



D^+ , D^0 and Λ_c^+ production in deep inelastic scattering at HERA

U+H



International Conference on High Energy Physics

ICHEP
PARIS 2010

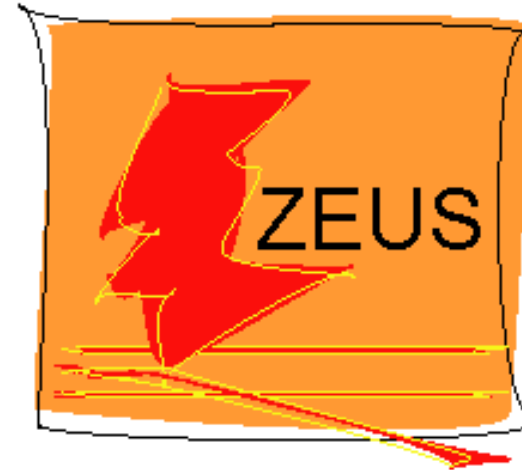
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Outline

This talk:

Measurements of charm production in DIS at HERA:

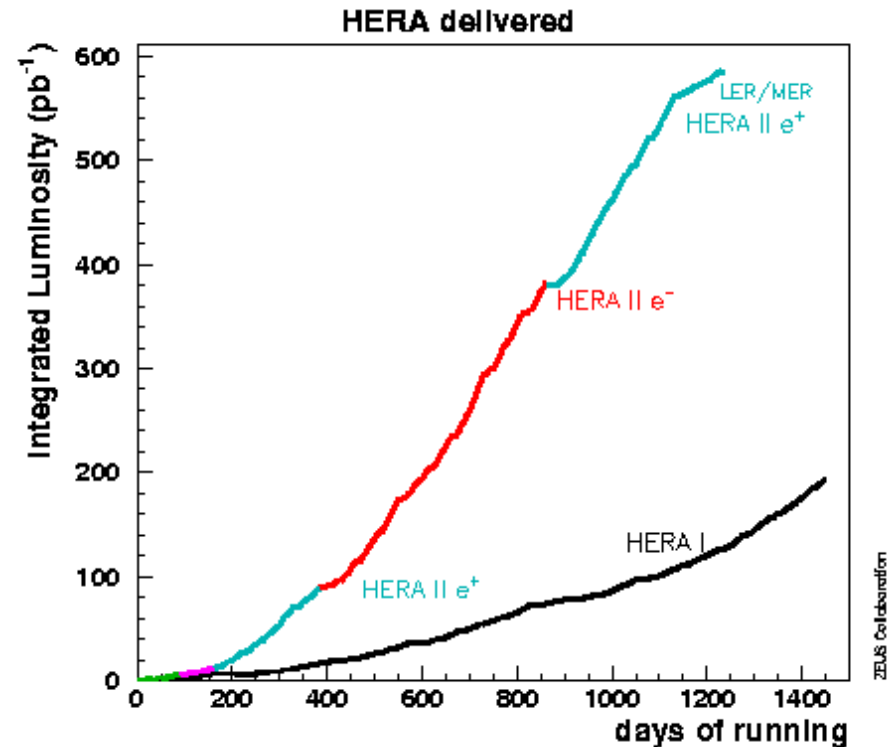
- **HERA I data:**

D^+ at threshold and Λ_c^+ production ([DESY-10-064](#))

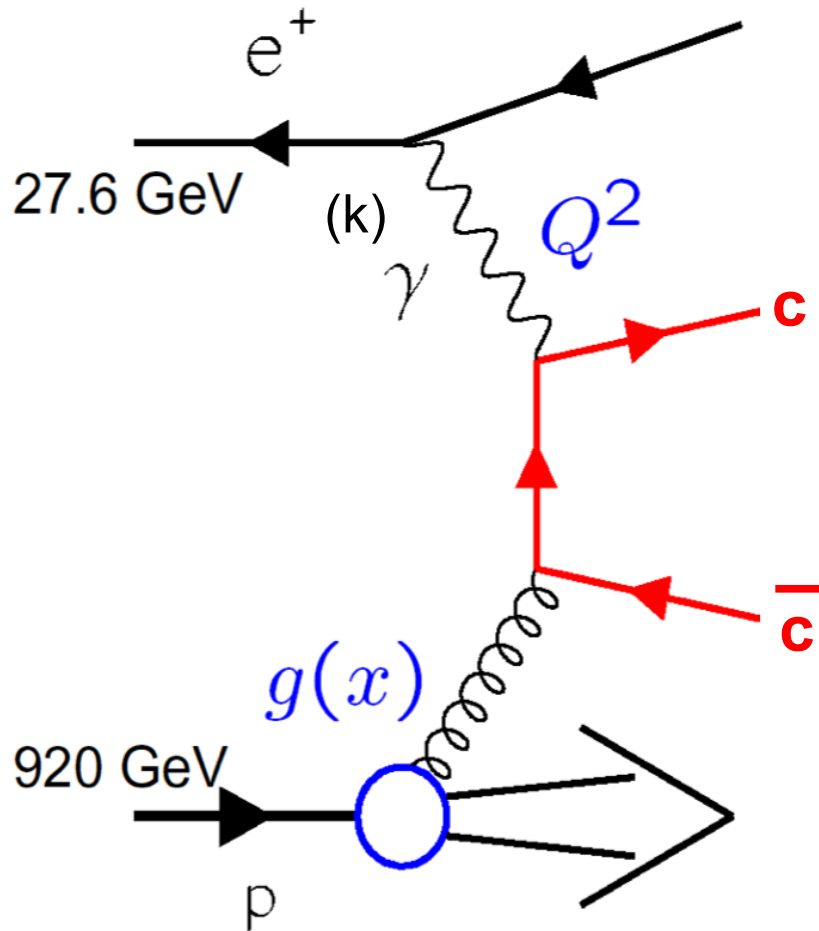
- **HERA II data:**

D^+ and D^0 cross sections with high precision, extraction of F_2^c

([ZEUS-prel-10-005](#),
[Eur. Phys. J. C 63: 171](#))



Charm production in DIS at HERA



- Dominant process for charm production in DIS ($Q^2 > \text{a few GeV}^2$): **Boson-Gluon-Fusion (BGF)**
- Multiple hard scales: $\mu^2 = m_c^2, p_T^2, Q^2$
- The charm contribution to the inclusive DIS cross section is up to 30%
- The double differential cross section for the production of open charm can be written as:

$$\frac{d^2 \sigma^{c\bar{c}}(x, Q^2)}{dx dQ^2} = \frac{2\pi \alpha^2}{xQ^4} \left\{ [1 + (1-y)^2] F_2^{c\bar{c}}(x, Q^2) - y^2 F_L^{c\bar{c}}(x, Q^2) \right\}$$

