Forward dijets in photoproduction

and the structure of the proton and photon

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Abstract

Dijet cross sections in photoproduction were measured to ..

1. compare them to NLO predictions using different photon PDFs, and to
2. use their sensitivity to the gluon PDF of the proton to get further constraints for the PDF fits.

Outline

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1. Introduction
   - Motivation
   - Data sample, event selection, and kinematics
   - Optimized dijet cross sections
   - Experimental and theoretical uncertainties
   - NLO calculations
2. Results
   - Dijet differential cross sections and comparison to NLO
   - Optimized cross sections
3. Conclusions

Motivation

- The inclusion of jet data in the ZEUS PDF fits already enhances the precision of the extracted gluon PDF.
- Looking into forward dijets to get handle on
  - γ PDF (at low x_γ)
  - gluon PDF (direct/high x_γ)
- Detailed studies have shown that forward dijets cross sections have particularly high sensitivity to the uncertainties on the gluon PDF.

Including these in the NLO fits will enhance the precision of the extracted gluon PDF

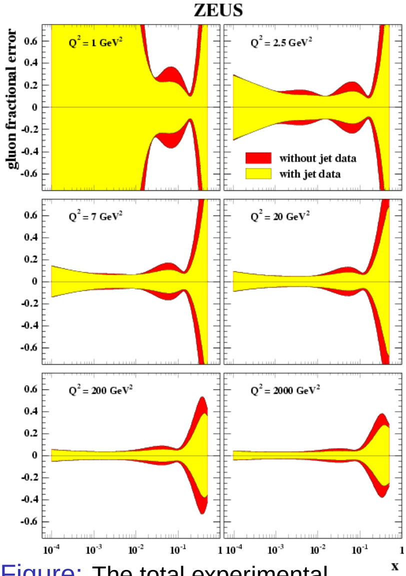


Figure: The total experimental uncertainty on the gluon PDF for the ZEUS-Jets fit (from DESY 05-050)

Motivation

Figure on the right shows E_T^{jet1} cross sections from dijets in resolved PhP

- At high E_T the predictions lie below the data.
- Which are inadequate?
  - NLO calculations?
  - Photon PDFs?
  - ...

This analysis compares other, newly measured cross sections with even more photon PDFs, including the most up-to-date ones

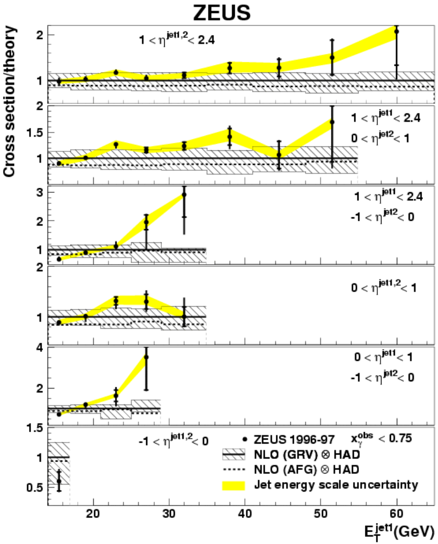


Figure: Ratio of cross sections to the central theoretical prediction as a function of E_T^{jet1} in resolved γ p (from `DESY 01-220`)

Data sample and event selection

Data Sample

ZEUS 98-00:

- $\int L = 81.8\,pb^{-1}$ (both $e^{-}p$ data and $e^{+}p$ data)

Monte Carlo:

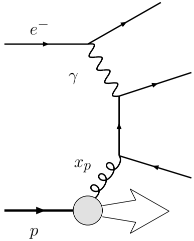
- PYTHIA 6.221
- HERWIG 6.505
- Cross sections unfolded bin-by-bin using PYTHIA

