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Recent results in diffraction at HERA

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On behalf of the H1 and the ZEUS collaborations

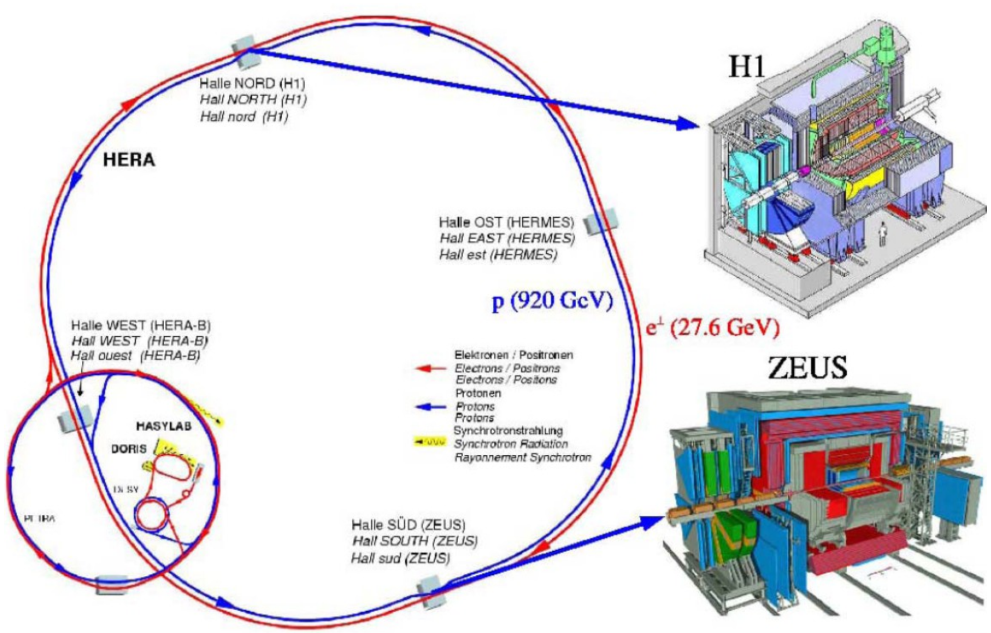
Outline:

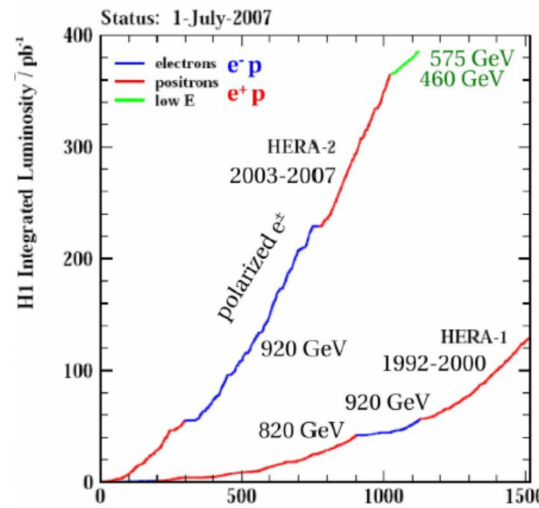
- **H1: Diffractive dijet production and tests of QCD factorisation**
- **ZEUS: Exclusive dijet production in diffractive deep-inelastic scattering (DIS)**
- **ZEUS: Measurement of cross section ratio $\sigma_{\psi(2S)}/\sigma_{J/\psi}$ in DIS**
- **H1: Exclusive photoproduction (γp) of ρ^0 with forward neutron**

HERA and Forward Detectors

The world's only electron/positron-proton collider at DESY, Hamburg.

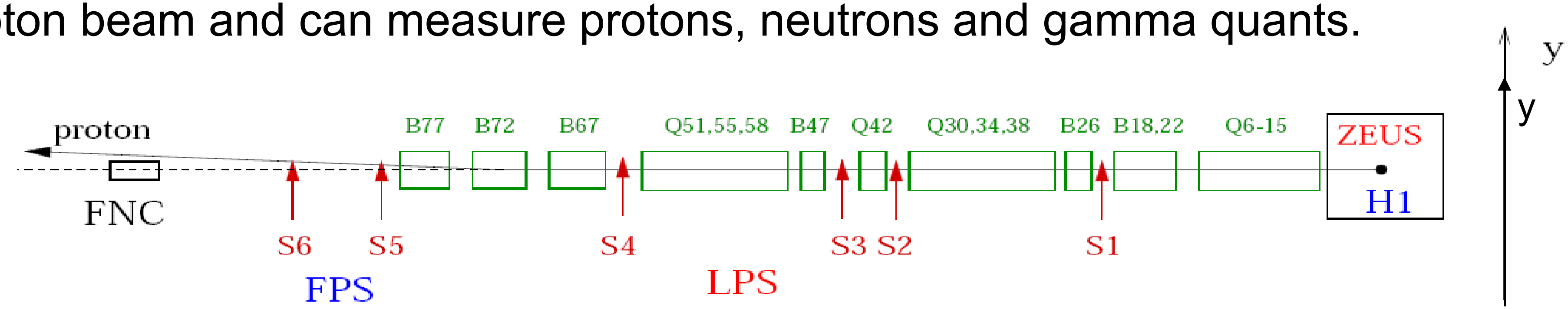
E_e = 27.6 GeV, E_p = 920 GeV (also 820, 460 and 575 GeV). $\sqrt{s}$ up to 320 GeV.





Total lumi: 0.5 fb^{-1} per experiment

Forward detectors (LPS,FPS,FNC,VFPS) are located 60-220m downstream proton beam and can measure protons, neutrons and gamma quants.



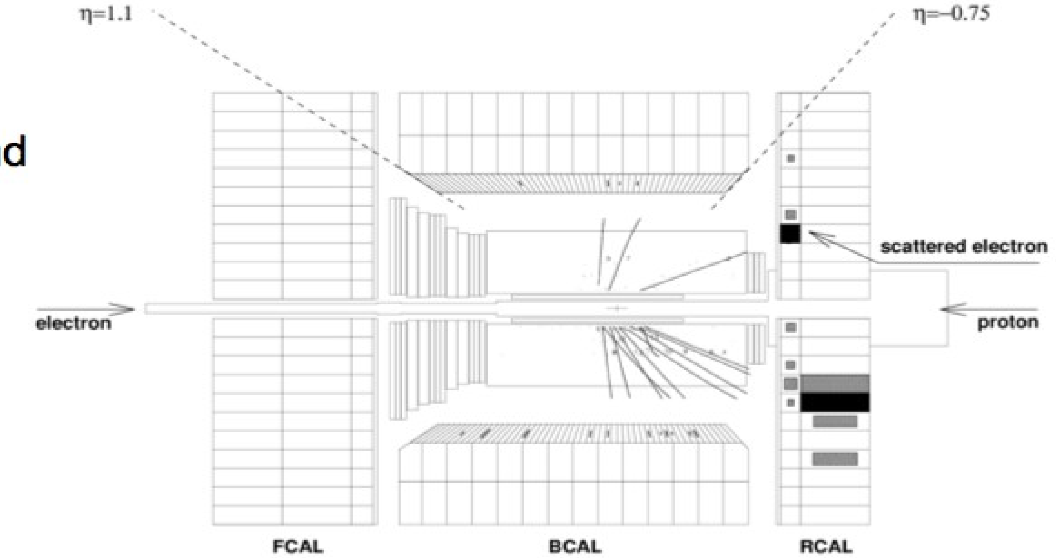
Experimental Methods

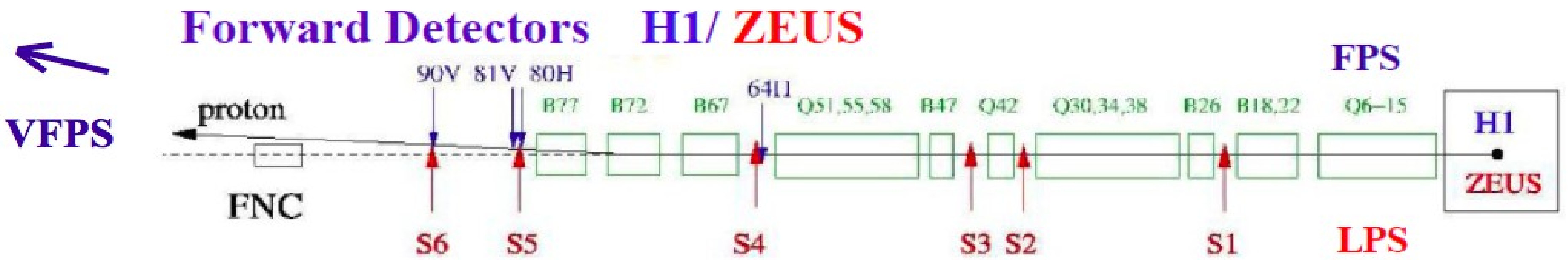
Large Rapidity Gap:

- contains proton dissociative background
- high statistics

proton spectrometer:

- clean measurement p-tagging
- no proton dissociative background
- low statistics

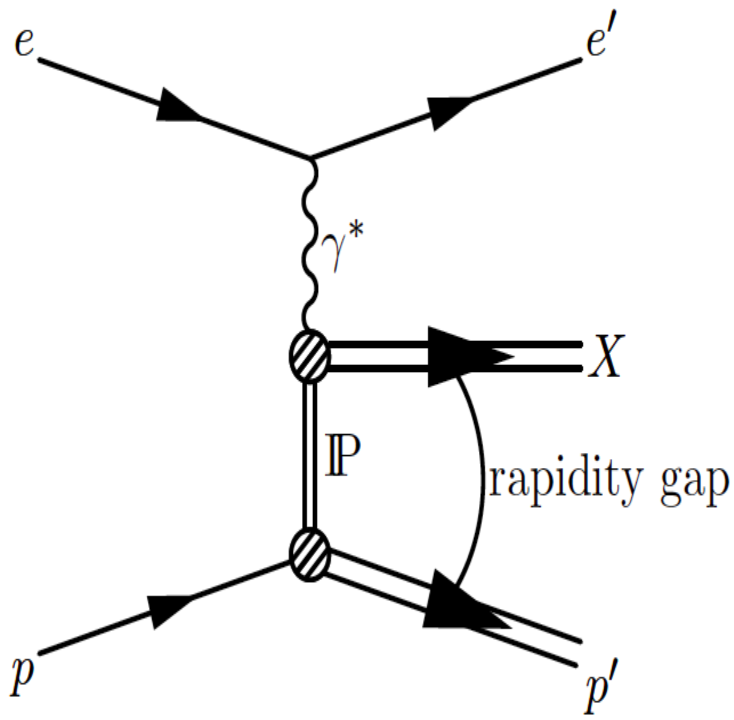




Diffractive kinematics

Q^2 Virtuality of the photon
$Q^2 \approx 0 \rightarrow$ photoproduction
$Q^2 \gg 0 \rightarrow$ deep inelastic scattering (DIS)

HERA: ~10% of low-x DIS events diffractive



Momentum fraction of the diffractive exchange

$$x_{IP} = \frac{q \cdot (p - p')}{q \cdot p} \approx \frac{Q^2 + M_X^2}{Q^2 + W^2} \approx 1 - \frac{E_p'}{E_p}$$

The fraction of exchanged momentum entering to the hard subprocess

$$\beta = \frac{x}{x_{IP}} \approx \frac{Q^2}{Q^2 + M_X^2}$$

4-momentum transfer squared $\quad t = (p - p')^2 = \frac{-p_T^2}{1 - x_{IP}}$

Inelasticity $\quad y = \frac{p \cdot q}{p \cdot k}$

Factorization in Diffraction

QCD factorization holds for inclusive and exclusive processes if:

- photon is point-like (Q^2 is high enough)
- higher twist corrections are negligible (problems around $\beta=1$)

QCD factorization theoretically proven for DIS (Collins 1998)

$$d\sigma^D(\gamma p \to Xp) = \sum_{parton_i} f_i^D(\beta, Q^2, x_{IP}, t) * d\hat{\sigma}^{\gamma i}(x, Q^2)$$

f_i^D — DPDFs, obeys DGLAP evolution, process independent

$d\hat{\sigma}^{\gamma i}$ — Process dependent partonic x-section, calculable within P-QCD

Assuming validity of DGLAP evolution and Regge vertex factorization the DPDFs are obtained by fitting of the inclusive (+ dijets) DIS data

Regge vertex factorization for DPDF:

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

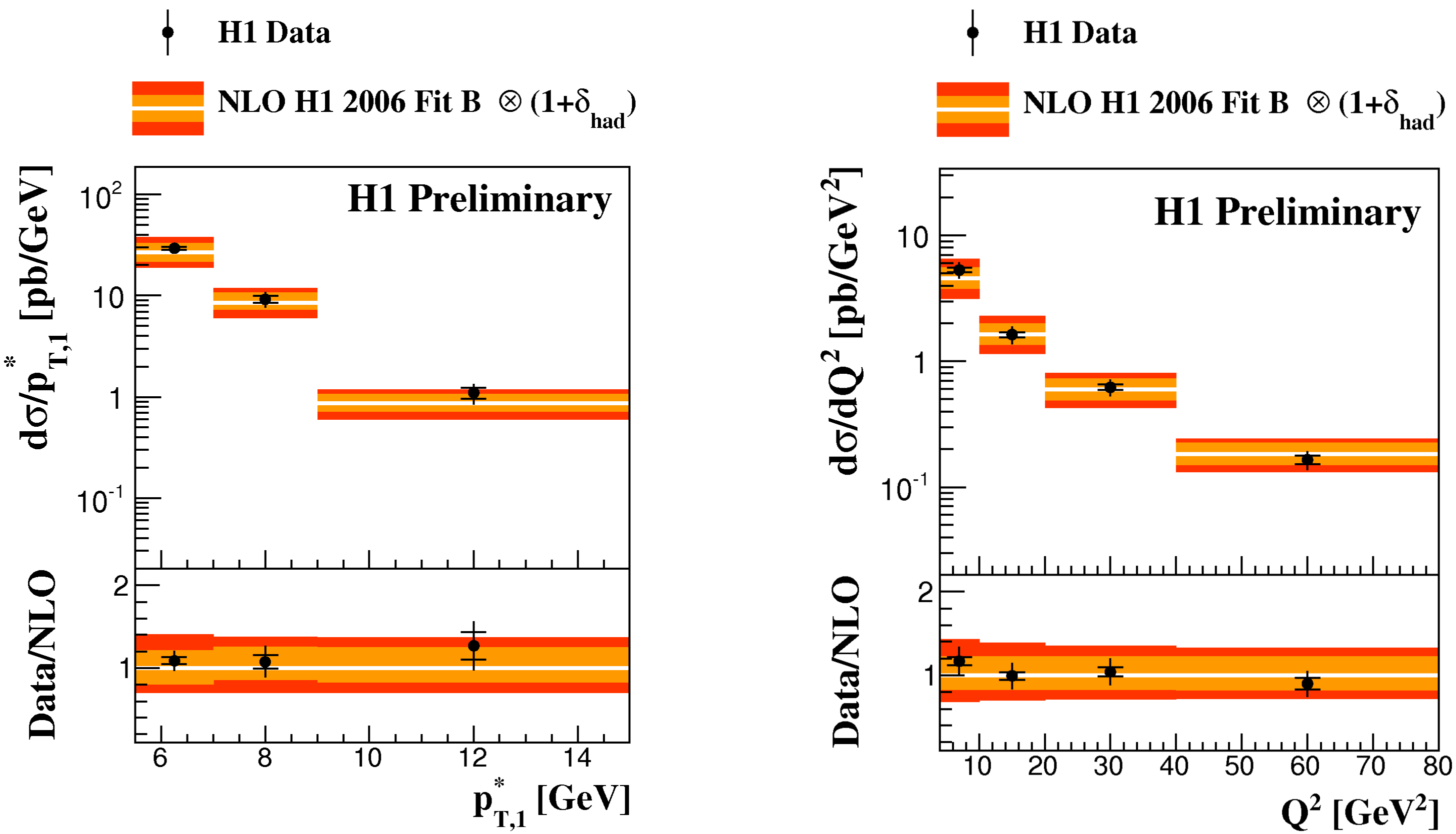
$f_{IP/p}(x_{IP}, t)$ — pomeron flux factor

