Exotic Spectroscopy at HERA

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for the ZEUS and H1 collaborations

CIPANP 2006, May 30- June 3 2006, Puerto Rico

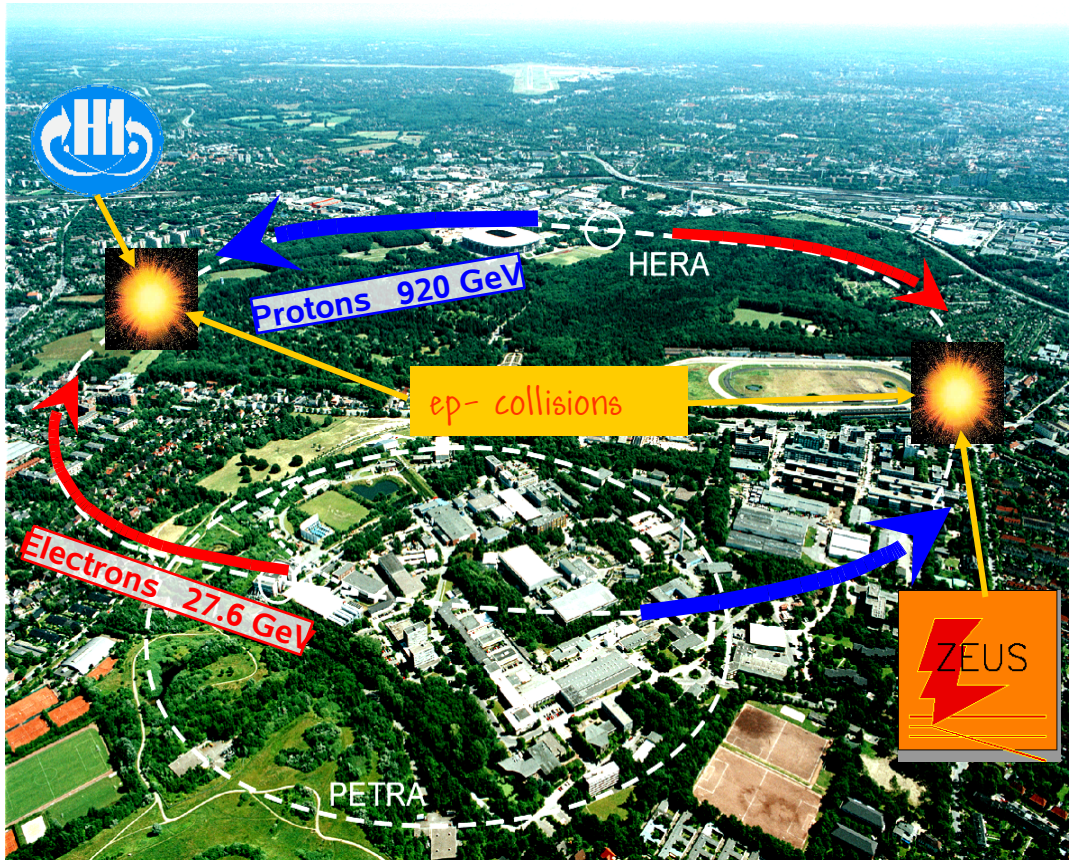
- **Strange Pentaquark Searches at HERA: θ+, Ξ--**
- **Charm Pentaquark Searches at HERA : θ_c**
- **Glueballs Searches in $K^0_s K^0_s$**
- **Summary**

* not covered in this talk: "non-exotics"
charmonium, bottomium, charmed and strange hadron production,
light hadrons, baryon production
HERMES, HERA-B results

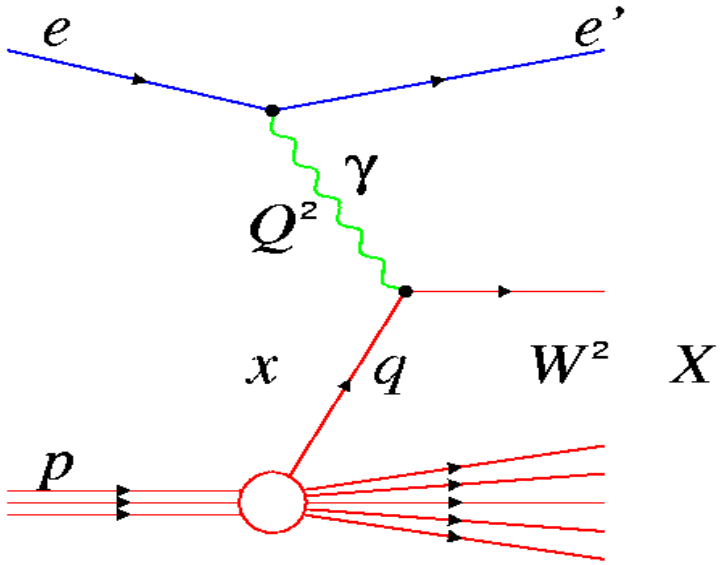
The HERA accelerator

E_e = 27.6 GeV → ← E_p= 920 (820) GeV

ep collisions at $\sqrt{s}$ ≈300-320 GeV



DESY, Hamburg, Germany



DIS kinematics:

pairs of Lorentz invariants:

- 4-momentum transfer squared
  $Q^2 = -q^2$
- Bjorken scaling variable: momentum fraction of proton carried by quark
  $x = Q^2/(2\,q\,P)$
- inelasticity $y = qP/kP$
- mass of the hadr. system $W^2 = (P + q)^2$
- DIS: $Q^2 > 1$ GeV^2
  photoproduction: $Q^2 < 1$ GeV^2

The HERA accelerator

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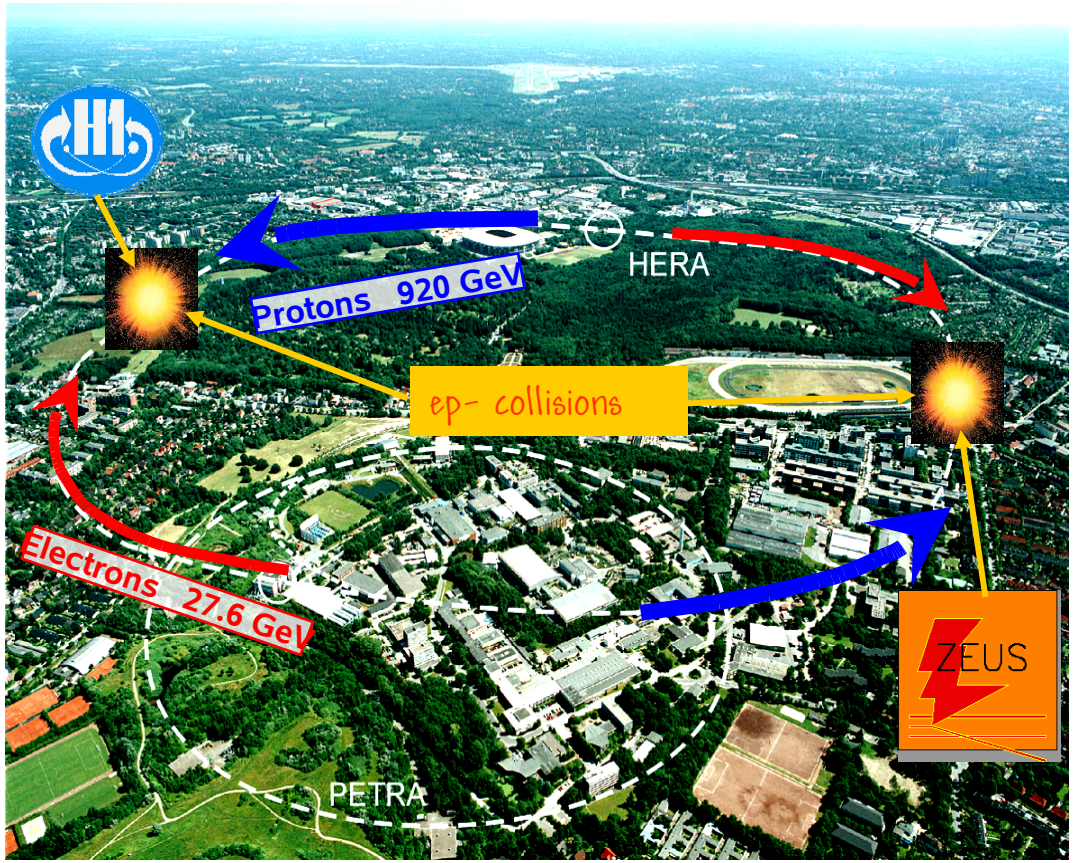

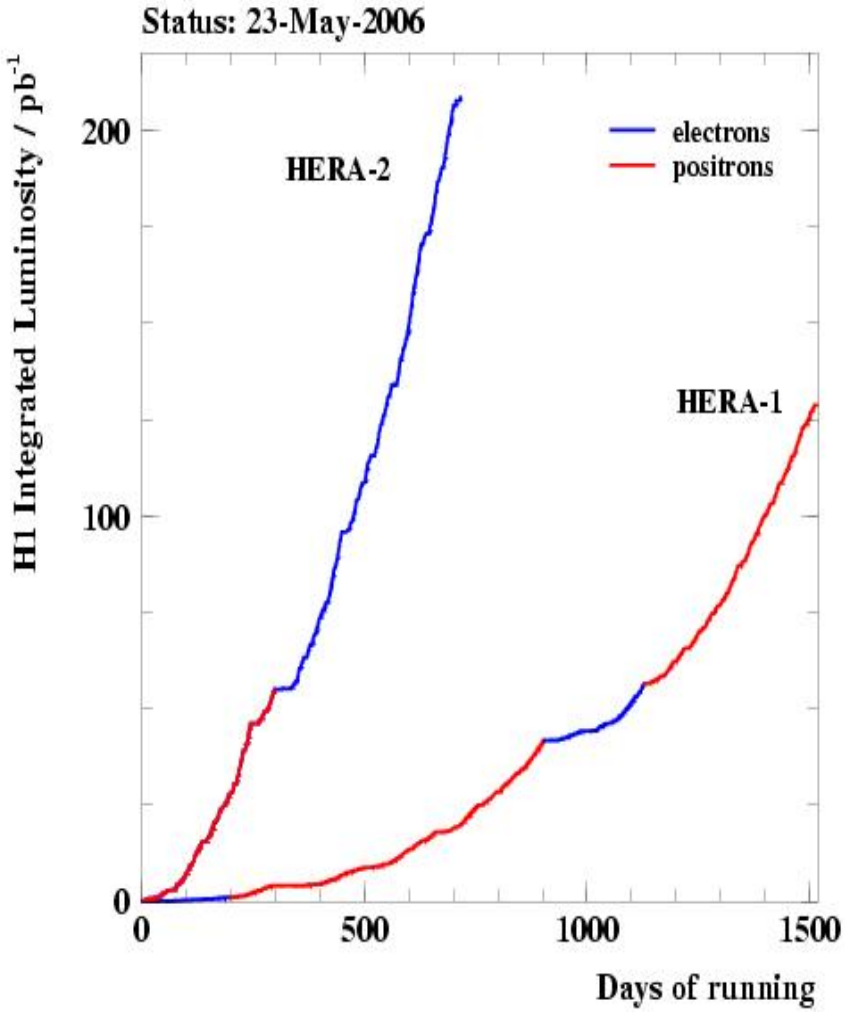

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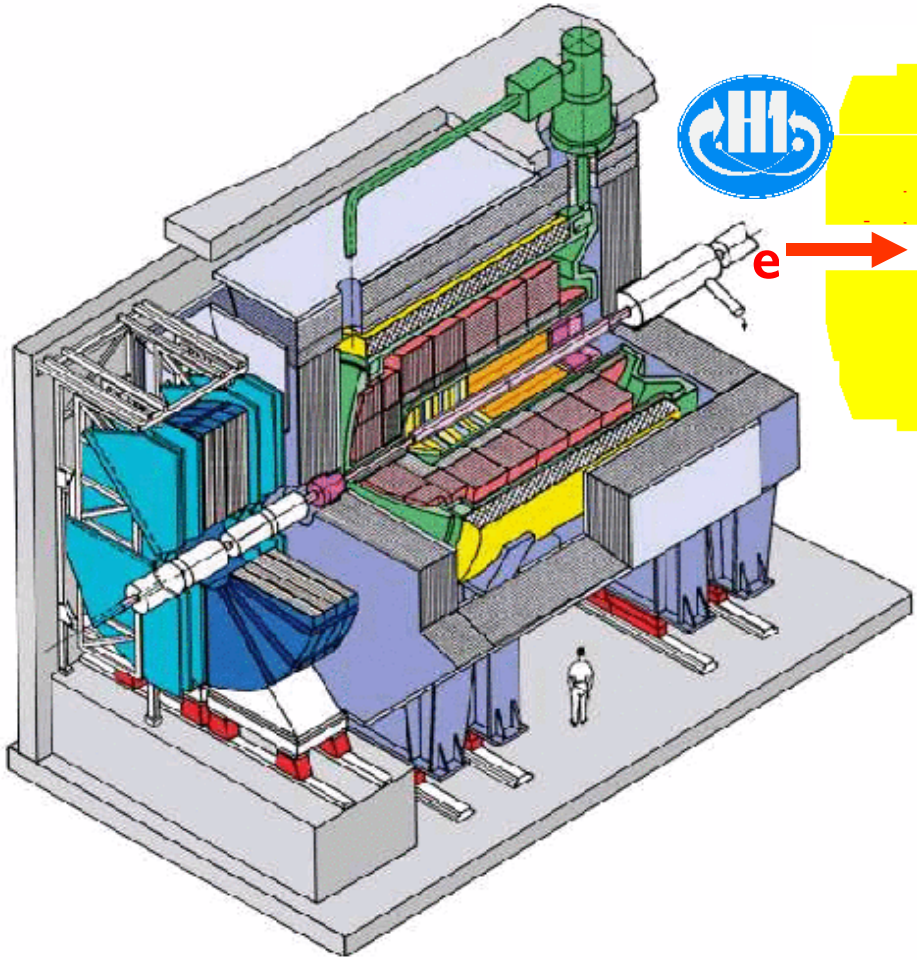
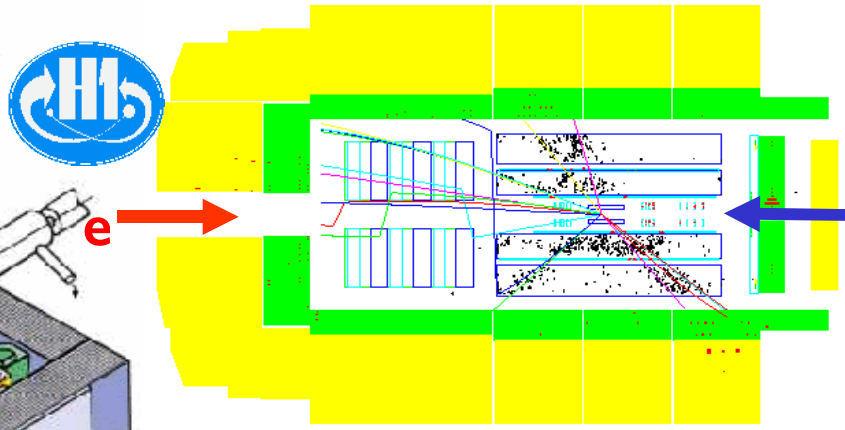
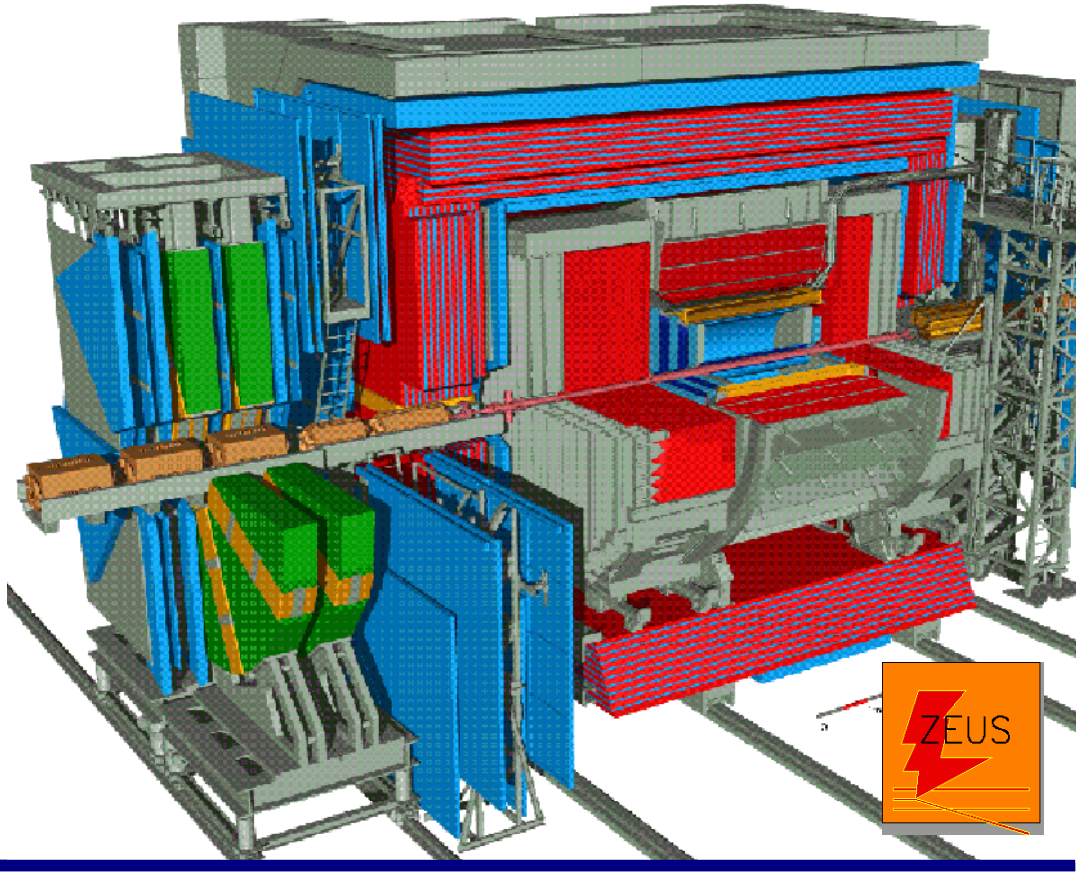
ZEUS and H1 detectors





