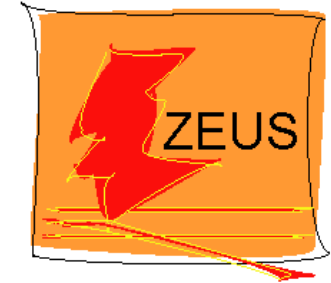




DIS2012
26-30 March 2012
Bonn



Combined Measurement of the Inclusive Diffractive Cross Sections at HERA

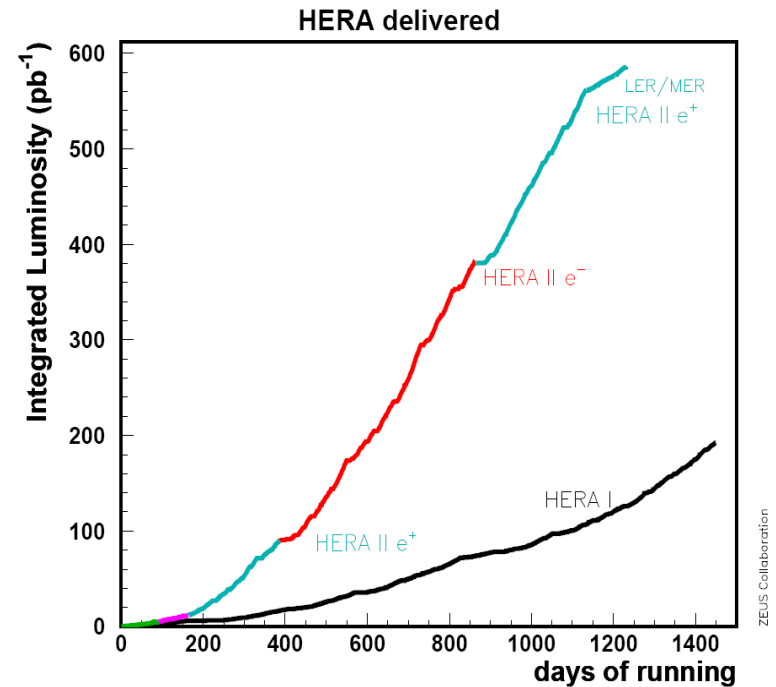
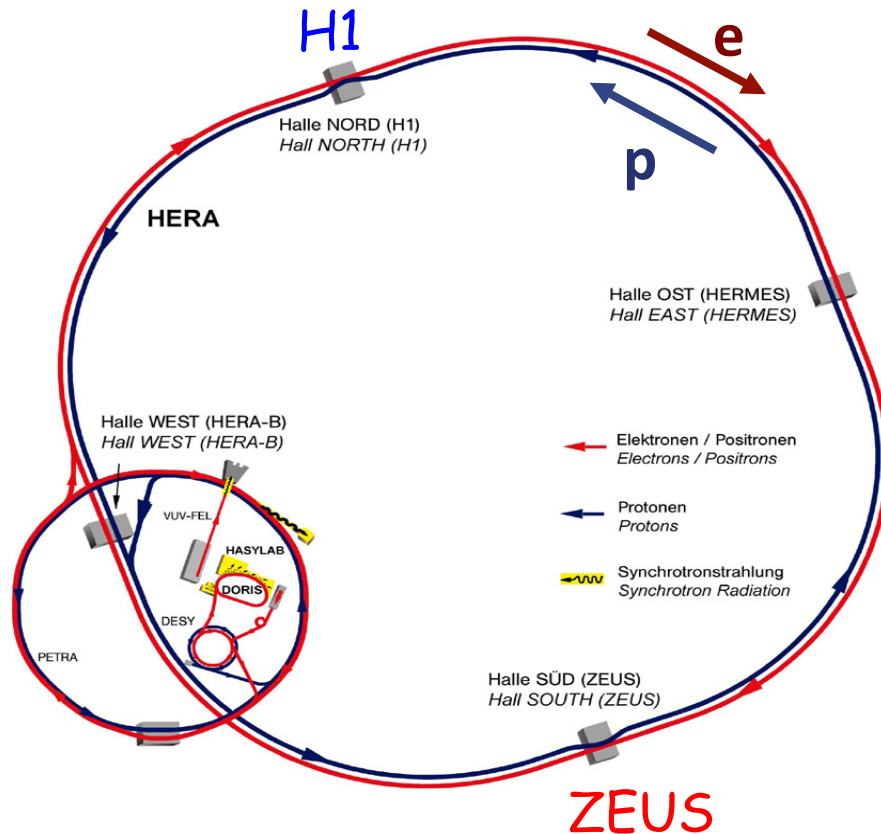
Valentina Sola
(Hamburg University)
on behalf of the H1 and ZEUS Collaborations



Universität Hamburg

- ❖ Diffraction in ep scattering
- ❖ Latest inclusive diffractive ep results
- ❖ Combination of diffractive cross sections

HERA Experiments

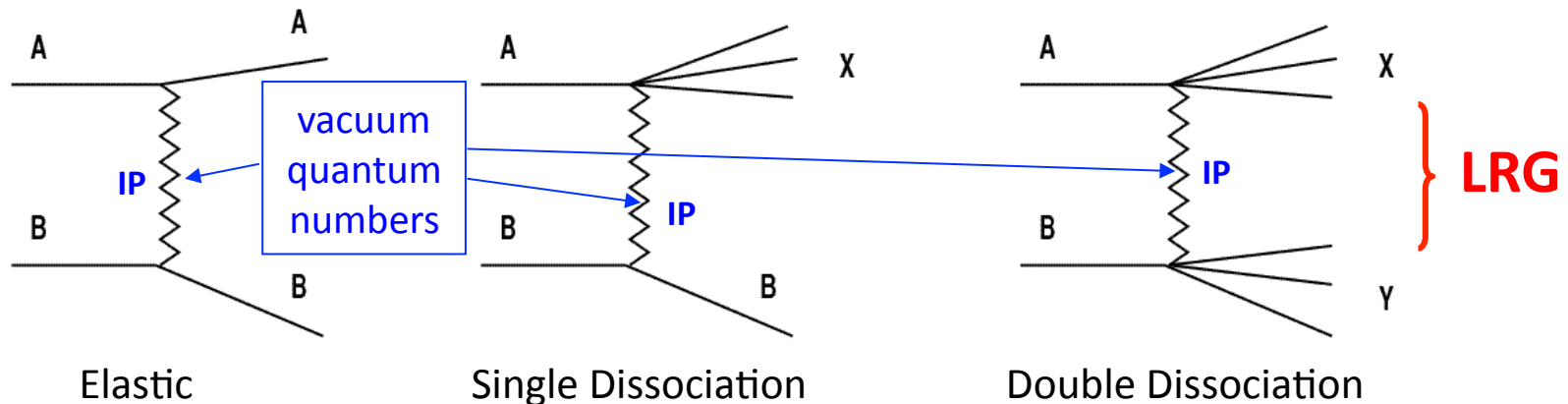


HERA I	1993-2000	$E_p = 820-920 \text{ GeV}$
HERA II	2003-2007	$E_p = 920-460-575 \text{ GeV}$
HERA I - II		$E_e = 27.5 \text{ GeV}$

0.5 fb⁻¹ collected by H1
and ZEUS experiments

Diffraction in Hadron Scattering

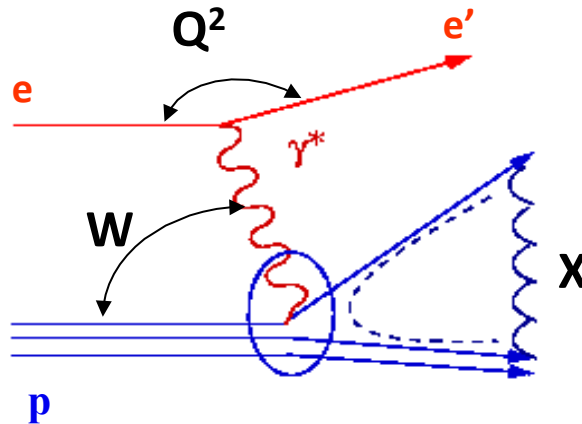
Diffraction is a feature of hadron-hadron interactions (30% of σ_{tot})



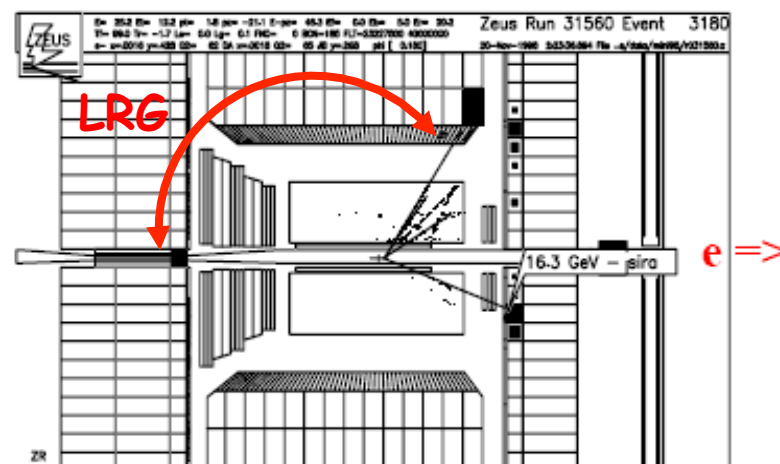
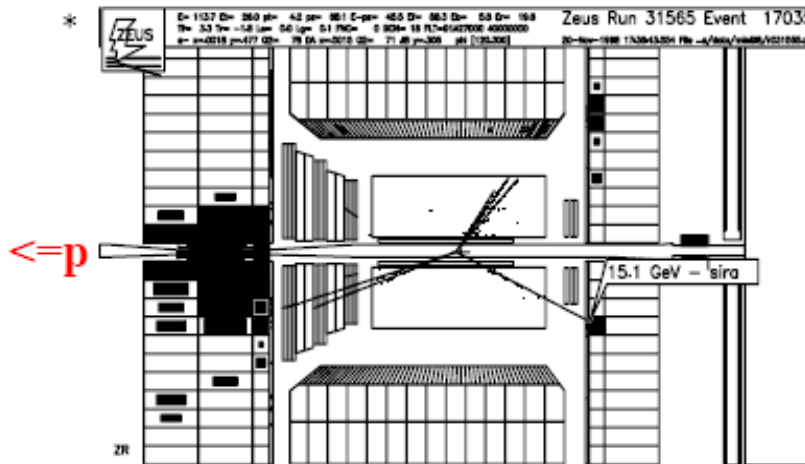
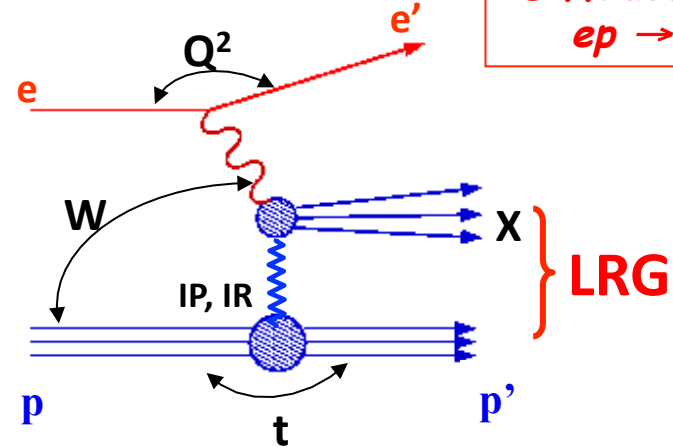
- ⇒ Beam particles emerge intact or dissociated into low-mass states
→ Very small fractional momentum losses (within a few %)
- ⇒ Final-state systems separated by large polar angle
(or pseudorapidity $\eta = -\ln[\tan(\theta/2)]$)
→ **Large Rapidity Gap (LRG)**
- ⇒ Interaction mediated by t-channel exchange of an object with vacuum quantum numbers (no colour)
→ **Pomeron (IP)**

