Diffractive Final States at HERA

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on behalf of H1 and ZEUS Collaborations

Workshop on Low x Physics
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- Introduction
- Models of Diffraction
- Global Event Shapes
- D* Measurements
- Dijet Production in DIS
- Photoproduction of Dijets

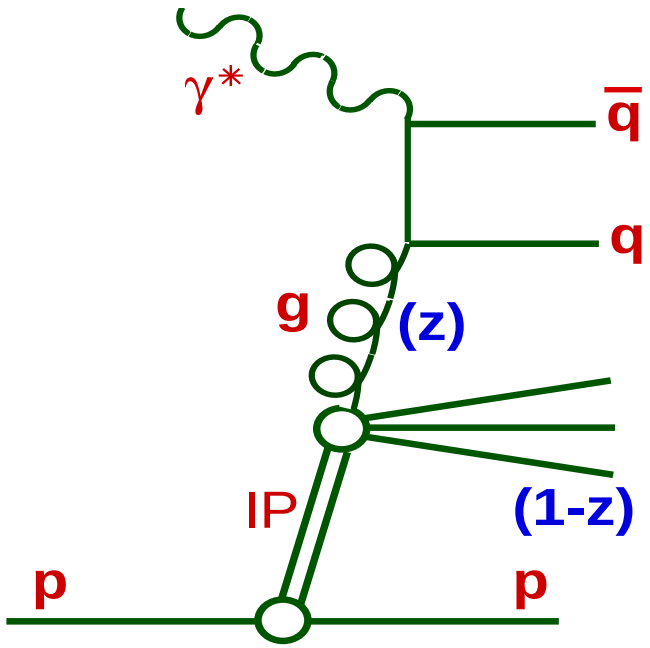
Motivation

Aims

- nature of diffractive exchange?
- test QCD factorisation

D* and Dijet Measurements

- sensitive to diffractive gluon via boson−gluon fusion
- high p_T and mass: applicability of pQCD



$$x_{IP} \approx \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

$$\beta \approx \frac{Q^2}{Q^2 + M_X^2}$$

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

Resolved Pomeron Model

Ingelman, Schlein

- QCD hard scattering factorisation:
  (proof by Collins)

$$\sigma^D = \sum_{partons\ i} f_i^D \otimes \hat{\sigma}^{\gamma^* i}$$

diffractive proton pdf

hard process

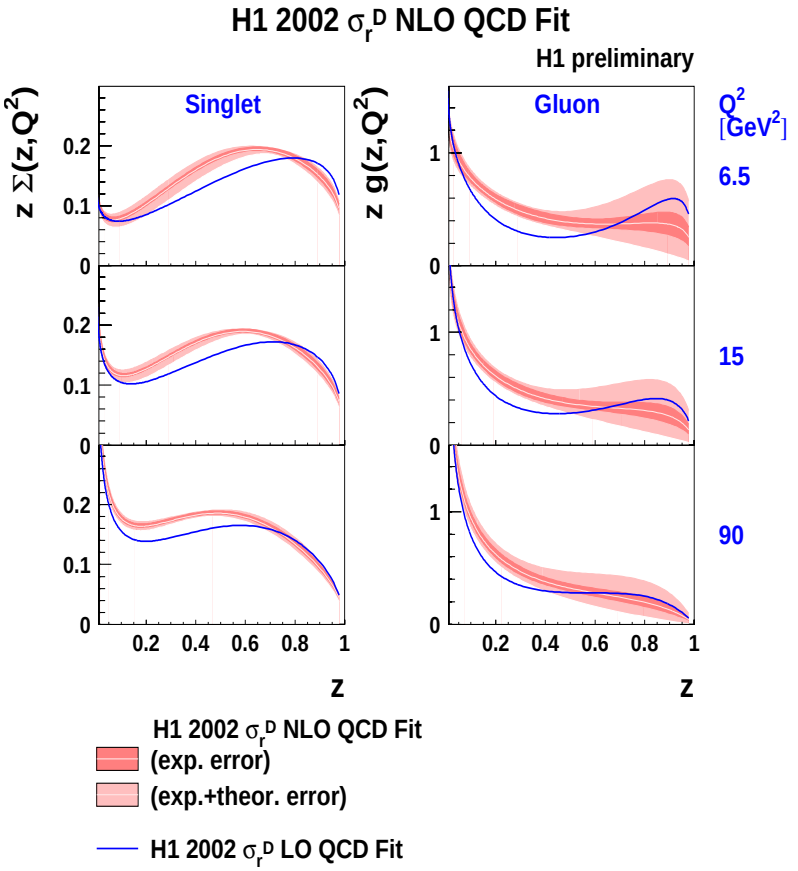
- + "Regge factorisation":
  (assumption, consistent with DIS data)

$$f_i^D = f_{IP/p}(x_{IP}) \quad f_i^{IP}$$

IP flux from proton

IP pdf

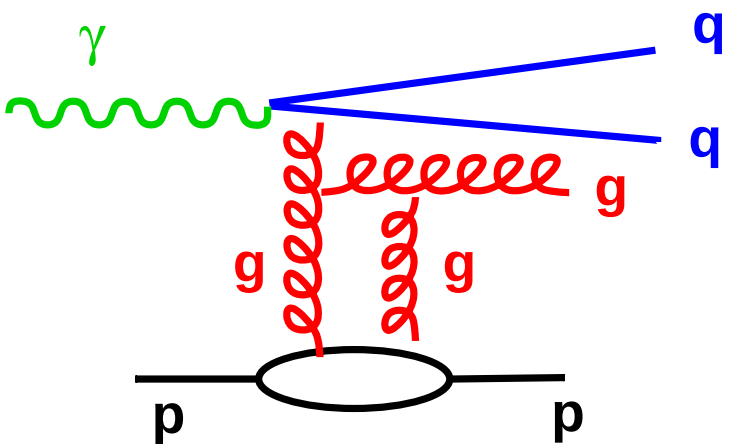
- diffractive PDFs:
  - from DGLAP QCD fits to inclusive diffr. DIS
  - dominated by gluons



Colour Dipole Models

- proton rest frame
- $\gamma \longrightarrow q\bar{q}$, $q\bar{q}g$ colour dipoles

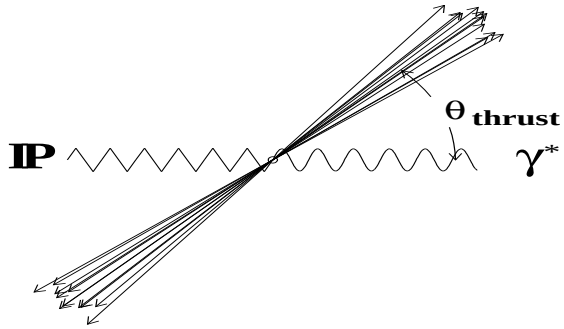
  dominant at large M_X
- dipoles scatter off proton via 2 gluon exchange

