A review of diffraction at HERA

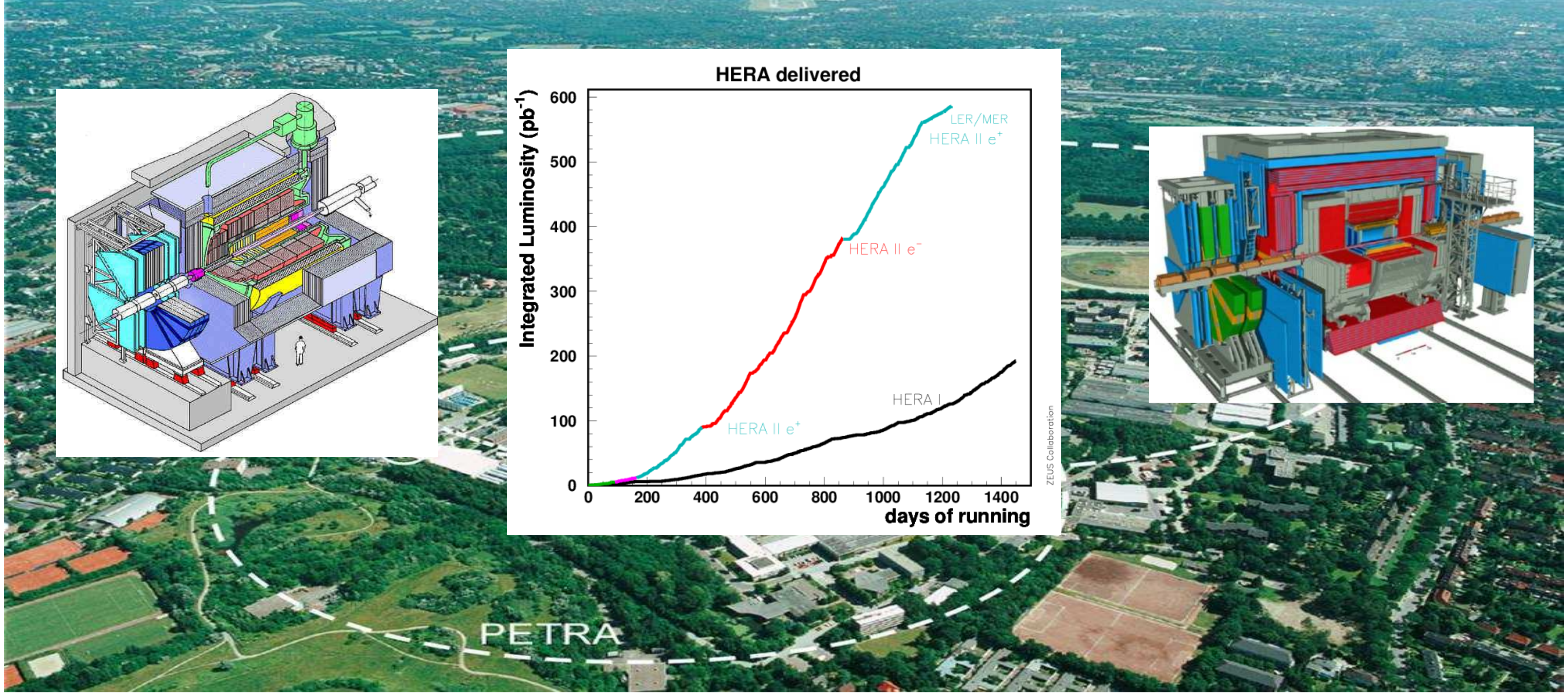
Janusz Malka (DESY)

on behalf of H1 and ZEUS Collaborations

XXII. International Workshop on Deep-Inelastic
Scattering and Related Subjects
Warsaw, 29/04/2014

HERA ep collider (1992 – 2007)

- **The world's only electron/positron-proton** collider at DESY, Hamburg
- **E_e = 27.6 GeV, E_p = 920 GeV** (820, 460, 575 GeV)
- **Two collider experiments: H1 and ZEUS**

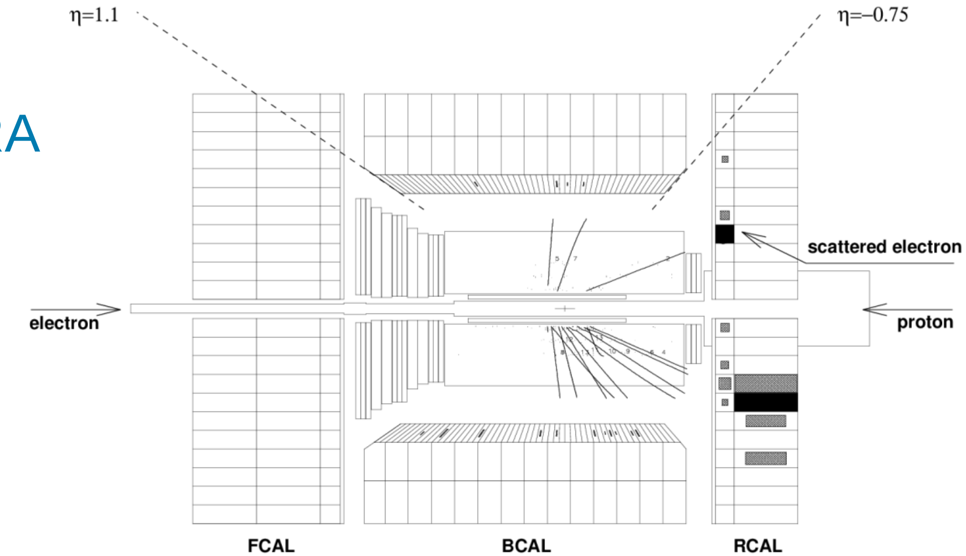


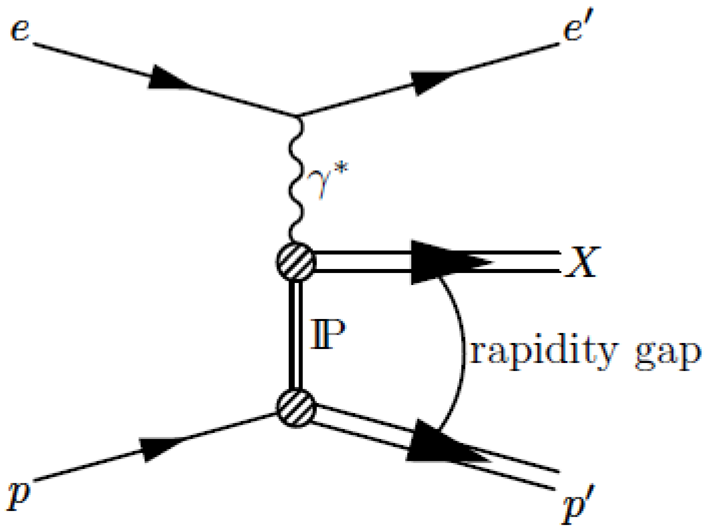
- **total luminosity ~ 0.5 fb^{-1}per experiment**

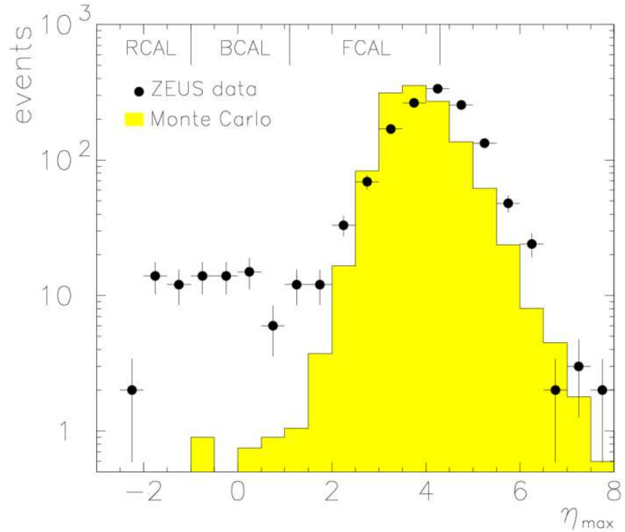
21 years of diffraction @ HERA

Physics Letters B 315 (1993) 481-493

- First observation of events with a Large Rapidity Gap in DIS at HERA
- An object carrying the quantum numbers of vacuum is exchanged between γ^* and p: Pomeron

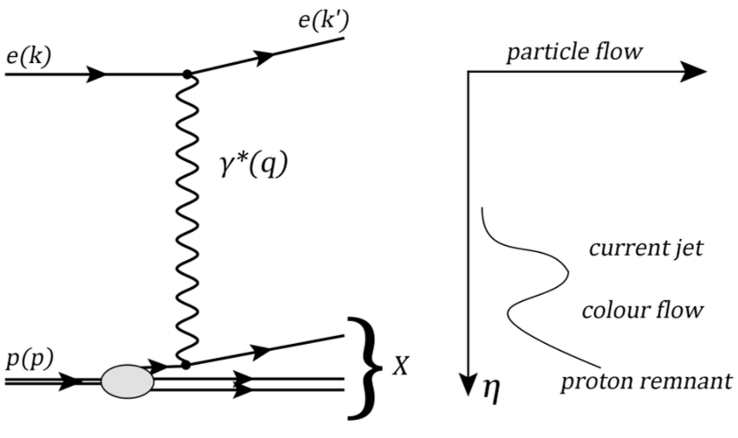






Diffractive scattering

Deep Inelastic Scattering (DIS)



