Inclusive dijet photoproduction in UPCs at the LHC in NLO QCD

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Work done with V. Guzey

DFG

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Research Training Group

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Bundesministerium für Bildung und Forschung

References

- V. Guzey, MK
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  Phys. Rev. C 99 (2019) 065202 [1811.10236]

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  Constraints on nuclear PDFs from dijet photoproduction at the LHC
  Eur. Phys. J. C 79 (2019) 396 [1902.05126]

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  Future physics opportunities for high-density QCD at the LHC with heavy-ion and proton beams
  WG5 of the CERN Workshop [1812.06772]

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- V. Guzey, MK
  Diffractive dijet photoproduction in UPCs at the LHC in NLO QCD
  JHEP 1604 (2016) 158 [1603.06055]

Motivation

A. Baltz, V. Guzey, MK et al., Phys. Rep. 458 (2008) 1

Ultraperipheral collisions (UPCs) of relativistic ions:

- Defined by large impact parameter ($b > 2\,R_A$)
- Suppression of short-range strong interactions
- Interaction by quasi-real photons $\rightarrow \gamma\gamma$ and γA scattering

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Examples of physics processes:

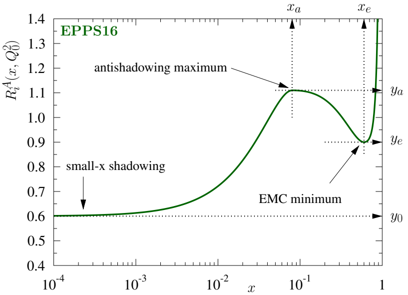
- Quarkonium and dilepton pair production
- Light-by-light scattering
- Searches for BSM physics
- Includive dijet photoproduction

Nuclear parton distribution functions

K. Kovarik, P. Nadolsky, D. Soper, Rev. Mod. Phys. (to appear), 1905.06957

Definition:

$$f_i^{p/A}(x, Q^2) = R_i^A(x, Q^2) f_i^p(x, Q)$$



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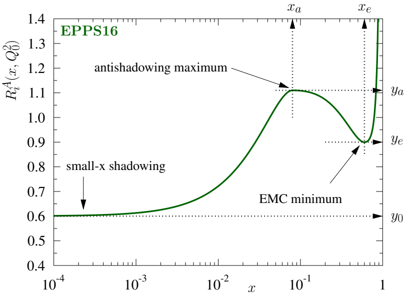
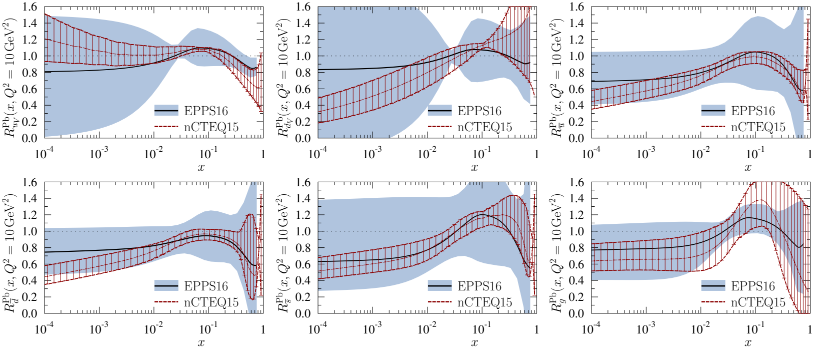


Regions:

- Shadowing: Surface nucleons absorb $q\bar{q}$ dipole, cast shadow
- Antishadowing: Imposed by momentum sum rule
- EMC effect: q_v suppression due to nuclear binding, pions, quark clusters, Nachtmann scaling, short-range correlations, ...
- Fermi motion: Nucleons move, $F_2^A = \int_x^A dz\ f_N(z)\ F_2^N(\frac{x}{z})$