$f_i^{IP}(\beta, Q^2)$ — pomeron PDF

Diffractive dijet in DIS using LRG method

H1prelim-14-014

Kinematic range: $4 < Q^2 < 80\ \mathrm{GeV}^2$; $0.1 < y < 0.7$; $p_T^{jet} > 5.5, > 4.0$ GeV

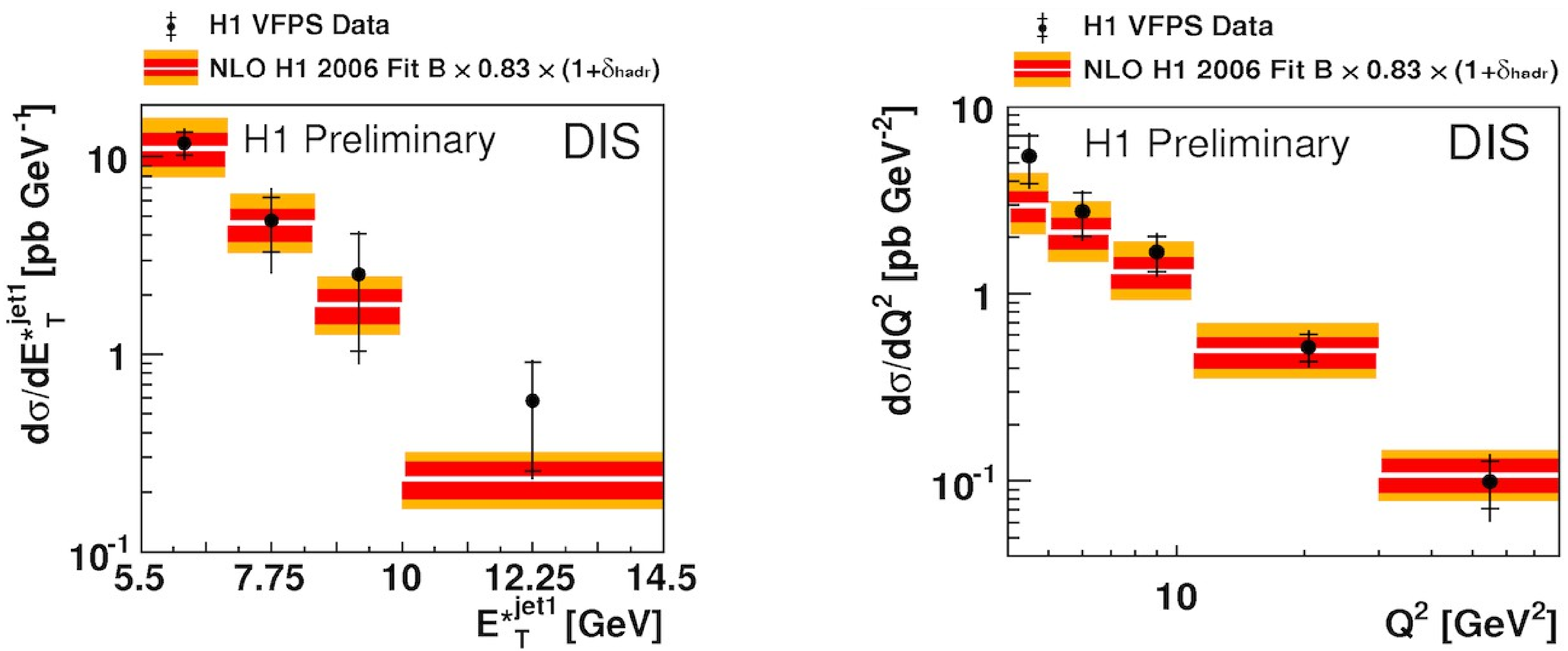


- Data compared to NLO with DPDF H1 2006 fit B
- NLO QCD predictions describe data
- Factorisation theorem holds

Diffractive dijet in DIS using VFPS

H1prelim-14-011

Kinematic range: $4 < Q^2 < 80$ GeV^2; $0.2 < y < 0.7$; $E_T^{jet} > 5.5, > 4.0$ GeV



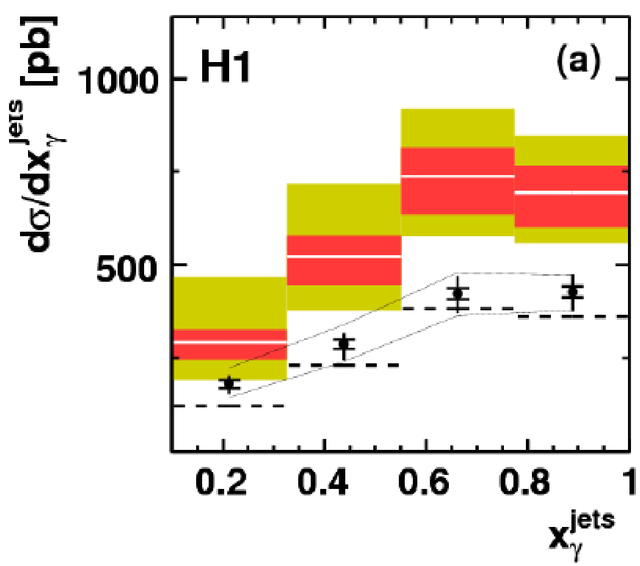
- Data compared to NLO with DPDF H1 2006 fit B
- NLO QCD predictions describe data
- Factorisation theorem holds

H1 and ZEUS measurements

The suppression is supposed to be stronger at low scales and low x_γ

Eur. Phys. J. C68 (2010) 381

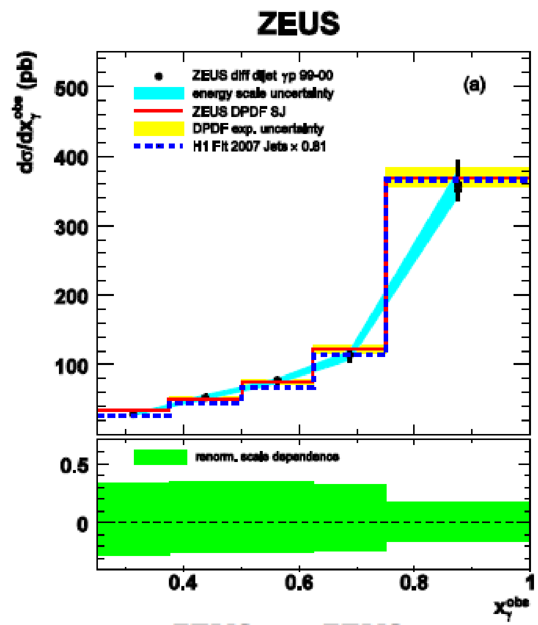
$E_T^{\text{jet1(2)}} > 5(4)\,\text{GeV}$



$\sigma_{data}^{H1} / \sigma_{NLO}^{H1} \approx 0.6$

Nucl. Phys. B381 (2010)

$E_T^{\text{jet1(2)}} > 7.5(6.5)\,\text{GeV}$



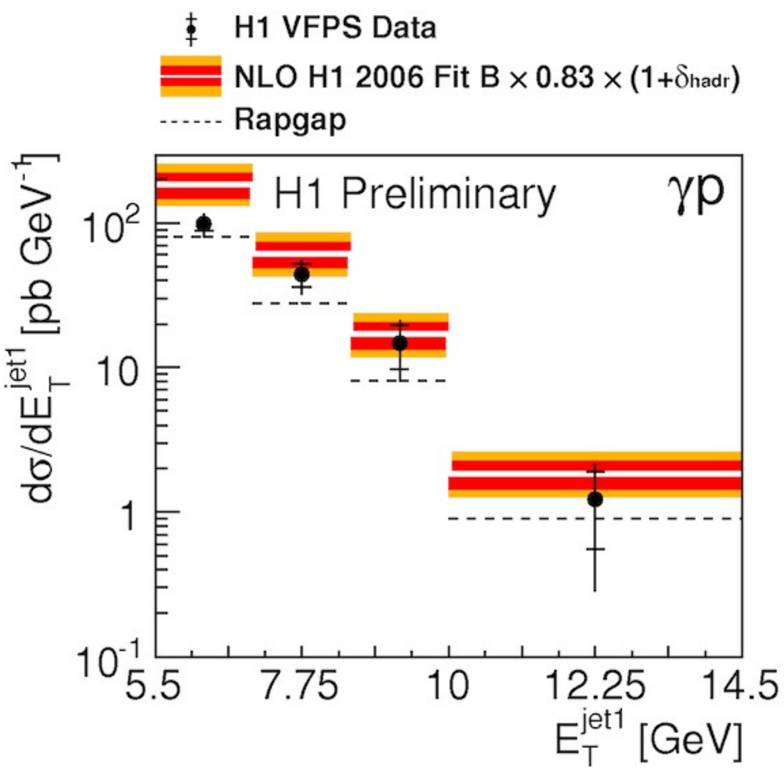
$\sigma_{data}^{ZEUS} / \sigma_{NLO}^{ZEUS} \approx 1.0$

