



U.S. DEPARTMENT OF
ENERGY



Angular correlations in exclusive dijet photoproduction in ultra-peripheral PbPb collisions at 5.02 TeV

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On behalf of the CMS Collaboration

Jet 3D 2020: 24 November 2020

Outline

- **Exclusive dijet photoproduction in UPC PbPb @5 TeV**
 - First step to access novel features of gluon distributions
 - Tomographic study of nucleons/nuclei at the future electron-ion collider (EIC)
- Motivation
- CMS Detector and analysis selections
- Systematic uncertainties
- Results

Exclusive dijets in UPC PbPb @5 TeV

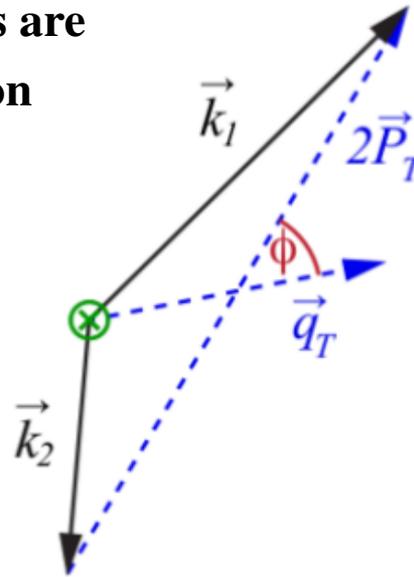
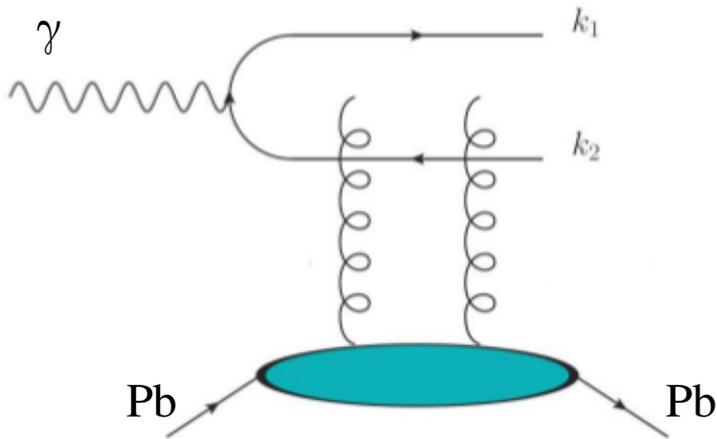


(CMS-PAS-HIN-18-011)

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)

Also see talk by Barbara Pasquini for more details

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

$$v_2 = \langle \cos(2\phi) \rangle,$$

where ϕ is the angle between \vec{P}_T and \vec{Q}_T :

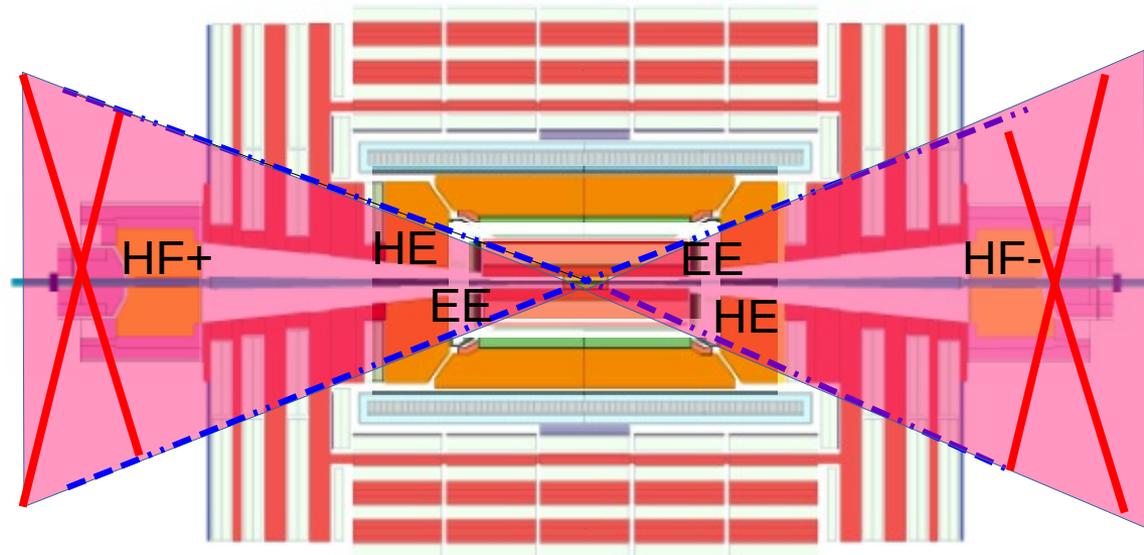
$$\cos(\phi) = \vec{Q}_T \cdot \vec{P}_T / (\|\vec{Q}_T\| \cdot \|\vec{P}_T\|)$$

Exclusive dijets in UPC PbPb @5 TeV



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- Analysis selections (part I):
 - At least one track in the central tracker
 - Particle flow jets using the anti- k_t algorithm with $R=0.4$
 - Only two jets $|\eta_{lab}| < 2.4$, $p_{T,1} > 30$ GeV, $p_{T,2} > 20$ GeV
 - Veto activity in the forward region ($2.8 < |\eta| < 5.2$): HF, HE and EE calorimeters



RAPGAP MC extensively exploited for ep collisions at HERA
is used for modelling exclusive dijet photoproduction via photon-gluon fusion