Q^2 = $-q^2$ - virtuality of the photon

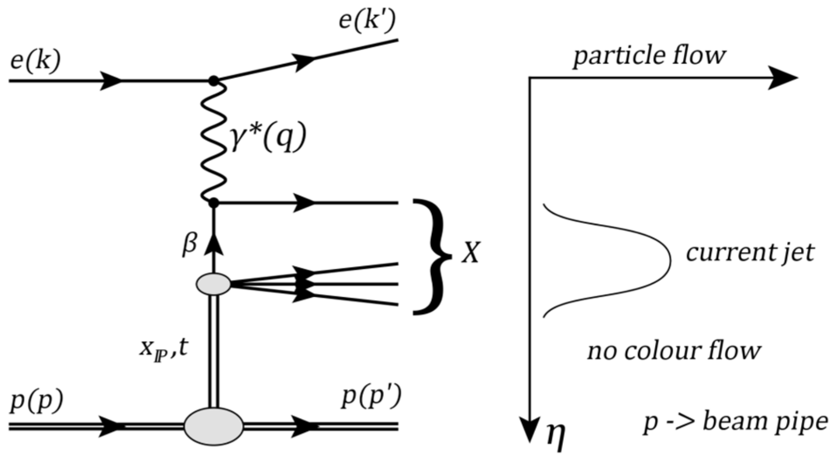
$Q^2 \approx 0$ photoproduction, $Q^2 > 0$ DIS

W photon-proton CME

x Bjorken-x: fraction of proton's momentum carried by struck quark

y = Pq/Pk inelasticity

Diffractive Scattering (DDIS)



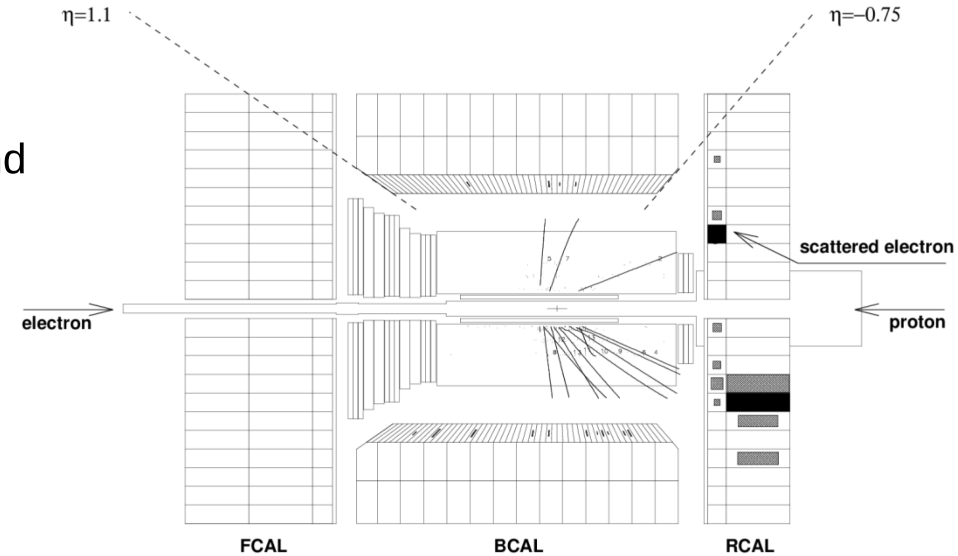
x_{IP} fraction of proton's momentum of the colour singlet system

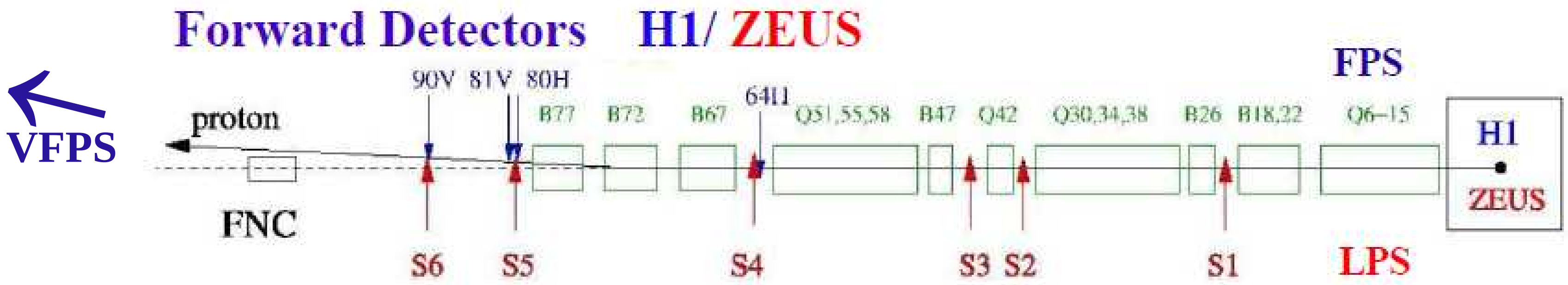
t = $(p-p')^2$ 4-momentum transfer squared at proton vertex

β = x/x_{IP} fraction of IP carried by the quark "seen" by photon

Experimental Methods

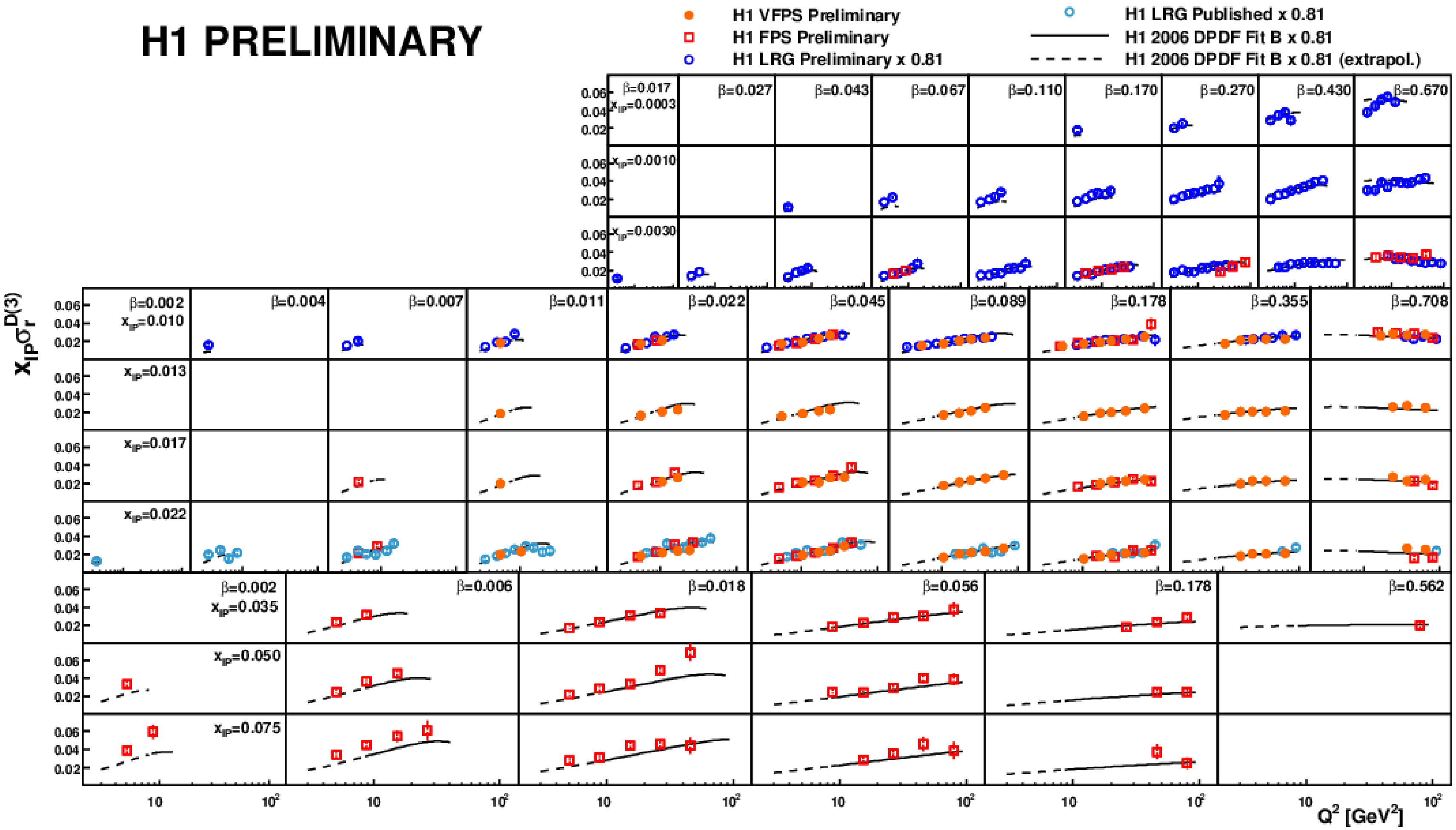
- **>** Large Rapidity Gap:
  - contains proton dissociative background
  - high statistics
- **>** proton spectrometer:
  - clean measurement p-tagging
  - no proton dissociative background
  - low statistics





