Measurement of charm production in DIS with D* mesons and extraction of F_2^{cc}

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on behalf of the ZEUS collaboration

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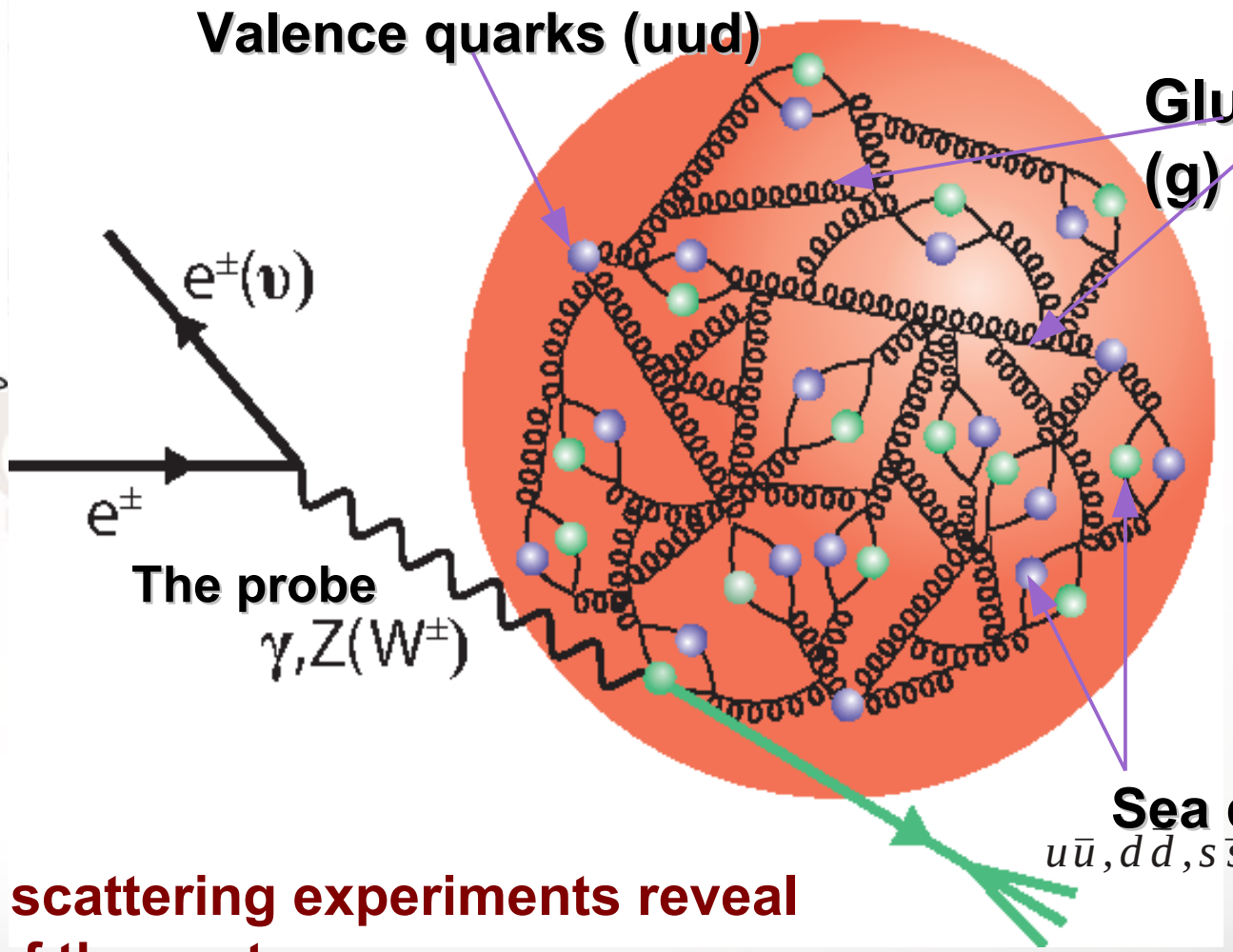
Outline

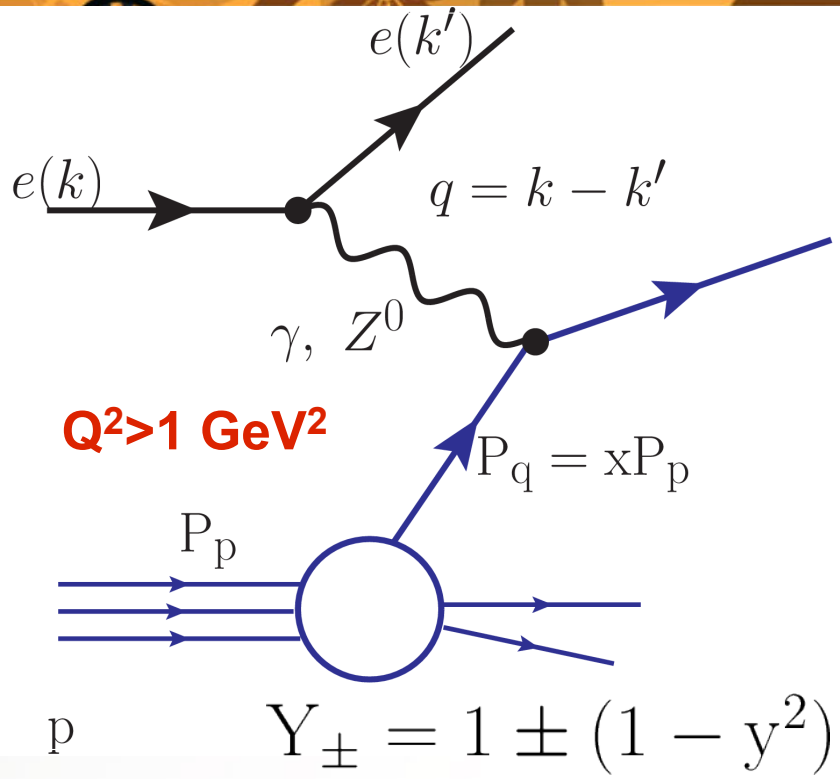
- **Introduction**
  - Deep-inelastic scattering
  - Heavy Flavor Production
  - ZEUS detector
- **Measurement of the $D^{*\pm}$ meson production**
  - Event selection and D* signal extraction
  - Cross section measurement
  - Results
- **Measurement of the charm reduced cross sections,** $\sigma_{red}^{c\bar{c}}$

Proton internal structure



Deep-inelastic scattering experiments reveal the structure of the proton

Deep-inelastic scattering



Q^2 – virtuality of the exchanged photon

$$Q^2 = -q^2 = (k - k')^2$$

x – Bjorken scaling variable

$$x = \frac{Q^2}{2P_p \cdot q}$$

y – inelasticity

$$y = \frac{P_p \cdot q}{P_p \cdot k}$$

$$Y_\pm = 1 \pm (1 - y^2)$$

Neutral Current (Z/ γ exchange)

$$\frac{d^2\sigma^{e^\pm p}}{dxdQ^2} = \frac{2\pi\alpha}{xQ^4}\left[Y_+ F_2(x,Q^2) \mp Y_- xF_3(x,Q^2) - y^2 F_L(x,Q^2)\right]$$

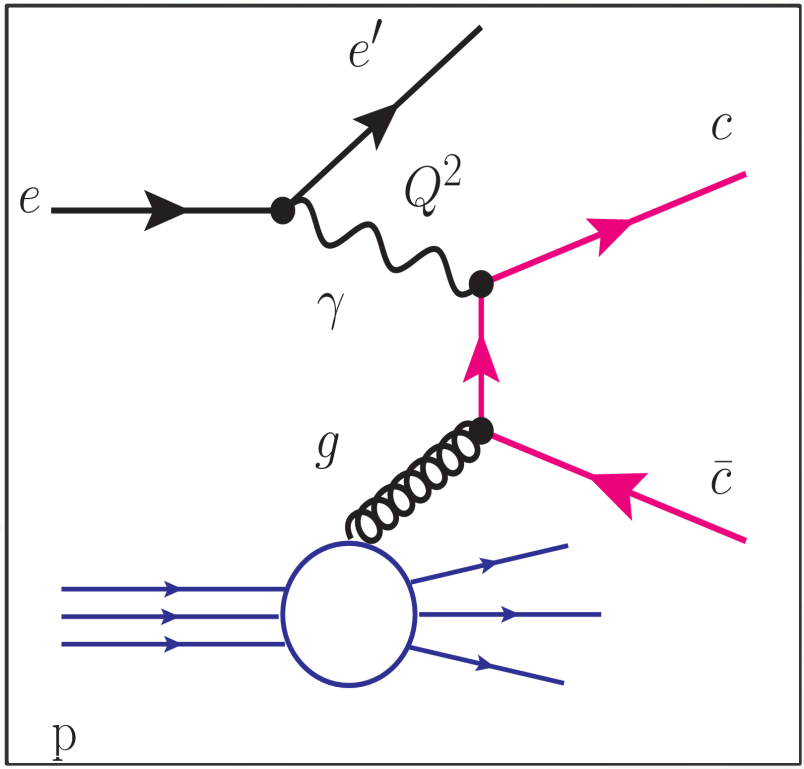
dominant, sensitive to sea quarks, gluon

sensitive to gluon, relevant at high y

sensitive to valence quarks, relevant at high Q^2

Heavy flavor production

- Heavy flavors are mainly produced via Boson-gluon fusion (**BGF**) thus directly sensitive to the **gluon density** of the proton
- **Charm quark** production takes a significant part of inclusive deep-inelastic scattering processes (up to **30%**)



