evidence for an anti-charmed baryon state

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on behalf of the H1 collaboration

Outline:

- Deep inelastic scattering at HERA
- Charm production
- Search for an anti-charmed baryon state
- Signal checks and significance estimate
- Summary

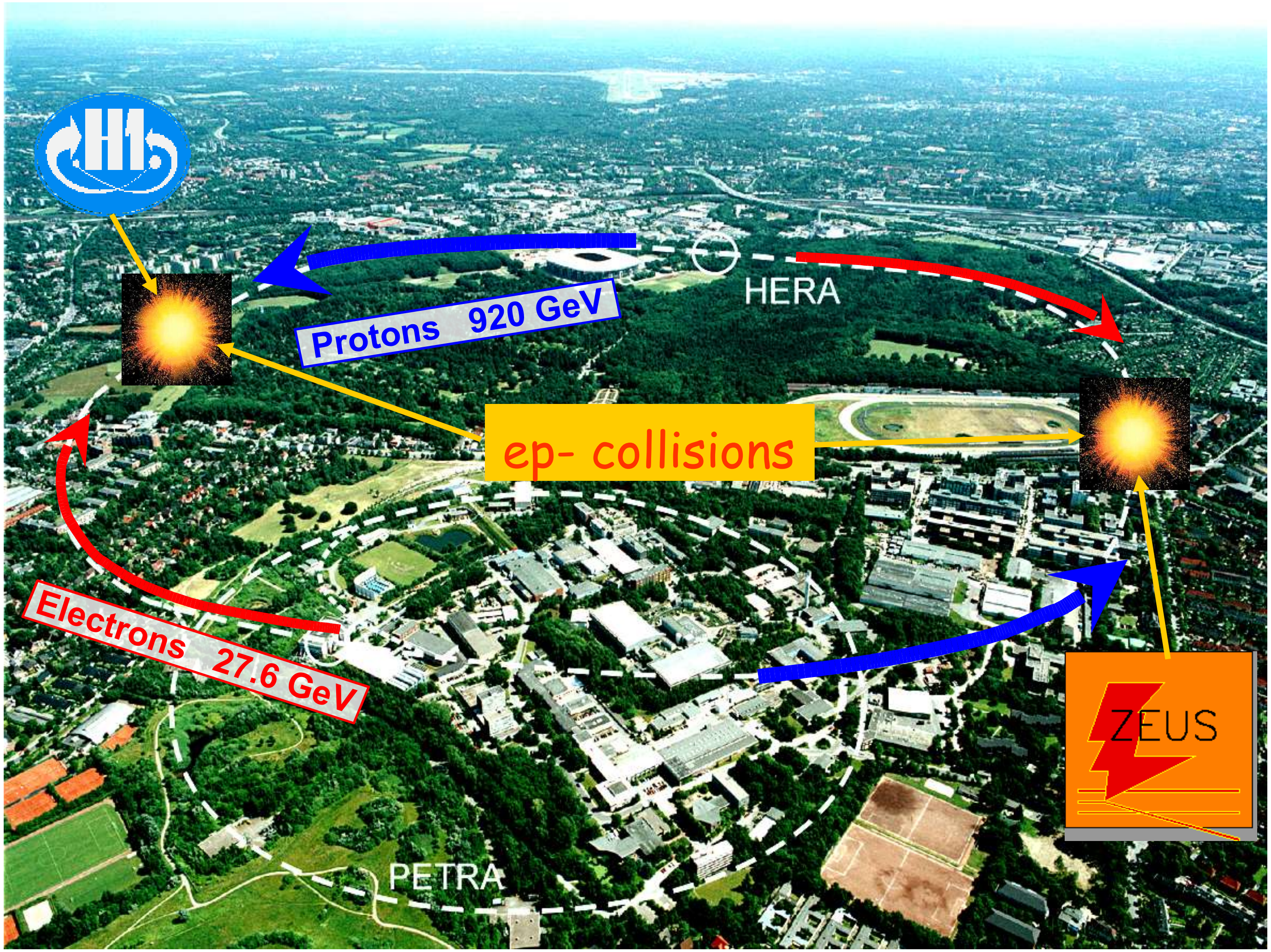
The HERA accelerator

E_e = 27.6 GeV

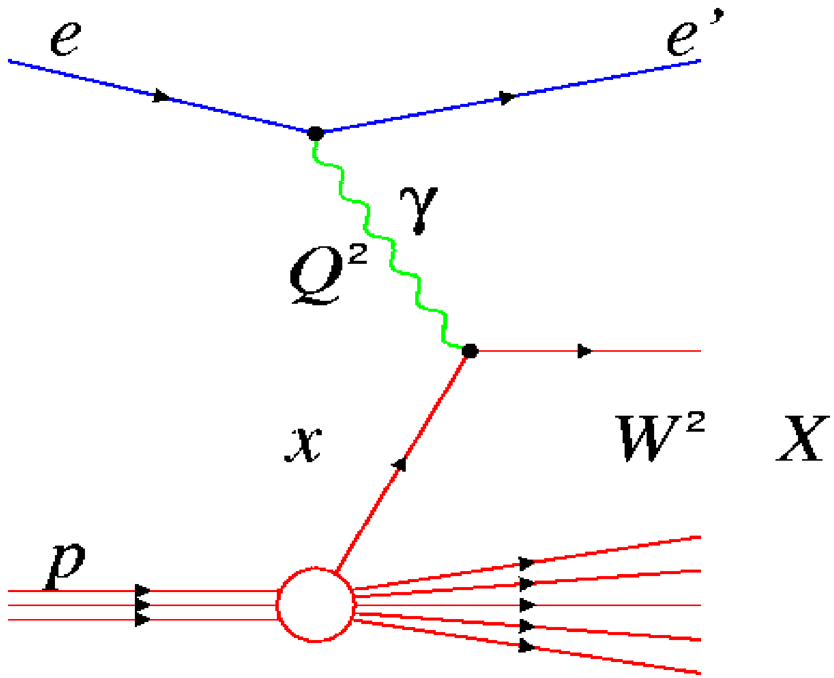
E_p= 920 (820) GeV

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

DESY
Hamburg
Germany



Deep-inelastic scattering (DIS) kinematics



E_e=27.6 GeV

E_p=920 (820) GeV

$\sqrt{s}$ ≈300-320 GeV

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 hadronic system
  $W^2 = (P + q)^2$

Kinematic regimes:

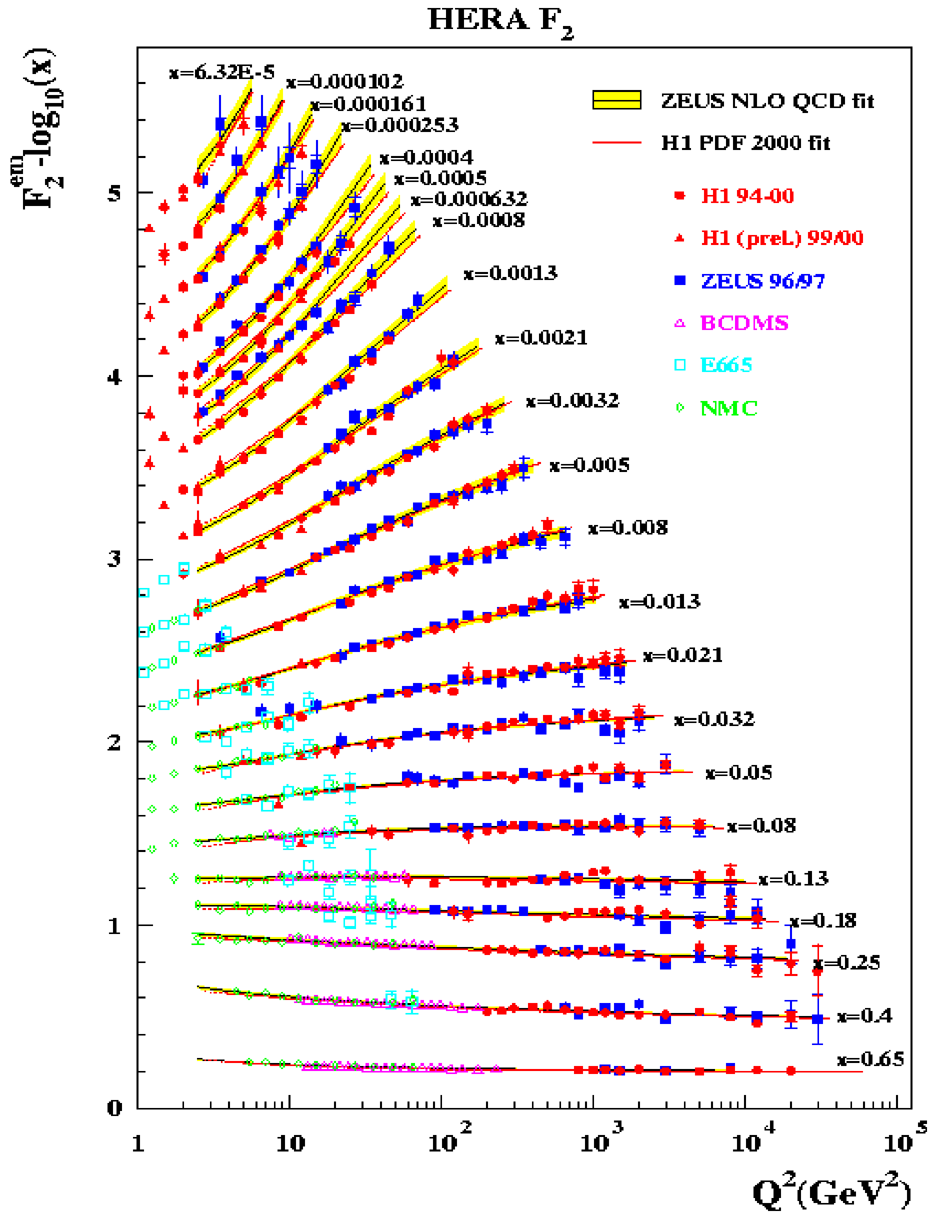
- **$Q^2 > 1$ GeV²: DIS scattered e in detector**
- **$Q^2 < 1$ GeV²: Photoproduction, γp scattered e in beampipe**

Physics at HERA

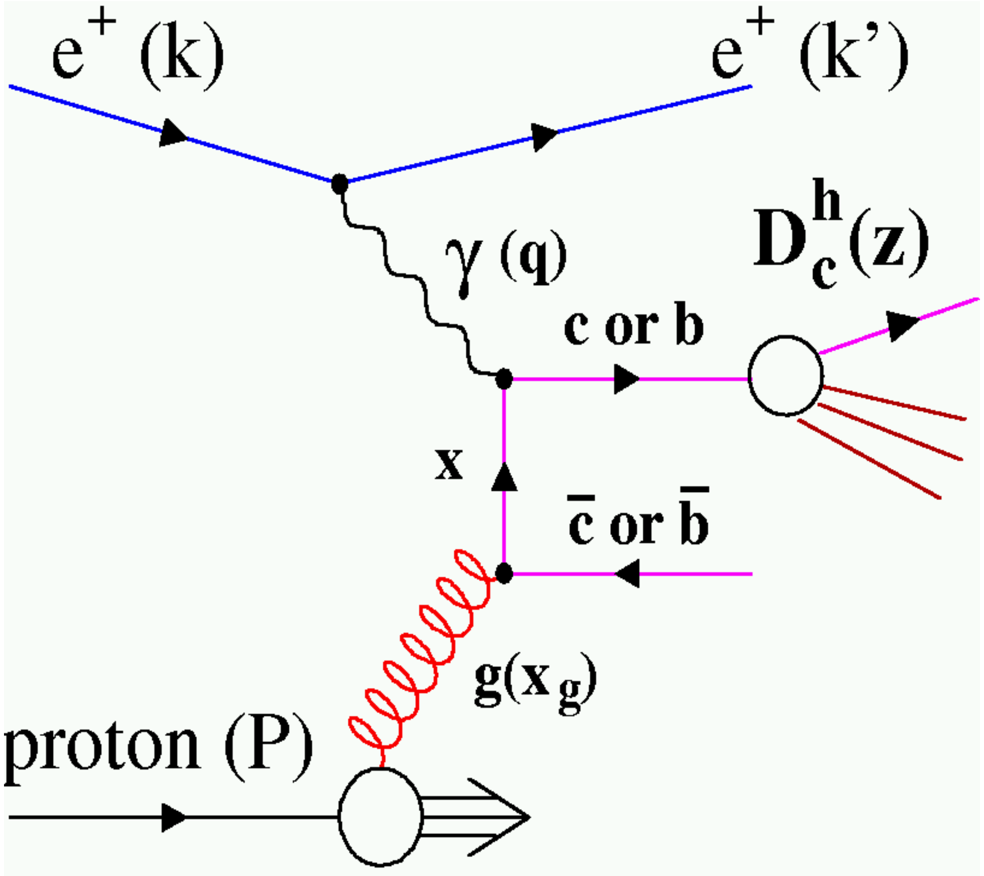
Main aim:
structure of the proton and
precision tests of
strong interactions (QCD)

properties of QCD:
- scaling violations
- asymptotic freedom

→ Nobel prize 2004
"for the discovery of asymptotic freedom in the theory of strong interactions"
D.J. Gross, H.D. Politzer,
F. Wilczek



