Spectroscopy at HERA

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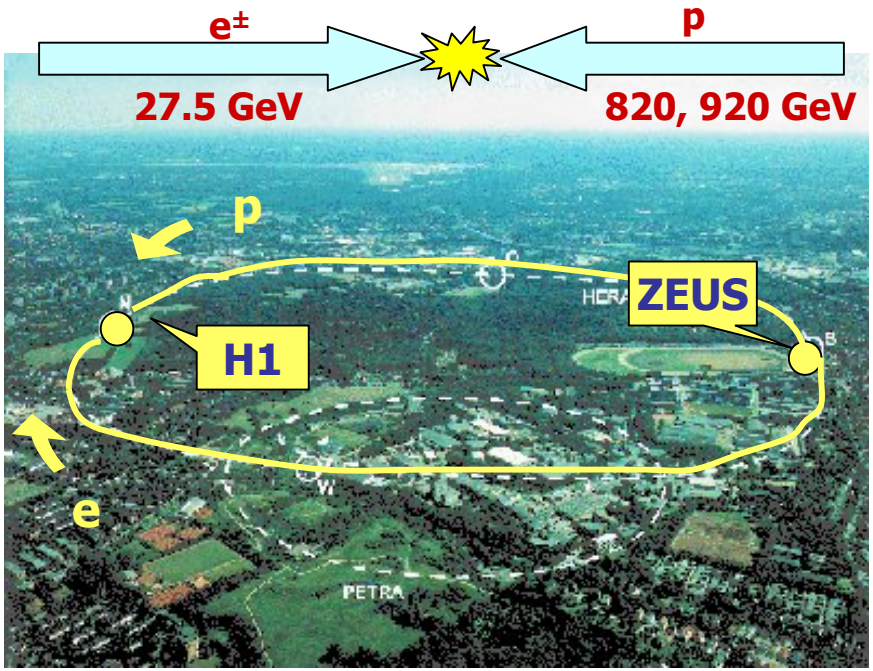
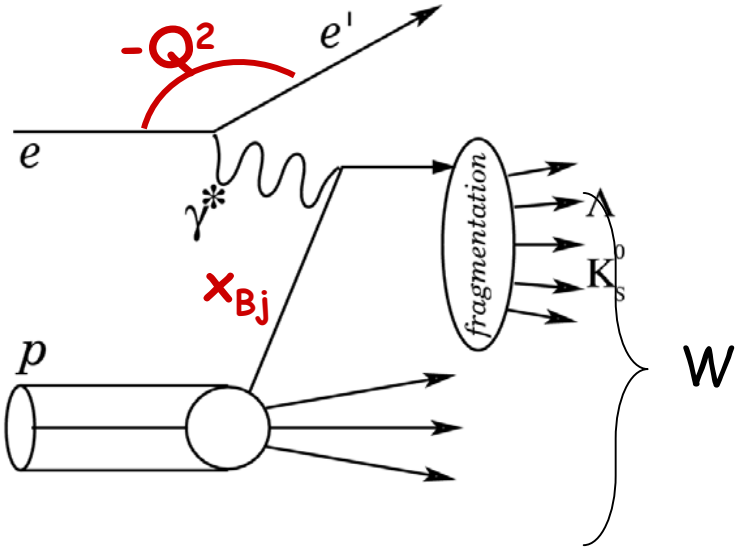
on behalf of
H1 and ZEUS Collaborations

Search for Strange Pentaquark $\theta^{\pm}$
Search for Double Strange Pentaquark Ξ^{--}
Search for Charm Pentaquark θ^{0}_{c}
Non-exotic hadronic resonances

The HERA Collider



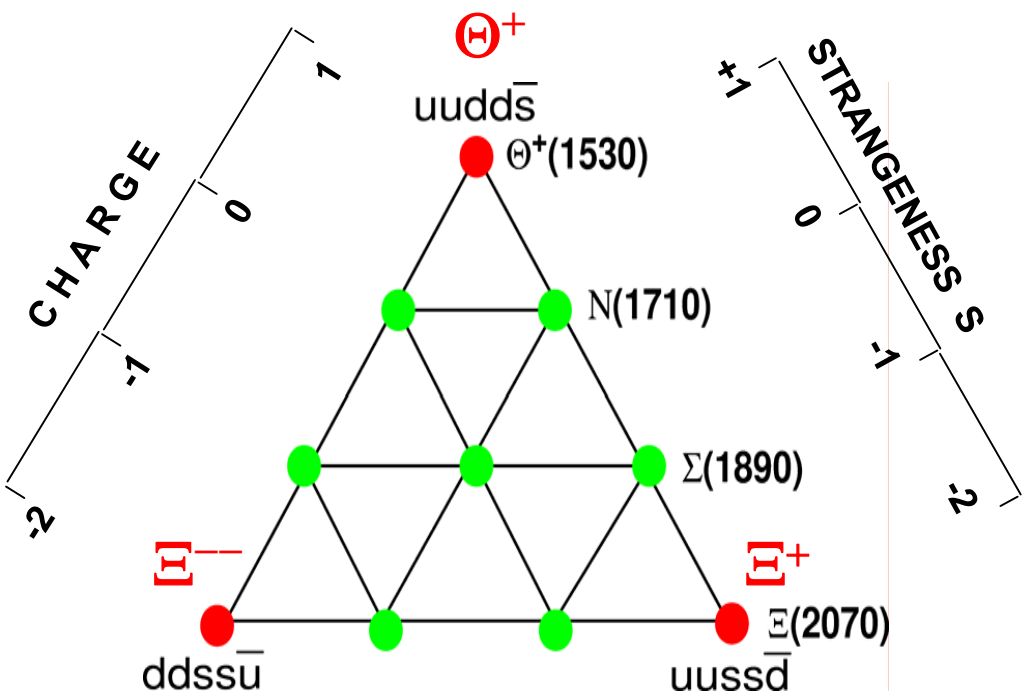


ep kinematics:

energy c.m.: $\sqrt{s}$=300-320 GeV
hadronic energy: $W=m(\gamma^* p)$
photon virtuality : Q^2
inelasticity: $y=Q^2/(x_{Bj}s)$:

two regions: $Q^2 \approx 0$ GeV^2 — photoproduction
$Q^2 > 1$ GeV^2 — electroproduction (DIS)

The strange Pentaquark anti-decuplet



Proposed by Diakonov, Petrov, Polyakov in 1997:

- **3 exotic baryons at corner**
- **Prediction of a width less than 15 MeV for the $\theta^+(1530)$ state**

QCD says no objection

Search for $\theta^+ \rightarrow p K^0_s$ / $\theta^- \rightarrow \bar{p} K^0_s$ (ZEUS)

DIS sample (Q^2>1 GeV^2):

- identify $K^0_s \rightarrow \pi^+\pi^-$:secondary vertex, removed:
  photon conversion to $e^\pm$ pairs
  $\Lambda \rightarrow p\pi$

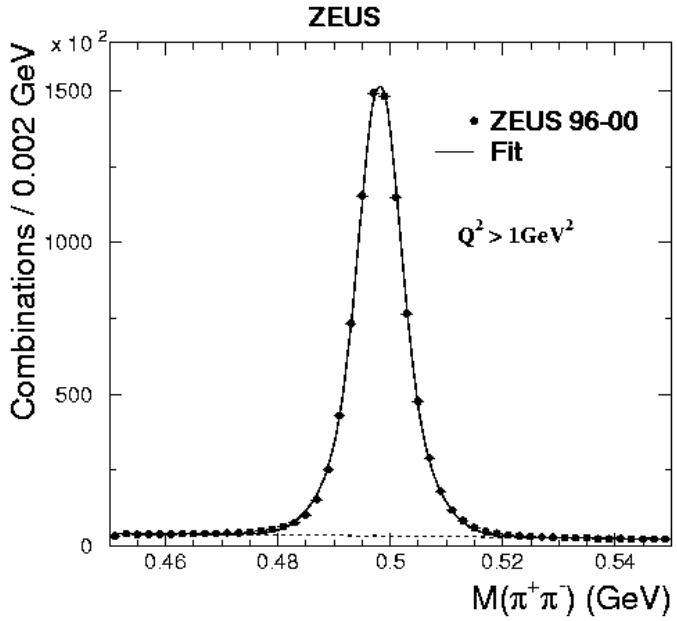
$P_T(K_s^0) \geq 0.3$ GeV, $|\eta(K_s^0)| \leq 1.5$

Number of $K_s^0 \approx 870000$

≈6% background

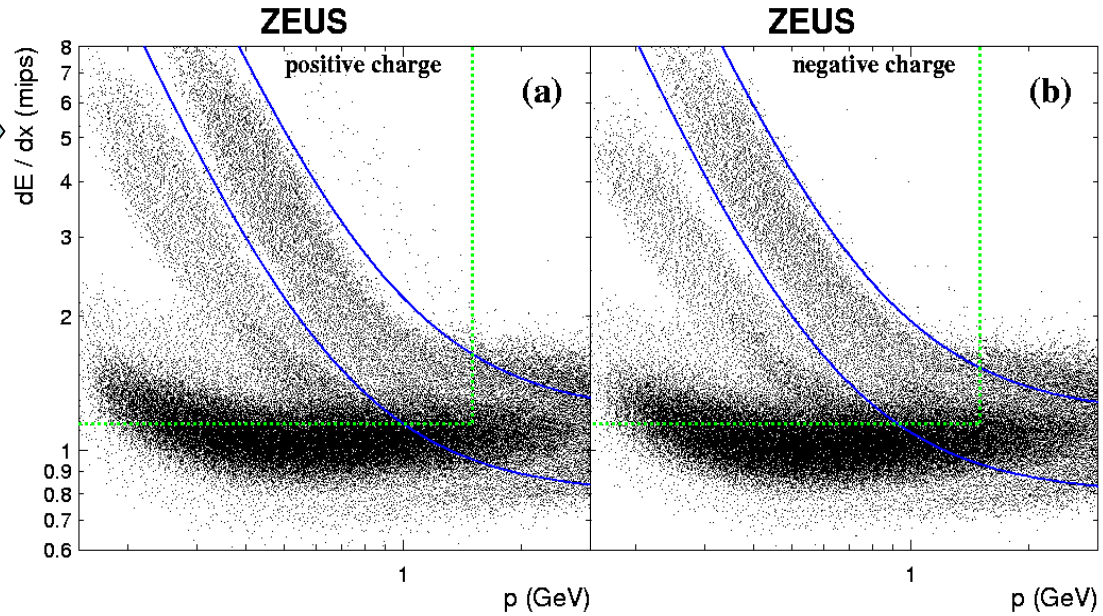
$M(K_s^0)$=498.12±0.01 MeV

PDG: 497.65±0.02 MeV

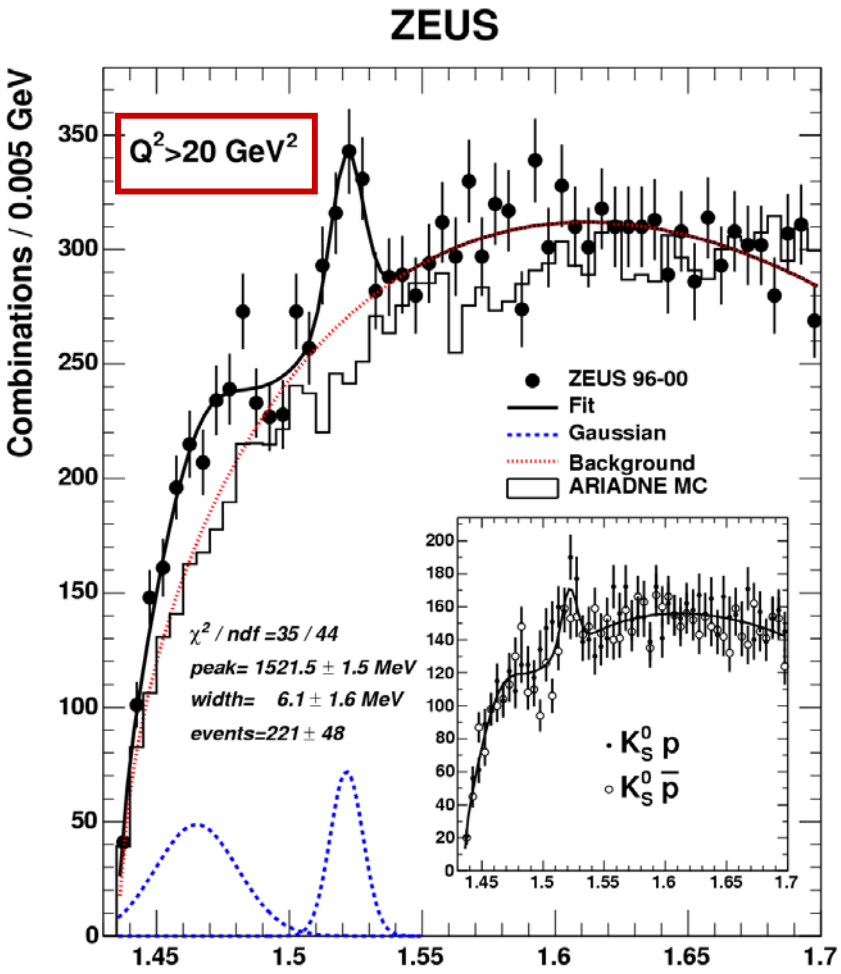


- identify p, $\bar{p}$ (dE/dx) band in the (dE/dx,p) plane (different for positive and negative particles)
  dE/dx>1.15 mips,
  P<1.5 GeV

