D^* in Diffraction and with a Leading Neutron

ZEUS

DIS 2004
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Nikolai N. Vlasov

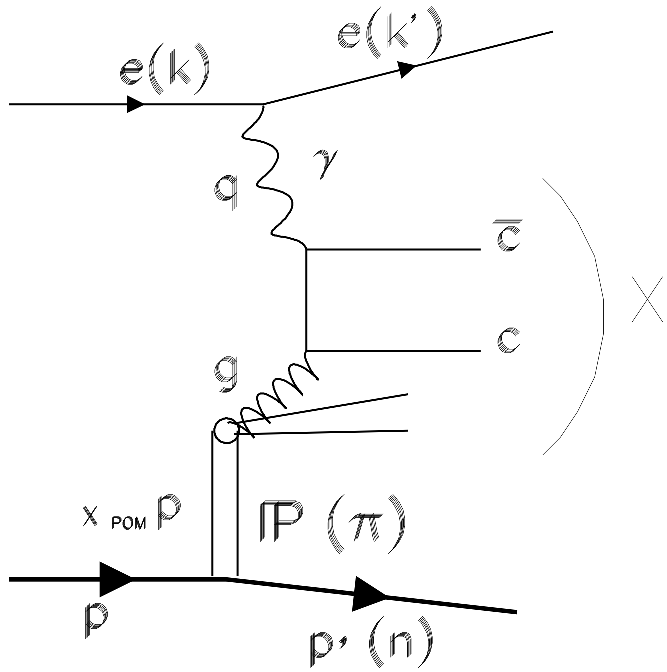
ALBERT-LUDWIGS-UNIVERSITÄT FREIBURG

On behalf of the ZEUS Collaboration

O U T L I N E

- **Introduction: motivation**
- **Diffractive charm production** →
  - Diffractive selection
  - DIS cross sections & $F_2^{D(3),c\bar{c}}$
  - $D^{*\pm}$ in photoproduction
  - Conclusions
- **Charm photoproduction associated with an leading neutron** →
  - Cross sections & ratios
  - Conclusions

Motivation



$$ep \to eXp(n) \to eD^* X' p(n)$$

- **charm-quark mass provides hard scale $\rightarrow$ applicability of pQCD**
- **Boson-gluon fusion mechanism dominates for charm production $\rightarrow$ sensitivity to gluon content of the exchanged particle**
- **To test diffractive and pion PDF's**

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

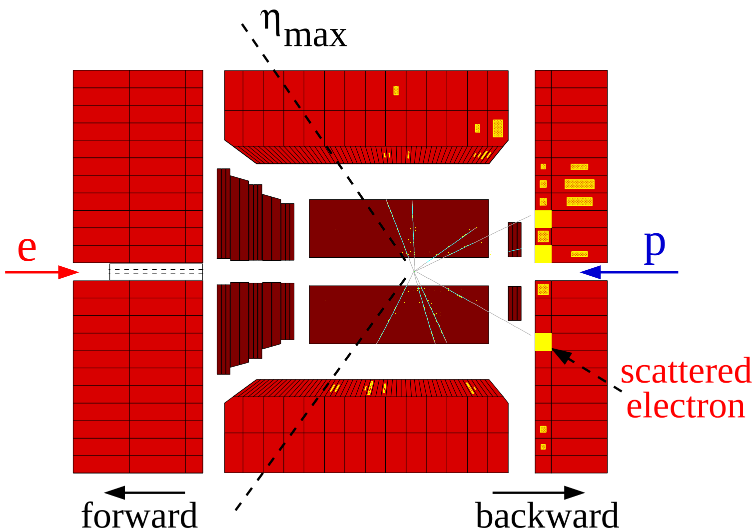
$$W^2 = (P + q)^2$$

$$x_{I\!P} = \frac{M_X^2 + Q^2}{W^2 + Q^2}$$

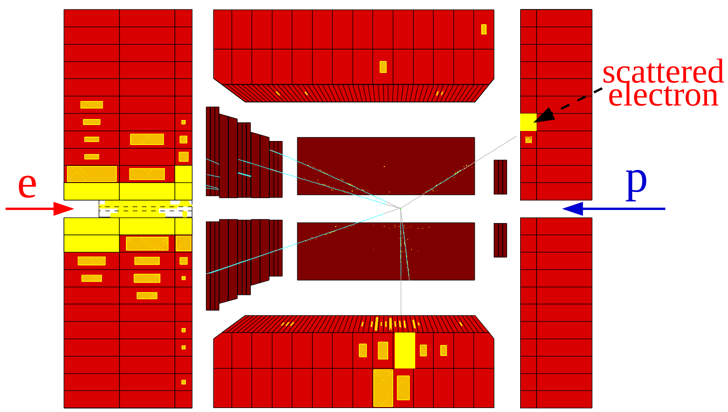
$$\beta = \frac{Q^2}{Q^2 + M_X^2}$$

$x(D^{*\pm}) = \frac{2|\bar{P}^*(D^{*\pm})|}{W}$, **where** $\bar{P}^*(D^*)$ **is** D^* **momentum in** γP **system**

