# Diffractive Jet Production in DIS - Testing QCD Factorization

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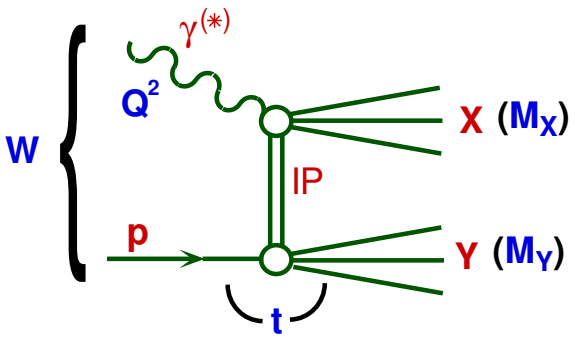
H1 Collaboration

DIS 2001, Bologna, April 2001

# Motivation

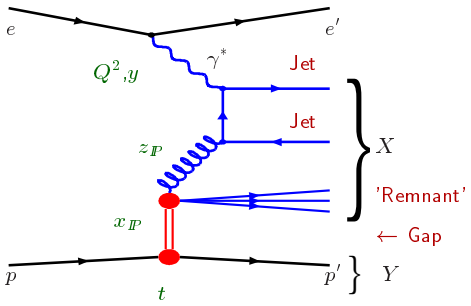
Diffractive DIS: probe colour singlet exch. w/ pointlike $\gamma^*$
$\Rightarrow$ Determine QCD structure:

[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]:

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

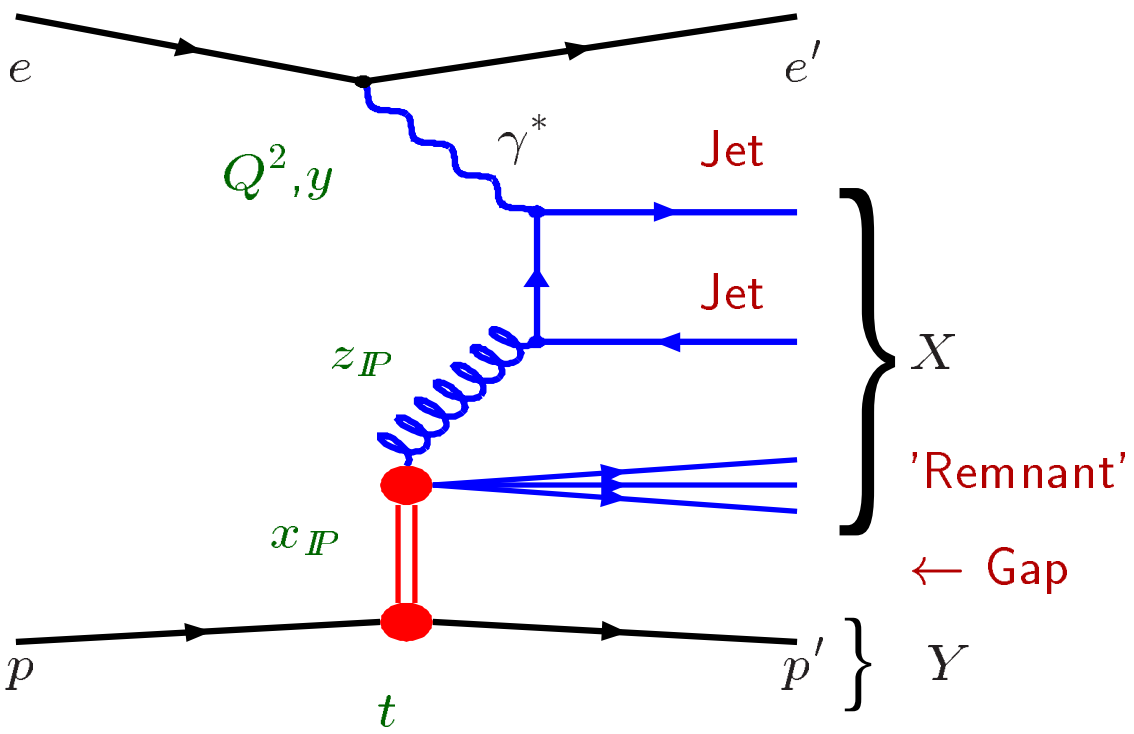
  - Constrain $g^D$ with jets
  - Consistent picture from $F_2^{D(3)}$ and Jets ?

- $x_{I\!P}$ (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 ($3.2 < \eta < 7.5$)

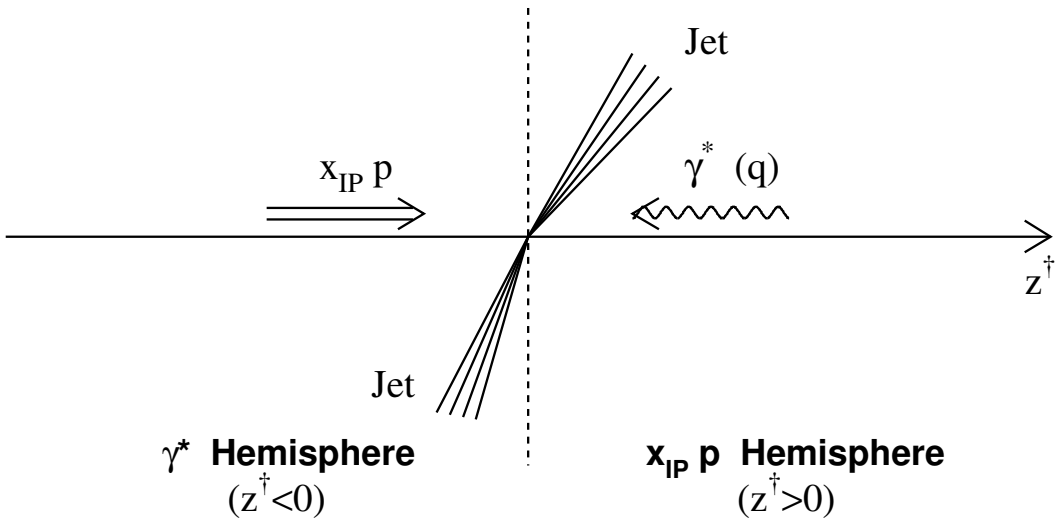
- Jet Selection:
  CDF cone algorithm in $\gamma^* p$-CMS, $p_T^* > 4$ GeV

