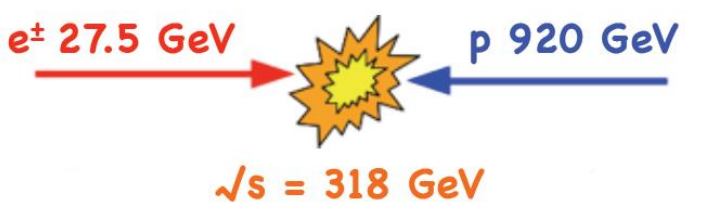
Diffractive and forward physics results from HERA

Alice Valkárová
Charles University, Prague

on behalf of H1 and ZEUS Collaborations

HERA collider experiments

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



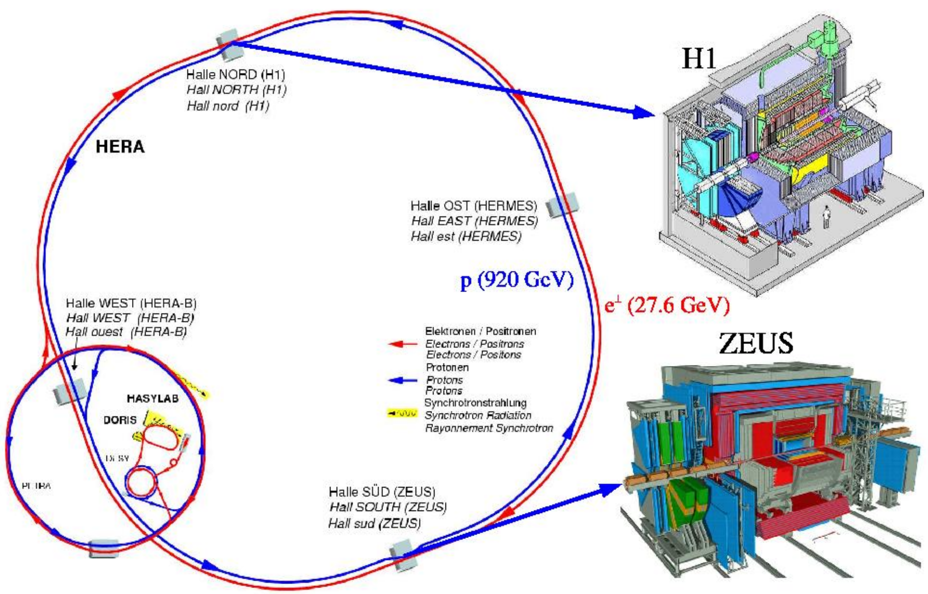
Diffraction

New era started with HERA:

H1: 31 publications about diffraction

ZEUS: 31 publications about diffraction

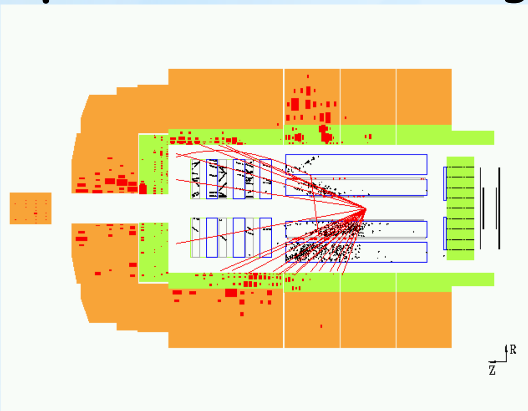
+ one common H1/ZEUS publication



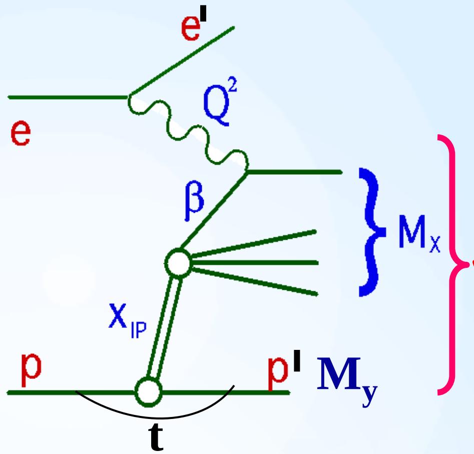
At HERA 10% of events are diffractive

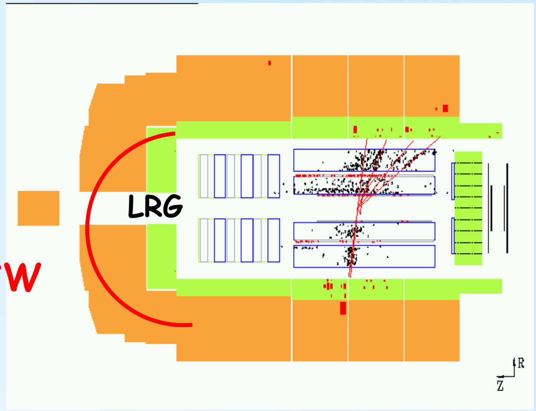
Diffractive kinematics

Deep inelastic scattering - DIS



Diffractive scattering





- Q^2- virtuality of the photon
- Q^2~0 GeV^2→ photoproduction
- Q^2>>0 GeV^2→ DIS
- W – total hadronic energy

- 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

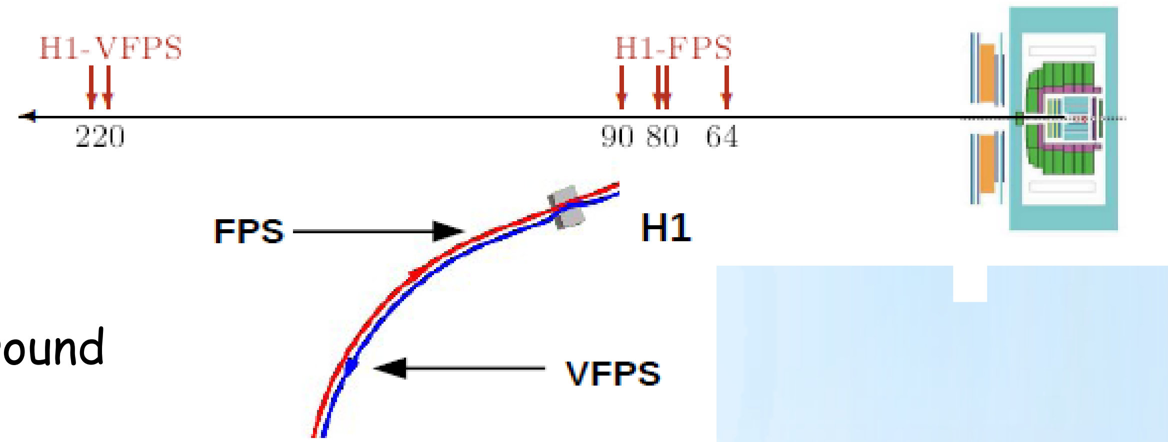
M_y > m_p proton dissociates,contribution should be understood