Diffractive Structure Function Measurements

- Experimental summary of H1 F_2^D measurements



- The data compare well with H1 Fit B prediction

Diffractive cross section

- In analogy to the inclusive DIS cross section, the inclusive diffractive cross section:

$$\frac{d^4\sigma^{ep\to e'Xp'}}{d\beta dQ^2 dx_{IP}dt} = \frac{2\pi\alpha^2}{\beta Q^4}\left[1-y+\frac{y^2}{2}\right]\sigma_r^{D(4)}(\beta,Q^2,x_{IP},t)$$

- reduced diffractive cross section is:

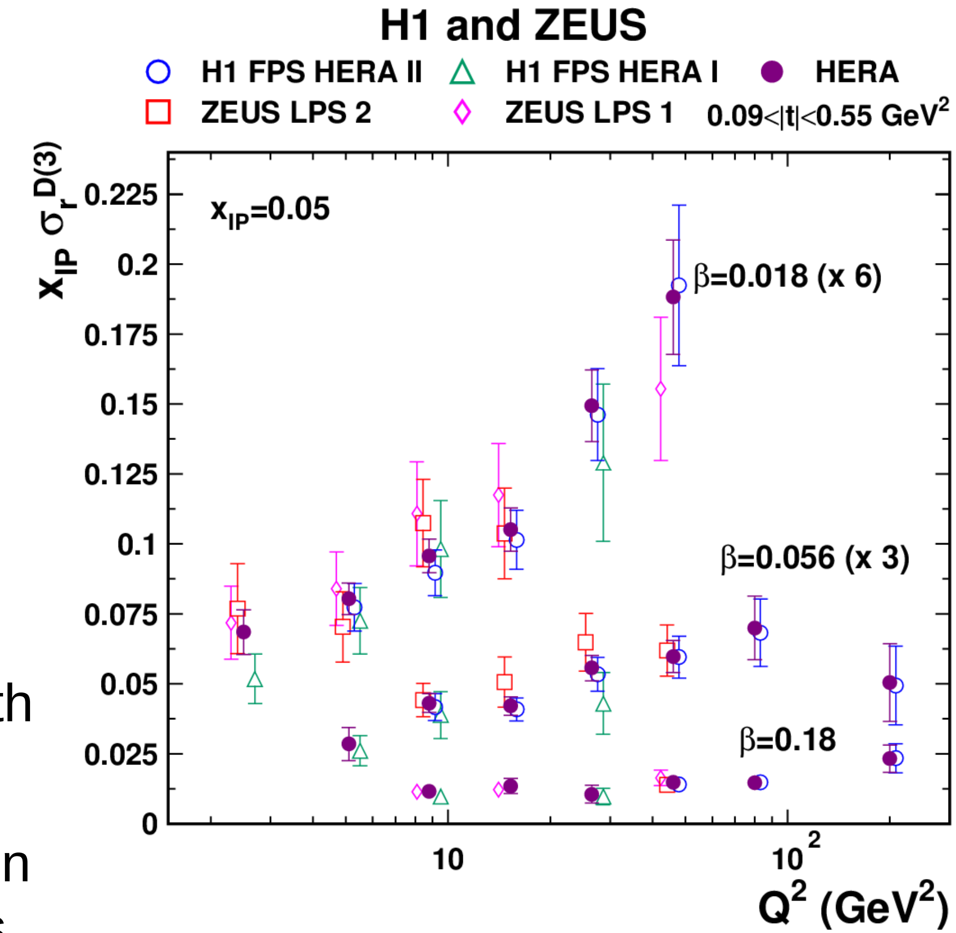
$$\sigma_r^{D(4)}(\beta,Q^2,x_{IP},t) = F_2^{D(4)}(\beta,Q^2,x_{IP},t) - \frac{2y^2}{2-2y+y^2}F_2^{L(4)}(\beta,Q^2,x_{IP},t)$$

- Integrate over t when proton is not tagged $\rightarrow$ $\sigma_r^{D(4)}(\beta,Q^2,x_{IP})$
- $\sigma_r^{D(4)} \approx F_2^{D(4)}$ at low and medium y
- $\sigma_r^{D(4)} = F_2^{D(4)}$ if $F_L^{D(4)} = 0$

HERA combined inclusive diffractive cross sections

Eur. Phys. J. C72 (2012) 2175

- Proton spectrometers to detect the leading protons
- First combined inclusive diffractive cross sections:
  - H1: EPJ C71 (2011) 1578
  - H1: EPJ C48 (2006) 749
  - ZEUS: Nucl. Phys B816 (2009) 1
  - ZEUS: EPJ C38 (2004) 43
- The input data are consistent with $\chi^2_{min}/\mathrm{ndof} = 133/161$
- Total uncertainty on cross section is 6% for the most precise points



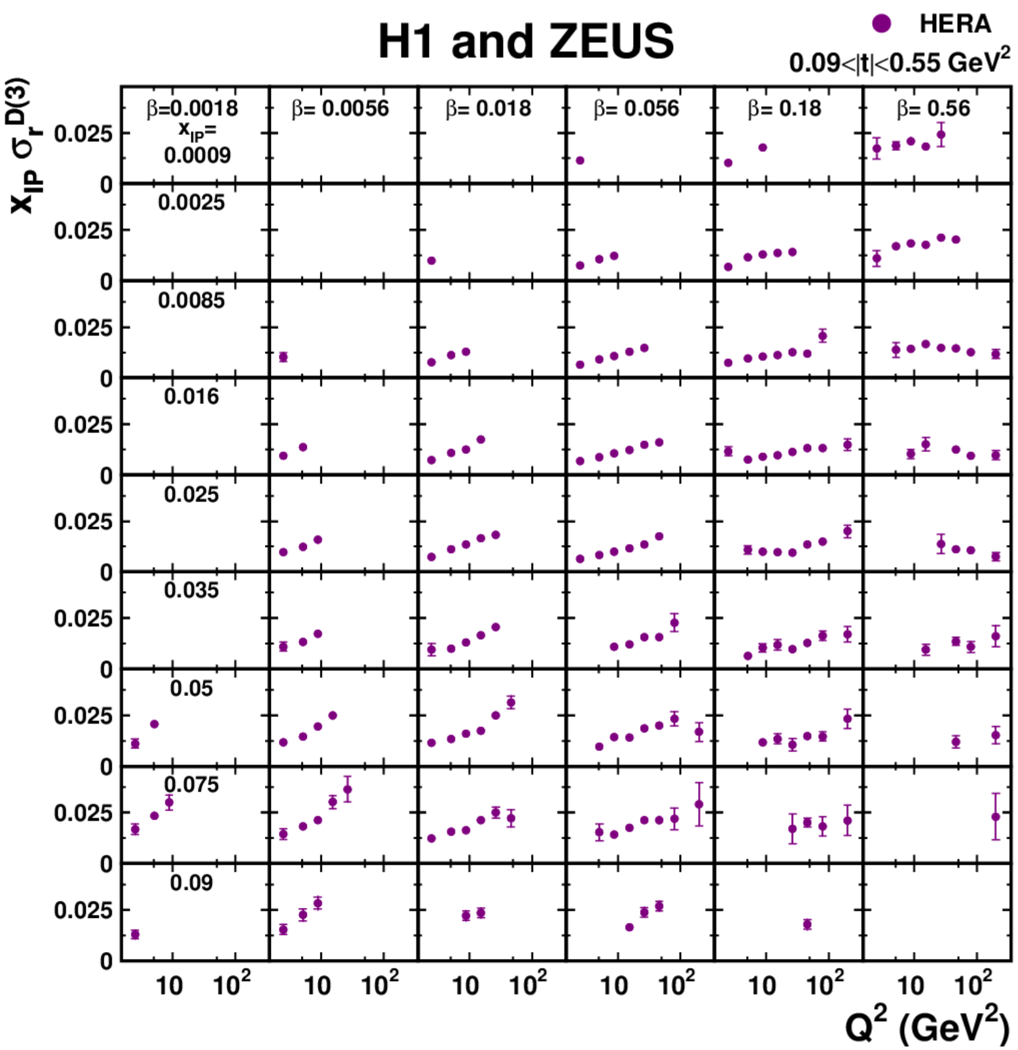
DESY

HERA combined inclusive diffractive cross sections

Eur. Phys. J. C72 (2012) 2175

- The combination results in more precise results and
- wide kinematic range:
  - $2.5 \leq Q^2 \leq 200$ GeV^2
  - $0.0018 \leq \beta \leq 0.816$
  - $0.00035 \leq x_{IP} \leq 0.09$
  - $0.09 < |t| < 0.55$ GeV^2

