Inclusive Diffraction at HERA

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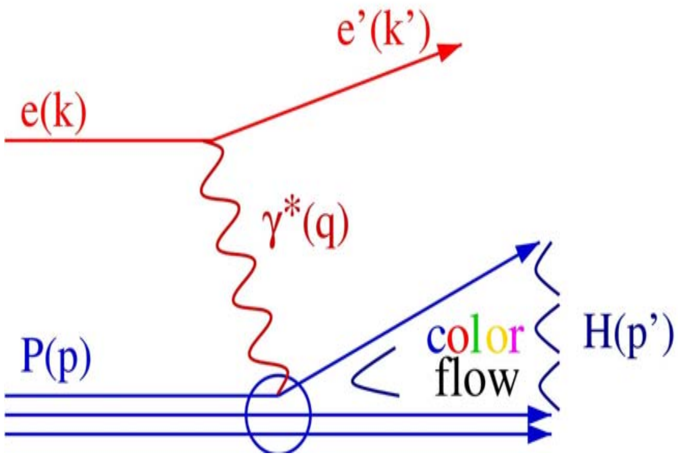
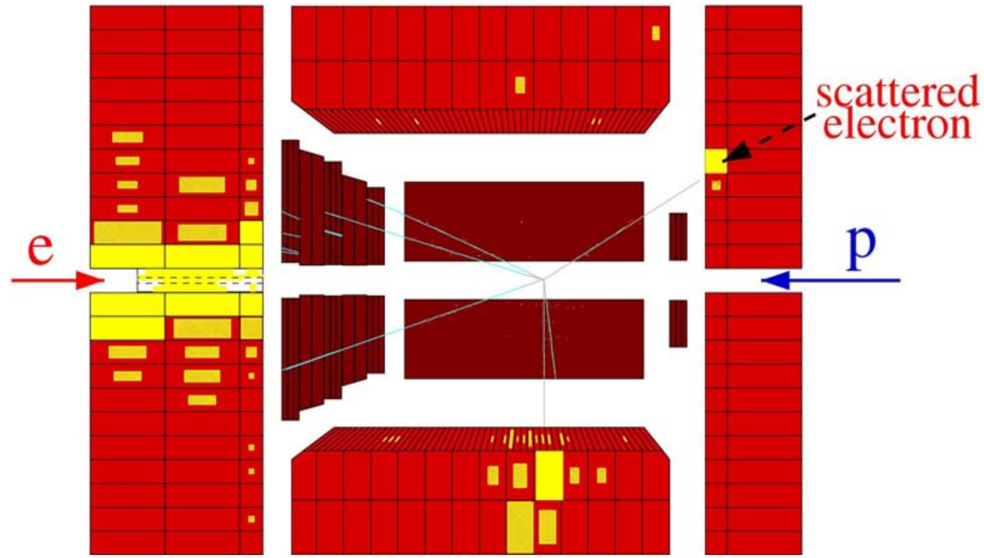
DESY

On behalf of H1 and ZEUS

Low-x Workshop 2011, Santiago de Compostela

Inclusive nondiffr. DIS events :





Measure energy and angle of scattered electron

$$s = (k+p)^2$$

center of mass energy squared

$$Q^2 = -q^2 = -(k-k')^2$$

virtuality, size of the probe

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

photon-proton center of mass energy squared

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

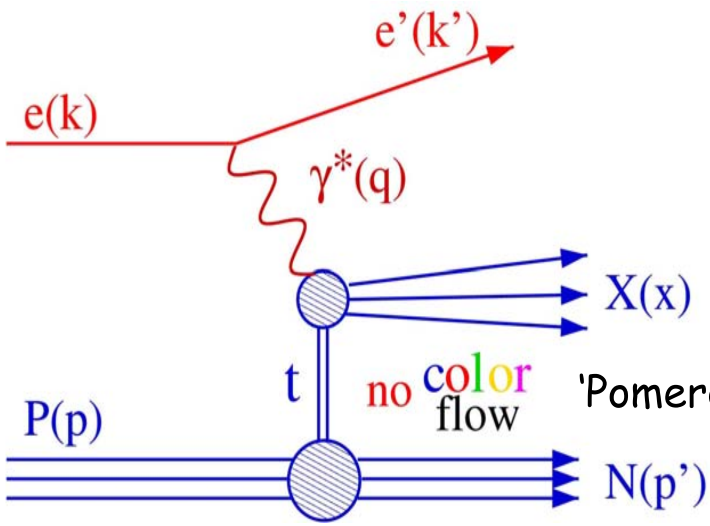
$$y = \frac{p \cdot q}{p \cdot k}$$

x: fraction of the proton momentum carried by the struck parton

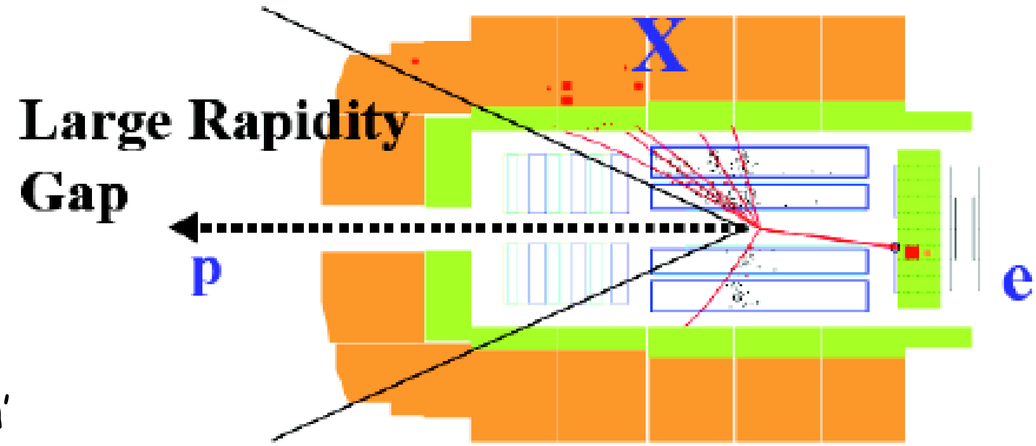
y: inelasticity, fraction of the electron momentum carried by the virtual photon

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

Diffractive DIS events :



← Proton or dissociative system



How to identify diffractive events? See later!

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

Depending on experimental method t is not measurable and integrated over.

$$x_{IP} = \frac{(p-p')\cdot q}{p\cdot q} = \frac{M_X^2+Q^2}{W^2+Q^2}$$

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

Proton Structure Functions

$$\frac{d^2\sigma_{\gamma^* p}}{dx dQ^2} = \frac{2\pi\alpha_{em}}{x \cdot Q^4}\left[1-(1-y)^2\right] \cdot \sigma_r(x,Q^2)$$

$$\sigma_r(x,Q^2) = F_2(x,Q^2) - \frac{y^2}{1+(1-y)^2} F_L(x,Q^2)$$

sizeable only at high y

xF_3 can safely be neglected at not too high Q^2 for HERA data

For HERA data typically:

$$y = \frac{Q^2}{x \cdot s} \approx 0.1$$

Diffractive Proton Structure Functions

Analogous to inclusive DIS:

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

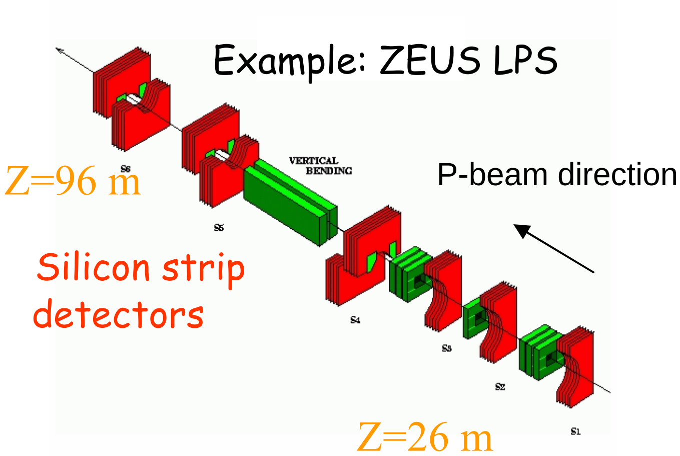
$$\sigma_r^{D(4)}(Q^2,t,x_{IP},\beta) = F_2^{D(4)}(Q^2,t,x_{IP},\beta) - \frac{y^2}{1+(1-y)^2} F_L^{D(4)}(Q^2,t,x_{IP},\beta)$$

If t is not measured and integrated over:

$$\sigma_r^{D(3)}(Q^2,x_{IP},\beta) = F_2^{D(3)}(Q^2,x_{IP},\beta) - \frac{y^2}{1+(1-y)^2} F_L^{D(3)}(Q^2,x_{IP},\beta)$$

