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XIII International Workshop on Deep Inelastic Scattering  
Madison, WI, USA 27th April - 1st May 2005
D* Production in Diffractive DIS

- **Process**: $ep \rightarrow e D^{*\pm} X' Y$
- Two distinct hadronic systems
- $X$ contains at least one $D^*$ meson
- $Y$: elas scattered $p$ or low mass state

- $x_{IP}$: longitudinal momentum fraction of diffractive exchange relative to proton
- $\beta$: longitudinal momentum fraction of quark entering hard subprocess relative to diffractive exchange
- $z_{IP}$: longitudinal momentum fraction of gluon relative to diffractive exchange
Factorise diffractive DIS into diffractive PDFs and hard scattering matrix elements

\[ \sigma (\gamma^* \rightarrow XP) \sim p_{q/p}(x_IP, t, x, Q^2) \otimes \sigma_{\gamma^* q}(x, Q^2) \]

- universal diffractive parton densities
- hard scattering matrix element same as incl. heavy flavour prod.

⇒ directly sensitive to gluon content of diffractive exchange
Diffractive Parton Densities

- Gluon contribution dominates (~75% of momentum of diffractive exchange)
- Singlet distribution well constrained
- Increased uncertainties for gluon distribution at higher $z$
- Boson-gluon fusion processes provide test of gluon diffractive PDFs (e.g. diffractive dijet and charm)
Event Selection

1999-2000 $\mathcal{L}=42.6$ pb$^{-1}$

**Kinematic Phase Space:**
- $2 < Q^2 < 100$ GeV$^2$
- $0.05 < y < 0.7$
- $p_T(D^*) > 2$ GeV
- $|\eta(D^*)| < 1.5$

**Diffractive Selection:**
- $M_Y < 1.6$ GeV
- $|t| < 1$ GeV$^2$
- $x_{IP} = \frac{Q^2 + M_X^2}{Q^2 + W^2} < 0.04$

Diffractive $D^{*\pm}$ yield: $N(D^*) = 140 \pm 16$

**Dominant systematic errors:**
- Track efficiency: $\pm 8\%$
- Model uncertainties (including p dissociation): $\pm 12\%$
Total Diffractive D*± Cross Section

- **H1 99-00 Prelim:**
  
  \[ 2 < Q^2 < 100 \text{ GeV}^2, \ 0.05 < y < 0.7, \ x_{IP} < 0.04, \ M_Y < 1.6 \text{ GeV}, \]
  
  \[ t < 1 \text{ GeV}^2, \ p_{T,D^*} > 2 \text{ GeV}, |\eta_{D^*}| < 1.5 \]

  \[ \sigma_{\text{vis}}(ep \rightarrow e D^{*\pm} X' Y) = 333 \pm 38 (\text{stat.}) \pm 57 (\text{sys.}) \text{ pb} \]

- **H1 96-97:**

  \[ \sigma_{\text{vis}}(ep \rightarrow e D^{*\pm} X' Y) = 246 \pm 54 (\text{stat.}) \pm 56 (\text{sys.}) \text{ pb} \]

- **ZEUS (rescaled to H1 kinematic phase space):**

  \[ \sigma_{\text{vis}}(ep \rightarrow e D^{*\pm} X' Y) = 305 \pm 25 (\text{stat.})^{+20}_{-34} (\text{sys.}) \text{ pb} \]

- **Good agreement between measured total cross sections**
Comparison to NLO Calculation ($x_{IP} < 0.04$)

H1 99-00 Prelim: $\sigma(e p \rightarrow e D^{*\pm} X ' Y) = 333 \pm 38$ (stat.) $\pm 57$ (sys.) pb

- NLO with NLO diffractive parton densities (HVQDIS):
  - NLO diff. parton densities from H1 2002 Prelim. NLO QCD fit

  - QCD Parameters: $m_c = 1.5$ GeV, $\Lambda_{QCD} = 0.2$ GeV, $N_f = 4$
  - Renormalisation and fragmentation scales: $\mu_f^2 = \mu_r^2 = Q^2 + 2 m_c^2$
  - Peterson fragmentation function: $\epsilon = 0.078$

- Uncertainties:
  - Vary $\mu_r^2$ and $\mu_f^2$ by $\frac{1}{4}$ and 4 (keeping $\mu_f^2 = \mu_r^2$)
  - Vary $m_c = 1.35 - 1.65$ GeV and $\epsilon = 0.035 - 0.1$

