# Diffraction and QCD

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on behalf of the H1 and ZEUS Collaborations

- Introduction
- Factorisation in Diffractive DIS
- $F_2^D$ QCD fits
- Dijet and $D^*$ Production
- Event Shapes and Three Jet Production

# Diffraction at HERA

At HERA:

- $Q^2 \sim 0, |t| \sim 0 \longrightarrow$ similar to soft hadronic diffraction

  ▷ Regge: diffraction is exchange of Pomeron

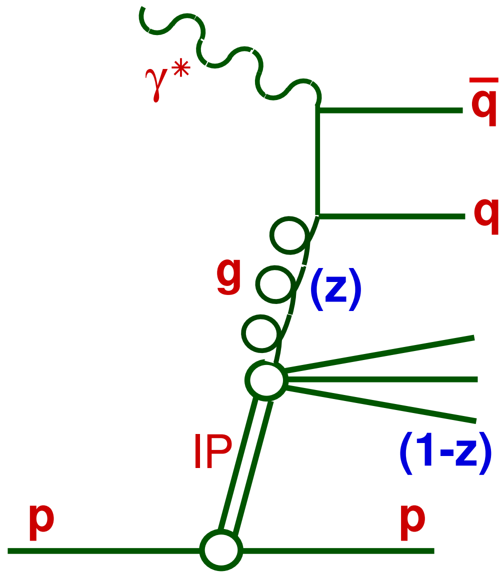
- Large $Q^2, \ |t|, \ P_T \ \mathrm{jets} \longrightarrow$ pQCD at $\gamma^* \mathbb{P}$ vertex

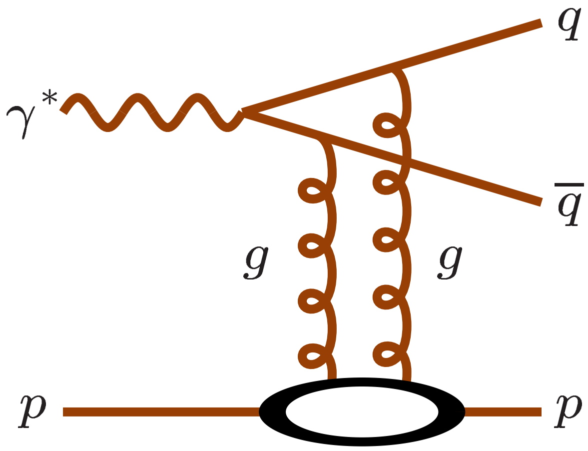
  ▷ QCD factorisation, $\gamma^*$ probes partonic content of $\mathbb{P}$

  ▷ CDM: in LO diffraction is 2 gluon colour singlet exchange between $\gamma^* \longrightarrow q\bar{q}, q\bar{q}g$ and proton

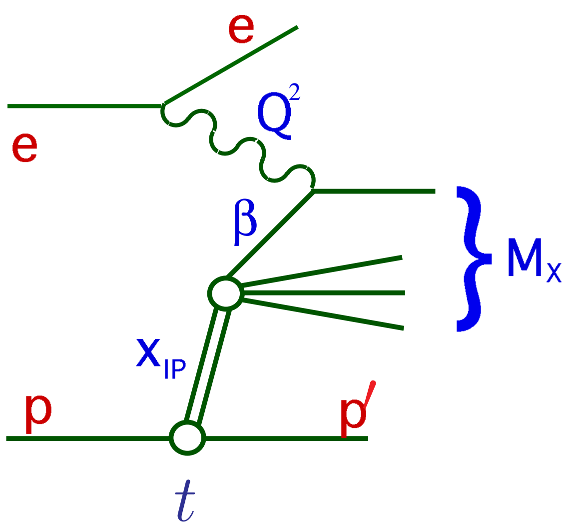
HERA $\Rightarrow$

Unique facility to probe partonic content of diffractive exchange ($\mathbb{P}$) and to study the transition from soft to hard regime



# Kinematics of Diffractive $ep$ Scattering




$$x_{I\!P} = \frac{q.(p-p')}{q.p} = x_{(\mathrm{I\!P}/\mathrm{p})}$$

$$\beta = \frac{Q^2}{q.(p-p')} = x_{(q/\mathrm{I\!P})}$$

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

$$t = (p-p')^2$$

$x_{I\!P}$ - fraction of proton momentum carried by $\mathrm{I\!P}$

$\beta$ - fraction of $\mathrm{I\!P}$ momentum carried by struck quark

$$\frac{d^4\sigma}{d\beta dQ^2 dx_{I\!P} dt} = \frac{4\pi\alpha^4}{\beta Q^4}(1-y+\frac{y^2}{2})F_2^{D(4)}(Q^2, x_{I\!P}, \beta, t)$$

If data integrated over $t \longrightarrow F_2^{D(3)}(Q^2, x_{I\!P}, \beta)$

# Factorisation in diffractive DIS

QCD factorisation proven in diffractive $ep$ (Collins 1997)

non-perturb pQCD

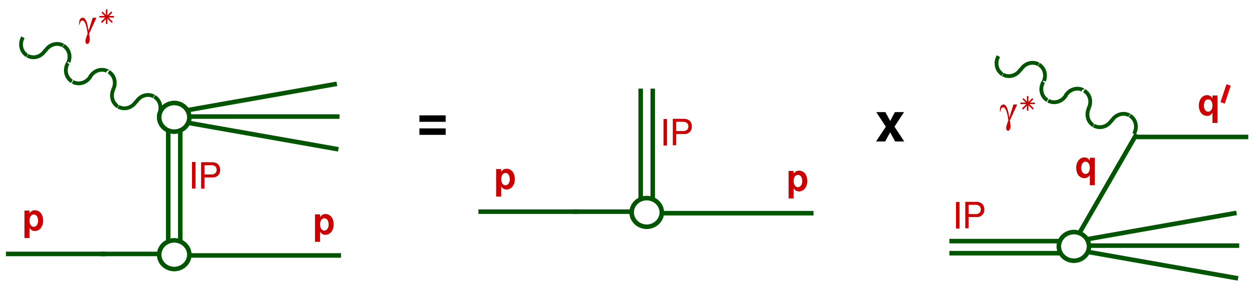
$$\sigma^D(\gamma^* p \to Xp) \sim \sum_i f_{i/p}^D(x_{I\!P}, t, x, Q^2) \otimes \hat{\sigma}_{\gamma^* i}(x, Q^2)$$

