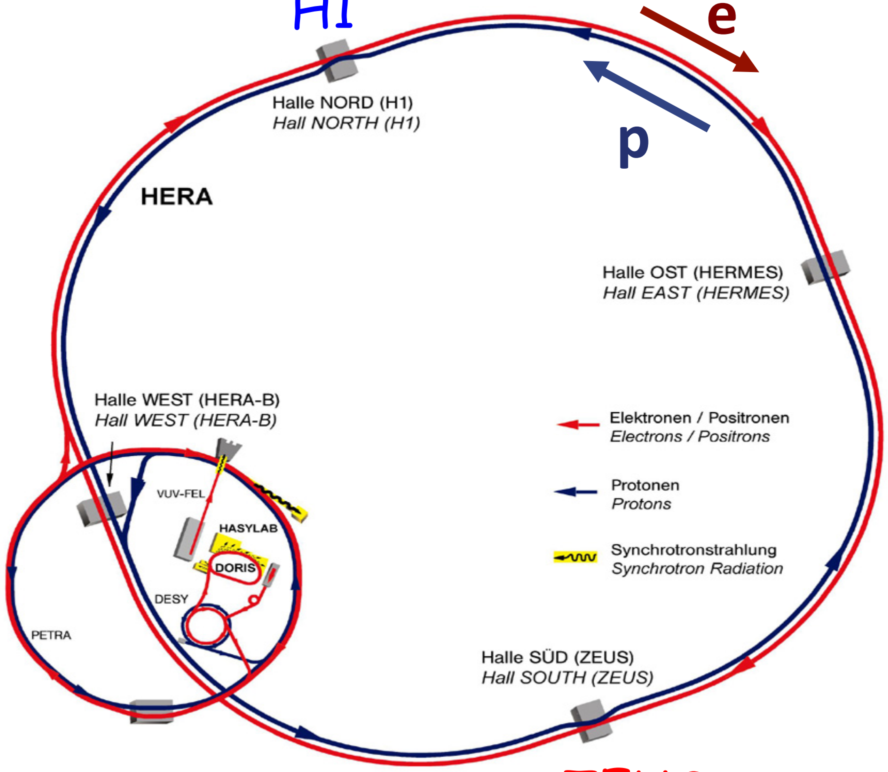
IFAE 2011
27-29 April 2011
Perugia

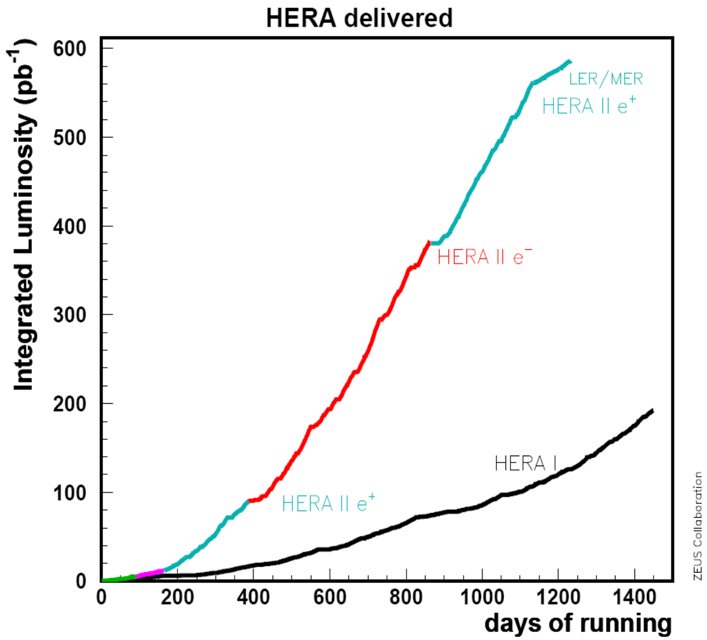
Combined Measurement of the Inclusive Diffractive Cross Sections at HERA

Valentina Sola
(Torino University and INFN)

- Diffraction in *ep* scattering
- Latest inclusive diffractive *ep* results
- QCD fits and diffractive PDFs extraction
- Combination of diffractive cross sections

HERA = Hoch Energie Ring Anlage





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

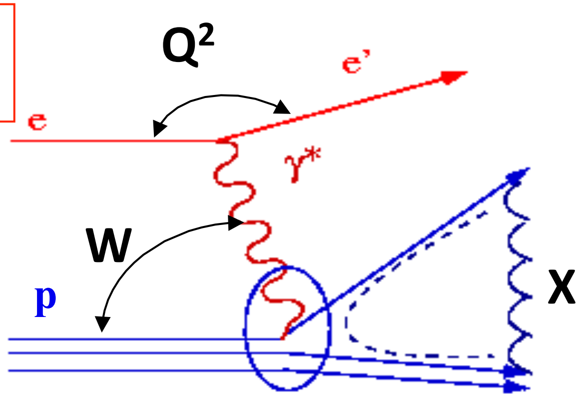
0.5 fb^{-1} collected by H1 and ZEUS experiments

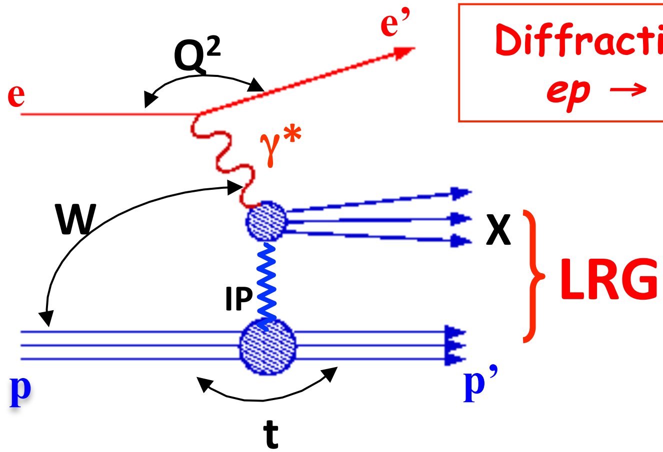
Final analyses of HERA data are underway

Diffraction at HERA

Standard DIS
ep → e'X

DIS
$Q^2 \geq 1$ GeV^2





Diffractive DIS
ep → e'Xp'

Q^2 = virtuality of exchanged photon

x = Bjorken scaling variable

y = inelasticity of virtual photon

W = invariant mass of γ*-p system

M_X = invariant mass of γ*-IP system

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

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

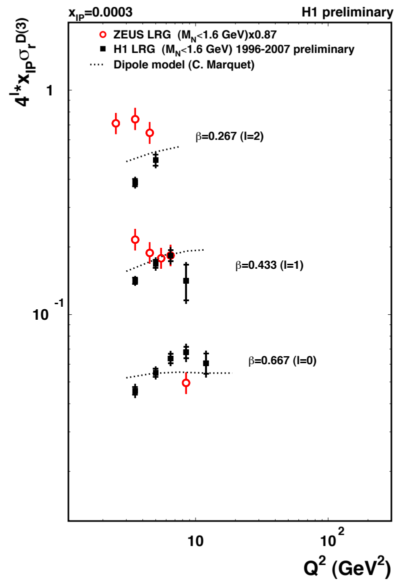
t = (4-momentum exchanged at p vertex)^2
typically: $|t| < 1$ GeV^2

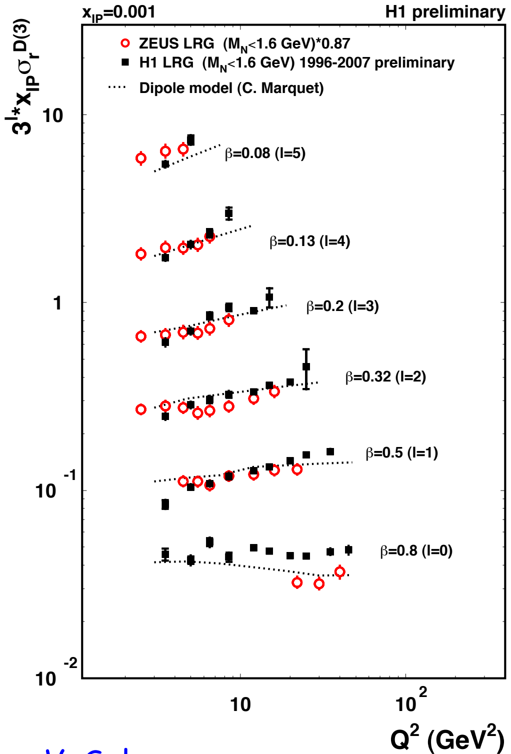
$$\frac{d^3\sigma^{ep\to e'Xp'}}{d\beta dQ^2 dx_{IP}} = \frac{2\pi\alpha^2}{\beta Q^4} Y_+ \underbrace{\left[F_2^{D(3)}(\beta, Q^2, x_{IP}) - \frac{y^2}{Y_+} F_L^{D(3)}(\beta, Q^2, x_{IP})\right]}_{\sigma_r^{D(3)}(\beta, Q^2, x_{IP})}$$

