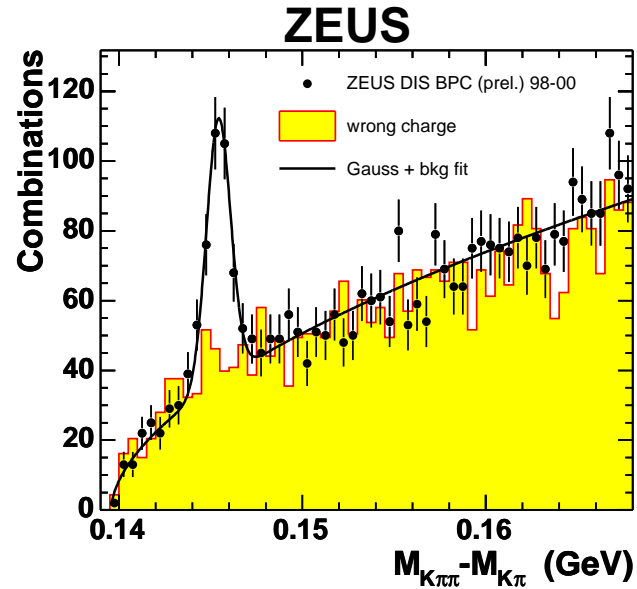


Open Charm production in DIS at HERA



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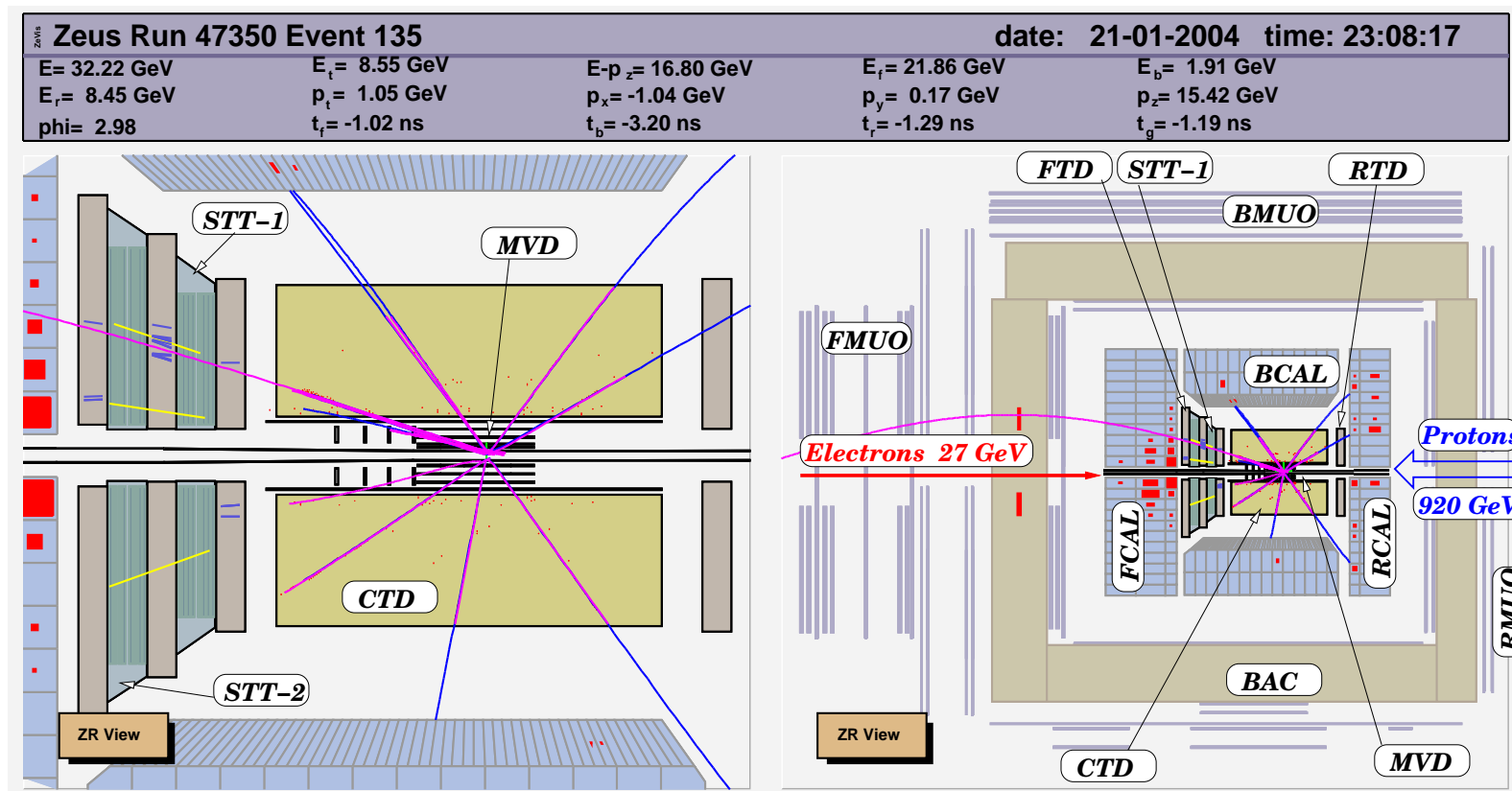
EPS (July 21st-27th 2005) in Lisboa, Portugal

OUTLINE

- **Introduction**
 - The ZEUS detector
 - ZEUS kinematic region
- **D* in DIS at $Q^2 > 1 \text{ GeV}^2$**
 - Cross sections HERA-I 98-00
 - New HERA-II data 2003-2005
- **D* in Photoproduction at $Q^2 \approx 0 \text{ GeV}^2$**
 - One plot results HERA-I 98-00
- **D* in DIS at low $Q^2 < 1 \text{ GeV}^2$**
 - Cross sections HERA-I 98-00
 - Combined plot
- **Summary**

ZEUS detector

- HERA is the storage ring which provides collisions between **920 GeV protons** and **27.5 GeV electrons or positrons**; $\sqrt{s} \approx 318$ GeV.
- ZEUS is multi-purpose detector with main components: **MVD** - *microvertex detector*, **CTD** - *central tracking detector*, **FDT,RTD** - *forward and rear tracking detector*, **FCAL,BCAL,RCAL** - *forward, barrel and rear calorimeter*, **FMUO,BMUO,RMUO** - *forward, barrel and rear muon detector*.

