Results on Inclusive Diffraction from HERA I (H1 and ZEUS)

Presented by B.Loehr on behalf of H1 and ZEUS

Data from the running period 1999-2000.

The (almost) 'last word' on inclusive diffraction from HERA I.

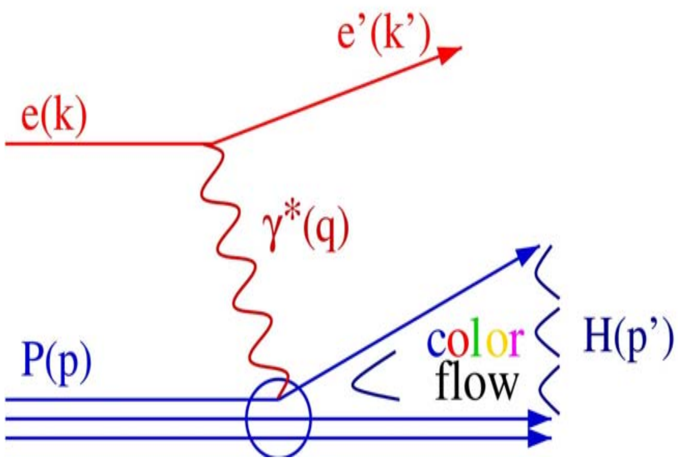
In the HERA II setup the ZEUS detector lost components for diffractive physics, namely the Leading Proton Spectrometer (LPS), and the Forward Plug Calorimeter (FPC).

The H1 detector lost the Proton Remnant Tagger (PRT) but kept the Forward proton Spectrometer (FPS) and even added a Very Forward Proton Spectrometer (VFPS) and some silicon based detectors in the forward region.

Measurements from three different methods.

We attempt to get a consistent picture of inclusive diffraction from both experiments and from all different methods for this running period.

Inclusive nondiffr. DIS events :



$$s = (k+p)^2$$ center of mass energy squared

$$Q^2 = -q^2 = -(k-k')^2$$ virtuality, size of the probe

$$W^2 = M_H^2 = (p+q)^2$$ γ^* - proton cms energy squared

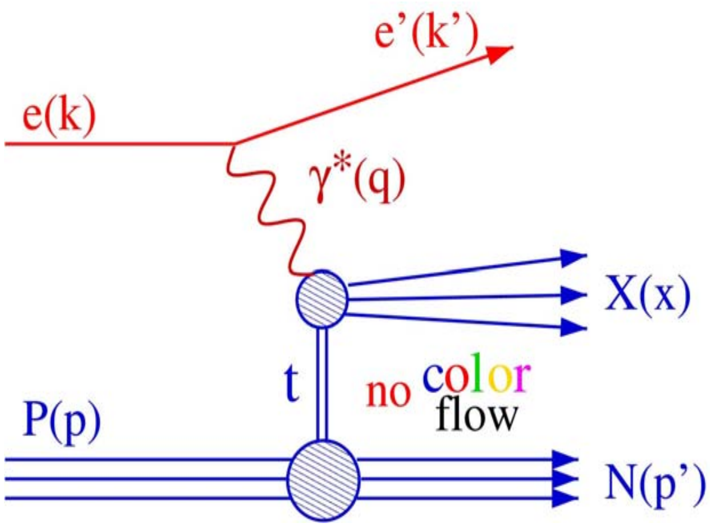
$$x = \frac{Q^2}{2p \cdot q} \qquad y = \frac{p \cdot q}{p \cdot k}$$

x: fraction of the proton carried by the struck parton

y: inelasticity, fraction of the electron momentum carried by the virtual photon

$$Q^2 = x \cdot y \cdot s$$

Diffractive DIS events :



For diffractive events in addition 2 variables

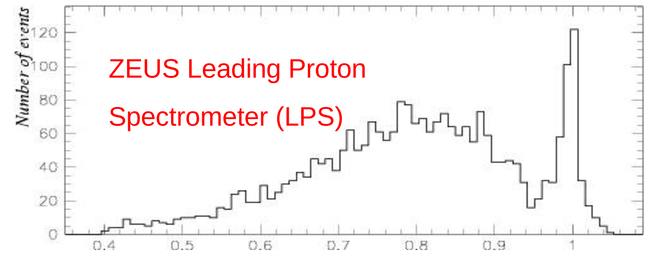
$$M_x$$ mass of the diffractive system x

$$t = (p-p')^2$$ four-momentum transfer squared at the proton vertex

$$x_{IP} = \frac{(p-p') \cdot q}{p \cdot q} = \frac{M_X^2 + Q^2}{W^2 + Q^2}$$ momentum fraction of the proton carried by the Pomeron

$$\beta = \frac{Q^2}{2(p-p') \cdot q} = \frac{x}{x_{IP}} = \frac{Q^2}{M_X^2 + Q^2}$$ fraction of the Pomeron momentum which enters the hard scattering

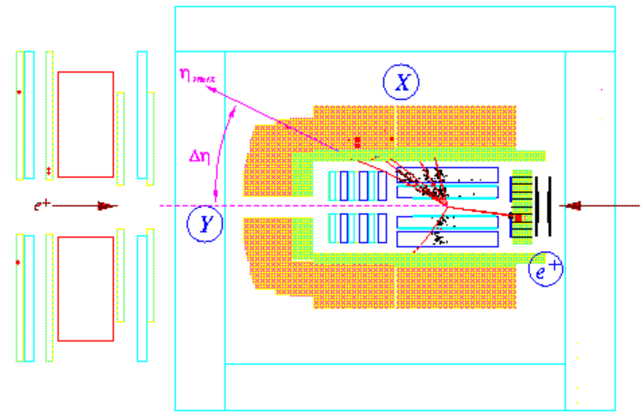
Methods to measure Inclusive Diffraction



$x_L = p_z'/p_z$

1.) Detection of the scattered proton:

- diffractive peak at x_L
- no contribution from proton dissociation events
- contribution from Reggeon exchanges
- only method to measure t-distribution
- **small acceptance -> limited statistics**

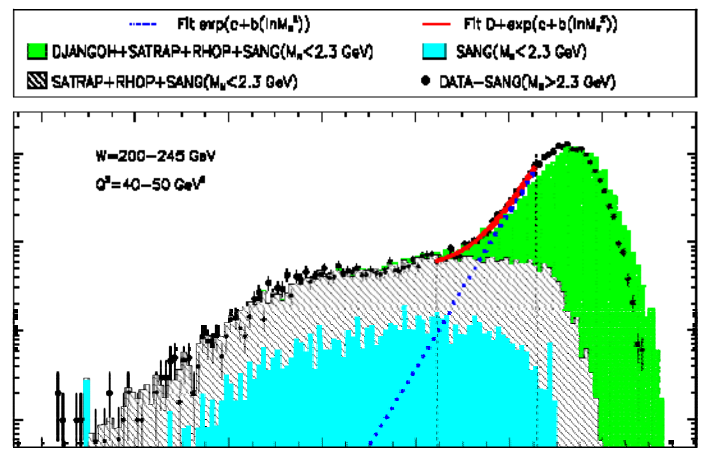


2.) Rapidity gap between incoming proton direction and first particle seen in the detector:

- contributions from proton dissociation events
- contributions from Reggeon exchanges
- **large acceptance**

3.) The M_X-method: exploits the mass distribution of the diffractive system

- contributions from proton dissociation events
- no contributions from Reggeon exchanges
- **large acceptance**



$\ln M_X^2$

All three methods initially measure different mixtures of different processes.

H1 and ZEUS Data Sets

H1:

FPS	28.4 pb^{-1}	Q^2= 2.7 - 24 GeV^2	Eur.Phys.J. C48(2006) 749	no p-dissociation
LRG	74.2 pb^{-1}	Q^2= 3.5 – 1600 GeV^2	Eur.Phys.J. C48(2006) 715	corr. to M_N < 1.6 GeV

ZEUS:

LPS	32.6 pb^{-1}	Q^2=2.5 - 40 GeV^2		no p-dissociation
LRG	62.2 pb^{-1}	Q^2=2.5 - 255 GeV^2		corr. to $M_N= m_p$
FPC I	4.2 pb^{-1}	Q^2=2.2 - 80 GeV^2	Nucl.Phys. B 713 (2005) 3	corr. to M_N < 2.3 GeV
FPC II	11.0 pb^{-1}	Q^2 = 20 - 40 GeV^2	hep-ex 0802.3017,	corr. to M_N < 2.3 GeV
	52.4 pb^{-1}	Q^2 = 40 - 450 GeV^2	accepted by Nucl.Phys. B	corr. to M_N < 2.3 GeV

$$\boxed{\frac{d^4\sigma_{\gamma^* p}}{dQ^2 dt dx_{IP} d\beta} = \frac{2\pi\alpha_{\mathrm{em}}}{\beta \cdot Q^2}\left[1-(1-y)^2\right] \cdot \sigma_r^{D(4)}(Q^2, t, x_{IP}, \beta)}$$

$$\boxed{\sigma_r^{D(4)}(Q^2, t, x_{IP}, \beta) = F_2^{D(4)}(Q^2, t, x_{IP}, \beta) - \underbrace{\frac{y^2}{1+(1-y)^2} F_L^{D(4)}(Q^2, t, x_{IP}, \beta)}_{}}$$

sizeable only at high y, if neglected $F_2 = \sigma_R$

If t is not measured, i.e. integrated over: $\sigma_r^{D(3)}(\beta, Q^2, x_{IP}) = \int \sigma_r^{D(4)}(\beta, Q^2, x_{IP}, t) dt$

$$\boxed{\frac{d^3\sigma_{\gamma^* p}}{dQ^2 dx_{IP} d\beta} = \frac{2\pi\alpha_{\mathrm{em}}}{\beta Q^2}\left[1-(1-y)^2\right] \cdot \sigma_r^{D(3)}(Q^2, x_{IP}, \beta)}$$

and anlogously $\boxed{F_2^{D(3)}(Q^2, x_{IP}, \beta)}$

H1 use $\sigma_r^{D(3)}(Q^2, x_{IP}, \beta)$

ZEUS use $F_2^{D(3)}(Q^2, x_{IP}, \beta)$ for the M_X results and neglect longitudinal contribution.

Factorisation and Diffractive Parton Distribution Functions

Diffractive DIS factorisation: proven theorem

$$\mathrm{d}\sigma^{ep\to eXY}(x,Q^2,x_{I\!P},t)=\sum_i \underbrace{f_i^D(x,Q^2,x_{I\!P},t)}_{\text{universal diffractive parton distribution function (dpdf)}}\otimes \underbrace{\mathrm{d}\hat{\sigma}^{ei}(x,Q^2)}_{\text{hard universal DIS cross section}}$$

Regge factorisation: not proven hypothesis

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

with

$$f_{I\!P/p}(x_{I\!P},t)=A_{I\!P}\cdot\frac{e^{B_{I\!P}t}}{x_{I\!P}^{2\alpha_{I\!P}(t)-1}}$$

This is the basis of the Regge fits used for the LPS/FPS data and LRG data to separate the diffractive (Pomeron) contribution from the Reggeon exchange contributions and to perform NLO DGLAP fits to its (Q^2, β)-dependence (see later).

Diffractive cross sections obtained with the FPS/LPS or LRG method may contain in some kinematical regions sizeable contributions from Reggeon exchanges.

Simultaneous fit and separation of the contributions by:

$$f_i^D(x, Q^2, x_{I\!P}, t) = f_{I\!P/p}(x_{I\!P}, t) \cdot f_i(\beta, Q^2) \; + \; n_{I\!R} \cdot f_{I\!R/p}(x_{I\!P}, t) \cdot f_i^{I\!R}(\beta, Q^2)$$

Pomeron contribution

relative normalisation

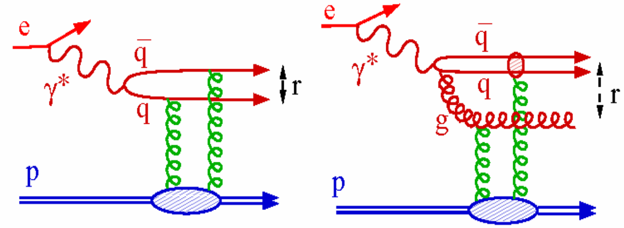
Reggeon contribution

$$F_2^{IP}(\beta, Q^2) = \sum_i f_i(\beta, Q^2)$$ diffractive (Pomeron) structure function

$$f_i(\beta, Q^2)$$ obey DGLAP evolution

Regge fits and DGLAP fits are performed simultaneously by H1 (see later).

