Diffractive Hadronic Final States

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on behalf of

ZEUS collaboration

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—— Outline ——

[1] Introduction
[2] Event shapes in diffractive DIS
[3] 3-Jet production in diffractive DIS
[4] Summary

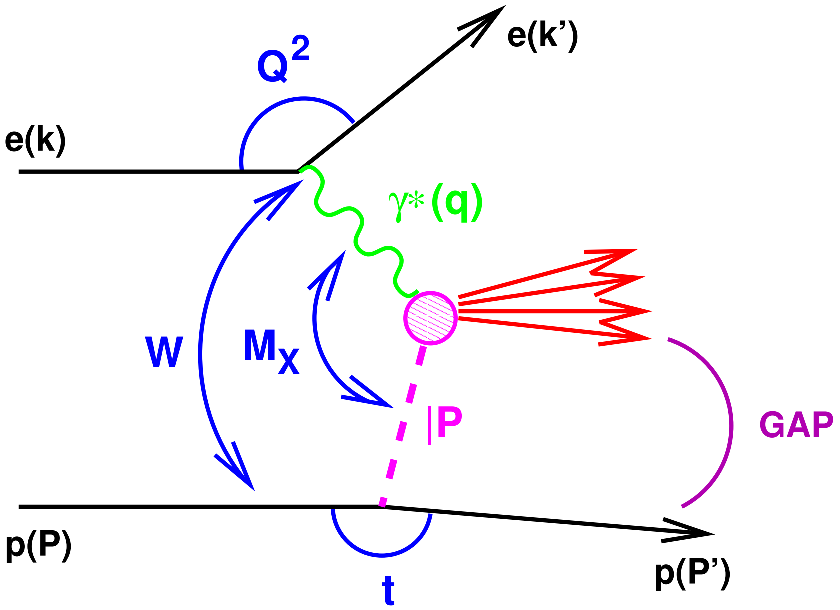
Introduction

Diffractive DIS at HERA

Hadronic final state : sensitive to underlying mechanism

This talk is on results from the study of hadronic final state in diffractive DIS at HERA.

$\Rightarrow$ studying event shapes and 3-jet production



$$Q^2 = -q^2$$

$$W = (q+P)^2$$

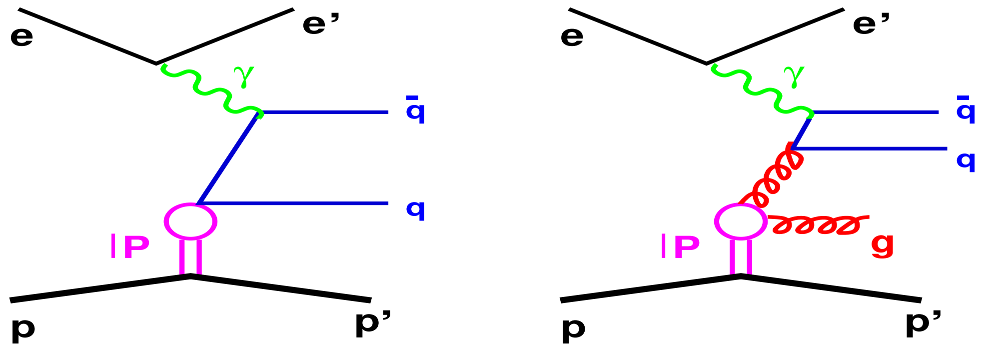
$$x_{I\!P} = \frac{M_X^2+Q^2-t}{W^2+Q^2-M_p^2}$$

$M_X \Rightarrow$ Mass of the hadronic system X

Models for diffraction

1. Resolved pomeron $\rightarrow$ (RAPGAP)

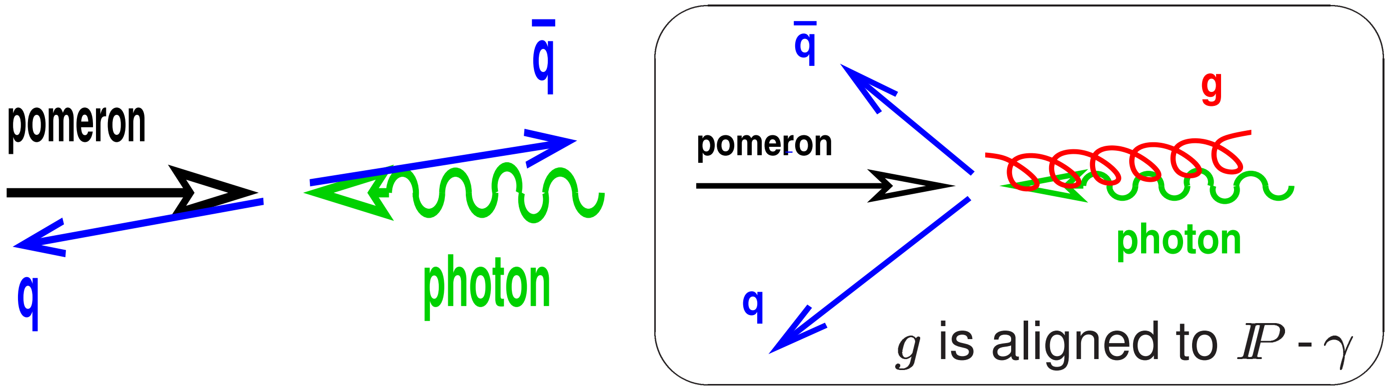
(G. Ingelman et al., Phys. Lett. B152 (1985) 256)



Pomeron consists of quarks and gluon, probed by γ of virtuality Q^2.

$\Rightarrow g(x), q(x)$: from H1fit2 (g - rich pomeron)

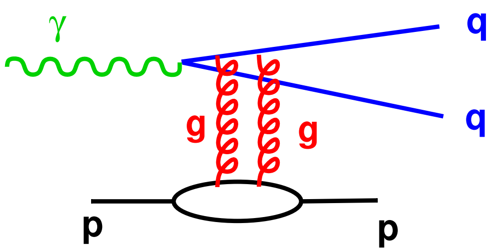
In the CMS of system X,

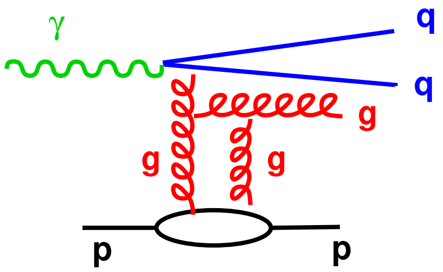


- For $q\bar{q}$, p_T of quarks relative to γ - $I\!P$ axis is set by hand to be $\exp(-5.5 \cdot p_T^2)$
- For $q\bar{q}g$, p_T of gluon is set to 0

2. p-QCD/dipole models (RIDI, SATRAP)

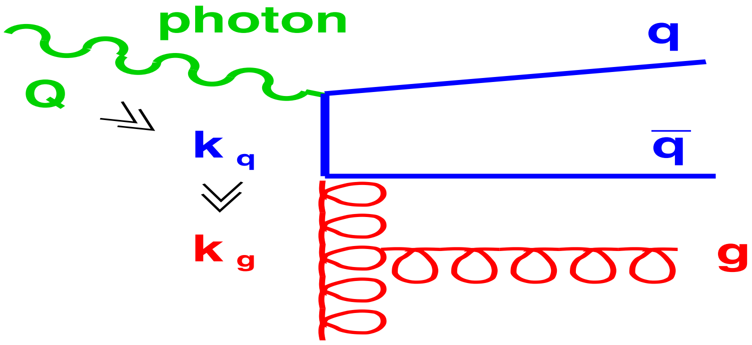
(M.G.Ryskin 1990 ; N.Nikolaev, G.Zakharov 1992 : M.Wusthoff 1997)





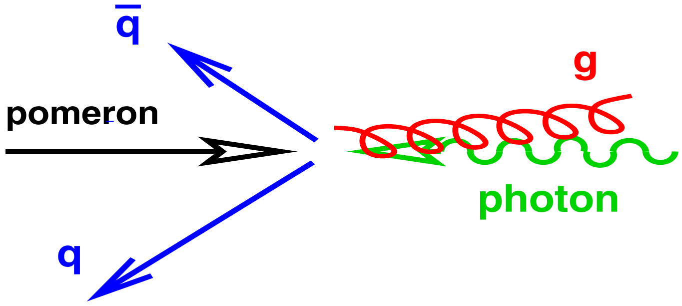
- Pomeron is described by 2 - gluon
- $g(x)$ from non - diffractive DIS
  - $\Rightarrow$ RIDI : CTEQ4M
  - $\Rightarrow$ SATRAP : Saturation model
- SATRAP describes inclusive diffractive cross section
- $q\bar{q}g$ contribution to σ becomes large as M_X increases.
  - $\Rightarrow$ For $M_X > 20$ GeV, 98 % of σ comes from $q\bar{q}g$.