Exclusive dijets in UPC PbPb @5 TeV

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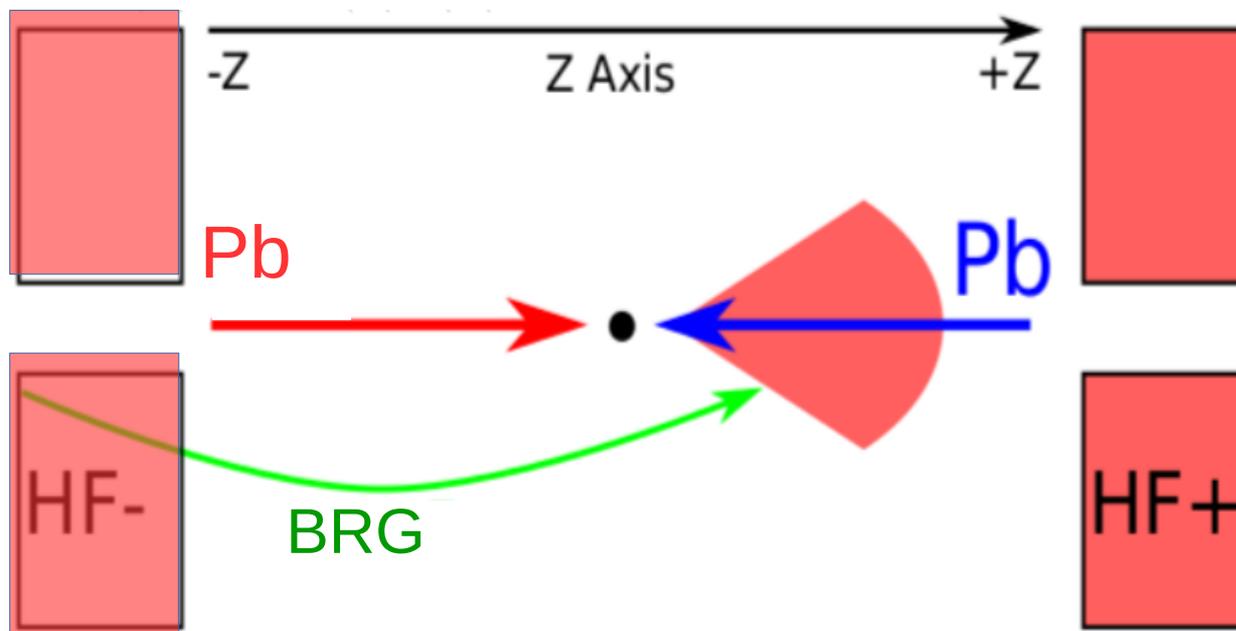


$\gamma + \text{Pb} \rightarrow \text{jet} + \text{jet} + \text{Pb}$ events are asymmetric in rapidity.

Rapidity Gap Selection: No track with $p_T > 0.2 \text{ GeV}$, $|\eta| < 2.5$

Two separate data sets are defined:

one of them has $\text{BRG} > \text{FRG}$, and the other $\text{FRG} > \text{BRG}$

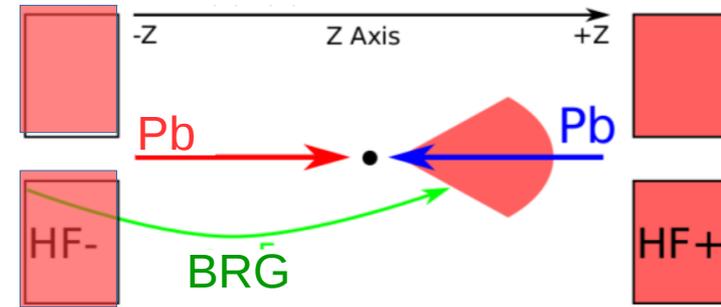


Samples are merged by changing the rapidity sign of the jets in the $\text{FRG} > \text{BRG}$ dataset.

Exclusive dijets in UPC PbPb @5 TeV

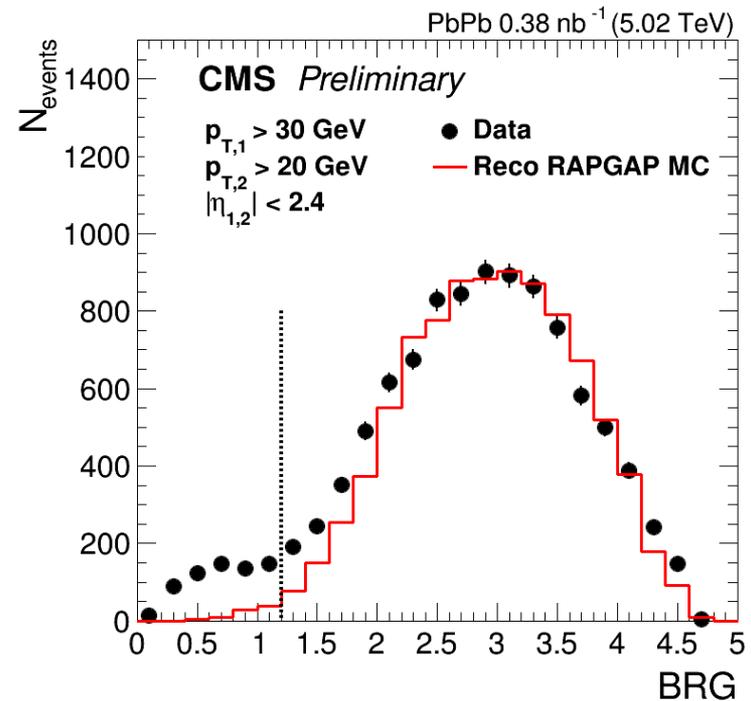
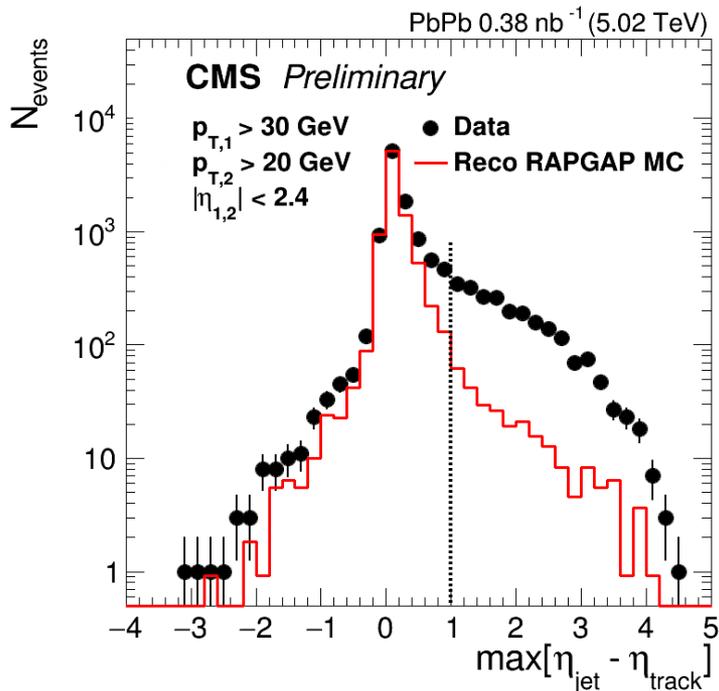