Diffraction at HERA

Standard DIS
 $ep \rightarrow e'X$



Diffractive DIS
 $ep \rightarrow e'Xp'$



Diffractive events contribute up to 15% of the inclusive DIS cross section

Kinematics and Cross Sections

Q^2 = virtuality of exchanged photon

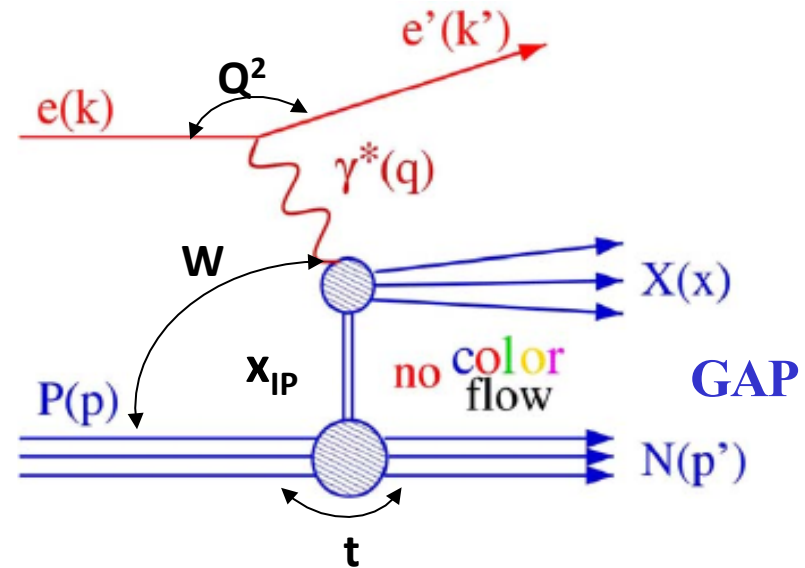
x = Bjorken scaling variable

y = inelasticity of virtual photon

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

$\beta = x/x_{IP}$ = fraction of IP momentum carried by struck parton

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



When N is a resonance or a low mass state

↪ proton dissociation (p-diss)

$$\frac{d^4\sigma_{ep \rightarrow e'Xp'}}{d\beta dQ^2 dx_{IP} dt} = \frac{2\pi\alpha^2}{\beta Q^4} Y_+ [F_2^{D(4)}(\beta, Q^2, x_{IP}, t) - \frac{Y_-^2}{Y_+} F_L^{D(4)}(\beta, Q^2, x_{IP}, t)]$$

where $Y_+ = 1 + (1-y)^2$

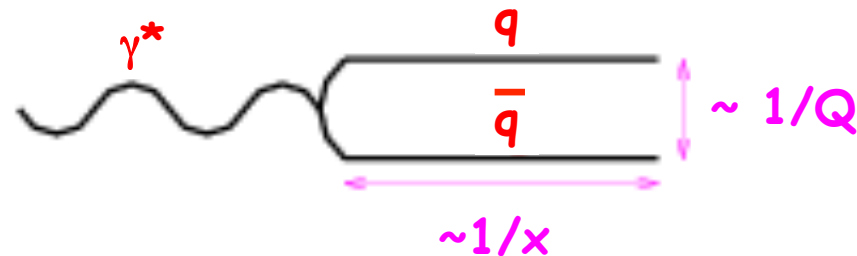
$$= \sigma_r^{D(4)}(\beta, Q^2, x_{IP}, t)$$

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

Why Diffraction at HERA?

Real and virtual photons can fluctuate in hadronic states

$\gamma^* \rightarrow \text{vector meson, } q\bar{q}, q\bar{q}g \dots$



(as seen in the proton rest-frame)

Q = 'negative mass' of the virtual photon

x = Bjorken scaling variable

At HERA very small x are reached:

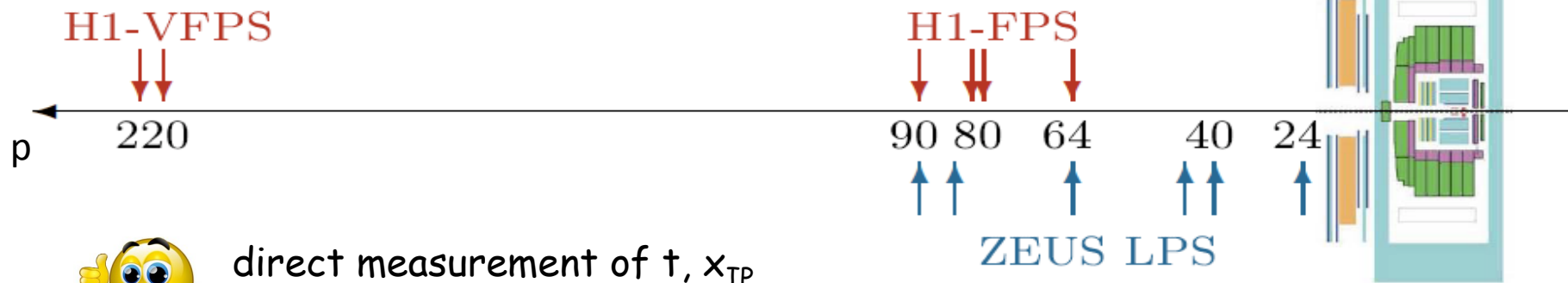
- long hadronic lifetime of the photon
- diffractive photon-proton scattering in perfect analogy with diffractive hadron-hadron scattering

At HERA high Q^2 are reached:

- short distances
- perturbative QCD

Signatures and Selection Methods

Proton Spectrometer (PS) method



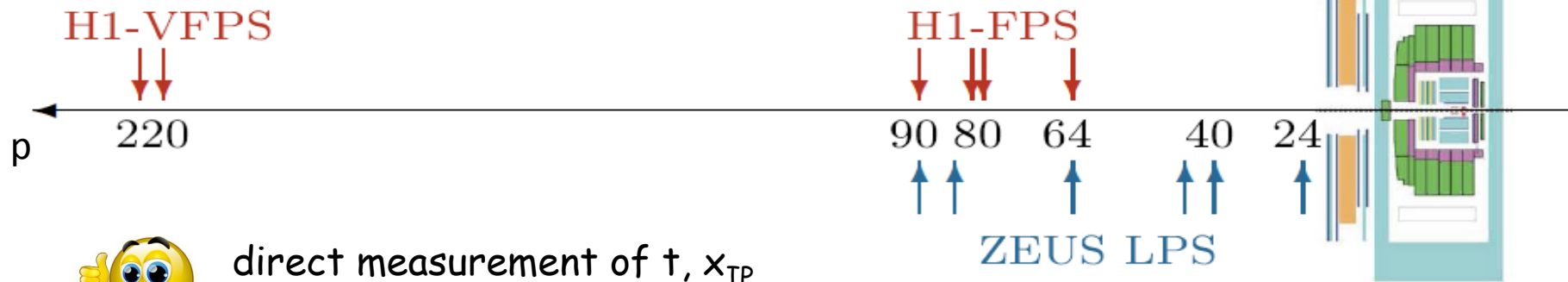
direct measurement of t , x_{IP}
high x_{IP} accessible
no p-diss contribution



