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Inclusive Diffraction at HERA

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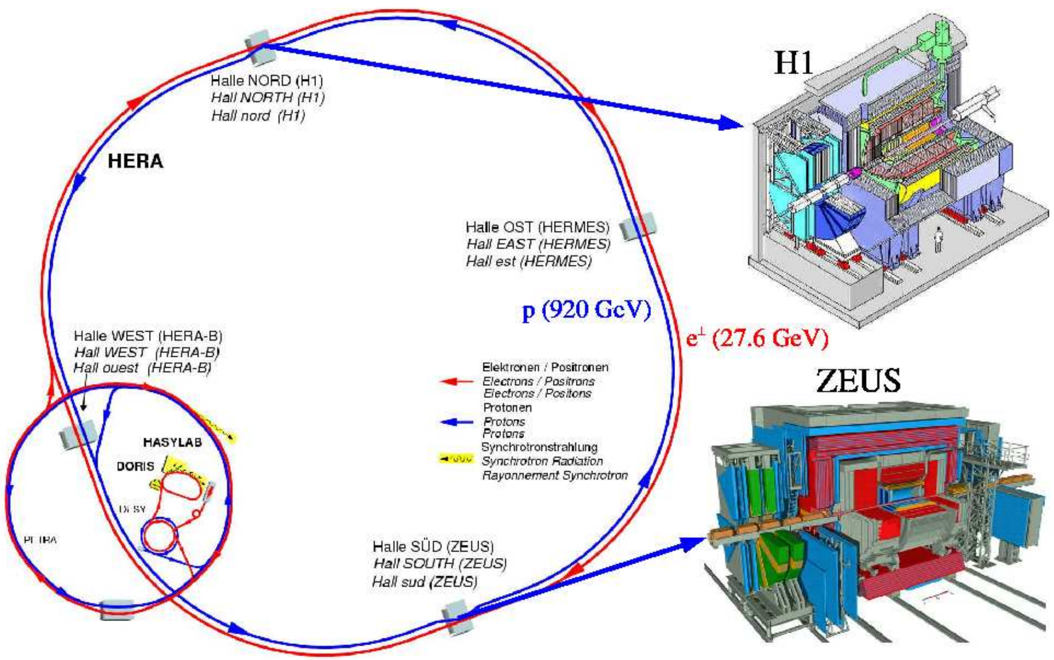
- Diffractive structure function data
- Regge fits and QCD fits
- Data comparisons
- H1/ZEUS weighted average

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……

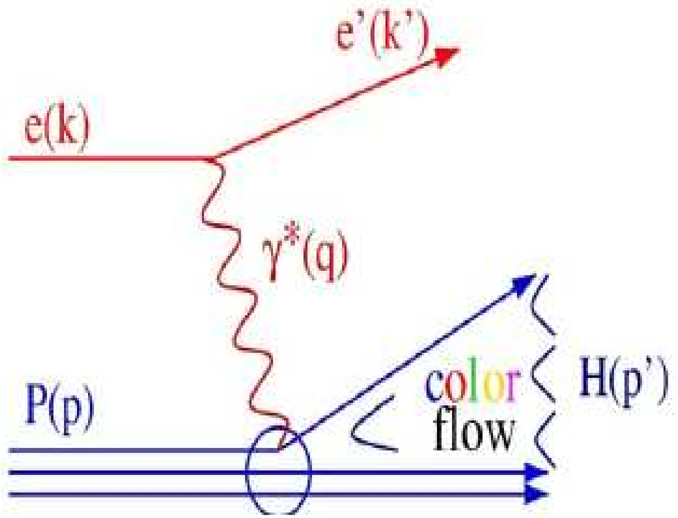


Detectors not originally designed for forward physics, but diffraction at HERA great success story!

ZEUS forward instrumentation no longer available in HERA II

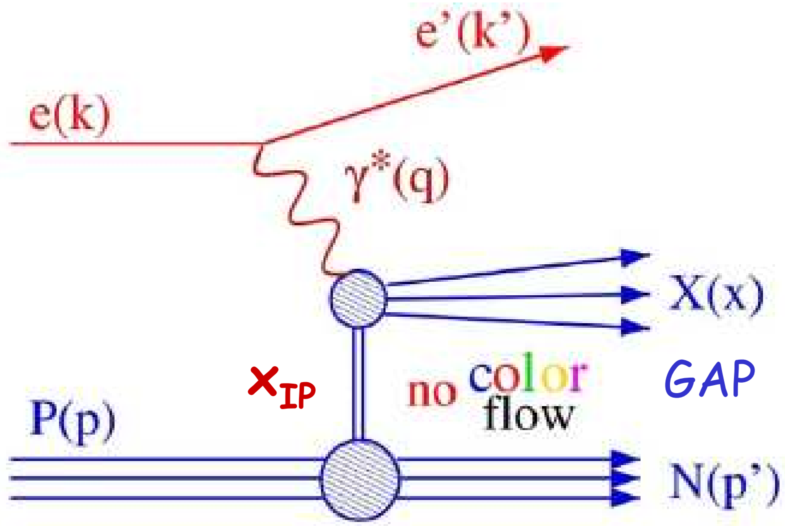
Diffractive DIS at HERA

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}

Kinematics of diffractive DIS

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

W = invariant mass of γ^*-p system

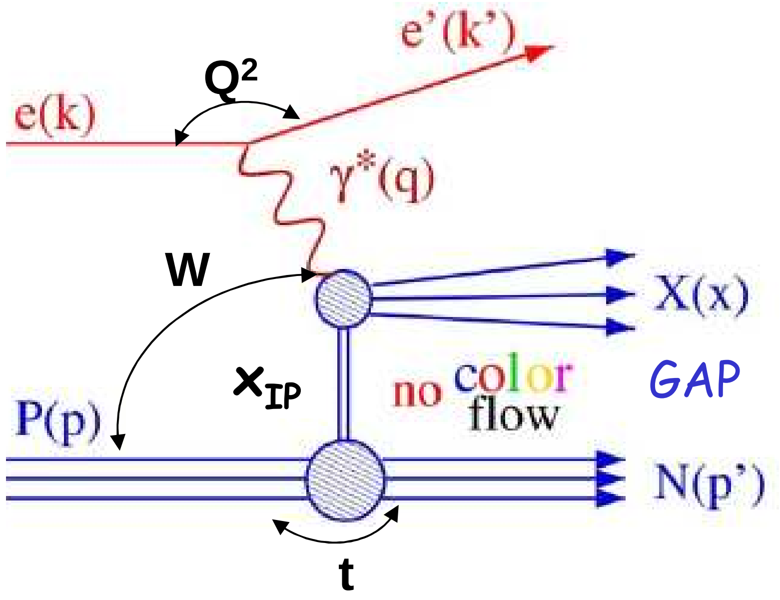
M_X = invariant mass of γ^* -IP system

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

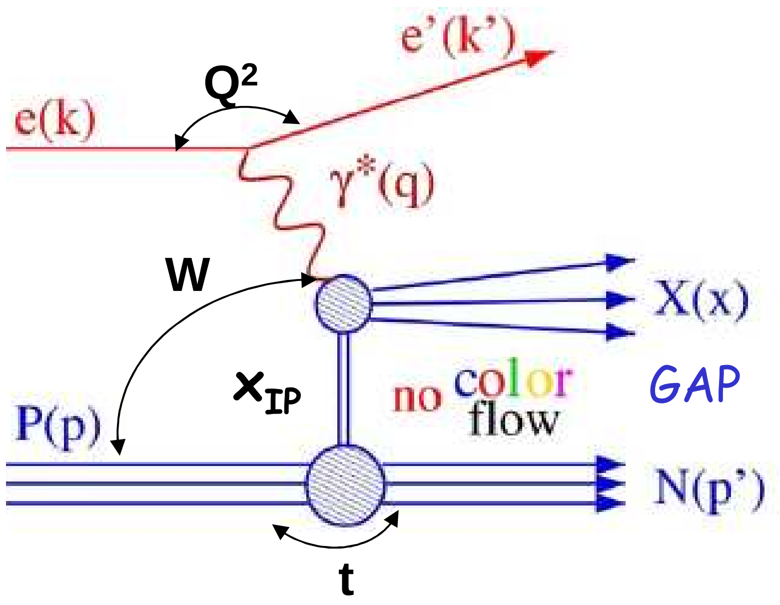


- Single diffractive dissociation: **N=proton**
- Double diffractive dissociation: **proton-dissociative system N**

  → **represents a relevant background**

Why study diffractive DIS?

- **Significant fraction of the inclusive DIS cross section**
- **New window on QCD**
  - transition from soft to hard regimes
  - parton dynamics at low x
  - applicability of QCD factorisation approach
- **DPDFs essential to predict diffractive processes and potential search channels at the LHC**



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

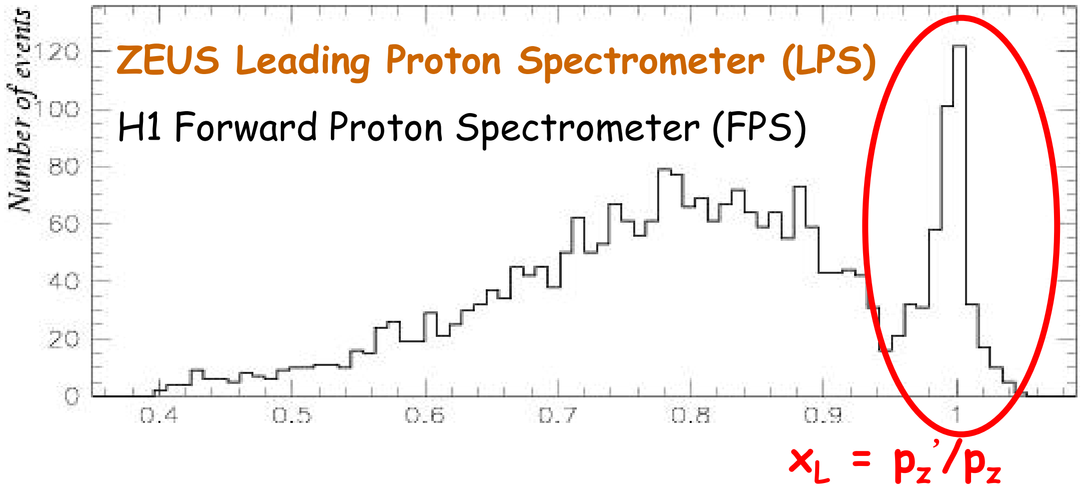
- **Assumption → proton vertex factorisation:**

Regge-motivated IP flux

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

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

Diffractive event selection

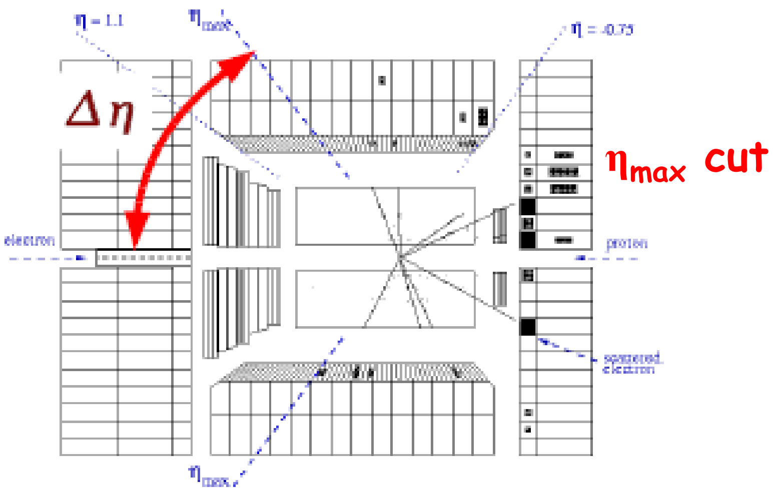


LPS method

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

CONS: low statistics

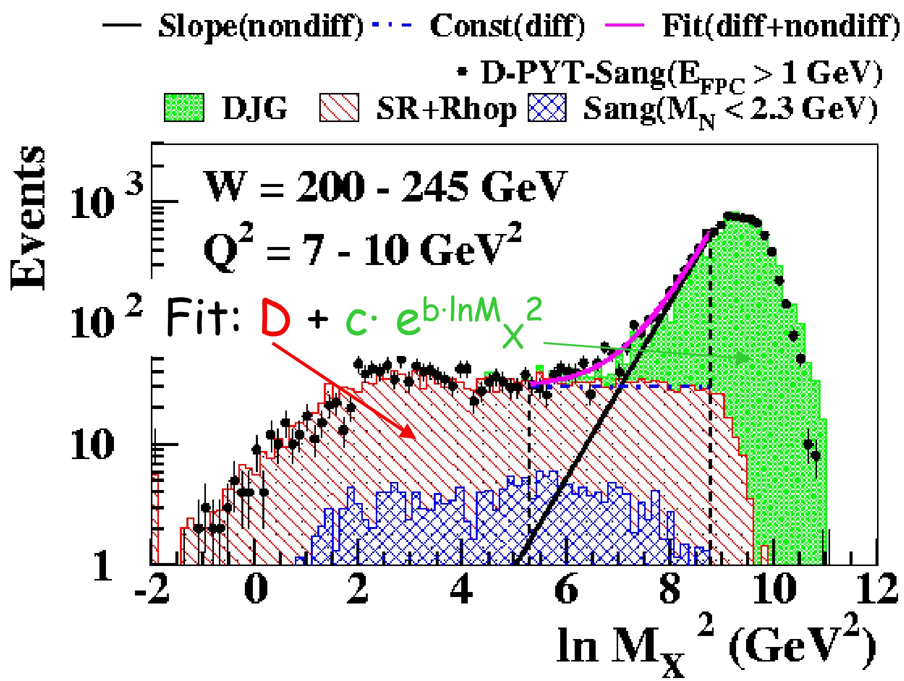
Large Rapidity Gap (LRG) method



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

CONS: p.-diss background

M_x method



Data sets

	Data set	x_{IP} coverage	M_N coverage
ZEUS	"ZEUS LPS" [arXiv:0812.2003, submitted to NPB]	x_{IP} up to 0.1	
	"ZEUS LRG" [arXiv:0812.2003, submitted to NPB]	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%

	Data set	x_{IP} coverage	M_N coverage
H1	"H1 FPS" [EPJ C48 (2006)]	x_{IP} up to 0.1	
	"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

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**

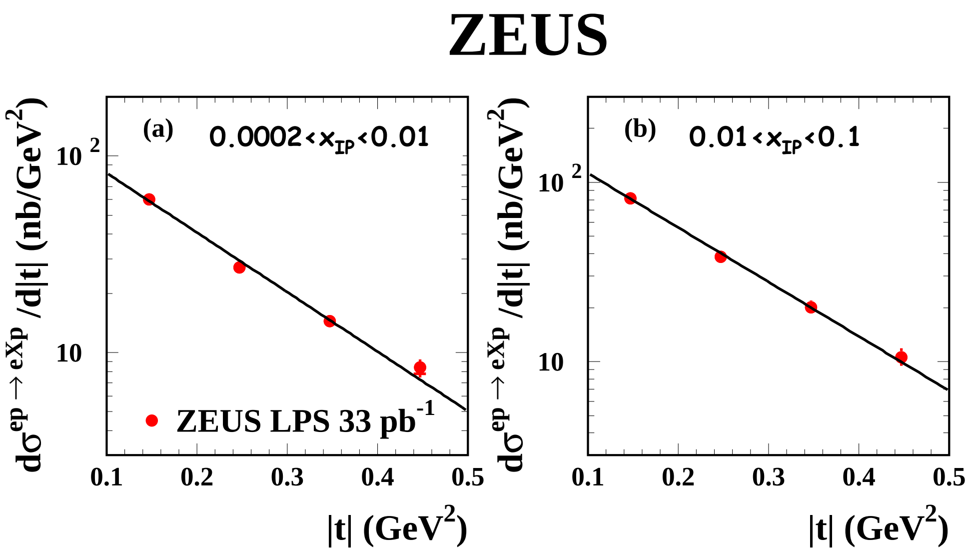
$$\sigma_r^{D(3)}(\beta,Q^2,x_{IP}) = \int \sigma_r^{D(4)}(\beta,Q^2,x_{IP},t)dt$$

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

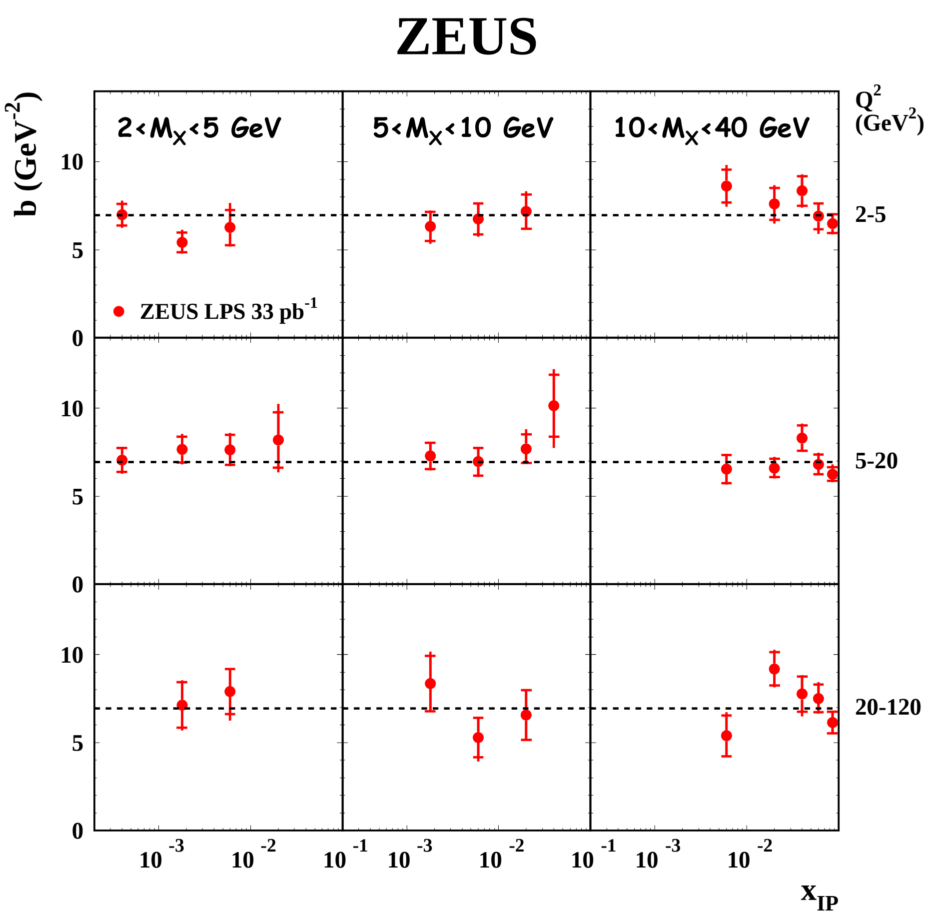
How does diffraction behave vs t, x_{IP}, Q^2 ?

