XX International Workshop on
Deep-Inelastic Scattering and
Related Subjects

26-30 March 2012, University of Bonn

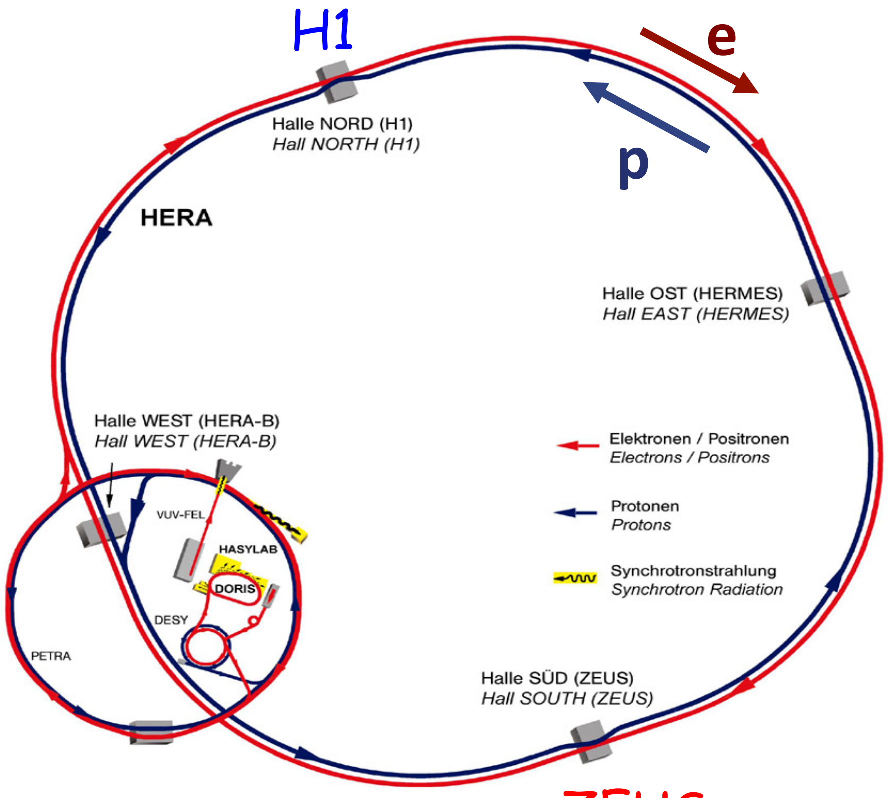
Combination of the Inclusive Diffractive Cross Sections at HERA

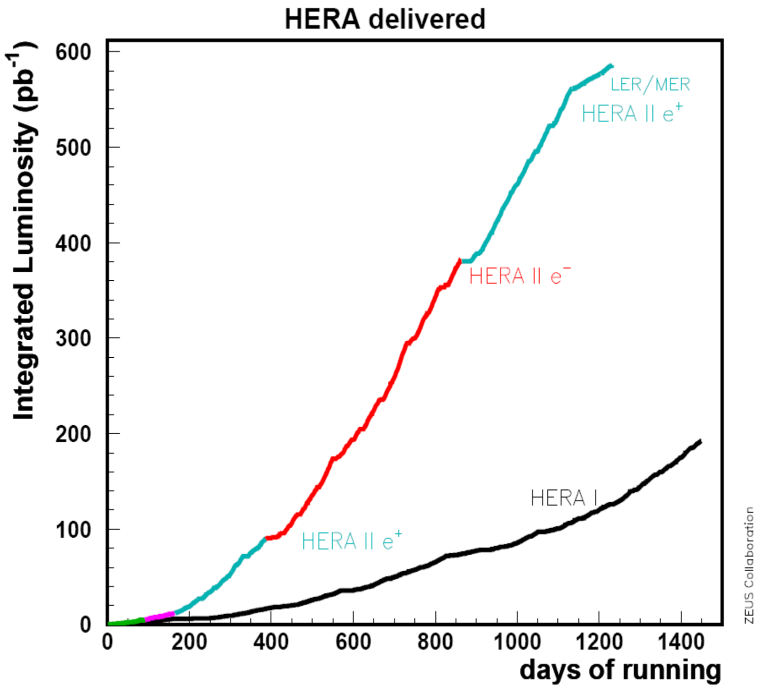
Valentina Sola
(Hamburg University)
on behalf of the H1 and ZEUS Collaborations

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

Universität Hamburg

HERA Experiments



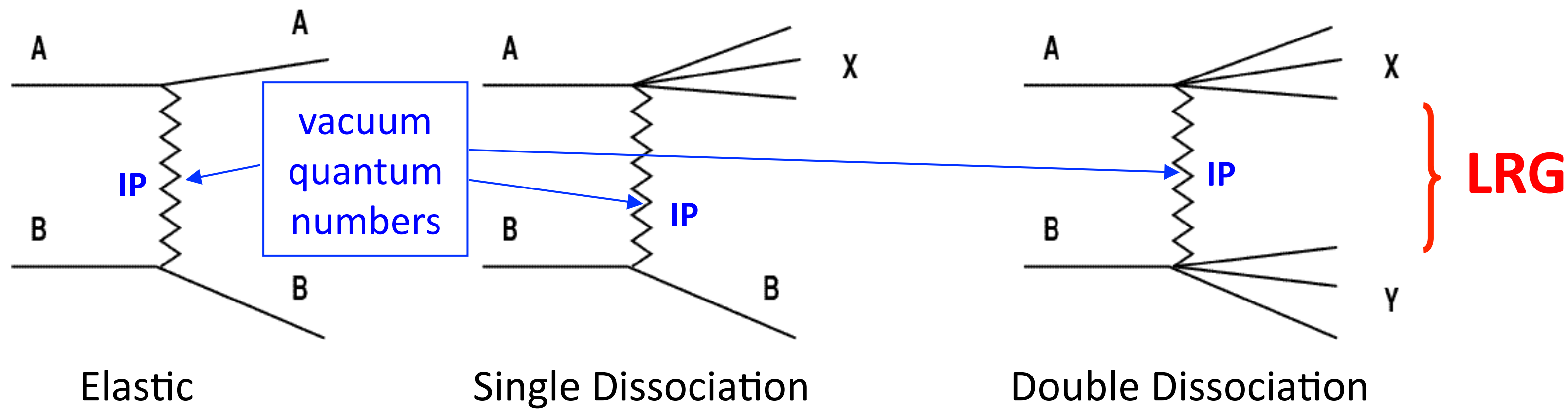


HERA I	1993-2000	E_p = 820-920 GeV
HERA II	2003-2007	E_p = 920-460-575 GeV
HERA I - II		E_e = 27.5 GeV

0.5 fb^{-1} collected by H1 and ZEUS experiments

Diffraction in Hadron Scattering

Diffraction is a feature of hadron-hadron interactions

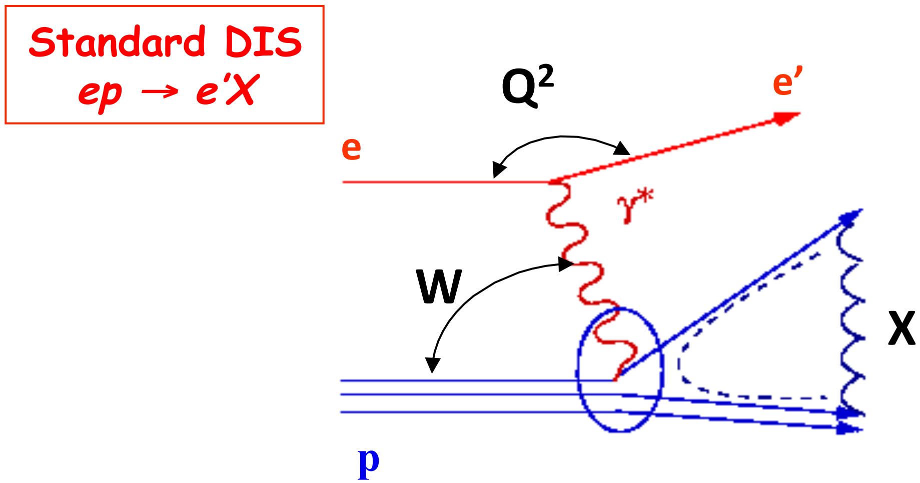


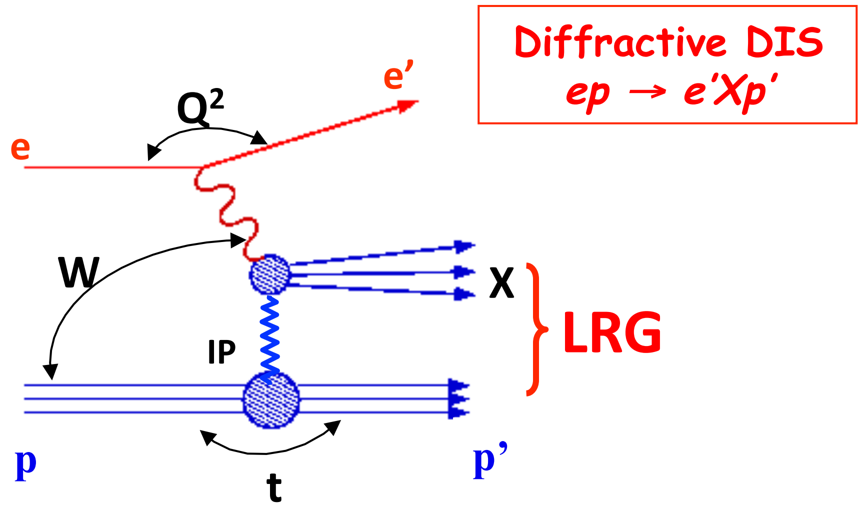
⇨ Beam particles emerge intact or dissociated into low-mass states
→ Very small fractional momentum losses (within a few %)

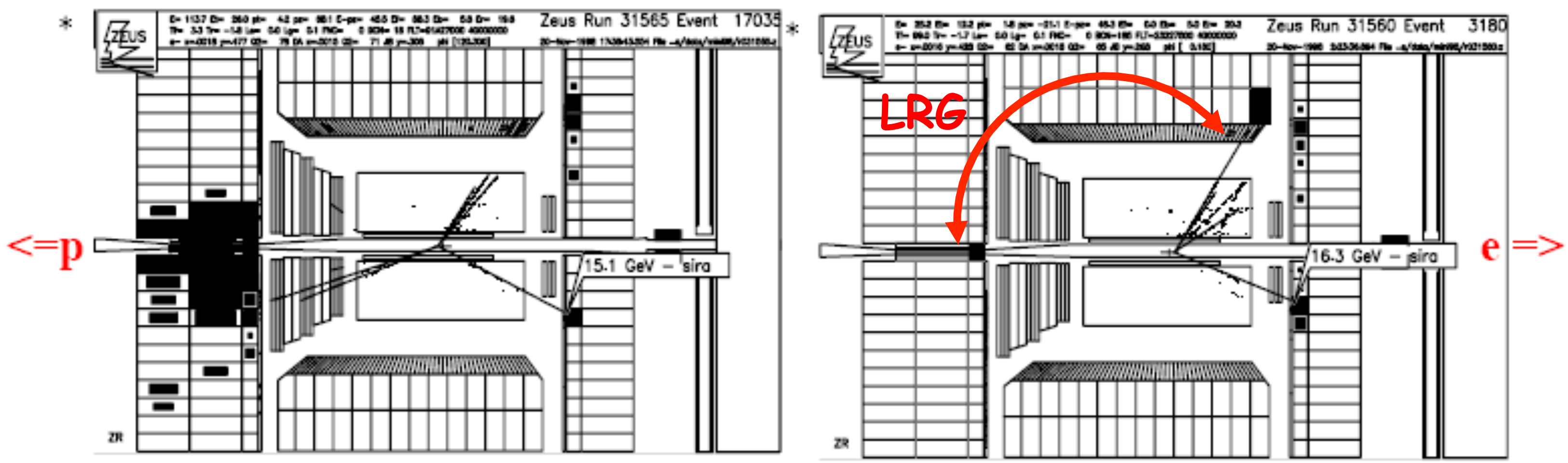
⇨ Final-state systems separated by large polar angle
(or pseudorapidity $\eta = -\ln[\tan(\theta/2)]$)
→ Large Rapidity Gap (LRG)

