Factorization in ep diffractive interactions

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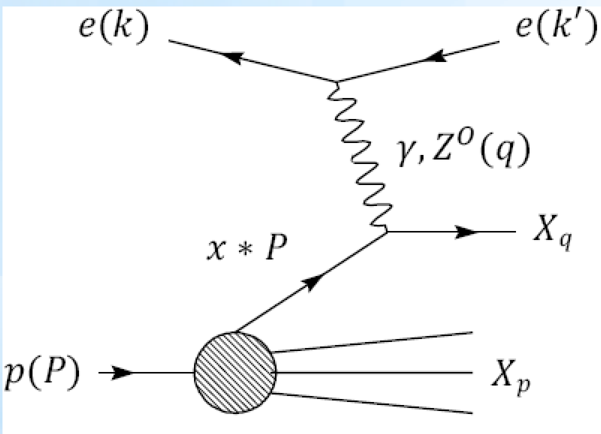
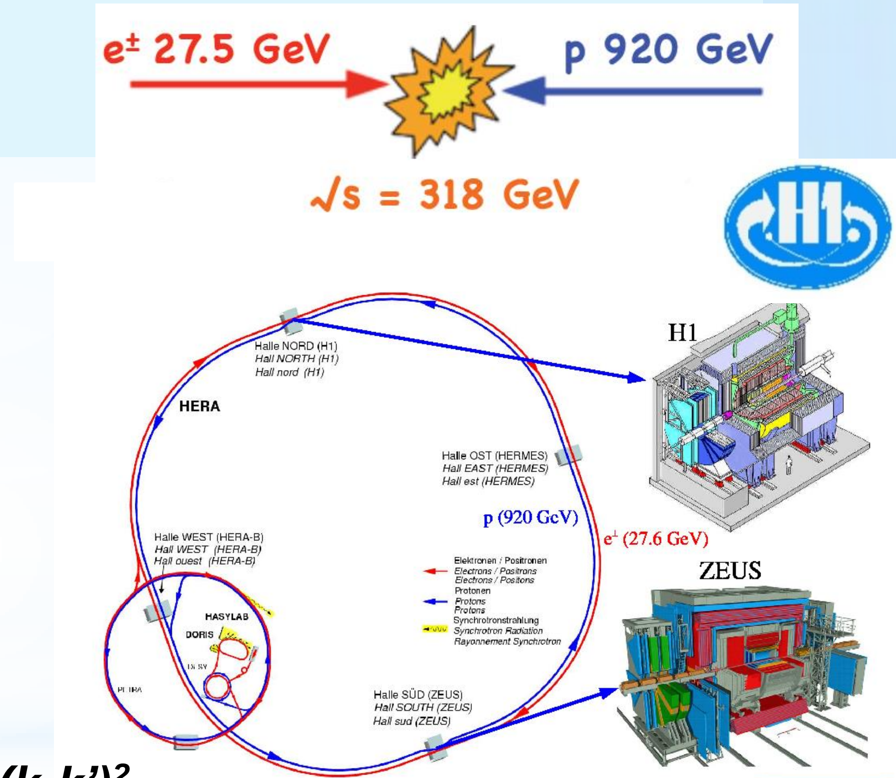
on behalf of H1 and ZEUS Collaborations

HERA collider experiments

- 27.5 GeV electrons/positrons on 920 GeV protons →√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 $x = Q^2/2qP$

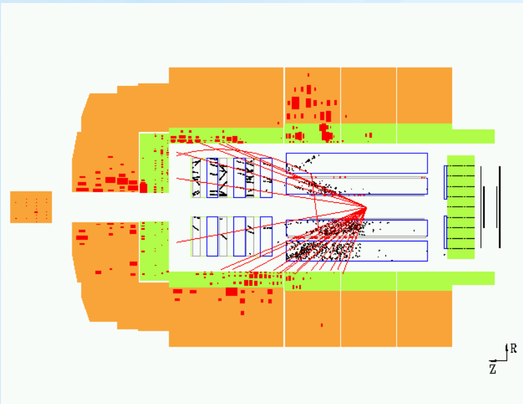
Two regimes:

$Q^2 <$ 1 GeV^2 photoproduction (γp)

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

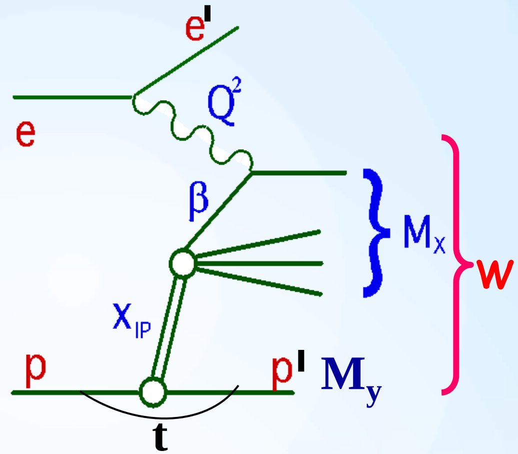
Diffractive kinematics

Non-diffractive ep interaction



- Q^2- virtuality of the photon
- Q^2~0 GeV^2→ photoproduction
- Q^2>>0 GeV^2→ 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

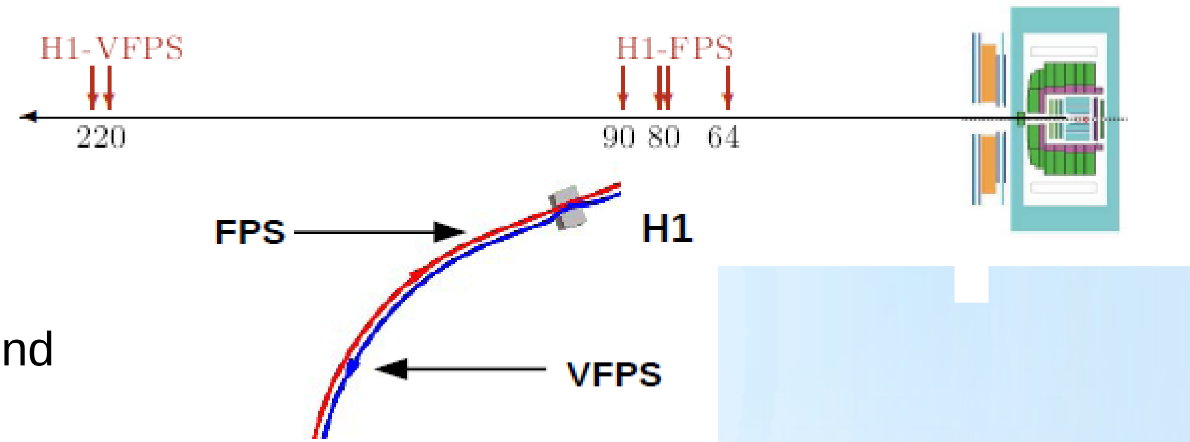
$M_y › m_p$ proton dissociates, contribution should be understood

Methods of diffraction selection

Proton spectrometers

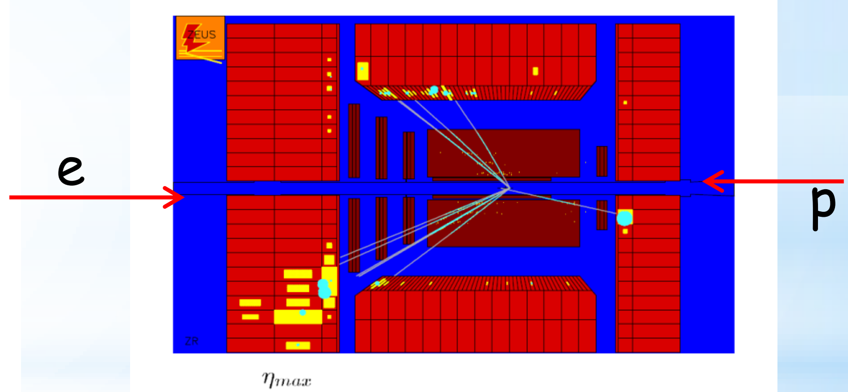
H1: VFPS (2005-2007)
FPS (1997-2007)
ZEUS: LPS (1997-2000)

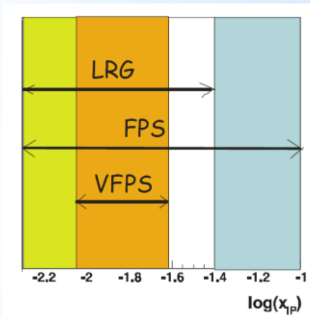
☺ free of p-dissociation background
☺ x_{IP} and t measurements
☺ access to high x_{IP} range (IP and IR)
☹ small acceptance, small statistics



Large Rapidity Gap

require no activity beyond η_{max}
☹ t not measured,integrated over $|t|<1\text{GeV}^2$
☺ very good acceptance at low x_{IP}
☹ p-diss background about 20% ☠



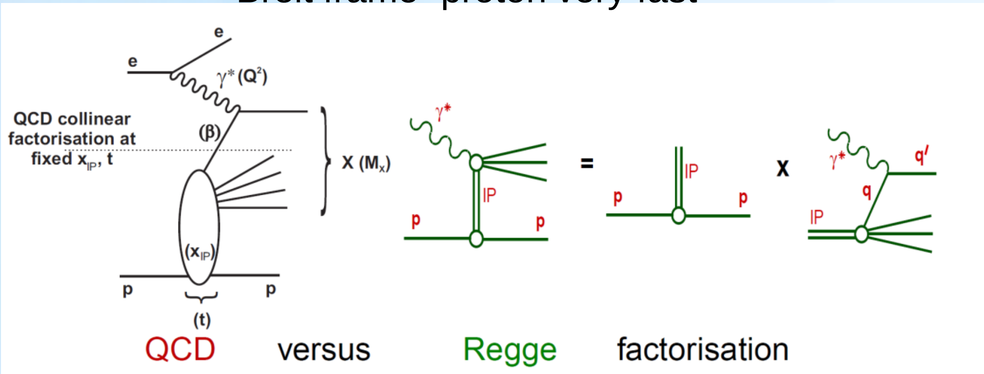


Different phase space and systematics – non-trivial to compare!

