Diffractive Charm Production in Deep Inelastic Scattering

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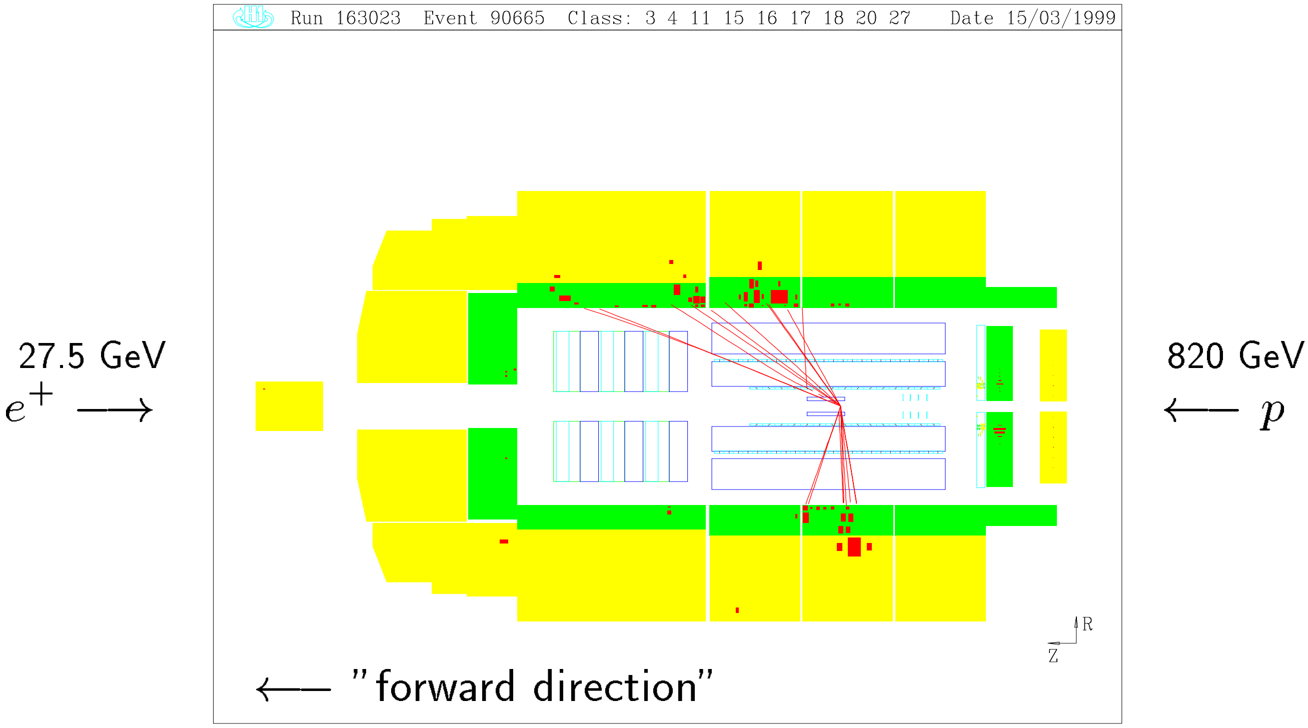
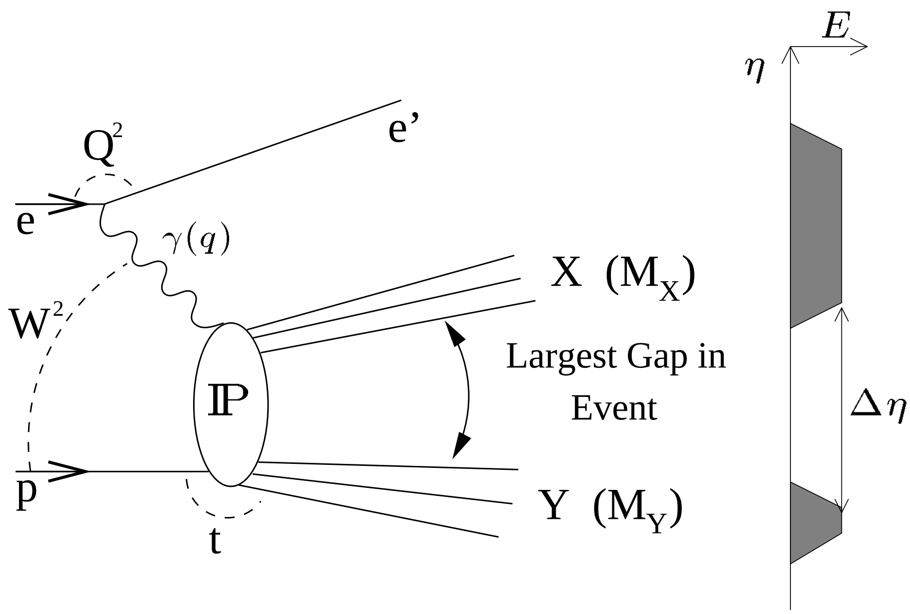
- Diffraction at HERA
- Models of diffractive charm production
- Data selection and measurement
- Discussion of results

Diffractive DIS events in the H1 detector



- Experimental Signature
  - ▷ 'Gap' in pseudorapidity $\eta = -\ln\tan(\theta/2)$ **and** no signals in very forward detectors. $\rightarrow$ Diffractive Event
- Deep Inelastic Scattering: Positron is measured in main detector

Kinematics of diffractive scattering



- Diffractive interactions $ep \to eXY$ due to Pomeron ($I\!P$) exchange ($I\!P$ carries vacuum quantum numbers)

DIS variables

$$Q^2 = -(l - l')^2$$

$$y = \frac{q \cdot p}{l \cdot p}$$

$$x = \frac{Q^2}{2(q \cdot p)}$$

Diffrative variables

$$t = (p - Y)^2$$

$$x_{I\!P} = \frac{q \cdot (p - Y)}{q \cdot p} \simeq \frac{(Q^2 + M_X^2)}{(Q^2 + W^2)}$$

