Factorisation in diffractive ep interactions

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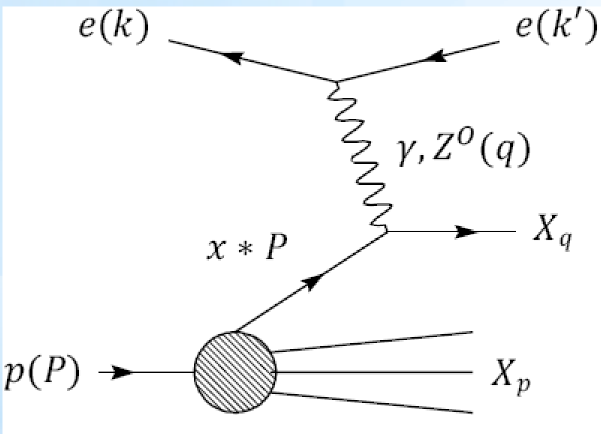
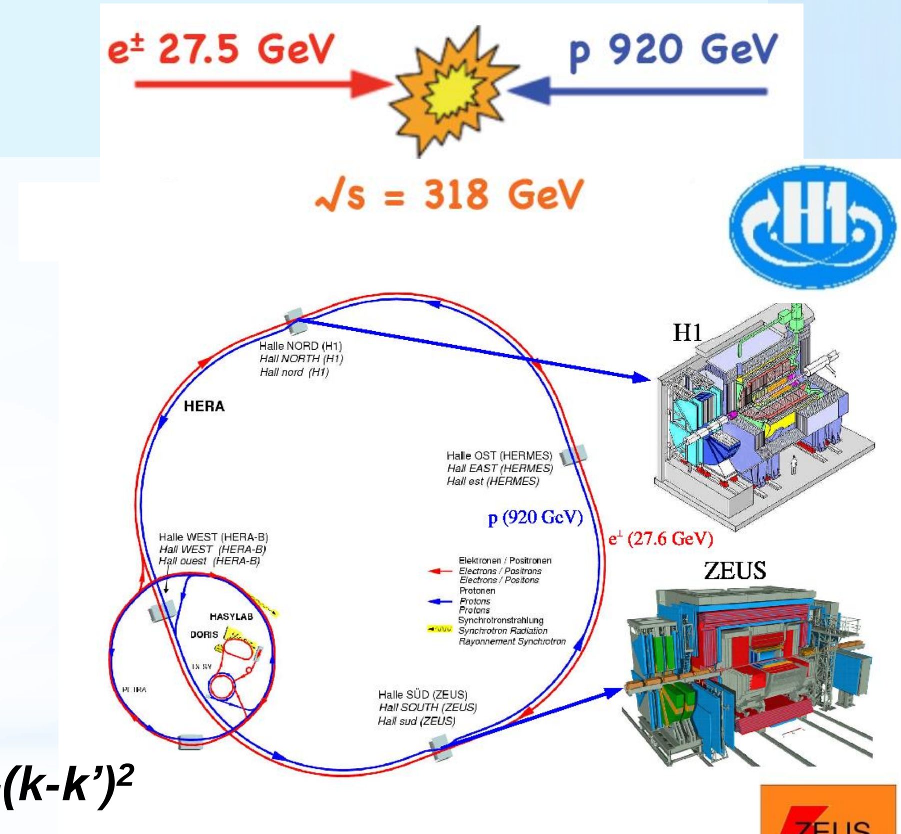
HERA collider experiments

- 27.5 GeV electrons/positrons on 920 GeV protons $\rightarrow \sqrt{s}$=318 GeV
- data taken in 1992-2007
- HERA I,II: ~ 500 pb^{-1} per experiment
- H 1 & ZEUS - 4π detectors





Virtuality of exchanged boson $Q^2 = -q^2 = -(k-k')^2$

Inelasticity $y = Pq/Pk$

Bjorken scaling variable $x = Q^2/2qP$

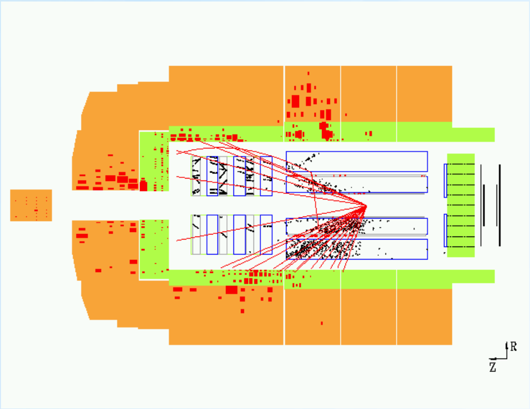
Two regimes:

$Q^2 < 1$ GeV^2 **photoproduction** (γp)

$Q^2 > 1$ GeV^2 **Deep Inelastic Scattering** (*DIS*)

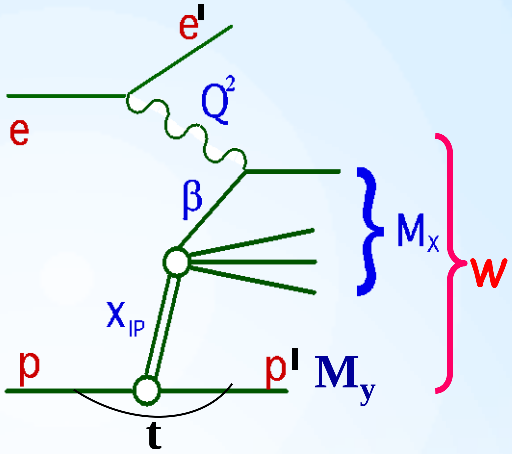
Diffractive kinematics

Non-diffractive ep scattering



- Q^2- virtuality of the photon
- $Q^2 \sim 0$ GeV$^2 \rightarrow$ photoproduction
- $Q^2 >> 0$ GeV$^2 \rightarrow$ DIS
- W – total hadronic energy

Diffractive scattering



- momentum fraction of color singlet exchange

$$x_{I\!P} = \xi = \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

- fraction of exchange momentum, coupling to γ

$$\beta = \frac{Q^2}{Q^2 + M_X^2} = x_{q/I\!P} = \frac{x}{x_{I\!P}}$$

- 4-momentum transfer squared (if proton is measured)

$$t = (p - p')^2$$

$M_y = m_p$ proton stays intact

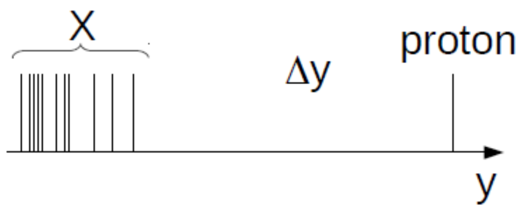
$M_y > m_p$ proton dissociates, contribution should be understood

Diffraction seen in detectors

Due to vacuum quantum number exchange

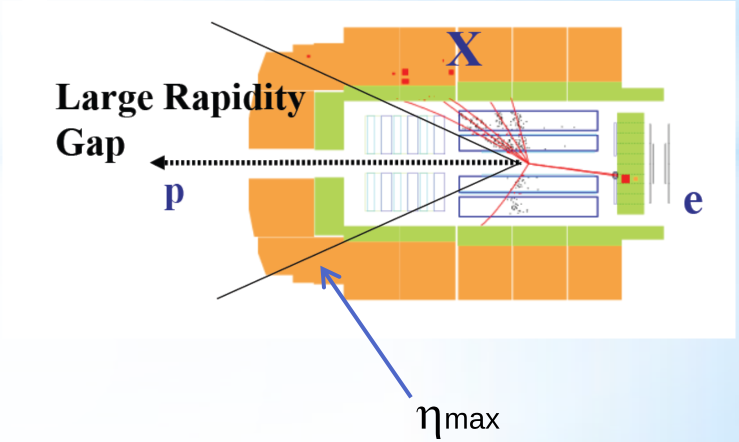
→ leading particle at relatively small t