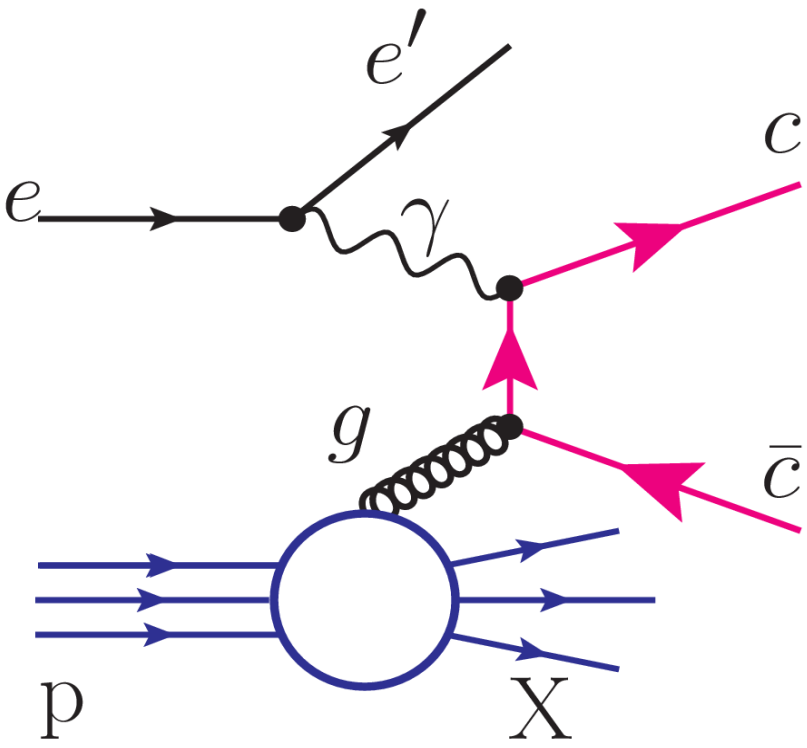
Fixed Flavor Number Scheme (FFNS) heavy quarks are massive, number of light flavors is fixed, $n_{fl}=3$ (charm production)

Zero Mass Variable Flavor Number Scheme (ZM-VFNS) heavy quarks are massless partons at $Q^2>>m_c^2$, $n_{fl}= n_{fl} +1$

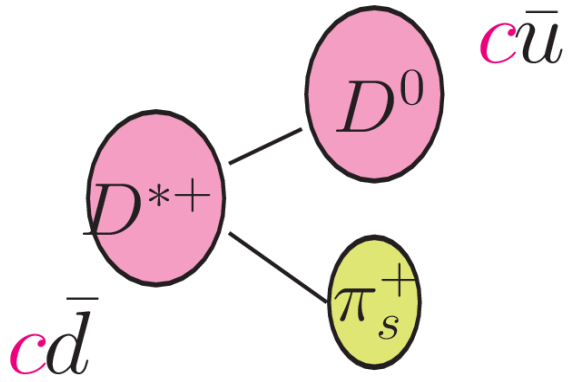
- **Test** of different heavy flavor treatment **schemes**

General Mass Variable Flavor Number Scheme (GM-VFNS) interpolation between FFNS for low Q^2 and ZM-VFNS for $Q^2>>m_c^2$, n_{fl} changes with a scale

Heavy flavor measurements



hadronisation

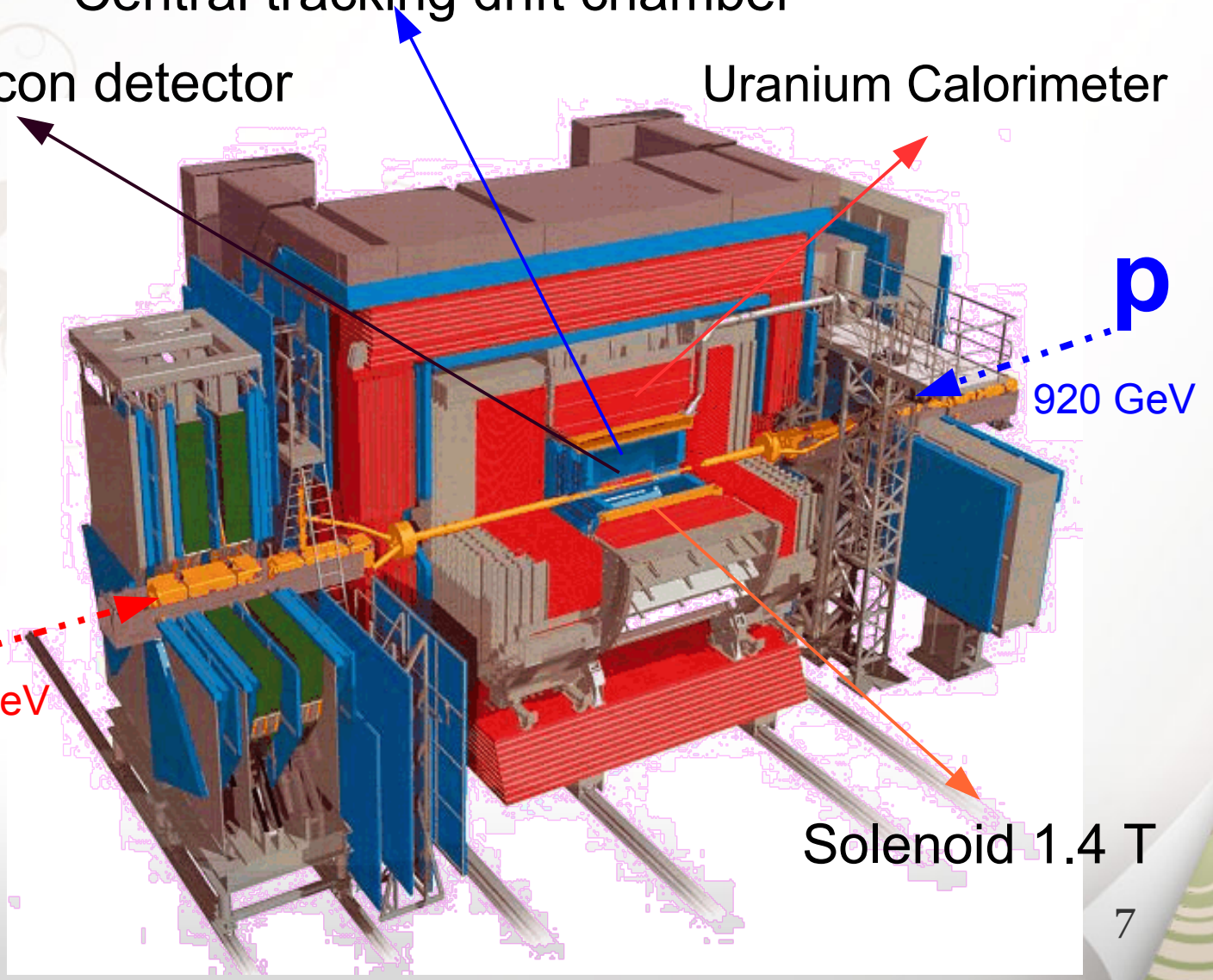


Branching ratio is 2.63 %

Measurement of charm contained meson production by the full reconstruction of the decay :

