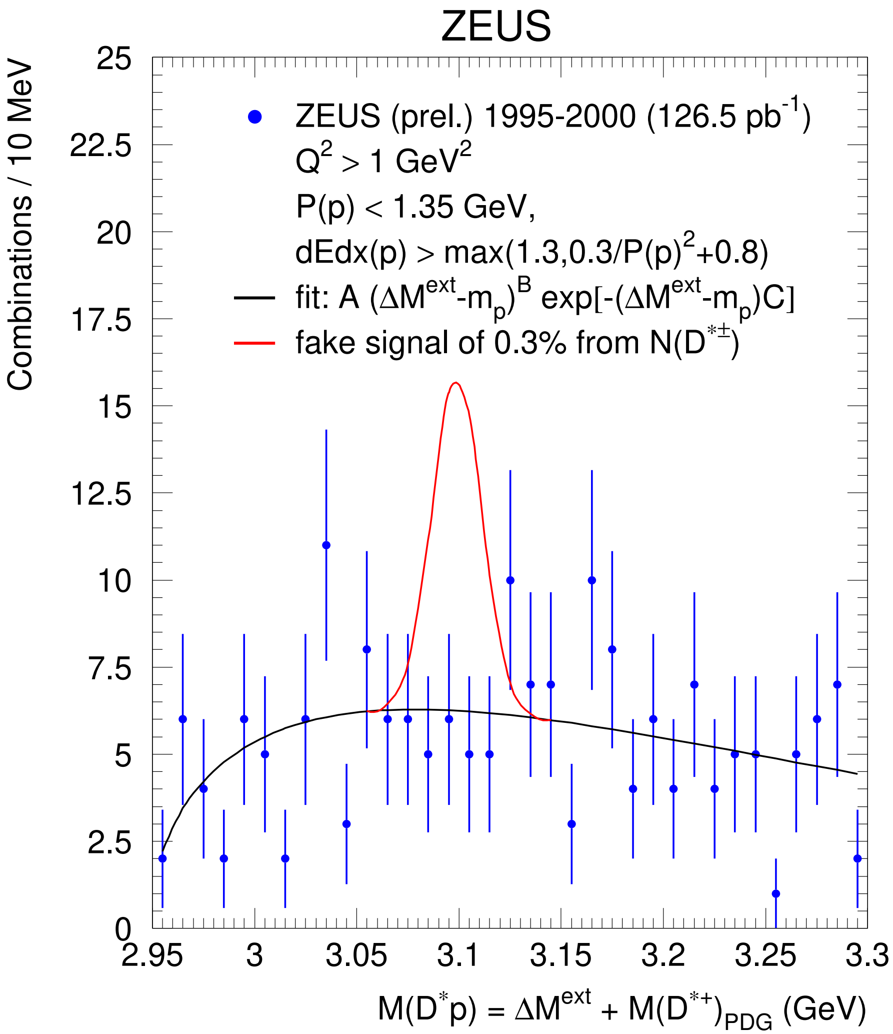
2) $(dE/dx)_p$ **band with** $P > 2\,$**GeV**