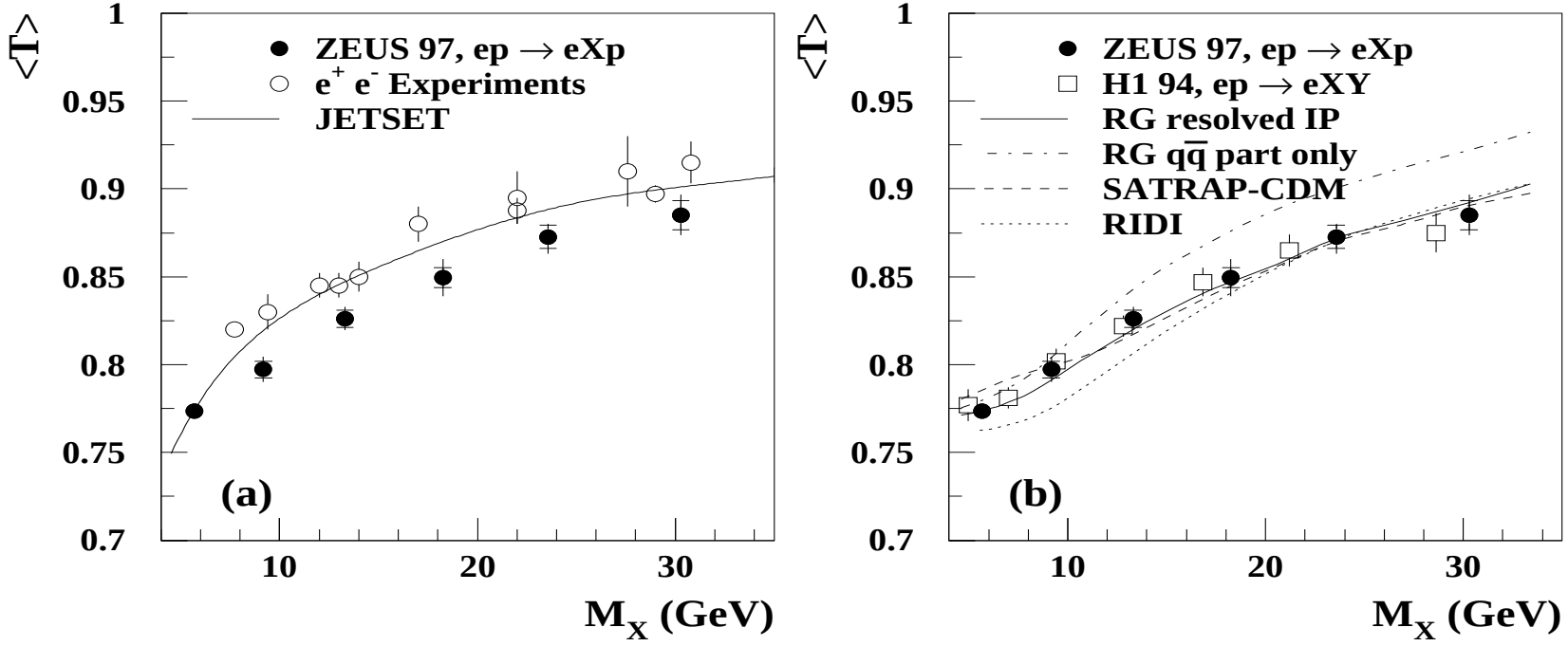


- cross sections related to gluon density in proton
- Saturation Model (Golec−Biernat, Wüsthoff)
  - strong k_T ordering: $k_T(g) << k_T(q,\bar{q})$
  - gluon density from inclusive DIS
- RIDI (Ryskin)
  - strong k_T ordering
  - gluon density from PDF (CTEQ)
- BJLW (Bartels, *et al.*)
  - no k_T ordering
  - free parameter: minimal gluon k_T

Event Shapes – Thrust

$$\text{Thrust } T = \max_{\mathbf{n}} \frac{\sum |\mathbf{n}\cdot\mathbf{p}_i|}{\sum |\mathbf{p}_i|}$$





- as M_X increases:
  system becomes more aligned along γ^*IP axis
- thrust smaller than in e^+e^-
- $q\bar{q}g$ important

Event Shapes – Seagull Distributions

transverse momentum vs. $x_F = \frac{2\,p_L}{M_X}$

p_L = projection of particle momentum along γ^* momentum in γ^*IP CMS

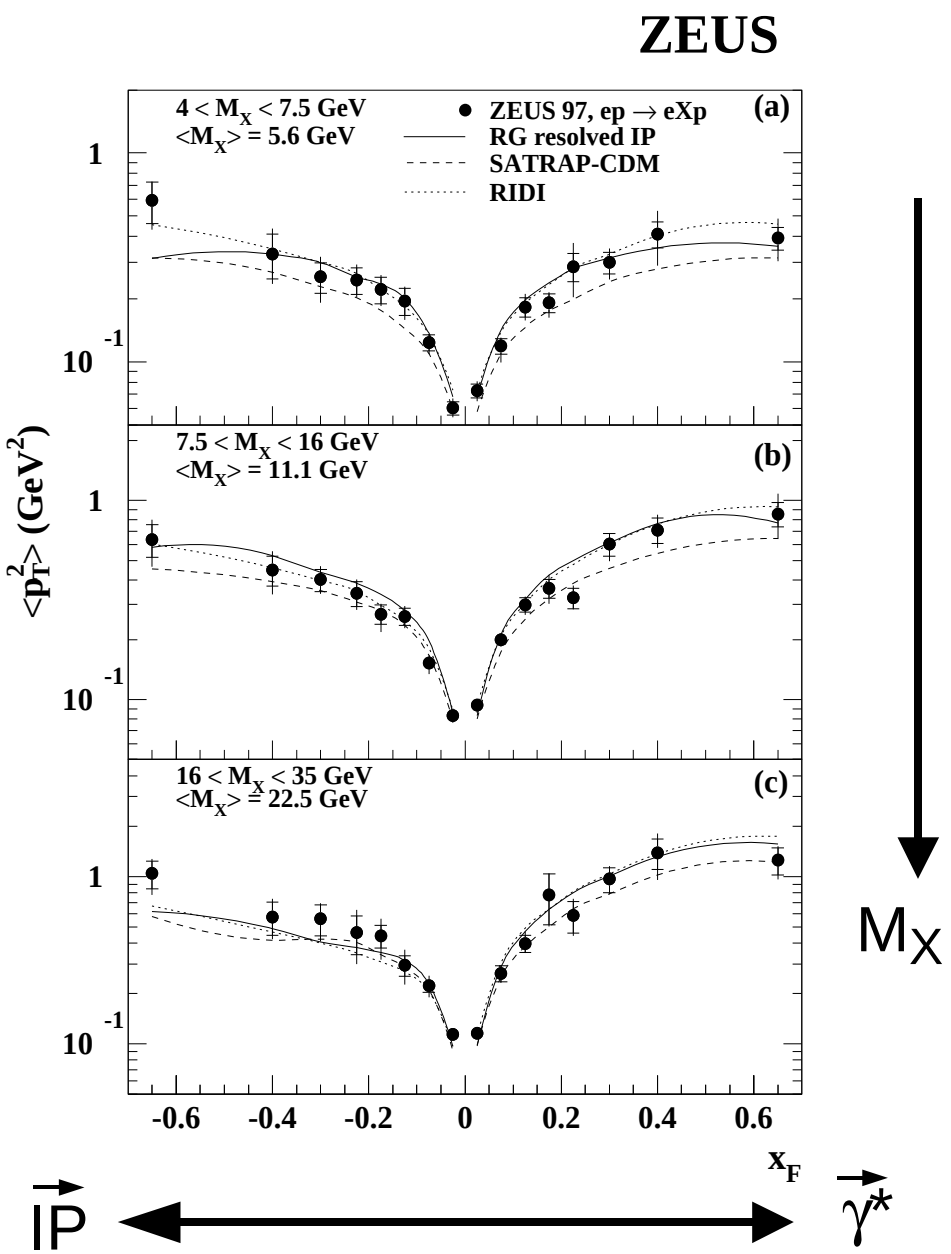
Asymmetry:

- more p_T in direction of photon momentum
- increases with M_X

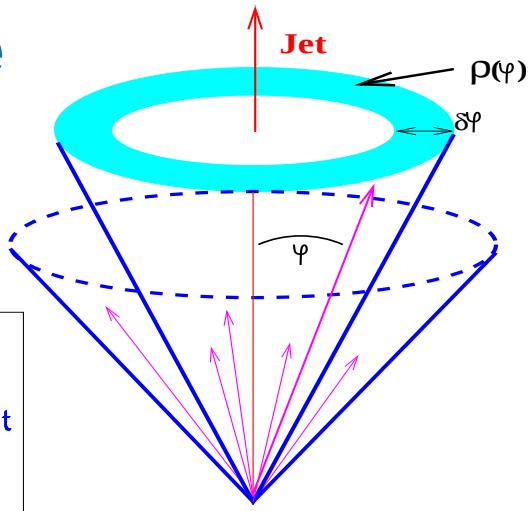
  due to $q\bar{q}g$?