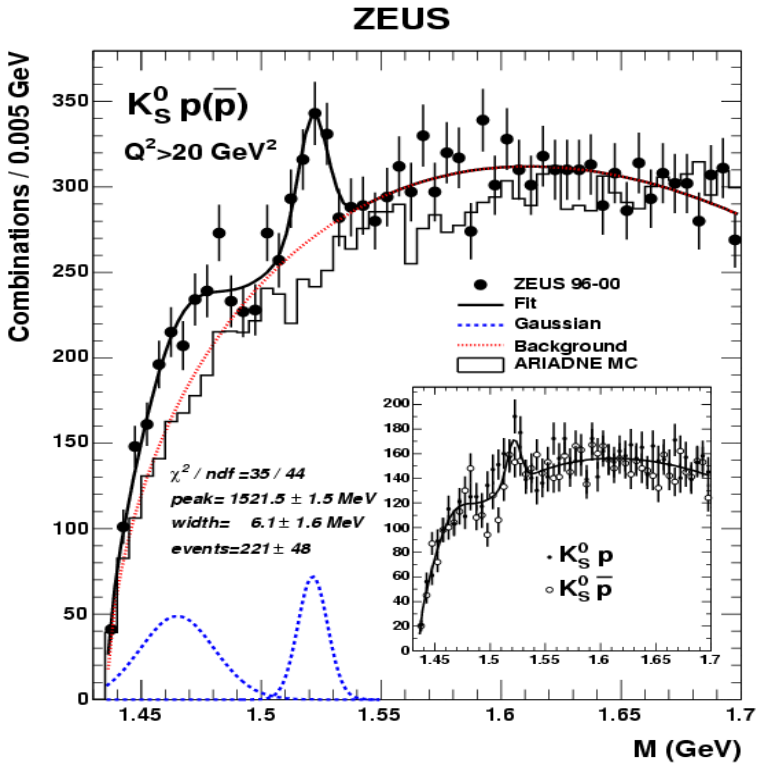
pseudorapidity η
$= -\ln \tan(\theta/2)$
positive η : forward,
towards proton direction

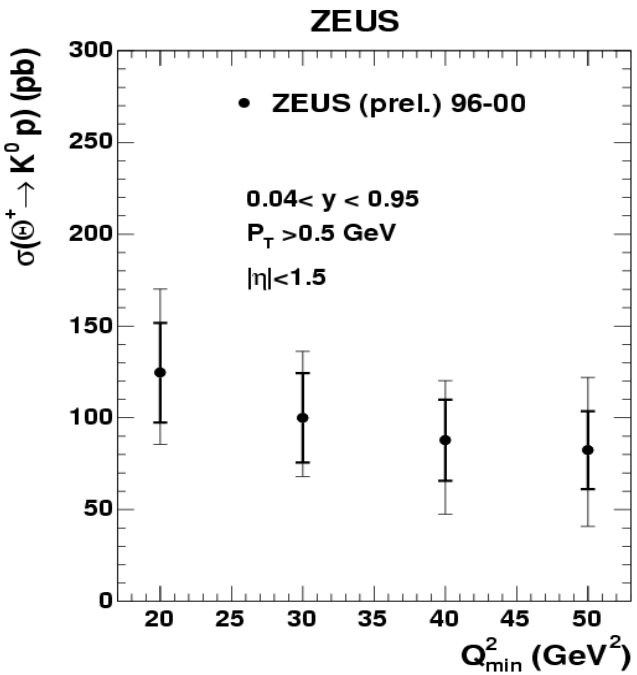


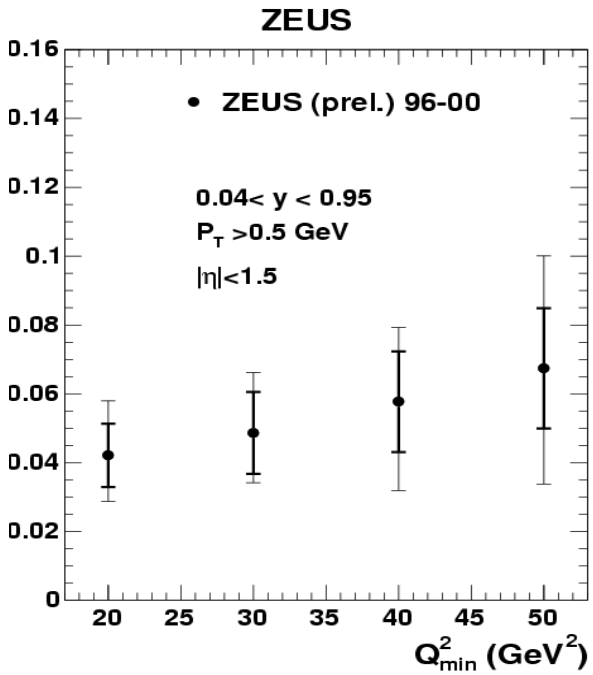
asymmetric detectors
tracking: vertex finding,
momentum and particle ID
calorimetry: scattered electron
and hadr. final state

Strange Pentaquark Searches at HERA : ZEUS results

- $\theta^+ \rightarrow K^0_S\, p$; $K^0_S \rightarrow \pi^+\pi^-$ displaced, secondary vertex protons: ionisation energy loss
- HERA I data Lumi=121 pb^{-1}
- $p_T(K^0_S p) > 0.5$ GeV, $|\eta(K^0_S p)|<1.5$, $Q^2>20$ GeV^2, $0.04 < y < 0.95$
- Fit of background + 2 Gaussians : 221 events at M=1521.5 ± 1.5(stat) +2.8-1.7(syst) MeV width σ=6.1 ± 1.5 MeV
- significance: ~4.6 σ
- anti-θ+ : 96 ± 34 events



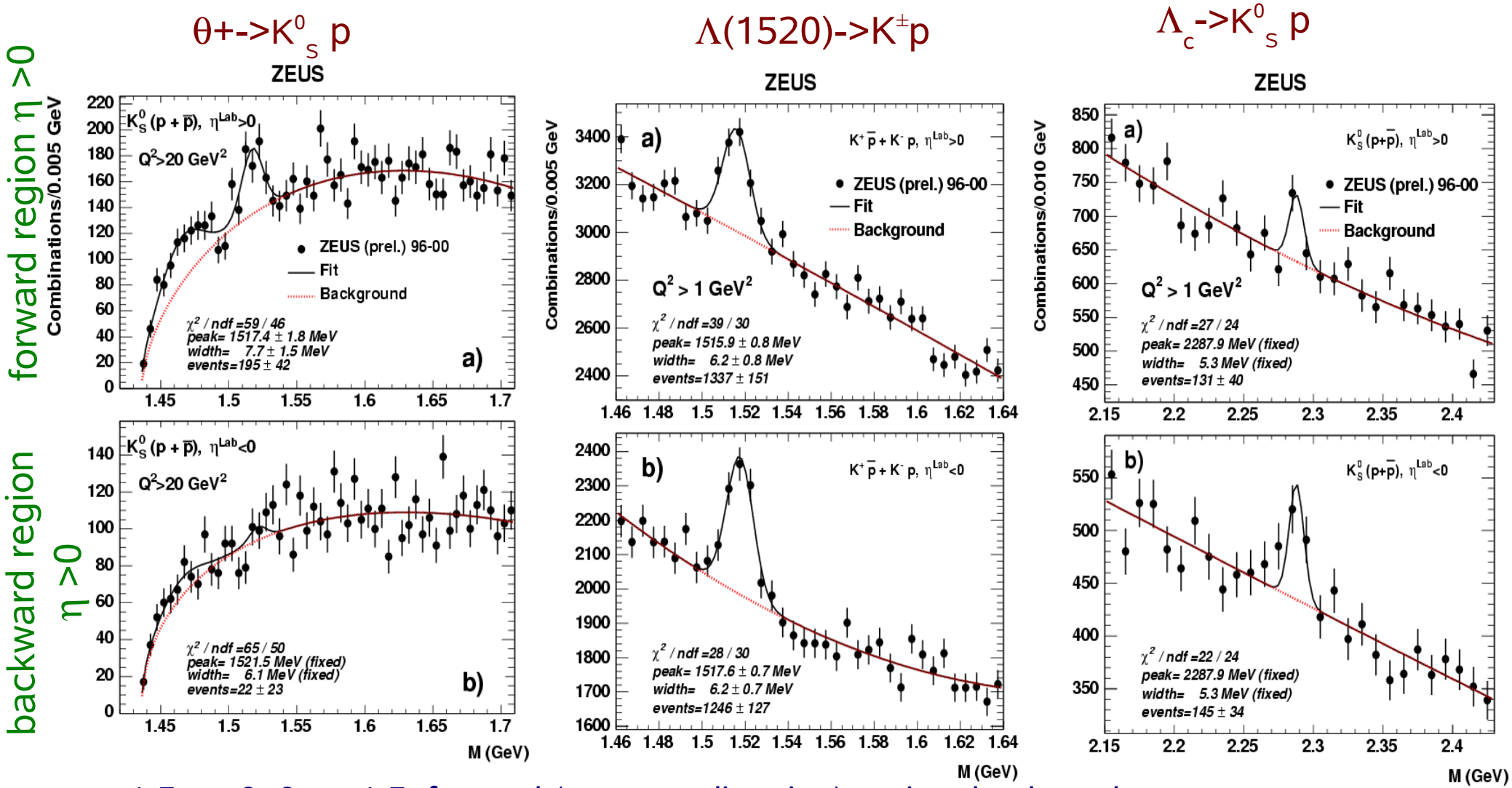




θ+ Cross Section (preliminary):
(MC Σ forced to decay like θ+)
σ(ep -> eθ+ X -> K^0 p X) =
125 ± 27 +36 -28 pb

θ+/Λ(1116) cross section ratio =
4.2 ± 0.9+ 1.2 -0.9 %

Strange Pentaquark Searches at HERA : ZEUS results



-1.5<η<0, 0<η<1.5: forward (= proton direction) region, backward

θ+ observed in forward region of central detector, asymmetry not seen for Λ(1520)

θ+ production related to proton remnant ?

Strange Pentaquark Searches at HERA : H1 results

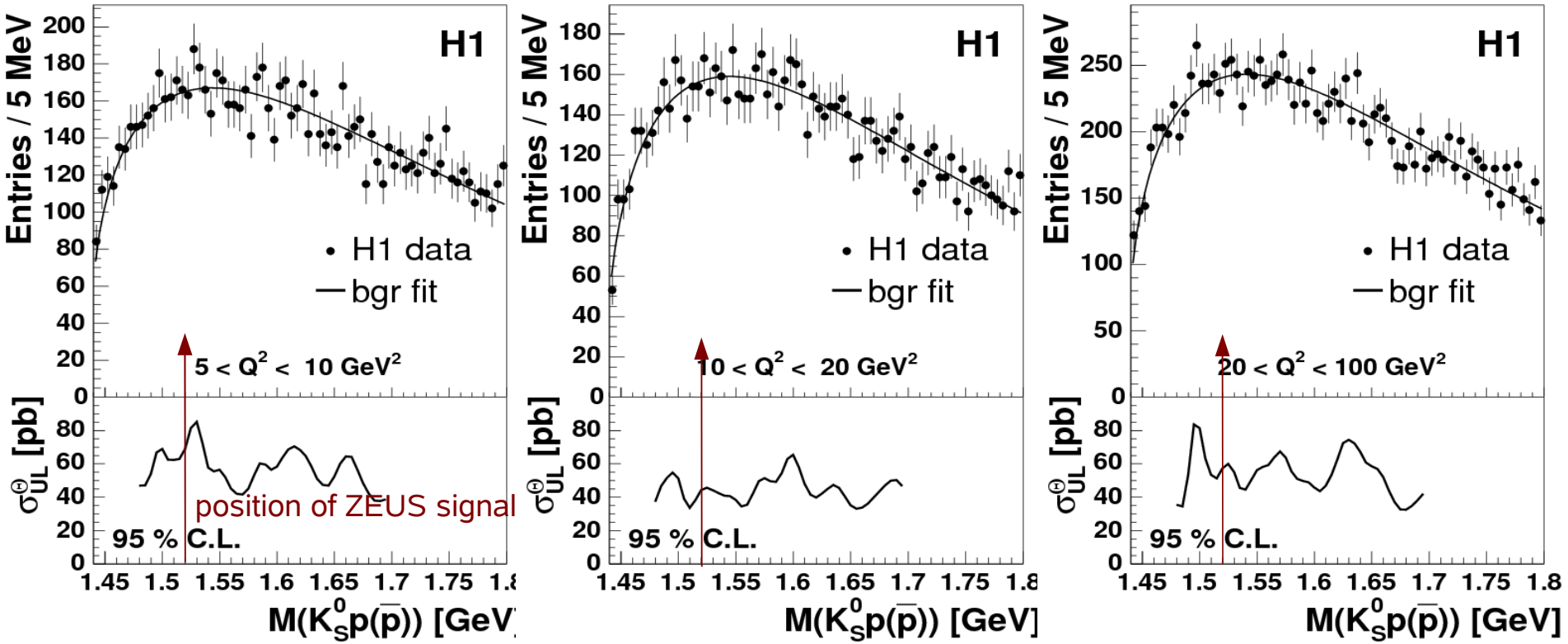
HERA I data, Lumi=75 pb^{-1}

in bins of Q^2 for visible kinematic range: $p_T(K^0_s p) > 0.5$ GeV, $|\eta| < 1.5$, $0.1 < y < 0.6$

upper limits on cross section $\sigma_{UL}(ep \to e\theta+X \to K^0 p\ X)$ and c.c.

signal MC Σ^* forced to decay to K0s p

modified frequentist approach (likelihood ratios), statistical and systematical uncertainties



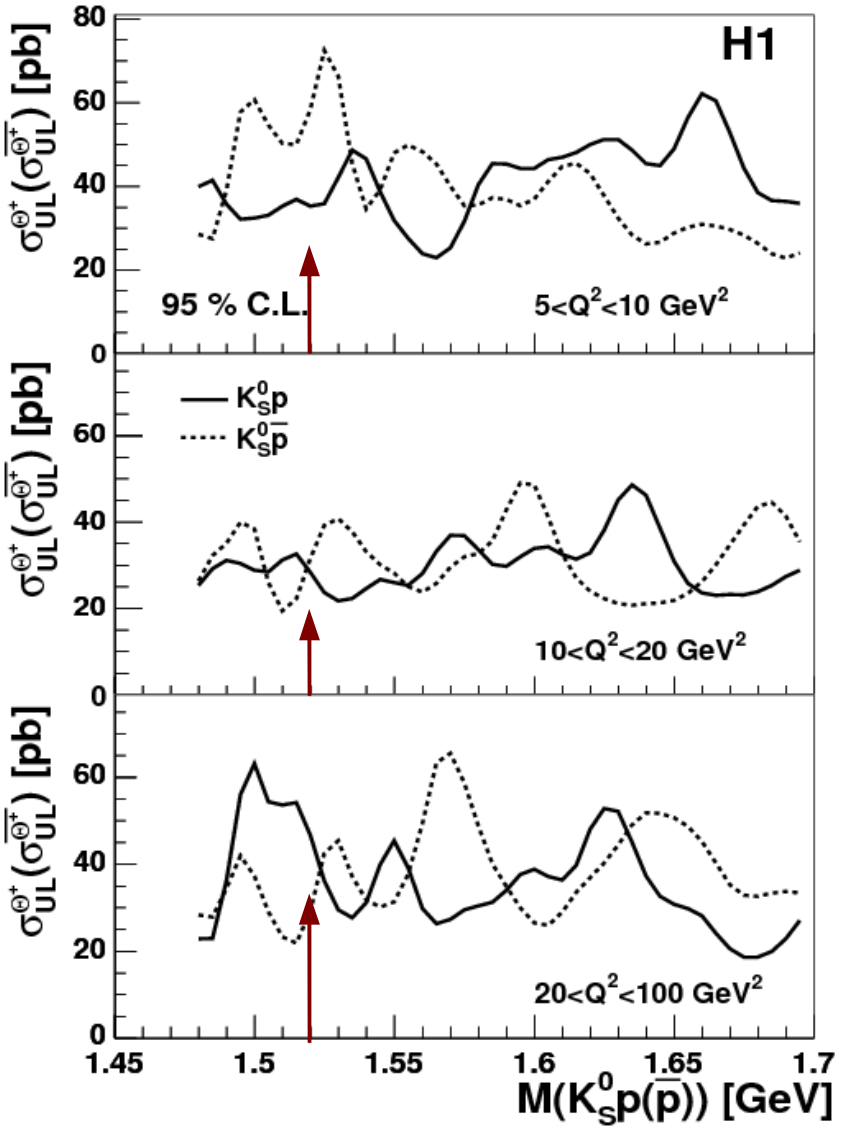
No signal observed, no fluctuation of upper limit at the same mass in different Q^2 bins