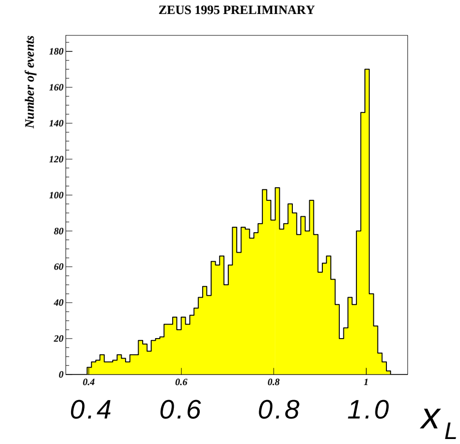
Experimental Methods to select Diffractive Events

1.) Detection of outgoing proton: FPS, LPS



$$x_L = \frac{p'}{p} \approx 1 - \mathbf{x}_{IP}$$

$$t = -\frac{p_T^2}{x_L} - \frac{(1-x_L)^2}{x_L} M_p^2$$



$x_L \approx 1$ -> diffractively scattered proton

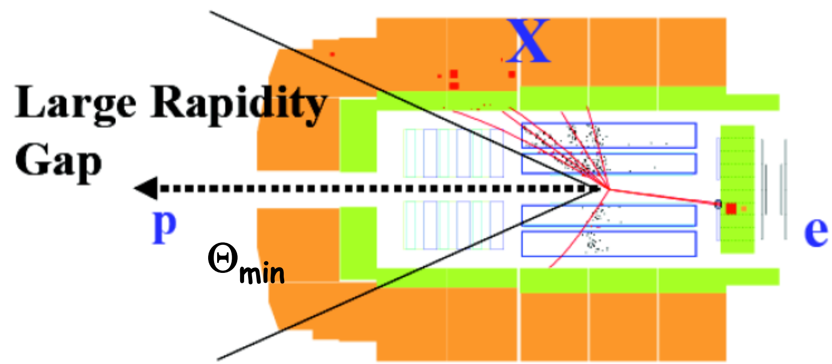
Practically free from proton dissociation, suffers from low statistics, contains Reggeon exchanges.

2.) Detection of a large rapidity gap

High statistics,

but contains contributions from proton dissociation and Reggeon exchanges,

no measurement of t possible, integrated over t.



$$\eta_{max} = -\ln \tan(\Theta_{min}/2)$$

New H1 Results from Proton tagged Data

Regge fit: Assumption: Regge/vertex factorization

$$F_2^{D(4)} = f_{I\!P}(x_{I\!P},t)F_{I\!P}(\beta,Q^2) + n_{I\!R}\cdot f_{I\!R}(x_{I\!P},t)F_{I\!R}(\beta,Q^2)$$

Pomeron contribution Reggeon contribution

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

$$\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha'_{IP}t$$

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

$$\alpha_{I\!R}(t) = \alpha_{I\!R}(0) + \alpha'_{I\!R}t$$

$F_{I\!R}(\beta,Q^2)$ from the parametrization of the pion trajectory

input from other measurements

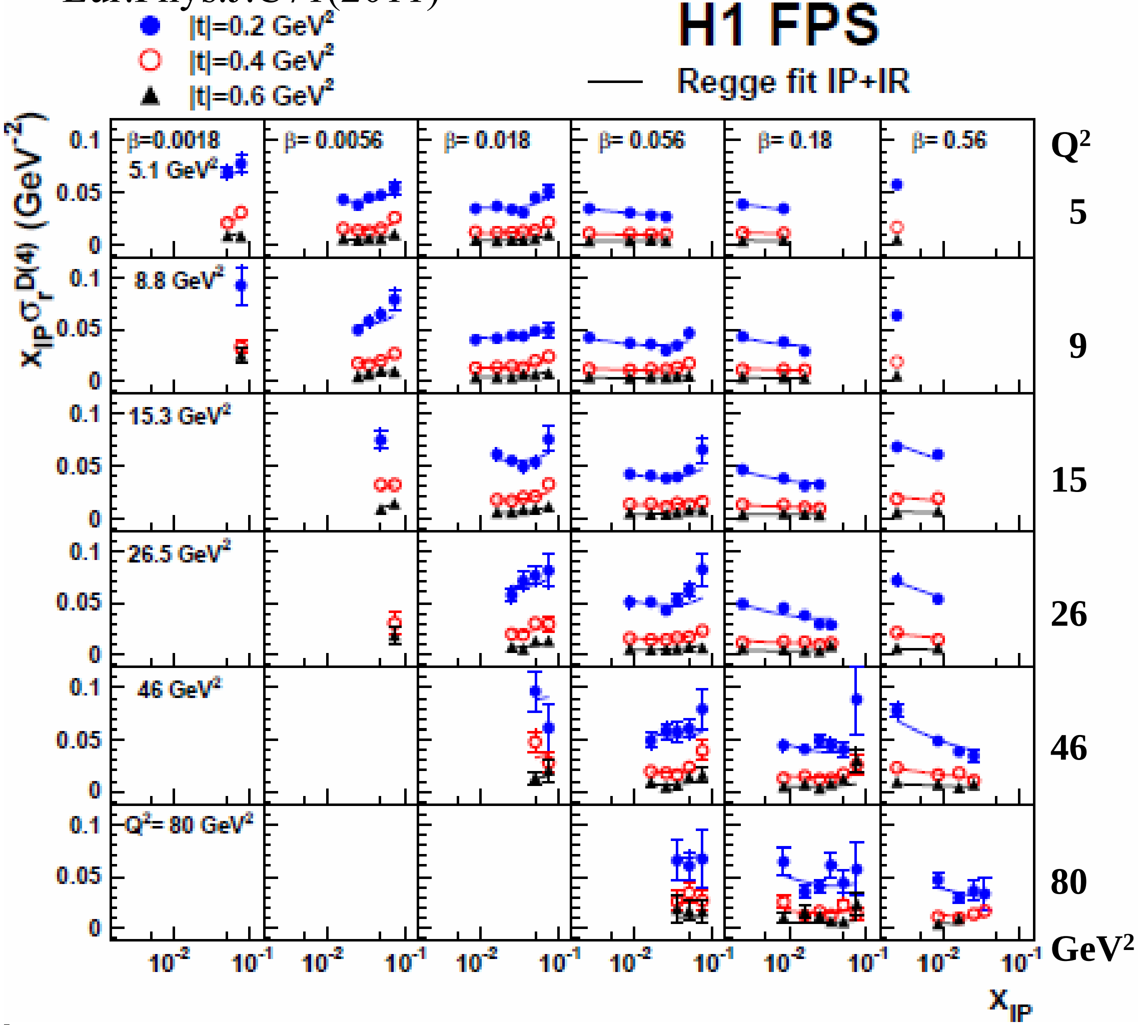
Input:

$$\alpha_{IR}(0) = 0.50$$

$$\alpha'_{IR} = 0.3\,GeV^{-2}$$

$$B_{IR} = 1.6\,GeV^{-2}$$

Eur.Phys.J.C71(2011)

