Hard probes in diffractive DIS at HERA

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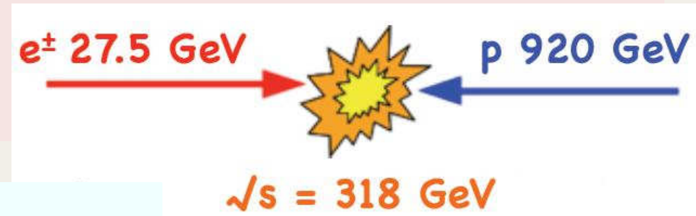
on behalf of H1 and ZEUS Collaborations

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

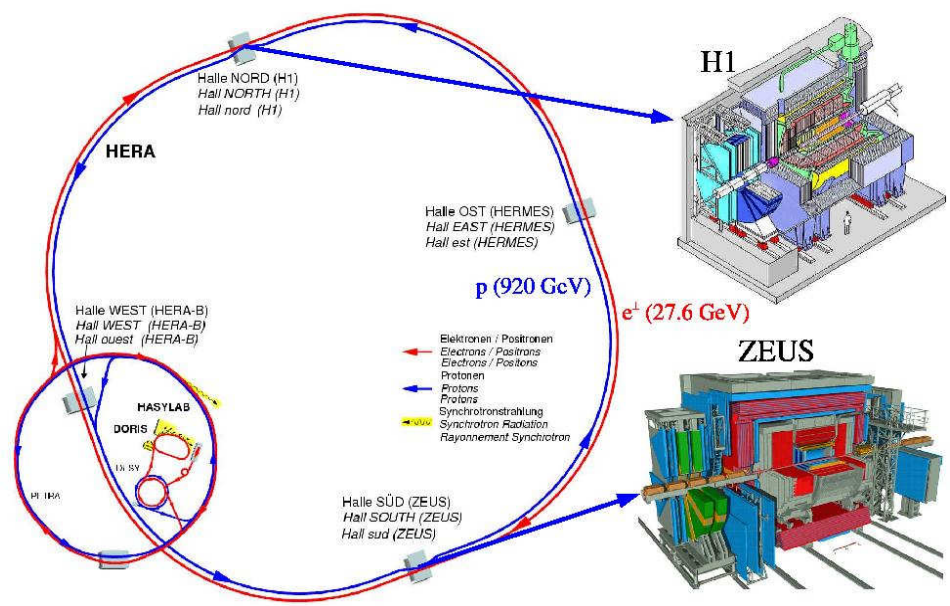


Why to study diffraction?

Fundamental aim:
understand high energy limit of QCD

Novelty:
probe partonic structure of diffractive exchange

Applications: study factorisation properties, transport PDFs to pp scattering (Tevatron, LHC).

