Production of exclusive dijets in diffractive deep inelastic scattering at HERA

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On behalf of the ZEUS Collaboration

Final results accepted by the ZEUS Collaboration

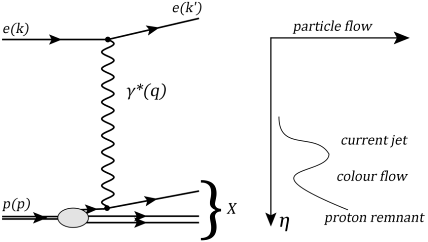
HERA ep collider 1992 – 2007, DESY, Hamburg

- The world's only electron/positron-proton collider
- $E_e = 27.6$ GeV and $E_p = 820(920)$ GeV (575, 460) HE(LE)

- Total integrated luminosity 0.5 fb^{-1}

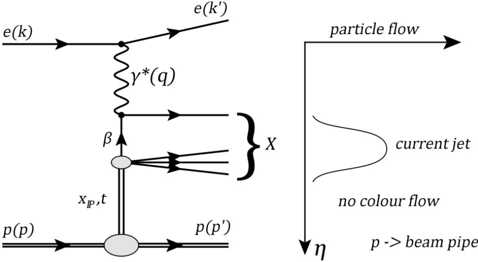
Diffraction in ep collisions

Deep Inelastic Scattering (DIS)



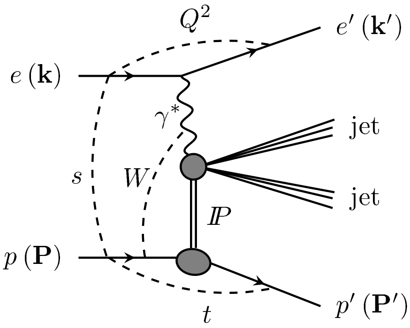
- $Q^2 = -q^2$ - virtuality of the photon
  $Q^2 \approx 0$ - photoproduction,
  $Q^2 \gg 0$ - DIS
- W - photon-proton center-of-mass energy
- x - Bjorken x - fraction of proton's momentum carried by struck quark

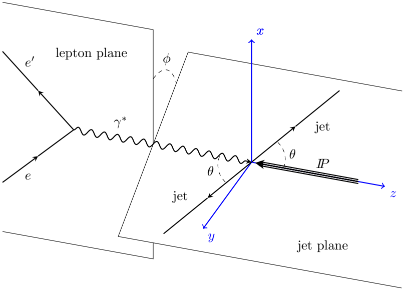
Diffractive Scattering



- x_{IP} - fraction of proton's momentum carried by exchanged color singlet
- $t = (p\text{-}p')^2$- four momentum transfer squared at proton vertex
- $\beta = x / x_{IP}$ - fraction of Pomeron momentum "seen" by the photon

Exclusive dijet production in diffractive DIS



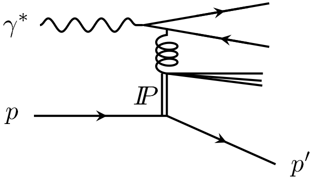


ϕ - the angle between lepton plane and jet plane

- Only dijet, scattered electron and proton in the final state
- ϕ distribution $\propto 1 + A \cdot \cos 2\phi$
- Parameter A sensitive to the nature of the object exchanged between the virtual photon and the proton

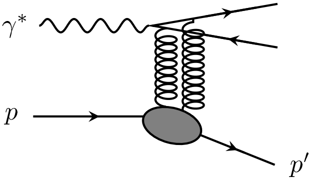
Models of $q\bar{q}$ production in diffractive DIS

Resolved-Pomeron model



- Gluon emitted from the Pomeron
- $q\bar{q}$ pair produced via Boson Gluon Fusion
- Positive A
- Cross section sensitive to the diffractive gluon distribution in the proton
- Pomeron remnant contributes to $q\bar{q}$ production

