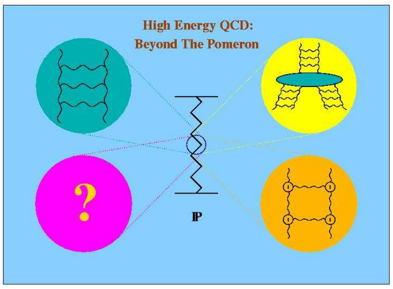
Hard Diffraction at HERA: Results from H1

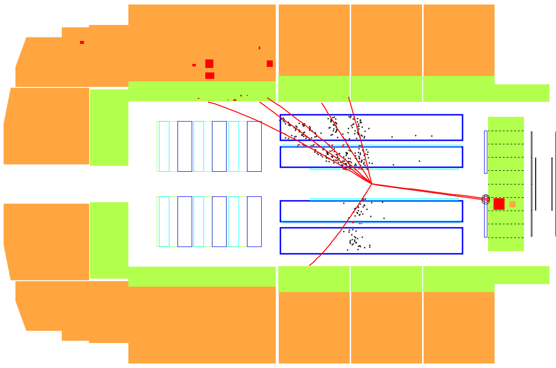
Frank-Peter Schilling / DESY
H1 Collaboration

High Energy QCD – Beyond the Pomeron
BNL, Brookhaven, May 2001

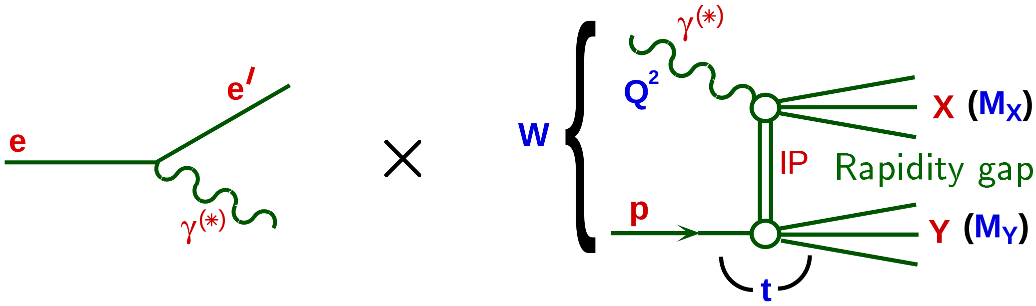


- Inclusive diffraction: F_2^D and the partonic interpretation
- A closer look:
  – Energy flow and thrust
- Diffractive final states in DIS:
  – Dijet and 3-jet production, open charm
- ... and in hadron-hadron(like) interactions:
  – Dijets in diffr. photoproduction [and at the Tevatron]

Hard Diffraction at HERA



Determine q, g structure of colour singlet exchange with point-like γ^* probe in large rapidity gap DIS events



$t = (p - p')^2$:	(momentum transfer)^2 at p vertex
M_X, M_Y:	Masses of X and Y

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

$\longrightarrow$ long. momentum fraction transferred from p to exchange

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

$\longrightarrow$ fraction of exchange momentum carried by q coupling to γ

F_2^D and Factorization(s)

Define diffractive structure function F_2^D:

$$\frac{d^5\sigma(ep \to eXY)}{dx_{I\!P}\, dt\, dM_Y\, d\beta\, dQ^2} = \frac{4\pi\alpha^2}{\beta Q^4}\left(1 - y + \frac{y^2}{2}\right) \times F_2^{D(5)}(x_{I\!P}, t, M_Y, \beta, Q^2)$$

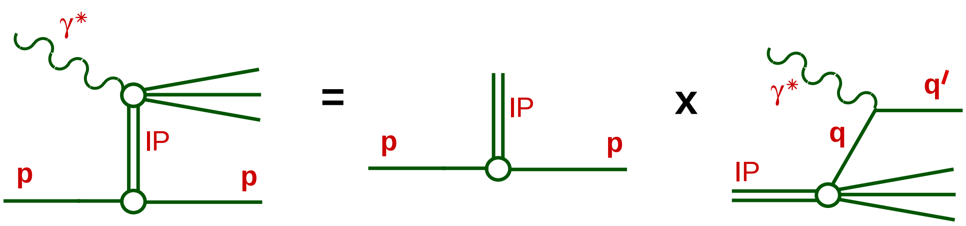
If Y not measured, integ. over M_Y,t $\rightarrow F_2^{D(3)}(\beta, Q^2, x_{I\!P})$

QCD Factorization: [proof John Collins, 1998]

$$F_2^D(x, Q^2, x_{I\!P}, t) \sim C_i \otimes p_i^D \quad (\text{+higher twist})$$

- valid at fixed $x_{I\!P}$, t
- p_i^D: 'conditional probabilities', obey DGLAP evolution
- determine p_i^D in inclusive diffr. scattering, then predict exclusive processes

Regge Factorization: [additional assumption]

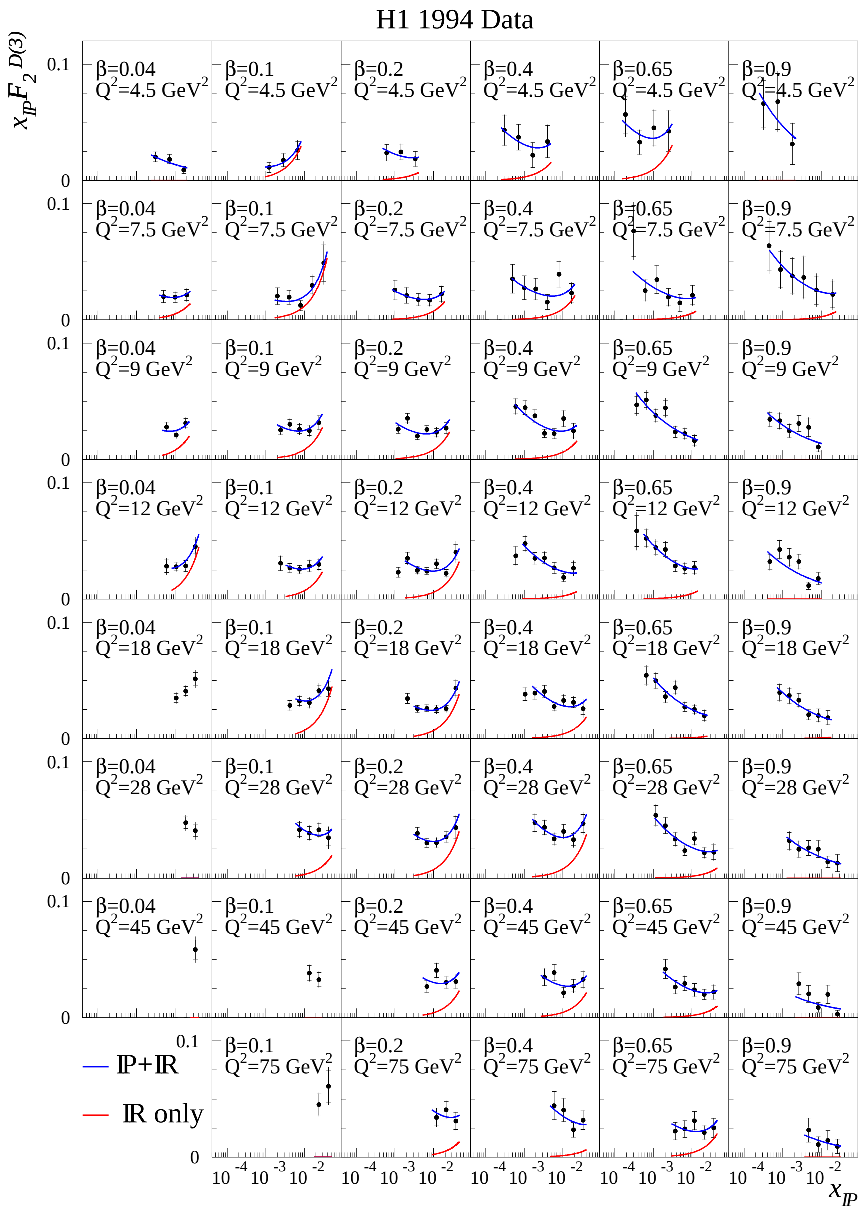


$$F_2^D(x_{I\!P}, t, \beta, Q^2) = f_{I\!P/p}(x_{I\!P}, t) \times F_2^{I\!P}(\beta, Q^2)$$