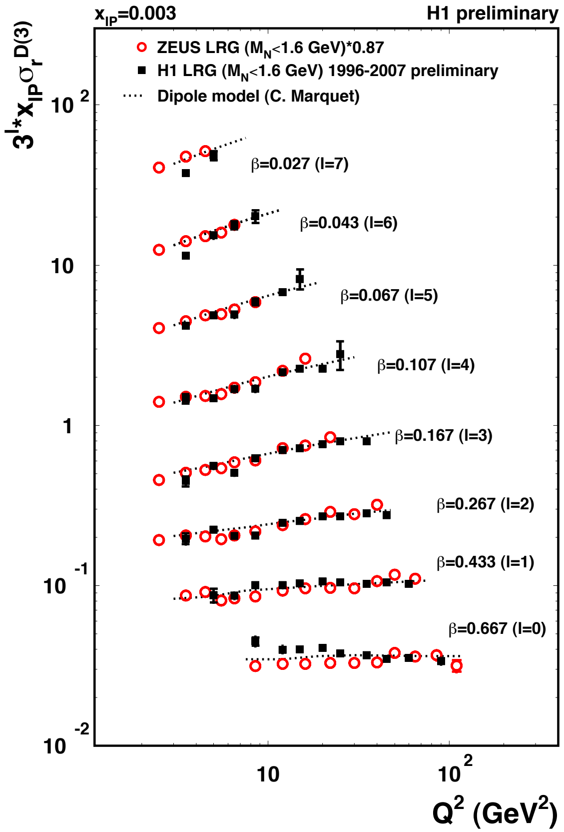
where $Y_+ = 1 + (1-y)^2$

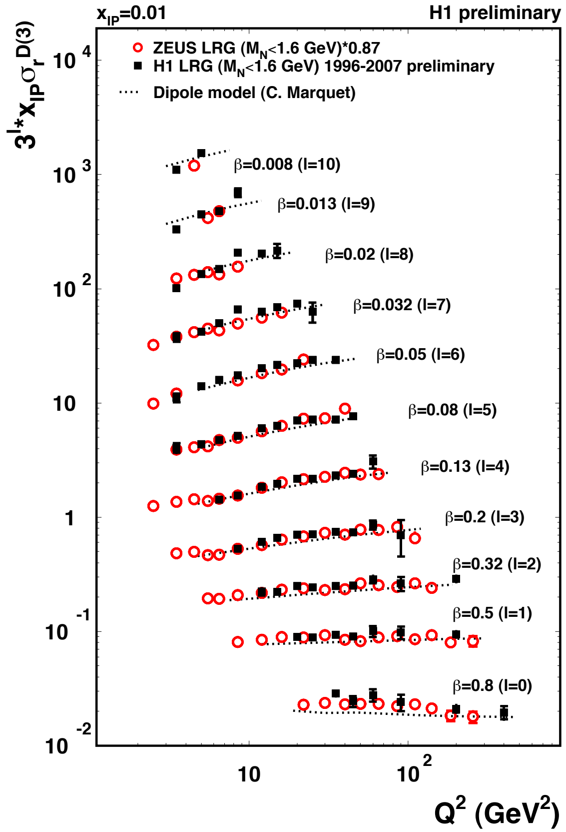
Diffractive events are selected exploiting the Large Rapidity Gap (LRG)

$\sigma_r^{D(3)}$ from H1 and ZEUS





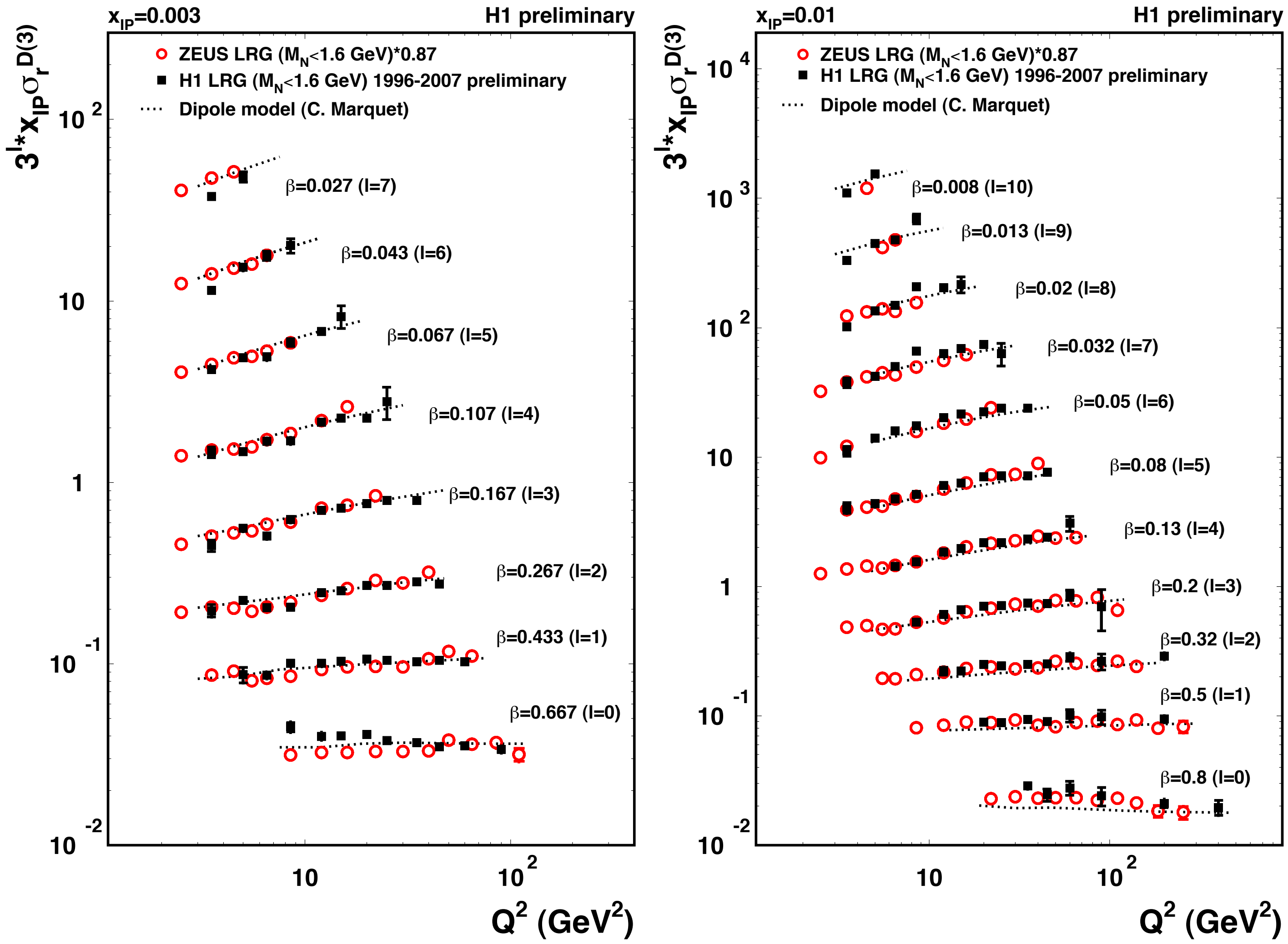




Diffractive measurements from HERA (LRG techinque)

- H1 '97 [Eur. Phys. J. C48 (2006) 715-748]
- ZEUS 2000 [Nucl.Phys. B816 (2009) 1-61]
- H1 '99/2000
  H1 '99 minimum bias
  H1 HERA II
  } [H1prelim-10-013]

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



ZEUS corrected to M_N < 1.6 GeV with PYTHIA MC

All available LRG data used by both Collaborations

Very precise measurements of the scaling violation for diffraction

Reduced cross section constrains quark density

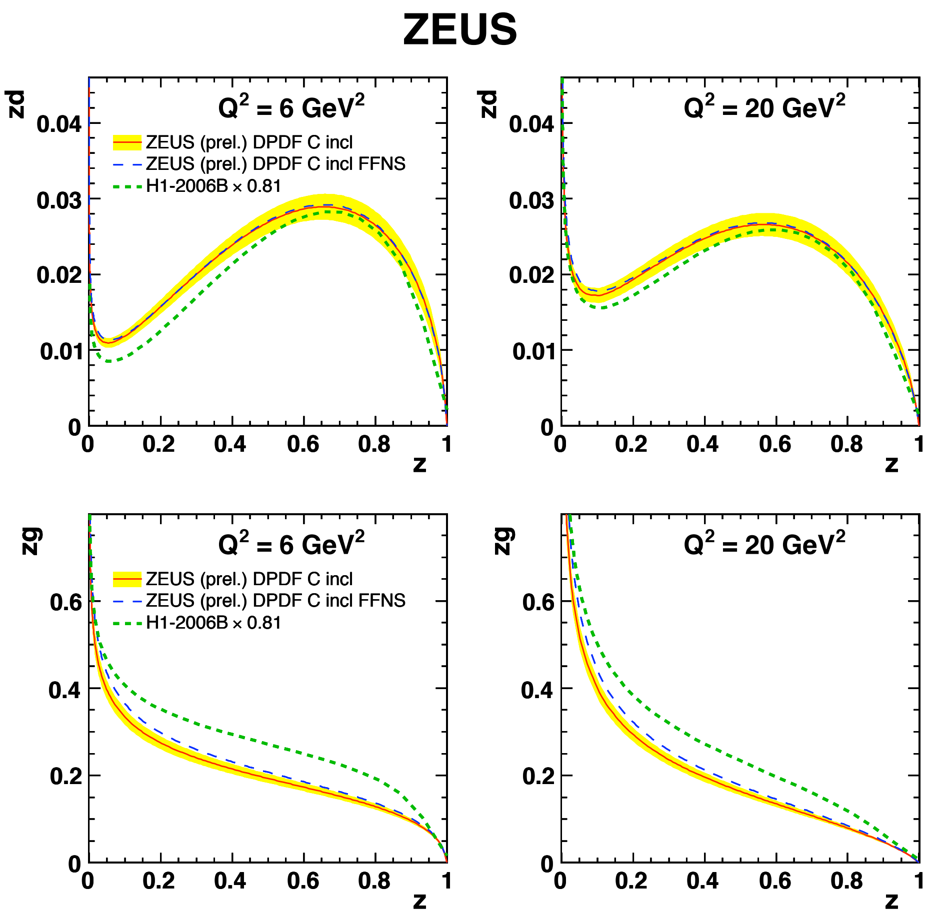
$\ln Q^2$ dependence constrains gluon density

⇨ QCD fits to data provide sets of diffractive PDFs

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

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	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^2_{exp}

