

Gluon imaging using azimuthal correlations in diffractive scattering at the Electron-Ion Collider

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Based on H.M, K. Roy, F. Salazar, B. Schenke, arXiv:2011.02464 [hep-ph]

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Exclusive production

DVCS and exclusive J/ψ production: $e + p \rightarrow \gamma(J/\psi) + p$

Advantages in exclusive scattering

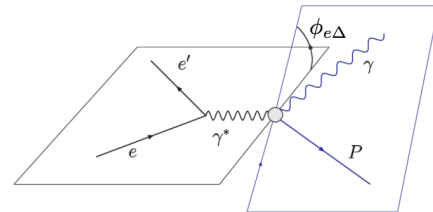
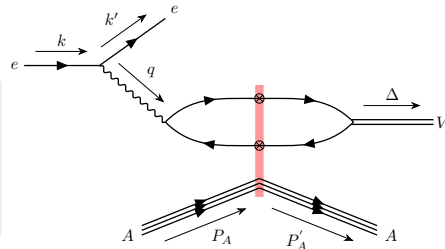
- No net color charge transfer: $\sim \text{gluon}^2$
- Possibility to measure total momentum transfer
Fourier conjugate to the impact parameter

This work (arXiv:2011.02464)

More differential measurement

$\Rightarrow$ more detailed probe of target structure

- Exclusive vector particle production differentially in both t and azimuthal angle $\phi_{e\Delta}$

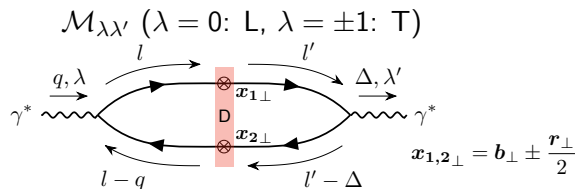


2011.02464 (top), CLAS collaboration (bottom)

Deeply Virtual Compton Scattering*

Calculate $\gamma^* + p \rightarrow \gamma^* + p$,
later take final state to be real photon or J/ψ

Results in agreement with Hatta, Yuan, Xiao, 1703.02085



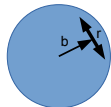
$$\mathcal{M}_{0,0} \sim \int_{\mathbf{b}} e^{-i\mathbf{\Delta} \cdot \mathbf{b}} \int_{\mathbf{r}} D(\mathbf{r}, \mathbf{b}) \int_z e^{-i\delta \cdot \mathbf{r}} z^2 \bar{z}^2 Q K_0(\varepsilon r) Q' K_0(\varepsilon' r)$$

$$\mathcal{M}_{\pm 1, \mp 1} \sim \int_{\mathbf{b}} e^{-i\mathbf{\Delta} \cdot \mathbf{b}} \int_{\mathbf{r}} e^{\pm 2i\phi_{r,b}} D(\mathbf{r}, \mathbf{b}) \int_z e^{-i\delta \cdot \mathbf{r}} z \bar{z} \varepsilon K_1(\varepsilon r) \varepsilon' K_1(\varepsilon' r)$$

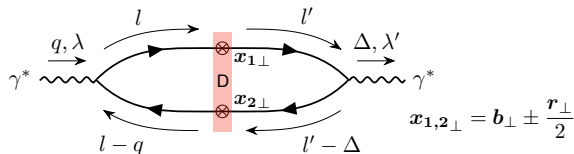
Similar results for $\mathcal{M}_{\pm 1, \pm 1}, \mathcal{M}_{\pm 1, 0}, \mathcal{M}_{0, \pm 1}$.

Neglecting the off-forward phase $\delta = (z - \bar{z})\mathbf{\Delta}/2$:

- $\mathcal{M}_{0,0} \sim$ angle independent part of dipole-target amplitude $D(\mathbf{r}, \mathbf{b})$
- $\mathcal{M}_{\pm 1, \mp 1}$: sensitive to $\cos(2\phi_{r,b})$ modulation of the dipole



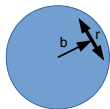
Deeply Virtual Compton Scattering*



$$\mathcal{M}_{\pm 1, \mp 1} \sim \int_{\mathbf{b}} e^{-i\mathbf{\Delta} \cdot \mathbf{b}} \int_{\mathbf{r}} e^{\pm 2i\phi_{r\Delta}} D(\mathbf{r}, \mathbf{b}) \int_z e^{-i\delta \cdot \mathbf{r}} z \bar{z} Q_{\epsilon} K_1(\epsilon r) \epsilon' K_1(\epsilon' r)$$