Charm Production at HERA



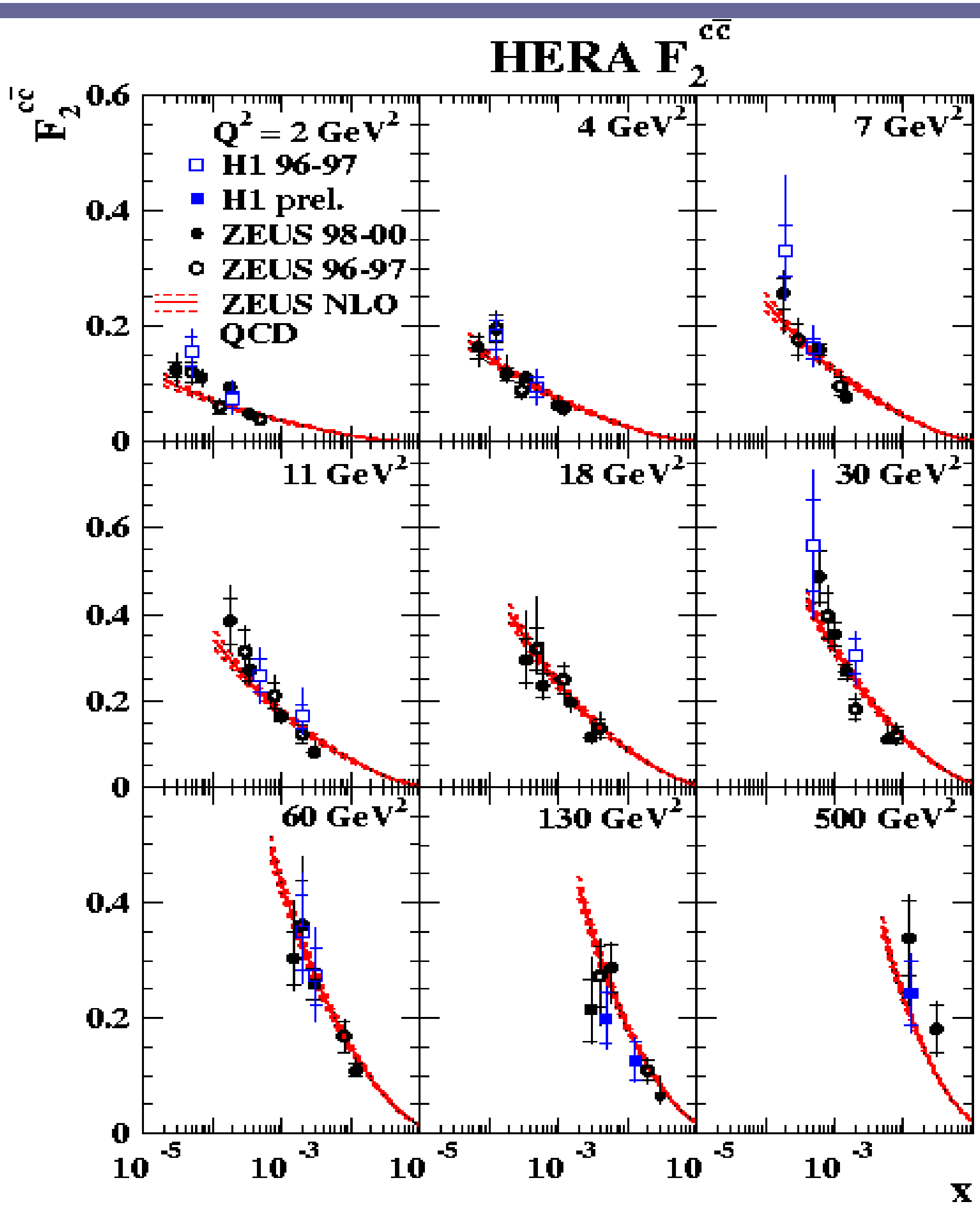
heavy quark mass:
charm no constituent of the proton in our kinematic range

→ copius production from gluon in the proton

charm production is dominated by Boson Gluon Fusion (BGF) in LO :

$$\gamma g \rightarrow cc\ (bb)$$

Charm Production at HERA (II)



Charm contribution to total cross section

ratio of structure functions:
F_2^{cc}/F_2
large, going up to ~30 %

HERA is a charm factory

Pentaquark searches

Search inspired by evidence for exotic narrow resonances in K+n
= candidates for strange pentaquark state θ+

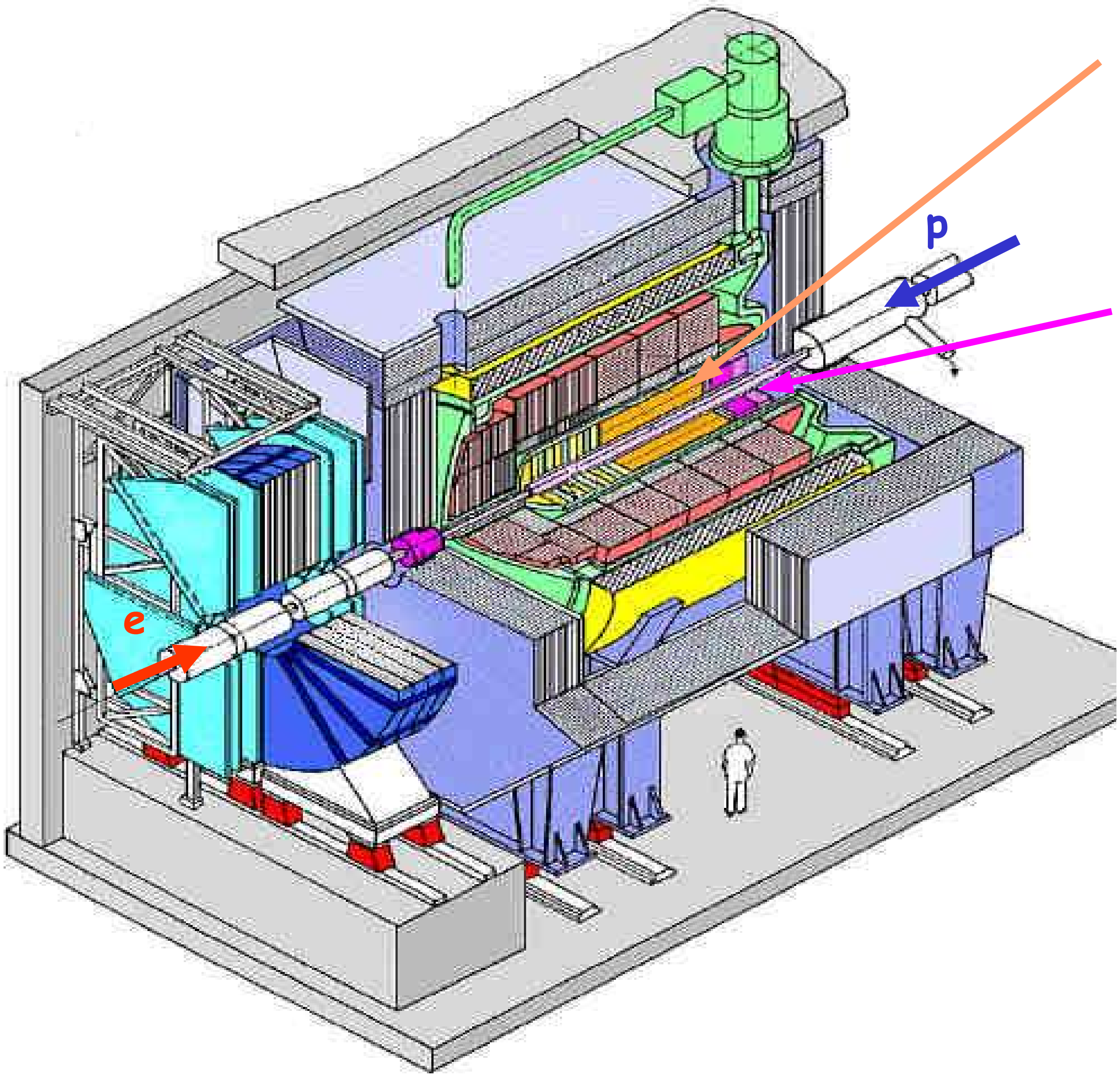
Why not charm?

Assume: θ+ produced by fragmentation from vacuum
- features of QCD vacuum are universal
- QCD is flavour blind

expect similar properties as for θ+ for a charmed pentaquark

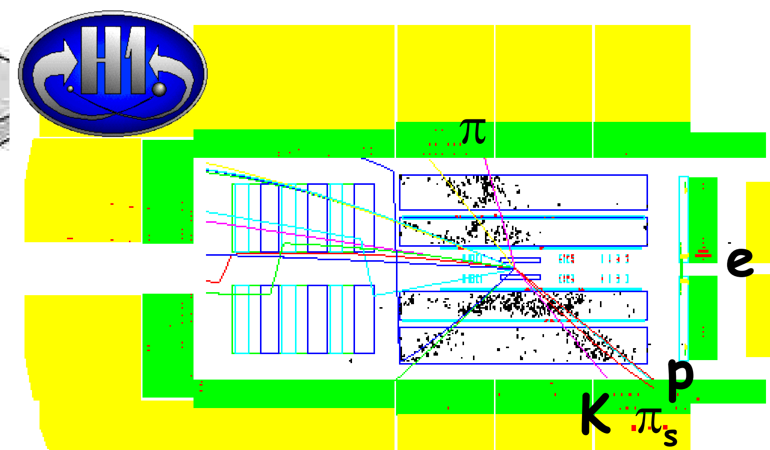
look for exotic baryonic charm resonance
e.g. combine charm meson with baryons
e.g. D* with protons

H1 detector at HERA



Central drift chamber CJC
rec. of D*, protons

backward
electromagnetic
calorimeter SpaCal
rec. of scattered e



D*p event in DIS

D* signal

Golden decay channel:

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

low branching ratio, but clean signal

$M(D^*) - M(D^0) = 145.4$ GeV
Q-value: 5 MeV

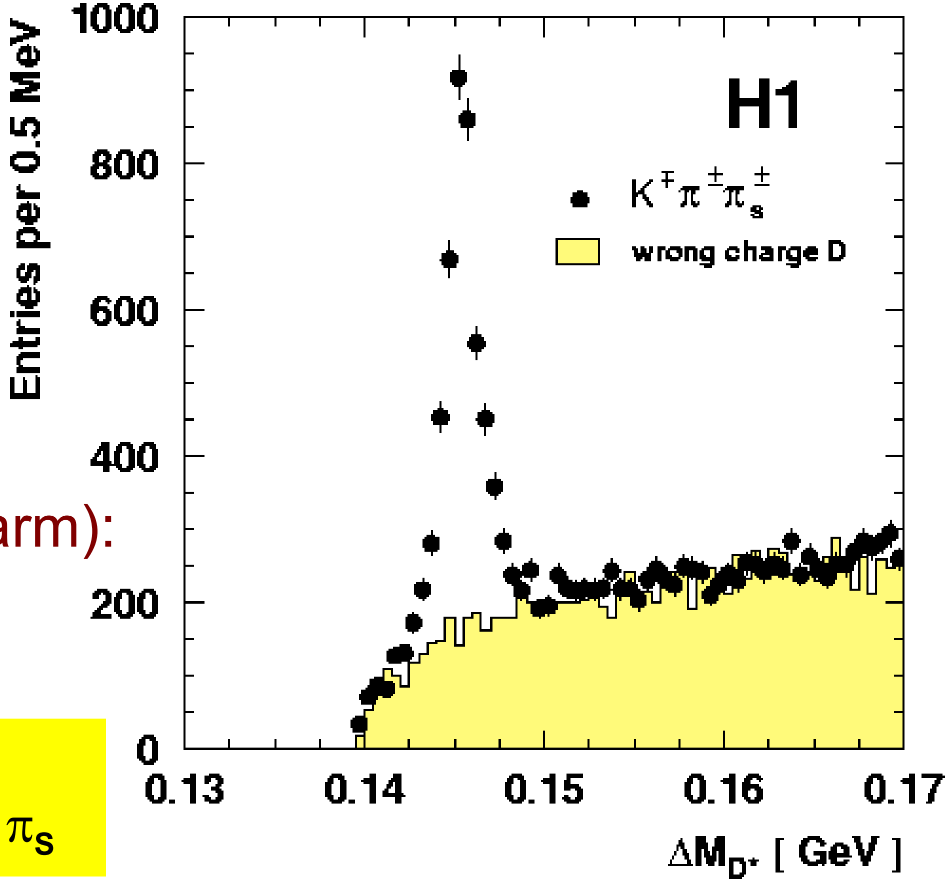
- apply "mass difference method":
  $\Delta M(D^*) = M(K \pi \pi_S) - M(K\pi)$

- Estimate combinatorial bgr (non charm):
  replace $D^0 \to K^- \pi^+$
  by 2 same charge tracks

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

DIS events:

- 96-00 data, Lumi 75 pb^{-1}
- scattered electron in calorimeter
- $1 < Q^2 < 100$ GeV², $0.05 < y < 0.7$

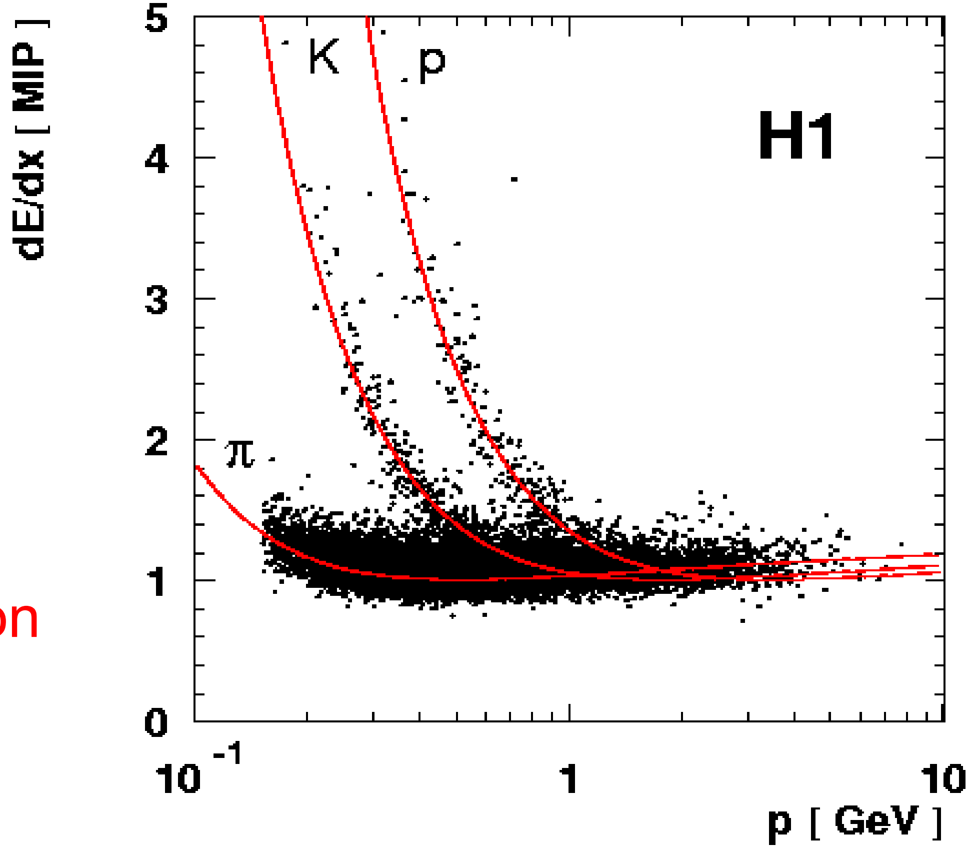


Proton selection

Particle identification via
energy loss dE/dx

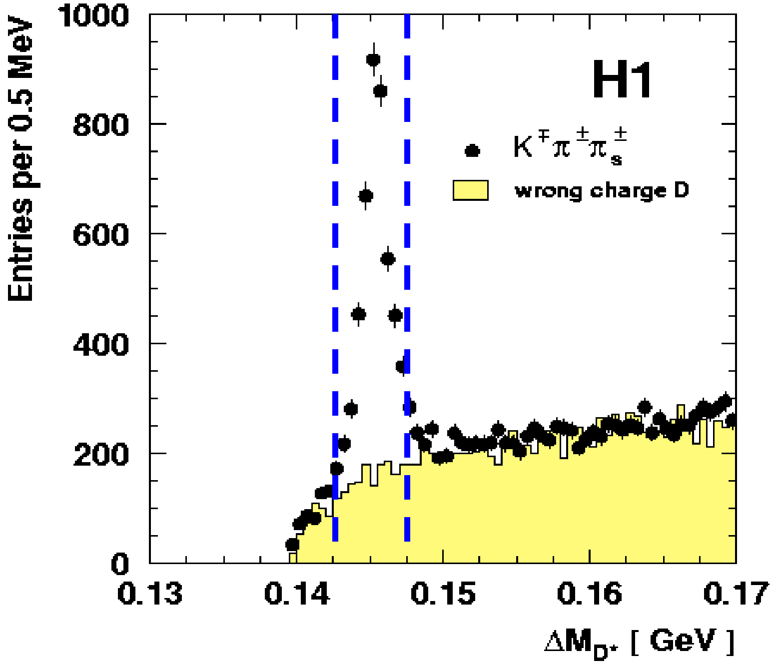
Resolution for mininal ionizing
particles ~8%

