NLO QCD predictions for dijet photoproduction in lepton-nucleus scattering at the EIC, LHeC, HE-LHeC, and FCC

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arXiv:2003.09129

Objectives:

- Calculate cross sections using NLO pQCD and nCTEQ15 and EPPS16 nPDFs
- Predictions for dijet average p_T, η , observed momentum fraction of nucleus (x_A^{obs}) and photon (x_γ^{obs})
- Compare kinematic reach of the four colliders

Goal:

Dijet photoproduction in e+A collisions can considerably reduce the current uncertainties of nPDFs.

Introduction

- Many e+A colliders approved (EIC) and planned (LHeC, HE-LHeC, FCC)
- **HERA experience:** photoproduction of jets and dijets provides useful complimentary information on the (mostly gluon) structure of hadrons
- **LHC experience:** dijet photoproduction in Pb-Pb UPCs reduces existing uncertainty in nPDFs at small x by factor ~2
- The c.o.m. energy increase from the EIC to LHeC and beyond extends the coverage in all four variables (p_T, η , x_A^{obs}, x_γ^{obs})
- LHeC, HE-LHeC will probe the dijet cross section down to $x_A^{obs} < 10^{-4}$ (10^{-5}at FCC) → 2 (3) orders smaller than at EIC

Formalism

- In the framework of collinear factorization and NLO pQCD, the cross section of dijet photoproduction is

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

  - ***a, b*:** parton flavors
  - $f_{\gamma/e}(y)$: flux of equivalent photons of the electron, depending on photon light-cone momentum fraction y
  - $f_{a/\gamma}(x_\gamma, \mu^2)$: is the PDF of the photon for the resolved photon case, μ is the factorization scale
  - $f_{b/B}(x_A, \mu^2)$: is the nPDF
- **dijet cross section has contributions:**
  - resolved photon (photon interacts with target partons through its quark-gluon structure)
  - direct photon (photon enters directly the hard scattering cross section)
- **At NLO:** separation btw. Resolved and direct photon contrib. depends on factorization scheme and scale μ
  - direct photon dominates the cross section at $x_\gamma \approx 1$
- Weizsacker-Williams approximation used for the photon flux of the electron

$$f_{\gamma/e}(y) = \frac{\alpha}{2\pi}\left[\frac{1+(1-y)^2}{y}\ln\frac{Q^2_{\max}(1-y)}{m_e^2 y^2} + 2m_e^2 y\left(\frac{1}{Q^2_{\max}} - \frac{1-y}{m_e^2 y^2}\right)\right]$$

- **HERA experience:** take $Q^2_{max} = 0.1\text{GeV}^2$, inelasticity $0 < y < 1$
- **Photon PDFs** (GRV HO parametrization); **nPDFs** (nCTEQ15 and EPPS16 parametrizations)

Analysis

- Anti-k_T algorithm with a jet radius of R = 0.4 (at most two partons in the jet)
- Following generic conditions on final-state jets:
  - Leading jet $p_{T,1} > 5$ GeV;
  - other jets $p_{T,i\neq1} > 4.5$ GeV to avoid an enhanced sensitivity to soft radiation
  - all jets have rapidities $|\eta_{1,2}| < 4$.
- In pQCD beyond LO, light-cone momentum fractions not directly measurable

  → Estimated, using the two highest transverse-energy jets ($p_{T1} > p_{T2}$):

$$x_\gamma^{\rm obs} = \frac{p_{T,1}e^{-\eta_1} + p_{T,2}e^{-\eta_2}}{2yE_e},$$

$$x_A^{\rm obs} = \frac{p_{T,1}e^{\eta_1} + p_{T,2}e^{\eta_2}}{2E_A},$$

	E_e, GeV	E_A, TeV	$\sqrt{s}$, GeV
EIC	21	0.1	92
LHeC	60	2.76	812
HE-LHeC	60	4.93	1,088
FCC	60	19.7	2,174