Two sources of correlations between $\mathbf{r}$ (which knows about the electron in DIS) and $\mathbf{\Delta}$

- *Intrinsic*: correlation between $\mathbf{r}$ and $\mathbf{b}$ in the dipole $D(\mathbf{r}, \mathbf{b})$
 - Related to elliptic gluon GPD [Hatta, Yuan, Xiao, 1703.02085](#)
- *Kinematic*: off-forward phase $e^{-i\delta \cdot \mathbf{r}}$ with $\delta = (z - \bar{z})\mathbf{\Delta}/2$
 - Different propagation axis, mixes polarizations



Azimuthal correlations in DVCS in DIS

Full calculation at $Q'^2 = 0$ including the photon flux $f(y)$ in [2011.02464](#)

In agreement with hatta, Yuan, Xiao, 1703.02085

$$\begin{aligned} \frac{d\sigma^{ep \rightarrow e\gamma p}}{dtd\phi_{e\Delta}} &\sim f_{TT}(y)[\mathcal{M}_{\pm 1, \pm 1}^2 + \mathcal{M}_{\pm 1, \mp 1}^2] + f_{TT, \text{flip}}(y)\mathcal{M}_{0, \pm 1}^2 \\ &\quad - f_{LT}(y)\mathcal{M}_{0, \pm 1}[\mathcal{M}_{\pm 1, \pm 1} + \mathcal{M}_{\pm 1, \mp 1}]\cos(\phi_{e\Delta}) \\ &\quad + f_{TT, \text{flip}}(y)\mathcal{M}_{\pm 1, \pm 1}\mathcal{M}_{\pm 1, \mp 1}\cos(2\phi_{e\Delta}) \end{aligned}$$

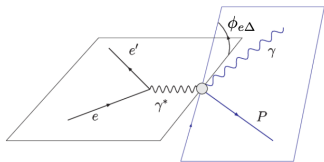


Figure: CLAS

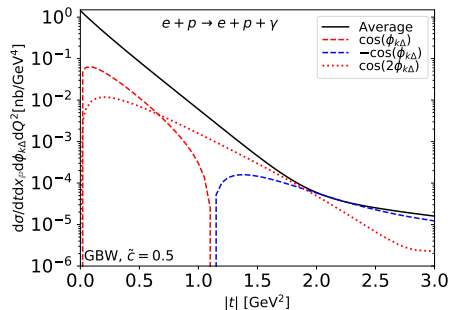
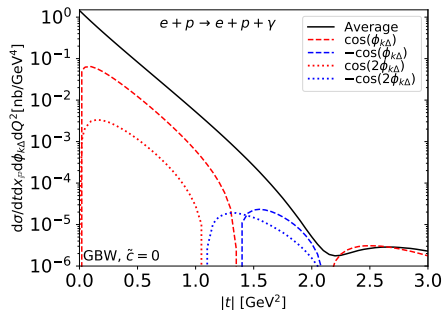
The $\cos(2\phi_{e\Delta})$ modulation in $ep \rightarrow e\gamma p$:
Access to $\mathbf{r}, \mathbf{b}$ correlations in the dipole D
via $\mathcal{M}_{\pm 1, \mp 1}$
 $\Rightarrow$ elliptic gluon GPD / Wigner distribution

y is the inelasticity in DIS

Toy model example

Demonstrate sensitivity on $\mathbf{r}, \mathbf{b}$ angular correlations in the dipole amplitude D , using GBW

$$D(\mathbf{r}, \mathbf{b}) = 1 - \exp \left[-\frac{\mathbf{r}^2 Q_{s0}^2}{4} T_p(\mathbf{b}) \left(1 + \tilde{c} \cos(2\phi_{rb}) \right) \right] \text{ with } T_p(\mathbf{b}) = e^{-\mathbf{b}^2/(2B_p)}$$