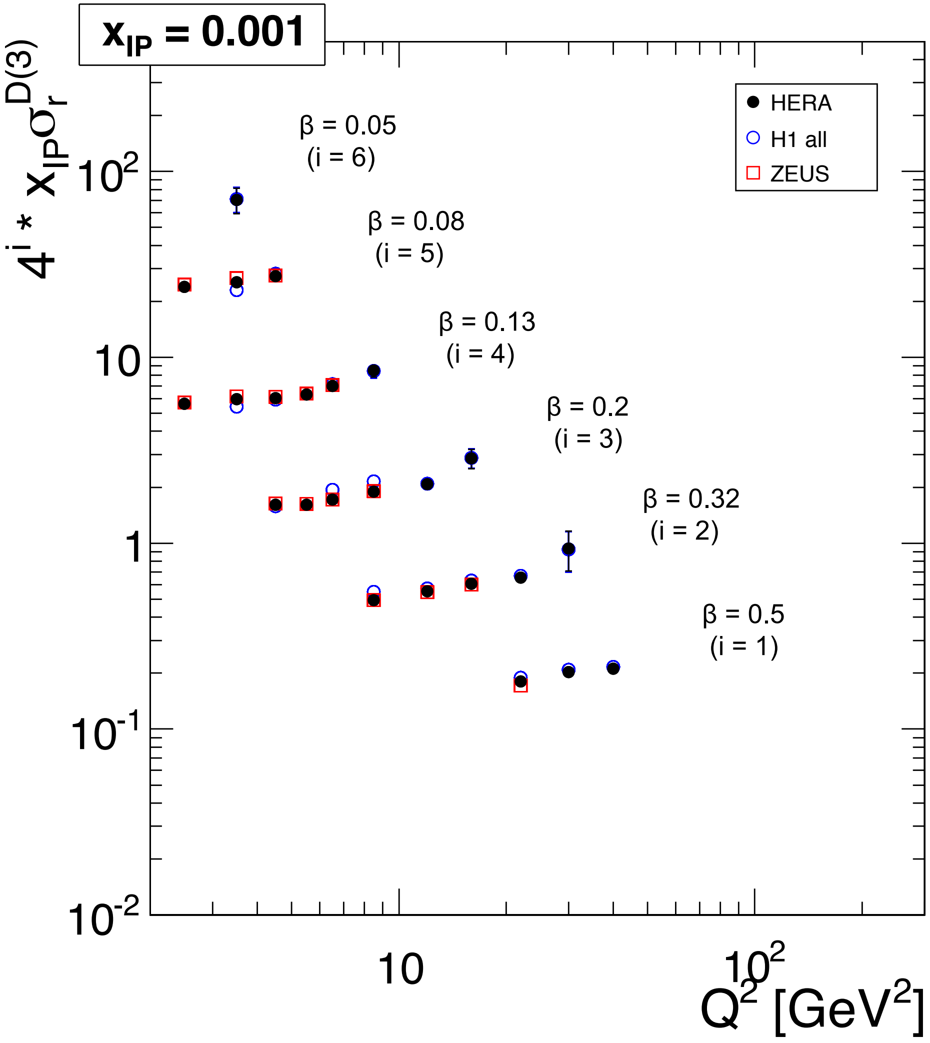
First Combination of $\sigma_r^{D(3)}$

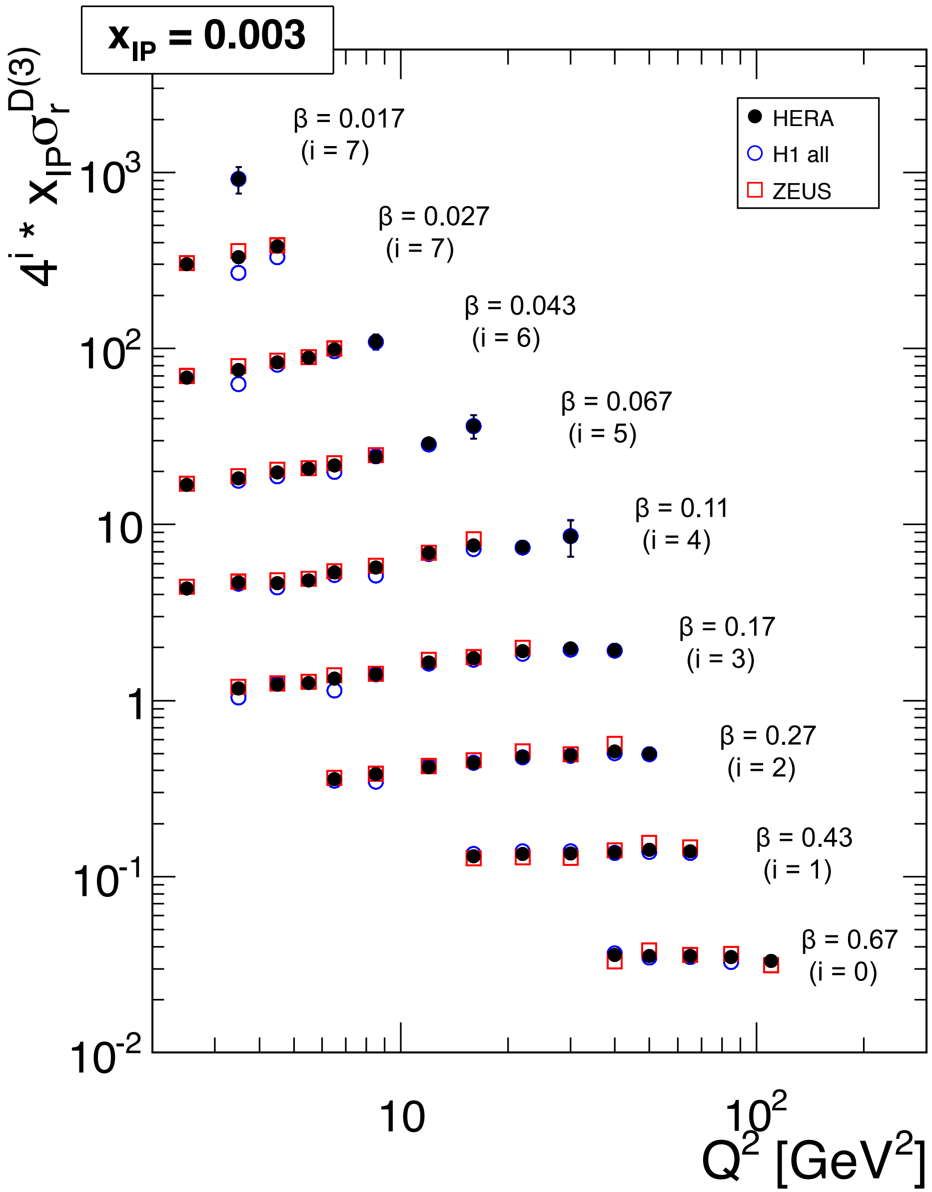
All the available data sets are used in the combination

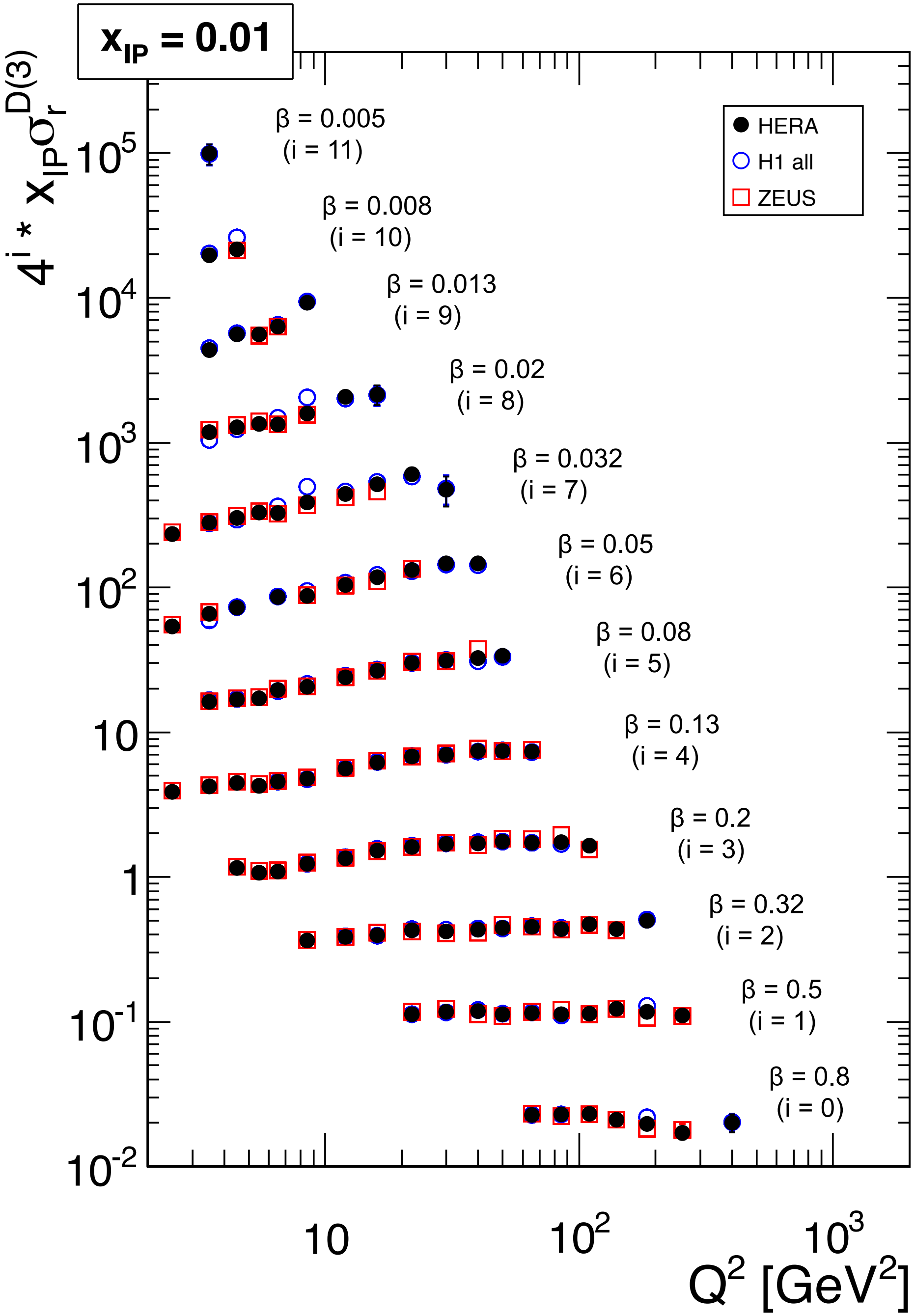
All samples are normalized to H1 '97 (M_N < 1.6 GeV)