Diffractive parton densities $f_{i/p}^D(x_{I\!P}, t, x, Q^2)$:

- express conditional proton parton probability distributions with final state proton at fixed $x_{I\!P}, t$
- evolve with $x, Q^2$ according to DGLAP evolution
- are universal for diffractive DIS (inclusive, jets, charm)

- Resolved Pomeron model (Ingelmann, Schlein)

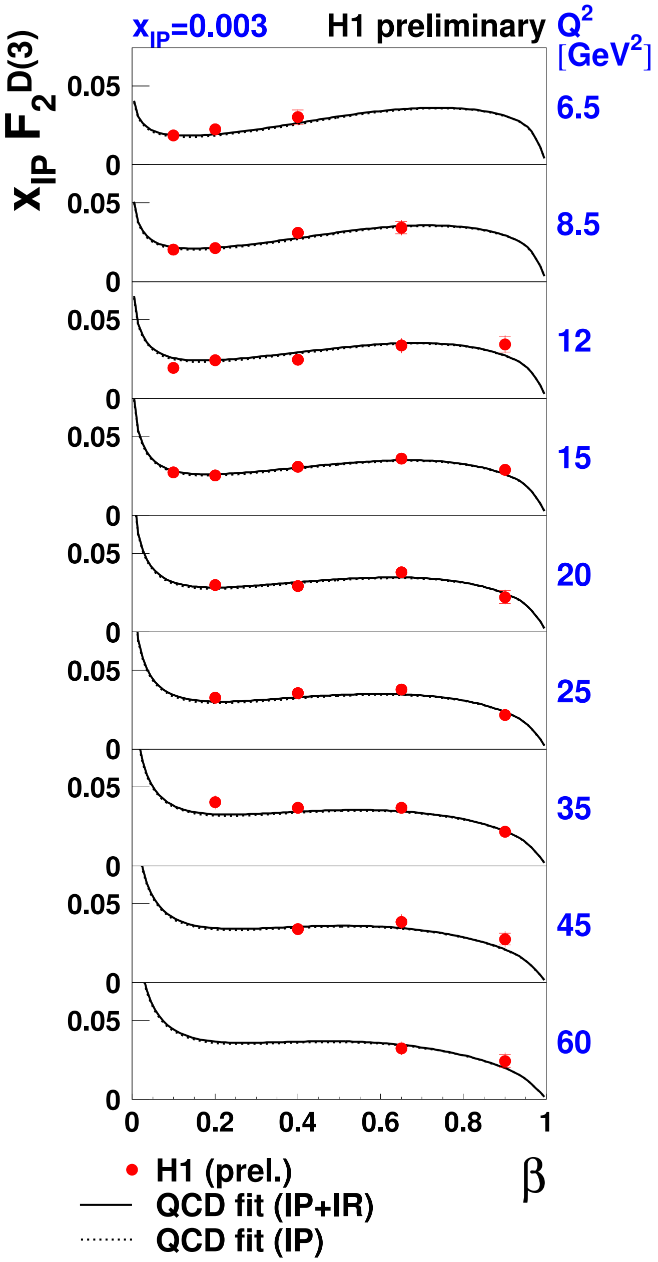
  Regge factorisation assumed in addition



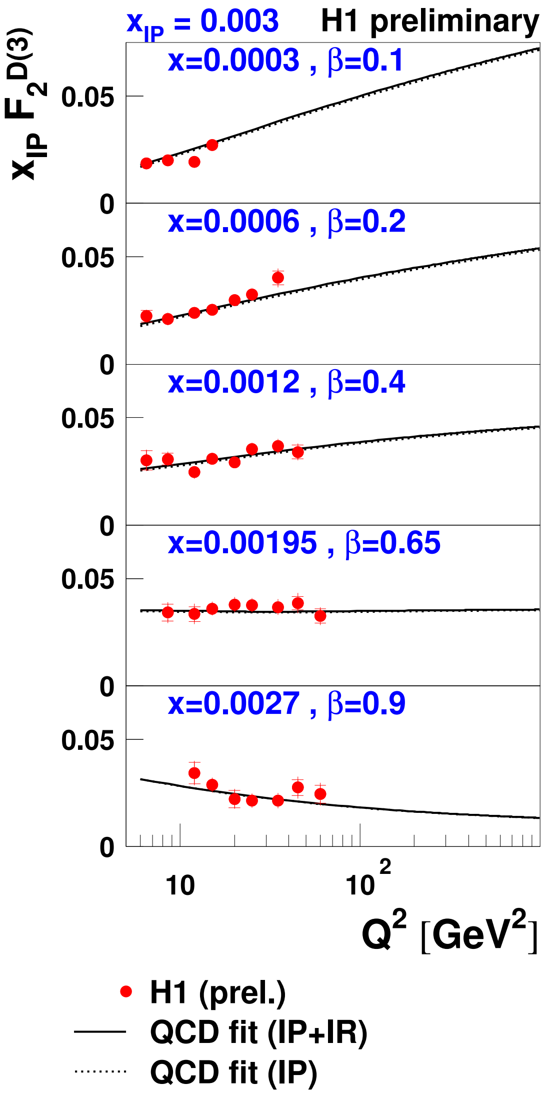

$$F_2^{D(4)}(Q^2, x_{I\!P}, \beta, t) = f_{\mathrm{I\!P}/\mathrm{p}}(x_{I\!P}, t) \cdot F_2^{\mathrm{I\!P}}(\beta, Q^2)$$

$$F_2^{\mathrm{I\!P}}(\beta, Q^2) = \sum_i e_i^2 \beta f_{i/\mathrm{I\!P}}(\beta, Q^2) \ + \ \mathrm{NLO\ corr}$$