$\tilde{c} = 0$, no $\phi_{r,b}$ dependence in D

$\tilde{c} = 0.5$, large $\phi_{r,b}$ dependence in D

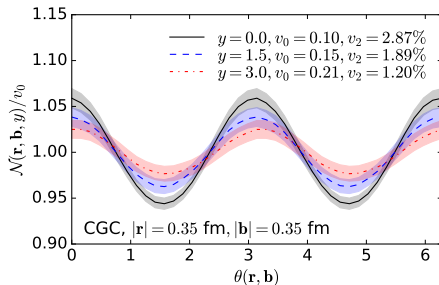
$\phi_{r,b}$ dependence in D significantly increases $\cos(2\phi_{k,\Delta})$ modulation in the DVCS cross section
Smaller effect on $\cos(\phi_{k,\Delta})$

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Predictions for the EIC, setup

EIC energies, consider $e + p$ collisions at $\sqrt{s} = 140$ GeV and $e + \text{Au}$ at $\sqrt{s} = 90$ GeV

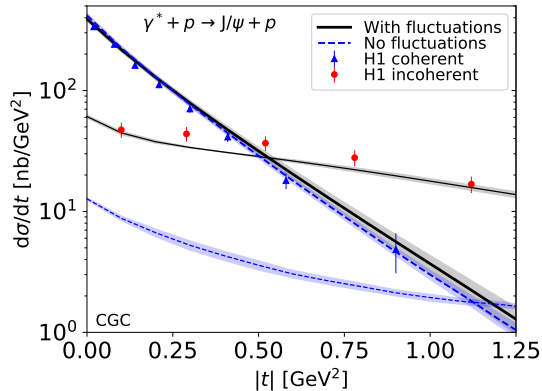
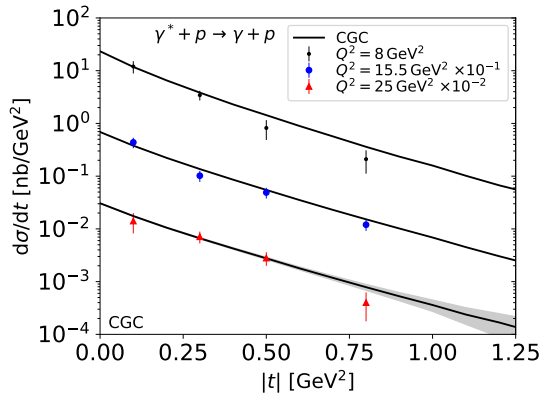
- Initial condition: MV model with $g^4 \mu^2 \sim Q_s^2 \sim T_p(\mathbf{b})$
- Small- x JIMWLK evolution up to $Y = \ln(0.01/x_{\mathbb{P}})$
- Wilson lines evolved event-by-event, result averaged over an ensemble of configurations



Angular modulation with $x = 0.01e^{-y}$
dependence computed from the CGC setup

Note: recent developments beyond MV for protons suggest negative v_2 , see talk
by Dumitru on Wed and [arXiv:2103.11682](https://arxiv.org/abs/2103.11682)

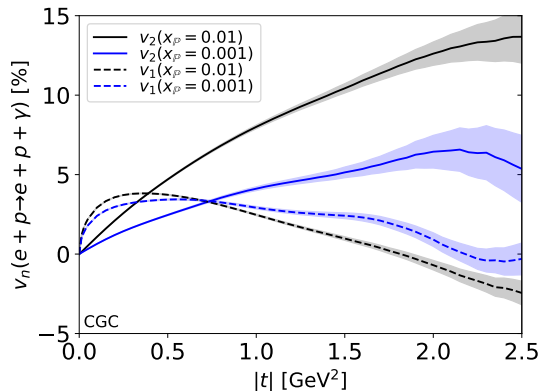
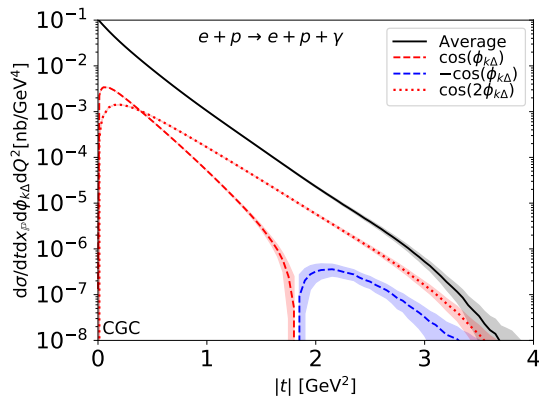
t spectra not sensitive to the angular dependence



Good description of the HERA DVCS and exclusive J/ψ data.

