Heavy flavour production at HERA

Katerina Lipka DESY Zeuthen

➡ **charm and beauty production**

- open charm production cross sections, charm contribution to F_2
- open beauty production cross sections
- charm and beauty contributions to F_2 at high Q^2

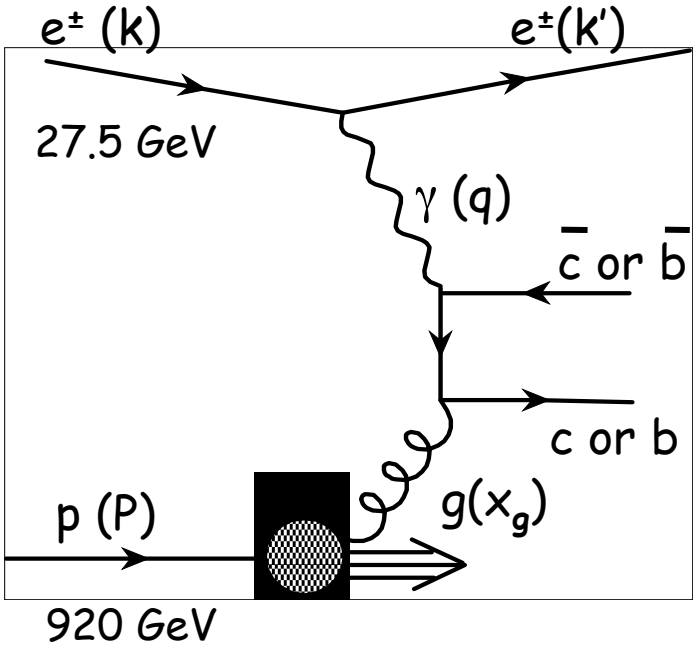
➡ **evidence for an anti-charmed baryon state**

QCD 2004 Montpellier

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: $\sqrt{s}$ = 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
- $Q^2 > 1$ GeV^2 : Electroproduction, DIS

Factorization:

proton structure $\otimes$ $\sigma_{\gamma g \rightarrow q\bar{q}}$ $\otimes$ photon structure $\otimes$ fragmentation function

m_c, m_b → hard scale for pQCD calculations

Models for heavy flavour production

proton structure $\otimes$ $\sigma_{\gamma g \to q\bar{q}}$ $\otimes$ photon structure $\otimes$ fragmentation function

- **proton structure:**
  - CCFM evolution of PDF
  - DGLAP evolution of PDF
- **photon structure:**
  - direct (pointlike photon)
  - resolved (hadron-like photon)
  - heavy flavour excitation
- fragmentation: non-perturbative (e.g. Peterson fragmentation)

pQCD NLO calculations

- **"massive" approach ($Q^2 \approx m_c^2, m_b^2$)**

  massive c (b) produced in BGF

  - DIS: HVQDIS
  - Photoproduction: FMNR

- **"massless" approach ($Q^2 \gg m_c^2, m_b^2$)**

  massless c (b) : active flavour in p or γ

Open charm tagging via D*

- tag charm in "golden " channel: $D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow K^- \pi^+ \pi_s^+$ (+ c.c.)
- apply "mass difference method": $\Delta M(D^*) = M(K \pi \pi_s) - M(K \pi)$

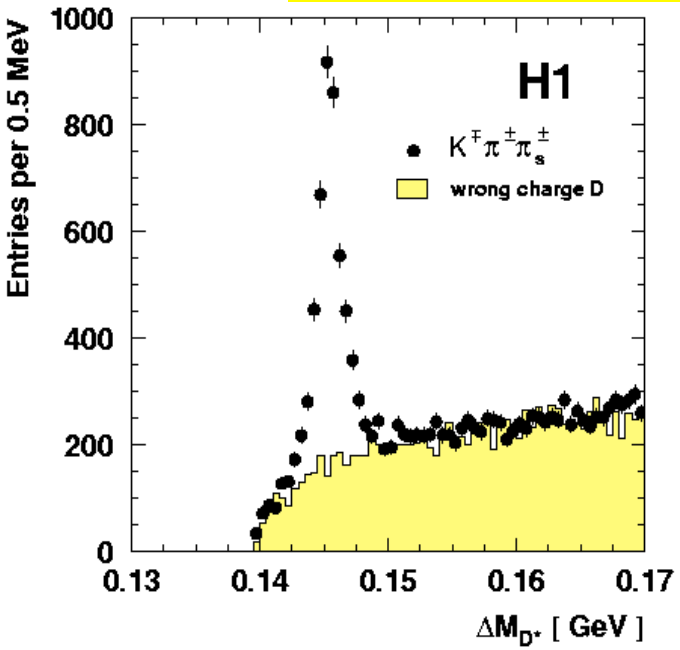
DIS:

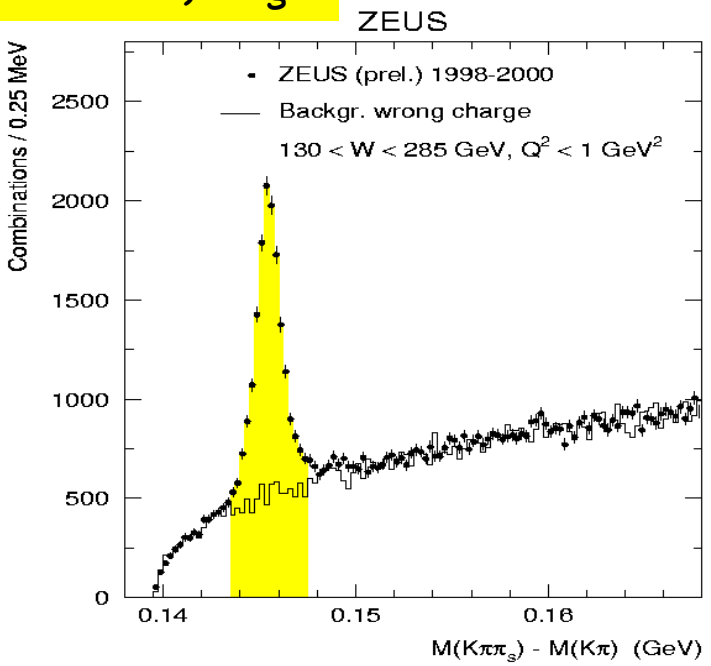
- scattered electron in calorimeter
- $1 < Q^2 < 100\ GeV^2$, $0.05 < y < 0.7$

Photoproduction:

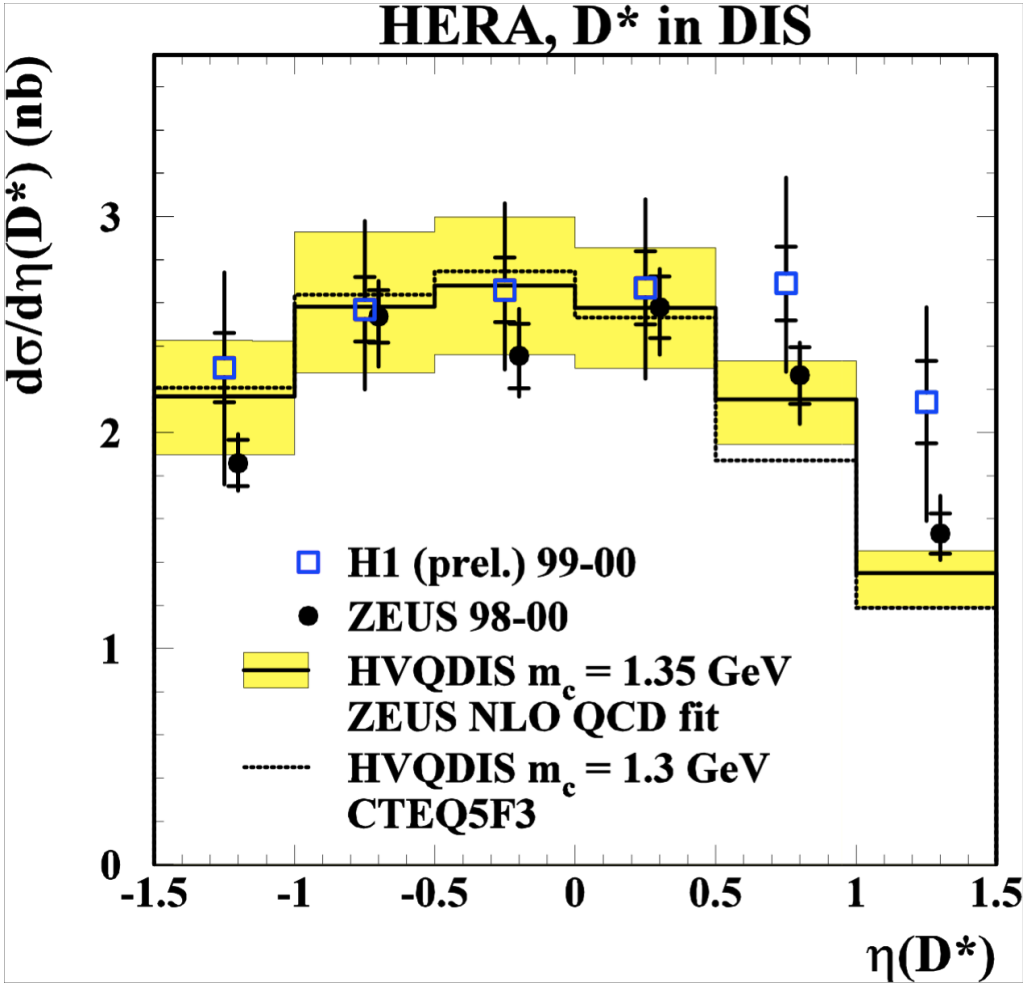
- electron escapes the main detector
- $Q^2 < 0.01\ GeV^2$