Strange Pentaquark Searches at HERA : H1 results

upper limits on cross section σ_{UL}(ep -> eθ+X -> K^0p X) and c.c. separately

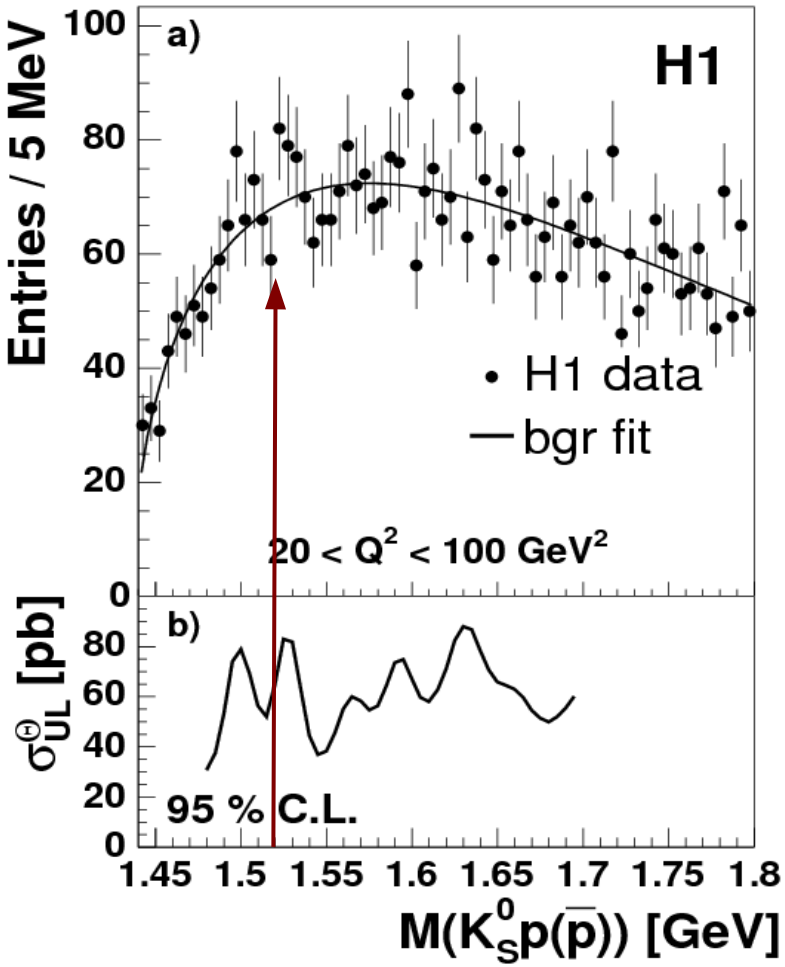
upper limits on θ+ or anti-θ+ of comparable size

No fluctuation at the same mass for particle or antiparticle or in different Q^2 bins



Strange Pentaquark Searches at HERA : H1 results

Comparison with ZEUS:
differences: Q^2 range, upper momentum cut on proton candidates (dE/dx selection)
Q^2>20 GeV^2, p(pr) < 1.5 GeV

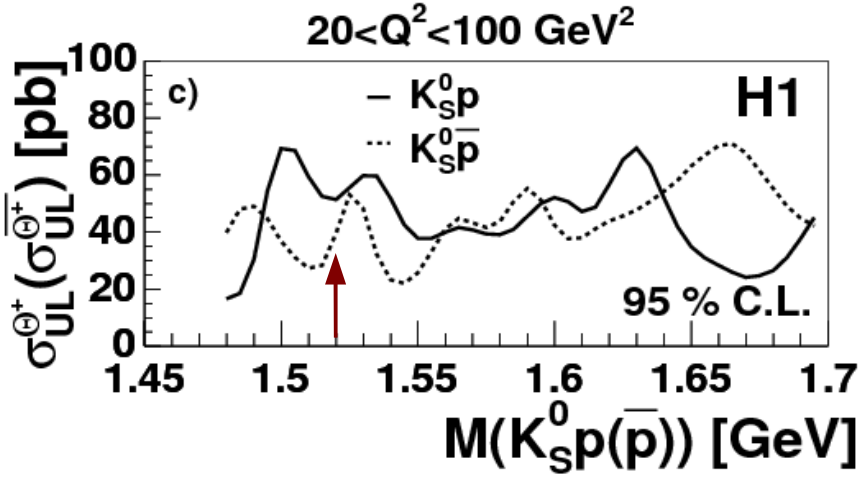


upper limit @ 95% CL at M~1.52 GeV
σ(M=1.52) < 72 pb

ZEUS cross section (preliminary):
$\sigma(ep \to e\theta^+ X \to K^0 p X) = 125 \pm 27\ ^{+36}_{-28}$ pb

note: different y-ranges
0.1 < y < 0.6 (H1) and 0.04 < y <0.95 (ZEUS)

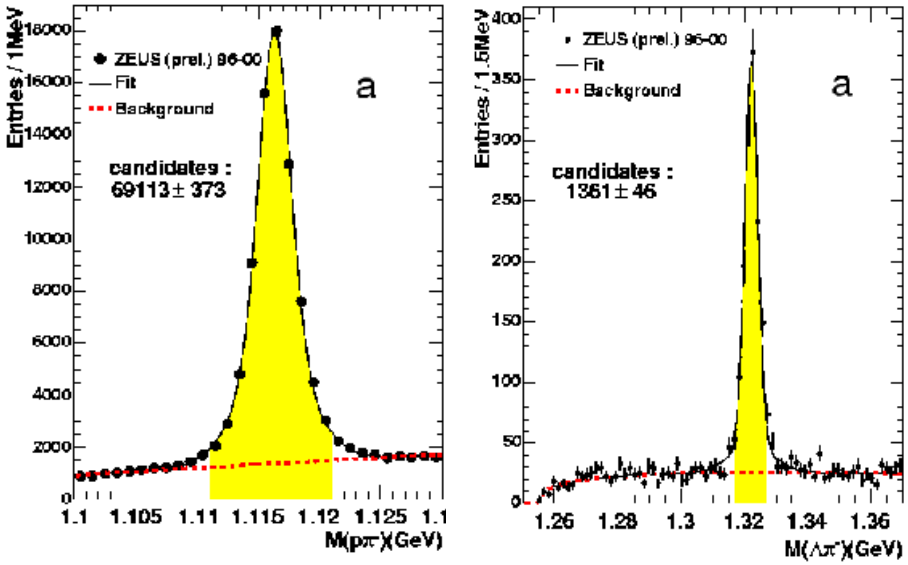
upper limit not in contradiction with cross section



Strange Pentaquark Searches at HERA : Ξ^{--} search at ZEUS

Like NA49 analysis, HERAI data 96-00, 105 pb-1

$\Xi^{--} \rightarrow \Xi^{-} \pi^{-}$; $\Xi^{-} \rightarrow \Lambda \pi^{-}$; $\Lambda \rightarrow p \pi^{-}$ (and c.c.)



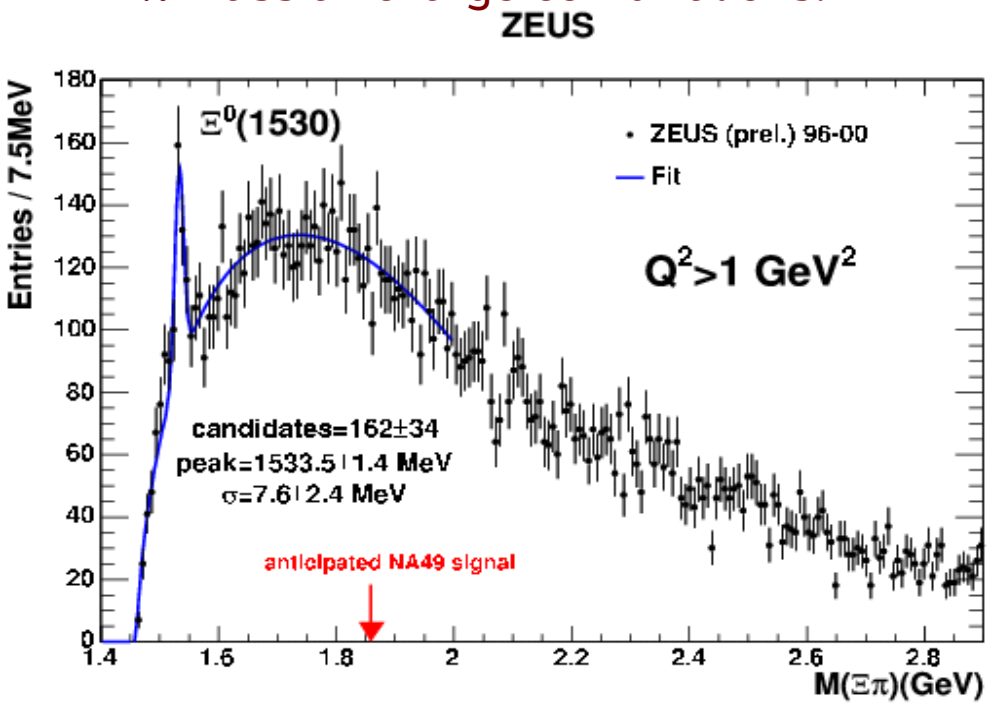
No Ξ^{--} signal!

upper limit @ 95% C.L.

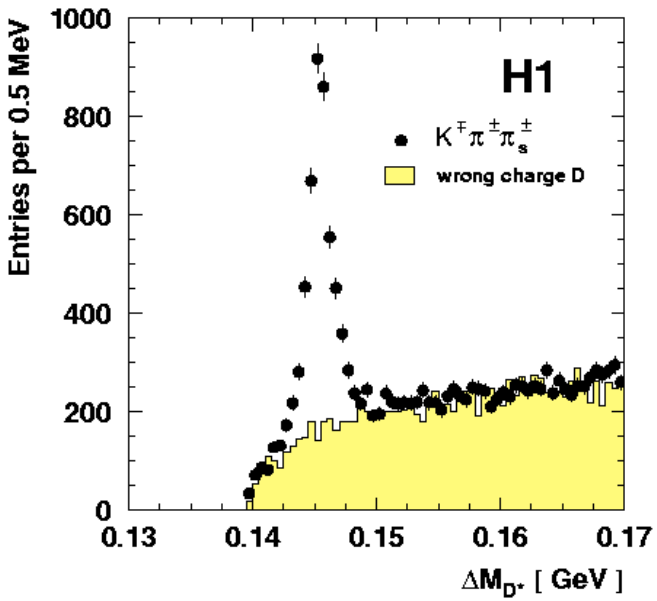
$N(\Xi^{--}) / N(\Xi^{0}_{3/2}(1530)) < 0.29$

NA49 signal not confirmed, but different phase space

$\Xi \pi$ mass all charge combinations:



Charm Pentaquark Searches at HERA : H1 results



DIS in HERAI (96-00) data, Lumi 75 pb^{-1}
$1 < Q^2 < 100\ GeV^2$, $0.05 < y < 0.7$
search for θ_c -> D* p

D* reconstruction: Golden decay channel:

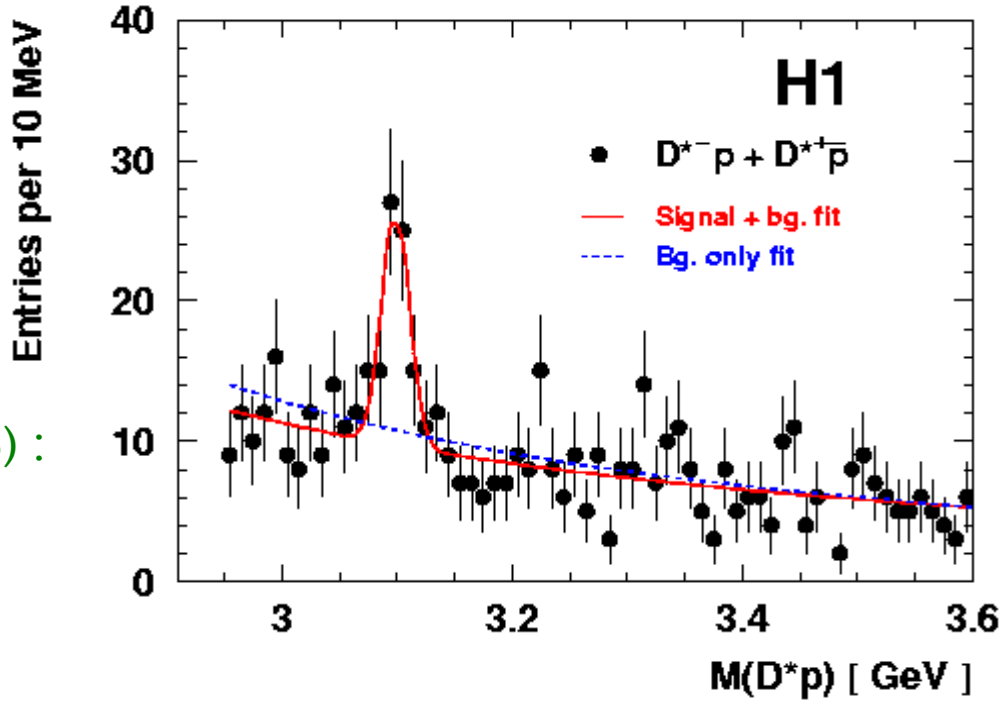
$D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow K^- \pi^+ \pi_s^+$ (+ c.c.)