ZEUS BEKW(mod) Fit



Dipole Model

Fit with BEKW model

(Bartels, Ellis, Kowalski and Wüsthoff, 1998)

- $x_{IP} F_2^{D(3)} = c_T \cdot F^T_{q\bar{q}} + c_L \cdot F^L_{q\bar{q}} + c_g \cdot F^T_{q\bar{q}g}$

$$F^T_{q\bar{q}} = \left(\frac{x_0}{x_{IP}}\right)^{n_T(Q^2)} \cdot \beta(1-\beta) \,,$$

$$F^L_{q\bar{q}} = \left(\frac{x_0}{x_{IP}}\right)^{n_L(Q^2)} \cdot \frac{Q_0^2}{Q^2+Q_0^2} \cdot \left[\ln\left(\frac{7}{4} + \frac{Q^2}{4\beta Q_0^2}\right)\right]^2 \cdot \beta^3(1-2\beta)^2 \,,$$

$$F^T_{q\bar{q}g} = \left(\frac{x_0}{x_{IP}}\right)^{n_g(Q^2)} \cdot \ln\left(1 + \frac{Q^2}{Q_0^2}\right) \cdot (1-\beta)^{\gamma}$$

assume $n_T(Q^2) = c_4 + c_7 \ln\left(1 + \frac{Q^2}{Q_0^2}\right)$, $n_L(Q^2) = c_5 + c_8 \ln\left(1 + \frac{Q^2}{Q_0^2}\right)$,

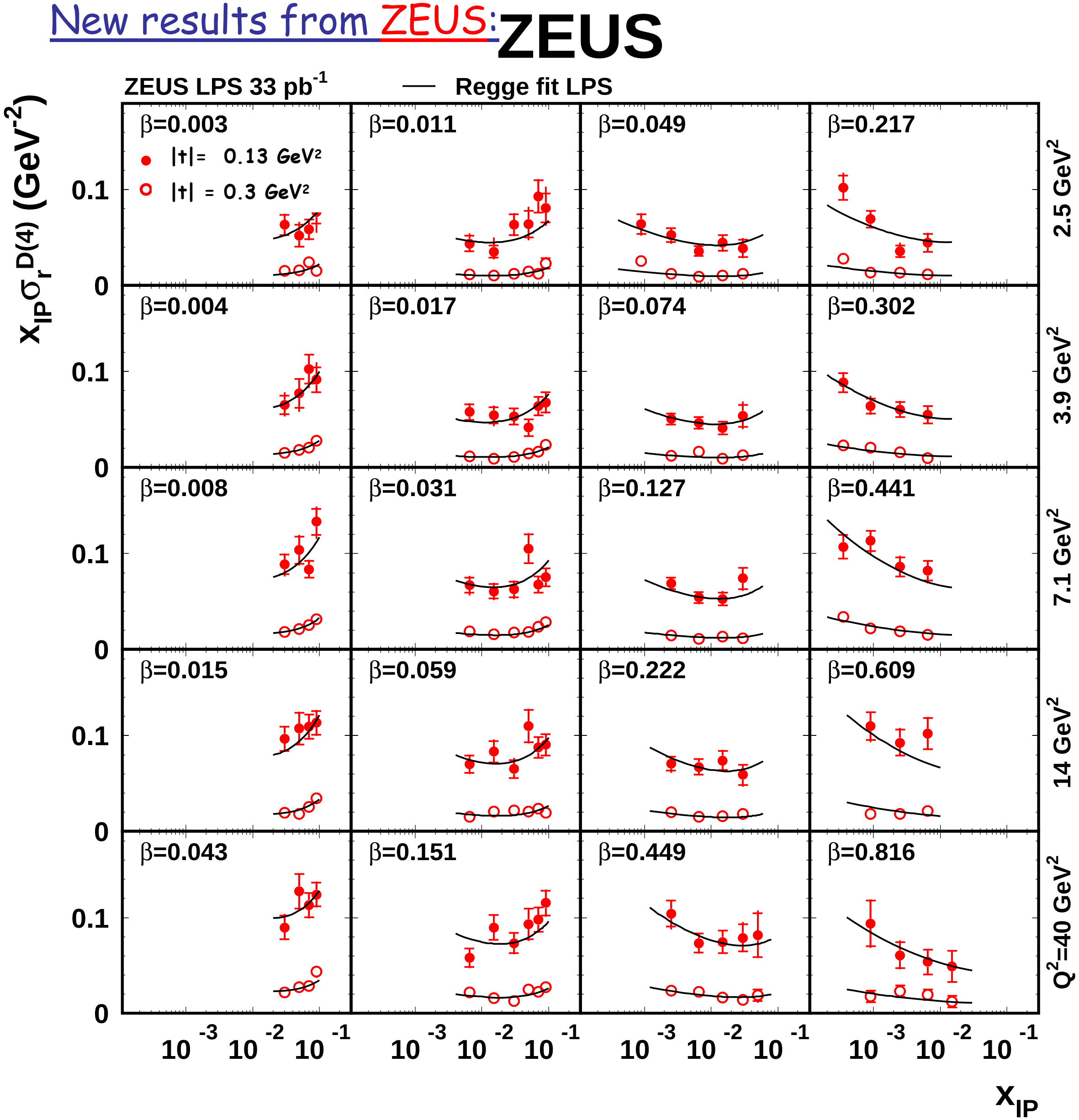
$$n_g(Q^2) = c_6 + c_9 \ln\left(1 + \frac{Q^2}{Q_0^2}\right)$$

The ZEUS data support taking $n_T(Q^2)=n_g(Q^2)=n_L(Q^2)= n_1 \cdot \ln(1+Q^2/Q^2_0)$

Taking x_0= 0.01 and Q^2_0= 0.4 GeV^2 results in the modified BEKW model with the 5 free papameters :

$$\boxed{c_T \,,\; c_L \,,\; c_g \,,\; n_1^{T,L,g} \,,\; \gamma}$$

New results from ZEUS:



Measurements at two different t-bins

$$|t| = 0.13\,\mathrm{GeV}^2 \text{ and}$$

$$|t| = 0.30\,\mathrm{GeV}^2$$

$$2.5\,\mathrm{GeV}^2 \le Q^2 \le 40\,\mathrm{GeV}^2$$

Large β:

$x_{IP}\sigma_r^{D(4)}$ falls with x_{IP}

Medium β:

at small x_{IP}, $x_{IP}\sigma_r^{D(4)}$ falls with x_{IP}

at large x_{IP}, $x_{IP}\sigma_r^{D(4)}$ rises with x_{IP}

→ Reggeon exchanges contribute

Small β:

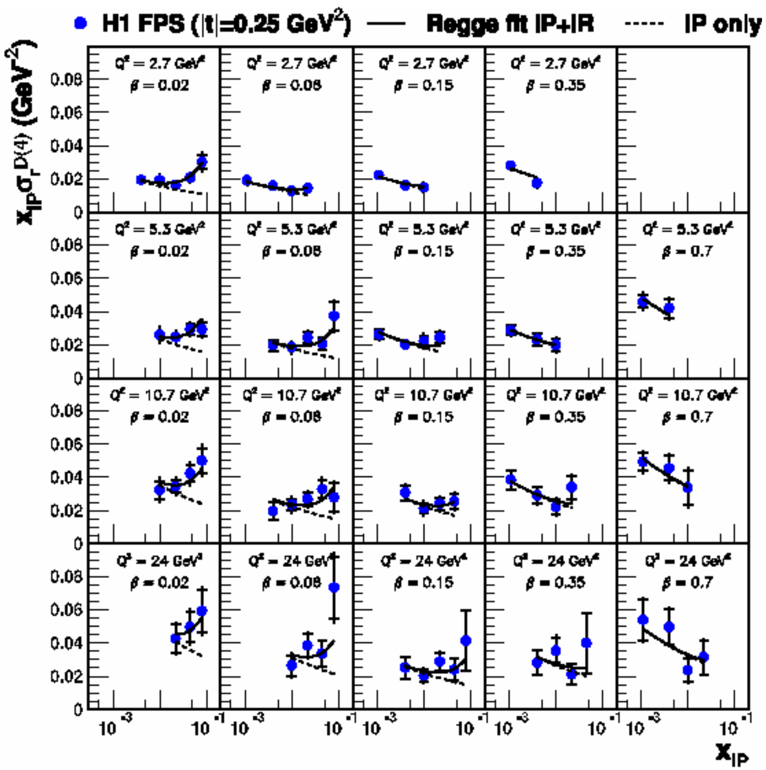
only high x_{IP}

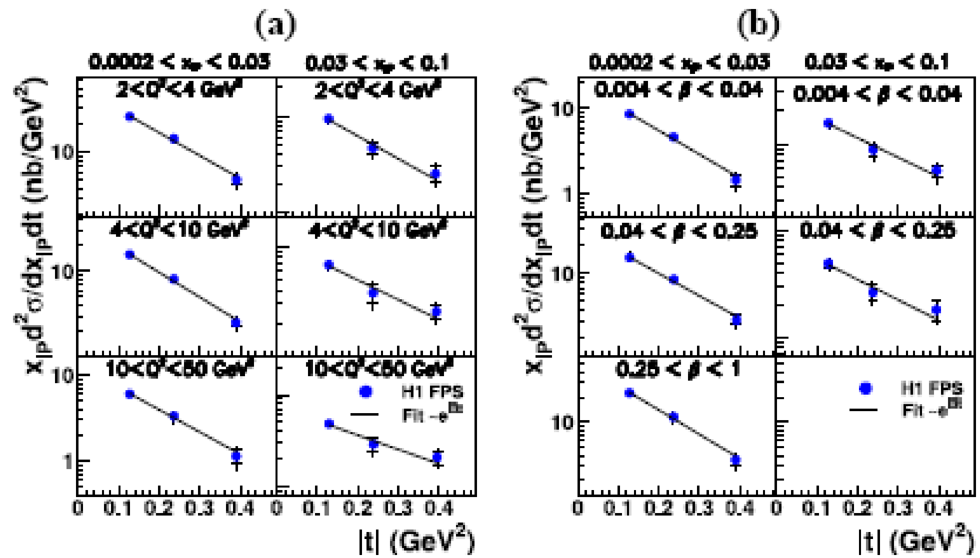
→ Reggeon exchanges dominate

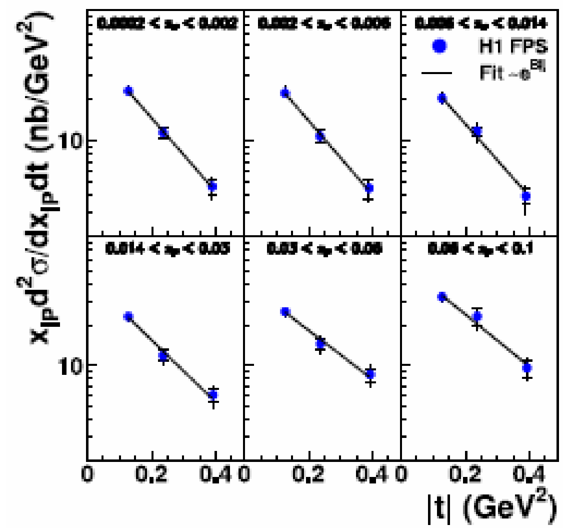
Behaviour is similar for the 2 t-bins

Published H1 results:

$2\ GeV^2 < Q^2 < 50\ GeV^2$

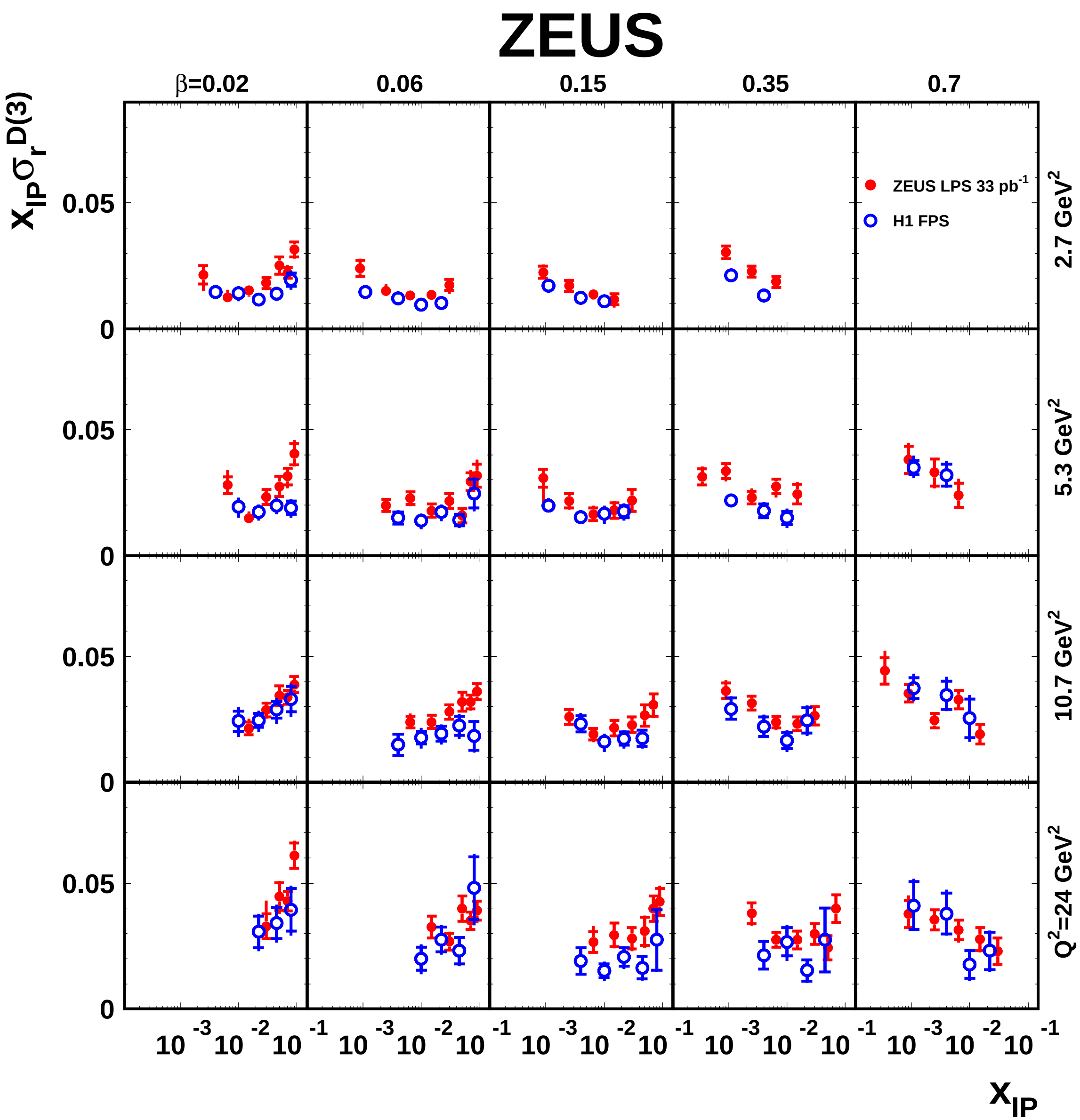






Fits to the form: $$x_{IP}\frac{d^2\sigma}{dx_{IP}dt} \propto e^{B\cdot t}$$

Slope B slightly lower for $x_{IP} > 10^{-2}$, possibly due to Reggeon contributions .



H1 FPS results:
Eur.Phys.J. C48(2006) 749

ZEUS LPS results:
M.Ruspa, XVI International Workshop On Deep Inelastic Scattering, UCL, 7-11 April, 2008

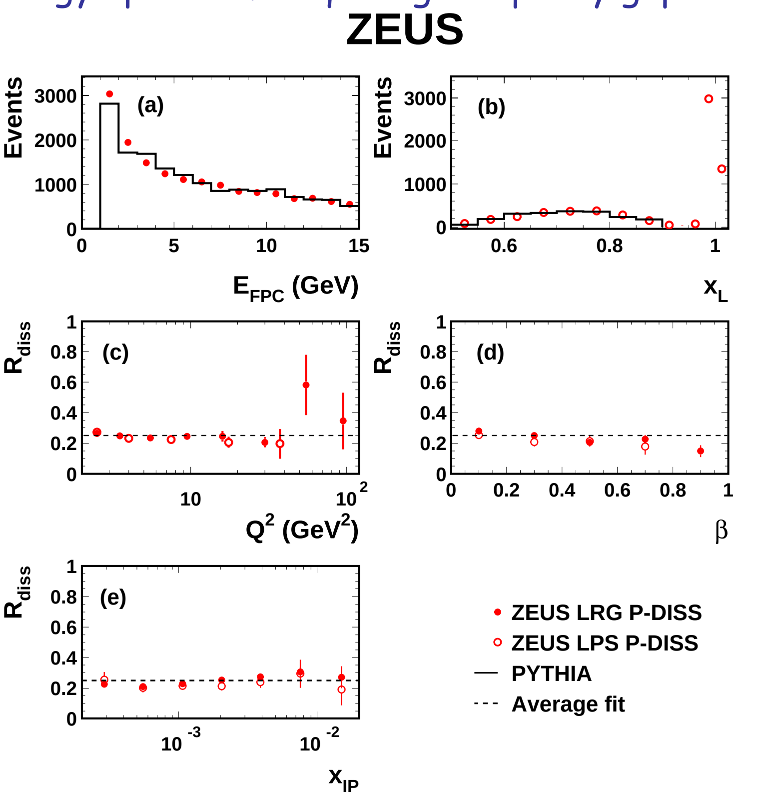
Not shown:
normalization uncertainties
LPS: +11% -7%
FPS: +10% -10%

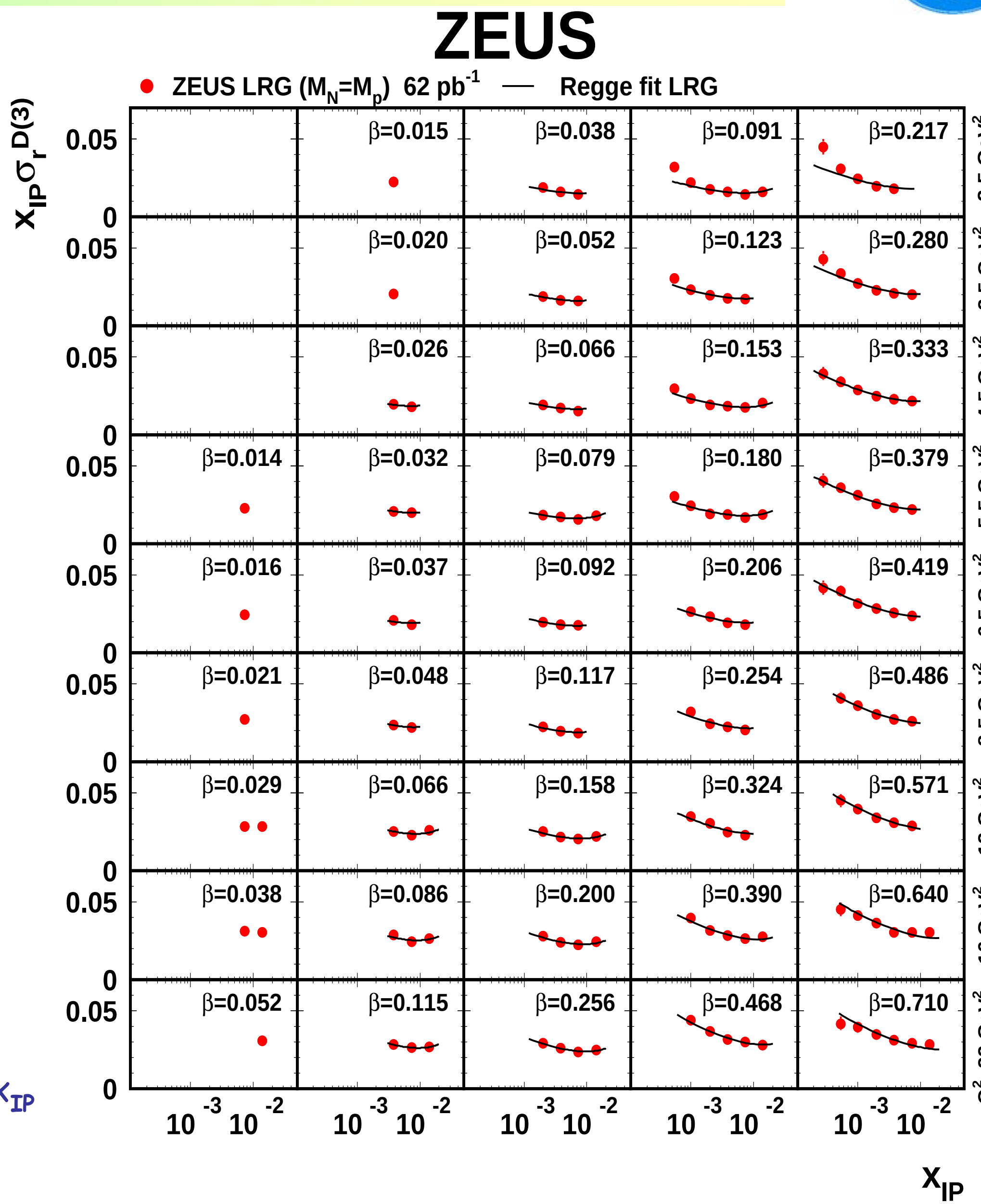
Good agreement between LPS and FPS data in shape and magnitude within the statistical errors and normalization uncertainties

ZEUS Results from the Large Rapidity Gap Method I

ZEUS LRG data corrected for proton dissociation to $M_N=m_p$

PYTHIA-MC tuned with LPS(x_L<0.9) data and Forward Plug Calorimeter (FPC) energy spectrum requiring a rapidity gap.





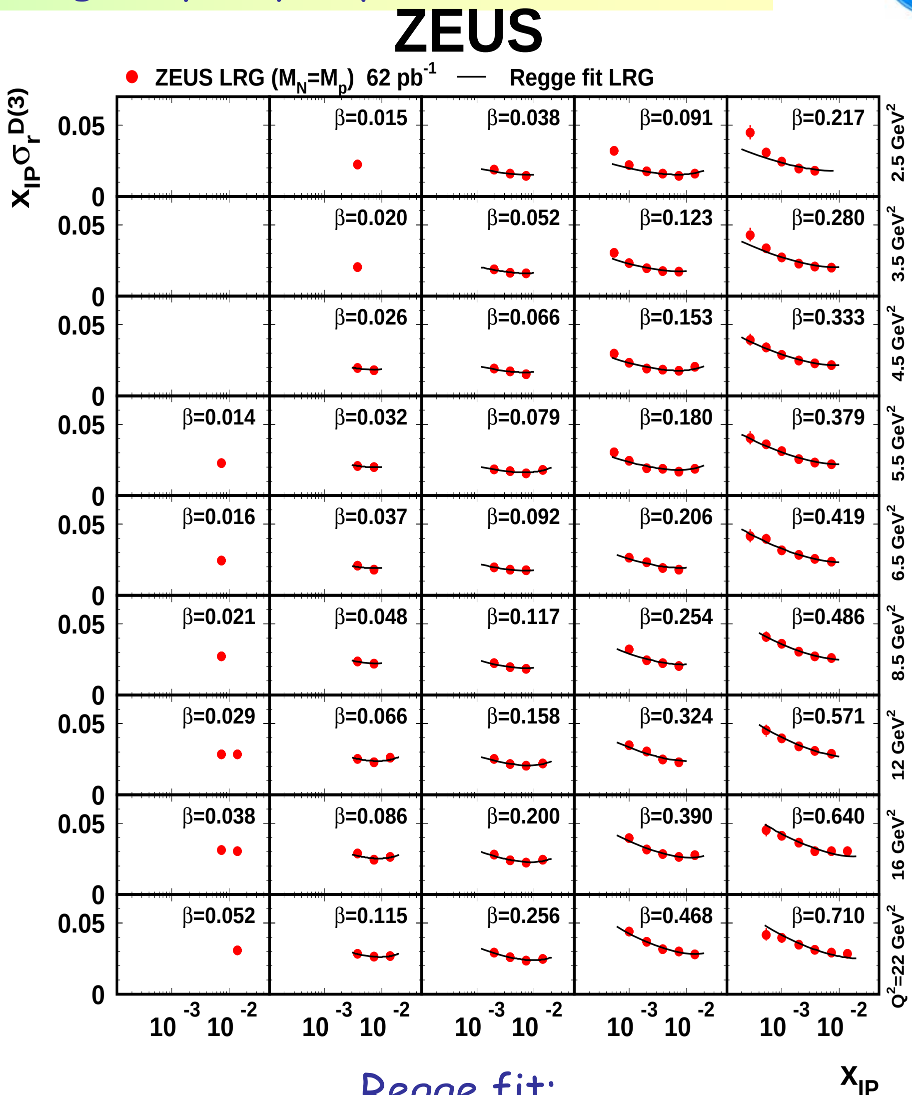
P-diss. contribution is independent Q^2, β, x_{IP}