Current status of nuclear PDF uncertainties

K. Eskola, P. Paakinen, H. Paukkunen, C. Salgado, EPJC 77 (2017) 163



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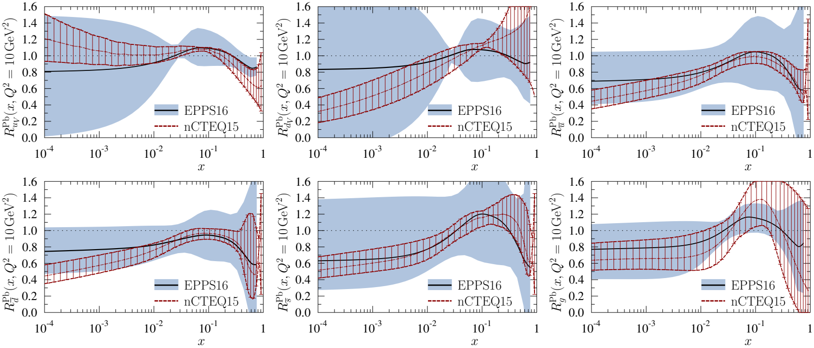


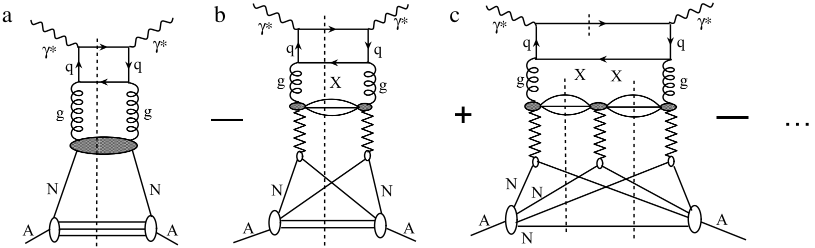
nCTEQ15: 740 data points, 18 parameters, χ^2/d.o.f. $= 0.814$

EPPS16: 1811 data points, 20 parameters, χ^2/d.o.f. $= 0.999$

Leading-twist model of nuclear shadowing

V. Guzey, L. Frankfurt, M. Strikman, Phys. Rep. 512 (2012) 255

Expansion in number of interacting nucleons:

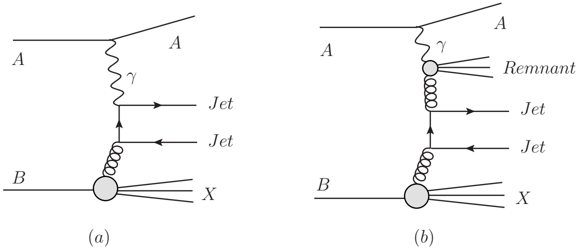


$$xf_{j/A}(x,Q_0^2) = Axf_{j/N}(x,Q_0^2) - 8\pi A(A-1)\,\Re e\frac{(1-i\eta)^2}{1+\eta^2}B_{\text{diff}}\int_x^{0.1} dx_{\mathbb{P}}\beta f_j^{D(3)}(\beta,Q_0^2,x_{\mathbb{P}})$$

$$\times\int d^2b\int_{-\infty}^{\infty}dz_1\int_{z_1}^{\infty}dz_2\rho_A(\vec{b},z_1)\rho_A(\vec{b},z_2)e^{i(z_1-z_2)x_{\mathbb{P}}m_N}e^{-\frac{A}{2}(1-i\eta)\sigma^j_{\text{soft}}(x,Q_0^2)\int_{z_1}^{z_2}dz'\rho_A(\vec{b},z')}$$

Inclusive dijet photoproduction at the LHC (1)

V. Guzey, MK, Phys. Rev. C (in press), 1811.10236



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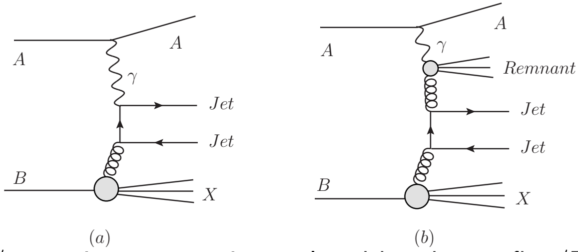

Hadronic/partonic cross sections related by photon flux/PDFs:

$$d\sigma(AB \to AB + 2\,\mathrm{jets} + X) = \sum_{a,b} \int dy \int dx_\gamma \int dx_A\, f_{\gamma/A}(y) f_{a/\gamma}(x_\gamma, \mu^2) f_{b/B}(x_A, \mu^2) d\hat{\sigma}(ab \to \mathrm{jets})$$