t dependence

LPS data

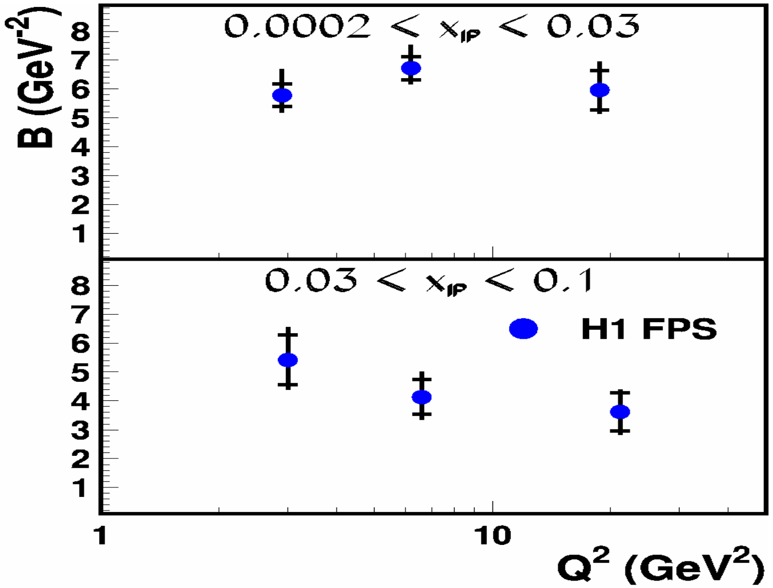


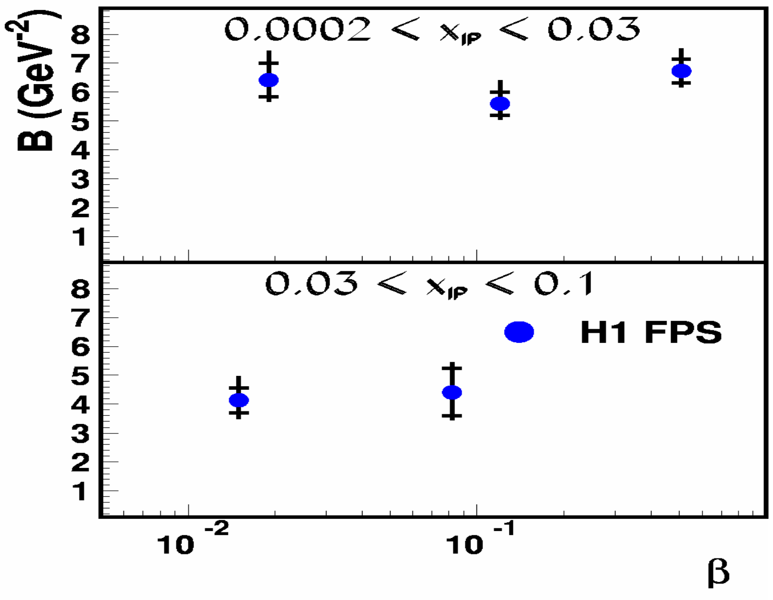
Fit to $e^{-b|t|}$ → $b = 7.0 \pm 0.4$ GeV^{-2}

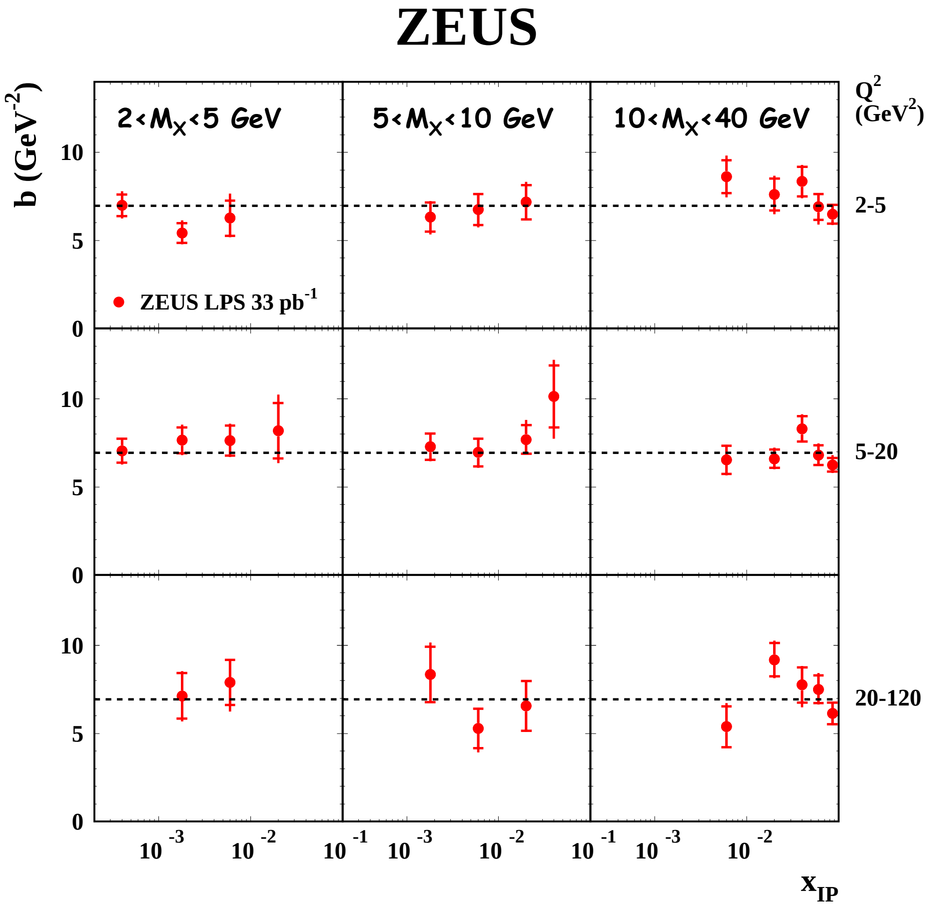


t dependence

LPS/FPS data



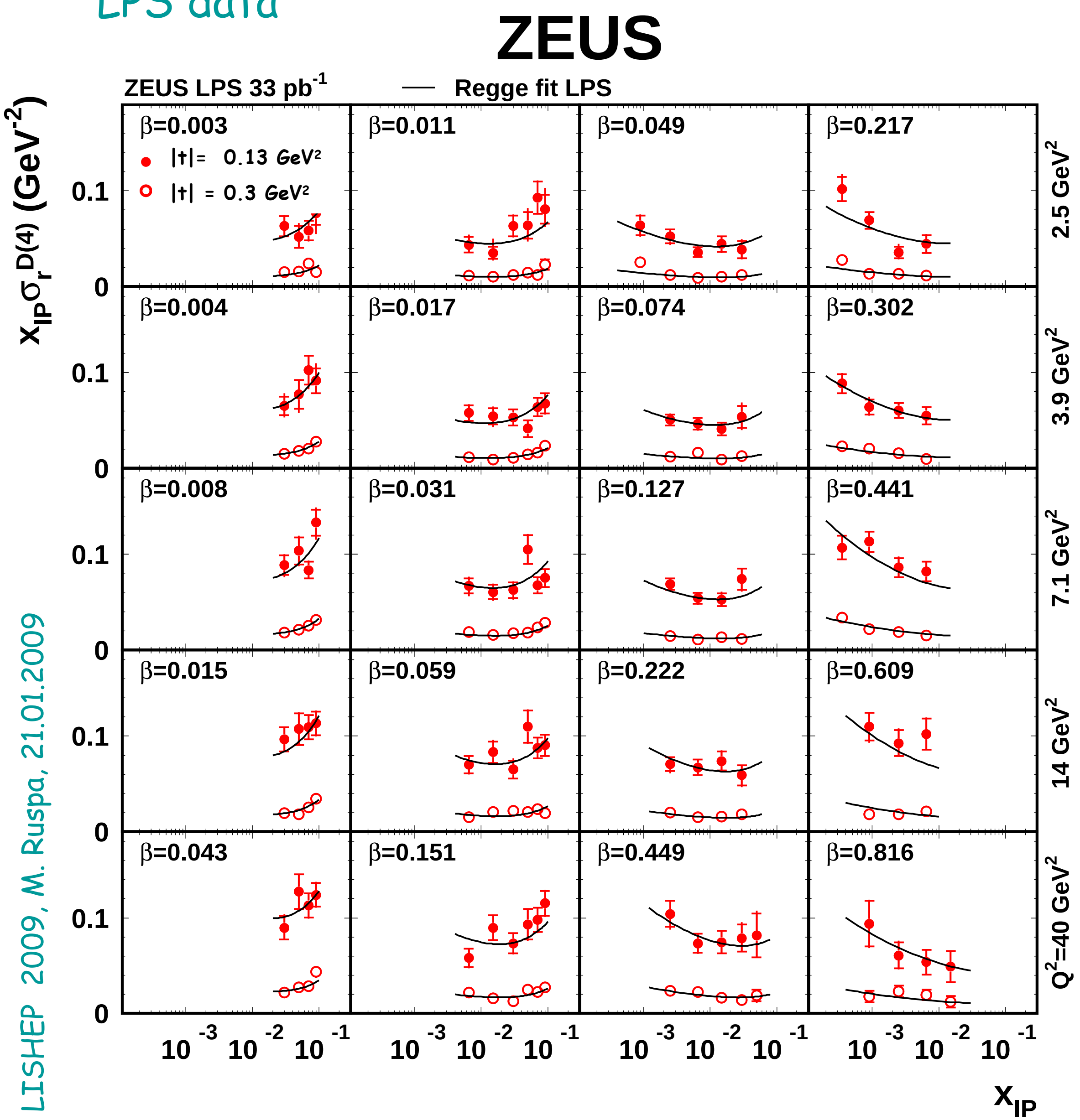




→ **Support Regge factorisation hypothesis**

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

LPS data



First measurement in two t bins

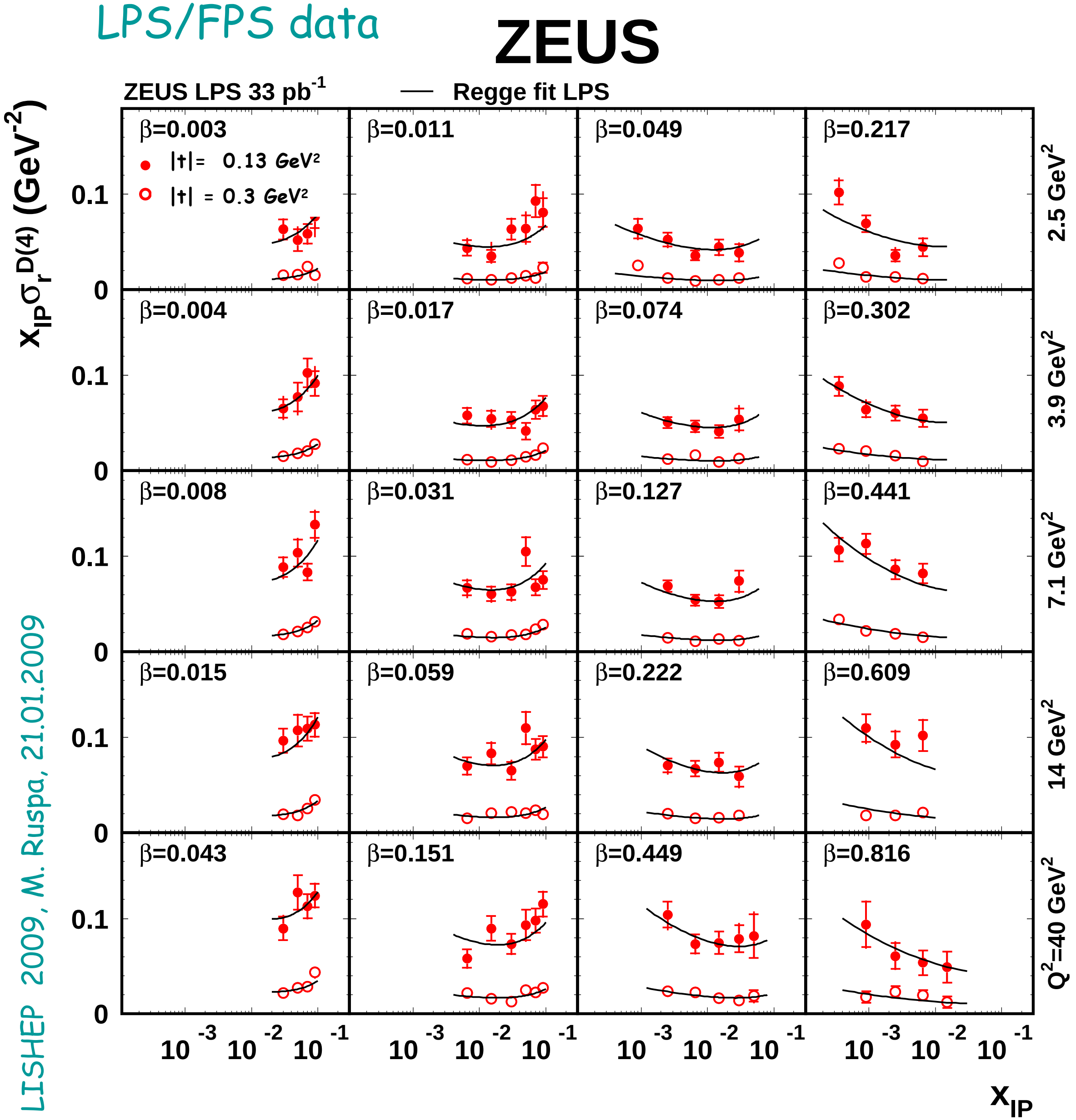
→ Low x_{IP}: $\sigma_r^{D(4)}$ falls with x_{IP} faster than $1/x_{IP}$

→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/FPS data



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

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

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

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

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

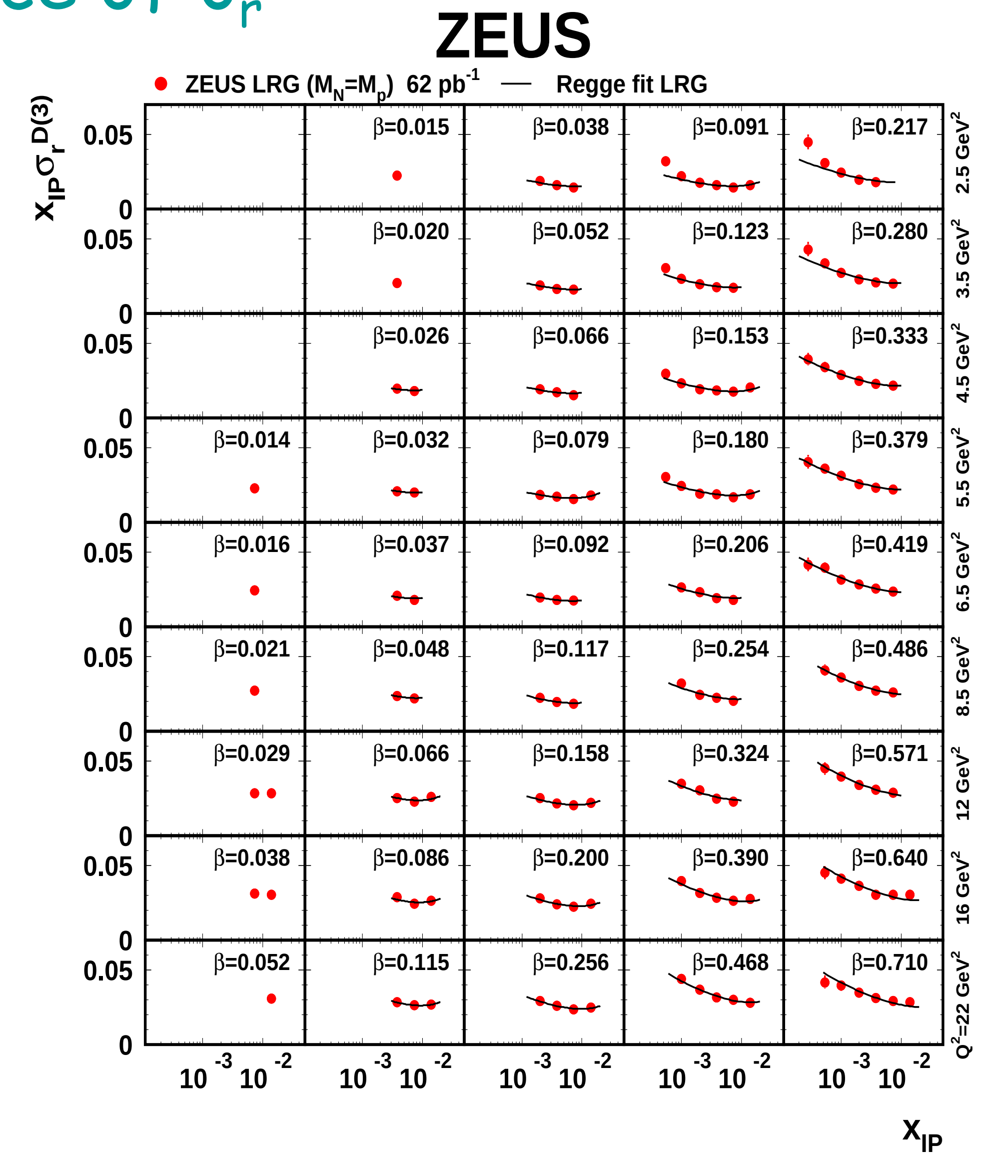
→ IP intercept consistent with soft IP (1.096)

