Connections between diffraction in DIS and diffraction at the LHC

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A short summary of DIS diffractive results useful for LHC

Diffraction 2012

Lanzarote, Spain, September 10-15 2012

HERA contribute – two colliding experiments

Many pubblications through the study of soft and hard diffraction at HERA:

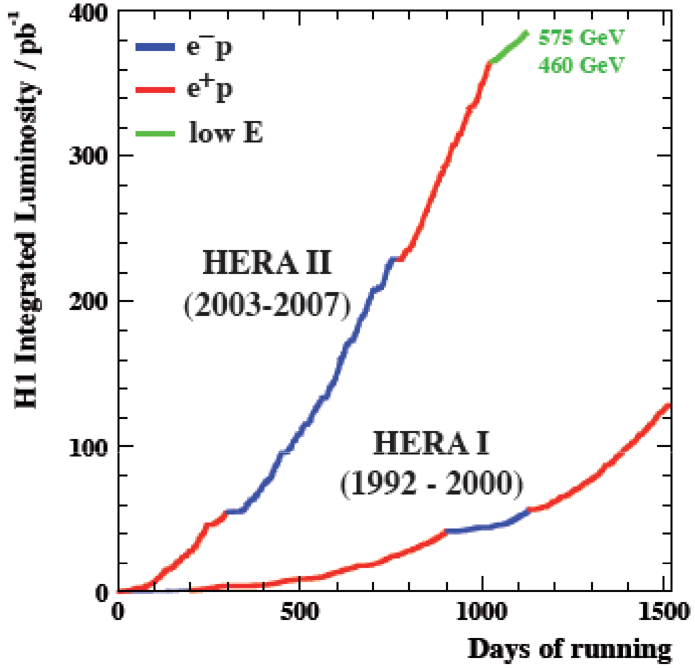
- ✓ Inclusive diffraction
- ✓ Exclusive diffraction

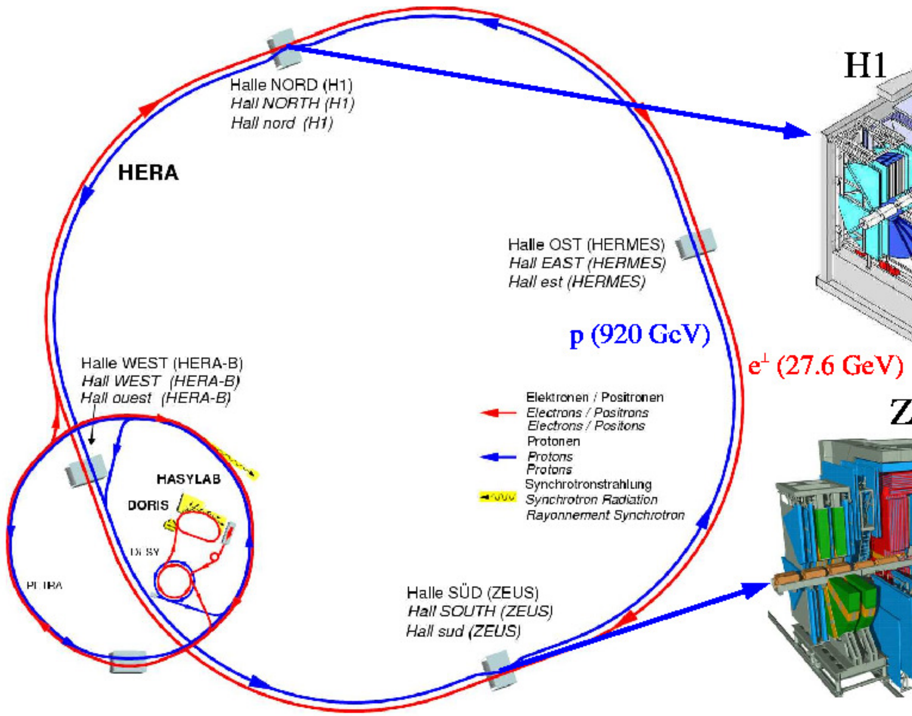
and many analyses ongoing

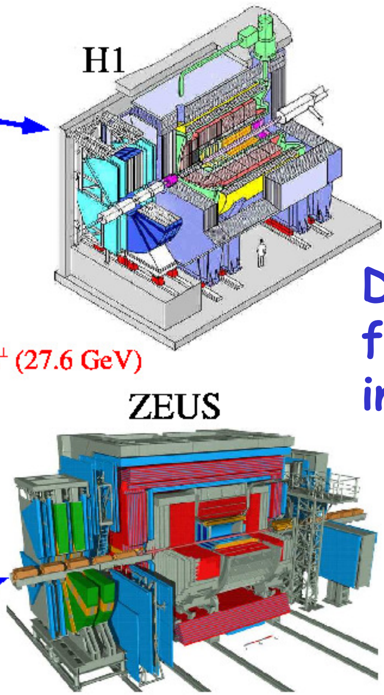
HERA: ~10% of events are diffractive

HERA I + HERA II ~0.5 fb^{-1}

27.5 GeV leptons on 920 GeV protons







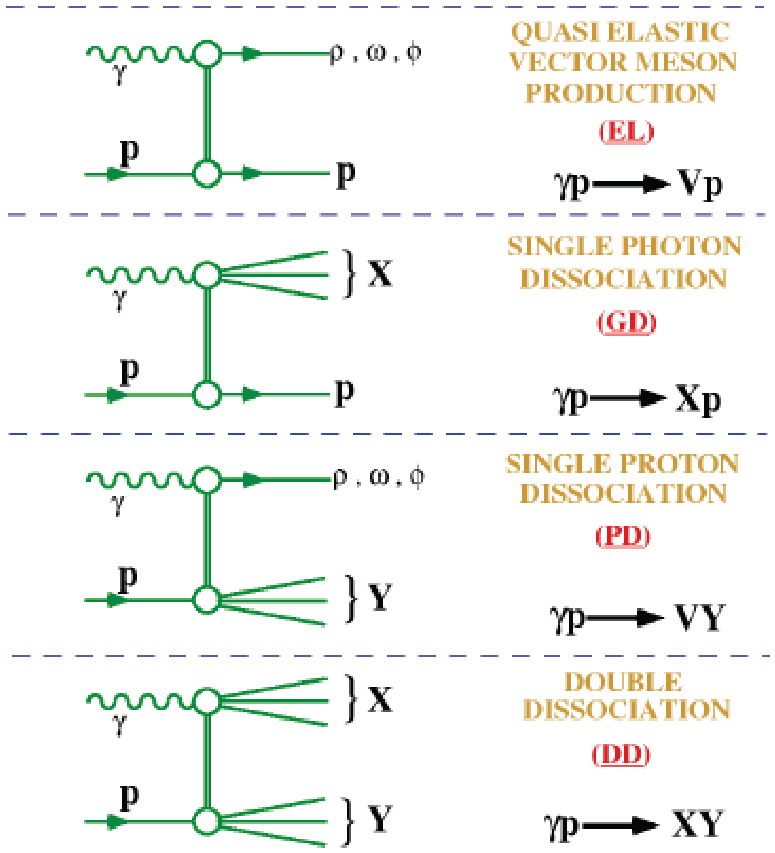
Detectors not originally designed for diffractive physics. Forward instrumentation added:

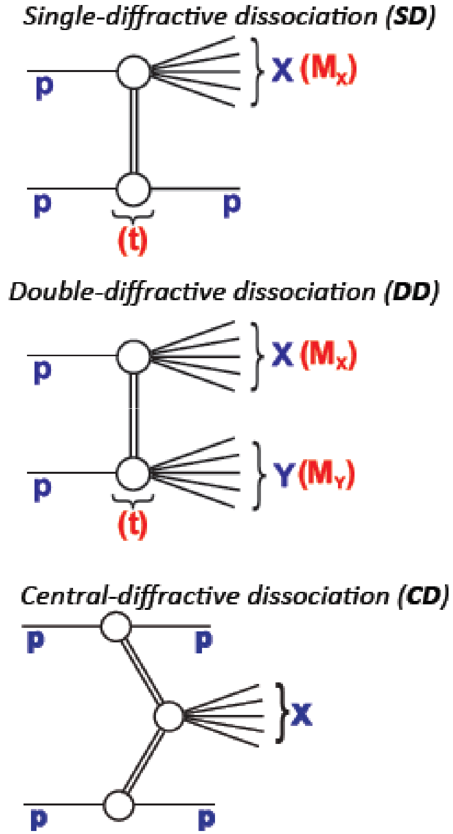
ZEUS LPS for HERA I only

H1 FPS for HERA I and II

H1 VFPS for HERA II

HERA and LHC

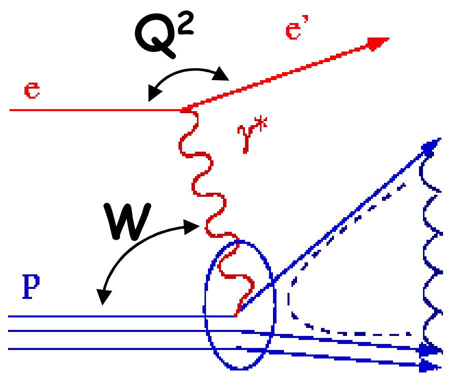


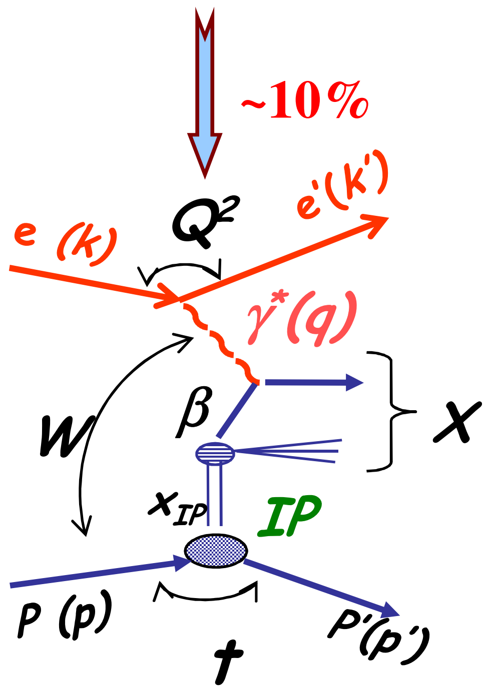


$\sigma_{tot} = \sigma_{ND} + \sigma_{SD} + \sigma_{DD} + \sigma_{CD} + \sigma_{EL}$

modelling diffractive contribute is necessary

Diffraction at HERA





Standard Deep Inelastic Scattering

DIS probes the partonic structure of the proton

Diffractive DIS

Diff DIS probes the partonic structure of colour singlet exchange: DPDFs

✓ exchange of colour singlet producing a rapidity gap in the particle flow → LRG method

✓ the scattered proton intact or quasi-intact (low-mass state) → Proton tagger method

The object exchanged carrying the vacuum quantum numbers (IP)

Kinematic variables

Standard DIS variables: x, W, Q^2 and three diffractive variables

Diffractive variables

t = squared 4-momentum transfer at proton vertex = $(p-p')^2$

x_{IP} = fraction of the p mom carried by the IP $\quad x_{IP} = \dfrac{q\cdot(p-p')}{q\cdot p} \approx \dfrac{Q^2+M_X^2}{Q^2+W^2}$

β = fraction of the IP mom carried by the struck quark $\quad \beta = \dfrac{Q^2}{2q\cdot(p-p')} \approx \dfrac{Q^2}{Q^2+M_X^2} = \dfrac{x}{x_{IP}}$

reduced cross section

$$\frac{d^4\sigma}{d\beta\, dQ^2 dx_{IP} dt} = \frac{4\pi\alpha^2}{\beta Q^4}\left[1-y+\frac{y^2}{2}\right]\sigma_r^{D(4)}(\beta,Q^2,x_{IP},t)$$

diffractive structure function

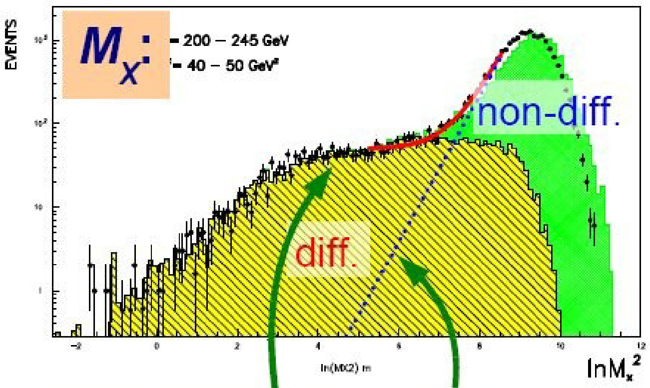
$$\sigma_r^{D(4)}(\beta,Q^2,x_{IP},t) = F_2^{D(4)} - \frac{y^2}{2(1-y+y^2/2)}F_L^{D(4)}$$

$F_2^{D(4)}$ integrated over t needed for LRG comparisons or when the outgoing proton is not detected (no measurement of t)

$$F_2^{D(3)}\left(x,Q^2,x_{IP}\right) = \int_0^\infty d\,|t|\,F_2^{D(4)}\left(x,Q^2,x_{IP},t\right)$$

Selection methods

1) M_X method



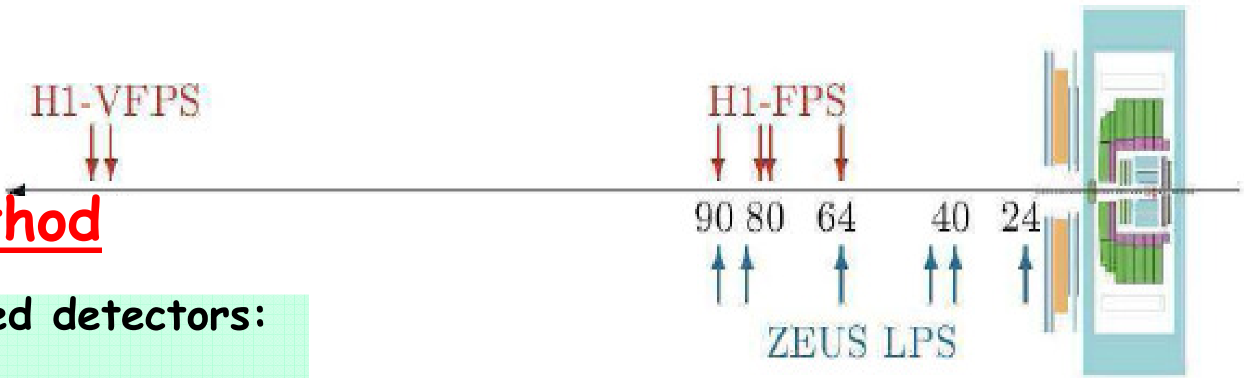
$$\frac{dN}{d\ln(M_X^2)} = D + c\exp(b\ln(M_X^2))$$