$F_2^{D(3)}$ at medium $Q^2 = 4.5 \ldots 75$ GeV^2

$x_{I\!P} F_2^D$ $\beta \rightarrow$

Q^2 $\downarrow$



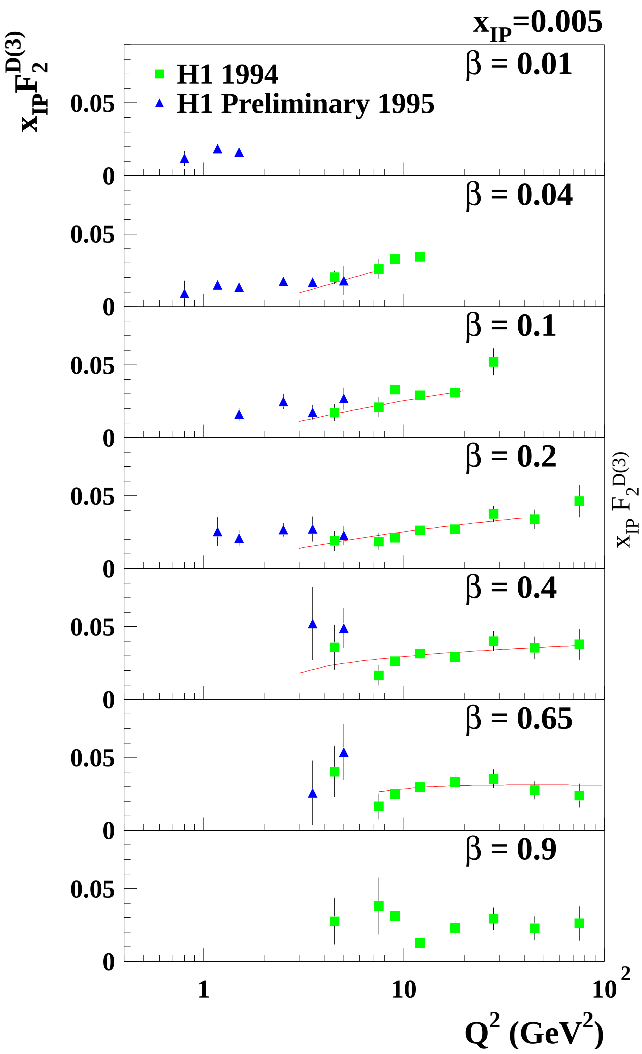
$x_{I\!P}$

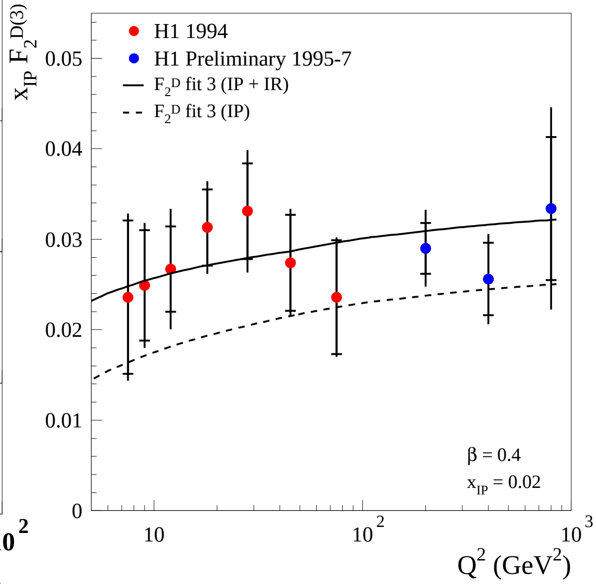
$$F_2^D \sim f_{I\!P/p}(x_{I\!P}, t)\ F_2^{I\!P}(\beta, Q^2)\ +\ f_{I\!R/p}(x_{I\!P}, t)\ F_2^{I\!R}(\beta, Q^2)$$

$$\alpha_{I\!P}(0) = 1.20 \pm 0.04 \qquad \alpha_{I\!R}(0) \approx 0.6$$

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

F_2^D vs Q^2 at fixed $x_{I\!P}$:



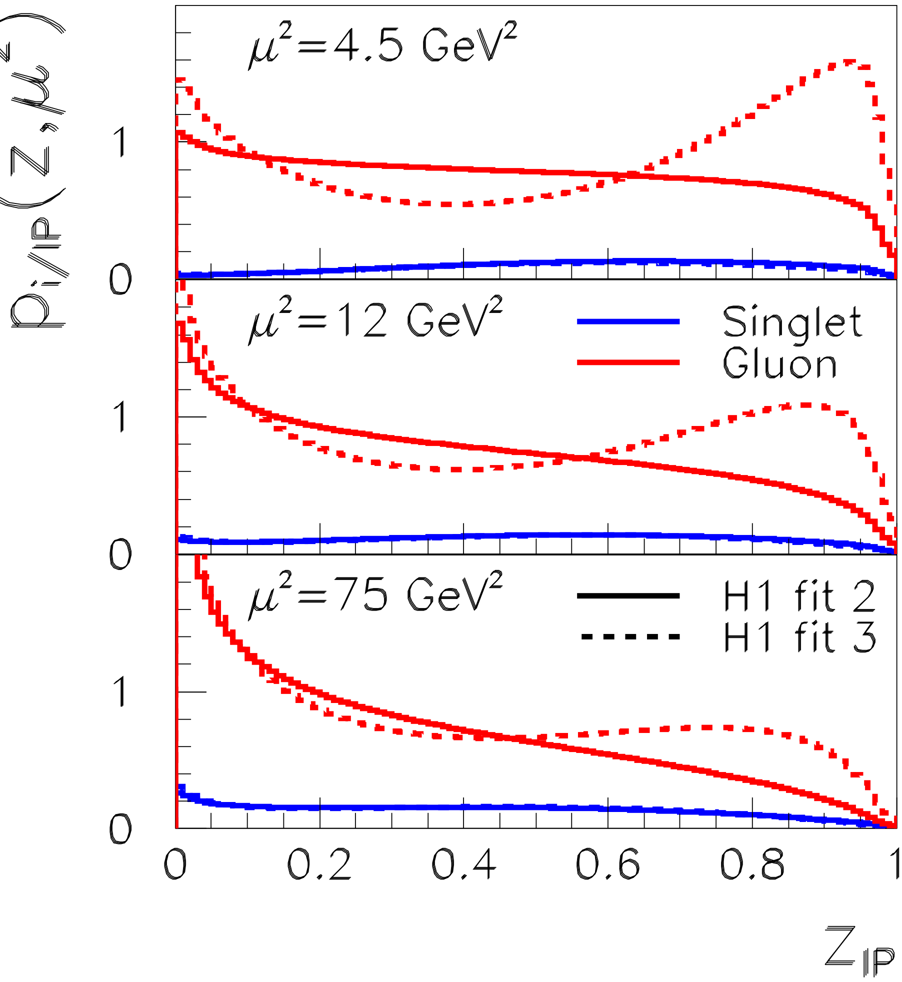


- flat or positive scaling violations over whole β and Q^2 range

Strongly suggestive of gluon dominated exchange !

