

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

## Inclusive Diffraction in DIS: LRG, LPS and $M_x$ methods

Marta Ruspa

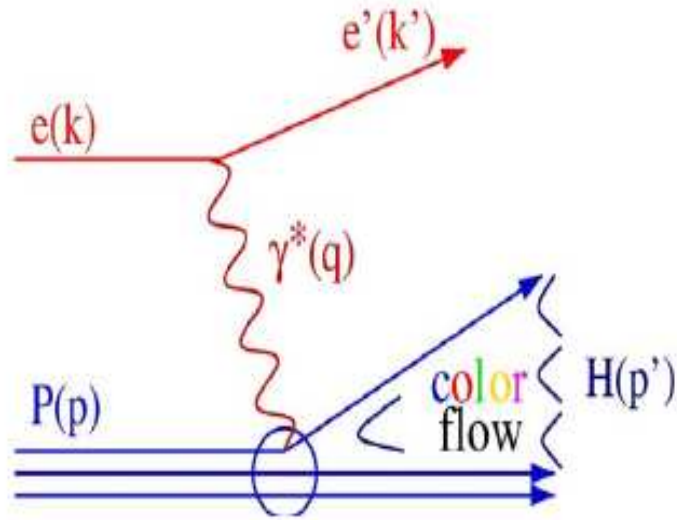
(Univ. Piemonte Orientale & INFN-Torino, Italy)

on behalf of

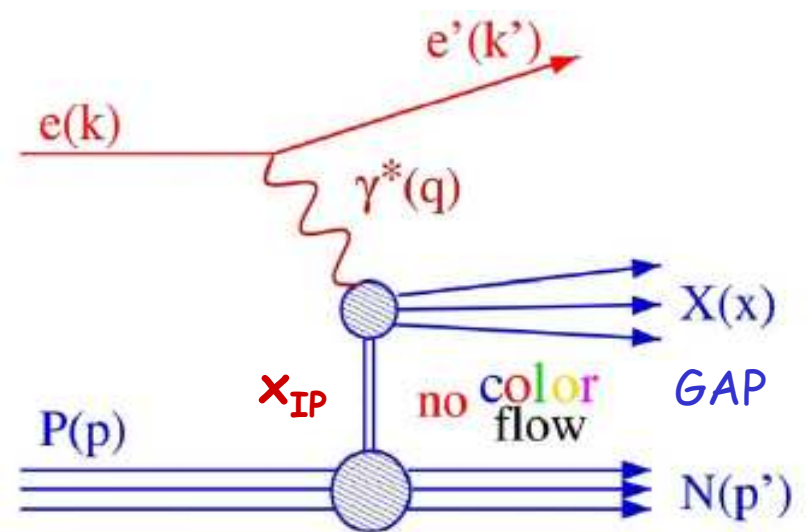


# Diffractive DIS at HERA

## Standard DIS



## Diffractive DIS



According to Regge phenomenology:

- exchanged Pomeron (IP) trajectory
- exchanged Reggeon (IR) and  $\pi$  when proton loses a higher energy fraction,  $X_{IP}$

# Kinematics of diffractive DIS

$Q^2$  = virtuality of photon =  
= (4-momentum exchanged at e vertex)<sup>2</sup>

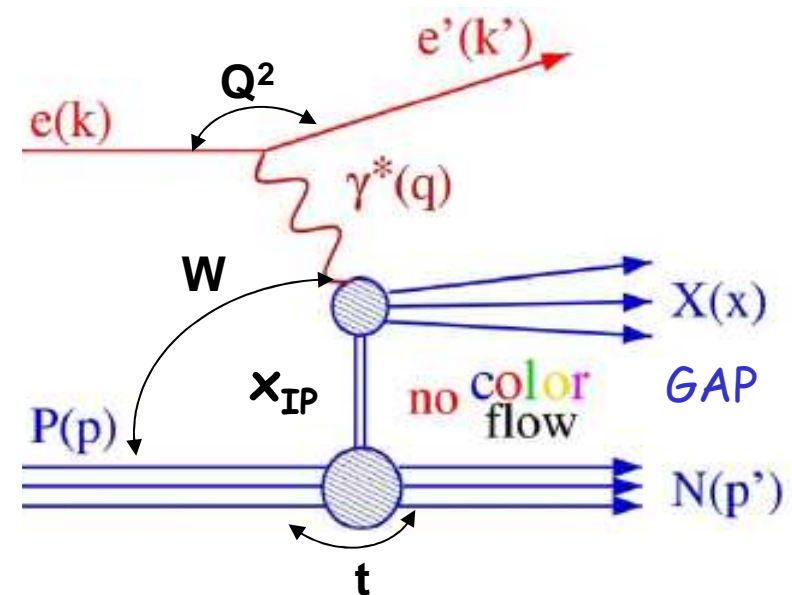
$W$  = invariant mass of  $\gamma^*$ -p system

$M_X$  = invariant mass of  $\gamma^*$  -IP system

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

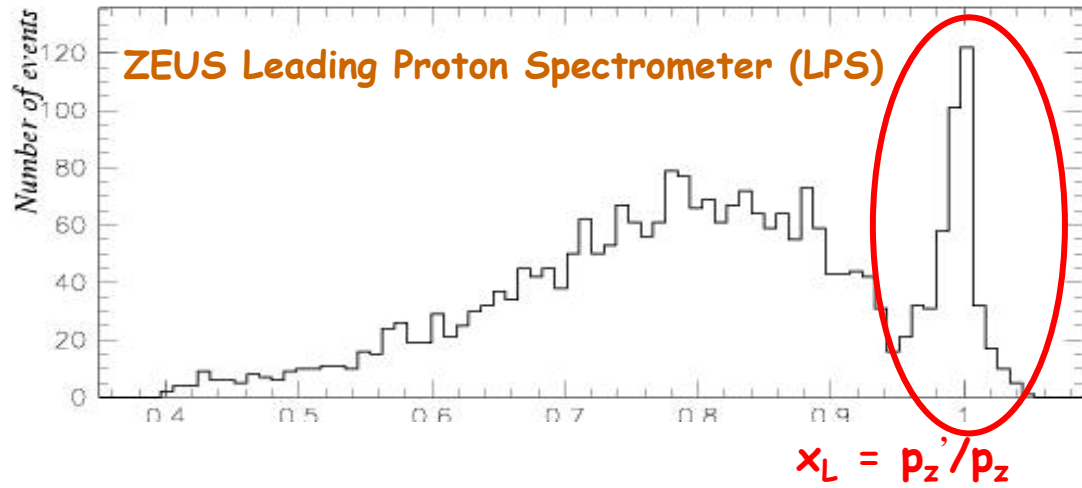
$\beta$  = Bjorken's variable for the IP  
= fraction of IP momentum carried by struck quark  
=  $x/x_{IP}$

$t$  = (4-momentum exchanged at p vertex)<sup>2</sup>  
typically:  $|t| < 1 \text{ GeV}^2$



- **Single diffraction:** N=proton
- **Double diffraction:** proton-dissociative system N  
→ represents a relevant background

# Diffractive event selection

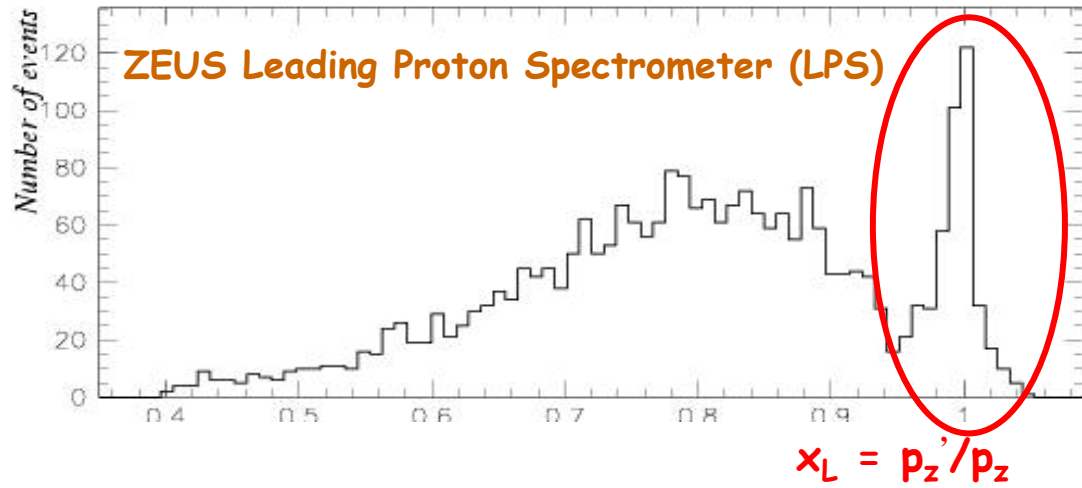


## LPS method

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

CONS: low statistics

# Diffractive event selection

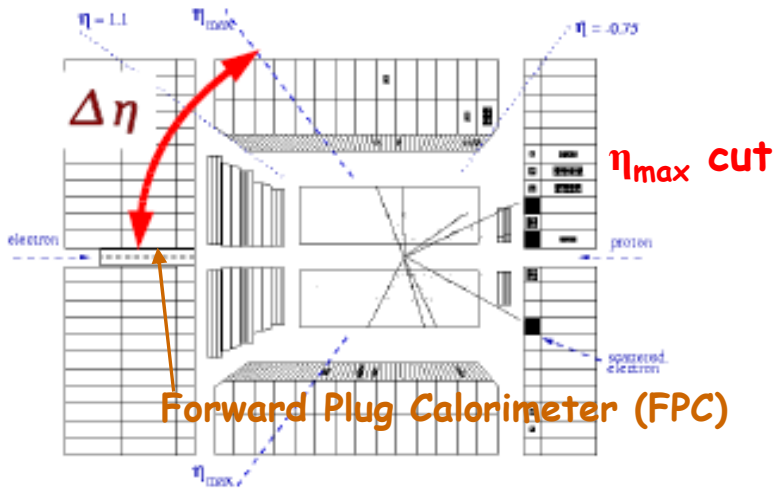


## LPS method

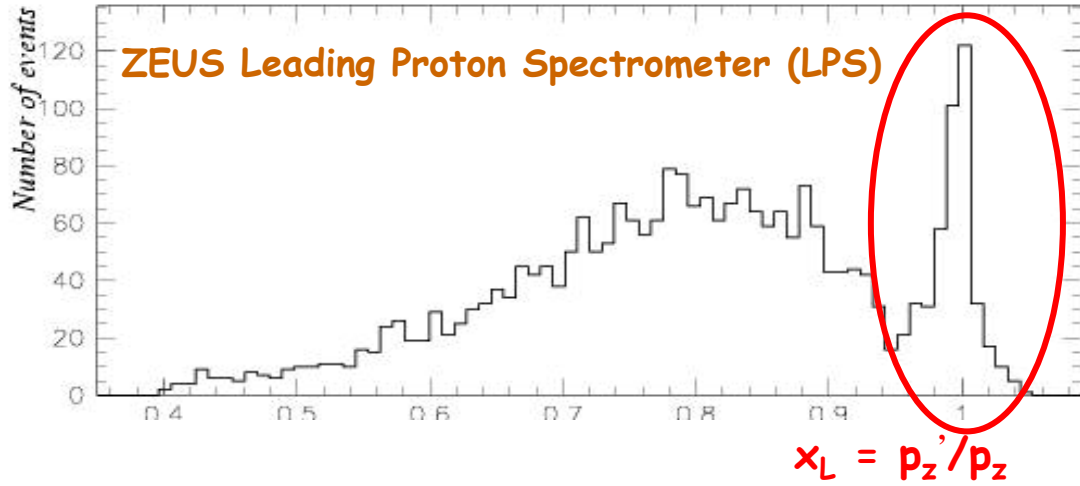
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## Large Rapidity Gap (LRG) method



# Diffractive event selection

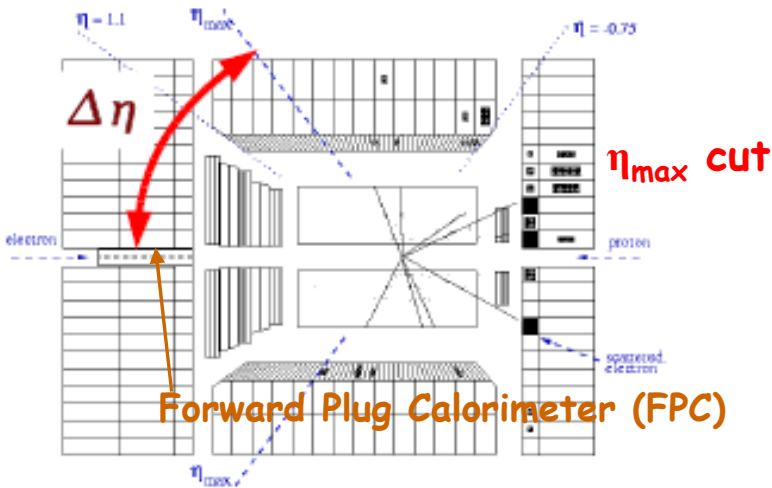


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## Large Rapidity Gap (LRG) method

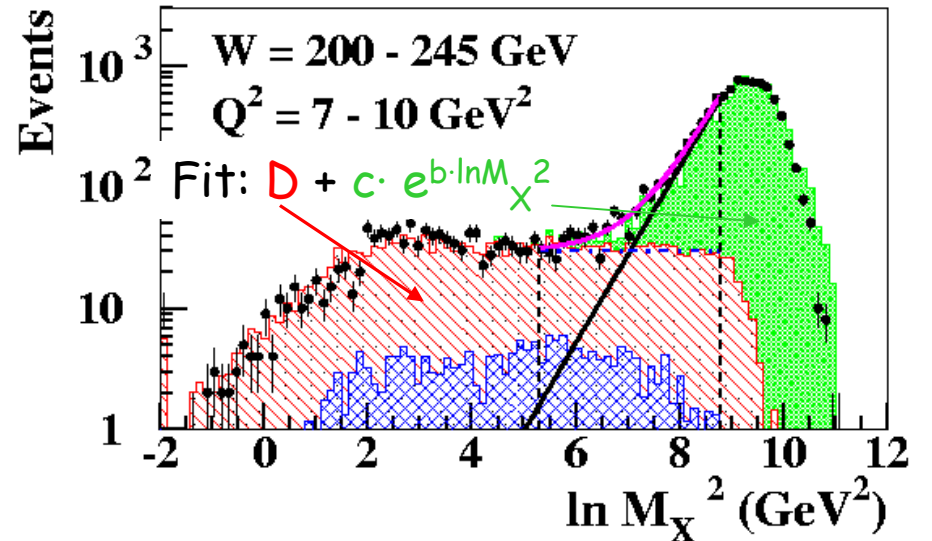


## $M_x$ method

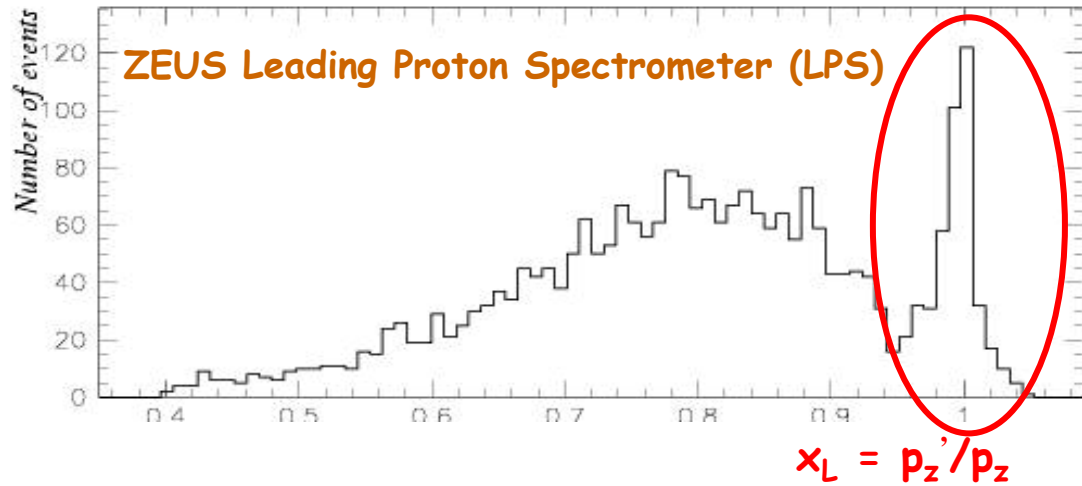
— Slope(nondiff)    ··· Const(diff)    — Fit(diff+nondiff)