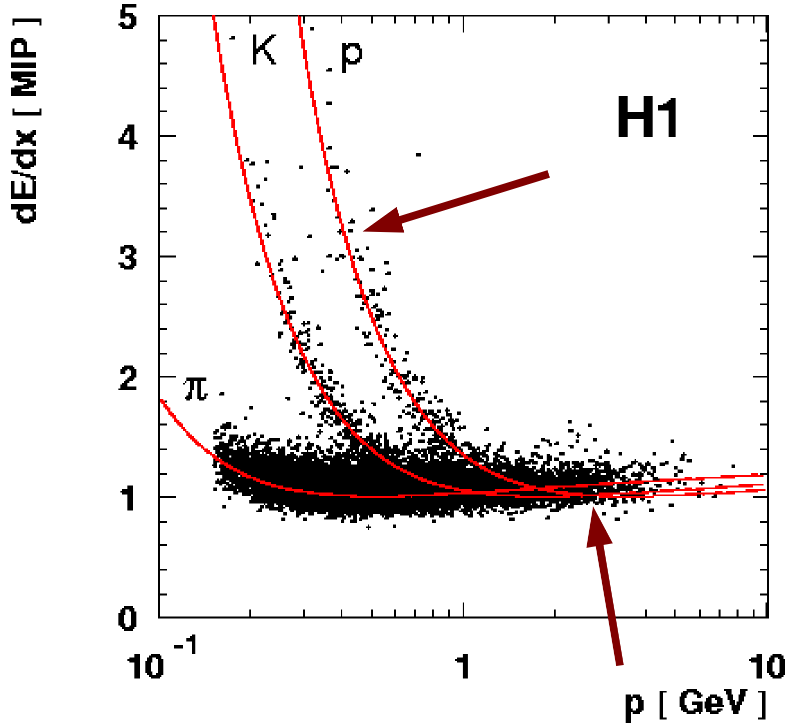
most probable dE/dx:
phenomenological parameterisation
(Bethe Bloch)



combining D* mesons and protons

3400 D* selected:





ΔM(D*) mass window: ±2.5 MeV

Now we have: resonstructed D* mesons and protons (from dE/dx)
what do we get if we combine them?

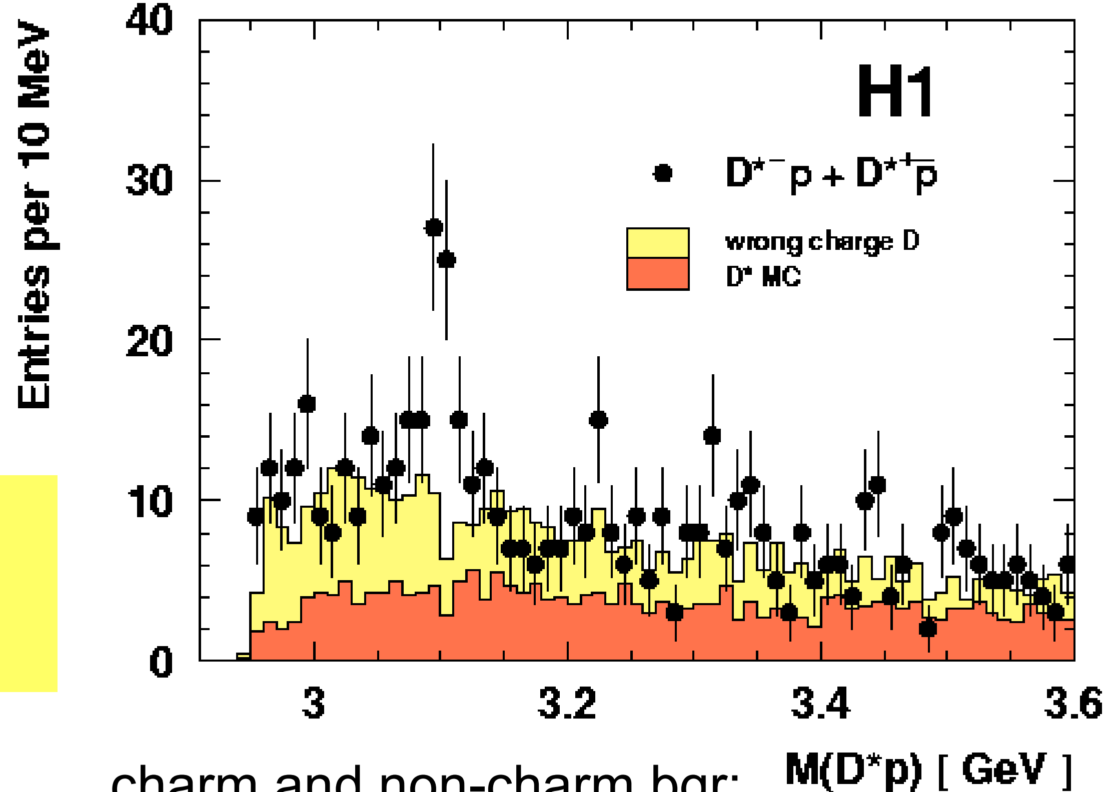
opposite sign D*p invariant mass distribution

Apply mass difference technique

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

narrow resonance at

M=3099±3(stat.) ±5 (syst.) MeV



2 bgr contributions:

charm: real D* with random track estimated with MC

non charm: estimated by wrong charge D

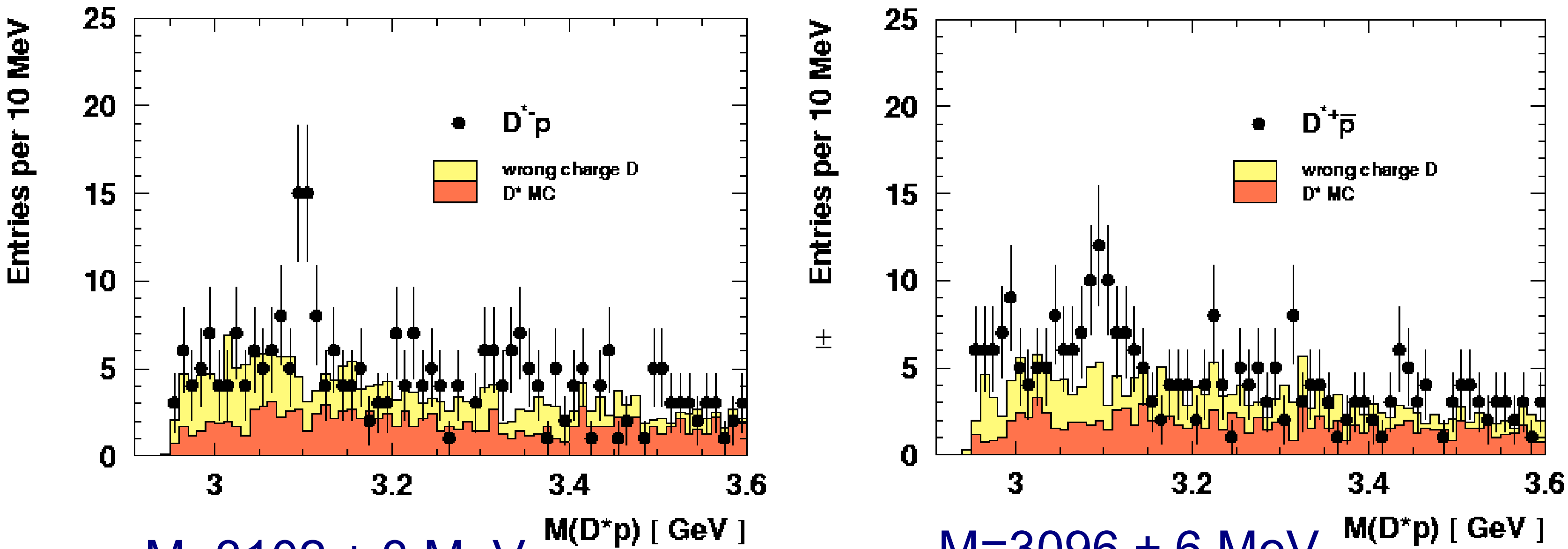
charm and non-charm bgr:

- no enhancement in D* Monte Carlo
- no enhancement in wrong charge D

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

Signal in both $D^{*-}p$ and in $D^{*+}\bar{p}$

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



M=3102 ± 3 MeV

M=3096 ± 6 MeV

charm and non-charm bgr:

- no enhancement in D* Monte Carlo
- no enhancement in wrong charge D

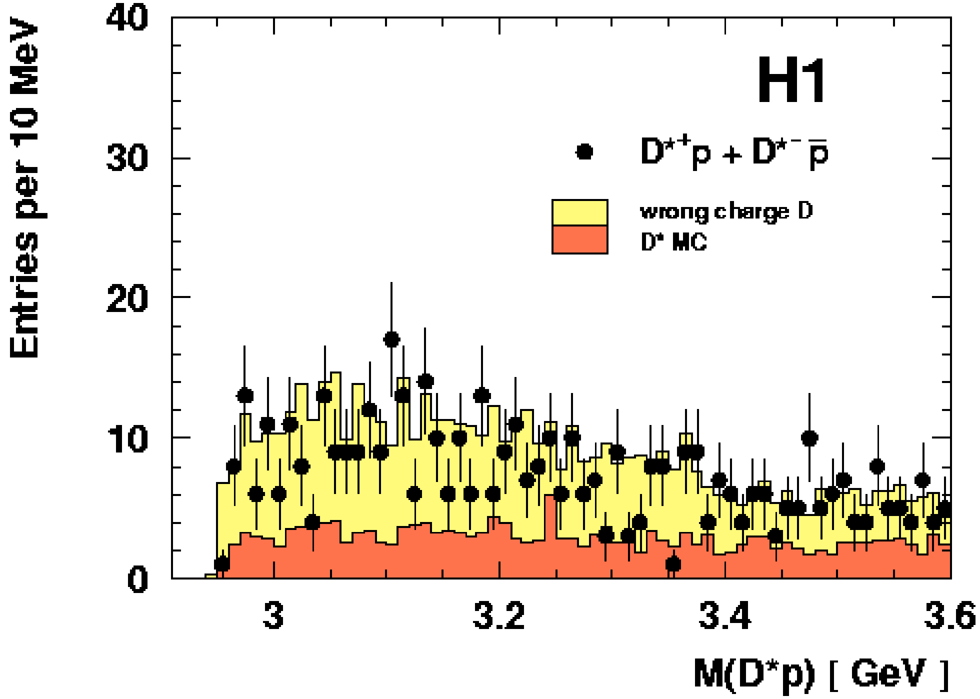
Signal visible in both charges $D^{*-}p$ and in $D^{*+}\bar{p}$ with similar strength and compatible mass

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

Signal visible also in like sign D*p ?

data consistent with
background estimation

No significant peak in
like sign D* p



charm and non-charm bgr:

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No significant peak in
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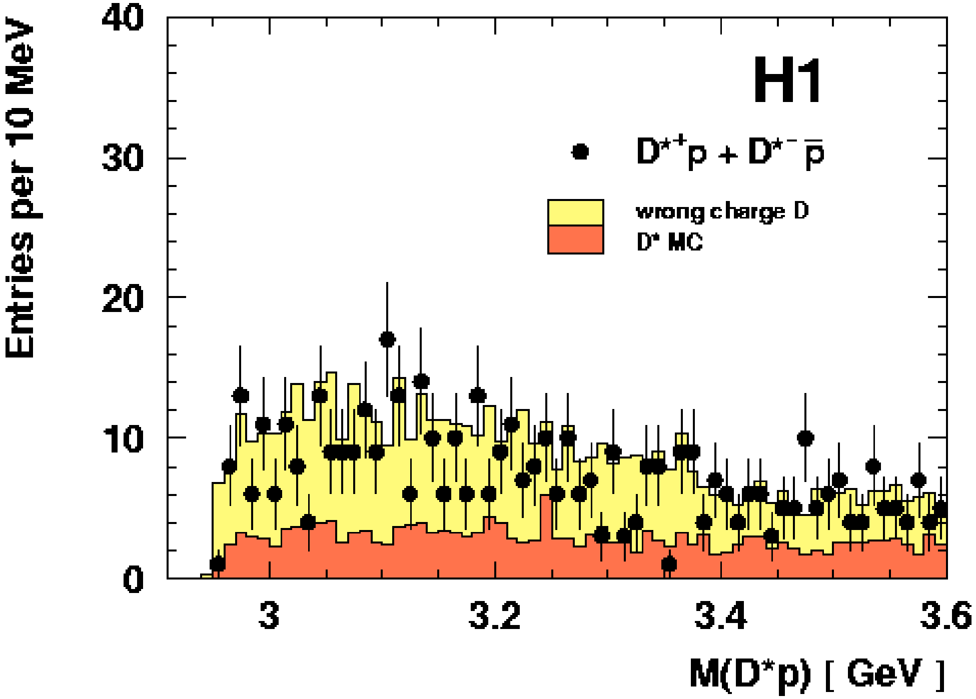
No!



charm and non-charm bgr:

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Background well described by D* MC
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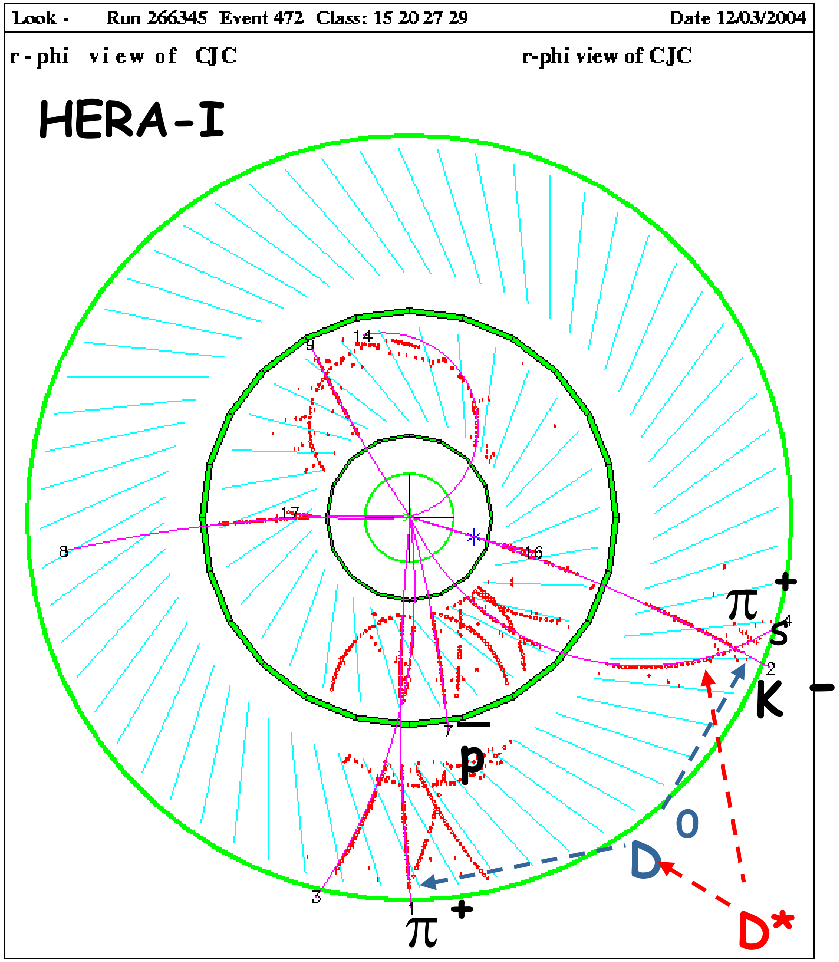
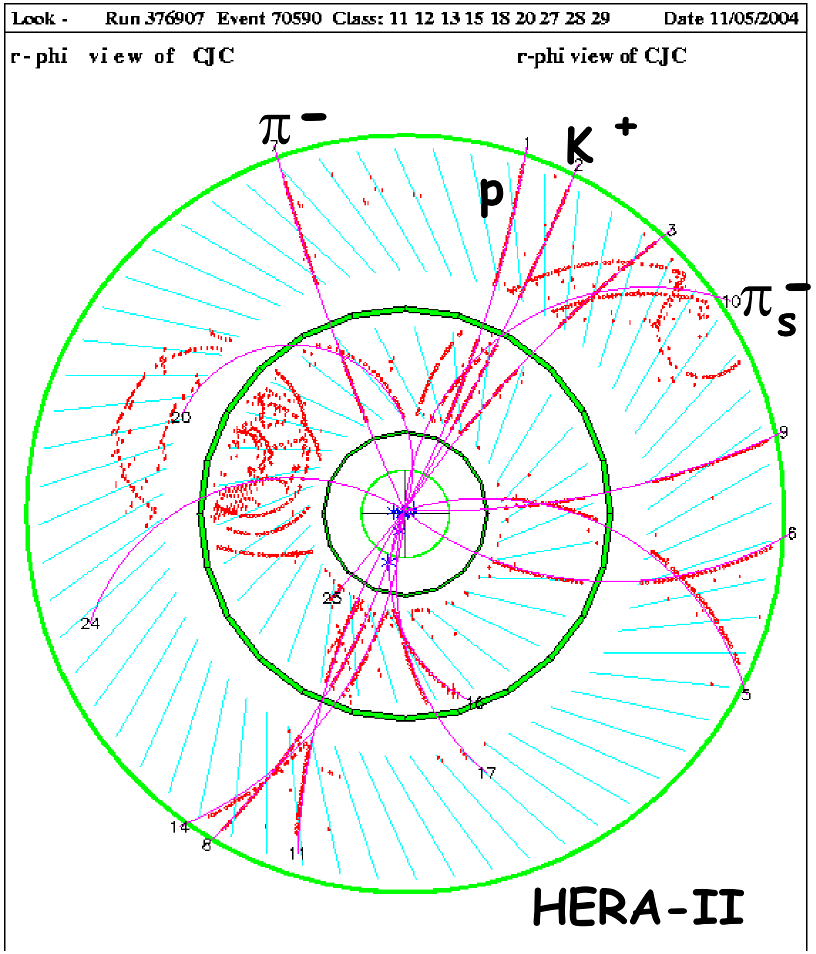
Signal faked by reconstruction problem?

Typical D*p candidates:





All signal events visually scanned – no anomalies

Signal faked by reconstruction problem?

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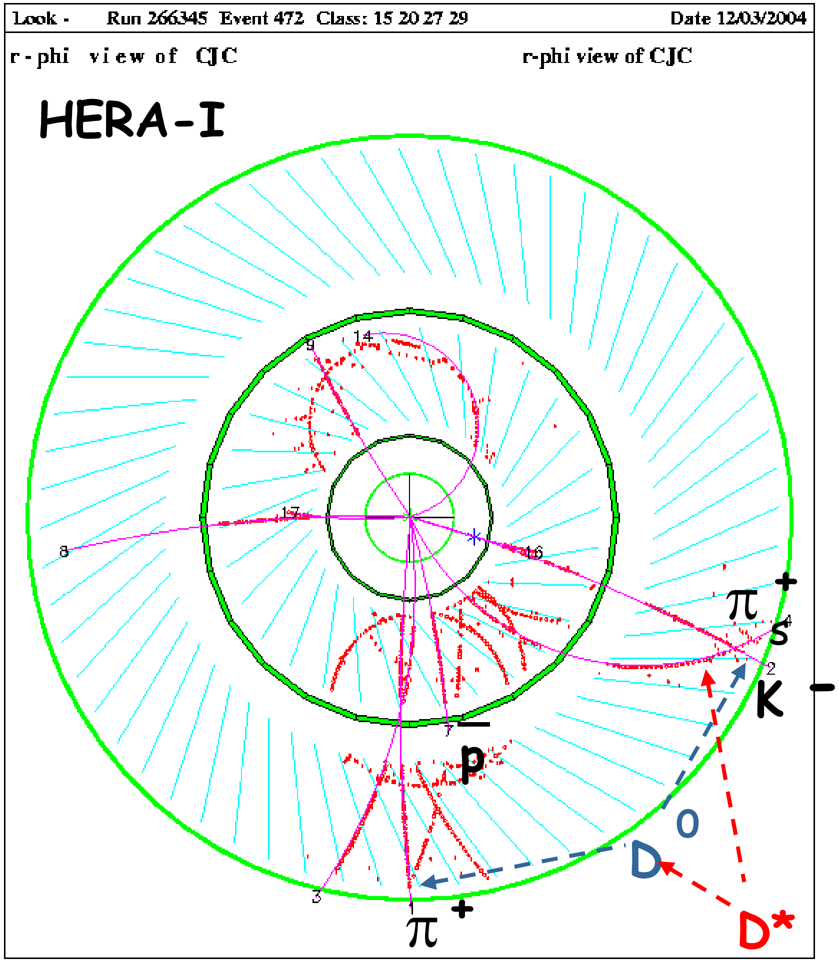
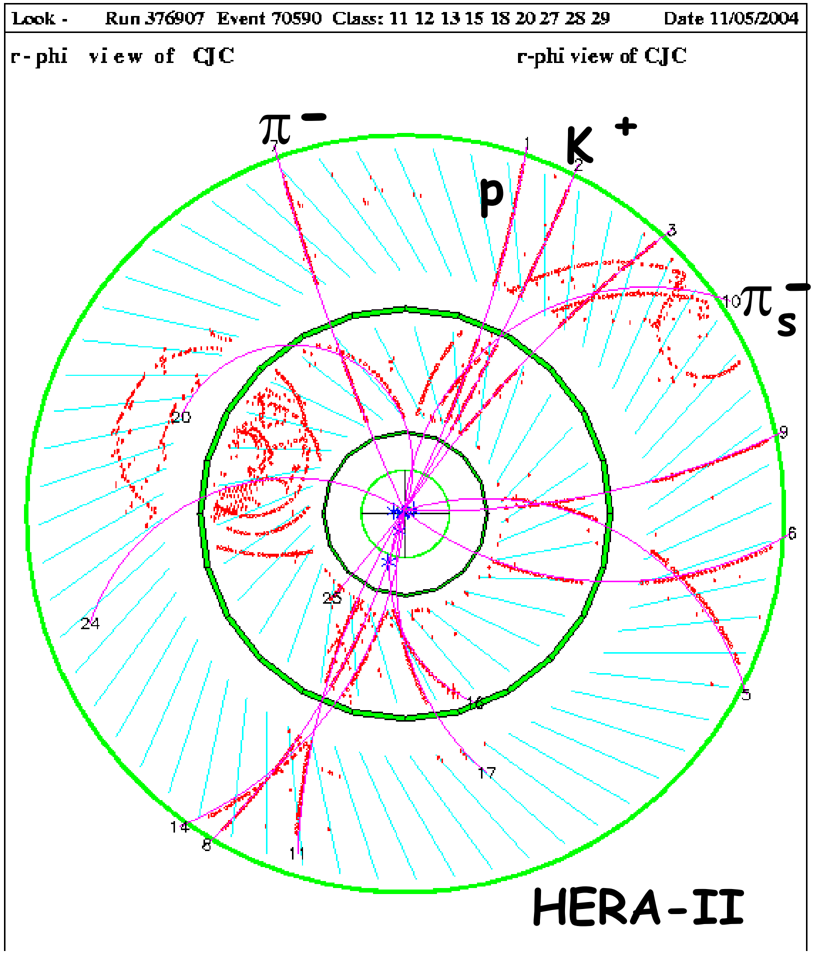
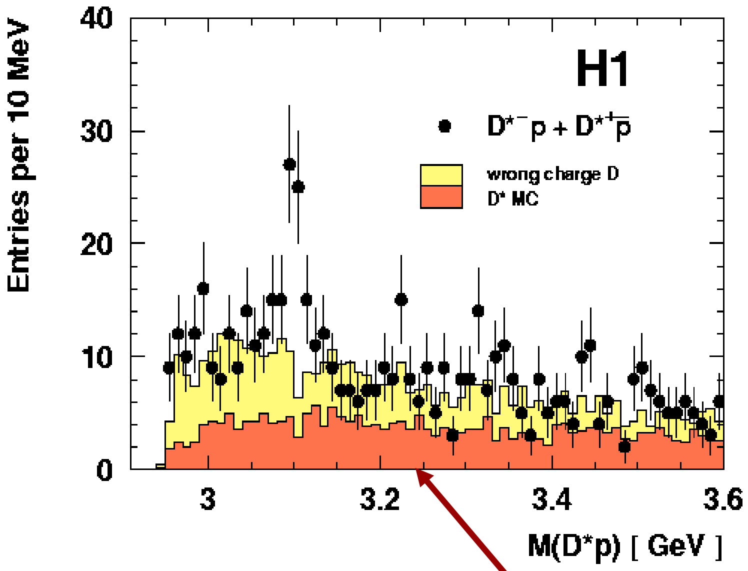




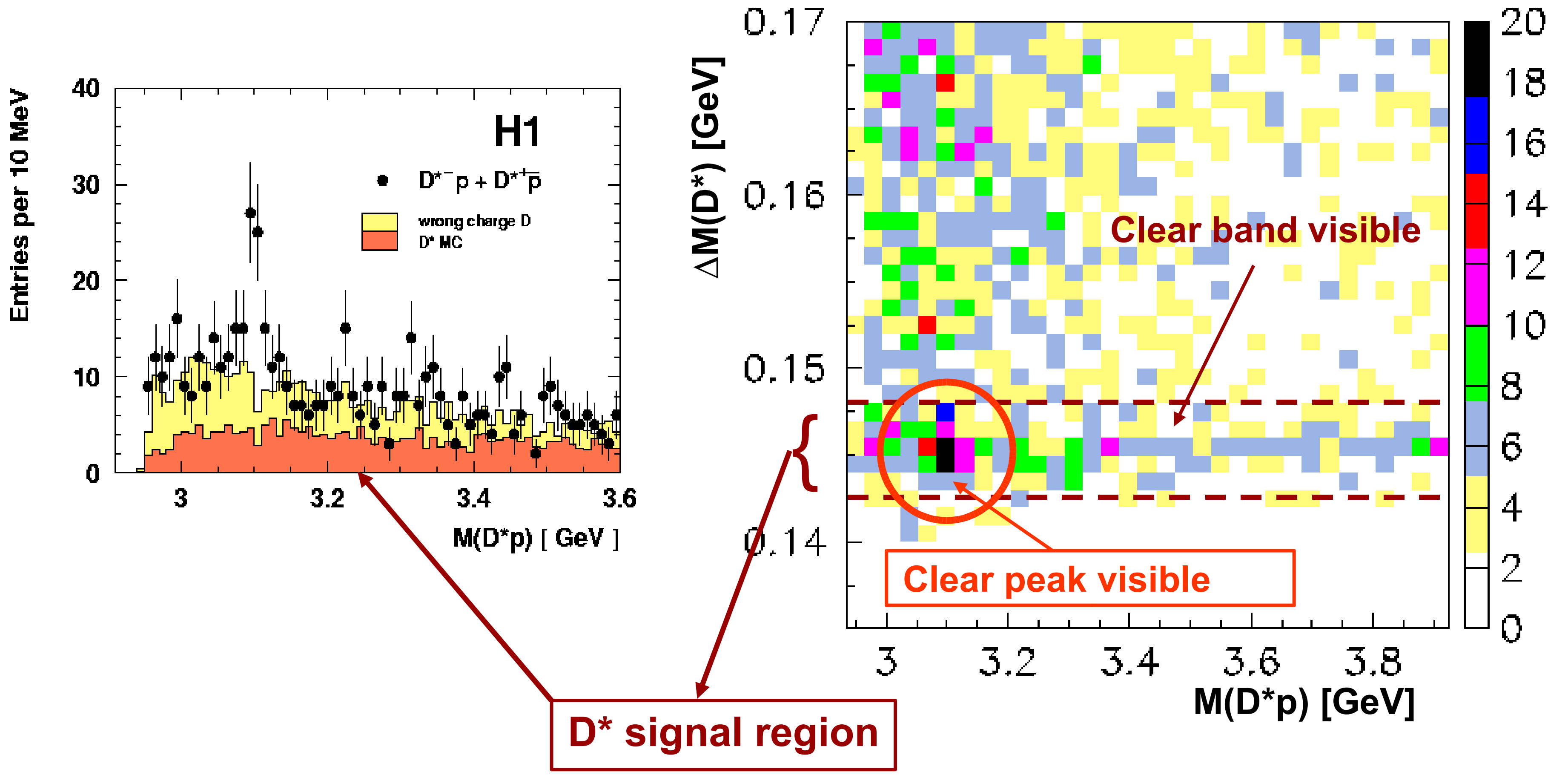
All signal events visually scanned – no anomalies **No!**

Does Resonance come from D*?