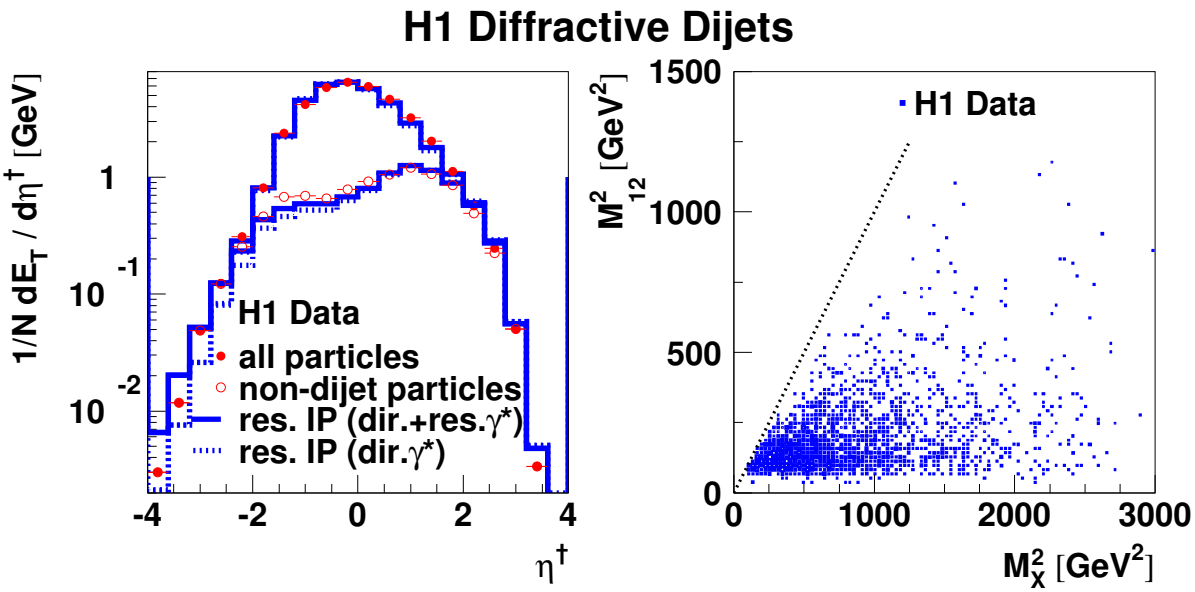
$$\mathcal{L}_{\rm int} = 18.0 {\rm pb}^{-1} \quad N_{2-{\rm Jet}} = 2.500 \quad N_{3-{\rm Jet}} = 130$$

- Correction to stable particle level
- Full assessment of systematic uncertainties

| |
|---|
| $4 < Q^2 < 80$ GeV$^2$ |
| $0.1 < y < 0.7$ |
| $x_{I\!P} < 0.05$ |
| $M_Y < 1.6$ GeV |
| $\lvert t \rvert < 1.0$ GeV$^2$ |
| $N_{\rm jets} \geq 2$ or $N_{\rm jets} = 3$ |
| $p_{T,jet}^* > 4$ 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!

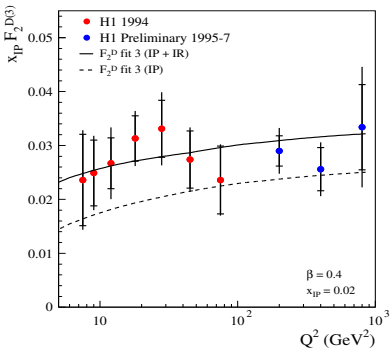
# Diffractive Parton Distributions

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:

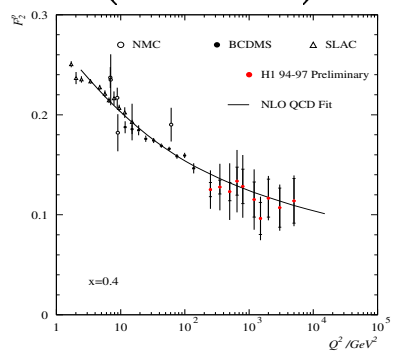
$F_2^D \quad (\beta = 0.4)$




$Q^2$

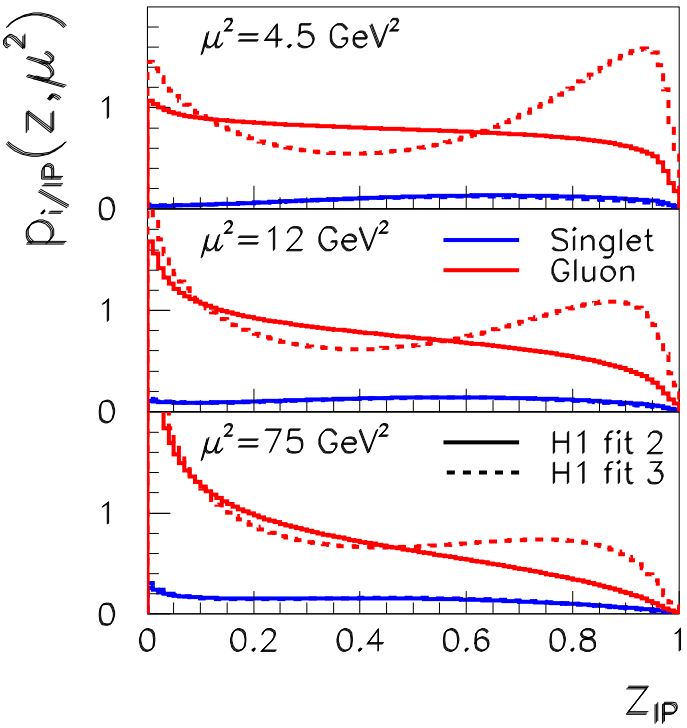
[flat/rising with $Q^2$]