Event Selection: Dijets in Photoproduction

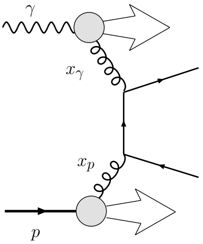
Kinematic region:	*Dijets:*
$Q^2 < 1\,\mathrm{GeV}$	$-1 < \eta < 3$,
$142\,\mathrm{GeV} < W_{\gamma p} < 293\,\mathrm{GeV}$	with at least one jet: $-1 < \eta_i < 2.5$
	$E_T^{\mathrm{jet1}} > 20\,\mathrm{GeV}$
	$E_T^{\mathrm{jet2}} > 15\,\mathrm{GeV}$

Triggering on dijets and inclusive jets

Kinematics in photoproduction



Direct process



Resolved process

Important kinematic variables

$E_T^{\text{jet1,2}}$ Transverse energy of the leading/trailing jet

$\eta^{\text{jet1,2}}$ Pseudorapidity of the leading/trailing jet

$\phi^{\text{jet1,2}}$ Azimuthal angle of the leading/trailing jet

$$x_\gamma^{obs} = \frac{E_T^{\text{jet1}} \cdot \exp^{-\eta^{\text{jet1}}} + E_T^{\text{jet2}} \cdot \exp^{-\eta^{\text{jet2}}}}{2 \cdot E_e \cdot y}$$

$$x_p^{obs} = \frac{E_T^{\text{jet1}} \cdot \exp^{\eta^{\text{jet1}}} + E_T^{\text{jet2}} \cdot \exp^{\eta^{\text{jet2}}}}{2 \cdot E_e \cdot y}$$

$$\bar{E}_T = \frac{E_T^{\text{jet1}} + E_T^{\text{jet2}}}{2}$$

$$\bar{\eta} = \frac{\eta^{\text{jet1}} + \eta^{\text{jet2}}}{2}$$

$$|\Delta\phi| = |\phi^{\text{jet1}} - \phi^{\text{jet2}}|$$

Optimized dijet cross sections

- Cross sections which show the largest sensitivity to the gluon (proton) PDF
- Sensitivity, in this context, is the uncertainty on the cross section which derives from the uncertainty on the underlying gluon PDF
- Including optimized cross sections in the PDF fits should further constrain the gluon PDF. To optimize, make forward measurements.

Experimental and theoretical uncertainties

Experimental sytematic uncertainties

- Energy scale uncertainty: varying the jet energies by $\pm 1\%$
- Model dependence: central correction factors derived from HERWIG instead of PYTHIA
- Cleaning cuts to remove DIS backgrounds and beam-gas events changed
- Fraction of direct processes in the MC sample varied
- Photon and Proton PDFs changed to WHIT2 and CTEQ4L respectively

Theoretical systematic uncertainties

- Hadronisation: half of the spread between PYTHIA and HERWIG
- α_S: CTEQ4 with three different $\alpha_S(M_Z)$ values
- Scale uncertainty: both μ_R and μ_F scales were varied

NLO calculations

- NLO calculations made using the code of Frixione and Ridolfi
- Nominal theory points made with CTEQ5M1 proton PDF and AFG04 photon PDF
- Other photon PDFs considered are

  AFG [Aurenche et al.]

  CJK [Cornet et al.]

  GRV [Glück et al.]

  SAL [Slominski et al.]

  - AFG04, AFG, GRV and CJK are performed using fits to LEP F_2^γ data
  - SAL uses ZEUS 96-97 γp data in addition to LEP F_2^γ data
  - CJK includes a better treatment of heavy quarks

