Hard diffraction in photoproduction

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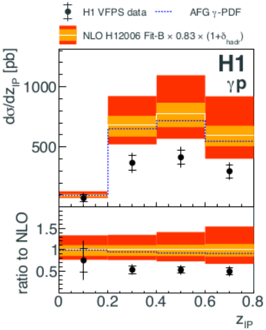
- Motivation
- Photoproduction framework in PYTHIA 8
- Hard diffraction in ep
- Hard diffraction in UPCs
- Conclusion and outlook

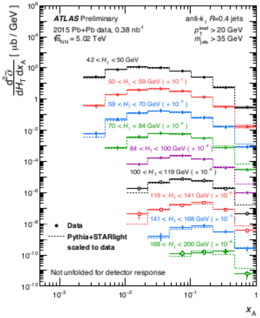
Motivation

- Explanation for factorisation breaking in photoproduction regime in ep collisions.
- ATLAS feasibility study of dijets in ultraperipheral collissions (UPCs). Wish to extend to diffractive dijets.

[H1: JHEP 1505 (2015) 056]



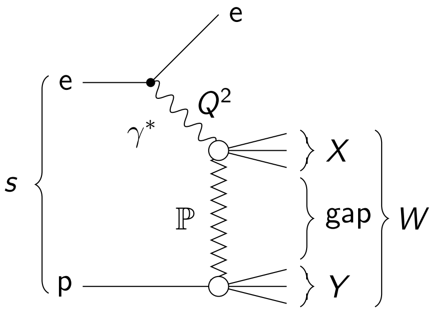
[ATLAS-CONF-2017-011]



Based on arXiv:1901.05261[hep-ph] with I. Helenius.

Photoproduction framework

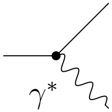
- Photoproduction: Low virtuality photons, $Q^2 \lesssim 1$ GeV^2
- Factorize photon flux, $f_\gamma(x, Q^2)$, from hard scattering
- Sample photon kinematics, x, Q^2, from flux
- Setup $\gamma\mathrm{p}$ subcollission with invariant mass of $W_{\gamma\mathrm{p}}$
- For single diffraction either $Y = p$ or $X = \rho, \phi, \omega, J/\psi$ etc.



Diffraction in ep

Photoproduction framework

Photon flux depends on beam particle:



- Q^2-integrated photon flux from leptons (Weizsäcker-Williams):

$$f_{\gamma/\mathrm{e}}(x) = \frac{\alpha_{\mathrm{em}}}{2\pi} \frac{1+(1-x)^2}{x} \log\left[\frac{Q^2_{\mathrm{max}}(1-x)}{m_{\mathrm{e}}^2 x^2}\right]$$

- Q^2-integrated photon flux from protons (Drees-Zeppenfeld) :

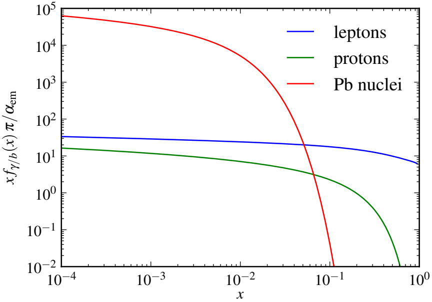
$$f_{\gamma/\mathrm{p}}(x) = \frac{\alpha_{\mathrm{em}}}{2\pi} \frac{1+(1-x)^2}{x} \left[\log(A) - \frac{11}{6} + \frac{3}{A} - \frac{3}{2A^2} + \frac{1}{3A^3}\right],$$

$$A = 1 + Q_0^2/Q^2_{\mathrm{min}} \quad , \quad Q_0^2 = 0.71\,\mathrm{GeV}^2$$

Photoproduction framework

- Photon flux from nuclei found in impact-parameter space
- Reject events where nuclei overlap, $b_{min} \sim R_{A_1} + R_{A_2}$

$$f_{\gamma/\mathrm{A}}(x) = \frac{\alpha_{\mathrm{em}} Z^2}{\pi x} \left[2\xi K_1(\xi) K_0(\xi) - \xi^2 (K_1^2(\xi) - K_0^2(\xi)) \right],$$
$$\xi = b_{\mathrm{min}}\, x\, m_N$$



