DIFFRACTION 2000
SESSION: 'Diffraction in lepton-hadron collisions I'
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Cetraro, Italy

Diffractive $D^{*\pm}(2010)$ Production in Deep Inelastic Scattering at HERA

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(On behalf of the H1 and ZEUS Collaborations)

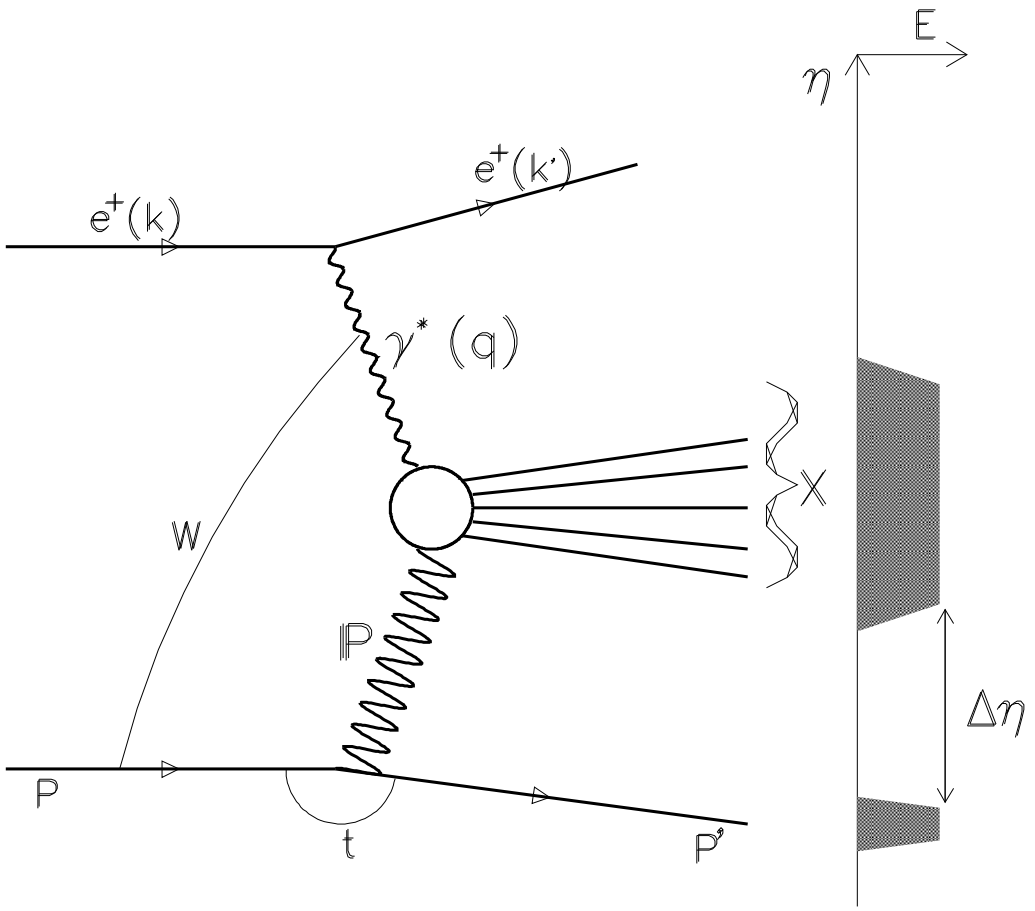
- Why measure open charm in diffraction ?
- Models of diffractive exchange
- Data Selection
- Results from ZEUS and H1
- Conclusions

Why measure open charm in diffraction ?

- Charm mass provides a hard scale $\rightarrow$ pQCD
- Charm is sensitive to role of gluons in diffractive exchange
- Open charm free from uncertainties relating to bound states, eg. J/ψ

- Study of charm provides test of underlying dynamics of diffraction
  - Resolved Pomeron Model?
  - 2 Gluon Exchange?
  - Soft Colour Interactions?

Event Kinematics



$$\mathbf{x_P} = \frac{\mathbf{M_X^2}+\mathbf{Q^2}}{\mathbf{W^2}+\mathbf{Q^2}}$$

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

$$\eta = -\ln\tan(\theta/\mathbf{2})$$

$$\mathbf{Q^2} = -(\mathbf{k}-\mathbf{k'})^2$$

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

$$\mathbf{y} = \frac{\mathbf{P\cdot q}}{\mathbf{P\cdot k}}$$

$$\mathbf{W^2} = (\mathbf{P}+\mathbf{q})^2$$

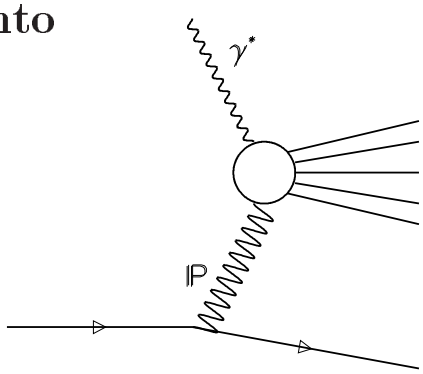
$$\mathbf{x_P}\beta = \mathbf{x}$$

$$\mathbf{Q^2} = \mathbf{xys}$$

Resolved Pomeron Models

(eg. Ingelman & Schlein,Donnachie & Landshoff)

- **Cross section factorises into $\mathbb{P}$omeron flux factor and parton density**



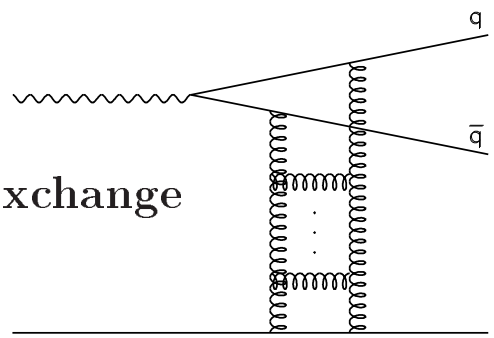
- **Charm produced by BGF $\rightarrow$ probe gluon content of $\mathbb{P}$**

- **QCD fits to HERA data**
  - **gluon-dominated $\mathbb{P}$**
  - **Implemented in RAPGAP based on H1 QCD fits to F_2^D**
  - **Used by Alvero, Collins, Terron and Whitmore (ACTW) to make fits to ZEUS and H1 diffractive DIS and γp data.**
  - **predicts large charm cross section**