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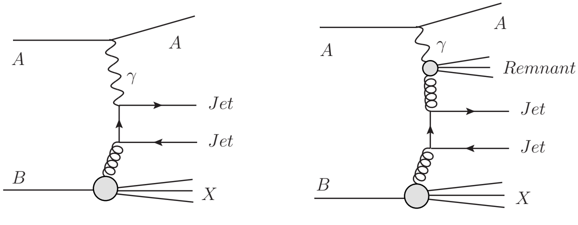

(a) (b)

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Photon flux for relativistic point-like charge Z:

$$f_{\gamma/A}(y) = \frac{2\alpha Z^2}{\pi} \frac{1}{y} \left[\zeta K_0(\zeta) K_1(\zeta) - \frac{\zeta^2}{2} (K_1^2(\zeta) - K_0^2(\zeta)) \right]$$

with $\zeta = y m_p b_{\min}$ (no strong int. for $b > b_{\min} = 2.1\, R_{\mathrm{Pb}} = 14.2\,\mathrm{fm}$).

Inclusive dijet photoproduction at the LHC (2)

V. Guzey, MK, Phys. Rev. C (in press), 1811.10236

Theoretical approach:

- Partonic cross section calculated in NLO QCD
- Scale choice: $\mu_r = \mu_f = 2E_{T,1}$ (NLO = LO, NLO' = 0)
- Photon PDFs: GRV HO
- Nuclear PDFs: nCTEQ15, $\Delta\sigma = \frac{1}{2}\sqrt{\sum_{k=1}^{31} \left(\sigma(f_k) - \sigma(f_{k+1})\right)^2}$

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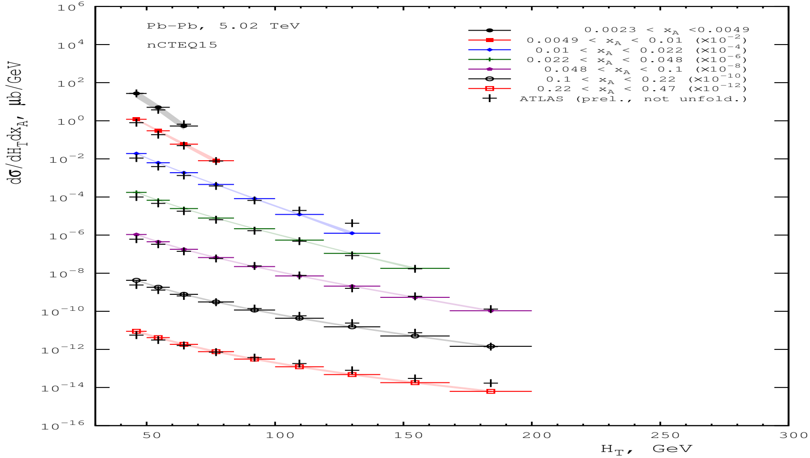
Experimental conditions:

- Anti-k_T algorithm, $R = 0.4$
- $E_{T,1} > 20$ GeV, $E_{T,2} > 15$ GeV, $H_T = \sum_i E_{T,i} > 35$ GeV
- Rapidities: $|\eta_{1,2}| < 4.4$
- Combined jet mass: $m_{\rm jets} > 35$ GeV

Comparison to preliminary ATLAS data (1)