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Photoproduction framework

- Cross section found by convolution:

$$\mathrm{d}\sigma(\mathrm{ep} \to 2\,\mathrm{jets}) = f_{\gamma/\mathrm{e}}(x) \otimes \mathrm{d}\sigma(\gamma\mathrm{p} \to 2\,\mathrm{jets})$$

- Split between direct and resolved photoproduction
- In direct the photon initiates the hard process:

$$\mathrm{d}\sigma_{\mathrm{dir}} = f_{j/\mathrm{p}}(x_j, Q^2) \otimes \mathrm{d}\sigma(\gamma j \to 2\,\mathrm{jets})$$

- In resolved photoproduction the photon fluctuates into hadronic state before hard process: either meson state (VMD) or anomalous state described by $\gamma \to \mathrm{q}\overline{\mathrm{q}}$ splitting kernel:

$$\mathrm{d}\sigma_{\mathrm{res}} = f_{i/\gamma}(x_\gamma, Q^2) \otimes f_{j/\mathrm{p}}(x_j, Q^2) \otimes \mathrm{d}\sigma(ij \to 2\,\mathrm{jets})$$

- Requires PDF for parton in hadronic photon, $f_{i/\gamma}(x_\gamma, Q^2)$

Photoproduction framework

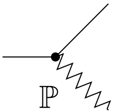
In PYTHIA 8, separation into VMD/anomalous not explicitly done in resolved photoproduction, but based on $\gamma \to \mathrm{q}\overline{\mathrm{q}}$ splitting kernel present in DGLAP evolution:

$$\frac{\partial f_{i/\gamma}(x_i, Q^2)}{\partial \log(Q^2)} = \frac{\alpha_{\mathrm{em}}(Q^2)}{2\pi} e_i^2 P_{i\gamma}(x_i) + \frac{\alpha_{\mathrm{s}}(Q^2)}{2\pi} \sum_j \int_{x_i}^1 \frac{\mathrm{d}z}{z} P_{ij}(z) f_{j/\gamma}(\frac{x_i}{z}, Q^2)$$

If resolved parton i is traced back to the original photon in ISR evolution, no further ISR, MPIs allowed below the scale Q_0^2 used in this splitting.

Photoproduction framework

For diffractive dijets:



- Factorize out Pomeron flux from proton, $f_{\mathbb{P}/\mathrm{p}}(x_{\mathbb{P}})$:

$$\mathrm{d}\sigma(\mathrm{ep} \to \mathrm{ep} + 2\,\mathrm{jets}) = f_{\mathbb{P}/\mathrm{p}}(x_{\mathbb{P}}) \otimes f_{\gamma/\mathrm{e}}(x) \otimes \mathrm{d}\sigma(\gamma\mathbb{P} \to 2\,\mathrm{jets})$$

- Factorize $\gamma\mathbb{P}$-system into hard process and Pomeron PDFs:

$$\begin{aligned}\mathrm{d}\sigma(\gamma\mathbb{P} \to 2\,\mathrm{jets}) = & f_{j/\mathbb{P}}(x_{j/\mathbb{P}}, Q^2) \otimes \mathrm{d}\sigma(\gamma j \to 2\,\mathrm{jets}) \\ & + f_{i/\gamma}(x_{\gamma}, Q^2) \otimes f_{j/\mathbb{P}}(x_{j/\mathbb{P}}, Q^2) \otimes \mathrm{d}\sigma(ij \to 2\,\mathrm{jets})\end{aligned}$$