$F_2 \quad (x = 0.4)$




$Q^2$

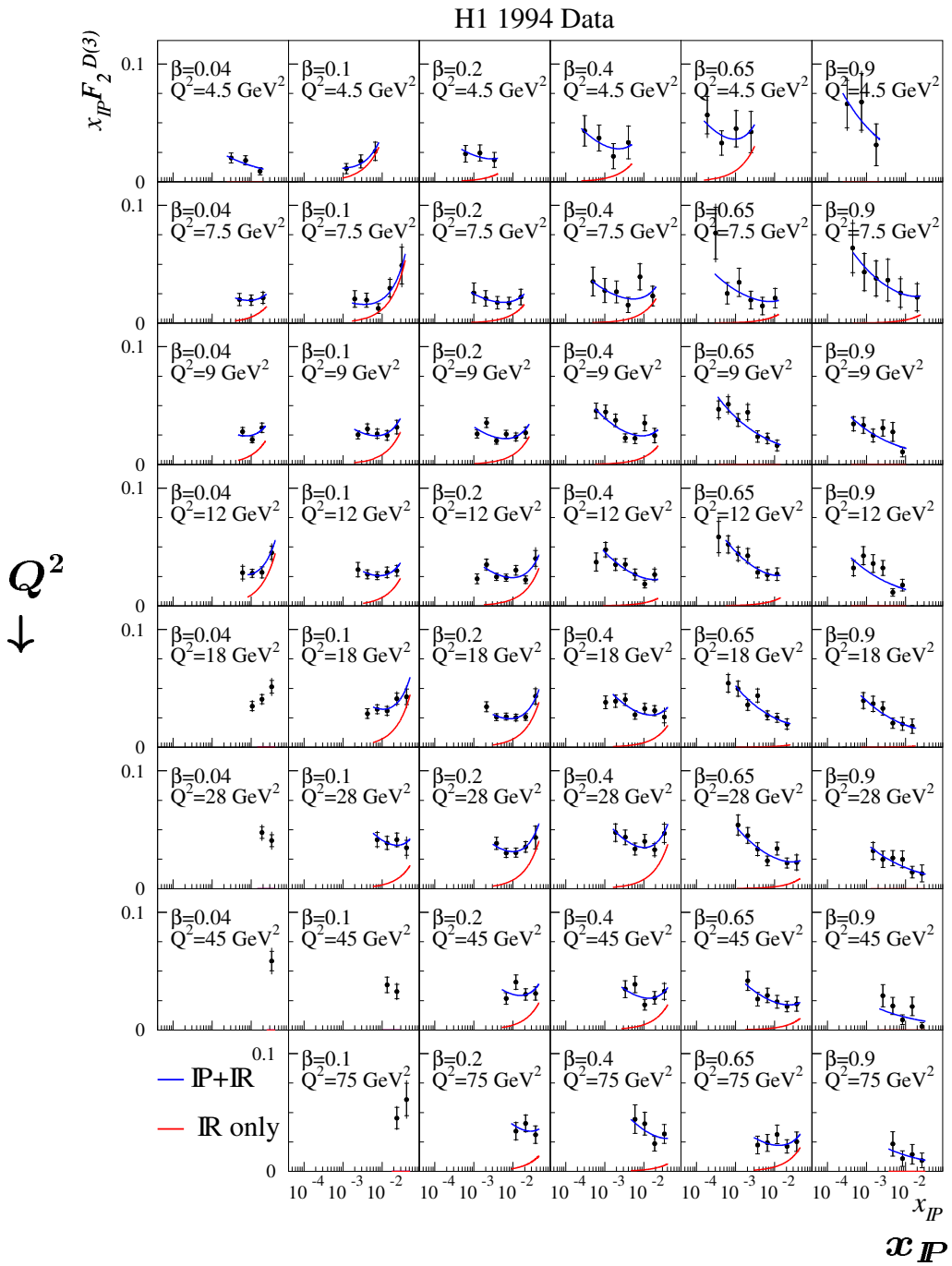
[steeply falling with $Q^2$]