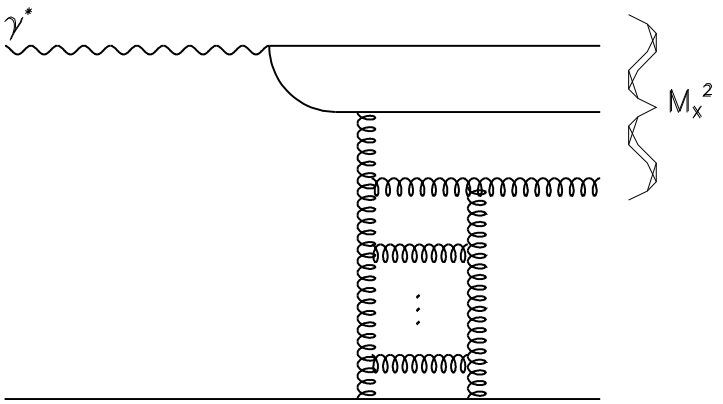
Perturbative QCD Models

(eg. Levin, Martin, Ryskin & Teubner; Bartels, Lotter, Jung & Wüsthoff)

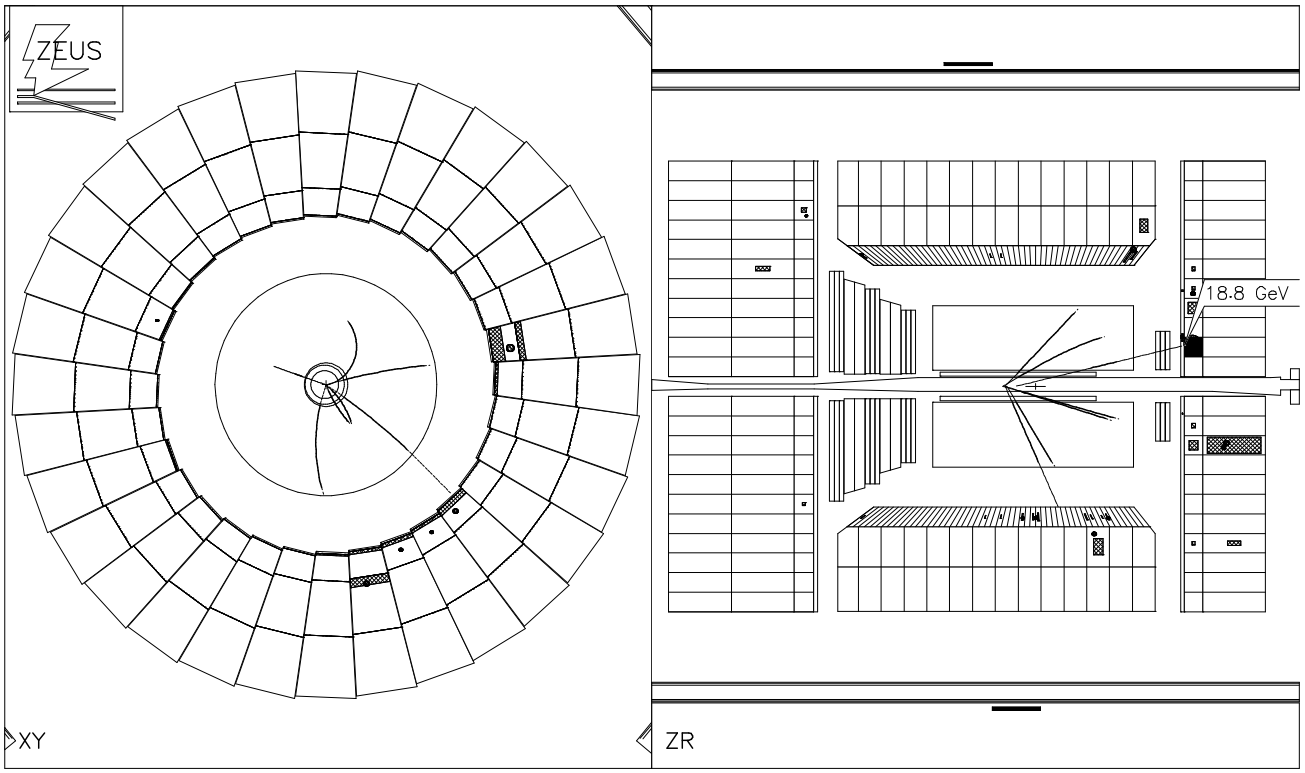
- **lowest order** $q\bar{q}$



- **t-channel gluon ladder exchange**
- **$\sigma \propto$ (gluon density)^2**
- **predict suppression of heavy flavour production at leading order**
- **Higher order processes . . .**
- **$\gamma^* \to q\bar{q}g$ — enhances cross section at higher masses (low β)**
- **Bartels, Jung & Wüsthoff** $p_T(g) > 1.5$ GeV