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No tracker activity far from the jets to reject non-exclusive and two-photon processes.

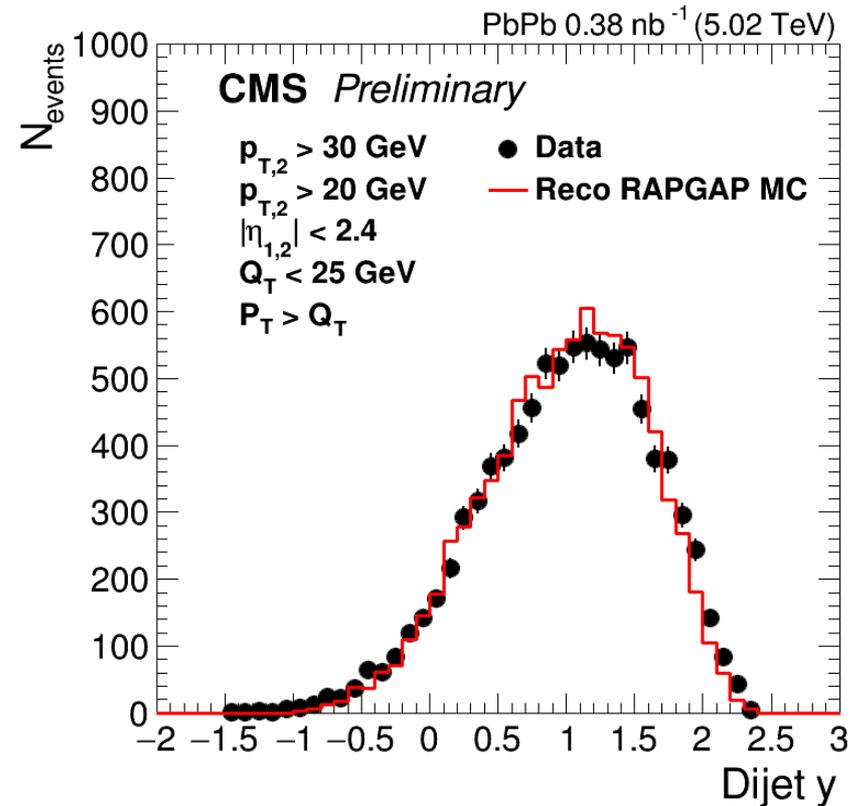
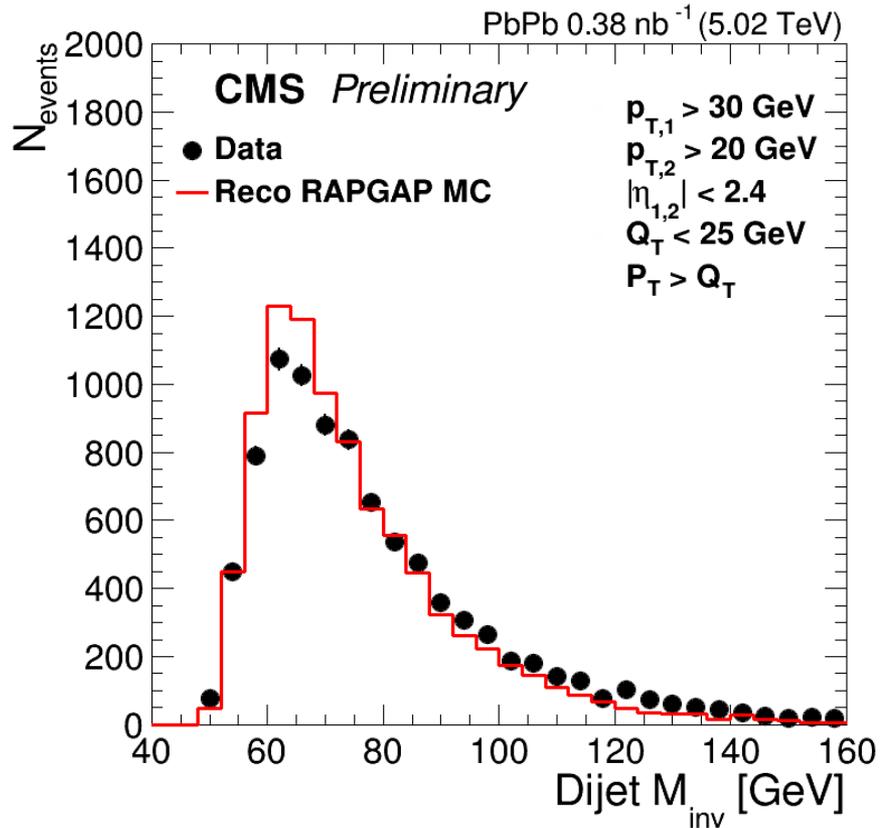
- $\max[\eta_{\text{jet}} - \eta_{\text{track}}] < 1$
- Backward Rapidity Gap (BRG) > 1.2



