# Final States in Diffraction at HERA

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for the H1 and ZEUS Collaborations

- Introduction
- Event Shapes
- Dijet Production
- Three-jet Production
- Conclusions

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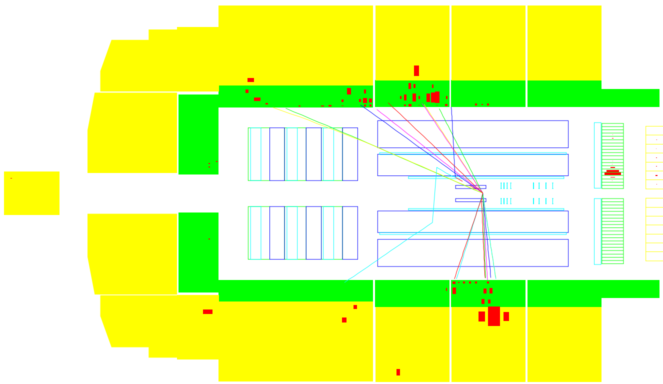
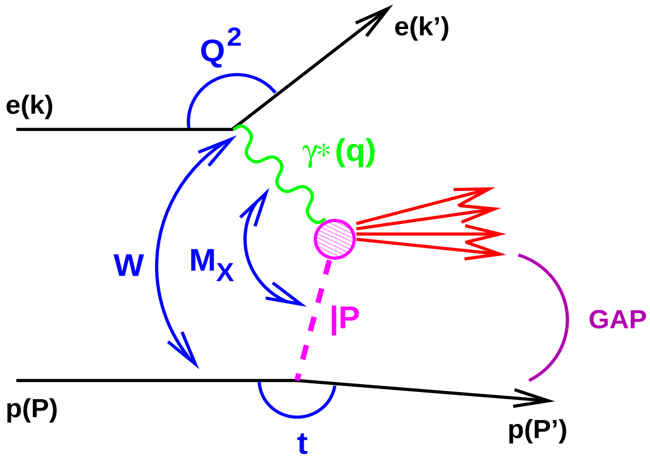
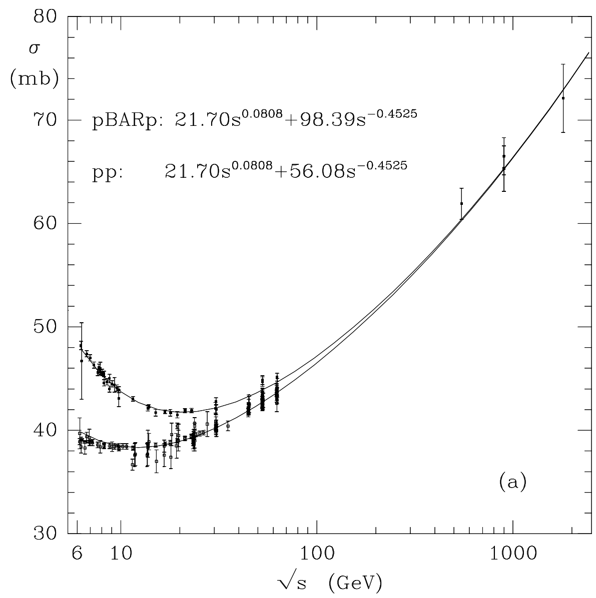
# Introduction (I)

Events with no activity in the forward direction
⇒ Large Rapidity Gap events (LRG).






Exchange of colour singlet ⇒ $I\!P$ exchange



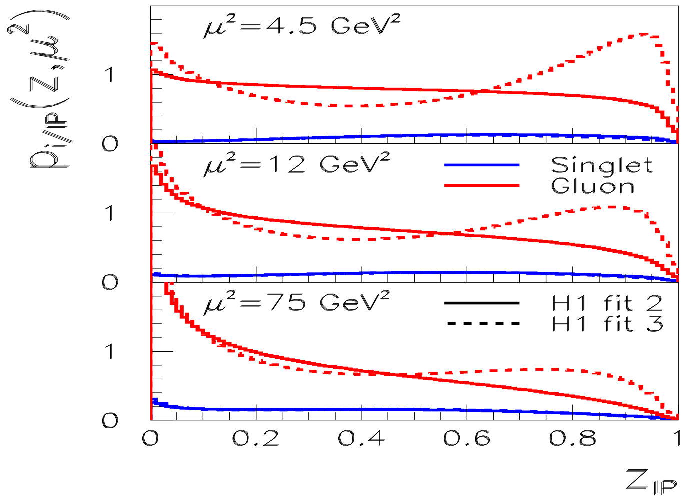

In hadron-hadron collisions the $I\!P$-trajectory describes the total cross section at high energies:

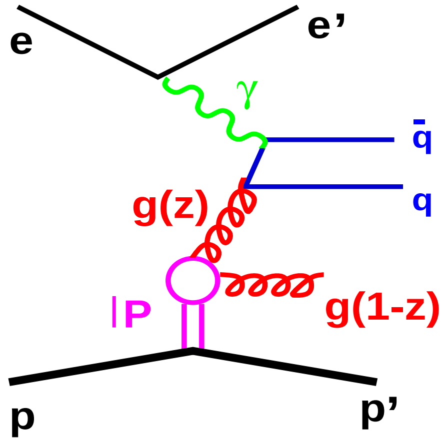
$$\sigma_{tot} \propto s^{\alpha_{I\!P}(0)-1}$$

⇒ The large $\gamma$-virtualities at HERA allow to study the $I\!P$-structure and formulate it in terms of QCD (quarks and gluons)

# Introduction (II)

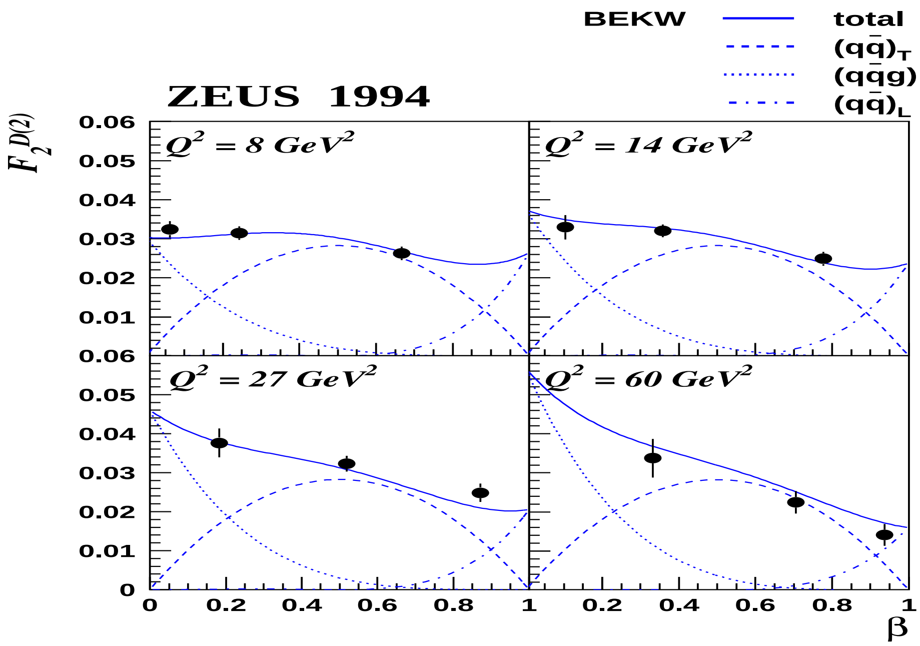
- Ingelman-Schlein factorisable model $\rightarrow$ Pomeron with partonic structure (quark and gluon densities)

