XVI International Workshop on Deep Inelastic Scattering
UCL, London, 7-11 April, 2008

Inclusive Diffraction in DIS: LRG, LPS and M_x methods

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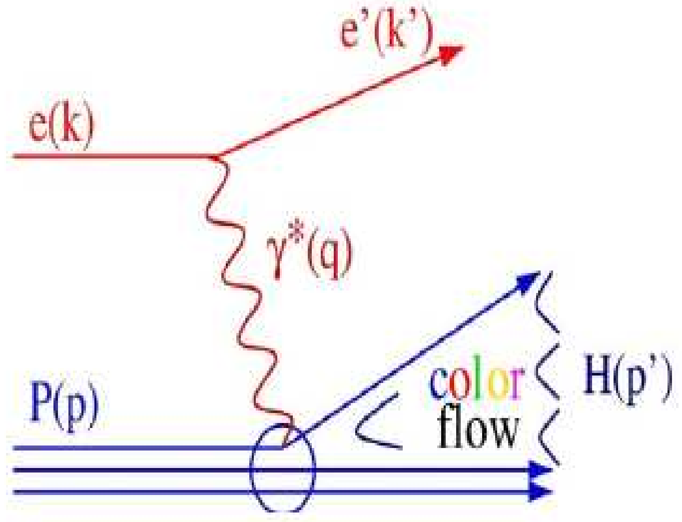
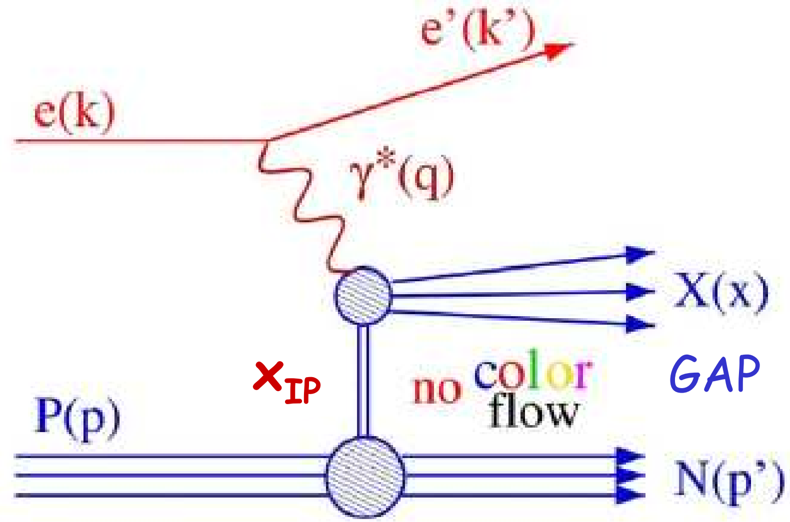
on behalf of ZEUS

Diffractive DIS at HERA

Standard DIS



Diffractive DIS



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

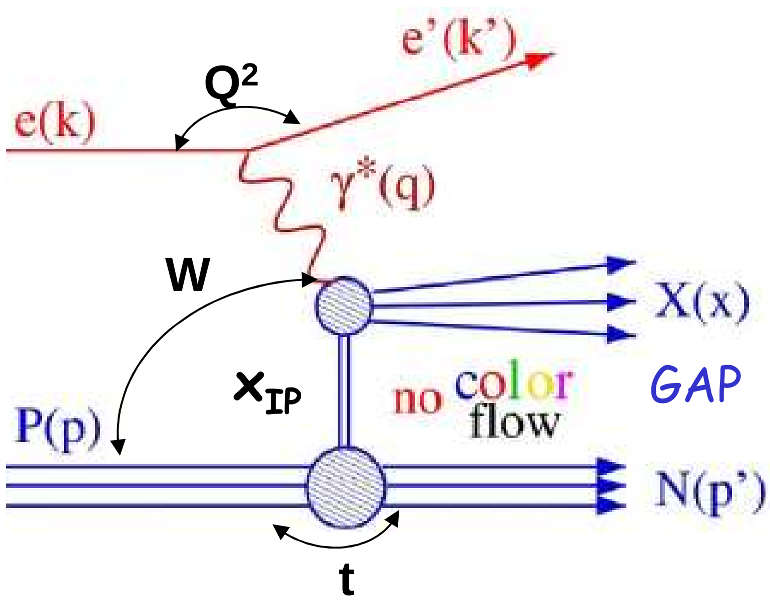
W = invariant mass of γ^*-p system

M_X = invariant mass of γ^* -IP system

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

ß = Bjorken's variable for the IP
= fraction of IP momentum carried by struck quark
= x/x_{IP}

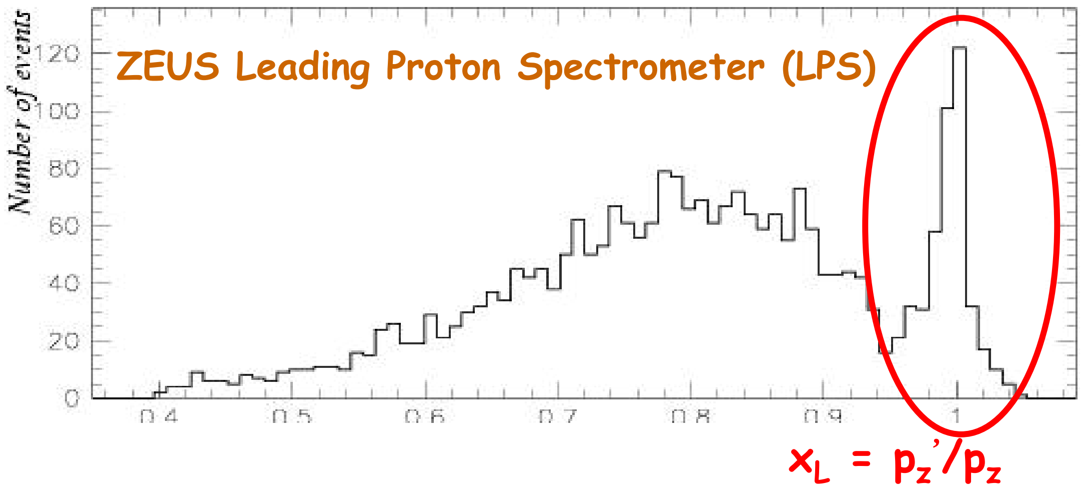
t = (4-momentum exchanged at p vertex)^2
typically: $|t|<1$ GeV^2



- **Single diffraction:** **N=proton**
- **Double diffraction:** **proton-dissociative system N**

  → **represents a relevant background**

Diffractive event selection

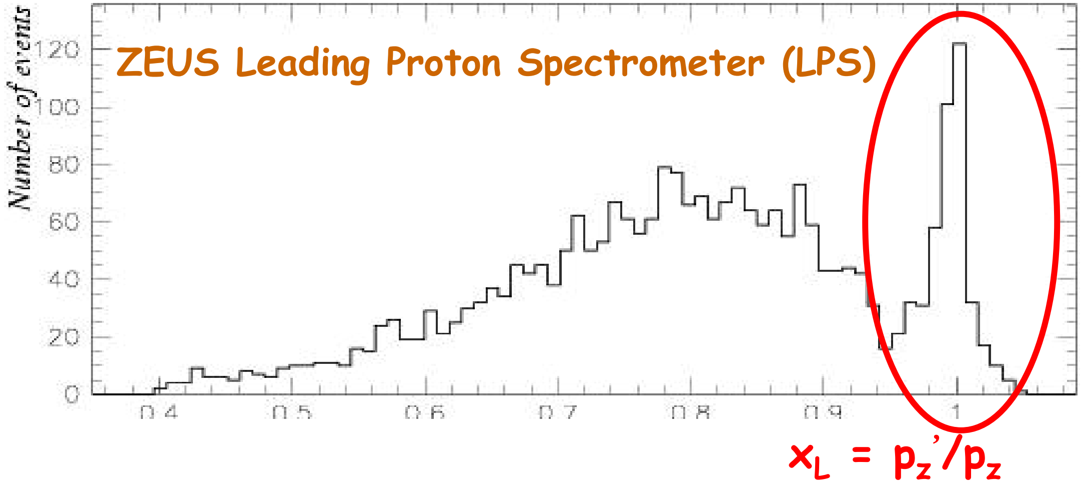


LPS method

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

CONS: low statistics

Diffractive event selection



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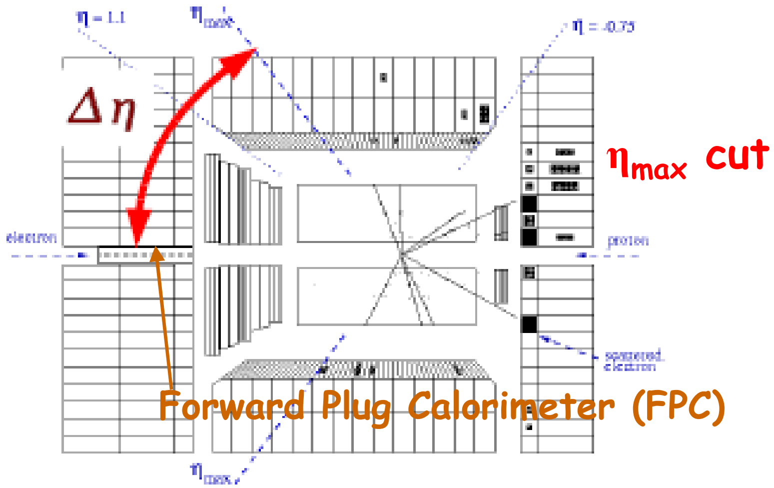
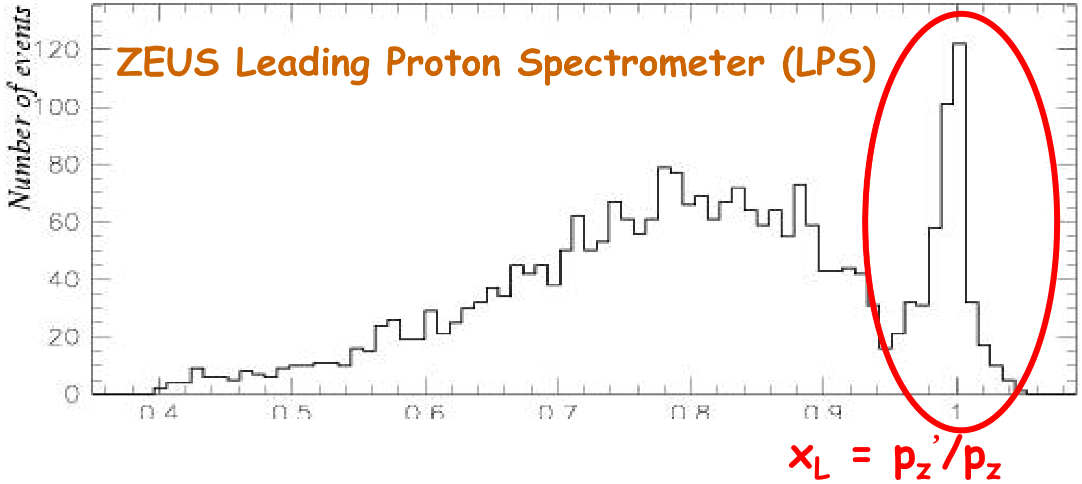
Large Rapidity Gap (LRG) method



Diffractive event selection



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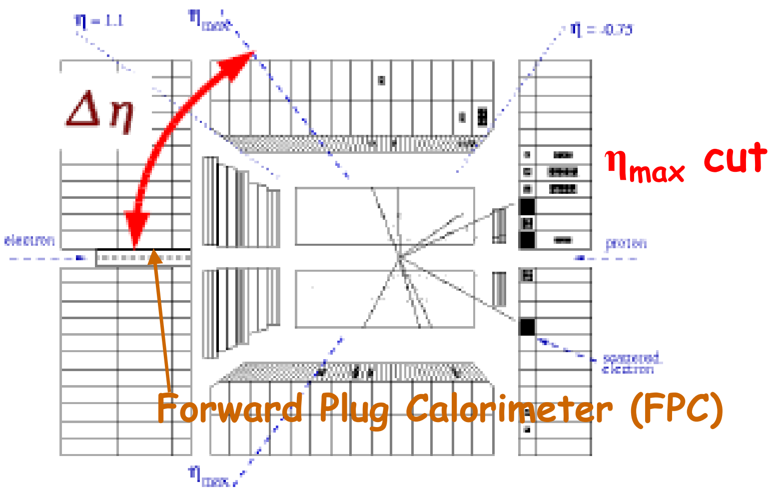
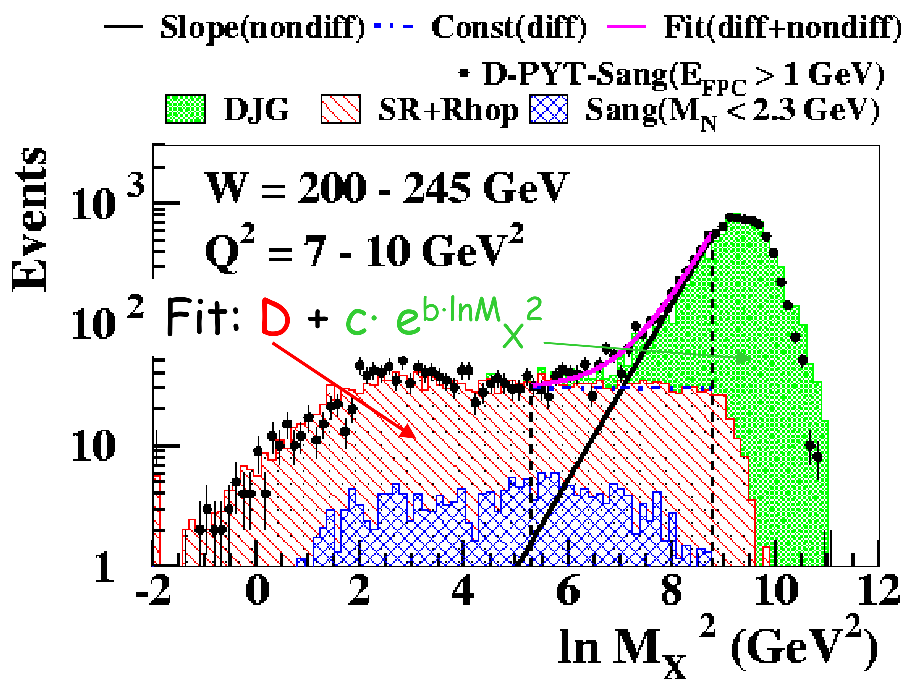


M_x method



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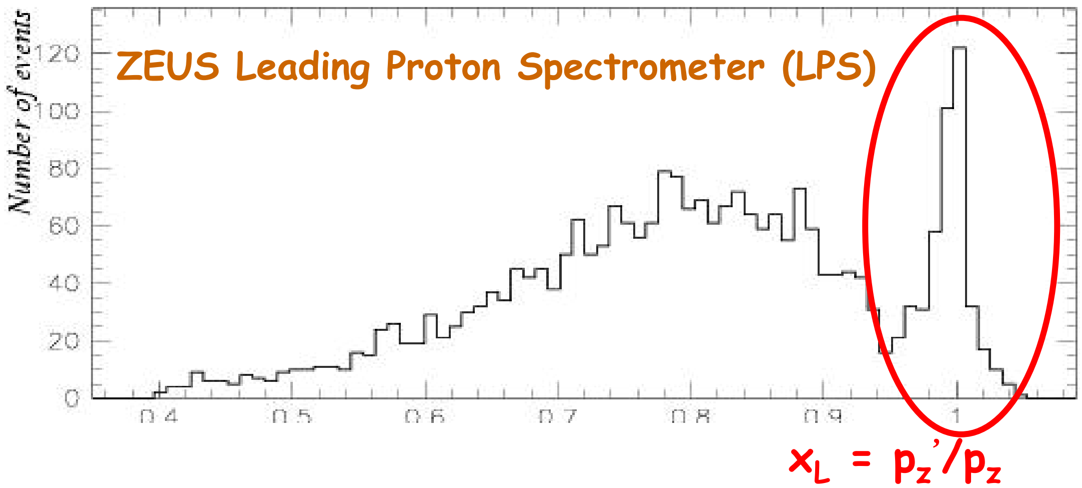