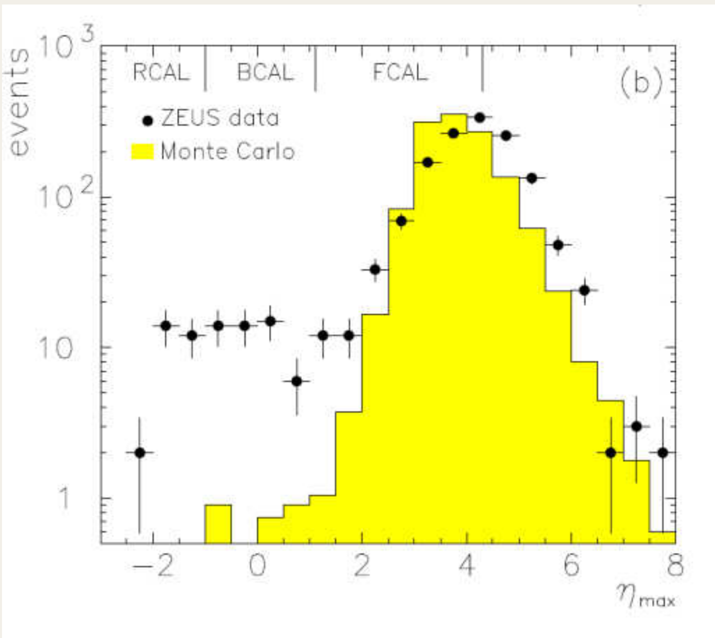


Historical reminder

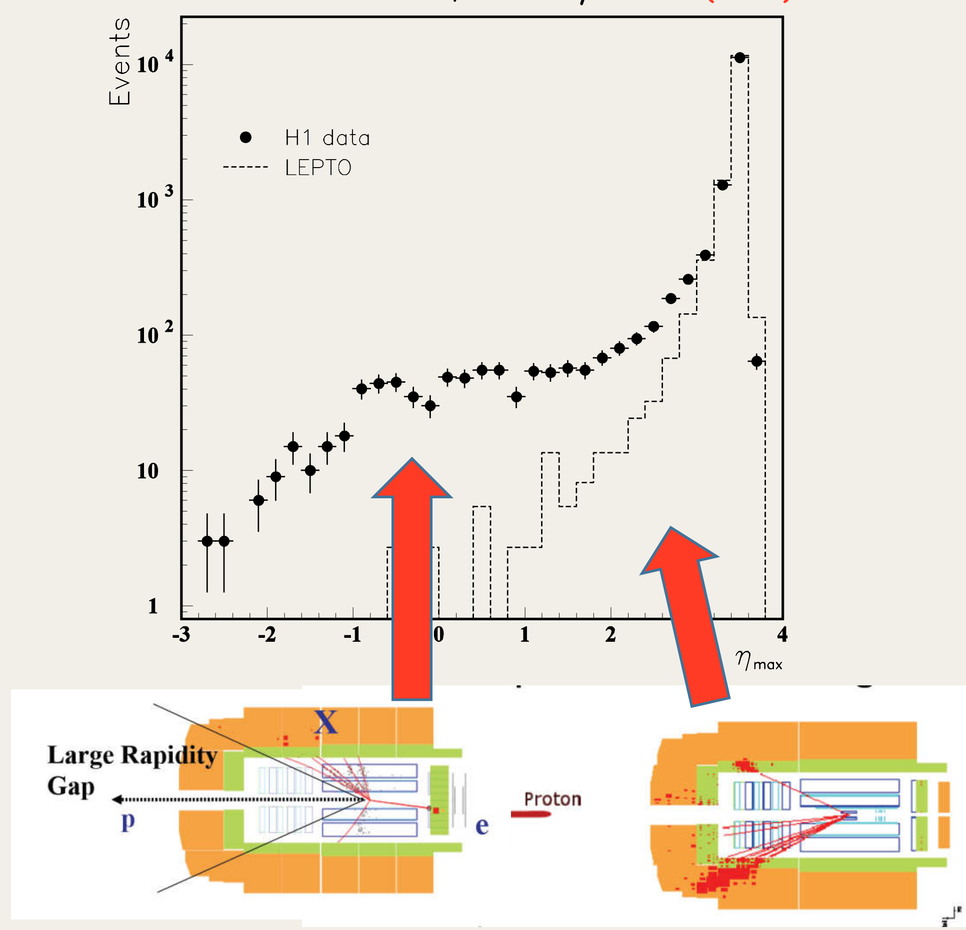
- **21 years** after the observation of diffractive DIS events at HERA!
- HERA opened **new era of diffraction studies**

1993-1994

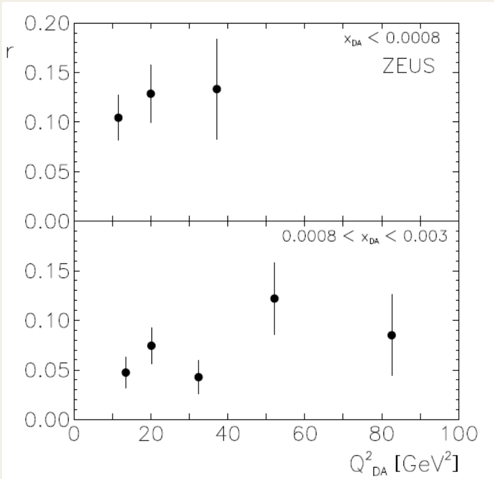
ZEUS Collab.,Physics Letters B 315 (1993) 481-493