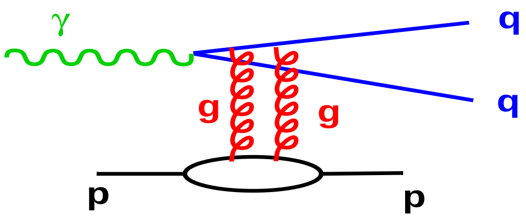


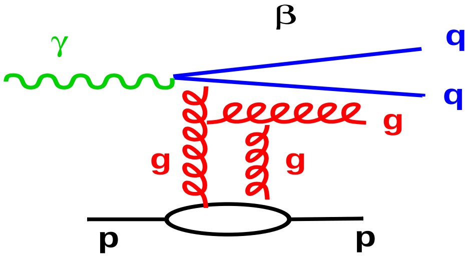




HERA data $\Rightarrow$ Pomeron dominated by gluons.

- pQCD inspired models ($\gamma$-dissociation picture) $\rightarrow$ Pomeron described as two-gluons exchange



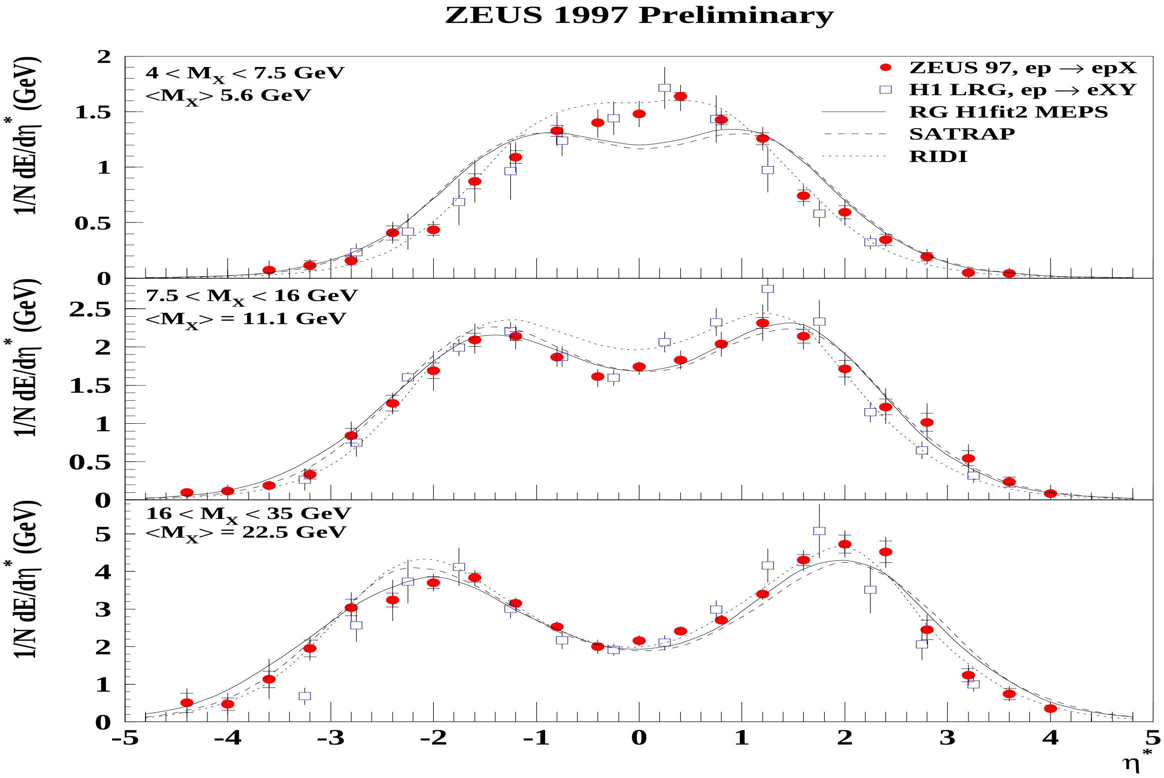



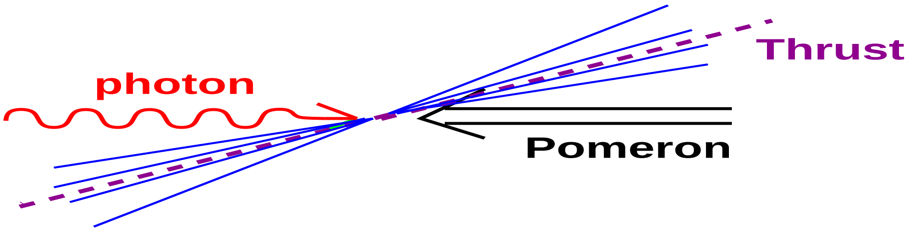

$q\bar{q}g$ contribution dominates at low-$\beta$ ($\beta = \frac{Q^2}{Q^2+M_X^2}$).

# Event Shapes in Diffractive DIS

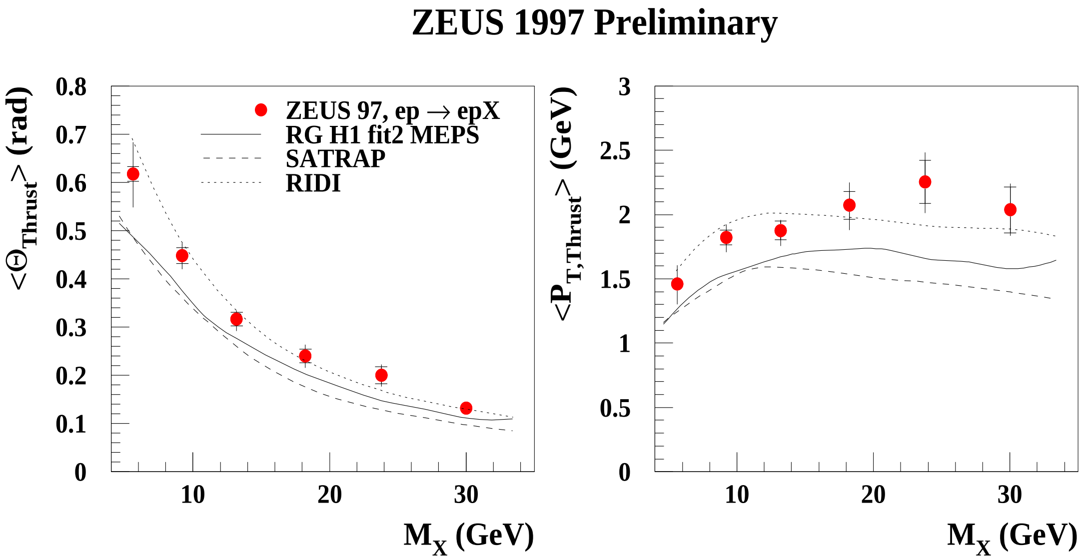
(ZEUS LPS : Contributed paper N$^o$ 876)

(H1 LRG: Phys. Lett. B428 (1998) 206)




⇒ Clear dijet structure for $M_X \geq 8$ GeV.