  → 3 jet study

- described by models



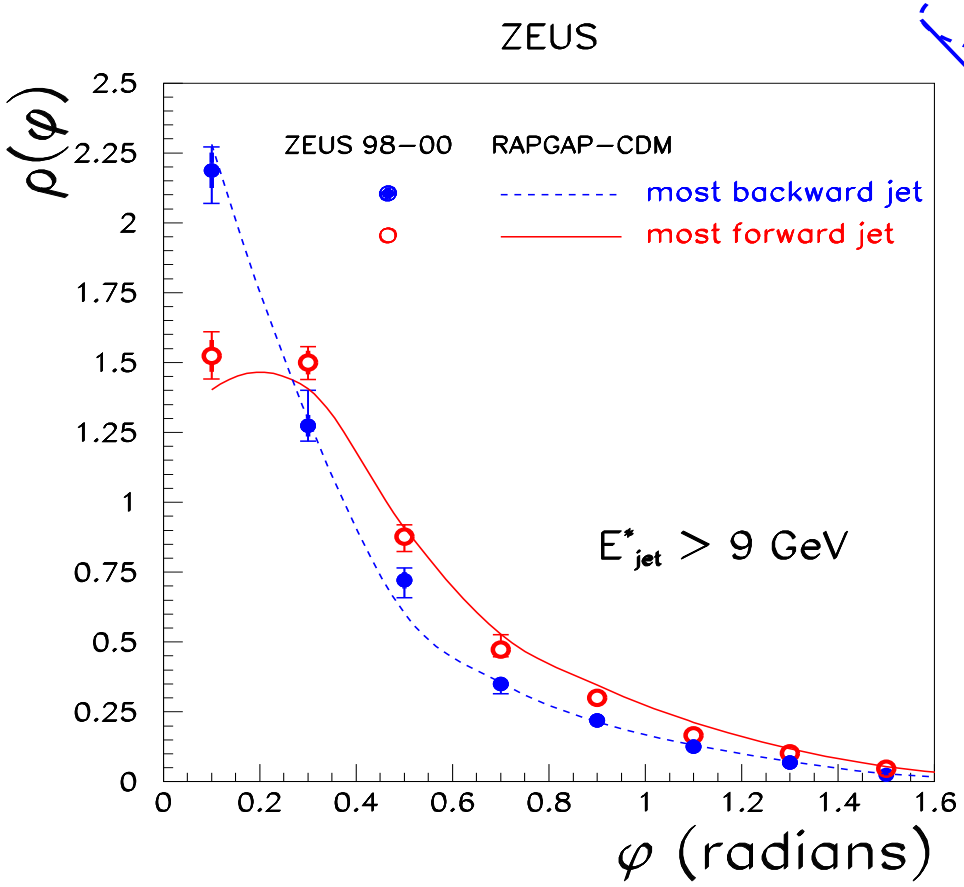
3 Jet Production – Jet Shape



most forward jet ("IP remnant")

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

$5 < Q^2 < 100\ \text{GeV}^2$
$200 < W < 250\ \text{GeV}$
$23 < M_X < 40\ \text{GeV}$
$x_{IP} < 0.025$



- broader than most backward jet → consistent with being initiated by gluon
- described by IP remnant model, also expected for dipole models

3 Jet Production – p_T of forward jet

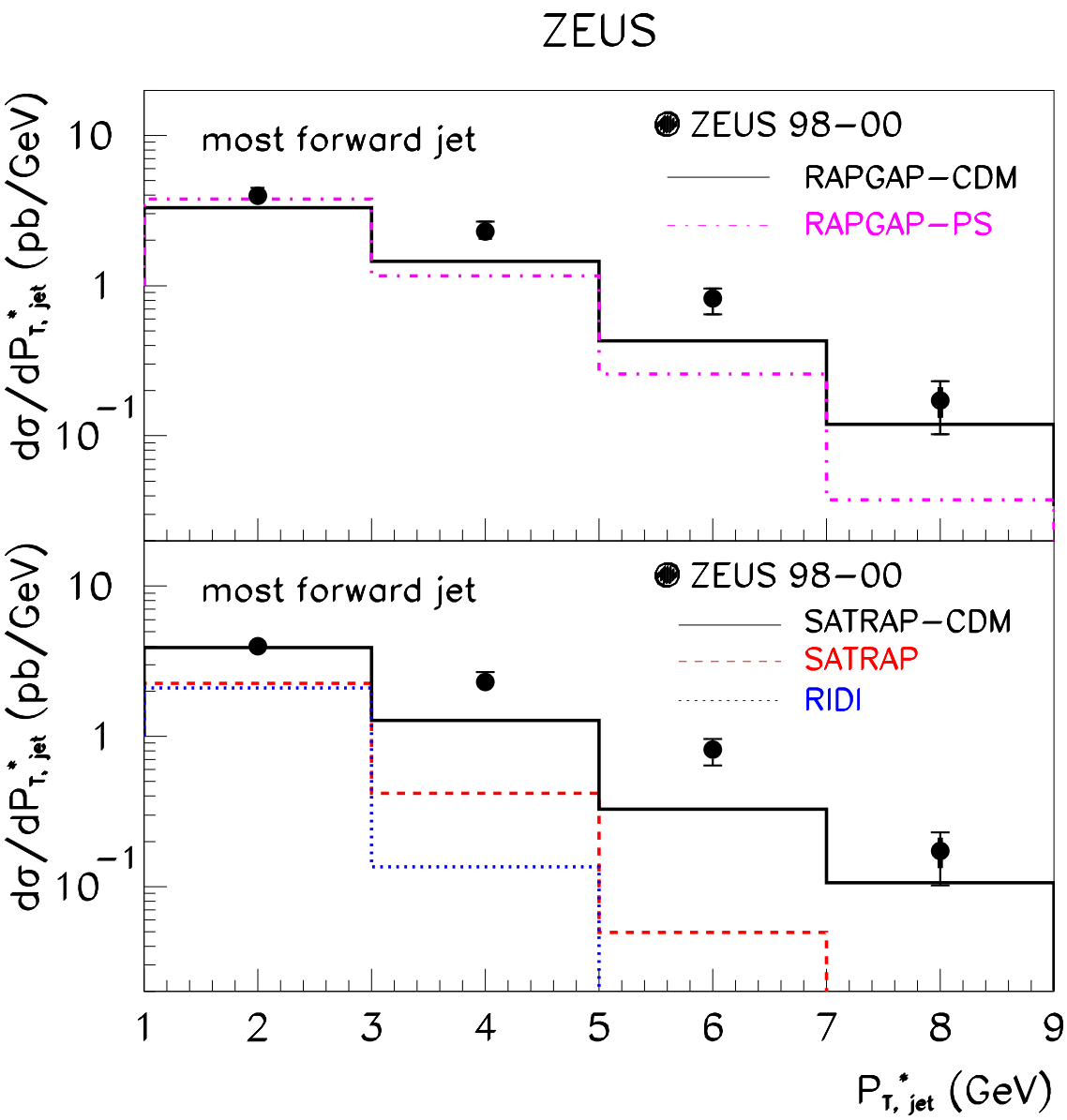
p_T spectrum of forward jet
("IP remnant")

