Measurement of diffractive dijet production at the H1 experiment

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HERA and luminosity

HERA (DESY, Hamburg): 1992 - 2007

- Total lumi H1, ZEUS: 0.5 fb^{-1} each

HERA-I 1992-2000 ~120 pb^{-1}

HERA-II 2003-2007 ~380 pb^{-1}

$E_{e+/e-}$ = 27.6 GeV

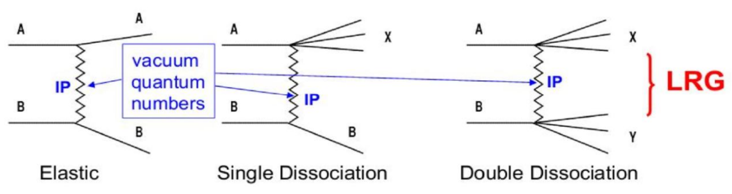
HERA-I (E_p = 820, 920 GeV) upgraded to HERA-II (E_p = 920 GeV)

Since April 2007 until the end of June

- Low energy run - LER - (E_p = 460 GeV)
- Medium energy run - MER - (E_p = 575 GeV)

} Measurement of F_L

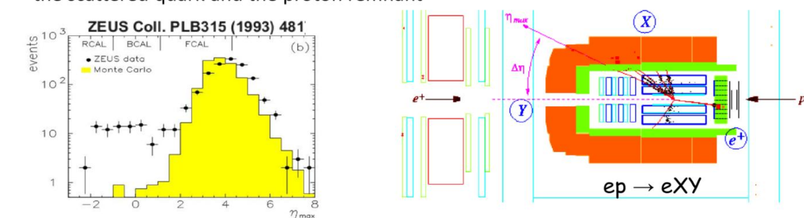
Diffraction in hadron scattering



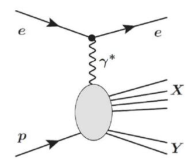
- Diffraction is a feature of hadron.hadron interactions (30% of σ_{tot})
- Beam particles emerge intact or dissociated into low.mass states
  → Very small fractional momentum losses (within a few %)
- Final.state systems separated by large polar angle (or pseudorapidity η = -ln[tan(θ/2)])
  → Large Rapidity Gap (LRG)
- Interaction mediated by t-channel exchange of an object with vacuum quantum numbers (no colour) → Pomeron (IP)

Diffraction at HERA

- Early observation at HERA (1993): Small fraction of DIS events with general properties inconsistent with the dominant mechanism of DIS where color is transferred between the scattered quark and the proton remnant



- Final state systems (X,Y) separated by large polar angle or pseudorapidity → LRG events

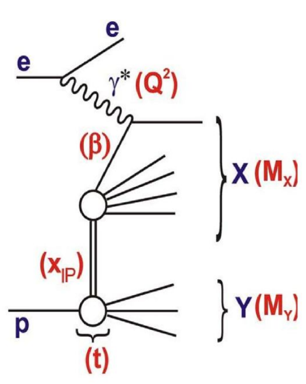


- No color flow between hadron systems Y and X
- Probing of the structure of color singlet exchange with virtual photon

- Diffractive events contribute up to 15% of the inclusive DIS cross section

Diffractive DIS kinematics

Standard DIS variables:
- x - momentum fraction carried by struck quark (q/p)
- Q^2 – γ* four momentum squared
- y – event inelascticity



Additional variables for diffraction process

t = squared 4-momentum transfer at proton vertex

x_{IP} = fractional momentum loss of proton carried by IP (momentum fraction IP/p)

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

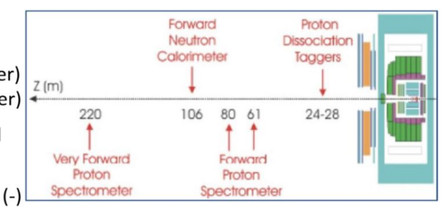
- $M_Y = m_p$ proton stays intact, needs detector setup to detect protons
- $M_Y > m_p$ proton dissociates background to be understood and disangled
- In most cases here, Y=p

Experimental methods

Proton tagging

→ Detection of the leading proton in forward detectors: FPS (Forward Proton Spectrometer) and VFPS (Very Forward Proton Spectrometer)

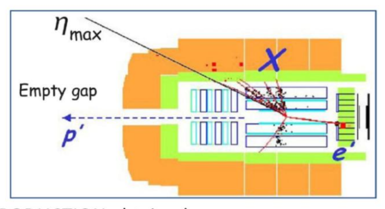
- Direct extraction of diffractive variables and no dissociation background (+)
- Small statistics due to the small acceptance (-)



Large Rapidity Gap (LRG) method

→ No activity in the forward detectors required

- High statistics
- Proton dissociation background



❖ To show here: new results on DIFFRCTIVE DIJET PRODUCTION obtained:
- from VFPS (**JHEP 1505 (2015) 056**)
- from LRG analyses (**JHEP 1503 (2015) 092**)

→ The methods have very different systematics!