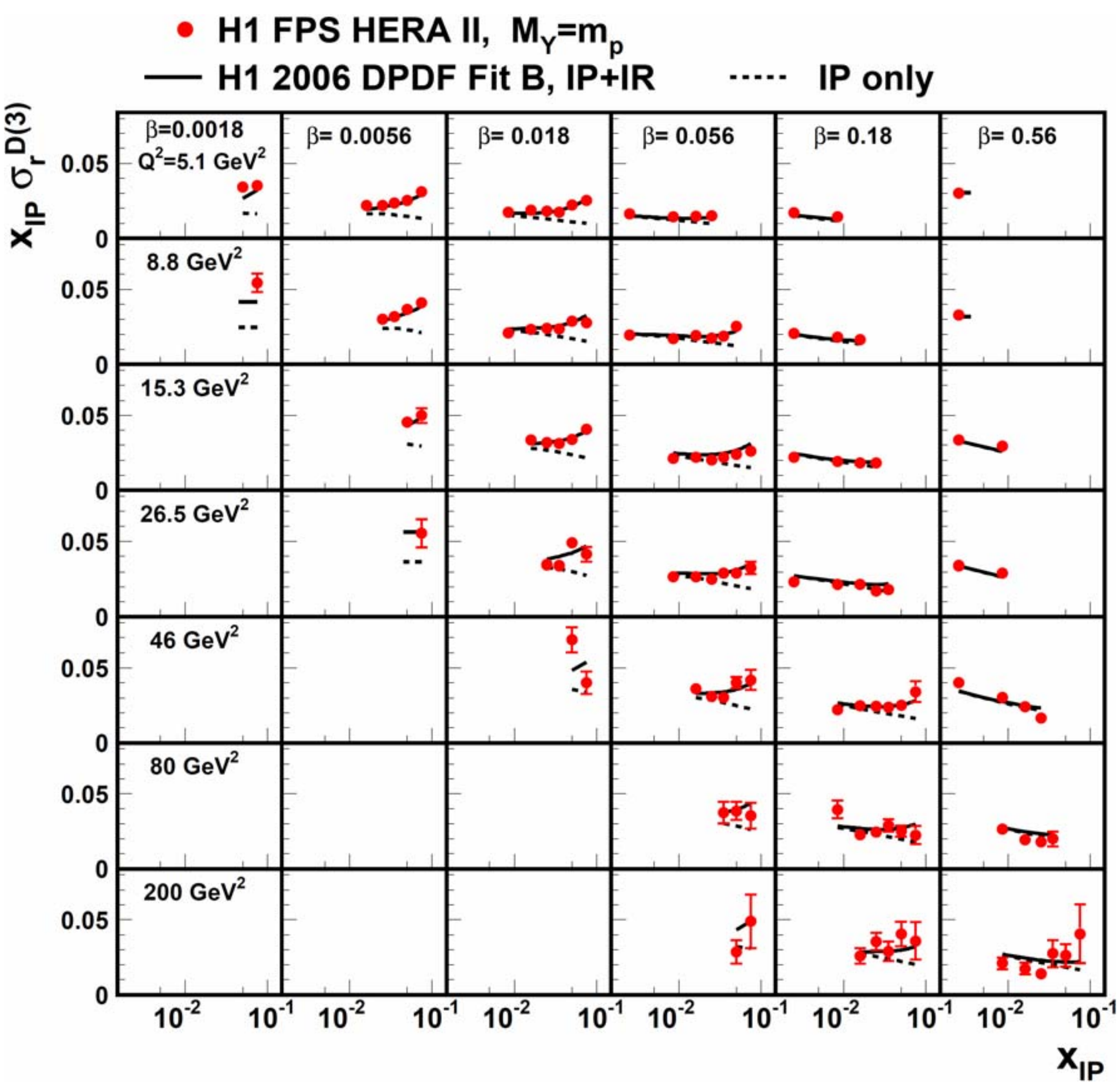


Fit Results

Parameter	Value
$\alpha_{I\!P}(0)$	1.10 ± 0.02 (exp.) $\pm\ 0.03$ (model)
$\alpha'_{I\!P}$	0.04 ± 0.02 (exp.) $^{+\,0.08}_{-\,0.06}$ (model) GeV^{-2}
$B_{I\!P}$	5.73 ± 0.25 (exp.) $^{+\,0.80}_{-\,0.90}$ (model) GeV^{-2}
$n_{I\!R}$	$[0.87 \pm 0.10$ (exp.) $^{+\,0.60}_{-\,0.40}$ (model)$] \cdot 10^{-3}$

New H1 Results from Proton tagged Data

H1 FPS data for $\sigma_r^{D(3)}$ from HERA II ; comparison with fit from LRG data



DPDF fit from earlier dataset, published 2006. Explanation see later.

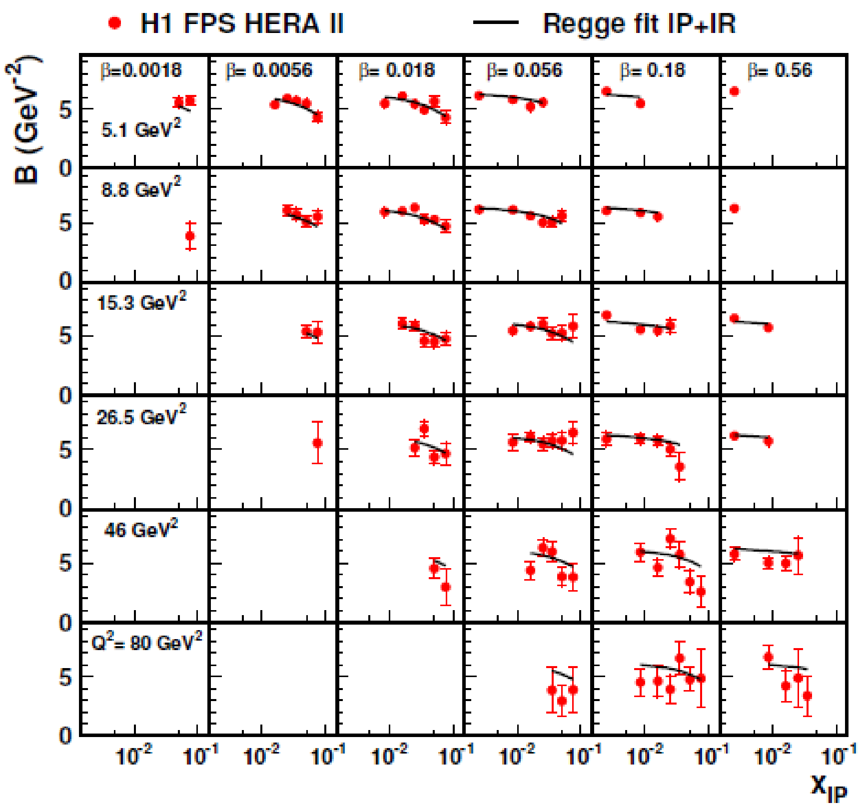
Dashed line shows the diffractive (Pomeron) contribution.

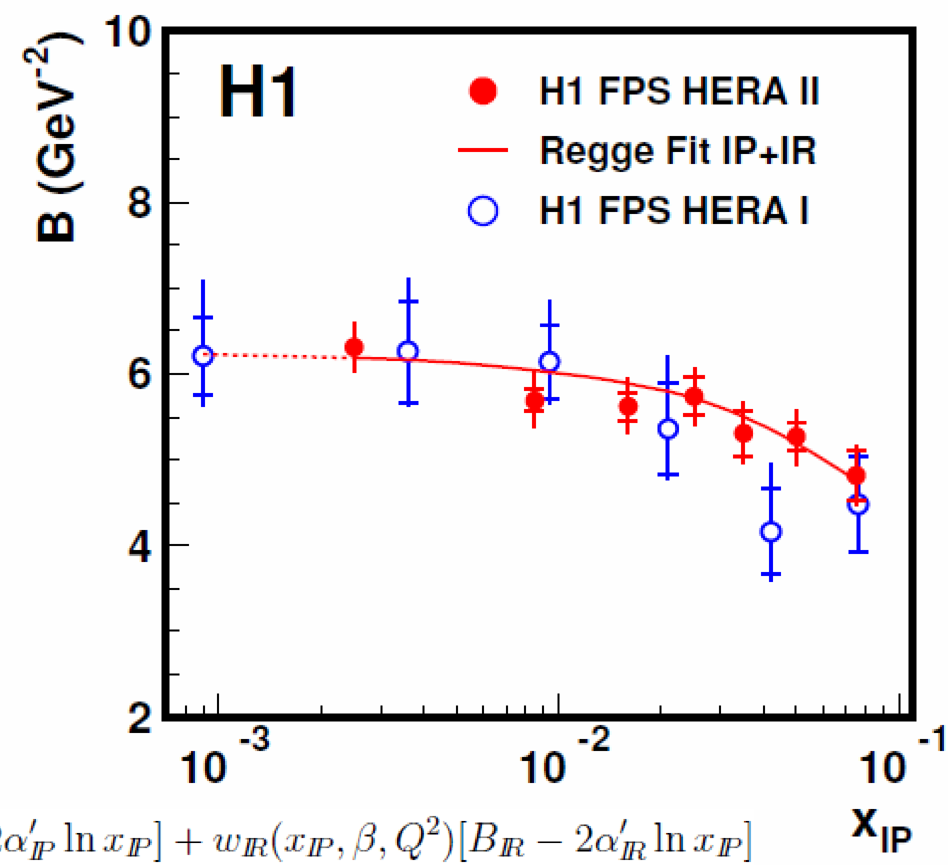
For $x_{IP} > 10^{-2}$ and high β considerable contributions from Regge trajectory exchanges are present.

