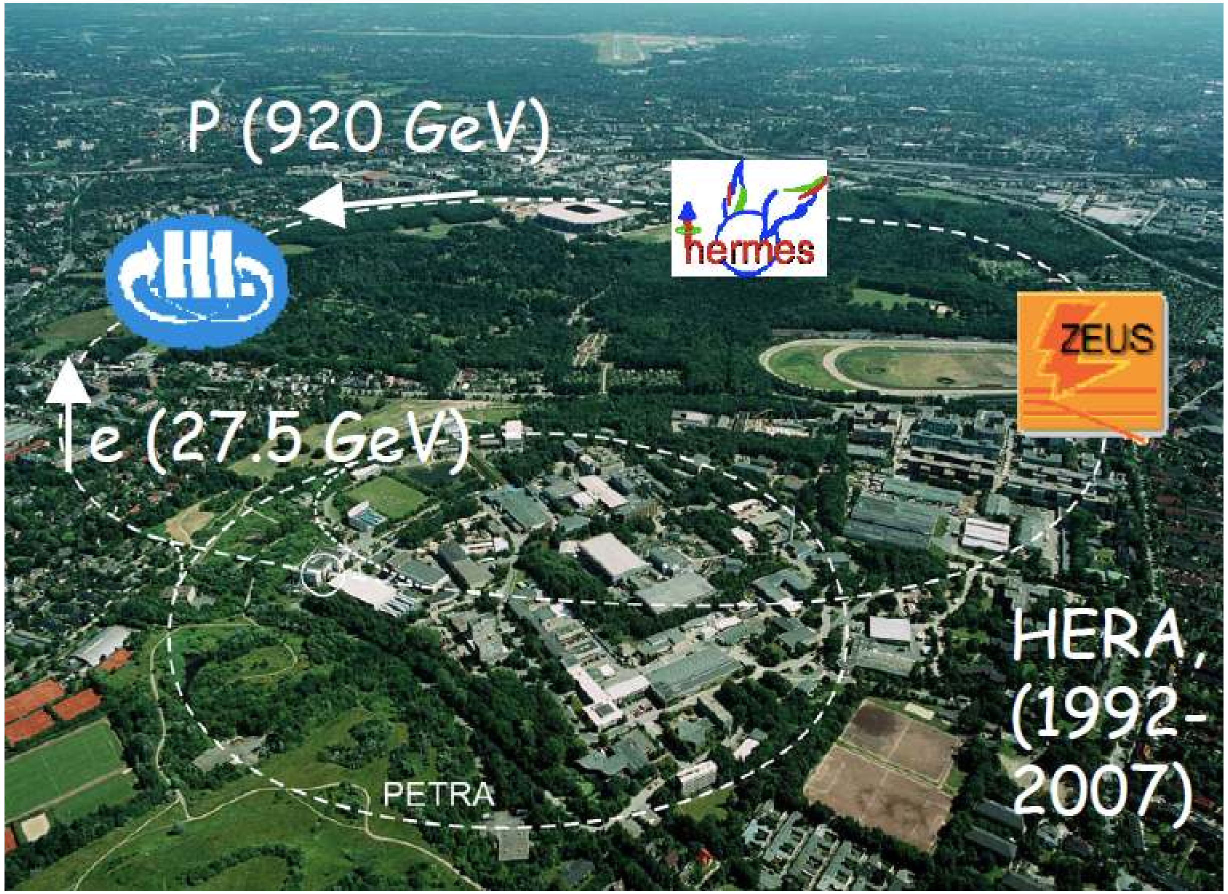
Rencontres de Moriond
QCD Session
La Thuile, 13-20 March 2010

Diffraction at HERA

Valentina Sola
on behalf of H1 and ZEUS Collaborations
(Torino University and INFN)

- Diffraction in ep scattering
- Latest inclusive diffractive ep results
- QCD fits and diffractive PDFs exctraction
- Direct measurement of F_L^D at HERA
- Factorization tests on php events

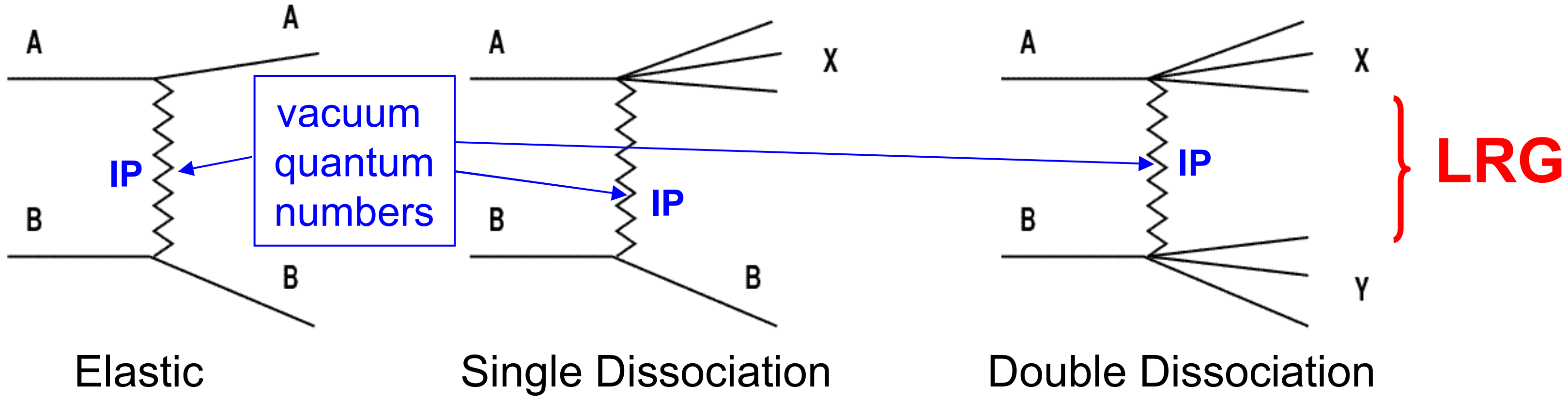
HERA Experiments



0.5 fb^{-1} collected by H1 and ZEUS experiments
Final analyses of HERA data are underway

Diffraction in Hadron Scattering

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



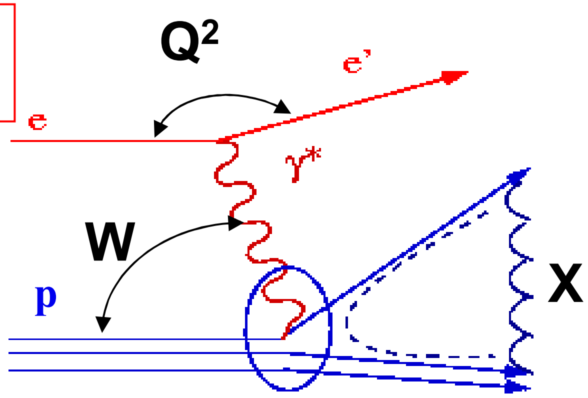
⇨ Beam particles emerge intact or dissociated into low-mass states
→ Very small fractional momentum losses (within a few %)

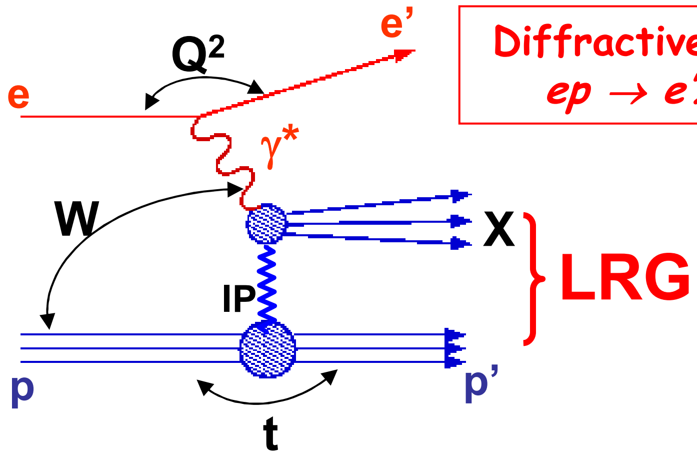
⇨ Final-state systems separated by large polar angle
(or pseudorapidity $\eta = -\ln[\tan(\theta/2)]$)
→ Large Rapidity Gap (LRG)

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

Diffraction at HERA

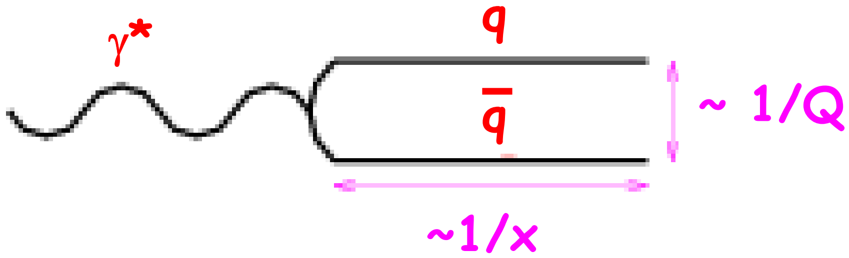
Standard DIS
$ep \to e'X$





Diffractive DIS
$ep \to e'Xp'$

Real and virtual photons can fluctuate in hadronic states



(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

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

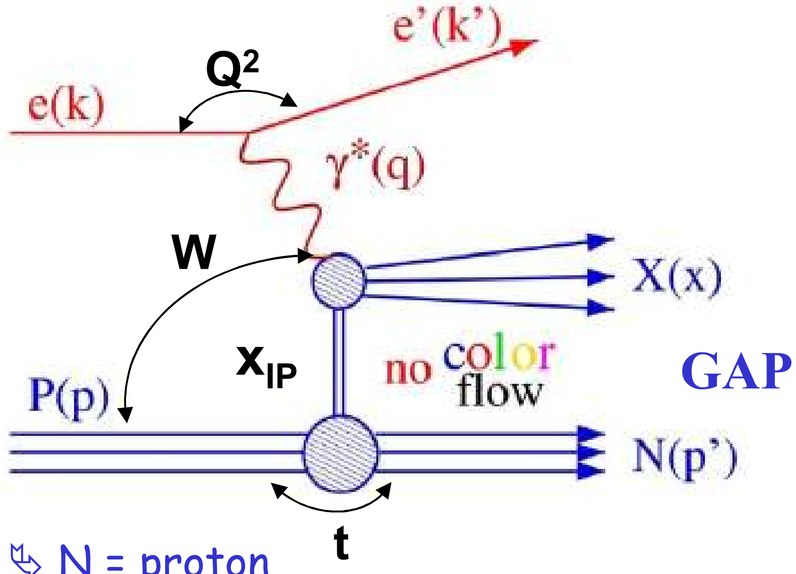
W = invariant mass of γ^*-p system

M_X = invariant mass of γ^*-IP system

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

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

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



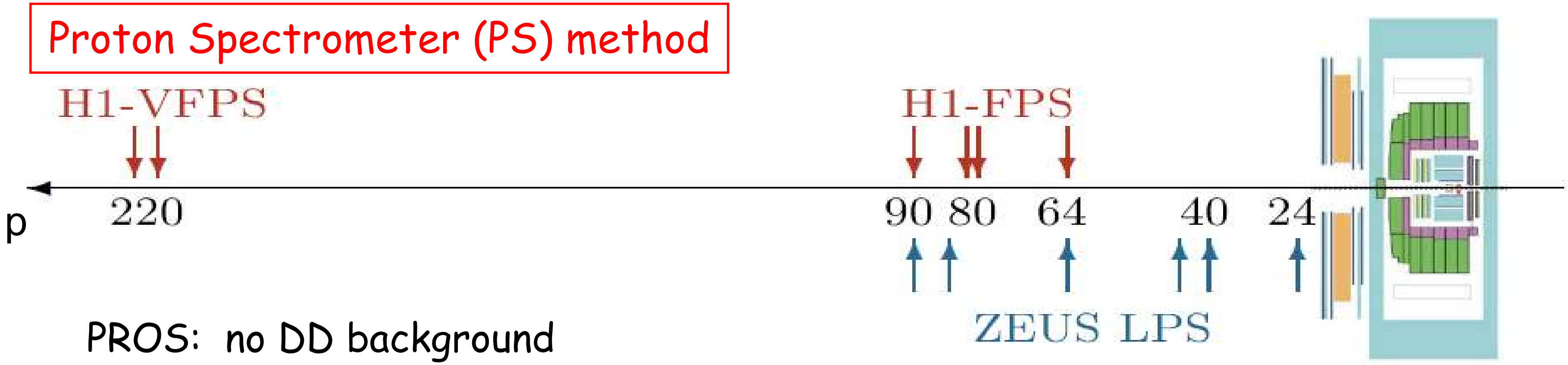
- N = proton
  → SD events
- N = proton dissociative system
  → DD events (background)