# $\beta$, $Q^2$ dependence of $F_2^{D(3)}$




New high precision H1 data



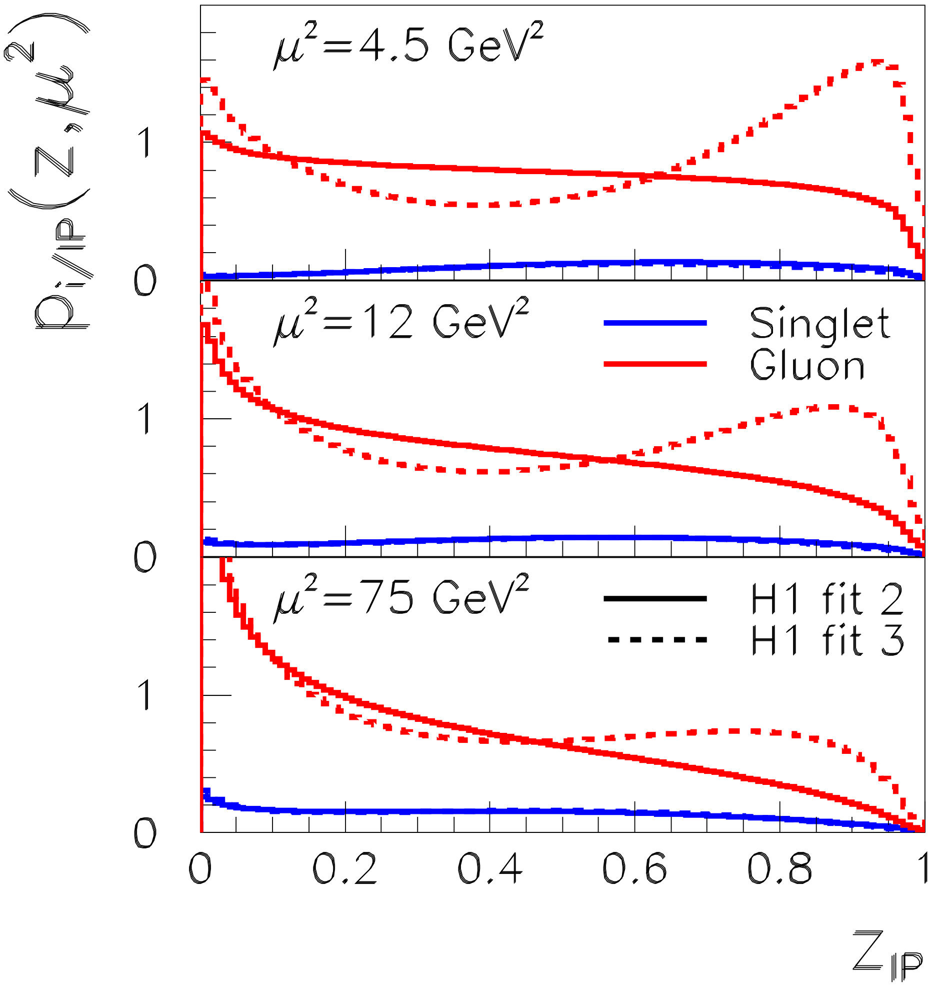

- $\beta$ dependence is relatively flat
- Rising scaling violations with $\ln Q^2$ up to large $\beta$
- Require large gluon contribution in diffractive PDFs, extending to large fractional momenta.