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

→ Assumption of Regge factorisation works

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

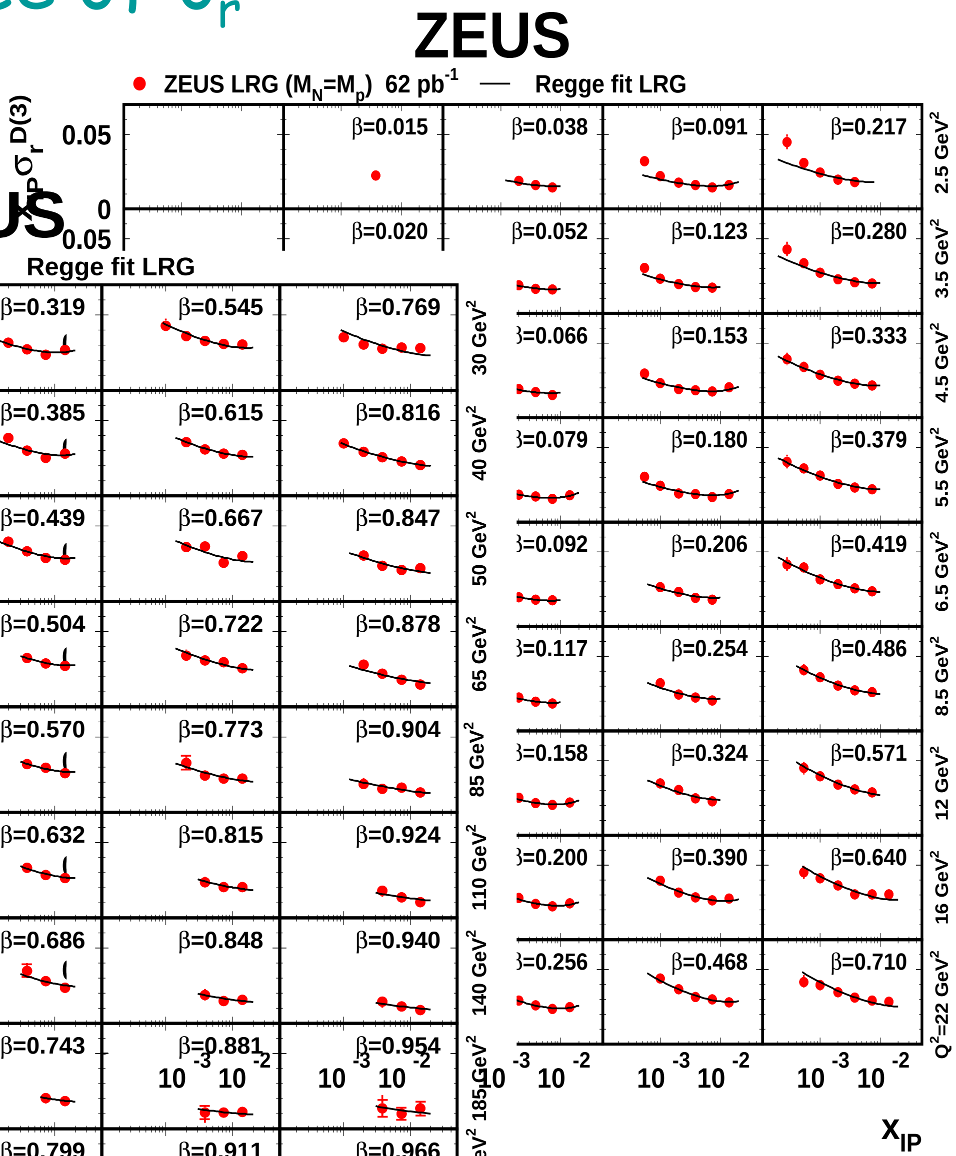
ZEUS LRG data

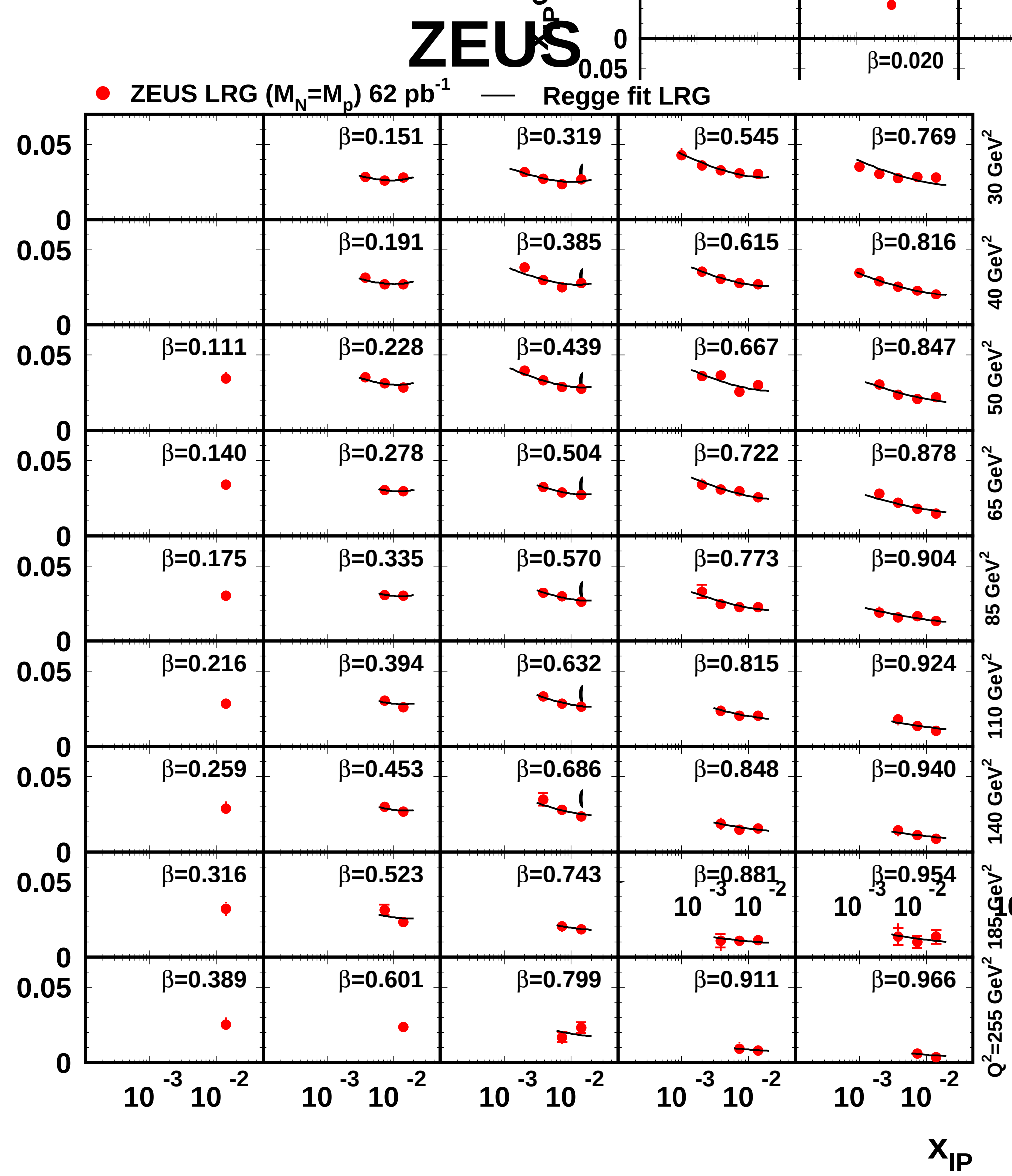


→ **Rise with x_{IP} not visible as x_{IP} < 0.02**

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

ZEUS LRG data



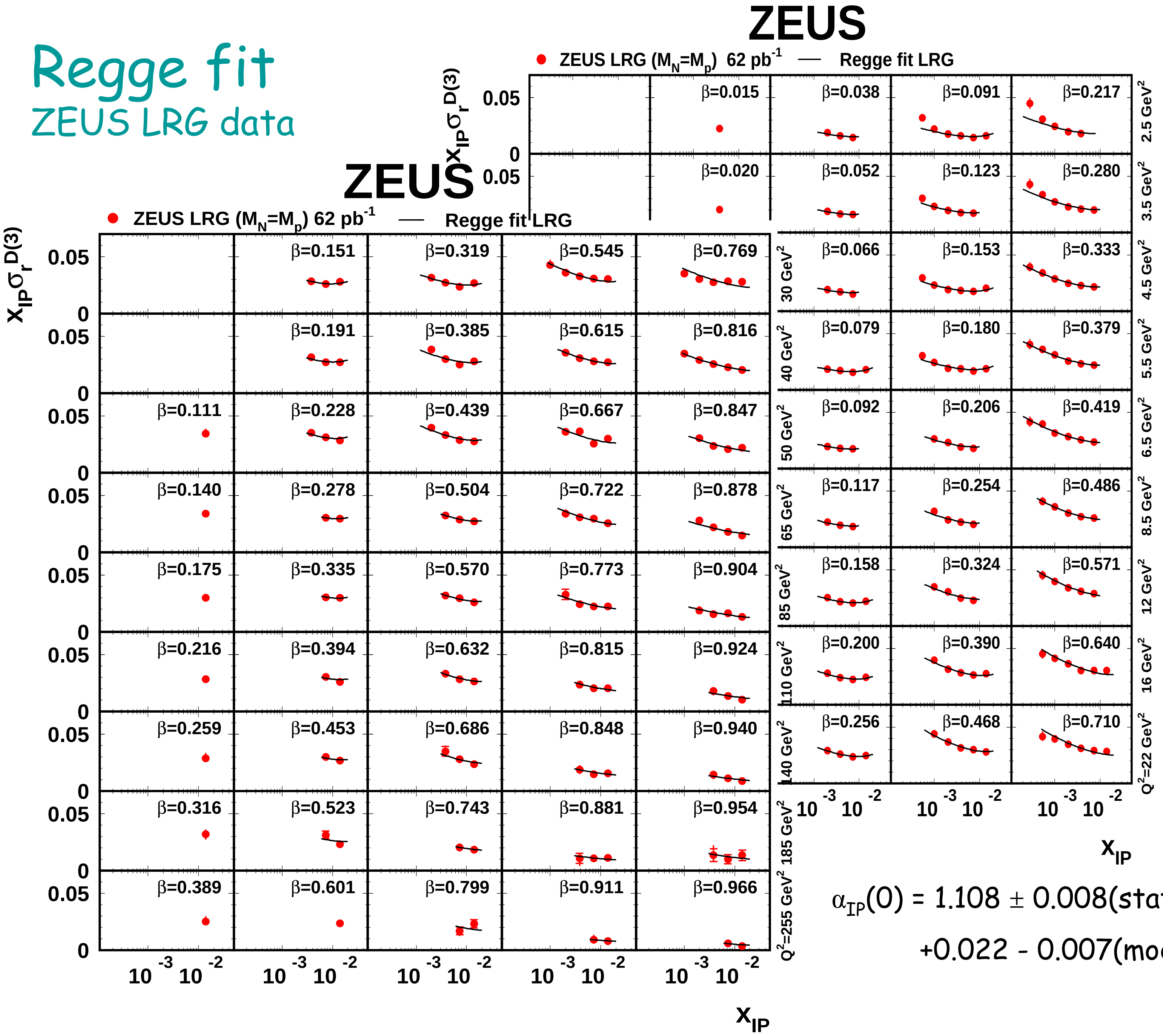


→ Rise with x_{IP} not visible as x_{IP} < 0.02

→ Wide kinematic coverage and very good statistical precision

Regge fit

ZEUS LRG data



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

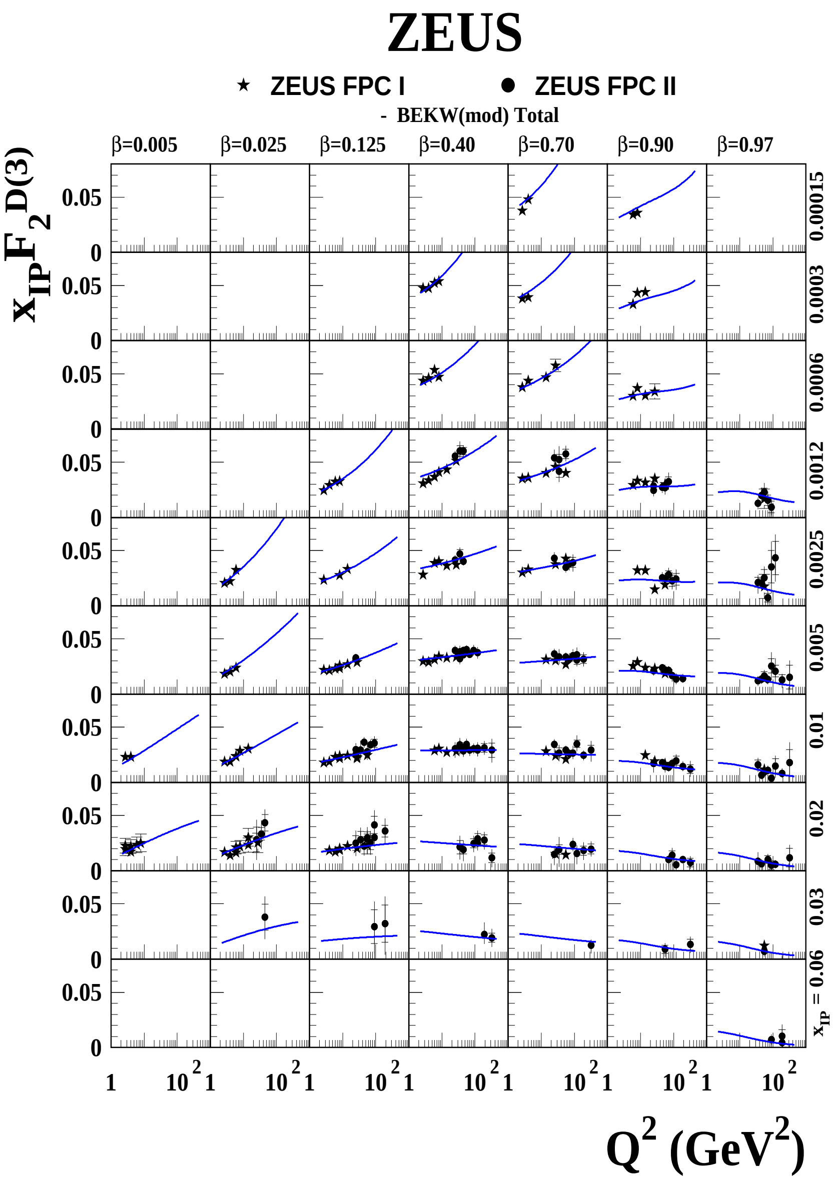
+0.022 - 0.007(model)

→ **Assumption of Regge factorisation works**

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

ZEUS FPC data

→ **At fixed β shape depends on x_{IP}: this data seem to contradict Regge factorisation assumption**



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!**

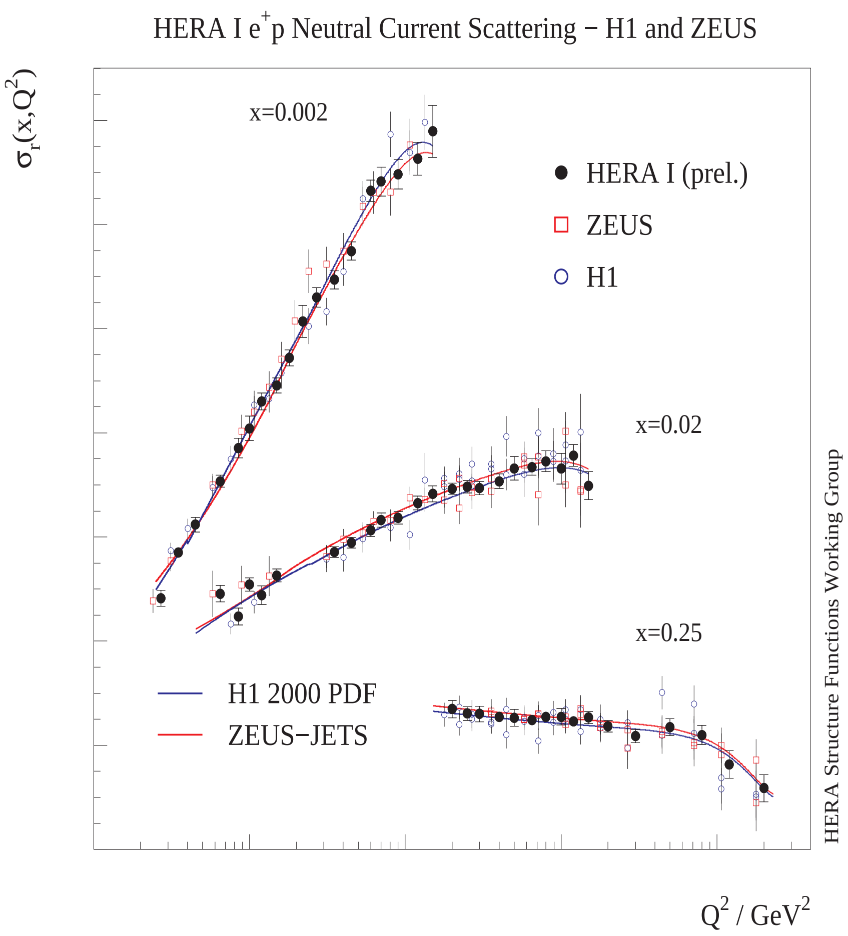
[Bartels, Ellis, Kowalski, Wustoff, see NPB 800 (008)]

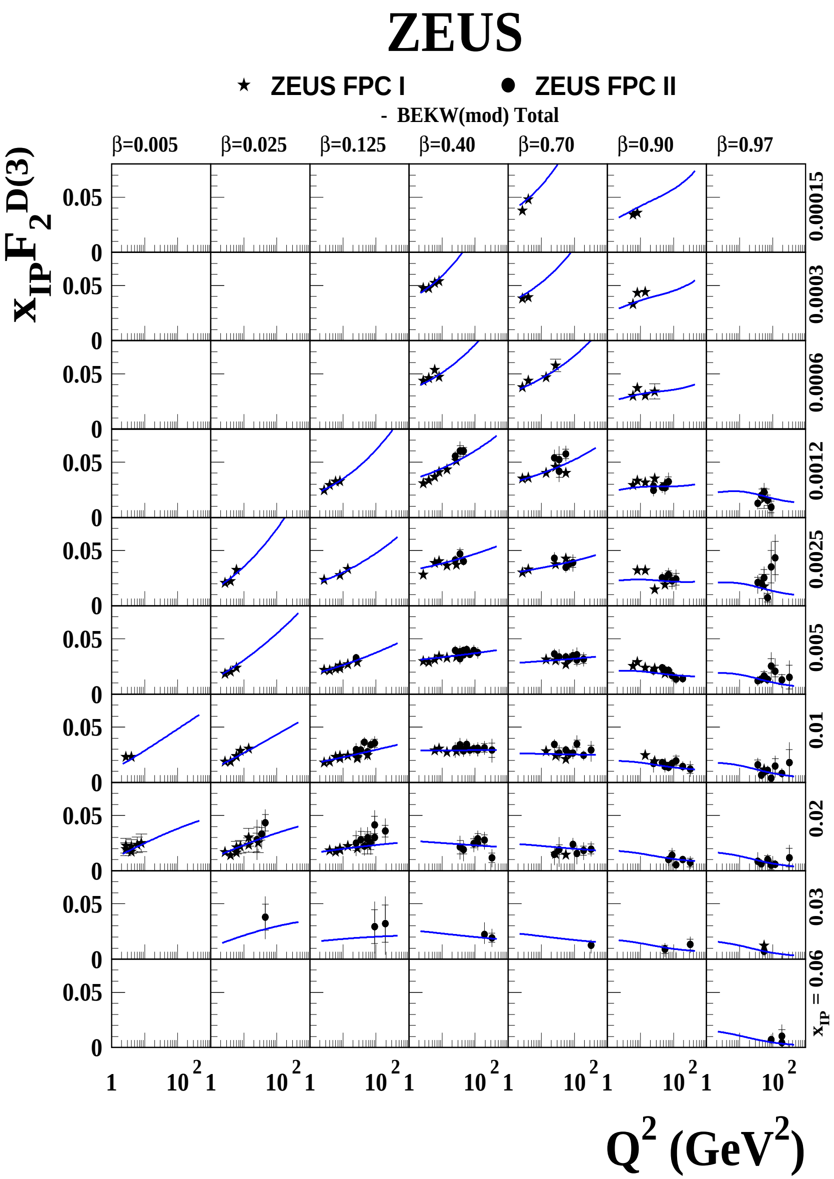
Mild violations should not affect QCD fits, which assume factorisation

