

# Production of $D^\pm$ and $\Lambda_c^\pm$ in DIS and $F_2^c$ measurement at ZEUS



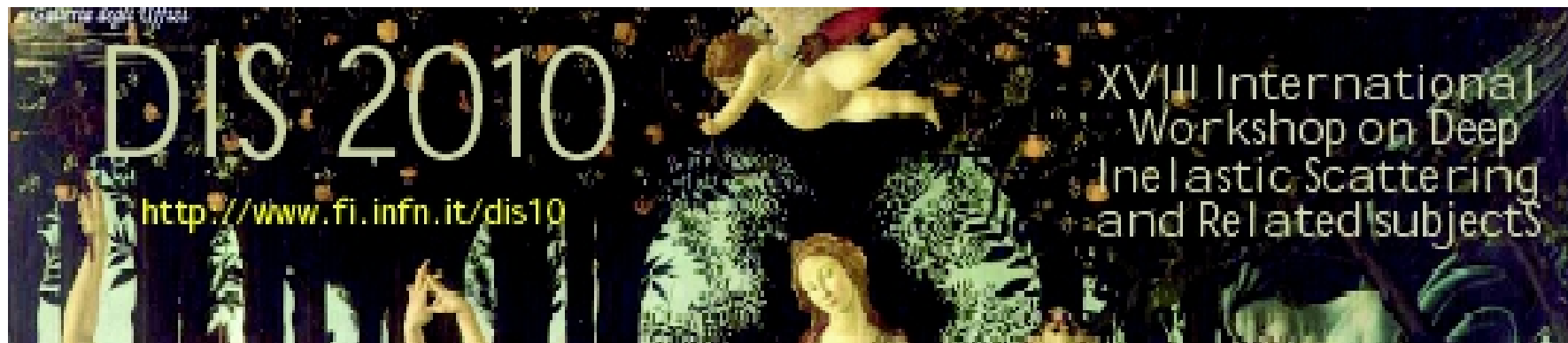
Mykhailo Lisovyi  
DESY & University of Hamburg



*on behalf of the*

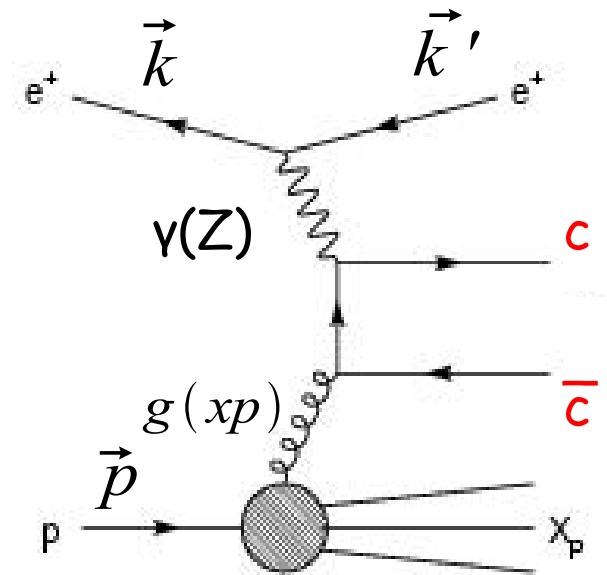


*Collaboration*



# Motivation

- Charm in DIS is predominantly produced via Boson-Gluon Fusion(BGF) process.
- Test of pQCD:  
multiple scales( $Q^2$ ,  $m_c$ ,  $p_T(c)$ ).
- Production is directly sensitive to gluon density in the proton.



Charm quark contribution to the structure function at low  $Q^2$ :

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

# pQCD approximations

## Massive scheme (FFNS):

- c and b massive;
  - valid for  $Q^2 \sim M_c^2$ ;
- c & b produced perturbatively  
(not part of proton or photon)

*DIS: Harris & Smith, HVQDIS*  
*fully differential NLO calculation*

## Massless scheme (ZM-VFNS):

- c and b massless;
  - valid for  $Q^2 \gg M_c^2$ ;
- c & b present in proton

*DIS: only inclusive calculation of  $F_2^{cc}$*

## Variable Flavor Number Scheme (GM-VFNS):

- equivalent to massive at small  $Q^2$ ;
  - equivalent to massless at high  $Q^2$ ;
- c & b present in proton

*DIS: only  $F_2^{cc}$*

# D<sup>+</sup> production at the threshold

- Charmed mesons were reconstructed in the decay

$$D^+ \rightarrow K_S^0 \pi^+ \rightarrow \pi^- \pi^+ \pi^+ (+ \text{c.c.}) \quad (\text{BR} = 1\%)$$

- Kinematic region:  
 $1.5 < Q^2 < 1000 \text{ GeV}^2$   
 $0.02 < y < 0.7$
- Data sample:  
 $120 \text{ pb}^{-1}$   
 (1996-2000)