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

The ZEUS detector

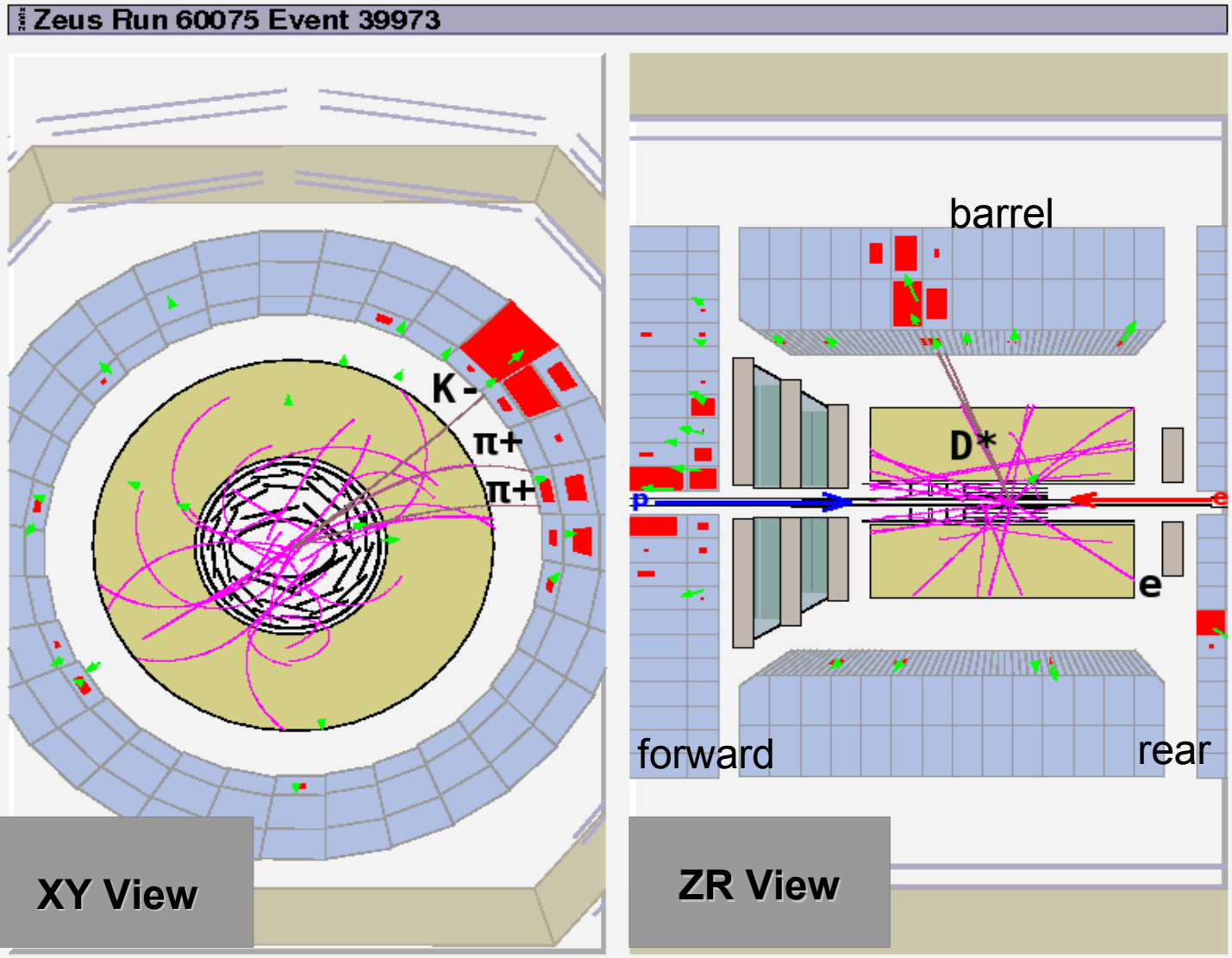


Multipurpose detector
~0.5 fb^{-1}

HERA I (1992-2000)

HERA II (2003-2007)

Event selection



DIS events:

Scattered electron in rear or barrel part of calorimeter with

$5<Q^2<1000\ GeV^2$

$0.02<y<0.7$

Sigma method of kinematic variables reconstruction

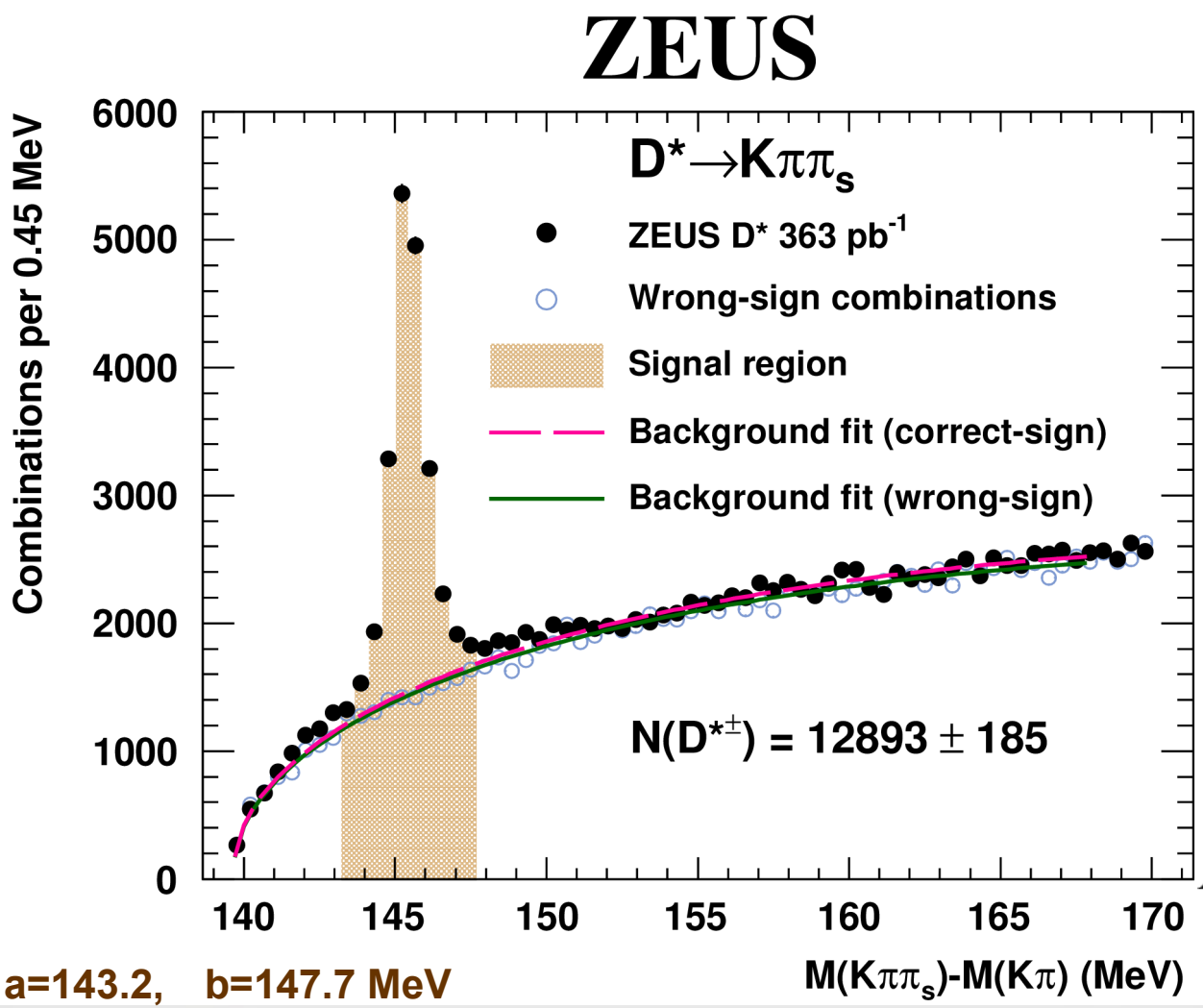
D* candidates:

3 tracks in the central region

$1.5 < p_T^{D^*} < 20\ GeV$

$|\eta=-\ln(\Theta/2)^{D^*}|<1.5$

D* signal extraction



Get the **shape** of background from the **wrong sign** combinations

$$f_{\mathrm{WS}}(\xi) = A\xi^{B}e^{-C\xi}$$

$$\xi = \Delta M - m_{\pi^+}$$

Get background **normalization** from **correct-sign** combinations

$$f_{\mathrm{CS}}(\xi) = D f_{\mathrm{WS}}(\xi)$$

$$N^{D^*} = \sum_{a}^{b} N(\mathrm{cs}) - \int_{a}^{b} f_{\mathrm{cs}}(\xi)\mathrm{d}\xi$$

1.4 % statistical precision Most precise D*s in ZEUS/DIS

Cross section definition

Number of D* mesons in DIS

$5 < Q^2 < 1000\ \mathrm{GeV}^2$,

$0.02 < y < 0.7$,

$1.5 < p_T^{D^*} < 20\ \mathrm{GeV}$,

$|\eta^{D^*}| < 1.5$

$$\frac{d\sigma}{d\chi} = \frac{\Delta N^{D^*}}{\Delta\chi \cdot \varepsilon \cdot B_r \cdot L} \cdot C_{\mathrm{QED}}$$

Correction for QED radiation (1-2 %)