H1 Collab., Nucl. Phys. B429 (1994) 477

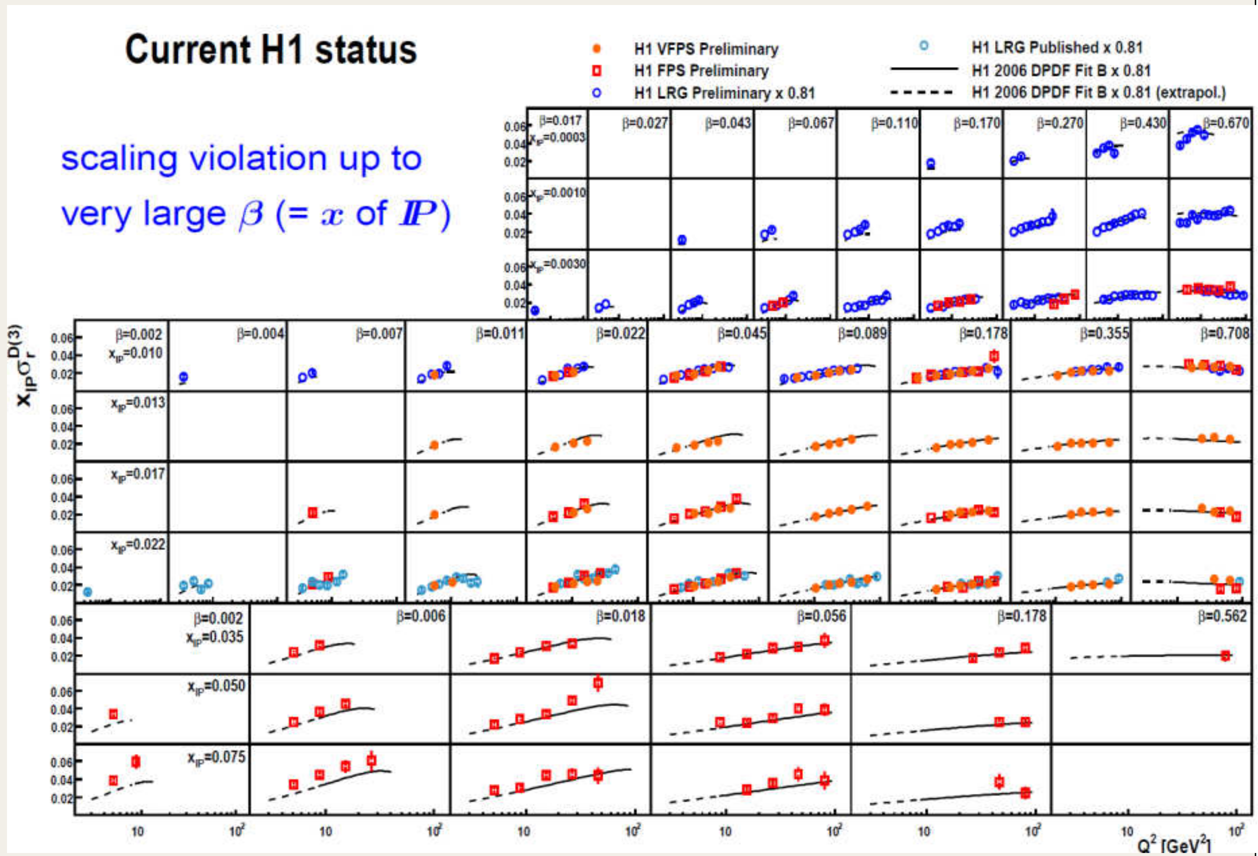


Historical reminder



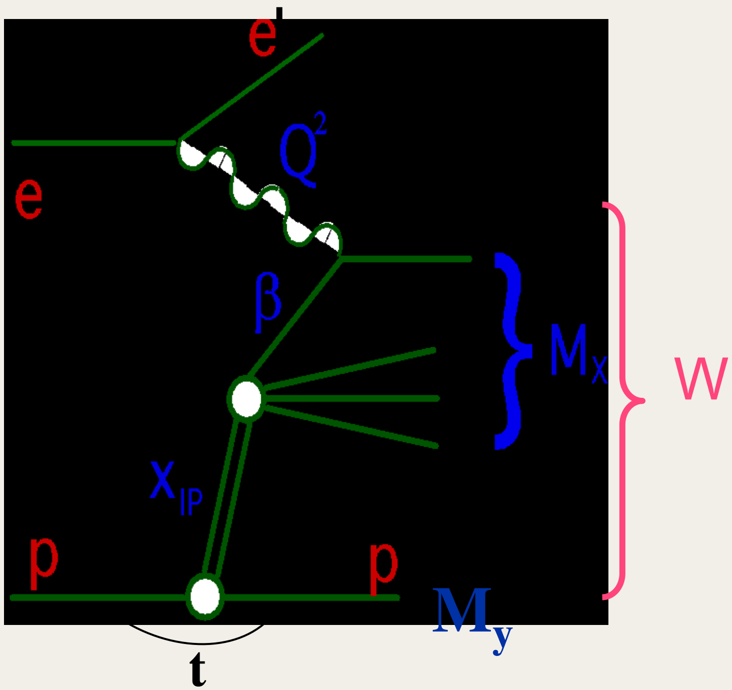
ZEUS Collab.,Physics Letters B 315 (1993) 481-493

1993



2014

Diffractive kinematics



$Q^2 \sim 0$ GeV$^2 \rightarrow$ photoproduction
$Q^2 \gg 0$ GeV$^2 \rightarrow$ deep inelastic scattering (DIS)

HERA: ~10% of events diffractive

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

momentum fraction of color singlet exchange

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

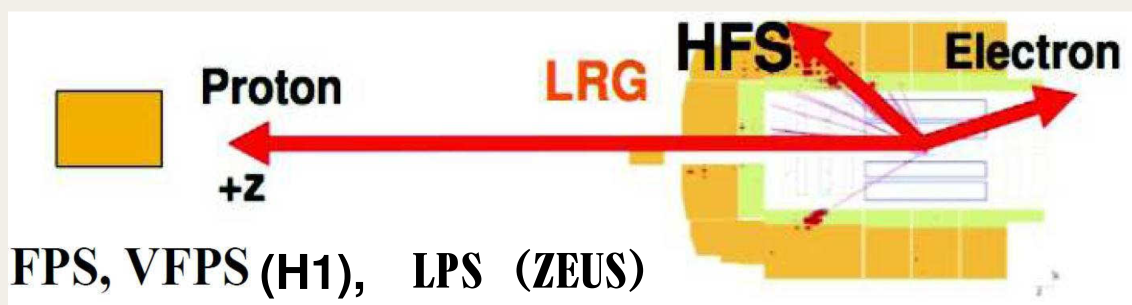
fraction of exchange momentum, coupling to γ

$t = (p - p')^2$ ⟶ 4-momentum transfer squared

$M_y = m_p$ proton stays intact, needs detector setup to detect protons
$M_y > m_p$ proton dissociates, contribution should be understood

