Evidence for a narrow anti-charmed baryon state

Katerina Lipka (H1) DESY Zeuthen

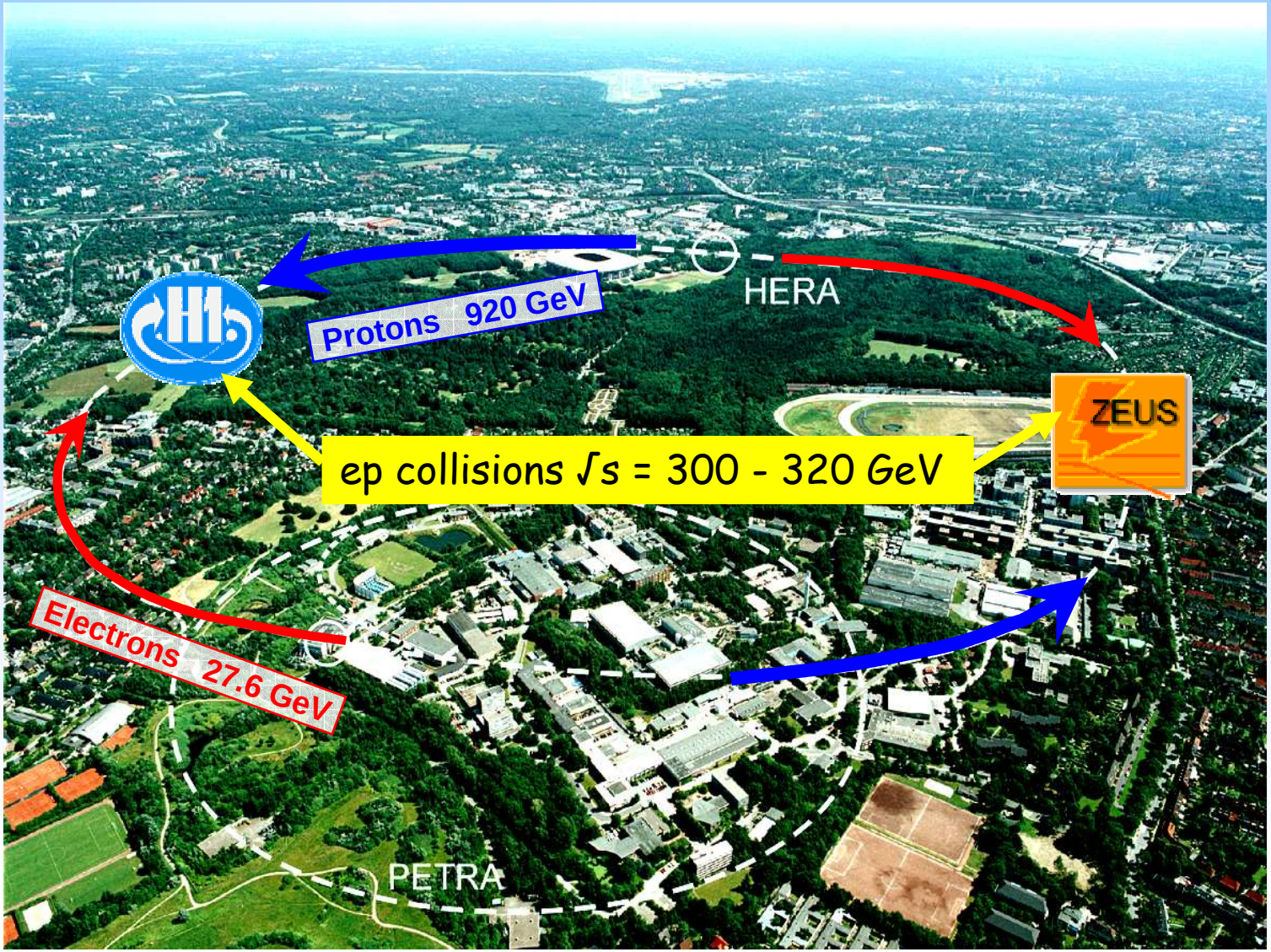
for

Collaboration

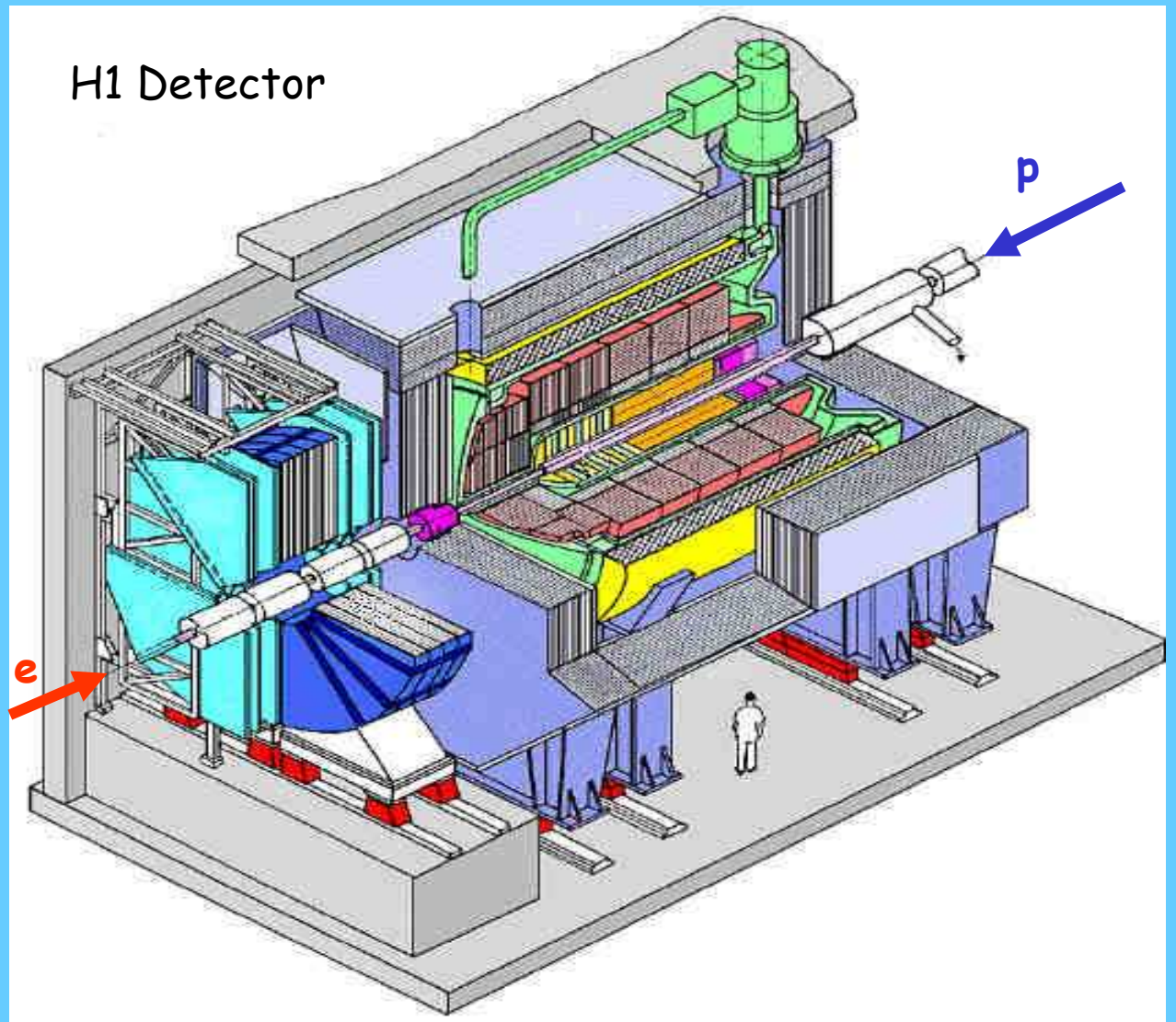
Exotic Hadrons 2005 Trento

H1 experiment at HERA accelerator

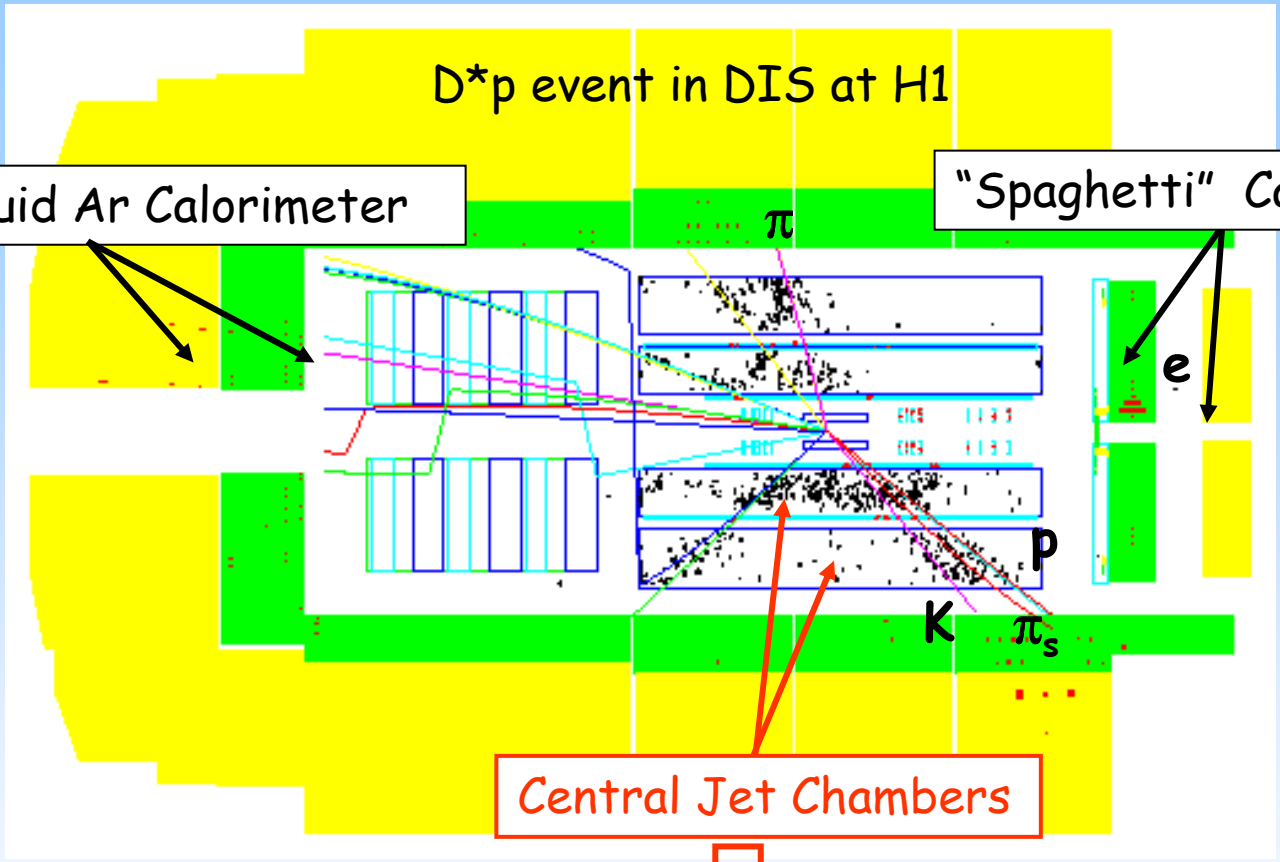
HERA accelerator at DESY (Hamburg, Germany)



H1 experiment at HERA accelerator



H1 experiment at HERA accelerator



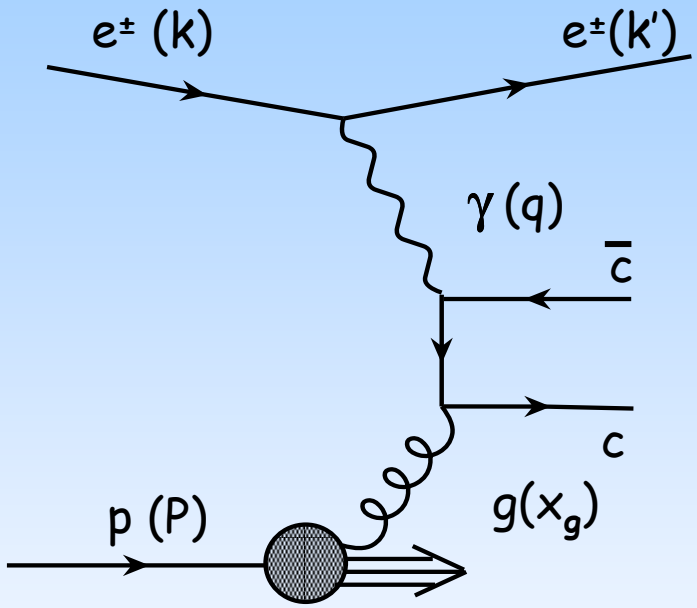
- drift chambers, acceptance: $20^o < \theta < 160^o$
- simultaneous charge and timing information
- B = 1.15 T → measure transverse momentum of charged particles

→ **Tracking , Particle ID via dE/dx**

Heavy flavour production at HERA

$e^{\pm}$ 27.5 GeV → ← p 920 GeV

Dominated by Boson – Gluon Fusion (BGF) in LO: $\gamma g \rightarrow c\bar{c}$ ($b\bar{b}$)



ep kinematics: $\sqrt{s}$ = 300 - 318 GeV

- 4-momentum transfer squared $Q^2 = -q^2$;
- Bjorken scaling variable $x = Q^2/(2\,q\,P)$
- inelasticity $y = qP/kP$
- mass of the hadronic system $W^2 = (P + q)^2$

Kinematic regimes:

- $Q^2 < 1$ GeV^2 : Photoproduction, γp (scattered electron escapes the main detector)
- $Q^2 > 1$ GeV^2 : Electroproduction, DIS (scattered electron detected)

Charmed pentaquark search at H1

Inspired by the evidence for the strange pentaquark Θ^+ in K^+n and $K^0_s p$

Why not a charmed pentaquark ?

