Spectroscopy in ep collisions at HERA

Dmitry Ozerov
ITEP/DESY

on behalf of the
H1 and ZEUS
collaborations

O U T L I N E:

Introduction

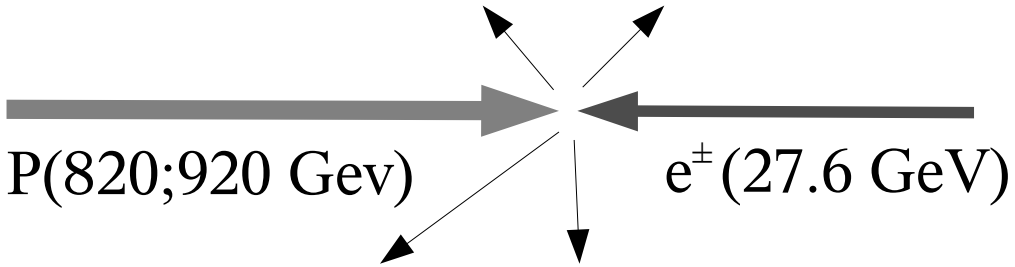
Search for the glueball in the $K_s^0 K_s^0$ final state

Search for the Strange Pentaquark Θ^+

Search for the Exotic baryon in the channels $\Xi\pi$

Search for the Charm Pentaquark decaying to $D^* p$

Summary



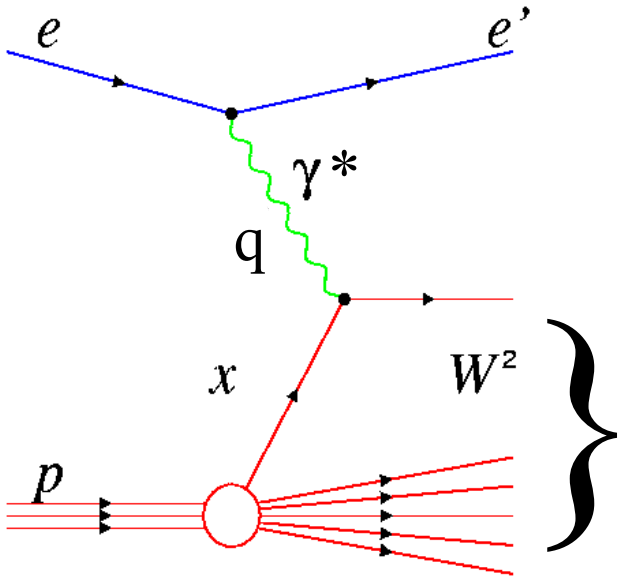
ep kinematics :

energy c.m. : $\sqrt{s}$ = 301-319 GeV

hadronic energy : W=m(γ*p)

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

inelasticity : $y = Q^2/(x_{Bj}\ s)$



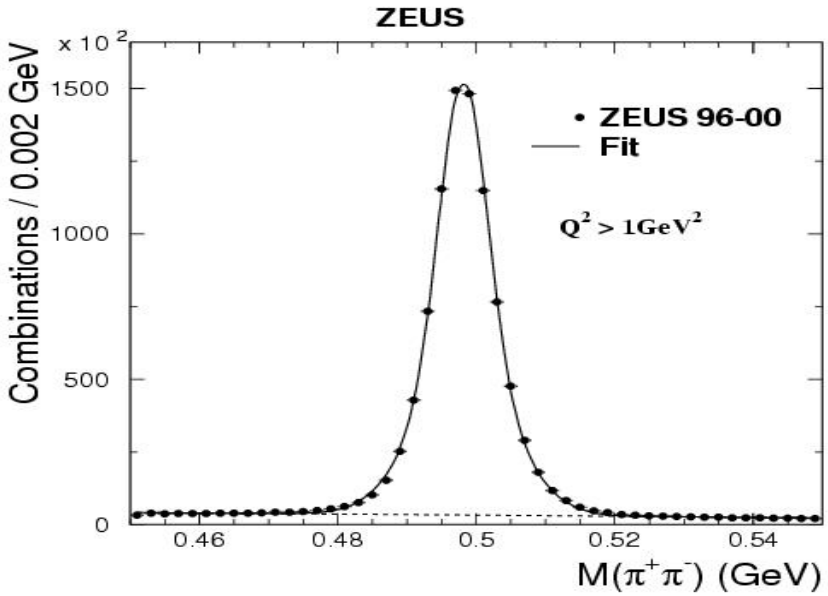
two regimes : $Q^2 \approx 0$ GeV^2 : **Photoproduction**

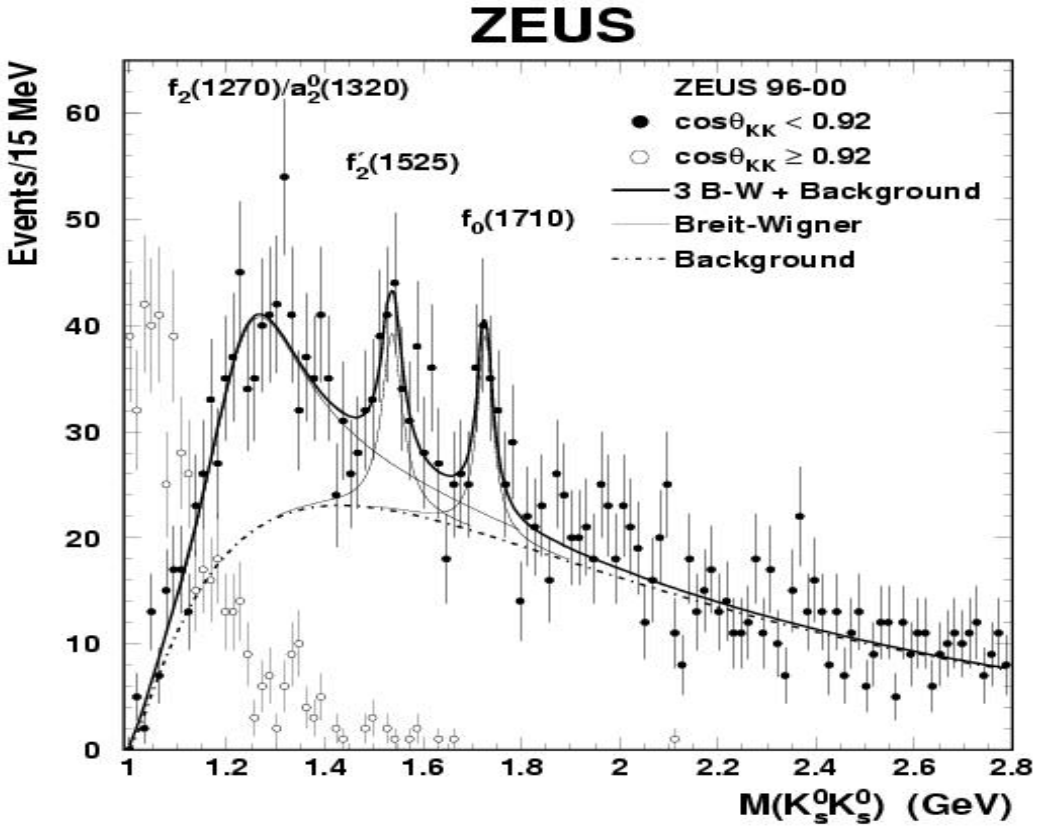
$Q^2 > 1$ GeV^2 : **Electroproduction (DIS)**

$K_s^0 K_s^0$ - resonances

ZEUS HERA-I data (121 pb^{-1})
DIS ($Q^2 > 1$ GeV^2)
866800 ± 1000 inclusive K_s^0 is used for:

- Glueball search (events with 2 K_s^0)
- Strange pentaquark search





$f_2'(1525)$ well seen.

Fit : $m = 1537^{+9}_{-8}$ MeV

$\Gamma = 50^{+34}_{-22}$ MeV

PDG: $m = 1525 \pm 5$ MeV

$\Gamma = 76 \pm 10$ MeV

Candidate for glueball f_0 :

Fit : m = 1726+7 MeV

$\Gamma = 38^{+20}_{-14}$ MeV

PDG: $m = 1714 \pm 5$ MeV

$\Gamma = 140 \pm 10$ MeV

Search for the pentaquark

$Q^2 > 20\ GeV^2$

Fit : background + two Gaussians

$\chi^2/ndf = 35/44$

Statistical significance(from fit):

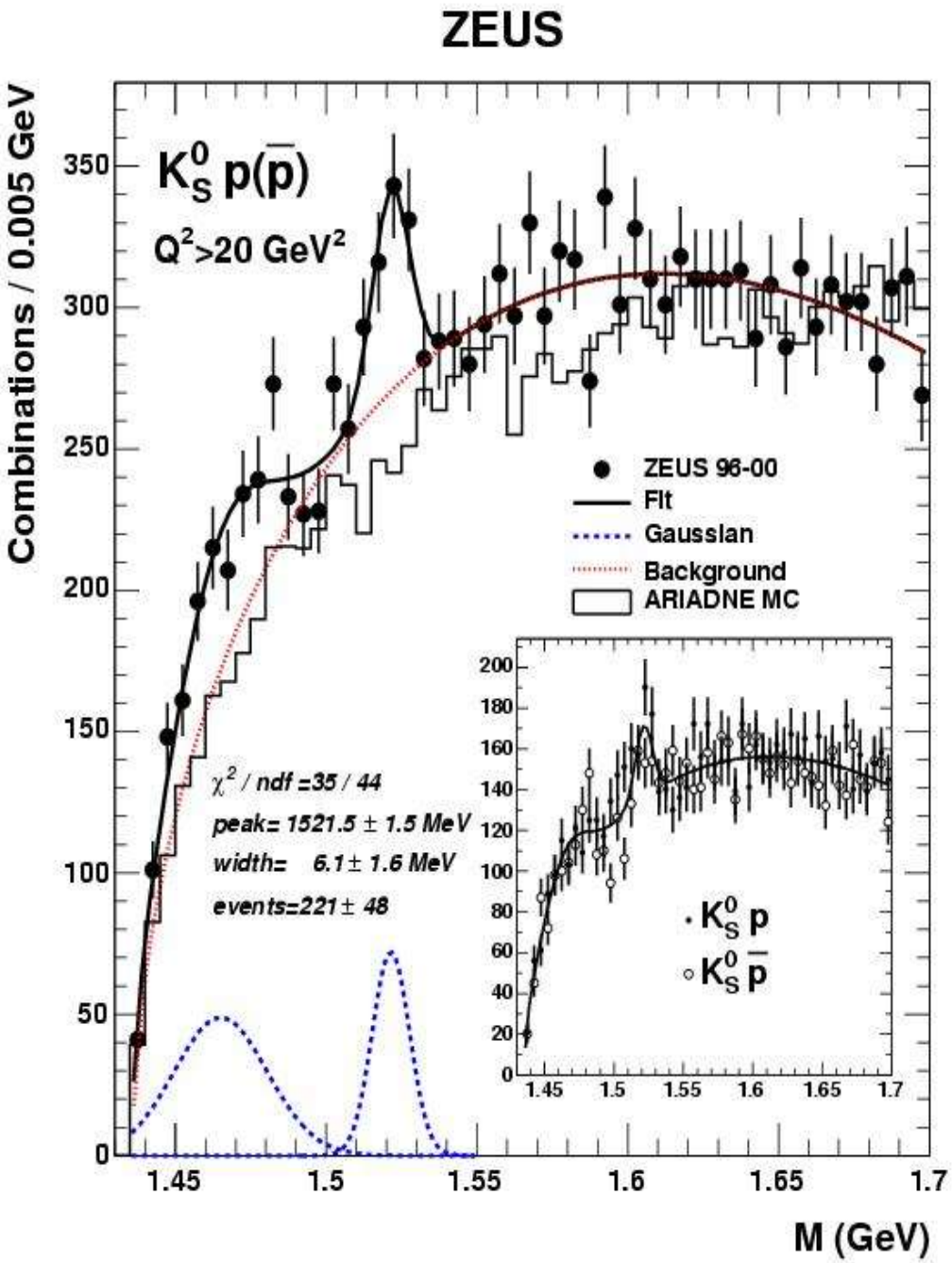
$(221 \pm 48) \sim 4.6\ \sigma$

Mass: $1521.5 \pm 1.5\ (stat)^{+2.8}_{-1.7}(sys)$ MeV

Gaussian width : 6.1 ± 1.5 MeV

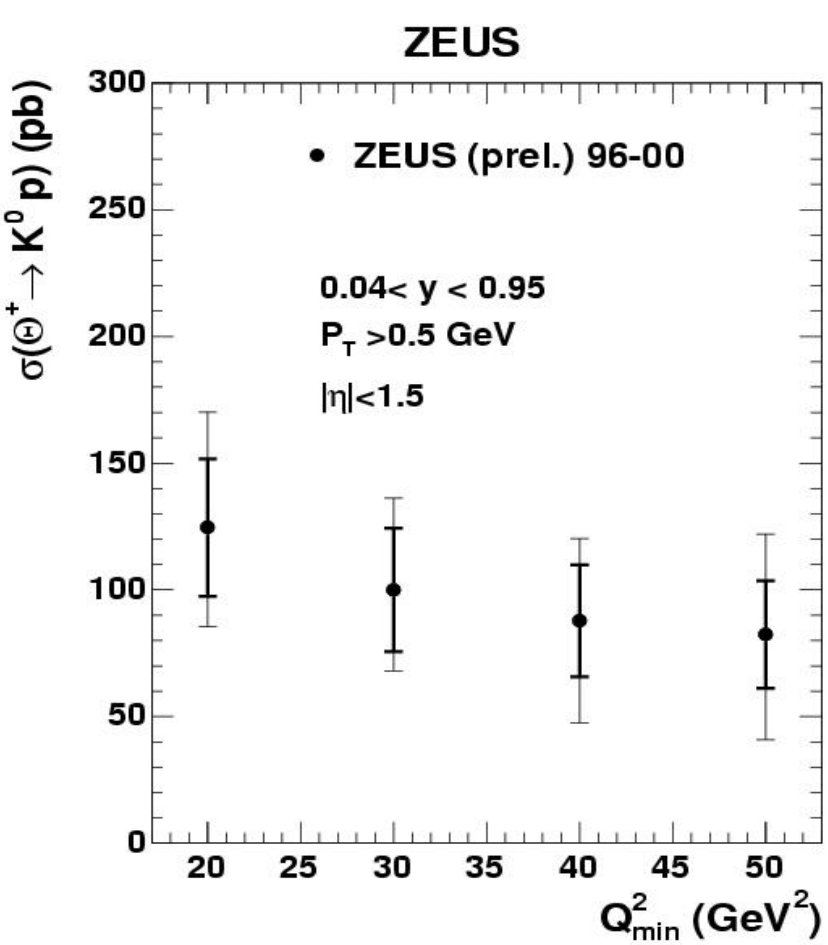
(Breit-Wigner fit gives width : 8 ± 4 MeV)

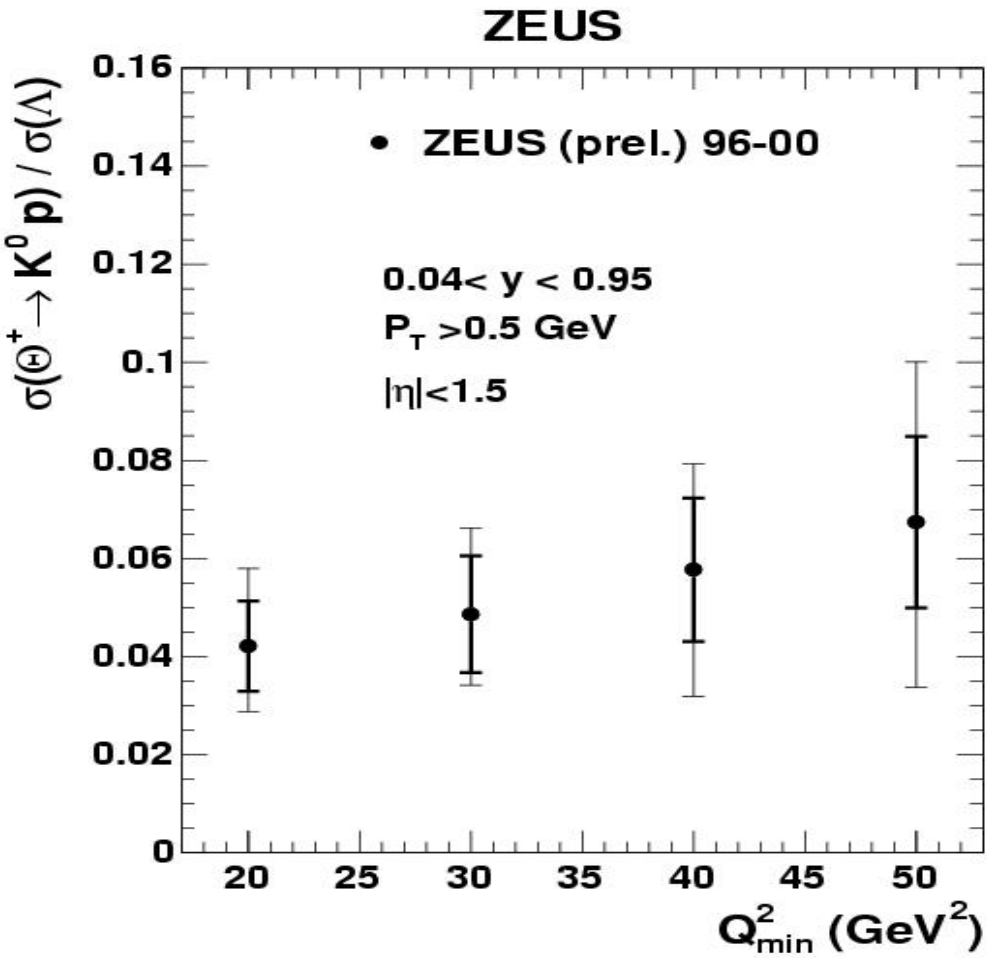
convoluted with gaussian-resolution of 2 MeV



inset : K_s^0-proton and K_s^0-antiproton

- Signal is seen in both charges
- fit to K_s^0-antiproton gives $(96 \pm 34) \sim 3\ \sigma$
- first observation of antipentaquark?