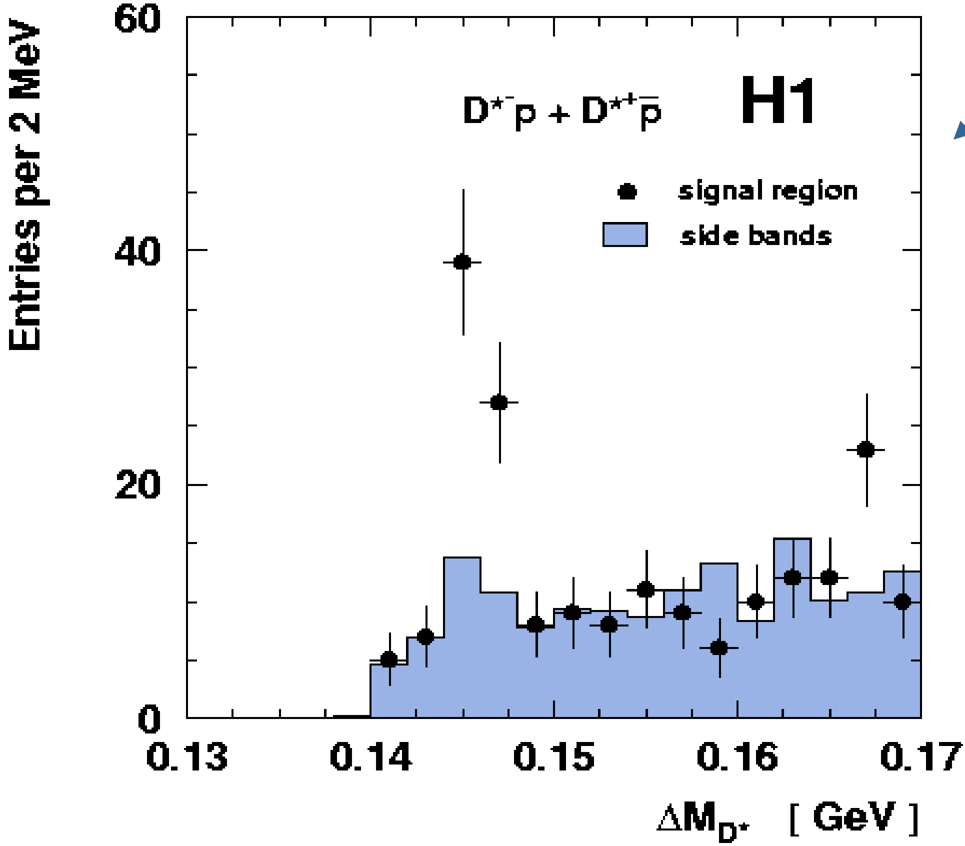
D* signal region

Does Resonance come from D*?

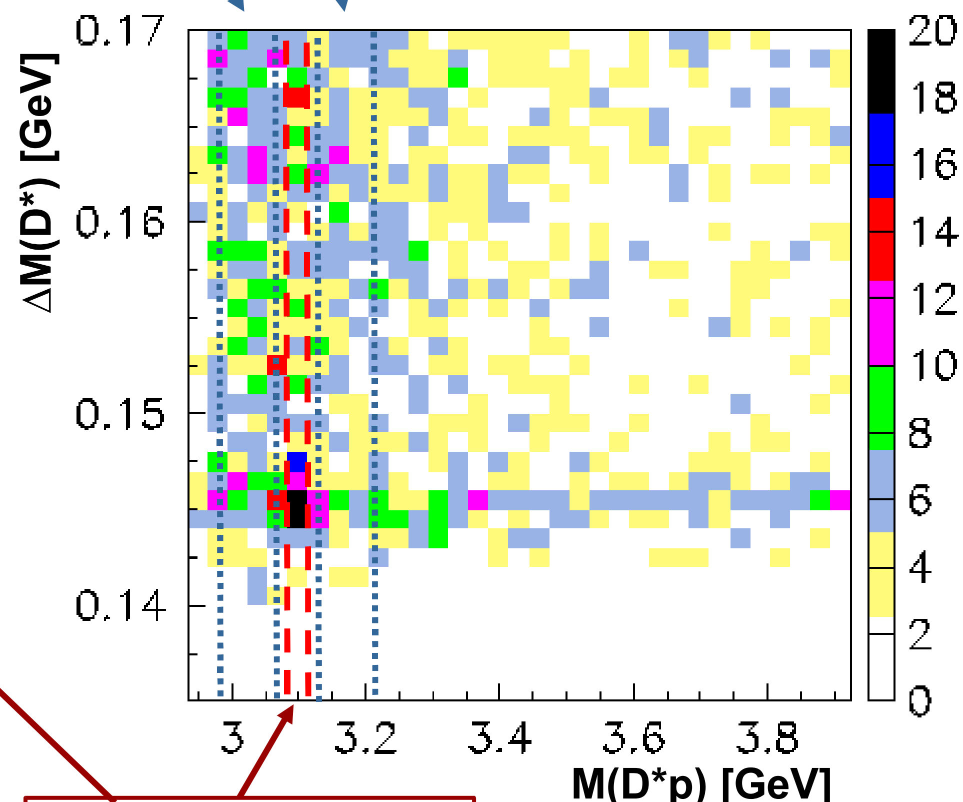


Does Resonance come from D*?

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



D*p Side bands



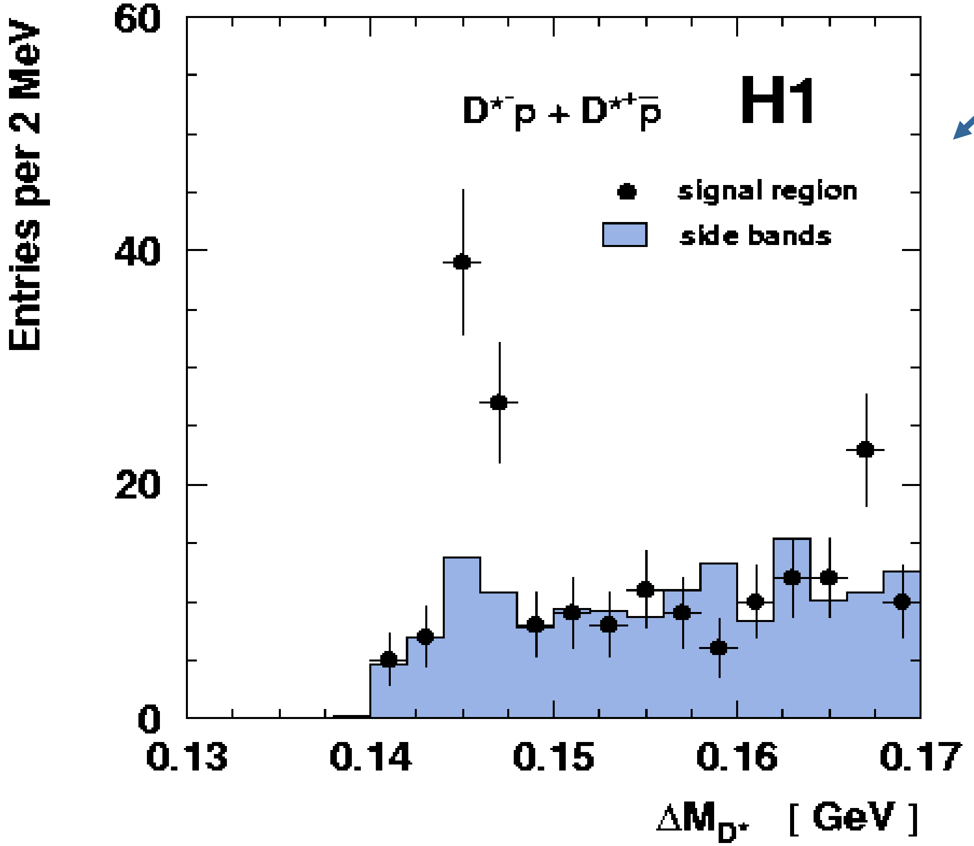
D*p signal region

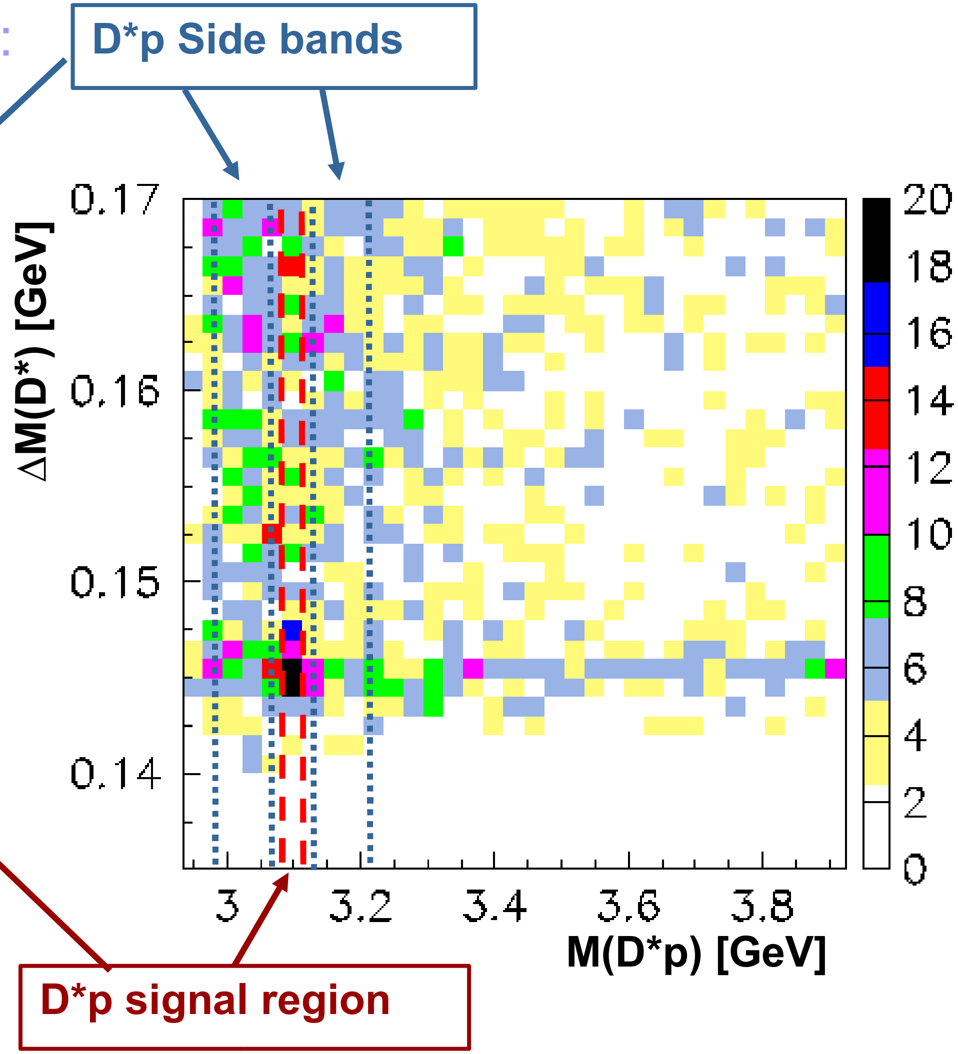
Side band scaled to the width of the signal window in M(D*p) no further normalization!

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

Does Resonance come from D*?

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



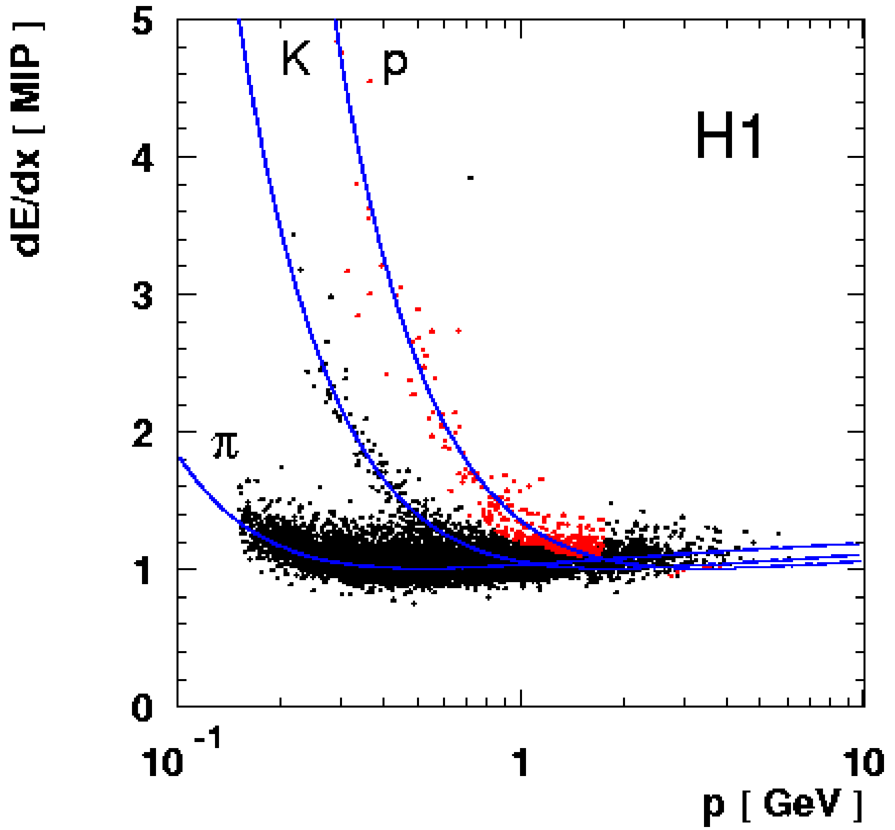


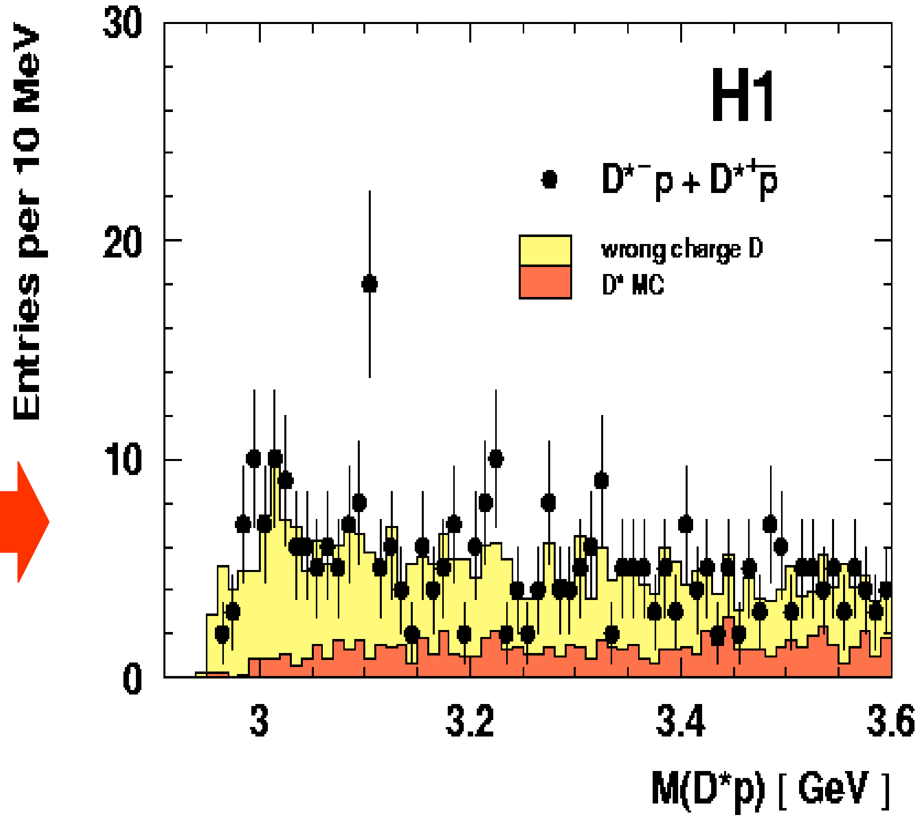
Side band scaled to the width
of the signal window in M(D*p)
no further normalization!