⇨ Interaction mediated by t-channel exchange of an object with no quantum numbers (no colour)
→ Pomeron (IP)

Diffraction at HERA







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

Kinematics and Cross Sections

Q^2 = virtuality of exchanged photon

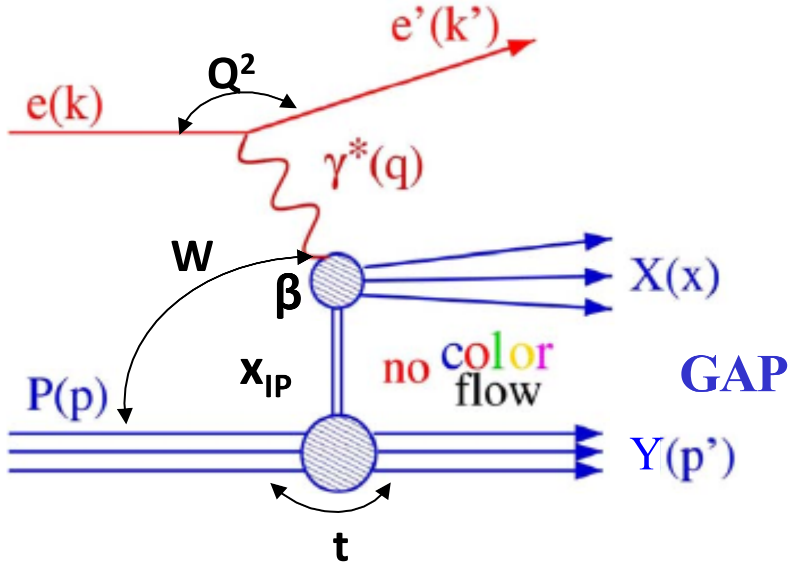
x = Bjorken scaling variable

y = inelasticity of virtual photon

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

β = x/x_{IP} = fraction of IP momentum carried by struck parton

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



When Y is a reasonace
or a low mass state
↳ proton dissociation (p-diss)

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

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

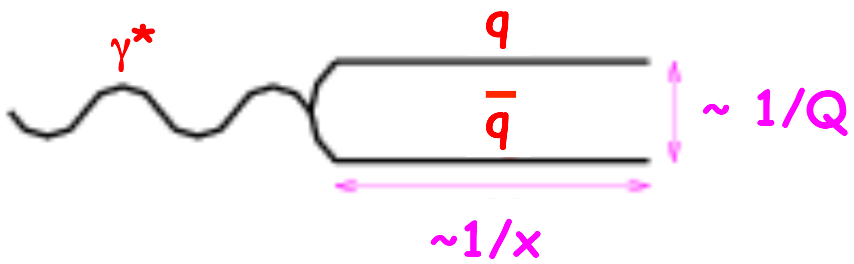
$= \sigma_r^{D(4)}(\beta,Q^2,x_{IP},t)$

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

Why Diffraction at HERA?

Real and virtual photons can fluctuate in hadronic states

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



Q = 'virtual mass' of the photon

x = Bjorken scaling variable

(as seen in the proton rest-frame)

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

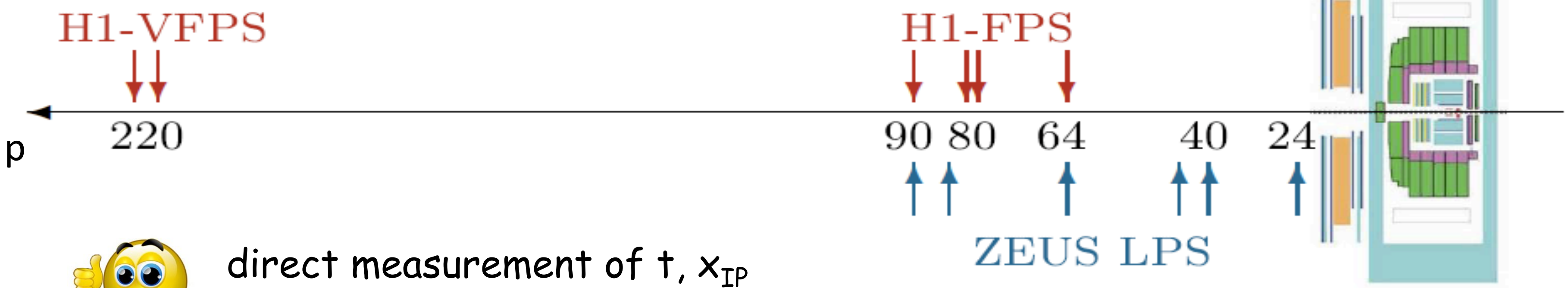
At HERA high Q^2 are reached:

→ short distances

→ perturbative QCD

Signatures and Selection Methods

Proton Spectrometer (PS) method

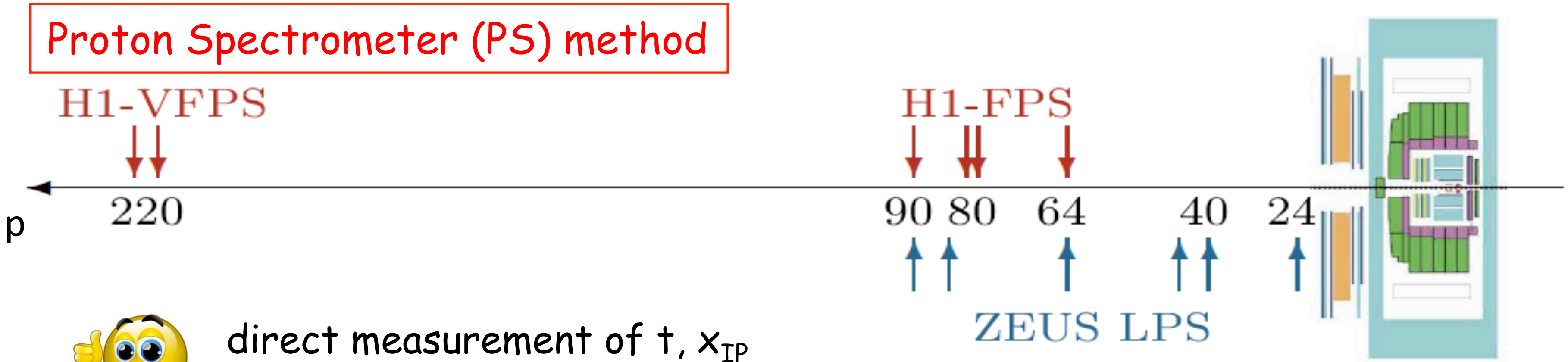


direct measurement of t, x_{IP}
high x_{IP} accessible
no p-diss contribution

low statistics

Signatures and Selection Methods

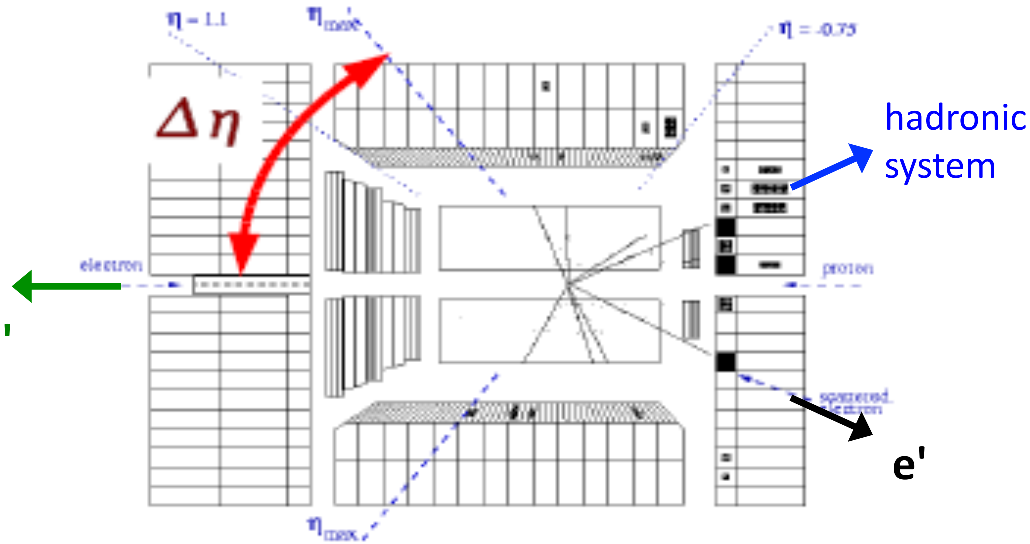
Proton Spectrometer (PS) method



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

- low statistics

Large Rapidity Gap (LRG) method

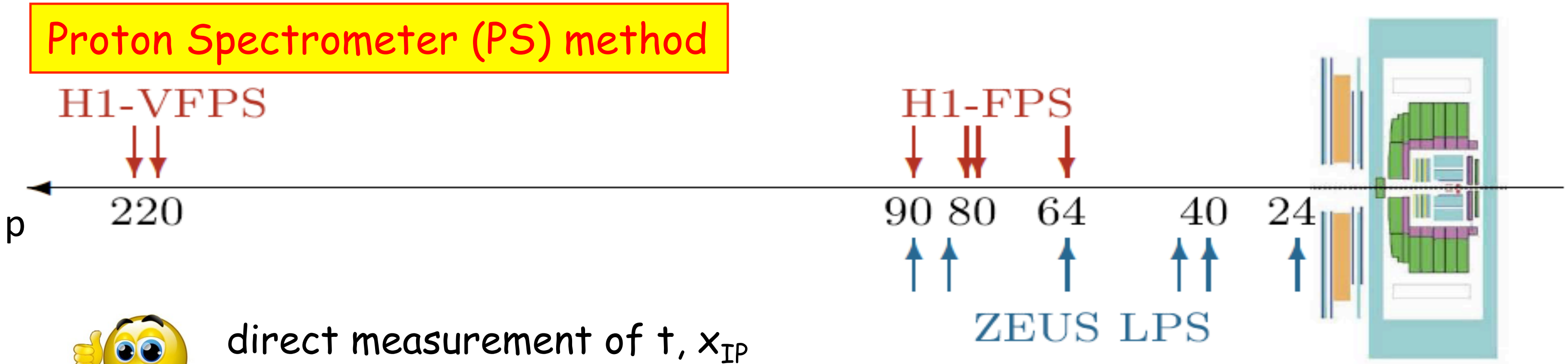


- near perfect acceptance at low x_{IP}

- p-diss contribution
- no t measurement

Signatures and Selection Methods

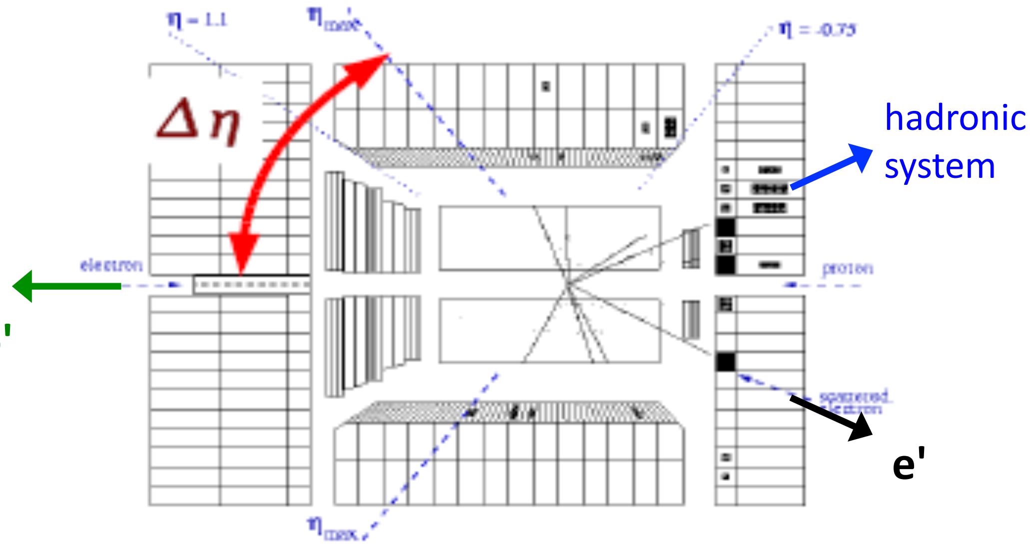
Proton Spectrometer (PS) method



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

- low statistics

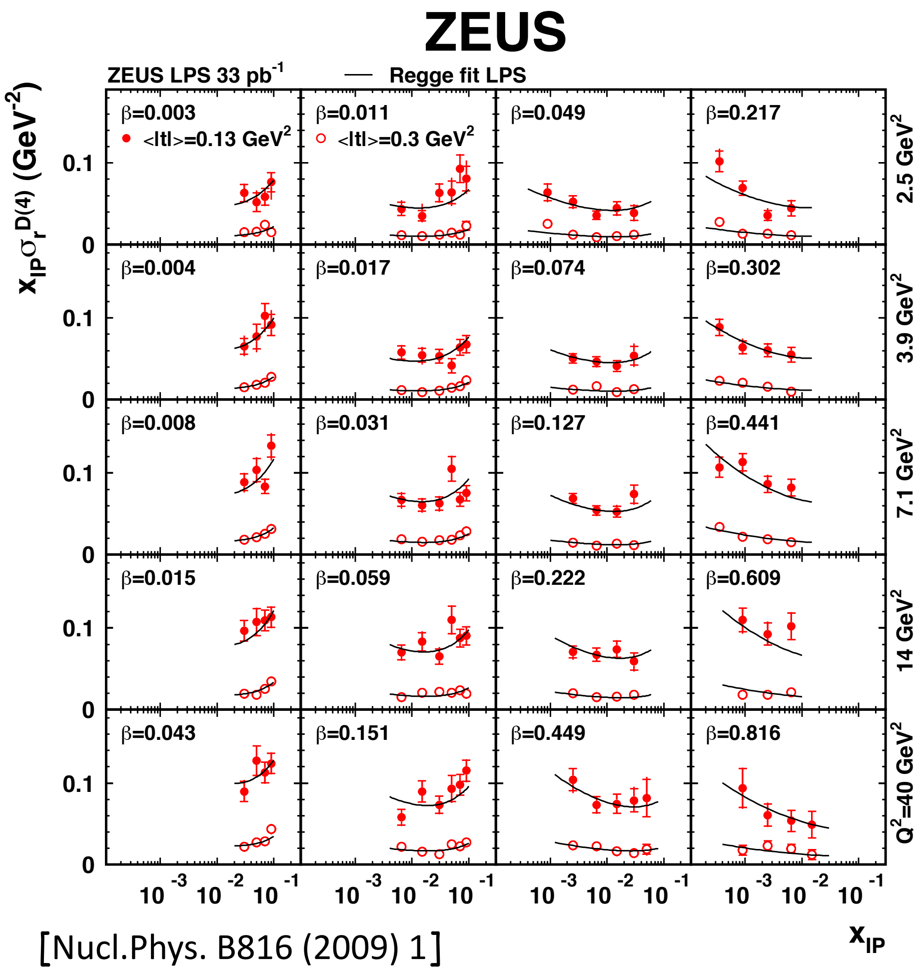
Large Rapidity Gap (LRG) method



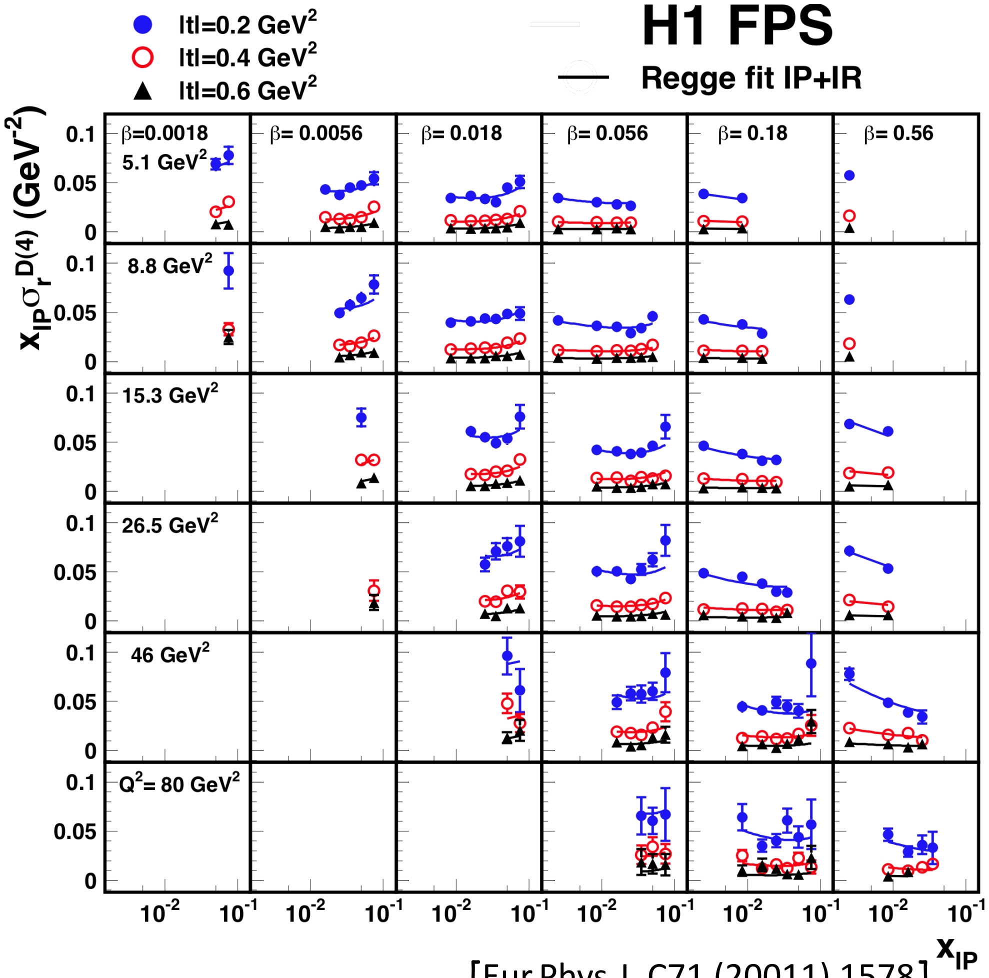
- near perfect acceptance at low x_{IP}

- p-diss contribution
- no t measurement

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



[Nucl.Phys. B816 (2009) 1]

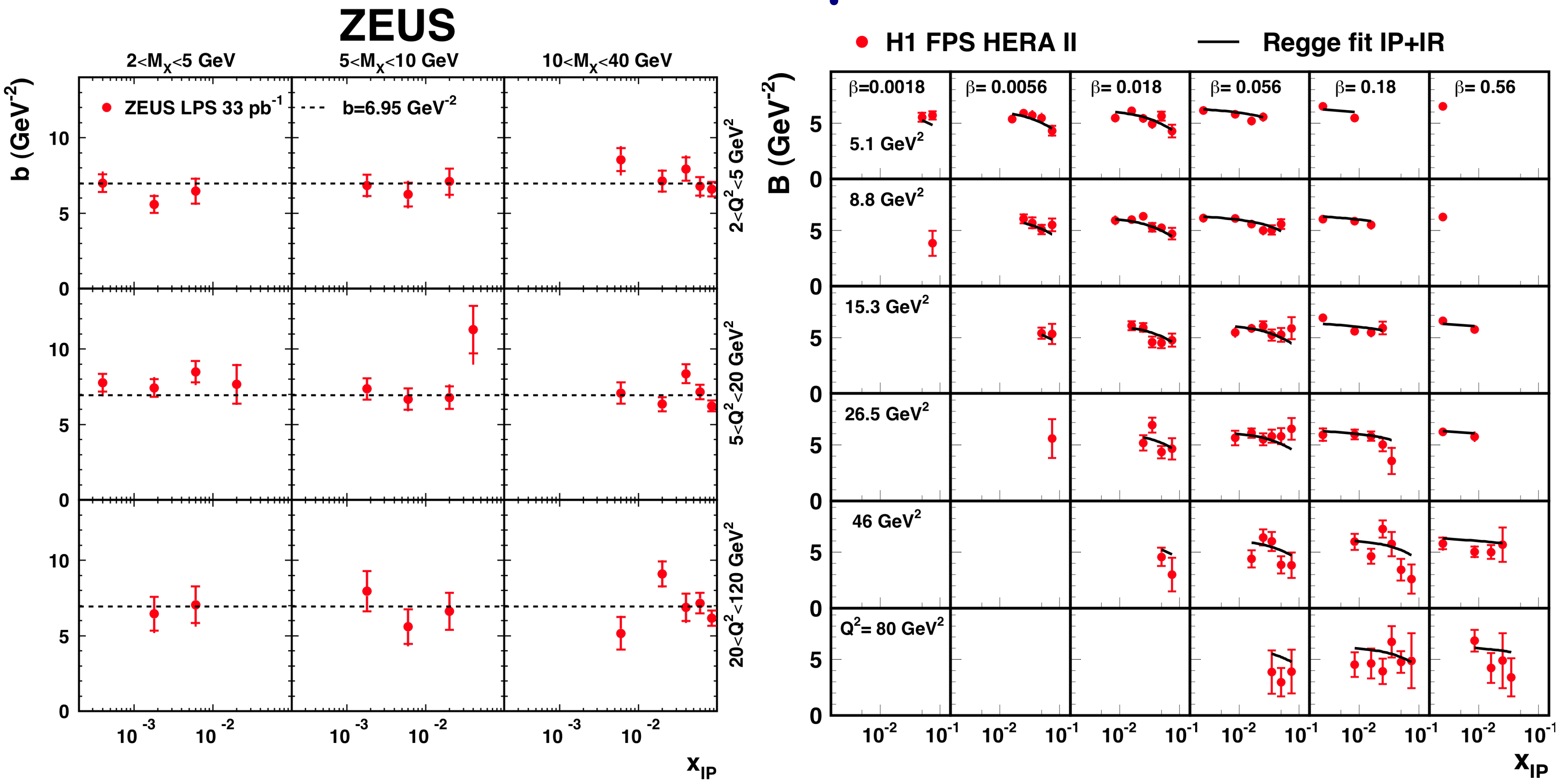


[Eur.Phys.J. C71 (20011) 1578]