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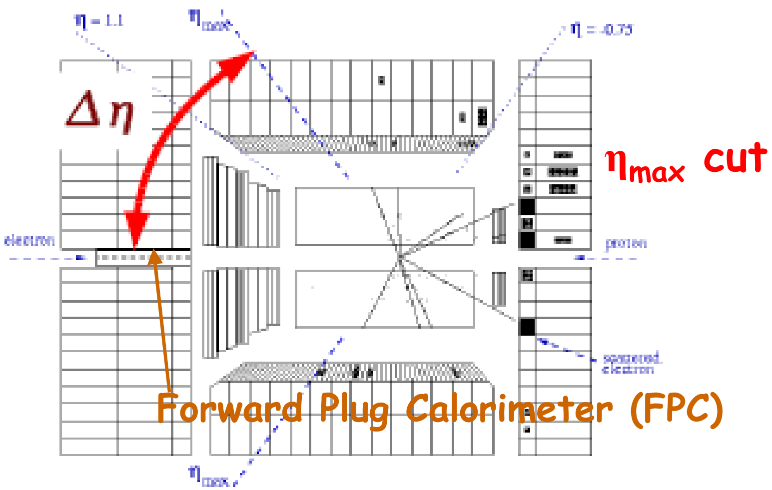
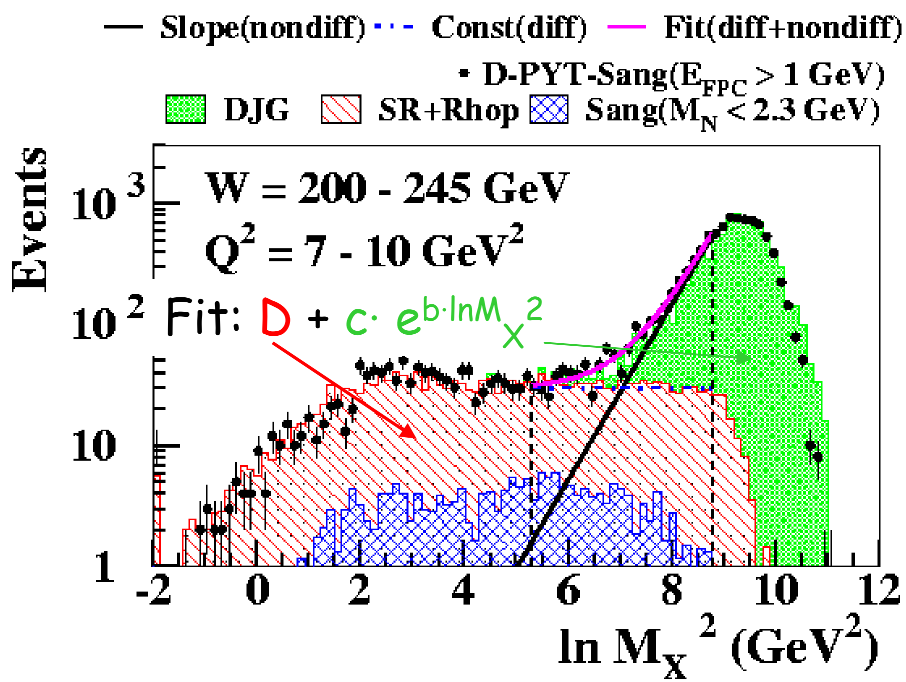


PROS: near-perfect acceptance at low x_{IP}

CONS: p.-diss background

M_x method



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 $R^D = 0$**

Will look at

- Q^2, t, x_{IP} dependence
- Regge fits
- Data comparisons

Data sets

- "LPS": 1999/2000 data, $2 < Q^2 < 120$ GeV^2, x_{IP} up to 0.1
- "LRG": 1999/2000 data, $2 < Q^2 < 305$ GeV^2, x_{IP} up to 0.02
- "FPC II" (M_x method): 1999/2000 data, $20 < Q^2 < 450$ GeV^2
  [hep-ph 0802.3017] IR contribution suppressed

35% of LPS events selected by LRG

Overlap LRG-M_X ~75%

➢ Will be compared to

- "FPC I" data [NPB 713 (2005)]
- H1 data: "H1 FPS" (Forward Proton Spectrometer) [EPJ C48 (2006)]
  "H1 LRG" [EPJ C48 (2006)]

Data sets

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ZEUS LRG corrected to $M_N = m_P$

ZEUS M_X corrected to $M_N < 2.3$ GeV

H1 LRG corrected to $M_N < 1.6$ GeV

➢ Will be compared to

- "FPC I" data [NPB 713 (2005)]
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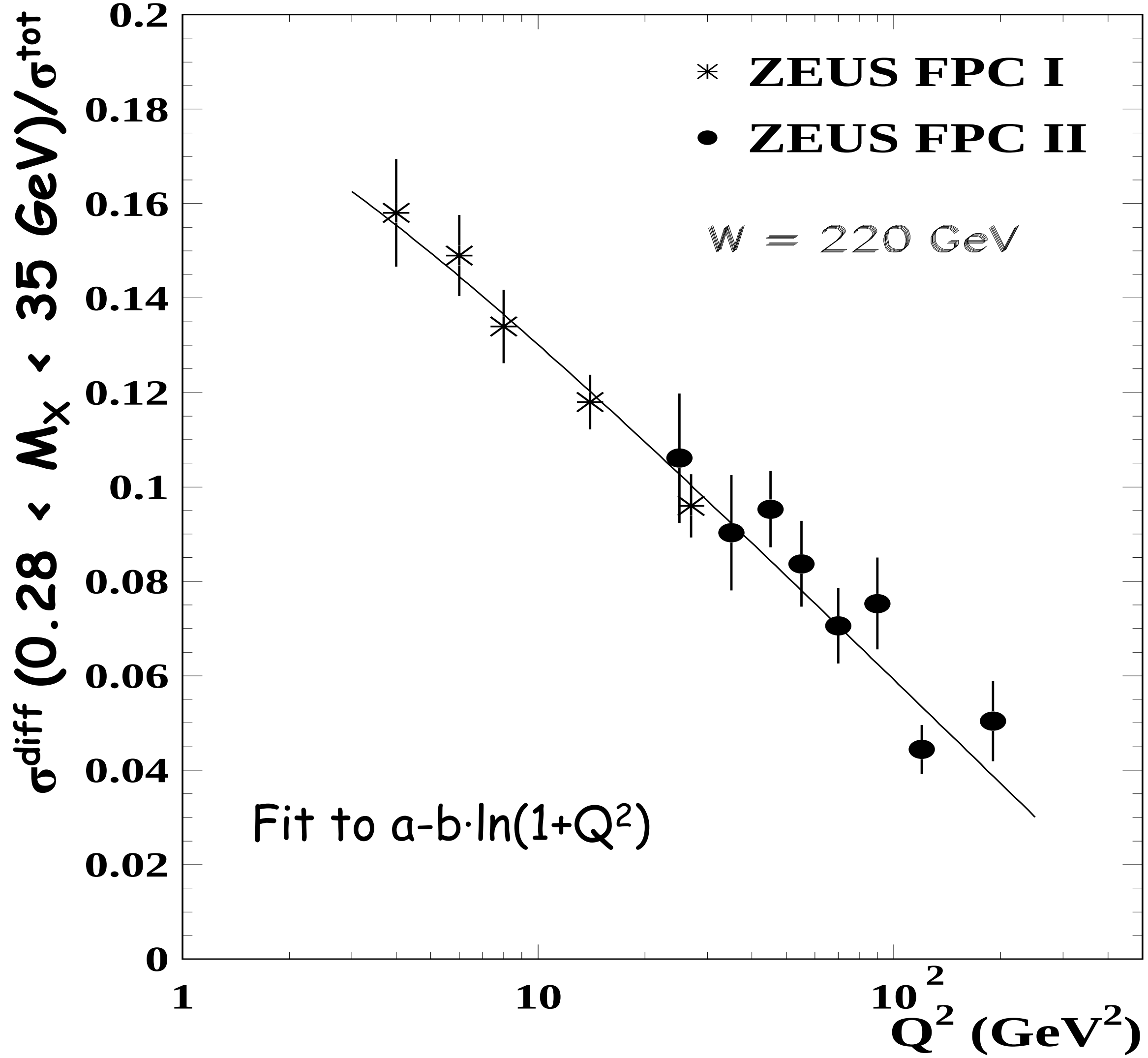
  "H1 LRG" [EPJ C48 (2006)]

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

Diffractive contribution to the total cross section

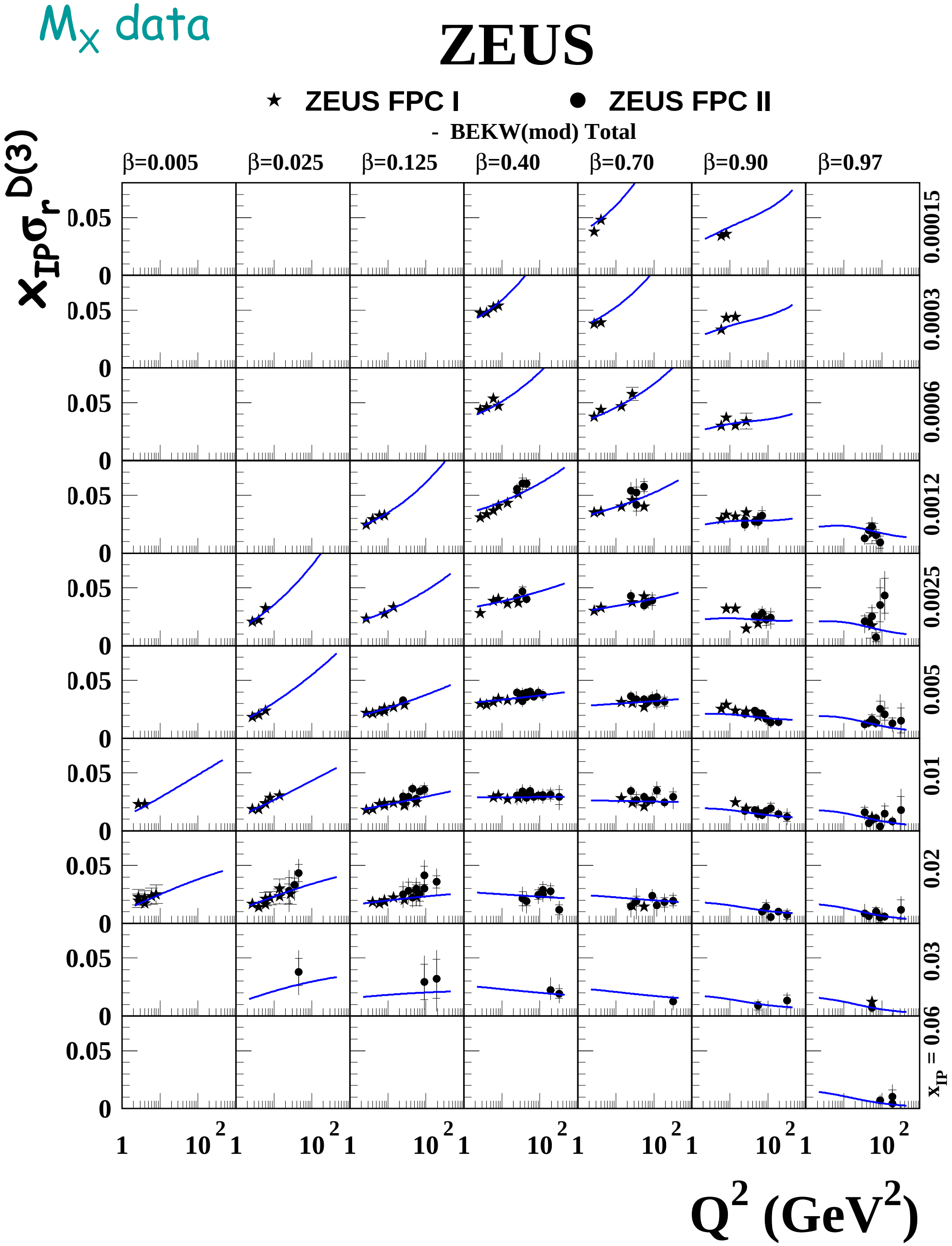
M_X data



→ $\sigma^{diff}/\sigma^{tot}$ decreases logarithmically with Q^2

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

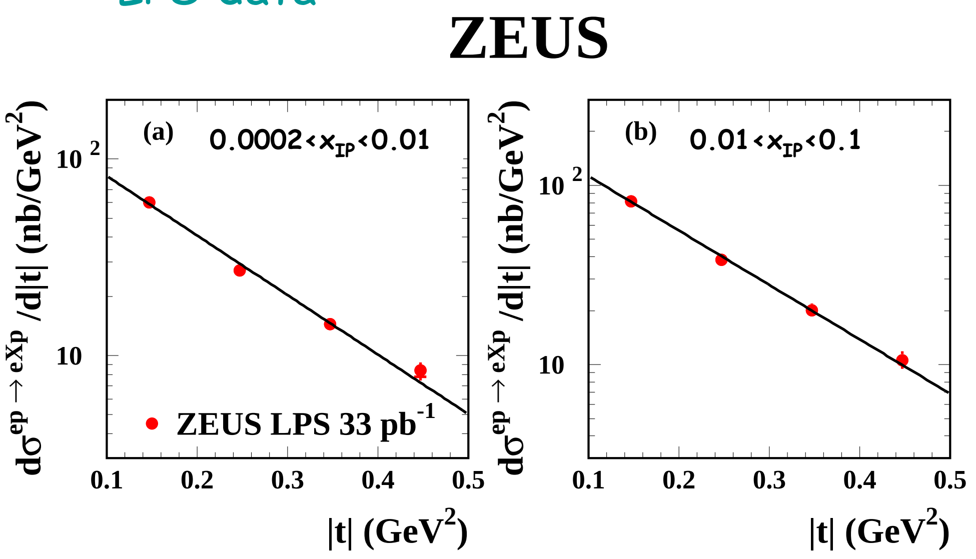
M_X data



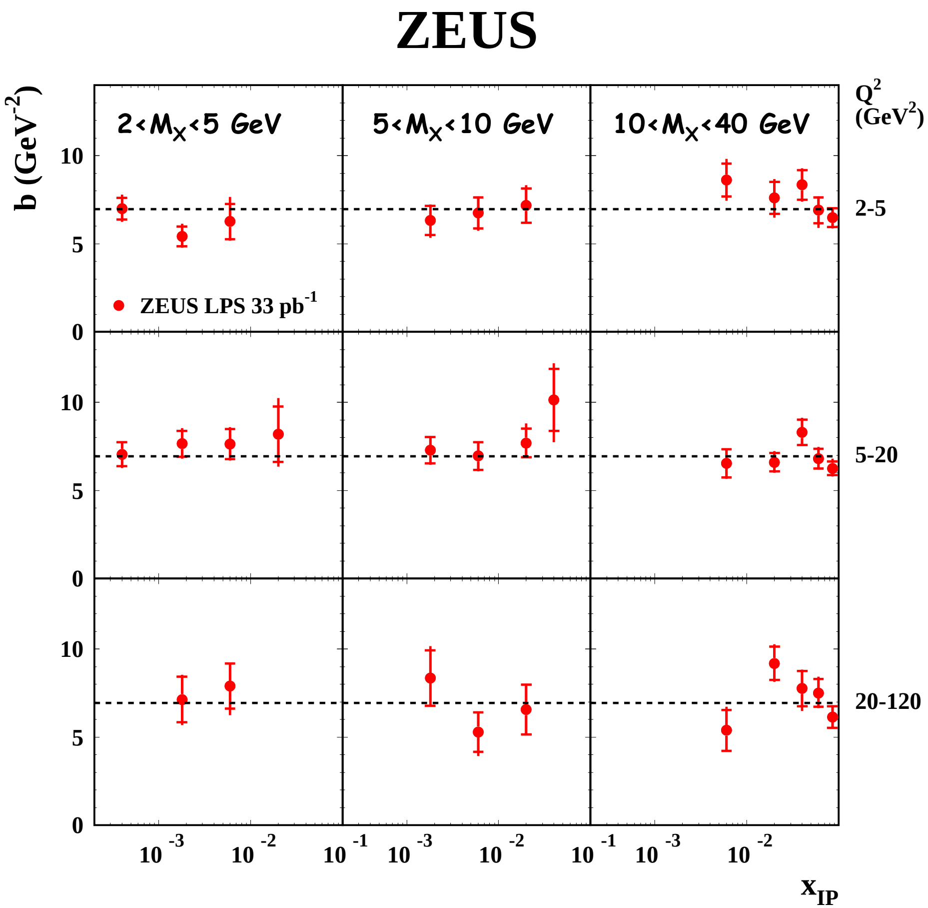
→ **Positive scaling violations up to high-β values: diffractive exchange is gluon-dominated**