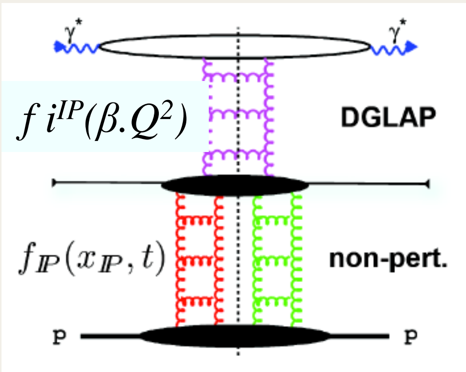
Experimental methods:

- selecting LRG events
- measuring p in Roman pots (60-220m from Int.Point)



Modelling of diffraction

QCD collinear factorisation theorem



Infinite momentum frame - partons

[H1 Coll. EPJC28 (2006) 715]

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

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

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

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

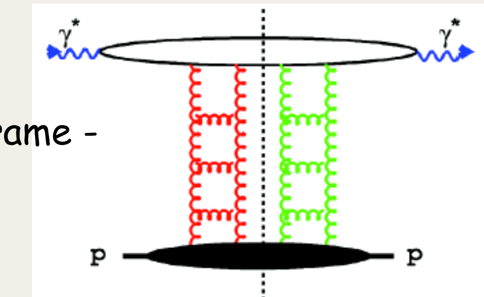
Pomeron flux factor

diffractive DPDF

DPDFs extracted from DIS data

Dipole model

Proton rest frame - dipoles

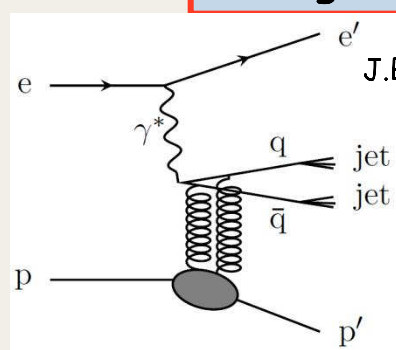


[C. Marquet PRD76 (2007) 094017]

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

Long living quark pairs interact with gluons of the proton

Two gluon exchange model



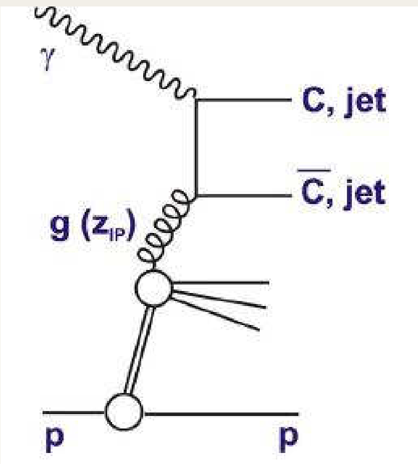
J.Bartels et al.,Phys.Lett.B386,(1996)389

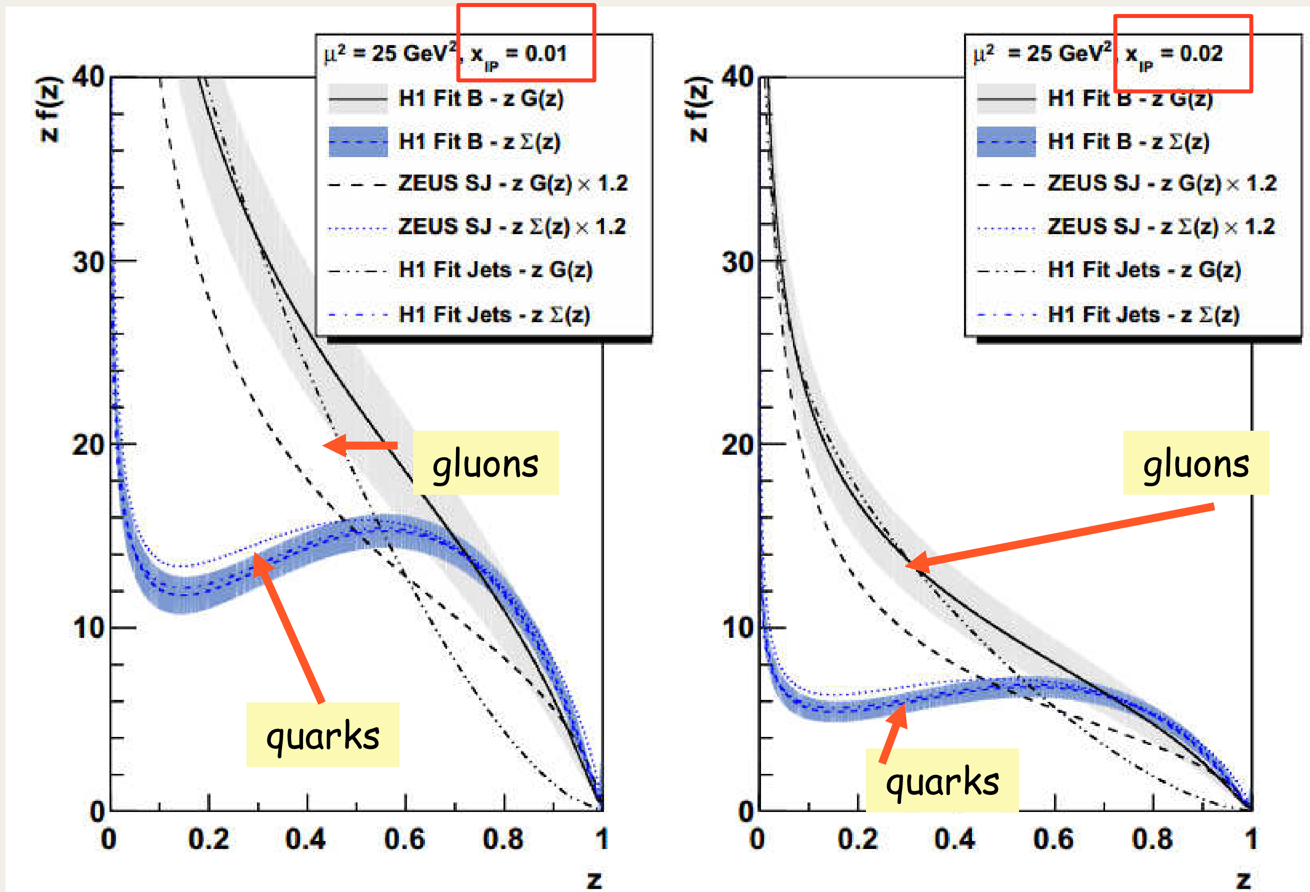
No extra parameters needed for DDIS, fully perturbative calculations based on proton PDF