Predictions - xsec

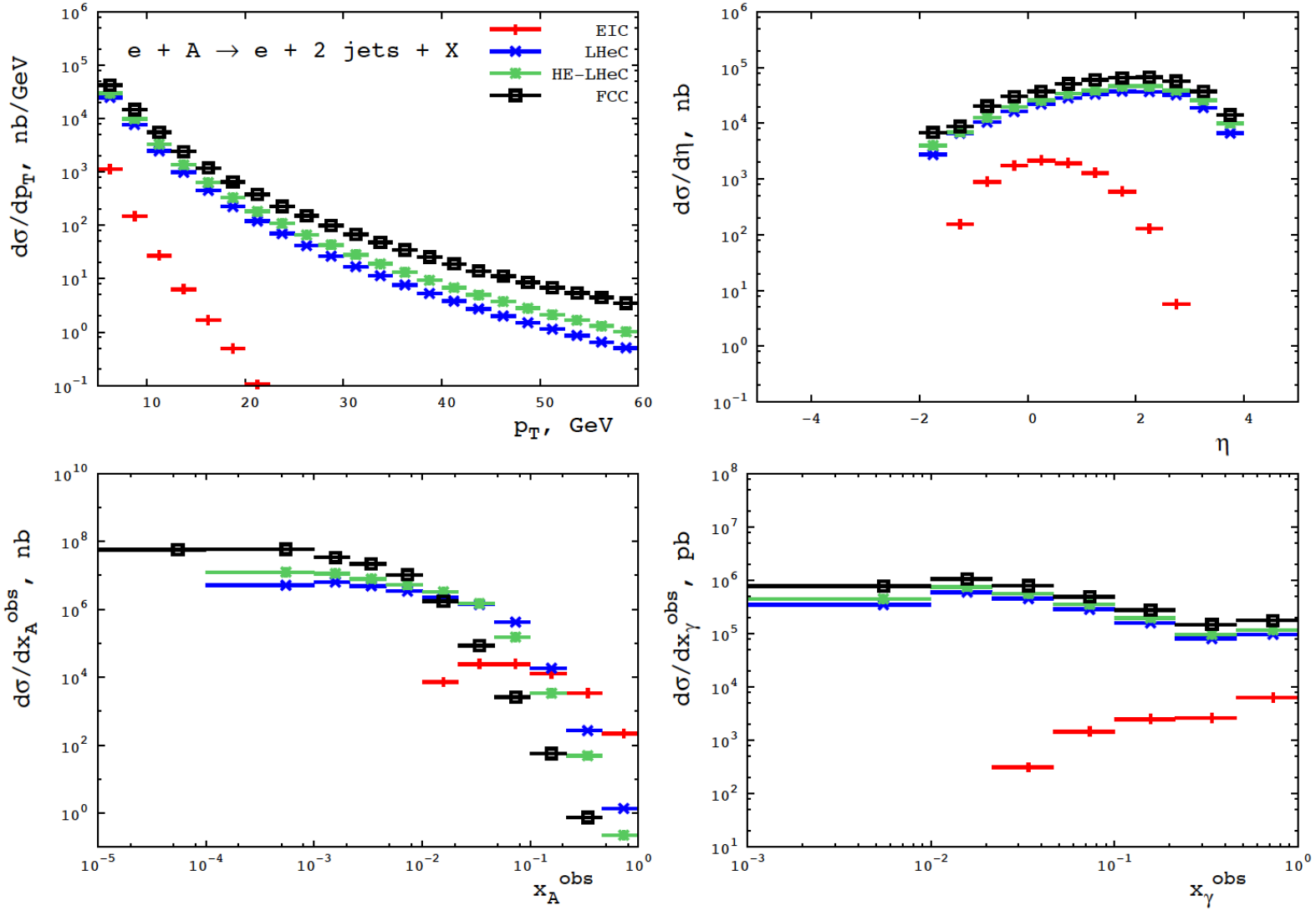


FIG. 1: NLO QCD predictions for the dijet photoproduction cross section in $eA \to e + 2\text{jets} + X$ electron–nucleus scattering at the EIC, LHeC, HE-LHeC, and FCC as a function of the average dijet transverse momentum $\bar{p}_T$, the average rapidity $\bar{\eta}$, and the momentum fractions x_A^{obs} and x_γ^{obs}. The calculation uses nCTEQ15 nPDFs.