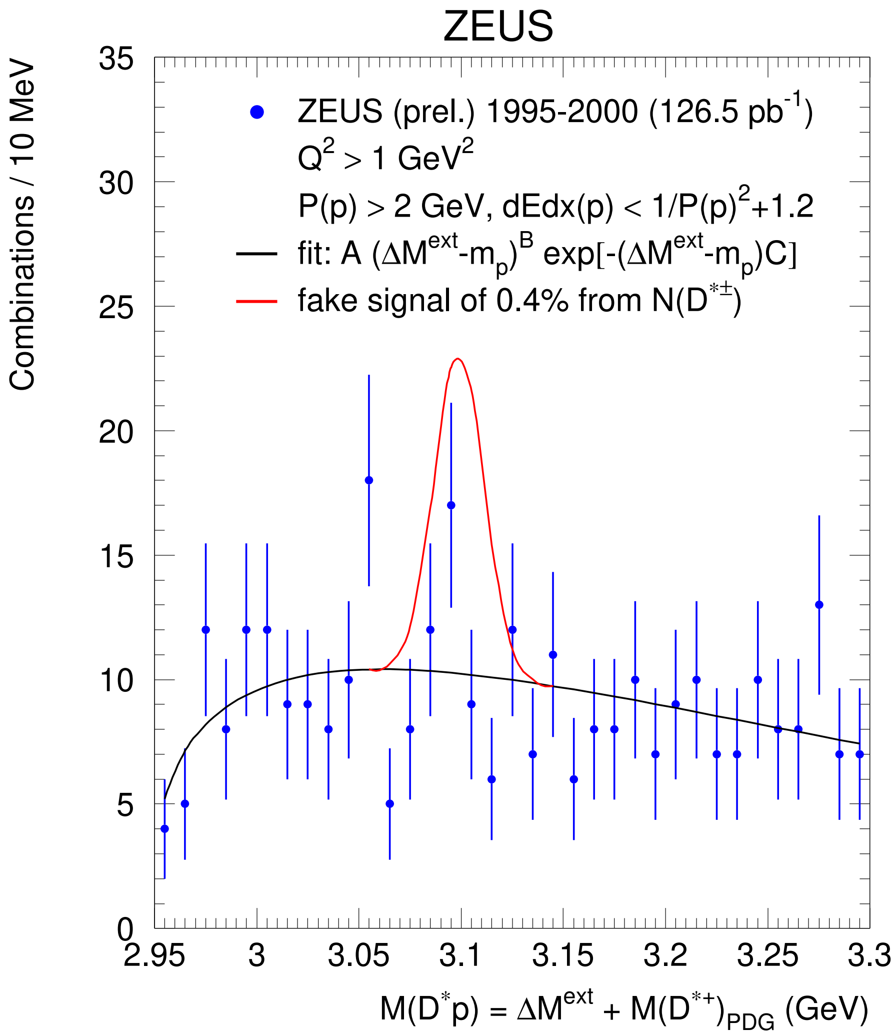
Backup: Systematic studies for Θ_c^0

- 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: Naïve signal expectations in DIS with $Q^2 > 1\,\mathrm{GeV}^2$