"mass difference method":
$\Delta M(D^*) = M(K \pi \pi_S) - M(K\pi)$, 3400 D* events

protons selected via dE/dx (as for strange PQ)

$M(D^*p) = m(K\pi\pi p) - m(K\pi\pi) + M_{D^*}$
signal at M=3099 ± 3 ± 5 MeV
σ=12 ± 3 MeV N_s=50.6 ±11.2

Nb (bgr only fit) = 51.7 ± 2.7 N_{s+b}=95
Background fluctuation probability (52 → 95) :
4 x 10^{-8} (Poisson) --> 5.4 σ (Gauss)



Charm Pentaquark Searches at HERA : H1 results

- Acceptance corrected ratio of D*p/D* for $1 < Q^2 < 100$ GeV^2 (prelim)

  visible range D*p:p_T>1.5, -1.5 < η < 1

  visible range D* from D*p and incl. D*:

  p_T>1.5, -1.5 < η < 1,z(D*)>0.2

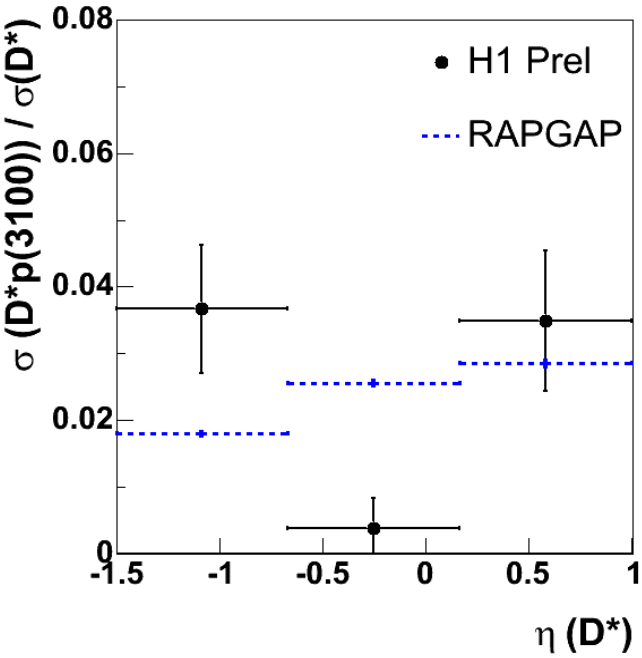
$R_{cor}(D^*p/D^*) = 1.59 \pm 0.33\ ^{+0.33}_{-0.45}$ %

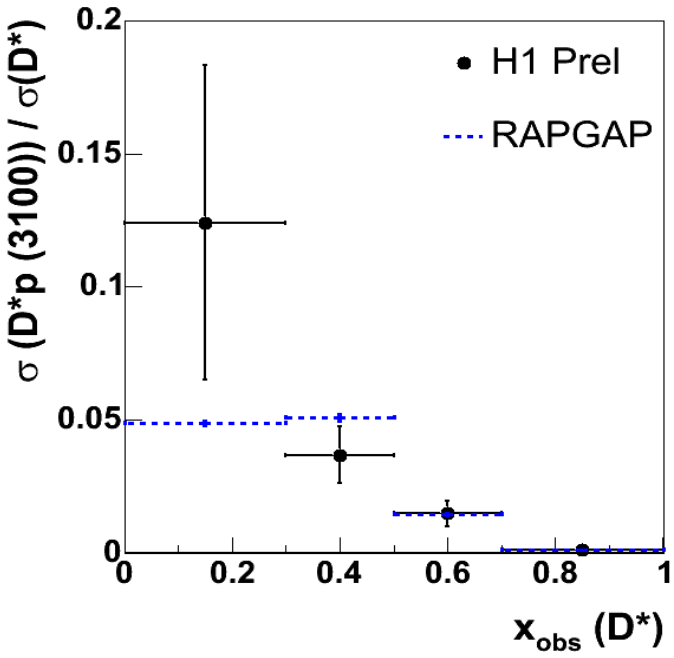
- differential ratio of cross sections:

- compared to inclusive D* production:
  suppressed in central region η

fragmentation variable x_{obs}

D* from D*p decays softer than normal, inclusive D*





Charm Pentaquark Searches at HERA : ZEUS results

θ_c -> D* p in the channels D*->K π π_s and D* -> K π π π π_s

95-00 data, Lumi =126 pb-1

Photoproduction (γp) and DIS

no θ_c signal

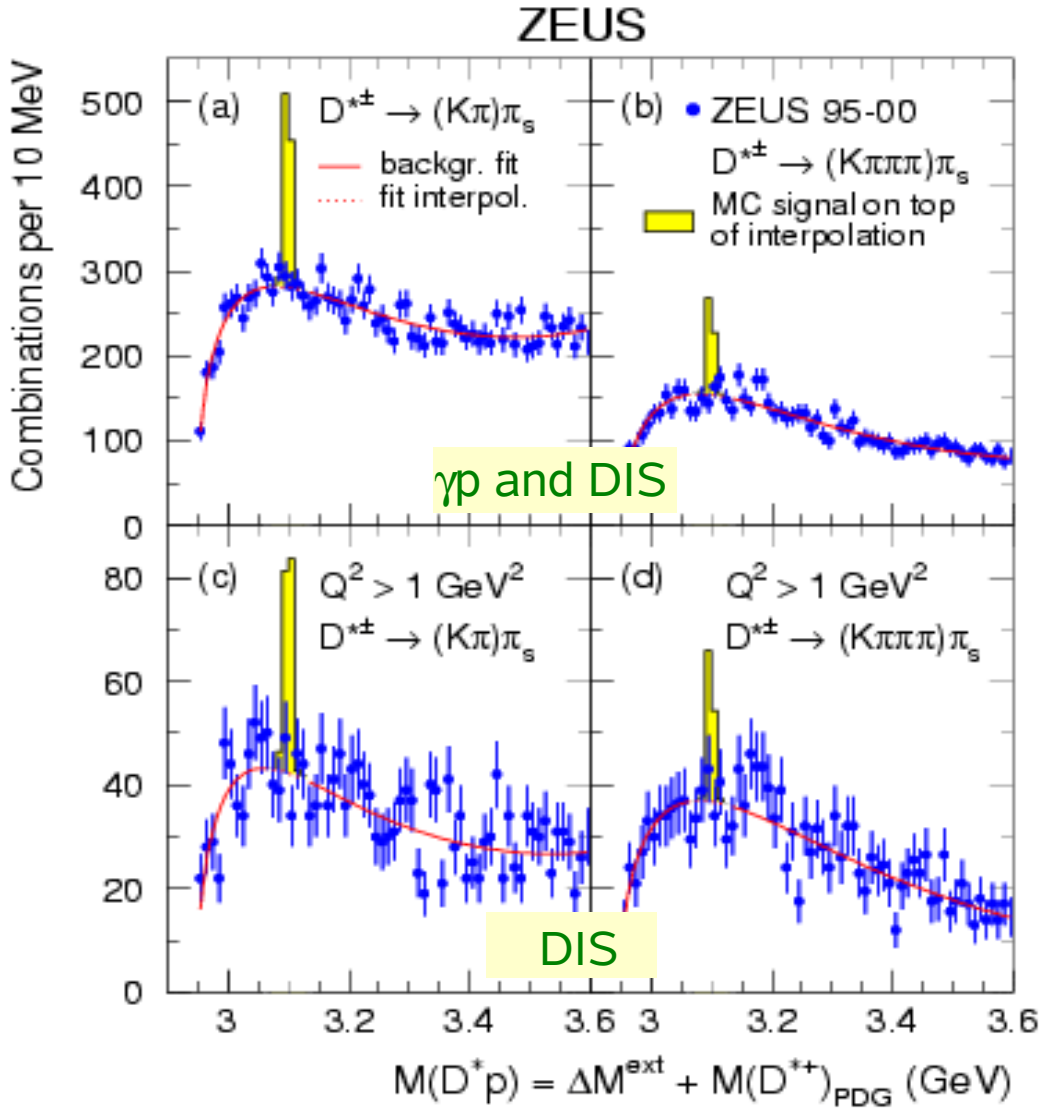
1% D* from D*p -> MC peaks
not seen (depends on phase space)

upper Limits @ 95 % C.L.:

Rcor < 0.59 % (K2π, DIS)

Rcor < 0.37 % (K2π & K4π, γp+DIS)

H1 ratio of cross sections excluded,
($R_{cor}(D^*p/D^*) = 1.59 \pm 0.33\ ^{+0.33}_{-0.45}$ %)
but differences in selection ..

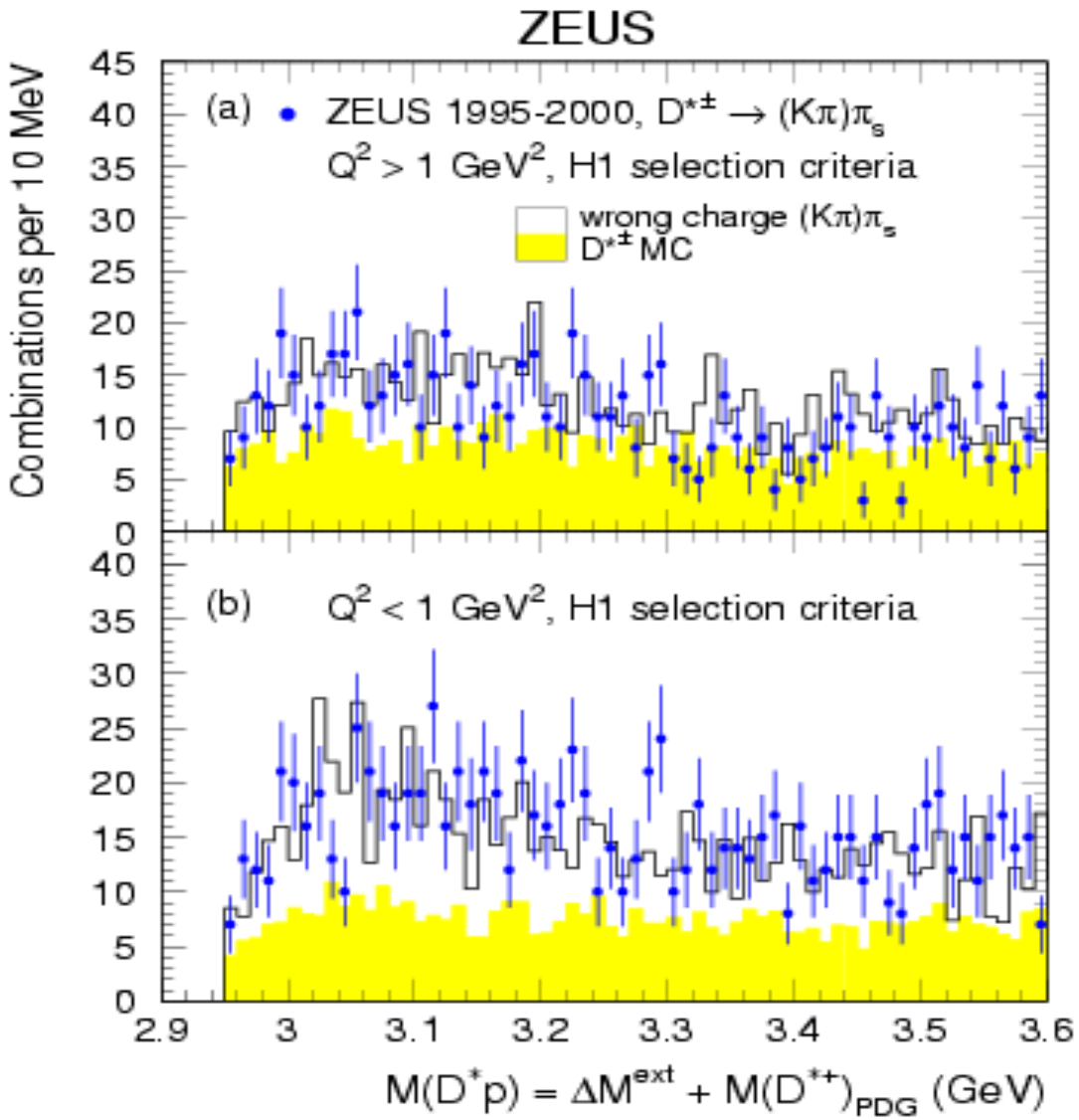


Charm Pentaquark Searches at HERA : ZEUS results

Main differences: ZEUS => "H1 selection"

- decay channel $K2\pi+K4\pi$ => $K2\pi$
- η range D* $-1.6 < \eta < 1.6$ => $-1.5 < \eta < 1$
- p_T of D* $p_T > 1.35$ GeV =>
  $p_T > 1.5$ GeV (DIS)
  $p_T > 2$ GeV (γp)
- inelasticity range $y < 0.95$ =>
  $0.05 < y < 0.7$ (DIS)
  $0.2 < y < 0.8$ (γp)
- ...

No signal observed!



Observation of $K^0_S K^0_S$ resonances in DIS at HERA (ZEUS)

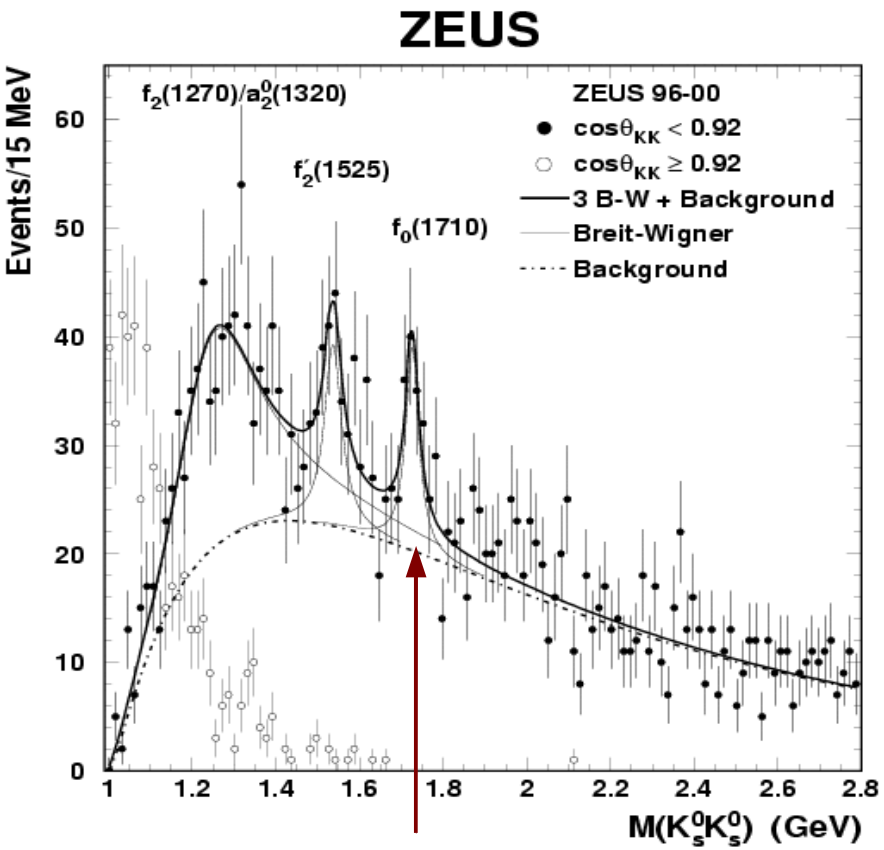
Glueball searches in $K^0_S K^0_S$ mass spectrum

HERA I data, L=121 pb^{-1}

$0.04 < y < 0.95$, $Q^2 > 4$ GeV^2

$\cos\theta_{KK} < 0.92$ suppress low $K^0_S K^0_S$ mass region

$p_T(K0s) > 200$ MeV



glueball candidate ???

lightest glueball candidate:
$J^{PC}=0^{++}$ mass: 1730 ±100 MeV
WA102: glueball candidate $f_0(1710)$

3 peaks seen

- $M=1274^{+17}_{-16}$ MeV $\Gamma=244^{+85}_{-58}$ MeV
  broad peak $f_2(1270)/a_2(1320)$

- $M=1537^{+9}_{-8}$ MeV $\Gamma=50^{+34}_{-22}$ MeV
  consistent with $f_2'(1525)$

- $M=1726 \pm 7$ MeV $\Gamma=38^{+20}_{-14}$ MeV
  $f_0(1710)$? (PDG: $\Gamma=125\pm10$MeV)
  glueball candidate ???

first observation of f',X(1726)
at an ep collider

Summary

- **Strange Pentaquark Searches at HERA: θ+**

  narrow state in $K^0_S p$ observed by ZEUS at ~1520 MeV

  $\sigma(ep \rightarrow e\theta^+ X \rightarrow K^0 p X) = 125 \pm 27\ ^{+36}_{-28}$ pb

  H1 does not observe a signal, upper limits do not exclude ZEUS cross section

- **$\Xi^{--} \rightarrow \Xi^- \pi^-$**

  ZEUS does not observe a signal, different phase space than NA49

- **Charm Pentaquark Searches at HERA : θ_c**

  narrow state in D*p observed by H1 at ~ 3099 MeV

  $R_{cor}(D^*p/D^*) = 1.59 \pm 0.33\ ^{+0.33}_{-0.45}$ % (in DIS)

  ZEUS does not confirm signal $R_{cor} < 0.59$ %

experimental situation on pentaquarks at HERA: unclear statistics of HERA II data will hopefully solve this!

