DIS2000
Working Group 4
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Diffractive $D^{*\pm}(2010)$ Production in Deep Inelastic Scattering at HERA

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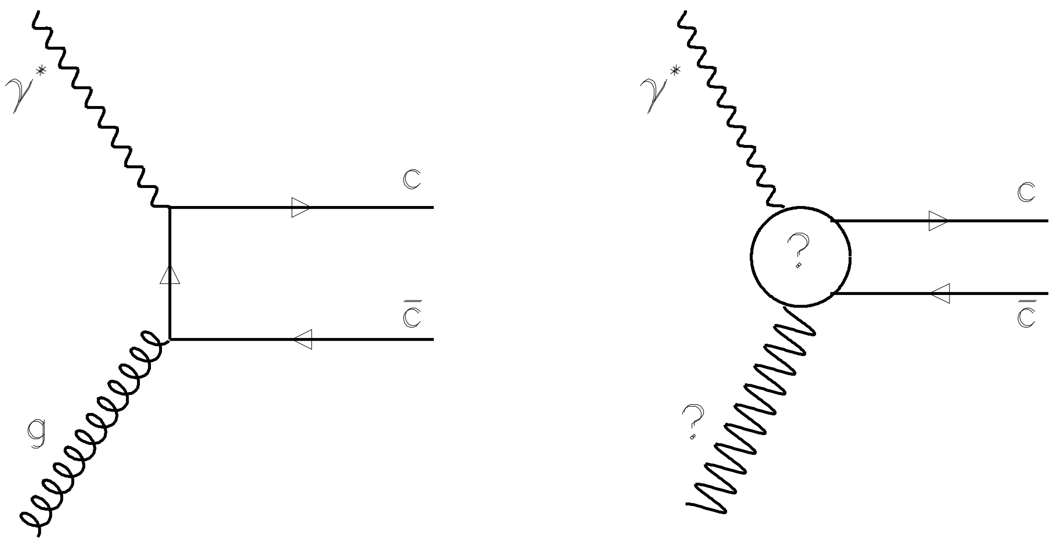
(On behalf of the H1 and ZEUS Collaborations)

- 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 → pQCD
- Charm is sensitive to role of gluons in diffractive exchange
- Open charm free from uncertainties relating to bound states, eg. J/ψ

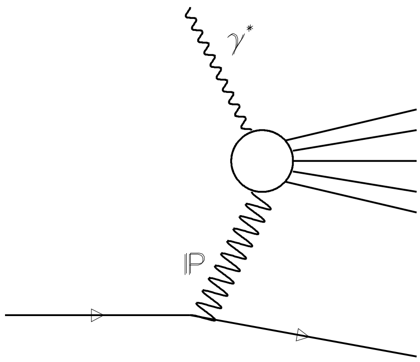


- Study of charm provides test of underlying dynamics of diffraction

Resolved Pomeron Models

(eg. Ingelman & Schlein,Donnachie & Landshoff)

- Based on Regge theory
  - $I\!\!P$omeron exchange



- Treat $I\!\!P$ as object with substructure

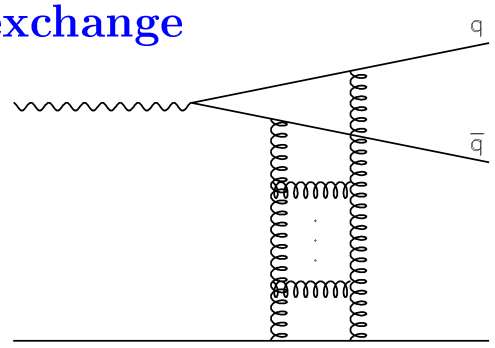
- Charm Production in diffractive DIS $\rightarrow$ probe gluon content of $I\!\!P$

- gluon-dominated $I\!\!P$
  - predicts large charm cross section
  - 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.

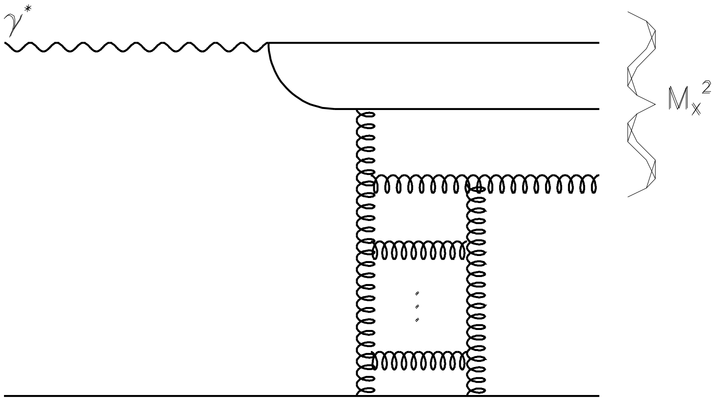
Perturbative QCD Models

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

- t-channel gluon ladder exchange



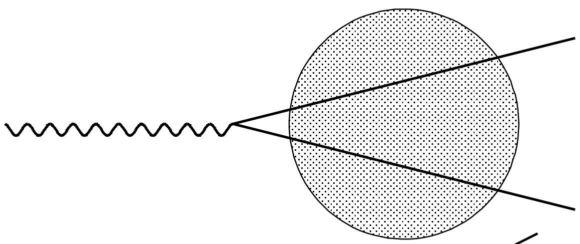
- $\sigma \propto$ (gluon density)^2
- predict suppression of heavy flavour production at leading order
- Implemented in RAPGAP v2.08/01 Generator
- Higher order processes ...
- $\gamma^* \to q\bar{q}g$ — enhances cross section at higher masses (low β)
- Implemented in RIDI v2.0 Generator



