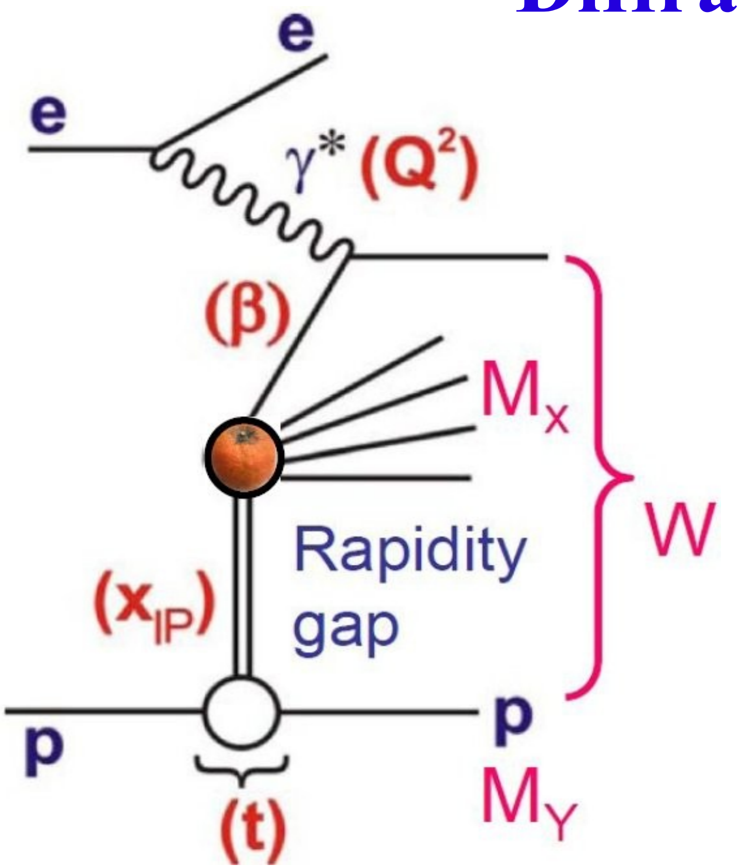
# DIS 2013

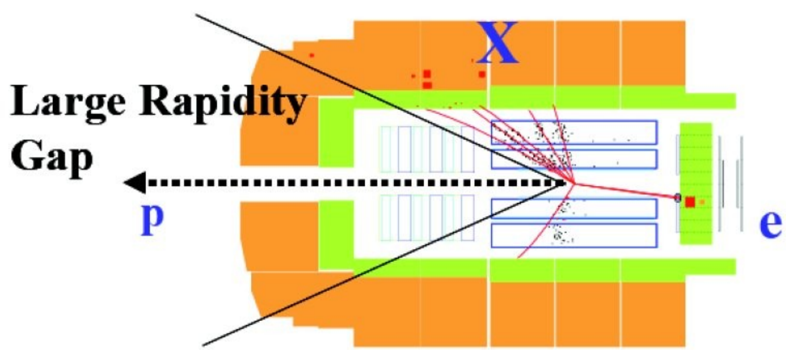
## Marseille
## 22-26 April 2013

# Combined
# Inclusive Diffractive Cross Sections
# Measured with Forward Proton Spectrometers
# in ep DIS at HERA

**Jan Olsson, DESY**
for the H1 and ZEUS
Collaborations

# Diffractive DIS at HERA



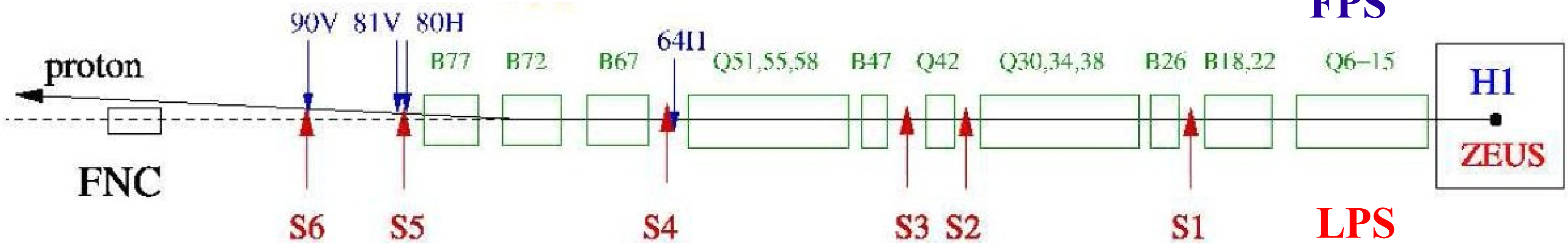




**Rapidity gap** $\sim \ln 1/x_{I\!P}$

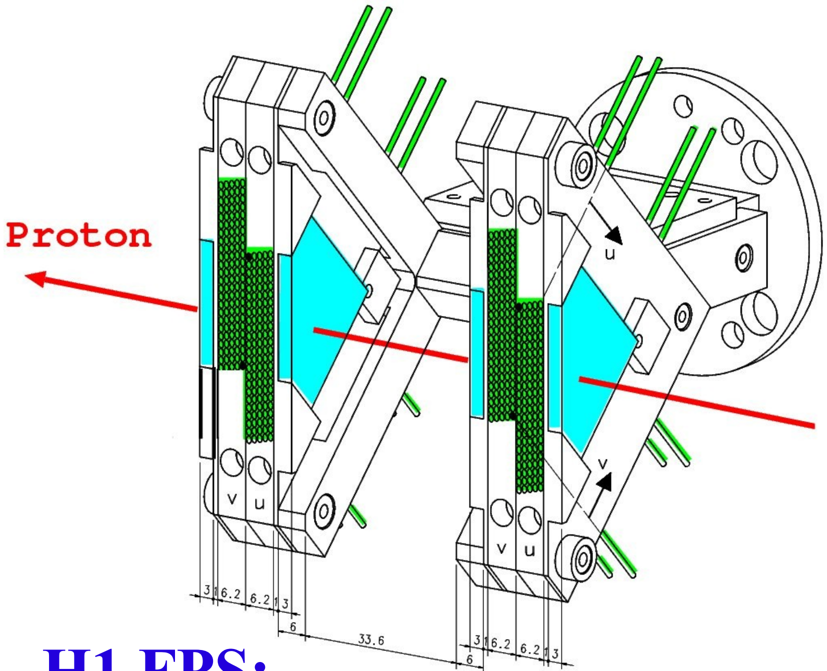
| | |
|---|---|
| $Q^2$ | **Photon Virtuality** $W$ $\gamma^* p$ **CM System Energy** |
| $\beta$ | **Momentum Fraction of the Colour Singlet ($I\!P$), carried by the struck Parton** |
| $M_X$ | **Mass of Hadronic System** $X$ $\beta \simeq Q^2/(Q^2+M_X^2)$ |
| $x_{I\!P}$ | **Momentum Fraction of the proton, carried by the Pomeron** $x = x_{Bj} = x_{I\!P} \cdot \beta$ |
| $t$ | **(Momentum Transfer)$^2$ at the proton vertex** |
| $M_Y$ | **Mass of proton or proton dissociation system** |