→ rapidity distributions of final state (VM, X) separated from leading particle by non-exponentially suppressed gaps – **Large Rapidity Gap (LRG)**



Both leading proton tagging or LRG detection used in H1 and ZEUS

Large Rapidity Gap - LRG



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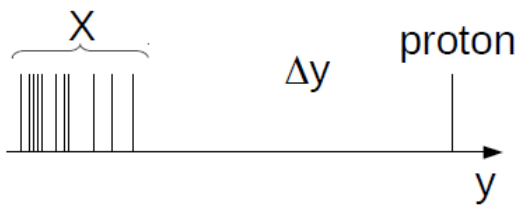

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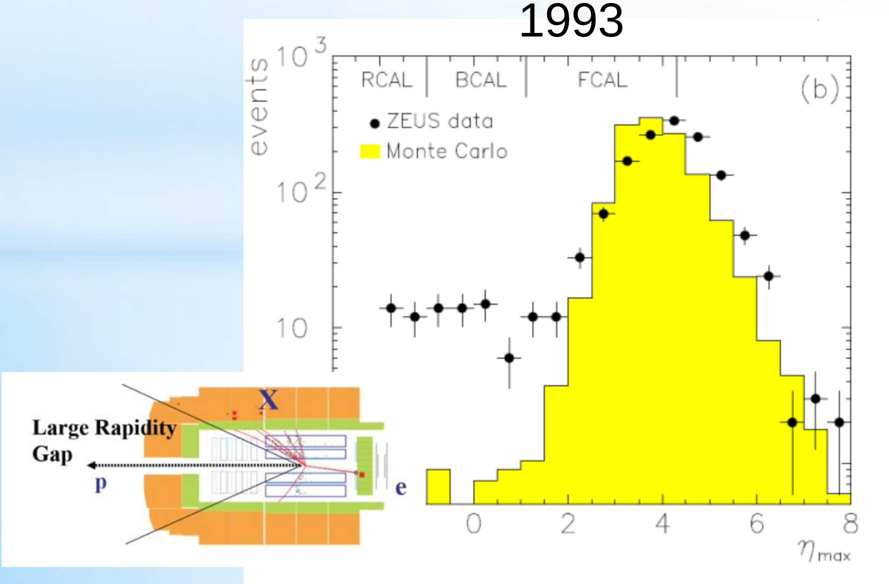
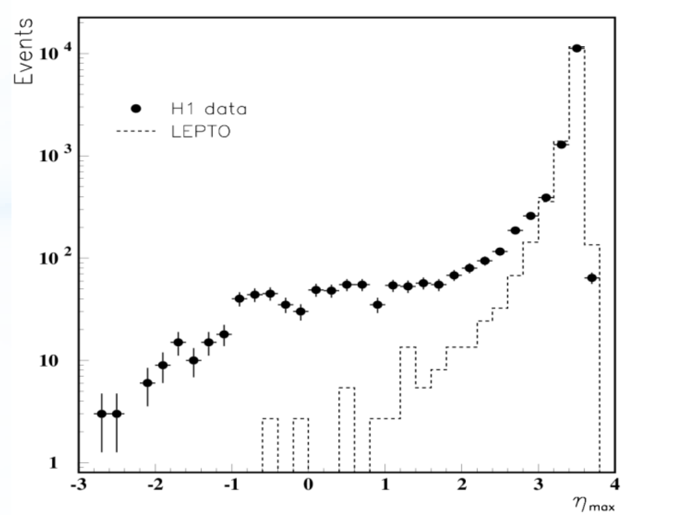
1993



1994



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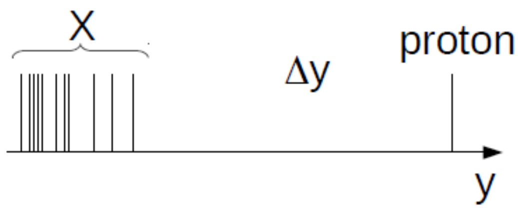

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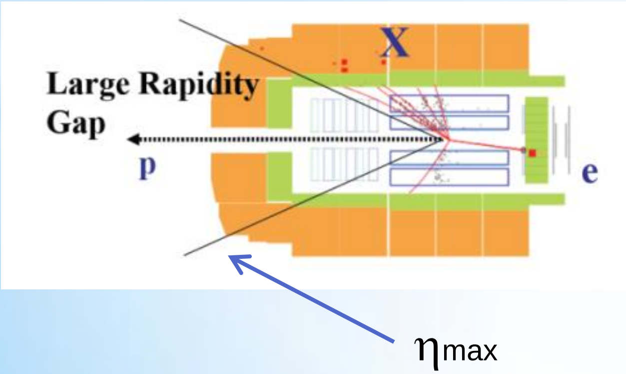

Large Rapidity Gap (LRG)

require no activity beyond η_{max}

☹ t not measured,integrated over |t|<1GeV^2

☺ very good acceptance at low x_{IP}

☹ p-diss background about 20% ☠

Diffraction seen in detectors

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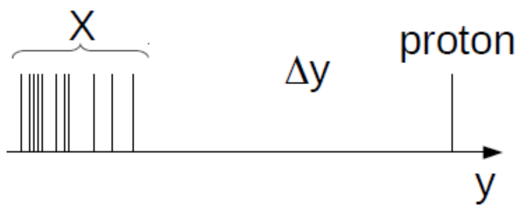

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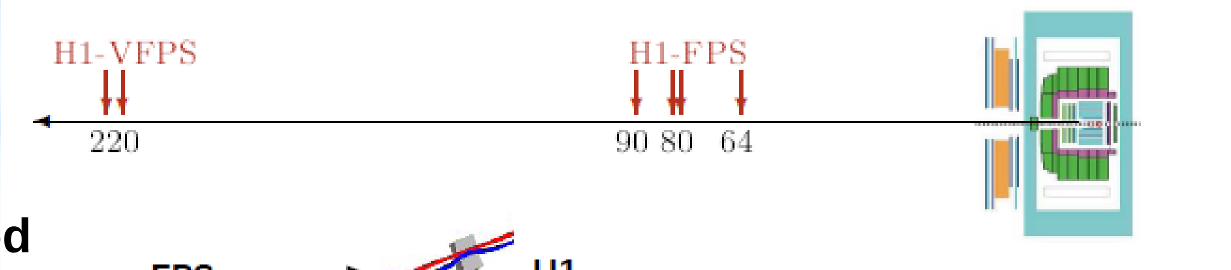
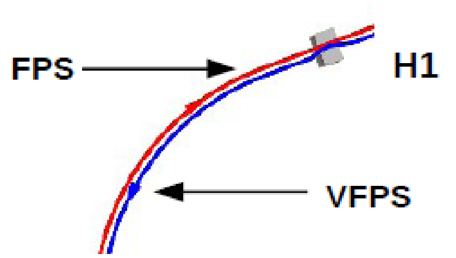


Proton tagging method



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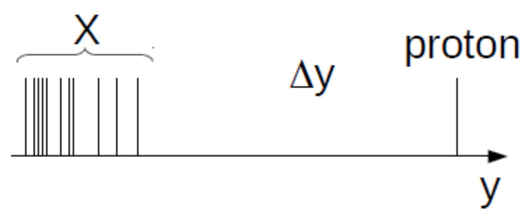

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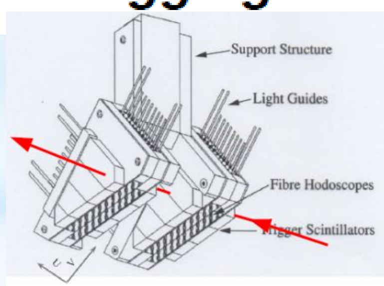