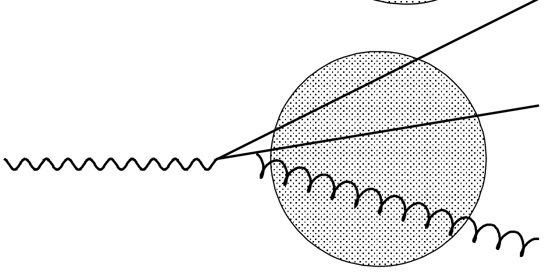
Soft Colour Interactions

(Edin, Ingelman & Rathsman; Buchmüller, Hebecker & McDermott)

- soft gluon interactions change colour structure $\rightarrow \sim 10$ % events have rapidity gap
- implemented in the AROMA 2.2 Generator
- Semi-Classical Model
  - γ^* fluctuates $\rightarrow$ partonic final state — interacts with "soft" colour field of proton . . .
- Implemented in the RAPGAP generator

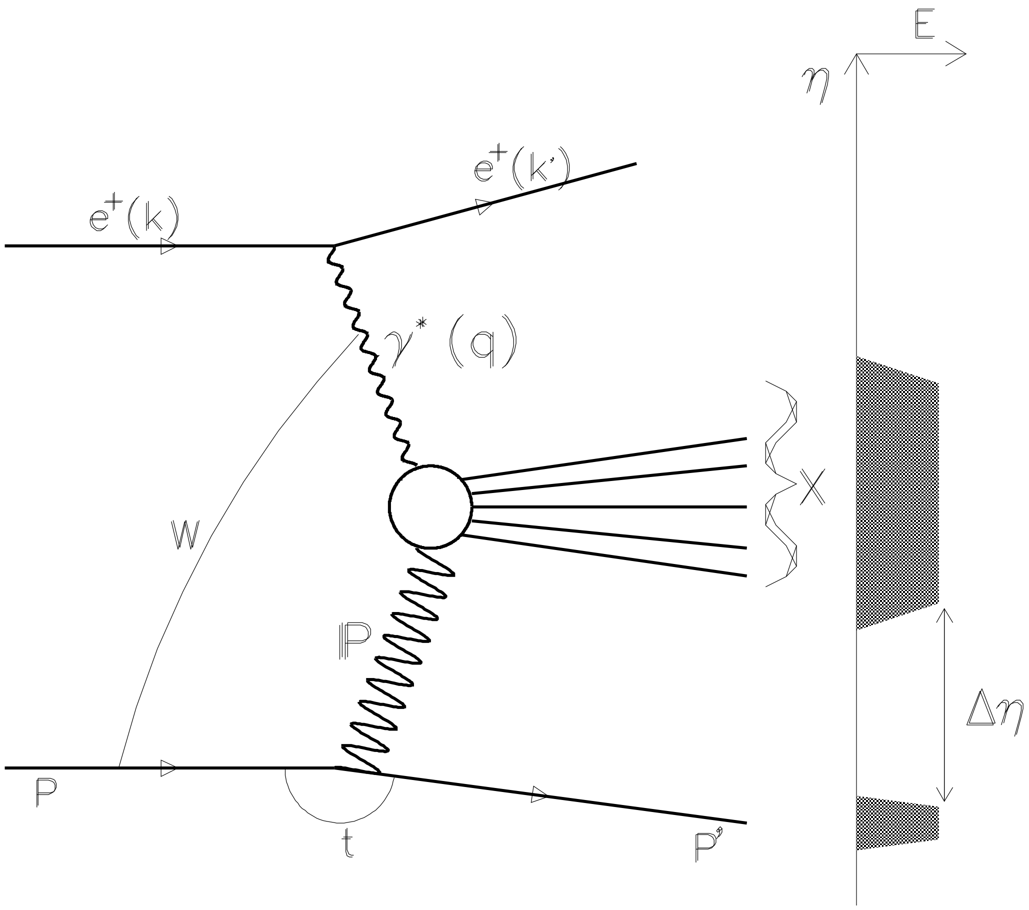


leading order



predicted dominant process for charm

Event Kinematics



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

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

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

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

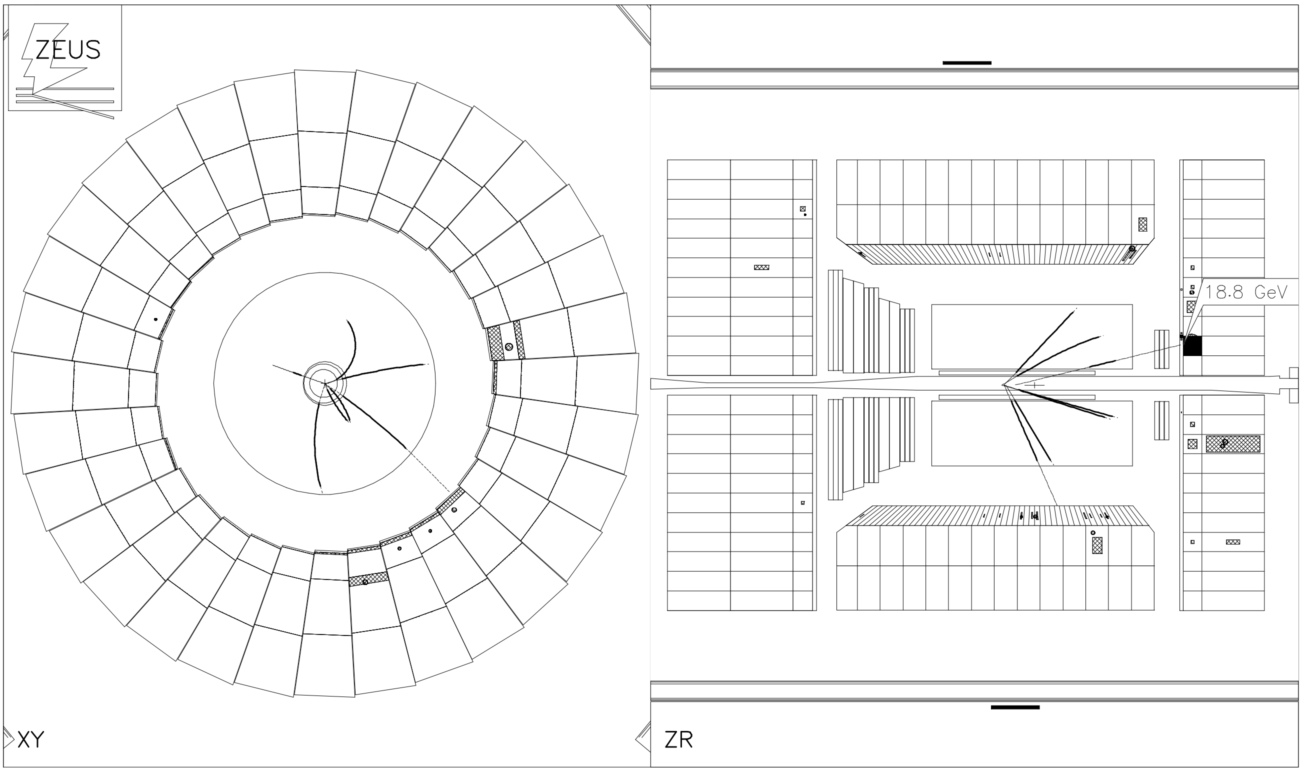
$$\mathbf{x} = \frac{\mathbf{Q^2}}{\mathbf{2P\cdot q}}$$