New H1 Results from Proton tagged Data

B slope from H1 FPS HERA II data

$$f_{I\!P}(x_{I\!P},t) = A_{I\!P} \cdot \frac{e^{B_{I\!P} t}}{(x_{I\!P})^{2\alpha_{I\!P}(t)-1}} \; ; \; f_{I\!R}(x_{I\!P},t) = A_{I\!R} \cdot \frac{e^{B_{I\!R} t}}{(x_{I\!P})^{2\alpha_{I\!R}(t)-1}} \; ; \; \frac{d\sigma}{dt} \propto e^{B \cdot t}$$





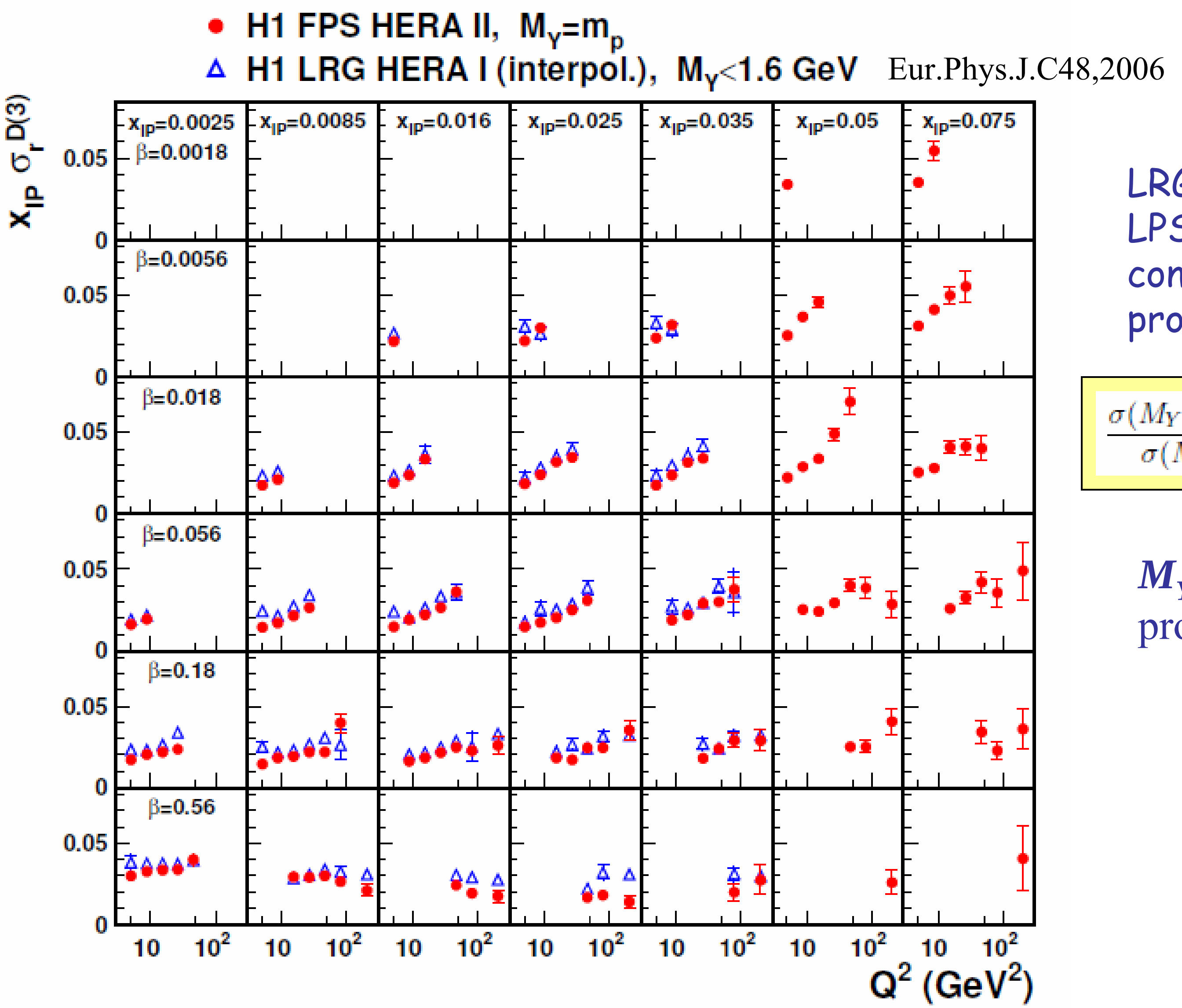
$$B(x_{I\!P},\beta,Q^2) = [1 - w_{I\!R}(x_{I\!P},\beta,Q^2)][B_{I\!P} - 2\alpha'_{I\!P} \ln x_{I\!P}] + w_{I\!R}(x_{I\!P},\beta,Q^2)[B_{I\!R} - 2\alpha'_{I\!R} \ln x_{I\!P}]$$

$w_{I\!R}(x_{I\!P},\beta,Q^2)$ fraction of $F_2^{D(3)}$ which is due to Reggeon exchanges.

For x_{IP} < 0.025 the Reggeon contribution is 5%, integrated over the kinematical range.

New H1 Results from Proton tagged Data

H1 comparison of FPS to LRG data



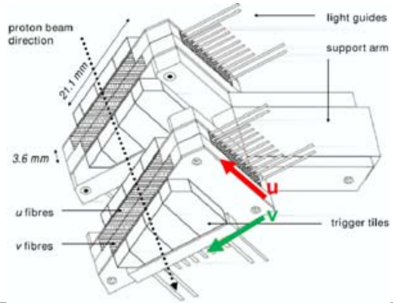
LRG data are higher than LPS data because of contribution from proton dissociation

$$\frac{\sigma(M_Y < 1.6\ \mathrm{GeV})}{\sigma(M_Y = m_p)} = 1.20 \pm 0.11\ (\mathrm{exp.})$$

M_Y is the mass of the proton dissociative system

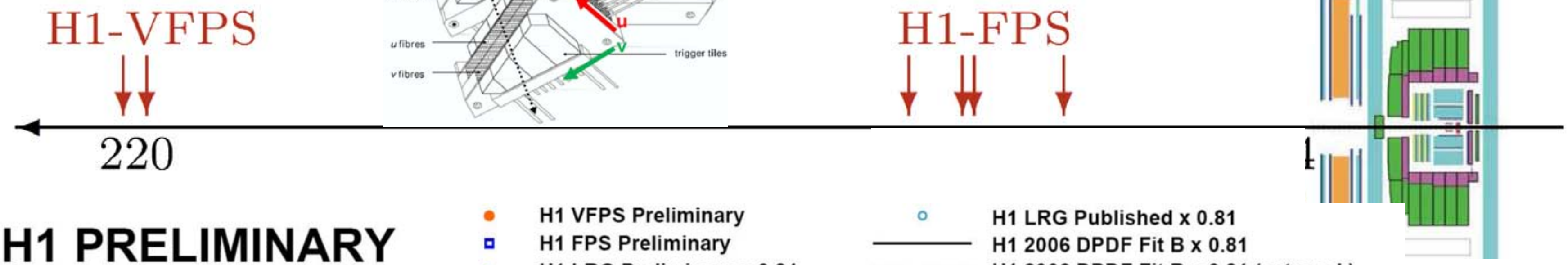
H1 Preliminary Results from VFPS tagged Data