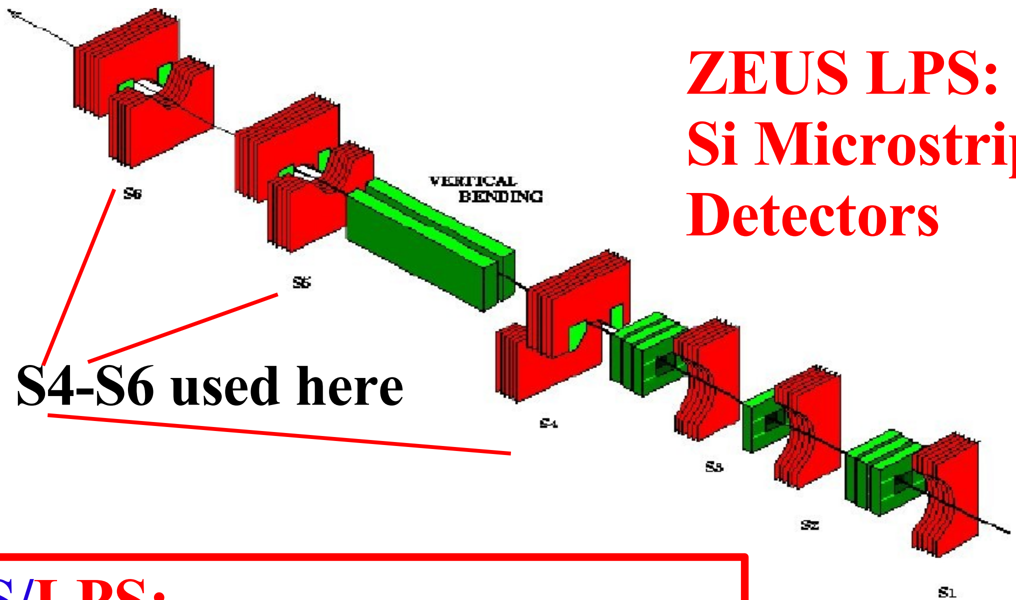
**LRG is an Experimental Signature:**
**H1 and ZEUS both analyzed**
**High Statististics LRG data samples,**
**Diffractive PDFs were determined**
**But:**
**Large systematic errors in LRG data:**
**Background of undetected p-diss. events**
**Need proton measurement !**

# Forward Detectors H1/ ZEUS




HERA provides magnetic spectrometer




**ZEUS LPS:**
**Si Microstrip**
**Detectors**

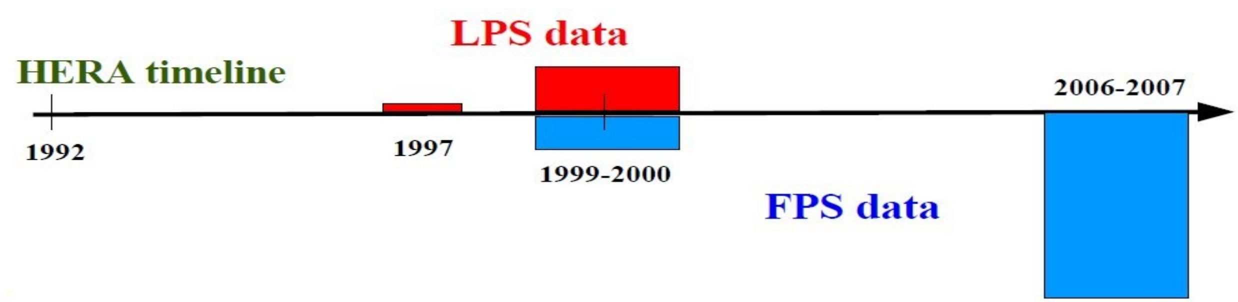
**H1 FPS:**
**Horizontal Roman Pots,**
**Scintillating Fibres,**
**PSPM Detectors**

**FPS/LPS:**
- Measurement of $t$
- No p-diss. background
- Larger range of $M_x(x_{I\!P})$
- Low acceptance, low statistics

# The H1 and ZEUS FPS / LPS Data Sets

| Data Set | $Q^2$ range [GeV $^2$] | $x_{I\!P}$ range | $y$ range | $\beta$ range | $t$ range [GeV $^2$] | Luminosity [pb $^{-1}$] | Ref. |
|---|---|---|---|---|---|---|---|
| H1 FPS HERA II | $4-700$ | $< 0.1$ | $0.03-0.8$ | $0.001-1$ | $0.1-0.7$ | 156.6 | [2] |
| H1 FPS HERA I | $2-50$ | $< 0.1$ | $0.02-0.6$ | $0.004-1$ | $0.08-0.5$ | 28.4 | [1] |
| | | | $W$ range [GeV] | $M_X$ range [GeV] | | | |
| ZEUS LPS 2 | $2.5-120$ | $0.0002-0.1$ | $40-240$ | $2-40$ | $0.09-0.55$ | 32.6 | [4] |
| ZEUS LPS 1 | $2-100$ | $< 0.1$ | $25-240$ | $> 1.5$ | $0.075-0.35$ | 3.6 | [3] |


[1] DESY 06-048, hep-ex/0606003
[2] DESY 10-095, arXiv:1010.1476
[3] DESY 04-131, hep-ex/0408009
[4] DESY 08-175, arXiv:0812.2003


**4 different data samples, 4 different kinematic regions**

**Additional normalisation uncertainty from Differences in the $t$ -dependence**

→ **Combine data only in restricted, common visible $t$-range:**

$$0.09 < |t| < 0.55 \text{ GeV}^2$$

**Before discussing the Combination, a Short Look at the two largest statistics data sets: ZEUS LPS 2 and H1 FPS HERA II**

# Diffractive DIS Cross Sections

$$\frac{d^4\sigma}{d\beta\, dQ^2\, dx_{I\!P}\, dt} = \frac{4\pi\alpha^2}{\beta Q^4}(1 - y + \frac{y^2}{2})\sigma_r^{D(4)}(\beta, Q^2, x_{I\!P}, t)$$

$$\sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{1+(1-y)^2} F_L^{D(4)}$$

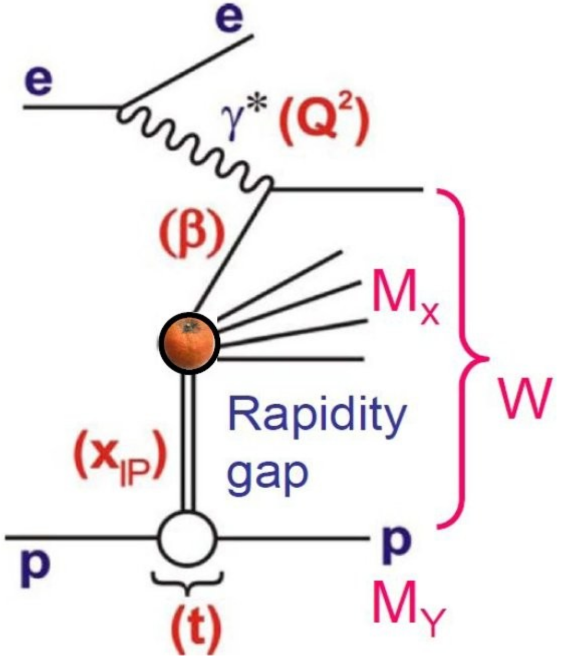
$$\sigma_r^{D(3)}(\beta, Q^2, x_{I\!P}) = \int \sigma_r^{D(4)}(\beta, Q^2, x_{I\!P}, t)dt$$