⇒ ~60% purity



Search for $\theta^+ \rightarrow p K^0_s$ / $\theta^- \rightarrow \bar{p} K^0_s$ (ZEUS)



Fit: background + two Gaussians

χ^2/ndf=35/44

Statistical significance(from fit):

(221±48) ~ 4.6 σ

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

Gaussian width: 6.1±1.6(stat) MeV

2nd gaussian:

M=1465.1±2.9 MeV

width=15.5±3.4 MeV

} Σ(1480) ??? PDG*

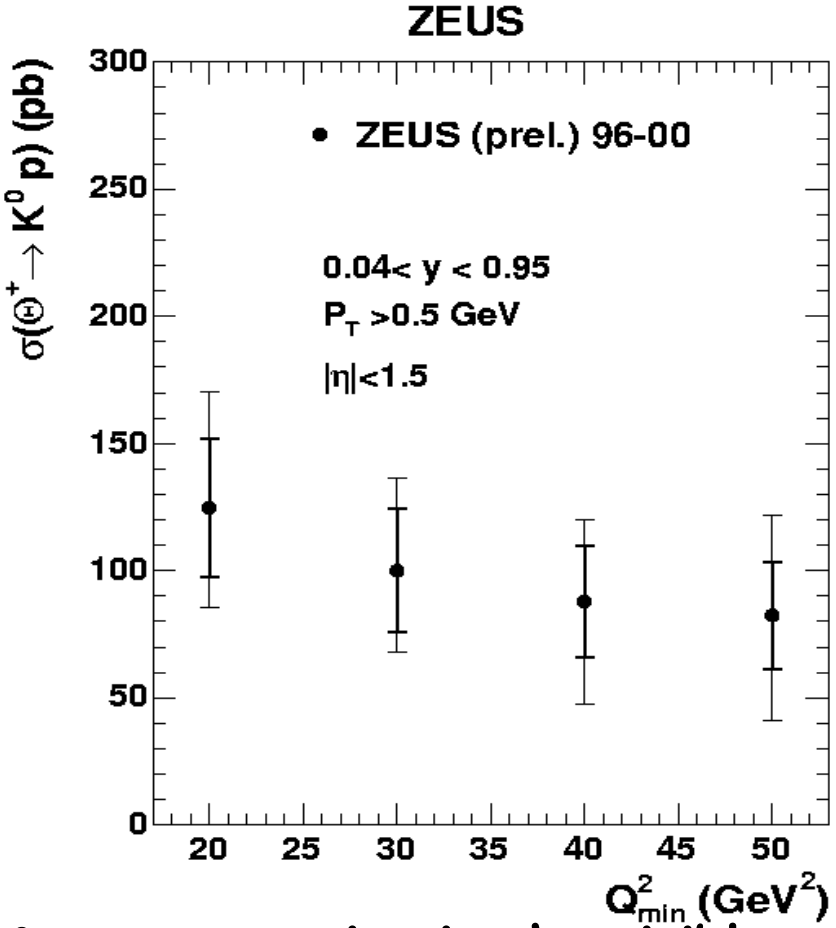
Signal seen in both charges

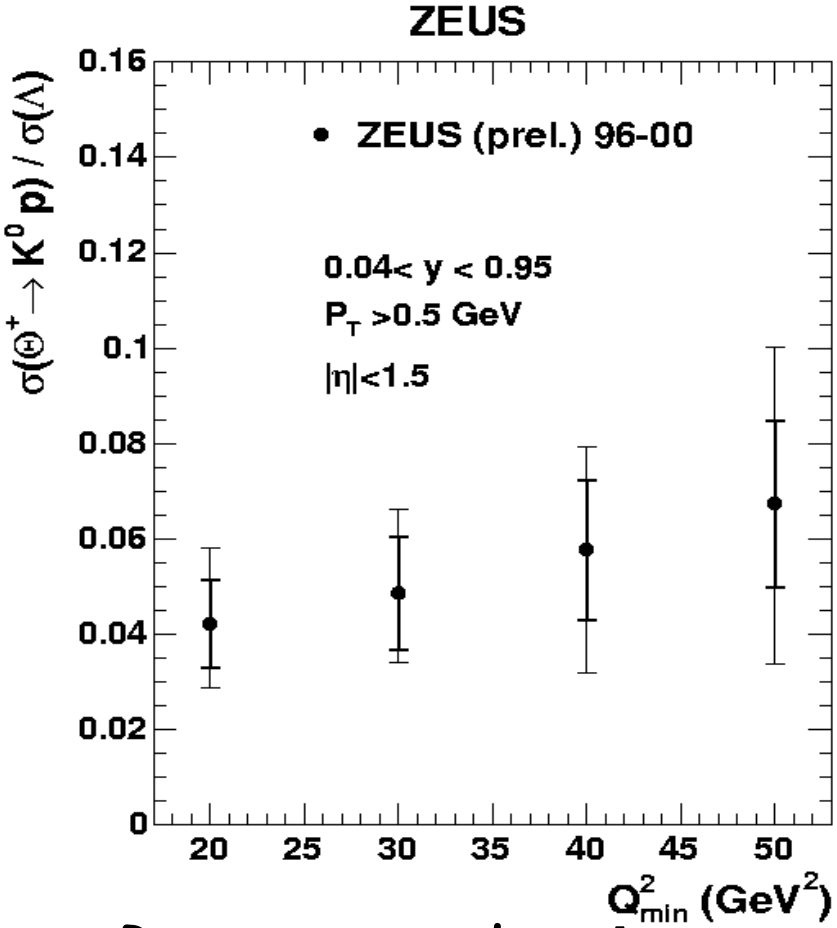
(K^0_s-antiproton fit, ~ 3 σ)

If interpreted as θ pentaquark

⇒ then 1st observation of antipentaquark ?

Cross section measurements of $\theta^{\pm}$ (ZEUS)





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

$Q^2 > 20$ GeV^2, $0.04 < y < 0.95$

$PT(\theta^{\pm}) \geq 0.5$ GeV, $|\eta(\theta^{\pm})| \leq 1.5$

$\sigma(ep \to e\theta^{\pm}X \to eK_s^0 pX) = 125 \pm 27^{+37}_{-28}$ pb

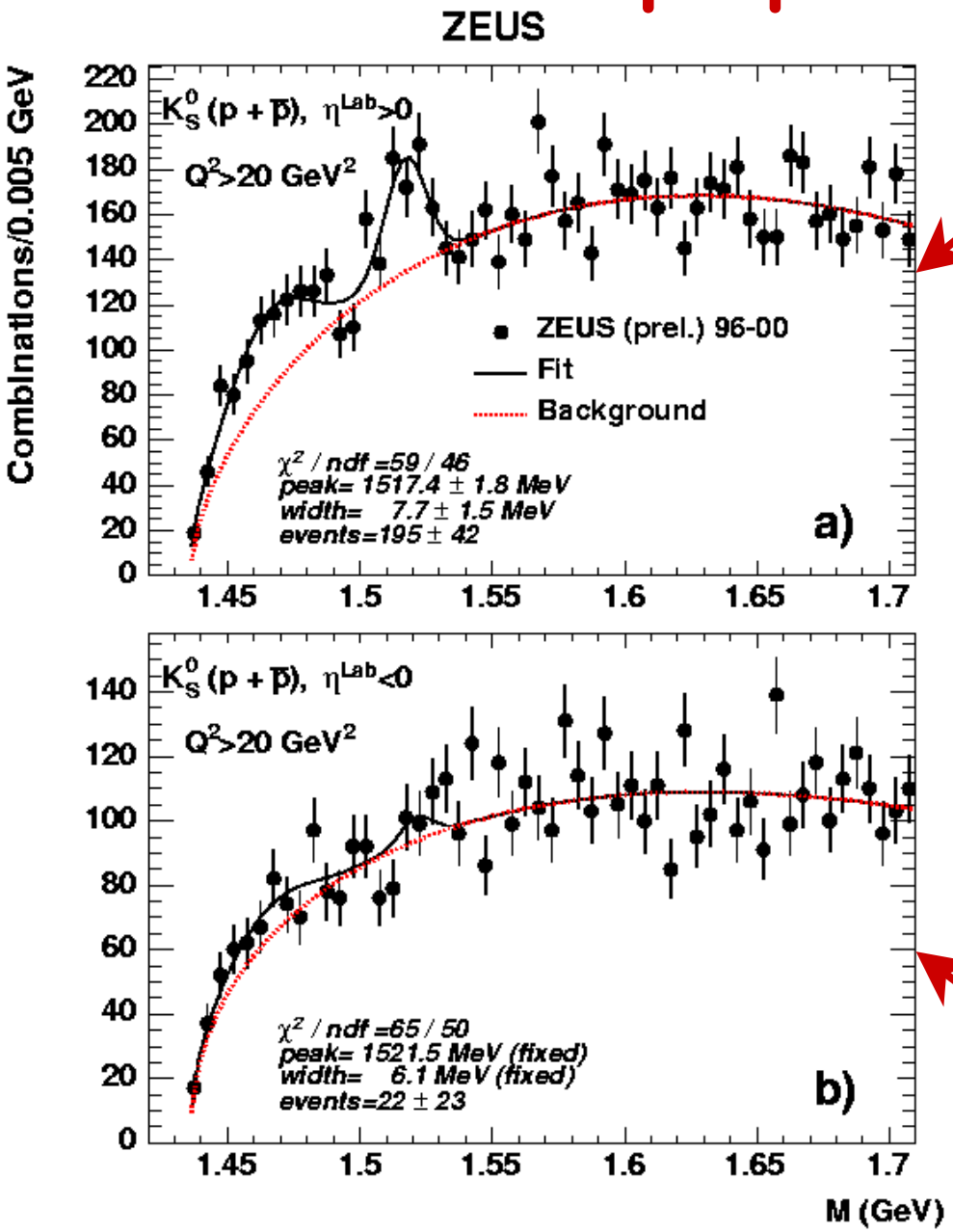
Rate compared to $\Lambda \to p\pi$:

$R = \sigma(\theta^{\pm} \to K_s^0 p)/\sigma(\Lambda \to p\pi)$

$= 4.2 \pm 0.9^{+1.2}_{-0.9}$ %

the same criteria of selection for Λ as for $\theta^{\pm}$

Production properties of $\theta^{\pm}$ (ZEUS)

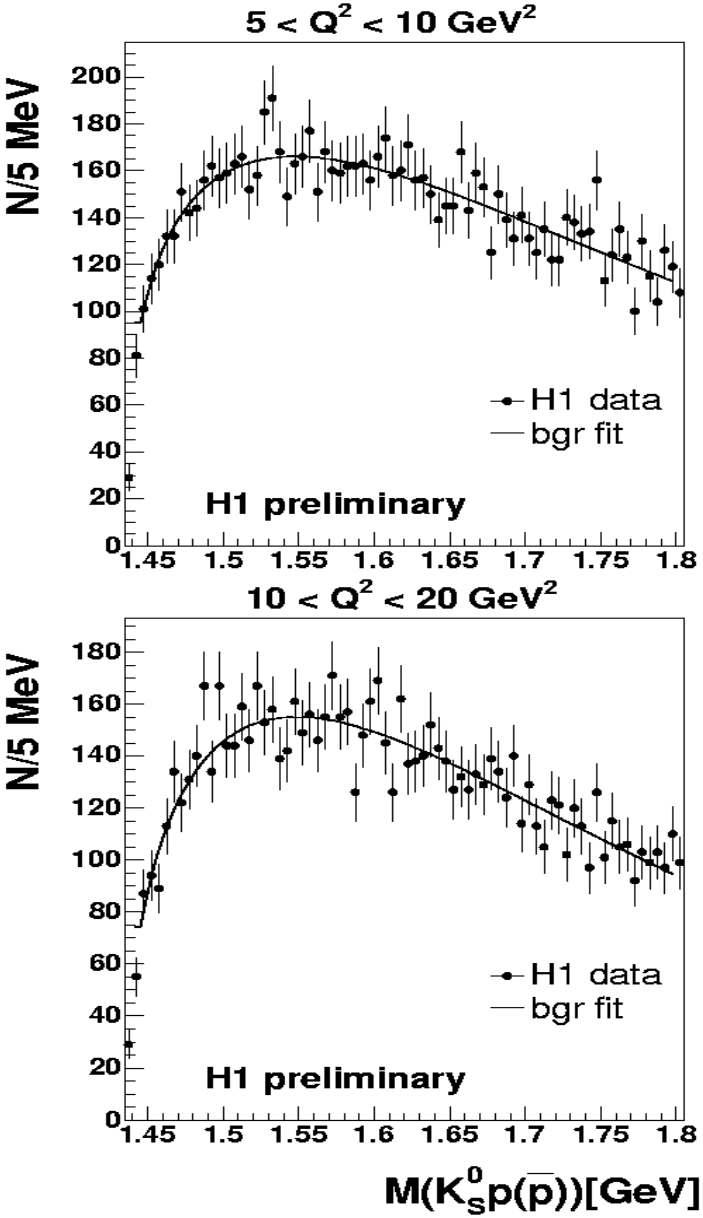


forward

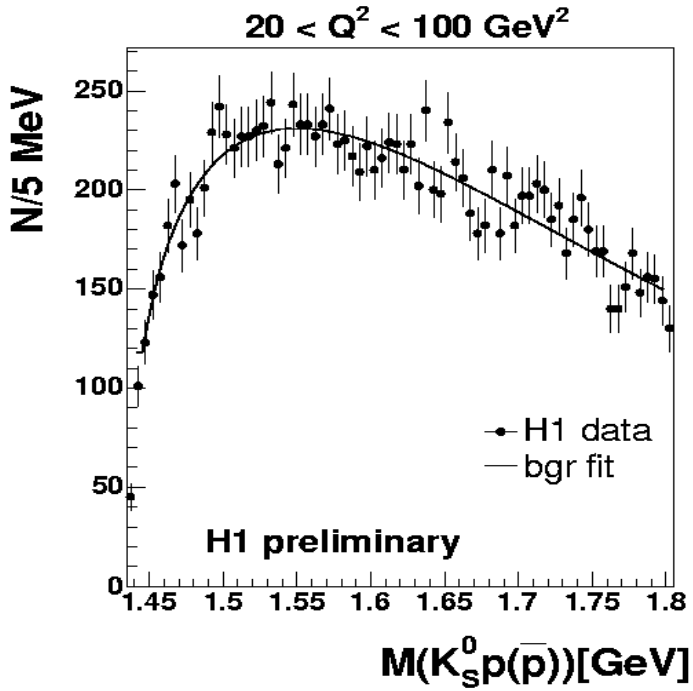
rear

The candidate $\theta^+(1520)$ signal was found to be produced predominantly in the forward pseudorapidity region, unlike the well established baryons, $\Lambda(1520)$ and Λ_c