$$\beta = \frac{Q^2}{2q \cdot (p - Y)} \simeq \frac{Q^2}{(Q^2 + M_X^2)}$$

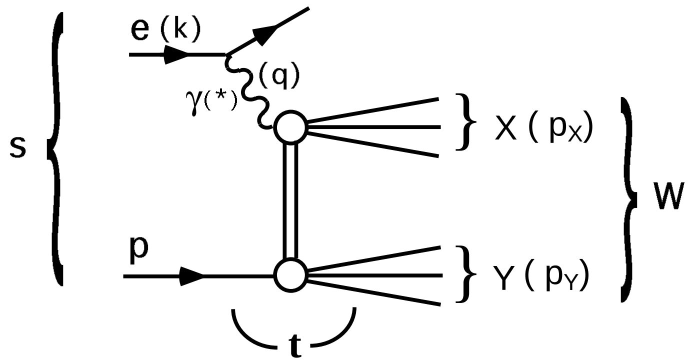
$$x = x_{I\!P} \cdot \beta$$

$$Q^2 = 4 \cdot E \cdot E' \cos^2 \frac{\theta}{2}$$

$$y = 1 - \frac{E'}{E} \sin^2 \frac{\theta}{2}$$

$$x = \frac{Q^2}{y \cdot s}$$

Diffractive structure function $F_2^{D(3)}$



- Interpret $I\!P$ as object with partonic structure

▷ Probe $I\!P$ structure in terms of diffractive structure function

$$\frac{d^3\sigma(ep \to eXY)}{d\beta dQ^2 dx_{I\!P}} = \frac{4\pi\alpha_{em}^2}{\beta Q^4}\left(1 - y + \frac{y^2}{2}\right) F_2^{D(3)}(x_{I\!P}, \beta, Q^2)$$

β is analogue of scaling variable x in inclusive DIS

▷ Assume factorization into two independent terms

$$F_2^{D(3)}(x_{I\!P}, \beta, Q^2) = f_{I\!P}(x_{I\!P}) \cdot F_2^{I\!P}(\beta, Q^2)$$

→ $I\!P$ flux $f_{I\!P}$ (Regge) proportional to $(1/x_{I\!P})^{1+2\varepsilon}$ (ε small)

▷ Express $I\!P$ structure function in terms of parton distributions

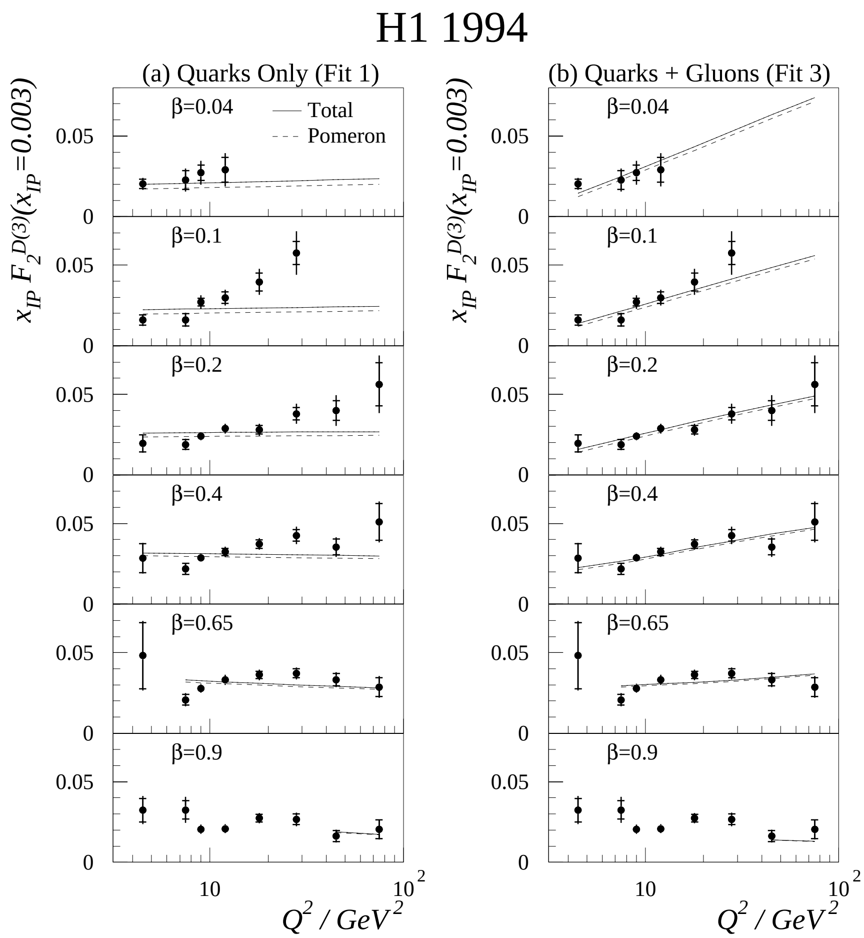
$$F_2^{I\!P}(\beta, Q^2) = \beta \sum_i e_i^2 \; f_i(\beta, Q^2)$$

▷ Determine PDF of $I\!P$ by QCD analysis ↔ DGLAP evolution

Scaling violation of $F_2^{D(3)}$

▷ Three different starting parameterizations for the PDF

- Fit 1: quarks dominated
- Fit 2 and 3: gluon dominated



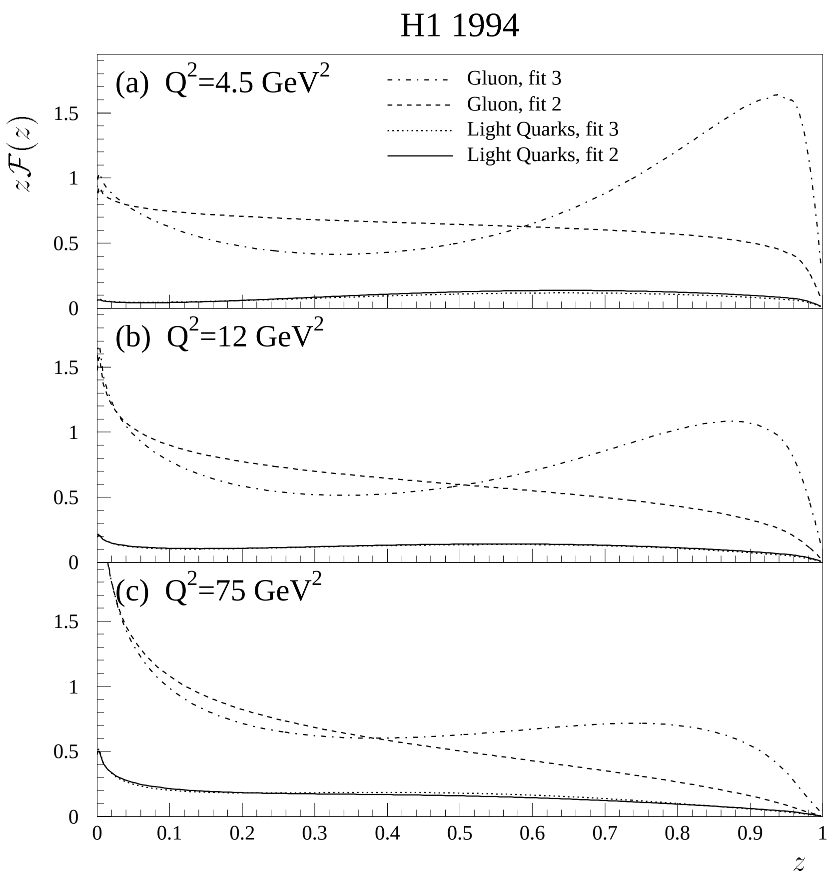
● Scaling violation rises with Q^2 for $\beta < 0.9$