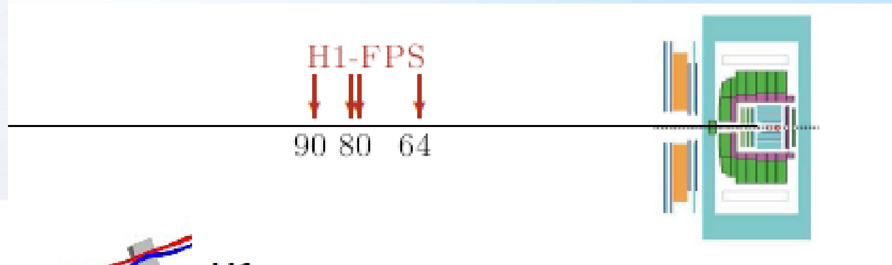

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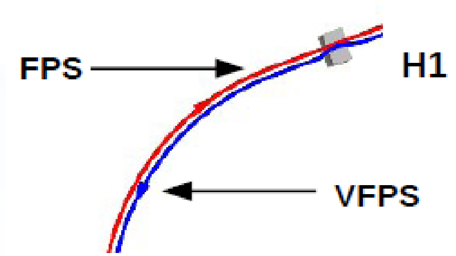

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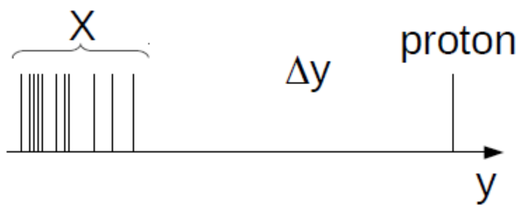


Both leading proton tagging or LRG detection used in H1 and ZEUS

Proton tagging method

H1: VFPS (2005-2007)
FPS (1997-2007)
ZEUS: LPS (1997-2000)

☺ free of p-dissociation background

☺ x_{IP} and t measurements

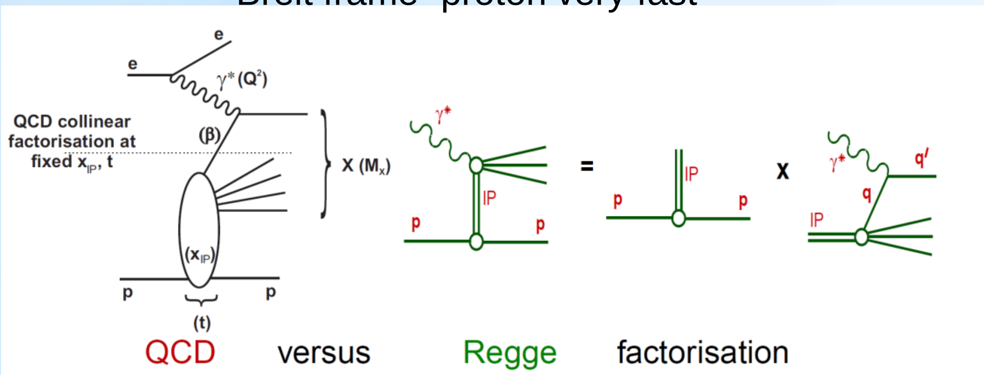
☺ access to high x_{IP} range (IP and IR)

☹ small acceptance, small statistics

Modelling of diffraction

QCD collinear factorisation theorem

Breit frame- proton very fast



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

DPDFs – obey DGLAP universal for diff. ep DIS

hard scattering cross section

Proton vertex factorisation (conjecture, e.g. Resolved Pomeron Model by Ingelman&Schlein)

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

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

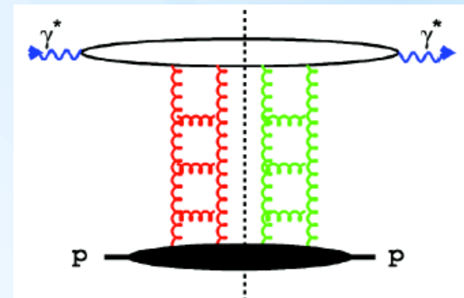
Pomeron flux factor

diffractive DPDF

Then DPDFs extracted from DIS data

Dipole models

Proton rest frame - dipoles



[C. Marquet PRD76 (2007) 094017]

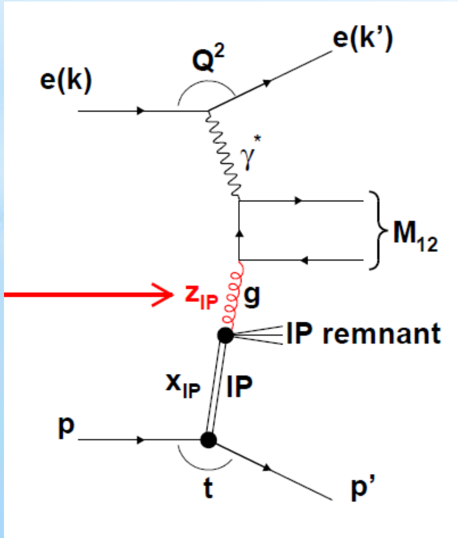
$$d\sigma^{\gamma^* p}_{diff}/dt \propto \int dz dr^2 \Psi^* \sigma^2_{q\bar{q}}(x,r^2,t)\Psi$$

γ* fluctuates into $q\bar{q}$,$q\bar{q}g$ states (color dipoles) of transverse size proportional to $1/\sqrt{(Q^2+M_{q\bar{q}}^2)}$

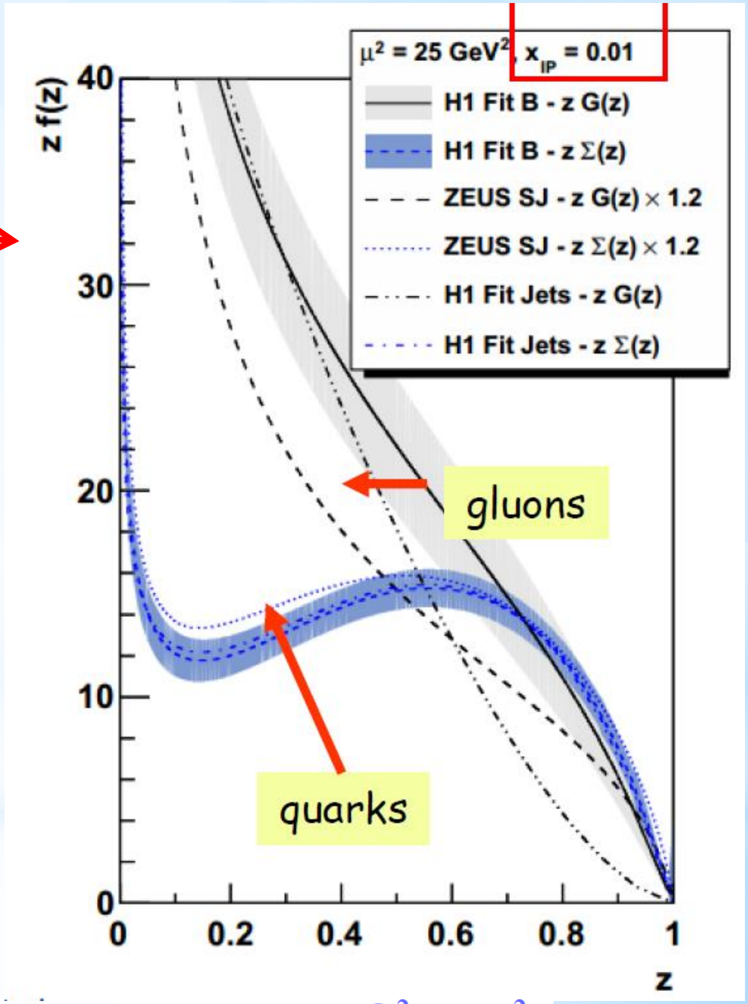
No extra parameters needed for DDIS

DPDFs in DIS- H1 and ZEUS

- DPDFs extracted from NLO DGLAP fit, using Regge factorisation
- **DPDFs: H1 fit B, H1 fit Jets, ZEUS fit SJ**
- Gluon exchange dominates (~ 70-75% of the Pomeron momentum), main differencies in fits
- **DPDFs used in NLO calculations to predict diffractive production of charm and dijets**