QCD factorisation

- QCD factorisation (Collins 1998)

$$d\sigma^{ep\to eXp}(\beta,Q^2,x_{IP},t)=\Sigma f_i^D(\beta,Q^2,x_{IP},t)\otimes d\sigma^{ei}(\beta,Q^2)$$

f_i^D – diffractive parton density functions (DPDFs) – evolutioning with DGLAP in Q^2

σ^{ei} – partonic cross sections, same as in inclusive DIS

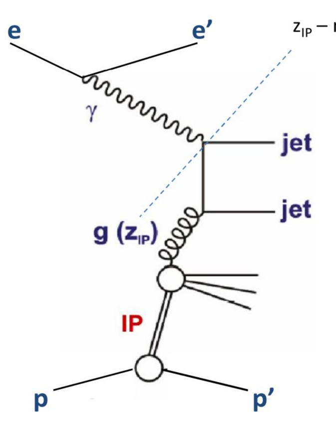
- Proton vertex factorisation (Ingelman, Schlein 1985) assume that DPDF factorizes into flux and pomeron PDF

$$f_i^D(\beta,Q^2,x_{IP},t)=f_{IP/p}(x_{IP},t)\cdot F_i^{IP}(\beta,Q^2)$$

Pomeron flux (Regge form) — Pomeron structure function

- H1 results are compared with QCD calculation using H12006 Fit-B which is based on diffractive DIS data with large-rapidity gap selection (Eur. Phys. J. C48 (2006) 715-748)

Diffractive dijet production



z_{IP} – momentum fraction in hard subprocess

Production mechanism of the dijets provide:
- additional tests of QCD (inspired) models of diffraction
- direct sensitivity to the gluon component of the Pomeron
- a benchmark for the DPDF and factorisation theorem
- constrain the DPDFs in a combination with the inclusive data

Two hard scales in the process:
- the virtuality of the photon
- the transverse energy of the jets

Diffractive dijet production - LRG

- Events are selected in a phase space which is extended compared to the measurement phase space in order to improve the precision of the measurement by accounting for migrations at the phase space boundaries.

	Extended Analysis Phase Space	Measurement Cross Section Phase Space
DIS	$3 < Q^2 < 100\ GeV^2$ $y < 0.7$	$4 < Q^2 < 100\ GeV^2$ $0.1 < y < 0.7$
Diffraction	$x_P < 0.04$ LRG requirements	$x_P < 0.03$ $\|t\| < 1\ GeV^2$ $M_Y < 1.6$ GeV
Dijets	$p^*_{T,1} > 3.0$ GeV $p^*_{T,2} > 3.0$ GeV $-2 < \eta^{lab}_{1,2} < 2$	$p^*_{T,1} > 5.5$ GeV $p^*_{T,2} > 4.0$ GeV $-1 < \eta^{lab}_{1,2} < 2$

- The measurement that will be presented here is based on a six times increased luminosity in comparison to the previous H1 measurement of dijet production with LRG.
- A more sophisticated data correction method than before.

Integrated cross section

$$\sigma^{dijet}_{meas}(ep\to eXY) = 73 \pm 2\ (stat.)\ \pm 7\ (syst.)\ pb$$
$$\sigma^{dijet}_{theo}(ep\to eXY) = 77\ ^{+25}_{-20}\ (scale)\ ^{+4}_{-14}\ (DPDF)\ \pm 3\ (had)\ pb$$