Methods of diffraction selection

Proton spectrometers

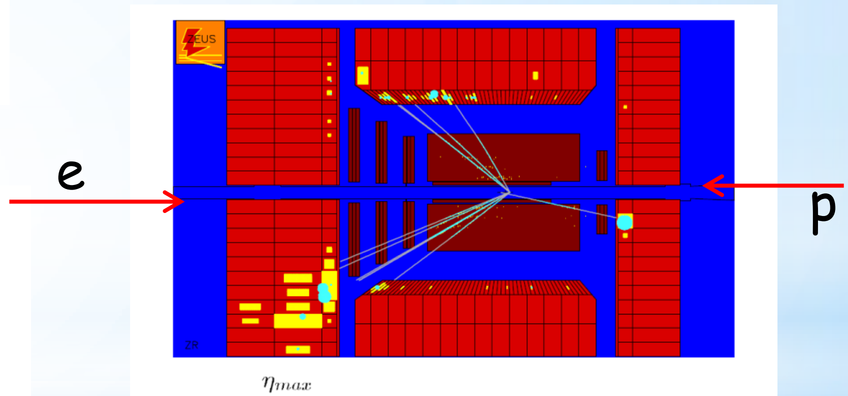
H1: VFPS (2005-2007)
FPS (1997-2007)
ZEUS: LPS (1997-2000)

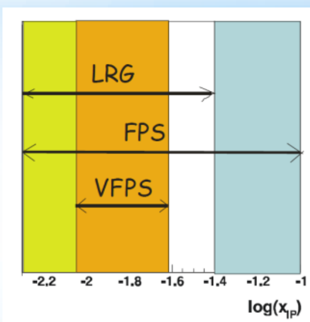
☺ free of p-dissociation background
☺ x_{IP} and t measurements
☺ access to high x_{IP} range (IP and IR)
☹ small acceptance, small statistics



Large Rapidity Gap

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

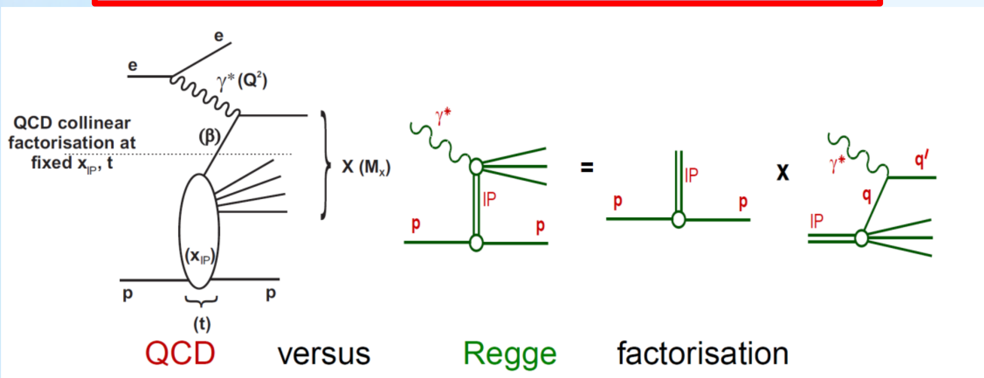




Different phase space and systematics – non-trivial to compare!

Modelling of diffraction

QCD collinear factorisation theorem



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

DPDFs – obey DGLAP universal for diff. ep DIS

hard scattering cross section

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

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

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

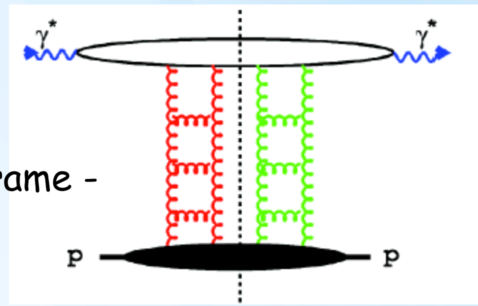
Pomeron flux factor

diffractive DPDF

Then DPDFs extracted from DIS data

Dipole model

Proton rest frame - dipoles



[C. Marquet PRD76 (2007) 094017]

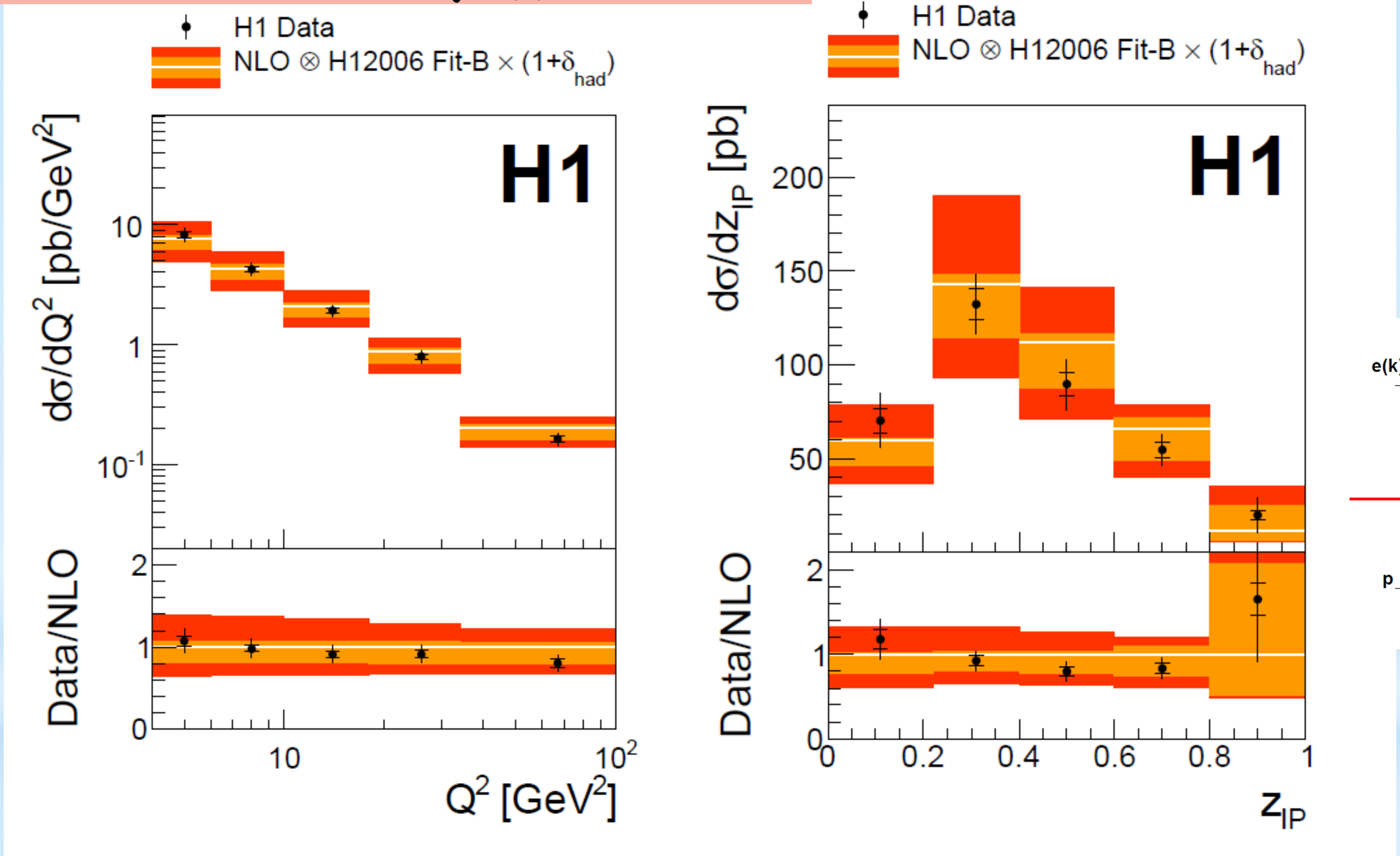
$$d\sigma^{\gamma^* p}_{diff}/dt \propto \int dz dr^2 \Psi^* \sigma^2_{q\bar{q}}(x, r^2, t) \Psi$$