2) LRG method

Large rapidity gap method:
No activity in the forward direction

High statistics, p-diss included
Measurements integrated over t

3) LPS/FPS method

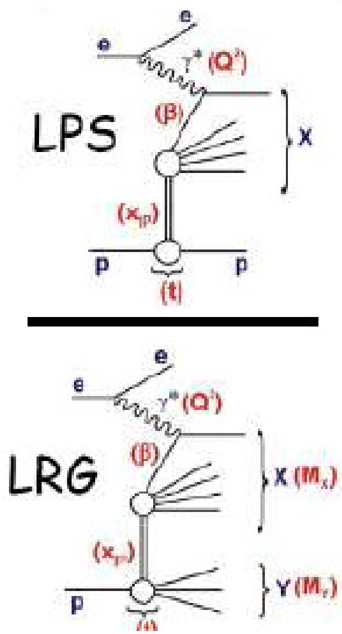


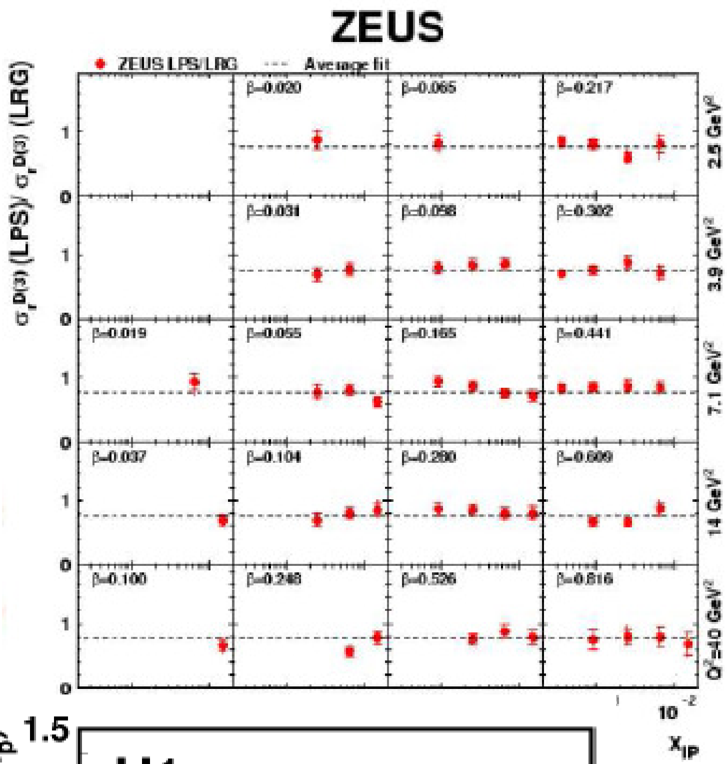
Proton tag method, dedicated detectors:
ZEUS-LPS for HERA I only
H1-FPS for HERA I and II
H1-VFPS for HERA II

Low statistics but no p-diss bkg and $M_Y=m_p$
Measurements of x_{IP} and t

Methods comparison

Comparison between methods

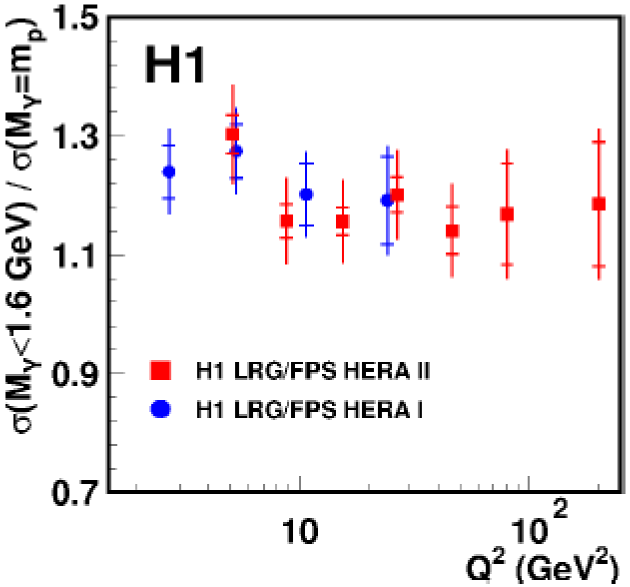




ZEUS Nucl.Phys. B816 (2009) 1

ZEUS estimate of p-diss fraction about 20%

No significant dependence on β, Q^2 and x_{IP}



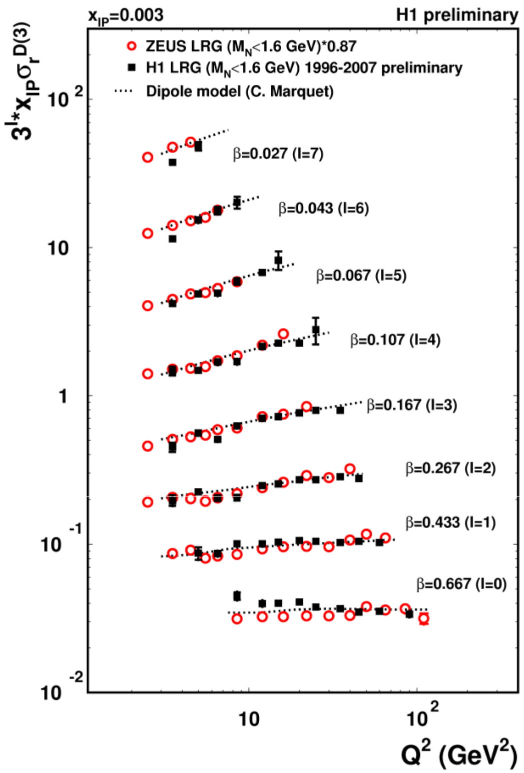
H1 EPJ C71 (2011) 1578

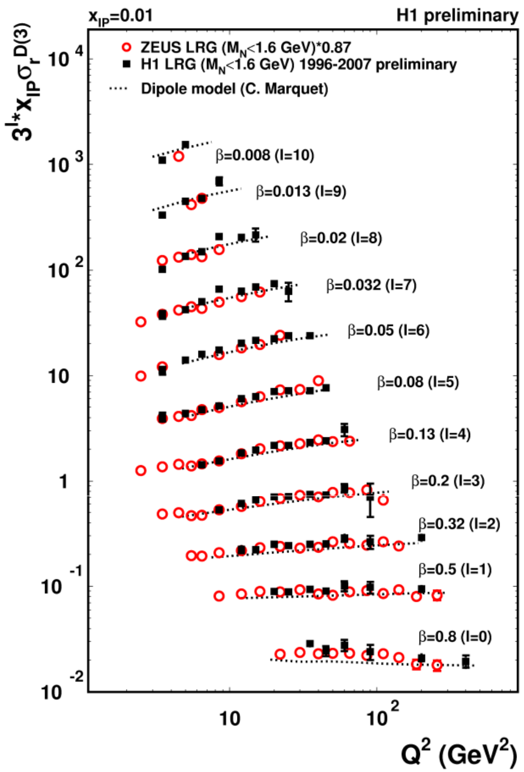
Same conclusions from H1 Combining FPS HERA I and HERA II data about 20%