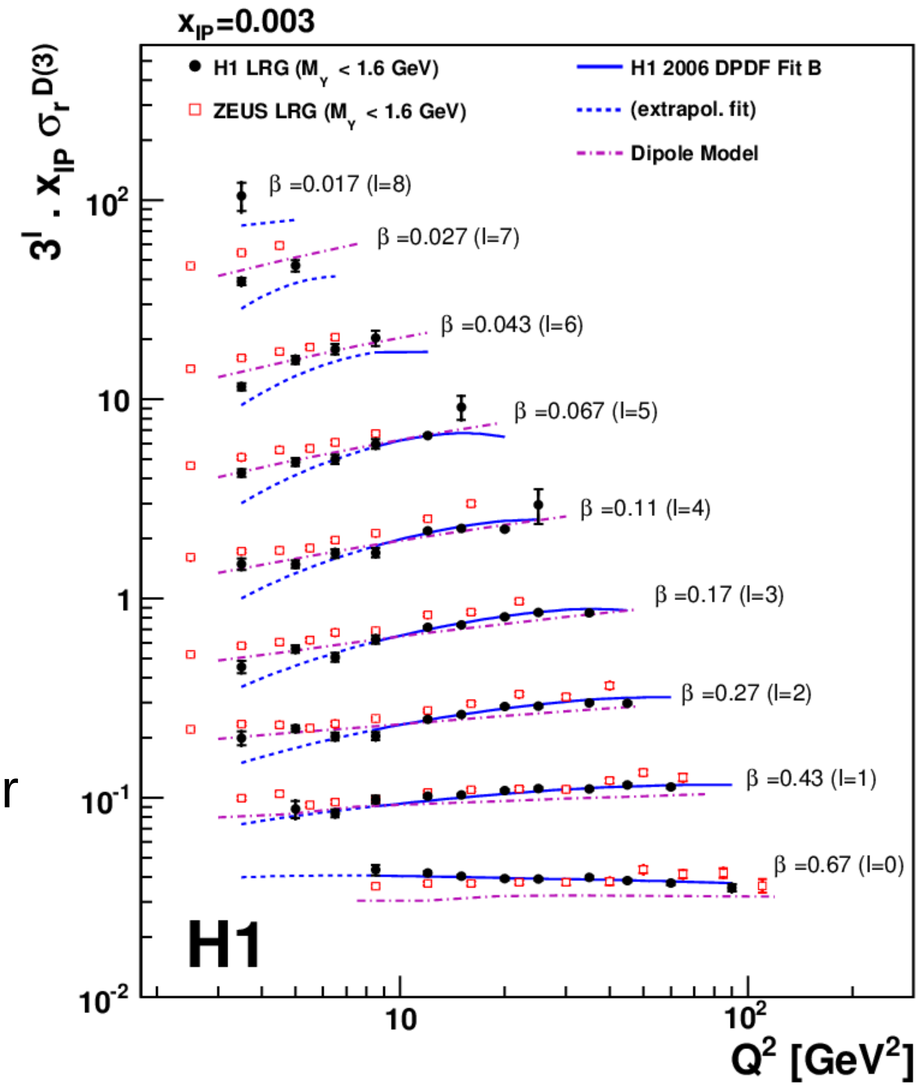
- The results provide the most precise determination of the absolute normalisation of $ep \rightarrow eXp$ cross section



Inclusive Diffractive DIS at HERA

EPJ C72 (2012) 2074

- Combined H1 measurements
- LRG method
- Increase in statistics
- reduction of uncertainties



- the dipole model can describe the low Q^2 kinematic domain better than H1 DPDF fits.
- DPDF fits are more successful to describe the region of high Q^2

Factorisation

- QCD factorisation - rigorously proven

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

DPDFs – obey DGLAP, universal for diff. ep DIS

hard scattering cross section

- proton vertex factorisation - conjecture

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

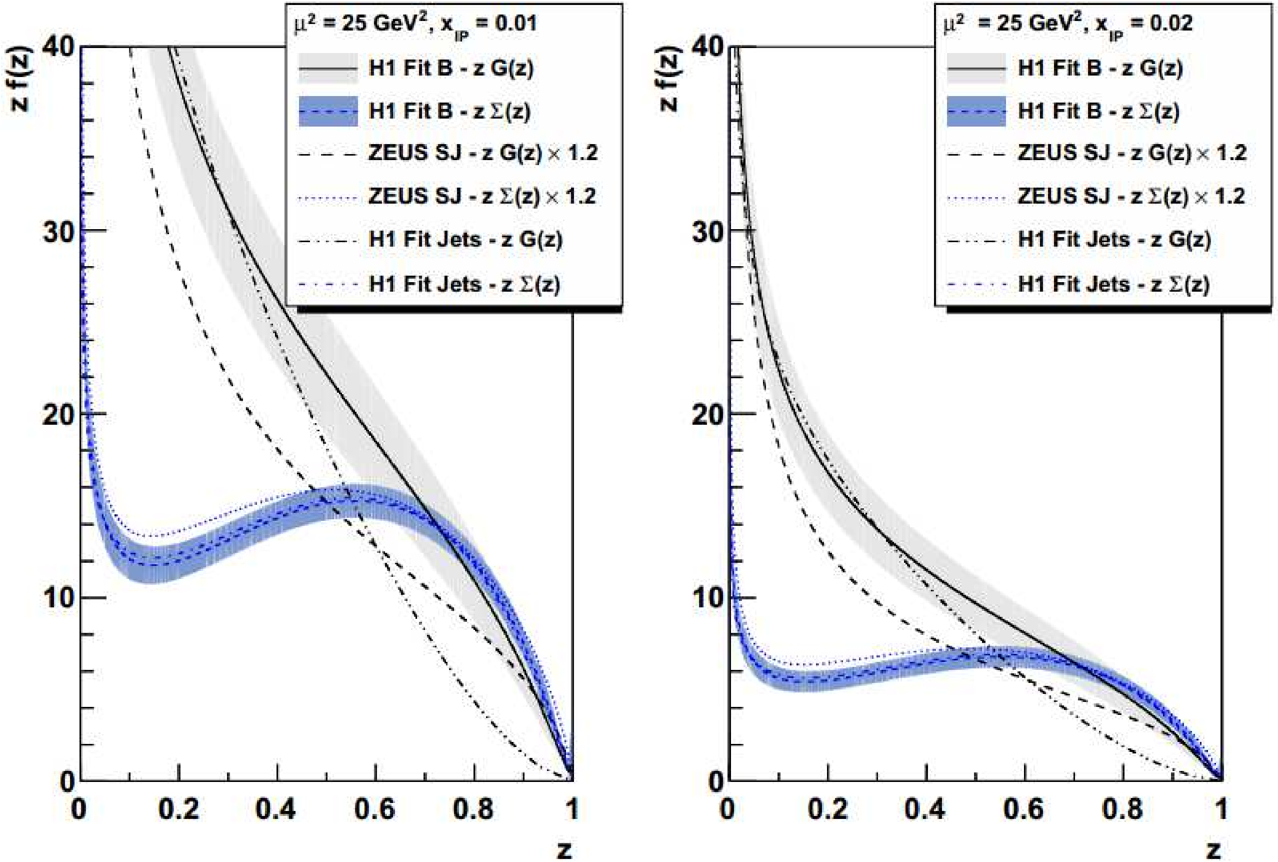
pomeron flux factor

pomeron PDF

Diffractive PDFs

R.Zlebcik,K.Cerny,A.Valkarova,EPJ C71, (2011) 1741

- DPDFs obtained by H1 and ZEUS from inclusive, dijet



- z - the longitudinal four-momentum fraction of the parton entering the hard sub-process with respect to pomeron

Inclusive Diffractive DIS at HERA: Pomeron Trajectory

EPJ C72 (2012) 2074

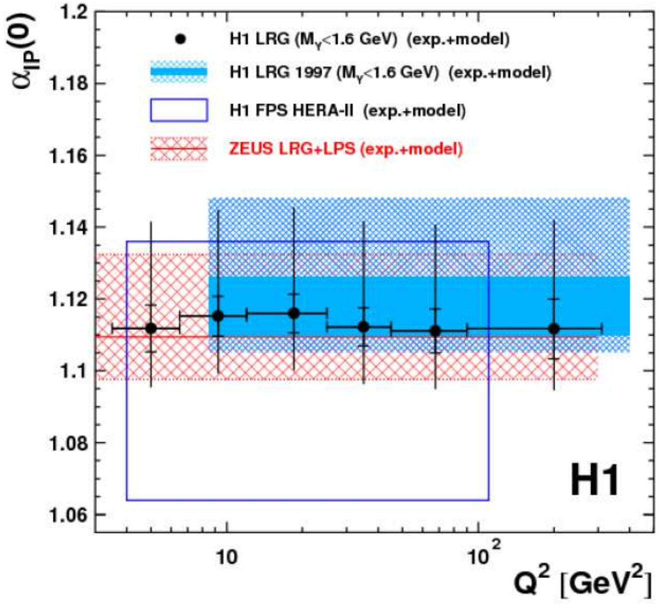
$$F_2^{D(3)}(Q^2,\beta,x_{\mathbb{P}}) = f_{\mathbb{P}/p}(x_{\mathbb{P}}) \; F_2^{\mathbb{P}}(Q^2,\beta) + n_{\mathbb{R}}\, f_{\mathbb{R}/p}(x_{\mathbb{P}}) F_2^{\mathbb{R}}(Q^2,\beta)$$

$$f_{\mathbb{P}/p}(x_{\mathbb{P}}) = \int_{t_{cut}}^{t_{min}} \frac{e^{B_{\mathbb{P}} t}}{x_{\mathbb{P}}^{2\alpha_{\mathbb{P}}(t)-1}} dt$$

parameterised

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

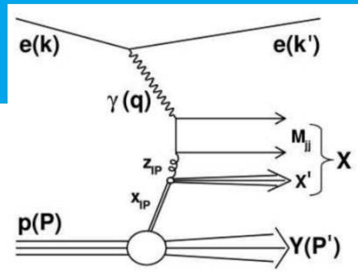
- No Q^2 dependence observed
- Agreement with previous measurements
- Consisted with “soft” pomeron
- Supports proton vertex factorisation