NLO predictions

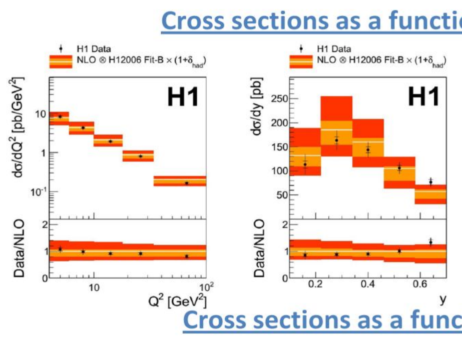
- NLOJET++ with five active flavors used for evaluation at NLO of QCD predictions of the dijet cross sections
- The two-loop approximation of the renormalisation group equation is used for the running of the strong coupling constant with a coupling strength of αs (M_Z) = 0.118.
- The cross sections are evaluated in intervals of x_{IP}, effectively replacing the beam proton by a pomeron (slicing method).
- The H12006 Fit-B DPDF set is used in the calculation.
- DPDF uncertainties are propagated to predicted cross sections.
- Renormalisation and factorisation scales used: $\mu_r^2 = \mu_f^2 = (p_T^*)^2 + Q^2$.
- Scale is varied by a factors of 0.5 or 2.

Experimental uncertainties

- In total - 10 %, with normalisation uncertainty dominating (8 %).

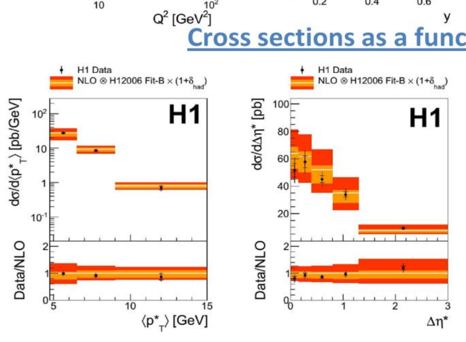
→ The uncertainty on the NLO prediction significantly larger than the experimental uncertainty.

Cross sections as a function of the DIS variables



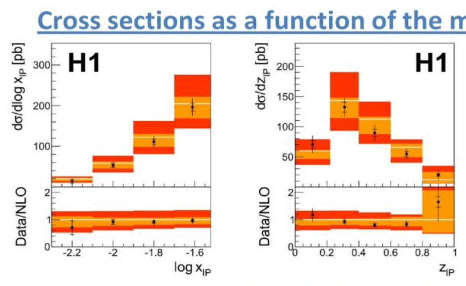
NLO prediction:
- Orange band – DPDF uncertainty
- Red band – total uncertainty

Cross sections as a function of the jet variables



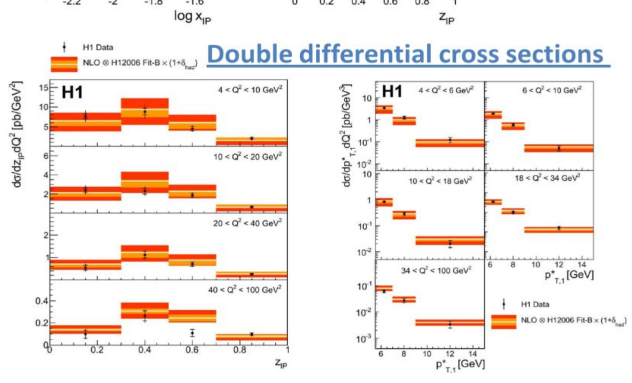
- DIS and jet variables well described by NLO prediction
- Better precision of data than NLO prediction

Cross sections as a function of the momentum fractions x_{IP} and z_{IP}



- Momentum fractions well described by NLO prediction
- Double differential cross sections well described by NLO prediction

Double differential cross sections



Extraction of α_S

- NLO works well → try to extract α_S
- The double-differential dijet cross sections as a function of Q^2 and $p^*_{T,1}$ are used to determine the value of the strong coupling constant α_s (M_Z).
- The value of α_s (M_Z) is determined by an iterative χ^2 -minimisation procedure using NLO calculations
- The fit yields a value of χ^2/ndof = 16.7/14 → good agreement of theory to data.

$$\alpha_s(M_Z) = 0.119 \pm 0.004\,(exp) \pm 0.002\,(had) \pm 0.005\,(DPDF) \pm 0.010\,(\mu_r) \pm 0.004\,(\mu_f)$$
$$= 0.119 \pm 0.004\,(exp) \pm 0.012\,(DPDF, theo)$$

- The result for α_s (M_Z) is consistent within the uncertainties with the world average
- The largest uncertainties arise from the estimate of the contributions from orders beyond NLO and from the poor knowledge of the DPDF.
- The largest contribution to the experimental uncertainty of 0.003 arises from the global normalisation uncertainty

→ First determination of α_s from diffractive dijet production.