Parton Distributions of Diffractive Exchange

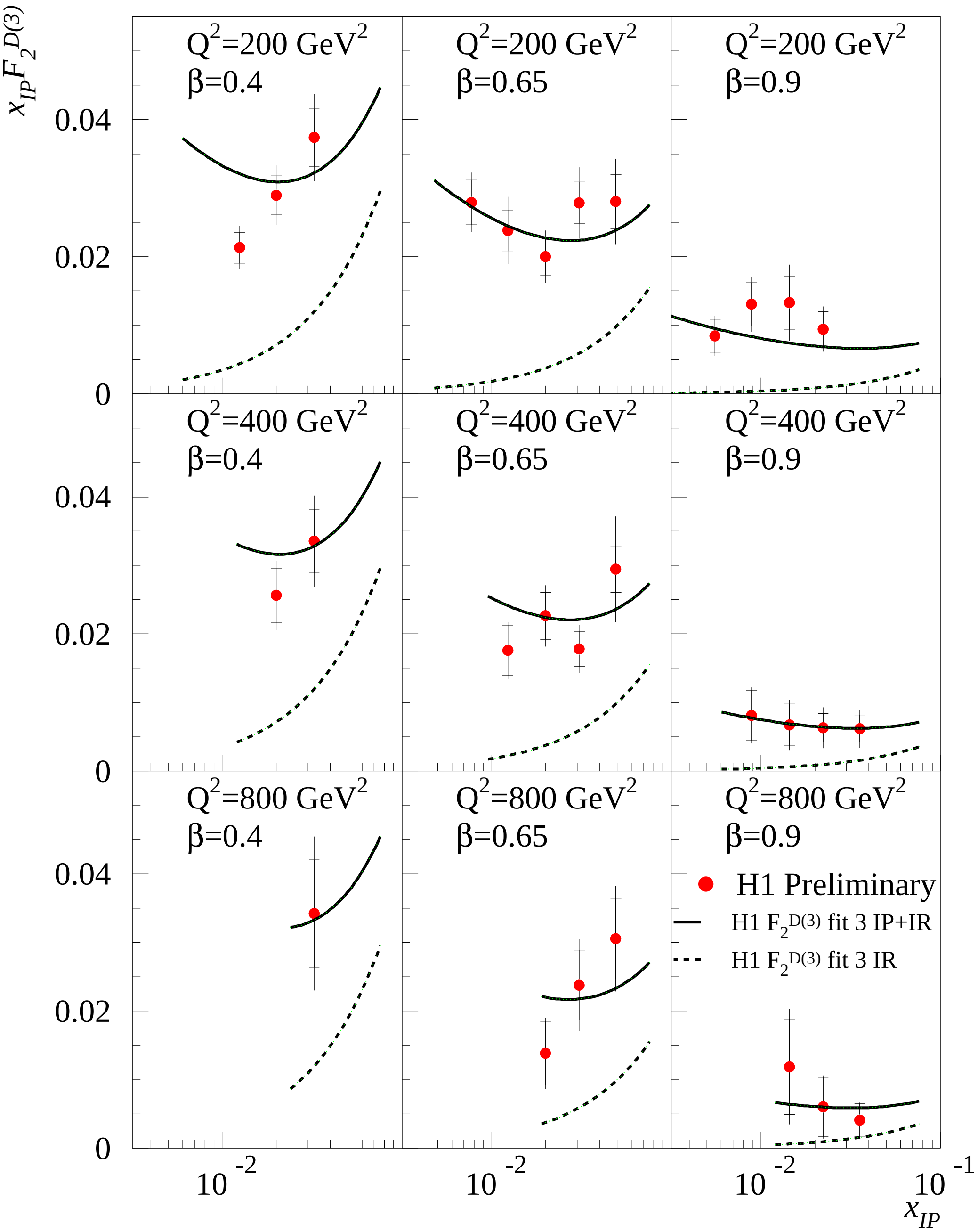
DGLAP QCD fit to F_2^D: $I\!P$ parton distributions:



- gluon $\gg$ quark singlet !
- Uncertainty on g^D, especially at large z !

Use to predict diffractive final state cross sections !

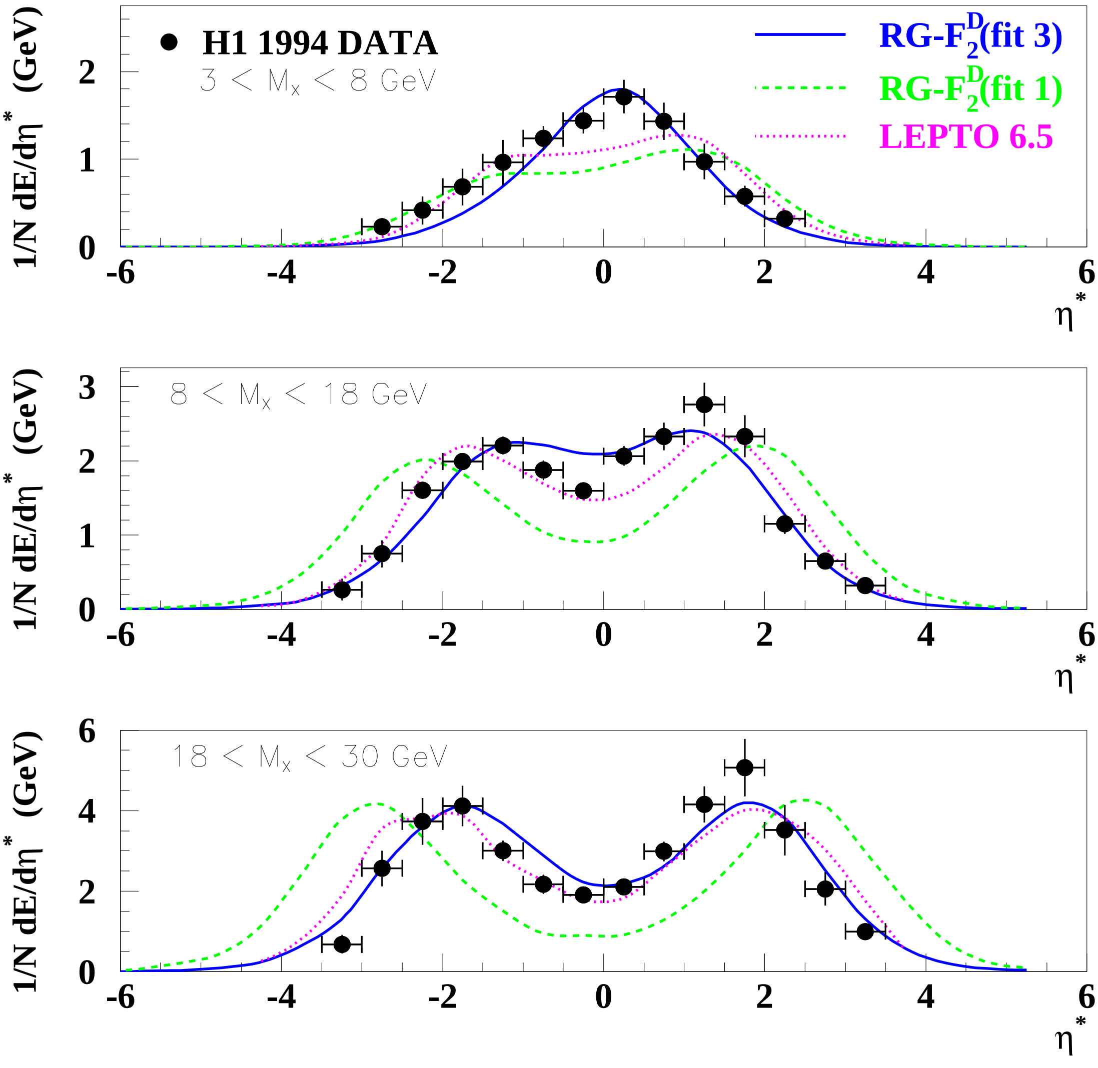
$F_2^{D(3)}$ at high $Q^2 = 200 \ldots 800\ \mathrm{GeV}^2$



- Good description by QCD fit extrapolated to high Q^2, even at high β (excluded from fit)

Confirmation: Energy Flow

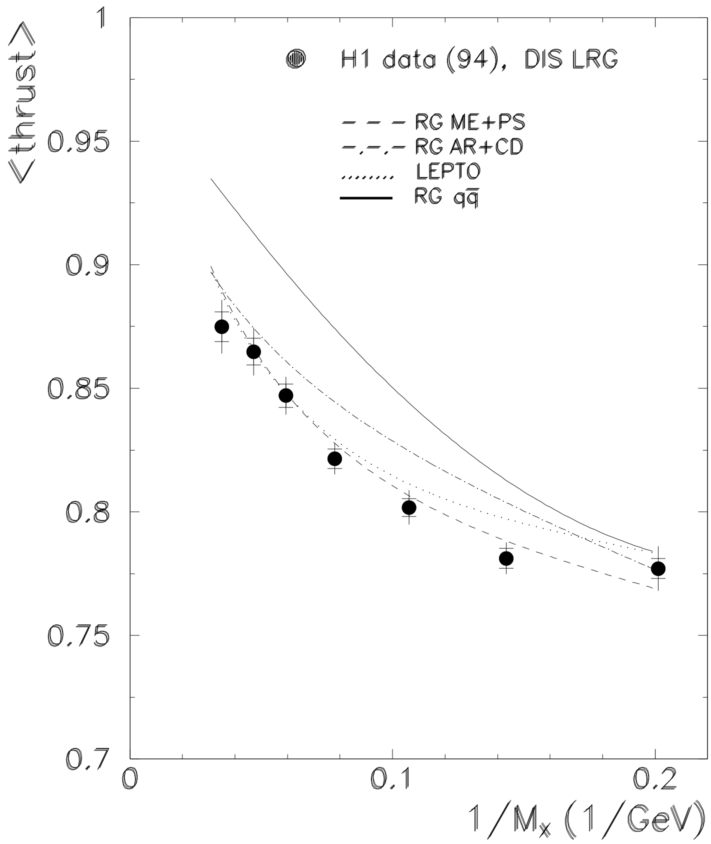
Average transverse energy as a function of η in M_X bins:



Need g-dominated $I\!P$ to model energy flow !