- fair description by Resolved IP Model and Saturation Model (SATRAP–CDM)

$5<Q^2<100$ GeV^2
$200<W<250$ GeV
$23<M_X<40$ GeV
$x_{IP}<0.025$

RIDI and orig. SATRAP:

- inadequate implementation of modelling of higher order processes



D* Measurements

high statistics measurement

L=82/pb
Q^2>1.5 GeV^2
x_{IP}<0.035
p_T^{D*}>1.5 GeV

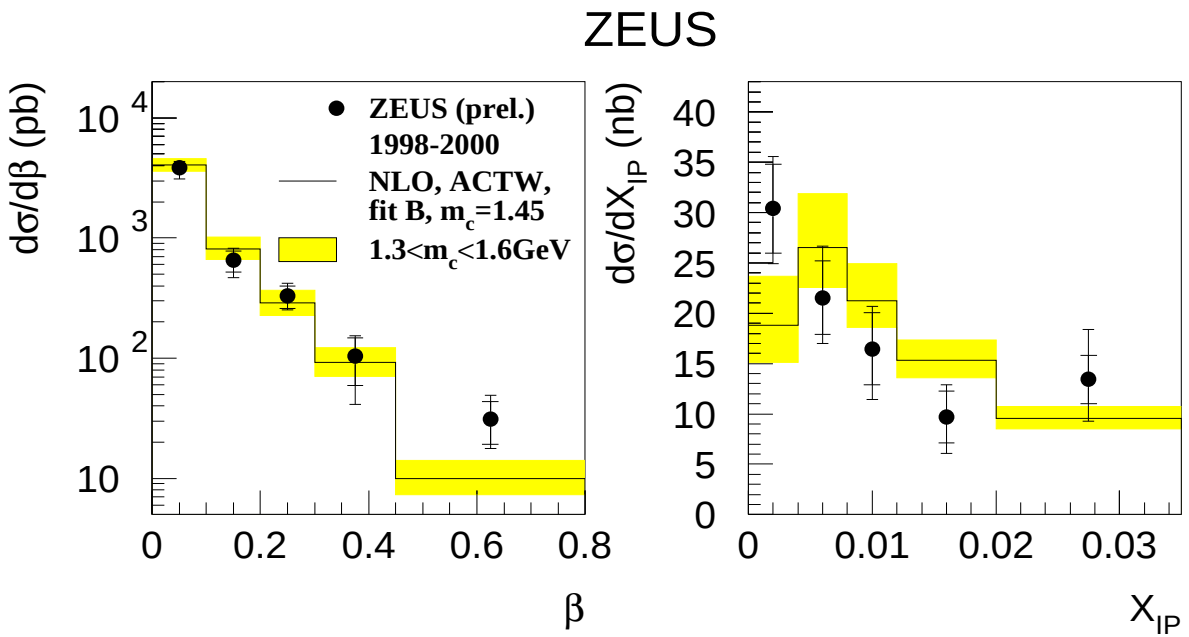
- Resolved IP Model:

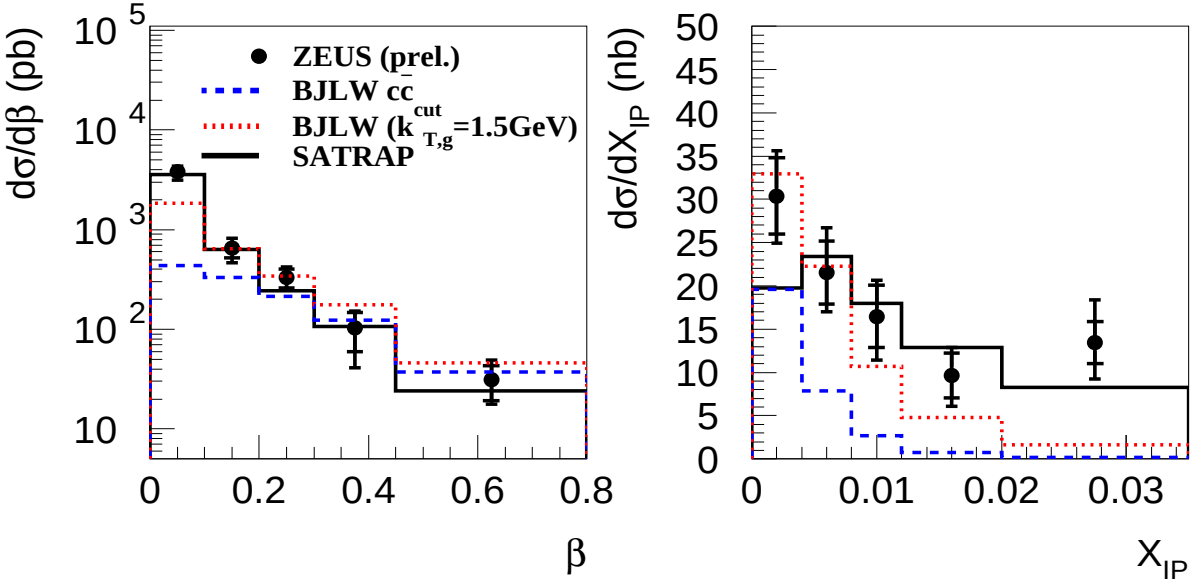
  ACTW (Alvero, et *al.*) Fit B, NLO

- Saturation Model:
  SATRAP−CDM

- BJLW: $k_T^{cut}(g)$=1.5 GeV
  $q\bar{q}g$ needed

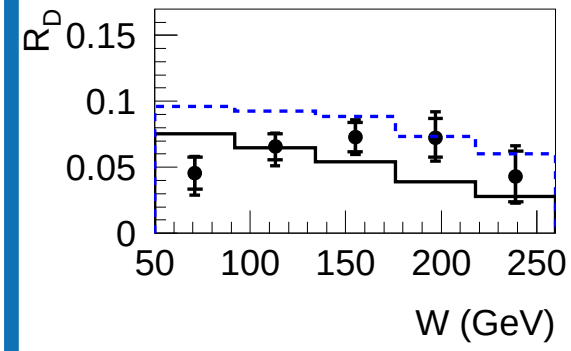
good description by models





D* Measurements II

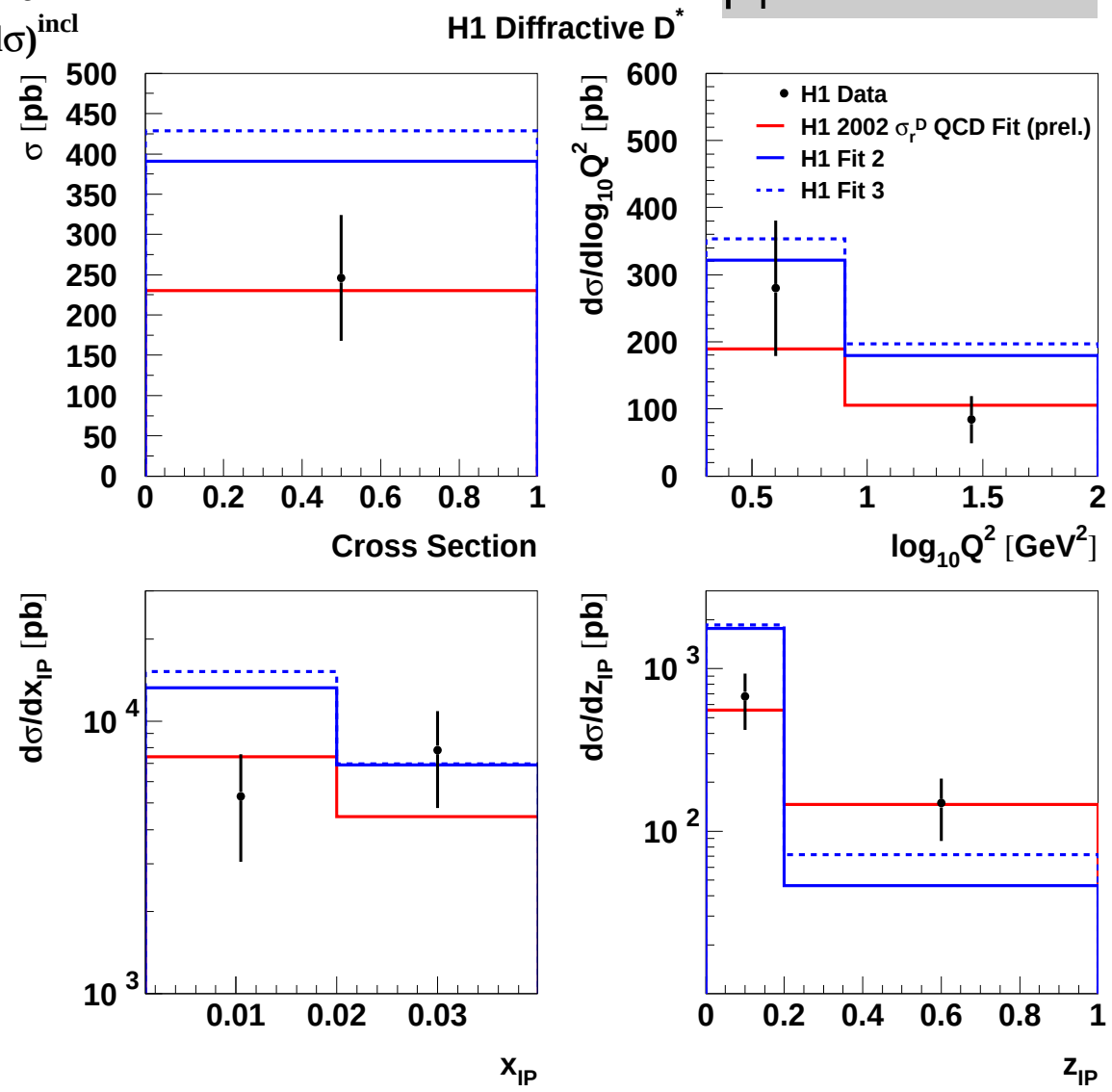
L=19/pb
$2<Q^2<100$ GeV^2
$x_{IP}<0.04$
$p_T^{D^*}>2$ GeV



- ZEUS (prel.) 1998-2000
- RAPGAP, ACTW, fit B
- RAPGAP, H1 fit2

$R_D = (d\sigma)^{diff}/(d\sigma)^{incl}$

- R_D=6% of inclusive D* are diffractively produced
  - ≈ described by IP Model
- Comparison to IP Model w/ new H1 Fit, LO:
  - consistent
  - large uncertainties of data and prediction

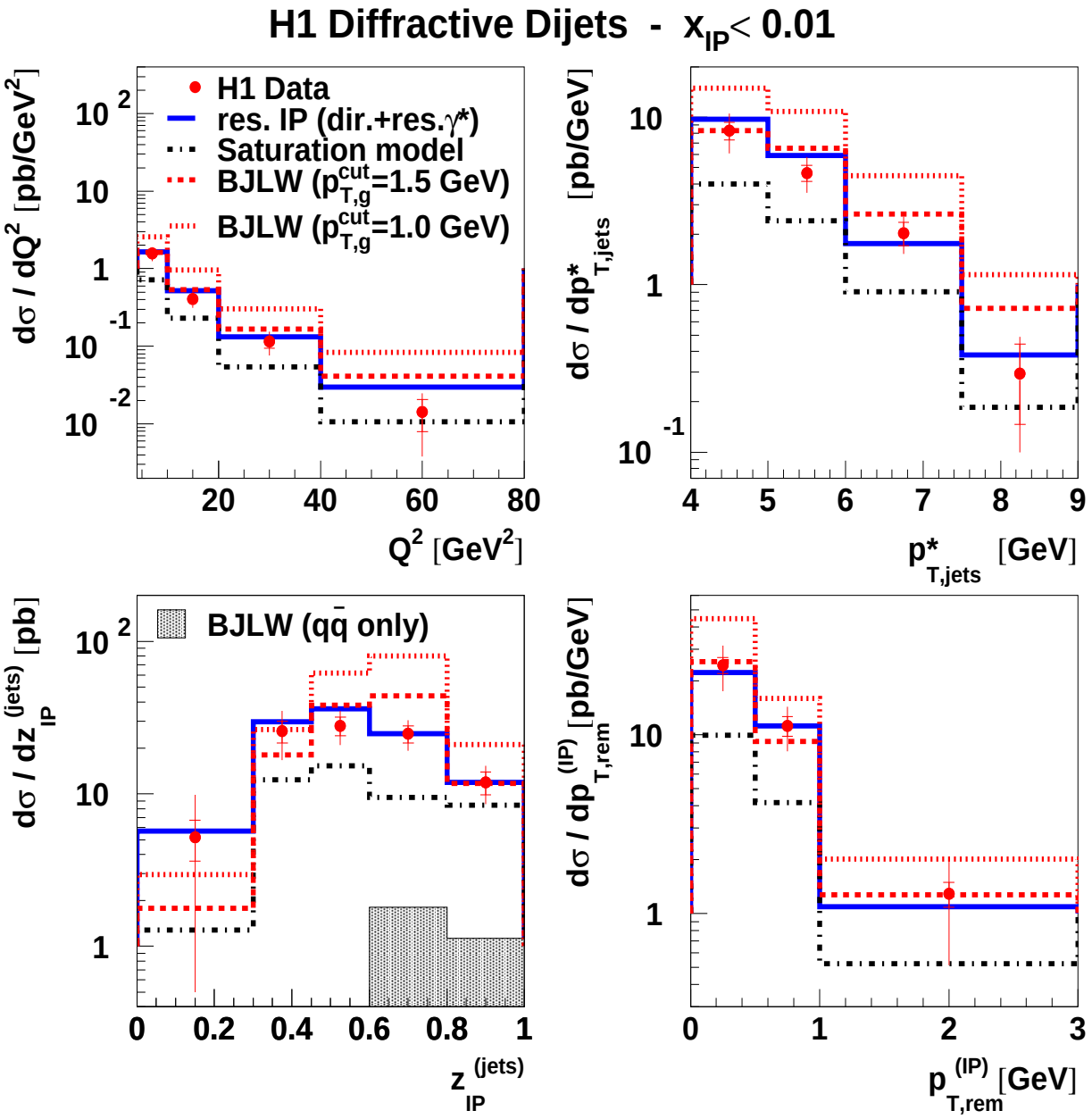


Diffractive Dijets in DIS

L=18/pb
$4<Q^2<80$ GeV^2
$p_T^{jet}>4$ GeV
$x_{IP}<0.01$

- ✔ IP Model:
  - H1 Fit 2, LO
  - very good description
- ✔ BJLW:
  - need $q\bar{q}g$
  - $k_T^{cut}(g)=1.5$ GeV
  - good description
- ✗ Saturation model too low