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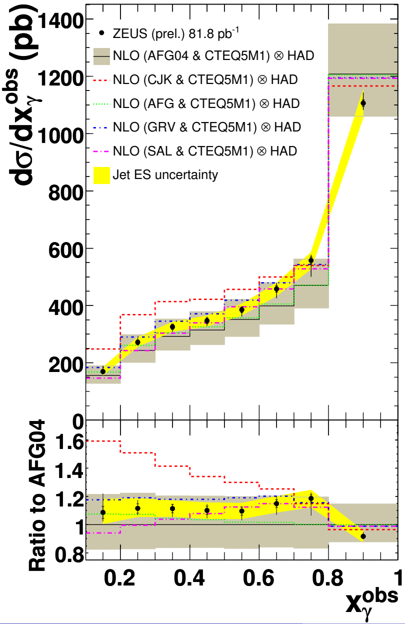
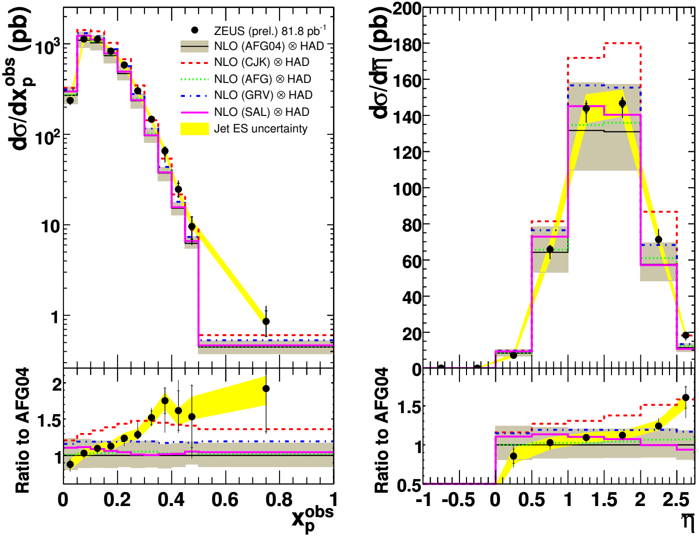
Cross sections as a function of x_γ^{obs}



- Large uncertainty towards low x_γ^{obs} due to choice of photon PDF
- Reasonable agreement between data and theory with all PDFs other than CJK

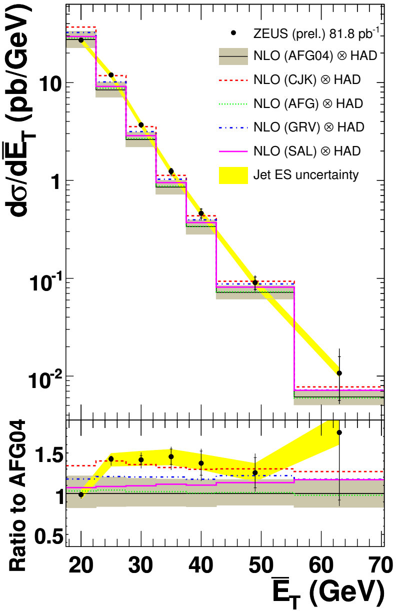
Cross sections as functions of x_p^{obs} and $\bar{\eta}$ for $x_\gamma^{obs} < 0.75$



Data lie between predictions in low x_p^{obs} bins but tend to lie above the predictions at higher x_p^{obs}.

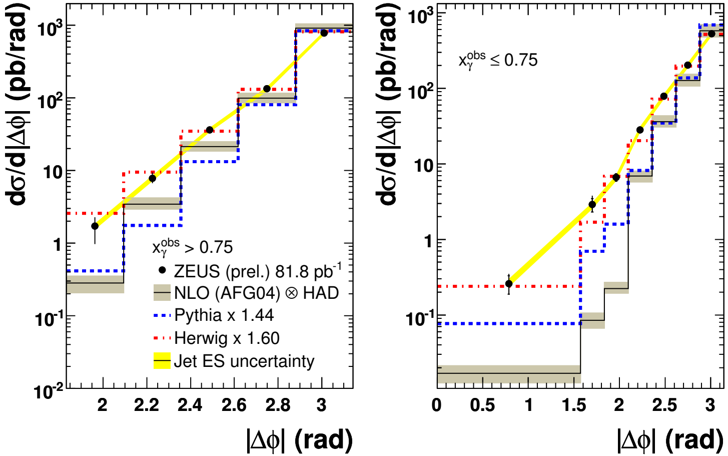
For $\bar{\eta}$ not too much discrepancy within the relevant uncertainties.