DPDFs in DIS

DPDFs obtained by H1 and ZEUS from inclusive, dijet (and D* measurements….)
DPDFs used in HERA analyses - H1 fit B, H1 fit Jets, ZEUS fit SJ
Main differences are in gluonic part.

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





Diffractive dijet production in DIS -

Previous HERA results:

- **H1**, LRG measurement, JHEP 0710:042, (2007)
- **ZEUS**, LRG measurement,EPJC 52 (2007),813
- **H1**, proton tagging -FPS, EPJC 72, (2012),1970
- **H1**, proton tagging - VFPS, R.Zlebcik talk in this workshop

All HERA results agree within errors with NLO QCD calculations

DDIS Dijet Selection
$4 < Q^2 < 80\ \mathrm{GeV}^2$ $0.1 < y < 0.7$
$p^*_{T,1} > 5.5\ \mathrm{GeV}$ $p^*_{T,2} > 4.0\ \mathrm{GeV}$ $-1 < \eta_{1,2} < 2$
$x_{I\!P} < 0.03$ $\lvert t \rvert < 1\ \mathrm{GeV}^2$ $M_Y < 1.6\ \mathrm{GeV}$

New H1 LRG measurement -
highest luminosity compared to former HERA measurements
HERA II data, luminosity ~ 290 pb^{-1}

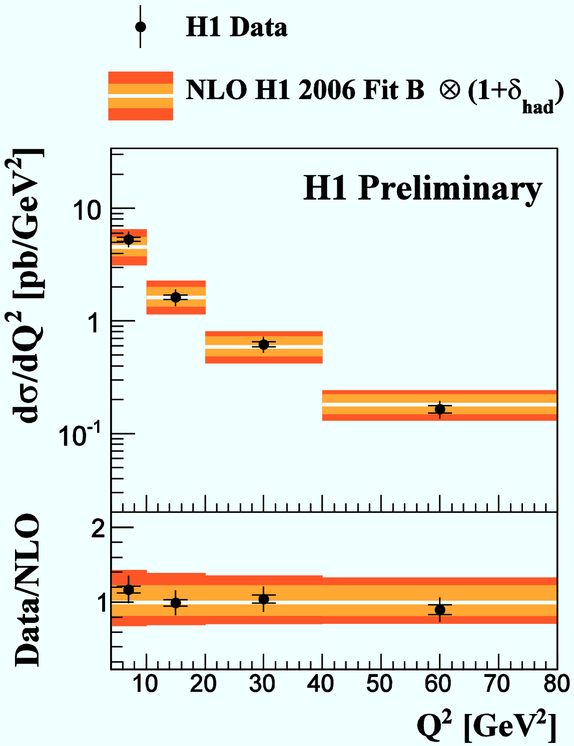
First LRG analysis with corrections for detector effects using
detector response matrix (program TUnfold)