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

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

$$\mathbf{x_P}\beta = \mathbf{x} \qquad \mathbf{Q^2} = \mathbf{xys}$$

Event Selection in ZEUS



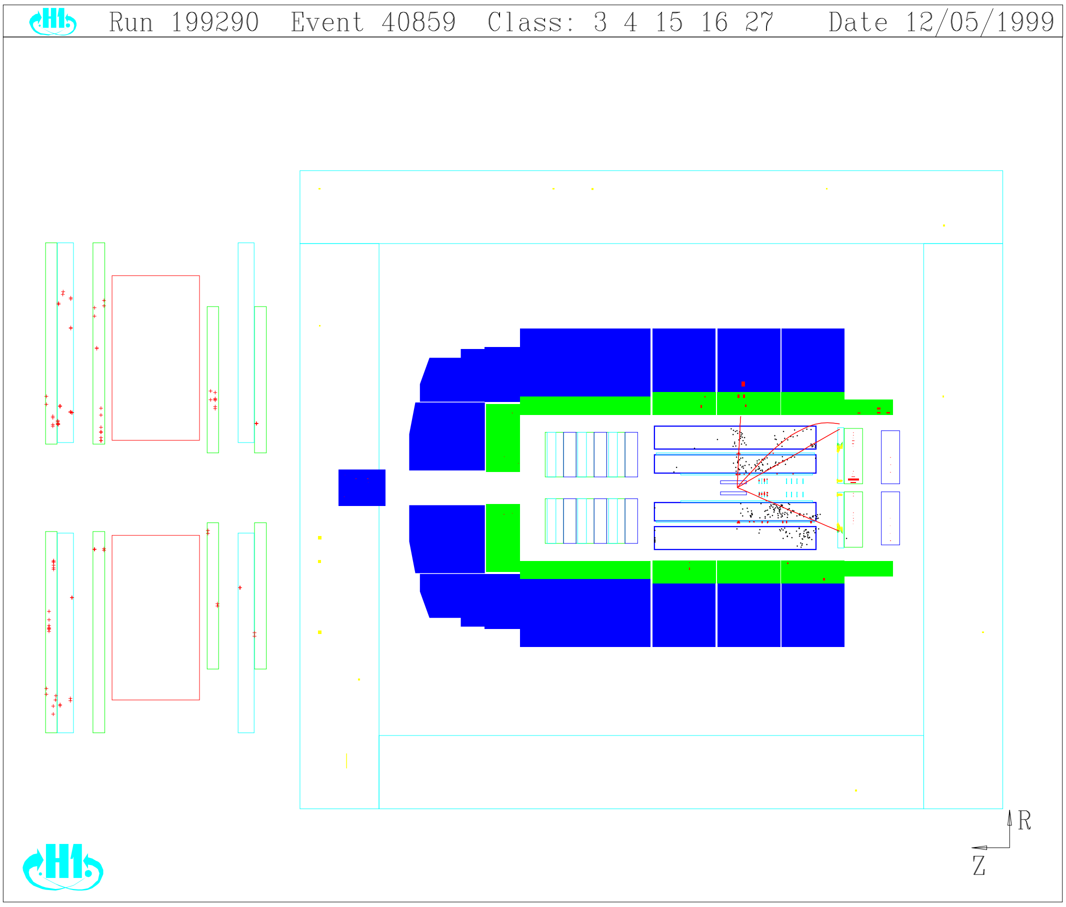
- $\eta_{MAX} < 2$ **requirement on system** X $(\eta = -\ln\tan\theta/2)$
  $\rightarrow$ **restricts** $x_{I\!P} < 0.016$