P_T of all partons are calculated according to matrix element. For $q\bar{q}g$ diagram, virtuality ordering is assumed



$\Rightarrow$ P_t quarks $\gg$ P_t gluon

In the CMS of system X (at high mass)



$\Rightarrow$ gluon is aligned to γ - $I\!P$ axis. ($< P_{T,g} > \sim 0.6$ GeV)

Event shapes in diffractive DIS

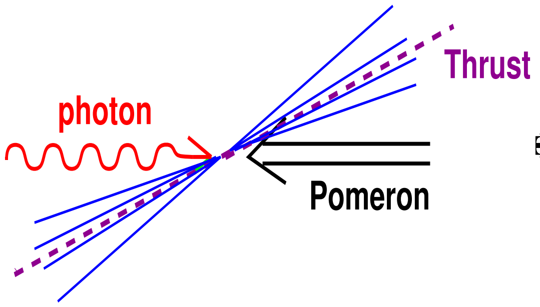
Proton is tagged using Leading Proton Spectrometer (LPS)

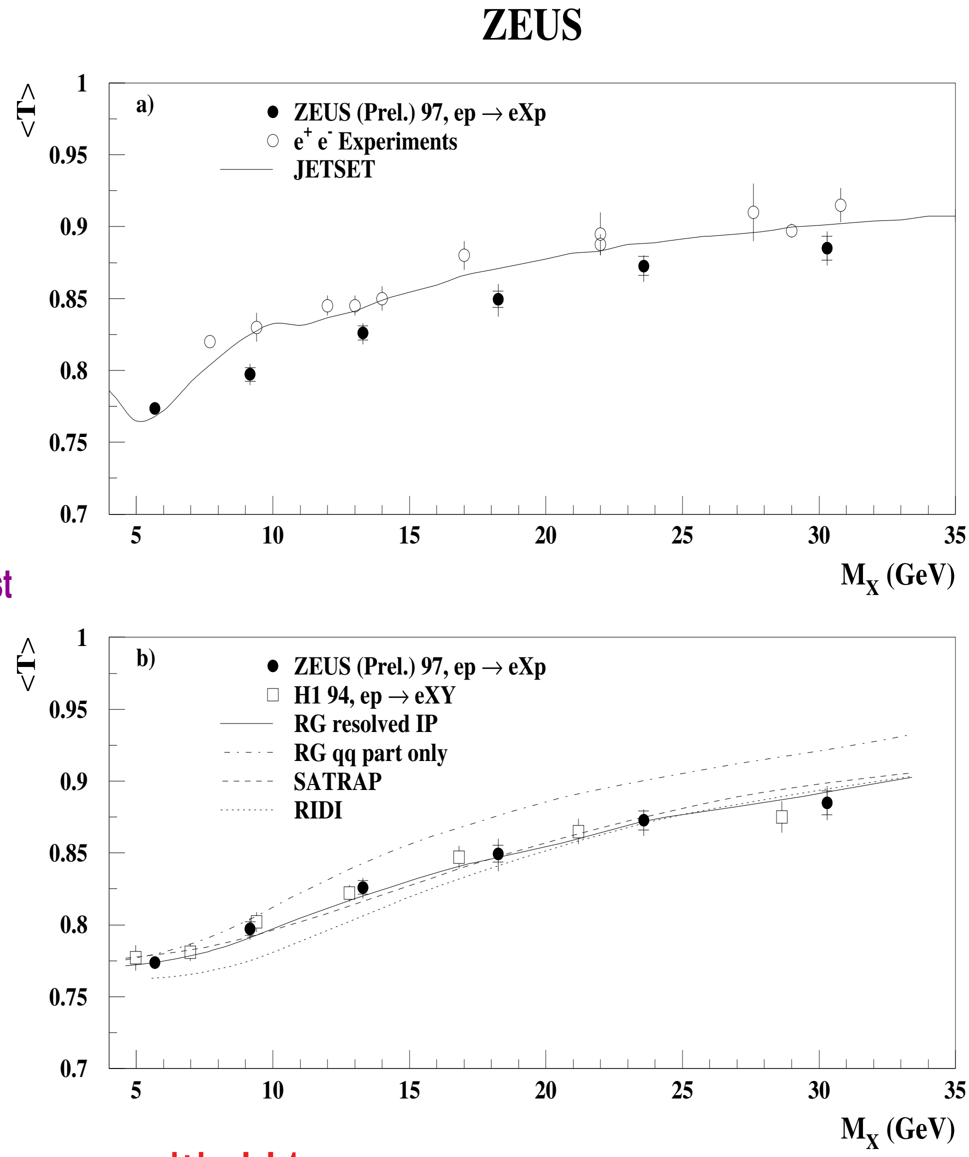
$4 < Q^2 < 150$ GeV^2,	$70 < W < 250$ GeV
$0.0003 < x_{I\!P} < 0.03$,	$4 < M_X < 35$ GeV
13.8 pb^{-1},	CMS of hadronic system (X)

Mean thrust value ($< T >$) as a function of M_X

$$T(\hat{n}) = \frac{\sum_i |\hat{n} \cdot p_i|}{\sum_i |p_i|}$$

$$(\hat{n} : \max T(\hat{n}))$$



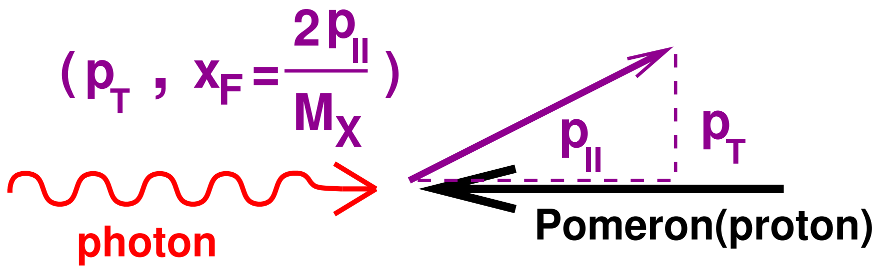


- $< T >$ now agrees with H1
  $\Leftarrow$ Definition of HFS changed such that short life time particles such as D+ are decayed.
- $< T >$ becomes larger as M_X increases
- $< T >$ in diffraction is smaller than in e+e-
- Resolved pomeron model (RAPGAP) describes data
  $q\bar{q}$ part only is too narrow $\sim$ e+e-
  $\Rightarrow$ Importance of $q\bar{q}g$ contribution in diffraction