t dependance

LPS data



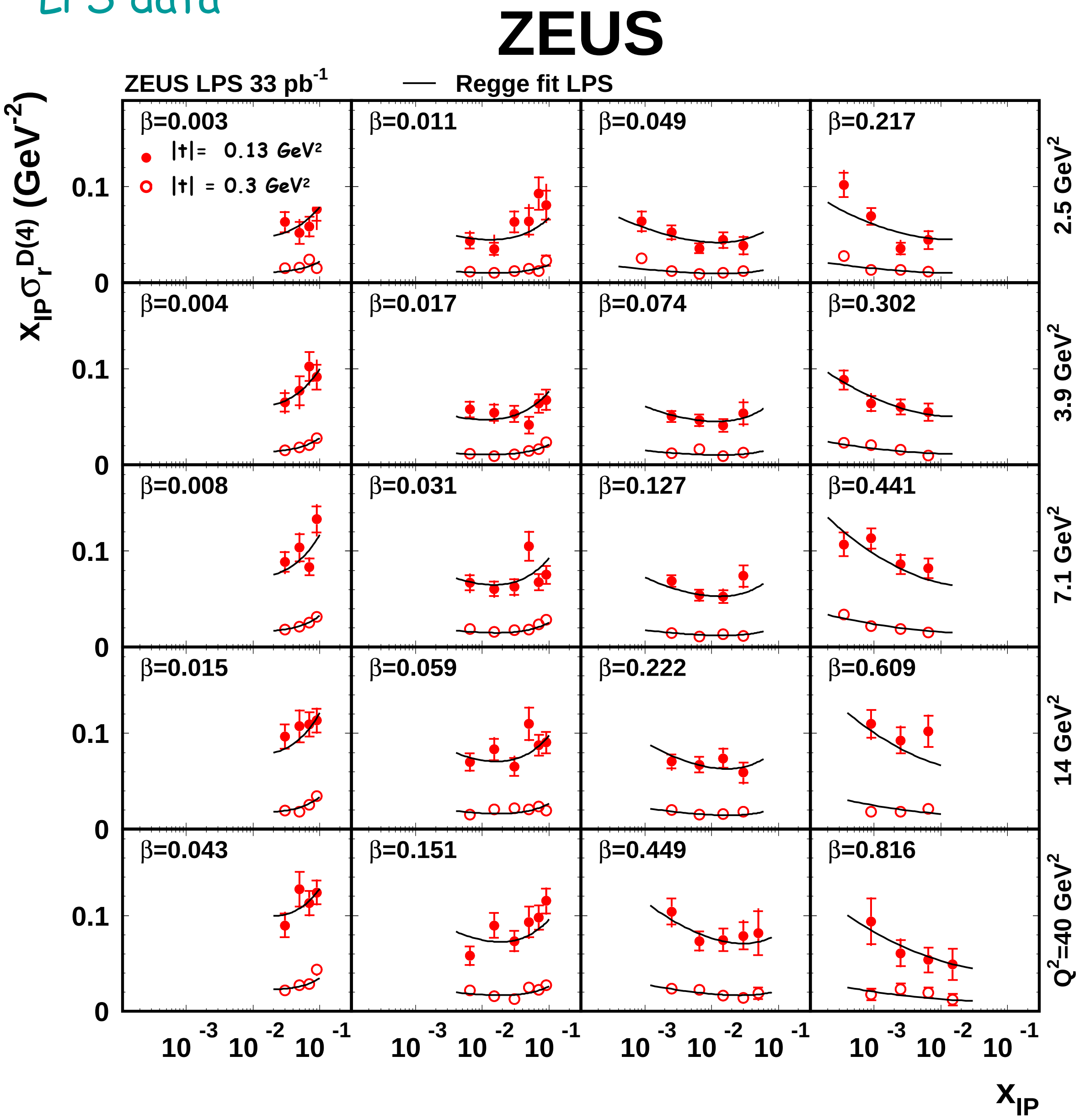
Fit to $e^{-b|t|}$ → $b = 7.0 \pm 0.4$ GeV^{-2}



Lack of Q^2 dependence and b much larger than in vector meson production
→ inclusive diffractive dissociation in DIS is a soft process

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

LPS data



First measurement in the two t bins

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

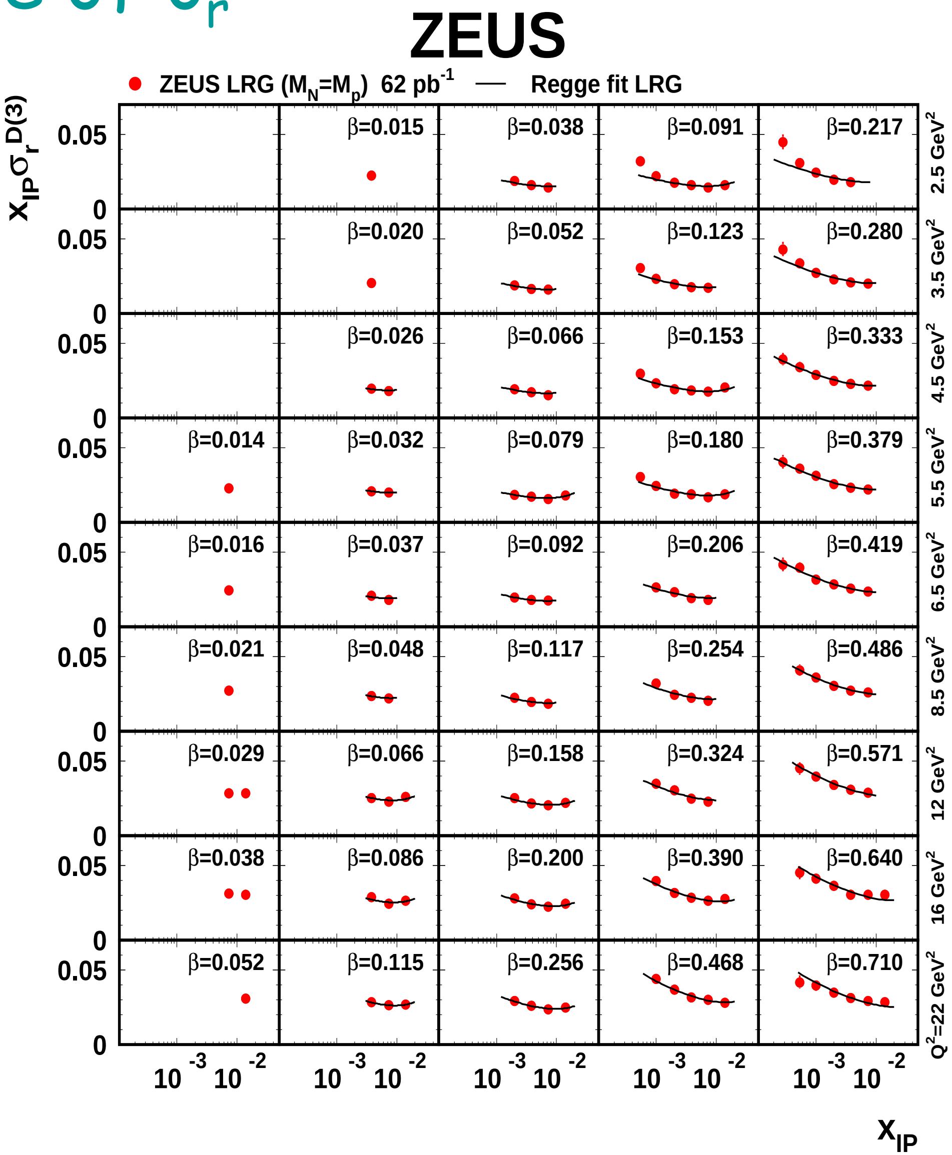
→High x_{IP}: $x_{IP}\sigma_r^{D(4)}$ flattens or increases with x_{IP} (Reggeon and π)

→ Same x_{IP} dependence in two t bins

Regge fit discussed later

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

LRG data

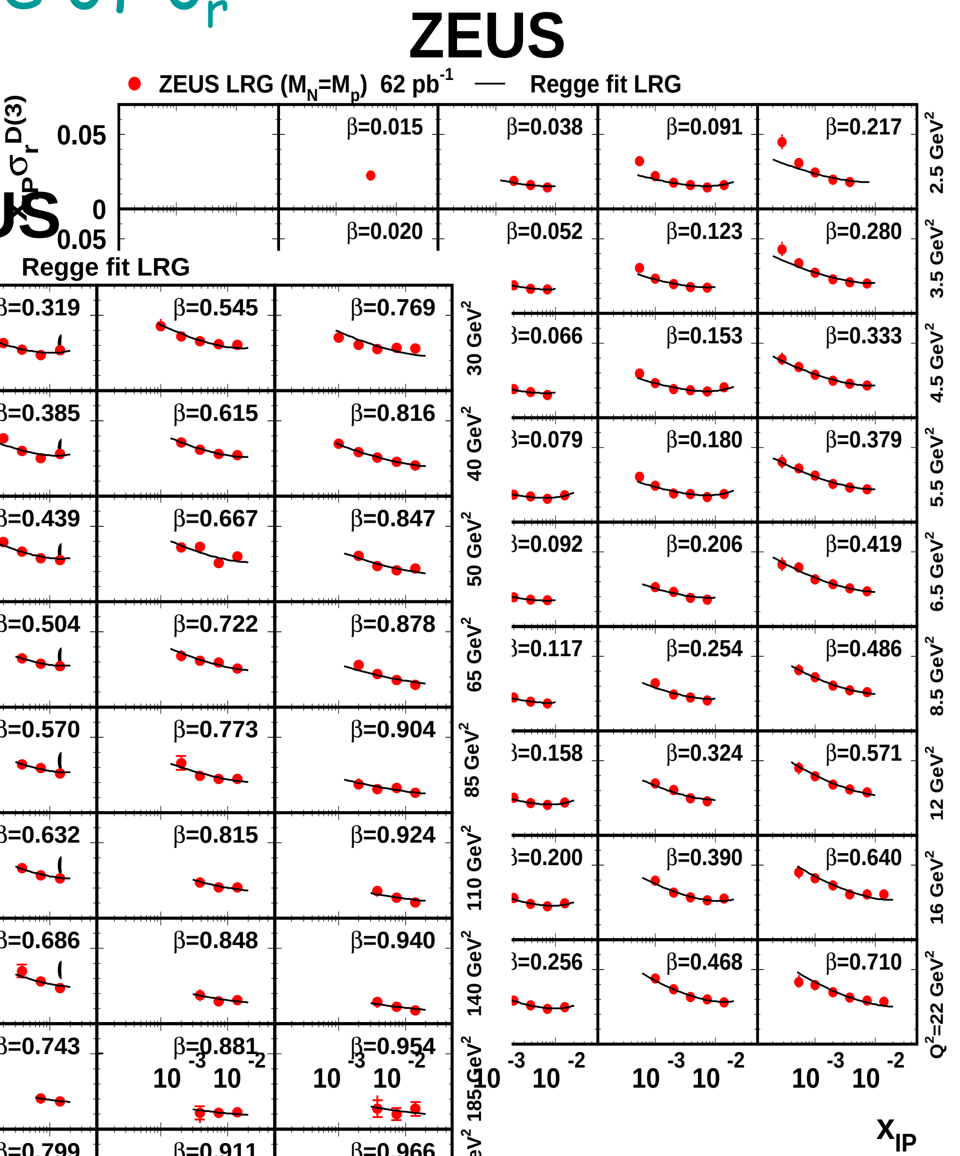


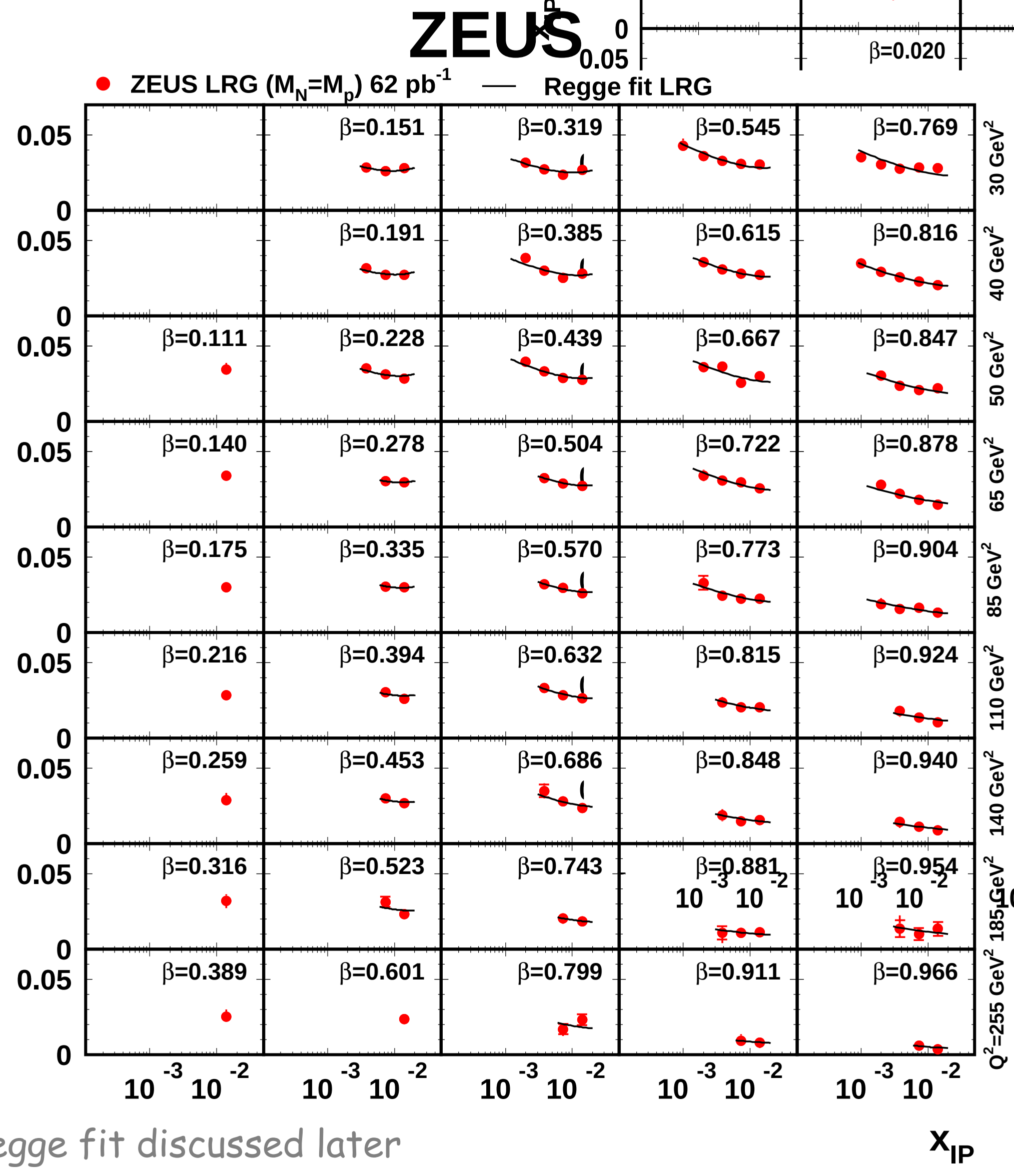
→ **Rise with x_{IP} not visible as $x_{IP} < 0.02$**

Regge fit discussed later

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

LRG data





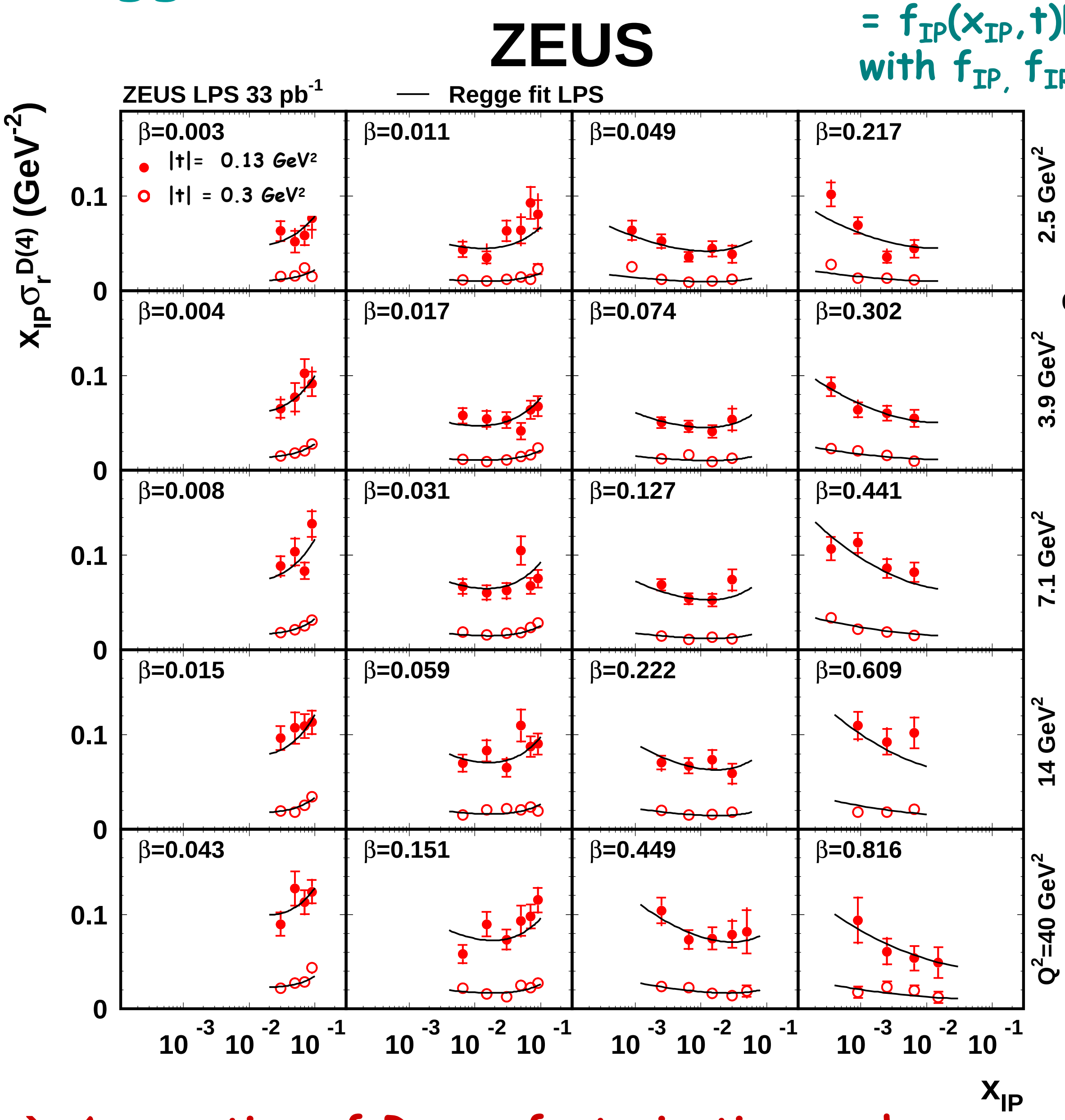
→ Rise with x_{IP} not visible as x_{IP} < 0.02

→ Wide kinematic coverage and very good statistical precision

Regge fit discussed later

Fitting the data...