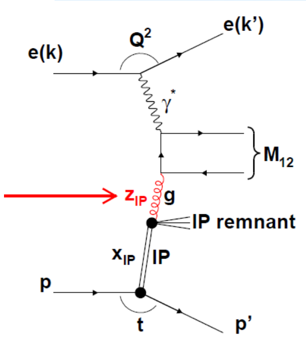
Long living quark pairs interact with gluons of the proton

No extra parameters needed for DDIS

Most recent -diffractive dijet production in DIS

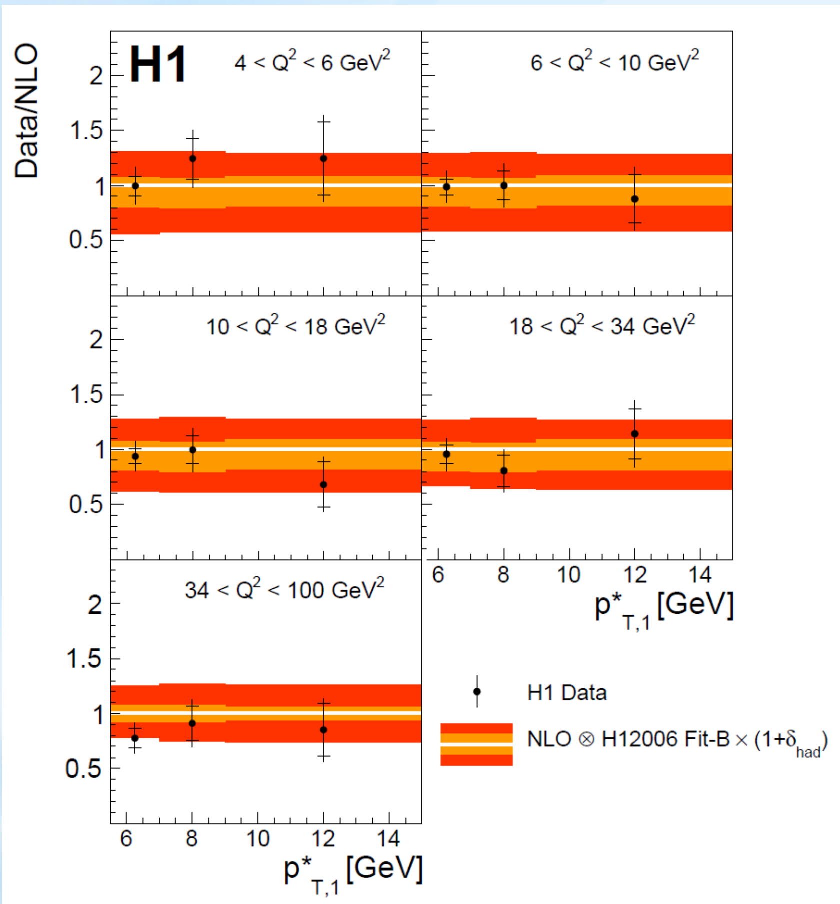
4 < Q^2 < 100 GeV^2, $E_T^*{}_{jet1(2)}$>5.5(4) GeV

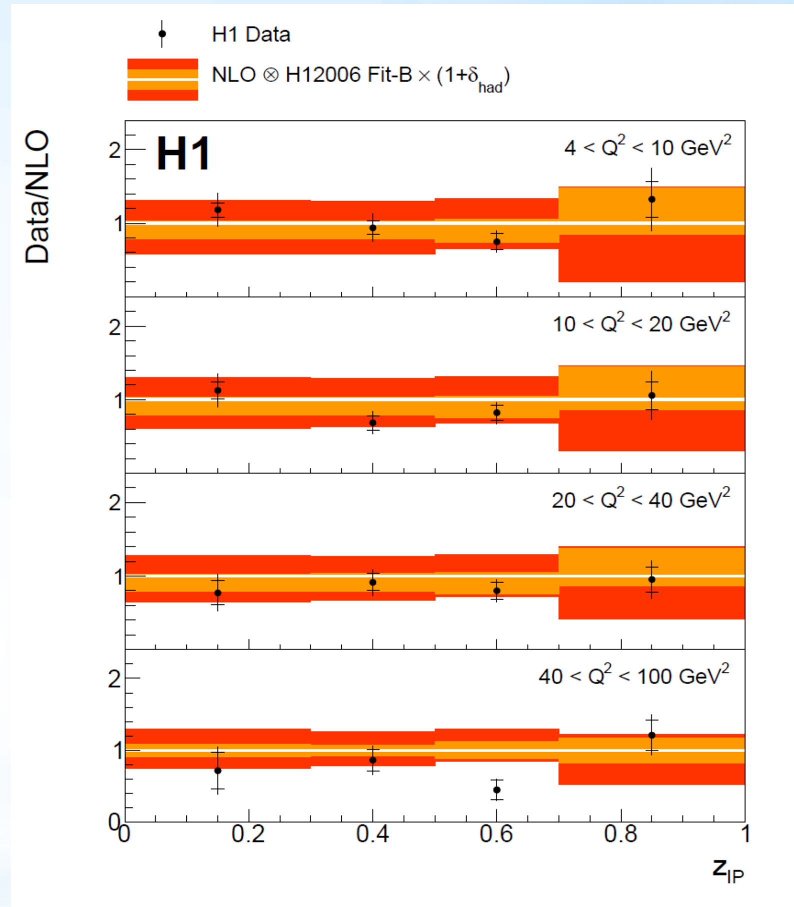




Measurements in agreement with NLO QCD calculations, factorisation confirmed.