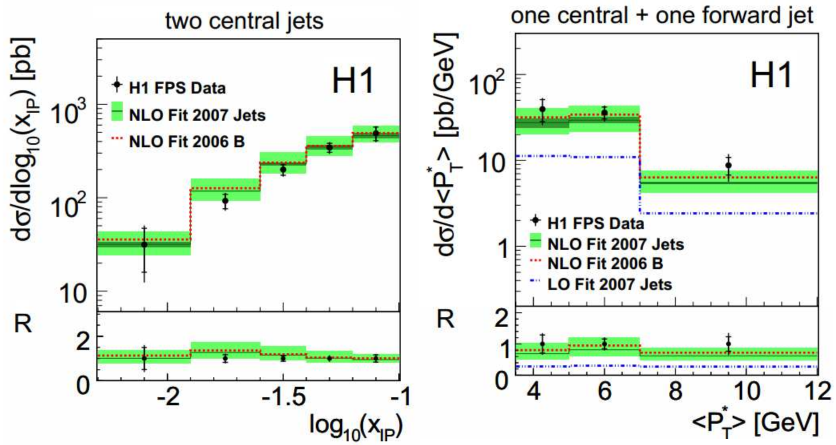
Diffractive dijets in DIS

Nucl. Physics B 831 (2010) 1-25

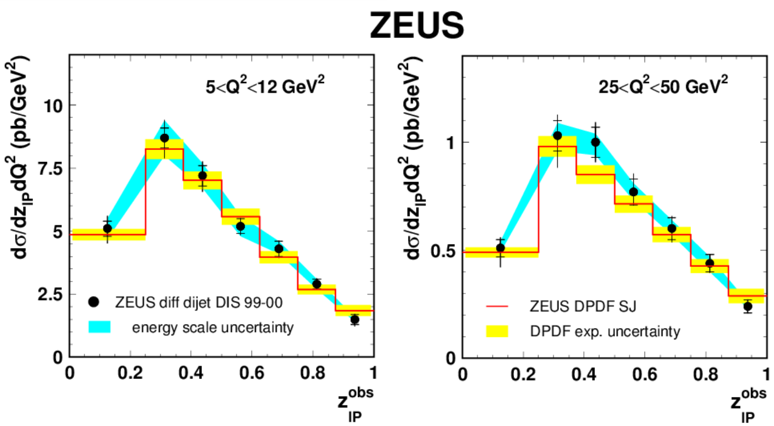
EPJ C72 (2012) 1970



- two hard scales in the process:
  - the virtuality of the photon
  - the transverse energy of the jets
- sensitivity to the gluon given by the production mechanism of the dijets
  - Boson-Gluon Fusion processes

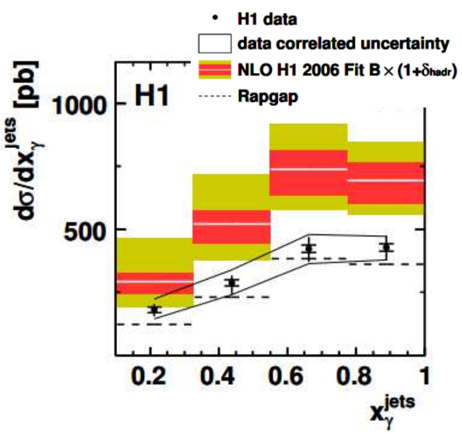


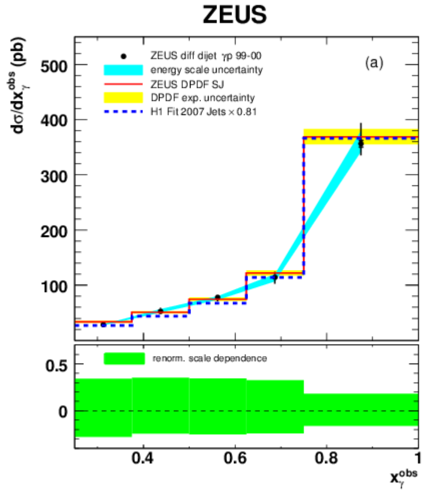
- The dijets in DDIS as a benchmark for the dPDFs and the factorisation theorem
- Supports universality of DPDFs
- The dijets data can be used to constrain the dPDFs in a combined with the inclusive data



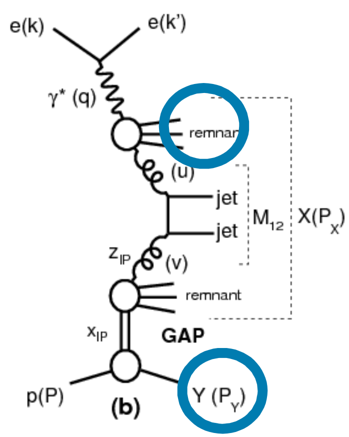
Diffractive dijets in PhP

- For dijet in DIS: the factorisation holds
- For dijets in PhP HERA results not fully decisive
  - different phase space
  - different selection of PhP tagged electron H1 vs. untagged ZEUS
- factorisation breaking observed by H1 but not observed by ZEUS





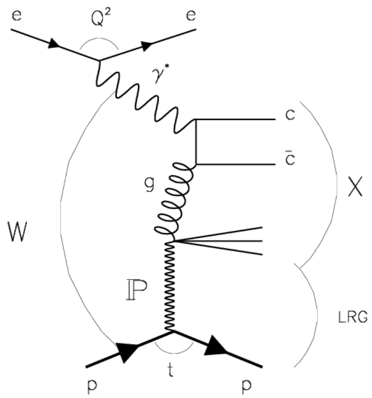
- in p − p collisions (TeVatron) the factorisation is broken
- real photon ($Q^2 \simeq 0$) can develop a hadronic structure
- resolved photoproduction theory predicts suppression
- the suppression is supposed to be stronger at low scales and low x,
- however no dependence of suppression-factor visible

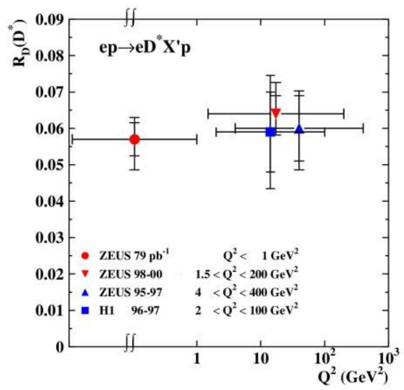


Diffractive photoproduction of $D^{*\pm}(2010)$ at HERA

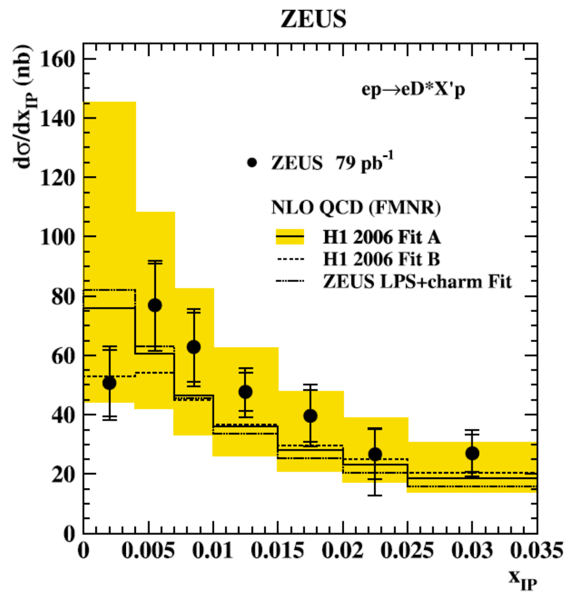
Eur. Phys. J. C 51 (2007) 301-315

- Charm provides a hard scale, ensuring the applicability of pQCD even for low Q^2
- mainly via direct photon reactions
- is sensitive to the gluon content of the diffractive exchange



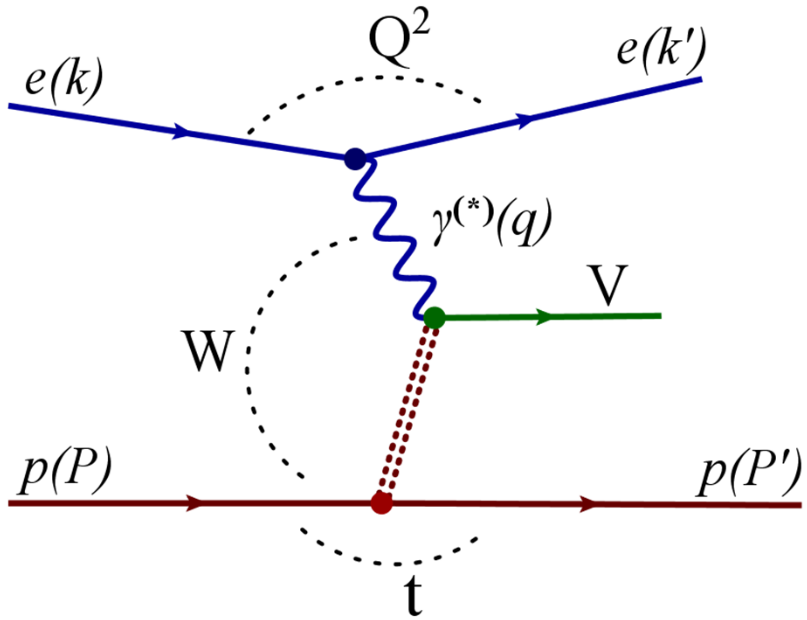


- The NLO QCD calculations reproduce the x_{IP} differential cross section in both shape and normalization.
- Supports the QCD factorisation theorem in diffraction, implying the universality of diffractive PDFs
- Large experimental and theoretical uncertainties