$R_{p\text{-}diss}$ = 25 +-1(stat)+-3(sys) %

ZEUS Results from the Large Rapidity Gap Method II

ZEUS LRG data:

$$2.5\,\mathrm{GeV}^2 \le Q^2 \le 255\,\mathrm{GeV}^2$$

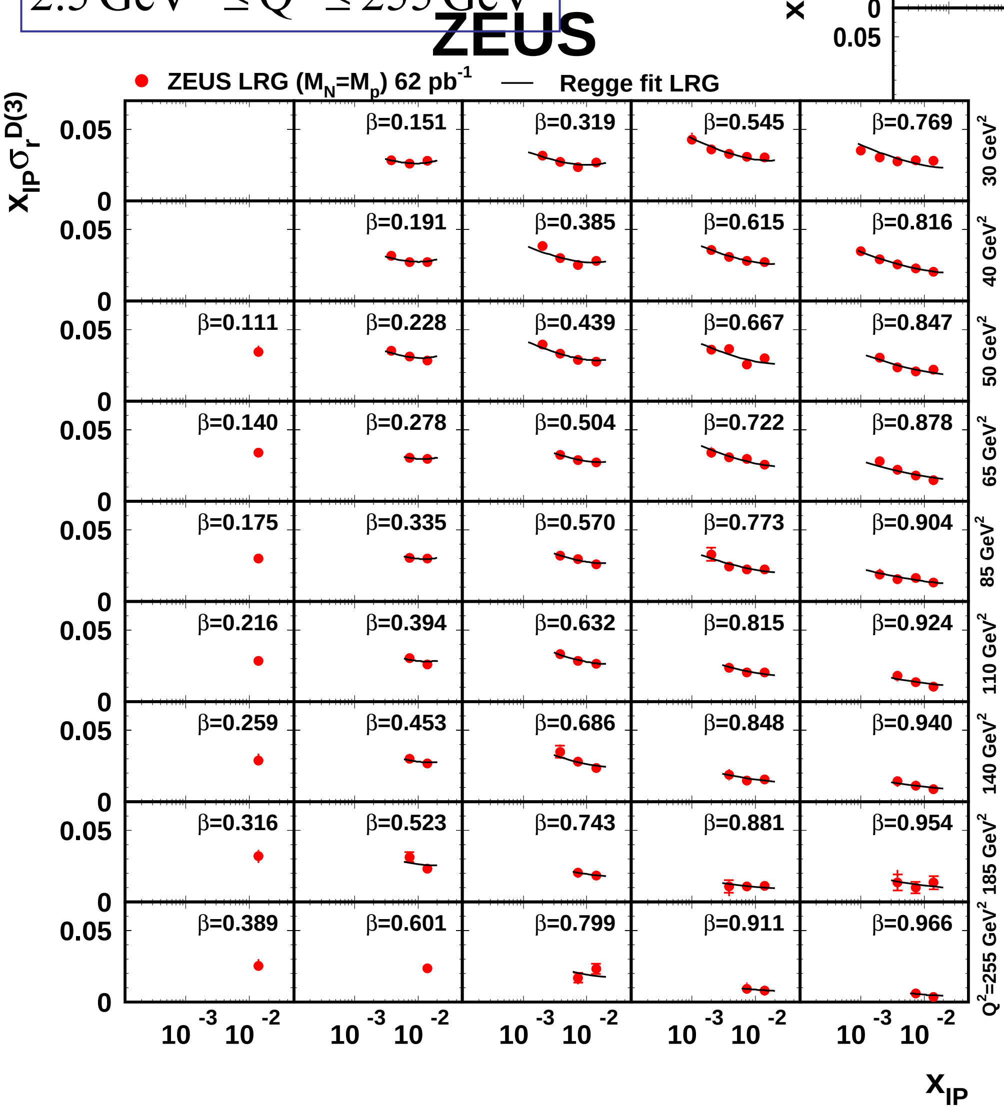


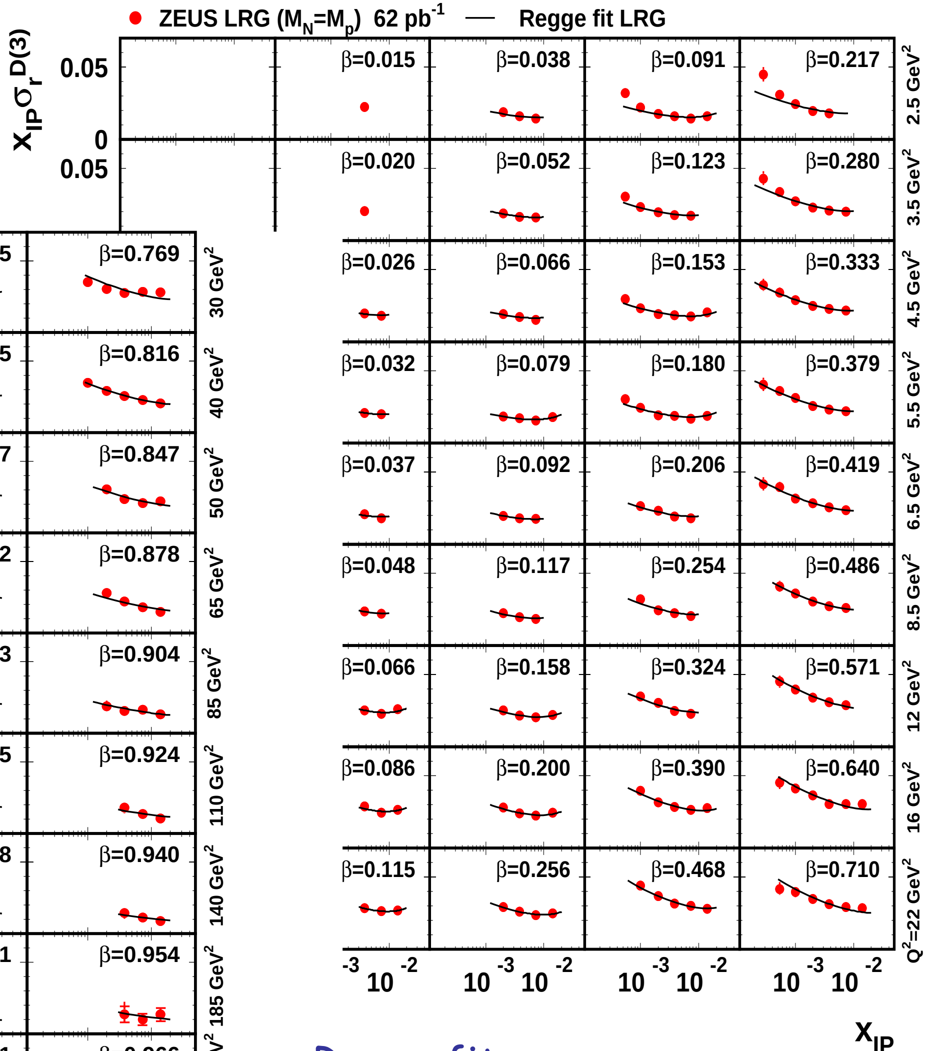
Regge fit:

$$\alpha_{IP}(0) = 1.108 \pm 0.008\,(\mathrm{stat+sys})$$
$$+0.008\,/\,-0.007\,(\mathrm{model})$$

ZEUS LRG data:

$$2.5\,\mathrm{GeV}^2 \leq Q^2 \leq 255\,\mathrm{GeV}^2$$



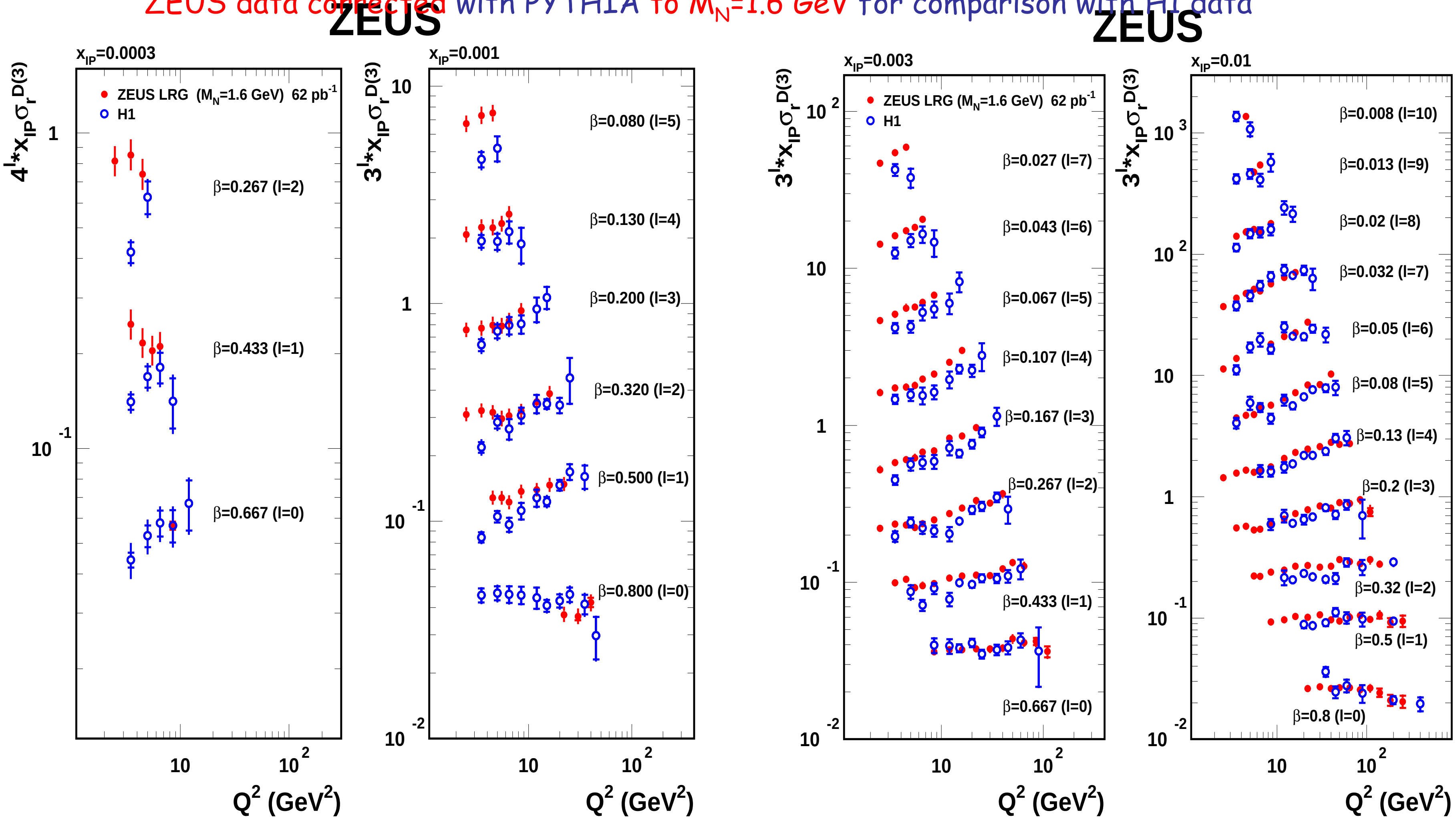


Regge fit:

$$\alpha_{IP}(0) = 1.108 \pm 0.008\,(\mathrm{stat+sys}) + 0.008 / -0.007\,(\mathrm{model})$$

