Diffractive Jet Production in DIS - Testing QCD Factorization

hep-ex/0012051, acc. by Eur. Phys. J. C

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H1 Collaboration

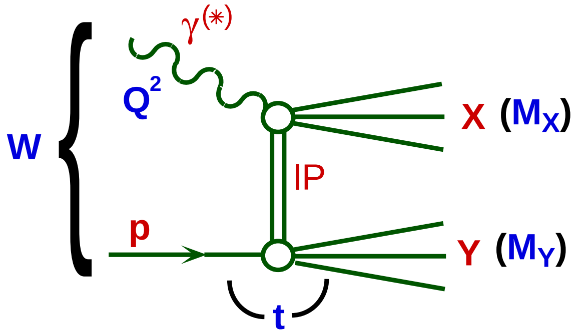
DIS 2001, Bologna, April 2001

Motivation

Diffractive DIS: probe colour singlet exch. w/ pointlike γ^*

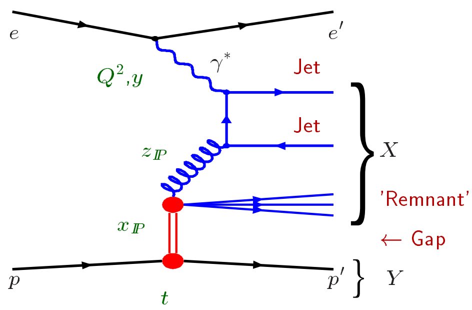
$\Rightarrow$ Determine QCD structure:

[Inclusive ($F_2^{D(3)}$)]



$\Rightarrow$ (mainly) sensitive to q

[Jet production]



$\Rightarrow$ sensitive to g

- Diffractive parton distributions:

  Factorization proof for diffr. DIS [Collins]:

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

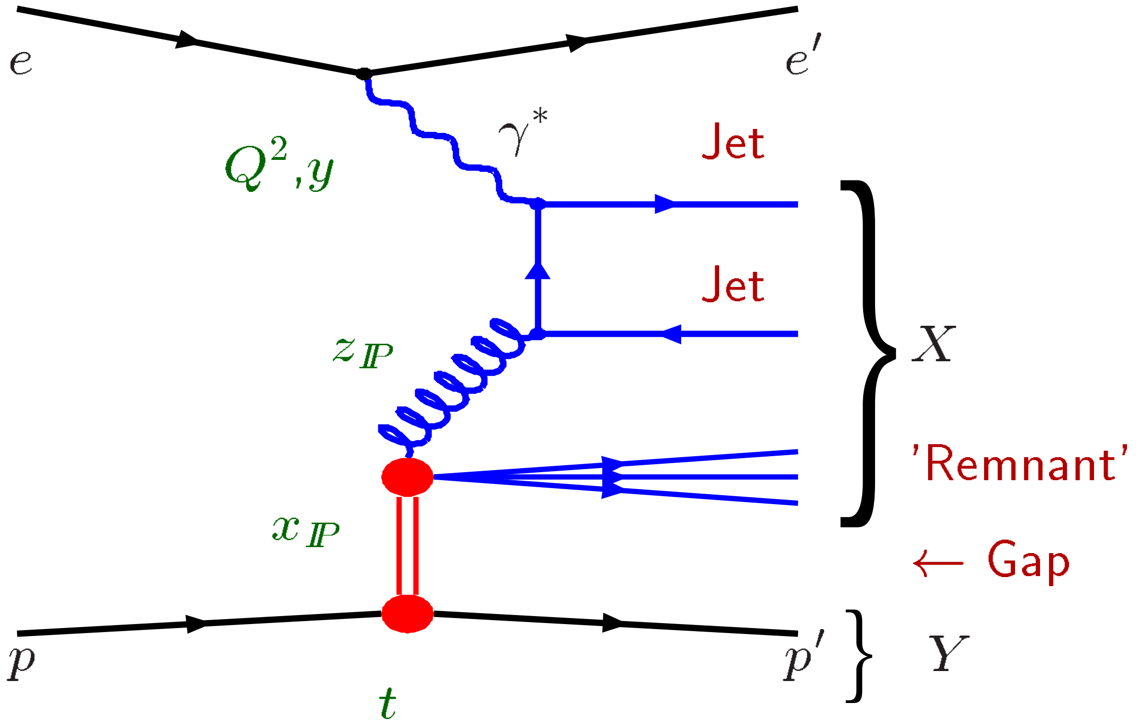
  - Constrain g^D with jets
  - Consistent picture from $F_2^{D(3)}$ and Jets ?

- $x_{I\!P}$ (Regge) factorisation / $\alpha_{I\!P}(0)$
- Resolved virtual photon contribution

- Colour dipole / 2-gluon exchange models
- Soft colour neutralization models

- 3-jet production

Kinematics



Q^2, y

– Usual DIS variables

M_X

– Invariant mass of X system

M_{12}

– Invariant mass of two leading jets

$x_{I\!P} \approx \frac{Q^2+M_X^2}{Q^2+W^2}$

– Momentum fraction carried by colourless exchange

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

– Momentum fraction of exch. entering hard scattering

Data Selection

- DIS Selection:
  Identification of scattered electron in "backward" calorimeter

- Diffractive Selection:
  "Rapidity gap" selection: no hadr. activity in "forward" (outgoing p) region ($3.2 < \eta < 7.5$)

- Jet Selection:
  CDF cone algorithm in $\gamma^* p$-CMS, $p_T^* > 4$ GeV

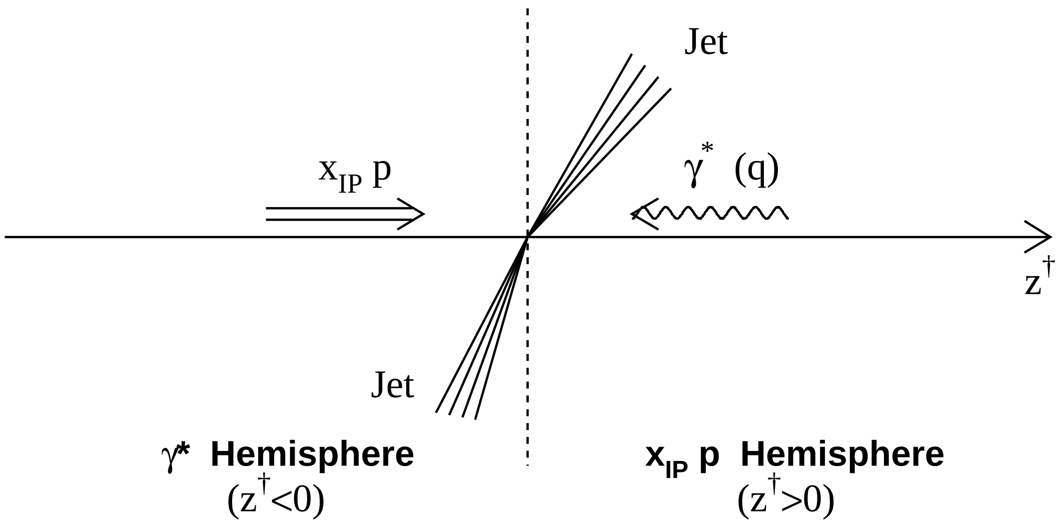
$$\mathcal{L}_{\text{int}} = 18.0\text{pb}^{-1} \quad N_{2-\text{Jet}} = 2.500 \quad N_{3-\text{Jet}} = 130$$