Most recent -diffractive dijet production in DIS



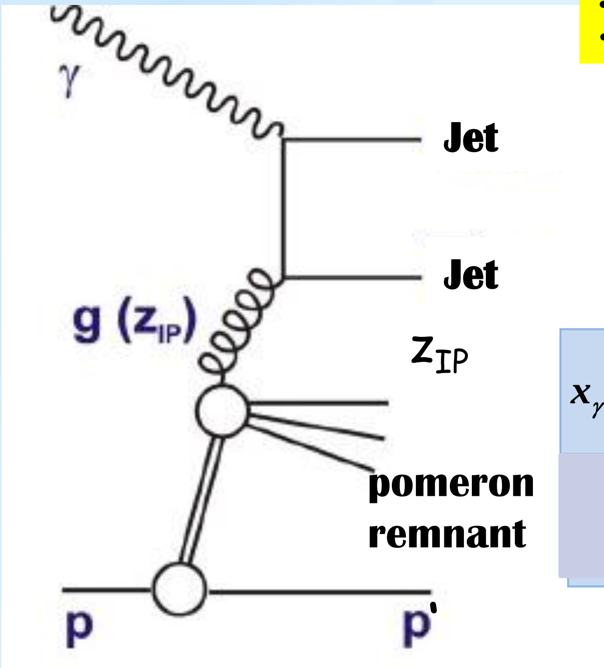


$$\alpha_s(M_Z) = 0.119 \pm 0.004\,(\mathrm{exp}) \pm 0.012\,(\mathrm{DPDF, theo})$$

Result is consistent within uncertanties with the world average

Factorisation tests in diffractive dijet photoproduction

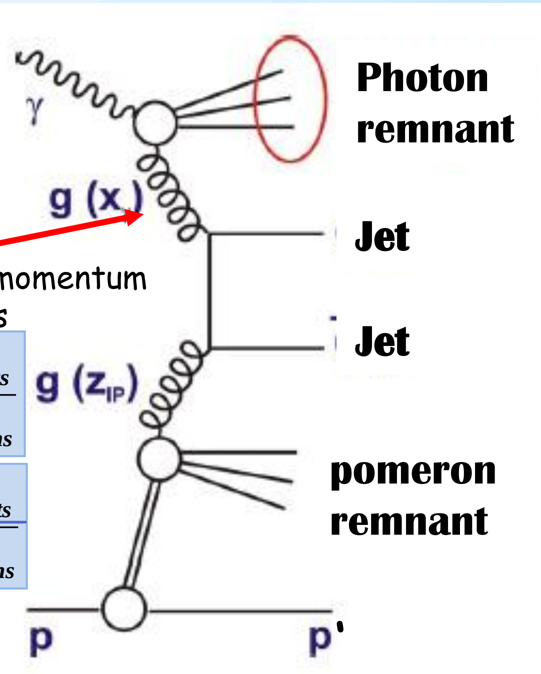
In LO QCD!



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 -> $x_\gamma = 1$

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))

no suppression

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

Factorisation tests in diffractive photoproduction

Not evident that factorisation should be valid also for **photoproduction**, in LO photoproduction contributions of resolved photon process

suppression factor

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

History -three independent measurements

- **H1** – LRG method, tagged photoproduction, $E_T^{jet1(2)} > 5(4)$ GeV,
  $S^2 = 0.5 \pm 0.1$
  EPJC C51 (2007),549

- **H1** – LRG method, tagged photoproduction , $E_T^{jet1(2)} > 5(4)$ GeV,
  $S^2 = 0.58 \pm 0.01 \pm 0.12(\text{exp}) \pm 0.14 \pm 0.09(\text{th})$
  EPJ C70 (2010),15

- **ZEUS** – LRG method, untagged photoproduction $E_T^{jet1(2)} > 7.5(6.5)$ GeV
  $S^2 \sim 1$
  Nucl.Phys. B381 (2010)

A new H1 measurement with different diffractive method selection – proton measured in forward proton spectrometer VFPS

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:

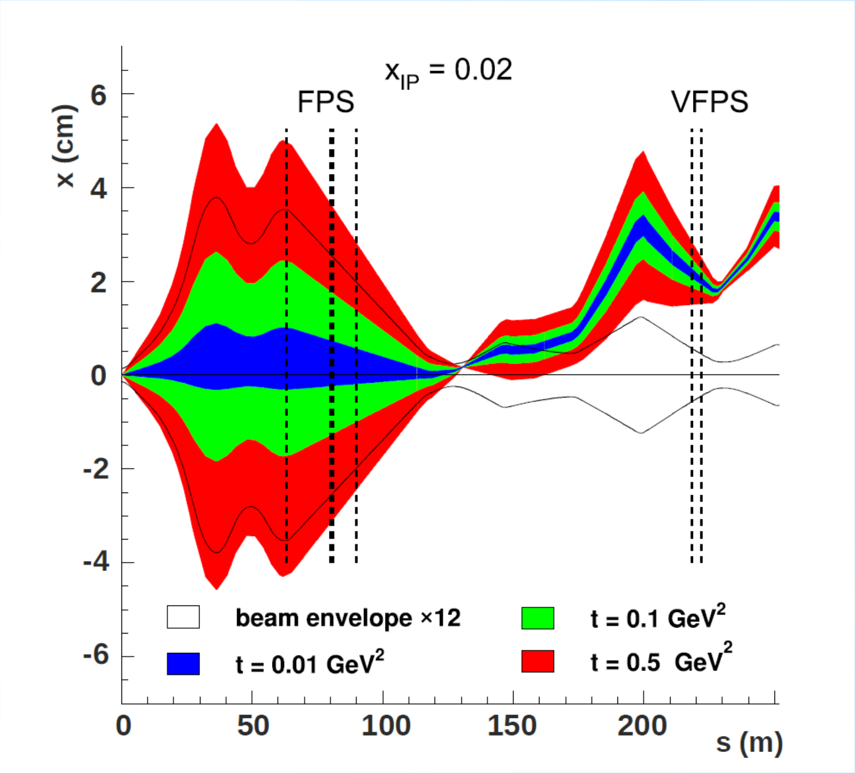
$0.01 < x_{IP} < 0.024$

$|t| < 0.6$ GeV^2

$z_{IP} < 0.8$

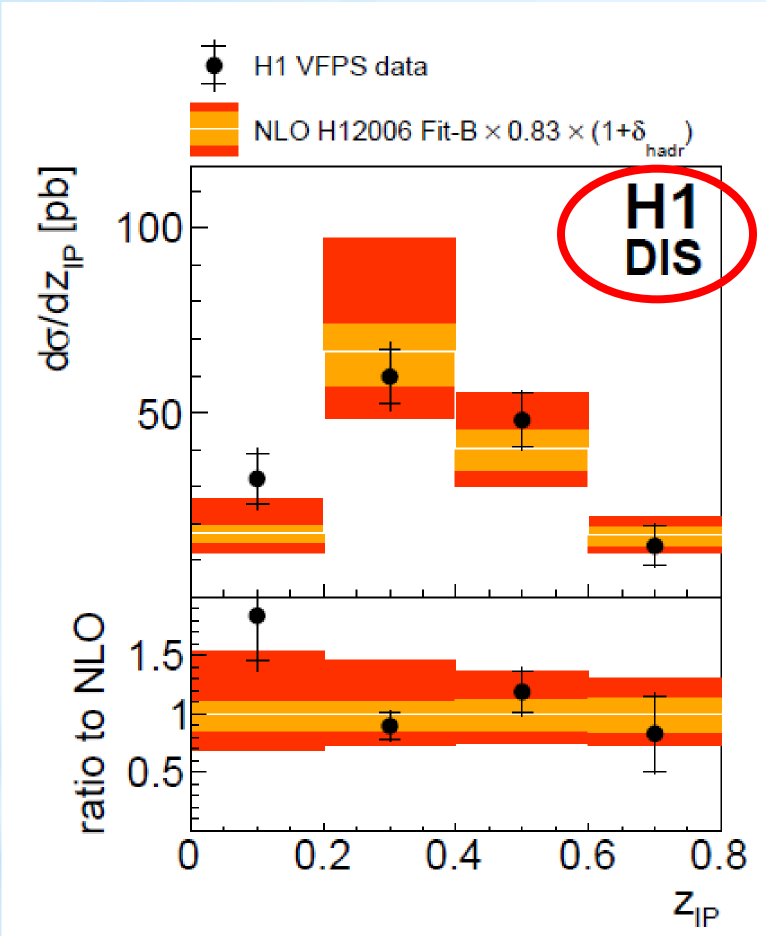
$E_T^*{}_{jet1(2)} > 5.5(4)$ GeV

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

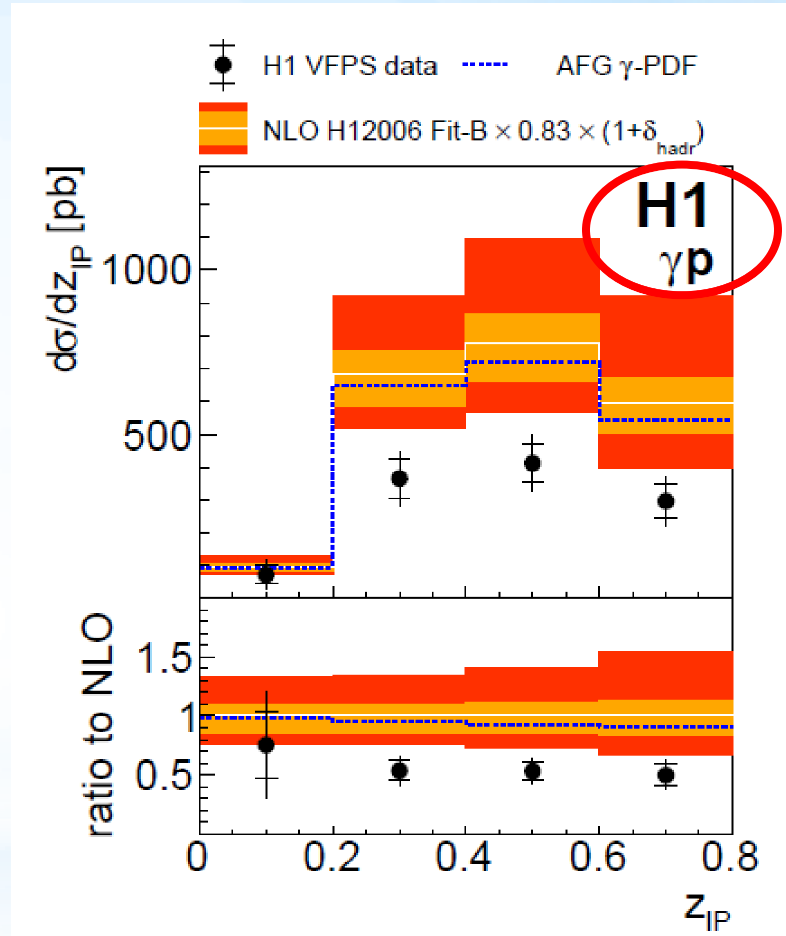


Independent cross-check of LRG measurements – without proton dissociation!

Diffractive dijet photoproduction & DIS

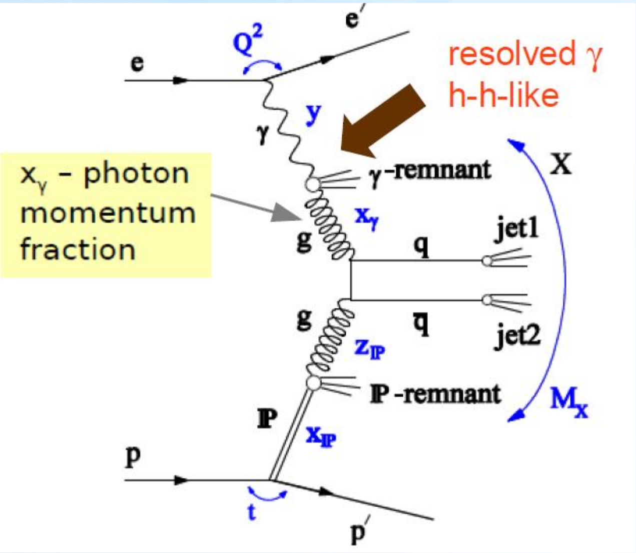


Data in agreement with NLO in DIS, within uncertainites



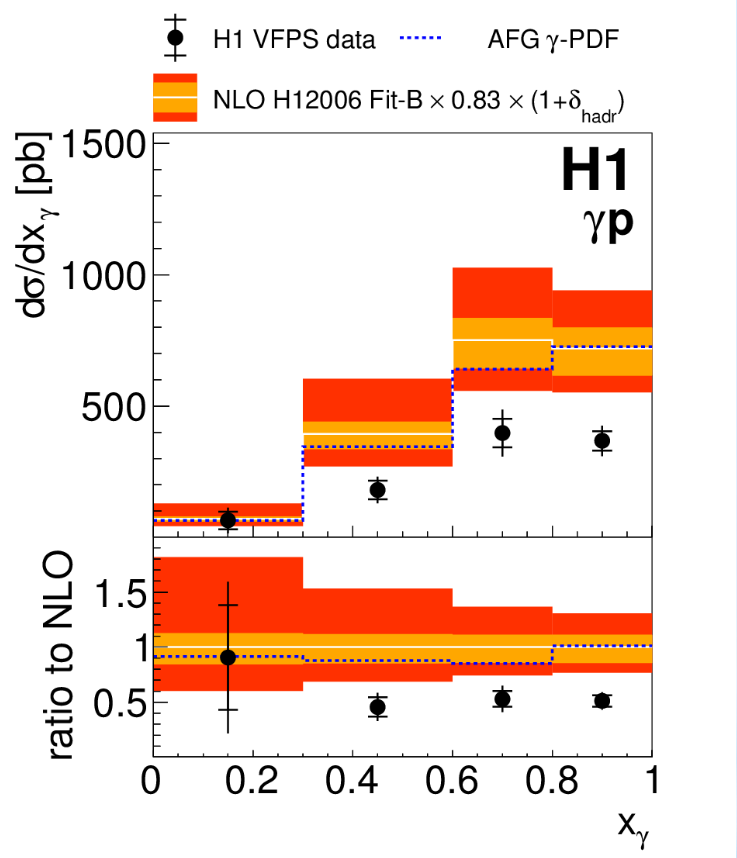
Data suppressed in comparison with NLO in photoproduction

