Evidence for a narrow anti-charmed baryon state

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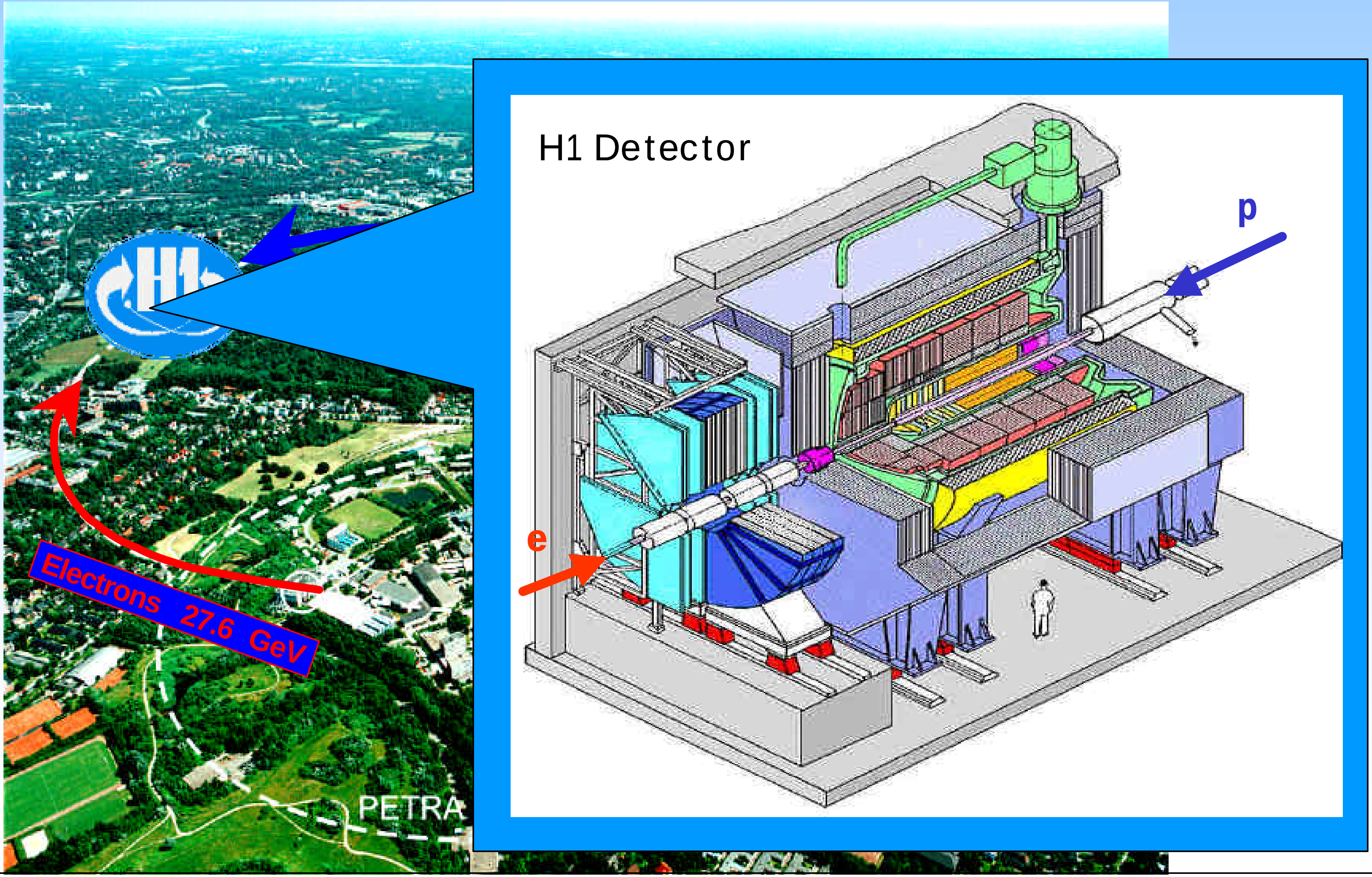
for

Collaboration

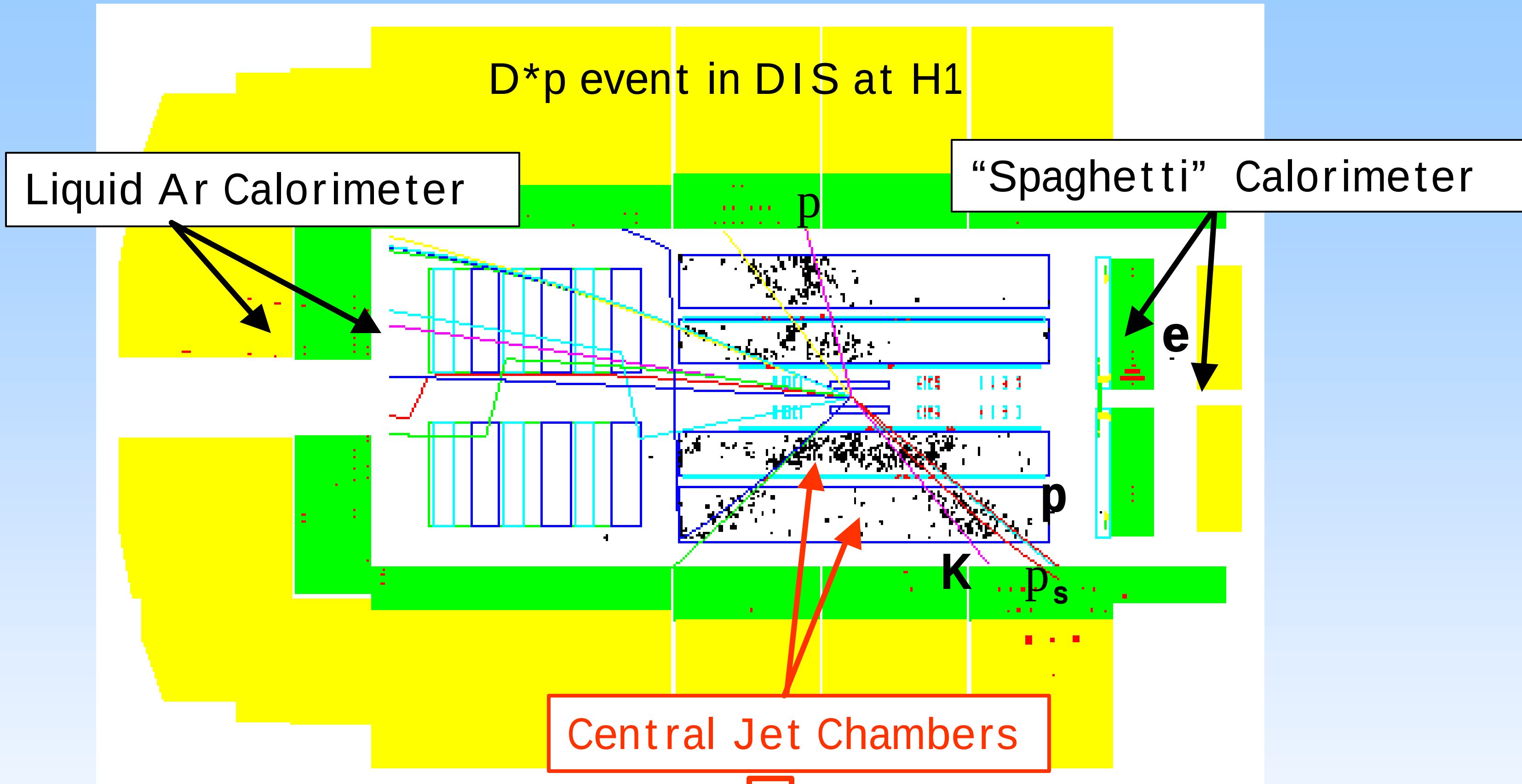
Exotic Hadrons 2005 Trento

H1 experiment at HERA accelerator

HERA storage ring at DESY (Hamburg, Germany)



H1 experiment at HERA accelerator



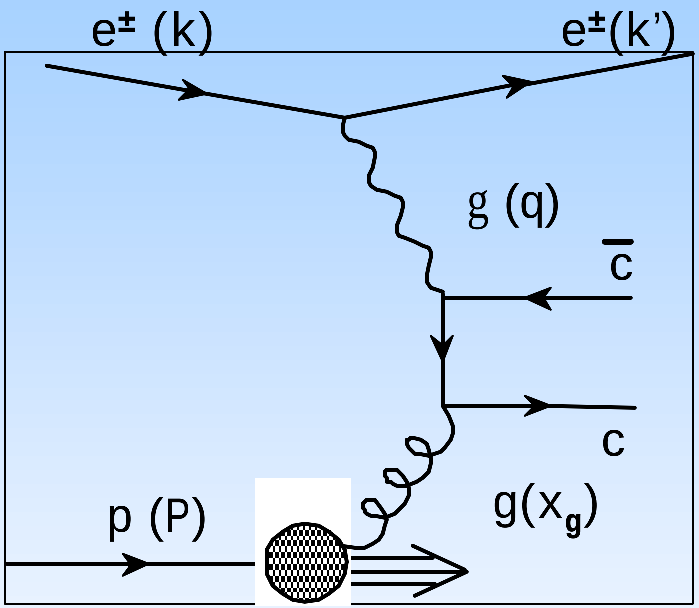
- drift chambers, acceptance: 20° < ? < 160°
- simultaneous charge and timing information
- B = 1.15 T ? measure transverse momentum of charged particles

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

Heavy flavour production at HERA

e± 27.5 GeV → ← p 920 GeV

Dominated by Boson – Gluon Fusion (BGF) in LO: g g ? cc (bb)



_ep_ kinematics: vs = 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, gp (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 Q^+ in K^+n and $K^0_s\,p$

Why not a charmed pentaquark ?

If Q+ formation is due to fragmentation process

→ **Features of Q_c similar to those of Q^+**

Look for charm pentaquark state via it's decay

Q_c ? charmed hadron + baryon

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

D* production at H1 is much more feasible experimentally

Selected channel: Q_c ® $D^{*-}p$ (+c.c.)

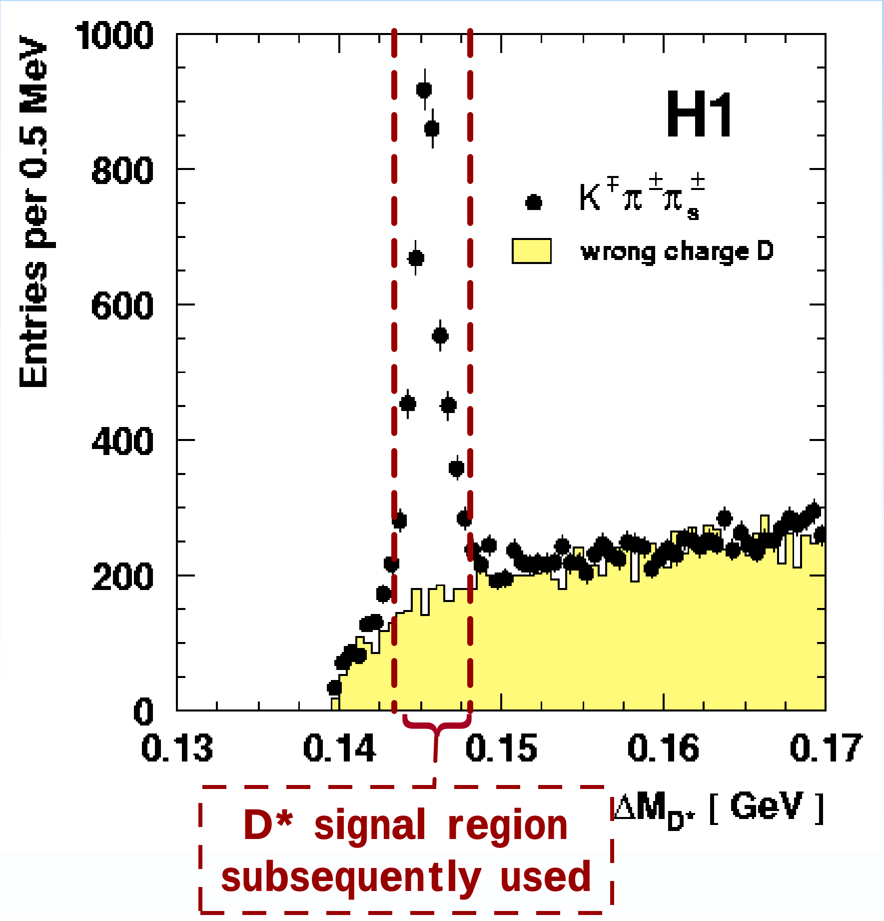
Charm pentaquark search at H1: D* Signal

- “golden ” channel: D^{*+}? D^0 p_s^+ ? K^- p^+ p_s^+ (+ c.c.)
- apply “mass difference method”: D M(D*) = M(K p p_s) – M (K p)
- 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