Luminosity (full HERAII) 363 ± 7 pb $^{-1}$

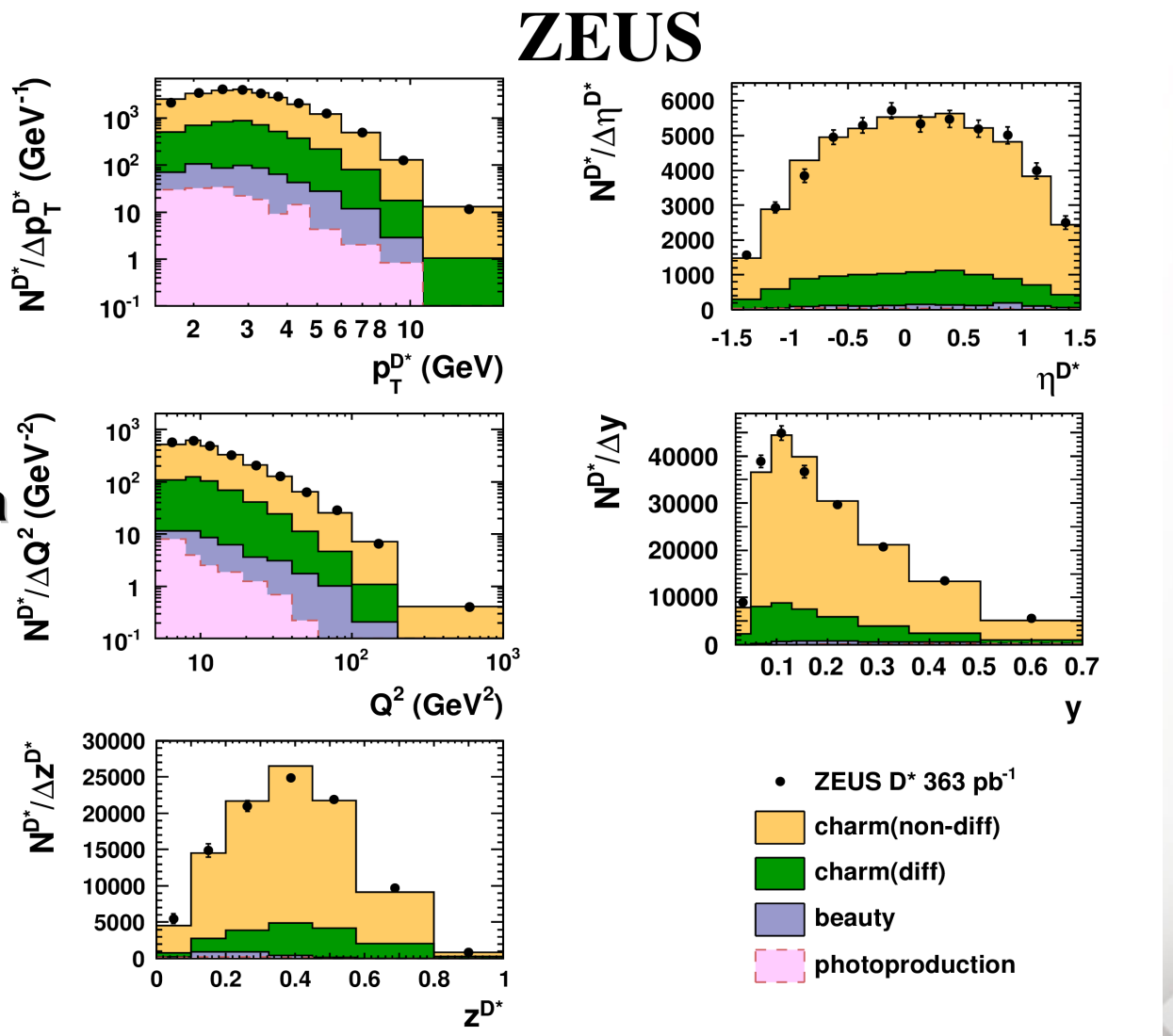
Branching ratio 2.63 %

Detector acceptance from Monte Carlo simulations

D* mesons from B meson decay are part of the acceptance(MC)

Control plots

Monte Carlo describes the data



Acceptance calculations are reasonable

Experimental uncertanties

- Main sources of systematic uncertainty:
  - Energy scale on the hadronic system (±1% up to ±10%)
  - Electron energy-scale (±1% up to ±7%)
  - Tracking efficiency (±2%)
  - Uncertainty of the amount of signal outside used ΔM window (from ±1.5% to ±3 %)
  - Monte Carlo reweightings (±2 %)
  - Luminosity measurement uncertainty (±1.9 %)

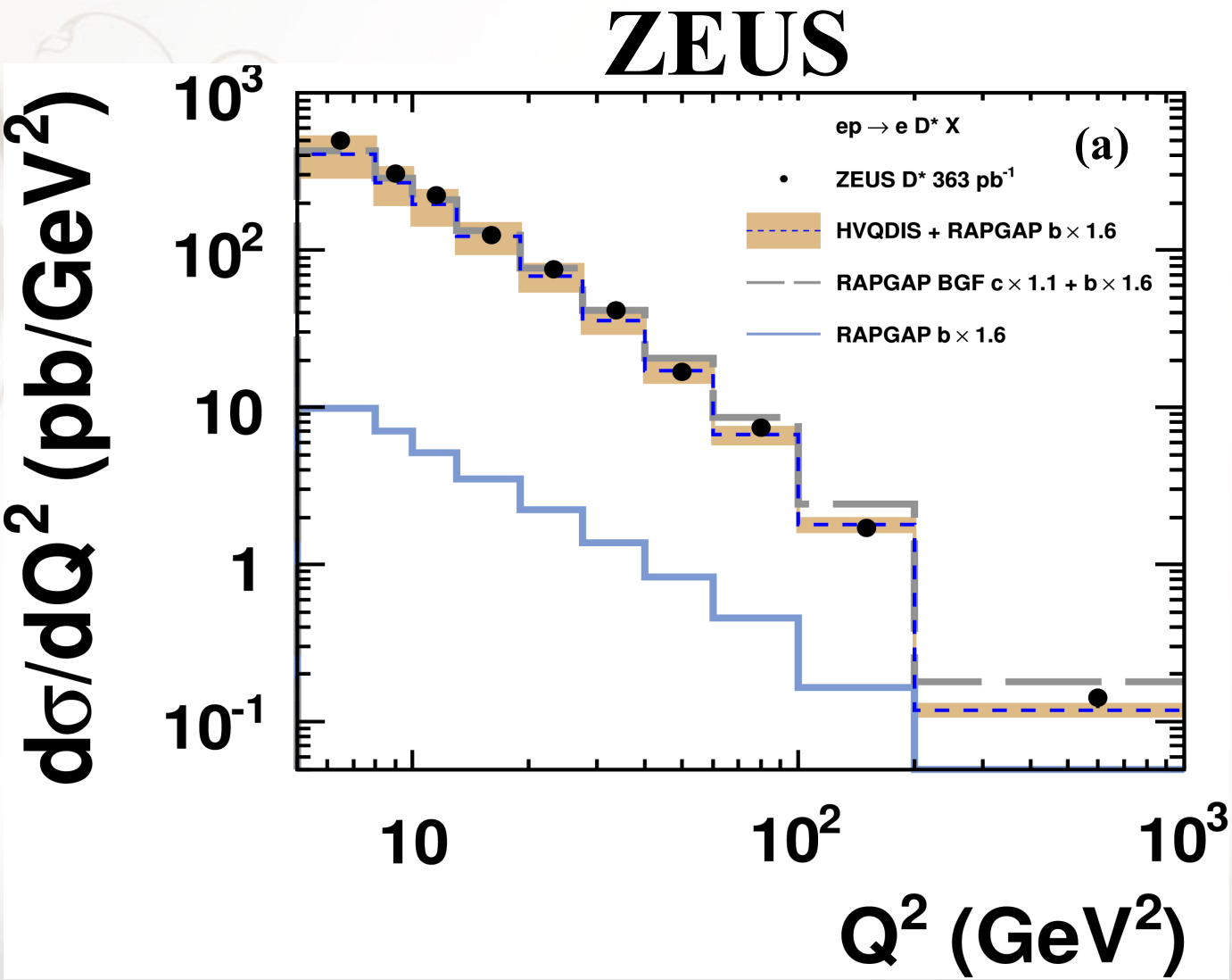
HVQDIS

- NLO HVQDIS by Harris & Smith:
  - **Fixed-flavor-number scheme:** $\alpha_s^{(nf=3)}(M_Z) = 0.105 \pm 0.002$
    - c quarks are massive. **m_c=1.50 GeV,** and produced in hard interactions
  - Kartevilishvili fragmentation as measured by ZEUS and H1
  - Fragmentation fraction **f(c->D*)=0.2287** as measured by ZEUS
  - PDF: **HERAPDF 1.0** (FFNS)
  - Scales were set to $\mu_R = \mu_F = \sqrt{(Q^2 + 4m_c^2)}$
  - Contribution from B mesons was taken from RAPGAP 3.0 (LO+ parton shower)

    The same procedure as for the HERA charm combination was used Eur. Phys. J. C73 (2013) 2311