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

- **Use two different decay channels**

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

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.**

Cross Section Unfolding

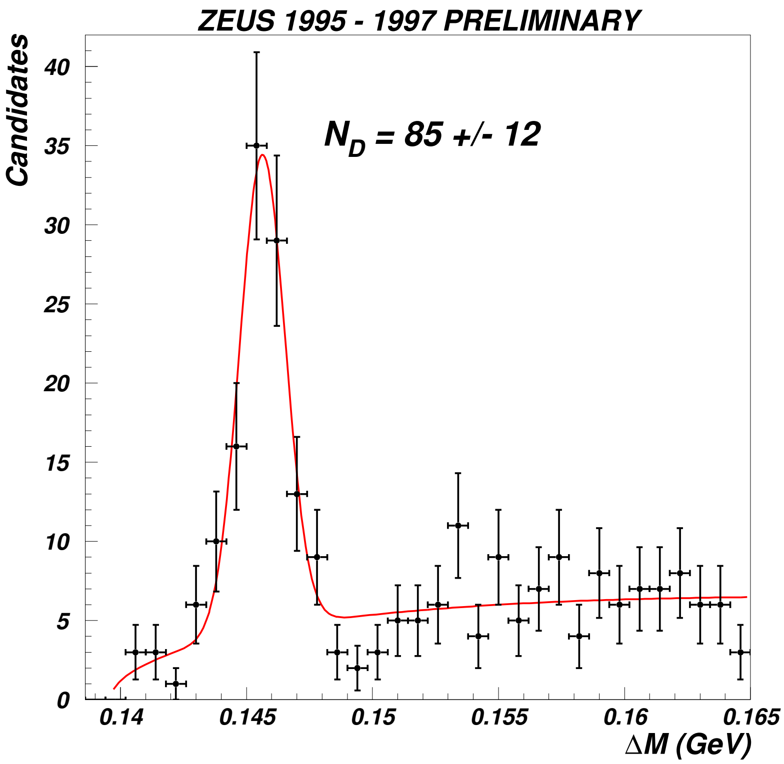
- **Correct for detector effects, trigger efficiencies etc. using samples of Monte Carlo events $\rightarrow$ "acceptance" $= A$**
- **Correct also for branching ratio $= BR$**

Cross section then defined as

$$\sigma = \frac{\mathbf{N_D}}{\mathbf{A \cdot BR \cdot} \mathcal{L}}$$

where $N_D =$ number of measured $D^{*\pm}$ candidates.

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



$4 < \mathbf{Q^2} < 400\ \mathbf{GeV^2}$

$0.02 < \mathbf{y} < 0.7$

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

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

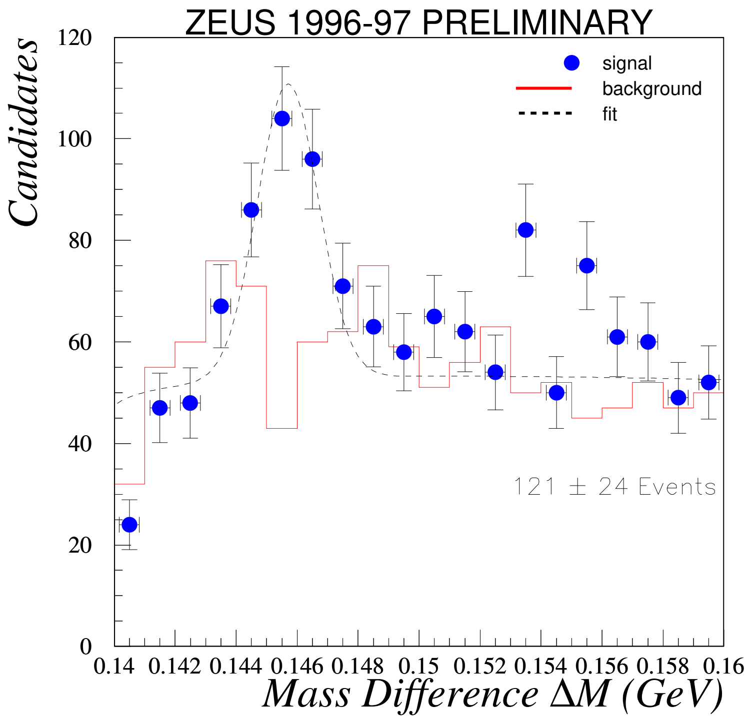
$\mathbf{x_P} < 0.016$

$\beta < 0.8$

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

(ZEUS preliminary)