$p_{T,rem}^{IP}$= p_T of IP remnant

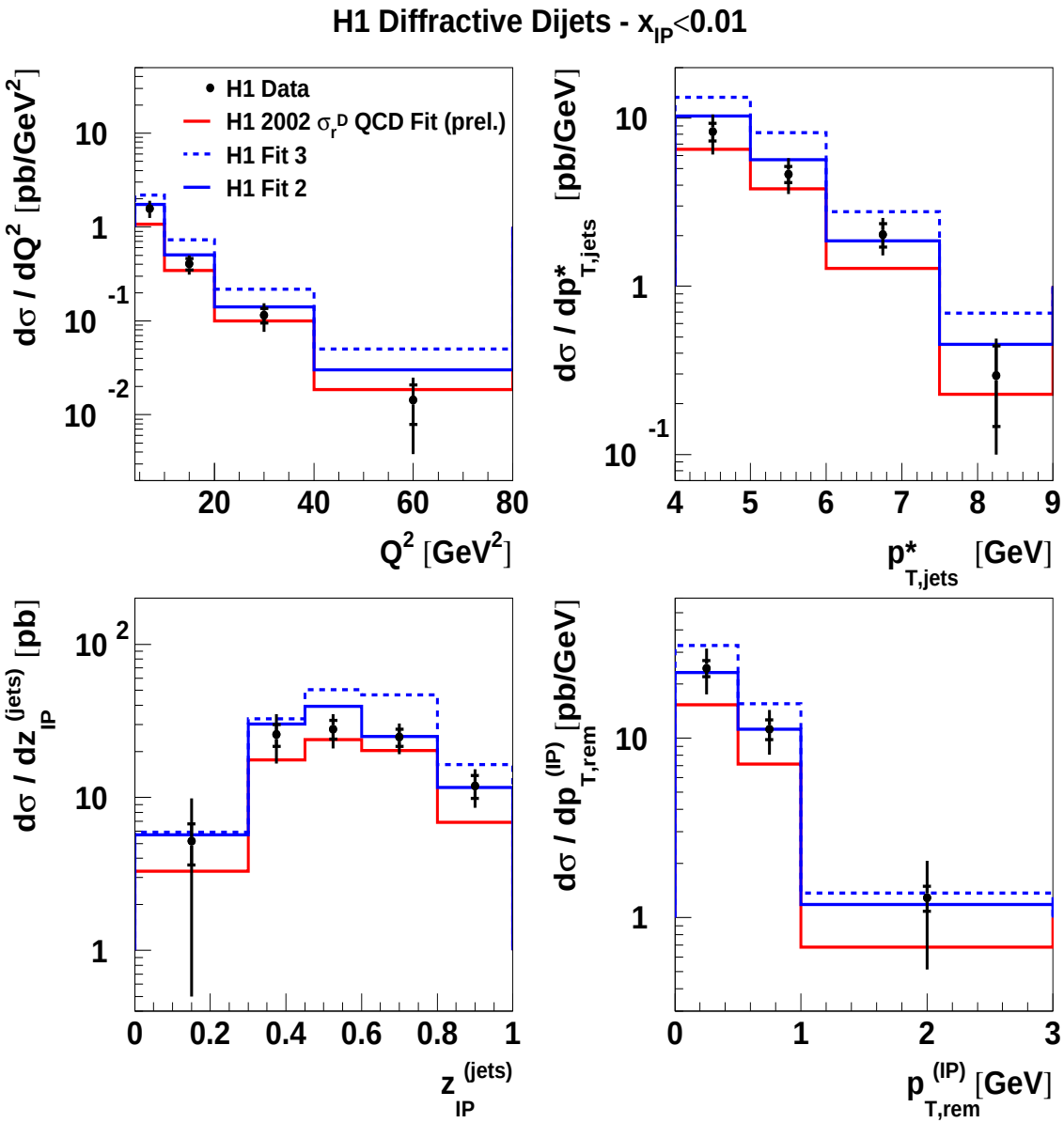


Dijets in DIS – New H1 Fits

Comparison to IP Model with new H1 fits

- shape remains well described
- Normalisation consistent with data when considering uncertainties:

  model parameters, scales, PDFs



Diffractive Dijets at the Tevatron

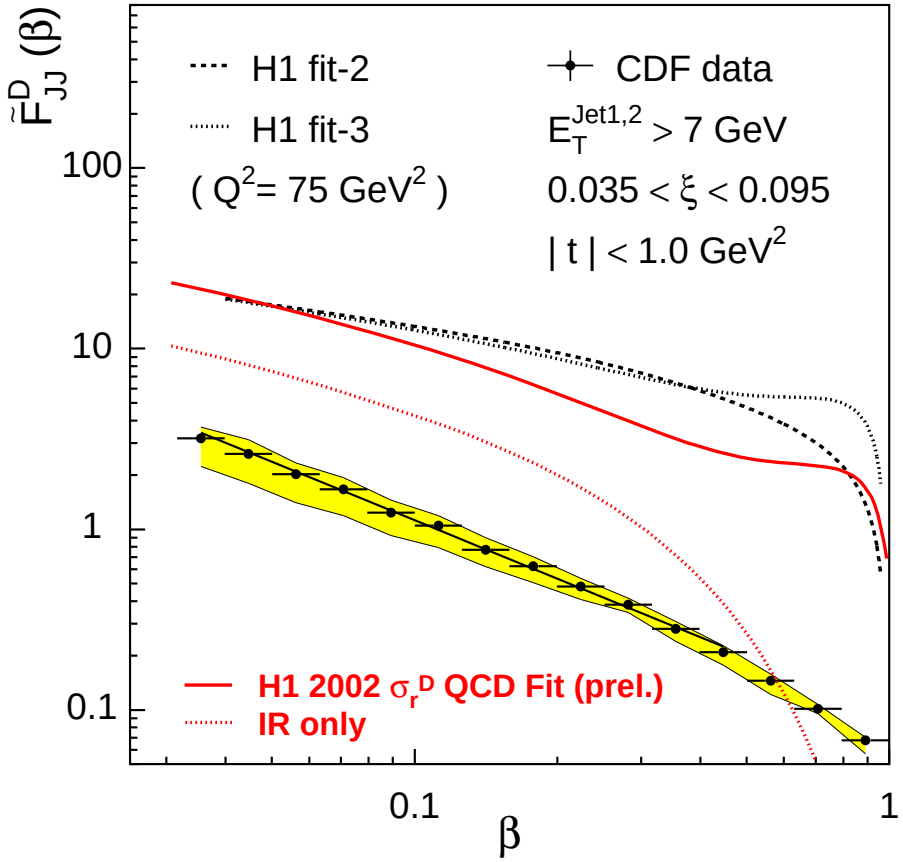
- IP partons which describe diffr. DIS Dijets overestimate $p\bar{p}$ diffractive dijet rate by factor ≈ 10