Confirmation: Thrust

Average thrust as function of $1/M_X$:



- Thrust smaller than in e^+e^-
  $\rightarrow g$ radiation more important
- ZEUS recently clearified long-standing disagreement with H1; now consistent

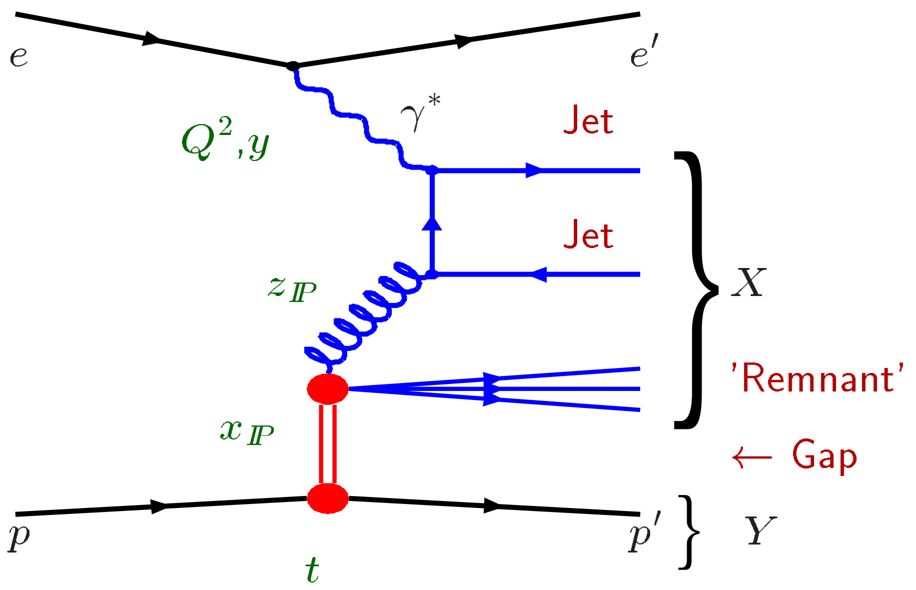
Need g-dominated $I\!P$ to model thrust !

Diffractive Dijet Production in DIS [hep-ex/0012051]

Motivation:

- Direct sensitivity to g^D through $\mathcal{O}(\alpha_s)$ process (boson gluon fusion):
- Jet P_T provides second hard scale

Kinematics (in partonic picture):



M_{12}

– Invariant mass of two leading jets

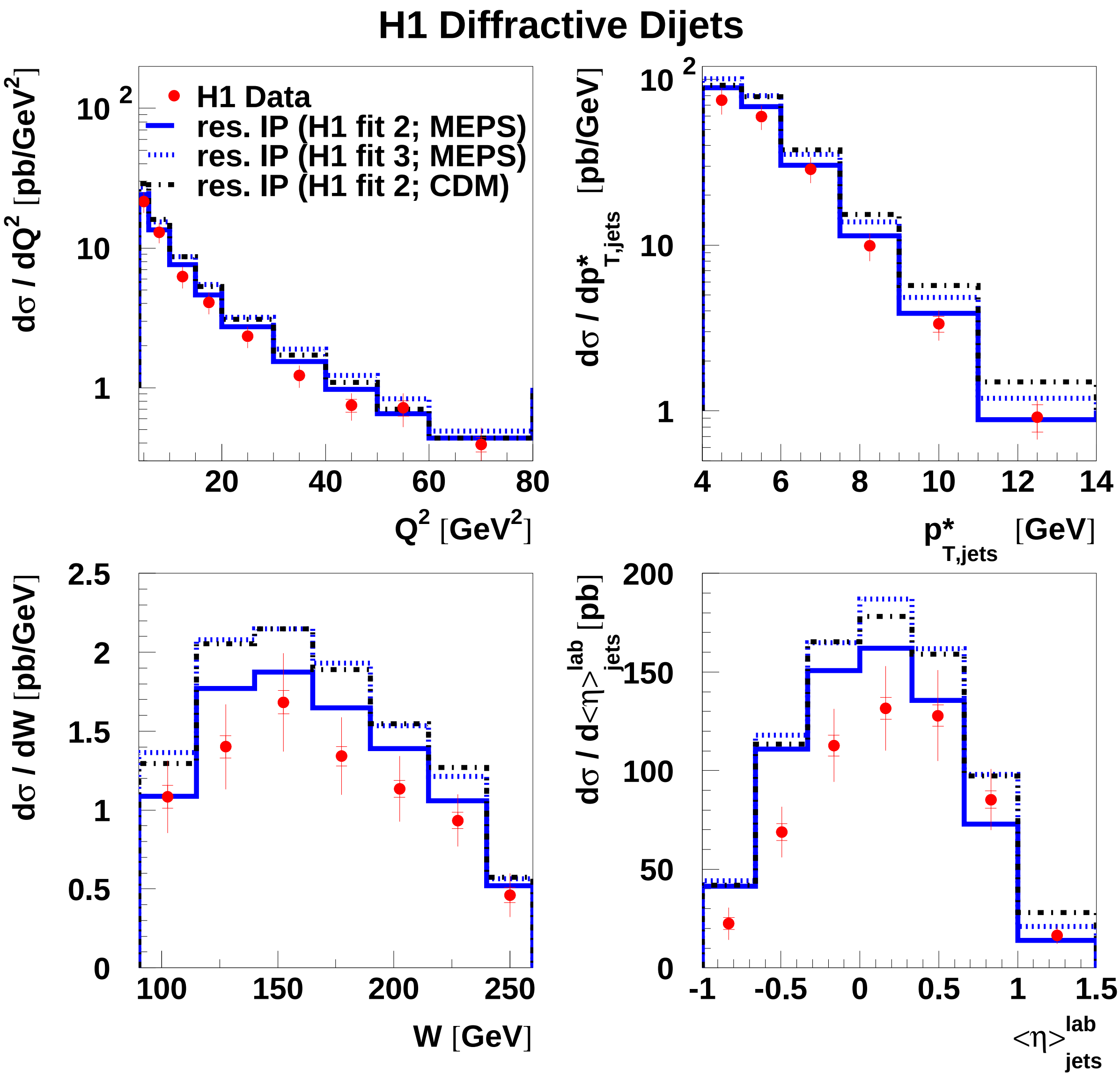
$$z_{I\!P}^{(jets)} \approx \frac{Q^2+M_{12}^2}{Q^2+M_X^2}$$

– Momentum fraction of exch. entering hard scattering

QCD Factorization @ Work

Predict diffr. dijet cross sections with PDF's obtained from inclusive $F_2^{D(3)}$ measurement:

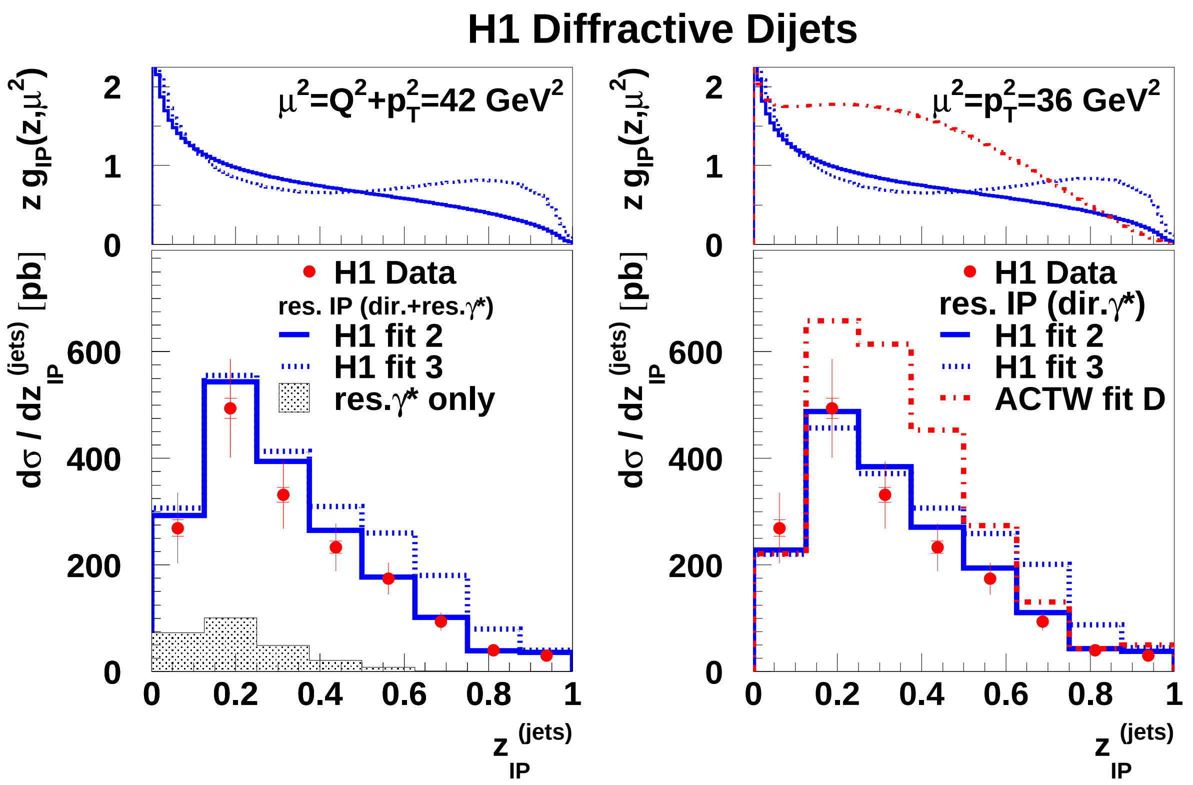
[resolved γ^* component included]



⇒ Consistent with QCD factorization in diffr. DIS !