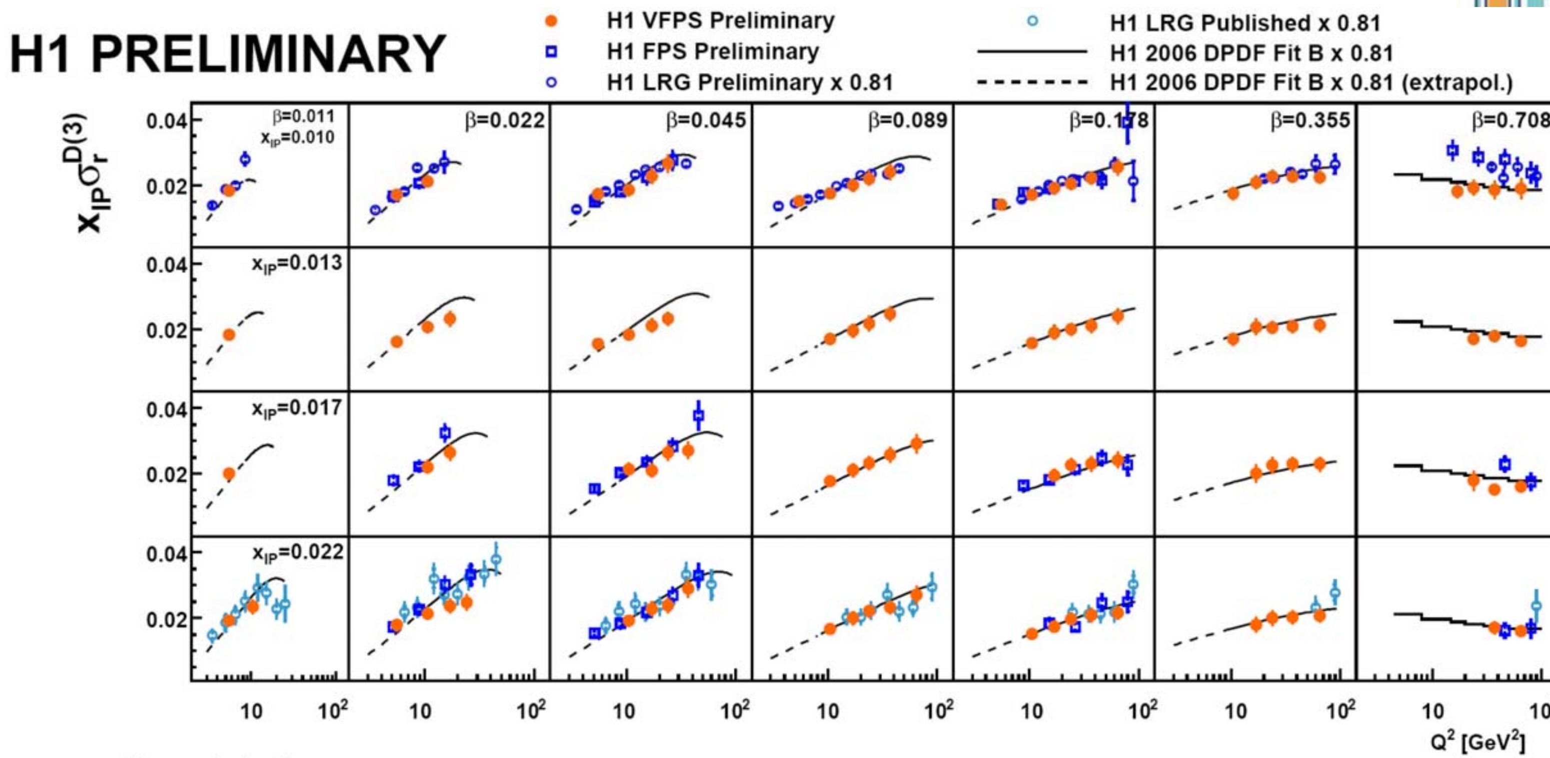
'Roman Pots' equipped with scintillating fibers



Large acceptance detector

See next talk by R.Polifka

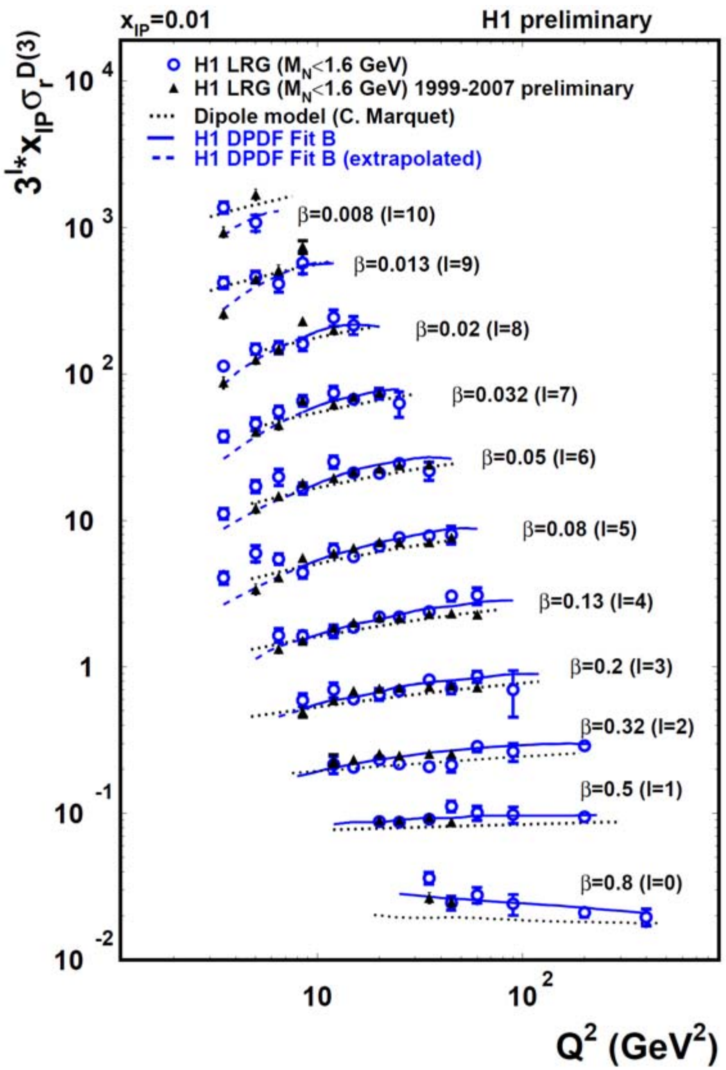




$$\frac{\text{VFPS}}{\text{FPS}} = 0.96 \pm 0.02(\text{stat.}) \pm 0.11(\text{syst.}) \pm 0.08(\text{norm.})$$

New H1 Results on LRG Data

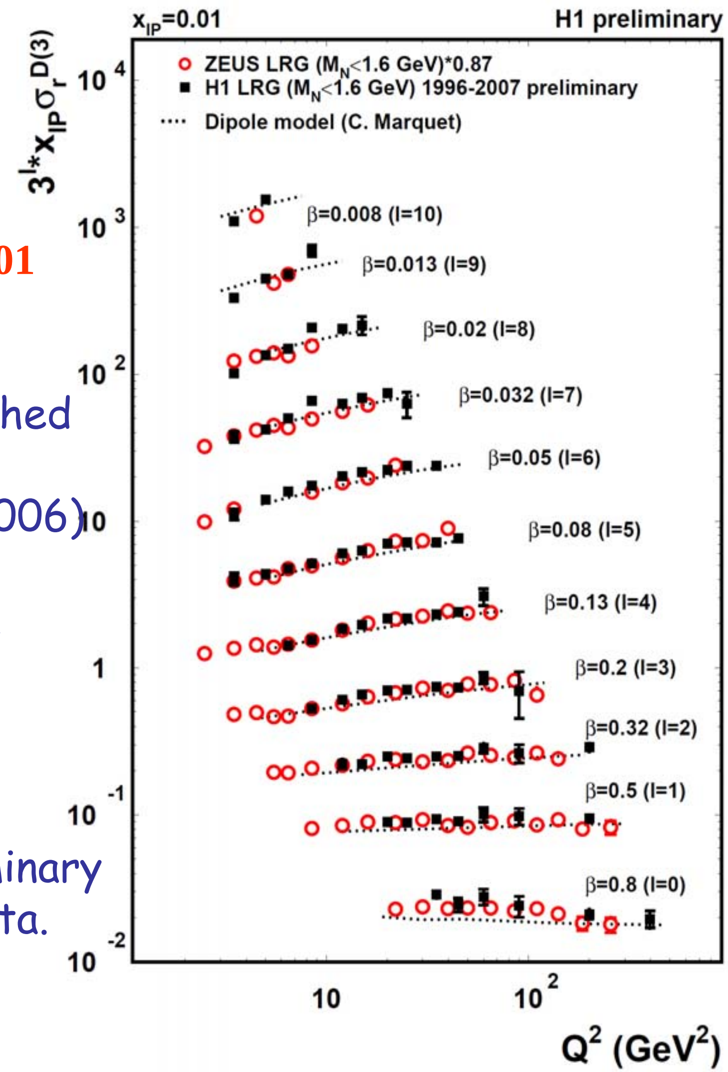
Preliminary results of LRG data from 1999-2000 (HERAI) and 2003-2007 (HERAII) in the range $3.5 < Q^2 < 90$ GeV^2 and $0.001 < x_{IP} < 0.1$.