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

Yes!

Does resonance come from protons?



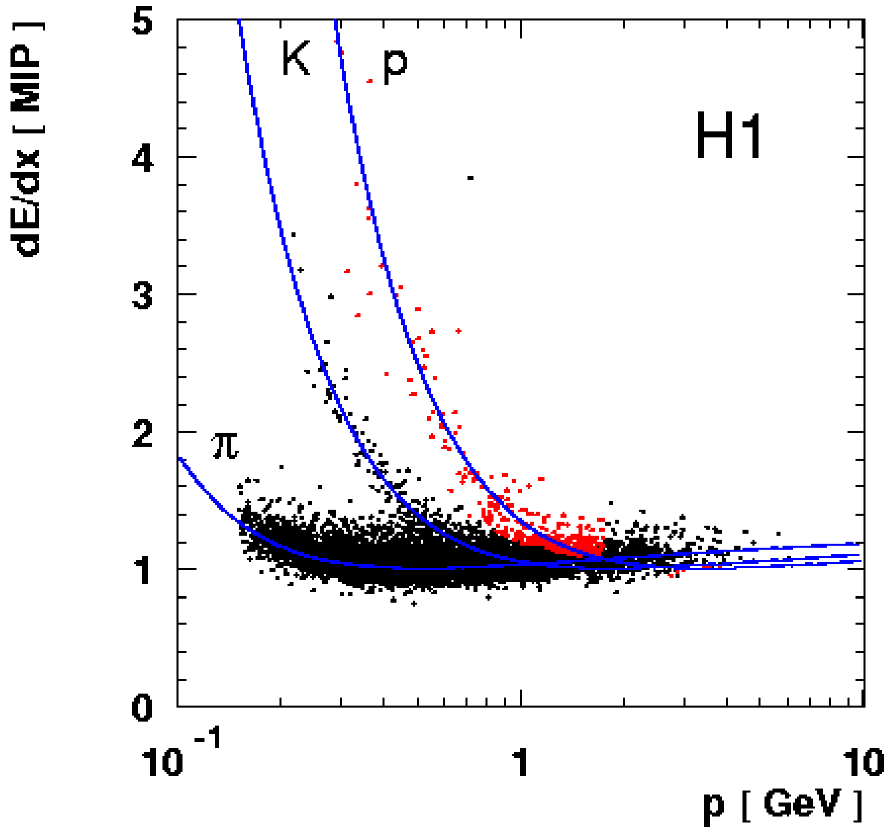


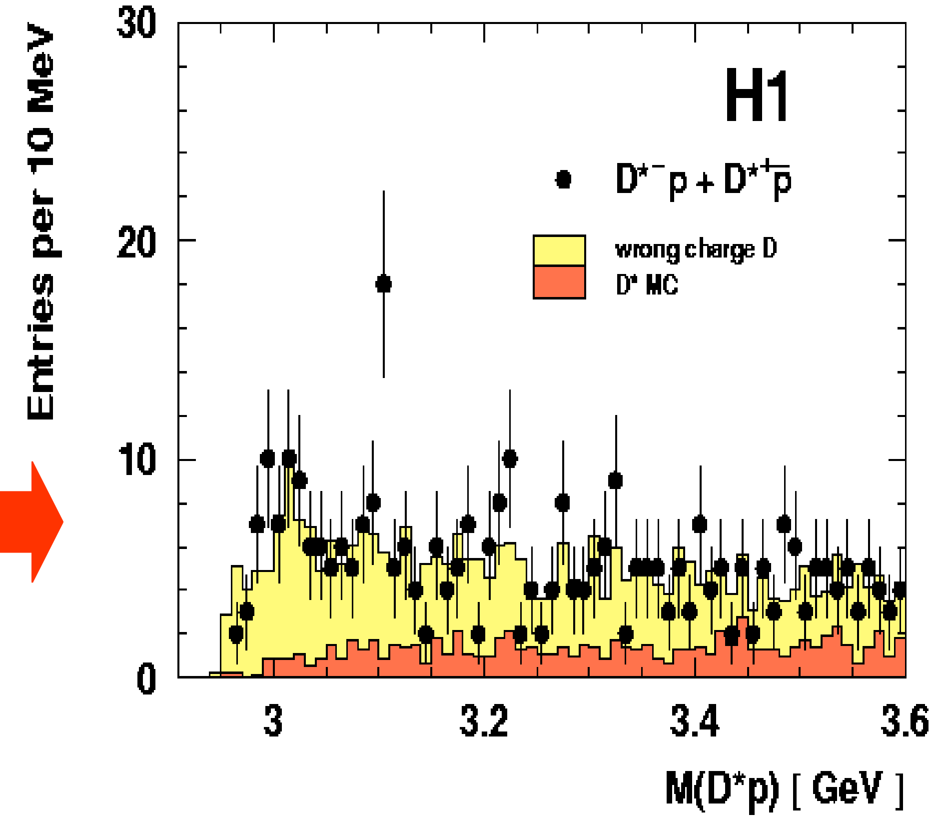
Use well identified protons with
- p(p) < 1.2 GeV
- dE/dx > 1.15
- good dE/dx particle identification

M(D*p)=3104±3 MeV

Signal is there for well identified protons

Does resonance come from protons?





Use well identified protons with
- p(p) < 1.2 GeV
- dE/dx > 1.15
- good dE/dx particle identification

M(D*p)=3104±3 MeV

Yes!

Signal is there for well identified protons

on and off resonance kinematics

- 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

on and off resonance kinematics

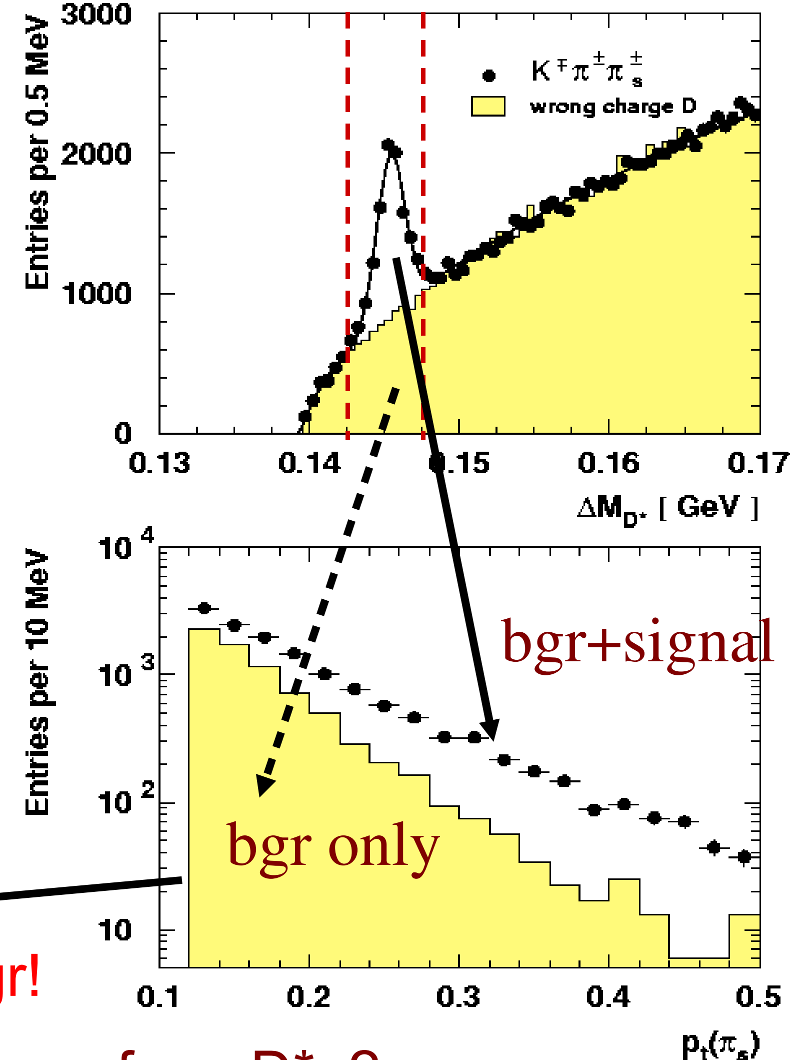
•single charged particles:
momentum spectrum steeply falling!
preserved in combinatorial bgr

• Particles from decay:
→ Lorentzboost
→ particles may be emitted in direction of flight

Harder momentum spectrum expected for particles from decay

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

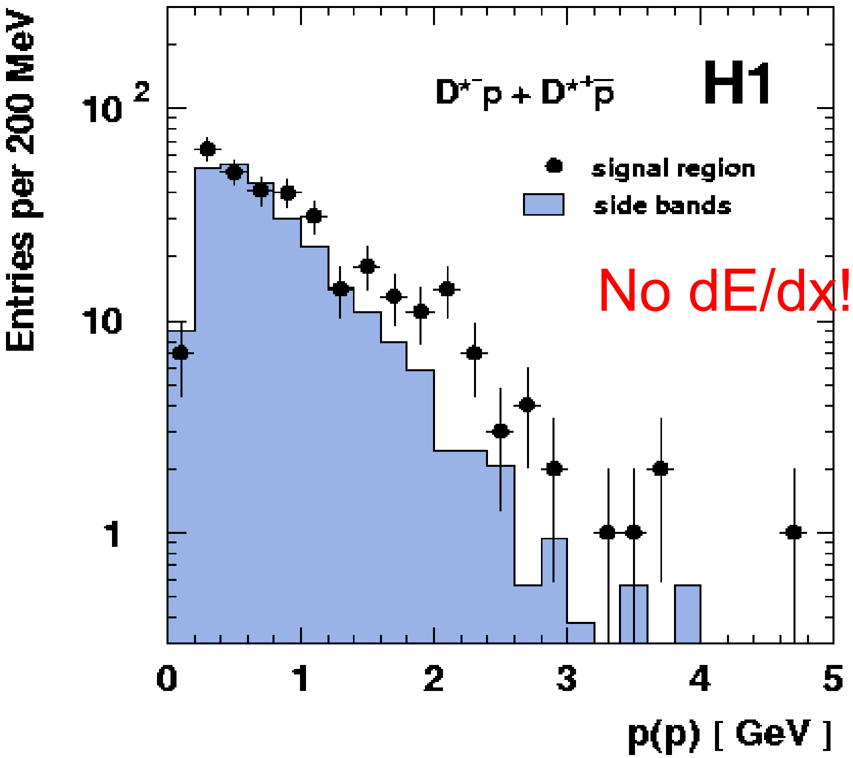
<u>example: π_s from D* (looser selection)</u>



How does it look for protons from D*p?

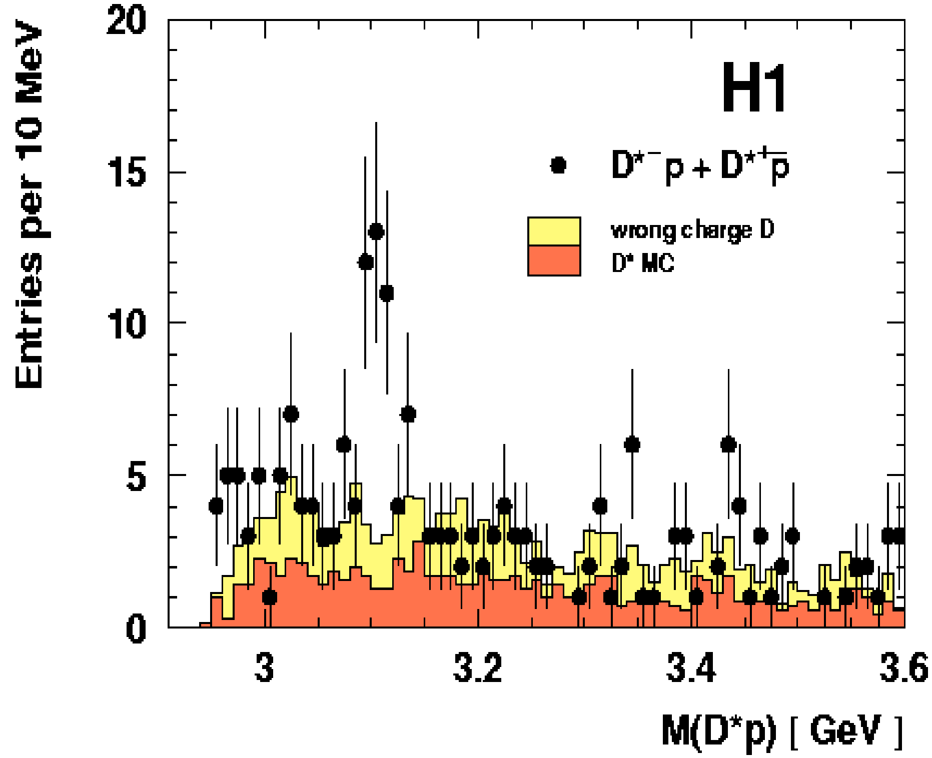
on and off resonance kinematics

momentum distribution of proton candidates (no particle identification)



Proton momentum spectrum harder for signal region than for sidebands

better S/B for higher momenta? D*p combinations for p(p)>2GeV (no proton selection)

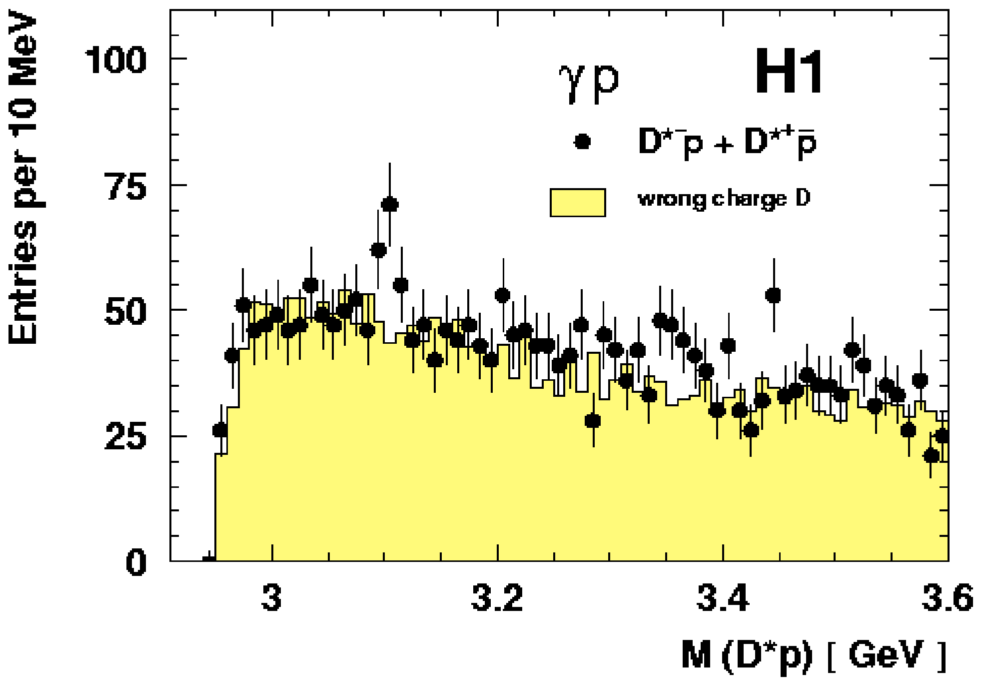


prominent signal is visible

Independent confirmation? Photoproduction analysis

$\gamma p, Q^2 < 1 GeV^2$

- Total: 4900 D*
- D*p peak at the same mass in γp
- larger bgr than in DIS
  non-charm bgr dominant (95%)
  well described by wrong charge D
- no enhancement in non-charm bgr