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

ZEUS FPC data

F_2





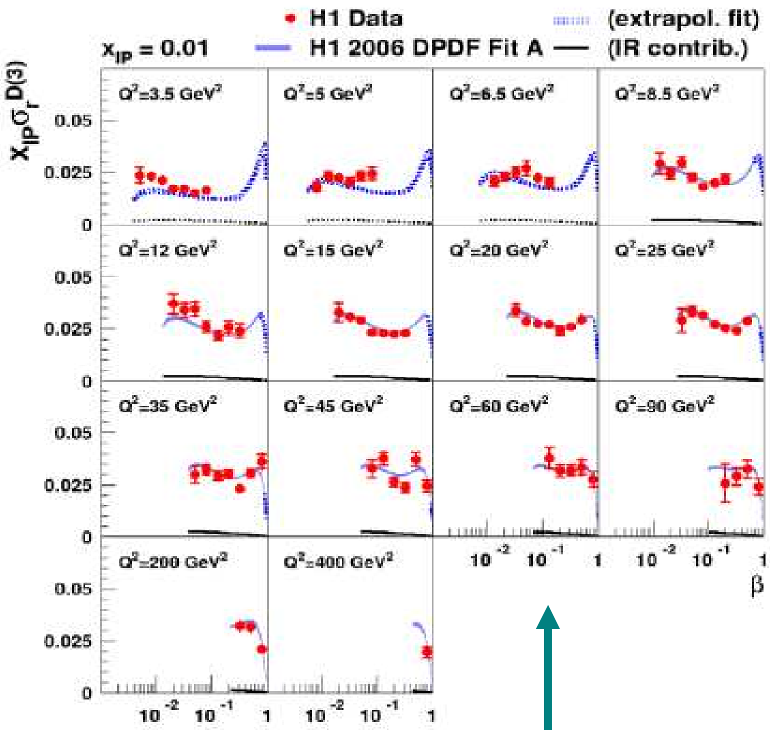
$\sigma_r^{D(3)}$ **shows positive scaling violations up to high-β values**

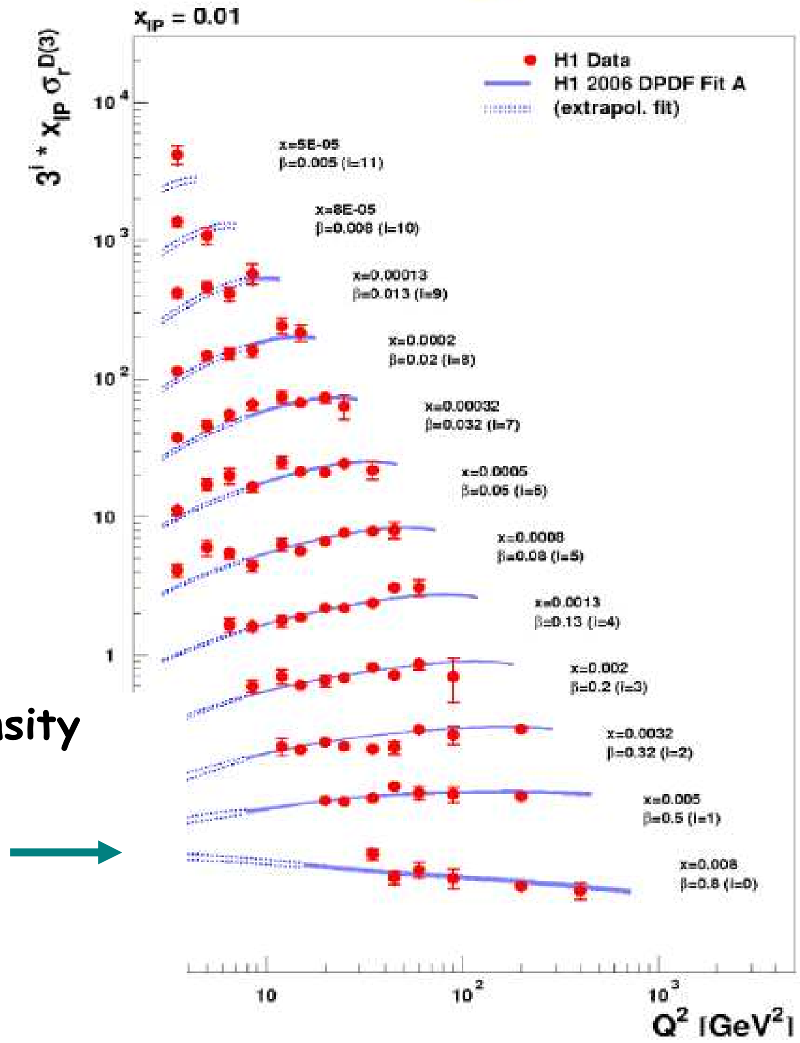
→ Diffractive exchange is gluon-dominated

Diffractive Parton Distribution Functions

DPDFs extraction

H1 LRG data





Reduced cross section constrains quark density

lnQ^2 dependence constrains gluon density

DPDFs extraction

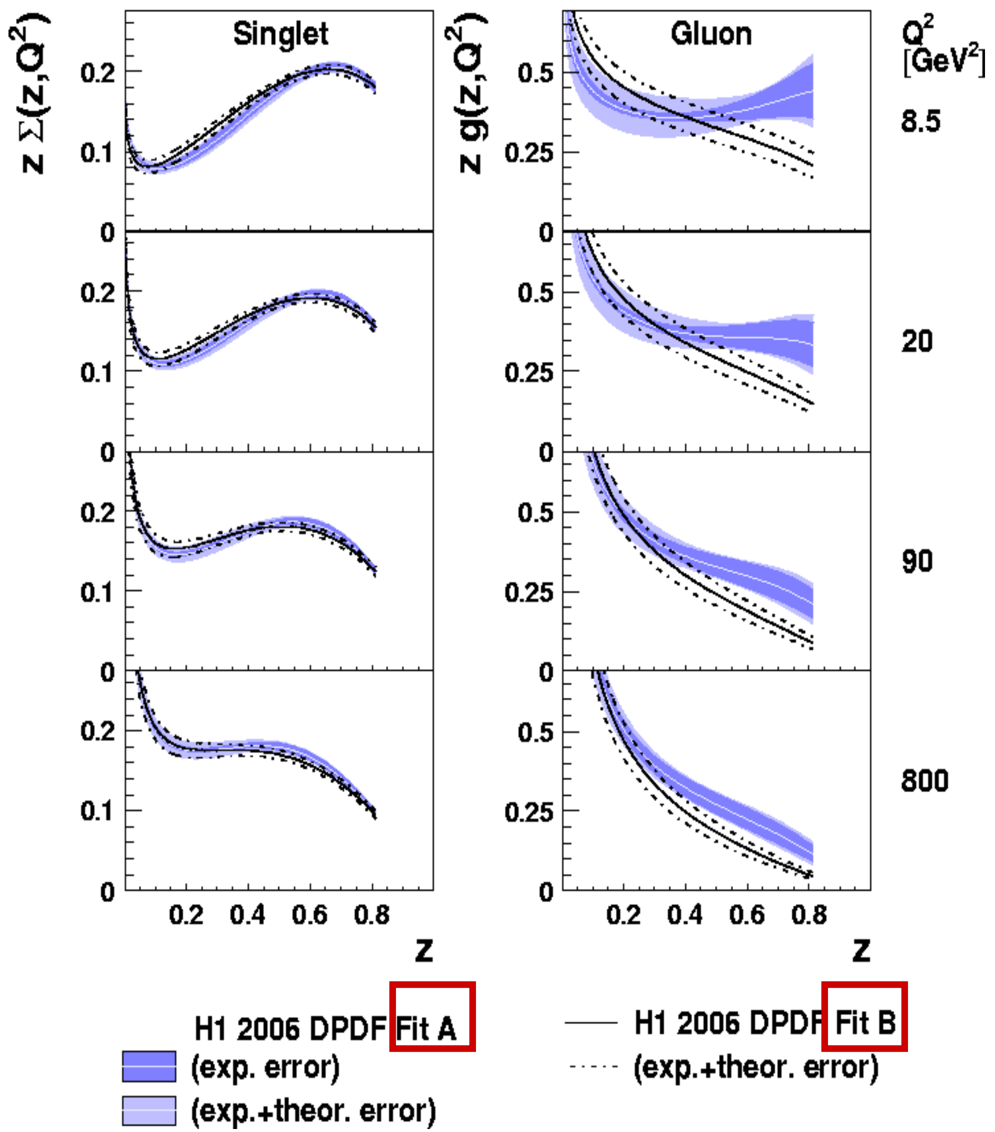
Regge factorisation assumed

Fit A: $zg(z,Q_0^2) = A(1-z)^C$
Fit B: $C=0$, gluon constant at Q_0^2

→ **Well constrained singlet**

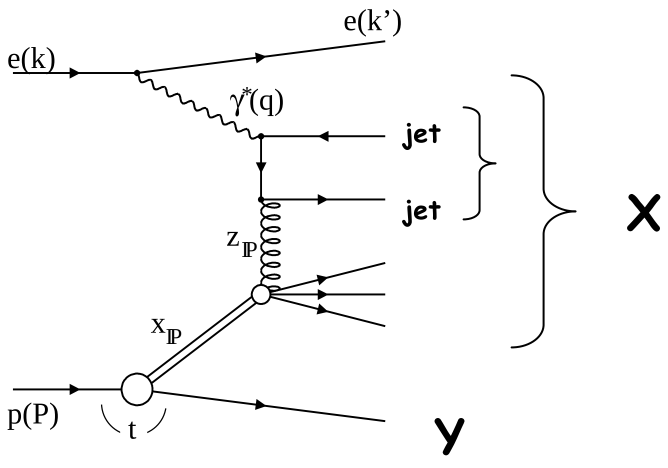
→ **Weakly constrained gluons, exp. at high values of z needed further input**

z = fractional momentum of the diffractive exchange participating to the hard scattering



Combined fit

H1 LRG+dijet data

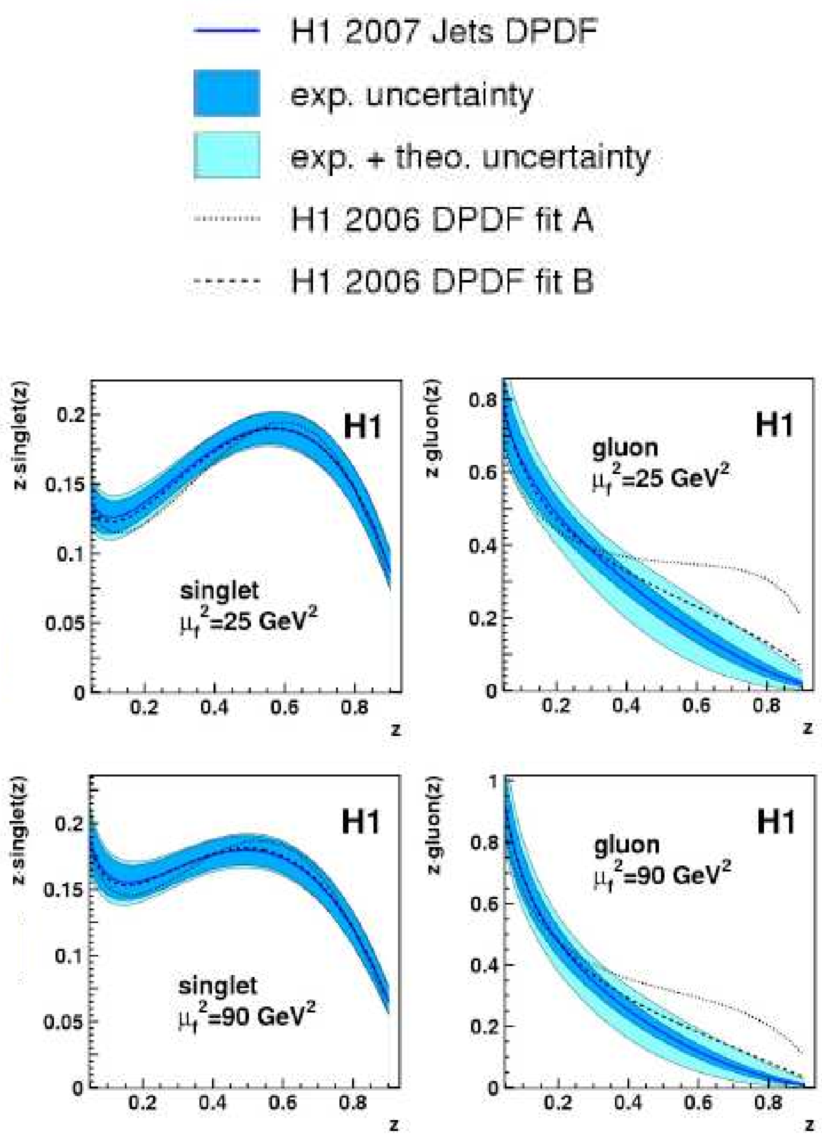


Fit A: $zg(z, Q_0^2) = A(1-z)^C$

Fit B: $C=0$, gluon constant at Q_0^2

Fit JET: $zg(z,Q_0^2)=Az^B(1-z)^C$

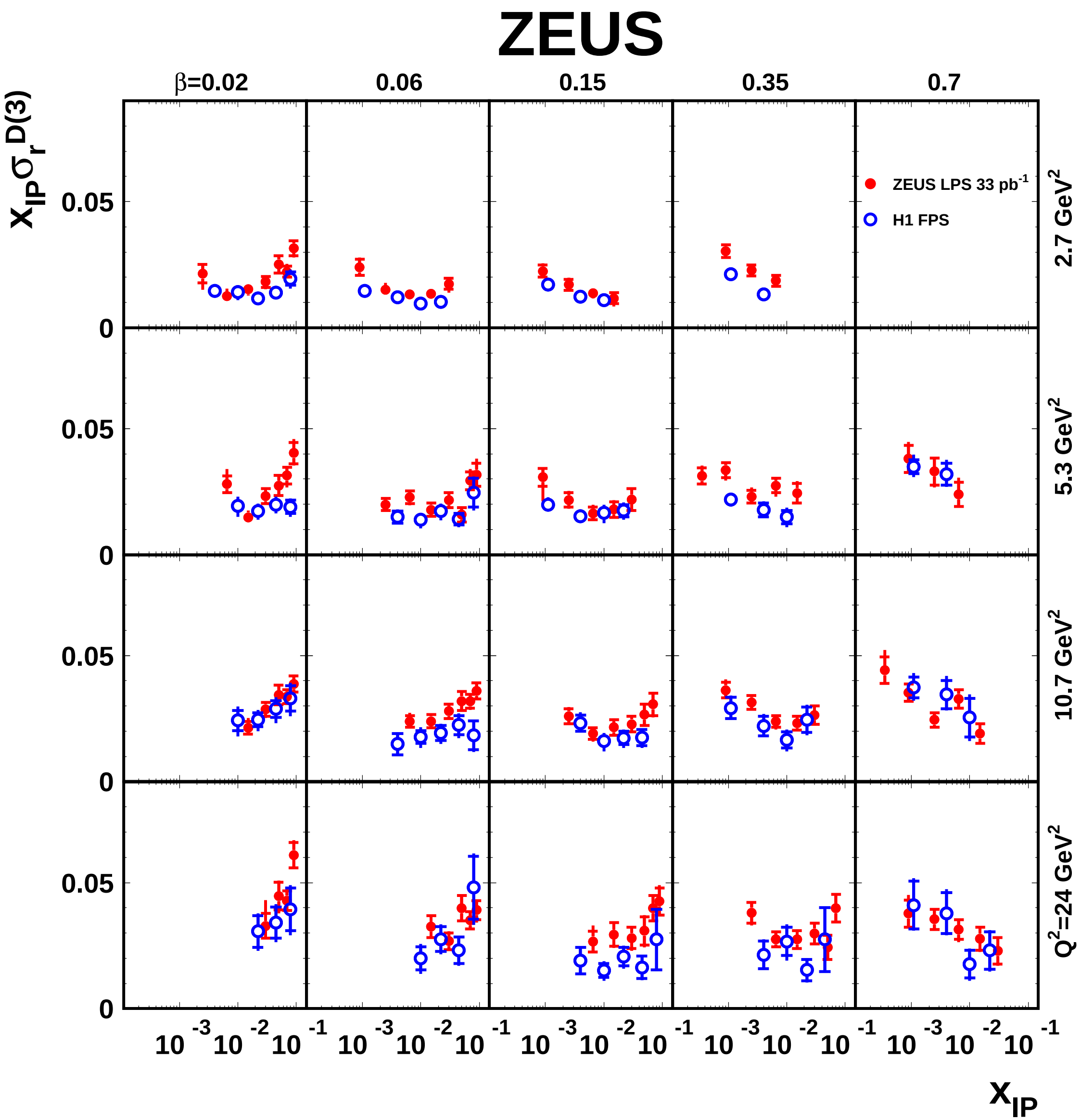
→ The singlet and gluons are constrained with similar precision across the whole kinematic range