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





Differential DIS charm cross section



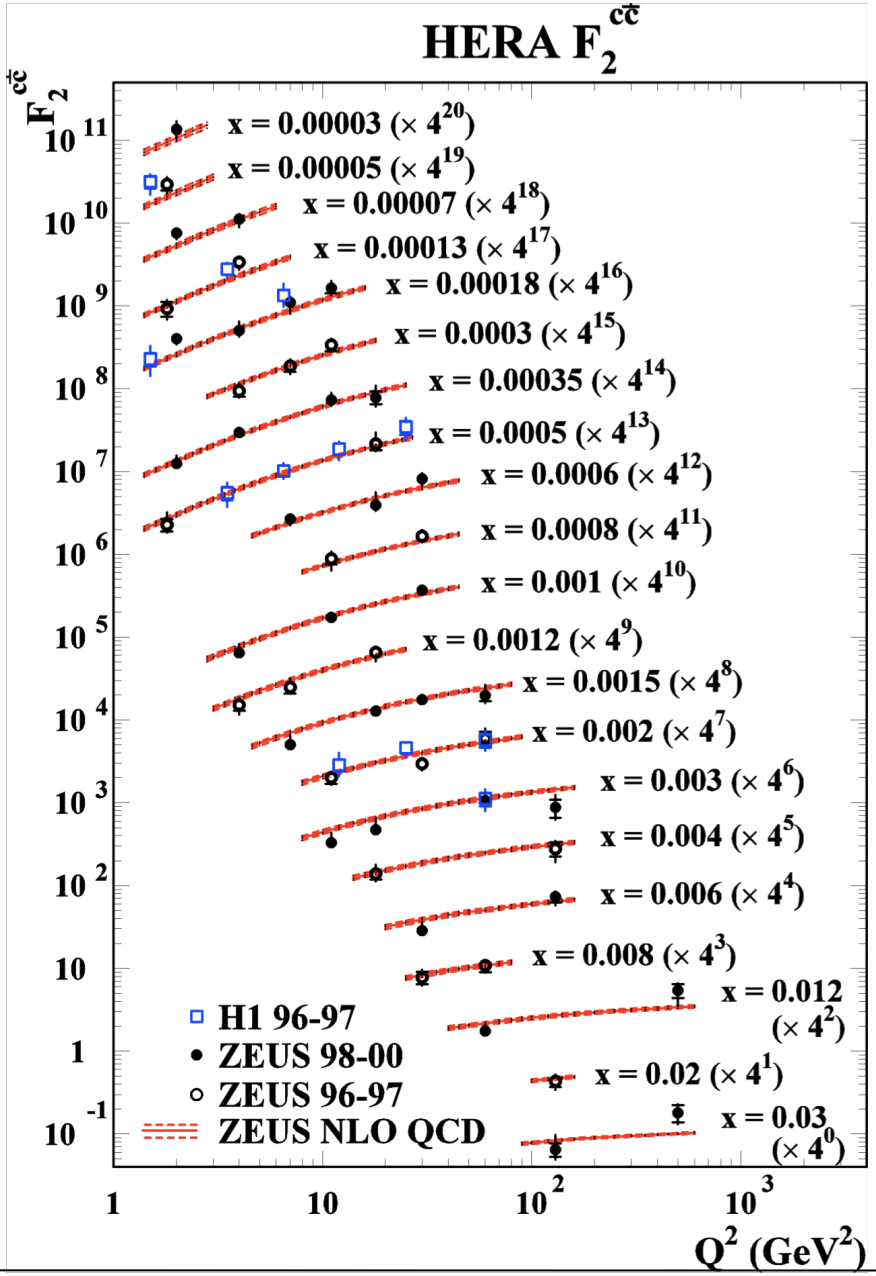
consistent with

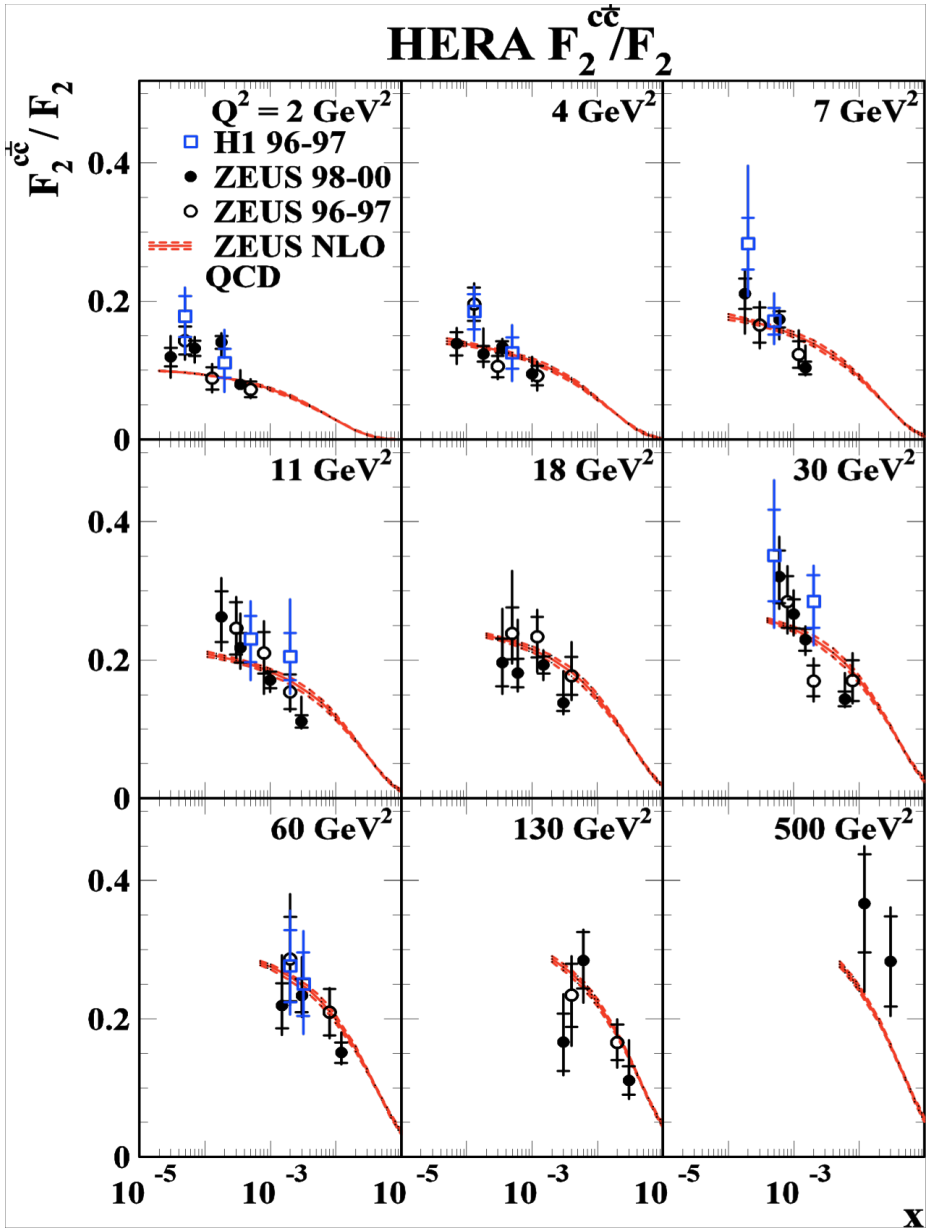
NLO calculations (massive)

<u>theoretical uncertainties due to:</u>

- proton PDF
- charm mass
- renormalization/factorization scale
- fragmentation

Charm contribution to proton structure function F_2

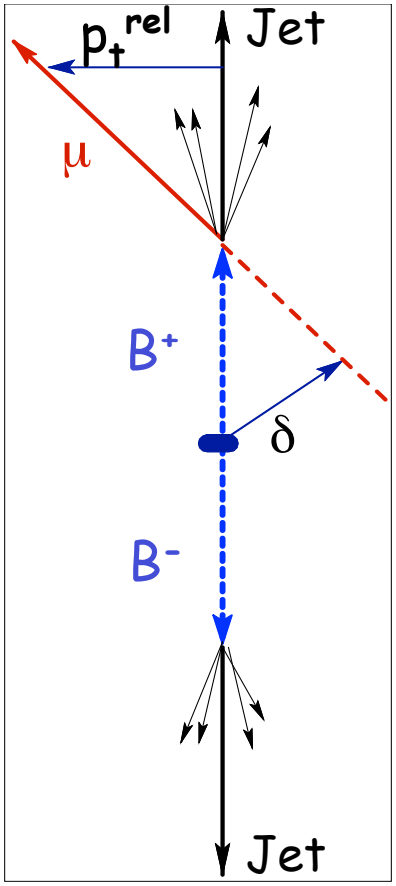




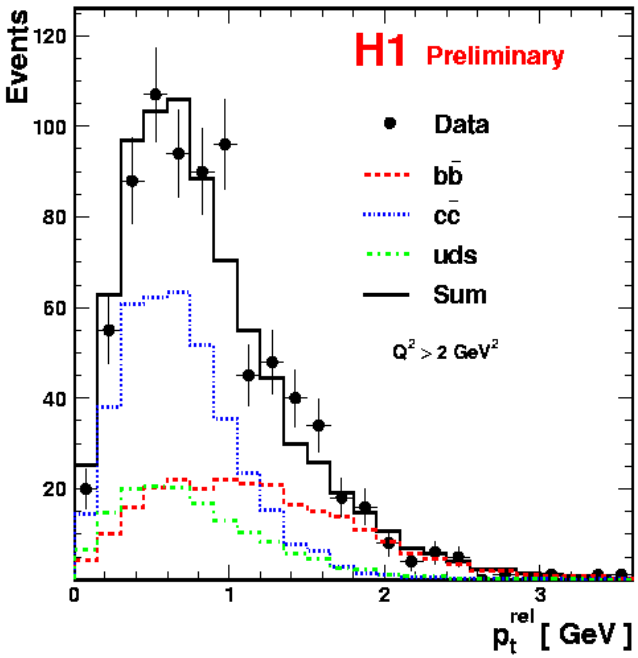
Open Beauty Production Measurement

Technique: inclusive semileptonic decays: $e^+p \to e^+ b\bar{b}X \to e^+ + \text{jet} + \mu^\pm + X$

- large b mass → muon p_t relative to the associated jet
- long b lifetime → impact parameter δ (measured with H1 Central Silicon Tracker)