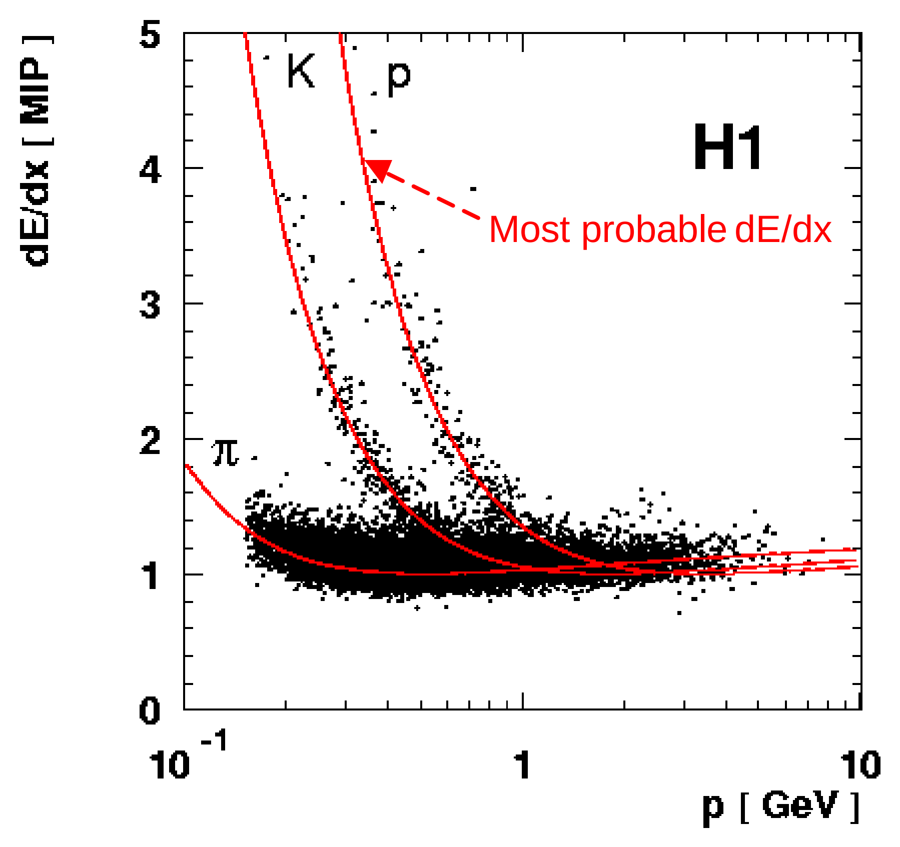
Non-charm induced background:

“wrong charge D” : fake D^0 (K^+ p^+/ K^- p^-) + p_s



Charm pentaquark search at H1: Proton selection

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



average dE/dx resolution (MIP) 8%

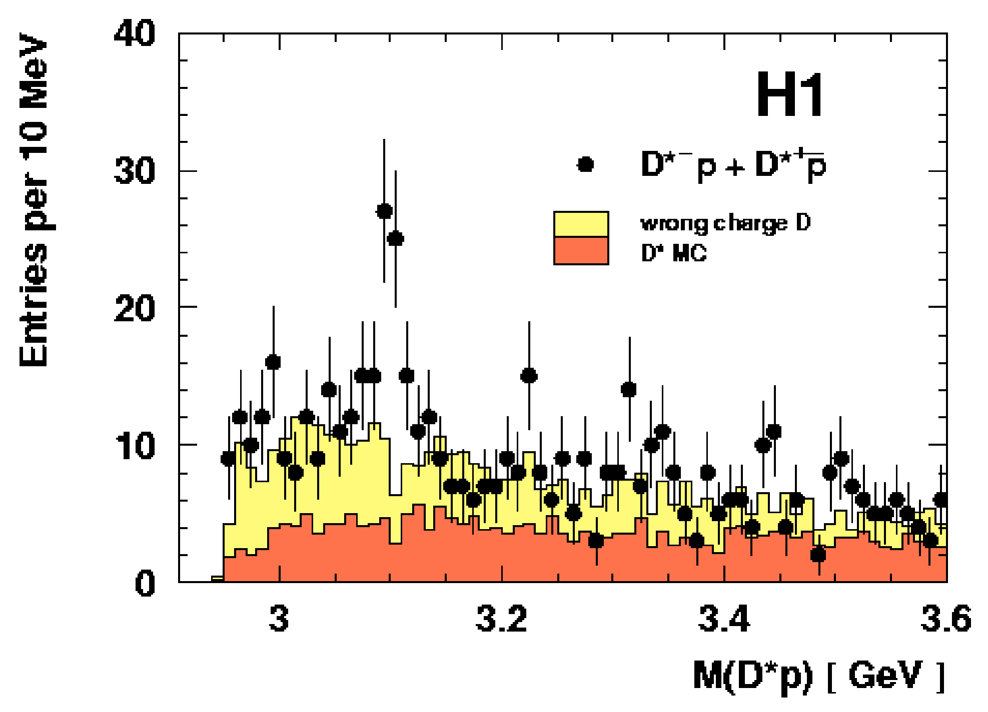
most probable dE/dx parameterized:

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



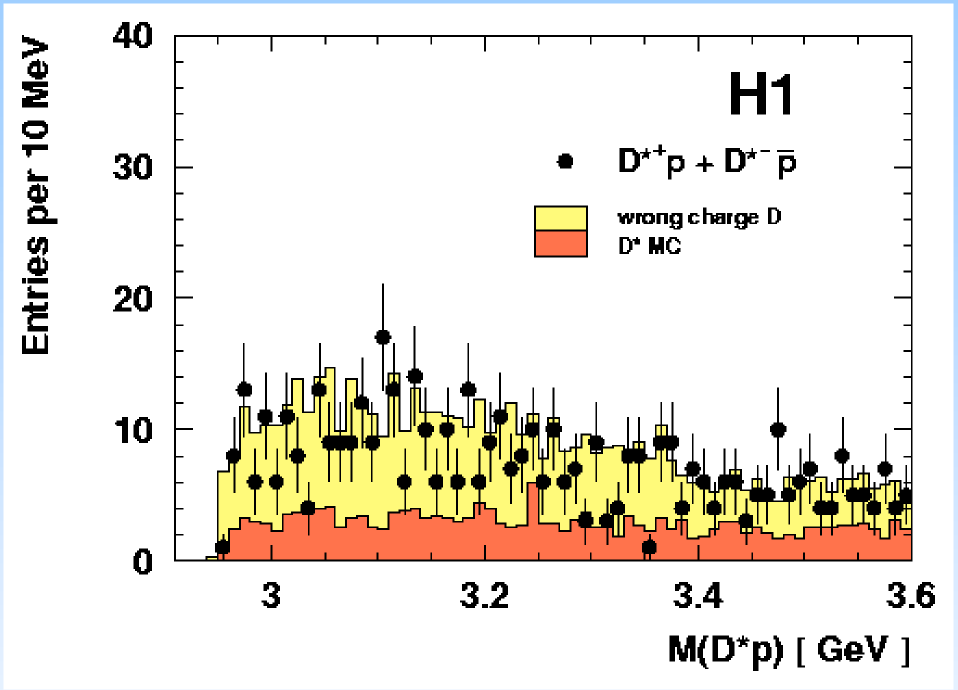
- significant peak in opposite charge D*p
- no enhancement in D* Monte Carlo
- no enhancement in wrong charge D

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

narrow resonance observed : M=3099± 3(stat.) ± 5 (syst.) MeV

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

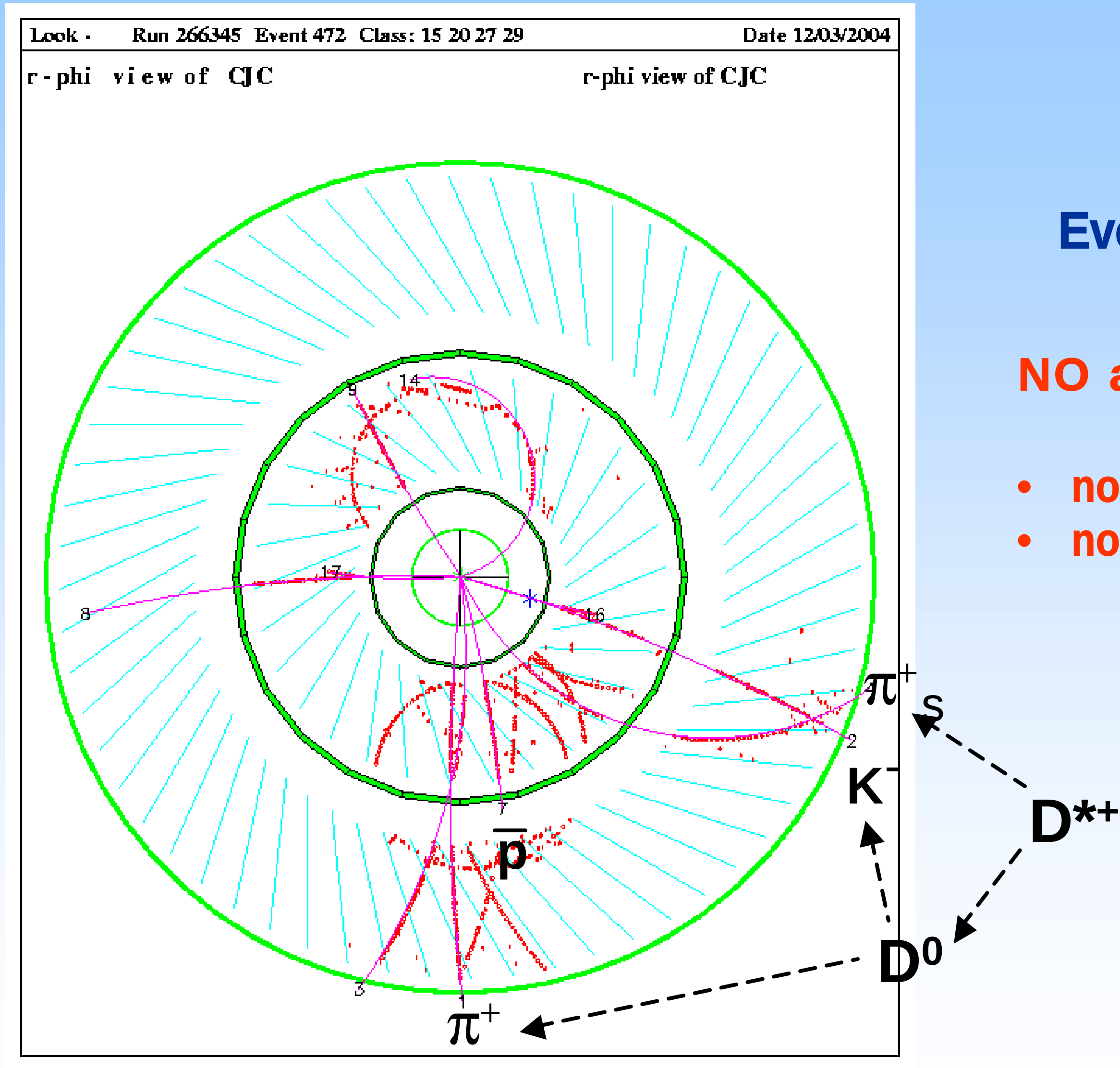
Invariant mass of the D*+p (D*- $\bar{p}$) system