⇒ Dominant aligned configurations w.r.t the $\gamma^* I\!P$ axis.

# Event Shapes in Diffractive DIS

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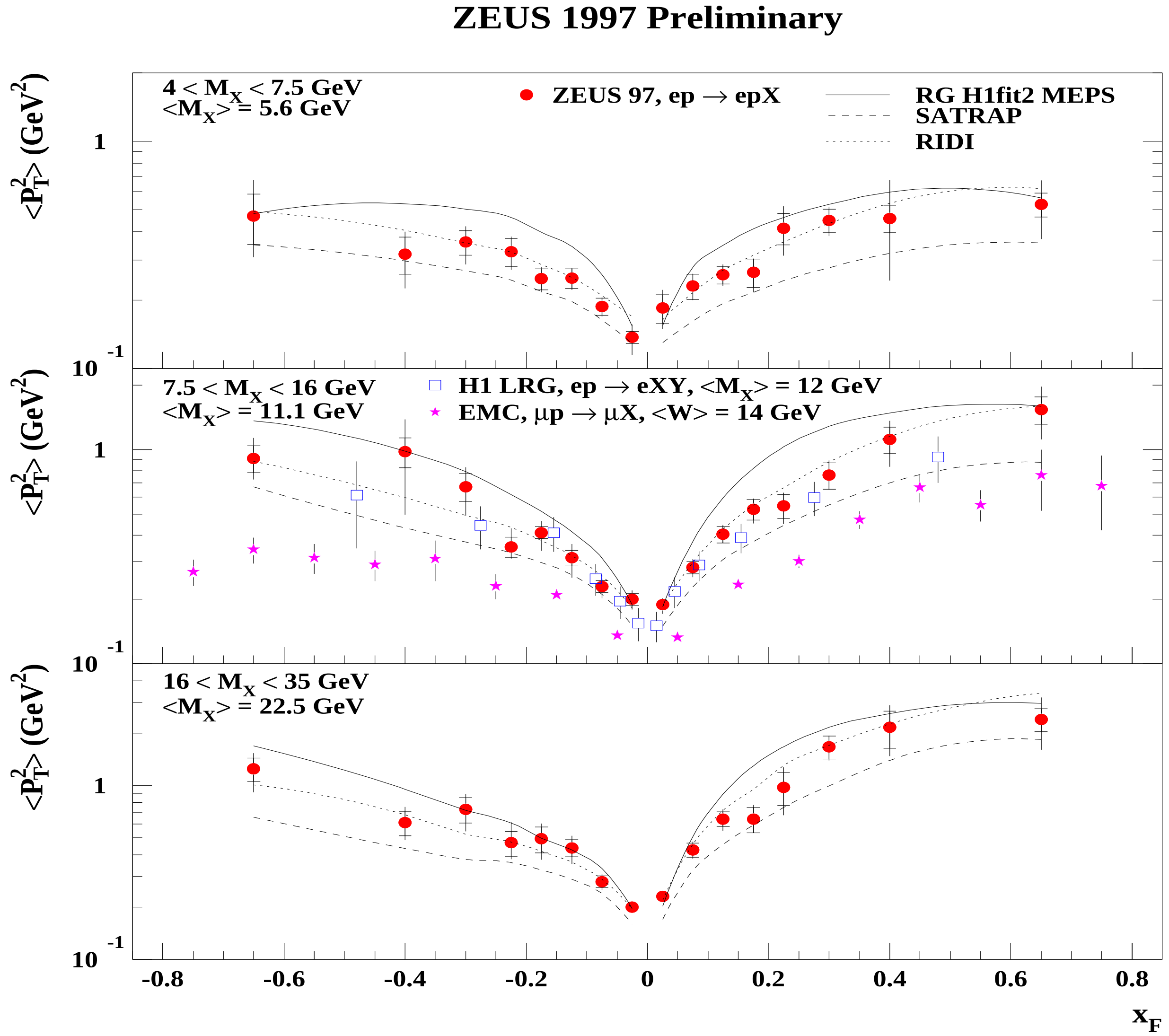
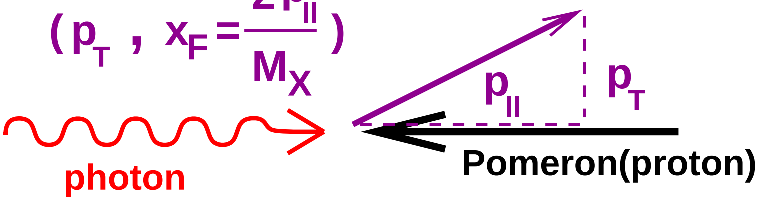
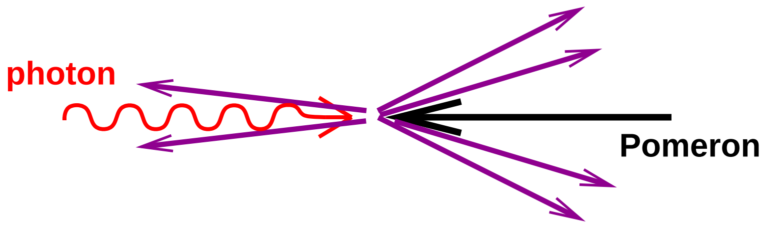



$(p_T\ ,\ x_F = \frac{2p_{\parallel}}{M_X})$



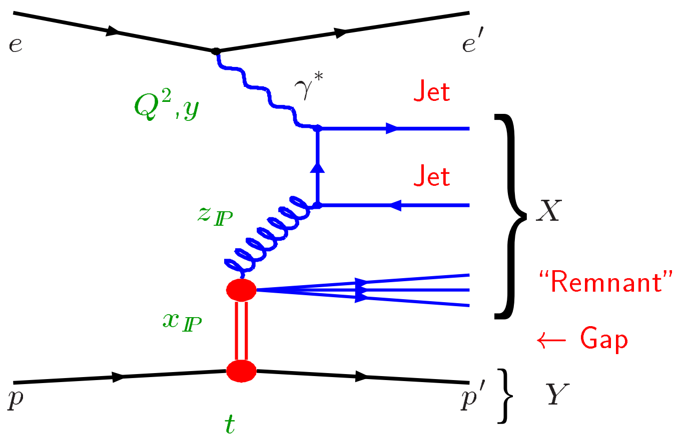

- $P_t$ suppression ($I\!P$-side) smaller than in $\gamma^* P$ data.
- At high masses ($> 16$ GeV) $\rightarrow$ larger $P_t$ in $\gamma$-side.