- **Glueballs Searches in $K^0_S K^0_S$**

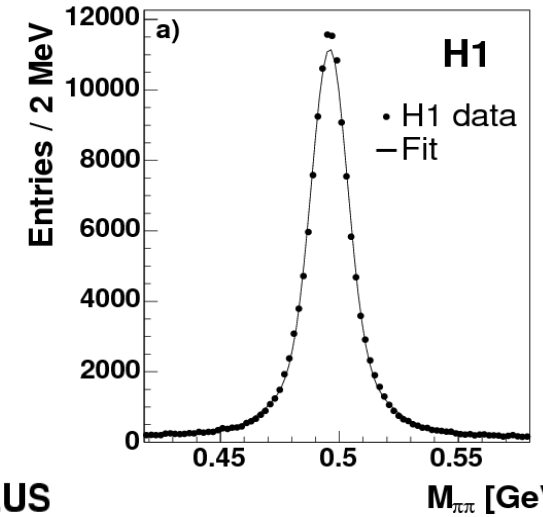
First observation of $K^0_S K^0_S$ states at an ep collider

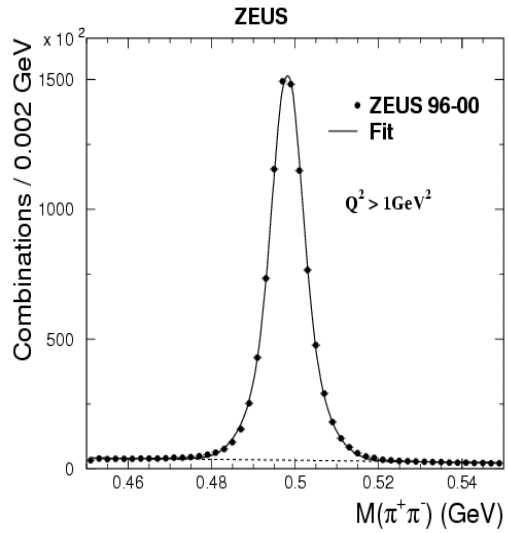
at 1525 MeV and 1726 MeV

Strange Pentaquark Searches at HERA: K0s and proton selection

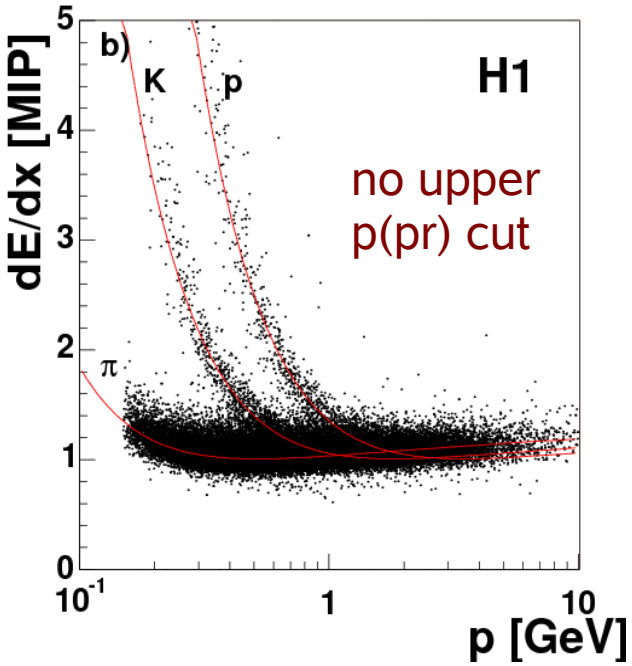
- θ+ -> K0s p
- K0s -> π+π– displaced, secondary vertex
  p_T(K0s) > 0.3 GeV |η(K0s)| < 1.5
- HERAI data ZEUS: 121 pb-1
  H1: 74 pb-1

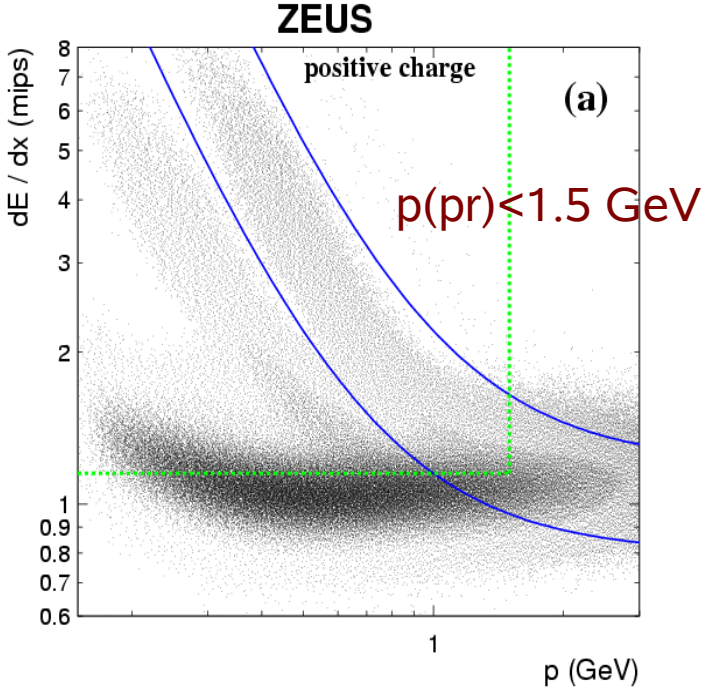
K0s signal:



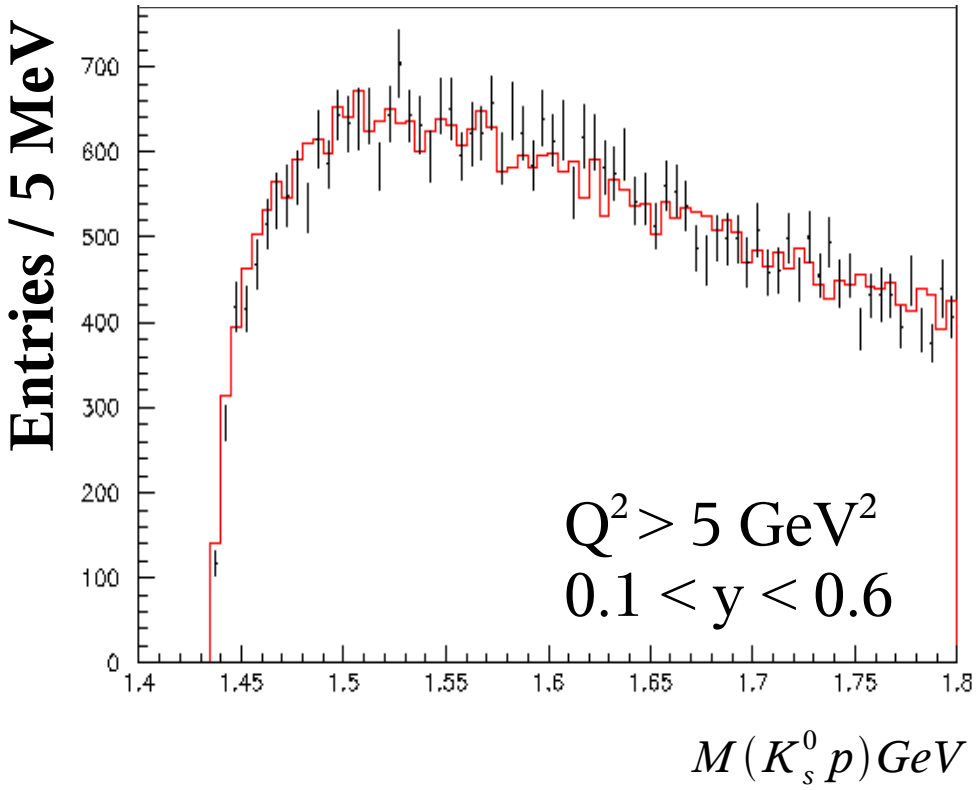


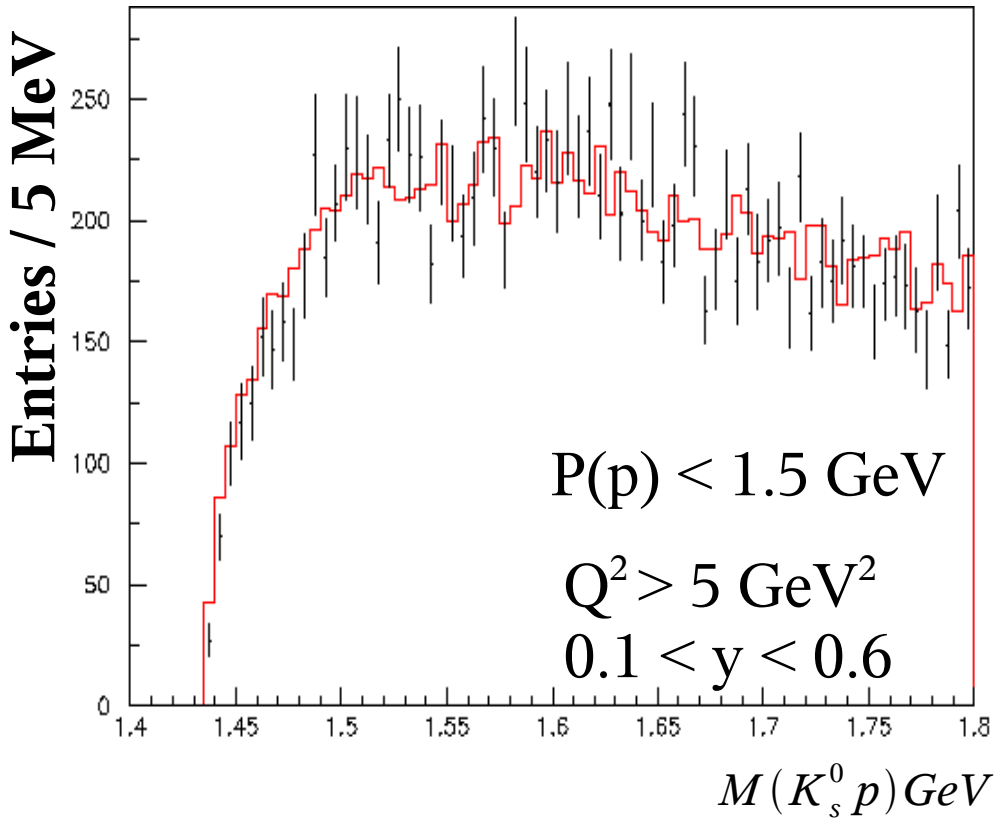
proton identification: ionisation energy loss





MC description

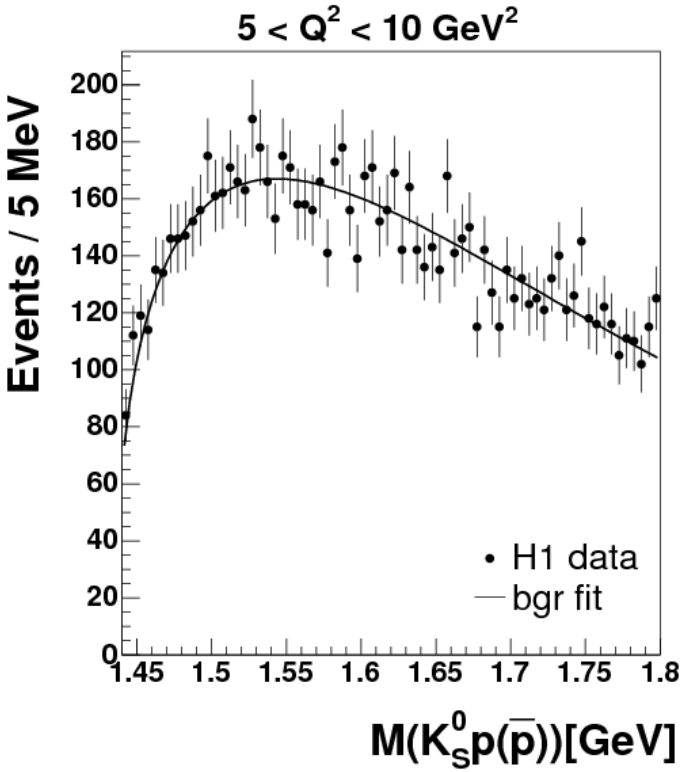


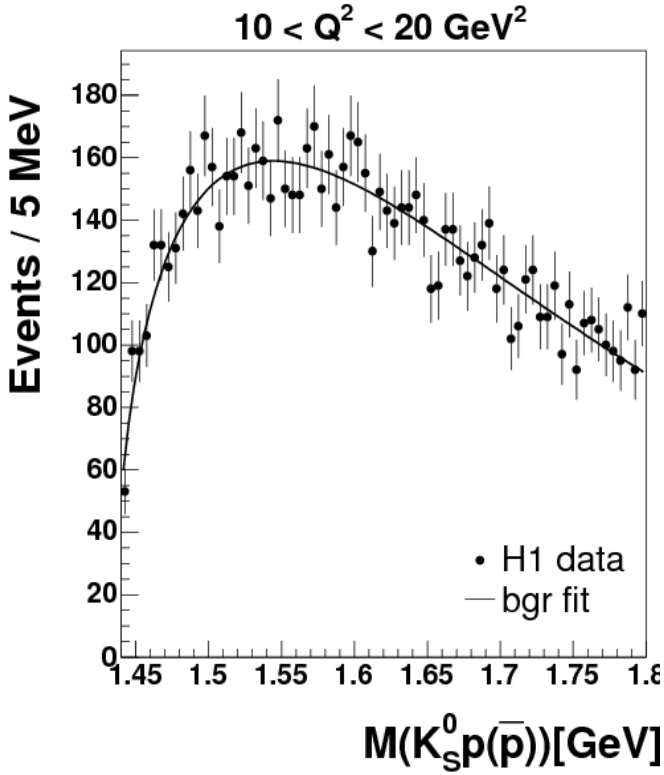


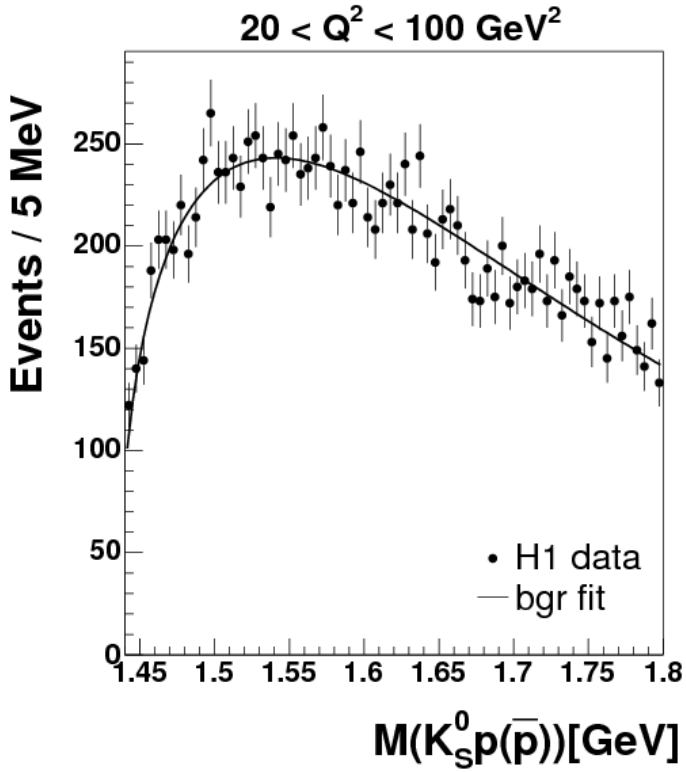
Good description of the shape of the M(K0sp) distribution by the inclusive MC

Strange Pentaquark Searches at HERA : H1 results

K0s p invariant mass in bins of Q^2
visible kinematic range : $P_T(K^0_s p) > 0.5$ GeV, $|\eta| < 1.5$



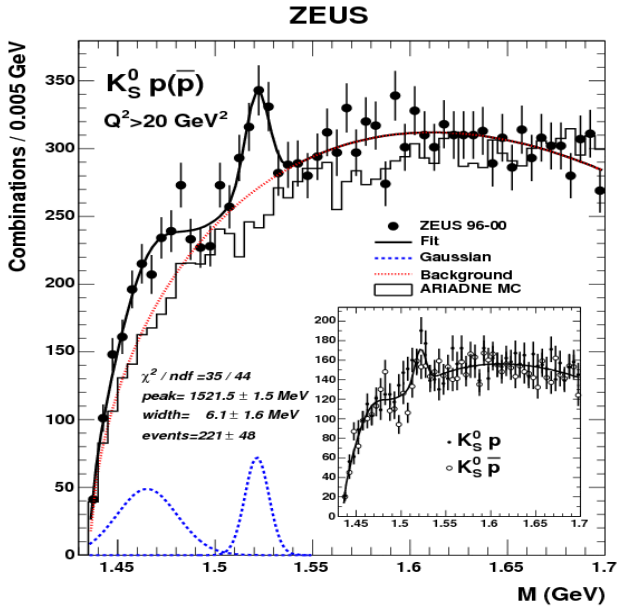


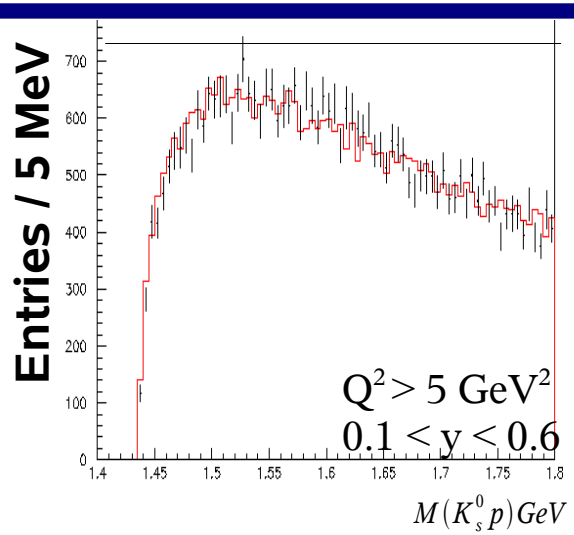


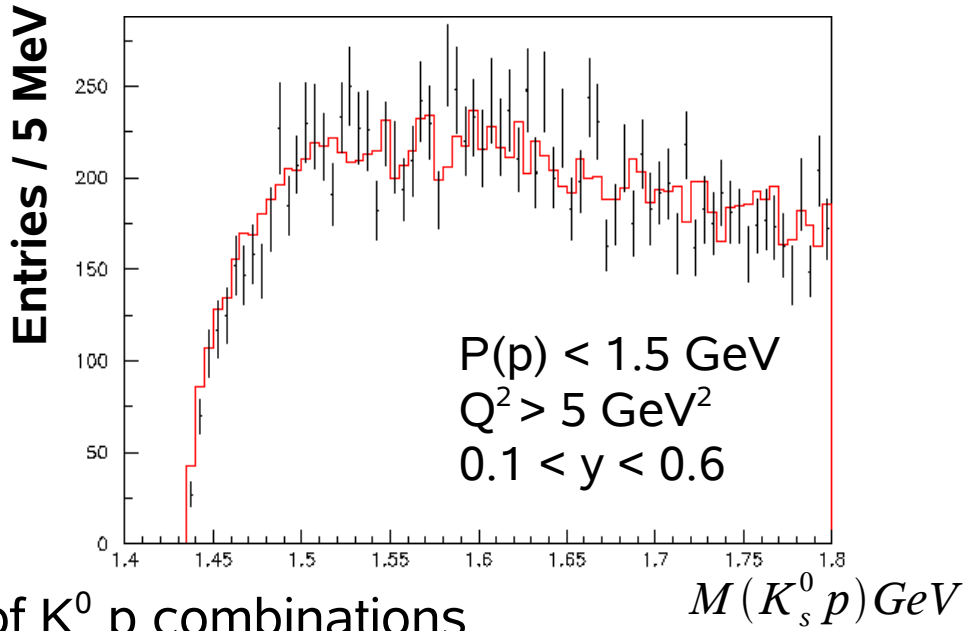
$$background = \alpha (M - M_{thr})^{\beta} \exp(-(M - M_{thr})\gamma),\ M_{thr} = M_p + M_{K^0_s}$$

No significant signal is observed in any of the Q^2 bins

MC description





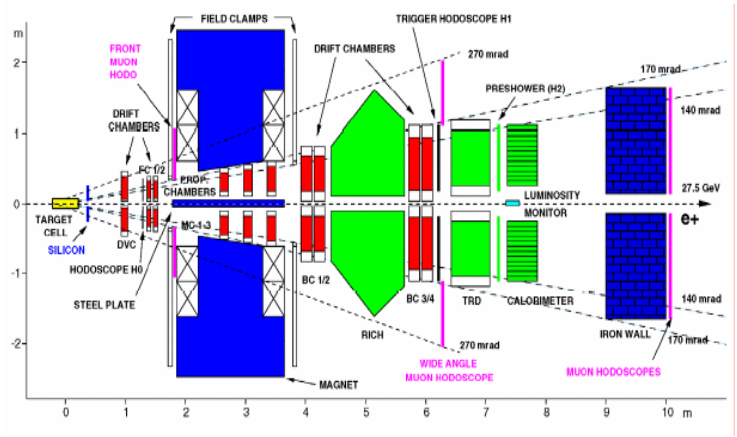


Compare the MC description of the shape of $K^0_s p$ combinations

for ZEUS (Q^2>20 GeV^2 case) and H1 (Q^2 > 5 GeV^2 case)
description of dE/dx in Monte Carlo crucial!