M_X method shows similar conclusions

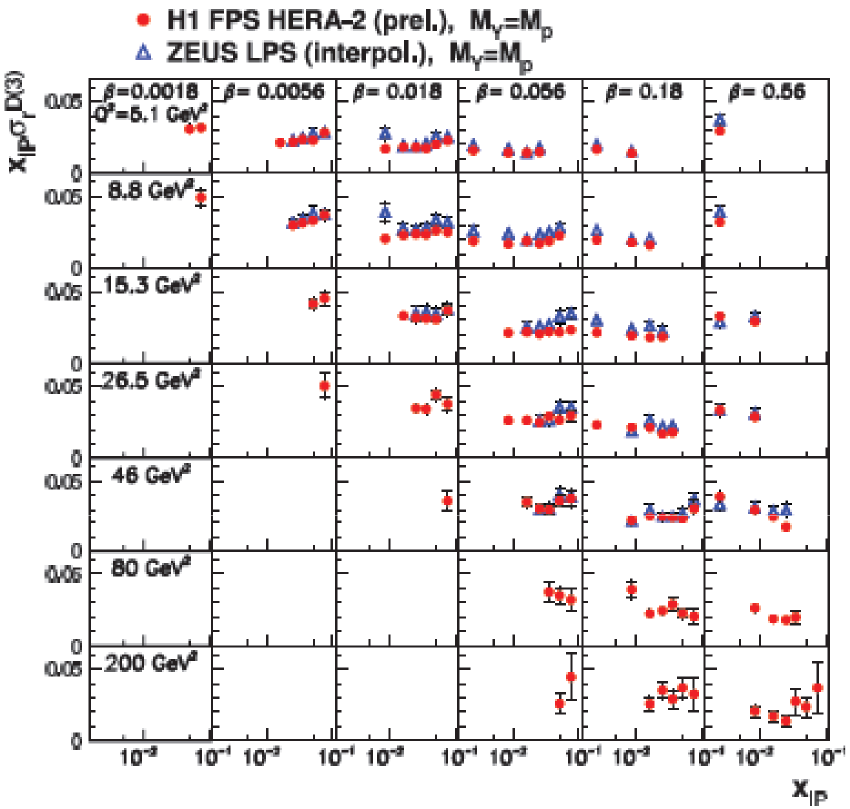
Comparison between experiments

LRG





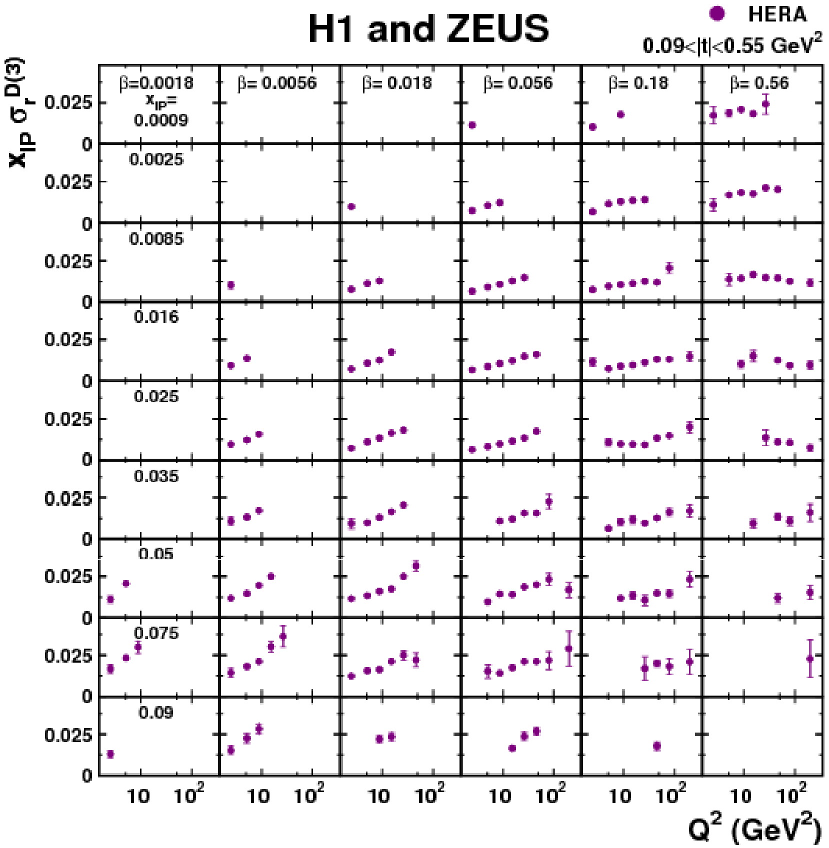
LPS/FPS

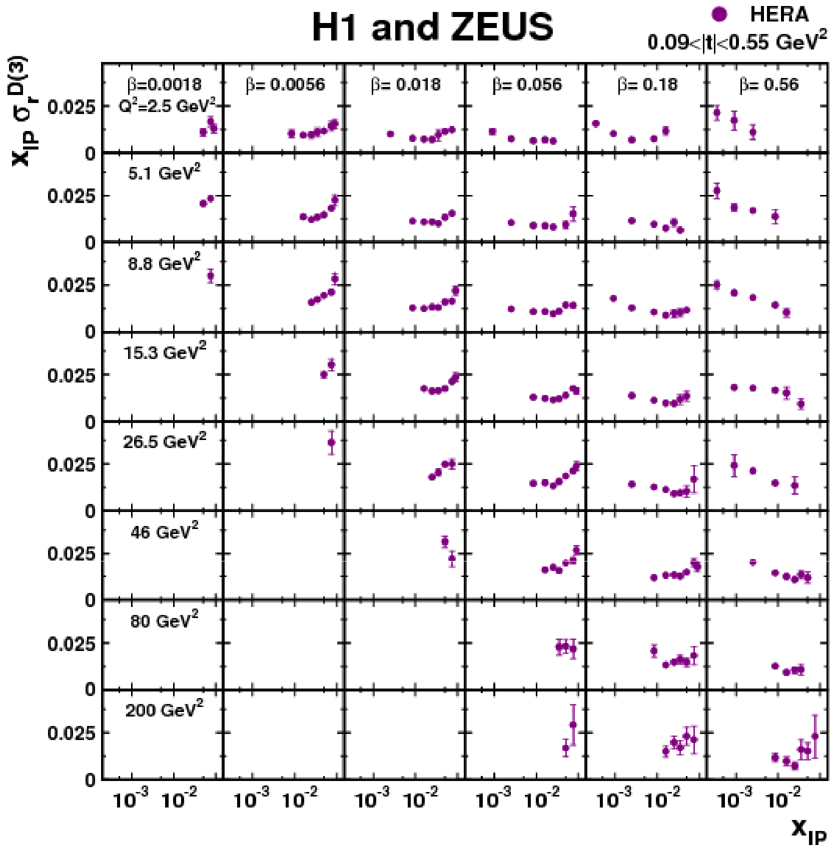


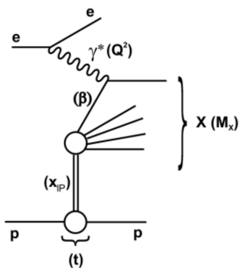
Both H1 and ZEUS inclusive data used to extract DPDFs

Combination H1 VFPS and ZEUS LPS

(DESY 12-100)