$Q^2, W, x_{Bj}$

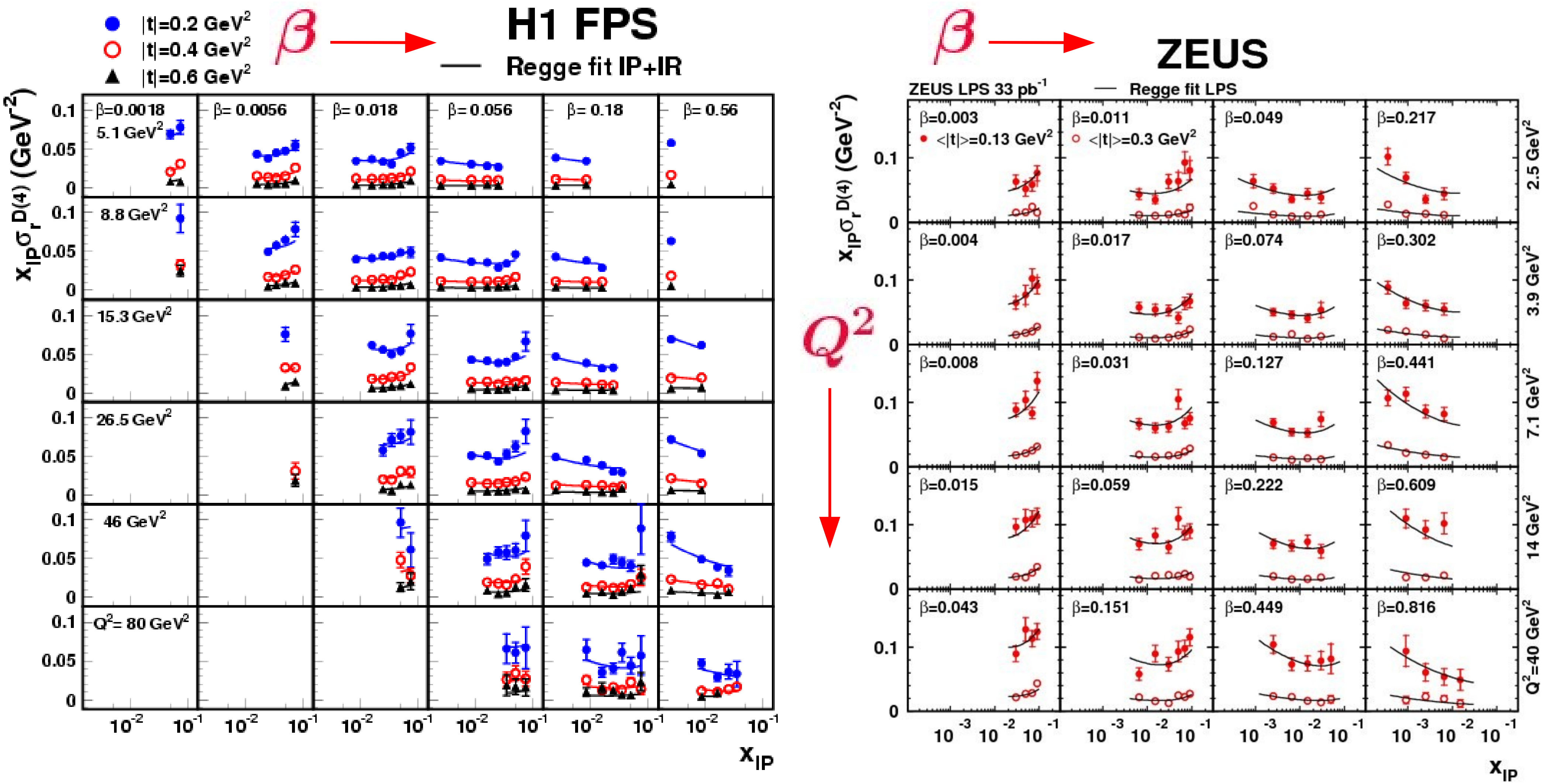
**reconstructed from Main Detectors**

$\beta, x_{I\!P}, t, M_X$

**reconstructed from FPS / LPS Detectors,**
**or from combined Main and PS Detectors**



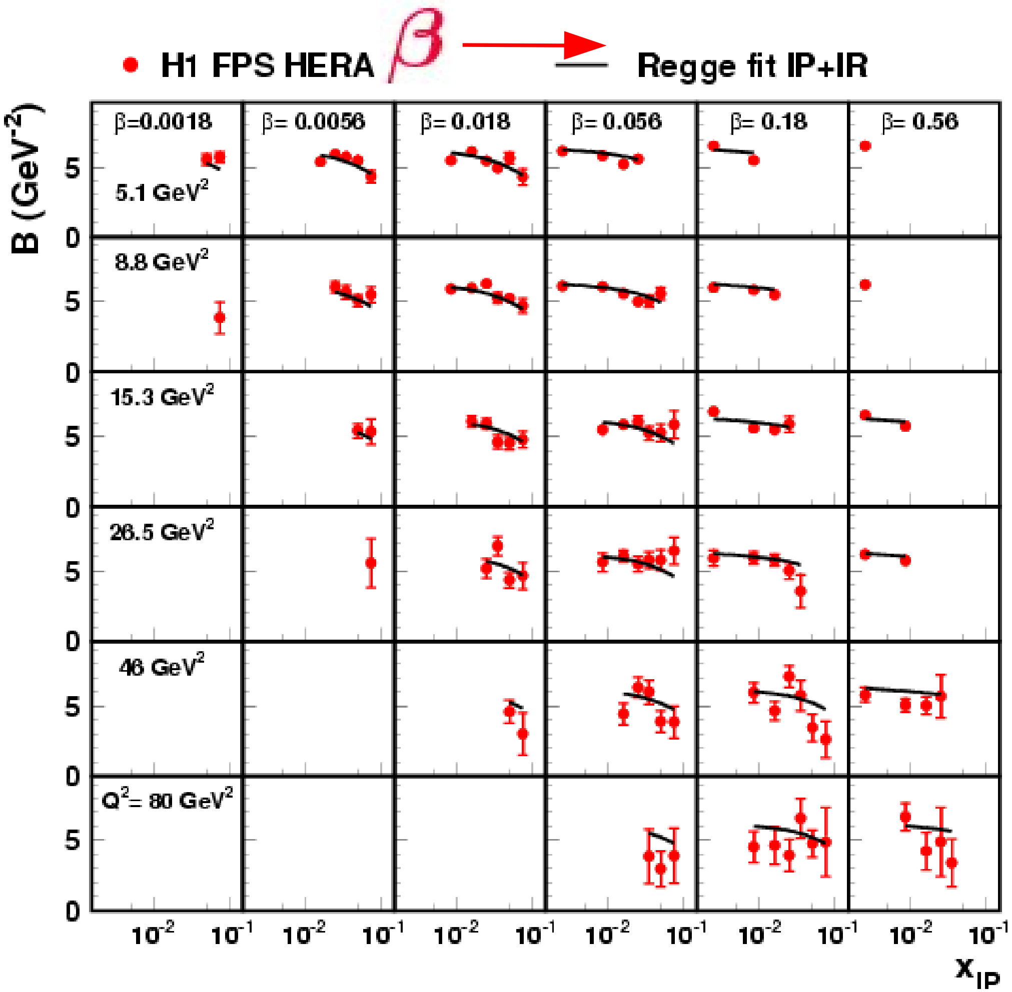
# Reduced Cross Section $\sigma_r^{D(4)}$ vs. $x_{I\!P}$, in bins of $t$, $\beta$ and $Q^2$