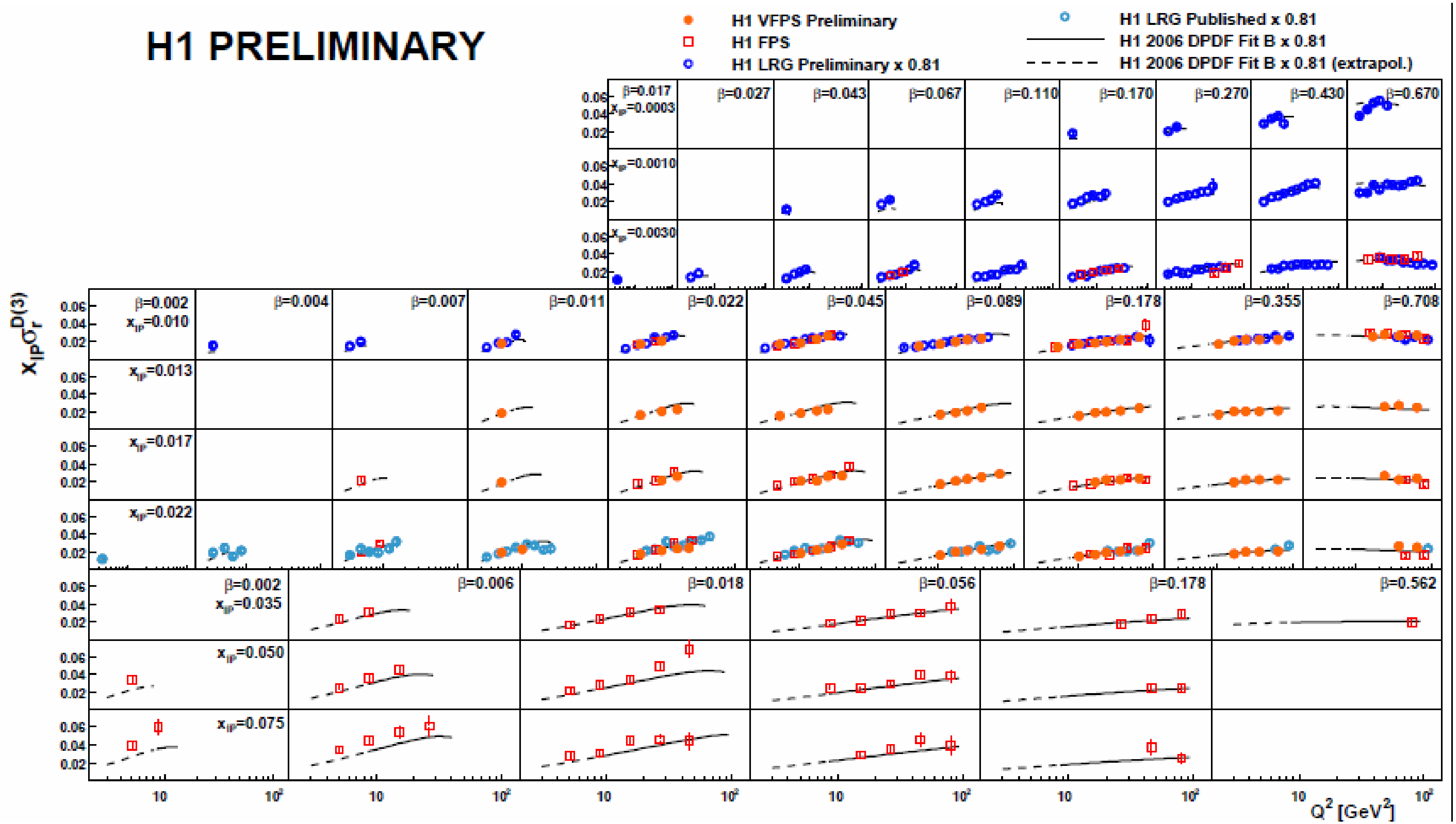
Example:
dataset at $x_{IP} = 0.01$

Good agreement between H1 published data (1996-1999) (Eur.Phys.J.C48,2006) and preliminary data (1999-2007).

Good agreement between H1 preliminary data and ZEUS data.



H1 summary of diffractive data



Data from different methods agree ⇒ convincing results

QCD Analysis of ZEUS Diffractive Data

The concept of diffractive parton distribution functions (DPDF)

$$\sigma_r^{D(3)}(Q^2, x_{IP}, \beta) = F_2^{D(3)}(Q^2, x_{IP}, \beta) - \frac{y^2}{1+(1-y)^2} F_L^{D(3)}(Q^2, x_{IP}, \beta)$$

QCD-factorization theorem for diffractive DIS:

$$F_{2/L}^{D(3)}(\beta, Q^2, x_{I\!P}) = \sum_i \int_\beta^1 \frac{dz}{z} C_{2/L,i}\left(\frac{\beta}{z}\right) \underbrace{f_i^D(z, x_{I\!P}; Q^2)}$$

DPDFs obey DGLAP evolution

Regge-factorization assumption:

$$f_i^D(z, x_{\mathbb{P}}; Q^2) = f_{\mathbb{P}}(x_{\mathbb{P}}) f_i(z, Q^2) + f_{\mathbb{R}}(x_{\mathbb{P}}) f_i^{\mathbb{R}}(z, Q^2) \quad ; \quad f_{I\!P,I\!R}(x_{I\!P}, t) = \frac{A_{I\!P,I\!R} e^{B_{I\!P,I\!R} t}}{x_{I\!P}^{2\alpha_{I\!P,I\!R}(t)-1}}$$

Parametrisation of DPDFs at $Q_0^2 = 1.8$ GeV^2

$$z f_{d,u,s}(z, Q_0^2) = A_q z^{B_q} (1-z)^{C_q}$$
$$z f_g(z, Q_0^2) = A_g z^{B_g} (1-z)^{C_g}$$
$$f_{\bar{q}} = f_q$$

Additional factor $e^{-\frac{0.001}{1-z}}$ included to ensure that distributions vanish for $z \to 1$.

Fit the DGLAP evolution with these parameterizations to inclusive diffractive data

9 parameters left free in fit: $A_{q,g},\ B_{q,g},\ C_{q,g},\ \alpha_{I\!R}(0),\ \alpha_{I\!P}(0),\ A_{I\!R}.$

QCD Analysis of ZEUS Diffractive Data

Nucl. Phys. **B** 831 (2010)

LRG sample: $2 < Q^2 < 305\ \mathrm{GeV}^2$, $40 < W < 240$ GeV, $2 < M_X < 25$ GeV, $0.0001 < x_{IP} < 0.02$

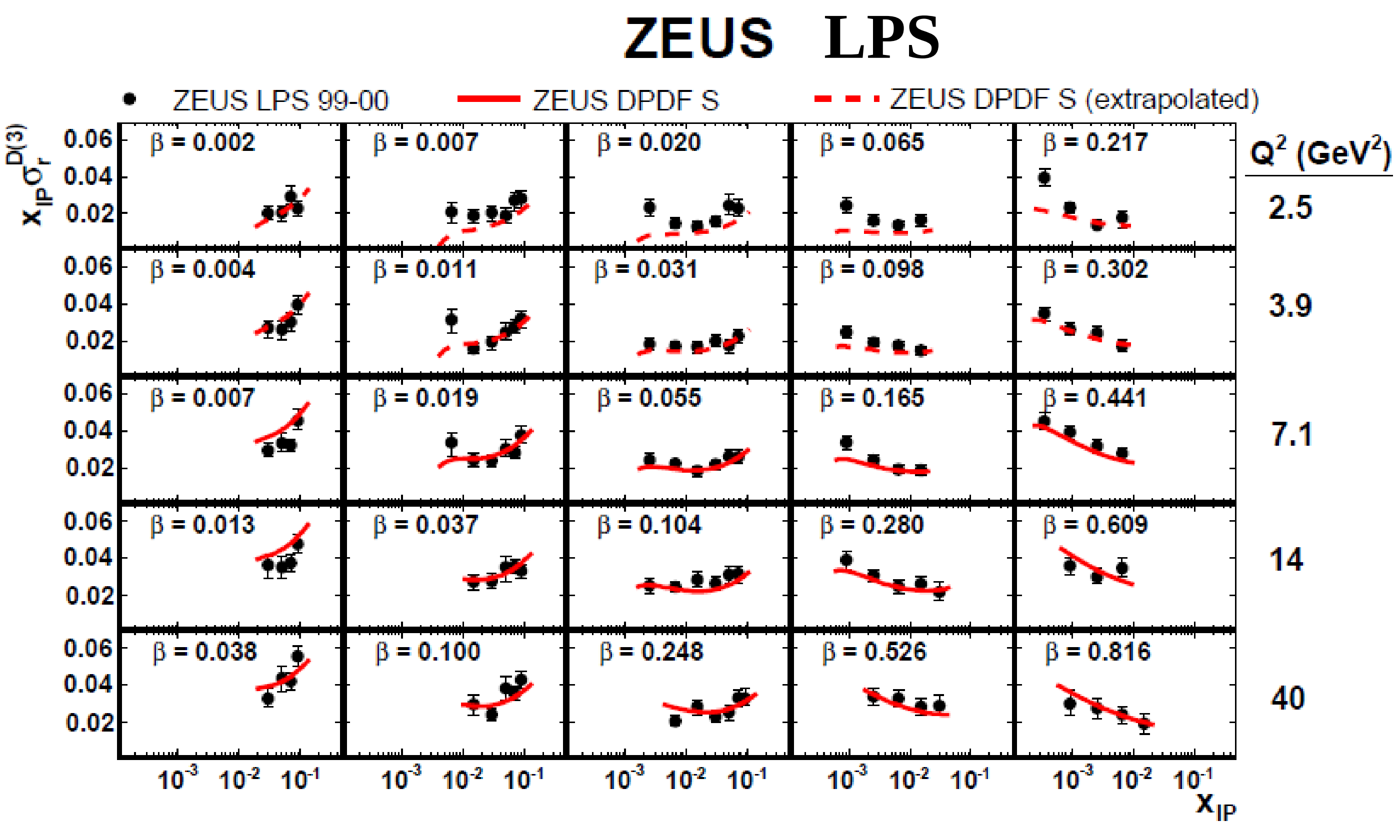
LPS sample: $2 < Q^2 < 120\ \mathrm{GeV}^2$, $40 < W < 240$ GeV, $2 < M_X < 40$ GeV, $0.002 < x_{IP} < 0.1$

Nucl. Phys. **B** 816 (2009)

Samples are corrected for proton dissociation where necessary.