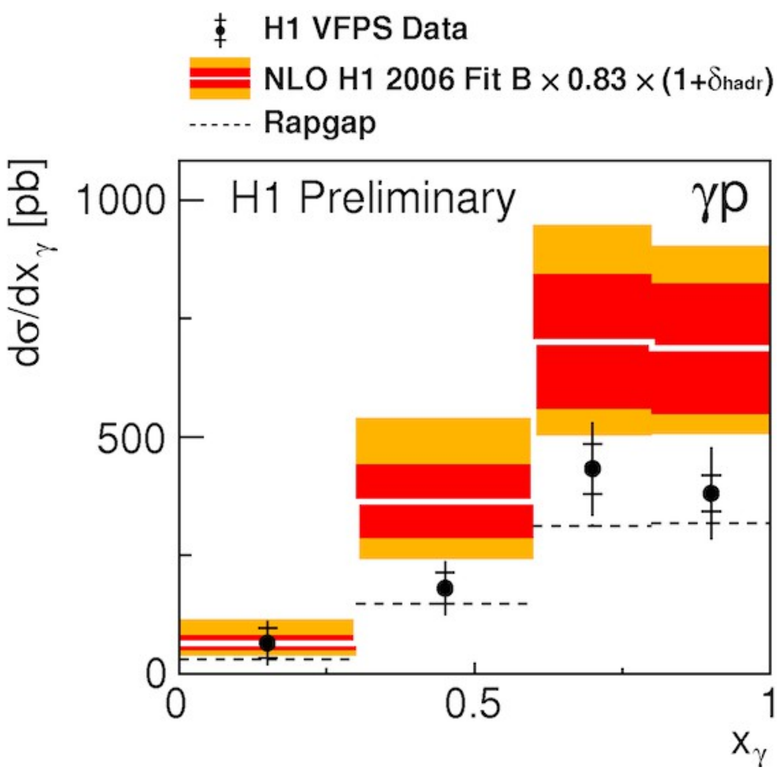
- Factorisation breaking observed by H1 but not observed by ZEUS
- No x_γ dependence of suppression factor visible

Diffractive dijet in γp using VFPS

H1prelim-14-011

Kinematic range: $Q^2 < 2$ GeV^2; $0.2 < y < 0.7$; $E_T^{jet} > 5.5, > 4.0$ GeV



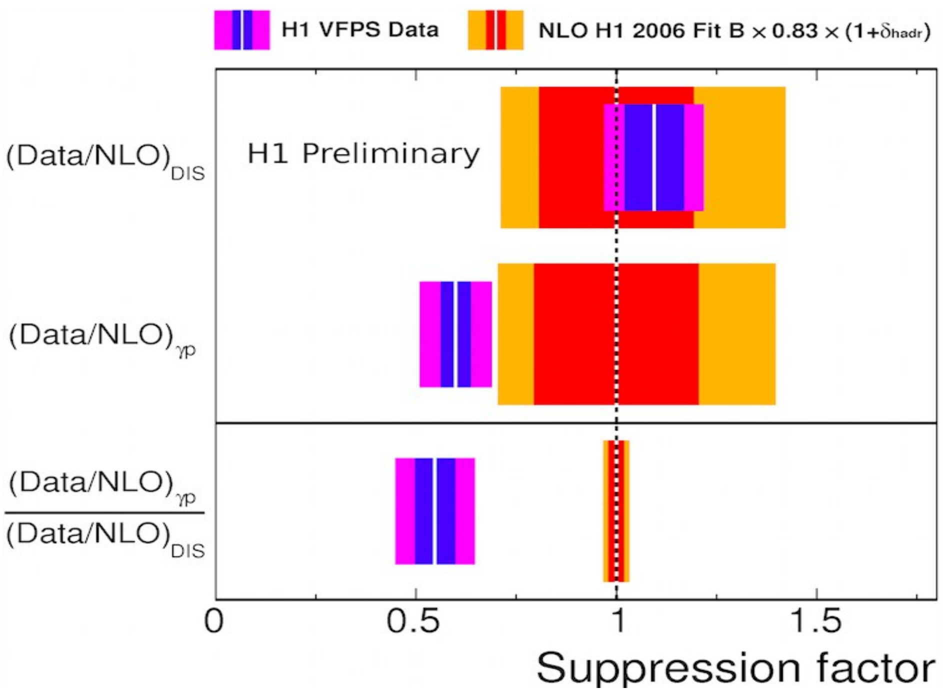


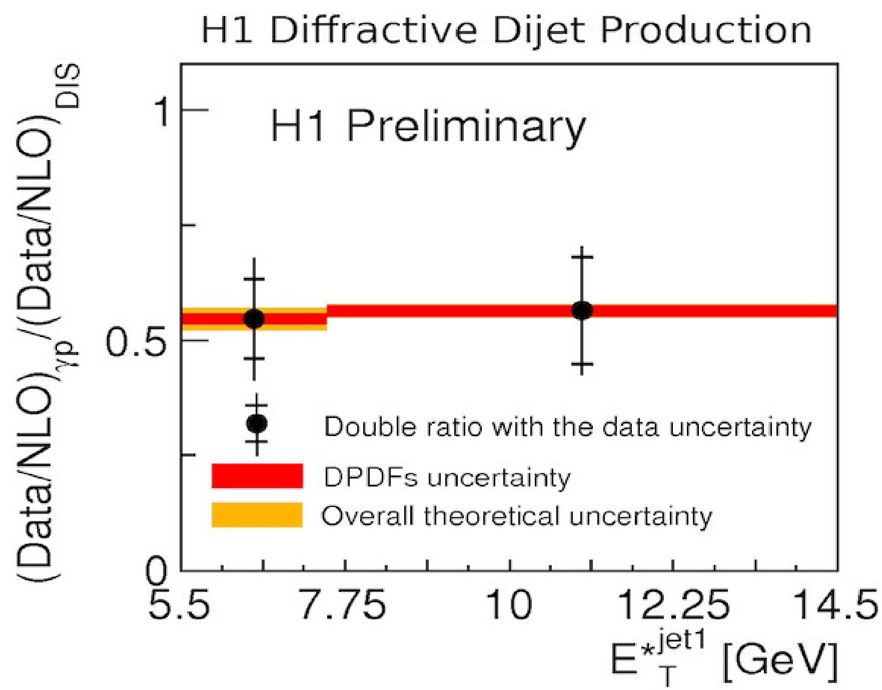
- Data compared to NLO with DPDF H1 2006 fit B
- Data lower than NLO prediction
- Consistent with previous H1 conclusions, here tagging the proton

Diffractive dijet γp/DIS ratio using VFPS

H1prelim-14-011

- Double ratio $(Data/NLO)_{\gamma p}$ / $(Data/NLO)_{DIS}$
- Many systematic errors cancel
- Results with VFPS confirm LRG measurement