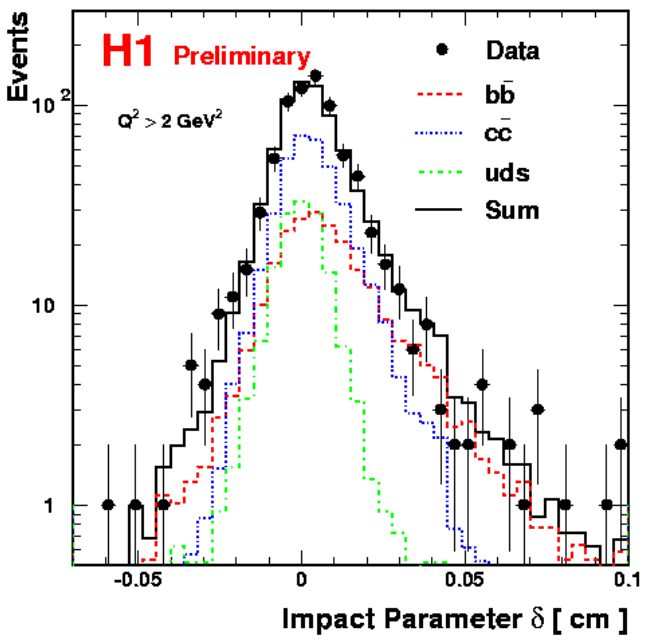


p_t^{rel}



$f_b = (28.8 \pm 2.8)$ %

δ

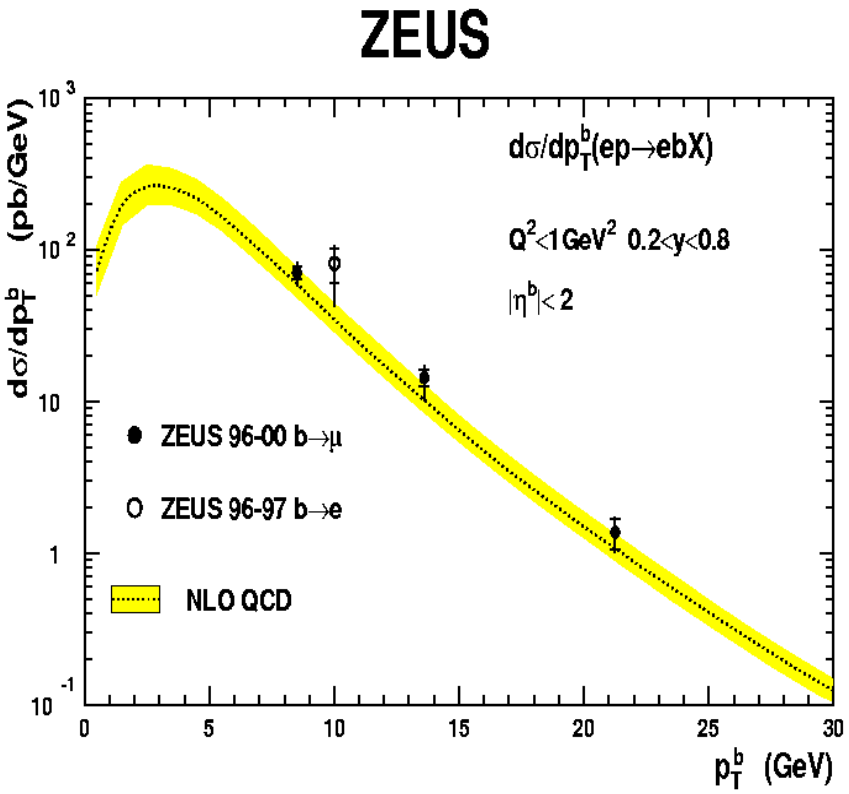


$f_b = (28.0 \pm 4.2)$ %

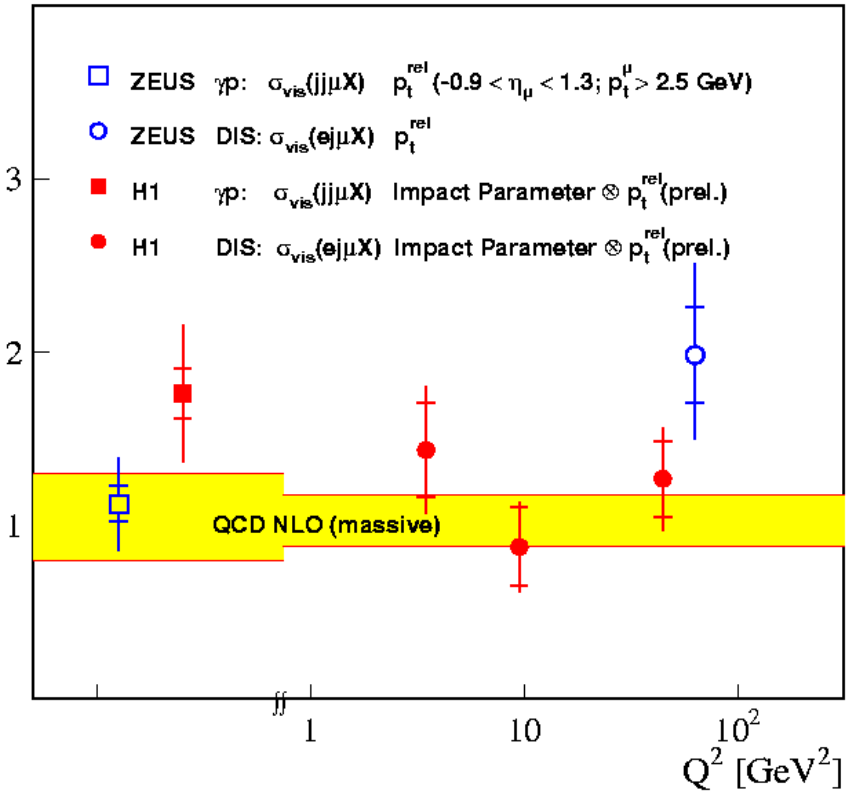
2-dimensional fit → beauty fraction $f_b = (30.7 \pm 2.5)$ %

Open Beauty Production Cross Sections

visible γp cross section



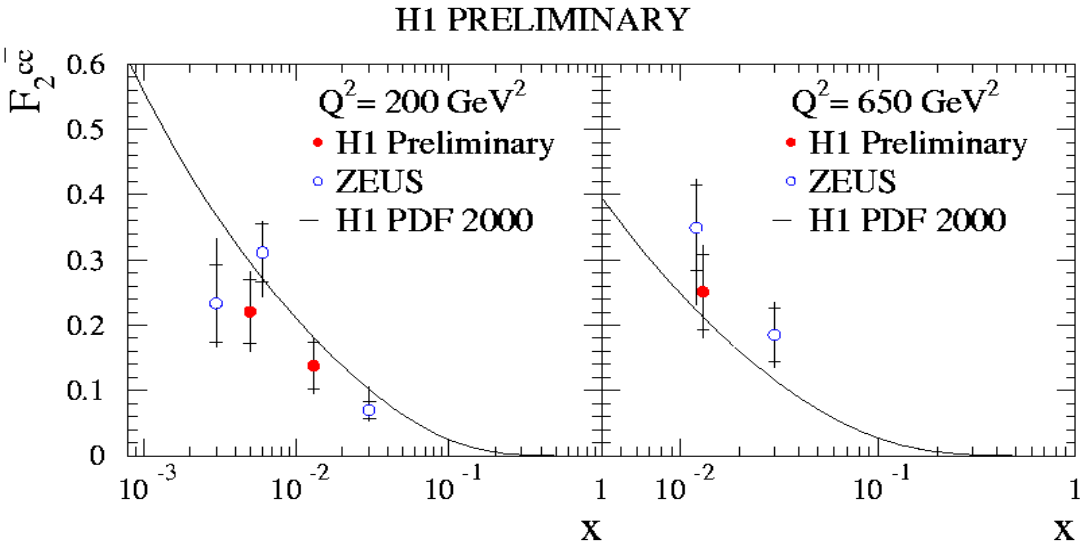
DIS and γp cross sections / Theory

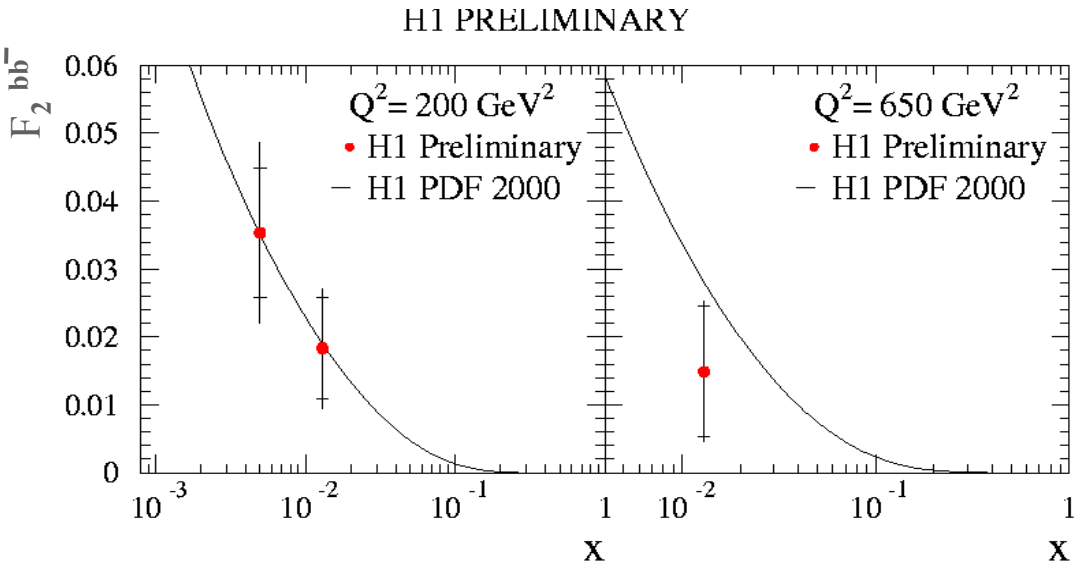


Consistent with the (massive) NLO calculation

Charm and Beauty Contributions to F_2 at high Q^2

Technique: flavour separation via lifetime of decay products





- **Kinematics:**

  $Q^2 > 110$ GeV^2, $0.07 < y < 0.7$

- **Method:** measurement of

  inclusive track impact parameter

(reconstructed in H1 Vertex Detector)

- **Extrapolation:** < 10%

F^c_2 , F^b_2 consistent with

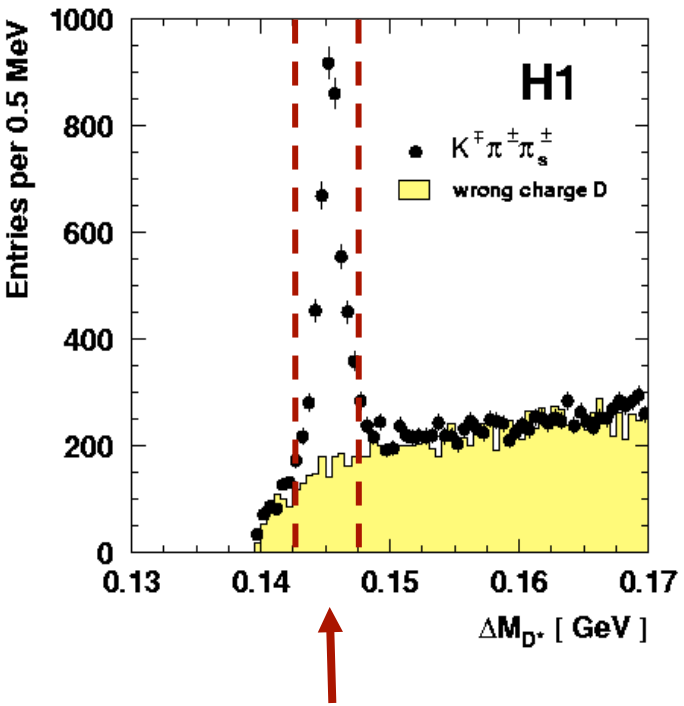
- QCD fits to H1 inclusive data (NLO, massless scheme)
- measurement via D*± (ZEUS)

Charm spectroscopy: exotic anti-charmed baryon state

search inspired by discoveries of the strange pentaquark: why not charm?

