DIS09
XVII International Workshop on Deep Inelastic Scattering
Madrid, 25-30 May, 2009

ZEUS inclusive diffraction (final) data

Marta Ruspa
(Univ. Piemonte Orientale & INFN-Torino, Italy)

- Diffractive structure function data

to introduce the talk on QCD fits by W. Slominsky

- Regge fits
- comparison among selection methods
- proton dissociation background treatment

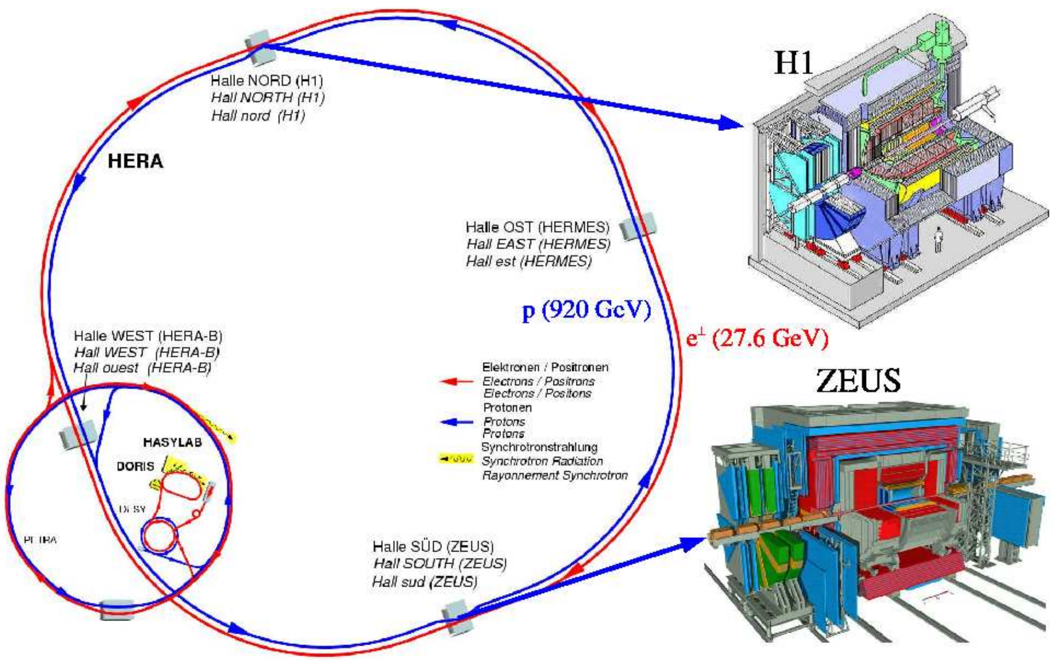
- H1/ZEUS comparison

to introduce the discussion at the end of the session

HERA collider experiments

- 27.5 GeV electrons/positrons on 920 GeV protons $\rightarrow\sqrt{s}$=318 GeV
- 2 collider experiments: **H1 and ZEUS**
- HERA I: 16 pb^{-1} e-p, 120 pb^{-1} e+p
  HERA II (after lumi upgrade): 500 pb^{-1}, polarisation of e+,e-

Closed July 2007, still lot of excellent data to analyse……

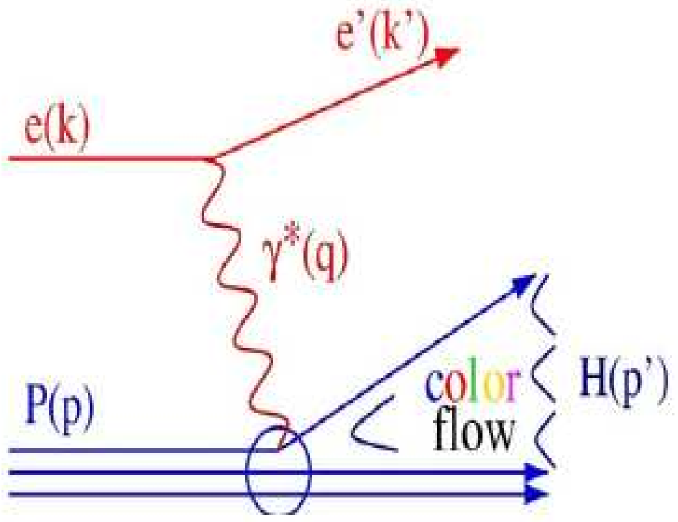


Detectors not originally designed for forward physics, but diffraction at HERA great success story!

ZEUS forward instrumentation no longer available in HERA II → ZEUS final diffractive structure function measurements based on HERA I data

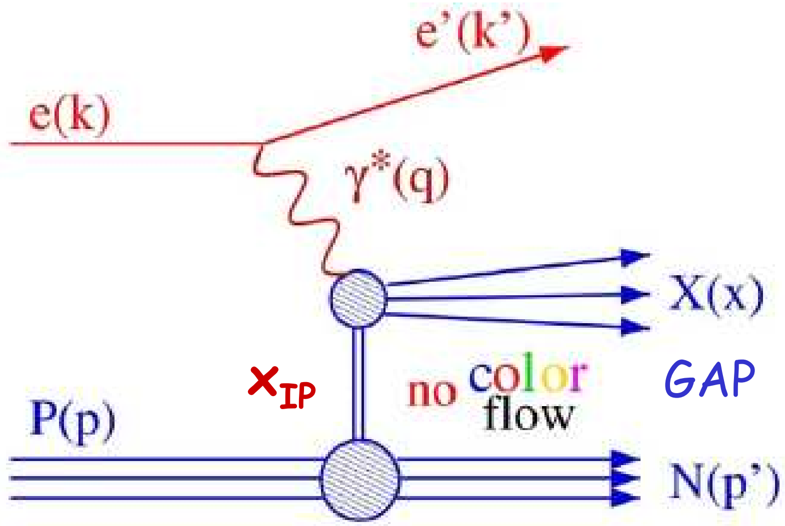
Diffractive DIS at HERA

Standard DIS



Probes proton structure

Diffractive DIS



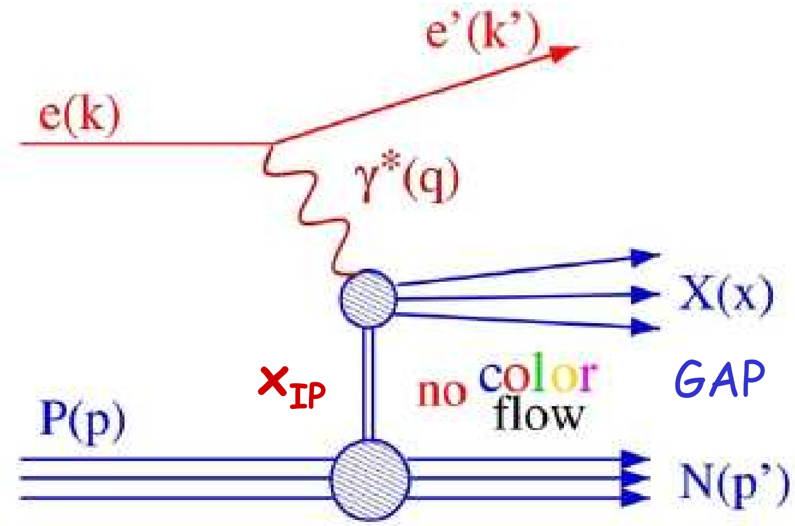
Probes structure of color singlet exchange

According to Regge phenomenology:

- exchanged Pomeron (IP) trajectory
- exchanged Reggeon (IR) and π when proton loses a higher energy fraction, x_{IP}

Diffractive DIS at HERA

Diffractive DIS



- Single diffractive dissociation: **N=proton**
- Double diffractive dissociation: **proton-dissociative system N**

  → ***represents a relevant background***

Kinematics of diffractive DIS

Q^2 = virtuality of photon =
= (4-momentum exchanged at e vertex)^2

W = invariant mass of γ^*-p system

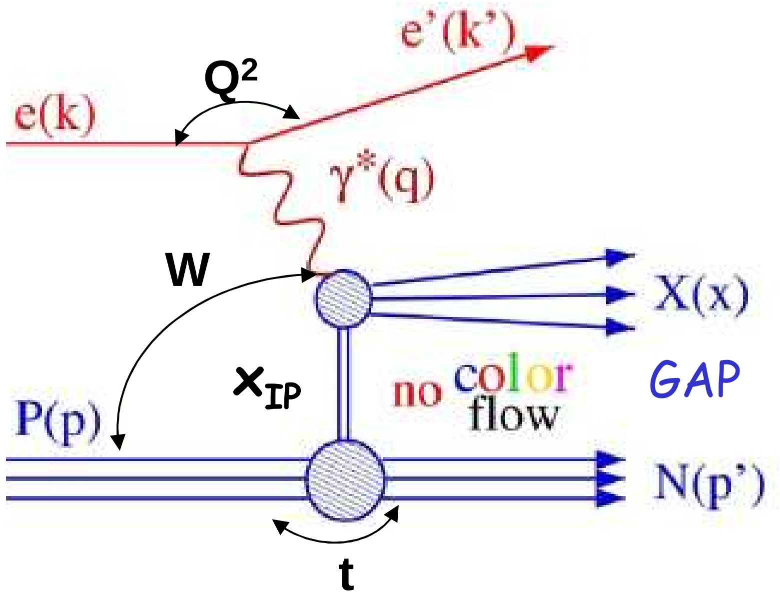
M_X = invariant mass of γ^* -IP system

x_{IP} = fraction of proton's momentum carried by IP

ß = fraction of IP momentum carried by struck quark

x = $\beta \cdot x_{IP}$, Bjorken's scaling variable

t = (4-momentum exchanged at p vertex)^2
typically: $|t|<1$ GeV^2



- **Single diffractive dissociation: N=proton**
- **Double diffractive dissociation: proton-dissociative system N**

→ **represents a relevant background**

Diffractive structure function

- **Diffractive cross section**

$$\frac{d\sigma^D_{\gamma^* p}}{dM_X} = \frac{\pi Q^2 W}{\alpha(1+(1-y)^2)} \cdot \frac{d^3\sigma^D_{ep\to e'Xp'}}{dQ^2 dM_X dW}$$

- **Diffractive structure function $F_2^{D(4)}$ and reduced cross section $\sigma_r^{D(4)}$**

$$\frac{d^2\sigma^{ep\to e'Xp'}}{d\beta dQ^2 dx_{IP} dt} = \frac{4\pi\alpha^2}{\beta Q^4}[1 - y + \frac{y^2}{2(1+R^D)}] \cdot F_2^{D(4)}(\beta, Q^2, x_{IP}, t)$$

$$= \frac{4\pi\alpha^2}{\beta Q^4}[1 - y + \frac{y^2}{2}] \cdot \sigma_r^{D(4)}(\beta, Q^2, x_{IP}, t)$$

- **When t is not measured**

$$\sigma_r^{D(3)}(\beta, Q^2, x_{IP}) = \int \sigma_r^{D(4)}(\beta, Q^2, x_{IP}, t) dt$$

- **$R^D = \sigma_L^{\gamma^* p \to Xp} / \sigma_T^{\gamma^* p \to Xp}$; $\sigma_r^D = F_2^D$ when $R^D = 0$**

QCD factorization in hard diffraction

- **Diffractive DIS, like inclusive DIS, is factorisable:**
  [Collins (1998); Trentadue, Veneziano (1994); Berera, Soper (1996)…]

universal partonic cross section

$$\sigma(\gamma^* p \to Xp) \approx f_{i/p}(z, Q^2, x_{IP}, t) \times \sigma_{\gamma^* q}(z, Q^2)$$

Diffractive Parton Distribution Function (DPDF)

$f_{i/p}(z, Q^2, x_{IP}, t)$ expresses the probability to find, with a probe of resolution Q^2, in a proton, parton i with momentum fraction z, under the condition that the proton remains intact, and emerges with small energy loss, x_{IP}, and momentum transfer, t – the DPDFs are a feature of the proton and evolve according to DGLAP

see talk by W. Slominski

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see talk by W. Slominski

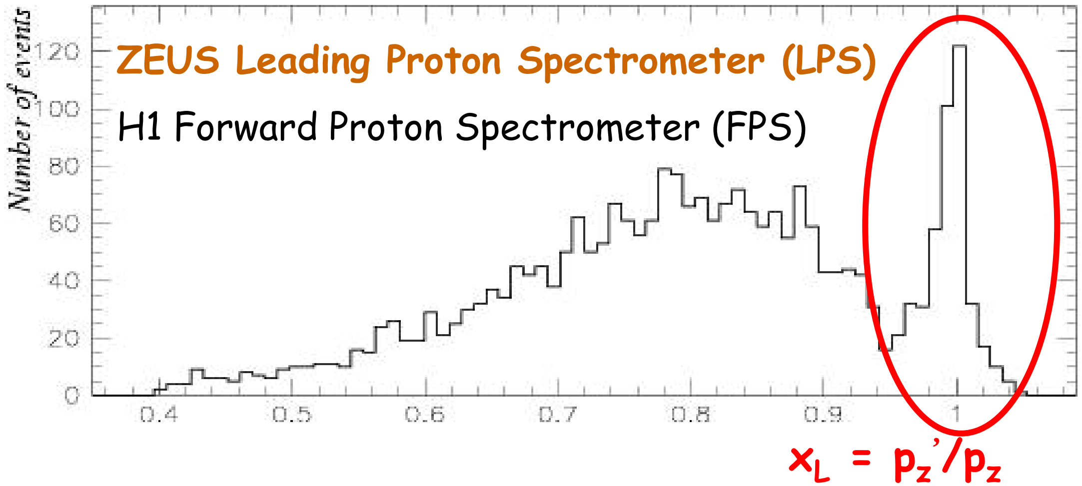
- **Assumption → proton vertex factorisation:**

Regge-motivated IP flux

$$\sigma(\gamma^* p \rightarrow Xp) \approx f_{IP/p}(x_{IP},t) \times f_{i/IP}(z,Q^2) \times \sigma_{\gamma^* q}(z,Q^2)$$

At large x_{IP}, a separately factorisable sub-leading exchange (IR), with different x_{IP} dependence and partonic composition

Diffractive event selection

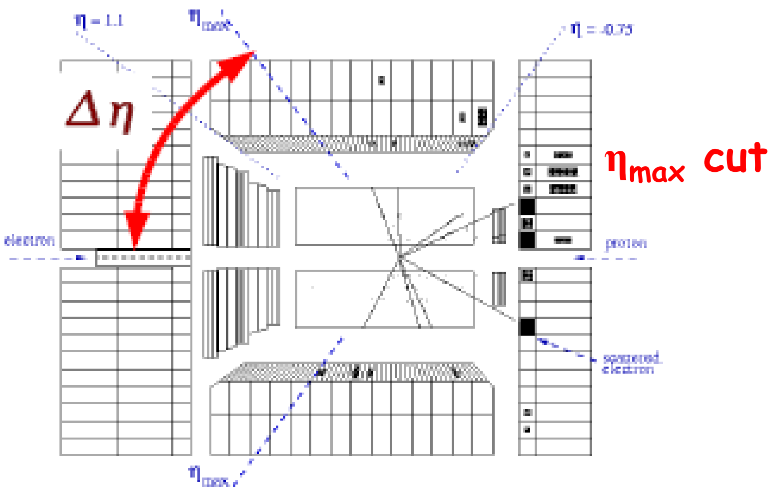


LPS method

PROS: no p-diss. background
direct measurement of t, x_{IP}
high x_{IP}, M_X accessible

CONS: low statistics

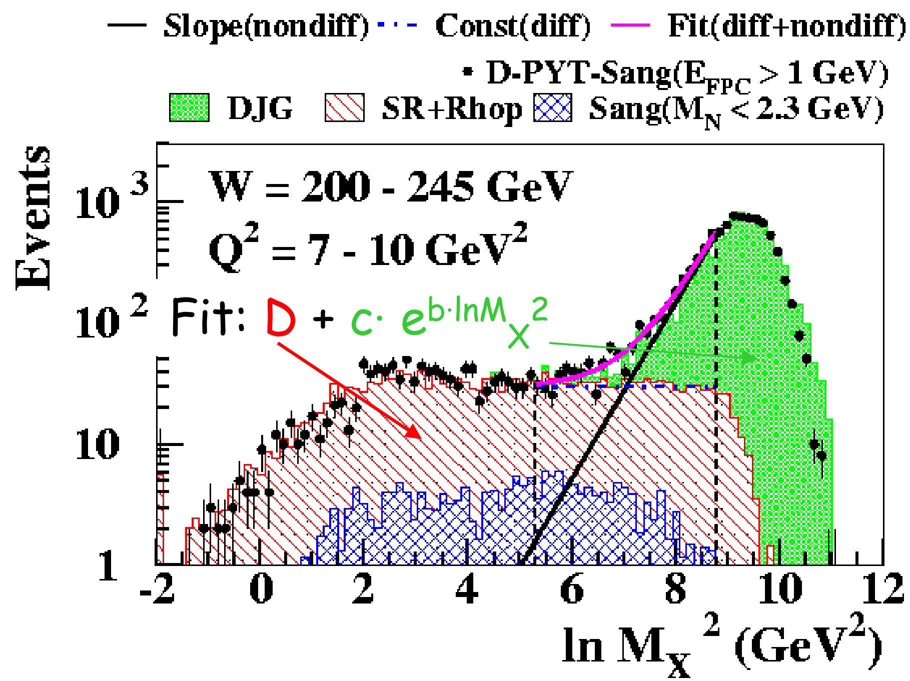
Large Rapidity Gap (LRG) method



PROS: near-perfect acceptance at low x_{IP}

CONS: p.-diss background

M_x method



How do diffractive data look vs t, x_{IP}, Q^2 ?