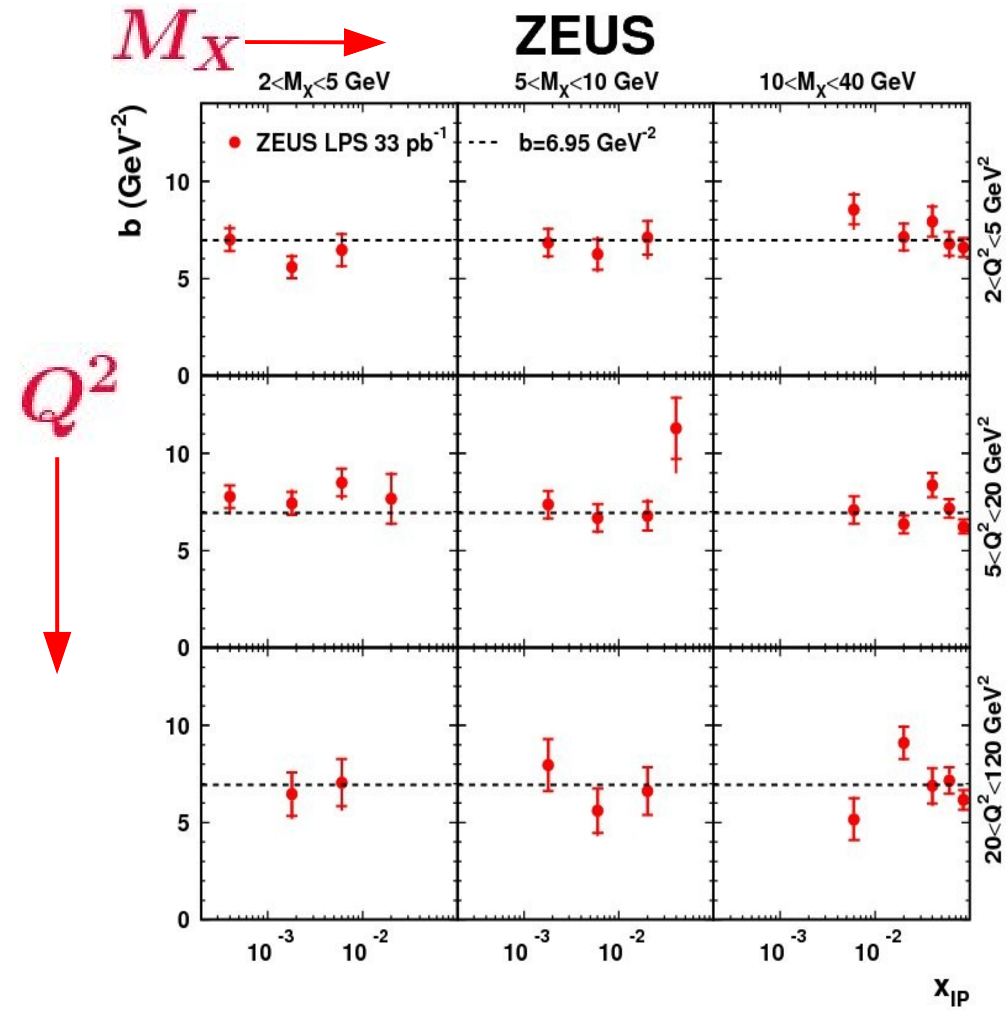



**Cross Section rises at low $\beta$ and large $x_{I\!P}$ values**

**Look in detail at the $t$ -dependence:**

# $t$-dependence of $\sigma_r$ :   Fits of $d\sigma/dt \sim e^{Bt}$




**H1:** Constant $B$ at low $x_{I\!P}$ values
Decreasing $B$ at larger $x_{I\!P}$ values
(Reggeon exchange becomes important)

**ZEUS:** Constant $B$ over the whole kin. range

# Regge Fit and the $x_{I\!P}$-dependence of the $t$-slope $B$

$F_2^{D(4)}$ sum of separately factorisable Pomeron and Reggeon contributions:

$$F_2^{D(4)}(x_{I\!P}, t, \beta, Q^2) = f_{I\!P}(x_{I\!P}, t) F_{I\!P}(\beta, Q^2) + n_{I\!R} \cdot f_{I\!R}(x_{I\!P}, t) F_{I\!R}(\beta, Q^2)$$

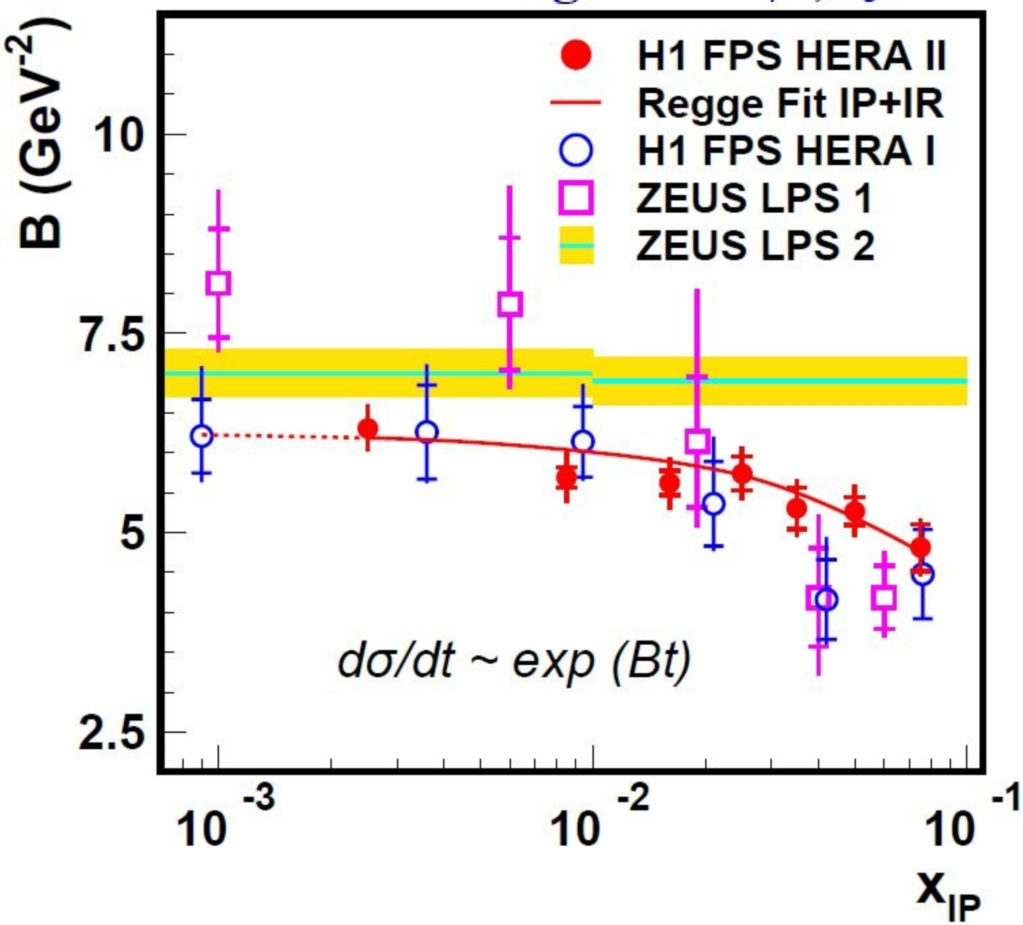
Pomeron and Reggeon Fluxes:

$$f_{I\!P,I\!R}(x_{I\!P}, t) \sim \frac{e^{B_{I\!P,I\!R} t}}{x_{I\!P}^{2\alpha_{I\!P,I\!R}(t)-1}}$$

Both Trajectories assumed linear:

$$\alpha_{I\!P,I\!R}(t) = \alpha_{I\!P,I\!R}(0) + \alpha'_{I\!P,I\!R} t$$

Data averaged over $\beta, Q^2$




H1 Fit gives $B \sim$ 5-6 GeV$^{-2}$,
and Reggeon exchange at large $x_{I\!P}$ values