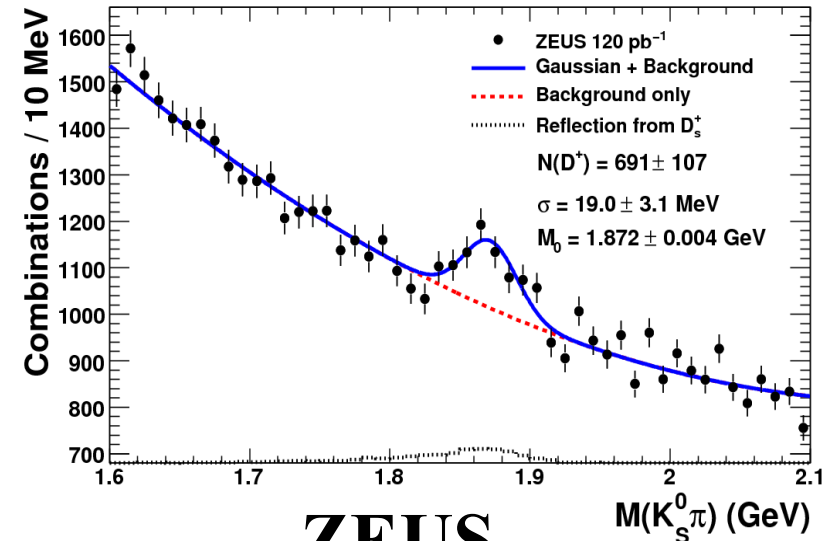
$$0 < p_T(D^+) < 10 \text{ GeV}$$

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

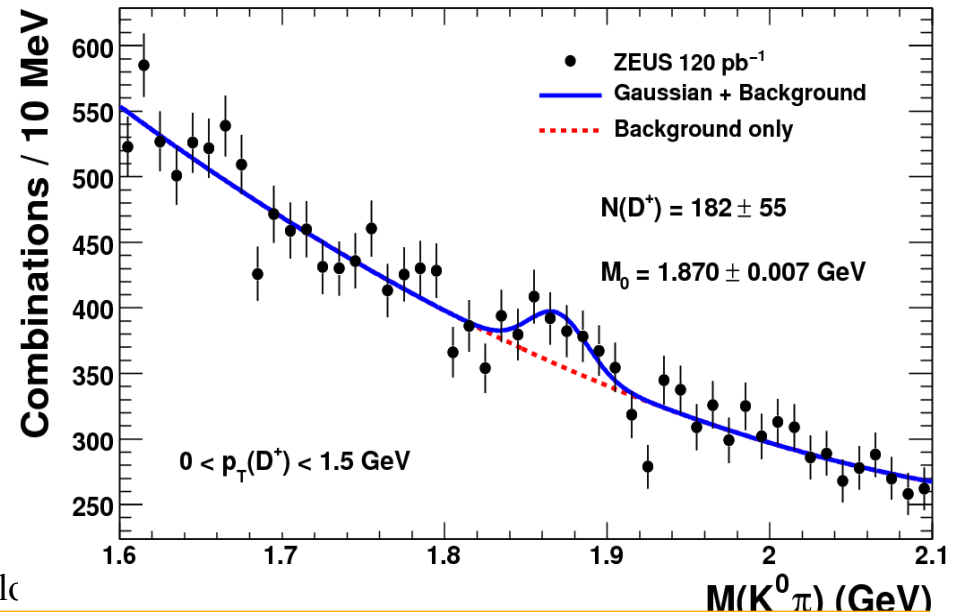
- Reconstruction of the neutral strange meson in the decay chain reduces combinatorial background significantly

Unique test of pQCD for  
 $p_T(D) > 0 \text{ GeV}$

ZEUS



ZEUS

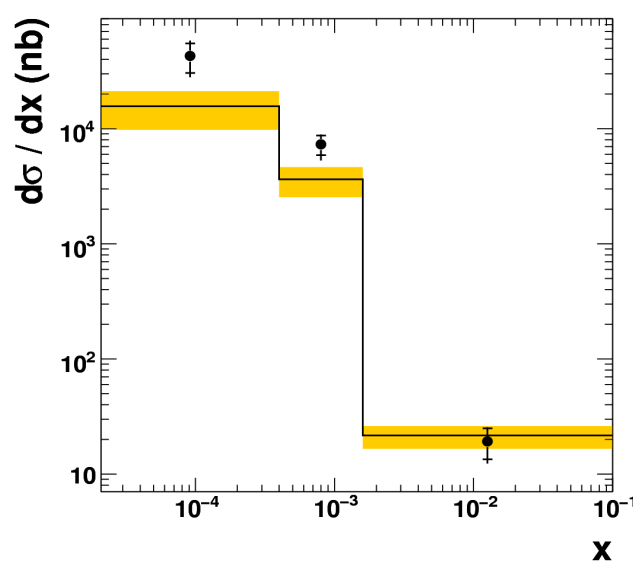
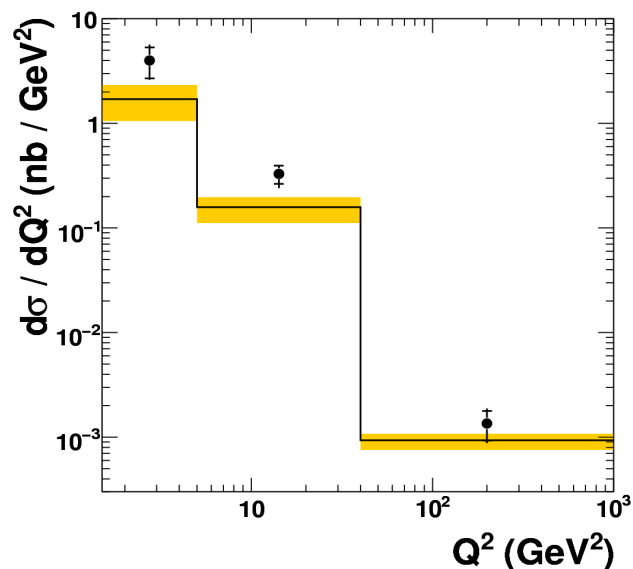
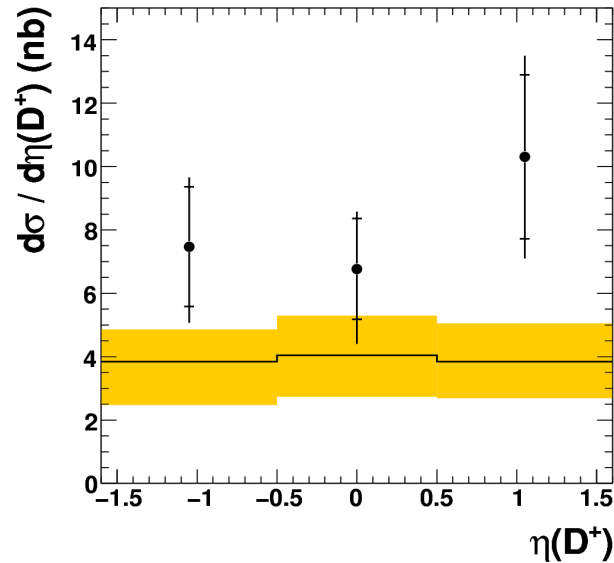
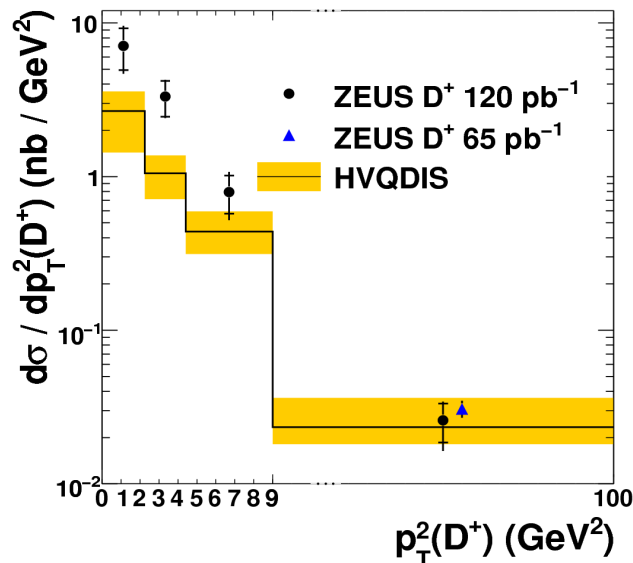