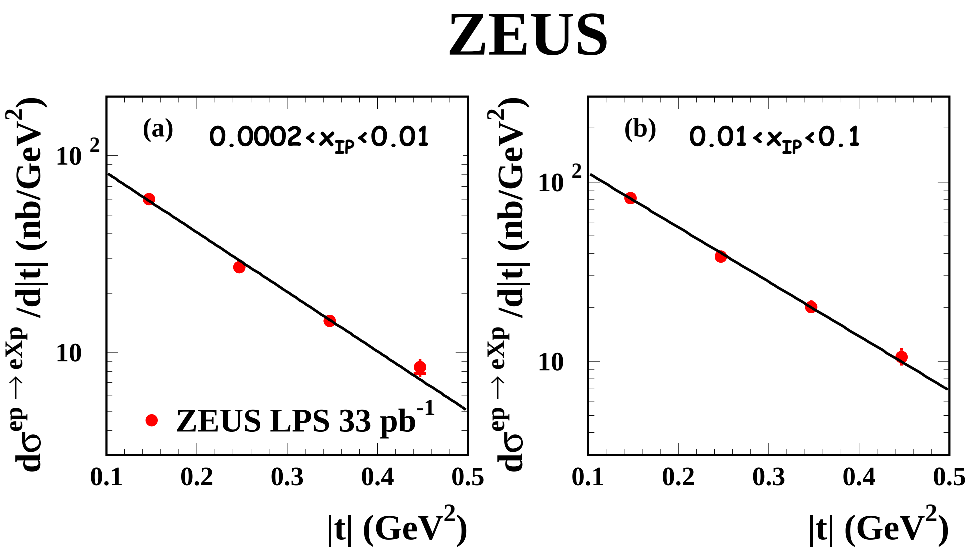
Data sets

ZEUS

	x_{IP} coverage
"ZEUS LPS" [NPB 816 ((2009)]	x_{IP} up to 0.1
"ZEUS LRG" [NPB 816 (2009)]	x_{IP} up to 0.02
"ZEUS FPC II" (M_X method) [NPB 800 (2008)]	IR suppressed
"ZEUS FPC I" (M_X method) [NPB 713 (2005)]	IR suppressed

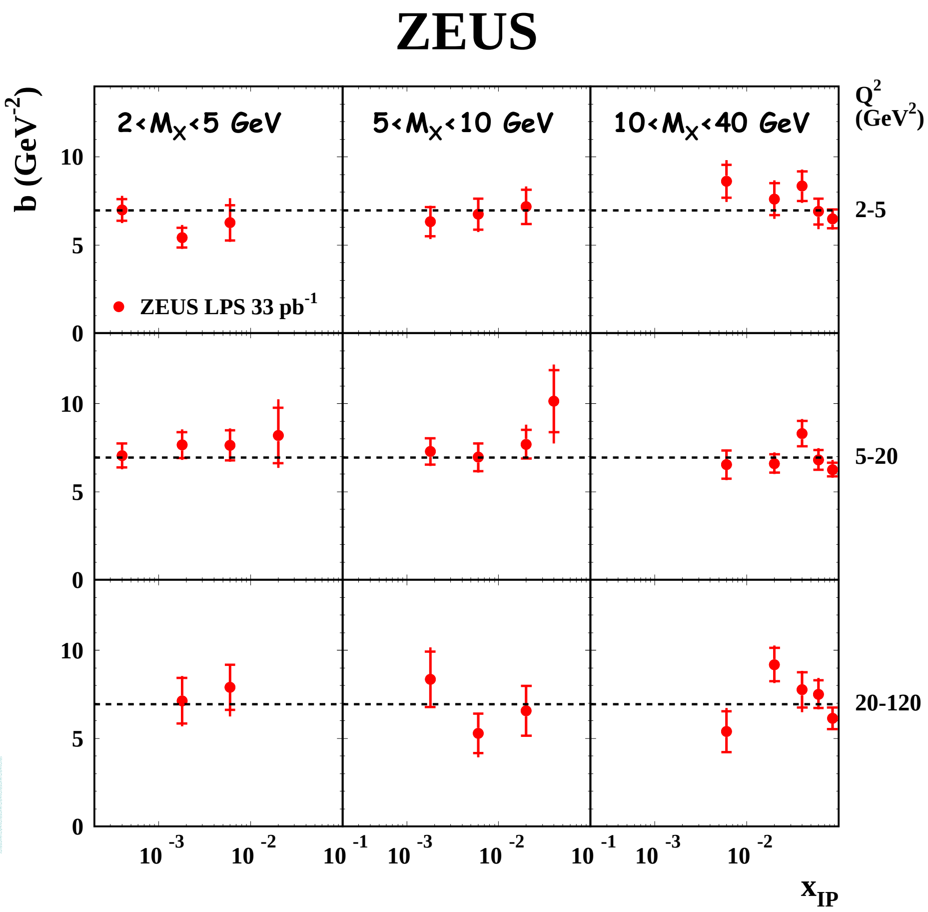
t dependence

LPS data



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

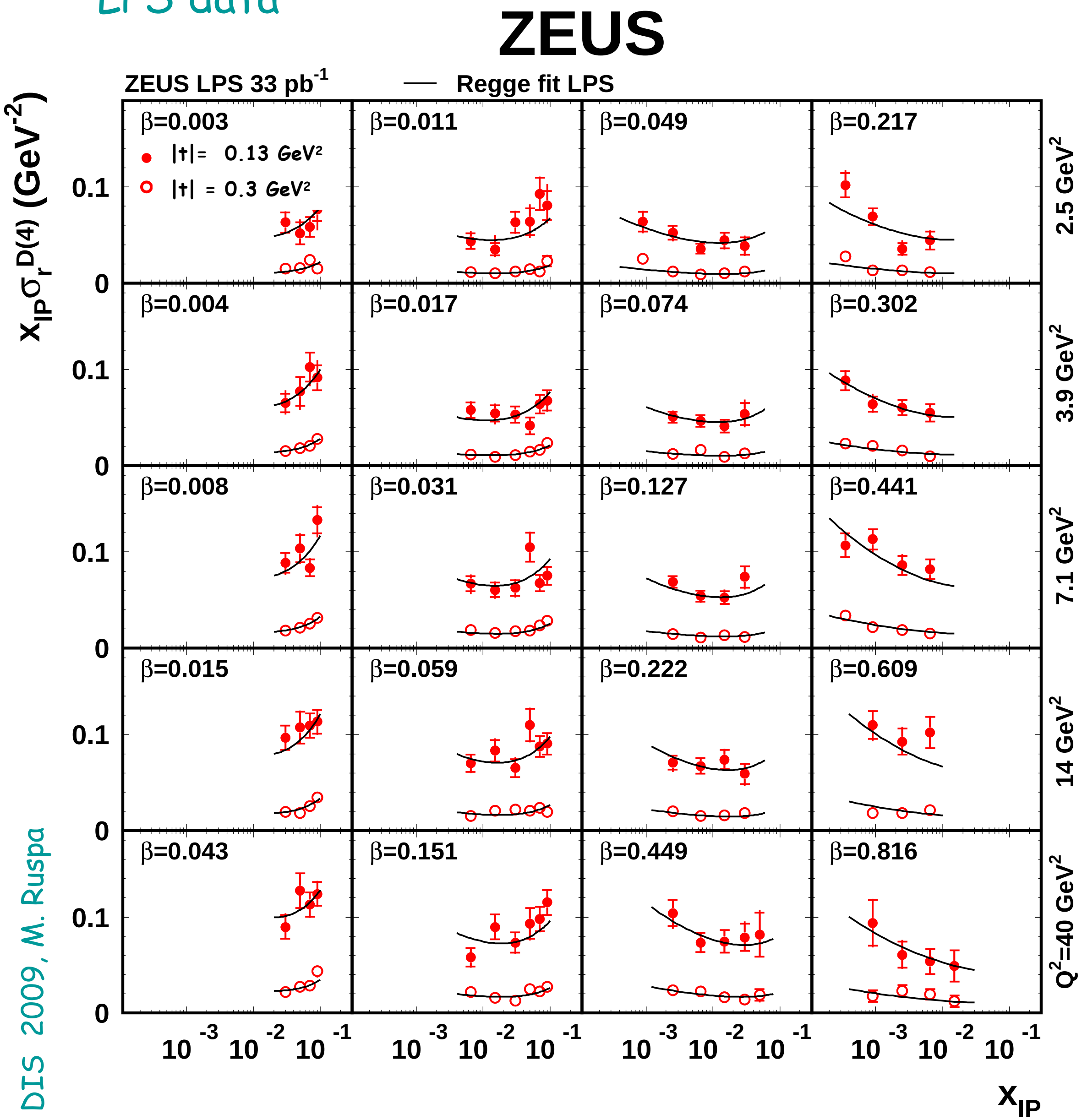
used in DPDF fits
see talk by W. Slominski



Lack of Q^2 dependence and b much larger than in vector meson production
→ features of a soft process

x_{IP} dependence of $\sigma_r^{D(4)}$

LPS data



First measurement in two t bins

→ Low x_{IP}: $\sigma_r^{D(4)}$ falls with x_{IP} faster than $1/x_{IP}$

→High x_{IP}: $x_{IP}\sigma_r^{D(4)}$ flattens or increases with x_{IP} (Reggeon and π)

→ Same x_{IP} dependence in two t bins

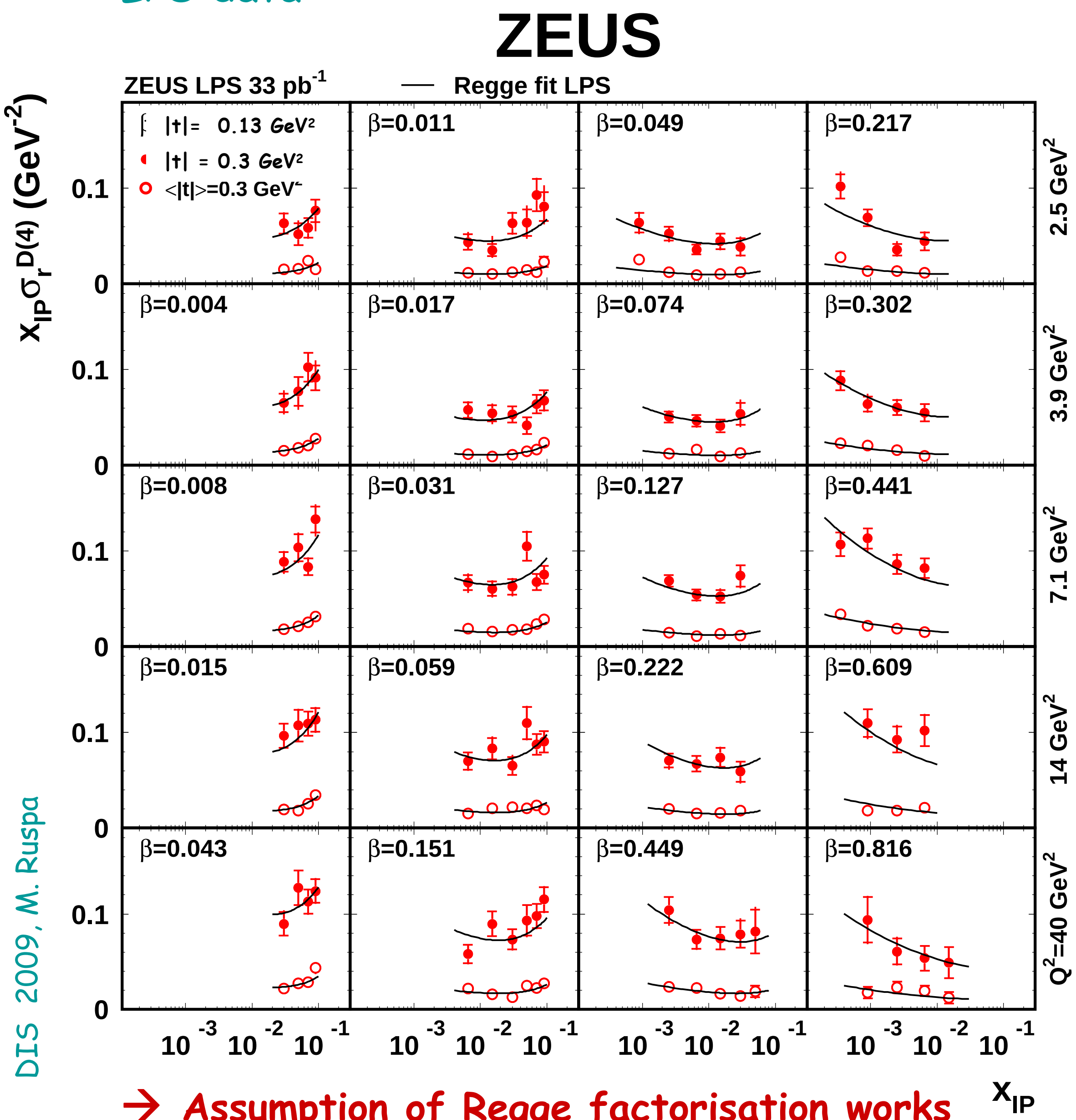
Regge fit

LPS data

$F_2^{D(4)}(\beta,Q^2,x_{IP},t) = f_{IP}(x_{IP},t)F_2^{IP}(\beta,Q^2) + n_{IR}\, f_{IR}(x_{IR},t)F_2^{IR}(\beta,Q^2)$

$f_{IP,IR} = \exp(B_{IP}t)/x_{IP}^{2\alpha(t)-1}$, $\alpha_{IP/IR}(t) = \alpha_{IP/IR}(0) + \alpha'_{IP/IR} \cdot t$

(red: parameters fitted)



→ Assumption of Regge factorisation works

$\alpha_{IP}(0) = +1.11 \pm 0.02(\text{stat}) + 0.01 - 0.02(\text{syst}) + 0.02(\text{model})$

$\alpha'_{IP} = -0.01 \pm 0.06(\text{stat}) + 0.04 - 0.08(\text{syst})$ GeV^{-2}

H1: $\alpha_{IP}' = +0.06 + 0.19 - 0.06$ GeV^{-2}

$\alpha_{IP}(0) = +1.114 \pm 0.018(\text{stat}) \pm 0.013(\text{syst}) + 0.040 - 0.020(\text{model})$

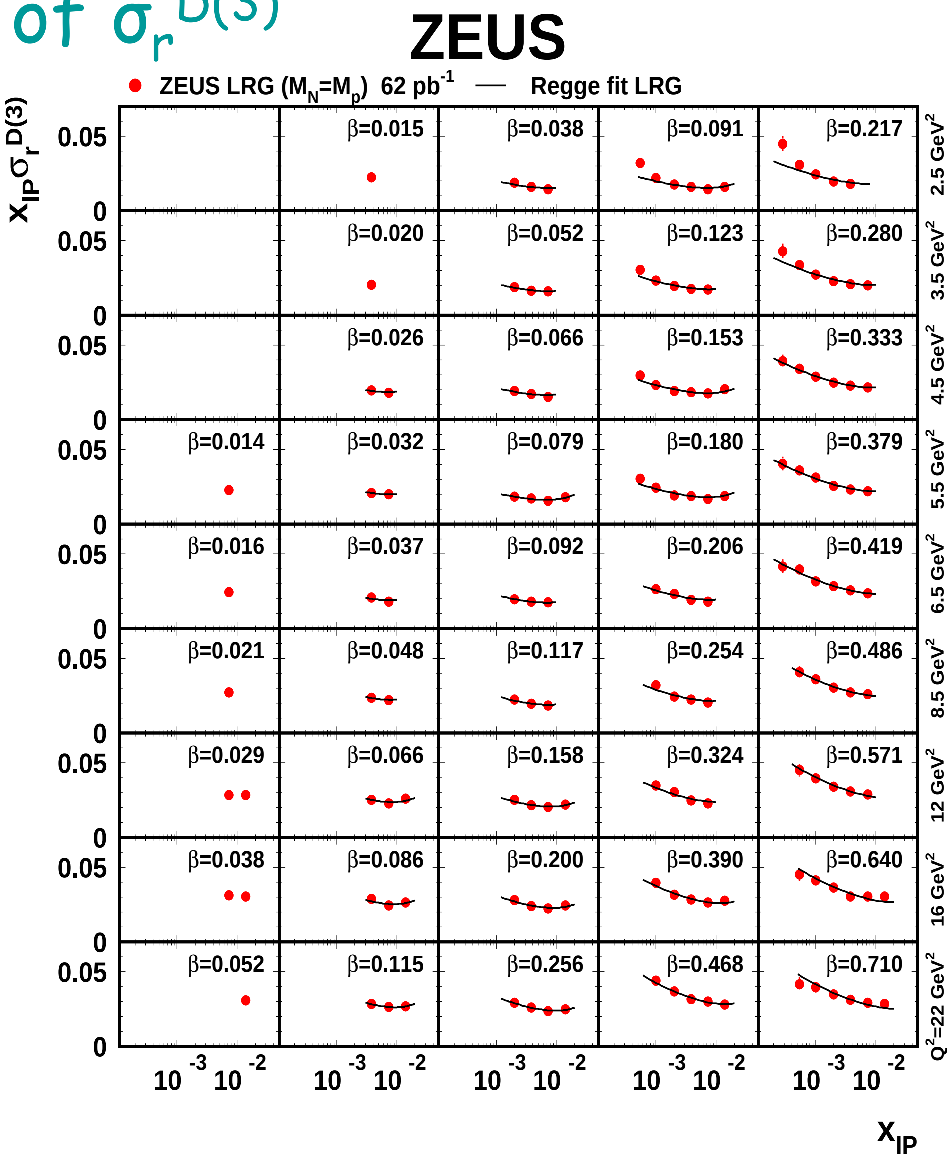
→ **IP intercept consistent with soft IP (1.096)**

→ **α'_{IP} significantly smaller than 0.25 GeV^{-2} of hadron-hadron collisions**