• D-PYT-Sang( $E_{FPC} > 1$  GeV)

■ DJG    ▨ SR+Rhop    ▩ Sang( $M_N < 2.3$  GeV)



# Diffractive event selection

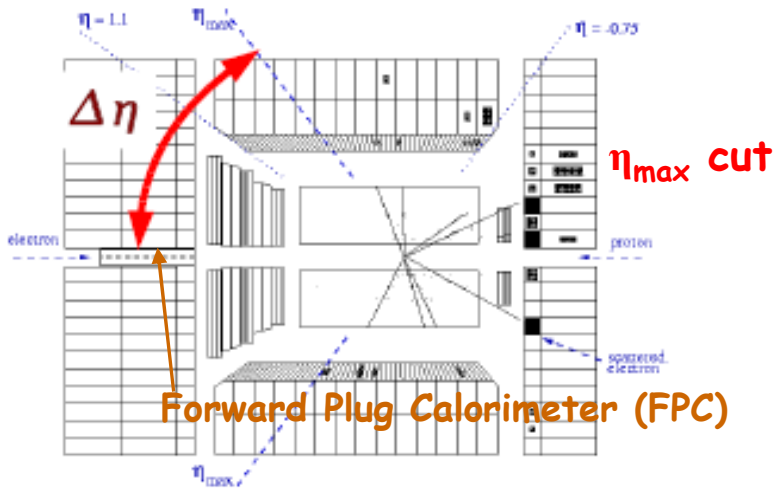


## LPS method

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  $x_{IP}$

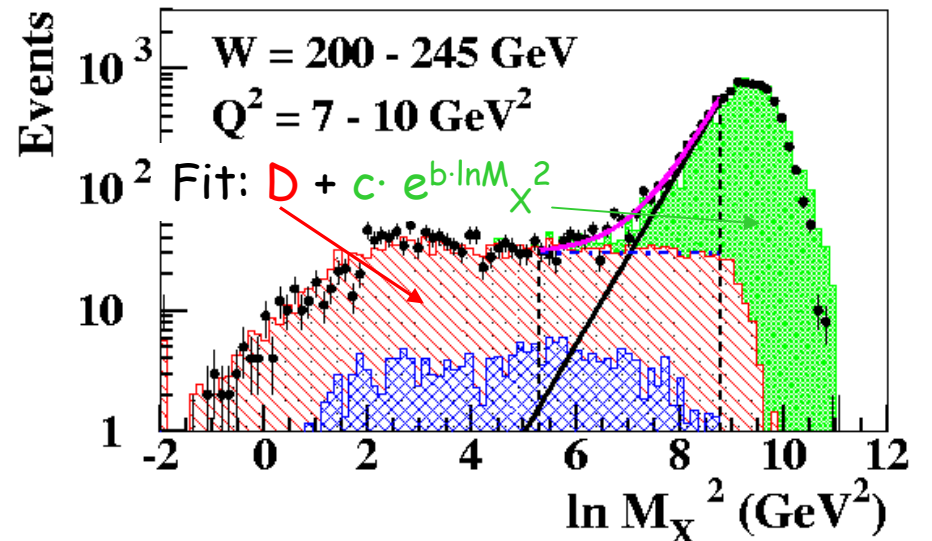
CONS: p.-diss background

## $M_x$ method

— Slope(nondiff)    ··· Const(diff)    — Fit(diff+nondiff)

• D-PYT-Sang( $E_{FPC} > 1$  GeV)

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# Diffractive structure function

- Diffractive cross section

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

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

$$\begin{aligned} \frac{d^2\sigma_{\gamma^*p \rightarrow e'Xp'}^D}{d\beta dQ^2 dx_{IP} dt} &= \frac{4\pi\alpha^2}{\beta Q^4} \left[1-y + \frac{y^2}{2(1+R^D)}\right] \cdot F_2^{D(4)}(\beta, Q^2, x_{IP}, t) \\ &= \frac{4\pi\alpha^2}{\beta Q^4} \left[1-y + \frac{y^2}{2}\right] \cdot \sigma_r^{D(4)}(\beta, Q^2, x_{IP}, t) \end{aligned}$$

- When  $t$  is not measured

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

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

Will look at

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



## Data sets

- **“LPS”**: 1999/2000 data,  $2 < Q^2 < 120 \text{ GeV}^2$ ,  $x_{IP}$  up to 0.1
- **“LRG”**: 1999/2000 data,  $2 < Q^2 < 305 \text{ GeV}^2$ ,  $x_{IP}$  up to 0.02
- **“FPC II”** ( $M_x$  method): 1999/2000 data,  $20 < Q^2 < 450 \text{ GeV}^2$   
 [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  $M_N < 2.3 \text{ GeV}$   
 H1 LRG corrected to  $M_N < 1.6 \text{ GeV}$

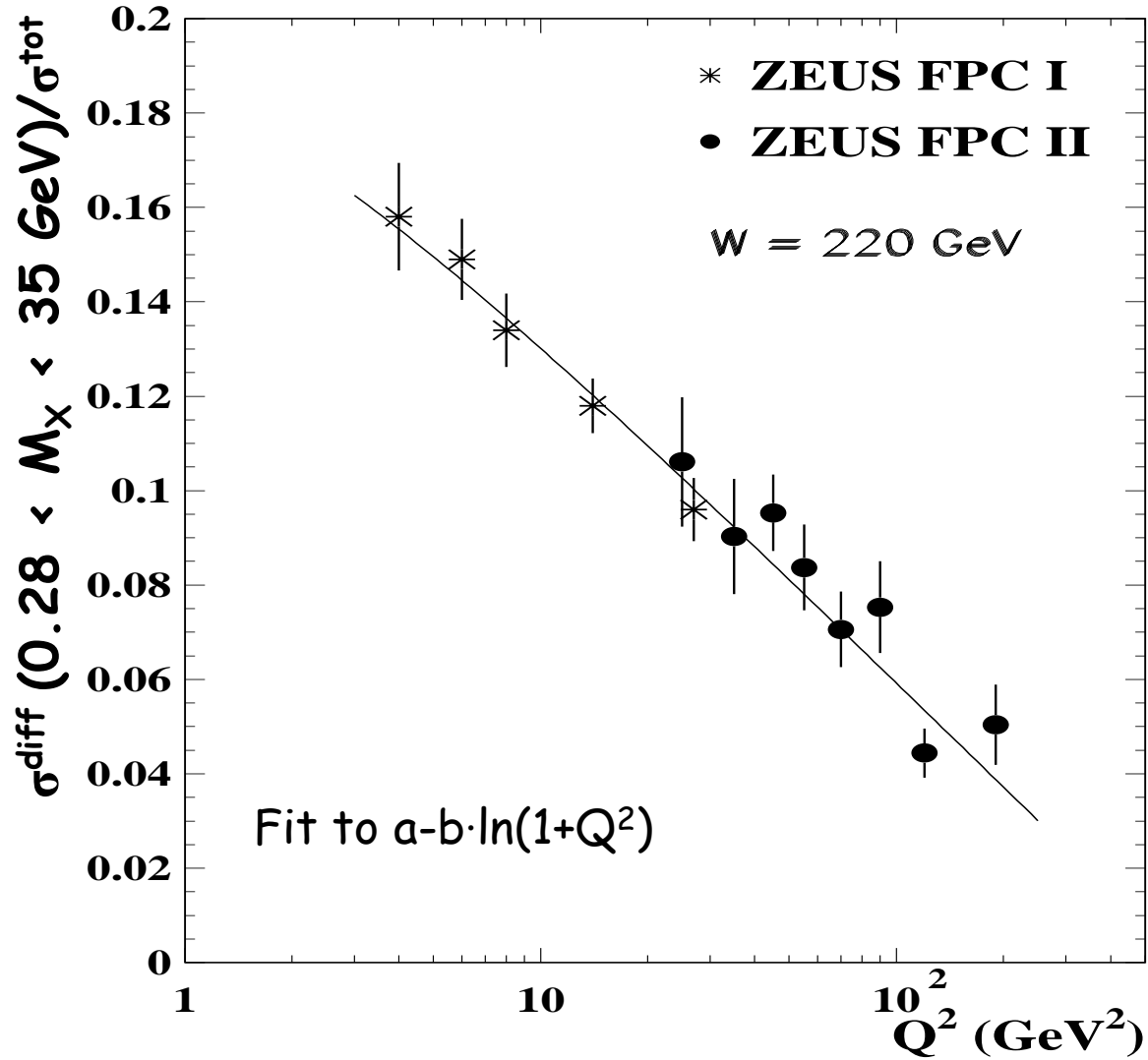
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**“H1 LRG”** [EPJ C48 (2006)]

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

# Diffractive contribution to the total cross section

$M_x$  data

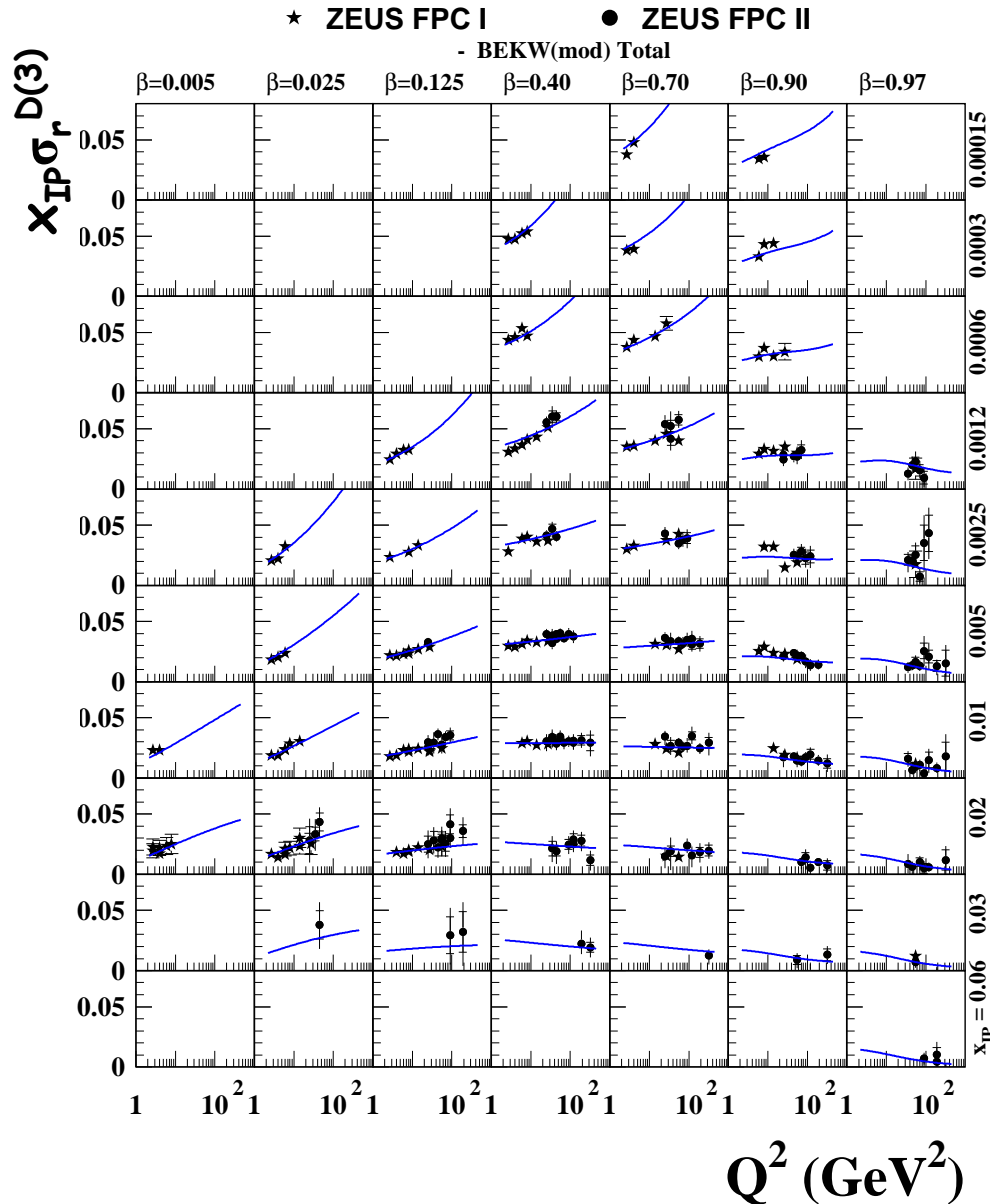


→  $\sigma^{\text{diff}} / \sigma^{\text{tot}}$  decreases logarithmically with  $Q^2$

# Q<sup>2</sup> dependence of $\sigma_r^{D(3)}$

M<sub>x</sub> data

## ZEUS

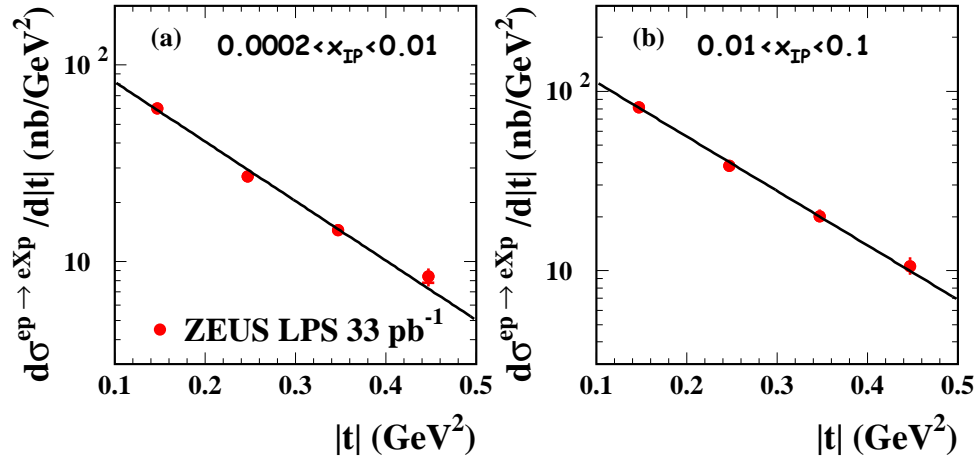


→ Positive scaling violations  
up to high- $\beta$  values: **diffractive**  
**exchange is gluon-dominated**