If Θ+ formation is due to fragmentation process

→ **Features of Θ_c similar to those of Θ^+**

Look for charm pentaquark state via it's decay

$\Theta_c \rightarrow$ charmed hadron + baryon

Charm fragmentation: $f(c \rightarrow D^+) = 0.248 \pm 0.014$, $f(c \rightarrow D^{*+}) = 0.233 \pm 0.009$

D* production at H1 is much more feasible experimentally

Selected channel: $\Theta_c \rightarrow D^{*-}p$ (+c.c.)

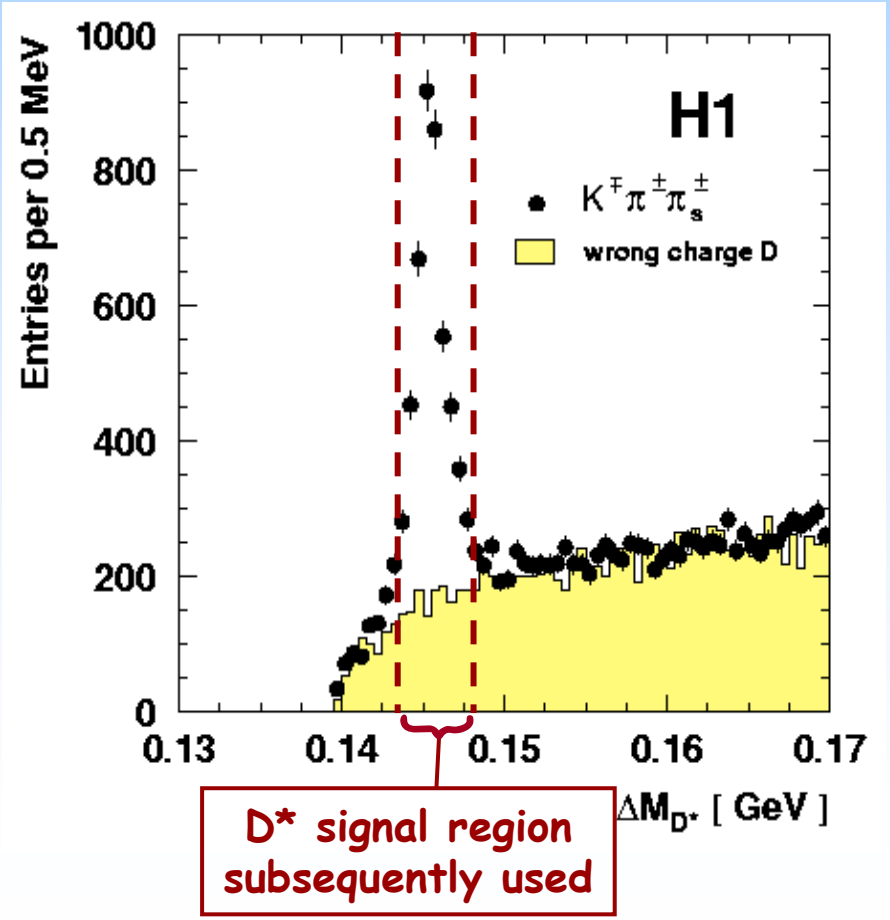
Charm pentaquark search at H1: D* Signal

- "golden " channel: $D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow K^- \pi^+ \pi_s^+$ (+ c.c.)
- apply "mass difference method": $\Delta M(D^*) = M(K \pi \pi_s) - M(K \pi)$
- 1996-2000 data, DIS regime ($Q^2 > 1$ GeV^2), Luminosity = 75 pb^{-1}

- good Signal/Background Ratio
- M(D*)-M(D0) = 145.4 MeV
- 3400 D* to start

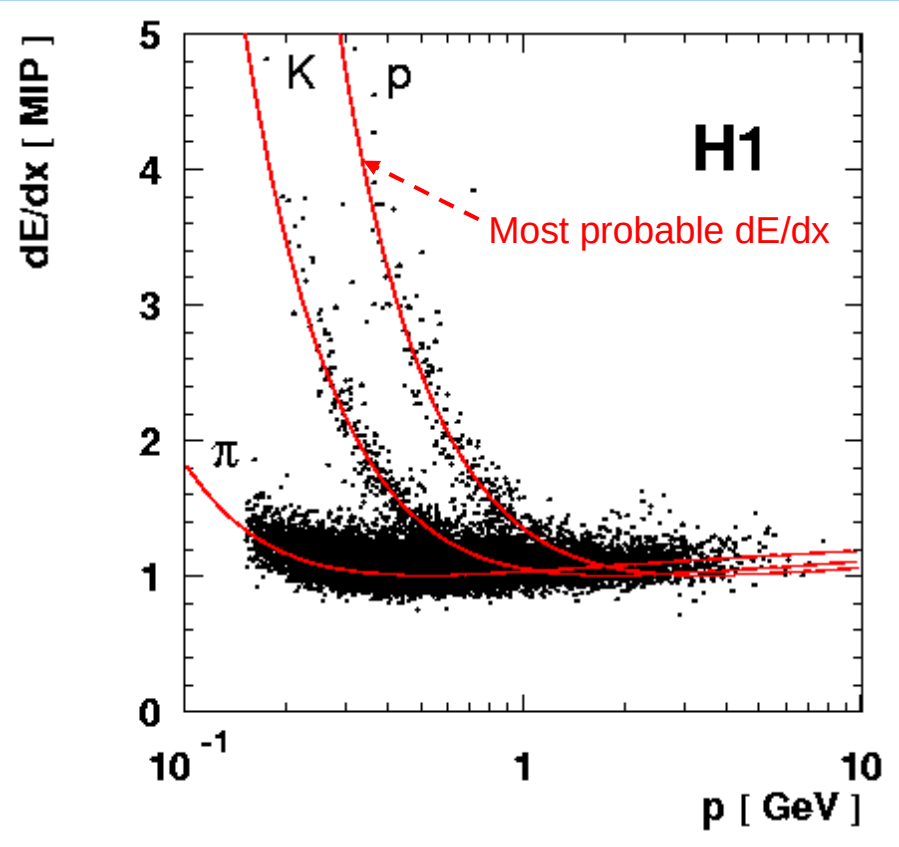
Non-charm induced background:

"wrong charge D" : fake D^0 ($K^+ \pi^+$/ $K^- \pi^-$) + π_s



Charm pentaquark search at H1: Proton selection

Particle identification at H1 via energy loss (dE/dx) measurement



average dE/dx resolution (MIP) 8%

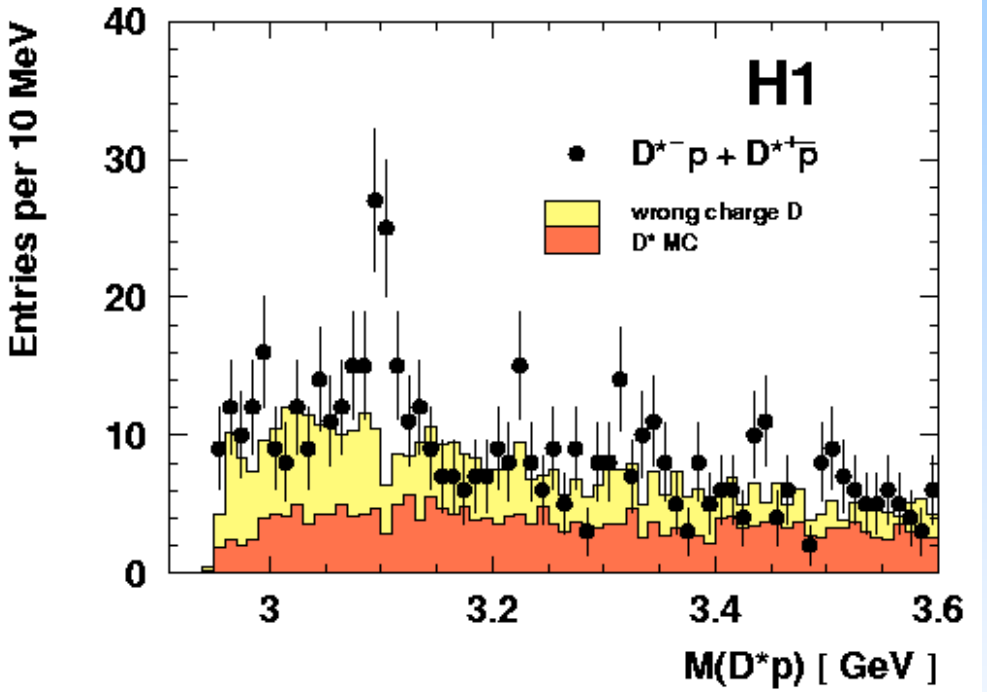
most probable dE/dx parameterized:

- Bethe-Bloch-like function
- accuracy 3 - 5 %

use dE/dx measurement for background suppression

Invariant mass of the $D^{*-}p$ ($D^{*+}\bar{p}$) system

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



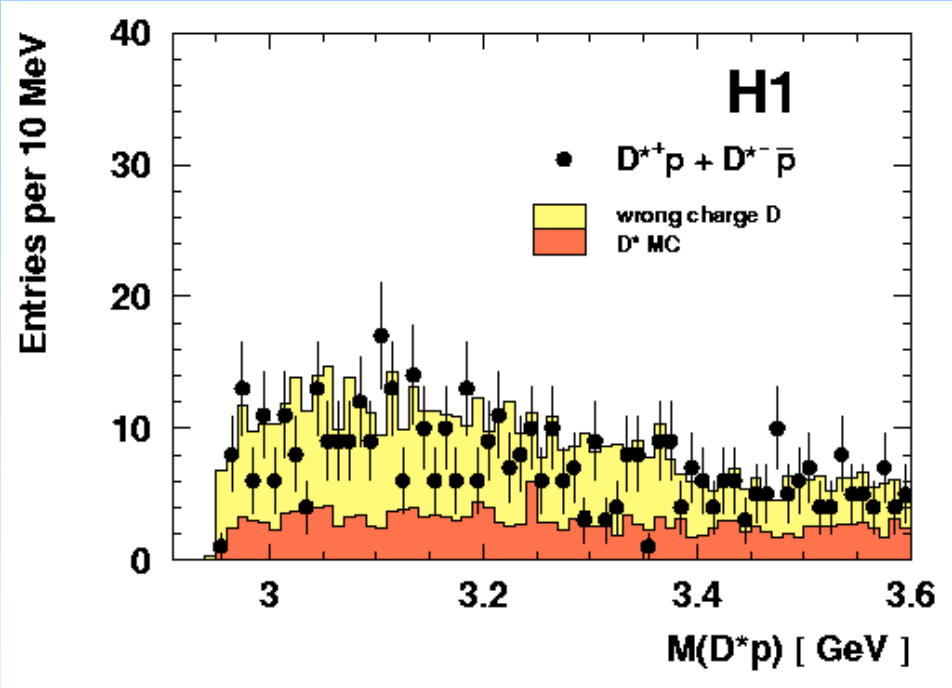
- significant peak in opposite charge D*p
- no enhancement in D* Monte Carlo
- no enhancement in wrong charge D

Background well described by D* MC and "wrong charge D" from data

narrow resonance observed : $M=3099\pm 3(stat.)\pm 5(syst.)$ MeV

- equally significant signal visible in separate $D^{*+}\bar{p}$ and $D^{*-}p$
- signal visible in different data taking periods

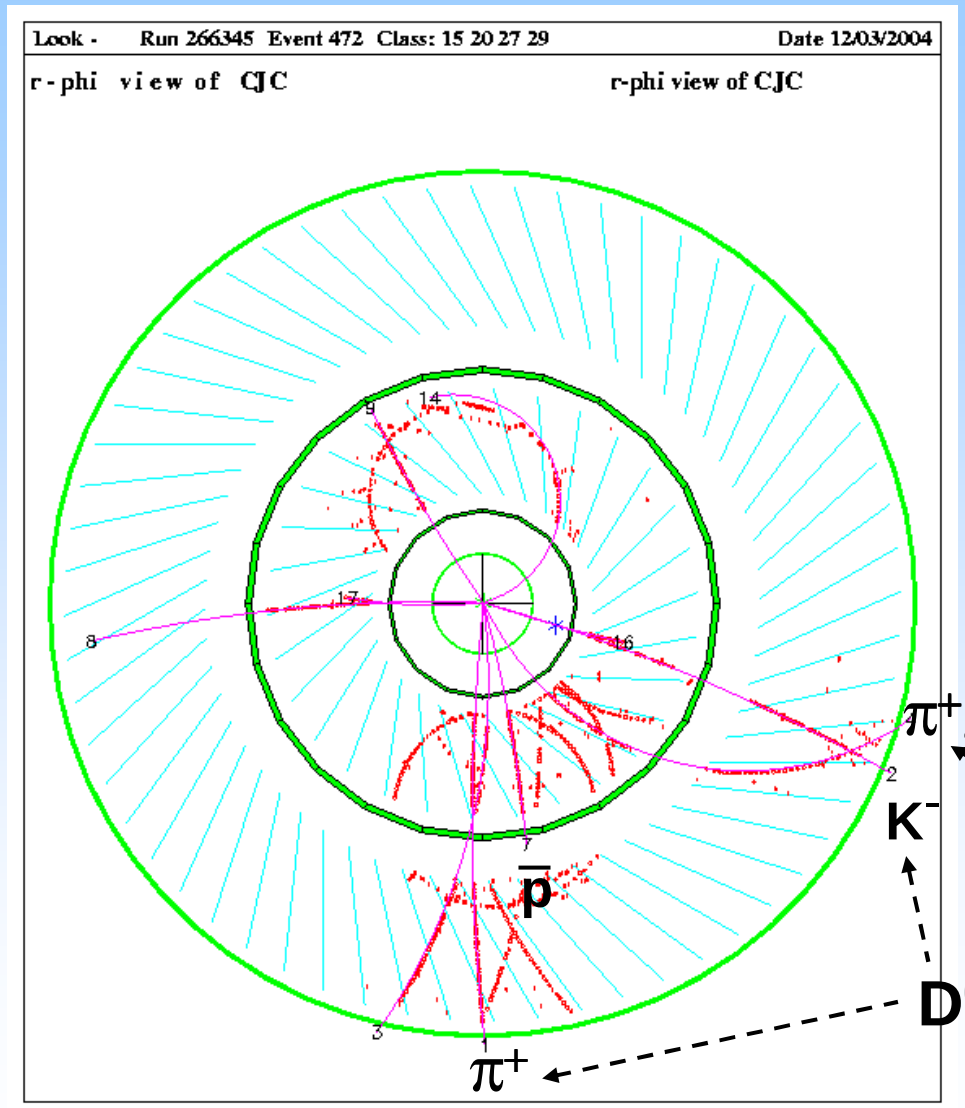
Invariant mass of the $D^{*+}p$ ($D^{*-}\bar{p}$) system