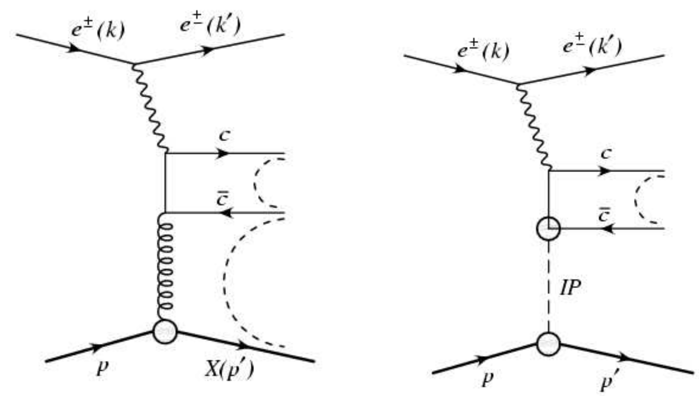
Diffractive Selection

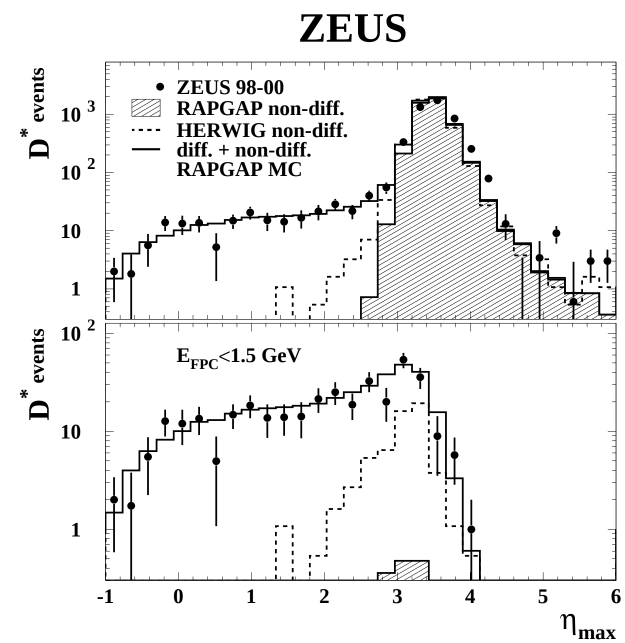


diffractive event



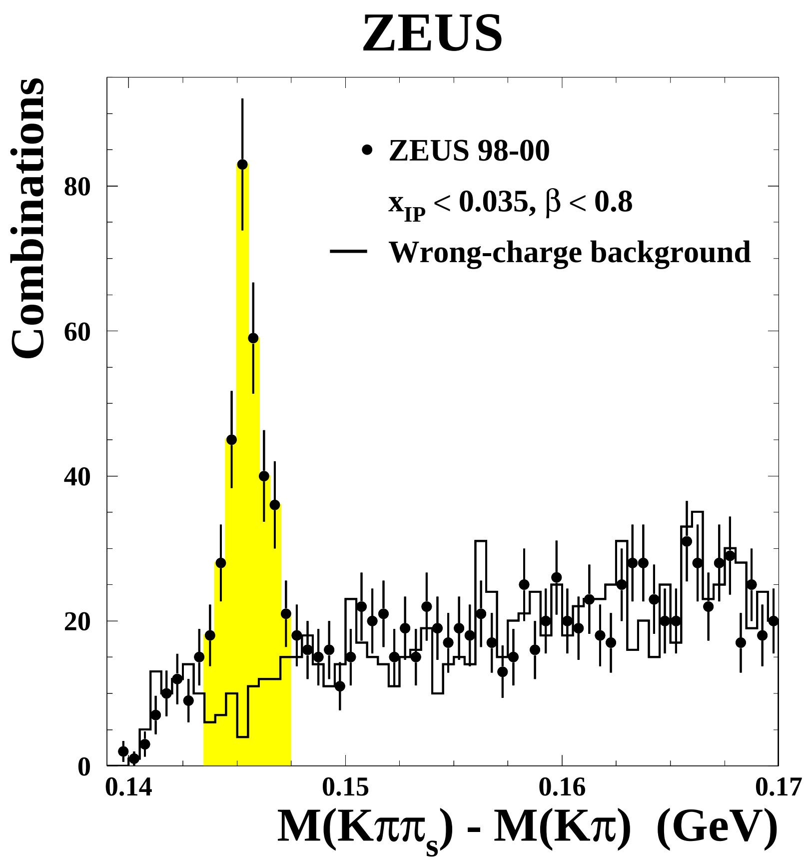
nondiffractive event





$\eta = -\ln(tg\frac{\theta}{2})$, η_{max} **: the largest** η **value in event**

DIffractive DIS: Integrated Cross Sections



$$1.5 < p_\perp(D^{*\pm}) < 10 \ \textbf{GeV}$$
$$-1.5 < \eta(D^{*\pm}) < 1.5$$
$$0.02 < y < 0.7$$
$$1.5 < Q^2 < 200 \ \textbf{GeV}^2$$
$$x_{I\!P} < 0.035 \ , \quad \beta < 0.8$$

Published ZEUS data :
Nuclear Physics B 672 (2003) 3-35
(DESY-03-094)

Integrated cross section :

$$\sigma = 521 \pm 43(stat)^{+34}_{-58}(syst)^{+25}_{-25}(p.dis.) \ \ \textbf{pb}$$

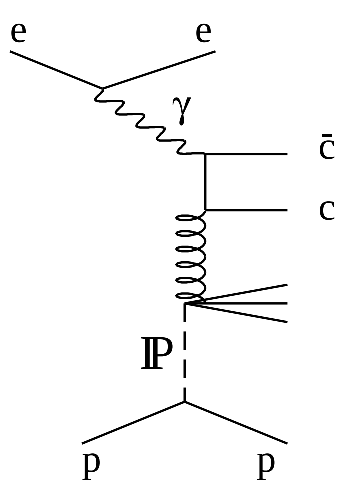
Integrated ratio :

$$R_D = \frac{\sigma^{diff}}{\sigma^{inc}} = 6.4 \pm 0.5(stat)^{+0.3}_{-0.7}(syst)^{+0.3}_{-0.3}(p.dis.) \ \ \%$$

Models of Diffractive Exchange

Resolved Pomeron model :

- **Assume Pomeron exchange**
- **Treat $I\!P$ as object with substructure**
- **Charm Production in diffractive DIS $\rightarrow$ probe gluon content of $I\!P$**



- **gluon-dominated $I\!P$**

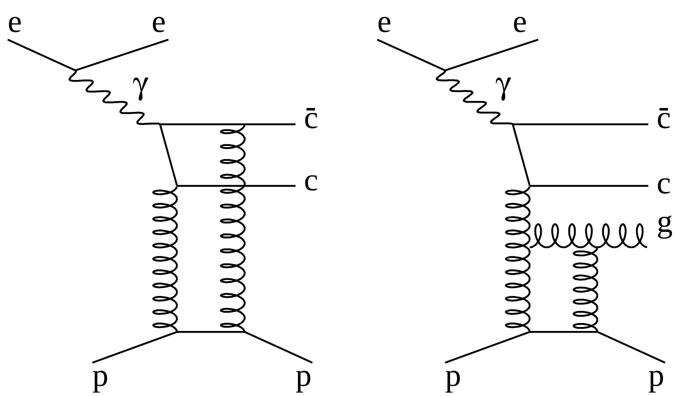
Examples :

– H1 QCD fit ("h1 fit2") in LO RAPGAP

– $ACTW$ (NLO QCD) with different diffractive PDFs. Gluon–dominated PDFs "B", "D" and "SG"

Models of Diffractive Exchange

Perturbative QCD models:



- t-channel gluon exchange
- $\sigma \propto (\textbf{gluon density})^2$
- **Higher order processes** $\gamma^* \to c\bar{c}g$ — **cancels suppression for large masses**

Examples :