# t dependence

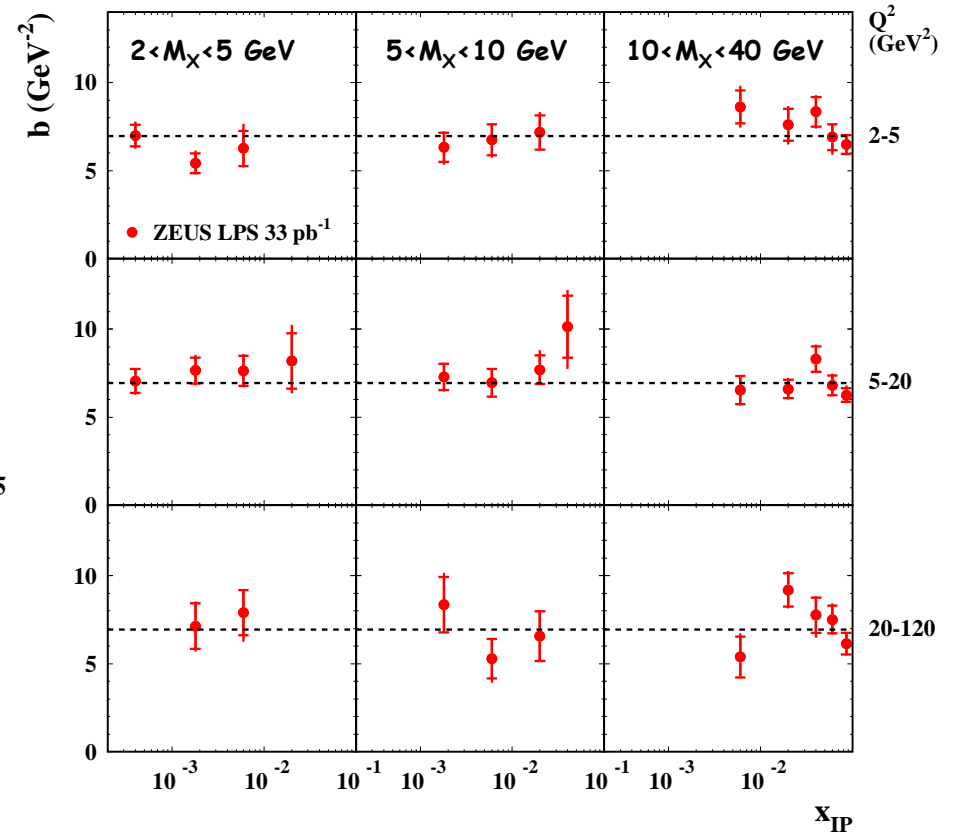
LPS data

ZEUS



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

ZEUS

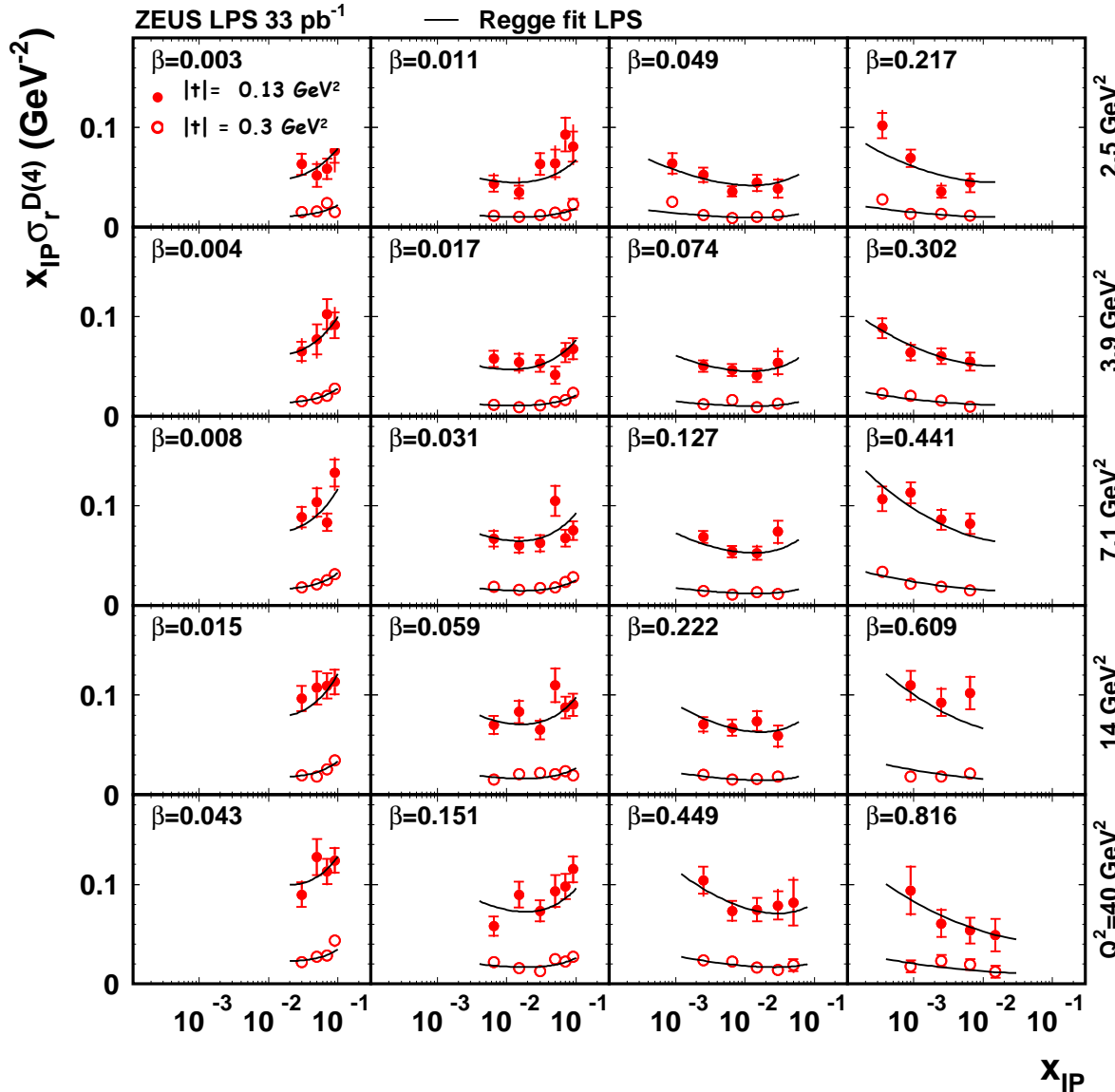


Lack of  $Q^2$  dependence and  $b$  much larger than in vector meson production  
 → inclusive diffractive dissociation in DIS is a soft process

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

LPS data

## ZEUS



First measurement in the two  $t$  bins

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

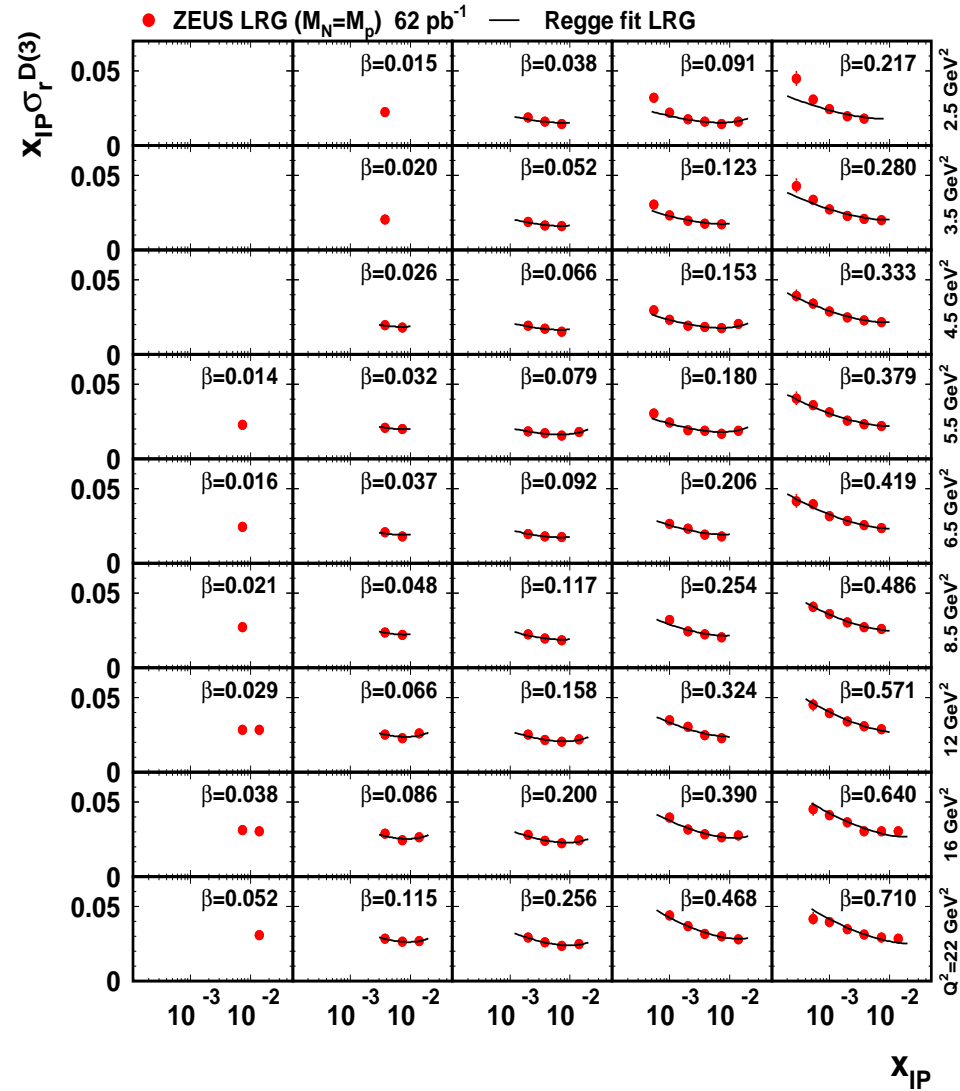
→ High  $x_{IP}$ :  $x_{IP}\sigma_r^{D(4)}$  flattens or increases with  $x_{IP}$  (Reggeon and  $\pi$ )

→ Same  $x_{IP}$  dependence in two  $t$  bins

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

LRG data

## ZEUS



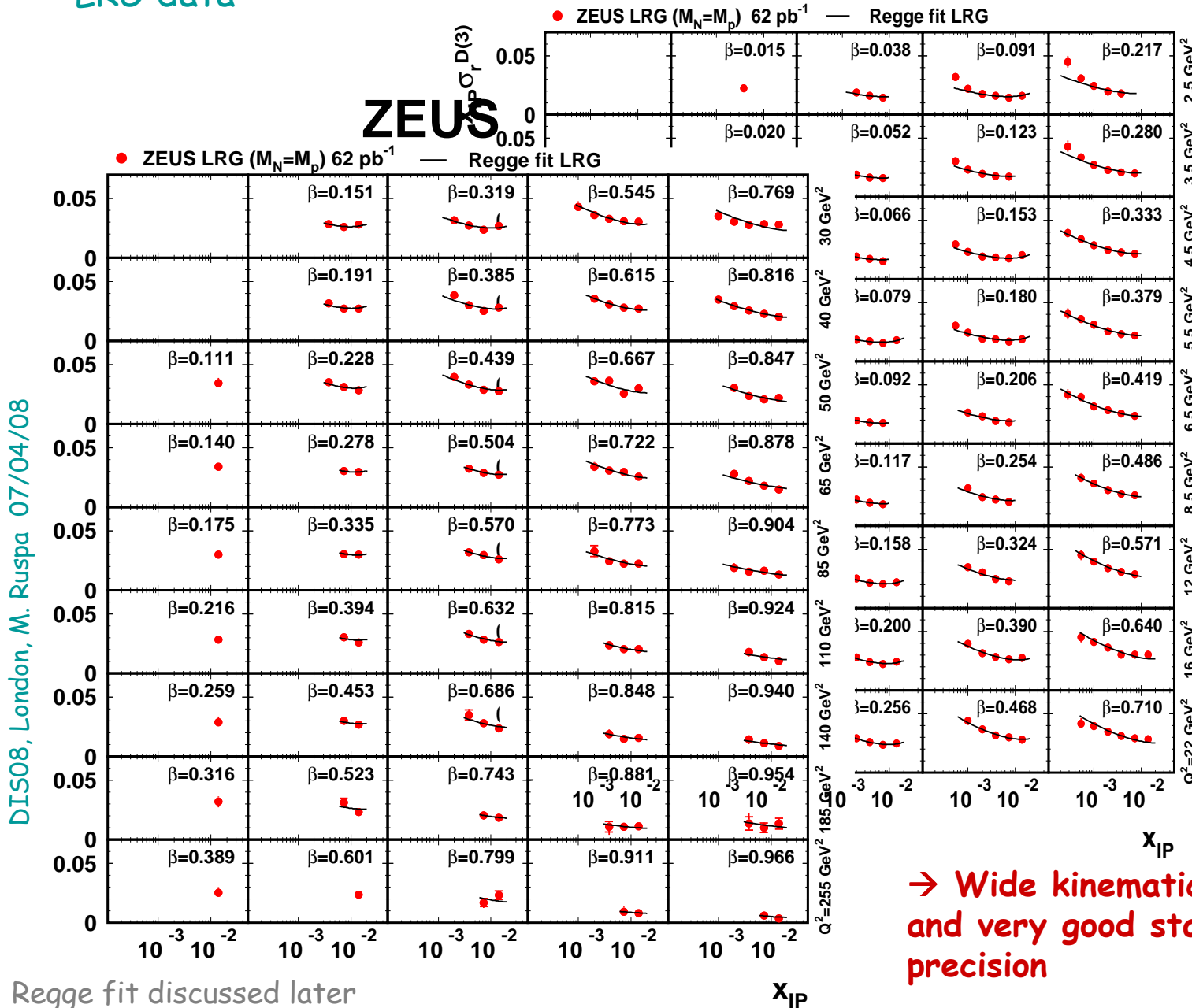
→ Rise with  $x_{IP}$   
not visible as  
 $x_{IP} < 0.02$



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

LRG data

## ZEUS



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

→ Wide kinematic coverage  
and very good statistical  
precision

Regge fit discussed later

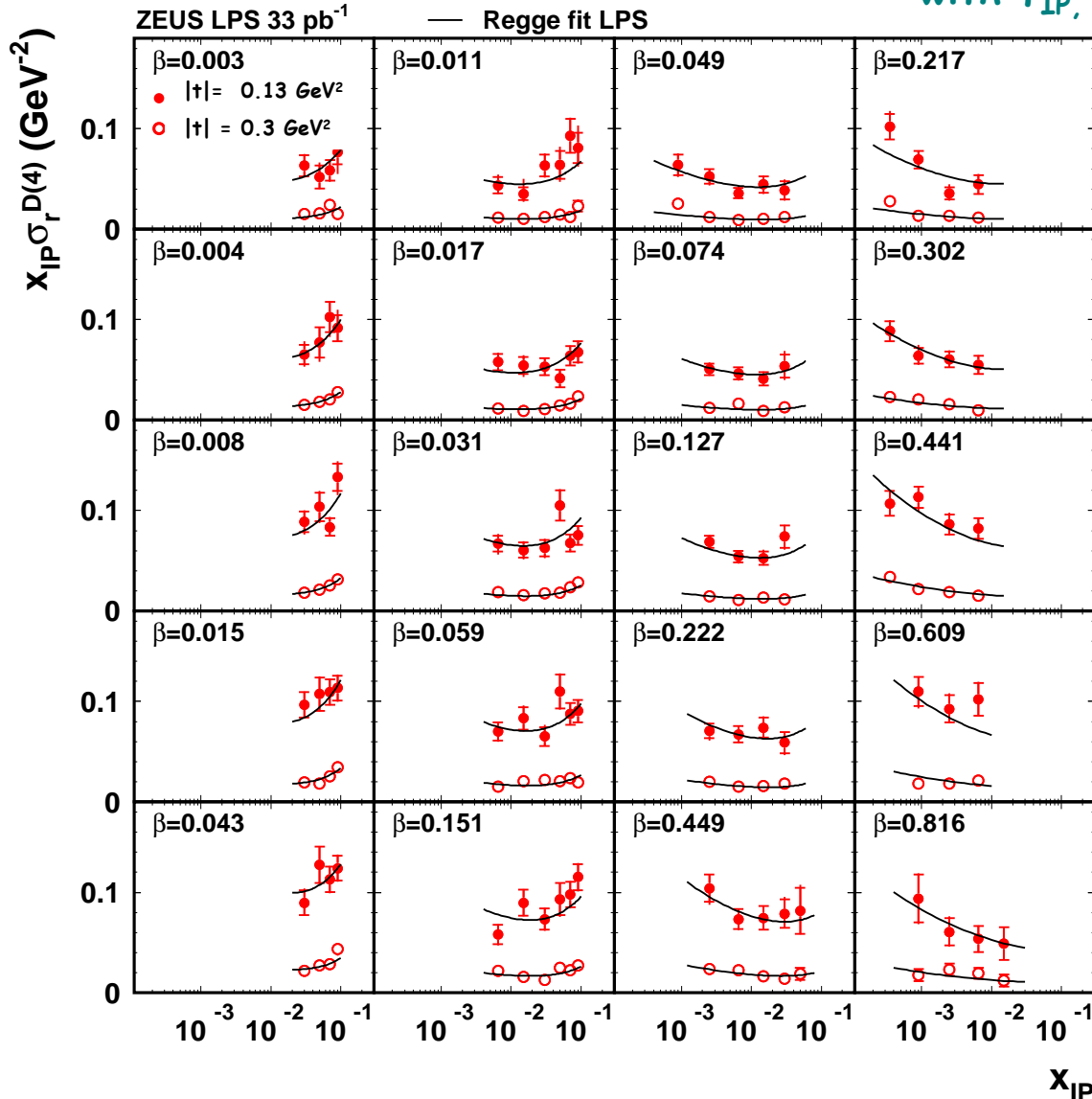
# Fitting the data...