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

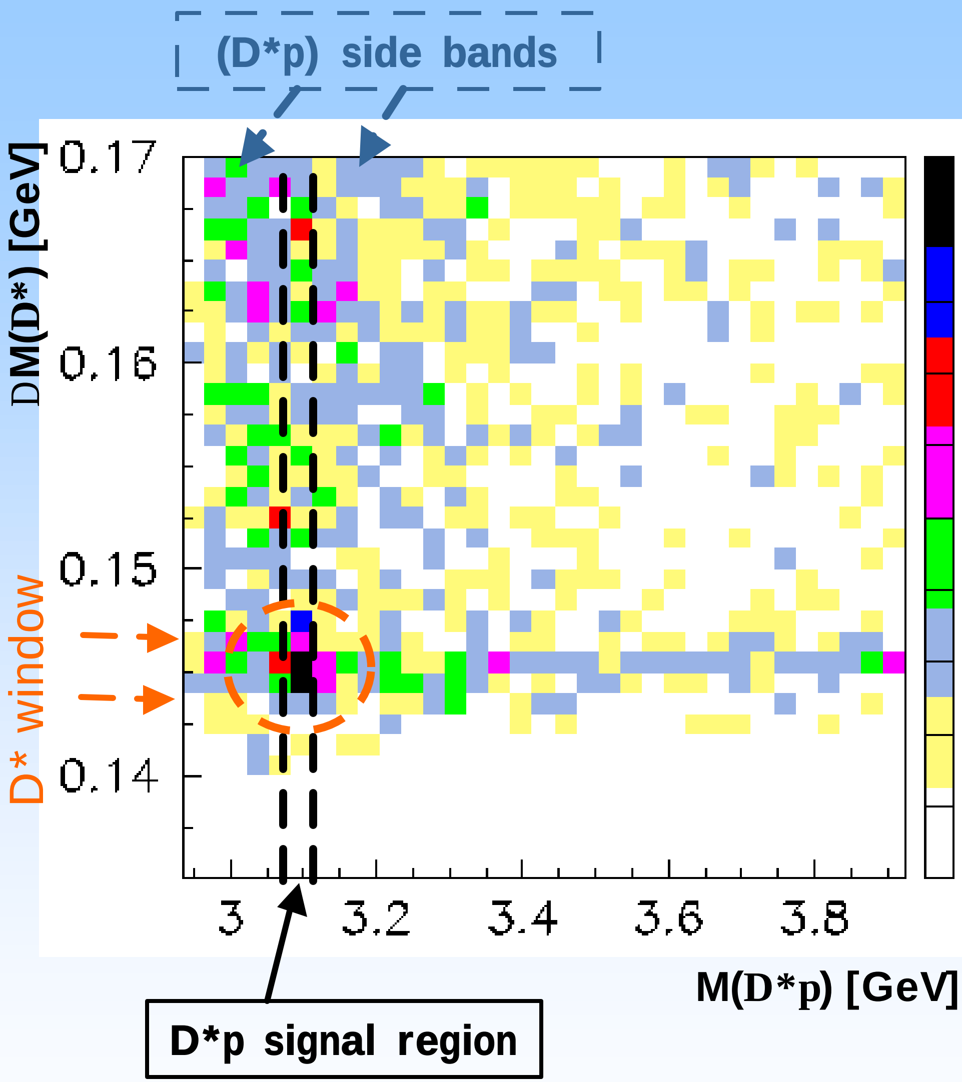


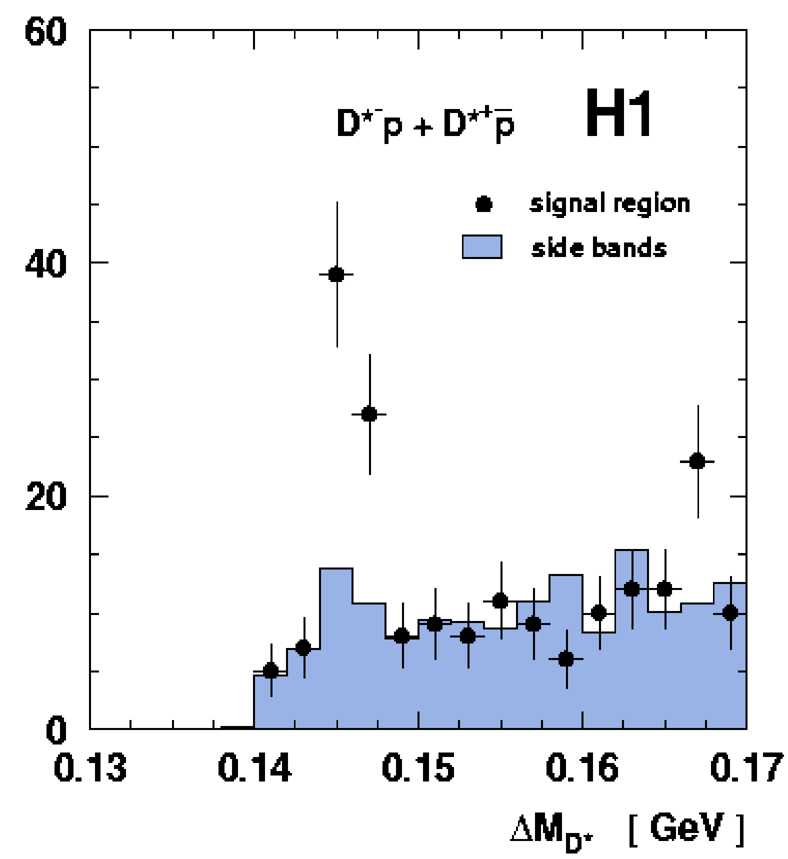
Events are scanned

NO anomalies observed:

- **no split tracks,**
- **no wrong reconstruction…**

Does the signal come from D* ?

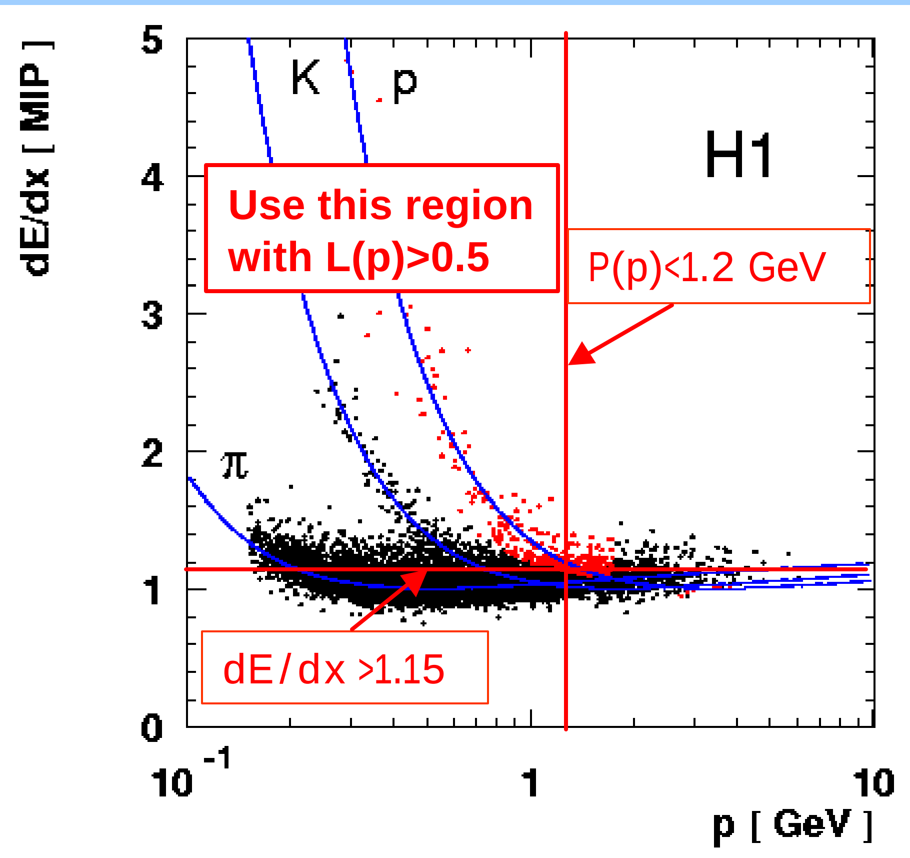


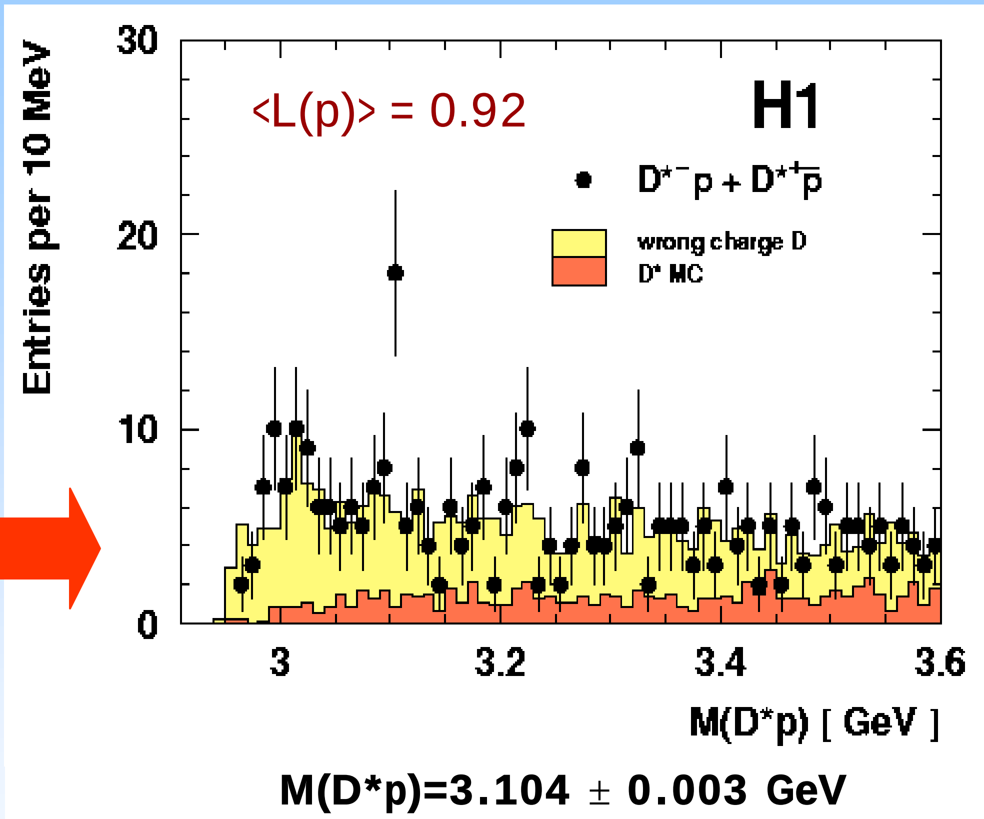


Normalization to the width of the windows in M(D*p)

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

Does the signal come from protons ?





Signal is there for well identified protons

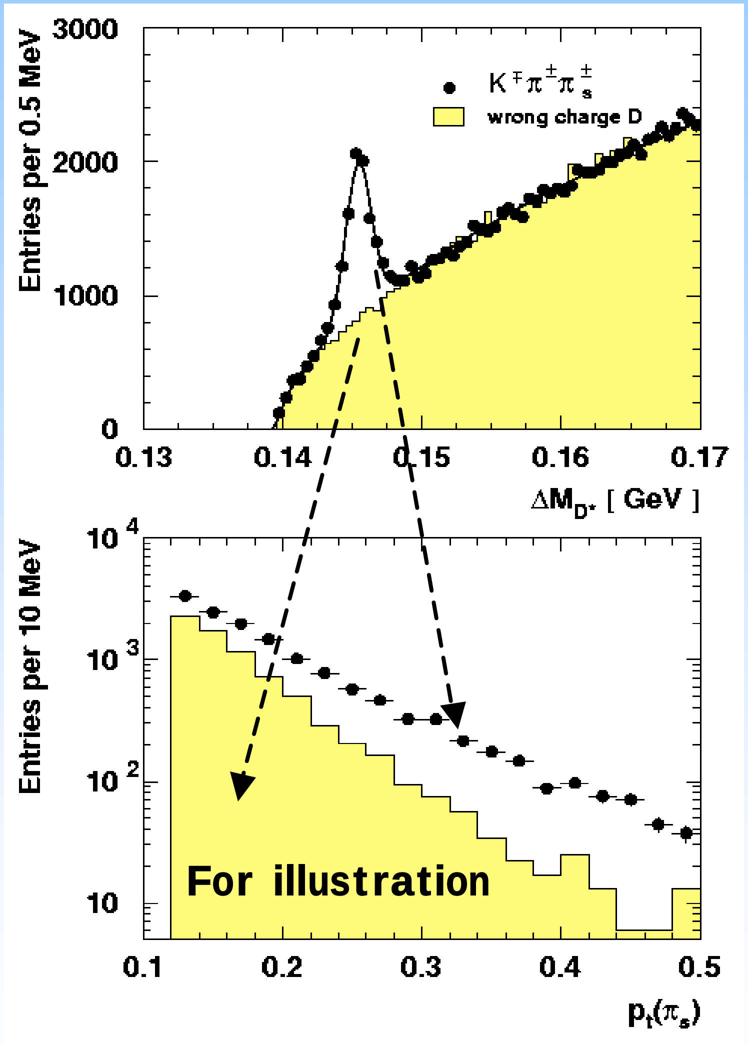
Does physics change on–resonance ?