Charm Pentaquark Searches at HERA : HERMES results

- peak is observed at 1528+-2.6 +-21.1 MeV in 290 pb^{-1}, quasi-real photoproduction (Q^2<<1GeV^2)
- width 8 MeV (exp. resolution)
- signigicance 3-5 σ
- background MC, mixed event background excited Σ* hyperons lie below 1500 and above 1550MeV
- No peak seen in M(Λπ+) or M(pK+)

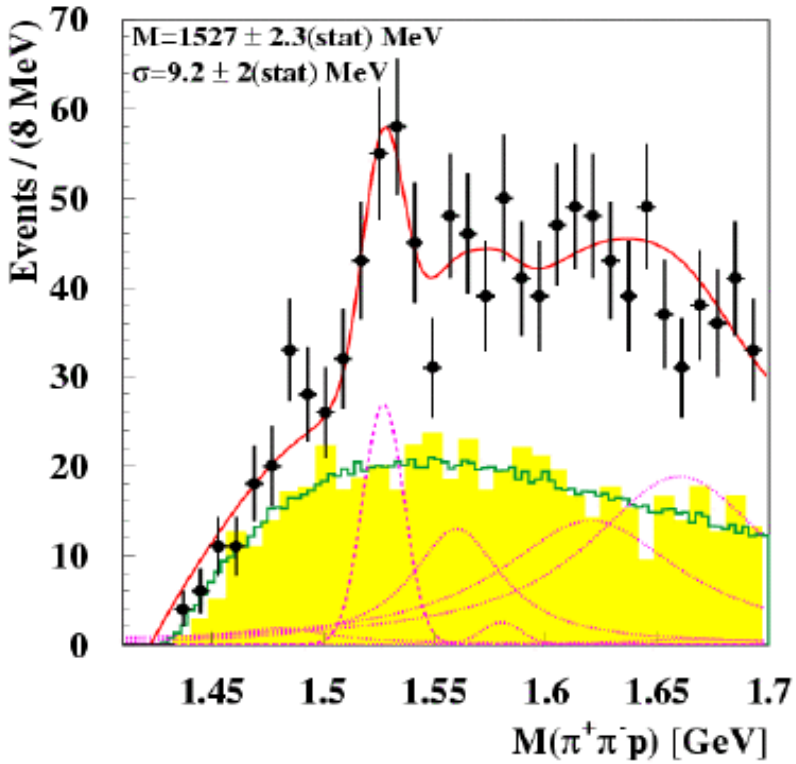


Production cross section:

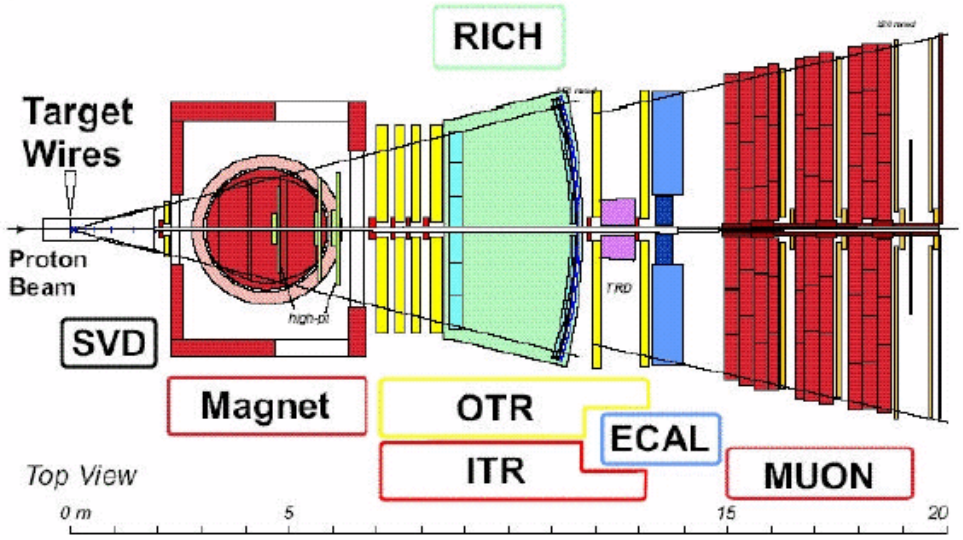
σ(θ+) = 100-220 nb ±25%(stat.)

σ(Λ(1520) = 62 ± 11nb

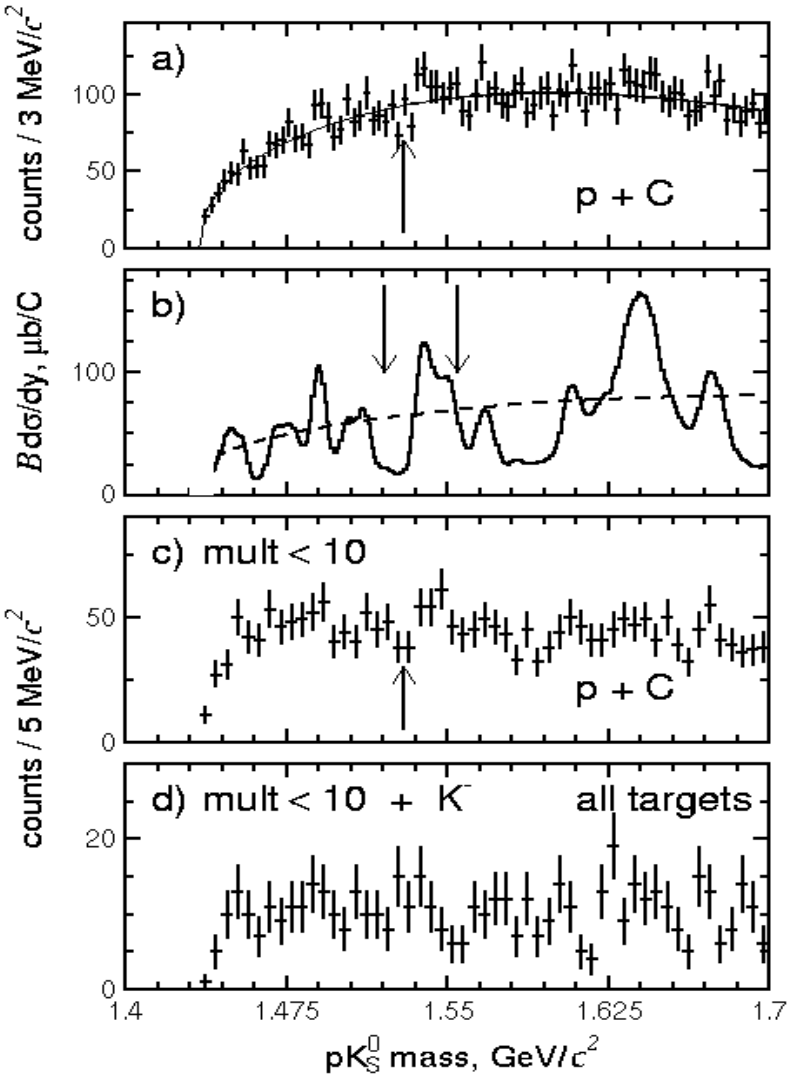
σ(Ξ^0(1530)) = 8.8 ± 24nb



Charm Pentaquark Searches at HERA : HERA B results

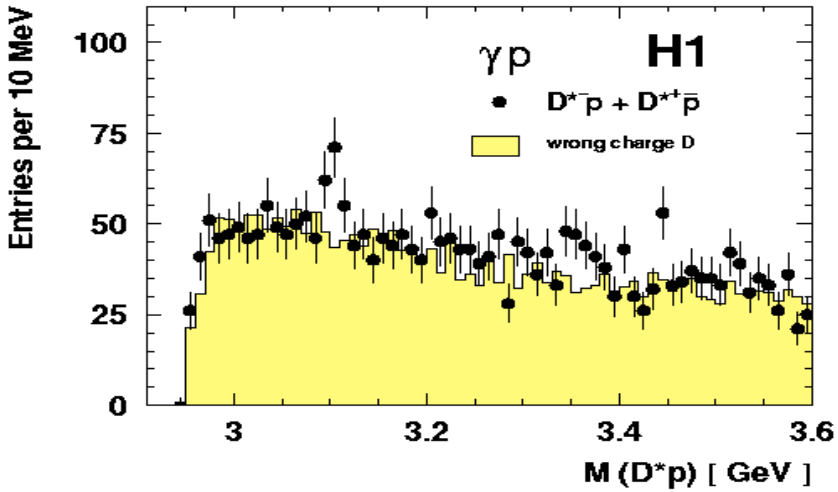


Strange pentaquark search
in p C collisions

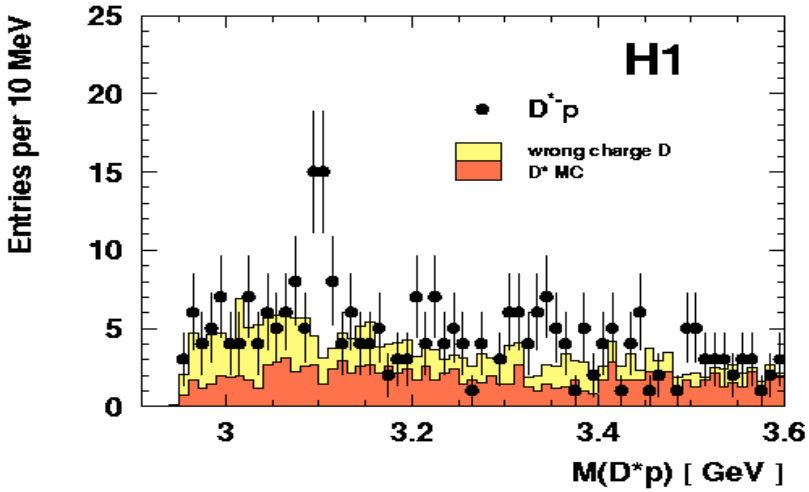


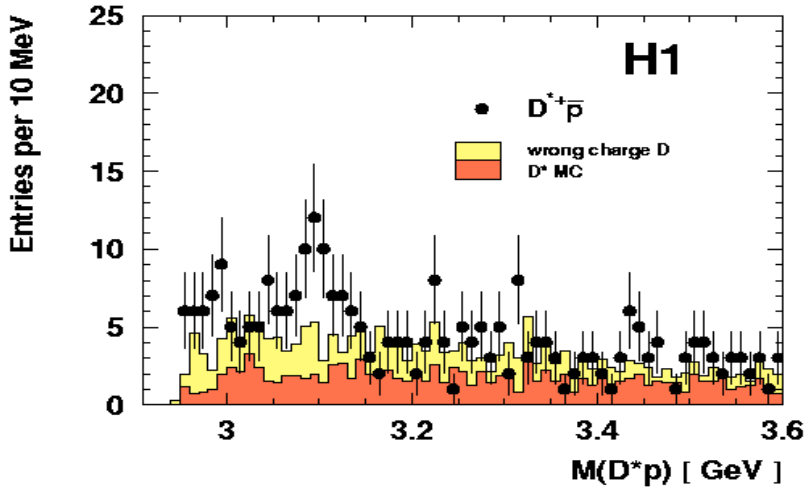
Charm Pentaquark Searches at HERA : H1 results

D*p signal in photoproduction



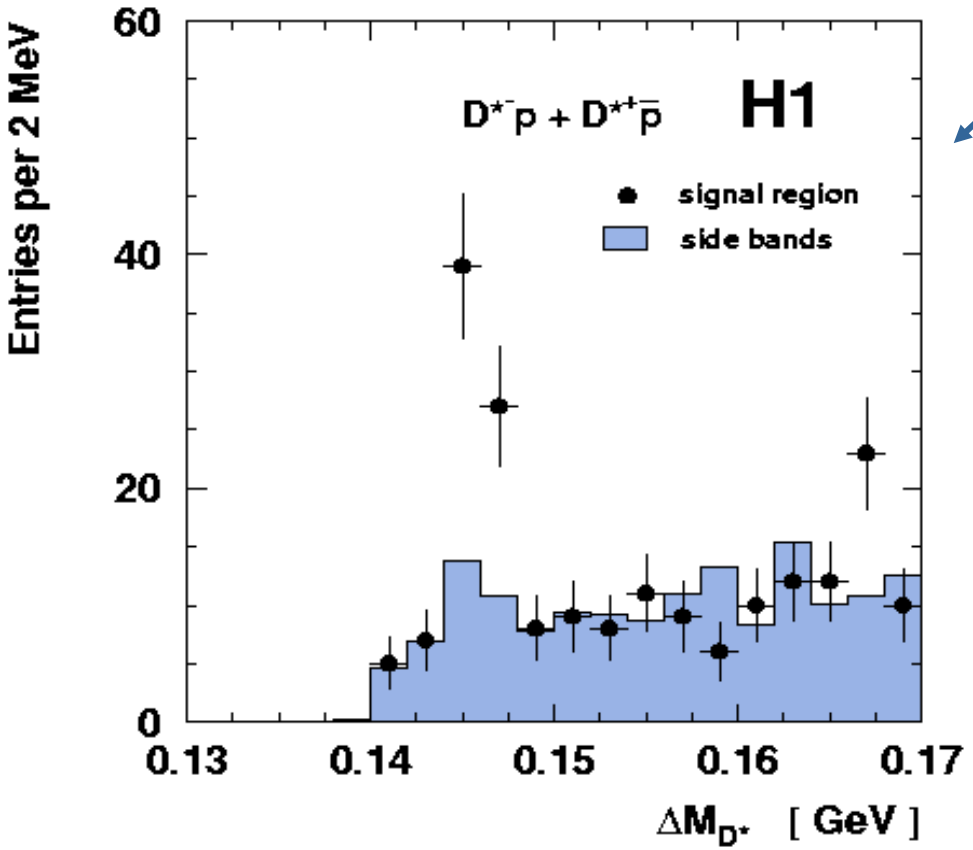
D*-p and D*+ pbar invariant mass spectrum



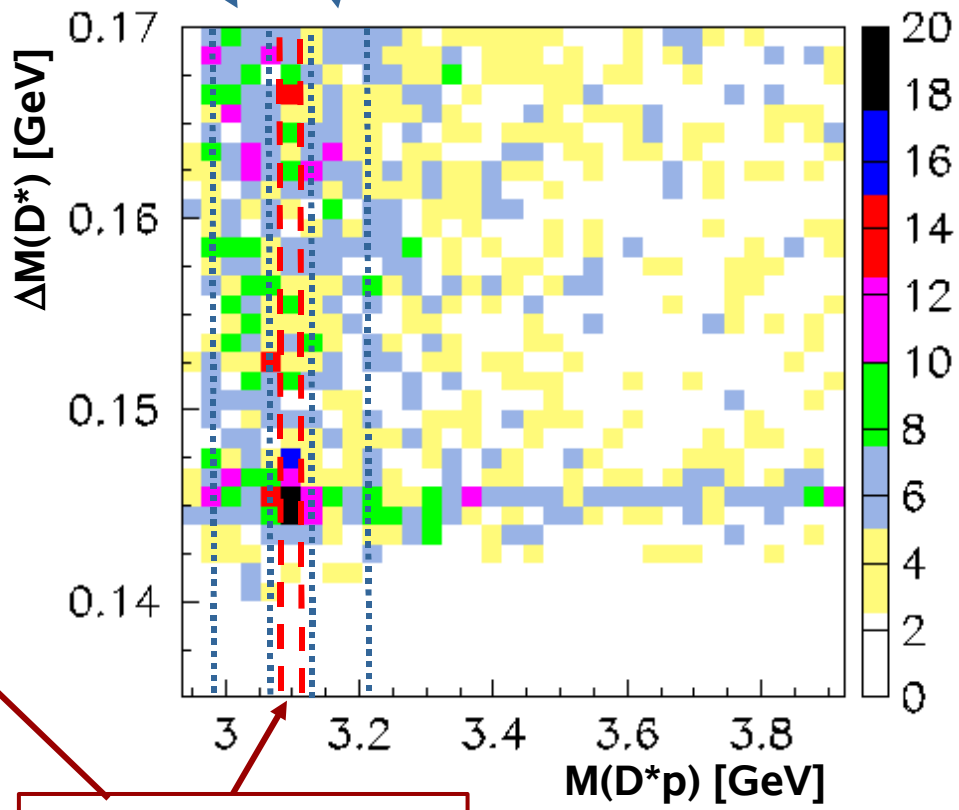


Does Resonance come from D*?