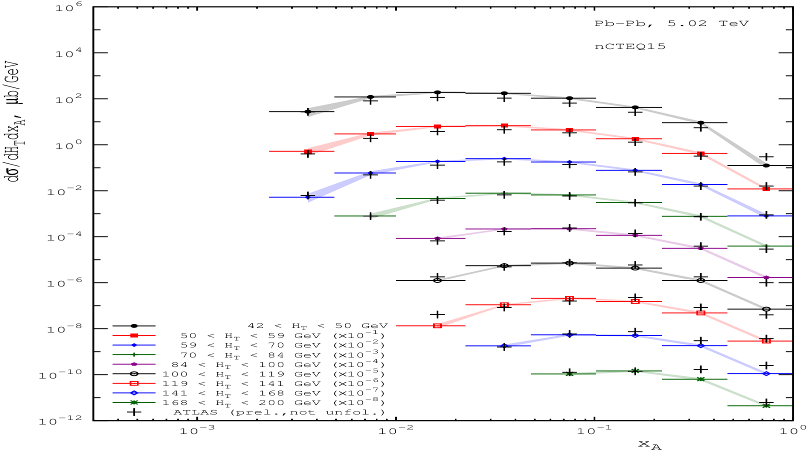
A. Angerami et al. [ATLAS Coll.], ATLAS-CONF-2017-011



Excellent agreement. NB: Data not unfolded for detector response.

Comparison to preliminary ATLAS data (2)

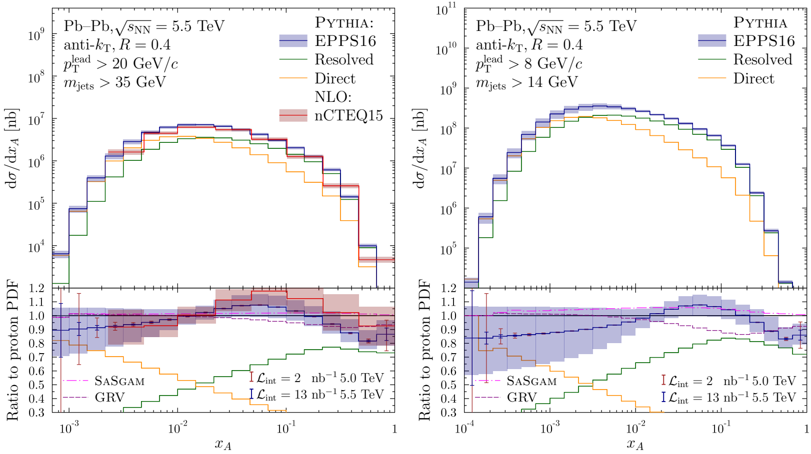
A. Angerami et al. [ATLAS Coll.], ATLAS-CONF-2017-011



Excellent agreement, also for z_γ distribution.

Inclusive dijet photoproduction at the HL-LHC

Z. Citron, V. Guzey, I. Helenius, MK, H. Paukkunen et al., 1812.06772



Large potential for improvement in nuclear shadowing region.
Resolved photon PDF uncertainty at low p_T and in EMC region.

Bayesian reweighting study of impact on nPDFs (1)

V. Guzey, MK, Eur. Phys. J. C 79 (2019) 396

Central fits $f^{0}_{j/A}$ (parton j) and error sets $f^{i\pm}_{j/A}$ ($i = 1 \ldots 2N$):

- nCTEQ15: $N = 16$ (based on CTEQ6.1M)
- EPPS16: $N = 20 + 28$ (nuclear + proton)

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Replicas ($k = 1 \dots N_{\rm rep}$, $N_{\rm rep} = 10,000$):

$$f^k_{j/A}(x, Q^2) = f^0_{j/A}(x, Q^2) + \frac{1}{2}\sum_{i=1}^{N}\left[f^{i+}_{j/A}(x, Q^2) - f^{i-}_{j/A}(x, Q^2)\right] R_{ki}$$

with normally distributed random number R_{ki} ($\mu = 0, \sigma = 1$).

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Pseudodata:

- NLO QCD prediction $d\sigma^0/dx_A$ with central PDFs $f^0_{j/A}$
- $N_{\mathrm{data}} = 9$ bins in x_A

Bayesian reweighting study of impact on nPDFs (2)

V. Guzey, MK, Eur. Phys. J. C 79 (2019) 396

χ^2 test function:

$$\chi_k^2 = \sum_{j=1}^{N_{\rm data}} \frac{(d\sigma^0/dx_A - d\sigma^k/dx_A)^2}{\sigma_j^2}$$

with assumed uncertainty $\sigma_j = \epsilon d\sigma^0/dx_A$ and $\epsilon = 0.05 \ldots 0.2$.