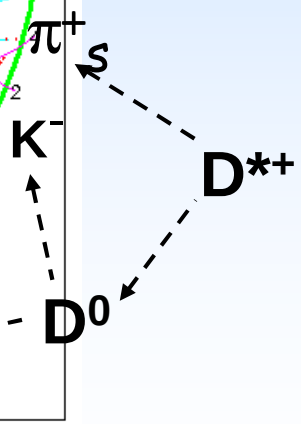


Background well described by D* MC and "wrong charge D" from data

- no significant peak in like-charge D*p
- no enhancement in D* Monte Carlo
- no enhancement in wrong charge D

A Typical D*p Event



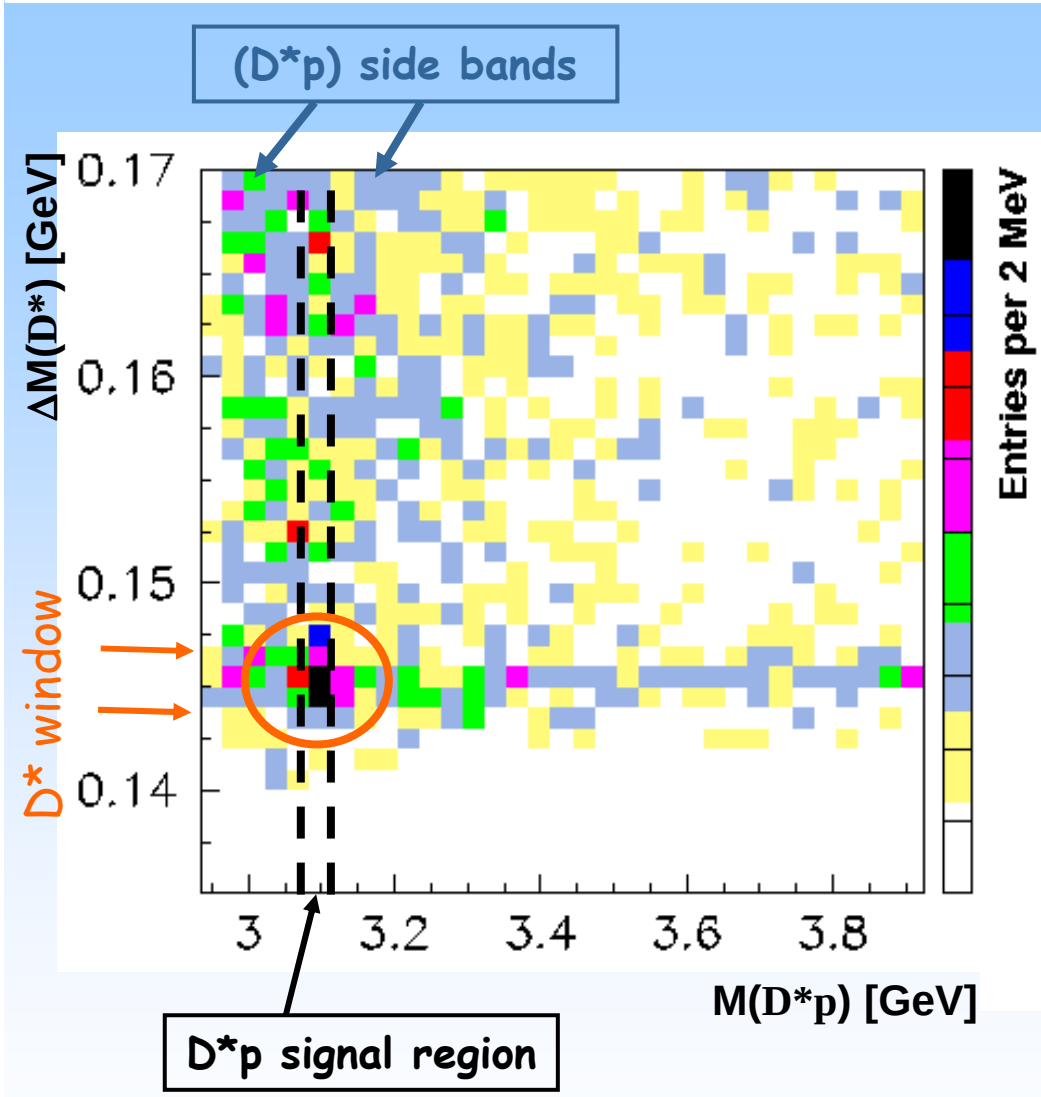


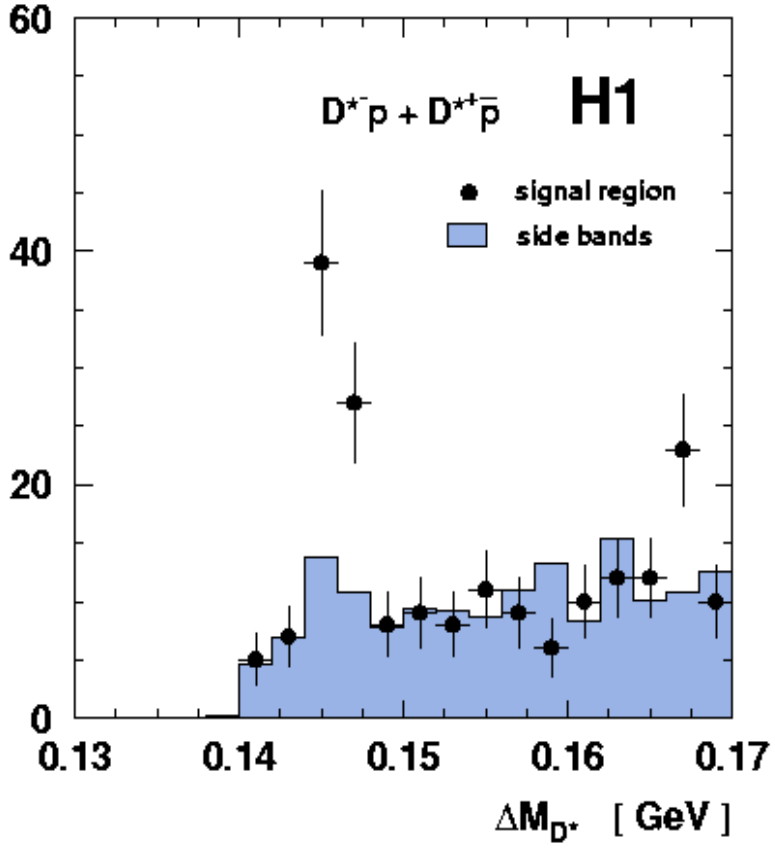
Events are scanned

NO anomalies observed:

- no split tracks,
- no wrong reconstruction…

Does the signal come from D* ?

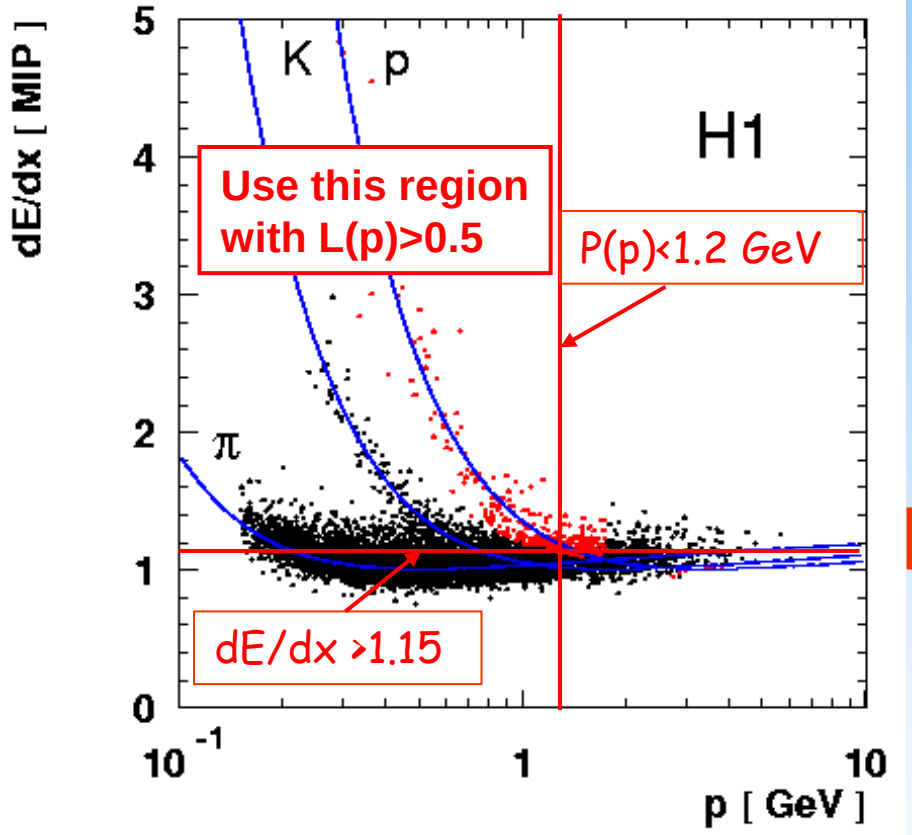


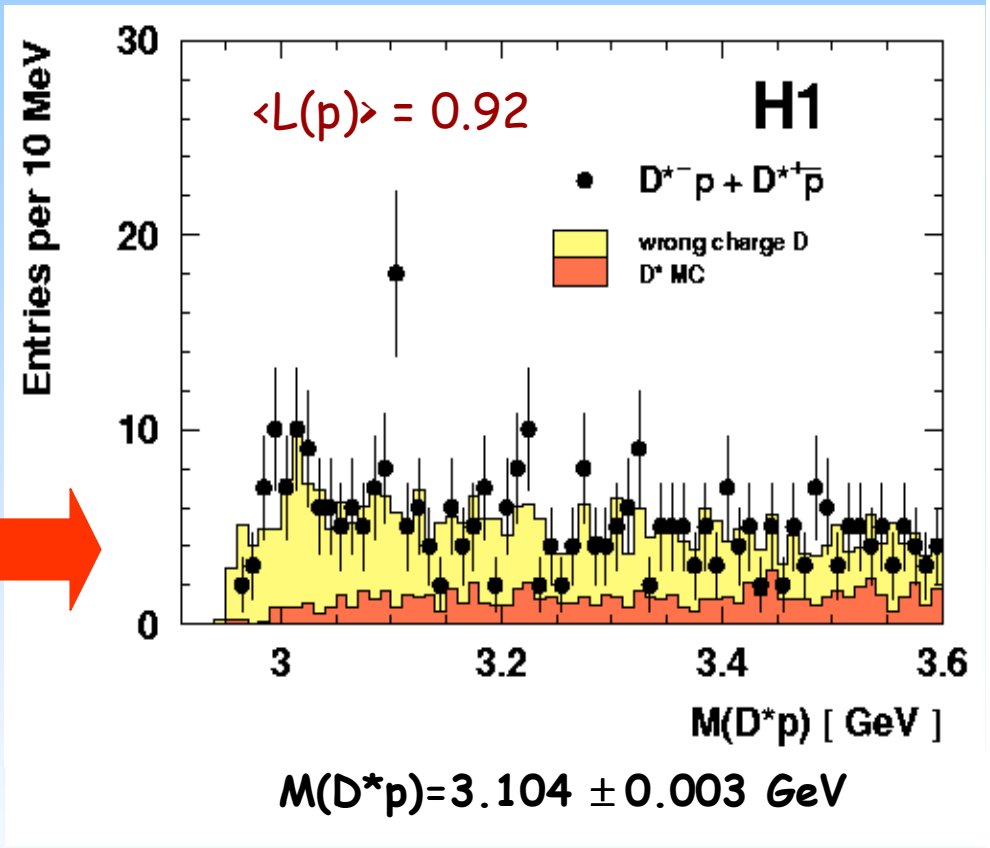


Normalization to the width of the windows in M(D*p)

→ the (D*p) signal region is richer in D*

Does the signal come from protons ?





Signal is there for well identified protons

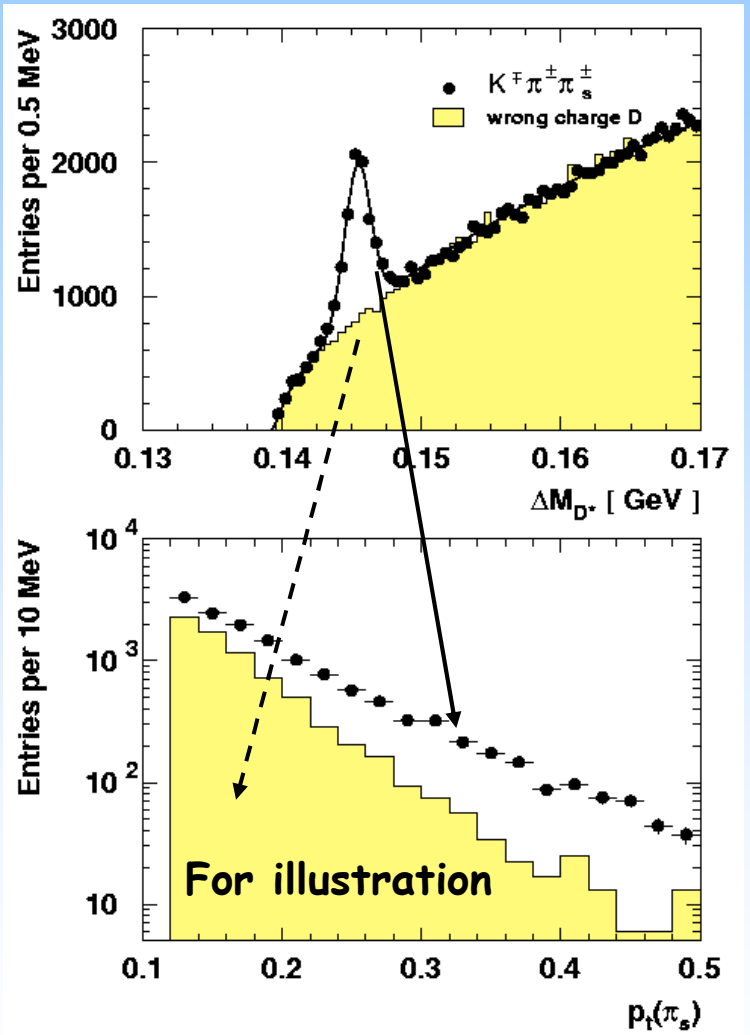
Does physics change on-resonance ?