Search for $\theta^+ \rightarrow p\, K^0_s$ / $\theta^- \rightarrow \bar{p}\, K^0_s$ (H1)

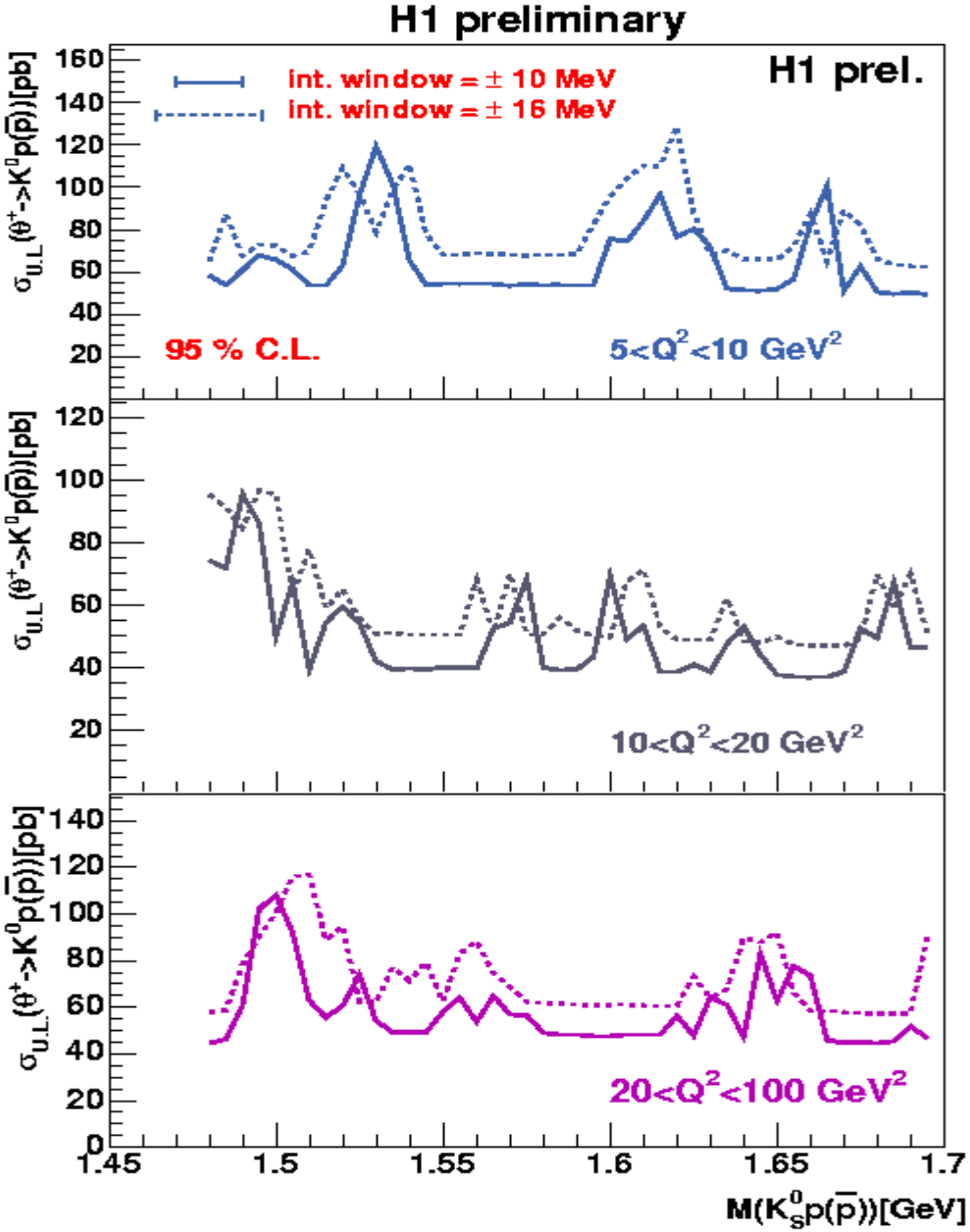


Similar analysis was done at H1:



no peak visible of $\theta^{\pm}$

Search for $\theta^+ \rightarrow p\, K^0_s$ / $\theta^- \rightarrow \bar{p}\, K^0_s$ (H1)



Upper limits on the cross section $\sigma_{\text{upper limits}}(ep \rightarrow eq^{\pm}X \rightarrow eK_s^0pX)$ at 95% confidence level in bins of Q^2

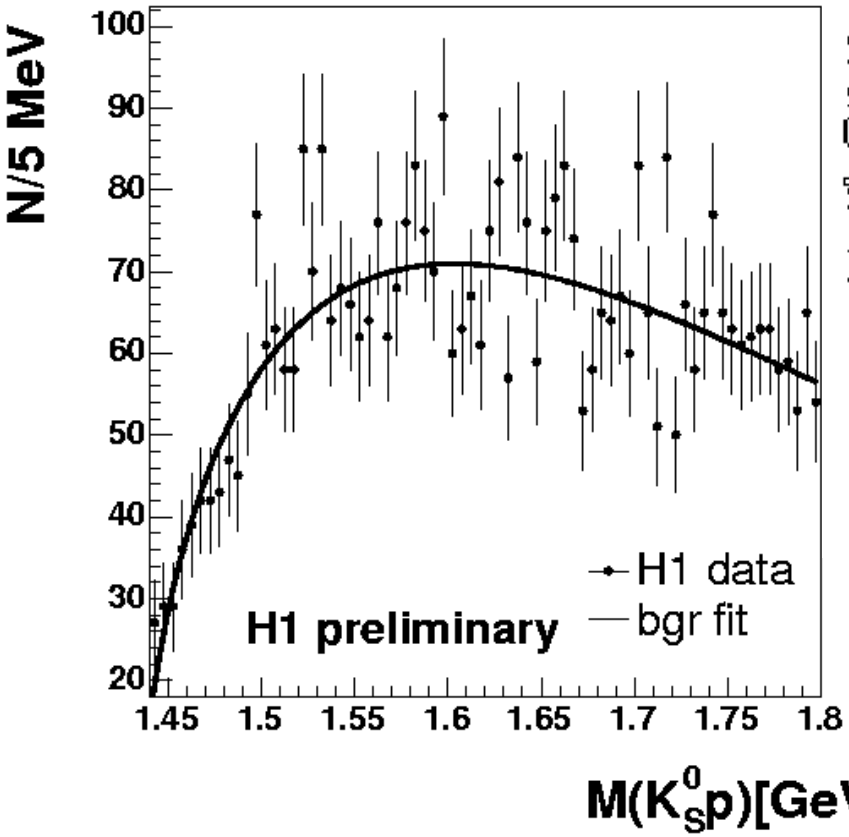
no single fluctuation at the same mass at the different Q^2 bins observed

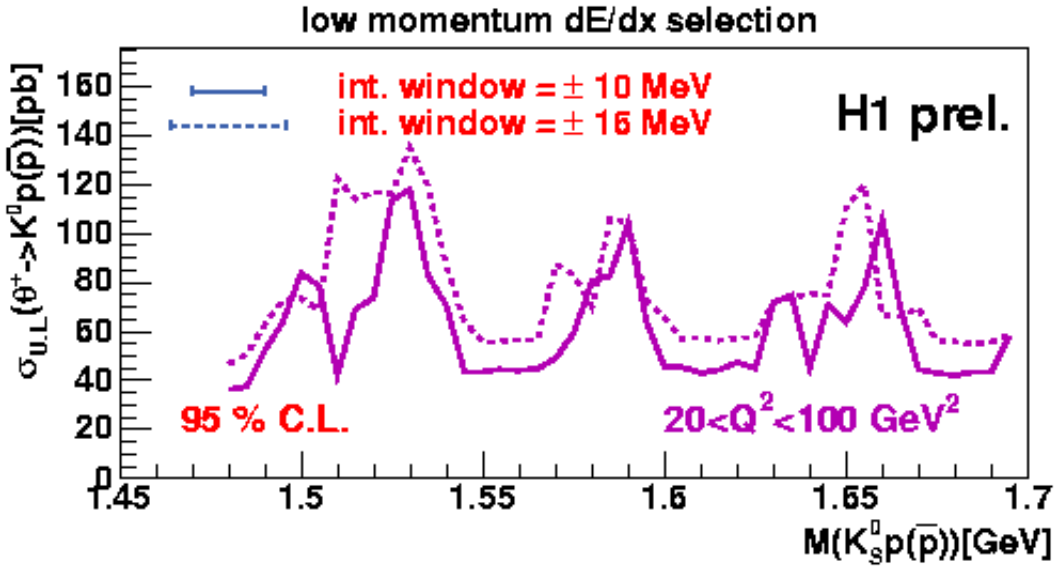
$\sigma_{\text{upper limits}}(ep \rightarrow eq^{\pm}X \rightarrow eK_s^0pX)$= 40-120 pb in $M(K_s^0p)$=1.48-1.7 GeV

no evidence for existing of $\theta^{\pm}$

Search for $\theta^+ \rightarrow p K^0_s$ / $\theta^- \rightarrow \bar{p} K^0_s$ (H1)

Comparison of H1 and ZEUS in similar phase space region





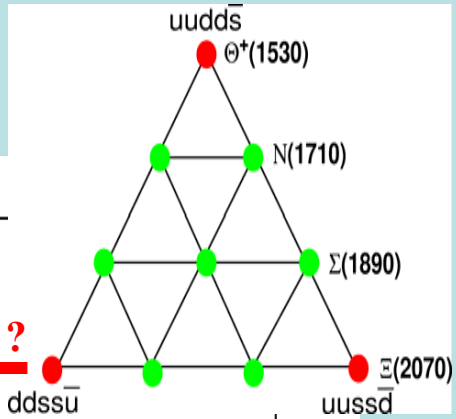
$\sigma_{upper\ limits}(ep \rightarrow eq^{\pm}X \rightarrow eK_s^0pX)$=
40-120 pb
in $M(K_s^0p)$=1.48-1.7 GeV

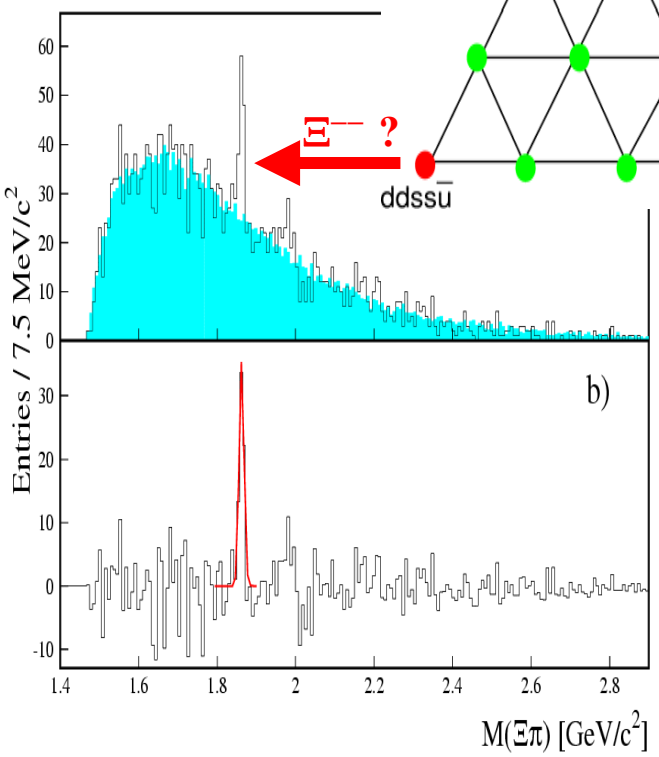
The resulting upper limit does not exclude the previously observed cross section at ZEUS

Search for Double Strange $\Xi^{--}_{3/2} \to \Xi^- \pi^-$

NA49 search for $\Xi^{--}_{3/2} \to \Xi^- \pi^-$
M = 1862 ± 2 MeV
width< 18 MeV, ~3 σ