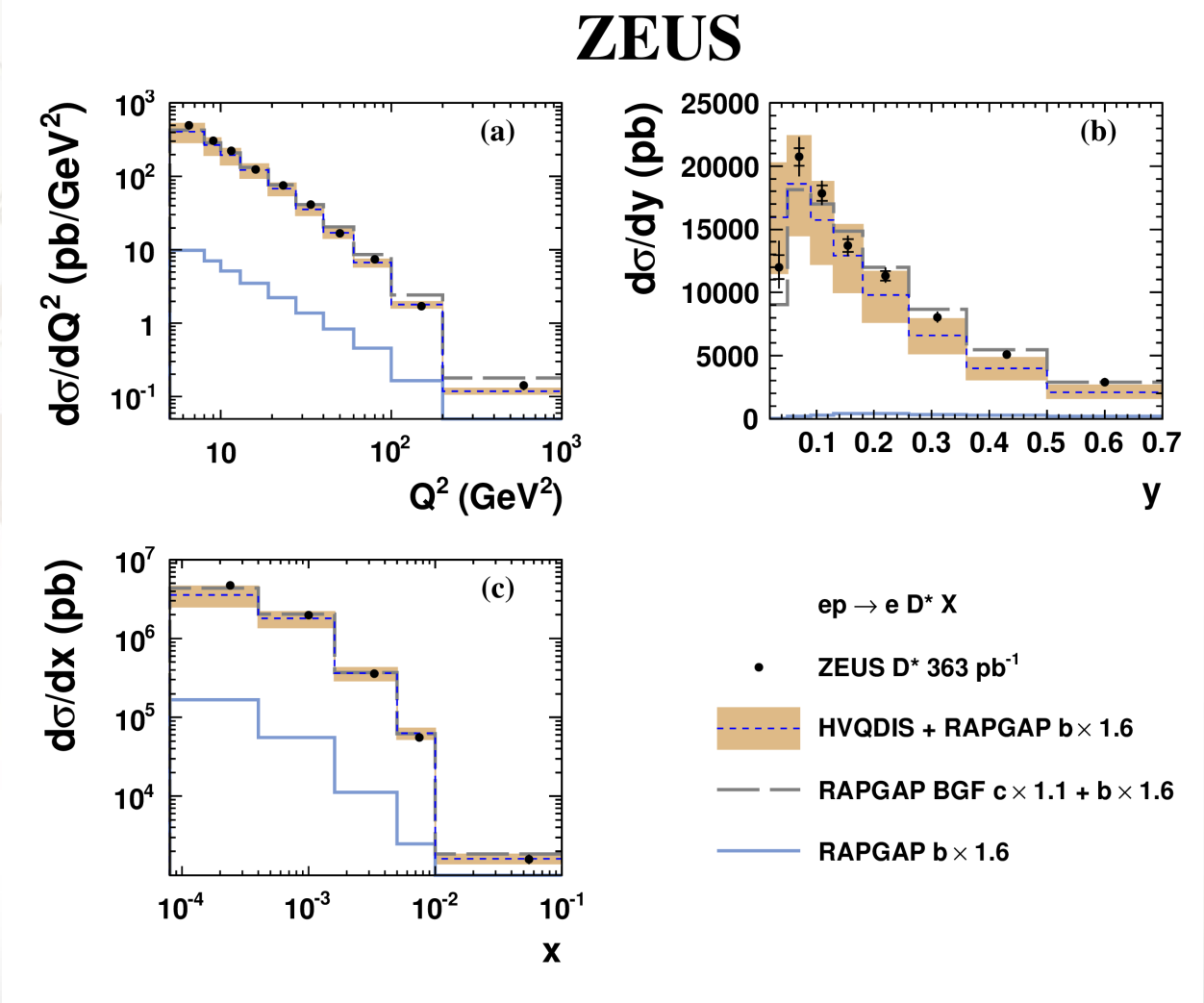
The predictions uncertainties were obtained through variation of the setting parameters

Results: single-differential cross sections, Q^2



NLO QCD predictions describe the data

Results: Q^2, y, x differential cross-sections



NLO QCD predictions describe the data

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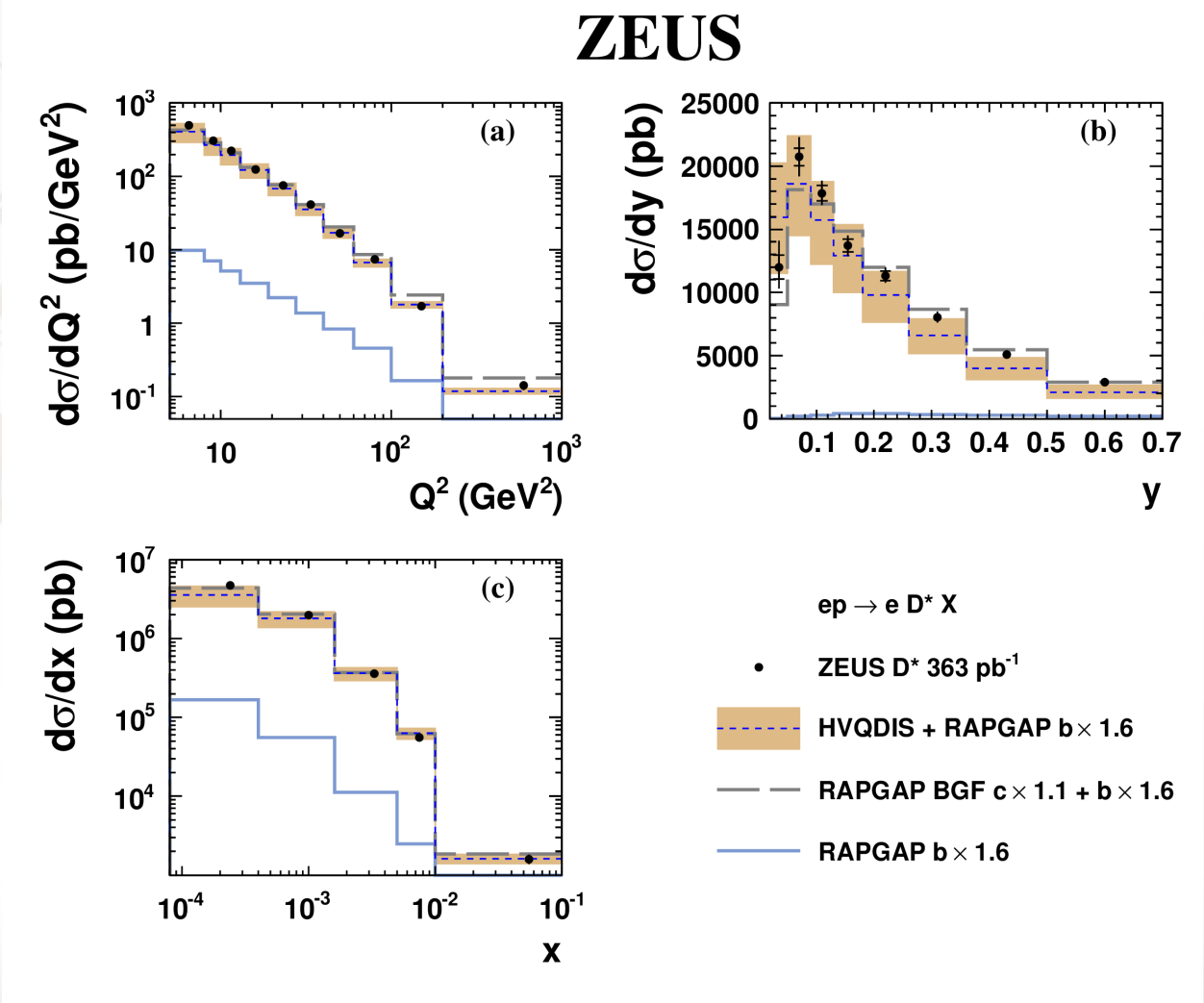
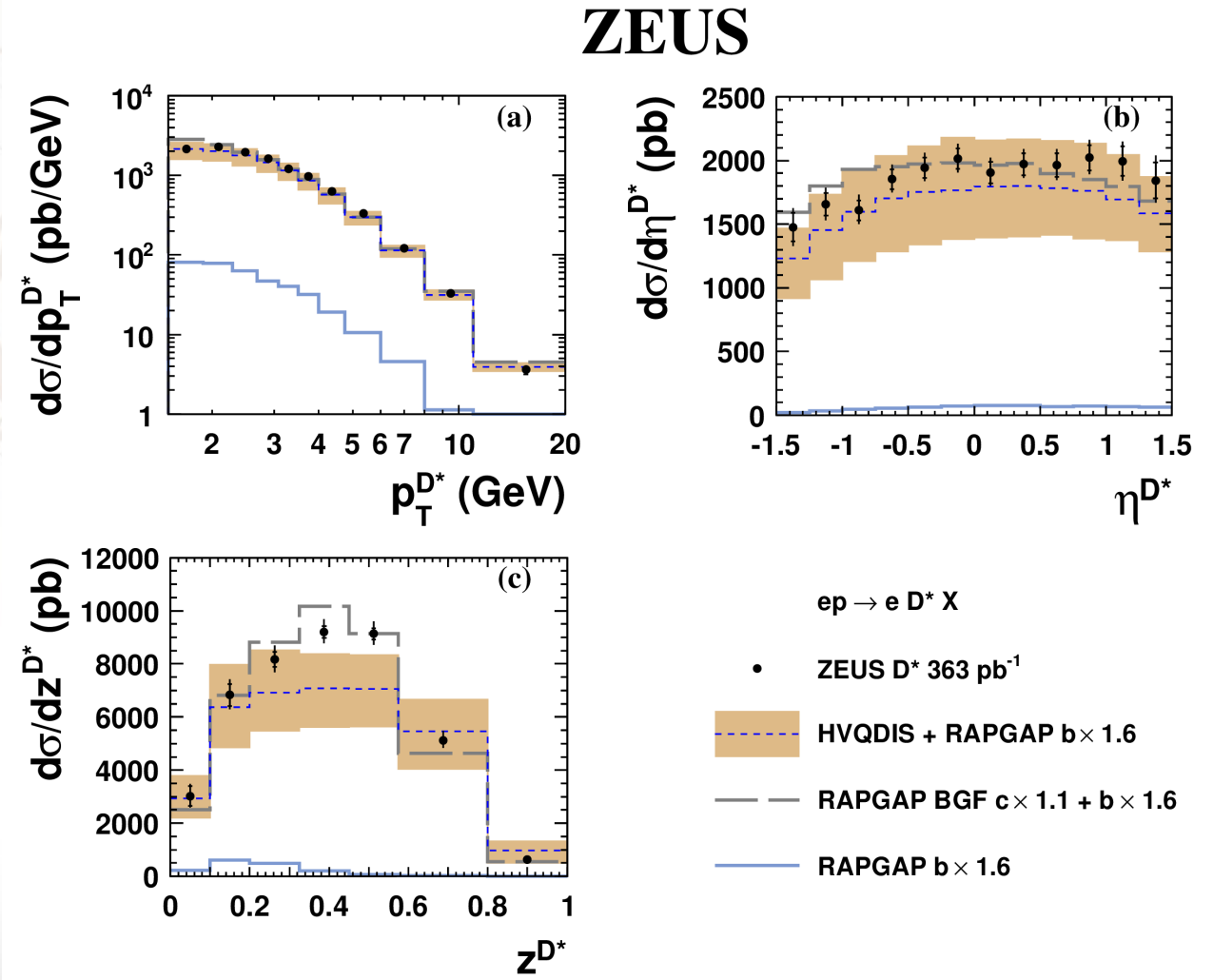


