Diffractive structure functions from HERA

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on behalf of H1 and ZEUS collaborations

XXXVI Rencontres de Moriond

" *QCD and high energy hadronic interactions*"

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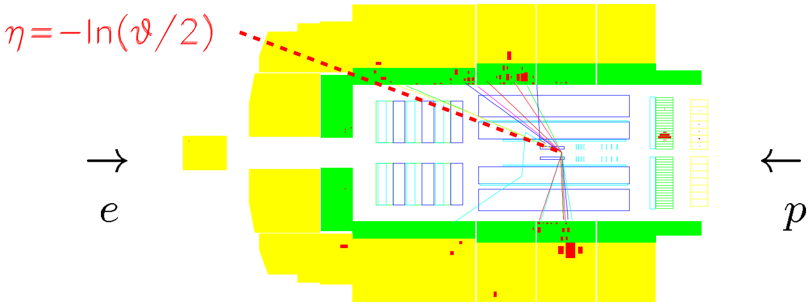
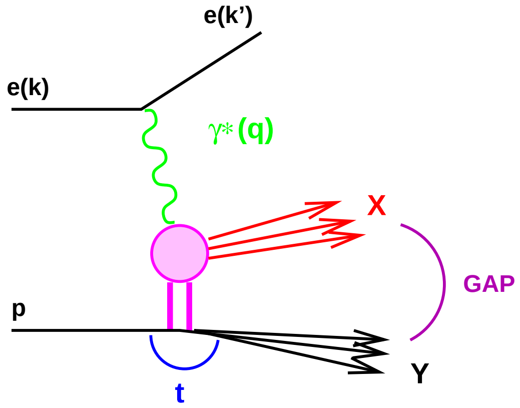
Diffraction at HERA

Events with no activity in the outgoing p direction:





Dissociation of the virtual photon with exchange of a colorless object.

Description in terms of:

- Regge theory:

  Diffractive and total γp cross section in photoproduction ($Q^2 = 0$). Universal 'soft' Pomeron trajectory:

  $\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha'_{IP} \cdot t \qquad \alpha_{IP}(0) \simeq 1.08$

- pQCD:

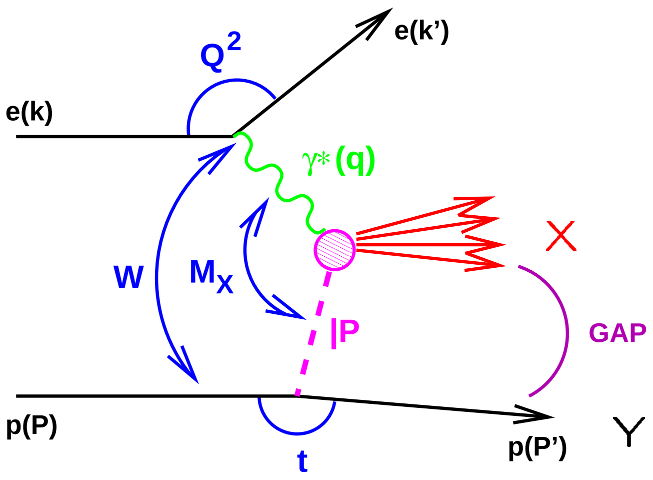
  QCD description of diffractive processes in presence of high scale (γ^* virtuality, high p_T jets, high t).

Experimental selection:

- Large rapidity gap
- X mass spectrum
- Leading proton with $p' \sim p$

Kinematics

Standard DIS variables:



- $Q^2 = -q^2 = (k' - k)^2$
- $x = Q^2/(2q \cdot p)$
- $y = (p \cdot q)/(p \cdot k)$
- $W = (q + p)^2$

In diffractive DIS two distinct hadronic systems:
more kinematic variables

- $t = (p - p')^2$ 4-momentum transfer at the p vertex
- $M_X^2 = (q + IP)^2$ $IP - \gamma$ invariant mass squared
- $x_{IP} = \frac{(P-P')\cdot q}{P\cdot q} \simeq \frac{M_x^2+Q^2}{W^2+Q^2}$ fraction of proton momentum carried by the IP
- $\beta = \frac{Q^2}{(P-P')\cdot q} = \frac{Q^2}{M_X^2+Q^2}$ fraction of IP momentum carried by the struck quark

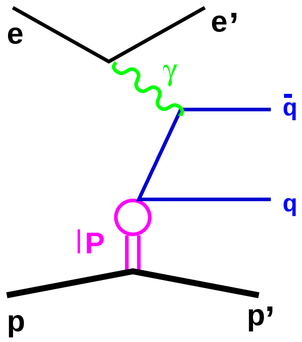
$$\frac{d^4\sigma_{ep}^{diff}}{d\beta dQ^2 dx_{IP} dt} = \frac{2\pi\alpha^2}{\beta Q^2}\left[1 + (1-y)^2\right] F_2^{D(4)}(\beta, Q^2, x_{IP}, t)$$