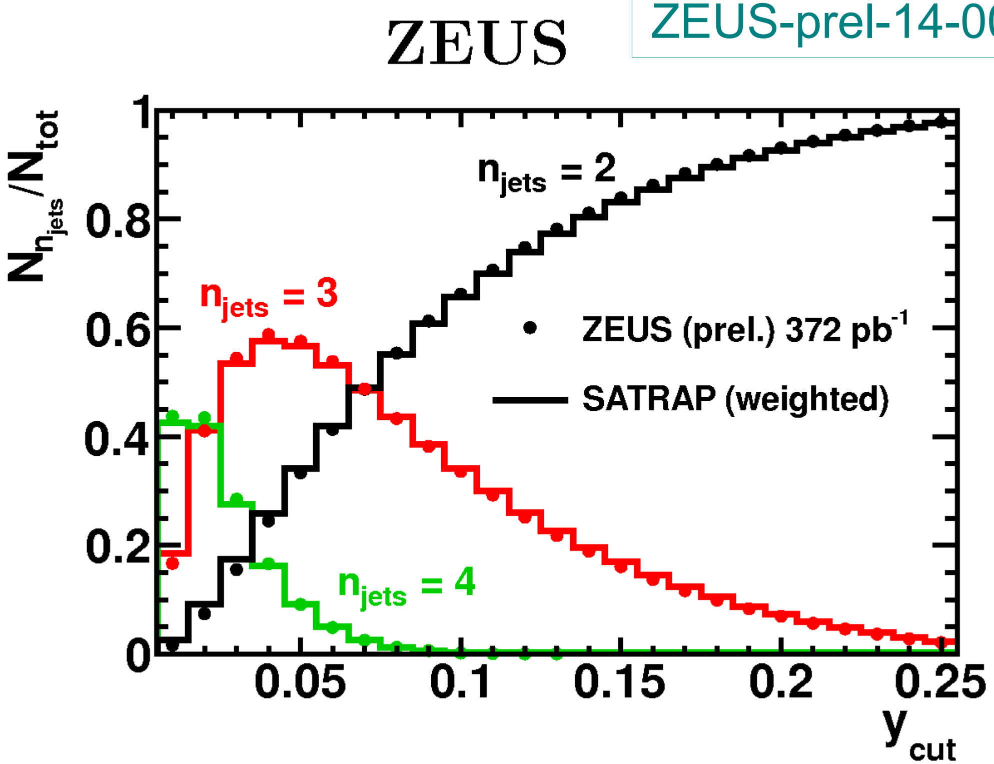


- Data/NLO: suppression factor in γp is 0.55
- No hint of dependence on E_T of leading jet
- Apparent difference between H1 and ZEUS not yet understood

Exclusive dijet production in DIS

ZEUS-prel-14-004

- Large Rapidity Gap method used to select diffractive events with
  → $Q^2 > 25$ GeV^2
  → $M_x > 5$ GeV
  → $90 < W < 250$ GeV
- exclusive k_T jet algorithm: objects are merged as long as
  $$k_T^2 < y_{cut} M_x^2$$
- exclusive dijet may originate from two, three, many partons state
- resolution parameter $y_{cut} = 0.15$ optimizes efficiency versus purity of dijet sample

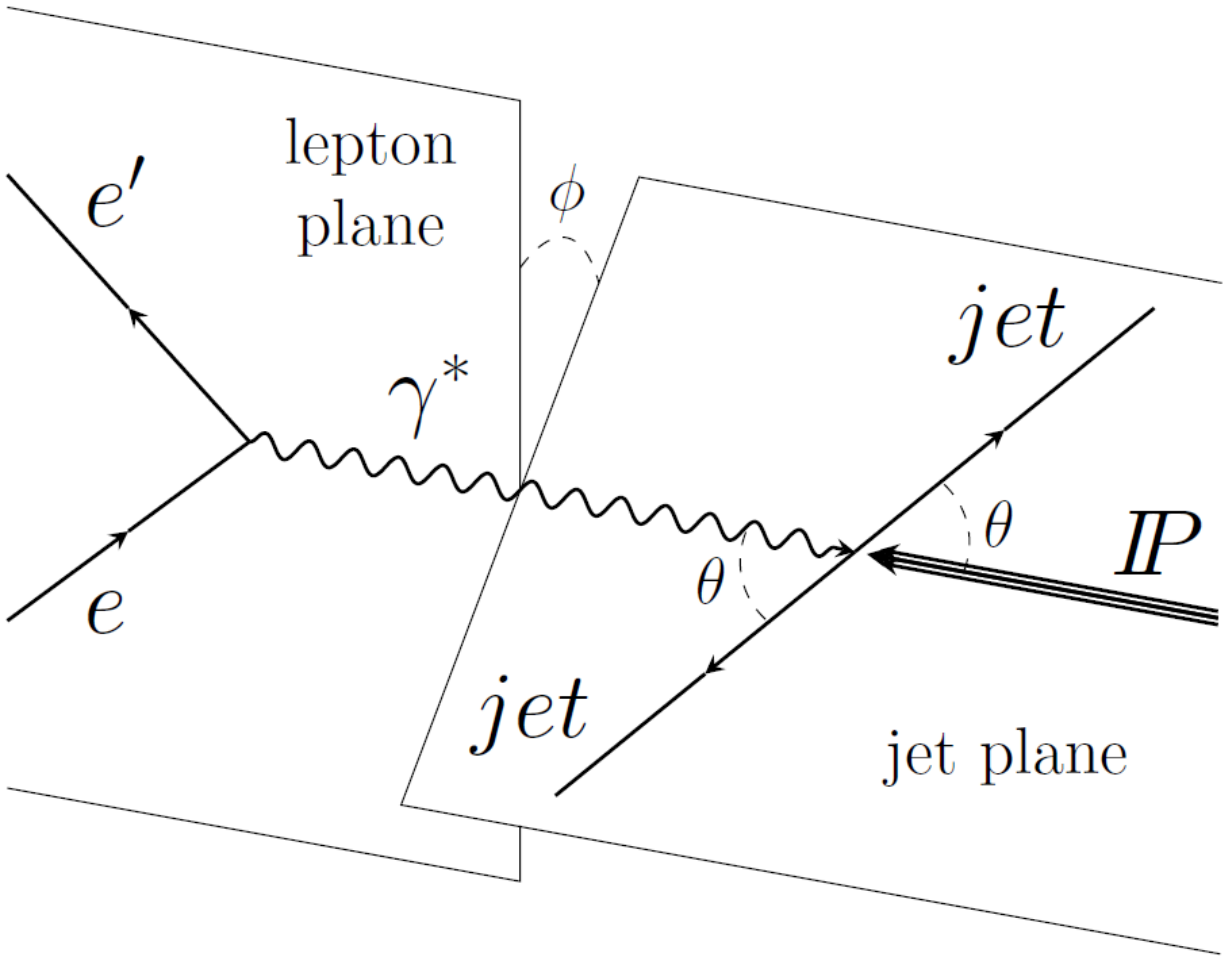


SATRAP:

- colour dipole model with saturation
- $q\tilde{q}$ and $q\tilde{q}g$ in a final state
- good agreement with data
- used for detector level corrections

Exclusive dijet production in DIS

ZEUS-prel-14-004



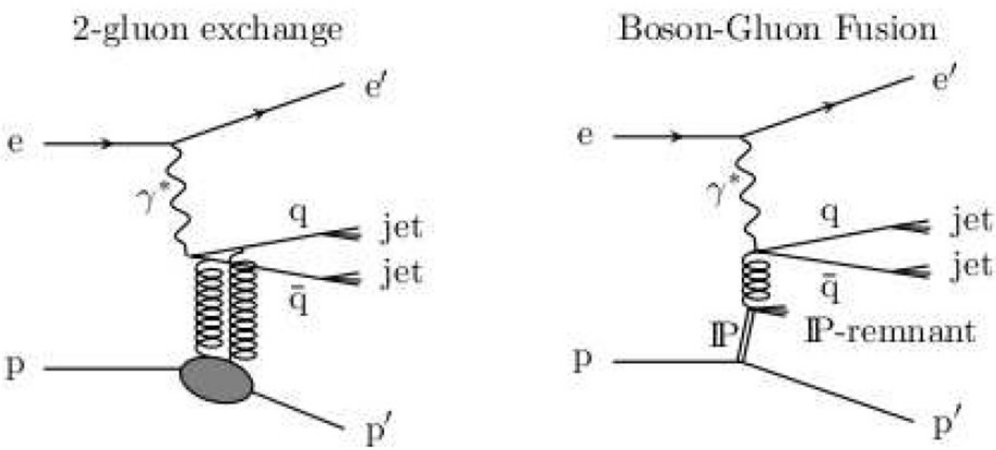
Definition of the dijet azimuthal angle φ:

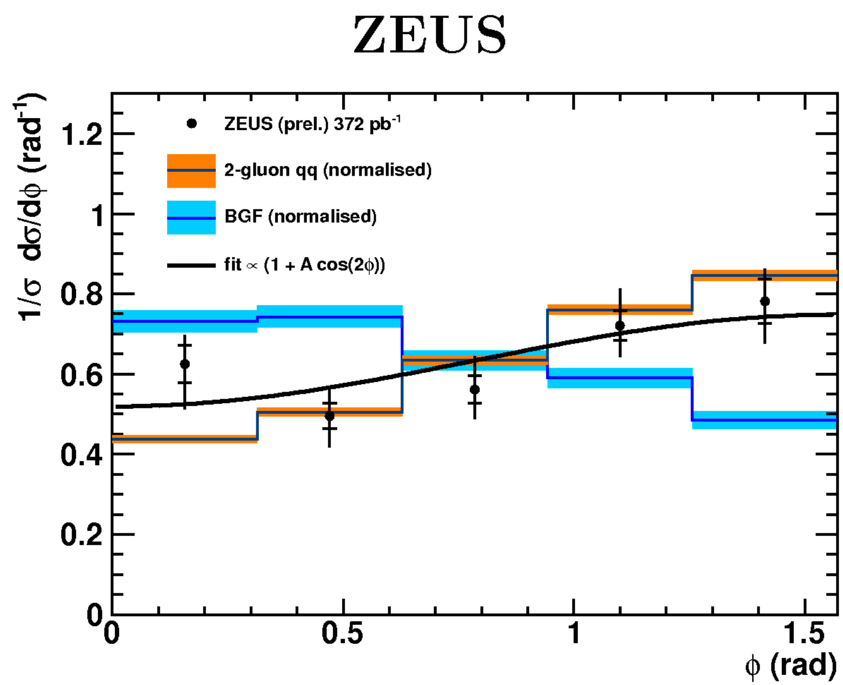
→ angle between two planes spanned in the γ*-pomeron system

Exclusive dijet production in DIS

ZEUS-prel-14-004

- Select two hard jets with $p_T > 2$ GeV to allow comparison to PQCD models





- Two-gluon exchange model (J. Bartels and H. Jung at al.)
- Resolved pomeron model (G. Ingelman and P. Schlein et al.)
- models predict different shape for dijet azimuthal angular distribution

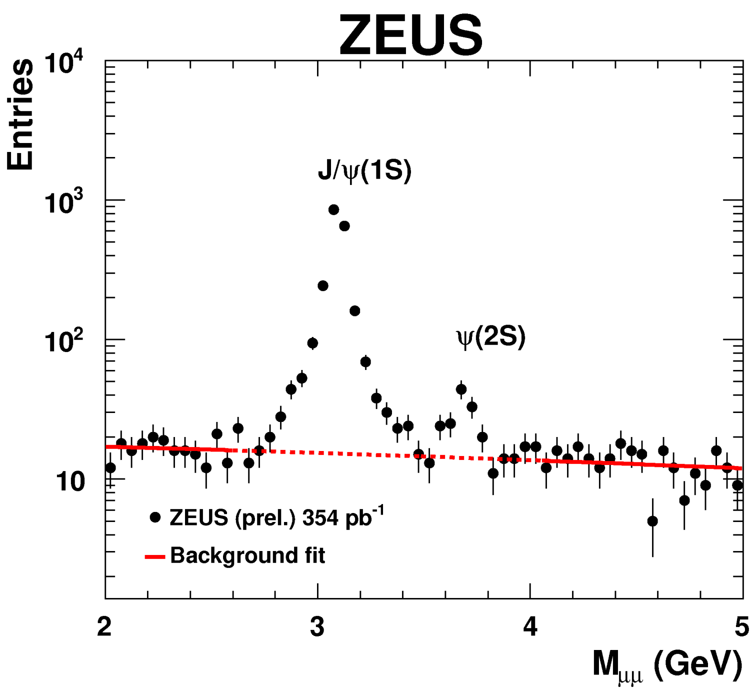
- Data favour the two-gluon exchange model prediction
- The Resolved Pomeron model (BGF) does not describe data

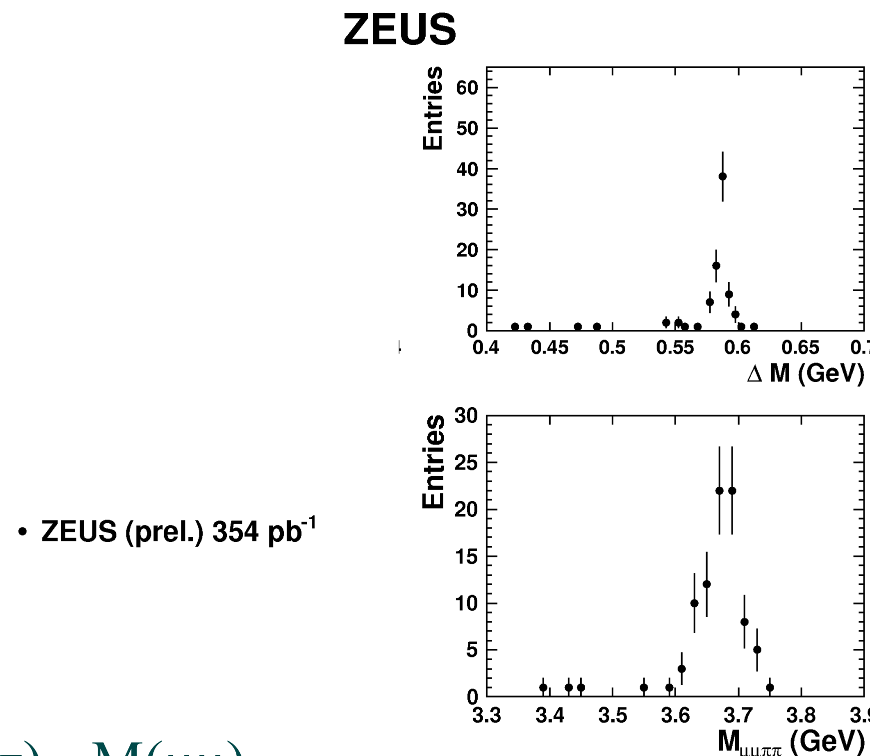
$\sigma_{\psi(2S)}/\sigma_{J/\psi}$ in DIS

ZEUS-prel-14-003

Kinematic range: $5 < Q^2 < 70$ GeV^2; $30 < W < 210$ GeV

- $J/\Psi(1S) \rightarrow \mu^+ + \mu^-$
- $\Psi(2S) \rightarrow \mu^+ + \mu^-$
- $\Psi(2S) \rightarrow J/\Psi + \pi^+ + \pi^-$
  $\rightarrow \mu^+ + \mu^- + \pi^+ + \pi^-$