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

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

Signatures and Selection Methods

Proton Spectrometer (PS) method



PROS: no DD background
direct measurement of t, x_{IP}
high x_{IP} accessible

CONS: low statistics

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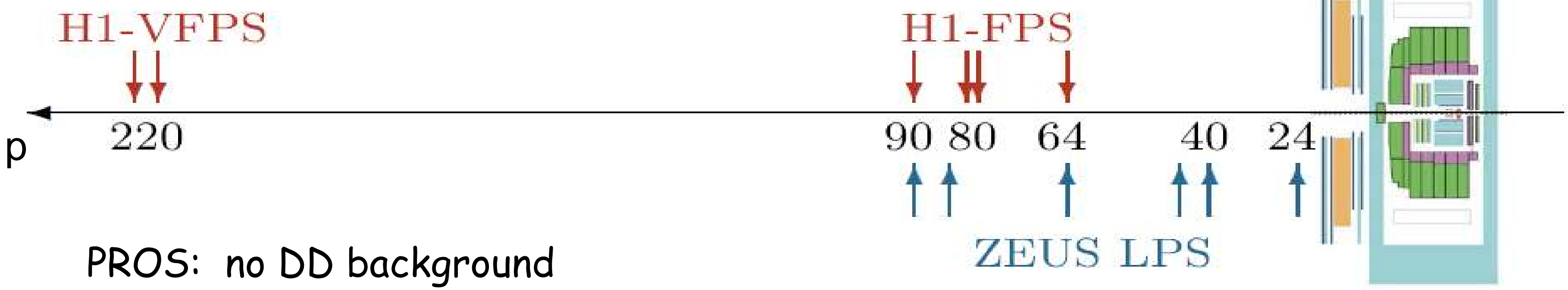

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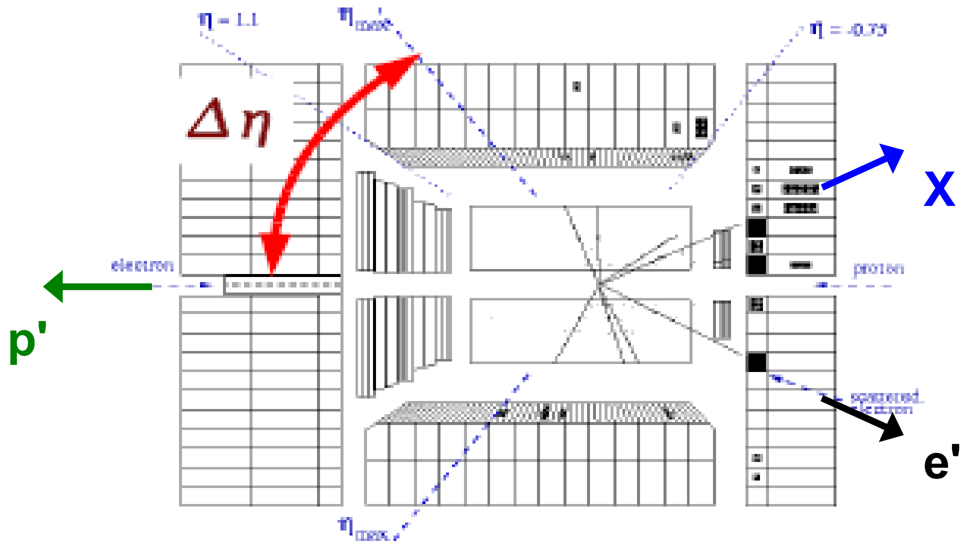
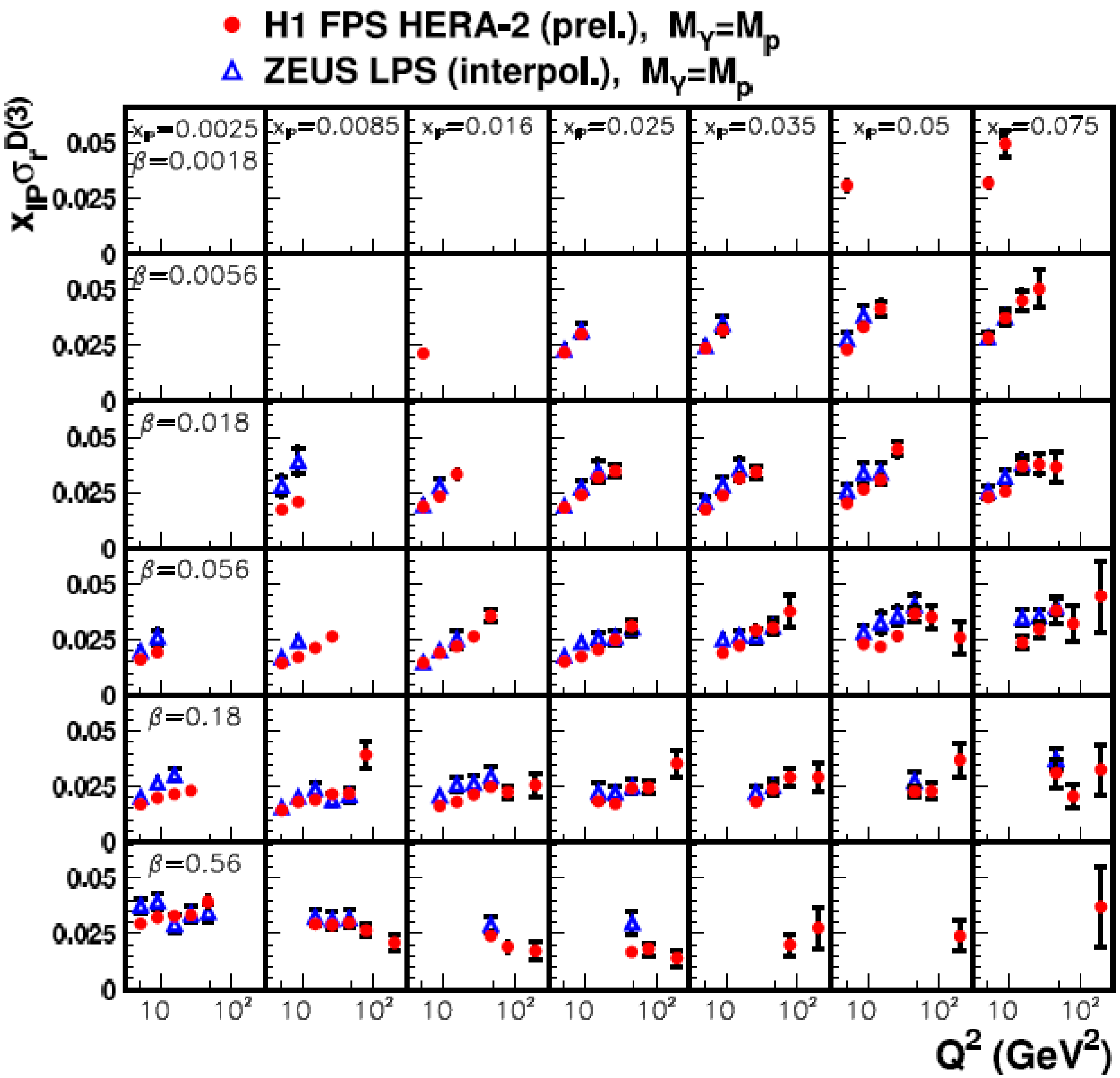
Large Rapidity Gap (LRG) method



PROS: near perfect acceptance
at low x_{IP}

CONS: DD background

H1 vs ZEUS PS Data

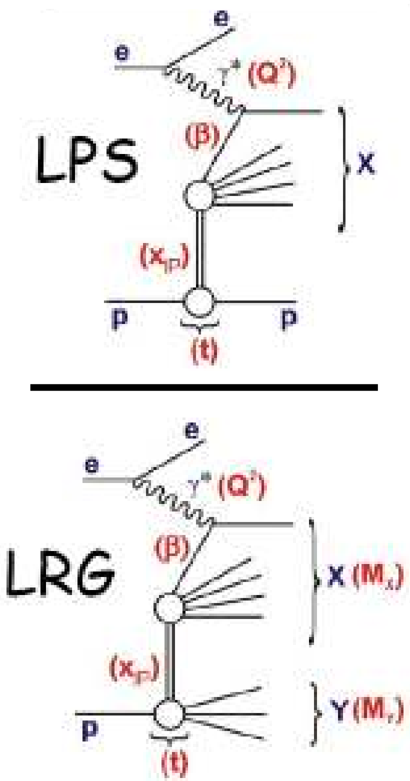


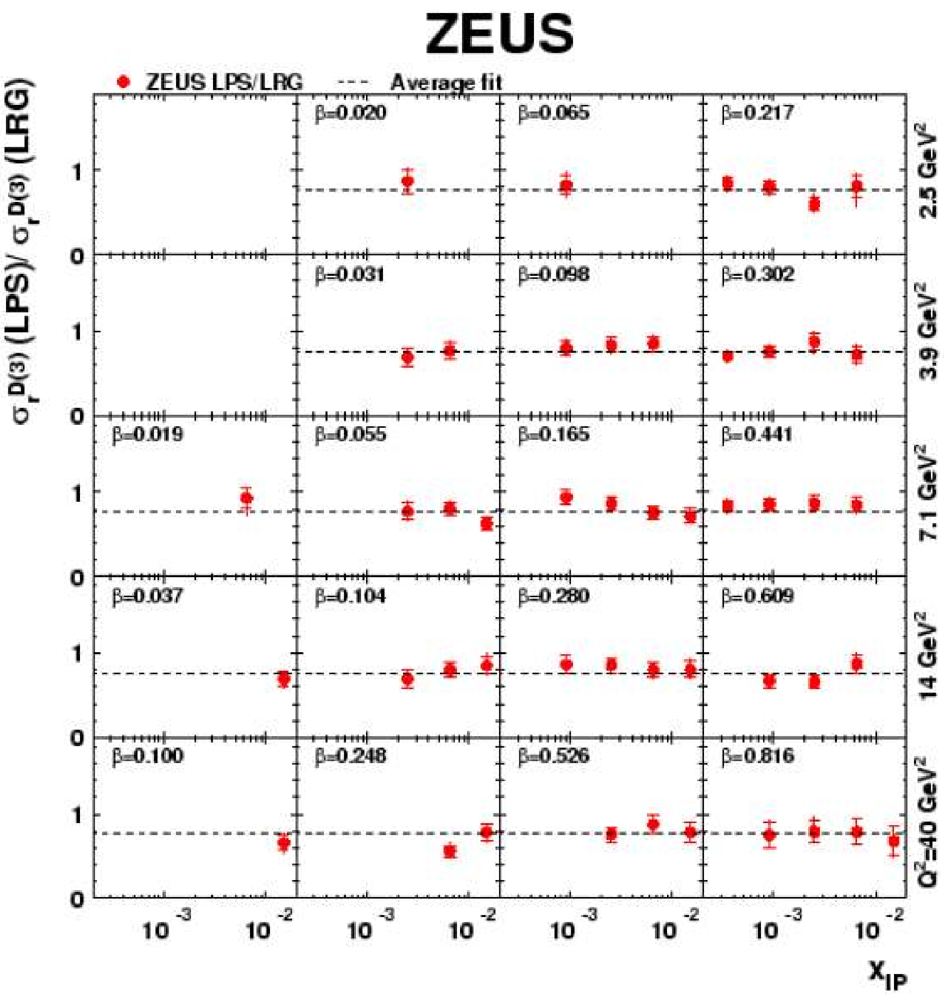
All available data used by both Collaborations

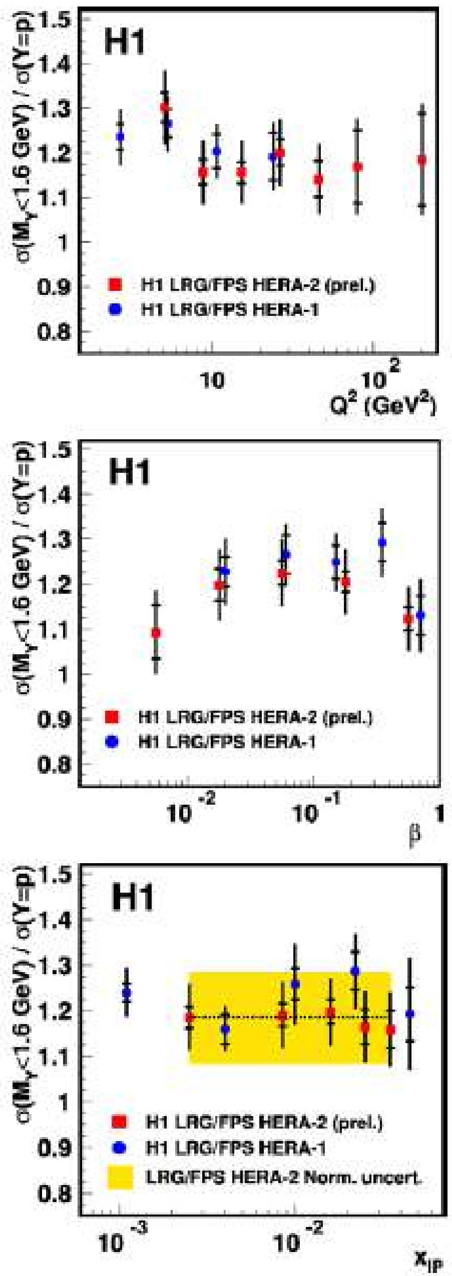
H1 HERA-II data (156 pb^{-1}) improve stats by factor of 20 and reach higher Q^2