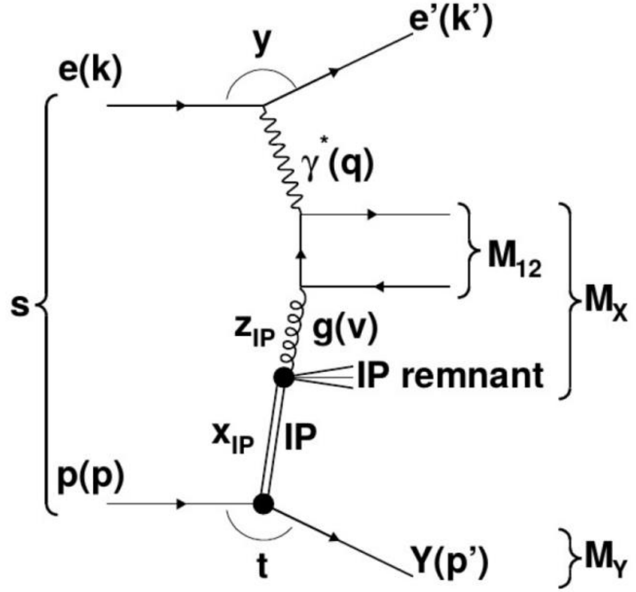
$$z_{IP} = \frac{\sum (E+p_z)_{jets}}{(E+p_z)_{hadrons}}$$



$$z = z_{IP} = \frac{Q^2+M_{12}^2}{Q^2+M_X^2}$$

Diffractive dijet production in DIS

JHEP 1503 (2015) 092



DIS	*2-jets*	*diffraction*
$4 < Q^2 < 100\ \mathrm{GeV}^2$	$p^*_{\mathrm{T},1} > 5.5\ \mathrm{GeV}$	$x_{I\!P} < 0.03$
$0.1 < y < 0.7$	$p^*_{\mathrm{T},2} > 4.0\ \mathrm{GeV}$	$\|t\| < 1\ \mathrm{GeV}^2$
	$-1 < \eta^{\mathrm{lab}}_{1,2} < 2$	$M_Y < 1.6\ \mathrm{GeV}$

Most precise DDIS dijet measurement from HERA

→ based on ~ 290 pb^{-1} of HERA-2 H1 data

→ LRG selection used

→ proton dissociation contribution up to M_Y< 1.6 GeV

→ detector effects controlled very well by simulation

→ data corrected with regularized unfolding (TUnfold)

→ single and double-differential x-sections measured

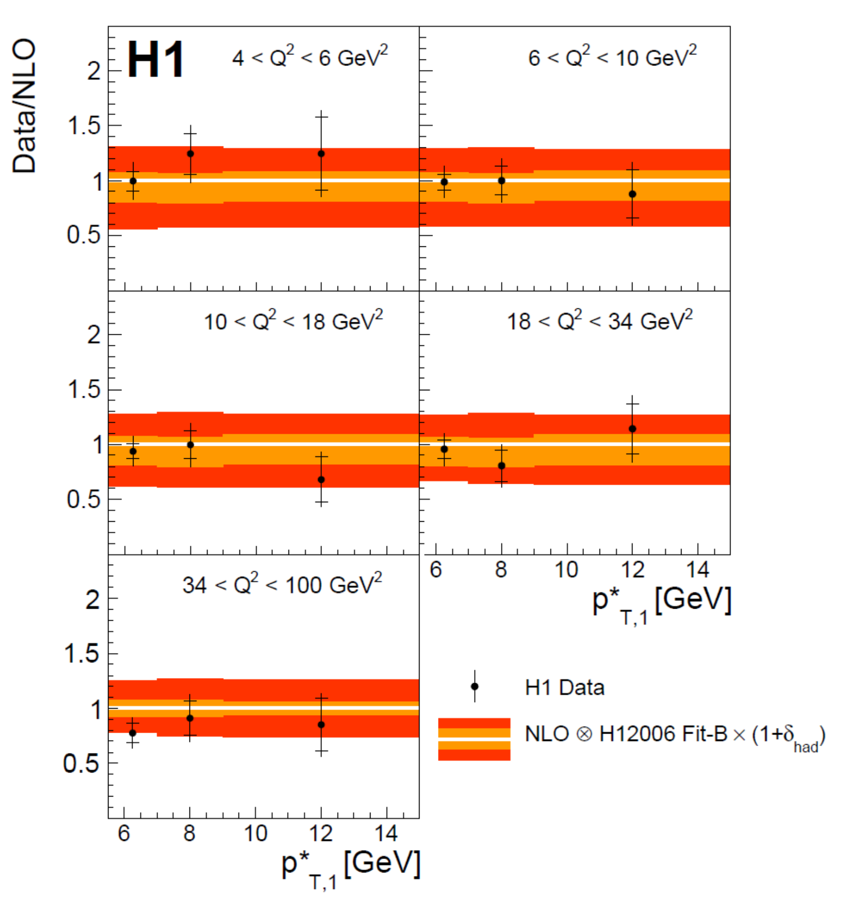
Compared with theory

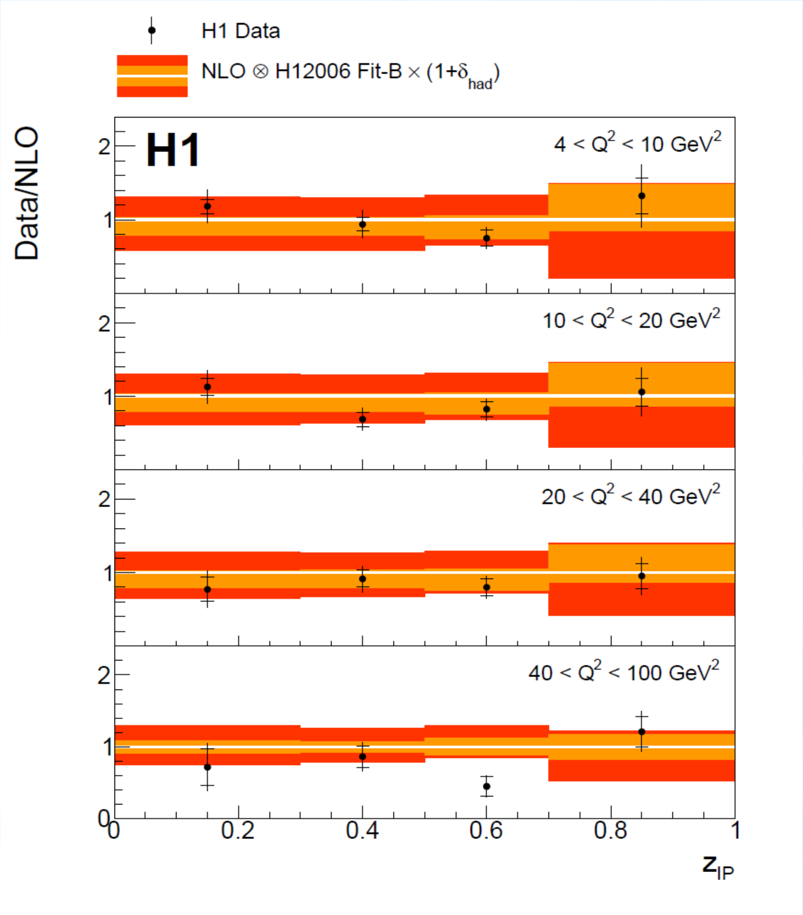
→ in NLO QCD (nlojet++)