Exclusive dijets in UPC PbPb @5 TeV

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Dijet kinematics



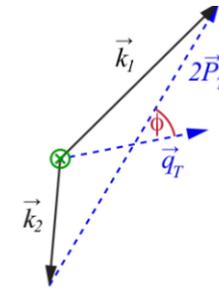
Good agreement between data and MC.

Photon flux in RAPGAP correctly tuned for the UPC γ Pb data.

Exclusive dijets in UPC

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Dijet kinematics

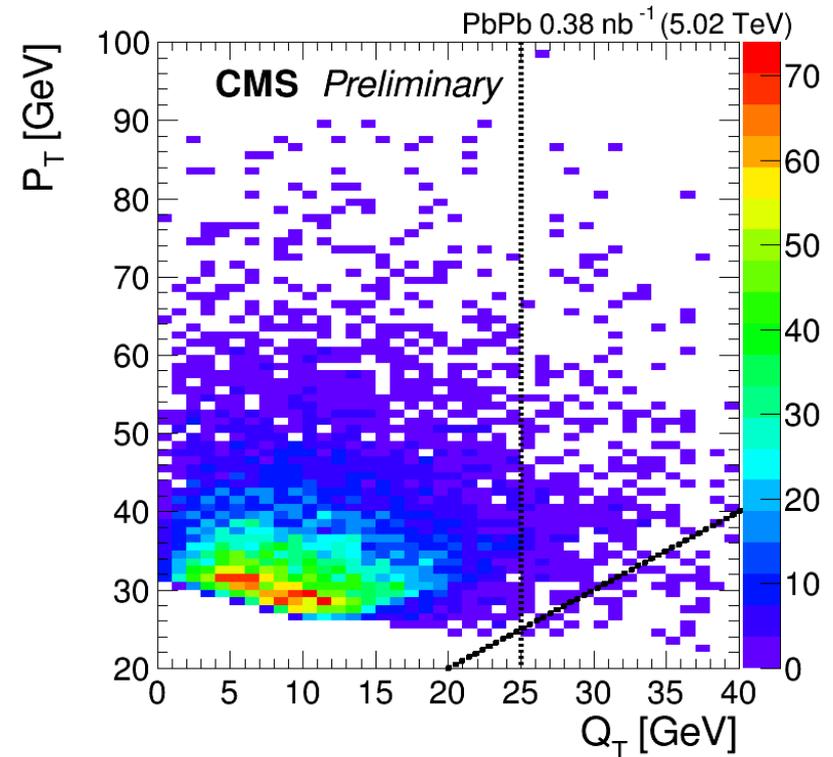
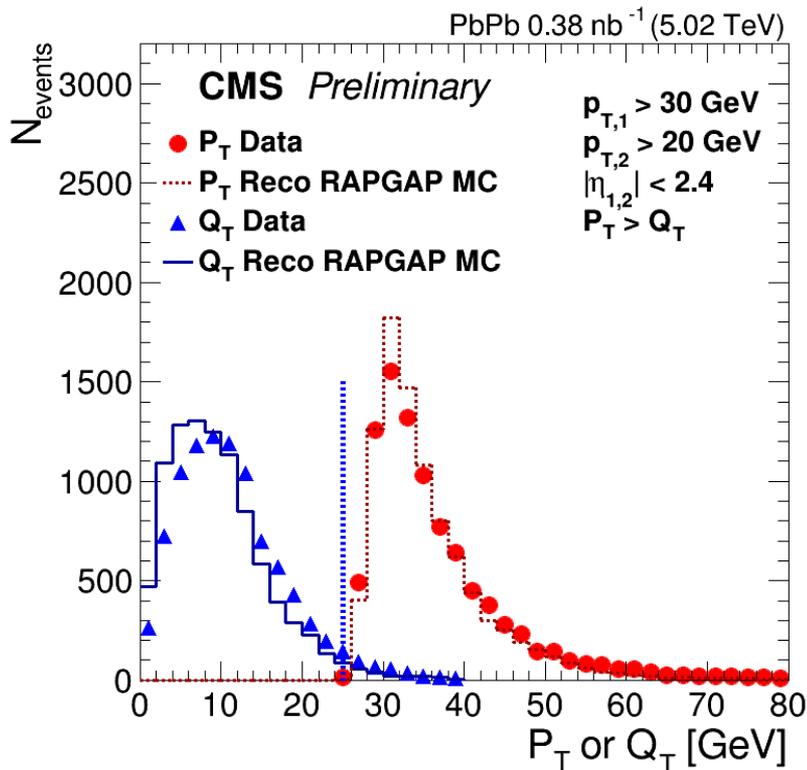


Vector sum of 2 jets:

$$\vec{Q}_T = \vec{k}_1 + \vec{k}_2$$

Vector difference of 2 jets

$$\vec{P}_T = \frac{1}{2}(\vec{k}_1 - \vec{k}_2)$$



The measurement is performed in $Q_T < 25$ GeV

9290 dijet events pass all analysis selections.