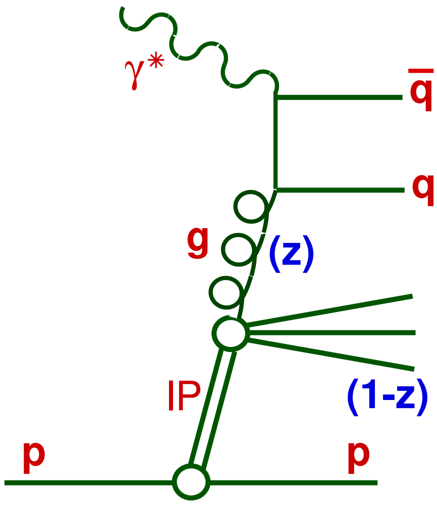
# Diffractive Parton Distributions

DGLAP QCD fit to $F_2^{D(3)} \rightarrow$ $\mathbb{P}$ parton distributions

$\triangleright$ direct constrain of quark density

$\triangleright$ gluon density from scaling violations

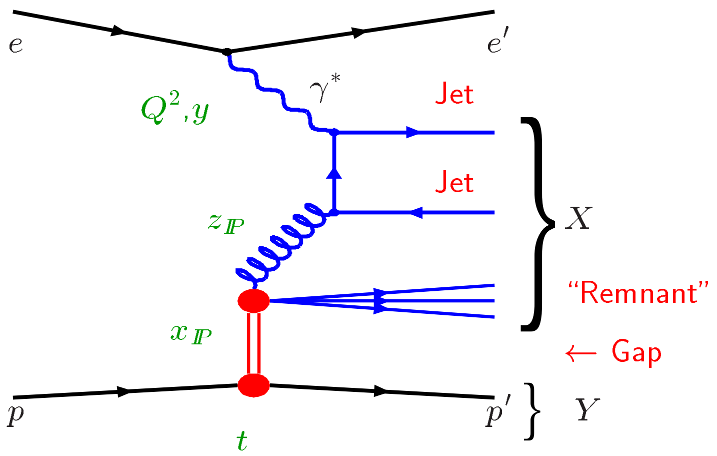


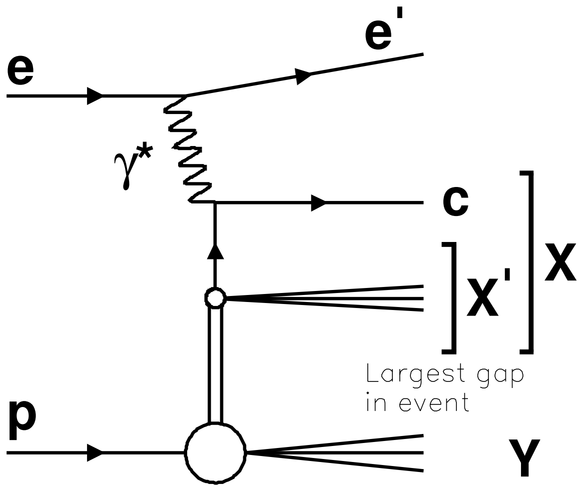




- gluon $\gg$ quark singlet (uds)
- Uncertainty on $g^D$, especially at large $z_{\mathbb{P}}$

$\Rightarrow$ Use to predict diffractive final state cross sections

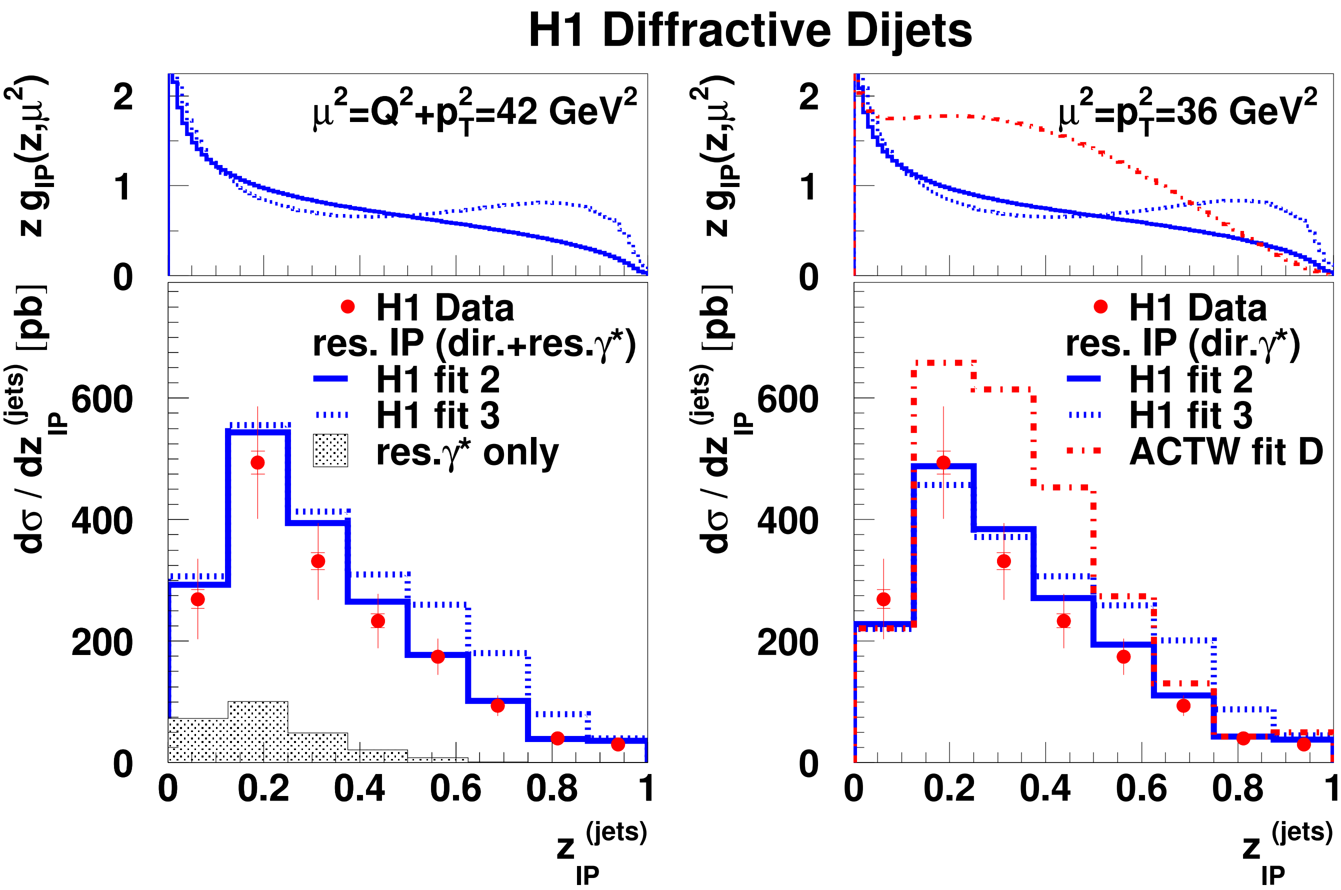
# Diffractive Dijet and $D^*$ Production




- High $P_T$ jets and $M_c$ provide a hard scale $\longrightarrow$ pQCD
- Direct sensitivity to gluon structure of colour singlet exchange (BGF process)
- Test of QCD factorisation and theoretical approaches:
  - ◇ Resolved Pomeron model
  - ◇ Colour Dipole models