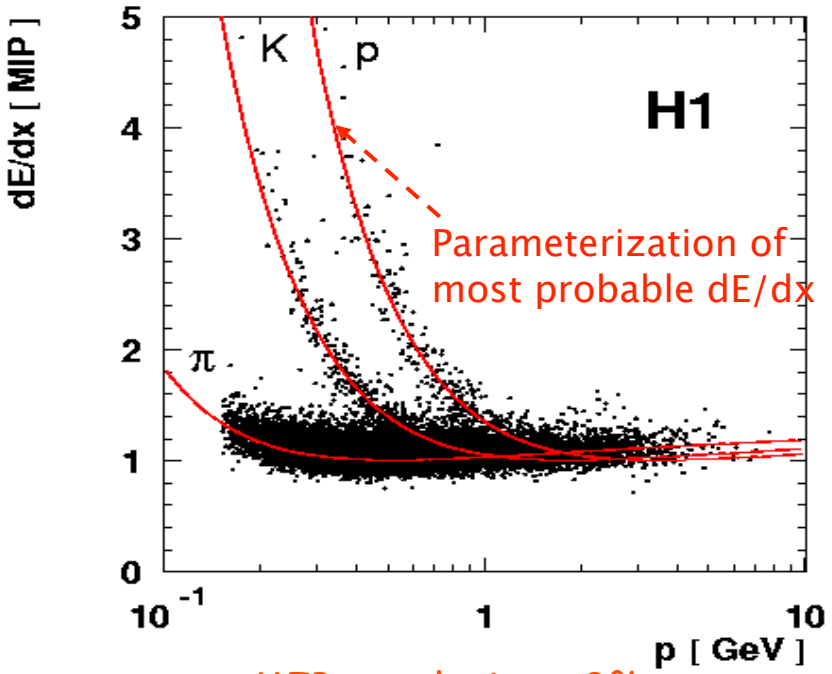
Experimentally suited signature: decay in $D^{*-}p$ ($D^{*+}\bar{p}$), data : DIS, L_{int}= 75 pb^{-1}

3400 D* selected:



events in 5 MeV window selected

Proton selection using dE/dx measurement



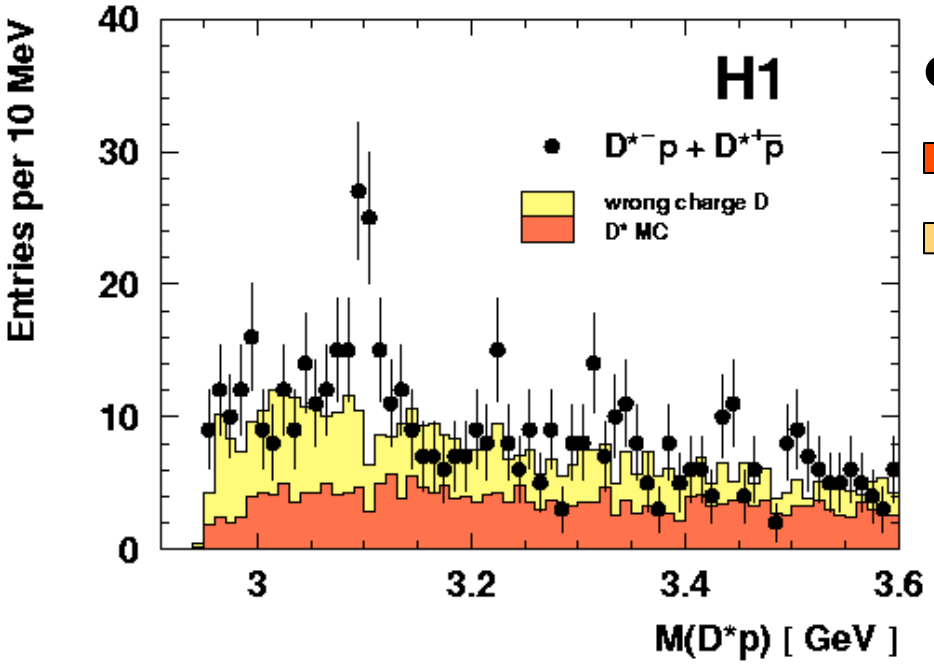
average MIP resolution : 8%

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

used for background suppression

D*p Mass Distribution

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



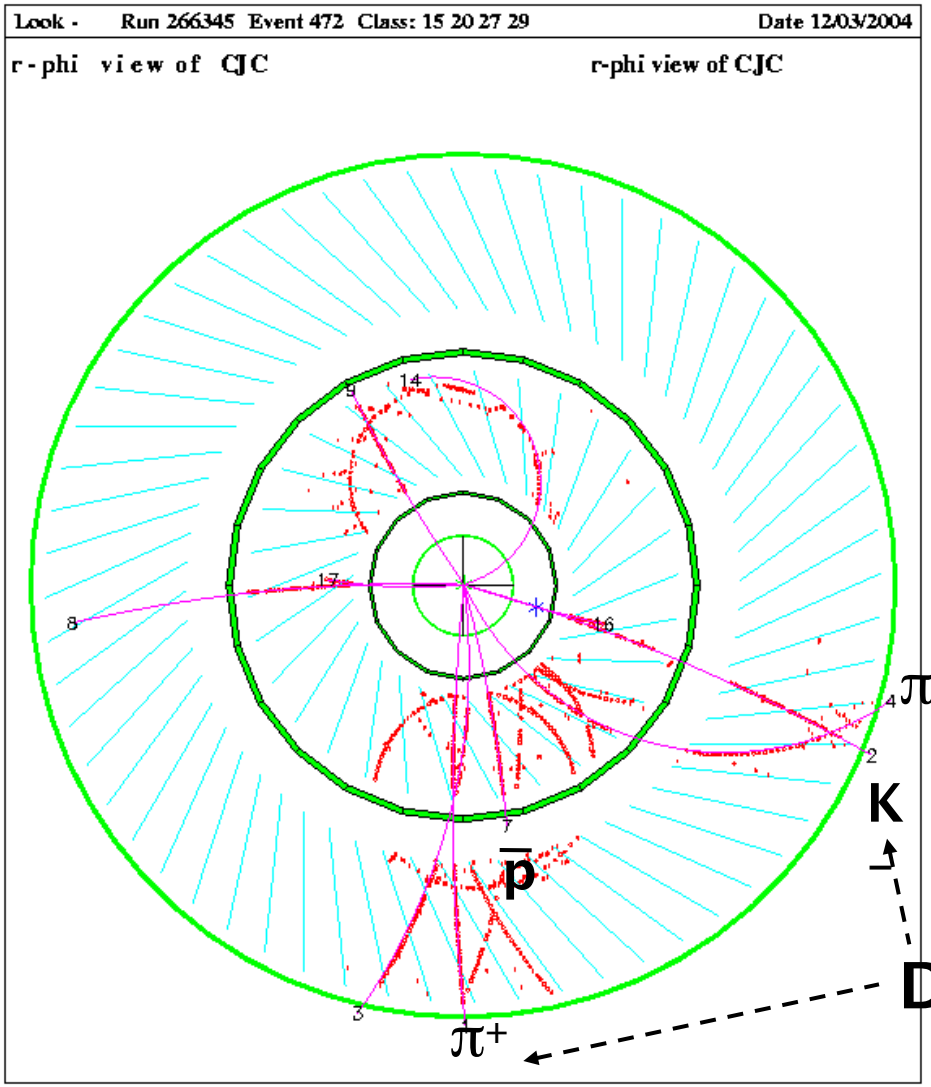
- significant peak in opposite charge D*p
- no enhancement in charm-induced background
- no enhancement in non-charm background

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
- no significant enhancement visible in like-charge D*p