α'_{IP}, B_{IP} used in DPDF fits
see talk by W. Slominski

x_{IP} dependence of $\sigma_r^{D(3)}$

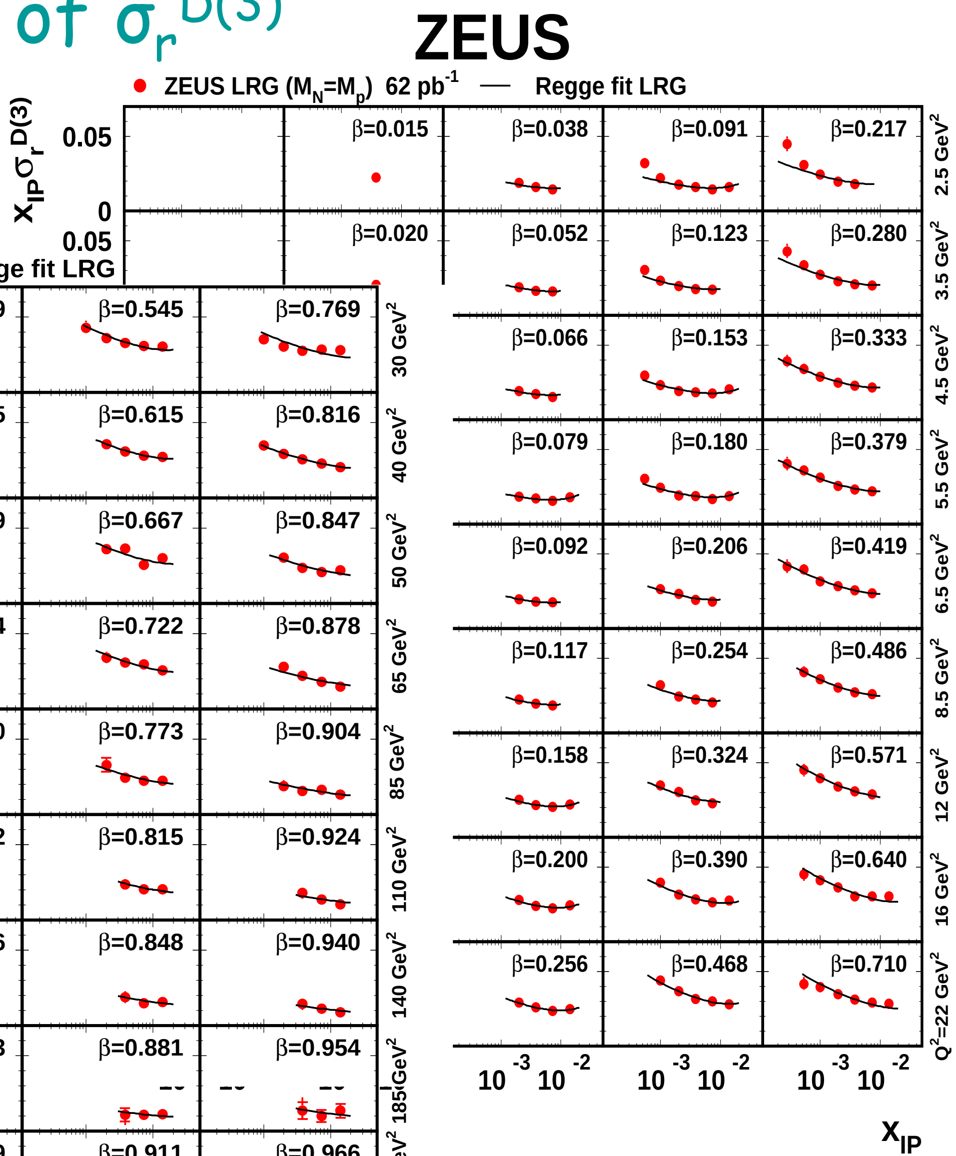
LRG data

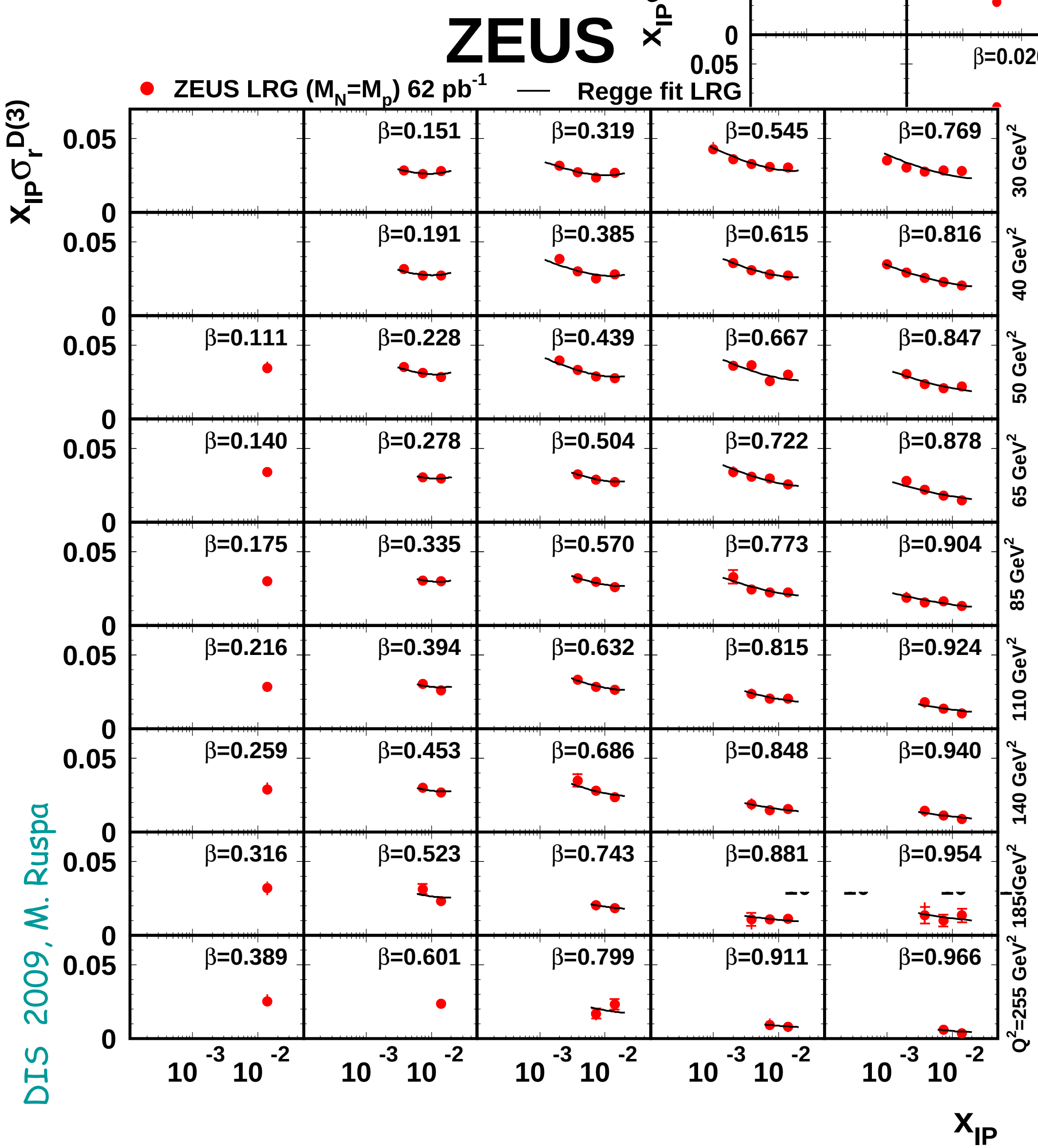


→ Rise with x_{IP} not visible as x_{IP} < 0.02

x_{IP} dependence of $\sigma_r^{D(3)}$

LRG data





→ Rise with x_{IP} not visible as x_{IP} < 0.02

→ Wide kinematic coverage and very good statistical precision

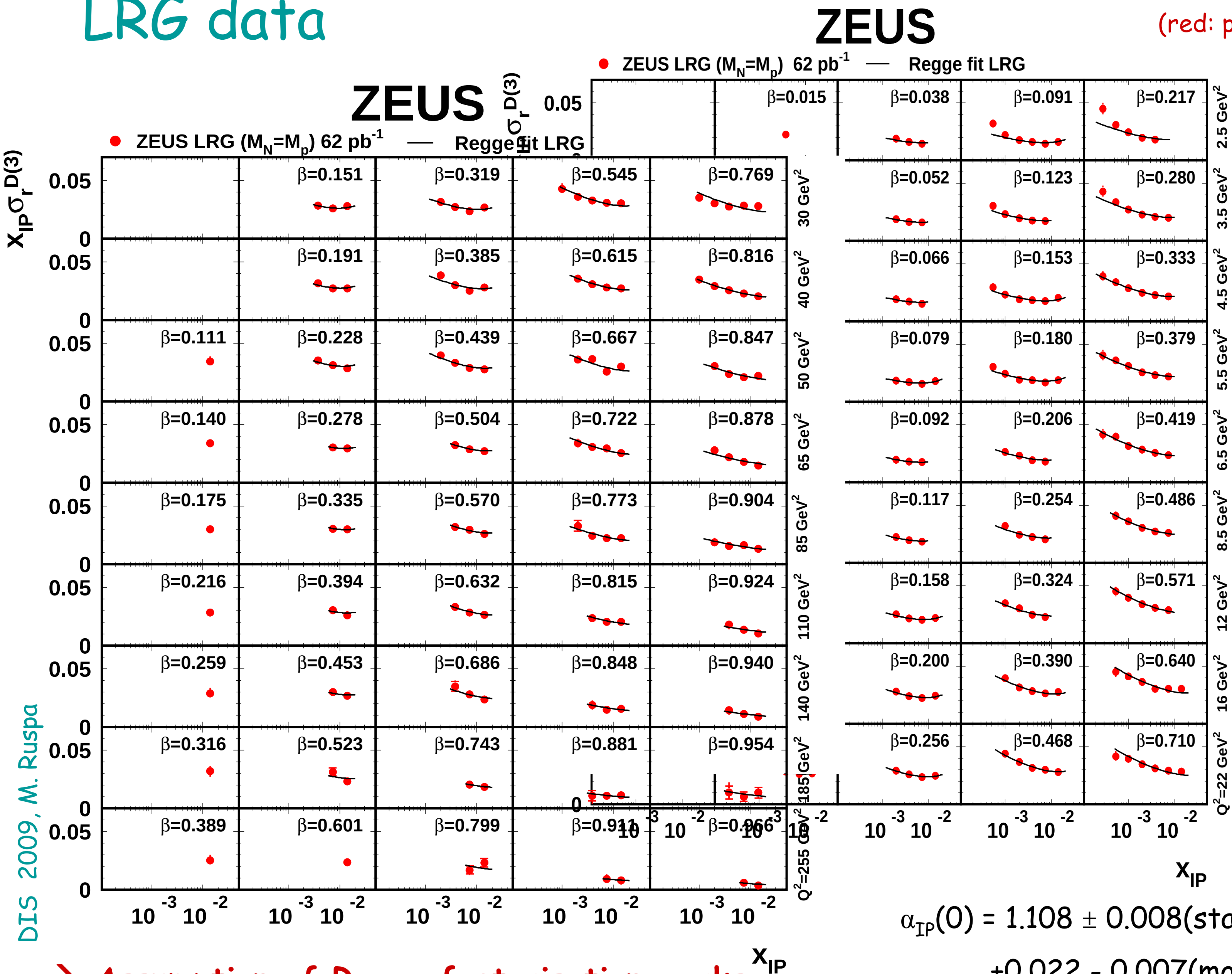
DIS 2009, M. Ruspa

Regge fit LRG data

$$F_2^{D(4)}(\beta,Q^2,x_{IP},t) = f_{IP}(x_{IP},t)F_2^{IP}(\beta,Q^2) + n_{IR}\cdot f_{IR}(x_{IR},t)F_2^{IR}(\beta,Q^2)$$

$$f_{IP,IR} = \exp(B_{IP}t)/x_{IP}^{2\alpha(t)-1},\quad \alpha_{IP/IR}(t) = \alpha_{IP/IR}(0) + \alpha'_{IP/IR}\cdot t$$

(red: parameters fitted)



→ Rise with x_{IP} not visible as x_{IP} < 0.02

$\alpha_{IP}(0) = 1.108 \pm 0.008$(stat+syst)

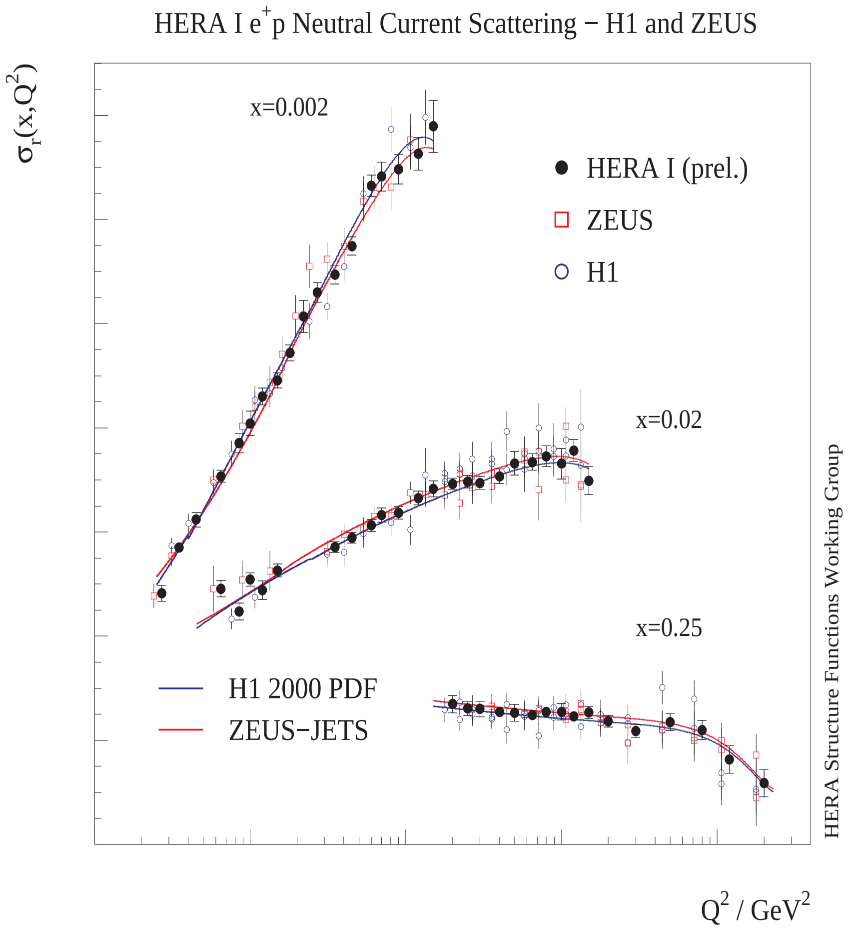
+0.022 - 0.007(model)

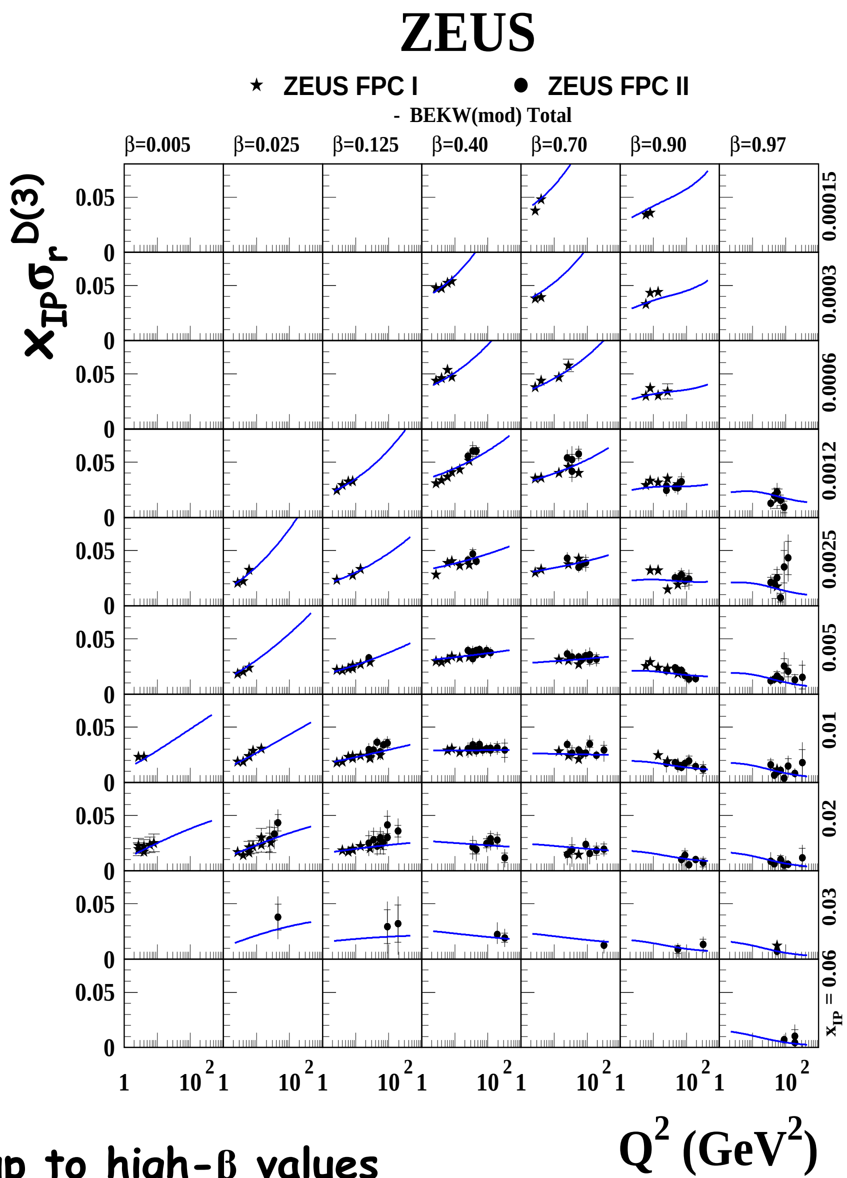
→ Assumption of Regge factorisation works

Q^2 dependence of $\sigma_r^{D(3)}$

M_X data

F_2





$\sigma_r^{D(3)}$ **shows positive scaling violations up to high-β values**

→ Diffractive exchange is gluon-dominated

see talk by W. Slominski

Comparison among selection methods

Data sets

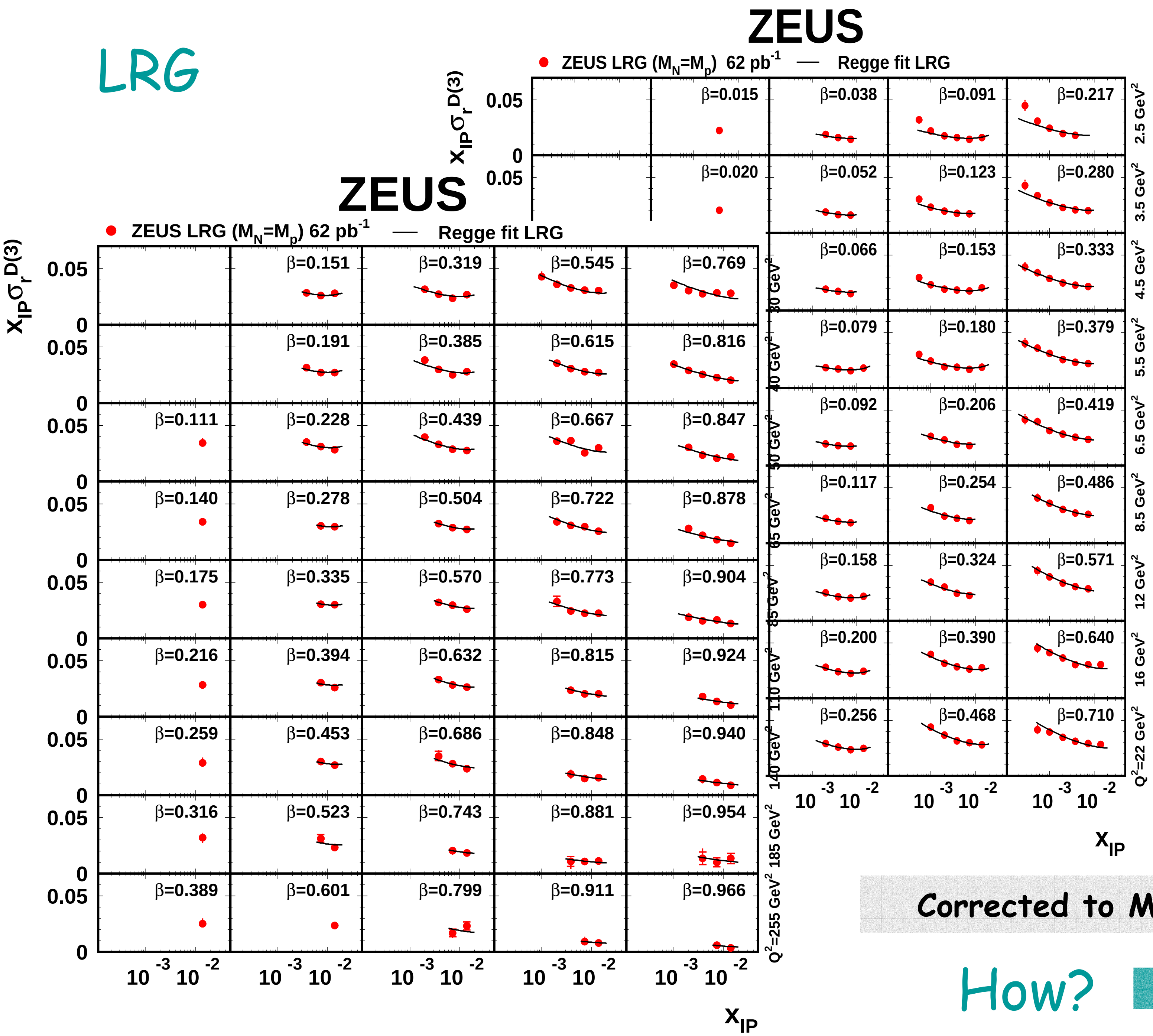
ZEUS

	x_{IP} coverage	M_N coverage
"ZEUS LPS" [NPB 816 (2009)]	x_{IP} up to 0.1	$M_N=m_p$
"ZEUS LRG" [NPB, 816 (2009)]	x_{IP} up to 0.02	$M_N=m_p$
"ZEUS FPC II" (M_X method) [NPB 800 (2008)]	IR suppressed	M_N < 2.3 GeV
"ZEUS FPC I" (M_X method) [NPB 713 (2005)]	IR suppressed	M_N < 2.3 GeV

35% of LPS events selected by LRG
Overlap LRG-M_X ~75%

Precise knowleadge (and correction) of p.-diss background key point in the data comparison!