# D<sup>+</sup> at the threshold: cross sections

$$\sigma(ep \rightarrow D^+ X) = 25.7 \pm 4.1 (\text{stat.})_{-5.2}^{+3.8} (\text{syst.}) \pm 0.8 (BR) \text{ nb}$$

$$\sigma^{HVQDIS} = 12.7_{-4.1}^{+3.8} \text{ nb}$$

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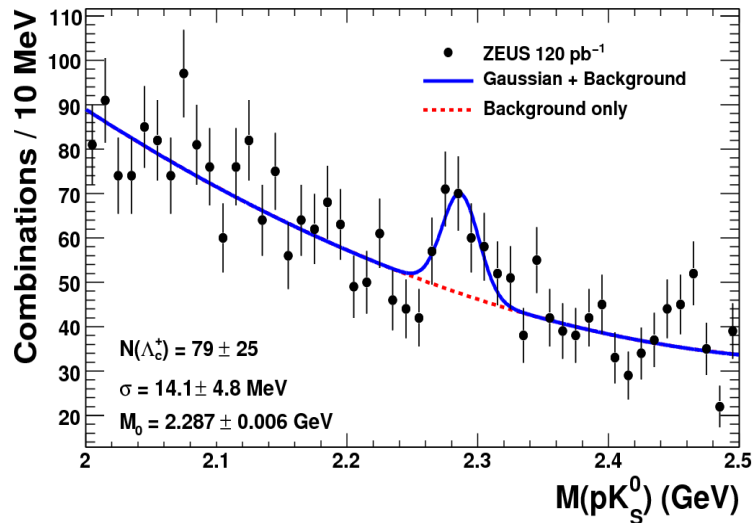


- Measurement agree with NLO QCD in FFN predictions within 2σ.
- Measurement is in good agreement with previously published result at higher p<sub>T</sub>(D<sup>+</sup>).
- First measurement at HERA in the region 0 < p<sub>T</sub>(D<sup>+</sup>) < 1.5 GeV.

# $\Lambda_c^+$ fragmentation fraction

$\Lambda_c^+ \rightarrow K_S^0 p^+ \rightarrow \pi^- \pi^+ p (+ \text{c.c.})$   
(BR = 0.80%)

**ZEUS**



$f(c \rightarrow \Lambda_c)$

**ZEUS(DIS)**  $0.117 \pm 0.033 (stat.)_{-0.022}^{+0.026} (syst.) \pm 0.027 (BR)$

**ZEUS(PHP)**  $0.144 \pm 0.022 (stat.)_{-0.022}^{+0.013} (syst.)_{-0.025}^{+0.037} (BR)$

**e<sup>+</sup>e<sup>-</sup> comb.**  $0.076 \pm 0.007 (stat. \otimes syst.)_{-0.016}^{+0.027} (BR)$

• Kinematic region:

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

$0.02 < \gamma < 0.7$

$0 < p_T(\Lambda_c) < 10 \text{ GeV}$

$|\ln(\Lambda_c)| < 1.6$

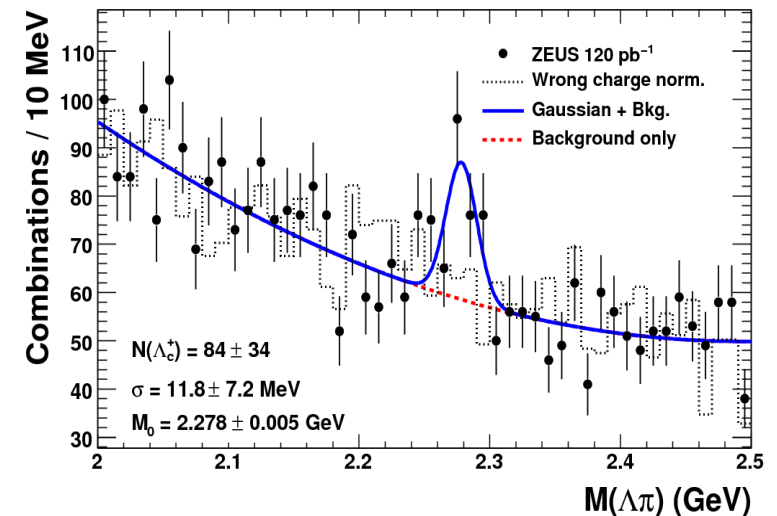
• Data sample:

$120 \text{ pb}^{-1}$

(1996-2000)

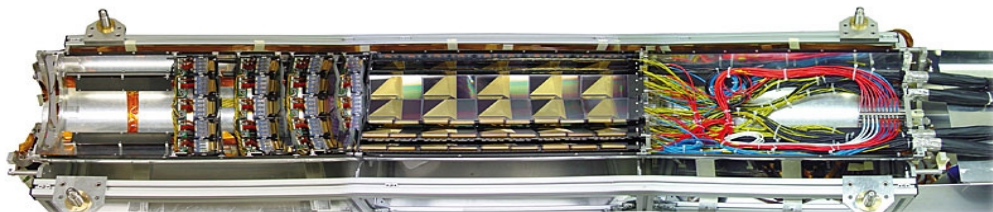
$\Lambda_c^+ \rightarrow \Lambda^0 \pi^+ \rightarrow p \pi^- \pi^+ (+ \text{c.c.})$   
(BR = 0.68%)

**ZEUS**



# Vertexing at ZEUS

- For the HERAII round silicon **Micro Vertex Detector** was installed at ZEUS.
- BMVD resolution:  $\sim 25 \mu\text{m}$ .