NA49



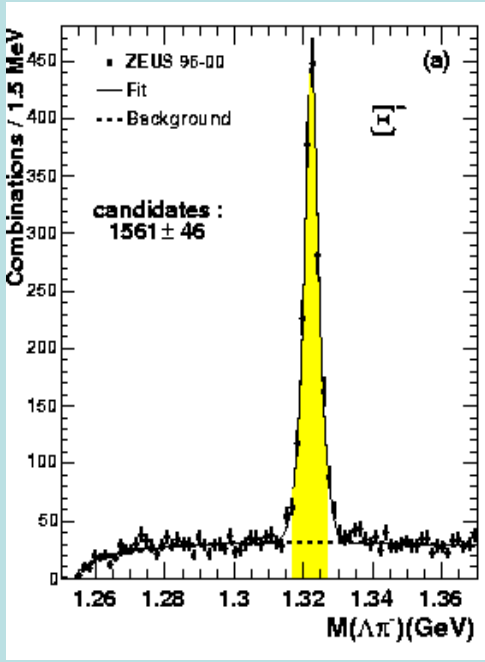


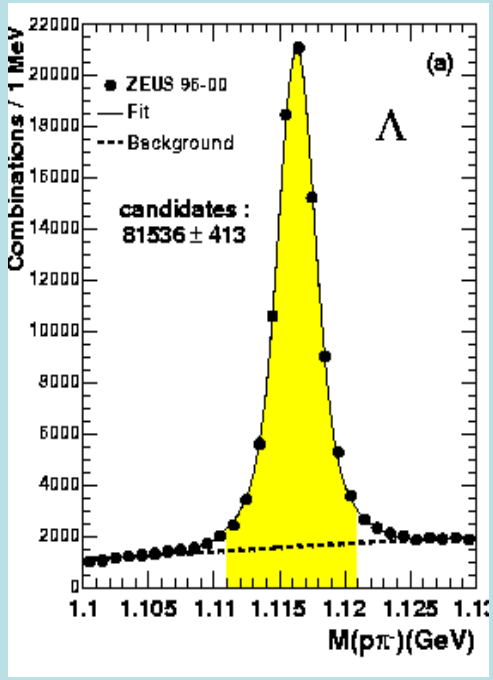
Similar analysis of NA49 repeated using ZEUS DIS data

$\Xi^{--}_{3/2} \to \Xi^- \pi^-$

$\to \Lambda^0 \pi^-$

$\to p\pi^-$

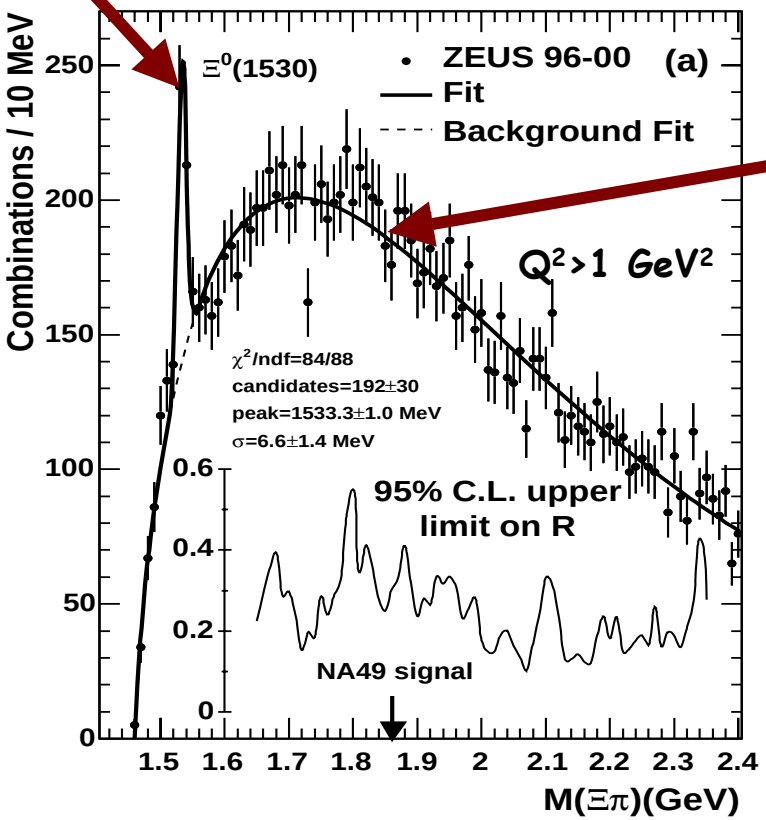




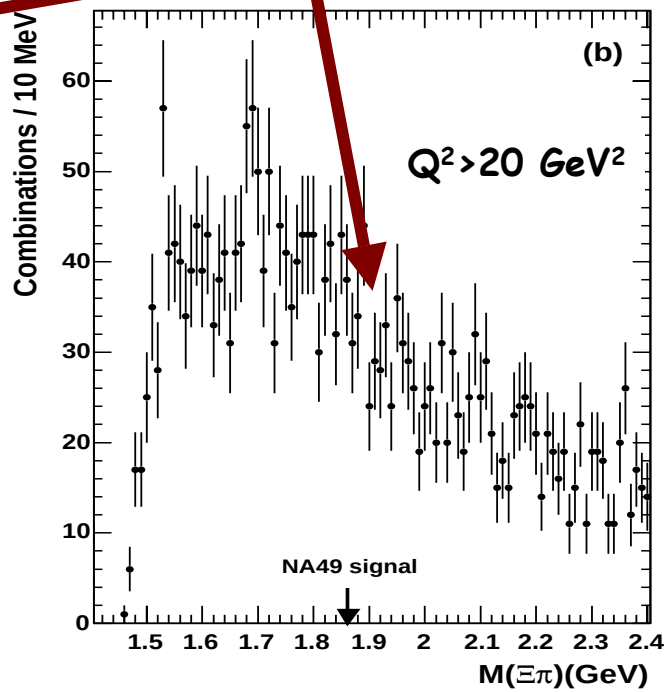
Ξ^-(+c.c.) ~ 2600, Λ(+c.c) ~ 130000 candidates

Search for Double Strange $\Xi^{--}_{3/2} \rightarrow \Xi^{-}\pi^{-}$

Clean Ξ^0 (1530)

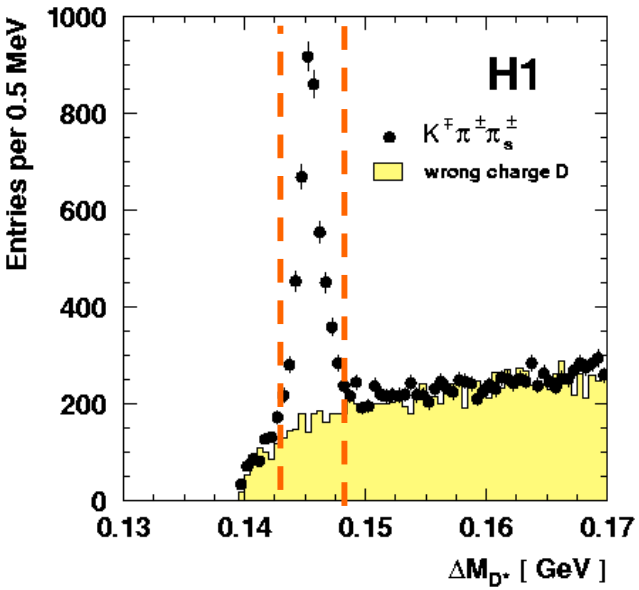


No pentaquark signal, for $Q^2>1$ and $Q^2>20$ GeV^2



No signal of NA49 observed by ZEUS
Different phase space?

Search for charmed PQ, $\theta_c \rightarrow D^*p$, in H1



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

1996-2000 Data 75 pb^{-1} $0.05<y<0.7$

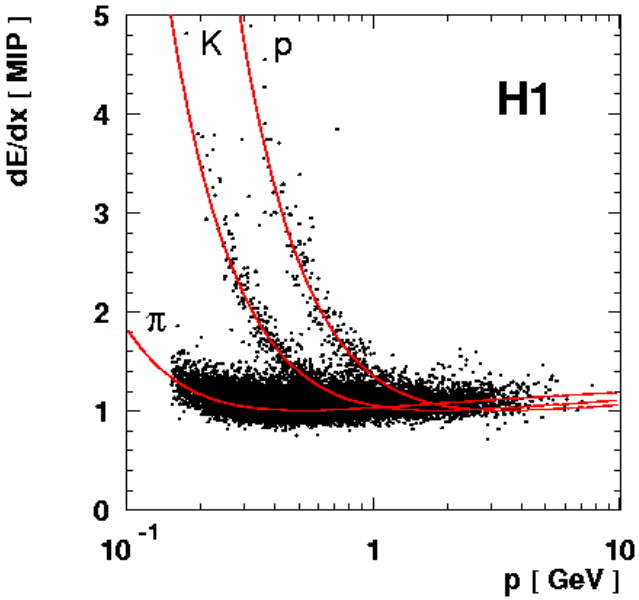
$D^{*+} \rightarrow D^0\pi_s^+ \rightarrow (K^-\pi^+)\pi_s^+$

$\Delta M_{D^*} = m(K\pi\pi_s) - m(K\pi)$

$p_T(D^*) > 1.5$ GeV, $-1.5 < |\eta(D^*)| < 1$

Inelasticity $z(D^*) > 0.2$

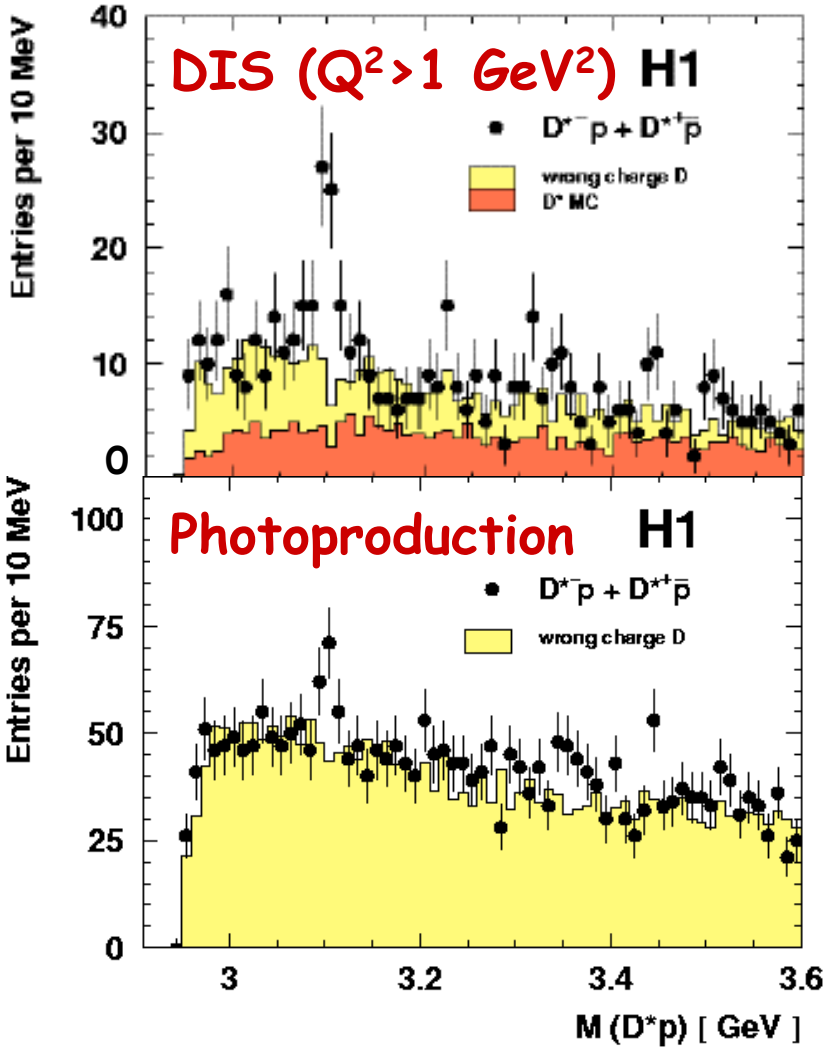
3400 events with D* in DIS



Proton identification by dE/dx

Search for charmed PQ, $\theta_c \rightarrow D^*p$, in H1

DIS and photoproduction samples:
$D^{*+} \rightarrow D^0\pi_s^+ \rightarrow (K^-\pi^+)\pi_s^+$ and identify p (dE/dx)



Use mass difference method:
$M(D^*p)=m(K\pi\pi p)-m(K\pi\pi)+M_{PDG}(D^*)$

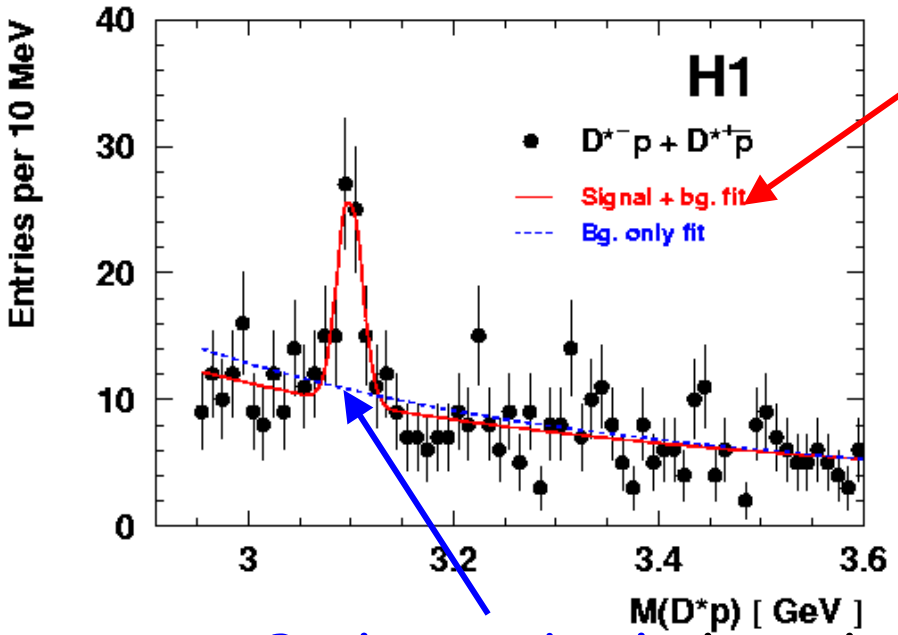
Data well described (except in the 3.1 GeV region) by