Combination concentrates in a safe kinematic region
M_X > 4 GeV

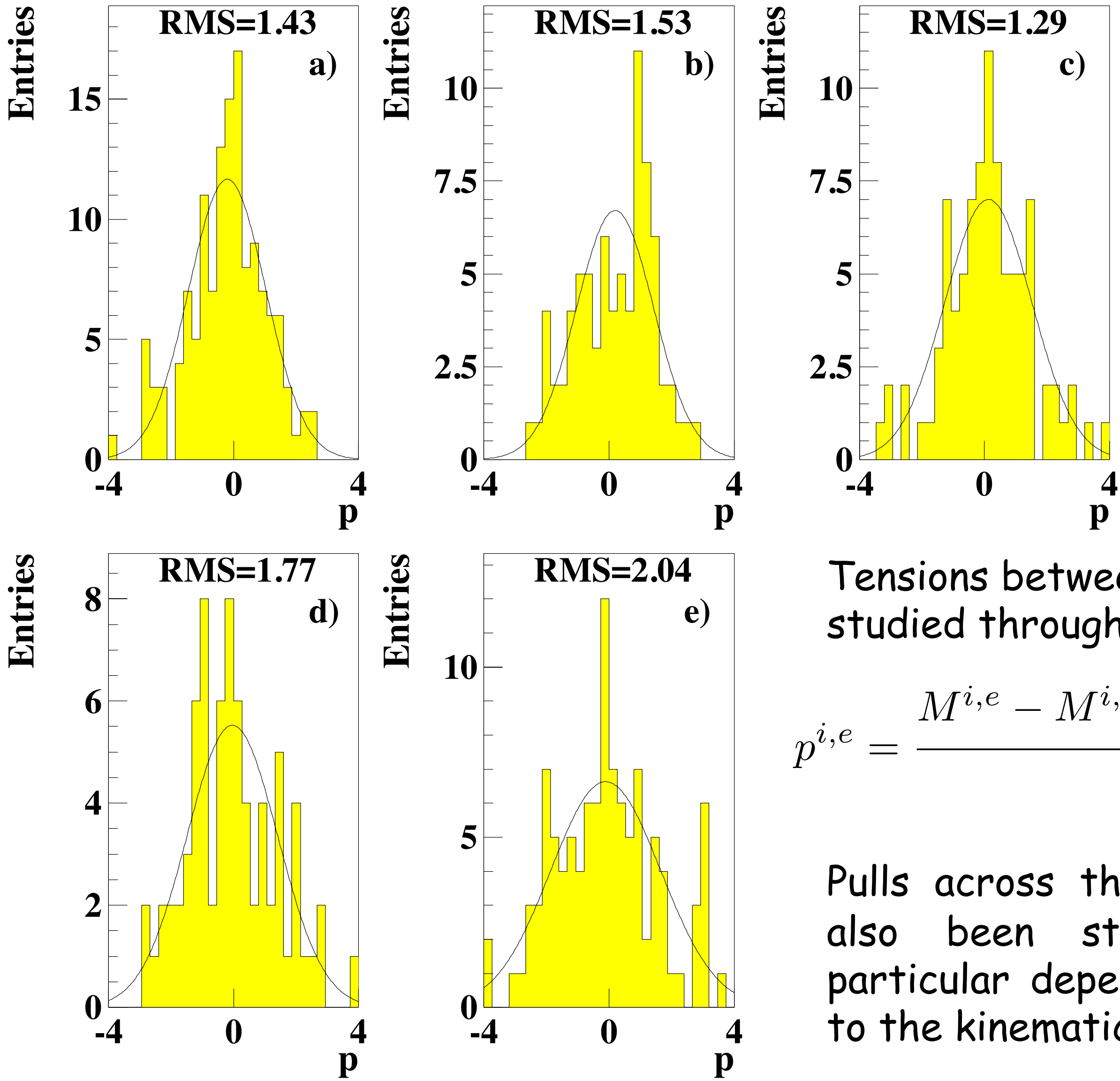
→ χ^2 / ndof = 845 / 364 = 2.32




$x_{IP} = 0.003$
$4^i * x_{IP}\sigma_r^{D(3)}$
HERA
H1 all
ZEUS
β = 0.017 (i = 7)
β = 0.027 (i = 7)
β = 0.043 (i = 6)
β = 0.067 (i = 5)
β = 0.11 (i = 4)
β = 0.17 (i = 3)
β = 0.27 (i = 2)
β = 0.43 (i = 1)
β = 0.67 (i = 0)
Q^2 [GeV^2]


$x_{IP} = 0.01$
$4^i * x_{IP}\sigma_r^{D(3)}$
HERA
H1 all
ZEUS
β = 0.005 (i = 11)
β = 0.008 (i = 10)
β = 0.013 (i = 9)
β = 0.02 (i = 8)
β = 0.032 (i = 7)
β = 0.05 (i = 6)
β = 0.08 (i = 5)
β = 0.13 (i = 4)
β = 0.2 (i = 3)
β = 0.32 (i = 2)
β = 0.5 (i = 1)
β = 0.8 (i = 0)
Q^2 [GeV^2]

Pull Distributions



a) H1 '97
b) H1 '99/2000
c) H1 99 mb
d) H1 HERA II
e) ZEUS 2000

Tensions between datasets can be studied through pull distributions

$$p^{i,e} = \frac{M^{i,e} - M^{i,ave}\left(1 - \sum_j \frac{\partial M^{i,ave}}{\partial \alpha_j} \Delta\alpha_{j,ave}\right)}{\sqrt{\sigma^2_{i,e} - \sigma^2_{i,ave}}}$$

Pulls across the phase space have also been studied, showing no particular dependence with respect to the kinematic variables

Conclusions

✓ After 15 years of running HERA provided unique diffractive data

✓ Combination of diffractive cross sections between H1 and ZEUS experiments is ongoing

⇨ χ^2 of the combination shows some inconsistency between datasets

⇨ lot of studies done to undertsand possible sources of disagreement

⇨ error treatment à la PDG can be used to reach a good consistency

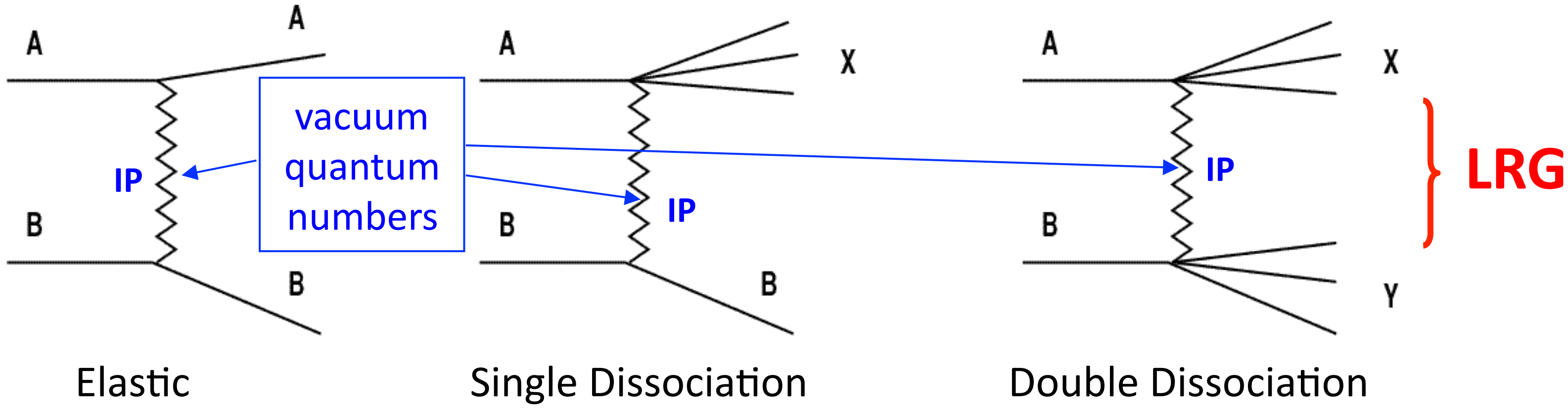
✓ A precise and unique set of diffractive PDFs can be extracted from the combined cross sections

⇨ DPDFs can be used to predict other diffractive processes

Thank You

Diffraction in Hadron Scattering

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



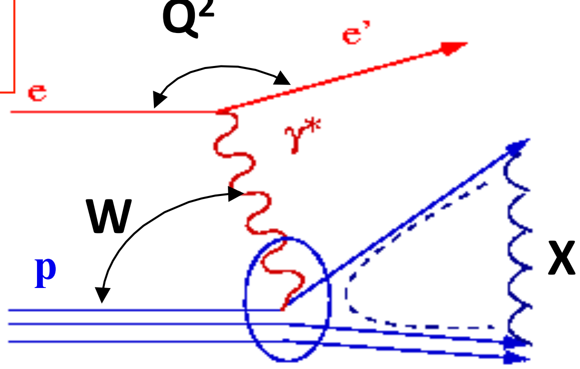
⇨ Beam particles emerge intact or dissociated into low-mass states
→ Very small fractional momentum losses (within a few %)

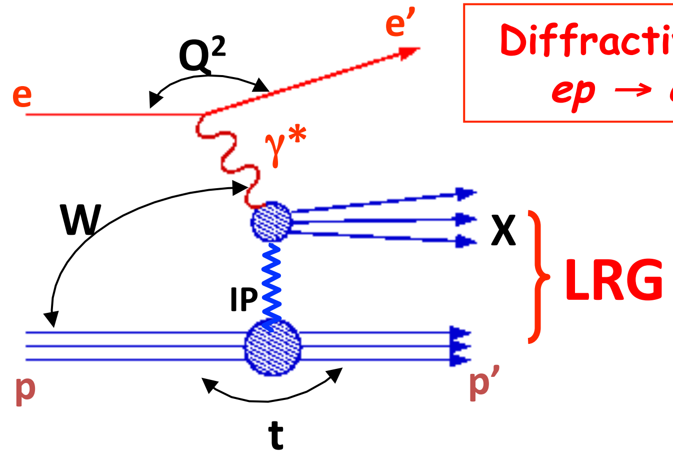
⇨ Final-state systems separated by a large polar angle
(or pseudorapidity $\eta = -\ln[\tan(\theta/2)]$)
→ Large Rapidity Gap (LRG)