$\Rightarrow$ 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

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

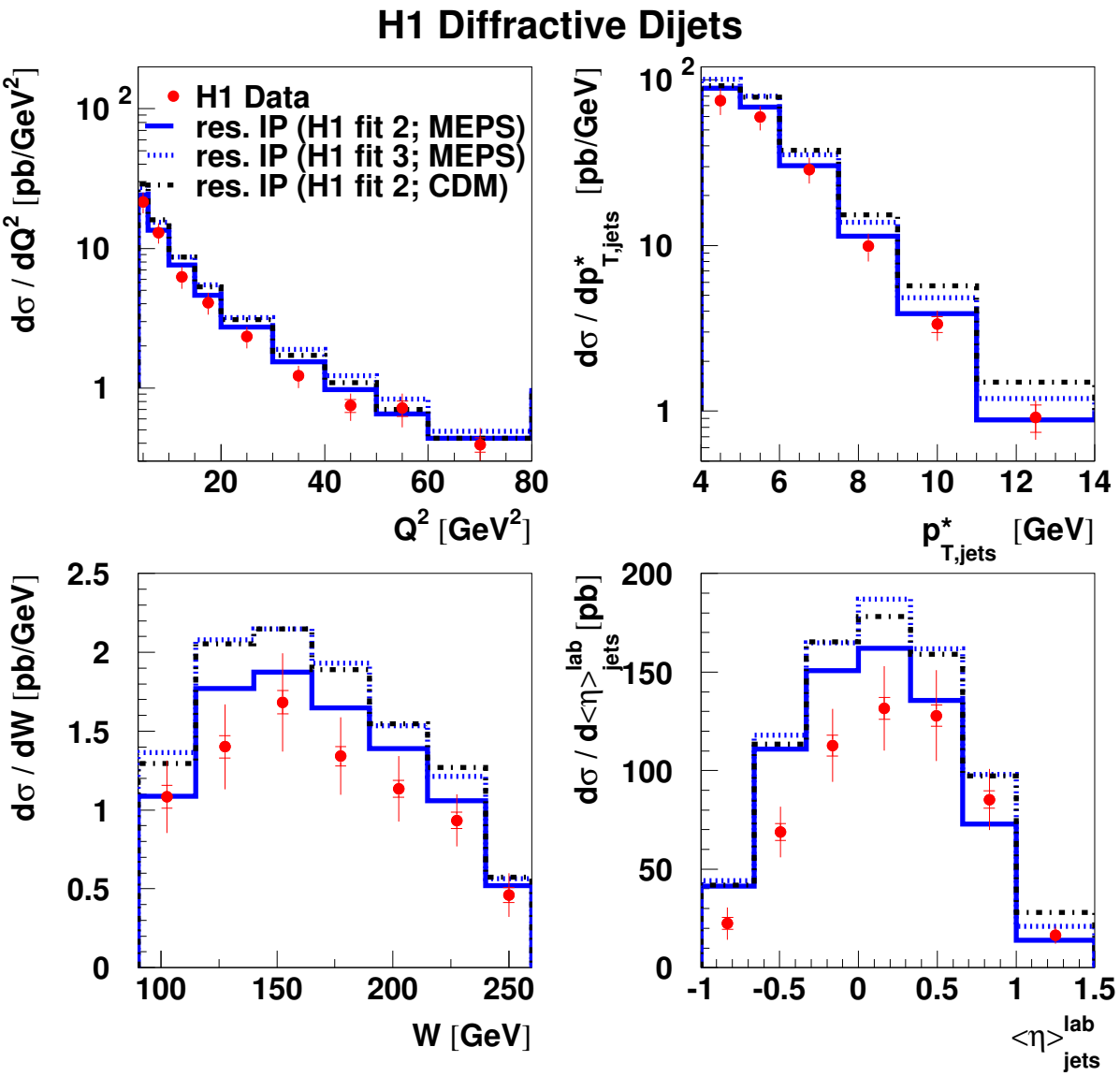



- Consistent with Regge factorization

# QCD Factorization @ Work

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

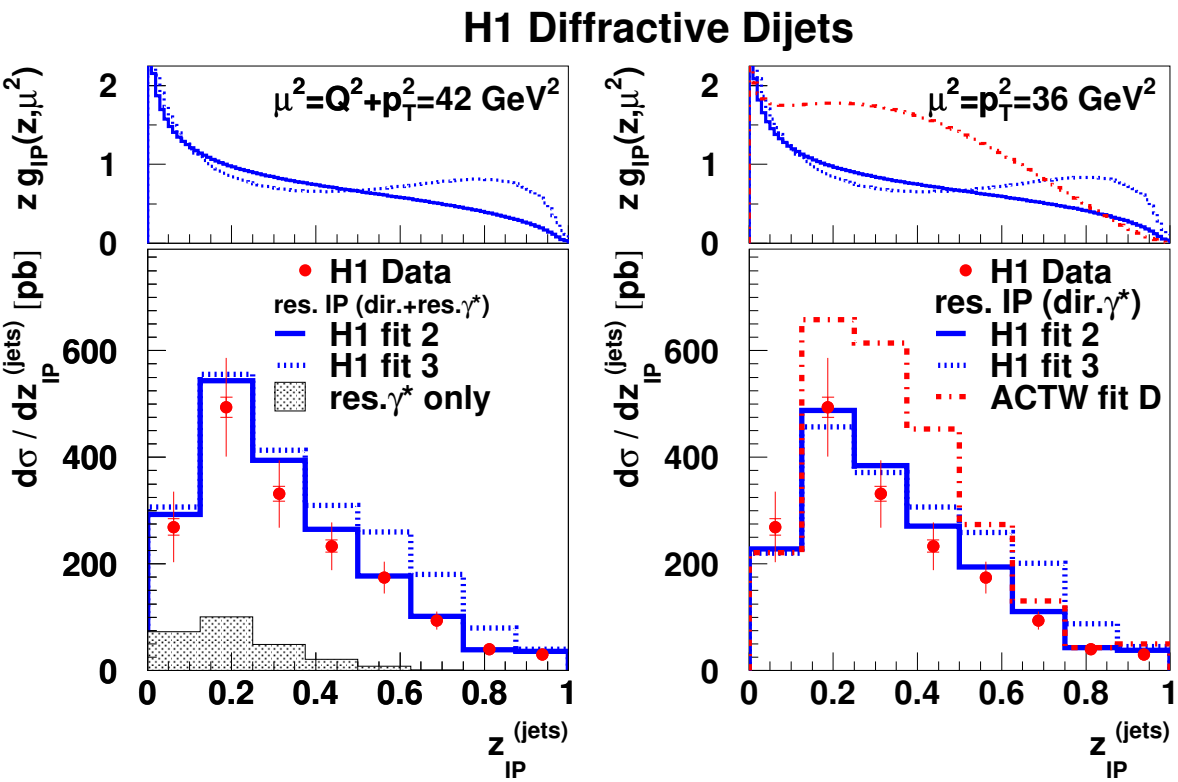
[resolved $\gamma^*$ component included]




⇒ Consistent with QCD factorization in diffractive DIS

# Diffractive Gluon Distribution

Dijets directly constrain shape and normalization of $g^D$:



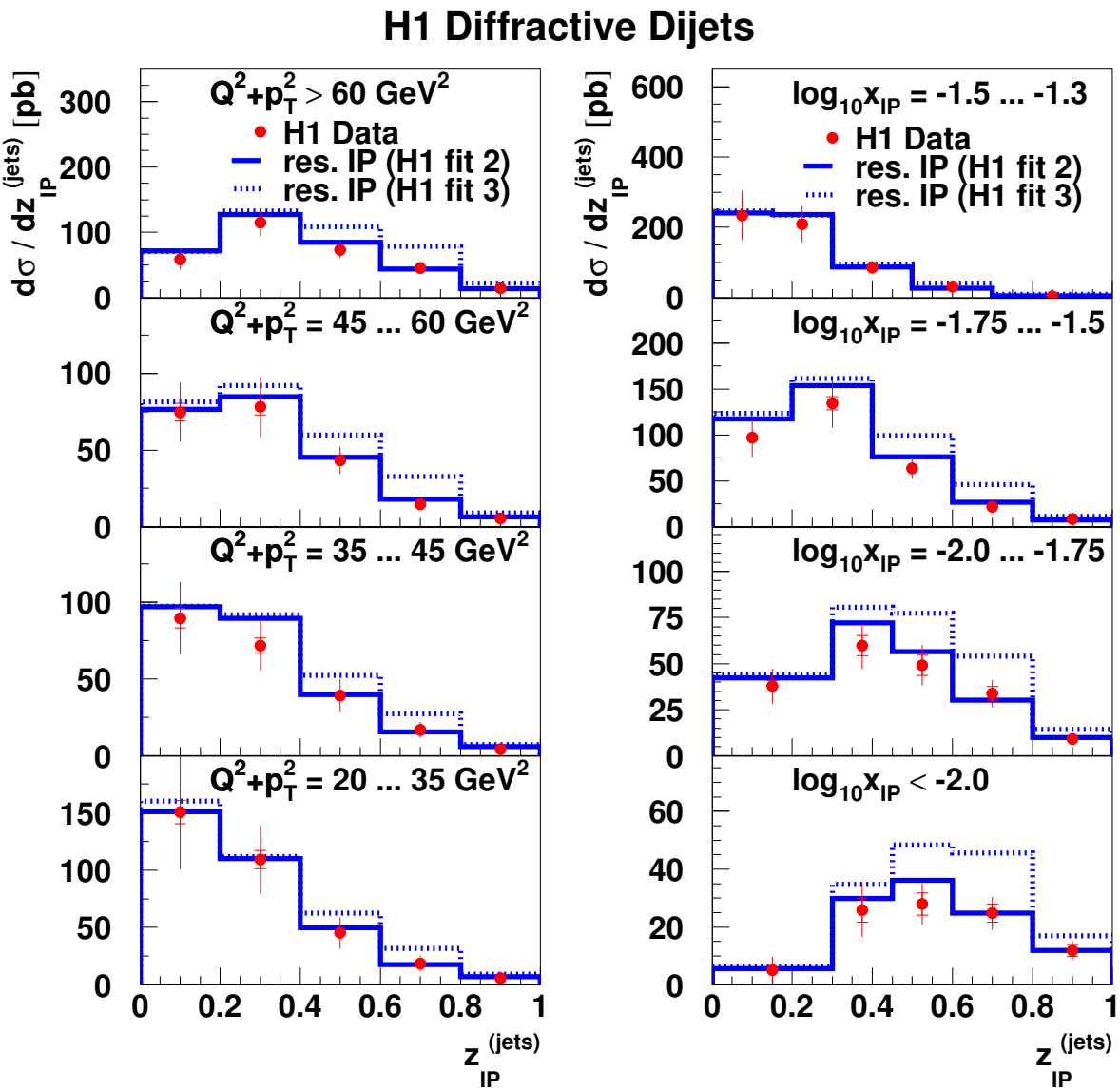

[res. $\gamma^*$, $I\!R$ and quark contributions small]

- 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



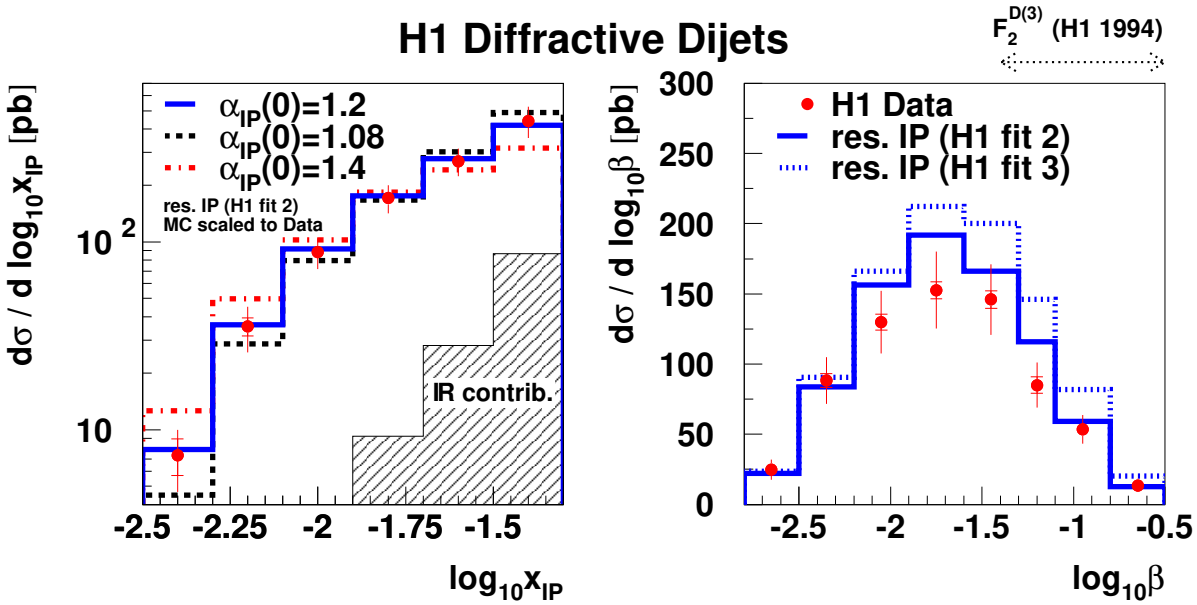

- Data consistent with DGLAP evolution of PDF's with factorization scale $\mu^2 = Q^2 + p_T^2$