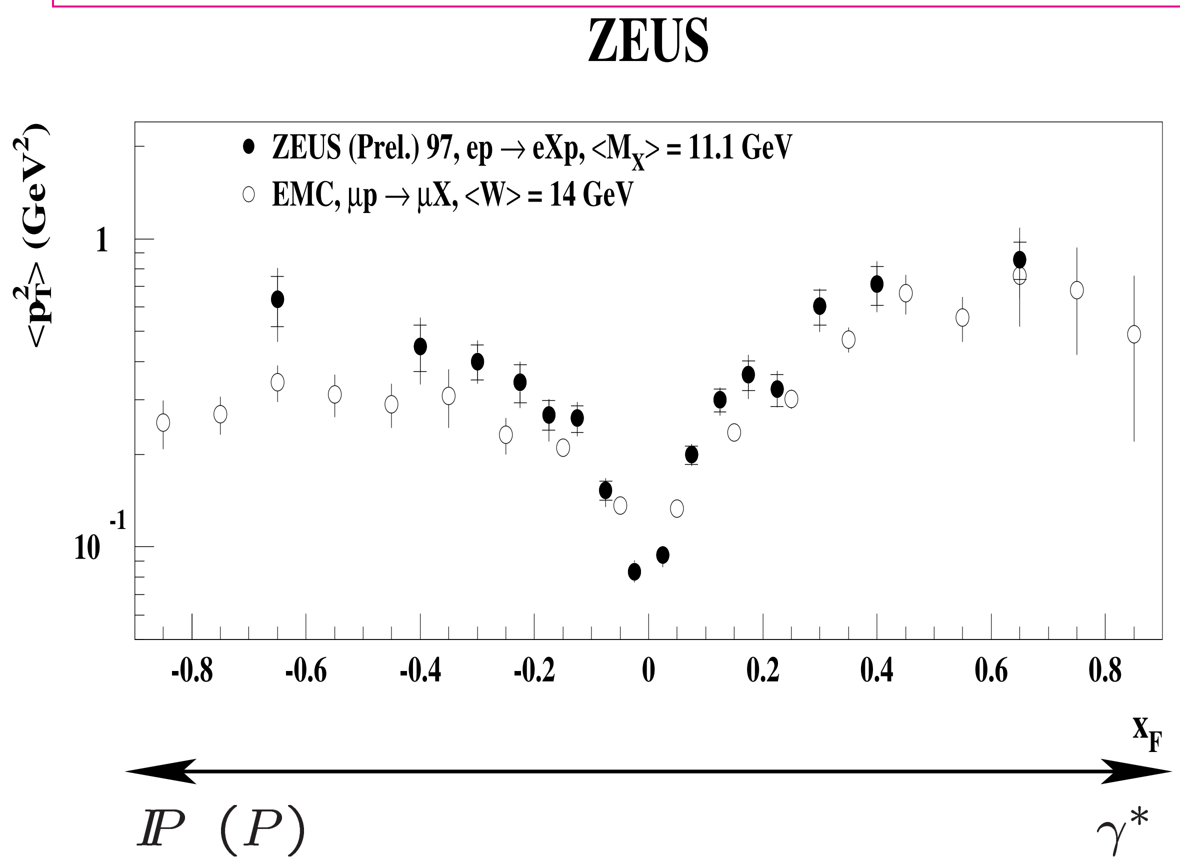
Average P_T^2 of particles as a function of x_F

$x_F \equiv p_L/p_L^{max}$, $\quad p_L^{max} \equiv M_X/2$ (diffractive DIS)

$p_L^{max} \equiv W/2$ (Non - diffractive DIS)



Comparison with non-diffractive DIS
in similar mass range : $7.5 < M_X < 16$ GeV



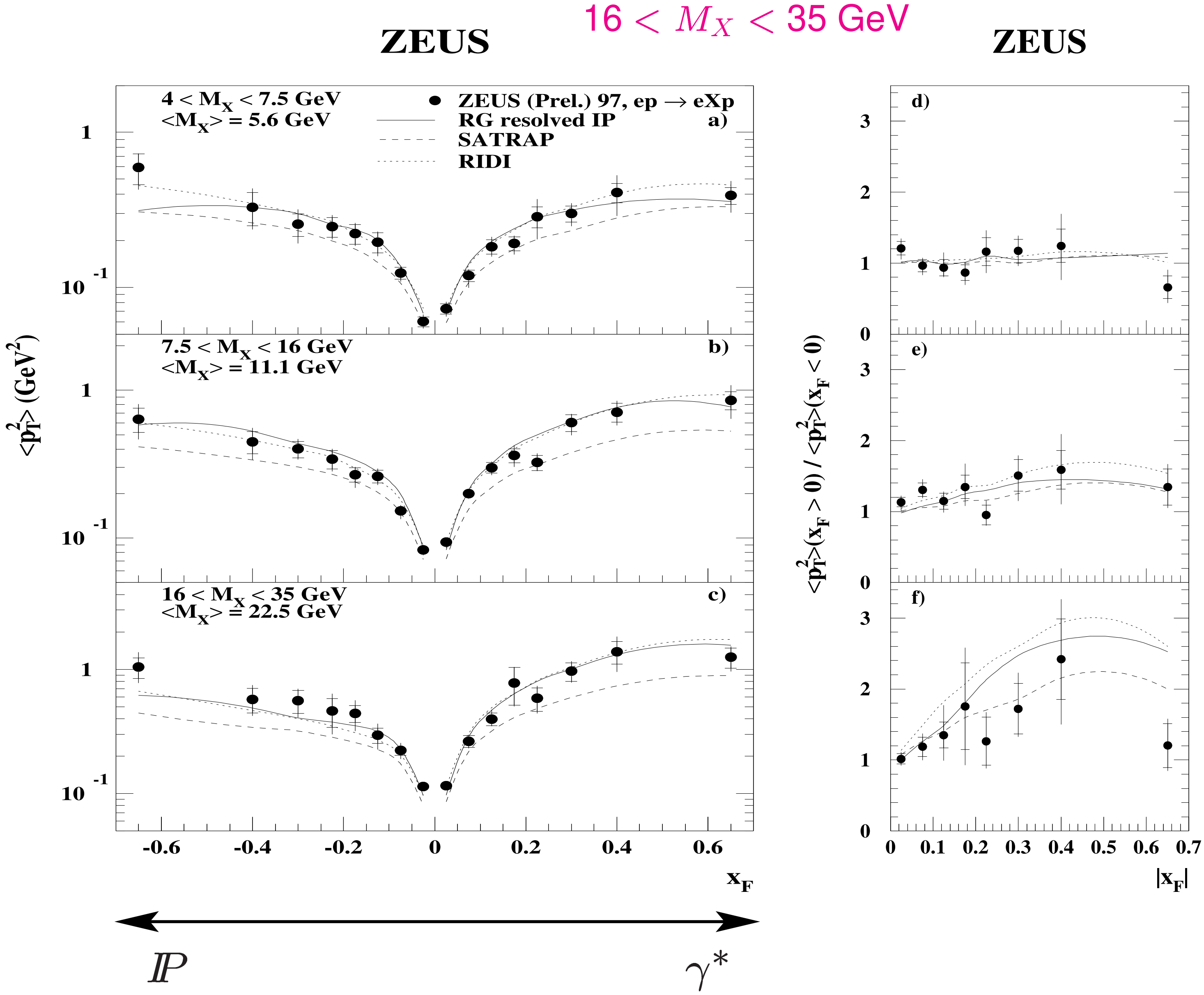
- Smaller asymmetry between $I\!P$ and γ hemispheres than in the non-diffractive DIS
- Larger $< P_T^2 >$ in $I\!P$ hemisphere observed than in non-diffractive DIS (Proton remnant)

$\Leftarrow$ less suppressed
since it is different object from proton remnant ?
or /and smaller object than proton remnant ?

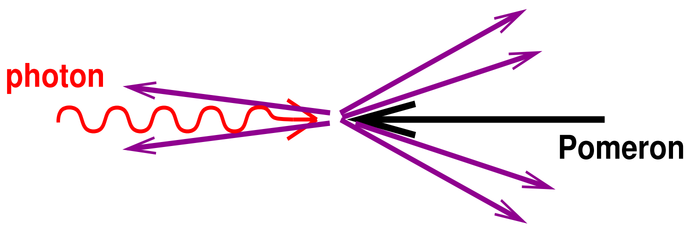
Average P_T^2 of particles as a function of x_F

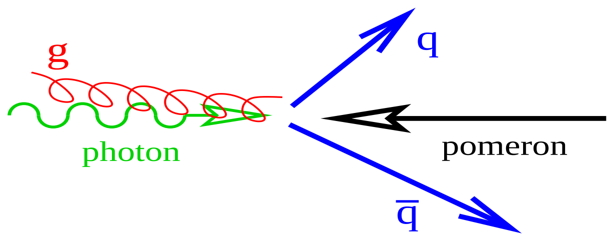
3 different M_X regions

$4 < M_X < 7.5$ GeV
$7.5 < M_X < 16$ GeV
$16 < M_X < 35$ GeV



- Asymmetry between $I\!P$ hemisphere and γ^* hemisphere grows as M_X increases
- Asymmetry is $\sim$ described by QCD models.





