Charm production in ep interactions at HERA
and
Evidence for a narrow exotic anti-charmed baryon state at H1

Katerina Lipka (H1) DESY Zeuthen

for the H1 and ZEUS Collaborations

➡ **open charm production**

- cross section
- charm contribution to the proton structure function
- fragmentation fractions and ratios

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

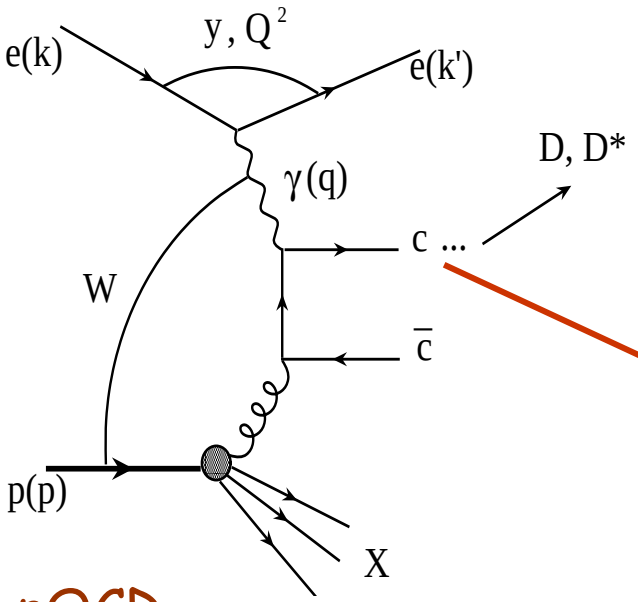
Moriond QCD 2004

Open charm production in ep scattering

dominated by

Boson-Gluon Fusion (BGF): m_c → hard scale for pQCD calculations

LO:



- test pQCD
- extract gluon density in the proton
- study the γ* structure
- study fragmentation process
- charm spectroscopy

ep kinematics

- momentum transfer squared $Q^2 = -q^2$;
- Bjorken scaling variable $x = Q^2/(2\,q\,p)$
- inelasticity $y = qp/kp$
- γp CMS energy $W^2 = (p + q)^2$

fragmentation: D kinematics

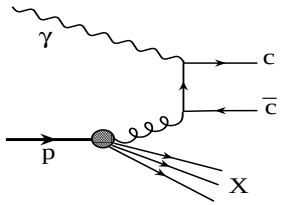
- pseudorapidity $\eta = -\ln(\tan \theta_D/2)$;
- transverse momentum $p_t(D)$
- D production elasticity $z = (E-p_z)_D/2yE_e$

HERA: p(920 GeV) e (27.5 GeV)

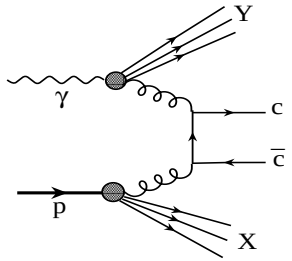
$\sqrt{s}$ = 320 GeV (from 1998 on)

Models for charm production

- **proton structure:**
  - CCFM evolution of PDF
  - DGLAP evolution of PDF
- **photon structure:**
  - direct (pointlike photon)



  - resolved (hadron-like photon)



- **fragmentation: non-perturbative models**

  (e.g. Peterson fragmentation)

Calculations in DGLAP sheme

pQCD NLO:

fixed order "massive" approach

- massive charm produced in BGF
- valid for $Q \approx m_c$

- **DIS: HVQDIS**
- **Photoproduction: FMNR**

resummed calculation in NLL:

all orders "massless" approach

- massless charm as an active flavor of proton or photon
- valid for $Q \gg m_c$

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": $\Delta M(D^*) = M(K \pi \pi_s) - M(K \pi)$

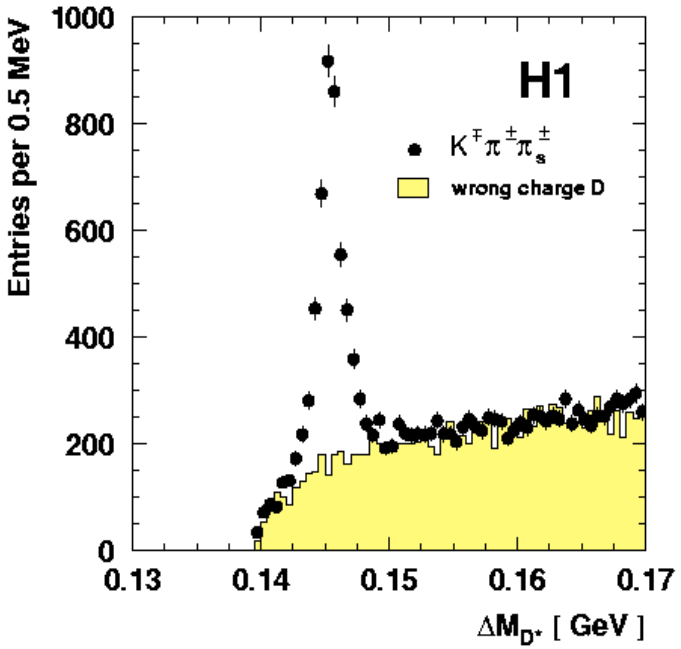
DIS:

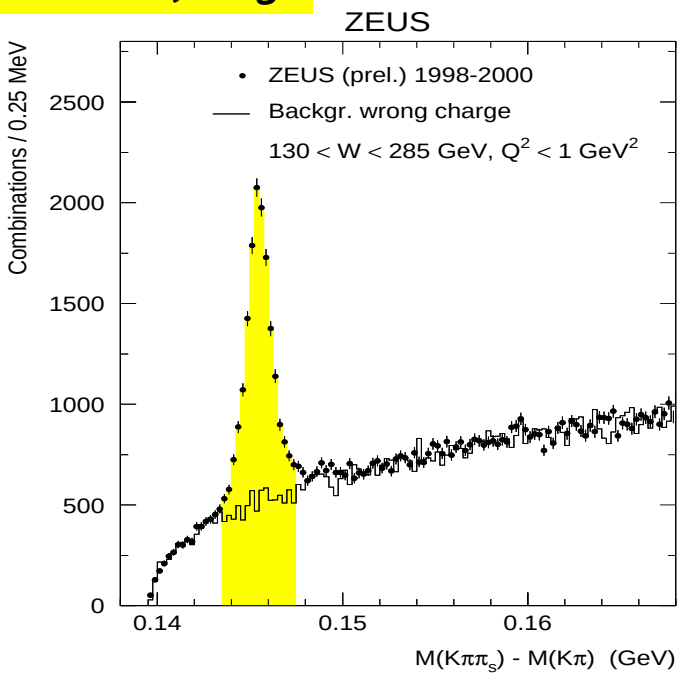
- scattered electron in calorimeter
- $2 < Q^2 < 100\ GeV^2$, $0.05 < y < 0.7$
- visible range: $p_t(D^*) > 1.5\ GeV$, $|\eta_{D^*}| < 1.5$

Photoproduction:

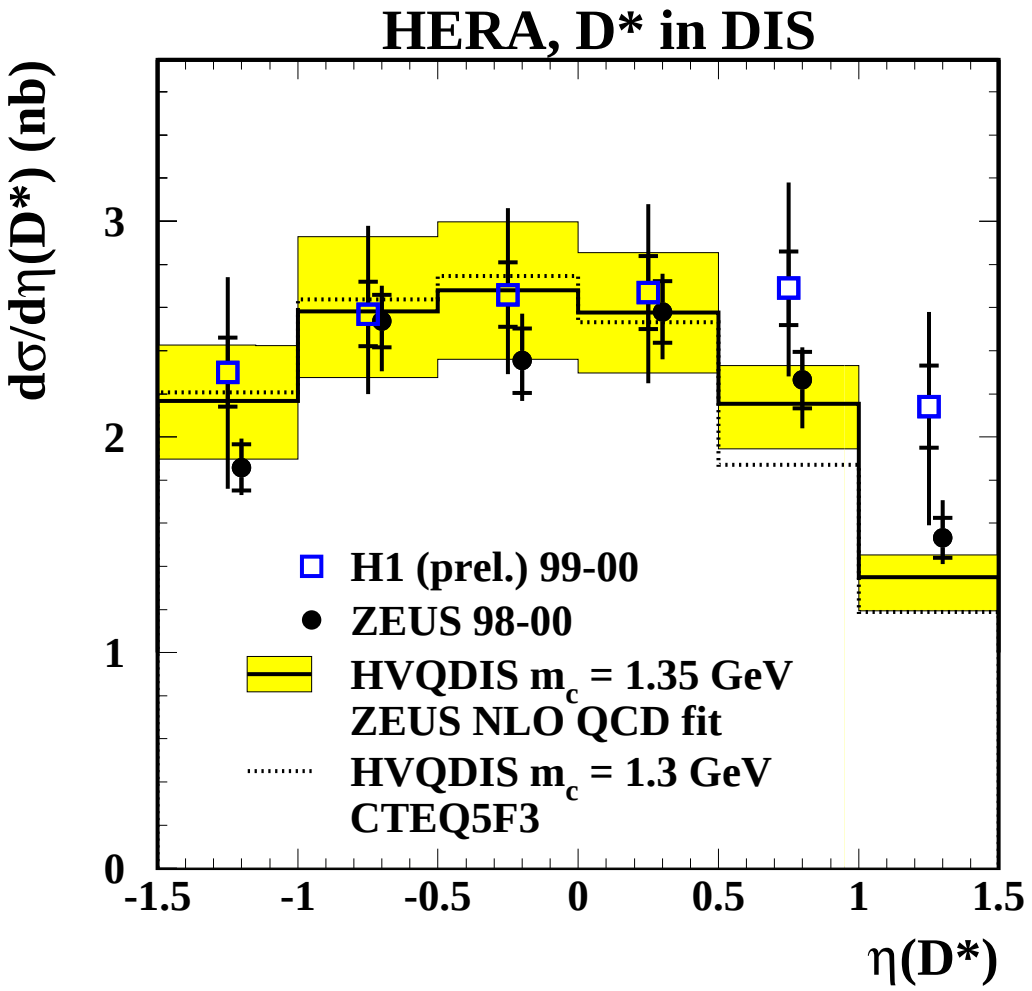
- electron escapes the main detector
- $Q^2 < 0.01\ GeV^2$
- visible range: $p_t(D^*) > 2.5\ GeV$, $|\eta_{D^*}| < 1.5$

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





Differential DIS cross section



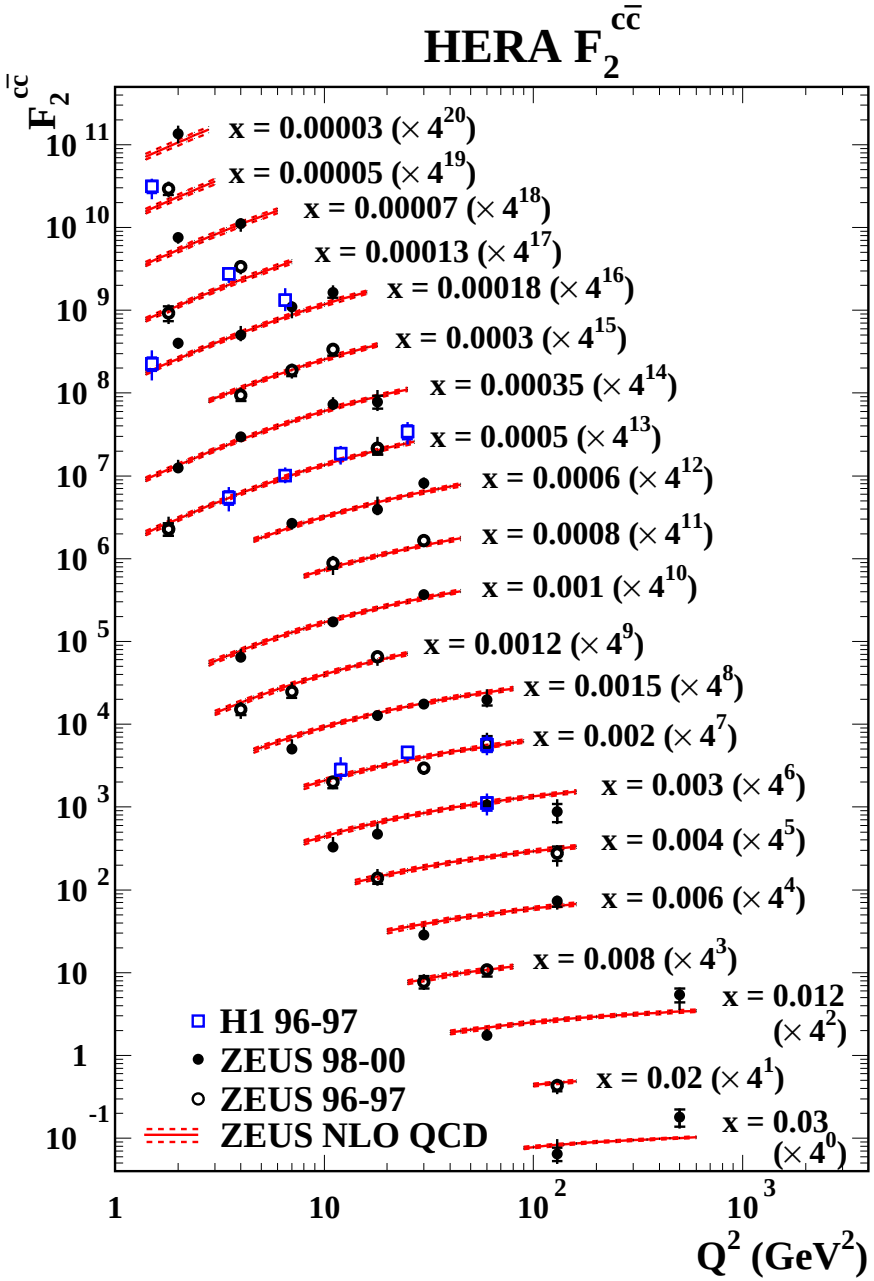
consistent with

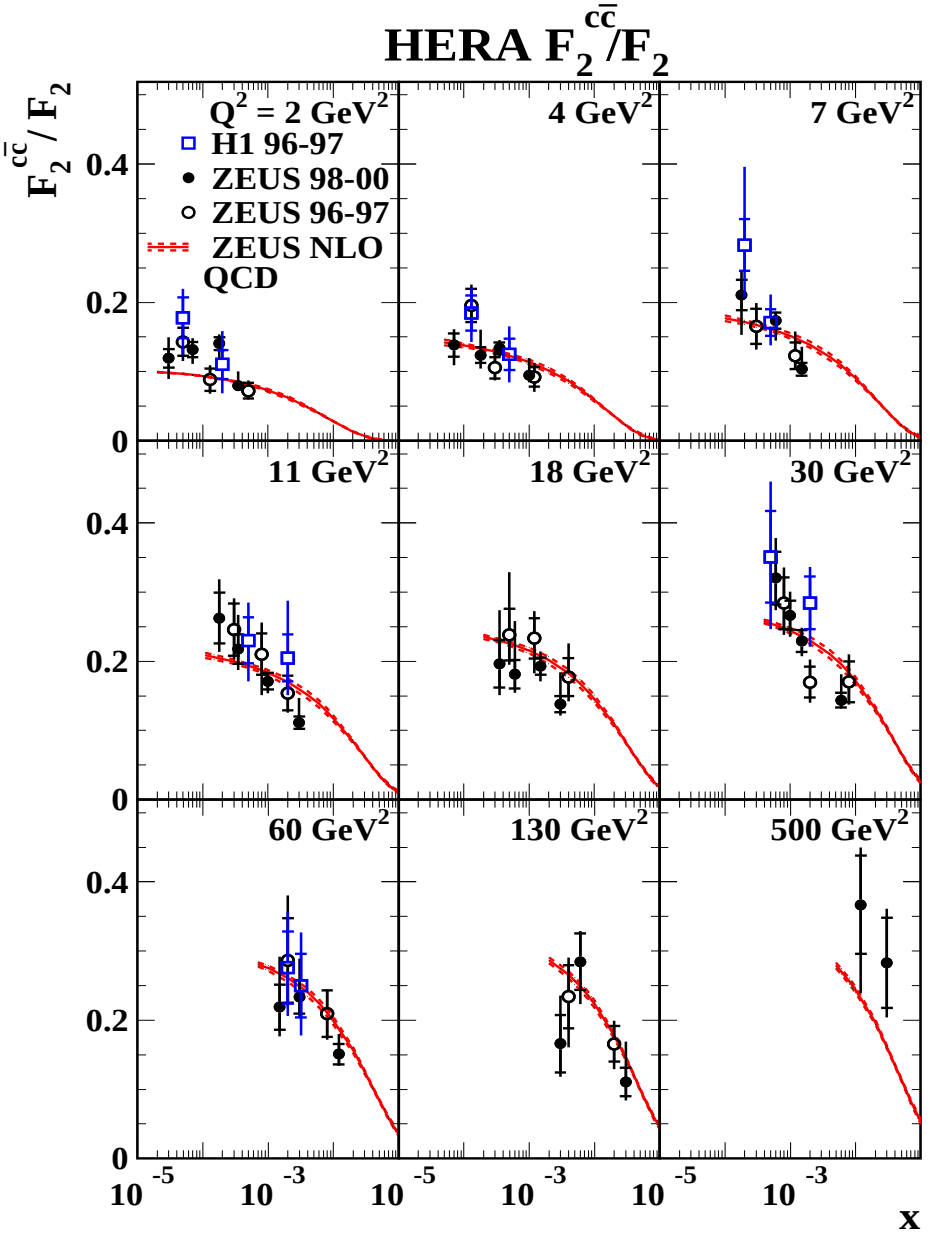
NLO calculations

theoretical uncertainties due to:

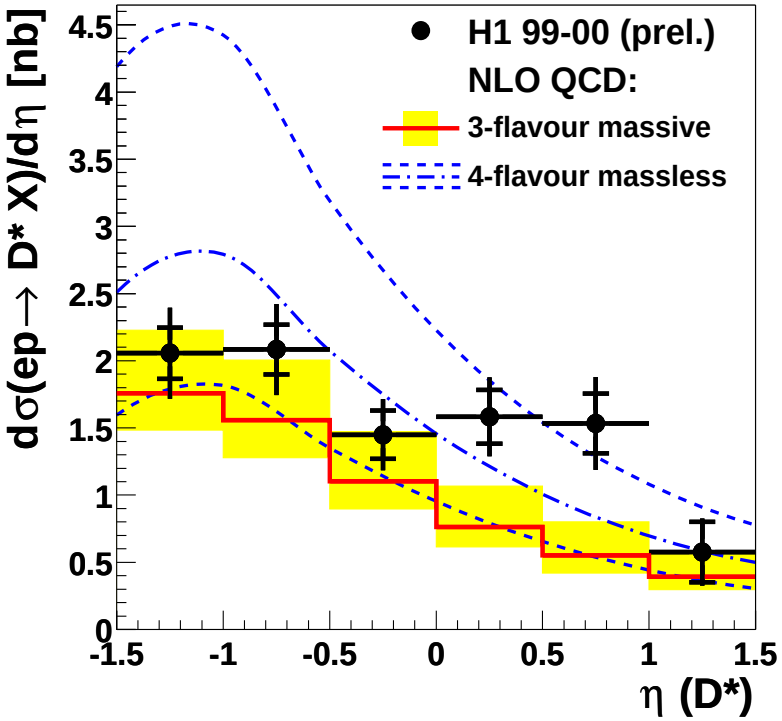
- proton PDF
- charm mass
- renormalization/factorization scale
- fragmentation

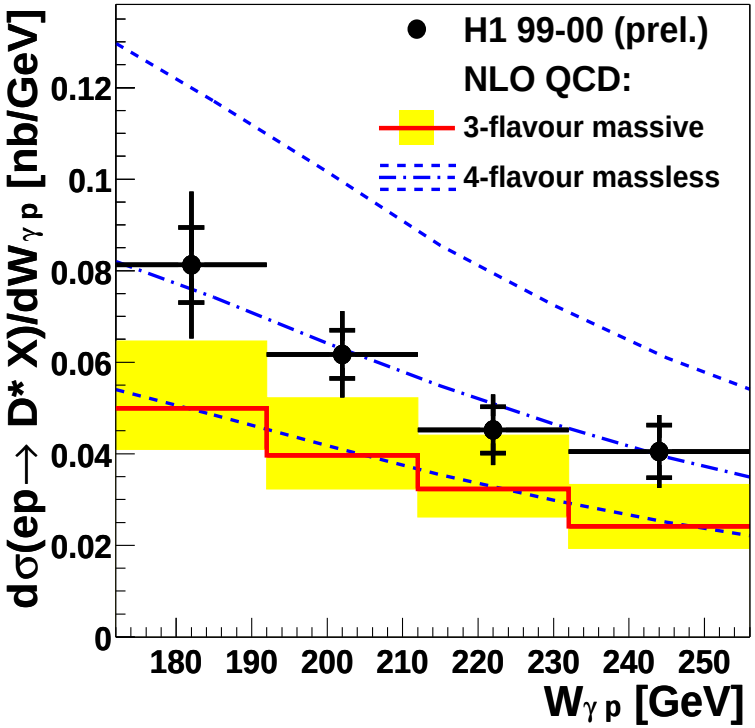
Charm contribution to proton structure function F_2





Photoproduction cross section





NLO calculations: large theoretical uncertainties

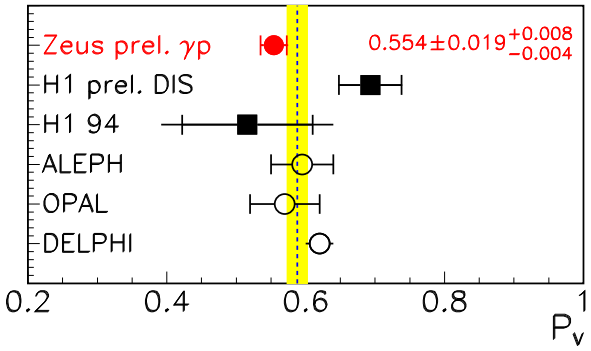
➡ not yet possible to distinguish between different charm treatments

Charm fragmentation

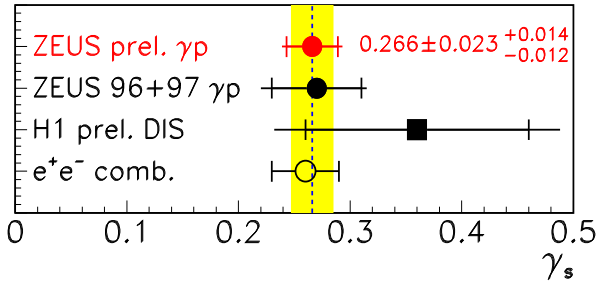
measurement of D^0, $D^{\pm}$,$D_s^{\pm}$,D^*, $\Lambda_c^{\pm}$ cross sections:

fragmentation ratios:

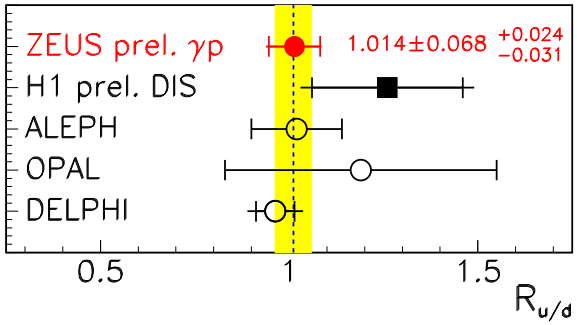
fraction of D produced in vector state



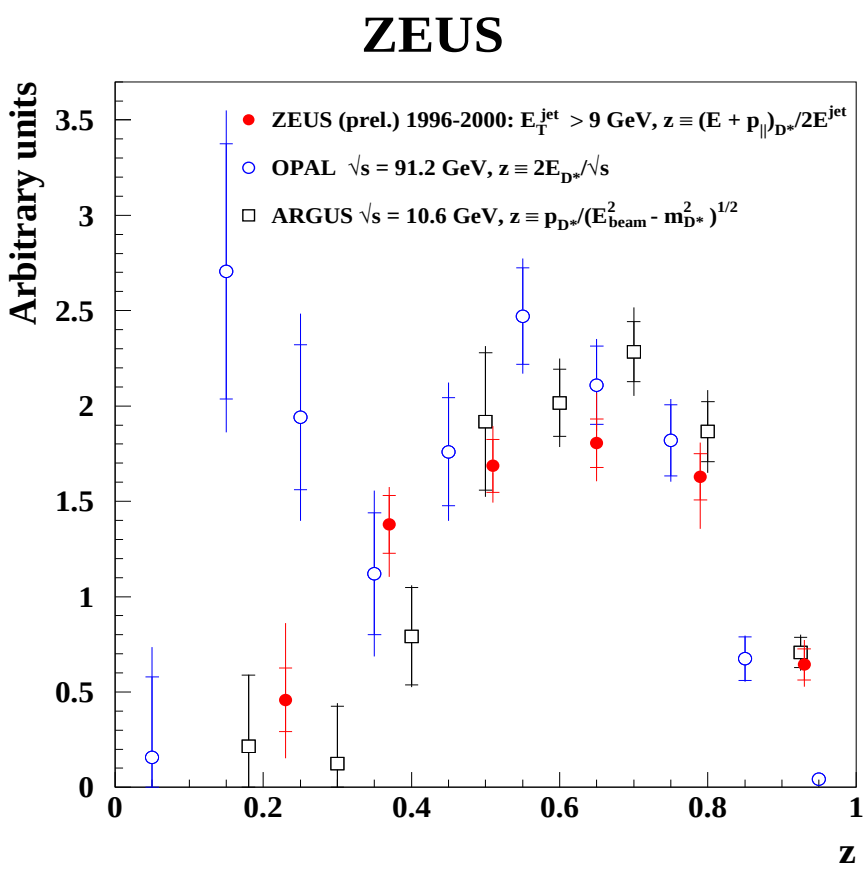
strangeness suppression



ratio of neutral and charged D



fragmentation function:



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

Summary of selected results on open charm production

- **visible DIS cross sections**
  - NLO DGLAP agrees with HERA data
- **recent F_2^c measurement**
  - good agreement with NLO fits to inclusive data

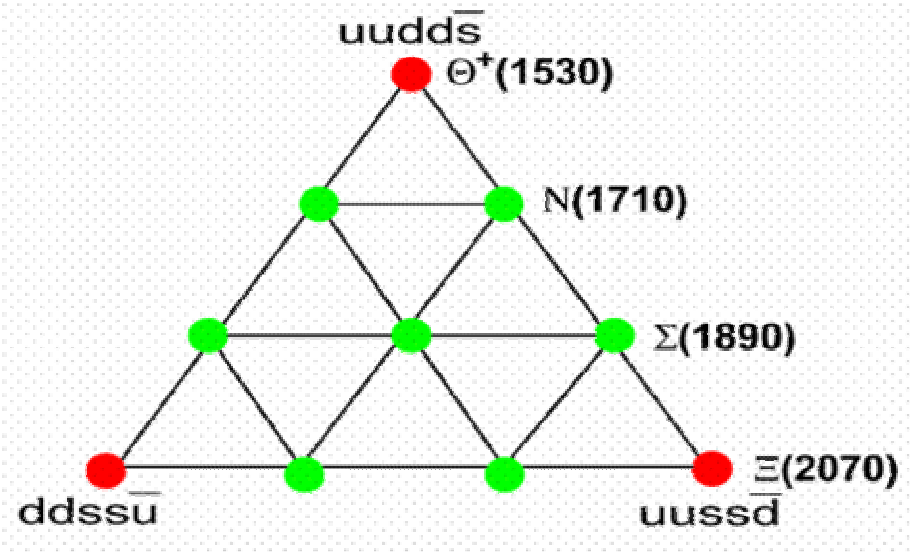
    ➡ direct test of gluon density
  - large charm contribution to F_2
- **visible photoproduction cross section**
  - still a challenge for the theory
- **charm fragmentation**
  - fragmentation ratios agree with world data
  - universality of charm fragmentation

Evidence for a narrow anti-charmed baryon

inspired by the recent discoveries of the strange pentaquark

Narrow resonance observed in (K N) - start of the pentaquark Era

- mass around 1540 MeV
- minimal quark content $uudd\bar{s}$
- interpreted as pentaquark Θ^+



Why not look for charming exotics?

Search for a possible signature in D^{*-} p and D^{*+} $\bar{p}$ combinations

D* Candidate Selection

- 1996 – 2000 Data

DIS (L_{int} =75 pb^{-1})

scattered electron in detector:

1 GeV^2 < Q^2 < 100 GeV

0.05 < y_e < 0.7

D^0 requirements:

$|M(K\ \pi) - M_{PDG}(D^0)| < 60$ MeV

D* requirements:

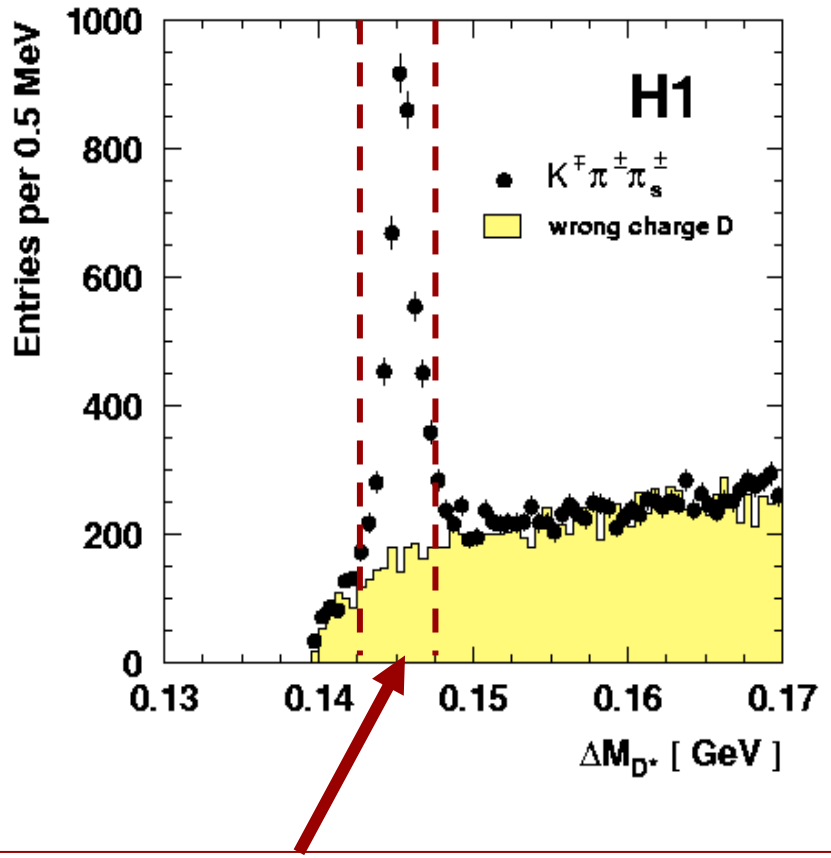
p_t (D*) > 1. 5 GeV

-1. 5< $|\eta(D^*)|$ < 1.

p_t (K) + p_t (π) > 2 GeV

Inelasticity z(D*) > 0.2

→ 3400 D*



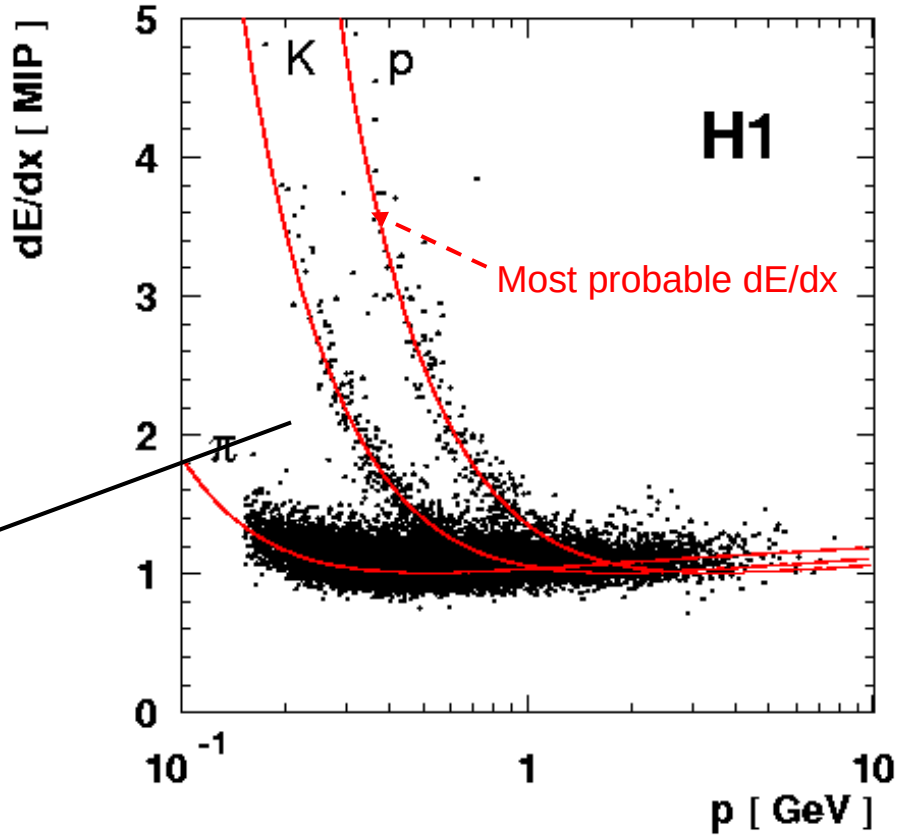
select only events in 5 MeV window

now combine this D* with a charged particle assigned the proton mass

Particle ID via ionisation loss measurement

- dE/dx calibrated for 1996 to 2000 data
- Parameterization accurate to 3-5%
- 8% average MIP resolution