– *BJLW* **(Bartels et al.) implemented in RAPGAP MC**

  - *unordered* k_T

– **"saturation" model implemented in** *SATRAP* **MC**

  - *strongly ordered* k_T : $p_T^g \ll p_T^q$

Factorisation in Diffraction

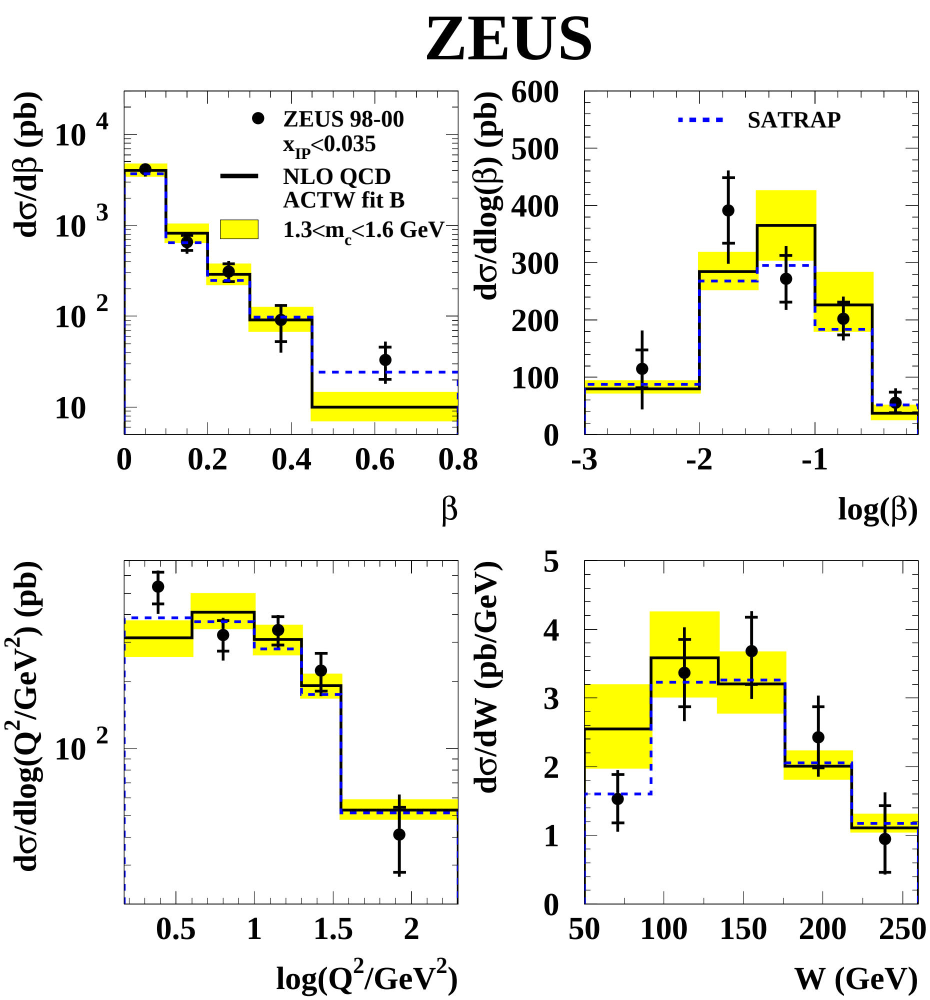
- **QCD Hard Scattering Factorisation (Collins et al):**

$$\frac{d^2\sigma(x,Q^2,x_{I\!P},t)^{\gamma^* p\rightarrow p' X}}{dx_{I\!P}dt} = \sum_i \int_x^{x_{I\!P}} d\xi \hat{\sigma}^{\gamma^* i}(x,Q^2,\xi) p_i^D(\xi,Q^2,x_{I\!P},t)$$

- $\hat{\sigma}^{\gamma^* i}$ **universal partonic cross sections, as in inclusive DIS**
- p_i^D **diffractive parton distributions, obey NLO DGLAP**

If QCD Factorisation works, the diffractive PDFs should predict cross sections for heavy quarks

Model Comparison with Diffractive DIS D^*



- **<u>Published ZEUS data</u> :**

  $Lumi = 82$ **pb**$^{-1}$ **(DESY-03-094)**
  $1.5 < Q^2 < 200\,$**GeV**^{2}**,** $0.02 < y < 0.7$**,**
  $x_{I\!P} < 0.035$**,** $\beta < 0.8$

  $p_T(D^{*\pm}) > 1.5\,$**GeV and** $|\eta(D^{*\pm})| < 1.5$

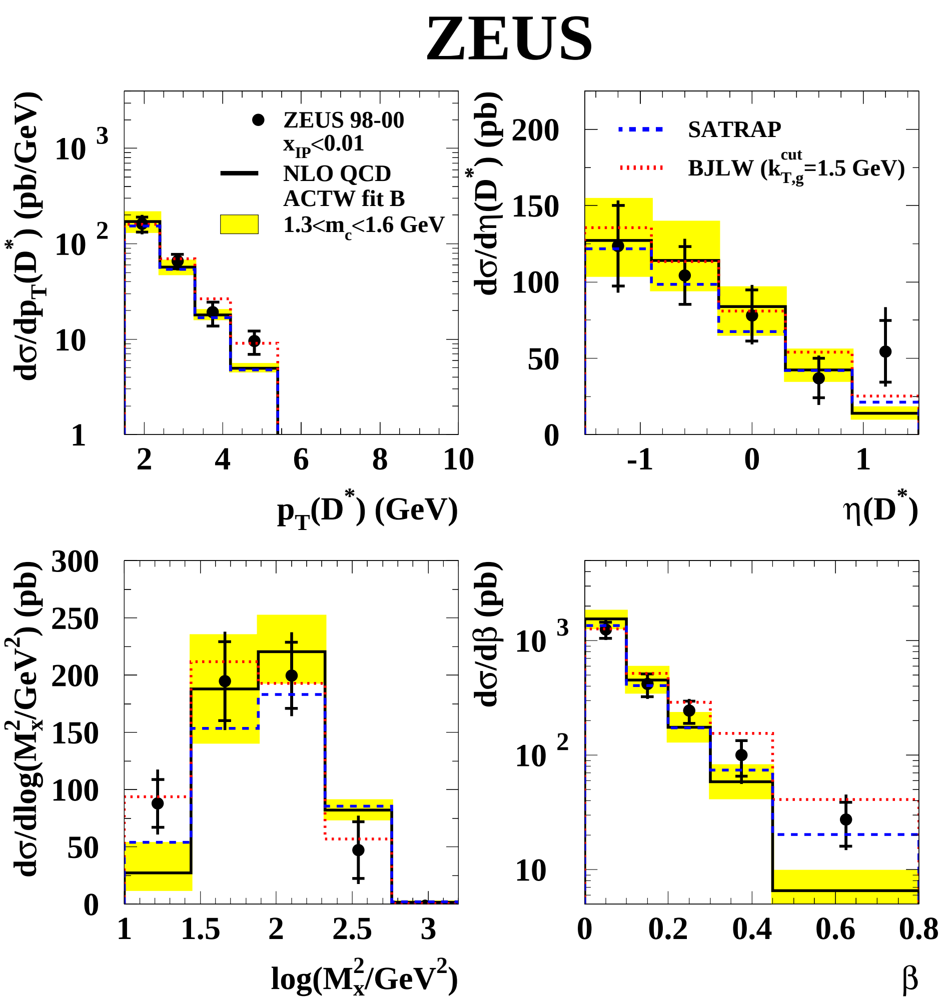
- **<u>ACTW NLO Calculations</u> :**

  Gluon dominated PDF "fit B"
  $\mu_R = \mu_F = \sqrt{Q^2 + 4m_c^2}$
  Peterson fragmentation with $\epsilon = 0.035$
  $f(c \to D^{*+}) = 0.235$