Diffractive Gluon Distribution

Dijets directly constrain shape and normalization of g^D:



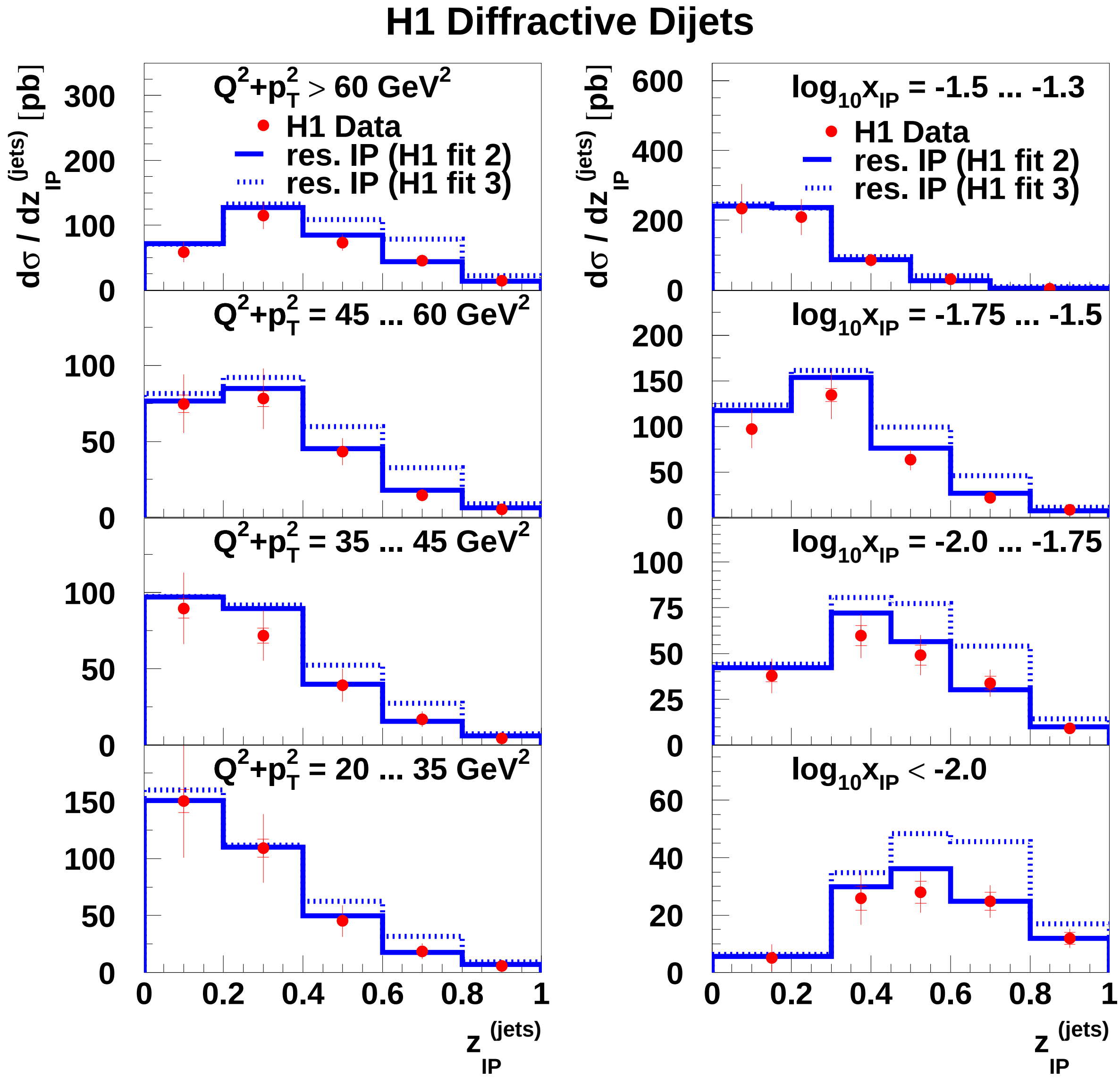
[res. γ^*, $I\!\!R$ and quark contributions small]

- H1 fit 2: very good agreement with data
- H1 fit 3: overshoots at high $z_{I\!\!P}$
- ACTW-D: too high

⇒ Support for factorizable diffr. PDF's in DIS which are gluon-dominated and rather flat in z

Proton rest frame picture: $q\bar{q}g \gg q\bar{q}$ states

Features of Diffractive PDF's

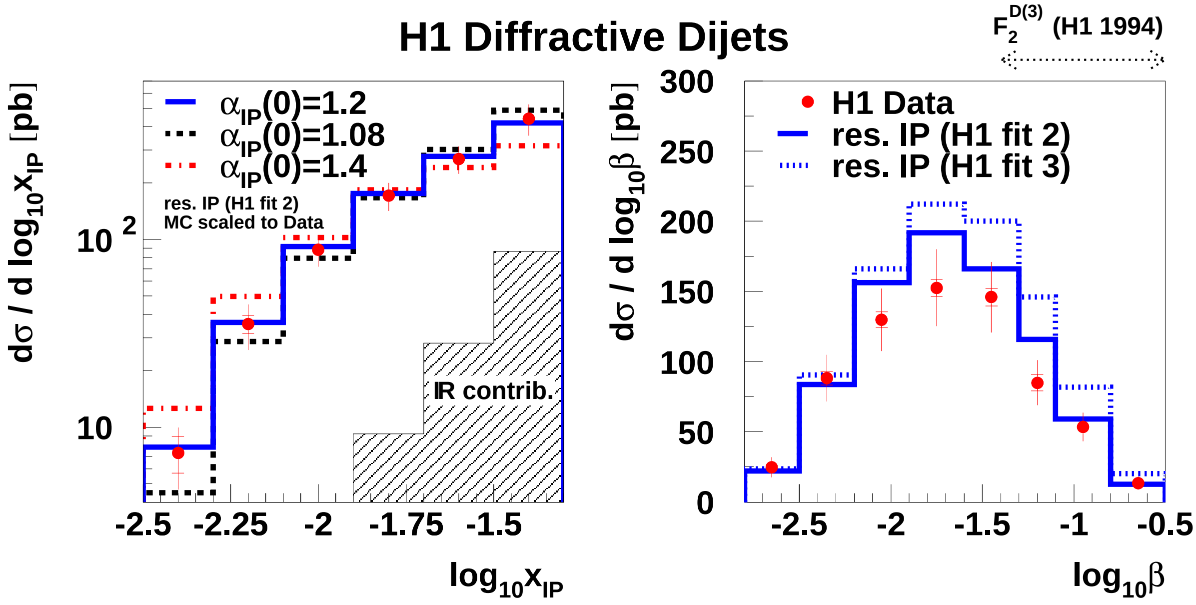


- Data consistent with DGLAP evolution of PDF's with factorization scale $\mu^2 = Q^2 + p_T^2$
- Also compatible with factorization of $x_{I\!P}$ dependence $[f_{I\!P/P}(x_{I\!P}) \otimes p_i^D(z, \mu^2)]$

  No visible variation of $\alpha_{I\!P}(0)$ with $z_{I\!P}$ [see BEKW]

Energy dependence $\alpha_{I\!P}(0)$

- Shape of $x_{I\!P}$ distribution sensitive to energy dependence of cross section:



Parameterization used:

$$f_{I\!P/P}(x_{I\!P}, t) \sim \left(\frac{1}{x_{I\!P}}\right)^{2\alpha_{I\!P}(t)-1} e^{Bt}$$

$$\alpha_{I\!P}(t) = \alpha_{I\!P}(0) + \alpha'_{I\!P} t \quad [B = 4.6\ \mathrm{GeV}^{-2},\ \alpha'_{I\!P} = 0.26\ \mathrm{GeV}^{-2}]$$

Fit Result:

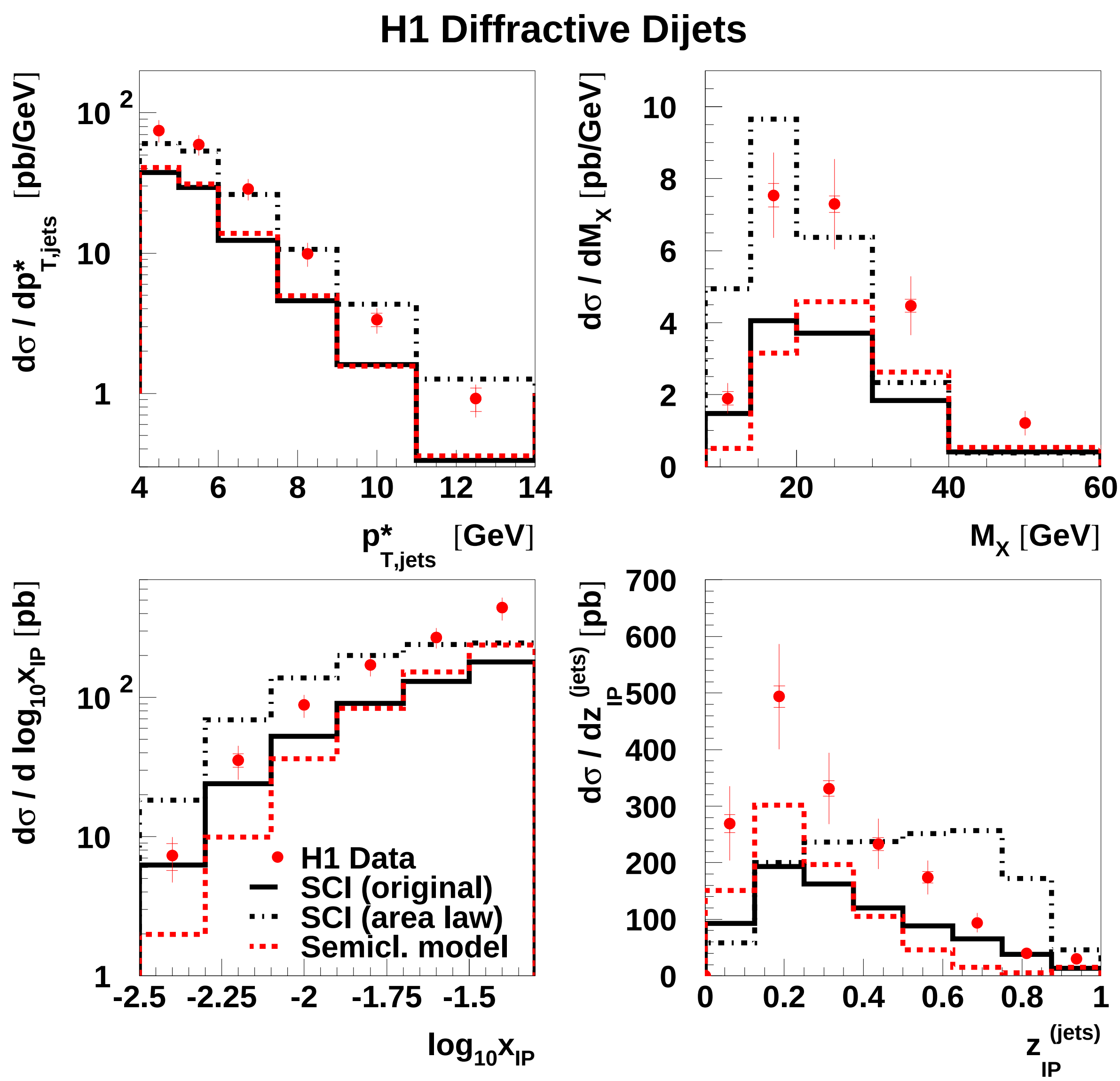
$$\alpha_{I\!P}(0) = 1.17\ ^{+0.03}_{-0.03}\ (\mathrm{stat.})\ ^{+0.06}_{-0.06}\ (\mathrm{syst.})\ ^{+0.03}_{-0.07}\ (\mathrm{model})$$

$\Rightarrow$ Consistent with H1-$F_2^{D(3)}$ [Q^2 similar]

- β distribution: Jets are small β, compared with F_2^D

Soft Colour Neutralization

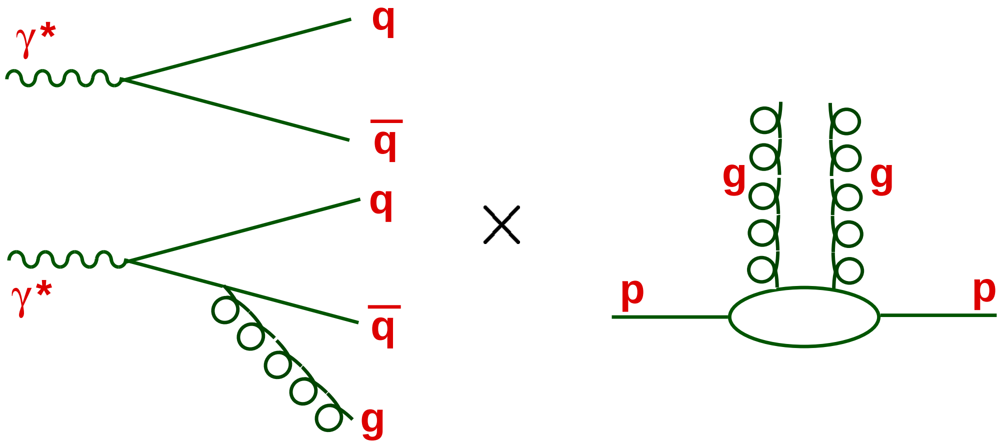
- Soft Colour Interactions SCI (Edin, Ingelman, Rathsman) original version and "generalized area law" (Rathsman)
- Semiclassical Model (Buchmüller, Gehrmann, Hebecker)



⇒ Sensitivity to differences between models which all (have been tuned to) describe $F_2^{D(3)}$!

Colour Dipole / 2-Gluon Exchange Models

Proton rest frame picture: $q\bar{q}$, $q\bar{q}g$ photon fluctuations scatter elastically off proton by 2-gluon exchange



$$\sigma_{T,L}^{\gamma^* p} \sim |\Psi_{T,L}(\alpha, \mathrm{r})|^2 \otimes \hat{\sigma}^2(r^2, x, \ldots)$$
$$\hat{\sigma}(x, \mathrm{r}) \sim \int \frac{\mathrm{d}^2\mathrm{k}_t}{k_t^2} \left[1 - \mathrm{e}^{i\mathrm{r}\cdot\mathrm{k}}\right] \alpha_s(k_t^2)\, \mathcal{F}(x, k_t^2)$$

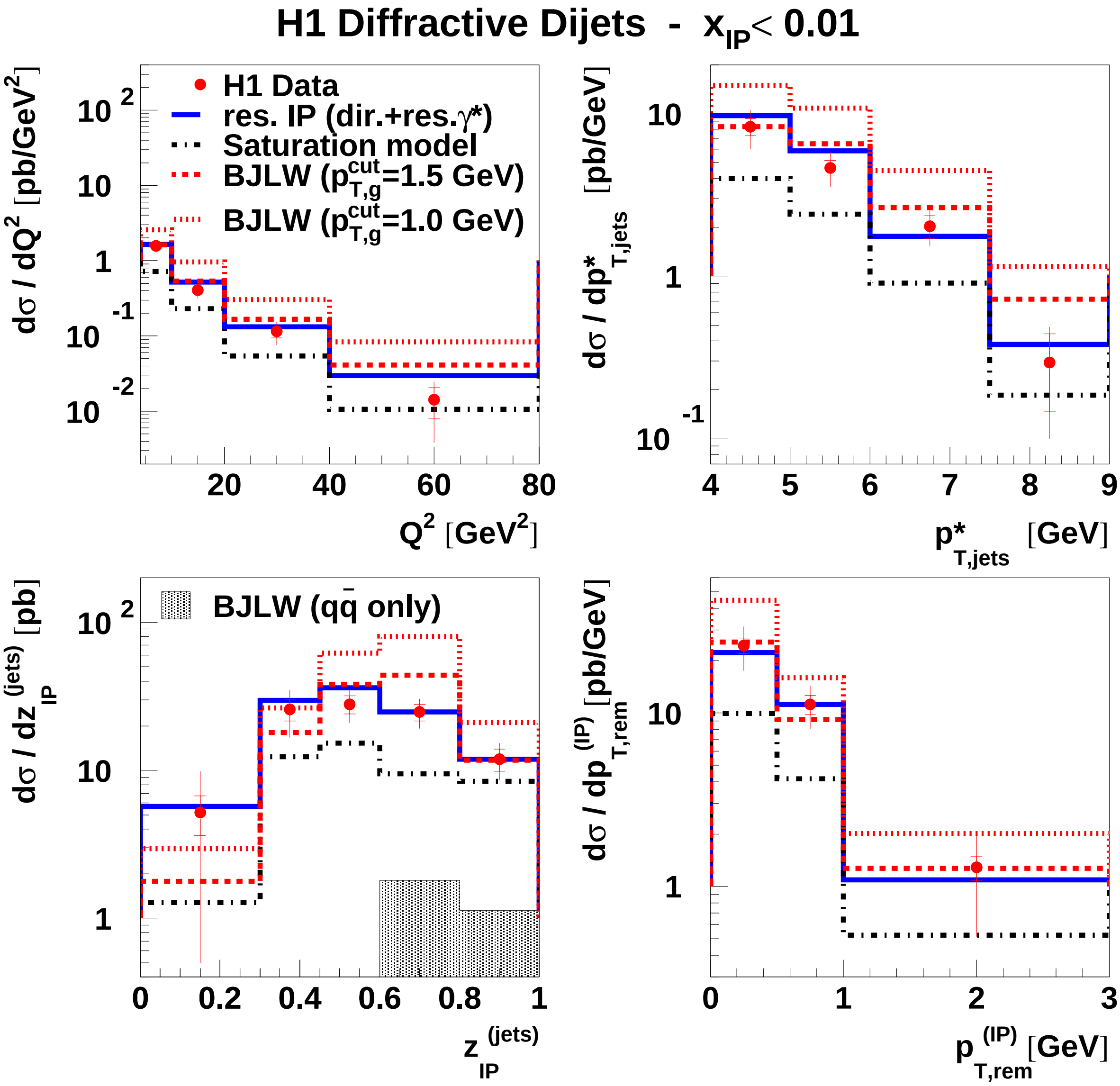
[$\mathcal{F}(x, k_t^2)$: unintegrated gluon distribution]