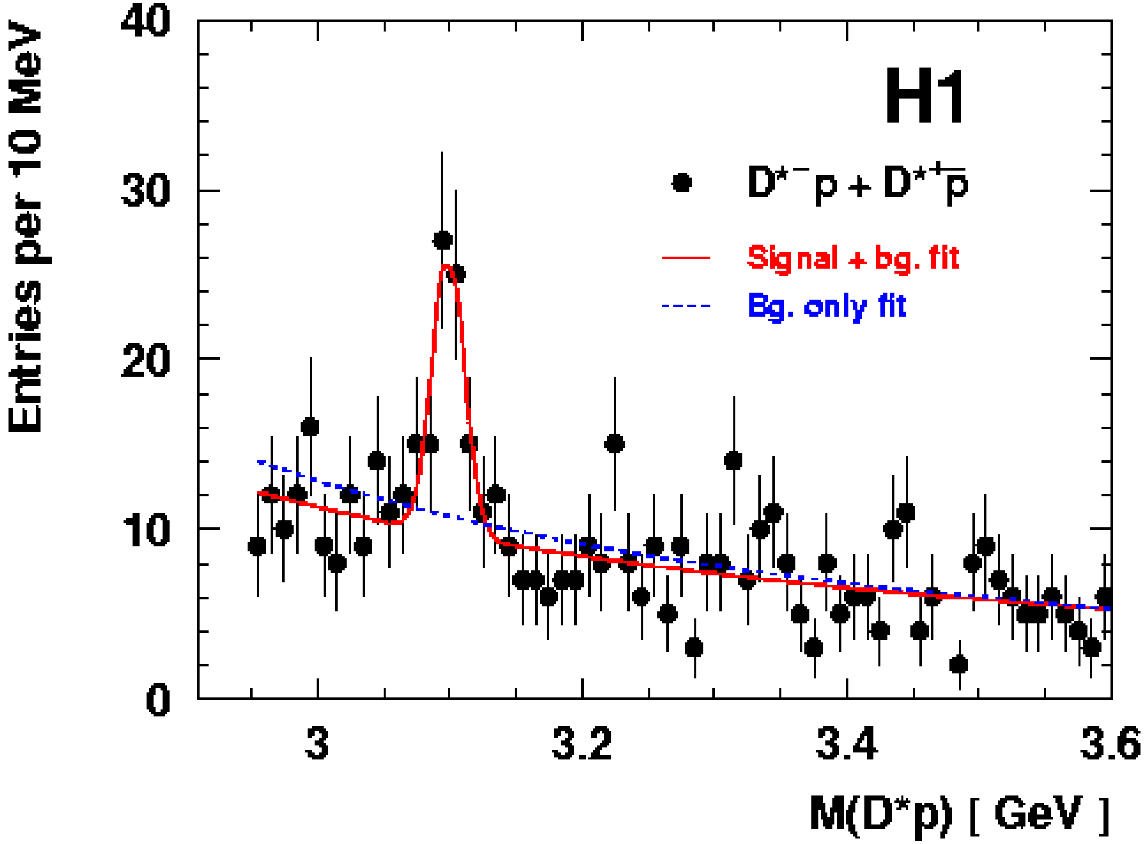


non-charm bgr dominant

no enhancement in wrong charge D

independent confirmation of the signal

Signal significance



signal+background fit:

mass:
3099 ± 3(stat) ± 5(syst.) MeV
width: 12 ± 3 MeV
(cons. with exp. resolution)

Numbers of signal and bgr
N_b=45.0 ± 2.8
(within ± 2σ =± 24MeV)
N_S=50.6 ±11.2
(1.46 ± 0.32 % of D* yield, uncorrected in acceptance)

for significance estimate:
bgr only hypothesis fit
N_b=51.7 +- 2.7
events in signal region: 95

Background fluctuation probability (52 → 95) :
4 x 10^{-8} (Poisson)
5.4 σ (Gauss)

Summary

- evidence for a neutral anti-charmed baryon state decaying to D*p in deep-inelastic scattering

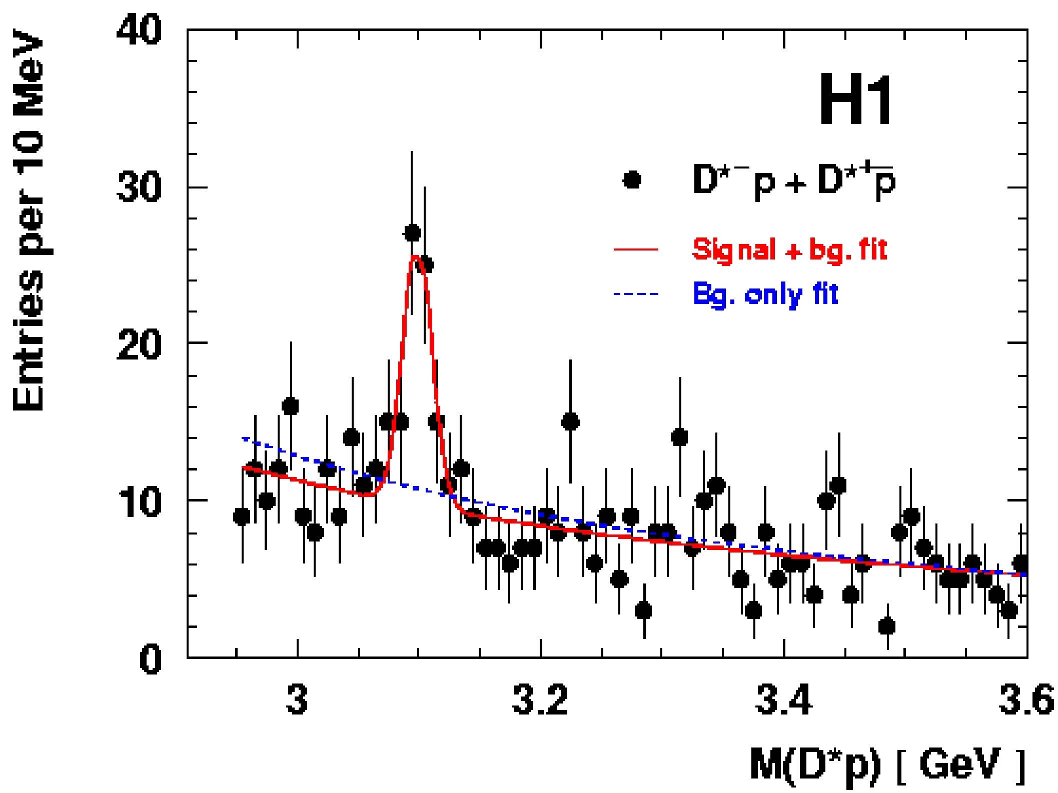
- signal is due to D* and protons
- harder proton momentum spectrum observed in the signal region than in sidebands as expected for decay
- Independent confirmation of signal in photoproduction

- probability for signal due to background fluctuation:
  4×10^{-8} (Poisson) corresponding to 5.4 σ (Gauss)

- directly comparible experiment: ZEUS
  controversy between ZEUS and H1 not settled

Backup slides

Details of fit



Charges	M[MeV]	[MeV]	N_S
$D^{*-}p + D^{*+}\bar{p}$	3099 ± 3	12 ± 3	50.6 ± 11.2
$D^{*-}p$	3102 ± 3	9 ± 3	25.8 ± 7.1
$D^{*+}\bar{p}$	3096 ± 6	13 ± 6	23.4 ± 8.6

All Checks (I)

check events

•signal events scanned visually: no anomalies

• double entries ?

1.) Within +- 24 MeV around peak: 1 double entry

2.) All M(D*p) < 3.6 GeV: 1.12 entries / event

signal from D*,p?

• backward D* analysis: signal region D* rich

• well identified protons (p<1.2, hard dE/dx): signal there

average norm. likelihood in signal region $\langle L_p \rangle = 0.92$

physics in signal and bgr region?

• physics on/off resonance: proton spectrum harder on resonance

peak stable?

• signal present in subsamples (in Q^2, x, y, η, p_t, data taking period)

• variations of binning and selection: mass, width stable

• signal present in photoproduction

All Checks (II)

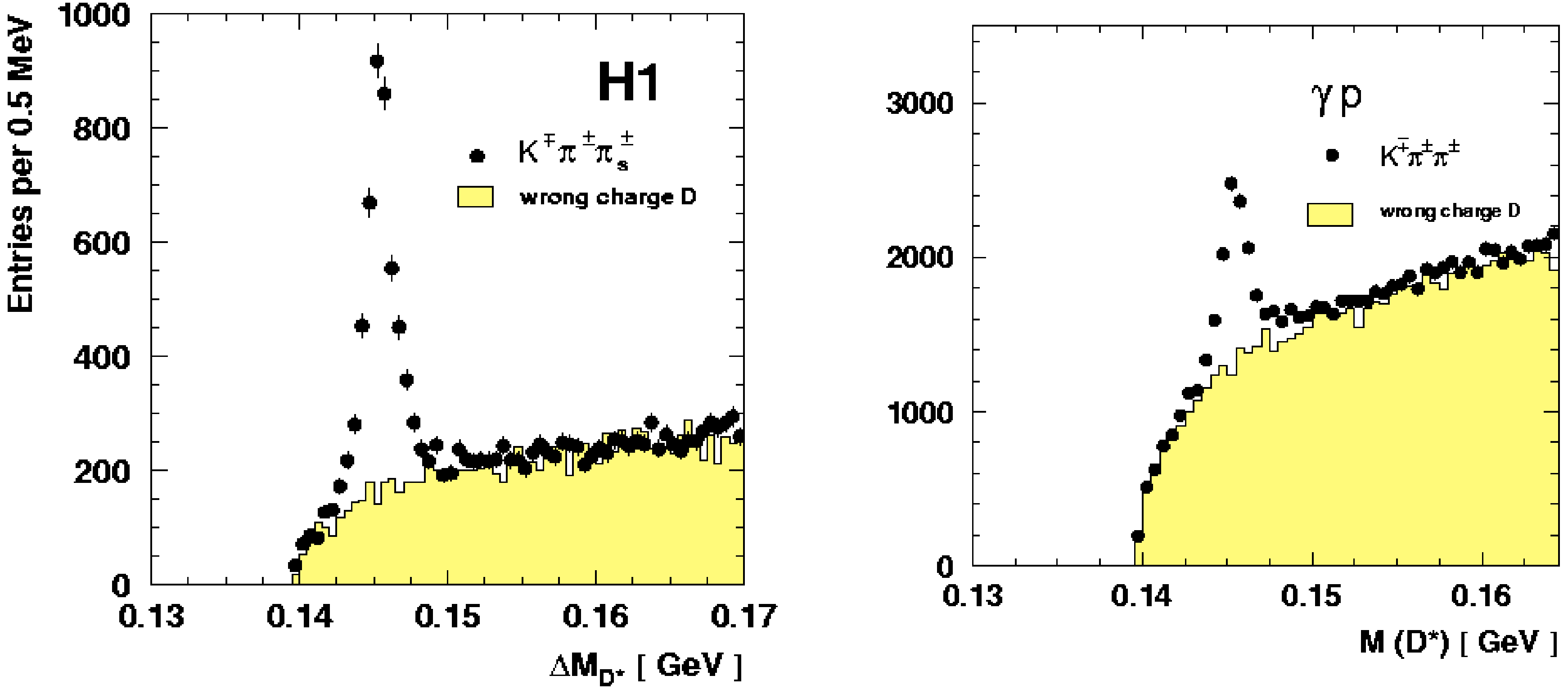
signal from bgr or from D*, protons?

- wrong charge D bgr instead of real D*: no peak
- D* sidebands instead of $\Delta M(D^*)$ signal window: no peak
- K, π selected (via dE/dx) instead of protons (p-mass assigned): no peak
- $K\pi$ combinations with masses above region where charm contributes: no peak

check refelections

- protons assigned K, π mass: no peak
- Invariant masses m(pK), m(pπ), m(pπ_s) and all other possible 2-particle masses: no res. structures
- reflections from D_1^0, D_2^{0*}: expected contribution (MC): 4 evts (±24MeV)
- Signal due to $D^{*0} \rightarrow D^0 \gamma \rightarrow D^0 e^+ e^-$? no (electrons misidentified as πs and proton)