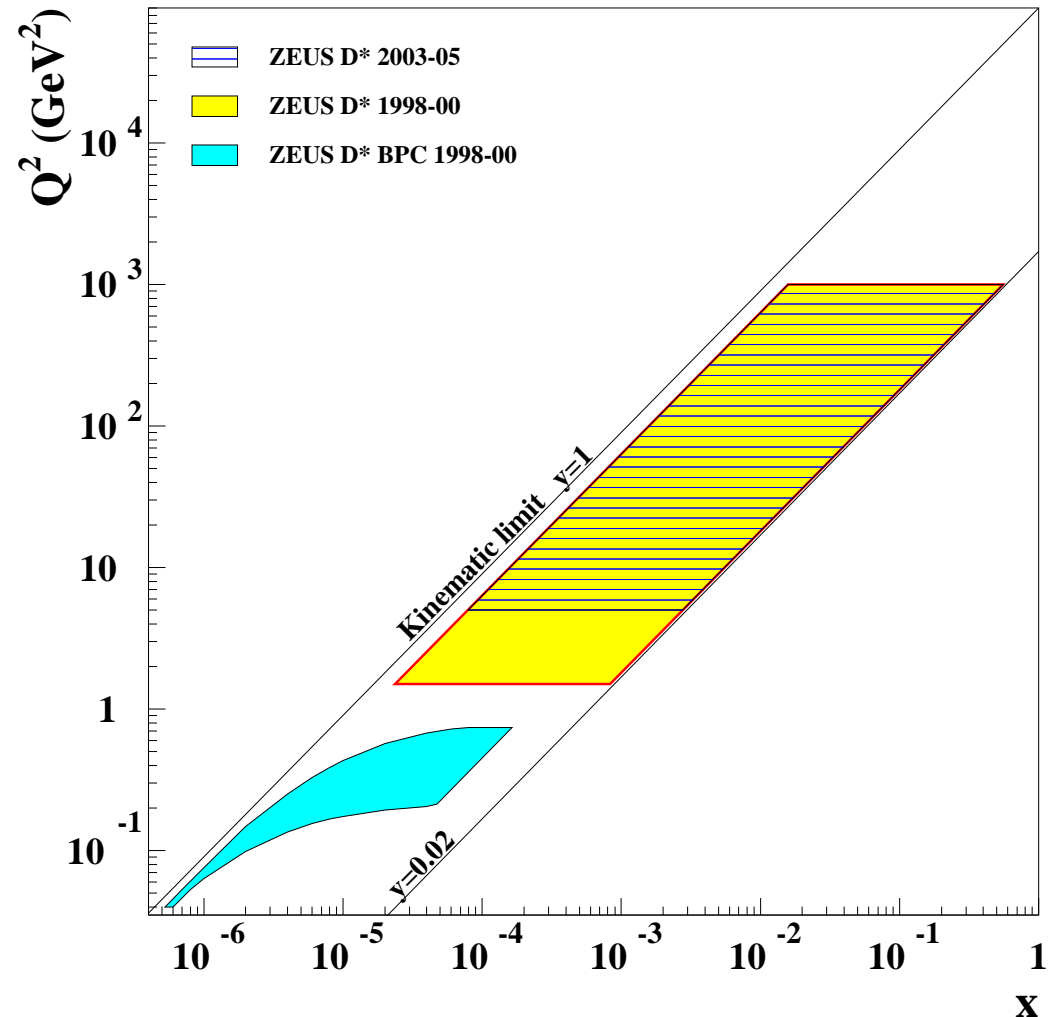


Charm Production at HERA

Charm quarks are produced copiously in $e^\pm p$ collisions at HERA and have been studied using $D^{*\pm}$ mesons.

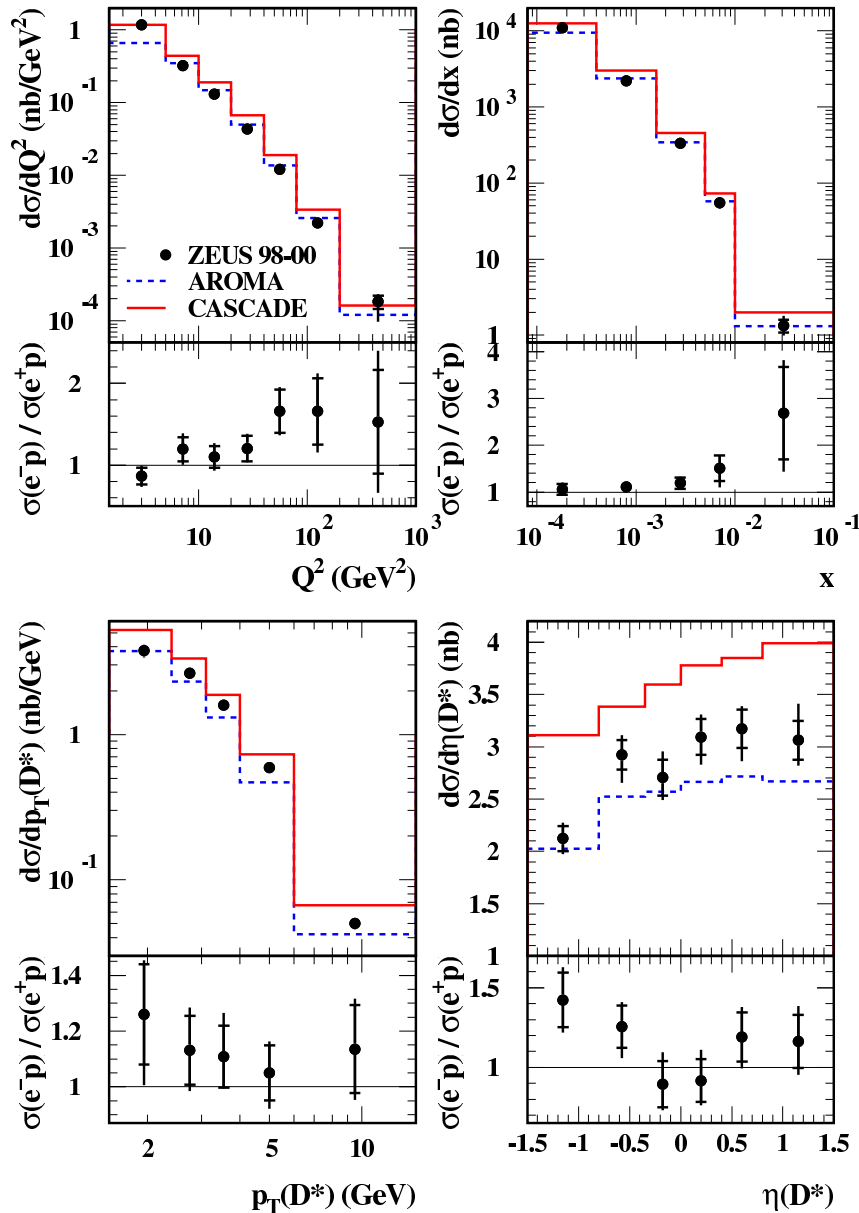
The (x, Q^2) kinematic plan shows the regions reachable for ZEUS:

1. **DIS** ($1.5 < Q^2 < 1000 \text{ GeV}^2$) region available with ZEUS Uranium Calorimeter (UCAL).
2. **PHP** ($Q^2 \approx 0 \text{ GeV}^2$)
3. **Transition region** between **PHP** and **DIS** ($0.05 < Q^2 < 0.7 \text{ GeV}^2$) (BPC-9800) can be reached with the Beam Pipe Calorimeter – detector covers small area near beam pipe, not reachable by UCAL.



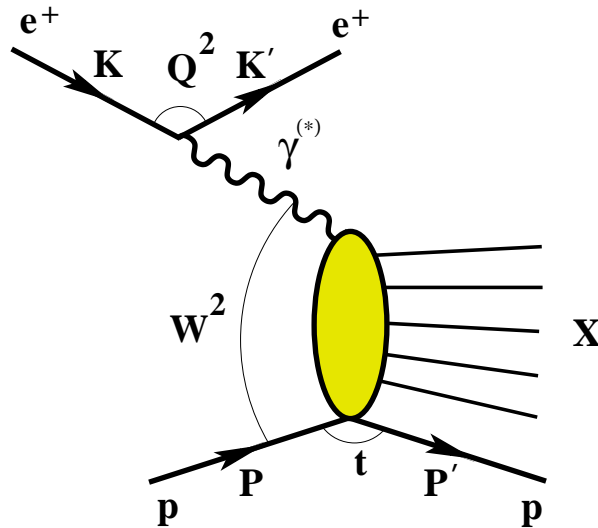
D* in DIS ($1.5 < Q^2 < 1000 \text{ GeV}^2$)

ZEUS



- Recently published HERA-I 98-00 data with $65 \text{ pb}^{-1} e^+p$ and $17 \text{ pb}^{-1} e^-p$
- The result is consistent with calculation in QCD
- Also, it was observed that $\sigma(e^-p) > \sigma(e^+p)$ for high Q^2 range.
- It was not expected and so the phenomenon was treated as a statistical fluctuation.
- We now have access to more HERA II data : $40 \text{ pb}^{-1} e^+p$ and $33 \text{ pb}^{-1} e^-p$ to investigate this difference.

DIS event selection in HERA-II



Kinematic variables:

- $Q^2 = 2E_e' E_e (1 + \cos \Theta_e)$
- $y_e = \frac{E_e'}{E_e} (1 - \cos \Theta_e)$
- $\delta = \sum_i E_i (1 - \cos \Theta_i)$

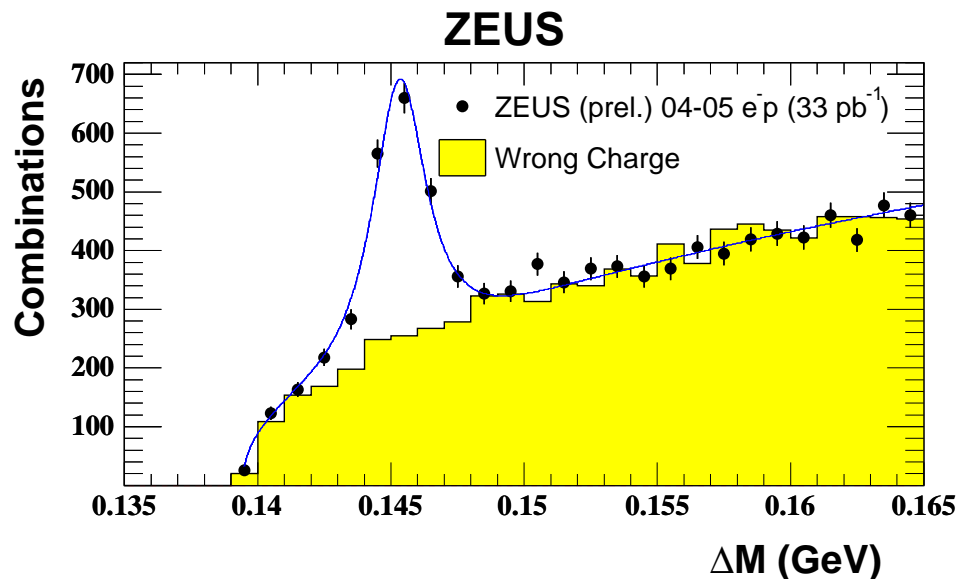
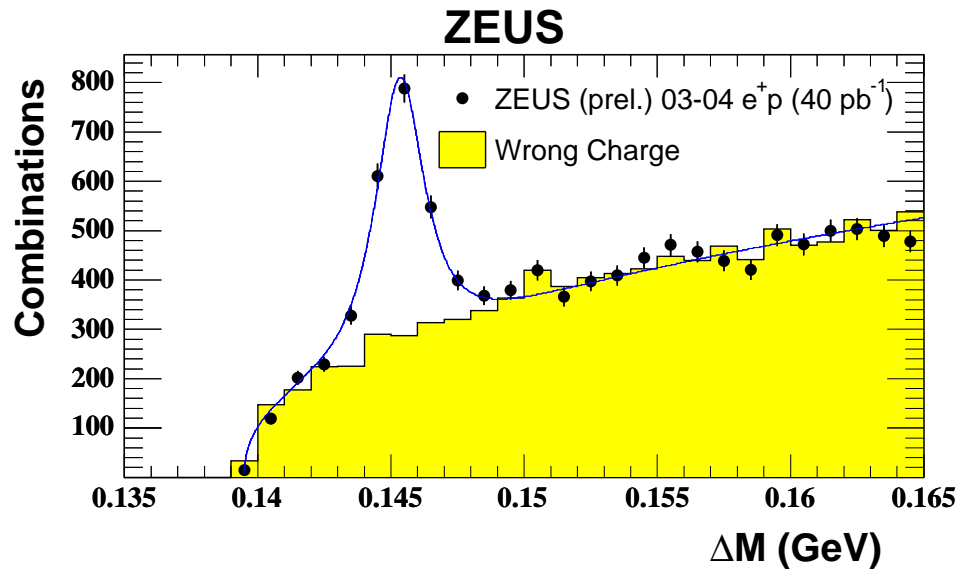
D* candidates:

- $D^{*+} \rightarrow D^0 \pi_s^+$ with $D^0 \rightarrow K^- \pi^+$
- $p_T(\pi_s) > 0.12 \text{ GeV}$
- $p_T(K, \pi) > 0.4 \text{ GeV}$
- $40 < \delta < 60 \text{ GeV}$

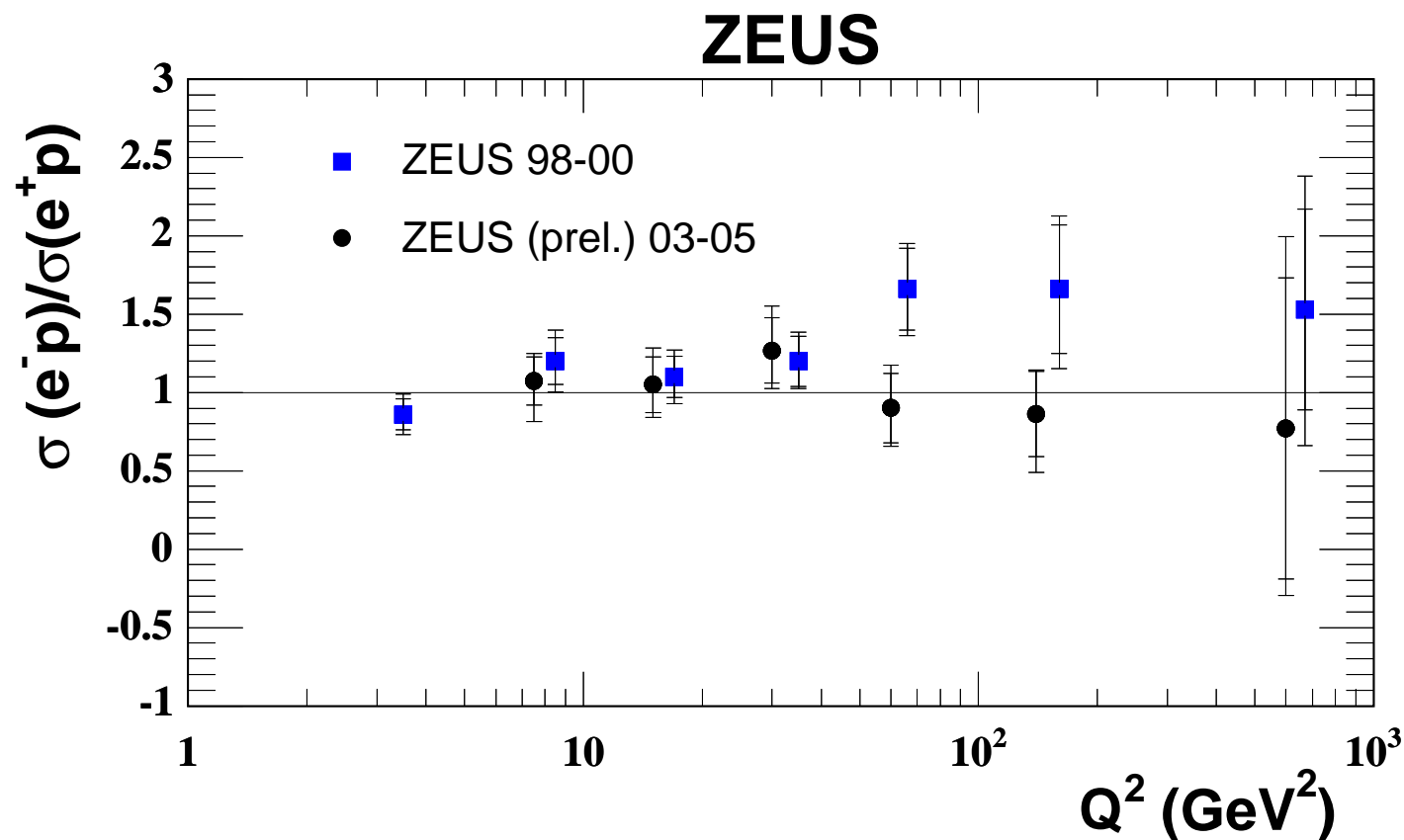
Kinematic Region:

- $5 < Q^2 < 1000 \text{ GeV}^2$
- $0.02 < y < 0.7$
- $|\eta(D^*)| < 1.5$
- $1.5 < p_T(D^*) < 15 \text{ GeV}$