# Regge fit to LPS data

## ZEUS

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

with  $f_{IP}$ ,  $f_{IR}$  IP and IR fluxes



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

$$\chi^2 / \text{ndf} = 162/153$$

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

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

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

→ IP intercept consistent with soft IP

→  $\alpha'_{IP}$  significantly smaller than  $0.25 \text{ GeV}^{-2}$  of hadron-hadron collisions

$$b \sim \alpha'_{IP} \cdot \ln x_{IP}$$

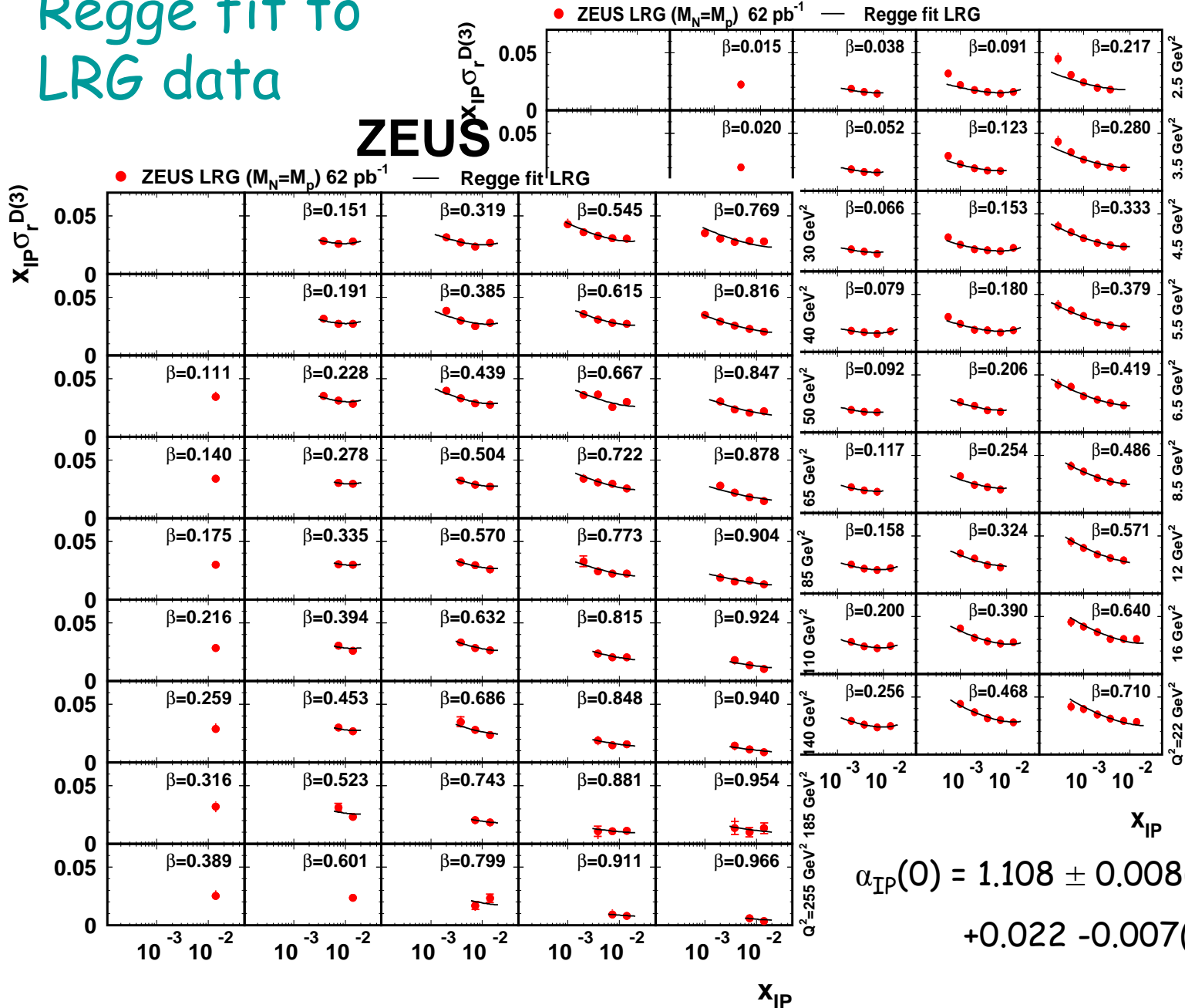
→ No strong dependence of  $b$  on  $x_{IP}$  (slide 14) expected from  $\alpha'_{IP} \approx 0$

→ Assumption of Regge factorisation works

# Regge fit to LRG data

# ZEUS

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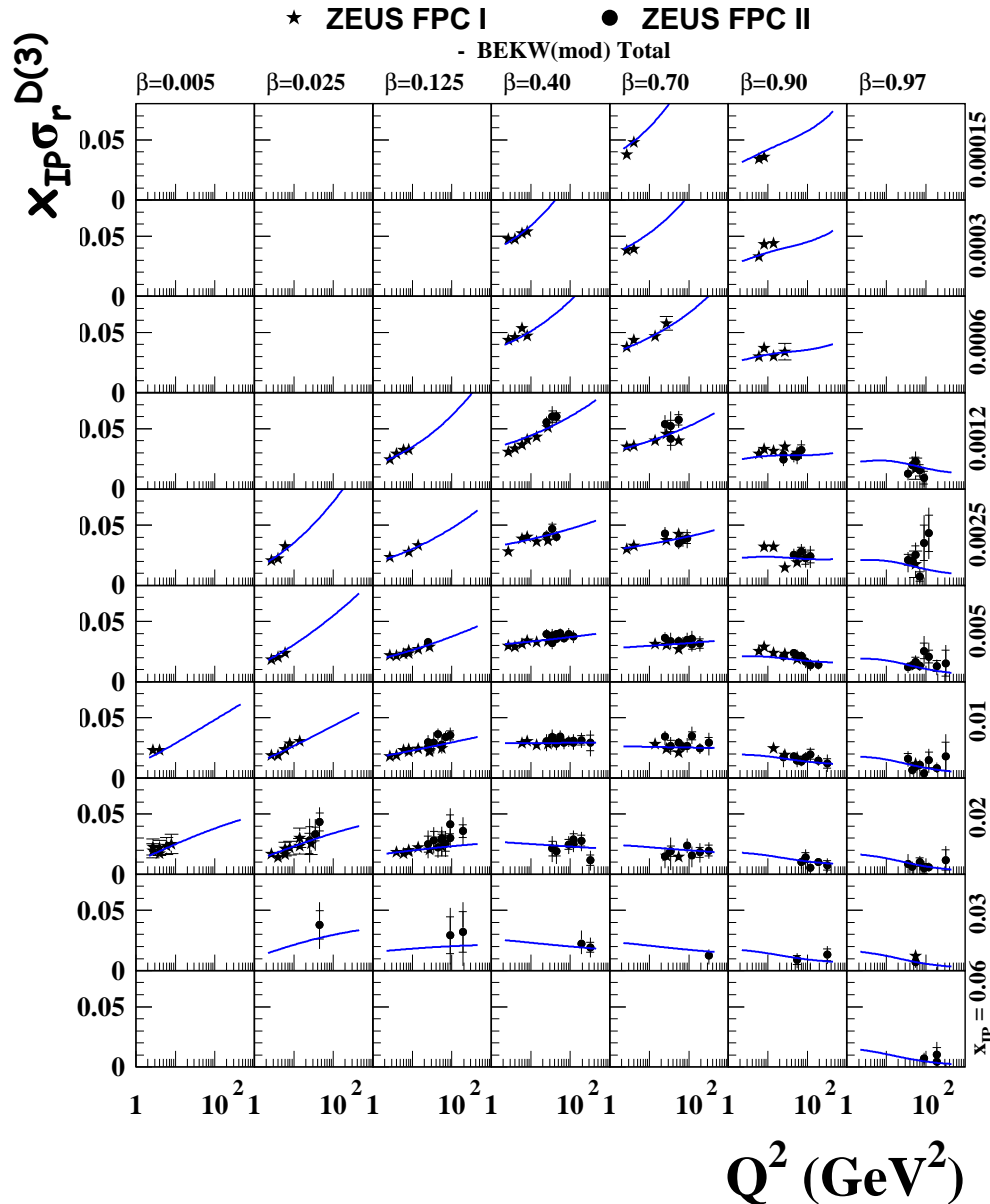


→ Assumption of Regge factorisation works

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

$\times$  data

## ZEUS



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

→ At fixed  $\beta$  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

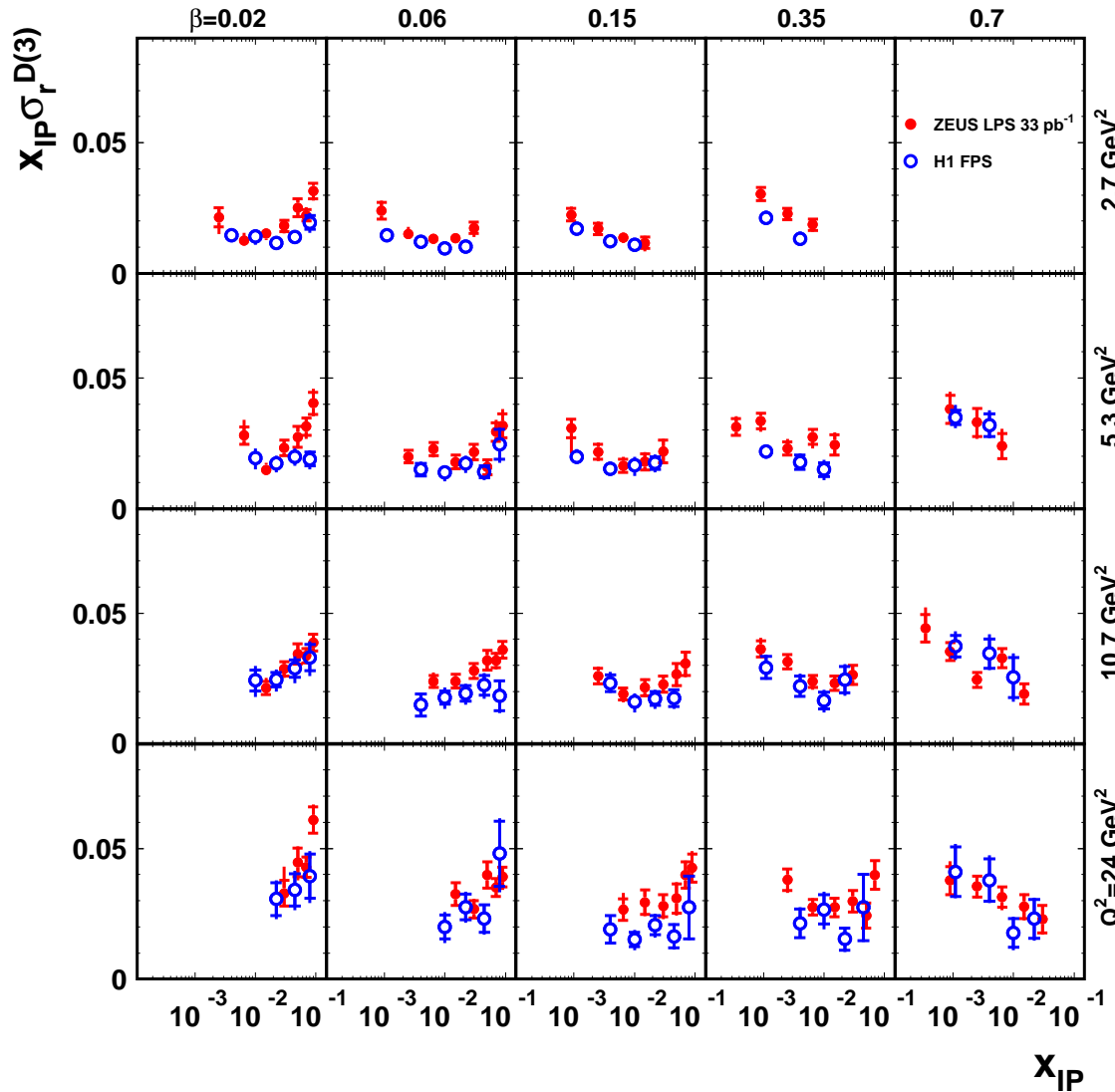
→ Data consistent with Regge factorisation; violation too mild to have impact on the fit quality

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

## ZEUS



The cleanest possible comparison in principle...

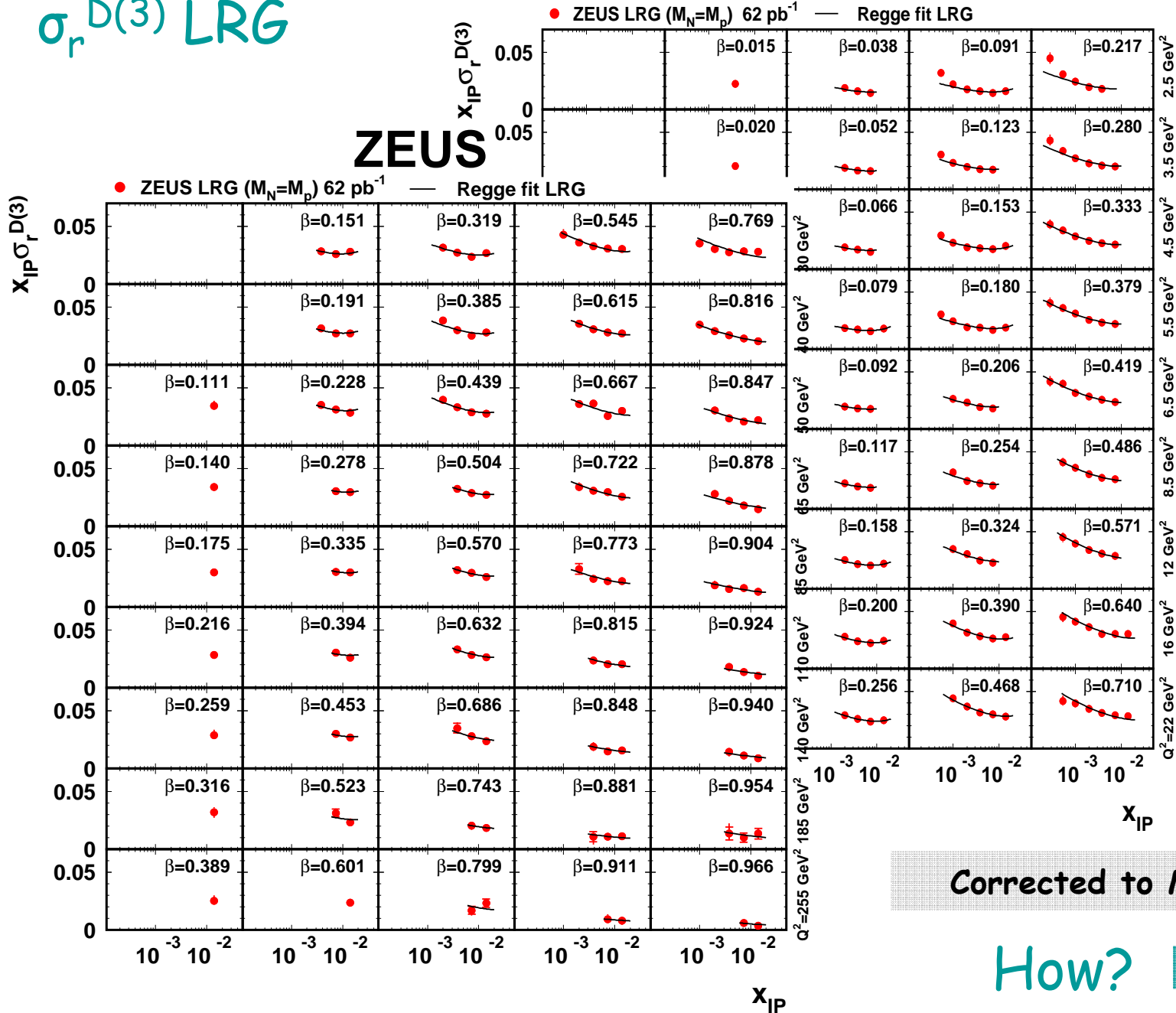
...but large normalisation uncertainties  
(LPS: +11-7%, FPS: +-10%)

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



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

# ZEUS



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Corrected to  $M_N = m_p$

How?