Event Selection in ZEUS



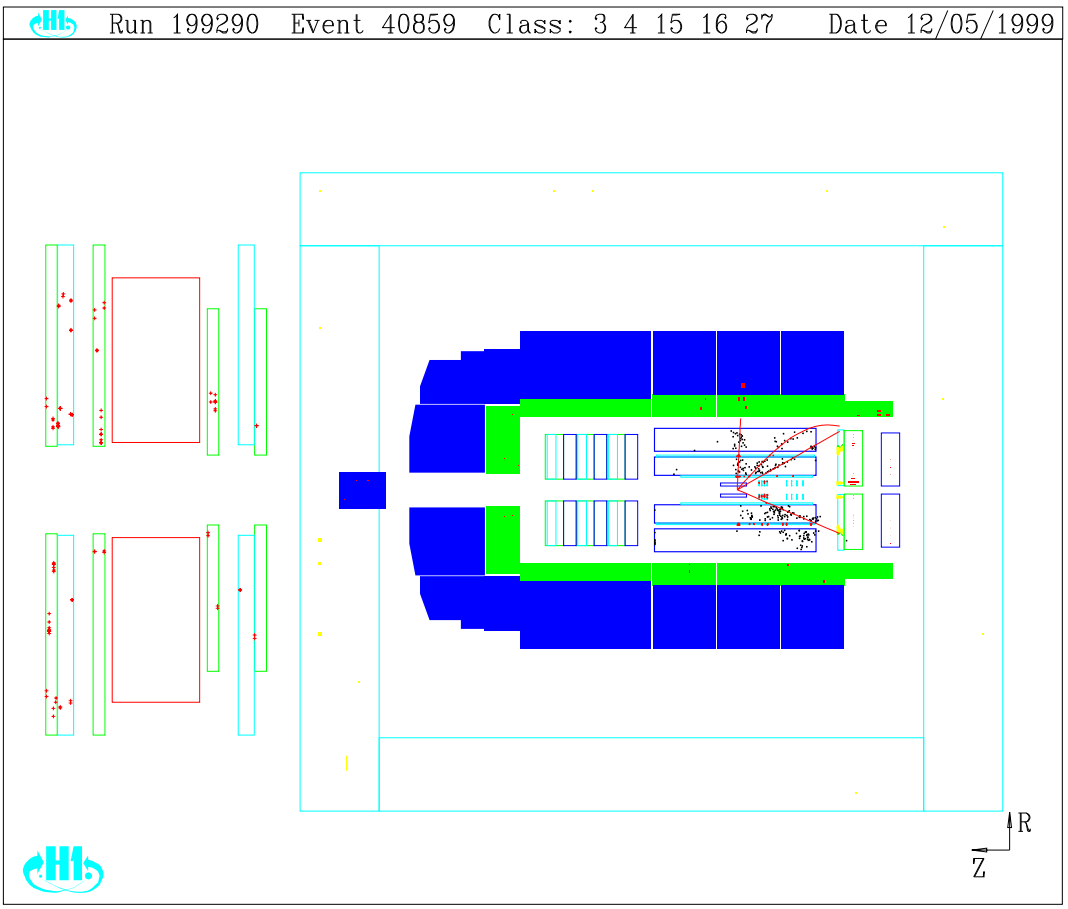
- $\eta_{MAX} < 2$ **requirement on system** X $(\eta = -\ln\tan\theta/2)$
  $\rightarrow$ **restricts** $x_{I\!P} < 0.016$

- **Upper limit on** $M_Y \approx 4$ **GeV**^{2}
  correct for proton dissociation — 31 ± 15 %

- **Use two different decay channels**

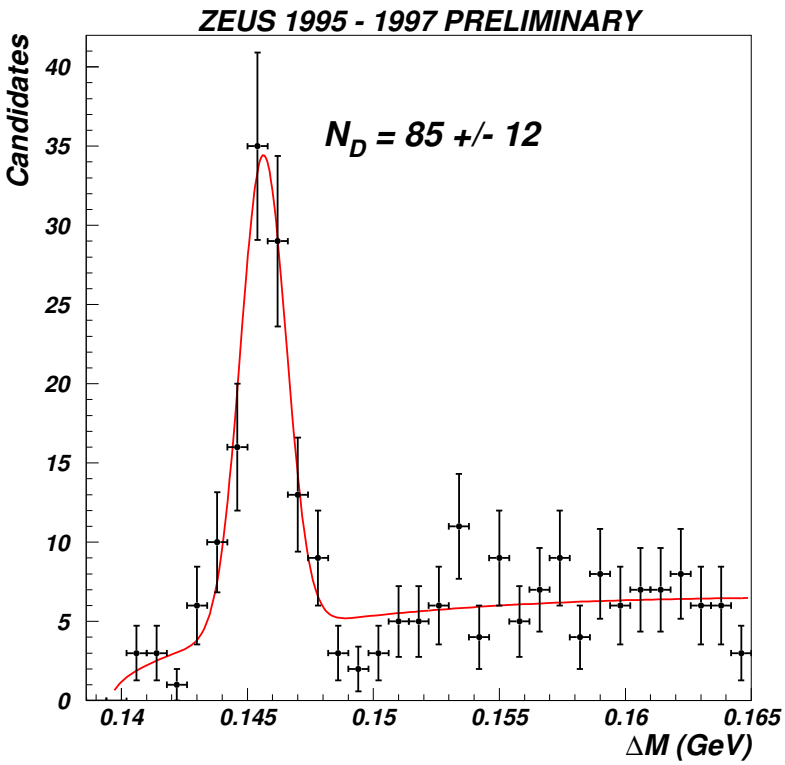
$$\mathbf{D}^{*+} \rightarrow \mathbf{D}^0\pi^+ \begin{cases} \nearrow \mathbf{D}^0 \rightarrow \mathbf{K}^-\pi^+ & + \textbf{(c.c.)} \quad 2.63\ \% \\ \searrow \mathbf{D}^0 \rightarrow \mathbf{K}^-\pi^+\pi^-\pi^+ & + \textbf{(c.c.)} \quad 5.19\ \% \end{cases}$$

Event Selection in H1



- $\eta_{MAX} < 3.3$ **requirement on system** X
  $\rightarrow$ **restricts** $x_{I\!P} < 0.04$
- **System** Y **not detected in forward detectors**
  $\rightarrow$ $M_Y < 1.6$ **GeV and** $|t| < 1$ **GeV**^{2}
- **Uses** $K2\pi$ **decay channel only.**

$D^* \to K2\pi$ Results ($\mathcal{L} = 44$ pb^{-1})