$\Theta^{\pm}$ cross section in the visible range :

$Q^2 > 20\ \mathrm{GeV}^2$, $0.04 < y < 0.95$

$P_T(\Theta^{\pm}) \geq 0.5\ \mathrm{GeV}, |\eta(\Theta^{\pm})| \leq 1.5$

$$\sigma(ep \rightarrow e\Theta^{\pm}X \rightarrow eK^0_s pX) = 125 \pm 27^{+37}_{-28}\ \mathrm{pb}$$

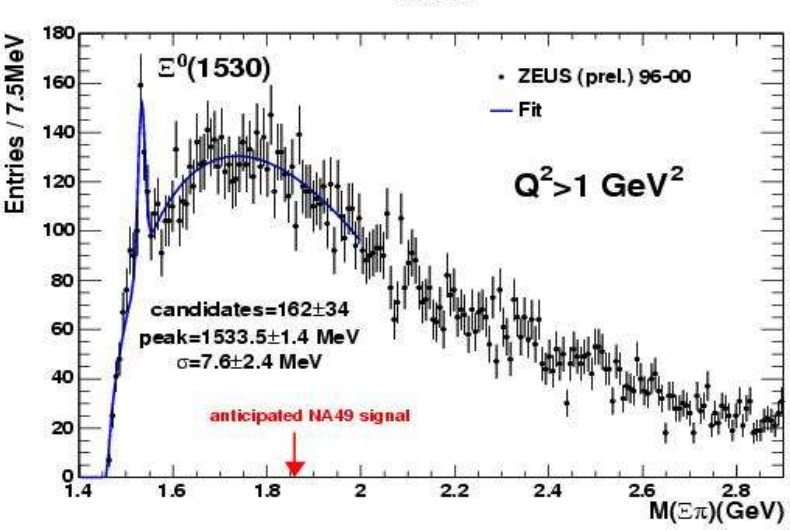
Rate compared to Λ ($\rightarrow p\pi$) :

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

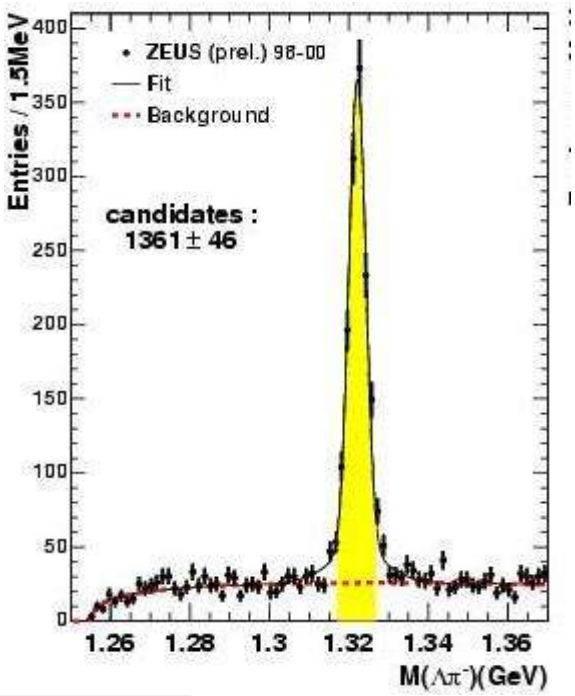
protons for Λ were selected in the same way (same momentum region) as for $\Theta^{\pm}$

Search for the double strange pentaquarks

$\Xi_{5q}^{--(0)} \rightarrow \Xi^{-(+)}\pi^-$ (observed by NA49)



Ξ^- (+ c.c.) ~ 2600 candidates



$\Xi_{5q}^{--} \rightarrow \Xi^- \pi^-$

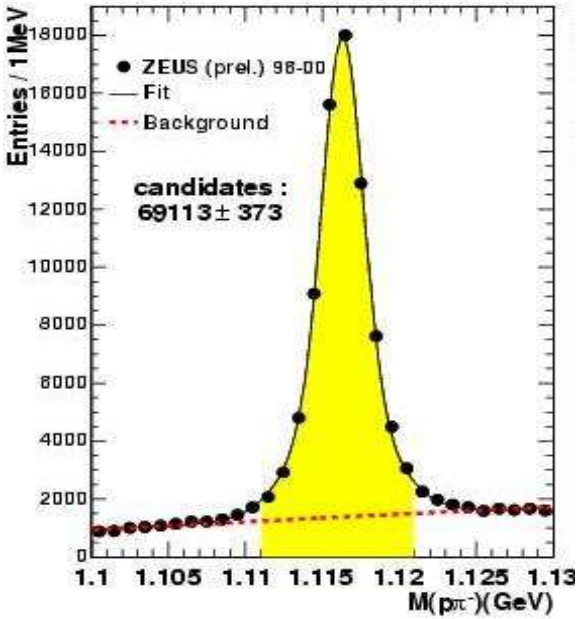
$\downarrow$

$\rightarrow \Lambda^0 \pi^-$

Decay chain: $\downarrow$

$\rightarrow p \pi^-$

Λ(+c.c.) ~ 130000



No signal at NA49 mass
Well known $\Xi^0(1530)$ signal is visible

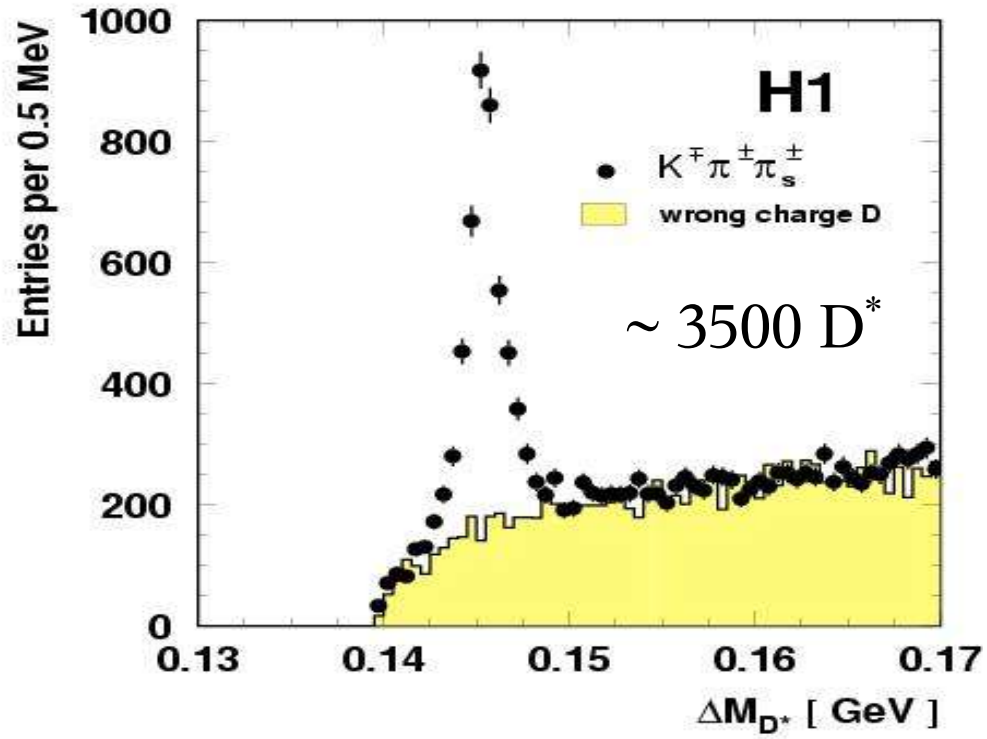
Different production mechanism ?

Search for the charmed pentaquark (with the decay $\Theta_c \to D^* p$ (+c.c.))

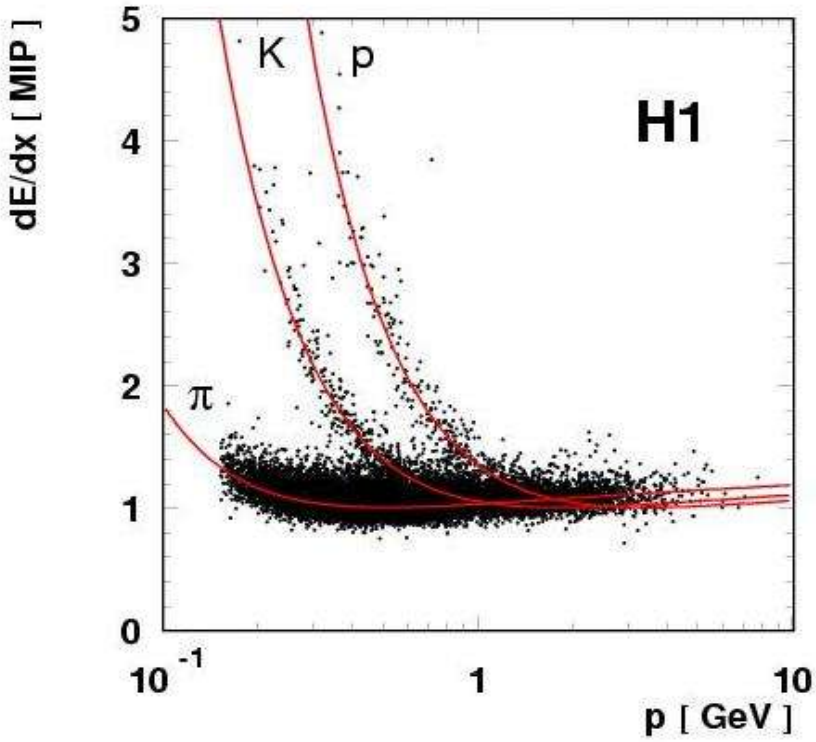
H1 search in DIS : $1 < Q^2 < 100$ GeV^2

75 pb^{-1} $0.05 < y < 0.7$

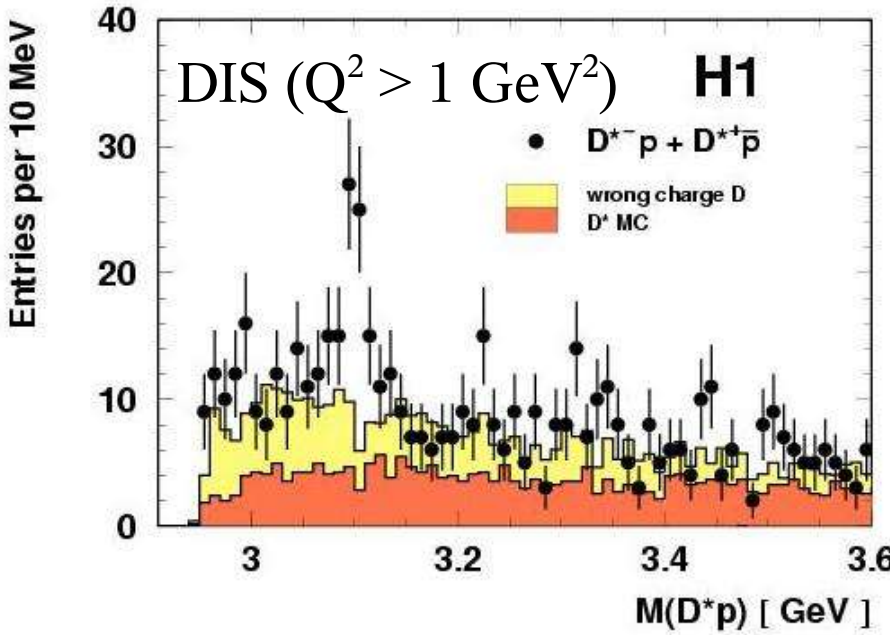
$D^{*+} \to D^0 \pi_s^+ \to (K^- \pi^+) \pi_s^+$

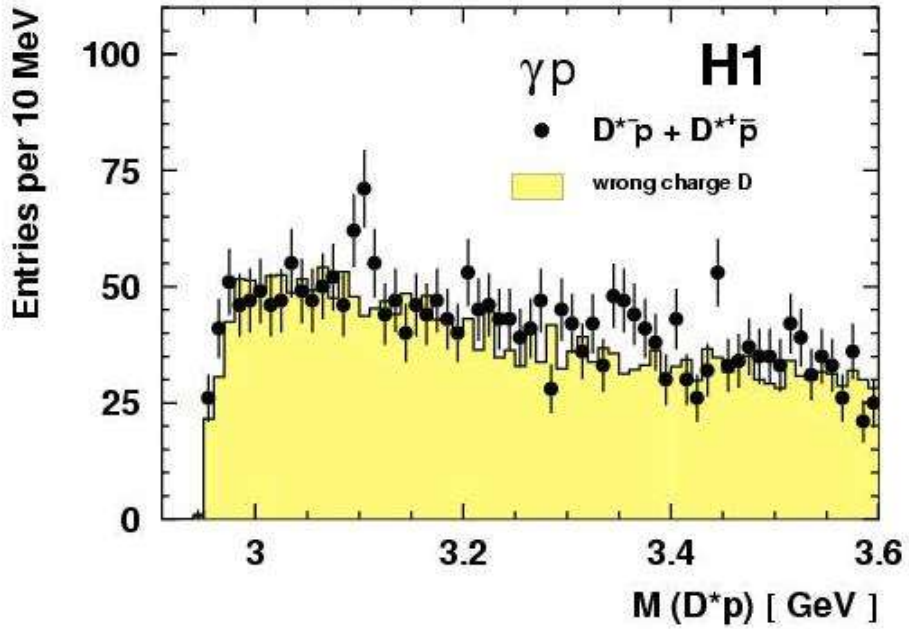


Proton identification by dE/dx



Evidence of narrow resonance signal in D*p (+c.c.)

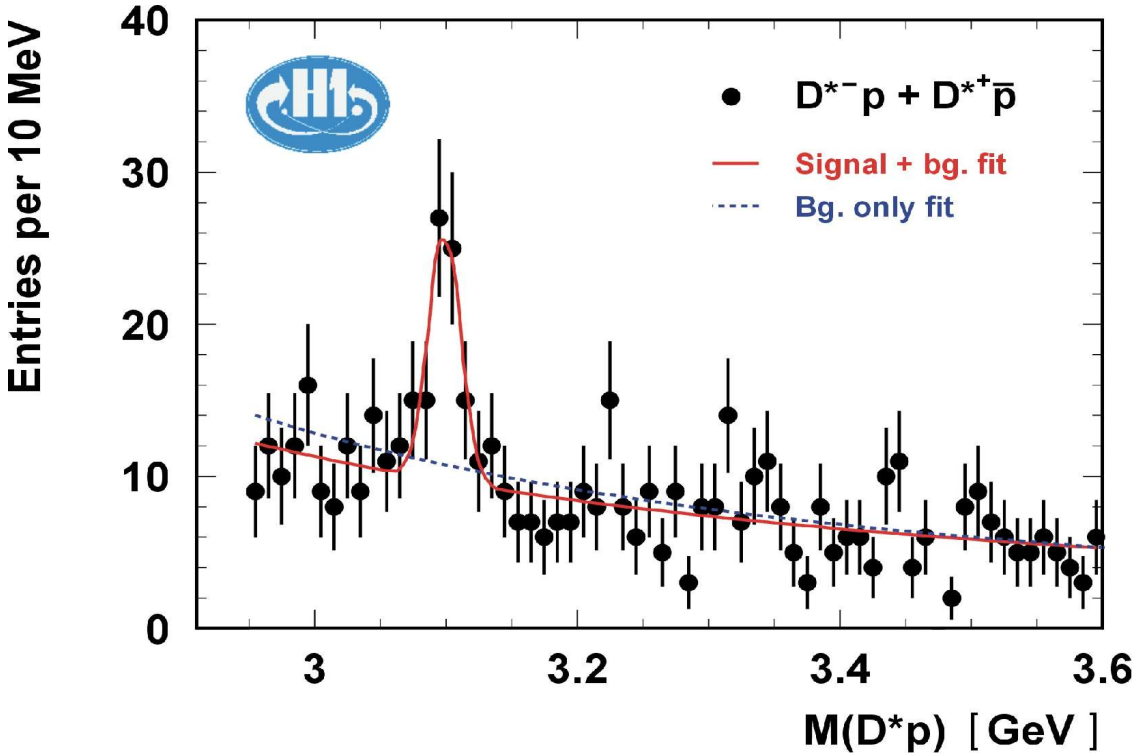




Signal at 3.1 GeV both in DIS and photoproduction samples

reasonable description by sum of :

- "wrong charge D^0" (non charm induced background)
- D^* combined with random p (MC)



Significance estimation

DIS sample

Fit : Gaussian + power law bkgr.