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

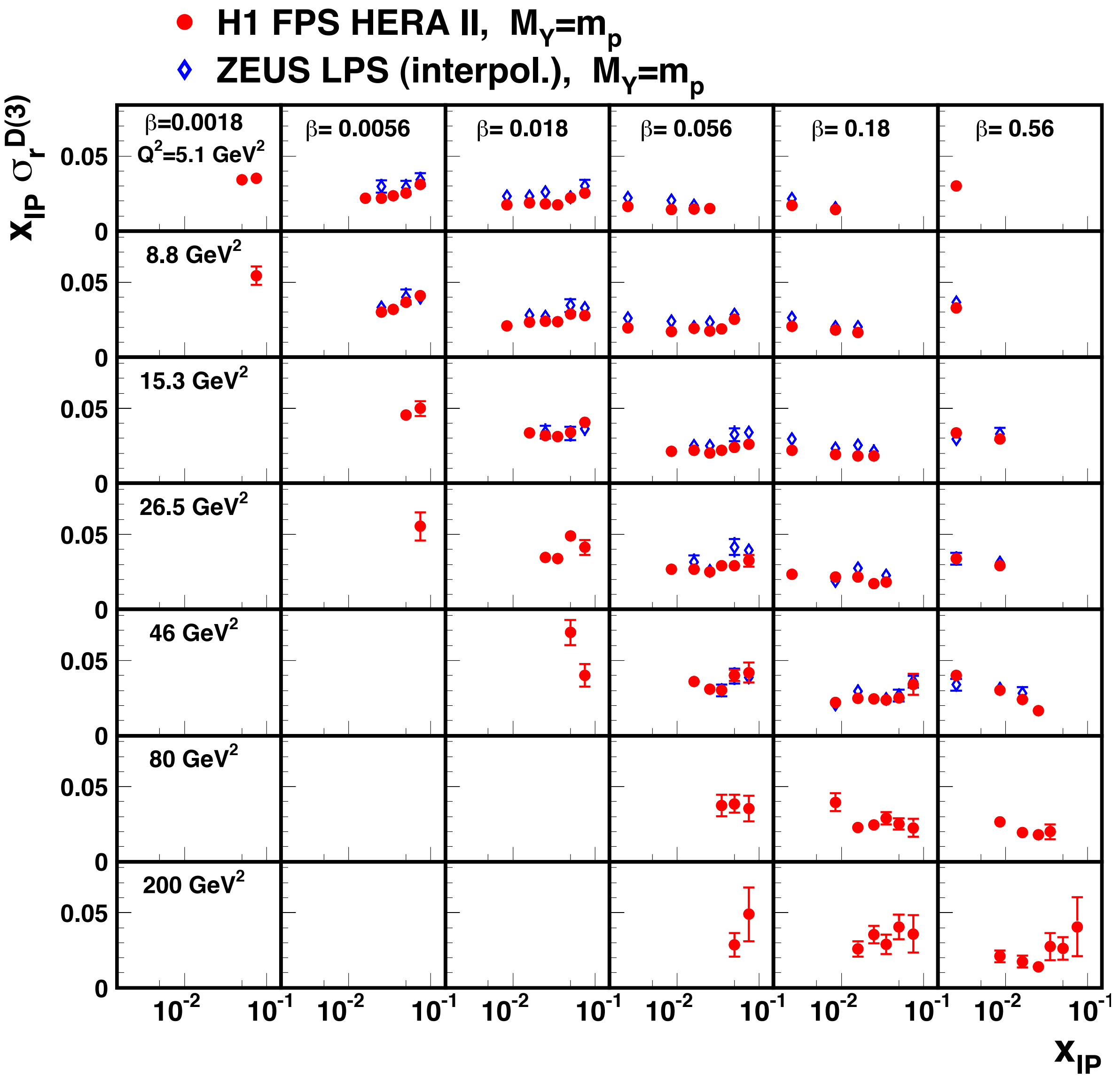
t-slope

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



- 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



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

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

Good agreement in shape between H1 and ZEUS

Fair agreement in normalization between H1 and ZEUS

H1 FPS HERA II norm unc ~ ± 6%

ZEUS LPS norm unc ~ + 11% - 7%

H1 FPS HERA II / ZEUS LPS =
0.85 ± 0.01 (stat) ± 0.03(syst)
+ 0.09 – 0.12 (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 GeV^2
  Norm unc ~ ± 4.8%

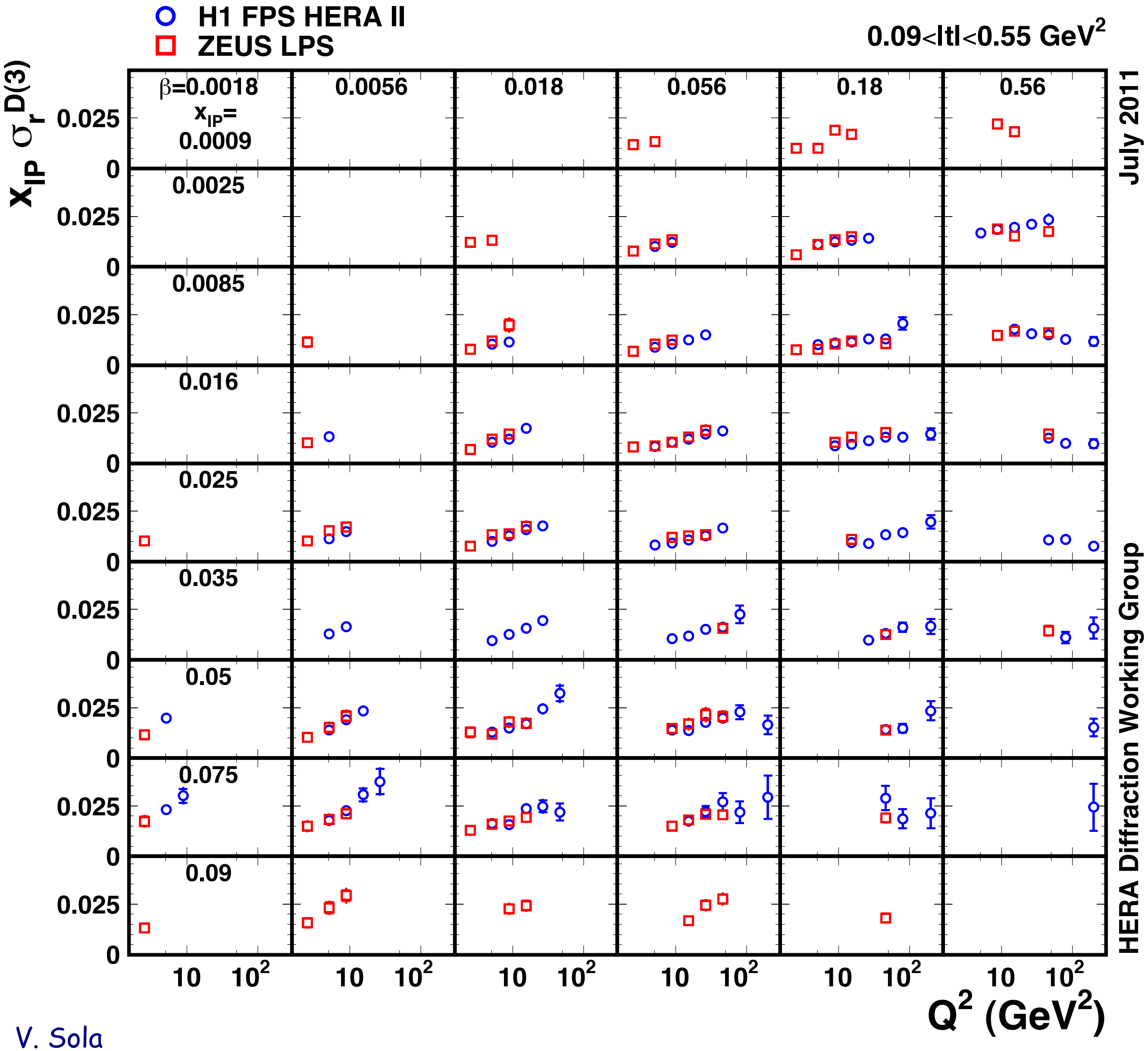
- ZEUS LPS
  [Nucl.Phys. B816 (2009) 1]
  Luminosity = 32.6 pb^{-1}
  Visible range $|t|$ = 0.09 – 0.55 GeV^2
  Norm unc ~ ± 7%

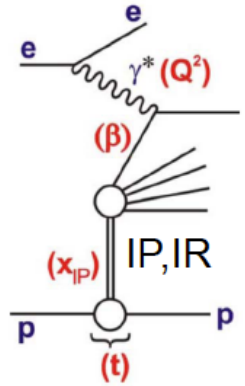
Combination performed in the ZEUS visible t range $|t|$ = 0.09 - 0.55 GeV^2

→ H1 FPS HERA II / ZEUS LPS = 0.91 ± 0.01 (stat) ± 0.03(syst) ± 0.08 (norm)

Prior to combining ZEUS cross section points swam to H1 (Q^2, β, x_{IP}) grid
using ZEUS DPDF SJ [Nucl.Phys. B831 (2010) 1]

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





Kinematic region covered by H1 and ZEUS data

Q^2 = 2.5 - 200 GeV^2

β = 0.0018 - 0.816

x_{IP} = 0.00035 - 0.09

|t| = 0.09 - 0.55

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]