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Weights ($\sum_k w_k = N_{\rm rep}$):

$$w_k = \frac{e^{-\frac{1}{2}\chi_k^2/T}}{\frac{1}{N_{\rm rep}} \sum_i^{N_{\rm rep}} e^{-\frac{1}{2}\chi_i^2/T}}$$

with tolerance $T = 35\,(52)$ for nCTEQ15 (EPPS16).

Bayesian reweighting study of impact on nPDFs (3)

V. Guzey, MK, Eur. Phys. J. C 79 (2019) 396

Reweighted nPDFs and their uncertainties:

$$\langle f_{j/A}(x,Q^2)\rangle_{\rm new} = \frac{1}{N_{\rm rep}}\sum_{k=1}^{N_{\rm rep}} w_k f^k_{j/A}(x,Q^2)\,,$$

$$\delta\langle f_{j/A}(x,Q^2)\rangle_{\rm new} = \sqrt{\frac{1}{N_{\rm rep}}\sum_{k=1}^{N_{\rm rep}} w_k\left(f^k_{j/A} - \langle f_{j/A}(x,Q^2)\rangle_{\rm new}\right)^2}$$

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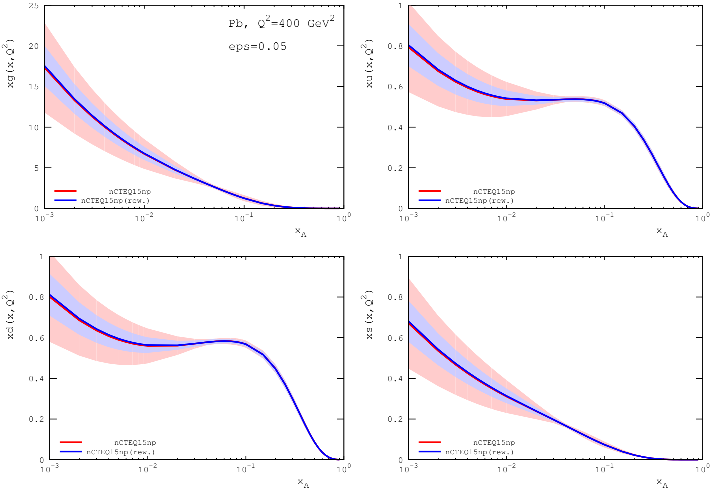
Effective number of contributing replicas:

$$N_{\rm eff} = \exp\left[\frac{1}{N_{\rm rep}}\sum_{k}^{N_{\rm rep}} w_k \ln(N_{\rm rep}/w_k)\right]$$

Impact of future ATLAS data on nPDFs

V. Guzey, MK, Eur. Phys. J. C 79 (2019) 396



nCTEQ15(np) uncertainties reduced by (more than) factor of two.

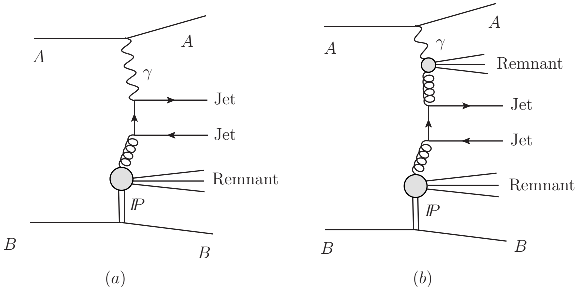
Effective number of contributing replicas

V. Guzey, MK, Eur. Phys. J. C 79 (2019) 396

ϵ	N_{eff}(nCTEQ15)	N_{eff}(nCTEQ15np)	N_{eff}(EPPS16)
0.05	4407	3982	5982
0.1	7483	7742	8727
0.15	8870	9107	9555
0.2	9464	9607	9818

Diffractive dijet photoproduction at the LHC

V. Guzey, MK, JHEP 1604 (2016) 158



Cross sections related by Pomeron flux/diffractive PDFs:

$$d\sigma = \sum_{a,b} \int dt \int dx_{\mathbf{P}} \int dz_{\mathbf{P}} \int dy \int dx_\gamma f_{\gamma/A}(y) f_{a/\gamma}(x_\gamma, \mu^2) f_{b/p}^{D(4)}(x_{\mathbf{P}}, z_{\mathbf{P}}, t, \mu^2) d\hat{\sigma}^{(n)}_{ab\to \mathrm{jets}}$$