• 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

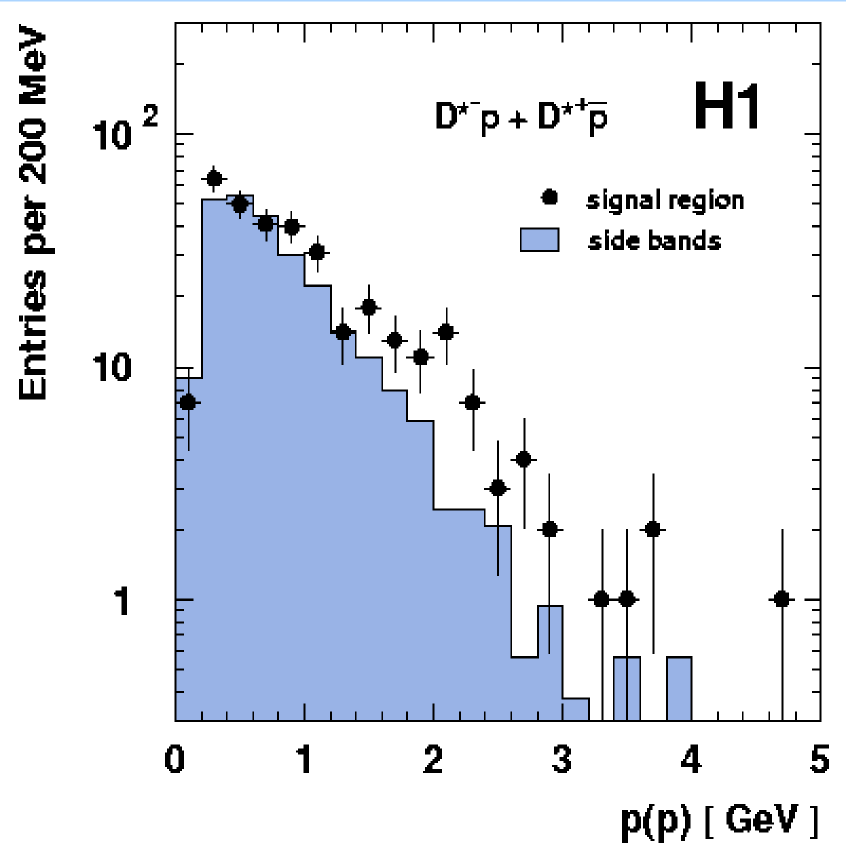
Example: momentum of p_s from D* harder than combinatorics :

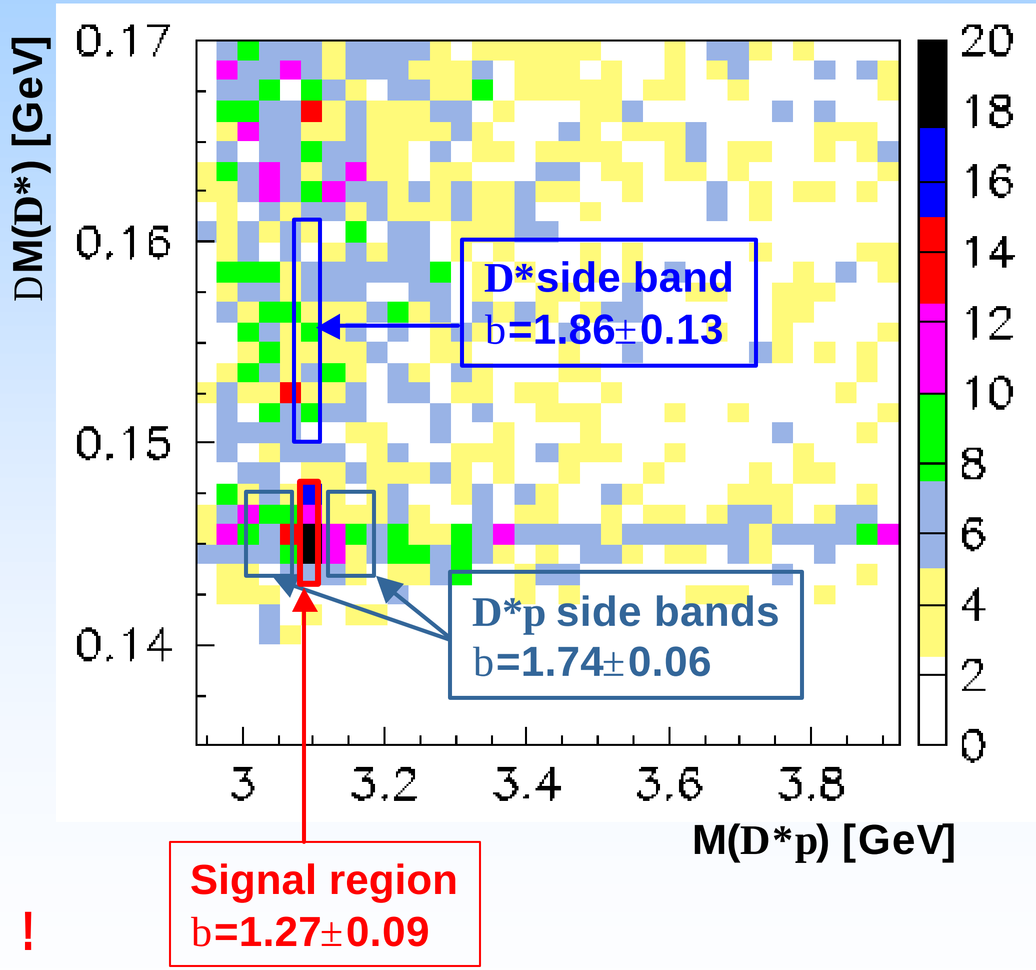


Does physics change on–resonance ?

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

momentum distribution in the signal region is harder than in sidebands



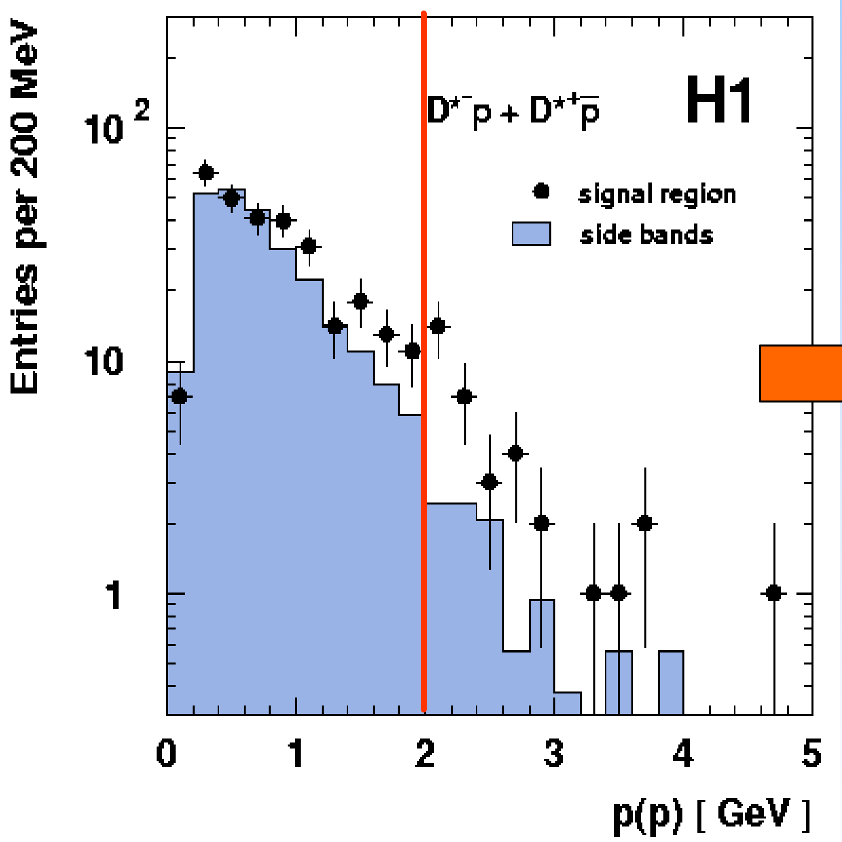


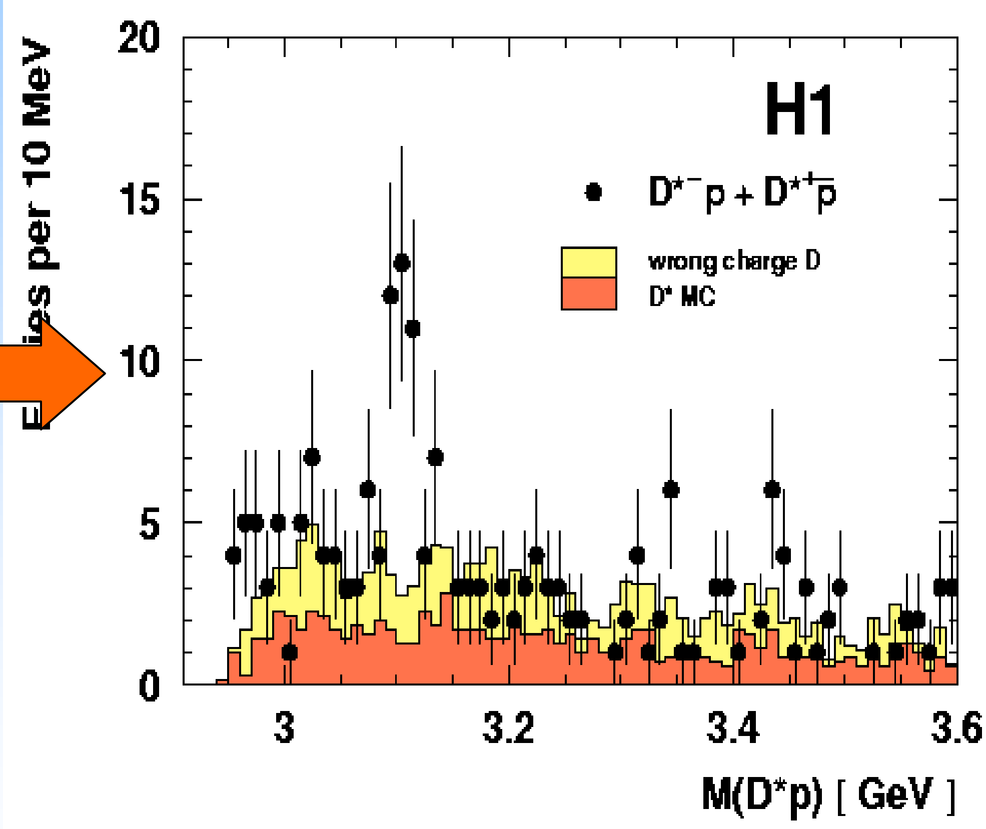
physics changes on-resonance !

Does physics change on–resonance ?

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

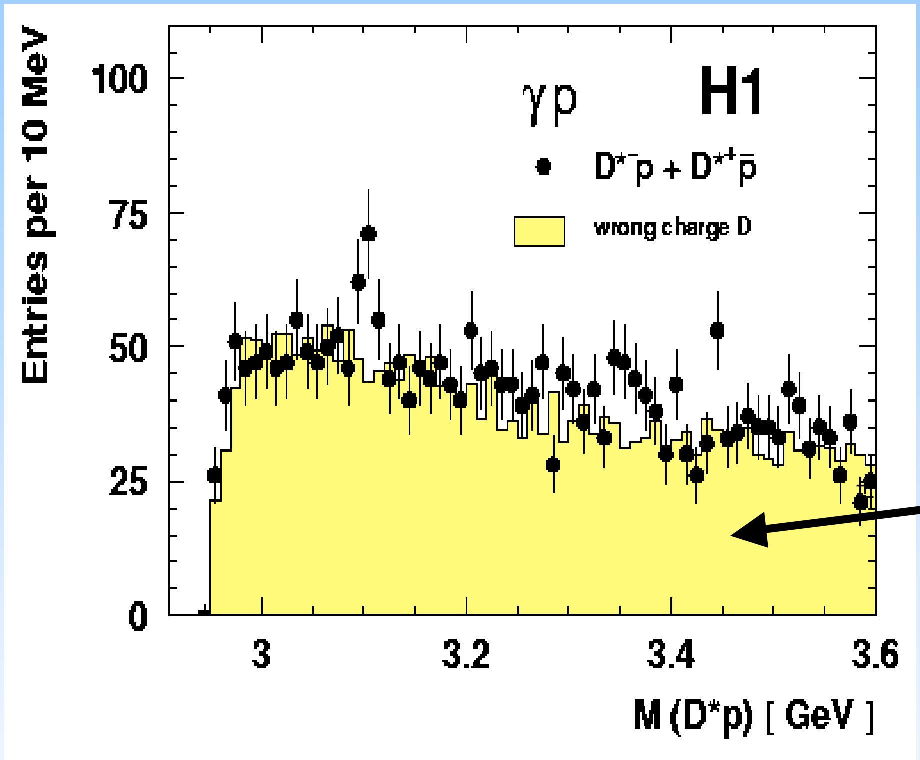
look into D*p combinations for p(p) > 2 GeV