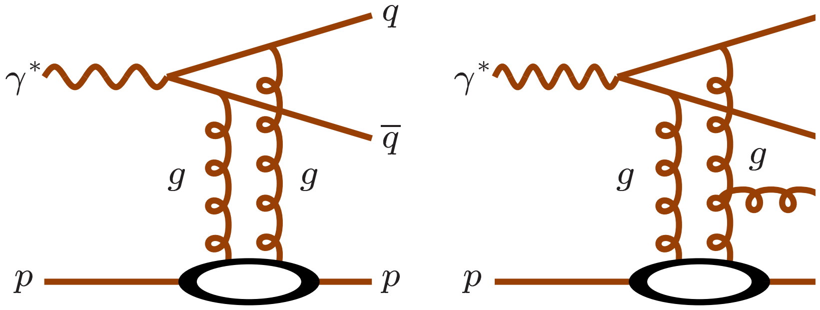
# Diffractive Dijet Production in DIS




- Constrain shape and normalization of gluon density in $\mathbb{P}$
- H1 QCD fit 2: very good agreement with data

$\Rightarrow$ Support for QCD factorisation and gluon dominated PDFs

# Colour Dipole Models




- $\gamma^* \to q\bar{q}, q\bar{q}g$ scatter elastically off the proton through $2g$ colour-singlet
- dipole cross section $\sigma \propto [x_{I\!P} G(x_{I\!P}, k_T^2)]^2$

## $k_T$ ordering

- no $k_T$ ordering ($k_T^g > k_T^q$ included)

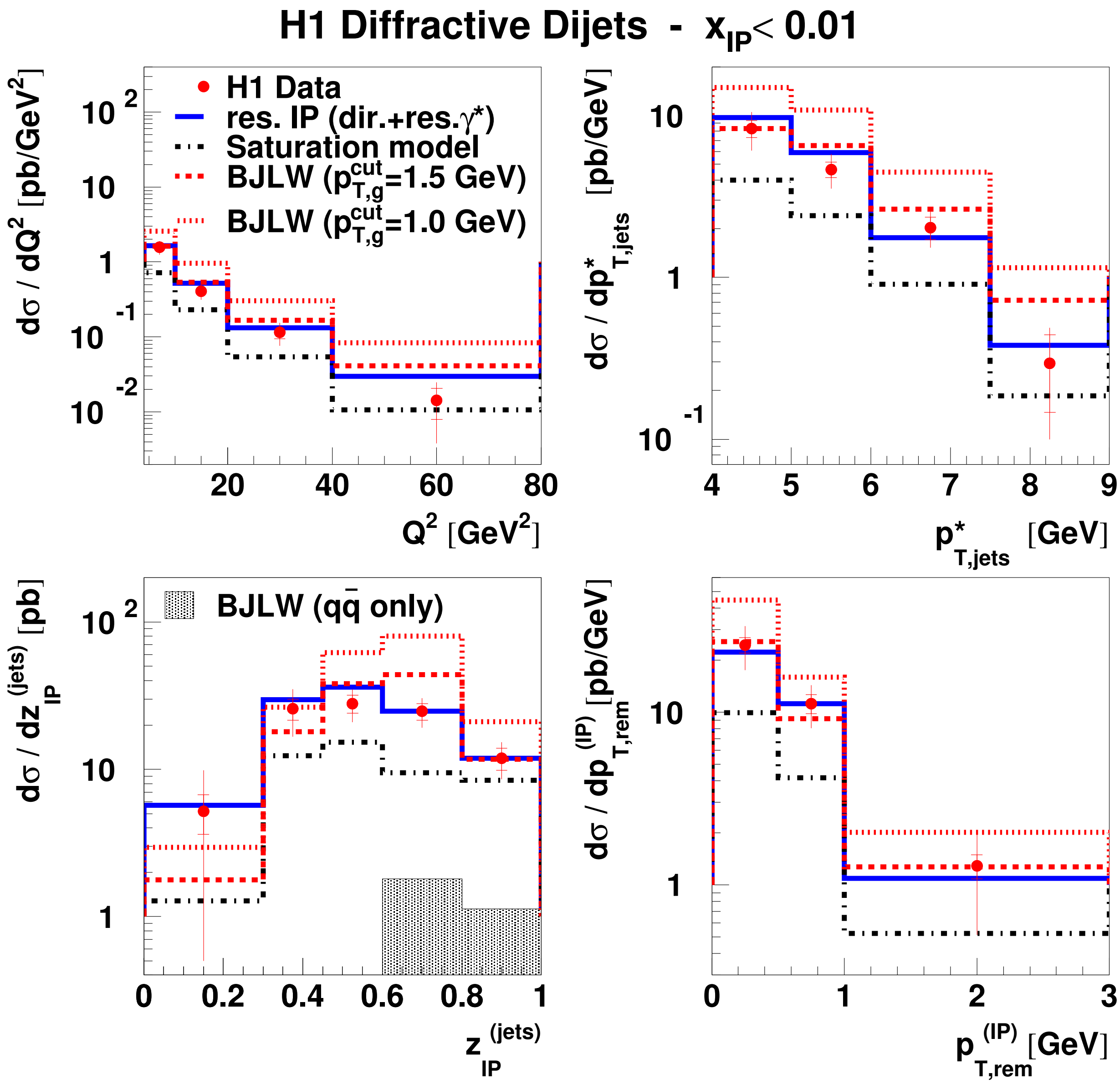
▷ BJLW model (Bartels, Jung, Lotter, Wüsthoff)

- strong $k_T$ ordering ($k_T^g \ll k_T^q$)

▷ Saturation model → SATRAP (G.-Biernat, Wüsthoff)

▷ RIDI model (Ryskin)