- **Good agreement with *ACTW* NLO predictions with diffractive PDF "fit B"**

- ***SATRAP* describes well the region** $x_{I\!P} < 0.035$

Model Comparison with Diffractive DIS D^*



- D^* for $x_{I\!P} < 0.01$ **(BJLW is only applicable)**

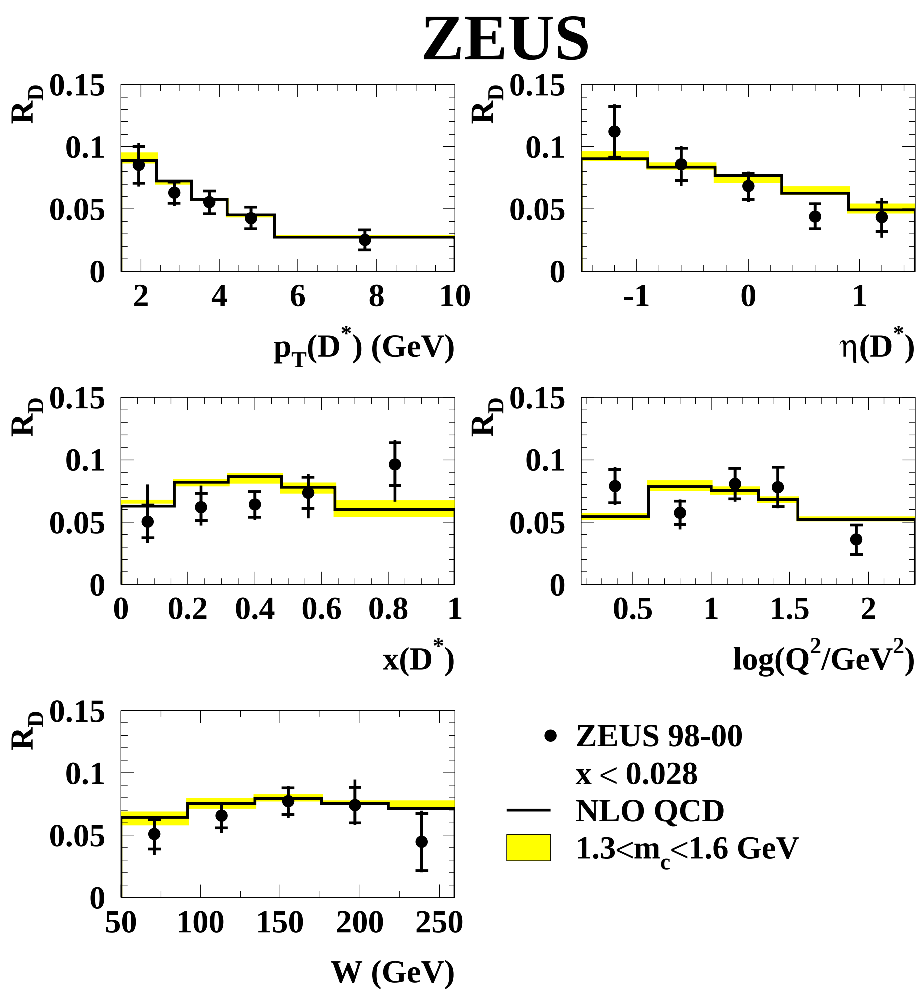
- **<u>SATRAP and BJLW Calculations</u> :**

  using proton PDF GRV94HO,
  $f(c \rightarrow D^{*+}) = 0.235$, $m_c = 1.45$ **GeV**
  $\mu_R = \mu_F = \sqrt{p_{c,T}^2 + 4m_c^2}$ $k_{T,g}^{\text{cut}} = 1.5$ **GeV**

- **Good agreement with *ACTW* NLO predictions with diffractive PDF "fit B"**

- **Good agreement with *BJLW* predictions and *SATRAP***

Ratio of Diffractive to Inclusive $D^{*\pm}$ Production



- Diffractive contribution is large at small $p_\perp(D^*)$ and negative $\eta(D^*)$
- R_D has no significant dependance on $x(D^*)$, Q^2 or W
- Good agreement with NLO QCD $(ACTW)$ predictions with diffractive PDF "fit B"

Open-Charm Contribution to $F_2^{D(3)}$

Open-charm contribution to the diffractive structure function of the proton:

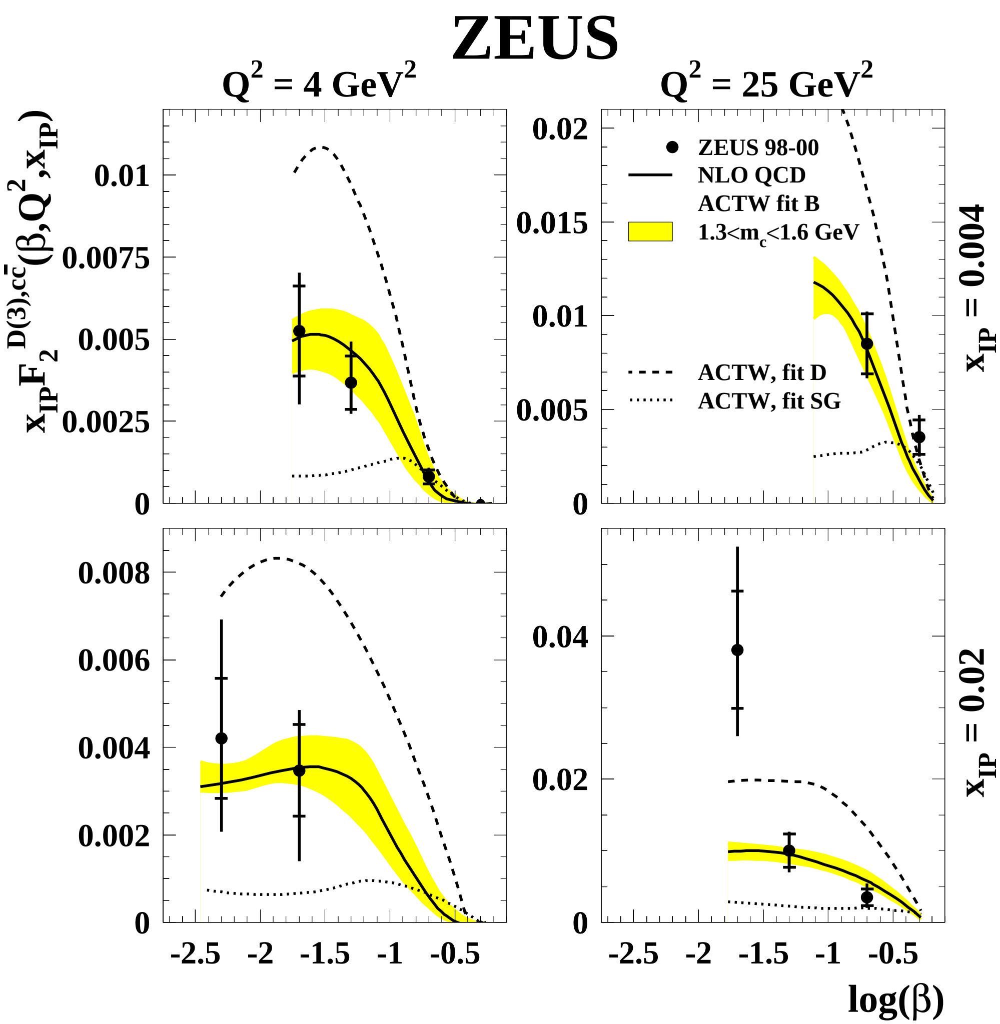
$$\frac{1}{2f(c \to D^{*+})} \frac{\mathrm{d}^3\sigma_{ep\to eD^{*\pm}X'p}}{\mathrm{d}x_{I\!P}\mathrm{d}\beta\mathrm{d}Q^2} = \frac{4\pi\alpha_{em}^2}{Q^4\beta}(1 - y + \frac{y^2}{2})F_2^{D(3),c\bar{c}}(\beta, Q^2, x_{I\!P})$$