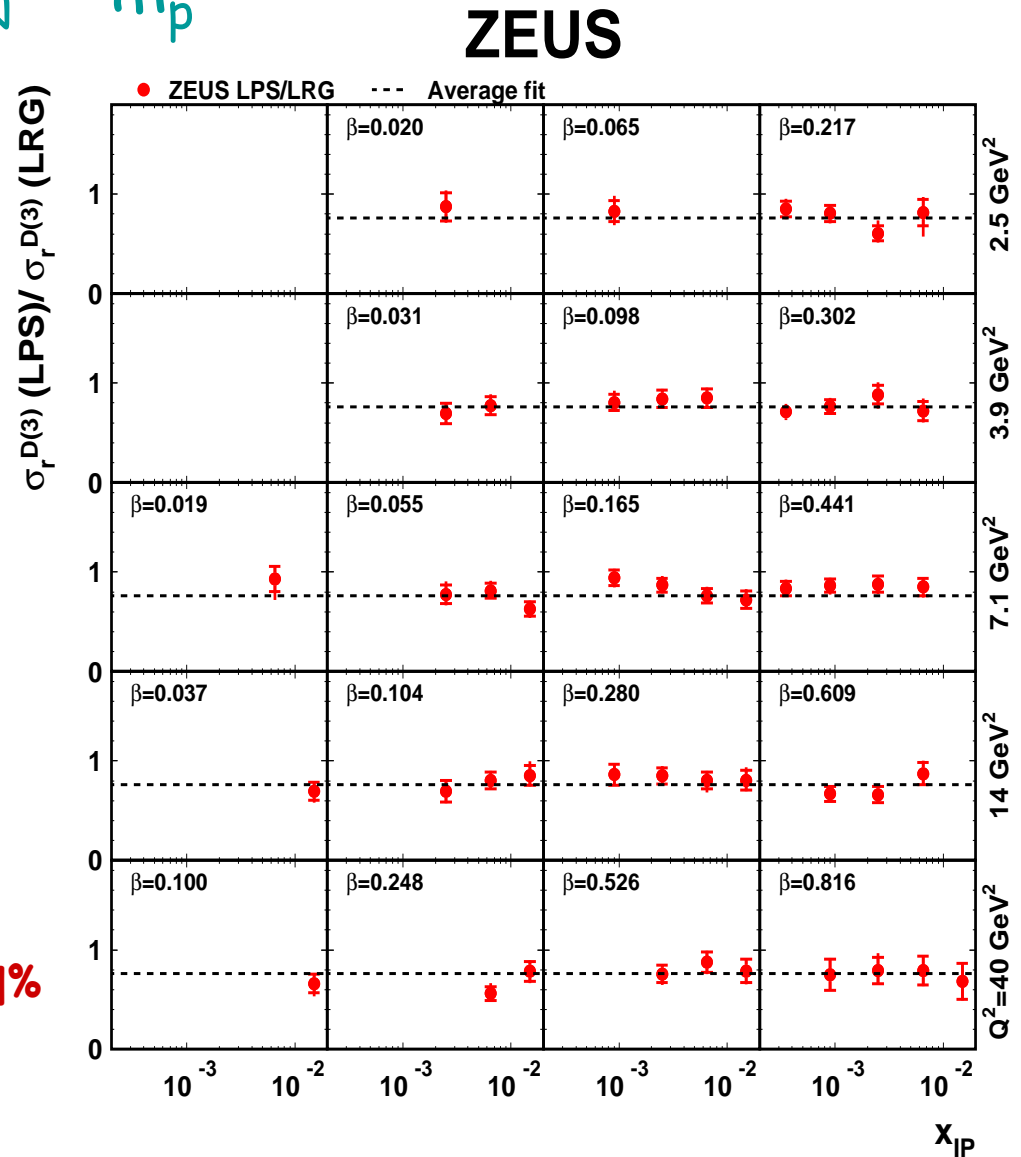
# LRG: correction to $M_N = m_p$

i) ratio LPS/LRG

→ LPS/LRG independent  
of  $Q^2$ ,  $x_{IP}$ ,  $\beta$

LPS/LRG =  $0.76 \pm 0.01(\text{stat})$   
 $+0.03-0.02(\text{sys}) +0.08-0.05(\text{norm})$

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



# LRG: correction to $M_N = m_p$

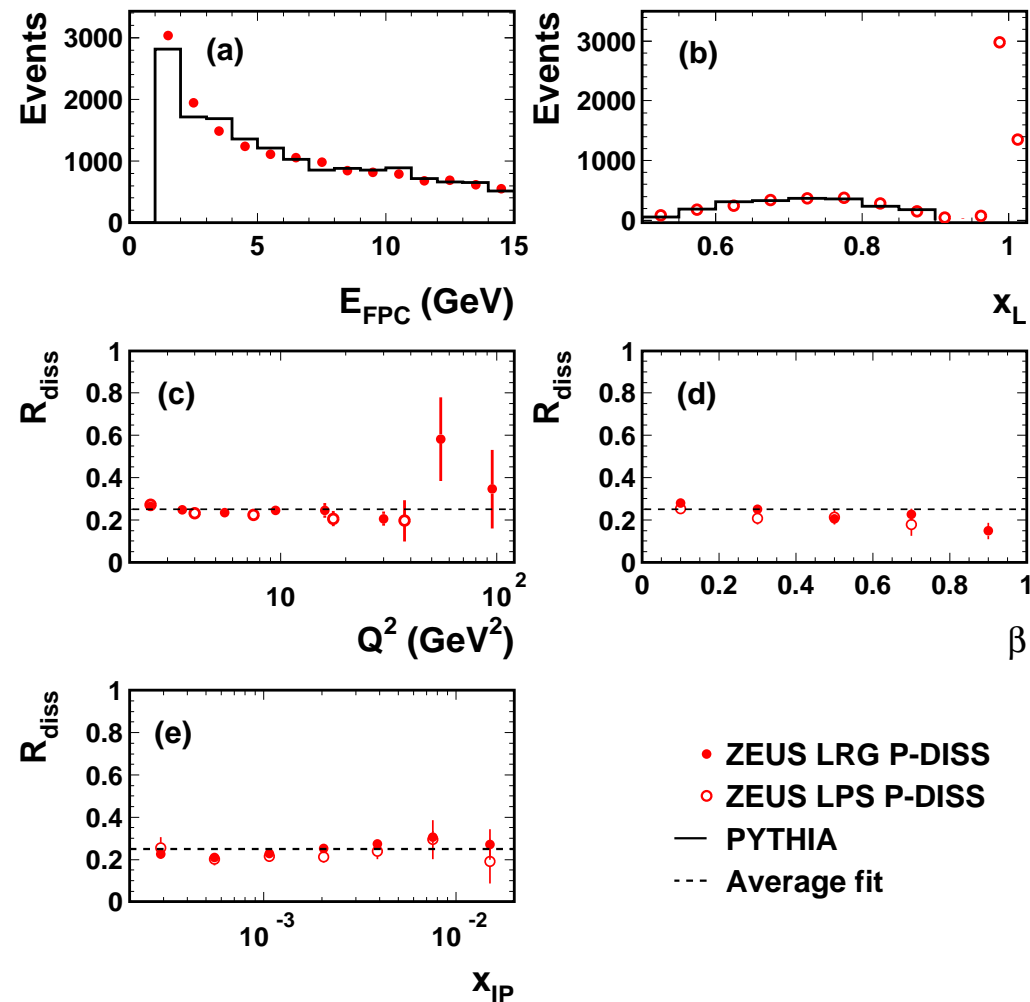
**ZEUS**

## 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 reweighted to best describe  $E_{FPC}$  and  $x_L$



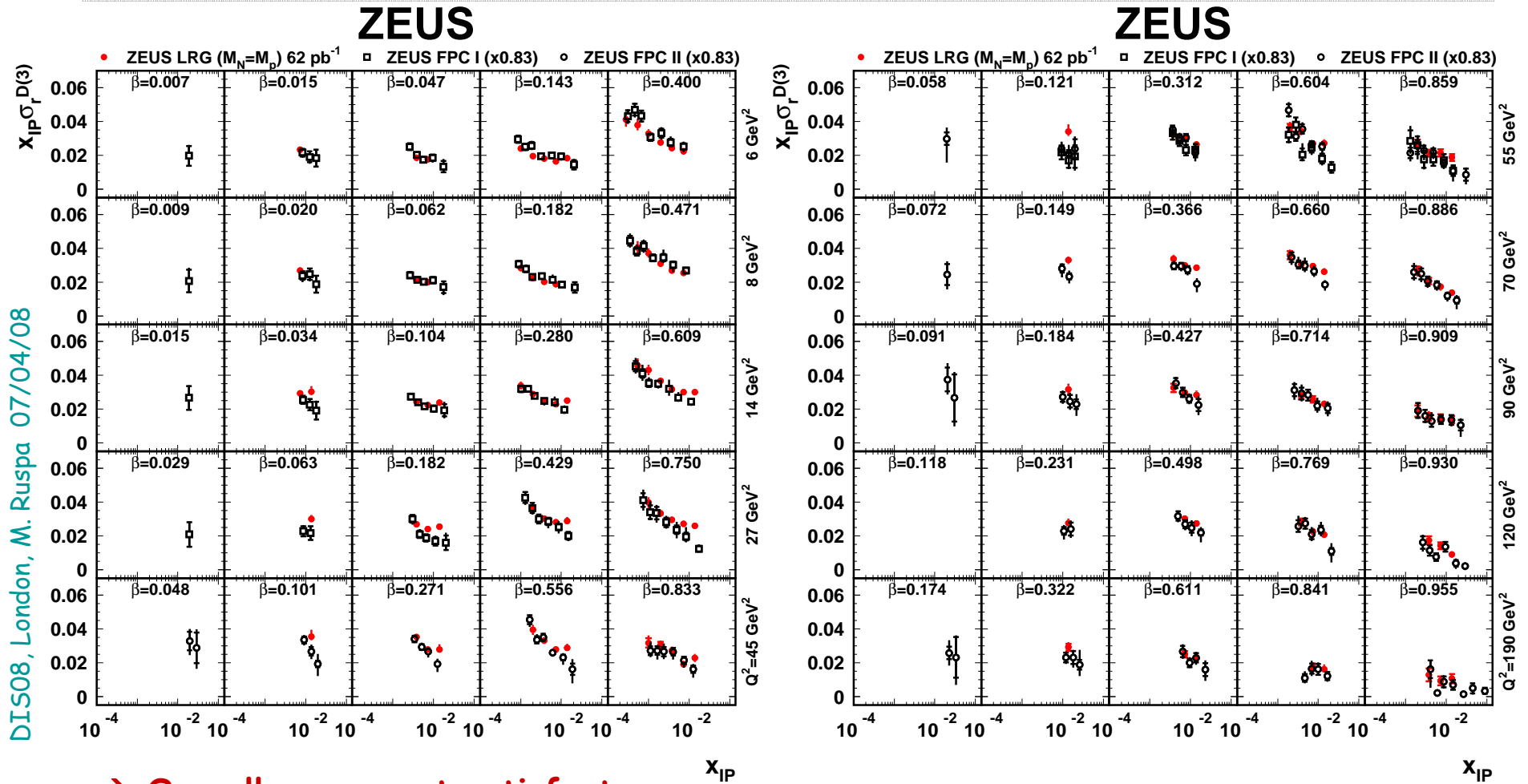
→ p-diss. background in LRG data  $R_{diss} = [25 \pm 1(\text{stat}) \pm 3(\text{sys}) ]\%$

→ consistent with the ratio LPS/LRG

→ 25% correction applied to LRG data

# $\sigma_r^{D(3)}$ LRG vs $M_x$

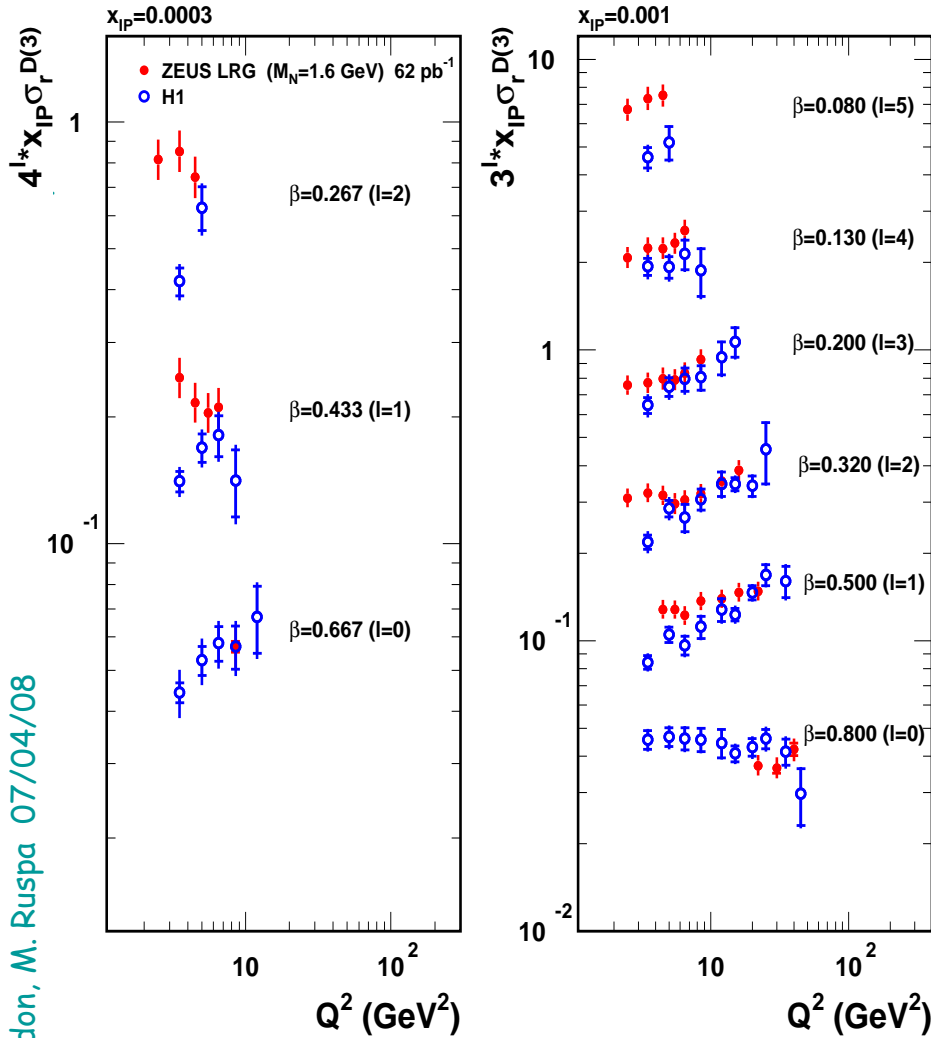
$M_x$  data ( $M_N < 2.3 \text{ GeV}$ ) normalised to LRG ( $M_N = m_p$ ): factor  $0.83 \pm 0.04$  determined via a global fit **estimates residual p-diss. background in  $M_x$  sample**