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



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

$\mathbf{0.04 < y < 0.7}$

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

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

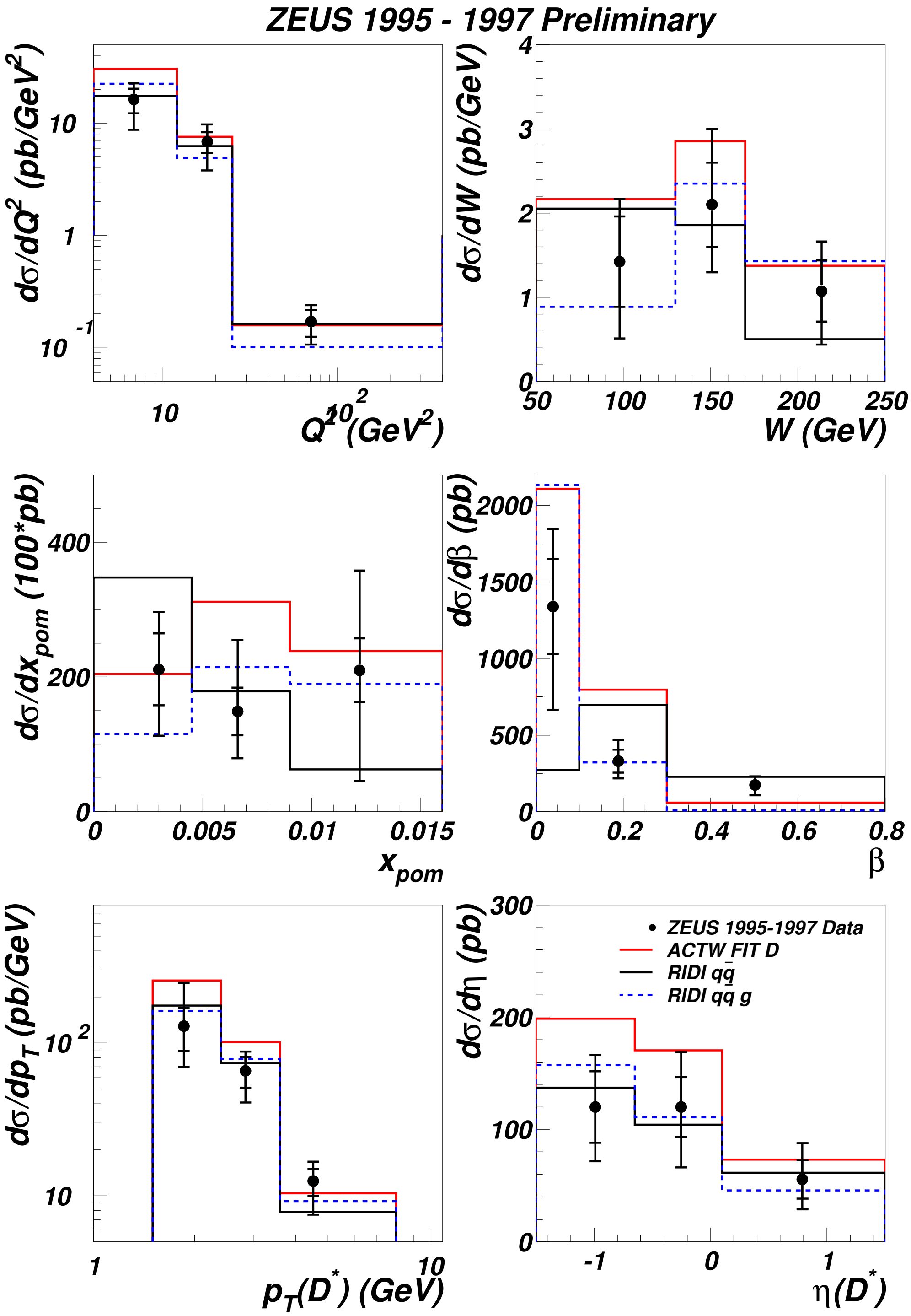
$\mathbf{x_P < 0.015}$

$\beta < \mathbf{0.8}$

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

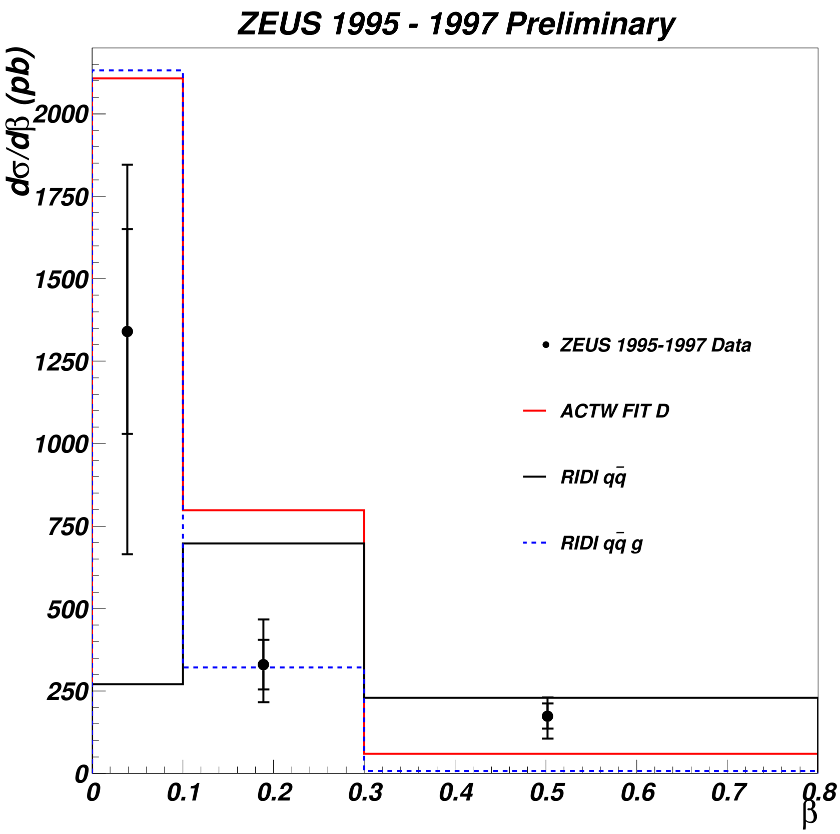
(ZEUS preliminary)