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

for a single data set

i = measured data point
j = correlated systematic error source

M^i measured central values

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

σ_i statistical and uncorrelated systematic uncertainties

σ_{α_j} correlated systematic uncertainties

⇨ Full χ^2 is the sum over all χ^2_{exp}

Procedural Uncertainties

Four procedural uncertainties are introduced

1. ZEUS swimming factors from H1 DPDF Fit B [Eur. Phys. J. C48 (2006) 715]
→ Average effect ~ 1%

2. Additive vs multiplicative nature of the error sources
→ Average effect ~ 4%

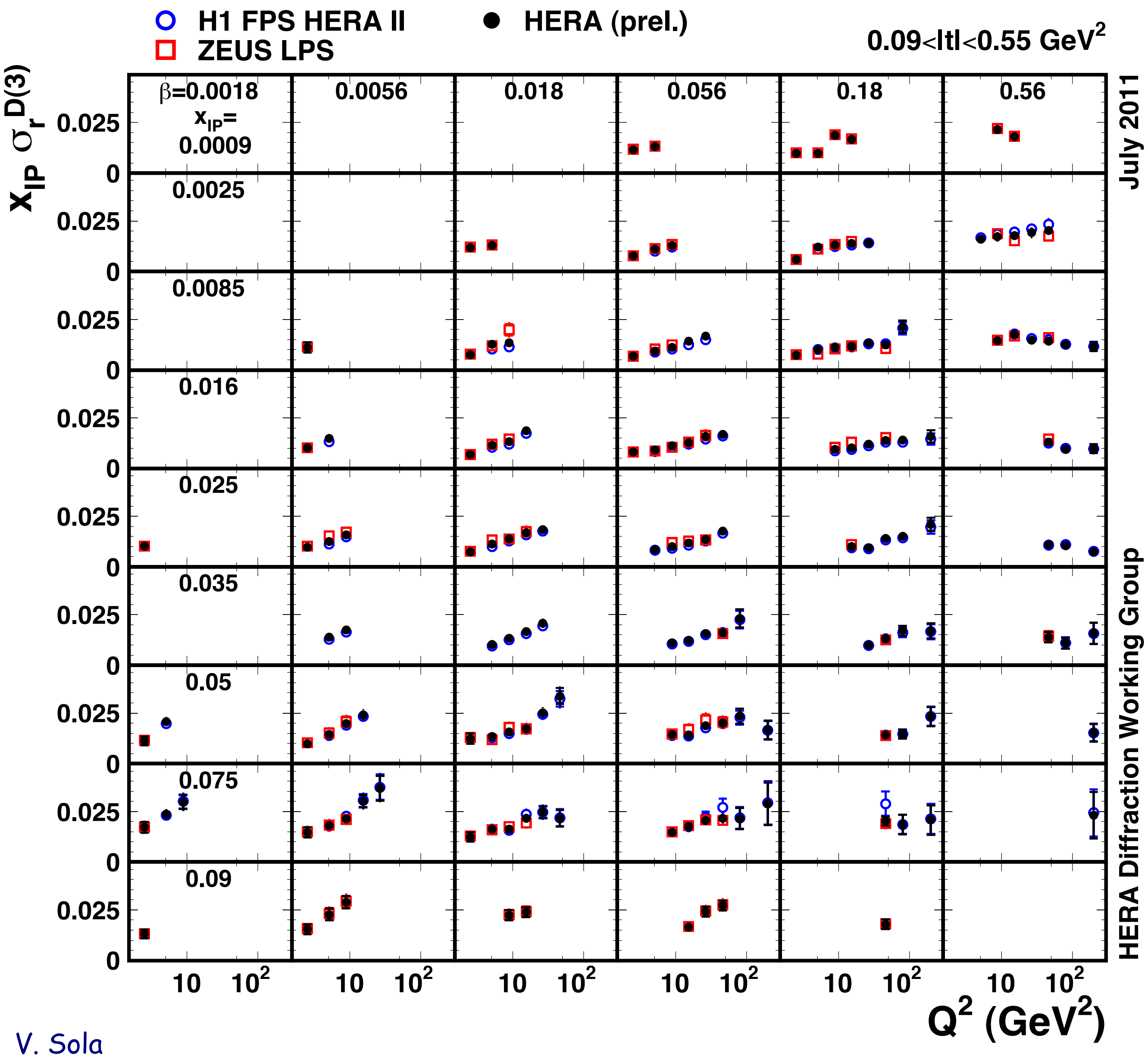
3. Correlated systematic error sources between H1 and ZEUS
Identified 4 uncertainties of possible common origin

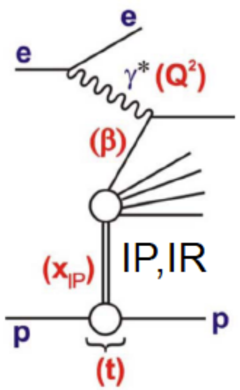
- electromagnetic energy scale
- backgroud subtraction
- x_{IP} reweighting
- t reweighting

Compare 2^4 averages taking all pairs as corr/uncorr in turn
→ Average effect ~ 1%