Normalized likelihood based on:
measured dE/dx & expectations
For π, K, p and resolution:
L(π)+L(K)+L(p) = 1

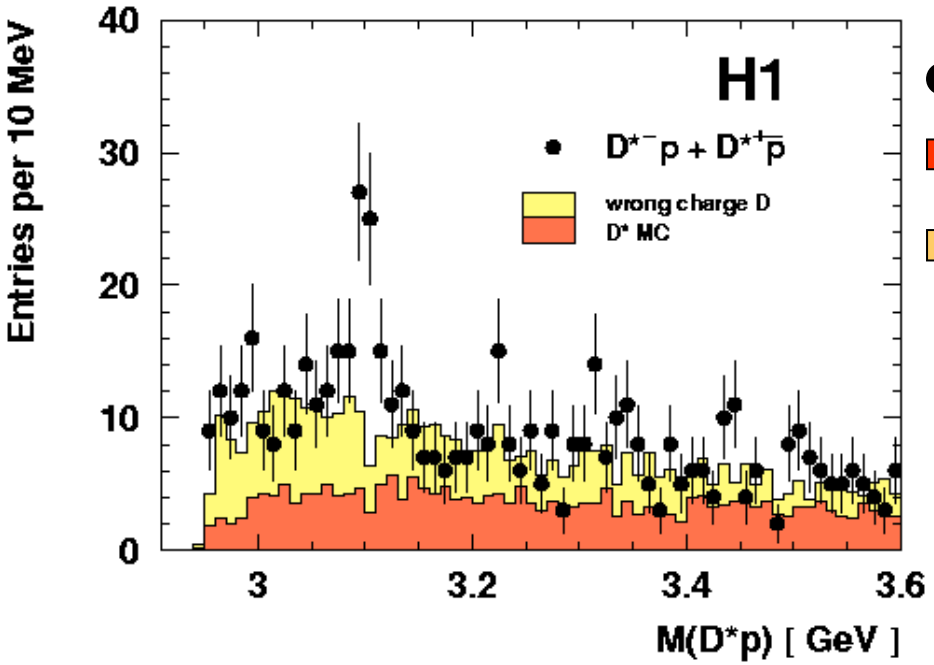


dE/dx used for background suppression

Final proton selection: L(p)>0.1 at p(p)>2 GeV
L(p)>0.3 at p(p)<2 GeV

D*p mass distribution: DIS 1996 - 2000

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



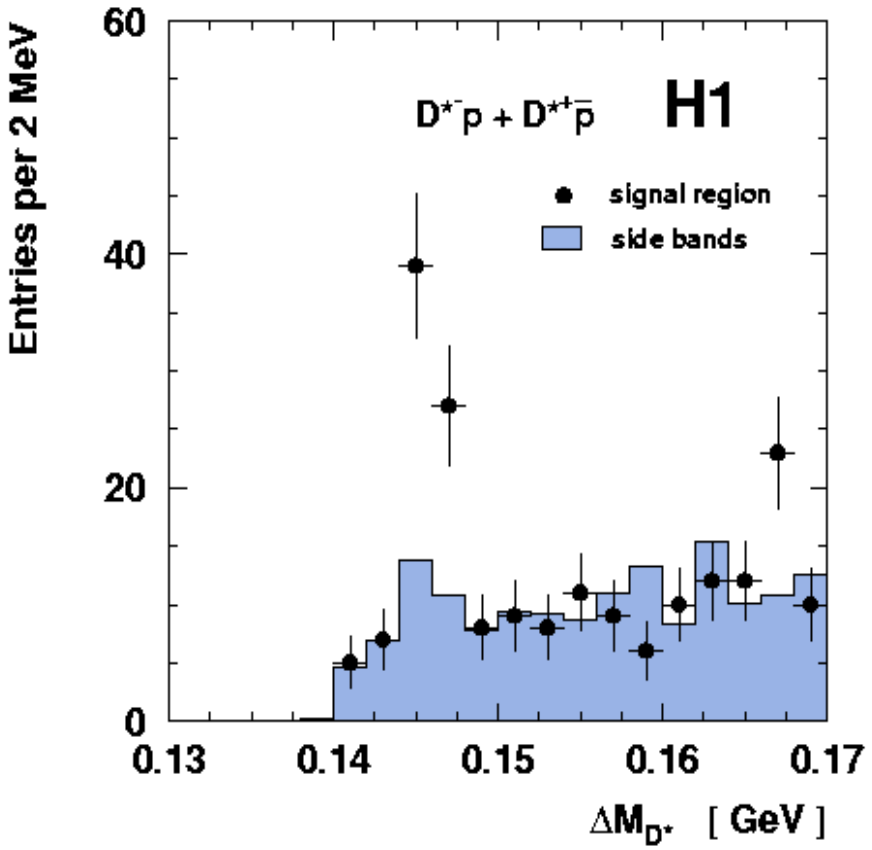
- significant peak in opposite charge D*p
- no enhancement in D* Monte Carlo
- no enhancement in wrong charge D

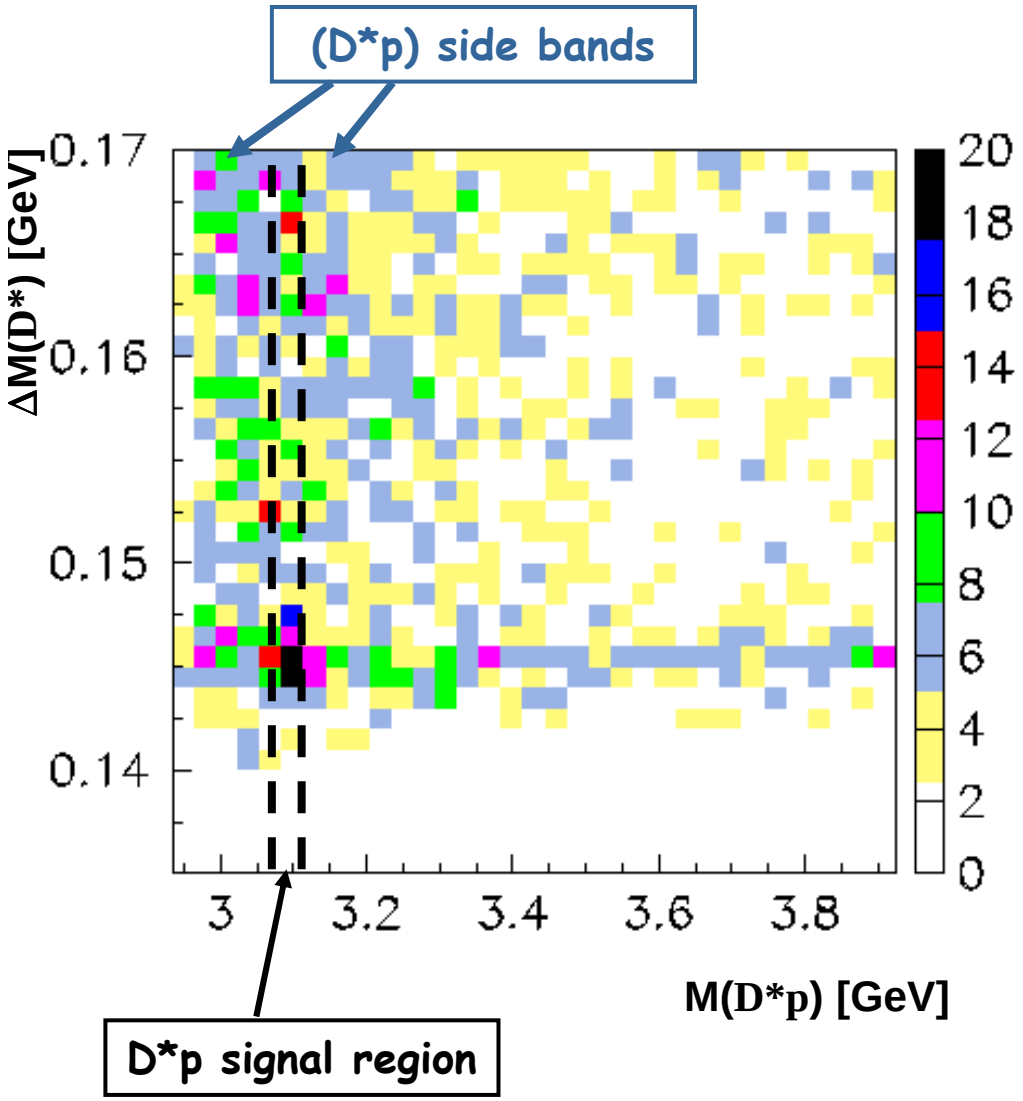
Background well described by D* MC and wrong charge D from data

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

Does the resonance come from D*?