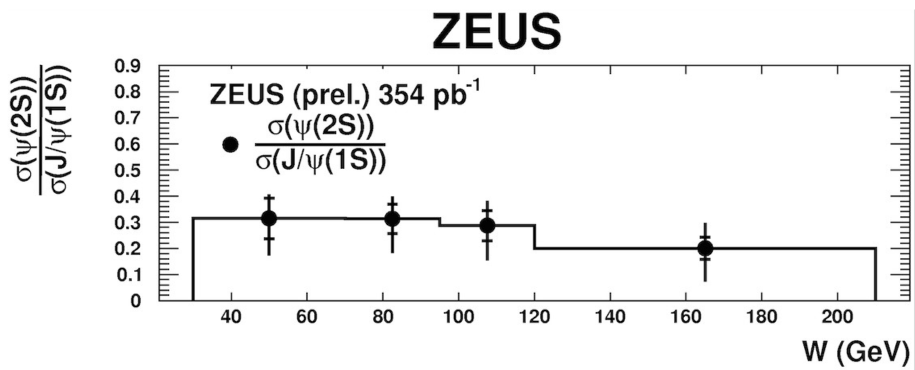


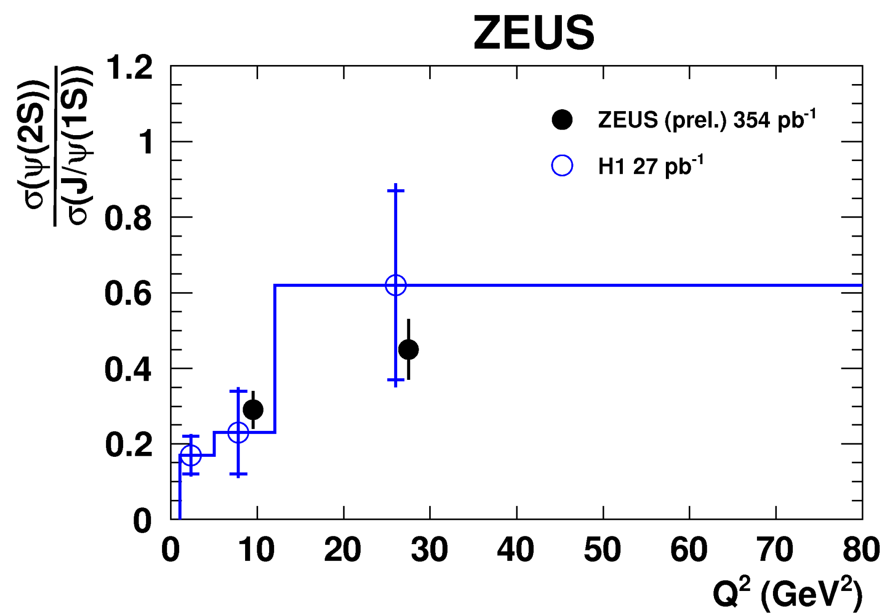
$$\Delta M = M(\mu\mu\pi\pi) - M(\mu\mu)$$

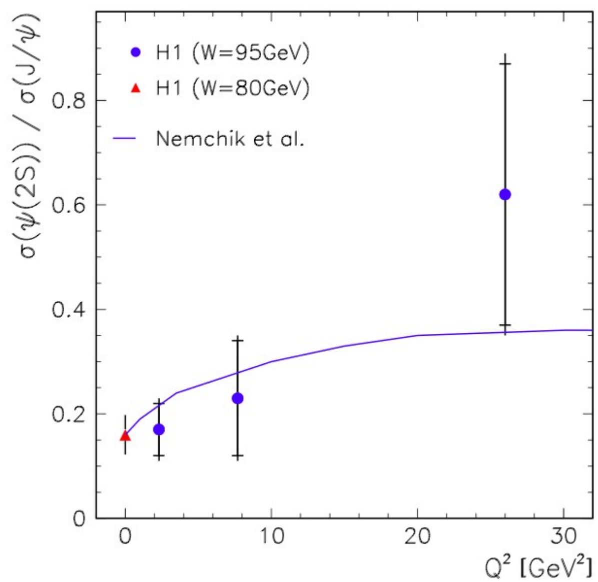
- Ratio insensitive to many systematic uncertainties
- Ratio gives information about the dynamics of the hard process
- PQCD predicts rise of the ratio with Q^2 reaching plateau at $Q^2 >> M_\Psi^2$

$\sigma_{\psi(2S)}/\sigma_{J/\psi}$ in DIS

ZEUS-prel-14-003







One of the models, new data closer to it

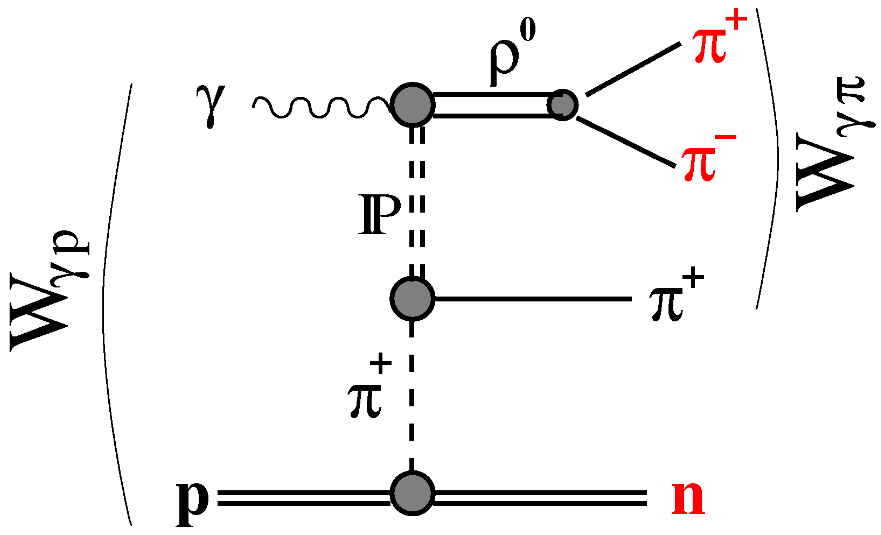
- Indication of an increase with Q^2
- Independent on W and |t|
- Results independent on Ψ(2S) decay channel

Photoproduction of ρ^0 with forward neutron

H1prelim-14-013

$\gamma^* + p \rightarrow \rho^0 + \pi^+ + n$

$\rho^0 \rightarrow \pi^+ + \pi^-$



$Q^2 < 2\ GeV^2$

$|t| < 1\ GeV^2$

$0.3 < m_{\pi\pi} < 1.5\ GeV$

$20 < W_{\gamma\pi} < 100\ GeV$

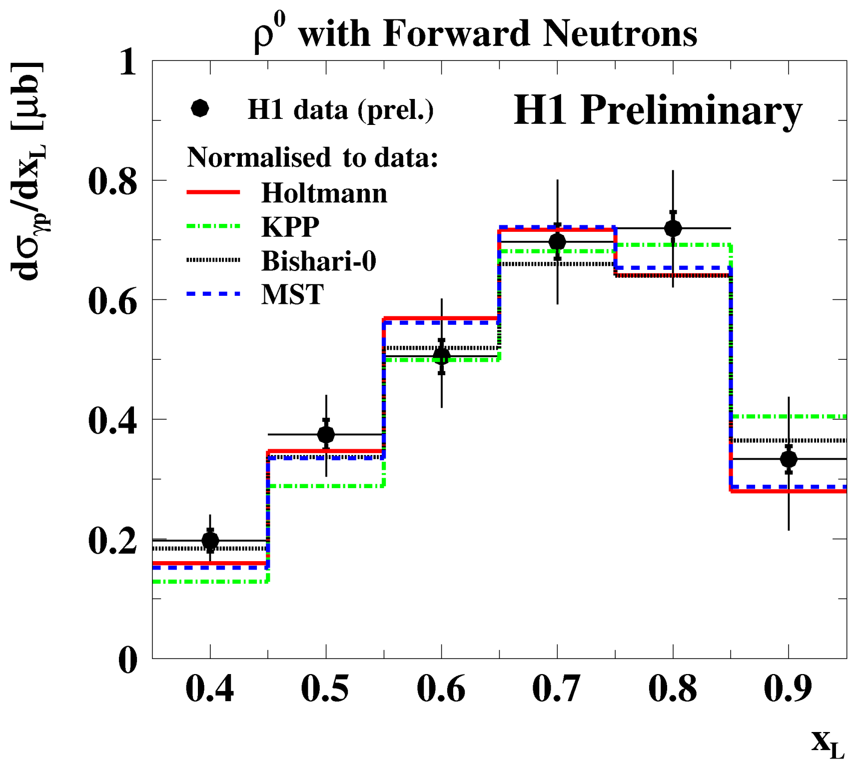
$E_n > 120\ GeV;\ \theta_n < 0.75\ mrad$