LRG



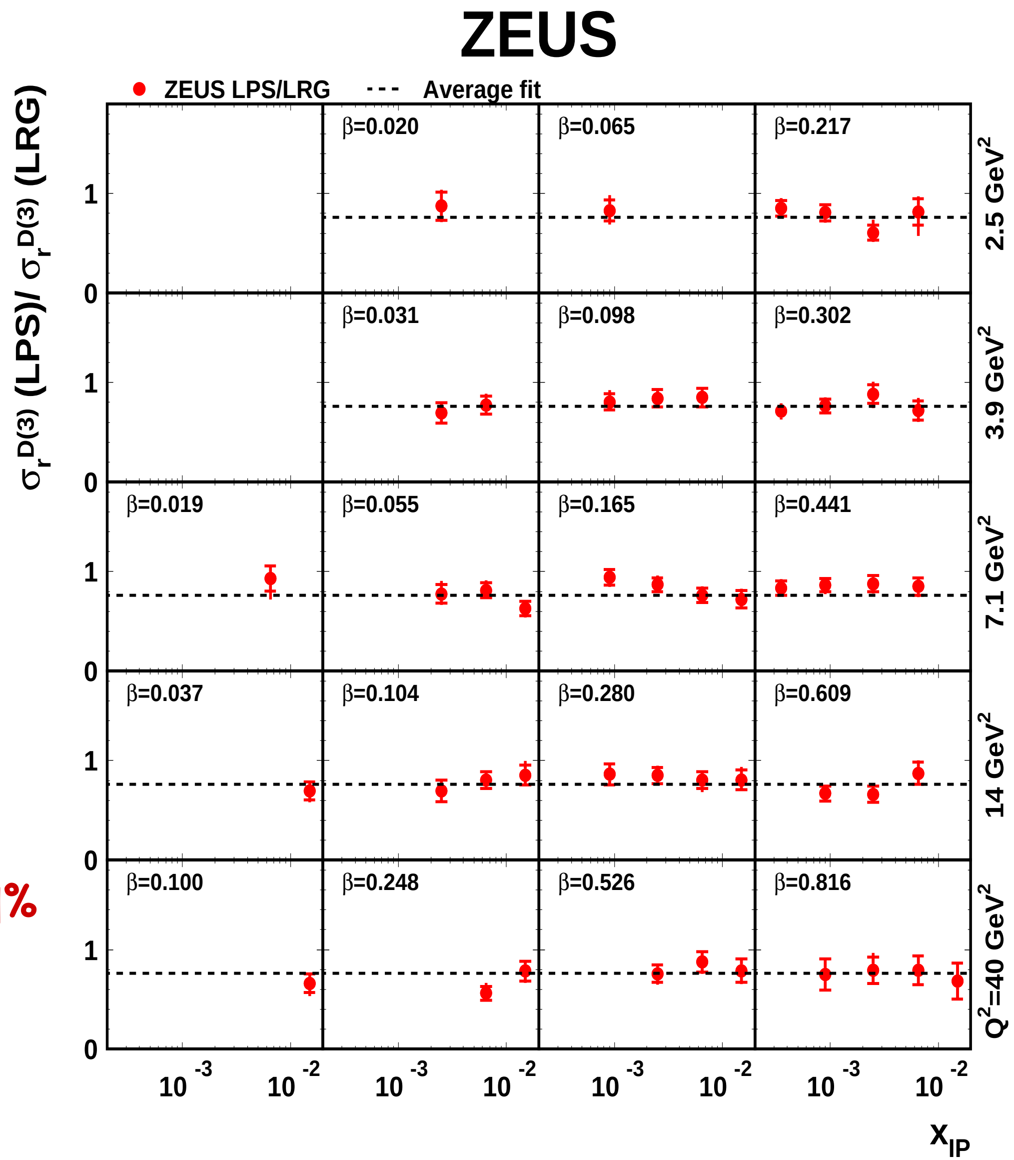
Corrected to $M_N = m_p$

How?

LRG: correction to $M_N = m_p$

i) ratio LPS/LRG

→ **LPS/LRG independent of Q^2, x_{IP}, β**



LPS/LRG = 0.76 +-0.01(stat) +0.03-0.02(sys) +0.08-0.05 (norm)

→ p-diss. background in LRG data:

[24 +-1(stat) +2-3(sys) +5-8(norm)]%

In itself a comparison LRG vs LPS!

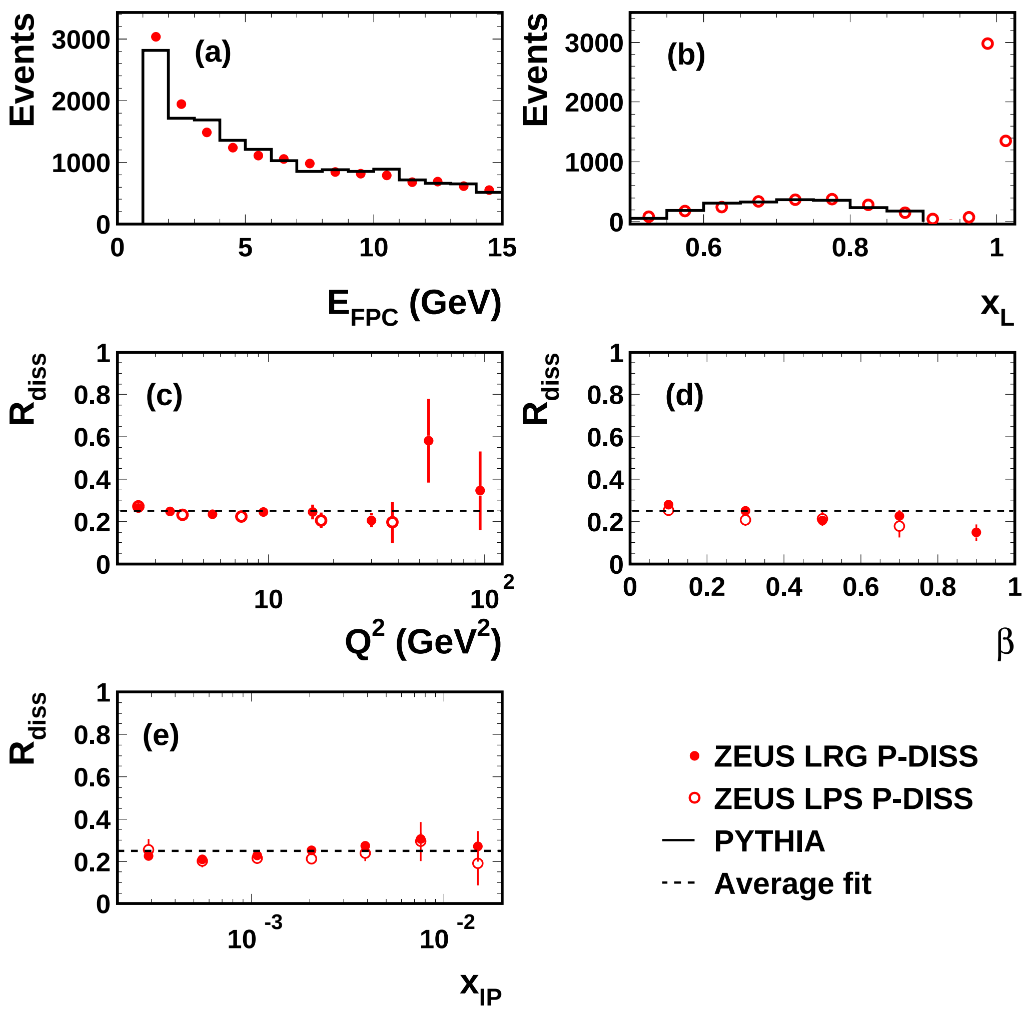
LRG: correction to $M_N = m_p$

ii) Monte Carlo (PYTHIA)

- 2 samples of proton-dissociative data, one with LPS (“LPS P-DISS”) and one with Forward Plug Calorimeter (“LRG P-DISS”)
  → coverage of full M_N spectrum

- PYTHIA reweigthed to best describe E_{FPC} and x_L

ZEUS



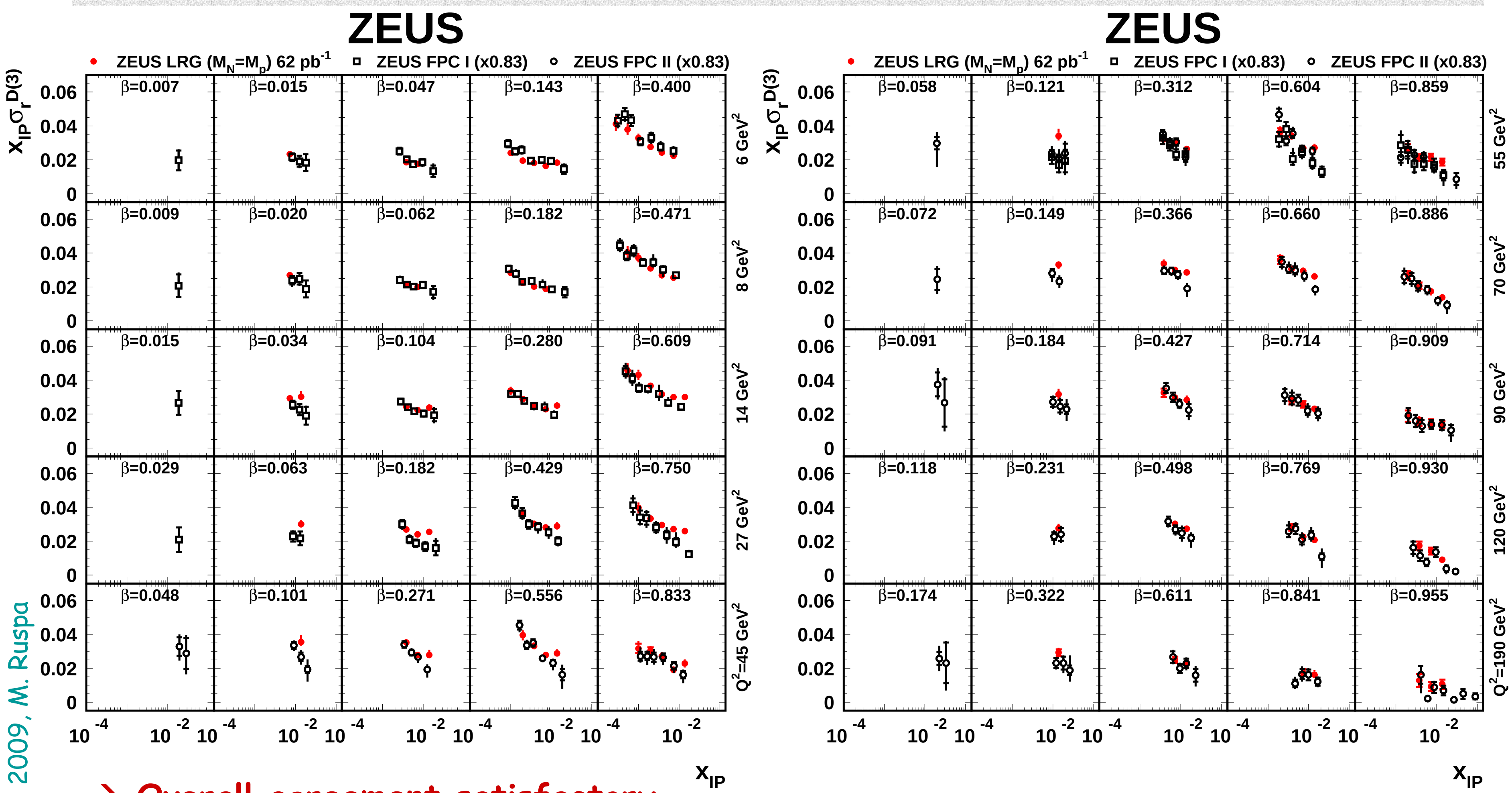
→ p-diss. background in LRG data R_{diss} = [25 +-1(stat) +-3(sys)]%

→ consistent with the ratio LPS/LRG

→ 25% correction applied to LRG data

LRG vs M_x

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 estimates residual p-diss. background in M_x sample



→ Overall agreement satisfactory

→ Different x_{IP} dependence ascribed to IR suppressed in M_x data

Comparison with H1

Data sets

		x_{IP} coverage	M_N coverage
ZEUS	"ZEUS LPS" [NPB, 816 (2009)]	x_{IP} up to 0.1	$M_N=m_p$
	"ZEUS LRG" [NPB, 816 (2009)]	x_{IP} up to 0.02	$M_N=m_p$
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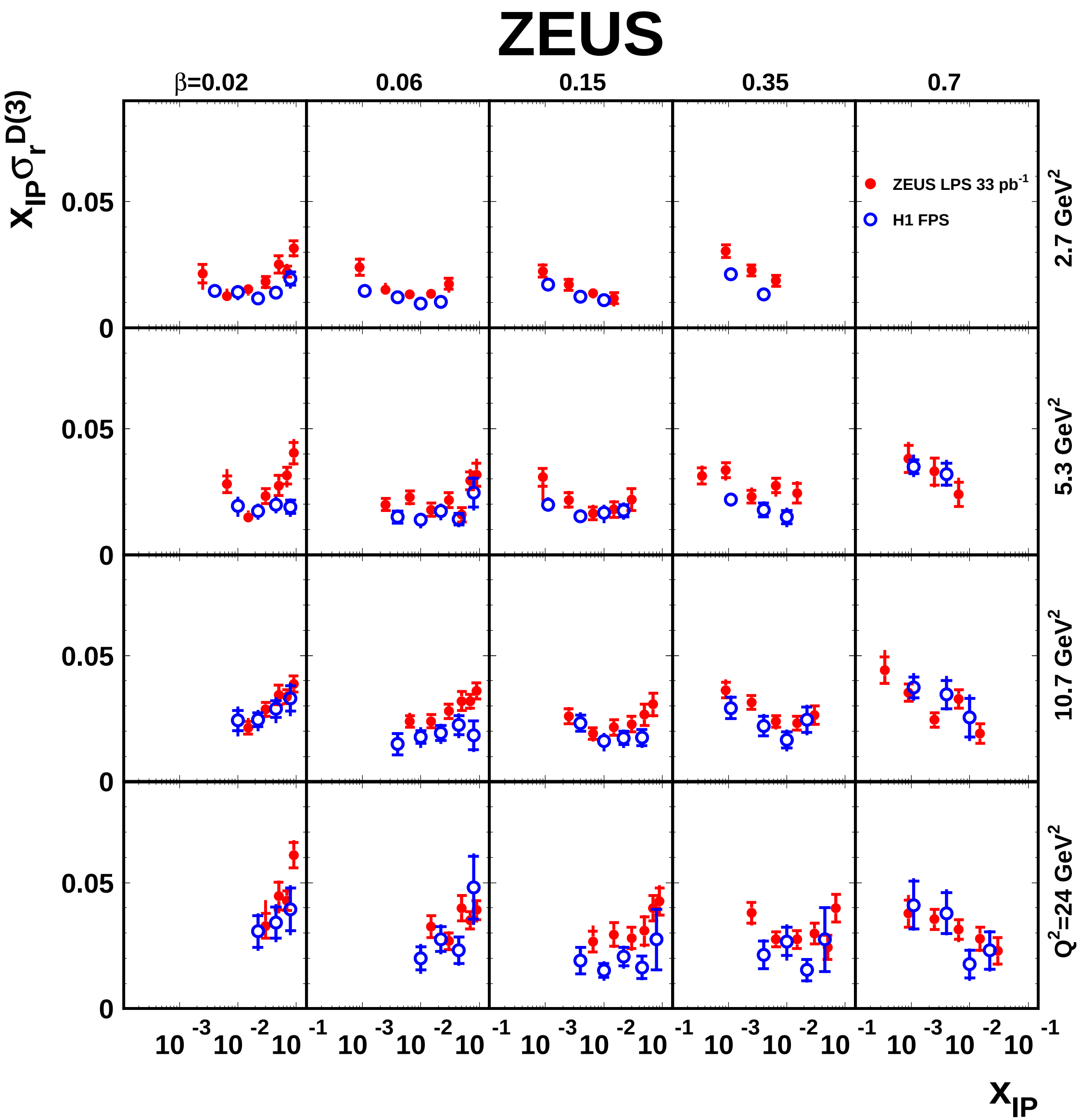
35% of LPS events selected by LRG
Overlap LRG-M_X ~75%

H1	"H1 FPS" [EPJ C48 (2006)]	x_{IP} up to 0.1	$M_N=m_p$
	"H1 LRG" [EPJ C48 (2006)]	x_{IP} up to 0.03	M_N < 1.6 GeV

FPS and LRG measurements statistically independent
and only very weakly correlated through systematics

ZEUS LPS vs H1 FPS



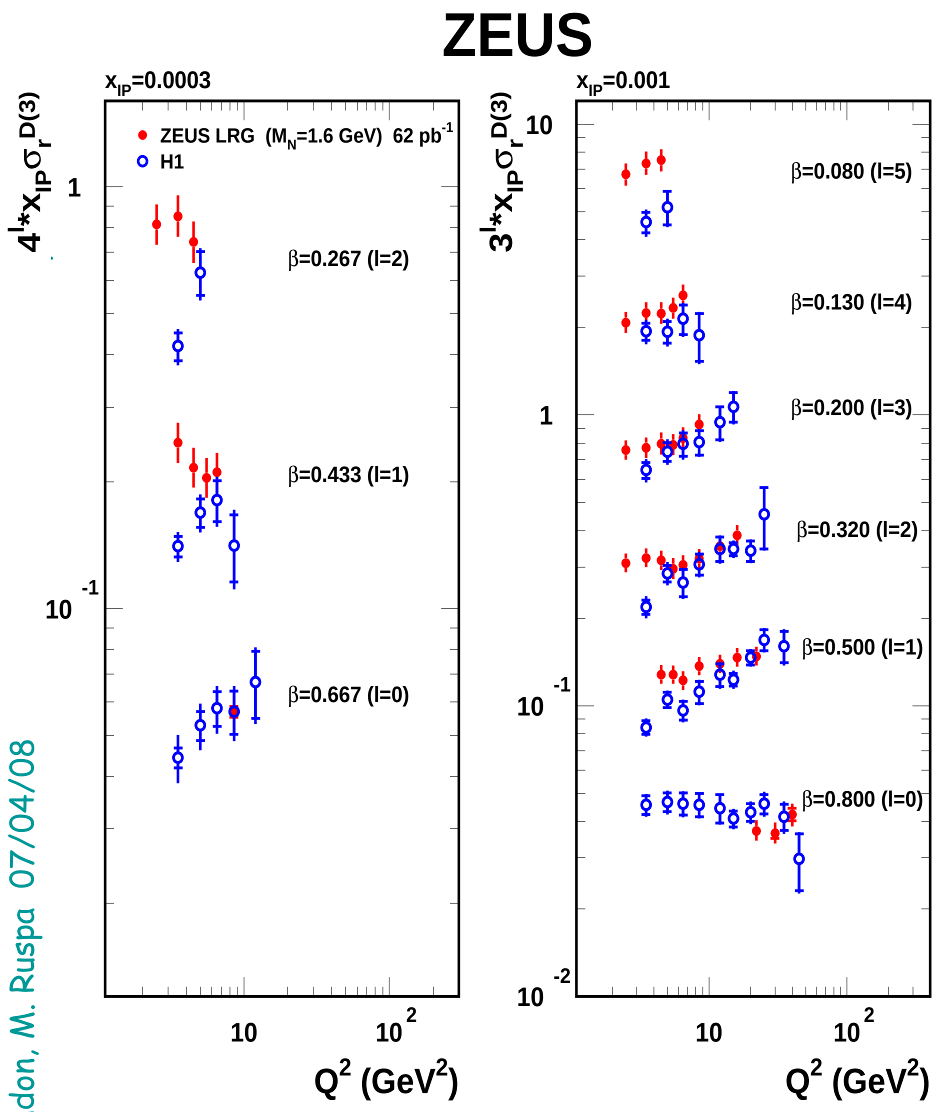
The cleanest possible comparison in principle…