Modelling of diffraction

QCD collinear factorisation theorem

Breit frame- proton very fast



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

DPDFs – obey DGLAP universal for diff. ep DIS

hard scattering cross section

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

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

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

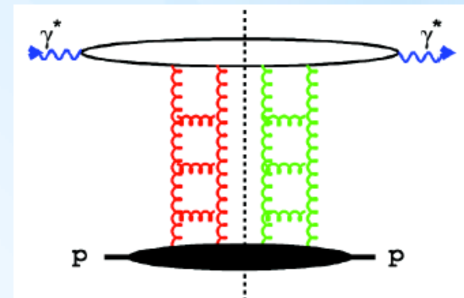
Pomeron flux factor

diffractive DPDF

Then DPDFs extracted from DIS data

Dipole models

Proton rest frame - dipoles



[C. Marquet PRD76 (2007) 094017]

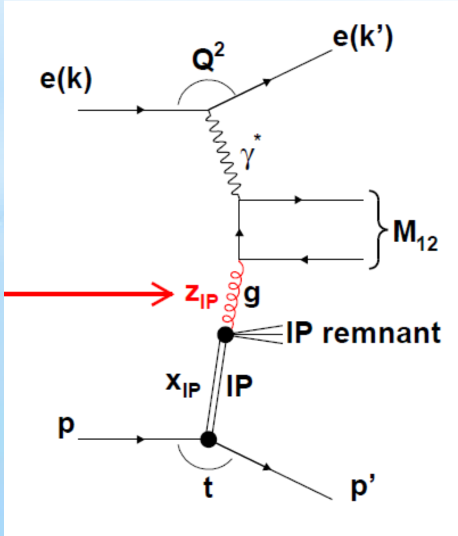
$$d\sigma_{diff}^{\gamma^* p}/dt \propto \int dz dr^2 \Psi^* \sigma_{q\bar{q}}^2(x,r^2,t)\Psi$$

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

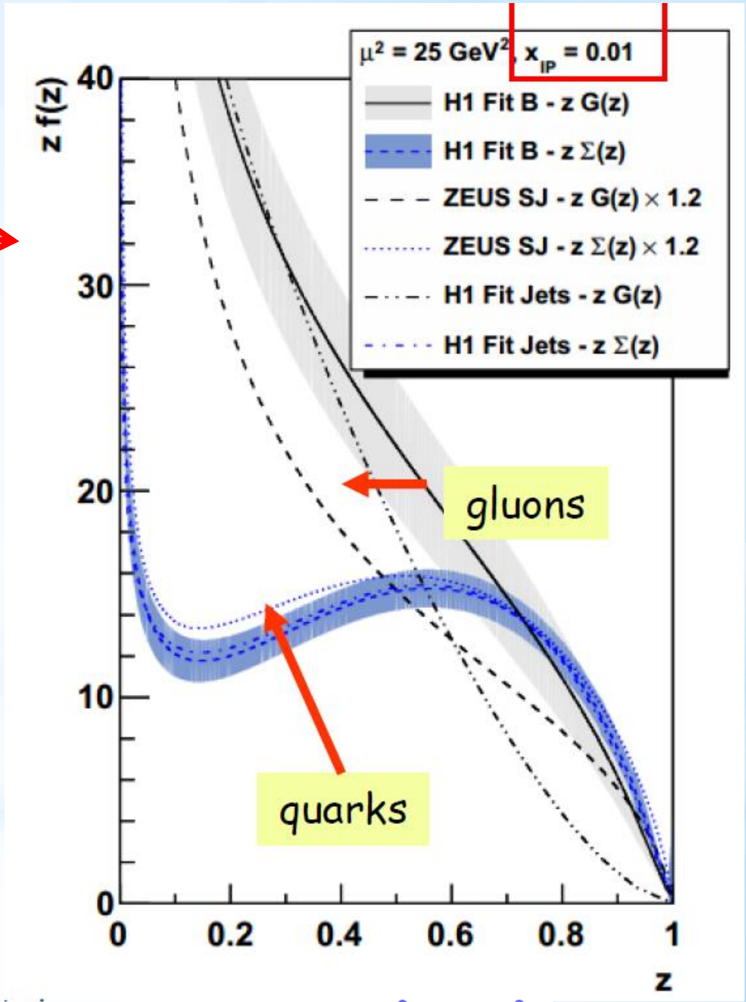
No extra parameters needed for DDIS

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**



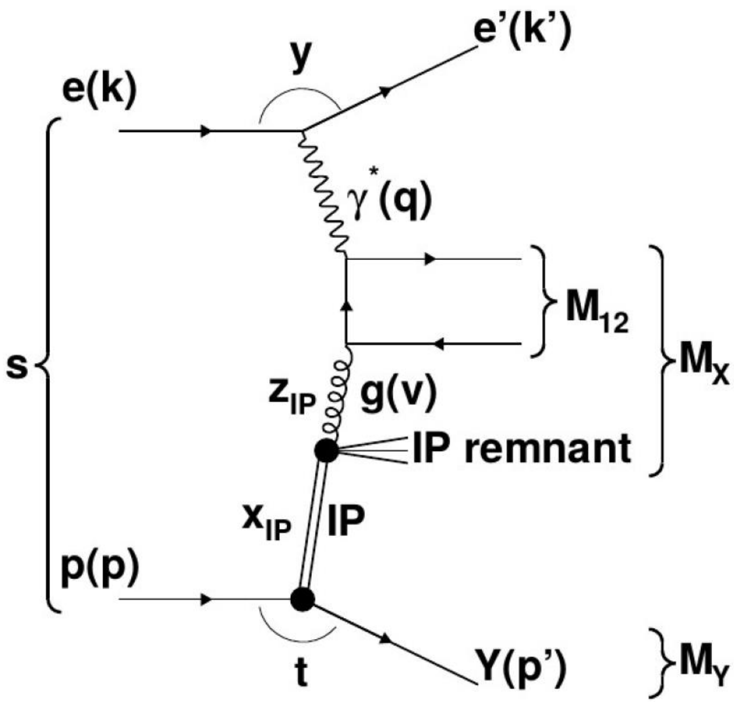
$$z_{IP} = \frac{\sum (E + p_z)_{jets}}{(E + p_z)_{hadrons}}$$



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

Diffractive dijet production in DIS

JHEP 1503 (2015) 092



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

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

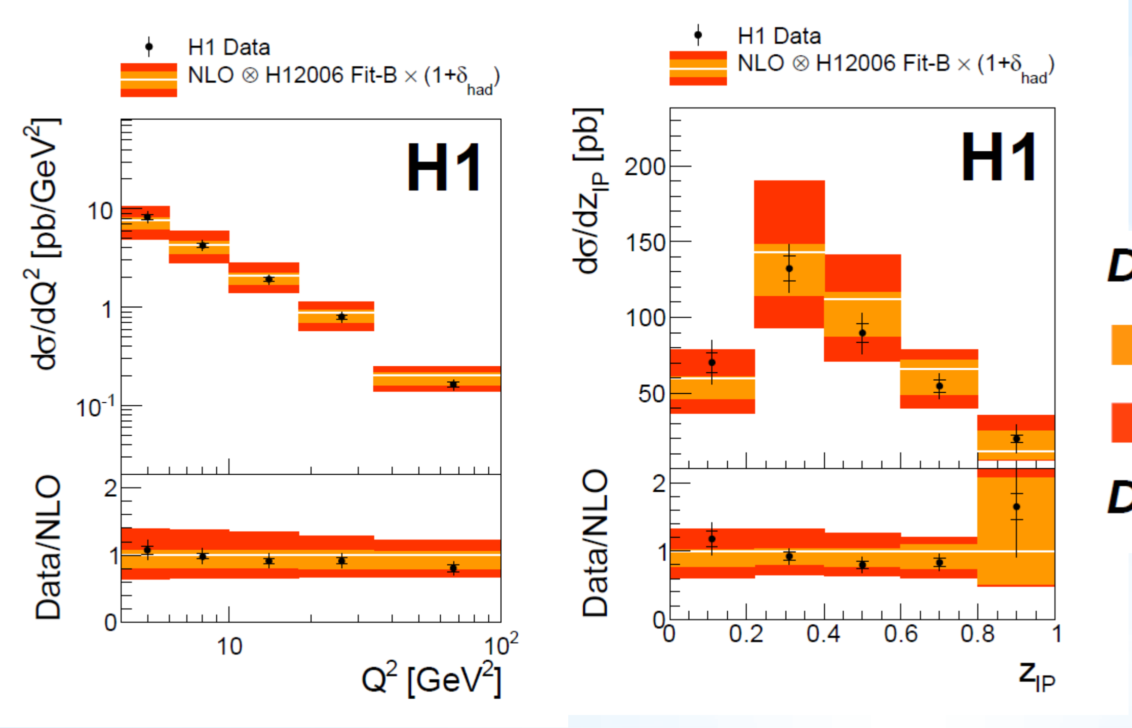
Compared with theory

→ in NLO QCD (nlojet++)