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

Diffraction at HERA

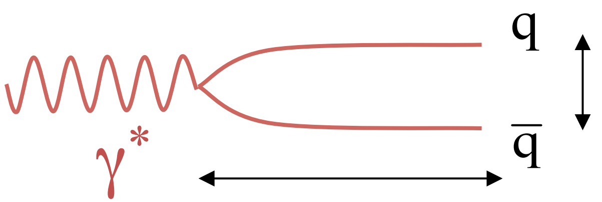
Standard DIS
ep → e'X





Diffractive DIS
ep → e'Xp'

Real and virtual photons can fluctuate in hadronic states ($q\bar{q}$, $q\bar{q}g$, ...)



$$\propto \frac{1}{\sqrt{Q^2 + M^2_{q\bar{q}}}}$$

$$\propto E_\gamma \sim W^2 \sim 1/x$$

(as seen in the proton rest-frame)

Q^2 = photon virtuality
x = Bjorken scaling variable

✓ Lifetime of $q\bar{q}$ dipole (hadron!) long because of large Lorentz boost (E_γ ~ 50 TeV at HERA)

→ Dipole interacts hadronically with the proton

✓ Transverse size proportional to $1/\sqrt{(Q^2+M_{qq}^2)}$

→ If dipole size small, its interaction with the proton can be treated perturbatively

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

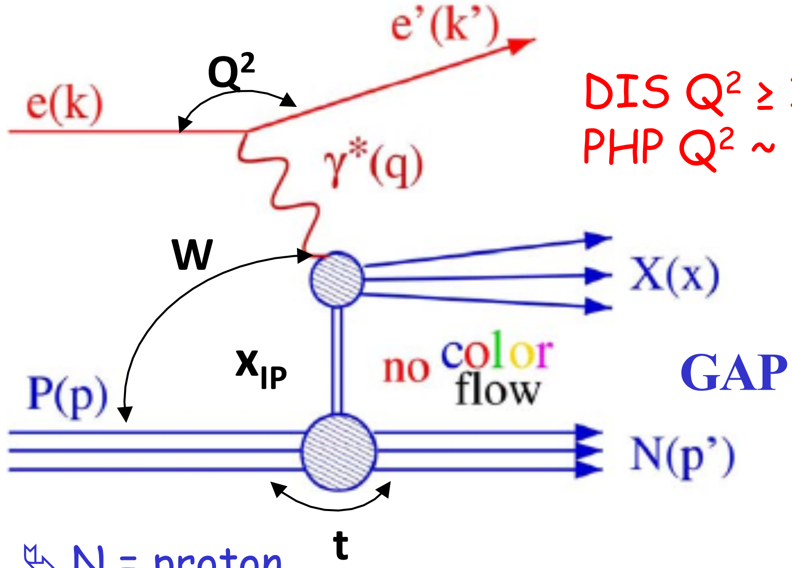
W = invariant mass of γ^*-p system

M_X = invariant mass of γ^*-IP system

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

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

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



DIS $Q^2 \geq 1$ GeV^2
PHP $Q^2 \sim 0$

- N = proton → SD events
- N = proton dissociative system → DD events (background)

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

where $Y_+ = 1 + (1-y)^2$ $\qquad = \sigma_r^{D(4)}(\beta,Q^2,x_{IP},t)$

When t is not measured $\sigma_r^{D(3)}(\beta, Q^2, x_{IP}) = \int \sigma_r^{D(4)}(\beta, Q^2, x_{IP}, t)\,dt$

Diffractive PDFs from NLO Fits

Inclusive Data

NLO QCD Fits:
- parametrize quark singlet and gluon at Q^2_0 = 1.8 GeV^2

$$z\, f_{u,d,s}(z, Q^2_0) = A_q\, z^{Bq}\, (1-z)^{Cq}$$
$$z\, f_g(z, Q_0^2) = A_g\, z^{Bg}\, (1-z)^{Cg}$$

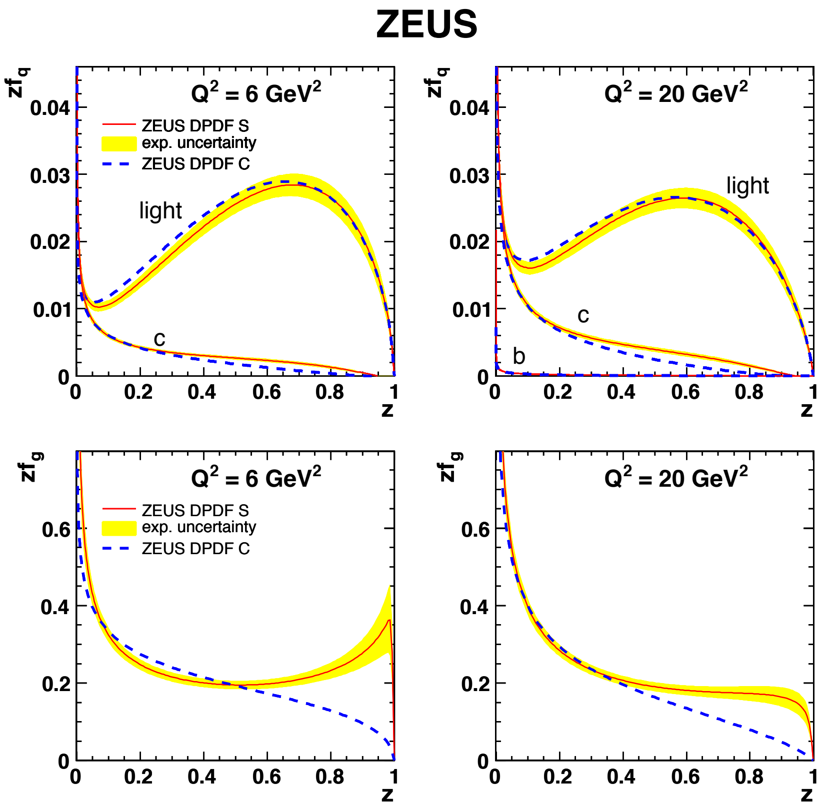
- evolve with NLO DGLAP and fit

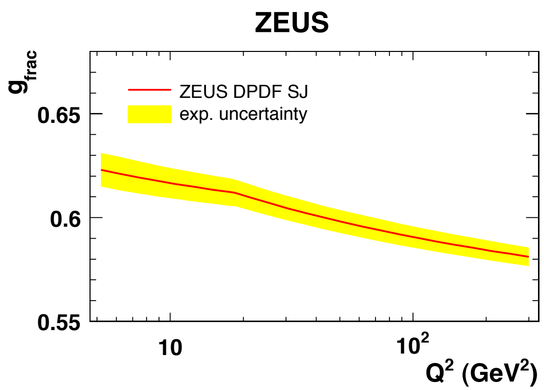
Different parametrizations

Well constrained singlet
Gluon weakly constrained in the high z_{IP} region (gluon density from $\ln Q^2$ dependence of σ_r^D)

DPDFs are gluon dominated

(z = momentum fraction of the diffr exchange entering the hard scattering)

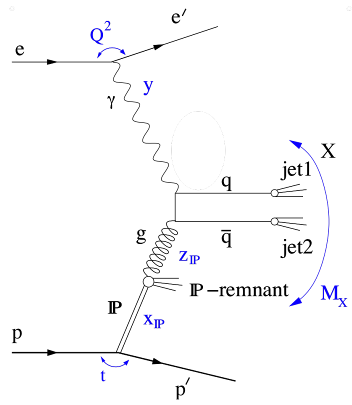




[Nucl.Phys. B831 (2010) 1-25]