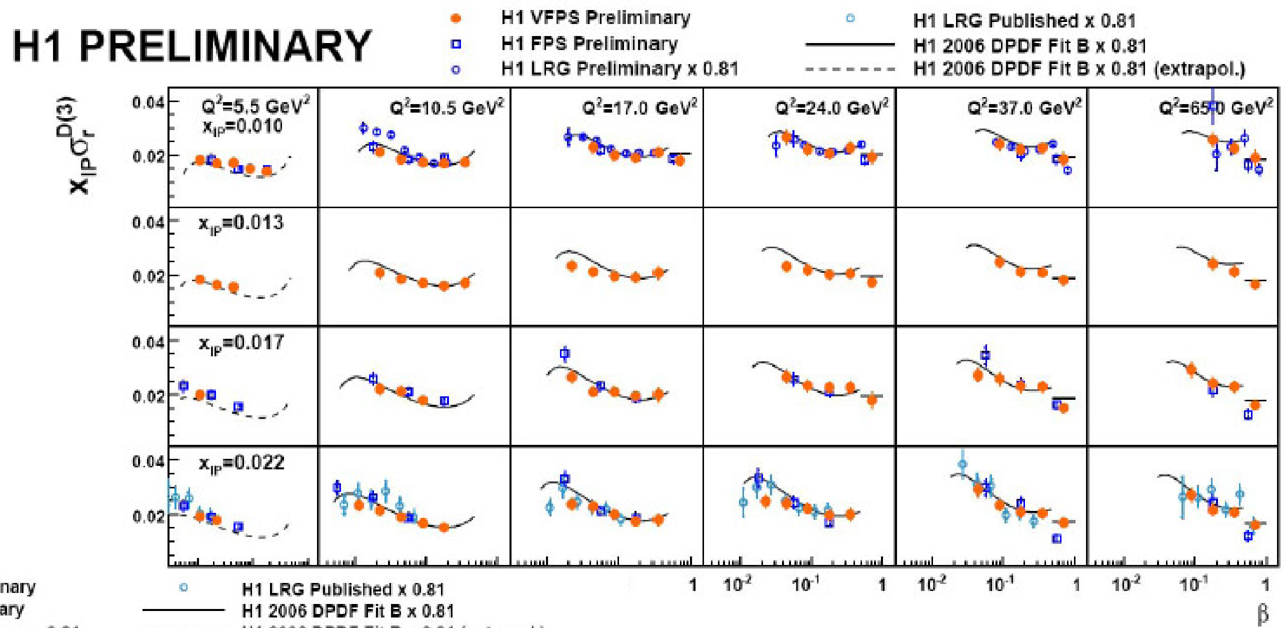


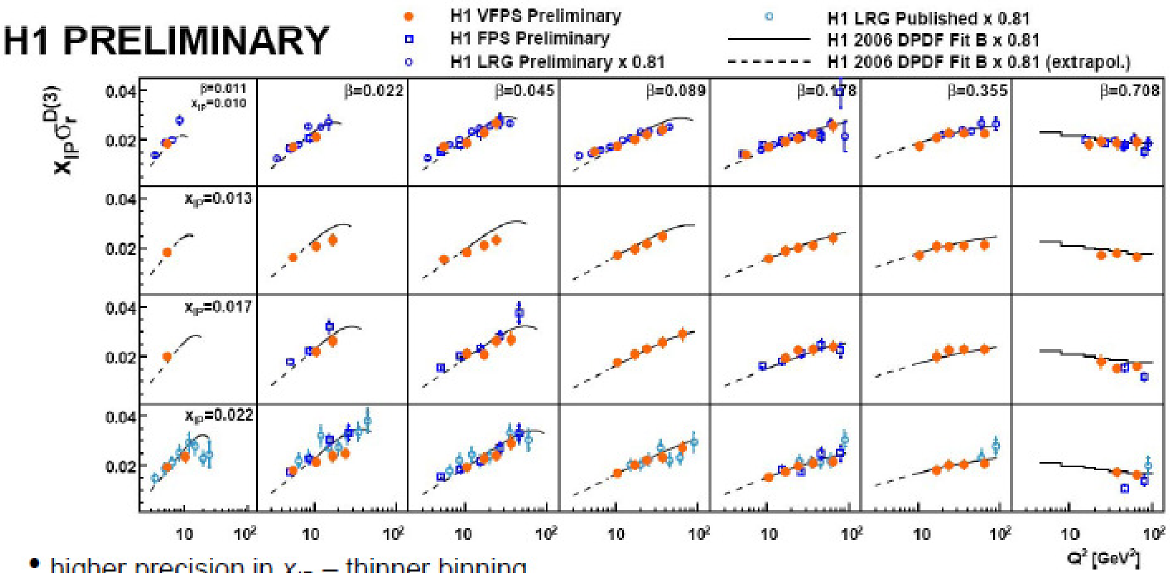
The combined data provide the most precise determination of the absolute normalisation of the diffractive cross section

see M. Ruspa talk

Results from H1 VFPS

VFPS:
(H1-prelim-10-14)
5< Q^2<100 GeV^2
95 pb^{-1}
FPS:
(H1-prelim-10-12)
5< Q^2<200 GeV^2
157 pb^{-1}
LRG:
(H1-prelim-10-11)
3.5< Q^2 GeV^2
370 pb^{-1}





- higher precision in x_{IP} – thinner binning

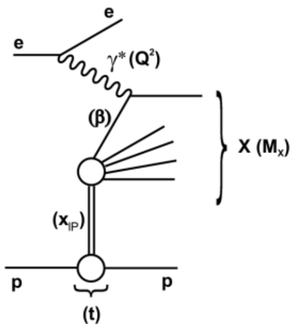
Positive scaling violations visible: a lot of gluons in DD

VFPS:
Covers complementary x_{IP} range w.r.t. LRG analysis

All the measurements in agreement with H1 2006 DPDF fit B

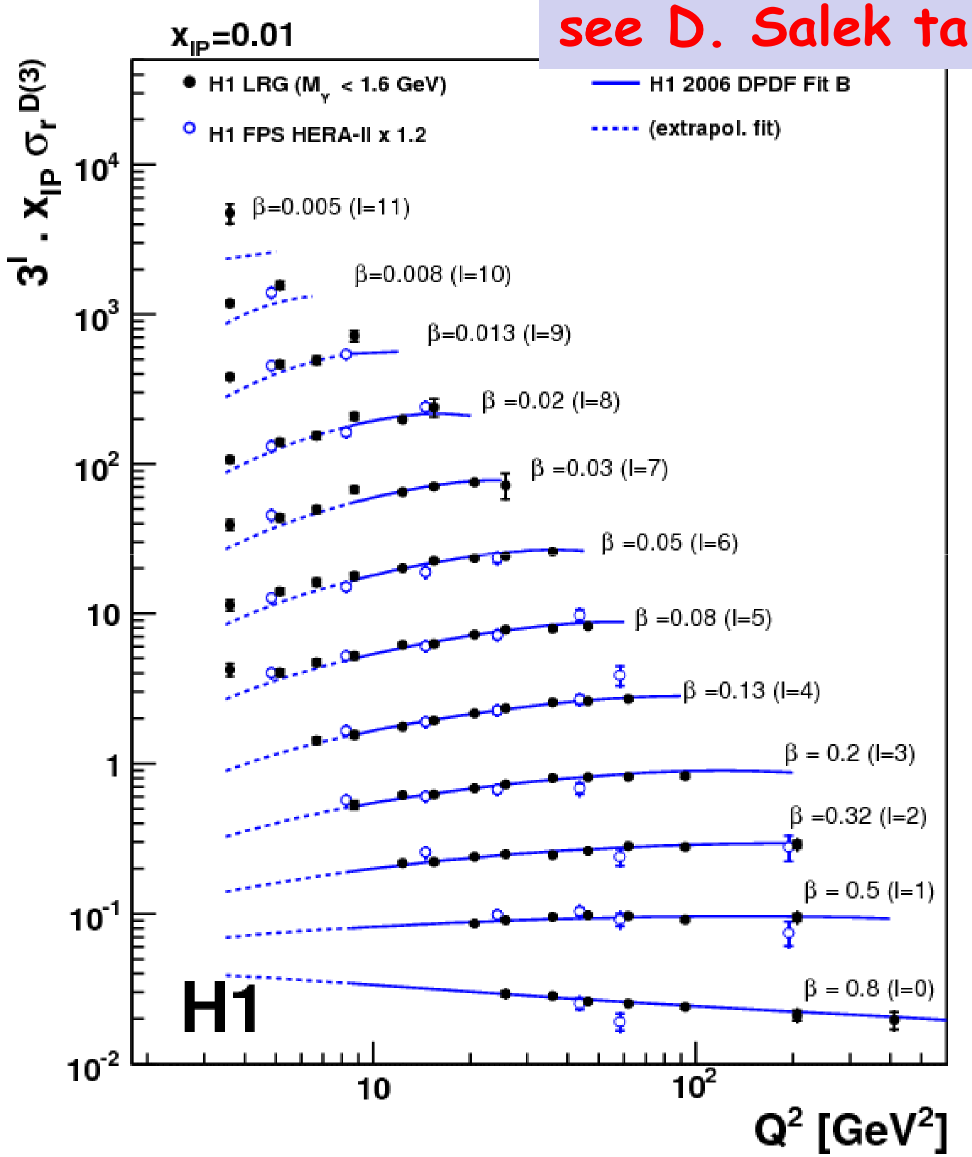
H1 LRG – all H1 data combined
(DESY 12-041)