Fair agreement (combined norm uncertainty ~10%)

LRG vs PS





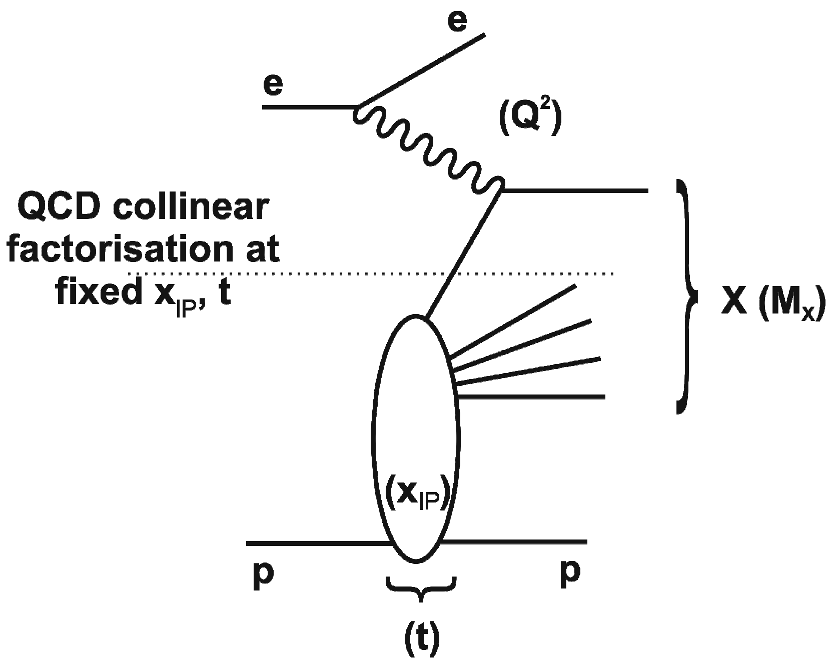


Estimation of DD contribution in LRG method

⇨ ratio flat both in ZEUS and H1

⇨ quantity of DD ~ 20%

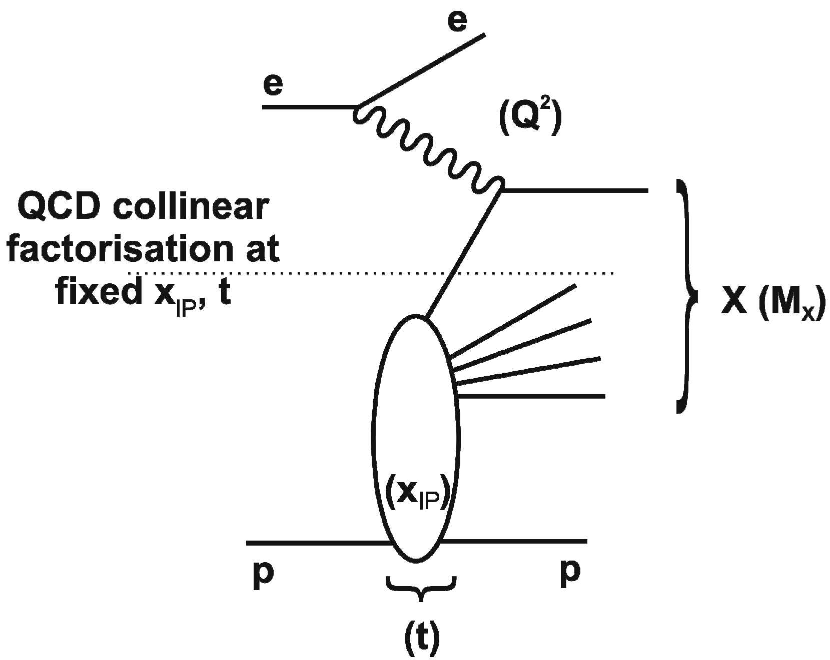
QCD Factorization in Hard Diffraction

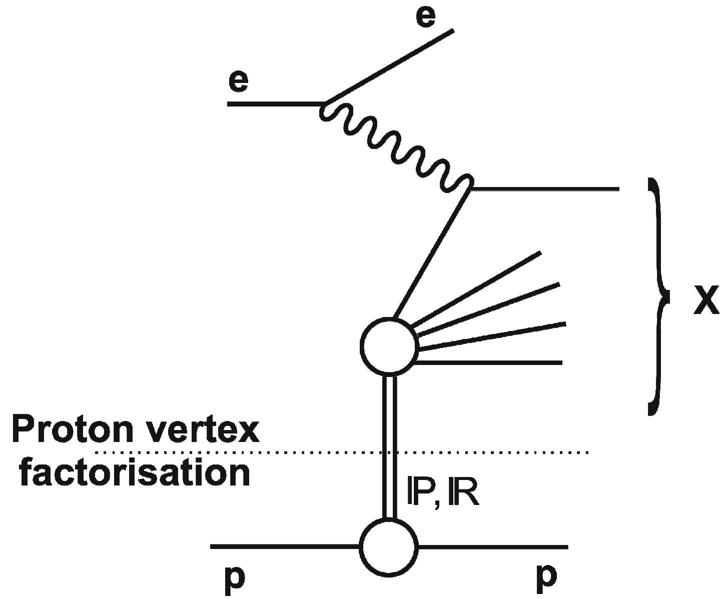


The QCD factorization theorem allows to write the diffractive structure functions as convolution of diffractive parton densities $f_i^D(z,Q^2,x_{IP},t)$ and universal partonic cross sections

$$d\sigma_{parton\ i}(\ ep \rightarrow eXp\ ) = f_i^D(z,\ Q^2,\ x_{IP},\ t) \otimes d\sigma^{ei}(z,\ Q^2)$$

QCD Factorization in Hard Diffraction





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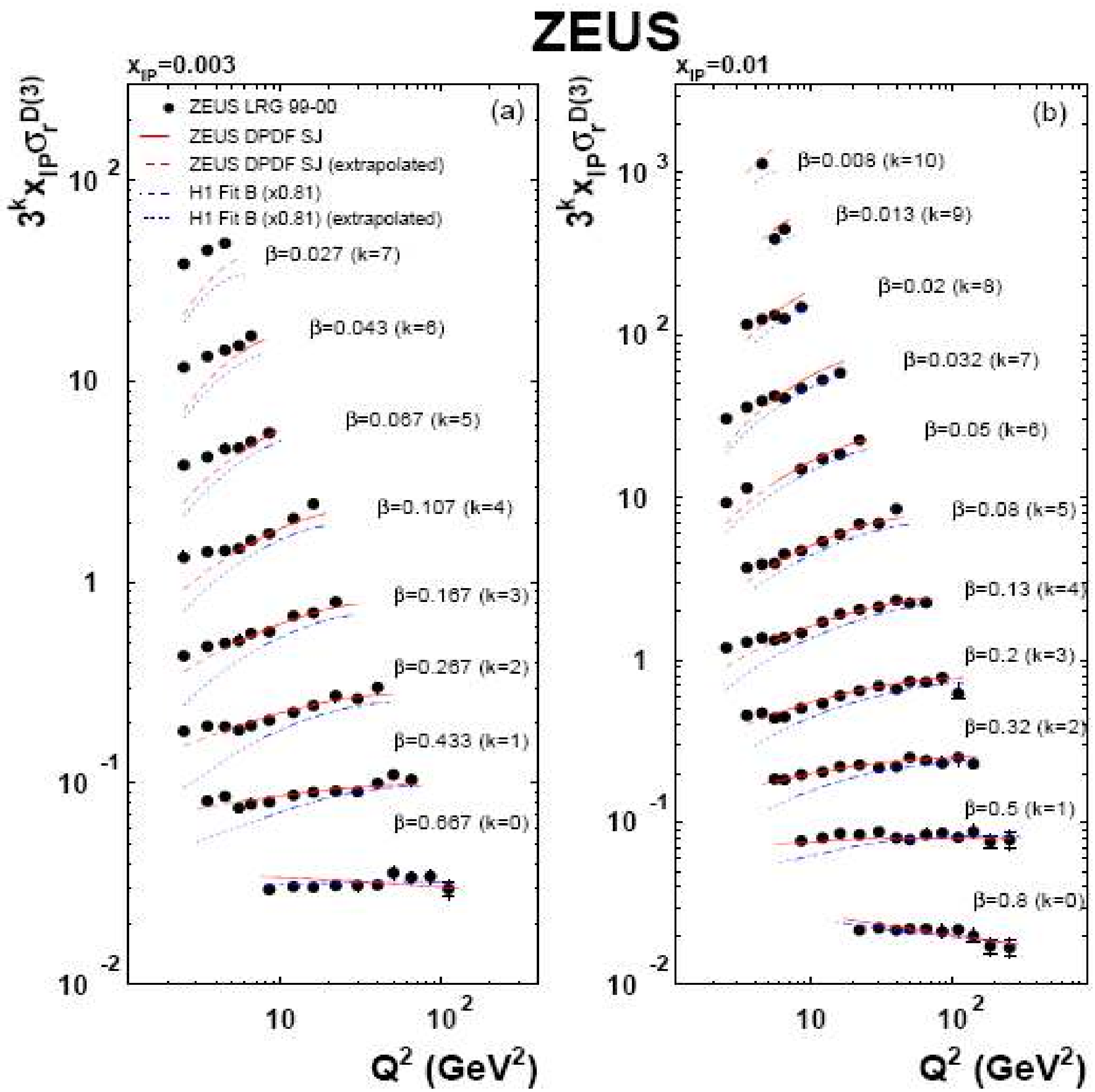
$$d\sigma_{\text{parton } i}(\, ep \rightarrow eXp\,) = f_i^D(z, Q^2, x_{IP}, t) \otimes d\sigma^{ei}(z, Q^2)$$

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

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

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



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

Inclusive Data

NLO QCD Fits:
- parametrize quark singlet and gluon at $Q^2_0 \sim 2$ GeV^2

$$z\, f_{u,d,s}(z, Q^2_0) = A_q\, z^{B_q} (1-z)^{C_q}$$
$$z\, f_g(z, Q_0^2) = A_g\, z^{B_g} (1-z)^{C_g}$$

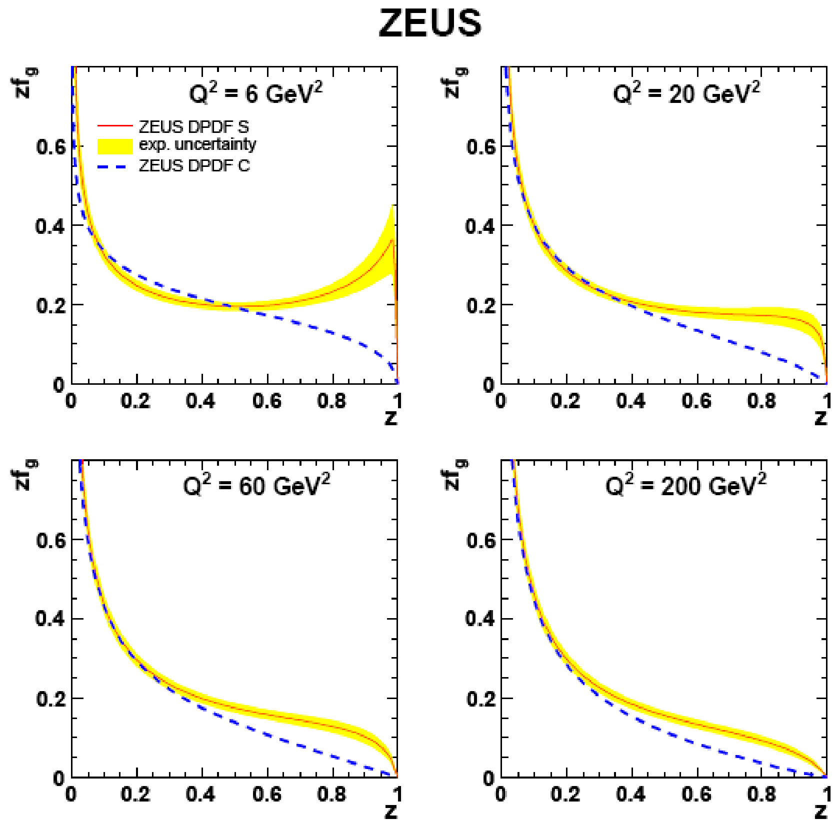
- evolve with NLO DGLAP and fit

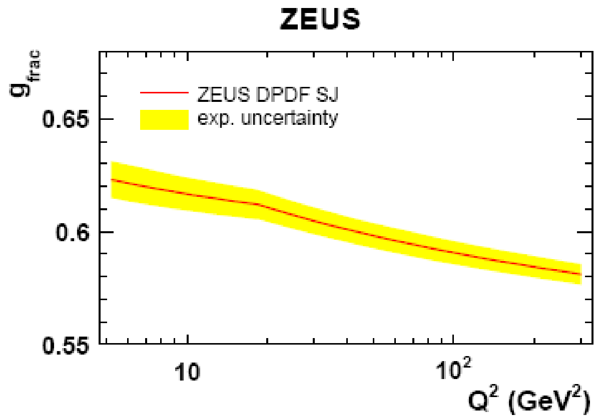
Different parametrizations

Well constrained singlet
Gluon weakly constrained in the high z_{IP} region (gluon density from $\ln Q^2$ dependence of F_2^D)