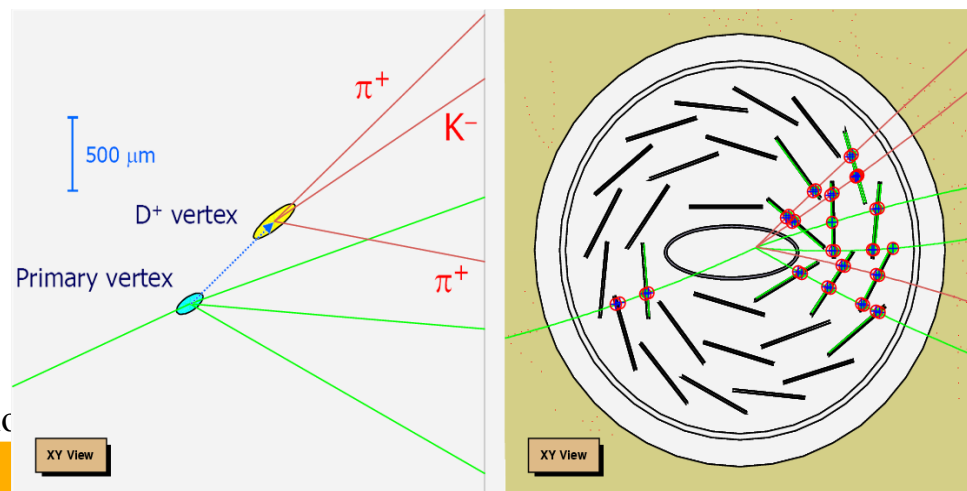
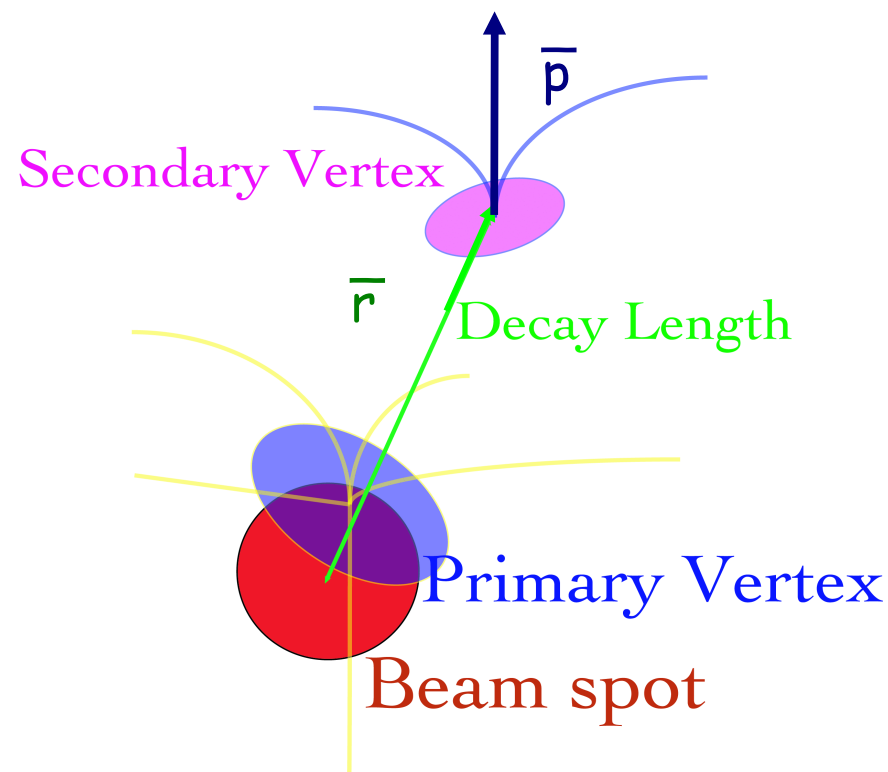
- Reconstruction of displaced from primary point of interaction vertices of  $D^+ \rightarrow K^- \pi^+ \pi^+$  (+ c.c.) decay.
- Lifetime tag based on decay-length significance  $S_l$ :

➤  $L_{xy}$ : 2D-vector from the primary to the decay vertex projected on the D meson momentum;

➤  $S_l = L_{xy} / \sigma(L_{xy})$

20/04/2010

DIS2010, Flo



# $D^+$ in DIS in HERAII (ZEUS-prel-10-005)

- Decay channel:

$$D^+ \rightarrow K^- \pi^+ \pi^+ (+ \text{c.c.})$$

(BR = 9.22 %)

- Data sample:

323 pb<sup>-1</sup>  
(2005-2007)

- Kinematic region:

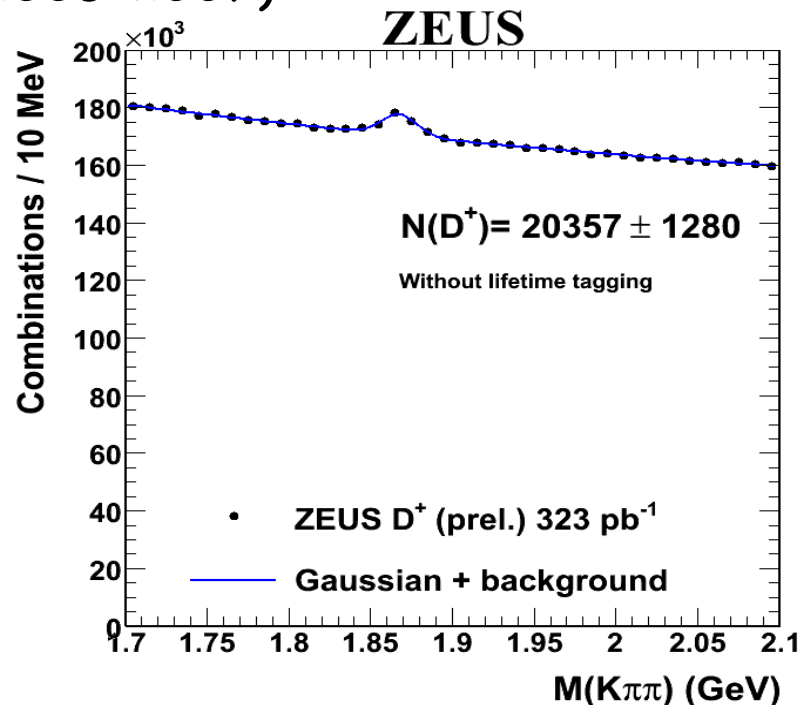
$$5 < Q^2 < 1000 \text{ GeV}^2$$

$$0.02 < y < 0.7$$

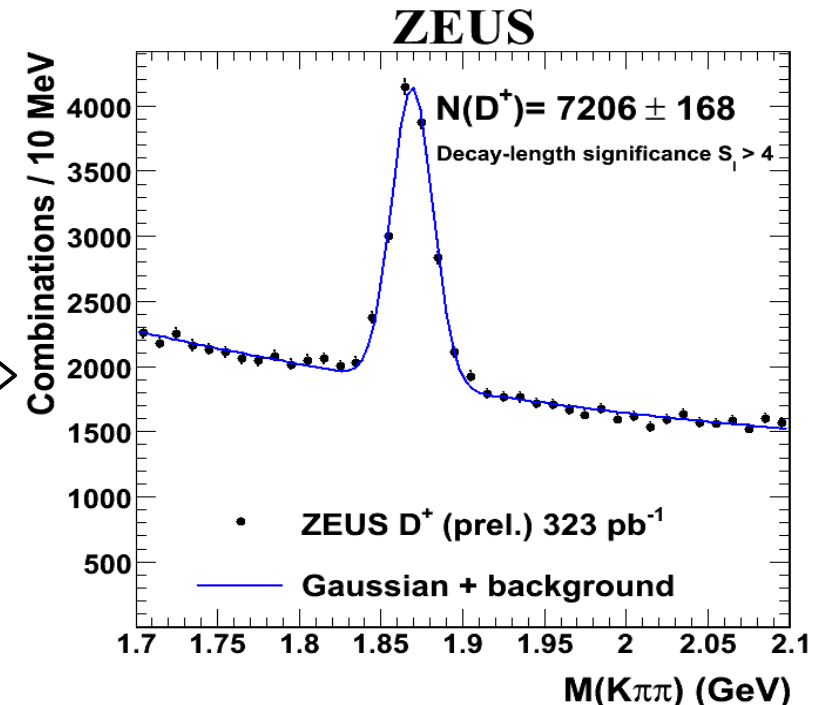
$$1.5 < p_T(D^+) < 15 \text{ GeV}$$

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

Significant  
improvement in  
Signal/Background  
ratio!

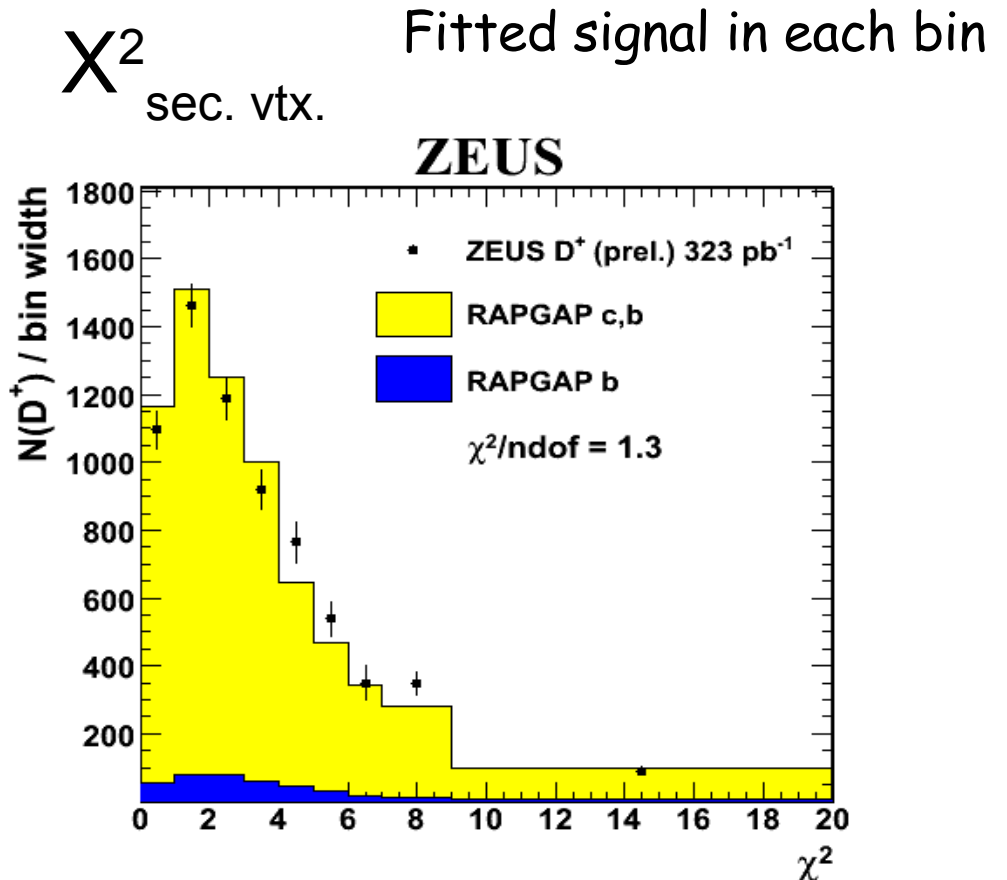
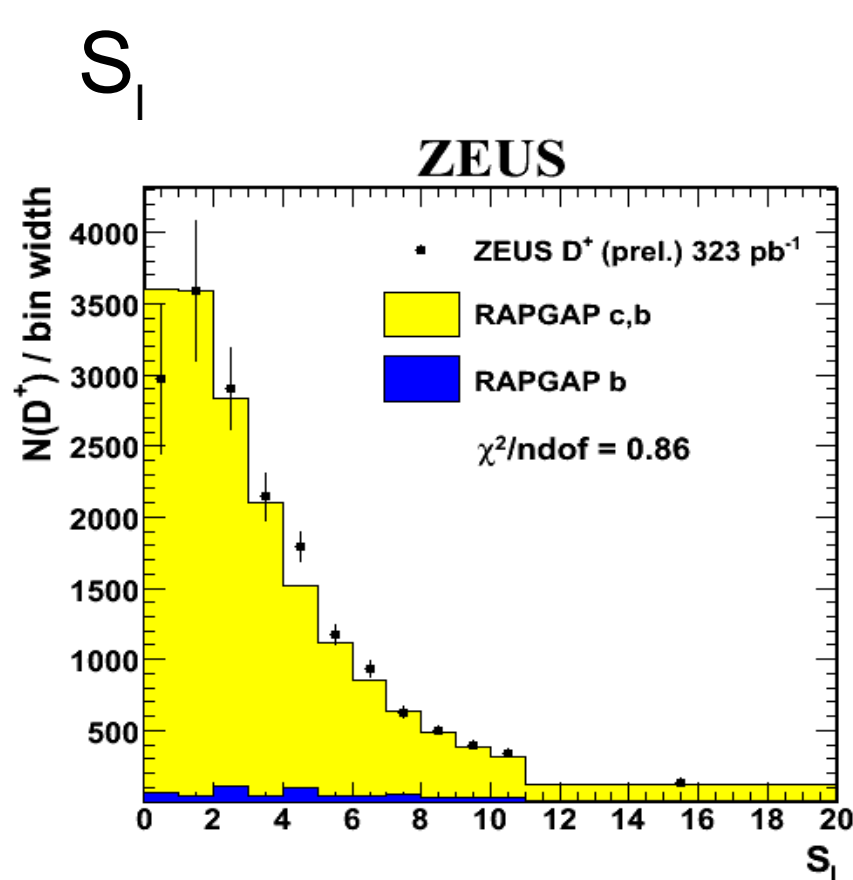