Newly analysed decay channel: $D^+ \rightarrow K_S^0 \pi^+$

New decay channel:

K_S^0 in the final state

→ Reduction of background

→ Access to the low transverse momentum region

Kinematic region:

$0 < p_T(D^+) < 10 \text{ GeV}$

$|\eta(D^+)| < 1.6$

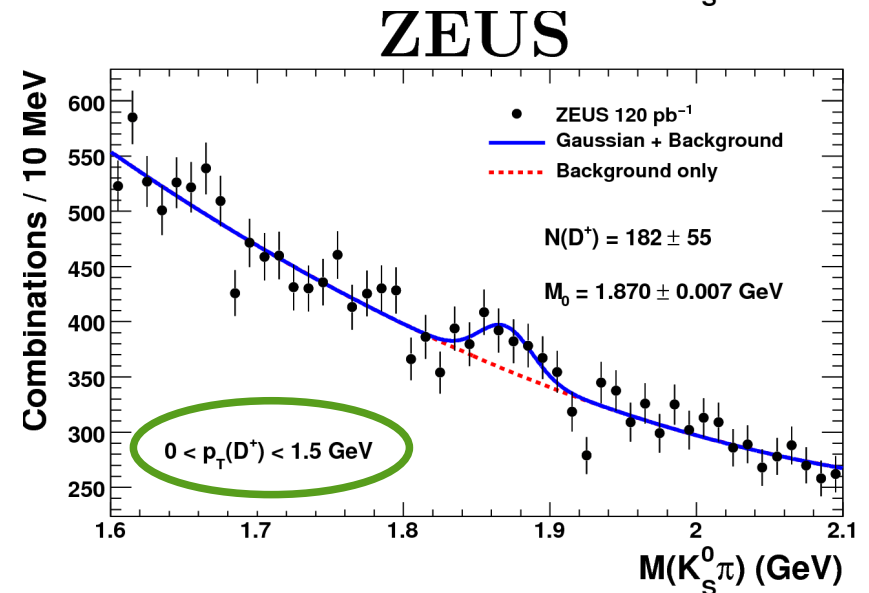
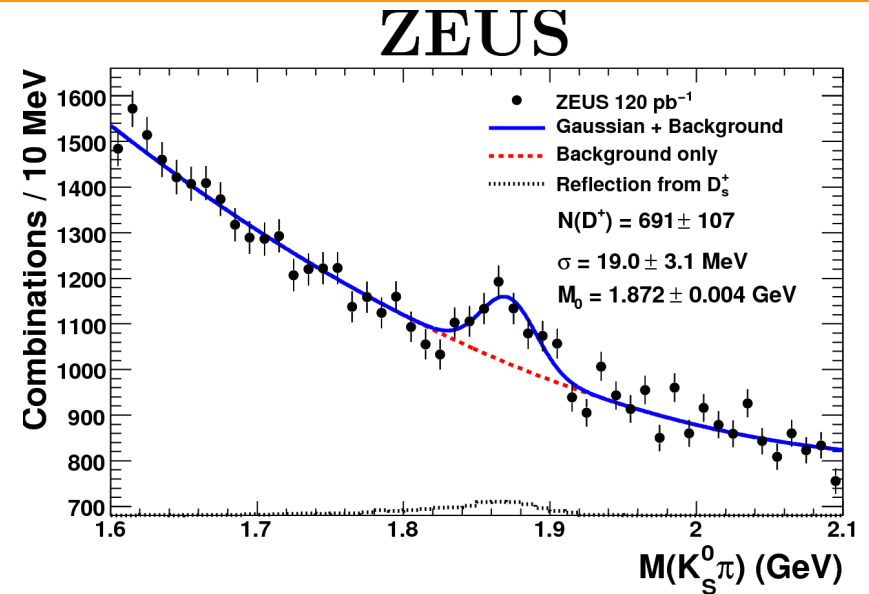
$1.5 < Q^2 < 1000 \text{ GeV}^2$

$0.02 < y < 0.7$

Data sample:

120 pb^{-1} (1996-2000),

only 17 pb^{-1} for $Q^2 < 20 \text{ GeV}^2$

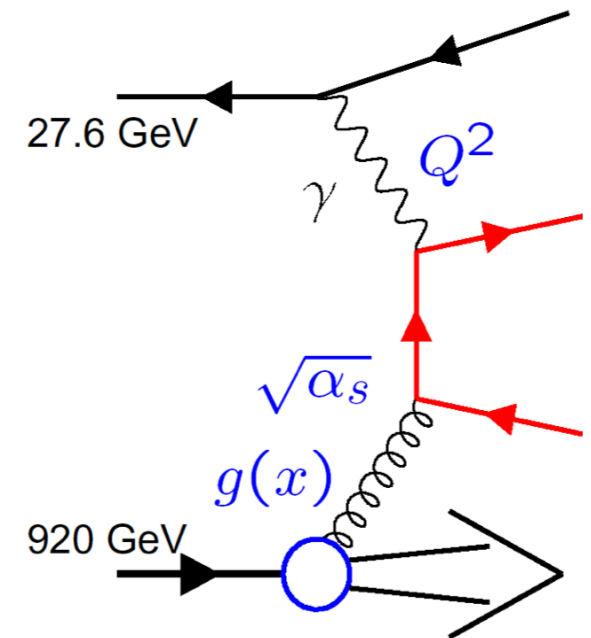


NLO QCD predictions from HVQDIS

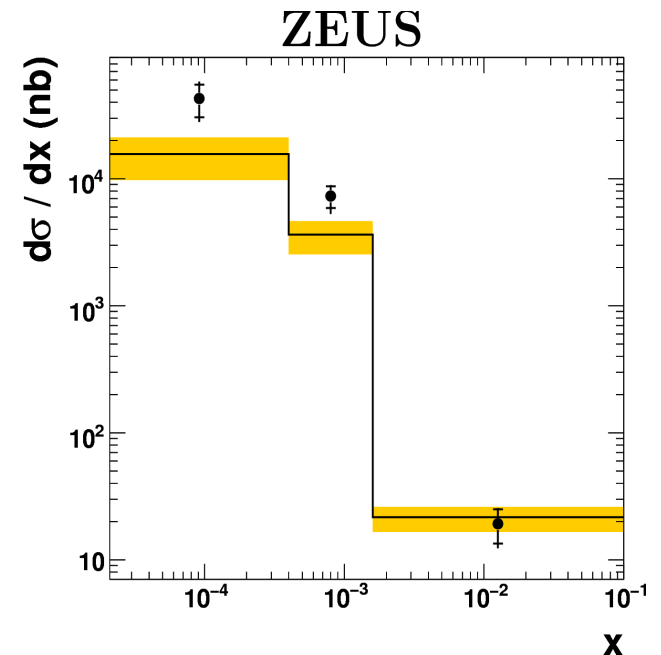
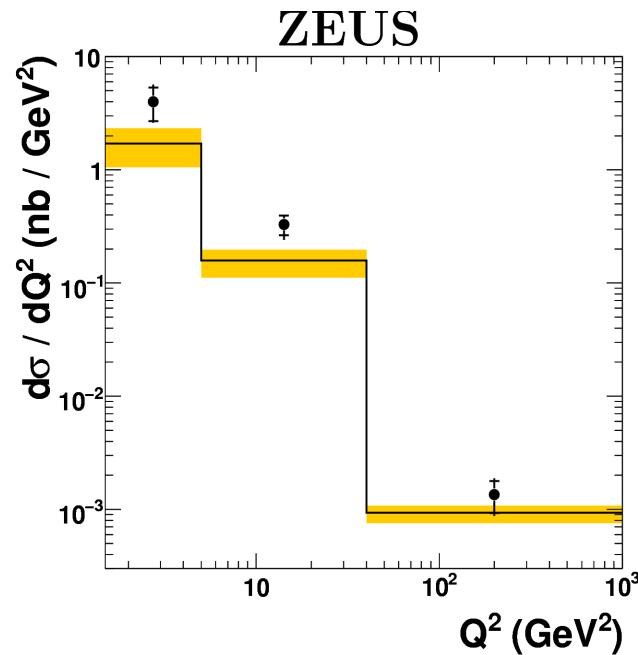
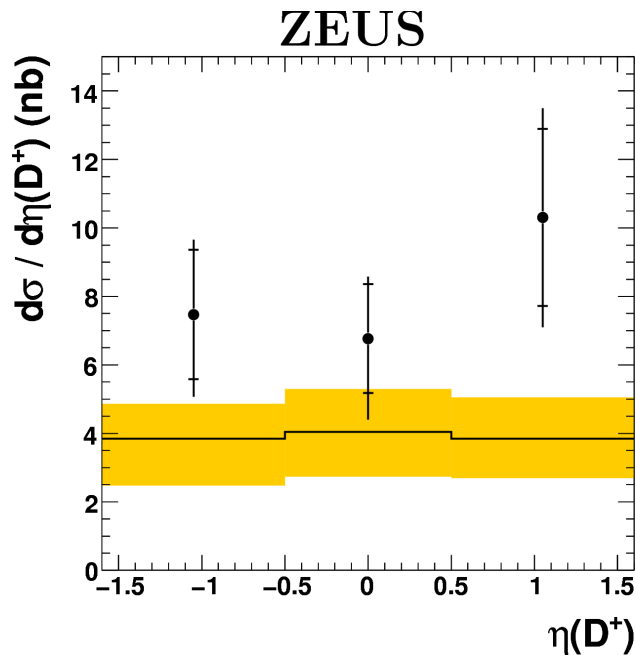
Visible cross sections are compared to predictions obtained using the HVQDIS program (Harris & Smith)

→ Fully differential NLO QCD prediction in the **Fixed Flavour number scheme (FFNS)**:

- **Charm (and beauty) are produced dynamically** (not part of proton or photon)
- c, b massive
- Neglects $[\alpha_s \ln(\mu^2 / m^2)]^n$
- **Valid at threshold**