ΔM(D*) in D*p – signal region and sidebands:



D*p Side bands



D*p signal region

Side band scaled to the width of the signal window in M(D*p) no further normalization!

D*p signal region is richer in D* than sidebands

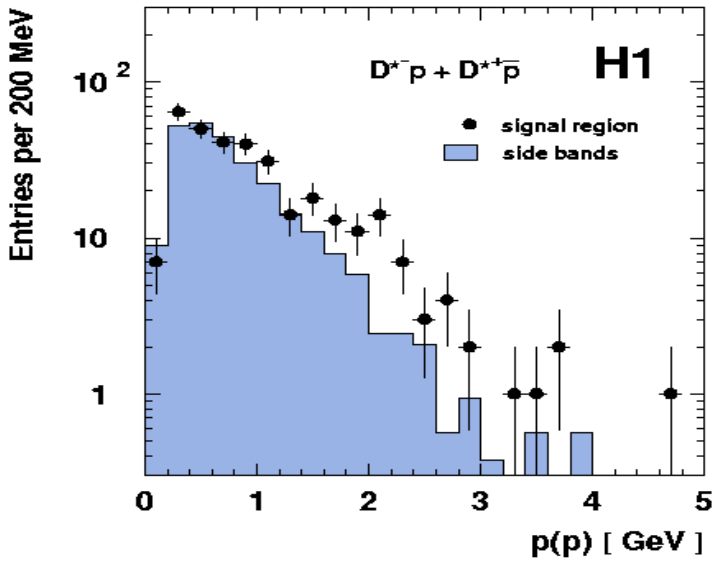
Yes!

on and off resonance kinematics of D*

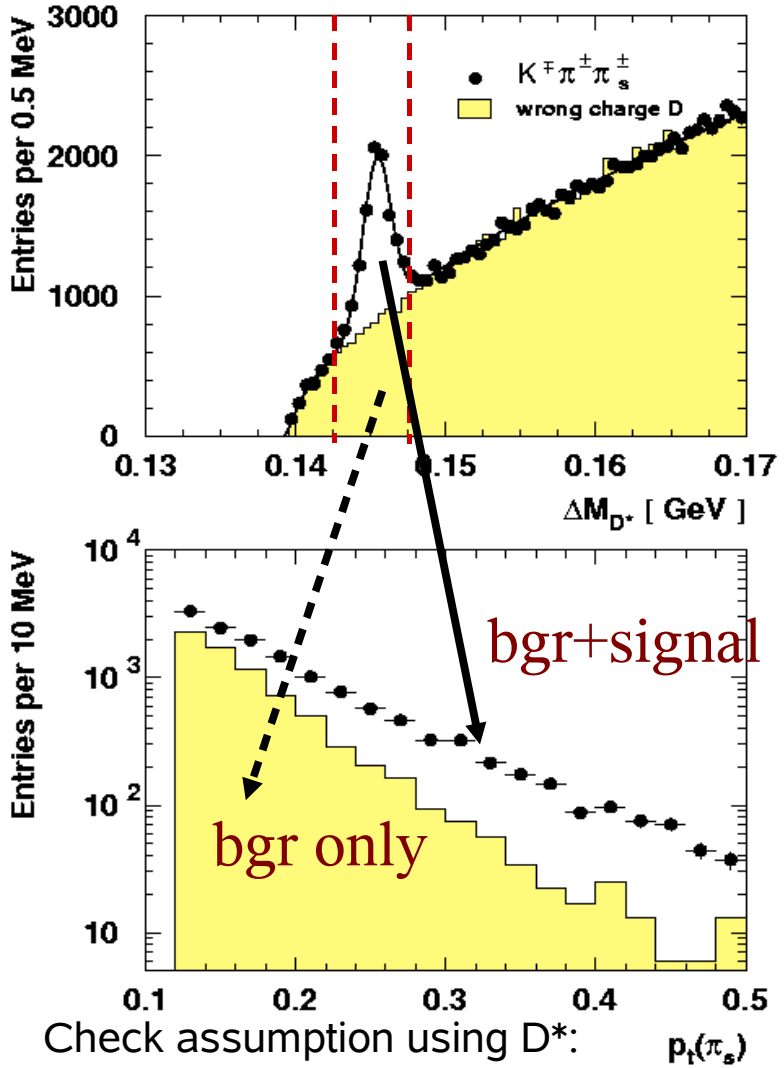
- single charged particles:
  momentum spectrum steeply falling!
  preserved in combinatorial bgr
- Particles from decay:
  → Lorentzboost
  → particles may be emitted in direction of flight

==> Harder momentum spectrum expected for particles from decay

proton momentum spectrum for D*p -signal and sideband region:



example: π_S from D* (looser selection)

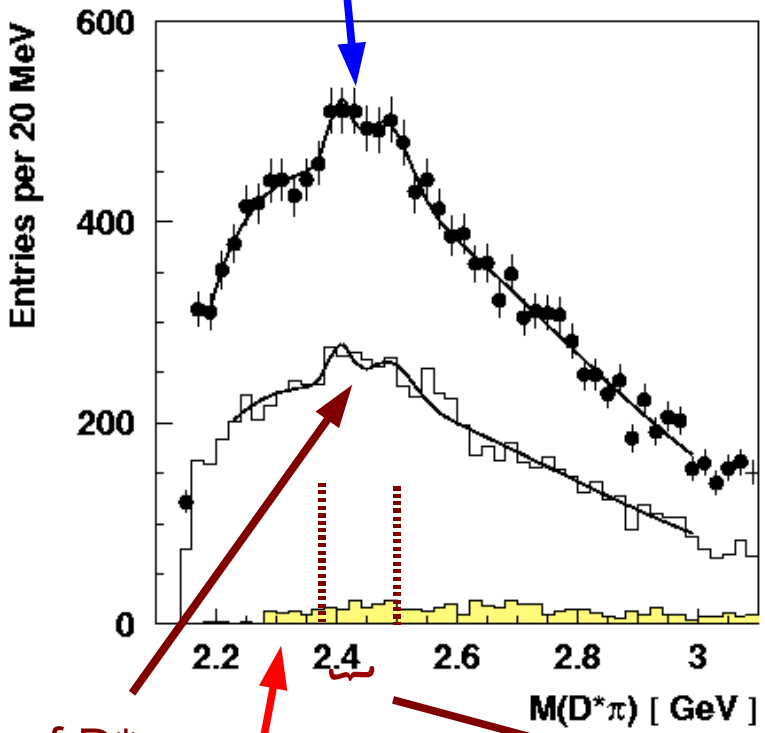


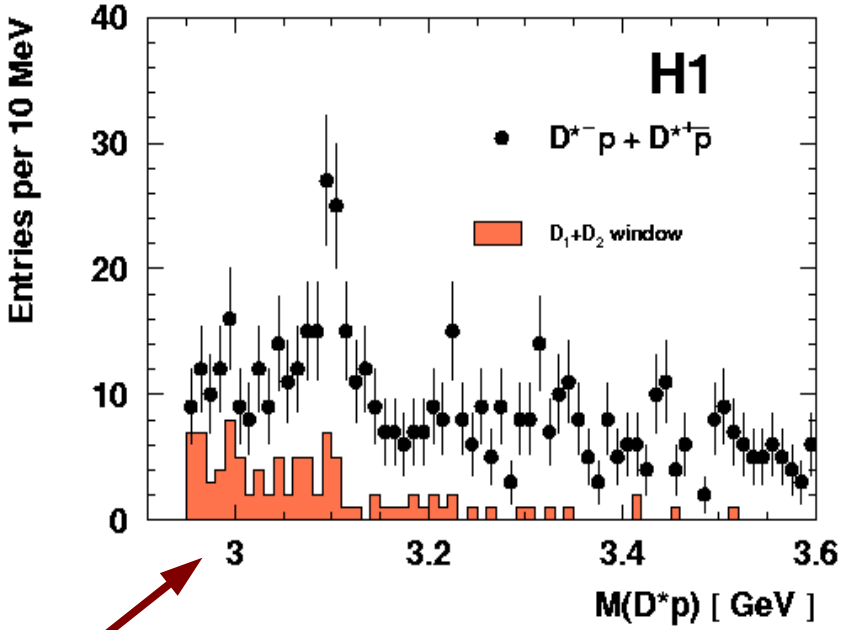
Check assumption using D*:
π_S momentum spectrum
harder for D* than for wrong charge D bgr!

Reflections from decays to D*π ?

loose D* cuts
π selection

D_1^0, $D_2^{0*} \rightarrow D^*\pi$





D* cuts of D*p
π selection

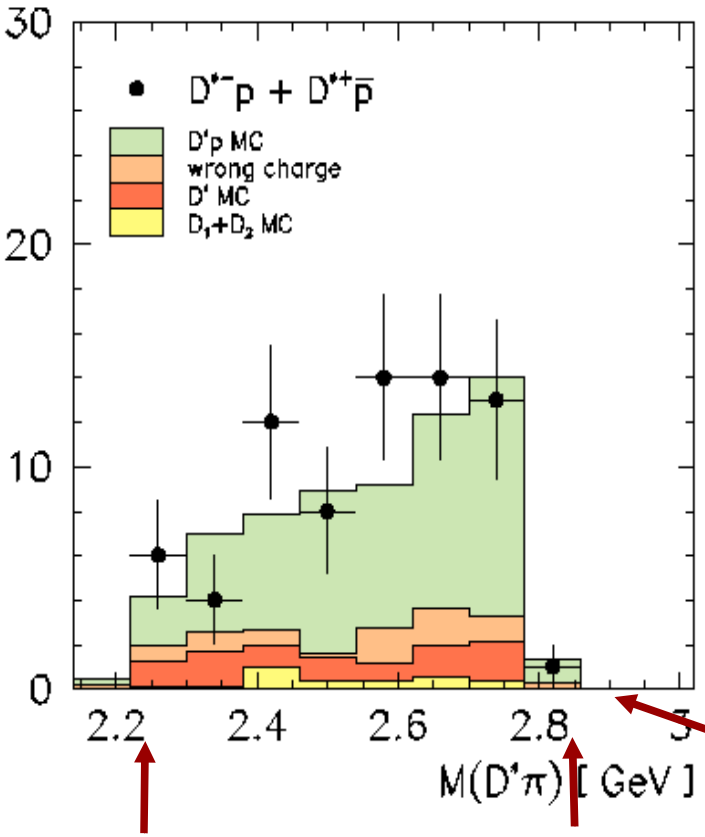
D* cuts of D*p
proton selection

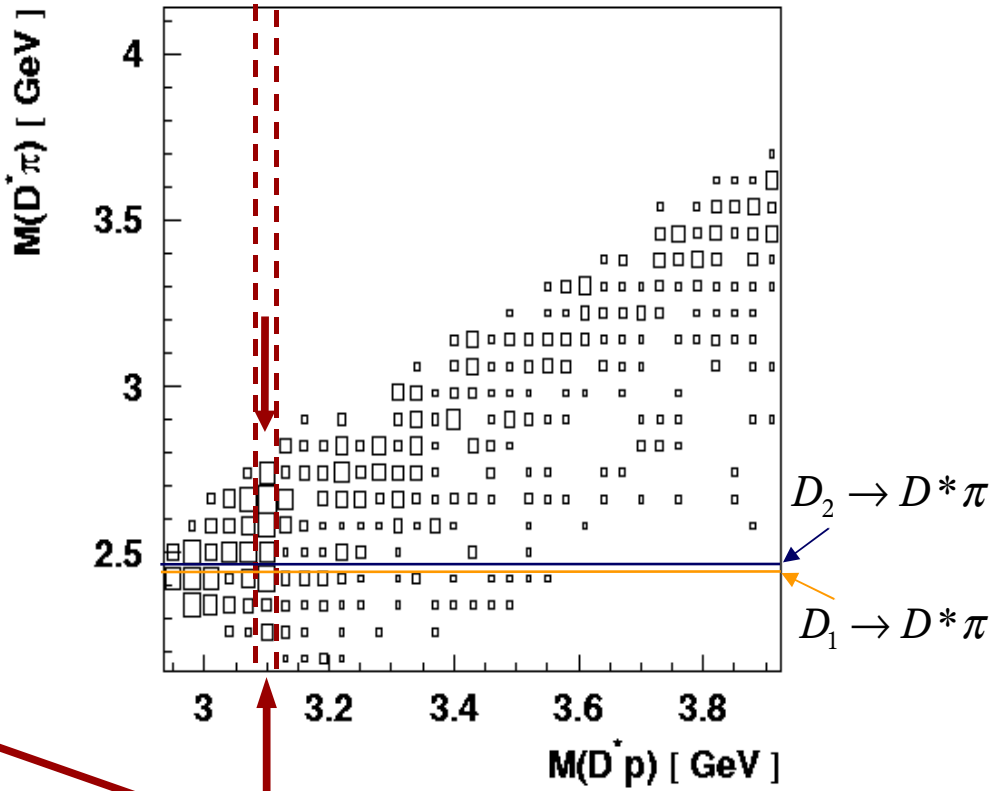
D_1 , D_2 window

Expect 3.5 decays (D_1^0, $D_2^{0*} \rightarrow D^*\pi$) in D*p signal

Reflections from decays to D*π ?

D_1^0, $D_2^{0*} \rightarrow D^*\pi$





Signal for X⟶D*p: available phase space in D*π completely used

go to the D*p signal region

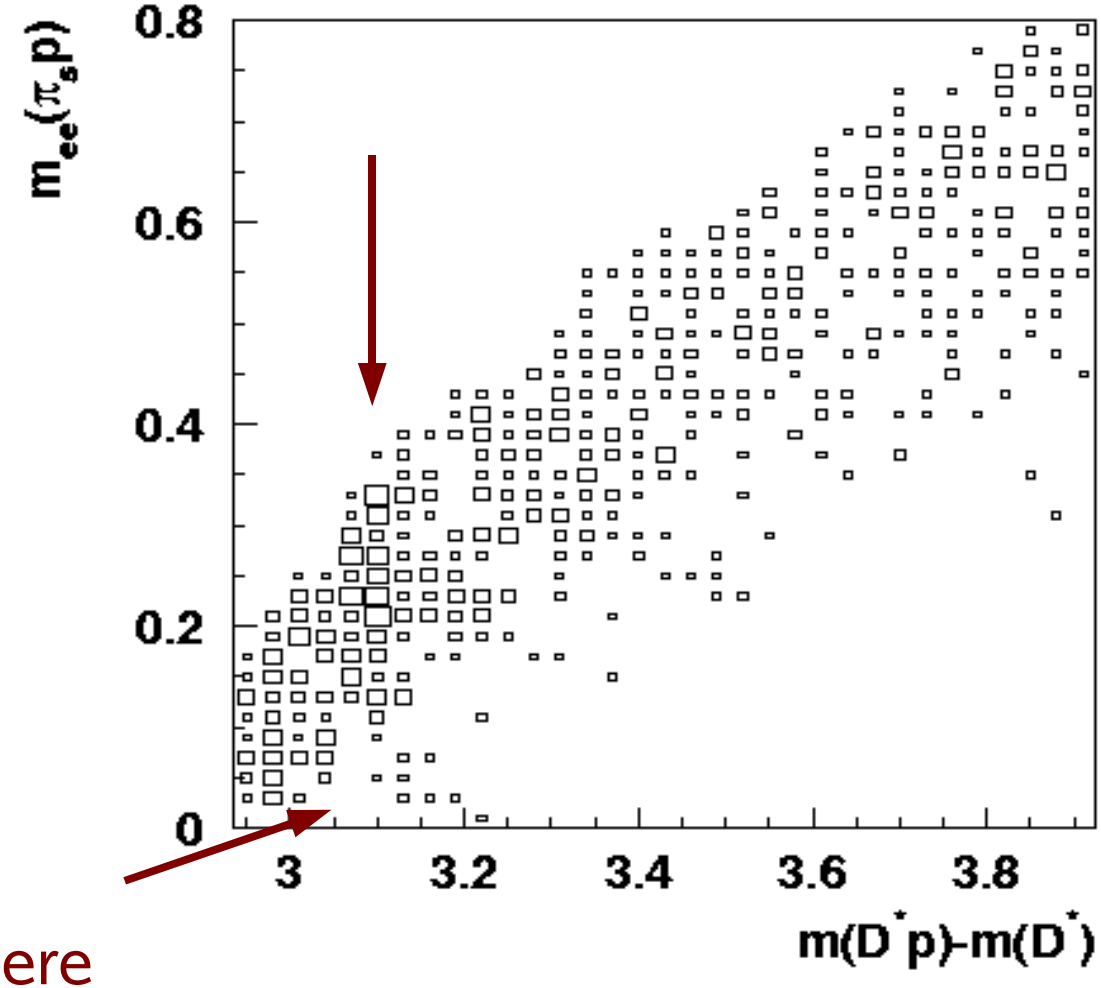
Within ±24 MeV around D*p signal:
4 events from D_1^0, D_2^{0*} expected

Could signal be due to decay $D^{0*} \rightarrow D^0 \gamma$?