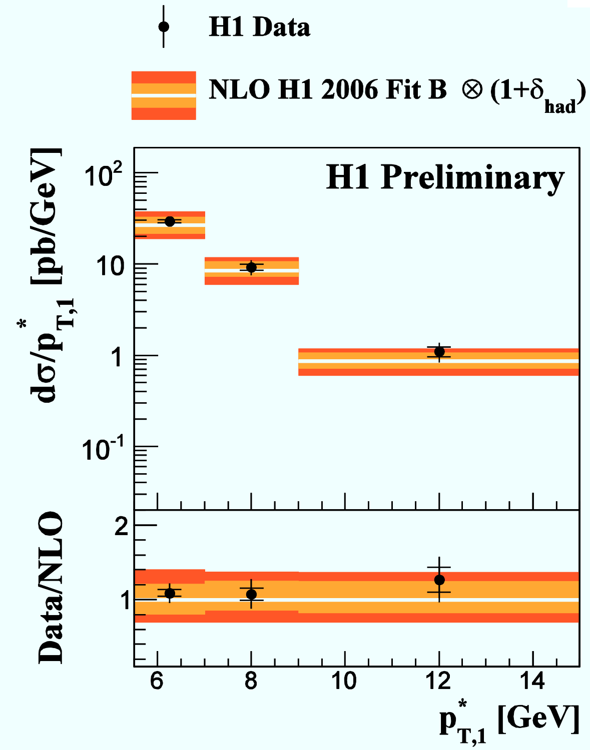
- $\sim$ 14000 events accepted

Diffractive dijet production in DIS -

- Data unfolded to hadron level using TUnfold, response matrix determined from MC generator RAPGAP
- QED radiation effects corrections applied using RAPGAP
- Measurements compared to NLO QCD predictions – program NLOJET++ using DPDF H12006 Fit B.
- Scale $\mu_r^2 = \mu_f^2 = (p_{T,1}^*)^2 + Q^2$, $N_f = 5$, $\Lambda_{QCD}=0.22$ MeV
- Hadronisation corrections – LO MC RAPGAP
- Theoretical uncertainty: scale variation, DPDF uncertainty and hadronisation