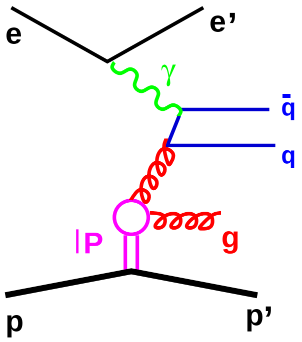
If t is not measured:

$$\frac{d^3\sigma_{ep}^{diff}}{d\beta dQ^2 dx_{IP}} = \frac{2\pi\alpha^2}{\beta Q^2}\left[1 + (1-y)^2\right] F_2^{D(3)}(\beta, Q^2, x_{IP})$$

Theoretical models

1. **Resolved Pomeron** (G.Ingelman and Schlein)





Hard factorization proven in ep (Collins 1997)

$$F_2^D \sim f_{i/p}^D \otimes \hat{\sigma}_i$$

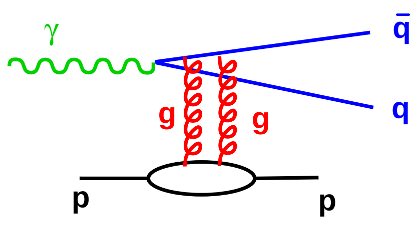
Regge factorization assumed:

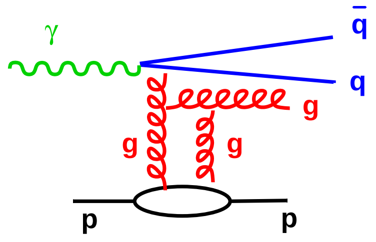
$$F_2^{D(4)} = f_{IP/p}(x_{IP}, t) \cdot F_2^{IP}(Q^2, \beta)$$

$$f_{IP}(x_{IP}, t) = e^{B_{IP}t} \left(\frac{1}{x_{IP}} \right)^{2\alpha_{IP}(0)-1} \sim \frac{1}{x_{IP}} e^{B_{IP}t}$$

$$F_2^{IP} = \sum_f e_f^2 \left(\beta \cdot q_f + \beta \cdot \bar{q}_f \right) \quad \text{(at LO)}$$

2. **pQCD exchange**





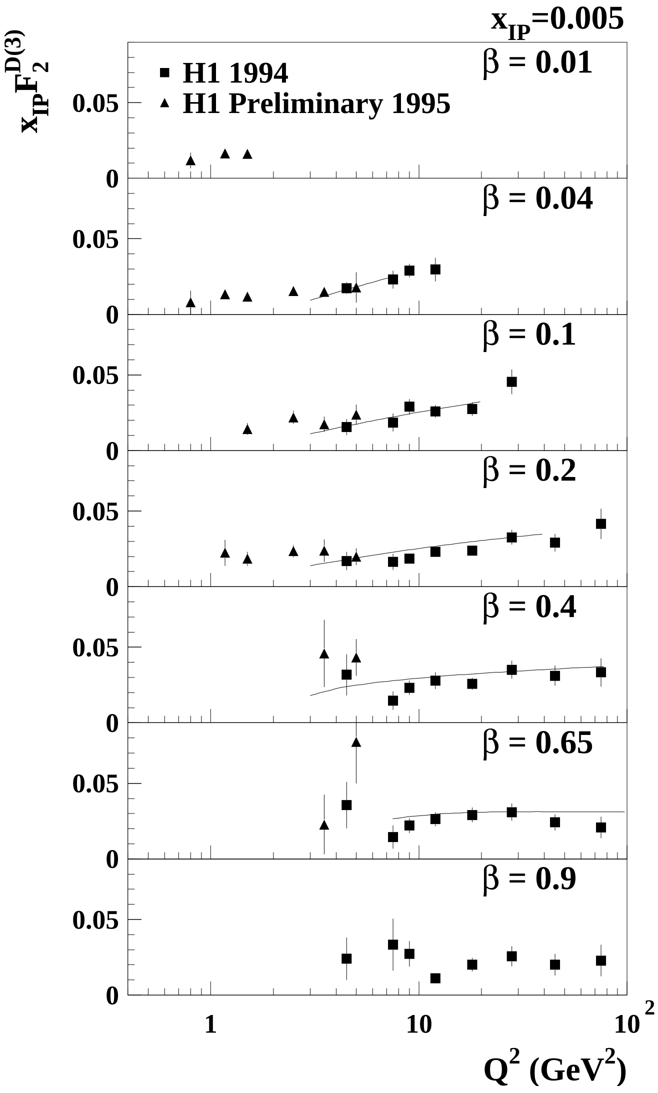
γ-dissociation in the p-rest frame

($\gamma \rightarrow q\bar{q}$, $q\bar{q}g$ with $\tau \sim 1/x$)

