Diffractive jet and charm production

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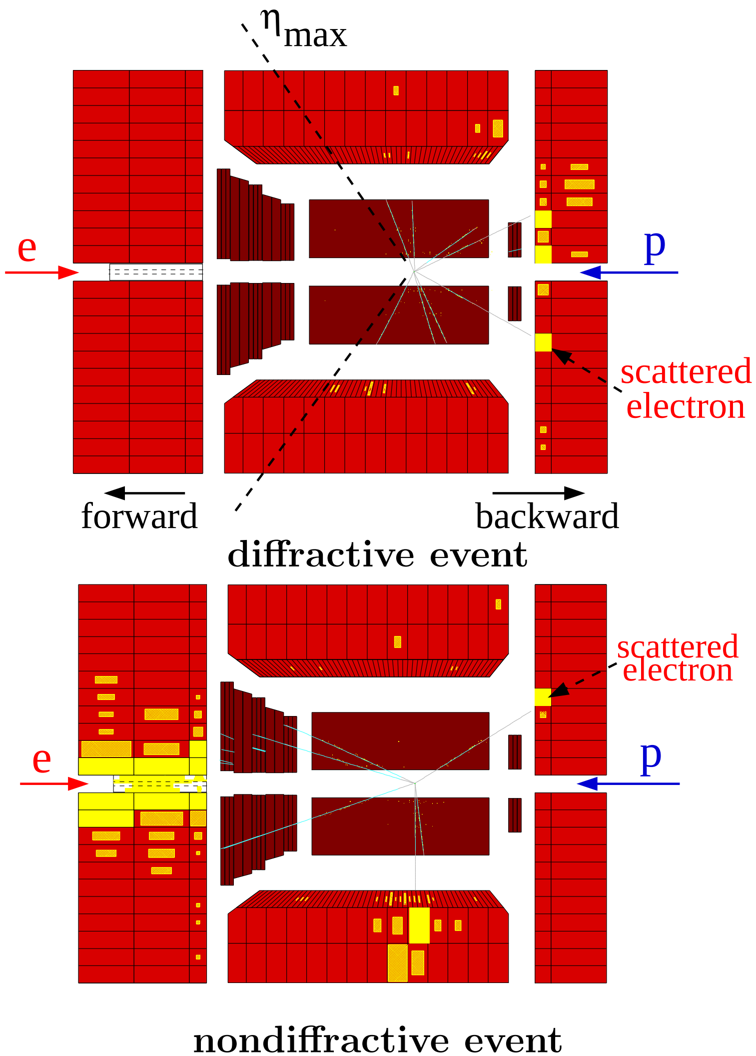
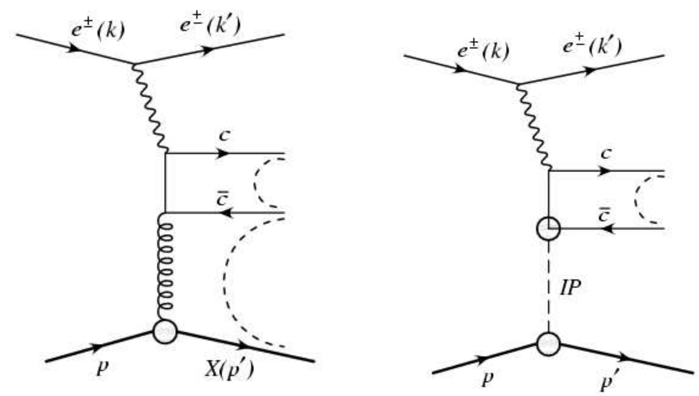
On behalf of
H1 and ZEUS Collaborations

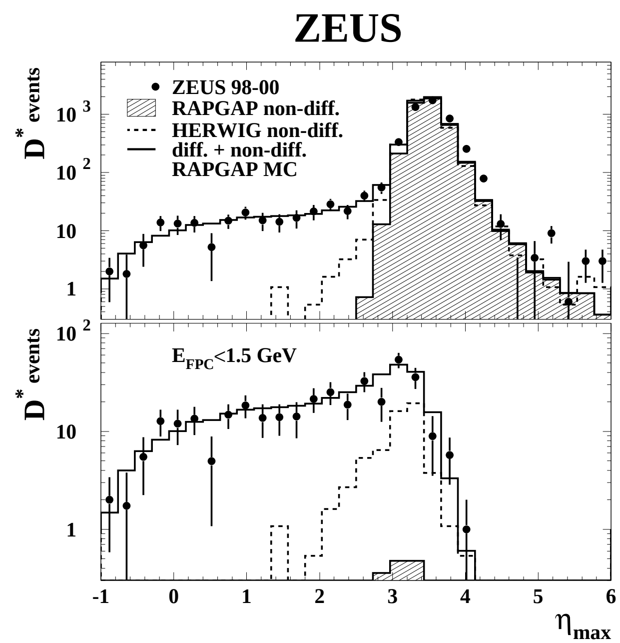
O U T L I N E

- Introduction
- Models of diffractive exchange
- Dijet Results
- $D^{*\pm}$ Results
- Diffractive 3-Jets
- Summary

Diffractive Selection

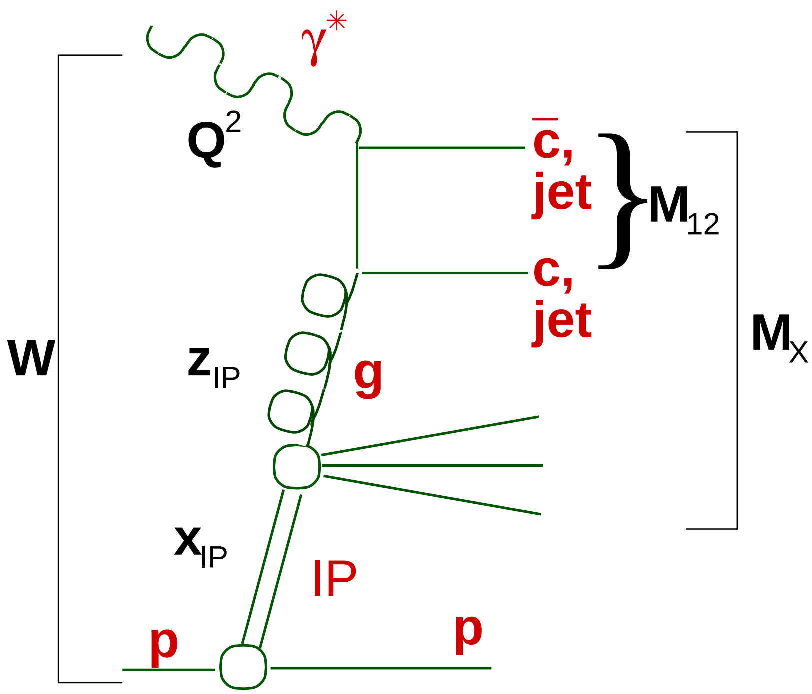






$\eta = -\ln(tg\frac{\theta}{2})$, $\eta_{\max}$ **: the largest** η **value in event**

Kinematic variables



Q^2 **- photon virtuality**

$W^2 = (\mathrm{P}+\mathrm{q})^2$ **-** $\gamma^* p$ **CMS energy**

M_X **- mass of diffractively produced system**

M_{12} **- mass of two jets or** $c\bar{c}$ **pair**

$x_{I\!P} = \frac{M_X^2+Q^2}{W^2+Q^2}$ **- momentum fraction of diffractive exchange w.r.t. proton**

$z_{I\!P} = \frac{M_{12}^2+Q^2}{M_X^2+Q^2}$ **or** $z_{I\!P}^{(3jets)} = \frac{M_{123}^2+Q^2}{M_X^2+Q^2}$

$(\beta = \frac{Q^2}{M_X^2+Q^2})$ **- momentum fraction of diffractive exchange entering hard process**

Factorisation in Diffraction

The combination of:

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

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

- $\hat{\sigma}^{\gamma^* i}$ **universal partonic cross sections, as in incl. DIS**
- p_i^D **diffractive parton distributions (conditional probabilities), obey NLO DGLAP**

and:

- **Regge Factorisation:** $x_{I\!P}$, t **dependance factorises out (Donnachie, Landshoff, Ingelman, Schlein)**

$$F_2^D(x_{I\!P},t,\beta,Q^2) = f_{I\!P/p}(x_{I\!P},t) F_2^{I\!P}(\beta,Q^2)$$

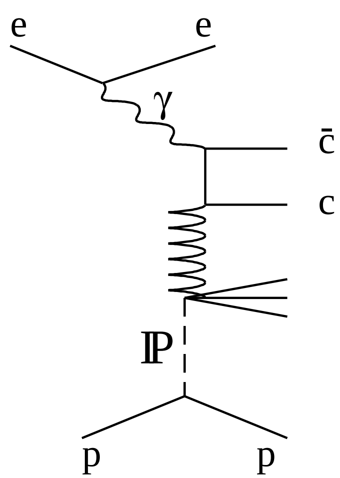
- **No proof in QCD; consistent with data at the present level of precision**

If QCD Factorisation works, the diffractive pdf's should predict cross sections for jets and heavy quarks

Models of diffractive exchange

Resolved Pomeron model :

- Based on Regge theory with Pomeron exchange
- Treat $I\!P$ as object with substructure
- Jet and Charm Production in diffractive DIS $\rightarrow$ probe gluon content of $I\!P$



- gluon-dominated $I\!P$

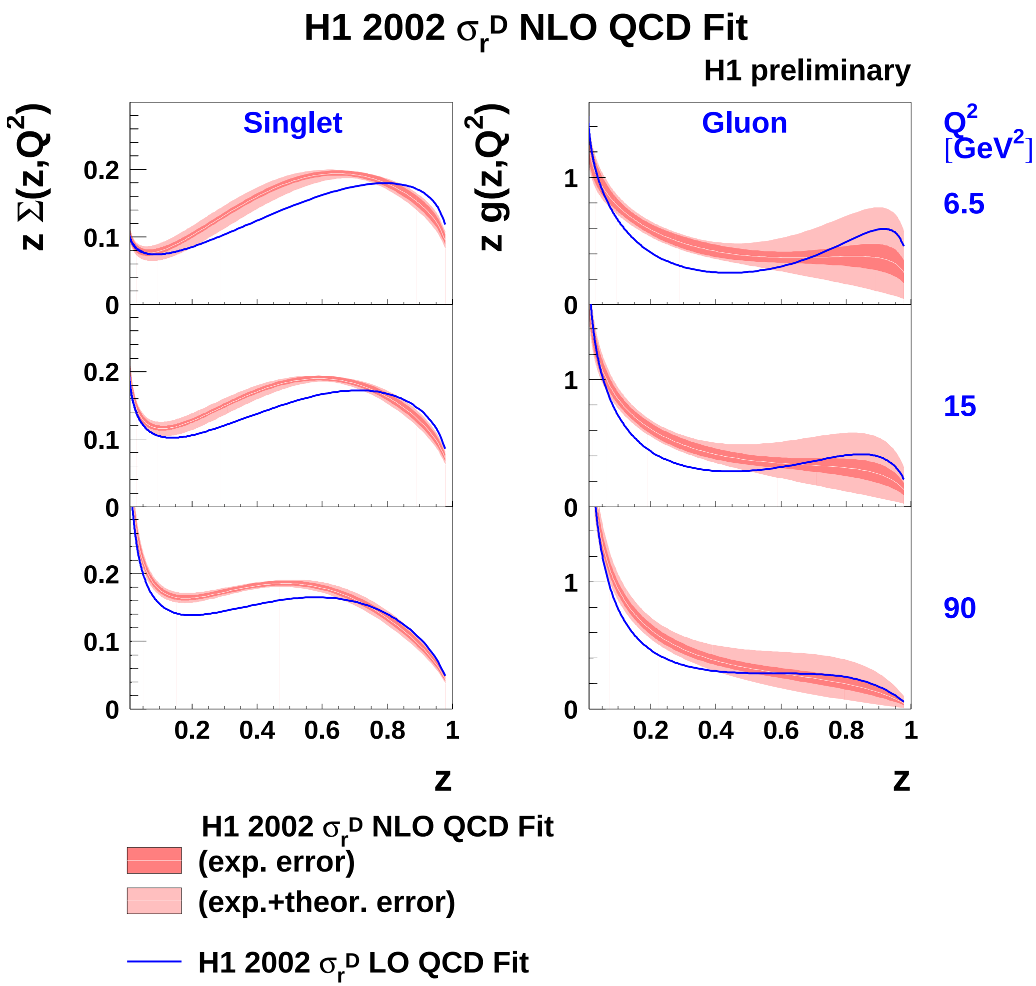
Examples :

– H1 QCD fit ("h1 fit2") in LO RAPGAP

– NLO QCD code *DISENT* (Seymour) c.f. Hautmann with H1 2002 σ_r^D NLO QCD Fit (Diffractive DIS jets)

– NLO QCD code *DHVQDIS* with H1 2002 σ_r^D NLO QCD Fit and fit by Alvero, Collins, Terron and Whitmore (*ACTW*) to ZEUS and H1 data. Gluon–dominated fits "B", "D" and "SG" (Diffractive DIS D^*)

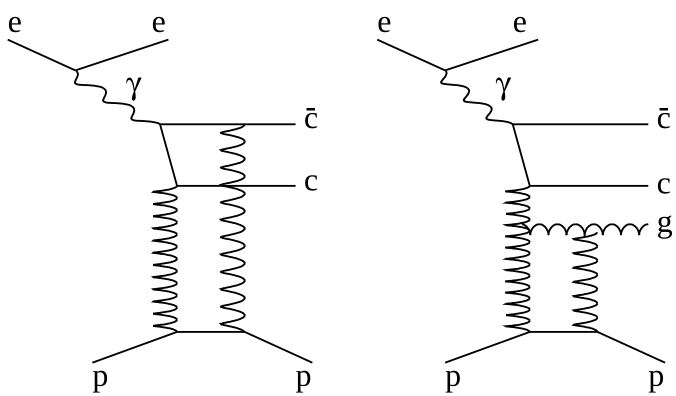
New H1 QCD Fits



- **New LO and NLO QCD fits to 1997 H1 $F_2^{D(3)}$ data**
- **First evaluation of experimental and theoretical uncertainties**
- **LO gluon density around 30 % lower than 1994 fit; fits are consistent withing errors**

Models of diffractive exchange

Perturbative QCD models:



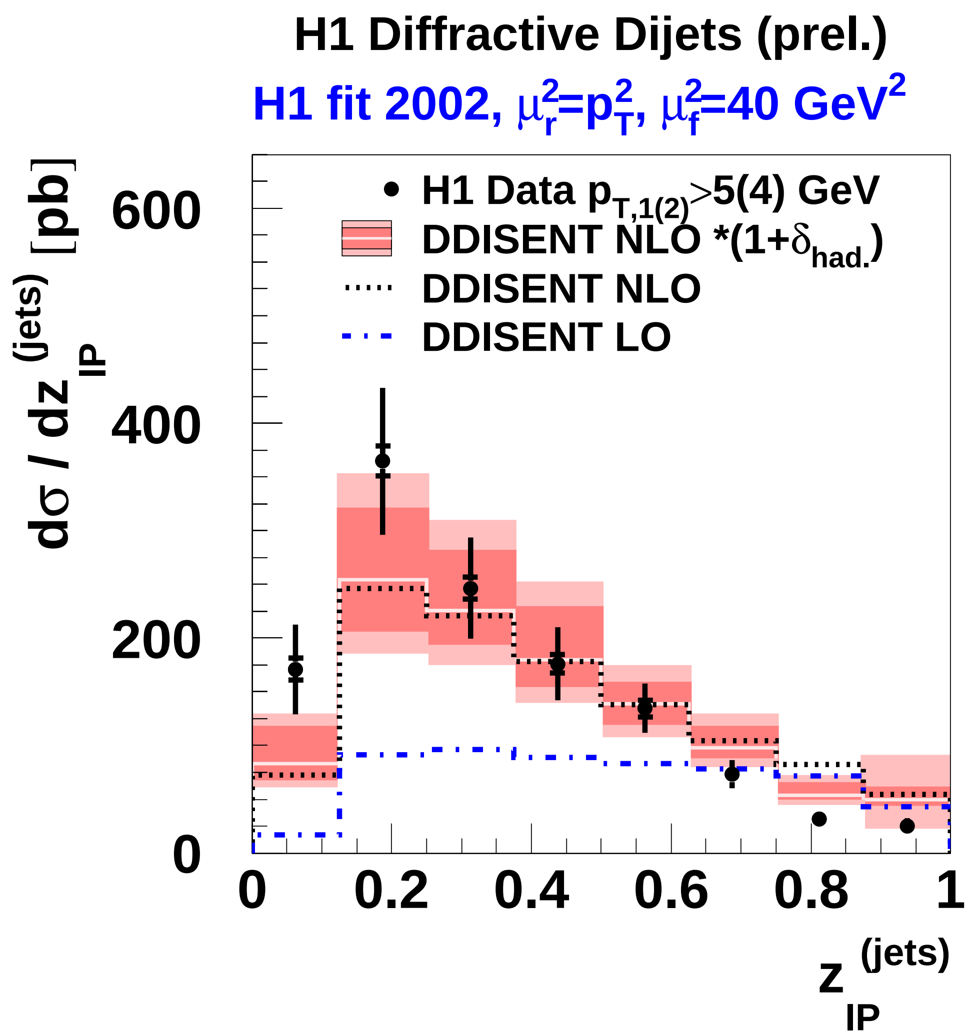
- t**-channel gluon exchange**
- $\sigma \propto$ **(gluon density)**^{2}
- **Higher order processes** $\gamma^* \to c\bar{c}g$ **— cancels suppression for large masses**