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

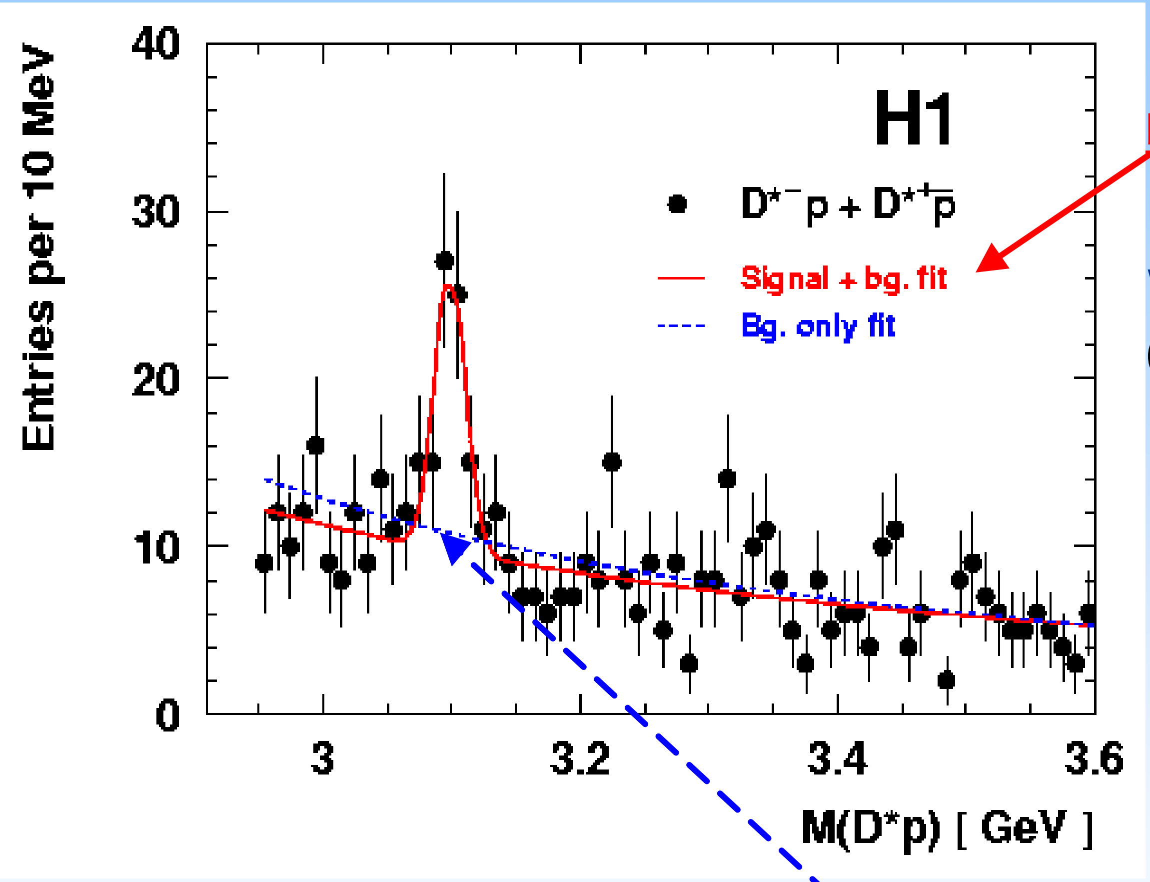
Background well described by wrong charge D from data

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 s (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

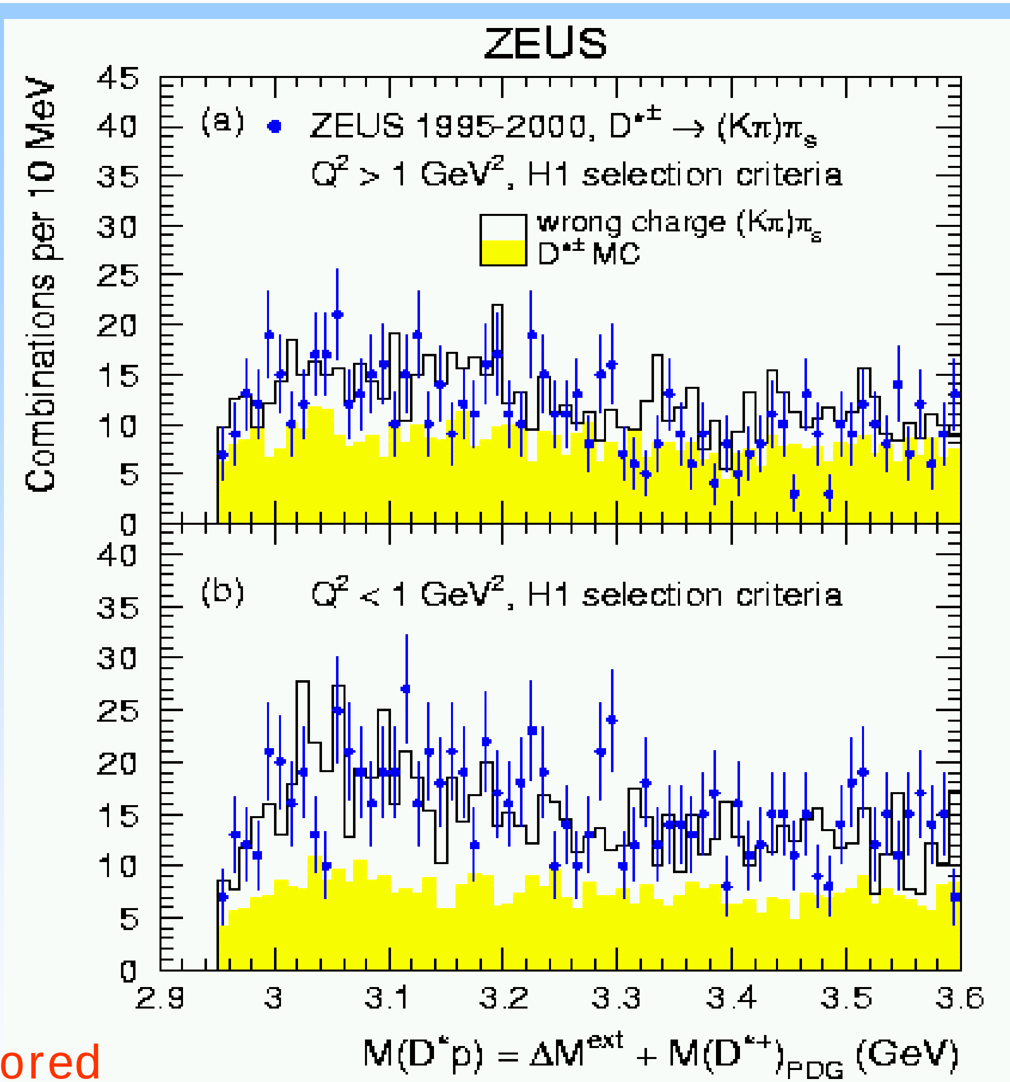
1995-2000 data, 127 pb^{-1}
selection of D*, p similar to H1

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
- Q_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

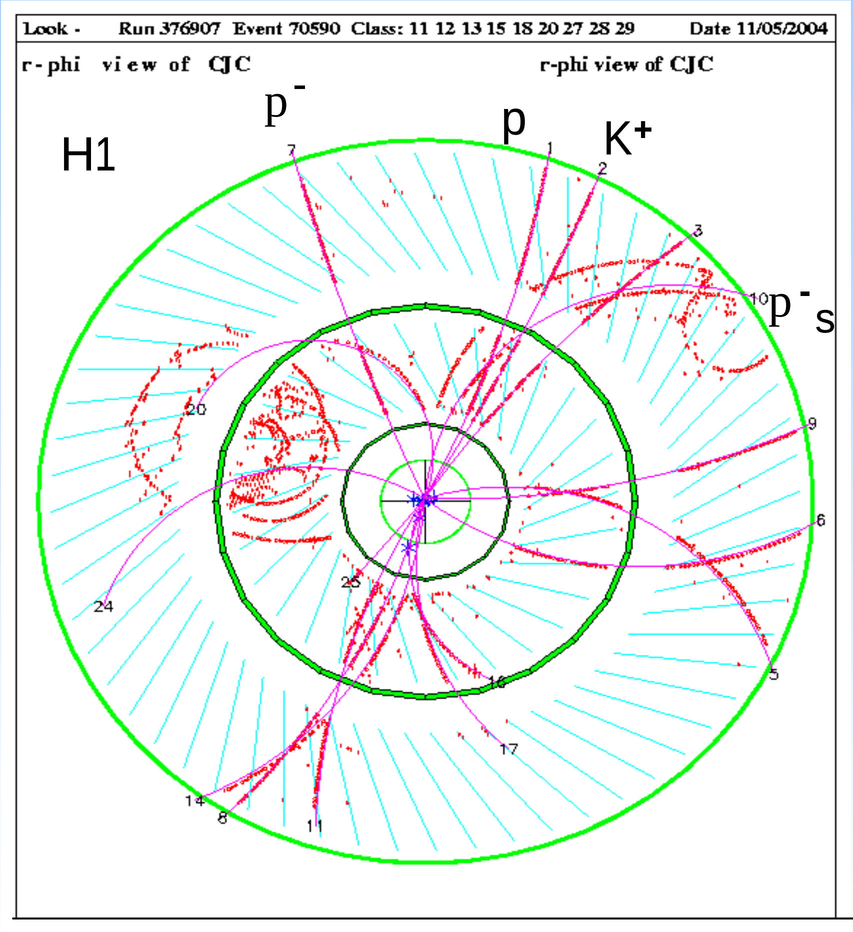
• no confirmation by ZEUS

→ **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 Q^+ at ZEUS

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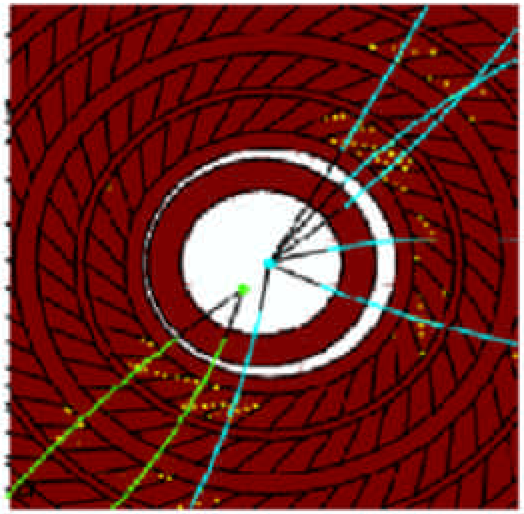
Collaboration

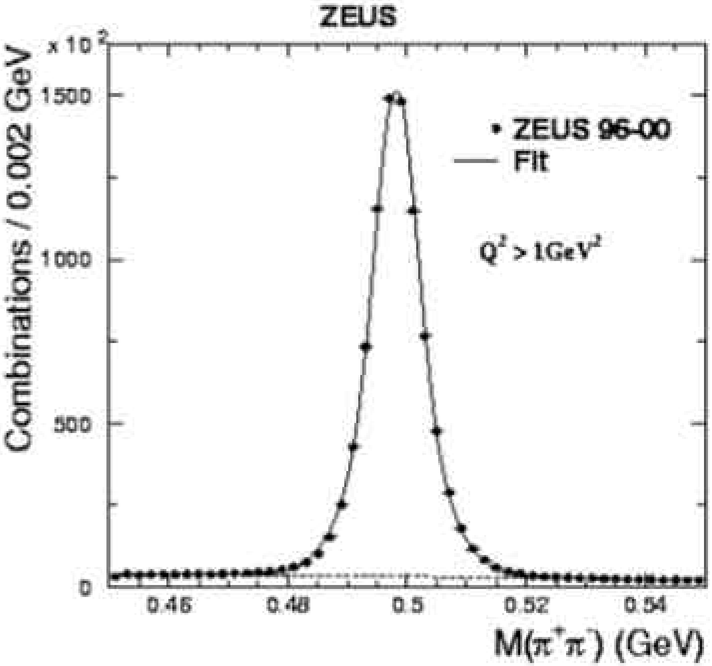
Exotic Hadrons 2005 Trento

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

R-ϕ

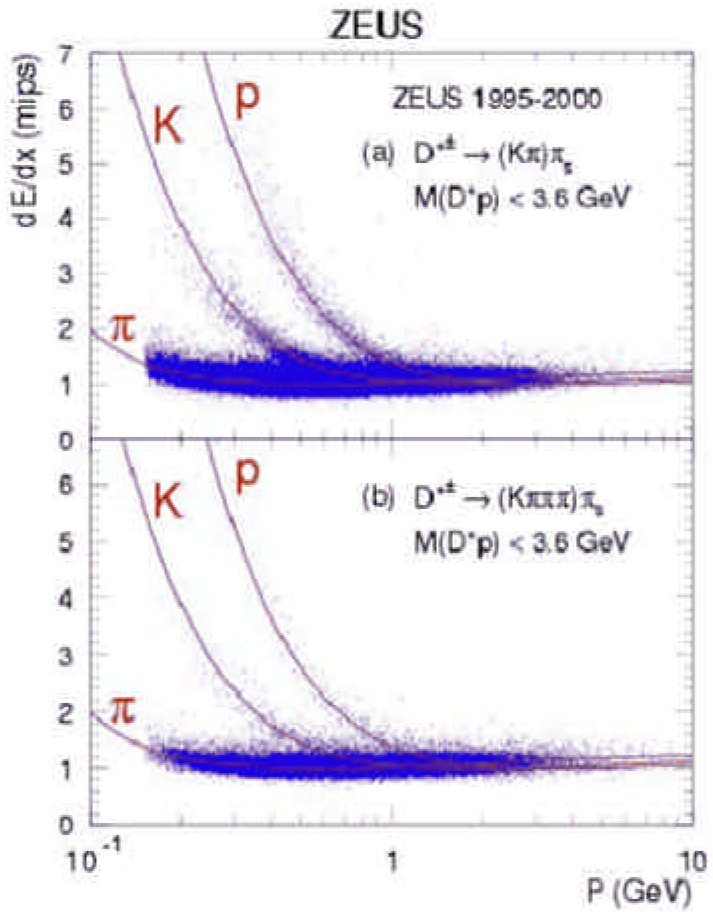




- Peak: 498.12 ± 0.01 MeV
- Background: $< 6\%$
- Candidates: $\sim 870{,}000$
- Resolution: $2 \pm .5$ MeV (MC + consistent w/ K* measurement)