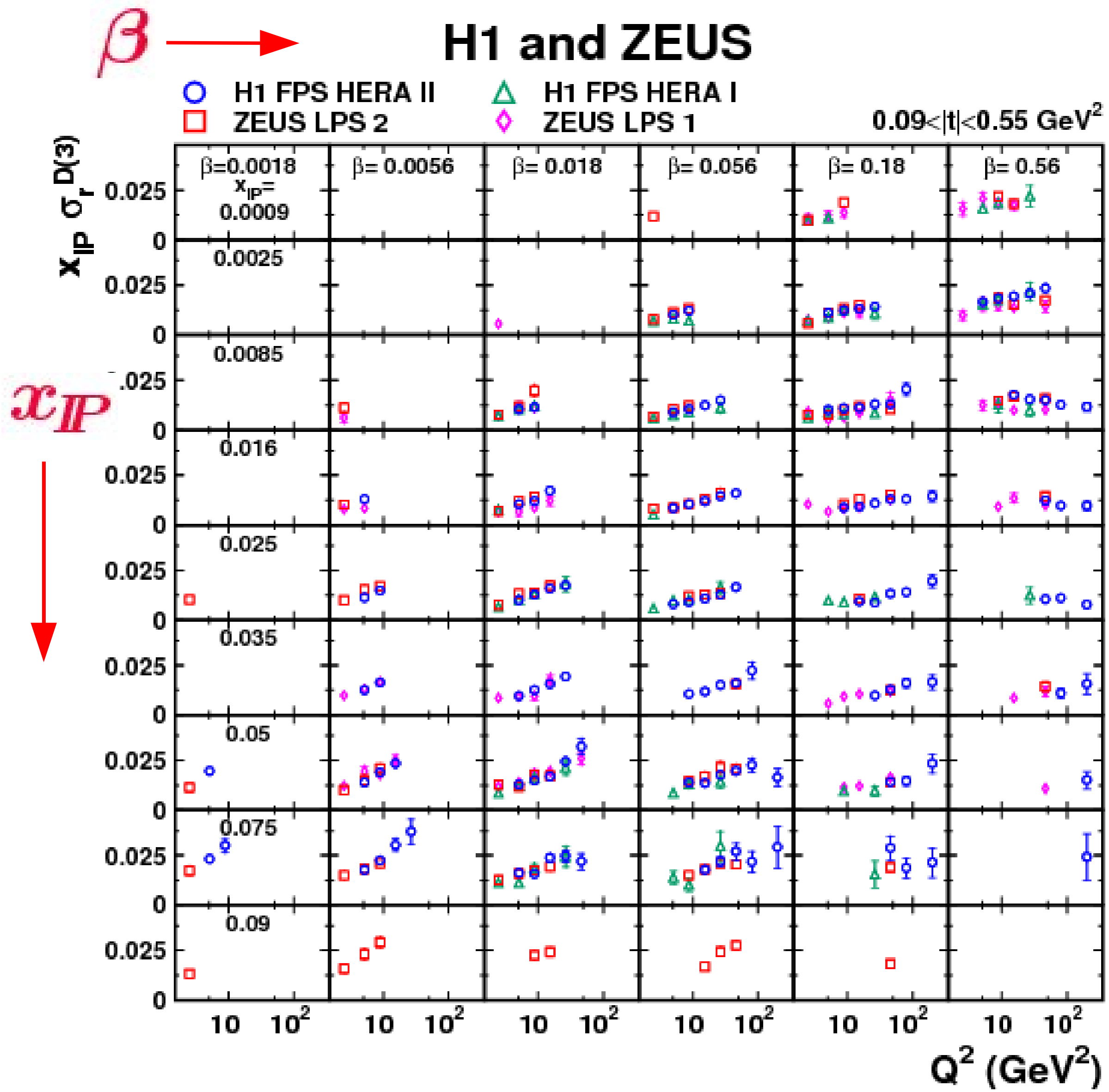
ZEUS find somewhat higher values, $B \sim 7$ GeV$^{-2}$,
and flat dependence over whole $x_{I\!P}$ range

t-slopes and intercept values consistent with Soft Pomeron

H1 Fit also gives the Pomeron Trajectory:

$$\alpha_{I\!P}(t) = [1.10 \pm 0.02 \pm 0.03] + [0.04 \pm 0.02^{+0.08}_{-0.06}]t$$

# $\sigma_r^{D(3)}$ vs. $Q^2$, in bins of $\beta$ and $x_{I\!P}$




Combination made in the common visible $t$-range of H1 and ZEUS, $0.09 < |t| < 0.55$ GeV$^2$

Combination made using $\sigma_r^{D(3)}(\beta, Q^2, x_{I\!P})$

The $\beta, Q^2, x_{I\!P}$ grid mostly defined by H1 Data ZEUS Data were "swum" to this grid using the ZEUS DPDF SJ

Phase Space of Combined Data:

$2.5 < Q^2 < 200$ GeV$^2$

$0.0018 < \beta < 0.816$

$0.00035 < x_{I\!P} < 0.09$

**Good agreement of FPS and LPS data !**

# Combination Method

Use the $\chi^2$ minimisation method of A.Glazov [AIP Conf.Proc.792 (2005) 237, DIS05]
(also used in other HERA combinations)

The basic assumption:

Both Experiments measure the Same Cross Section

$$\chi^2_{exp}(m,b) = \sum_i \frac{\left[m^i - \sum_j \gamma^i_j m^i b_j - \mu^i\right]^2}{\delta^2_{i,stat}\mu^i\left(m^i - \sum_j \gamma^i_j m^i b_j\right) + \left(\delta_{i,uncor} m^i\right)^2} + \sum_j b_j^2$$

Input to the fit:

- $\mu^i$: the measured cross section value at point $i$ $(\beta_i, Q^2_i, x_{\mathbb{P}i})$
- $\delta_{i,stat}$: the statistical uncertainty
- $\delta_{i,uncor}$: the uncorrelated systematic uncertainty
- $\gamma^i_j$: the correlated systematic uncertainty from source $j$

Note: all uncertainties are relative

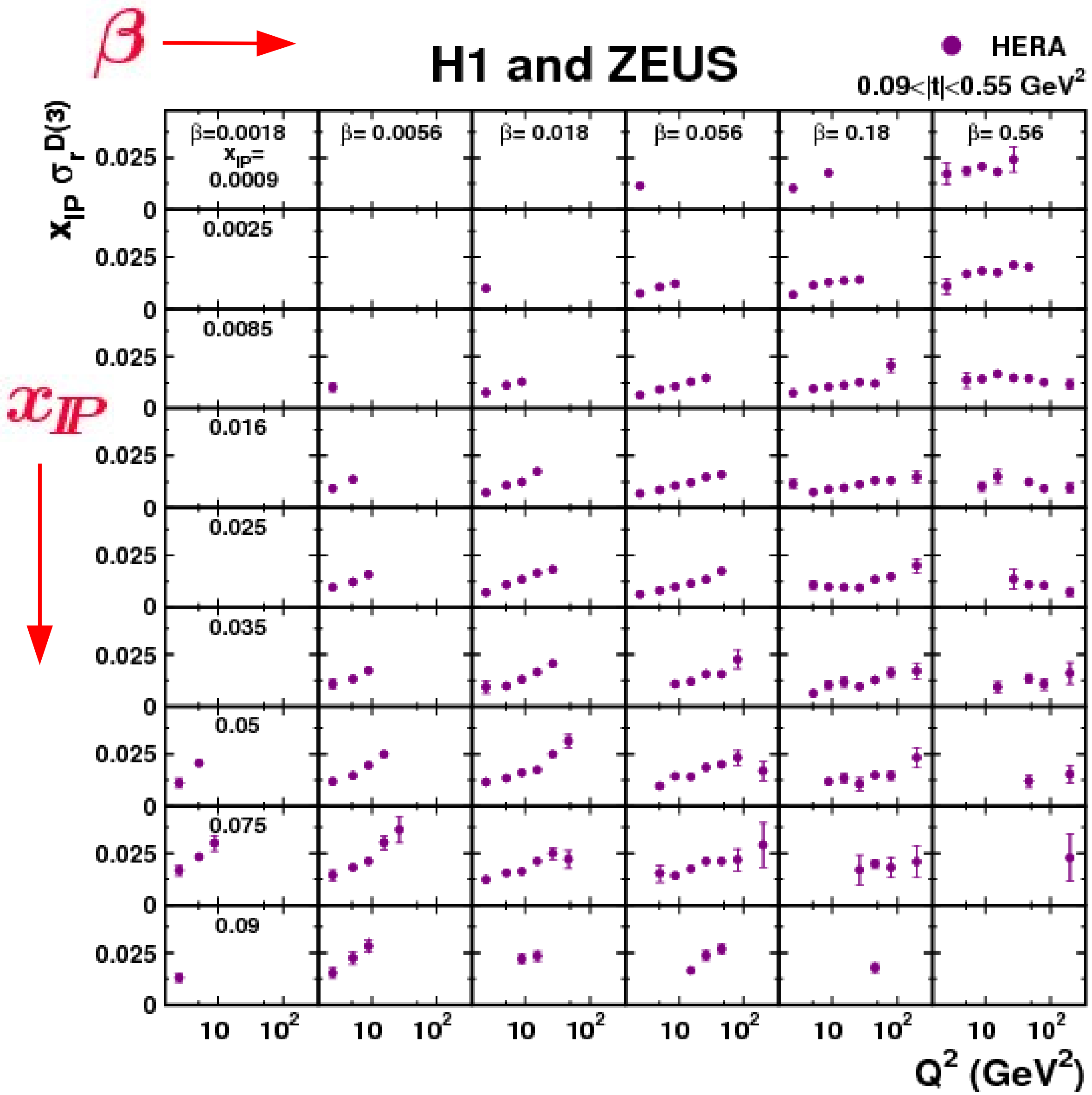
$m^i$ and $b_j$ are determined by the fit:

- $m^i$: Combined cross section value at point $i$
- $b_j$: Shift of correlated systematic uncertainty source $j$

**Advantages:**
- The experiments Calibrate each other
- Substantial Reduction of systematic uncertainties
- Data Consistency check from value of $\chi^2/ndf$
- Model Independence

Due to the correlated systematic uncertainties, also unique data points are affected and may shift in value and obtain better precision

# HERA $\sigma_r^{D(3)}$ vs. $Q^2$, in bins of $\beta$ and $x_{I\!P}$




**Results:**

191 x-sec. Measurements from 352 Data points

$\chi^2/ndf = 133/161$

**Uncertainties:**

Av. Stat.: 11%,

Av. Exp.: 13.8%

Av. Total: 14.3%,

Smallest Total: 6%

Normalisation: 4%,

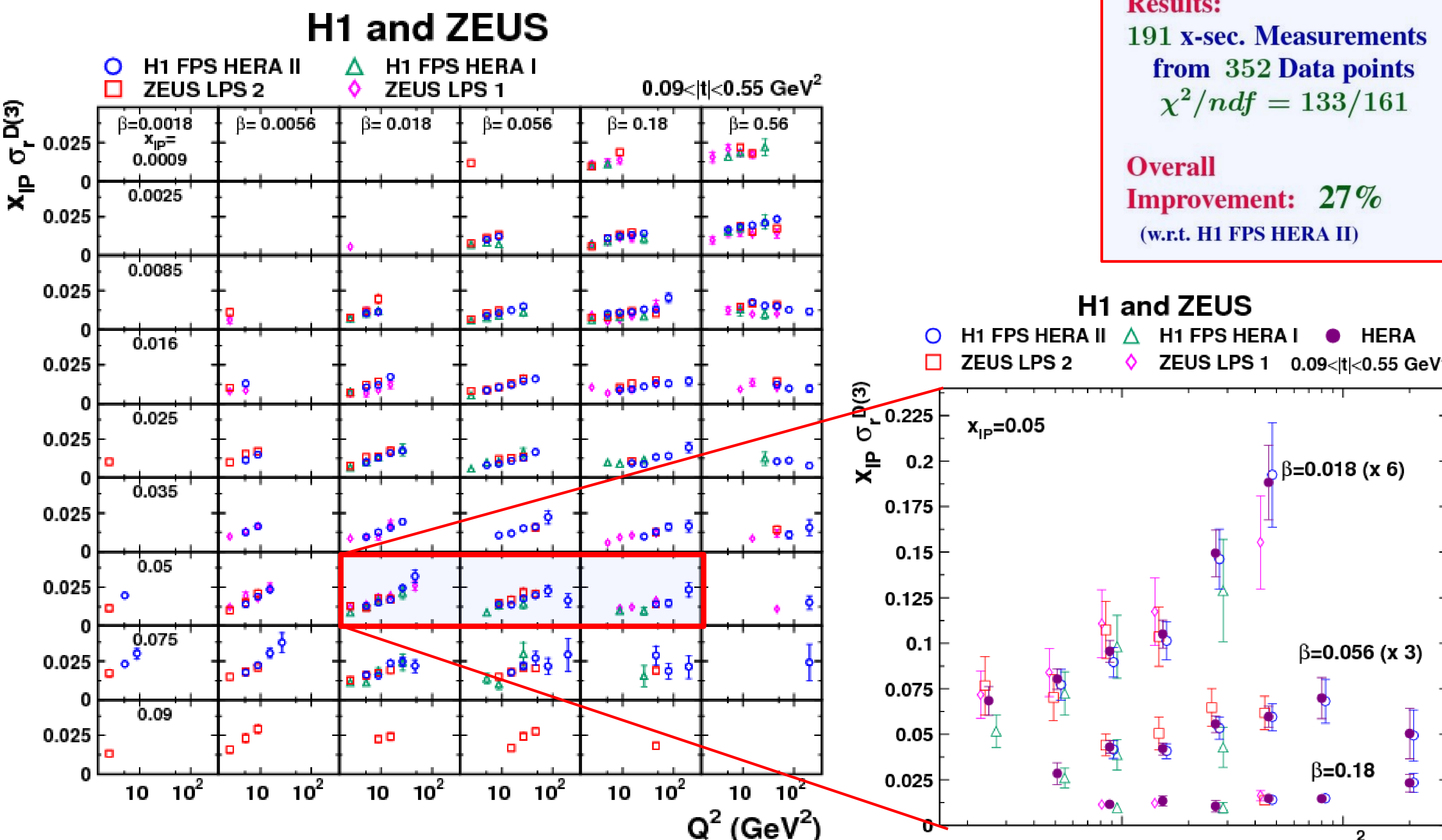
Procedural: 2.9%

**Overall Improvement: 27%**

(w.r.t. H1 FPS HERA II)

**The most precise Measurements of Scaling Violations in Diffractive DIS**

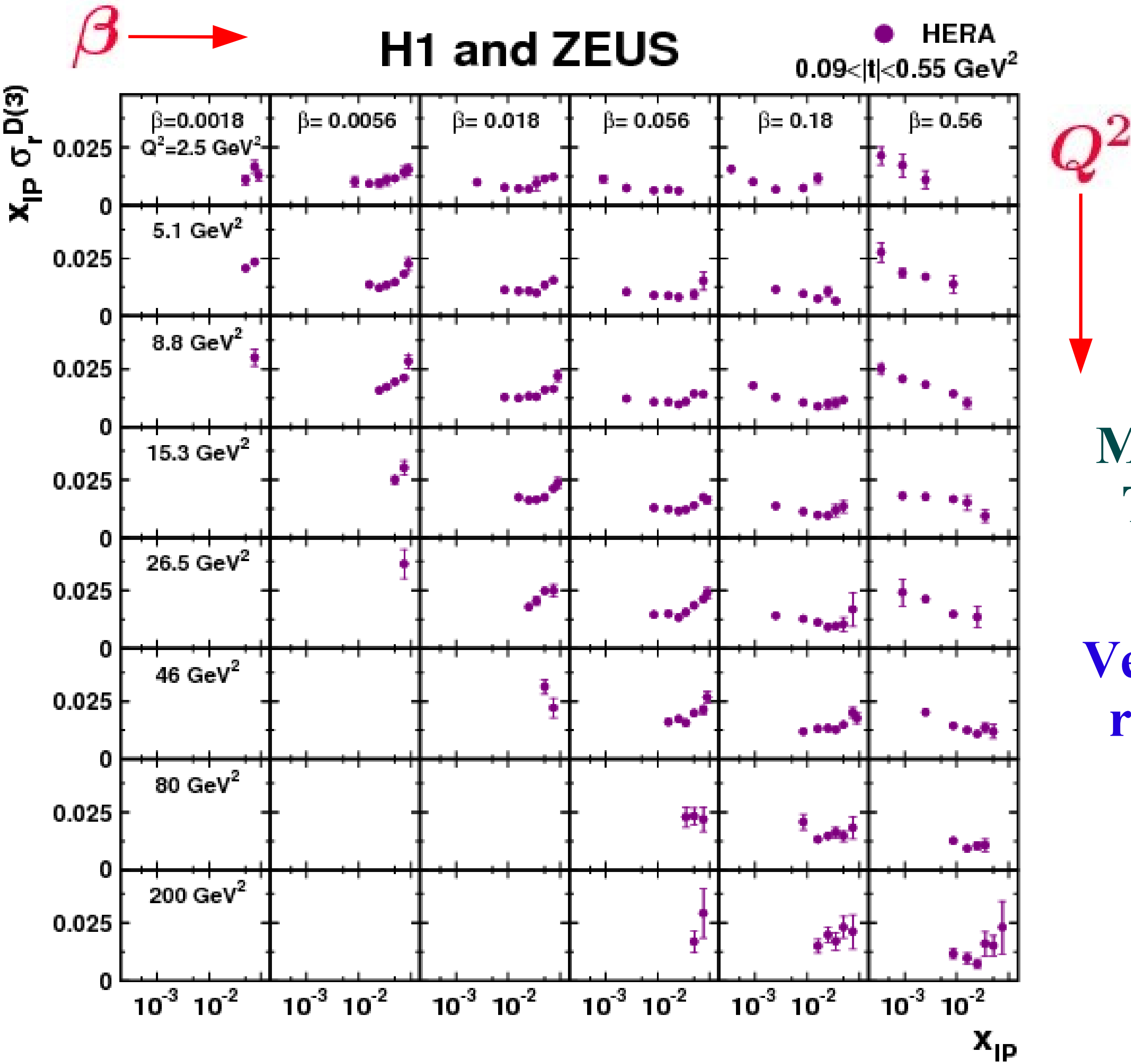
# H1 and ZEUS $\sigma_r^{D(3)}$ vs. $Q^2$, in bins of $\beta$ and $x_{I\!P}$