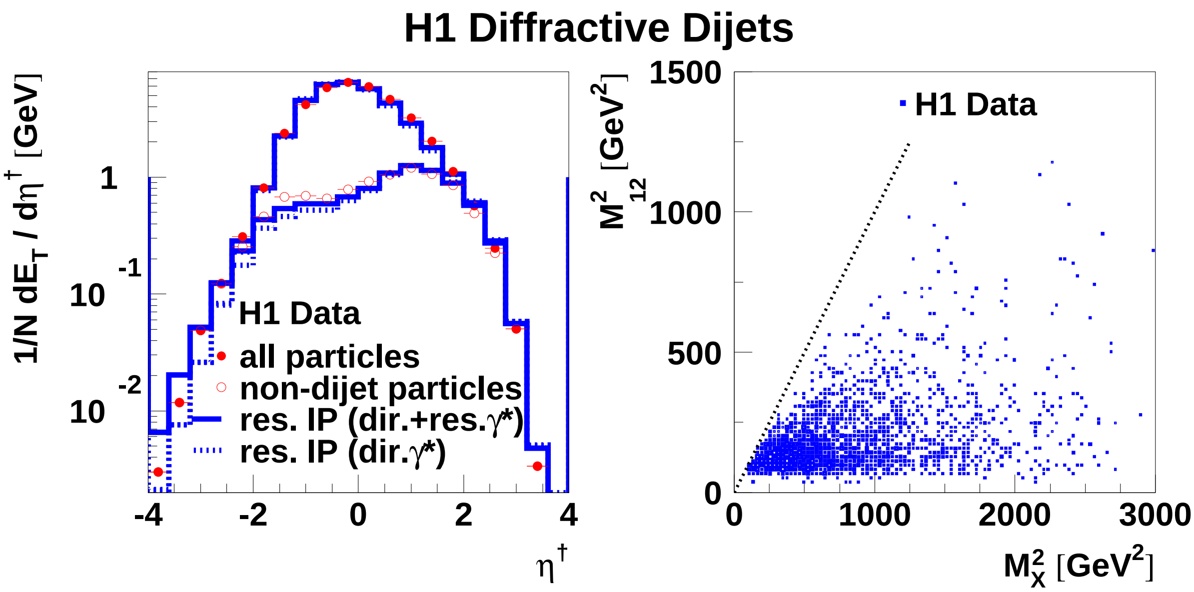
- Correction to stable particle level

- Full assessment of systematic uncertainties

$4 < Q^2 < 80$ GeV^2 $0.1 < y < 0.7$
$x_{\mathbb{P}} < 0.05$ $M_Y < 1.6$ GeV $\lvert t \rvert < 1.0$ GeV^2
$N_{\text{jets}} \geq 2$ or $N_{\text{jets}} = 3$ $p^*_{T,jet} > 4$ GeV $-3 < \eta^*_{jet} < 0$

General Properties of Dijet Events





- Significant energy not contained in dijets, some preference for $I\!P$ hemisphere
- $M_{12} \ll M_X$ typically

$\Rightarrow$ exclusive 2-jets just small part of cross section!

Diffractive Parton Distributions

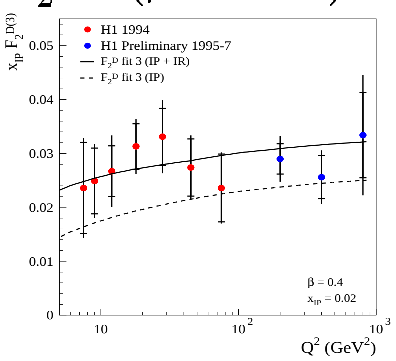
H1 F_2^D Fits: Hard sc. factorization $\otimes$ Regge factorization:
(universality of diffr. PDF's with $x_{I\!P}$ [t])

$$F_2^{D(4)} = f_{I\!P/P}(x_{I\!P}, t) \otimes F_2^{I\!P}(\beta, Q^2)$$

where $F_2^{I\!P}(\beta, Q^2) = \sum_i e_i^2 q^{I\!P}(z, \mu^2)$

Scaling violation analysis of $F_2^{D(3)}$ yields parton distributions:

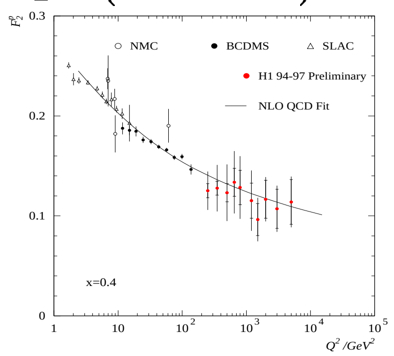
$F_2^D \quad (\beta = 0.4)$



Q^2

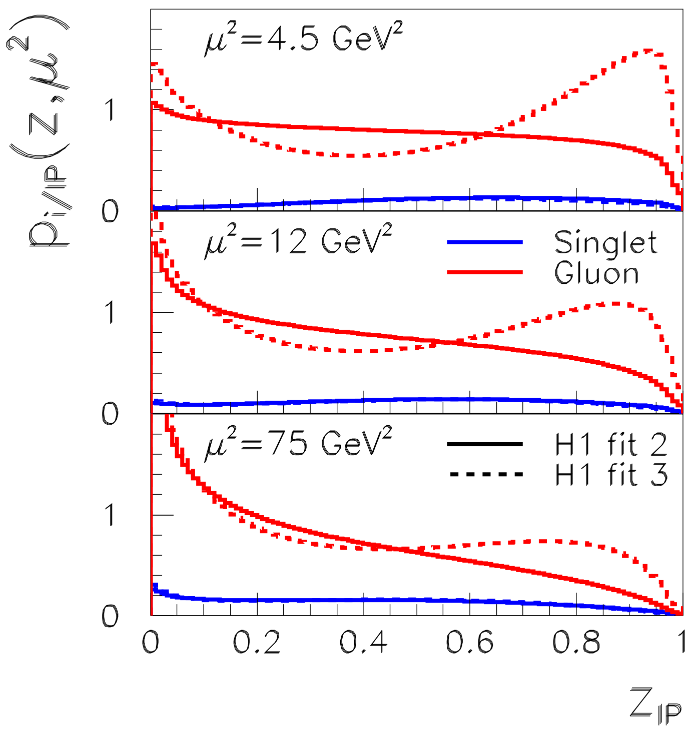
[flat/rising with Q^2]