Pomeron described as two-gluon exchange

pQCD analysis of $F_2^{D(3)}$

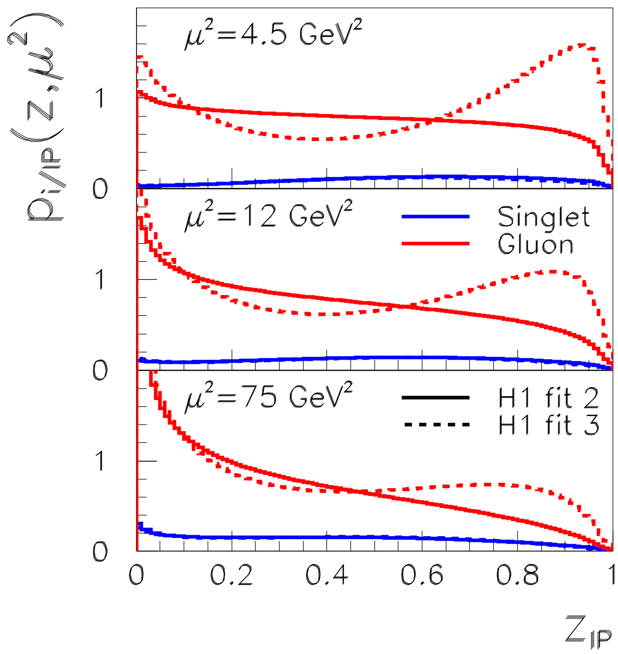
$x_{IP}F_2^D = F_2^{IP}$



Rising scaling violation also at large β (~ 0.2)

$\Downarrow$

indication of large gluon contents in the Pomeron



NLO DGLAP evolution of $F_2^{IP}(\beta, Q^2)$

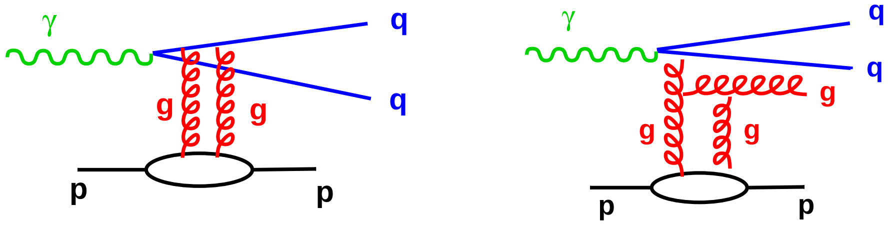
$\downarrow$

Pomeron momentum carried by gluons:
(~ 90 % at $Q^2 = 4.5$ GeV^2, ~ 80 % at $Q^2 = 75$ GeV^2)

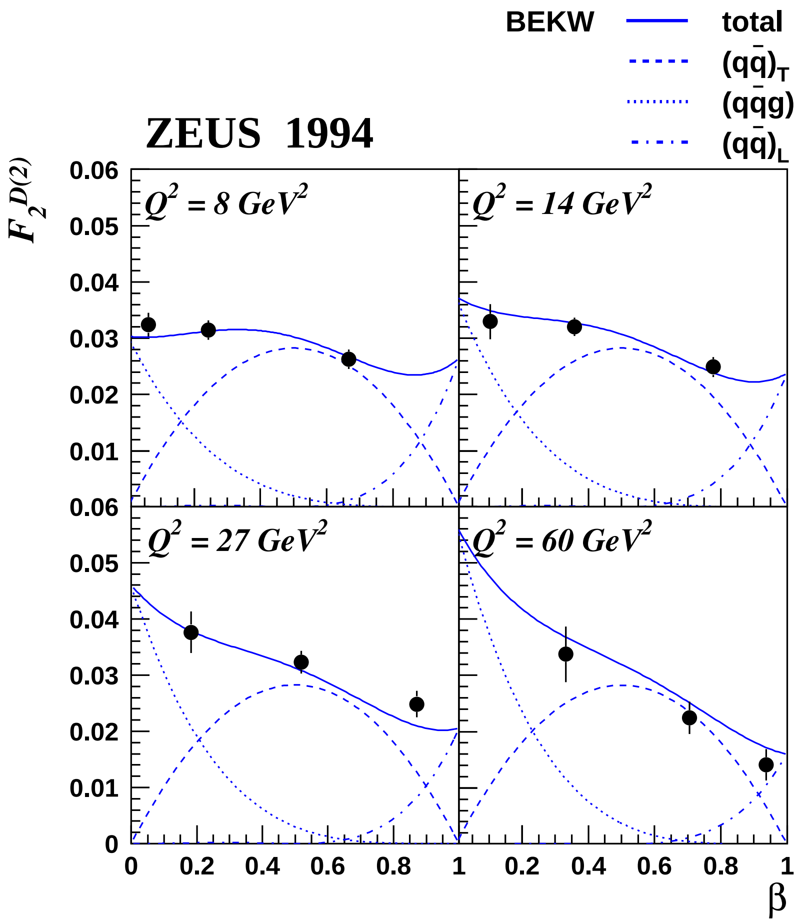
Dominant process is photon-gluon fusion.
Gluon distribution not well constrained by inclusive diffractive data.