Hard diffraction in pp with PYTHIA 8

Assume a regular PDF can be split into a diffractive (D) and non-diffractive (ND) part:

$$f_{i/\mathrm{p}}(x_i, Q^2) = f_{i/\mathrm{p}}^{\mathrm{ND}}(x_i, Q^2) + f_{i/\mathrm{p}}^{\mathrm{D}}(x_i, Q^2) \ ,$$
$$f_{i/\mathrm{p}}^{\mathrm{D}}(x_i, Q^2) = \int_{x_i}^{1} \frac{\mathrm{d}x_{\mathbb{P}}}{x_{\mathbb{P}}} f_{\mathbb{P}/\mathrm{p}}(x_{\mathbb{P}}) f_{i/\mathbb{P}}(\frac{x_i}{x_{\mathbb{P}}}, Q^2) \ ,$$

Define tentative probability for diffraction ("PDF" probability):

$$P_A^{\mathrm{D}} = \frac{f_{i/B}^{\mathrm{D}}(x_i, Q^2)}{f_{i/B}(x_i, Q^2)} \quad , \quad P_B^{\mathrm{D}} = \frac{f_{i/A}^{\mathrm{D}}(x_i, Q^2)}{f_{i/A}(x_i, Q^2)} \ ,$$

Gap survival introduced with MPI framework ("MPI" probability)

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MPI parameters in Pythia 8

- Probability for MPIs from $2 \to 2$ QCD cross sections

$$\frac{\mathrm{d}P_{\mathrm{MPI}}}{\mathrm{d}p_{\perp}^2} = \frac{1}{\sigma_{\mathrm{ND}}(\sqrt{s})} \frac{\mathrm{d}\sigma_{2\to 2}}{\mathrm{d}p_{\perp}^2}$$

- Divergent for $p_{\perp} \to 0$
- Regularized by screening parameter $p_{\perp 0}$

$$\frac{\mathrm{d}\sigma_{2\to 2}}{\mathrm{d}p_{\perp}^2} \propto \frac{\alpha_S(p_{\perp}^2)}{p_{\perp}^4} \to \frac{\alpha_S(p_{\perp 0}^2 + p_{\perp}^2)}{(p_{\perp 0}^2 + p_{\perp}^2)^2}$$

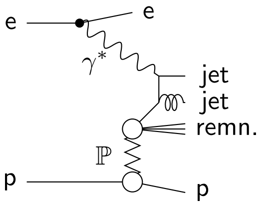
- Energy dependence through

$$p_{\perp 0}(\sqrt{s}) = p_{\perp 0}^{\mathrm{ref}} \left(\frac{\sqrt{s}}{\sqrt{s_{\mathrm{ref}}}} \right)^p$$

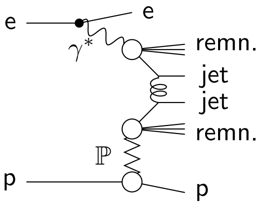
- For pp $p_{\perp 0}^{\mathrm{ref}} = 2.28\ \mathrm{GeV}$, while $\gamma\mathrm{p}$ has $p_{\perp 0}^{\mathrm{ref}} = 3.00\ \mathrm{GeV}$

Hard diffraction in ep

- Tentative probability equals full probability for diffraction in direct events
- Gap survival introduced in resolved events, by requiring no additional MPIs in the γp system, as these would destroy the rapidity gap



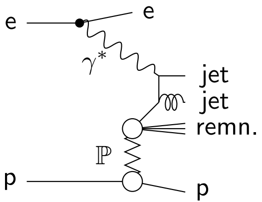
Diffractive dijets in direct photoproduction



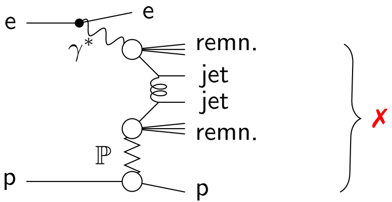
Diffractive dijets in resolved photoproduction