  breakdown of factorisation

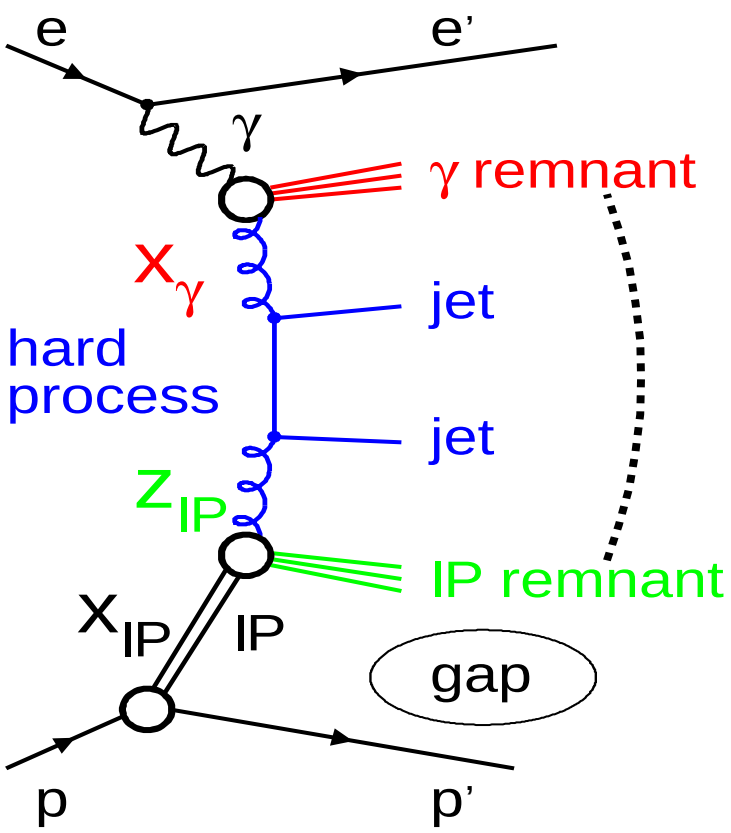
  confirmed by new H1 Fits

- due to additional hadron remnant?

→ investigate in Photoproduction



Dijets in Diffractive Photoproduction



transition from DIS to $p\bar{p}$ collisions:

resolved

direct (no γ remnant)