Proton Identification

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

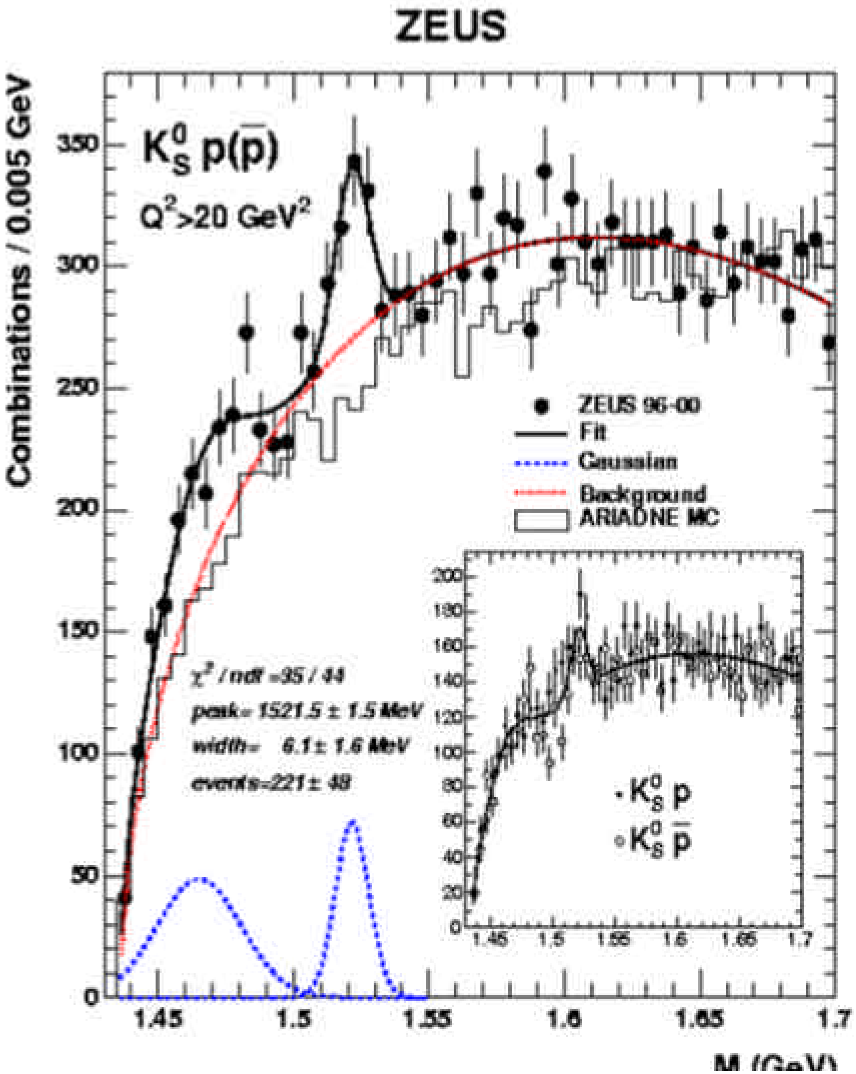


- expectations tuned using tagged protons and pions from Λ and K^0_S decays
- Strange pentaquark
  $\mathrm{dE/dx} > 1.15$ mips
  $P(p) < 1.5$ GeV
  $\sim 60\%$ proton purity
- Charmed pentaquark
  $l_p > 0.15 \Rightarrow$
  $A(l_p > 0.15) = 85.0 \pm 0.1\%$

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

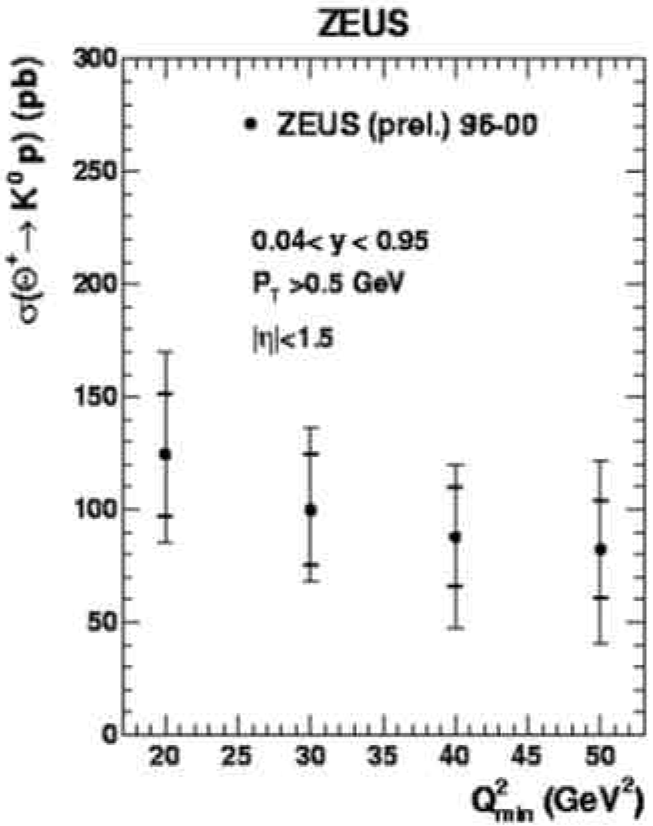
Θ^+ Signal $\Rightarrow p_T(\Theta^+) > 0.5$ GeV, $|\eta(\Theta^+)| < 1.5$, $Q^2 > 20\ \mathrm{GeV}^2$

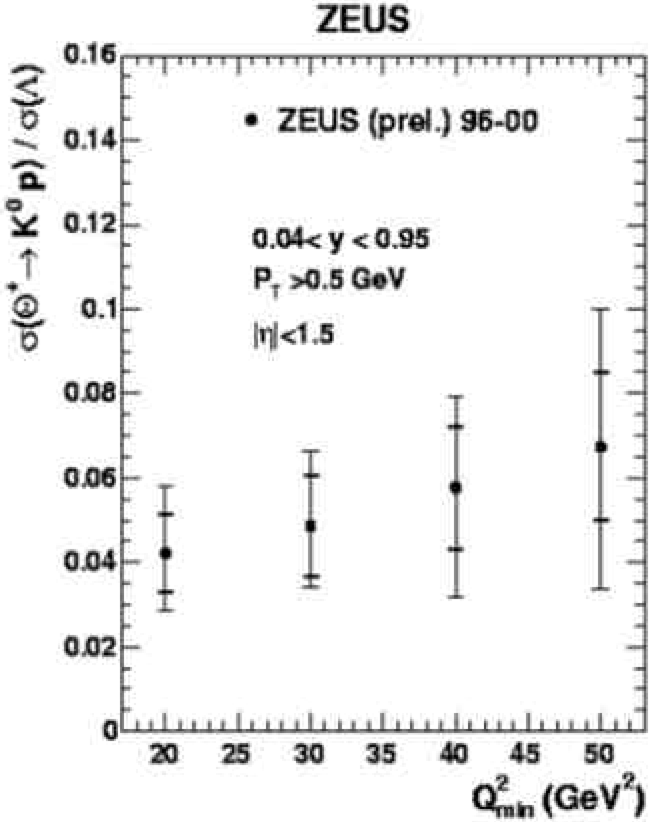
- $M: 1521.5 \pm 1.5(\mathrm{stat})^{+2.8}_{-1.7}(\mathrm{syst})$
- Gaussian W: 6.1 ± 1.5 MeV
  BW Fit: $\Gamma = 8 \pm 4$ MeV
  $\Rightarrow$ compatible w/ experimental resolution ~ 2 MeV
- Fit: 3P Background + 2 Gaussians $\Rightarrow \sim 4.6\ \sigma$
- $\chi^2/\mathrm{ndf} = 35/44$
- single Gaussian 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 ($\Theta^+ \to K^0 p$ / $\Lambda \to p\pi$)

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



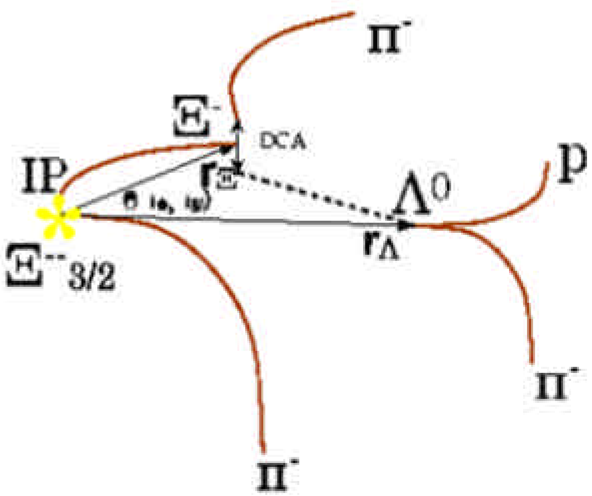


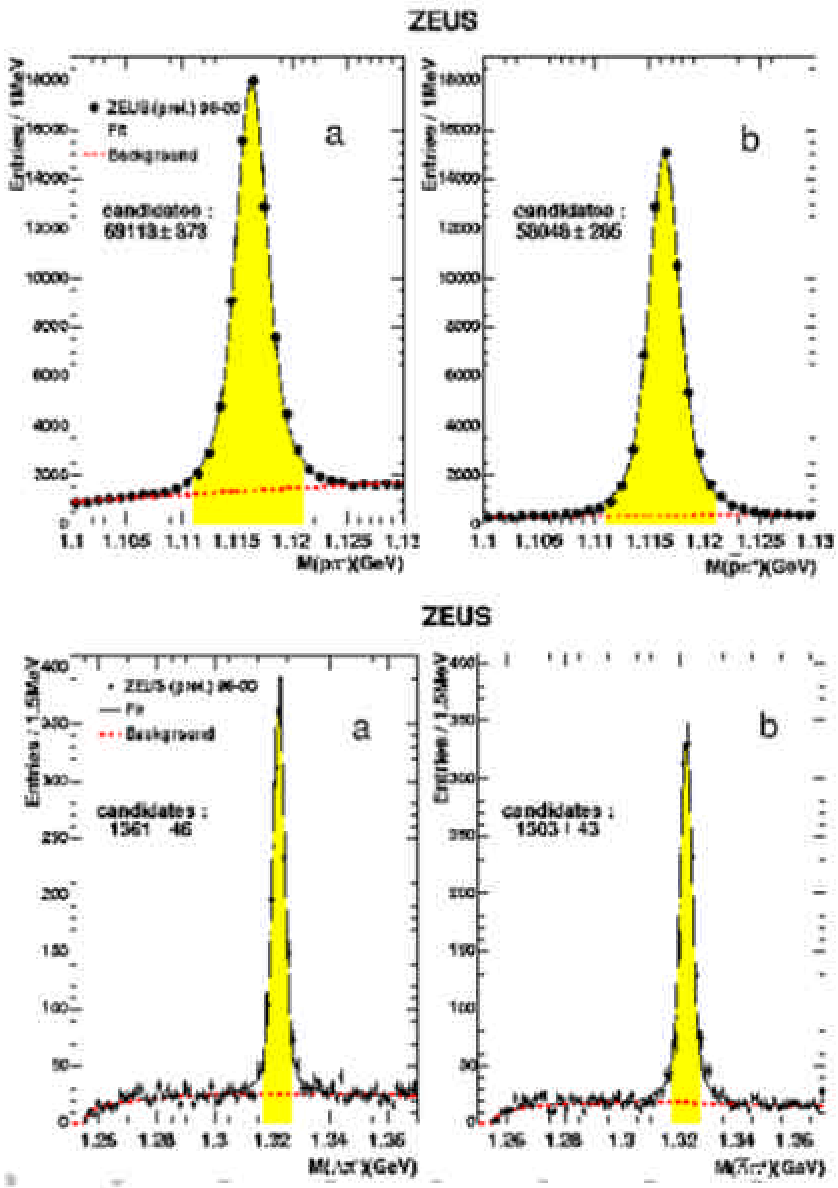
- $\sigma(ep \to e\Theta^+ X)$: $125 \pm 27(\mathrm{st})^{+45}_{-40}(\mathrm{sy})$ pb
- N($\Theta^+ \to K^0 p(\bar{p})$) / N($\Lambda(p\pi)$) as function of Q^2_{min}:
  $4.2 \pm 0.9(\mathrm{st})^{+1.2}_{-0.9}(\mathrm{sy})\%$ $\Rightarrow$ production rate consistent w/ a constant