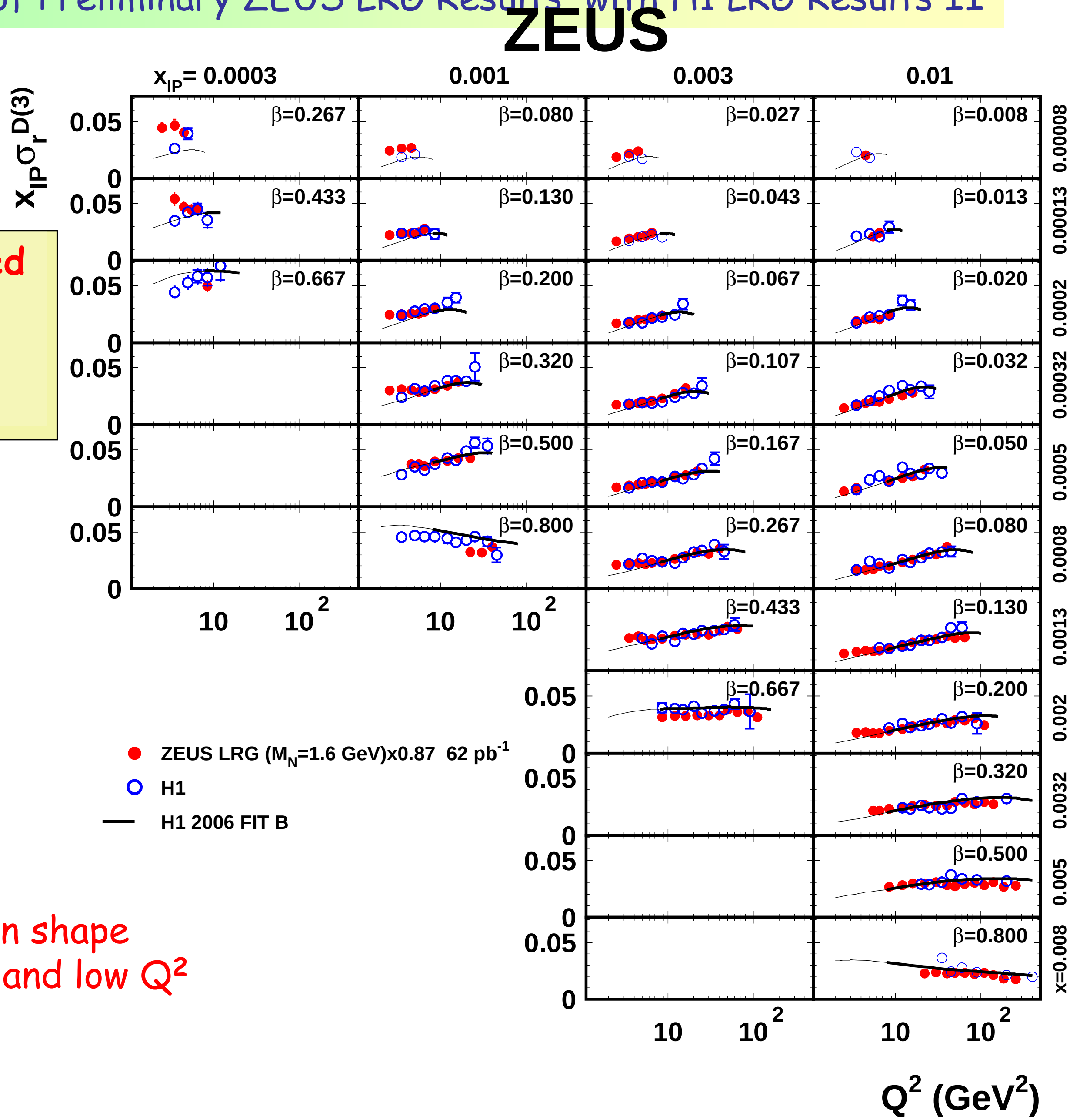
Comparison of Preliminary ZEUS LRG Results with H1 LRG Results I

ZEUS data corrected with PYTHIA to M_N=1.6 GeV for comparison with H1 data



- Fair agreement in shape except at low Q2, some slight differences in b-dependence
- Overall normalisation difference of 13%, covered by uncertainty of p-diss. correction (8%) and relative normalisation uncertainty (7%)

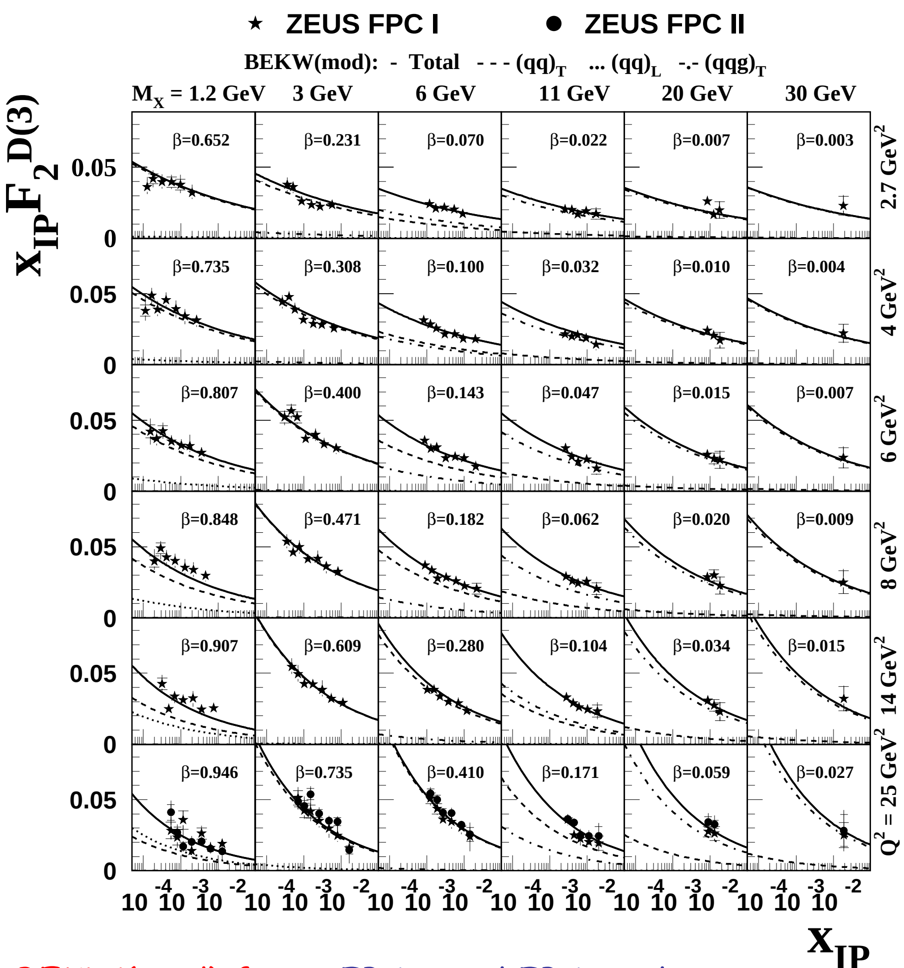
ZEUS data normalised to H1 data in this plot

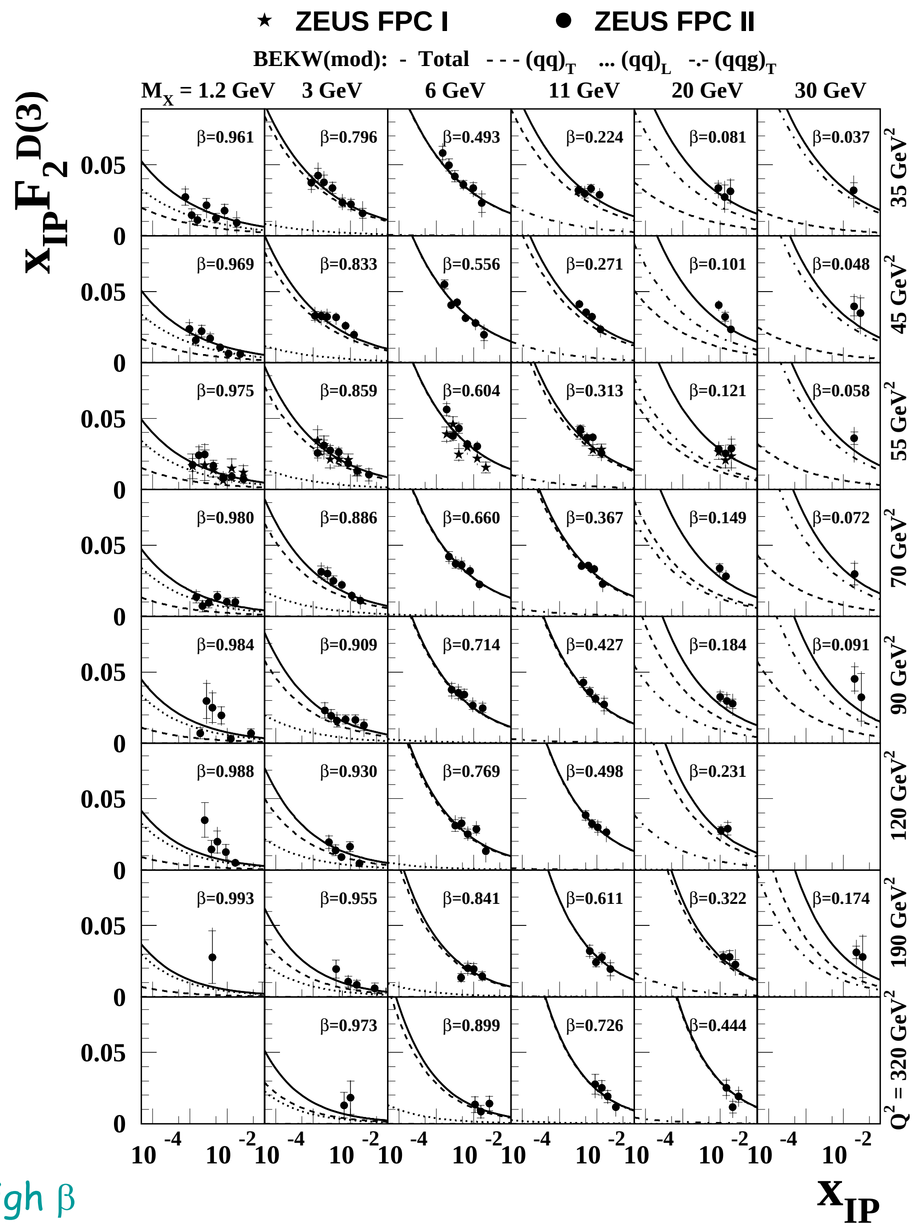


Solid line is the H1 2000 Fit B (see later)

Good agreement in shape except at low x_{IP} and low Q^2

Results from ZEUS with the M_x-Method and the BEKW(mod) Fit





BEKW(mod) fit to FPC I and FPC II data:

> 400 points, 5 parameters, $\chi^2/n = 0.71$

At all Q^2: $(qq)_T$ dominates at medium β

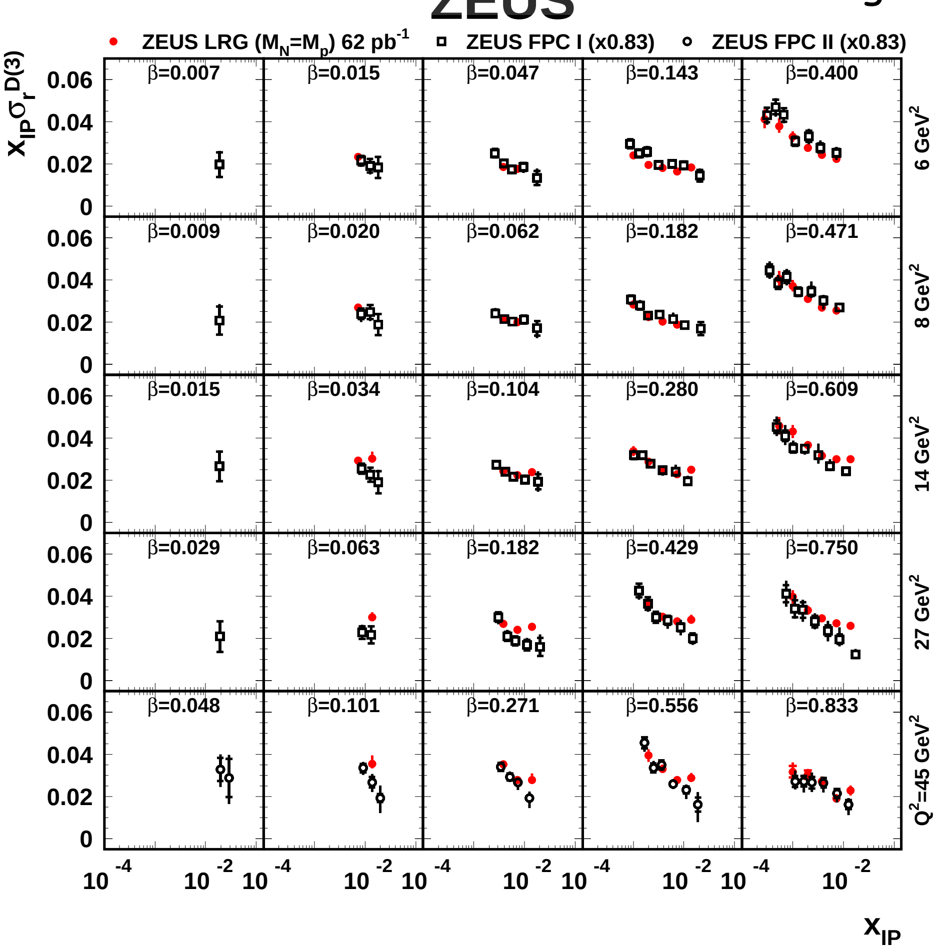
$(qqg)_T$ dominates at low β

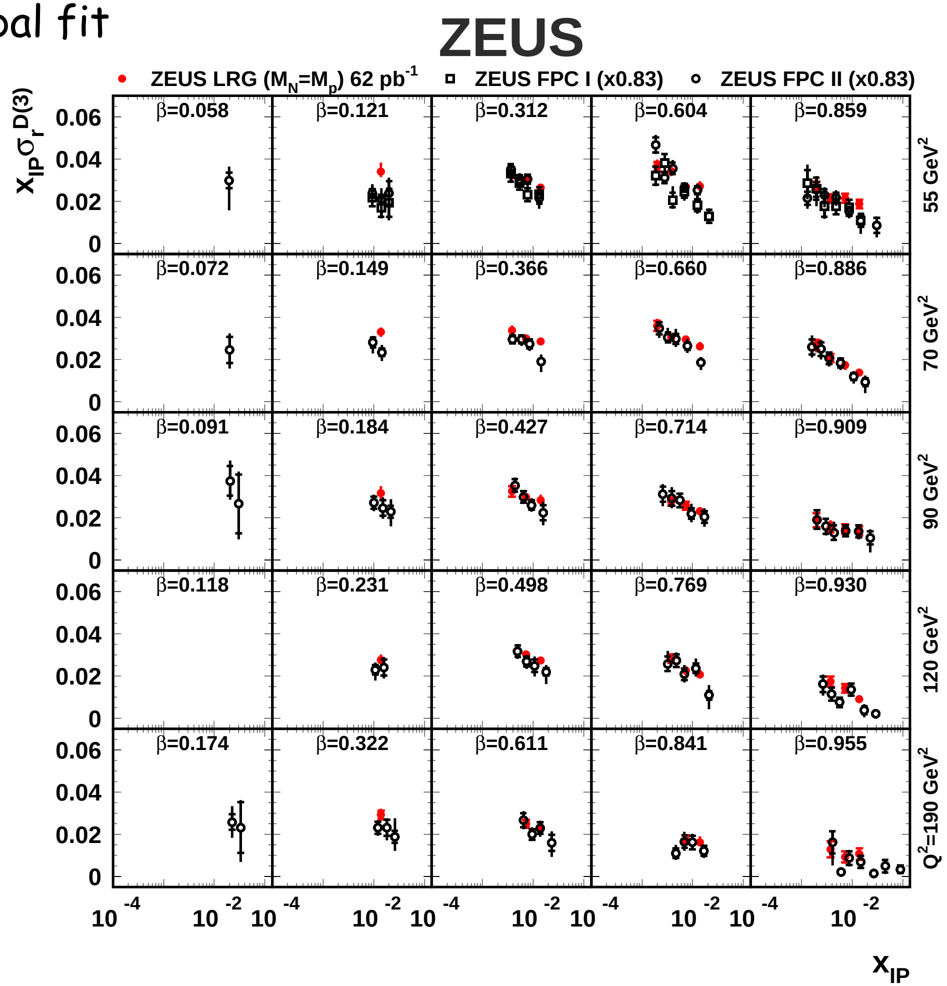
$(qq)_L$ contributes significantly at very high β

Comparison ZEUS M_x Results with ZEUS LRG Results

For comparison, M_x data (M_N<2.3 GeV) normalised to LRG (M_N=m_p):

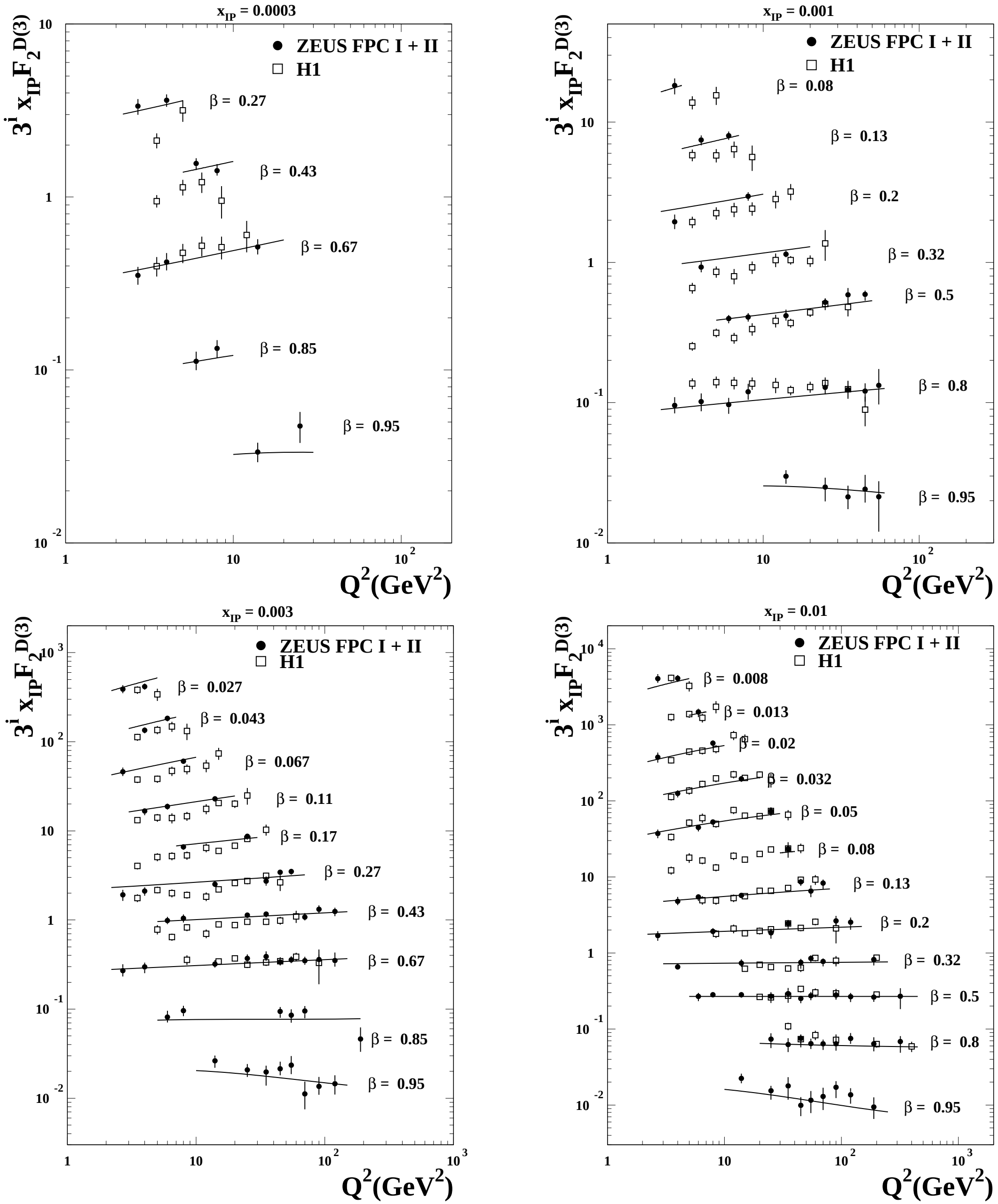
factor 0.83 ± 0.04 determined via a global fit





Overall satisfactory agreement for x_{IP}<0.01 after multiplying M_x data by factor 0.83,
for higher x_{IP} Reggeon contributions are possible in the LRG data.

Comparison ZEUS M_x Results with H1 LRG Results



ZEUS BEKW(mod) fit

ZEUS M_X data for M_N> 2.3 GeV

H1 LRG data for M_N> 1.6 GeV

Qualitative agreement except overall normalisation.

Different Q^2-dependence seen in some β-bins.

There are indications for a slightly different β-dependence.

From the ZEUS FPC I+II data:

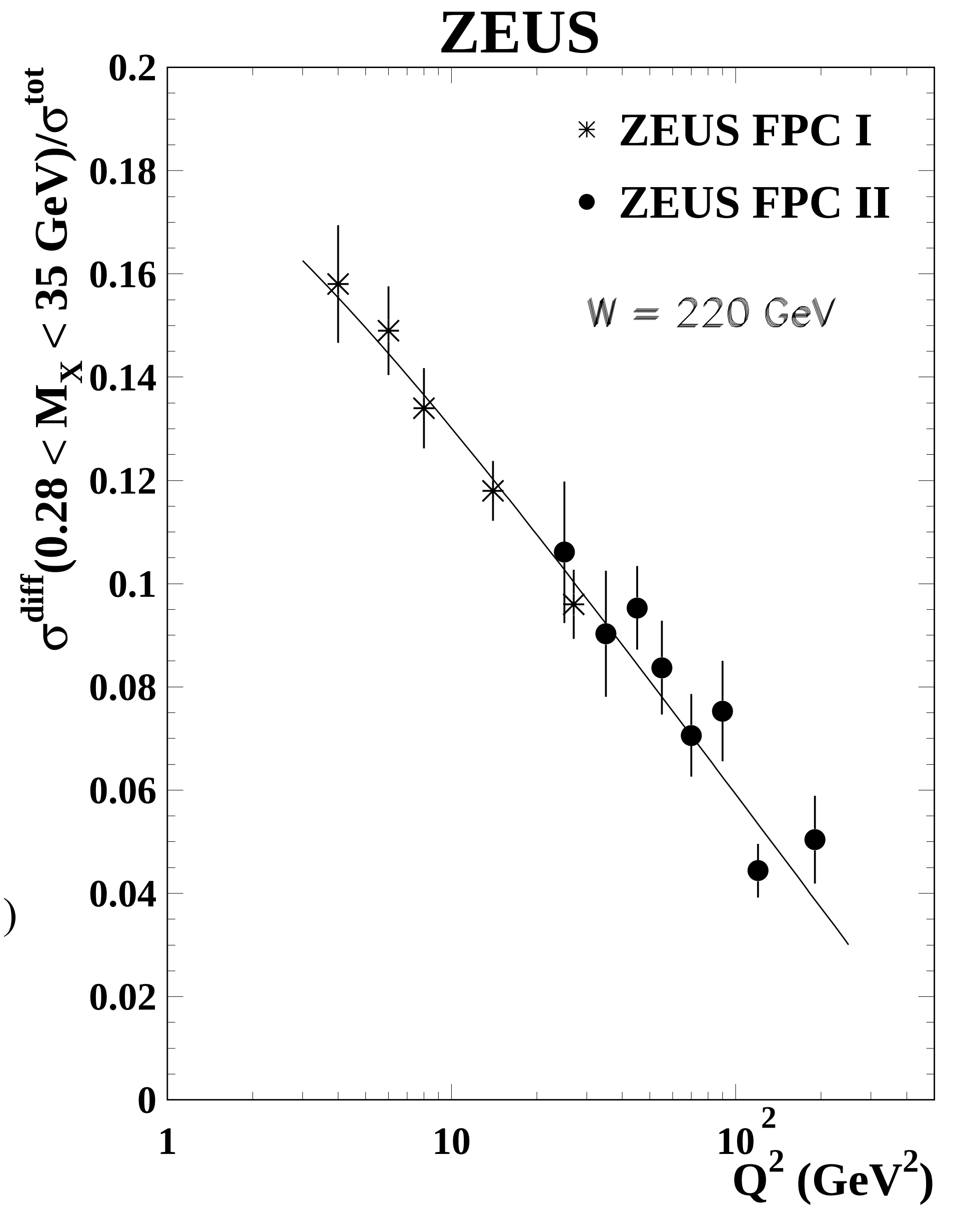
$$R^{diff} \equiv \frac{\sigma^{diff}(0.28 < M_X < 35\text{GeV})}{\sigma^{tot}}$$

Diffraction is a sizable fraction of the total DIS cross-section

The ratio of diffraction to total DIS falls only logarithmically with Q^2

Fit gives:

$$R^{diff}_{fit} = (0.207 \pm 0.008) - (0.032 \pm 0.002) \cdot \ln(1 + Q^2)$$



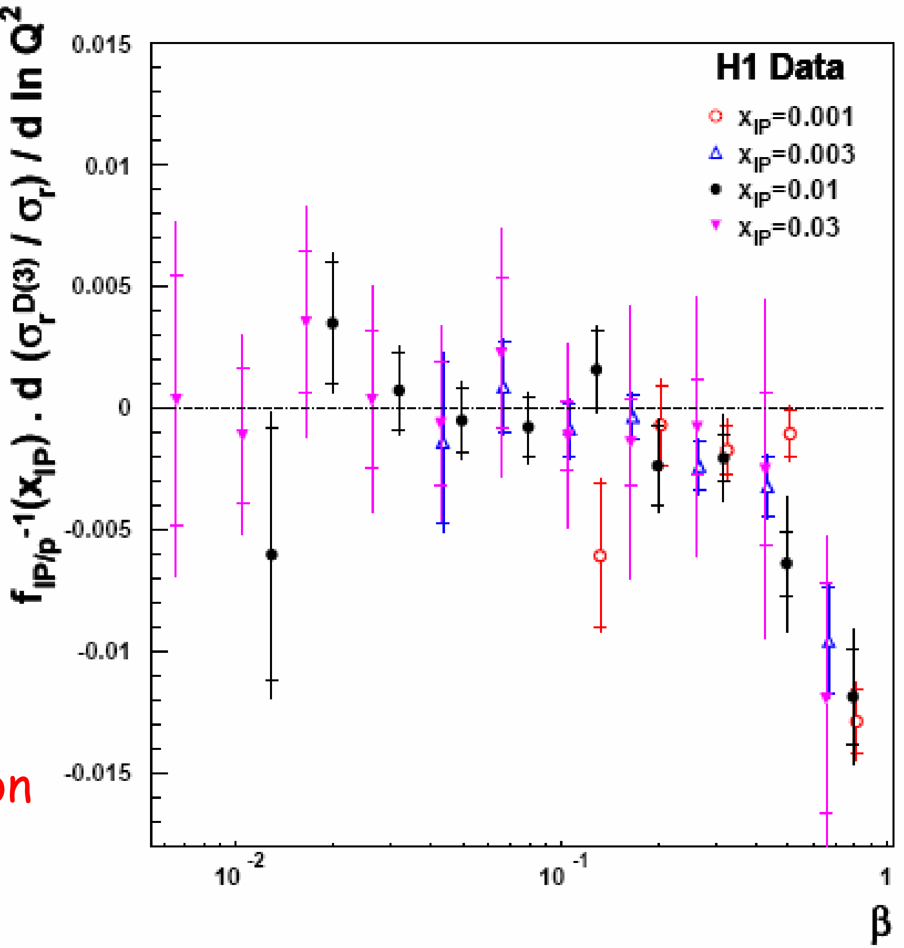
Ratio of Diffractive Reduced DIS to Reduced DIS Cross-Section (H1)