→ hadronization corrections from MC

→ using H1 2006 DPDF Fit B

Diffractive dijet production in DIS



Data more precise than theory

DPDF uncertainties

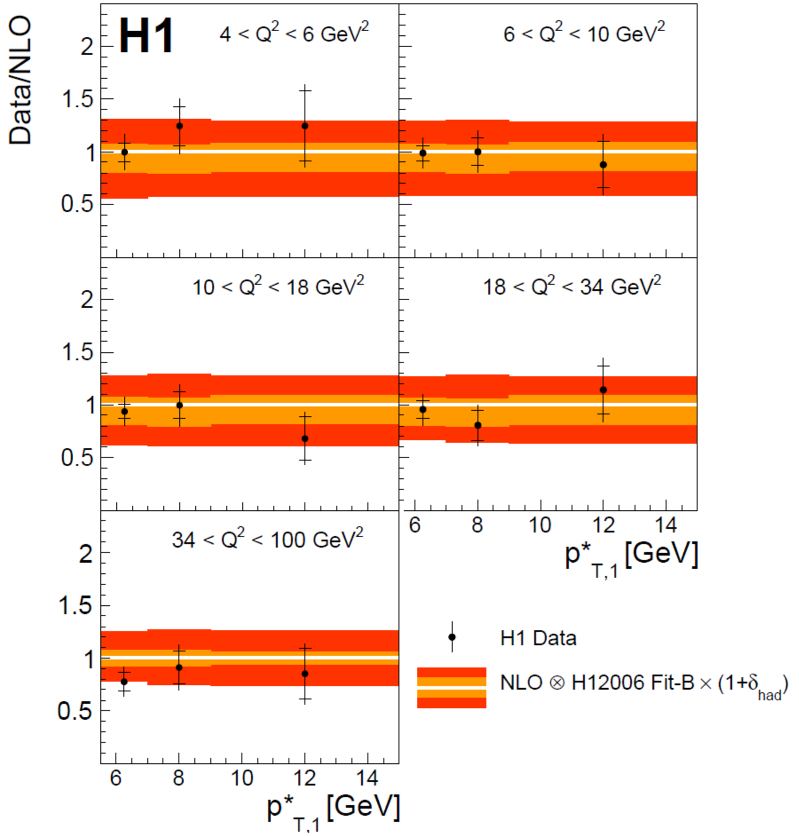
DPDF & scale uncertainties

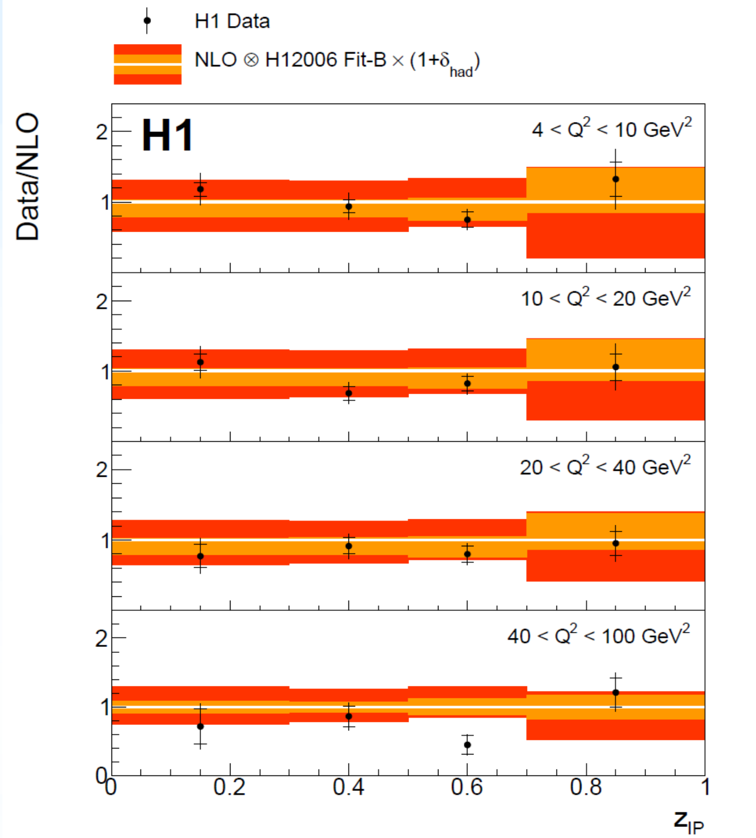
Data well described by theory

$$\sigma^{dijet}_{meas}(ep \to eXY) = 73 \pm 2\ (\text{stat.})\ \pm 7\ (\text{syst.})\ \text{pb}$$

$$\sigma^{dijet}_{theo}(ep \to eXY) = 77\ ^{+25}_{-20}\ (\text{scale})\ ^{+4}_{-14}\ (\text{DPDF})\ \pm 3\ (\text{had})\ \text{pb}$$

Diffractive dijet production in DIS





Double-differential cross sections

→ agreement with QCD at NLO

→ precision of the data allows the extraction of α_s ... in agreement with world average

… not a competitive means for α_s extraction

… supports readiness of the data for DPDF fits

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

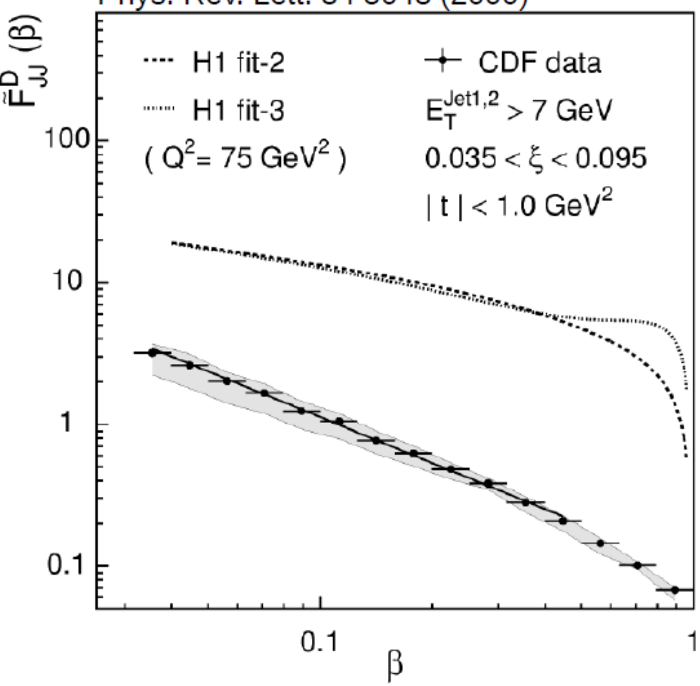
Factorisation tests in diffractive production

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

→ order of magnitude overestimation of predicted $\bar{p}p$ 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

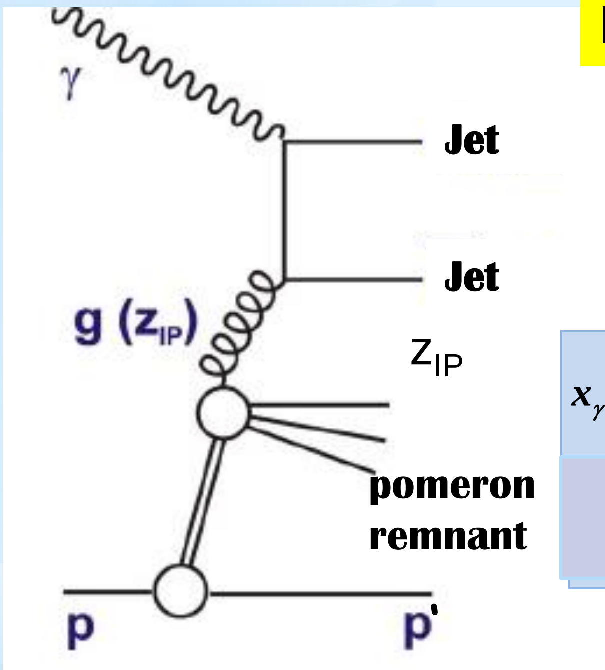
→ several approaches exist to calculate so called **Survival probability <S^2>**

… 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

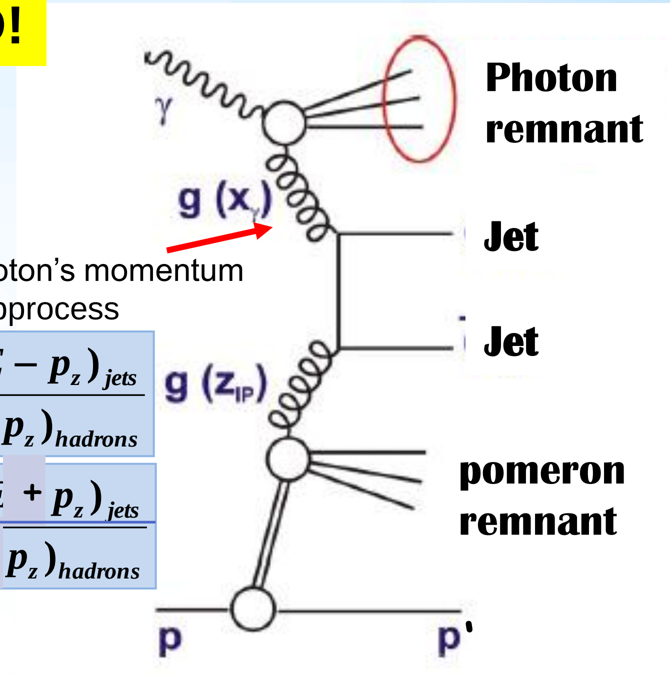
In LO QCD!