$\Rightarrow$ possibly explained by large $q\,\overline{q}\,g$ contribution at high M_X

$\Downarrow$

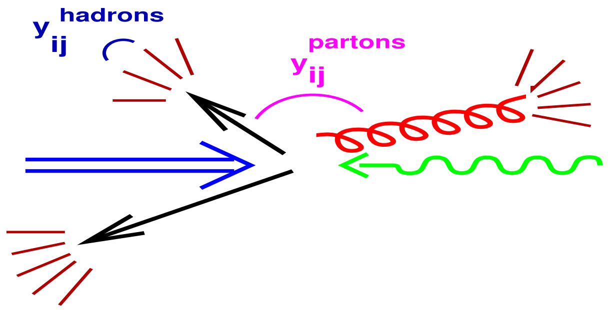
Jet study

3-jet production in diffractive DIS

Diffractive signal selected : $\eta^{\text{hadron}}_{\text{max (LAB)}} \leq 3.0 \Leftarrow \Delta\eta \simeq 2$

Jet algorithm

• use Exclusive k_T - algorithm with E-scheme in the CM frame of hadronic final state (X)
$\Rightarrow$ tag forward jet



• y_{cut} is chosen to be 0.05
$\Rightarrow$ good parton - hadron correlation

Selection of the kinematic range

$$5 \text{ GeV}^2 \leq Q^2 \leq 100 \text{ GeV}^2$$

$$23 \text{ GeV} \leq M_X \leq 40 \text{ GeV}$$

$$200 \text{ GeV} \leq W \leq 250 \text{ GeV}, \qquad x_{\mathbb{P}} \leq 0.025$$

$$\eta^{\text{hadron}}_{\text{max (LAB)}} \leq 3.0$$

$$-2.3 \leq \eta_{\text{(LAB)}} \text{ of all Jets} \leq 2.3$$

$\Leftarrow M_X \geq 23$ GeV $\leftarrow$ high M_X region
good parton - hadron correlation

$\Leftarrow W$ and $x_{\mathbb{P}}$ range :
hadronic system (X) has small boost to Lab system.

$\Leftarrow \left|\eta^{\text{jet}}_{\text{(LAB)}}\right| < 2.3$ to avoid bias from $\eta^{\text{hadron}}_{\text{max (LAB)}}$ cut.

$\boxed{42.7\ \text{pb}^{-1} \rightarrow 891 \text{ events with 3-jet}}$

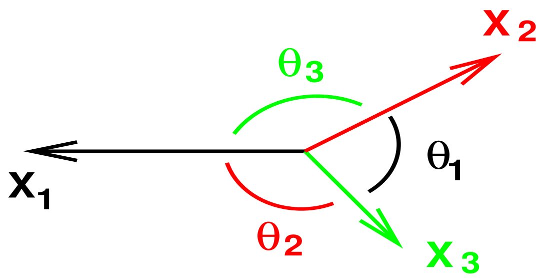
3-jet topologies (1)

$$x_i = \frac{2 \cdot \left|P_i^{\text{jet}}\right|}{\sum_j \left|P_j^{\text{jet}}\right|}$$

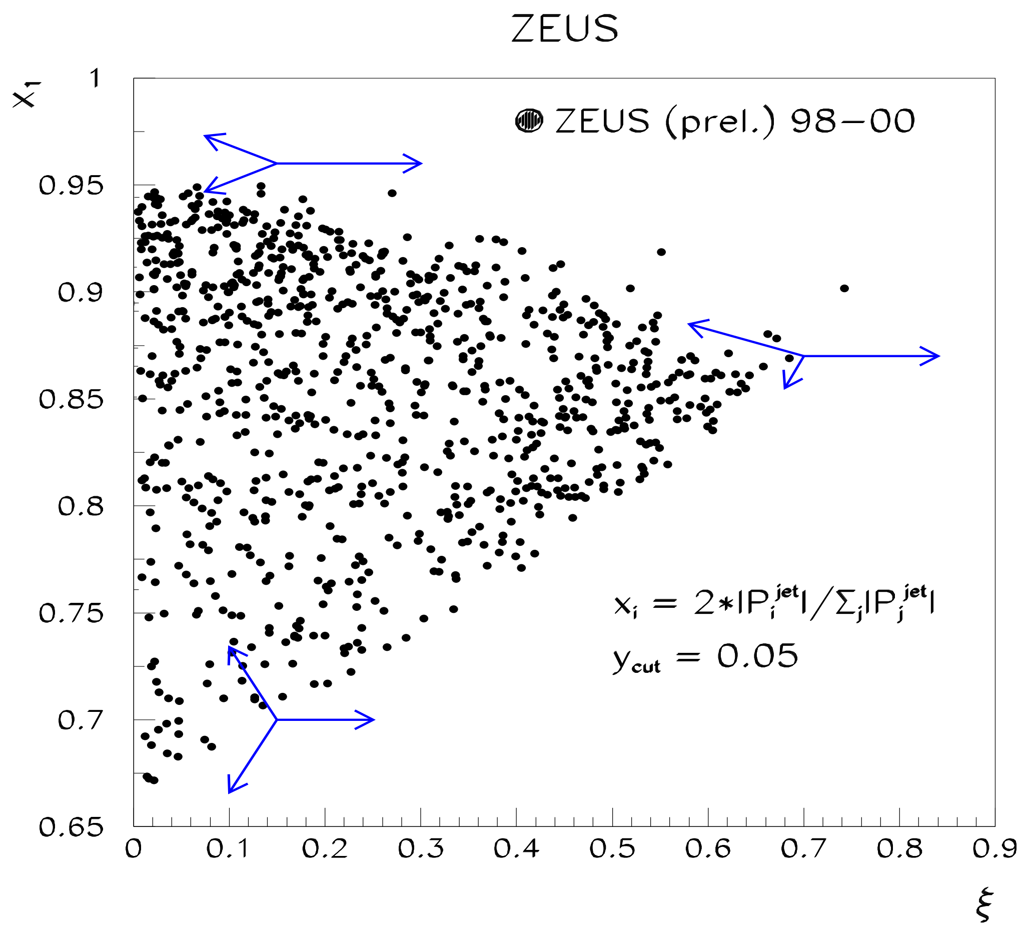
$$x_1 \geq x_2 \geq x_3$$

$$x_1 + x_2 + x_3 = 2$$

$$\Rightarrow x_1,\ \ \xi \equiv (x_2 - x_3)/x_1$$

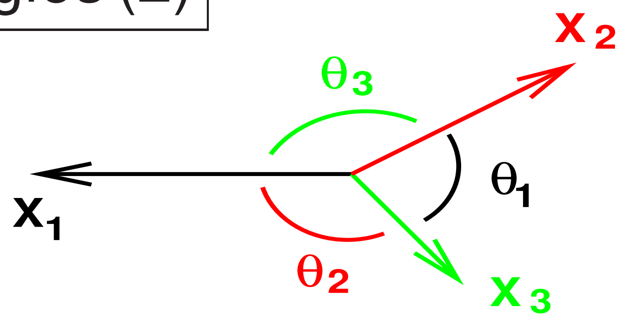


$$x_i \simeq \frac{2 \cdot sin\theta_i}{sin\theta_1 + sin\theta_2 + sin\theta_3}$$