Examples :

– two-gluon exchange model implemented in RAPGAP generator Bartels et al. (*BJLW*);
unordered k_T

– two-gluon exchange "saturation" model implemented in *SATRAP* generator;
strongly ordered k_T : $p_T^g \ll p_T^q$

NLO Comparison with Diffractive DIS Jets



- **Published H1 data :**

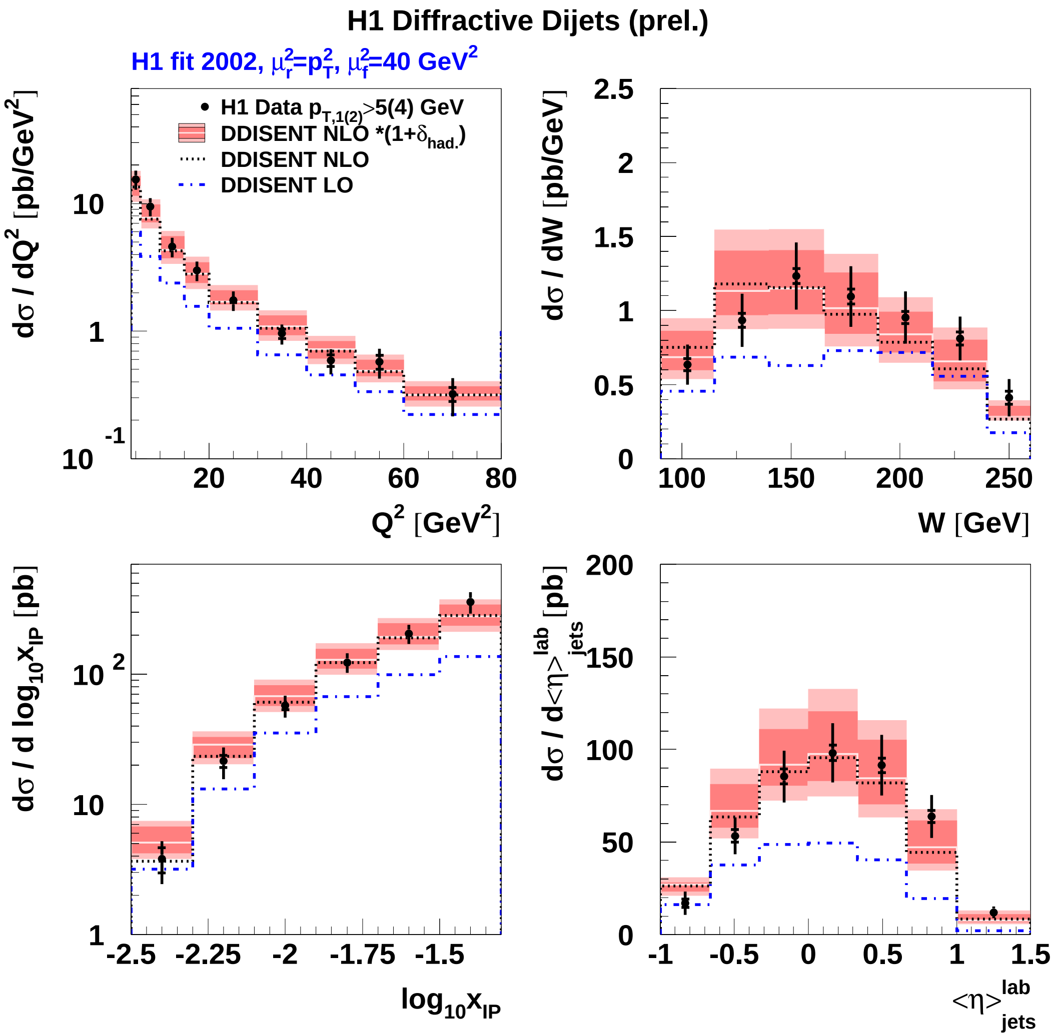
  (Eur. Phys. J. C20 (2001) 29)
  $4 < Q^2 < 80$ **GeV**^{2}, $0.1 < y < 0.7$, $x_{I\!P} < 0.05$
  Jets: CDF cone, $p_{T,jet} > 4$ **GeV**

  Data corrected to $p_{T,1(2)} > 5(4)$ **GeV** $(\sim 25\%)$
  as NLO are unstable if $p_{T,1} \sim p_{T,2}$

- **DISENT NLO Calculations :**

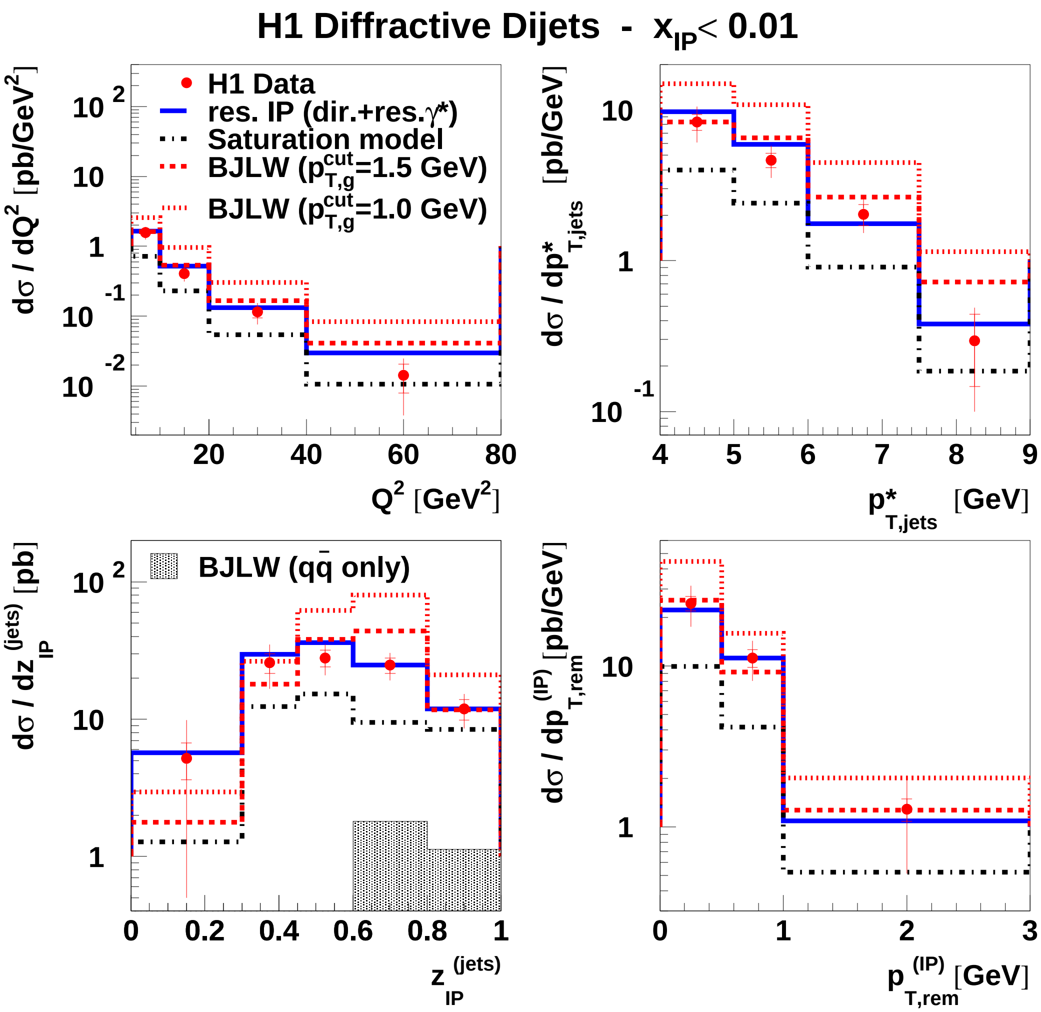
  $\mu_R^2 = p_T^2$, $\mu_F^2 = 40$ **GeV**^{2}
  Inner band : $0.25\mu_R^2 - 4\mu_R^2$ $(\sim 20\%)$
  Hadronization corrections applied $(\sim 10\%)$
  outer band is *hadr.corr* $\oplus$ μ_R^2 *unc.*

NLO Comparison with Diffractive DIS Jets



- Size of NLO corrections is higher for small Q^2 and p_T
- pdf uncertainty is not shown
- Reasonable agreement with Resolved Pomeron model (the NLO calculation uncertainties are very large though...)