- **Determine extrapolation factors to full $p_T(D^{*\pm})$ and $\eta(D^{*\pm})$ phase space using the ACTW NLO "fit B" (~ 3.5)**
- **In each bin $F_2^{D(3),c\bar{c}}$ determined using:**

$$F_2{}^{D(3),c\bar{c}}_{\mathrm{meas}}(\beta_i, Q_i^2, x_{I\!P,i}) = \frac{\sigma^{i,\mathrm{meas}}_{ep\to eD^{*\pm}X'p}}{\sigma^{i,\mathrm{ACTW}}_{ep\to eD^{*\pm}X'p}} F_2{}^{D(3),c\bar{c}}_{\mathrm{ACTW}}(\beta_i, Q_i^2, x_{I\!P,i}),$$

where the cross sections σ^i in bin i are those for $p_T(D^{*\pm}) > 1.5$ GeV and $|\eta(D^{*\pm})| < 1.5$

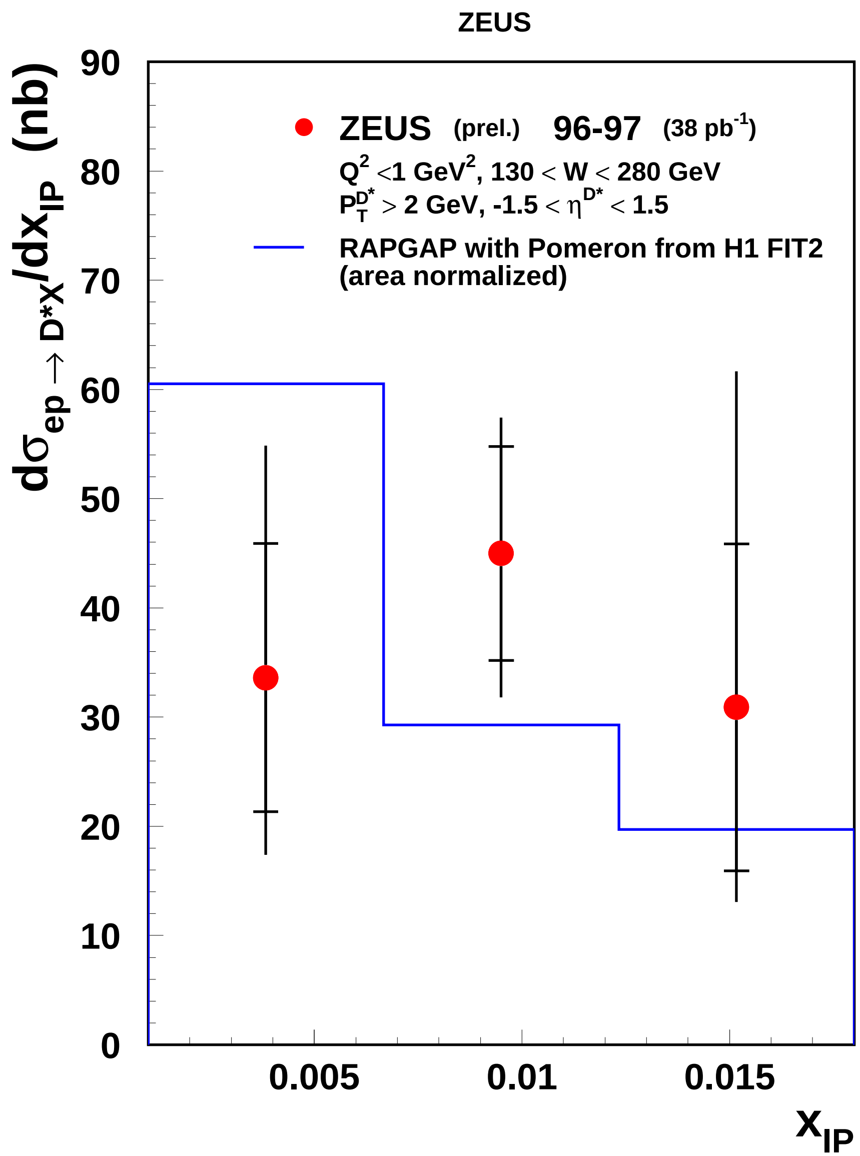
Open-Charm Contribution to $F_2^{D(3)}$



- **For all values of Q^2 and $x_{I\!P}$, $F_2^{D(3),c\bar{c}}$ rises as $\beta \to 0$**
- **The data exclude PDFs D and SG and consistent with B.**

Strong sensitivity to the diffractive parton densities

$D^{*\pm}$ Diffractive Cross Sections in Photoproduction



- **Preliminary ZEUS 96-97 data :**

  $Q^2 < 1$ **GeV**^{2}, $130 < W < 280$ **GeV**,
  $x_{I\!P} < 0.018$
  $p_T(D^{*\pm}) > 2$ **GeV**, $|\eta(D^{*\pm})| < 1.5$

- $\sigma = 0.74 \pm 0.21(stat)^{+0.27}_{-0.18}(syst) \pm 0.16(p.dis.)$ **nb**

- **Good agreement with Resolved Pomeron model in shapes of measured cross sections**

Diffractive DIS Summary

1. **Total diffractive cross section of DIS $D^{*\pm}$ production in the kinematic range $1.5 < p_\perp(D^{*\pm}) < 10$ GeV, $-1.5 < \eta(D^{*\pm}) < 1.5$, $0.02 < y < 0.7$, $1.5 < Q^2 < 200$ GeV^2, $x_{I\!P} < 0.035$ and $\beta < 0.8$ is :**
$$521 \pm 43(stat)^{+34}_{-58}(syst)^{+25}_{-25}(p.dis.)\ \textbf{pb}$$