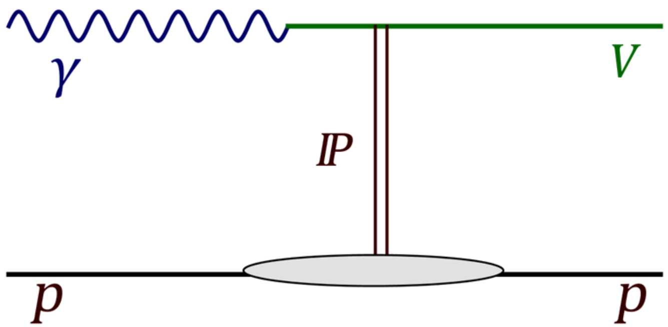
- Fraction R_D is approximately independent of Q^2

Vector Meson production

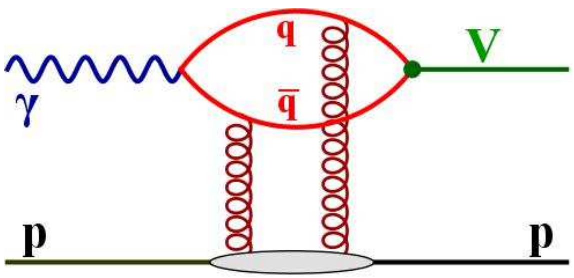


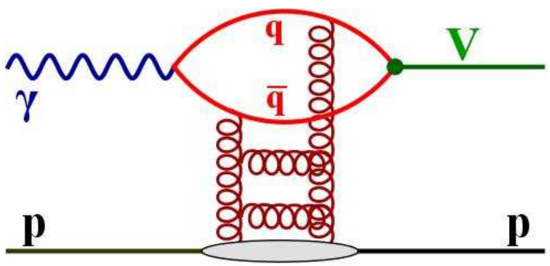
Vector Meson production

- Soft physics: Vector Dominace Model, Regge theory



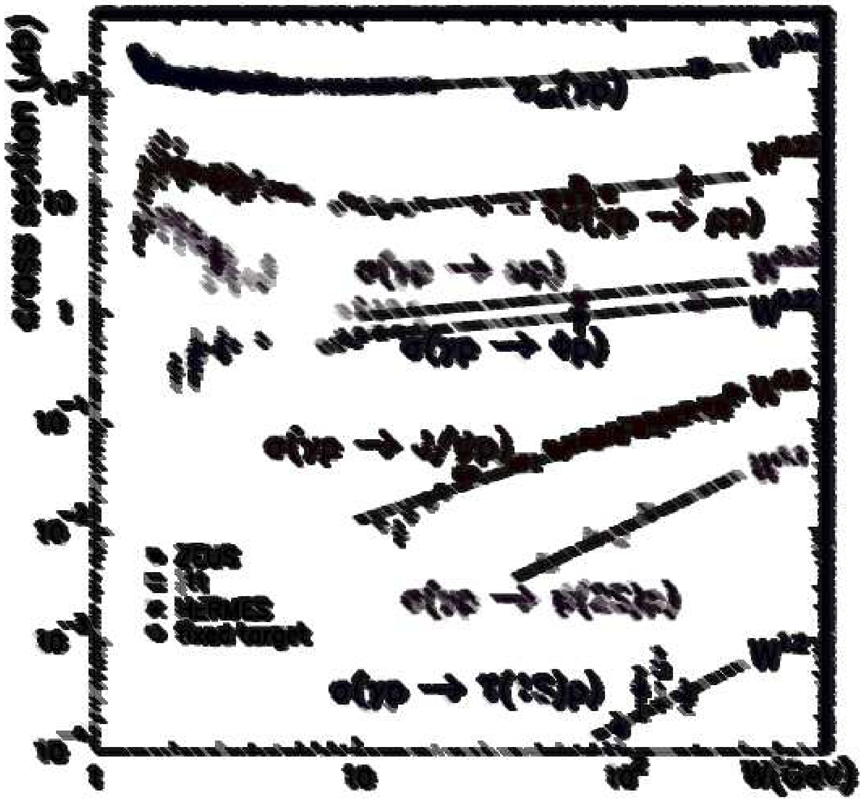
- In presence of a hard scale (M_{VM}, Q^2, t) calculations in pQCD are possible

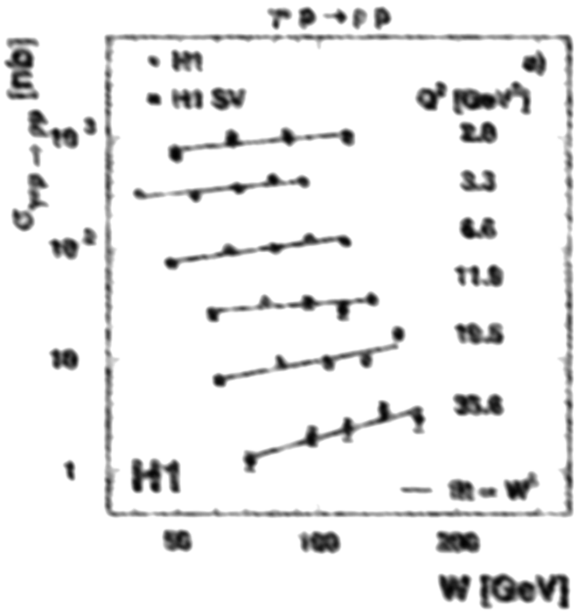




Vector Meson production: W-dependence

- The cross section dependence on W can be parameterised as: $\sigma \propto W_{\gamma p}^{\delta}$





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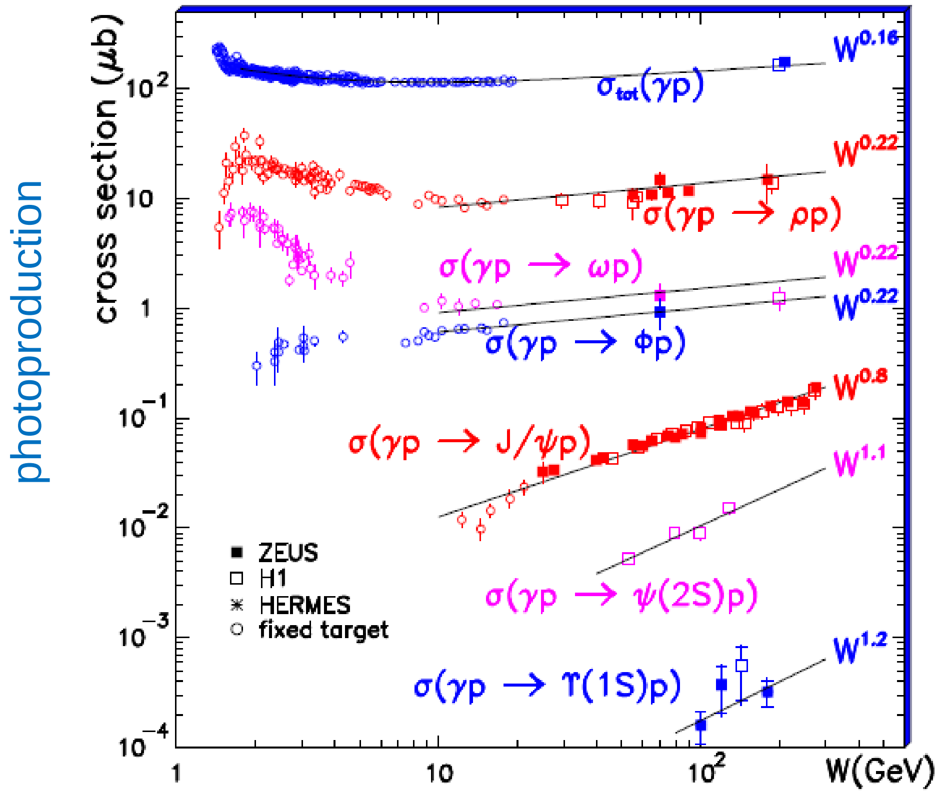

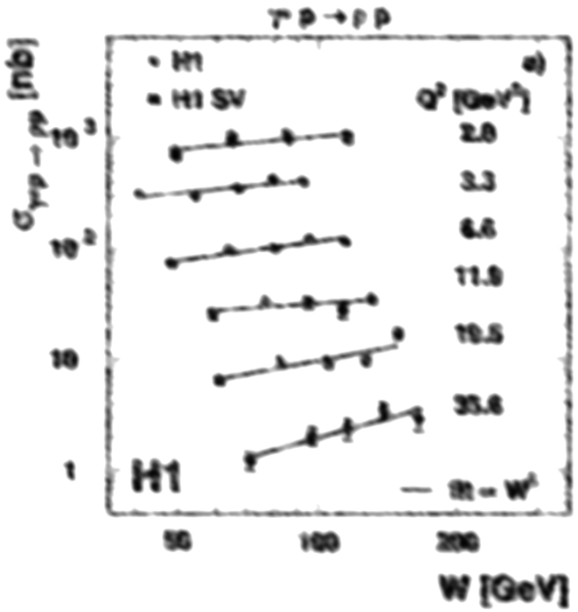

- The rapid rise of cross section with Wγp , can be explain by increasing gluon density with decreasing of fractional momentum $x \propto 1/W_{\gamma p}^{2}$