low statistics

Signatures and Selection Methods

Proton Spectrometer (PS) method



direct measurement of t , x_{IP}
high x_{IP} accessible
no p-diss contribution



low statistics

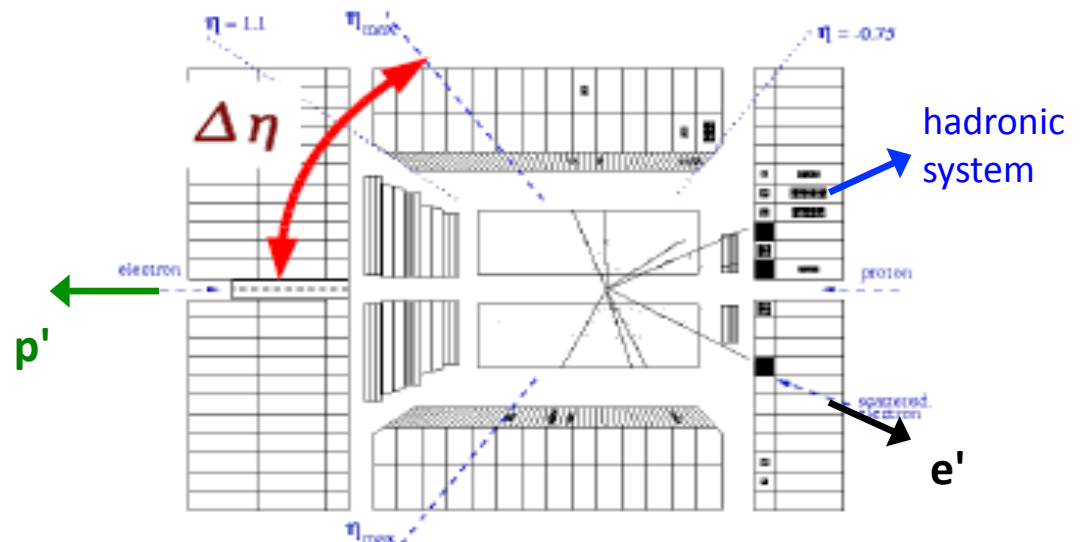


near perfect acceptance
at low x_{IP}



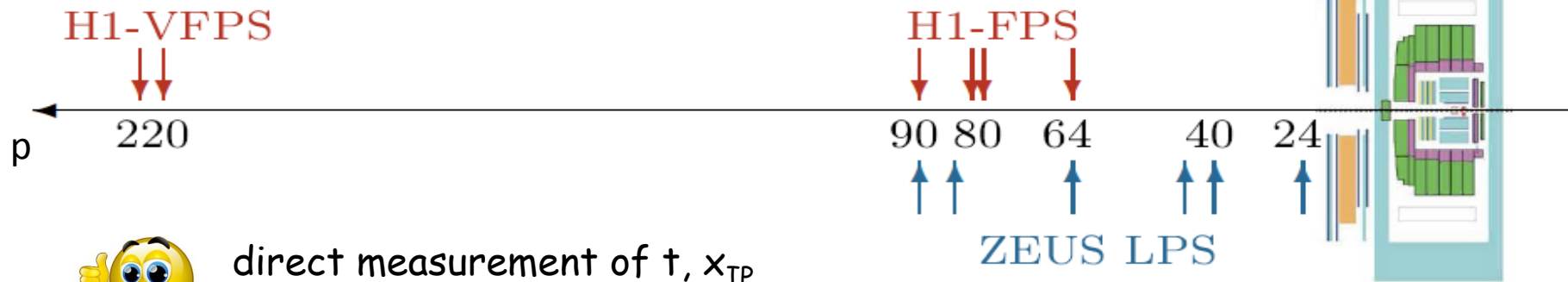
p-diss contribution
no t measurement

Large Rapidity Gap (LRG) method



Signatures and Selection Methods

Proton Spectrometer (PS) method



direct measurement of t , x_{IP}
high x_{IP} accessible
no p-diss contribution



low statistics

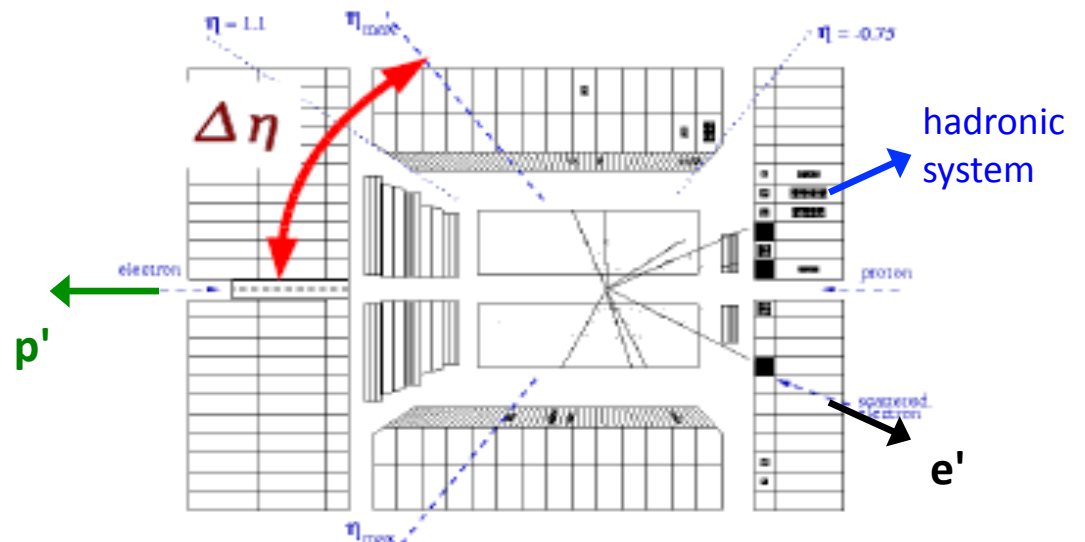


near perfect acceptance
at low x_{IP}

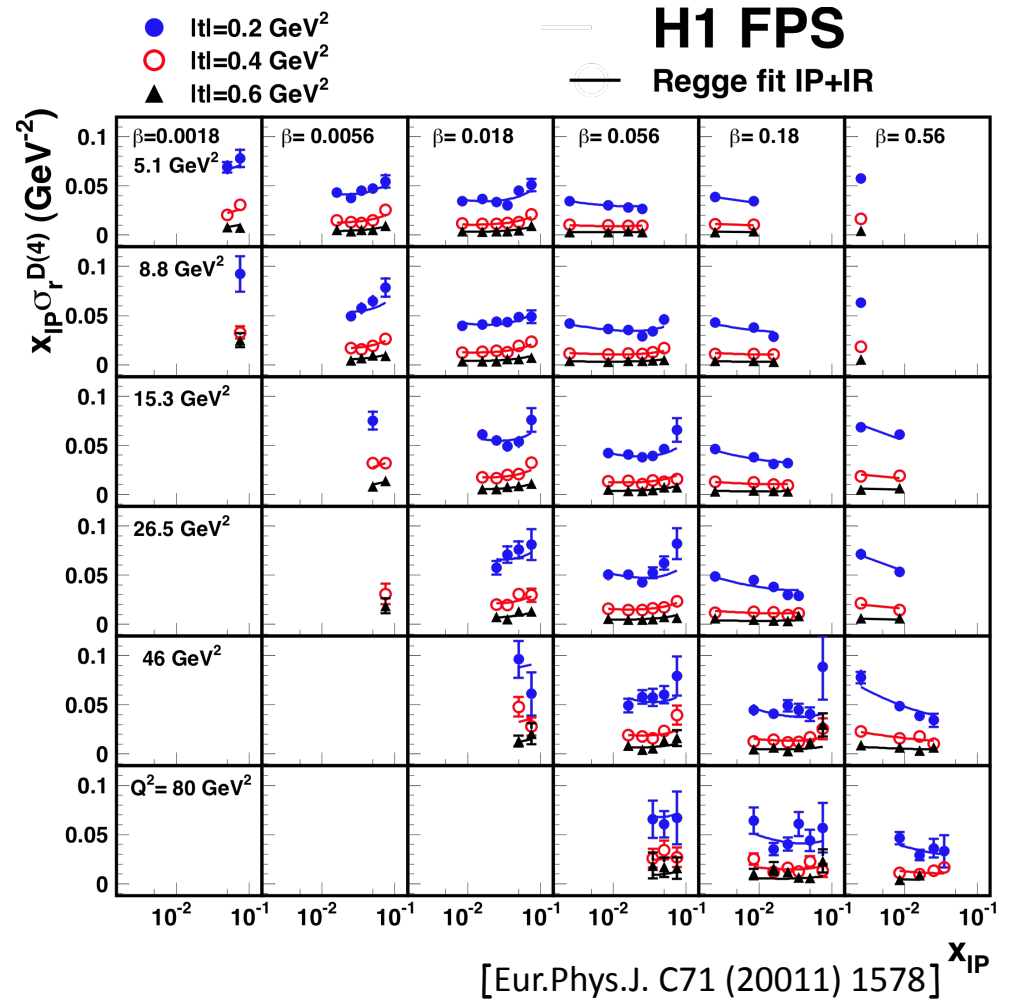
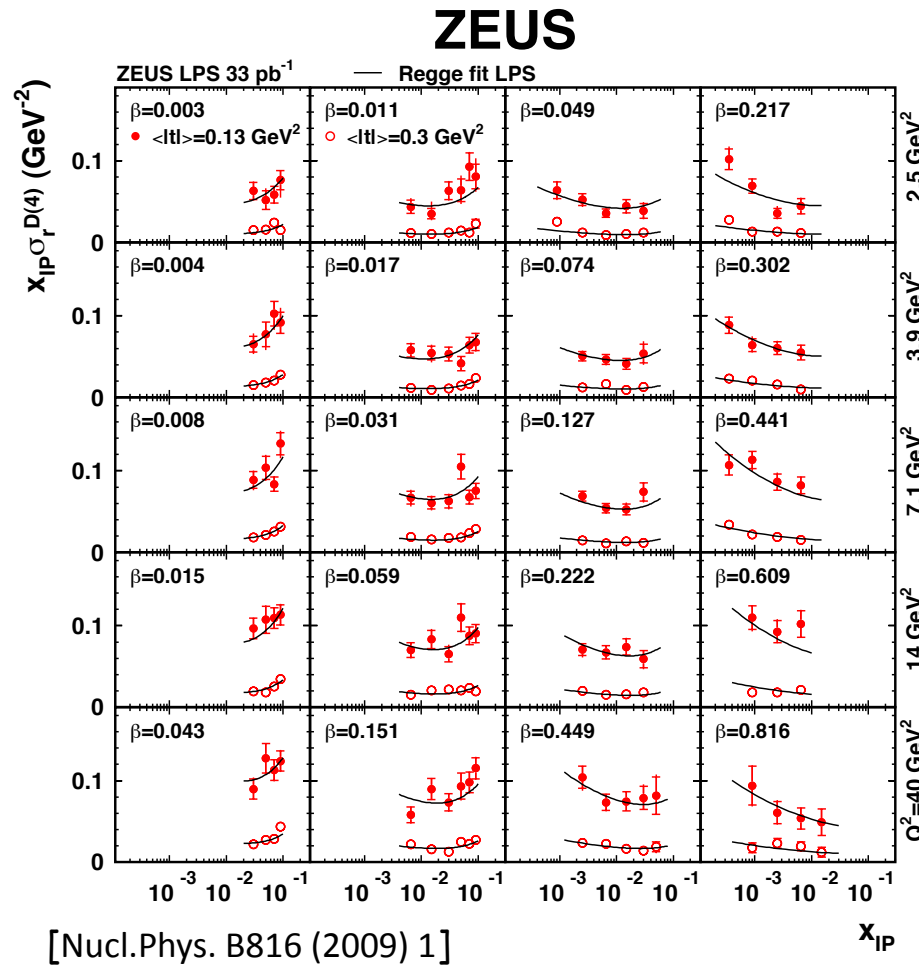


p-diss contribution
no t measurement

Large Rapidity Gap (LRG) method



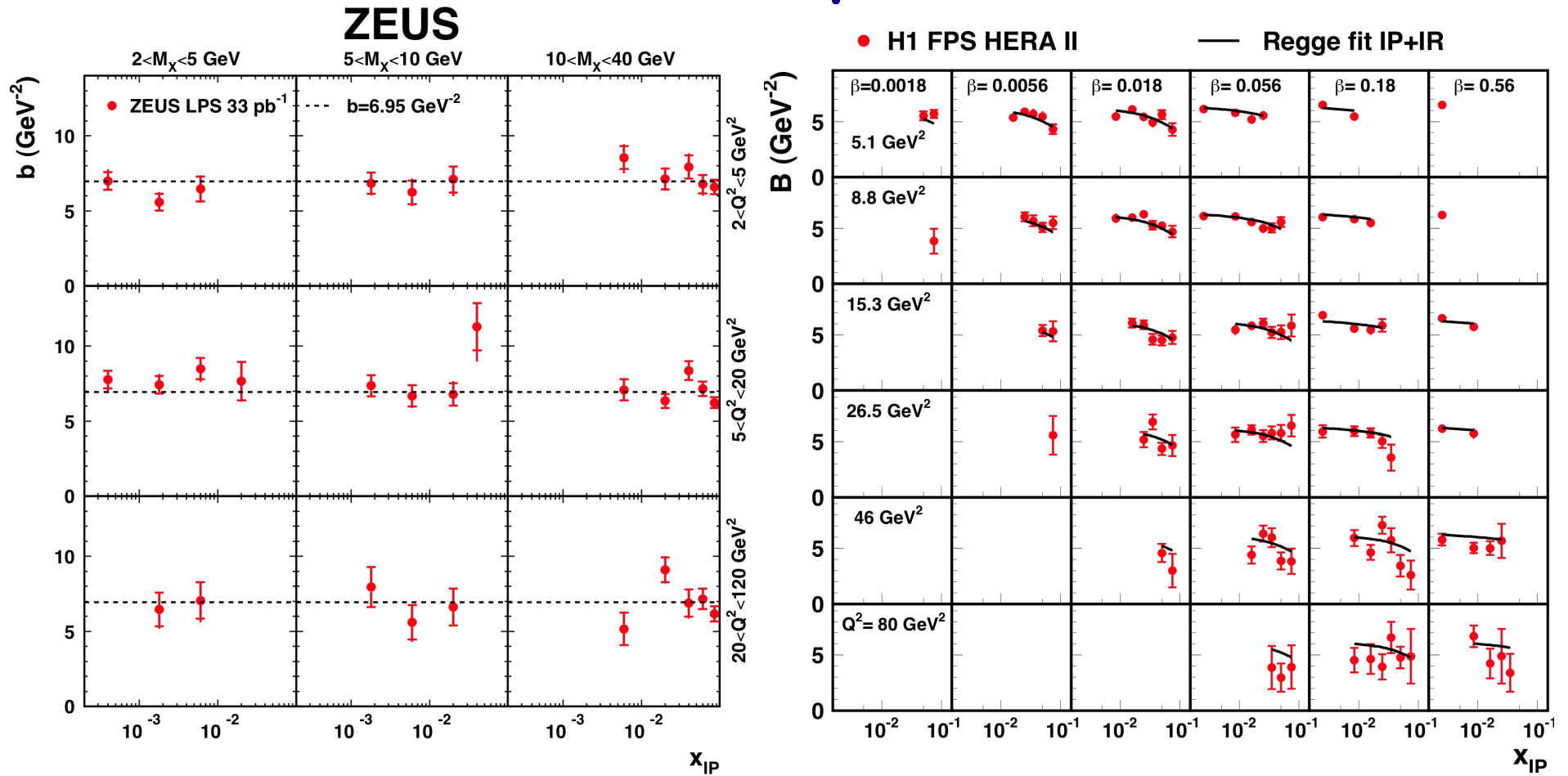
$\sigma_r^{D(4)}$ from Proton Spectrometers