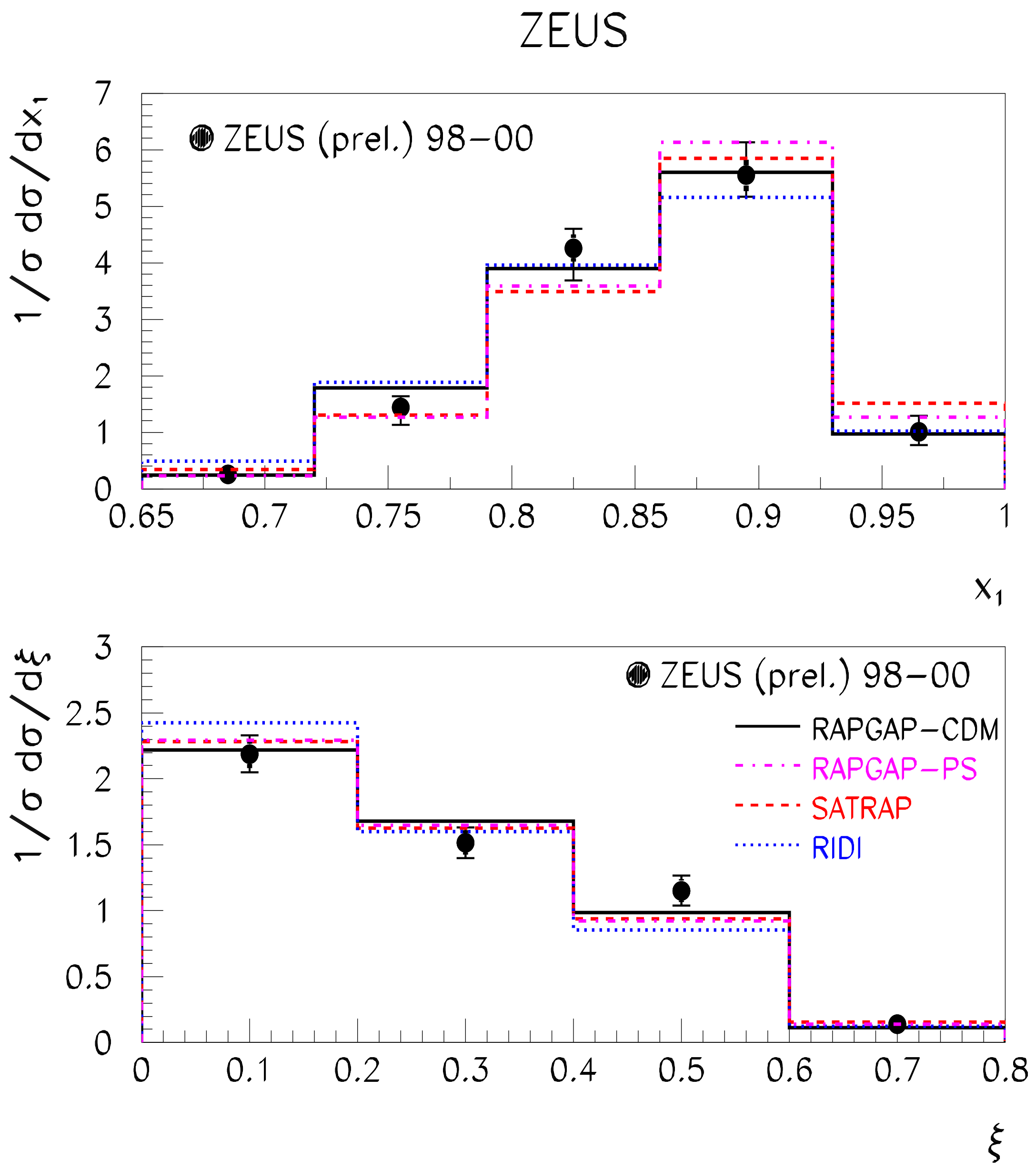


- Dominant configuration :
  x_1 large, x_2 and x_3 similar

3-jet topologies (2)



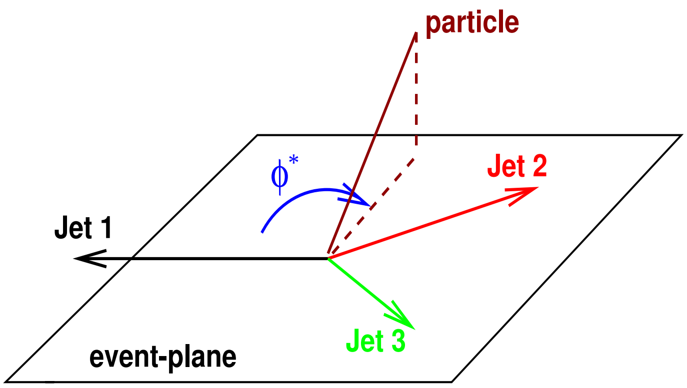
$$x_1, \ \ \xi \equiv (x_2 - x_3)/x_1$$

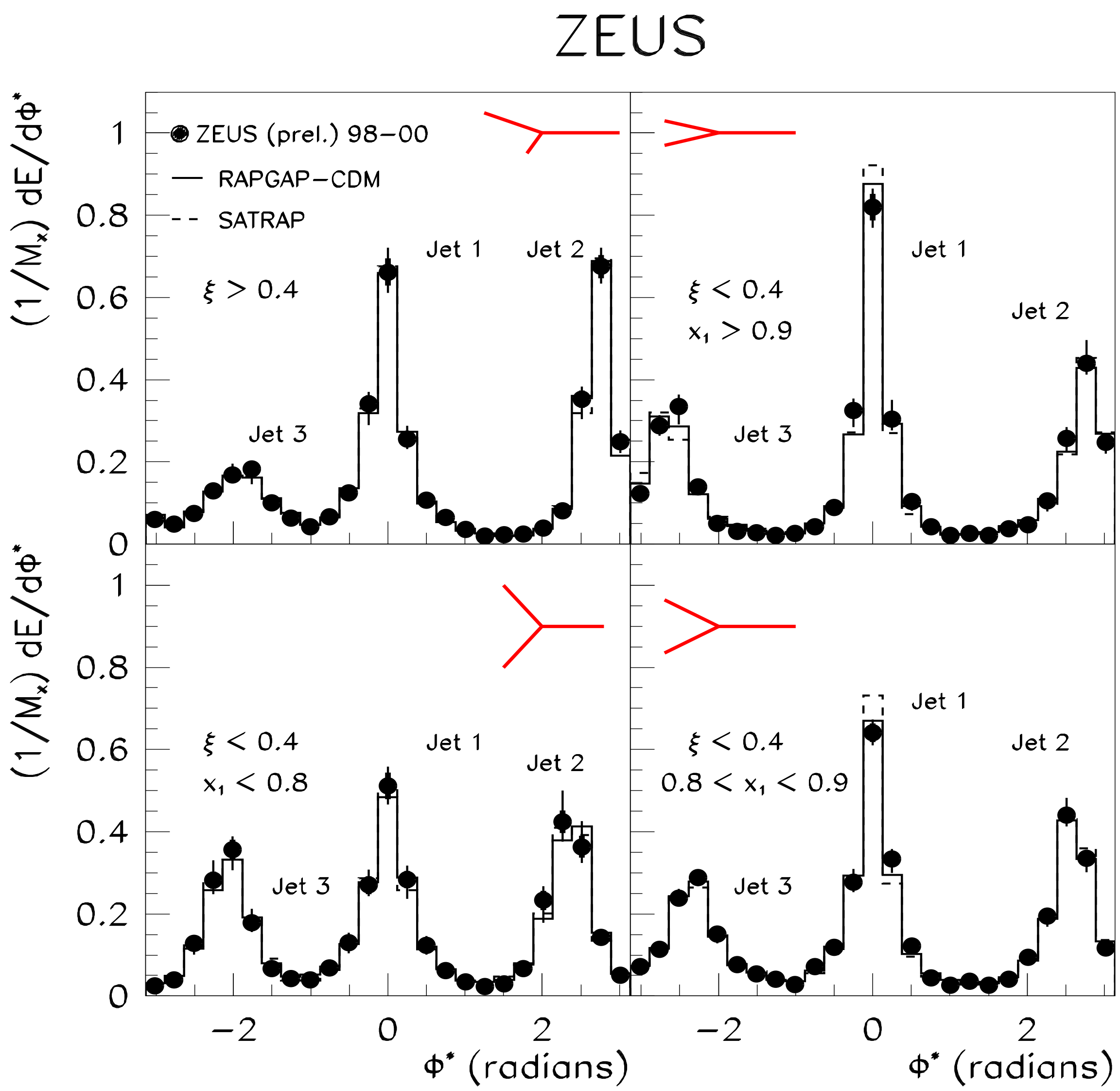


Shape of x_1 and ξ distributions are described by both resolved $I\!P$ model and dipole models