$4 < Q^2 < 400$ GeV^2

$0.02 < y < 0.7$

$1.5 < p_T(D^{*\pm}) < 8$ GeV

$|\eta(D^{*\pm})| < 1.5$

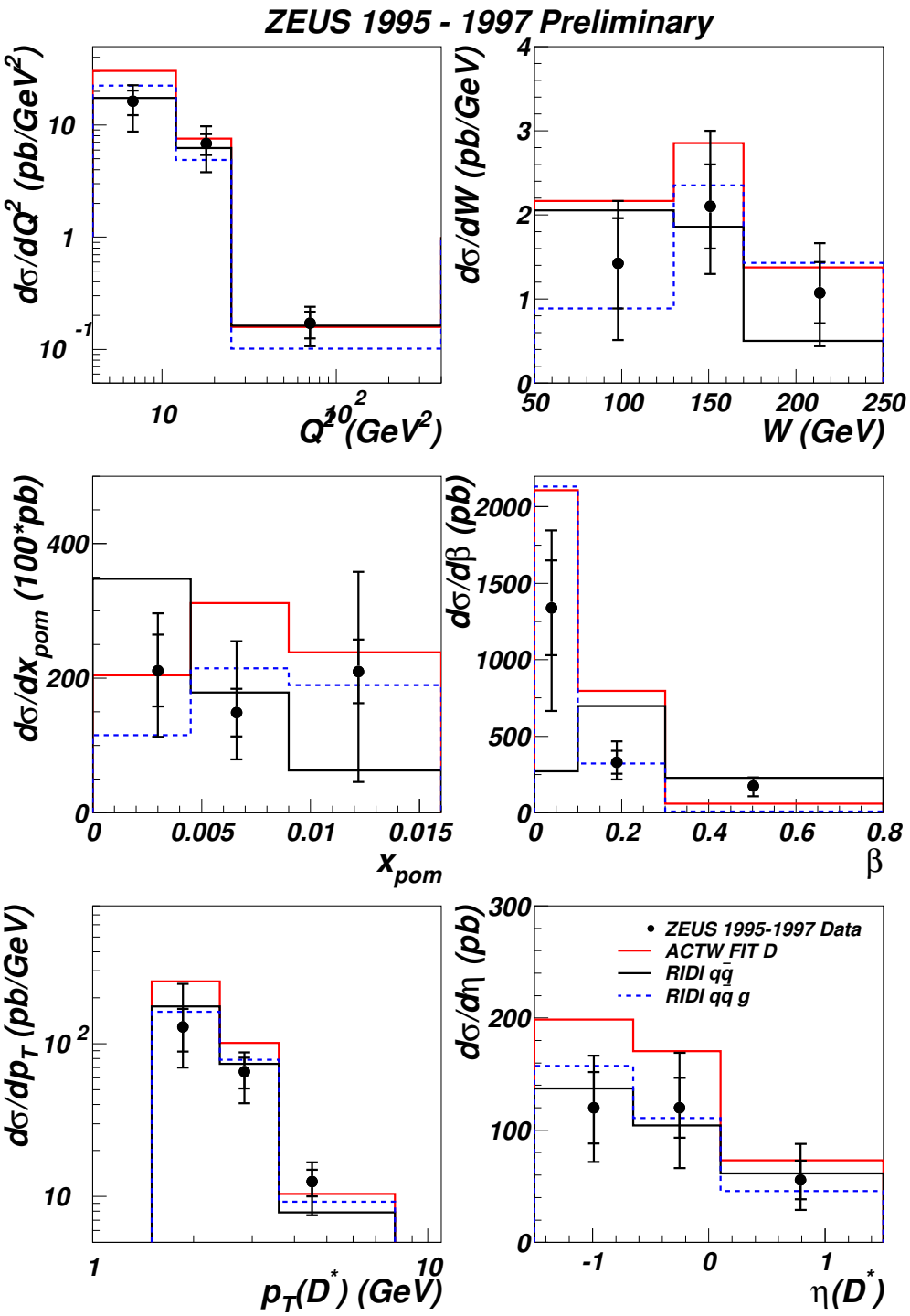
$x_P < 0.016$

$\beta < 0.8$

$$\sigma(ep \to eD^{*\pm}Xp) = 281 \pm 41(\text{stat})^{+79}_{-73}(\text{syst})\ \text{pb}$$

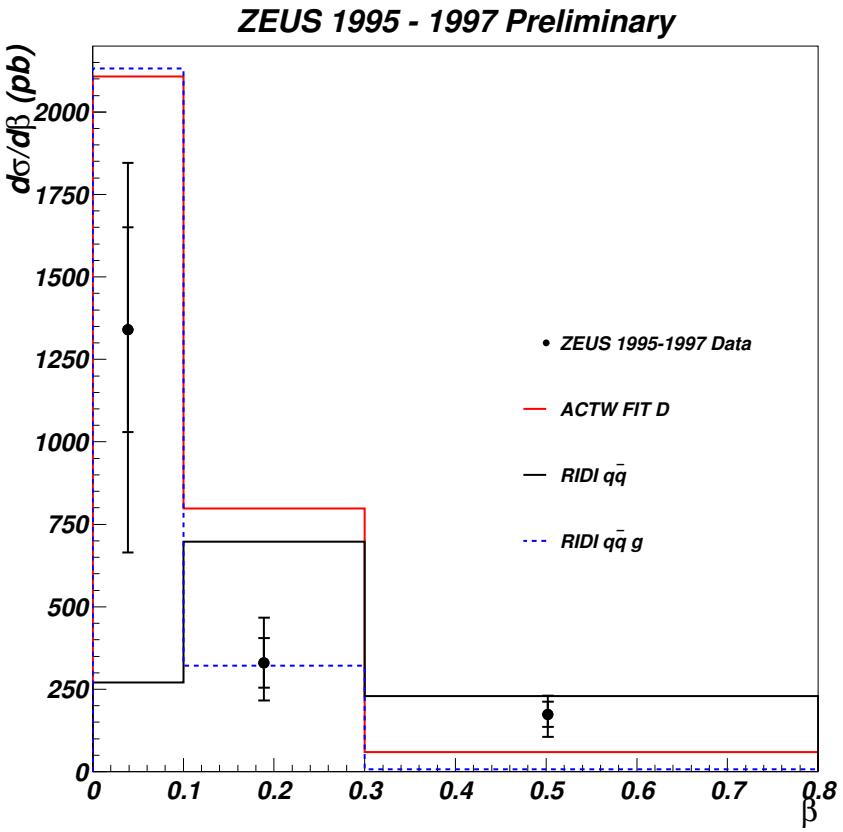
(ZEUS preliminary)

Differential Cross Sections
$(D^* \to K2\pi)$



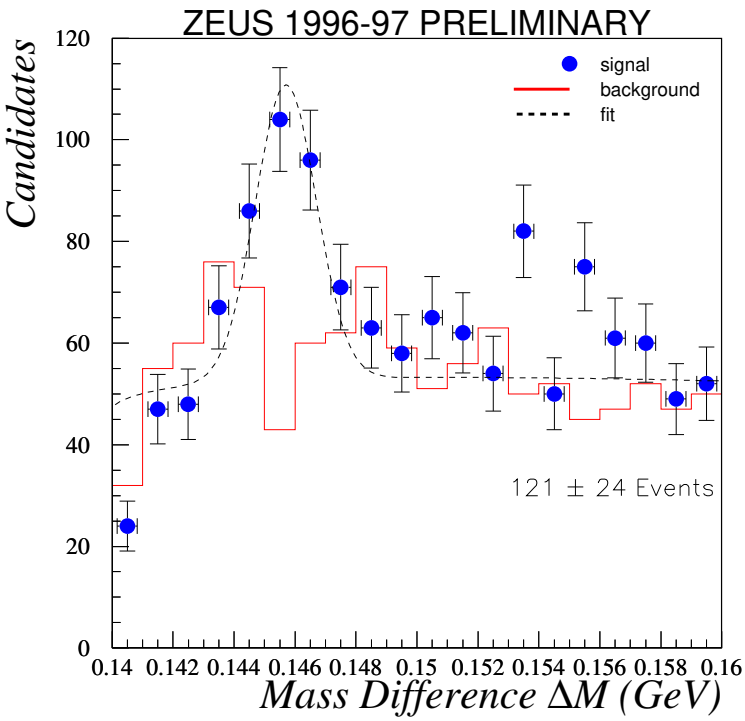
- RIDI $q\bar{q}$ and $q\bar{q}g$ final states — compare shapes
- ACTW — compare shape and normalisation