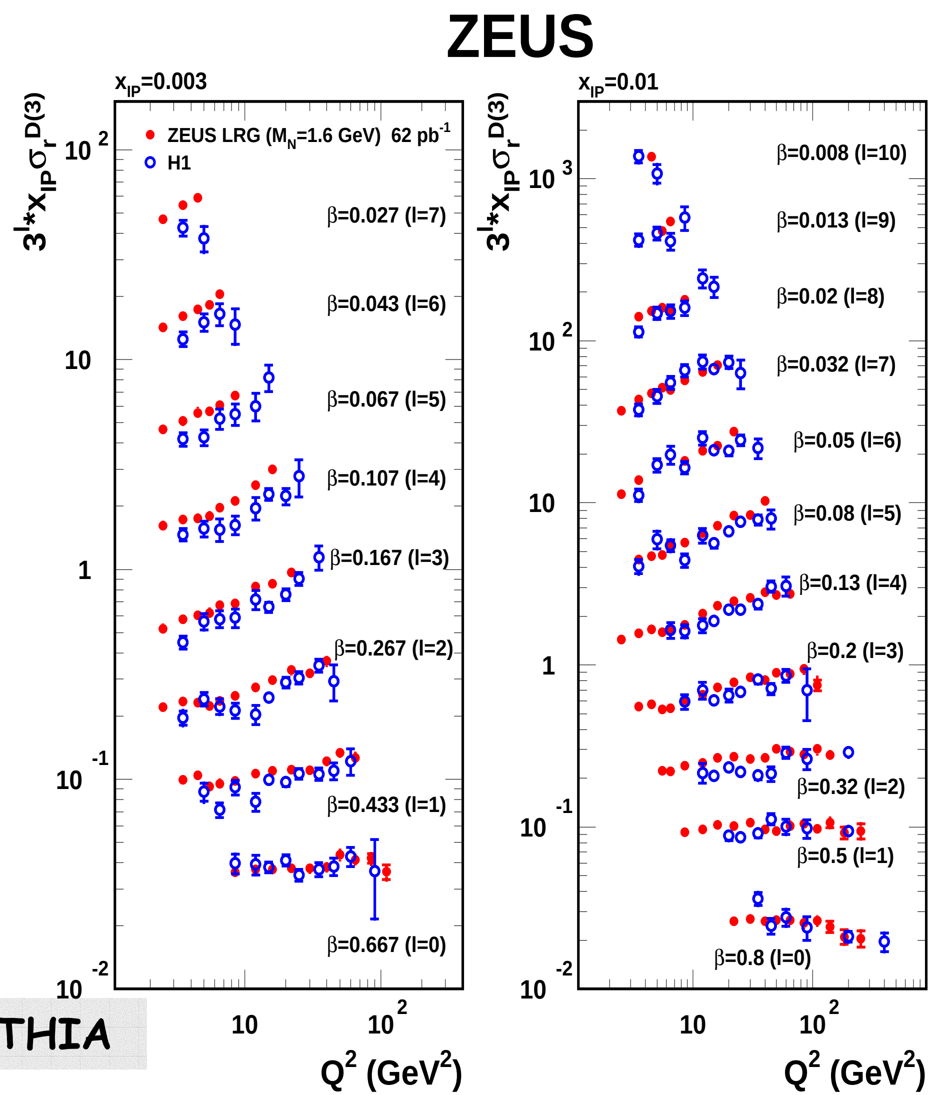
…but large normalisation uncertainties (LPS:+11-7%, FPS: +-10%)

New comparison plot available with HERA II FPS data!
see talk by M.Kapishin

→ ZEUS and H1 proton-tagged data agree within normalisation uncertainties

ZEUS LRG vs H1 LRG



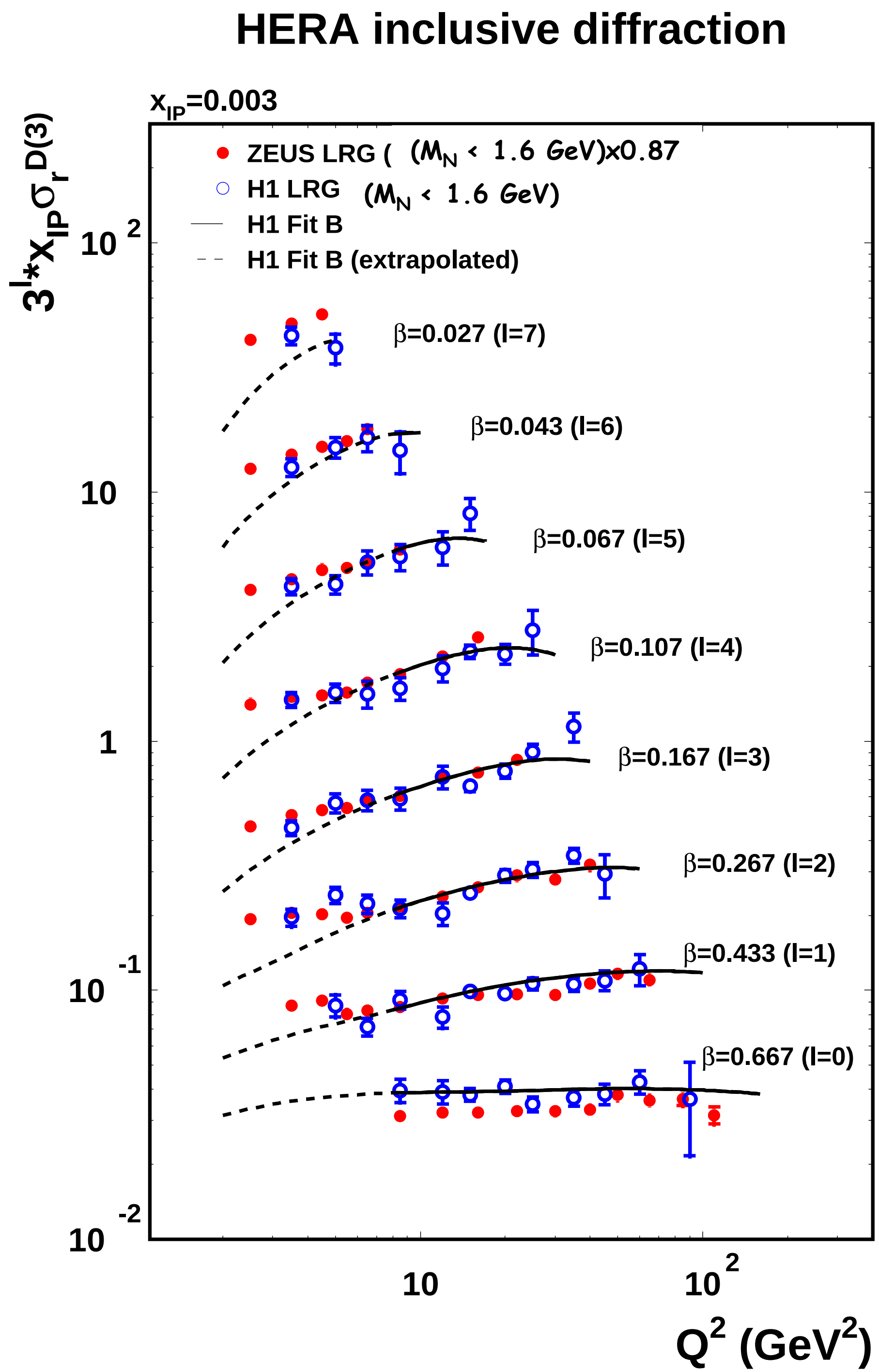


ZEUS corrected to M_N < 1.6 GeV with PYTHIA

→ Remaining normalisation difference of 13% (global fit) covered by uncertainty on p-diss. correction (8%) and relative normalisation uncertainty (7%)

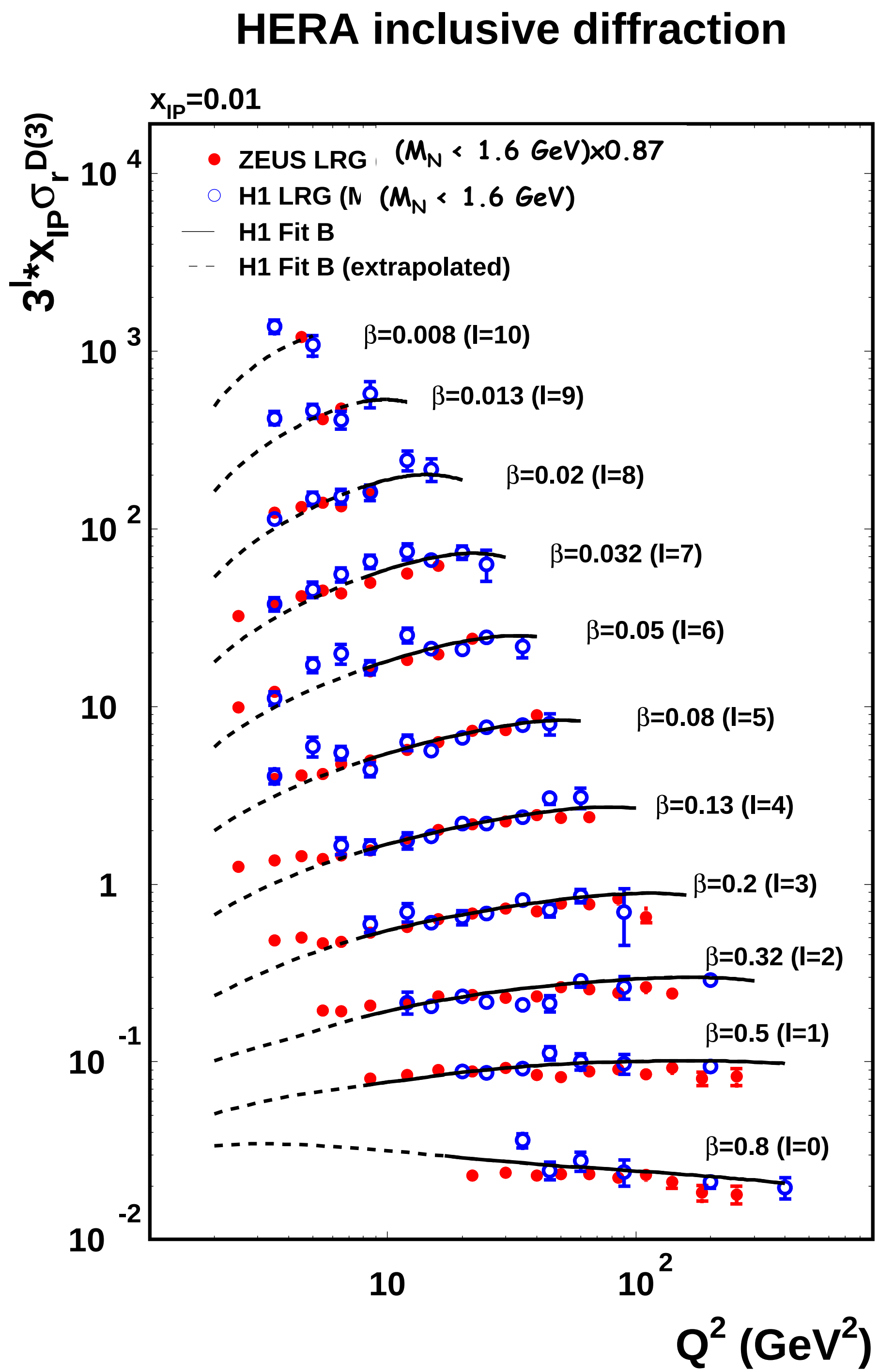
→ Shape agreement ok except low Q^2

Towards HERA inclusive diffraction!



→ Time for data combination, global fits!

Towards HERA inclusive diffraction!



→ Time for data combination, global fits!

Summary and beyond

- Final ZEUS results on inclusive diffraction – same data analysed in three independent ways:
  - Proton tag requirement
  - Large rapidity gap requirement
  - Shape of the mass distribution of the hadronic final state

- Proton dissociation background under control

- Vertex factorisation assumption works to a good approximation

→ QCD fits, talk by W. Slominsky

- Consistent results between different methods and data sets

- ZEUS results consistent with H1 results within uncertainties

→ Discussion on data combination

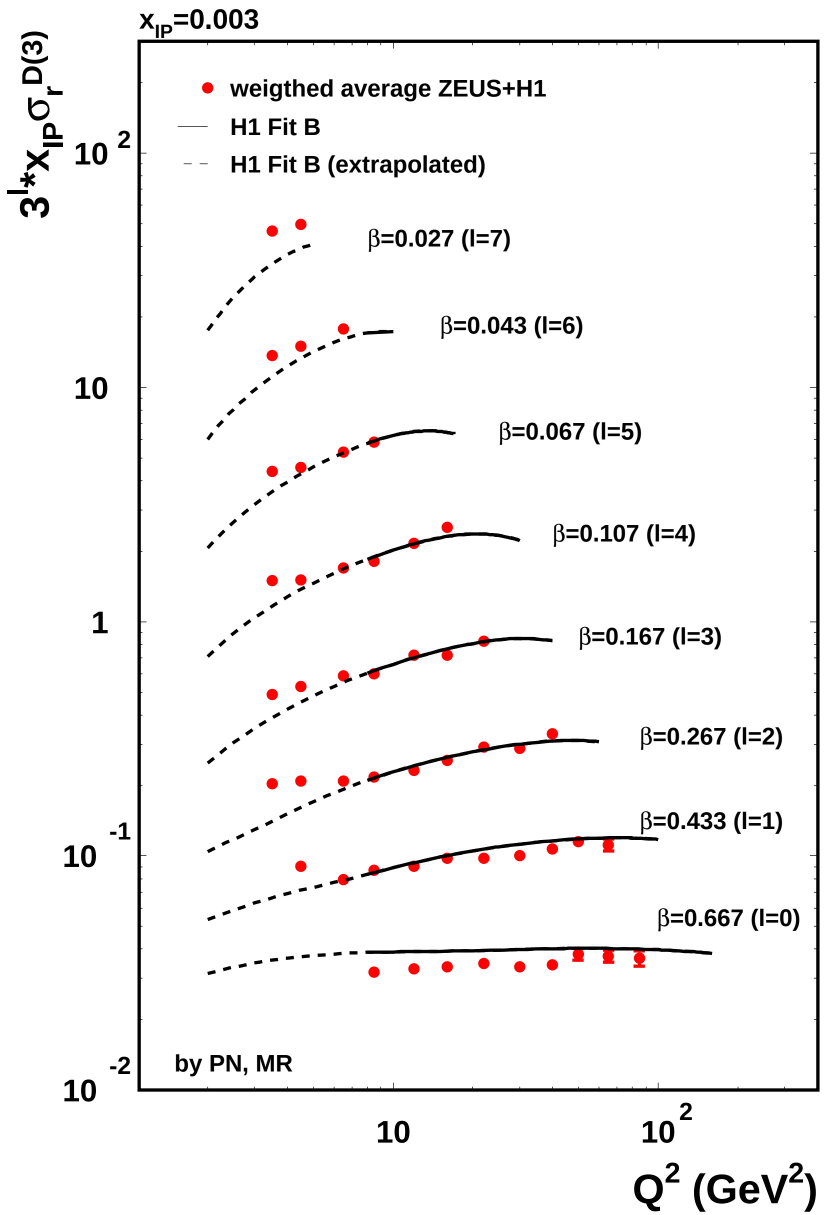
Backup

First step towards the data combination

Error weigthed average:

- before averaging, H1 points swum to ZEUS Q^2 values with H1 fit B
- ZEUS normalised to H1 applying 13% factor (see slide 36) → **normalisation uncertainty of combined data beyond 10%**
- **correlations between systematic errors ignored so far**

Hints at precision achievable through combination: for many points errors at 3-4% level (excluding normalisation uncertainty)



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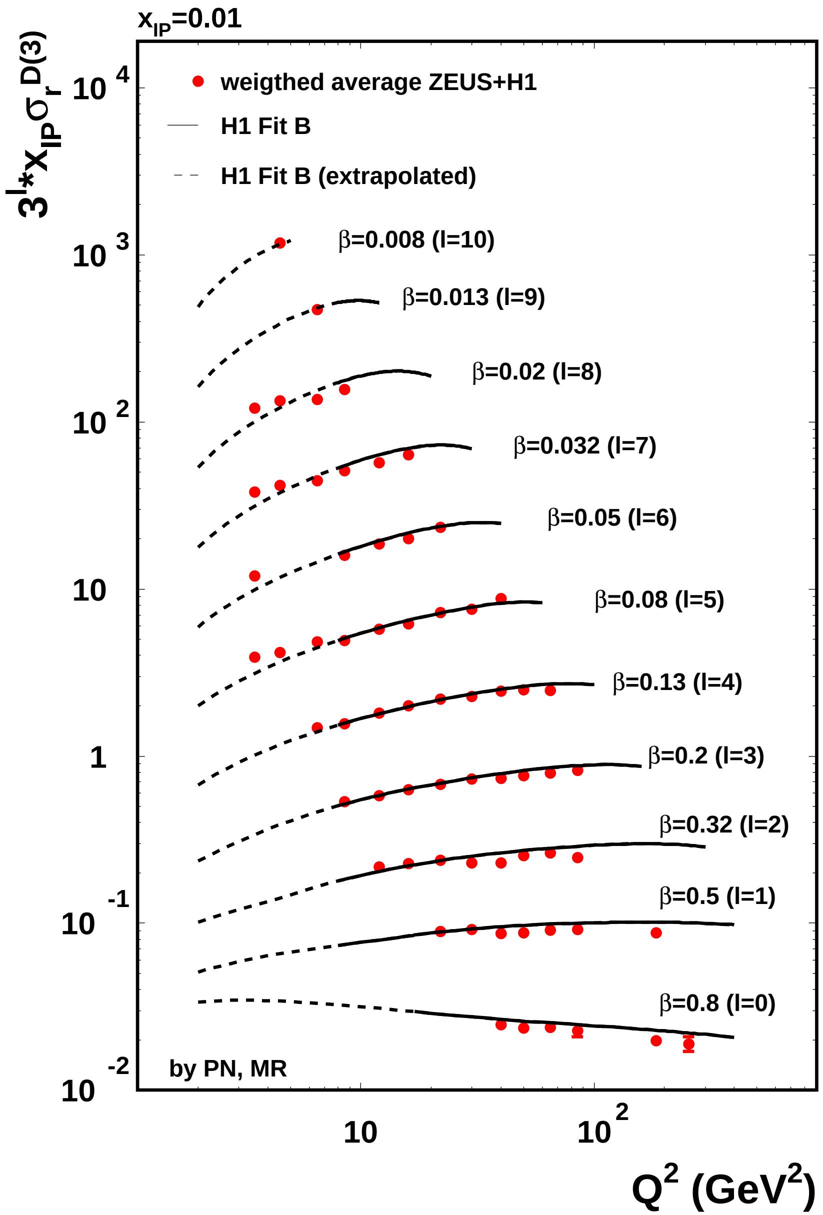
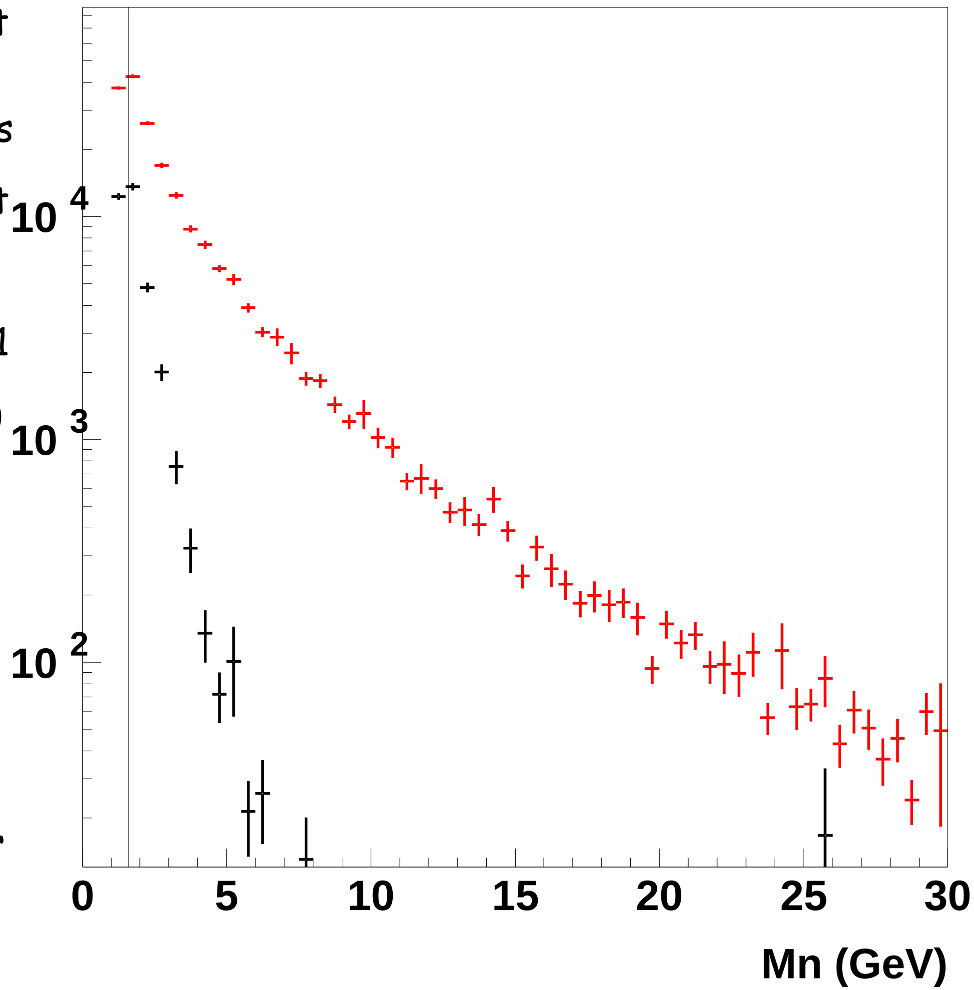