→ Overall agreement satisfactory

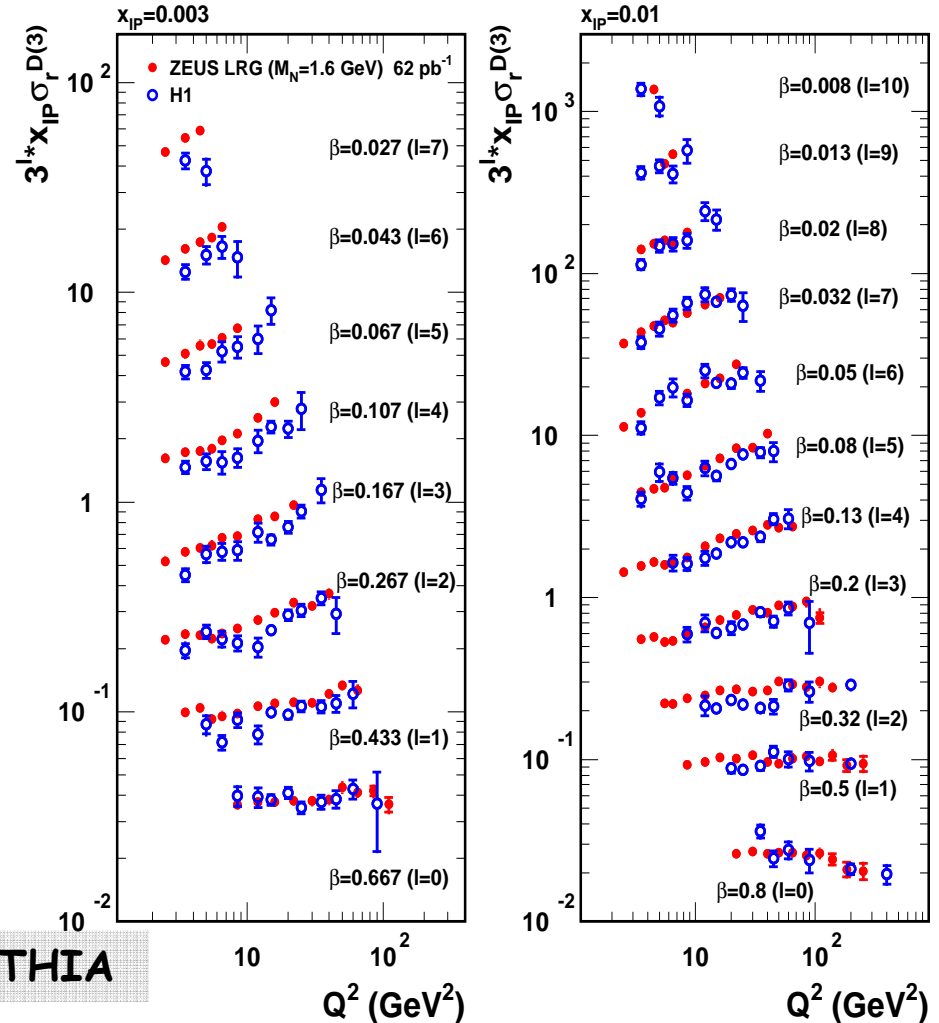
→ Different  $x_{IP}$  dependence ascribed to IR suppressed in  $M_x$  data

# ZEUS



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

## ZEUS



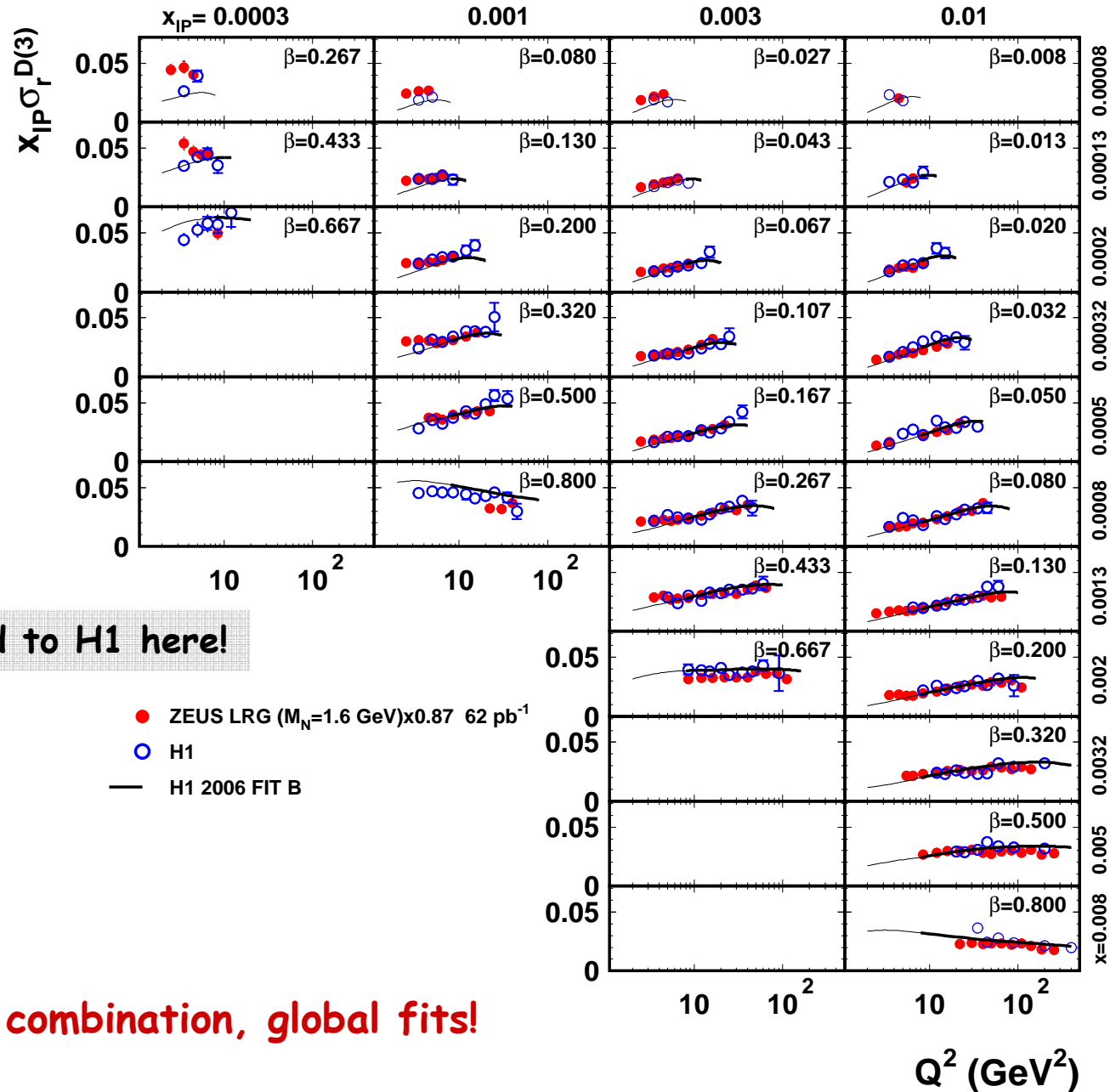
ZEUS corrected to  $M_N < 1.6$  GeV with PYTHIA

→ 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



**ZEUS normalised to H1 here!**

- ZEUS LRG ( $M_N=1.6 \text{ GeV}$ ) $\times 0.87 \text{ 62 pb}^{-1}$
- H1
- H1 2006 FIT B

**Time for data combination, global fits!**

# Highlights

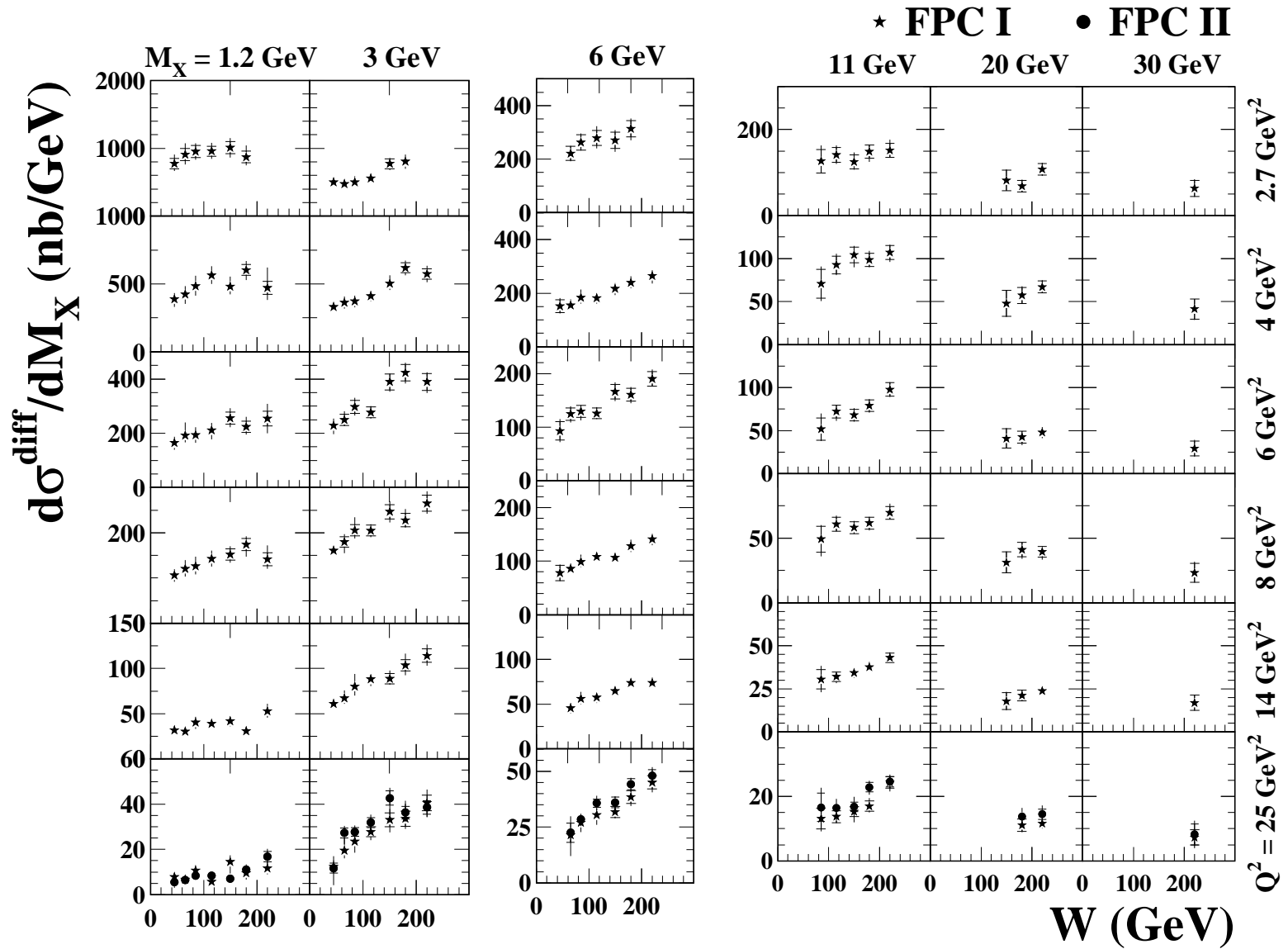
- Final ZEUS results on inclusive diffraction - same data analysed in three independent ways:
  - Proton tag requirement
  - Large rapidity gap requirement
  - Shape of the mass distribution of the hadronic final state
- 4-fold differential reduced cross section, measured for the first time in two  $t$ -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 $d\sigma^{\text{diff}}/dM_X$

M<sub>X</sub> data



→ Low M<sub>X</sub>: moderate increase with W and steep reduction with Q<sup>2</sup>

→ Higher M<sub>X</sub>: **substantial rise with W** and slower decrease with Q<sup>2</sup>

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

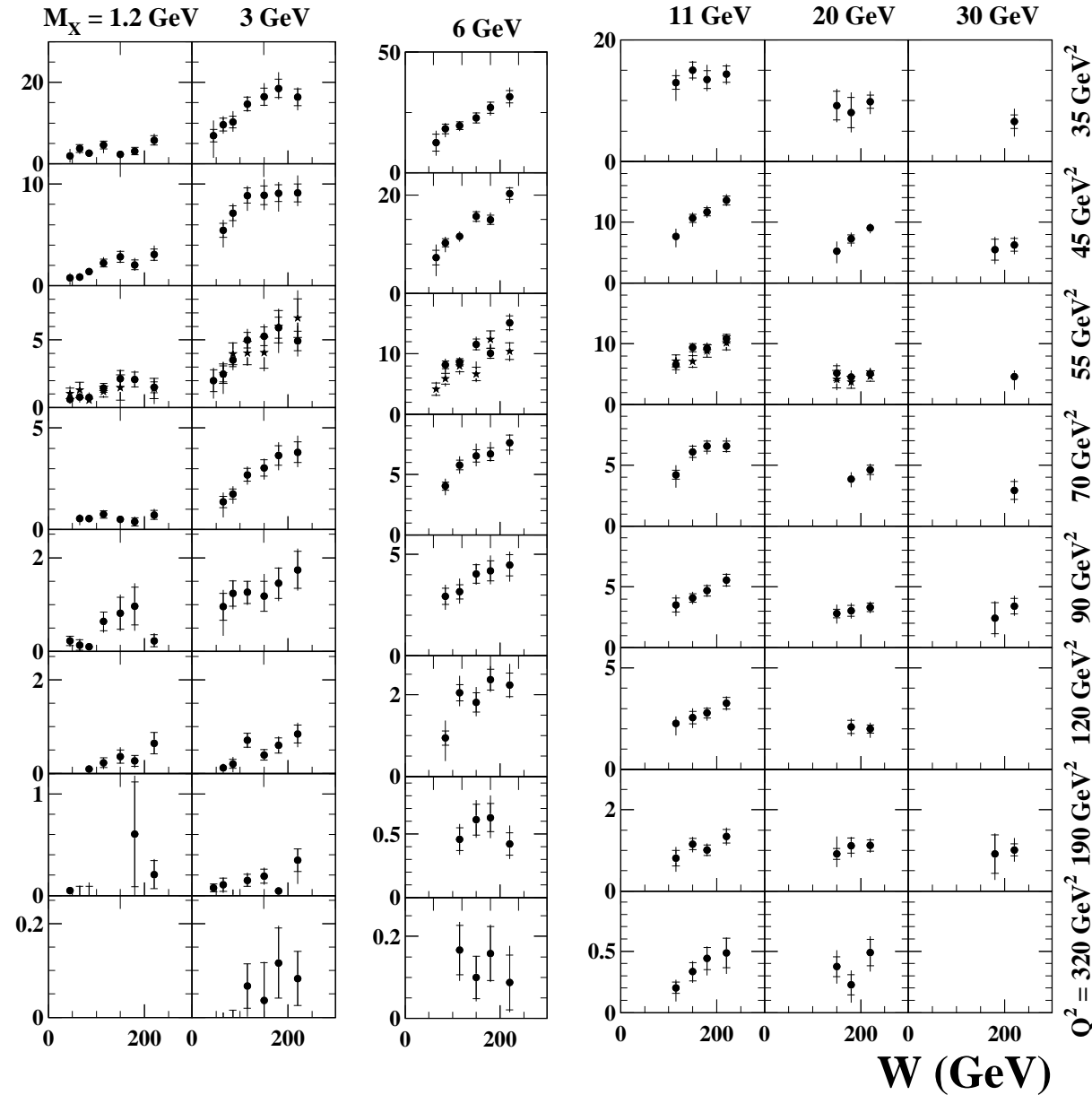
$M_X$  data

ZEUS

★ FPC I ● FPC II

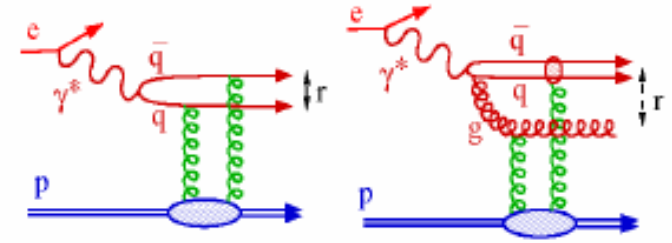
$d\sigma^{\text{diff}}/dM_X$  (nb/GeV)