4. Point-to-point correlated vs uncorrelated systematic error sources
→ Average effect < 1%, up to 10% at lowest x_{IP}

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



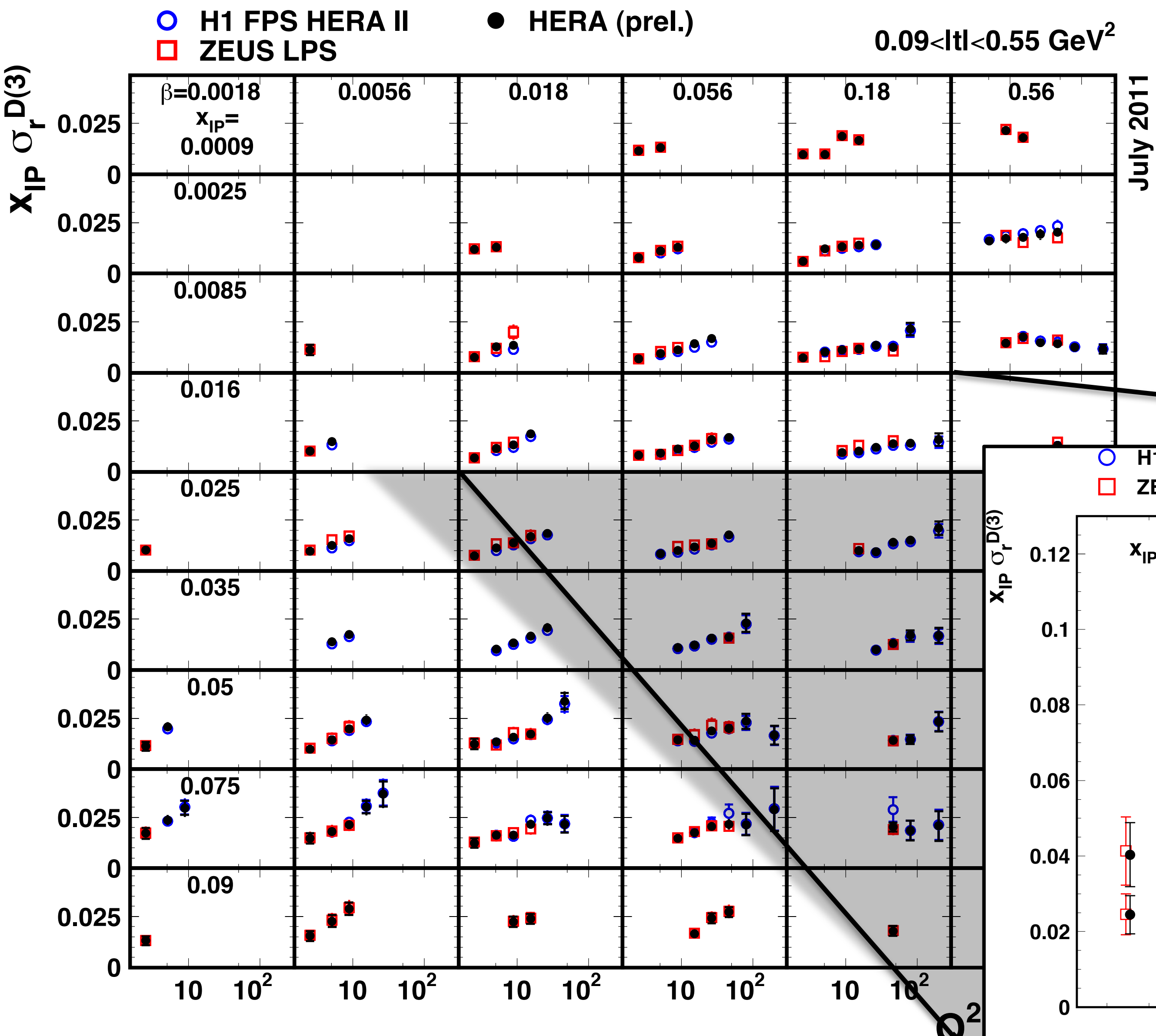


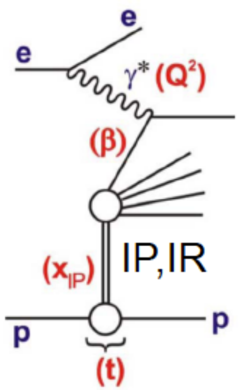
$\chi^2/ndf = 52/58$

Nice and precise measurement of the scaling violation in diffraction

Improvement in precision with respect to the H1 FPS HERA II data by ~ 20%

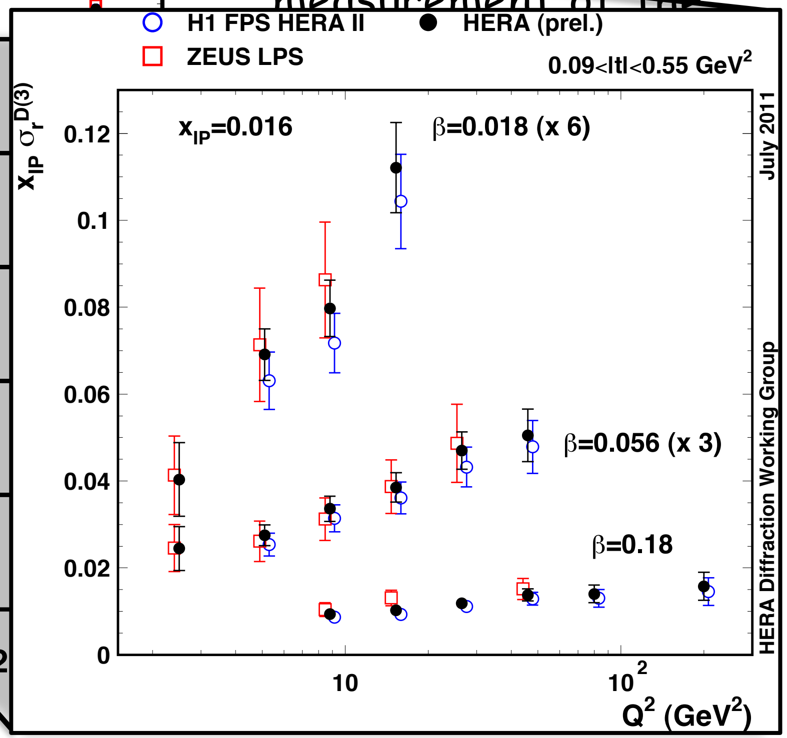
Combined $\sigma_r^{D(3)}$





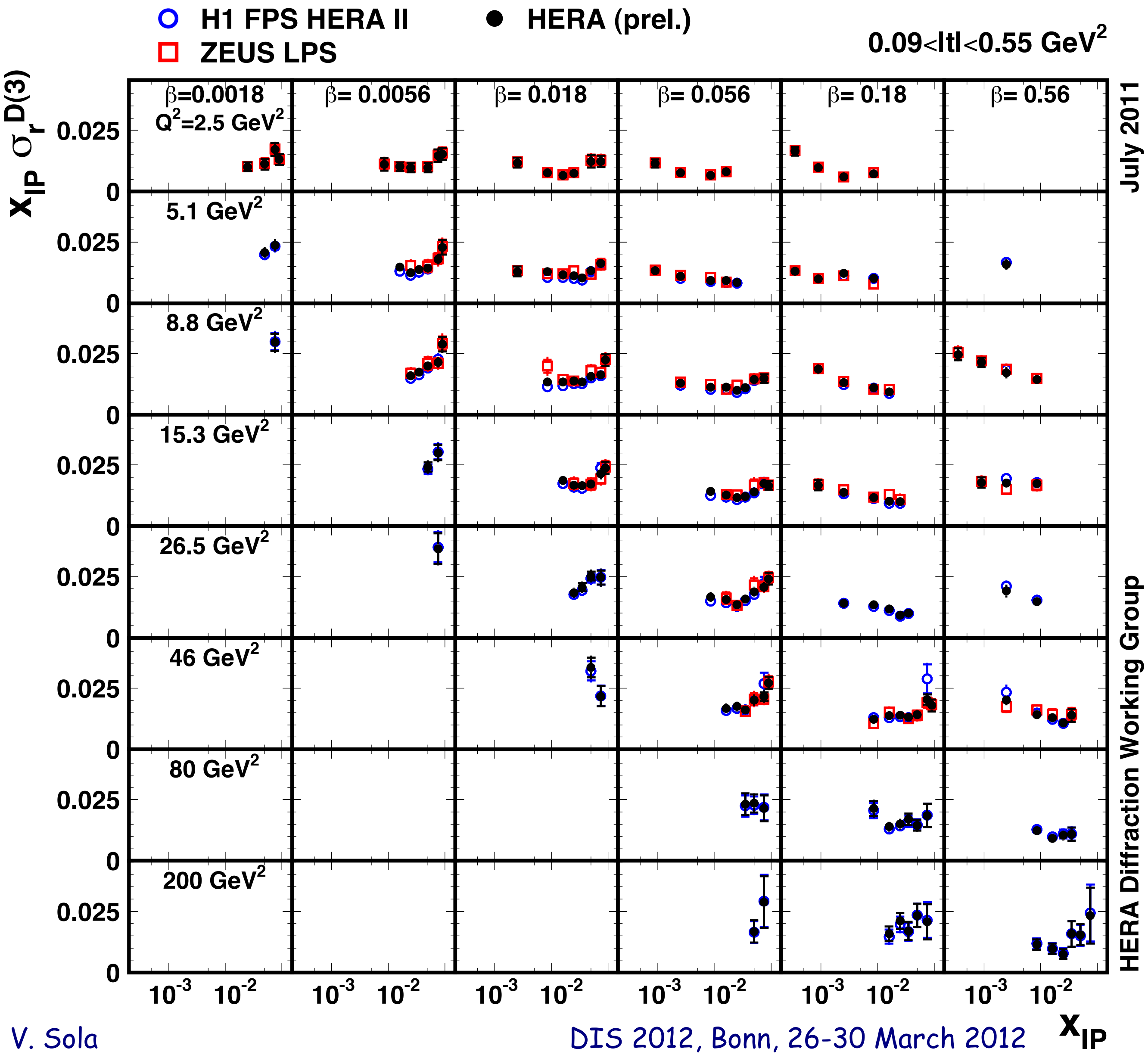
$\chi^2/ndf = 52/58$

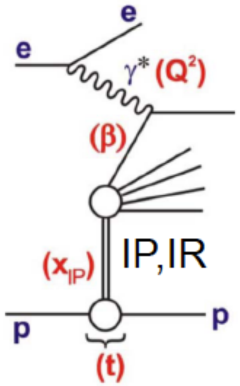
Nice and precise measurement of the



V. Sola

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



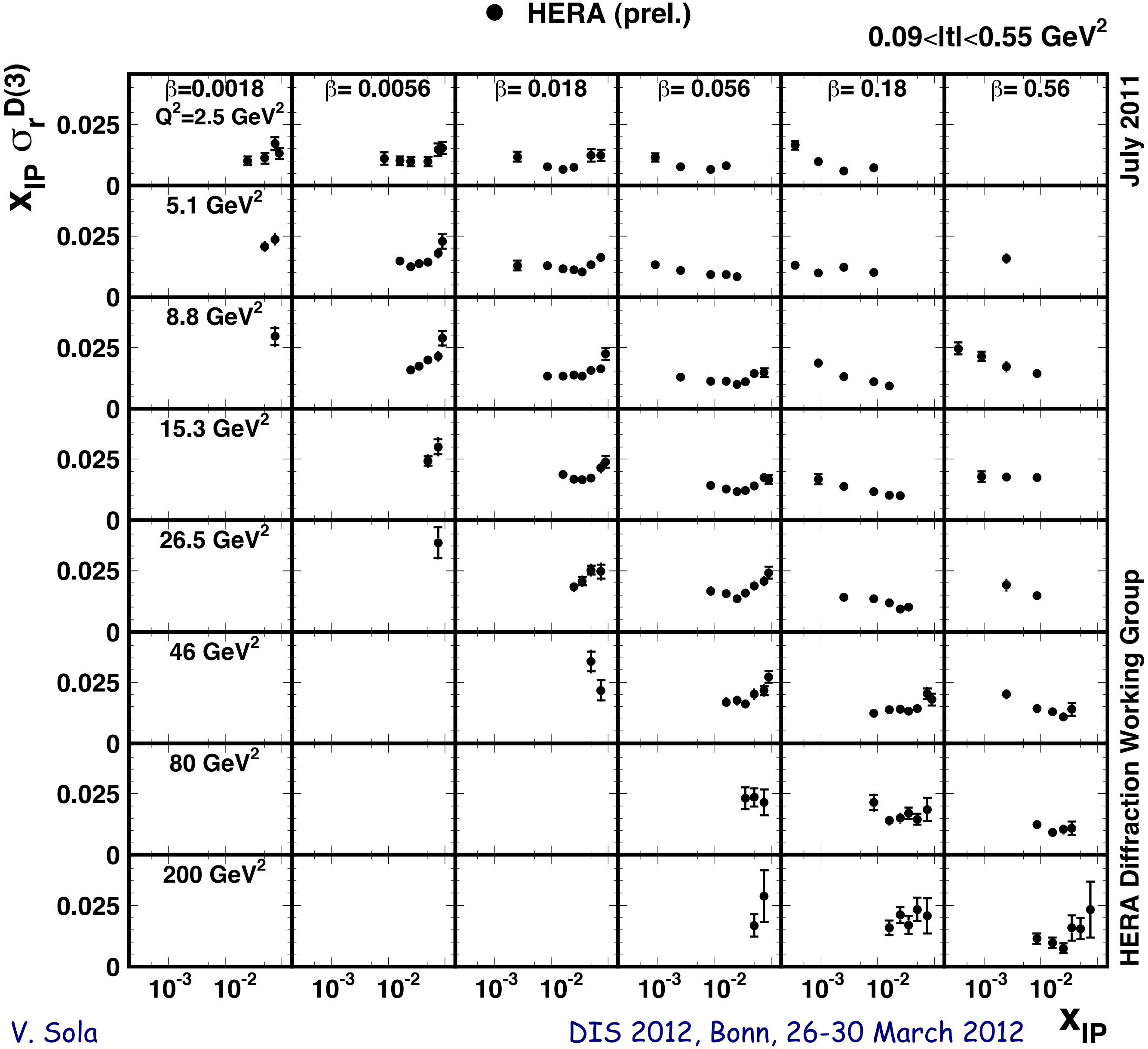


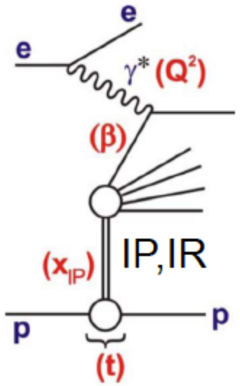
$\chi^2/ndf = 52/58$

Nice and precise measurement of the x_{IP} dependence of $\sigma_r^{D(3)}$

Improvement in precision with respect to the H1 FPS HERA II data by ~ 20%

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





$\chi^2/ndf = 52/58$

Nice and precise measurement of the x_{IP} dependence of $\sigma_r^{D(3)}$

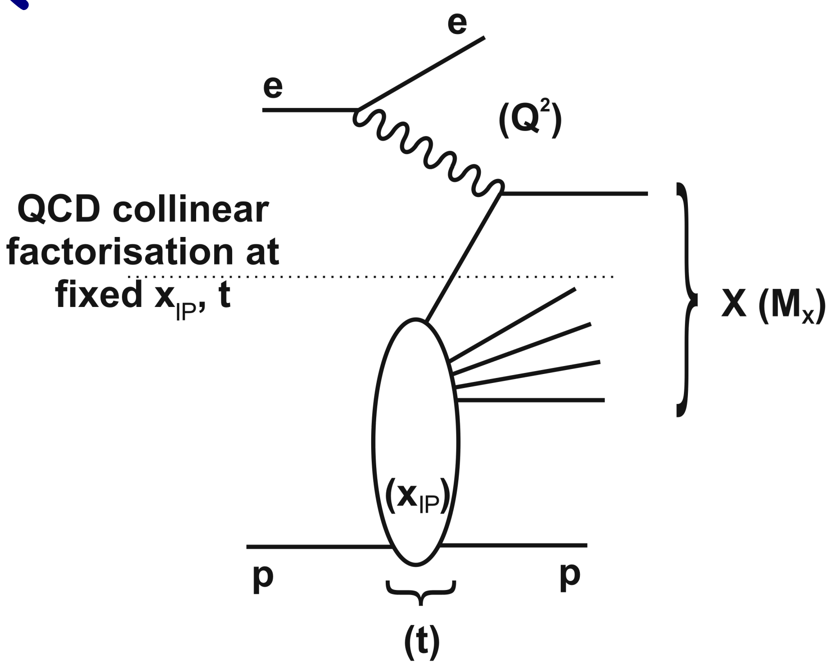
Improvement in precision with respect to the H1 FPS HERA II data by ~ 20%

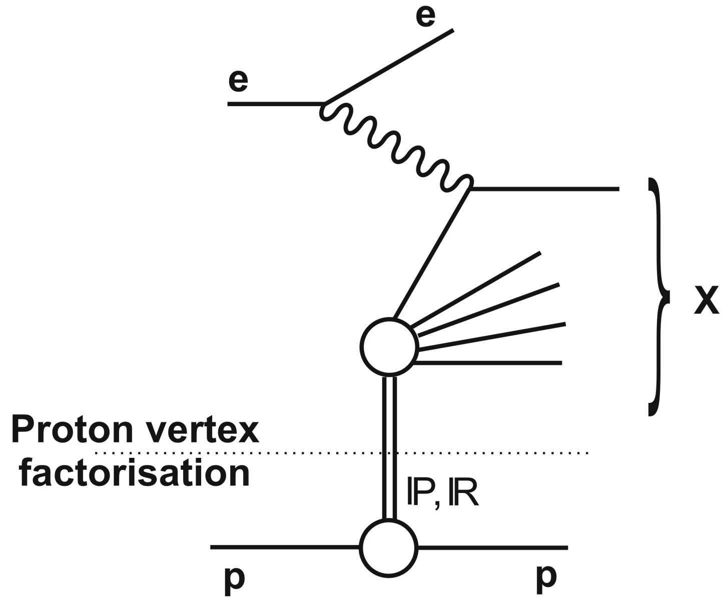
Summary

- ✓ 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
  - ⇨ results are about to be published
- ✓ Looking forward to combining all LRG, FPS and VFPS data