See A. Valkarova's talk

Comparison between data sets

ZEUS LPS vs H1 FPS



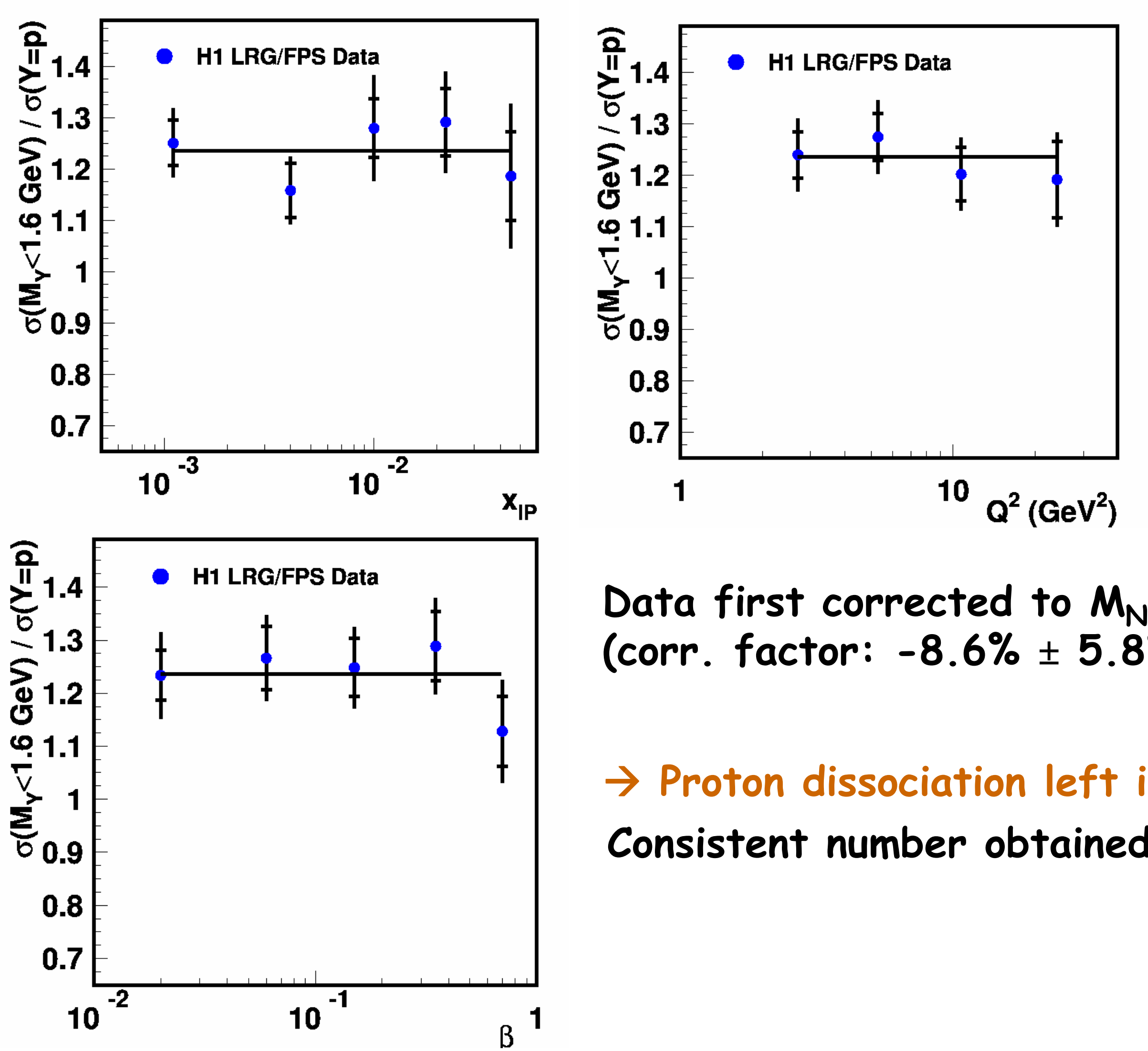
The cleanest possible comparison in principle...

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

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

H1 LRG vs H1 FPS

Proton dissociation-background in the H1 LRG data



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

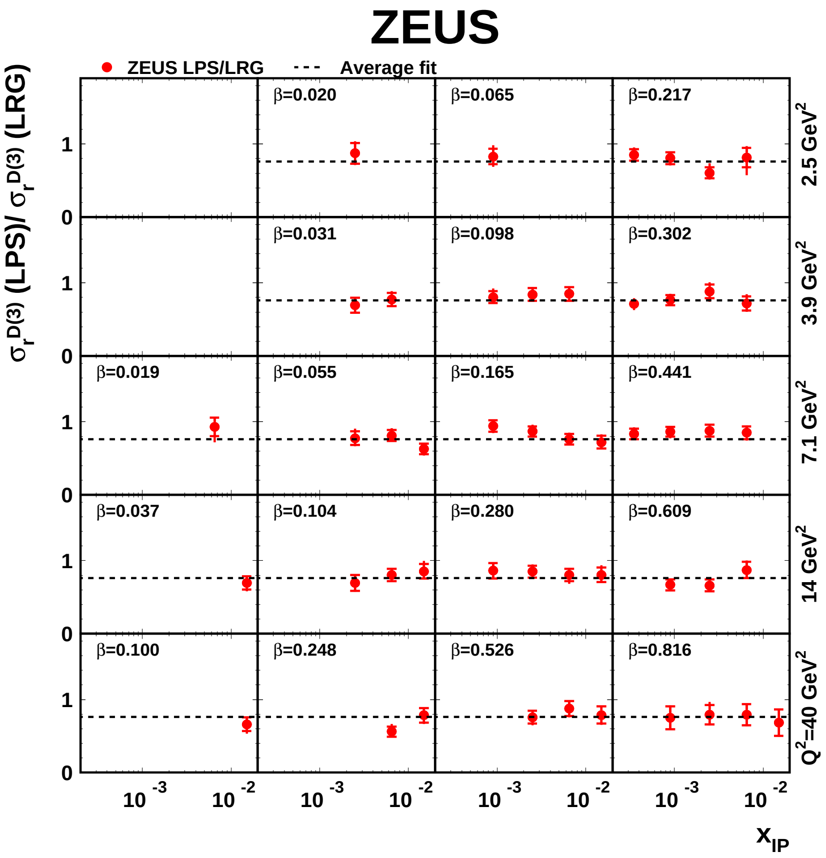
Data first corrected to M_N < 1.6 GeV
(corr. factor: -8.6% ± 5.8%)

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

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

ZEUS LRG vs ZEUS LPS

Proton dissociation-background in the ZEUS LRG data



→ LPS/LRG independent of Q^2, x_{IP}, β, as in the H1 case: proton vertex factorises

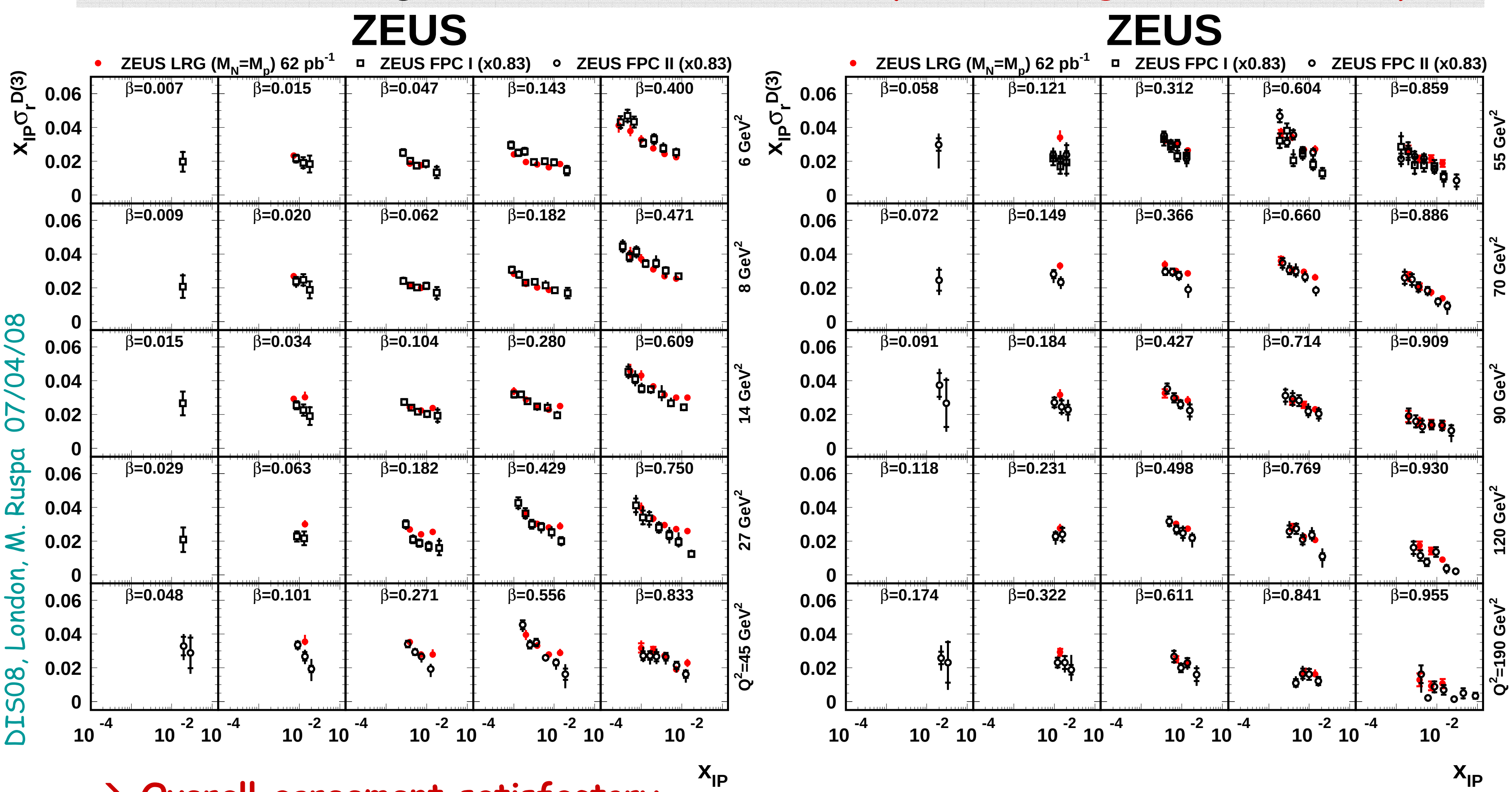
→ Fraction of proton-dissociative background in the ZEUS LRG data: [24 +-1(stat) +2-3(sys) +5-8(norm)]%

Consistent number obtained with PYTHIA: [25 +-1(stat) +-3(sys)]%

- Similarity between ZEUS and H1 p.-diss fraction expected given similar forward detector acceptance
- Precise knowleadge (and correction) of p.-diss background key point in the data comparison!

ZEUS LRG vs ZEUS FPC

FPC data (M_N < 2.3 GeV) normalised here to LRG (M_N=m_p): factor 0.83 ± 0.04 (determined via a global fit) estimates residual p-diss. background in FPC sample



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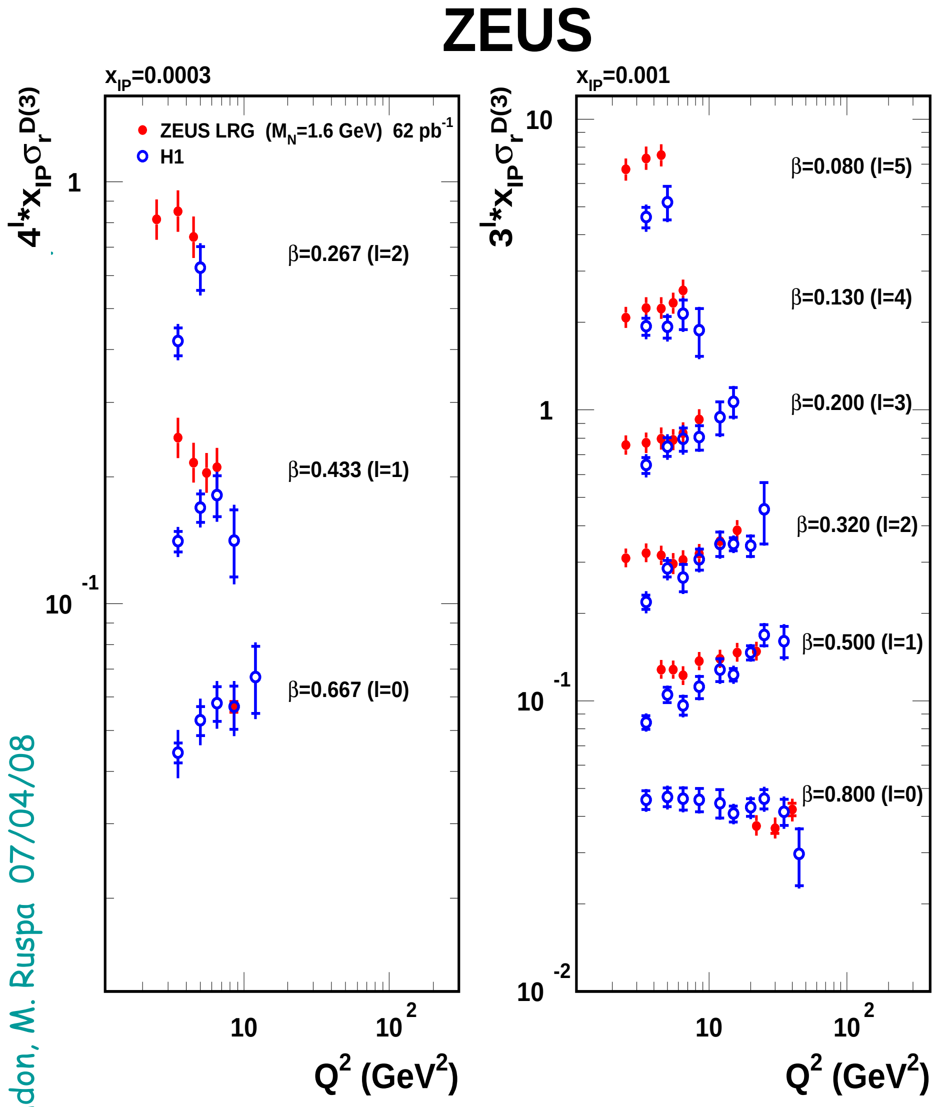
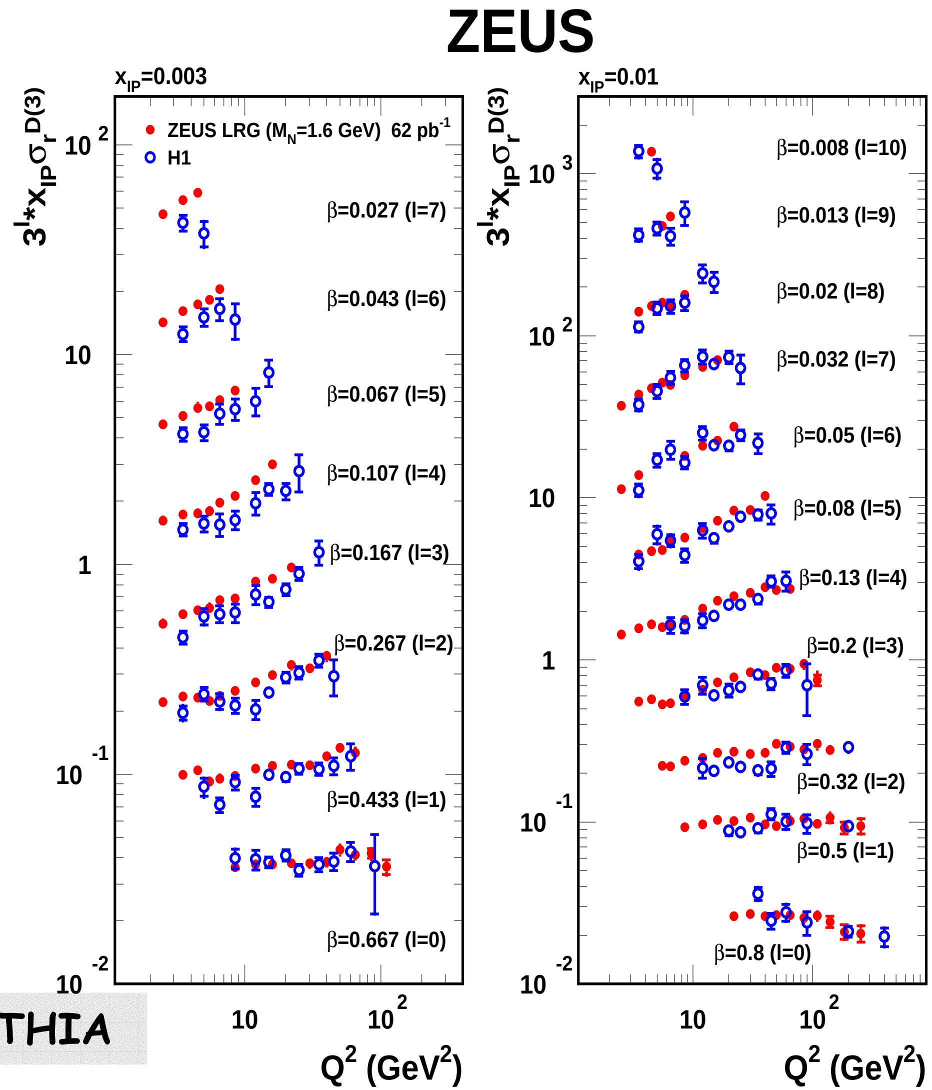
→ Overall agreement satisfactory