**Results:**
191 x-sec. Measurements
from 352 Data points
$\chi^2/ndf = 133/161$

**Overall Improvement: 27%**
(w.r.t. H1 FPS HERA II)

# HERA $\sigma_r^{D(3)}$ vs. $x_{I\!P}$, in bins of $\beta$ and $Q^2$




**Most Data Points have Total Precision of ~6%**

**Very precise data, ready for new analysis together with Combined LRG Data !**

# SUMMARY

- **Diffractive Data from H1 and ZEUS combined for the first time**

  [Eur.Phys.J. C72 (2012) 2175;  arXiv:1207.4864;  DESY 12-100]

- **Proton Spectrometer data from H1 FPS & ZEUS LPS**
  - **are consistent with each other**
  - **in the Combination Procedure undergo**

    **Mutual Calibration and Reduction of Systematic Errors;**

    **Large Gain of Precision in the Combined Data**

- **The Combined Data allow a Precise Normalisation of the**

  $ep \rightarrow eXp$ **Cross Section**
  - **Important input to the Large Rapidity Gap data analysis**
  - **Model Independent determination of background due to proton dissociative diffractive scattering**

## OUTLOOK

- **Combination of high statistics LRG Data from H1 and ZEUS**
- **HERA DPDF Determination from all Combined Data**

# Backup

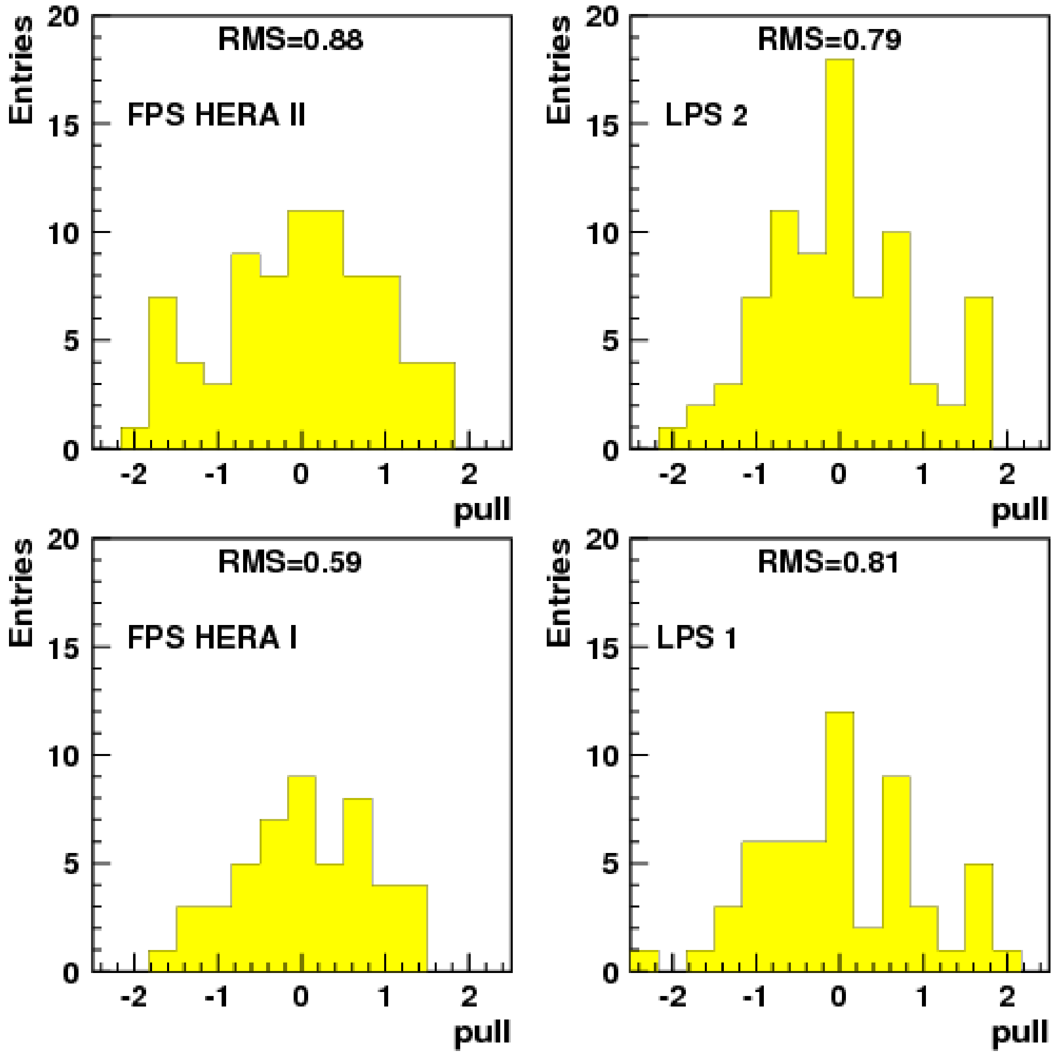
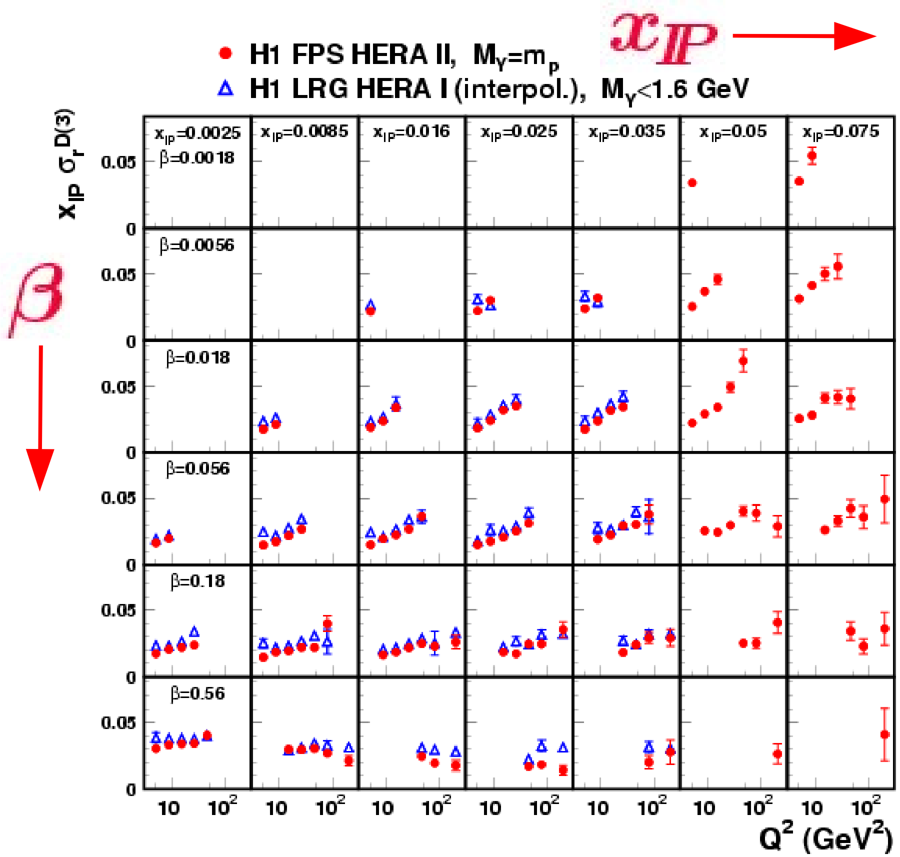