A Typical Event

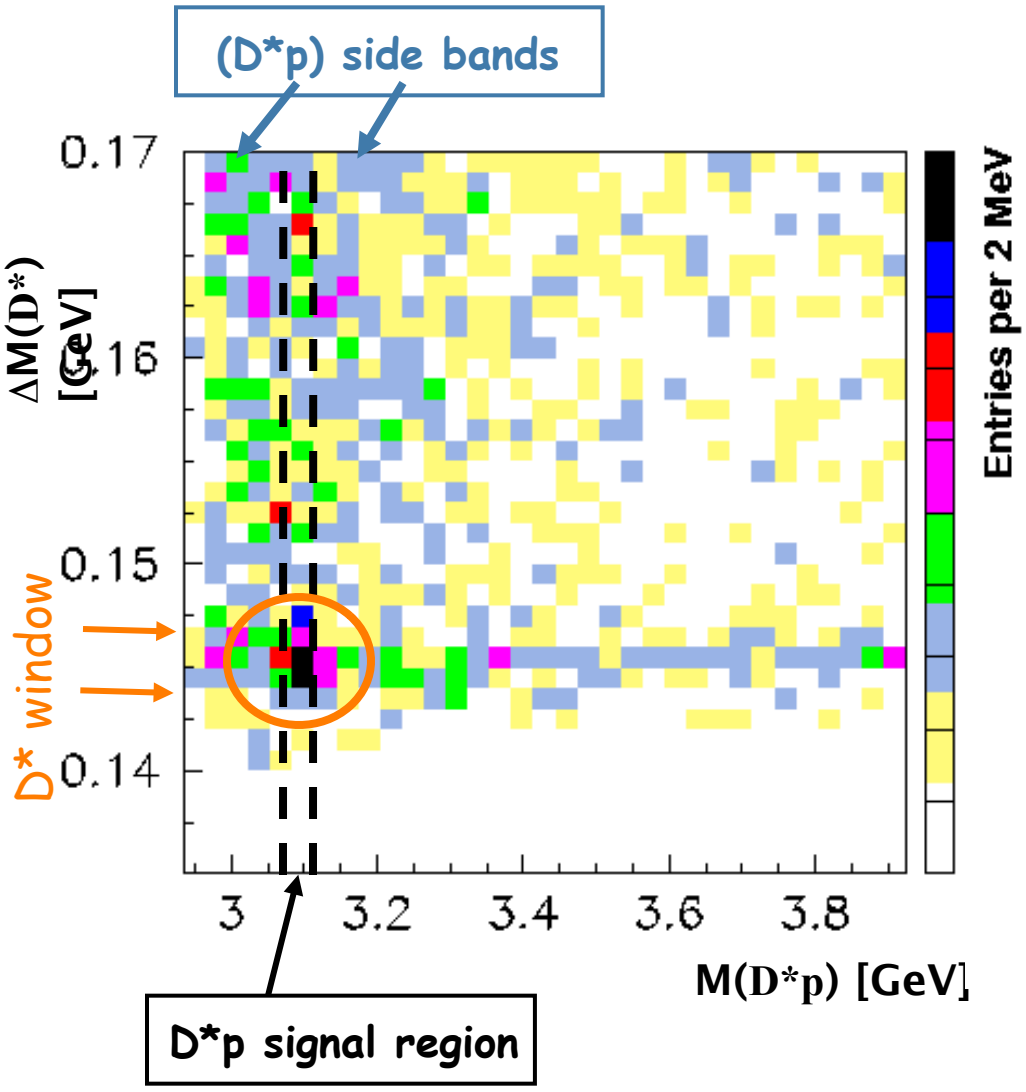


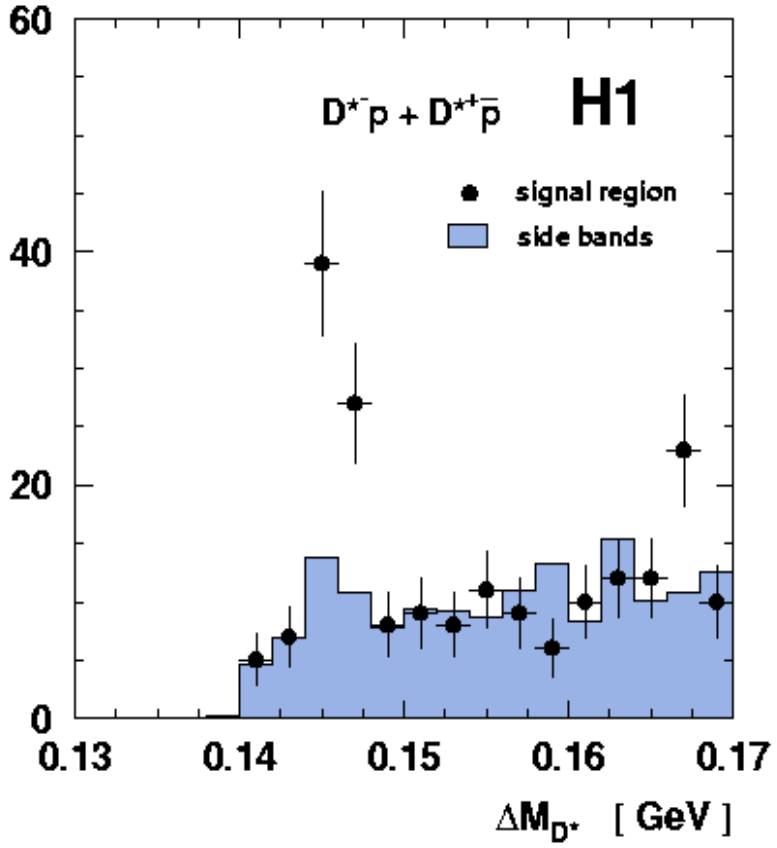
Events are scanned:

NO anomalies observed:

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

Does the resonance come from D*?





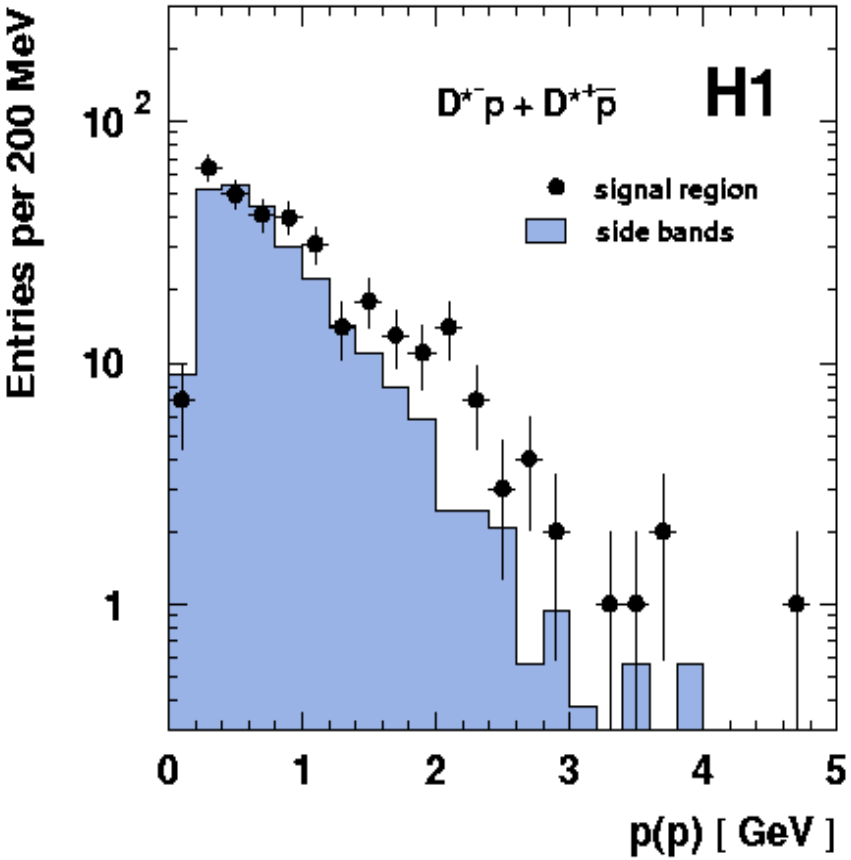
width of the windows in M(D*p) taken into account

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

Is the physics different in D*p signal region?

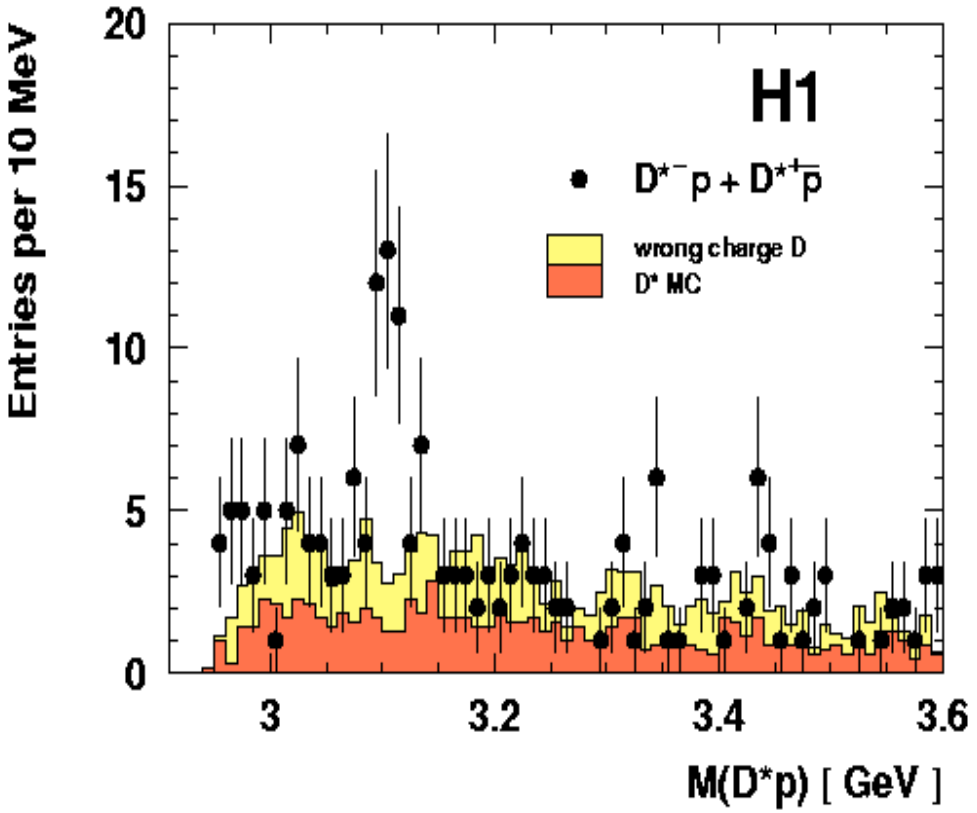
look into momentum distribution of proton candidates without dE/dx cut

momentum distribution in the signal region is harder than in sidebands



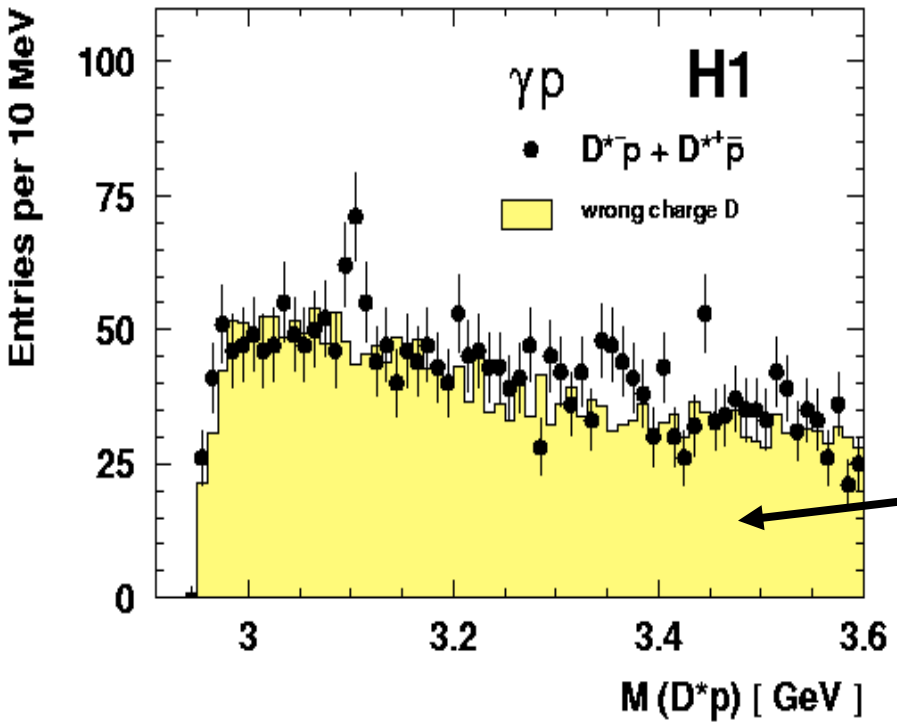
physics changes !