× Fit 1 does not describe scaling violation of $F_2^{D(3)}$

√ Fit 3 gives a good description of data

$\mathbb{P}$ parton distributions resulting from fit 2 and 3

quarks	gluons
$z\mathcal{F}_q(z, Q^2) = u + \bar{u} + d + \bar{d} + s + \bar{s}$	$z\mathcal{F}_g(z, Q^2)$



- In both fit 2 and 3 the fractional $\mathbb{P}$ momentum carried by gluons decreases with increasing Q^2 from $\sim 90\%(4.5\text{GeV}^2)$ to $\sim 80\%(75\text{GeV}^2)$

$\Rightarrow$ Data favour large gluon component in $\mathbb{P}$

Why measure open charm in diffraction ?

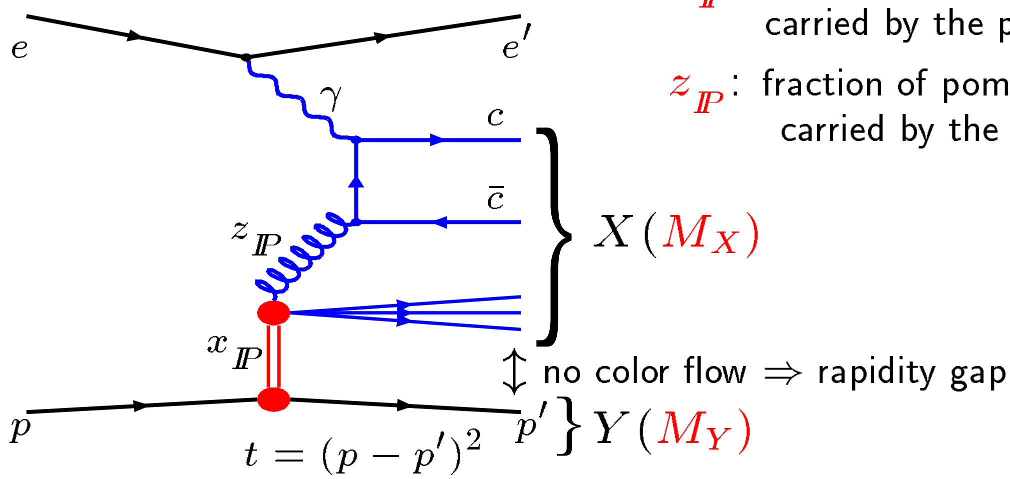
- Charm directly probes the role of gluons in diffractive exchange
- Charm mass provides a hard scale $\rightarrow$ pQCD
- Open charm free from uncertainties relating to bound states, eg. J/ψ

- Study of charm tests underlying dynamics of diffraction
  - ▷ Resolved pomeron model?
  - ▷ 2 gluon exchange?
  - ▷ Soft Color Interactions?

Models of diffractive Charm–Production

- Resolved Pomeron Model

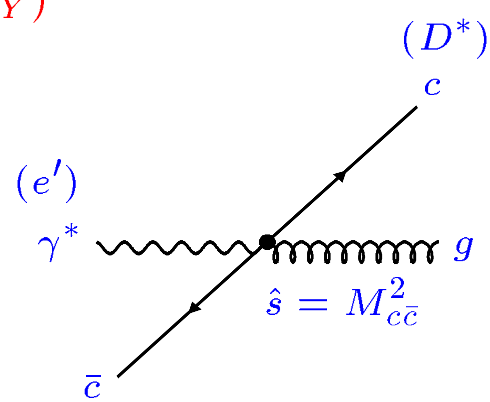
(e.g.Ingelmann, Schlein)



$x_{I\!P}$: fraction of proton momentum carried by the pomeron

$z_{I\!P}$: fraction of pomeron momentum carried by the gluon

$$z_{I\!P} = \beta\left(1 + \frac{\hat{s}}{Q^2}\right) \simeq \frac{M^2_{c\bar{c}}+Q^2}{M^2_X+Q^2}$$

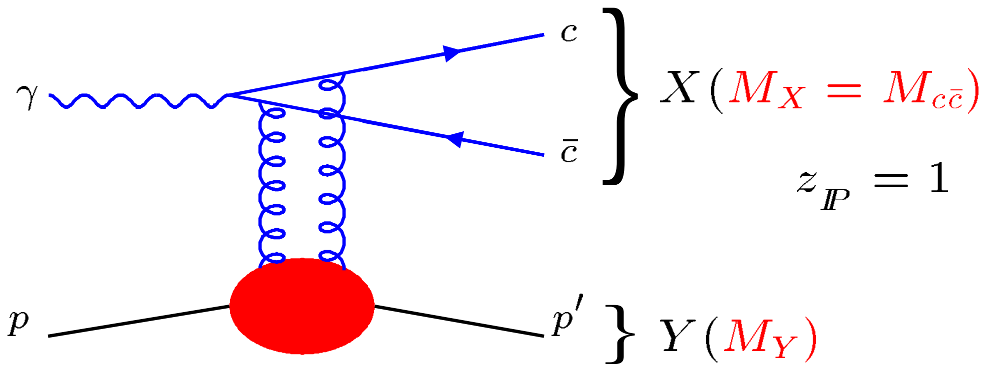


▷ Hadronic observable $z^{obs}_{I\!P}$ reconstructed using e' and D^*

→ Implemented in Monte Carlo generator RAPGAP

- 2–Gluon–Model

(e.g.Bartels, Lotter, Wüsthoff)