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

Signal at 3.1 GeV both in DIS and photoproduction samples

Search for charmed PQ, $\theta_c \rightarrow D^*p$, in H1

Significance estimate (DIS sample)



Fit: Gaussian +power law bg

Mass: 3099±3(stat)±5(sys) MeV

Width: 12 ± 3 MeV

(consistent with experimental resolution)

Numbers of signal and bg within 2σ

N_s=50.6 ± 11.2, N_b=45.0 ± 2.8

(~1% of D* yield)

Background only hypothesis: N_b=51.7±2.7

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

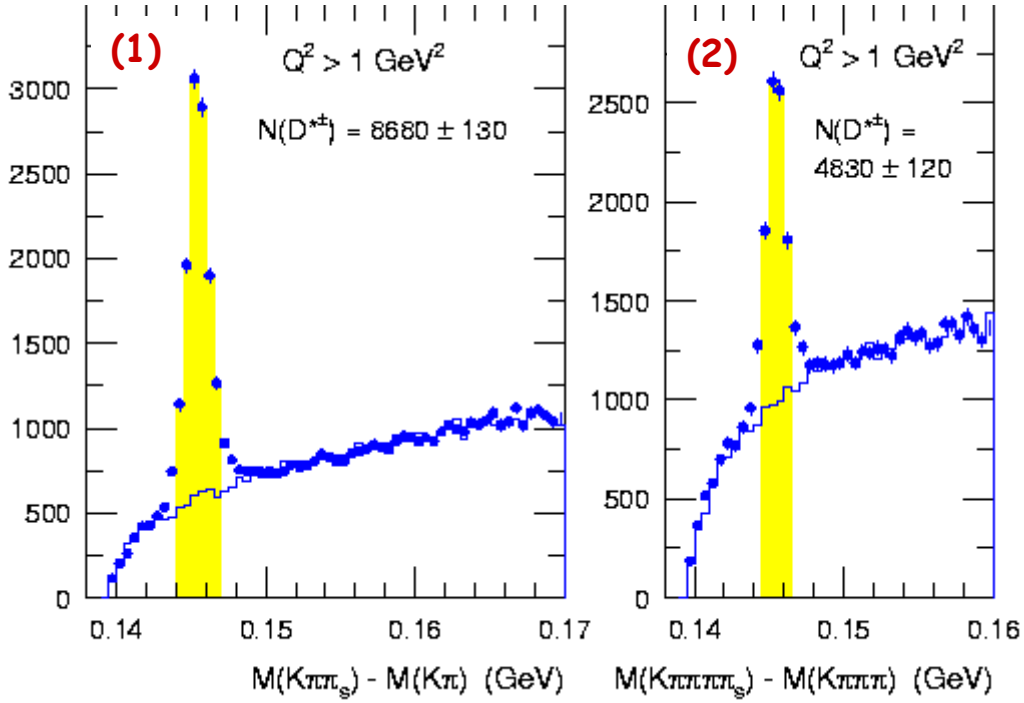
From the change in the maximum log-likelihoods of fits (w and w/o signal hypothesis) statistical significance is 6.2σ

Search for $\theta_c \rightarrow D^*p$ in ZEUS

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

Two D* channels:

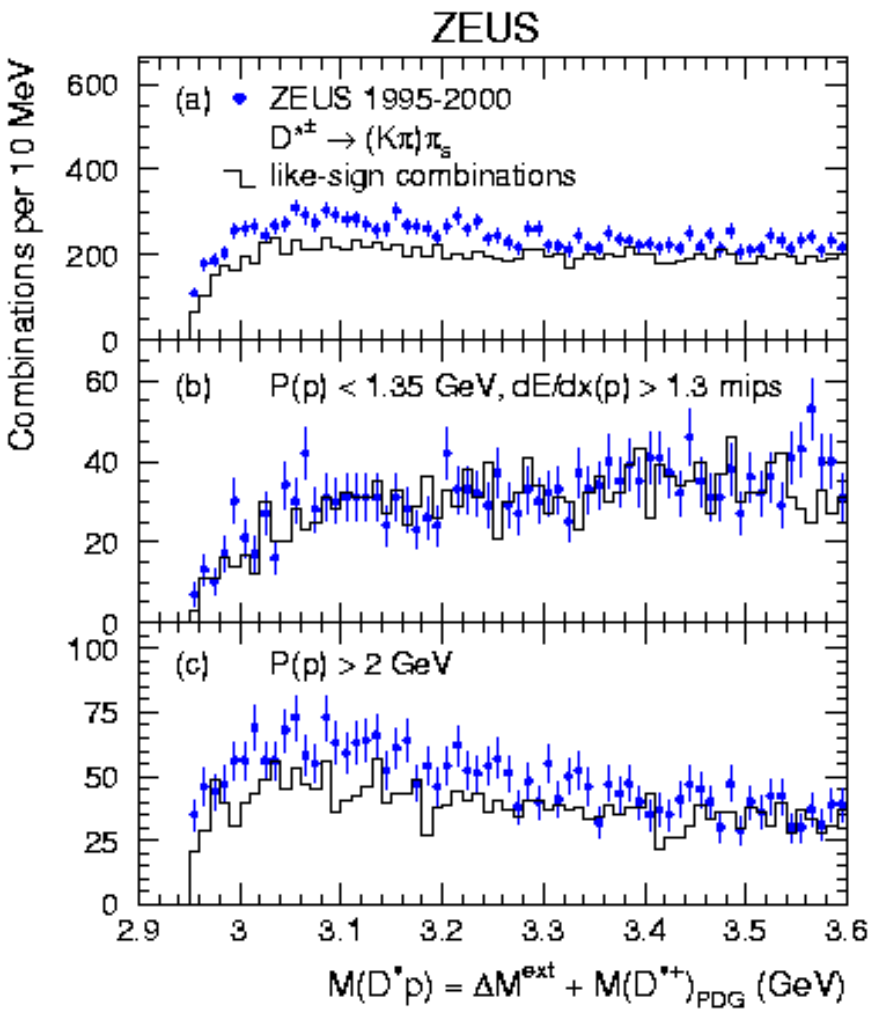
$D^{*+} \rightarrow D^0\pi_s^+ \rightarrow (K^-\pi^+)\pi_s^+$ (1) $D^{*+} \rightarrow D^0\pi_s^+ \rightarrow (K^-\pi^+\pi^+\pi^-)\pi_s^+$ (2)

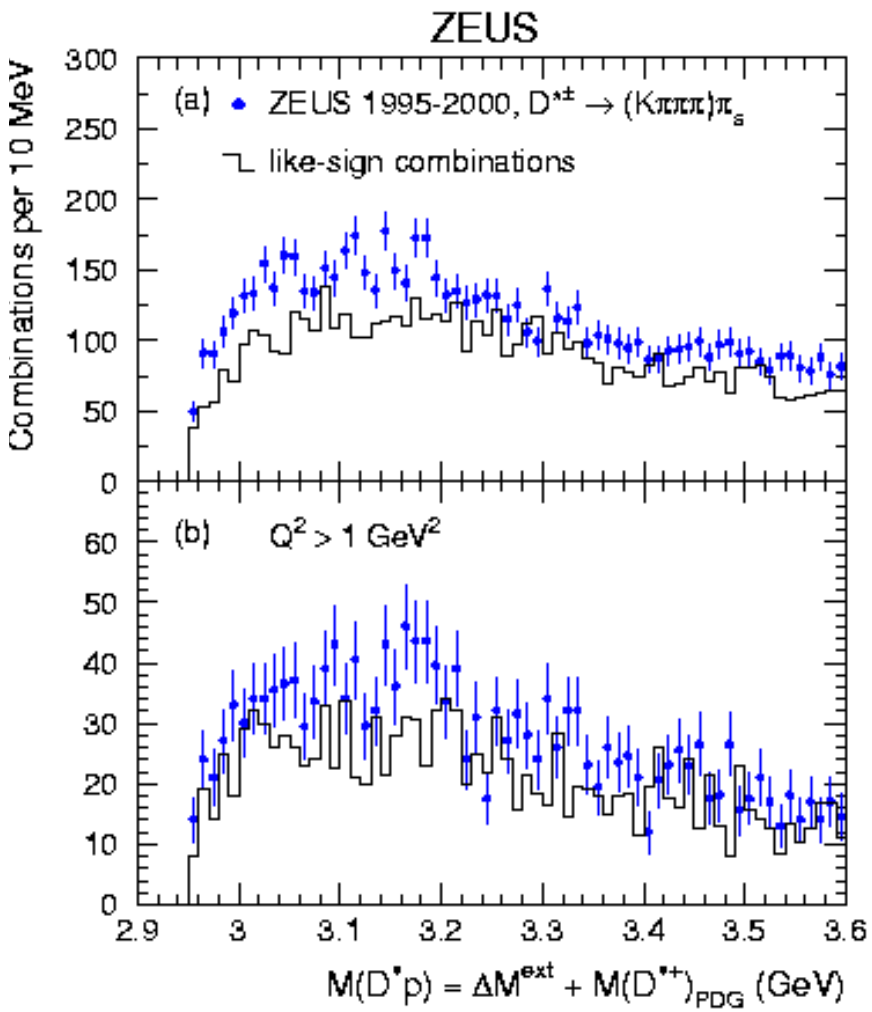


$N_{(1)+(2)}(D^*) \approx 62500$ (inclusive)

$N_{(1)+(2)}(D^*) \approx 13500$ ($Q^2 > 1$ GeV^2)

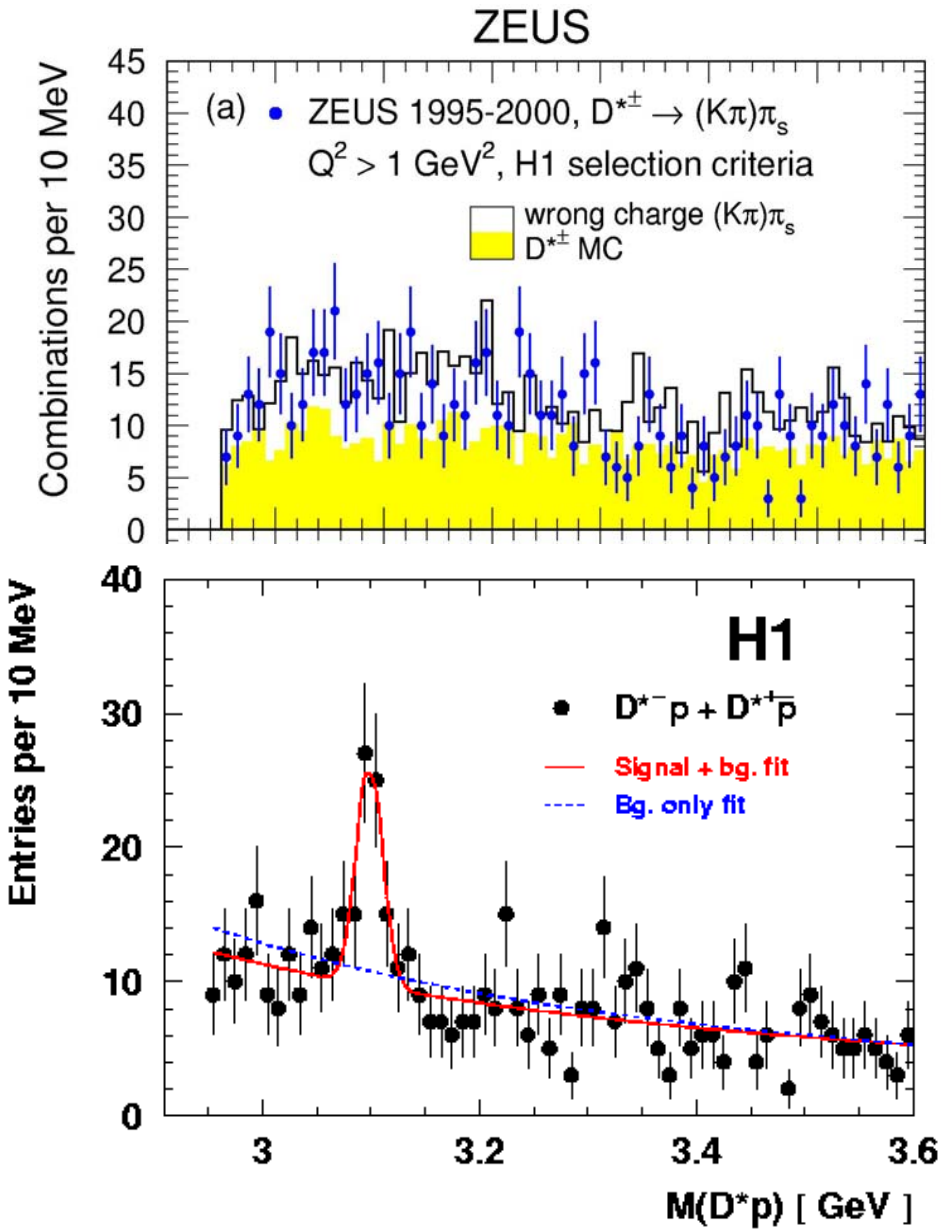
Search for $\theta_c \rightarrow D^*p$ in ZEUS