Cross sections as a function of $\bar{E}_T$ for $x_\gamma^{obs} < 0.75$



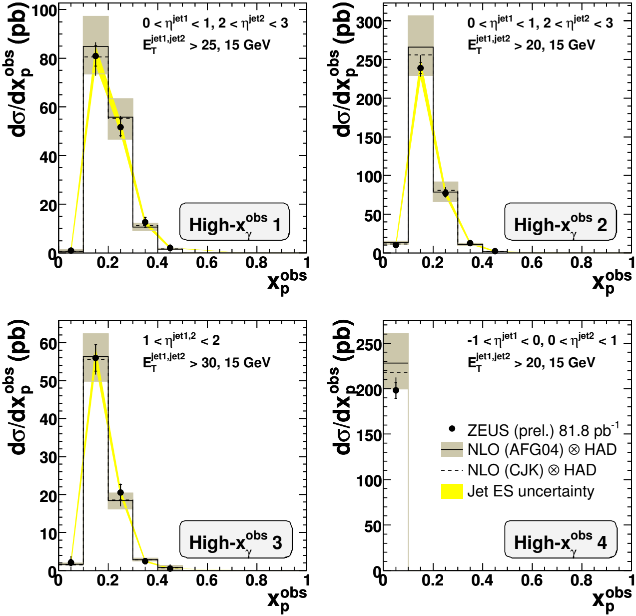
Agreement is good in the lowest $\bar{E}_T$ bin but the data tend to lie above the predictions at higher $\bar{E}_T$.

Cross sections as a function of $|\Delta\phi|$



- Very poor description by NLO
- Poor description by PYTHIA
- Good description by HERWIG

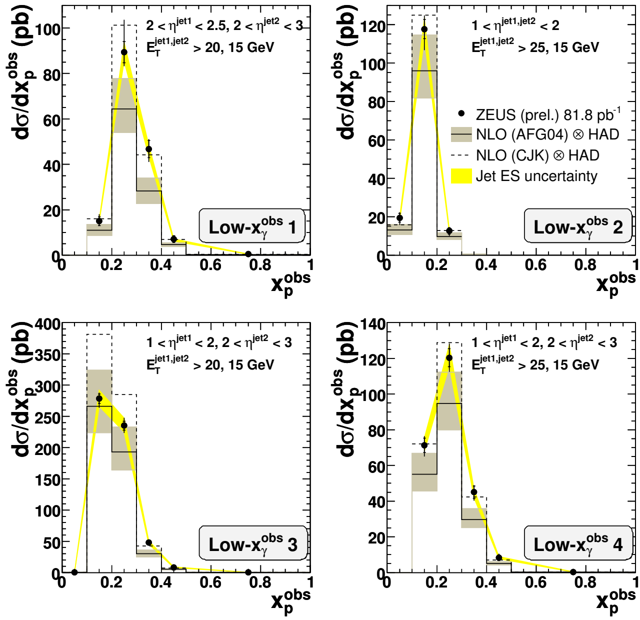
High x_γ^{obs} optimized cross sections



Good agreement between high-x_γ^{obs} optimized cross sections and NLO

Due to the underlying direct process at high-x_γ^{obs}, these cross sections are not so sensitive to the photon PDF and therefore give a good handle on the proton

Low x_γ^{obs} optimized cross sections



Reasonable agreement between low-x_γ^{obs} optimized cross sections and NLO.

Data still give handle on proton PDF but require to take photon PDFs and their systematics into account.

Outline

Summary & Conclusions

- 98-00 high-E_T forward dijet cross sections have been measured
- Good agreement of the *direct* enriched cross sections with NLO pQCD, large photon PDF uncertainties associated with *resolved* enriched cross sections
- No photon PDF provides an adequate description of ZEUS resolved γp data across all the regions of phase space and variables studied during this analysis.
- $|\Delta\phi|$ cross sections are inadequately described by NLO and are intrinsically sensitive to higher-orders.
- Data have the potential to further constrain the parton densities of the proton and photon and should be used in future fits.