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



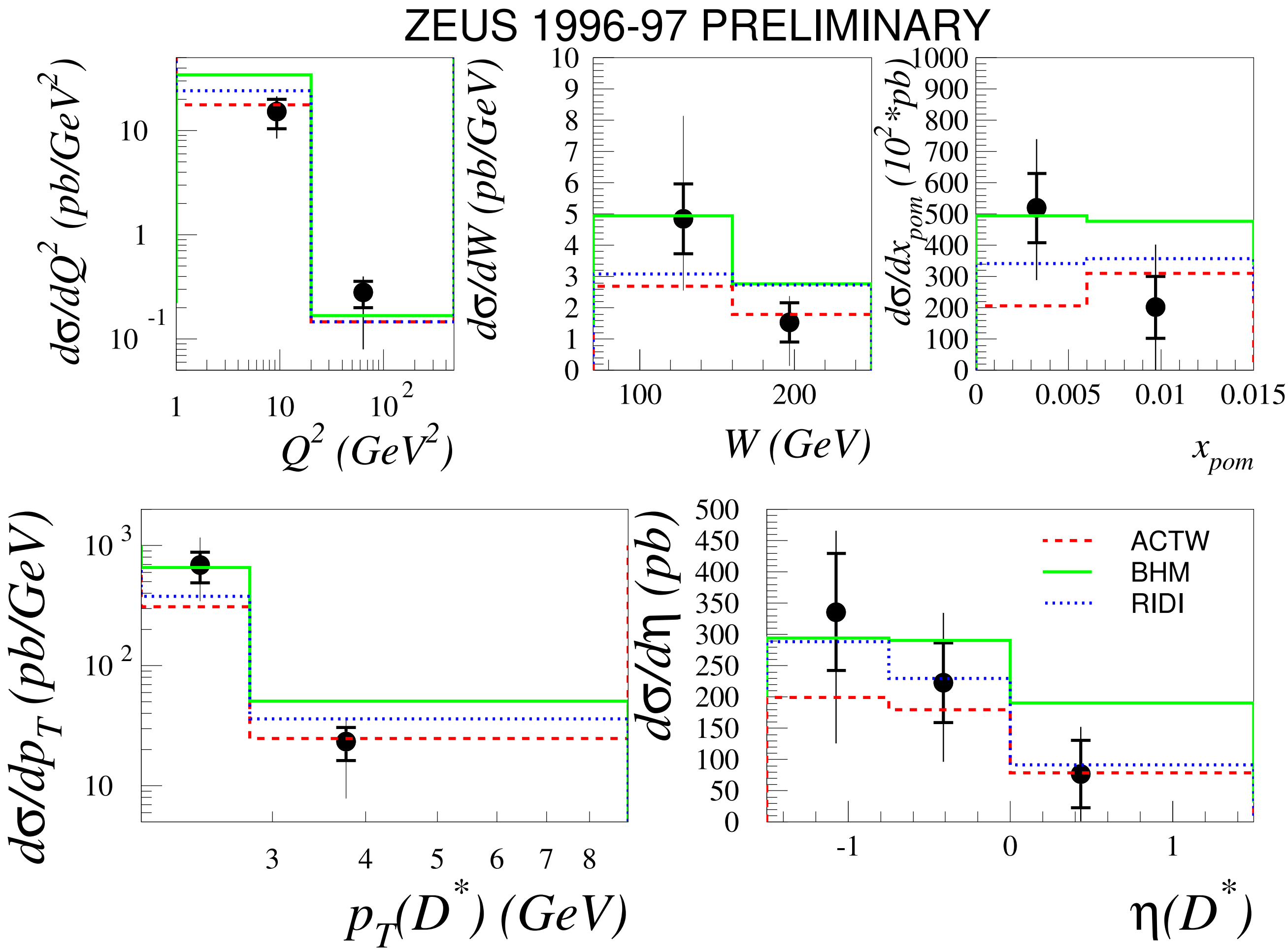
- Reasonable description of the data, but ...

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 ?

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



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

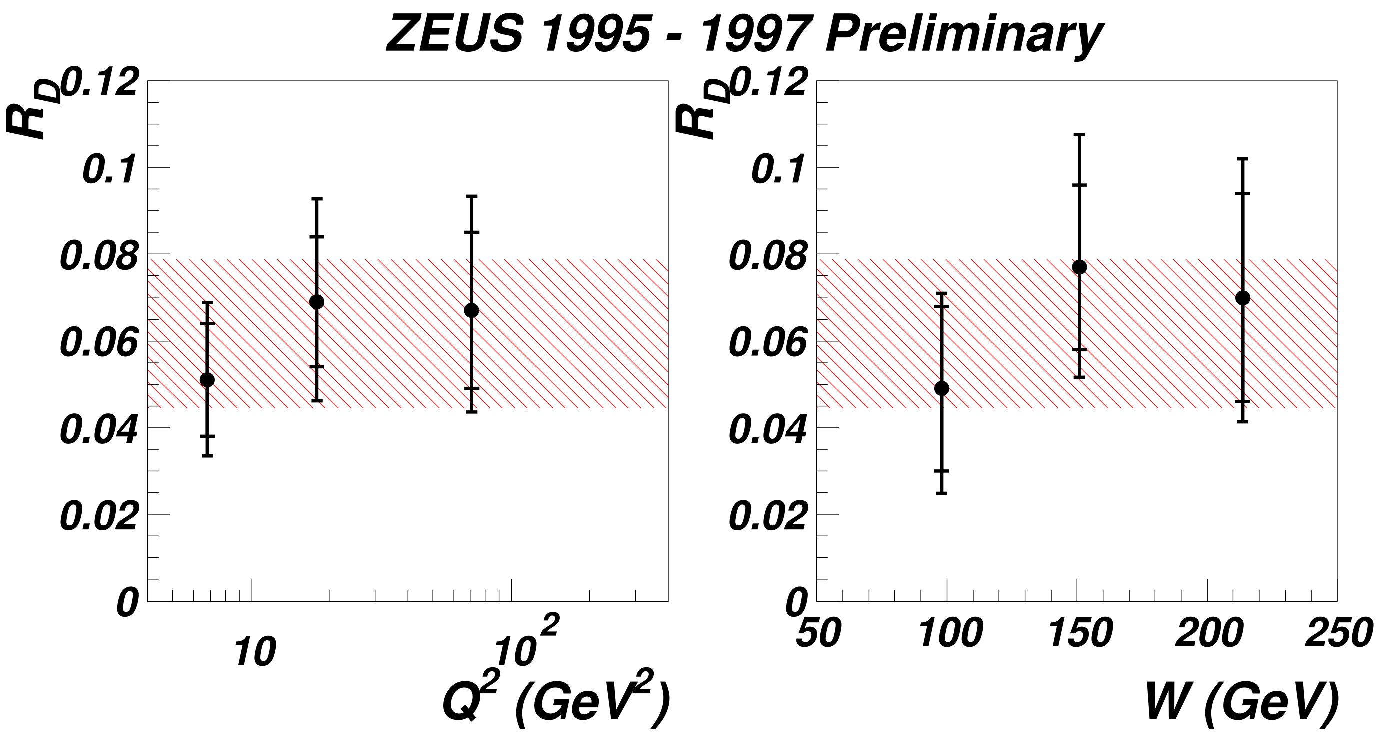
Findings consistent with $K2\pi$ channel