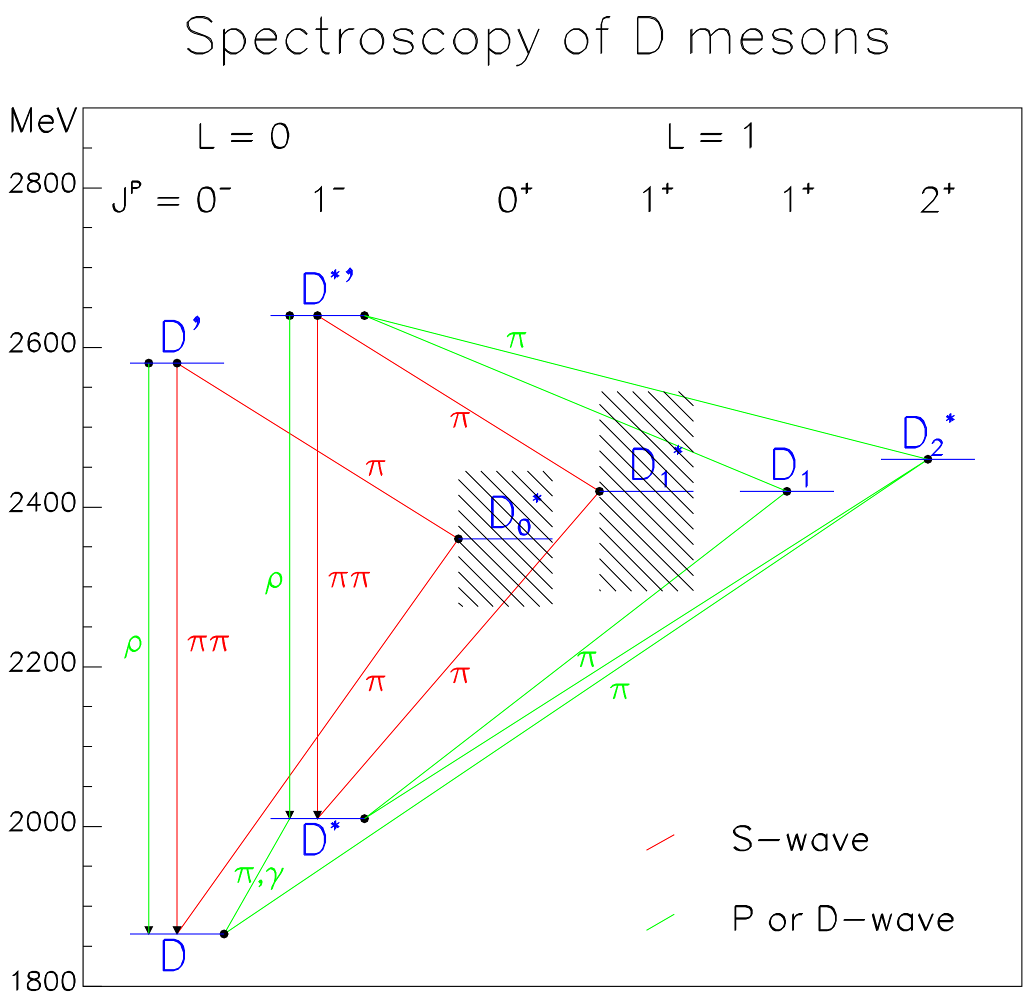




sensitivity is smaller

so large signals are certainly not here

Backup: Excited Charm Mesons



In HQET:

two doublets of P-wave D mesons

Wide: D_0^* $(J^P = 0^+)$, D_1^* $(J^P = 1^+)$

Narrow: D_1 (1^+), D_2^* (2^+)

Non-strange P-wave mesons:

$D_1^0(2420)$,$D_2^{*0}(2460)$

Both are narrow ($\approx$ 20 MeV)

and decay to D^* π

Charm-strange P-wave mesons:

$D_{s1}^{\pm}(2536)$,$J^P = 1^+(?)$

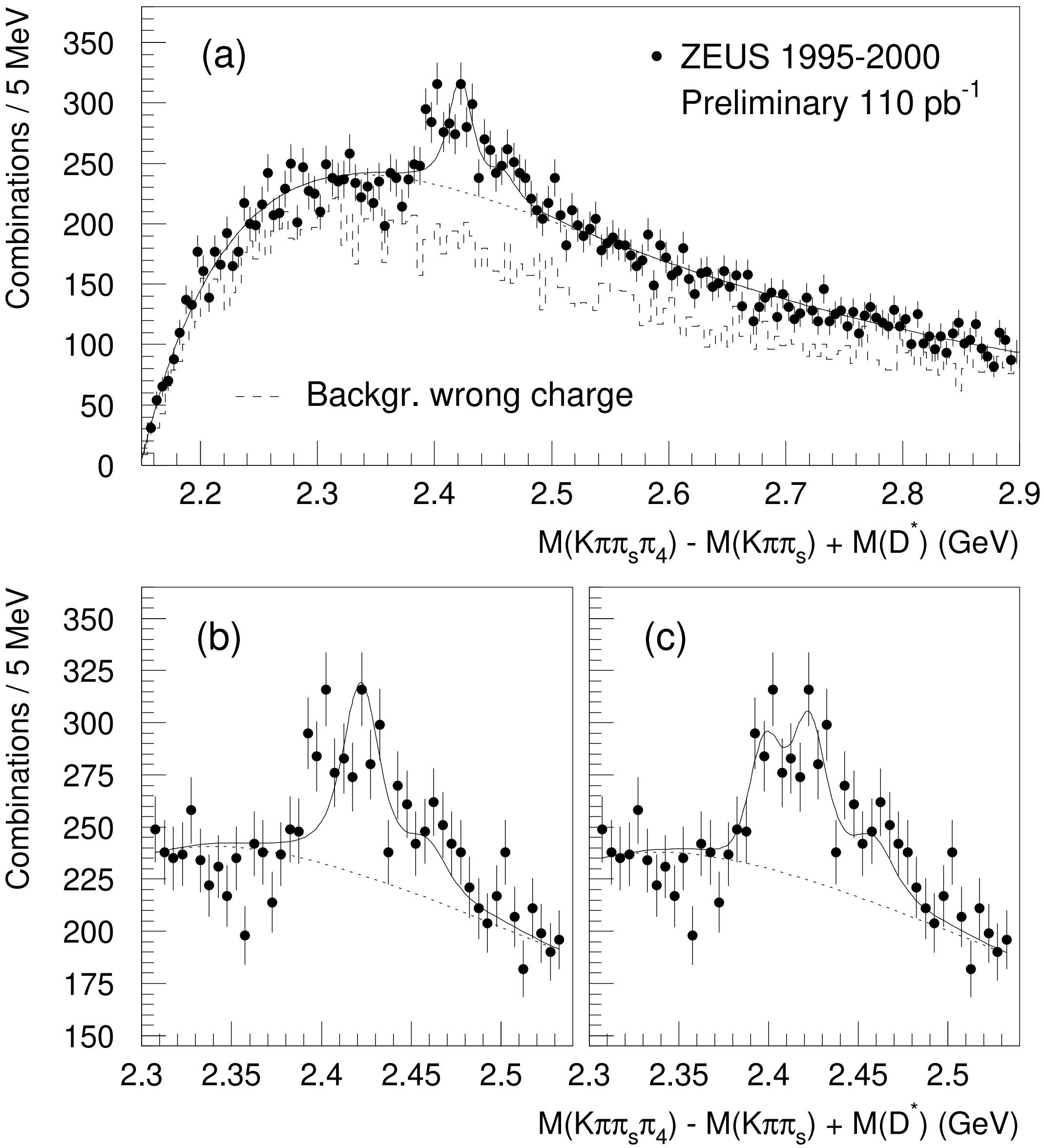
$D_{sJ}^{\pm}(2573)$,$J^P = 2^+(??)$

ZEUS 1995-2000 PHP+DIS

$$D^{*+} \rightarrow D^0\pi_s^+ \rightarrow (K^-\pi^+)\pi_s^+ \text{ (+c.c.)}$$

$$p_\perp^{D^*} > 2 \text{ GeV} \; , \; |\eta^{D^*}| < 1.5$$

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

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

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

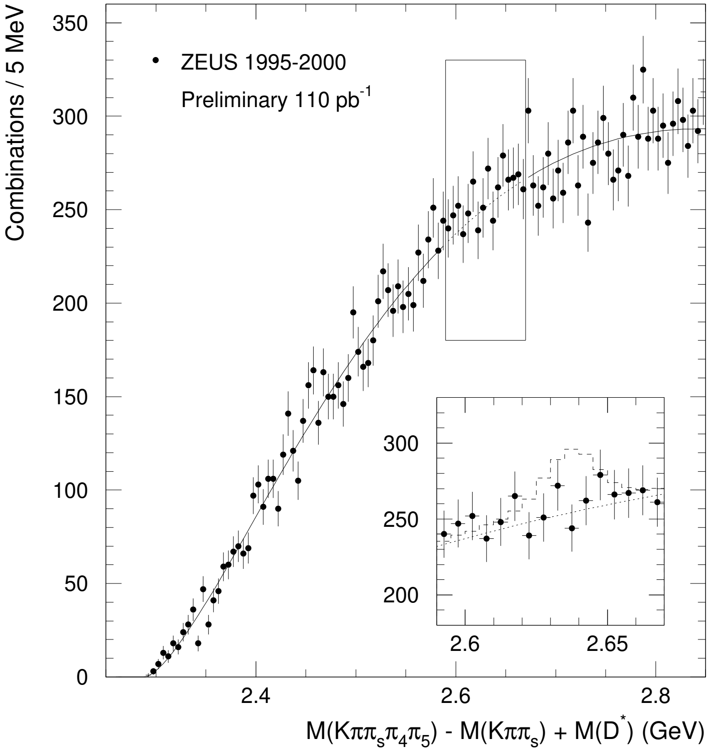
Additional narrow bump ?

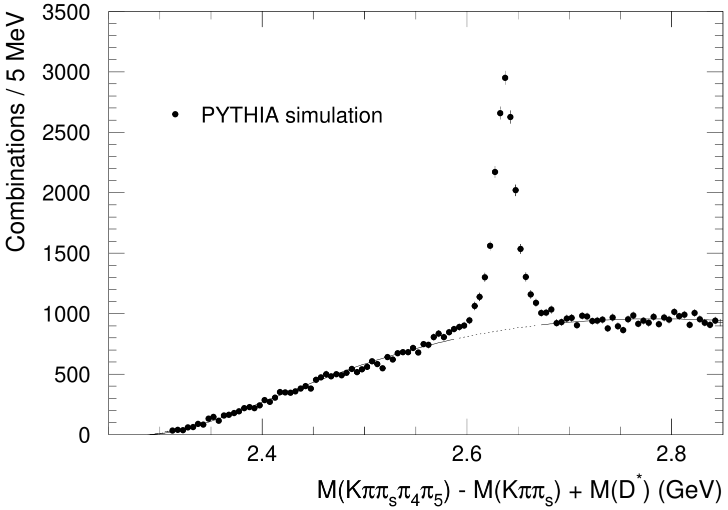
$N = 211 \pm 49$

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

New D meson ? Interference ?