Vector Meson production: W-dependence

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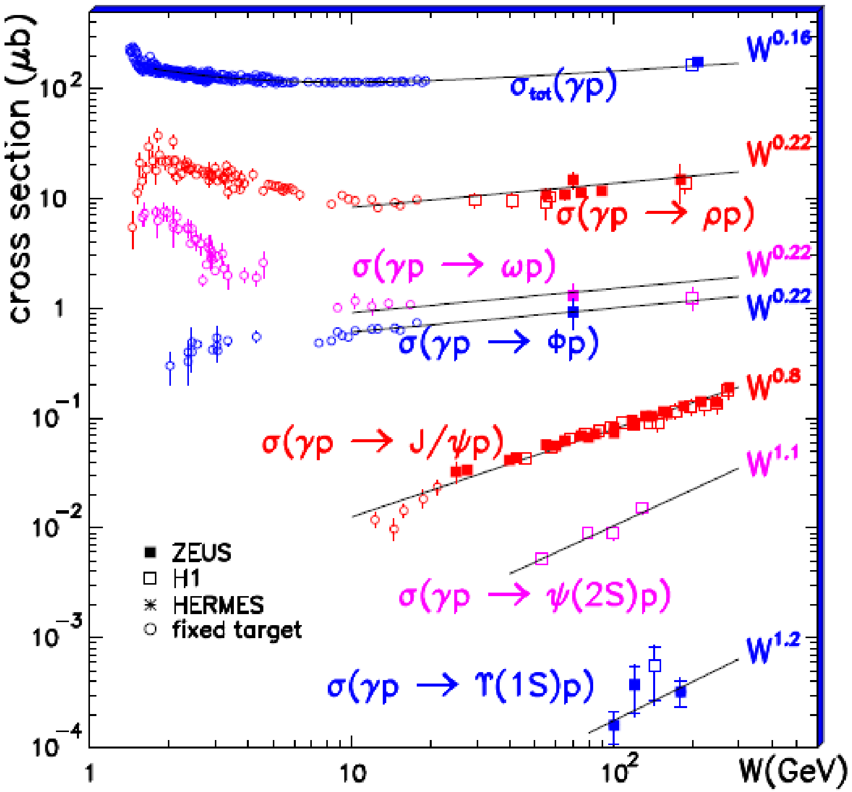
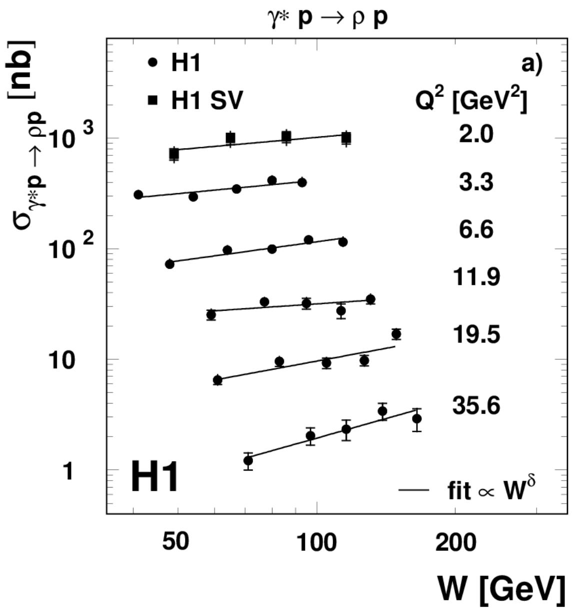
photoproduction

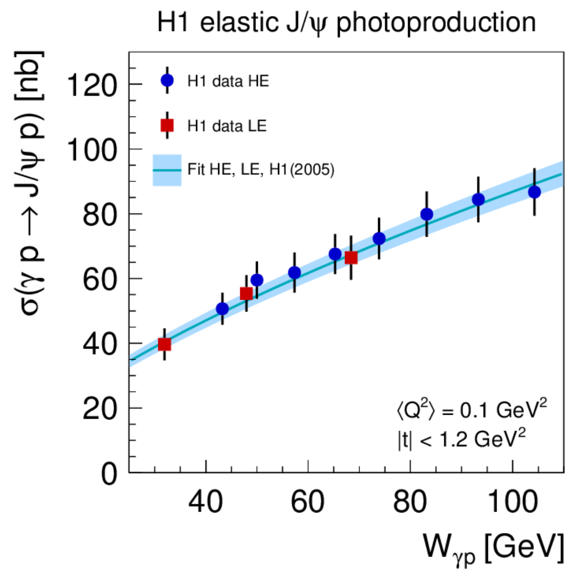


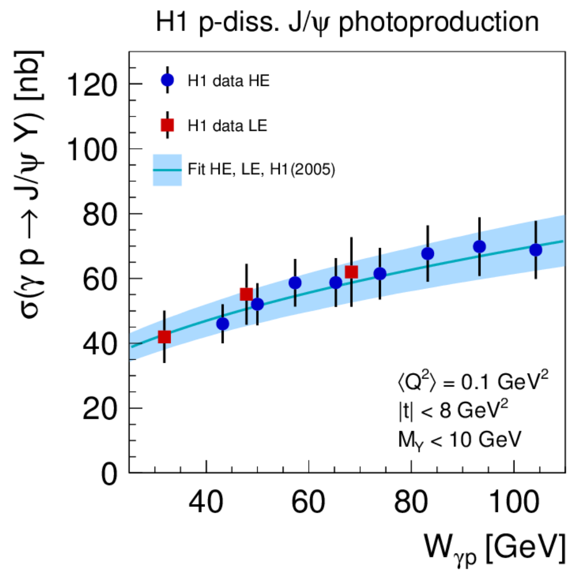
electroproduction (DIS)



> The rapid rise of cross section with Wγp , can be explain by increasing gluon density with decreasing of fractional momentum $x \propto 1/W_{\gamma p}^{2}$

Elastic and p-diss cross sections as a function of Wγp





Phys. J. C73 (2013) 2466

- Fit model:
  - Parametrisation (for elastic and p-diss.):

$$\sigma = N\,(W_{\gamma p} / W_0)^{\delta} \text{ with } W_0 = 90\text{GeV}$$

- Simultaneous fit of elastic and p-diss cross sections:
  - including correlations, including previous H1 hep-ex/0510016
- Results:

$$\gamma p \to J/\psi p: \quad \delta_{el} = 0.67 \pm 0.03$$

$$\gamma p \to J/\psi Y: \quad \delta_{pd} = 0.42 \pm 0.05$$

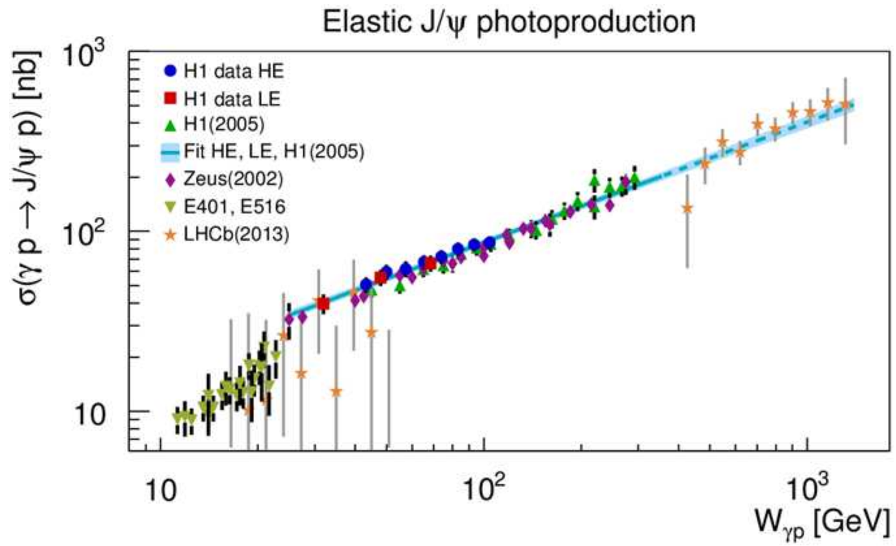
$$\delta_{el} = \delta_{pd} - \delta_{el} : \quad -0.25 \pm 0.06$$

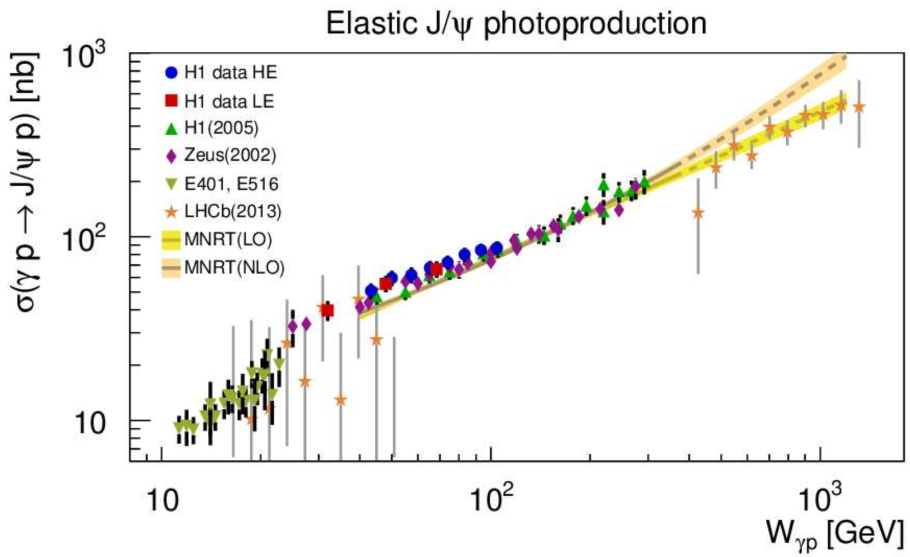
- A dependence of cross section ratio as a function of $W_{\gamma p}$ is observed