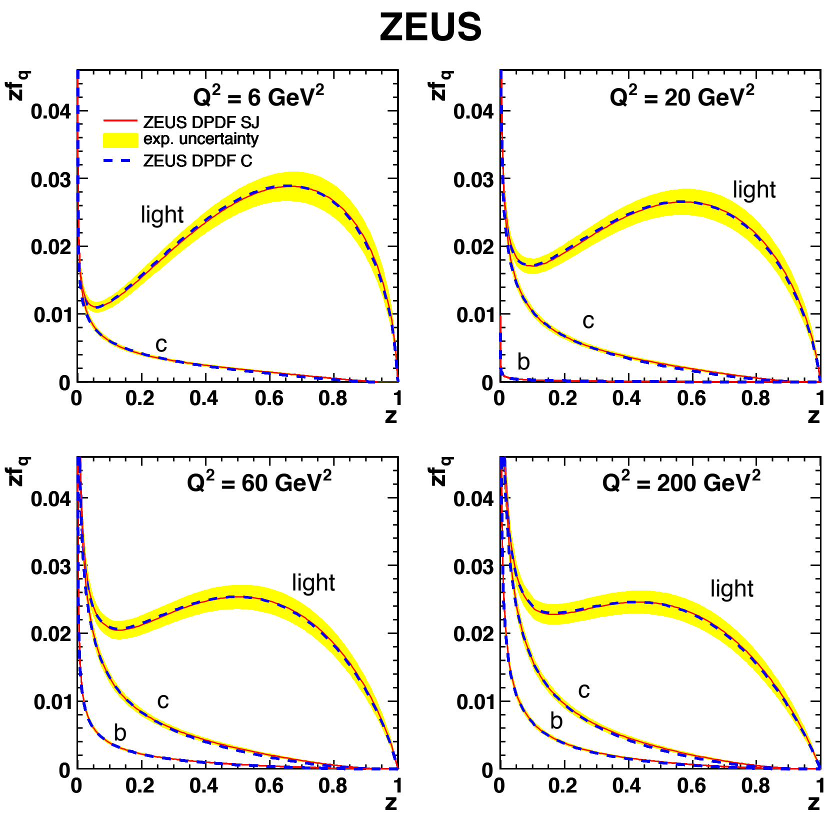
Diffractive PDFs from NLO Fits

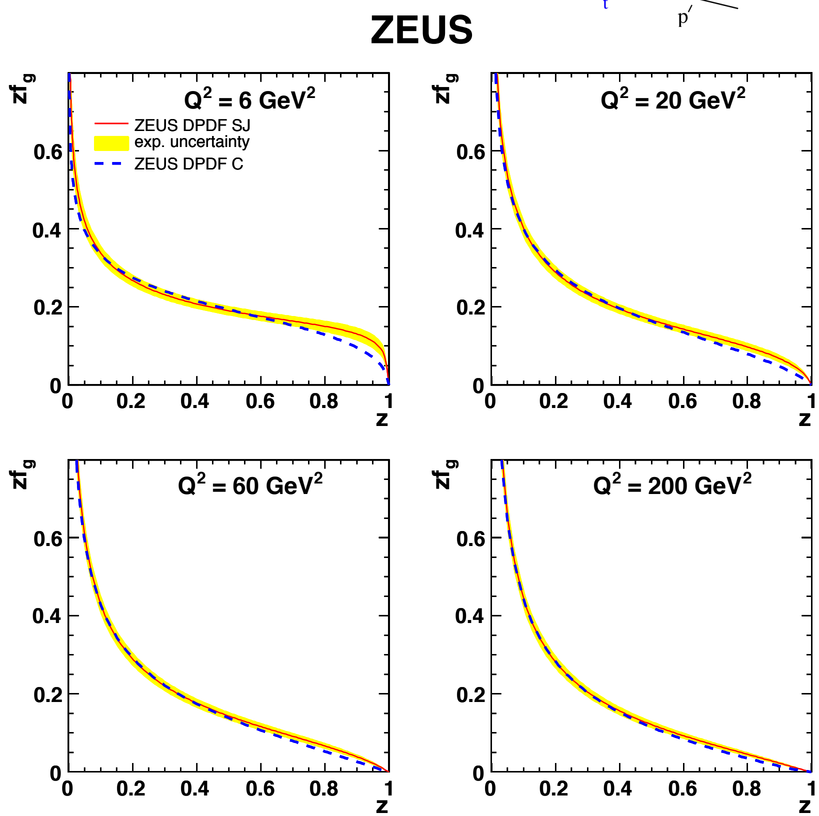
Inclusive and Dijet Data



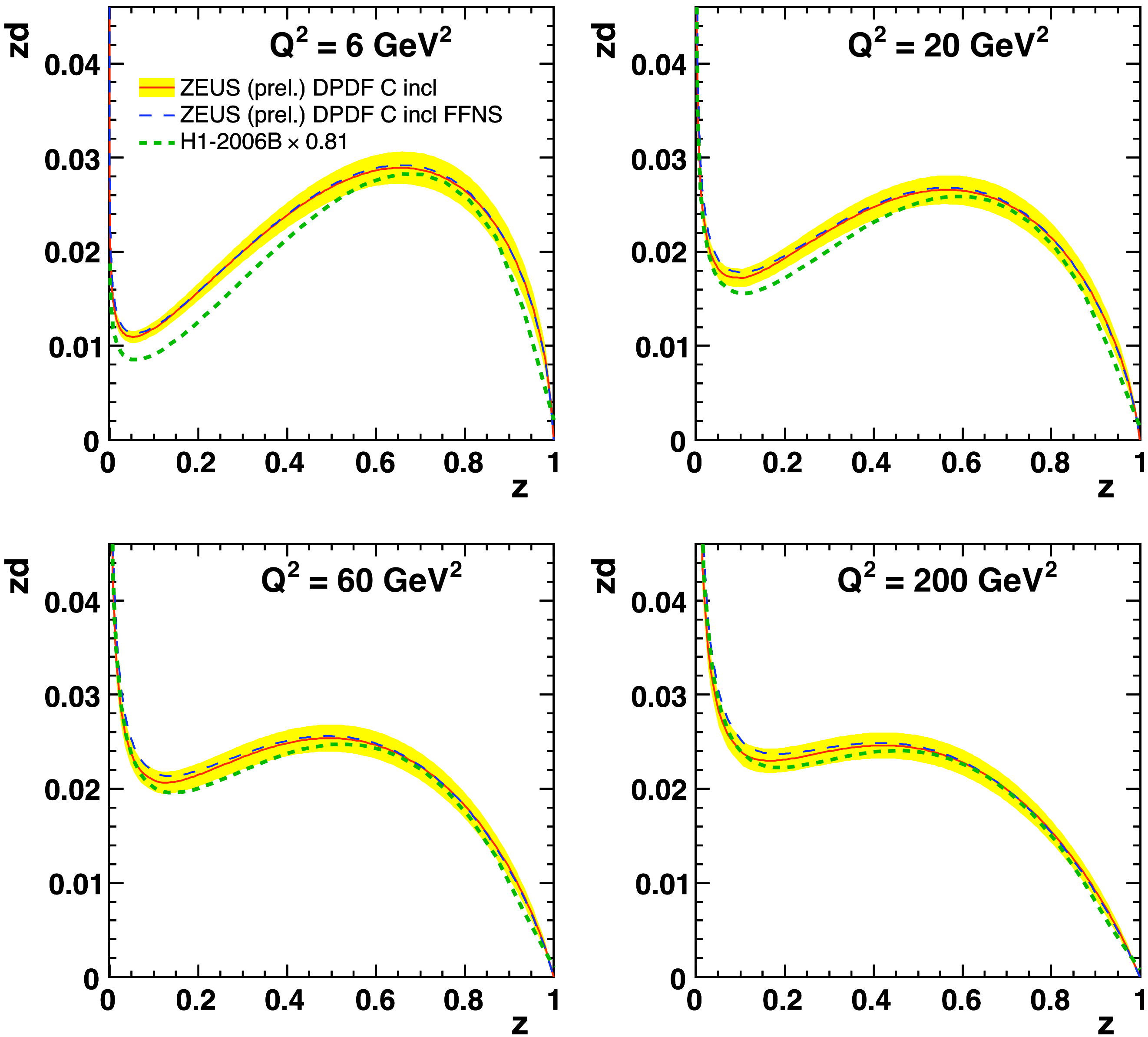
Diffractive dijet data are directly sensitive to the gluon as the photon-gluon fusion contributes at first order

Singlet and gluon constrained with similar precision across the whole kinematic range



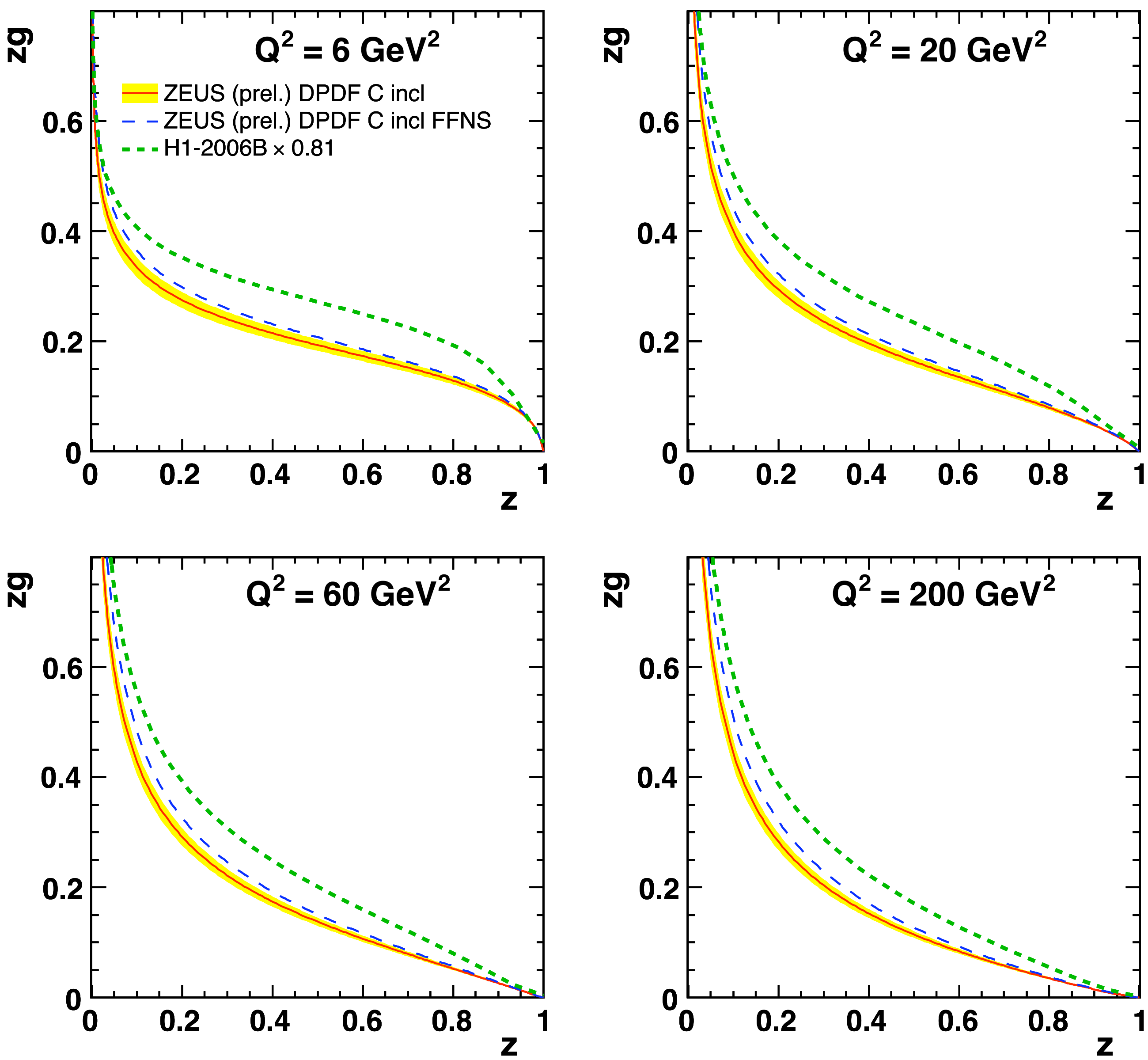


ZEUS



zd
z
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
0.01
0.02
0.03
0.04
0.2
0.4
0.6
0.8
1