- 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:

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

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

Fit Result:

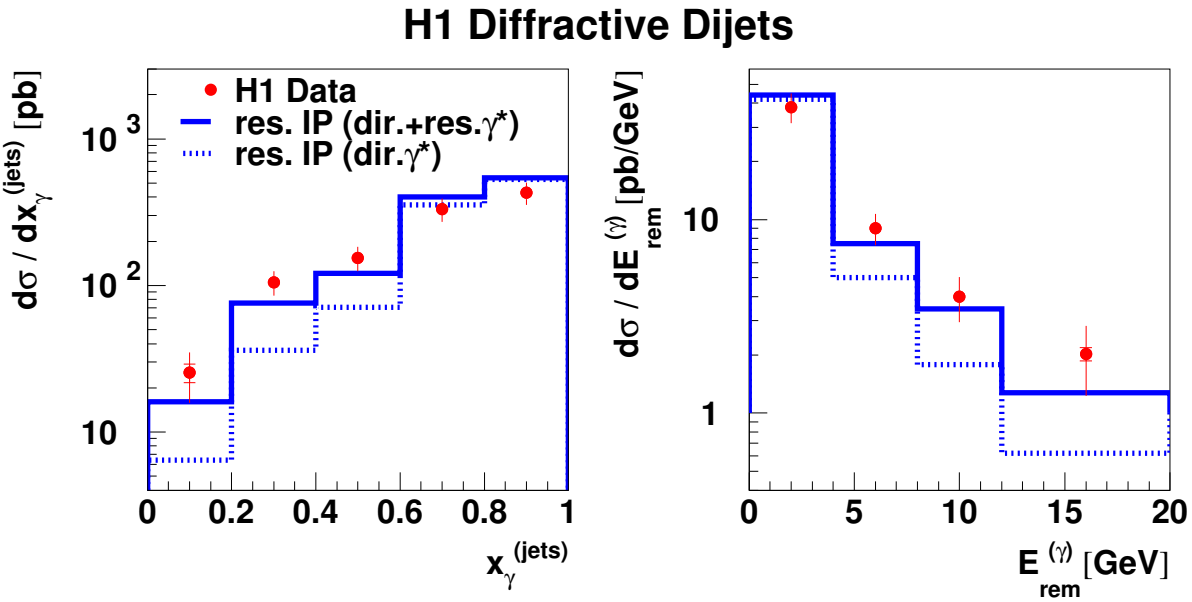
$$\alpha_{I\!P}(0) = 1.17\ ^{+0.03}_{-0.03}\ (\mathrm{stat.})\ ^{+0.06}_{-0.06}\ (\mathrm{syst.})\ ^{+0.03}_{-0.07}\ (\mathrm{model})$$

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

- $\beta$ distribution: Jets are small $\beta$, 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]



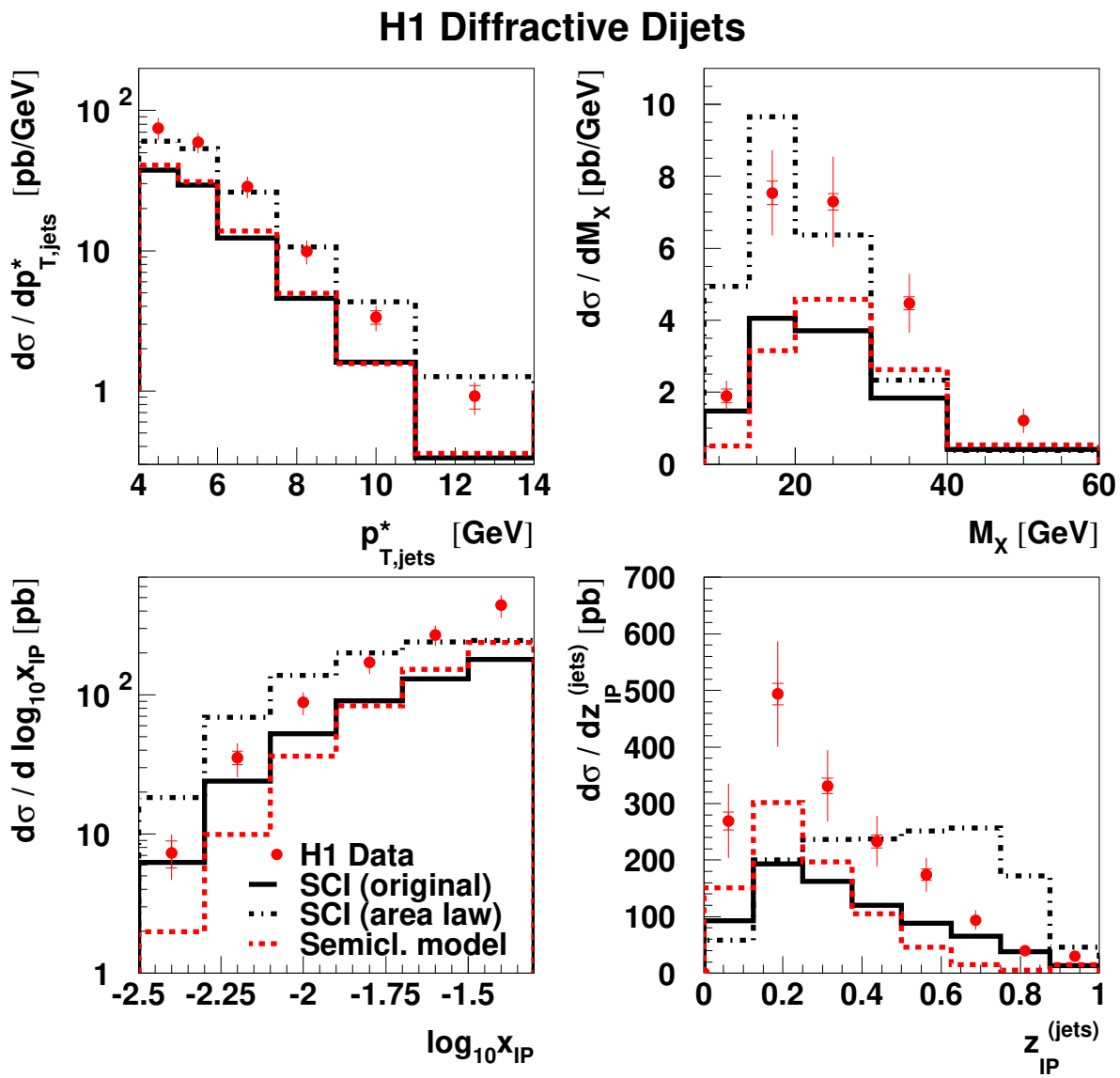

$x_\gamma^{(jets)} = \frac{(E-p_Z)_{jets}}{(E-p_Z)_X}$ $E_{rem}$ in $\gamma^*$ hemisphere