Mass : 3099 ± 3(stat) ± 5(sys) MeV
Width : 12 ± 3 MeV

(consistent with experimental resolution)

within 2 σ :

$N_S = 50.6 \pm 11.2$

$(N_S + N_B) = 95$

Poisson probability (4×10^{-8}) for flat background (51.7 ± 2.7 events) to fluctuate to 95 events corresponds to 5.4 σ

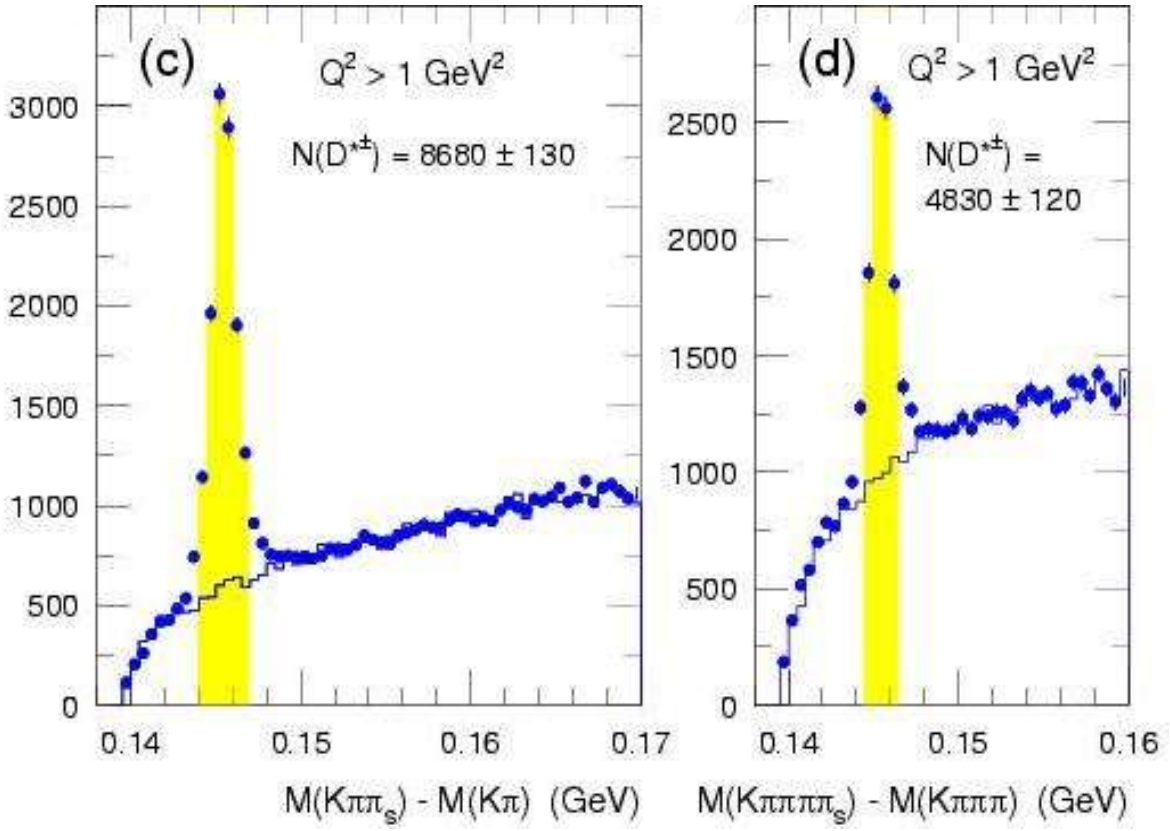
From the change in the maximum log-likelihoods of fits (w and w/o signal hypothesis) statistical significance is 6.2 σ

Search for the charmed pentaquark with ZEUS data sample

1995-2000 data (126 pb^{-1})

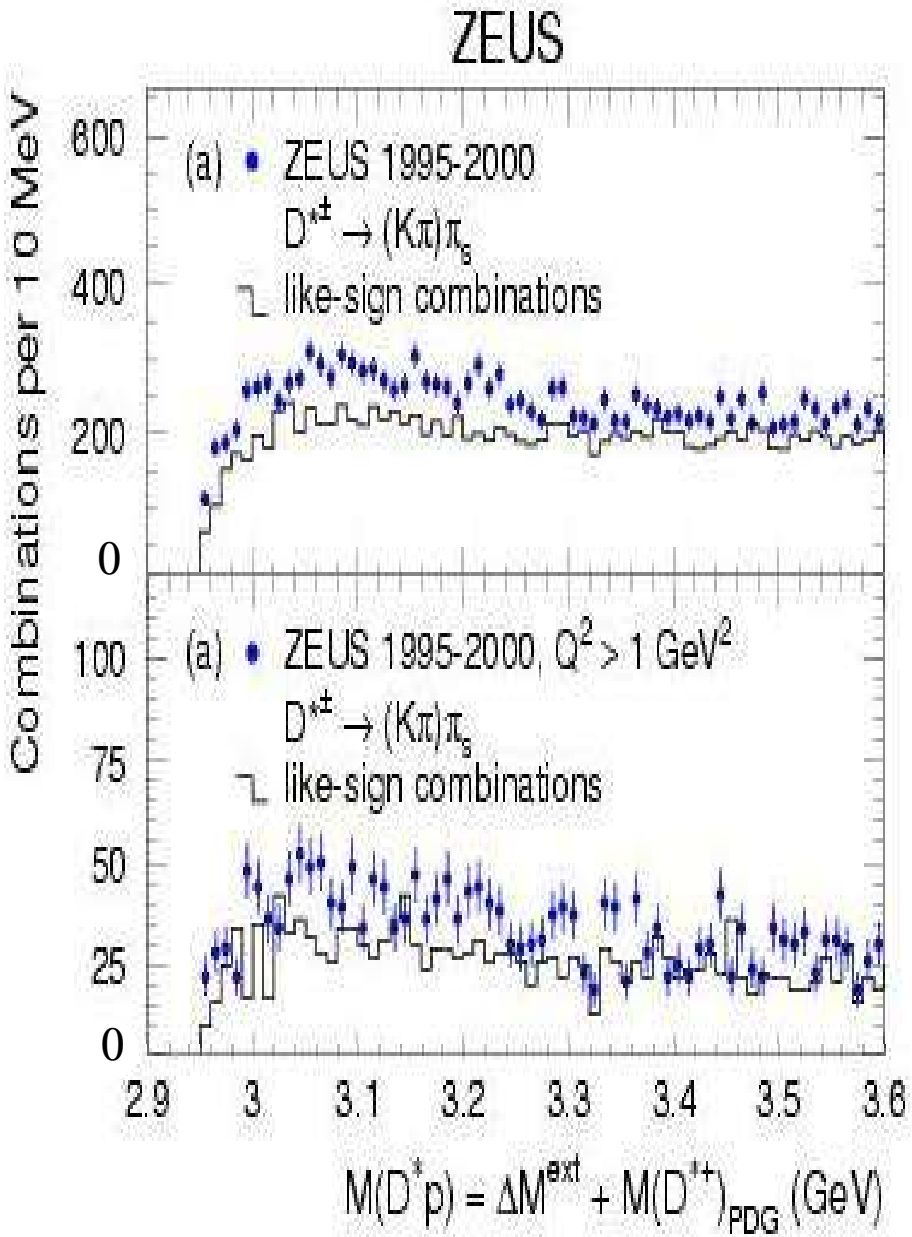
Two D* decay channels:

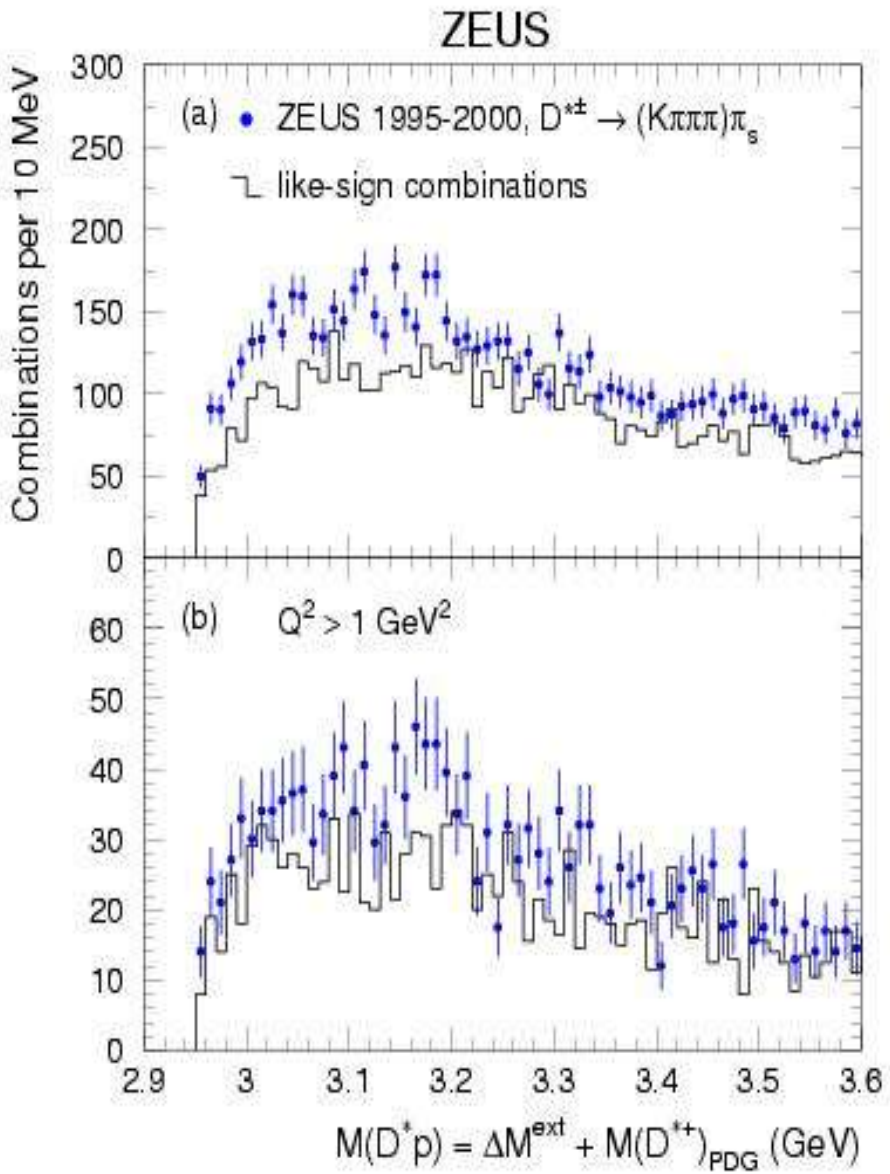
$D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow (K^-\pi^+)\pi_s^+$ $\quad$ $D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow (K^-\pi^+\pi^+\pi^-)\pi_s^+$



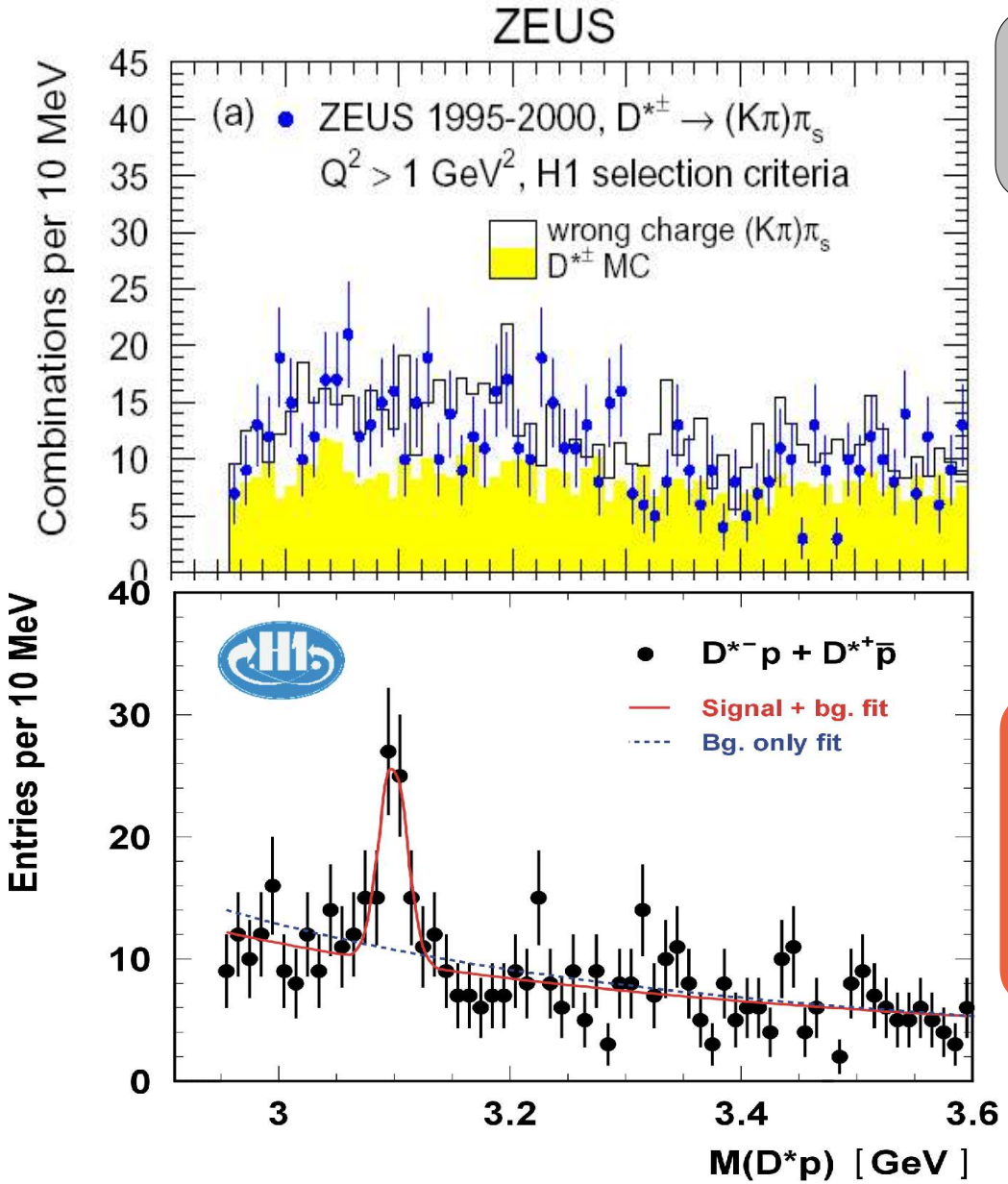
N(D*) ~ 62500 (inclusive)

N(D*) ~ 13500 ($Q^2 > 1$ GeV^2)





No hint for the signal observed by H1 at 3099 MeV



Comparison of H1 and ZEUS in similar phase space region

ZEUS didn't observe Θ_c signal in a data sample 1.7 times of H1 data sample.

Observation of ZEUS and H1 are not compatible

N_Θ / N_{D^*} :

< 0.0035 (ZEUS)

~ 0.01 (H1)

More quantitative comparisons require detector efficiency corrections.

Conclusion

- First observation in ep DIS of the states (in $K_s^0 K_s^0$):
  at mass 1537 MeV (possibly $f'_2(1525)$)
  at mass 1726 MeV (close to glueball candidate $f_0(1710)$)

- Evidence for a narrow baryonic state at mass 1521.5 MeV decaying to $K_s^0 p$ (+ c.c.) in central fragmentation region. Consistent with the observed $\Theta(1540)$ pentaquark state.

- No evidence for the NA49 $\Xi\pi$ signal at 1862 MeV

- Evidence from H1 for the narrow resonance in $D^* p$ system at mass 3099 MeV
  With larger statistics ZEUS does not see this signal