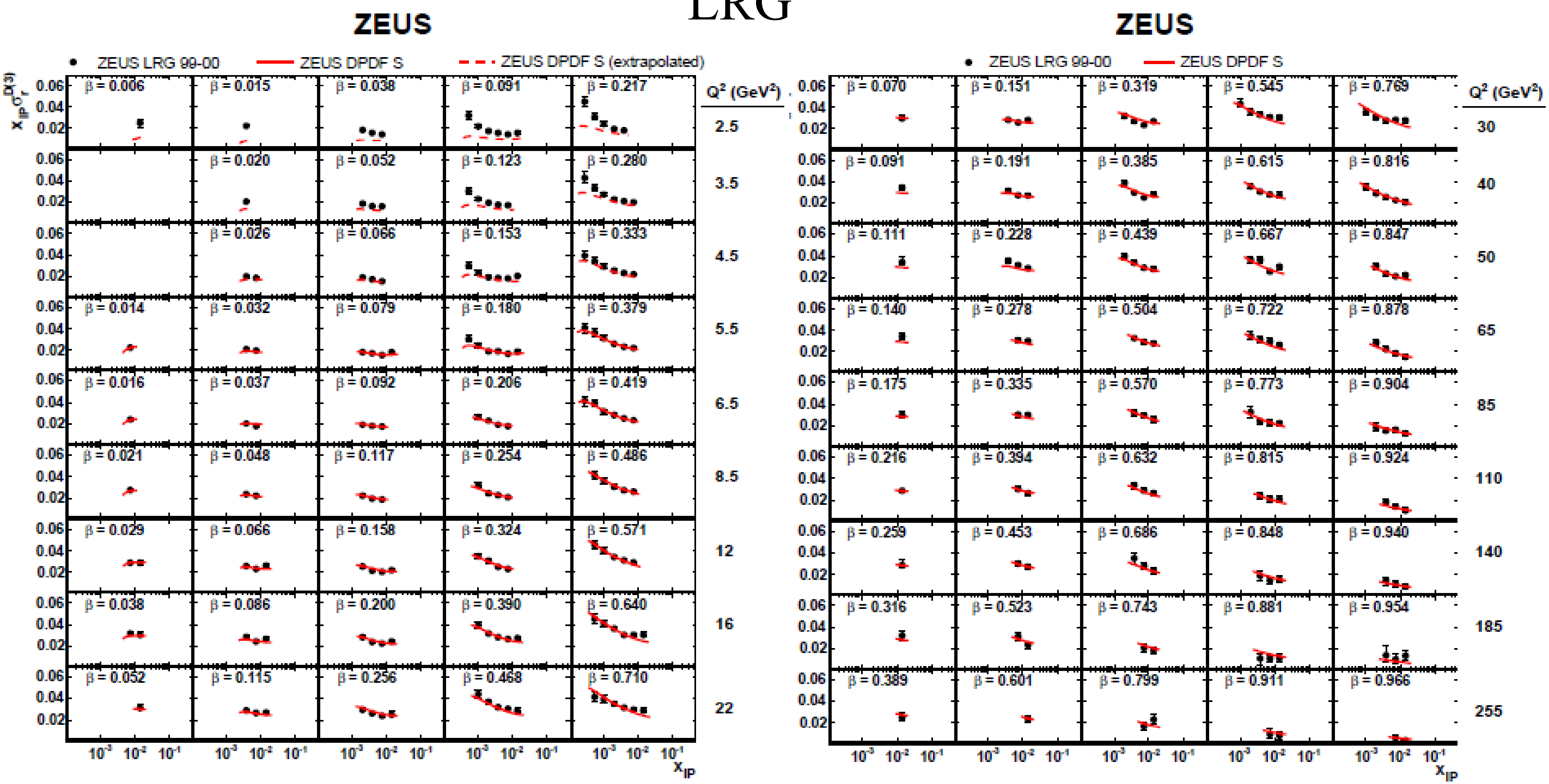
Two fits: 'Standard' A_g, B_g, C_g as free parameters → ZEUS DPDF S

'Constant' $B_g = C_g = 0$ → ZEUS DPDF C



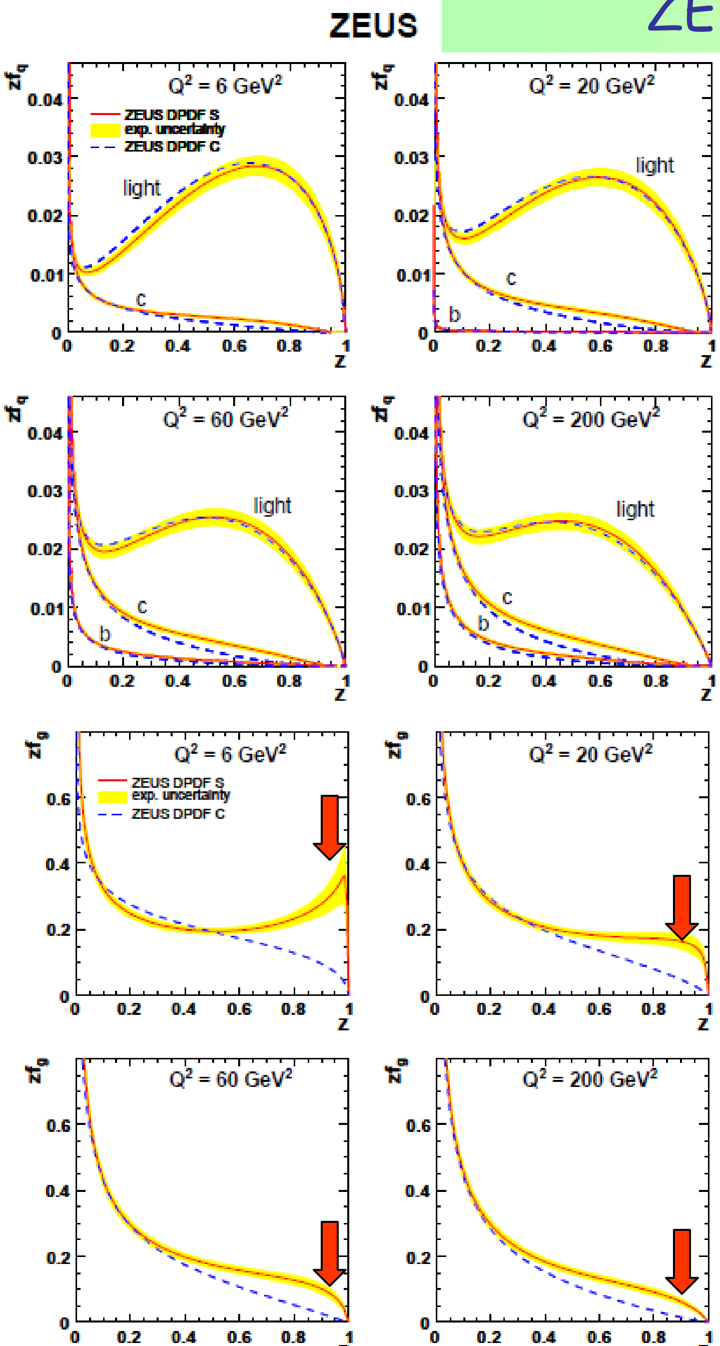
QCD Analysis of ZEUS Diffractive Data

LRG



ZEUS DPDF S and **ZEUS DPDF C** fits are of equally good quality.