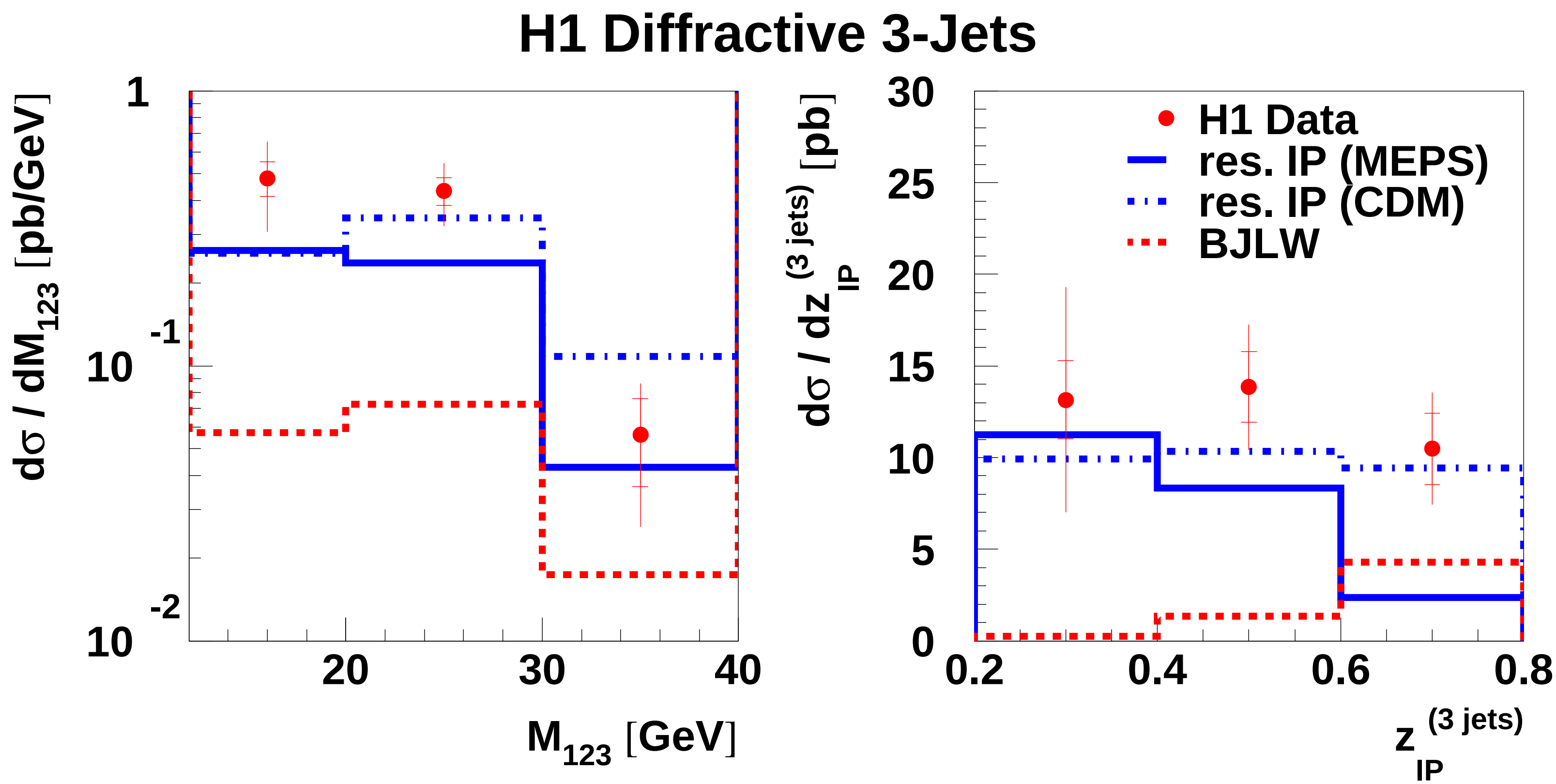
Perturbative QCD Models Comparison with DIS Jets



- Dijets for $x_{I\!P} < 0.01$;
  $p^{(I\!P)}_{T,rem}$ - remnant in the Pomeron hemisphere in $\gamma^* I\!P$ c.m. frame
- *Saturation* model reproduces shapes of xsections; underestimates the rate by a factor of ~ 2
- Reasonable agreement with *BJLW* model for $p^{cut}_{T,g} = 1.5$ GeV
- $q\bar{q}$ contribution is quite small
- Good description of the $p^{(I\!P)}_{T,rem}$ by both resolved Pomeron and BJLW.

  The data are not able to discriminate between models with "soft" remnant and those with a third high-p_T parton.

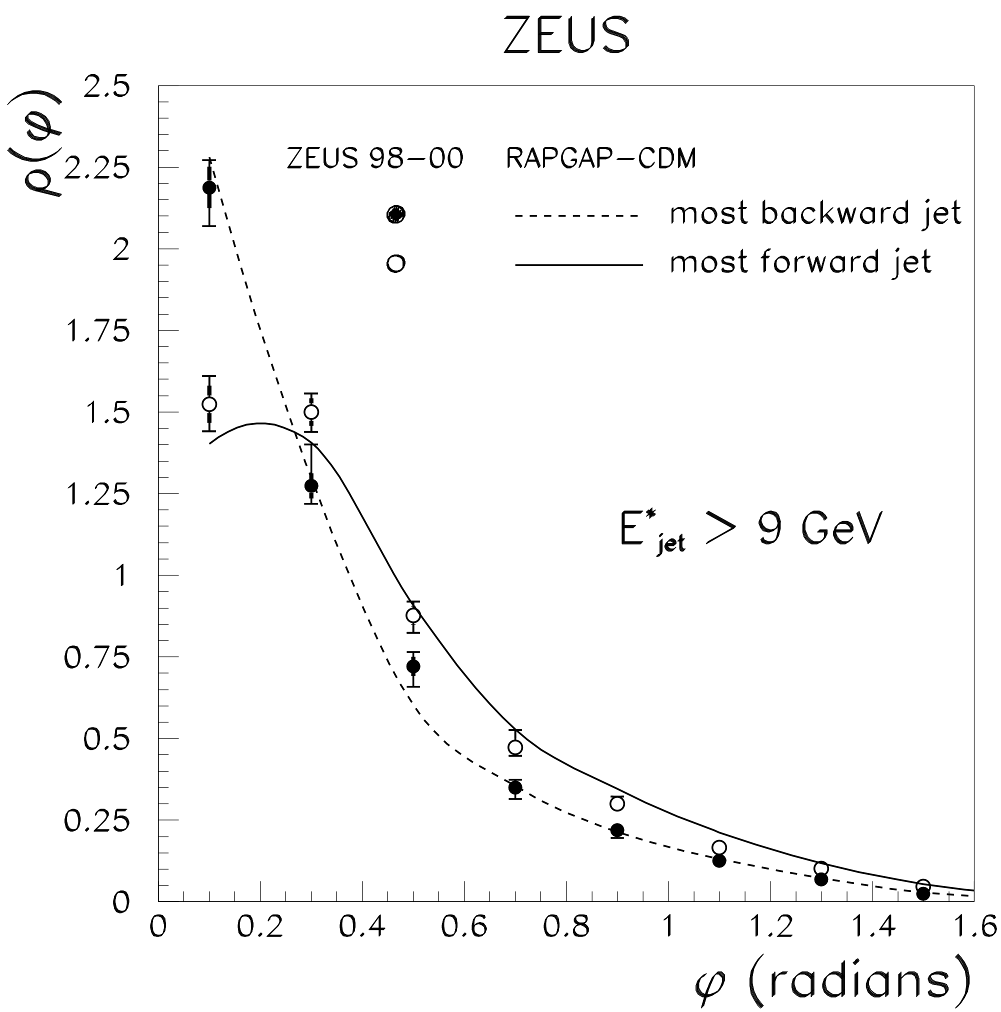
Models Comparison with DIS 3-Jets



- Resolved Pomeron, "h1 fit2" pdf with parton shower model "MEPS" and color dipol approach "CDM"
- *BJLW* model for $p_{T,g}^{cut} = 1.5$ GeV
- Agreement with "h1 fit2", CDM