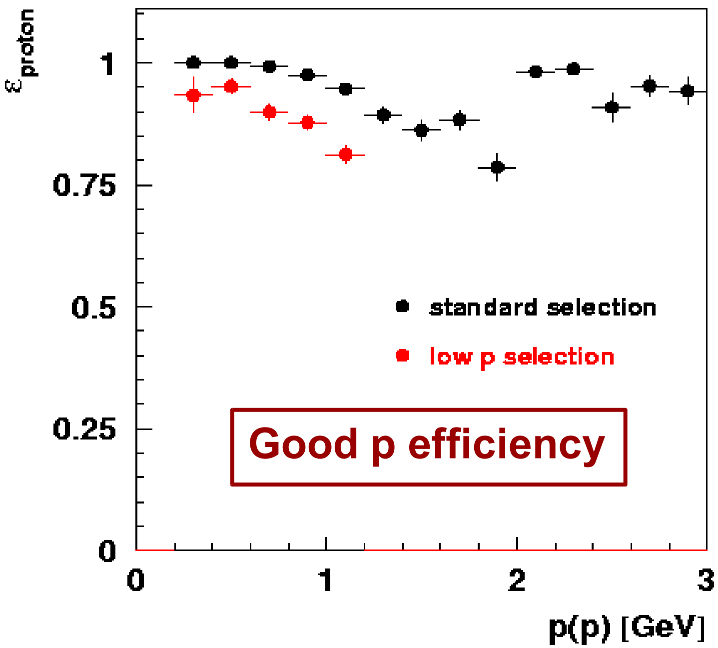
D* signal in DIS and photoproduction



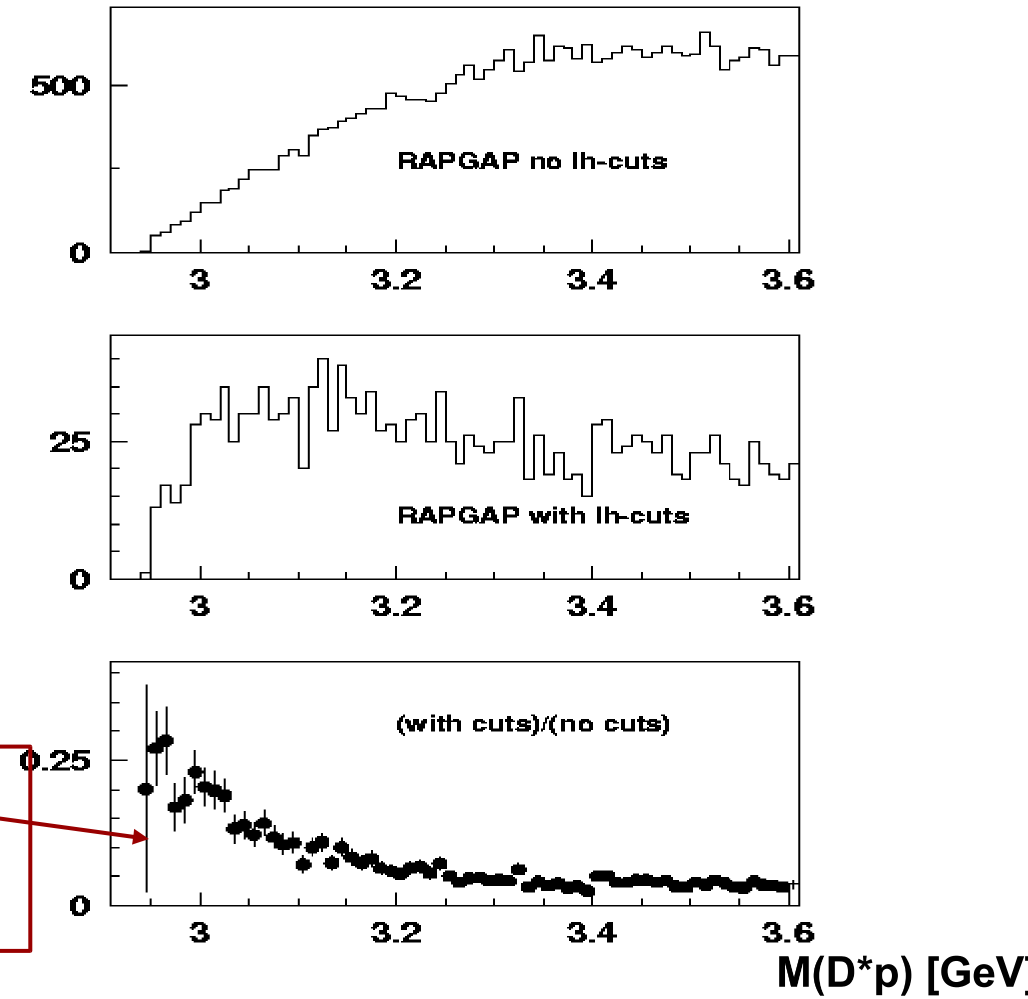
- DIS cleaner signal
- photoproduction: supporting evidence

Acceptance effects?

Proton efficiency



"Pion survival probability"



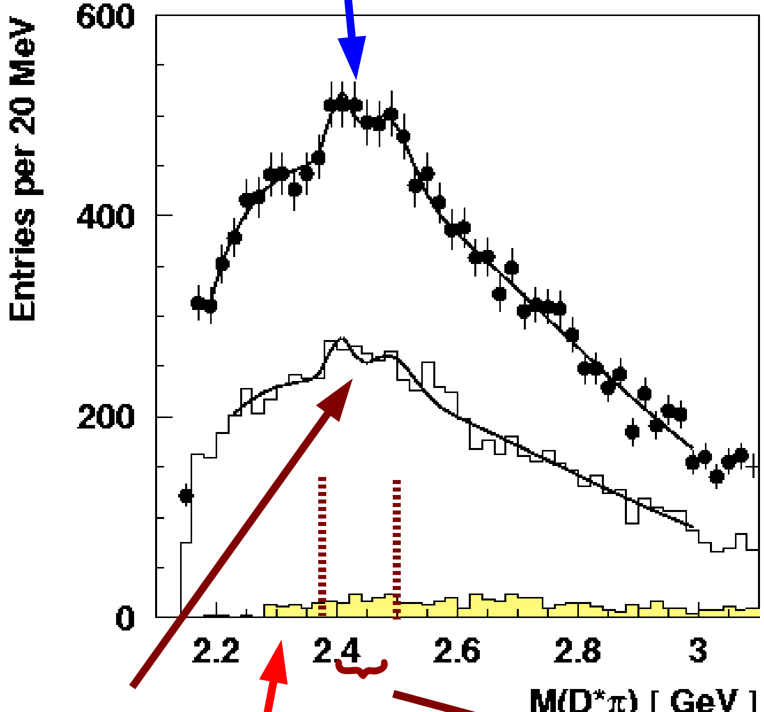
Smooth variation with M(D*p)
Shape reflects opening of phase space

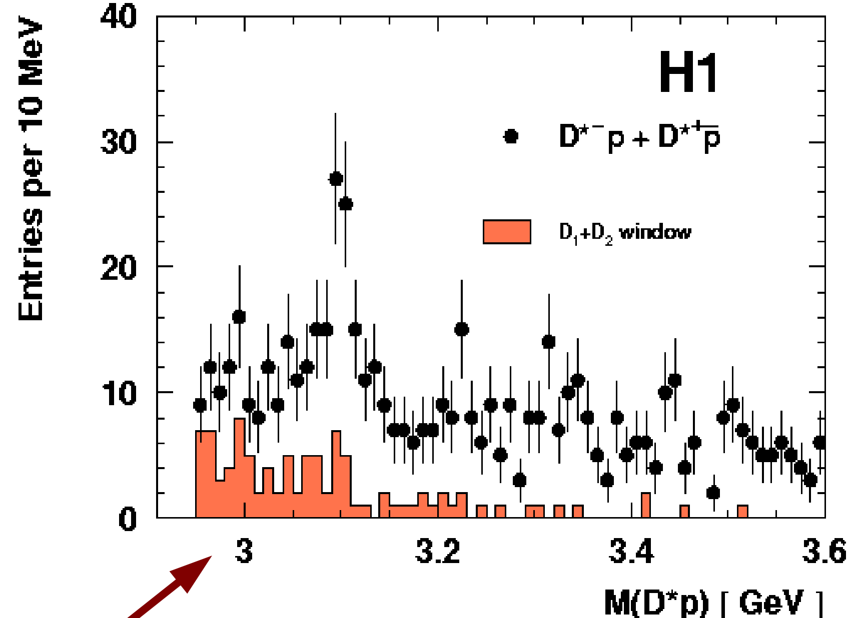
$$M(D^*p) = m(K\pi\pi p) - m(K\pi\pi) + M_{PDG}(D^*)$$

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

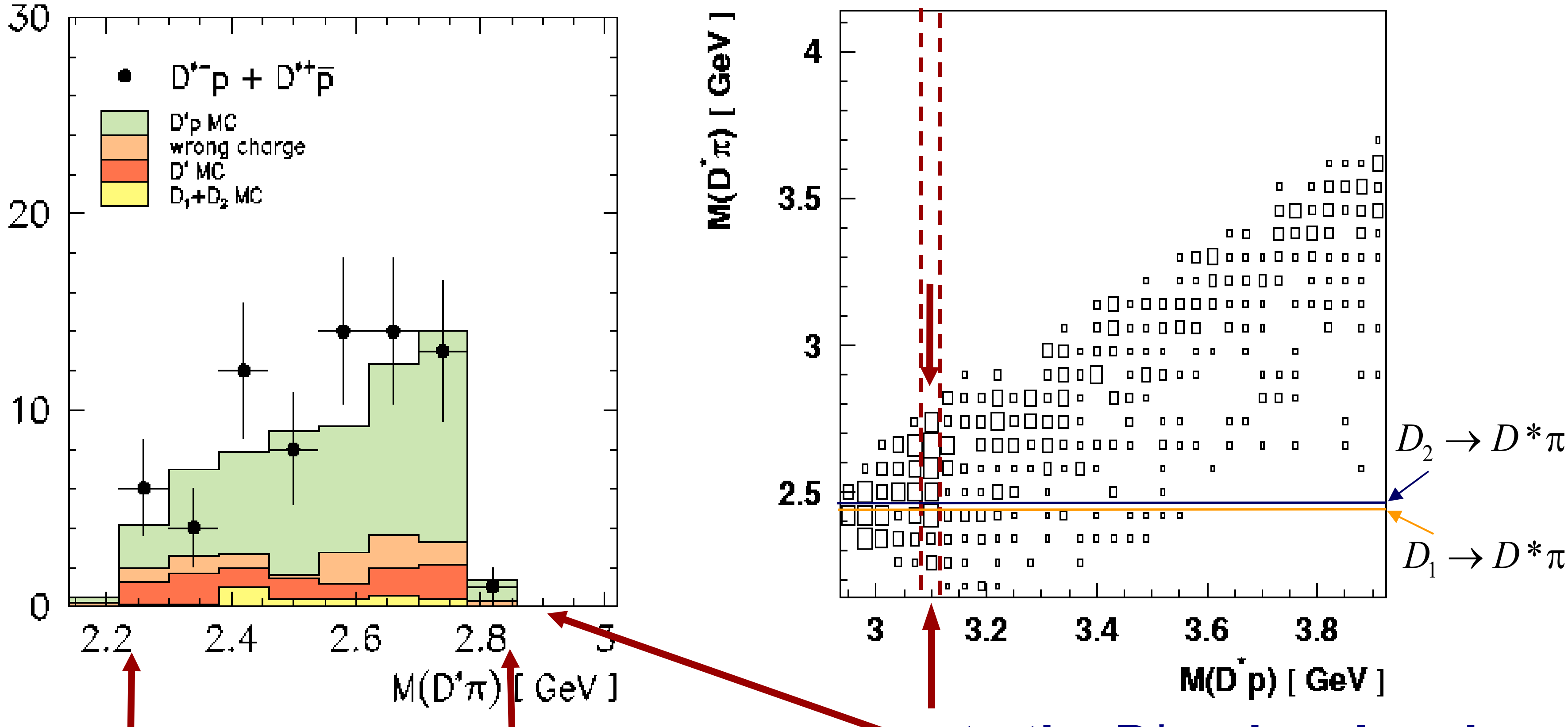
D* cuts of D*p
proton selection

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$_2^{0*}$ $\longrightarrow$ D*π



Signal for X$\longrightarrow$D*p: available phase space in D*π completely used

go to the D*p signal region

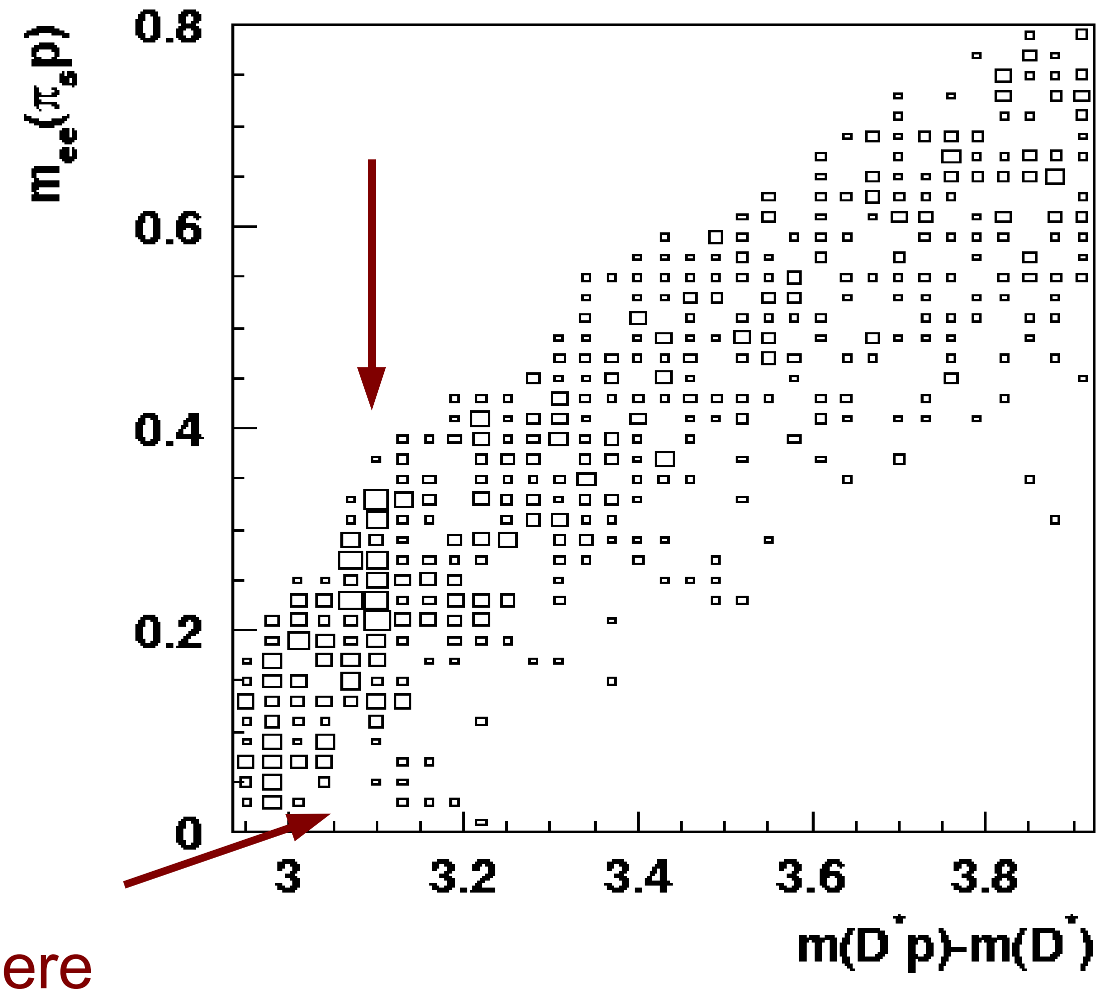
Within ±24 MeV around D*p signal:
4 events from D$_1^0$, D$_2^{0*}$ expected

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

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

electrons

- asymmetric in energy
- misidentified as proton and π_s ?



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

Non observation at ZEUS

D* decay channels:

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

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

> 60000 D*

DIS (Q^2>1GeV^2) and photoproduction (Q^2<1GeV^2)
1995-2000 data, 127 pb^{-1}

No peak observed
results not compatible with H1

Upper limit on $R(\theta^0_c \rightarrow D^*p/D^*)$: 0.35%
(both channles, Q^2>1GeV^2)