→ hadronization corrections from MC

→ using H1 2006 DPDF Fit B

Diffractive dijet production in DIS





$$\alpha_s(M_Z) = 0.119 \pm 0.004\,(\text{exp}) \pm 0.012\,(\text{DPDF, theo})$$

Result is consistent within uncertanties with the world average

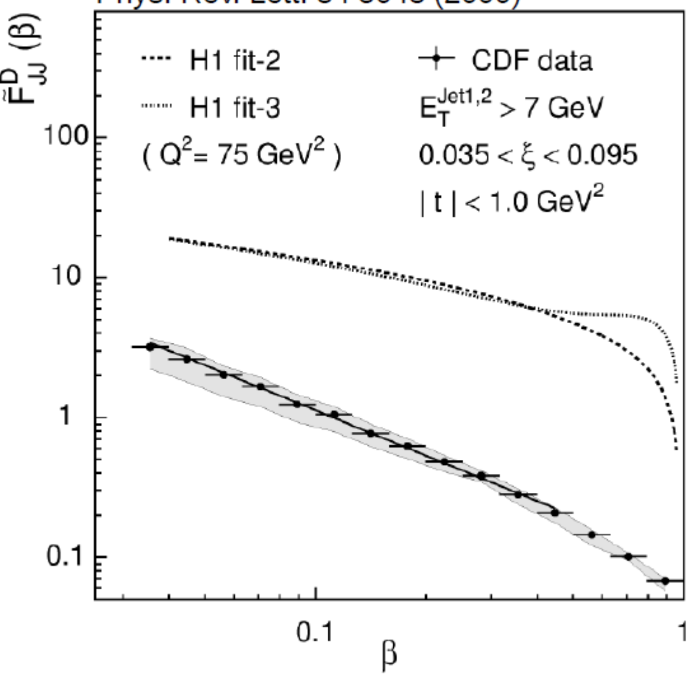
Factorisation tests in diffractive production

! DPDFs are not portable to diffractive hadron-hadron (pp) processes !

→ order of magnitude overestimation of predicted $p\bar{p}$ dijet rates first observed by CDF → **Factorization breaking**

$$S^2 = \frac{\sigma\,(\text{data})}{\sigma\,(\text{theory}_{(\text{NLO QCD})})}$$

Phys. Rev. Lett. 84 5043 (2000)



Absorptive effects occur

→ change of event kinematics

→ rescattering or unitarity corrections

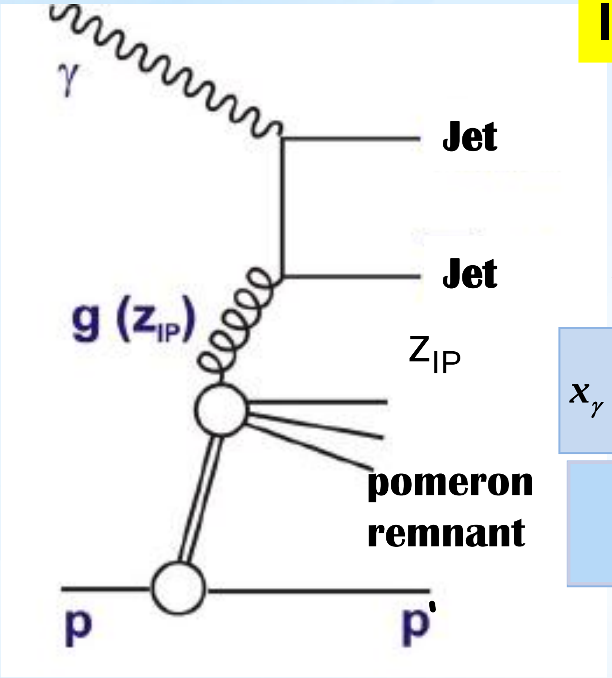
→ several approaches exist to calculate so called **Survival probability $<S^2>$**

… i.e. probability of diffractive event to retain the diffractive signature

Tested in diffractive dijet photoproduction at HERA due to γ 's partonic fluctuations (hadron-like object)

Factorisation tests in diffractive dijet photoproduction

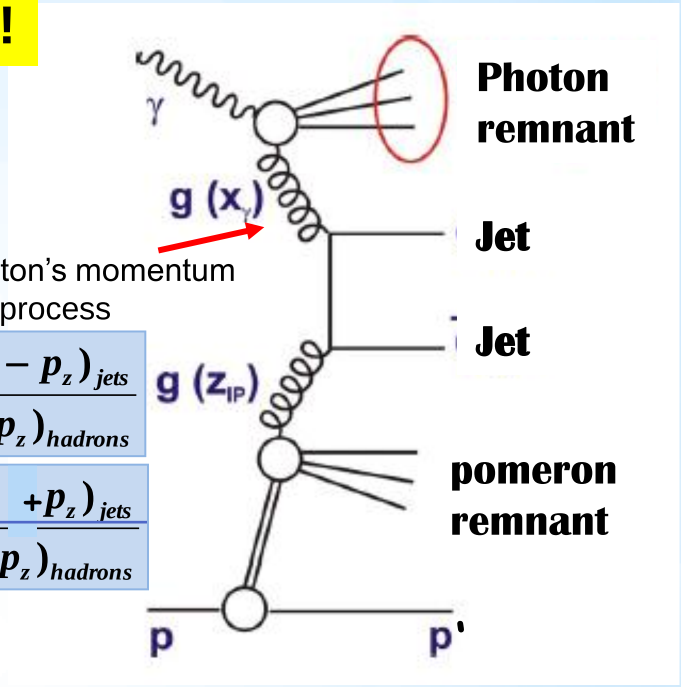
In LO QCD!



x_γ - fraction of photon's momentum in hard subprocess

$$x_\gamma = x_\gamma^{OBS} = \frac{\sum (E - p_z)_{jets}}{(E - p_z)_{hadrons}}$$

$$z_{IP} = \frac{\sum (E + p_z)_{jets}}{(E + p_z)_{hadrons}}$$



direct photoproduction:
photon directly involved in hard scattering -> $x_\gamma = 1$

no suppression expected

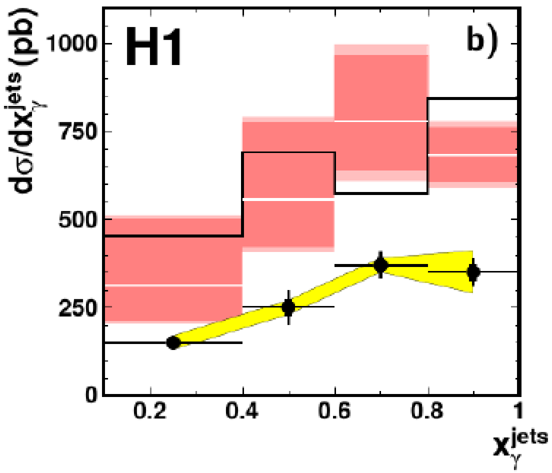
resolved photoproduction:
photon fluctuates into hadronic system, which takes part in hadronic scattering, dominant at $Q^2 \simeq 0$ -> $x_\gamma < 1$

Theor.prediction of Kaidalov, Khoze, Martin, Ryskin (European Journal of Physics 66,373 (2010))