DPDFs are gluon dominated

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



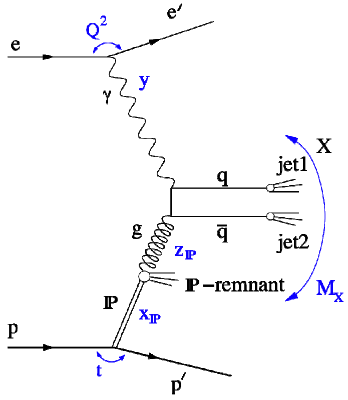


[Nucl.Phys. B831 (2010) 1-25]

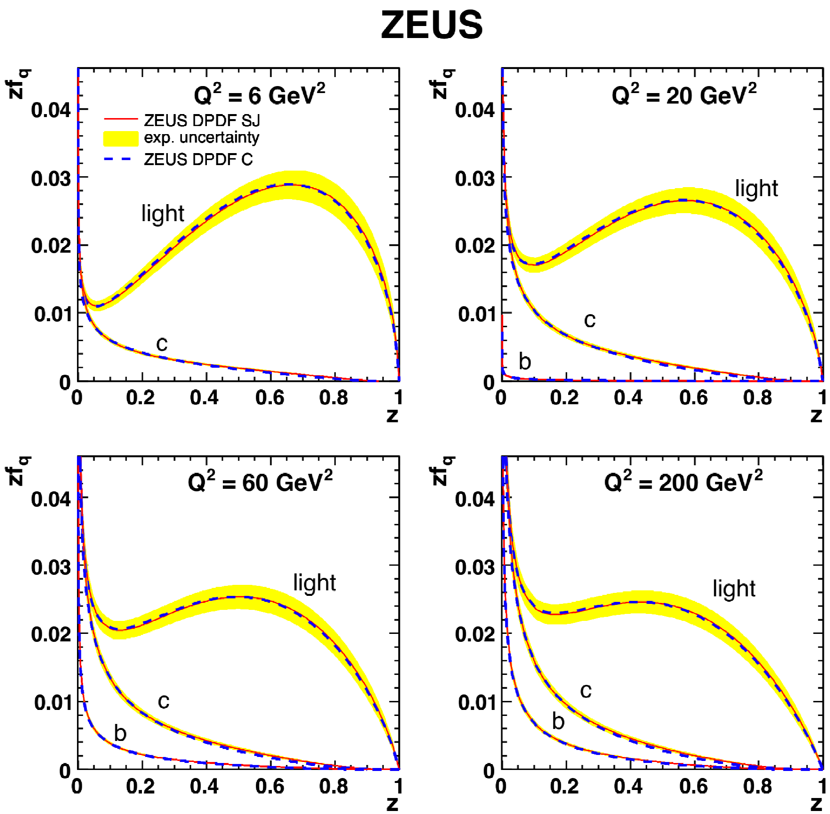
Diffractive PDFs from NLO Fits

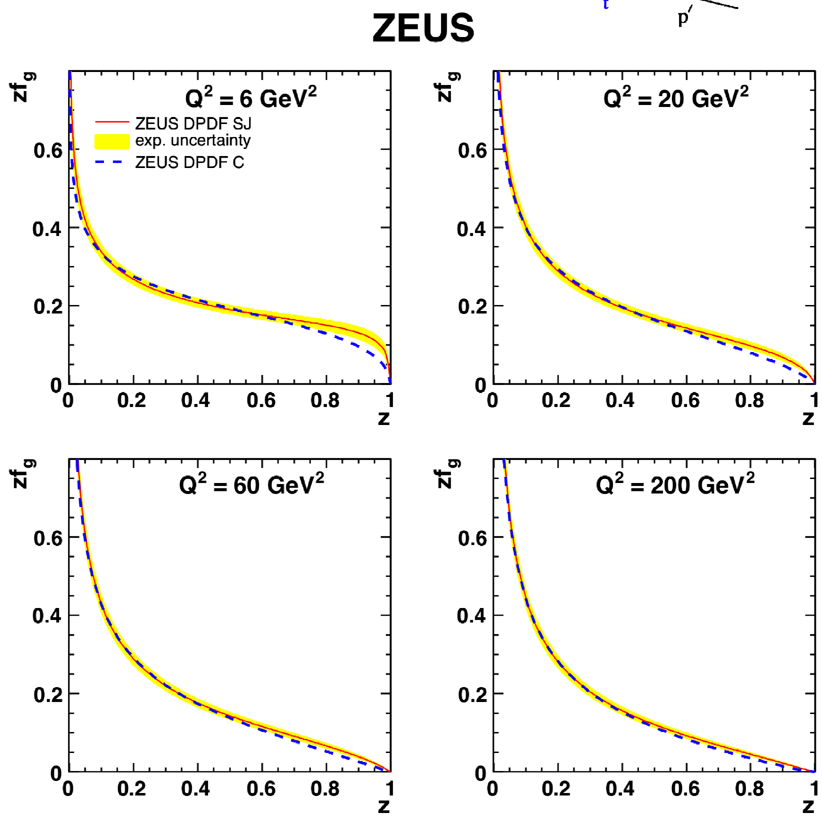
Inclusive and Dijet Data

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





First Measurement of F_L^D

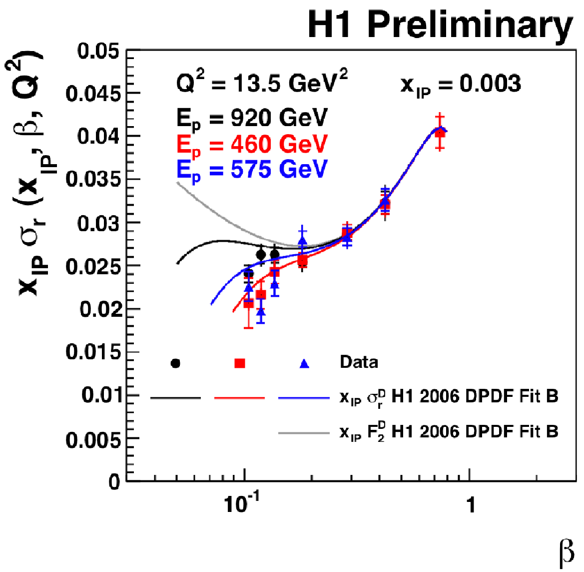
$$\sigma_r^D = F_2^D - \frac{y^2}{Y_+} F_L^D \qquad F_L^D \sim \alpha_S \times g(x)$$

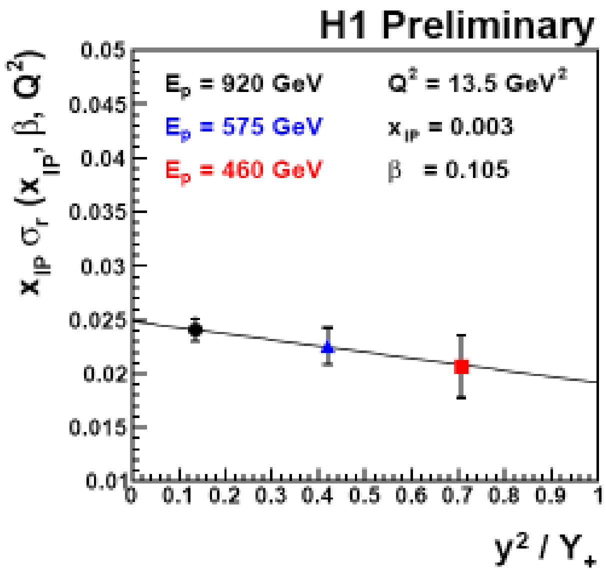
Challenging measurement, requires good understanding of the detector

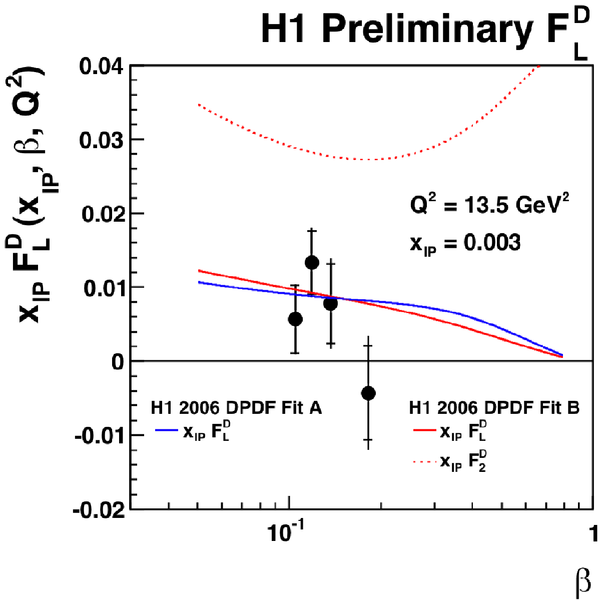
Measurement is performed with data taken at 3 proton beam energies: 920, 460 and 575 GeV

($Q^2 = sxy$, $x = \beta x_{IP}$)

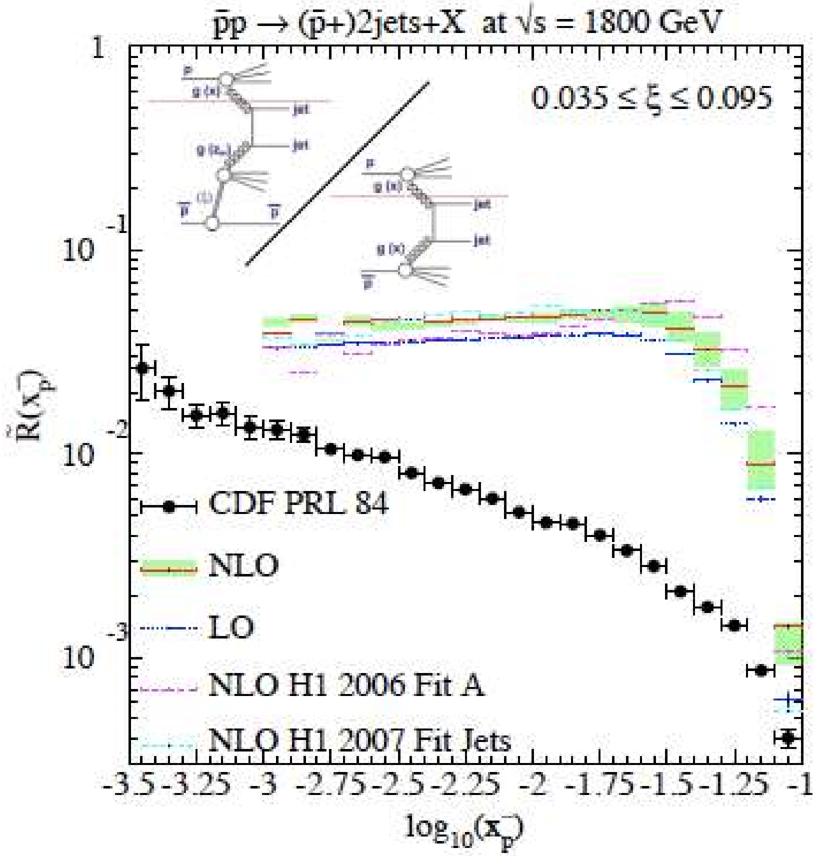
⇨ At fixed Q^2 and x_{IP}, high y corresponds to low β