Regge fit to LPS data



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

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

χ^2 /ndf = 162/153

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

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

H1: α_{IP}' = 0.06 +0.19 -0.06 GeV^{-2}

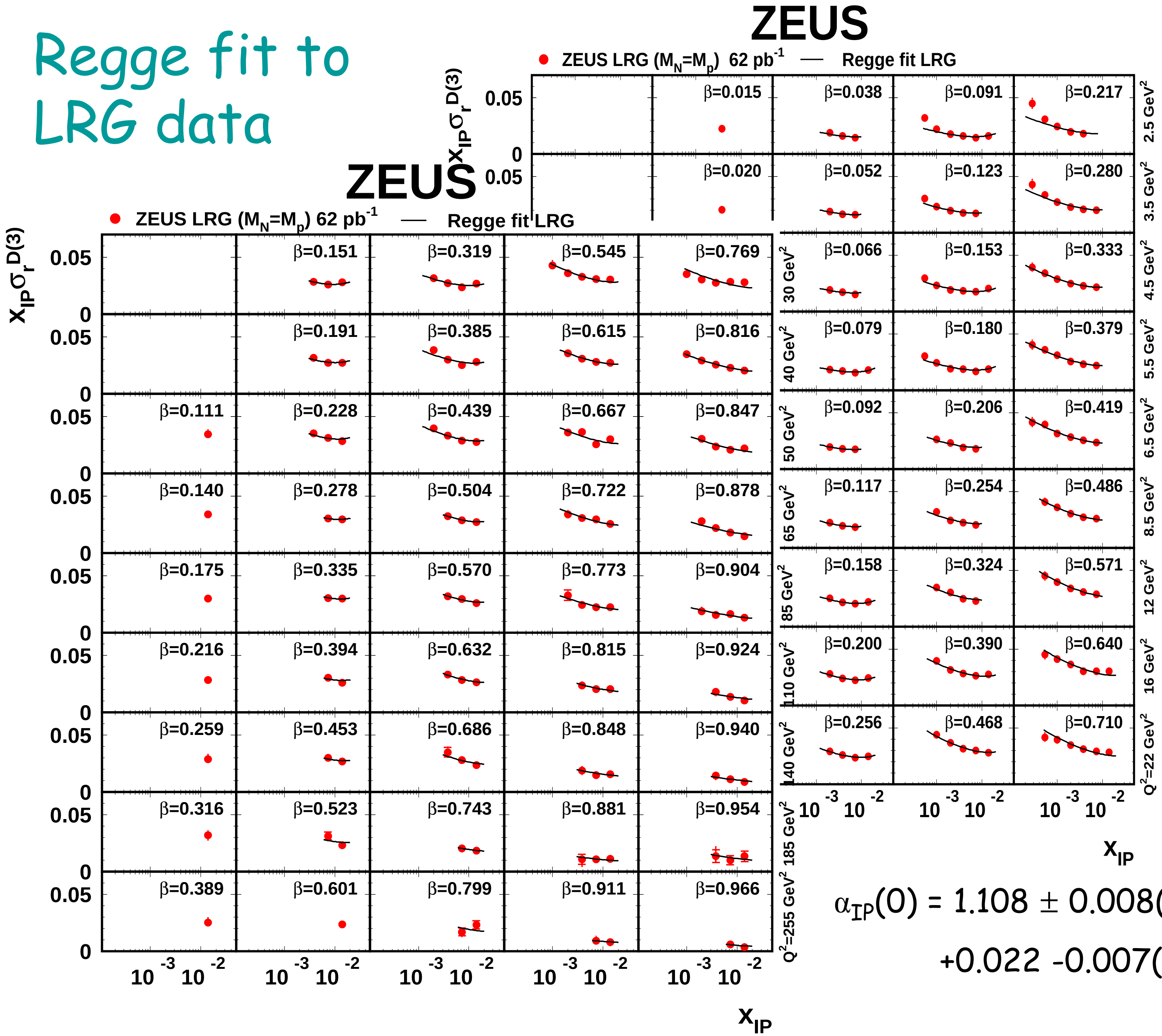
→ **IP intercept consistent with soft IP**

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

$b \sim \alpha'_{IP} \cdot \ln x_{IP}$
→ No strong dependence of b on x_{IP} (slide 14)
expected from $\alpha'_{IP} \approx 0$

→ **Assumption of Regge factorisation works**

Regge fit to LRG data



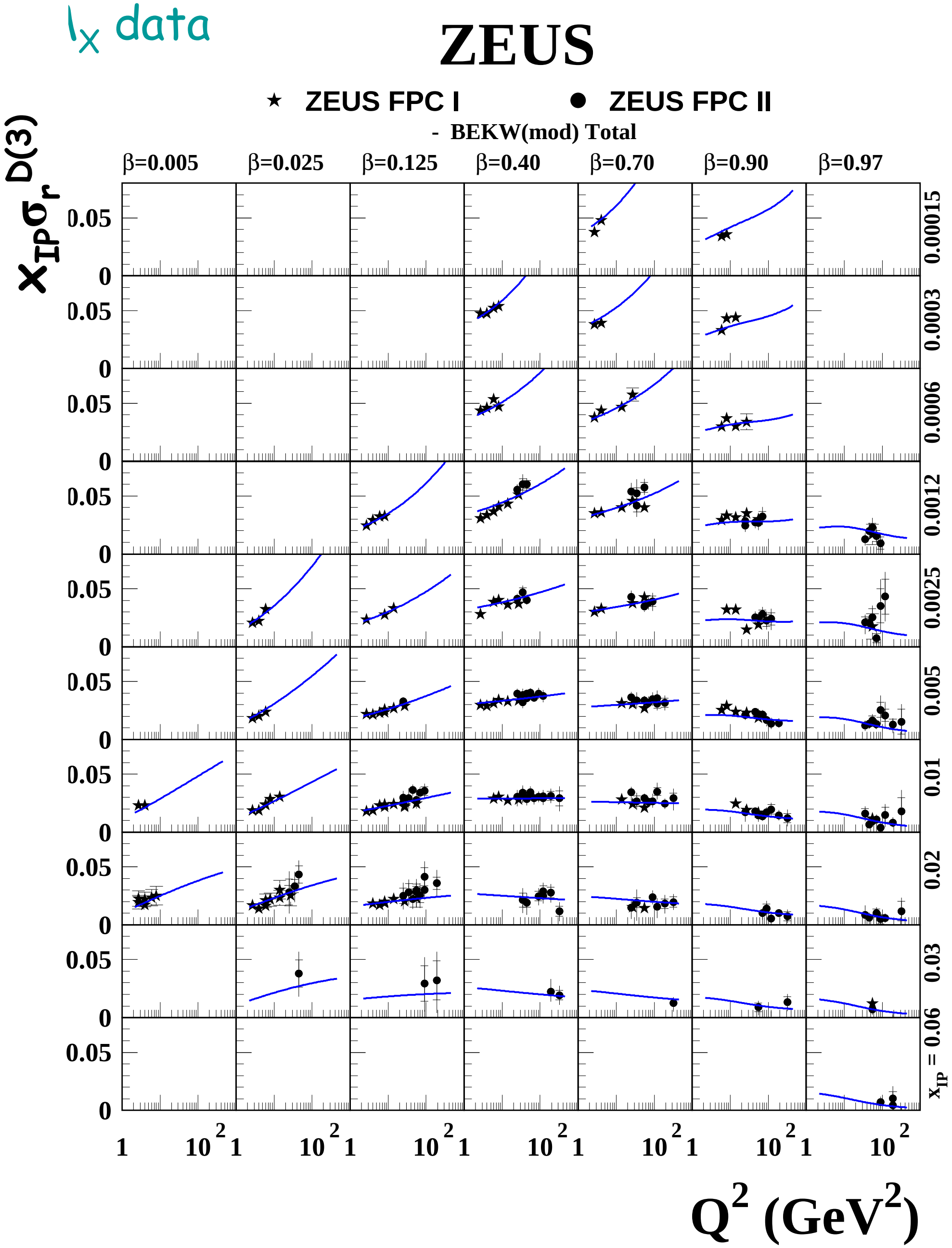
$$\alpha_{IP}(0) = 1.108 \pm 0.008(\text{stat+syst})$$

$$+0.022\ -0.007(\text{model})$$

→ **Assumption of Regge factorisation works**

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

l_X data



→ Scaling violations of $F_2^{D(3)}$ up to high β values : diffractive exchange is gluon-dominated

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

Regge factorisation: yes or no?

Apparent contradiction:

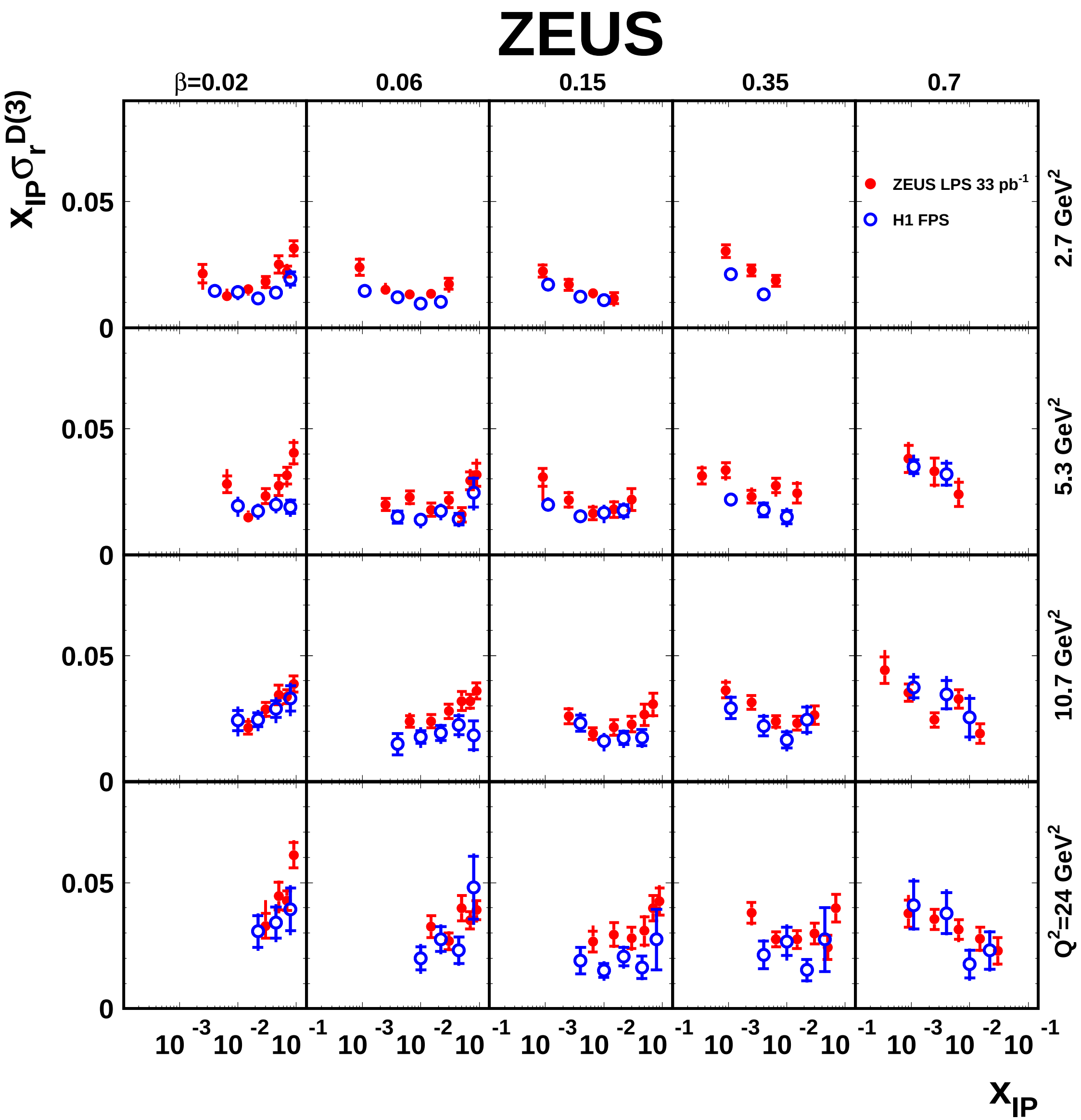
- Regge fit works within errors for LPS and LRG data
- M_x and LRG (see later) show violation of Regge factorisation

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

What if we fitted LPS/LRG without assuming Regge factorisation or M_x data assuming it? Not done yet...