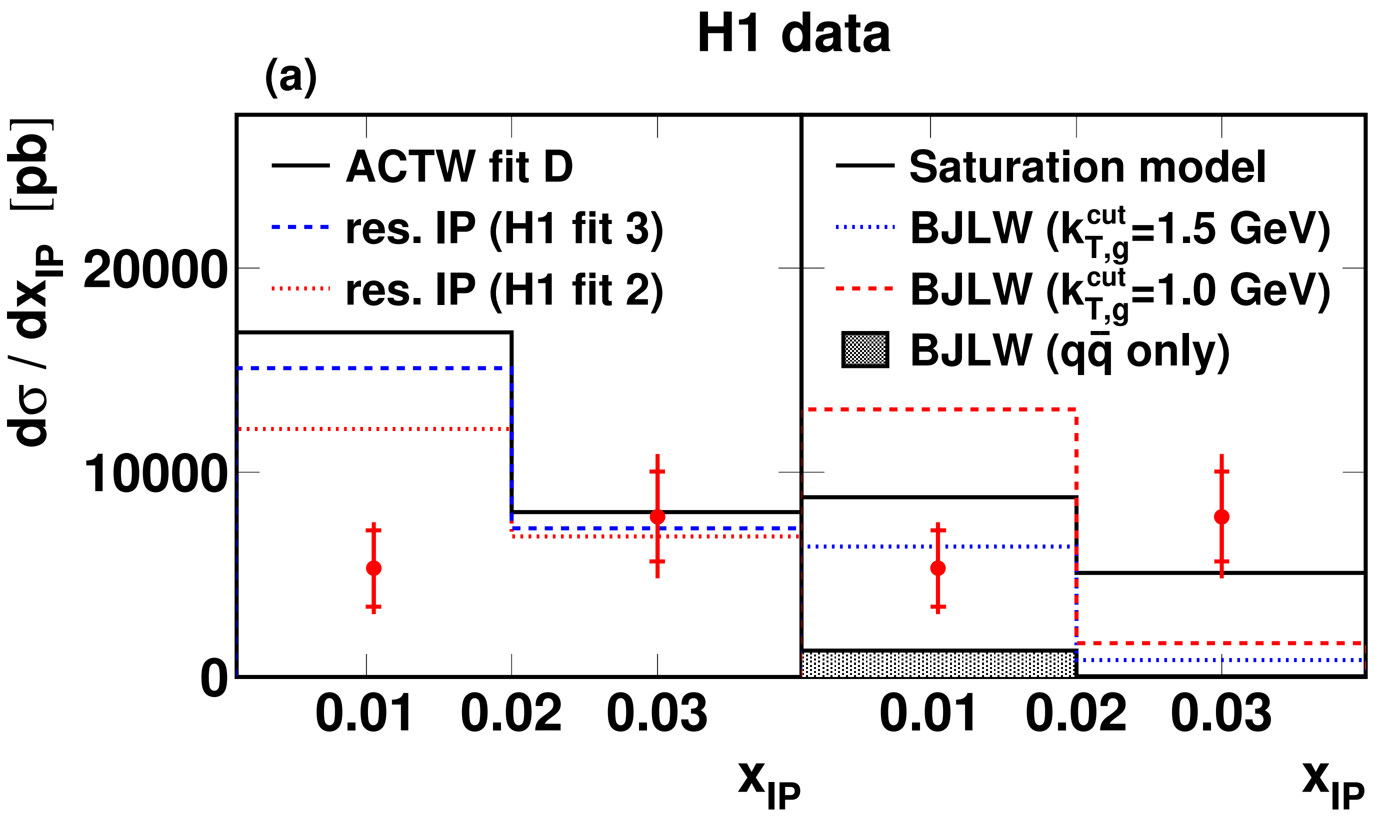
# Dijets vs Colour Dipole Models




- 2 gluon exchange BJLW model (non-ordered $k_T$) describes data well
- Saturation model (strong $k_T$ ordering) is too low

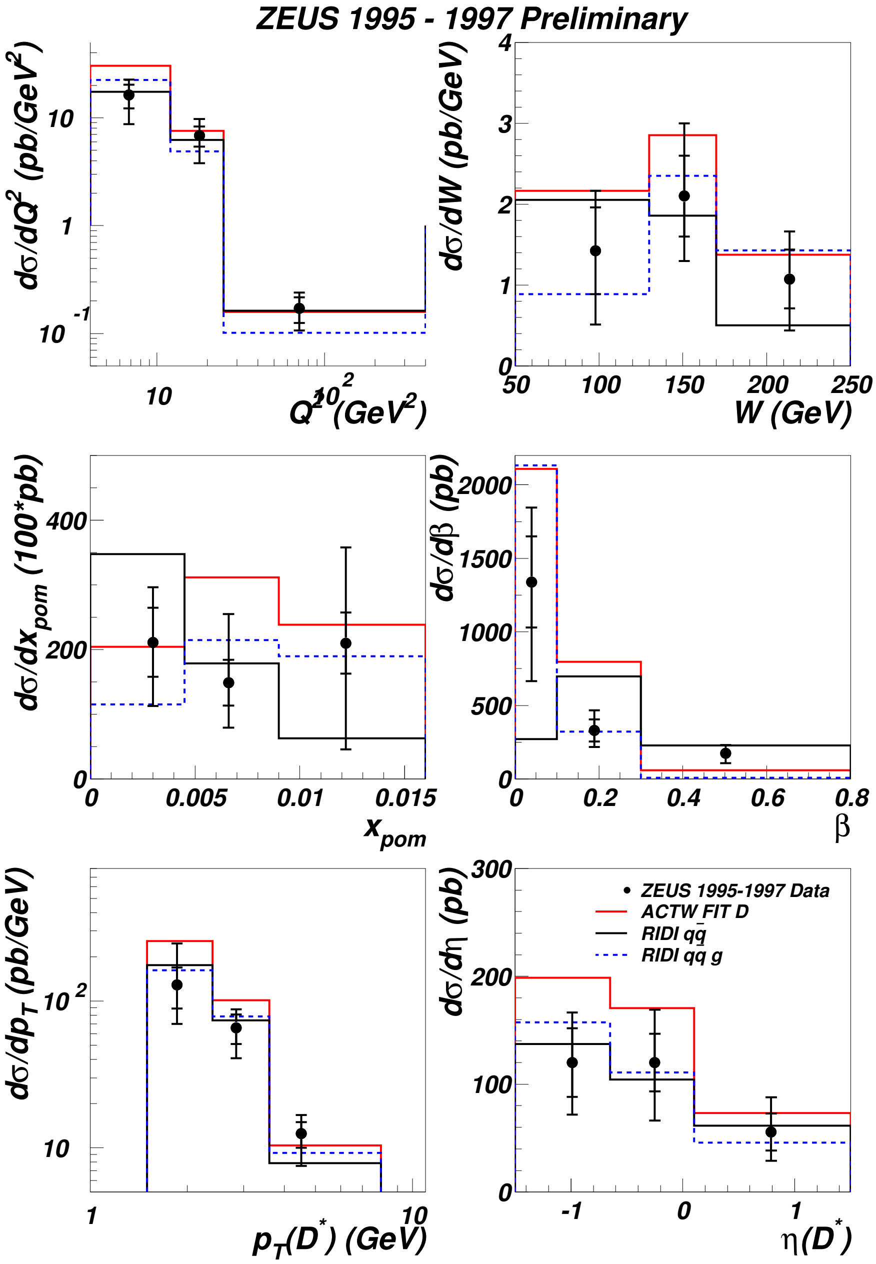
  $\Rightarrow$ non-ordered $k_T$ contributions are important ?