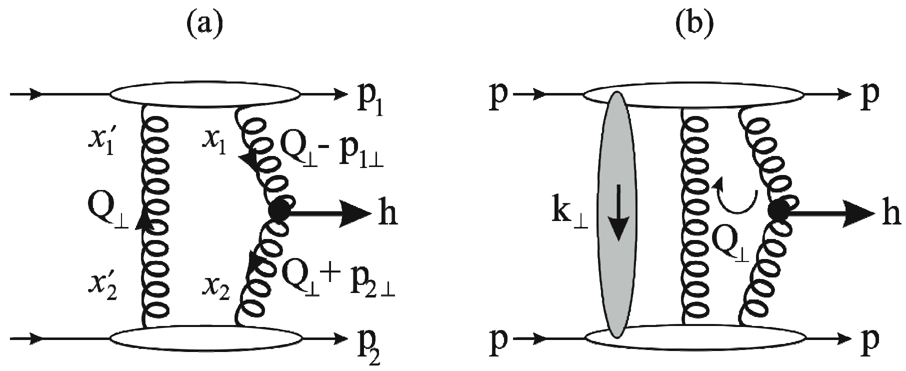




Factorisation Test at Tevatron



When trying to use universal DPDFs extracted at HERA to predict diffractive dijets at CDF we find a large suppression factor



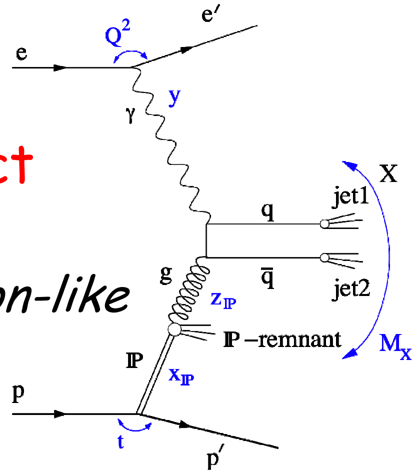
Suppression expected in QCD and understood in terms of soft interactions between the hadrons and their remnants suppressing the Large Rapidity Gap

⇨ To understand diffraction at LHC a detailed undertanding on this mechanism is needed

Factorization Test at HERA

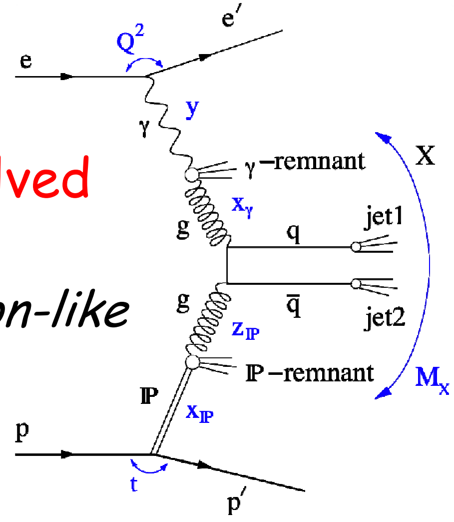
Direct

Less hadron-like



Resolved

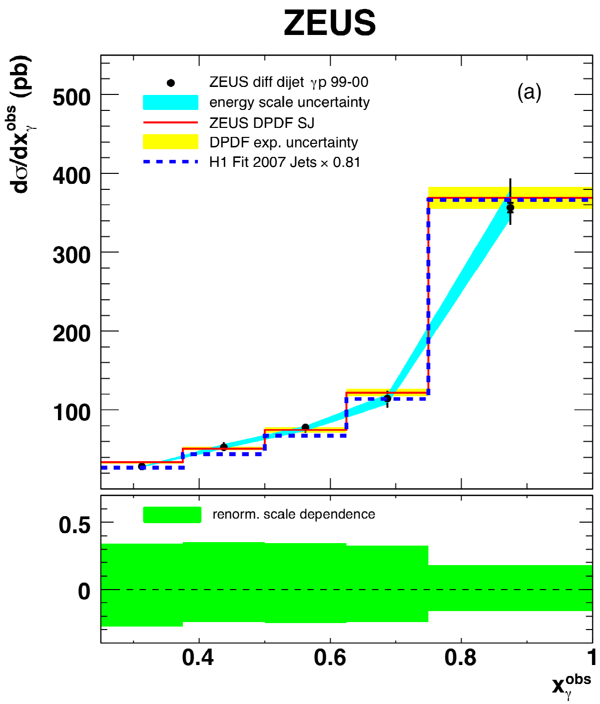
More hadron-like

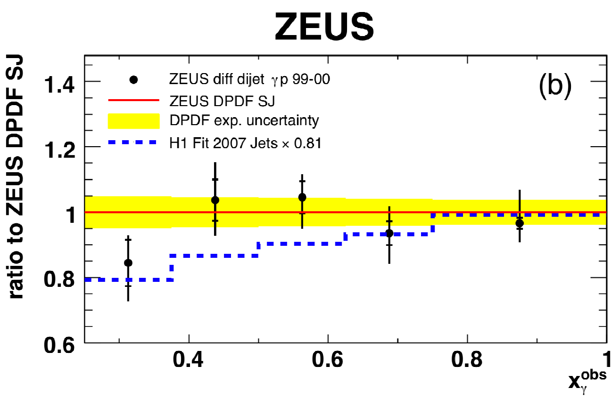


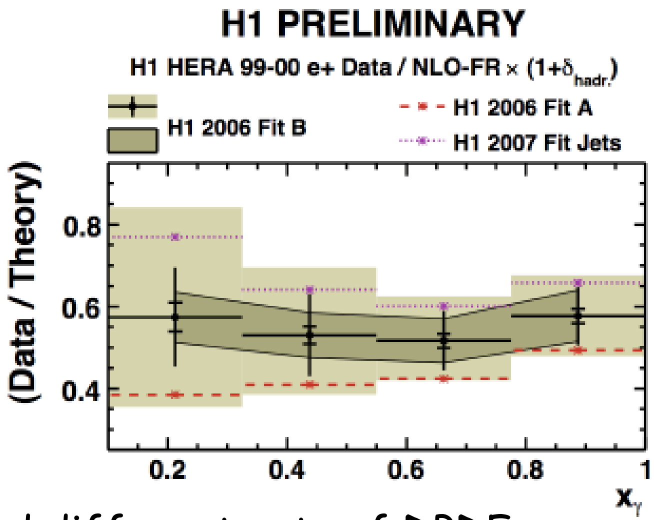
Use photoproduction at HERA as a hadron-hadron process

How hadron-like the proton is depends on the x_γ variable

Expect Resolved (low x_γ) to be more suppressed than Direct (high x_γ)





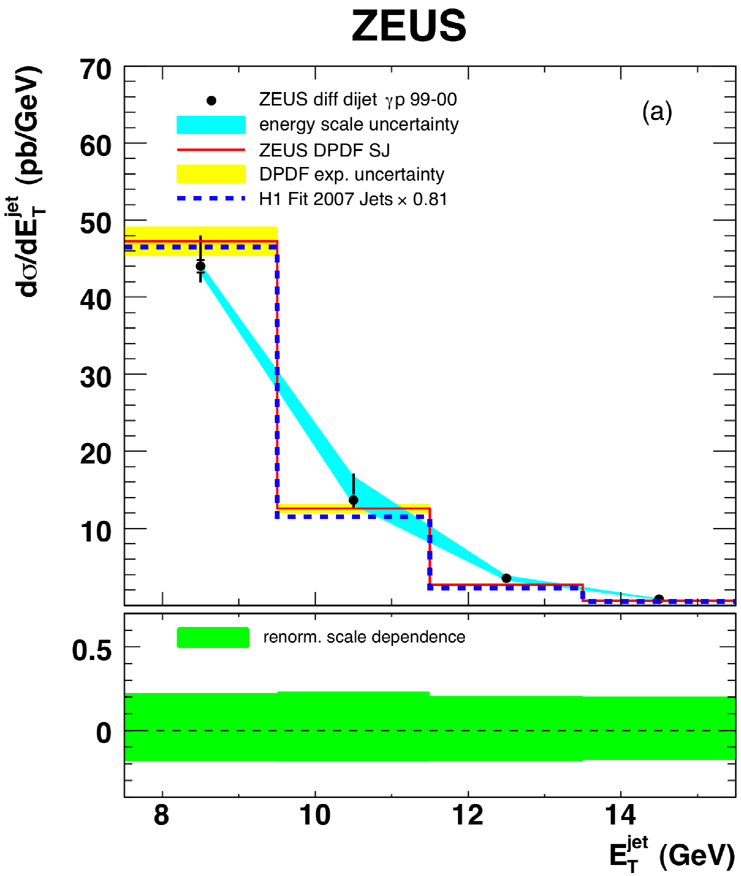


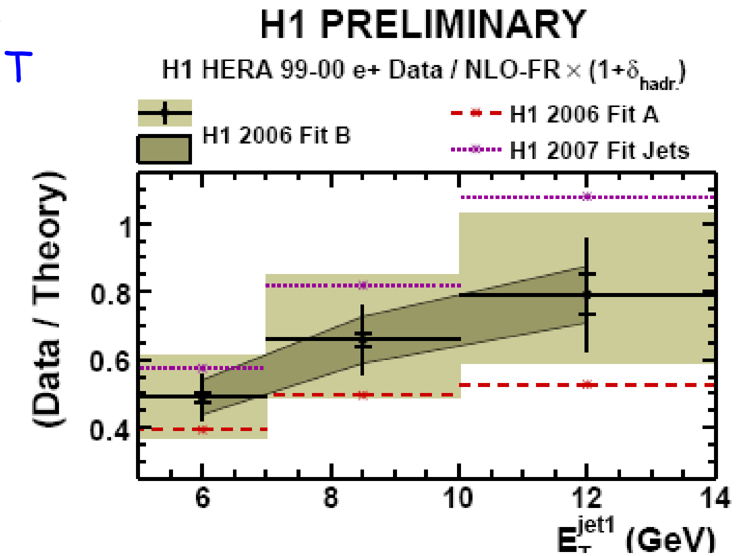
(different E_T region and different sets of DPDFs between ZEUS and H1)

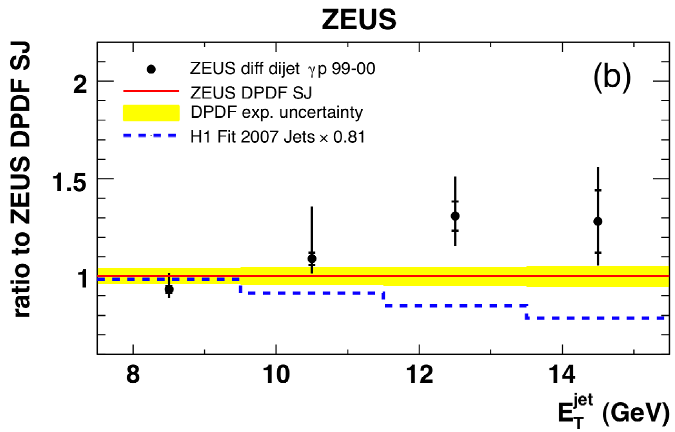
⇨ No evidence of suppression of resolved contribution

Factorization Test at HERA

Dijet photoproduction vs E_T



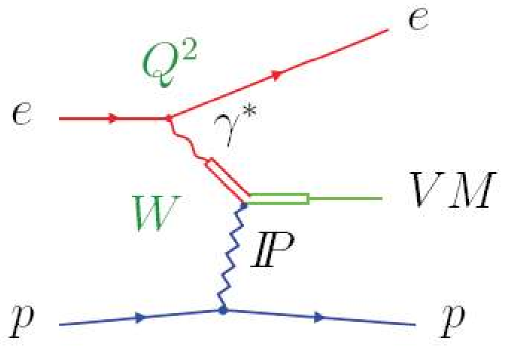




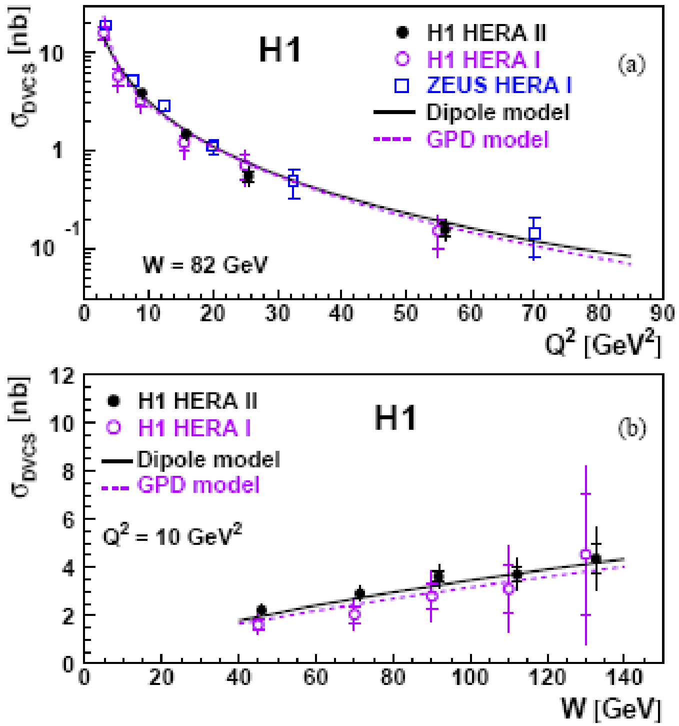
Data compared to NLO calculations using HERA DPDFs to test E_T dependence