- collision energy dramatically expands the kinematic coverage
- At the LHeC, HE-LHeC, and FCC, one probes the dijet cross cross section in the wider ranges

Predictions - nPDFs

EIC - nCTEQ15

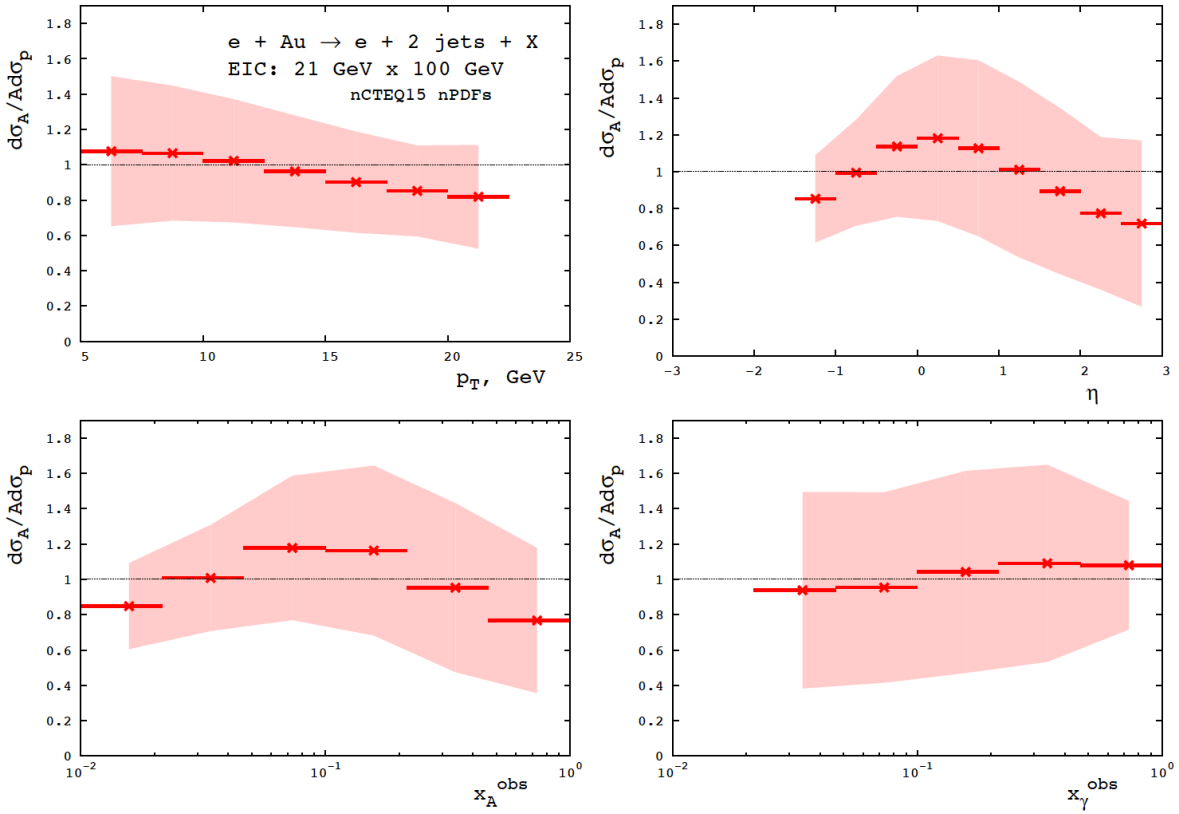


FIG. 2: NLO QCD predictions for the ratio of the cross sections of dijet photoproduction on nuclei and the proton as a function of $\bar{p}_T$, $\bar{\eta}$, $x_A^{\rm obs}$, and $x_\gamma^{\rm obs}$ in the EIC kinematics. The calculation uses central values of nCTEQ15 nPDFs (solid lines) and 32 sets of error PDFs (shaded band).