# Diffractive $D^*$ Production in DIS




- Resolved $I\!P$ model consistent with data at high $x_{I\!P}$, but fail at low $x_{I\!P}$
- Saturation model gives better description of data, small $q\overline{q}$ contribution is present at low $x_{I\!P}$

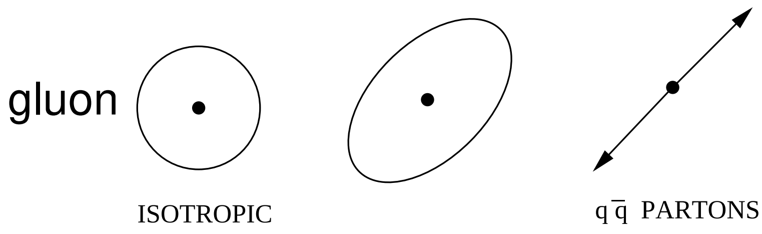
# Diffractive $D^*$ Production in DIS

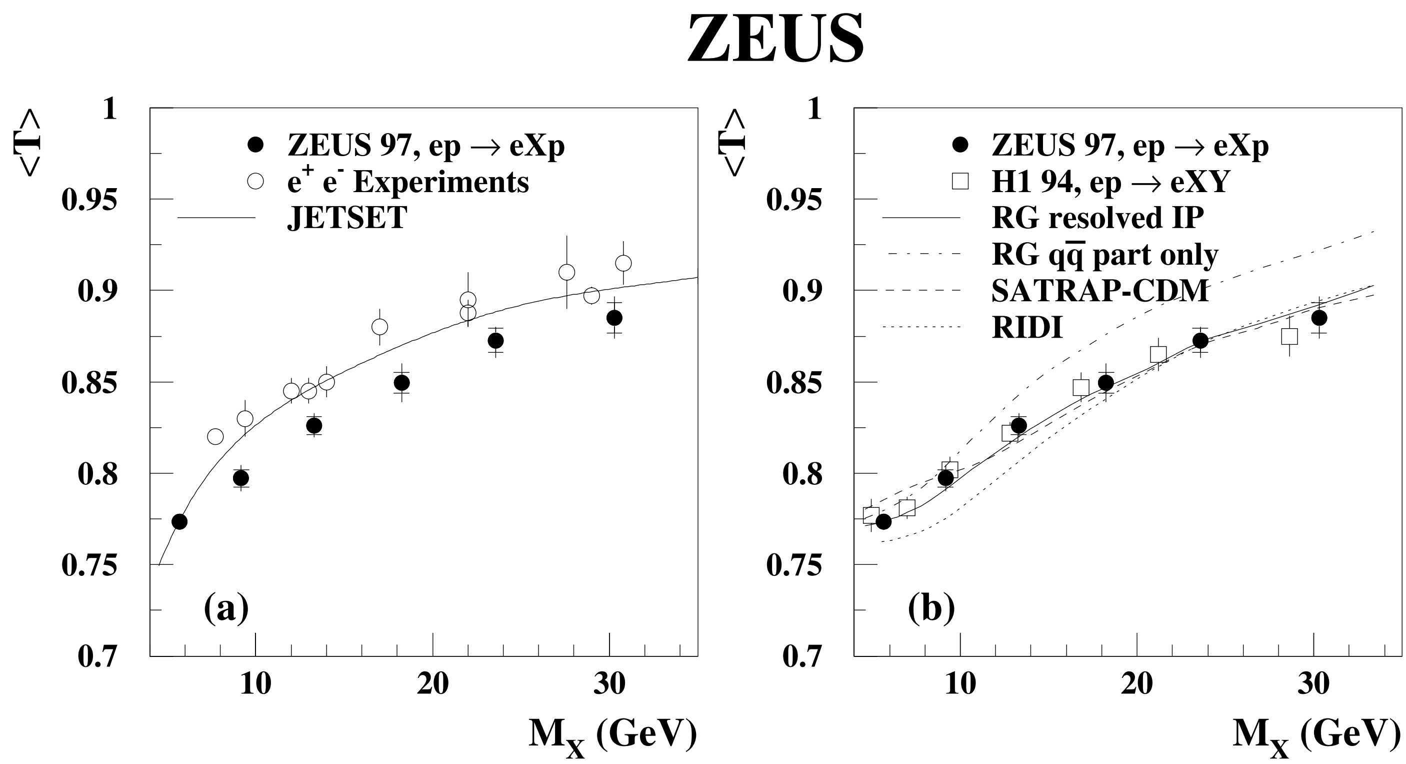



- Resolved $\mathbb{P}$ model (ACTW) and 2-gluon exchange model (RIDI $q\bar{q}$ and $q\bar{q}g$) describe the data except for $\beta$ distribution $\Rightarrow$ require combination of $q\bar{q}$ and $q\bar{q}g$ components