NLO QCD predictions describe the data

Results: p_T, η, z differential cross-sections

$z=(E-p_z)^{D^*}/(2E_e y)$

Fraction of the photon momentum carried by the D* in p rest frame

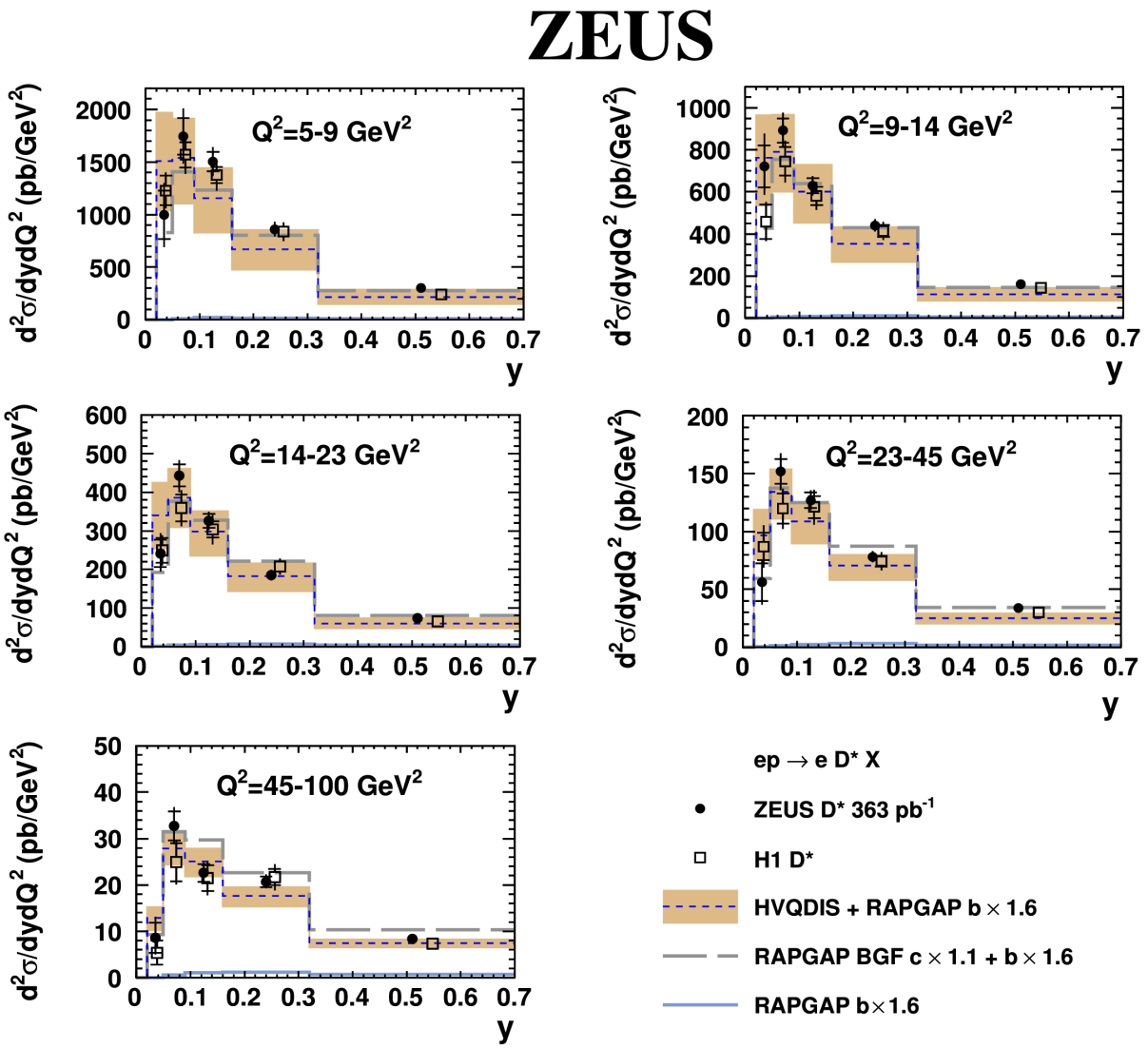


NLO QCD predictions describe the data

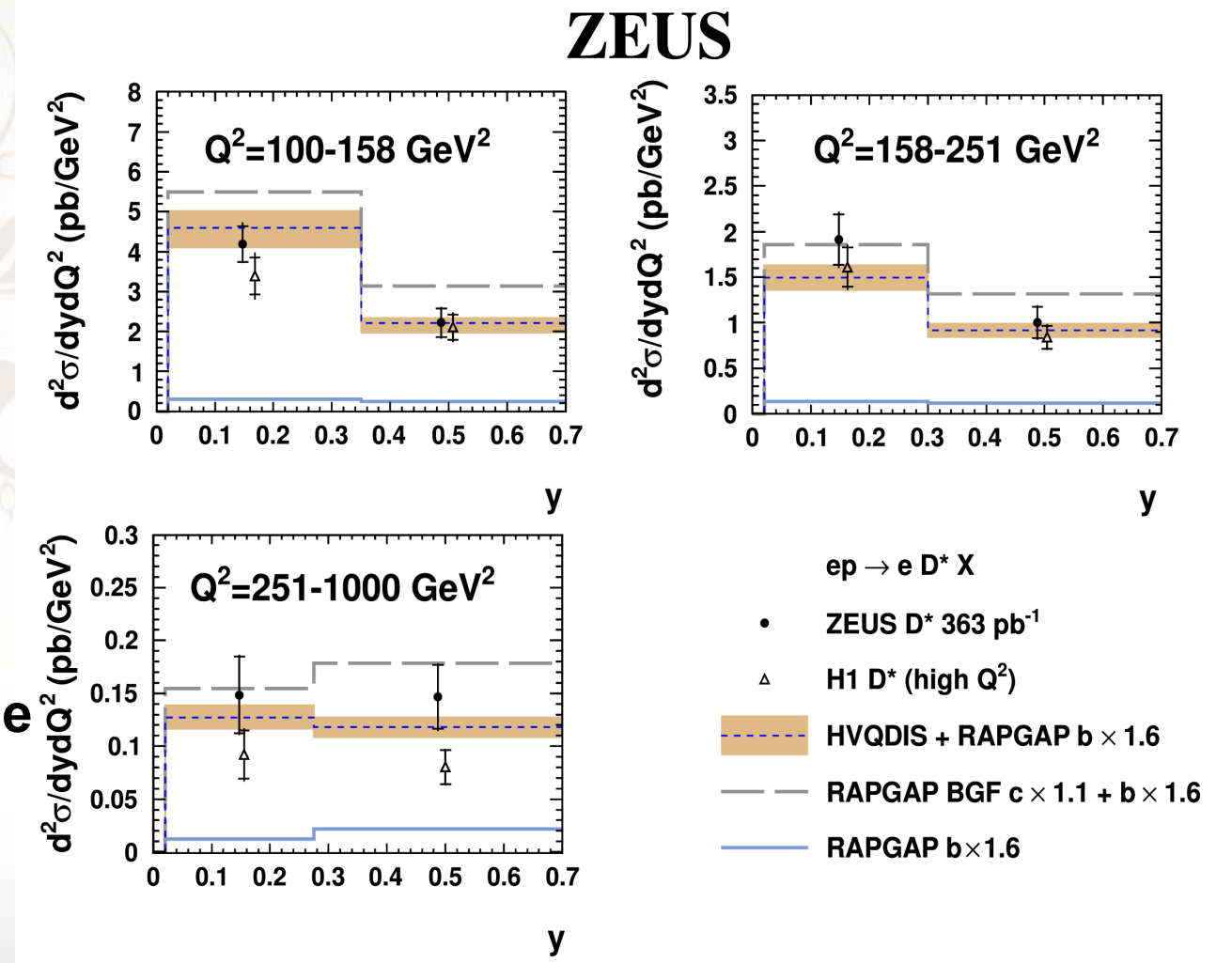
Results: double-differential cross-sections, Q^2 <100 GeV^2