Cross sections: $d\sigma/d\eta(D^+)$, $d\sigma/dQ^2$, $d\sigma/dx$



- **ZEUS D^+ 120 pb⁻¹**

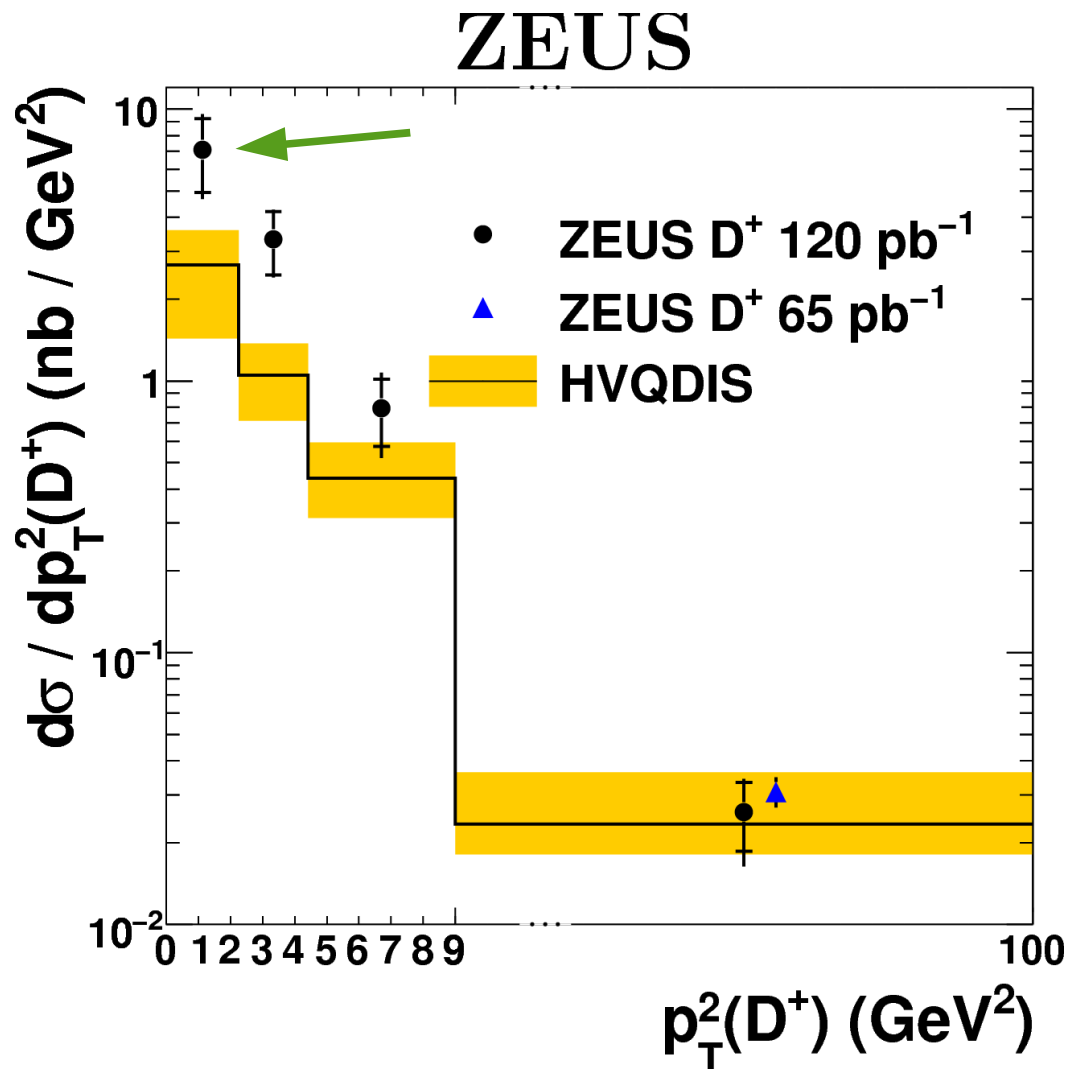
HVQDIS

The data are reasonably described by HVQDIS

Parameters and variations:

- ZEUS-S FFNS PDF (varied within uncertainty)
- $m_c = 1.5 \text{ GeV}$ (1.35 – 1.65 GeV)
- $\mu_R^2 = \mu_F^2 = Q^2 + 4m_c^2$ (separately multiplied by 4 and 0.25)
- Peterson $\epsilon = 0.079$ (0.01 - 0.1)

Cross sections: $d\sigma/dp_T^2(D^+)$



- The data are in good agreement with a previous ZEUS measurement (using $D^+ \rightarrow K^- \pi^+ \pi^+$) for $p_T(D^+) > 3 \text{ GeV}$

- The data are in reasonable agreement with HVQDIS

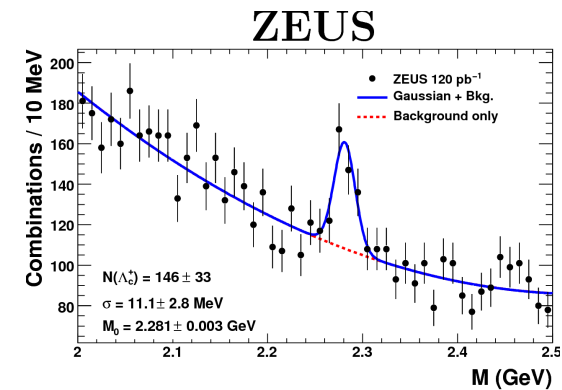
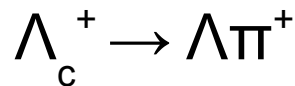
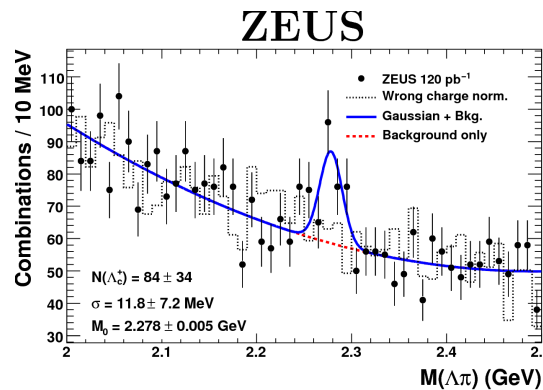
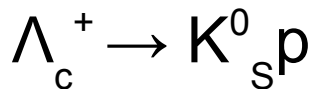
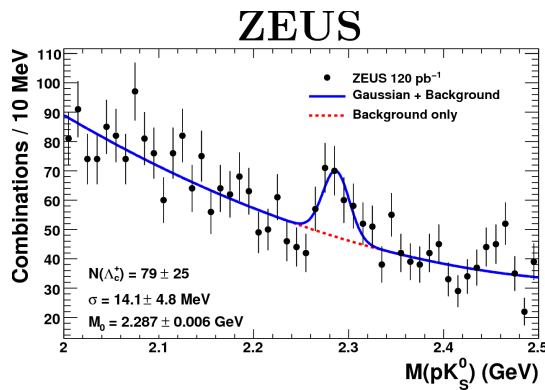
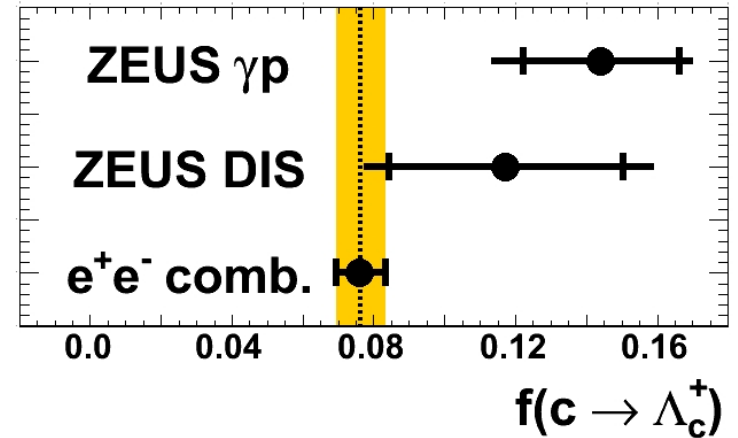
$f(c \rightarrow \Lambda_c^+)$ in DIS

Motivation:

- Test fragmentation universality
 - Affects knowledge of $f(c \rightarrow D^+, D^*, \dots)$
- Important for precise F_2^c from D mesons

Difficult measurement at HERA (statistics!)

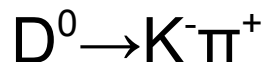
→ **Combine two decay channels**
(same kinematic range as for $D^+ \rightarrow K_S^0 \pi^+$)



both channels

Reconstruction of D^+ and D^0 mesons using lifetime information

Decay channels:

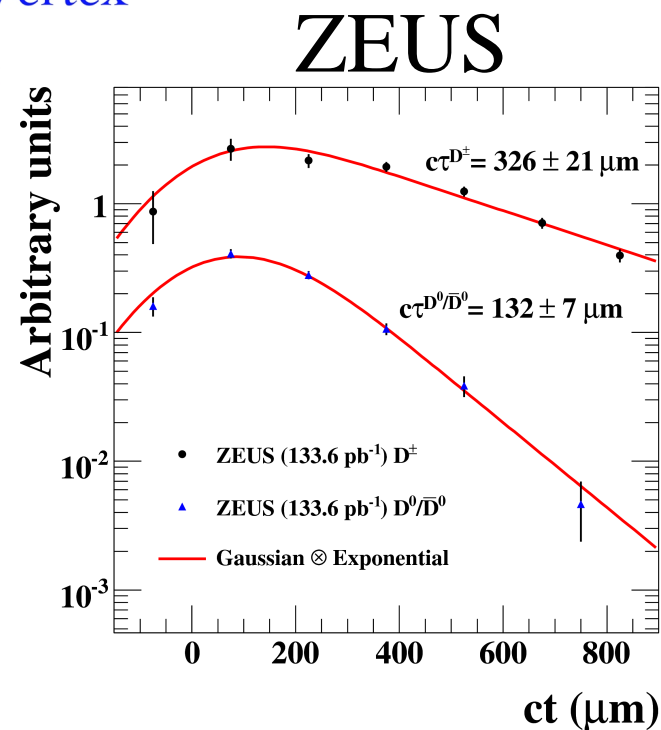
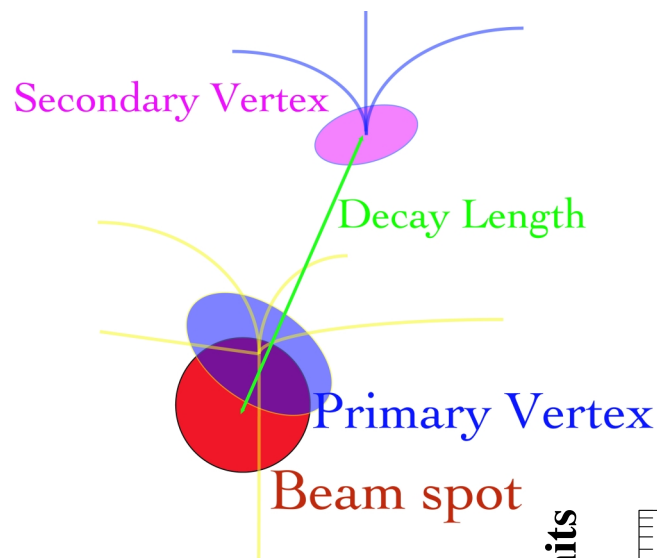


Micro Vertex Detector (HERA II):

→ **Reconstruct secondary decay vertices**

L_{XY} : 2D distance between the secondary vertex and the primary interaction point projected onto the D Meson momentum vector

$$S_i = L_{XY} / \sigma(L_{XY})$$



D⁺ and D⁰ measurement

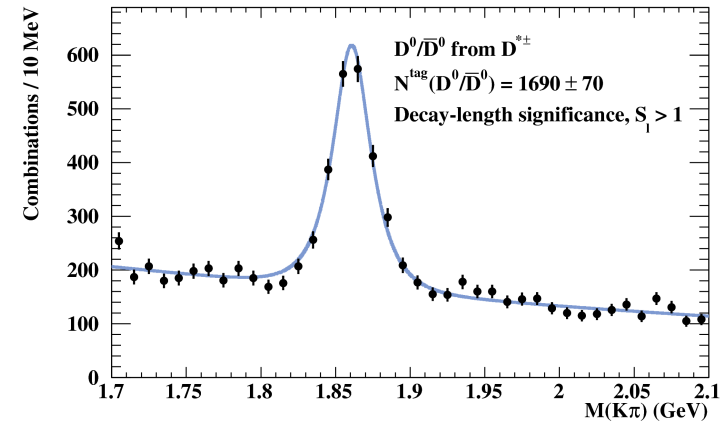
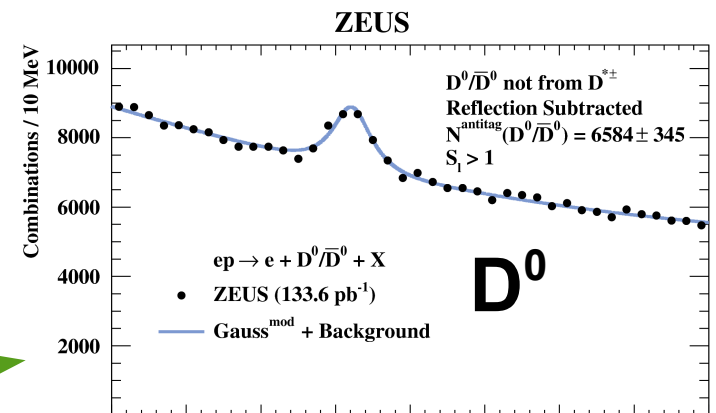
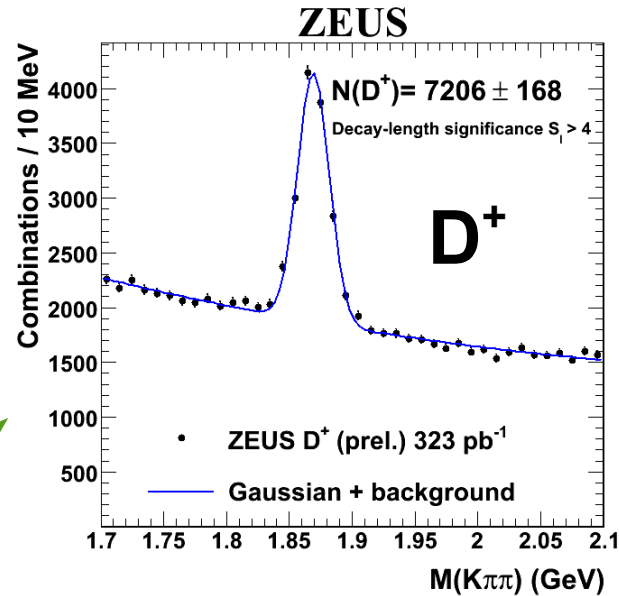
Kinematic region:

$1.5 < p_T(D^+, D^0)$
 $< 15 \text{ GeV}$
 $|\eta(D^+, D^0)| < 1.6$
 $5 < Q^2 < 1000 \text{ GeV}^2$
 $0.02 < y < 0.7$