- Single particle momentum spectra are steeply falling

- Harder spectrum for particles from decay due to mass release

- Harder spectrum for particles from decay of charmed hadrons due to hard charm fragmentation

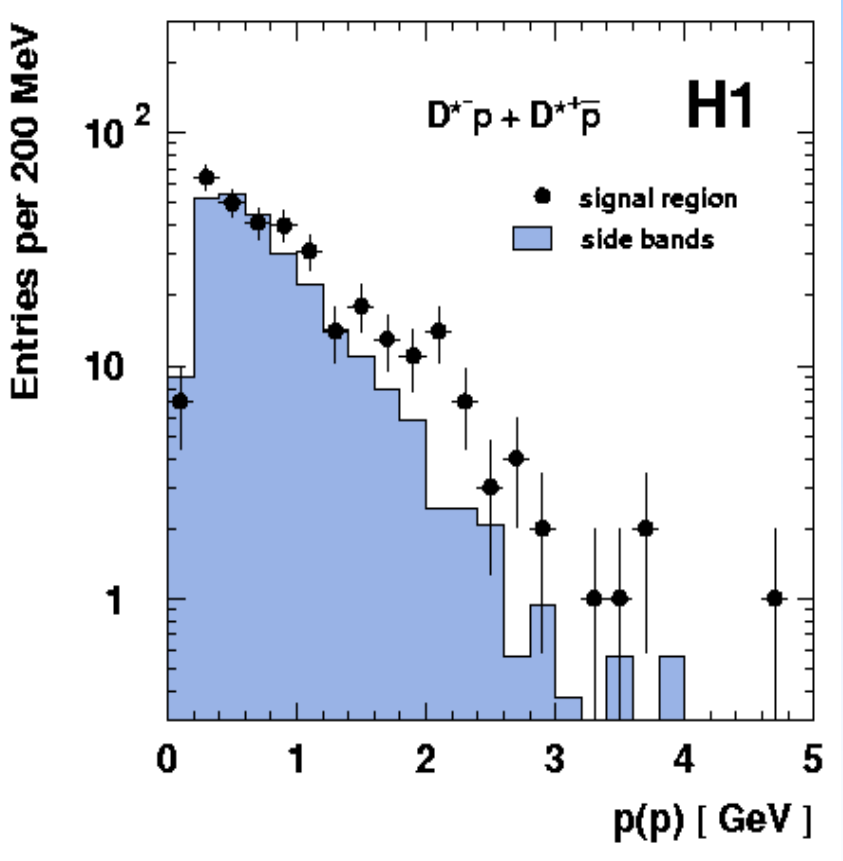
Example: momentum of π_s from D* harder than combinatorics :

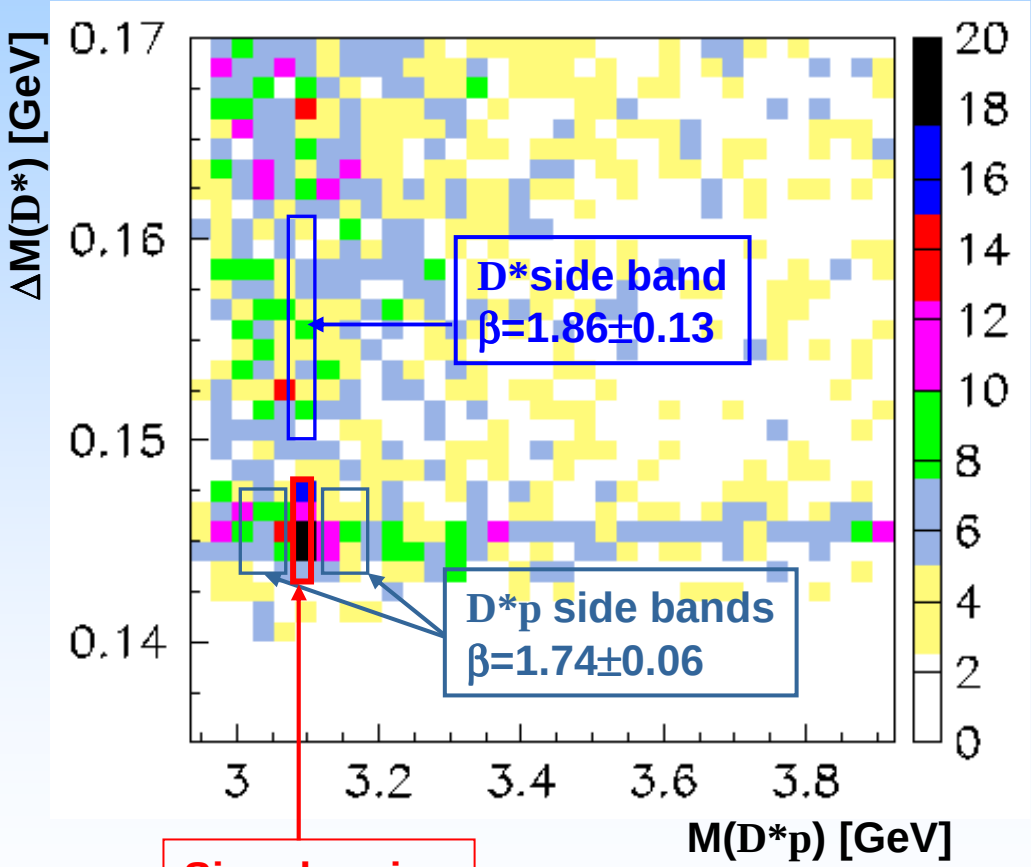


Does physics change on-resonance ?

look into momentum distribution of proton candidates without dE/dx cut

momentum distribution in the signal region is harder than in sidebands



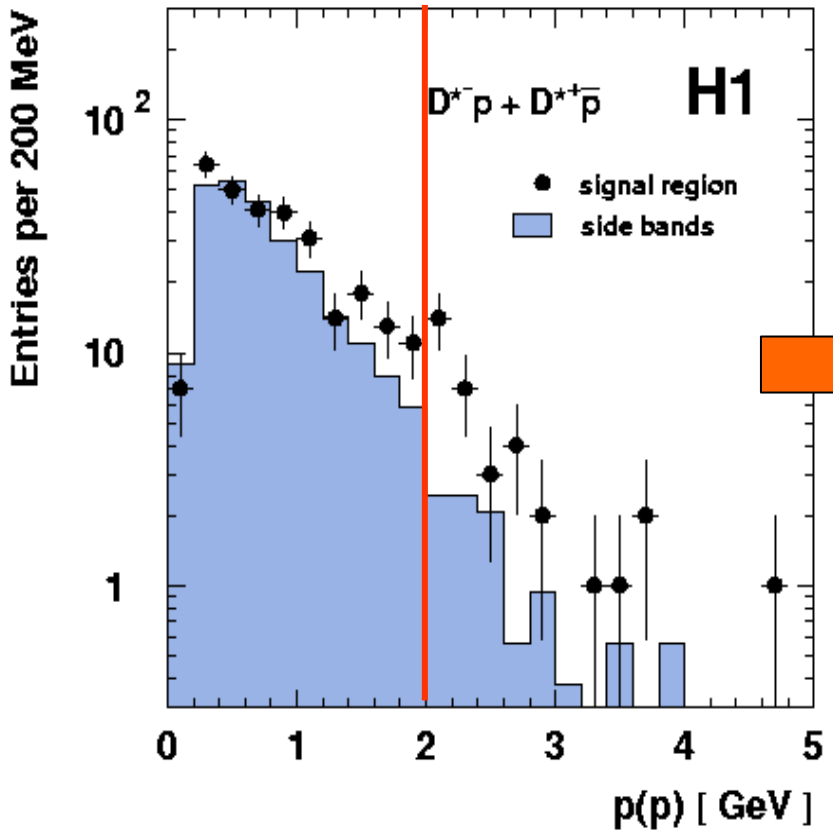


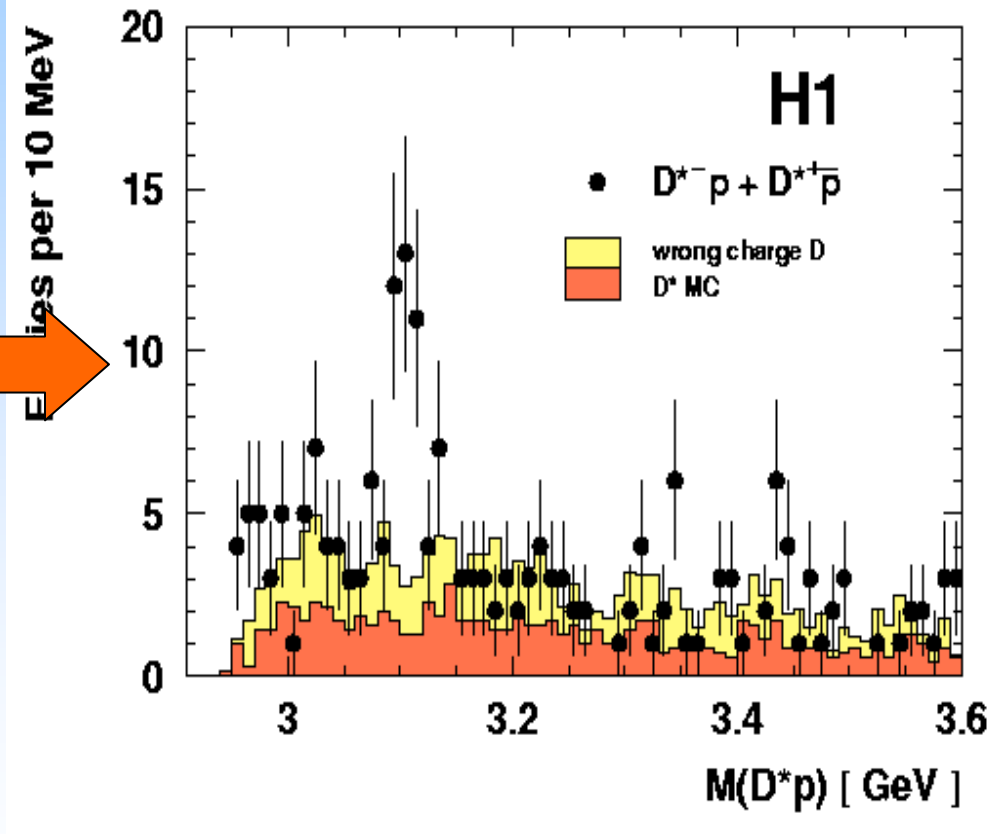
physics changes on-resonance !

Does physics change on-resonance ?

look into momentum distribution of proton candidates without dE/dx cut

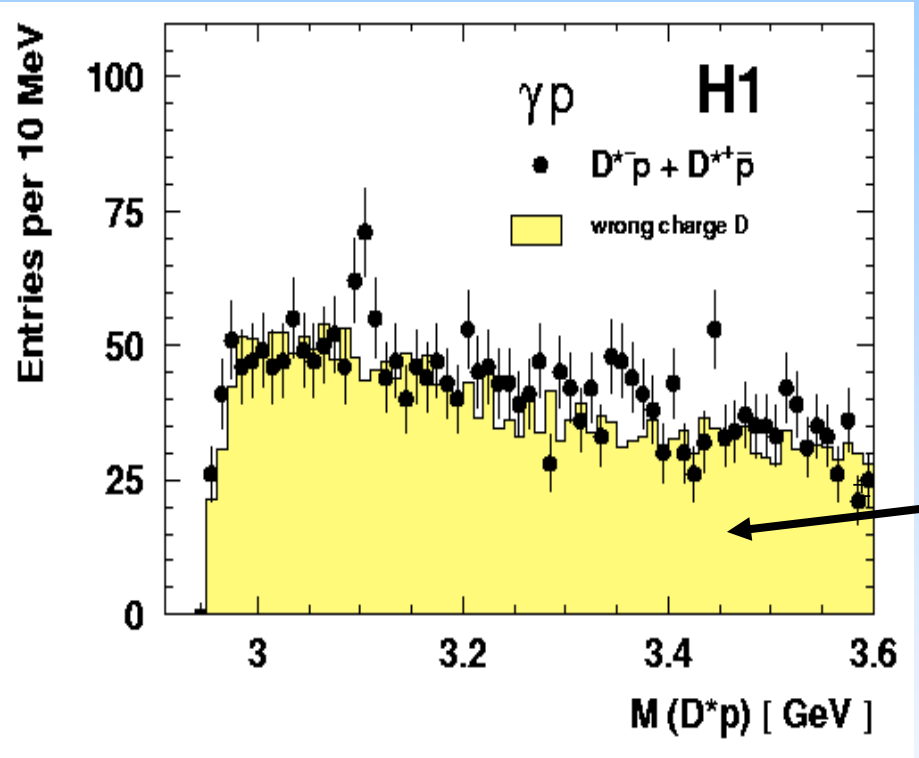
look into D*p combinations for p(p) > 2 GeV





prominent signal is visible

D*p signal in photoproduction



- total: 4900 D* to start
- peak observed at the same mass
- no enhancement in non-charm bg
- 95 % bg due to non-charm