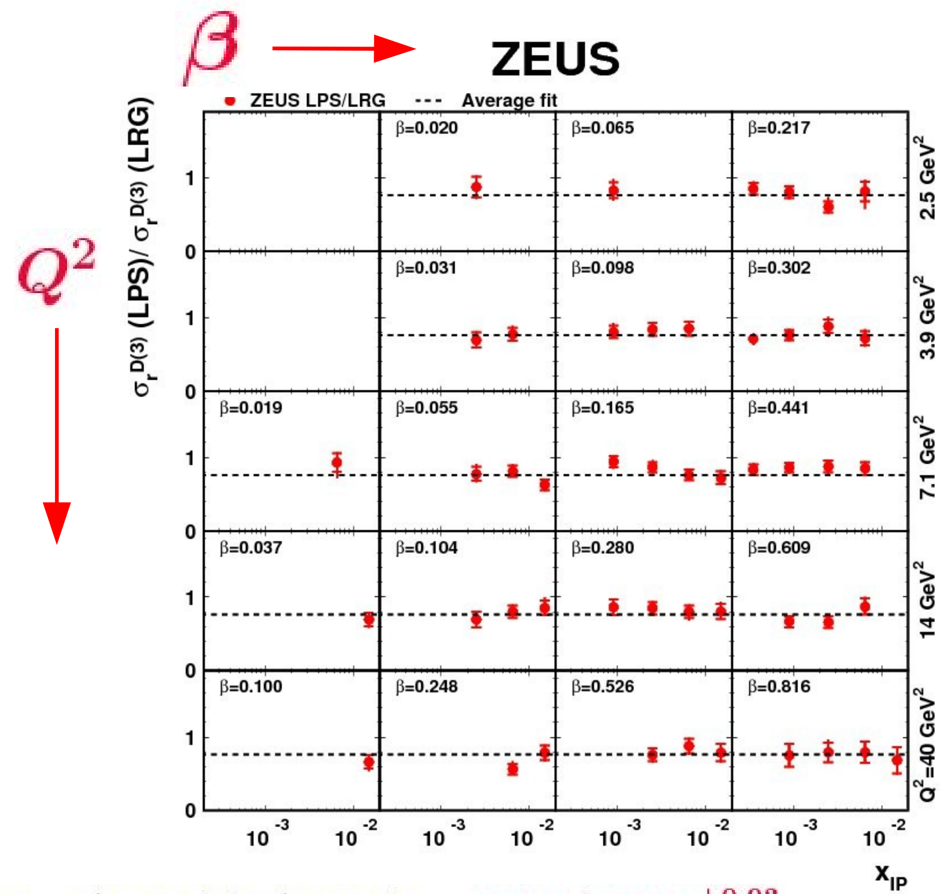

**Fig. 3: Pull distributions for the individual data sets. The root mean square gives the root mean square of the distributions.**

| Source | Shift ($\sigma$ units) | Reduction factor % |
|---|---|---|
| FPS HERA II hadronic energy scale $x_{I\!P} < 0.012$ | $-1.61$ | 56.9 |
| FPS HERA II hadronic energy scale $x_{I\!P} > 0.012$ | 0.13 | 99.8 |
| FPS HERA II electromagnetic energy scale | 0.49 | 85.9 |
| FPS HERA II electron angle | 0.67 | 66.6 |
| FPS HERA II $\beta$ reweighting | 0.15 | 90.4 |
| FPS HERA II $x_{I\!P}$ reweighting | 0.05 | 98.3 |
| FPS HERA II $t$ reweighting | 0.70 | 79.8 |
| FPS HERA II $Q^2$ reweighting | 0.09 | 97.6 |
| FPS HERA II proton energy | 0.05 | 45.6 |
| FPS HERA II proton $p_x$ | 0.62 | 74.5 |
| FPS HERA II proton $p_y$ | 0.27 | 86.5 |
| FPS HERA II vertex reconstruction | 0.07 | 97.0 |
| FPS HERA II background subtraction | 0.84 | 89.9 |
| FPS HERA II bin centre corrections | $-1.05$ | 87.3 |
| FPS HERA II global normalisation | $-0.39$ | 84.4 |
| FPS HERA I global normalisation | 0.81 | 48.9 |
| LPS 2 hadronic energy scale | $-0.02$ | 55.0 |
| LPS 2 electromagnetic energy scale | $-0.14$ | 62.4 |
| LPS 2 $x_{I\!P}$ reweighting | $-0.32$ | 98.2 |
| LPS 2 $t$ reweighting | $-0.26$ | 86.4 |
| LPS 2 background subtraction | 0.40 | 94.9 |
| LPS 2 global normalisation | $-0.53$ | 67.7 |
| LPS 1 global normalisation | 0.86 | 44.1 |

Table 3: Sources of point-to-point correlated systematic uncertainties considered in the combination. For each source the shifts resulting from the combination in units of the original uncertainty and the values of the final uncertainties as percentages of the original are given.

# FPS / LPS data vs. LRG data

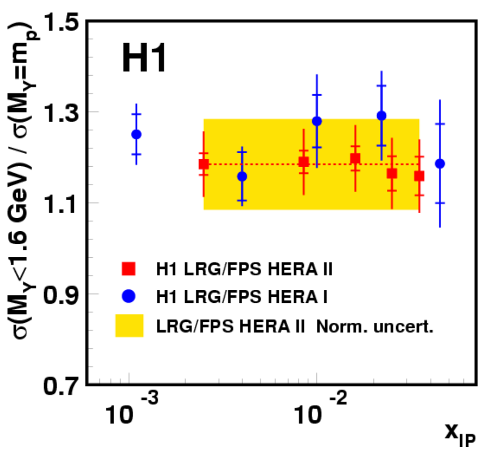



ZEUS: $\sigma(LPS)/\sigma(LRG) = 0.76 \pm 0.01^{+0.03}_{-0.02}$

H1: $\sigma(LRG, [M_Y < 1.6\ \mathrm{GeV}])/\sigma(FPS) = 1.20 \pm 0.11$

DIFFVM: $\sigma(LRG)/\sigma(FPS) = 1.15^{+0.15}_{-0.08}$




p-diss. bgrd in LRG data normalised by FPS/LPS data

p-diss. bgrd show same dependences as FPS/LPS data

→ No significant effect on DPDFs expected (which are determined from LRG data)