2. **Relative contribution of diffractive mechanism to inclusive D^* in DIS production is : $R_D = 6.4 \pm 0.5\ (stat)^{+0.3}_{-0.7}\ (syst)^{+0.3}_{-0.3}\ (p.diss.)\ \%$**

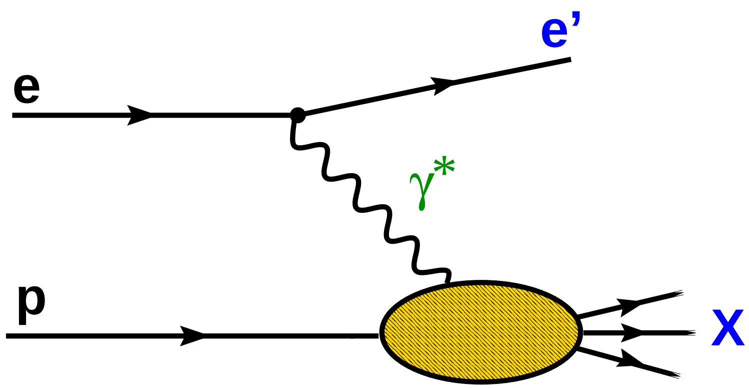
3. **Diffractive relative contribution is large at small $p_\perp(D^*)$ and negative $\eta(D^*)$. R_D has no significant dependence on $x(D^*)$, Q^2 or W.**

4. **The diffractive open charm contribution, $F_2^{D(3),c\bar{c}}$, to the proton structure function rises as $\beta \to 0$. for all values of Q^2 and $x_{I\!P}$.**

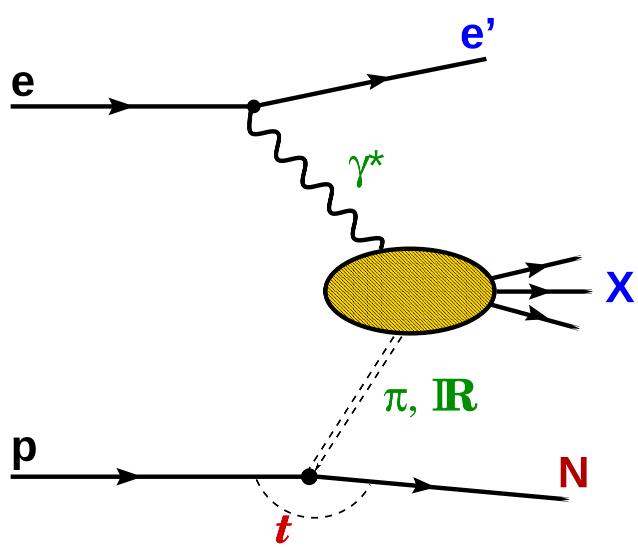
5. **No significant difference in predictions of different models was observed. Data described by both resolved pomeron and two-gluon exchange models**

Charm Photoproduction Associated with a Leading Neutron

Standard Fragmentation :



Particle Exchange :



- Significant part of ep scattering at HERA contains a baryon in final state $0.2 < x_L < 1$, $x_L = E_{LB}/E_P$
- Production mechanism not completely understood; Exchange models are usually applied to describe data

Published ZEUS data :

DESY-03-221 (submitted to Physics Letters B)

One-pion-exchange model

Electroproduction cross section can be written as pion flux factor $f_{\pi/p}(x_L, t)$, and $e\pi$ cross section:

$$\frac{d\sigma_{ep\to e'nX}}{dx_L\,dt} = f_{\pi/p}(x_L, t)\sigma^{e\pi}(s'),$$

where $s' = s(1 - x_L)$ is squared center-of-mass energy of the $e\pi$ system

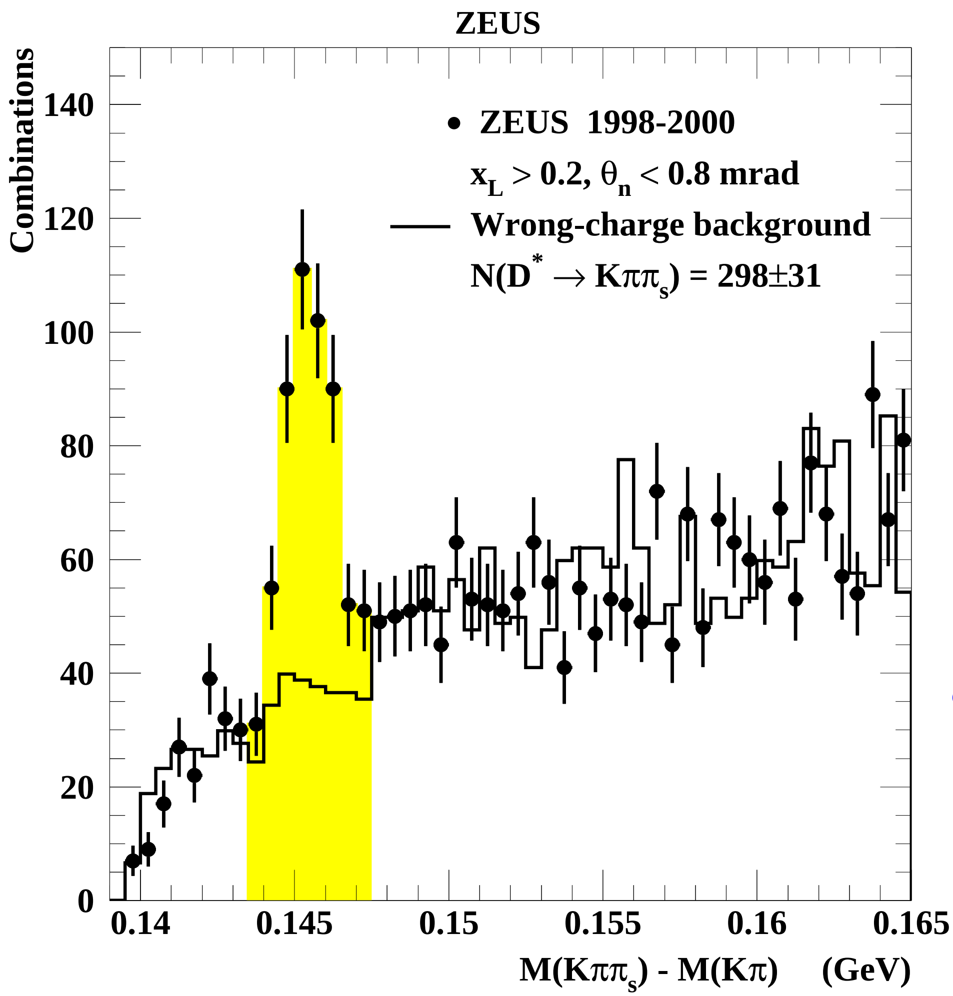
The general form of pion flux factor :

$$f_{\pi/p}(x_L, t) \sim (1 - x_L)^{1-2\alpha(t)} \left[F(x_L, t)\right]^2$$

Examples of flux factor parametrizations are:

- f_1**: light-cone form factor,** $\alpha(t) = 0$
- f_2**:** $F(x_L, t) = 1$**,** $\alpha(t) =$ **pion Regge trajectory**
- f_3**: Exponential form factor,** $\alpha(t) =$ **pion Regge trajectory**
- f_4**: Monopole form factor,** $\alpha(t) = 0$

Results on Neutron Tagged D^*



- $ep \to eD^{*\pm}nX$
- $Q^2 < 1$ **GeV**^{2},
  $130 < W < 280$ **GeV**,
  $p_T(D^{*\pm}) > 1.9$ **GeV**, $|\eta(D^{*\pm})| < 1.5$

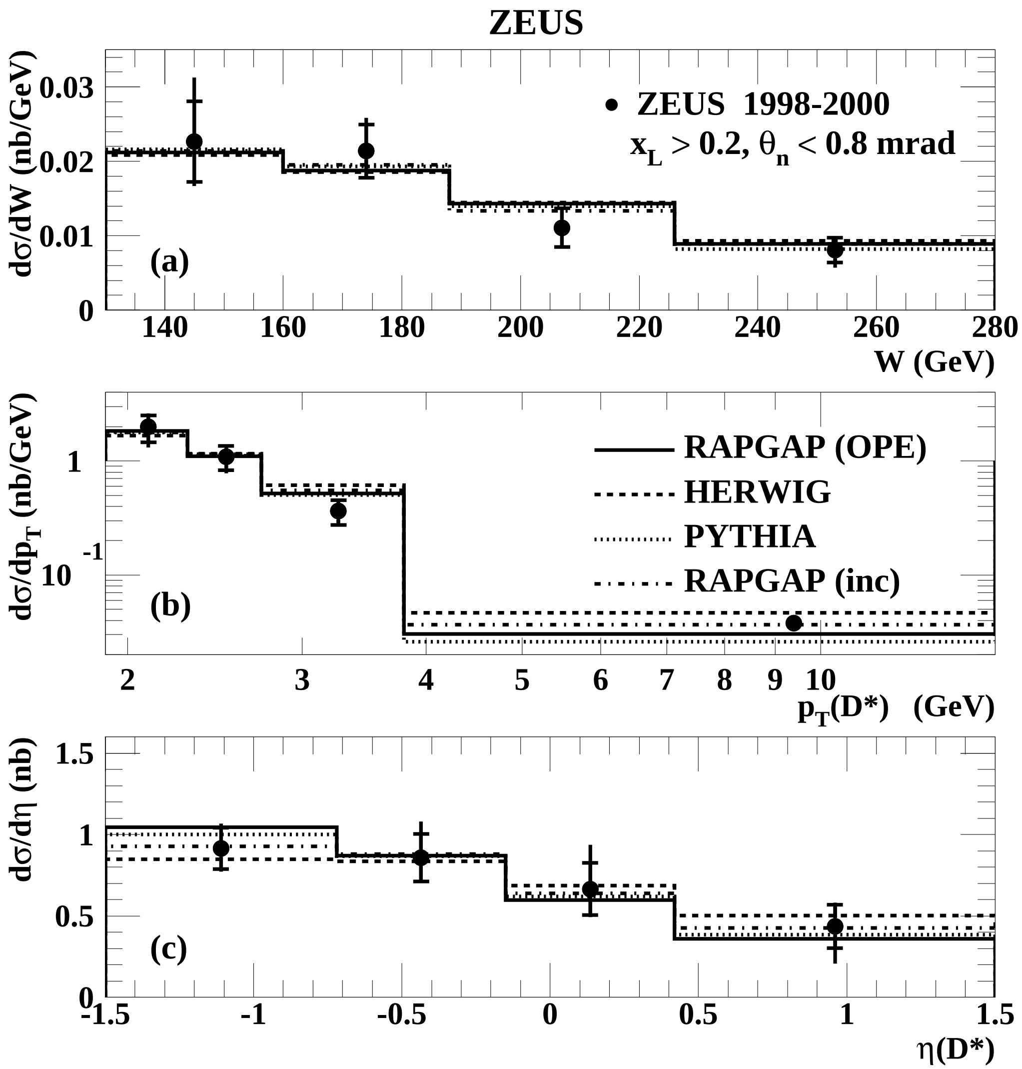
  Neutron detected in ZEUS Forward Neutron Calorimeter
  $0.2 < x_L < 1$, $\theta_n < 0.8\ mrad$

$$\sigma = 2.08 \pm 0.22(stat)^{+0.12}_{-0.18}(syst) \pm 0.05(B.R.)\ nb$$

Ratio of neutron-tagged to inclusive D^* production :

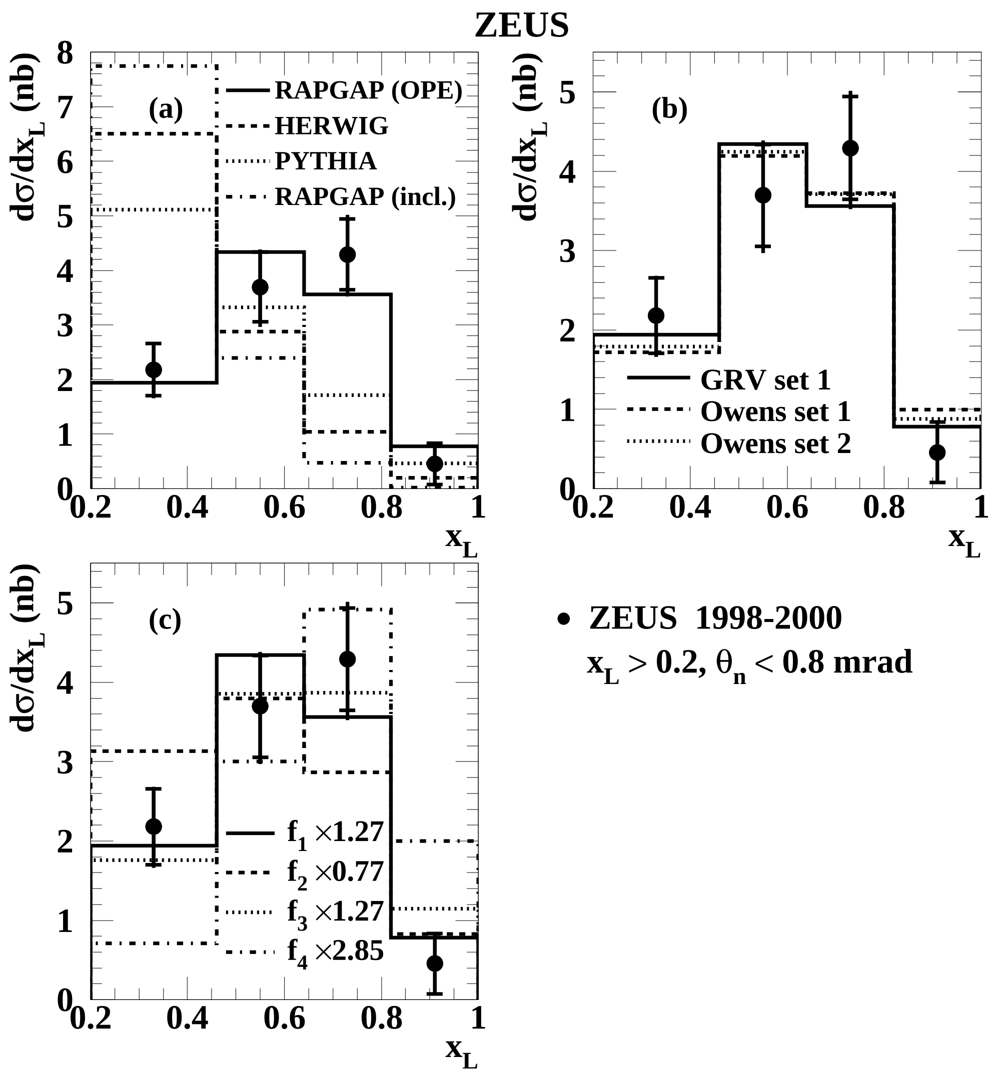
$$R_D = \frac{\sigma^{neut}}{\sigma^{incl}} = 8.85 \pm 0.93(stat)^{+0.48}_{-0.61}(syst)\ \%$$