The two experiments agree and have similar precision in the same kinematic range

NLO QCD predictions describe the data



Results: double-differential cross-sections, $100 < Q^2 < 1000$ GeV^2



Fixed-Flavor-Number-Scheme works up to Q^2 =1000 GeV ^{2}

Reduced cross sections
extraction techniques

- **Reduced cross sections** are directly connected to the **charm contribution to the proton structure** function F_2

$$\sigma_{\mathrm{red}}^{c\bar{c}}(x,Q^2) = F_2^{c\bar{c}}(x,Q^2) - \frac{y^2}{1+(1-y)^2} F_L^{c\bar{c}}(x,Q^2).$$

- **Extrapolate** double-differential D* production cross sections **to the full D* phase space** with HVQDIS theoretical predictions

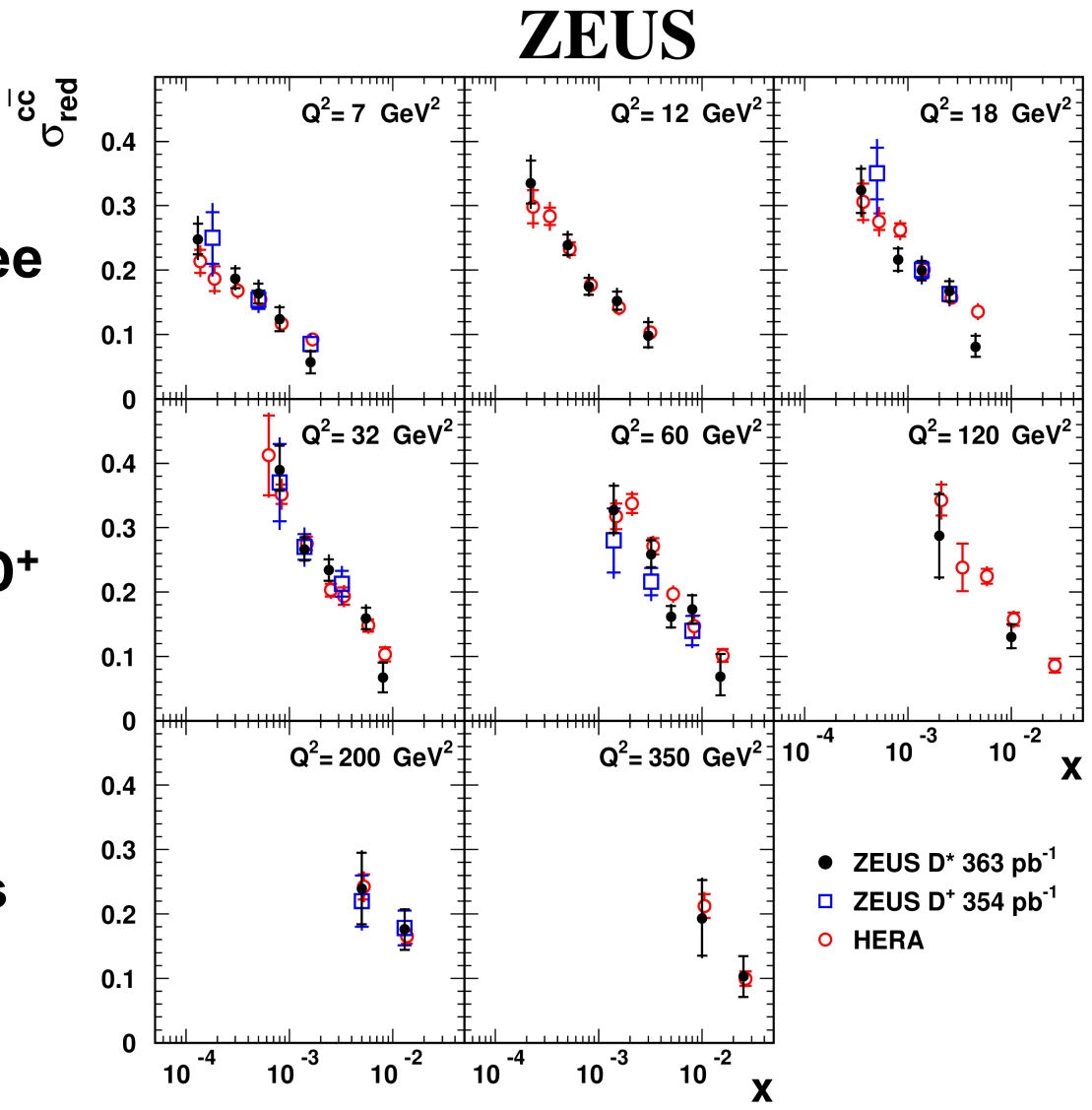
$$\sigma_{\mathrm{red}}^{c\bar{c}}(x,Q^2) = \left(\sigma_{\mathrm{vis}} - \sigma_{\mathrm{vis}}^{\mathrm{beauty}}\right) \left(\frac{\sigma_{\mathrm{red}}^{c\bar{c}}(x,Q^2)}{\sigma_{\mathrm{vis}}}\right)_{\mathrm{Hvqdis}}$$

Results: comparison to the recent HERA measurements

Measurements agree with H1 and ZEUS combined results

and with recent ZEUS D^+ measurements

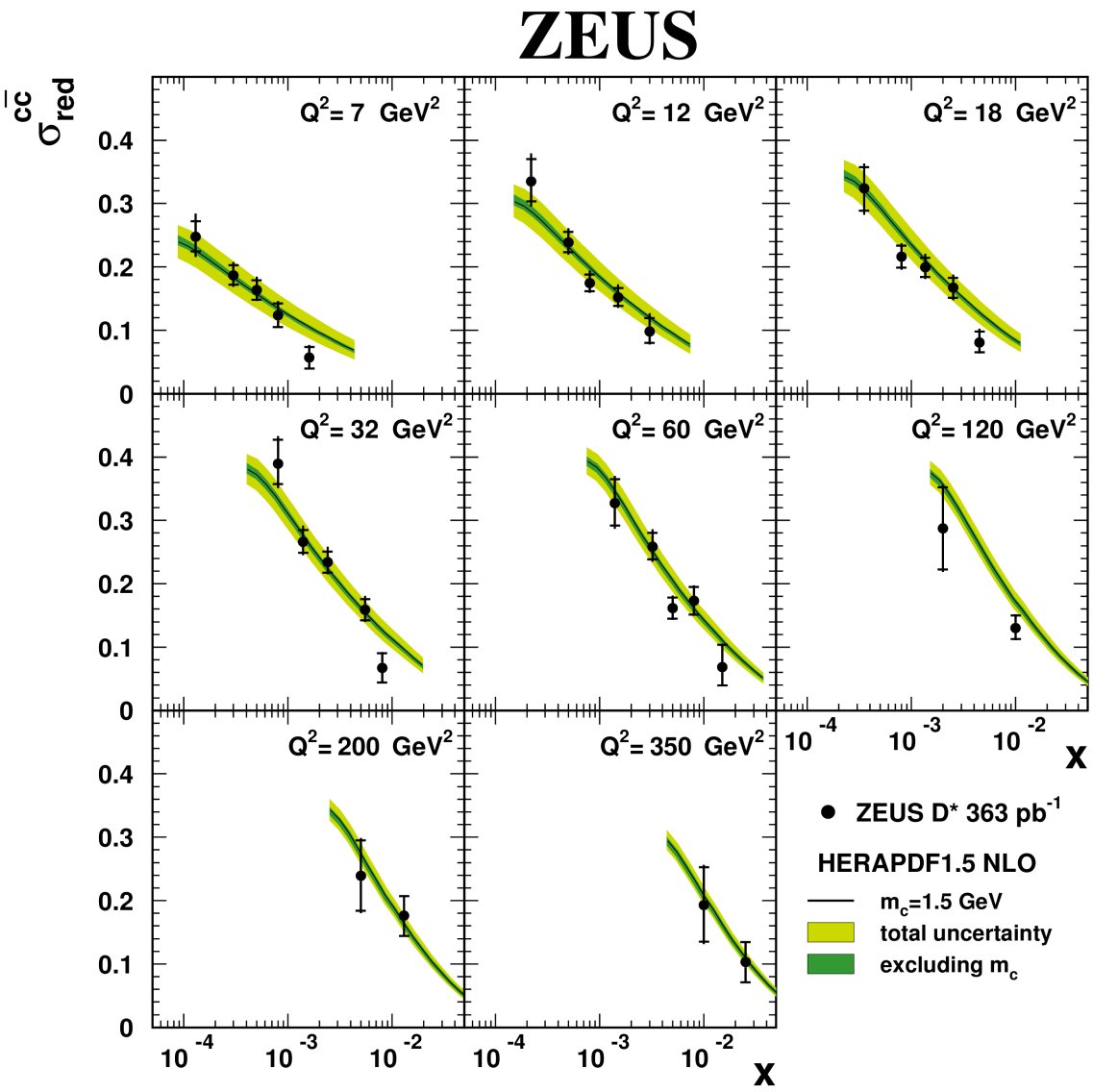
The most precise charm measurements at ZEUS