Search for NA49 signal with ZEUS: I

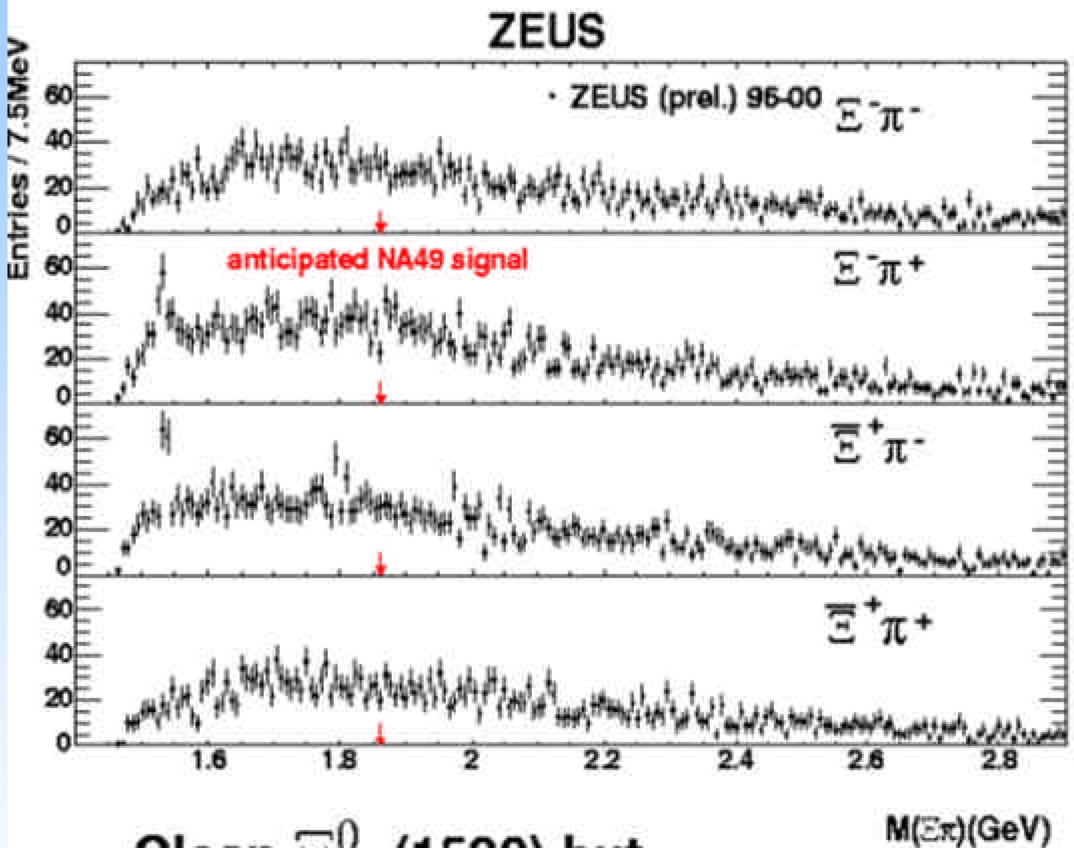
NA49 analysis repeated

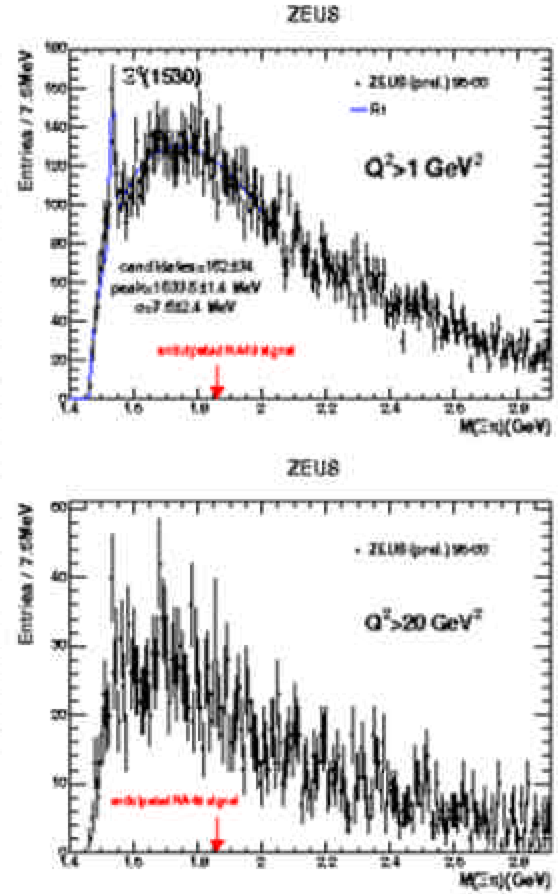
- $\Xi^{--} \rightarrow \Xi^-\pi^- \rightarrow \Lambda^0\pi^- \; \pi^- \rightarrow$ $p\pi^-\pi^-\pi^-$
- Inclusive DIS event sample: $96-00$ data $\Rightarrow 105 \text{ pb}^{-1}$
- high stats, small bground





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 $Q^2 > 20$ 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

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

  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

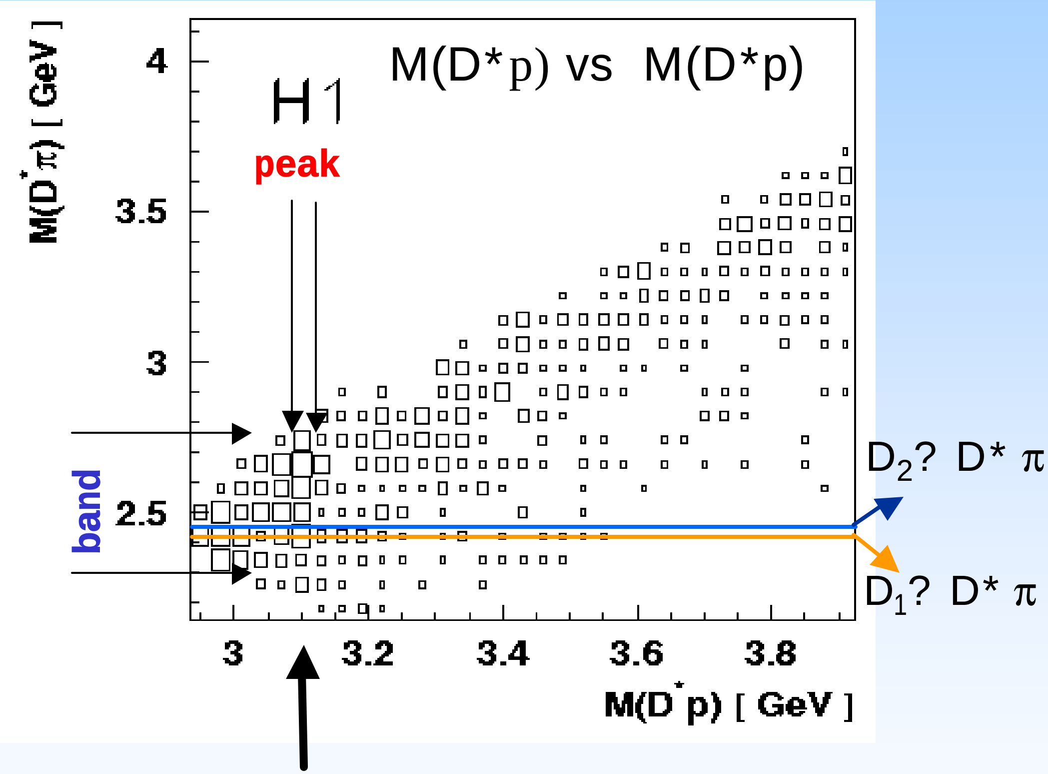
- more than 62,000 reconstructed D^*'s
- ZEUS data are incompatible with H1 report of

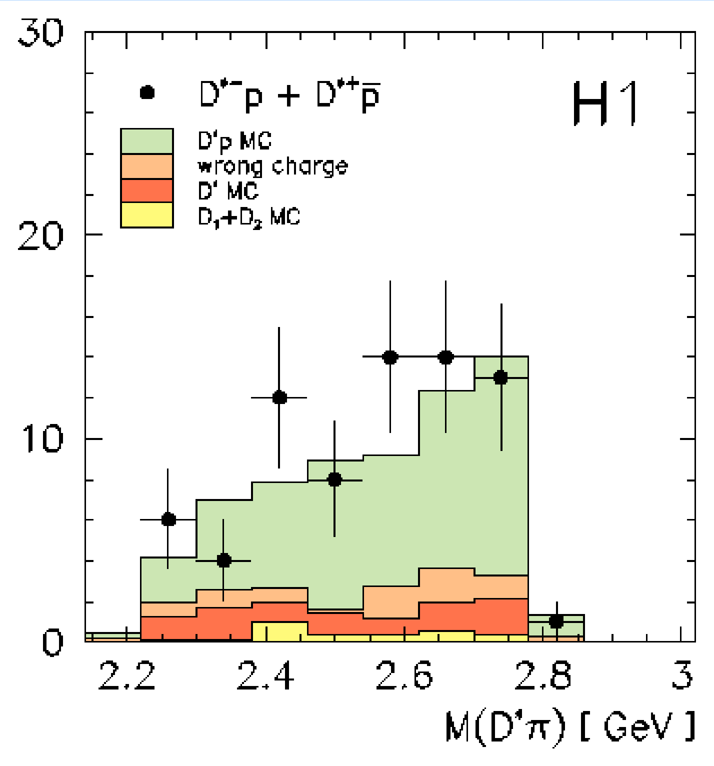
  Θ_c contributing 1% of D^* production ratio

Spare slides

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

Assign pion mass hypotheses to the proton candidate





Look into D*p invariant mass

distribution in D*p signal region

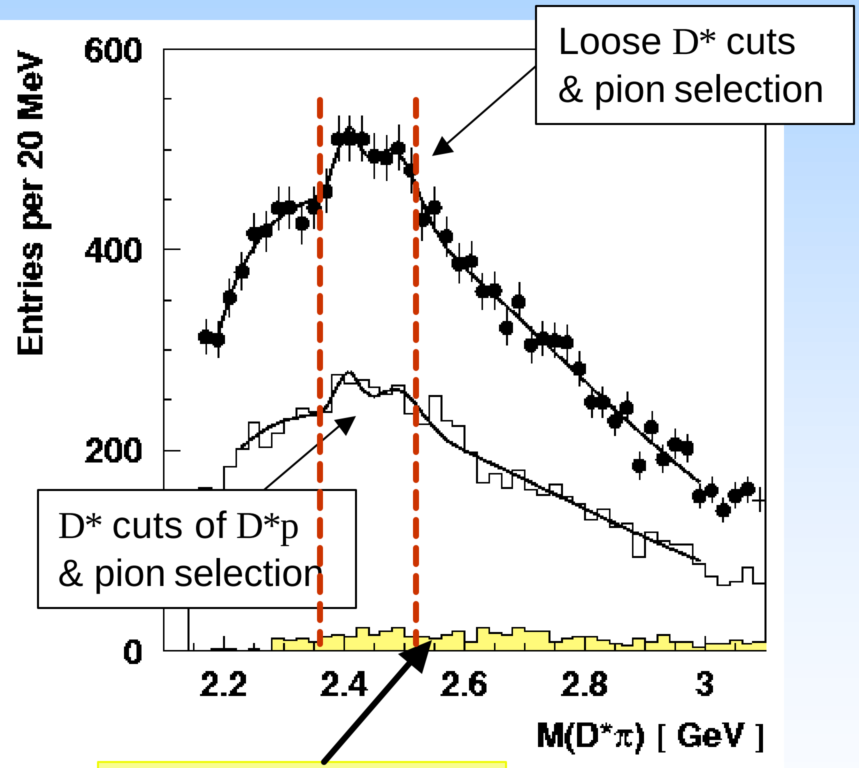
Pion hypothesis excluded !