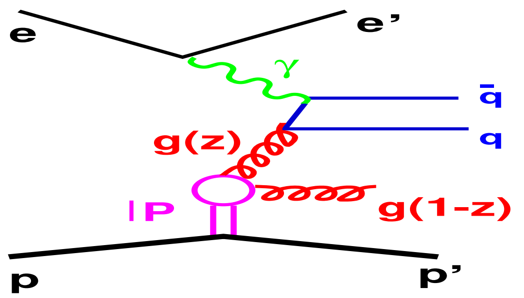
Energy flow in the 3-jet plane

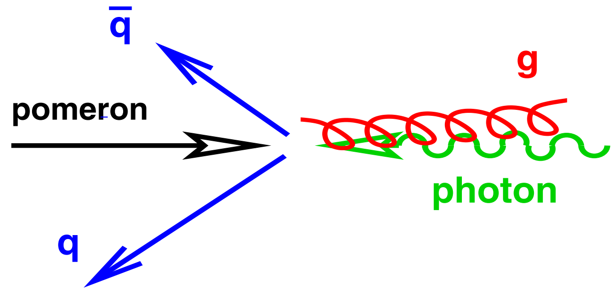
$$E_{\rm jet1} \geq E_{\rm jet2} \geq E_{\rm jet3}$$



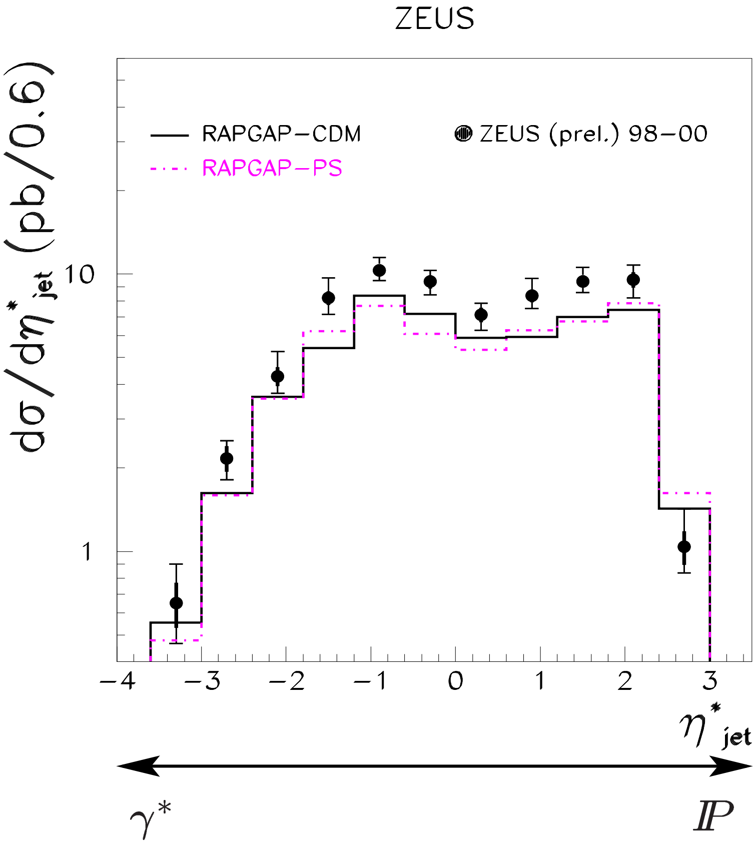


- Clear 3-jet structure is seen in all (x_1, ξ) region
- Enegy flow in the plane is well described by RAPGAP (CDM) and SATRAP



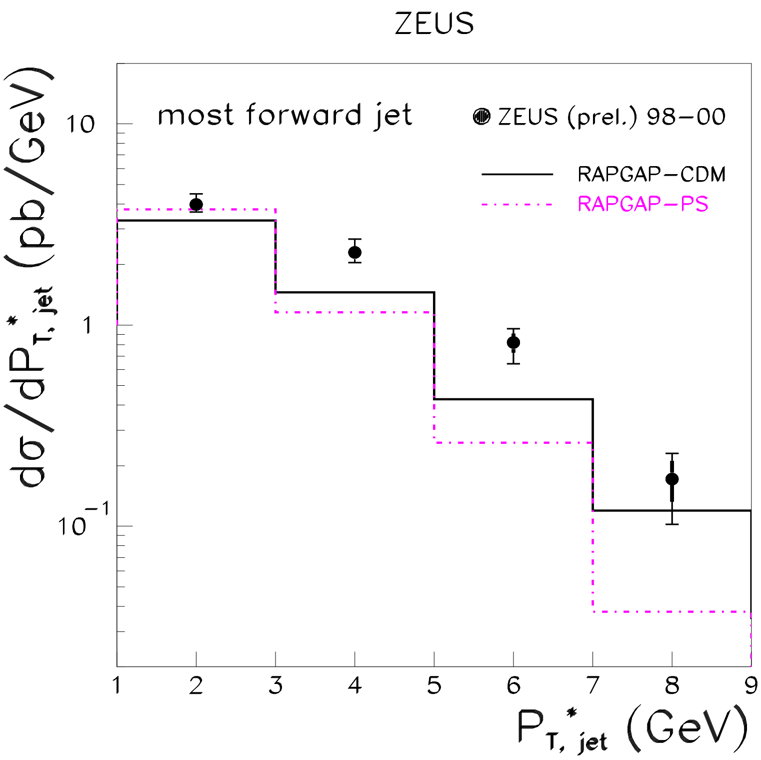


3-jet η^* differential cross section

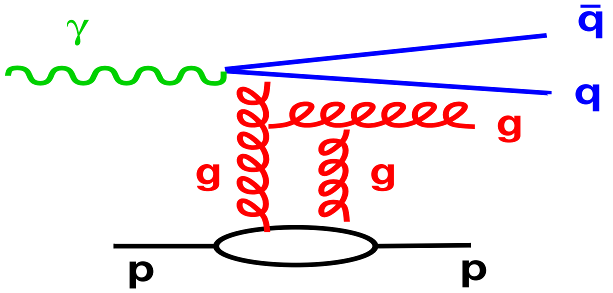


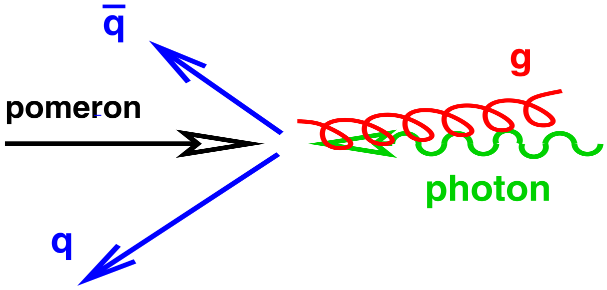
- Peaks at ~ 2 and $\sim$ -1. Shape of the η^* distribution is described by g-rich resolved pomeron model (RAPGAP, H1fit2)
- Normalization is underestimated by $\sim 20\,\%$
- CDM and PS have similar prediction