D* Signal in 2003-2005 data



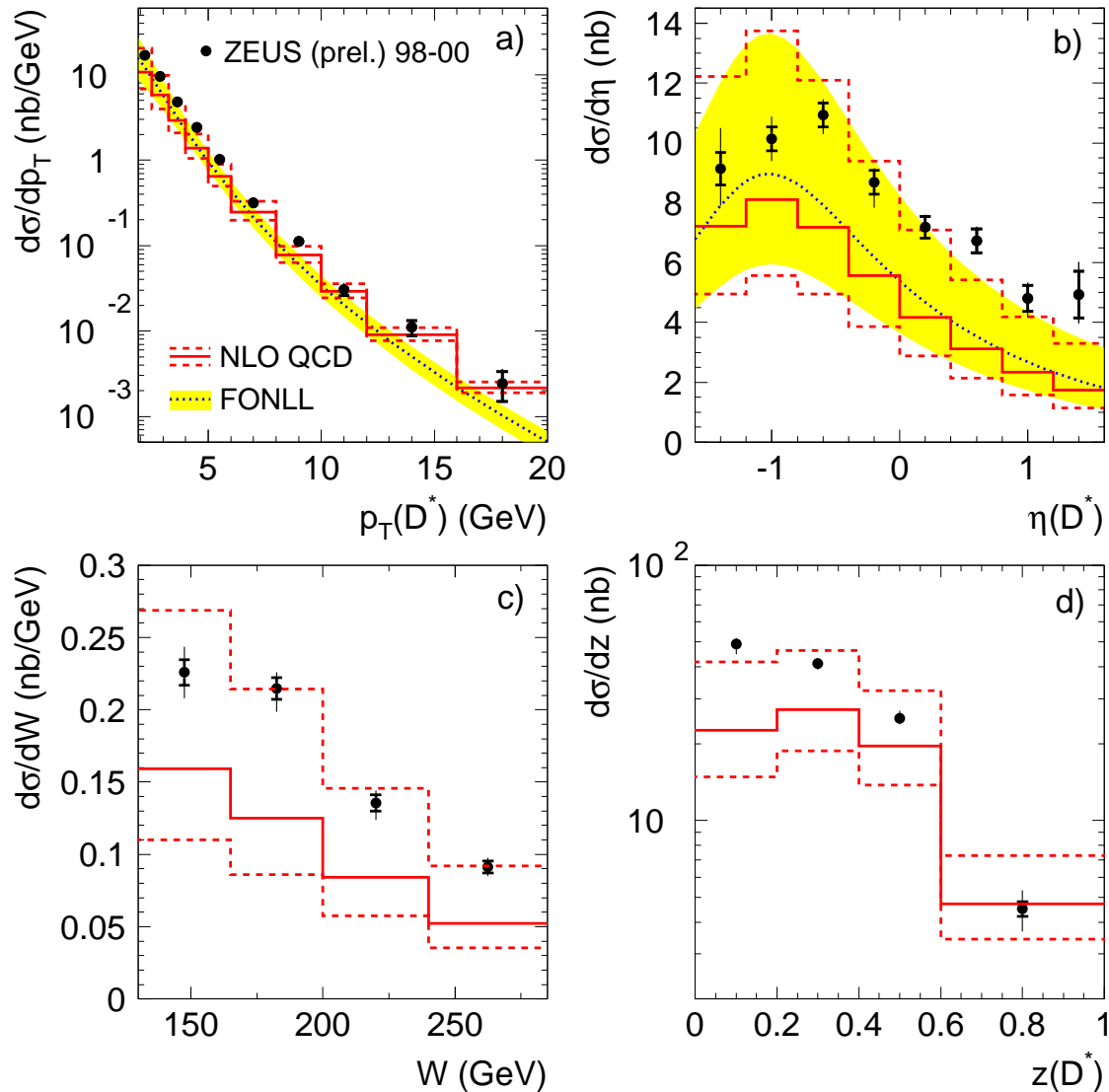
- $\Delta M = M_{D^*} - M_{D^0} = M_{K\pi\pi} - M_{K\pi}$
- Background subtraction in window:
 $0.143 < \Delta M < 0.148 \text{ GeV}$
 $1.8 < M_{D^0} < 1.92 \text{ GeV}$
- gives $1237.7 \pm 64.2 D^*$ for e^+p data
- $rate = N_{D^*}/\mathcal{L}$
- e^+p rate = $30.7 \pm 1.8 / \text{pb}^{-1}$
- and for e^-p data:
- $1117.8 \pm 60.4 D^*$
- e^-p rate = $33.5 \pm 1.8 / \text{pb}^{-1}$
- Rates are consistent

DIS D^* cross section ratio

Results suggest very strongly that observed e^+p/e^-p excess in HERA I at high Q^2 was a statistical fluctuation.

Charm in Photoproduction

ZEUS



- ZEUS-9800 data, $\mathcal{L} = 78.7 \text{ pb}^{-1}$
- $D^{*+} \rightarrow D^0 \pi_s^+$ with $D^0 \rightarrow K^- \pi^+$
- **Kinematic region:**
 - $130 < W < 285 \text{ GeV}^2$
 - $Q^2 < 1 \text{ GeV}^2$
 - $|\eta(D^*)| < 1.6$
 - $1.9 < p_T(D^*) < 20 \text{ GeV}$
- **inelasticity:**
 $z(D^{*\pm}) = \mathbf{P} \cdot \mathbf{p}(D^{*\pm}) / \mathbf{P} \cdot \mathbf{q}$
- The NLO calculation generally good describes the data.
- However, the central NLO predictions systematically underestimate the data

Charm Production in transition $PHP \rightarrow DIS$ region

- Charm production occurs via direct and resolved processes.
- **Charm in DIS** ($Q^2 > 1.5 \text{ GeV}^2$) dominated by Boson Gluon Fusion (direct)
- Significant resolved contribution to **charm photoproduction** ($Q^2 \approx 0 \text{ GeV}^2$)
- It is interesting to investigate the low Q^2 transition region between PHP and DIS.
- Does NLO QCD model still describe the data ?