- *BJLW* for $x_{I\!P} < 0.01$ is too low as 3-jet sample originates from region $x_{I\!P} > 0.01$; higher multiplicity photon fluctuations (as $q\bar{q}gg$) are not yet available in MC

Models Comparison with DIS 3-Jets



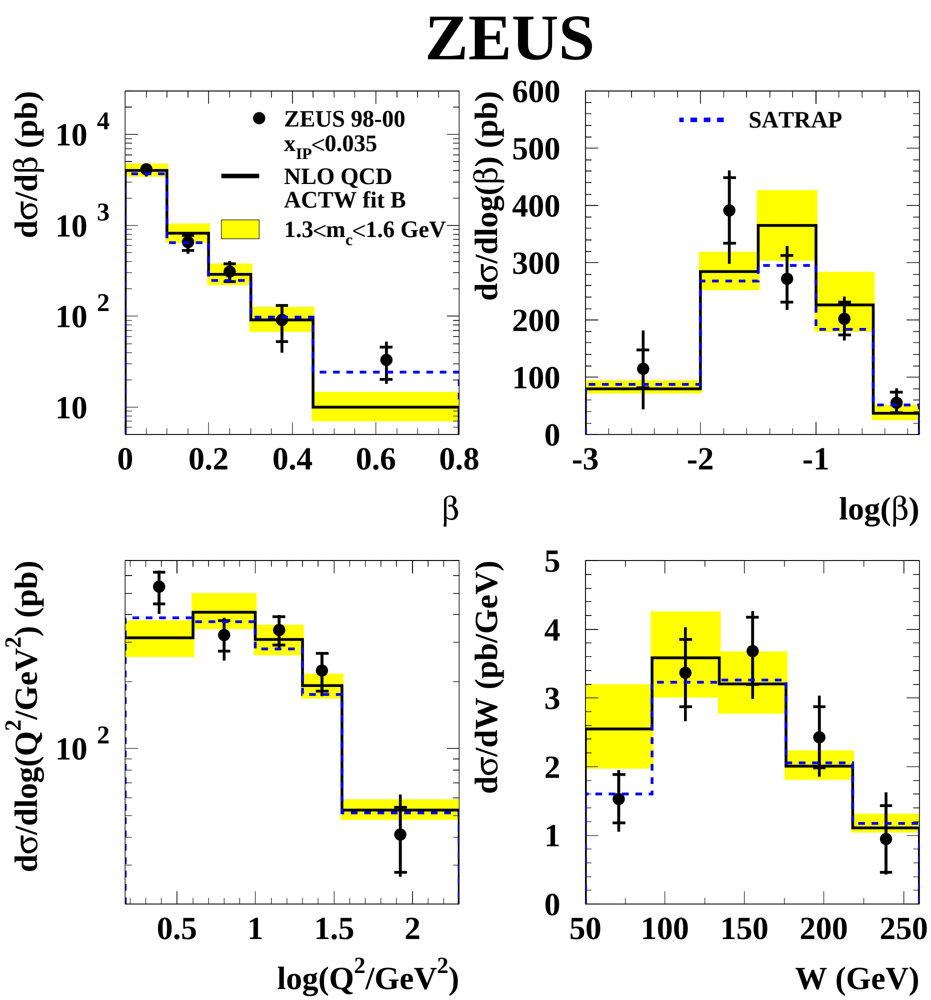
- **<u>Published ZEUS data</u> :**

  (Phys. Lett. B 516 (2001))
  $5 < Q^2 < 100$ **GeV^2**, $200 < W < 250$ **GeV,**
  $23 < M_X < 40$ **GeV,** $x_{I\!P} < 0.025$
  Jets: exclusive k_T-algorithm
  $\rho(\varphi) = \langle \frac{1}{\delta\varphi} \frac{E^{jet}(\varphi \pm \delta\varphi/2)}{E^{jet}} \rangle$

- **Jet in Pomeron direction (most forward jet) is broader than jet in photon direction (most backward jet)**

- **Measurements described by model with gluon in $I\!P$ direction**

Model Comparison with Diffractive DIS D^*



- **Published ZEUS data :**

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

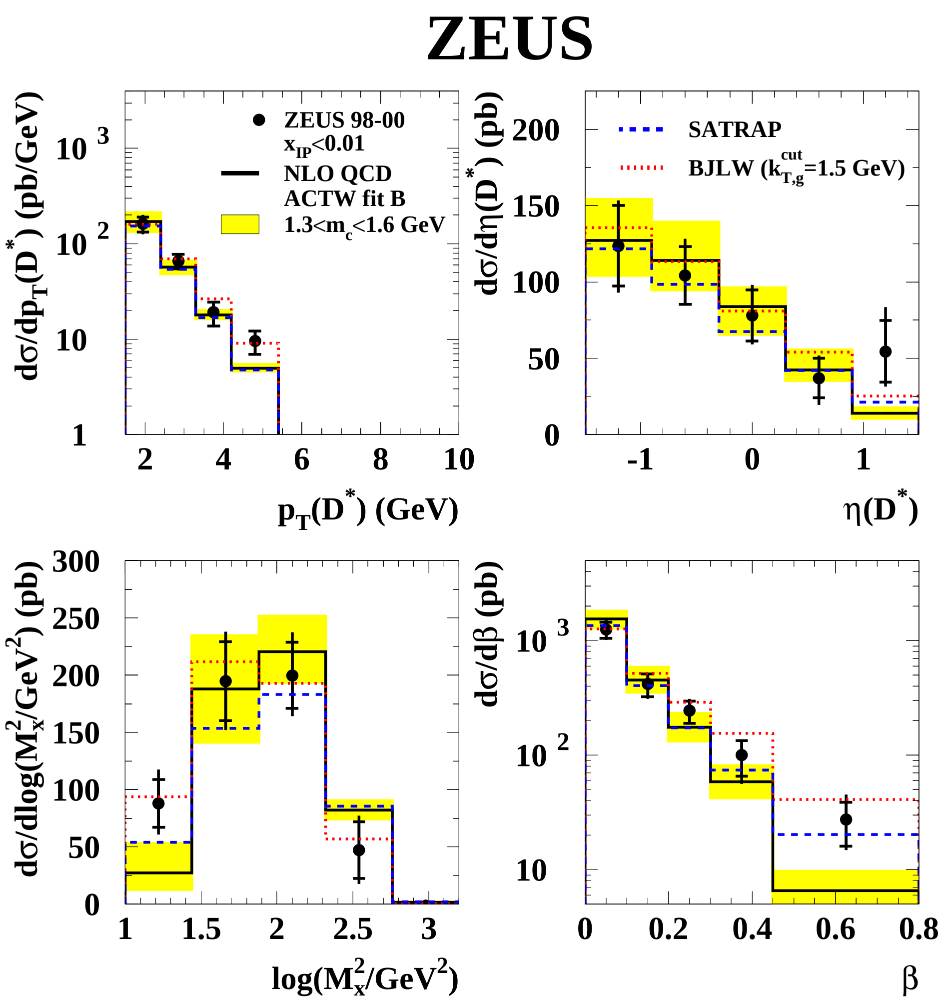
  $D* \rightarrow K\pi\pi$
  $p_T(D^{*\pm}) > 1.5\,$**GeV and** $|\eta(D^{*\pm})| < 1.5$

- **ACTW NLO Calculations :**

  Gluon dominated pdf "fit B"
  $\mu_R = \mu_F = \sqrt{Q^2 + 4m_c^2}$
  The NLO error band : $1.3 < m_c < 1.6$ **GeV**
  Peterson fragmentation with $\epsilon = 0.035$
  The probability for charm to fragment into a $D^{*\pm}$ **meson was set to :**
  $f(c \rightarrow D^{*+}) = 0.235$