$S_1 > 4$



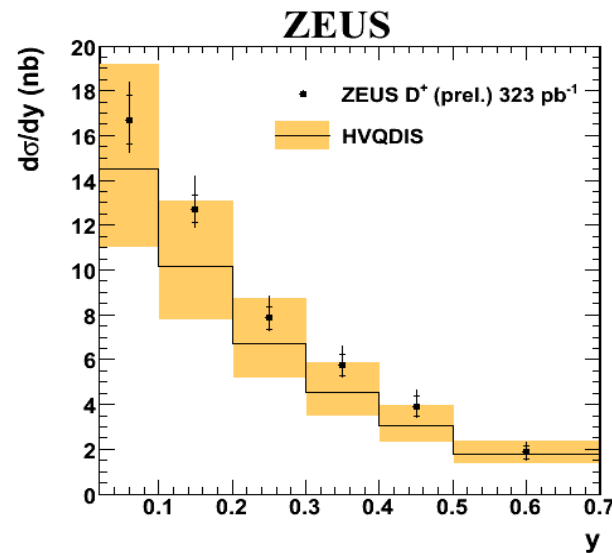
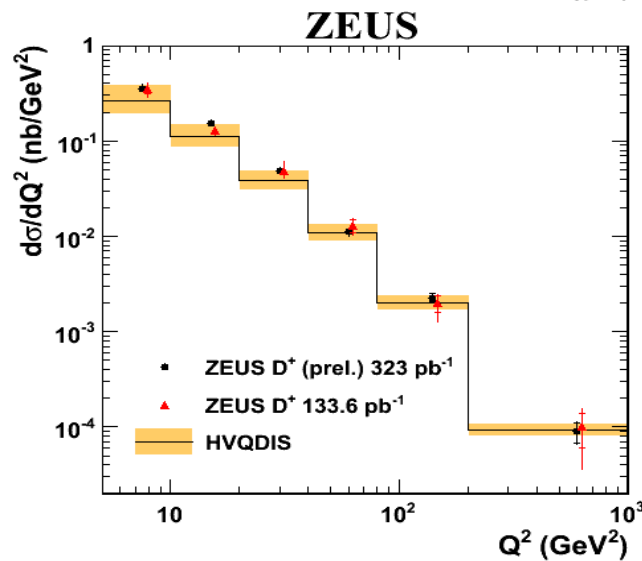
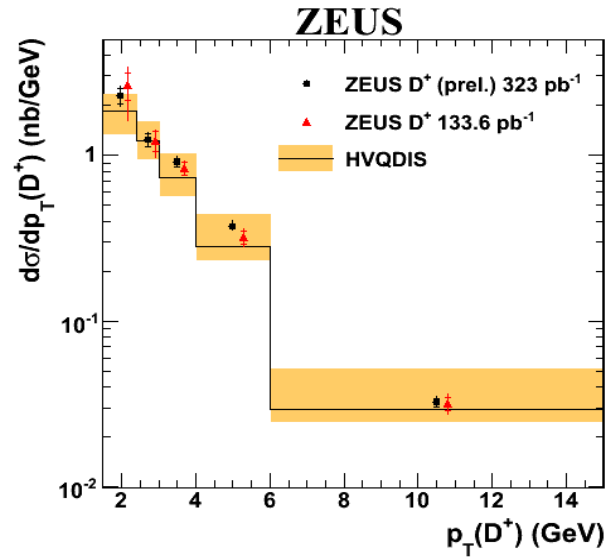
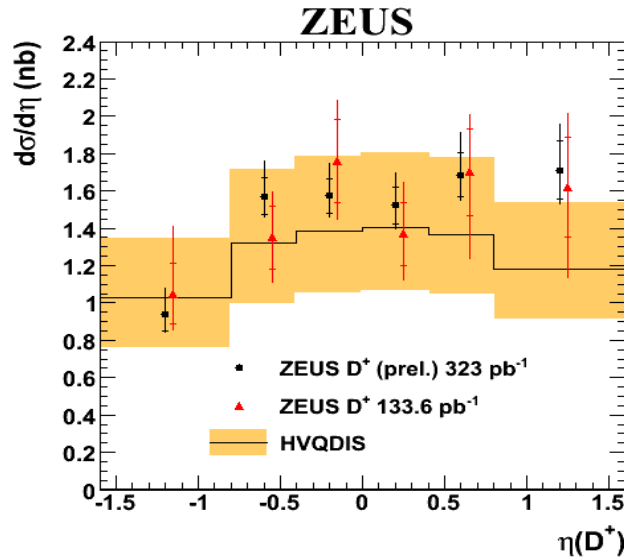


# Secondary vertices reconstruction quality



- Cuts used in the analysis:  $\chi^2 < 10$  and  $S_1 > 4$ .
- Significantly reduced systematics due to higher quality of reconstruction (EPJ C 63 171 (2009)).