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

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

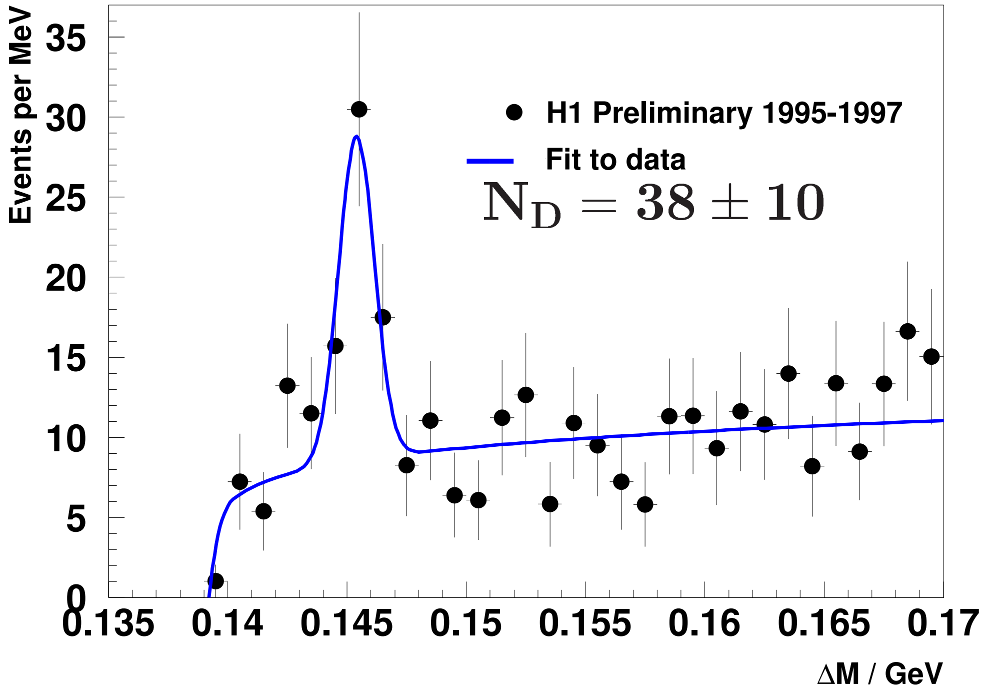
$$\textbf{Ratio } (K4\pi) = 8.9 \pm 2.4(stat)^{+1.7}_{-1.6}(syst)\ \%$$

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})

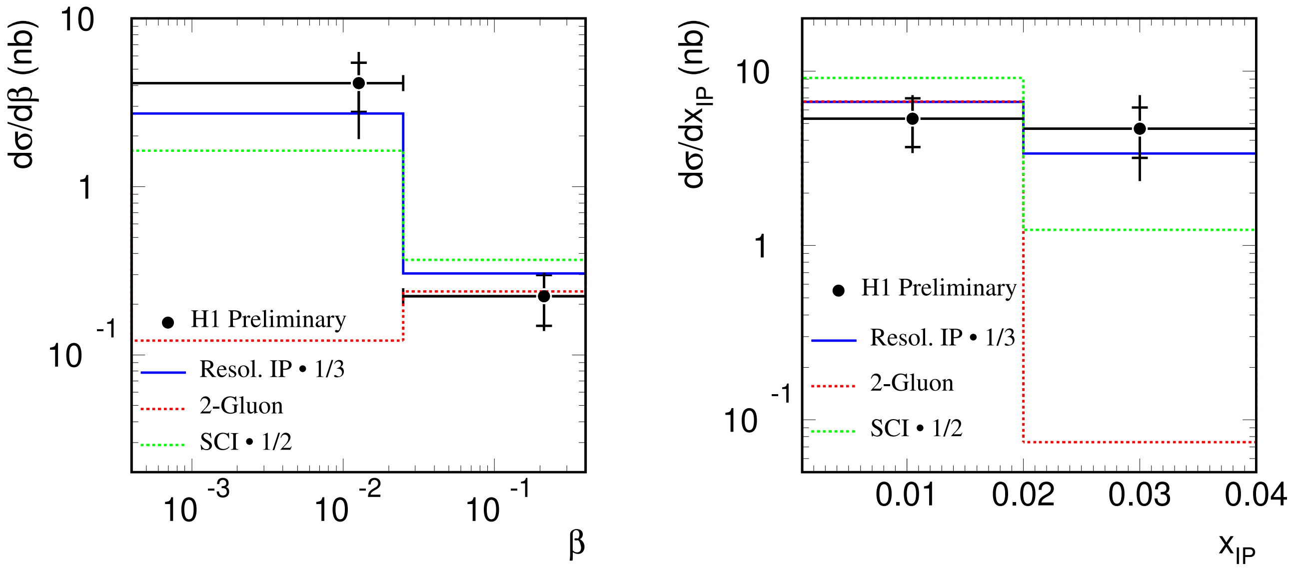


$$
\begin{array}{rcl}
2 < & Q^2 & < 100 \ \mathbf{GeV}^2 \\
0.05 < & y & < 0.7 \\
 & p_T(D^{*\pm}) & > 2 \ \mathbf{GeV} \\
 & |\eta(D^{*\pm})| & < 1.5 \\
 & x_{I\!P} & < 0.04 \\
 & M_Y & < 1.6 \ \mathbf{GeV} \\
 & |t| & < 1 \ \mathbf{GeV}^2
\end{array}
$$