- BJLW Model [Bartels et al.]:
  - calculation for high p_T diffractive final states
  - $p_{T,g} > p_{T,q}$ included (unordered p_T)
  - $\mathcal{F}(x, k_T^2)$: Derivative of GRV NLO

- Saturation Model [Golec-Biernat,Wüsthoff]:
  - $p_{T,g} \ll p_{T,q}$ required (p_T ordering)
  - $\mathcal{F}(x, k_T^2)$ parameterized from fit to $F_2(x, Q^2)$

Colour Dipole / 2-Gluon Exchange Models

$x_{I\!P} < 0.01$ $\Rightarrow$ avoid $I\!R$ exch.; P PDF's g-dominated



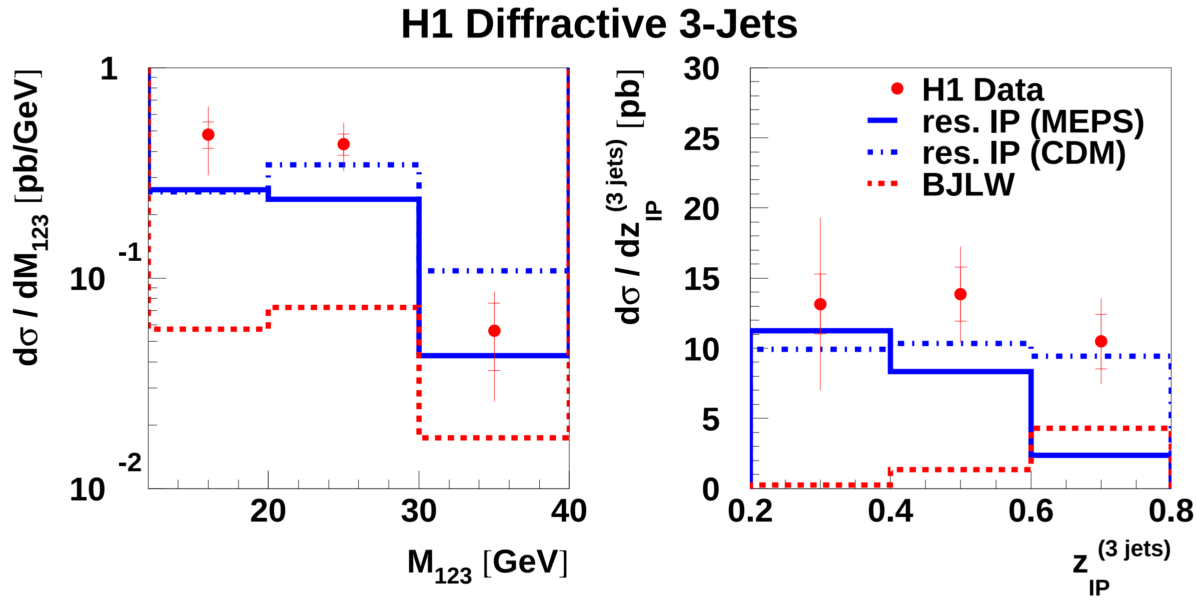
p_T of "$I\!P$ remnant"

- tiny $q\bar{q}$ contribution
- BJLW $\sim$ OK if $p_{T,g} > 1.5$ GeV
- Saturation Model too low
- $p_{T,rem}^{(I\!P)}$ not able to discriminate ;-(

3-Jet Production

Features:

- Limited statistics: 130 3-jets for $\mathcal{L} = 18.0\ \text{pb}^{-1}$
- Kinematically forced to $x_{I\!P} > 0.01$

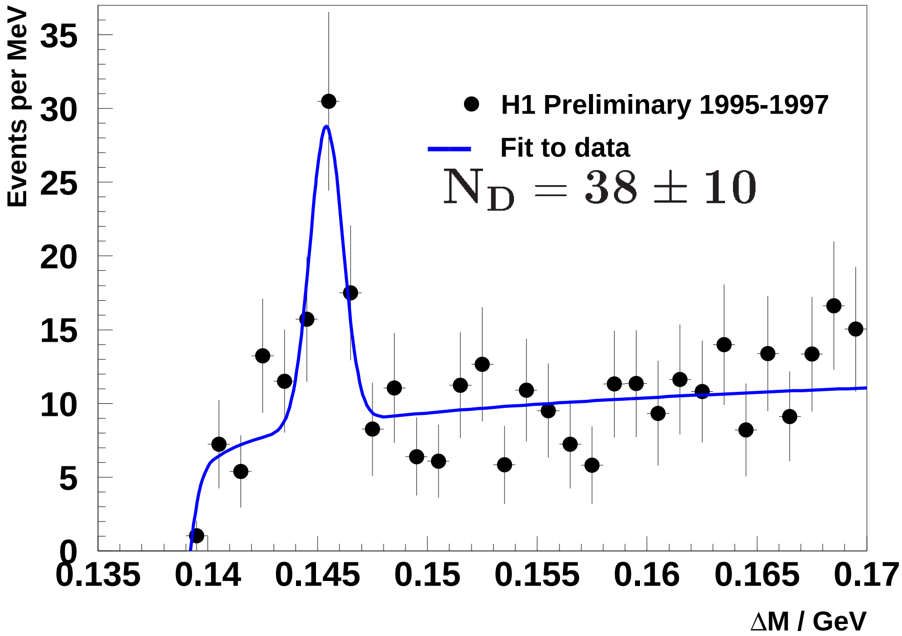


- Data above LO QCD prediction based on diffr. PDF's if MEPS is used for higher order approximation
- CDM does better job

[Difference MEPS/CDM much smaller for dijets]

- 2-gluon exchange (BJLW) low

Diffractive Open Charm Production (D^*)