H1 2002 Prelim NLO: $\sigma_{vis}(e p \rightarrow e D^{*\pm} X ' Y) = 241^{+66}_{-39}$ pb

- Prediction lower than data, but consistent within uncertainties
- Data and NLO agreement supports hard scattering factorisation
Comparison to LO Calculation \((x_{IP}<0.04)\)

H1 99-00 Prelim: \(\sigma (ep \rightarrow e D^{*\pm} X' Y) = 333 \pm 38\) (stat.) \(\pm 57\) (sys.) pb

- \(O(\alpha_s)\) MEs + LO diff. parton densities (RAPGAP):
  - QCD Parameters: \(m_c = 1.5\) GeV, \(\Lambda_{QCD} = 0.2\) GeV, \(N_f = 4\)
  - \(D^*\) fragmentation by Lund string model
  - Renormalisation and fragmentation scales: \(\mu_f^2 = \mu_r^2 = Q^2 + p_T^2 + 2m_c^2\)

H1 2002 Prelim ME+PS: \(\sigma_{\text{vis}} (ep \rightarrow e D^{*\pm} X' Y) = 224\) pb

- Predictions lower than data
Differential Cross Sections ($x_{IP} < 0.04$)

- Compare data to NLO calculation in collinear approach
- **Inner error bar:** renormalisation scale uncertainty
- **Outer error bar:** inner $\Theta$ charm mass and Peterson fragmentation uncertainties
- NLO calculations below data, but reproduce data within uncertainties
Differential Cross Sections \((x_{IP} < 0.04)\)

- Differential cross sections in diffractive variables also reproduced by NLO calculation within uncertainties
$x_{IP}$ and $p_T(D^*)$ Cross Sections

- Compare $x_{IP}$ cross section to
  - NLO calculation
  - LO calculation (RAPGAP)
- RAPGAP prediction in agreement with full NLO calculations

- Compare $p_T$ cross section to ZEUS data rescaled to H1 kinematic range using RAPGAP
- Good agreement between H1 and published ZEUS data
- Data reproduced by NLO calculation within uncertainties
BJKLW Two Gluon Model

- Describe diffractive exchange as colour singlet exchange of at least two gluons
- Couple directly to $c\bar{c}$ pair or to $c\bar{c}g$
- Unintegrated gluon distributions from inclusive structure function $F_2$
- Only valid for small $x_{IP}$ (quark exchange neglected)
- $p_T > 1.5$ GeV cut for gluon in $c\bar{c}g$
  $\Rightarrow$ use perturbation theory

Comparisons to Calculations ($x_{IP} < 0.01$)

H1 99-00 Prelim: $\sigma(ep \to e D^{*\pm} X'Y) = 131 \pm 24\,(stat.) \pm 24\,(sys.)\,pb$

- NLO with NLO diff. parton densities (HVQDIS):
  H1 2002 Prelim NLO: $\sigma_{vis}(ep \to e D^{*\pm} X'Y) = 76^{+17}_{-10}\,pb$

- $O(\alpha_s)$ MEs + LO diff. parton densities (RAPGAP):
  H1 2002 Prelim ME+PS: $\sigma_{vis}(ep \to e D^{*\pm} X'Y) = 76\,pb$
    - Predictions lower than data

- pert. 2-gluon, unintegrated gluon density (CCFM):
  CCFM set 1 BJKLW ($p_T > 1.5\,GeV$):
  $\sigma_{vis}(ep \to e D^{*\pm} X'Y) = 139\,pb$
    - Visible cross section well reproduced by 2-gluon model
Differential Cross Sections ($x_{IP} < 0.01$)

- Compare $x_{IP} < 0.01$ cross sections to
  - NLO calculation
  - perturbative 2-gluon
- Only extra free parameter $p_T > 1.5$ GeV for gluon in $c \overline{c} g$ (also used for inclusive jets)
- Data described by both NLO and two gluon models
Conclusions

- New measurement of diffractive open charm in DIS at HERA
- Total visible cross section:
  \[ \sigma_{\text{vis}}(ep \rightarrow e D^{\ast \pm} X' Y) = 333 \pm 38(\text{stat.}) \pm 57(\text{sys.}) \text{ pb} \]
  - agreement with previous H1 and ZEUS measurements
- LO and NLO models:
  - lie below data, but describe data within uncertainties
  - describes shape of data well
- Agreement supports validity of QCD factorisation in DIS
- Two gluon model describes inclusive and differential cross sections in range of validity \( x_{IP} < 0.01, p_T < 1.5 \text{ GeV} \)