# Dijet Production in Diffractive DIS

(H1 Collab., Contributed paper N$^o$ 960)

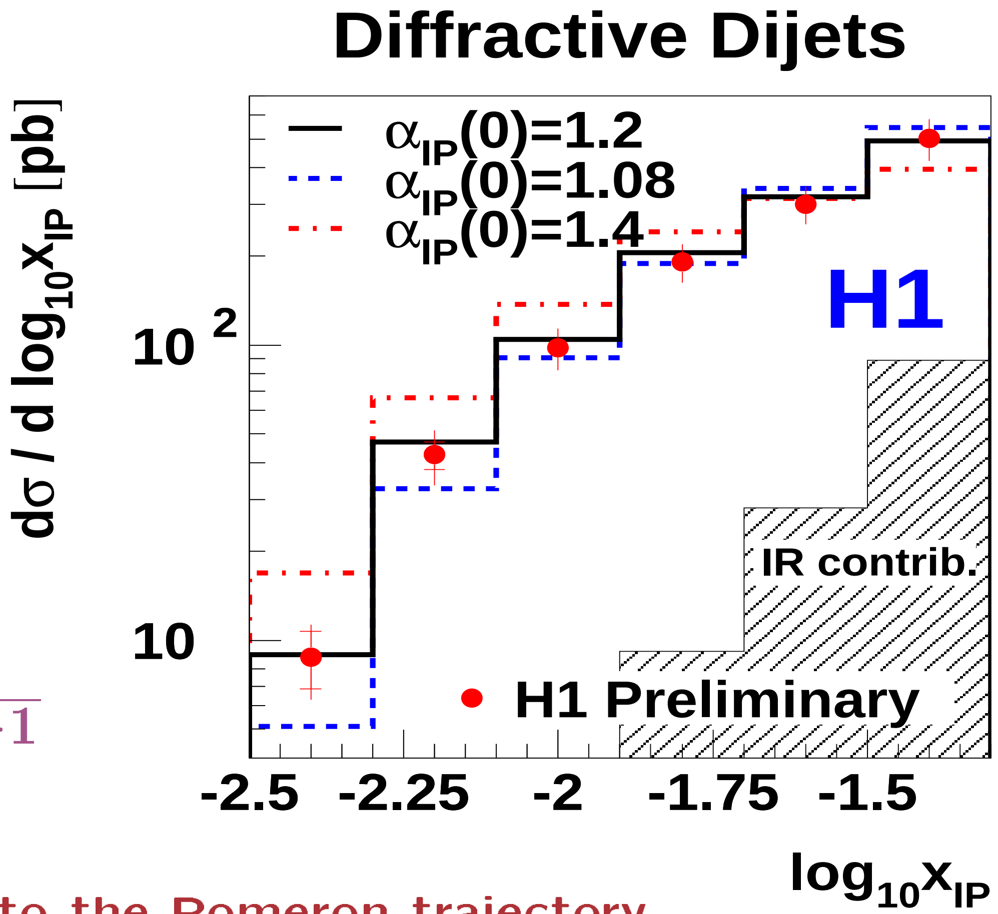
$4 < Q^2 < 80$ GeV$^2$
$0.1 < y < 0.7$
$x_{I\!P} < 0.05$
$M_Y < 1.6$ GeV
$|t| < 1.0$ GeV$^2$




Cone algorithm (R=1.0) in the $\gamma^* p$-CMS
$P^*_{T,jet} > 4$ GeV and $-3 < \eta^*_{jet} < 0$
($L = 17.9\text{pb}^{-1} \rightarrow \sim 2500$ dijet events)

$$F_2^{D(3)}(\beta, Q^2; x_{I\!P}) = f_{I\!P/p}(x_{I\!P}) F_2^{D(2)}(\beta, Q^2) + \ldots$$

$$\frac{1}{x_{I\!P}^{2\cdot\alpha_{I\!P}(0)-1}}$$

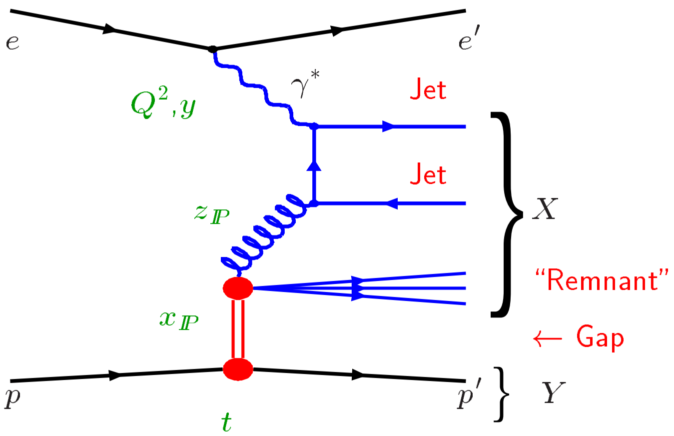



- Sensitivity to the Pomeron trajectory.
- Dijet data prefers $\alpha_{I\!P}(0) \sim 1.2 \rightarrow$ ($F_2^{D(3)}$ analysis).

# Dijet Production in Diffractive DIS

(H1 Collab., Contributed paper N$^o$ 960)

## Resolved $I\!P$ model:



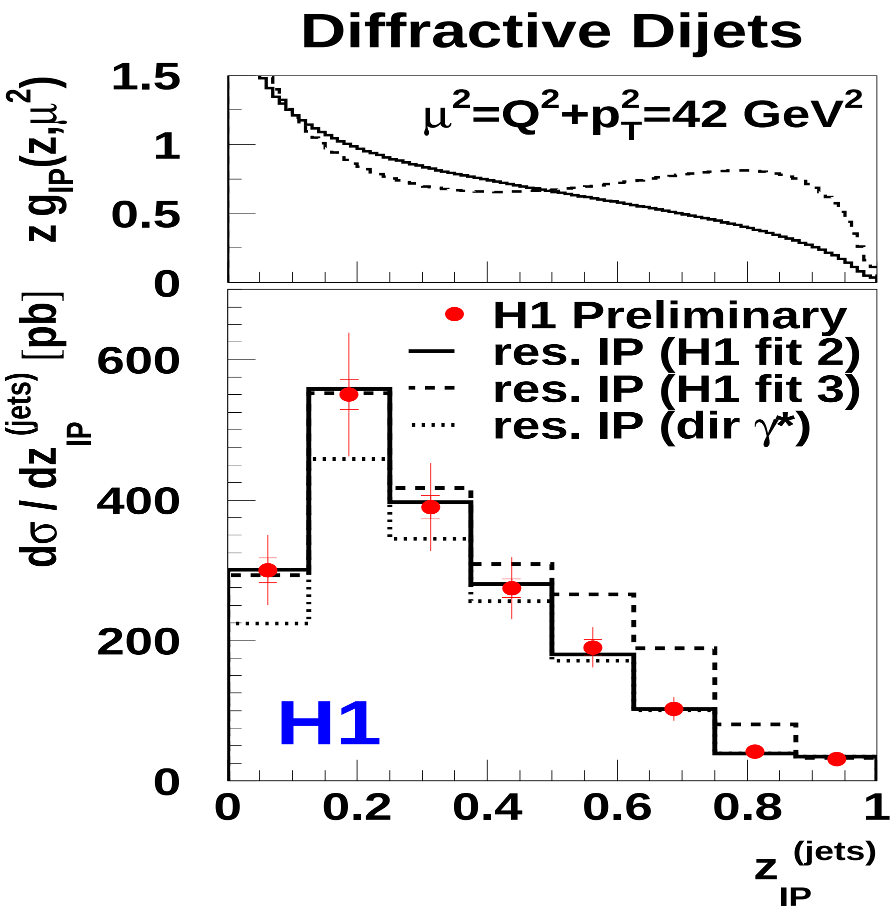

→ Dijets sensitive to gluon in $I\!P$ (from BGF)

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

$$F_2^{I\!P} = \sum_i e_i^2 \; f_{q_i/I\!P}(z, \mu^2)$$

Gluon density: $f_{g/I\!P}(z, \mu^2)$

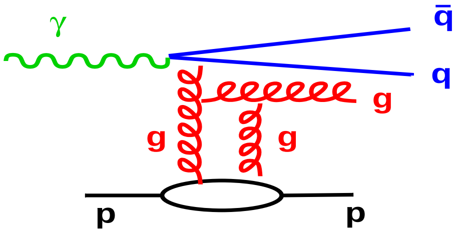
large-$z_{I\!P}$ region constrained by dijet data!

