Probes of nuclei in Ultra-Peripheral Collisions: selection of latest results

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APS GHP Meeting 2021: 16 April 2021
Outline

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  • $J/\psi$ photoproduction
• Dijet photoproduction in UPCs
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  • Exclusive dijet photoproduction
• Summary
Physics of UPCs

- Nuclei “miss” each other ($b > 2R$)
- Electromagnetic interaction dominates over strong
- Photon flux grows with the square of the charge, $Z^2$
Probes of nuclei in UPC

- UPCs at RHIC and LHC: the most energetic photon-nuclei interactions
- Low-x physics and search for the nonlinear parton dynamics (saturation regime)
Probes of nuclei in UPC: $\rho^0$ photoproduction

Central black region growing with decrease of $x$

Momentum transfer of $\rho^0$-meson is sensitive to saturation effects
Probes of nuclei in UPC: $\rho^0$ in AuAu UPC

- The t-distribution from coherent $\rho^0$ photoproduction probes the distribution of interaction sites within the nucleus.  

STAR Phys. Rev. C 96 054904

Two diffractive minima observed in the t-distribution.

Nuclei act as a black disk.

The Fourier transform of $d\sigma/dt$ gives the distribution of interaction sites within the nucleus.

See talk by Spencer Klein at DIS 2021 for more details.
Probes of nuclei in UPC: $\rho_0$ in pPb UPC

- Cross-section measured as a function of $W_{\gamma p}$

Change in the shape of t-distribution with energy.
Photoproduction process is sensitive to the gluon density squared in the nucleon (nucleus) at LO

\[
\frac{d\sigma_{\gamma p,A\rightarrow VM,p,A}}{dt}\bigg|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 [xG(x,Q^2)]^2
\]

\[
\sigma_{\gamma p\rightarrow VMp} = \frac{1}{b} \frac{d\sigma_{\gamma p,A\rightarrow VM p,A}}{dt}\bigg|_{t=0}
\]

Probe gluon distributions in the nuclei at low-x

\[
x = (M_{VM}/W_{\gamma Pb})^2
\]

Energy of the collision

\[
(W_{\gamma Pb})^2 = 2 \cdot E_{Pb} \cdot M_{VM} \cdot \exp(-y)
\]

\(E_{Pb}\) – ion beam energy

\(M_{VM}\) – mass of the Vector meson

\(y\) – rapidity of the vector meson
Probes of nuclei in UPC: $J/\psi$ in PbPb UPC

- The cross-section of coherent $J/\psi$ photoproduction as a function of rapidity or $|t|$ probe the nuclear shadowing and saturation effects.

**ALICE arXiv:2101.04577**

Cross-section below Pb nuclear form factor model and closer to the shape predicted by shadowing (LTA) or saturation (b-BK) models.
Future prospects (Run3 data at LHC)


Nuclear suppression factor $\sim$ nPDF
Dijet photoproduction

Going beyond single particle production makes it possible to obtain even more detailed information about the nuclear structure.
Probes of nuclei in UPC (inclusive dijet production)

\[ H_T = E_{T,\text{jet1}} + E_{T,\text{jet2}} \sim 2Q \]

Inclusive dijet production gives new input into nPDFs
Probes of nuclei in UPC (inclusive dijet production)

- NLO pQCD vs. ATLAS data as a function of the dijet transverse momentum $H_T = E_{T \text{jet}_1} + E_{T \text{jet}_2}$ and nuclear momentum fraction $x_A = (m_{\text{jets}} / \sqrt{s_{\text{NN}}}) e^{-y_{\text{jets}}}$

- Shape and normalization of the ATLAS data are reproduced well. Note that the data is preliminary and has not been corrected for detector response.

Just one step from extraction nPDFs
Probes of nuclei in UPC (exclusive dijet production)

Exclusive dijet photoproduction is the only process directly sensitive to the Wigner gluon distribution. e.g., Y. Hatta, B.-W. Xiao, and F. Yuan, *Phys. Rev. Lett.* 116, 202301 (2016)

Wigner and Husimi gluon distributions are the most fundamental gluon distribution

Vector sum of 2 jets: \[ \vec{Q}_T = \vec{k}_1 + \vec{k}_2 \]

Vector difference of 2 jets: \[ \vec{P}_T = \frac{1}{2} (\vec{k}_1 - \vec{k}_2) \]

Elliptic gluons: predicted non-trivial angular correlations of the gluon Wigner distributions. Depend on impact parameter and gluon transverse momentum.

The magnitude of the spatial momentum anisotropy is measured by the second Fourier harmonic of the azimuthal distribution

\[ \nu_2 = \langle \cos(2\phi) \rangle, \]

where \( \phi \) is the angle between \( P_T \) and \( Q_T \): \[ \cos(\phi) = \frac{\vec{Q}_T \cdot \vec{P}_T}{\| \vec{Q}_T \| \cdot \| \vec{P}_T \|} \]
Exclusive dijets in UPC PbPb @5 TeV
(CMS-PAS-HIN-18-011)

Effect of decorrelation in data:
Peaks at 0 and $\pi$ are much less pronounced than in RAPGAP MC prediction.

$<\cos(2\phi)>$ reaches a constant value $\sim 0.4$ at $Q_T > 5$ GeV

Soft gluons emitted from the final state jets tend to be aligned with the jet directions.

Emissions slightly outside the jet cones: $\sim q_\perp$ - the recoil momentum against these gluons.

$q_\perp$ points to jet directions on average, resulting in a positive $<\cos(2\phi)>$. 

$<\cos(2\phi)>$ reaches a constant value at $Q_T > 5$ GeV both in data and theory.

Lower value is expected in data after unfolding.
Summary

• Ultra-peripheral collisions are the energy frontier for electromagnetic probes of the nuclei.

• Vector meson photoproduction
  • Light vector meson photoproduction has been used to observe diffraction patterns from gold nuclei.
  • Determine the hadronic size and shape of the gold nucleus.
  • Lead-target data demonstrates moderate shadowing, consistent with leading order twist or saturation models.

• UPC Dijets in PbPb at 5 TeV
  • Inclusive dijet production gives new input into nPDFs
  • Measurement of exclusive dijets is the first (and essential) step to extract the gluon Wigner/Husimi gluon distributions.

Thank you for your attention!
Probes of nuclei in UPC: $\rho_0$ in pPb UPC

- The $t$-distribution measured as a function of $W_{\gamma p}$ allows to extract the Pomeron trajectory.

Regge fit $b = b_0 + 2 \, \alpha' \ln\left(\frac{W}{W_0}\right)^2$

Pomeron trajectory extracted using the CMS data only:

$$\alpha' = 0.28 \pm 0.11 \text{ (stat)} \pm 0.12 \text{ (syst)}$$

Consistent with the ZEUS value $(0.23 \pm 0.15 \text{ (stat.}) \pm 0.10 \text{ (syst.)})$ and Regge expectations.