pQCD-motivates models of $F_2^{D(3)}$

BEKW model (Bartels, Ellis, Kowalski, Wüsthoff)



$$x_{IP}F_2^{D(3)}(\beta, x_{IP}, Q^2) = c_T F_{q\bar{q}} + c_L F_{q\bar{q}} + c_g F_{q\bar{q}g}$$

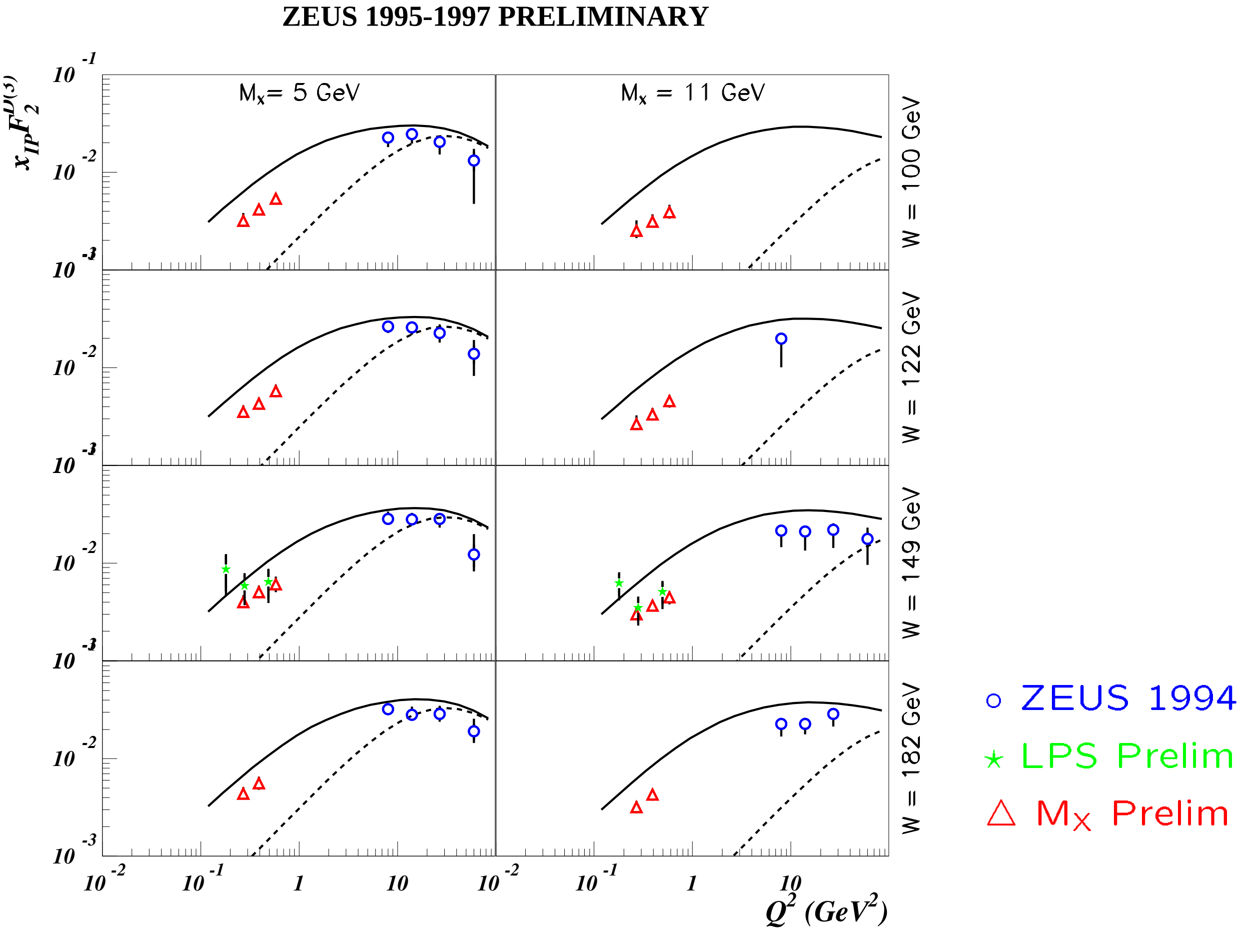


$q\bar{q}g$ is the main contribution at low β. $\left(\beta = \frac{Q^2}{M_X^2+Q^2}\right)$