Backup slides

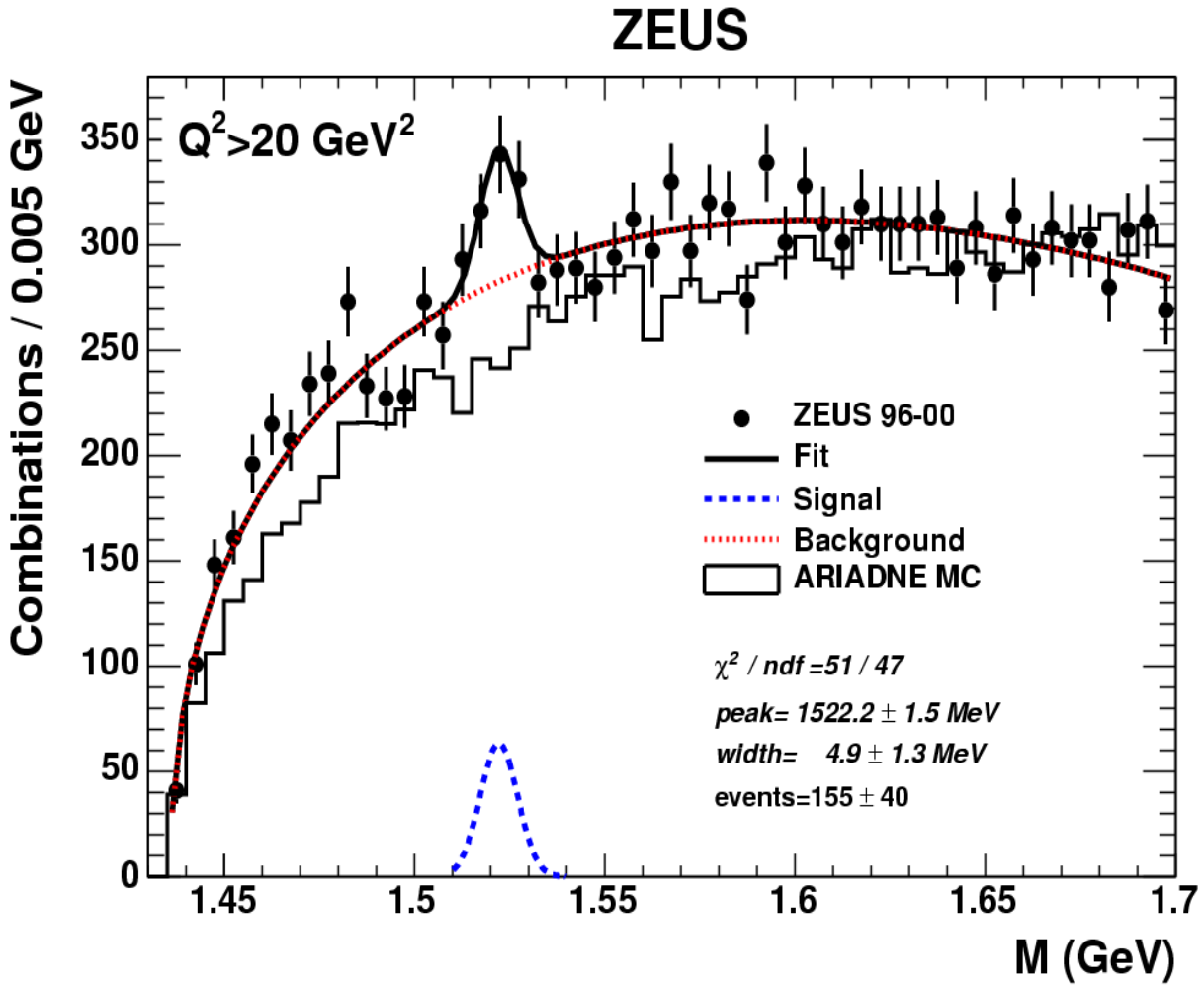
Fit : background + 1 gaussian

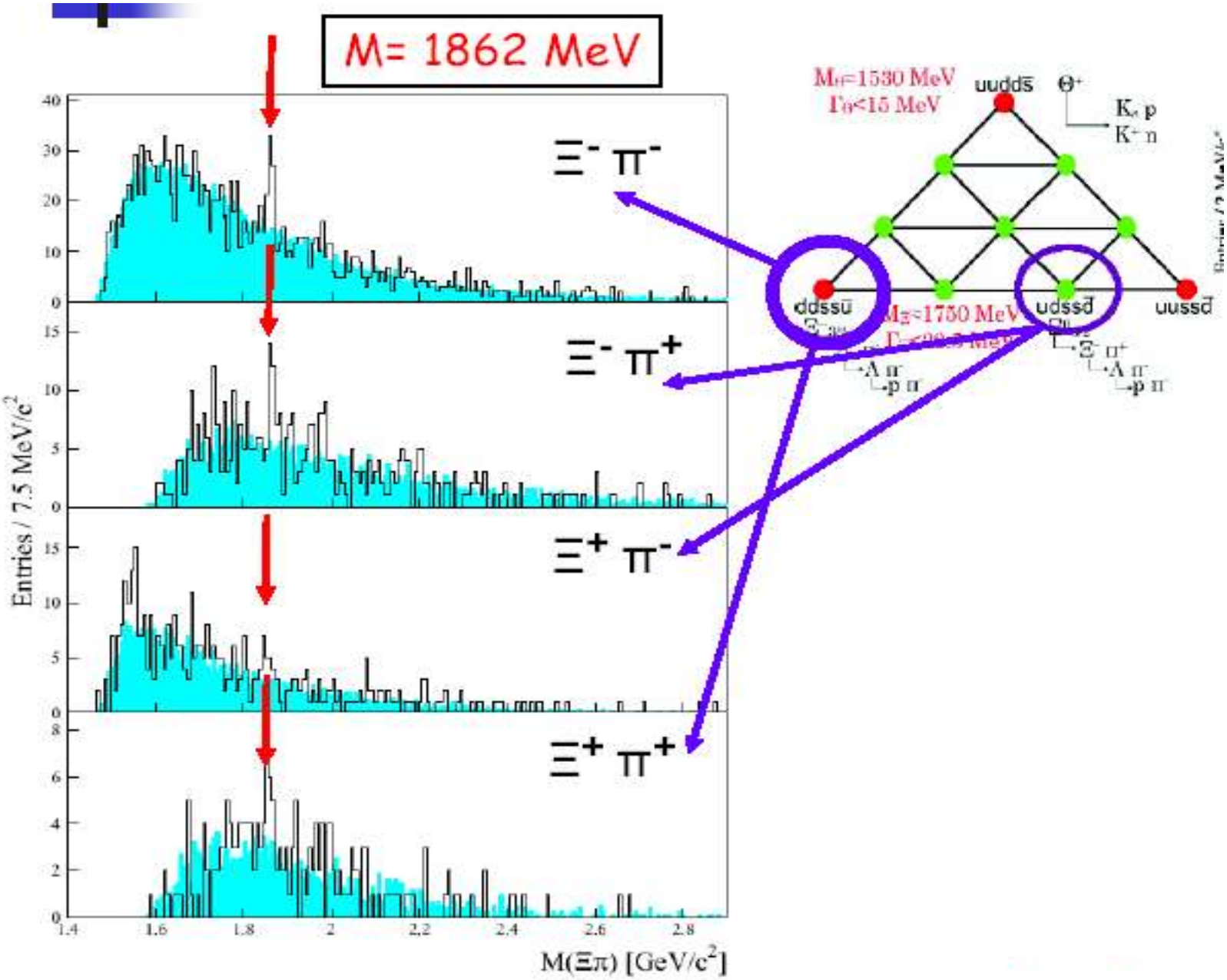
χ^2/ndf = 51/47

Mass : 1522.2 ± 1.5 MeV

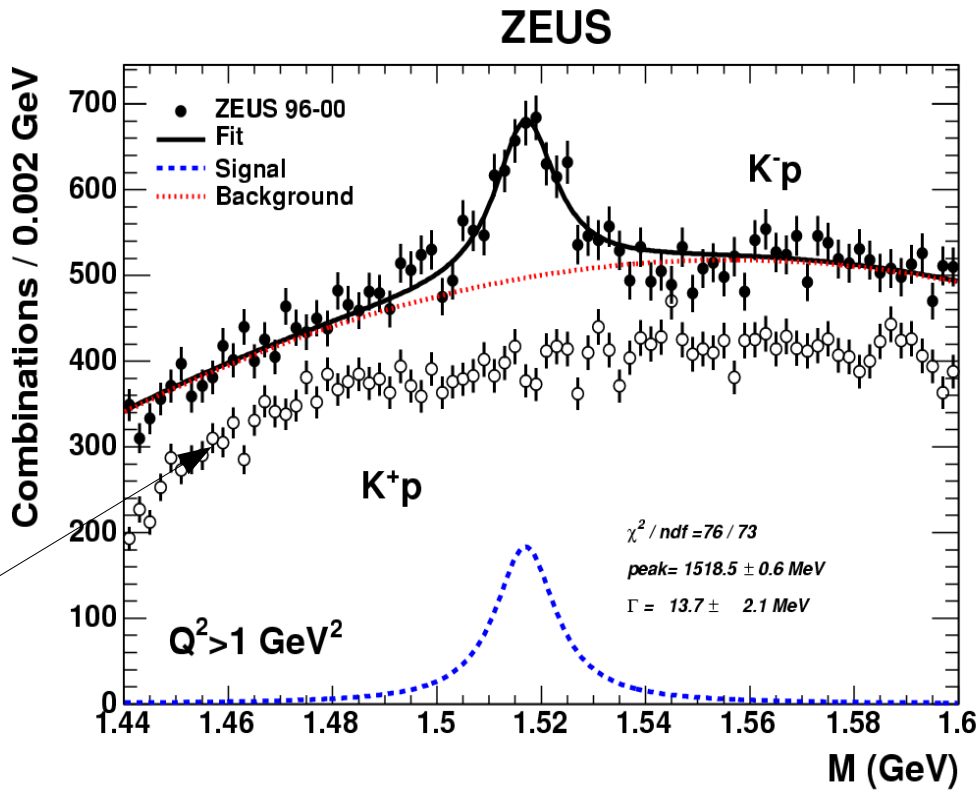
Width : 4.9 ± 1.3 MeV

(width consistent with the experimental resolution)



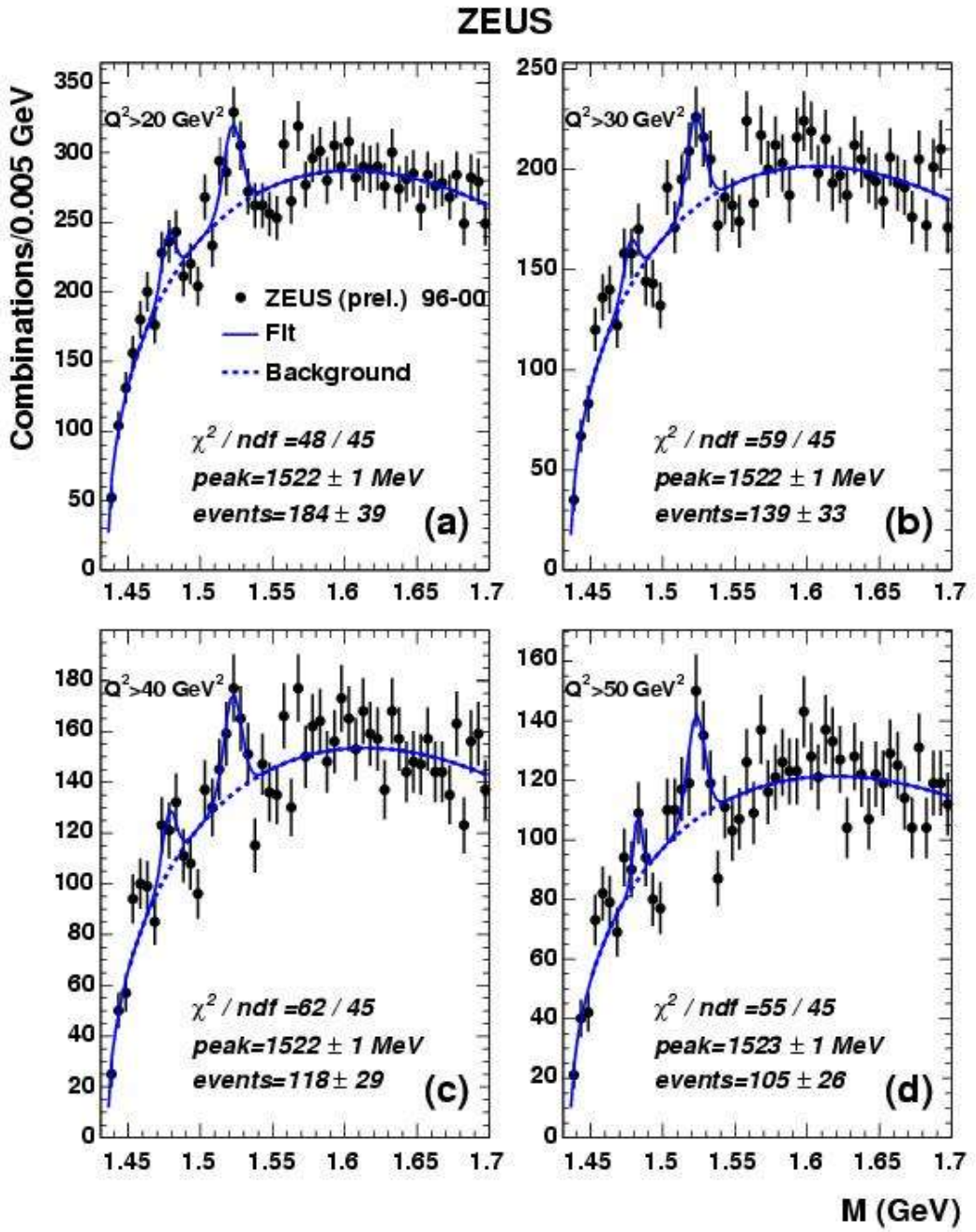

M= 1862 MeV
Ξ⁻ π⁻
Ξ⁻ π⁺
Ξ⁺ π⁻
Ξ⁺ π⁺
Entries / 7.5 MeV/c²
M(Ξπ) [GeV/c²]
MΘ=1530 MeV
ΓΘ<15 MeV
uudds̄
Θ⁺
dssū
udssd̄
uussd̄
MΞ=1750 MeV

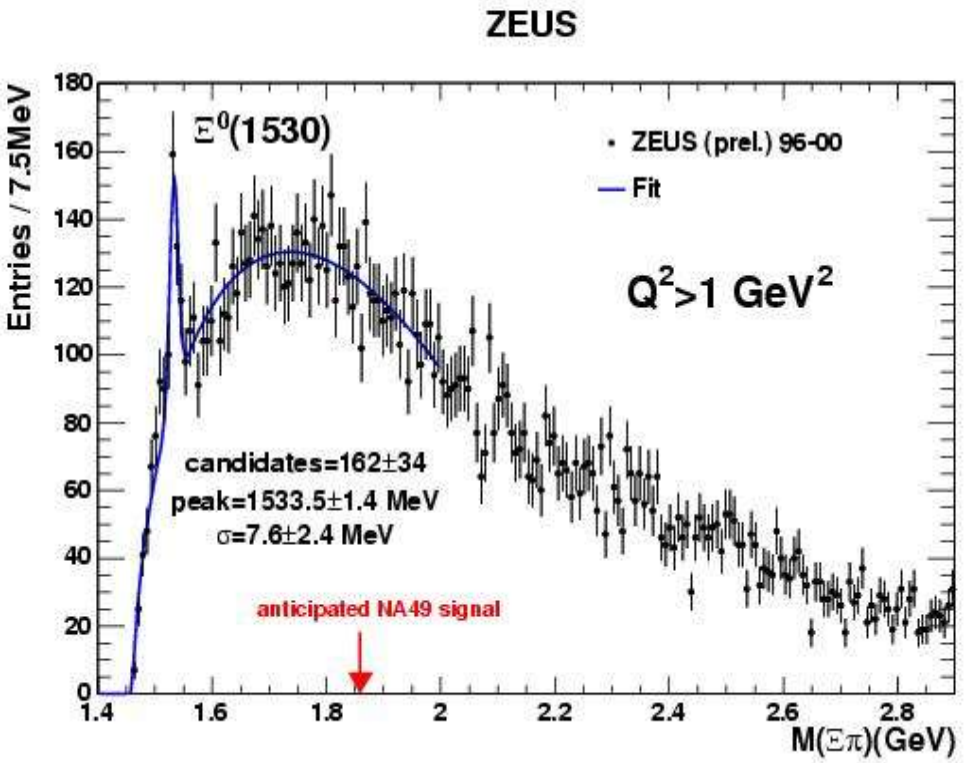
$\Lambda(1520) \rightarrow K^- p + c.c.$
Mass : 1519.5 ± 1.0 MeV
Width : 15.6 ± 1.0 MeV



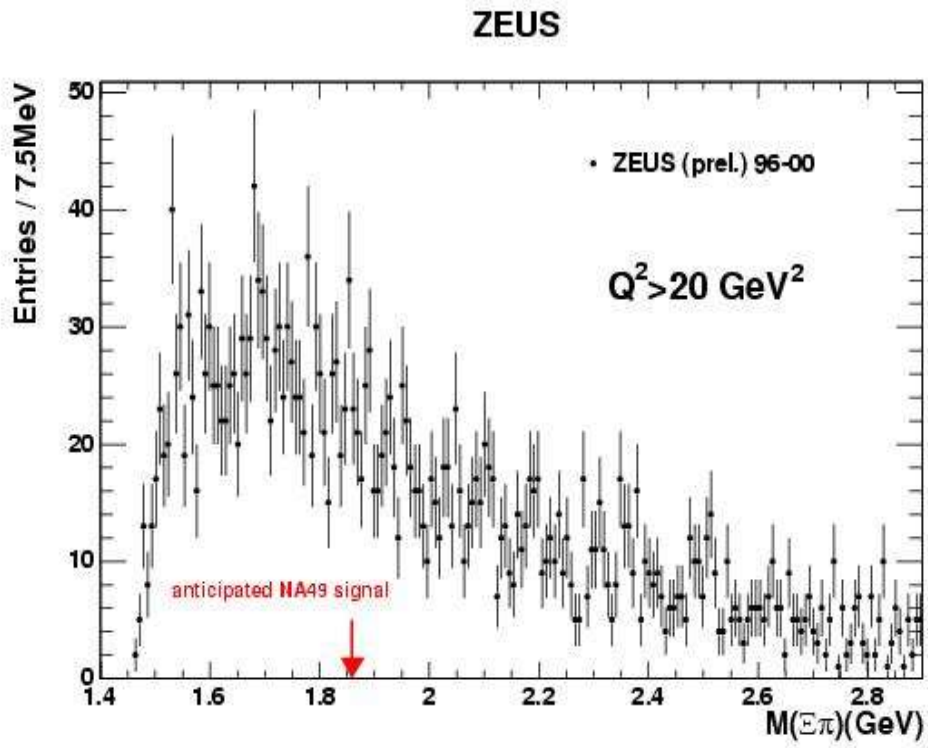
No evidence for Θ^{++}

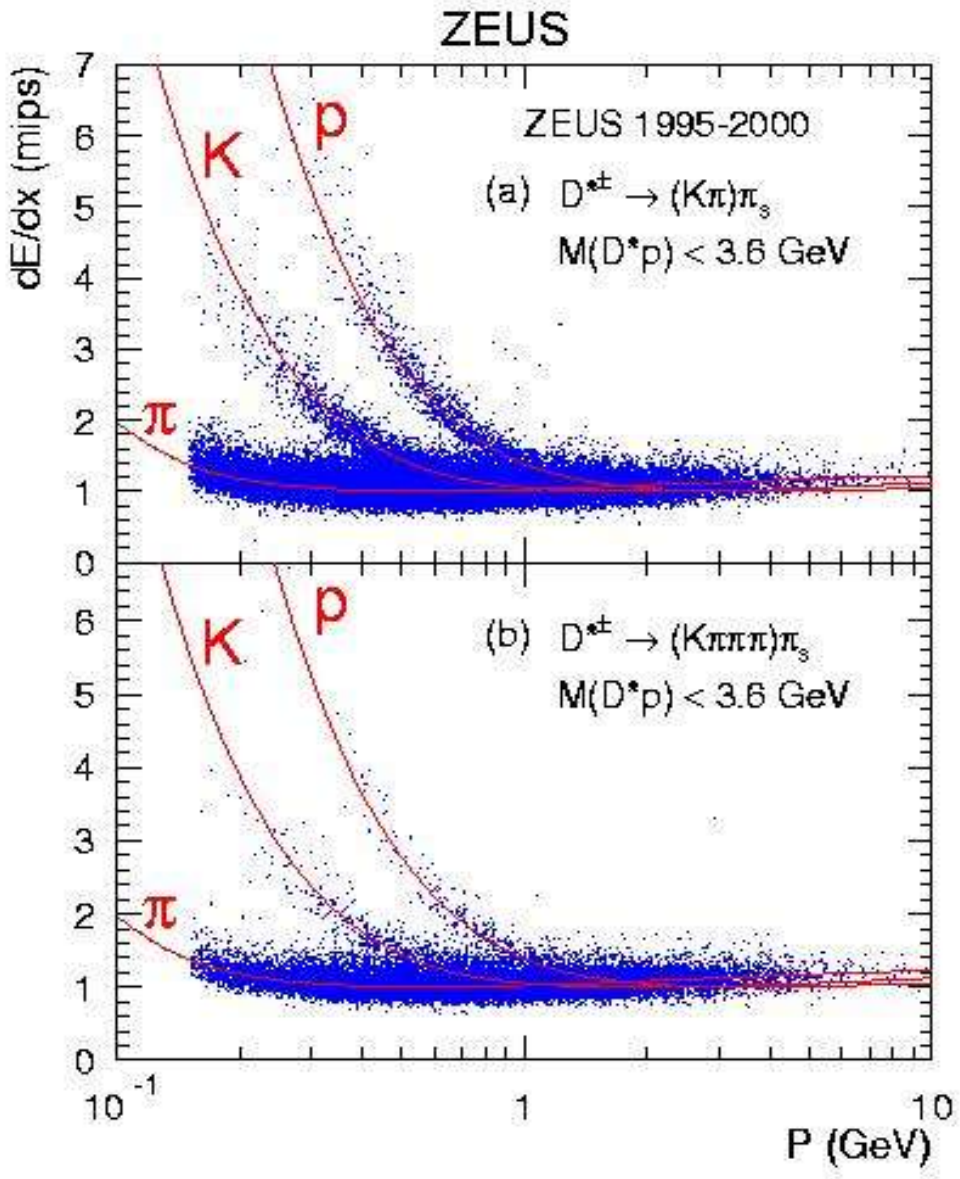
$\Theta^+(1530)$ signal for different Q^2_{min}.
($Q^2 > 20, 30, 40, 50$ GeV^2)