No hint for the signal observed by H1 at 3099 MeV

Search for $\theta_c \rightarrow$ D*p :H1 / ZEUS



Comparison of H1 and ZEUS in similar phase space region

ZEUS didn't observe θ_c signal in a DIS data sample 1.7 times of H1 data sample (neither in photoproduction)

Acceptance corrected $R_{cor}(D^*p(3100)/D^*)$

H1:

kinematic region: $1 < Q^2 < 100\ GeV^2$ and $0.05 < y < 0.7$

In the visible D*p range: $p_T(D^*p) > 1.5\ GeV$, $-1.5 < \eta(D^*p) < 1.0$

And visible D* range: $p_T(D^*) > 1.5\ GeV$, $-1.5 < \eta(D^*) < 1.0$, $z(D^*) > 0.2$

$R_{cor}(D^*p(3100)/D^*) = (1.59 \pm 0.33(stat)\ ^{+0.33}_{-0.45}\ (syst))\%$ (preliminary)

ZEUS:

kinematic region: $Q^2 > 1\ GeV2$ and $y<0.95$

phase space: $p_T(D^*) > 1.5\ GeV$, $-1.5 < \eta(D^*) < 1.0$

95% C.L. upper limit:

$R_{cor}(D^*p(3100)/D^*) < 0.59\%$ ($< 0.51\%$ for both D^0-decay channels)

ZEUS: full kinematic region (DIS + photoproduction)

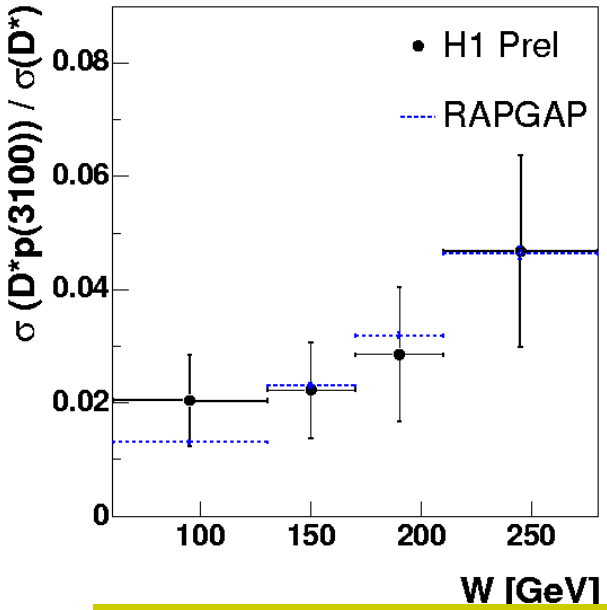
95% C.L. upper limit:

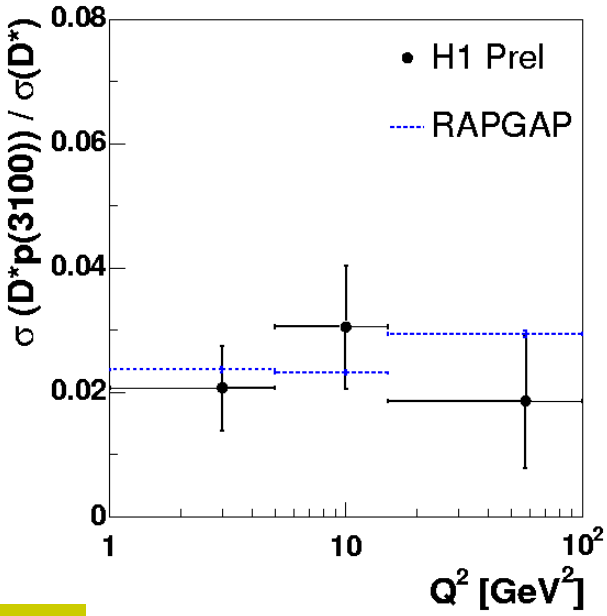
$R_{cor}(D^*p(3100)/D^*) < 0.47\%$ ($< 0.37\%$ for both D^0-decay channels)

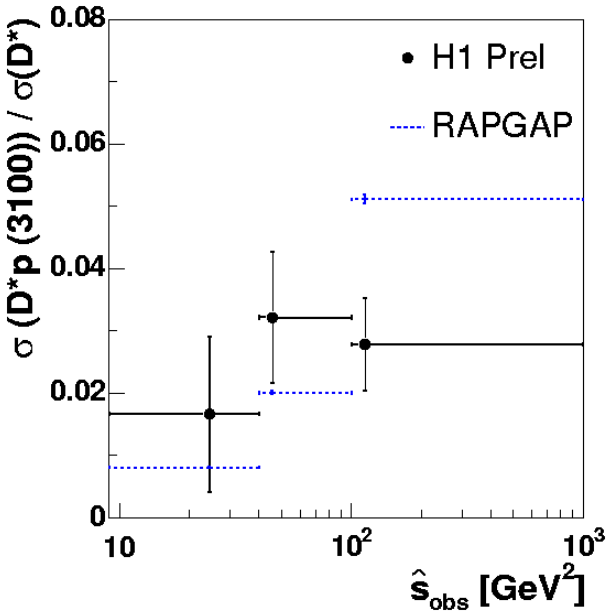
Observation of ZEUS and H1 are not compatible

σ(D*p(3100))/σ(D*) vs. event kinematical variables

MC used for the acceptance correction and comparison: RAPGAP 3.1 MC
D*p(3100) was introduce by appropriate changing of mass and decay of $D_1(2420)$ and $D_2^*(2460)$ (isotropic decay)







(statistical errors only on the plots)

$\hat{s}_{obs}$ – *invariant mass of* $(c\bar{c})$ *system*

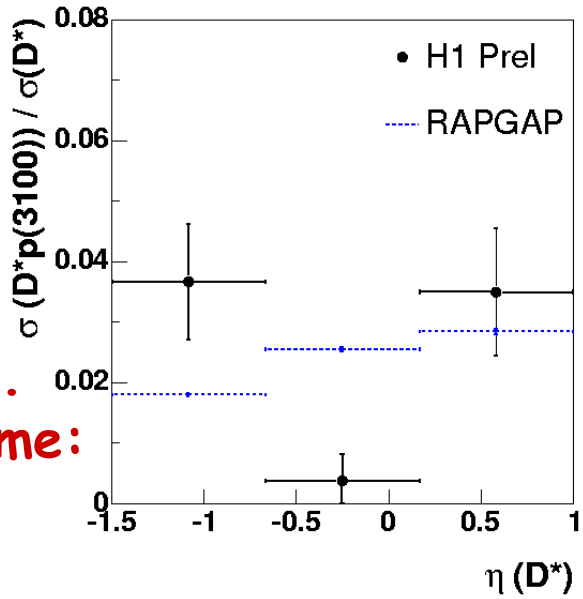
The model prediction is normalized to the observed ratio
$\sigma(D^*p(3100))/\sigma(D^*) = 2.48 \pm 0.52^{+0.85}_{-0.64}$ %

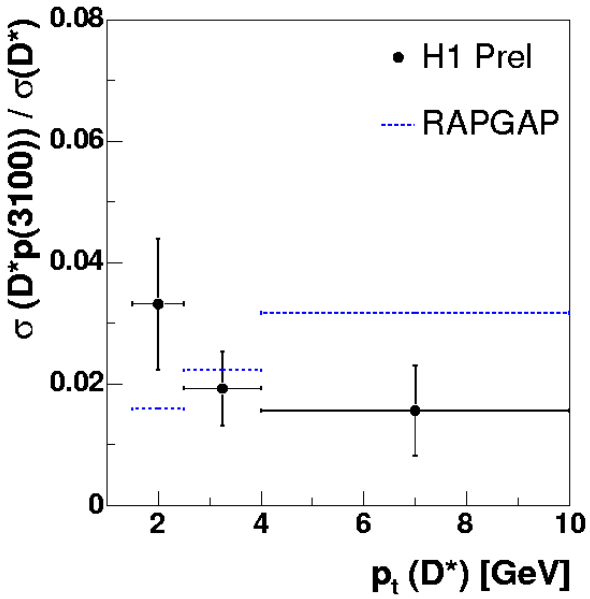
W and Q^2 distributions well described by MC

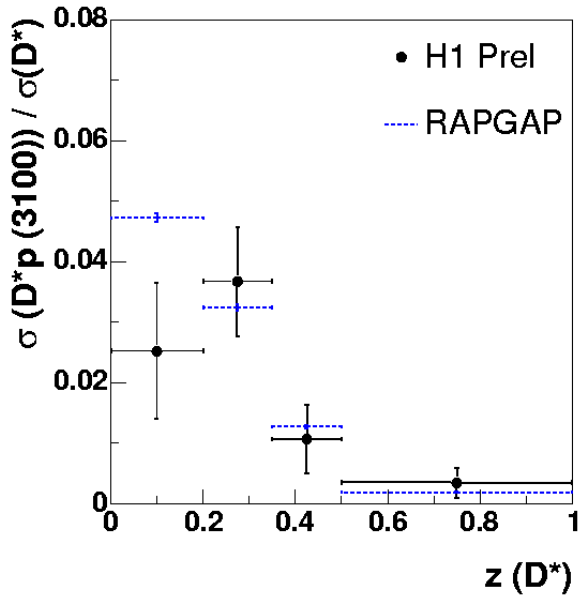
Different behavior of $\hat{s}_{obs}$ for data and MC

σ(D*p(3100))/σ(D*) as a function of D* variables

Lab. frame:

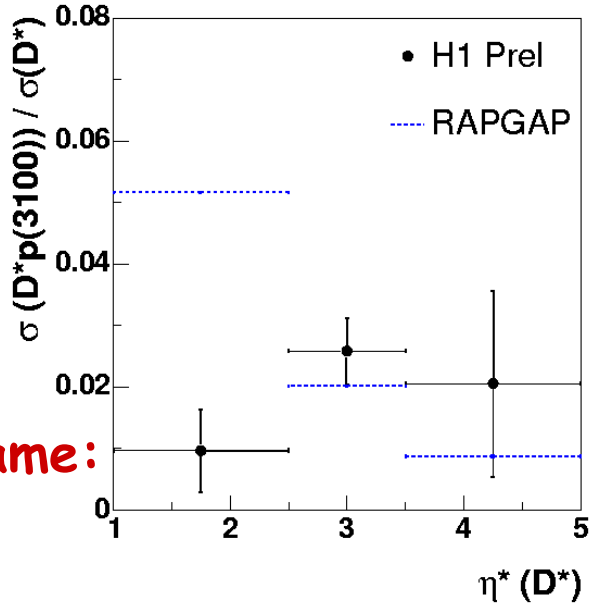






(statistical errors only on the plots)

γp frame:



Production of D*p is suppressed for central η both in the lab. and γp frames

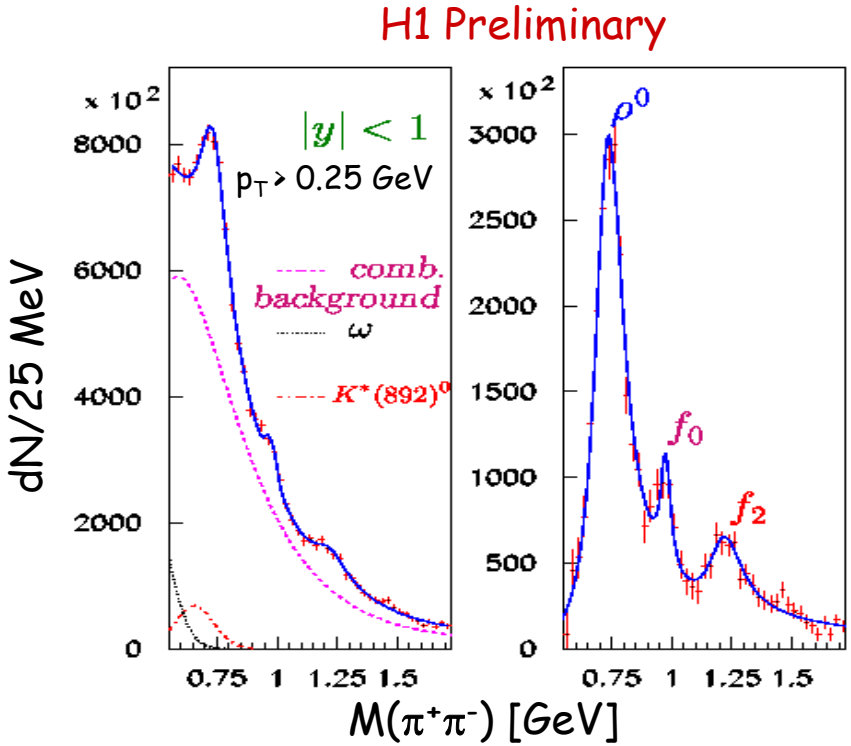
D* from the decay of D*p are significantly softer in p_T(D*) and z(D*) compared to the inclusive D*