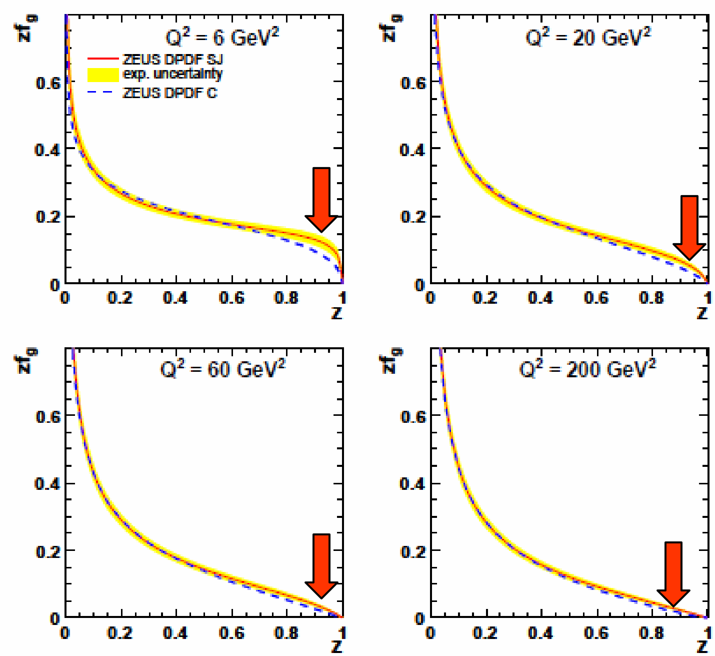
ZEUS Diffractive Dijet Fit



DPDF-fits to inclusive diffractive data are mainly sensitive to the charged quark parameters. Therefore they do not constrain very well the gluon distributions, in particular at lower Q^2.

include diffractive dijet data in the fit !

Fit ZEUS DPDF SJ is closer to ZEUS DPDF C fit, light quark DPDFs mainly unchanged.
Inclusion of dijets resolves the ambiguity for the gluon distribution at high z.



Measurement of the Diffractive Longitudinal Structure Function F_L^D by H1

$$\sigma_r^{D(3)}(Q^2, x_{IP}, \beta) = F_2^{D(3)}(Q^2, x_{IP}, \beta) - \frac{y^2}{1+(1-y)^2} F_L^{D(3)}(Q^2, x_{IP}, \beta)$$

Measurements of σ_r^D done so far in kinematical regions where F_L^D can be neglected or it is corrected for by taking F_L^D from pQCD predictions.

F_L^D is strongly correlated to the diffractive gluon density.

Necessary to measure F_L^D directly.

$$F_L^D = \frac{\partial \sigma_r^D}{\partial (y^2 / Y_+)}$$ with $$Y_+ = \frac{1}{1+(1-y)^2}$$ $$y = \frac{Q^2}{x_{IP}\beta} \cdot \frac{1}{s}$$

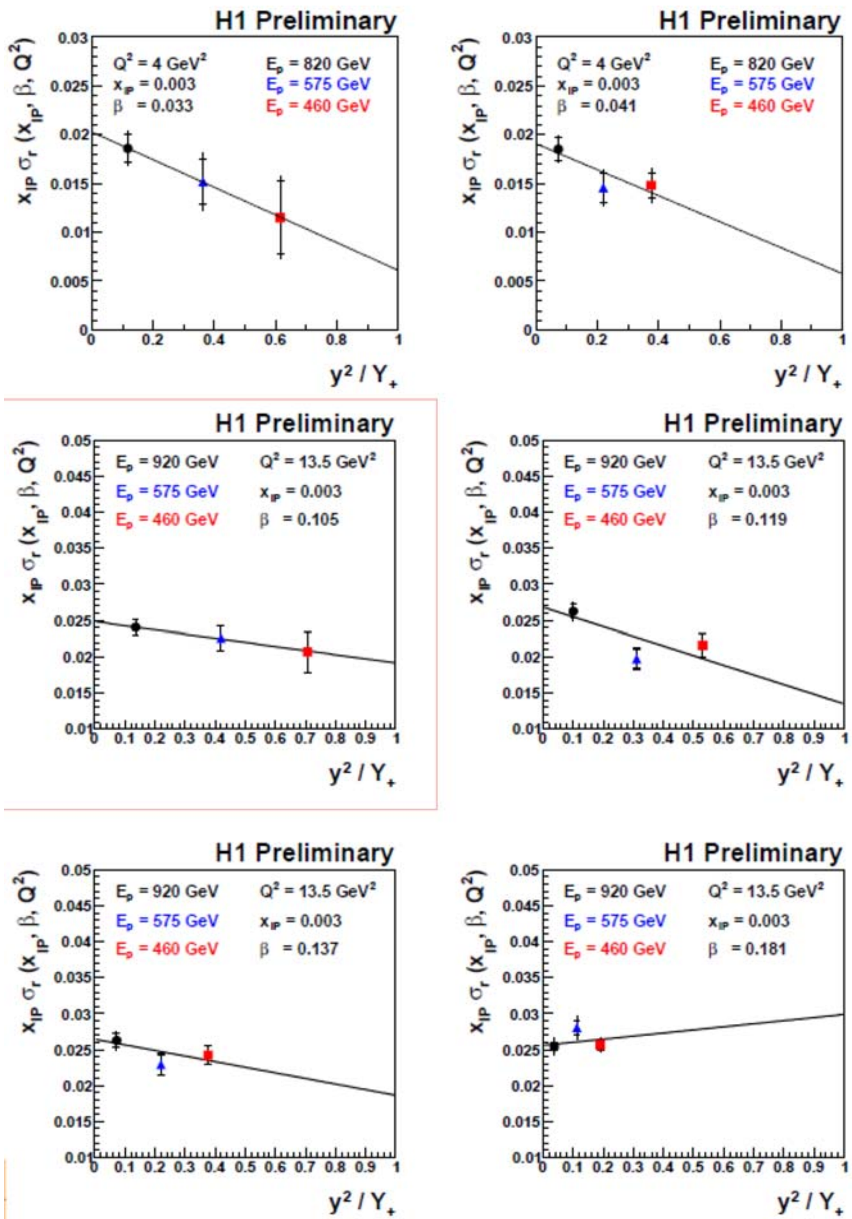
⇨ measure σ_r^D at fixed Q^2, x_{IP}, β for different values of y.

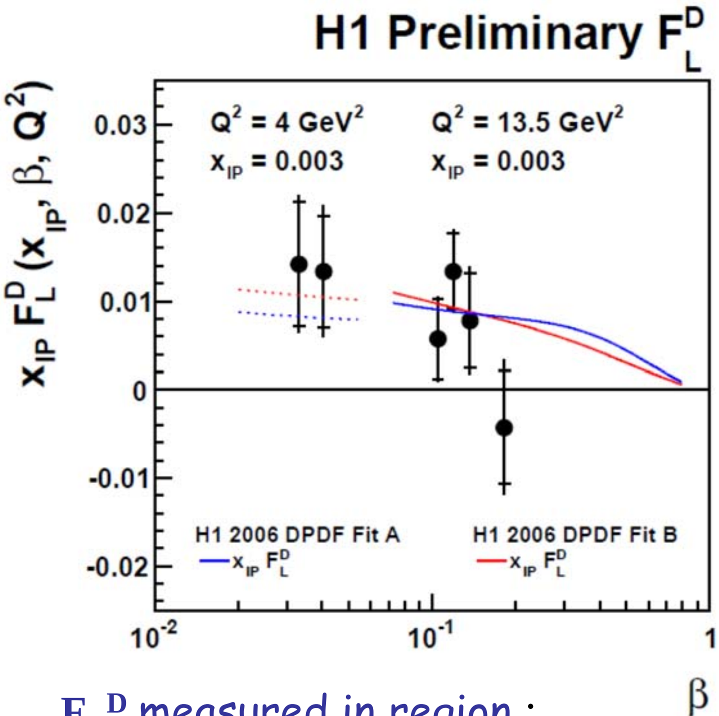
Vary center of mass energy squared $s = 4 \cdot E_e E_p$

Keep electron energy E_e, vary proton energy E_p.

$E_p =$ 920 GeV, 575 GeV, 460 GeV

Measurement of the Diffractive Longitudinal Structure Function F_L^D by H1





F_L^D measured in region :

$2.5 < Q^2 < 32$ GeV²

These values are then shifted to:

$Q^2 = 4$ GeV² and $Q^2 = 13.5$ GeV²

Cross sections normalized to
H1 2006 DPDF Fit B,
This changes the normalization by < 4%

Summary and Outlook

Achievements so far:

- Wealth of inclusive diffractive data available from both experiments and different methods;
- Results of both experiments from proton tagged (FPS/LPS) data and large rapidity gap (LRG) data show fair agreement within the errors.

Still planned to do:

- Measurements of the diffractive longitudinal structure function F_L^D are still missing. Both collaborations are working on these measurements. Preliminary results from H1 exist. A publication from H1 is immanent;
- Work on the combination of H1-FPS data with ZEUS-LPS data is in progress. A combined dataset is expected soon;
- The combination of the H1 and ZEUS LRG data needs some more time but is foreseen;
- The final goal is to arrive at a set of HERA diffractive PDFs as for DIS.