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→ Substantial rise with  $W$

# Fit with BEKW parameterisation (Bartels, Ellis, Kowalski, Wustoff 1988)



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

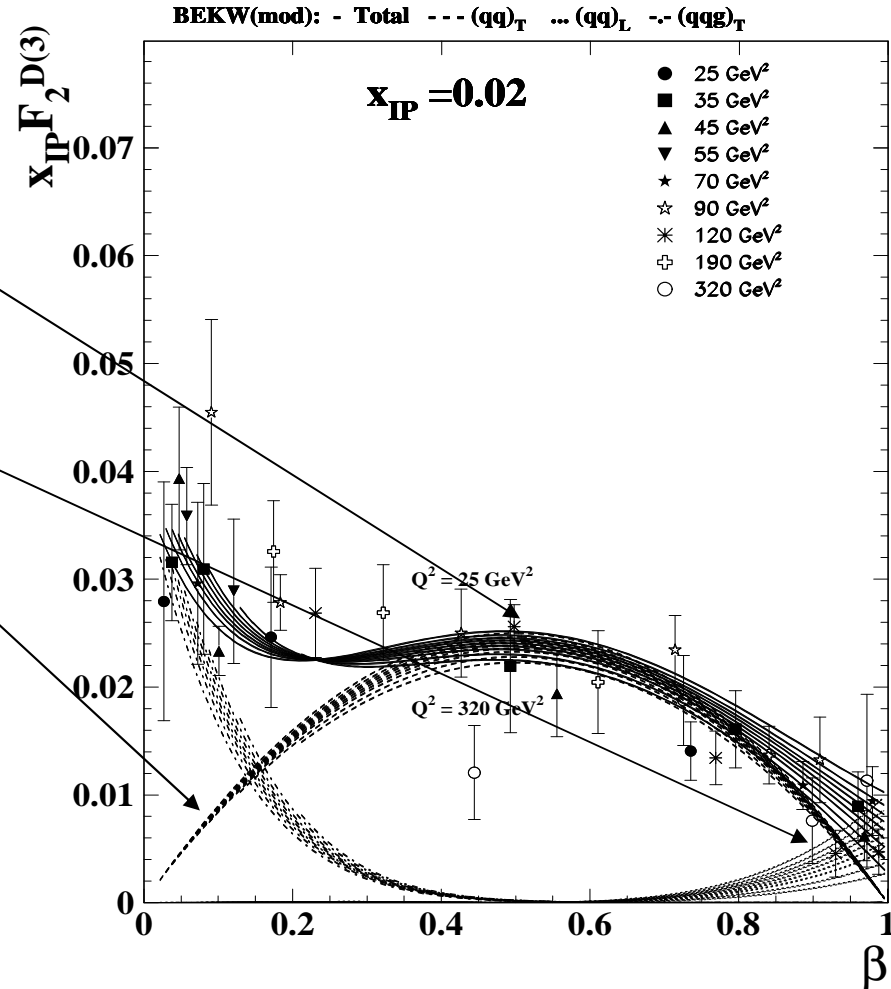
$$F_{q\bar{q}}^T \sim \beta(1-\beta)$$

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

$$F_{q\bar{q}}^L \text{ limited to } \beta \sim 1$$

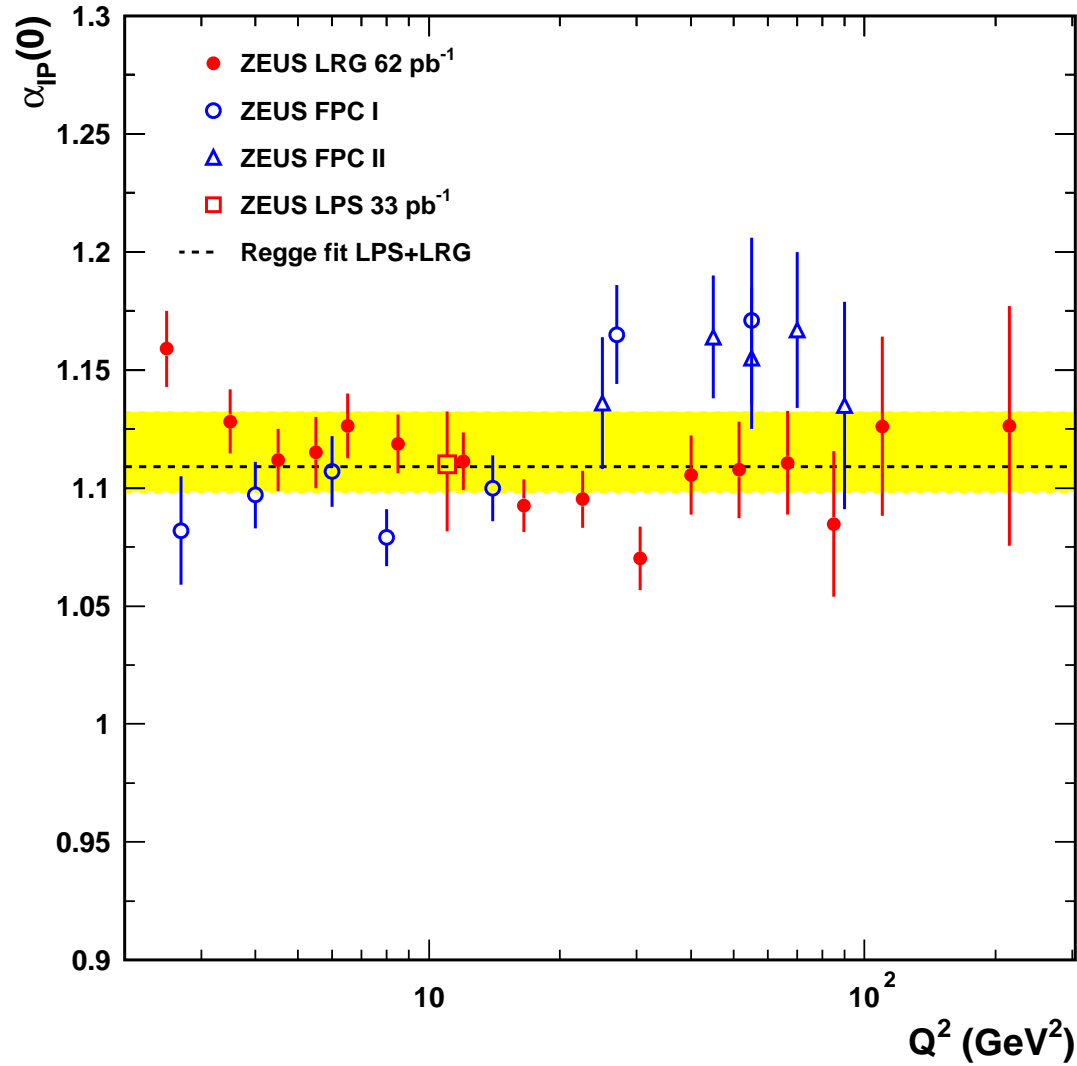
→ Fit gives a good description of the 427 data points FPC I + II

**ZEUS**



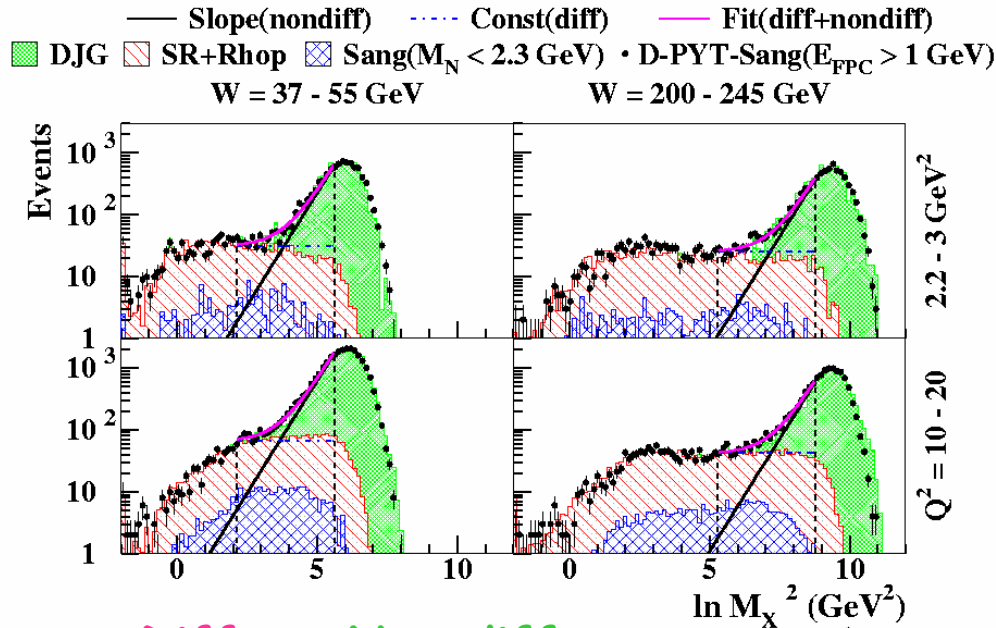
# $Q^2$ dependance of $\alpha_{IP}(0)$

## ZEUS



→  $\alpha_{IP}(0)$  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.

$$\frac{dN}{d \ln M_x^2} = D + c \cdot \exp(b \cdot \ln M_x^2)$$

- $D, c, b$  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  $\eta=5$

→ higher  $M_x$  and lower  $W$

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

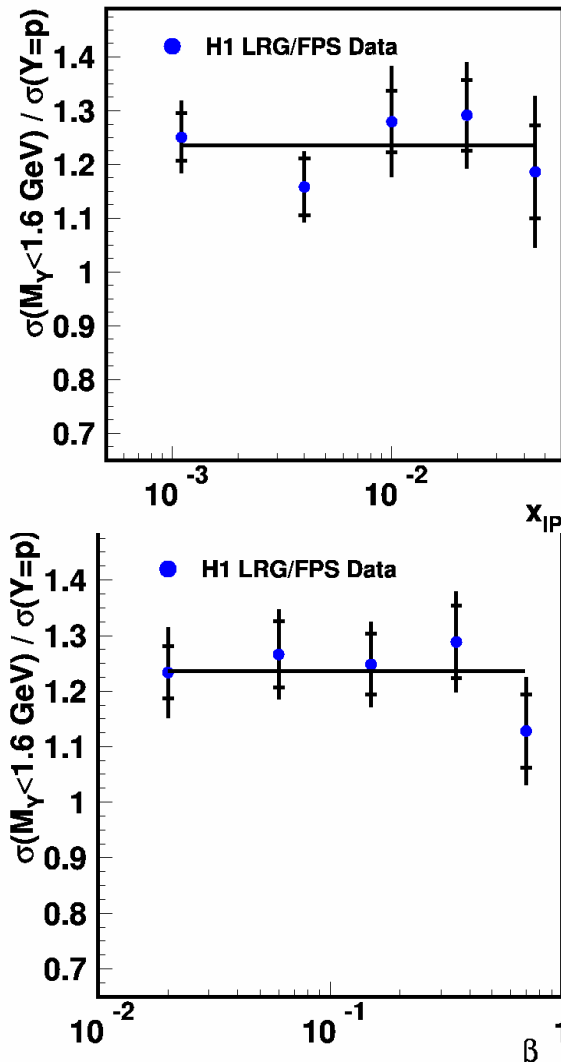
## So far ZEUS published:

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

- 2 H1 publications in 2006
  - FPS (DESY06-048) 99/00 data ( $3 < Q^2 < 24 \text{ GeV}^2$ )
  - LRG (DESY 06-049) 97 minimum bias data ( $Q^2 < 13.5 \text{ GeV}^2$ )  
97 data ( $13.5 < Q^2 < 105 \text{ GeV}^2$ )  
99/00 data ( $133 < Q^2 < 1600 \text{ GeV}^2$ )

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

# Proton dissociation @H1: ratio LRG vs FPS



- Data first corrected to  $M_\gamma < 1.6 \text{ GeV}$   
(corr. factor:  $-8.6\% \pm 5.8\%$ )

$H1 \text{ LRG} / H1 \text{ FPS} = 1.23 \pm 0.03(\text{stat}) \pm 0.16(\text{sys})$

→ Proton dissociation in H1 LRG data :  $[19 \pm 11]\%$

- Also study with DIFFVM:

$\text{Ratio} = 1.15 \pm 0.15 \pm 0.08 \rightarrow [13 \pm 11 \pm 6]\%$



## Proton dissociation@ ZEUS: summary

- from direct measurement of the ratio LPS/LRG data (before correction to  $M_y = m_p$ ):  
ZEUS LPS/ZEUS LRG =  $0.76 \pm 0.01(\text{stat}) \pm 0.03(\text{sys}) \pm 0.05(\text{norm})$   
→  $[24 \pm 1(\text{stat}) \pm 3(\text{sys}) \pm 5(\text{norm})]\%$
- from PYTHIA:  $[25 \pm 1(\text{stat}) \pm 3(\text{sys}) ]\%$