Diffractive dijet production – detection of the leading proton

- Proton detected in Very Forward Proton Spectrometer (VFPS) located 220 m downsteram main detectors full geometric acceptance down to t = 0
  → used for the first time, such that the diffractive sample is free of background from low-mass proton dissociative states.
- The measurement is performed in **photoproduction** with photon virtualities $Q^2 < 2\ GeV^2$ and in **deep-inelastic scattering** with 4 $GeV^2 < Q^2 < 80\ GeV^2$.

	Photoproduction	DIS
Event kinematics	$Q^2 < 2\,GeV^2$	$4\,GeV^2 < Q^2 < 80\,GeV^2$
	$0.2 < y < 0.7$	
Diffractive phase space	$0.010 < x_P < 0.024$	
	$\|t\| < 0.6\,GeV^2$	
	$z_P < 0.8$	
Jet phase space	$E_T^{*jet1} > 5.5\,GeV$	
	$E_T^{*jet2} > 4.0\,GeV$	
	$-1 < \eta^{jet1,2} < 2.5$	

→Identical phase space: for DIS – scattered electron detected for PHP – absence of scattered electron.

Integrated ep diffractive dijet cross sections in γp and DIS

	PHP	DIS
Data [pb]	237 ±14 (stat) ±31 (syst)	30.5 ±1.6 (stat) ±2.8 (syst)
NLO QCD [pb]	$430\ ^{+172}_{-98}$ (scale) $^{+48}_{-61}$ (DPDF) ±13 (hadr)	$28.3\ ^{+11.4}_{-6.4}$ (scale) $^{+3.0}_{-4.0}$ (DPDF) ±0.8 (hadr)
RAPGAP [pb]	180	18.0
Data/NLO	0.551±0.078 (data)$^{+0.230}_{-0.149}$ (theory)	1.08±0.11 (data)$^{+0.45}_{-0.29}$ (theory)

- DIS NLO prediction – NLOJET++ (checked using DISENT NLO) - needs to be corrected for dissociation effects since in this analysis the proton is detected, $M_Y = m_p$.

  Global correction factor applied (obtained by comparing H1 experimental results on diffractive cross sections obtained from LRG and from Forward Proton Spectrometer (FPS) EPJC71 (2011) 1578).
  $\sigma(M_Y = m_P) / \sigma(M_Y < 1.6\ GeV) = 0.83$

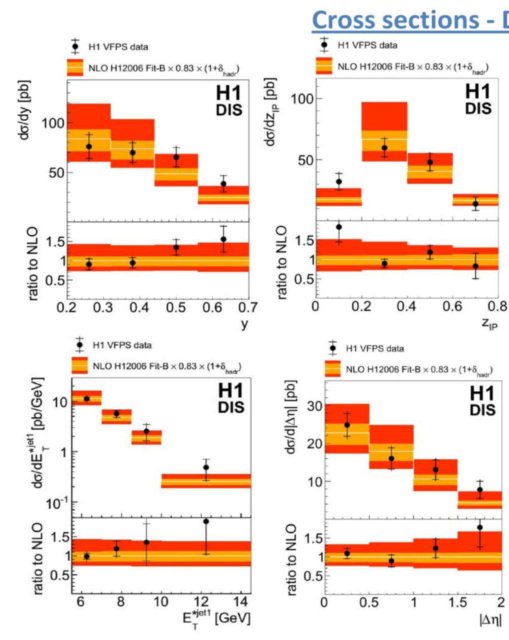
  → **DIS cross section consistent with NLO**

- NLO in the γp regime uses the the FKS program

  The NLO calculations for photoproduction are consistent with calculations performed by Klasen and Kramer

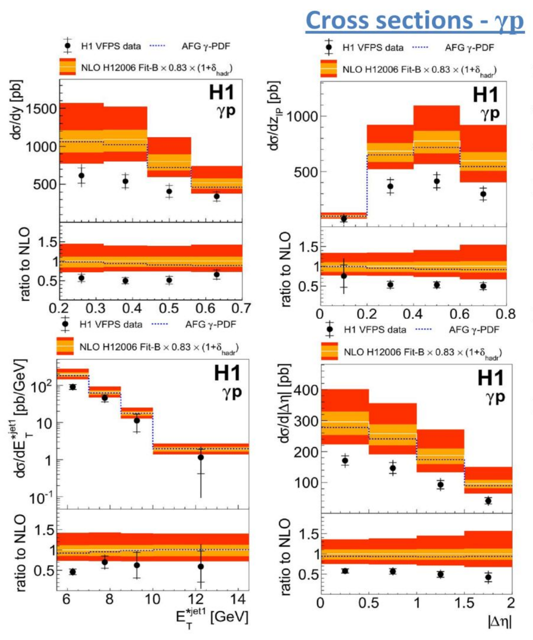
  Scale choice: $\mu_r^2 = \mu_f^2 = \langle E_T^* \rangle^2$
  → **γp cross section off (not due to proton dissociation) by about factor of 2 – consistent with previous measurements from H1**