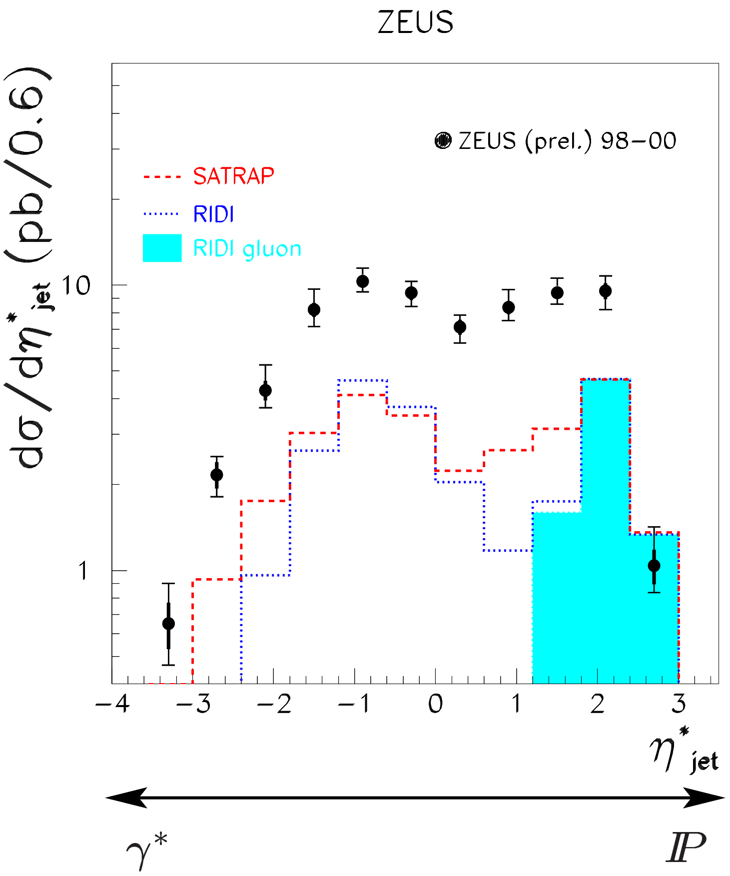
P_T^* of most forward ($I\!P$-side) jet

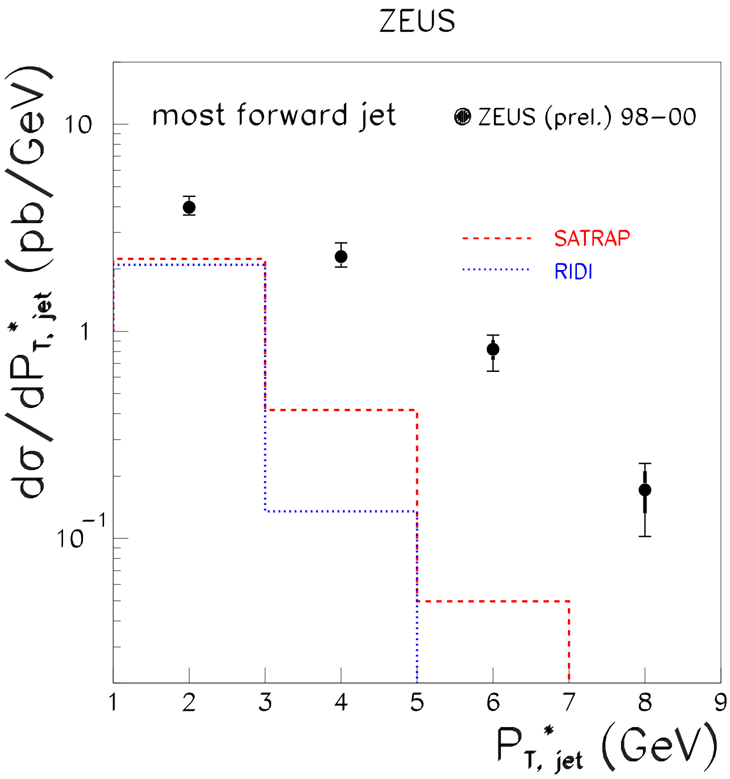


- Shape of $P^*_{T,jet}$ distribution is described by RAPGAP.
- CDM and PS follow the trend, CDM slightly better.









SATRAP and RIDI fail in normalization $\sim$ half

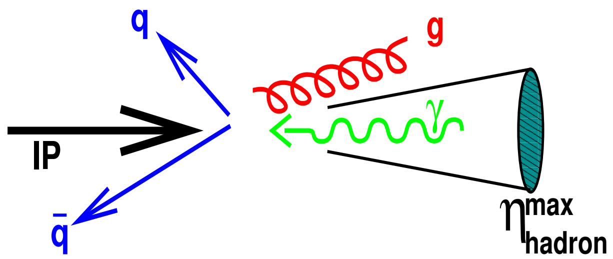
although SATRAP describes inclusive diffractive σ well

$\Uparrow$

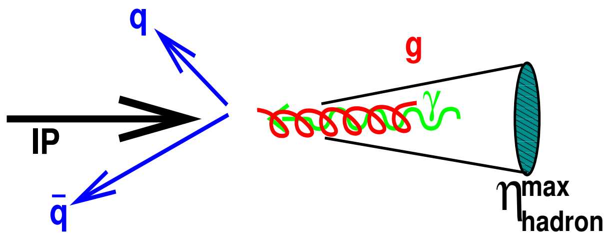
Low "survival probability" by η cuts $\eta^{\text{hadron}}_{\text{max (LAB)}}$, $\eta^{\text{jet}}_{\text{lab}}$

due to the steeper $P_{T,jet}$ distribution of most forward jet

Large part of the cross section is hidden behind η cuts



selected

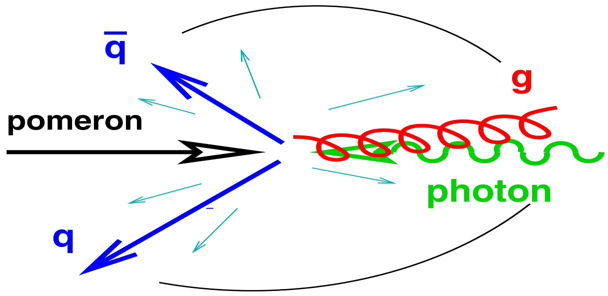


cannot see

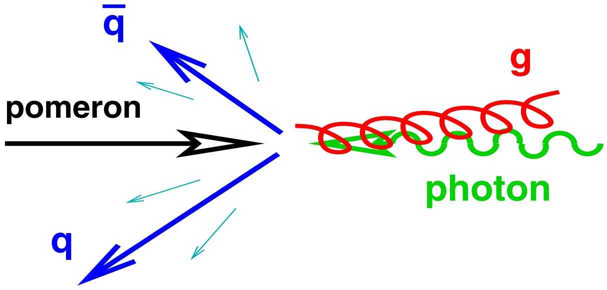
Interface CDM to SATRAP

RAPGAP (CDM,MEPS) better describes $P_T^{\text{forward jet}}$ though it has aligned configuration in parton level ($P_t^{\text{gluon}} = 0$)

Difference :
parton shower in RAPGAP and SATRAP, RIDI.



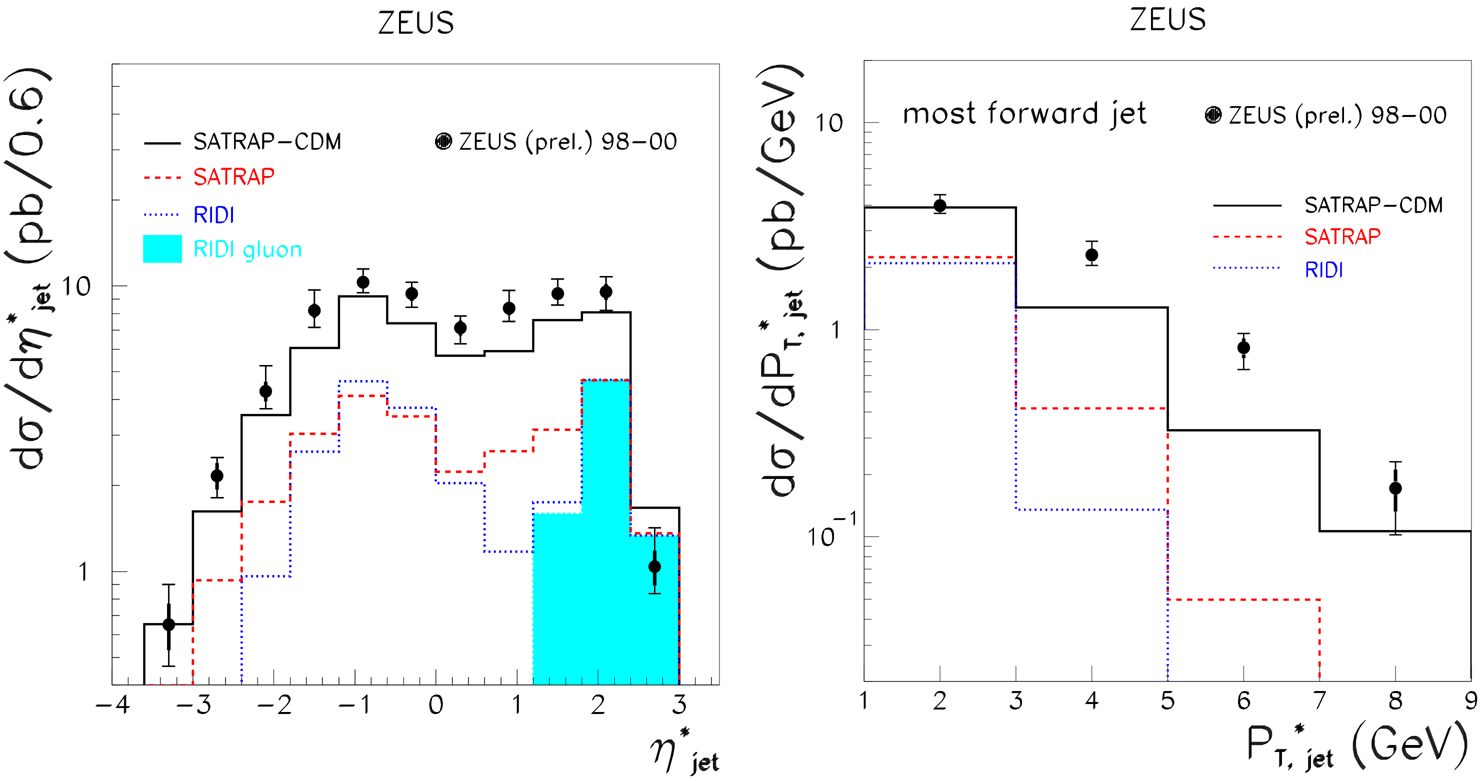
RAPGAP



SATRAP,RIDI

SATRAP has only parton shower applied to $q\bar{q}$ system (RIDI is $\sim$ same)