Resolved $\gamma^*$ 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 $E_{rem}^{\gamma}$

# Soft Colour Neutralization

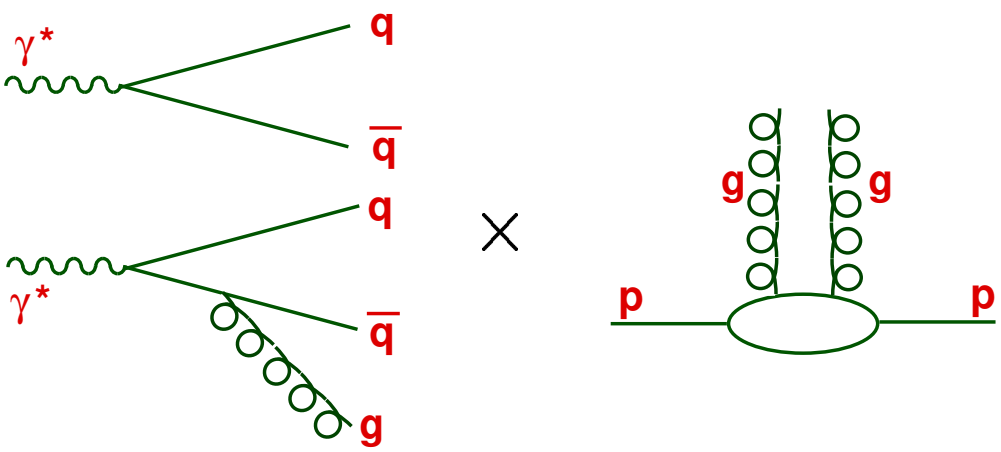
- Soft Colour Interactions SCI (Edin, Ingelman, Rathsman)
  original version and "generalized area law" (Rathsman)
- Semiclassical Model (Buchmüller, Gehrmann, Hebecker)




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

# 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




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

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

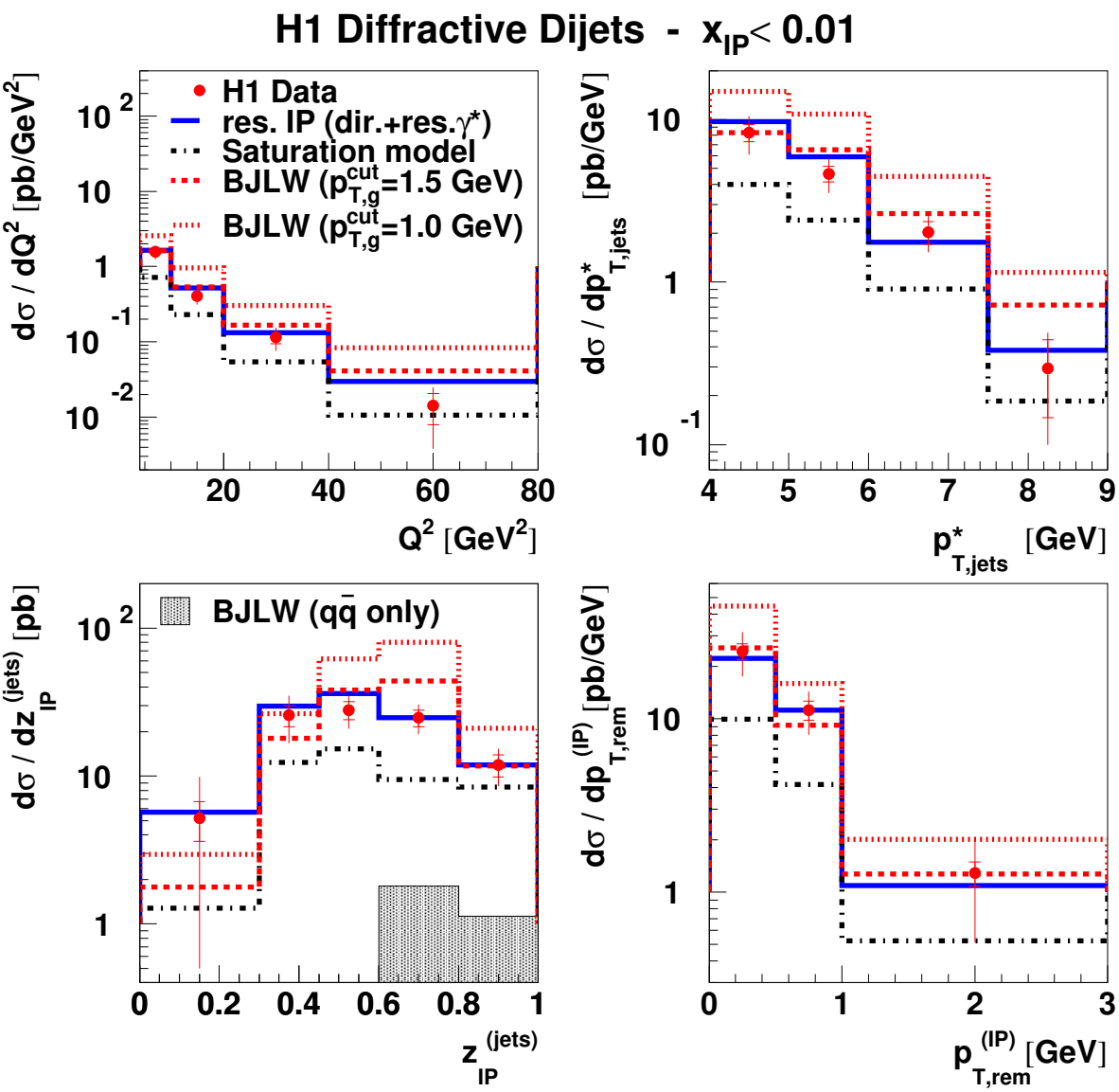
[$\mathcal{F}(x, k_t^2)$: unintegrated gluon distribution]