Beam Pipe Calorimeter in ZEUS

- Beam Pipe Calorimeter (BPC) – the detector for low- Q^2 physics.
- BPC covers the range $0.045 \text{ GeV}^2 < Q^2 < 0.7 \text{ GeV}^2$
- Energy resolution $\frac{\Delta E}{E} = \frac{17\%}{\sqrt{E}}$
- Spatial resolution $\sim 1 \text{ mm}$

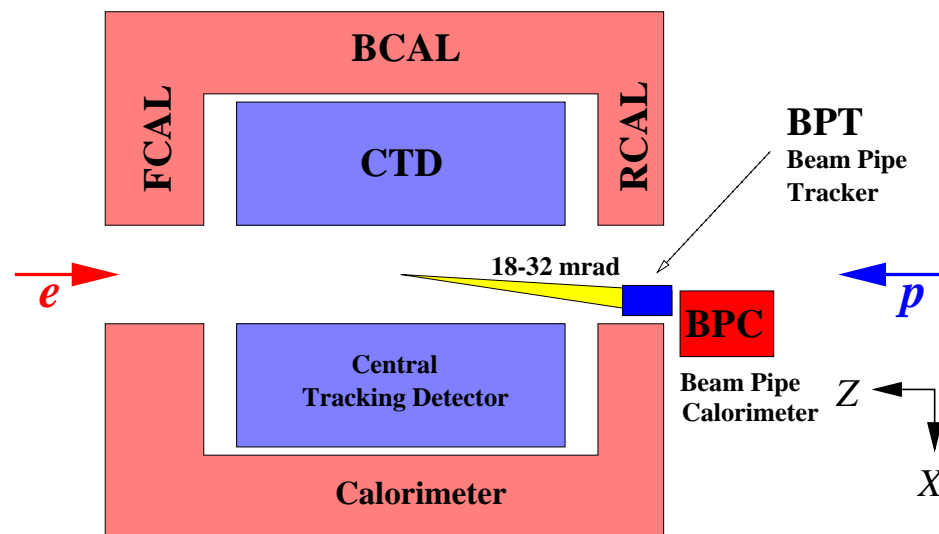
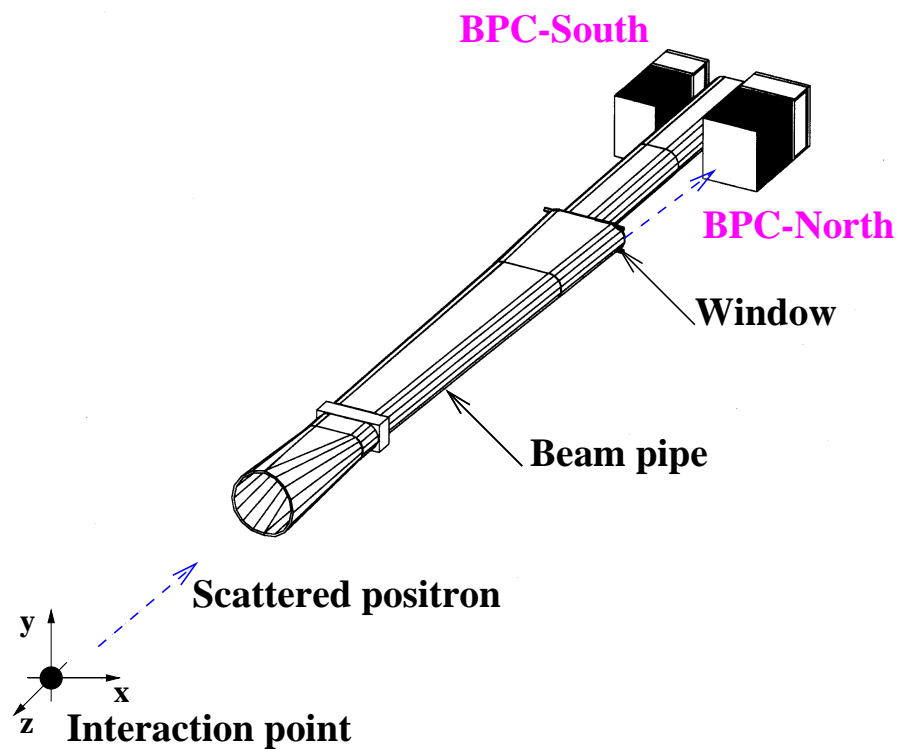
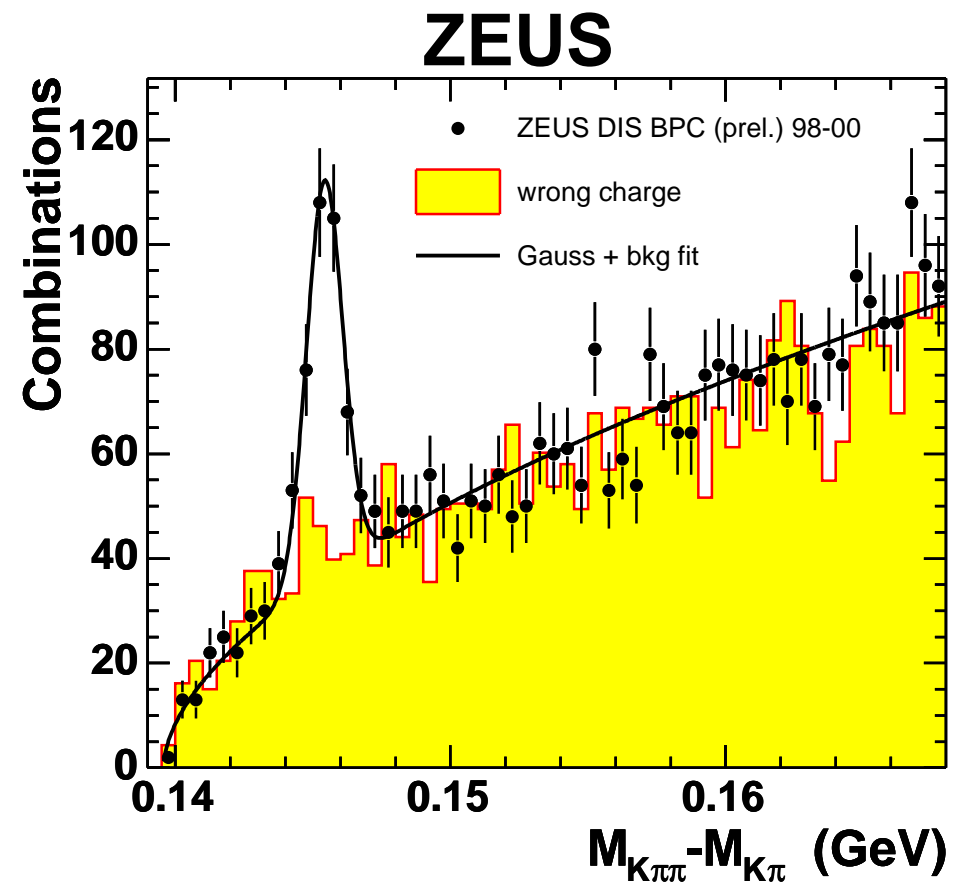