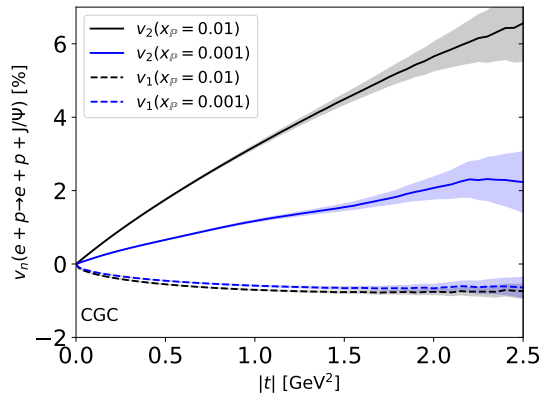
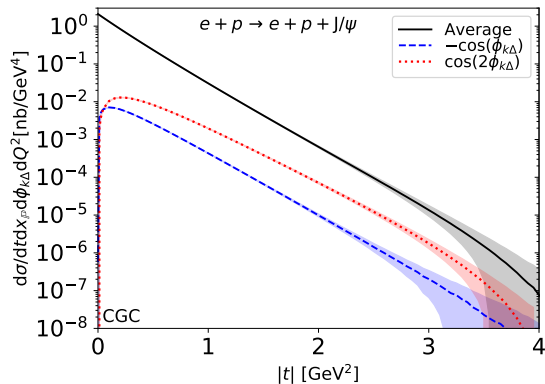
To compute J/ψ , we replace γ^* wave function by Boosted Gaussian describing vector mesons

Coherent DVCS at the EIC: spectra and relative modulation



- Significant 5 ... 10% $\cos(2\phi_{k\Delta})$ modulation at $|t| \gtrsim 0.5 \text{ GeV}^2$
- Small- x evolution decreases anisotropies $\Rightarrow$ decreasing $v_n = \langle \cos(n\phi_{k\Delta}) \rangle$

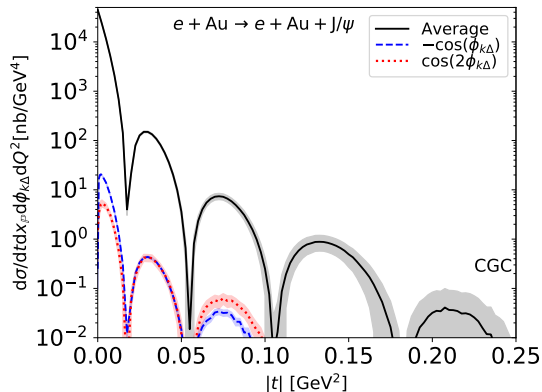
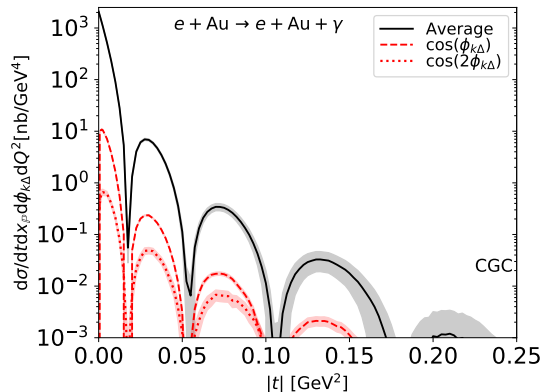
Coherent J/ψ at the EIC: spectra and relative modulation



- Significant $\cos(2\phi_{k\Delta})$ modulation in J/ψ production
- Very small v_1 , as that is dominated by the off-forward phase $e^{-i\delta \cdot r}$
 $\Rightarrow$ small contribution at small $r \sim 1/M_V$.