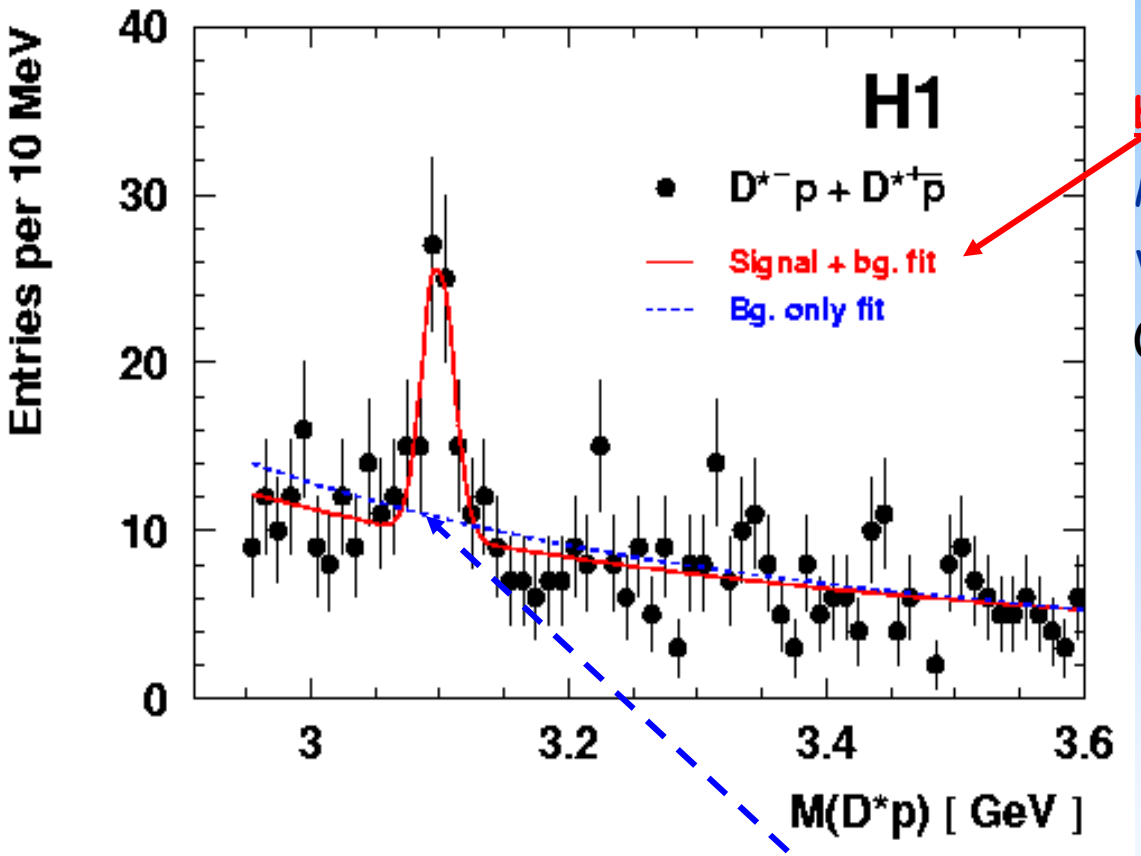
Background well described by wrong charge D from data

Photoproduction more difficult due to large non-charm background

but

independent confirmation of the signal

Significance estimate



background + signal hypothesis Fit:

Mass: 3099 ± 3(stat) ± 5(syst) MeV

Width: 12 ±3 MeV

(consistent with experimental resolution)

Numbers of signal and background within ± 24 MeV

$N_b = 45.0 \pm 2.8$

$N_s = 50.6 \pm 11.2$ (~ 1% of D* yield)

Significance estimate based on the background only hypothesis (binning free)

→ Background fluctuation probability: 4×10^{-8} (Poisson) ≡ 5.4 σ (Gauss)

Difference in likelihood of background and signal+background fit: $\sqrt{2\Delta \log L} = 6.2\sigma$

(Test independent of peak position)

Search for a charmed pentaquark at ZEUS

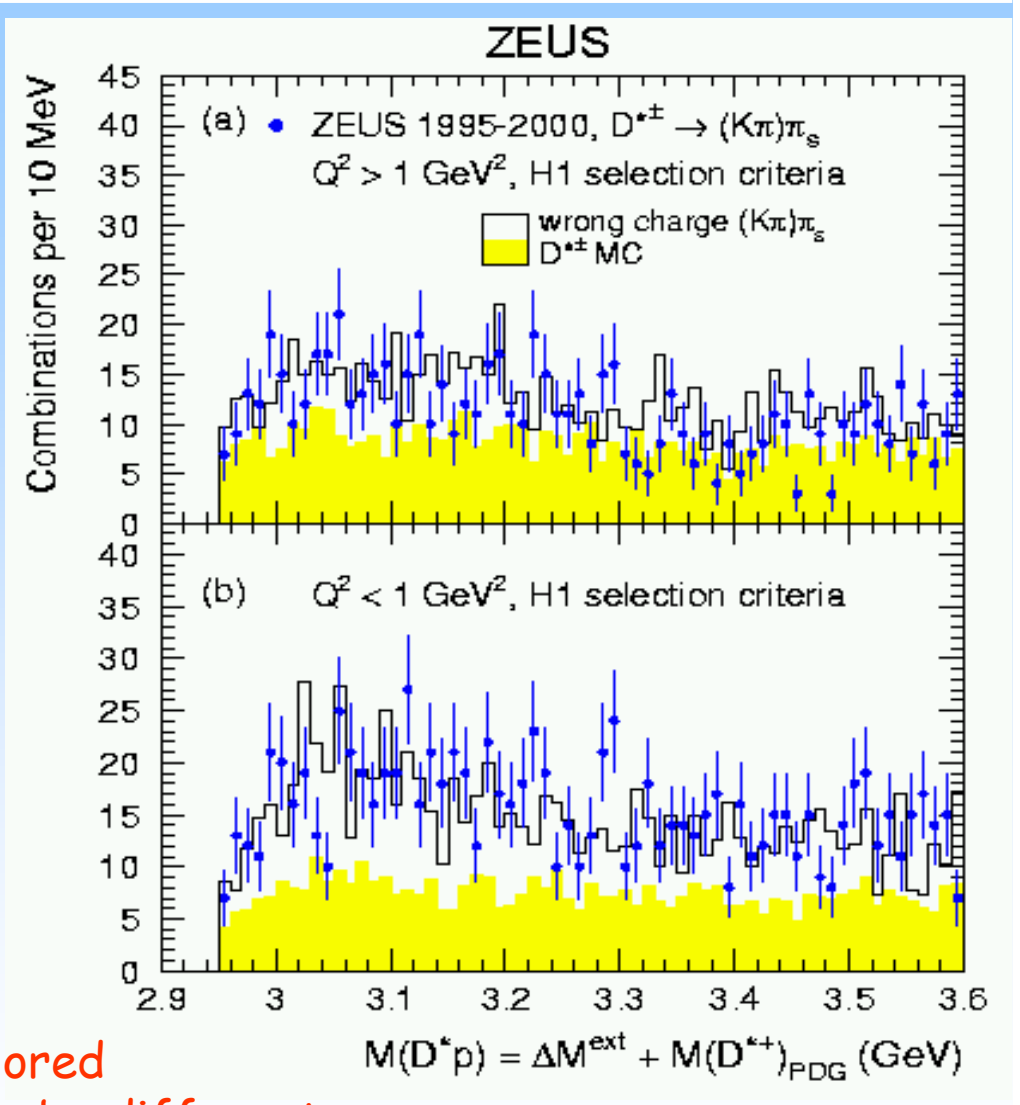
1995-2000 data, 127 pb^{-1}
selection of D*, p similar to H1

DIS (Q^2>1 GeV): N (D*) = 5920
γp (Q^2<1 GeV): N (D*) = 11670

No signal seen in D*p

Limits on Θ_c/D* for DIS:

$R(\Theta_c \rightarrow D^*p/D^*) < 0.51\%$ @95% C.L



H1 vs ZEUS

- different phase space might be explored
- Θ_c and D* production mechanism may be different
- more work to understand the differences has to be done

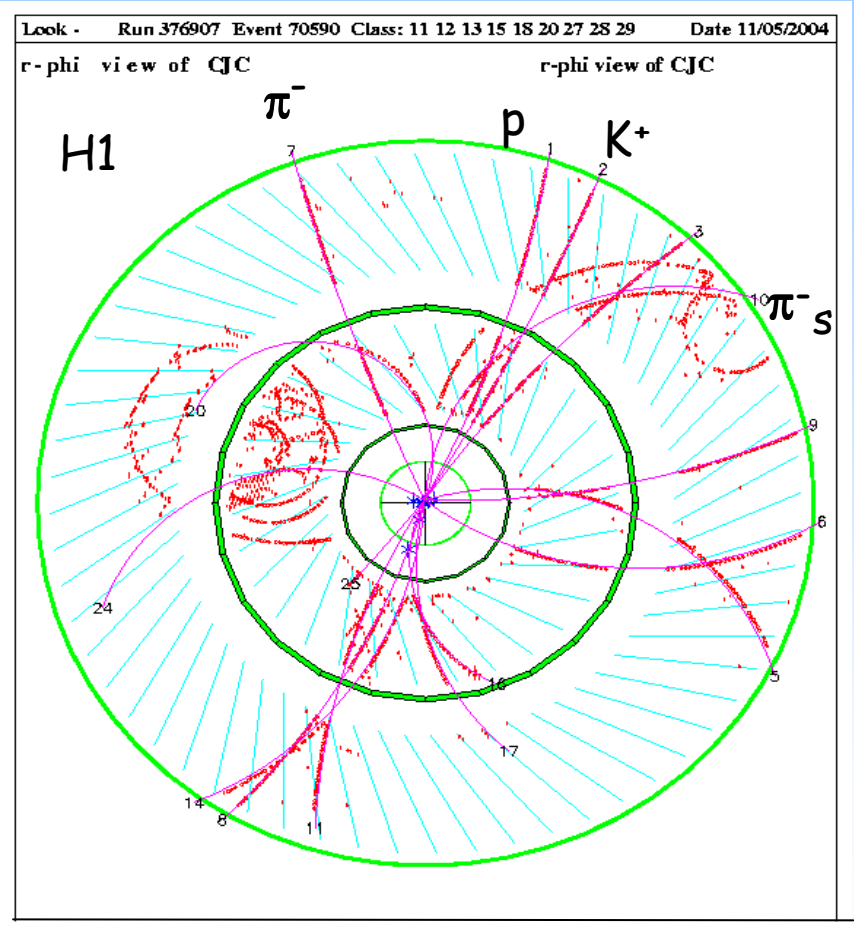
Summary and Outlook

- evidence for a narrow state decaying to D*p in DIS at H1 , candidate for $uudd\bar{c}$ + c.c
- signal due to D* mesons and protons
- harder proton spectrum in the signal region
- signal is visible in photo-production
- no confirmation by ZEUS

→ **more understanding of D*p production dynamics needed**

- acceptance corrected yields on the way
- new data on the way

D*p candidate event in HERA-II



Recent Results on Θ^+ at ZEUS

Amita Raval (ZEUS) DESY Hamburg

for

Collaboration

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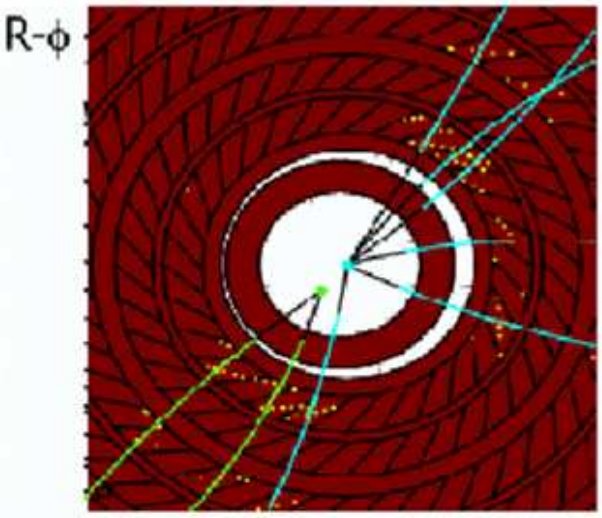
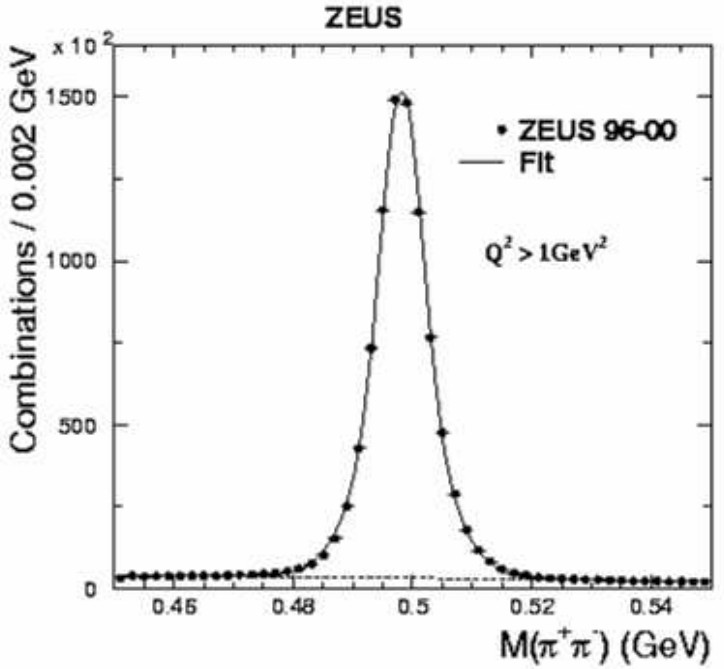
Search for Strange Pentaquark: K^0_S Selection

- $\Theta^+ \to K^0_S p$ $(\bar{\Theta}^- \to K^0_S \bar{p})$
  reconstruct $K^0_S p(\bar{p})$ inv mass
- Inclusive DIS event sample:
  $96-00$ data $\Rightarrow 121\ \mathrm{pb}^{-1}$
- K^0_S Selection
  $p_T(K^0_S) > 0.3$, $|\eta(K^0_S)| \leq 1.5$
  remove Λ and γ conversions