Small suppression at small E_T
Both data still compatible

Flash on Exclusive Results (ep → epVM)



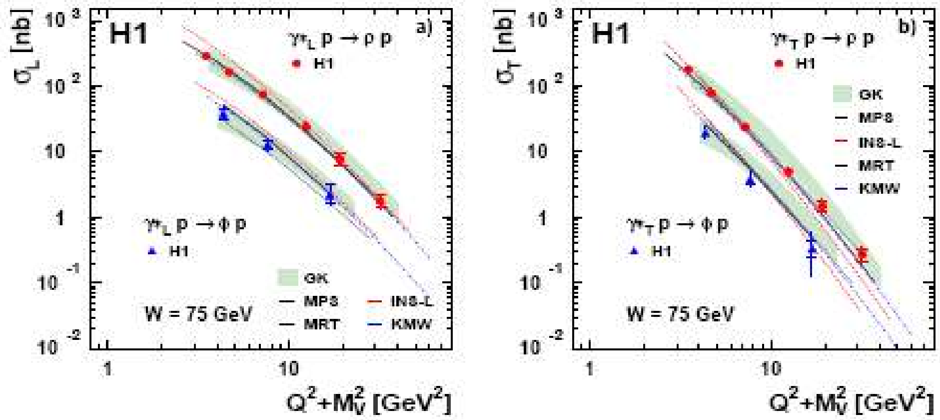
DVCS $\gamma^*p \to \gamma p$



[Phys.Lett. B681 (2009) 391-399]

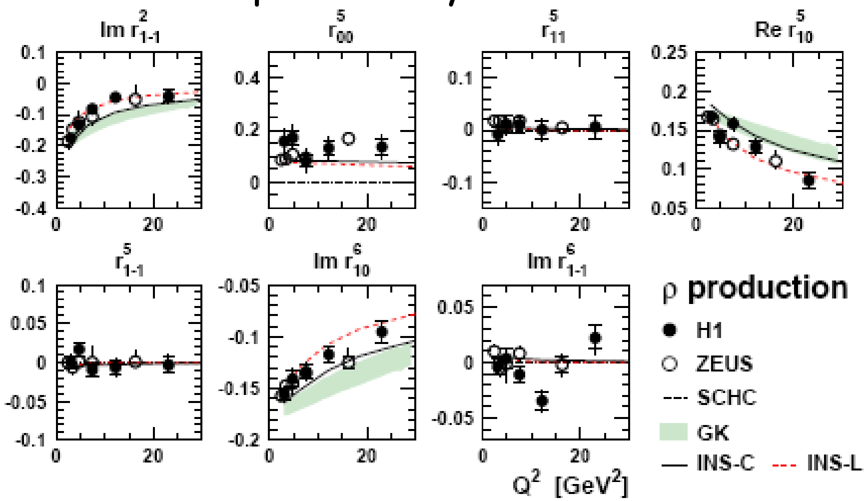
ρ and φ production

$\gamma^*p \to \rho p$
$\gamma^*p \to \varphi p$



[arXiv:0910.5831]

Some spin density martix elements



⇨ Lot of new physics results on this subject

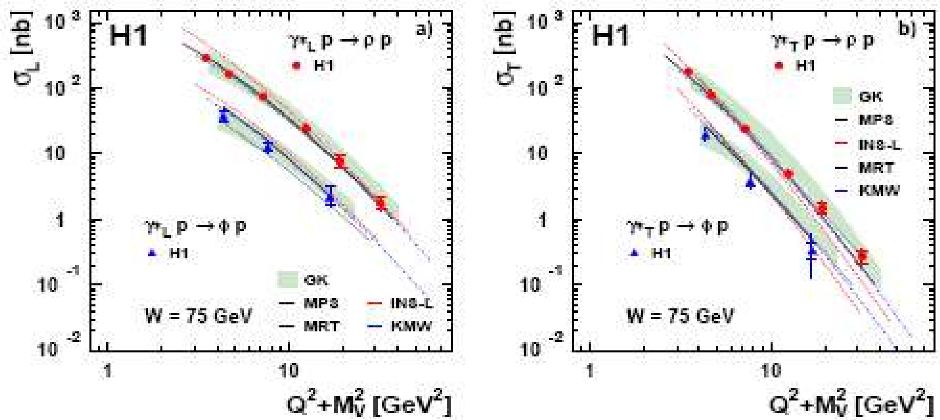
Flash on Exclusive Results (ep → epVM)

Precision data in general agreement with QCD models (testing especially dipole and GPD models)

ρ and φ production

$\gamma^* p \to \rho p$

$\gamma^* p \to \varphi p$



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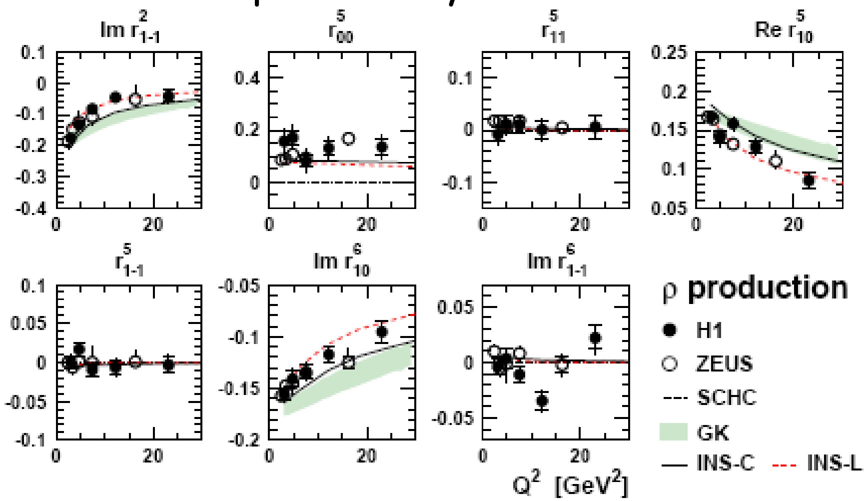
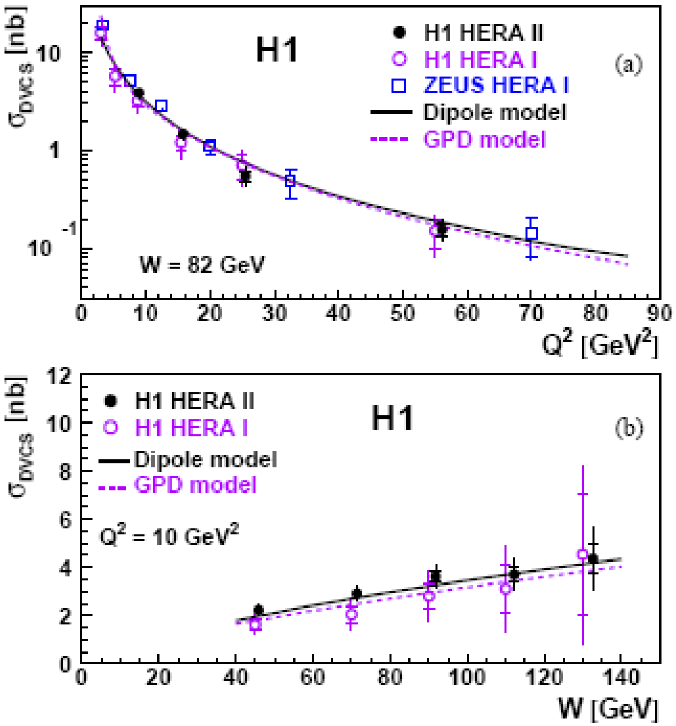


DVCS

$\gamma^* p \to \gamma p$



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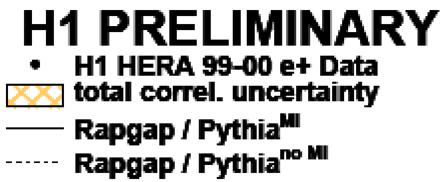
Summary

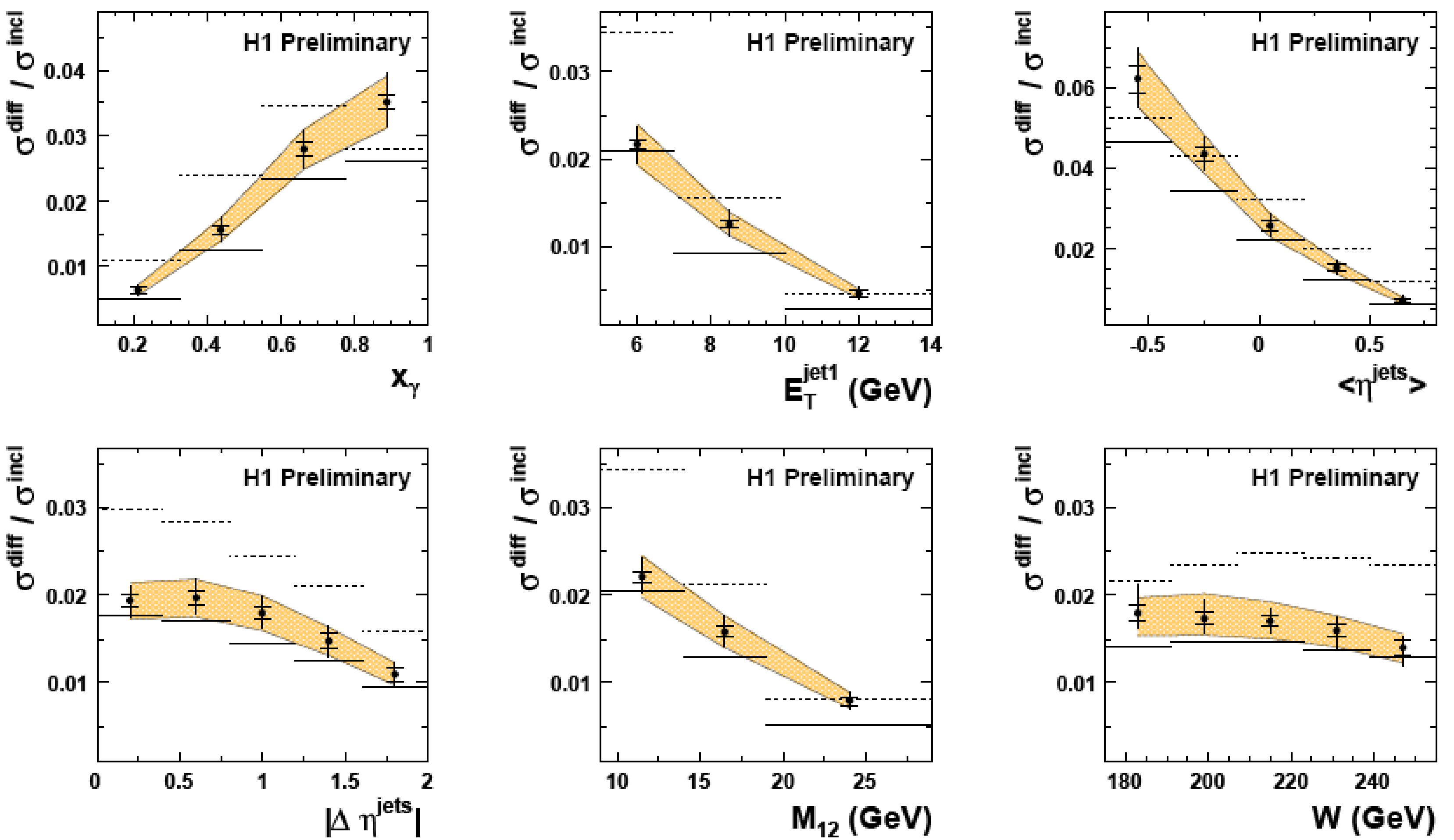
- ✓ After 15 years of running HERA provided unique diffractive data
- ✓ Consistency reached between different experiments, methods and data sets
- ✓ DPDFs well constrained which can be used to predict other processes
  - ⇨ Inclusion of dijet data in the QCD fits provides a much better constraint of the gluon density at high fractional momentum
- ✓ First measurement of F_L^D in agreement with predictions
- ✓ Detailed understanding of hard diffractive photoproduction needed
  - ⇨ No x_γ dependence, but a possible E_T dependence
- ✓ Lot of new results on exclusive diffraction (DVCS, ρ and φ)

The End

Diffractive photoproduction of jets



Lot of work ongoing in order to make jet photoproduction knowledge as precise as possible