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

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

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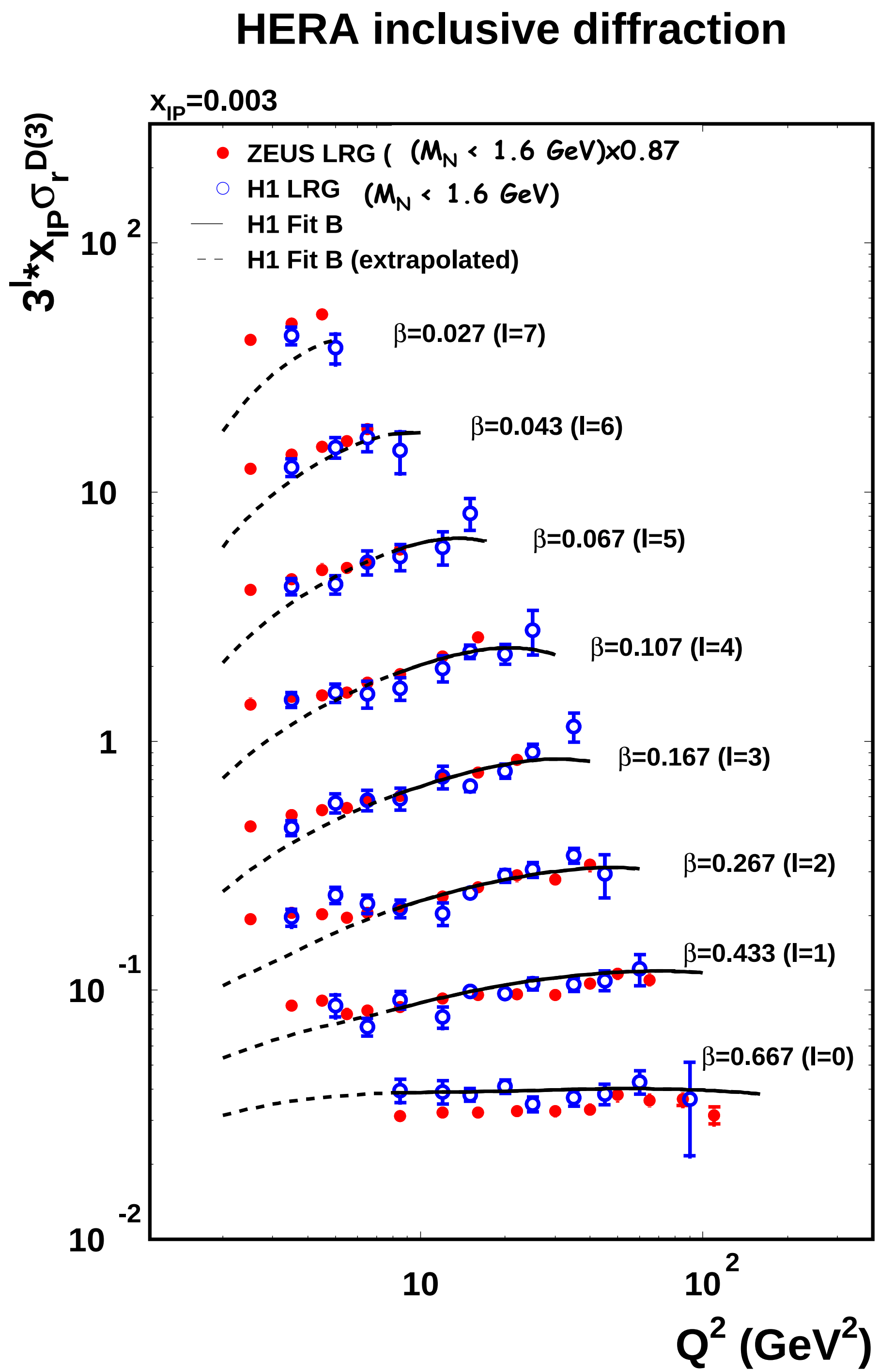
Towards HERA inclusive diffraction!

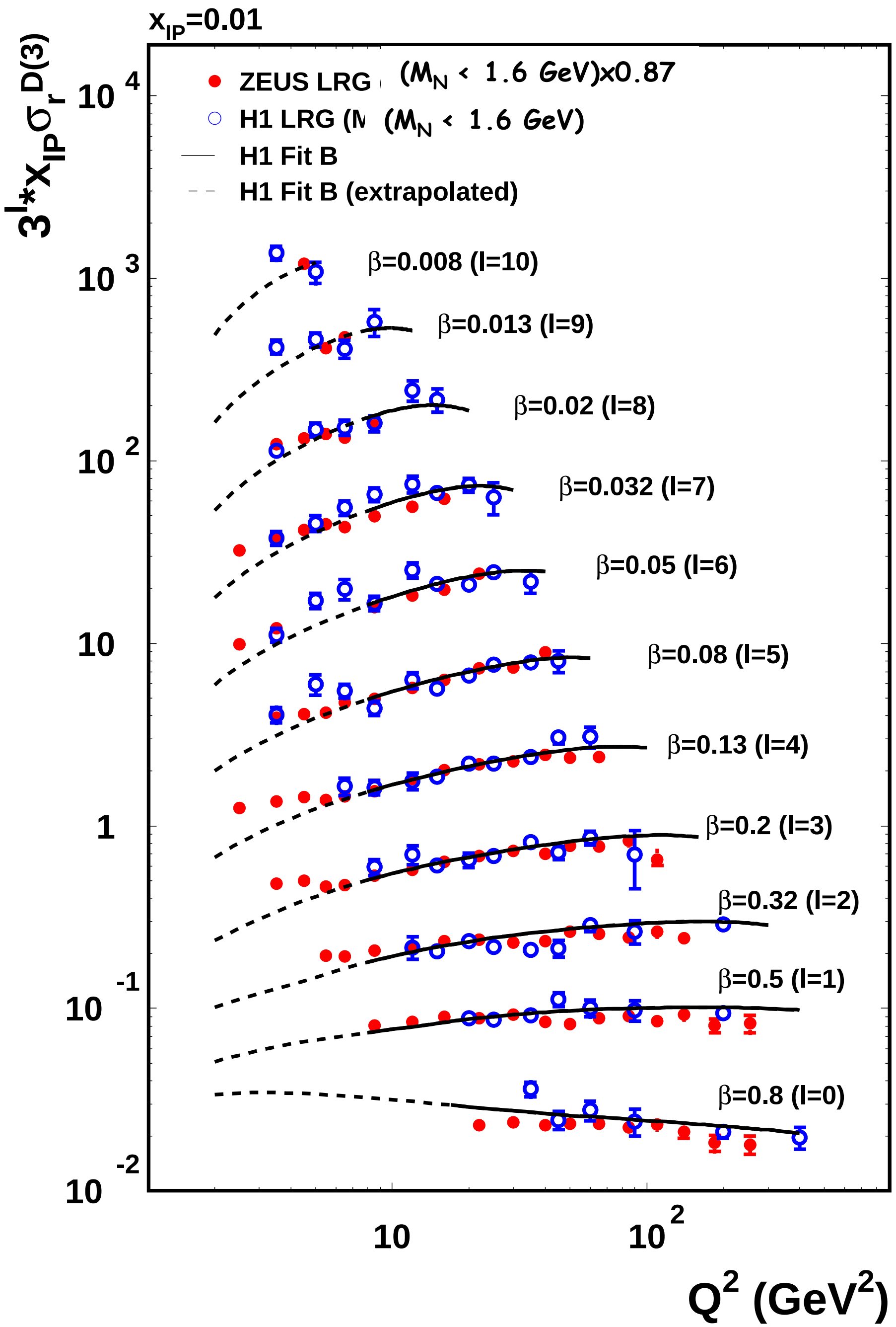


→ Time for data combination, global fits!

Towards HERA inclusive diffraction!

→ Time for data combination, global fits!

HERA inclusive diffraction

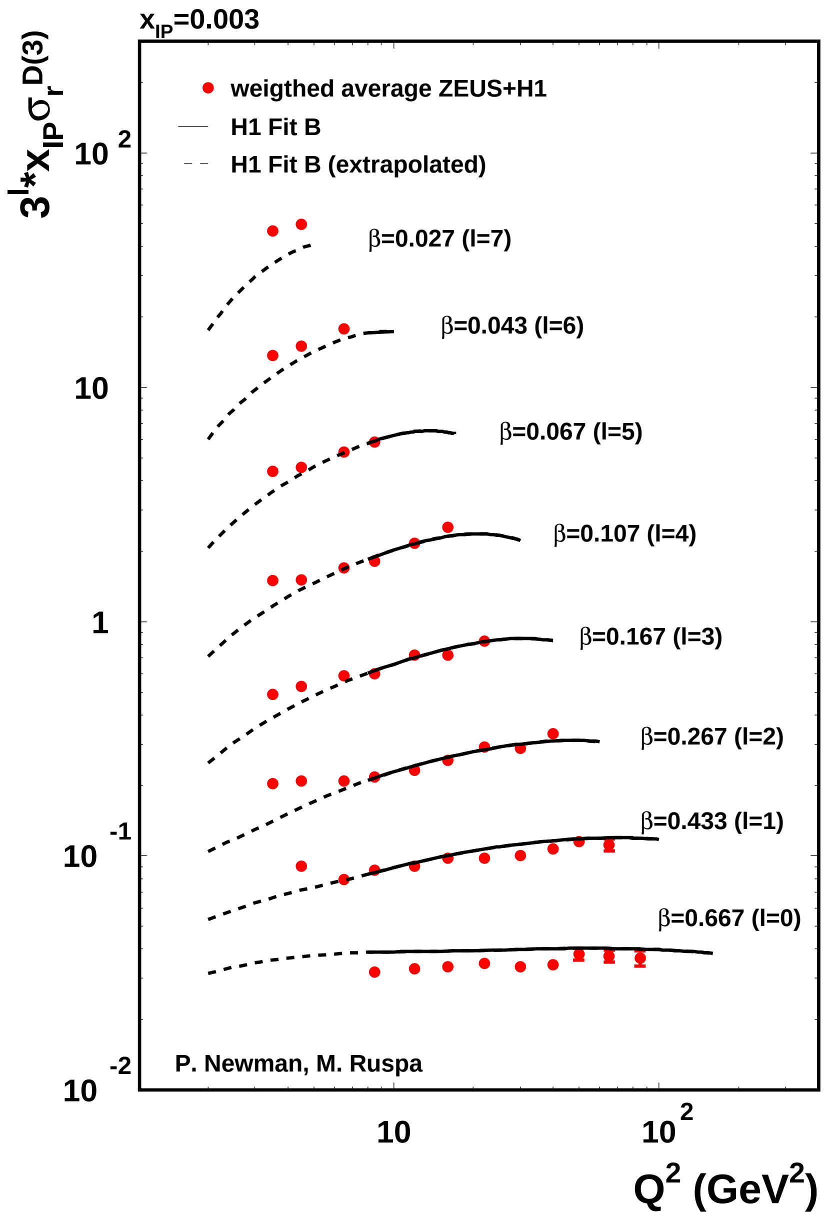


First step towards the data combination

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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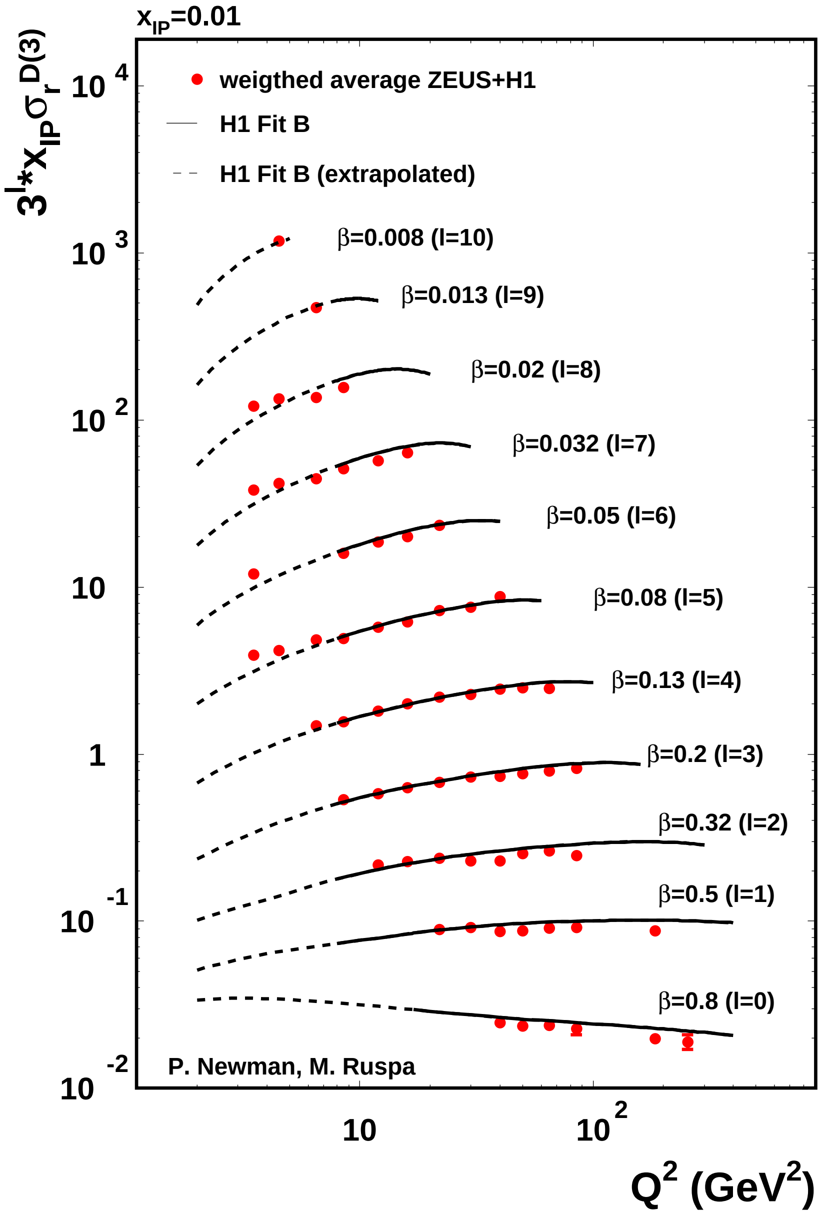


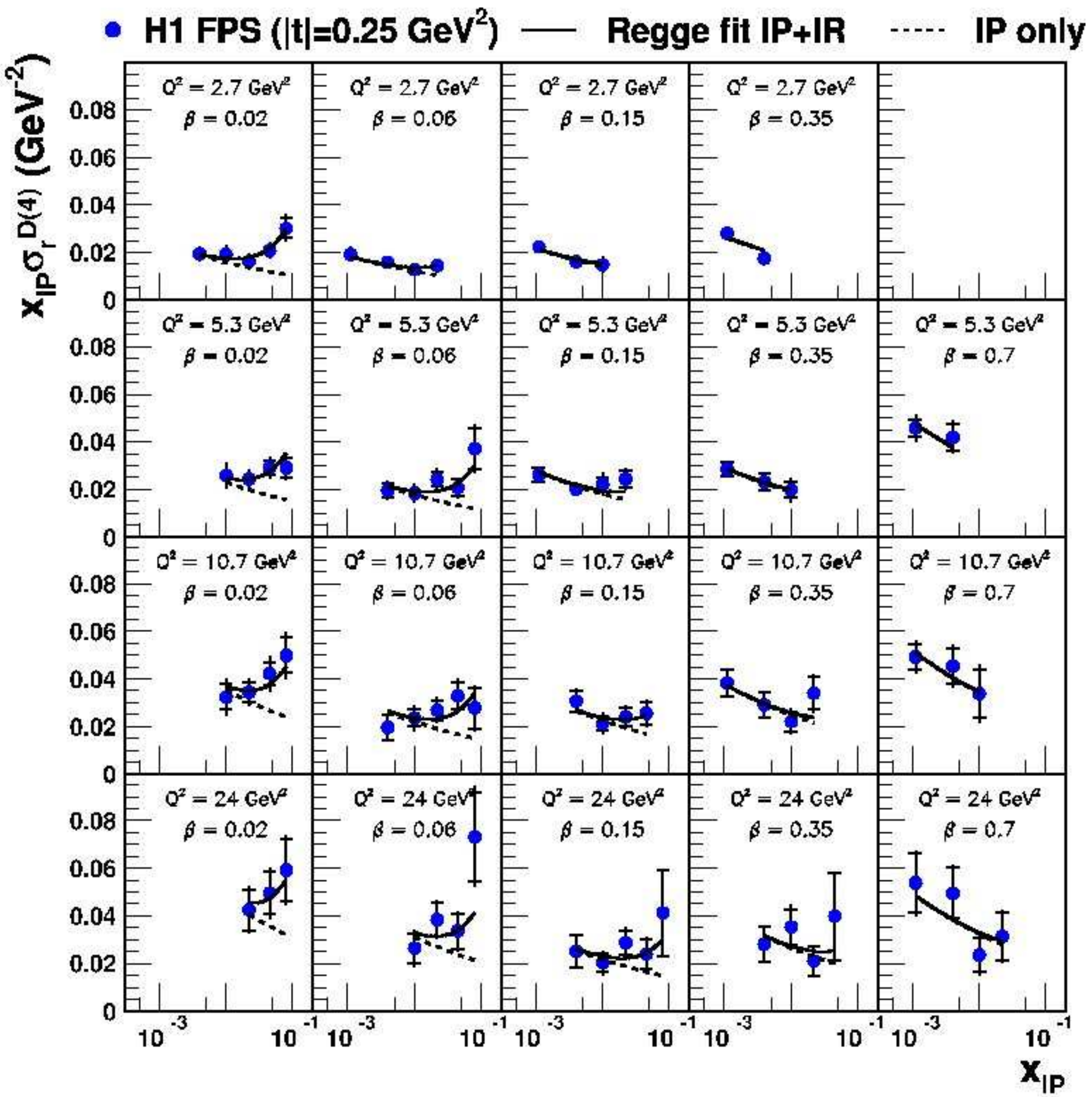
Highlights

- A wealth of inclusive diffractive data from ZEUS and H1: consistency reached between different experiments, methods and data sets
- Data ready to be combined and/or fitted globally!
- Diffractive parton density functions available which can be used to predict other processes
  - Inclusion of dijet data in the QCD fits provides a much better constraint of the gluon density at high fractional momentum