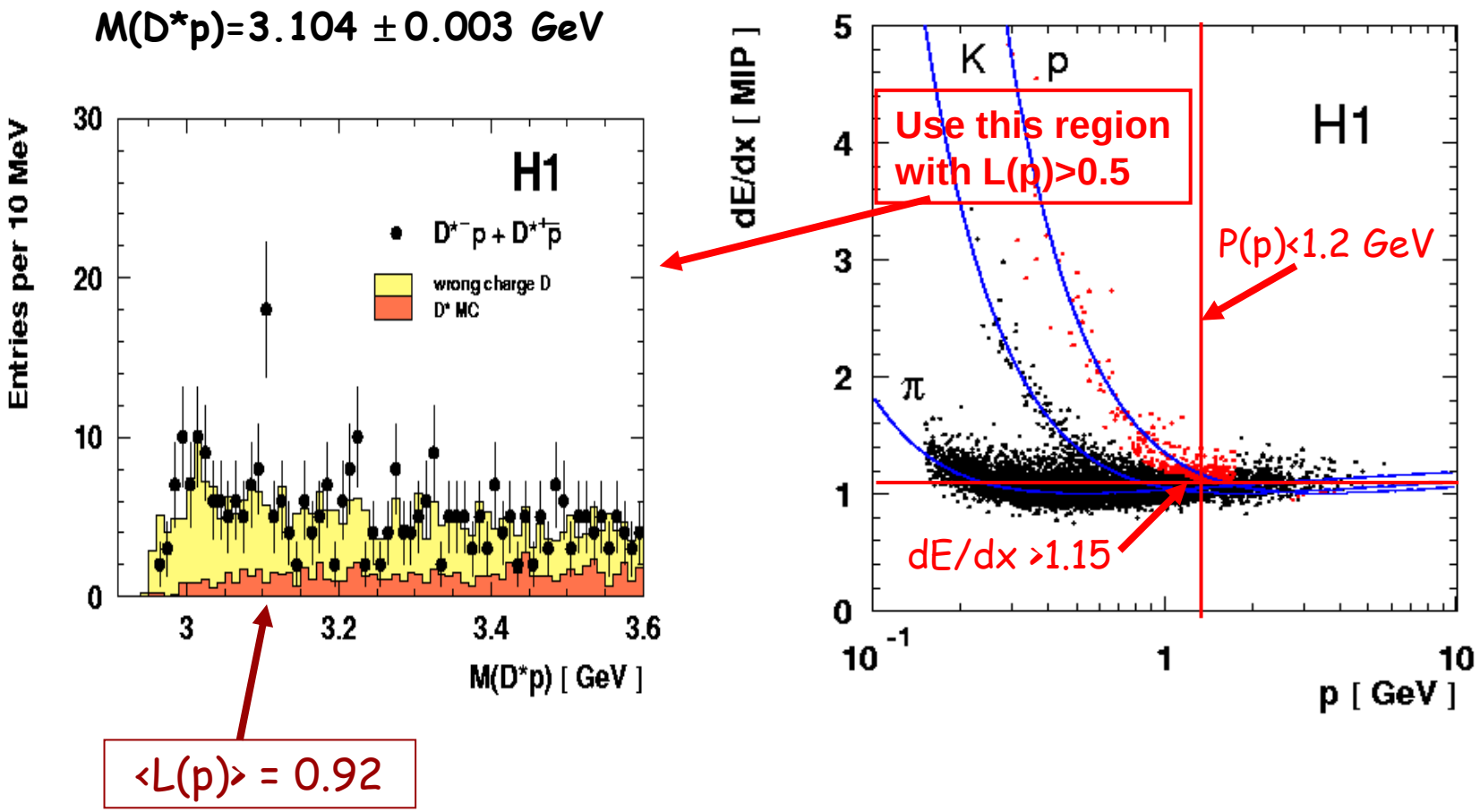




Normalization to the width
of the windows in M(D*p)

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

Look into low momentum protons

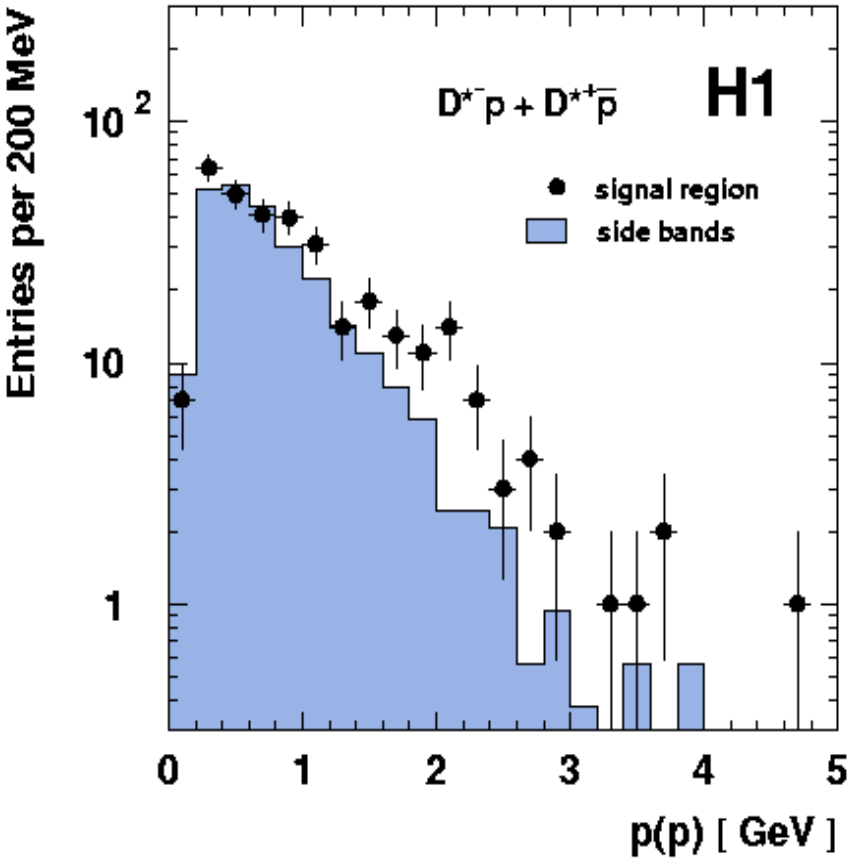


Signal is there for well identified protons

Is the physics different in the (D*p) signal region?