Thank You

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

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

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

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

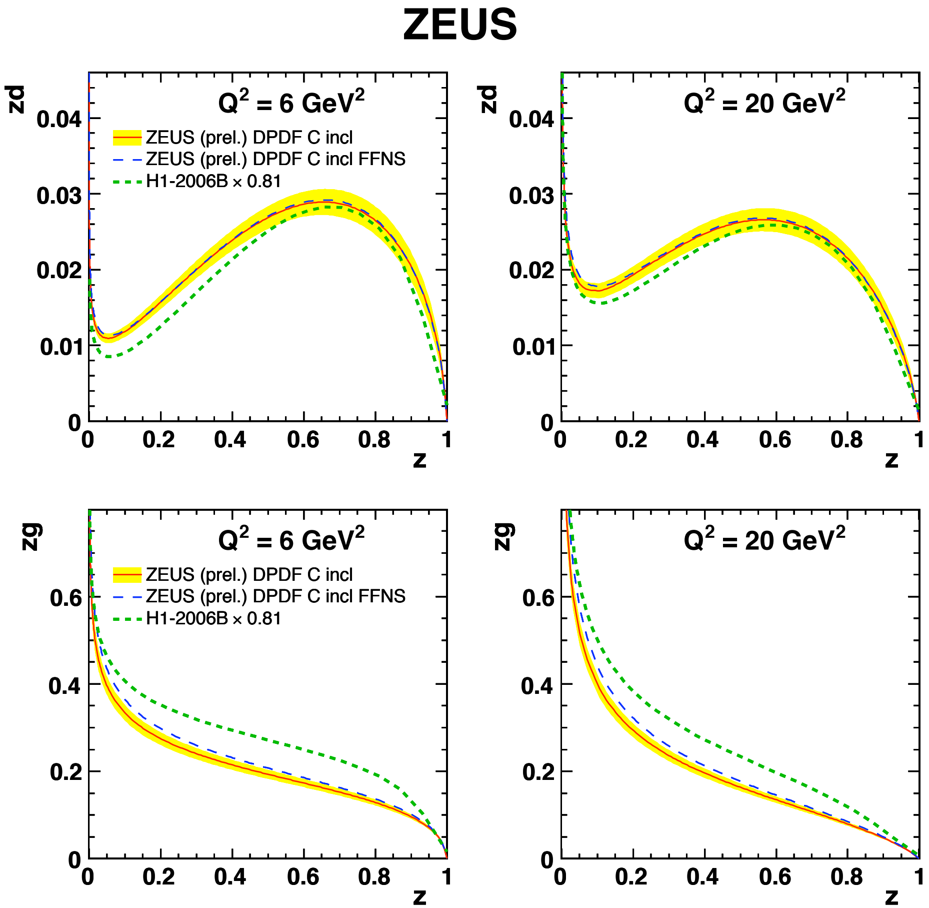
⇨ Universal DPDFs apply in DIS when vacuum quantum numbers are exchanged

Diffractive PDFs from NLO Fits

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)



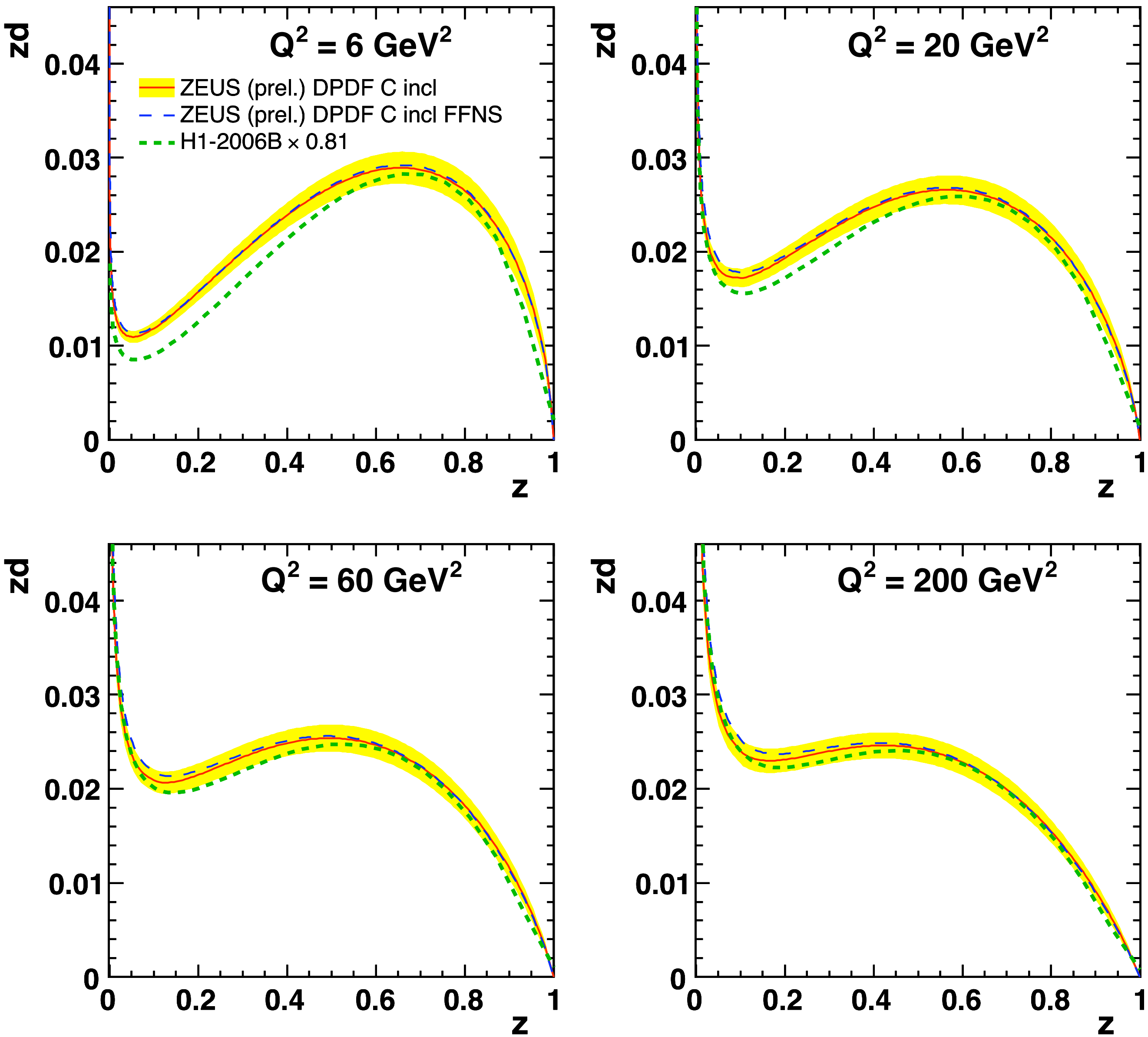
Diffractive Parton Density Functions are obtained fitting the H1 and ZEUS diffractive reduced cross sections (published data sets only)

Differencies 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

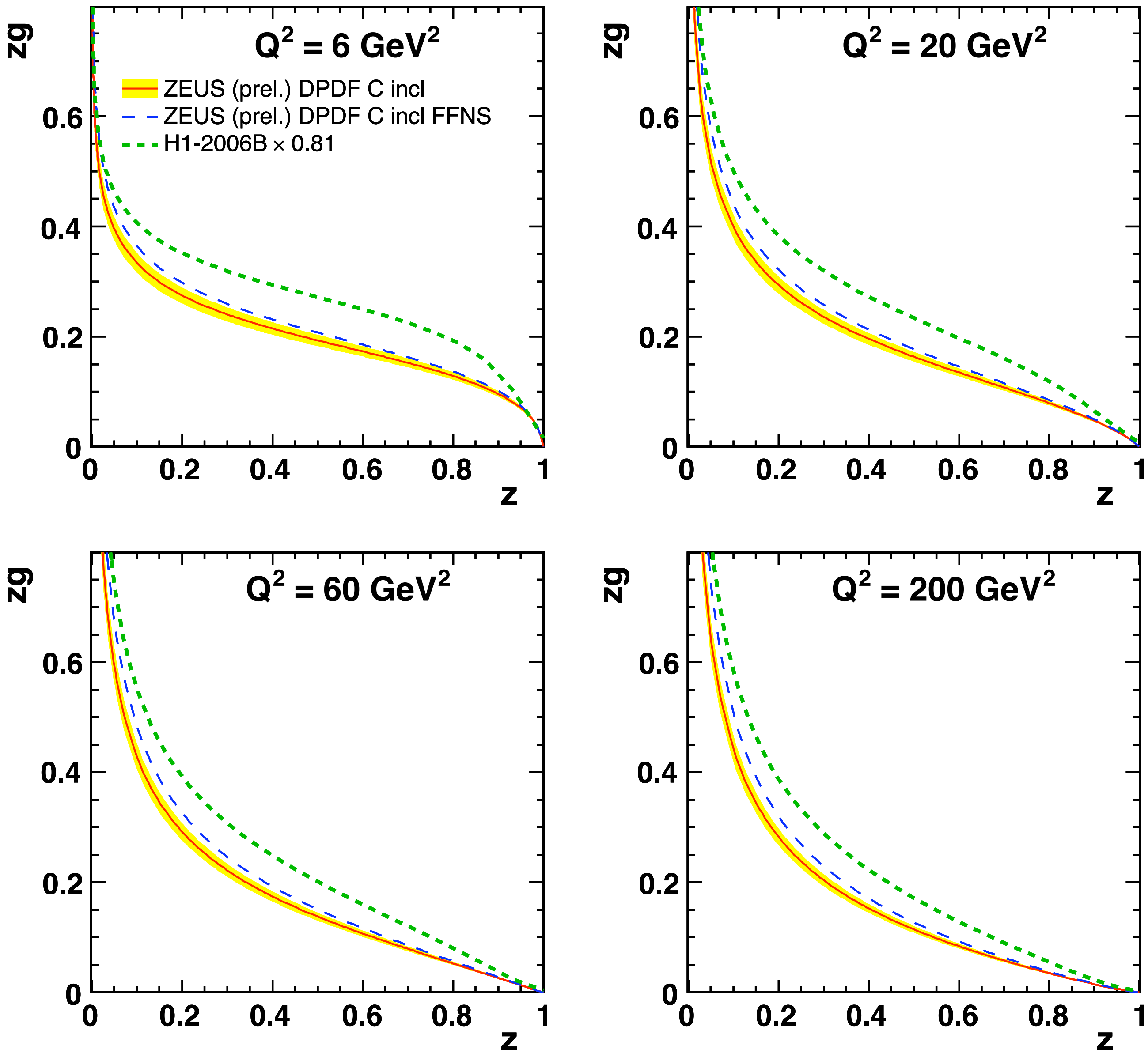
⇨ First attempt to combine H1 and ZEUS diffractive cross sections

ZEUS



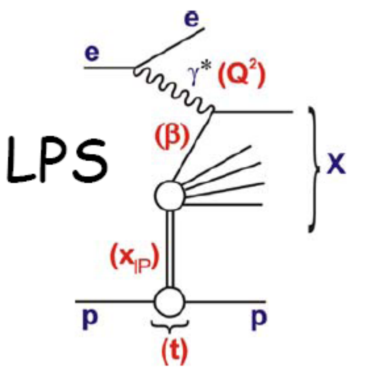
zd
Q^2 = 6 GeV^2
ZEUS (prel.) DPDF C incl
ZEUS (prel.) DPDF C incl FFNS
H1-2006B × 0.81
Q^2 = 20 GeV^2
Q^2 = 60 GeV^2
Q^2 = 200 GeV^2
0.04
0.03
0.02
0.01
0
0.2
0.4
0.6
0.8
1
z