Results: comparison HERAPDF1.5

General-Mass - Variable - FNS works well

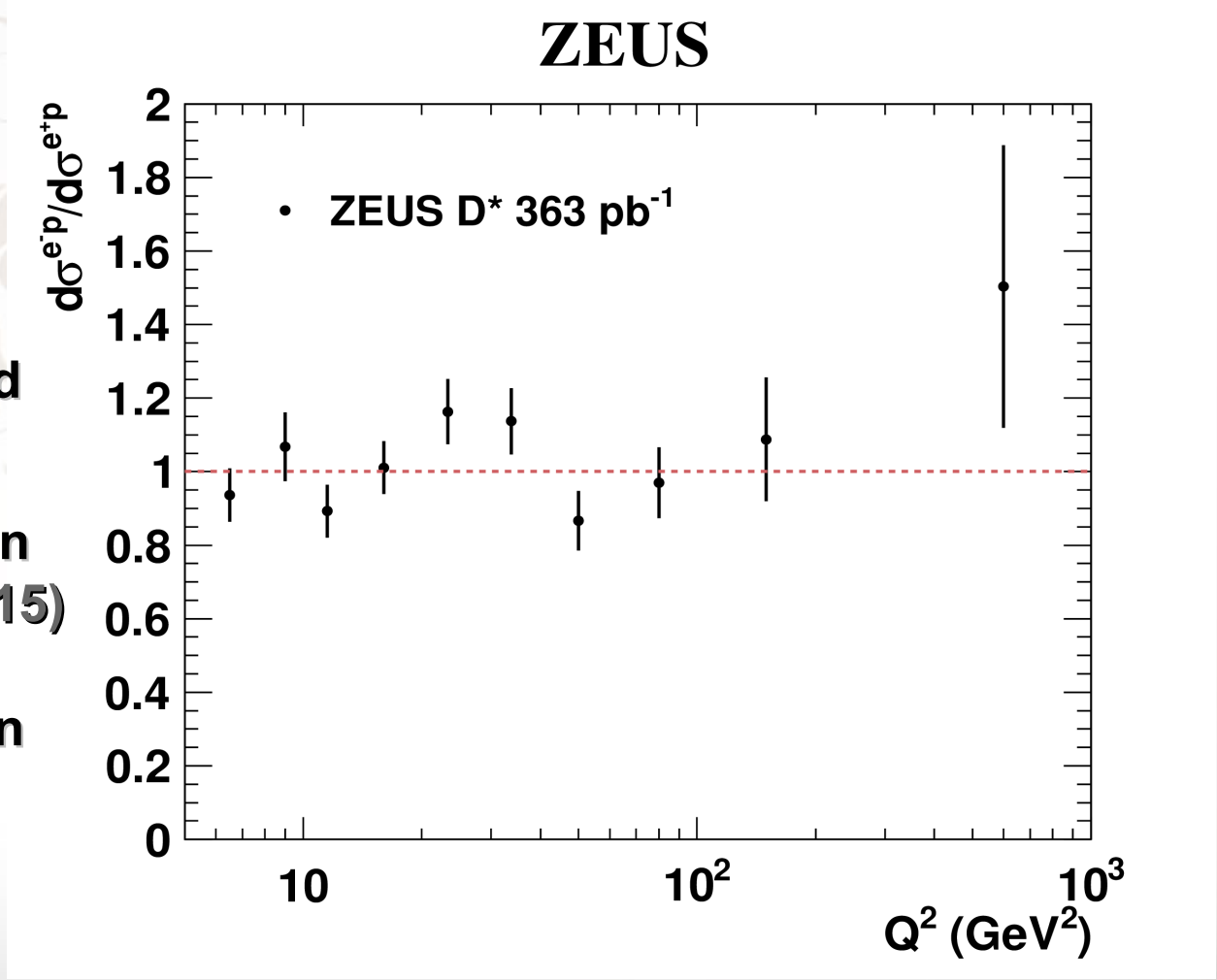
HERAPDF1.5 NLO
(no charm data in the fit)
describes the data



Positron/Electron asymmetry

No asymmetry found

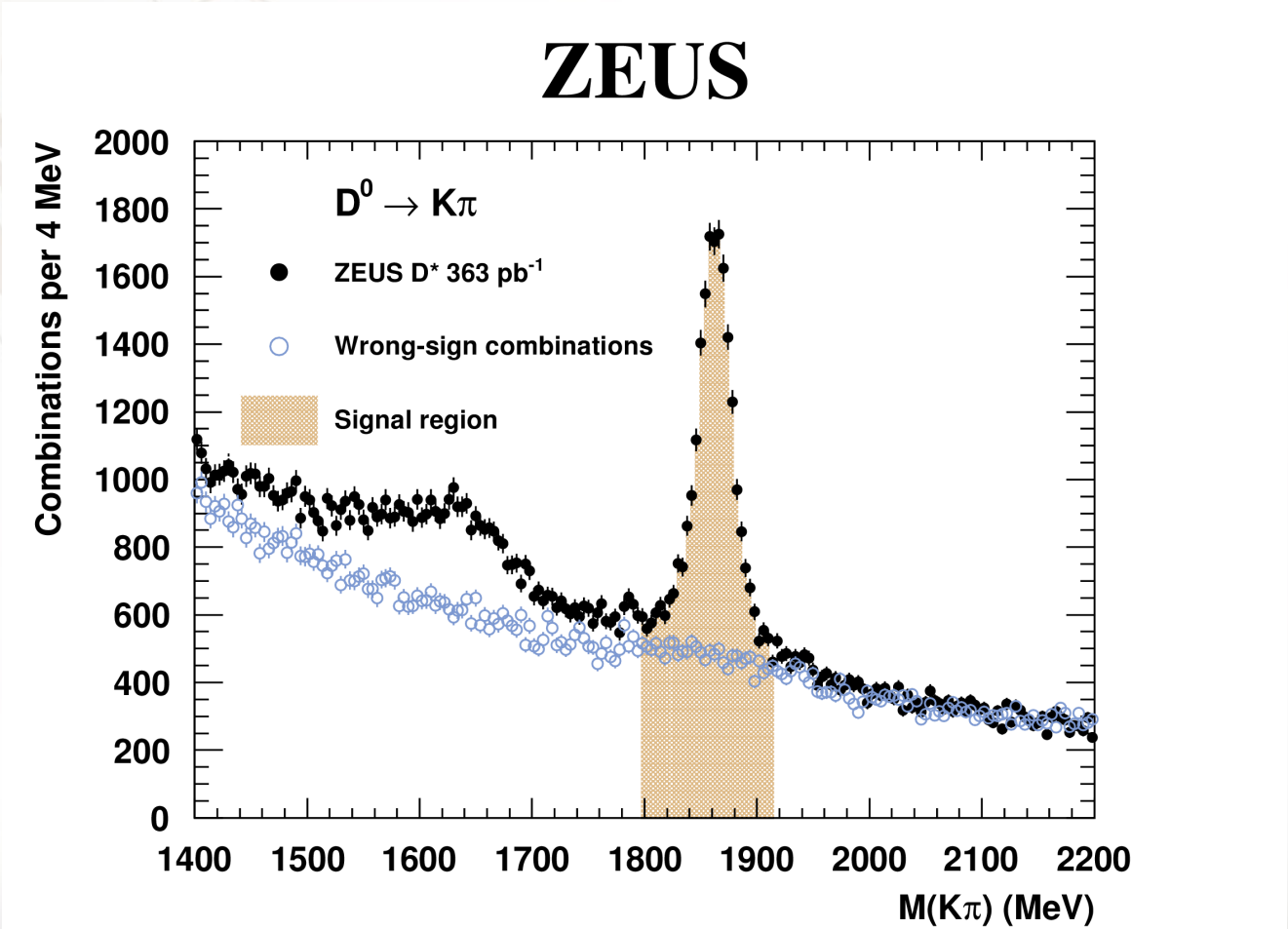
conforming that the previous observation (HERA I, DESY-03-115) indeed was due to a statistical fluctuation



Summary

- **New measurement of D* production in DIS were presented;**
- The measurements are the most precise charm quark production measurements at ZEUS;
- **Charm contribution to the structure function was measured;**
- QCD predictions describe the data;
- Fixed-Flavor and General-Mass variable flavor number schemes work in the studied kinematic region;
- **Measurements agree with combined H1ZEUS results and will further improve new HERA combination and will put further constraints on PDFs.**

Backup


ZEUS
$D^0 \rightarrow K\pi$
ZEUS D* 363 pb^{-1}
Wrong-sign combinations
Signal region
Combinations per 4 MeV
M(Kπ) (MeV)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
1400
1500
1600
1700
1800
1900
2000
2100
2200