# Event Shapes in Diffractive DIS

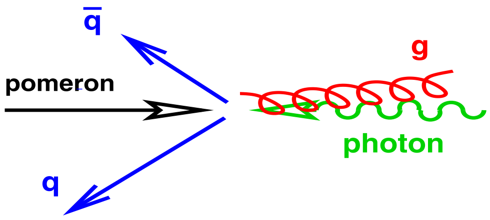
$$1/2 < T < 1$$

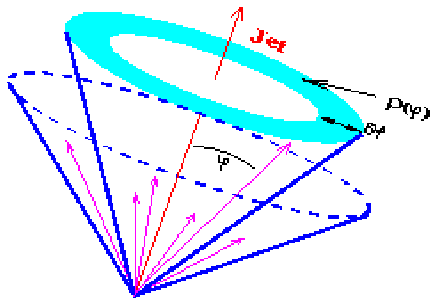


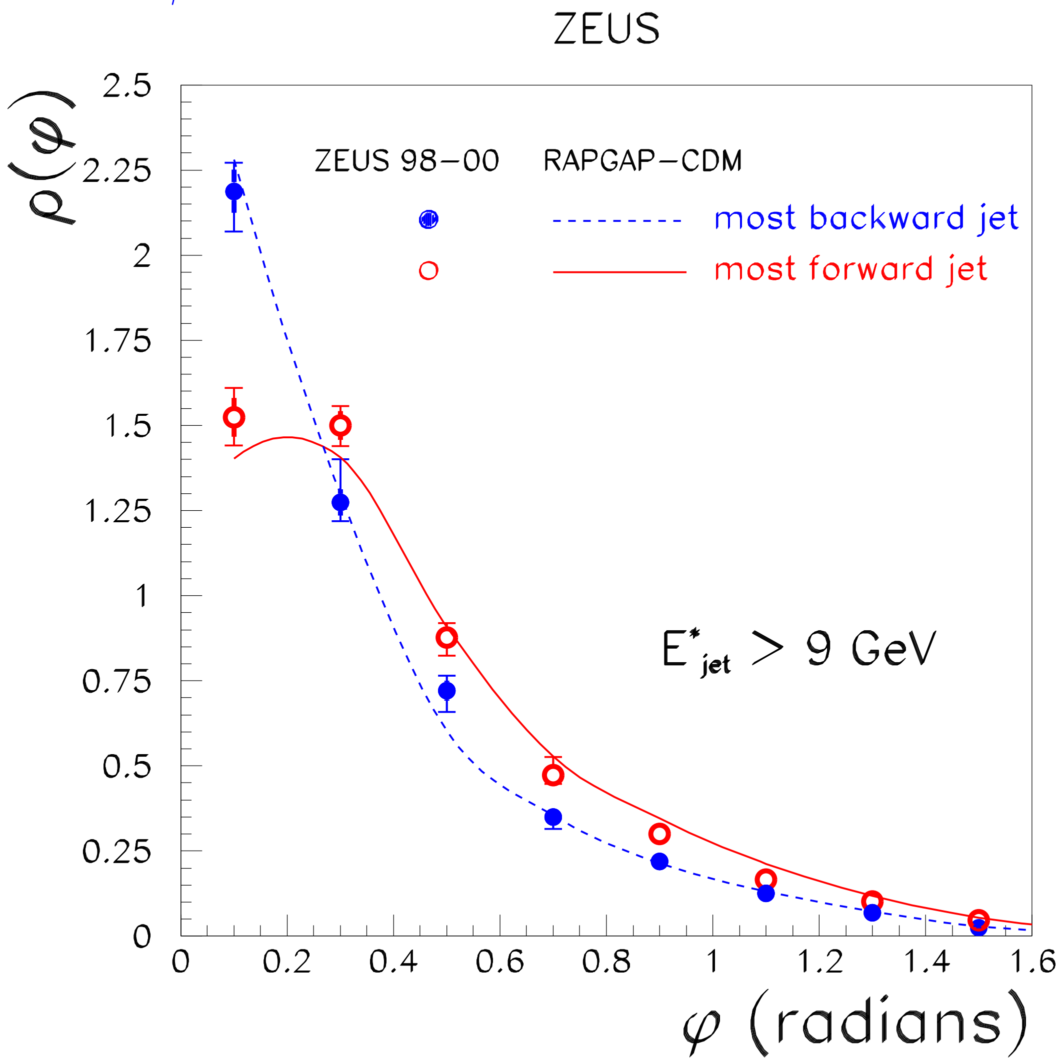

- Thrust indicate more isotropic diffractive final state than
  $e^+e^- \to q\bar{q} \to \text{hadrons}$
  $\Rightarrow$ importance of $\gamma^* \to q\bar{q}g$ contribution in diffractive DIS
- Final state becomes more collimated at high $M_X$
- Resolved $\mathbb{P}$ model with PDFs from $F_2^D$ describes data

# Diffractive Three Jet Production




$$\rho(\phi) = \langle \frac{1}{\delta\phi} \frac{E^{jet}(\phi \pm \delta\phi/2)}{E^{jet}} \rangle$$




- most forward jet ($\mathbb{P}$ direction) is broader than most backward jet ($\gamma^*$ direction)
- data consistent with gluon in $\mathbb{P}$ direction

# Summary

Consistent picture of inclusive diffraction and hadronic final states in DIS at HERA:

- Support QCD factorisation for inclusive and dijet production
- Diffractive PDFs dominated by gluon contribution
- Dijets favour for non-ordered $k_T$ distributions
- Significant contribution of $q\bar{q}g$ in parton final state with gluon emitted in $\mathbb{P}$ direction
- Resolved Pomeron model is successful in description of variety of diffractive DIS data