Two-Gluon-Exchange

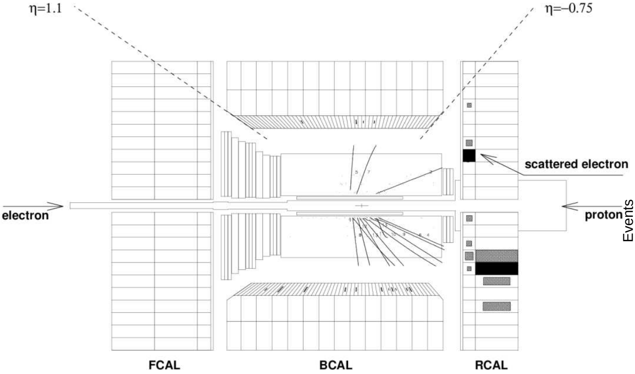


- Virtual photon fluctuates into a $q\bar{q}$
- Two gluons from the proton couples to $q\bar{q}$ pair
- Negative A
- Cross section sensitive to the gluon distribution in the proton
- Promising reaction to probe the off-diagonal gluon distribution
- Emission of additional gluon also contributes to $q\bar{q}$ production

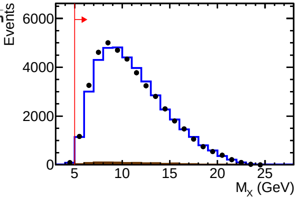
MC simulation

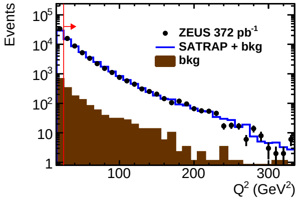
- Diffractive sample simulated with SATRAP generator
  - Two-Gluon-Exchange with color dipole model and saturation
  - $q\bar{q}$ and $q\bar{q}g$ in a final state
  - Hadronisation was simulated with the JETSET
  - Radiative corrections taken into account with the HERACLES
  - Also used for proton-dissociation process assuming the interaction at the lepton and at the proton vertex factorizes, where the intact proton was replaced with a dissociated proton.
  - Used for detector level corrections
- Non-diffractive and photoproduction backgrounds were estimated based on MC predictions of ARIADNE and PYTHIA 6.2
- For the model predictions at hadron level RAPGAP generator was used where Resolved-Pomeron model (G.Ingelman and P.Schlein et al.) and Two-Gluon-Exchange (J. Bartels and H. Jung et al.) are implemented

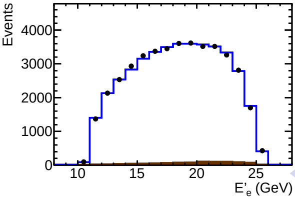
Selection of diffractive DIS events

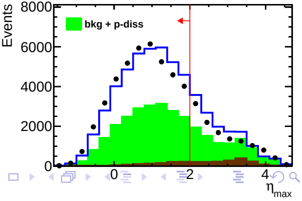


- $E'_e > 10$ GeV
- $Q^2 > 25$ GeV^2
- $M_X > 5$ GeV
- $\eta < 2$; $x_{IP} < 0.01$





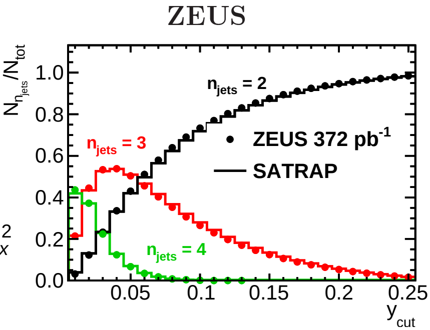


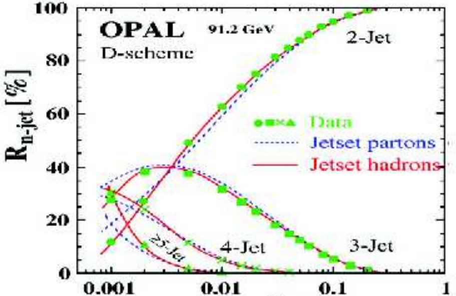


- Durham jet algorithm in γ^*–Pomeron rest frame as implemented in FastJet:
  - objects i, j are merged as long as