Differential Cross Sections $(D^* \to K2\pi)$



- Resolved Pomeron model (ACTW)
  - Does not adequately describe β distribution !
- 2-gluon exchange model (RIDI $q\bar{q}$ and $q\bar{q}g$)
  - Neither component can describe the data by itself
  - Require combination of components for description of β distribution

$D^* \to K4\pi$ Results ($\mathcal{L} = 37.7$ pb^{-1})



$1 < \mathbf{Q^2} < 480$ GeV^2

$0.04 < \mathbf{y} < 0.7$

$2 < \mathbf{p_T(D^{*\pm})} < 9$ GeV

$|\eta(\mathbf{D^{*\pm}})| < 1.5$

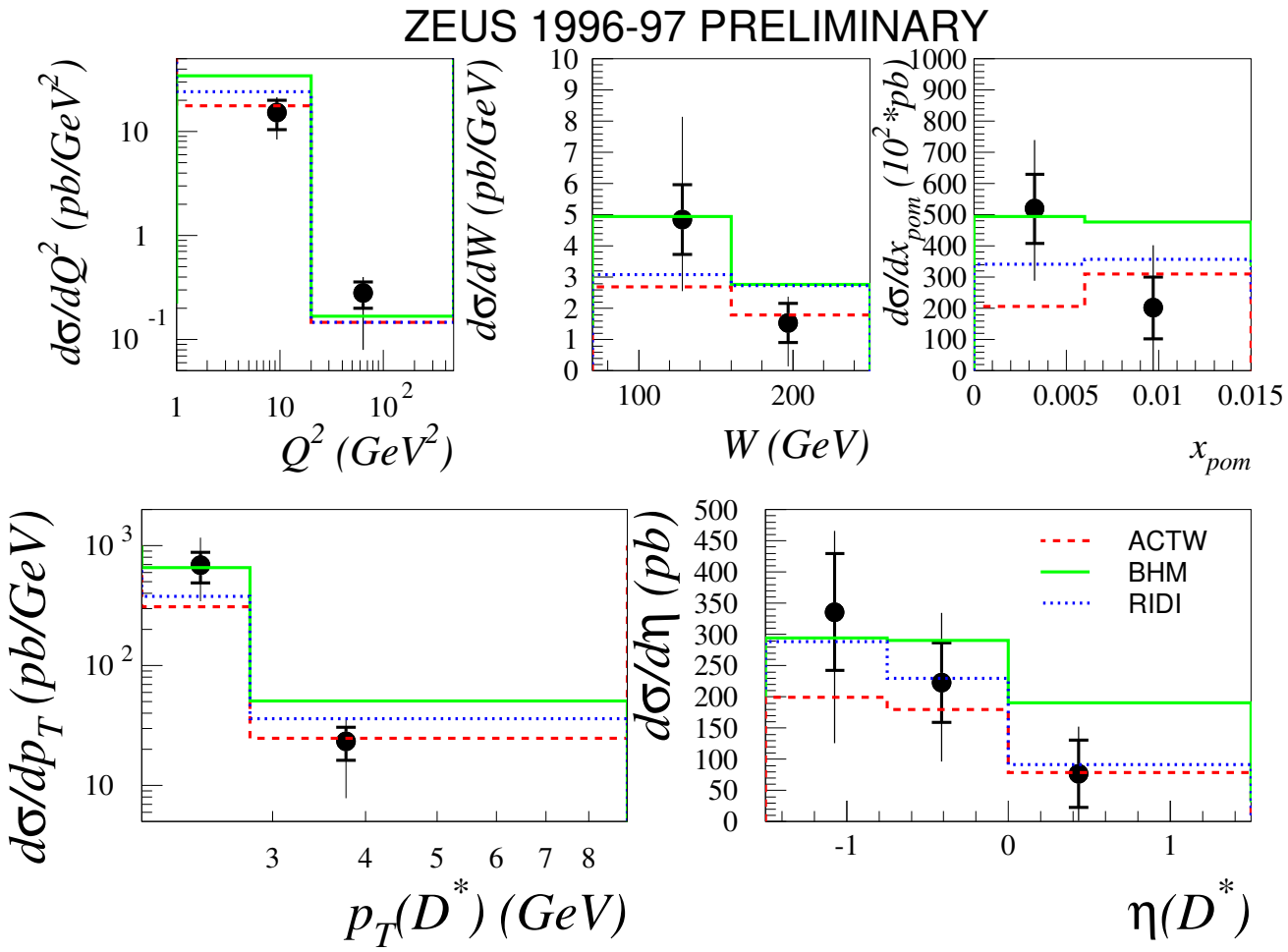
$\mathbf{x_P} < 0.015$

$\beta < 0.8$

$$\sigma(\mathbf{ep \to eD^{*\pm}Xp}) = \mathbf{526 \pm 110(stat)^{+200}_{-240}(syst)\ pb}$$

(ZEUS preliminary)

Differential Cross Sections $(D^* \to K4\pi)$



- RIDI sample = combination of $q\bar{q} + q\bar{q}g$ final states — compare shapes only
- ACTW prediction — compare shape and normalisation