ZEUS LRG: correction to $M_N < 1.6$ GeV

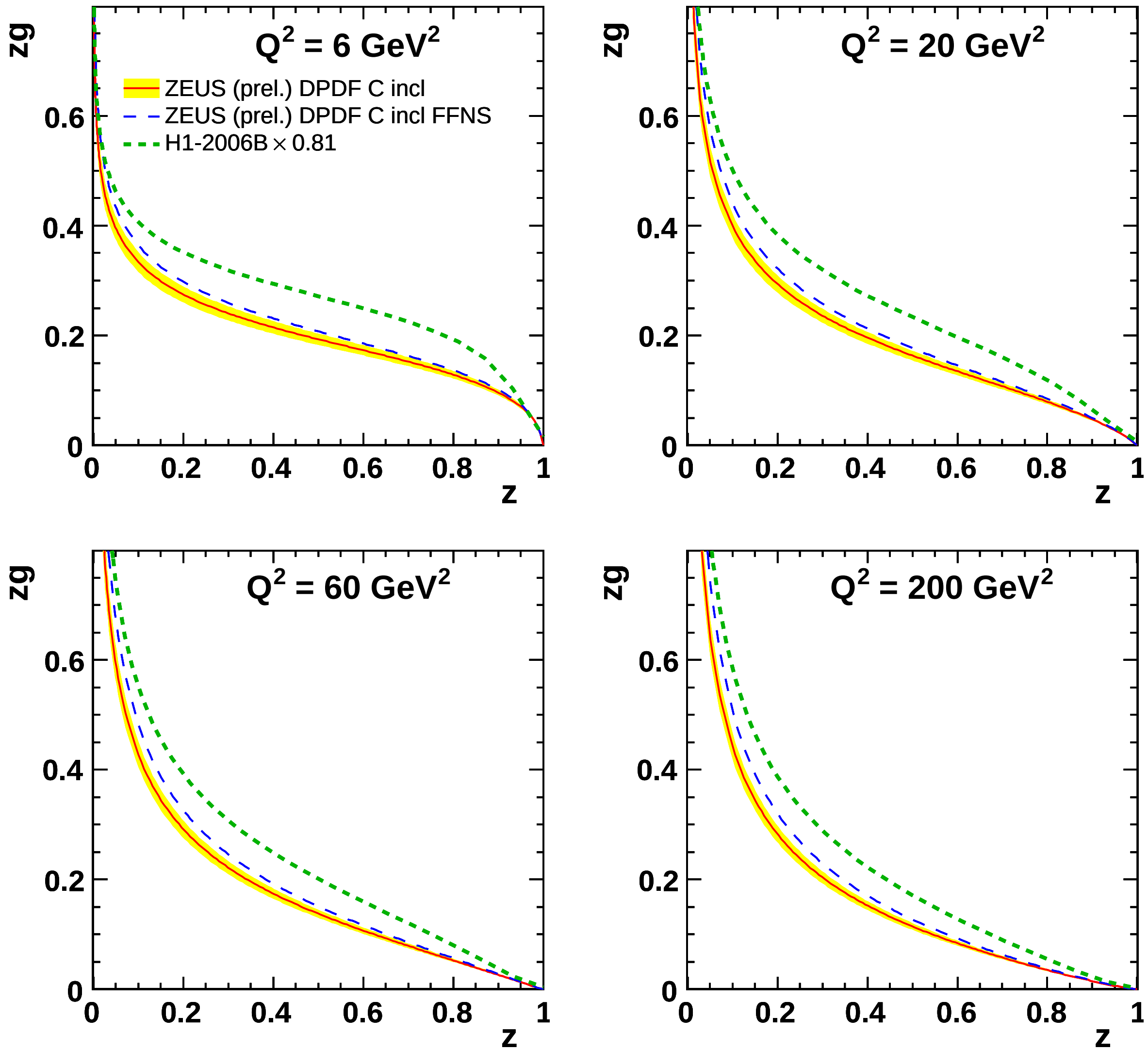
'The plot in attachment shows MN distribution at generated level by red histogram and after all selection cuts by black histogram. When we apply all selection cuts in LRG analysis the MN shape of p-diss background looks like black histogram. We calculate acceptance using SATRAP which knows nothing about MN. It means that after acceptance correction the remaining p-diss background still has the shape of the black histogram. The integral under this black histogram is our 25%. If we want to compare with H1 we should remove from the acceptance corrected cross section the remaining p-diss background (25%) and add the integral over generated MN shape (red histogram) up to Mn=1.6 GeV. The correction factor is

(sigma_elastic_data+sigma_pdiss_MC(MN<1.6)) /sigma_data where

- sigma_data = acceptance corrected cross section with p-diss backgound
- sigma_elastic_data = acceptance corrected cross section without p-diss background, it is just sigma_data*0.75
- sigma_pdiss_MC(MN<1.6 - p-diss MC prediction for Mn<1.6 GeV

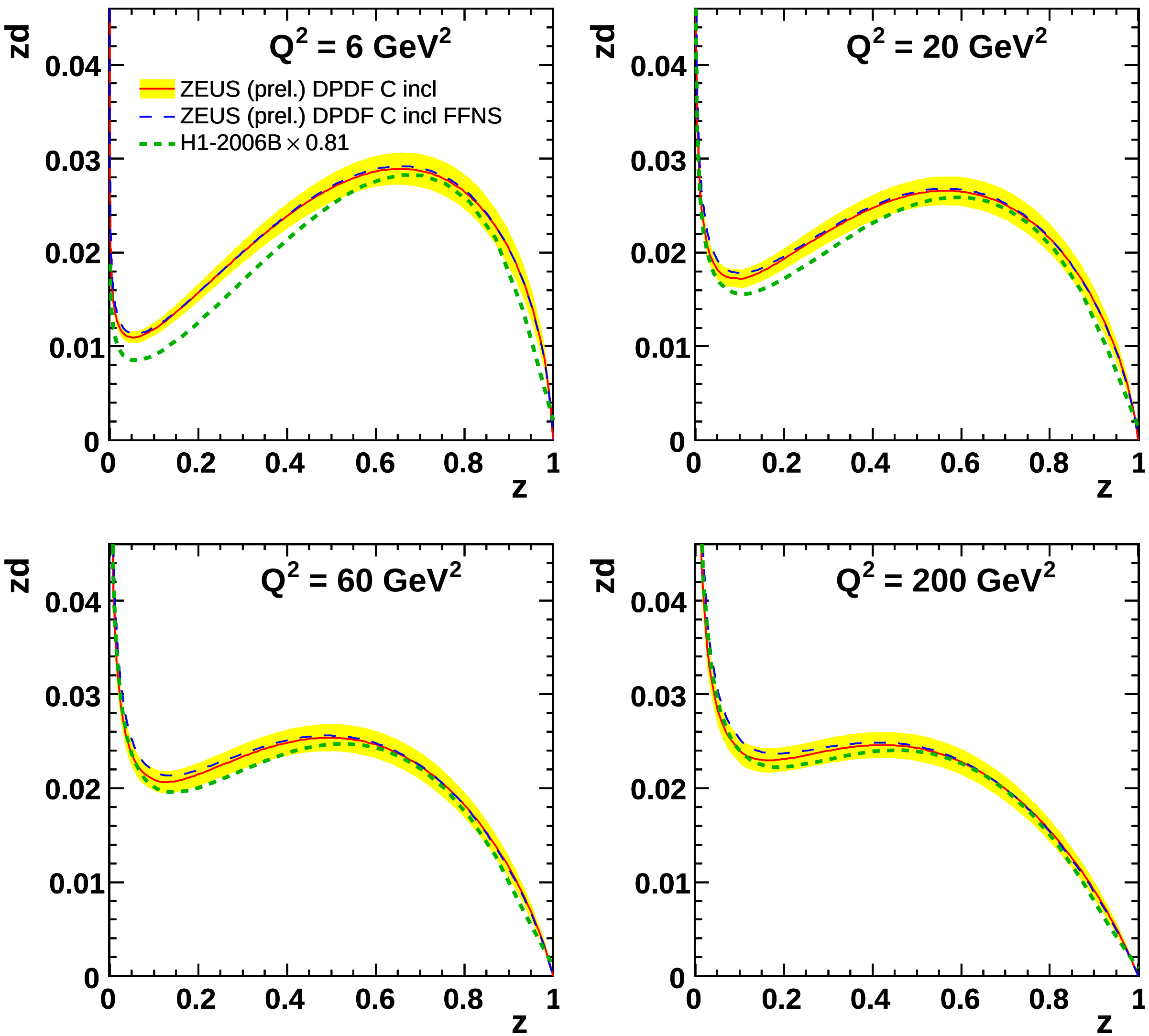


ZEUS

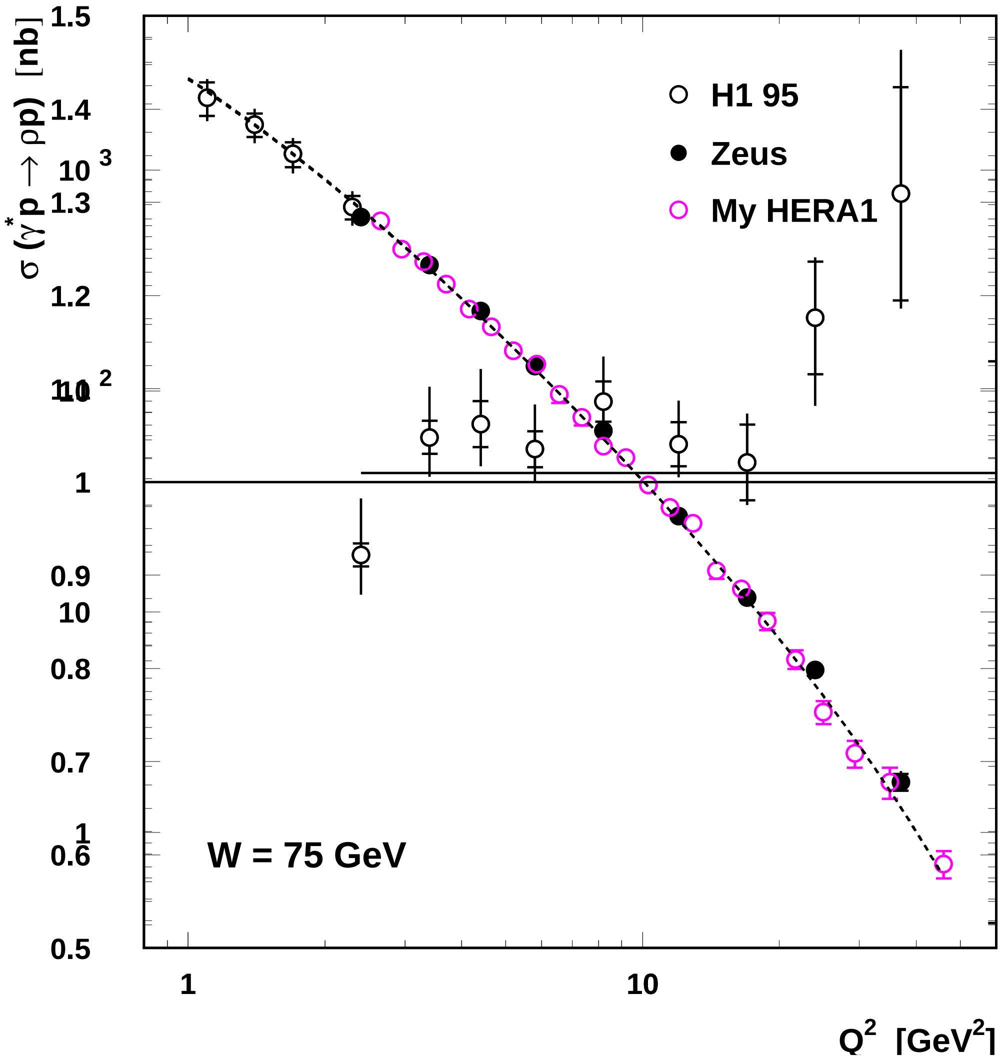


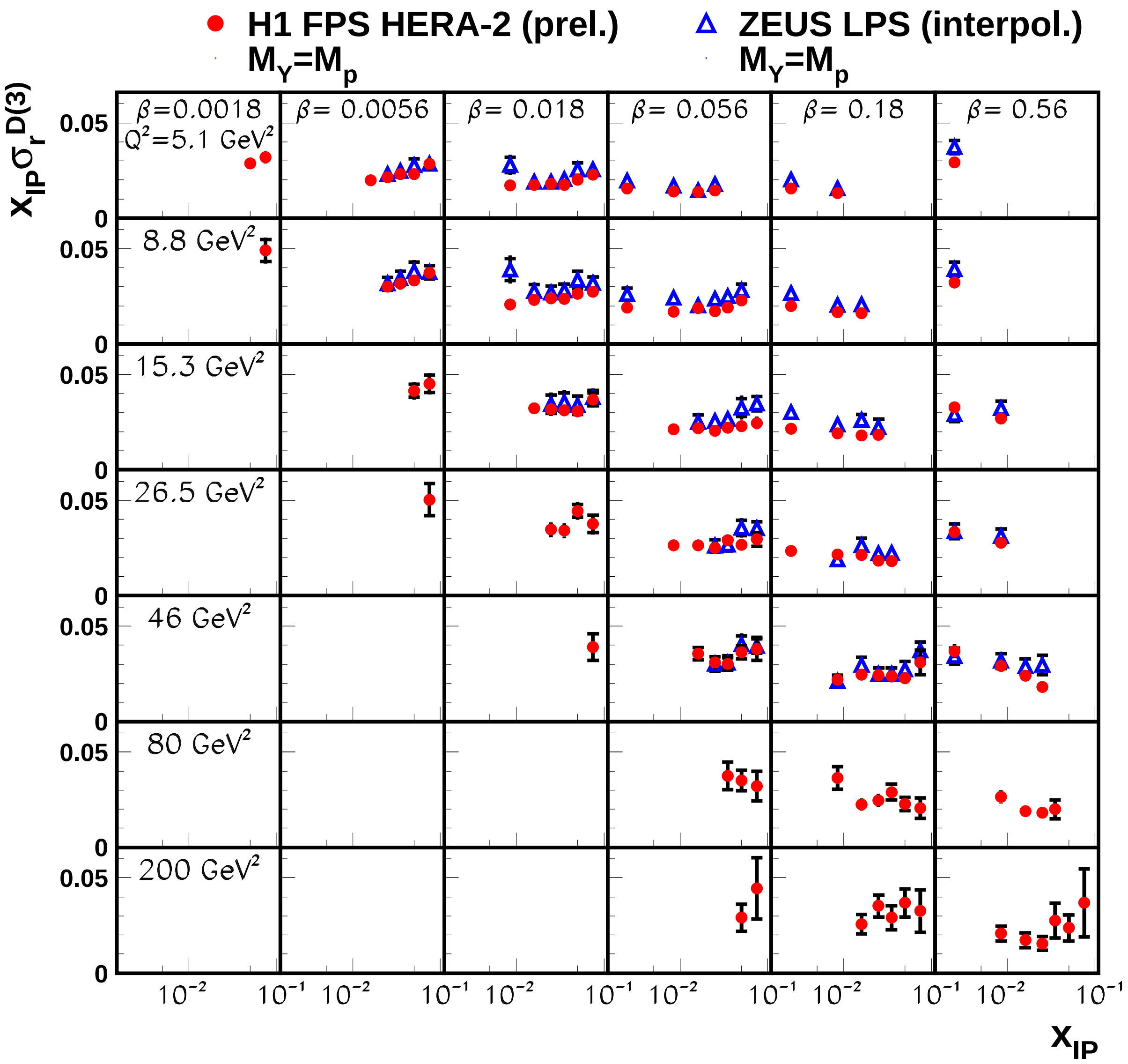
zg
Q^2 = 6 GeV^2
ZEUS (prel.) DPDF C incl
ZEUS (prel.) DPDF C incl FFNS
H1-2006B × 0.81
Q^2 = 20 GeV^2
Q^2 = 60 GeV^2
Q^2 = 200 GeV^2
0
0.2
0.4
0.6
0.8
1
z

ZEUS



zd
Q^2 = 6 GeV^2
Q^2 = 20 GeV^2
Q^2 = 60 GeV^2
Q^2 = 200 GeV^2
ZEUS (prel.) DPDF C incl
ZEUS (prel.) DPDF C incl FFNS
H1-2006B × 0.81
0.04
0.03
0.02
0.01
0
0.2
0.4
0.6
0.8
1
z


H1 95
Zeus
My HERA1
W = 75 GeV
σ (γ* p → ρp) [nb]
Q² [GeV²]
1.5
1.4
1.3
1.2
1
0.9
0.8
0.7
0.6
0.5
10 3
10 2
10
1
1
10



H1 FPS HERA-2 (prel.)
$M_Y=M_p$
ZEUS LPS (interpol.)
$M_Y=M_p$
$x_{IP}\sigma_r^{D(3)}$
β=0.0018
β= 0.0056
β= 0.018
β= 0.056
β= 0.18
β= 0.56
Q^2=5.1 GeV^2
8.8 GeV^2
15.3 GeV^2
26.5 GeV^2
46 GeV^2
80 GeV^2
200 GeV^2
0.05
0
10^{-2}
10^{-1}
x_{IP}

Regge factorisation: yes or no?
(my interpretation)

Apparent contradiction:

- Regge fit works within errors for LPS/FPS and LRG data
- FPC and LRG (see later) show violation of Regge factorisation

→ **Data consistent with Regge factorisation; violation too mild to have impact on the fit quality**

What if we fitted LPS/FPS/LRG without assuming Regge factorisation?