Factorization Test at HERA

Direct

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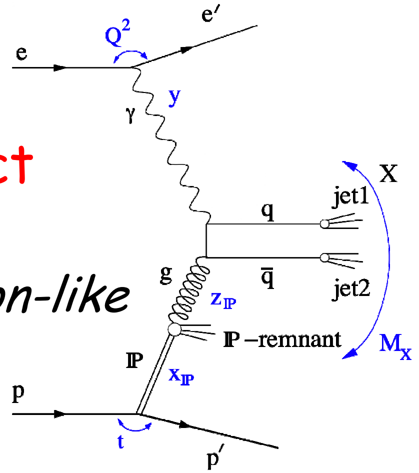
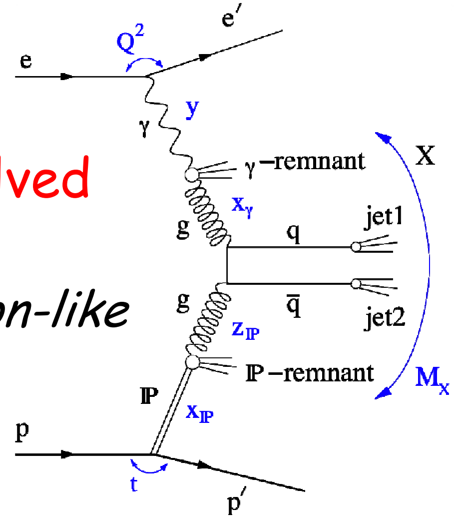


Resolved

More hadron-like



Use photoproduction at HERA as a hadron-hadron process

How hadron-like the proton is depends on the x_γ variable

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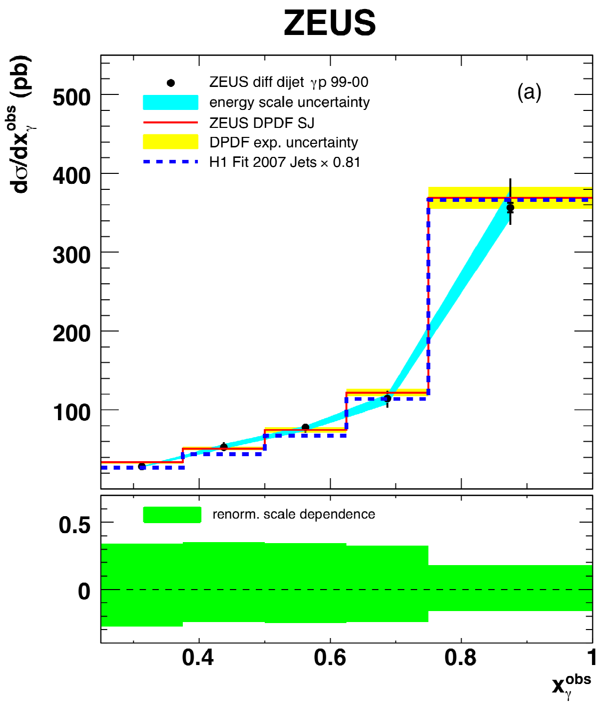
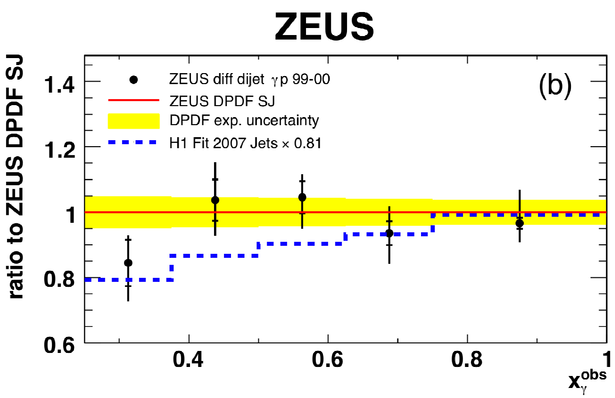
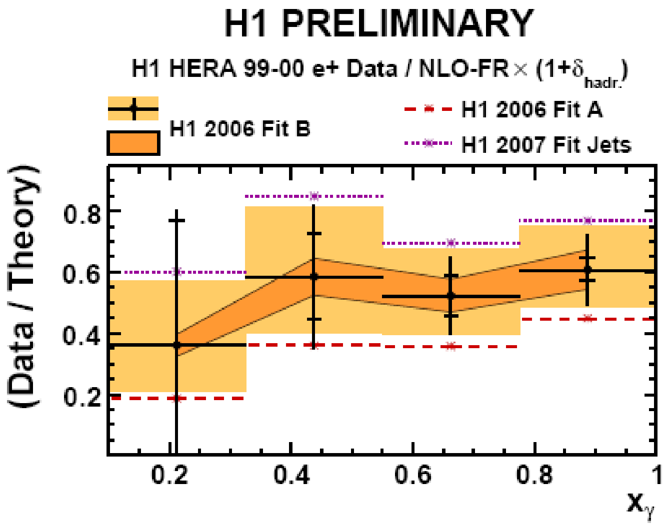




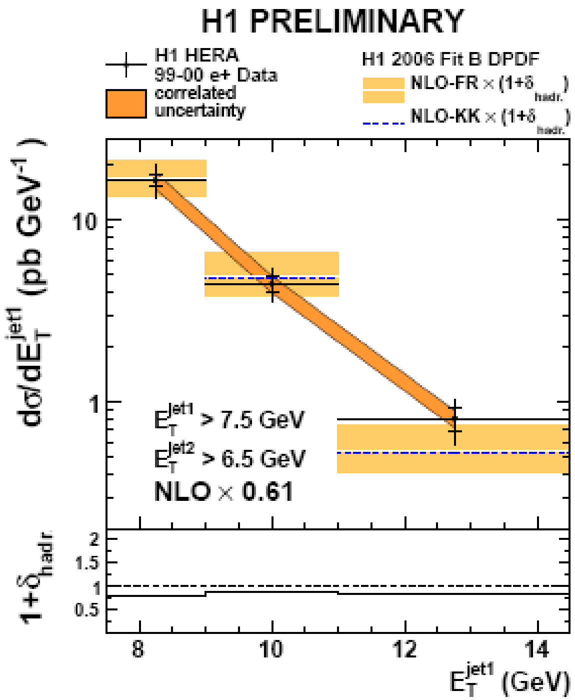


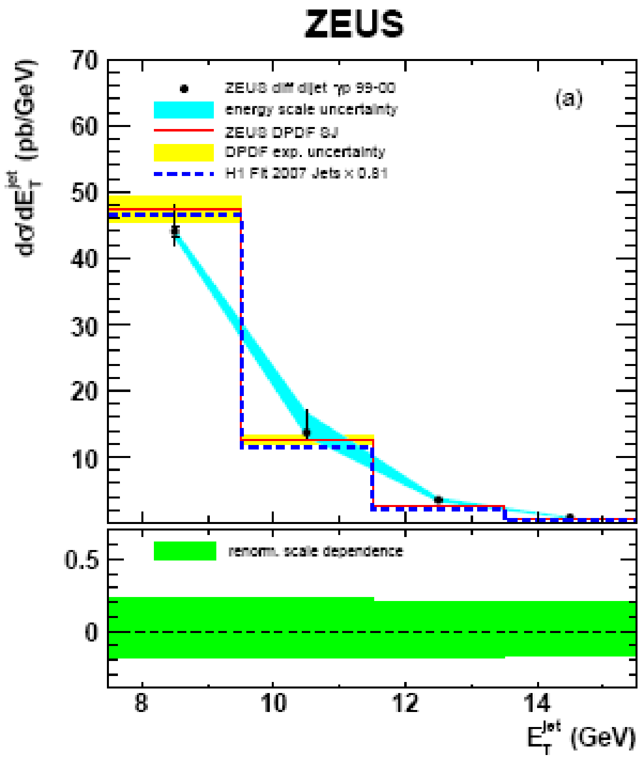
(same E_T region between ZEUS and H1)

⇨ No evidence of suppression of resolved contribution

Factorization Test at HERA

Dijet photoproduction vs E_T





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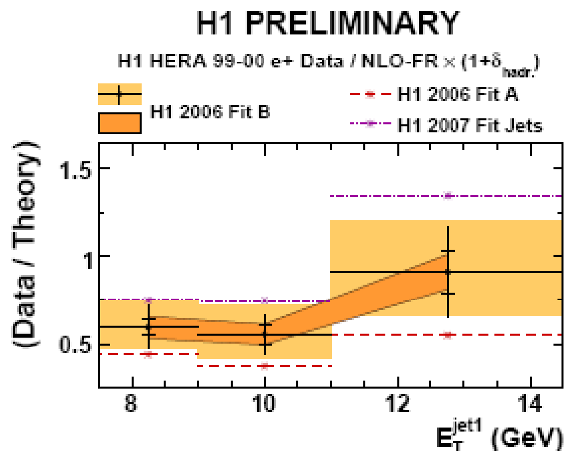
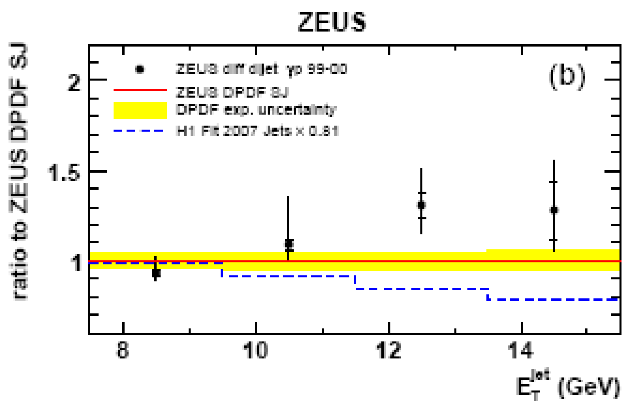
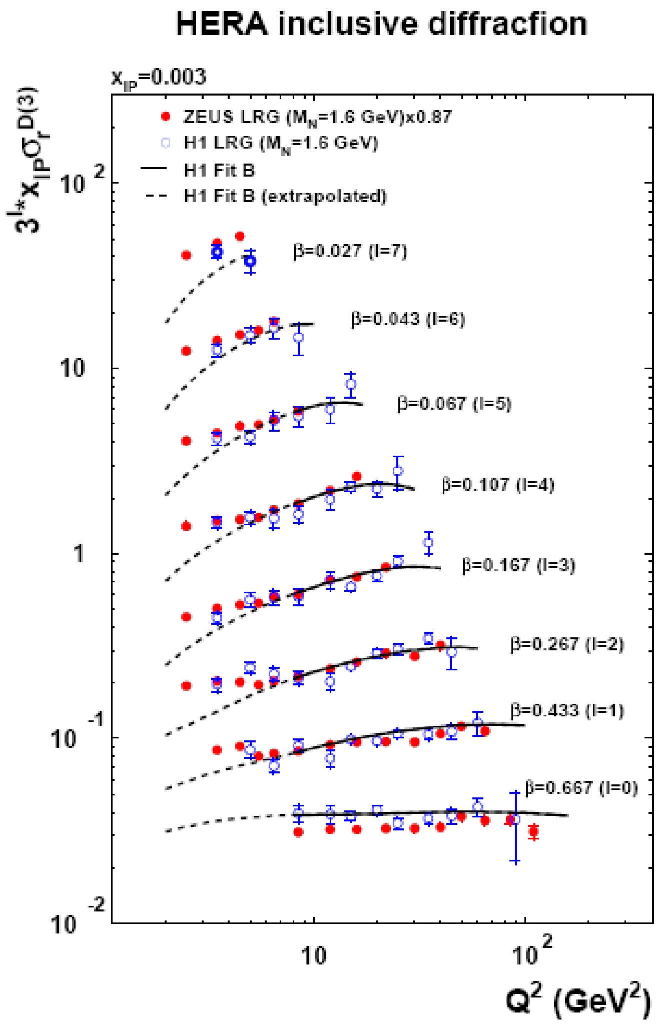
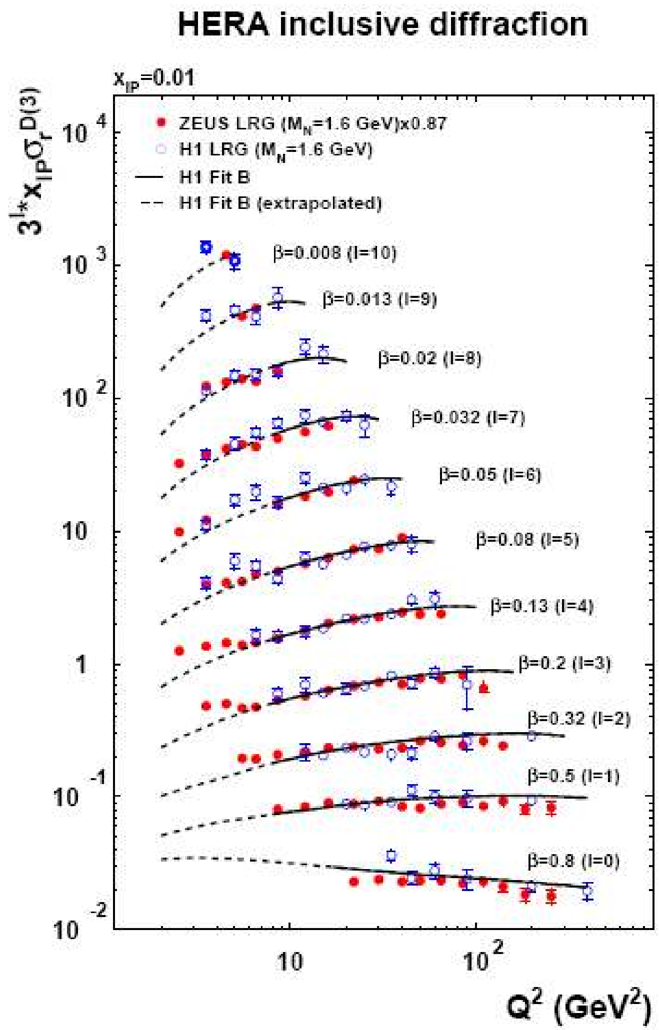