$F_2 \quad (x = 0.4)$



Q^2

[steeply falling with Q^2]



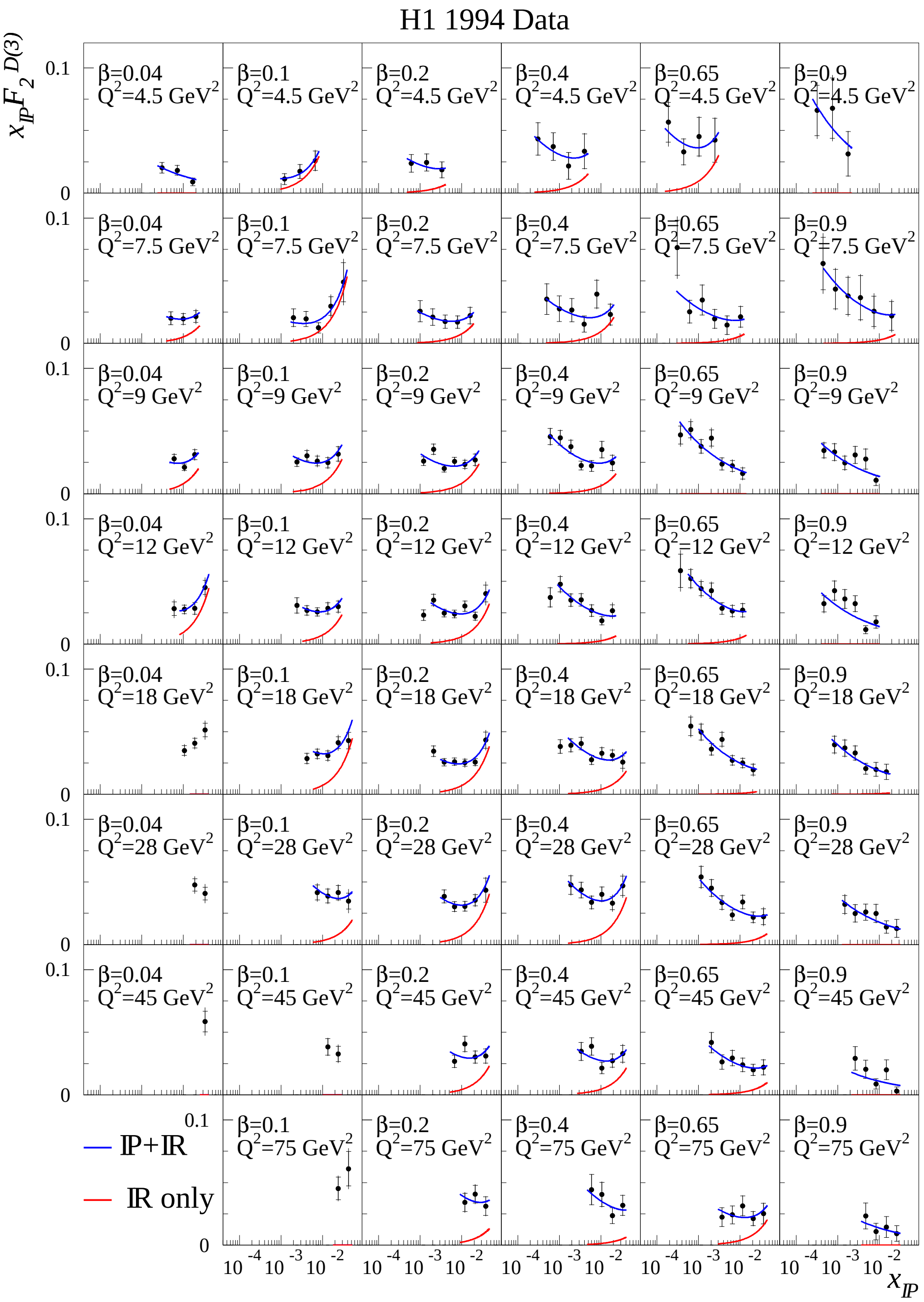
$\Rightarrow$ diffr. PDF's strongly dominated by gluons

$\Rightarrow$ direct access to g^D with diffr. jets!