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

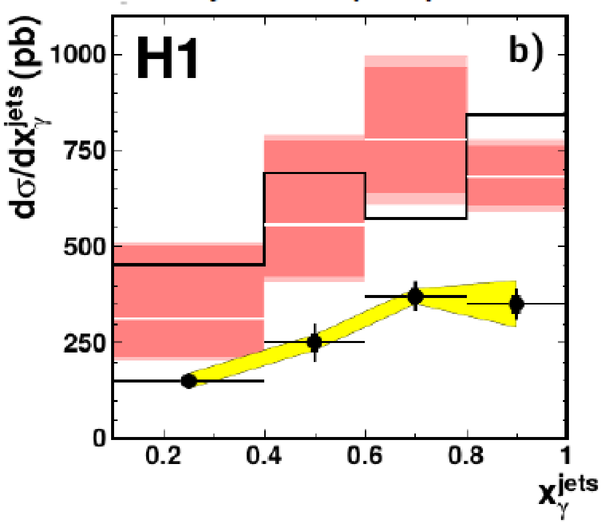
resolved photoproduction:
photon fluctuates into hadronic system, which takes part in hadronic scattering,dominant at $Q^2 \simeq 0$ -> $x_\gamma < 1$

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

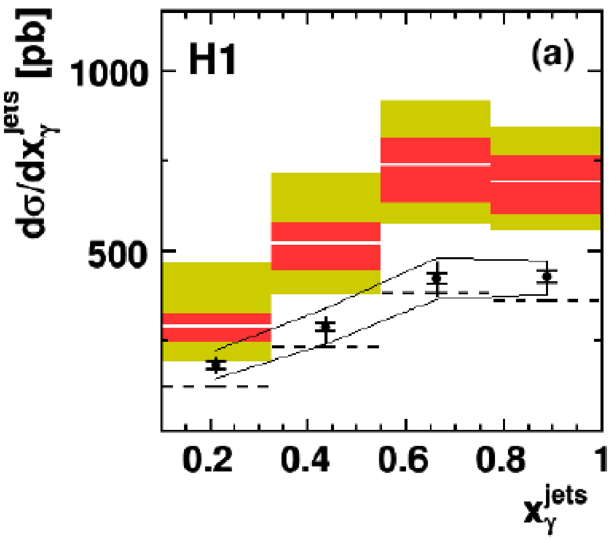
suppression: quarks **0.71(0.75)** E_T^{jet1} >5 (7.5) GeV
gluons **0.53(0.58)** E_T^{jet1} >5 (7.5) GeV

History – factorisation tests in γp

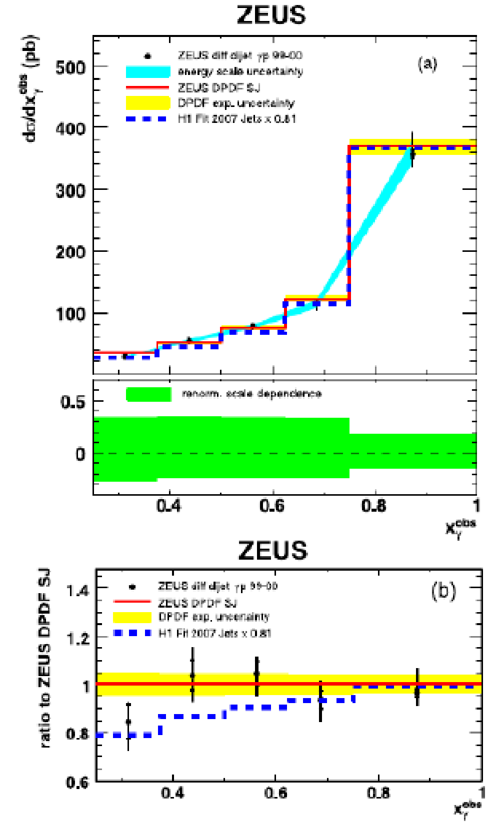
Eur.Phys.J.C 51 (2007) 549



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:

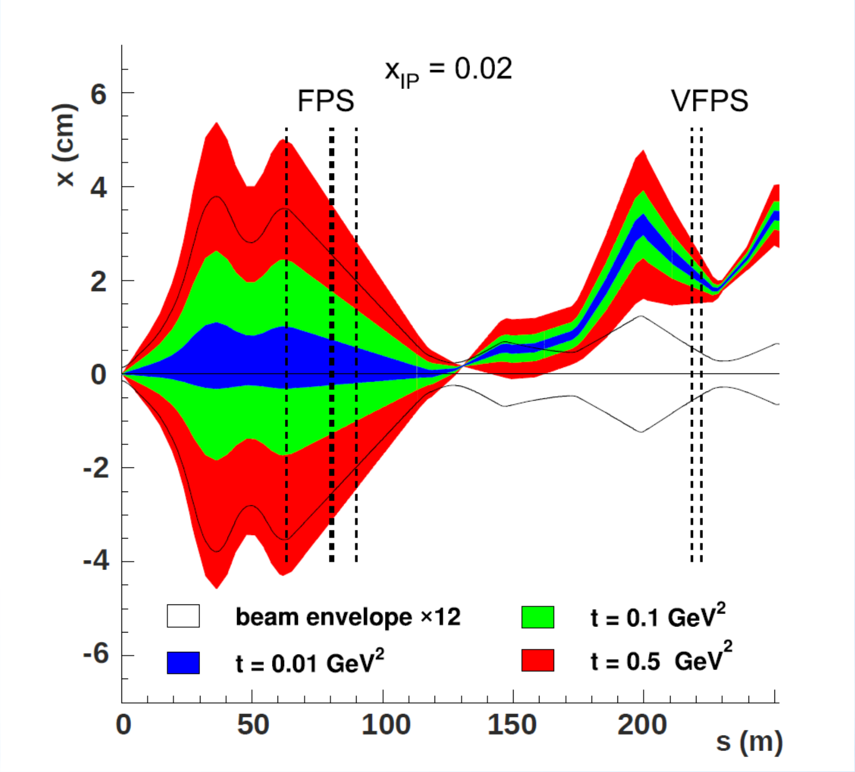
$0.01 < x_{IP} < 0.024$

$|t| < 0.6\ GeV^2$

$z_{IP} < 0.8$

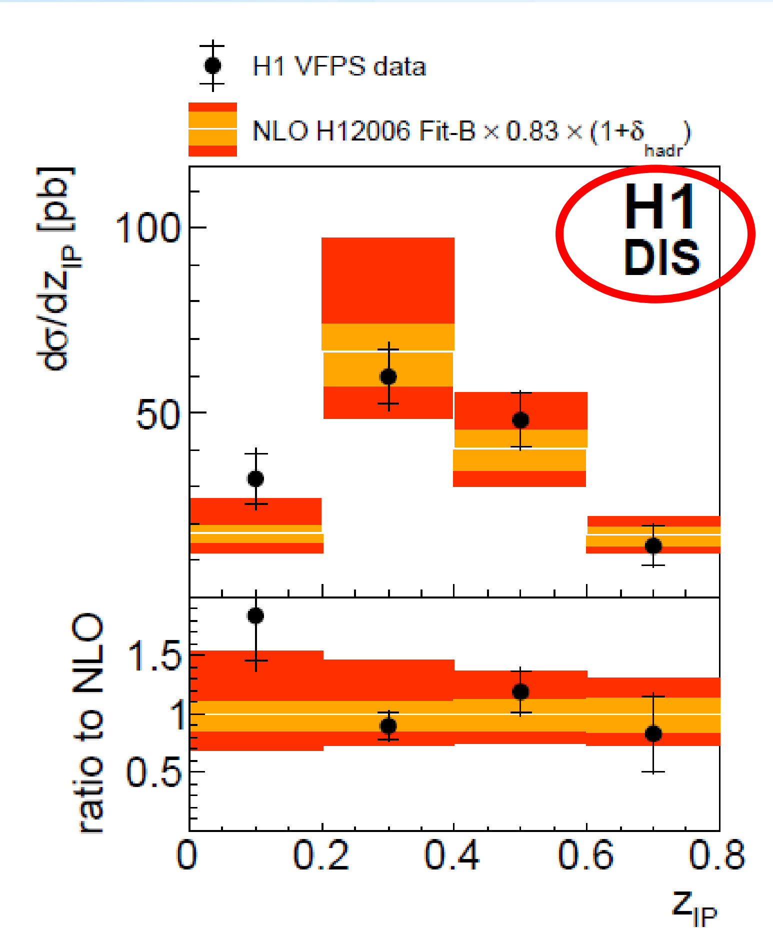
$E_{T\ jet1(2)}^{*} > 5.5(4)\ GeV$

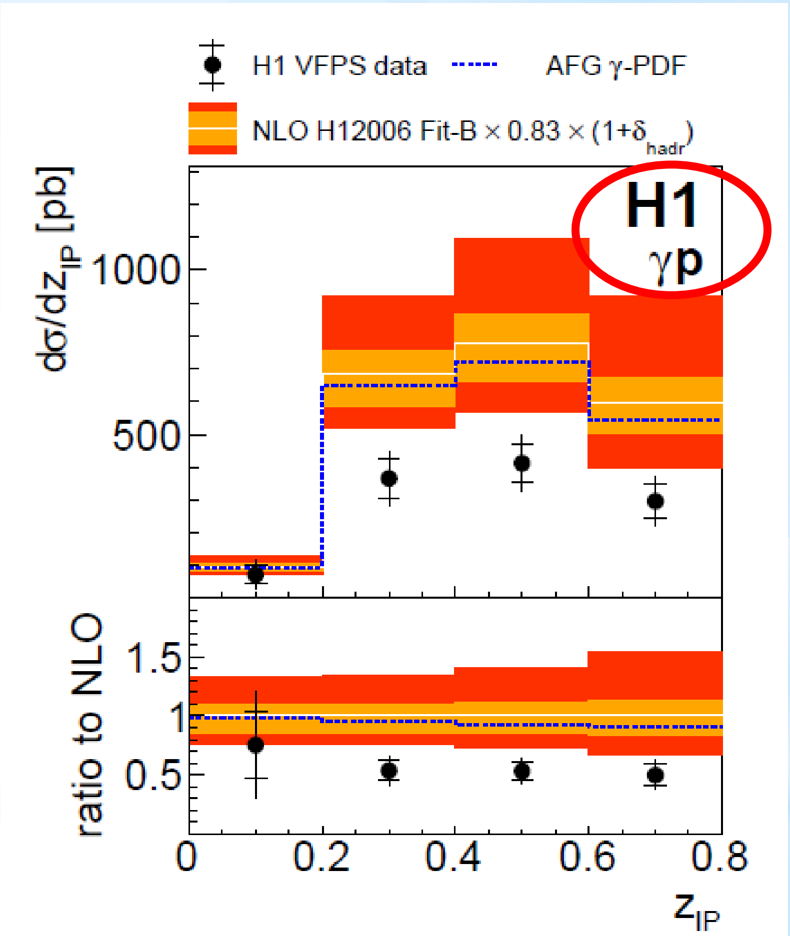
$-1 < \eta_{jet1(2)} < 2.5$



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

Diffractive dijet photoproduction & DIS

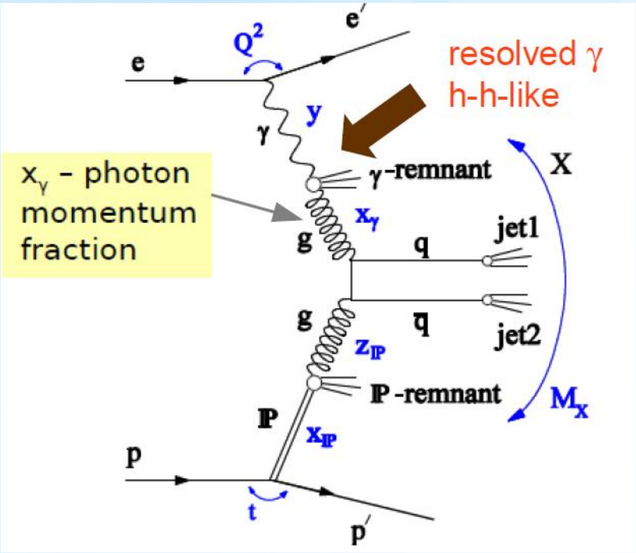


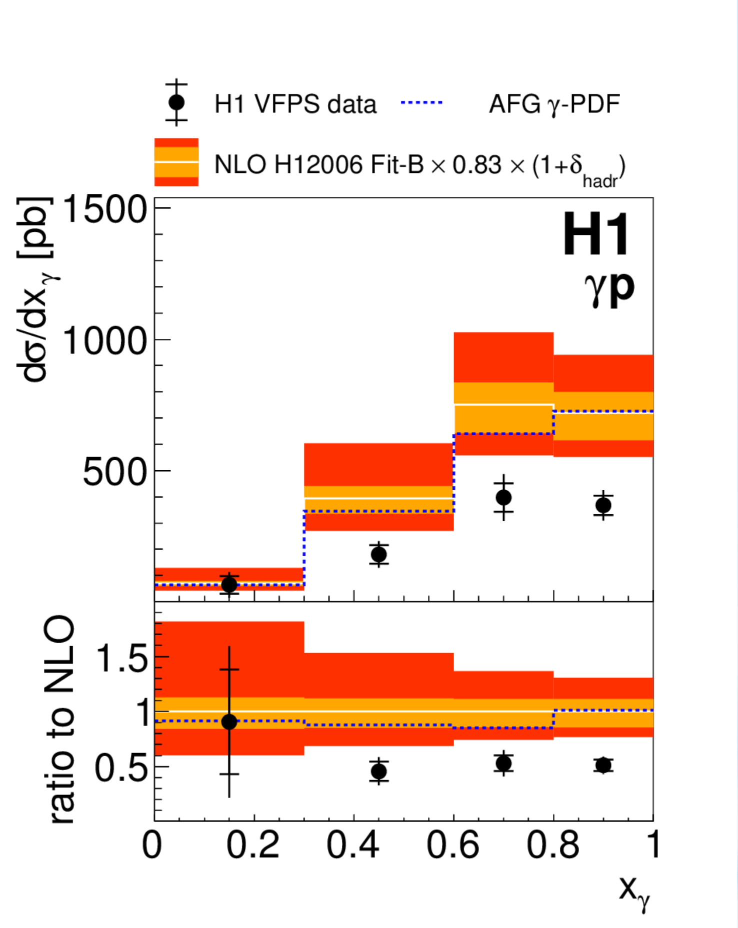


Data in agreement with NLO in DIS, within uncertainites

Data suppressed in comparison with NLO in photoproduction

Diffractive dijet photoproduction

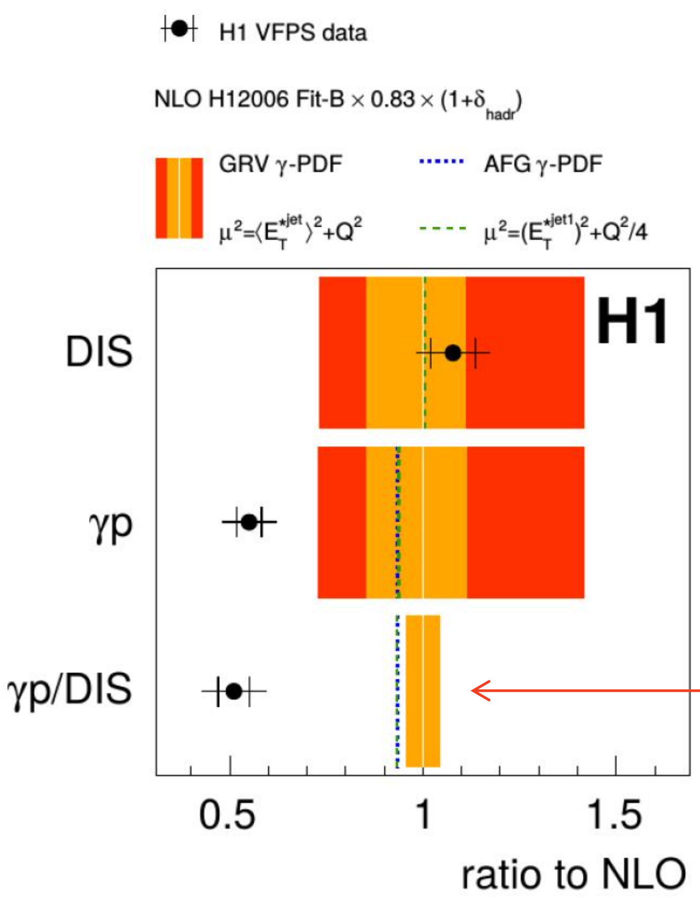




$$x_\gamma = x_\gamma^{OBS} = \frac{\sum (E - p_z)_{jets}}{(E - p_z)_{hadrons}}$$