Ξπ (combined) distribution for different Q^2 cuts

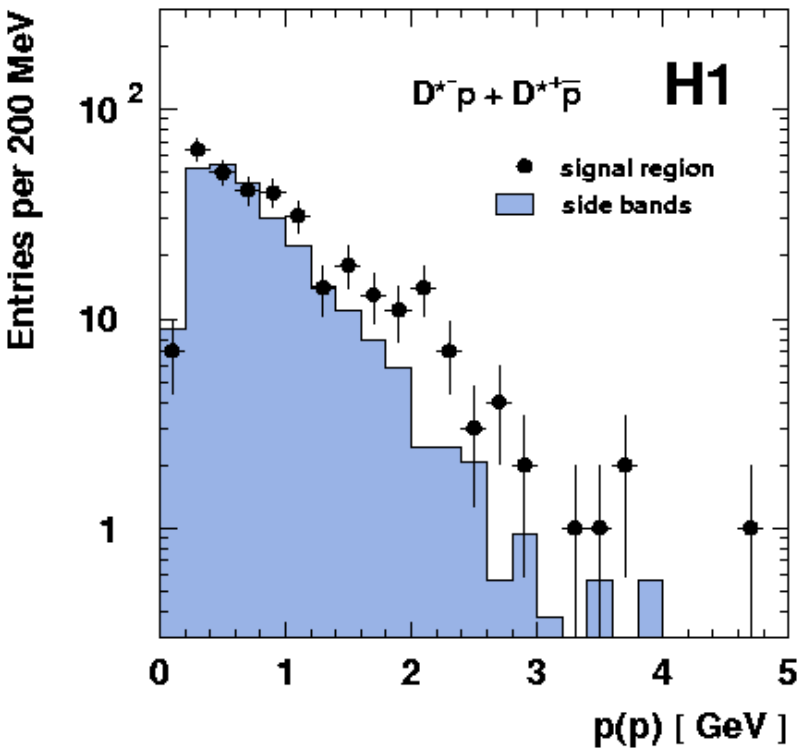




Improved calibration for the dE/dx (w.r.t. Θ^+ analysis)

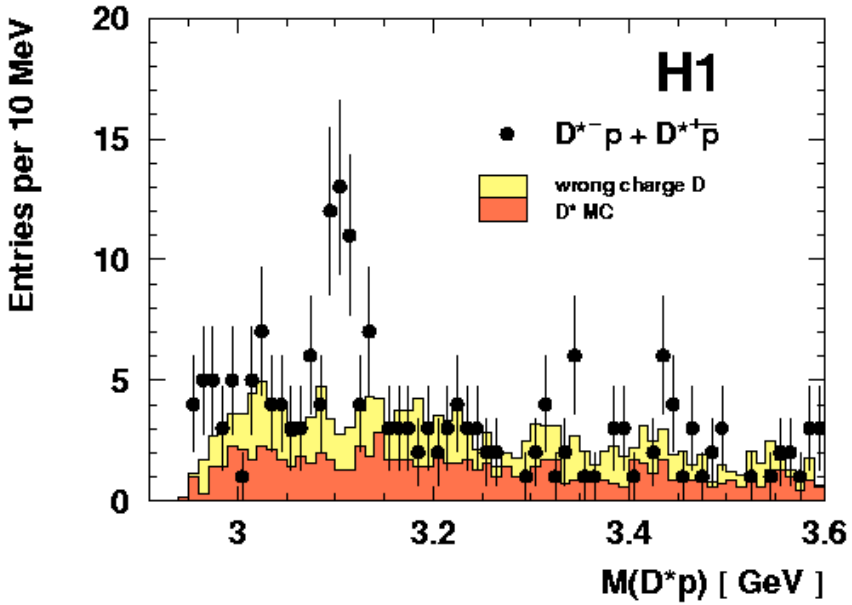
resolution for dE/dx ~ 9 %

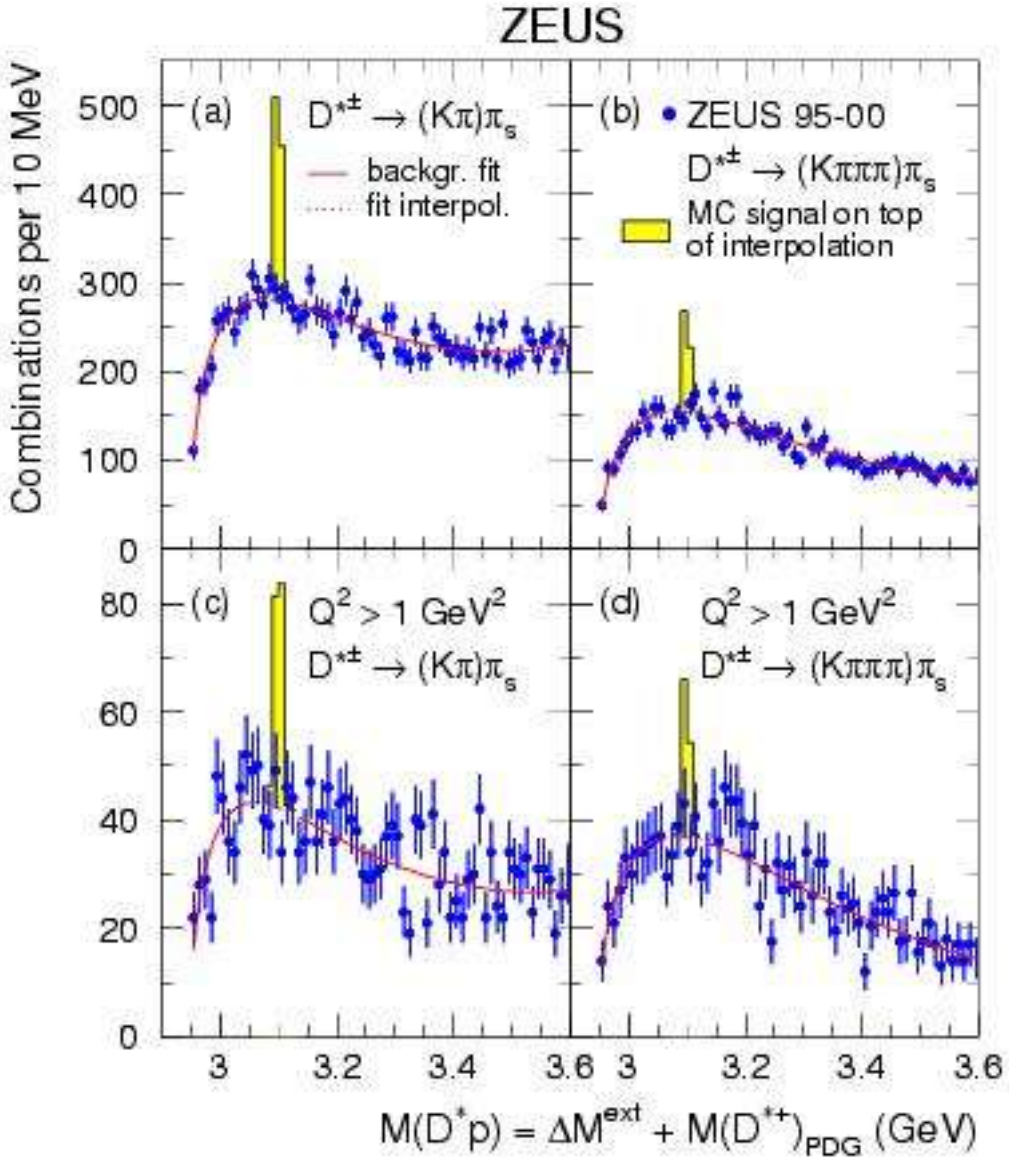
tuned using protons from $\Lambda(1116)$ decay



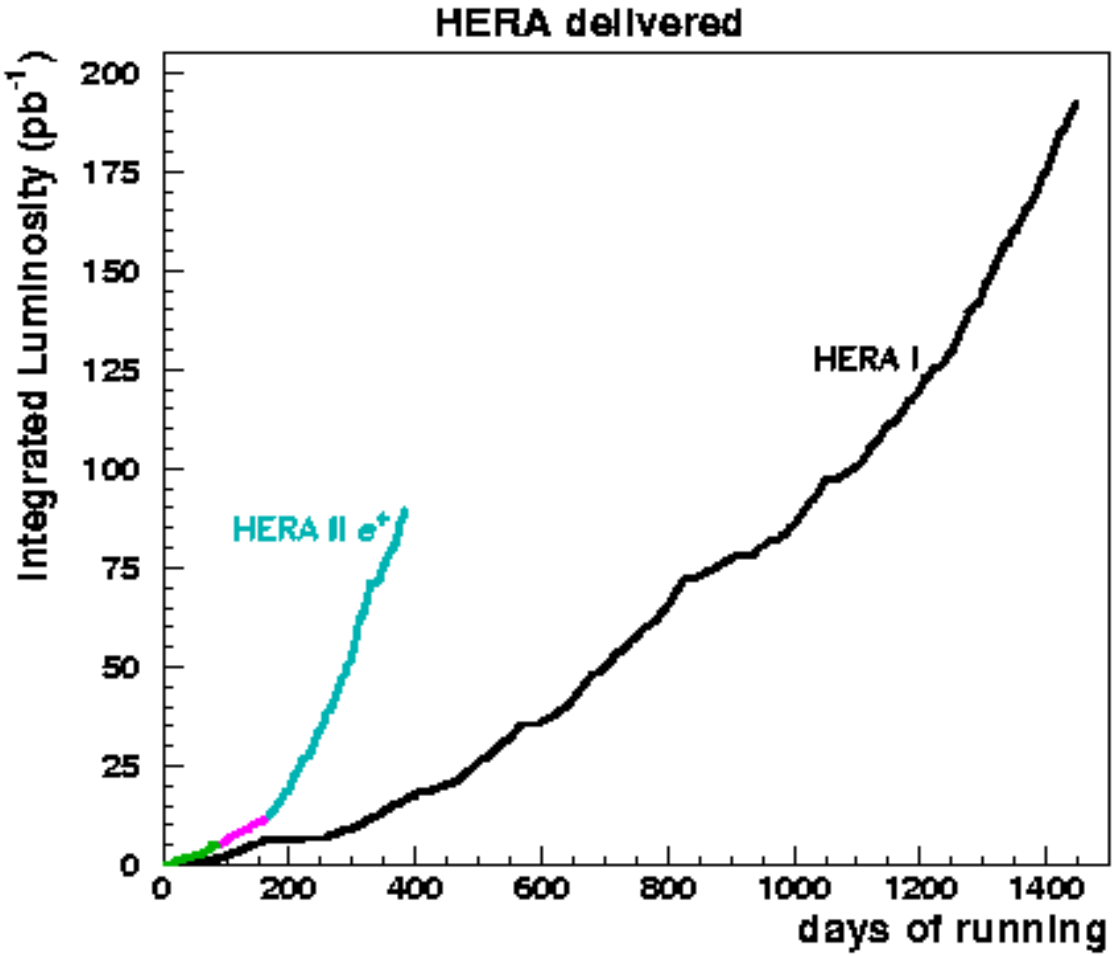
Momentum distribution
for the proton for signal region
and sidebands

Signal is visible for
the proton momentum > 2 GeV
(without proton identification
by dE/dx)

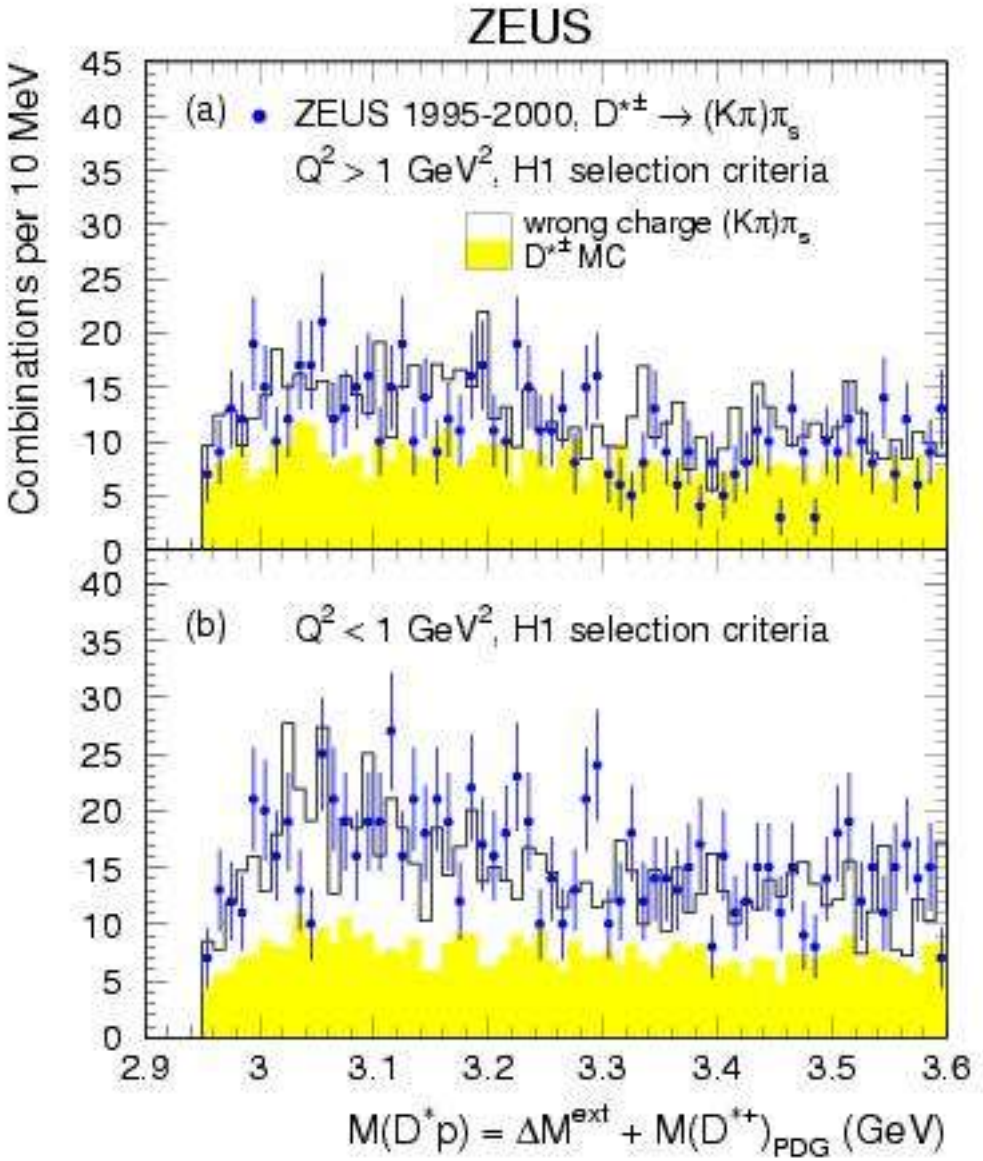




Expected signal for the charm pentaquark normalized to the rate of 1% of observed D^*

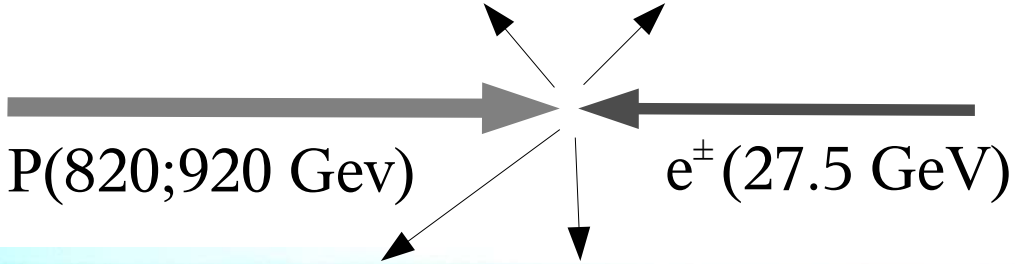


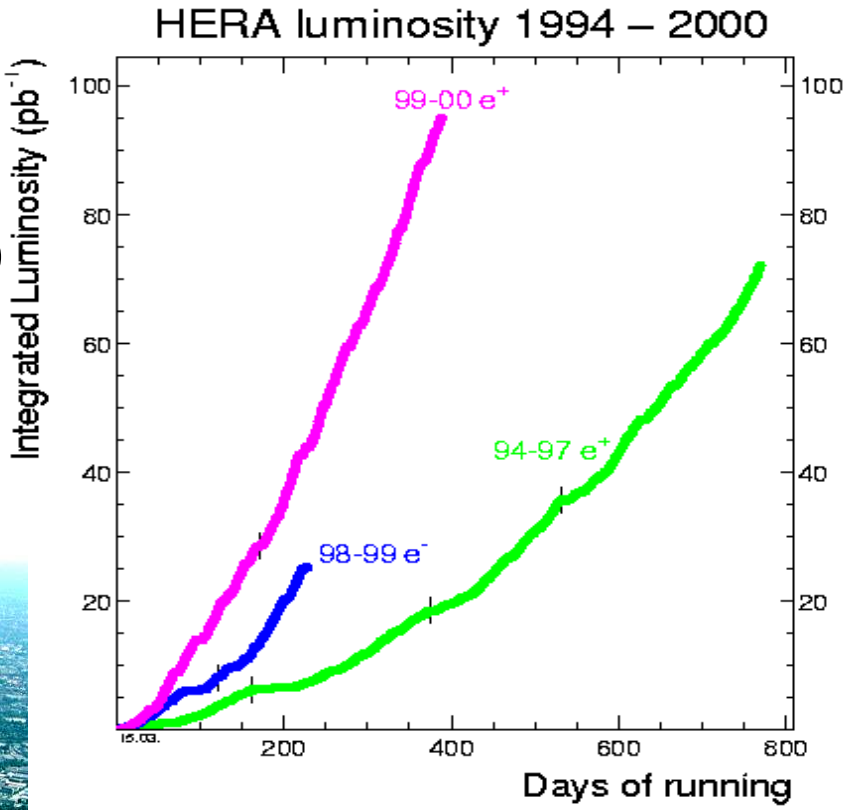
Expectation for the HERA II:
plenty of lumi and new discoveries