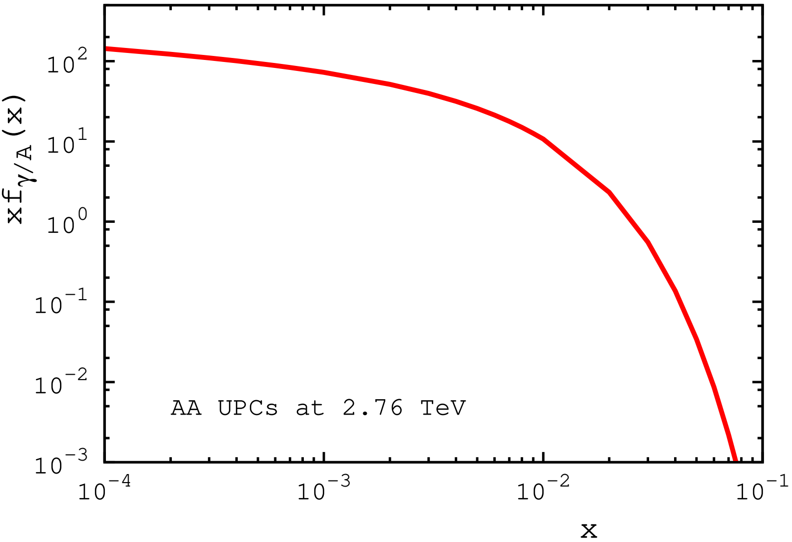
Photon flux: $f_{\gamma/A}(x) = \int d^2b\, \Gamma_{AA}(b) f_{\gamma/A}(x, b)$

Probability for the nuclei to not interact strongly (Glauber model):

$$\Gamma_{AA}(b) = \exp\left(-\sigma_{NN}^{\mathrm{tot}}(s) \int d^2\vec{b}_1\, T_A(\vec{b})\, T_A(\vec{b}_1 - \vec{b}) \right)$$

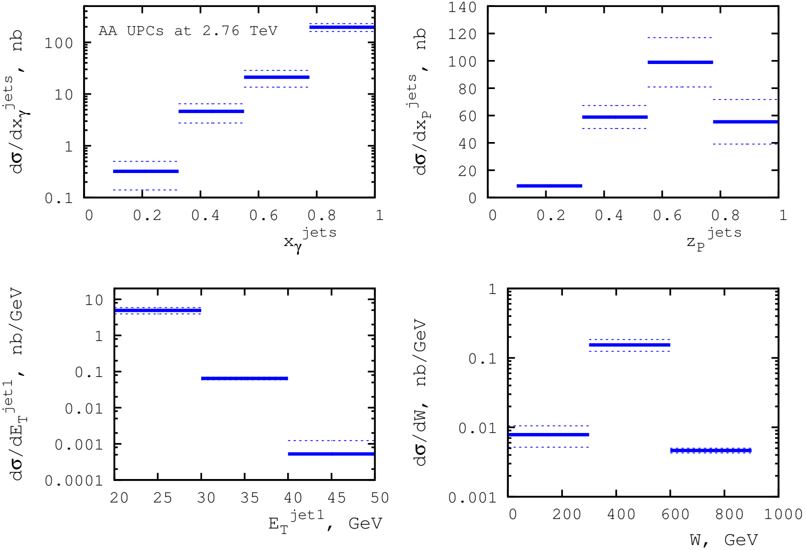
Photon spectrum in lead ions

V. Guzey, MK, JHEP 1604 (2016) 158



Diffractive photoproduction of dijets

V. Guzey, MK, JHEP 1604 (2016) 158



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Photoproduction in UPCs:

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- Final states: Dileptons, quarkonia, dijets, ...

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Diffractive dijets:

- Photon flux in lead ions calculated with Glauber model
- Diffractive nPDFs unknown → assume LT nuclear shadowing
- First NLO QCD predictions, including scale uncertainties