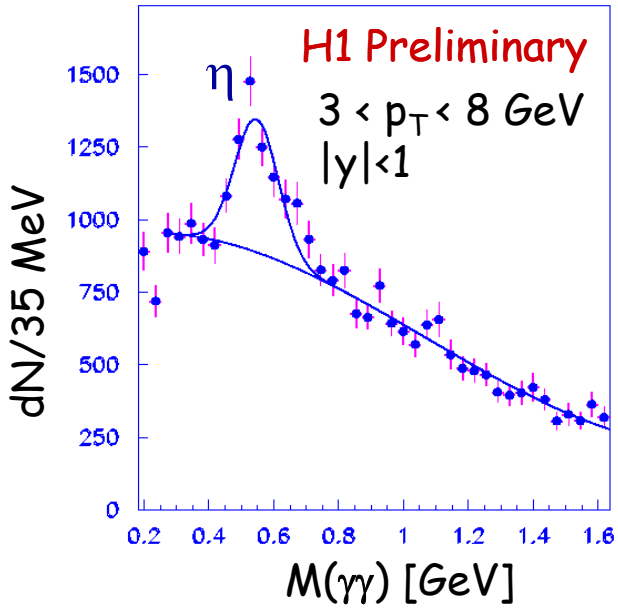
Non-exotic particles production

In ZEUS and H1 are measured production of well-known hadrons: pions, K^0_s, Λ, protons, charm mesons, J/ψ …
The latest result is the cross section measurement of

Inclusive photoproduction of η, ρ^0, $f_0(980)$ and $f_2(1270)$ mesons at H1

Photoproduction sample 2000: $Q^2 \approx 0$, 38.7 pb^{-1}, $W_{\gamma p}$=210 GeV

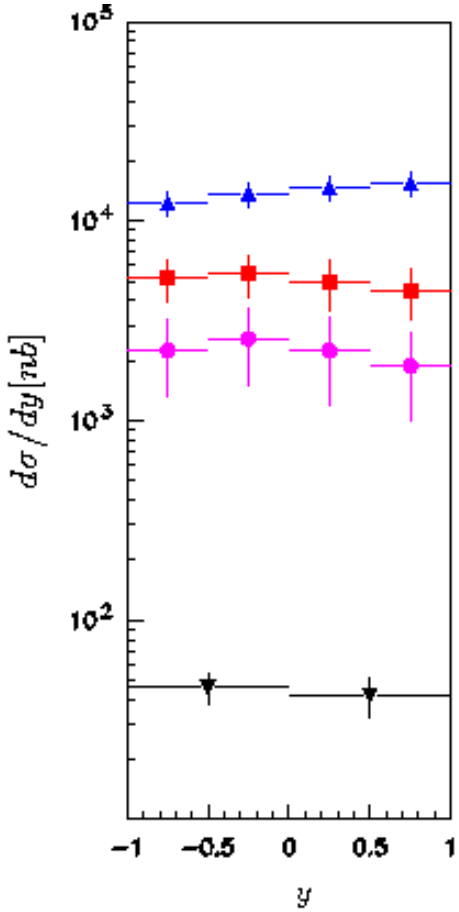


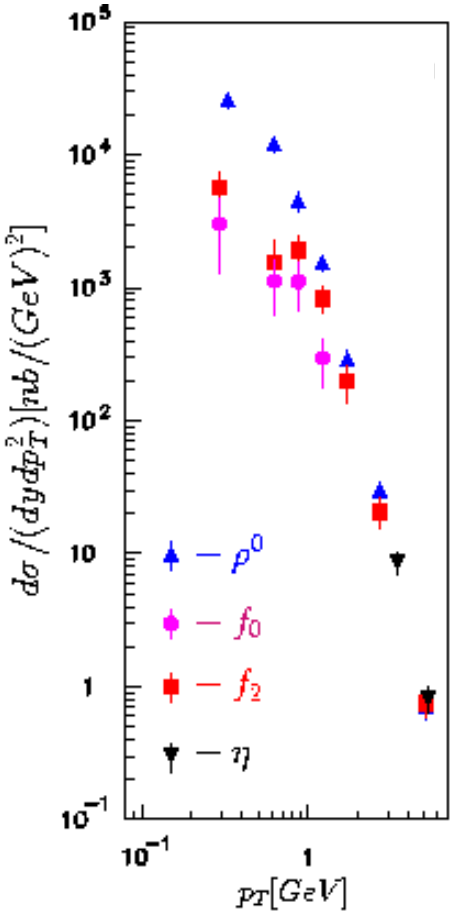


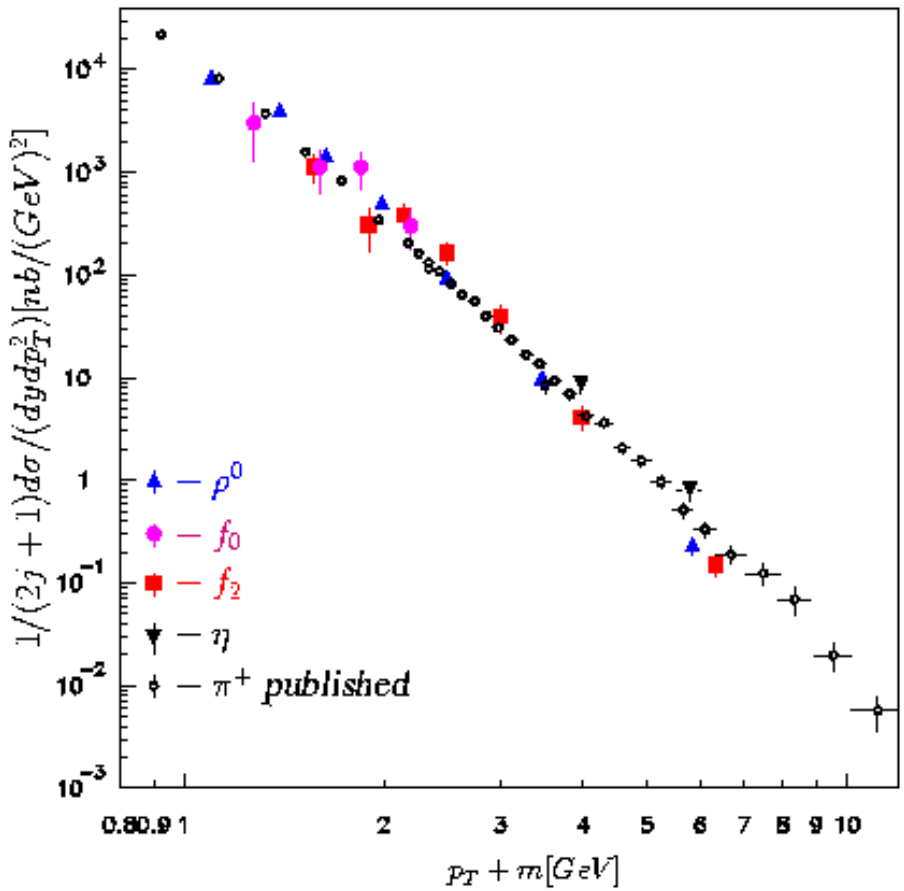
η, ρ^0, $f_0(980)$ and $f_2(1270)$ mesons at H1

H1 Preliminary

$\langle W_{\gamma p} \rangle = 210$ GeV







Flat distribution in rapidity space

The universal behaviour of hadrons is observed

Conclusions

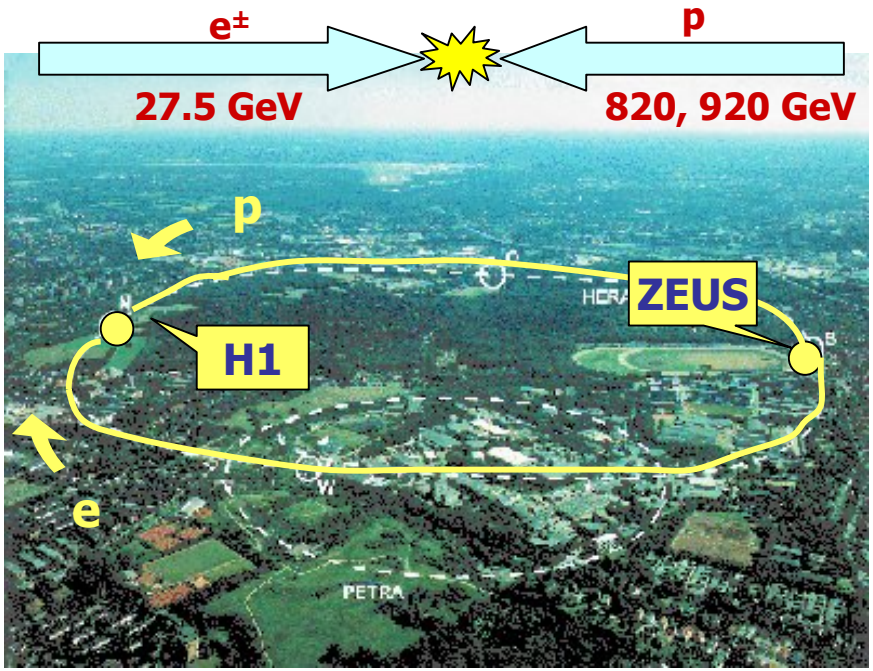
- $\theta^+(1530)$: evidence for a narrow baryonic state at mass 1521.5 decaying to $K^0_s p$ (ZEUS). H1 does not observe this state but upper limit does not exclude ZEUS observation.
- $\Xi^{--}(1860)$: no evidence for the NA49 $\Xi^-\pi^-$ signal at 1862 MeV (ZEUS)
- $\theta^0_c(3100)$: evidence from H1 for the narrow resonance in D*p system at mass 3099 MeV. With larger statistics ZEUS does not see this signal

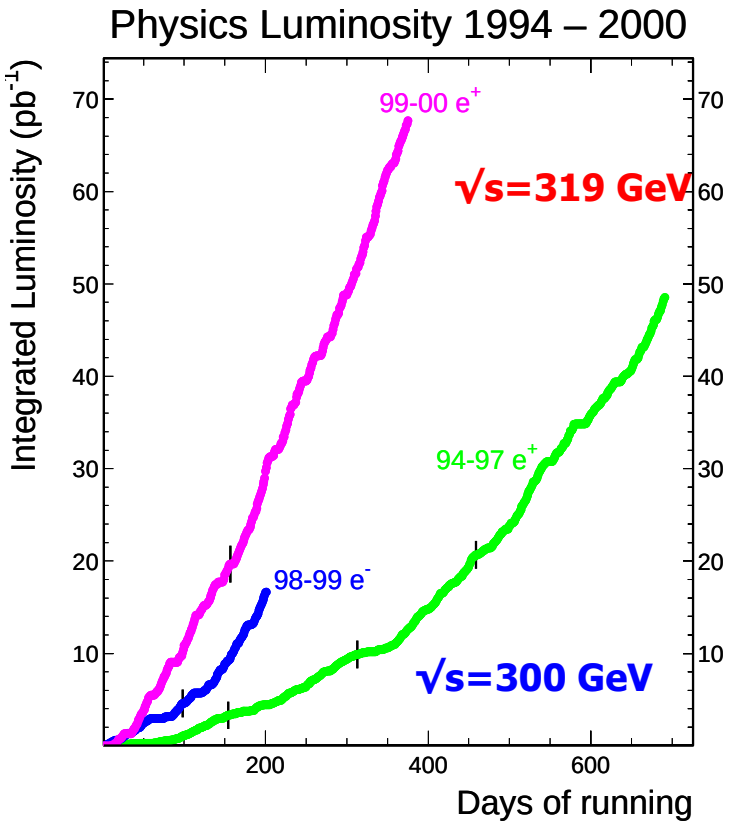
Need more statistics (HERA2) to confirm or to exlude the observations

- η, ρ^0, f_0, f_2: The inclusive cross-section for hadronic resonances has the same behavior as observed for long-lived hadrons