$P_T > Q_T$: “back-to-back limit”

Exclusive dijets in UPC PbPb @5 TeV



(CMS-PAS-HIN-18-011)

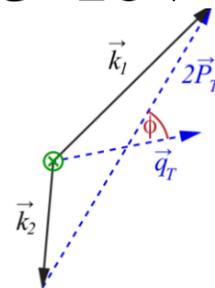
Systematic uncertainties:

- Jet Energy Scale Correction (JES): $\pm 2\%$
- Jet Energy Scale non-closure (JESnc): -5%
- Jet Energy Resolution (JER): 15% for 20 GeV jets
- Jet Angular Resolution (JAR): 0.03 for 20 GeV jets
- Rapidity Gap Selection (PUR): BRG > [0,2]
- Trigger Efficiency (TR)

Q_T [GeV]	JES	JESnc	JER	JAR	PUR	TR	Total
0-5	0.042	0.011	0.008	0.009	0.002	0.009	0.046
5-10	0.036	0.021	0.004	0.006	0.008	0.008	0.044
10-15	0.027	0.017	0.007	0.004	0.007	0.009	0.035
15-20	0.021	0.020	0.032	0.003	0.001	0.006	0.044
20-25	0.008	0.029	0.091	0.002	0.006	0.008	0.096

Exclusive dijets in UPC PbPb @5 TeV

(CMS-PAS-HIN-18-011)

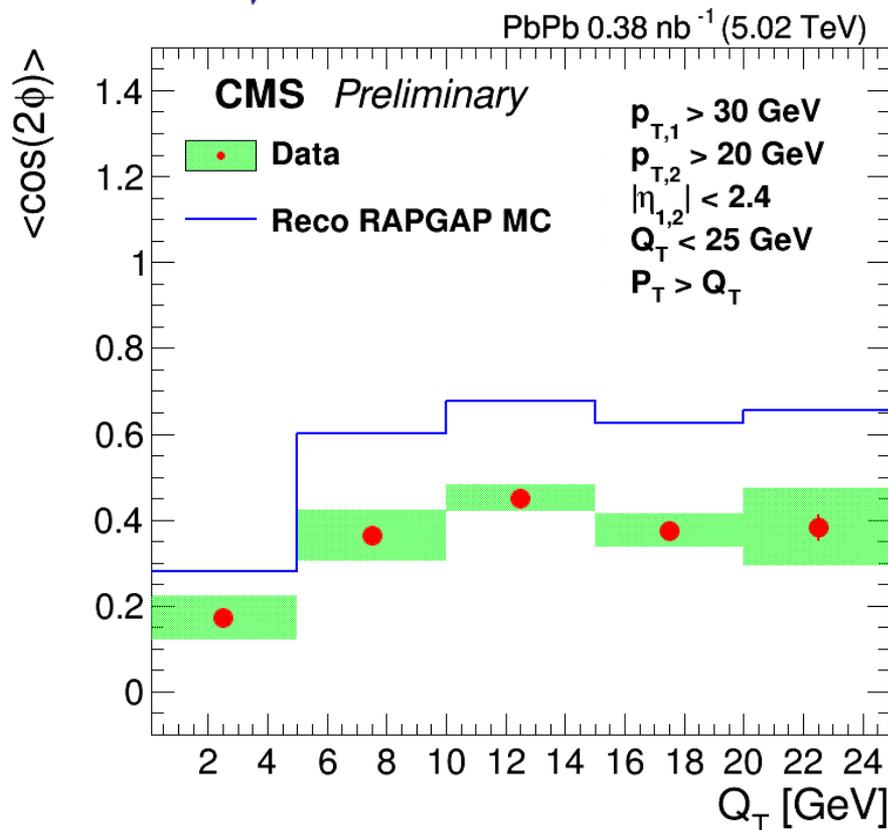
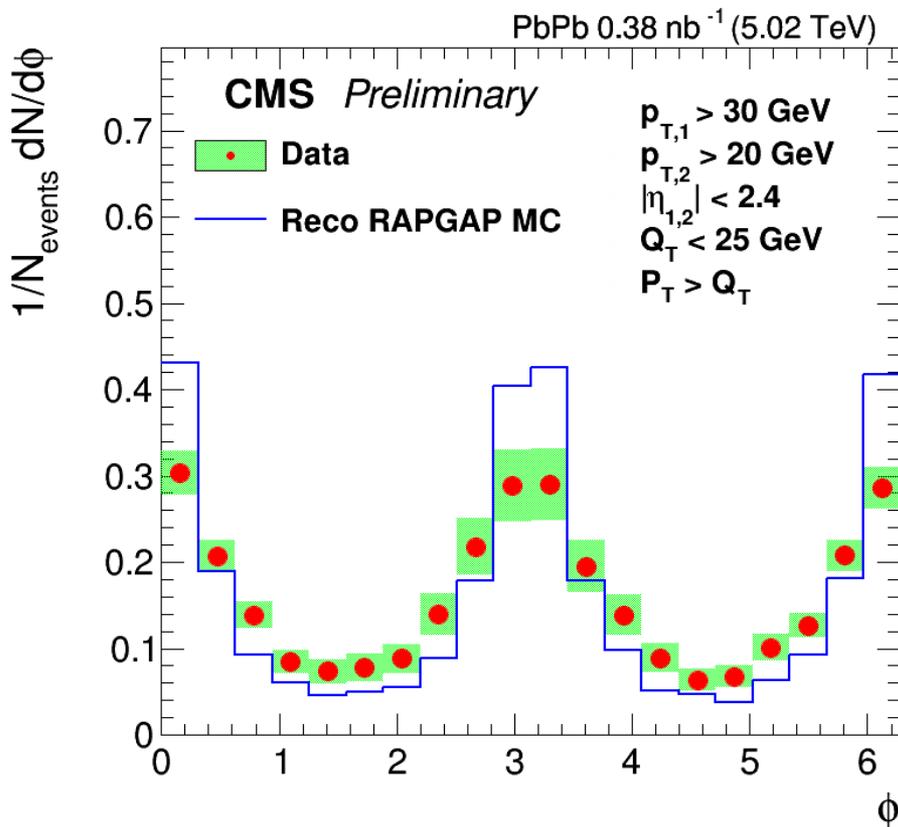