Comparison between data sets

$\sigma_r^{D(3)}$ LPS vs H1 FPS

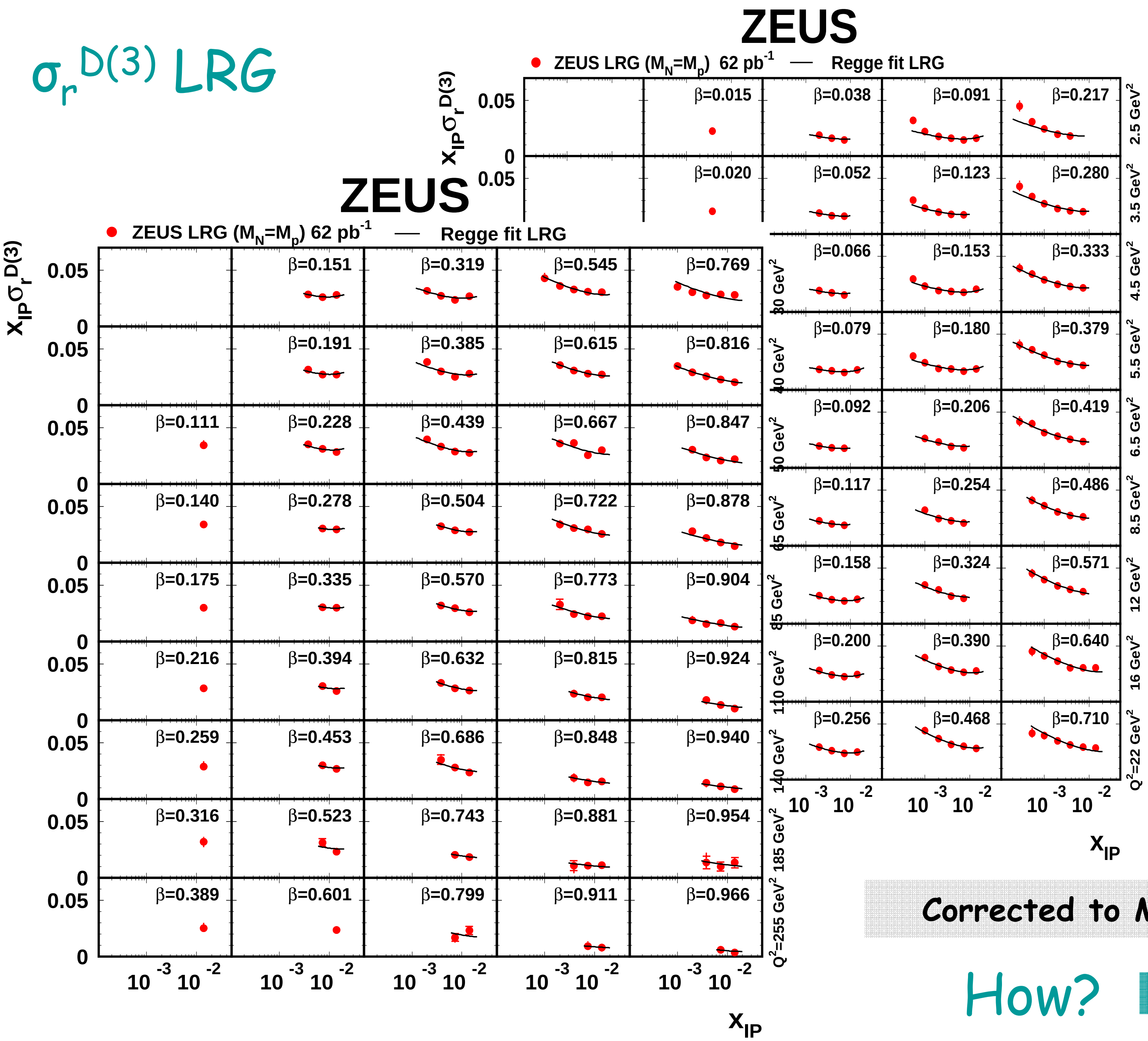


The cleanest possible comparison in principle…

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

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

$\sigma_r^{D(3)}$ LRG



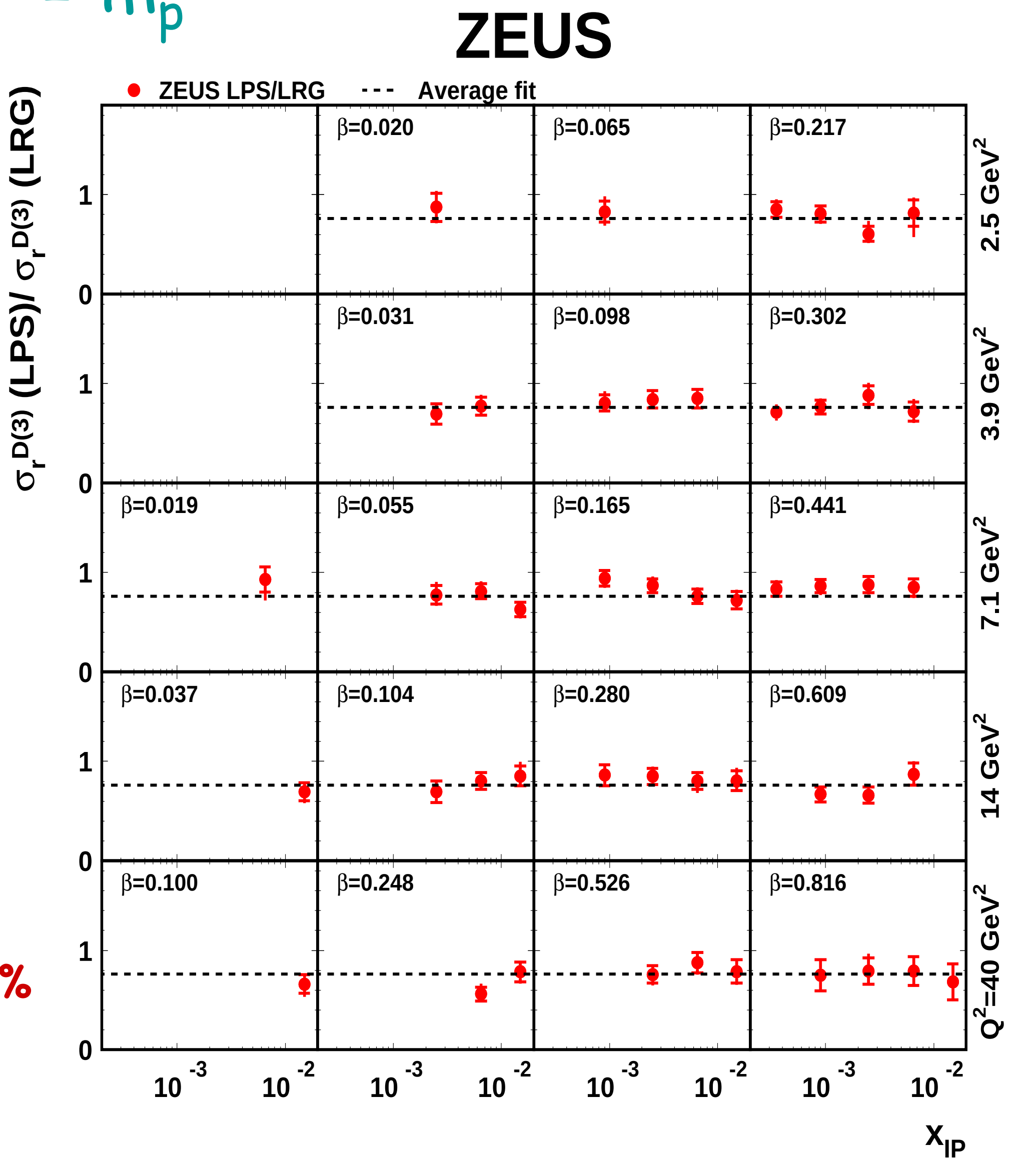
Corrected to $M_N = m_p$

How?

DIS08, London, M. Ruspa 07/04/08

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)

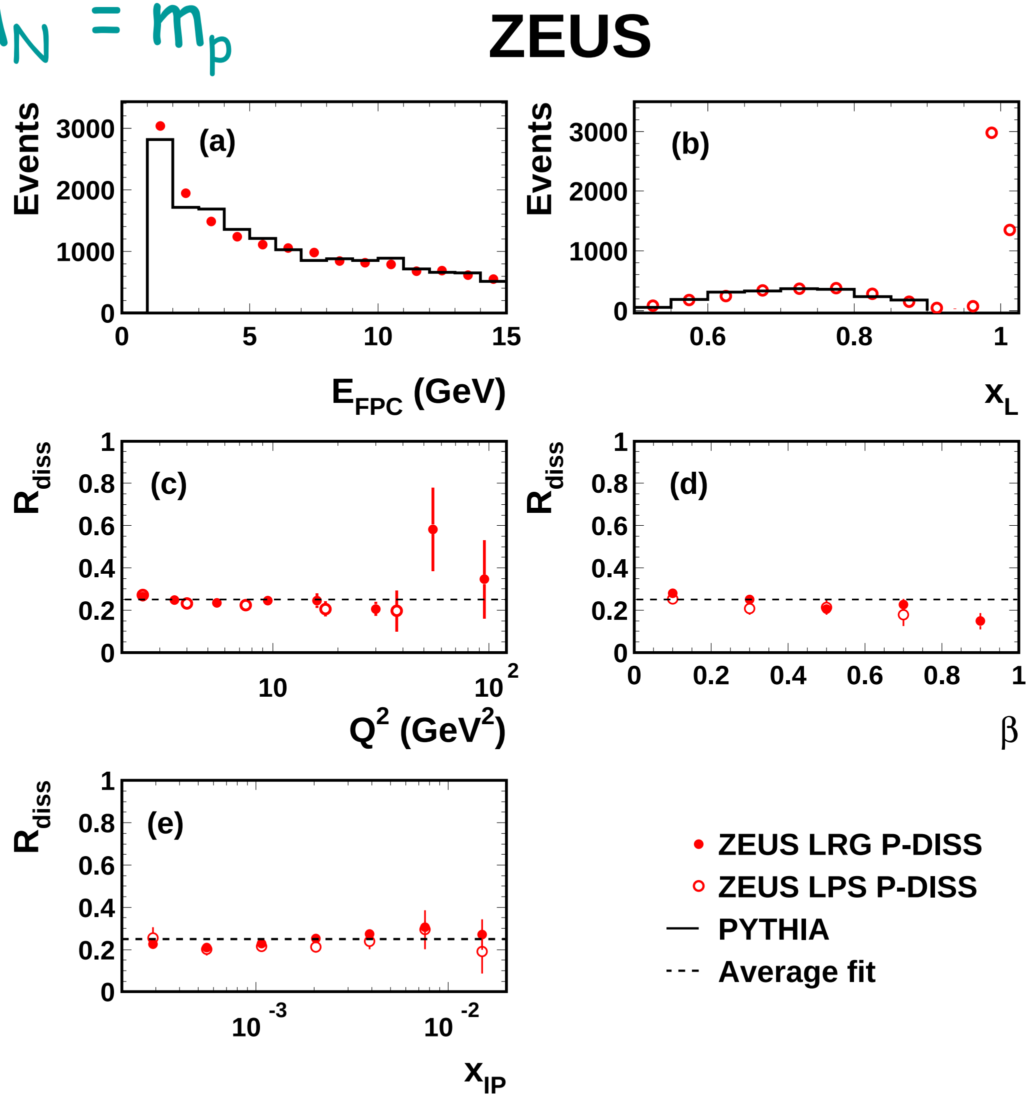
→ p-diss. background in LRG data: [24 +-1(stat) +2-3(sys) +5-8(norm)]%

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



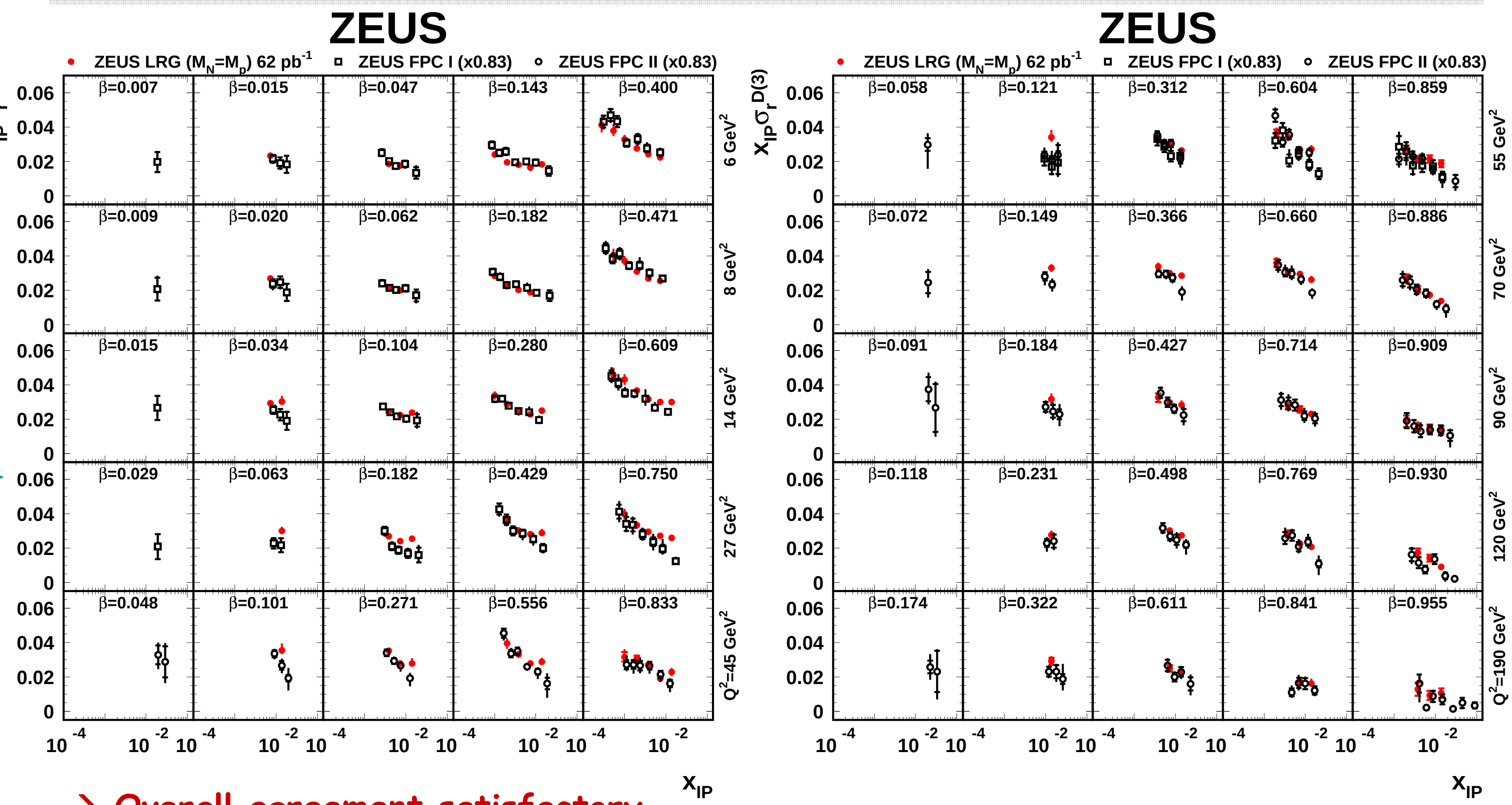
→ p-diss. background in LRG data R_{diss} = [25 +-1(stat) +-3(sys)]%