Results on Neutron Tagged D^*



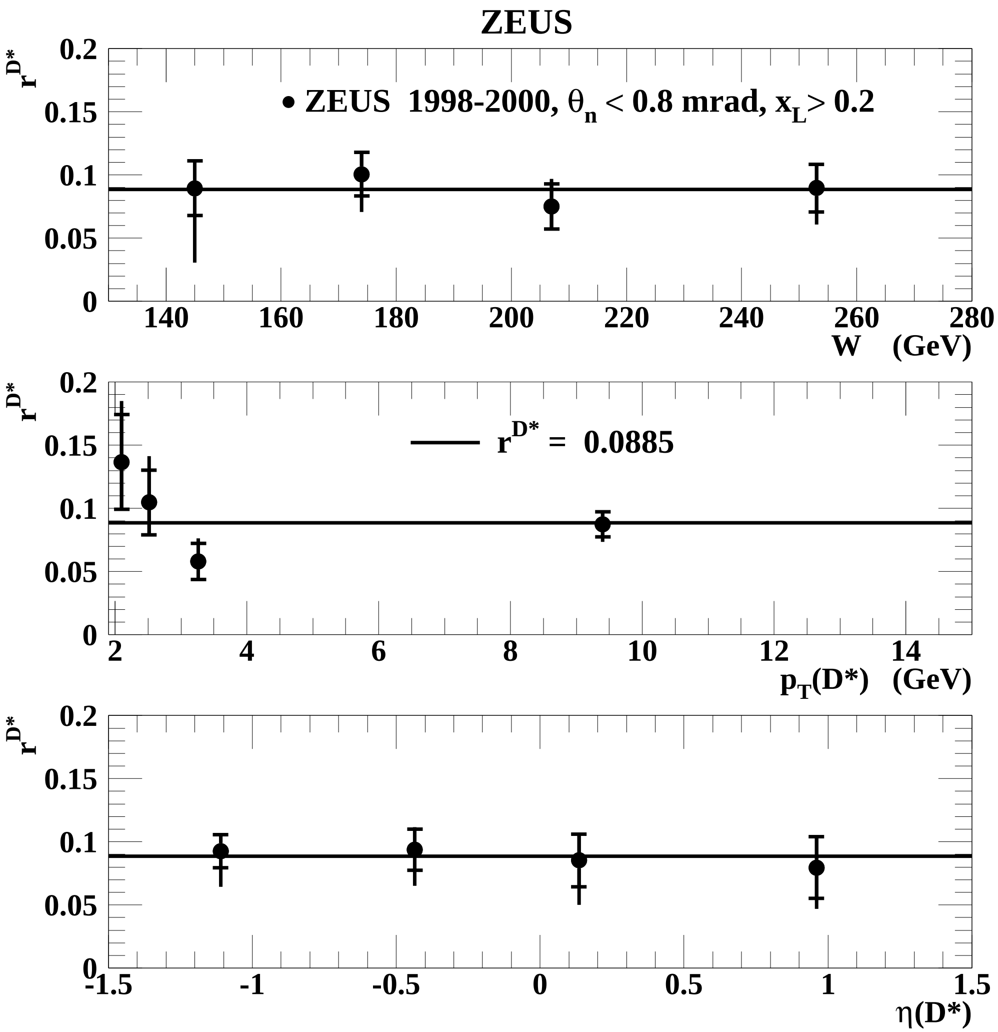
- Differential cross sections
- One Pion Exchange model
  RAPGAP (OPE)
  Standard fragmentation
  HERWIG, PYTHIA, RAPGAP(in
- Area normalised distributions
  comparison of shapes only
- For W, $P_T(D^*)$ and $\eta(D^*)$ all models
  describe the data

Results on Neutron Tagged D^*



- Cross sections for x_L
- One Pion Exchange model describe data
- Standard fragmentation fails
- Data have little sensitivity to choice of pion structure function
- Light-cone (f_1) and exponential (f_3) pion form factors are compatible with data in shape

Results on Neutron Tagged D^*



- **Ratios of neutron tagged D^* to inclusive D^* photoproduction**
- **Line: inclusive ratio**
- **Ratios are flat with respect to W, $P_T(D^*)$ and $\eta(D^*)$**

Neutron Tagged D^* Summary

1. **Integrated cross section of neutron tagged D^* in the kinematic range $Q^2 < 1$ GeV^2, $130 < W < 280$ GeV, $0.2 < x_L < 1$, $p_\perp(D^{*\pm}) < 1.9$ GeV and $-1.5 < \eta(D^{*\pm}) < 1.5$ is :**

$$2.08 \pm 0.22(stat)^{+0.12}_{-0.18}(syst) \pm 0.05(B.R.)\ nb$$

2. **Ratios of neutron tagged D^* to inclusive D^* photoproduction is :**

$$8.85 \pm 0.93(stat)^{+0.48}_{-0.61}(syst) \quad \%$$

3. **Good agreement with particle exchange model;**
   One pion exchange model describes x_L shape well

4. **Data have little sensitivity to choice of pion structure function**

New HERA II data are coming !

- **Significant improvement in statistics**
- **Addition of new tracking detectors**
- **Improved triggering**
  - **will permit to constrain model parameters**
  - **will require further model developments**