Backup: search for radially excited $D^{*\prime\pm}$ meson





$\underline{D^{*\prime\pm} \to D^{*\pm}\pi^+\pi^-}$

Observed by DELPHI ($\sim 5\sigma$): $M = 2637\,\mathbf{MeV}$

$\Gamma < 15\,\mathbf{MeV}$

CLEO and OPAL did not confirm

$\Longleftarrow$ **ZEUS search**

$$\Delta M^{ext} = M(K\pi\pi_S\pi_4\pi_5) - M(K\pi\pi_s)$$

Search window: $2.59 < \Delta M^{ext} + M(D^{*+}) < 2.67\,\mathbf{GeV}$

covers both predictions and DELPHI's observation

after backgr. subtraction: "$N(D^{*\prime\pm})$"$= 91 \pm 75$

Using world average for $f(c \to D^*)$**:**

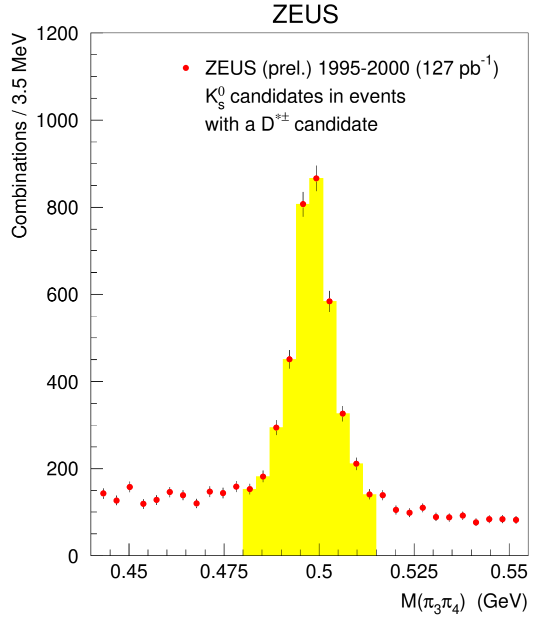
$$f(c \to D^{*\prime+}) \cdot B_{D^{*\prime+}\to D^{*+}\pi^+\pi^-} < 0.7\% \quad (95\% \quad \text{C.L.})$$

(ZEUS prel.)

somewhat stronger than the 0.9% **limit obtained by OPAL**

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

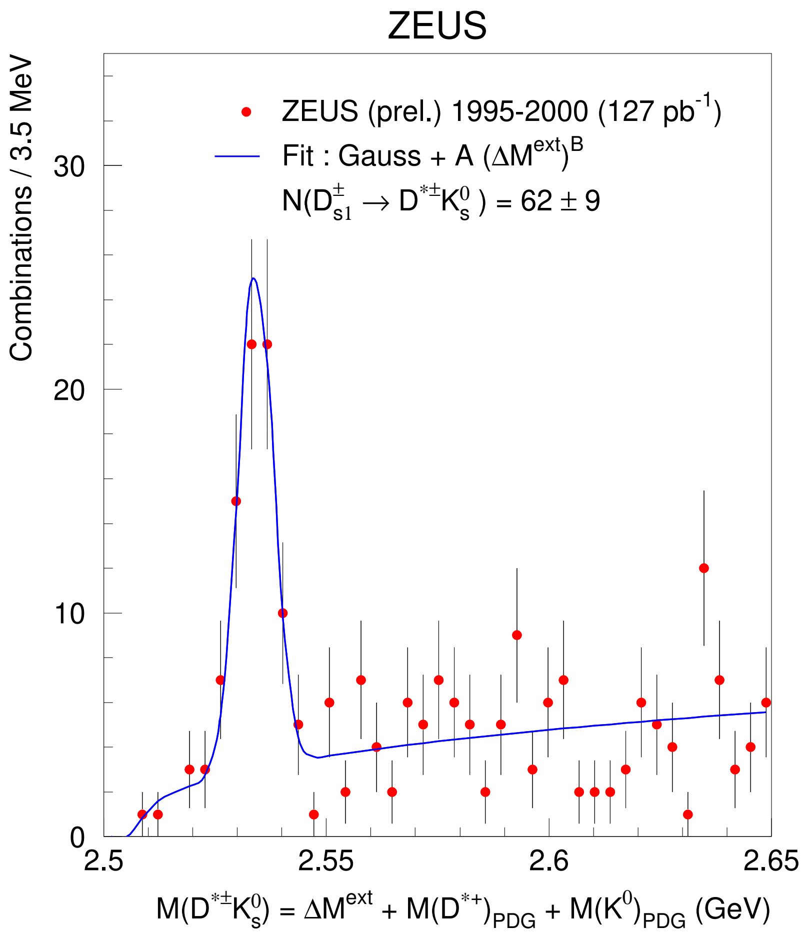
$$D_{s1}^{\pm}(2536) \rightarrow D^{*\pm}K_s^0\ , \qquad K_s^0 \rightarrow \pi^+\pi^-$$