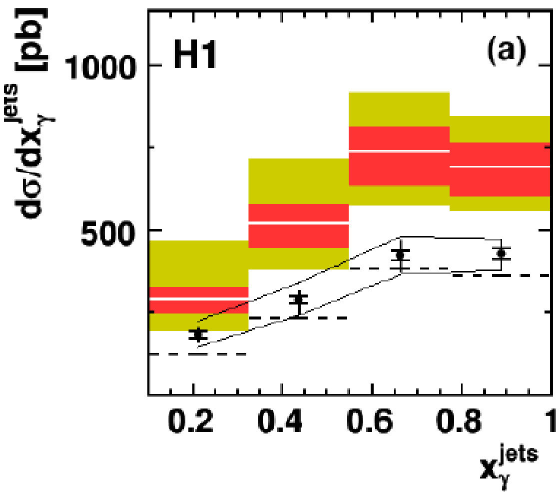
suppression: quarks **0.71(0.75)** E_T^{jet1} >5 (7.5) GeV
gluons **0.53(0.58)** E_T^{jet1} >5 (7.5) GeV

History – factorisation tests in γp

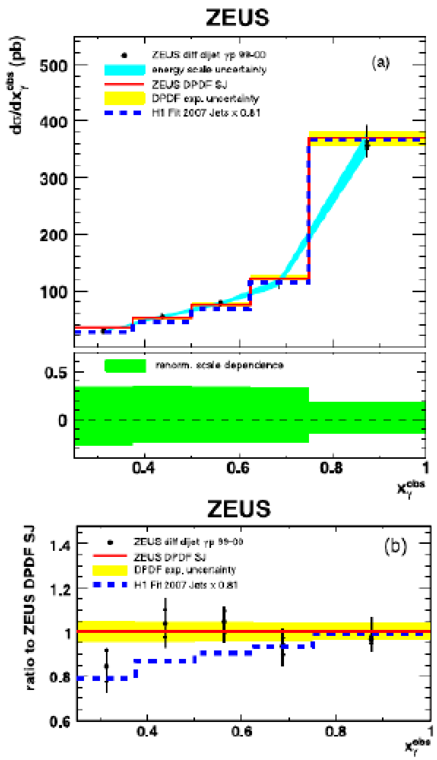
Eur.Phys.J.C 51 (2007) 549



Eur.Phys.J.C70 (2010) 15



Nucl. Phys. B 831 (2010) 1-25



Previous H1 and ZEUS (LRG) analyses

→ H1: 2007 (S^2 ~ 0.5), 2010 (S^2 ~ 0.6)

→ ZEUS: 2010 (S^2 ~ 1)

Suppression is not dependent on x_γ

Diffractive dijet photoproduction & DIS- measurement in Very Forward Proton Spectrometer

DIS & **photoproduction**

$4 < Q^2 < 80\ GeV^2$ $Q^2 < 2\ GeV^2$

other cuts identical:

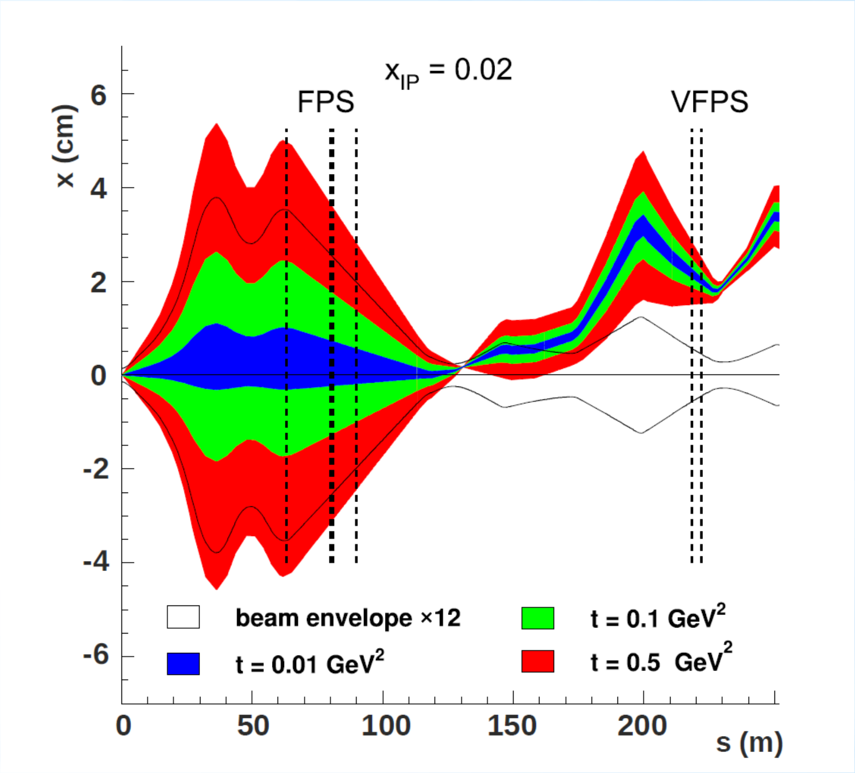
$0.01 < x_{IP} < 0.024$

$|t| < 0.6\ GeV^2$

$z_{IP} < 0.8$

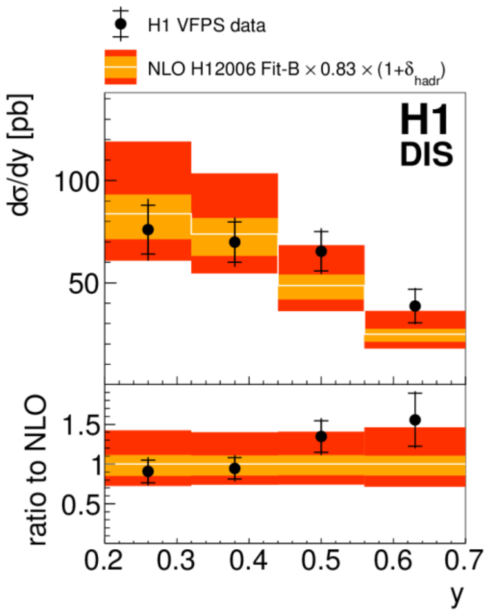
$E_T^*{}_{jet1(2)} > 5.5(4)$ GeV

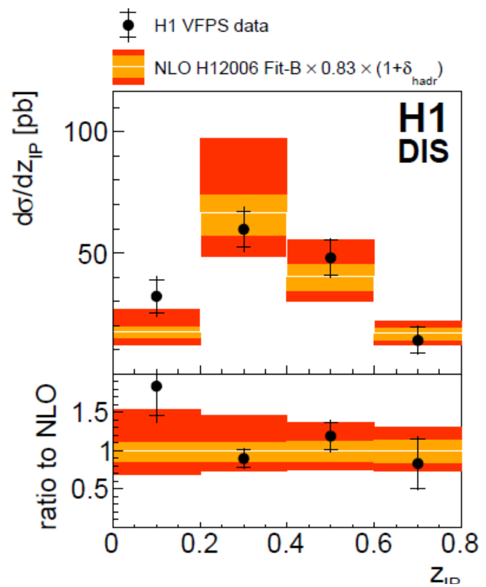
$-1 < \eta_{jet1(2)} < 2.5$

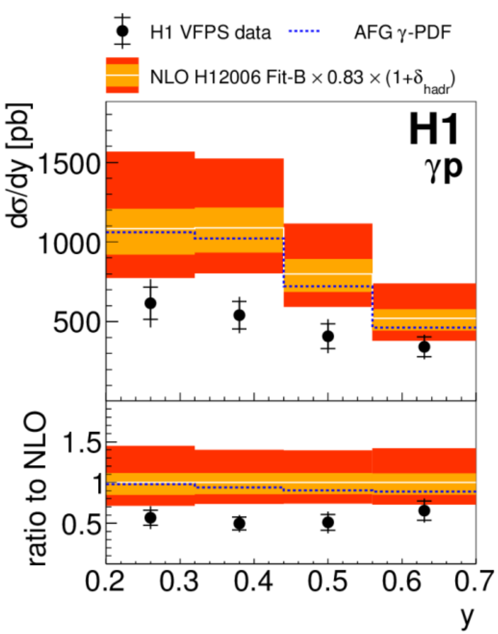


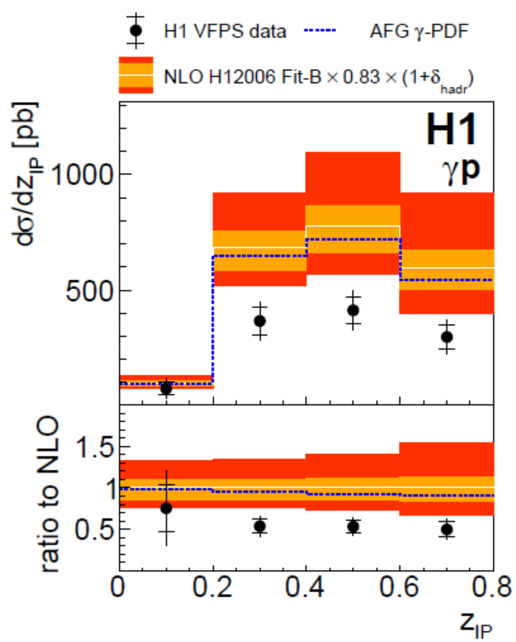
Independent cross-check of LRG measurements – without proton dissociation!

Diffractive dijet DIS & γp









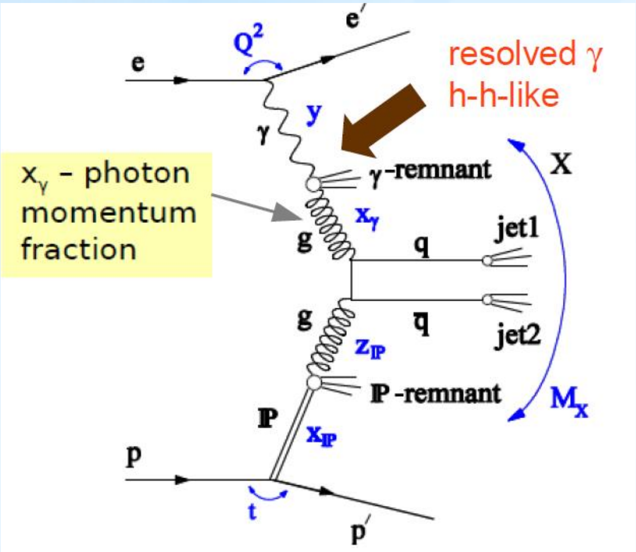
DIS

Data in agreement with NLO in DIS, within uncertainites

γp

Data suppressed in comparison with NLO in photoproduction

Diffractive dijet photoproduction



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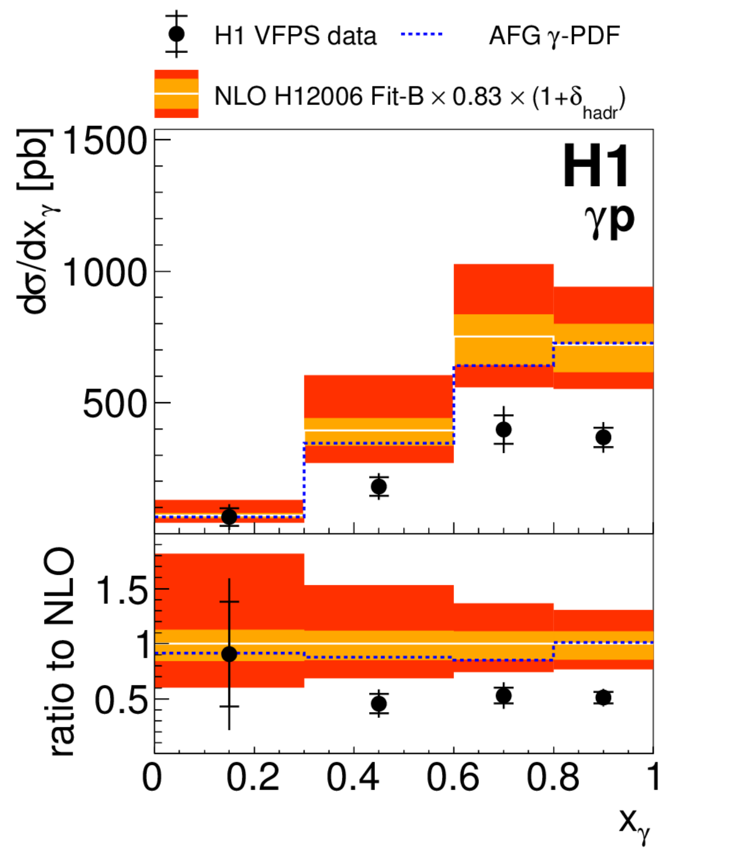
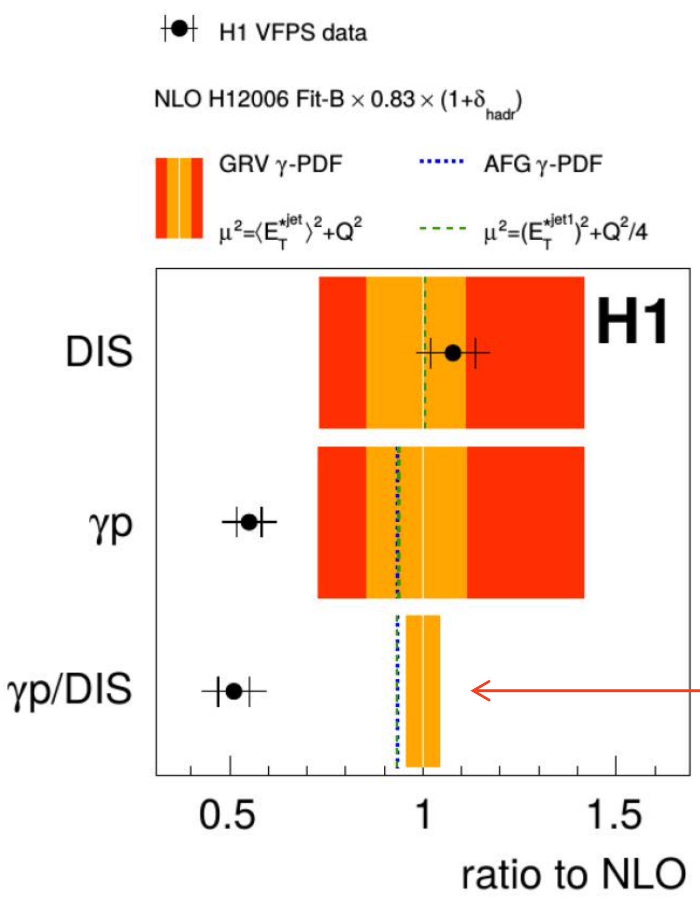


The suppression seems to be not dependent on x_γ .
It is in agreement with previous H1 and ZEUS observations!