Diffractive DIS at low Q^2

$0.2 < Q^2 < 0.7\ GeV^2$ (ZEUS BPC)

$x_{IP} F_2^D = F_2^{IP}$



Saturation model (K.Golec-Biernat and Wüsthoff)

$$\sigma^{diff} \sim \int d^2r \int dz |\ \Psi(z,r)\ |^2 \hat{\sigma}^2_{dipole}(r)$$

Effective dipole cross section in the impact parameter space:

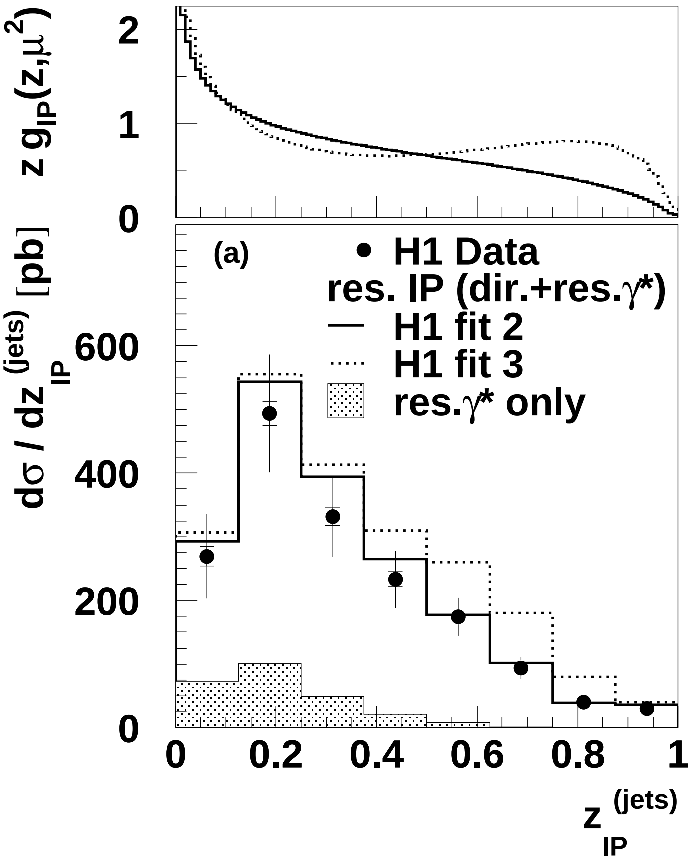
$$\hat{\sigma}_{dipole}(r) = \hat{\sigma}_0 \left[1 - \exp\left(-\frac{r^2}{4R_0^2(x)}\right)\right]$$

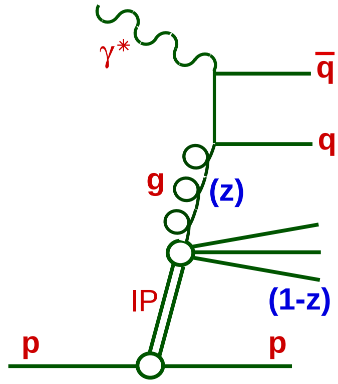
The model (tuned on inclusive ep data) describes the transition.
Important contribution of $q\bar{q}g$ at low Q^2.

Di-jet production in diffractive events

High p_T jet production sensitive to the shape of pomeron gluon distribution.

(H1) Cone algorithm in the $\gamma^* p$ rest-frame, 2-jets.
$p^*_{T,jet} > 4$ GeV, $-1.0 < \eta^{lab}_{jet} < 2.2$, $4 < Q^2 < 80$ GeV^2.