$F_2^{D(3)}(x_{I\!P}, \beta, Q^2)$ from H1

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

$Q^2 \downarrow$



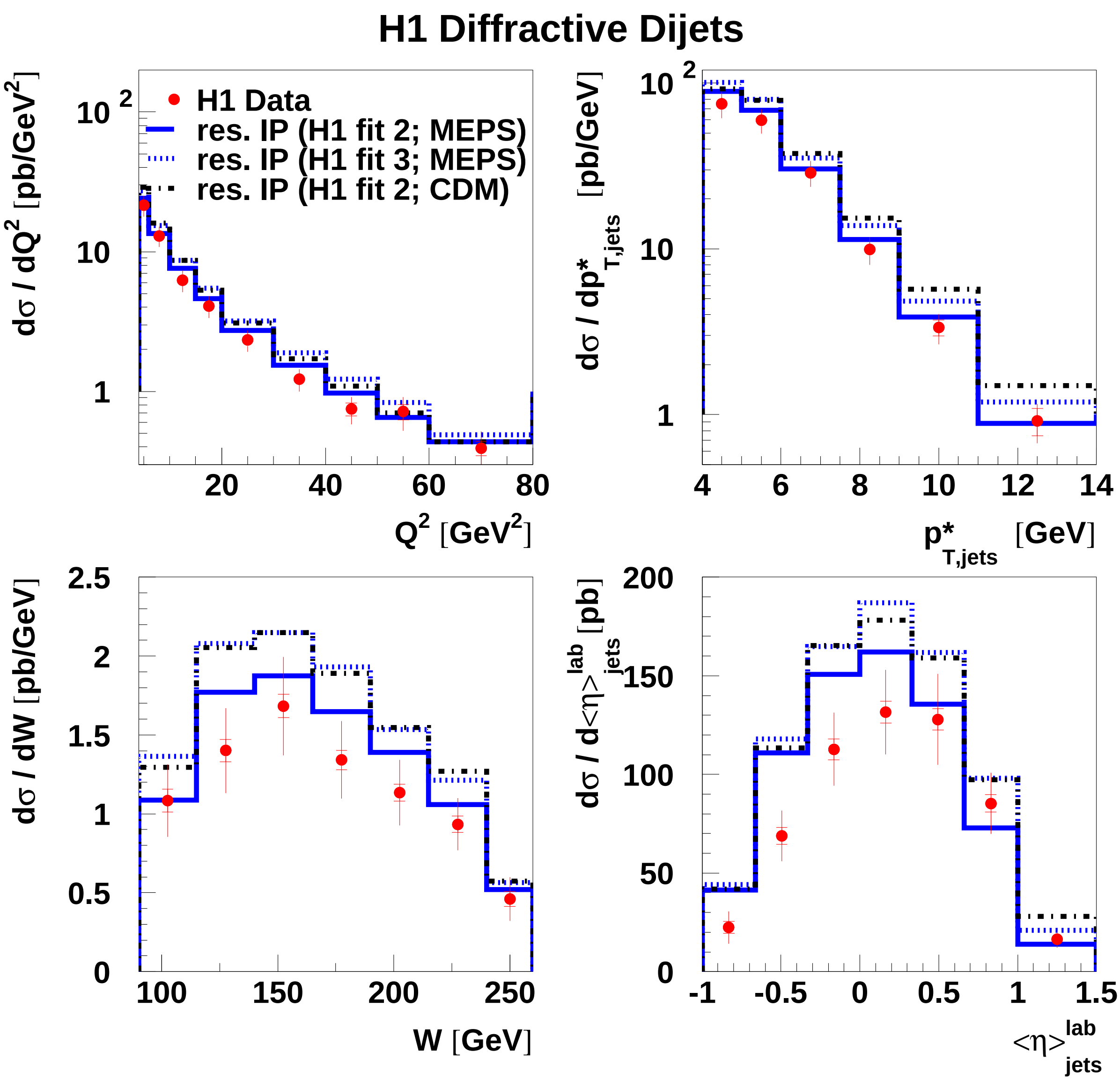
$x_{I\!P}$

- Consistent with Regge factorization

QCD Factorization @ Work

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

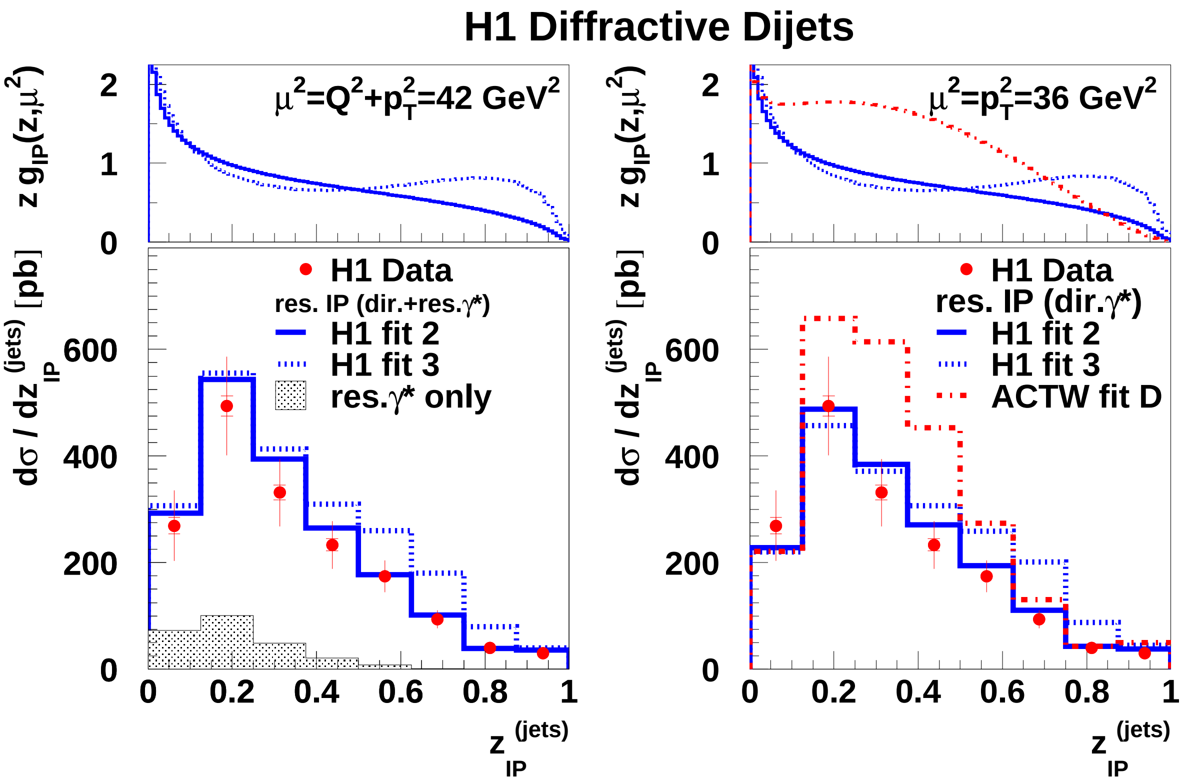
[resolved γ^* component included]



⇒ Consistent with QCD factorization in diffractive DIS

Diffractive Gluon Distribution

Dijets directly constrain shape and normalization of g^D:



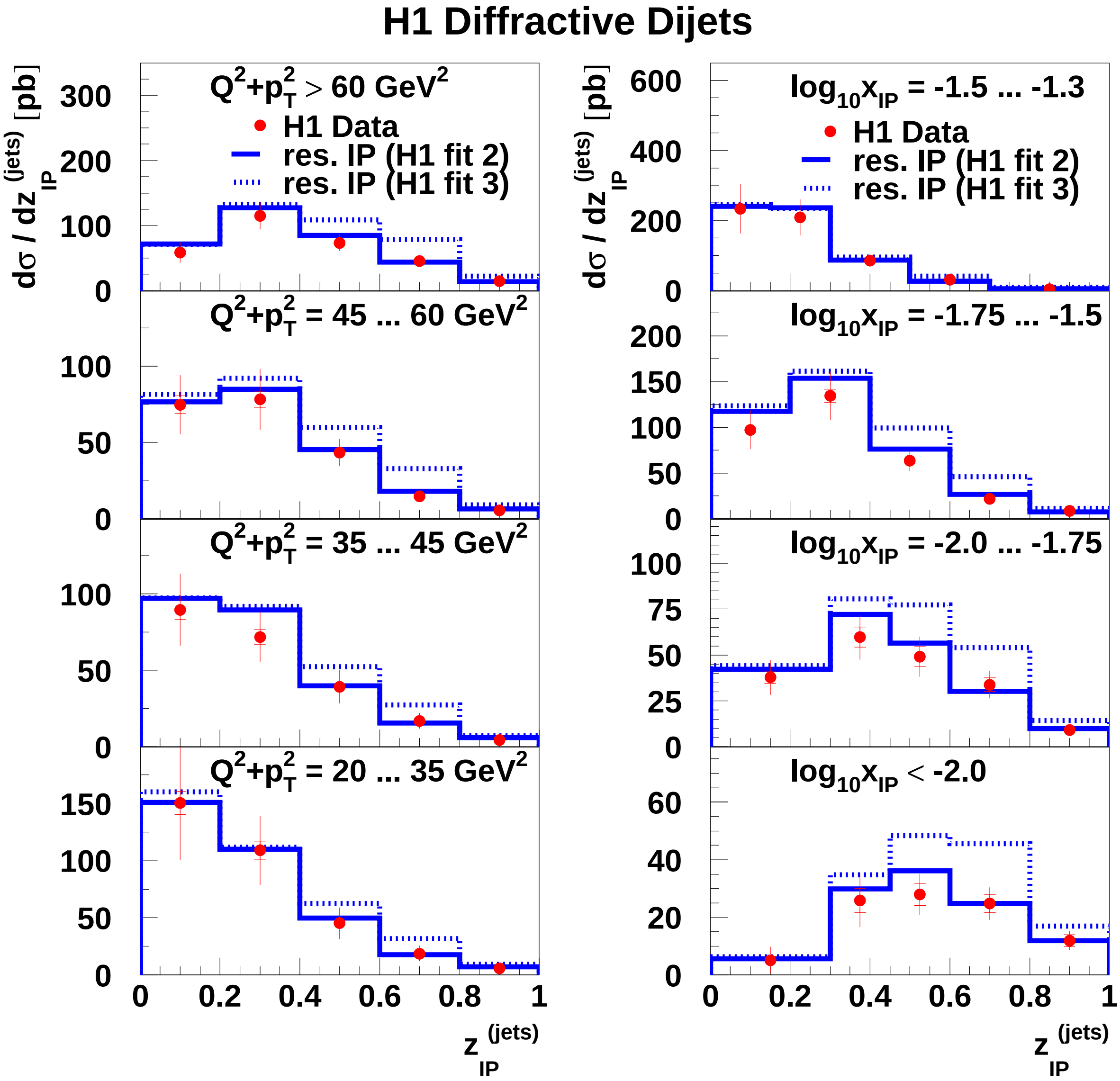
[res. γ^*, $I\!\!R$ and quark contributions small]

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

$\Rightarrow$ Strong support for fully factorizable diffr. PDF's in DIS which are gluon-dominated with momentum distr. flat in z

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

Features of Diffractive PDF's



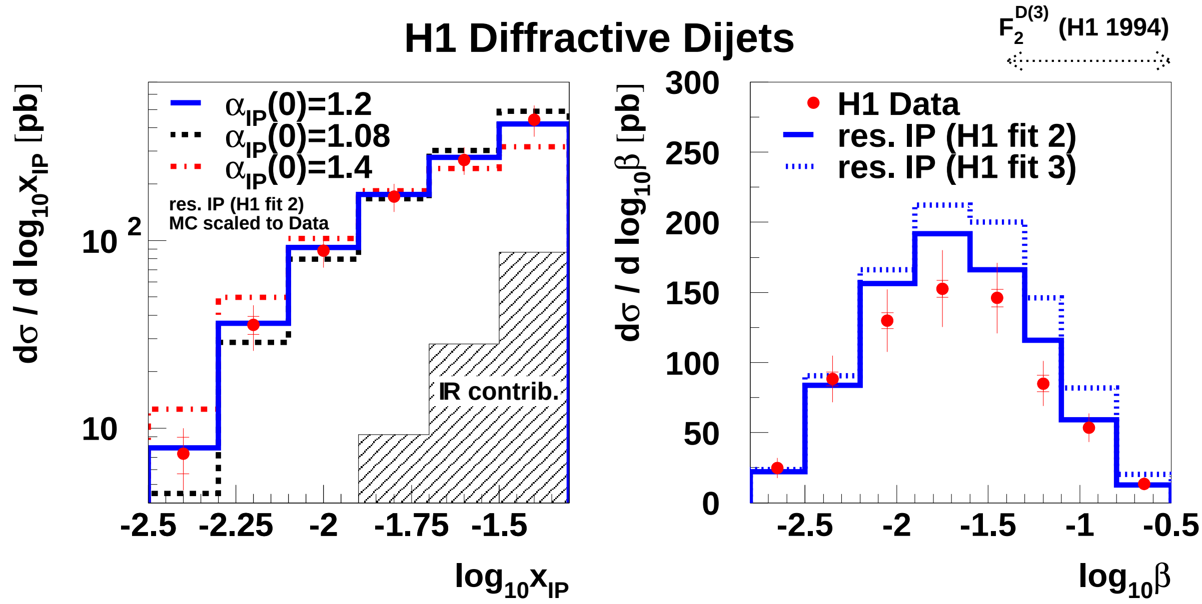
- Data consistent with DGLAP evolution of PDF's with factorization scale $\mu^2 = Q^2 + p_T^2$

- 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:

$$f_{I\!P/P}(x_{I\!P}, t) \sim \left(\frac{1}{x_{I\!P}}\right)^{2\alpha_{I\!P}(t)-1} e^{Bt}$$
$$\alpha_{I\!P}(t) = \alpha_{I\!P}(0) + \alpha'_{I\!P} t \quad [B = 4.6 \text{ GeV}^{-2}, \alpha'_{I\!P} = 0.26 \text{ GeV}^{-2}]$$