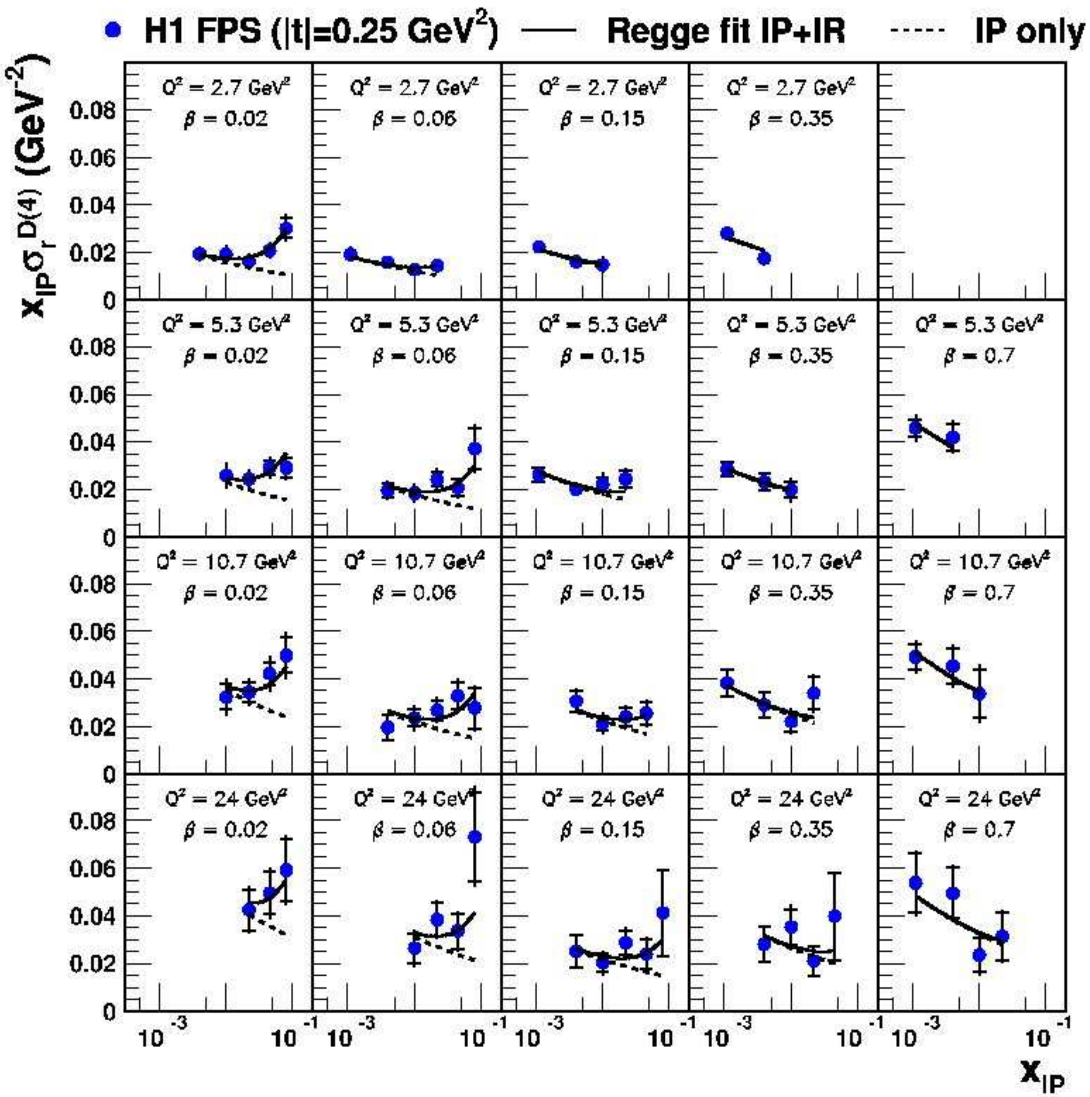
Not done yet but done for the FPC data → **BEKW fit works well!**

[Bartels, Ellis, Kowalski, Wustoff, see NPB 800 (008)]

Mild violations should not affect QCD fits, which assume factorisation

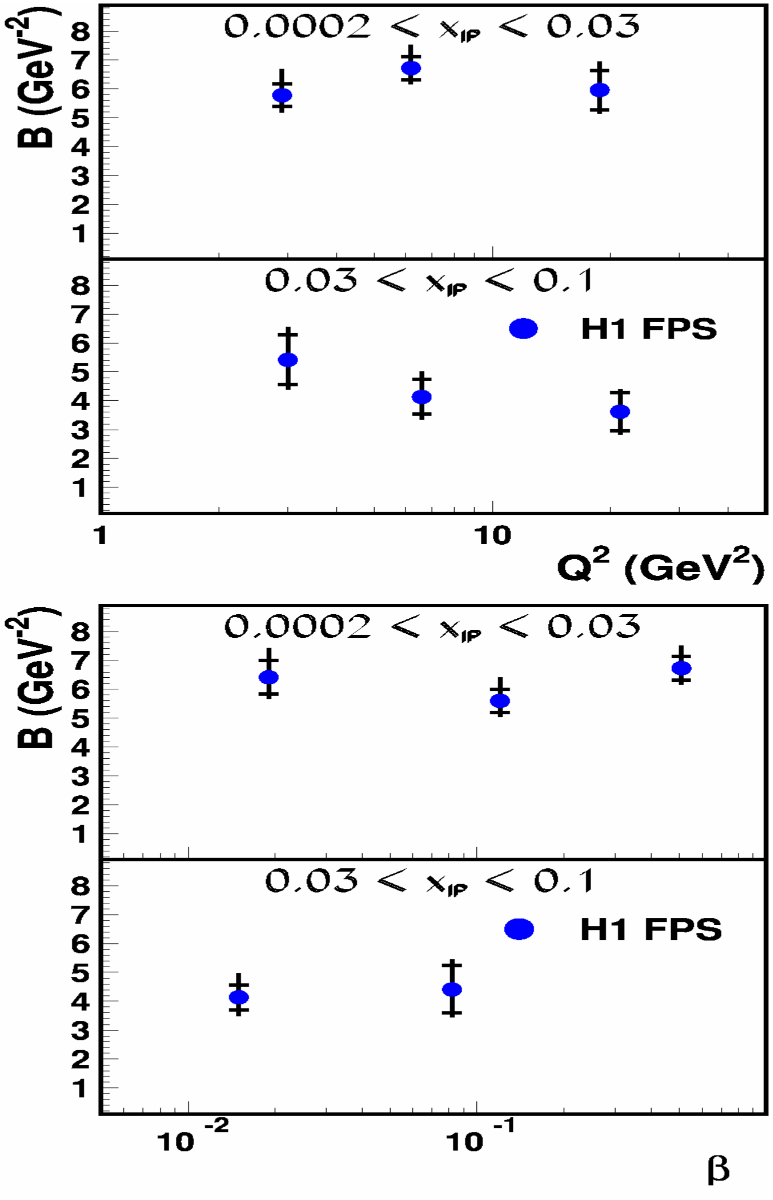
x_{IP} dependence of $\sigma_r^{D(4)}$

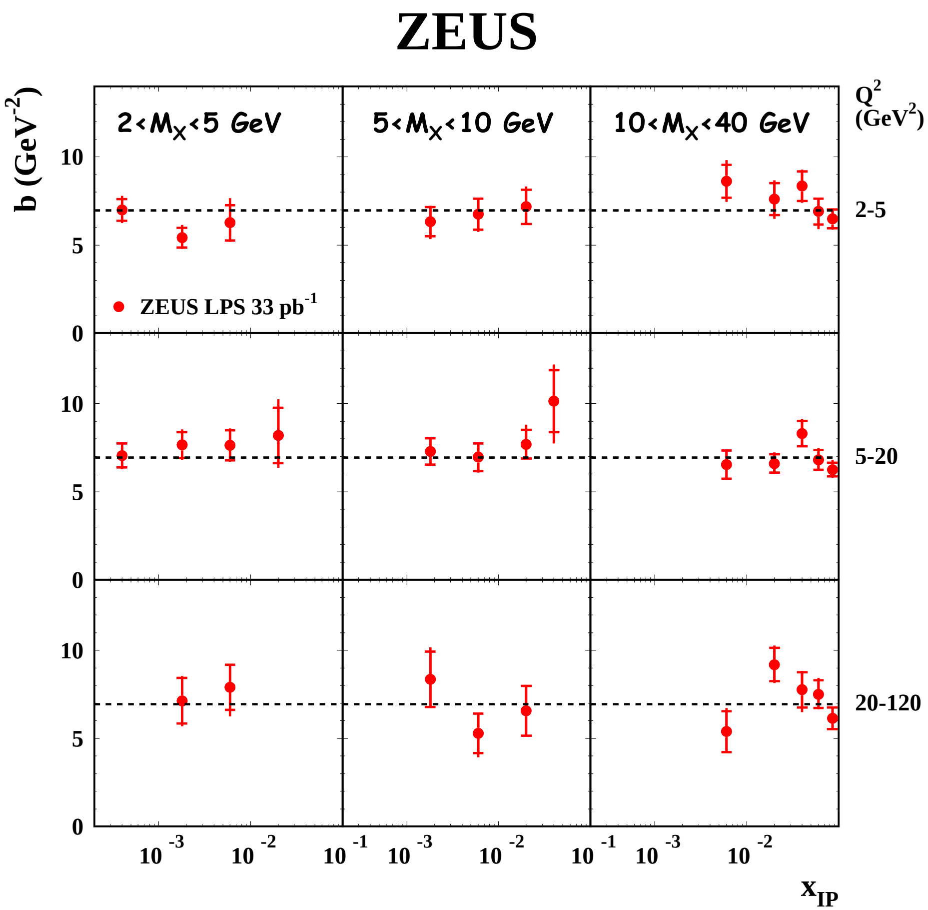
FPS data



t dependence

LPS/FPS data

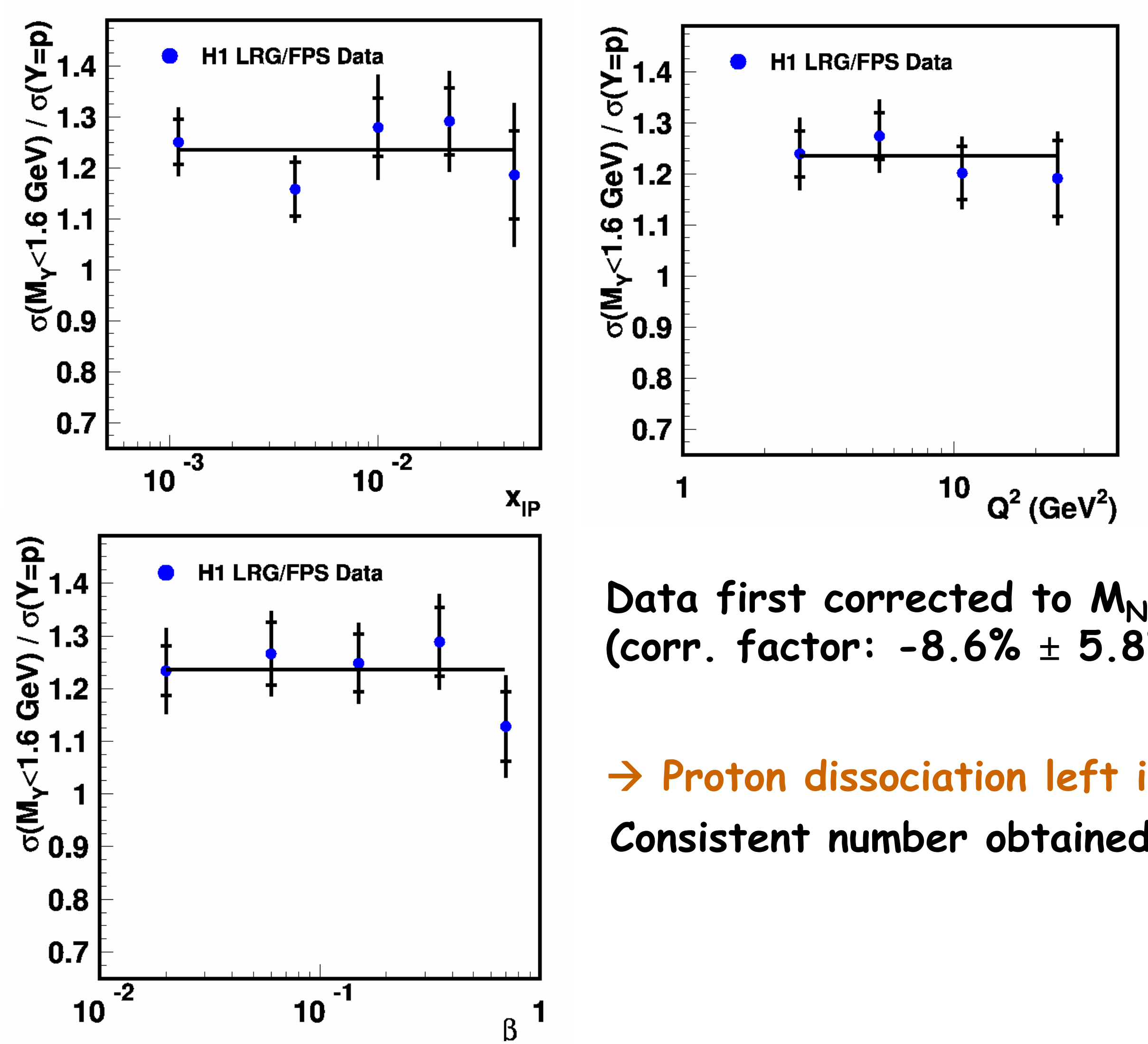




→ Support Regge factorisation hypothesis

H1 LRG vs H1 FPS

Proton dissociation-background in the H1 LRG data



→ **LRG/FPS independent of x_{IP}, Q^2, β**

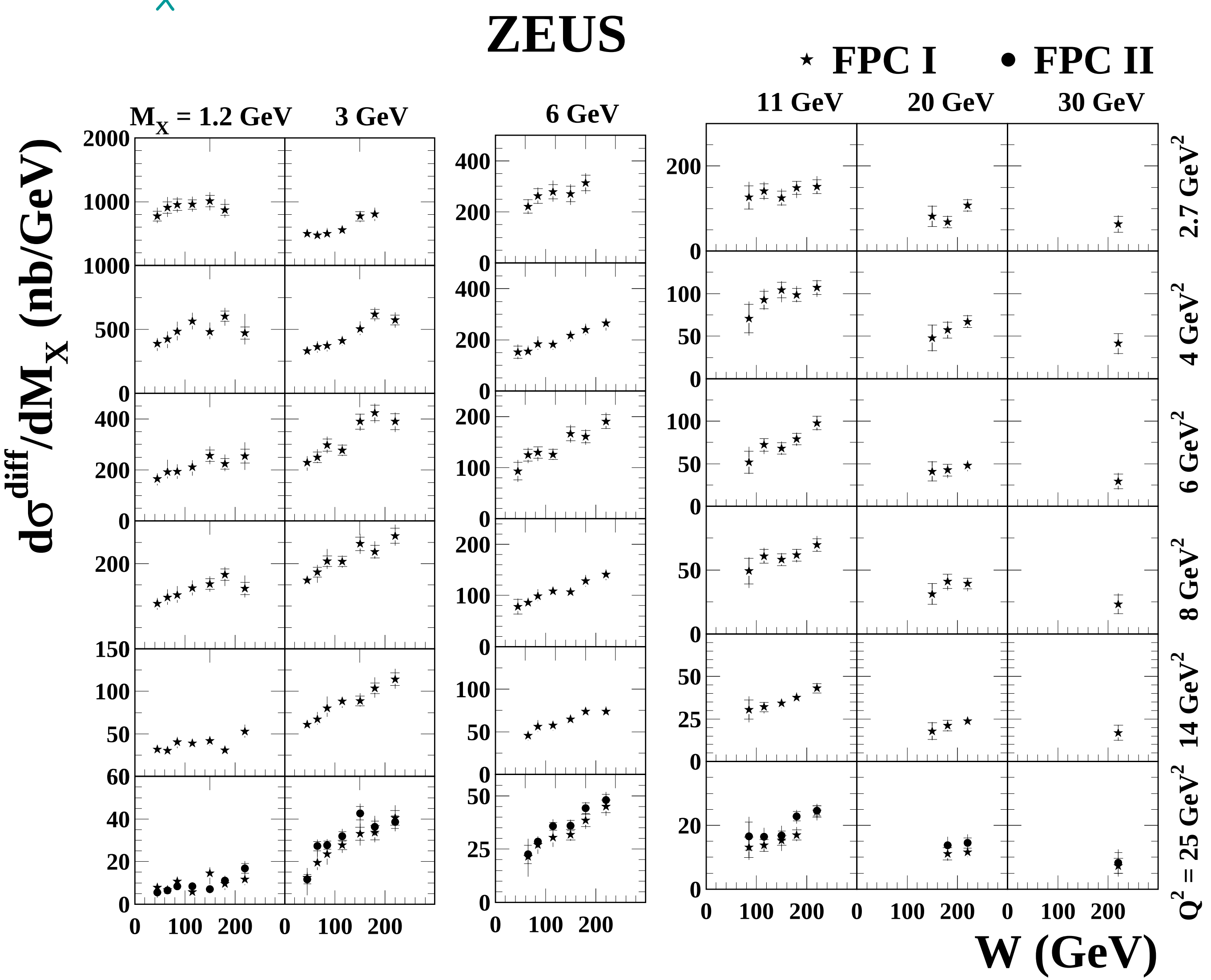
Data first corrected to M_N < 1.6 GeV (corr. factor: -8.6% ± 5.8%)