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

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

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



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

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

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

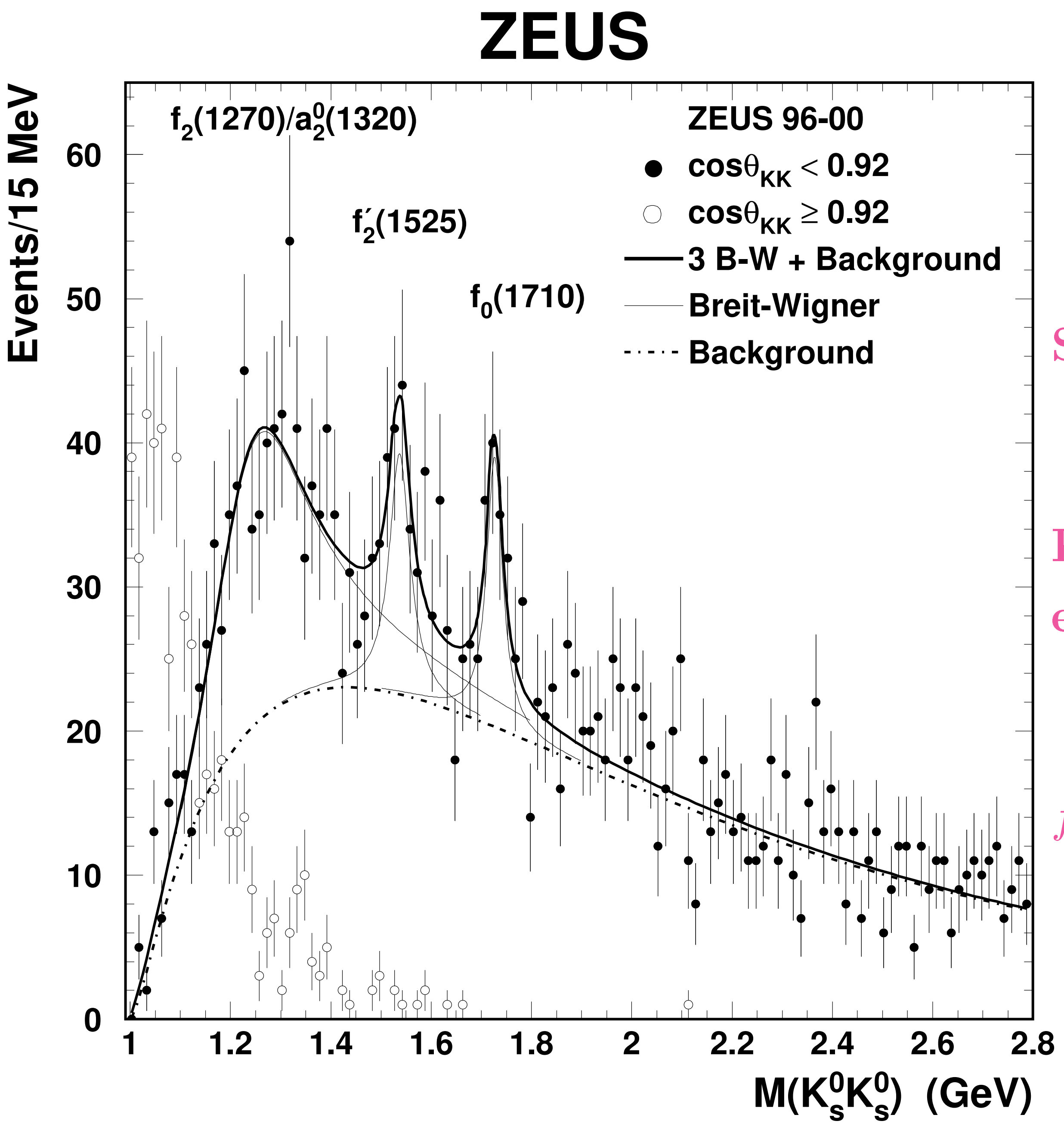
CLEO ($D_{s1}^{+} \rightarrow D^{*0}K^+$) : $R = -0.23^{+0.40}_{-0.32}$

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 ??