see D. Salek talk



Data Set	Q^2 range (GeV^2)	Proton Energy E_p (GeV)	Luminosity (pb^{-1})
New data samples			
1999 MB	$3 < Q^2 < 25$	920	3.5
1999-2000	$10 < Q^2 < 105$	920	34.3
2004-2007	$10 < Q^2 < 105$	920	336.6
Previously published data samples			
1997 MB	$3 < Q^2 < 13.5$	820	2.0
1997	$13.5 < Q^2 < 105$	820	10.6
1999-2000	$133 < Q^2 < 1600$	920	61.6

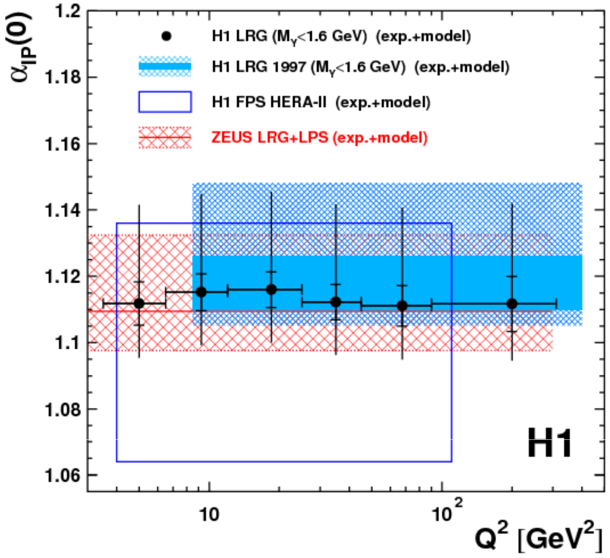
$|t|<1\ GeV^2$
$M_Y<1.6\ GeV$
$3<Q^2<1600\ GeV^2$
$x_{IP}<0.05$



All the measurements in agreement with H1 2006 DPDF fit B

H1 LRG – Pomeron intercept
(DESY 12-041)

see D. Salek talk

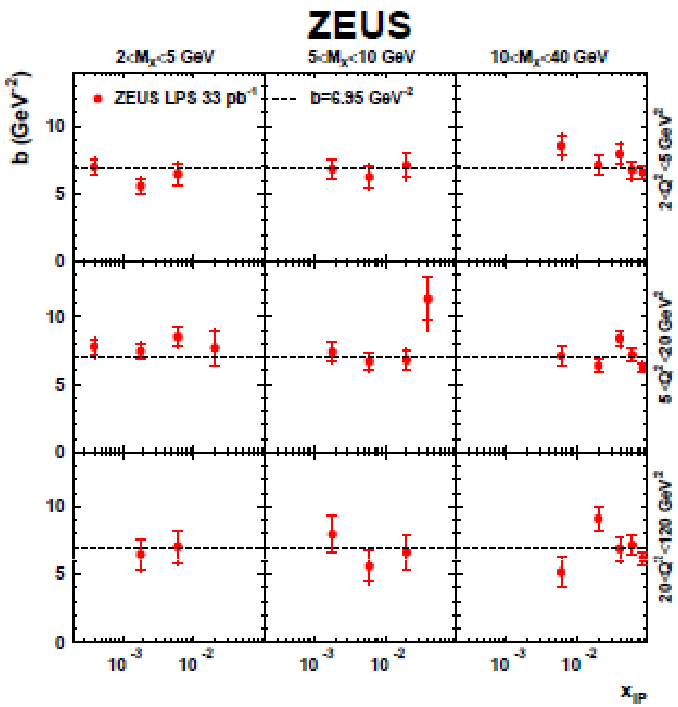


$$\alpha(t) = \alpha(0) + \alpha' t$$

$$\alpha_{I\!P}(0) = 1.113 \pm 0.002\,(\text{exp.})\,^{+0.029}_{-0.015}\,(\text{model})$$

No Q^2 dependence
Very good agreement with previous DIS and PHP results

Proton vertex factorization: $f_{IP}(x_{IP}, t)$



b does not depend on β, Q^2 at fixed x_{IP}: consistent with factorization

Can be used for LHC MCs

ZEUS-LPS

$$\alpha_{IP}(0) = 1.11 \pm 0.02(\textit{stat.}) \pm 0.02(\textit{syst.}) \pm 0.02(\text{mod})$$

$$\alpha'_{IP} = -0.01 \pm 0.06(\text{exp.})^{+0.04}_{-0.08}(\textit{systy.}) \pm 0.04(\text{mod.})\, GeV^{-2}$$

$$b = 7.1 \pm 0.7(\textit{stat.})^{+1.4}_{-0.7}(\textit{syst})\, GeV^{-2}$$

H1-FPS:

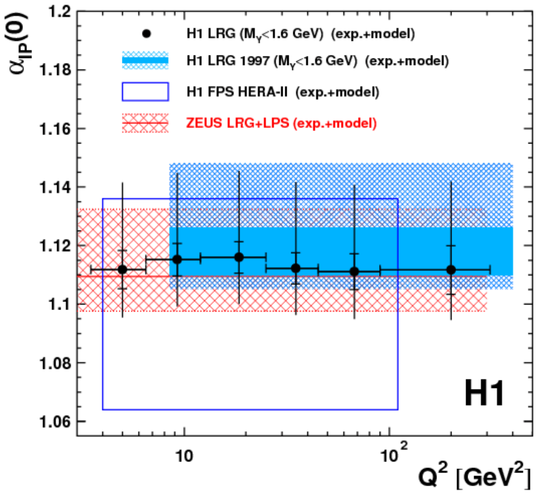
$$\alpha_{IP}(0) = 1.12 \pm 0.02(\text{exp.}) \pm 0.02(\text{mod.})$$

$$\alpha'_{IP} = 0.04 \pm 0.02(\text{exp.}) \pm 0.03(\text{mod.})\, GeV^{-2}$$

$$b = 5.7 \pm 0.3(\text{exp.}) \pm 0.6(\text{mod.})\, GeV^{-2}$$

H1-LRG:

$$\alpha_{IP}(0) = 1.113 \pm 0.002(\text{exp.})^{+0.029}_{-0.015}(\text{mod.})$$

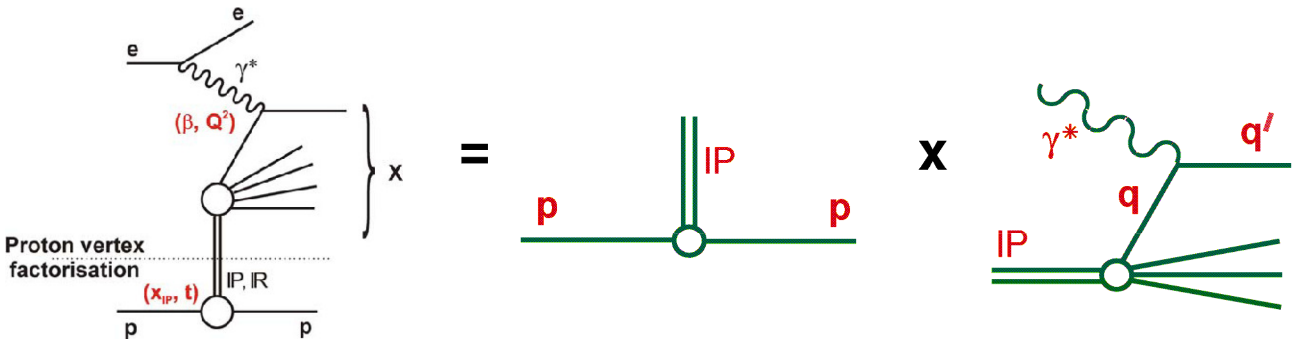


Diffractive PDFs

QCD collinear factorization theorem proved also for DDIS (Collins 1998):

$$\sigma(\gamma^* p \to Xp) \approx f_i(z,Q^2,x_{IP},t) \otimes \hat{\sigma}_{\gamma^* i}(z,Q^2)$$

variables describing proton vertex (x_{IP}, t) factorize from those at photon vertex (β, Q^2) to good approximation



$$\sigma(\gamma^* p \to Xp) \approx f_{IP}(x_{IP},t) \times f_i(z,Q^2) \otimes \hat{\sigma}_{\gamma^* i}(z,Q^2)$$

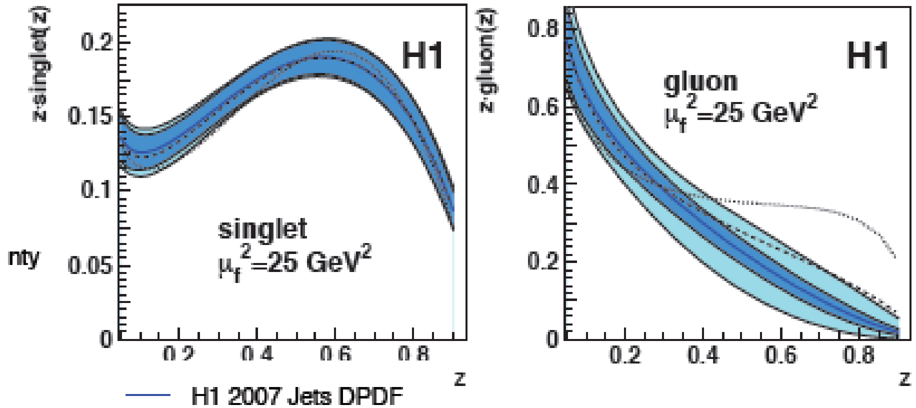
Regge motivated pomeron flux:

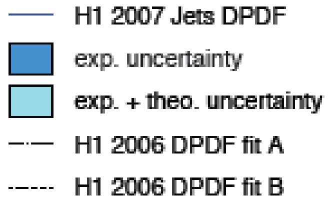
$$f_{IP}(x_{IP},t) = \frac{e^{Bt}}{x_{IP}^{2\alpha(t)-1}}$$

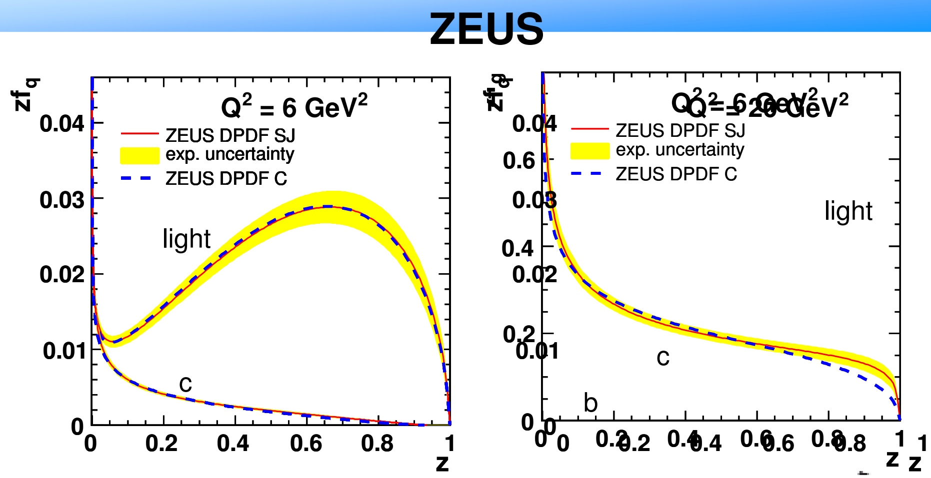
B and α(t) extracted from HERA data

DPDFs: Universal partonic distribution function, obey evolution equations, apply when vacuum quantum numbers are exchanged

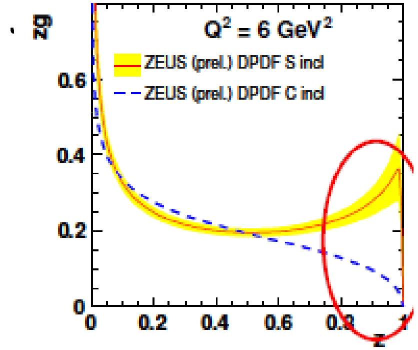
HERA dPDFs







z: fraction of the $I\!P$ mom carried by the struck parton (a generalisation of β)



Several QCD factorisation tests with final states with a hard scale (dijets, charm, ...) confirm that the factorization holds in DDIS!

PDFs included in various MCs

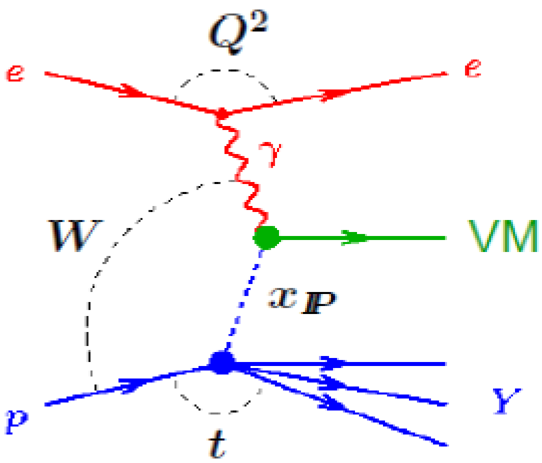
Combining inclusive and dijet data constrains the gluon and quark densities with comparable precision for all z

HERA DPDFs from the H1+ZEUS combined measurements (?)