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



prominent signal is visible

D*p signal observed 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

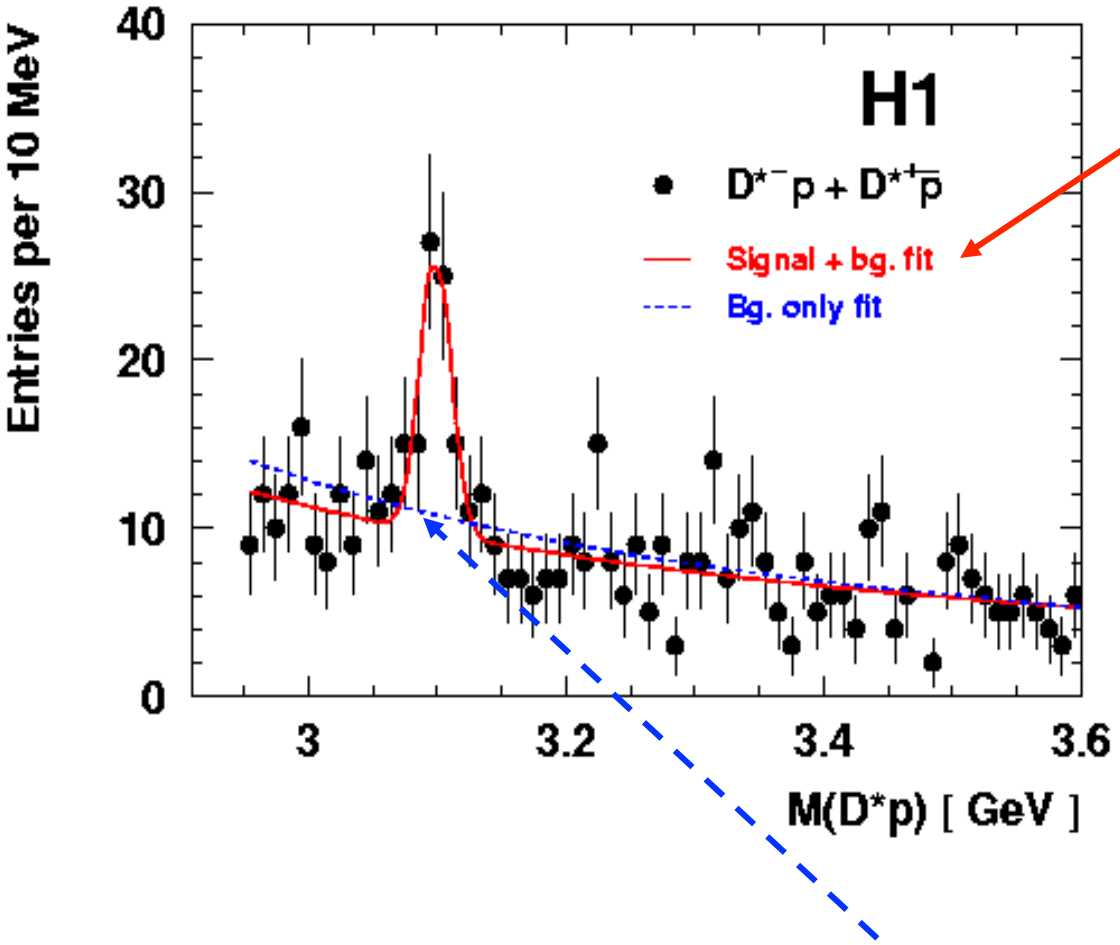
Background well described by wrong charge D from data

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 ± 2.8

N_s = 50.6 ± 11.2 (~ 1% of D* yield)

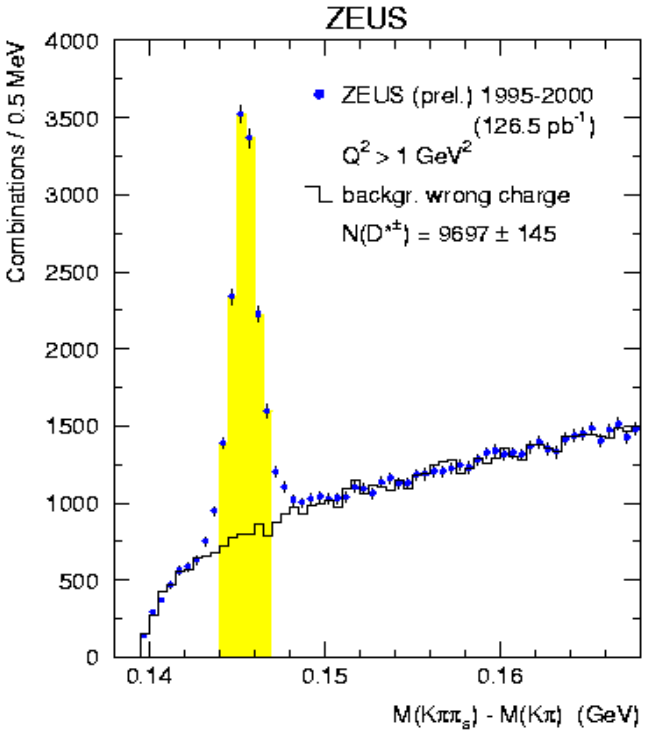
Significance estimate based on the background only hypothesis (binning free)

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

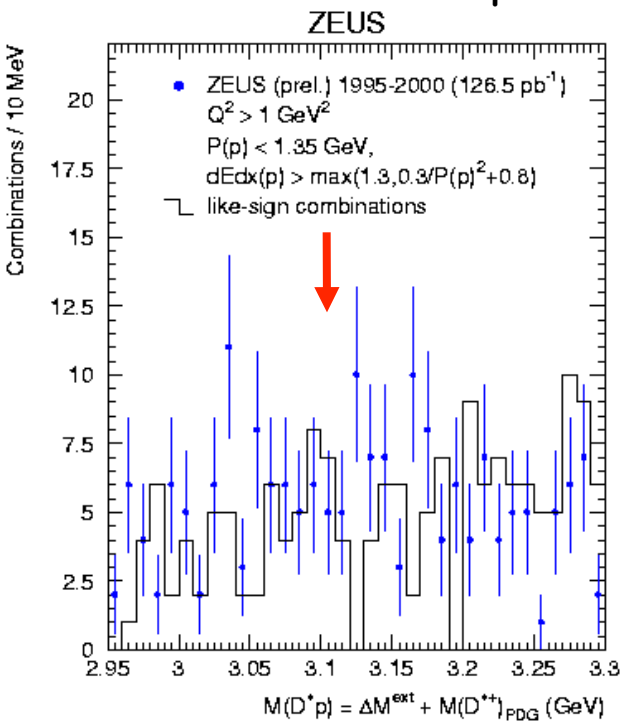
Search for D*p signal at ZEUS

- DIS D* sample 1995-2000, $Q^2 > 1$ GeV^2, selected ~ 9700 D*
  - $p_T(D^*) > 1.35$ GeV, $|\eta_{D^*}| < 1.6$, $dE/dx\,(p) < 1/P(p)^2 + 1.2$

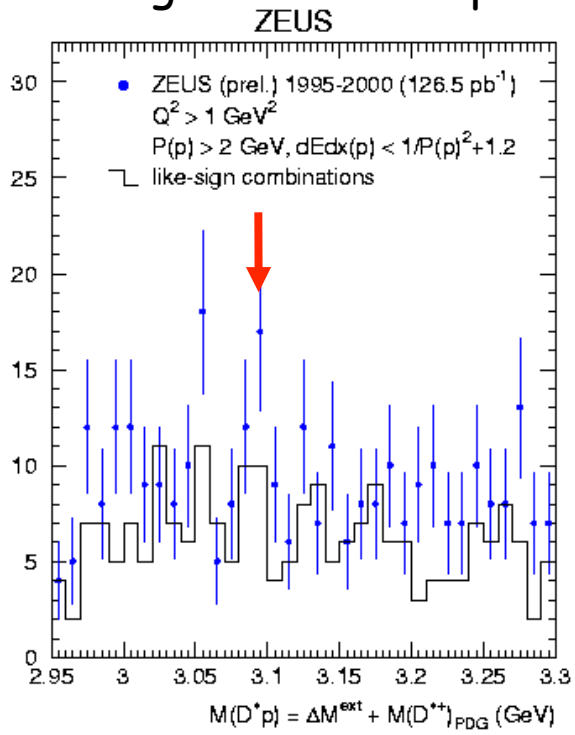
ZEUS **PRELIMINARY:**



low momentum p



high momentum p



– no evidence for a signal at 3.1 GeV

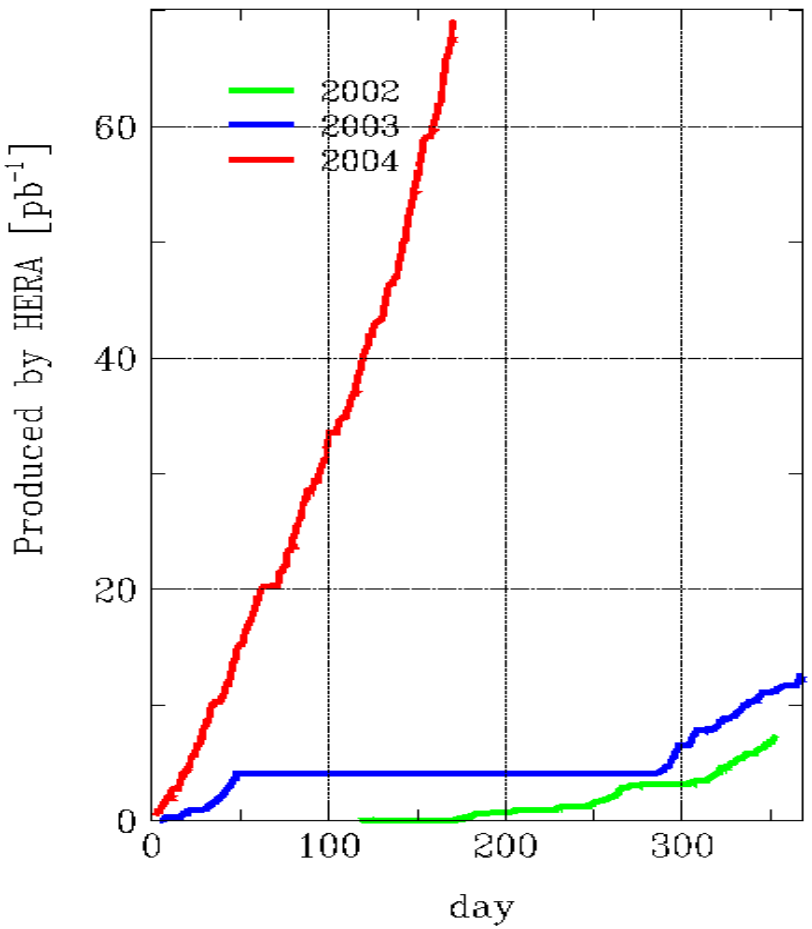
- Photoproduction (~ 43000 D* candidates): no evidence for a signal at 3.1 GeV