Backup

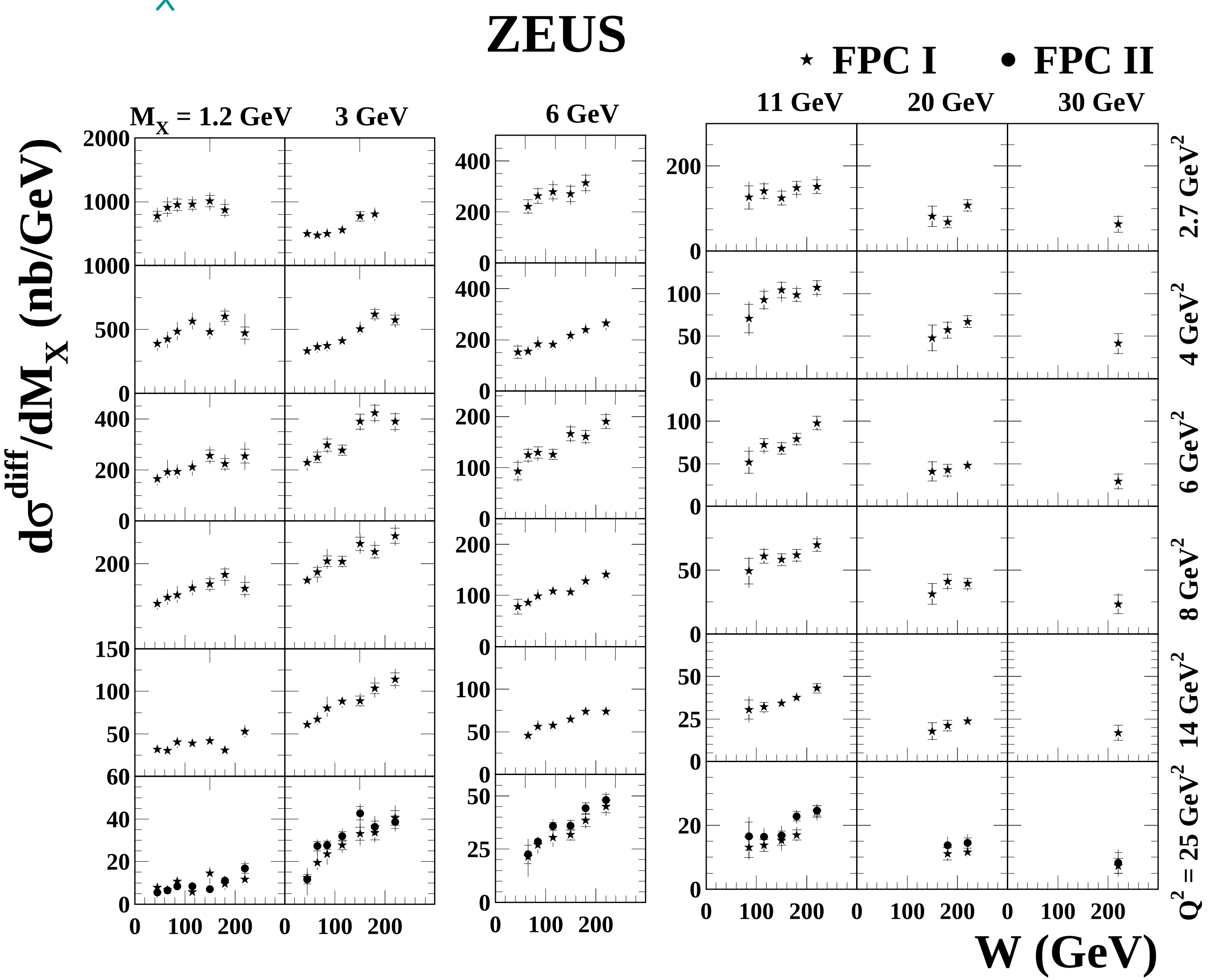
x_{IP} dependence of $\sigma_r^{D(4)}$
FPS data

LISHEP 2009, M. Ruspa, 21.01.09



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

ZEUS M_X data

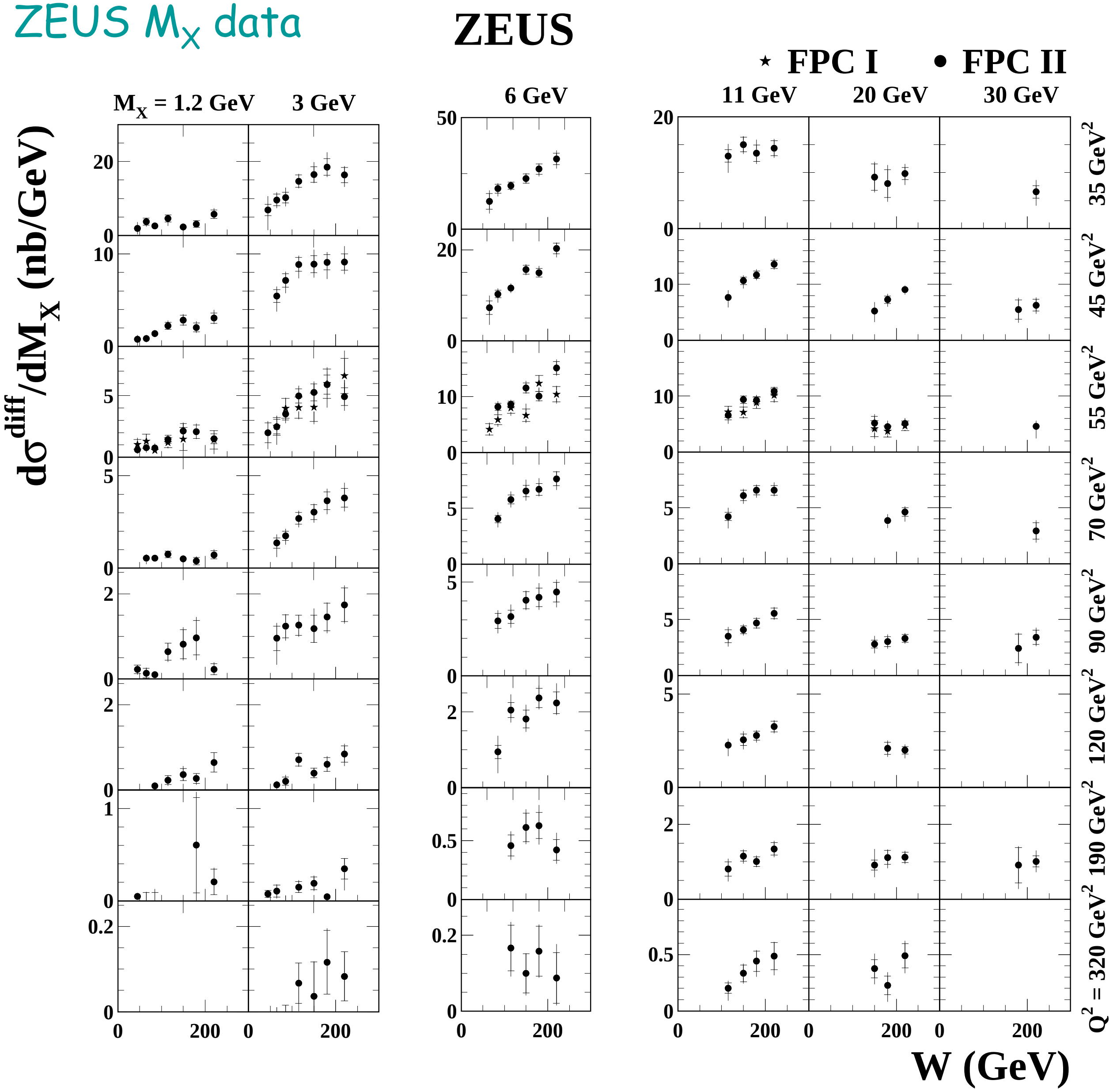


→ Low M_X: moderate increase with W and steep reduction with Q^2

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

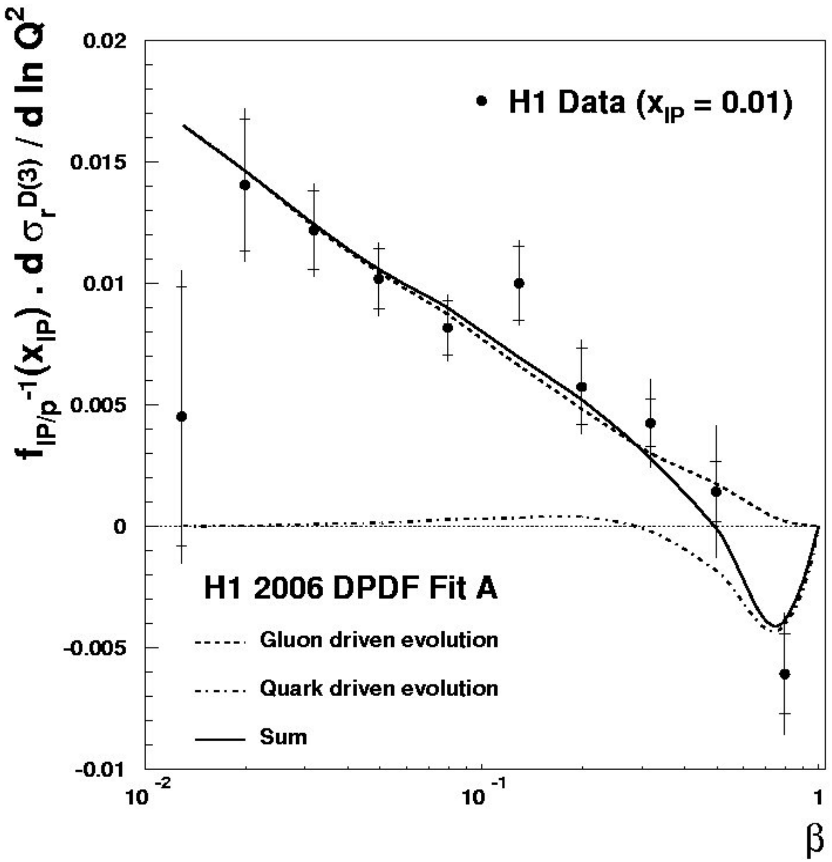
W dependence of $d\sigma^{diff}/dM_X$

ZEUS M_X data



→ Substantial rise with W

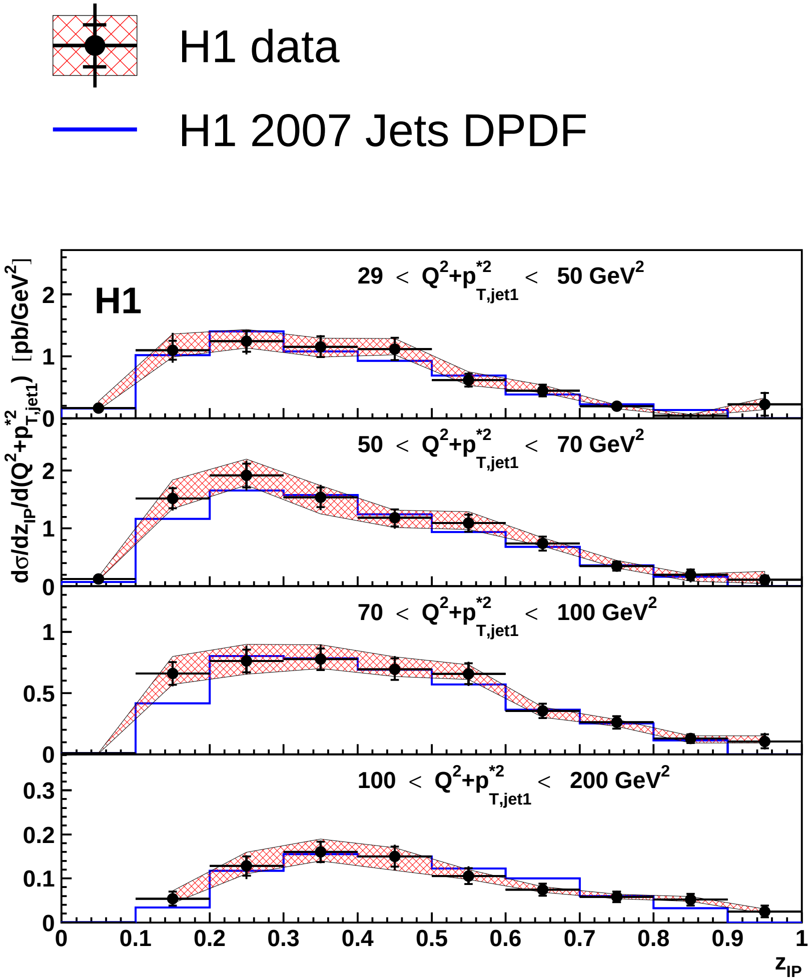
Why is the high β gluon so poorly known?

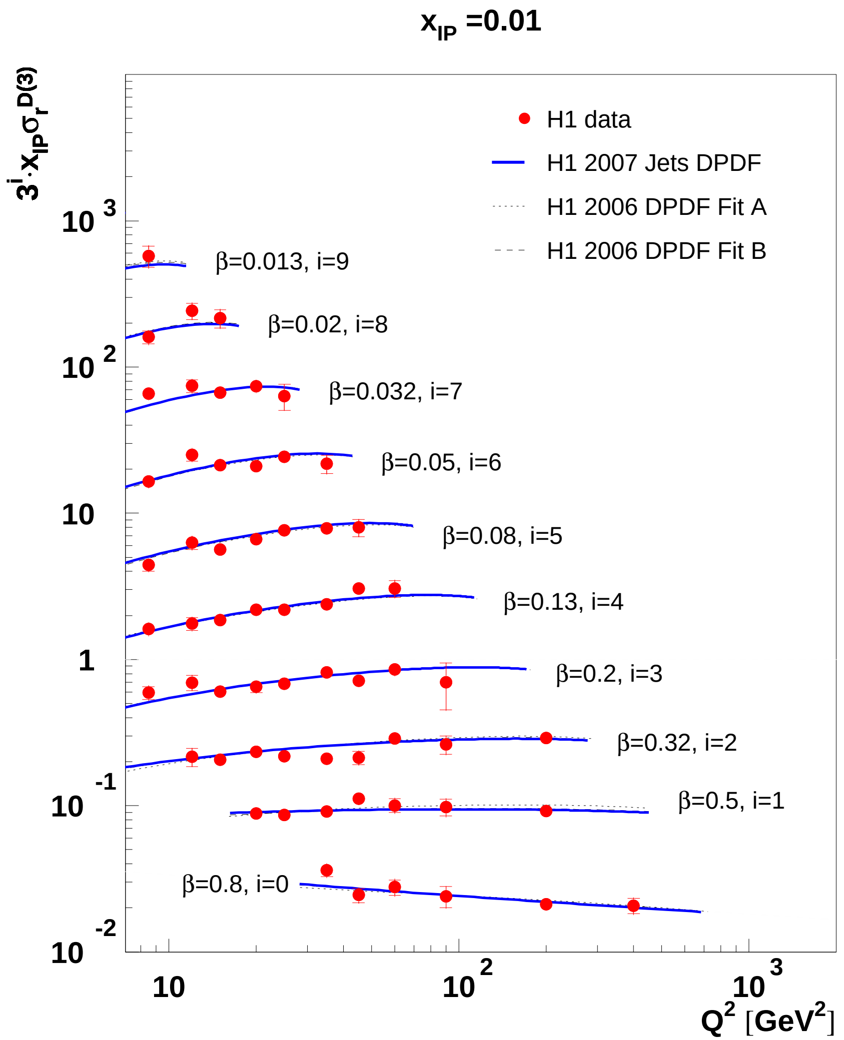


- **Low β:** evolution driven by g → qqbar, **Q^2 dependence of $\sigma_r^{D(3)}$ sensitive to the gluon density**
- **With increasing β** relative error on derivative and hence on the gluon density larger
- **High β:** evolution driven by q → qg **Q^2 dependence of $\sigma_r^{D(3)}$ not sensitive to the gluon density**