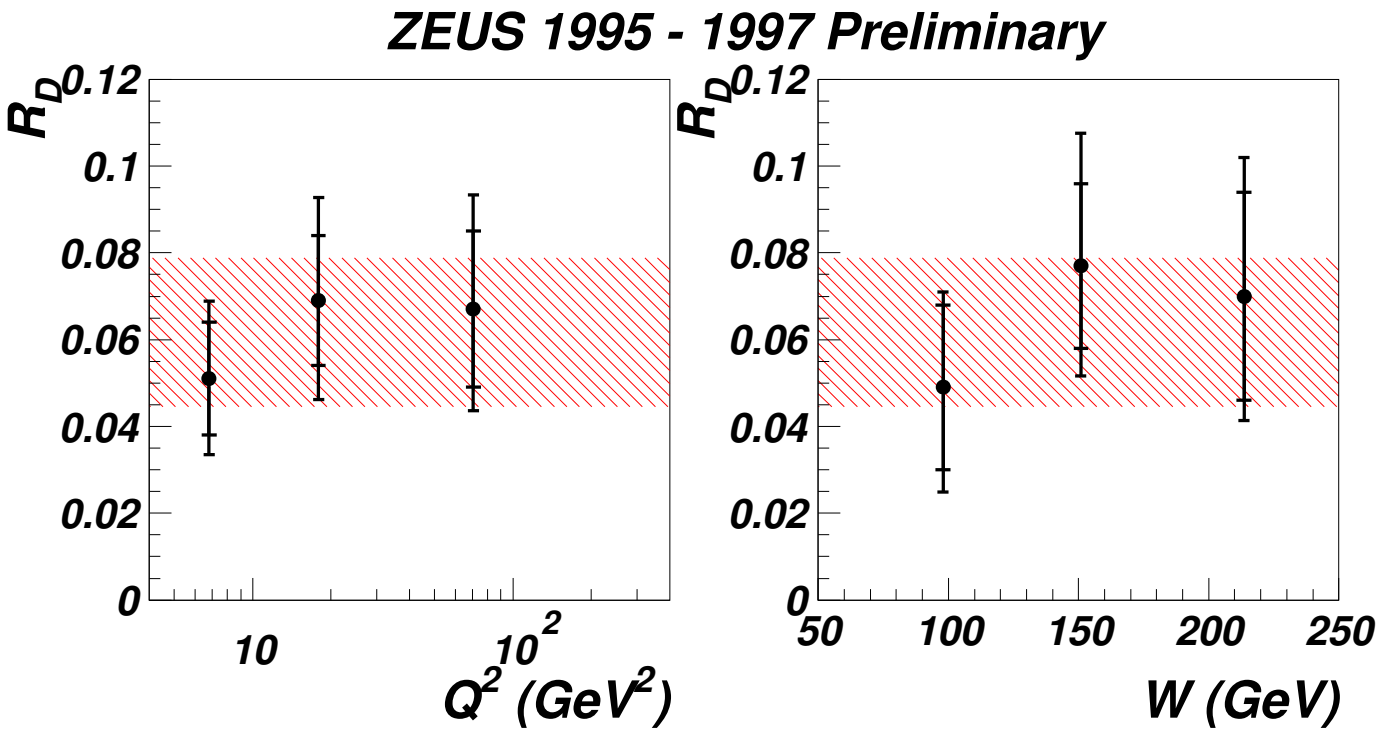
Findings consistent with $K2\pi$ channel

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

$$\textbf{Ratio}\ (K2\pi) = 6.1 \pm 0.9(stat)^{+1.5}_{-1.4}(syst)\ \%$$

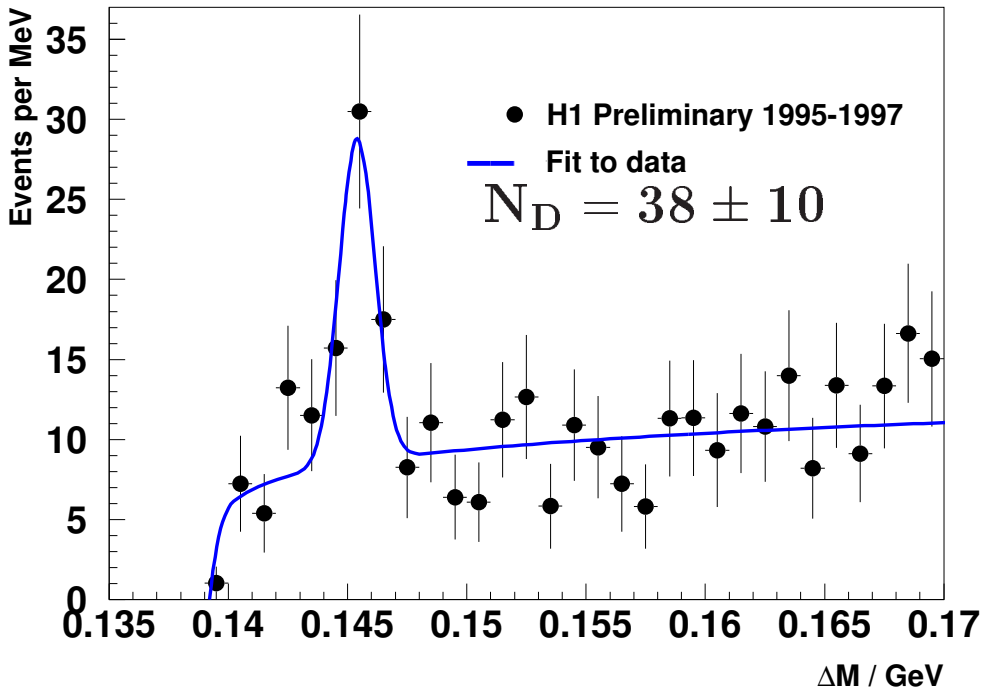
$$\textbf{Ratio}\ (K4\pi) = 8.9 \pm 2.4(stat)^{+1.7}_{-1.6}(syst)\ \%$$

Consistent with ratio in inclusive DIS 5 — 10 %



- No significant Q^2 or W dependence observed

$D^* \to K2\pi$ Results ($\mathcal{L} = 21$ pb^{-1})