$D^{0*} \rightarrow D^0 \gamma \rightarrow D^0 e^+e^-$

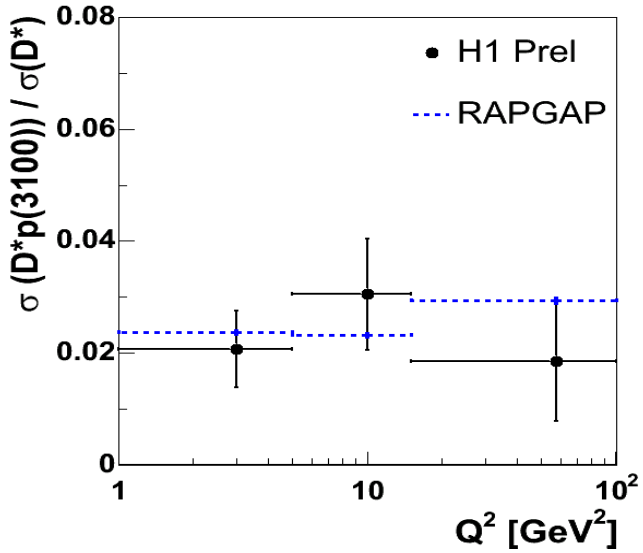
electrons

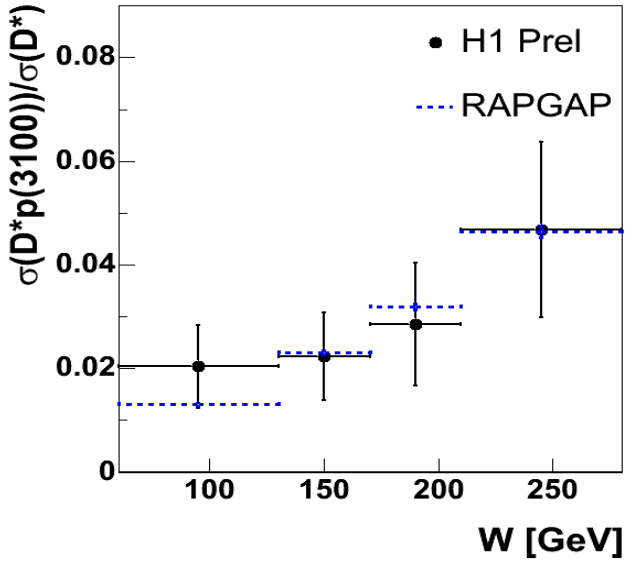
- asymmetric in energy
- misidentified as proton and π_s ?

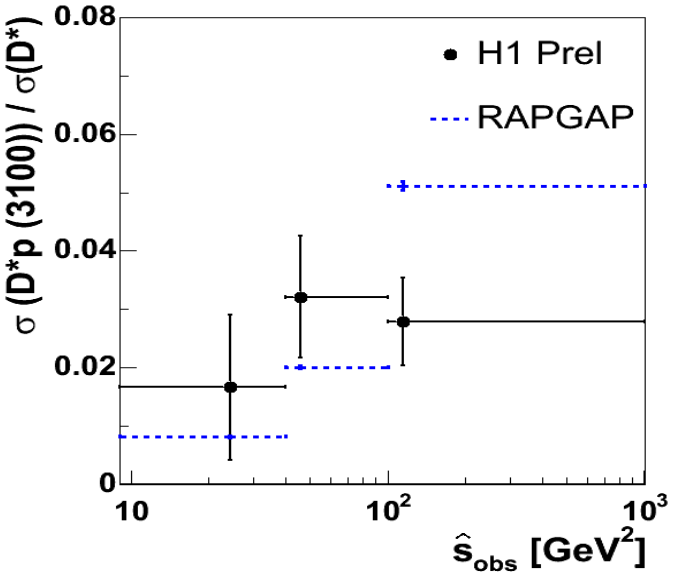


No accumulation at small m_{ee} in D*p signal region or elsewhere

Differential cross section ratios



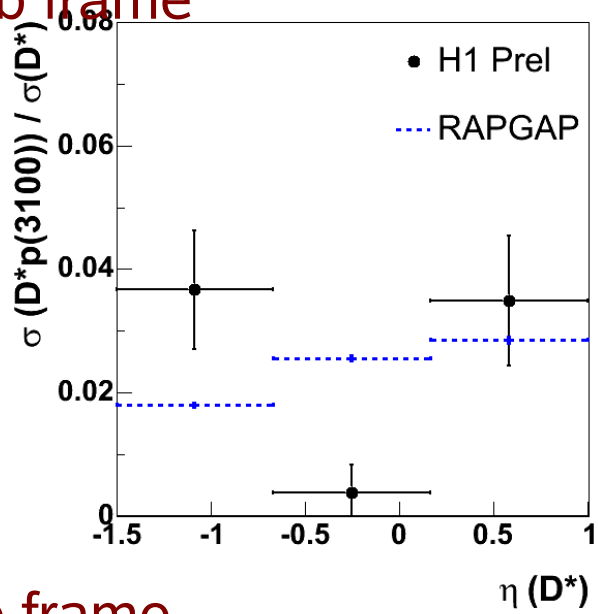


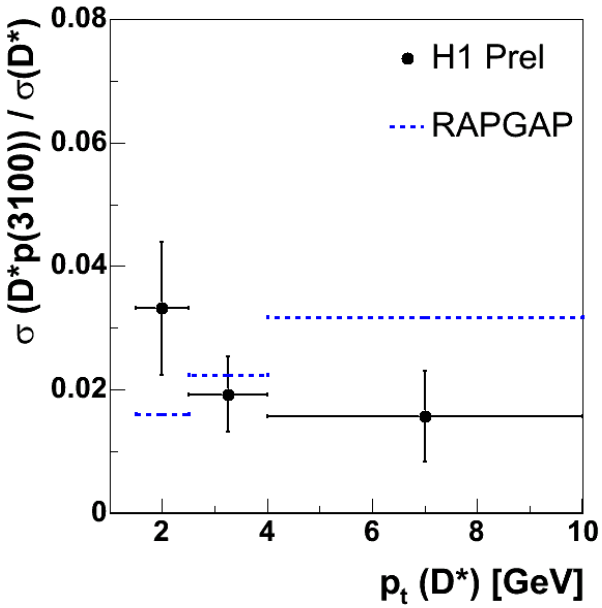


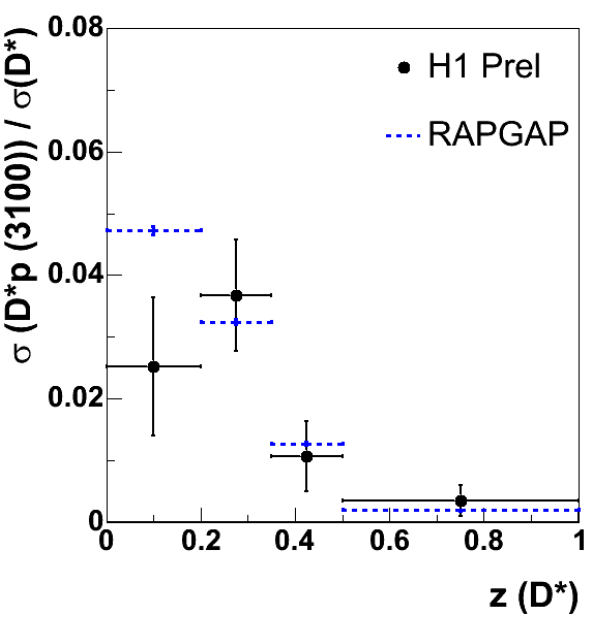
Charm Pentaquark Searches at HERA : H1 results

Differential cross section ratios

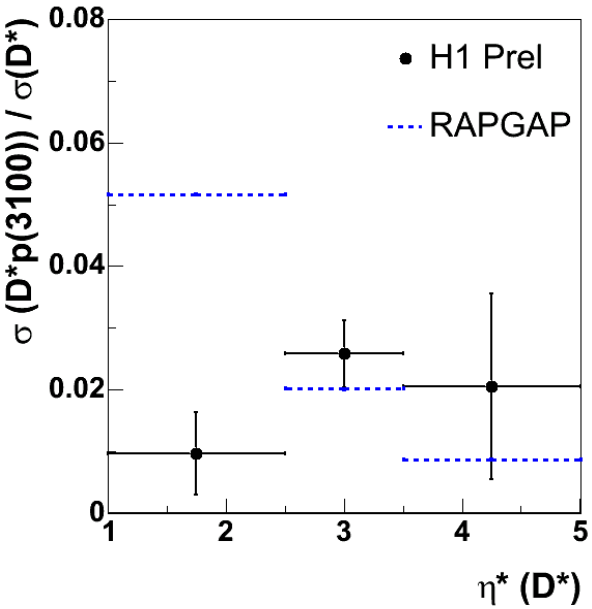
Lab frame







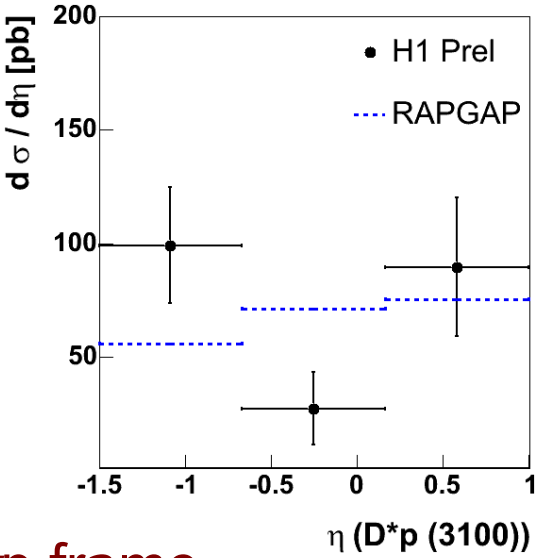
γp frame

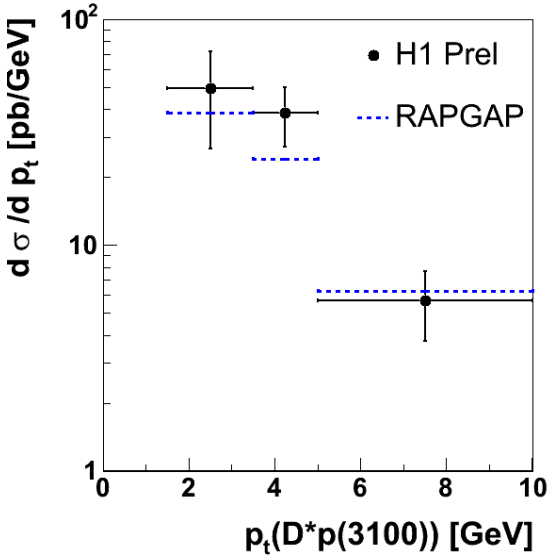


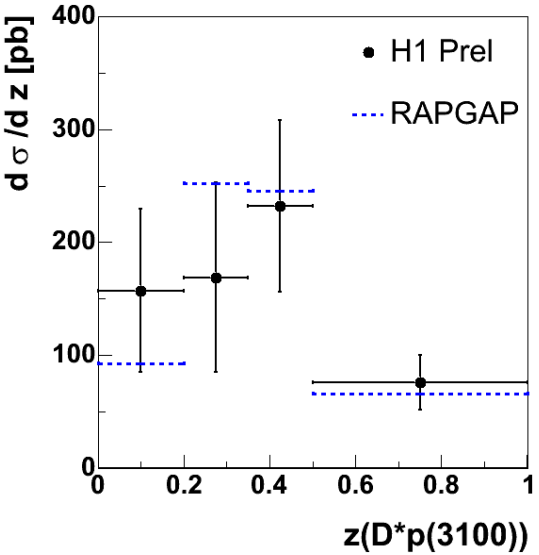
Charm Pentaquark Searches at HERA : H1 results

Differential cross section ratios

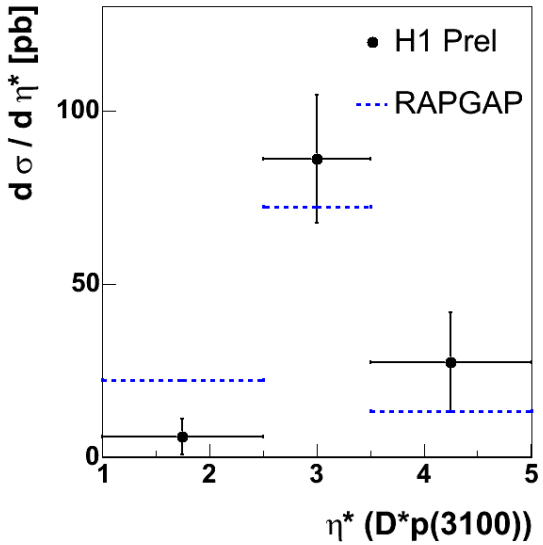
Lab frame



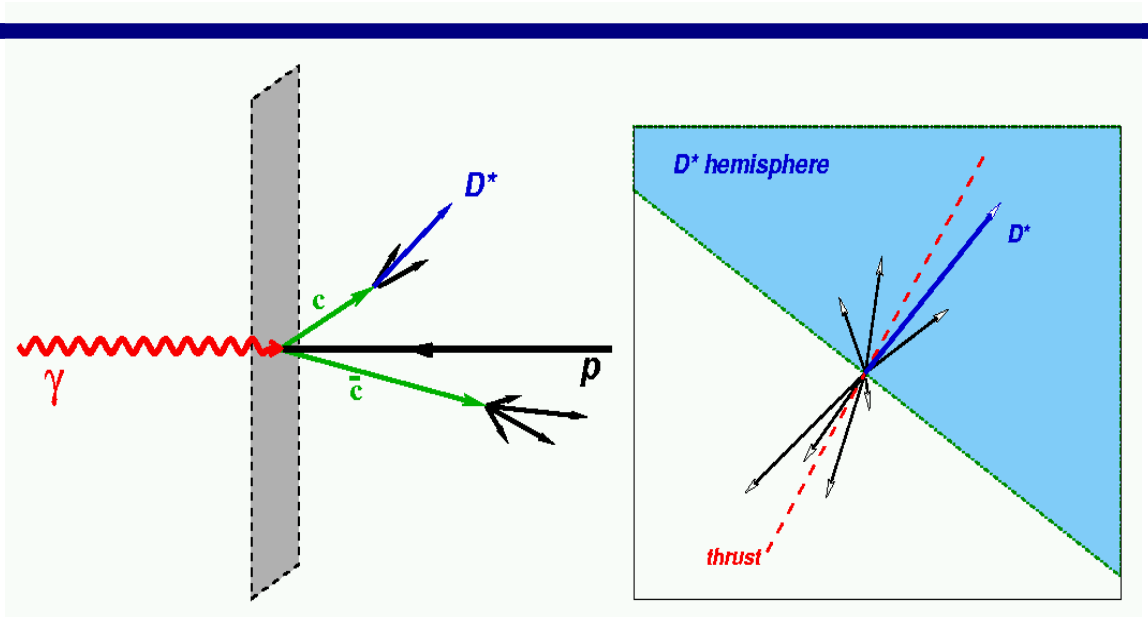




γp frame



Charm Pentaquark Searches at HERA : H1 results



Differential cross section ratios