Precise measurement of $\sigma_r^{D(4)}$ in bins of $|t|$

t-slope

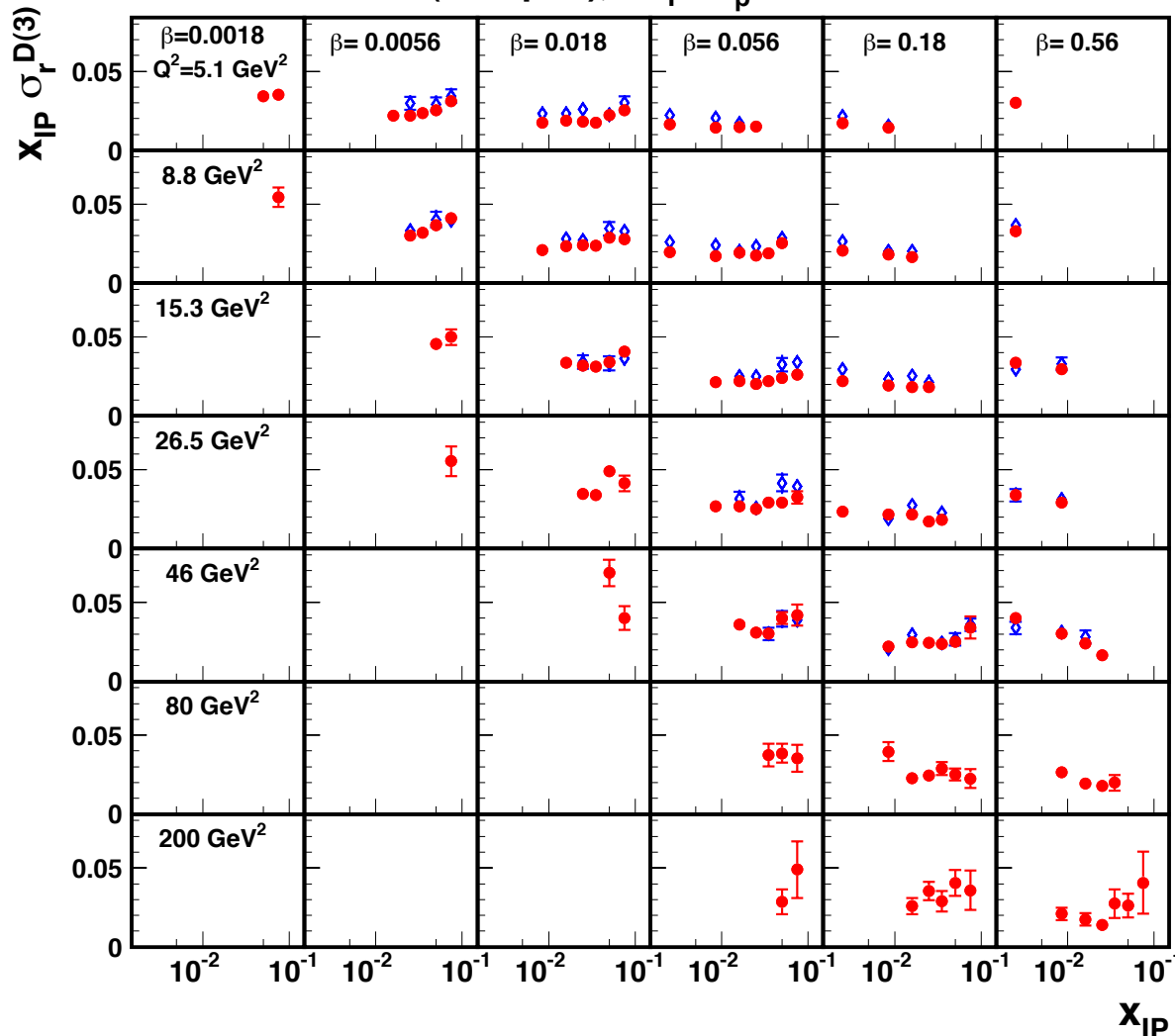
$$d\sigma/dt \sim e^{bt}$$



- ◆ ZEUS t-slope equal to 7 GeV⁻² (constant through the kinematics)
- ◆ H1 t-slope between 5 and 6 GeV⁻² (depending on x_{IP})

$\sigma_r^{D(3)}$ from Proton Spectrometers

- H1 FPS HERA II, $M_Y = m_p$
- ♦ ZEUS LPS (interpol.), $M_Y = m_p$



$$\sigma_r^{D(3)} = \int_{-1}^{t_{\min}} \sigma_r^{D(4)} dt$$

The measured b parameters are used to perform the integration to the range $|t| < 1 \text{ GeV}^2$

Good agreement in shape between H1 and ZEUS

Fair agreement in normalization between H1 and ZEUS

H1 FPS HERA II norm unc $\sim \pm 6\%$
 ZEUS LPS 2 norm unc $\sim +11\% - 7\%$

H1 FPS HERA II / ZEUS LPS 2 =
 $0.85 \pm 0.01 \text{ (stat)} \pm 0.03 \text{ (syst)}$
 $+ 0.09 - 0.12 \text{ (norm)}$

Data Sets for Combination

Data sets used for the first diffractive H1 & ZEUS combination

➤ H1 FPS HERA II

[Eur.Phys.J. C71 (2011) 1578]

Luminosity = 156.6 pb⁻¹

Visible range $|t| = 0.1 - 0.7 \text{ GeV}^2$

Norm unc $\sim \pm 4.8\%$

➤ H1 FPS HERA I

[Eur.Phys.J. C48 (2006) 749]

Luminosity = 28.4 pb⁻¹

Visible range $|t| = 0.08 - 0.5 \text{ GeV}^2$

Norm unc $\sim \pm 10\%$

➤ ZEUS LPS 2

[Nucl.Phys. B816 (2009) 1]

Luminosity = 32.6 pb⁻¹

Visible range $|t| = 0.09 - 0.55 \text{ GeV}^2$

Norm unc $\sim \pm 7\%$

➤ ZEUS LPS 1

[Eur.Phys.J. C38 (2004) 43]

Luminosity = 3.6 pb⁻¹

Visible range $|t| = 0.075 - 0.35 \text{ GeV}^2$

Norm unc $\sim \pm 11\%$

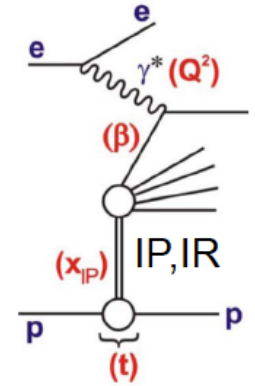
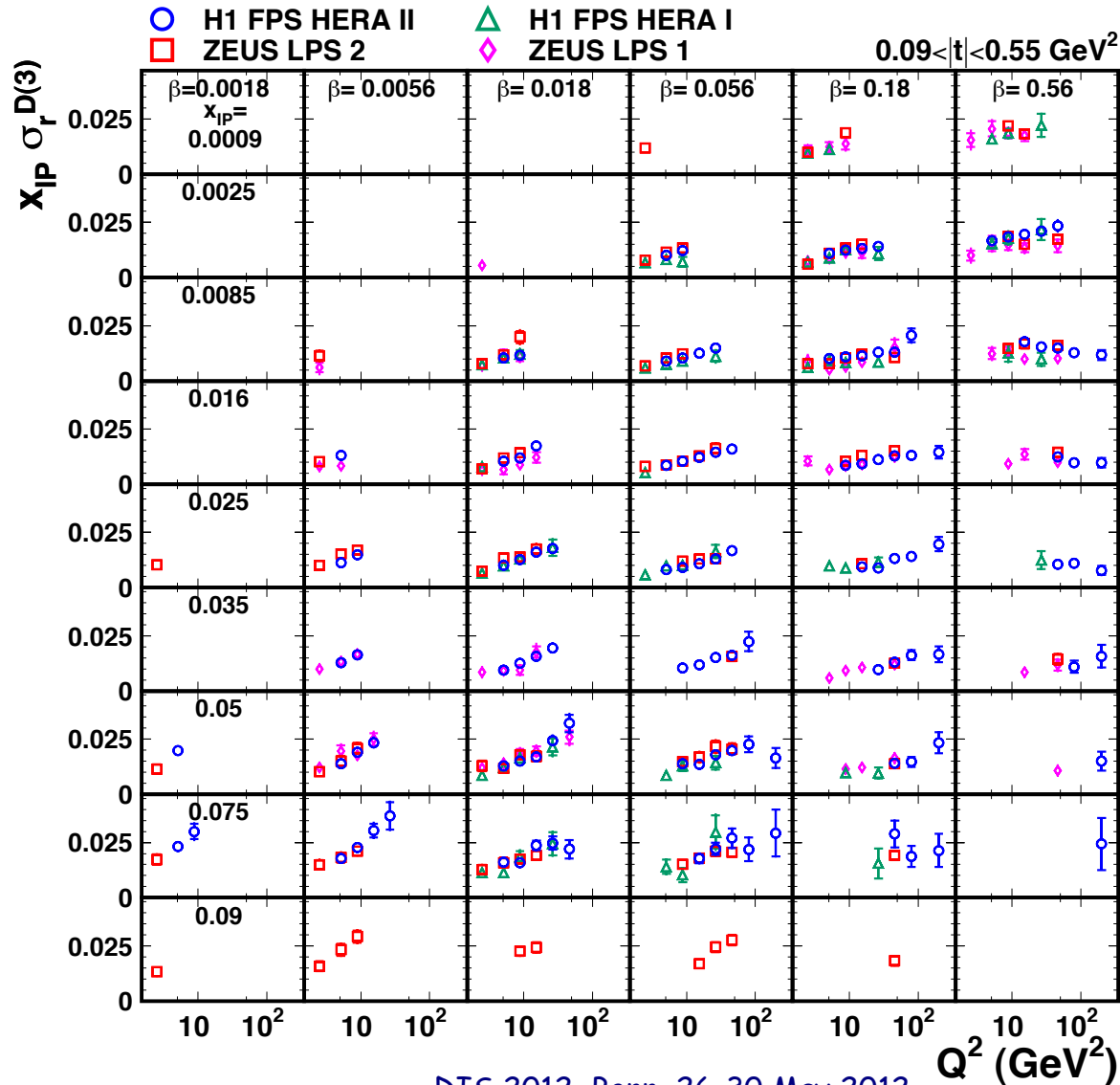
Combination performed in the ZEUS visible t range $|t| = 0.09 - 0.55 \text{ GeV}^2$

→ H1 FPS HERA II / ZEUS LPS 2 = $0.91 \pm 0.01 \text{ (stat)} \pm 0.03 \text{ (syst)} \pm 0.08 \text{ (norm)}$

Prior to combining cross section points swam to H1 FPS HERA II (Q^2 , β , x_{IP})

$\sigma_r^{D(3)}$ for Combination

H1 and ZEUS



Kinematic region
covered by H1
and ZEUS data

$$\begin{aligned}
 Q^2 &= 2.5 - 200 \text{ GeV}^2 \\
 \beta &= 0.0018 - 0.816 \\
 x_{IP} &= 0.00035 - 0.09 \\
 |t| &= 0.09 - 0.55
 \end{aligned}$$