Diffractive dijet photoproduction



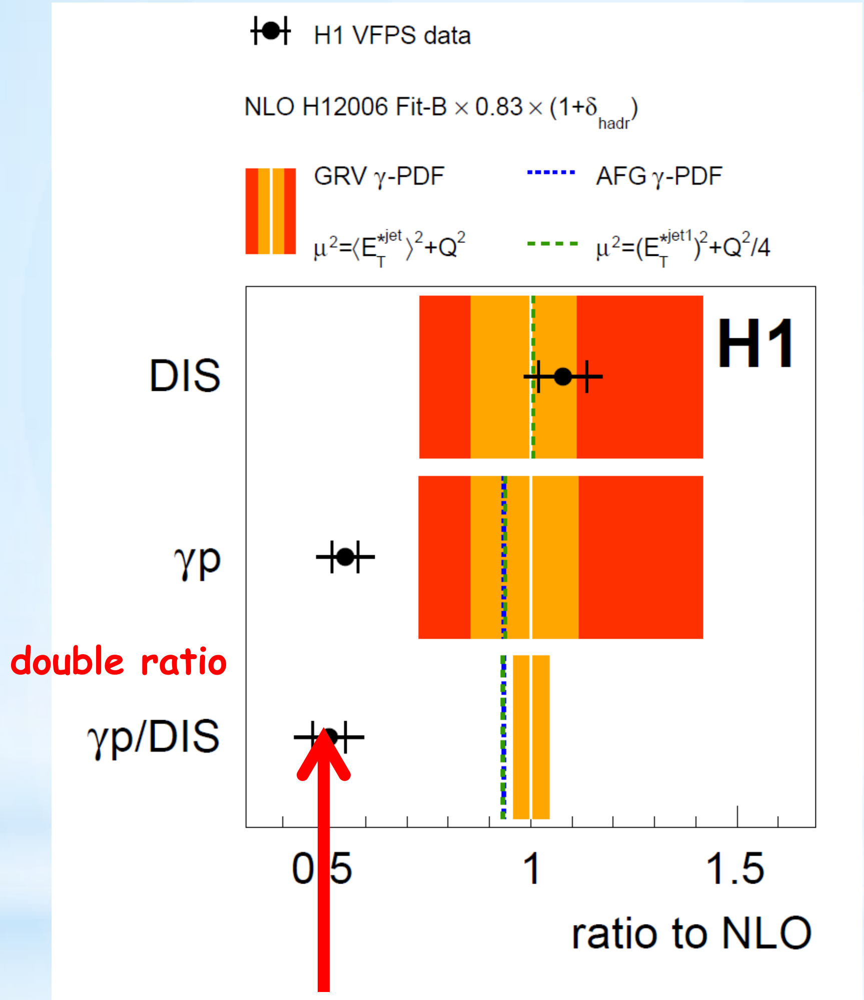
x_γ - photon momentum fraction

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



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

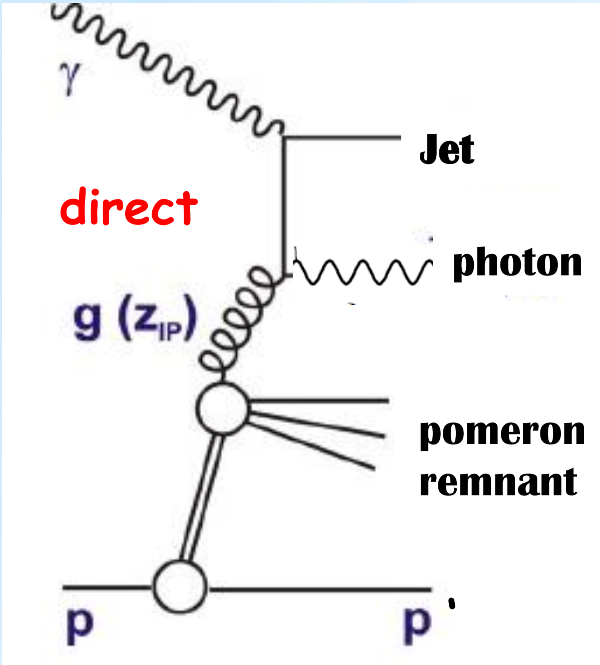
Diffractive dijet photoproduction & DIS



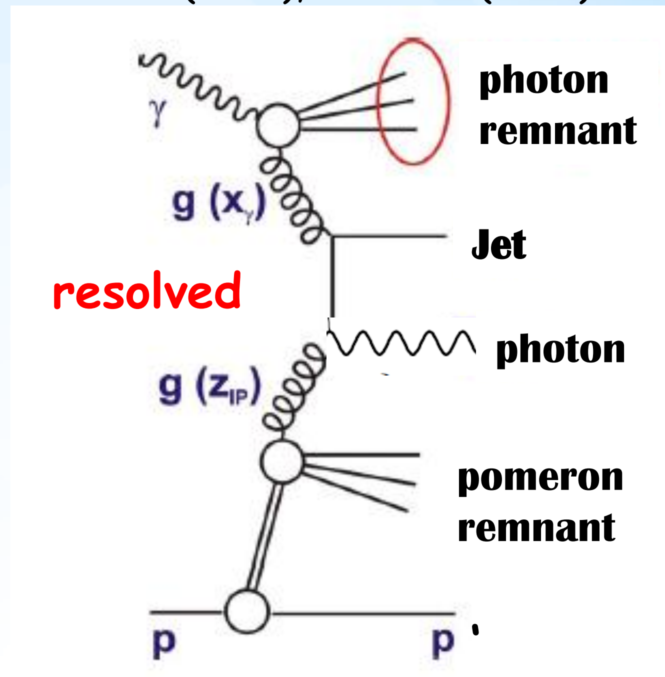
Previous H1 measurements confirmed, factorisation breaking in diffractive dijet photoproduction by factor ~ 0.5 observed

New - diffractive prompt (isolated) photons

Previous ZEUS inclusive mesurements: Phys.Lett.730(2014), JHEP 08 (2014) 03



LO



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

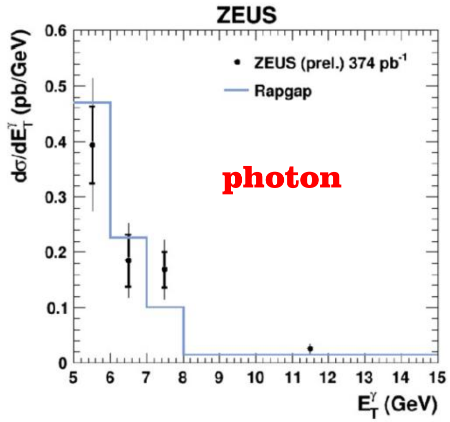
Diffractive selection – LRG, $\eta_{max} < 2.5$ $x_{IP} < 0.03$

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

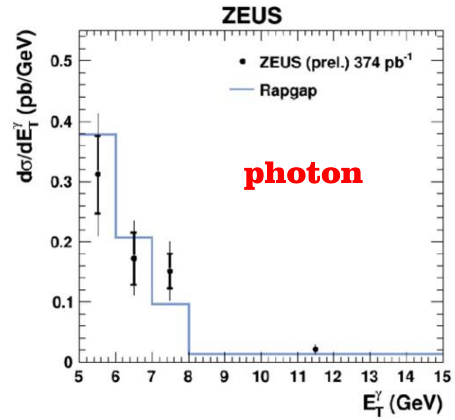
Jets: use k_T-cluster algorithm, $-1.5 < \eta^{jet} < 1.8$, $E_T^{jet} > 4$ GeV.