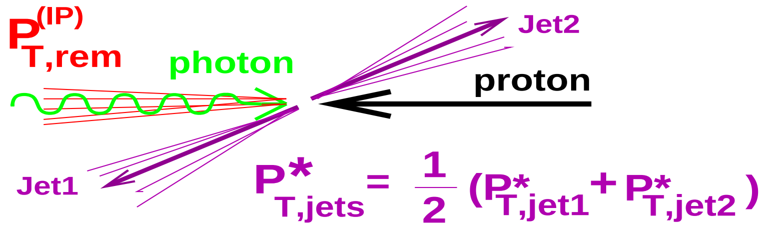


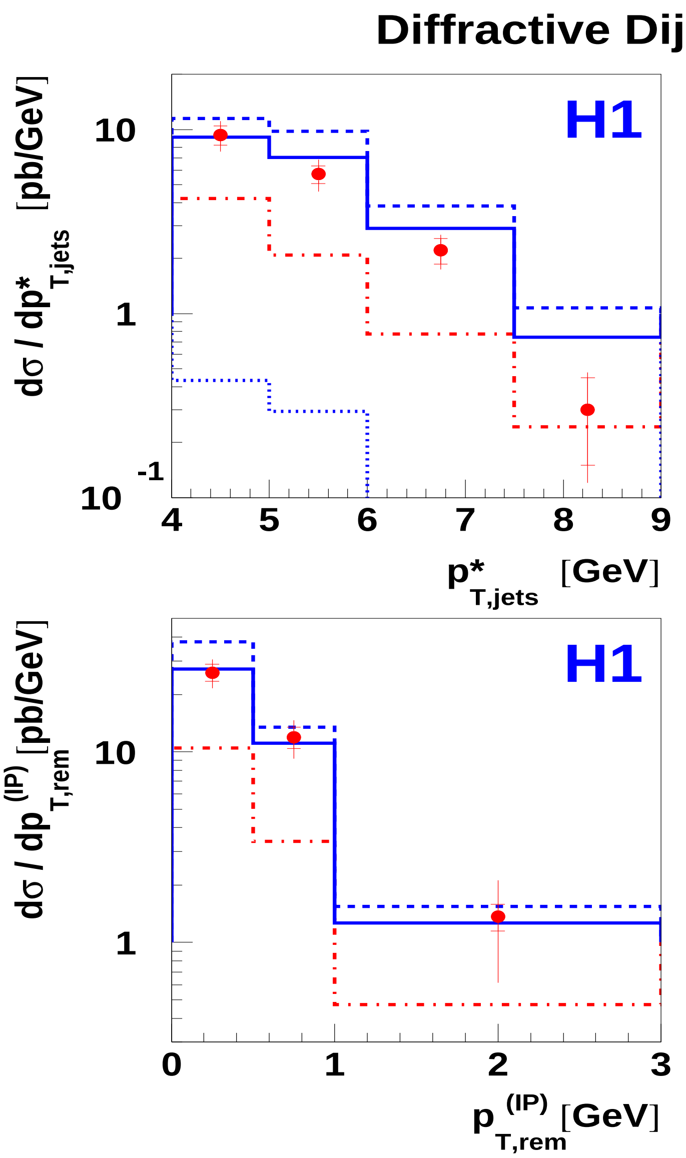

- Gluon-dominated Pomeron describes the data.
- Sensitivity to $f_{g/I\!P}$ → flat distribution preferred.
- $z_{I\!P}^{jets}$ peaks at $\sim 0.2$ → large Pomeron remnant.

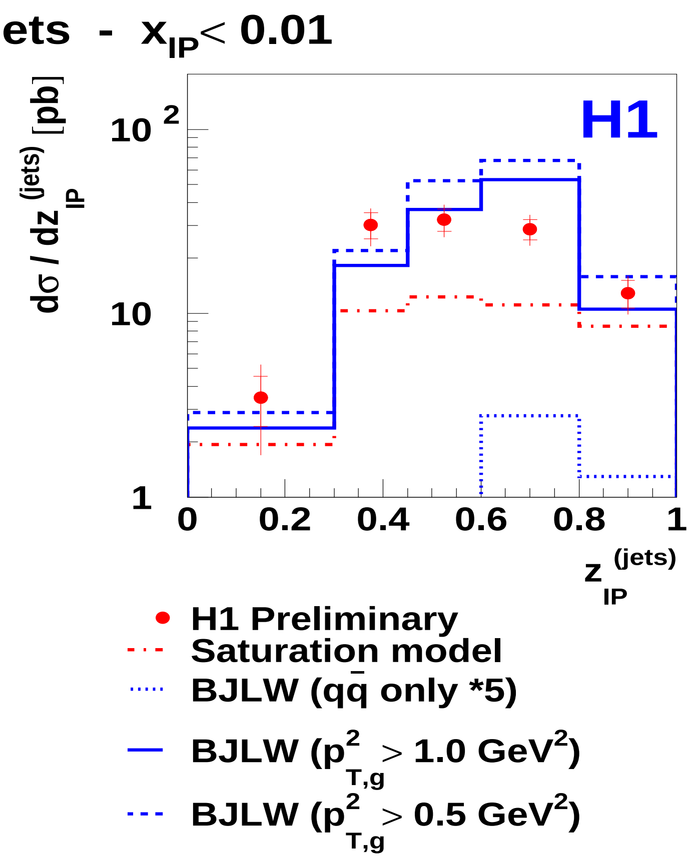
# Dijet Production in Diffractive DIS

(H1 Collab., Contributed paper N$^o$ 960)




Dominant $q\bar{q}g$ contrib.

- Saturation Model → factor 2 too low.
  ($k_t$ ordering, gluon-distribution, t-dependence..?)

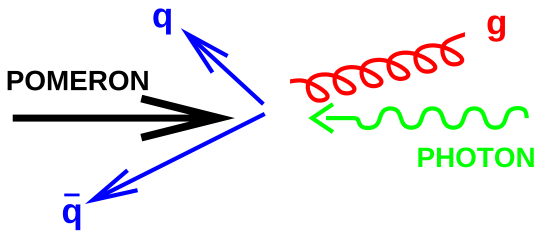
- Bartels, Jung, Lotter, Wüsthoff model → roughly describes the data with $p^2_{t,(cut)}(\text{gluon}) = 1.0$ GeV$^2$.

- for $p^2_{t,(cut)}(\text{gluon}) = 0.5$ GeV$^2$ → x-section overestimated → suppression of low-$p_t$ gluon radiation ?