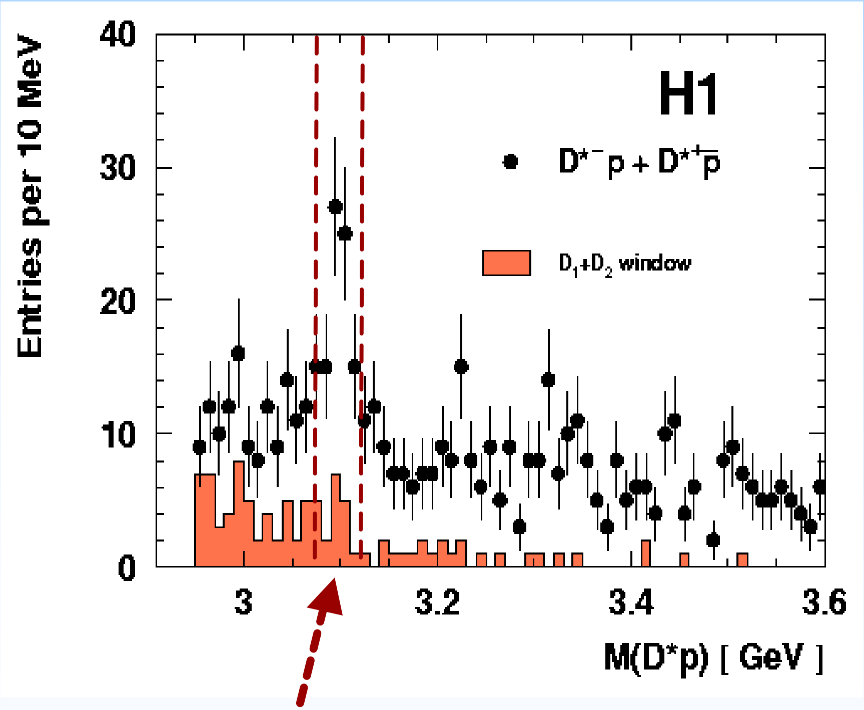
Example of a kinematic test: possible D*p reflection ?

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

Does it happen in our case?

D*p mass spectrum





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

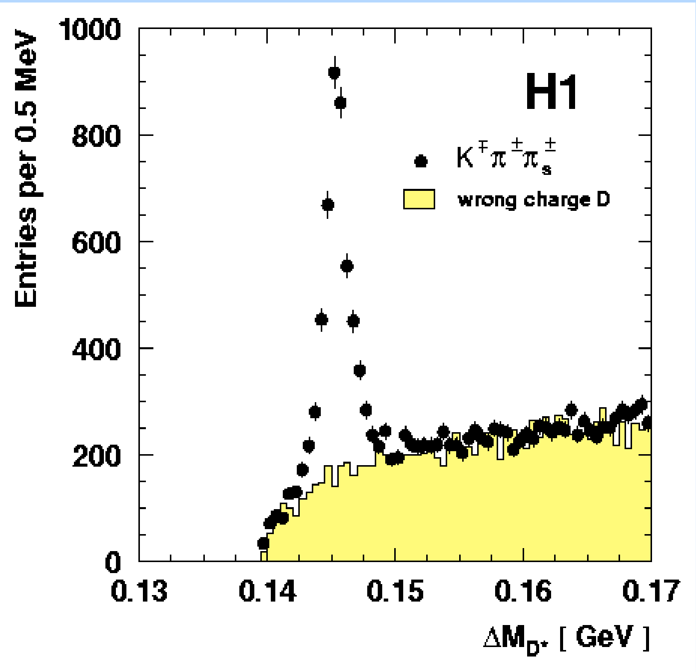
Expected only 3.5 events from data

The signal can not be a reflection !

D* in DIS and Photoproduction

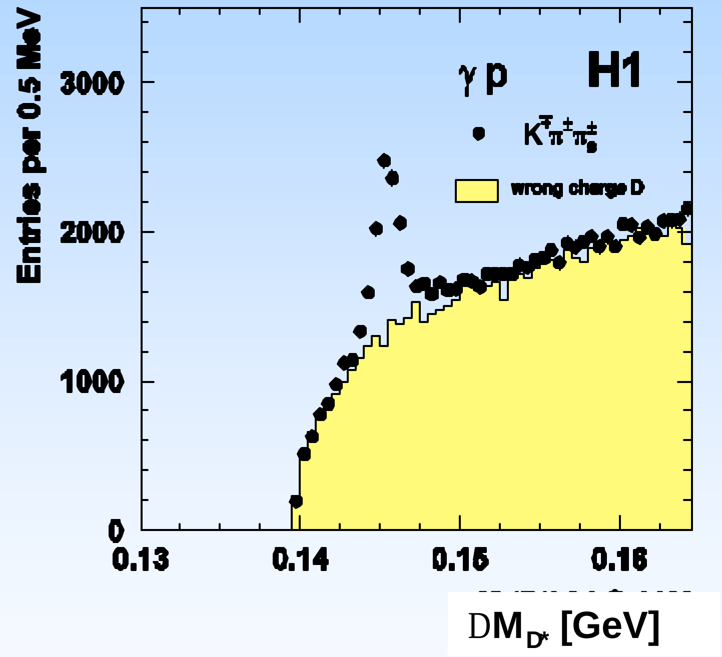
Deep Inelastic Scattering (DIS):

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



Photoproduction (gp):

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



"wrong charge D" : fake D^0 (K^+ p^+/ K^- p^-) + p_S : non-charm induced background

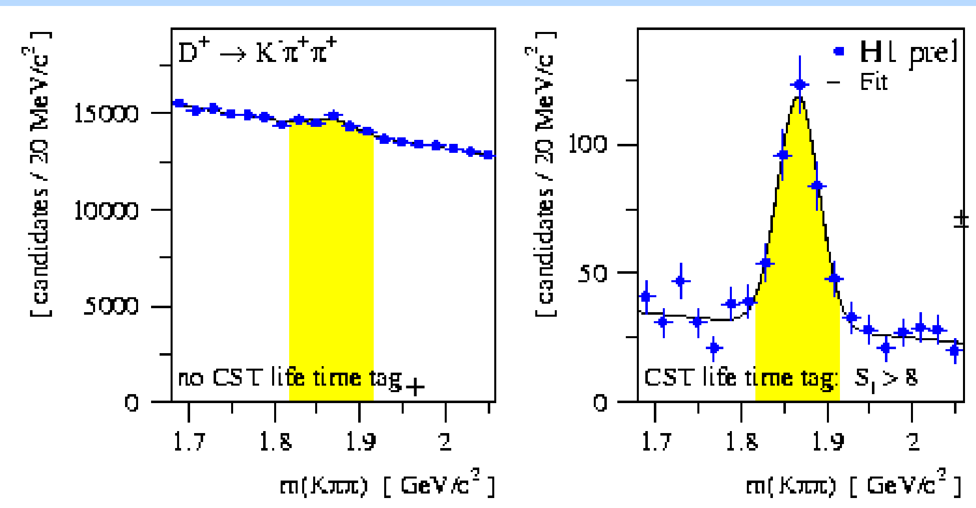
Non-charm induced background much higher in the case of Photoproduction

D*+ vs D+ in H1 detector

D pseudoscalar meson

fragmentation: f(c ® D^{+})= 0.248 ± 0.014

without — with lifetime tag

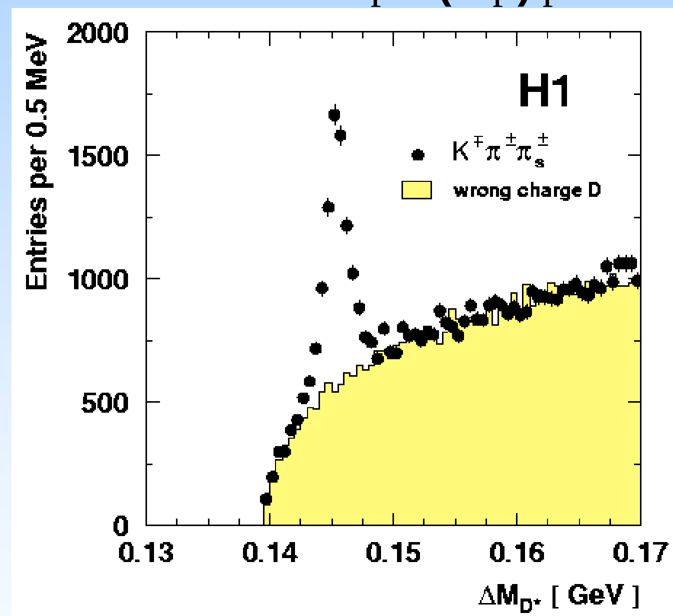


too high background — too low statistics

D* vector meson

f(c ® D^{*+})= 0.233 ± 0.009

D*® D ^{0} p ® (K p) p



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

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^{**}? D^*p (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 ® $c\bar{c}$ X**

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

prelim.

Negative results for q$_c$ from:

ALEPH	**e^+e^- ® Z^0 ® $c\bar{c}$**
FOCUS	**gN ® $c\bar{c}$ X**
CDF	**$p\bar{p}$ ® $c\bar{c}$ X**
BELLE	**e^+e^- ® U(4s) ® $B^0\bar{B}^0$**

Not contradicting H1

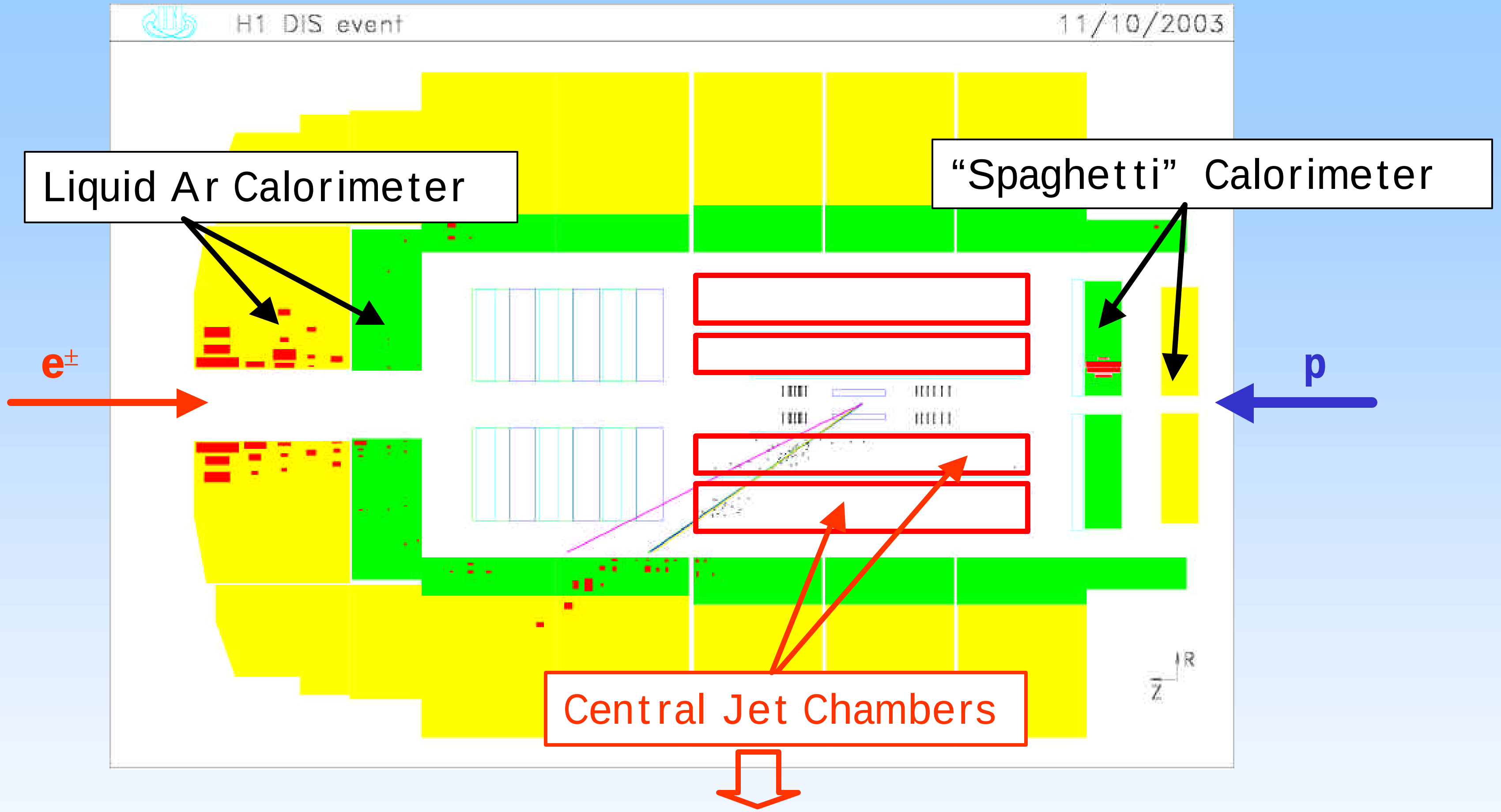
$B(B^0 \rightarrow \Theta_c p\pi) \times B(\Theta_c \rightarrow D^*p) / B(\Theta_c \rightarrow D^*pp\pi) < 11\%$ @ 90% C.L.

ZEUS **ep ® $c\bar{c}$ X**

Different physics processes investigated

Physics seen by ZEUS should be directly comparable to H1

H1 experiment at HERA accelerator



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

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