Vector sum of 2 jets:

$$\vec{Q}_T = \vec{k}_1 + \vec{k}_2$$

Vector difference of 2 jets

$$\vec{P}_T = \frac{1}{2}(\vec{k}_1 - \vec{k}_2)$$



Similar trend between data and RAPGAP,
but RAPGAP prediction is above the data.

$\langle \cos(2\phi) \rangle$ reaches a constant value
 ~ 0.4 at $Q_T > 5$ GeV

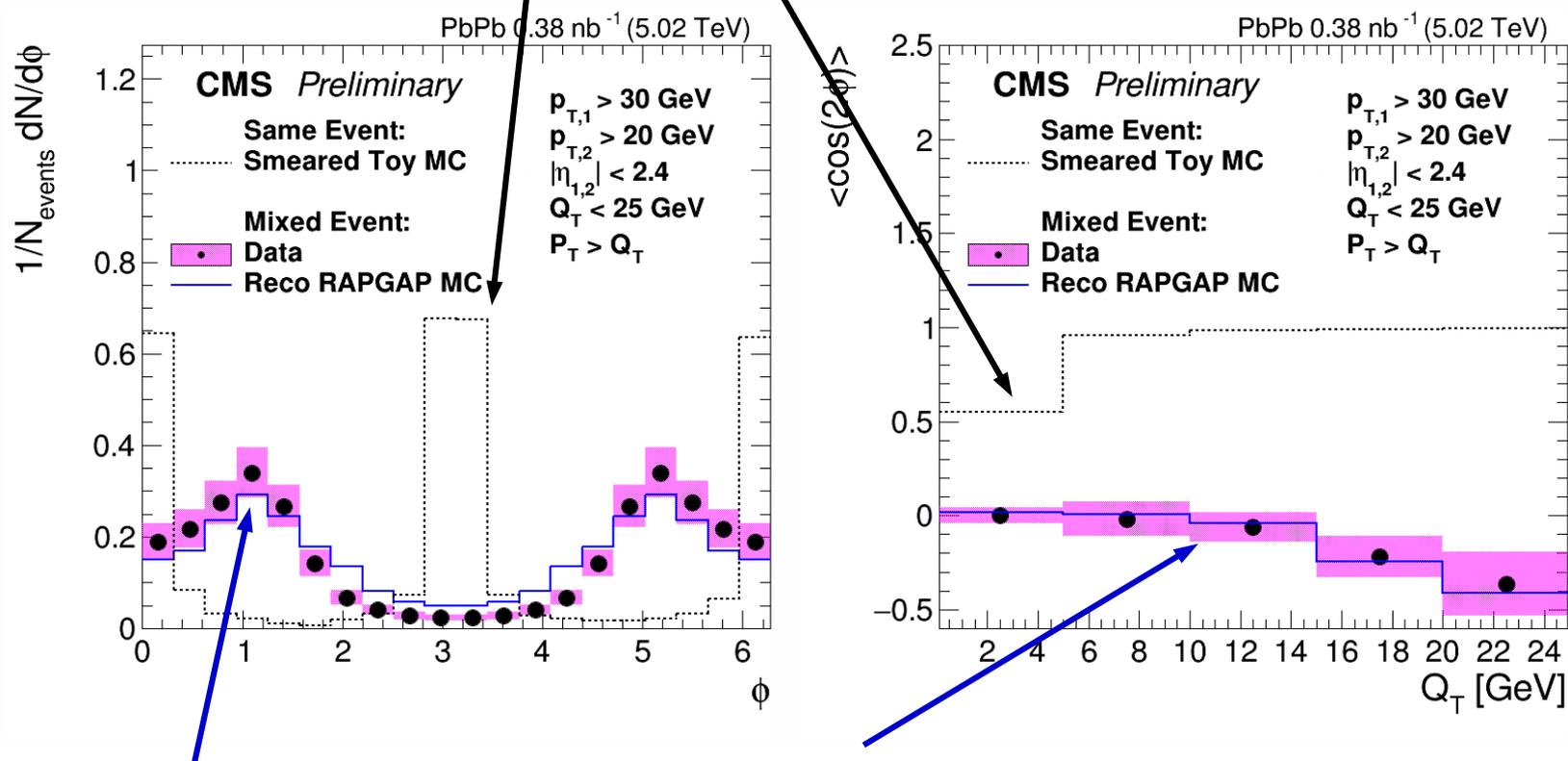
Exclusive dijets in UPC PbPb @5 TeV

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Analysis cross checks

Toy MC: back-to-back jets with detector resolution effects $\langle \cos(2\phi) \rangle \rightarrow 1$