Back up slides

The HERA Collider

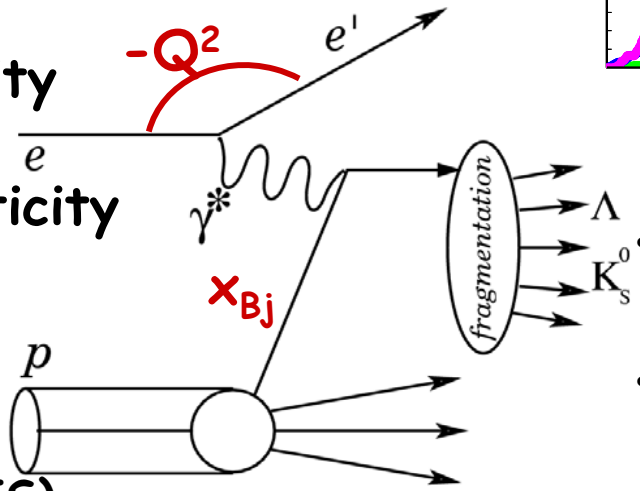




Q^2 : photon virtuality

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

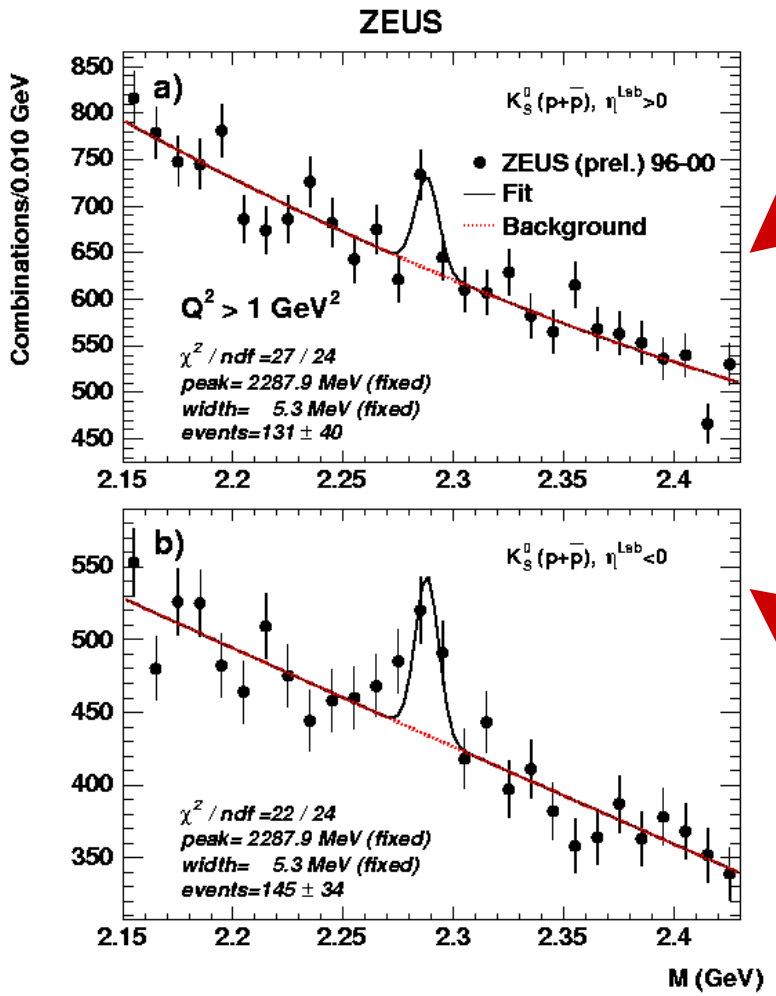
$Q^2 \approx 0$ GeV^2:
photoproduction
$Q^2 > 1$ GeV^2:
electroproduction (DIS)



- HERA I data sample 94-00:
  L ≈ 120 pb^{-1} / experiment
- Two colliding experiments:
  ZEUS, H1
- HERA II data taking on-going

Production properties of $\Lambda(1520)$ and Λ_c (ZEUS)

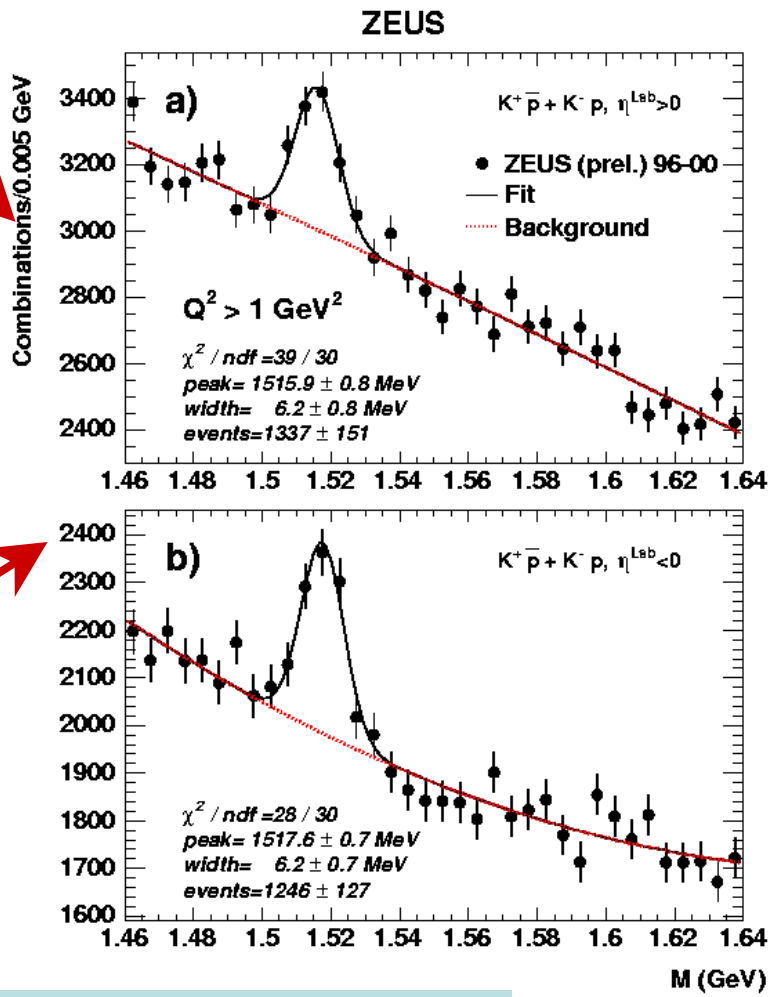
Λ_c production



forward

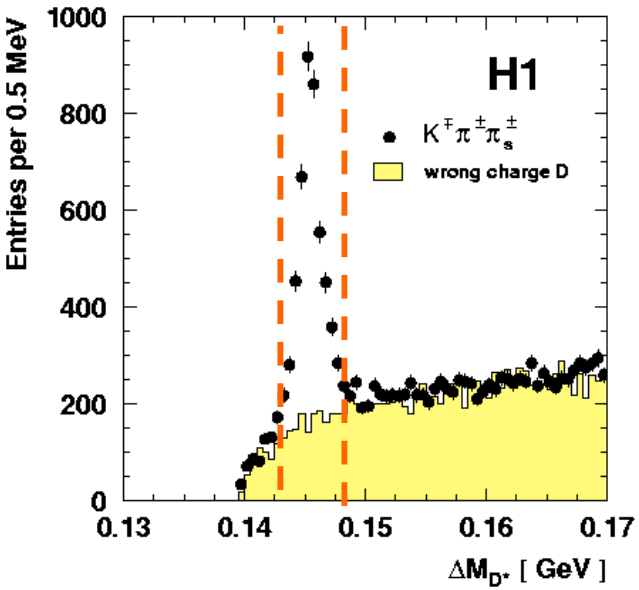
rear

$\Lambda(1520)$ production



The number of extracted Λ_c and $\Lambda(1520)$ candidates are about the same for forward and rear regions

Search for charmed PQ, $\theta_c \rightarrow D^*p$, in H1



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

1996-2000 Data 75 pb^{-1} $0.05<y<0.7$

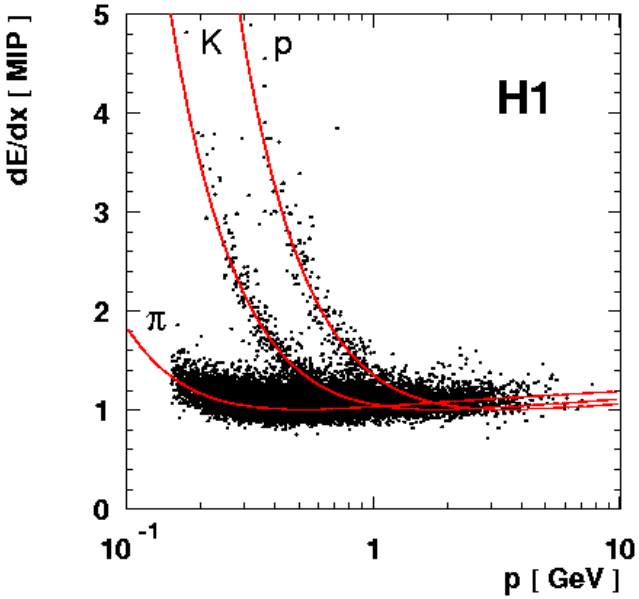
$D^{*+} \rightarrow D^0\pi_s^+ \rightarrow (K^-\pi^+)\pi_s^+$

$\Delta M_{D^*} = m(K\pi\pi_s) - m(K\pi)$

$p_T(D^*) > 1.5$ GeV, $-1.5 < |\eta(D^*)| < 1$

Inelasticity $z(D^*) > 0.2$

3400 events with D* in DIS



Proton identification by dE/dx

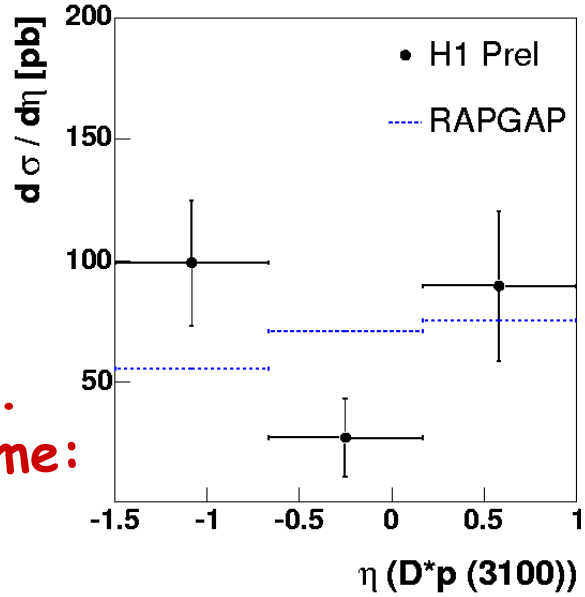
Normalized likelihood based on:

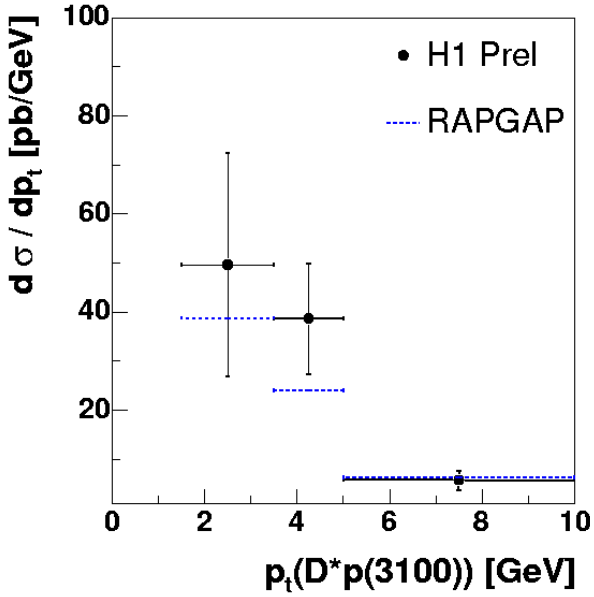
$L(\pi)+L(K)+L(p) = 1$

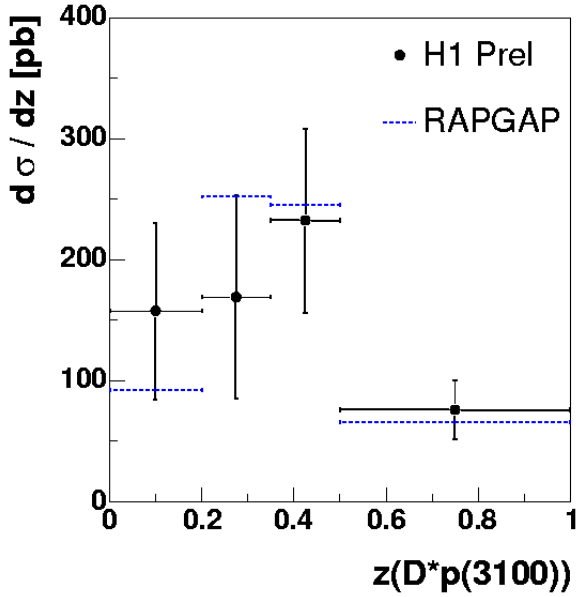
- $P_T(p) > 0.12$ GeV
- $L(p) > 0.1$ for $p(p) > 2$ GeV
- $L(p) > 0.3$ for $p(p) < 2$ GeV

σ(D*p(3100)) as a function of (D*p) variables

Lab. frame:

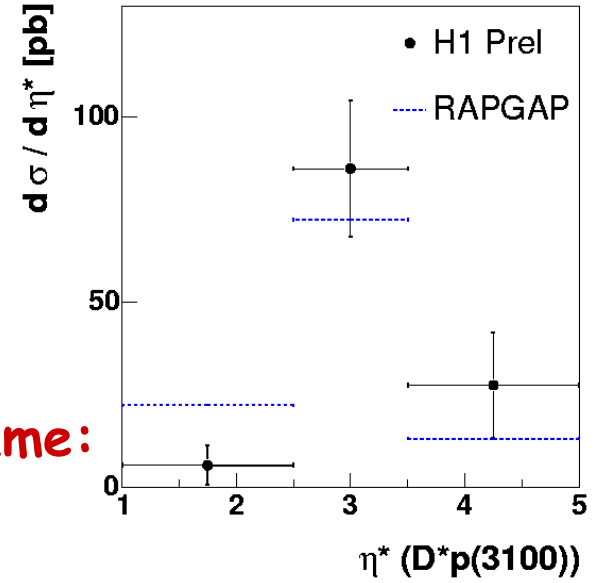






(statistical errors only on the plots)

γp frame:



Features of D*p production:

- Suppressed for central η in the lab and γp frames
- MC describes well p_T and z distributions