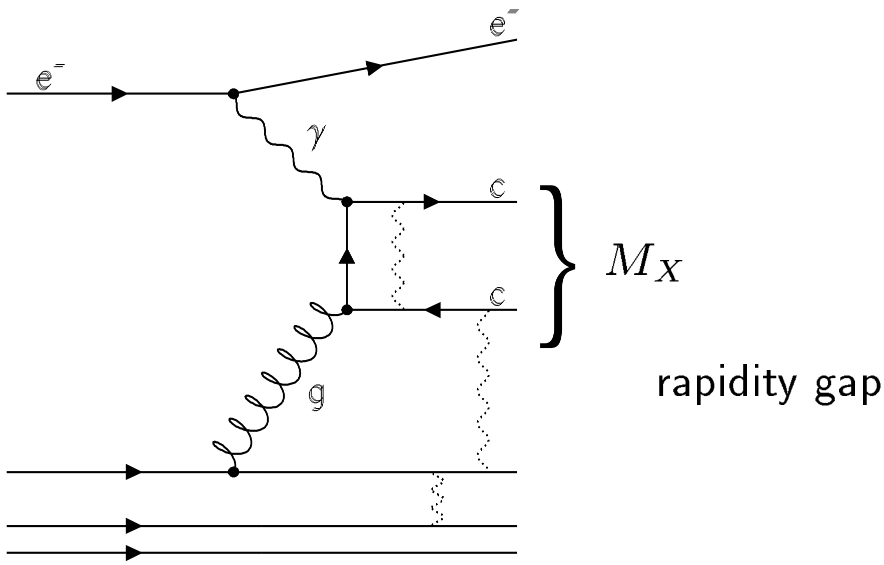
▷ Diffractive charm production by perturbative $2g$-exchange

▷ Cross section $\sigma \sim (gluon\ density)^2$ in the proton

$\rightarrow$ Implemented in RAPGAP

(e.g. Rathsman, Ingelmann)

- Soft Color Interactions (SCI)



▷ Soft color exchange between outgoing partons

$\Rightarrow$ net color singlet exchange

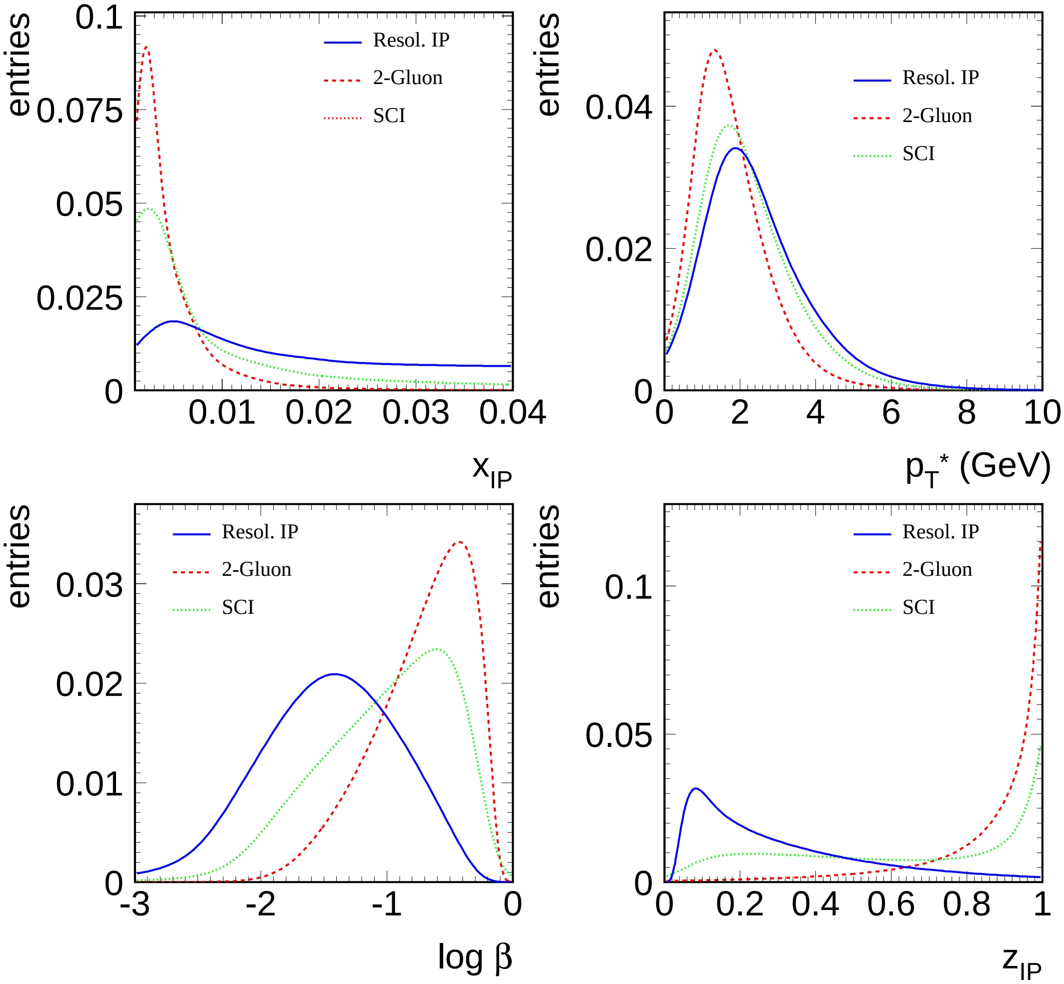
▷ Around 10% of charm events have a large rapidity gap

▷ Gluon radiation from $c\bar{c}$ supressed by charm quark mass

$\Rightarrow$ low mass system X $(z_{I\!P} \to 1)$

$\rightarrow$ Implemented in AROMA 2.2.

Model comparison



$$x_{I\!P} \simeq \frac{(Q^2+M_X^2)}{(Q^2+W^2)}$$

p_T^*:

Transverse momentum of c quark in $\gamma^* I\!P$ CMS

$$\beta \simeq \frac{Q^2}{(Q^2+M_X^2)}$$

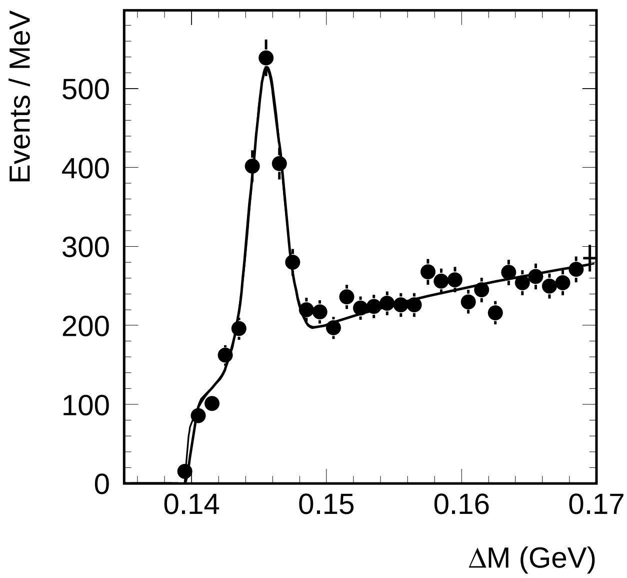
$$z_{I\!P} \simeq \frac{M_{c\bar{c}}^2+Q^2}{M_X^2+Q^2}$$