ZEUS



zg
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
0.2
0.4
0.6
0.8
1
z

Motivation

- 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
  $\rightarrow$ Experiments cross calibrate each other
- The combination method uses an iterative χ^2 minimization which include full error correlations
  (A. Glazov – DIS05 & HERA-LHC WS, code available)
- The combined cross sections can be used as single input in a QCD analysis to extract unique and precise proton's diffractive PDFs

χ^2 Definition

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

for a single data set

i = measured data point
j = correlated systematic error source

M^i	measured central values
$M^{i,true}$	fitted combined H1 – ZEUS values
σ_i	statistical and uncorrelated systematic uncertainties
σ_{α_j}	correlated systematic uncertainties
$\frac{\partial M^i}{\partial \alpha_j}$	sensitivity of datum i to systematic j
$\Delta\alpha_j$	fitted shift of correlated uncertainties

Cross calibration of the correlated systematics between different data sets

If all $\Delta\alpha_j = 0 \rightarrow$ standard weighted average

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

Caveat

- In principle a nice simple χ^2 which allows minimization by linear equations
- Unbiased for uncertainties independent of the central value (additive)
- However, for cross sections, many uncertainties are proportional to the central value (multiplicative)
- This introduces a bias, as a smaller M^i will have a smaller relative error and hence give a smaller overall χ^2

⇘ This can be avoided modifying the χ^2 definition that use an iterative procedure

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

for a single data set

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

Uncertainties

- Statistical uncertainties are uncorrelated

- Systematic uncertainties
  - point-to-point uncorrelated errors, added in quadrature to statistical errors giving total point-to-point uncorrelated uncertainties (additive)
  - point-to-point correlated errors (e.g. energy scales), often common for different measurements (e.g. PS, LRG) of a given experiment and run period (multiplicative or additive?)
  - overall normalization uncertainty (multiplicative)

- Further systematic uncertainties correlated between H1 and ZEUS (e.g. MC simulation, calibration methods, ...) are possible and need to be carefully studied

Combination - Instructions for Use

Combine H1-ZEUS diffractive cross sections with fitting combination code

Combination code can be used in two different configurations

- correlations among systematic uncertainties neglected
  (as equivalent to weighted average, where all the uncertainties are treated as uncorrelated and added in quadrature)
- full correlation among systematic uncertanties (treated as multiplicative)

The output of the fit to the correlated systematic uncertainties will look like e.g.

```
Fitted systematics:

1   dlar_h1      0.1723   0.3938
2   dele_h1      3.3292   0.3340
```

where e.g.

```
dlar_h1   0.1723   0.3938
```

means that H1 LAr hadronic energy scale changes by 0.17 original sigma and the related uncertainty is reduced of a factor 0.3938

Fitted Systematics

1	dlar_h197	0.7248	0.7823
2	dele_h197	2.0106	0.4554
3	dtheta_h197	-0.5638	0.6529
4	dnoise_h197	-0.7904	0.4354
5	dbg_h197	0.2076	0.5496
6	dplug_h197	-0.2302	0.9074
7	dspa_h197	-0.0040	0.6489
8	dlar_h19900	1.1257	0.5392
9	dele_h19900	-0.4945	0.4984
10	dtheta_h19900	0.5423	0.7683
11	dnoise_h19900	-0.9545	0.5831
12	dbg_h19900	0.4001	0.9954
13	dplug_h19900	1.0683	0.8672
14	dspa_h19900	0.0000	1.0000
15	dlar_h1mb99	-1.2597	0.5507
16	dele_h1mb99	0.9095	0.6361
17	dtheta_h1mb99	-1.8743	0.6120
18	dnoise_h1mb99	-0.2522	0.4532
19	dbg_h1mb99	-0.9254	0.7381
20	dplug_h1mb99	1.2627	0.8012
21	dspa_h1mb99	0.0000	1.0000
22	dlar_h1hera2	2.0647	0.4001
23	dele_h1hera2	-0.5357	0.4052
24	dtheta_h1hera2	-0.1390	0.3149
25	dnoise_h1hera2	-2.1922	0.4605
26	dbg_h1hera2	-0.6079	0.9953
27	dplug_h1hera2	0.0000	1.0000
28	dspa_h1hera2	0.0000	1.0000
29	dxpom_h1th	-0.6335	0.7000
30	dbeta_h1th	1.0876	0.5394
31	dq2_h1th	-0.7961	0.8429
32	Eescale_zeus	-0.9661	0.4124
33	Ehscale_zeus	-1.0712	0.5011
34	xpomW_zeus	0.6447	0.5677
35	zufoC_zeus	-1.8189	0.8564

First Combination of $\sigma_r^{D(3)}$

All the published data sets are used in the combination

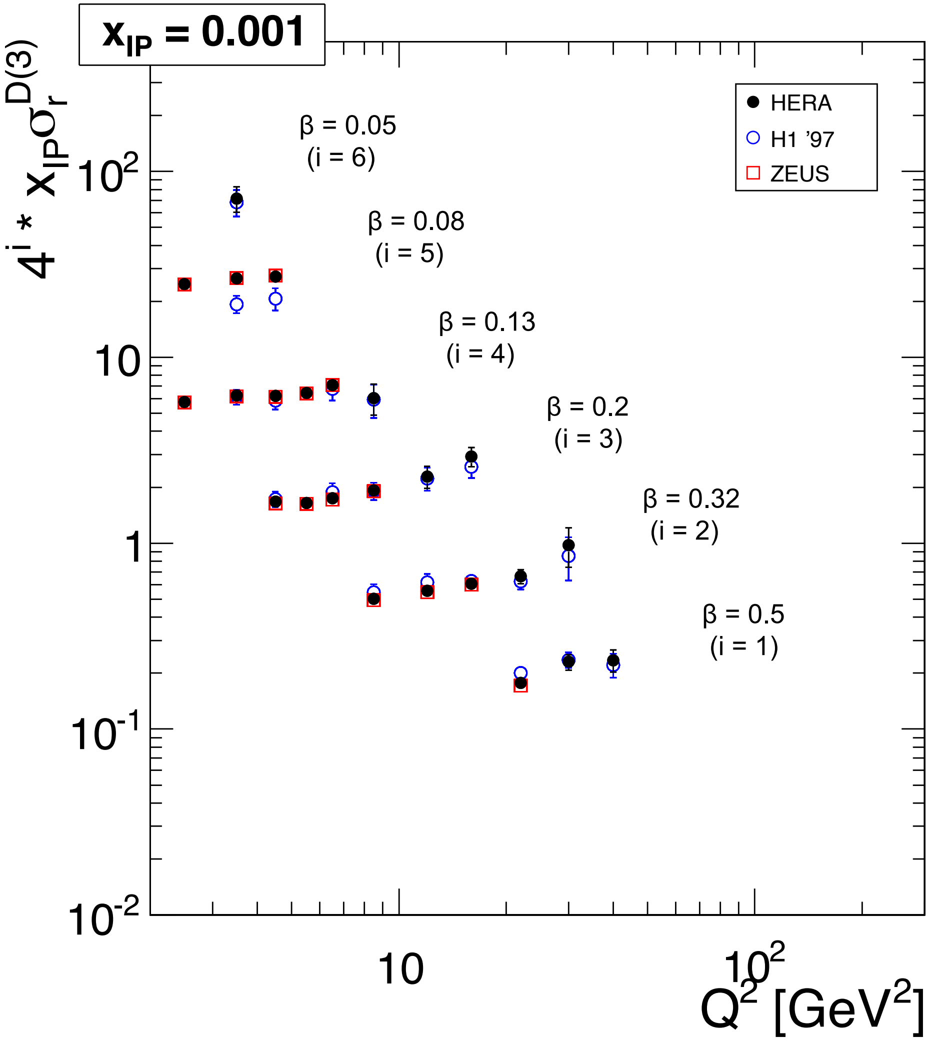
All samples are normalized to H1 '97 (M_N < 1.6 GeV)

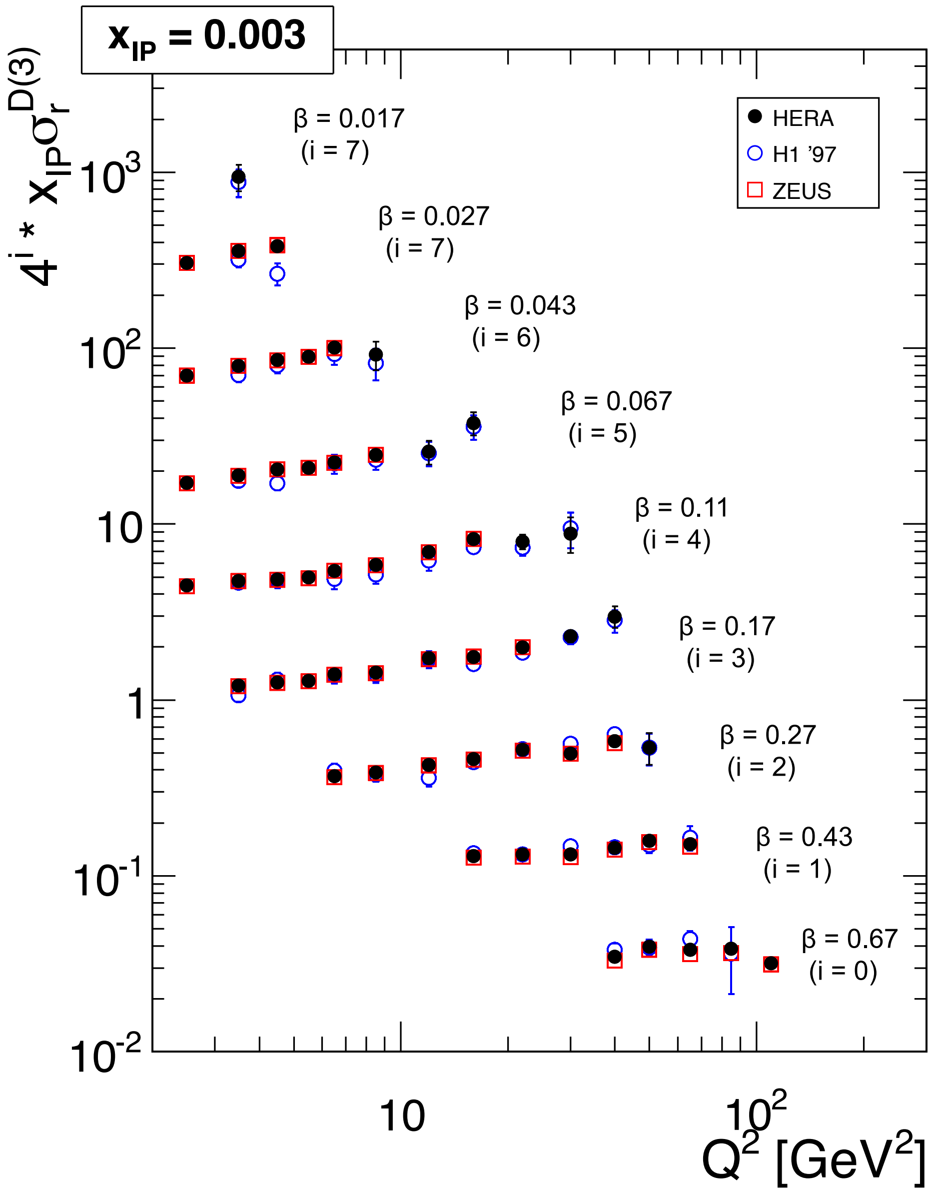
Combination concentrates in a safe kinematic region