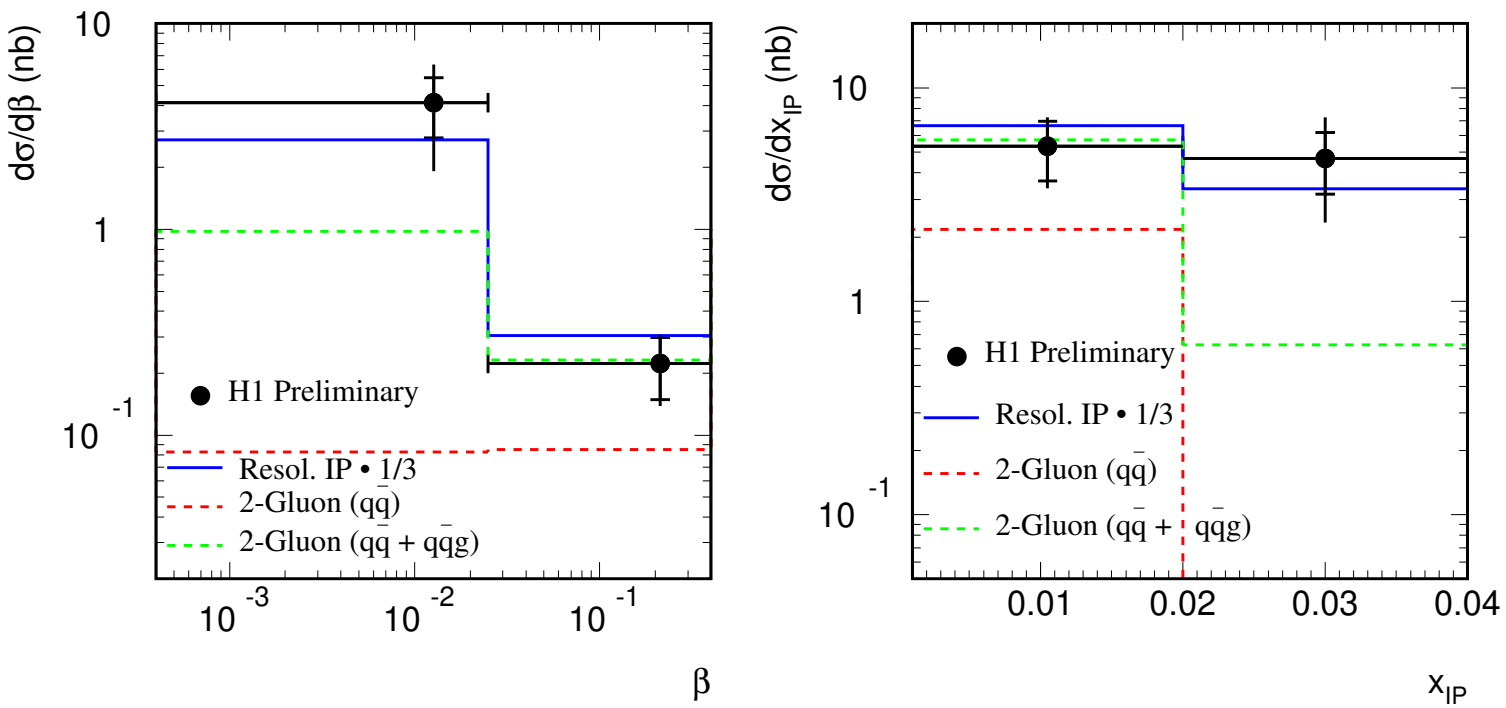


$$
\begin{aligned}
2 < \quad & Q^2 & < 100 \ \mathbf{GeV}^2 \\
0.05 < \quad & y & < 0.7 \\
& p_T(D^{*\pm}) & > 2 \ \mathbf{GeV} \\
& |\eta(D^{*\pm})| & < 1.5 \\
& x_{I\!P} & < 0.04 \\
& M_Y & < 1.6 \ \mathbf{GeV} \\
& |t| & < 1 \ \mathbf{GeV}^2
\end{aligned}
$$

$$\sigma(\mathbf{ep \to eD^{*\pm}XY}) = \mathbf{154 \pm 40(stat) \pm 35(syst)\ pb}$$

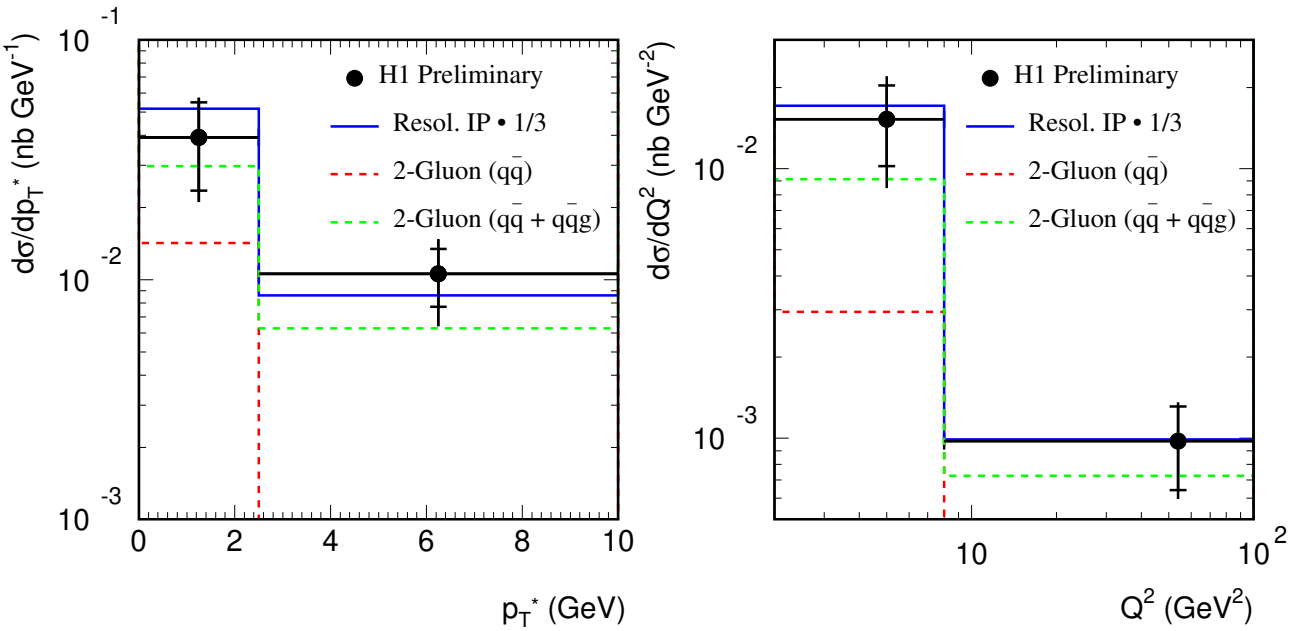
(H1 preliminary)