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

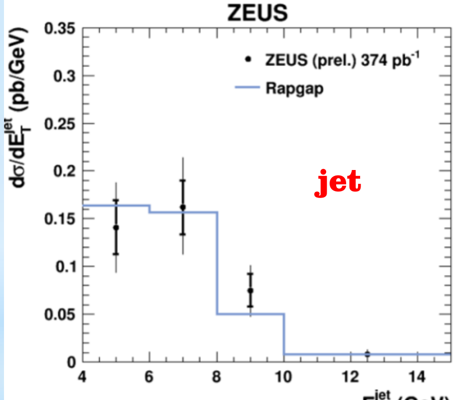
Diffractive production of prompt (isolated) photons



Inclusive photon

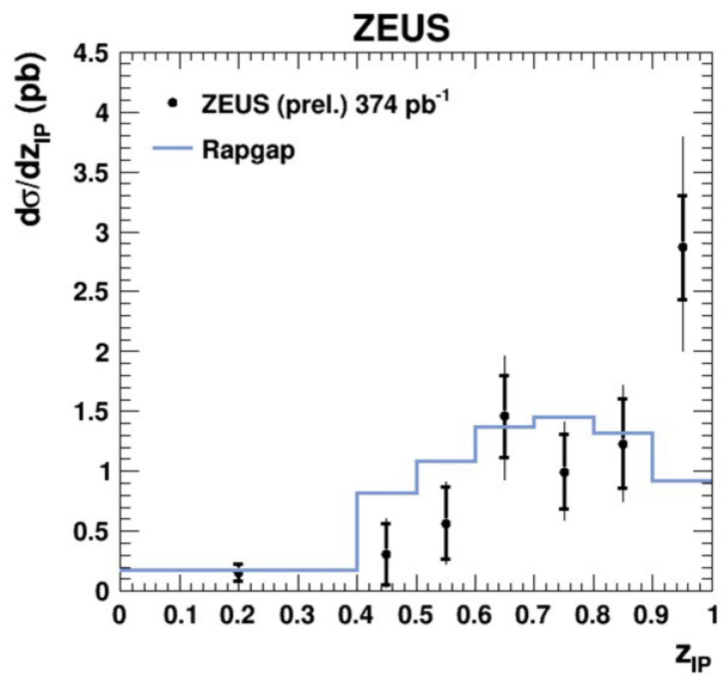


Photon + jet



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.

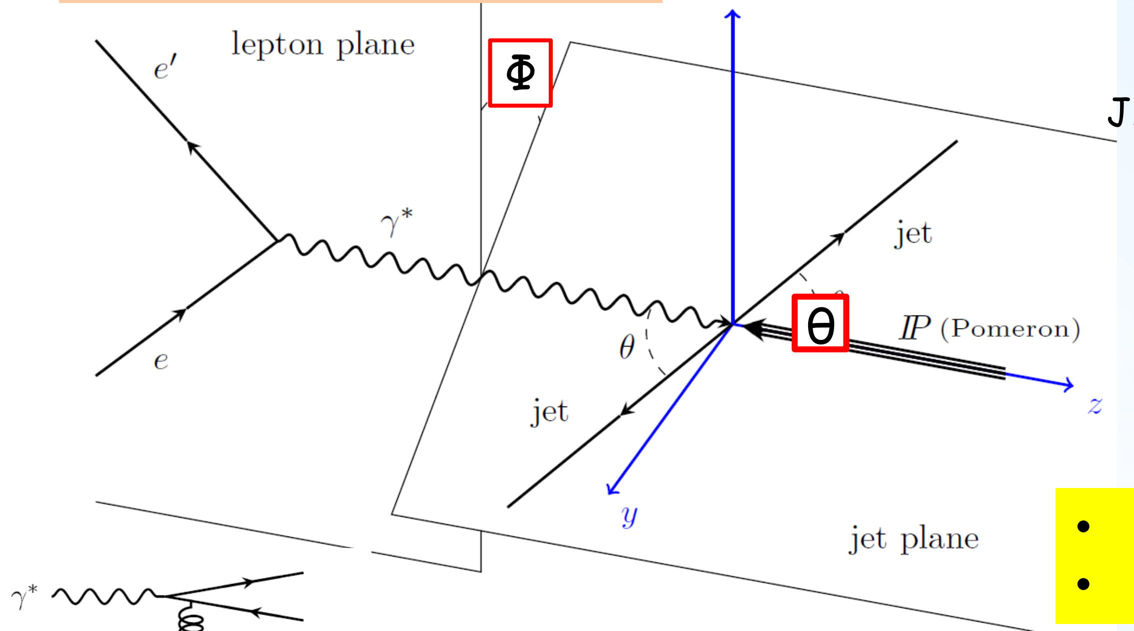
Preliminary – in future planed comparison with NLO calculations – first test of QCD factorisation using this process

New - exclusive dijets in diffractive DIS

How to distinguish between diffractive models???

e + p → e' + p' + jet + jet

DESY-15-070 (2015),sent to EPJC

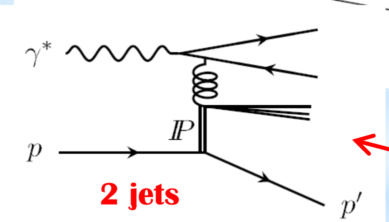


J.Bartels et al.,Phys.Lett.B386,(1996)389

Φ – angle between lepton and jet planes
Θ – polar angle of jet

$$d\sigma/d\phi \propto 1 + A\cos(2\phi)$$

- Two gluon exchange – negative A
- Boson-Gluon fusion - positive A

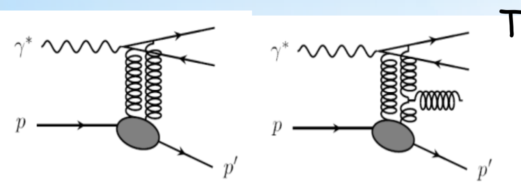


2 jets

BGF –Resolved-Pomeron model (Ingelman,Schlein et al.)

Two-Gluon-Exchange model (Bartels,Jung et al.)