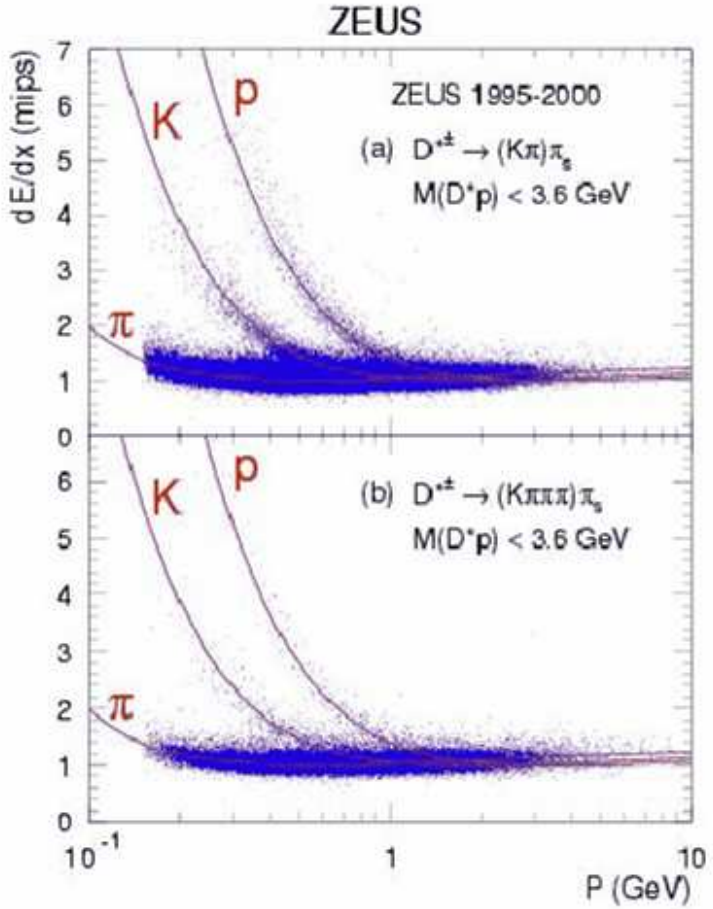




- Peak: 498.12 ± 0.01 MeV
- Background: $< 6\%$
- Candidates: $\sim$ 870,000
- Resolution: $2 \pm .5$ MeV (MC + consistent w/ K^* measurement)

Proton Identification

(anti)proton selection $\Longrightarrow$ define ionization band in dE/dx



- expectations tuned using tagged protons and pions from Λ and K^0_S decays
- Strange pentaquark

  $dE/dx > 1.15$ mips

  $P(p) < 1.5$ GeV

  $\sim 60\%$ proton purity
- Charmed pentaquark

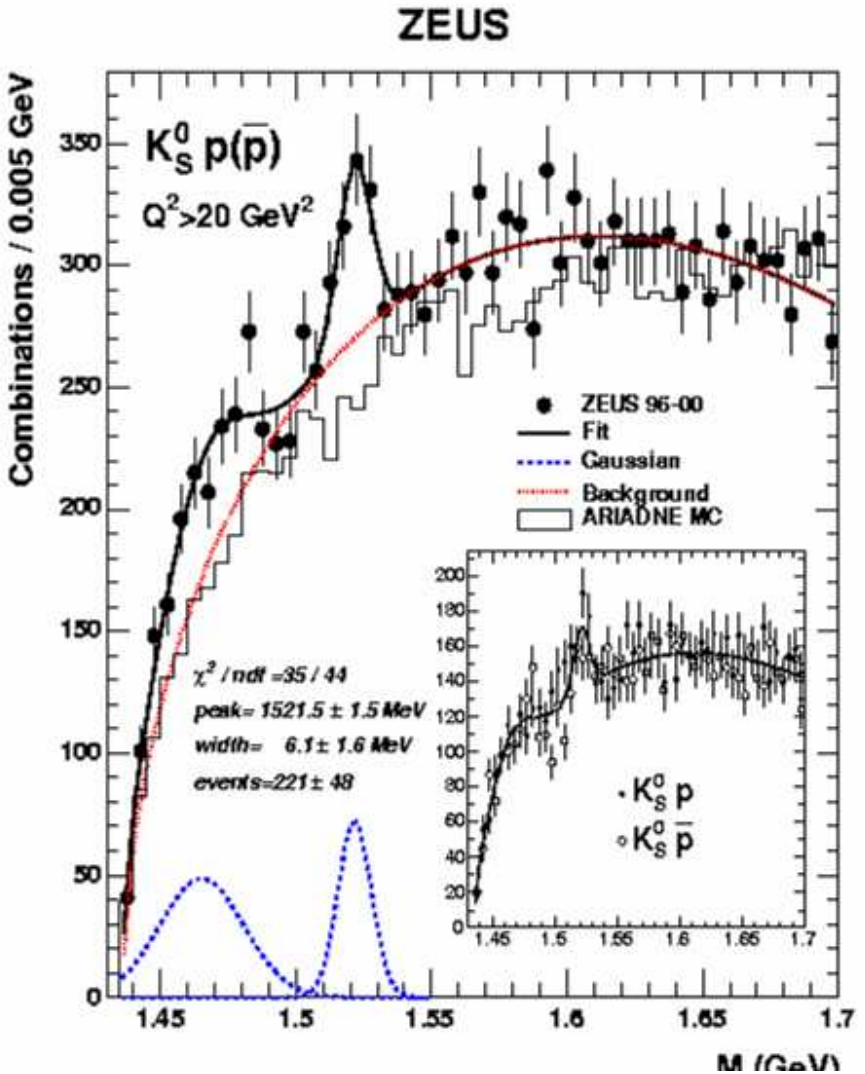
  $l_p > 0.15 \Rightarrow$

  $A(l_p > 0.15) = 85.0 \pm 0.1\%$

Search for Strange Pentaquark: (Phys. Lett. B 591)

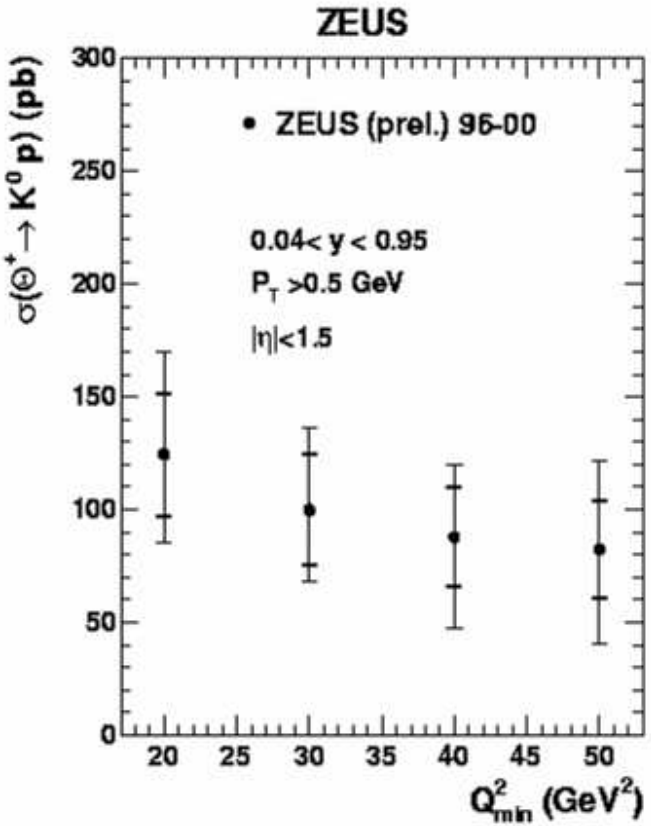
Θ^+ Signal $\Rightarrow$ $p_T(\Theta^+) > 0.5$ GeV , $|\eta(\Theta^+)| < 1.5$, $Q^2 > 20$ GeV^2

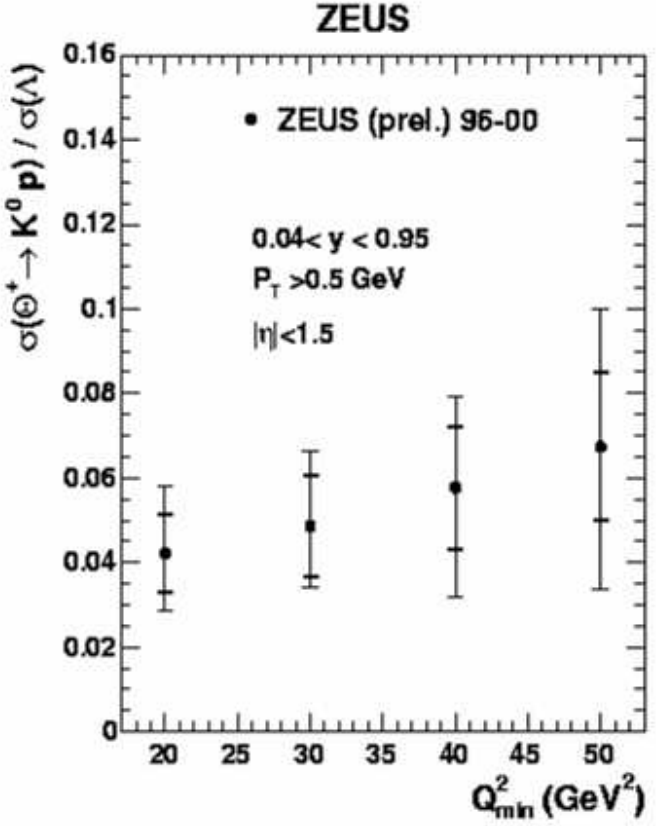
- $M : 1521.5 \pm 1.5(\text{stat})^{+2.8}_{-1.7}(\text{syst})$
- Gaussian W: 6.1 ± 1.5 MeV
  BW Fit: $\Gamma = 8 \pm 4$ MeV
  $\Rightarrow$ compatible w/ experimental resolution ~ 2 MeV
- Fit: 3P Background + 2 Gaussians $\Rightarrow \sim 4.6\,\sigma$
- $\chi^2/\text{ndf} = 35/44$
- single Gaussian fit $\Rightarrow$ worse χ^2/ndf, peak robust
- if $K^0_S p$ interpreted as Θ^+ then $K^0_S \bar{p} \Rightarrow \bar{\Theta}^-$(antipentaquark)?



Θ^+ Cross sections and ratios ($\Theta^+ \to K^0 p$ / $\Lambda \to p\pi$)

$Q^2 > 20\ \mathrm{GeV}^2, \quad P_T > 0.5\ \mathrm{GeV}, \quad |\eta| < 1.5$



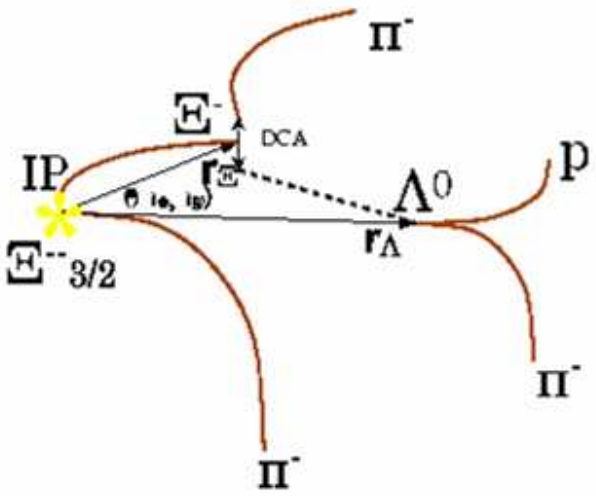


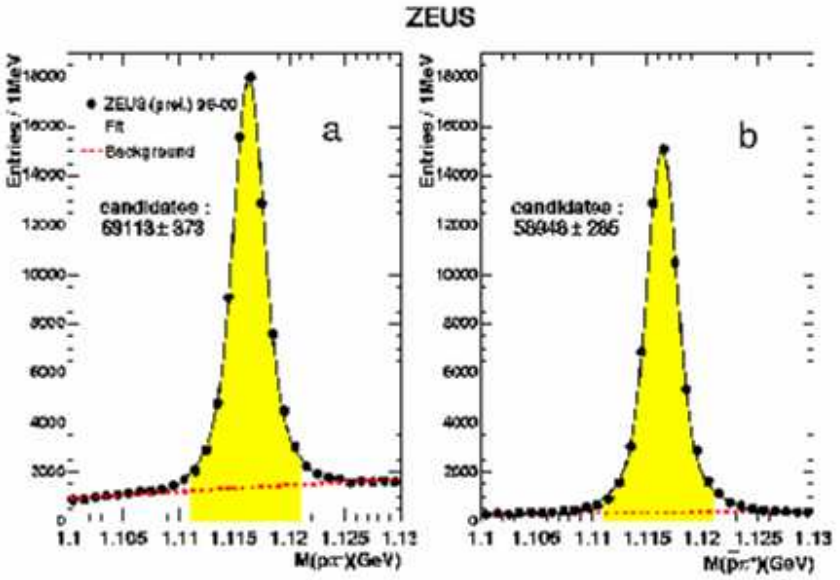
- $\sigma(ep \to e\Theta^+ X)$: $125 \pm 27(st)^{+45}_{-40}(sy)$ pb
- $N(\Theta^+ \to K^0 p(\bar{p}))$ / $N(\Lambda(p\pi))$ as function of Q^2_{min}:
  $4.2 \pm 0.9(st)^{+1.2}_{-0.9}(sy)\%$ ⇒ production rate consistent w/ a constant

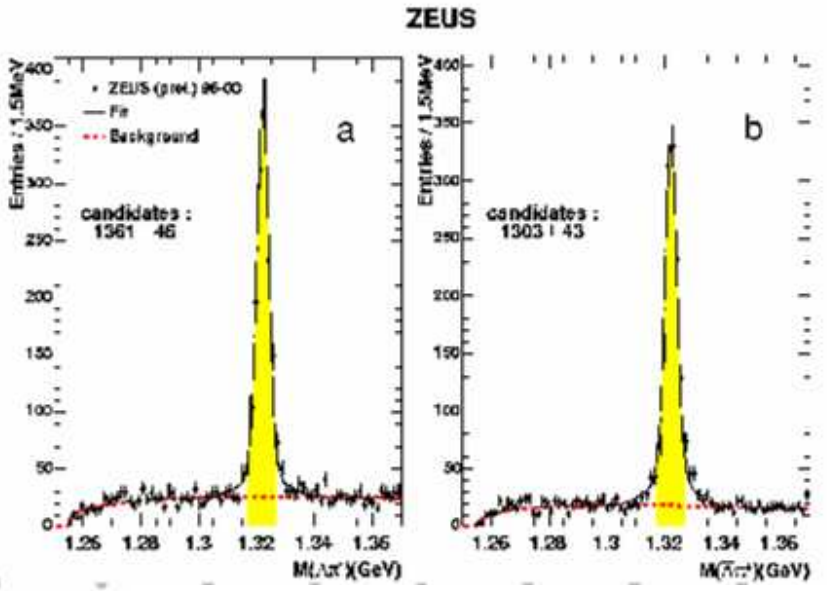
Search for NA49 signal with ZEUS: I

NA49 analysis repeated

- $\Xi^{--} \rightarrow \Xi^{-}\pi^{-} \rightarrow \Lambda^{0}\pi^{-}\ \pi^{-} \rightarrow p\pi^{-}\pi^{-}\pi^{-}$
- Inclusive DIS event sample: $96-00$ data $\Rightarrow 105\ \mathrm{pb}^{-1}$
- high stats, small bground