Summary

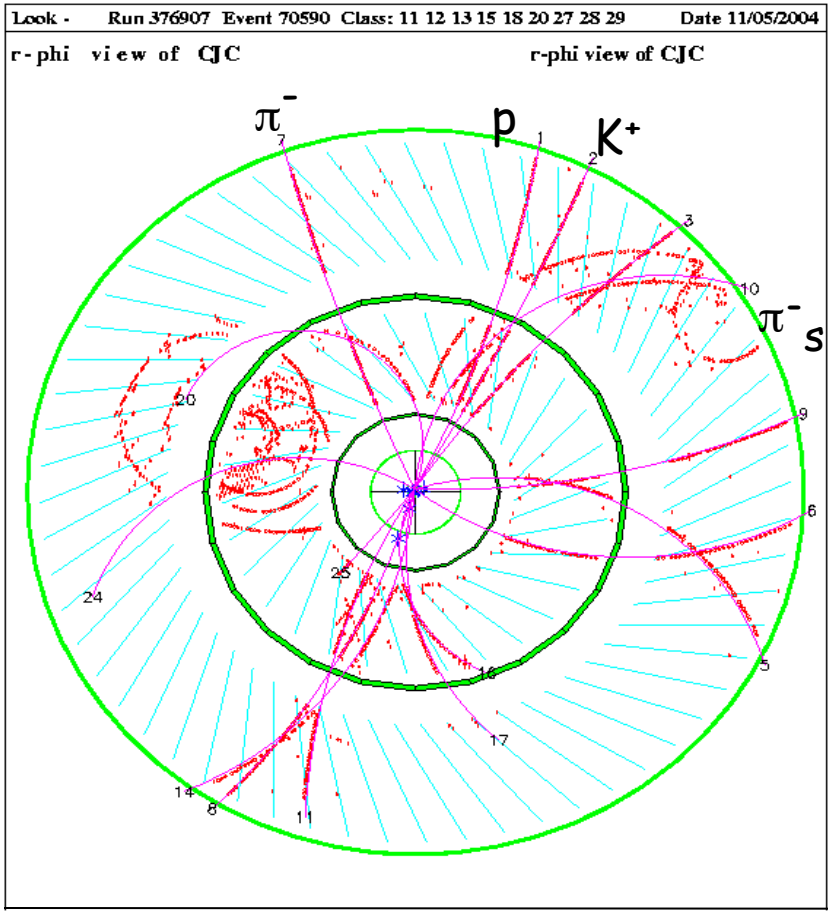
- **visible open charm cross sections in DIS**
  - NLO DGLAP agrees with HERA data
- **recent F_2^c measurement**
  - good agreement with NLO fits to inclusive data
    - ➡ constrain on the gluon density
  - large charm contribution to F_2
- **visible beauty cross sections**
  - consistent with NLO pQCD expectation
- **charm and beauty contribution to F_2 at high Q^2**
  - agreement with NLO pQCD fit to inclusive data
- **evidence for an exotic anti-charmed baryon state at H1**
  - decay into $D^{*-}p$ (+c.c.): quark content $uudd\underline{c}$ (+c.c.)
  - not confirmed by ZEUS

Outlook: HERA-II is on the way

HERA-II Luminosity



D*p candidate event in HERA-II



Stay tuned for more charming, beautiful and exotic data from HERA !

Thank you!

Spare slides

Charm and Beauty Contributions to F_2 at high Q^2

Technique: flavour separation via lifetime of decay products

- Kinematics: $Q^2 > 110\ GeV^2$, $0.07 < y < 0.7$
- Lifetime: indirect measurement via

  inclusive impact parameter δ (using H1 CST)
- Parameters: track significance S_1 and S_2

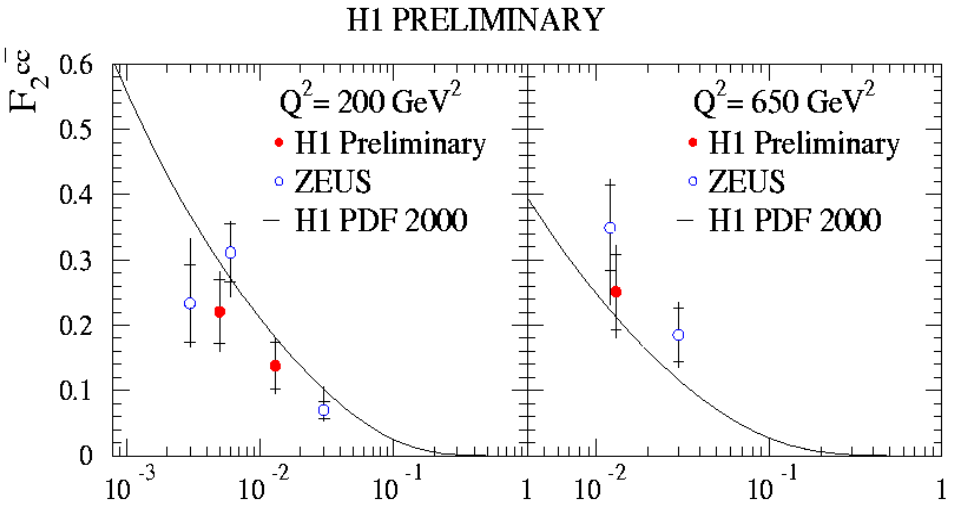
  $S_1 = \delta/\sigma(\delta)$ highest significance track,

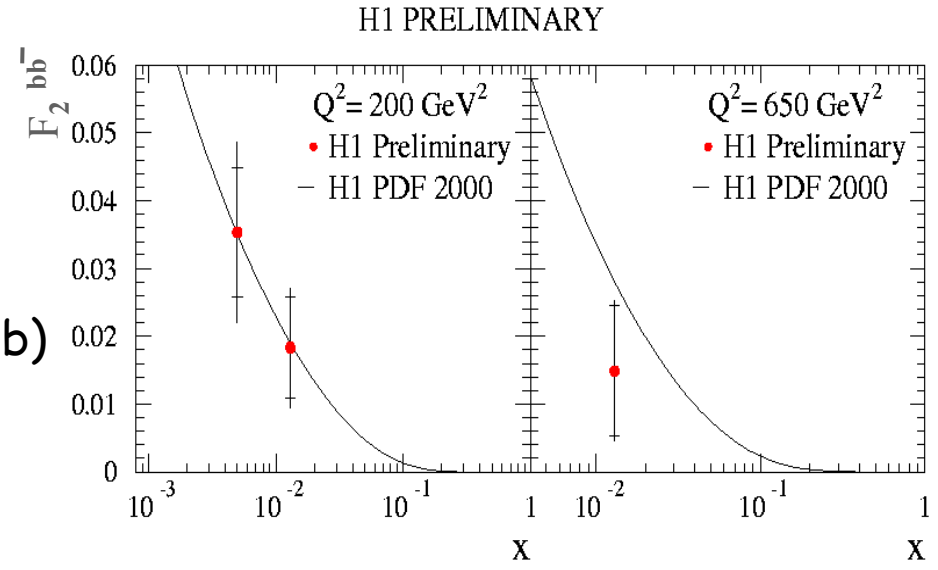
  S_2 - 2nd highest significance track
- Simultaneous fit to S_1 and S_2:

  quark fractions, differential cross sections,

  Contributions to F2 consistent with

  → extract $F_2^{c\bar{c}}$, $F_2^{b\bar{b}}$
- NLO QCD fits, (massless scheme for c, b)
- ZEUS measurement (tagging via D*±)



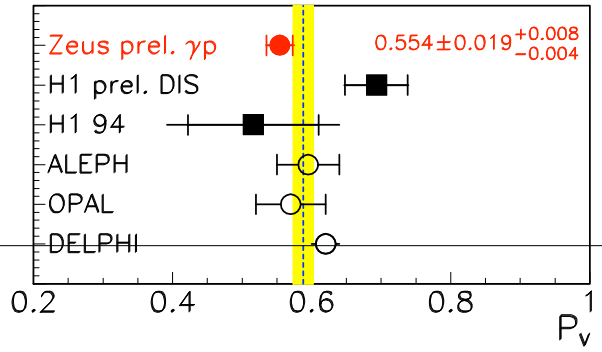


Charm fragmentation

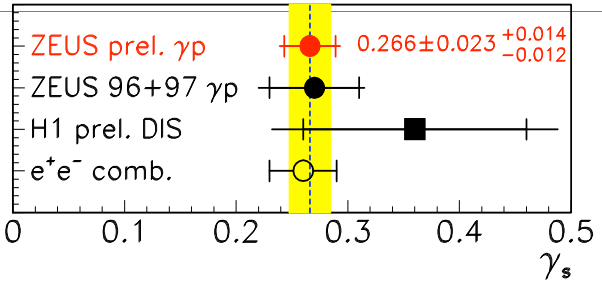
measurement of D^0, $D^{\pm}$, $D_s^{\pm}$, D^*, $\Lambda_c^{\pm}$ cross sections:

fragmentation ratios:

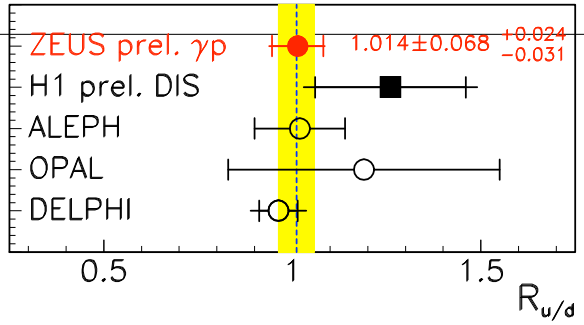
fraction of D produced in vector state



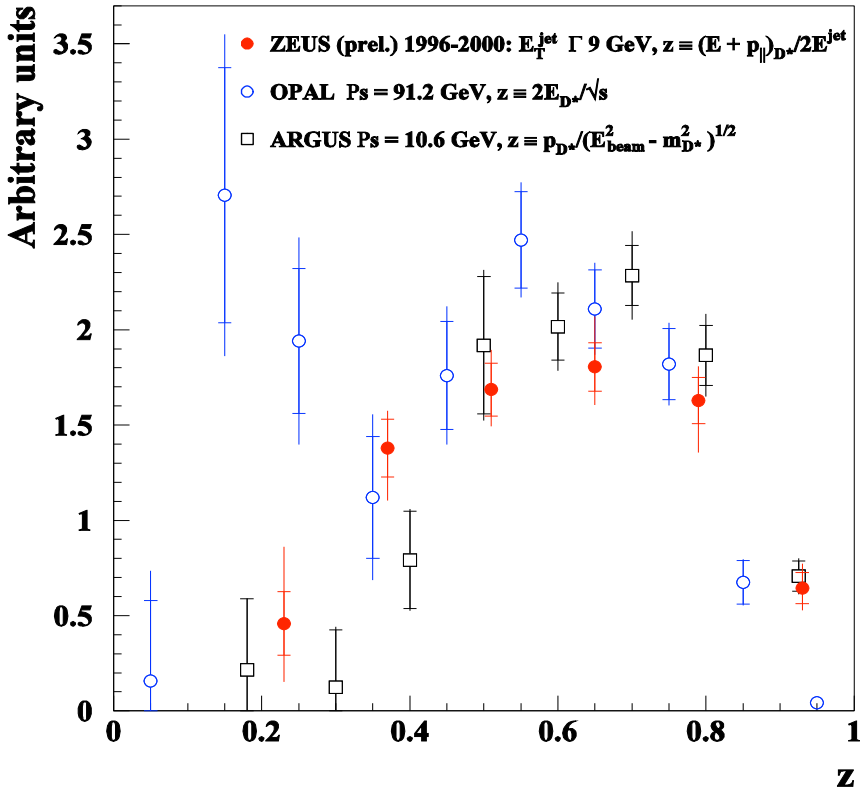
strangeness suppression



ratio of neutral and charged D



fragmentation function:



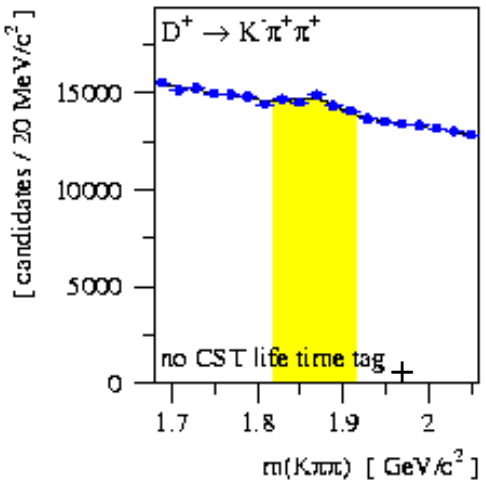
HERA data agree with e^+e^-: universality of charm fragmentation

Reconstruction of D-mesons

D pseudoscalar meson

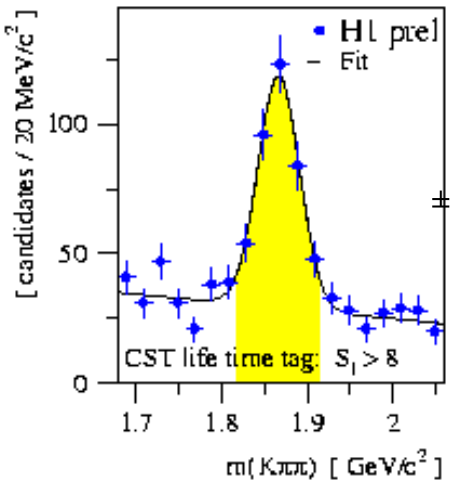
fragmentation: $f(c \to D^+) = 0.248 \pm 0.014$

without



too high background

with lifetime tag

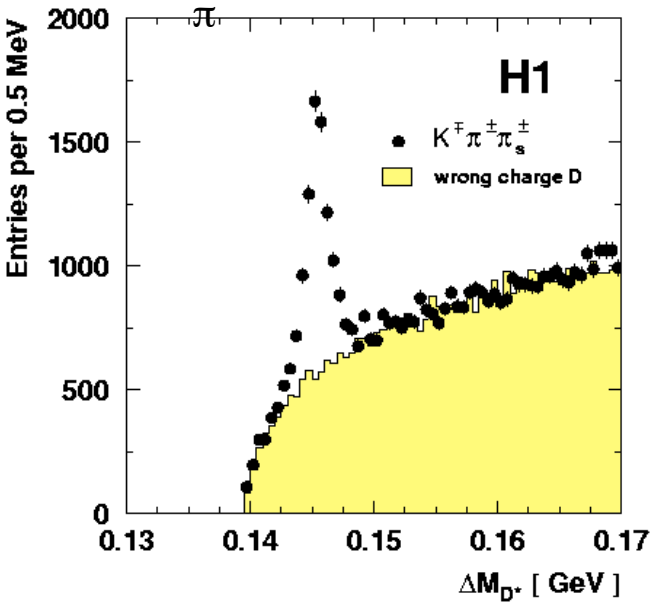


too low statistics

D* vector meson

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

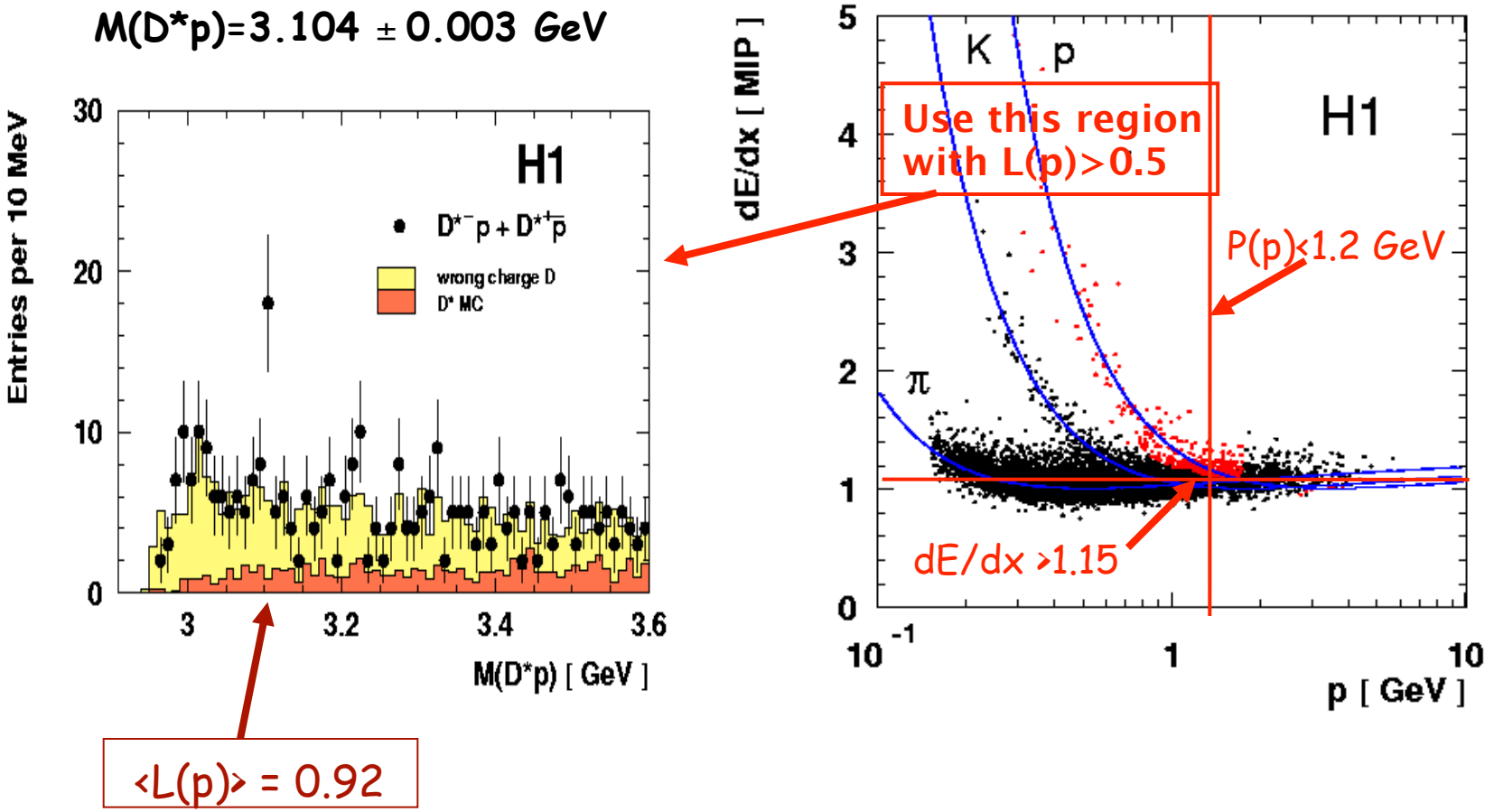
$D^* \to D^0\pi \to (K\pi)\pi$



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

D* is more feasible for such analysis !

Is the signal due to protons ?



Signal is there for well identified protons

Summary of anti-charmed baryon state

Narrow resonance in D*p observed in DIS at H1:

- Mass of 3099± 3 (stat.) ± 5 (syst.) MeV
- RMS width of the resonance is 12 ± 3(stat.) MeV
  (consistent with the experimental resolution)
- The background fluctuation probability is smaller than $4*10^{-8}$
- The signal is also observed in an independent photoproduction sample
- Data have been subjected to many kinematical tests which are all found to be only consistent with the D*p hypothesis.
- Possible interpretation: anti-charmed baryon decaying to D^{*-} p (+ c.c.)
- Minimal quark content: uuddc $\rightarrow$ candidate for a charmed pentaquark

PRELIMINARY result of searches at ZEUS: no confirmation

Further investigations of the D*p resonance

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

All tests we could think of are passed !