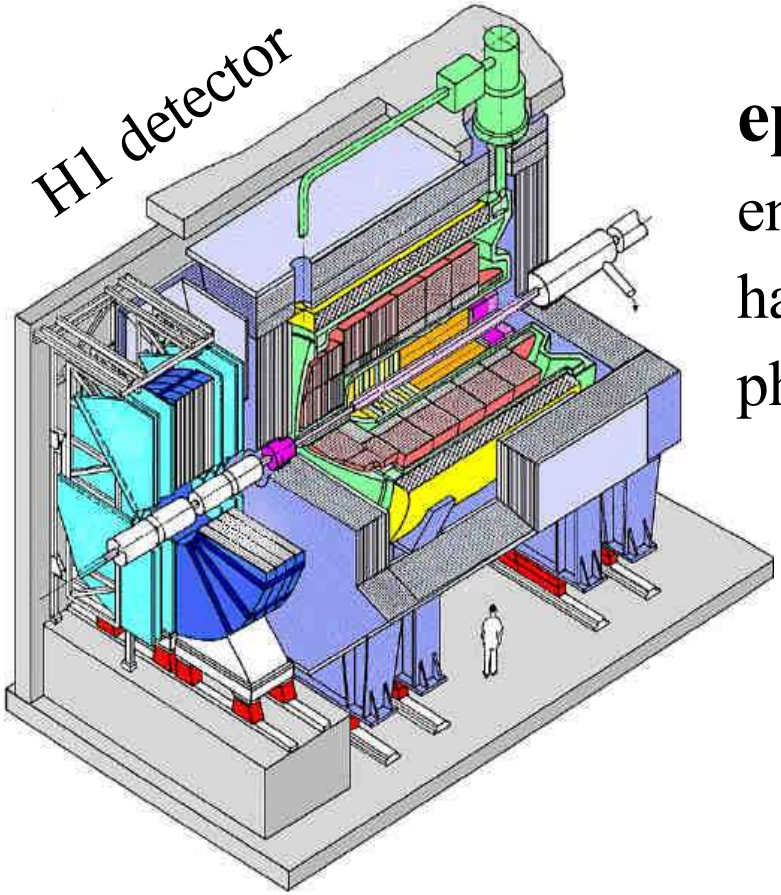
No signal in ZEUS data with the cuts close to H1

Collider HERA is the unique machine to study QCD.
A lot of precise measurements and unexpected discoveries (see plenary talks)





Glueballs and pentaquarks are not forbidden by QCD, but extremely interesting because they bring new information into the field



ep kinematics :

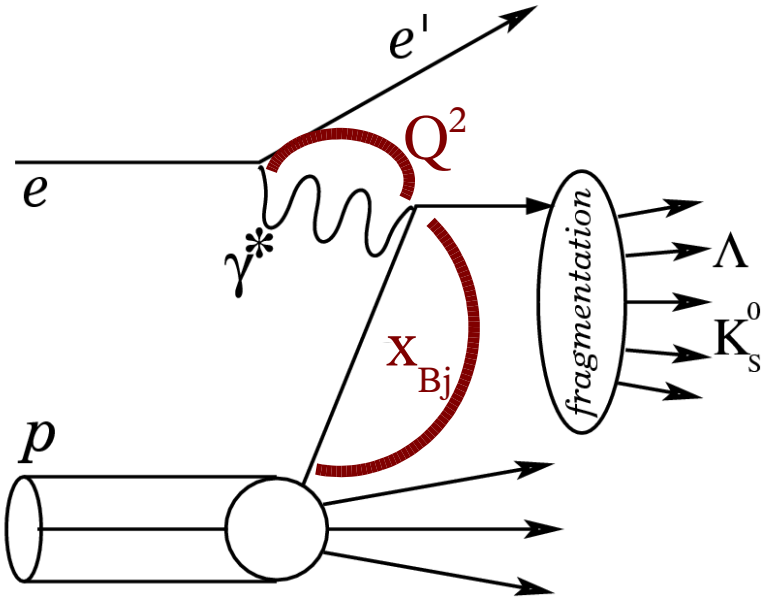
energy c.m. : $\sqrt{s}$ = 300-318 GeV

hadronic energy : $W=m(\gamma p)$

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

two regimes : $Q^2 \approx 0$ GeV^2 : **Photoproduction**

$Q^2 > 1$ GeV^2 : **Electroproduction (DIS)**

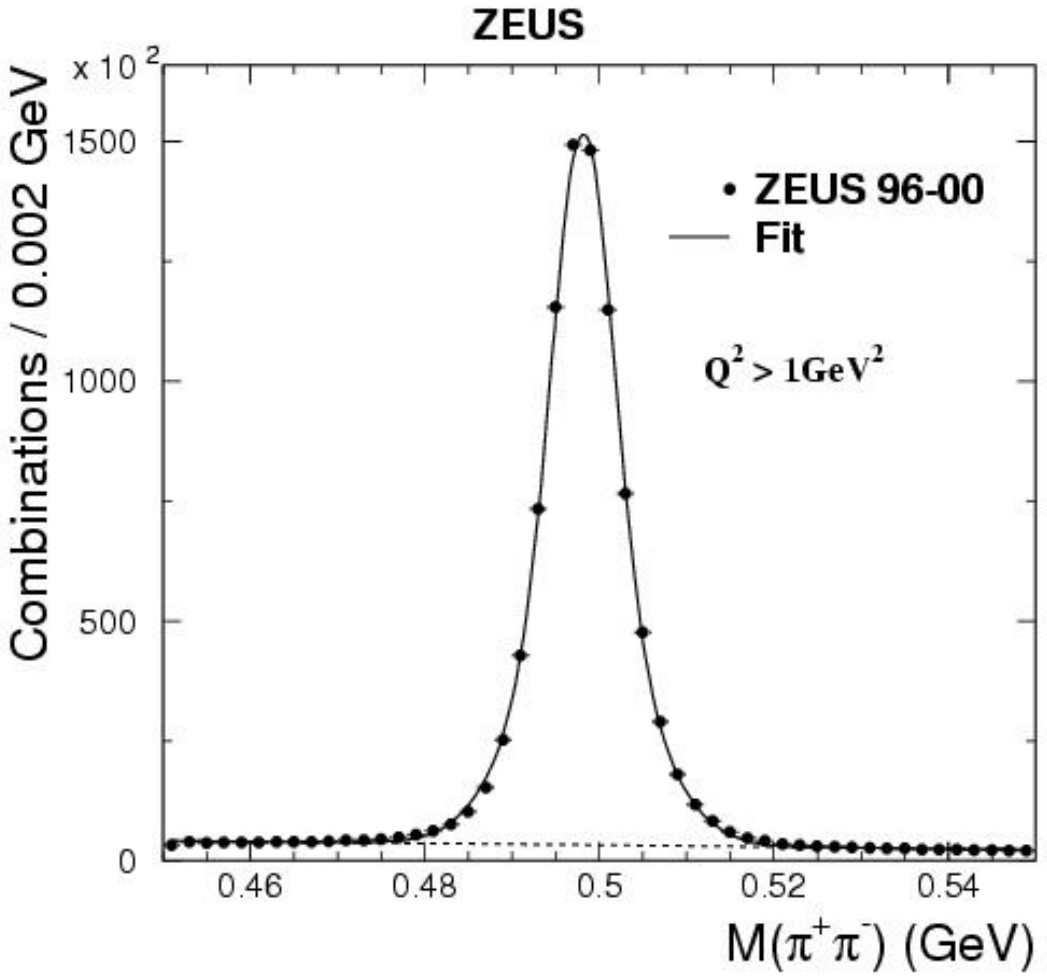


inelasticity : $y = Q^2/(x_{Bj}\ s)$

production elasticity : $z(D^*) = (E-p_z)/(2yE_e)$

pseudorapidity : $\eta = -\ln(\tan(\theta/2))$

ZEUS HERA-I data (121 pb^{-1})
DIS ($Q^2 > 1\ GeV^2$)



- K_s^0 reconstructed from secondary vertex tracks
- removed:
  photon conversion to $e^{\pm}$ pairs;
  $\Lambda \rightarrow p\pi$;
- $P_T(K_s^0) \geq 0.3$ GeV
- $|\eta(K_s^0)| \leq 1.5$
- Number of K_s^0 : 866800 ± 1000
- ≈ 6 % background

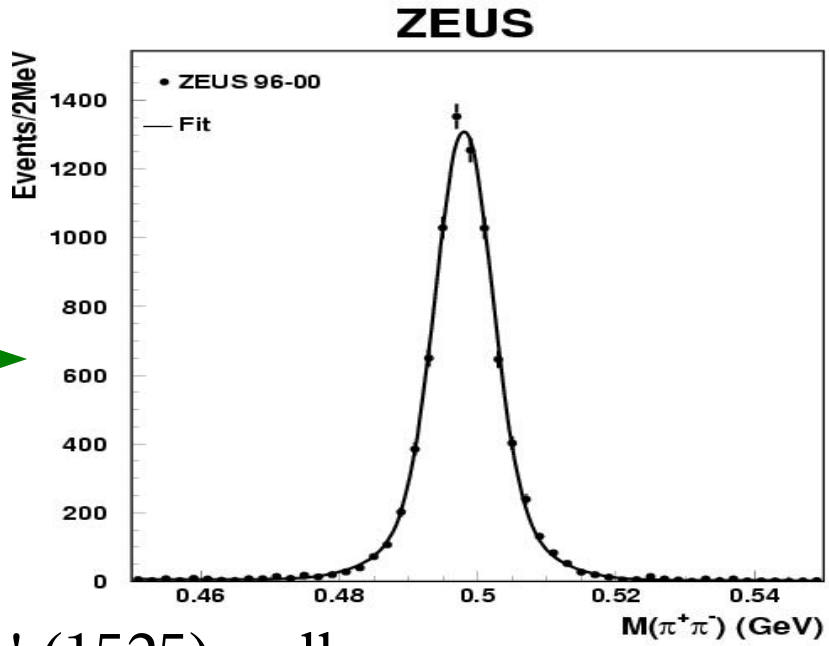
$m(K_s^0)$ = 498.12±0.01(stat) MeV
(PDG : 497.65±0.02)

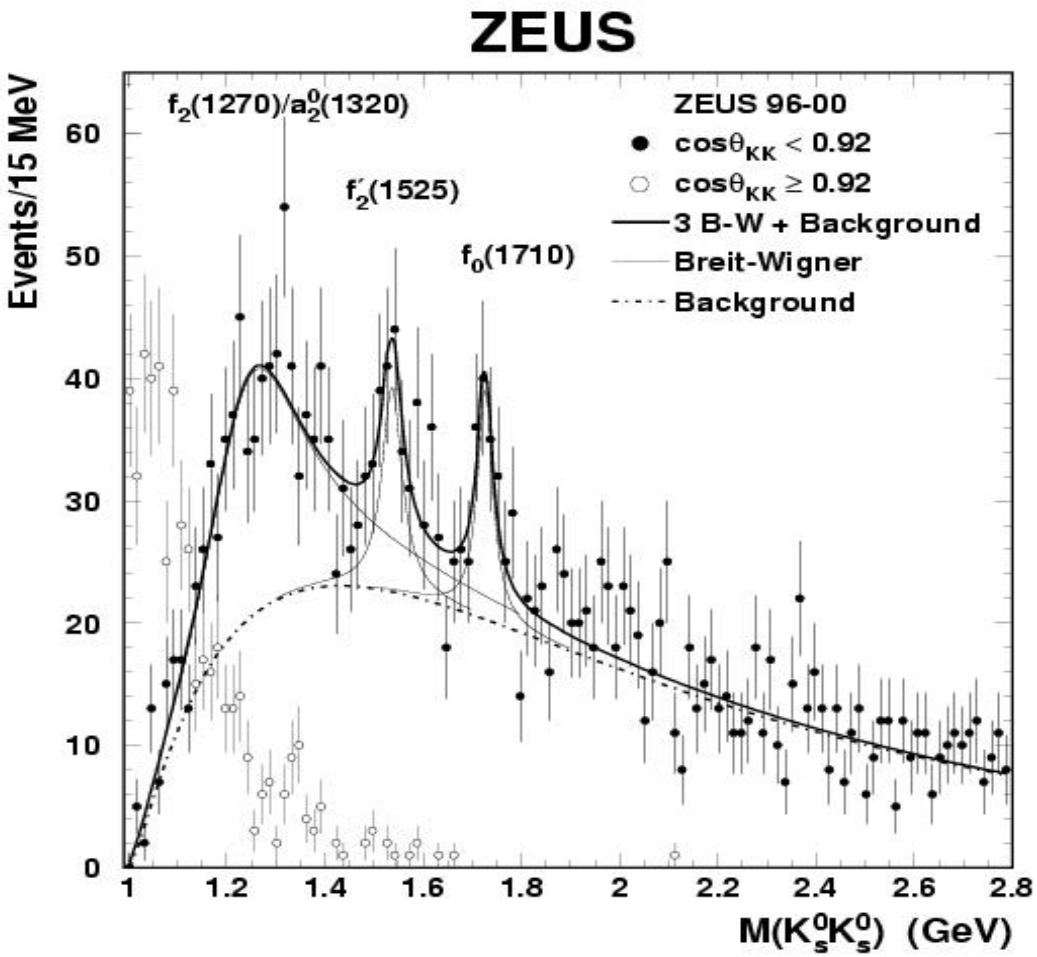
Select events with 2 identified K^0_s

kinematical region : $Q^2 > 1$ GeV^2

$50 < W < 250$ GeV

Very clean sample of K^0_s





$f'_2(1525)$ well seen.

Fit : m = 1537+34-22 MeV

Γ = 50 + 34 – 22 MeV

PDG: m = 1525 ± 5 MeV

Γ = 76 ± 10 MeV

Candidate for glueball f_0 :

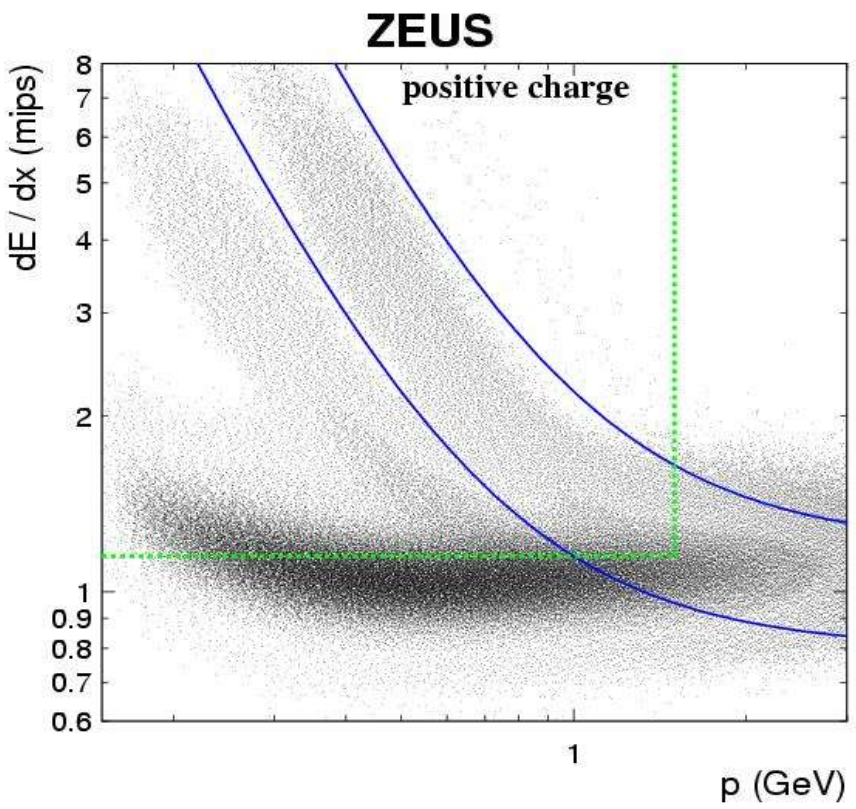
Fit : m = 1726+7 MeV

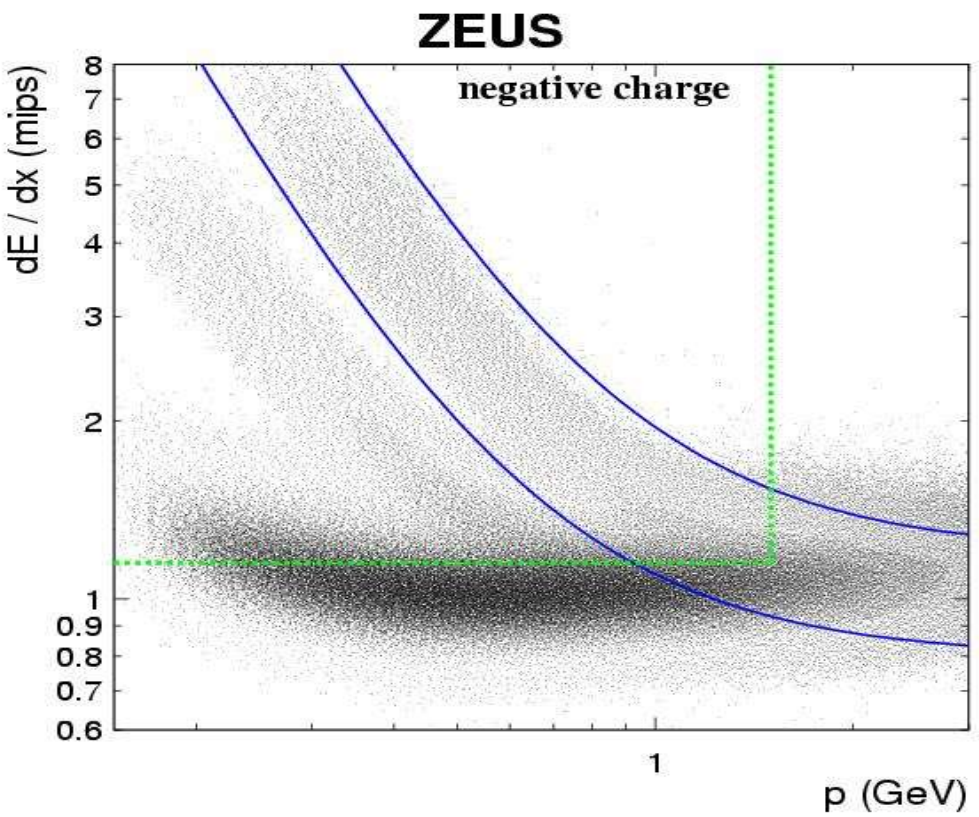
Γ = 50 + 34 – 22 MeV

PDG: m = 1714 ± 5 MeV

Γ = 140 ± 10 MeV

The possibility to identify protons by measuring ionization loss of particle in the tracker. Disadvantage of the method : good identification only at low momentum.