Diffractive dijet photoproduction & DIS



Profits from cancellations of scale uncertainties

→ theory / theory, if varied simultaneously

No significant dependence on kinematics

→ only global ratios are shown

$1.08 \pm 0.11\ (\text{data})^{+0.45}_{-0.29}\ (\text{theory})$

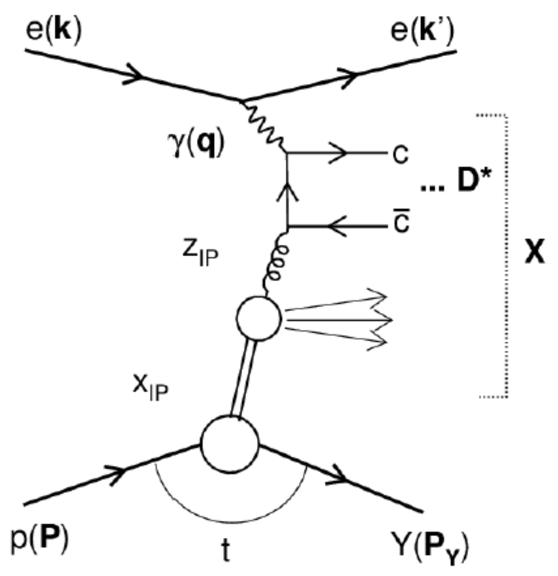
$0.551 \pm 0.078\ (\text{data})^{+0.230}_{-0.149}\ (\text{theory})$

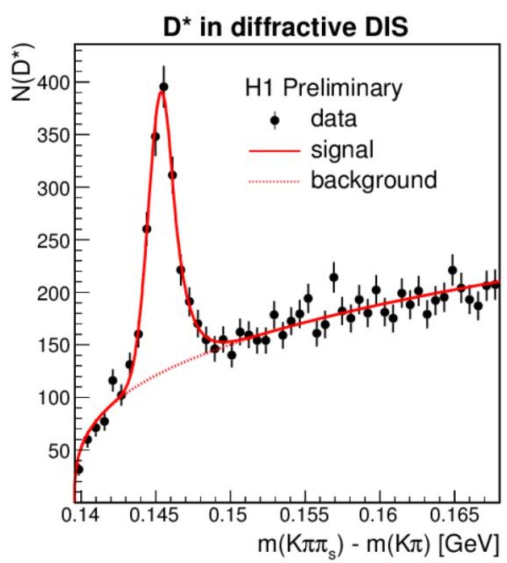
$0.511 \pm 0.085\ (\text{data})\ ^{+0.022}_{-0.021}\ (\text{theory})$

double ratio

Previous H1 measurement confirmed!

Diffractive D* production in DIS





- hard scale -> mass of D*
- sensitive to gluon content

Charm contribution to F_2^D ~ 20% - similar as for inclusive DIS

→ based on 280 pb^{-1} HERA-2 data

(previous H1 publ. at 50 pb^{-1} H1 HERA 1)

→ open charm tagged with D*

$$D^{*+} \rightarrow D^0 \pi^+_{slow} \rightarrow (K^- \pi^+) \pi^+_{slow} + C.C.$$

→ fits of $\Delta m = m(D^*_{cand}) - m(D^0_{cand})$

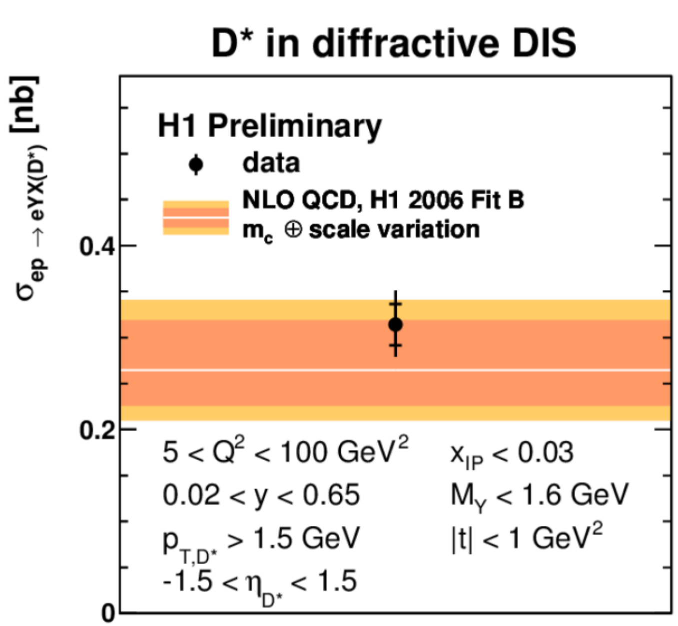
→ large rapidity gap selection

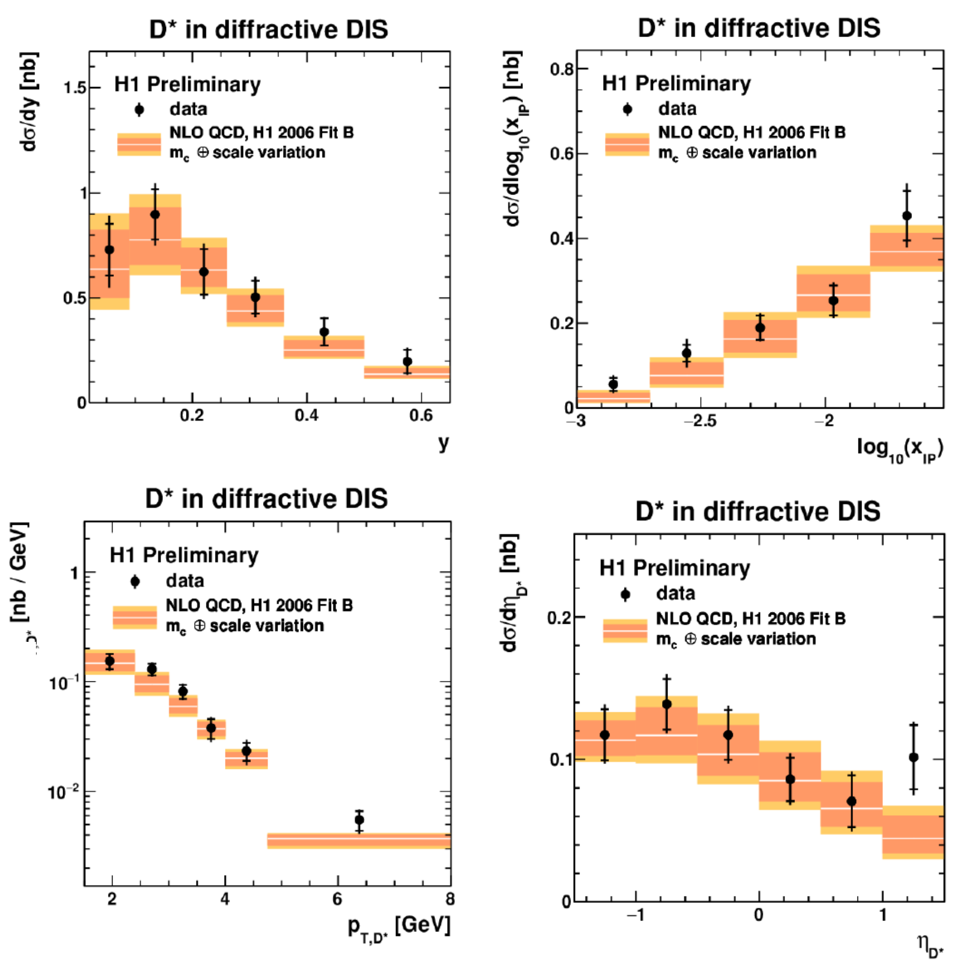
$5 < Q^2 < 100$ GeV^2 $0.02 < y < 0.65$

$p_{t,D^*} > 1.5$ GeV $|\eta_{D^*}| < 1.5$ … in lab

$x_{IP} < 0.03$

Diffractive D* production in DIS





NLO QCD prediction agree well within errors with measured cross sections

→ new test of factorization

Final measurement might serve as an input to DPDF fits

Conclusions

- H1 and ZEUS measured inclusive diffractive cross sections using different methods of diffraction selection and determined **Diffractive Parton Density Functions (DPDFs)**.

- Measured DPDFs were applied in NLO calculations to wide variety of observables for DIS and photoproduction – **tests of QCD collinear factorisation**.

  - In diffractive DIS QCD factorisation confirmed

  - In dijet photoproduction ZEUS results consistent with factorisation, H1 measured suppression factor S^2~0.5 using both LRG and proton detection selection

  - In diffractive D* production within large uncertainties QCD factorisation confirmed for both DIS and photoproduction