# 3-Jet Production in Diffractive DIS

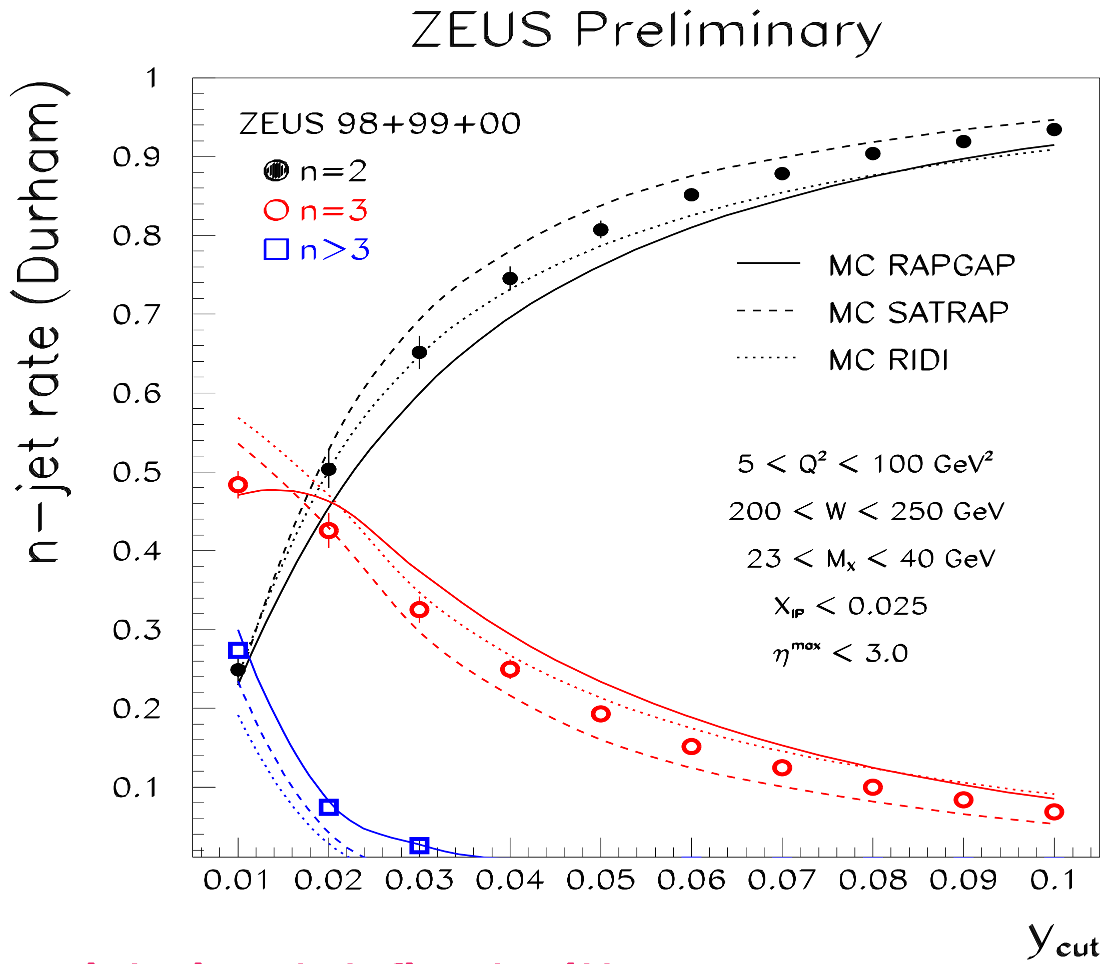
(ZEUS Collab., Contributed paper N$^o$ 872)

$5 < Q^2 < 100$ GeV$^2$
$200 < W < 250$ GeV
$x_{I\!P} < 0.025$
$23 < M_X < 40$ GeV
$\eta^{\max}_{\text{hadron}} < 3.0$




In PETRA $e^+e^-$ experiments $\Rightarrow$ three-jet production was observed for $\sqrt{s}$ in the range $29 \lesssim \sqrt{s} \lesssim 36$ GeV

Exclusive $k_T$ algorithm in the $\gamma^* I\!P$-CMS (E-scheme)

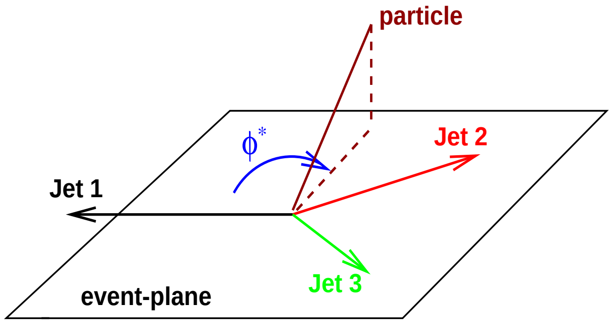


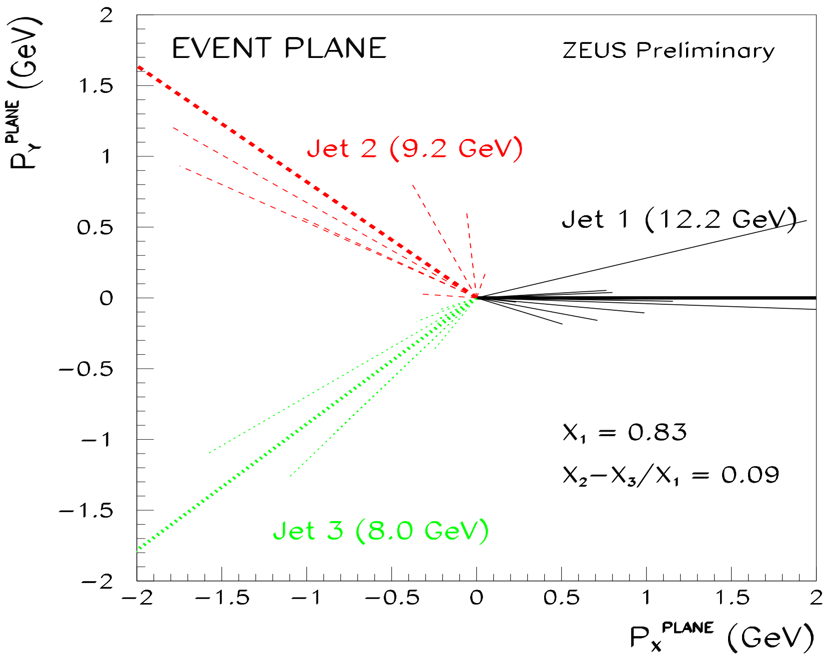

- three-jet signal defined with $y_{\text{cut}} = 0.05$
(good parton-hadron correlation)
- RAPGAP (Resolved gluon-dominated $I\!P$)
- SATRAP (Saturation Model)
- RIDI (Ryskin pQCD approach)