From H1 LRG data:

Logarithmic Q^2-derivative of ratio $\sigma_r^{D(3)}/\sigma_r$ at fixed x_{IP}

Divide by flux factor $f_{IP/p}(x_{IP})$ to compare values at different x_{IP}

⇨



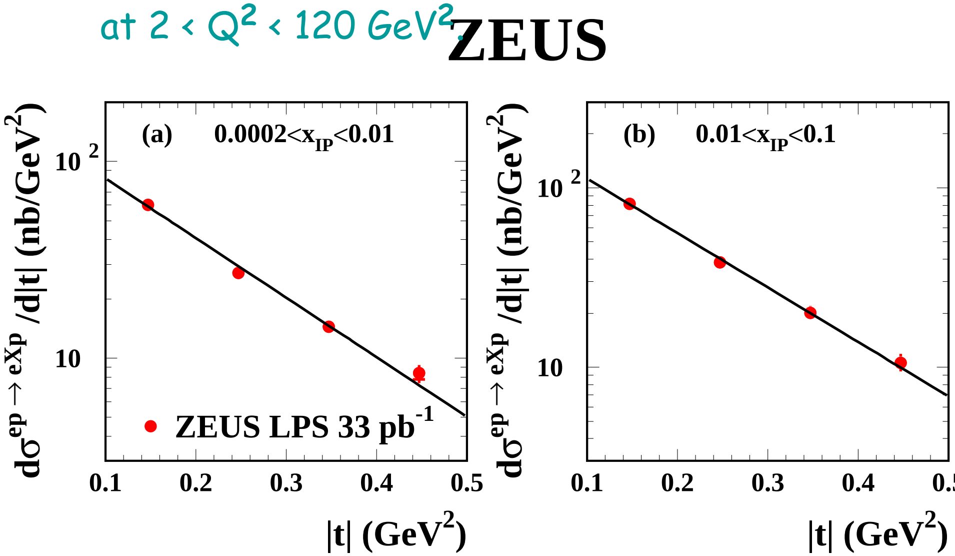
Results at different x_{IP} as a function of β fall approximately on the same curve.

Logarithmic derivatives are compatible with zero up to β values of about 0.01 and become negative for larger β values.

The t dependence of the Diffractive Cross-Section I

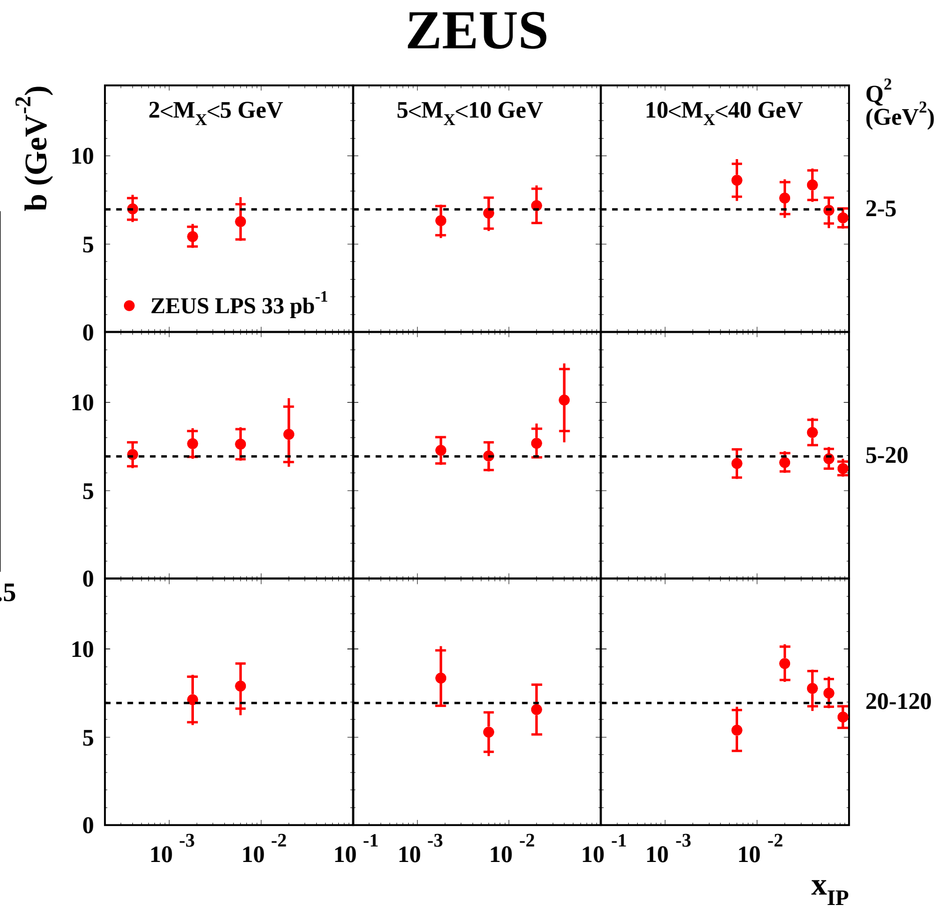
From ZEUS LPS data:

Measurements in two different t intervals at $2 < Q^2 < 120$ GeV^2



Fit to $e^{-b|t|}$ → $b = 7.0 \pm 0.4$ GeV^{-2}

This is lower than for soft vector-meson production ($b \sim 10$-12 GeV^{-2}) but considerably higher than for hard vector-meson production ($b \sim 4$ GeV^{-2}) .

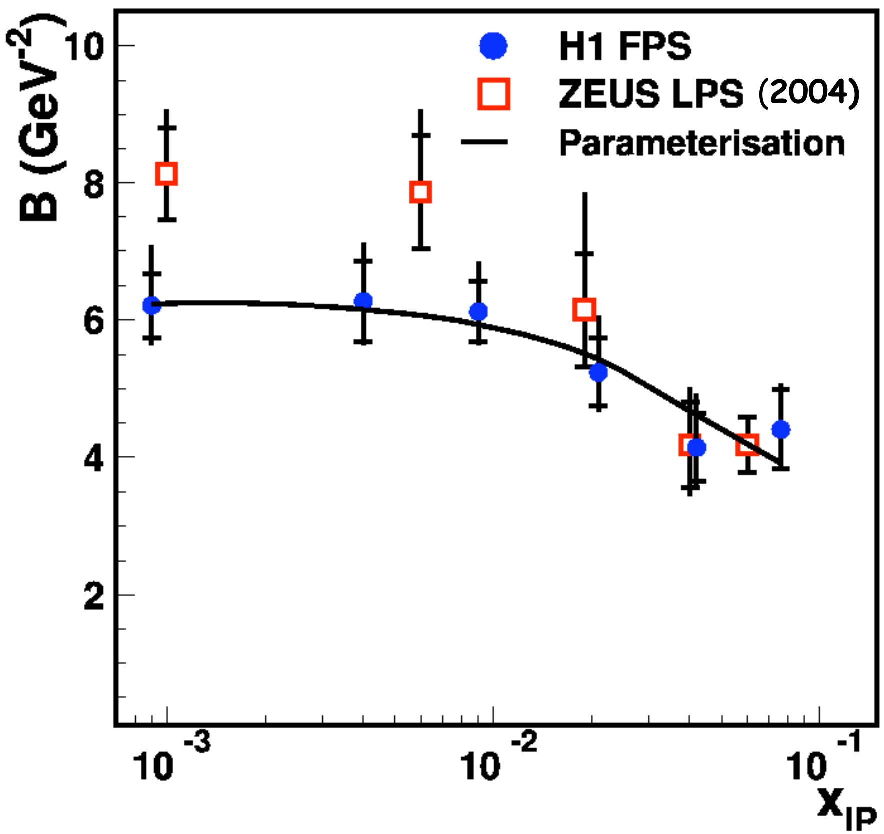


The t slope does not depend on Q^2, x_{IP} or β.

Inclusive diffraction is more a soft process.

From H1 FPS data:

Measurements in 3 different t-intervals
at 2 < Q.