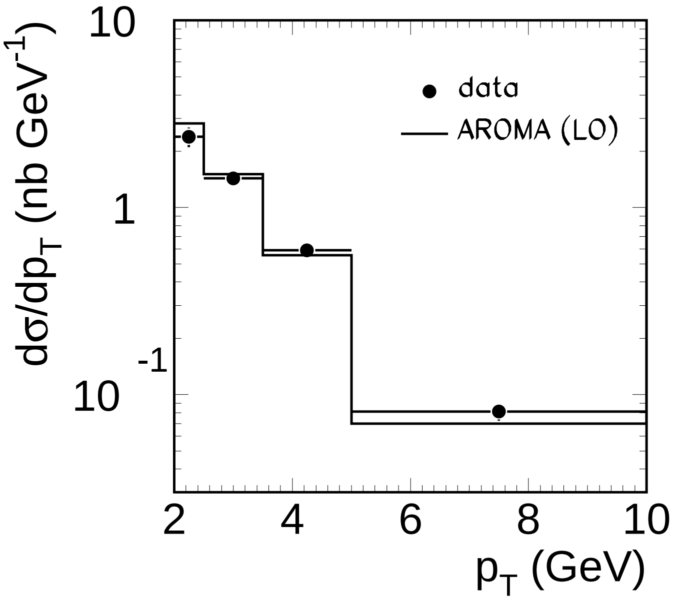
- $z_{I\!P}$ distribution peaks towards high values for both 2 gluon and SCI model ($z_{I\!P} \approx M_{c\bar{c}}/M_X$) .
- Res. $I\!P$ model predicts $z_{I\!P}$ dominated by low values

Data and event selection

- Data selection
  - ▷ Integrated lumi 95, 96, 97 $\Rightarrow \mathcal{L} = 21.7\ pb^{-1}$
  - ▷ Trigger: 6 GeV positron + tracks in central detector
- Kinematic region
  - ▷ $2\text{GeV}^2 < Q^2 < 100\text{GeV}^2$
  - ▷ $0.05 < y < 0.7$
  - ▷ $p_T(D^*) > 2$ GeV
  - ▷ $|\eta(D^*)| < 1.5$
- Selection of charm events
  - ▷ Standard track quality cuts

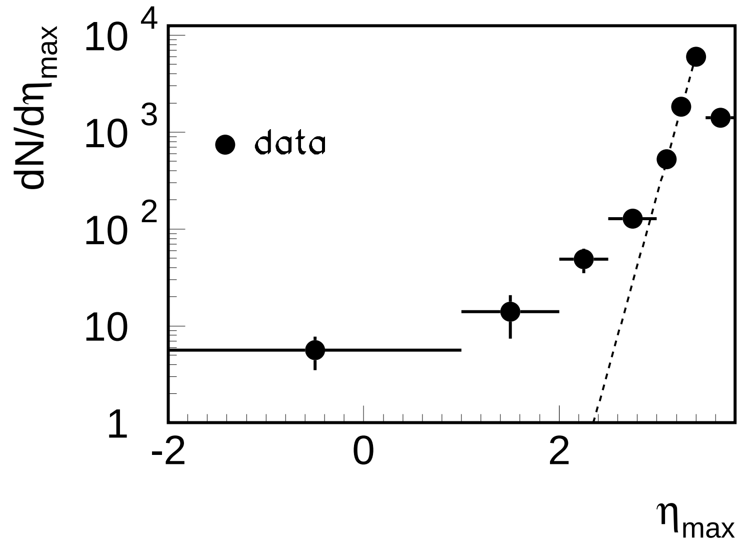
Inclusive D^* mesons





- Reconstruction of $D^\star$ mesons
  - ▷ Mass difference $\Delta m = M(K^-\pi^+\pi^+) - M(K^-\pi^+)$
  - ▷ Fit function: $a(\Delta m - m_\pi)^b +$ Gauss
  - ⇒ Number of $D^\star$ mesons: $N_{D^*} = 1015 \pm 55$
  - ⇒ Width: $\sigma_{\Delta m} = 1.12 \pm 0.06$ MeV
  - ⇒ Overall and differential cross sections in good agreement with expectation
  - $\surd$ $D^\star$ and DIS selection efficiencies understood.

Selection of diffractive events



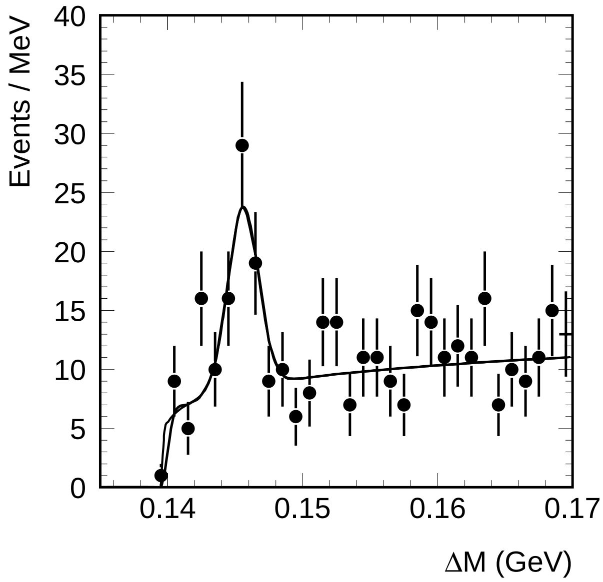
η_{max} pseudorapidity of most forward cluster in liquid argon calorimeter with $E > 300$ MeV

- ▷ $\eta_{max} < 3.3$
- ▷ No signals in forward detectors: N_{hit} in fwd-$\mu \leq 1$ and no hit in any scintillators of proton remnant tagger

- Kinematic region defined by ...
  - ▷ η_{max}–cut on system X
    $\Rightarrow x_{I\!P} = \frac{\sum_X (E+p_z)}{2 \cdot E_p} < 0.04$
  - ▷ No detection of system Y in forward detectors
    $\Rightarrow M_Y < 1.6$ GeV and $|t| < 1\text{GeV}^2$

$\sum_X (E + p_z)$ calculated using tracks and clusters

Diffractive Cross Section



▷ Number of diffractive $D^\star$ mesons: $N_{D^*} = 41 \pm 9$

⇒ Cross Section in visible kinematic region

$2 < Q^2 < 100$ GeV^2, $0.05 < y < 0.7$, $p_T(D^\star) > 2$ GeV,

$|\eta(D^\star)| < 1.5$, $x_{I\!P} < 0.04$, $M_Y < 1.6$ GeV and $|t| < 1$ GeV^2

$$\sigma(ep \to e(D^{*\pm}X)Y) = (184 \pm 42(stat.) \pm 46(syst.))\ \text{pb}$$

Model predictions $\sigma(ep \rightarrow e(D^{*\pm}X)Y)$

- Measurement $184 \pm 42 \pm 36$ pb

▷ RAPGAP resolved $I\!P$

$\mu^2 = Q^2 + p_\perp^2 + 4m_c^2$
$m_c = 1.5$ GeV
$\lambda_{QCD} = 0.25$ GeV, $N_f = 5$