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

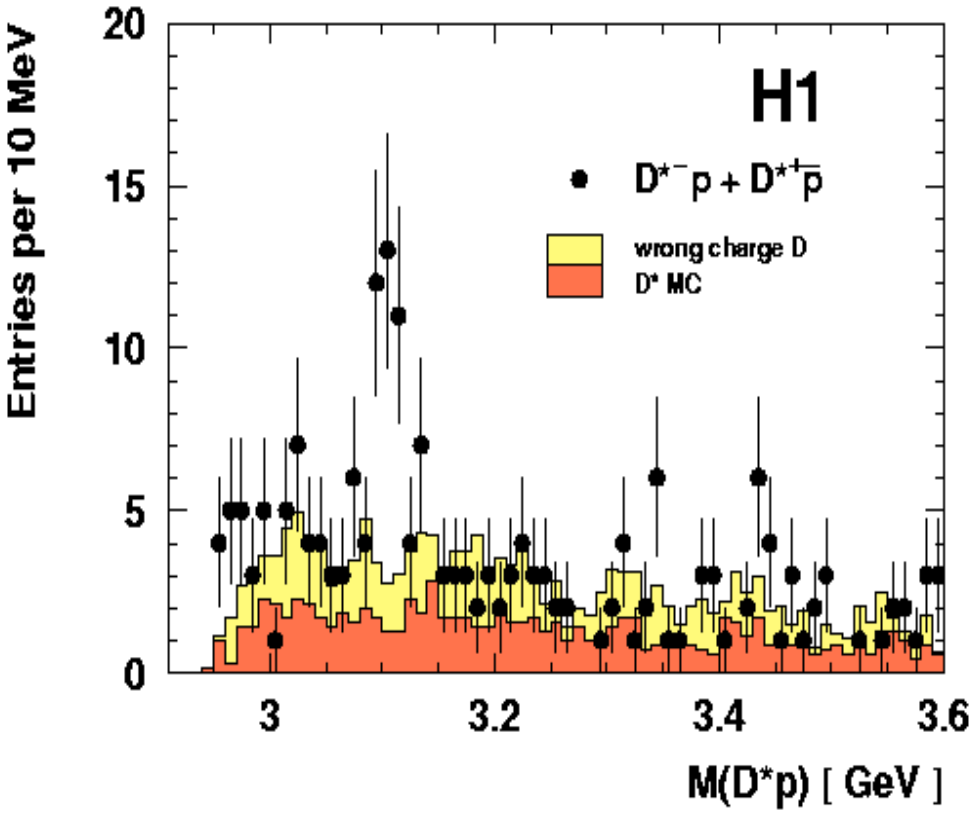
momentum distribution in the signal region is harder than in sidebands



physics changes !

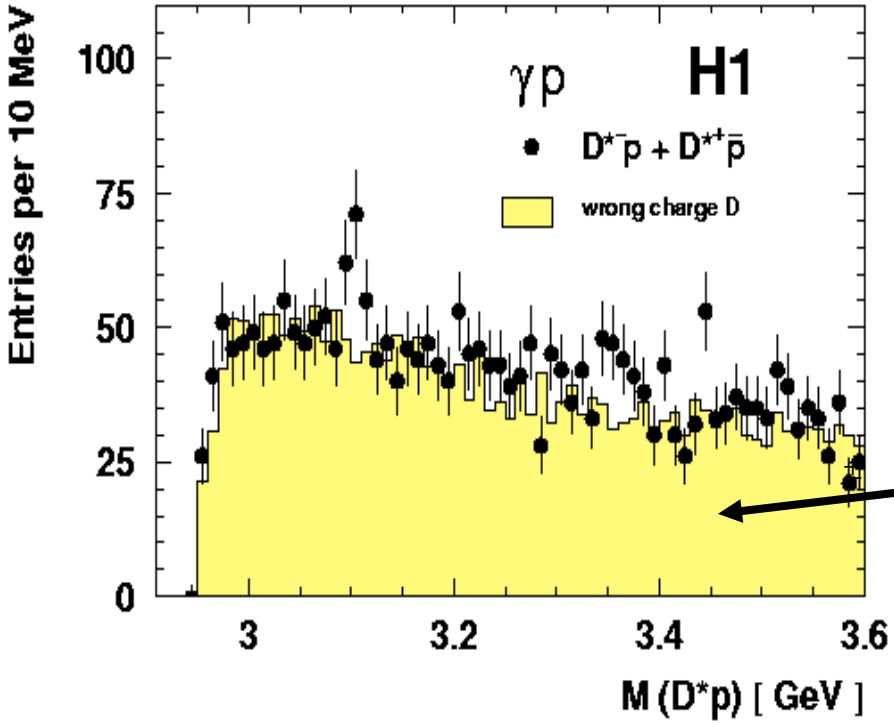
look into D*p combinations

for p(p) > 2 GeV



prominent signal is visible

D*p 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

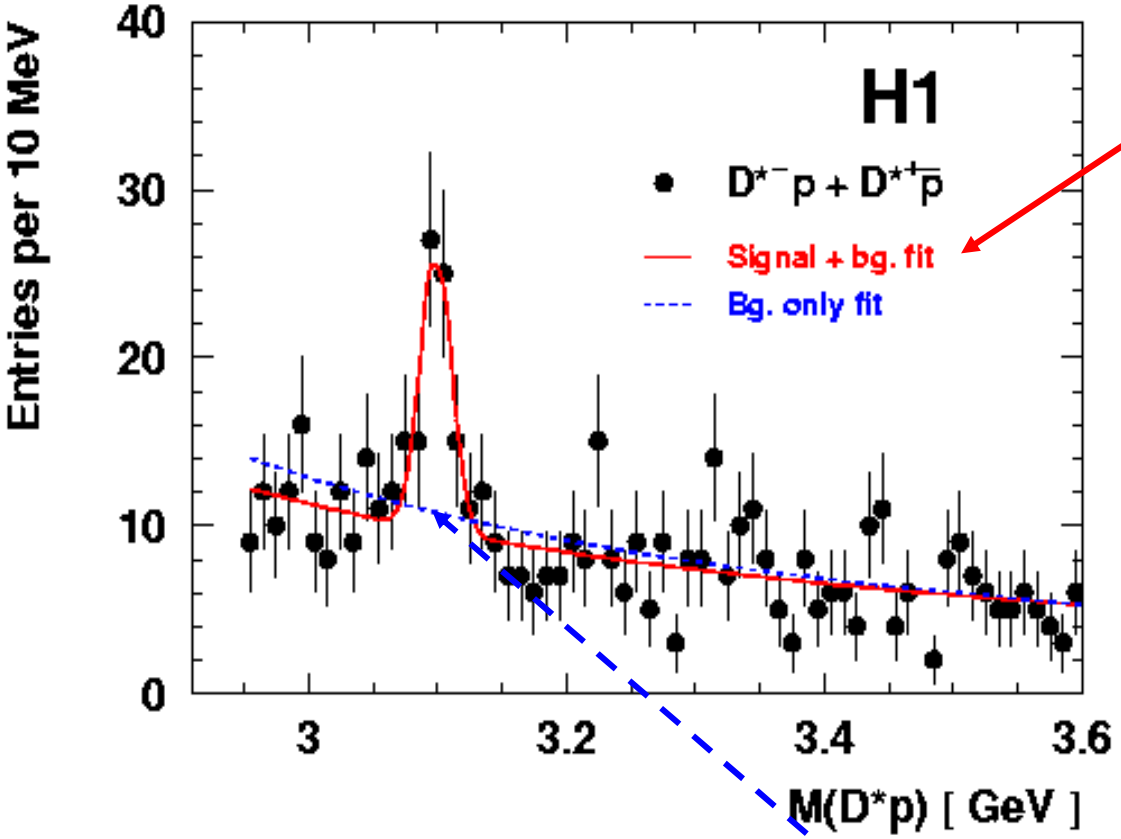
Background well described by wrong charge D from data

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 bg. within 2σ

N_b = 45.0 ± 2.8

N_s = 50.6 ± 11.2 (~ 1% of D* yield)

5.4 σ

- Significance estimate based on the background only hypothesis N_b = 51.7±2.7
- Use of different background functions as well as the background model from data and MC
- Significance determined in a binning free method

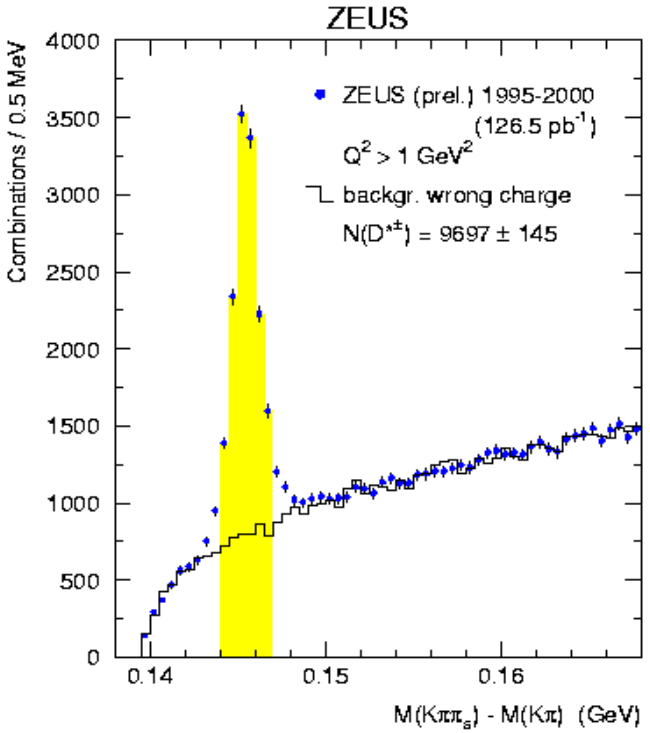
→Background fluctuation probability 4×10^{-8} (Poisson) ≡ 5.4 σ (Gauss)