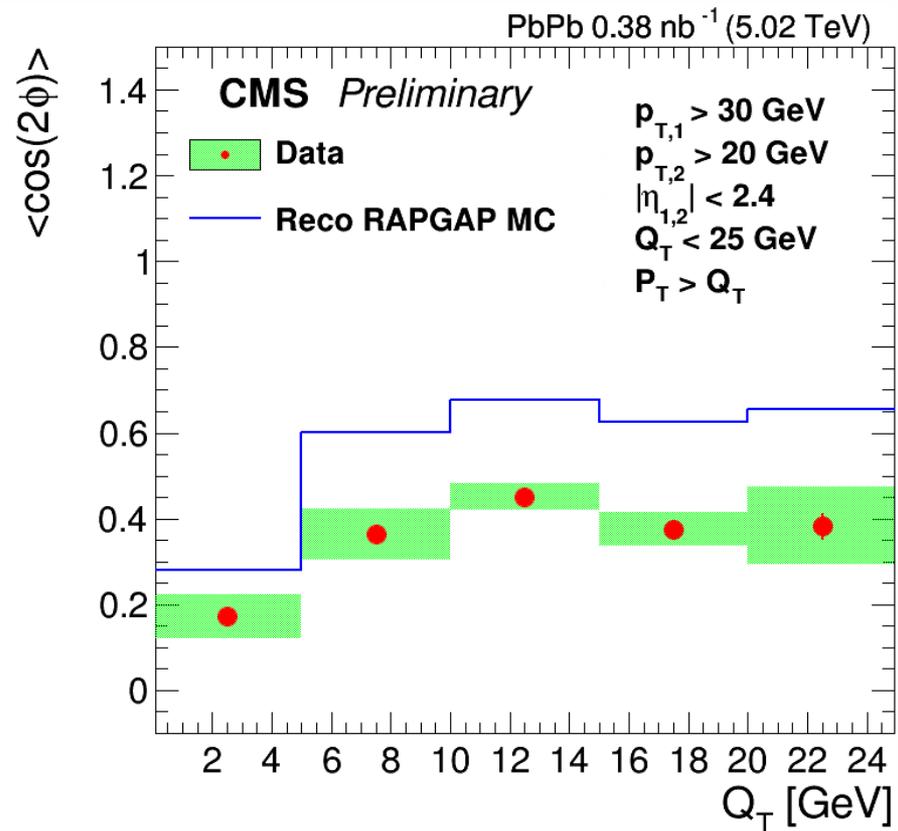
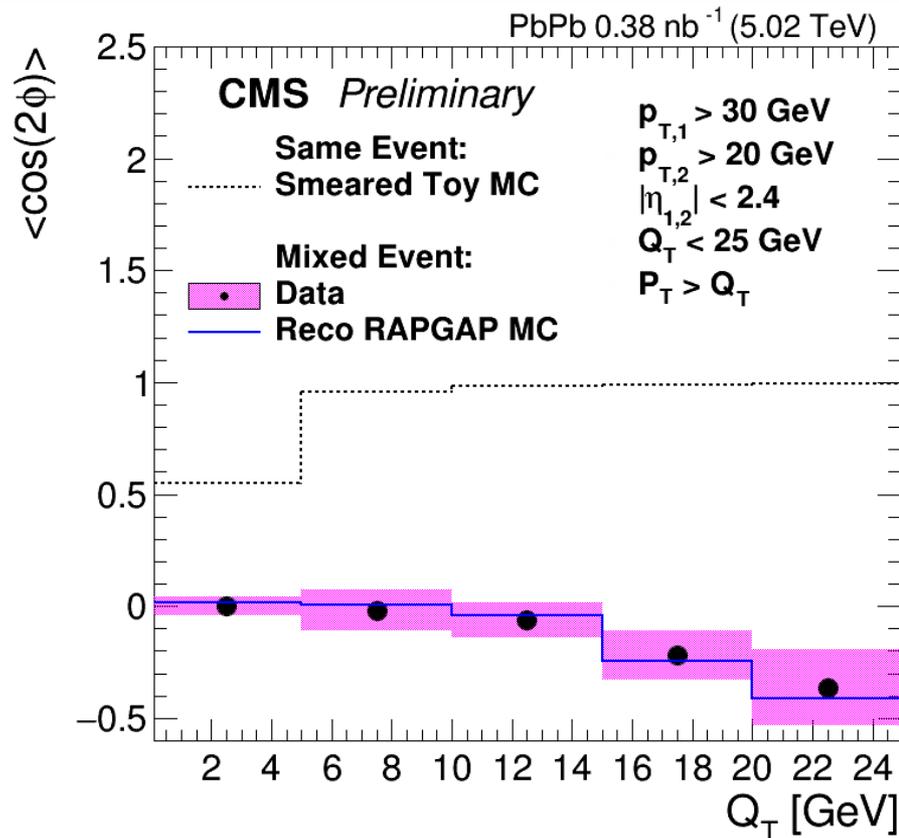
Mixed events have no physical correlation (mixing with other 5 selected events):
negative $\langle \cos(2\phi) \rangle$ value

Exclusive dijets in UPC PbPb @5 TeV



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$\langle \cos(2\phi) \rangle$ in data is below back-to-back expectation and RAPGAP prediction



Data calls for theorists to explain the observed Q_T dependence.