EIC – EPPS16

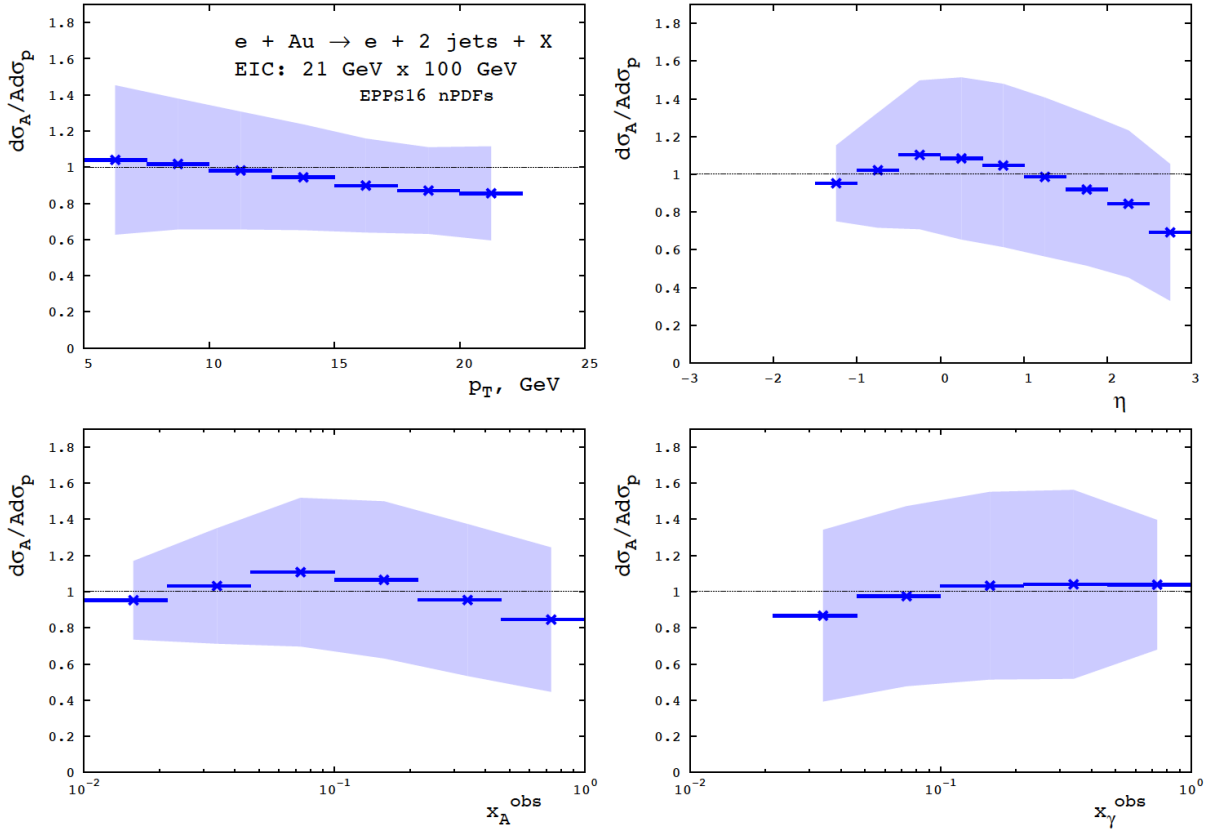