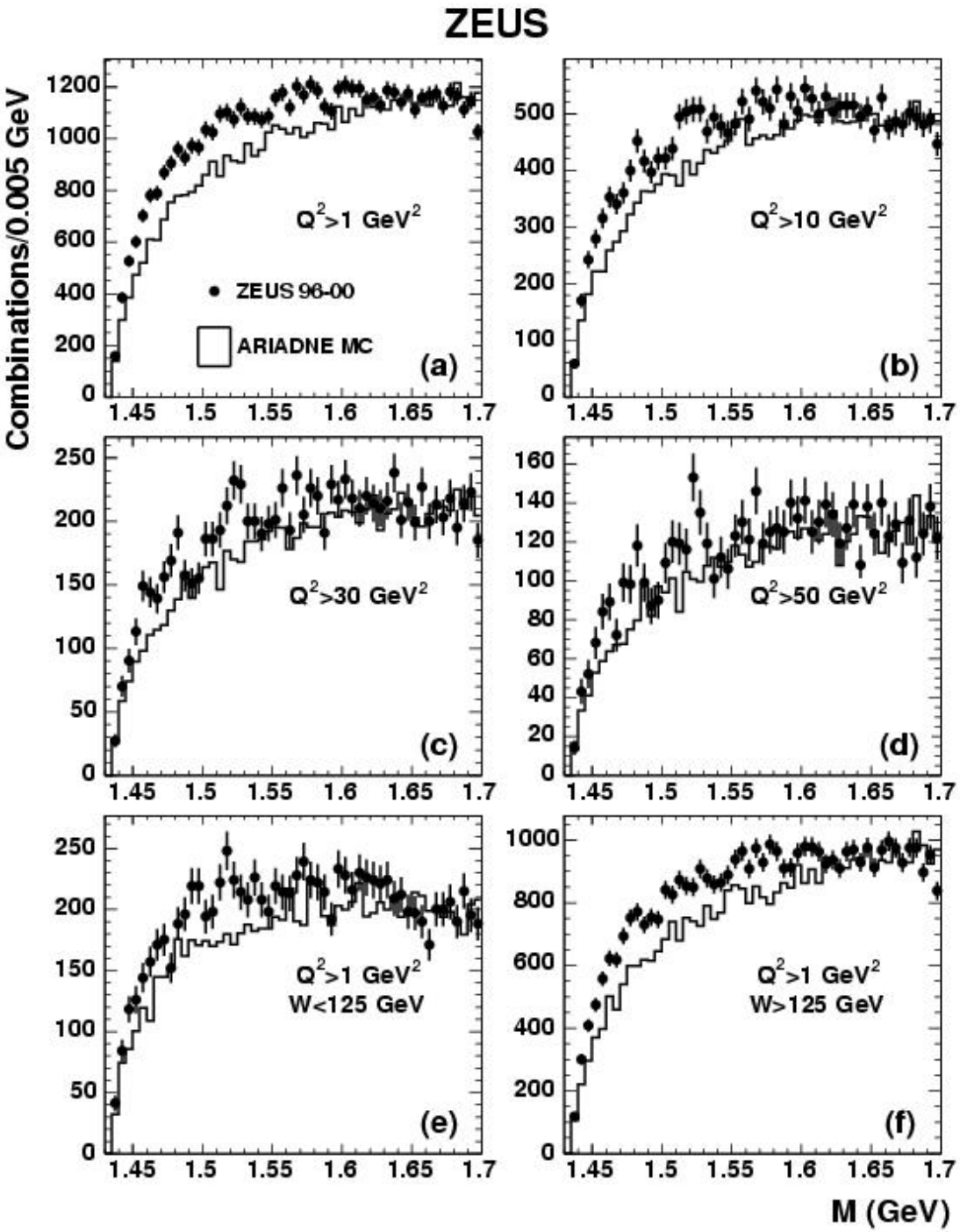
Cuts :
bands in the (dE/dx,P) plane (different for positive and negative particles)
dE/dx > 1.15 mips, P < 1.5 GeV => ~60% purity

$(\text{protons} - K_s^0) + (\text{antiprotons} - K_s^0)$

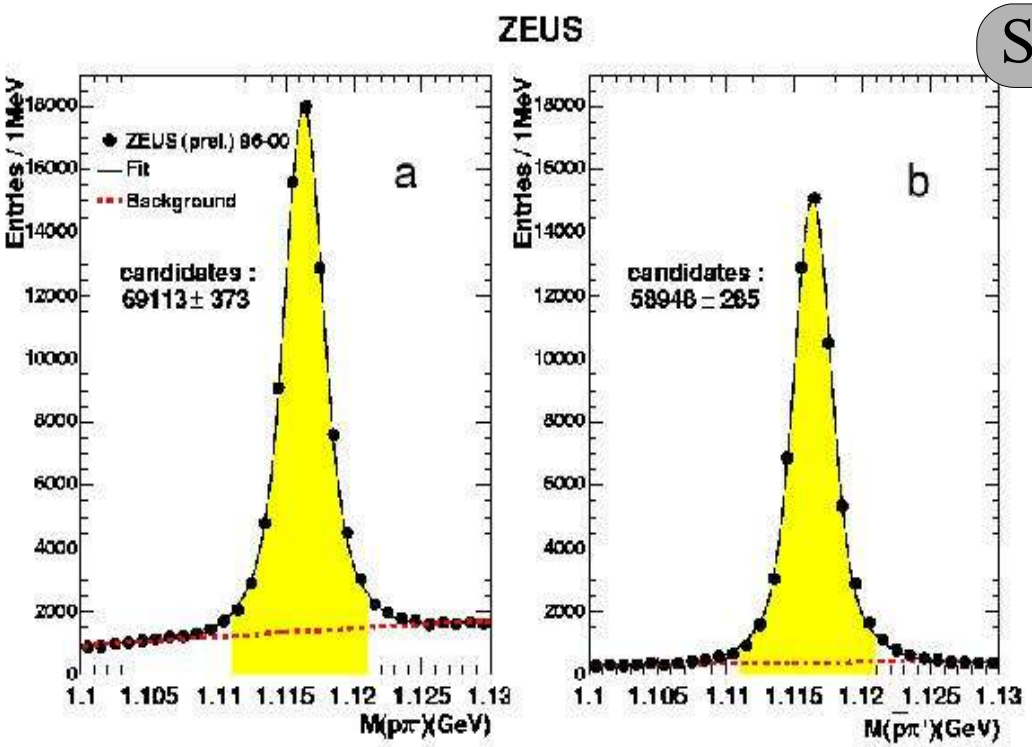
- Large (combinatorial) background
- Some structure at ~1525 MeV become visible for $Q^2 > 10$ GeV^2
- at low Q^2 (> 1GeV^2) signal is visible for low W

MC : ARIADNE (JETSET)

- normalized to data above 1.65 GeV
- does not reproduce the shape (missing Σ(1480)*, Σ(1560)** ... bumps in MC ?)



Search for the double strange pentaquarks



$\Xi_{5q}^{--(0)} \rightarrow \Xi^{-(+)}\pi^-$ (observed by NA49)

Decay chain:

$\Xi_{5q}^{--} \rightarrow \Xi^- \pi^-$

$\downarrow$

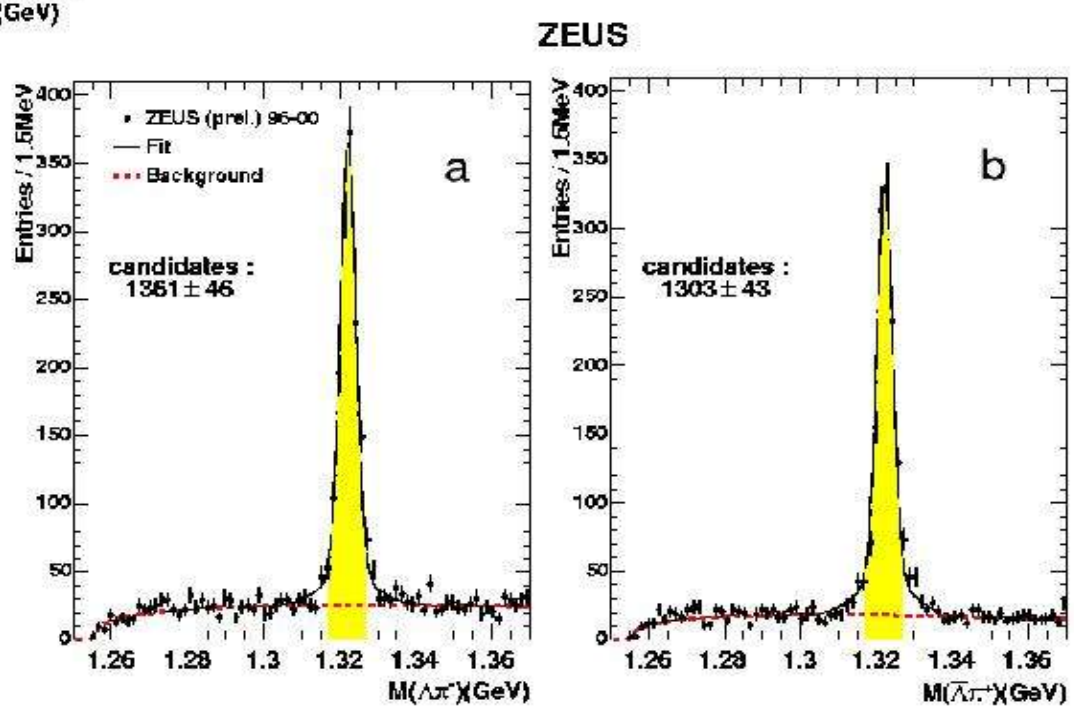
$\rightarrow \Lambda^0 \pi^-$

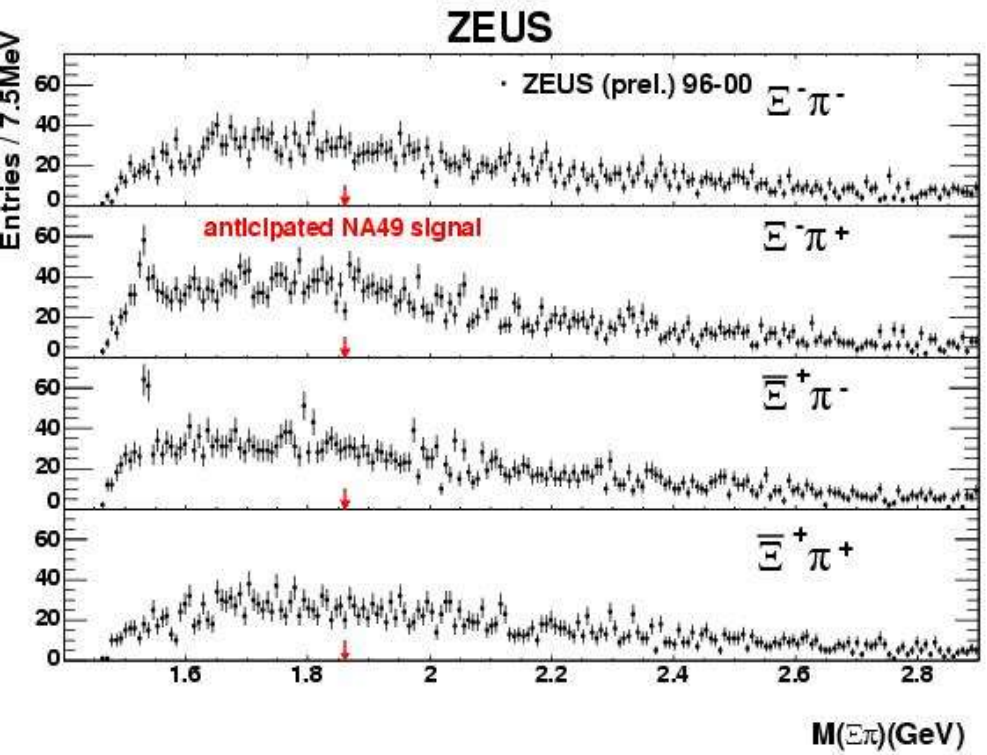
$\downarrow$

$\rightarrow p \pi^-$

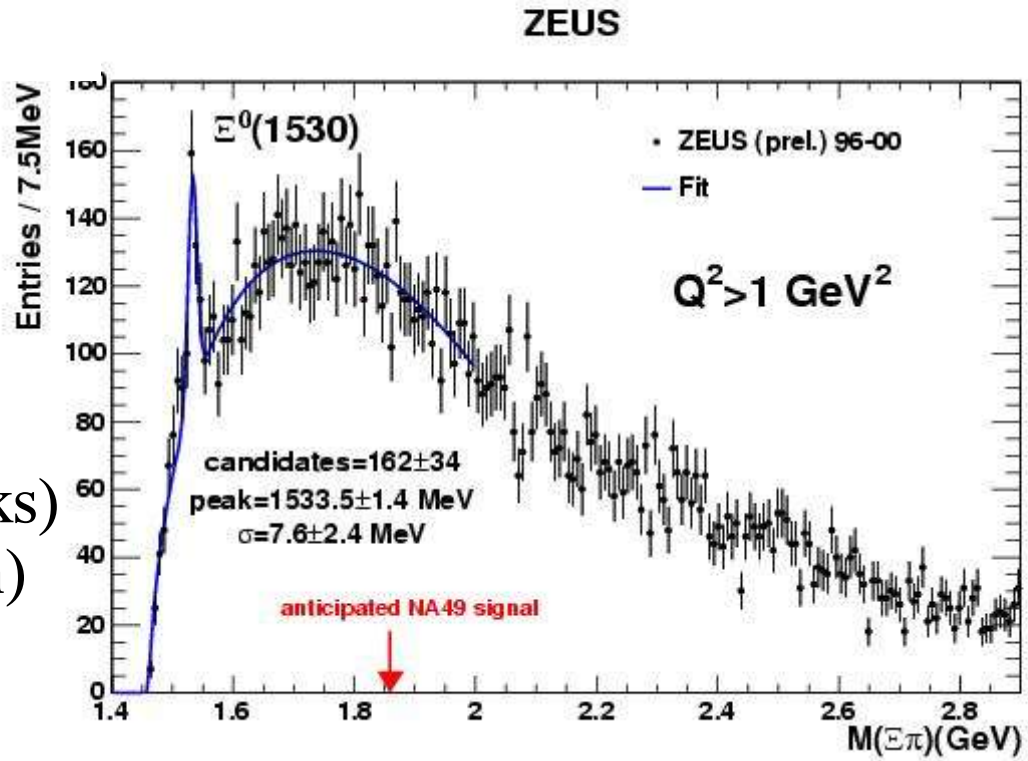
ZEUS search in DIS ($Q^2 > 1$ GeV^2)

well identified Λ(+c.c.) (~ 130000)
and Ξ^- (+ c.c.) (~ 2600 candidates)





Combine Ξ with the π :
4 different combinations (--,-+,+-,++)
No signal at NA49 mass
Well known $\Xi^0(1530)$ signal is visible



(Different production mechanism?)
NA49 – forward region(valence quarks)
ZEUS – central region (fragmentation)

Search for the charmed pentaquark (with the decay $\Theta_c \to D^* p$ (+c.c.))