Hard diffraction in ep

- Tentative probability equals full probability for diffraction in direct events
- Gap survival introduced in resolved events, by requiring no additional MPIs in the $\gamma\mathrm{p}$ system, as these would destroy the rapidity gap



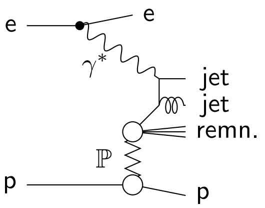
Diffractive dijets in direct photoproduction



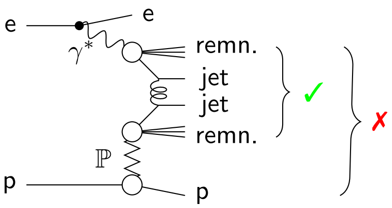
Diffractive dijets in resolved photoproduction

Hard diffraction in ep

- Tentative probability equals full probability for diffraction in direct events
- Gap survival introduced in resolved events, by requiring no additional MPIs in the γp system, as these would destroy the rapidity gap



Diffractive dijets in direct photoproduction



Diffractive dijets in resolved photoproduction

Hard diffraction in ep

H1 2007 [EPJC 51 (2007) 549]

- $Q^2 < 0.01\ \mathrm{GeV}^2$
- $E_\perp^{*\,\mathrm{jet}\,1} > 5.0\ \mathrm{GeV}$
- $E_\perp^{*\,\mathrm{jet}\,2} > 4.0\ \mathrm{GeV}$
- $-1 < \eta^{\mathrm{jet}\,1,2} < 2.0$
- $x_{\mathbb{P}} < 0.03$

ZEUS 2008 [EPJC 55 (2008) 177]

- $Q^2 < 1\ \mathrm{GeV}^2$
- $E_\perp^{\mathrm{jet}\,1} > 7.5\ \mathrm{GeV}$
- $E_\perp^{\mathrm{jet}\,2} > 6.5\ \mathrm{GeV}$
- $-1.5 < \eta^{\mathrm{jet}\,1,2} < 1.5$
- $x_{\mathbb{P}} < 0.025$

Baseline setup

- dPDFs from H1 Fit B LO
- γPDFs from CJKL
- $p_{\perp 0}^{\mathrm{ref}} = 3.00\mathrm{GeV}$

Observables:

- W (H1)
- M_X (ZEUS)
- $z_{\mathbb{P}} = \frac{\sum_{\mathrm{jet}=1,2}(E^{\mathrm{jet}}+p_z^{\mathrm{jet}})}{\sum_{i\in X}(E^i+p_z^i)}$

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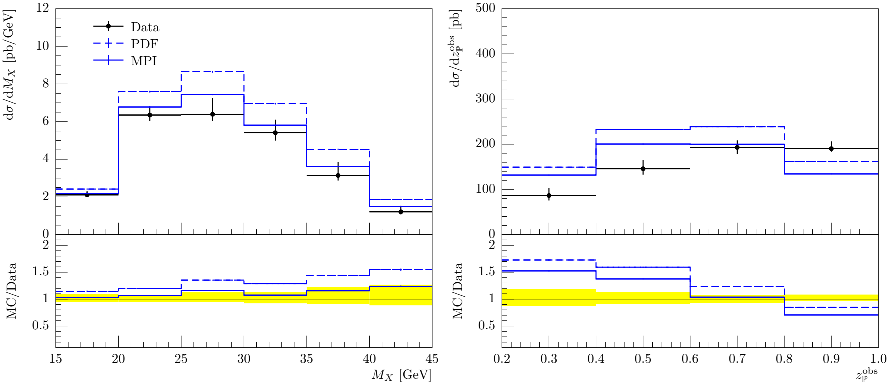
Hard diffraction in ep