    $$k_t^2 = \min(E_i^2, E_j^2)\sin^2(\theta_{i,j}) < y_{cut} M_x^2$$

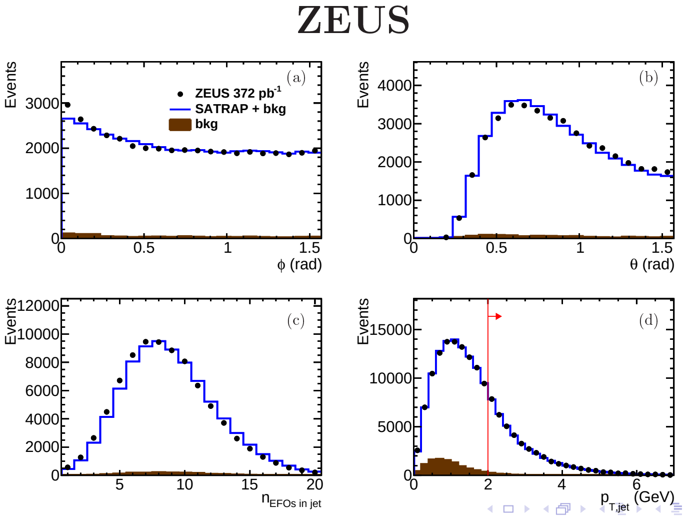
  - objects with the smallest separation are merged first
  - each object had to be associ to a jet (exclusive mode)
- Algorithm developed for $e^+ + e^- \to \gamma^* \to jets$
- Better performances than other algorithms developed for inclusive lepton-hadron or hadron-hadron processes





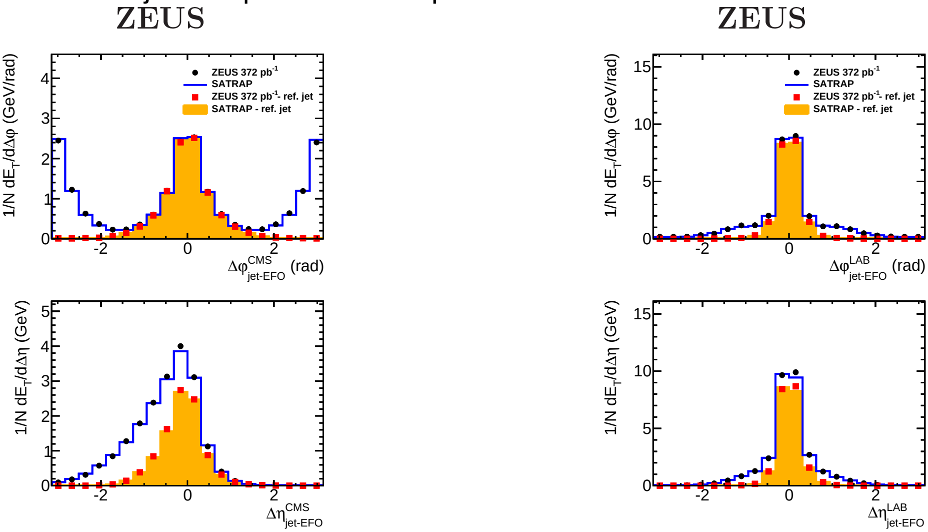
Jet selection

- Jets were reconstructed with a resolution parameter $y_{cut} = 0.15$
- Select two hard jets $p_t > 2$ GeV to allow comparison to pQCD models



Transverse energy flow around jet

Reference jet with positive Z-component of the momentum



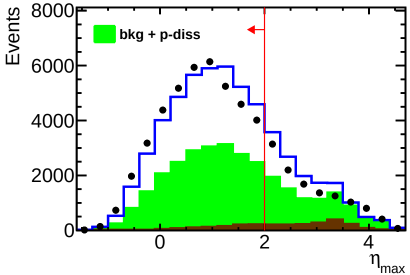
Distributions well reproduced by the SATRAP MC

Dijet production with proton dissociation

$e + p \rightarrow e + \text{jet1} + \text{jet2} + Y$ M_Y - mass of the proton dissociated system