Fit Result:

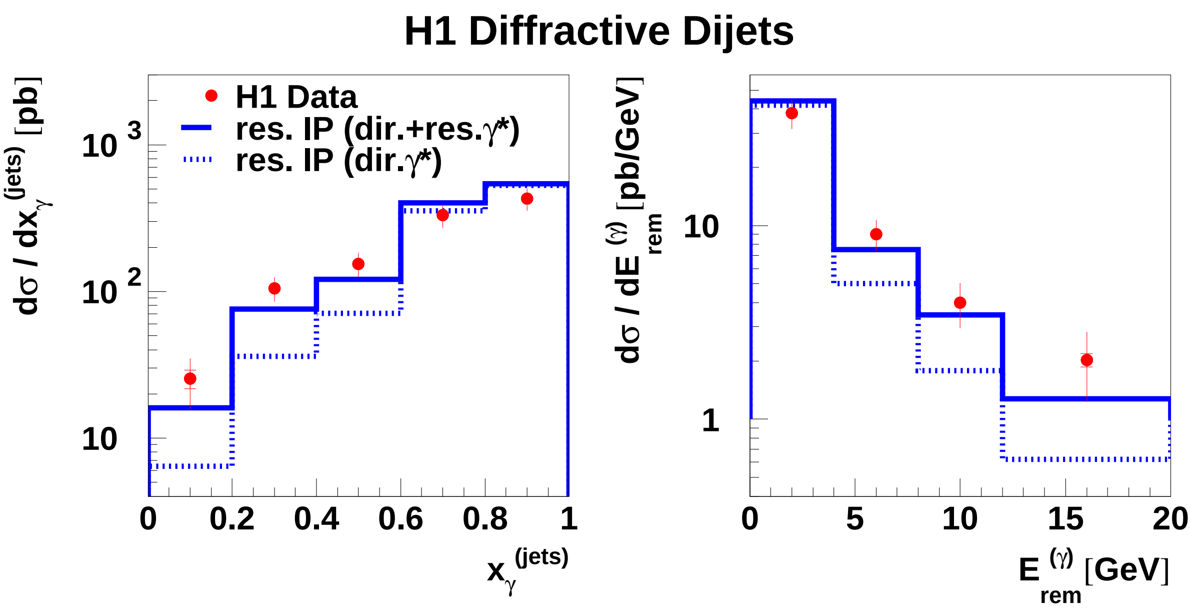
$$\alpha_{I\!P}(0) = 1.17 \ {}^{+0.03}_{-0.03} \ (\text{stat.}) \ {}^{+0.06}_{-0.06} \ (\text{syst.}) \ {}^{+0.03}_{-0.07} \ (\text{model})$$

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

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

Resolved Virtual Photon Contribution

Since $Q^2 > 4\ \mathrm{GeV}^2$, $p_T^2 > 16\ \mathrm{GeV}^2$
$\Rightarrow$ Jets can "resolve virtual photon"
[expected from inclusive dijet production]



$$x_\gamma^{(jets)} = \frac{(E-p_Z)_{jets}}{(E-p_Z)_X}$$

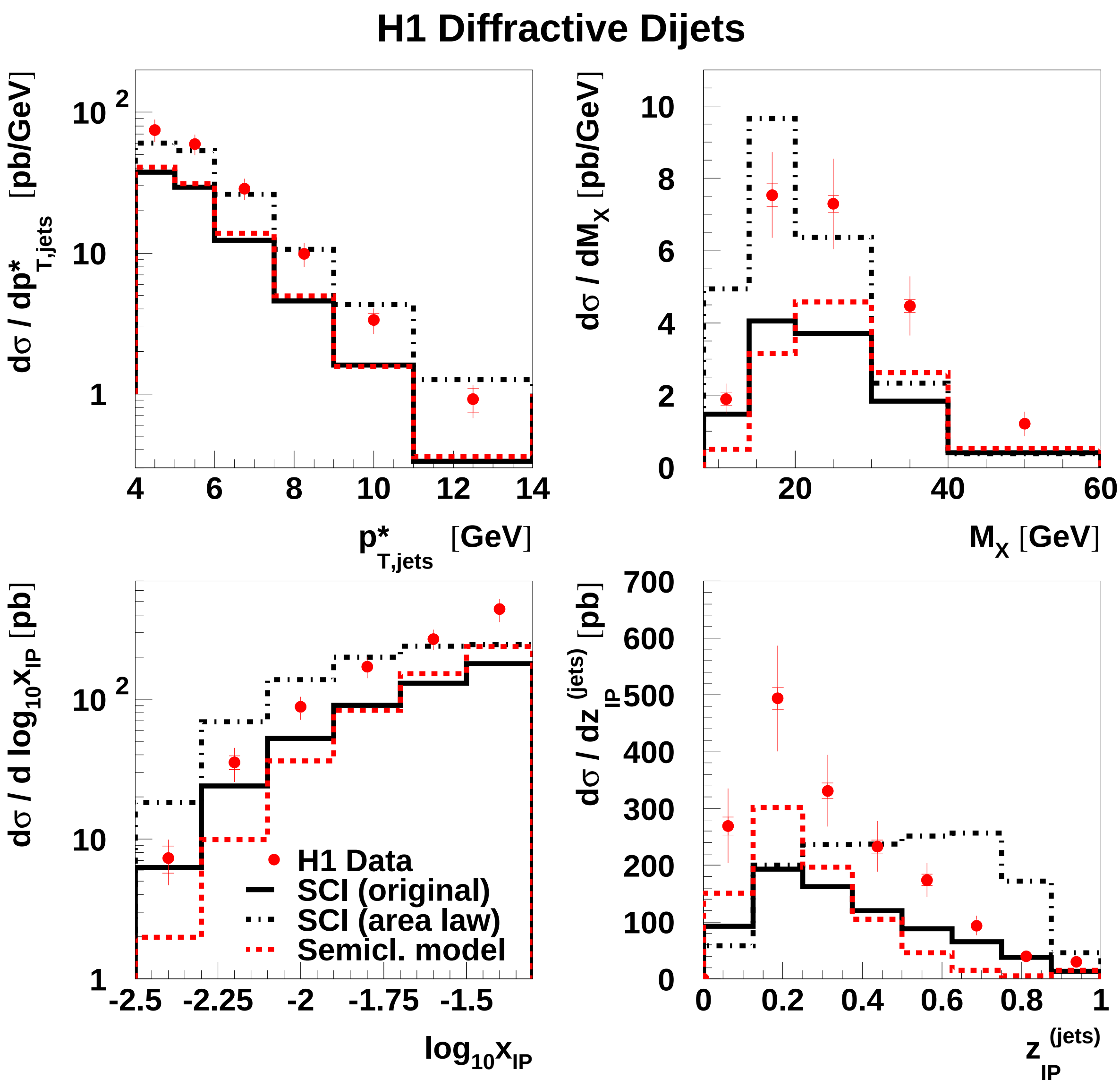
E_{rem} in γ^* hemisphere

Resolved γ^* contribution according to
"SaS-2D" parameterization [Schuler,Sjöstrand]