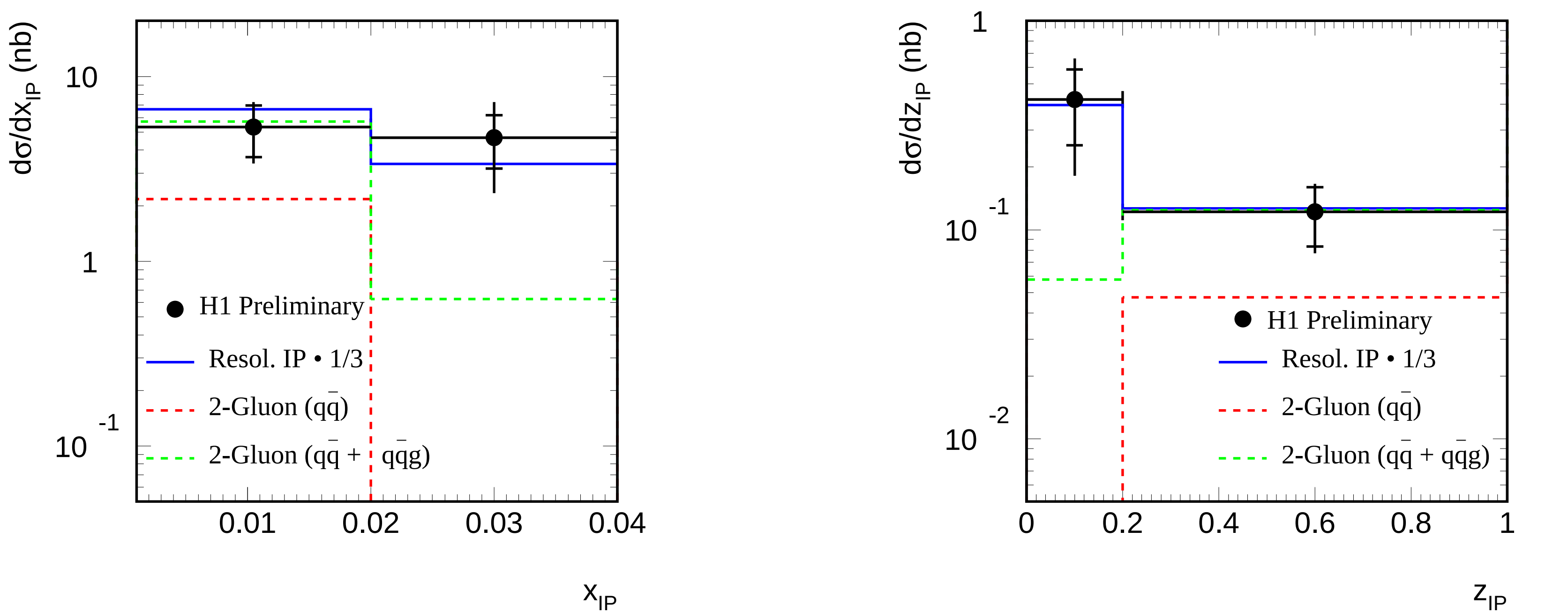
$$
\begin{aligned}
2 < \quad & Q^2 & < 100\ \mathbf{GeV}^2 \\
0.05 < \quad & y & < 0.7 \\
& p_T(D^{*\pm}) & > 2\ \mathbf{GeV} \\
& |\eta(D^{*\pm})| & < 1.5 \\
& x_{I\!P} & < 0.04 \\
& M_Y & < 1.6\ \mathbf{GeV} \\
& |t| & < 1\ \mathbf{GeV}^2
\end{aligned}
$$

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

(H1 preliminary)

Statistics still very limited.

Diffractive D^* Production



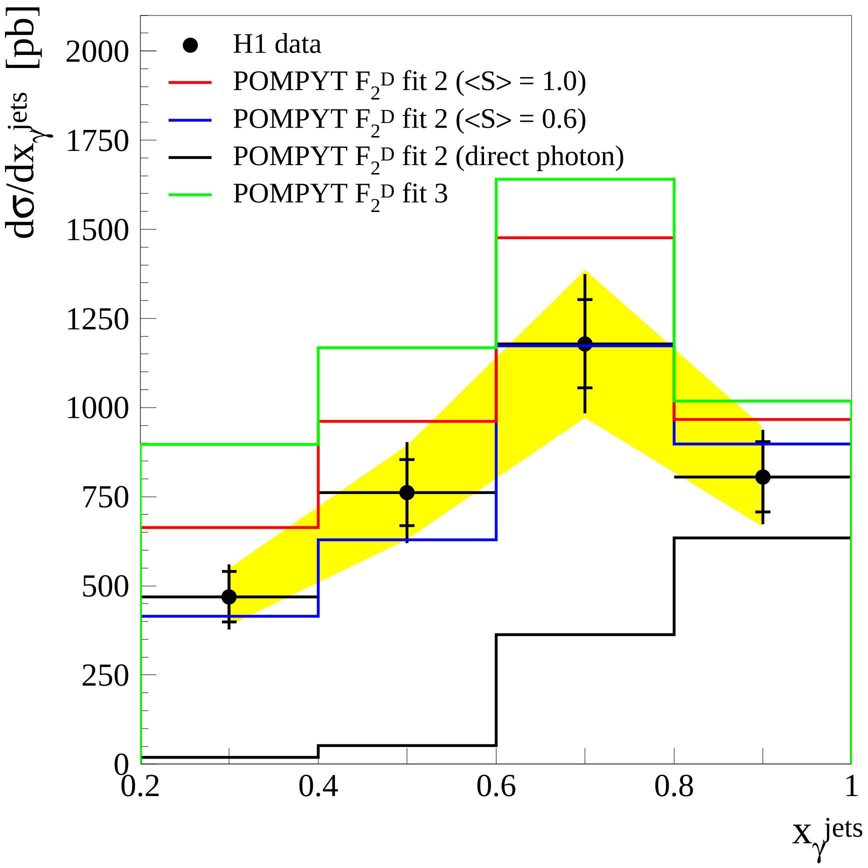
$\Rightarrow$ H1 fit predicts three times higher cross section !

$\Rightarrow$ Broken factorization (Errors still large)?

$\Rightarrow$ 2-gluon, $q\bar{q} + q\bar{q}g$ calculation (Bartels et al.) OK at small $x_{I\!P}$, high $z_{I\!P}$!

Dijets in Diffr. Photoproduction ($Q^2 \approx 0$)

x_γ dependence of cross section:



- Resolved γ similar to hadron-hadron
- Suppression factor $S = 0.6$ at small x_γ necessary !

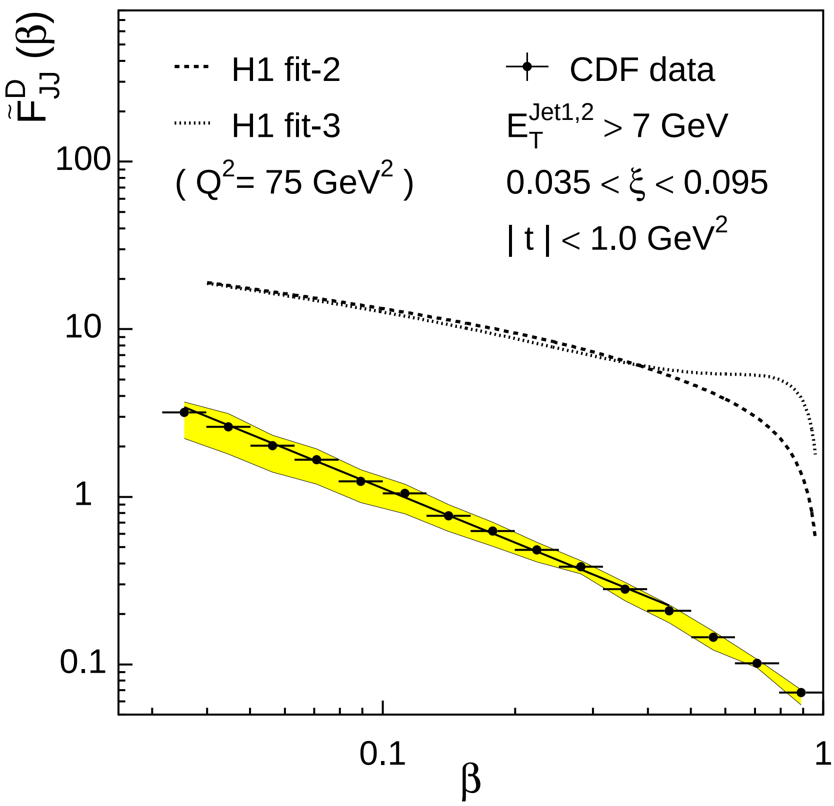
⇒ Factorization broken ? (Large errors...)

[New measurement in progress...]

Crossing the Atlantic: Factorization broken!

CDF measurement of diffractive dijet production
with leading anti-proton in $p\bar{p}$ collisions:

Effective diffr. structure function $\bar{F}^D_{JJ}(\beta)$



- Prediction based on diffractive PDF's extracted at HERA one order of magnitude above measured cross section!

⇒ Serious breaking of factorization!

Important to understand to get unified picture!

Summary and Conclusions

Diffractive dijet production (and F_2^D):

- Diffr. Dijets tightly constrain diffractive gluon distribution g^D (shape and norm.), in contrast to $F_2^{D(3)}$ measurements
- Data favour diffr. PDF's, evolving with DGLAP, strongly dominated by gluons with momentum distribution rel. flat in z ("H1 fit 2")
- Consistent picture from $F_2^{D(3)}$ and jet measurements: Concept of factorizing diffr. PDF's in DIS [Collins] works.
- Consistent with factorizing $x_{I\!P}$ dependence with $\alpha_{I\!P}(0) = 1.17$ ("Regge factorization")
- SCI and Semiclassical models not yet able to simultaneously give correct shape and normalizations of jet cross sections
- Improved models calculations based on 2-gluon exchangecan describe part of dijet cross section

Indications for breakdown of Factorization ?

- Suppression of open charm (D^*)
- Suppression of $x_\gamma < 1$ dijets for $Q^2 \approx 0$