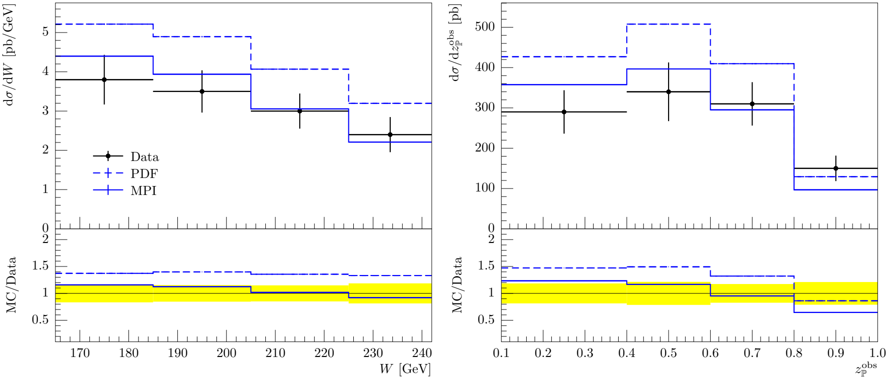
ZEUS 2008:



- PDF sample overshoots data
- Better agreement with additional gap suppression
- Some distributions not well described (eg. $x_\gamma, z_\mathbb{P}$)

Hard diffraction in ep

H1 2007:



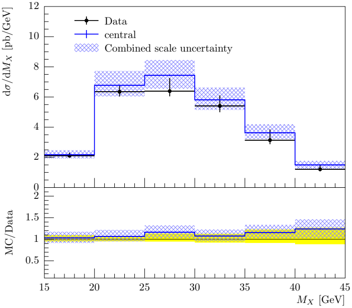
- PDF sample overshoots data
- Better agreement with additional gap suppression
- Some distributions not well described (eg. $x_\gamma, z_{\mathbb{P}}$)

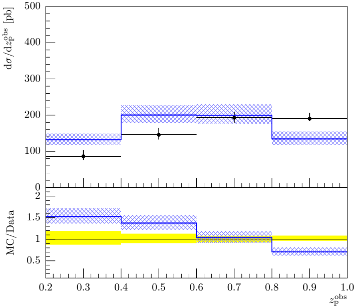
Hard diffraction in ep

Uncertainties arise from:

- LO ME
- dPDFs
- γPDFs
- MPI parameters

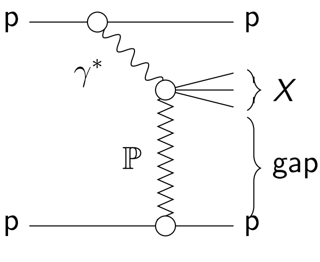
ZEUS 2008:



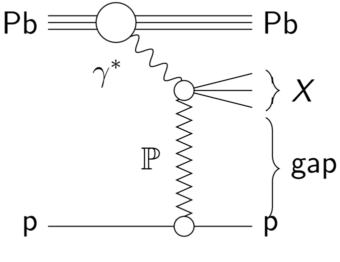


Hard diffraction in UPCs

- Predictions for pp and pPb.
- Photon flux from either side in pp, flux from lead dominates in pPb
- Currently PbPb not possible as additional interactions between resolved photon and other nucleons should be taken into account in gap suppression



Diffraction in UPC pp



Diffraction in UPC pPb

Hard diffraction in UPCs

Cuts:

- $\sqrt{s_{\mathrm{NN}}} = 5.0$ TeV (pp), $\sqrt{s_{\mathrm{NN}}} = 13.0$ TeV (pPb)
- $E^{1}_{\perp,\mathrm{min}} = 8.0$ GeV
- $E^{2}_{\perp,\mathrm{min}} = 6.0$ GeV
- $M_{\mathrm{jets,min}} = 14.0$ GeV
- $x_{\mathbb{P}}^{\mathrm{max}} = 0.025$
- $|\eta^{\mathrm{max}}| = 4.4$