$F_2^{D(3)}$ fit 2 — 540 pb

$F_2^{D(3)}$ fit 3 — 630 pb

$F_2^{D(3)}$ fit 1 — 60 pb

$m_c = 1.35$ GeV

$F_2^{D(3)}$ fit 2 — 610 pb

$m_c = 1.5$ GeV
$\lambda_{QCD} = 0.239$ GeV, $N_f = 4$

$F_2^{D(3)}$ fit 2 — 500 pb

▷ 2 gluon model

GRV LO — 122 pb
GRV HO — 80 pb

▷ SCI

$\mu^2 = \hat{s}$ — 400 pb

Systematic Errors

$\rightarrow$ 17.5% acceptance correction using simulation of different generators RAPGAP (res. $I\!P$) and AROMA (SCI) $(x_{I\!P}, z_{I\!P}, \beta, t)$

$\rightarrow$ 10% uncertainty of fitting procedure

$\rightarrow$ 4.5% uncertainty in measured energy of scattered electron

$\rightarrow$ 7.5% reconstruction efficiency of CJC (three tracks)

$\rightarrow$ 6% trigger efficiency

$\rightarrow$ 6% M_Y smearing (DIFFVM MC–Generator)

$\rightarrow$ 6% noise in forward detectors

$\rightarrow$ 2.5% high $x_{I\!P}$ background ($x_{I\!P} > 0.1$ or $M_Y > 5$ GeV)

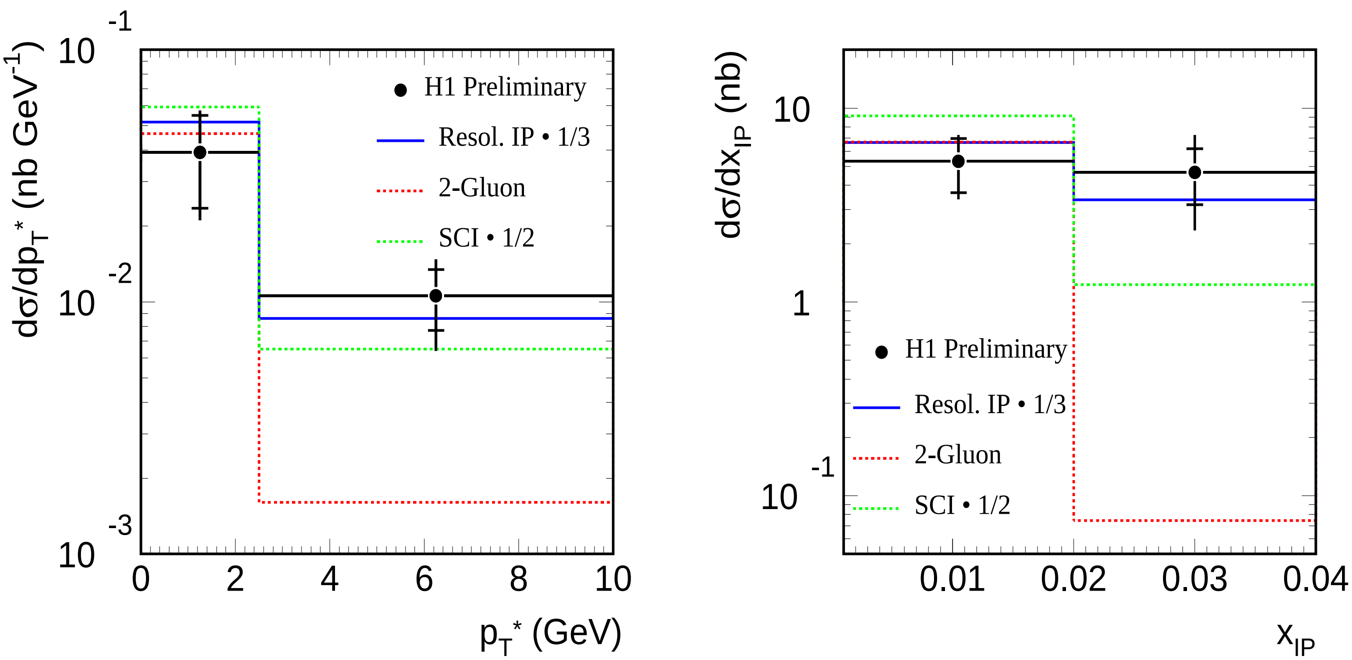
$\rightarrow$ 3% branching fraction

$\rightarrow$ 1.5% luminosity

$\rightarrow$ 1.5% Δm mass reflections

$\Rightarrow$ 25% **total**

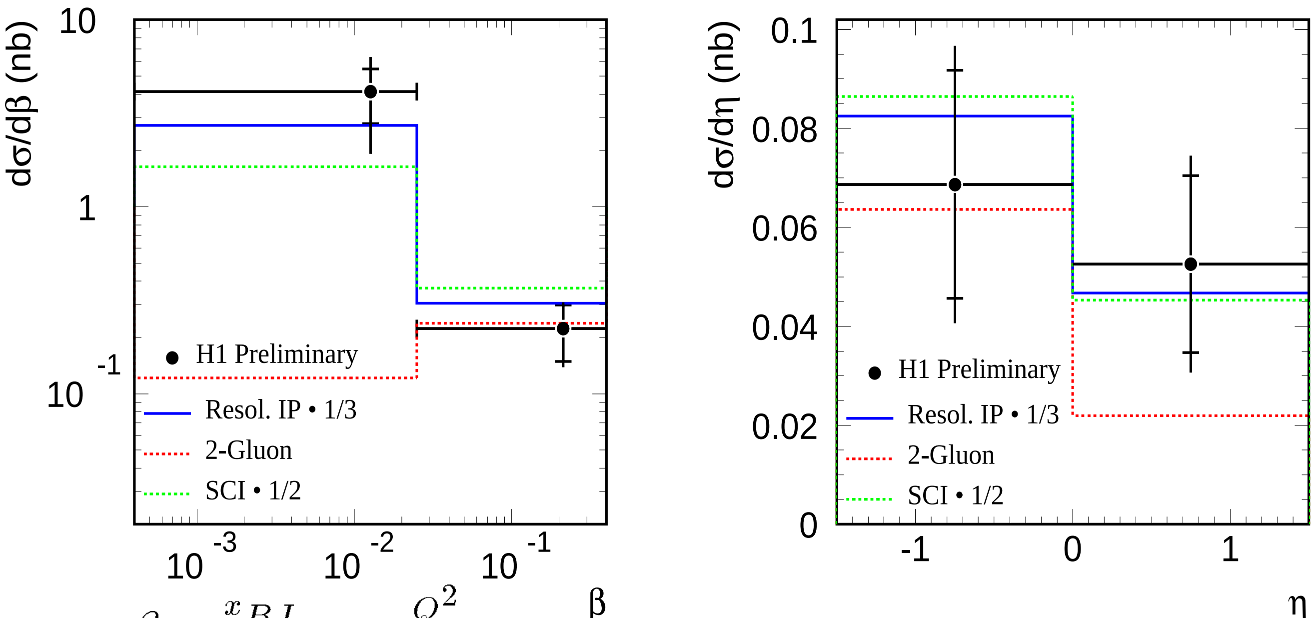
Differential cross sections in p_T^* and $x_{I\!P}$