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

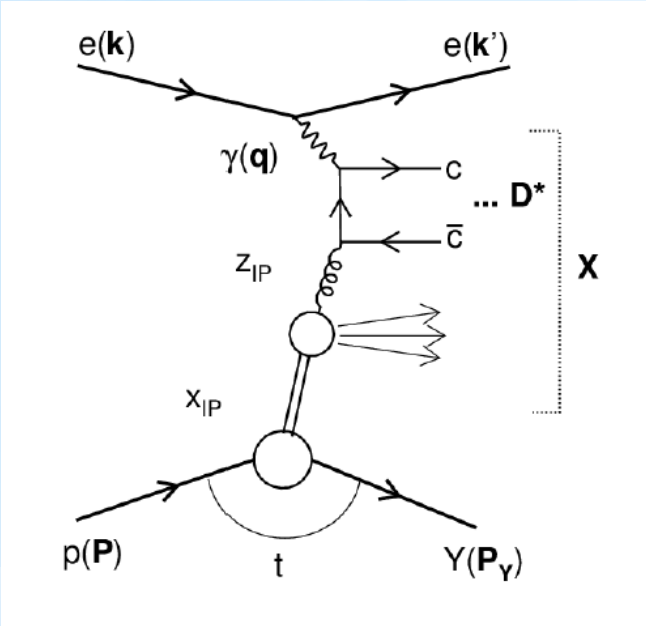
$1.08 \pm 0.11\ (\text{data})^{+0.45}_{-0.29}\ (\text{theory})$

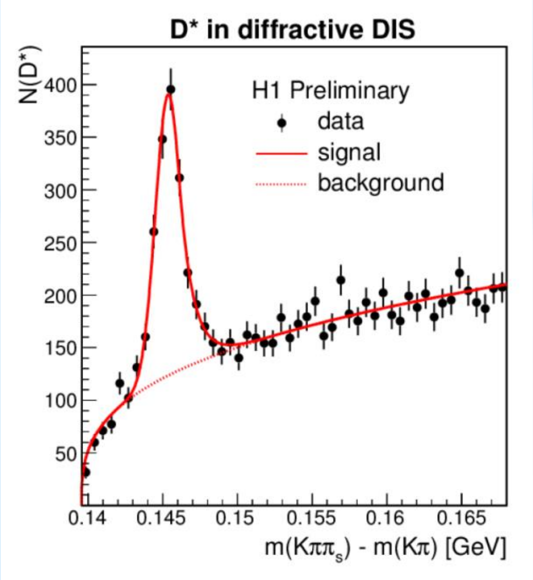
$0.551 \pm 0.078\ (\text{data})^{+0.230}_{-0.149}\ (\text{theory})$