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Nuclear targets at the EIC

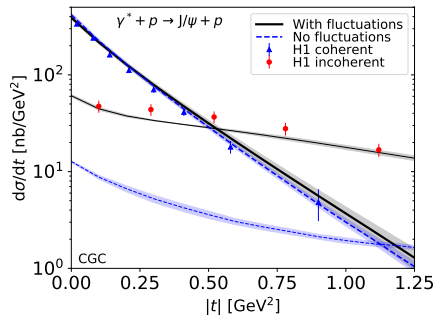
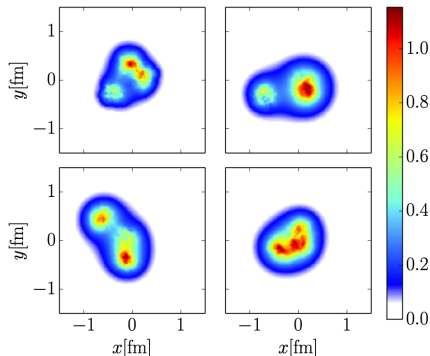


Much smaller modulations with nuclear targets:

Smoother target, smaller density gradients $\Rightarrow$ smaller dependence on $\phi_{r,b}$

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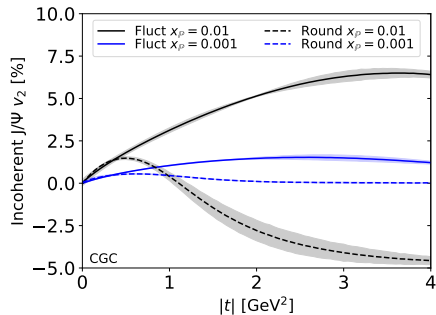
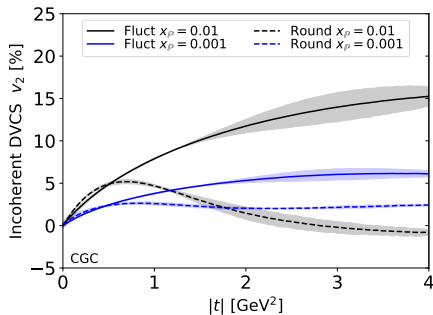
Incoherent diffraction



Incoherent cross section $\sim$ covariance $\langle \mathcal{M}^2 \rangle - \langle \mathcal{M} \rangle^2$ is sensitive to the (amount of) fluctuations [H.M, Schenke, 1603.04349](#)

Potential to access fluctuations in detail by studying azimuthal correlations in $e + p \rightarrow e + \gamma + p^*$ and $e + p \rightarrow e + J/\psi + p^*$

Incoherent modulation



- Substructure changes v_2 at $|t| \gtrsim 0.5 \text{ GeV}^2$ where one is sensitive to small distance scales
- Significantly larger modulations with fluctuations
- JIMWLK evolution also suppresses incoherent v_2

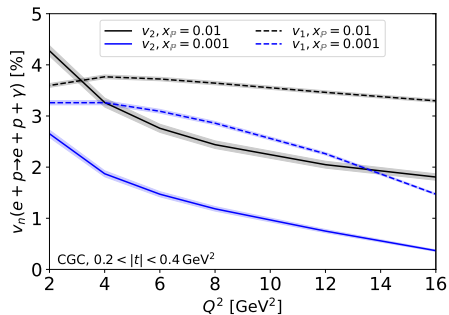
Conclusions and outlook

- Calculate azimuthal correlations between e and the exclusively produced γ or J/ψ
- Identify *intrinsic* (related to elliptic gluon GPD) and *kinematical* contributions
- EIC prediction: significant 5...10% azimuthal modulations with proton targets
- Modulations suppressed at high W /small $x_{\mathbb{P}}$
- Very small modulations with nuclear targets

Outlook:

- Distinguish different fluctuating geometries using incoherent v_n ?
- LCPT calculation of the dipole-proton amplitude, different $\phi_{r,b}$ systematics, effect here?
Talk by Dumitru on Wednesday, and [arXiv:2103.11682](#)
- NLO Talk by Penttala on Thursday, and [arXiv:2104.02349](#)

Virtuality dependence



$$0.2 < |t| < 0.04$$

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Dipole size $\sim 1/Q^2$

- Smaller density gradients seen by dipoles at high Q^2
 $\Rightarrow$ Smaller *intrinsic contribution*, decreasing v_2
- Small dipoles also result in small contribution from off-forward phase $e^{-i\delta \cdot \mathbf{r}}$, visible v_1 .
- Additional effect: At the kinematical $y = 1$ boundary modulations vanish
In DVCS at $x_{\mathbb{P}} = 0.001$ this is at $Q^2 \approx 20\text{GeV}^2$.