Figure:Zeus Note 99-056

Event Selection

- Data from 98-00 ($\mathcal{L} \approx 82\text{pb}^{-1}$)
- BPC cuts:
 - ▷ $0.05 < y < 0.85$
 - ▷ $0.05 < Q^2 < 0.7 \text{ GeV}^2$
 - ▷ $35 < E - p_z < 65 \text{ GeV}$
- D^* cuts:
 - ▷ $p_T(D^*) > 1.5 \text{ GeV}$
 - ▷ $|\eta(D^*)| < 1.5$
 - ▷ $p_T(\pi_s) > 0.12 \text{ GeV}$
 - ▷ $p_T(K, \pi) > 0.45 \text{ GeV}$
- Clear D^* signal observed
- Unbinned maximum likelihood fit used for number of D^*
- Fit to ΔM signal gives $253 \pm 22 D^*$



Total Cross Section

- Total Number of $D^* = 253 \pm 22$
 - Luminosity = 82.2 pb^{-1}
 - Kinematic range:
 - ▷ $p_t(D^*) > 1.5 \text{ GeV}$
 - ▷ $|\eta(D^*)| < 1.5$
 - ▷ $0.05 < y < 0.85$
 - ▷ $0.05 < Q^2 < 0.7 \text{ GeV}^2$
 - HERWIG and RAPGAP used for acceptance calculation
- Measured cross section:**
- $$\sigma = 10.1 \pm 1.0 \begin{matrix} +1.1 \\ -0.8 \end{matrix} \text{ nb}$$
- HVQDIS cross section:**
- $$\sigma = 8.6 \begin{matrix} +1.9 \\ -1.8 \end{matrix} \text{ nb}$$
- HVQDIS is NLO pQCD calculation used for comparison with data:
 - ▷ ZEUS NLO pdf used with:

$$M_c = 1.35 \text{ GeV}$$
 - ▷ Renormalization and factorization scale:

$$\mu^2 = (Q^2 + 4M_c^2)$$
 - ▷ Peterson fragmentation parameter:

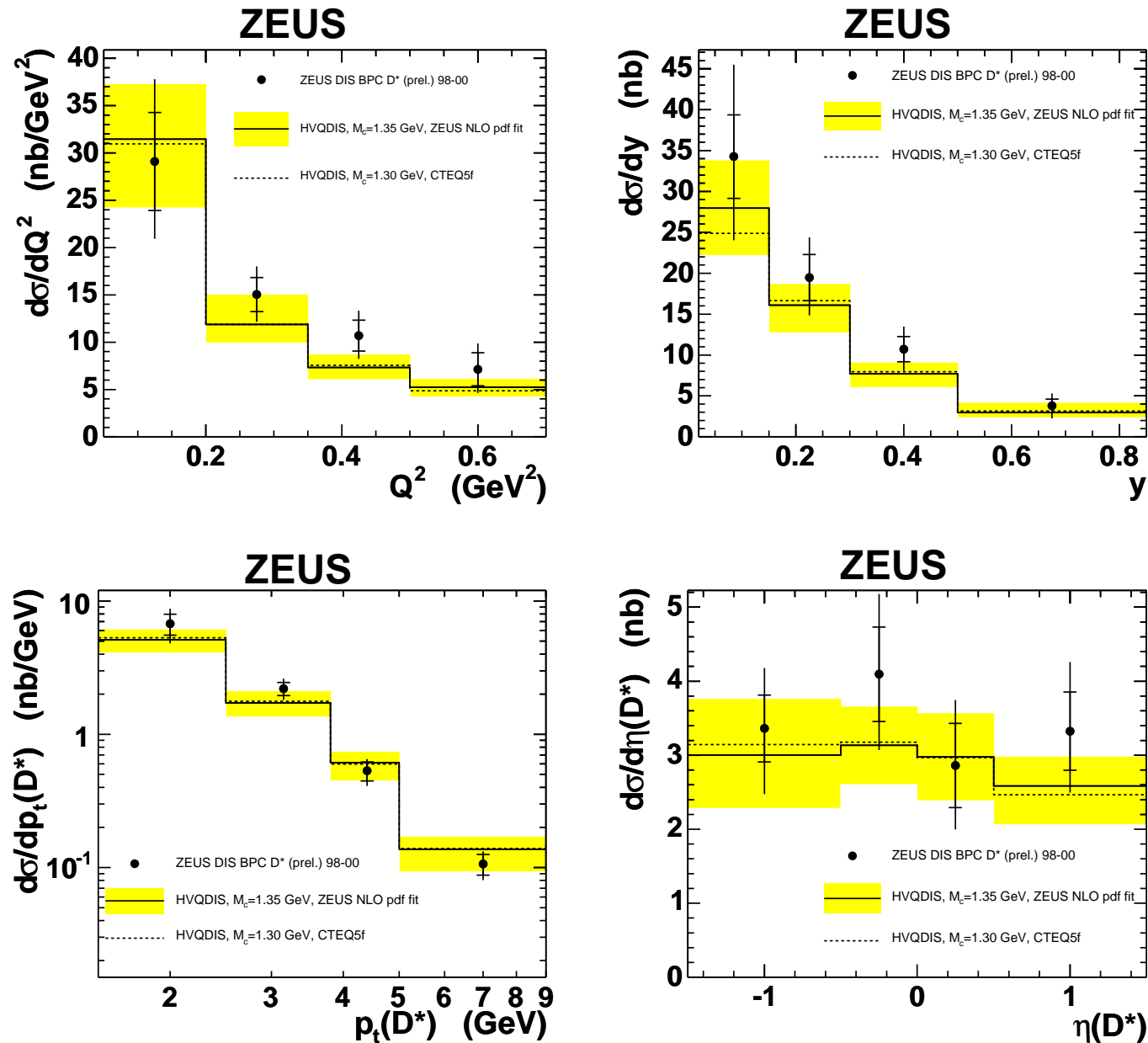
$$\epsilon = 0.035$$
 - also varying 3 parameters:
 - ▷ scale:

$$1/4(Q^2 + 4M_c^2) < \mu^2 < 4(Q^2 + 4M_c^2)$$
 - ▷ mass of charm quark:

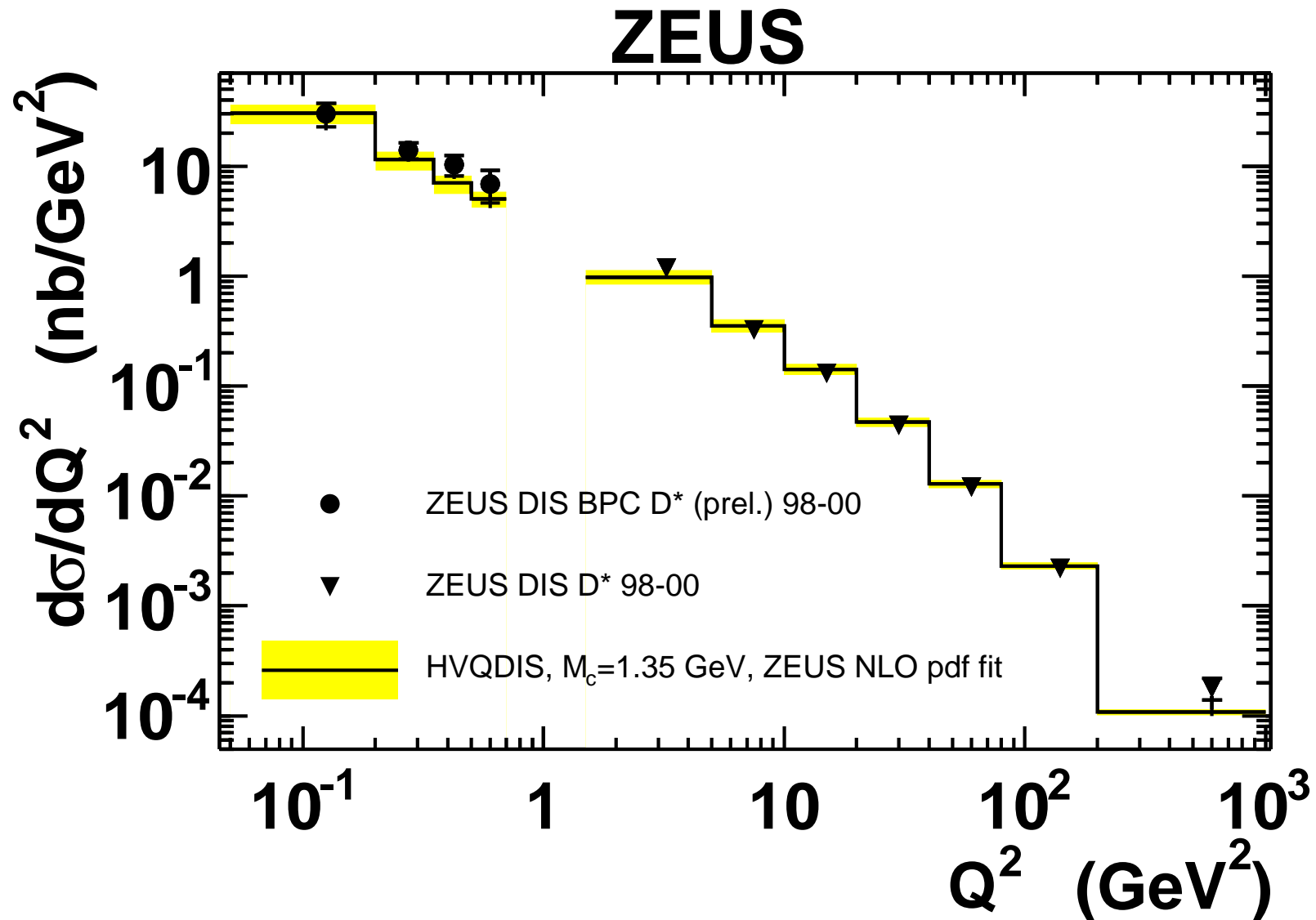
$$1.2 \text{ GeV} < M_c < 1.5 \text{ GeV}$$
 - ▷ fragmentation:

$$0.02 < \epsilon < 0.005$$

BPC D^* differential cross sections



Comparison BPC D^* cross section with D^* DIS



NLO pQCD describes charm production in DIS over 4 orders of magnitude in Q^2

Summary

- HERA-II data:
 - ▷ no difference observed in D^* rate for e^-p and e^+p collisions
- Measured D^* Production in new kinematic region:
 - ▷ Measurements of charm in transition region between **DIS** and **PHP**
 - ▷ Extends previous results in DIS to lower Q^2
- HVQDIS calculation produces a good description of the measured data:
 - ▷ Combined with DIS measurements, see agreement over 4 orders of magnitude in Q^2 between data and HVQDIS