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

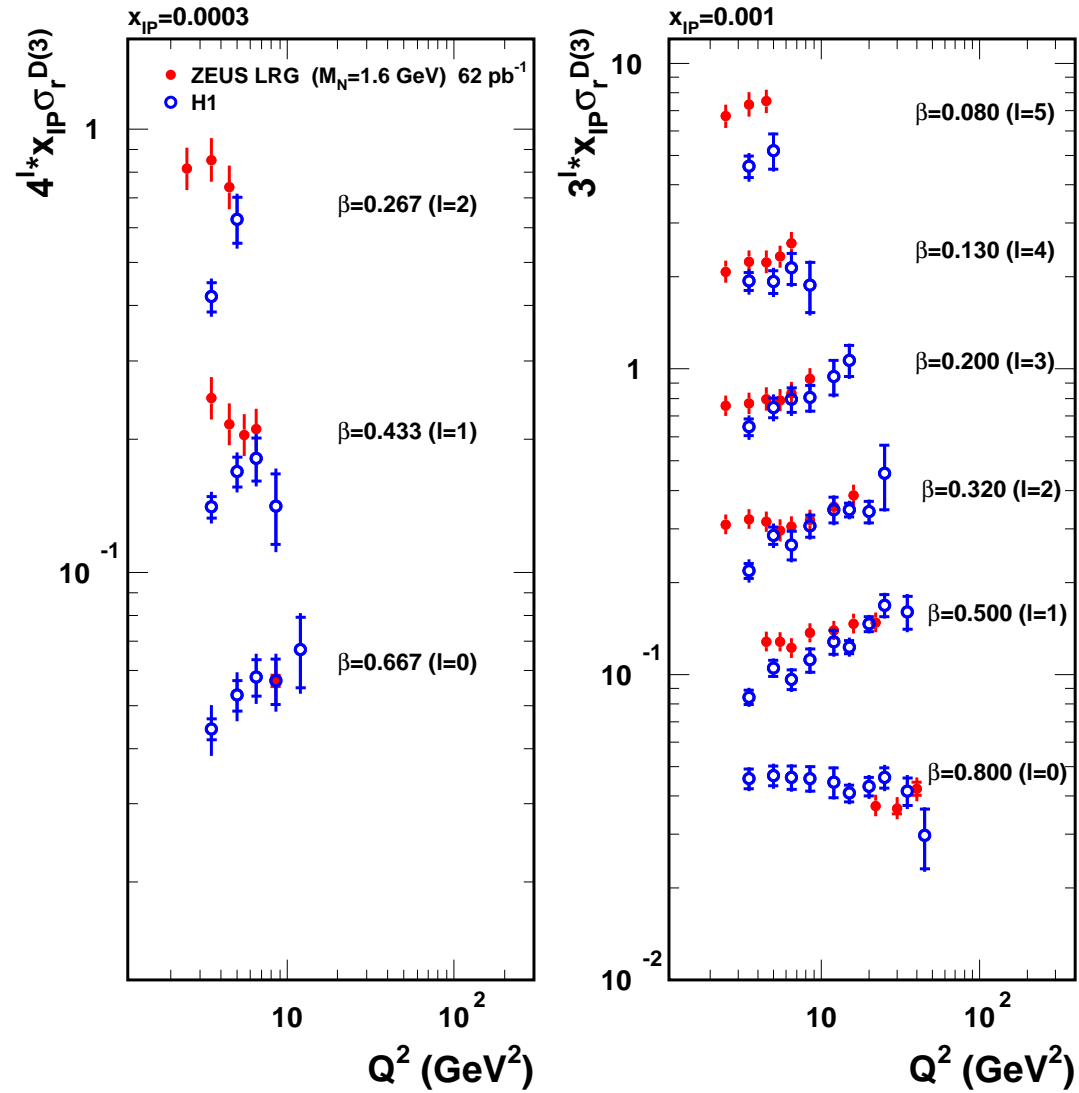
## Proton dissociation @H1: summary

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

These numbers quantify the background for  $M_y < 1.6 \text{ GeV}$

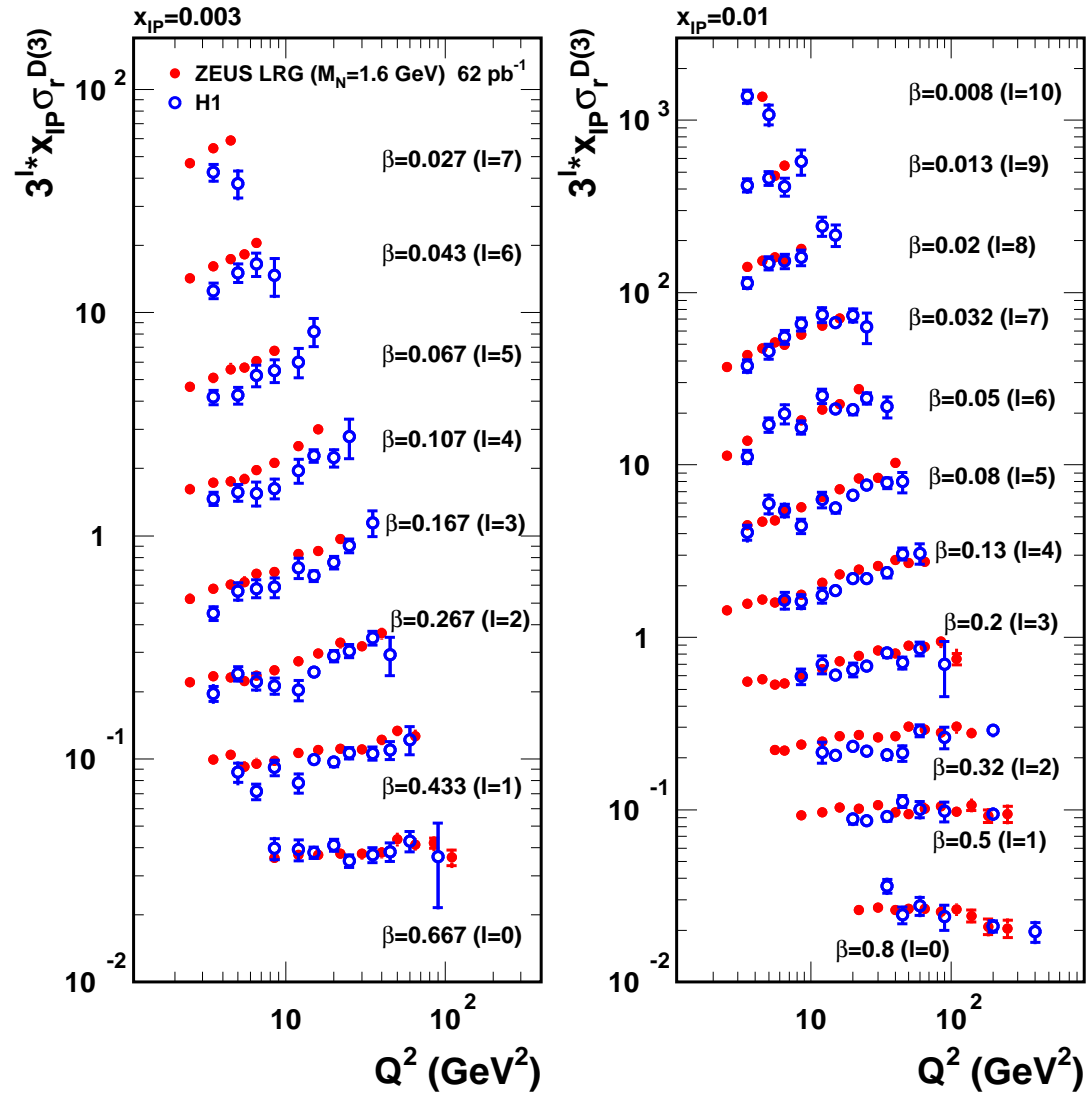
# $\sigma_r^{D(3)}$ ZEUS LRG vs H1 LRG

## ZEUS



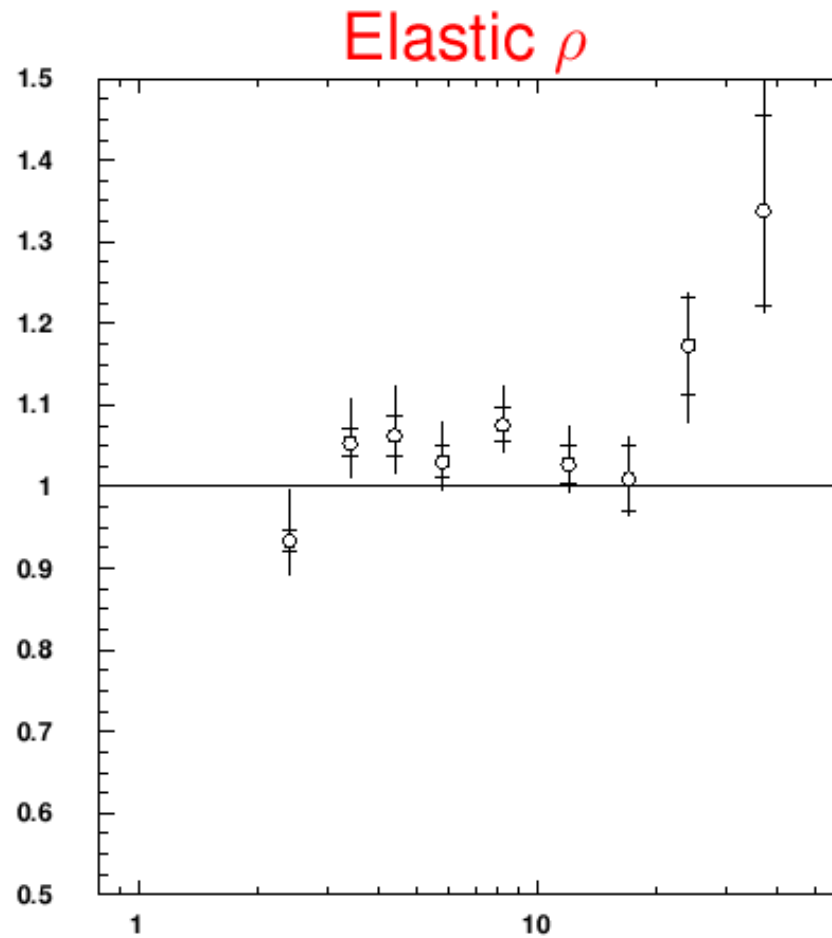
# $\sigma_r^{D(3)}$ ZEUS LRG vs H1 LRG

## ZEUS



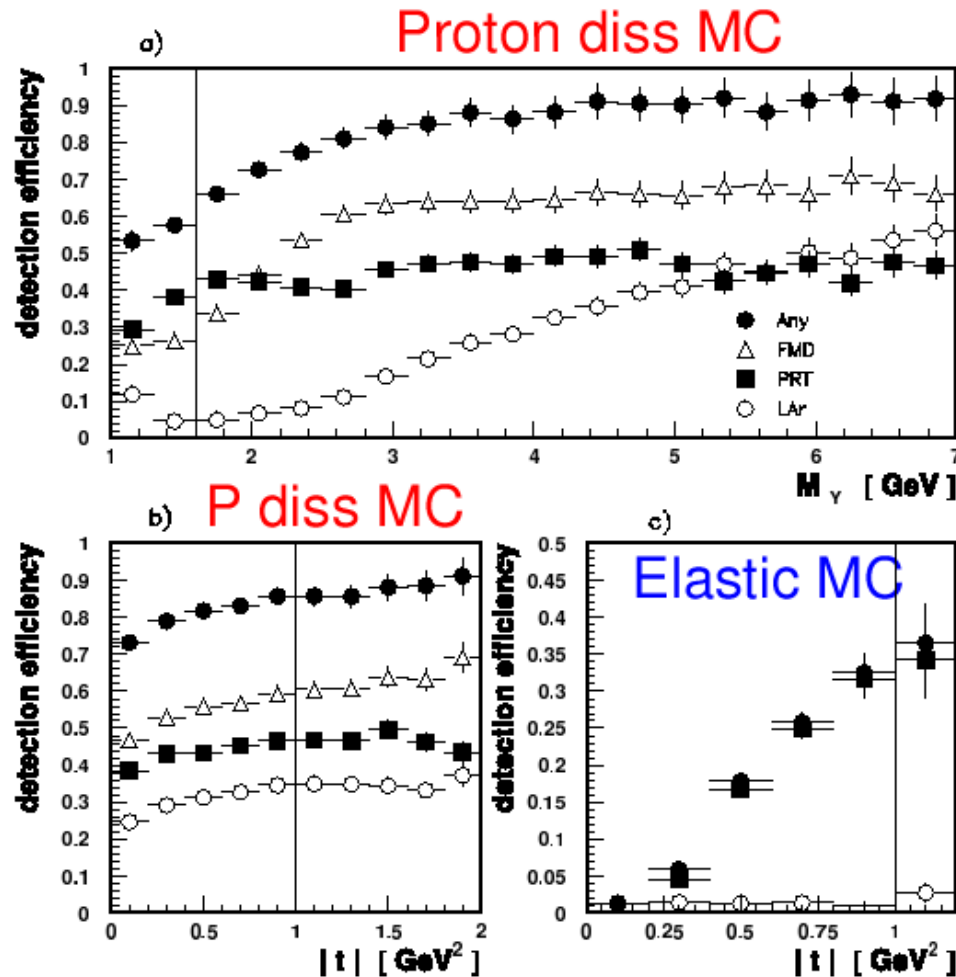
## What about the exclusive measurements?

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 tagging eff > 60%  
for  $M_Y > 1.6$  GeV

→ Correct up to 1.6 GeV

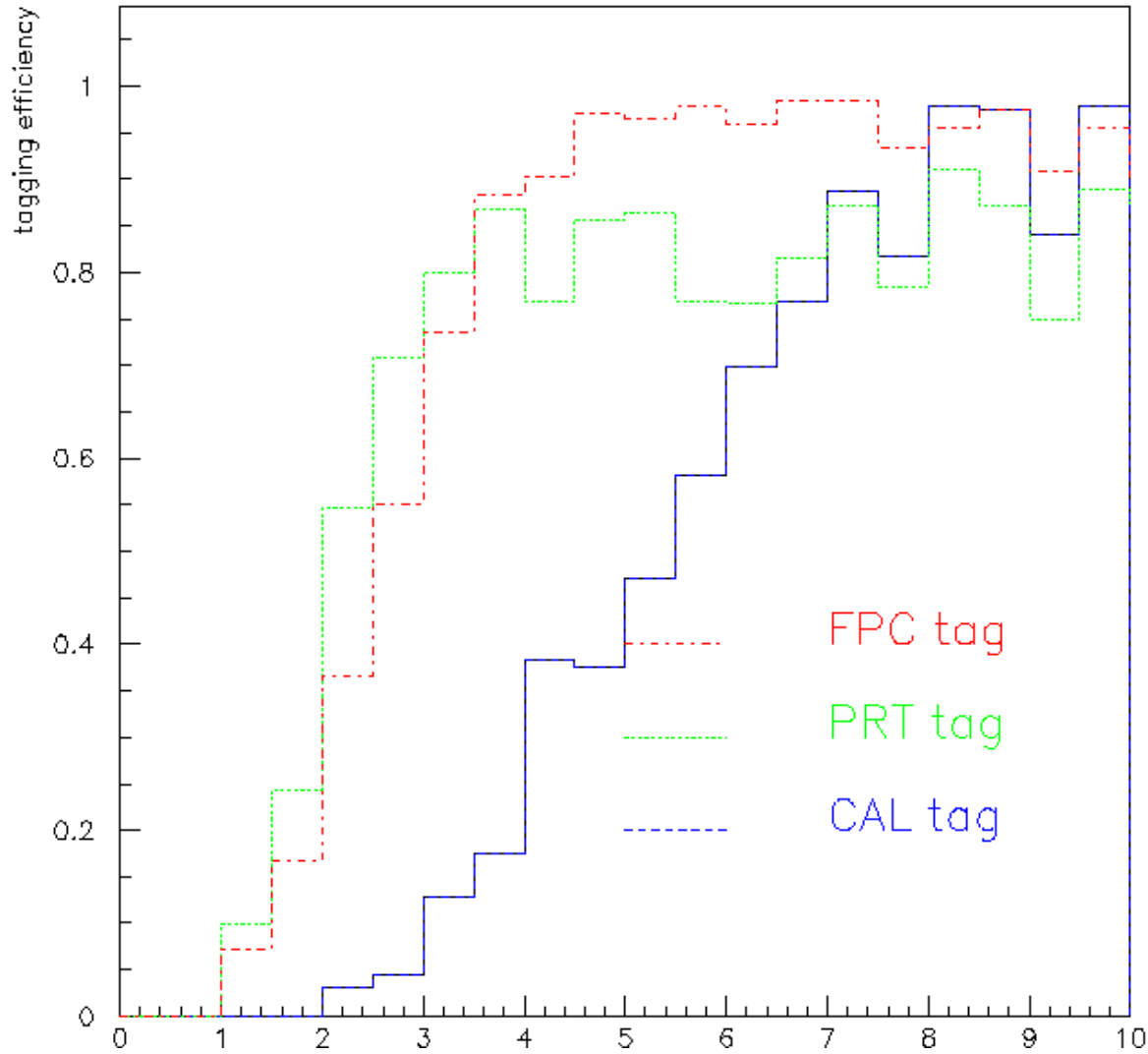
**Elastic tagging:**

Total tagging eff > 10%  
for  $|t| > 0.5$  GeV<sup>2</sup>

→ Cut at 0.5 GeV<sup>2</sup>

(from P. Thompson PhD Thesis)

# ZEUS forward detector sensitivity



Proton tagging is  
more than 60%  
efficient for  
 $M_Y > 2.3 \text{ GeV}$