- $x_\gamma^{(jets)}$ cross section:
  Improvement at low $x_\gamma^{(jets)}$ if resolved contribution is added
- Corresponding improvement at high E_{rem}^γ

Soft Colour Neutralization

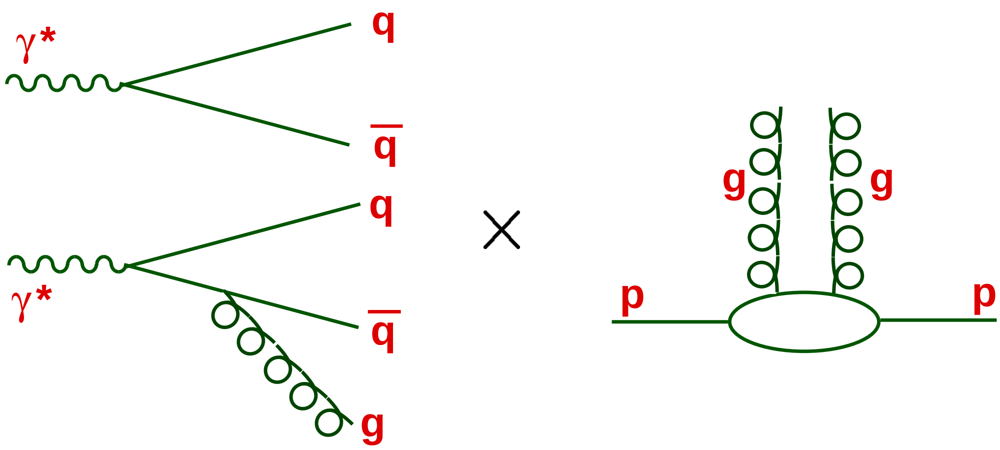
- Soft Colour Interactions SCI (Edin, Ingelman, Rathsman)
  original version and "generalized area law" (Rathsman)
- Semiclassical Model (Buchmüller, Gehrmann, Hebecker)



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

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



$$\sigma_{T,L}^{\gamma^* p} \sim |\Psi_{T,L}(\alpha, \mathrm{r})|^2 \otimes \hat{\sigma}^2(r^2, x, \ldots)$$

$$\hat{\sigma}(x, \mathrm{r}) \sim \int \frac{\mathrm{d}^2\mathrm{k}_t}{k_t^2} \left[1 - \mathrm{e}^{i\mathrm{r}\cdot\mathrm{k}}\right] \alpha_s(k_t^2)\, \mathcal{F}(x, k_t^2)$$

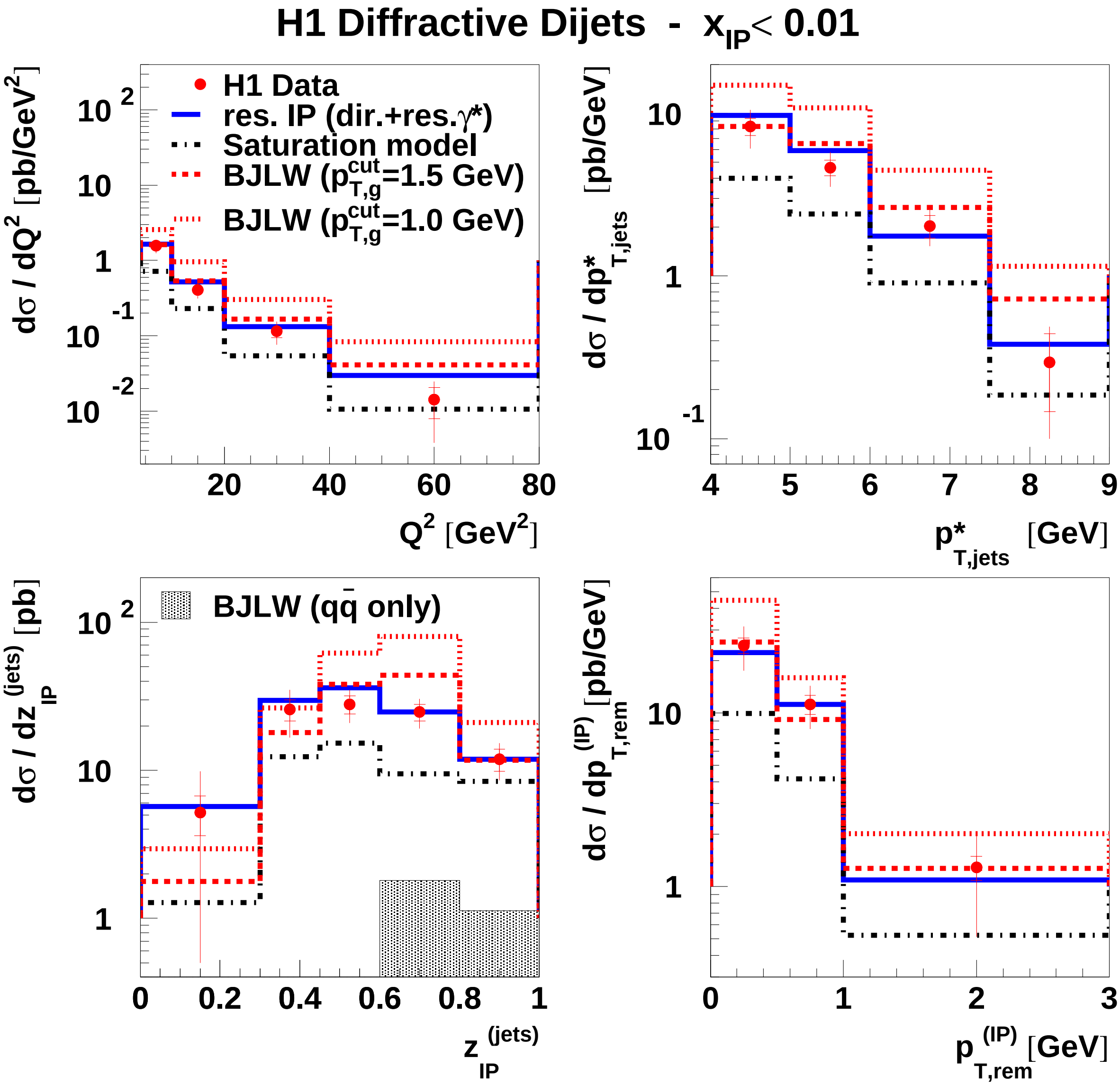
[$\mathcal{F}(x, k_t^2)$: unintegrated gluon distribution]