Combination Method

- ✧ The key assumption is that H1 and ZEUS experiments are measuring the same cross sections at the same kinematical points
- ✧ Averaging H1 and ZEUS diffractive data provides a model independent tool to study consistency of the data and to reduce systematic uncertainties
→ Experiments cross calibrate each other
- ✧ The combination method uses an iterative χ^2 minimization which includes full error correlations [A. Glazov, AIP Conf. Proc. 792 (2005) 237]

$$\chi_{exp}^2(M^{i,true}, \Delta\alpha_j) = \sum_i \frac{[M^{i,true} - (M^i + \sum_j \frac{\partial M^i}{\partial \alpha_j} \frac{M^{i,true}}{M^i} \Delta\alpha_j)]^2}{(\sigma_i \frac{M^{i,true}}{M^i})^2} + \sum_j \frac{(\Delta\alpha_j)^2}{\sigma_{\alpha_j}^2}$$

for a single data set

i = measured data point

j = correlated systematic error source

M^i measured central values

σ_i statistical and uncorrelated systematic uncertainties

$M^{i,true}$ fitted combined H1 - ZEUS values

σ_{α_j} correlated systematic uncertainties

⇒ Full χ^2 is the sum over all χ_{exp}^2

Procedural Uncertainties

Three procedural uncertainties are introduced

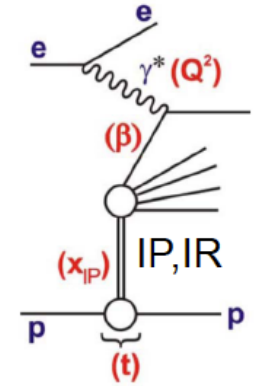
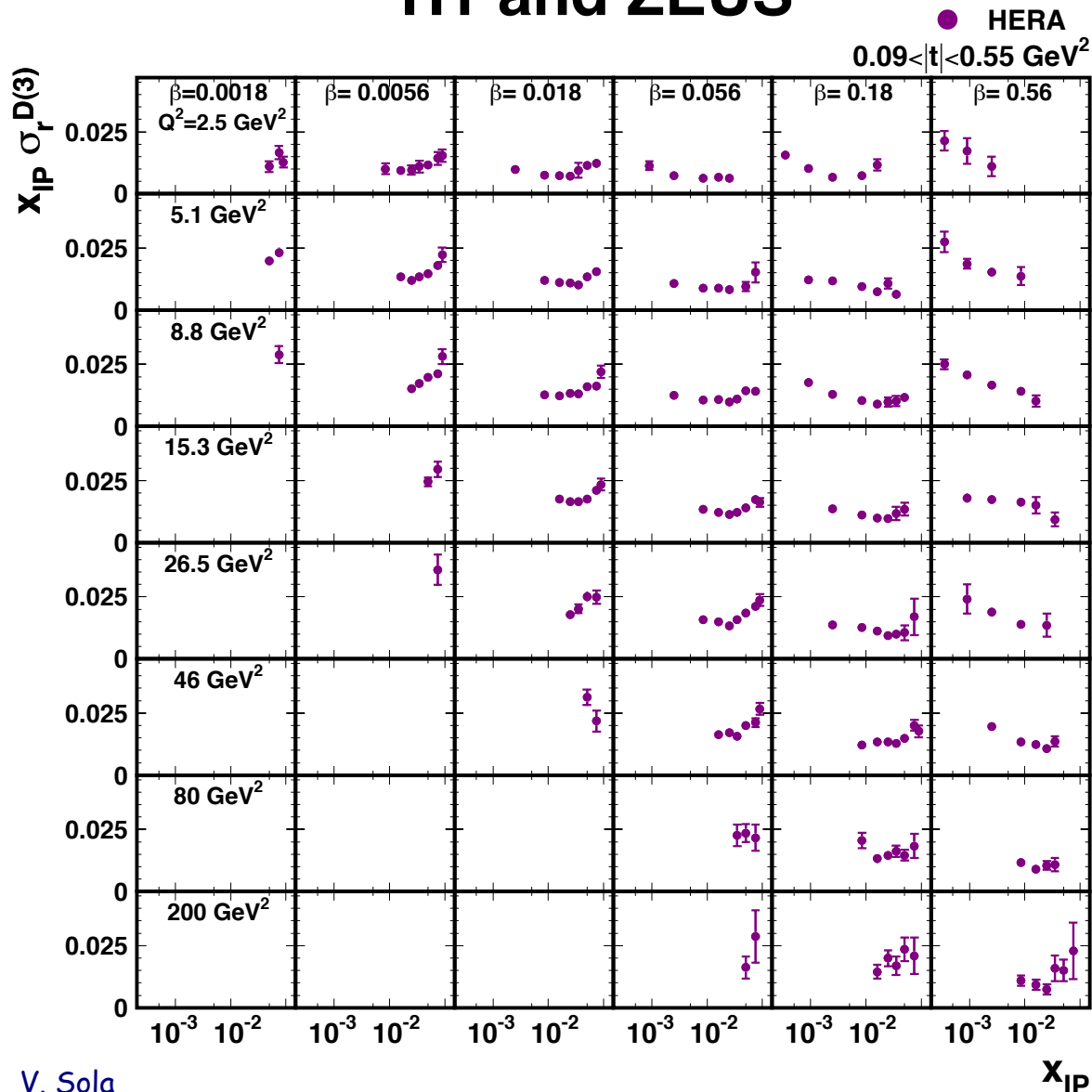
1. Swimming factors
→ Average effect negligible
2. Additive vs multiplicative nature of the error sources
→ Average effect $\sim 1\%$
3. Correlated systematic error sources between H1 and ZEUS
Identified 3 uncertainties of possible common origin
 - ♦ electromagnetic energy scale
 - ♦ x_{IP} reweighting
 - ♦ t reweightingCompare 2^3 averages taking all pairs as corr/uncorr in turn
→ Average effect $\sim 1.4\%$

Fitted Systematics

Source	Symbol	Shift (σ units)	Reduction %
FPS HERA II hadronic energy scale $x_P < 0.012$	$\delta_{had1,H1}$	-1.61	56.9
FPS HERA II hadronic energy scale $x_P > 0.012$	$\delta_{had12,H1}$	0.13	99.8
FPS HERA II electromagnetic energy scale	$\delta_{ele,H1}$	0.49	85.9
FPS HERA II electron angle	$\delta_{\theta,H1}$	0.67	66.6
FPS HERA II β reweighting	$\delta_{\beta,H1}$	0.15	90.4
FPS HERA II x_P reweighting	$x_{P,H1}$	0.05	98.3
FPS HERA II t reweighting	$\delta_{t,FPS}$	0.70	79.8
FPS HERA II Q^2 reweighting	$\delta_{Q^2,H1}$	0.09	97.6
FPS HERA II proton energy	$\delta_{E_p,FPS}$	0.05	45.6
FPS HERA II proton p_x	$\delta_{p_x,FPS}$	0.62	74.5
FPS HERA II proton p_y	$\delta_{p_y,FPS}$	0.27	86.5
FPS HERA II vertex reconstruction	$\delta_{vtx,FPS}$	0.07	97.0
FPS HERA II background subtraction	$\delta_{bgd,FPS}$	0.84	89.9
FPS HERA II bin centre corrections	$\delta_{bcc,FPS}$	-1.05	87.3
FPS HERA II global normalisation	$\delta_{norm,FPSHERAII}$	-0.39	84.4
FPS HERA I global normalisation	$\delta_{norm,FPSHERAI}$	0.81	48.9
LPS 2 hadronic energy scale	$\delta_{had,ZEUS}$	-0.02	55
LPS 2 electromagnetic escale	$\delta_{ele,ZEUS}$	-0.14	62.4
LPS 2 x_P reweighting	$\delta_{x_P,ZEUS}$	-0.32	98.2
LPS 2 t reweighting	$\delta_{t,LPS}$	-0.31	86.4
LPS 2 background subtraction	$\delta_{bgd,ZEUS}$	0.40	94.9
LPS 2 global normalization	$\delta_{norm,LPS2}$	-0.53	67.7
LPS 1 global normalization	$\delta_{norm,LPS1}$	0.86	44.09

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

H1 and ZEUS



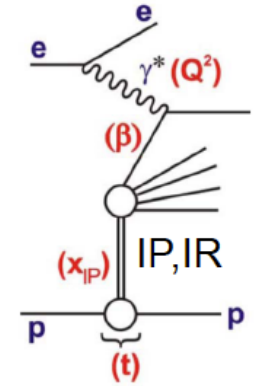
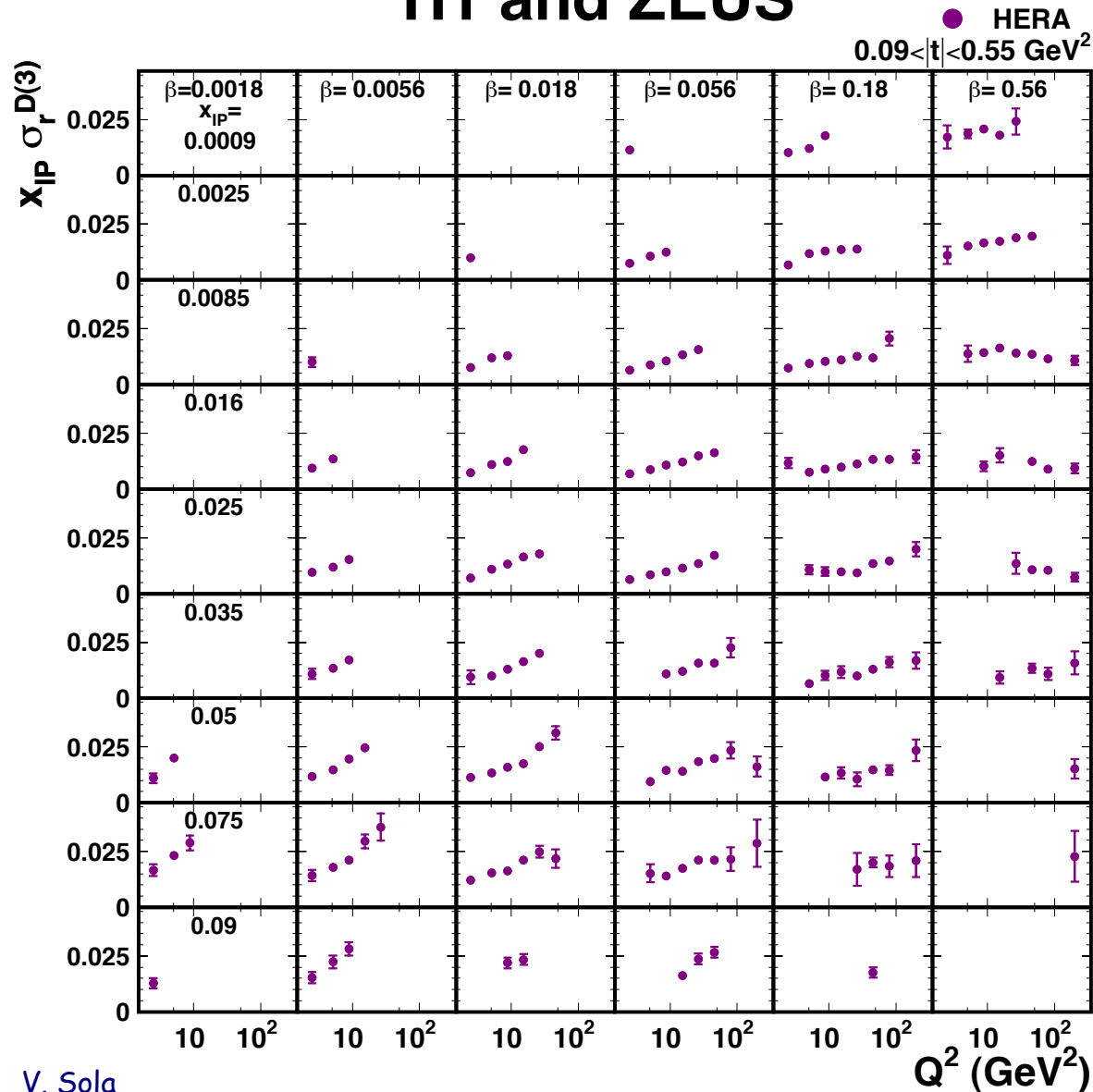
$$\chi^2/\text{ndf} = 133/161$$