Diffractive dijet production in DIS -

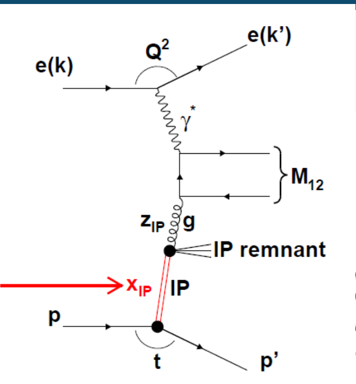


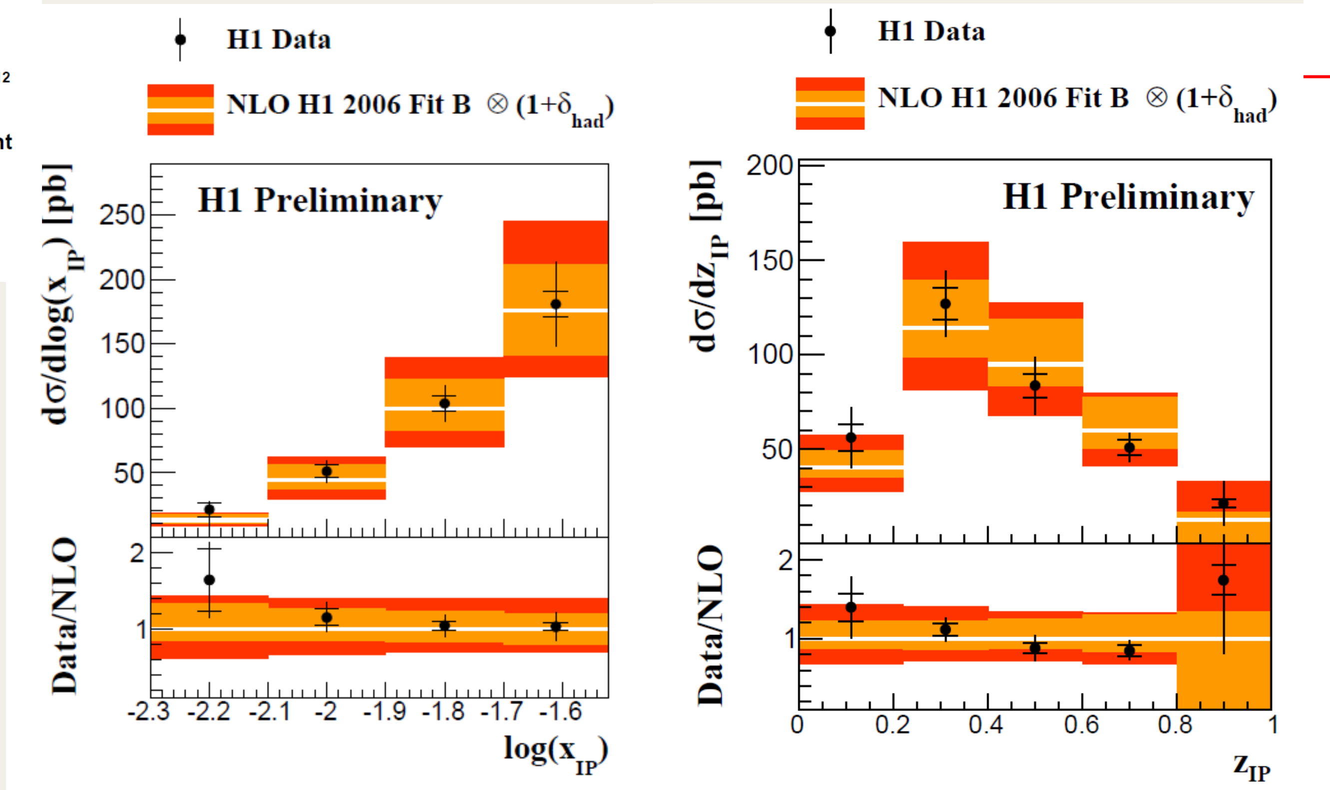


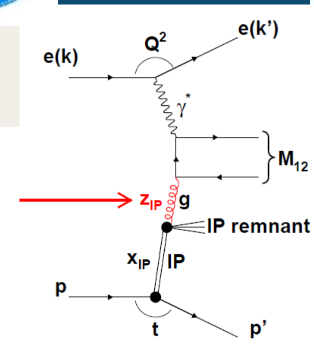
- Inner error bars of data points - statistical uncertainty, outer error bars - systematic uncertainties added in quadrature
- NLO QCD inner band - uncertainty of hadronisation and DPDF fit added in quadrature, outer band – total uncertainty (incl.QCD scale uncertainty)

- Data well described by prediction within experimental and theory uncertainty

Diffractive dijet production in DIS -







- Experimental uncertainty of measurement in z_{IP} lower than DPDF fit uncertainty, gluon DPDF might be further constrained

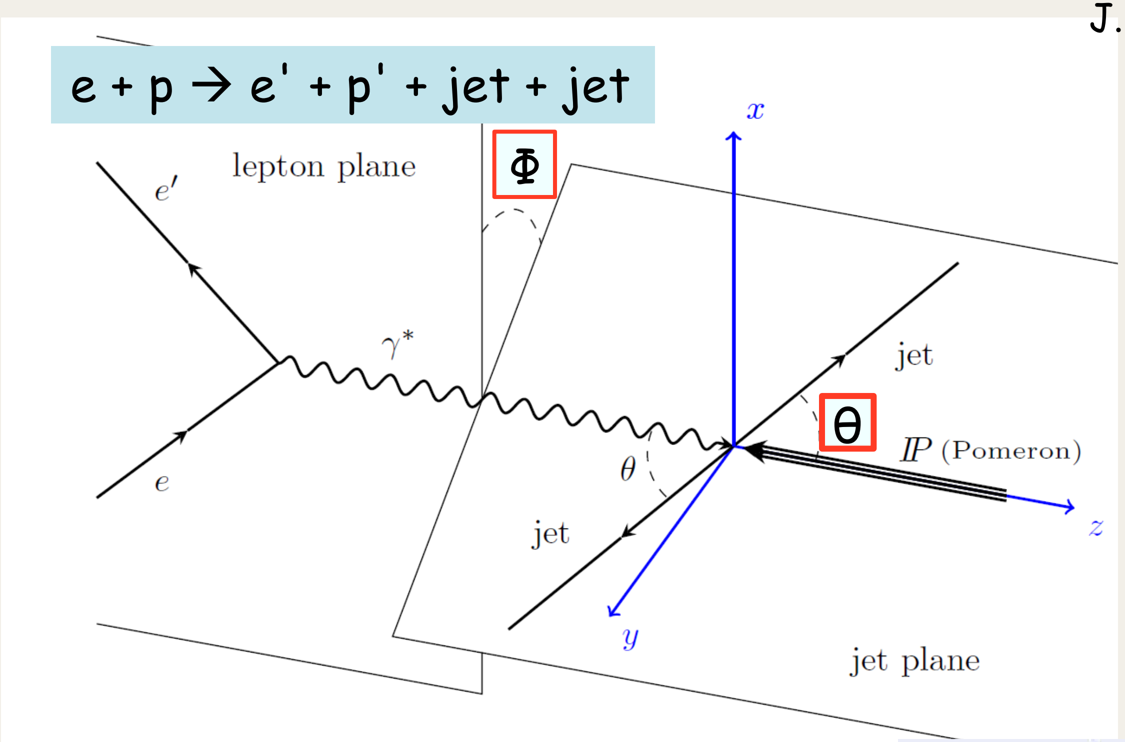
Measurements in agreement with NLO QCD calculations, factorisation confirmed.

Diffractive dijet production in γ*IP CMS

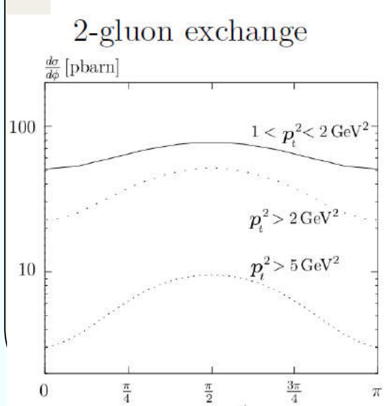
How to distinguish between theoretical diffractive models???