- 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 $F_2(x, Q^2)$

2-Gluon Exchange (II)

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

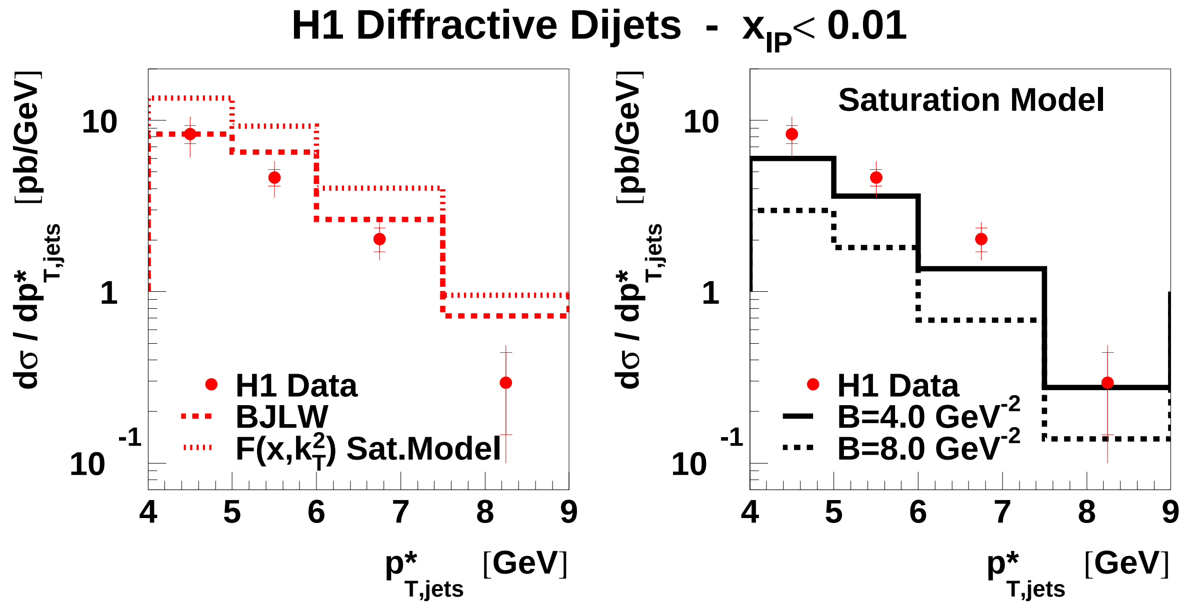


p_T of "$I\!P$ remnant"

- 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 ;-(

2-Gluon Exchange (III)

Variation of parameters in 2-gluon models:



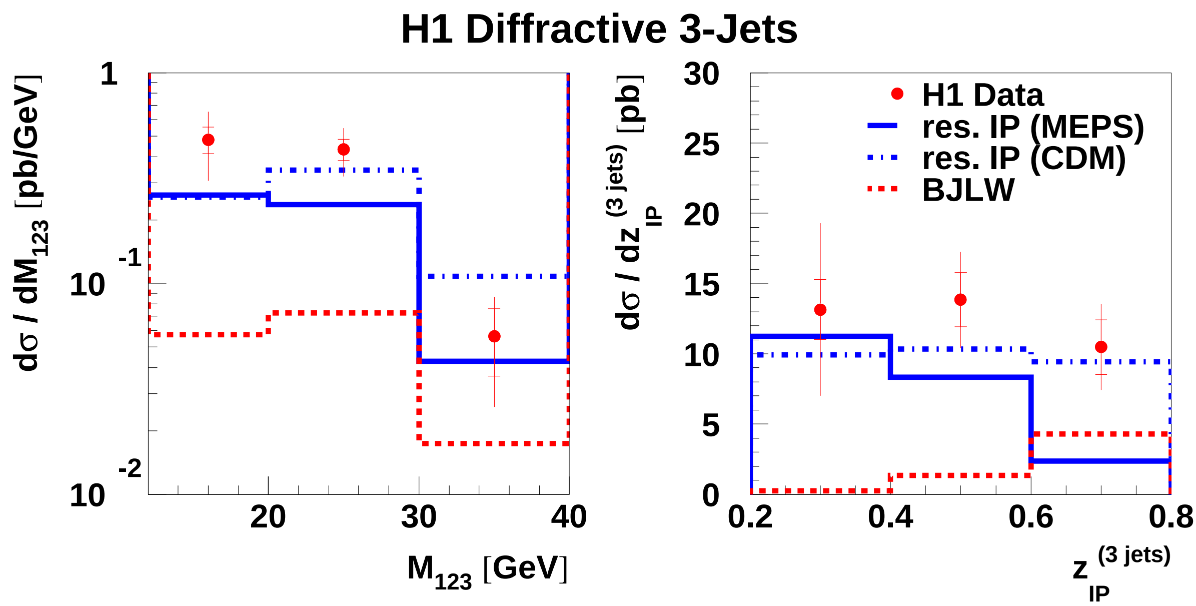
- BJLW Model:
  Use $\mathcal{F}(x, k_T^2)$ from Saturation model instead of GRV
  $\Rightarrow$ gluon parameterization in Saturation model seems very large

- Saturation Model:
  Variation of $B = 6.0 \ \mathrm{GeV}^{-2}$ (e^{Bt}, normalization of σ^D)
  $\Rightarrow$ Close to data if $B = 4.0 \ \mathrm{GeV}^{-2}$, then however $F_2^{D(3)}$ no longer described

3-Jet Production

Features:

- Limited statistics: 130 3-jets for $\mathcal{L} = 18.0\ \mathrm{pb}^{-1}$
- 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

Summary and Conclusions

- 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")
- In P rest frame: $q\bar{q}g \gg q\bar{q}$ configurations
- 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 exchange can describe part of dijet cross section