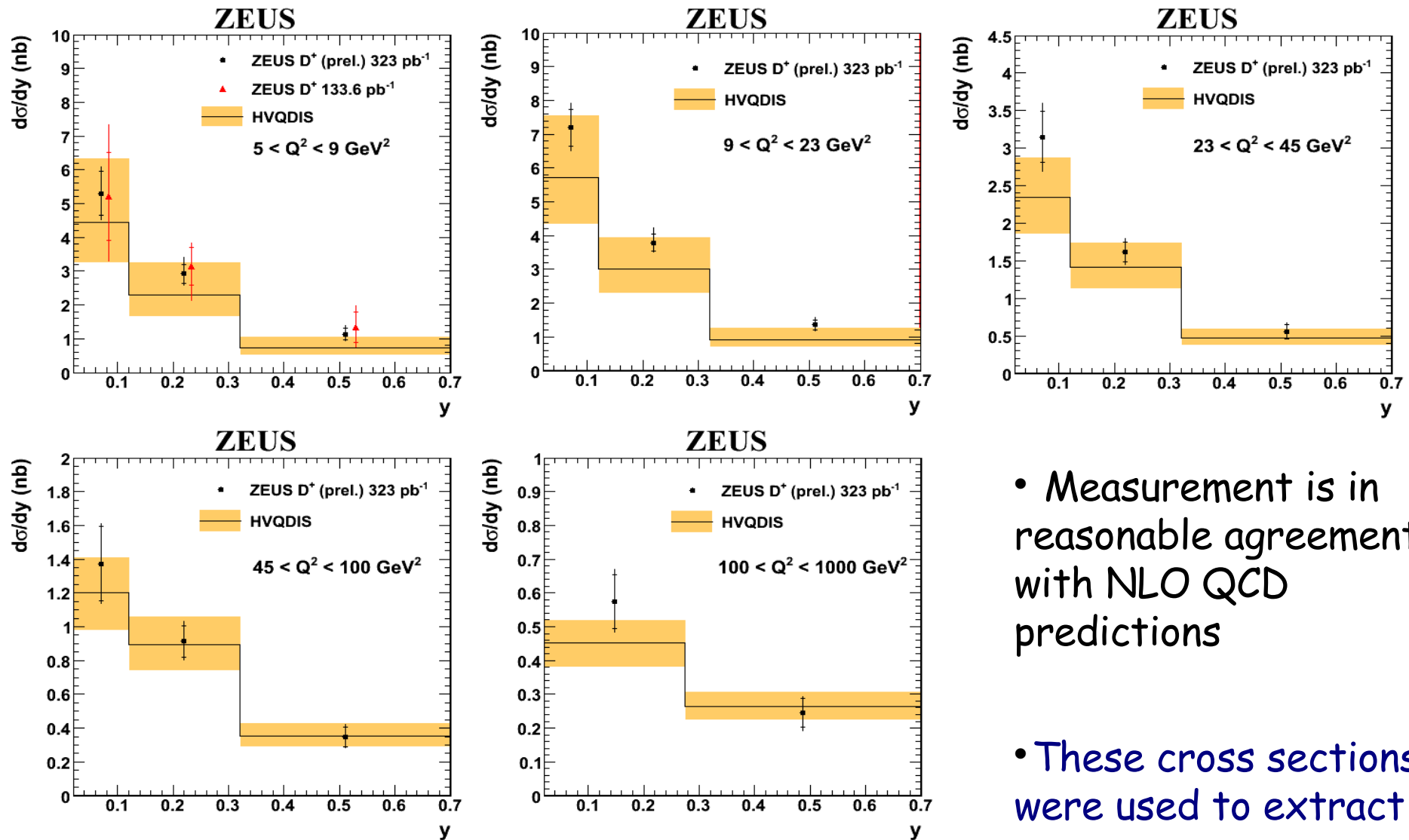
# D<sup>+</sup> in HERAII: cross sections



- The dominant systematic uncertainties come from tracking efficiency and MC model.
- Measurement is in reasonable agreement with NLO QCD predictions by HVQDIS program.
- Improved statistical precision and size of systematics, comparing to the published D<sup>+</sup> results.

$$\sigma(ep \rightarrow D^+ X) = 4.73 \pm 0.14 (stat.)_{-0.22}^{+0.49} (syst.) \pm 0.11 (BR) \text{ nb} \quad \sigma^{HVQDIS} = 3.96_{-0.96}^{+1.15} \text{ nb}$$

# D<sup>+</sup> in HERAII: cross sections



- Measurement is in reasonable agreement with NLO QCD predictions

- These cross sections were used to extract  $F_2^c$

# $F_2^c$ extraction

- Measurement is performed in a restricted kinematic region.
- Extrapolation is performed based on NLO QCD calculations.

Measured cross section in a bin ( $Q_i^2, y_i$ )

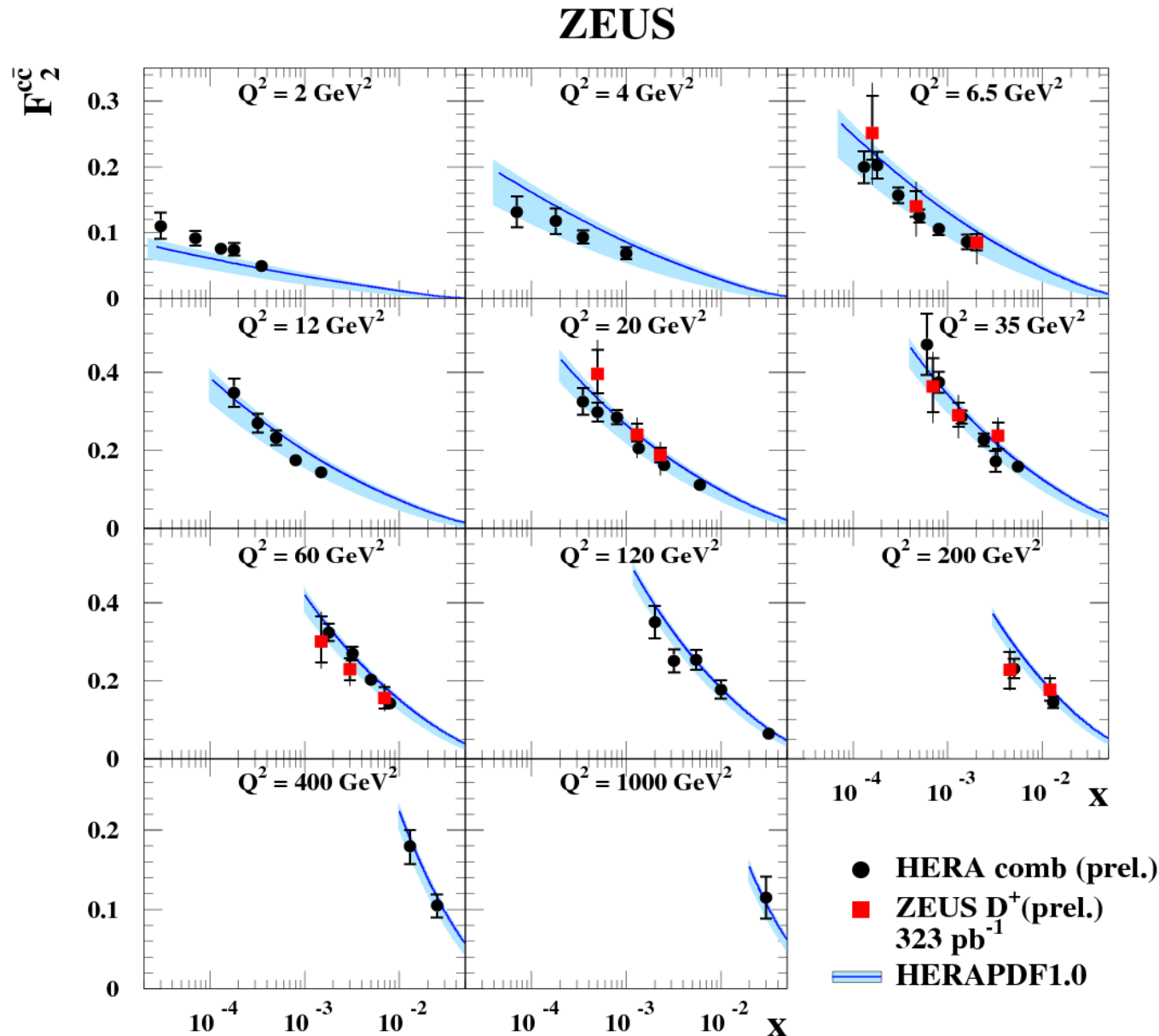
$$F_{2,meas}^{c\bar{c}}(x_i, Q_i^2) = \frac{\sigma_{i,meas}(ep \rightarrow e' D^+ X)}{\sigma_{i,theo}(ep \rightarrow e' D^+ X)} F_{2,theo}^{c\bar{c}}(x_i, Q_i^2)$$