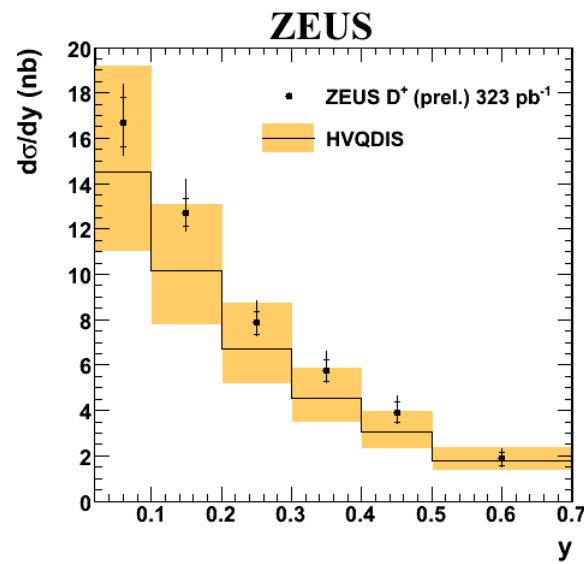
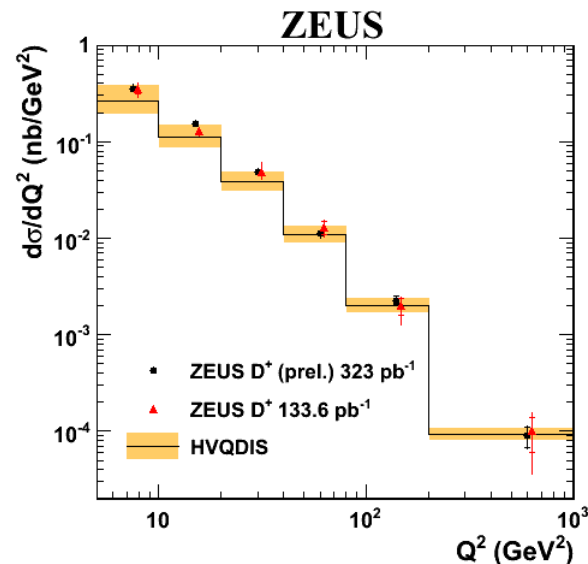
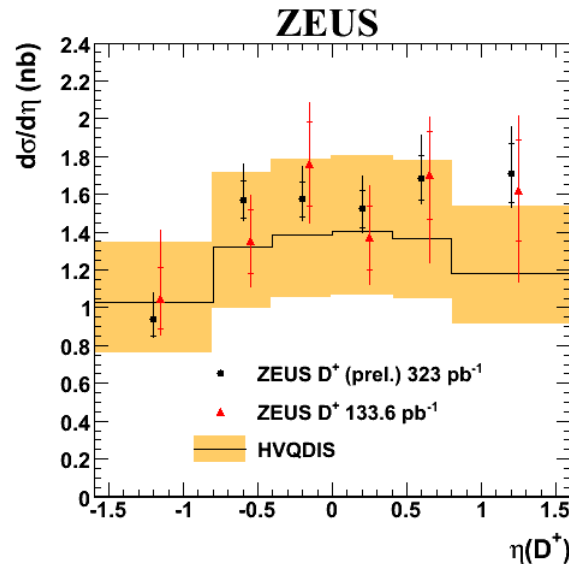
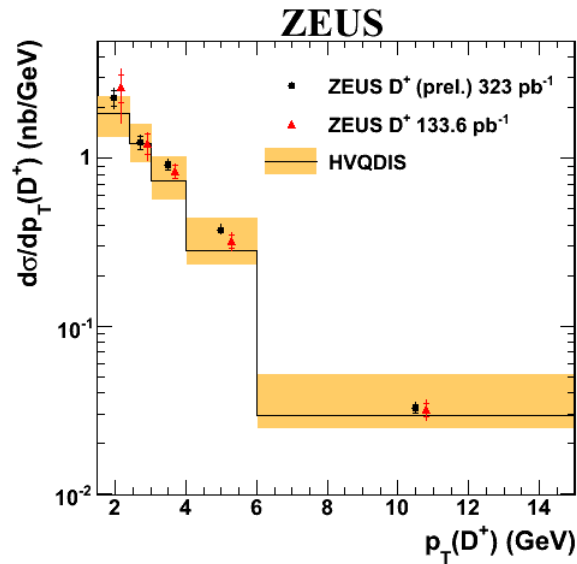
Data sample:

323 pb⁻¹ (2005-2007) for D⁺
 134 pb⁻¹ (2005) for D⁰

D⁰ mesons not originating
 from D^{*+} decays were
 used for the cross section
 measurement



D⁺ cross sections



- The measurements are described by HVQDIS (same parameters as for the HERA I analysis)

- The published (05) and preliminary (05-07) results are in good agreement and the precision has improved significantly

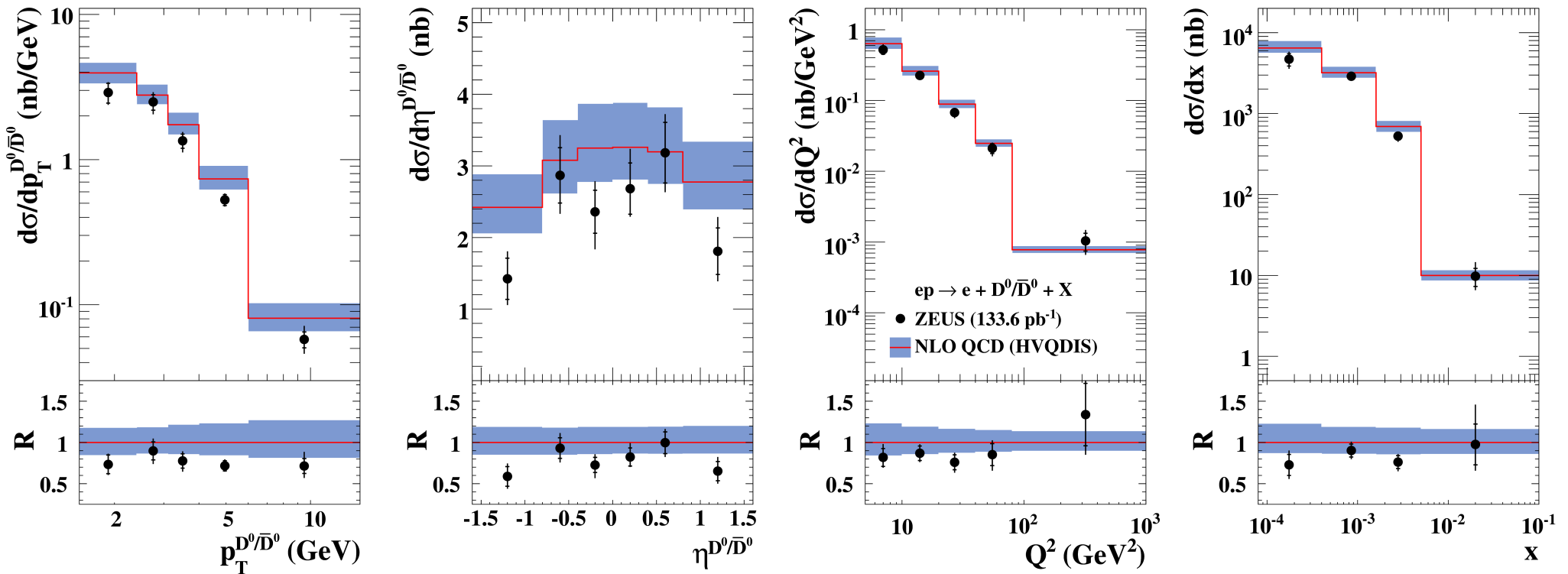
- Competitive precision as D⁺ measurements in HERA I