Improvement in precision with respect to the H1 FPS HERA II data by $\sim 27\%$

Total uncertainty on the combined data $\sim 14\%$, down to $\sim 5\%$

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

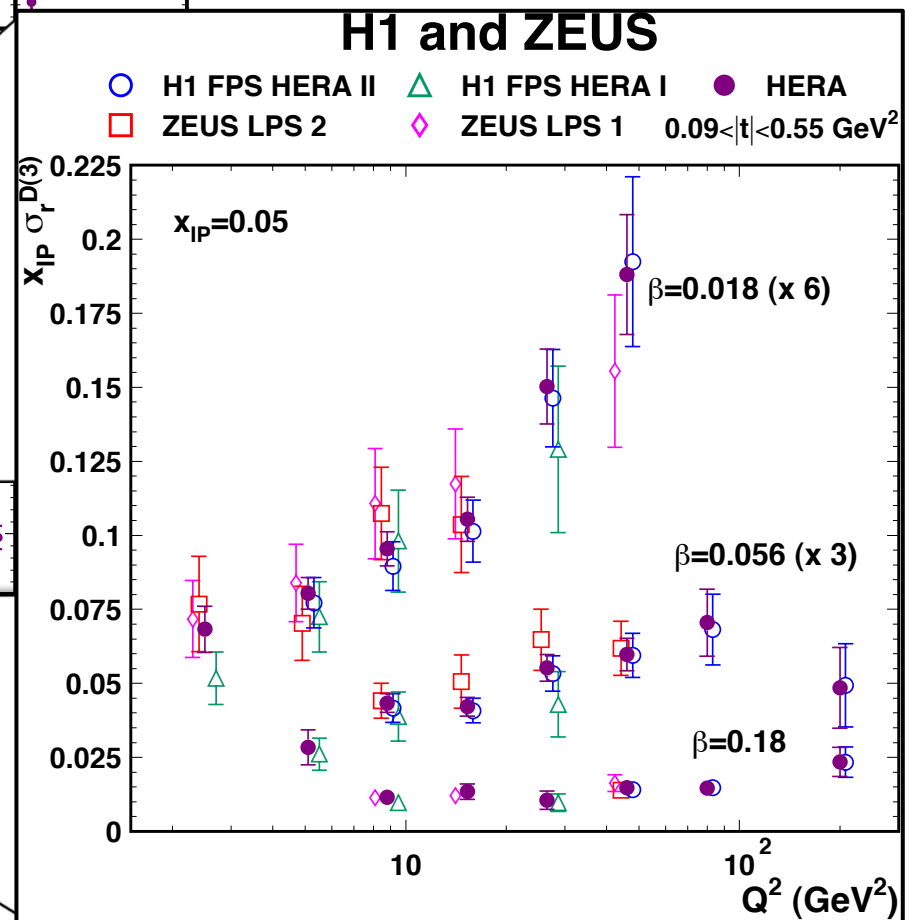
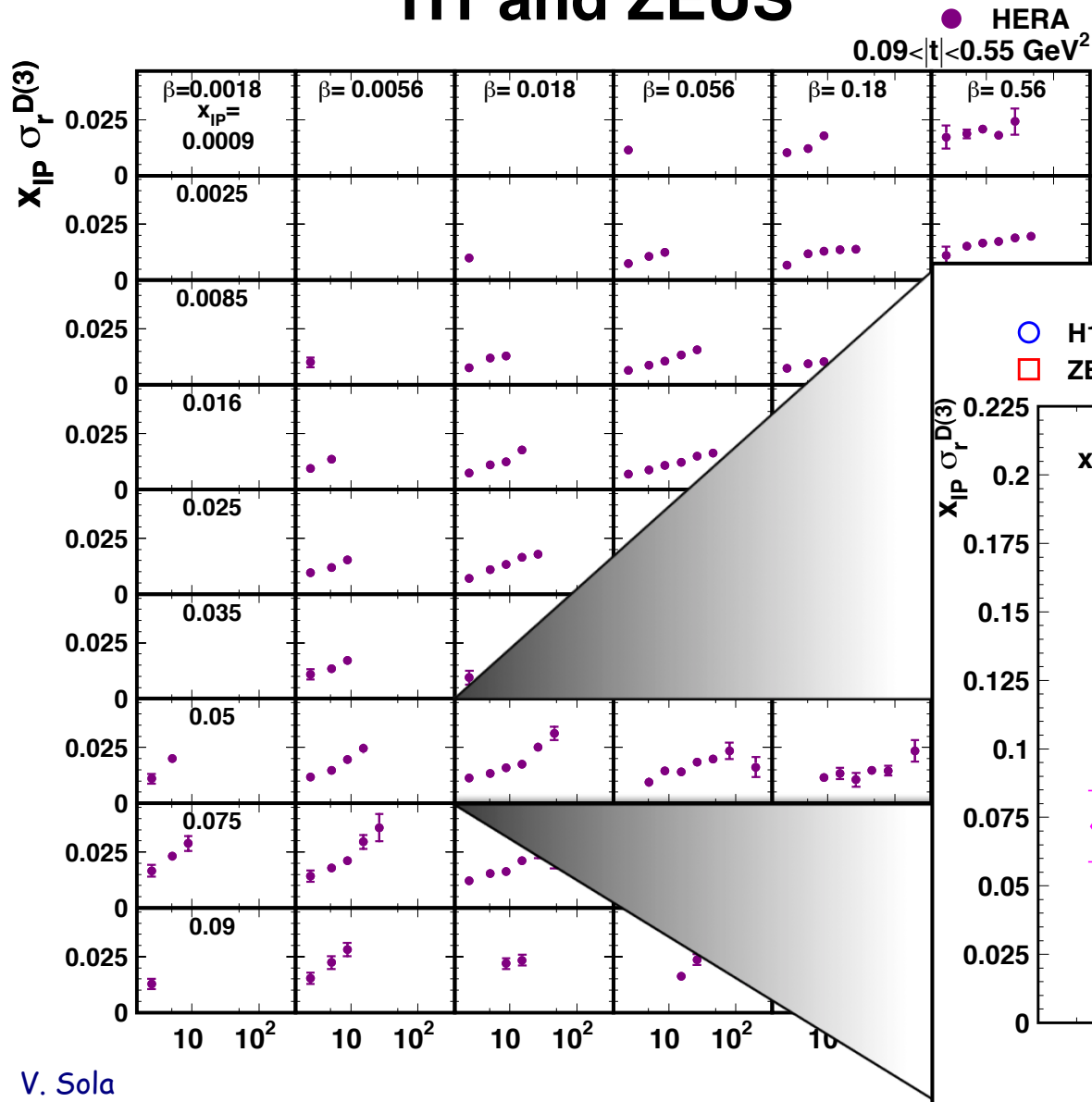
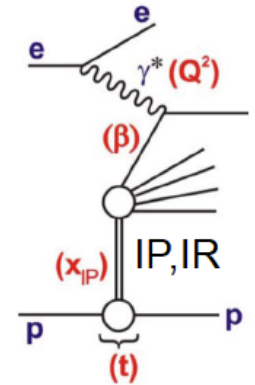
H1 and ZEUS



Nice and precise measurement of the scaling violation in diffraction

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

H1 and ZEUS

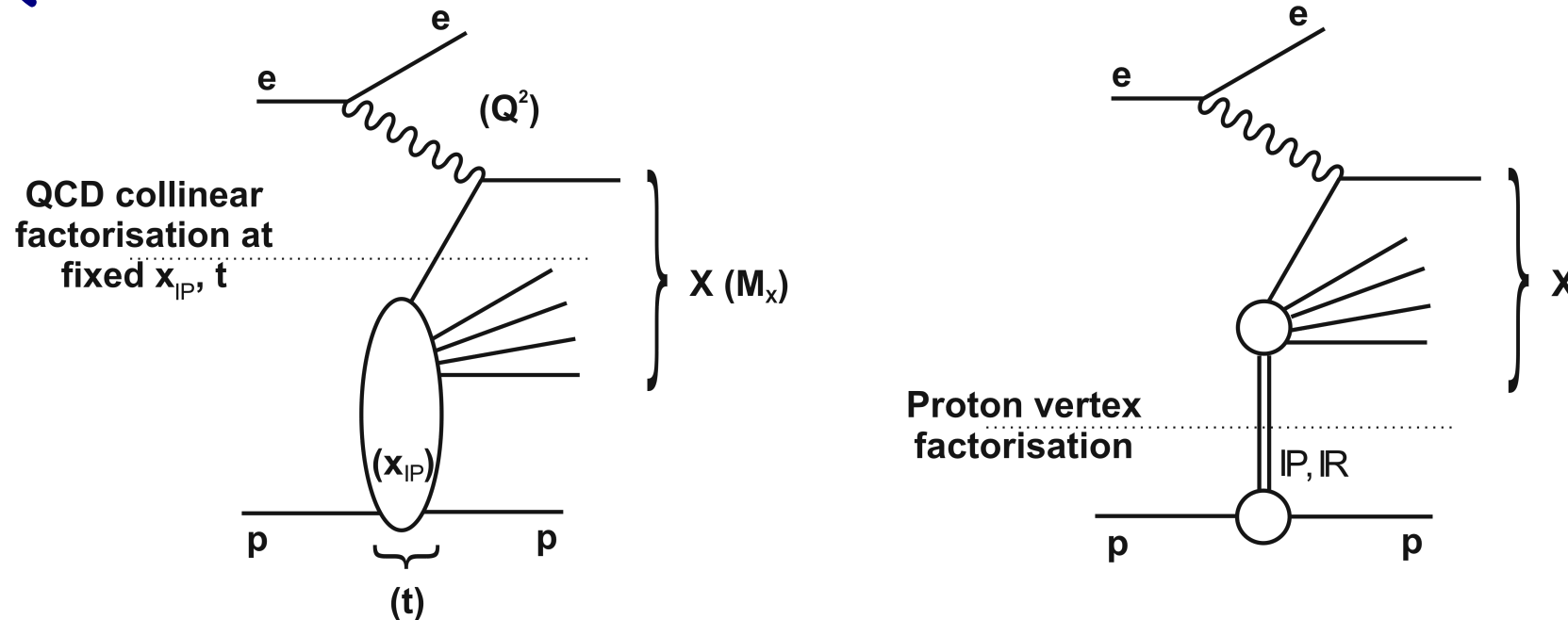


Summary

- ✓ 15 years of running HERA provided unique diffractive data
- ✓ First combination of the H1 and ZEUS diffractive data
 - ⇒ combined proton-tag results
 - ⇒ consistency between datasets
 - ⇒ the two experiments calibrate each other resulting in a reduction of systematic uncertainties
- ✓ Looking forward to combining all LRG, FPS and VFPS data

Backup

QCD Factorization in Hard Diffraction



The QCD factorization theorem in diffractive DIS allows to write the diffractive cross section as a convolution of universal diffractive parton densities $f_i^D(x, Q^2, x_{IP}, t)$ and partonic cross sections

$$\sigma^D(\gamma^* p \rightarrow X p) \sim f_i^D(x, Q^2, x_{IP}, t) \otimes \sigma_{\gamma^* i}(x, Q^2)$$