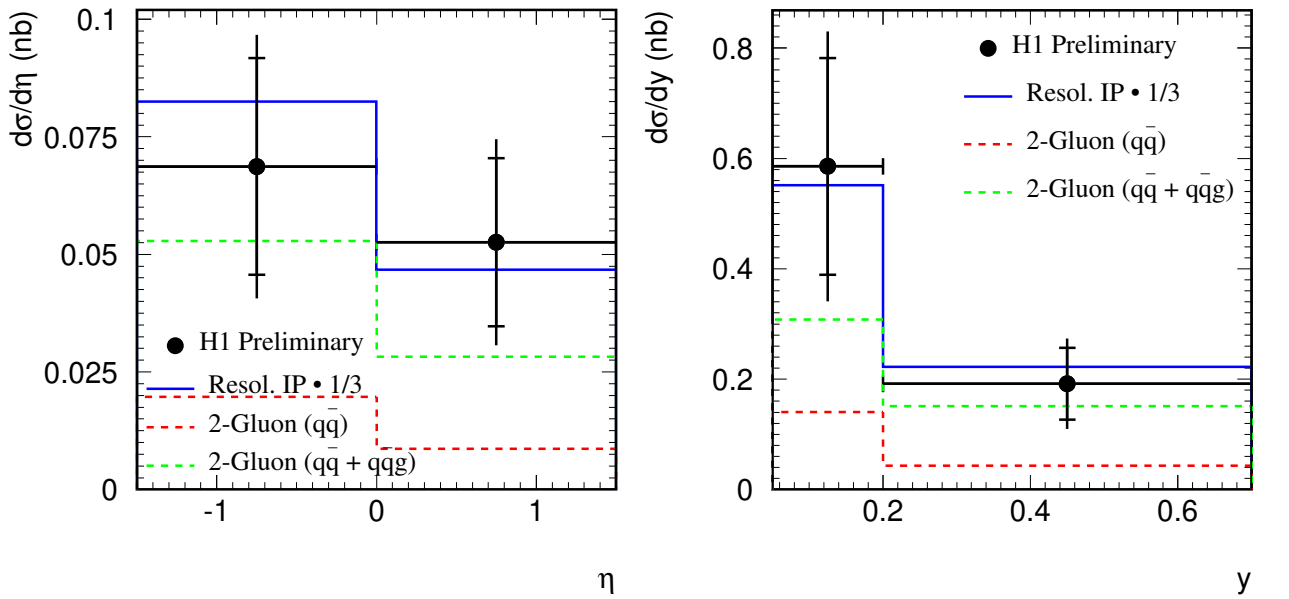
Differential Cross Sections



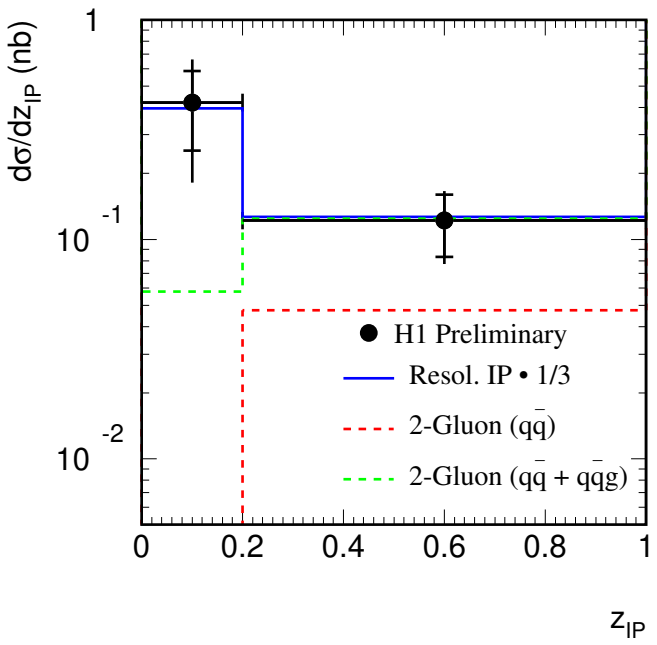
- shapes **not normalisation** well-reproduced by Pomeron exchange model
- 2-gluon exchange ($\gamma^* \to q\bar{q}$) only valid for low masses (high β)
- 2-gluon exchange ($\gamma^* \to q\bar{q}g$) contributes to higher masses (low β)
- large $x_{I\!P}$; no sub-leading (quark) exchange

Differential Cross Sections





Differential Cross Section - $z_{I\!P}^{obs}$



$z_{I\!P}$ — **fraction of the pomeron's momentum carried by the gluon**

- **Reconstruct $z_{I\!P}^{obs}$ from scattered e^+ and $D^{*\pm}$**

$$z_{I\!P} = \beta \cdot (1 + \frac{s}{Q^2}) = \frac{M_{c\bar{c}}+Q^2}{M_X^2+Q^2}$$

- **See significant amount of low $z_{I\!P}$ $D^{*\pm}$ production**
  - **expected from resolved $I\!P$ model**
  - **not expected from models in which hadronic final state $= c\bar{c}$ pair**
  - **In 2-gluon exchange — need real gluon corrections**

Comparison between ZEUS and H1 Results

- **CANNOT DIRECTLY COMPARE RESULTS !**
- **Compare to identical model for each result — use RAPGAP**
  - $m_c = 1.35$ **GeV**
  - $\Lambda_{QCD} = 0.25$ **(5 flavours)**
  - $\mu^2 = Q^2 + p_T^2 + 4m_c^2$
  - **H1 fit 2**
- **ZEUS:** $281 \pm 41(stat)^{+79}_{-73}(syst)$ **pb**
  - **RAPGAP** $I\!P$ **only:** 309 **pb**
  - **RAPGAP** $I\!P + I\!R$**:** 320 **pb**
- **H1:** $154 \pm 40(stat) \pm 35(syst)$ **pb**
  - **RAPGAP** $I\!P$ **only:** 466 **pb**
  - **RAPGAP** $I\!P + I\!R$**:** 504 **pb**

Discrepancy between results remains — we don't know why !

Conclusions

- **Total and differential diffractive DIS $D^{*\pm}$ cross sections measured by both ZEUS and H1.**
- **Shape of most distributions described well by $I\!P$ exchange model, but ...**

  — ZEUS β distribution is not adequately described

  — Pomeron exchange in RAPGAP reproduces ZEUS normalisation, but fails for H1 results — factor of ~ 3 too high
- **Neither Bartels et al. $q\bar{q}$ nor RIDI $q\bar{q}$ contribution can describe ZEUS and H1 cross sections**

  — need contribution from $q\bar{q}g$ processes ...

  — Bartels et al. $q\bar{q} + q\bar{q}g$ contribution can describe H1 $x_{I\!P}$ cross section at low $x_{I\!P}$ when $p_T(g) > 1.5$ GeV
- **Need to expand dataset to get final answer !**