- **ZEUS D⁺ (prel.) 323 pb⁻¹**
- **ZEUS D⁺ 133.6 pb⁻¹**

— HVQDIS

D⁰ cross sections

ZEUS



All cross sections are reasonably described by HVQDIS

$ep \rightarrow e + D^0/\bar{D}^0 + X$
 ● ZEUS (133.6 pb⁻¹)
 ■ NLO QCD (HVQDIS)

Extraction of F_2^c

Extrapolation needed:

Measured cross section
in bin i

$$F_{2,meas}^{c\bar{c}}(x_i, Q_i^2) = \frac{\sigma_{meas,i}}{\sigma_{theo,i}} \times F_{2,theo}^{c\bar{c}}(x_i, Q_i^2)$$

Calculated using
HVQDIS (FFNS)

Calculated at NLO
in FFNS

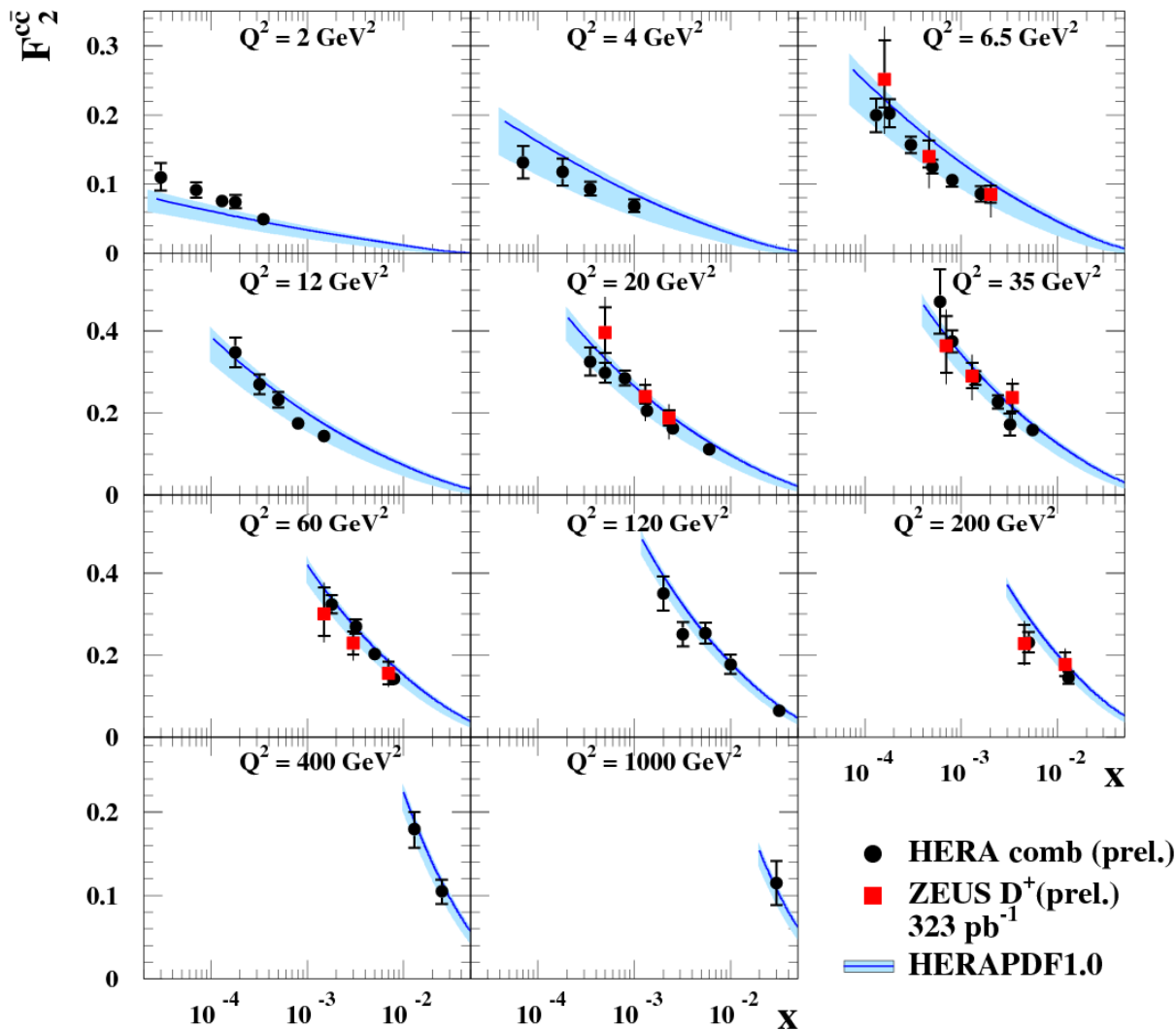
Extrapolation factors for D^+ and D^0 measurement:

1.5 (at high Q^2) – 3.2 (at low Q^2)

→ Lower than in previous D^+ and D^0 analysis due to lower $p_T(D^+, D^0)$ cut

F_2^c as a function of x in bins of Q^2

ZEUS



- Preliminary D^+ results are compared to H1+ZEUS combination of all available tagging methods (except D^+ prel.)