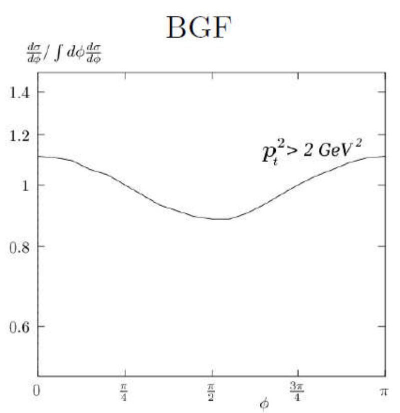
J.Bartels et al.,Phys.Lett.B386,(1996)389

$e + p \rightarrow e' + p' + jet + jet$



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

Diffractive dijet production in γ*IP CMS

Kinematic region

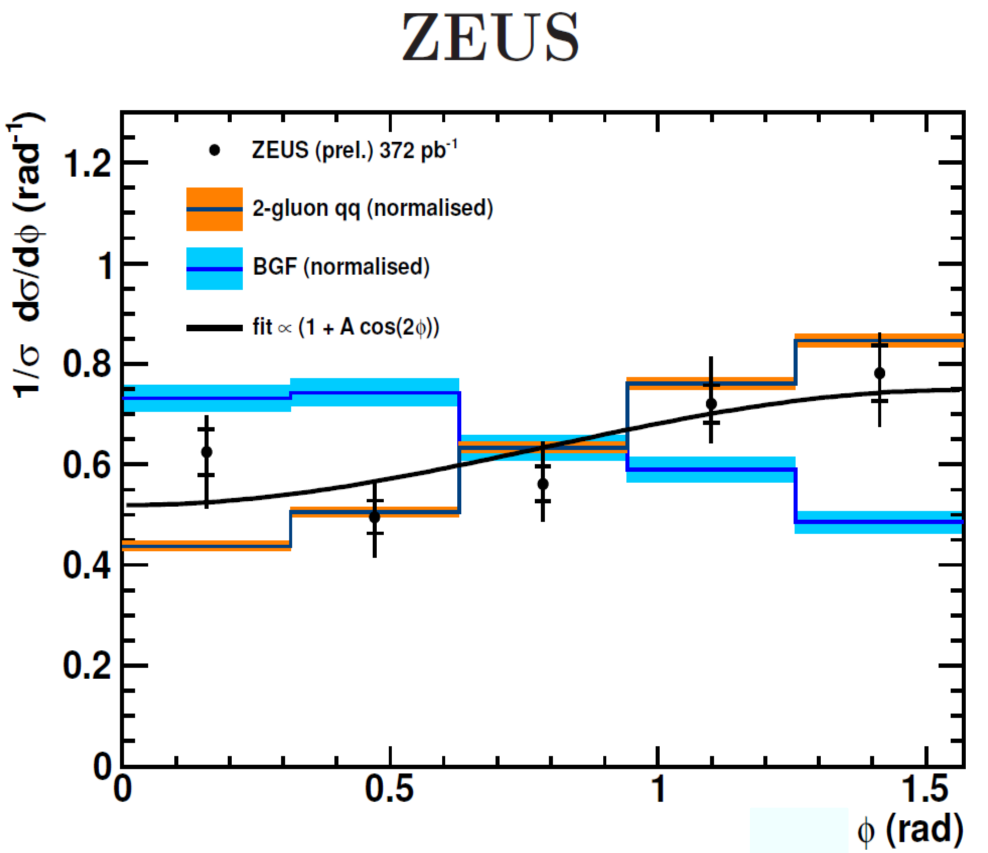
$$
\begin{aligned}
90\ \mathrm{GeV} < \ & W && < 250\ \mathrm{GeV} \\
25\ \mathrm{GeV}^2 < \ & Q^2 && \\
& x_{I\!P} && < 0.01 \\
0.5 < \ & \beta && < 0.7 \\
& n_{\mathrm{jets}} && = 2 \\
2\ \mathrm{GeV} < \ & p_{T\ \mathrm{jet}} &&
\end{aligned}
$$

LRG selection of diffraction

- Jet finder – exclusive k_t jet algorithm
- For corrections model SATRAP used (method of singular value decomposition with regularisation – NIM, A372 (1996),469)
- Unfolded data compared to :

2-gluon exchange model – RAPGAP 3.01/26
Boson-Gluon-Fusion model (resolved pomeron) - RAPGAP 3.01/26

Diffractive dijet production in γ*IP CMS



Fit

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

	A
fit	$-0.18 \pm 0.06(\text{stat.})^{+0.06}_{-0.09}(\text{sys.})$
2-gluon(qq) MC	$-0.34 \pm 0.01(\text{stat.})$
BGF MC	$0.21 \pm 0.02(\text{stat.})$

- Negative A favours two gluon exchange model
- None of the models is able to describe the normalisation of x-section

Conclusions

- New H1 measurement of diffractive dijet production in DIS using LRG method of identification of diffractive events → measurements described by NLO QCD predictions with H1 DPDF fit B

- **Factorisation in DIS diffractive dijet production confirmed.**

- The shape of the azimuthal angular distributions of exclusive dijets in diffractive DIS has been measured for the first time by ZEUS

- **The measurement prefers 2-gluon exchange model of $q\bar{q}$ production over Boson Gluon Fusion model.**