- 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

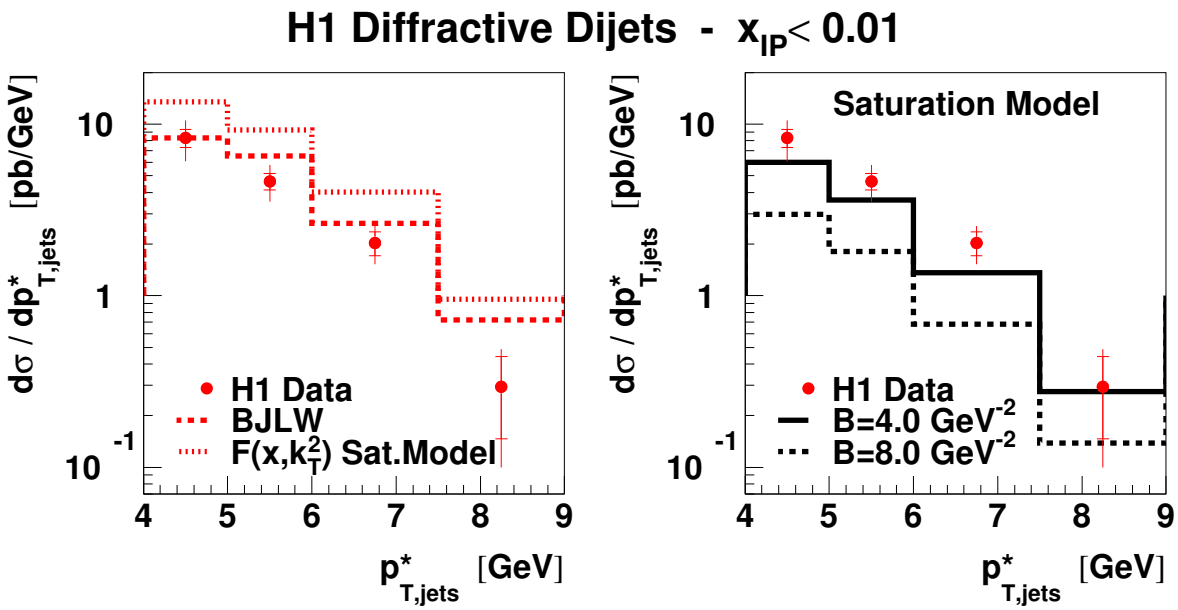



$p_T$ of "$I\!P$ remnant"

- 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:

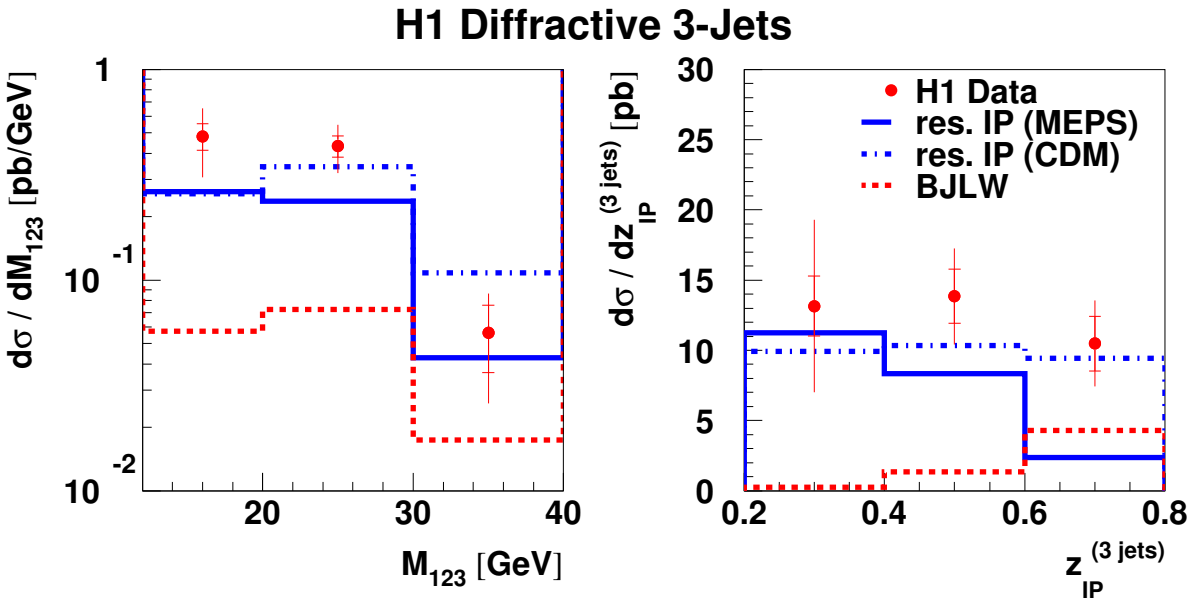



- BJLW Model:
  Use $\mathcal{F}(x, k_T^2)$ from Saturation model instead of GRV
  $\Rightarrow$ gluon parameterization in Saturation model seems very large

- Saturation Model:
  Variation of $B = 6.0\ \mathrm{GeV}^{-2}$ ($e^{Bt}$, normalization of $\sigma^D$)
  $\Rightarrow$ 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