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

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

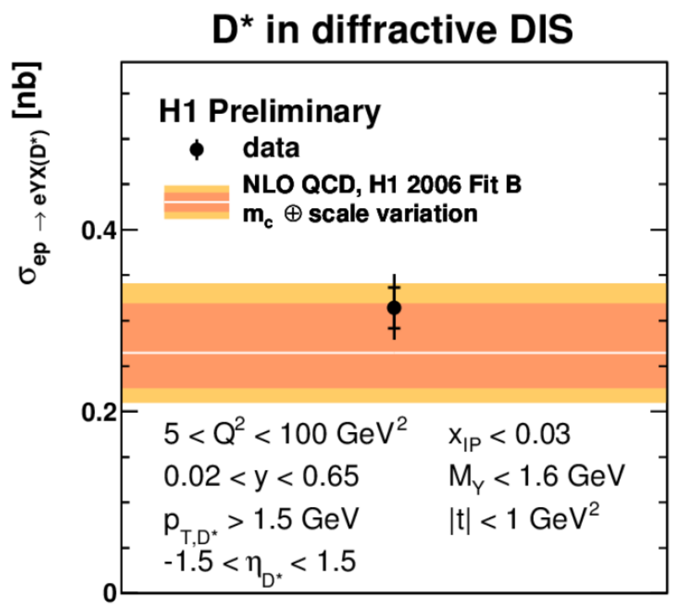
→ large rapidity gap selection

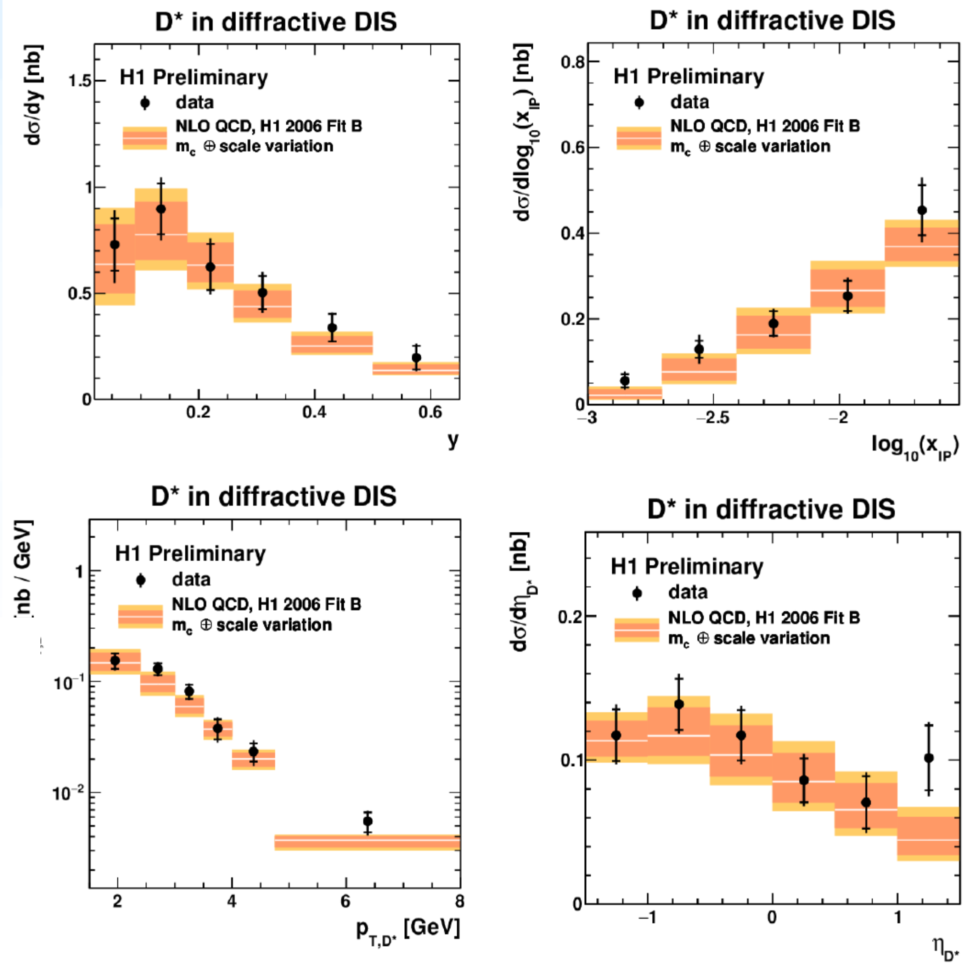
$5 < Q^2 < 100$ GeV^2 $0.02 < y < 0.65$

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

$x_{IP} < 0.03$

Diffractive D* production in DIS



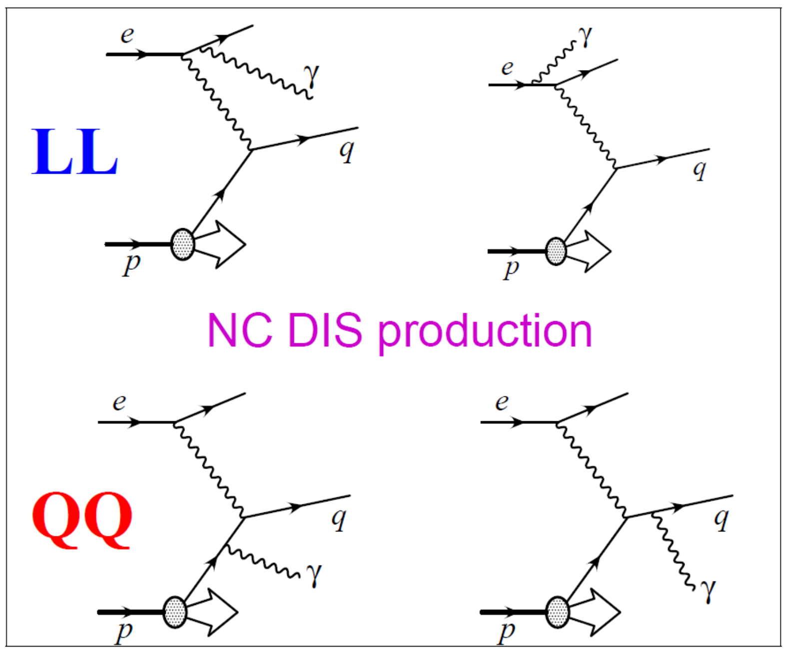


NLO QCD prediction agree well within errors with measured cross sections

→ new test of factorization

Final measurement might serve as an input to DPDF fits

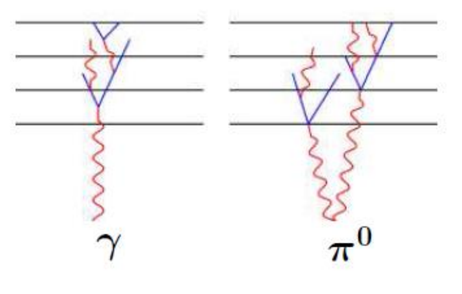
Prompt photons in DIS



LL-photons are emitted from incoming or outgoing lepton

QQ- photons are emitted from a quark as a part of hard process

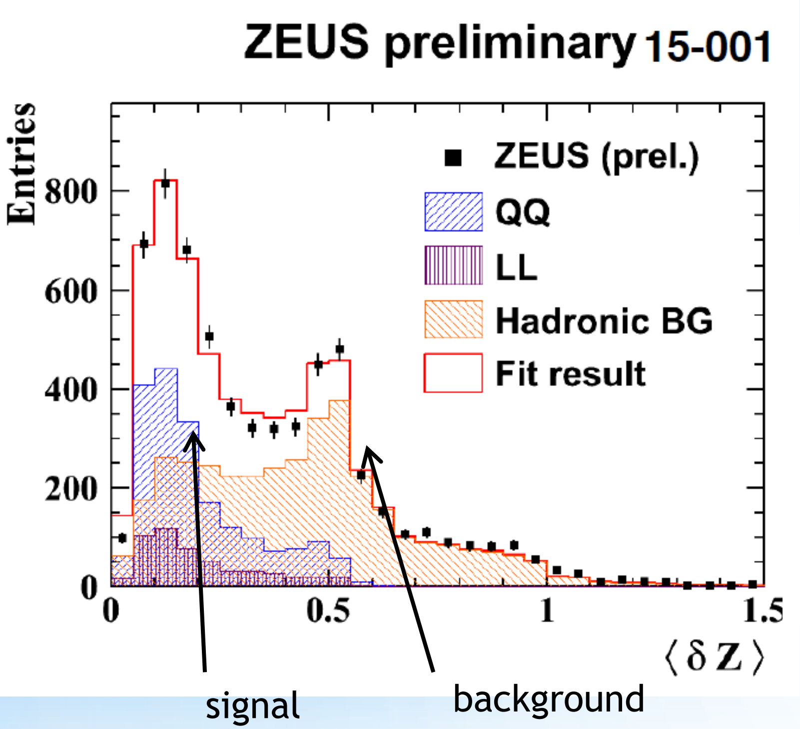
Test of QCD, unaffected by hadronisation



- Free of hadronisation corr. for photon -> direct link to parton level
- Sensitivity to parton and photon PDFs
- Important SM background to possible New physics

- Low statistics as compared to jets
- Difficult background from π/η/ decays -> systematics ~5-10%

Extraction of the photon signal



Method to distinguish the signal from hadronic background based on MC fit of δZ distribution

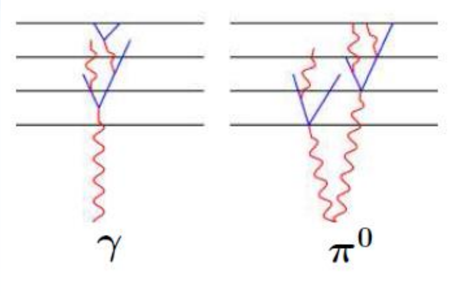
Energy-weighted mean width of the electromagnetic shower(cluster) in calorimeter relative to its centroid:

$$\langle \delta Z \rangle = \frac{\sum_i |z_i - z_{cluster}| \cdot E_i}{l_{cell} \sum E_i}$$

$Z_{i,}$ ($Z_{cluster}$) *Z* position of the *i-th* cell (centroid of the electromag. cluster),
l_{cell} - width of the cell ,
E_i- energy recorded in the cell

In each bin of each measured physical quantity, photon signal + hadronic background is fitted

This fit allows to **separate statisticaly prompt photon signal** (left peak) from **background** dominated by photons from π^0 decay (right peak)



Models used for comparison

Signal: **QQ photons** – **MC PYTHIA**, DIS events with additional radiation from the quark line

LL photons – **MC HERACLES & DJANGOH**, higher QCD effects included using color-dipole model as implemented in **ARIADNE**

Background: Photonic decays of neutral mesons produced in DIS - **DJANGOH**

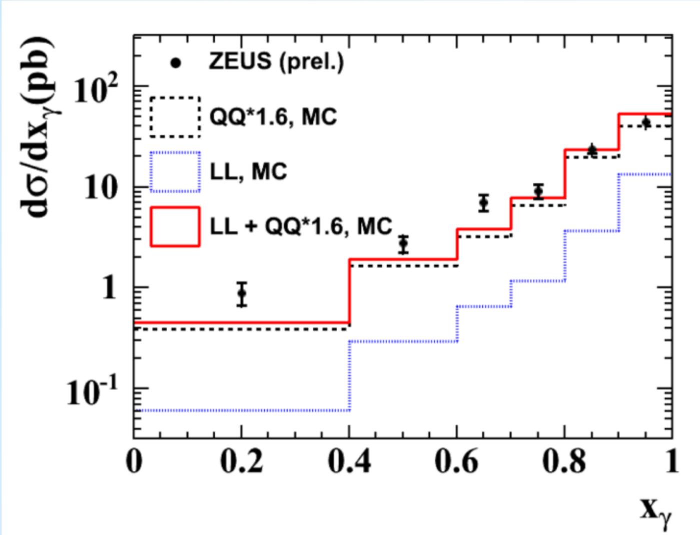
Theoretical calculations (BLZ):

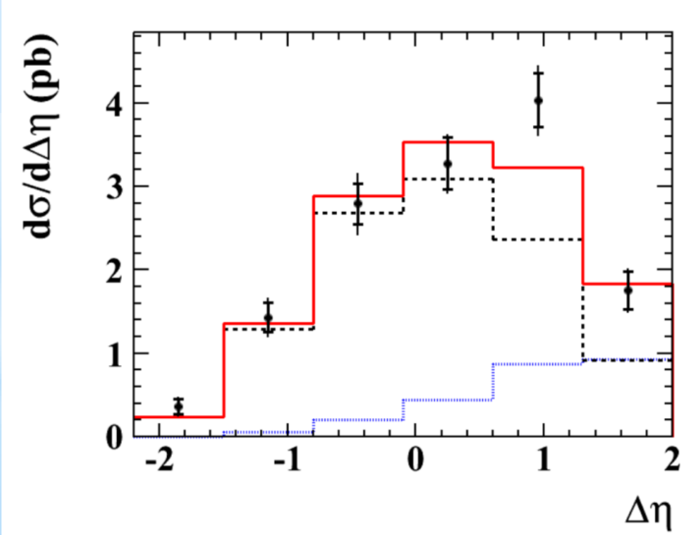
k_t - factorization QCD approach

Baranov, **L**ipatov and **Z**otov, Phys. Rev. D 81 (2010) 094034

Photon radiation from the quarks as well as from the lepton is taken into account

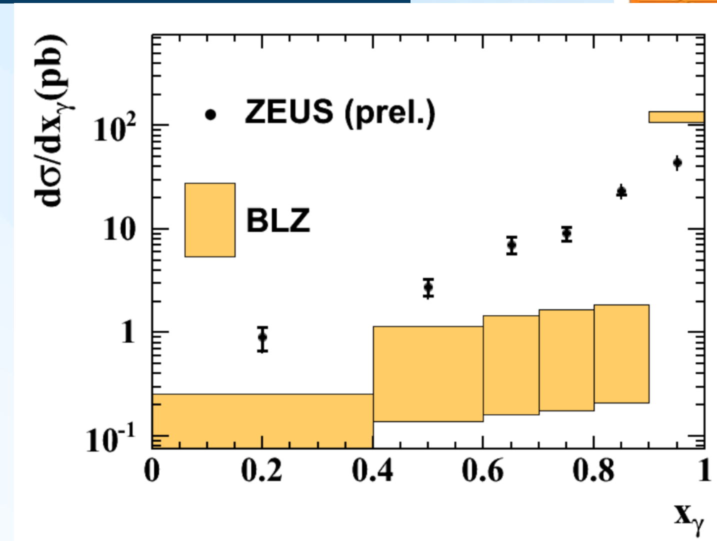
Cross sections compared to models

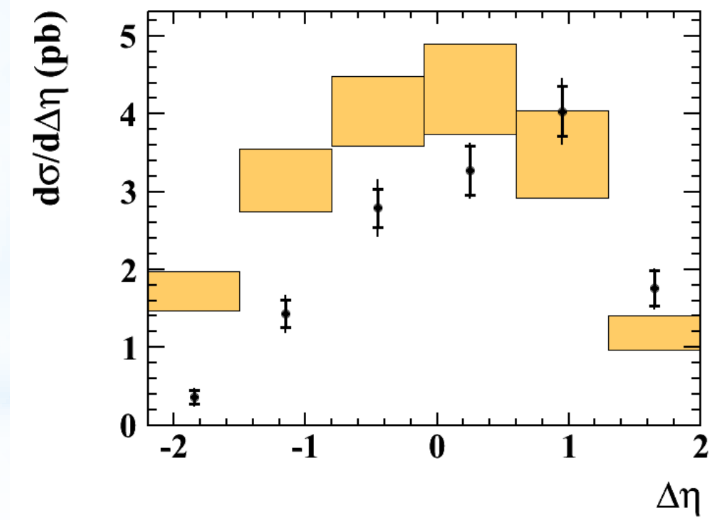




$$x_\gamma = \frac{\sum_{jet,\gamma}(E-p_z)}{2y_{JB}E_e}$$

$$\Delta\eta = \eta_{jet} - \eta_\gamma$$





Cross sections compared to
LL(DJANGOHH) + QQ(PYTHIA) ∗**1.6**
Shapes are fairly decribed

BLZ calculations describe shapes of data distributions not so well (mainly x_γ and $\Delta\eta$)

Conclusions

- New H1 measurement of **diffractive dijet** production in **DIS** → measurements described by NLO QCD predictions using H1 DPDF,value of $\alpha_s(M_Z)$ obtained from this measurement is in agreement with world average.