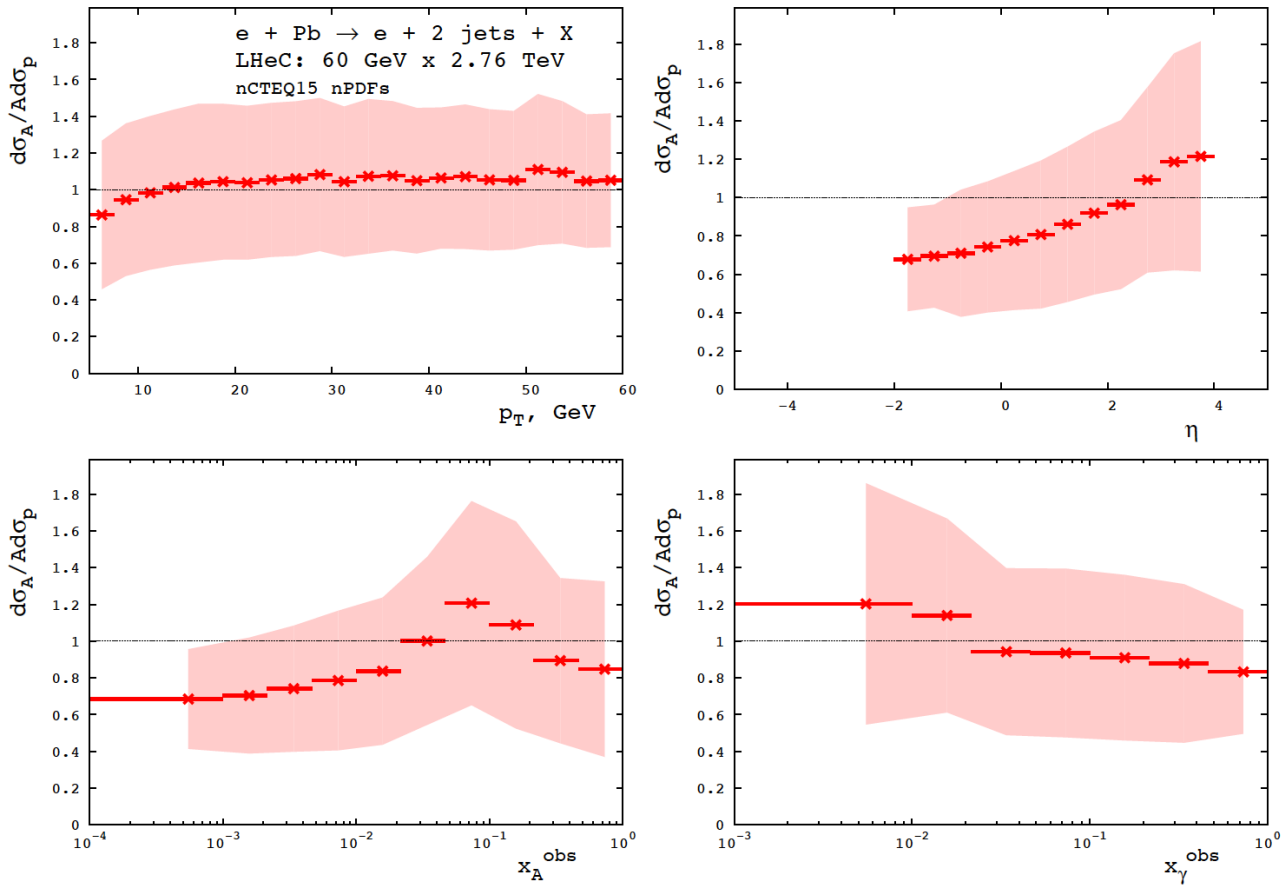