RAPGAP

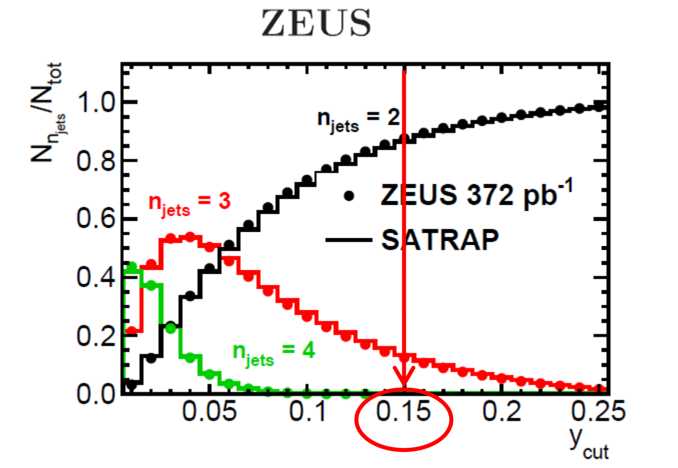


2 jets 3 jets

Exclusive dijets in diffractive DIS

e + p → e' + p' + jet + jet   only dijet, electron and proton in the final state

Durham jet algorithm in γ*IP rest frame in exclusive mode – all objects in jets



Y_{cut}=0.15

Hadron cross sections unfolded as a function of β and Φ

- $Q^2 > 25$ GeV^2
- $90 < W < 250$ GeV
- $x_{IP} < 0.01$
- $M_X > 5$ GeV
- $N_{jets} = 2$ (with $y_{cut} = 0.15$)
- $p_{T,jet} > 2$ GeV.

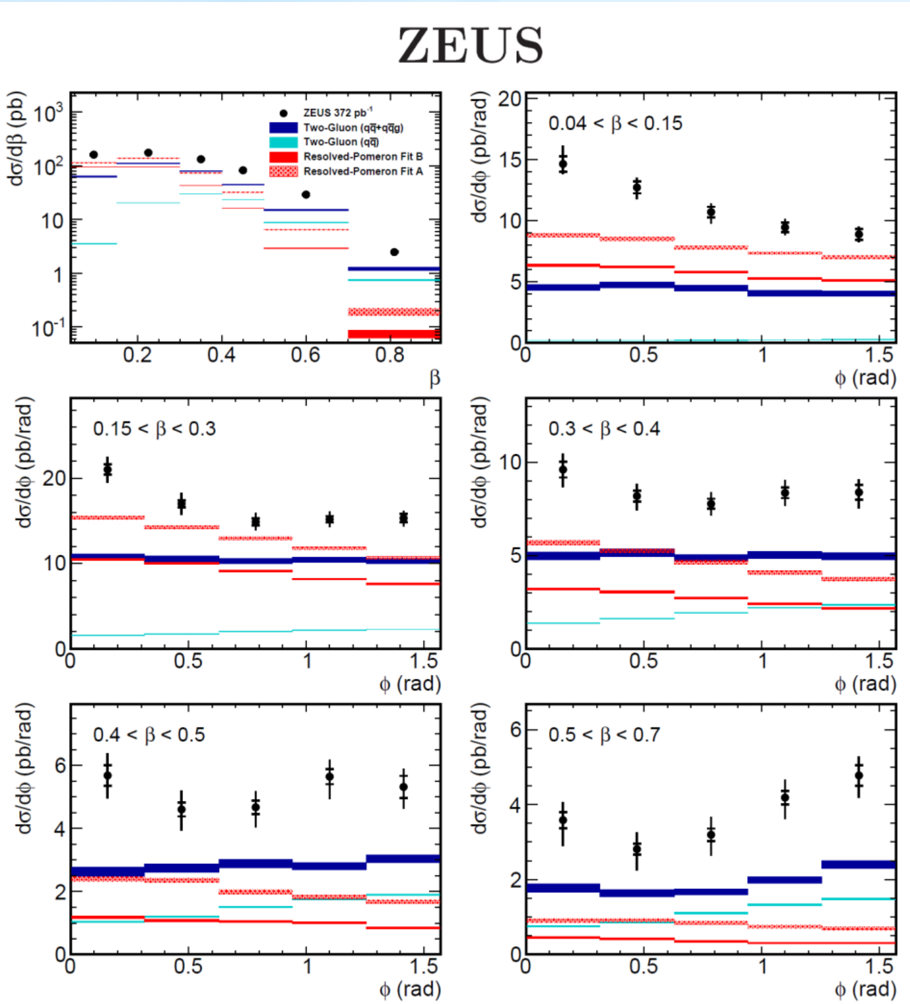
Proton dissociation background

$$f_{\rm pdiss} = 45\% \pm 4\%({\rm stat.}) \pm 15\%({\rm syst.})$$

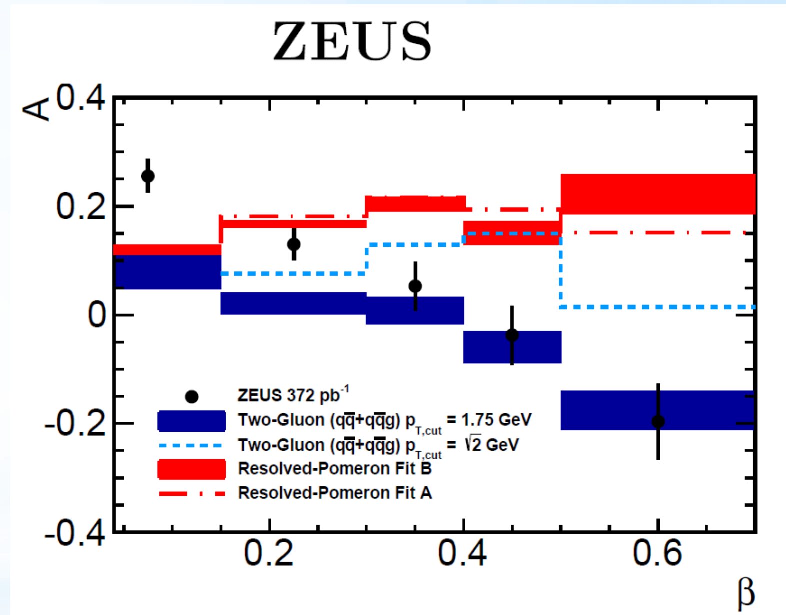
Measured cross sections reweighted by

$$(1 - f_{\rm pdiss}) = 0.55$$

Exclusive dijets in diffractive DIS



The measured and predicted cross sections do not agree by factor about 2.
NLO corrections large???



The Two Gluon model is more successful in describing of data (region β > 0.3) than Resolved Pomeron model (large uncertainty due to p-diss subtraction, is not shown here)

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!

- New ZEUS measurement of prompt inclusive photons and photons with a jet in diffractive photoproduction. Shapes of diff.cross sections agree with RAPGAP except of z_{IP}.
- New ZEUS measurement of exclusive dijets in DIS diffraction, MC cross section significantly larger than predicted by models, Two-Gluon-Exchange model predicts reasonably well the measured value of A as a function of β for β>0.3.