H1 search in DIS : $1 < Q^2 < 100$ GeV^2

75 pb^{-1} $\quad 0.05 < y < 0.7$

$D^{*+} \to D^0 \pi_s^+ \to (K^-\pi^+)\pi_s^+$

$\underline{D^0}$: $P_T(K) > 0.5$ GeV

$P_T(\pi) > 0.25$ GeV

$P_T(K)+P_T(\pi) > 2$ GeV

$|m(K\pi)-m(D^0)| < 60$ MeV

$\underline{D^*}$: $P_T(\pi_s^+) > 0.12$ GeV

$P_T(D^*) > 1.5$ GeV

$-1.5 < \eta(D^*) < 1$

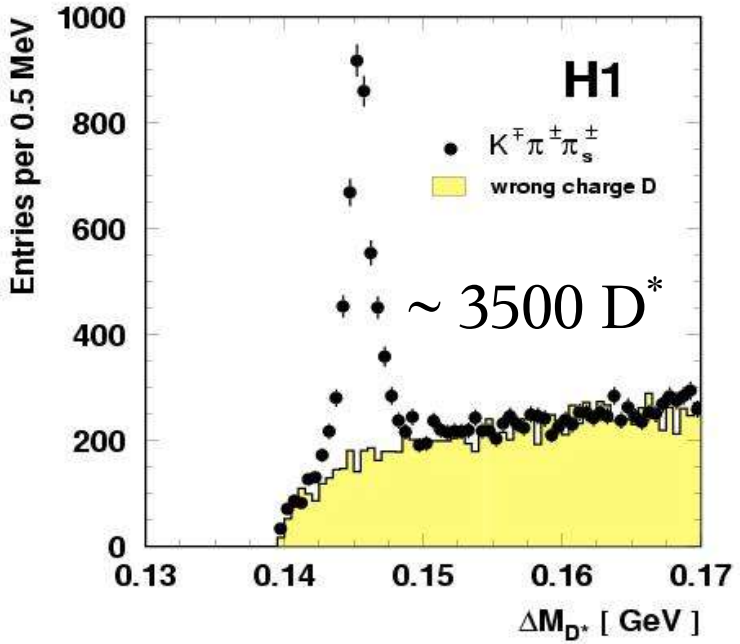
$|\Delta m(D^*)-m(D^*)+m(D^0)| < 2.5$ MeV

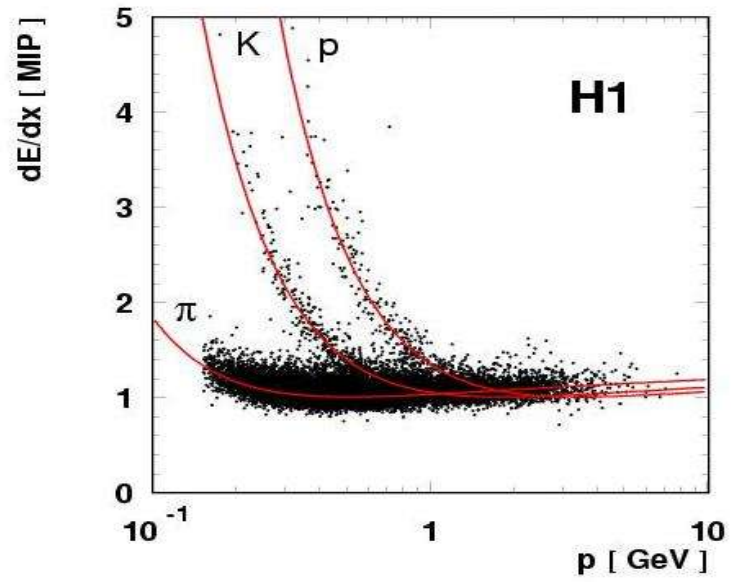
$z(D^*) > 0.2$

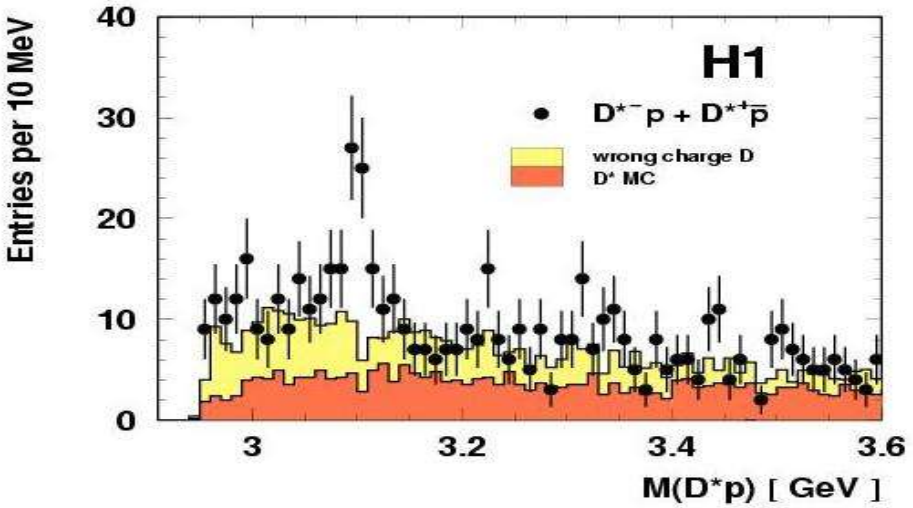
$\underline{p}$: $P_T(p) > 0.12$ GeV

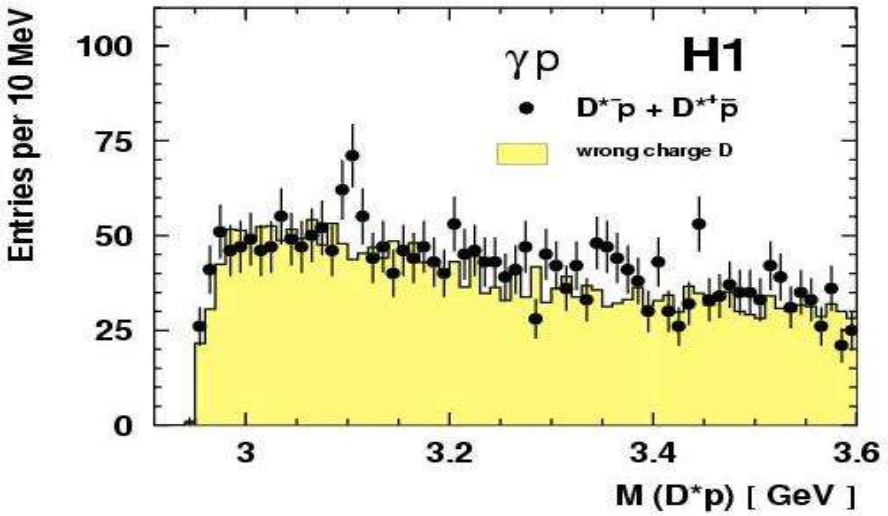
$L_p > 0.3$ for $p(p) < 2$ GeV

$L_p > 0.1$ for $p(p) > 2$ GeV



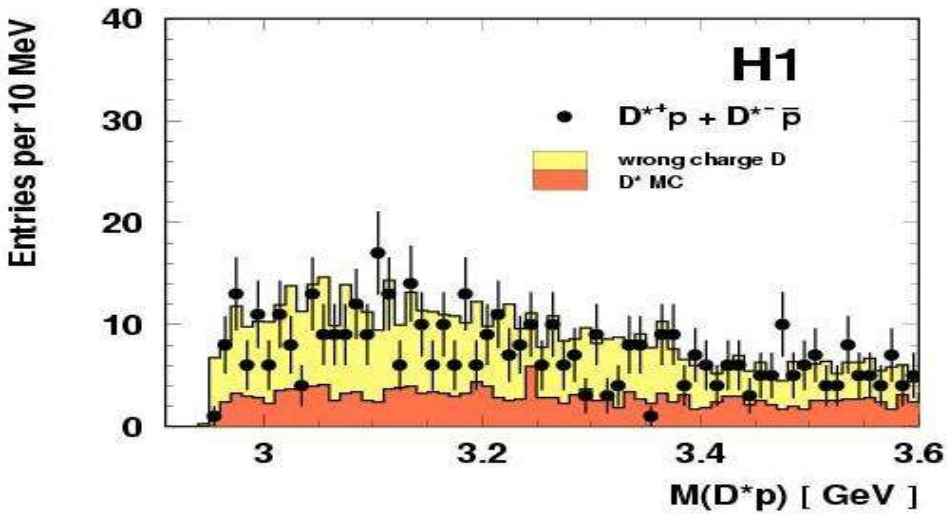






Signal at 3.1 GeV both in DIS and photoproduction samples
reasonable description by sum of "wrong charge D^0" and
D^* combined with random p (MC)

No significant signal in same charge combination



ZEUS search 1995-2000 data (126 pb^{-1})

Two D* decay channels:

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

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

$PT(D^*) > 1.35$ GeV for $(K\pi)\pi_s$

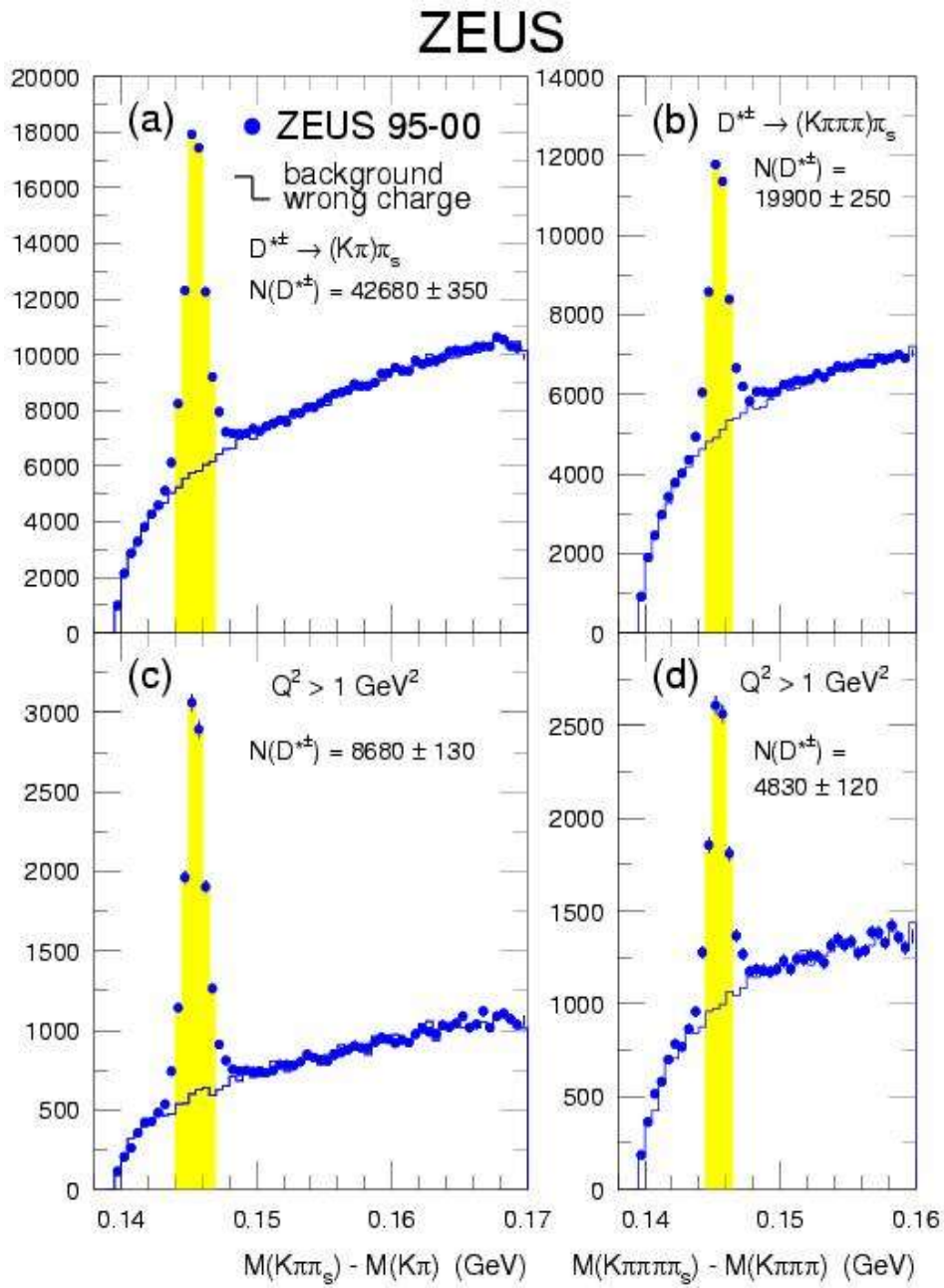
$PT(D^*) > 2.8$ GeV for $(K\pi\pi\pi)\pi_s$

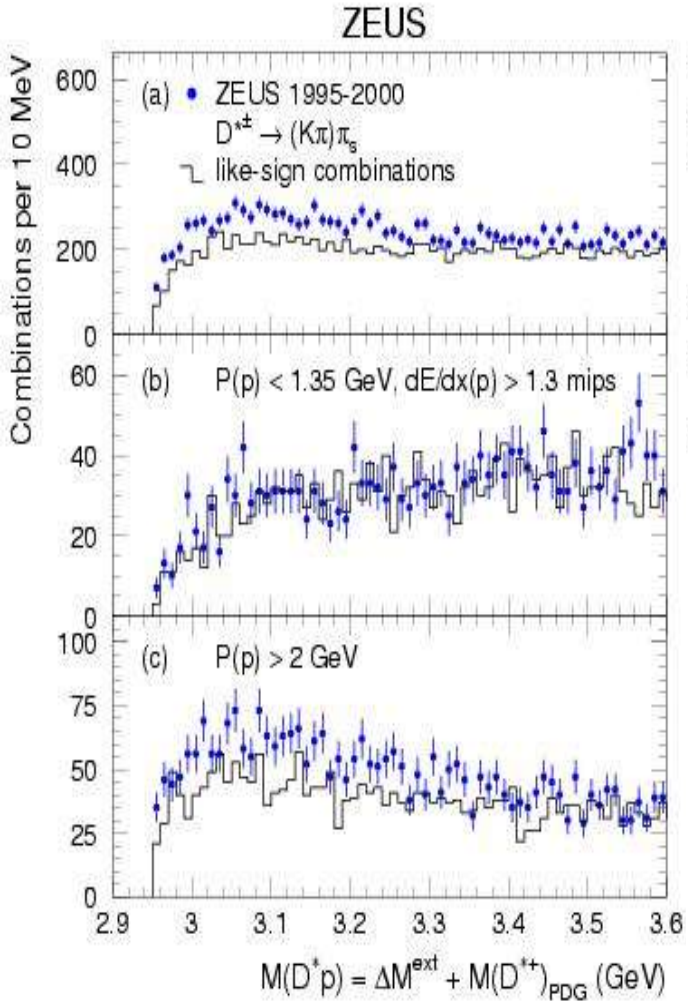
$|\eta(D^*)| < 1.6$

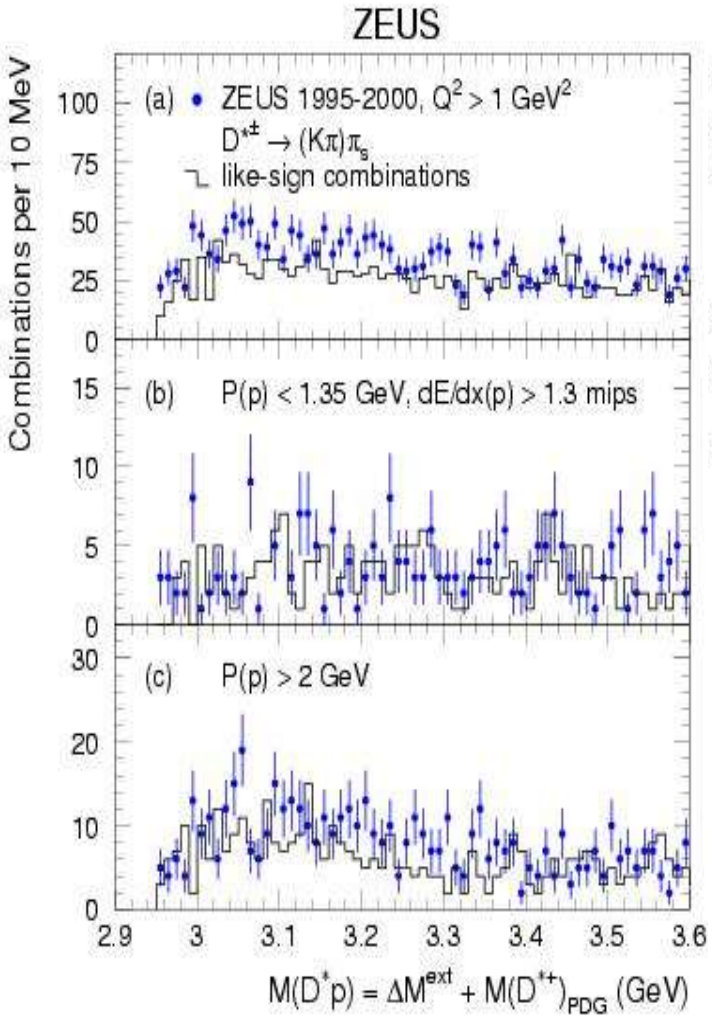
$N(D^*) \sim 62500$ (inclusive)

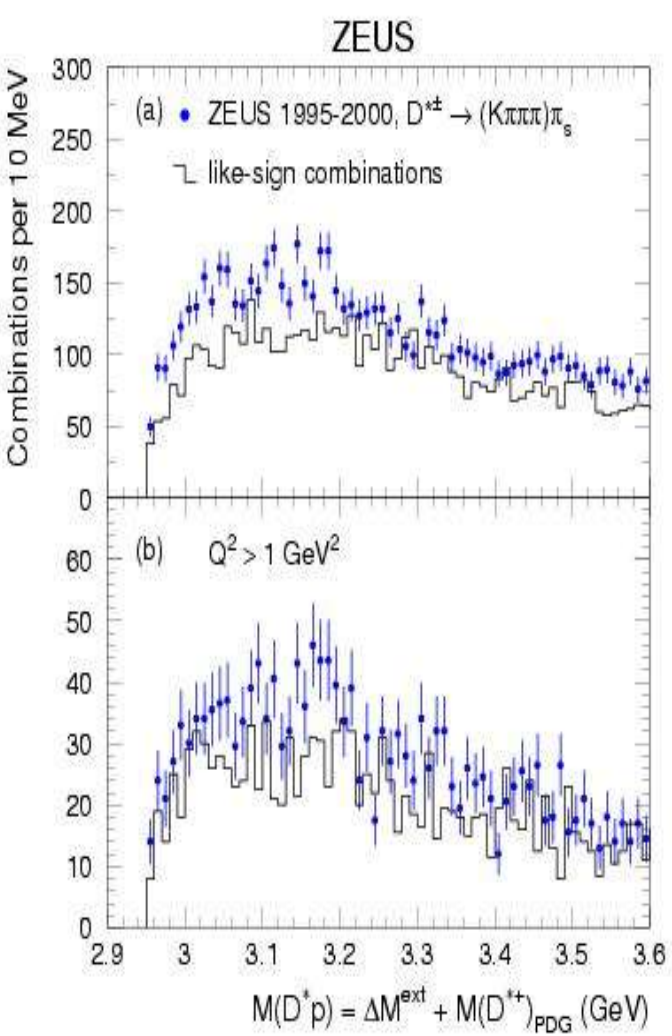
$N(D^*) \sim 13500$ ($Q^2 > 1$ GeV^2)

Selection of proton by dE/dx (better calibrated w.r.t. Θ^+ analysis), cross checked and tuned using protons from Λ decays









No hint for the H1 signal in either distribution