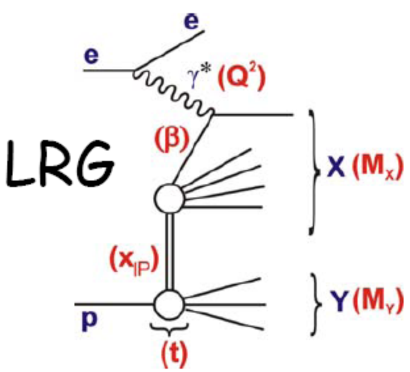
ZEUS

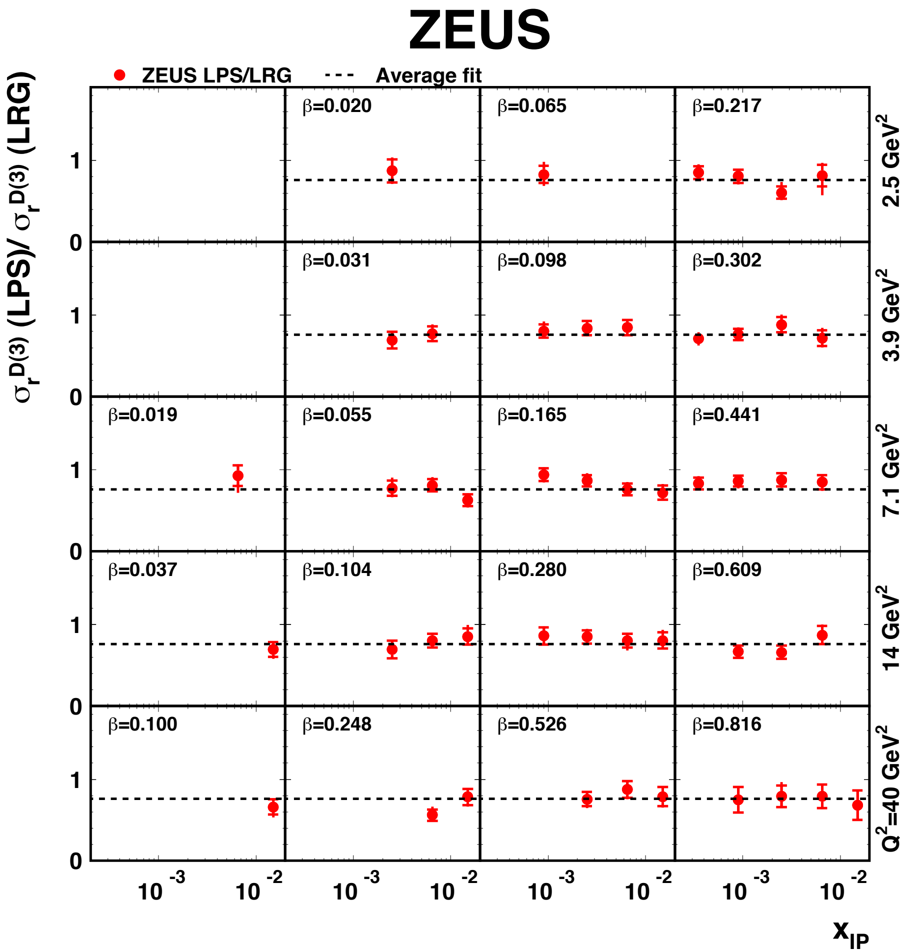


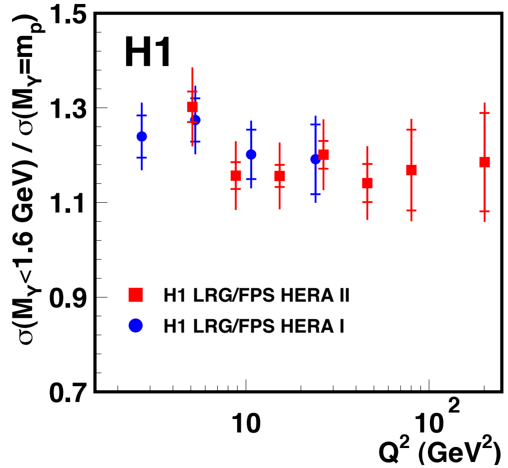
Q^2 = 6 GeV^2
ZEUS (prel.) DPDF C incl
ZEUS (prel.) DPDF C incl FFNS
H1-2006B × 0.81
Q^2 = 20 GeV^2
Q^2 = 60 GeV^2
Q^2 = 200 GeV^2
zg
z
0
0.2
0.4
0.6
0.8
1

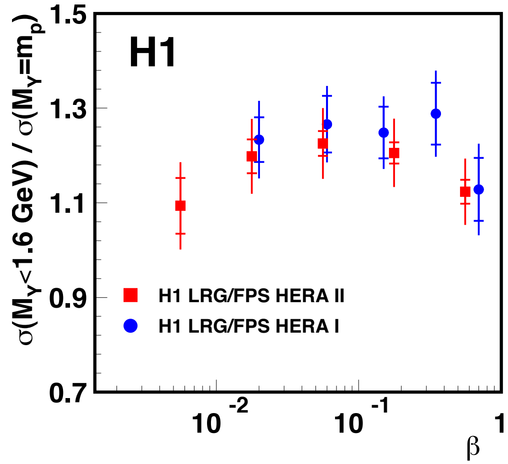
LRG vs PS

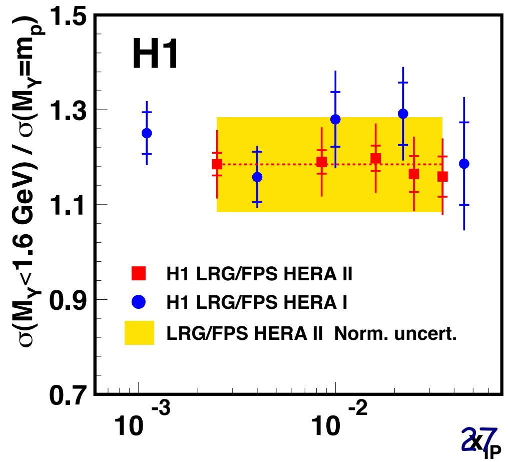








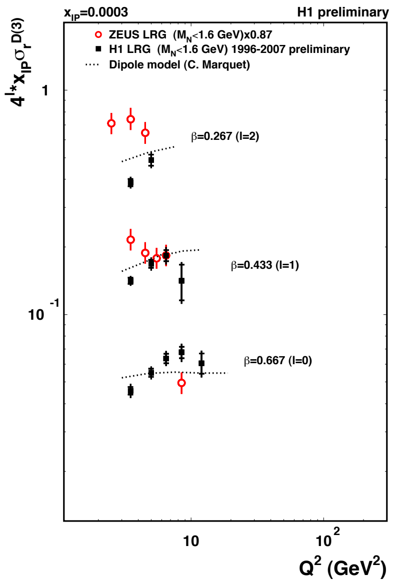


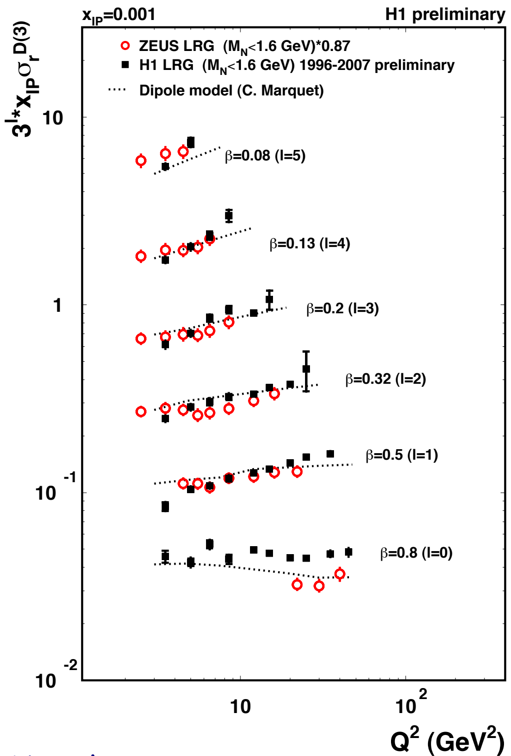


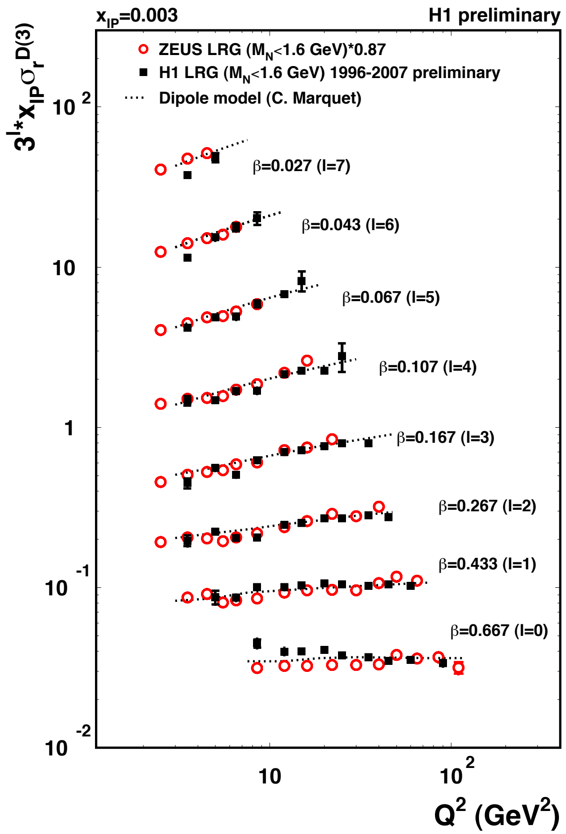
Estimation of p-diss contribution in LRG method
→ ratio flat both in ZEUS and H1

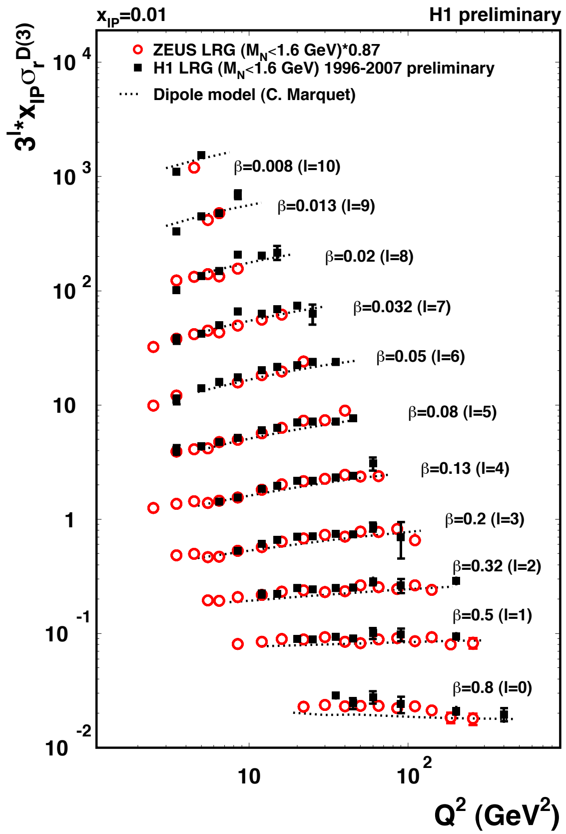
⇨ PS data give the absolute normalization of $\sigma_r^{D(3)}$

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

t-slope vs x_{IP}