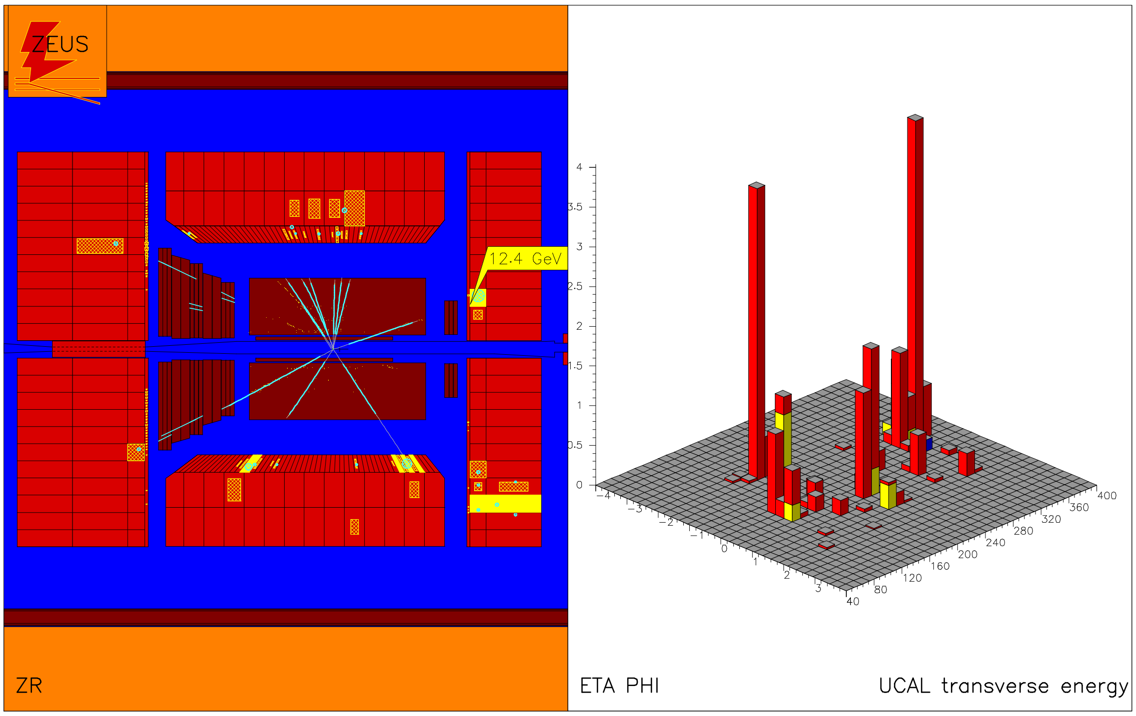
# 3-Jet Production in Diffractive DIS

(ZEUS Collab., Contributed paper N$^o$ 872)

$23 < M_X < 40$ GeV
$N_{\rm jet} = 3 \ \ (y_{\rm cut} = 0.05)$
$-2.3 < \eta^{\rm jet}_{\rm lab} < 2.3$
$(L = 39 {\rm pb}^{-1} \rightarrow$ 678 evts.)




**Evidence for three-jet production in LRG events!**

# 3-Jet Production in Diffractive DIS

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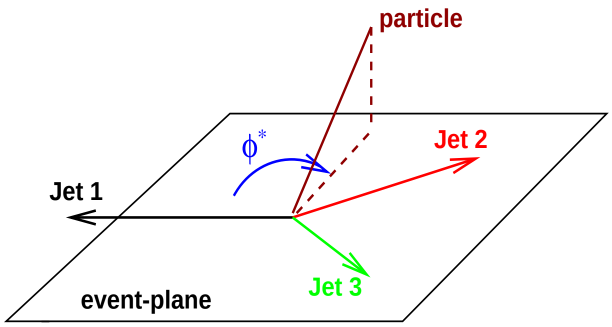
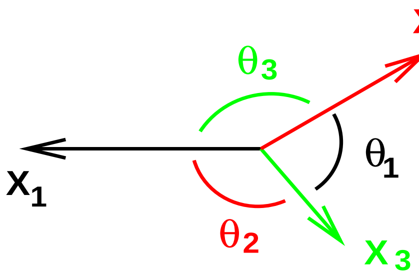


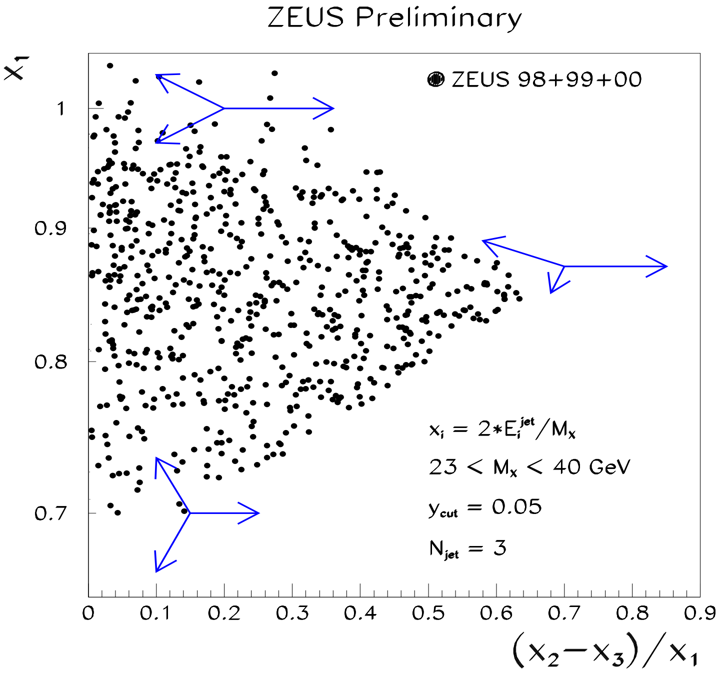

$$x_i = \frac{2 \cdot E_i^{\rm jet}}{M_X}$$

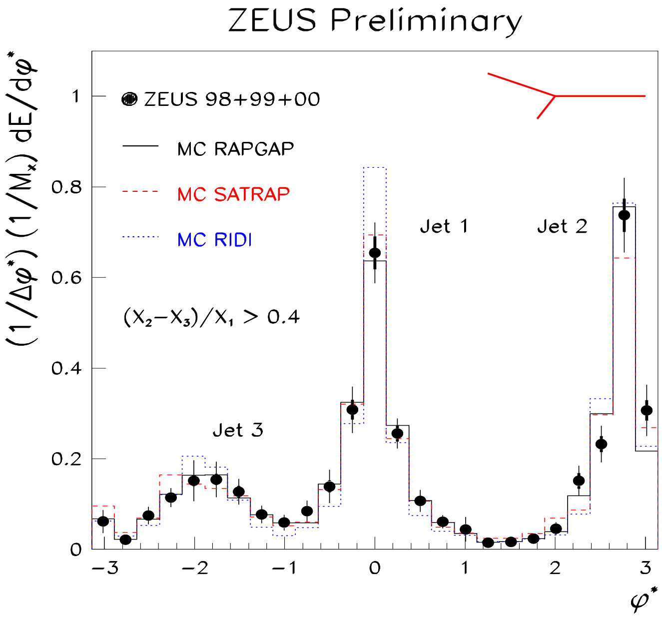
$$x_1 \geq x_2 \geq x_3$$

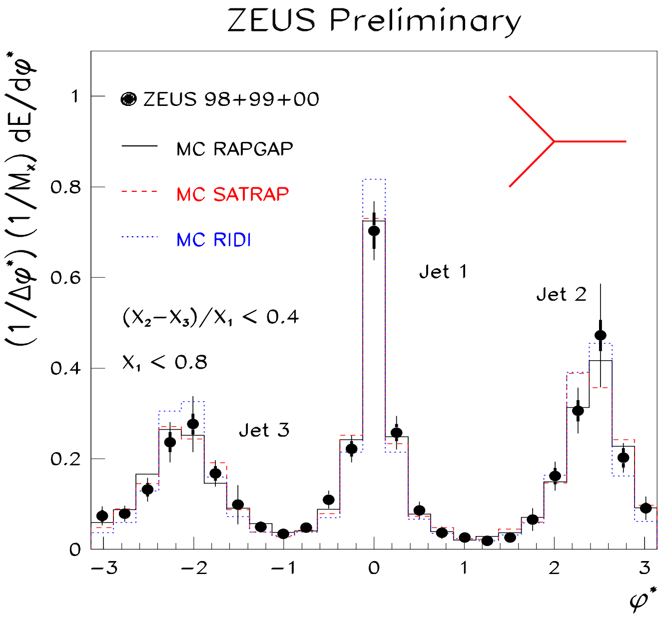
$$x_1 + x_2 + x_3 = 2$$




$$x_i \simeq \frac{2 \cdot sin\theta_i}{sin\theta_1 + sin\theta_2 + sin\theta_3}$$




- Different three-jet topologies are observed in the data.