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

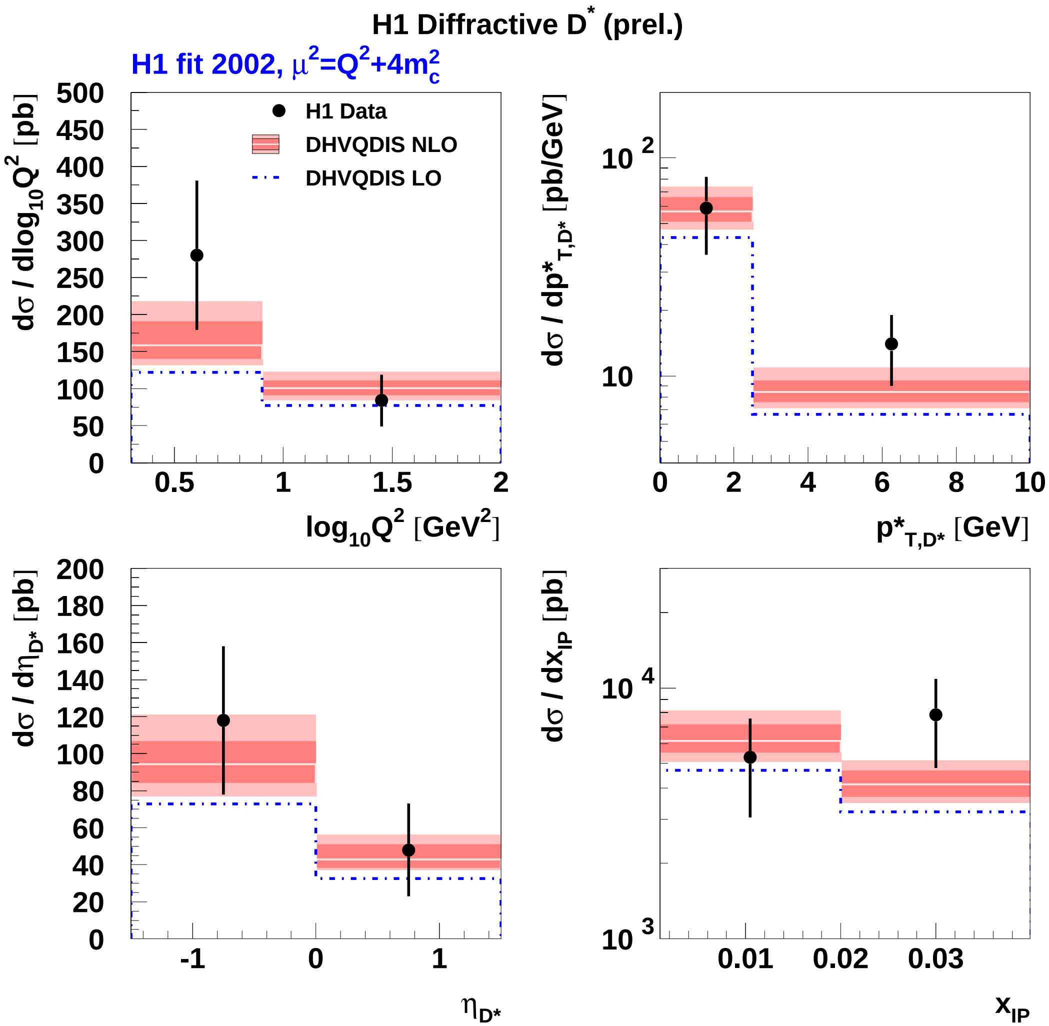
Model Comparison with Diffractive DIS D^*



- D^* **for** $x_{I\!P} < 0.01$
- **Two-gluon exchange models :**

  SATRAP and BJLW using MC RAPGAP proton PDF GRV94HO,
  $f(c \to D^{*+}) = 0.235$, $m_c = 1.45$ **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** *saturation model*

Model Comparison with Diffractive DIS D^*



- **Published H1 data :**

  (Phys. Lett. B520 (2001) 191)
  $2. < Q^2 < 100\,\mathbf{GeV}^2$, $0.05 < y < 0.7$,
  $x_{I\!P} < 0.04$
  $D* \to K\pi\pi$
  $p_T(D^{*\pm}) > 2\,\mathbf{GeV}$ **and** $|\eta(D^{*\pm})| < 1.5$

- **DHVQDIS NLO Calculations :**

  pdf H1 2002 σ_r^D **NLO QCD Fit**
  $\mu_R = \mu_F = \sqrt{Q^2 + 4m_c^2}$
  Peterson fragmentation with $\epsilon = 0.078$
  $m_c \;=\; 1.45$ **GeV,** $f(c \to D^{*+}) = 0.233$
  Inner NLO band : $0.25\mu_R^2 - 4\mu_R^2$ $(\sim 20\%)$
  outer band also includes :
  $1.35 < m_c < 1.65$ **GeV** $(\pm 12\%)$
  $0.035 < \epsilon < 0.100$ $(+21/-7\%)$

- **Good agreement with *DHVQDIS* for $x_{I\!P} < 0.04$**

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

The open-charm contribution to the diffractive structure function of the proton can be related to the cross section, measured in the full D^* kinematic region, by

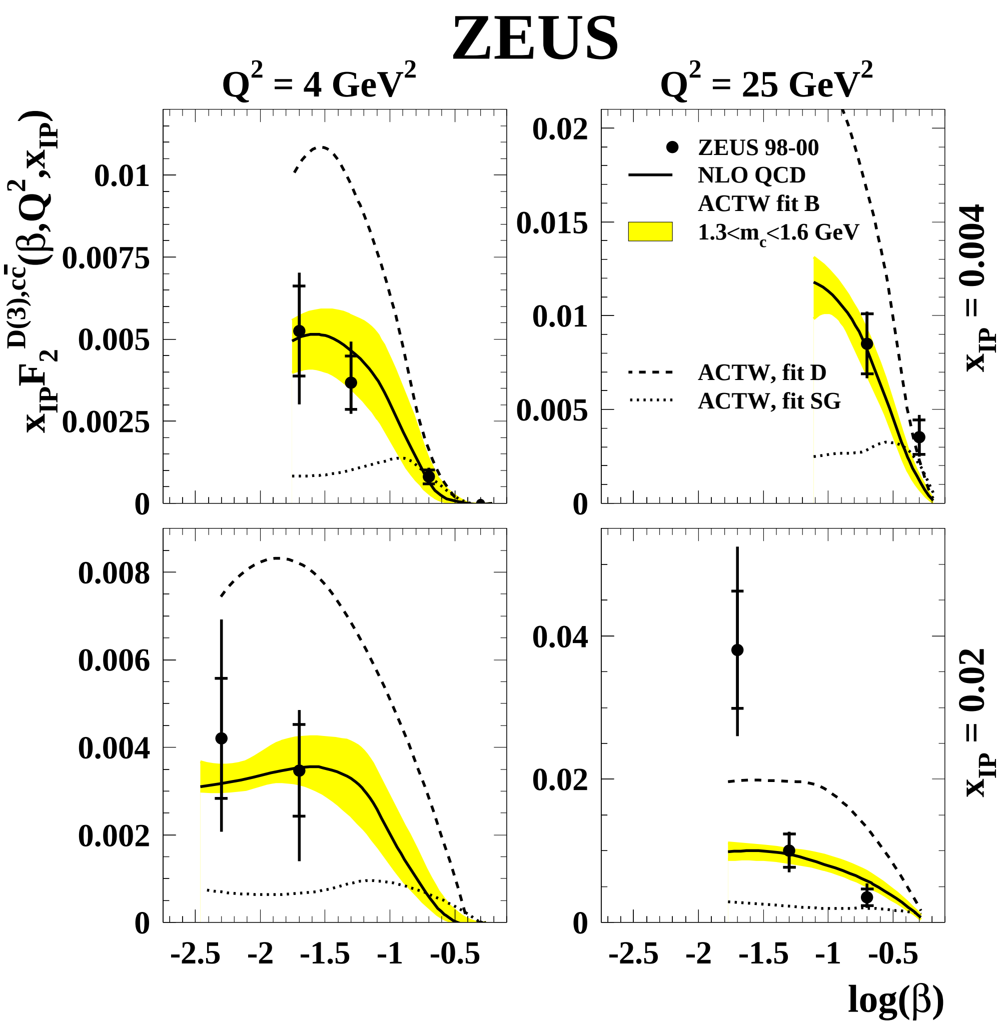
$$\frac{1}{2f(c \rightarrow D^{*+})} \frac{\mathrm{d}^3\sigma_{ep\rightarrow eD^{*\pm}X'p}}{\mathrm{d}x_{I\!P}\mathrm{d}\beta\mathrm{d}Q^2} = \frac{4\pi\alpha_{em}^2}{Q^4\beta}(1-y+\frac{y^2}{2})F_2^{D(3),c\bar{c}}(\beta, Q^2, x_{I\!P})$$