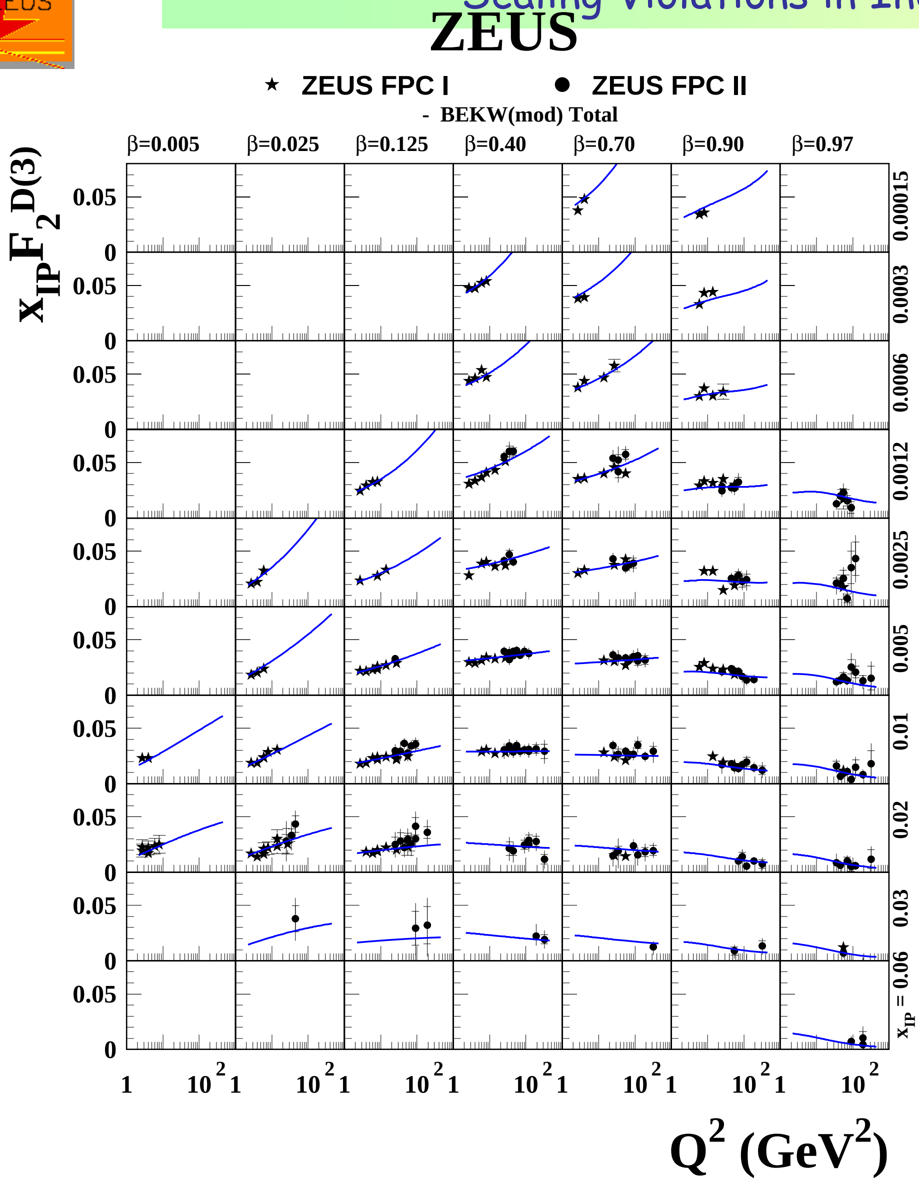


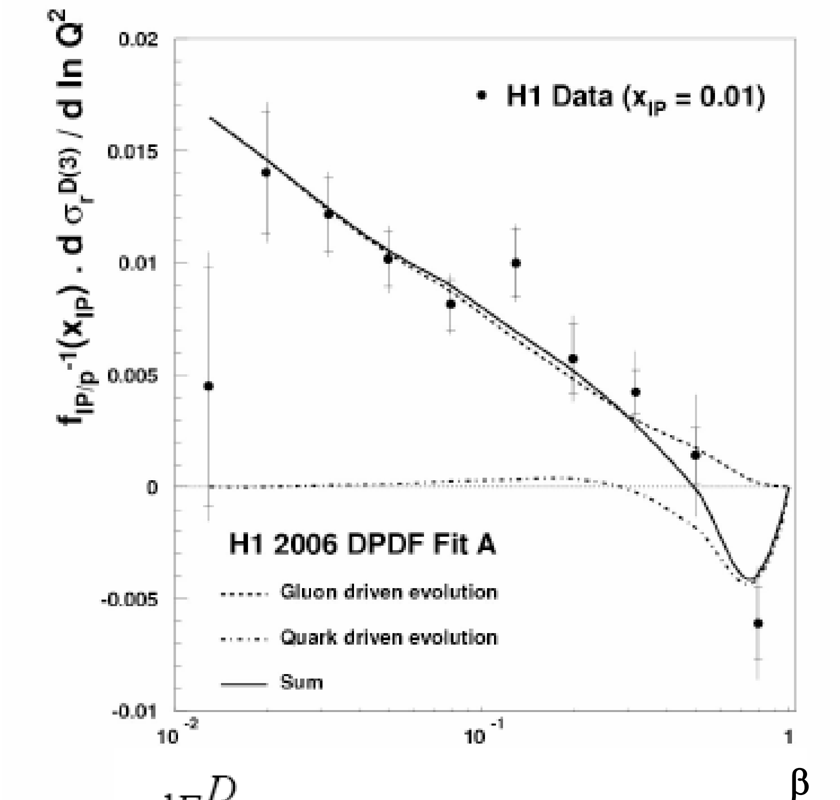
In the Regge framework the effective slope is

$$B = B_{IP} - 2\alpha'_{IP} \cdot \ln x_{IP}$$

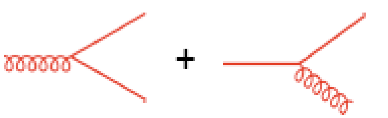
Range of Fit	$\alpha'_{I\!P}$ (GeV^{-2})	$B_{I\!P}$ (GeV^{-2})
$0.0009 \le x_{I\!P} \le 0.0094$	$0.02 \pm 0.014^{+0.21}_{-0.09}$	$6.0 \pm 1.6^{+2.4}_{-1.0}$
$0.0009 \le x_{I\!P} \le 0.021$	$0.10 \pm 0.010^{+0.16}_{-0.07}$	$4.9 \pm 1.2^{+1.6}_{-0.7}$

The value of B_{IP} from H1 is in agreement with the ZEUS values within the errors for $x_{IP}<10^{-2}$.
For higher x_{IP}, Reggeon contributions can become important.





$$\frac{dF_2^D}{d\ln Q^2} \sim \frac{\alpha_s}{2\pi}\left[P_{qg}\otimes g \;+\; P_{qq}\otimes\Sigma\right]$$



dominates at low β

dominates high β

Sizable scaling violations in inclusive diffraction

$x_{IP}F_2^{D(3)}$ as a function of β for

$$25\,\mathrm{GeV}^2 \le Q^2 \le 320\,\mathrm{GeV}^2$$

Medium β:

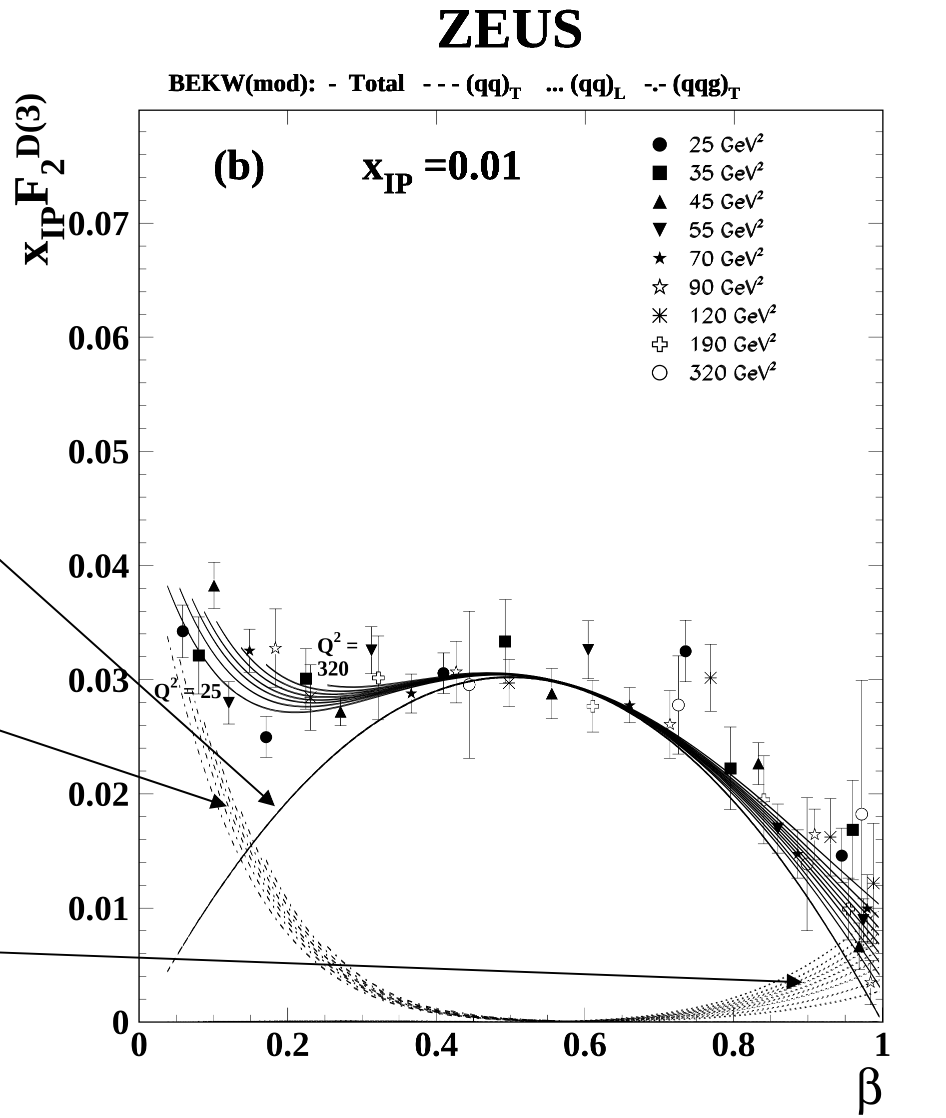
dominated by $(qq)_T$ contribution ~ $\beta(1-\beta)$

Small β:

$(qqg)_T$ contribution rises and dominates

Very high β:

$(qq)_L$ contribution becomes significant



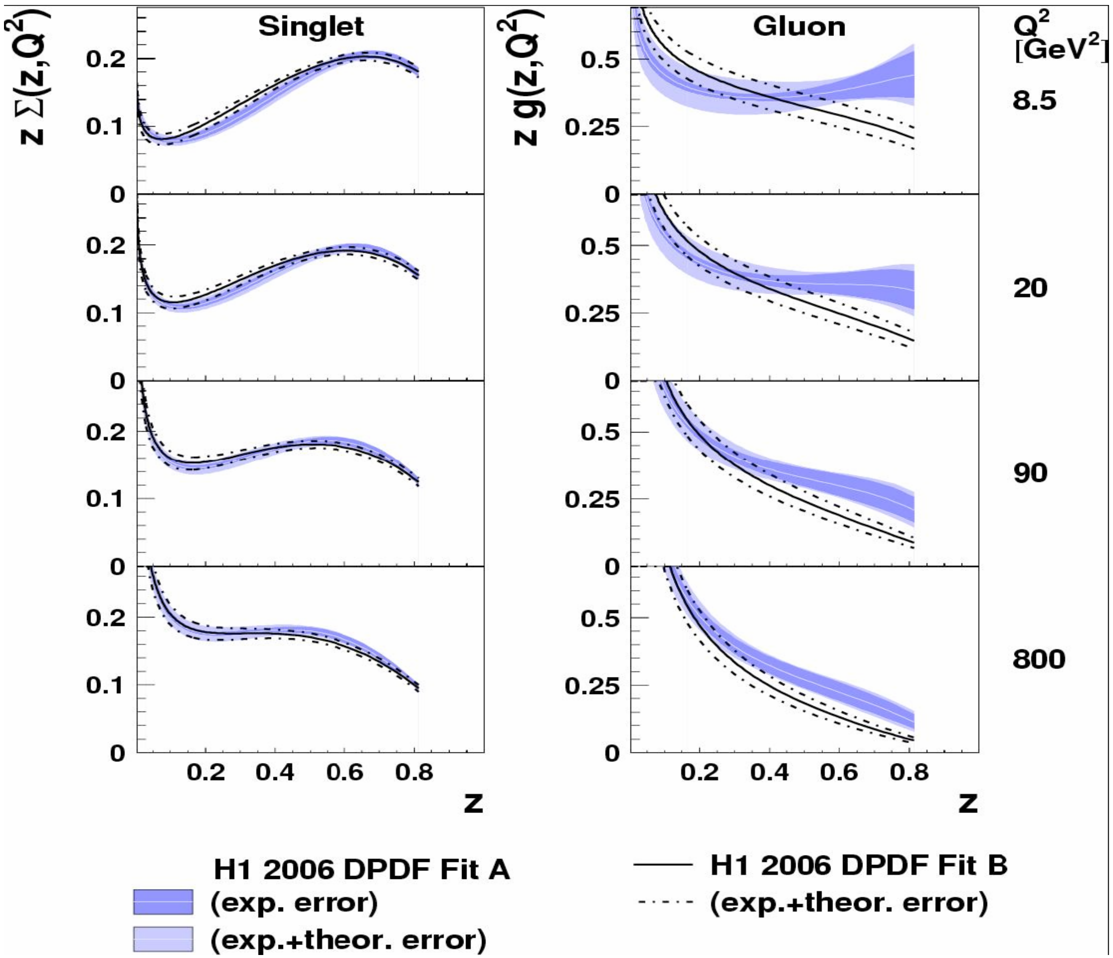
Diffractive Parton Distribution Functions (DPDF)

Assuming Regge factorisation:

$$f_i^D(x,Q^2,x_{I\!P},t) = f_{I\!P/p}(x_{I\!P},t)\cdot f_i^{I\!P}(\beta=\frac{x}{x_{I\!P}},Q^2)$$

$$f_{I\!P/p}(x_{I\!P},t) = A_{I\!P}\cdot\frac{e^{B_{I\!P}t}}{x_{I\!P}^{2\alpha_{I\!P}(t)-1}}$$

Parametrize: quark singlet density $z\Sigma(z,Q_0^2) = A_q z^{B_q}(1-z)^{C_q}$ and gluon density $zg(z,Q_0^2) = A_g(1-z)^{C_g}$



Fit data with:

$$Q^2 \geq 8.5\,\mathrm{GeV}^2,\ M_X > 2\,\mathrm{GeV},\ \beta \leq 0.8$$

Fit A:

$Q_0^2 = 1.75\ \mathrm{GeV}^2$

$\chi^2 \sim 158 / 183$ d.o.f.

Fit B:

$\chi^2 \sim 164 / 184$ d.o.f.

$Q_0^2 = 2.5\ \mathrm{GeV}^2$

Summary and Conclusions

- Three different experimental methods to measure inclusive diffraction:
  - proton tagging
  - large rapidity gap
  - M_X-method.
- Results from these 3 methods contain different contributions from Reggeon exchanges and from proton dissociation.
- Contributions from Reggeon exchanges are small for $x_{IP}<10^{-2}$.
- There is no unique way to correct the measurements for proton dissociation.
- Apart from differences in the overall normalisation due to proton dissociation contributions, there is fair agreement between the different measurements for Q^2 values above 10 GeV^2.
- More results expected from HERA II running period
- It may be possible in the future to perform a common fit for diffractive PDFs with suitable normalisations of the different data sets.