- adjustable photon remnant

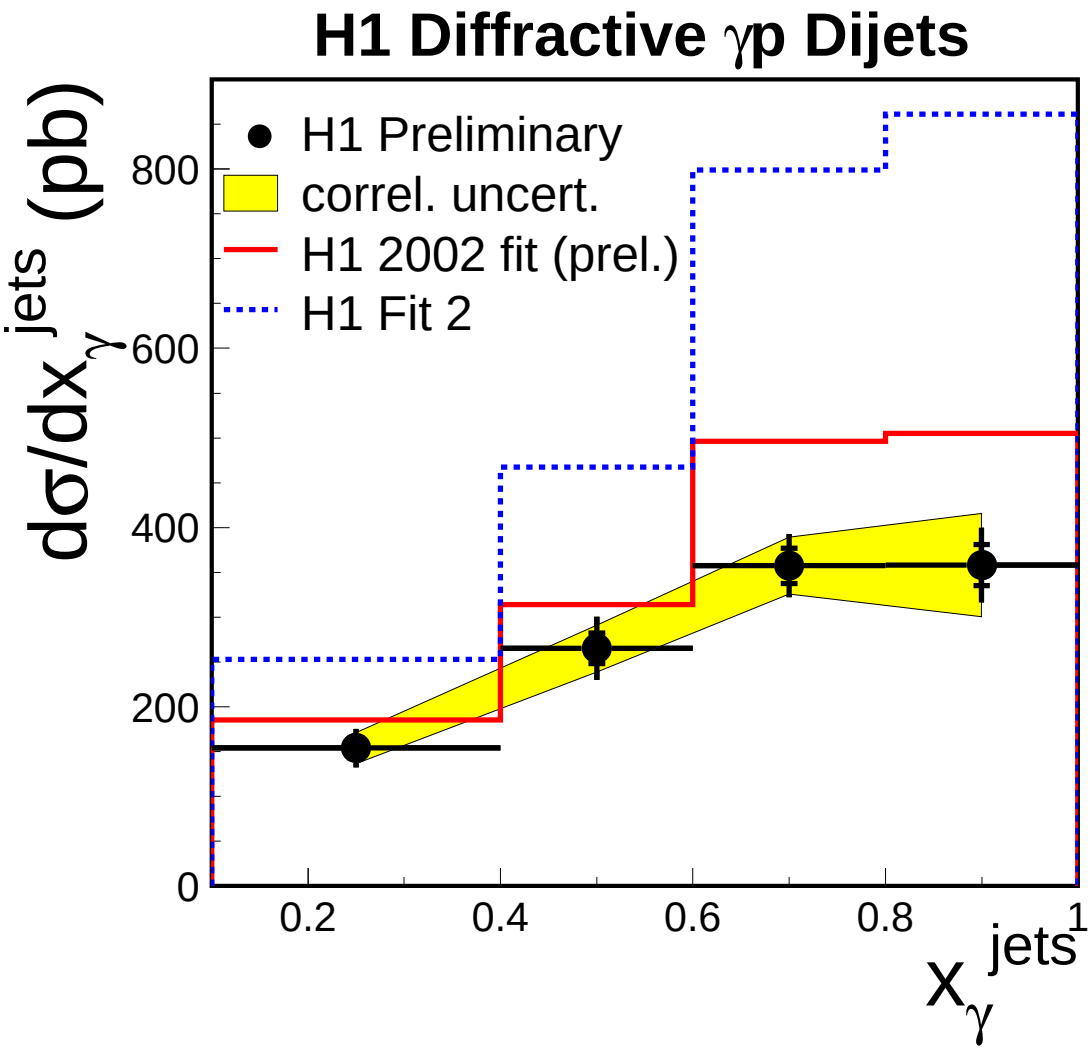
  γ remnant energy $\propto 1-x_\gamma$

- different parton final states accessible

  more gluons from γ for low x_γ

Diffractive γp Dijets – x_γ

L=18/pb
Q^2<0.01 GeV^2
incl. k_T algorithm
$p_T^{jet}(1,2)$>5,4 GeV
x_{IP}<0.03



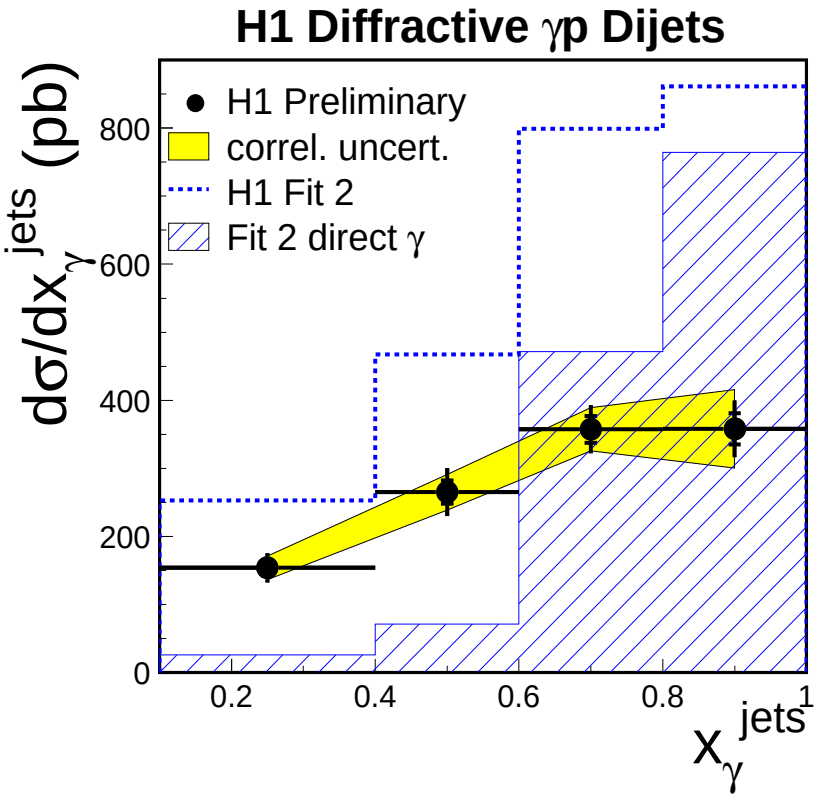
comparison to IP Model
with new H1 Fit

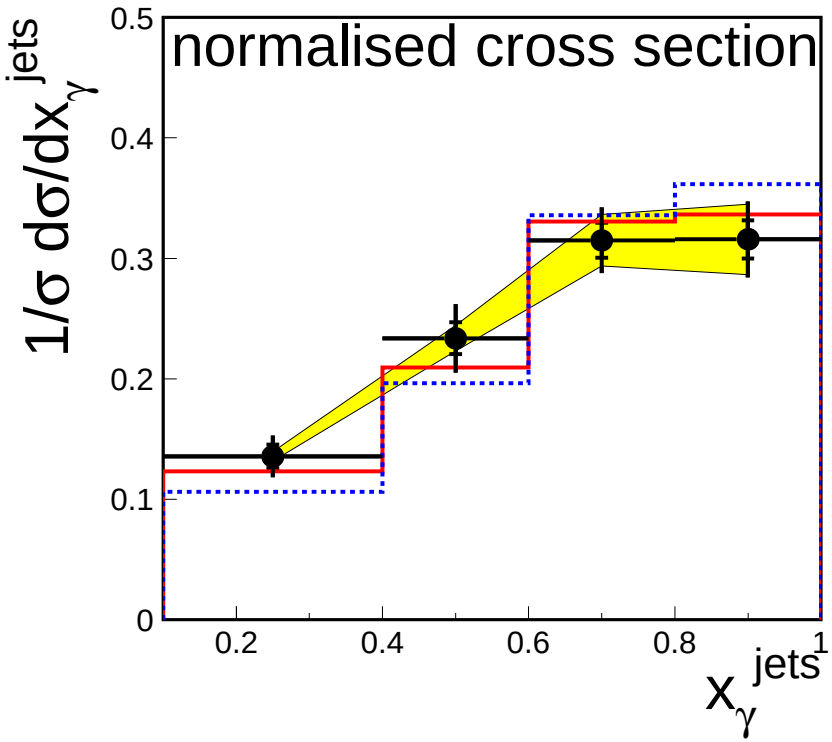
- normalisation compatible within uncertainties
- shape described

Diffractive γp Dijets – x_γ

comparison to diffr. DIS dijets (≈H1 Fit 2) within Resolved IP Model at LO:

- γp dijets suppressed by factor 1.8
- direct photon processes suppressed





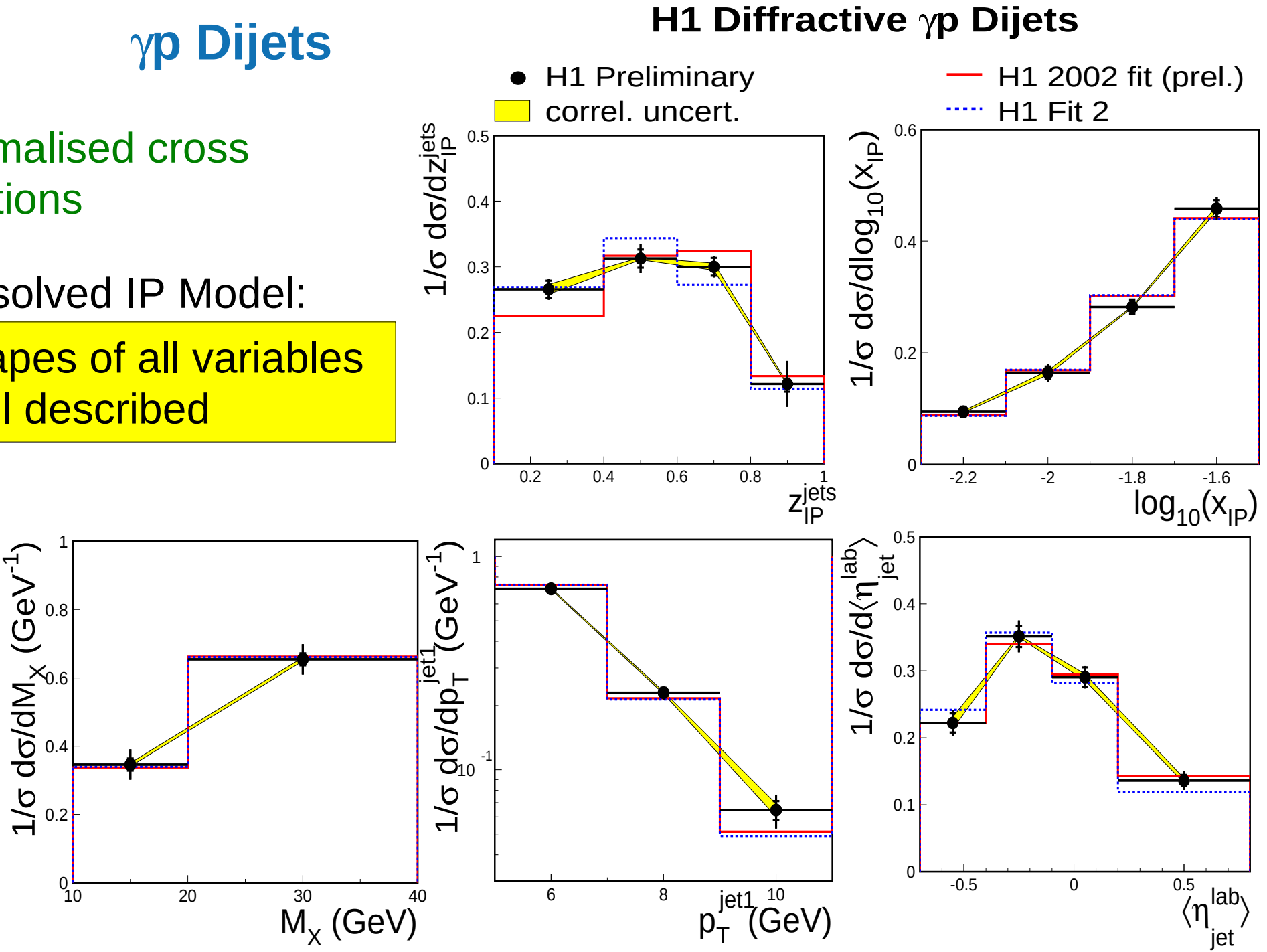
- Shape well described
  - ➔ direct and resolved photon processes suppressed by same factor
  - ➔ no indication of subprocess dependence

γp Dijets

normalised cross sections

- Resolved IP Model:

shapes of all variables well described



Summary

- Diffractive Final States well described by
  - Resolved IP Model with gluon dominated IP
  - pQCD Dipole Models with inclusion of $q\bar{q}g$
- Evidence for gluon remnant from diffractive exchange
- IP Model with new H1 Fits agree with DIS and γp dijets, and D* cross sections within uncertainties
- Within IP Model at LO:
  - γp dijets suppressed with respect to DIS dijets by factor 1.8
  - direct and resolved photon processes suppressed by same factor
  - no indication of subprocess dependence