Baseline setup

- dPDFs from H1 Fit B LO
- γPDFs from CJKL

Observables:

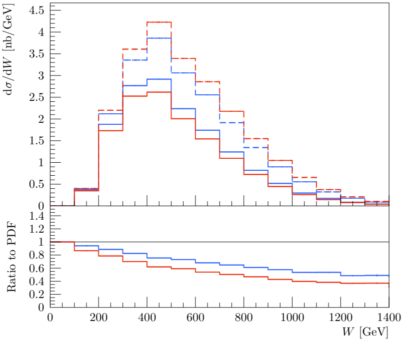
- W

- Two values of MPI screening parameter used: $p^{\mathrm{ref}}_{\perp 0} = 2.28\mathrm{GeV}$ (red lines) and $p^{\mathrm{ref}}_{\perp 0} = 3.00\mathrm{GeV}$ (blue lines)
- Dashed lines are “PDF” samples, solid lines “MPI” samples

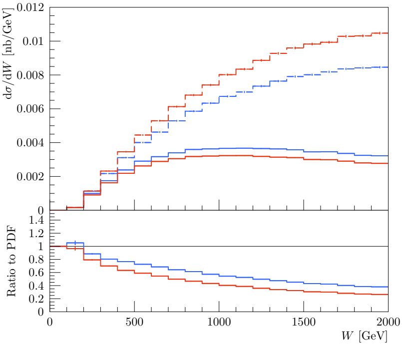
Hard diffraction in UPCs

$p_{\perp 0}^{\mathrm{ref}} = 2.28\mathrm{GeV}$ and $p_{\perp 0}^{\mathrm{ref}} = 3.00\mathrm{GeV}$

pPb:



pp:

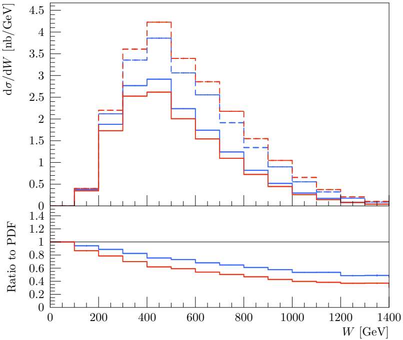


- Rejecting additional MPIs reduces cross section drastically as compared to HERA
- Suppression stronger in pp as harder flux leads to larger $W_{\gamma\mathrm{p}}$, allowing for more MPIs

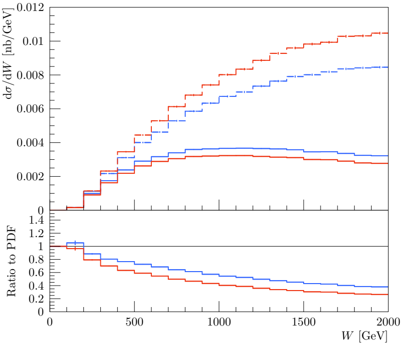
Hard diffraction in UPCs

$p_{\perp 0}^{\mathrm{ref}} = 2.28\mathrm{GeV}$ and $p_{\perp 0}^{\mathrm{ref}} = 3.00\mathrm{GeV}$

pPb:



pp:



- Lower MPI-screening value allows for more MPIs, thus leads to larger suppression
- UPCs provide ideal place to test gap-survival model, as effects are more pronounced here w.r.t. HERA

Conclusion and outlook

- Hard diffraction for photoproduction available, without any new parameters.
- Reasonable description of HERA data with gap suppression.
- Several theoretical uncertainties, e.g. dPDF, γPDF, MPI parameters.
- Ratio DIS/photoproduction could be used to reduce theoretical uncertainties (DIS description not ready yet).
- Predictions for UPCs at LHC presented.
- Gap suppression larger here due to higher $W_{\gamma\mathrm{p}}$.
- Excellent place to test model (awaiting data).
- Extension to eA or UPC PbPb with Angantyr expected.

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