# 3-Jet Production in Diffractive DIS

(ZEUS Collab., Contributed paper N$^o$ 872)

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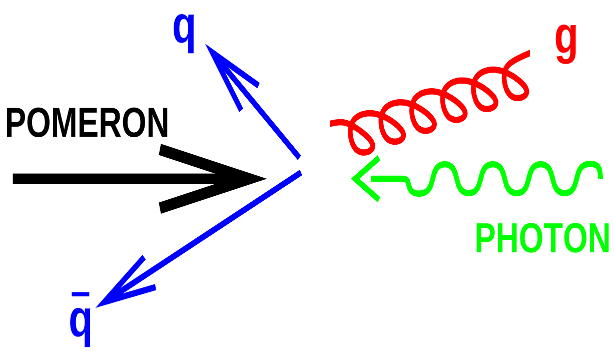
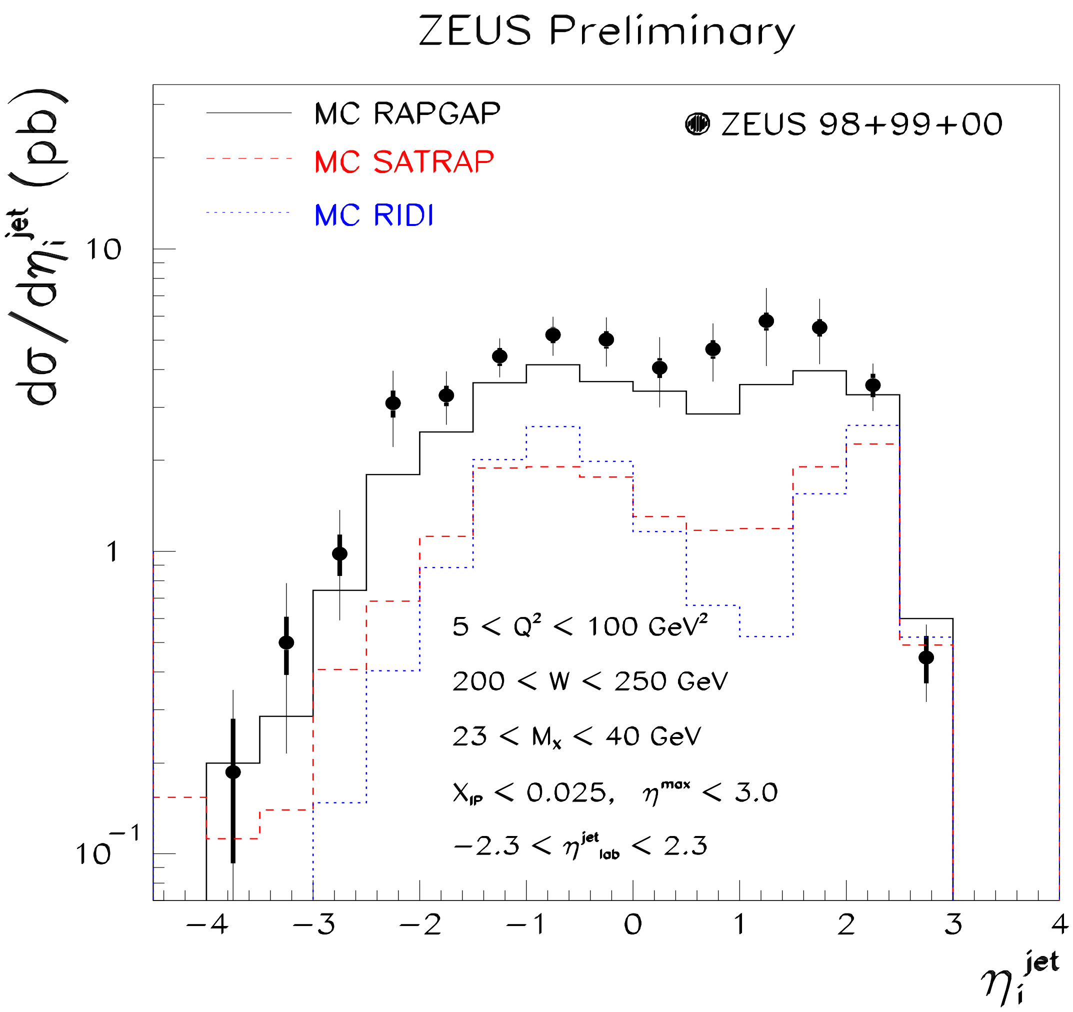
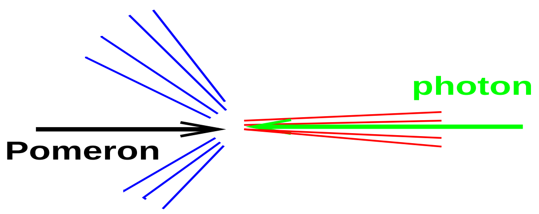



- Gluon-dominated resolved $I\!P$ describes the data.

- Saturation Model and Ryskin's pQCD Model too low. (shape indicates that larger $p_t$(gluon) is needed)



# Summary and Conclusions

- Event Shape:

  - Dominant aligned configurations w.r.t. $\gamma^* I\!P$ axis.
  - At high masses ($> 16$ GeV) larger $< p_t^2 >$ in $\gamma$-side.

- Jet Production:

  - Evidence for three-jet production ($\gamma I\!P$ cms).
  - Jet measurements well described by a factorisable model with a gluon-dominated Pomeron.
  - Dijet x-sections sensitive to $\alpha_{I\!P}(0)$ and $f_{g/I\!P}(z, \mu^2)$.
    - Same $\alpha_{I\!P}(0)$ for dijet and inclusive measurements.
    - Flat gluon distribution (no leading gluons!) preferred.
  - BJLW pQCD model with $p^2_{t,cut}(\mathrm{gluon}) > 1$ GeV$^2$ roughly describes the measured dijet x-sections.
  - Saturation model and Ryskin's pQCD model do not describe the measured x-sections.
    $\Rightarrow$ larger $p_t$(gluon) is needed(?)

- Some new results not covered by this talk:

  - Open charm production in diffractive DIS
    (ZEUS Collab., Contributed paper N$^o$ 874)
  - Energy flow between jets in $\gamma P$
    (H1 Collab., Contributed paper N$^o$ 962)