Additionally, assuming Regge factorization, the diffractive parton densities are written as a term depending on x_{IP} (Pomeron flux) times the Pomeron parton densities

$$f_i^D(x, Q^2, x_{IP}, t) \sim f_{IP/p}(x_{IP}, t) \otimes f_{i/IP}^D(x/x_{IP}, Q^2)$$

⇒ Universal DPDFs apply in DIS when vacuum quantum numbers are exchanged

Diffractive PDFs from NLO Fits

ZEUS

NLO QCD Fits:

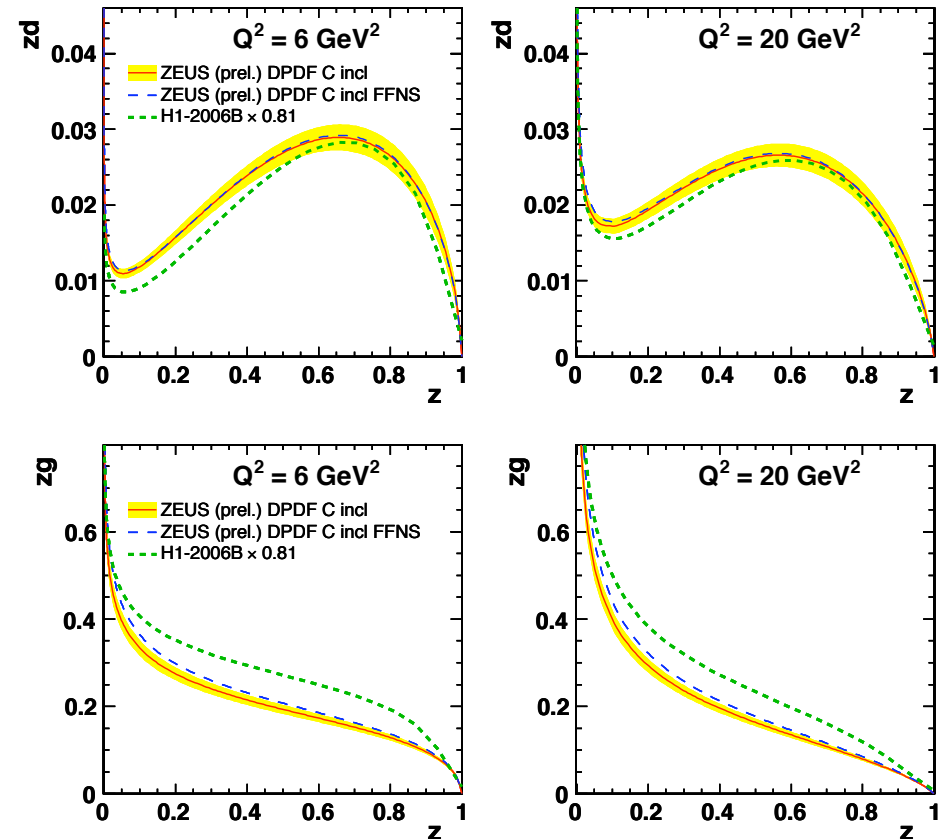
- parametrize quark singlet and gluon at fixed Q^2
- evolve with NLO DGLAP and fit
(z = momentum fraction of the diffractive exchange entering the hard scattering)

Diffractive Parton Density Functions are obtained fitting the H1 and ZEUS diffractive reduced cross sections (published data sets only)

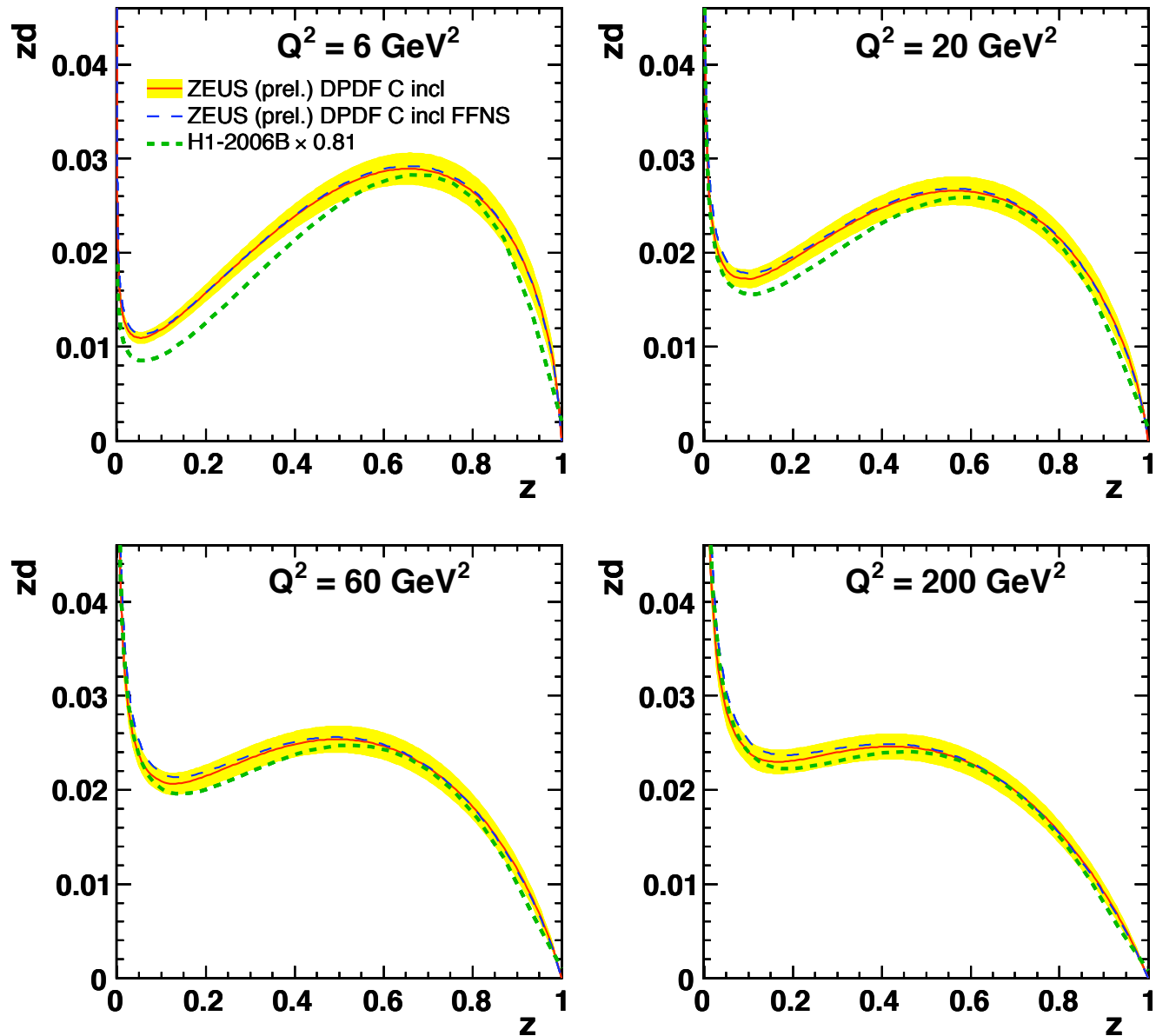
Differences in the reduced cross sections are reflected in different parton distribution extraction

In order to obtain a precise and unique set of diffractive PDFs from HERA a deep and careful understanding of the H1 vs ZEUS results is needed

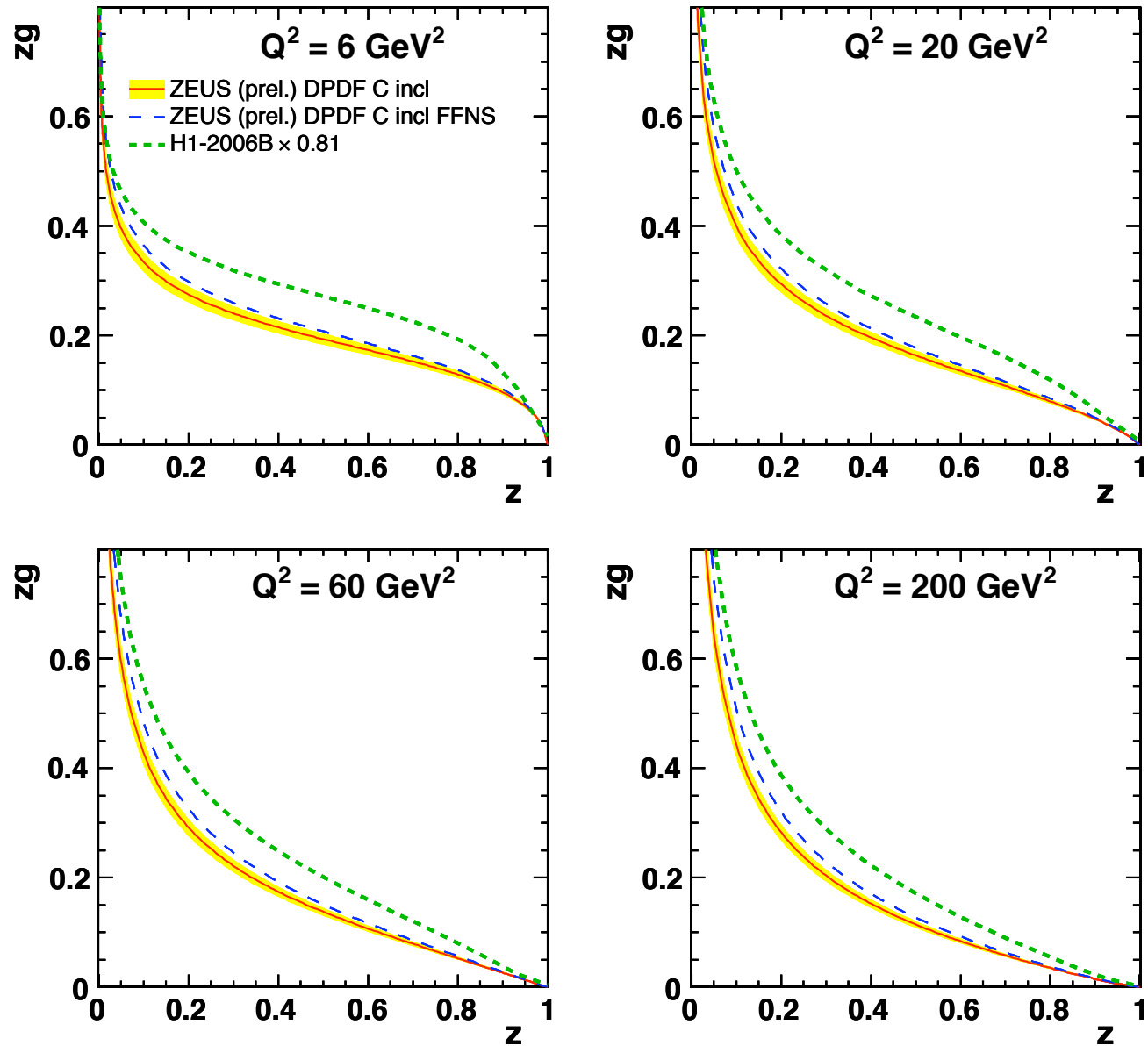
⇒ First attempt to combine H1 and ZEUS diffractive cross sections