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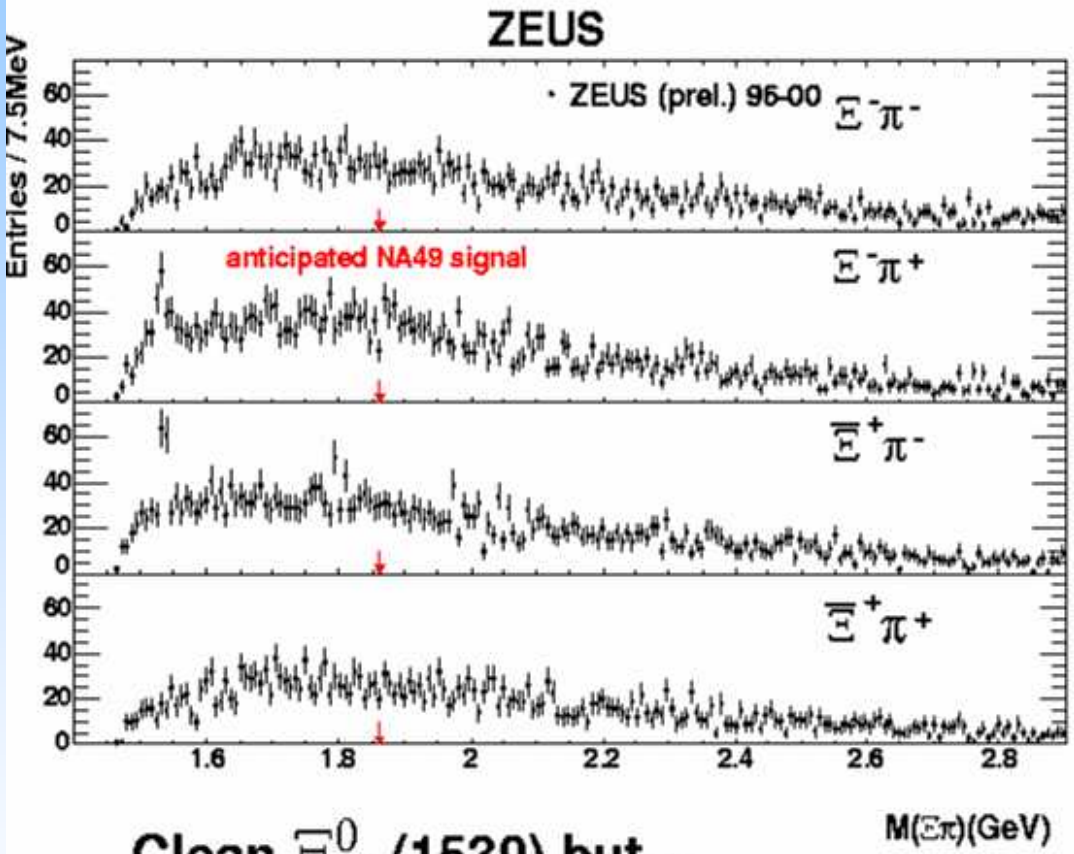
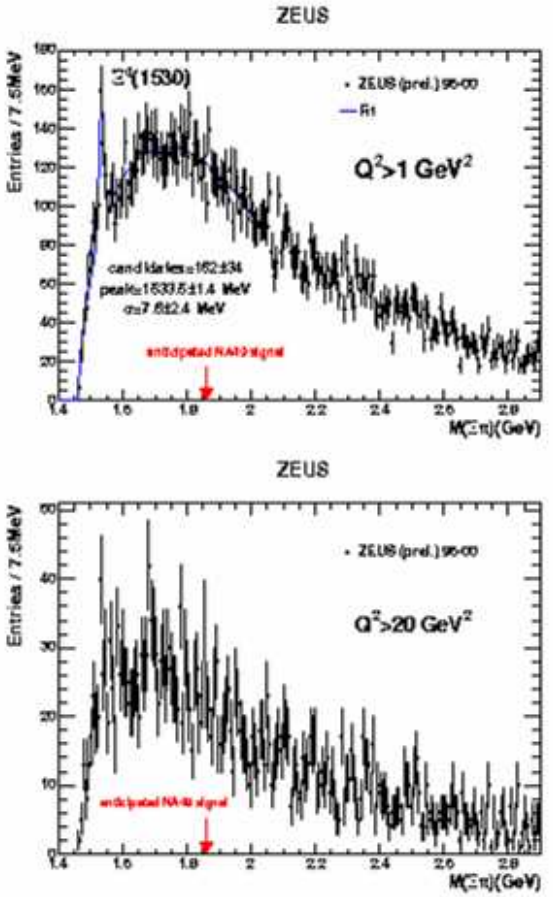
Search for NA49 signal with ZEUS: II



Clean $\Xi^0_{3/2}(1530)$ but...

NO pentaquark signal

(produced in forward region?)



Four channels combined

In Summary ...

$\Theta^+(1522) \Rightarrow$ peak seen in $M(K^0_S p)$ and $M(K^0_S \bar{p})$

- For $Q^2 > 20\ \mathrm{GeV}^2$:

  $M : 1521.5 \pm 1.5(\mathrm{stat})^{+2.8}_{-1.7}(\mathrm{syst})$

  natural width compatible with detector resolution

  $\Longrightarrow$ consistent with strange pentaquark

- $\Theta^+(\rightarrow K^0 p)\ /\ \Lambda(\rightarrow p\pi) \Longrightarrow \sim 4\%$

  production rate consistent with a constant ...

- $K^0_S \bar{p}$: first evidence of antipentaquark? $\Rightarrow$ fragmentation

$\Xi^{--}(1860) \Rightarrow$ No Signal

- not confirmed by ZEUS

$\Theta_c(3099) \Rightarrow$ No Signal

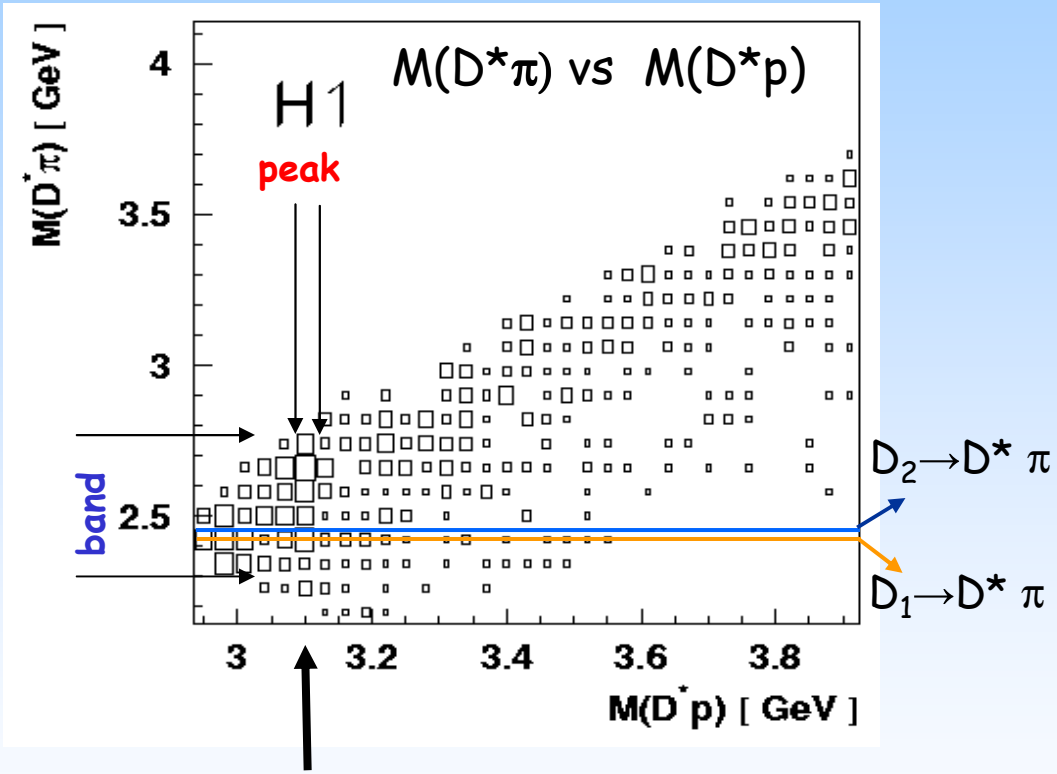
- more than 62,000 reconstructed D^*'s
- ZEUS data are incompatible with H1 report of

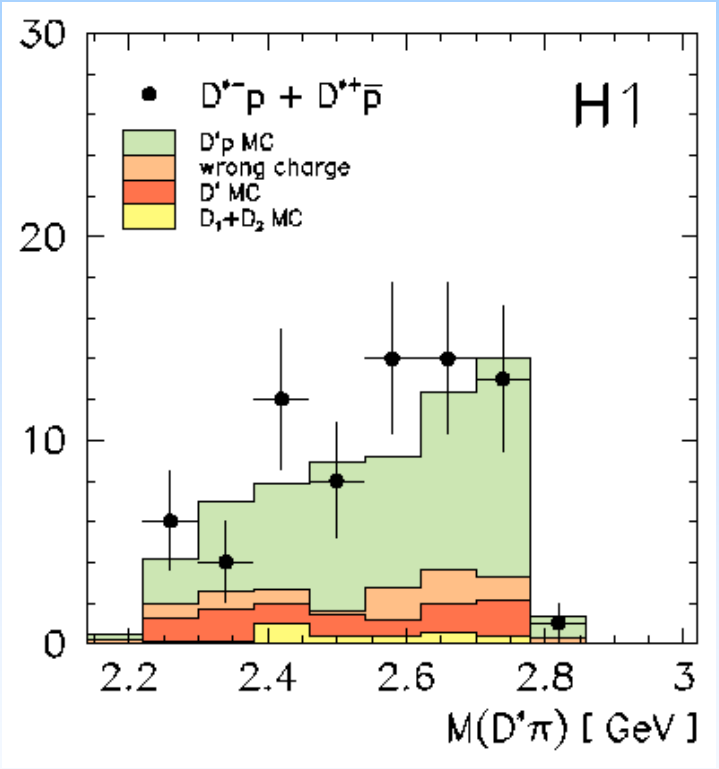
  Θ_c contributing 1% of D^* production ratio

Spare slides

Example of a kinematic test: possible D*π reflection ?

Assign pion mass hypotheses to the proton candidate





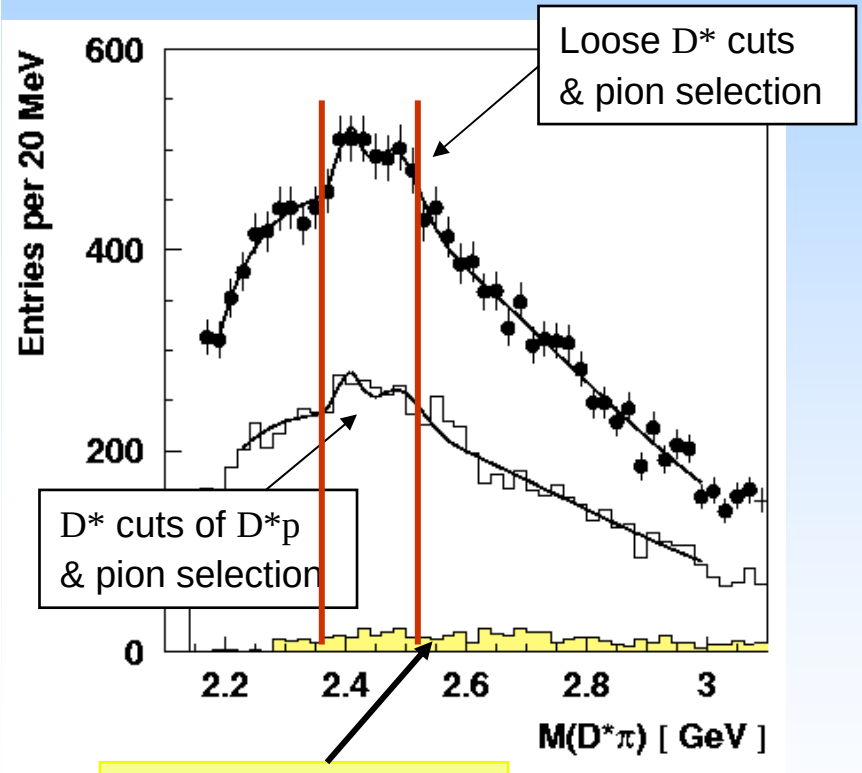
Look into D*π invariant mass distribution in D*p signal region

Pion hypothesis excluded !

Example of a kinematic test: possible D*π reflection ?