- Fine tuning of the p-diss MC with enriched in p-diss sample:
  - only particles with $\eta < 2$ were used to reconstruct jets and kinematical variables
  - events with particles in the range $2 < \eta < 3.5$ were rejected
  - remaining sample with particles in the range $\eta > 3.5$ consisted almost entirely of diffractive dijets with a detected p-diss system.

$$\frac{d\sigma_{\gamma p \rightarrow \text{jet1}+\text{jet2}+Y}}{dM_Y^2} = \frac{1}{M_Y^{1.4\pm0.6}}$$



- fraction of p-diss was determined by a fit to the distribution of η_{max}

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

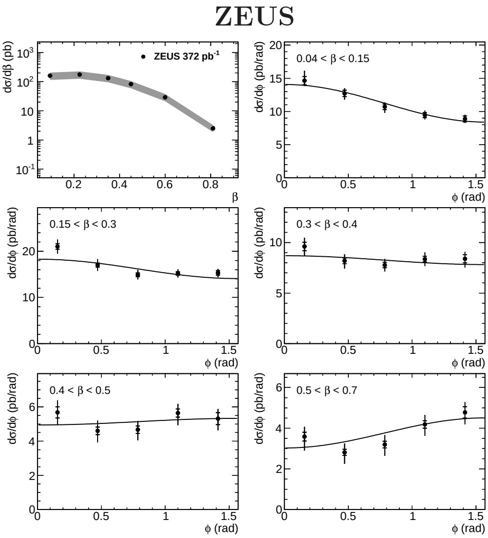
- uncertainty is model independent. The similar central value was obtained for other diffractive processes or assuming that $\sigma_{\text{el}}/\sigma_{\text{p-diss}} \approx 1$

Unfolding of hadron level cross sections

- Hadron level cross sections were unfolded as a function of β and ϕ in the kinematical region
  - $Q^2 > 25$ 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.

- Two–dimensional unfolding in $\phi - p_{T;jet}$ or $\beta - p_{T;jet}$ space
- The response matrix was based on the weighted SATRAP MC simulation
- Unfolding done using Singular Value Decomposition as implemented in the TSVDUnfold package

Differential cross sections



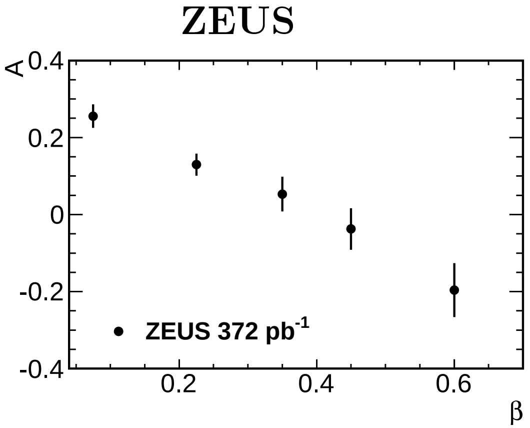
- ϕ distribution well described by theoretically predicted:

$$1 + A\cos 2\phi$$

- Fits include the full statistical covariance matrix and the systematic uncertainties using the profile method

Shape of ϕ distribution vs. β

- $1 + A \cos 2\phi$

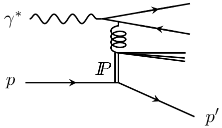


- A decreases with increasing β and changes sign around $\beta = 0.4$

Model predictions

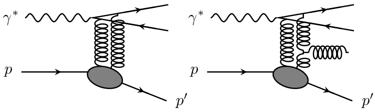
- Hadron–level model predictions were obtained by MC simulation
- The hadronisation was simulated with was simulated with color dipole model as implemented in ARIADNE
- The generated events do not include proton dissociation

Resolved-Pomeron model



- Prediction based on diffractive gluon density obtained from fits (H1 2006 fits A and B) to H1 data
- The shape of the ϕ distribution is essentially identical in all models based on the BGF process (Resolved-Pomeron and the Soft Colour Interactions)