NLO QCD in FFNS by HVQDIS

- $m_c = 1.5 \text{ GeV}$  (1.35 .. 1.65 GeV);
- $\varepsilon = 0.079$  (0.01 .. 0.1);
- $f(c \rightarrow D^+) = 0.216$  ( $\pm$  experimental errors);
- $\mu_{r,f}^2 = Q^2 + 4m_c^2$  (varied separately;  $1/4 \cdot (Q^2 + 4m_c^2) \dots 4 \cdot (Q^2 + 4m_c^2)$ );
- ZEUS-S FFNS NLO PDF fit (upper and lower predictions).

$$f^{Peterson}(z) \propto \frac{1}{z(1 - 1/x - \epsilon/(1-z))^2}$$

# $F_2^c$ from $D^+$



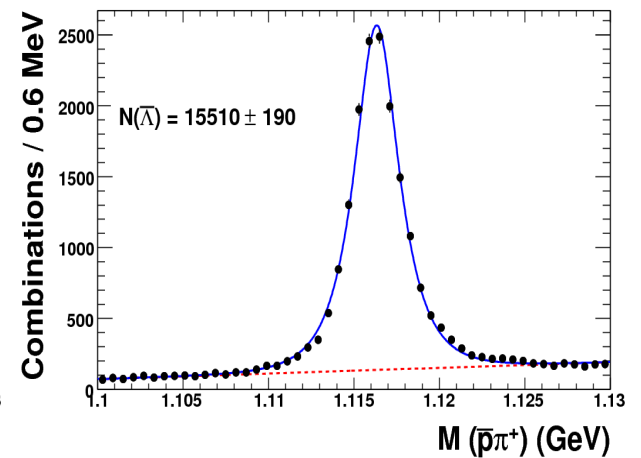
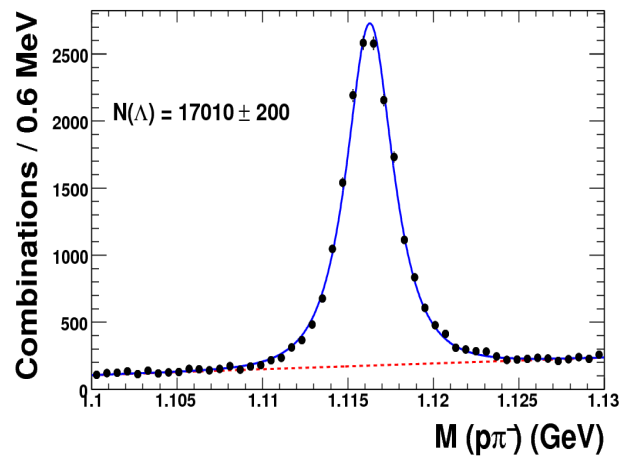
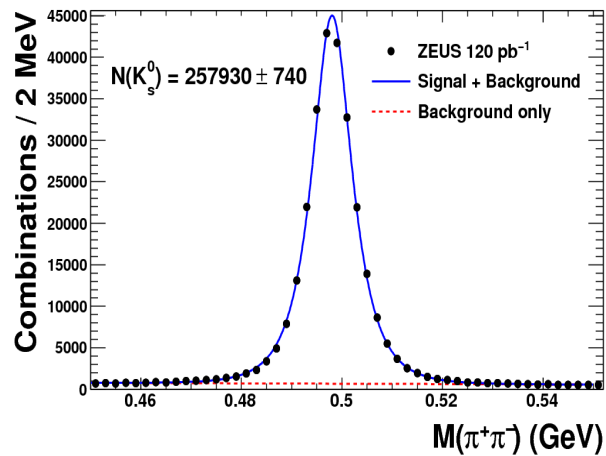
- $F_2^c$  was extracted with 323  $\text{pb}^{-1}$  data of HERAII
- HERA comb (prel.) includes all published H1 and ZEUS  $F_2^c$  results ( $D^*$ , VTX,  $\mu$ , ...)
- New  $D^+$  results are in agreement with the preliminary combined HERA  $F_2^c$  results
- The results are well described by HERAPDF1.0 prediction

# Summary

- Charm production was measured using the decay channels  $D^+ \rightarrow K_S^0 \pi^+ (+ \text{c.c.})$ ,  $\Lambda_c^+ \rightarrow K_S^0 p (+ \text{c.c.})$ ,  $\Lambda_c^+ \rightarrow \Lambda^0 \pi^+ (+ \text{c.c.})$  and  $D^+ \rightarrow K^- \pi^+ \pi^+ (+ \text{c.c.})$ .
- Measurement of  $D^+ \rightarrow K_S^0 \pi^+$  decay in HERAI gives a unique opportunity to test pQCD at the threshold and to check validity of extrapolation.
- The fragmentation fraction  $f(c \rightarrow \Lambda_c)$  is measured for the first time in DIS from a combination of two  $\Lambda_c^+$  decay channels.
- Measurement of  $D^+ \rightarrow K^- \pi^+ \pi^+$  decay in HERAII has the highest precision among  $D^+$  results at HERA.
- The charm component of the proton structure function,  $F_2$ , was measured by ZEUS from  $D^+$  cross sections and results agree with HERA combined data and prediction.

# $D^\pm$ at the threshold (BACKUP)

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