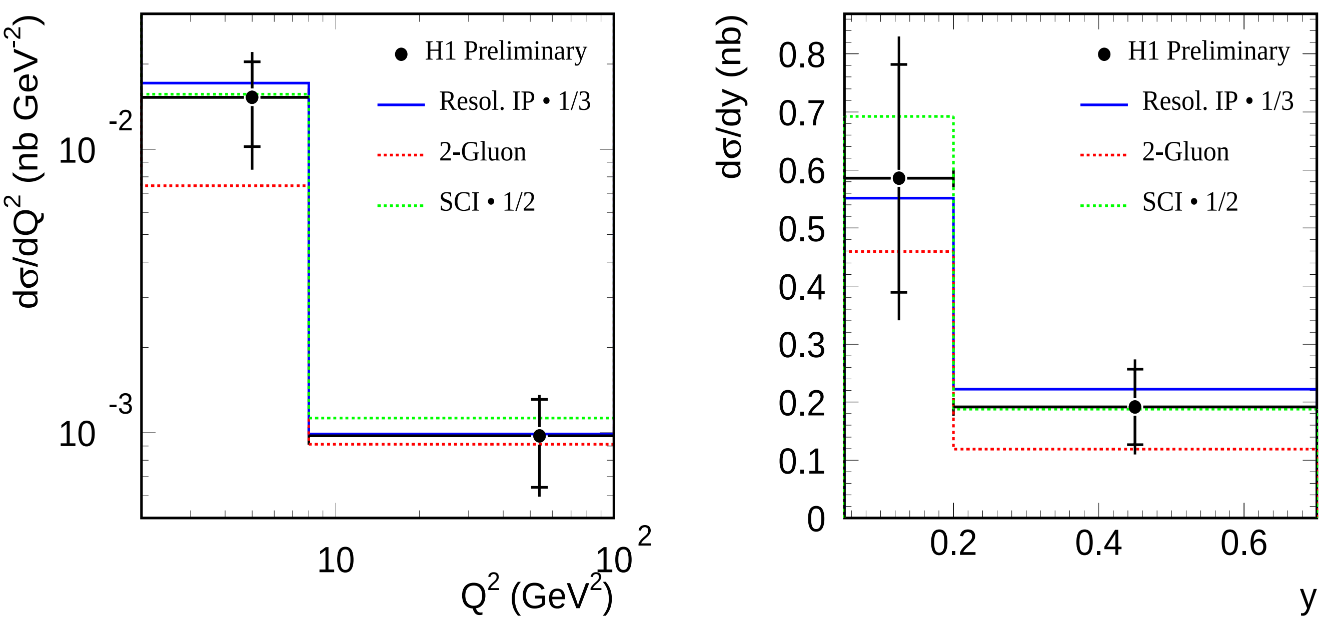
p_T^*: Transverse momentum of D^*
in $\gamma^* I\!P$ CMS

- Shape of spectra agree well with resolved $I\!P$ model
- Resolved $I\!P$ and SCI model fail in overall normalisation
- 2 gluon model matches the data in low p_T^* and low $x_{I\!P}$ range but fails in high p_T^*, high $x_{I\!P}$ (M_X) range

More differential cross sections

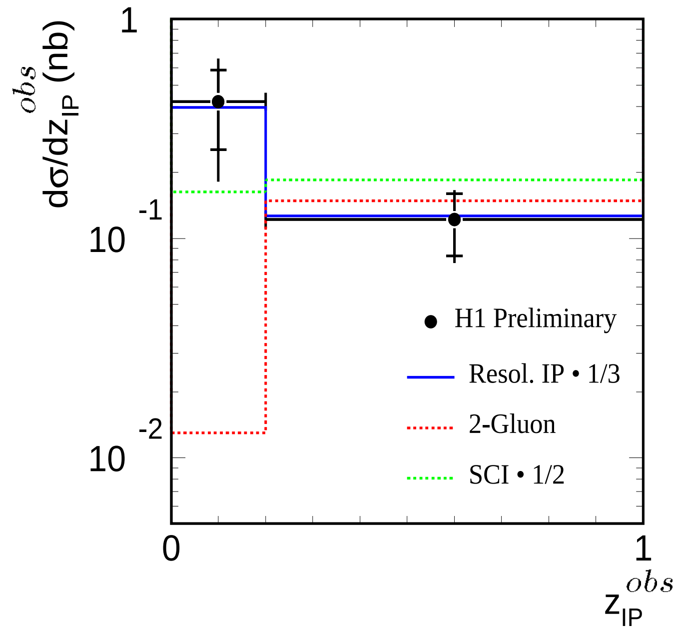


$$\beta = \frac{x_{BJ}}{x_{I\!P}} = \frac{Q^2}{Q^2+M_X^2}$$



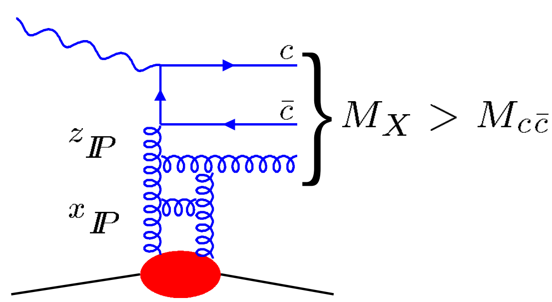
- Low β region not described by 2 gluon model

Differential cross section $d\sigma/dz_{I\!P}{}^{obs}$



$$z_{I\!P} \simeq \frac{M_{c\bar{c}}^2+Q^2}{M_X^2+Q^2}$$

- ▷ The data show a sizeable fraction of charm production at low $z_{I\!P}^{obs}$ ('resolved pomeron interaction')
- ▷ Models where the hadronic system X predominantly consists of $c\bar{c}$ system alone are disfavoured
- ▷ In a perturbative 2 gluon approach higher order contributions are clearly required, e.g.