FIG. 3: NLO QCD predictions for the ratio of the cross sections of dijet photoproduction on nuclei and the proton as a function of $\bar{p}_T$, $\bar{\eta}$, $x_A^{\rm obs}$, and $x_\gamma^{\rm obs}$ in the EIC kinematics. The calculation uses central values of EPPS16 nPDFs (solid lines) and 40 sets of error PDFs (shaded band).

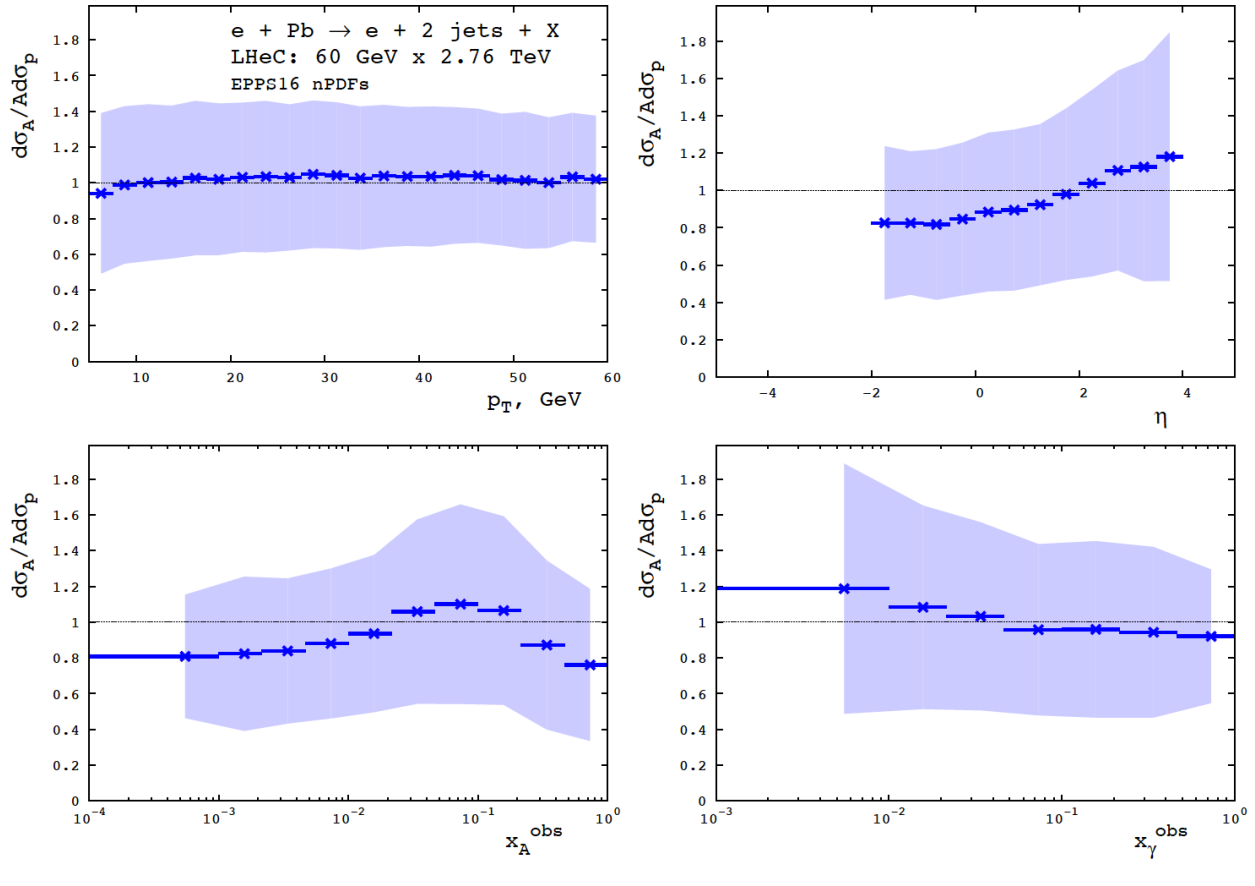
- Magnitude of nuclear modifications of the dijet cross section is ~10–20% and is smaller than the the current theoretical uncertainties of nCTEQ15 and EPPS16 nPDFs

Predictions - nPDFs

LHeC - nCTEQ15



LHeC – EPPS16



Results for the HE-LHeC and FCC closely resemble those for the LHeC

- Nuclear modifications are more pronounced in the kinematics of LHeC (HE-LHeC, FCC) so that the predicted nuclear suppression is compatible with the uncertainty band due to nPDFs.
- LHeC extends the coverage on $x_A^{obs} \approx 10^{-4}$ → significantly enounces sensitivity to nuclear modifications of nPDFs at small x

Conclusions

- Calculated the cross section of inclusive dijet photoproduction in e+A at future lepton-nucleus colliders as EIC, LHeC, HE-LHeC, and FCC using NLO pQCD and nCTEQ15 and EPPS16 nPDFs
- Made predictions for the cross section distributions as functions of the dijet p_T, η , x_A^{obs}, x_γ^{obs}
- Found that an increase of the collision energy from the EIC to the LHeC and beyond extends the coverage in all four considered variables
- Calculated the ratio of the dijet cross sections on a nucleus and the proton, $\sigma_A/(A\sigma_p)$, and showed that it exhibits clear nuclear modifications
- Found that in the important case of the x_A^{obs}dependence, the shape of $\sigma_A/(A\sigma_p)$ repeats that of $g_A/(Ag_p)$ and reveals a strong suppression due to nuclear shadowing for $x_A^{obs} < 0.01$
  - This indicates that measurements of the cross section of dijets photoproduction at future e+A colliders will be very beneficial to reduce current uncertainties of nPDFs