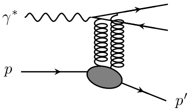
Two-Gluon-Exchange model

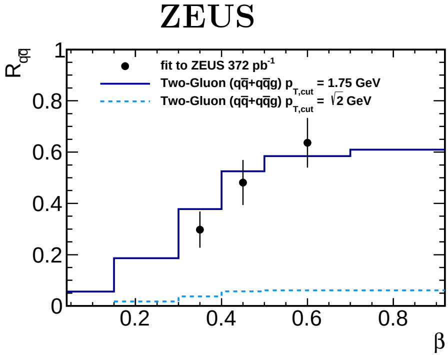


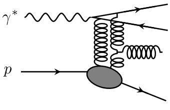
- Prediction based on GRV parameterisation of the gluon density
- The $q\bar{q}g$ final state is sensitive to the parton-level cut $p_{T,cut}$
- Consequence of the fact that two of the partons form a single jet.

$q\bar{q}$ dijet component in the Two-Gluon-Exchange model

- ϕ distributions predicted for $q\bar{q}$ and $q\bar{q}g$ have different shapes
- Ratio $R_{q\bar{q}} = \sigma(q\bar{q})/(\sigma(q\bar{q}) + \sigma(q\bar{q}g))$ can be determined by studying the measured ϕ distributions.
- Predicted $R_{q\bar{q}}$ by the model depends on the applied $p_{T,cut}$

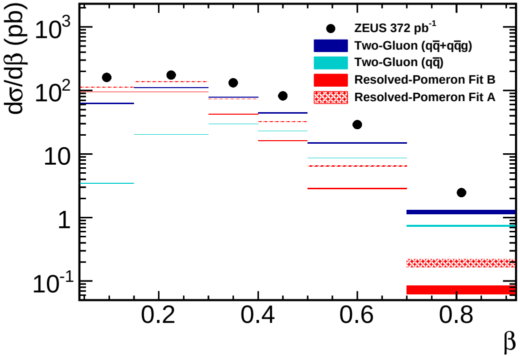






- The $p_{T,cut}$ value of $\sqrt{2}$ GeV used in the original calculation significantly underestimates the ratio.
- The measured ratio can be well described with $p_{T,cut} = 1.75$ GeV

Comparison to model predictions $d\sigma/d\beta$



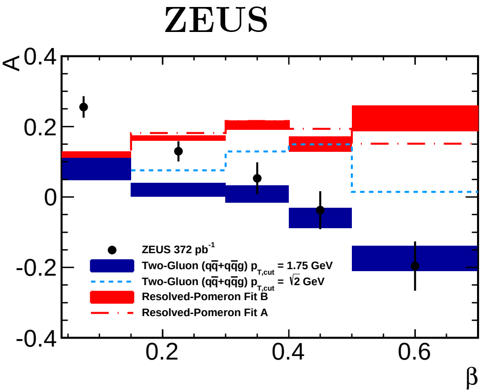
Resolved-Pomeron model

- Prediction decreases with increasing β faster than data
- Difference between data and prediction is less pronounced for fit A than for fit B

Two-Gluon-Exchange model

- Prediction describes the shape of the β distribution reasonably well
- Large difference in normalization could indicate that the NLO corrections are large or effect of the off-diagonal gluon distribution is significant
- However large uncertainty due to the p-diss subtraction make the difference not significant

Boxes correspond to statistical uncertainty only



Resolved-Pomeron model

- Almost constant, positive value of A in the whole β range

Two-Gluon-Exchange model

- Value of A varies from positive to negative
- Model agrees quantitatively with the data in the range $0.3 < \beta < 0.7$

Boxes correspond to statistical uncertainty only

Summary

- The first measurement of diffractive production of exclusive dijets in DIS was presented
- The measured absolute cross sections are larger than those predicted by both the Resolved-Pomeron and the Two-Gluon-Exchange models
- The difference between the data and the Resolved-Pomeron model at $\beta > 0.4$ is significant
- The Two-Gluon-Exchange model predictions agree with the data within the experimental uncertainty and are themselves subject to possible large theoretical uncertainties
- The shape of the ϕ distributions was parameterised as motivated by theory by $1 + A \cos 2\phi$
- The Two-Gluon-Exchange model predicts reasonably well the measured value of A as a function of β