$$z_{IP}^{jets} = \frac{Q^2 + M_{12}^2}{Q^2 + M_X^2}$$

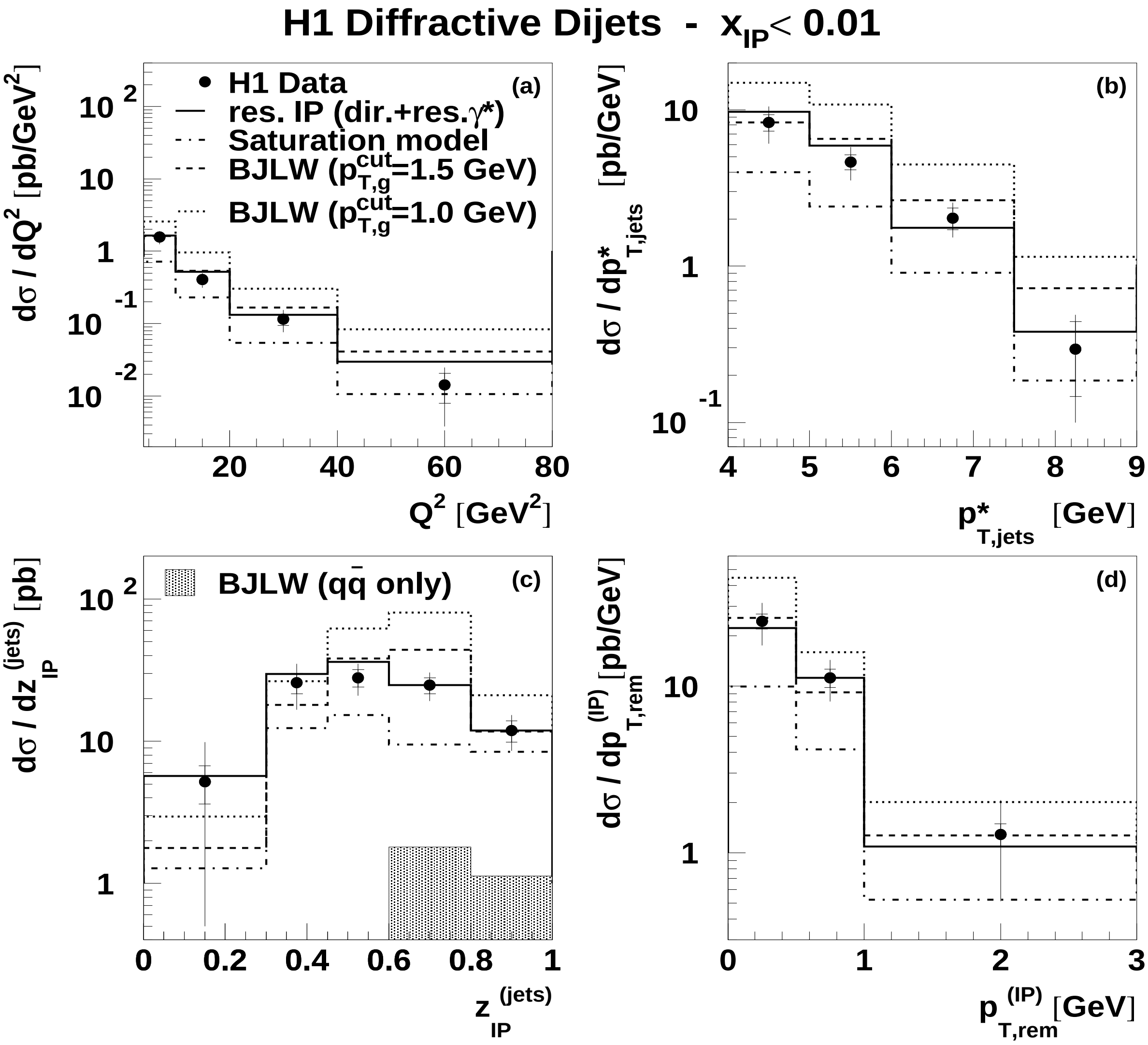
momentum fraction of exchange coupling with γ^*

$\sim$ fraction of energy of the X system contained in the two jets.

- z_{IP} distribution favours 'flat gluon' distribution.
- large fraction of the energy not contained in the jets

Di-jet production in diffractive events

Comparison with models:



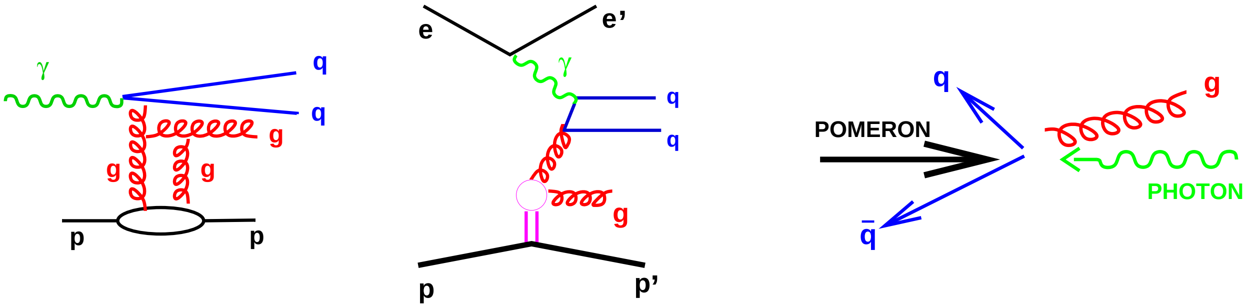
- resolved Pomeron model (flat gluon distribution)
- Saturation model
- 2-gluon exchange
  BELW model (Bartels, Ewerz, Lotter, Wüsthoff)

  large $q\bar{q}g$ contribution ($p_{T,g}^{cut} = 1.5$ GeV)