→ Proton dissociation left in H1 LRG data: [19+-11]%

Consistent number obtained with DIFFVM: [13 +11 -6]%

W dependence of $d\sigma^{diff}/dM_X$

ZEUS M_X data

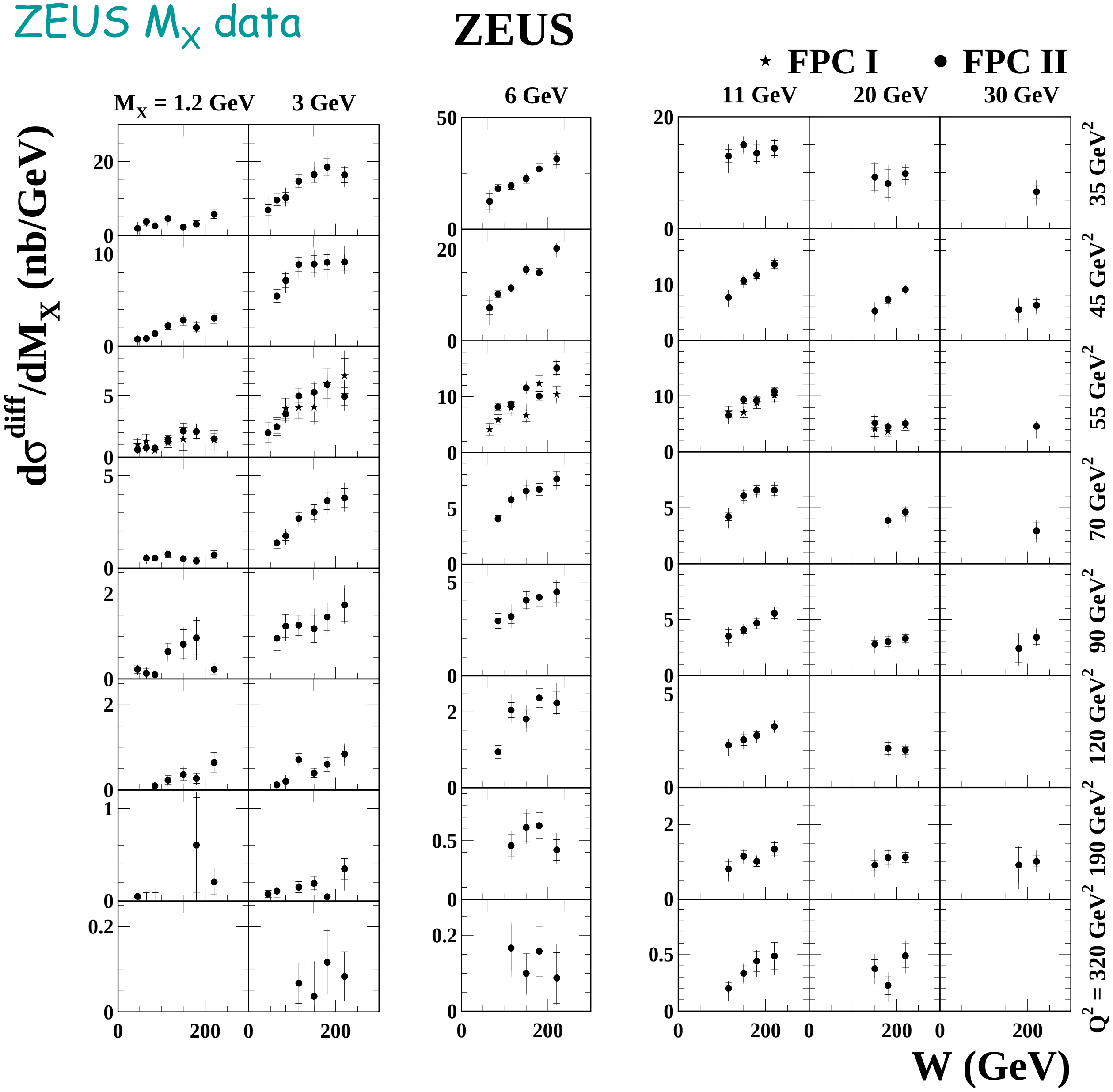


→ Low M_X: moderate increase with W and steep reduction with Q^2

→ Higher M_X: substantial rise with W and slower decrease with Q^2

W dependence of $d\sigma^{diff}/dM_X$

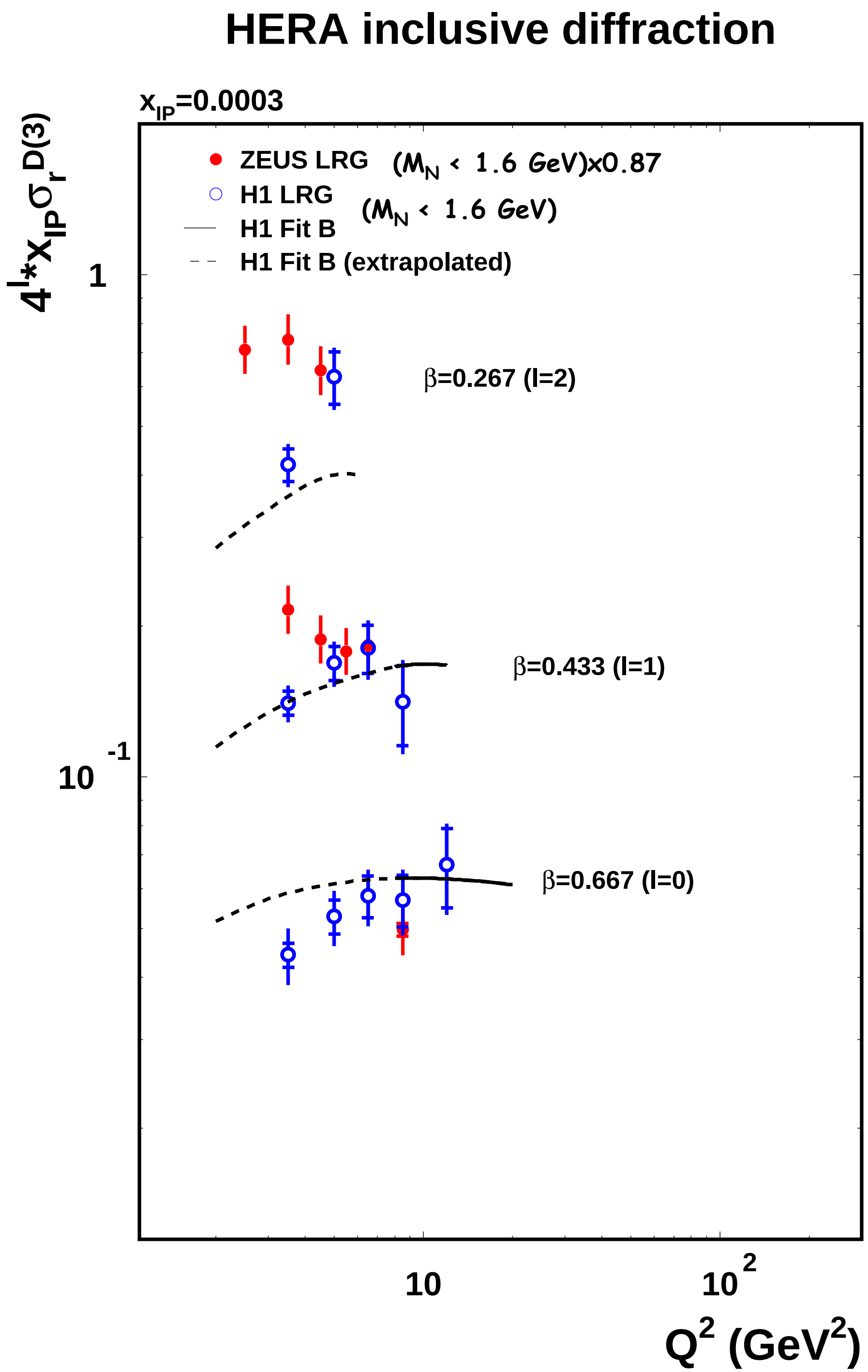
ZEUS M_X data



→ Substantial rise with W

HERALHC Workshop, M. Ruspa, 27/05/08

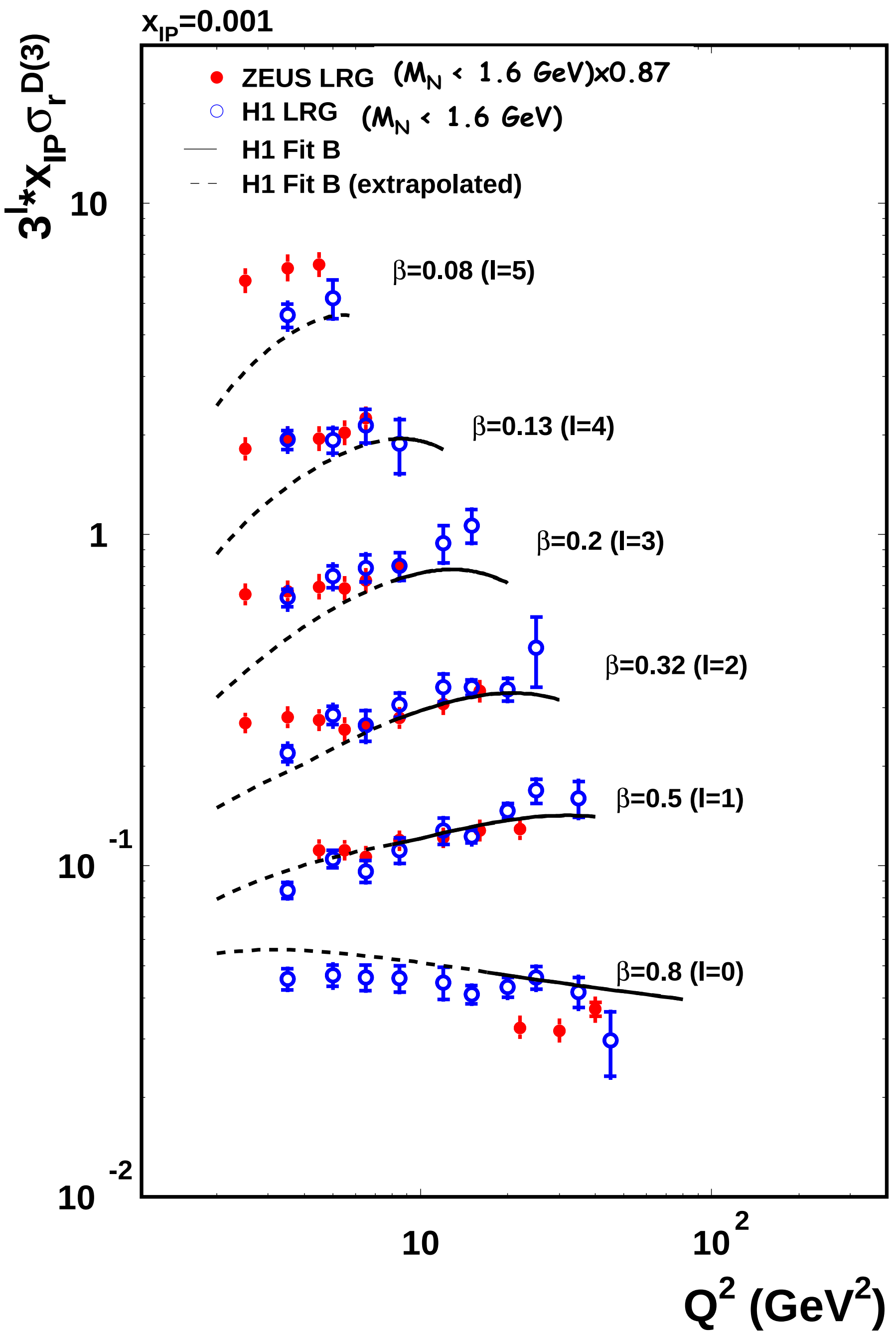
Towards HERA inclusive diffraction!



→ Time for data combination, global fits!

Towards HERA inclusive diffraction!

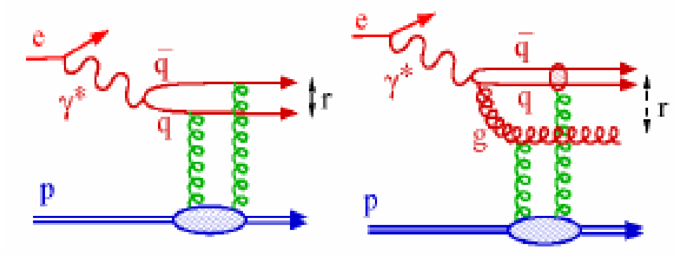
HERA inclusive diffraction



→ Time for data combination, global fits!

Fit with BEKW parameterisation

(Bartels, Ellis, Kowalski, Wustoff 1988)



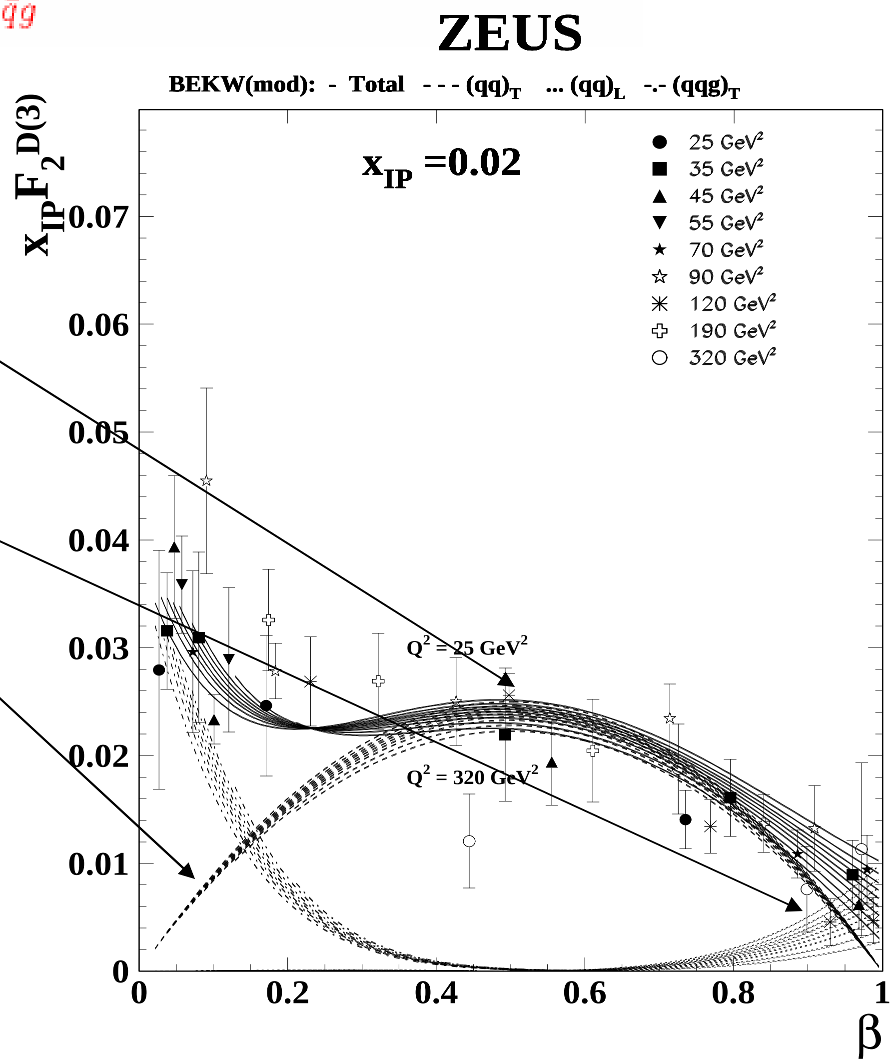
$$x_{IP} F_2^{D(3)} = c_T \cdot F_{q\bar{q}}^T + c_L \cdot F_{q\bar{q}}^L + c_g \cdot F_{q\bar{q}g}^T$$

$$F_{q\bar{q}}^T \sim \beta(1-\beta)$$

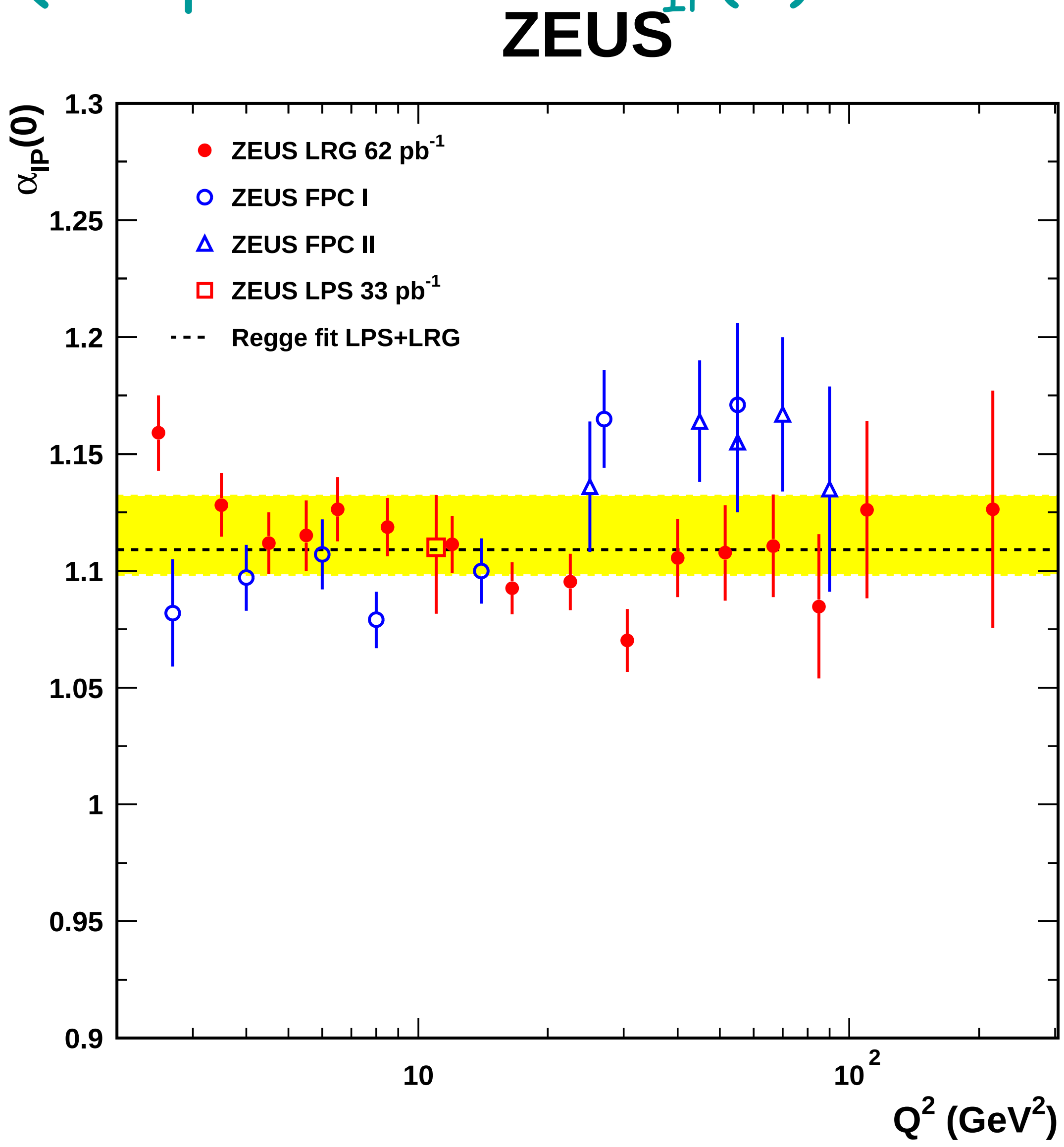
$$F_{q\bar{q}g}^T \sim (1-\beta)^\gamma$$

$F_{q\bar{q}}^L$ limited to β ~1

→ **Fit gives a good description of the 427 data points FPC I + II**



Q^2 dependence of $\alpha_{IP}(0)$



→ $\alpha_{IP}(0)$ does not exhibit a significant dependance on Q^2