H1 vs ZEUS Normalized LRG Data





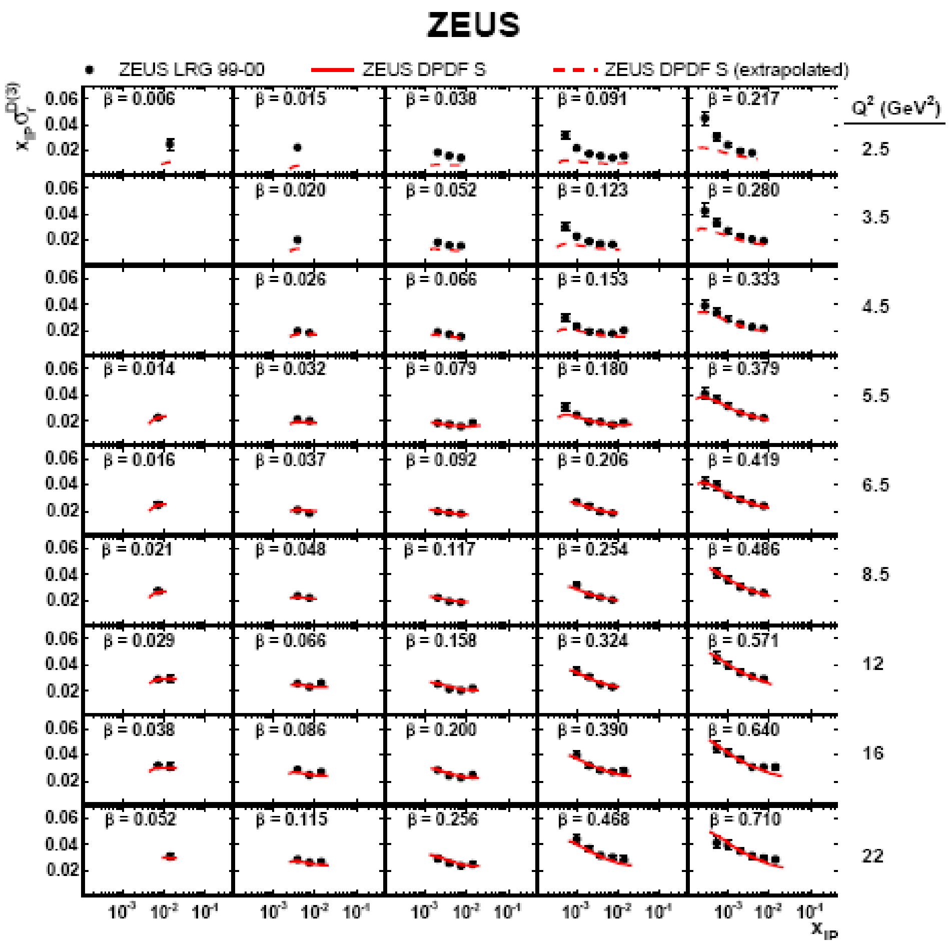
Final ZEUS LRG data (62 pb^{-1}) reach new level of stats precision

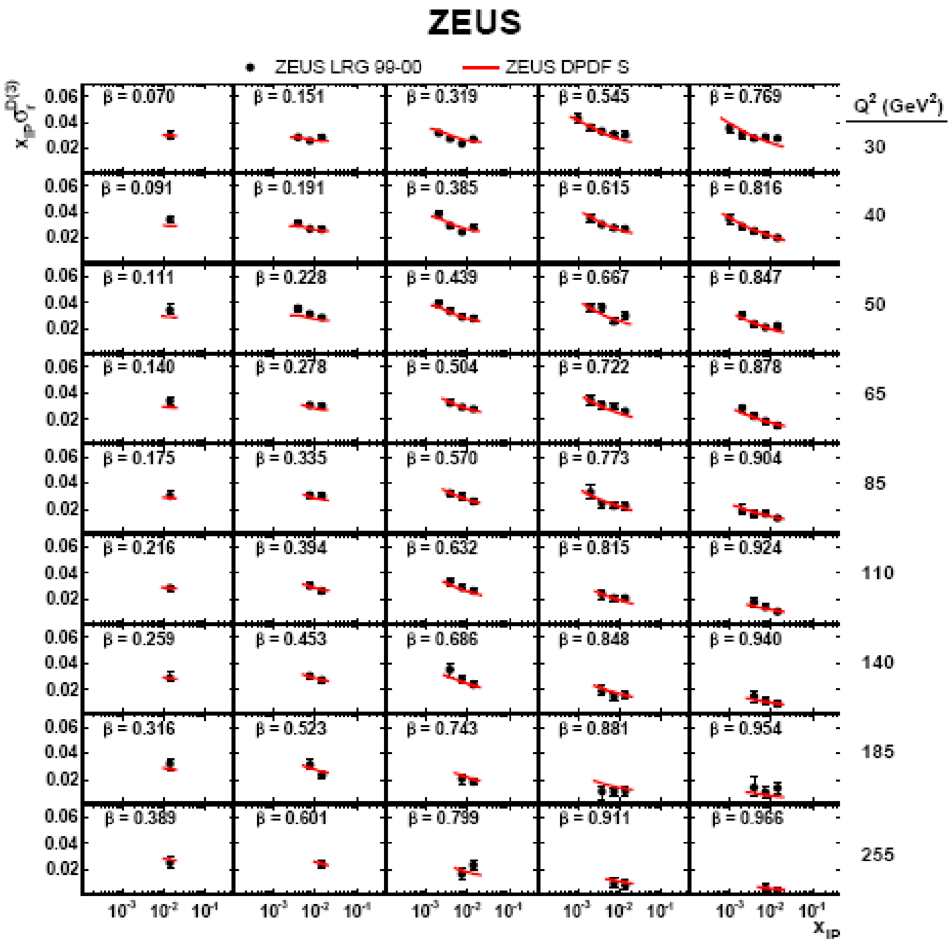
Remaining norm difference of 13% (global fit) covered by uncertainty on DD correction (8%) and relative norm uncertainty (7%)

Shape agreement ok except low Q^2

ZEUS corrected to M_N < 1.6 GeV with PYTHIA MC

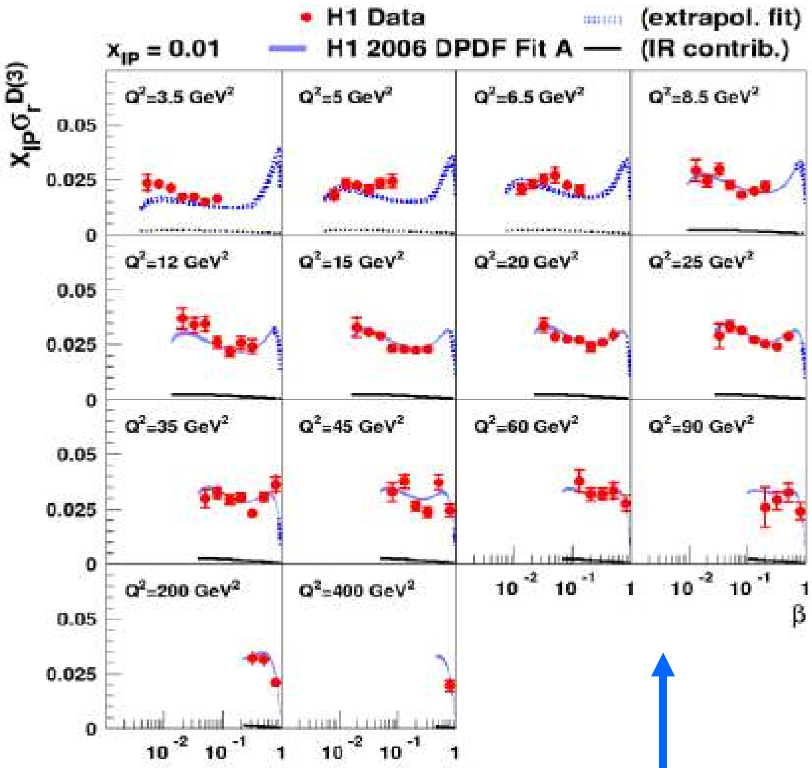
x_{IP} Dependence of $\sigma_r^{D(3)}$

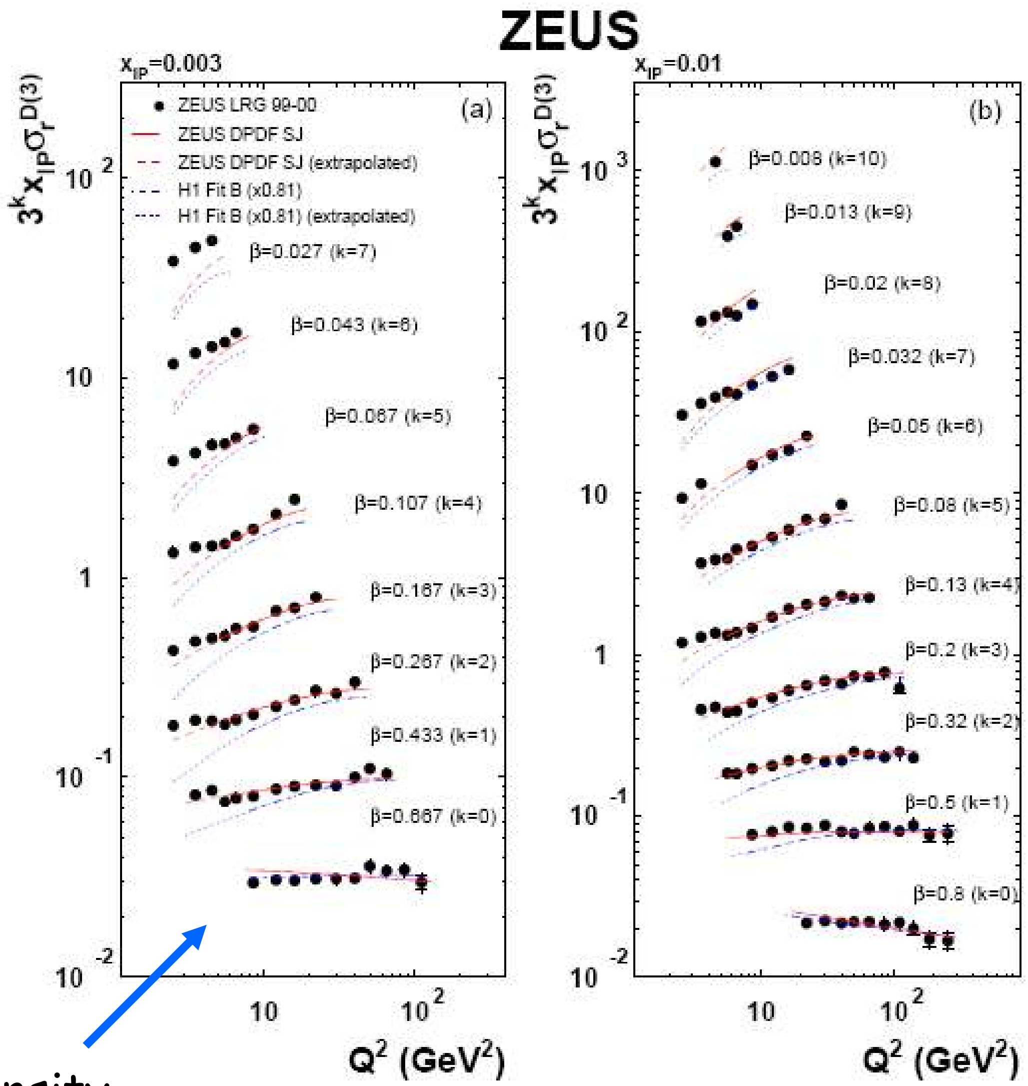




Wide kinematic coverage and very good statistical precision

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





Reduced cross section constrains quark density

lnQ^2 dependence constrains gluon density