Combined fit

H1 LRG+dijet data





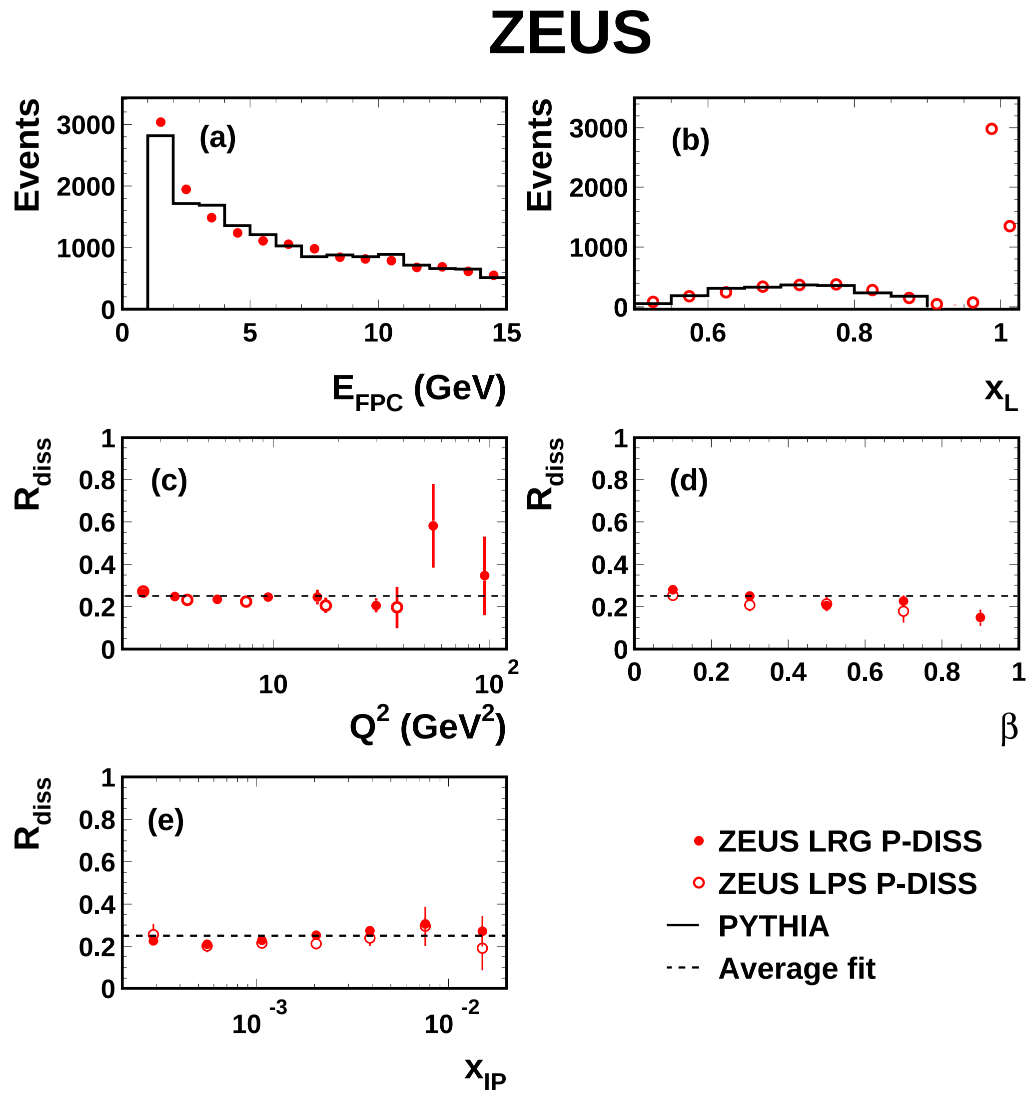
See A. Valkarova's talk

Proton dissociation @ZEUS: 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

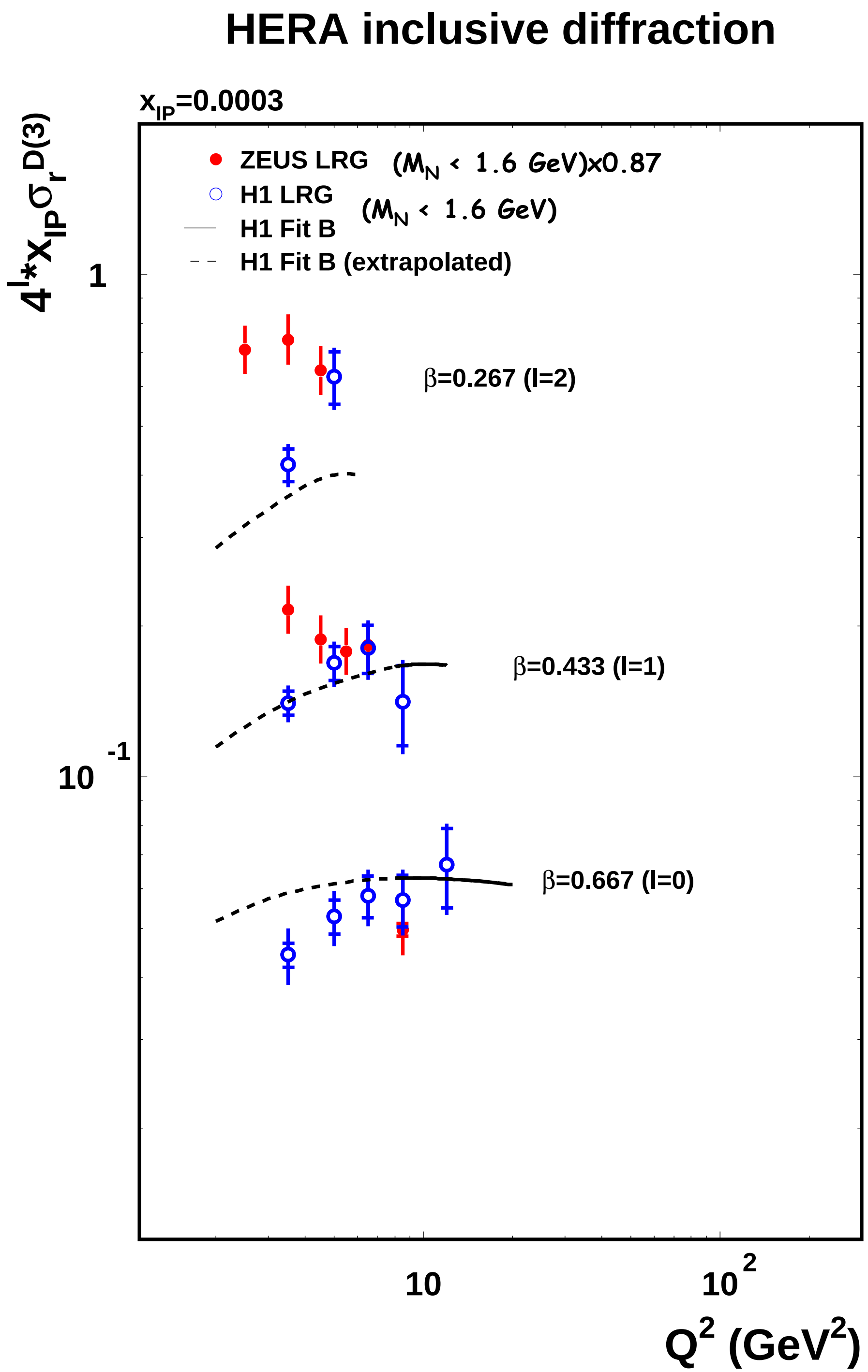


→ p-diss. background in LRG data R_{diss} = [25 +-1(stat) +-3(sys)]%

→ consistent with the ratio LPS/LRG

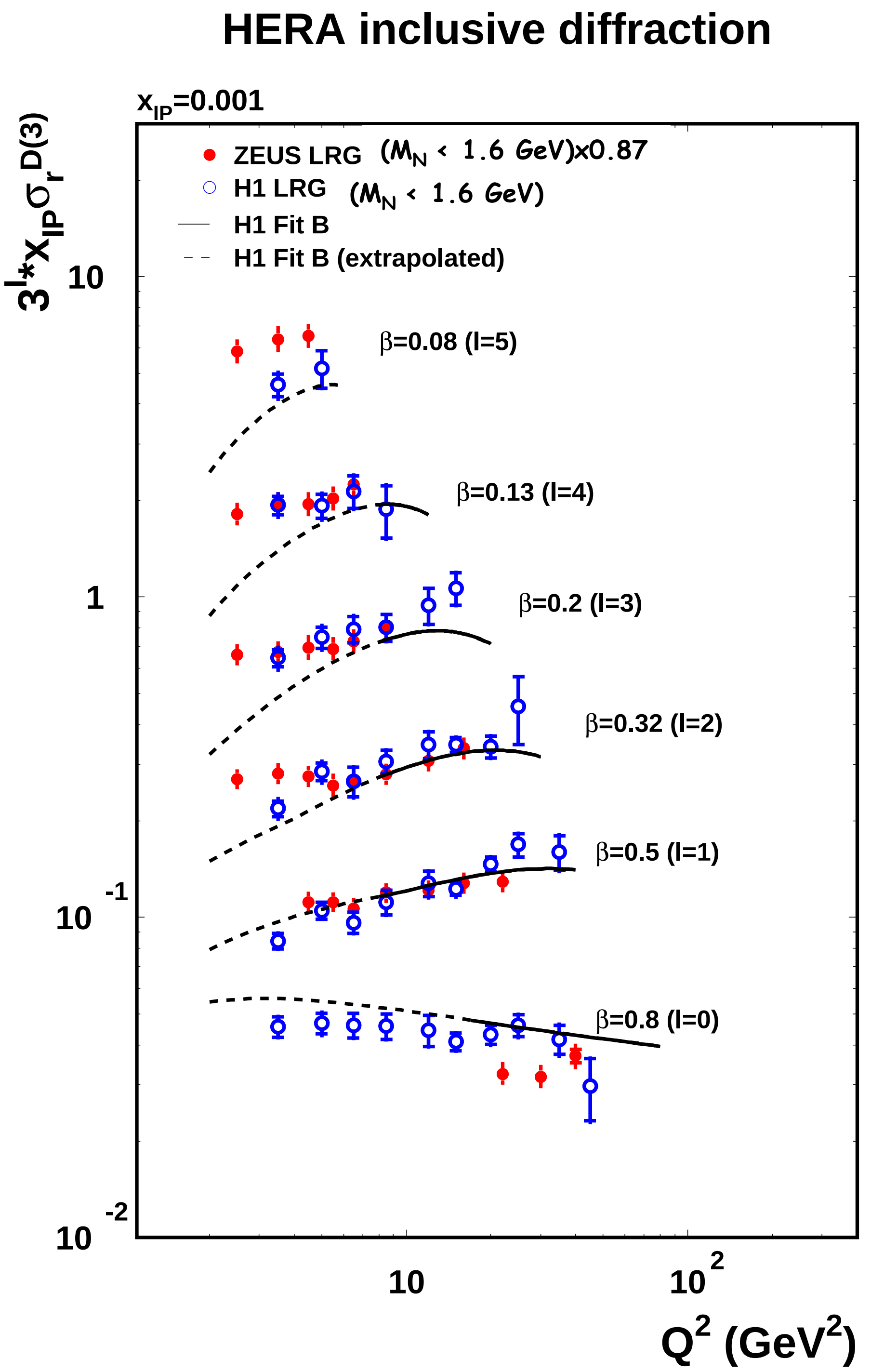
→ 25% correction applied to LRG data

Towards HERA inclusive diffraction!



→ Time for data combination, global fits!

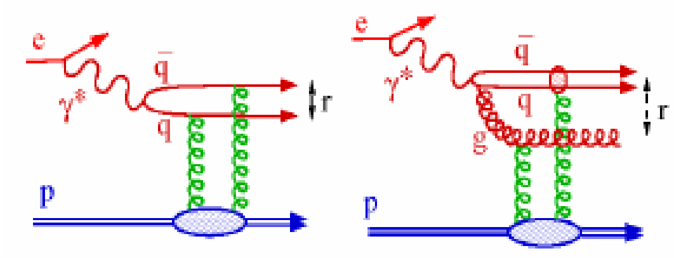
Towards HERA inclusive diffraction!



→ Time for data combination, global fits!

Fit with BEKW parameterisation

(Bartels, Ellis, Kowalski, Wustoff 1988)



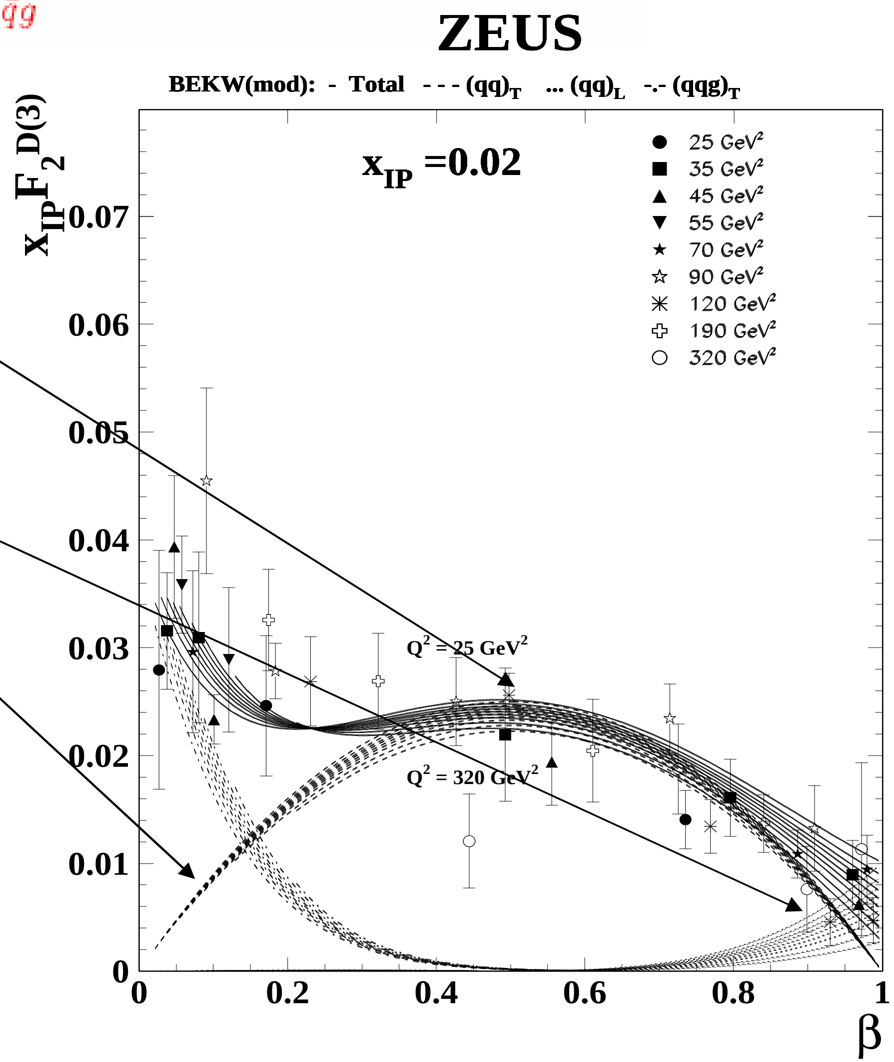
$$x_{IP} F_2^{D(3)} = c_T \cdot F_{q\bar{q}}^T + c_L \cdot F_{q\bar{q}}^L + c_g \cdot F_{q\bar{q}g}^T$$

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

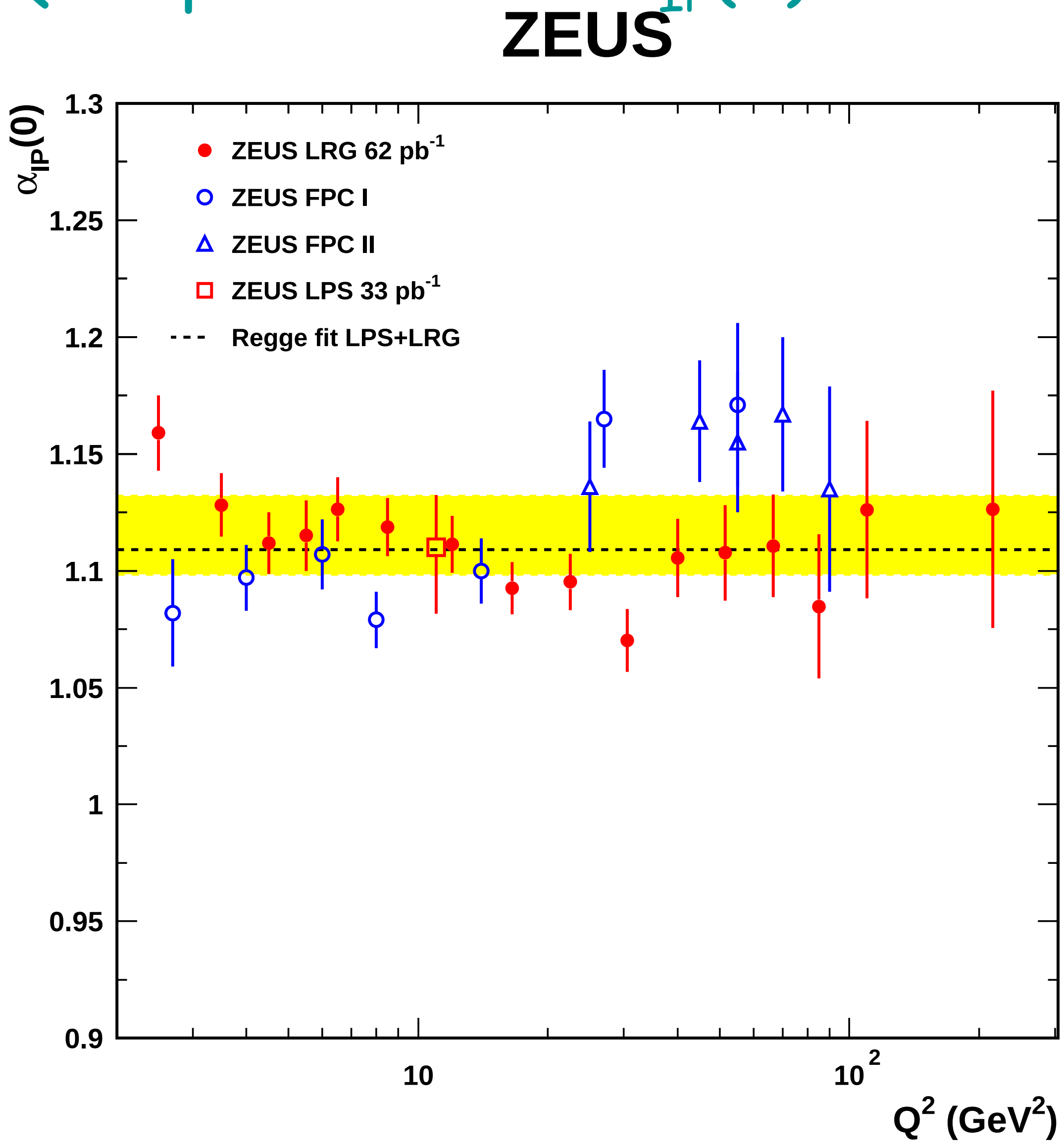
$$F_{q\bar{q}g}^T \sim (1-\beta)^\gamma$$

$F_{q\bar{q}}^L$ limited to β ~1

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

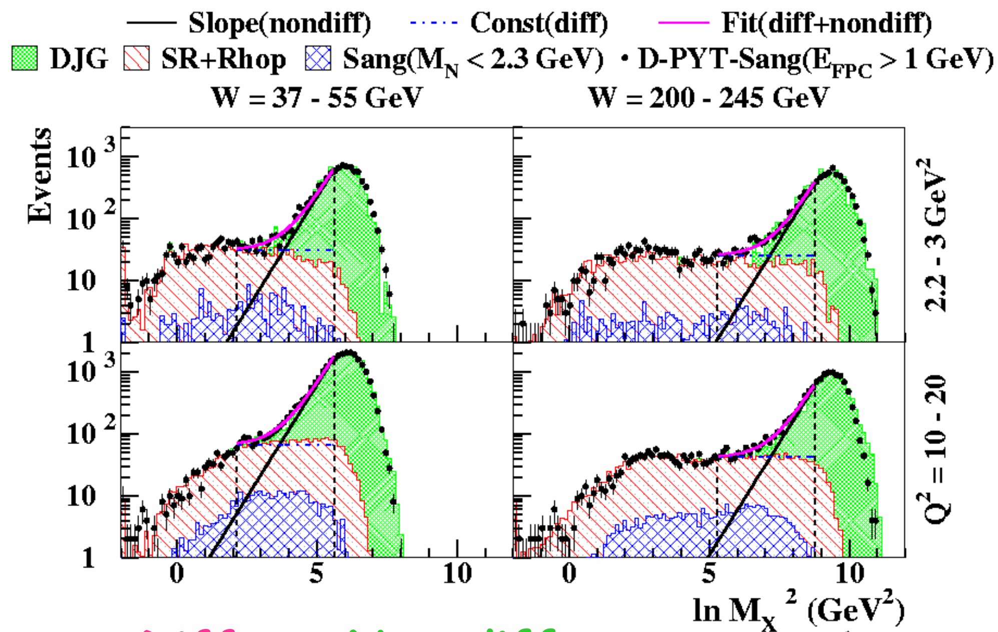


Q^2 dependance of $\alpha_{IP}(0)$



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

M_X method



Properties of M_x distribution:

- exponentially falling for decreasing M_x for non-diffractive events

- flat vs ln M_x^2 for diffractive events

Diffr. Non-diffr.

$$\frac{dN}{dlnM_X^2} = D + c \cdot exp(b \cdot lnM_X^2)$$

- D, c, b from a fit to data
- contamination from reaction $ep \rightarrow eXN$

Forward Plug Calorimeter (FPC):

CAL acceptance extended by 1 unit in pseudorapidity from $\eta=4$ to $\eta=5$

$\rightarrow$ higher M_x and lower W

$\rightarrow$ if $M_N > 2.3$ GeV deposits $E_{FPC} > 1$ GeV recognized and rejected!