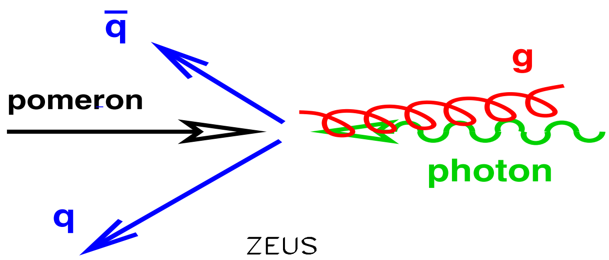
$\Rightarrow$ Interface CDM to SATRAP

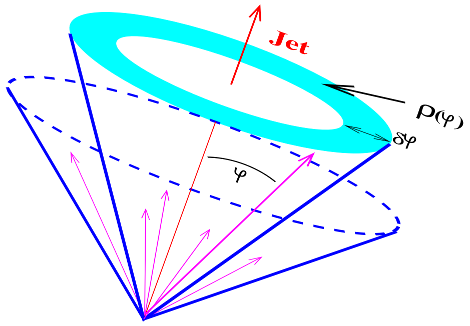


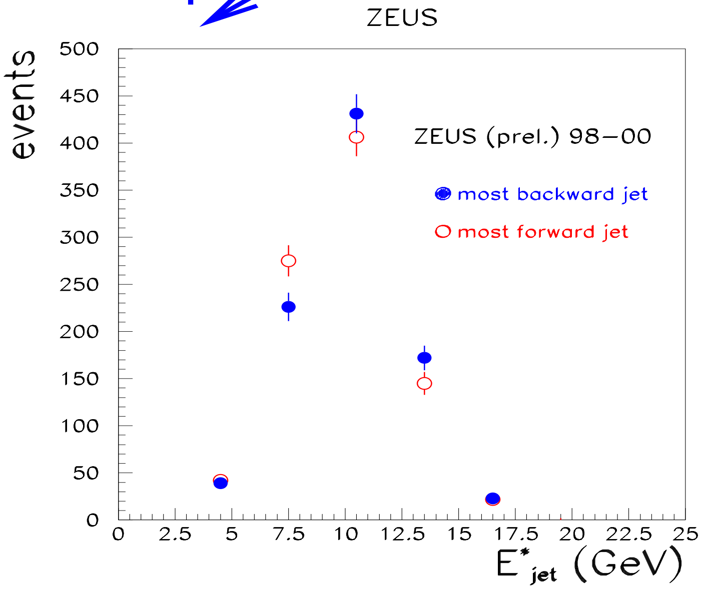
- Normalization of SATRAP recovers
- Higher P_T of the forward jet

$\Rightarrow$ Higher order QCD radiation is important

Jet shape in diffractive DIS 3jet events

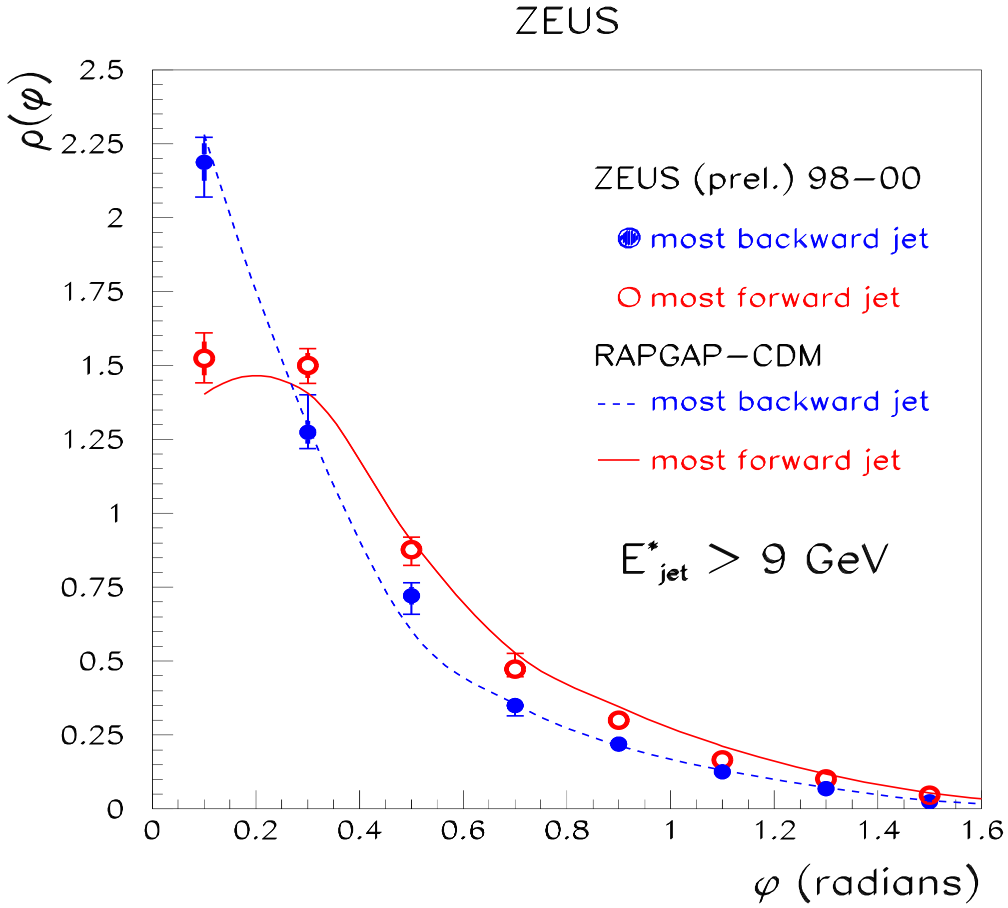






$$\rho(\varphi) = \left\langle \frac{1}{\delta\varphi} \frac{E^{\text{jet}}(\varphi \pm \delta\varphi/2)}{E^{\text{jet}}} \right\rangle$$

$\sim$ Same E_{jet} distribution
most forward / backward jet



- Most forward jet is broader than most backward jet
- Data are described by the model where g is emitted to the $I\!P$ side and one of q is emitted to the γ side.
  $\Rightarrow$ Supports the picture

Summary

Properties of hadronic final state in diffractive DIS are studied in the CMS of hadronic system (X), using event shape variables and 3-jets.

1. $< T >$ and "seagull" plot support the presence of $q\bar{q}g$ contribution

2. 3-jet production is studied in $23 < M_X < 40$ GeV, using exclusive k_T algorithm to tag forward jet.

   - 3-jet topology is studied, which is described by models.

   - Cross section as a function of η^* and P_T^* of most forward jet are presented.

     $\Rightarrow$ After allowing parton shower around forward region, g-rich resolved $I\!P$ model (RAPGAP) and QCD/dipole model (SATRAP) give similar description, to roughly describe data.

   - Most forward ($I\!P$ direction) jet is broader than most backward side jet (γ direction) , which is consistent with models with g emitted to $I\!P$ side.

From HFS study we have learned :
$q\bar{q}g$ contribution is important in diffraction,
3 jet data strongly supports that in high mass :