Cross sections - DIS



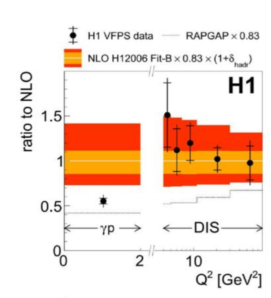
NLO prediction:
- Orange band – DPDF uncertainty
- Red band – total uncertainty
- 4 main sources of systematic uncertainty contributing about equally
  → 9.1 % in total in DIS
- Model uncertainty is uncorrelated between DIS and γp, so there is no cancellation in cross section ratios
- DIS, momentum fraction and jet variables well described by NLO prediction
- E_T of a jet somewhat harder than NLO expectations

Cross sections - γp



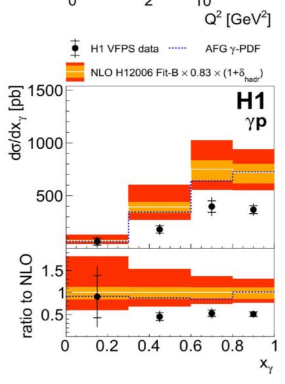
NLO prediction:
- Orange band – DPDF uncertainty
- Red band – total uncertainty
- 4 main sources of systematic uncertainty contributing about equally
  → 12.8 % in total in γp
- Model uncertainty is uncorrelated between DIS and γp, so there is no cancellation in cross section ratios
- DIS, momentum fraction and jet variables well described by NLO prediction in shape, but are off in normalisation

Q^2 and x_γ dependence



The same phase space for DIS and γp → Q^2 distributon of ratio exp/NLO possible

→ No Q2 dependence observed, , suppression only in γp



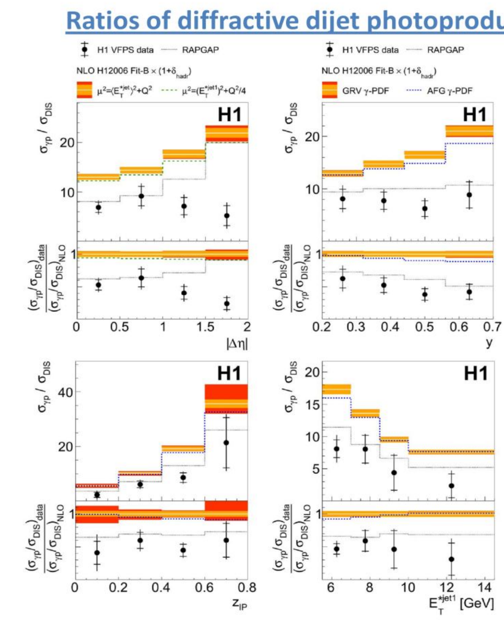
- If suppression is related to resolved photon
  → x_γ dependence of the γp cross section

  x_γ - longitudinal fraction of the photon momentum entering the hard subprocess

  $$x_\gamma = (E - p_z)_{jets} / (E - p_z)_X$$

- No x_γ dependence – consistent with earlier measurements

Ratios of diffractive dijet photoproduction to DIS cross sections



- Shape dependence possible only Δη distribution but the limited experimental precision does not allow for strong conclusions to be made
- Small dependence on E_T in DIS and PHP cancels in ratio

- New measurements of diffractive dijet production in ep DIS using two approaches:
  - large rapidity gap method
  - detection of a leading proton in the VFPS (simultaneous measurement of DIS and photoproduction)
- DIS data well described by NLO
- Photoproduction suppressed by a factor ~ 0.5 (earlier measurement obtained with LRG method confirmed)
  → Suppression is not related to proton dissociation.
- α_s determined from difractive dijet data using LRG
  → the new data provide a solid potential for further constraint of DPDF fits and other QCD analysis