Exclusive dijets in UPC PbPb @5 TeV



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Recent theoretical calculations by *Yoshitaka Hatta, Bo-Wen Xiao, Feng Yuan, and Jian Zhou* [arXiv:2010.10774 \[hep-ph\]](https://arxiv.org/abs/2010.10774)

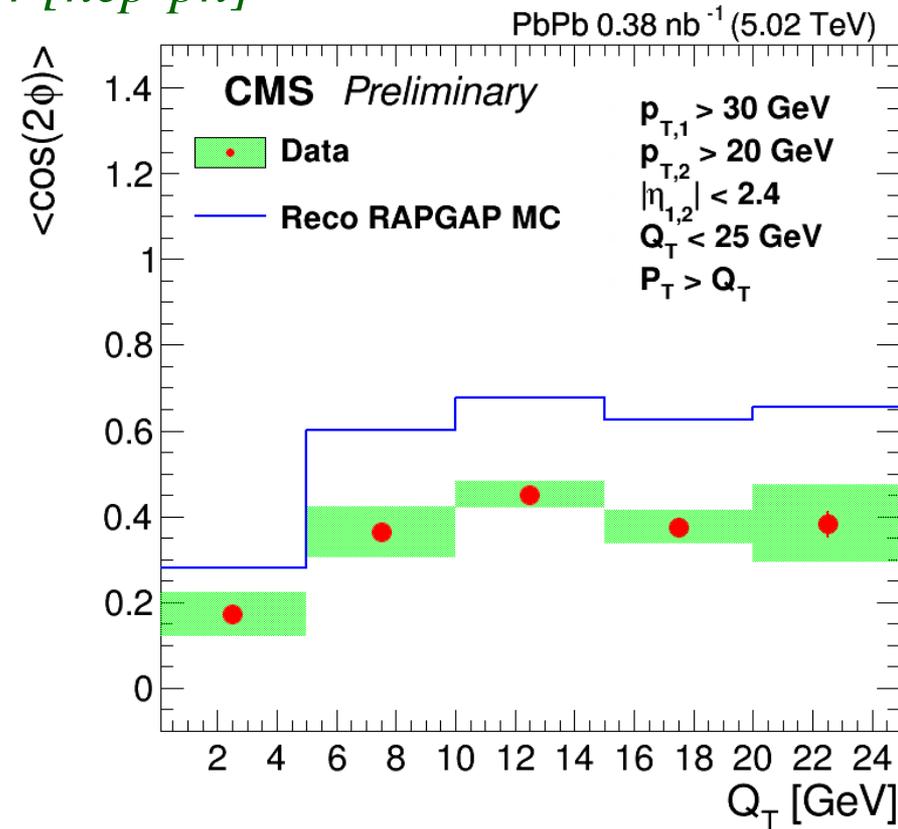
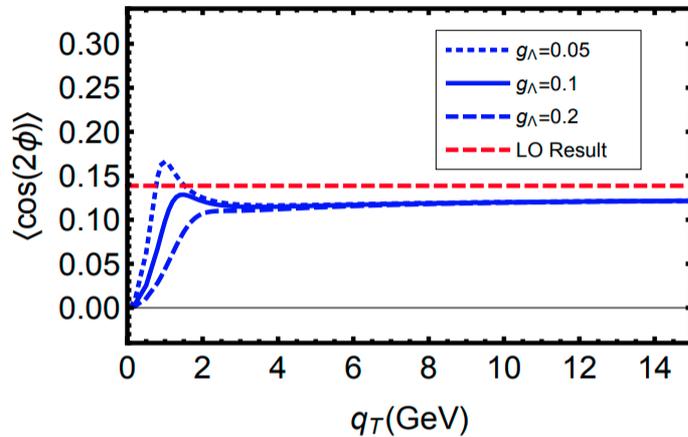


FIG. 2. Anisotropy in diffractive dijet production $\gamma + A \rightarrow q\bar{q} + A$ in ultra peripheral heavy ion collisions at the LHC. The kinematics correspond to the CMS measurements [34] with the leading jet $P_{\perp} = 35\text{GeV}$ and the two jets are at the same rapidity $\Delta y_{12} = 0$. The figure shows $\langle \cos(2\phi) \rangle$ as a function of q_{\perp} , where ϕ is the azimuthal angle between q_{\perp} and P_{\perp} .

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

Lower value is expected in data after unfolding.

Summary

- **First measurement of azimuthal anisotropy from UPC Dijets in PbPb at 5 TeV**
 - Q_T dependence of $\langle \cos(2\varphi) \rangle$ in data not described by RAPGAP MC prediction, and below back-to-back dijets
 - The latest theoretical calculations have a similar trend as observed in data
 - First (and essential) step to extract the gluon Wigner/Husimi distributions, believed to be most fundamental gluon distribution

Thank you for your attention!

Thank you for your attention!

CMS results on UPCs - published

- “Coherent J/ψ photoproduction in ultra-peripheral PbPb collisions at $\sqrt{s_{\text{NN}}} = 2.76$ TeV with the CMS experiment”, Phys. Lett. B 772 (2017) 489
- “Measurement of exclusive $\rho(770)^0$ photoproduction in ultraperipheral pPb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV”, Eur. Phys. J. C 79 (2019), no. 8, 702
- “Measurement of exclusive Υ photoproduction from protons in pPb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV”, Eur. Phys. J. C 79 (2019), no. 3, 277
- “Evidence for light-by-light scattering and searches for axion-like particles in ultraperipheral PbPb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV”, Phys. Lett. B 797 (2019)

CMS results on UPCs

New Preliminary from summer 2020

- *“Angular correlations in exclusive dijet photoproduction in ultra-peripheral PbPb collisions at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$ ”*

CMS-PAS-HIN-18-011

- *“First measurement of the forward rapidity gap distribution in pPb collisions at $\sqrt{s_{NN}} = 8.16 \text{ TeV}$ ”*

CMS-PAS-HIN-18-019

- *“Search for elliptic azimuthal anisotropies in γp interactions within ultra-peripheral pPb collisions at $\sqrt{s_{NN}} = 8.16 \text{ TeV}$ ”*

CMS-PAS-HIN-18-008

- *“Observation of forward neutron multiplicity dependence of dimuon acoplanarity in ultra-peripheral PbPb collisions at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$ ”*

CMS-HIN-19-014