→ consistent with the ratio LPS/LRG

→ 25% correction applied to LRG data

$\sigma_r^{D(3)}$ 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



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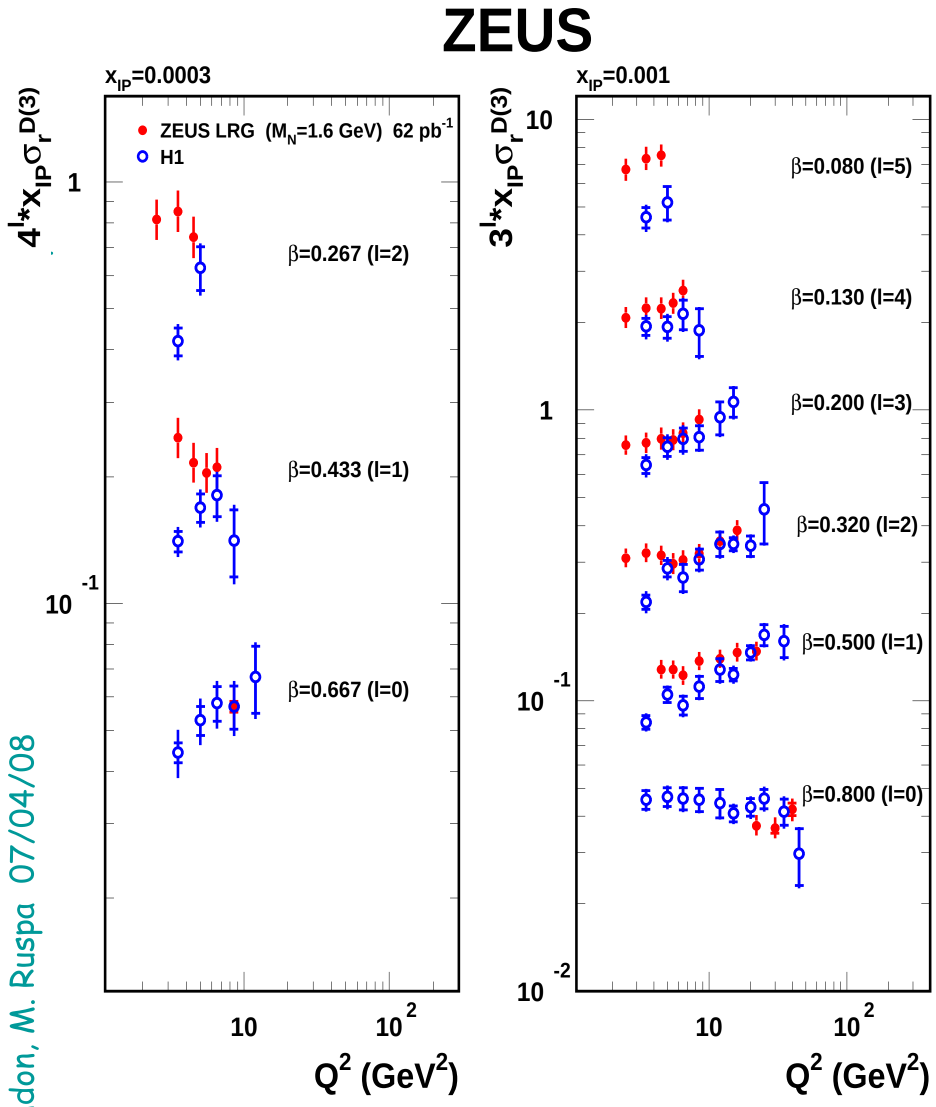
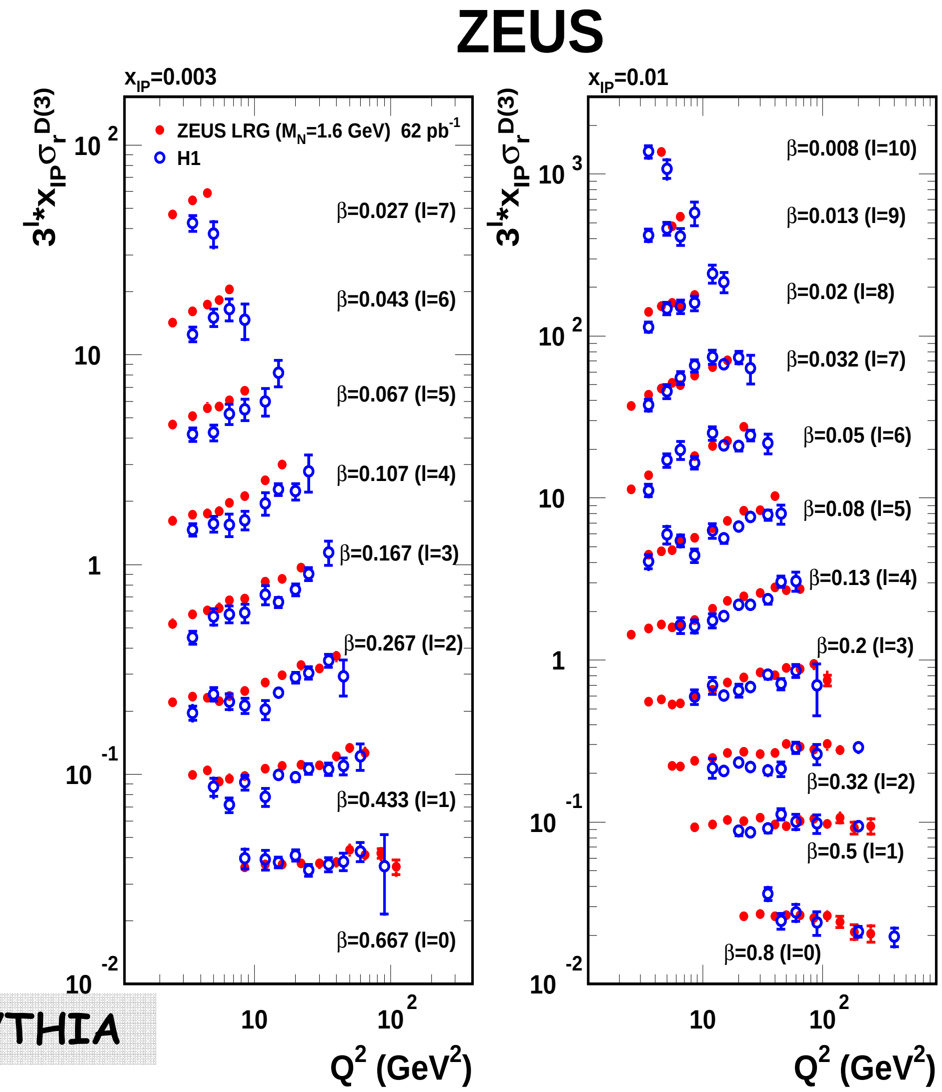
→ Overall agreement satisfactory

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

$\sigma_r^{D(3)}$ LRG ZEUS vs H1



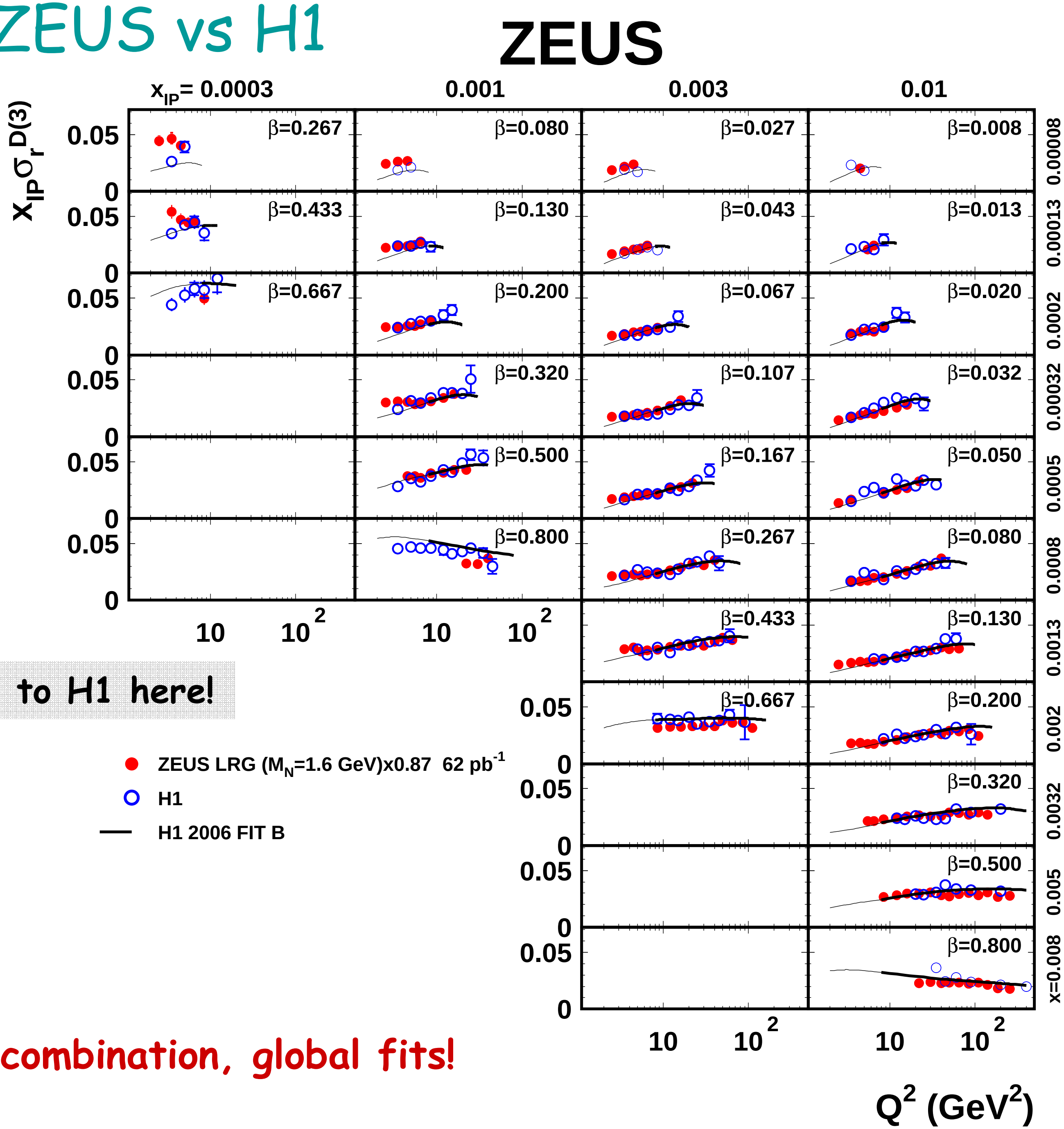


ZEUS corrected to M_N < 1.6 GeV with PYTHIA

→ 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

$\sigma_r^{D(3)}$ LRG ZEUS vs H1



ZEUS normalised to H1 here!

Time for data combination, global fits!

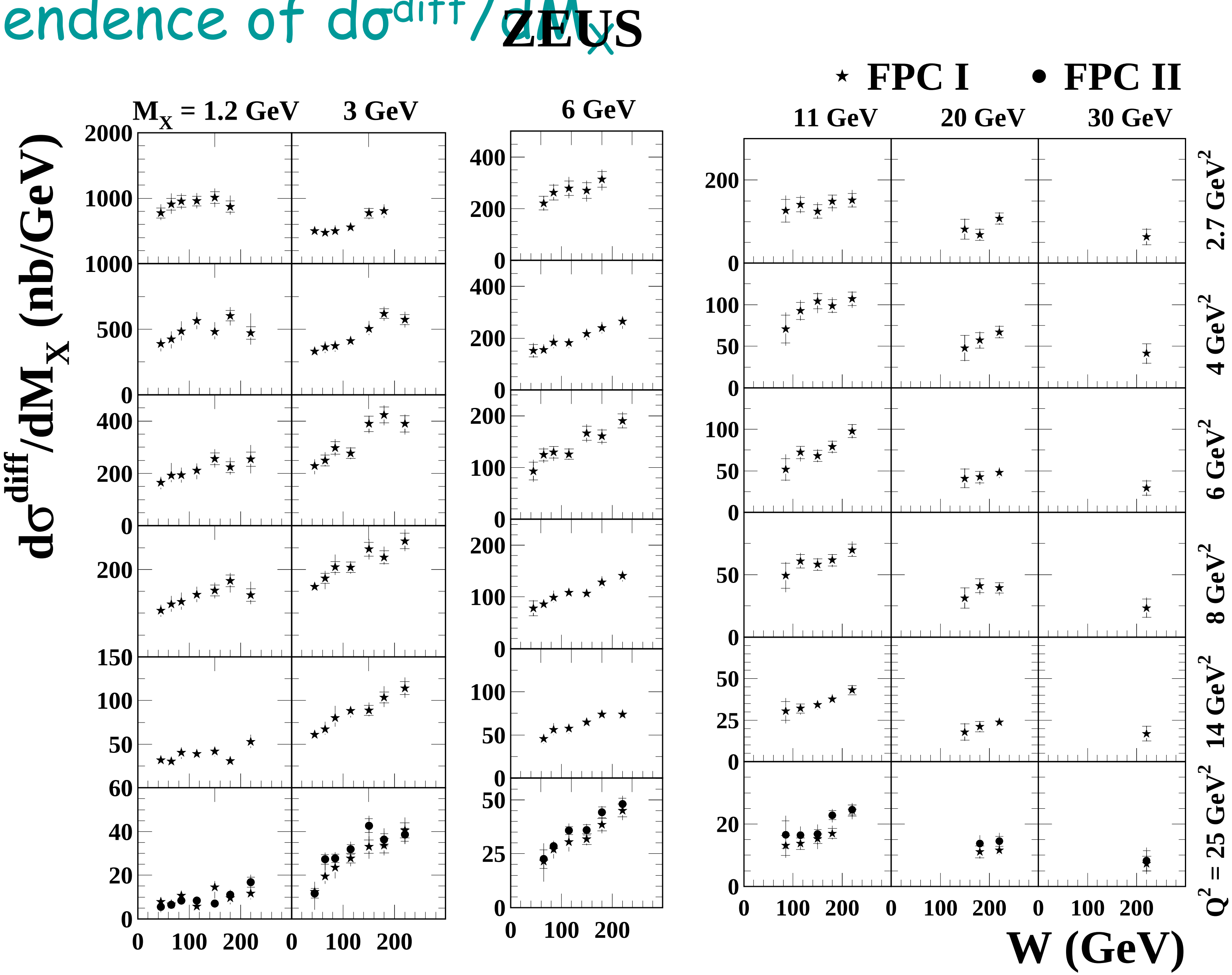
Highlights

- 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
- 4-fold differential reduced cross section, measured for the first time in two t-bins, shows same x_{IP} dependence ($\alpha'_{IP} = 0$)
- Proton dissociation background under control
- Consistent results between different methods and data sets
- ZEUS results consistent with H1 results within uncertainties
- Data can now be combined and/or fitted globally!

Backup

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

M_X data

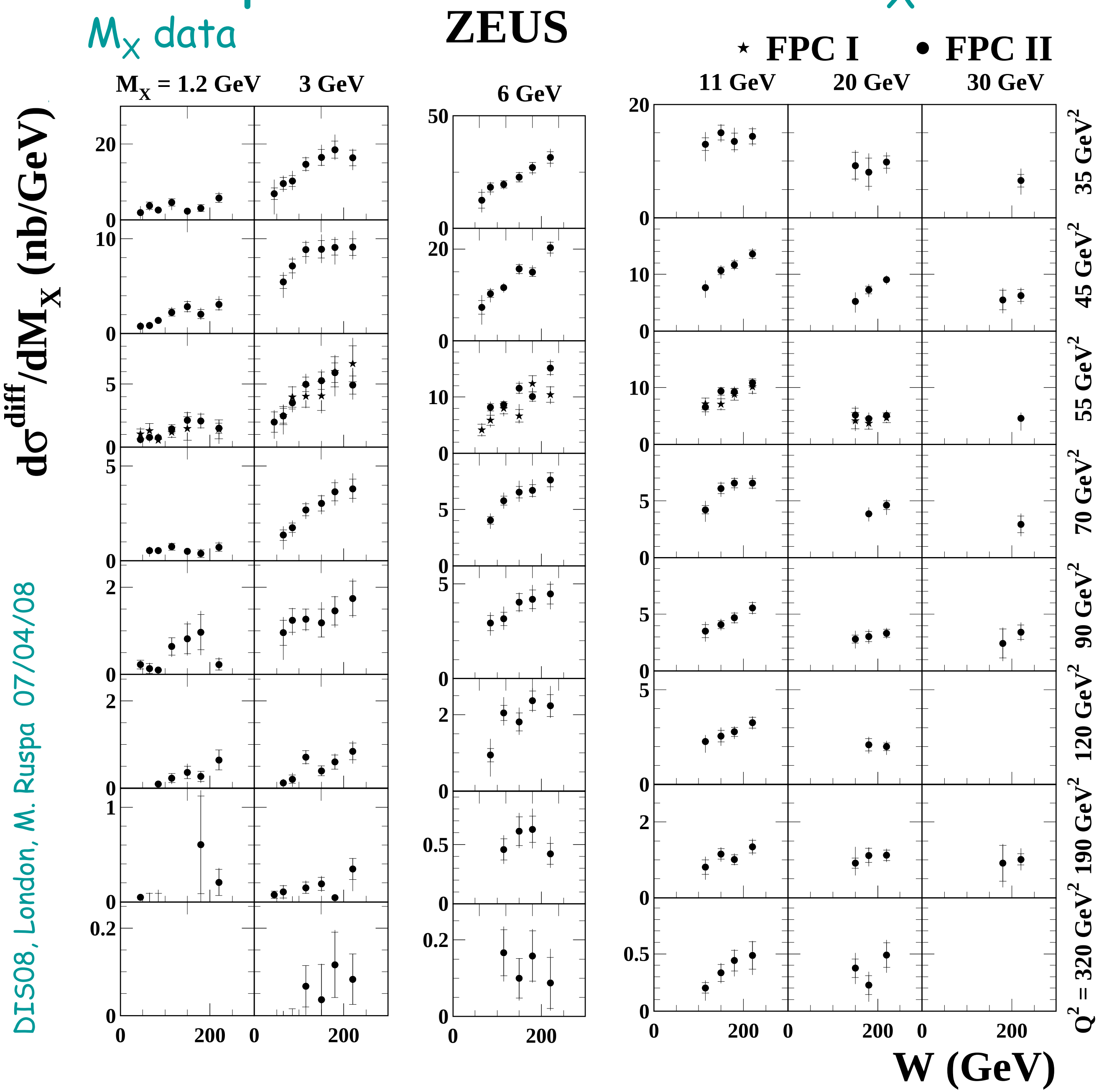


→ Low M_X: moderate increase with W and steep reduction with Q^2

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

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

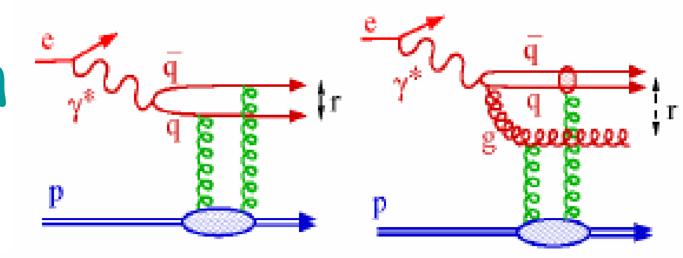
M_X data



→ Substantial rise with W

Fit with BEKW parameterisation

(Bartels, Ellis, Kowalski, Wustoff 1988)