Exclusive diffraction contribute

$V=(\rho, \omega, \phi, J/\psi, \Upsilon, \gamma)$

see D. Szuba talk



- *W*, *Q²* and *t* cross section dependence for VM and DVCS
- Pomeron trajectory

To investigate the transition from soft to hard is possible at HERA
Important fot LHC a model to merge soft and hard regimes

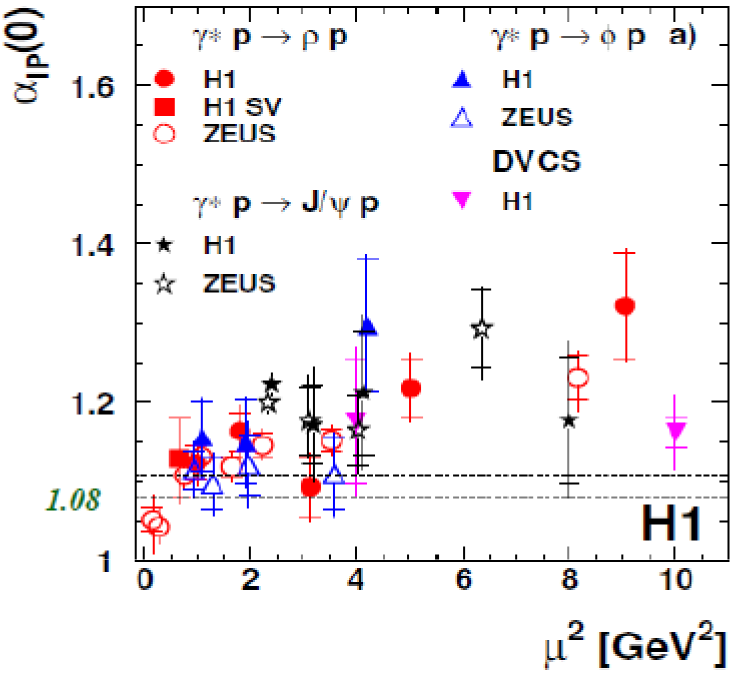
$$\sigma(W) \propto W^{\delta}$$

δ expected to increase from soft (~0.2, "soft Pomeron") to hard (~1., "hard Pomeron")

$$\frac{d\sigma}{dt} \propto e^{-b|t|}$$

b expected to decrease from soft (~10 GeV^{-2}) to hard (~4-5 GeV^{-2})

Energy dependence in DIS



$$\sigma(W) \propto W^{\delta}$$

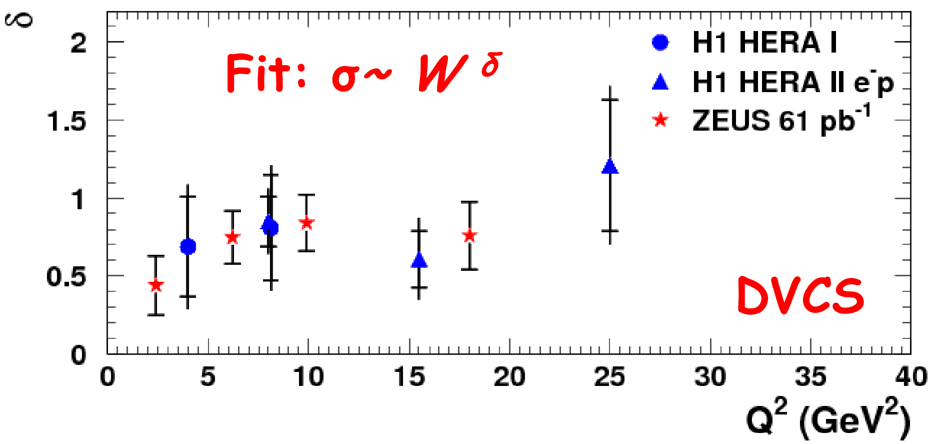
$$\delta(t) = 4(\alpha_{IP}(t) - 1)$$

$$\rightarrow \quad \alpha_{IP}(0) = 1 + \delta/4 + \alpha'_{IP} / \langle |t| \rangle$$

$$\mu^2 = (Q^2 + M^2)/4$$

Common hardening of $\alpha_{IP}(0)$ with μ^2

Soft contribute for light VM up to μ^2~5 GeV^2



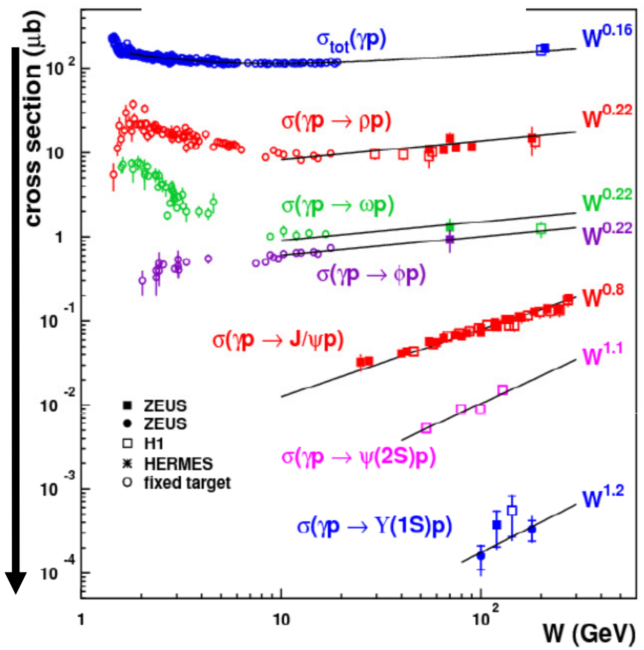
DVCS dependence indicates a hard regime

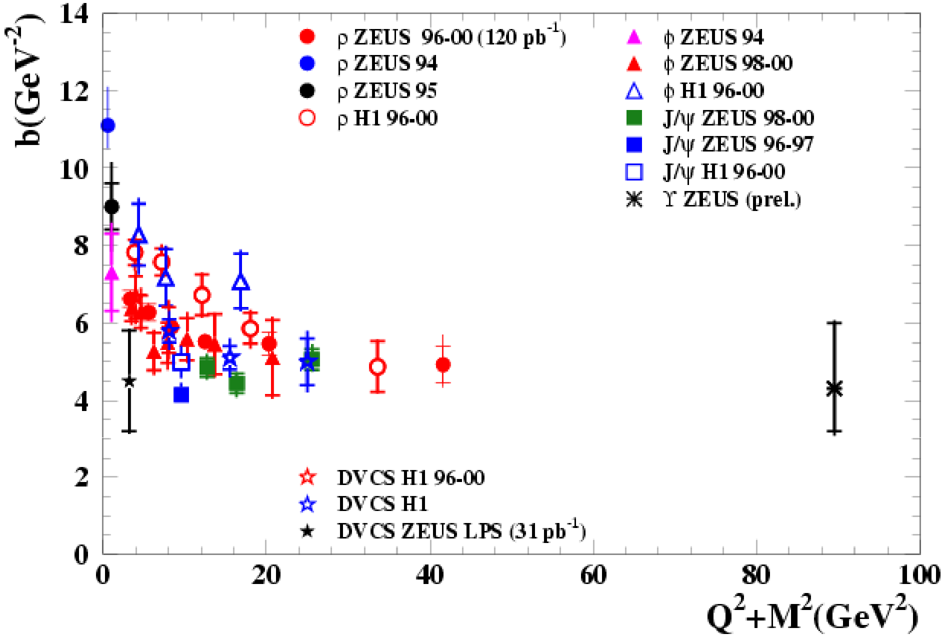
ZEUS: JHEP05(2009)108
H1: Phys.Lett.B659:796-806,2008

Energy dependence in PHP ant t-slope results

σ (γ p → V p), Q^2=0

$\mathbf{M_V}$





As the VM mass increases, the process gets harder: large M_V supplies a scale for hard processes → apply pQCD models

b decreases with (Q^2 + M^2)
from ~10GeV^{-2} to ~5GeV^{-2}
(from soft to hard)

Same slope for all VM vs (Q^2 + M^2)

Summary

A rich research program has been carried out at HERA that has allowed us to improve our knowledge on diffraction. New more precise results are available.

Knowledge and experience gained into the LHC diffractive program:

- DPFS;
- Pomeron Flux Modelling;
- ...

Study of diffraction may help the realisation of a MC that includes "soft" and "hard" processes.