Outline

4. Appendix
   - Event selection
   - Systematics
   - Optimized dijet cross sections
   - References

Data sample and event selection

Data Sample

ZEUS 98-00:

- $\int L = 81.8\,pb^{-1}$ (both e^-p data and e^+p data), $\sharp^{dijet}_{events} = 31,203$

Monte Carlo:

- PYTHIA 6.221, $\sum MC = 0.44 \cdot MC_{res} + 0.56 \cdot MC_{dir}$
- HERWIG 6.505, $\sum MC = 0.42 \cdot MC_{res} + 0.58 \cdot MC_{dir}$

Event Selection: Dijets in Photoproduction

Event Cuts:	*Dijets:*
$-40\,cm < z_{vtx} < 40\,cm$	$-1 < \eta < 3$,
$n^{trk}_{vtx} > 0.1$	with at least one jet: $-1 < \eta_i < 2.5$
no $e^- \vee (E^{'}_{el} < 5\,GeV \wedge y_{el} > 0.7)$	$E_{T,Jet1} > 20\,GeV$
$0.15 < y_{JB} < 0.7$	$E_{T,Jet2} > 15\,GeV$
$\frac{p_T}{\sqrt{E_T}} < 1.5\,\sqrt{GeV}$	

Triggering on dijets and inclusive jets

Experimental systematic uncertainties

Systematic	*Variation*	$\pm$
ES uncertainty	measured jet energies varied by $\pm 1\%$	5%
$\lvert z_{vtx} \rvert$ cut	vertex cut $\pm$ 10 cm	
N^{vtx}_{trks}/N_{trks}	ratio vertex fitted tracks cut $\pm$ 0.05	
$\frac{p_T}{\sqrt{E_T}}$	missing E_T cut $\pm$ 0.25 GeV$^{0.5}$	1%
E_e Cut	E_{el} cut $\pm$ 1 GeV	
y_{el} cut	y_{el} cut $\pm$ 0.05	
MC weights	varied within limits of fits (Dir.: 0.34/0.70)	$^{+2}_{-5}\%$
E_T corr.	used corrections derived from HERWIG	4%
Accept. correction	unfolding performed using HERWIG	
CTEQ4L	Proton PDF changed from CTEQ5L to CTEQ4L	1.5%
WHIT2	Photon PDF changed from GRV to WHIT2	2.5%

Table of optimized dijet cross sections

	Label	x_γ^{obs} Cut	$E_{T,1}$ Cut	$E_{T,2}$ Cut	η^1 Cut	η^2 Cut
Direct enriched	High-x_γ 1	$x_\gamma^{obs} > 0.75$	20	15	$2 < \eta < 2.5$	$2 < \eta < 3$
	High-x_γ 2	$x_\gamma^{obs} > 0.75$	25	15	$1 < \eta < 2$	$1 < \eta < 2$
	High-x_γ 3	$x_\gamma^{obs} > 0.75$	20	15	$1 < \eta < 2$	$2 < \eta < 3$
	High-x_γ 4	$x_\gamma^{obs} > 0.75$	25	15	$1 < \eta < 2$	$2 < \eta < 3$
Resolved enriched	Low-x_γ 1	$x_\gamma^{obs} < 0.75$	25	15	$0 < \eta < 1$	$2 < \eta < 3$
	Low-x_γ 2	$x_\gamma^{obs} < 0.75$	20	15	$0 < \eta < 1$	$2 < \eta < 3$
	Low-x_γ 3	$x_\gamma^{obs} < 0.75$	25	15	$1 < \eta < 2$	$1 < \eta < 2$
	Low-x_γ 4	$x_\gamma^{obs} < 0.75$	20	15	$-1 < \eta < 0$	$0 < \eta < 1$

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