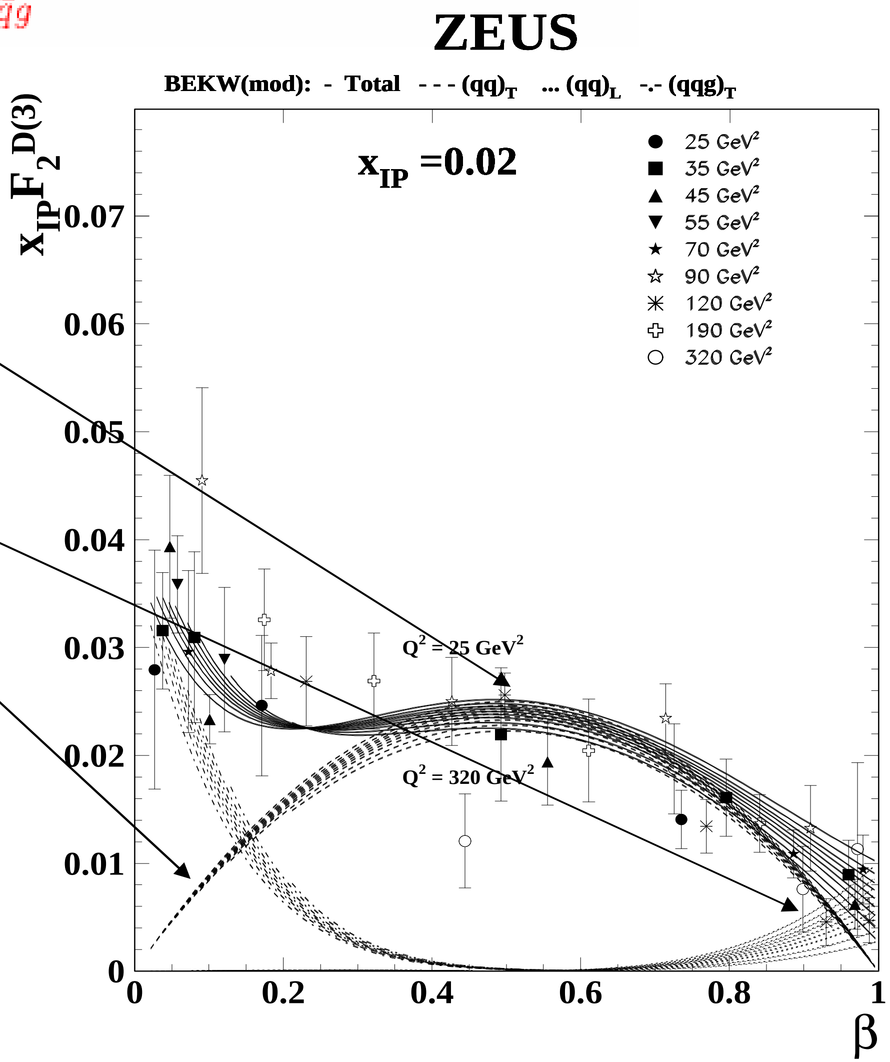


$$x_{IP}F_2^{D(3)} = c_T \cdot F_{q\bar{q}}^T + c_L \cdot F_{q\bar{q}}^L + c_g \cdot F_{q\bar{q}g}^T$$

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

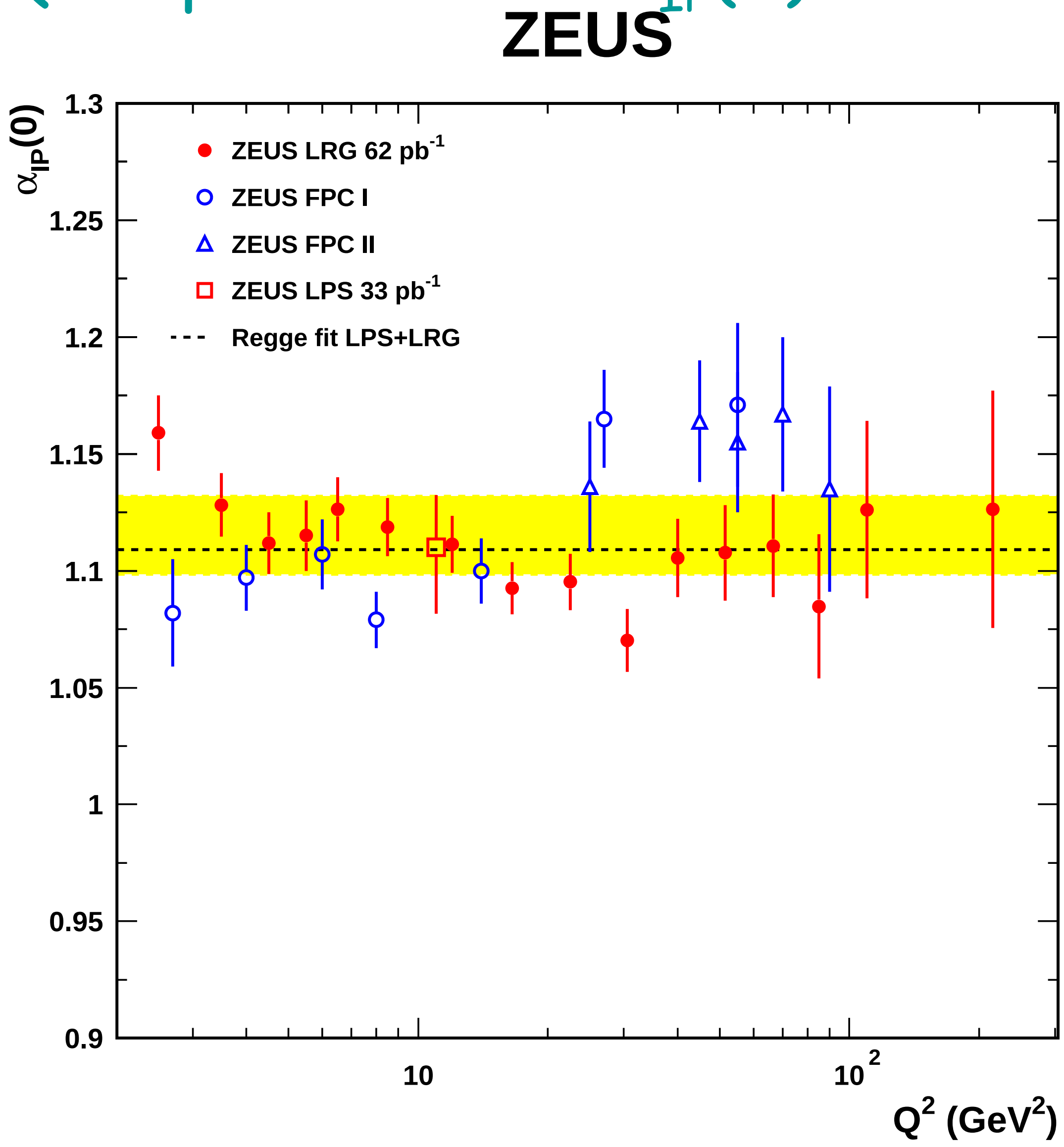
$$F_{q\bar{q}g}^T \sim (1-\beta)^\gamma$$

$F_{q\bar{q}}^L$ limited to β ~1



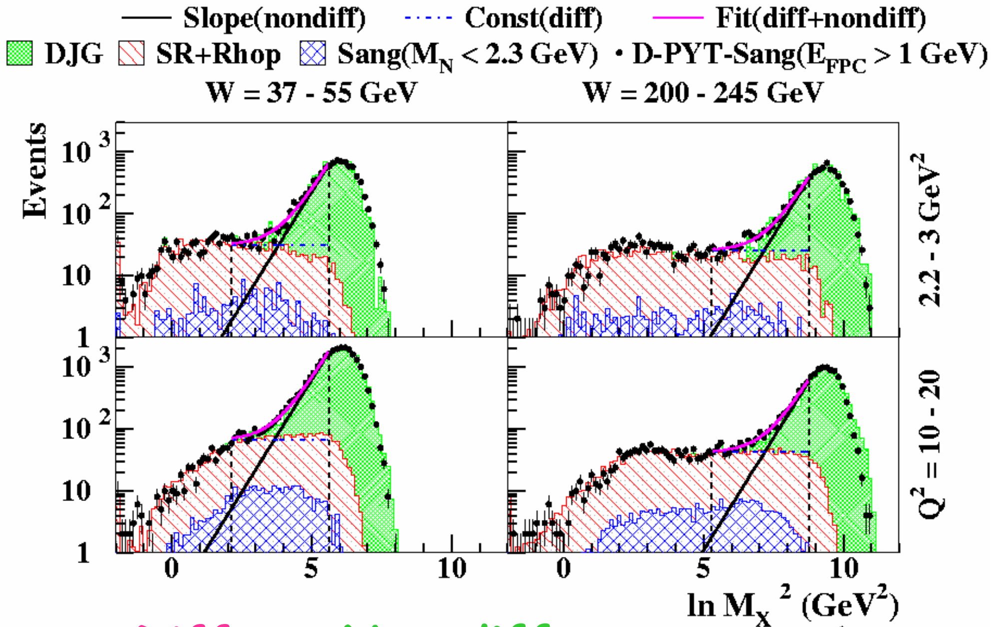
→ Fit gives a good description of the 427 data points FPC I + II

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 $ep \to eXN$

Forward Plug Calorimeter (FPC):

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

$\to$ higher M_x and lower W

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

So far ZEUS published:

- **DESY-05-011:** M_X 1998-1999 data, lumi= 4.2pb^{-1} , 2.2<Q2<80 GeV^2
- **DESY-04-031:** LPS 1997 data, lumi= 12.8pb^{-1}, 0.03<Q^2<0.6 GeV^2 & 2<Q^2<100 GeV^2
- **DESY-02-029:** LPS 1995 data, lumi= 3.3 pb^{-1}, 0.17<Q^2<0.7 GeV^2 & 3<Q^2<80 GeV^2
  M_X 1996 data, lumi= 6.2 pb^{-1} , 0.17<Q^2<0.7 GeV^2
- **DESY-98-084:** M_X 1994 data, lumi= 2.6 pb^{-1}, 7<Q^2<140 GeV^2
- **DESY-97-184:** LPS 1994 data, lumi= 900nb^{-1}, 5<Q^2<20 GeV^2
- **DESY-96-018:** M_X 1993 data, lumi= 543 nb-1 10<Q2<56 GeV2
- **DESY-95-093:** LRG 1993 data, lumi=0.54 pb-1, 8<Q2<100 GeV2

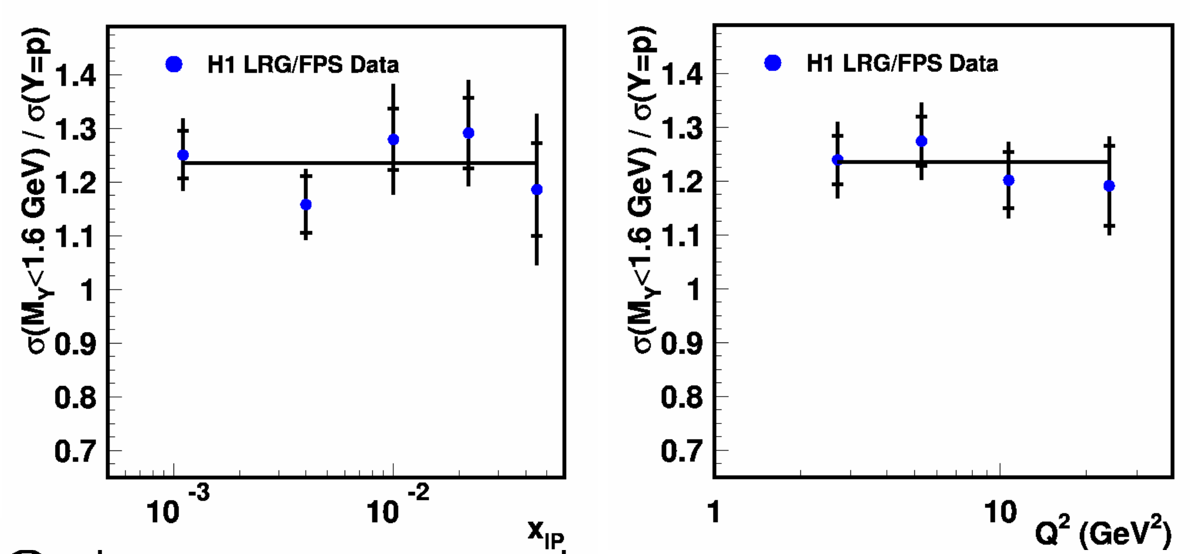
- 2 H1 publications in 2006

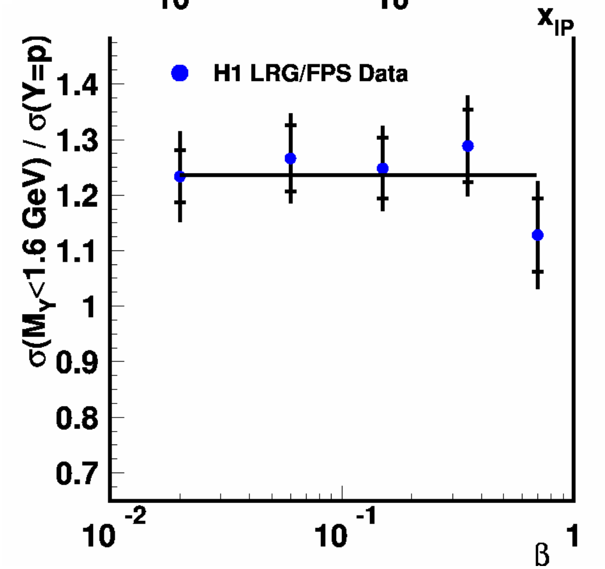
  -FPS (DESY06-048) 99/00 data ($3 < Q^2 < 24$ GeV^2)

  -LRG (DESY 06-049) 97 minimum bias data ($Q^2 < 13.5$ GeV^2)
  97 data ($13.5 < Q^2 < 105$ GeV^2)
  99/00 data ($133 < Q^2 < 1600$ GeV^2)

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

Proton dissociation @H1: ratio LRG vs FPS





- Data first corrected to M_Y < 1.6 GeV

  (corr. factor: -8.6% ± 5.8%)

H1 LRG /H1 FPS = 1.23 +-0.03(stat) +-0.16(sys)

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

- Also study with DIFFVM:

  Ratio= 1.15 +0.15-0.08 → [13 +11 -6]%

Proton dissociation@ ZEUS: summary

- from direct measurement of the ratio LPS/LRG data (before correction to $M_Y = m_p$:
  ZEUS LPS/ZEUS LRG = 0.76 +-0.01(stat) +-0.03(sys) +-0.05 (norm)
  → [24 +-1(stat) +-3(sys) +-5(norm)]%