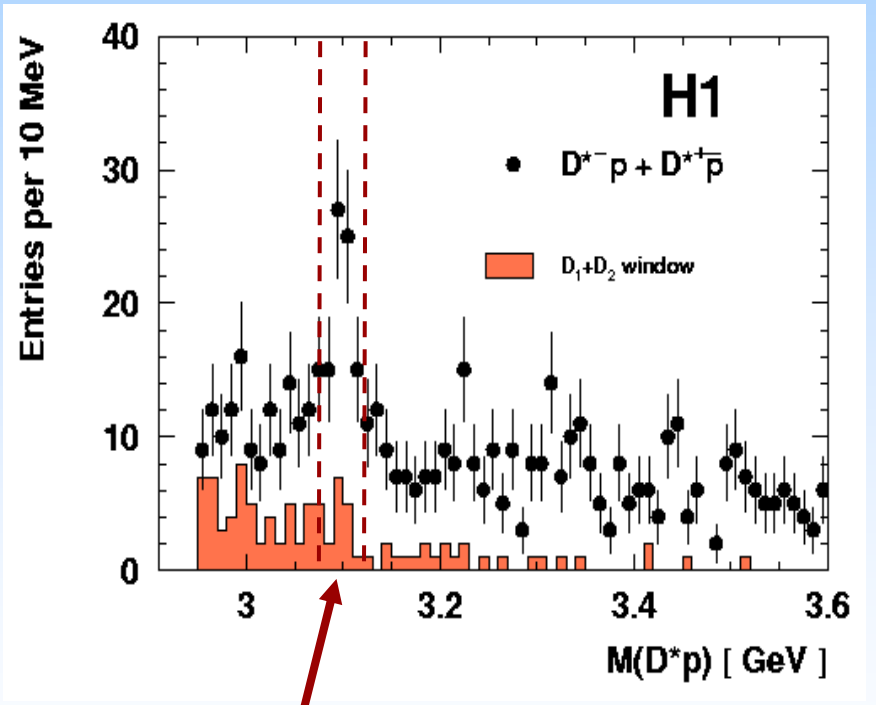
Reflection: assigning pion a proton mass shifts M(D*π) towards higher values

Does it happen in our case?



D* cuts of D*p
& proton selection
(consistent with MC)

D*p mass spectrum



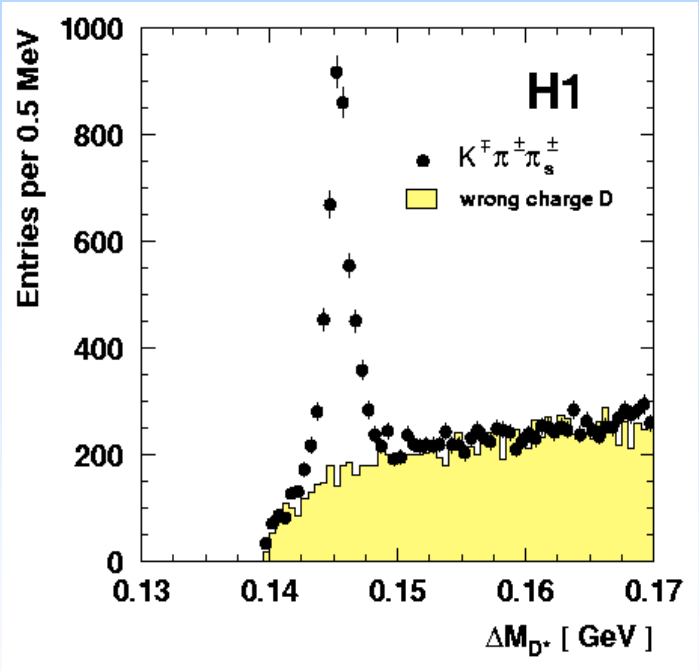
Expected only 3.5 events from data

→ The signal can not be a reflection !

D* in DIS and Photoproduction

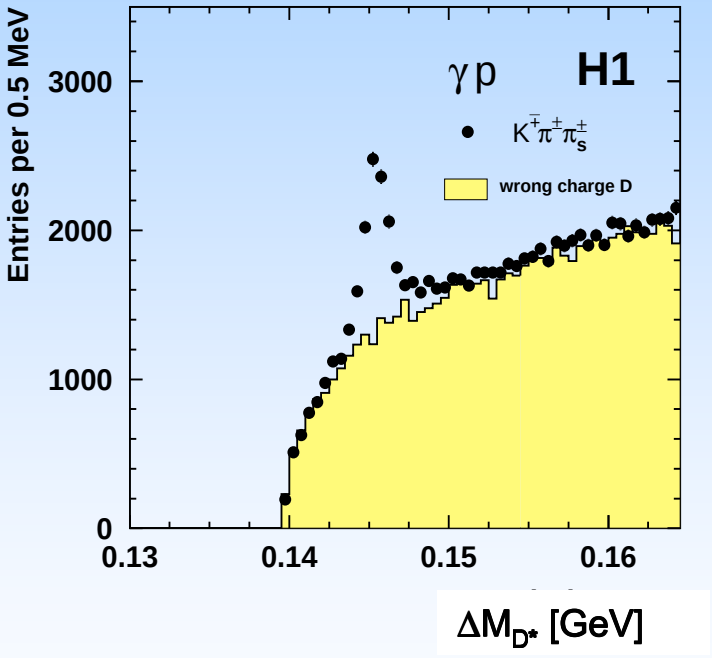
Deep Inelastic Scattering (DIS):

- scattered electron in SpaCal
- $2 < Q^2 < 100\ GeV^2$, $0.05 < y < 0.7$



Photoproduction (γp):

- electron escapes the main detector
- $Q^2 < 1\ GeV^2$



"wrong charge D" : fake D^0 ($K^+\ \pi^+$/ $K^-\ \pi^-$) + π_s : non-charm induced background

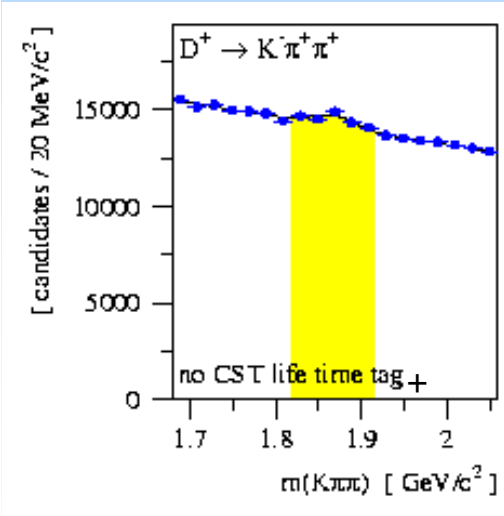
Non-charm induced background much higher in the case of Photoproduction

D*+ vs D+ in H1 detector

D pseudoscalar meson

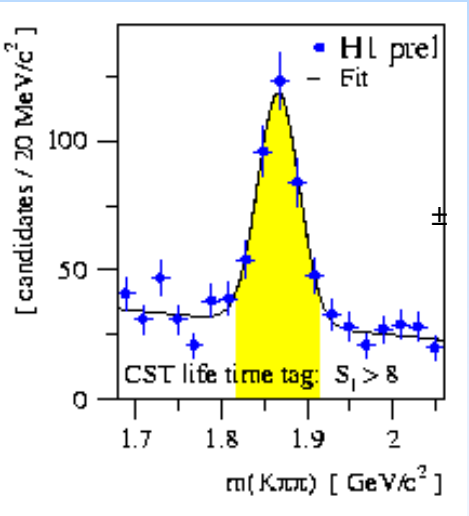
fragmentation: $f(c \to D^{+}) = 0.248 \pm 0.014$

without



too high background

with lifetime tag

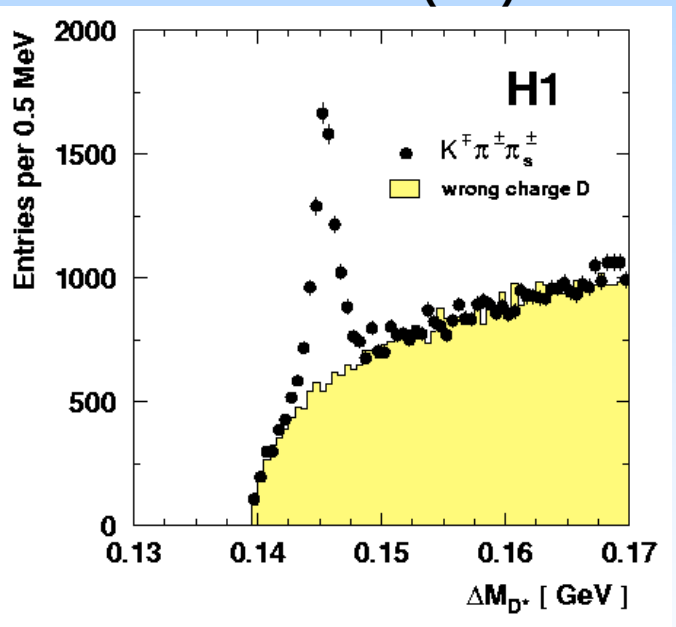


too low statistics

D* vector meson

$f(c \to D^{*+}) = 0.233 \pm 0.009$

$D^* \to D^0\pi \to (K\pi)\pi$



Mass difference technique $\Delta M(D^{*\pm}) = m(K^{\mp}\pi^{\pm}\pi) - m(K^{\mp}\pi^{\pm})$

→ D* is more feasible for charmed PQ search !

Summary of additional investigations

- **Events are scanned:** no anomalies found
- **Acceptance effects:** looks OK
- **Reflections from D_1, D_2, $D^{**} \rightarrow D^* \pi$ (expect 3.5 events in D*p signal):** no!
- **Mass correlations among the particles making the D* and the D*p system**
  - search for real or fake peak structures, e.g Λ, Δ … no enhancement
- **All possible mass hypotheses applied to the particles making D*p system**
  - search for real or fake peak structures, e.g K_s, ϕ, f_2 … no enhancement
- **mass correlations among the proton candidate and the remaining charged particles of the event with possible mass assignments have been looked at**
  - search for real or fake peak structures, e.g K_s, ϕ, Δ … no enhancement

All tests we could think of are passed !

Summary of additional investigations

H1 observation in $ep \rightarrow c\bar{c}\,X$

$R(\Theta_c \rightarrow D^*p/D^*) = 1.46 \pm 0.32\ \%$ (uncorrected) **prelim.**

Negative results for θ_c from:

ALEPH	$e^+e^- \rightarrow Z^0 \rightarrow c\bar{c}$
FOCUS	$\gamma N \rightarrow c\bar{c}\,X$
CDF	$p\bar{p} \rightarrow c\bar{c}\,X$
BELLE	$e^+e^- \rightarrow \Upsilon(4s) \rightarrow B^0\bar{B}^0$

Not contradicting H1

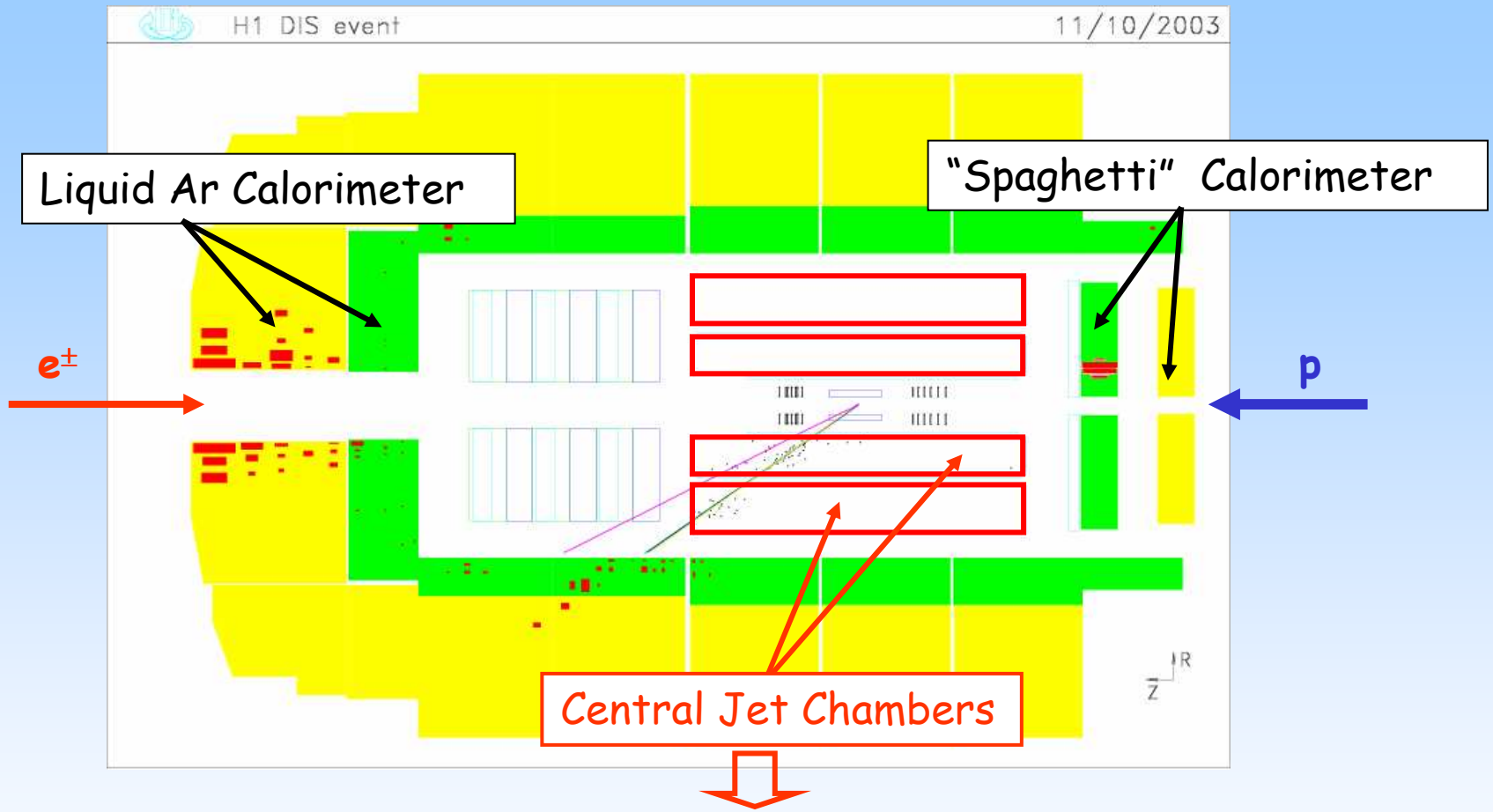
$B(B^0 \rightarrow \Theta_c p\pi) \times B(\Theta_c \rightarrow D^*p) / B(\Theta_c \rightarrow D^*pp\pi) < 11\%$ @ 90% C.L.

ZEUS $ep \rightarrow c\bar{c}\,X$ ⟵

Different physics processes investigated

Physics seen by ZEUS should be directly comparable to H1

H1 experiment at HERA accelerator



- drift chambers, acceptance: $20^o < \theta < 160^o$
- simultaneous charge and timing information
- B = 1.15 T → measure transverse momentum of charged particles

→ **Tracking , Particle ID via dE/dx**