ZEUS

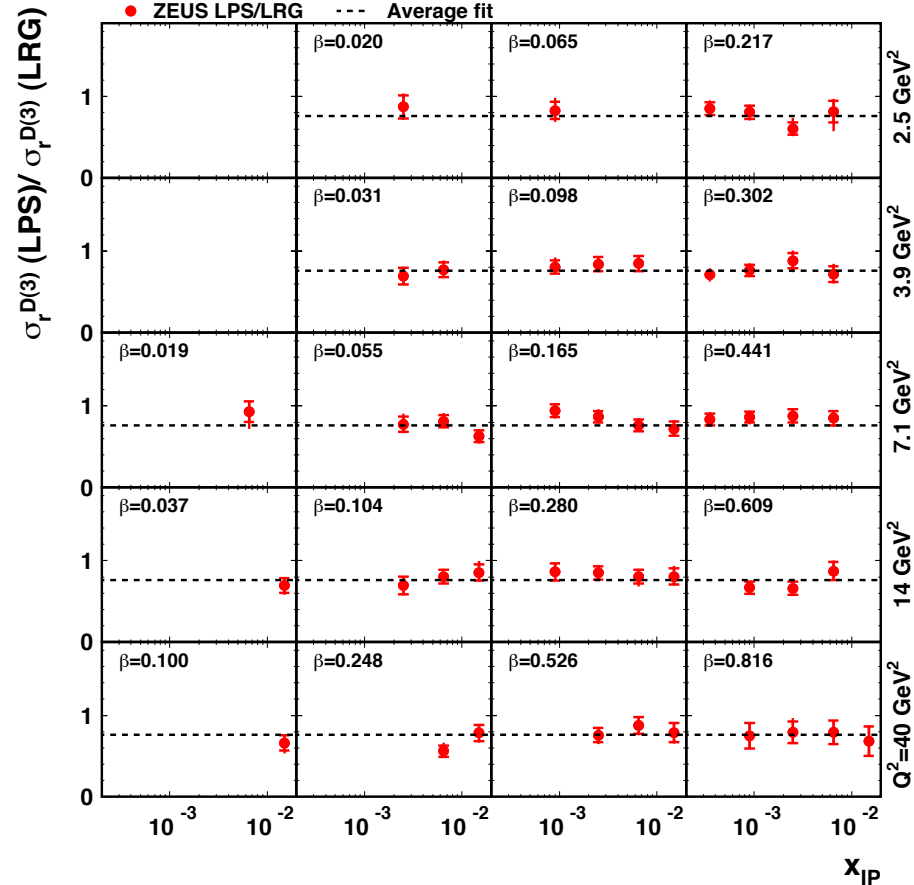
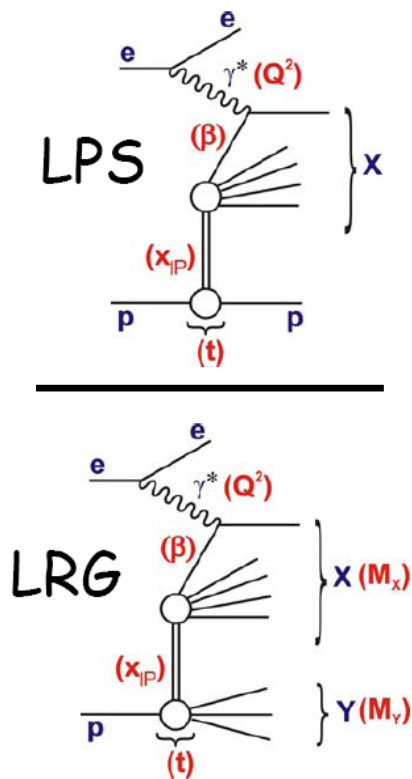


ZEUS



LRG vs PS

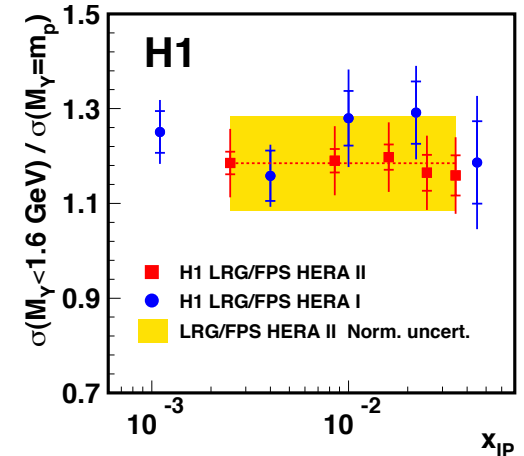
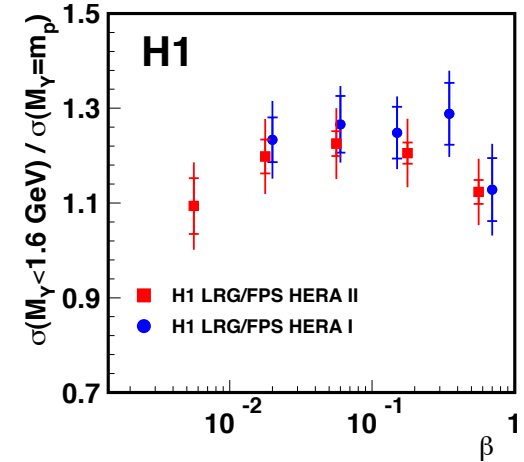
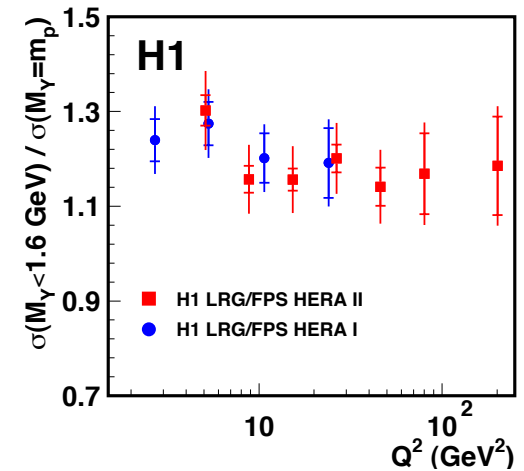
ZEUS



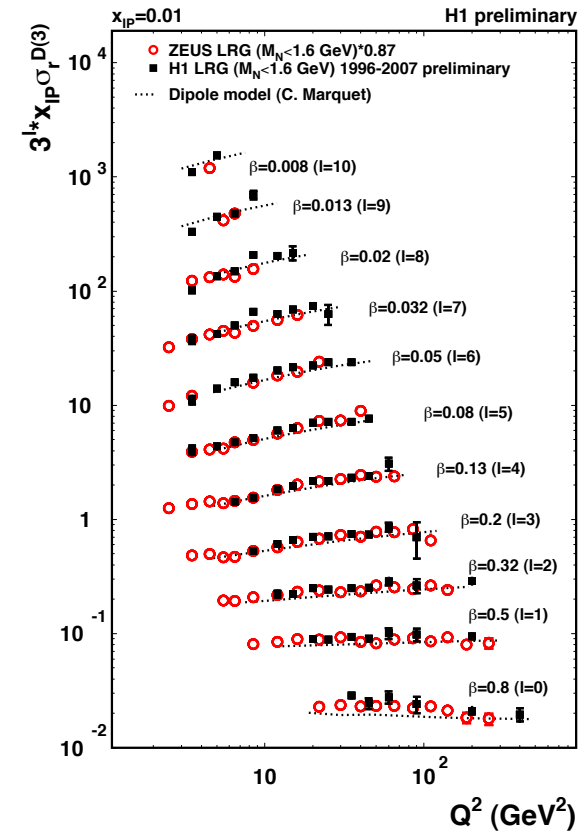
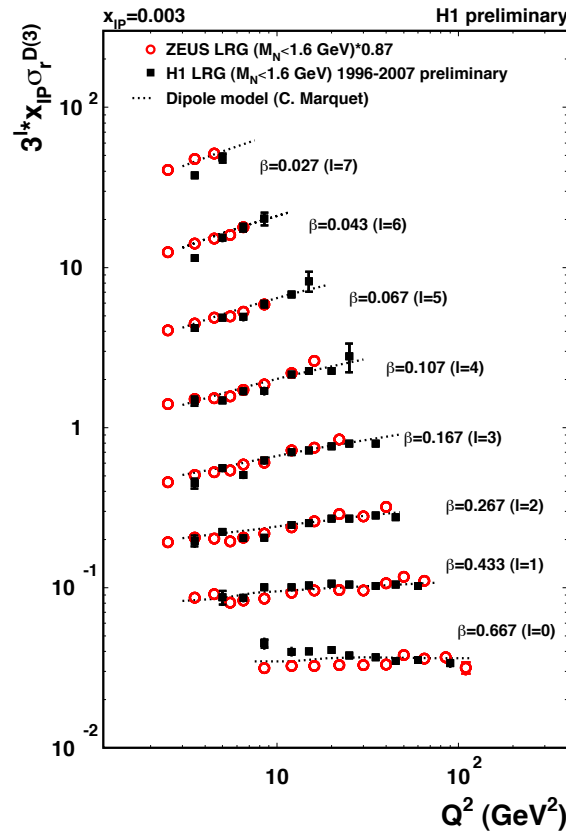
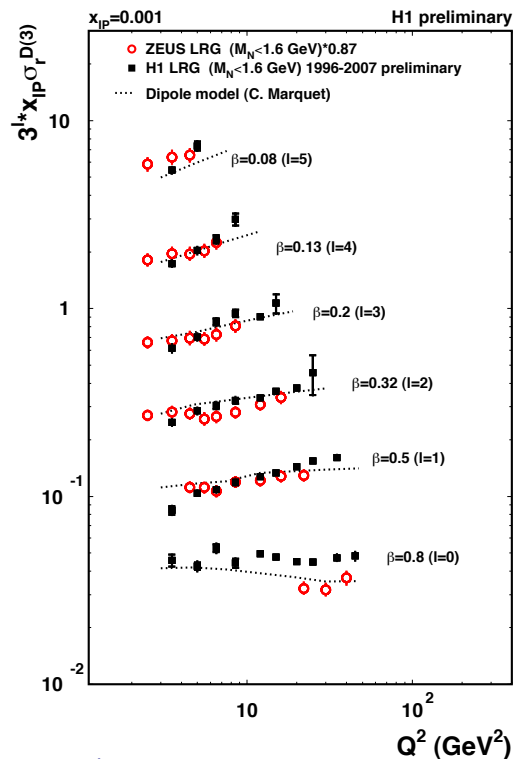
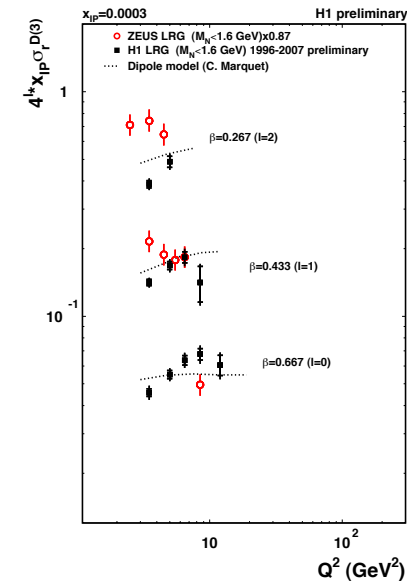
Estimation of p-diss contribution in LRG method

→ ratio flat both in ZEUS and H1

⇒ PS data give the absolute normalization of $\sigma_r^{D(3)}$



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



Inclusive diffractive measurements from HERA (LRG method)

- H1 '97 [Eur. Phys. J. C48 (2006) 715]
- **ZEUS '99/2000** [Nucl.Phys. B816 (2009) 1]
- H1 '99/2000
- H1 '99 minimum bias
- H1 HERA II

[H1prelim-10-013]

DIS 2012, Bonn, 26-30 May 2012

t -slope vs x_{IP}