M_X > 4 GeV

The consistency of the combined data is given by

→ χ^2 / ndof = 157 / 113 = 1.35





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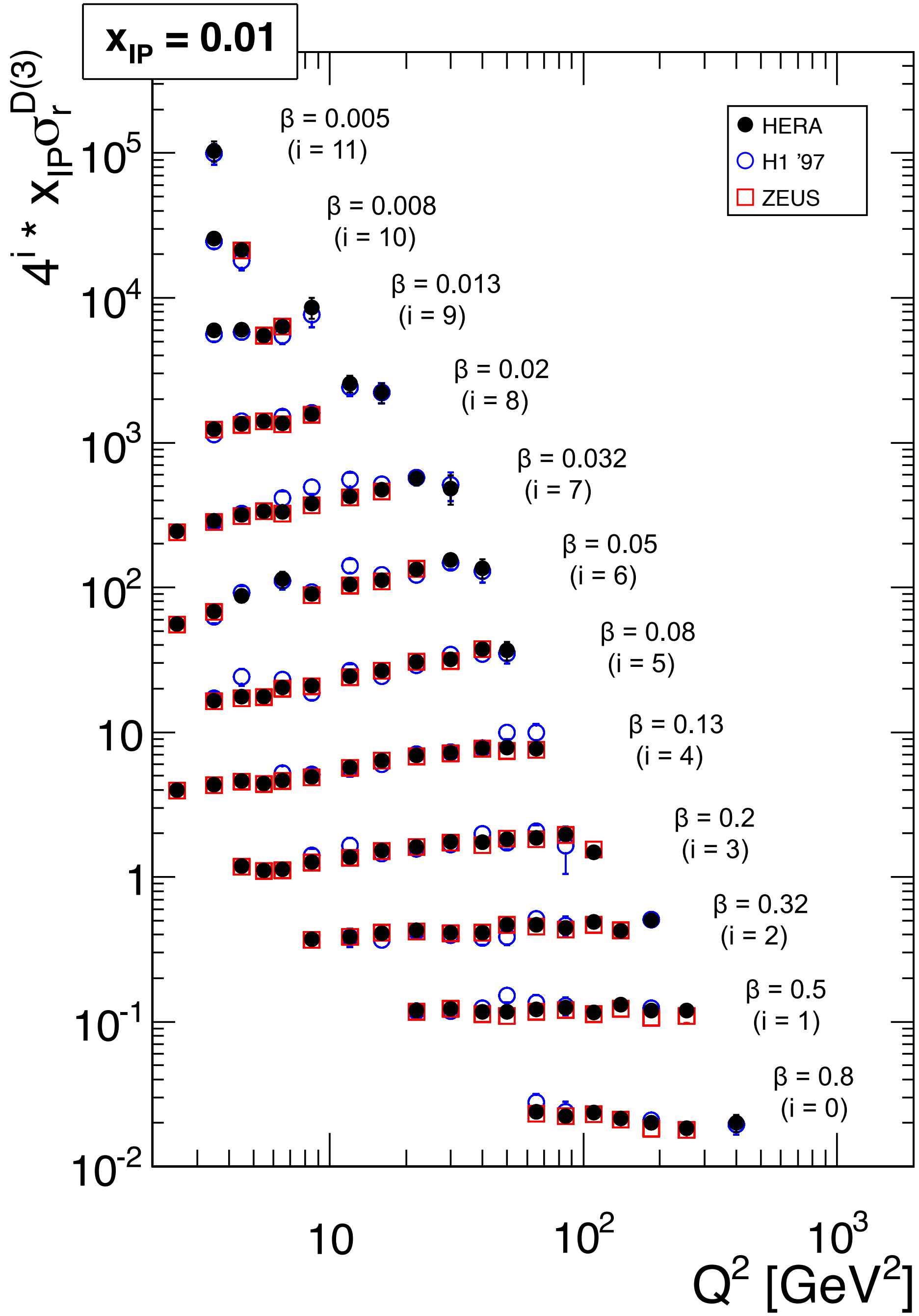
β = 0.27 (i = 2)
β = 0.43 (i = 1)
β = 0.67 (i = 0)
Q^2 [GeV^2]

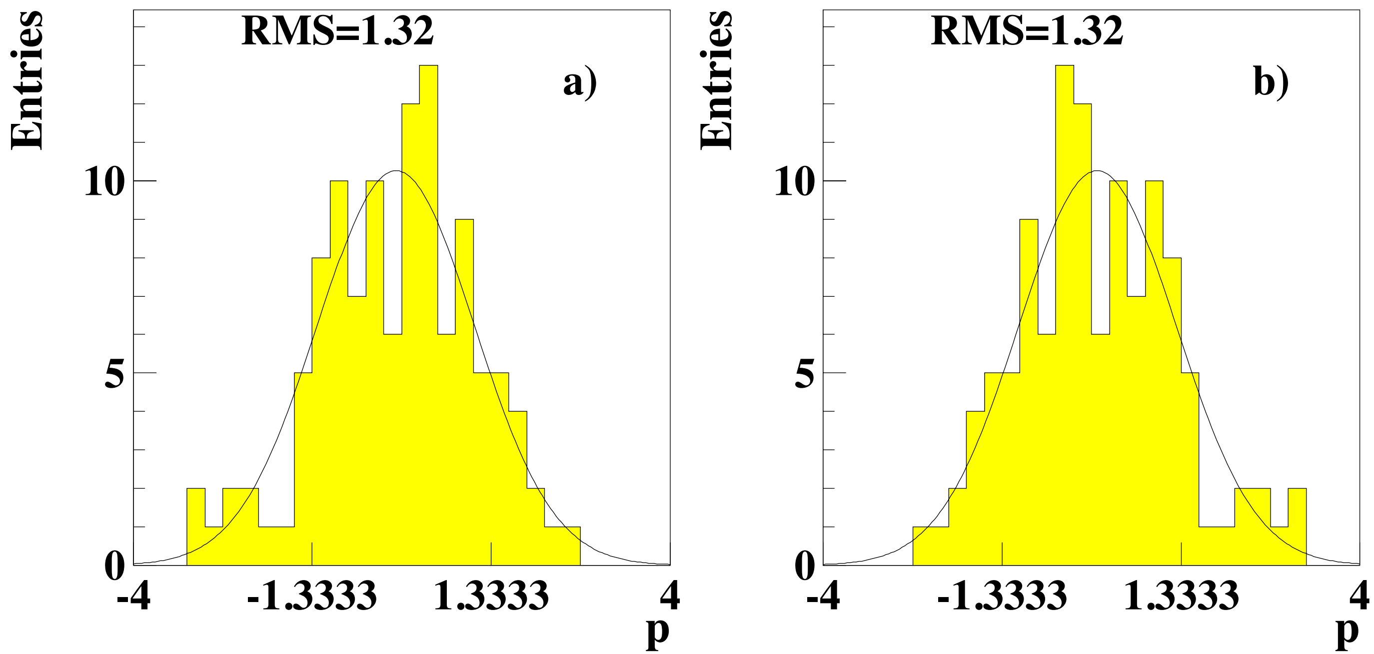


x_{IP} = 0.01
$4^i * x_{IP}\sigma_r^{D(3)}$
HERA
H1 '97
ZEUS
β = 0.005 (i = 11)
β = 0.008 (i = 10)
β = 0.013 (i = 9)
β = 0.02 (i = 8)
β = 0.032 (i = 7)
β = 0.05 (i = 6)
β = 0.08 (i = 5)
β = 0.13 (i = 4)
β = 0.2 (i = 3)
β = 0.32 (i = 2)
β = 0.5 (i = 1)
β = 0.8 (i = 0)
Q^2 [GeV^2]

Fitted Systematics

1 dlar_h197	0.8073	0.8059
2 dele_h197	1.9010	0.5060
3 dtheta_h197	-0.0809	0.6964
4 dnoise_h197	-0.7210	0.4709
5 dbg_h197	-0.0023	0.5899
6 dplug_h197	-0.1483	0.9205
7 dspa_h197	0.3700	0.7490
29 dxpom_h1th	-0.5589	0.9036
30 dbeta_h1th	-0.1587	0.8687
31 dq2_h1th	0.4911	0.9483
32 Eescale_zeus	0.8228	0.7092
33 Ehscale_zeus	-0.7763	0.7819
34 xpomW_zeus	0.6389	0.8301
35 zufoC_zeus	-0.5341	0.9668

Pull Distributions



a) H1 '97
b) ZEUS 2000