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

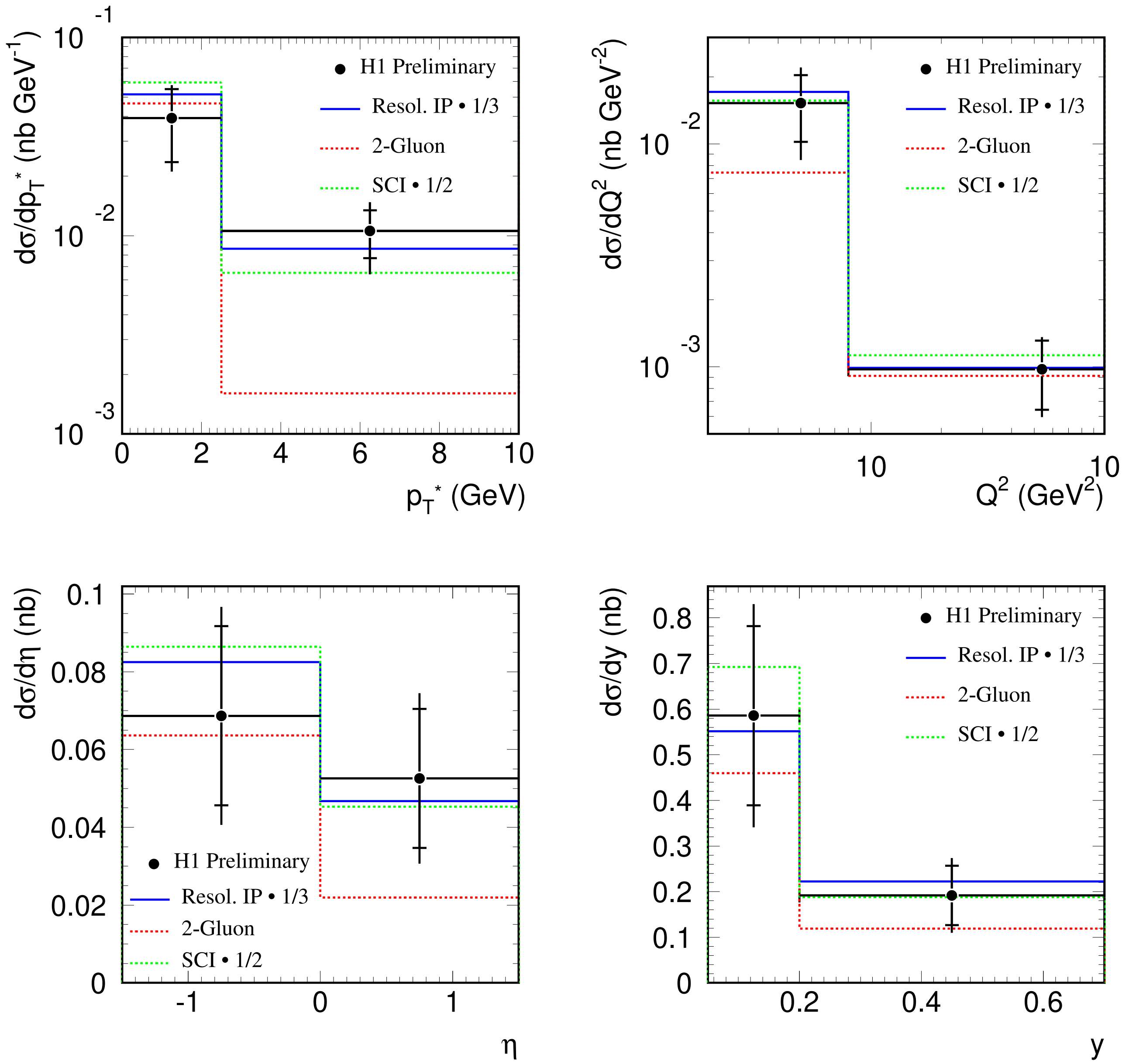
(H1 preliminary)

Differential Cross Sections

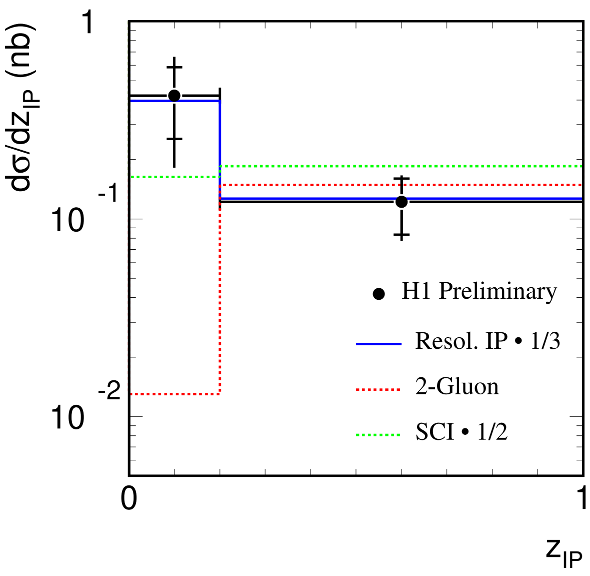


- **shapes are well-reproduced by Pomeron exchange model**
- **Pomeron exchange and SCI model (a la AROMA) fail in normalisation**
- **2-gluon exchange ($\gamma^* \to q\bar{q}$ only) only valid for low masses (high β)**

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 ± 9 **pb**
  - **RAPGAP** $I\!\!P$ + $I\!\!R$**:** 320 ± 12 **pb**
- **H1:** $154 \pm 40(stat) \pm 35(syst)$ **pb**
  - **RAPGAP** $I\!\!P$ **only:** 466 ± 12 **pb**
  - **RAPGAP** $I\!\!P$ + $I\!\!R$**:** 504 ± 15 **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 ...**

- **New 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. ($q\bar{q}$ only) nor RIDI $q\bar{q}$ contribution can describe ZEUS and H1 cross sections**

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

- **Soft Color Interactions give fair description of shape of H1 results**

- **Semi-Classical model gives fair description of ZEUS results**

- **Need to expand dataset to get final answer !**