- **The 3d differential cross section was measured & $log(\beta)$ for different Q^2 and $x_{I\!P}$ regions**
- **Extrapolation factors of the measured cross sections to the full $p_T(D^{*\pm})$ and $\eta(D^{*\pm})$ phase space were estimated using the ACTW NLO "fit B" predictions (~ 3.5)**
- **In each bin $F_2^{D(3),c\bar{c}}$ was determined using the formula**

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

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

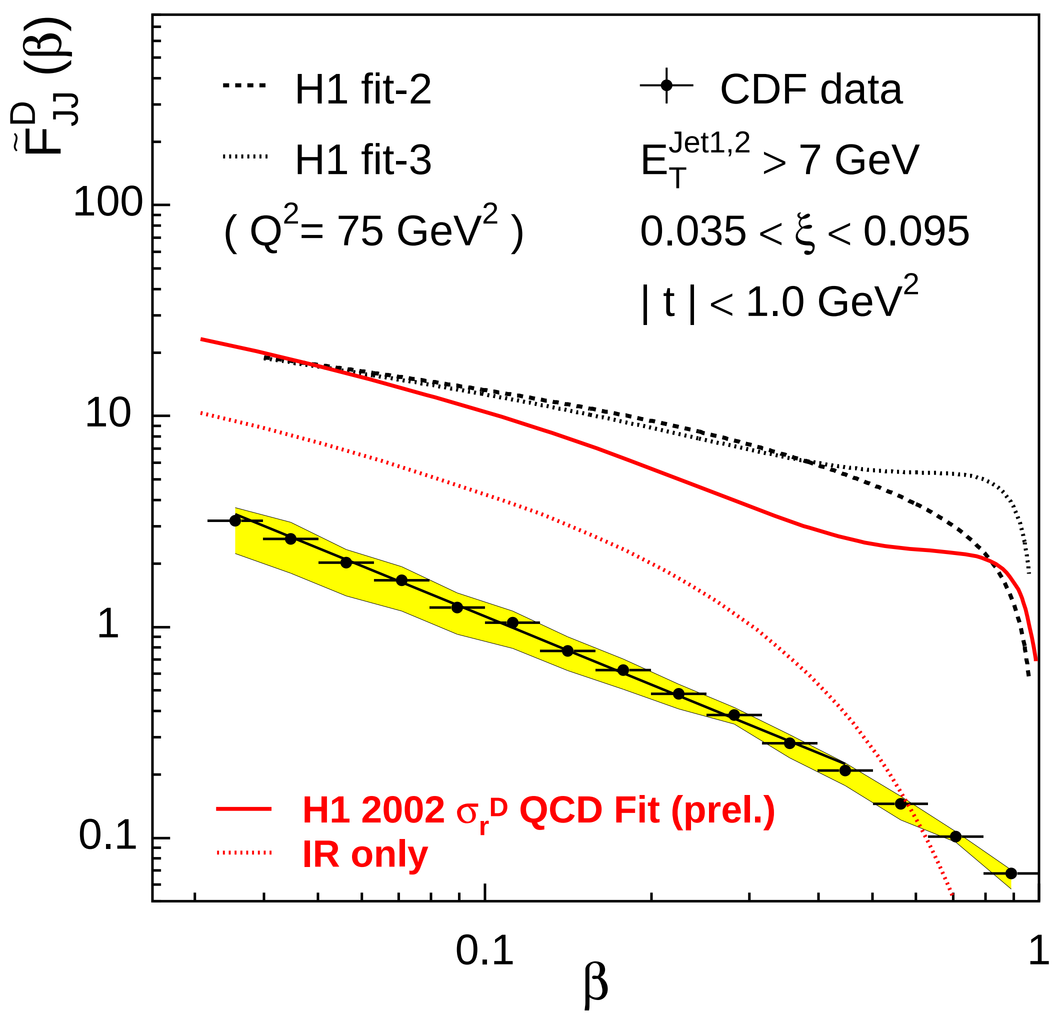
Open-Charm Contribution to $F_2^{D(3)}$



- 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 fits D and SG and concistent with B.

Strong sensitivity to the diffractive parton densities

Dijets with tagged $\bar{p}$ at CDF



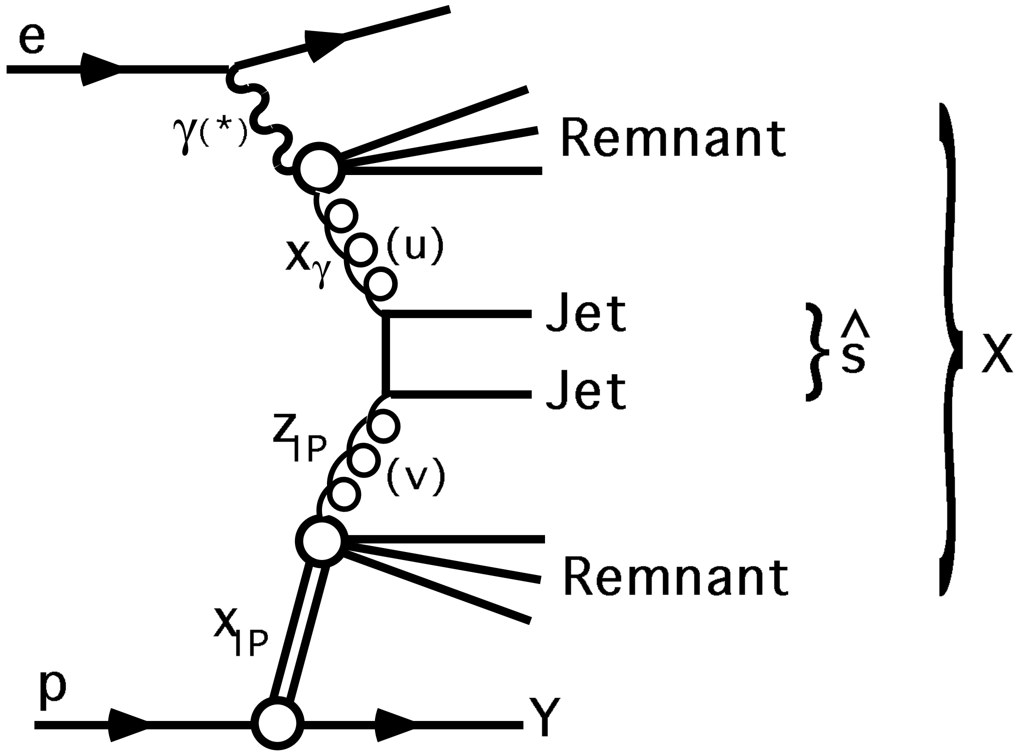
- **The HERA pdf's used to predict the TEVATRON $p\bar{p} \to pX$ results**

$$F^D_{jj}(\beta, \mu^2) = \{\beta g(\beta, \mu^2) + \tfrac{4}{9}\beta q(\beta, \mu^2)\} \otimes f_{I\!P/p}(x_{I\!P})$$

- **Prediction based on H1 pdf's one order of magnitude above CDF dat The breakdown of factorisation ?**

- **The diffractive rate is supressed due to secondary interactions with hadronic system (anti-proton break ing up) ?**

Dijets in Diffractive Photoproduction



QCD Factorisation works in diffractive DIS; tested with charm and jets.