- For HERA combined F_2^c → see talk by M. Corradi

- The data are well described by HERAPDF1.0

- The black points, the red points are and HERAPDF1.0 are based on independent data sets

Summary

- The production of the charmed hadrons D^+ , D^0 and Λ_c^+ in DIS has been studied in detail at HERA
- The measurements are reasonably described by NLO QCD predictions
- For the first time the threshold region and $f(c \rightarrow \Lambda_c^+)$ were investigated in DIS using new decay channels
- Precise measurements of D^+ and D^0 have been obtained using lifetime tags and the corresponding contribution to F_2 has been extracted

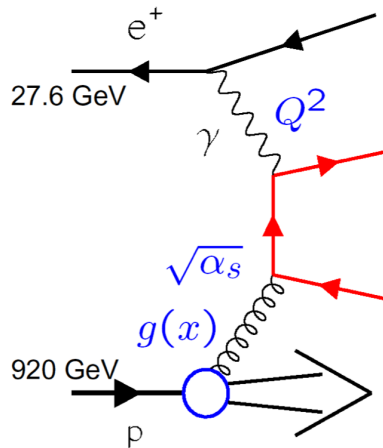
Backup slides

pQCD Treatment of charm (and beauty) production in DIS

Massive, FFNS:

c and b produced dynamically
(not part of proton or photon)

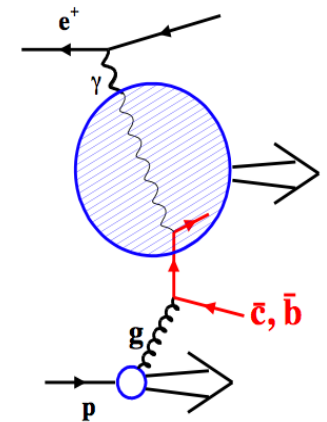
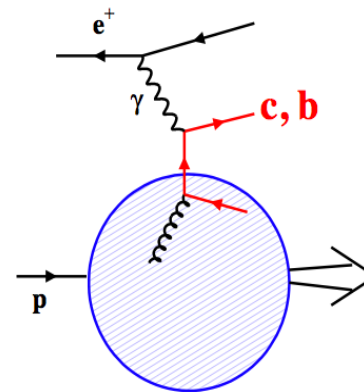
- c, b massive
- Neglects $[\alpha_s \ln(\mu^2 / m^2)]^n$
- Valid at threshold



Massless, ZM-VFNS:

**c and b massless partons in
proton and photon**

- c, b massless
- Resums $[\alpha_s \ln(\mu^2 / m^2)]^n$
- Valid for $\mu^2 \gg m^2$

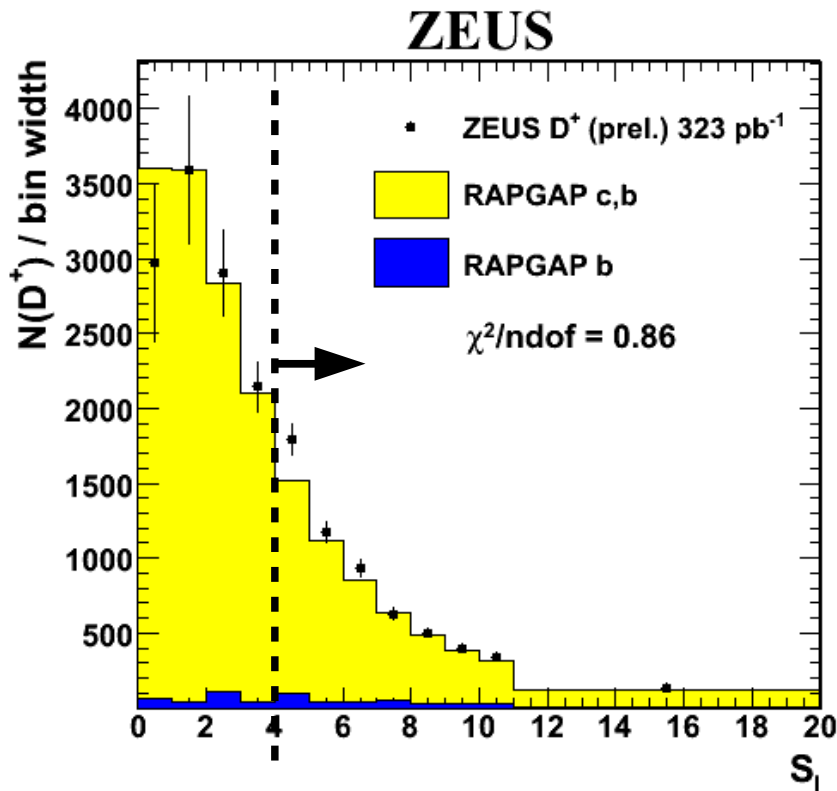


Variable Flavour Number Scheme, (GM)-VFNS:

Interpolates / matches between both approaches

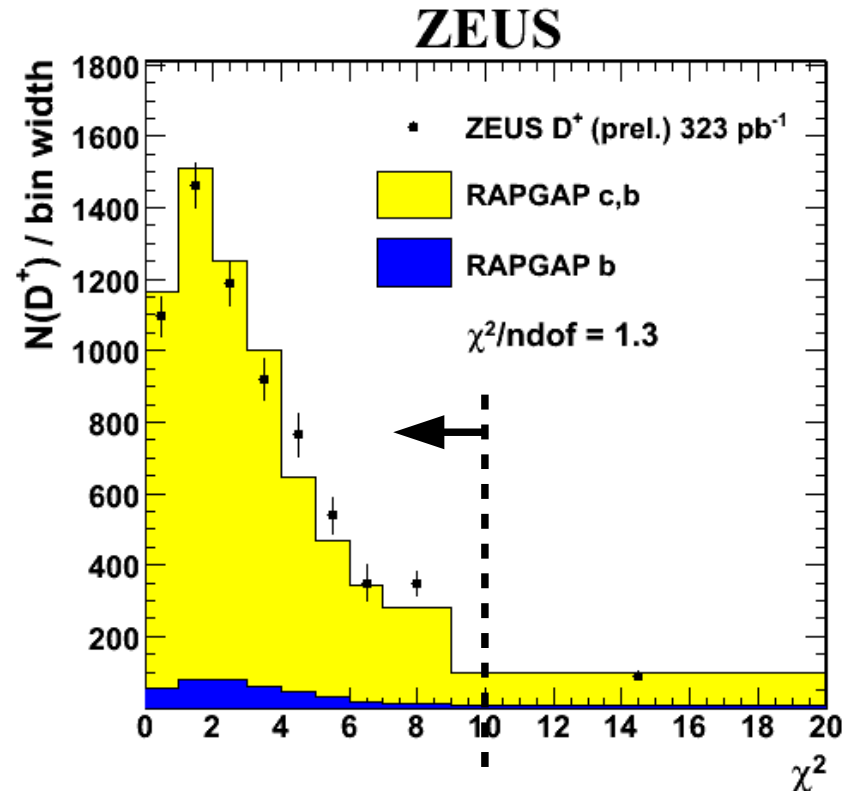
- **Massive at low Q^2 , massless at high Q^2**

Secondary vertex reconstruction



Example: $D^+ \rightarrow K^- \pi^+ \pi^+$

$$S_1 > 4$$



$$\text{Chi}^2 < 10$$

→ Lifetime and vertex quantities are well reproduced by the MC