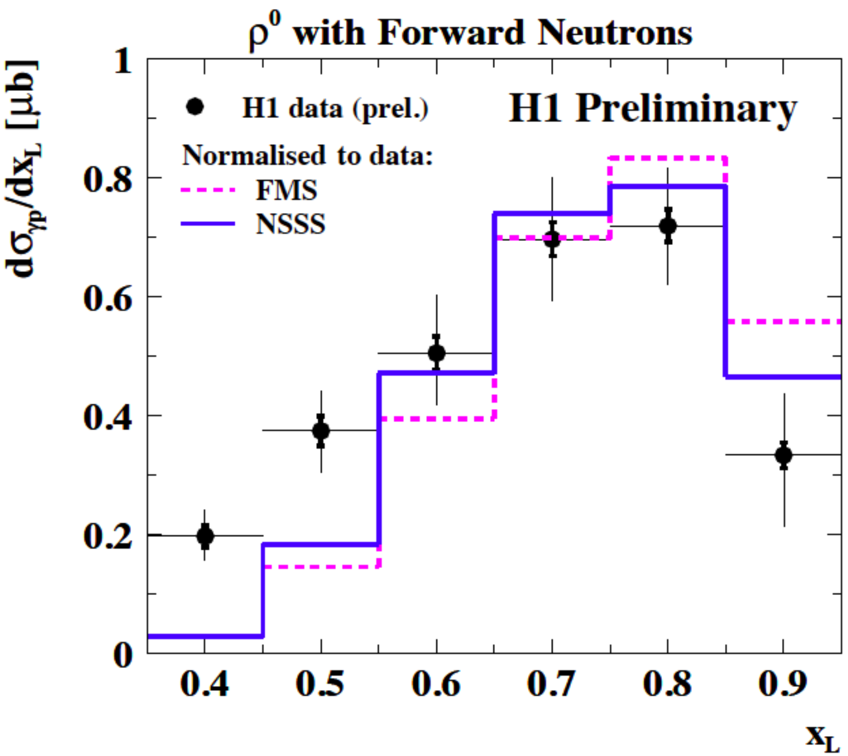
$0.35 < x_L = E_n/E_p < 0.95$

- The photon from electron beam scatters elastically on the pion emitted from the proton producing a ρ^0
- Measure two pions and the leading neutron
- Theoretical model: exchange of two Regge trajectories in a double peripheral scattering process

Photoproduction of ρ^0 with forward neutron

H1prelim-14-013



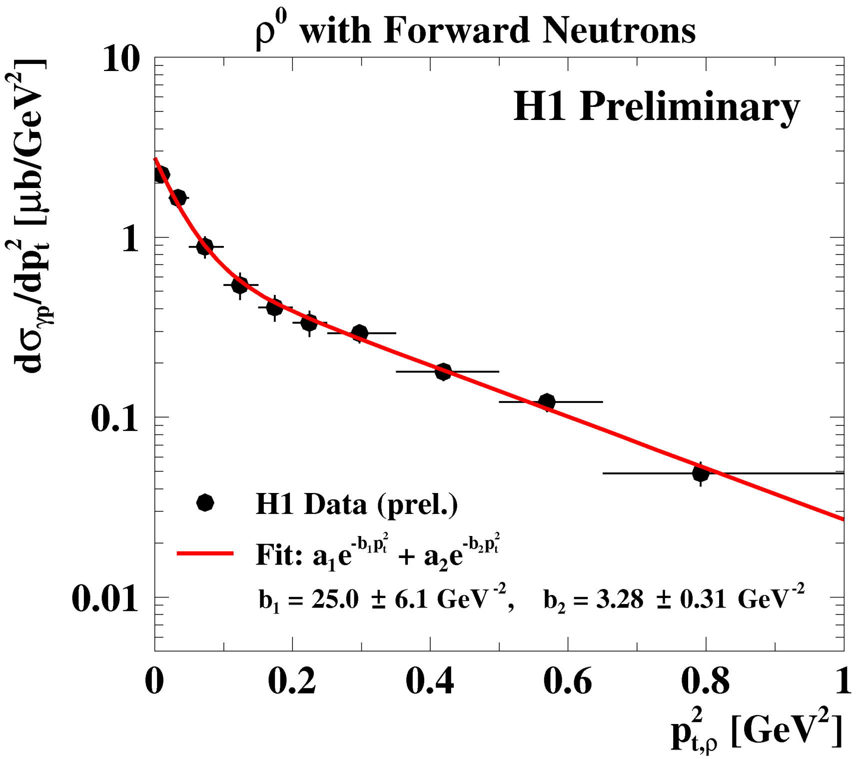


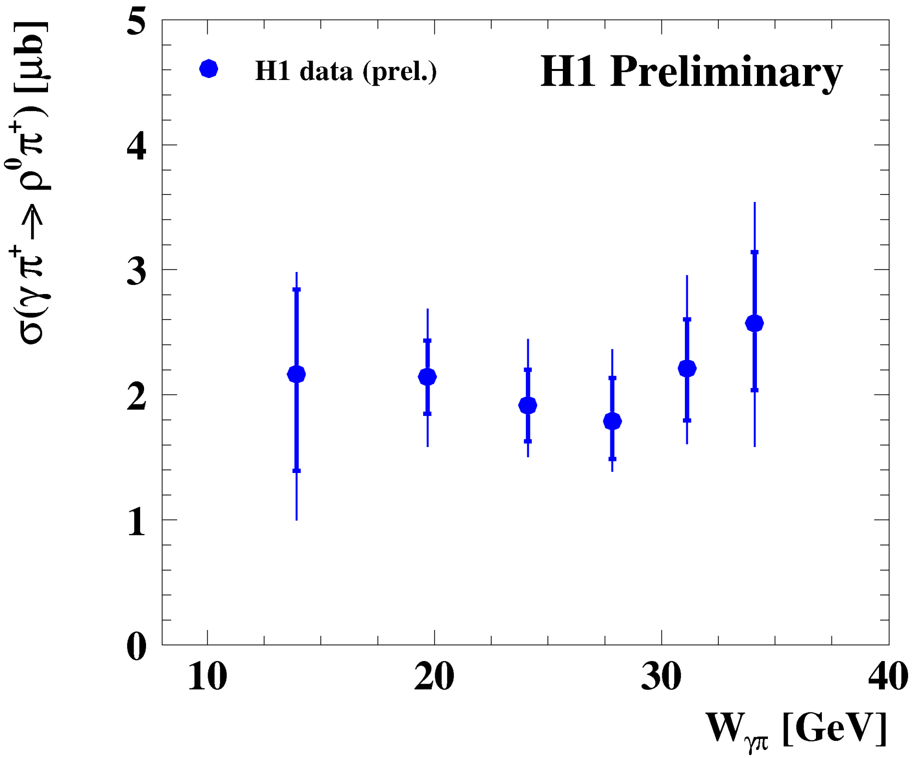
- Shape well described by model predictions
- Models differ in calculating the pion flux

Examples of pion fluxes excluded by data

Photoproduction of ρ^0 with forward neutron

H1prelim-14-013





$\sigma(\gamma p \to \rho^0\pi^+)$ vs $p_{t,\rho}$

$\sigma(\gamma\pi^+ \to \rho^0\pi^+)$ vs $W_{\gamma\pi}$

- IP and π^+ exchange
- Two slopes as predicted for a double-peripheral process

- Holtmann pion flux used
- $\sigma_{\gamma\pi}^{el}/\sigma_{\gamma p}^{el} = 0.21 \pm 0.06$ at W = 22 GeV

Summary

- Diffraction at HERA is rich field of interesting physics

- Diffractive dijet production in γp and DIS with leading proton (H1)
  $\rightarrow$ in agreement with H1(LRG) (H1 data/theory ~0.6 independent on x_γ)
  $\rightarrow$ new measurement of double ratios data/NLO in γp and DIS shows suppression of 0.55 for PHP independent on kinematics

- Diffractive dijets in DIS with LRG (H1)
  $\rightarrow$ confirms factorisation in DDIS
  $\rightarrow$ experimental errors small enough to provide constraints at highest z_{IP}

- Exclusive dijet production in DIS, measured by ZEUS, agrees with a model prediction based on a colourless two-gluon exchange

- The cross section ratio $\sigma_{\psi(2S)}/\sigma_{J/\psi}$ was measured by ZEUS with improved precision

- Photoproduction of exclusive ρ^0 associated with leading neutron, measured by H1, was used to extract the elastic cross section $\sigma(\gamma\pi^+ \rightarrow \rho^0\pi^+)$ for the first time at HERA