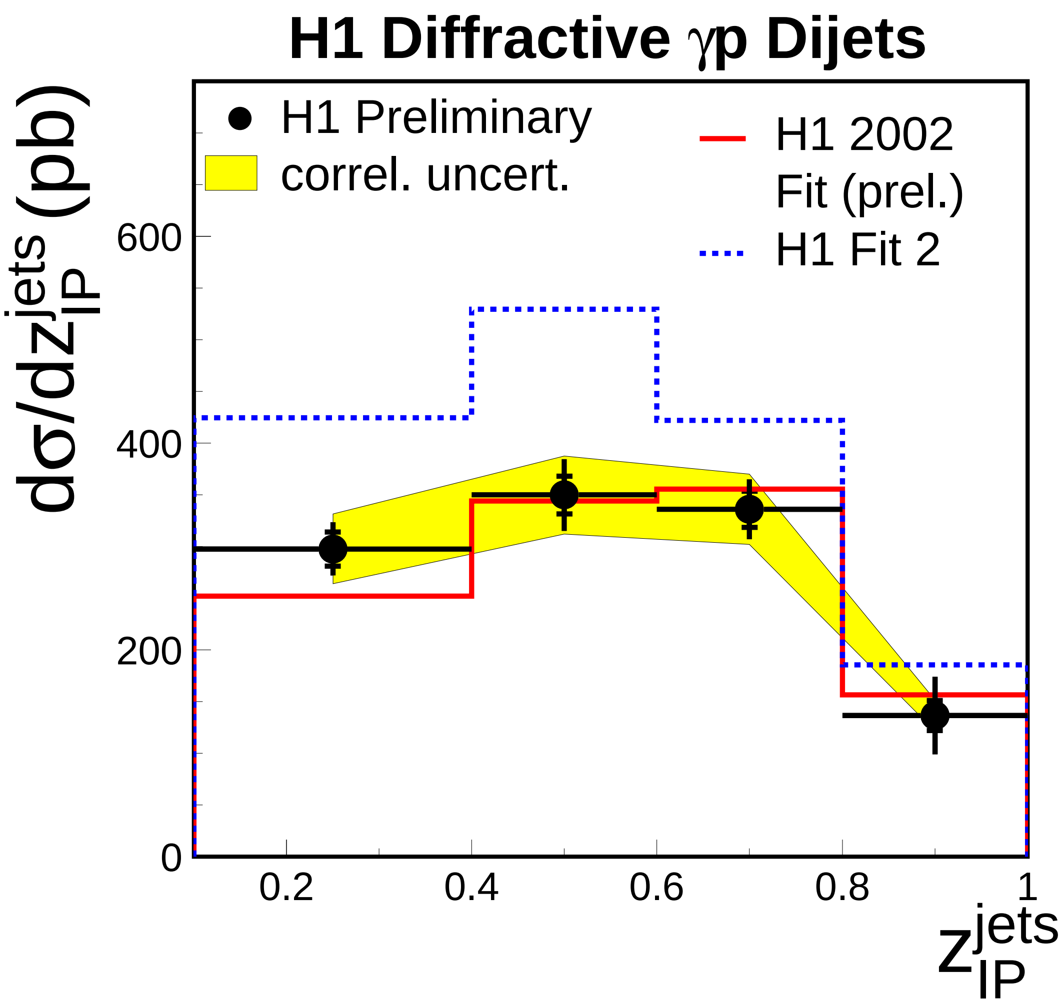
Is it breaking in Photoproduction ?

Quasi-real photon ($Q^2 \approx 0$) can fluctuate into hadronic system.

x_γ - momentum fraction of photon entering the hard process;

- **$x_\gamma = 1$ - DIS-like direct interaction;**
- **$x_\gamma < 1$ - Resolved photon interaction, similar to hadron-hadron scattering**

Dijets in Diffractive Photoproduction



- **Prelim. H1 data :**

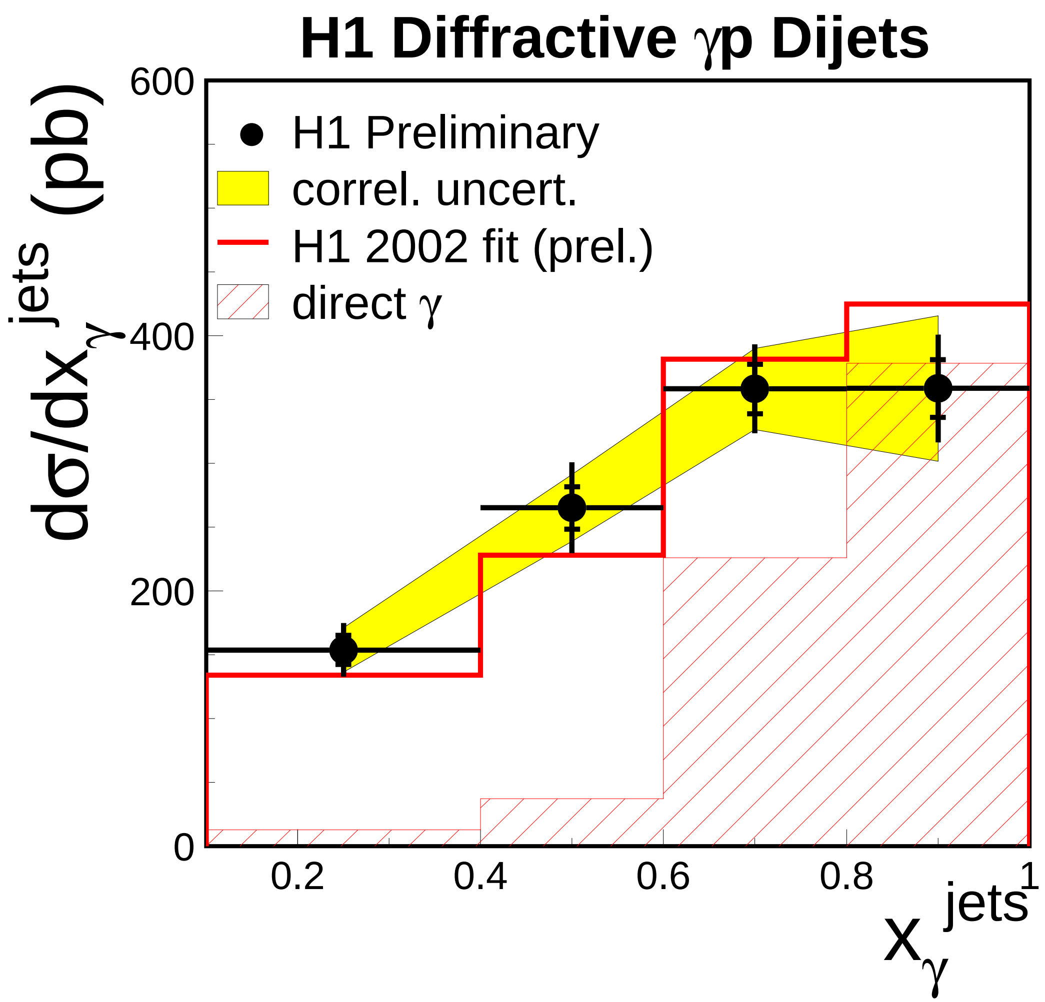
  $Q^2 < 0.01\,\mathbf{GeV^2}$, $165 < W < 240$ **GeV**,
  $x_{I\!P} < 0.03$
  Jets: inclusive k_T algoritm
  $p_{T,1(2)} > 5(4)$ **GeV**

- **MC :**

  LO RAPGAP $\oplus$ parton showers
  $\mu_R = p_T^2$

- **New 2002 LO fit from H1 describes data well**

Dijets in Diffractive Photoproduction



- **New 2002 LO fit from H1 describes direct and resolved contribution**
- **Direct comparison DIS vs γp :**

$$\frac{(\frac{Model}{Data})_{\gamma p}}{(\frac{Model}{Data})_{DIS}} = 1.25 \pm 0.30(exp.)$$

- **No supression of γp with respect to the DIS diffractive jets**

Summary

- **Consistent picture of inclusive diffraction and hadronic final states in DIS. QCD Factorisation even works in dijet photoproduction in HERA. The breakdown of factorisation in CDF ?**

- **Resolved Pomeron model is successful in description of DIS Jet and D^* data**

- **Two-gluon-exchange BJLW model describes DIS Jet and D^* cross sections for $x_{I\!P} < 0.01$, if a minimum value for the transverse momentum of the final-state gluon of $k_{T,g}^{\mathrm{cut}} = 1.5\,\mathbf{GeV}$**

- **Two-gluon-exchange saturation model reproduces D^* cross sections but underestimates the rate of dijets by a factor of ~ 2**

- **Significant contribution of $q\bar{q}g$ with gluon emitted in $I\!P$ direction**

Prospects at HERA II

- **New tools for diffraction:**
  - **Factor** ~ 10 **increase in statistics by the end 2006**
  - **New proton spectrometer (H1 VFPS)**

- **Measured with VFPS** $0.01 < x_{I\!P} < 0.02$ **region with acceptance close to** $100\ \%$ **gives high yields of exclusive final state channels to test pdfs; e.g.** ~ 30000 **DIS dijets,** 500 **DIS** D^*

- **New HERA II data are coming;**
  - **will permit to constrain diffractive model parameters;**
  - **will require further model developments**