Comparison to other experiments

Phys. J. C73 (2013) 2466

- H1 measurement in the transition region from fixed target to previous HERA data
- Good agreement with previous HERA measurements
- Fixed target data: steeper slope, lower normalization
- Fit to H1 data extrapolated to higher $W\gamma p$ describes the LHCb data
- LO and NLO fit to previous J/ψ data and extrapolated to higher $W\gamma p$.





p-diss cross sections as a function of t

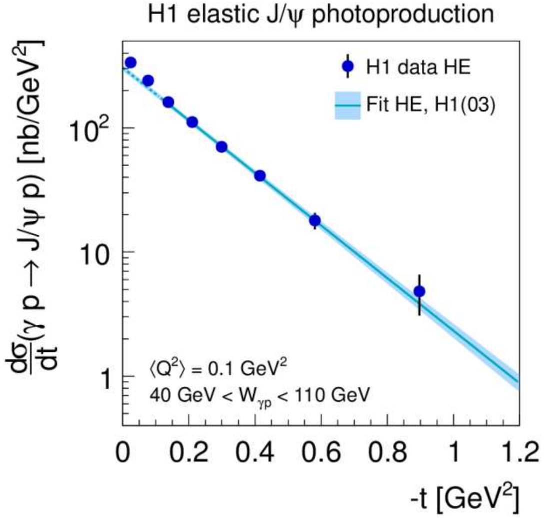
Phys. J. C73 (2013) 2466

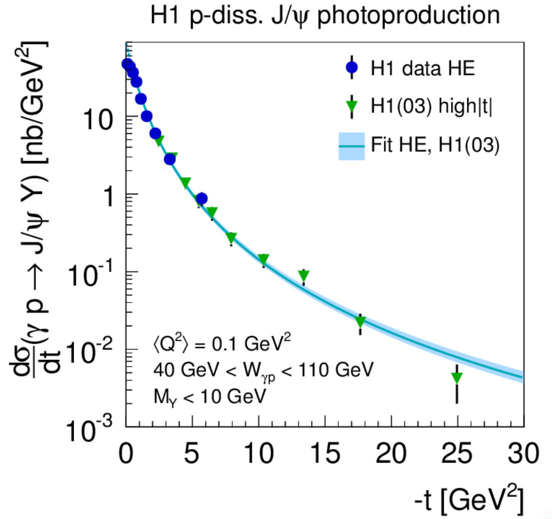
- The t-dependence of elastic cross section carries information about the transverse size of the interaction region
  - elastic: $d\sigma/dt = N_{el}\, e^{-b_{el}|t|}$
- p-diss cross section dominant for | t | > 1 GeV^2
  - p-diss: $d\sigma/dt = N_{pd}\,(1 + (b_{pd}/n)|t|)^{-n}$
- Results:

HE: $\gamma p \to J/\psi p$: $b_{el} = (4.88 \pm 0.15)$ GeV^{-2}

$\gamma p \to J/\psi Y$: $b_{pd} = (1.79 \pm 0.12)$ GeV^{-2} $n = 3.58 \pm 0.15$

- The new data extend the reach to small values of |t|
- Good agreement in overlap region



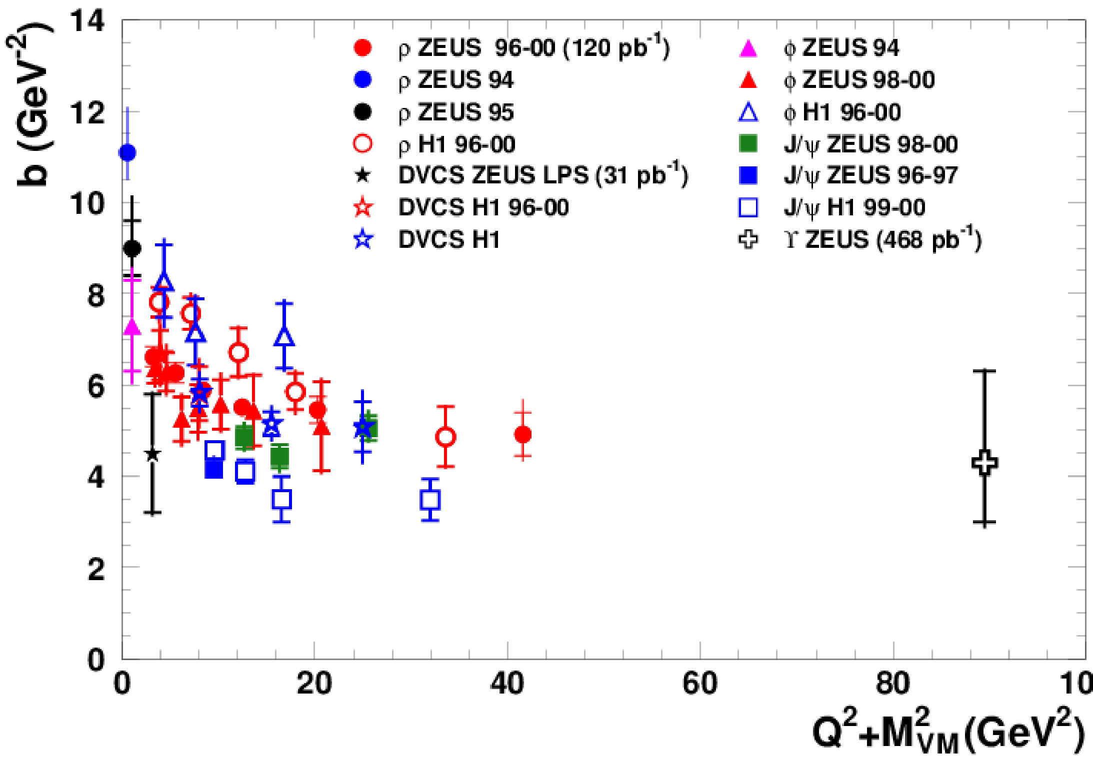


VM production and DVCS: $b(Q^2+M^2_{VM})$

Phys.Lett.B 708 (2012) 14

- Analysis doubles the explored range
- In agreement with an asymptotic behaviour of $Q^2 + M^2_{VM}$
- In optical model approach: $b \approx (R^2_p + R^2_{VM})/4$
- The first measurement of b-slop:

  $b = 4.3\ ^{+2.0}_{-1.2}\ ^{+0.5}_{-0.6}\ \mathrm{GeV}^{-2}$



- consistent with predictions based on pQCD models ($b = 3.68\ \mathrm{GeV}^{-2}$)
  Cox, Forshaw, Sandapen, JHEP 0906 (2009) 034
- size of interaction region is getting smaller with $Q^2 + M^2_{VM}$

Summary

- HERA delivers diffractive results since 21 years with many interesting measurements using different experimental methods, and more ...

Session: Small-x, Diffraction and Vector Mesons:

Marcin Guzik (ZEUS):	*Exclusive dijet production in diffractive deep inelastic scattering at HERA*
Jan Olsson (H1):	*Analysis of Feynman Scaling in Photon and Neutron Production in the Very Forward Direction in Deep-Inelastic Scattering at HERA*
Radek Zlebcik (H1):	*Diffractive Dijet Production with Leading Proton in ep Collisions at HERA*
Sergey Levonian (H1):	*Exclusive Photoproduction of Rho Meson with Leading Neutron at HERA*
Boris Pokorny (H1):	*Dijet production with large rapidity gap in deep-inelastic scattering at HERA*

Session: Heavy Flavours:

Nataliia Kovalchuk (ZEUS):	*Recent results on Charmonium production at HERA*

Summary

- Combined spectrometer data provide better precision
- Hard diffraction is present, dominated by gluons
- Inclusive Diffraction measurements support proton vertex factorisation
- Diffractive factorisation confirmed by dijet measurements in DIS
- The suppression that takes place for the dijet diffractive photoproduction is not yet understood
- NLO QCD calculations provides good description of open charm php data
- Vector meson production provides opportunity to test the property of diffraction and proton structure

Thank you for attention

Observation of Events with a Large Rapidity Gap in Deep Inelastic Scattering at HERA

ZEUS Collaboration

July 12, 1993

Abstract

In deep inelastic, neutral current scattering of electrons and protons at $\sqrt{s} = 296$ GeV, we observe in the ZEUS detector events with a large rapidity gap in the hadronic final state. They occur in the region of small Bjorken x and are observed up to Q^2 of 100 GeV^2. They account for about 5% of the events with $Q^2 \geq 10$ GeV^2. Their general properties are inconsistent with the dominant mechanism of deep inelastic scattering, where color is transferred between the scattered quark and the proton remnant, and suggest that the underlying production mechanism is the diffractive dissociation of the virtual photon.