Change in likelihood of the two fits: 6.2 σ

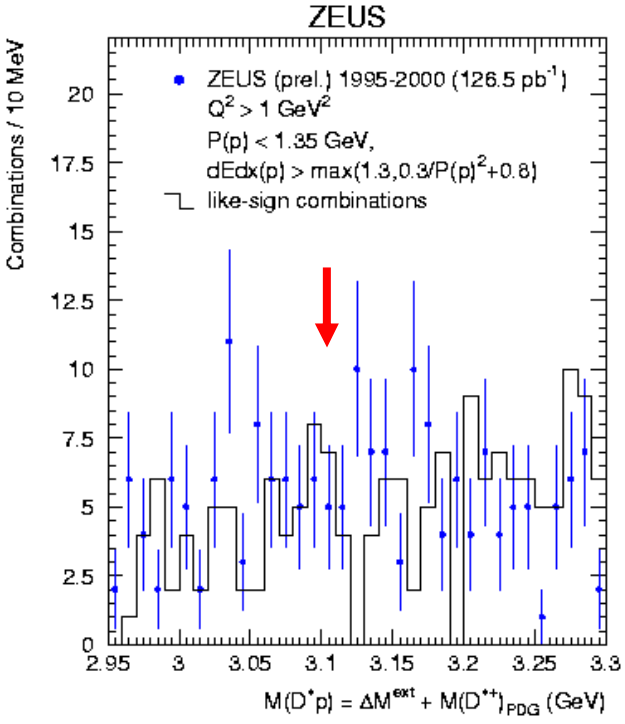
Search for charmed pentaquark in ZEUS

- DIS D* sample 1995-2000, $Q^2>1$ GeV^2: ~9700 D*
- $p_T(D^*) > 1.35$ GeV, $|\eta_{D^*}|<1.6$, p (dE/dx) and D*p cuts similar to H1

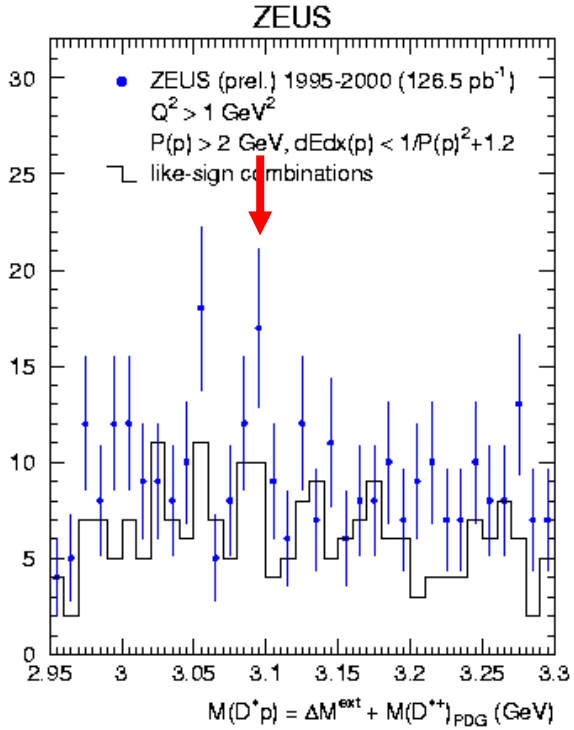
ZEUS **PRELIMINARY:**



low momentum p



high momentum p

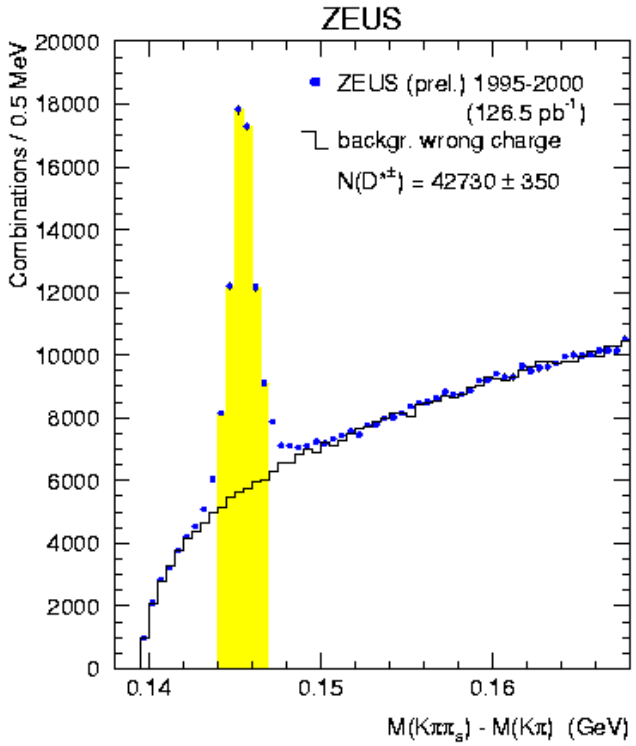


no evidence for a signal at 3.1 GeV

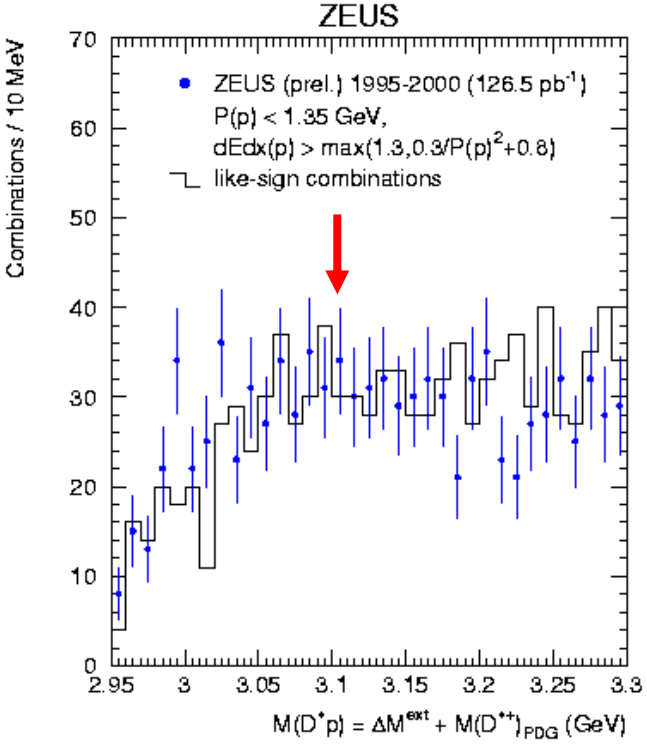
Search for charmed pentaquark in ZEUS

- ZEUS inclusive D* sample 1995-2000: ~43000 D*
- same D*, p and D*p cuts as for DIS selection

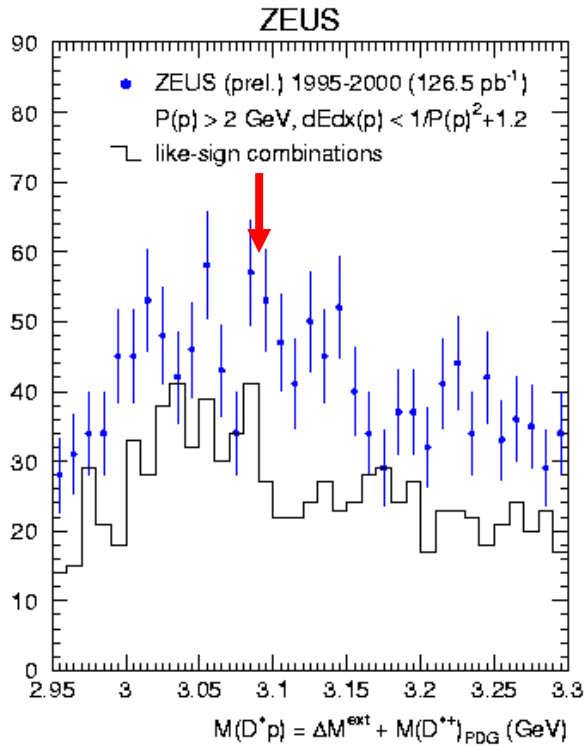
ZEUS **PRELIMINARY:**



low momentum p



high momentum p



no evidence for a signal at 3.1 GeV

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: $uudd\bar{c} \rightarrow$ candidate for a charmed pentaquark

PRELIMINARY result of searches at ZEUS: no confirmation