Three jet production in diffractive DIS

high mass region: $25 < M_X < 40$ GeV
high W: $200 < W < 250$ GeV

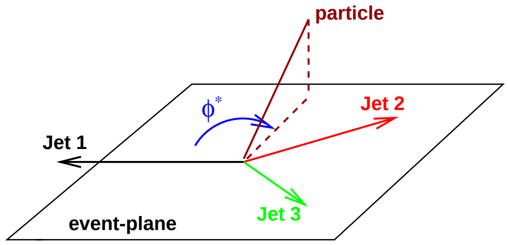
$\eta_{max} < 3.0$ $\quad x_{IP} < 0.025$ $\quad 5 < Q^2 < 100\text{GeV}^2$

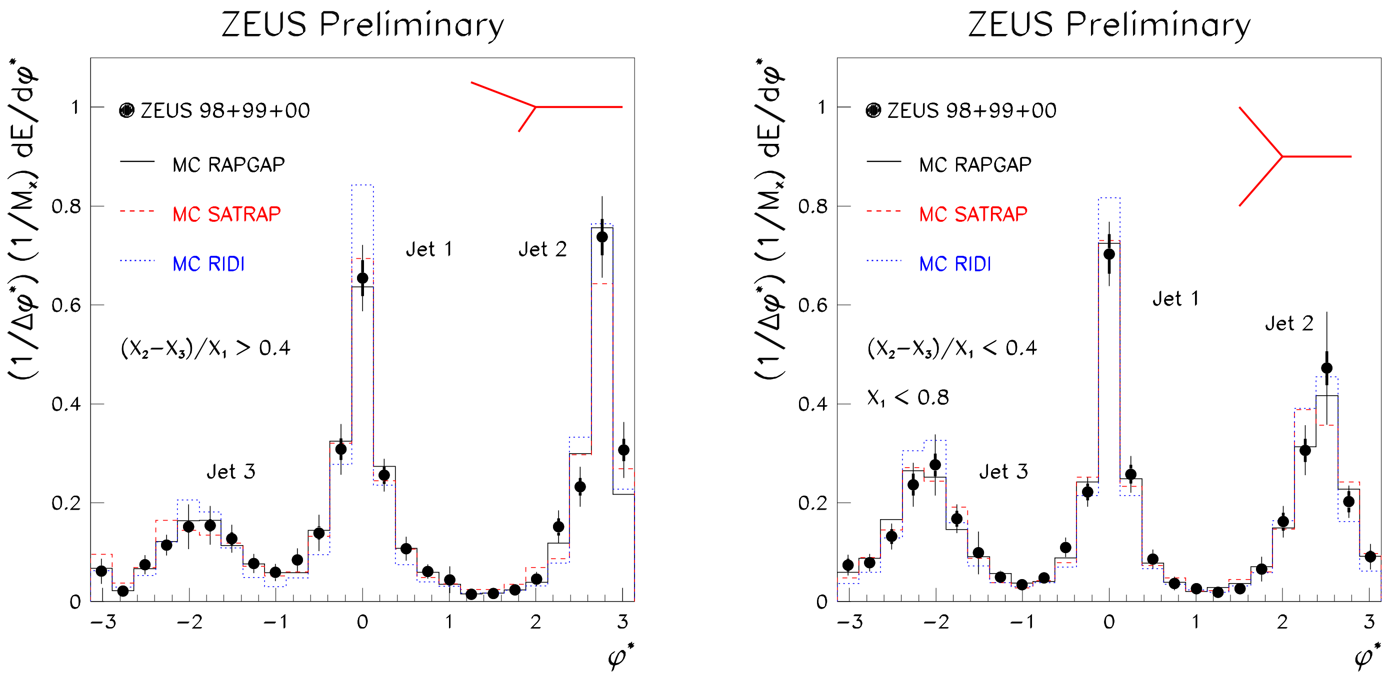


Exclusive K_T-algorithm
in the $IP - \gamma$ center of mass:

$$y_{ij} = \frac{2 \cdot min(E_i^2, E_j^2)(1 - \cos\theta_{ij})}{M_X^2}$$

$y_{cut} = 0.05$ $\qquad | \eta_{lab}^{jet} < 2.3 |$





Jet shapes

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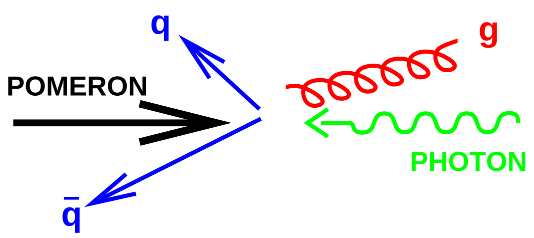
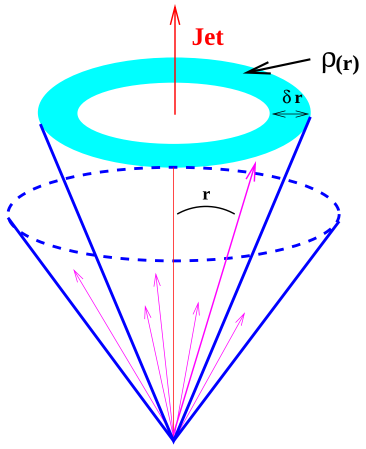
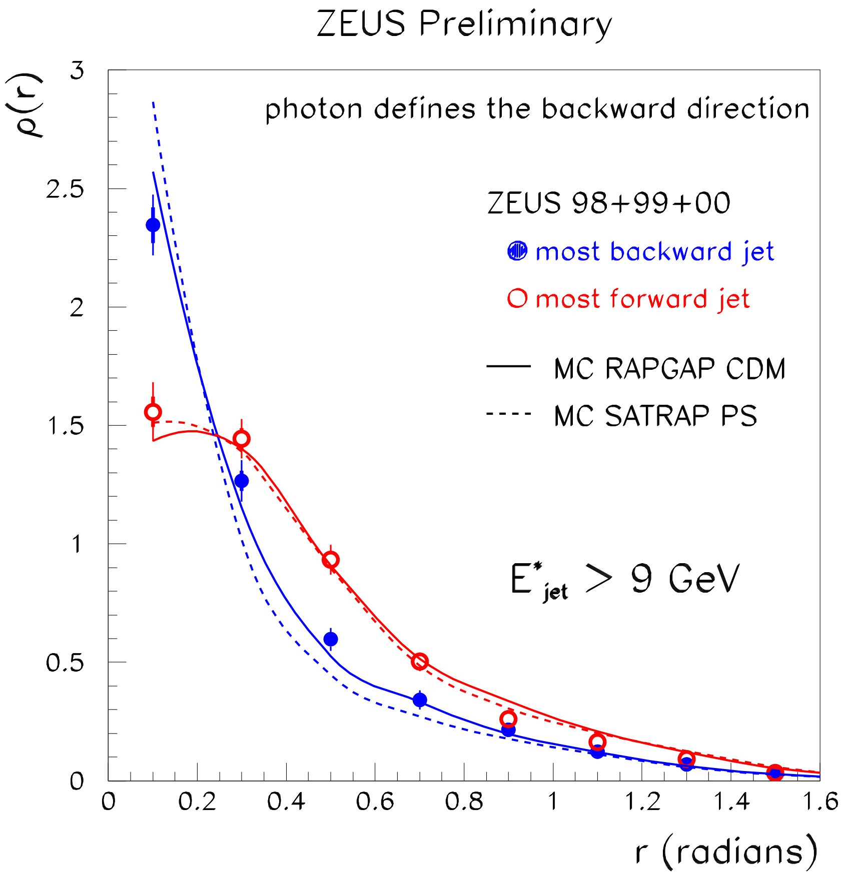




$$\rho(r) = \frac{1}{\delta r} \cdot \frac{E^{jet}(r \pm \delta r/2)}{E^{jet}}$$



(similar energy distribution for the two jets)

Jet in the IP direction broader than the jet in the γ direction

(expected for a gluon-initiated jet in the IP direction)

Summary

HERA measurements provide a consistent picture of diffraction in terms of:

- Regge theory (soft processes)
- pQCD (in presence of high scales)

1. Inclusive diffraction well described by:
   - Resolved Pomeron model with a large gluon content of the $I\!P$.
   - pQCD dipole models.
2. Recent results on inclusive diffraction at low Q^2. Transition to $Q^2 \to 0$ and relation with inclusive F_2^p data described by saturation model.
3. 2-jet production described by pQCD calculations.
4. Clear signal of three jet production in diffractive events. Evidence for a gluon remnant from the Pomeron.