- from PYTHIA: [25 +-1(stat) +-3(sys)]%

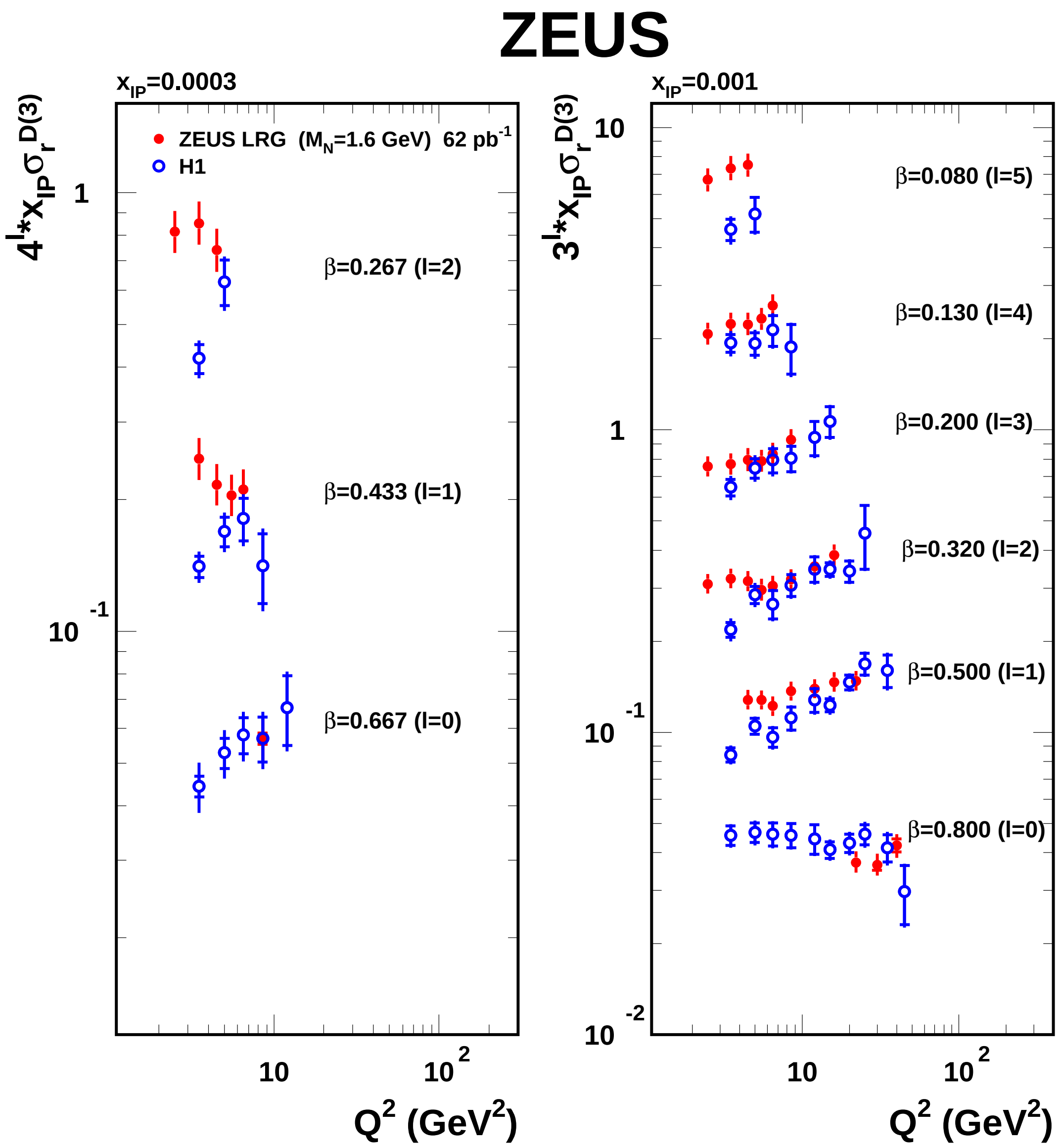
ZEUS LRG data corrected to $M_Y = m_p$ by subtracting 25%

Proton dissociation @H1: summary

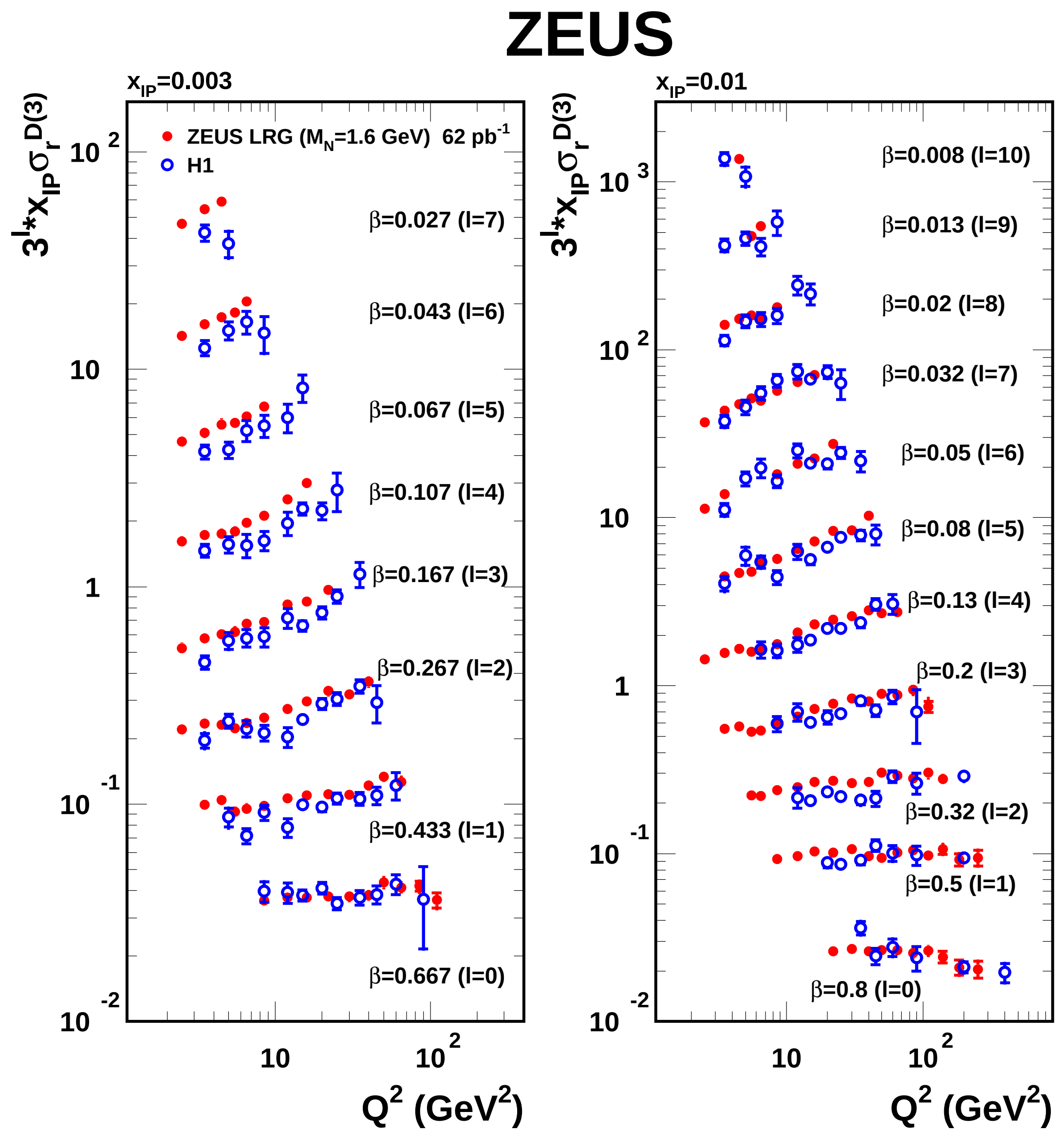
- data corrected to $M_Y < 1.6$ GeV (corr. factor: -8.6% ± 5.8%)
- from direct measurement of the ratio between FPS and LRG data (DESY 06-049):
  H1 LRG/H1 FPS = 1.23 +- 0.03(stat) +- 0.16(sys) → [19 +- 11]%
- from DIFFVM: 1.15 +0.15-0.08 → [13 +11 -6]%

These numbers quantify the background for $M_Y < 1.6$ GeV

$\sigma_r^{D(3)}$ ZEUS LRG vs H1 LRG

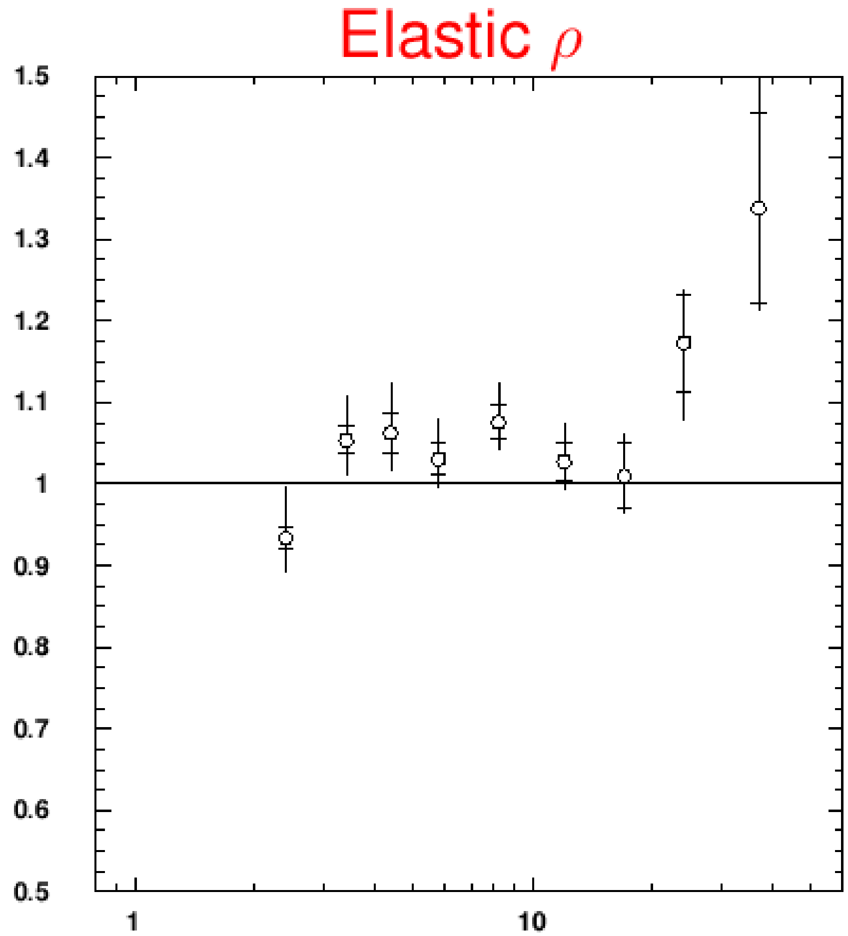


$\sigma_r^{D(3)}$ ZEUS LRG vs H1 LRG



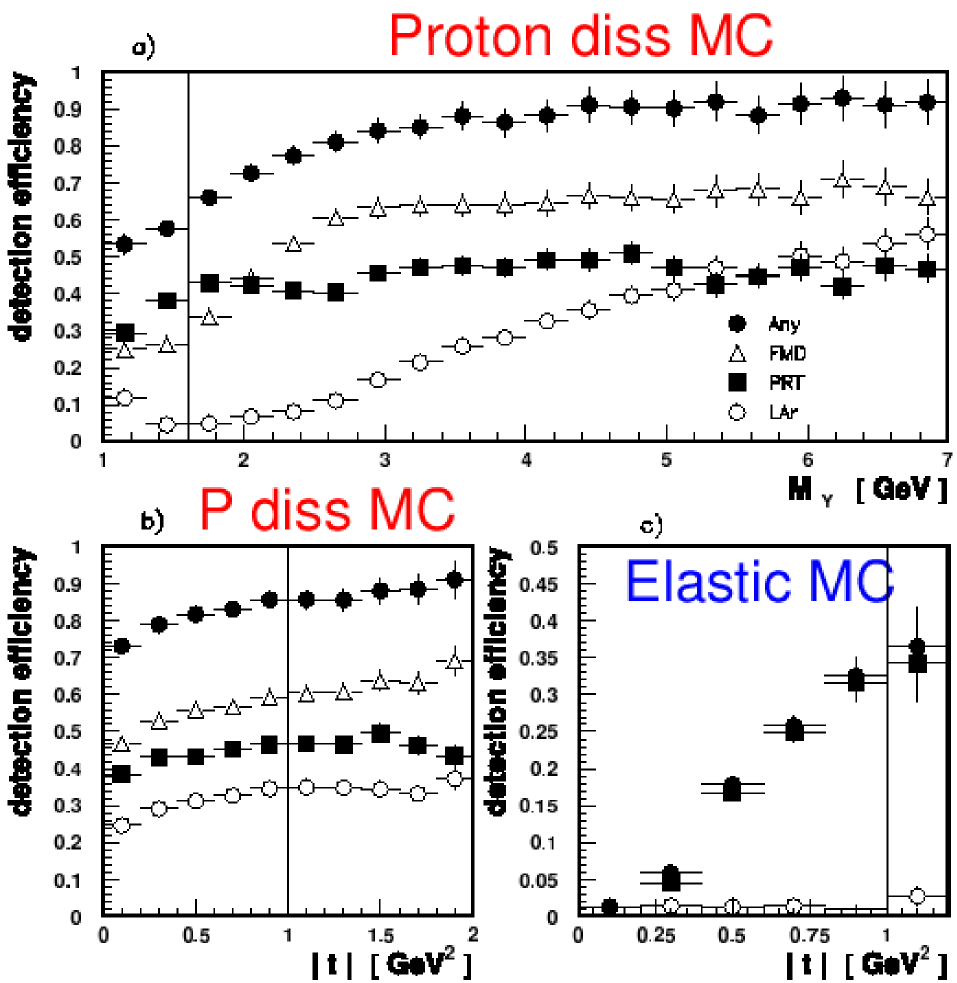
What about the exclusive measurements?

Ratio ZEUS data/fit to forthcoming H1 data →



→ Rho results compatible within errors (except high Q^2 maybe)

H1 tagging efficiency



Proton diss tagging:

Total taggging eff $> 60\%$ for $M_Y > 1.6$ GeV

$\rightarrow$ Correct up to 1.6 GeV

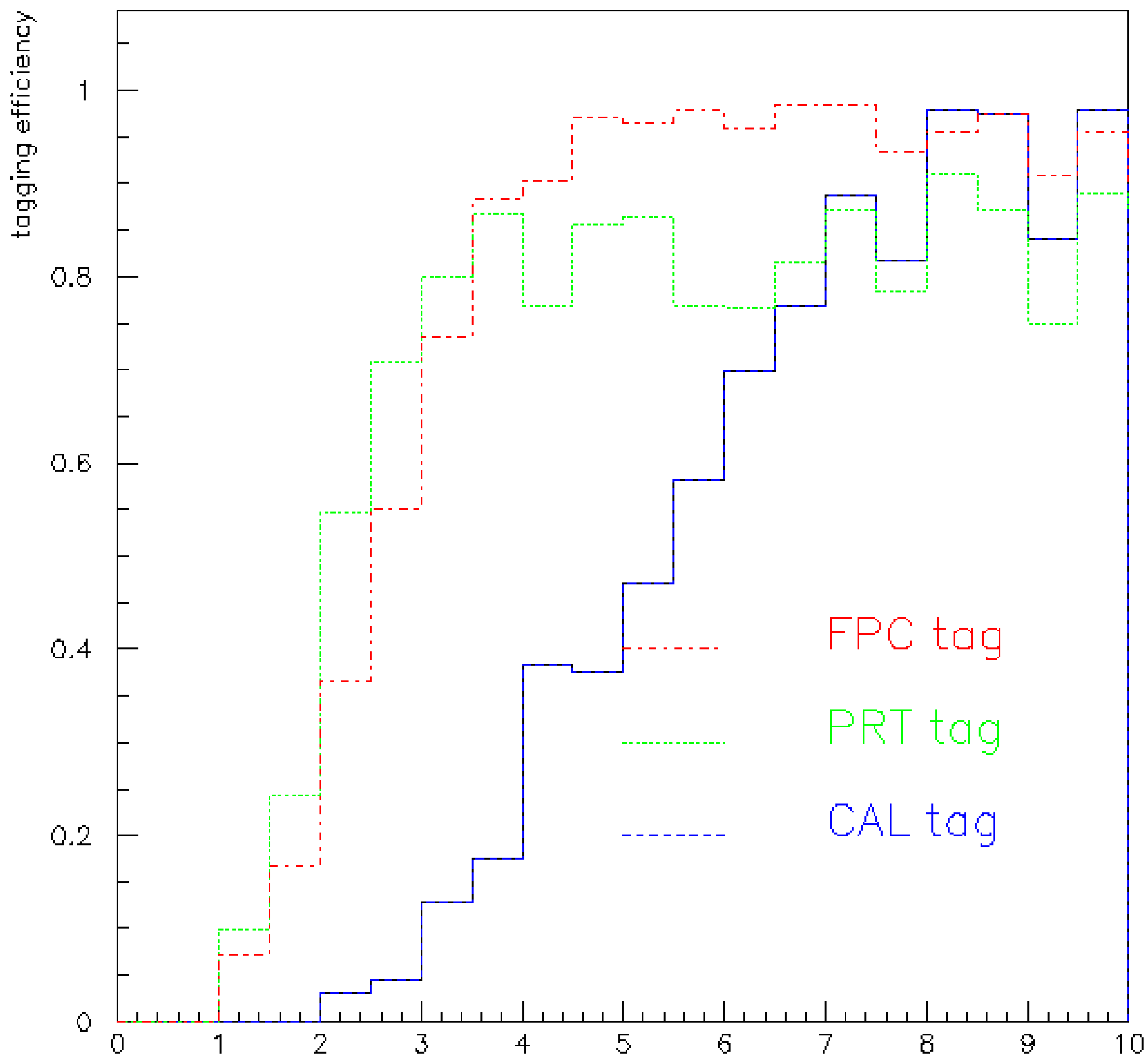
Elastic tagging:

Total taggging eff $> 10\%$ for $|t| > 0.5$ GeV^2

$\rightarrow$ Cut at 0.5 GeV^2

(from P. Thompson PhD Thesis)

ZEUS forward detector sensitivity



Proton tagging is more than 60% efficient for $M_Y > 2.3$ GeV