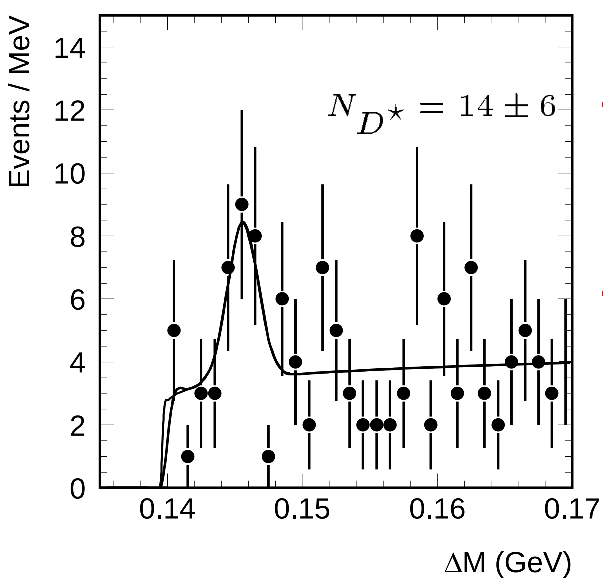
Comparison between ZEUS and H1 results

H1	ZEUS
$2 < Q^2 < 100$ GeV^2	$3 < Q^2 < 150$ GeV^2
$0.05 < y < 0.7$	$0.02 < y < 0.7$
$p_T(D^\star) > 2$ GeV	$p_T(D^\star) > 1.5$ GeV
$\eta max < 3.3$ $0 < x_{I\!P} < 0.04$	$\eta max < 1.5$ $0.002 < x_{I\!P} < 0.012$
$M_Y < 1.6$ GeV $\quad |t| < 1$ GeV^2	$M_Y = m_P$
$0 < \beta < 1.0$	$0 < \beta < 0.8$
Results	
$N_{D^\star} = 41 \pm 9 \quad (\mathcal{L} = 21.72$ pb$^{-1})$	$N_{D^\star} = 59 \pm 9 \quad (\mathcal{L} = 43.3$ pb$^{-1})$
$184 \pm 42(stat.) \pm 46(syst.)$ pb	$379 \pm 66(stat.)^{+99}_{-140}(syst.)$ pb

! Cannot directly compare results

- ZEUS in agreement with resol. $I\!P$ prediction (326 pb)

  but within $\sim 1.3\sigma$ compatible with being factor 3 below



- efficiency drops from $\mathcal{O}(40\ \%)$ to $\mathcal{O}(10\ \%)$ consistent with ZEUS ε
- Cross section $\sigma = (166 \pm 74)$ pb still factor 2 below resol. $I\!P$ model

$\Rightarrow$ H1 and ZEUS only hardly compatible within large errors

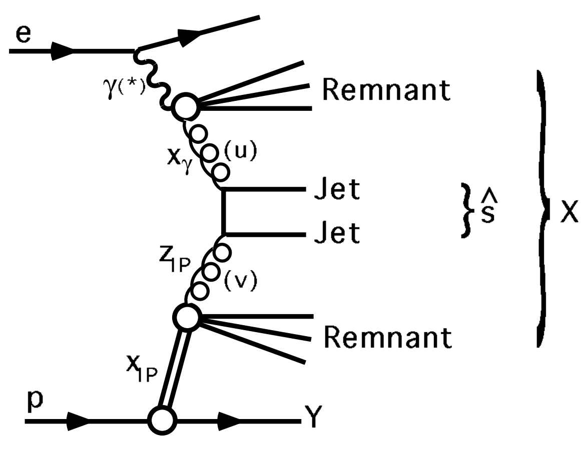
Diffractive dijet production in DIS

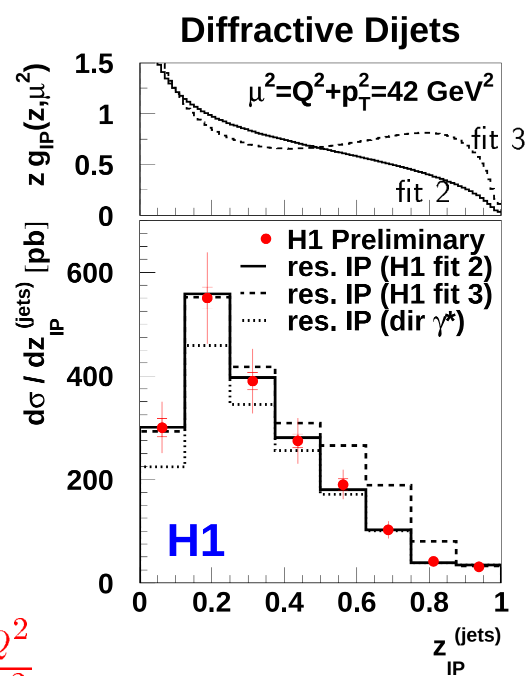
- $I\!P$ structure is tested at H1 with dijets production

▷ High p_T jets ($p^*_{T,jets} > 4$ GeV in $\gamma^* p$ CMS) introduce hard scale $\mu^2 \rightarrow$ production mechanism PGF

▷ Kinematic range: $4 < Q^2 < 80$ GeV^2, $0.1 < y < 0.7$

$x_{I\!P} < 0.05$, $M_Y < 1.6$ GeV and $|t| < 1$ GeV^2





$$z^{jets}_{I\!P} = \frac{M^2_{12} + Q^2}{M^2_X + Q^2}$$

- Resolved $I\!P$ model (fit 2) in perfect agreement with data in both shape and overall normalization

$\Rightarrow$ Diffractive dijet data support the resolved $I\!P$ model

Conclusions

- Use charm as key to diffractive interactions
- Measurements of differential cross sections have been presented; they are able to discriminate between different models
  - ▷ 2 gluon approach does not describe data

    $\longrightarrow$ need contribution from $q\bar{q}g$ processes
  - ▷ Distributions are well described in shape by the resolved $I\!P$ model
- In the probed range, about 4.5% of charm production is diffractive - this is below the expectation based on the resolved $I\!P$ model with experimental parton distributions

  - H1 dijet and ZEUS $D^\star$ consistent with expectation
- Descrepancy not solvable with present experimental precision

  $\Rightarrow$ Need to expand dataset to get final answer !