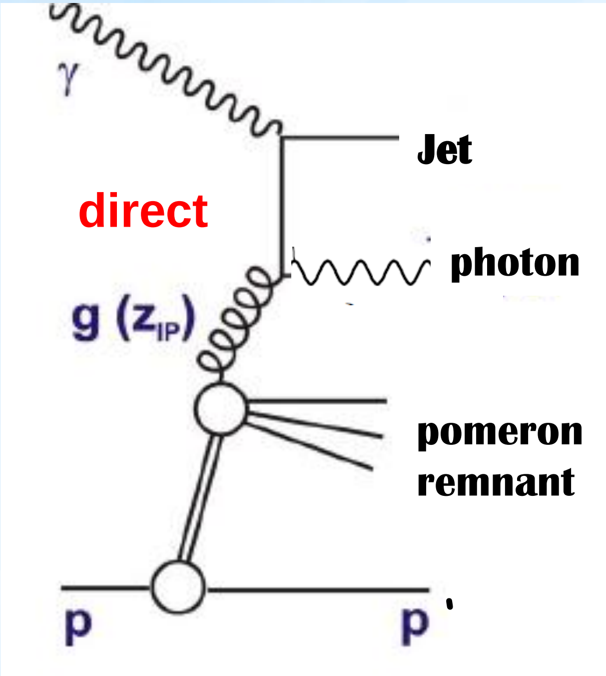
- New H1 measurement of **diffractive photoproduction & DIS dijets** using VFPS proton spectrometer →
  DIS dijets in agreement with NLO QCD prediction,
  suppression factor 0.5 ± 0.1 in photoproduction dijets observed,
  consistent with factorisation breaking!

- Recent H1 preliminary result on **D* production in DIS** supports the validity of collinear factorization

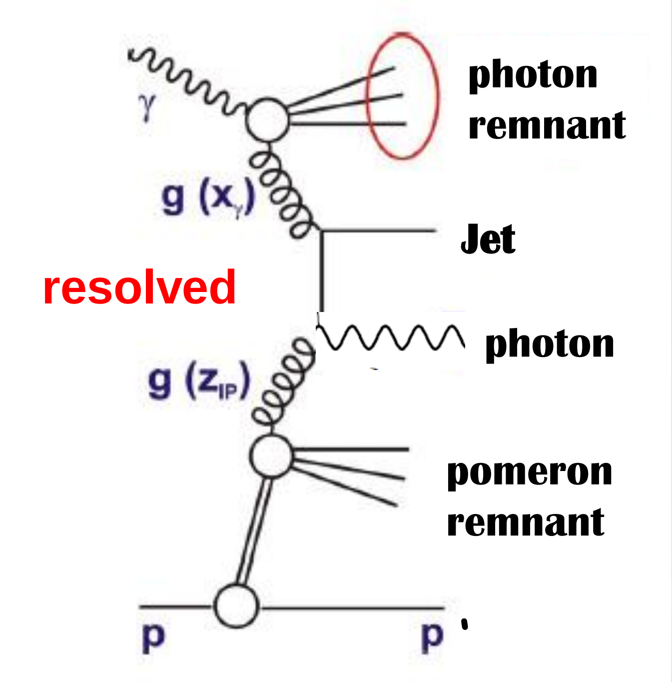
- **Prompt photons in DIS** measured by ZEUS. Predictions for the sum of the expected LL contributions (DJANGOH) and QQ contributions (PYTHIA) rescaled by factor 1.6 → good description of the shapes of the kinematic variables.
  The calculations of BLZ describe the data not so well.

Backup

Diffractive prompt (isolated) photons



LO



HERA II ($374 pb^{-1}$) and I data ($91 pb^{-1}$, used for normalization), untagged photoproduction

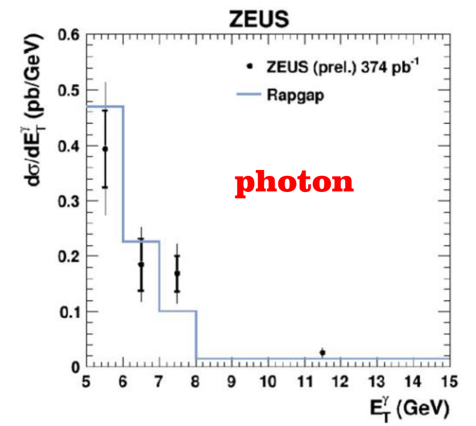
Diffractive selection – LRG, $\eta_{max} < 2.5$ $x_{IP} < 0.03$

Photons: $E_T^\gamma > 5$ GeV, $-0.7 < \eta^\gamma < 0.9$

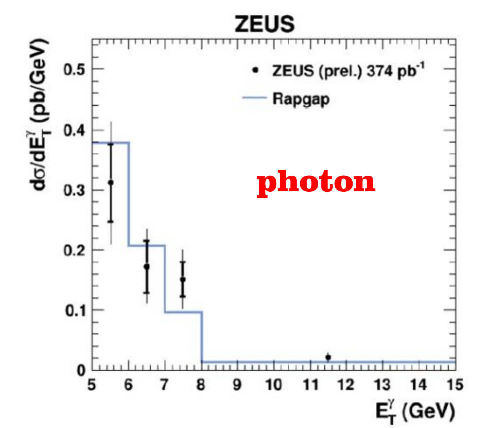
Jets: use k_T-cluster algorithm, $-1.5 < \eta^{jet} < 1.8$, $E_T^{jet} > 4$ GeV.

Signal MC = RAPGAP with H1 fitB DPDF and γ-PDF SASG 1D LO

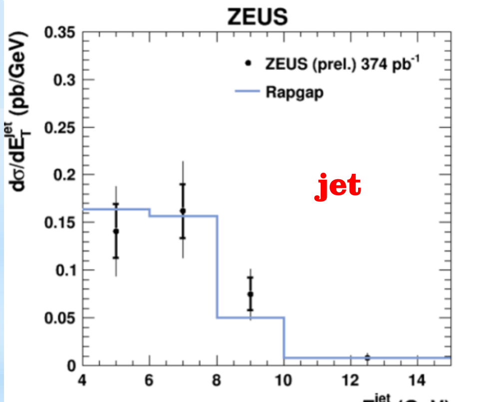
Diffractive production of prompt (isolated) photons



Inclusive photon

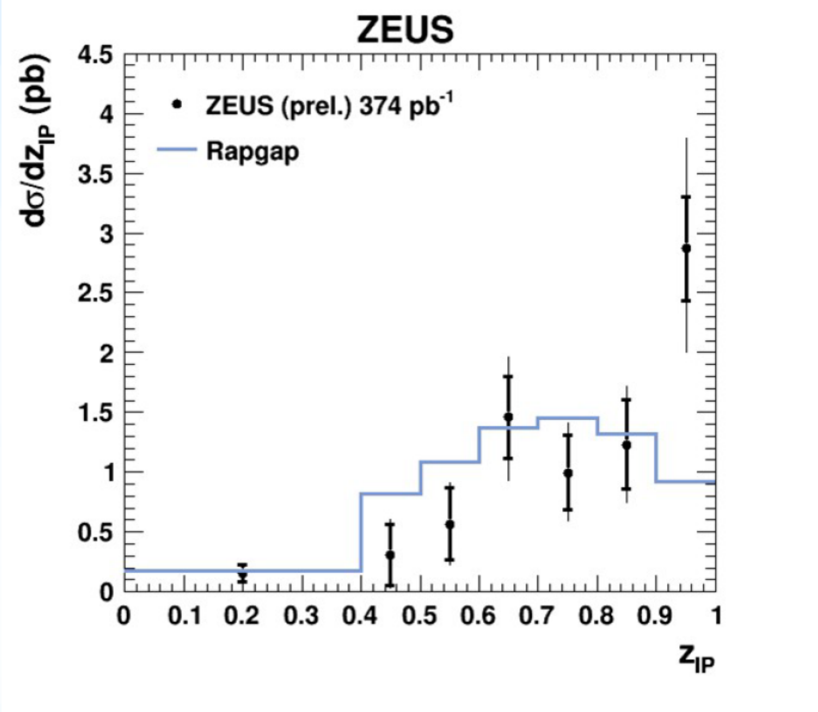


Photon + jet



Photon + jet

Fair description by RAPGAP within uncertainties



A peak at z_{IP} close to 1 is not described by RAPGAP. Note, that H1 fit B not fitted in this region, it is only exptrapolated. Region z_{IP} ~ 1, no activity except jet and γ.

Preliminary – in future planed comparison with NLO calculations – first test of QCD factorisation using this process