Observation of forward neutron multiplicity dependence of di-muon acoplanarity in ultra-peripheral PbPb collisions at 5.02TeV

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on behalf CMS Collaboration
3rd May 2022

Motivation

- The $(\gamma\gamma \rightarrow \ell^{+}\ell^{-})$ process provided a penetrating probe that occurs at non-negligible rates in ultra-relativistic heavy-ion collisions due to the intense electromagnetic fields generated by ions.

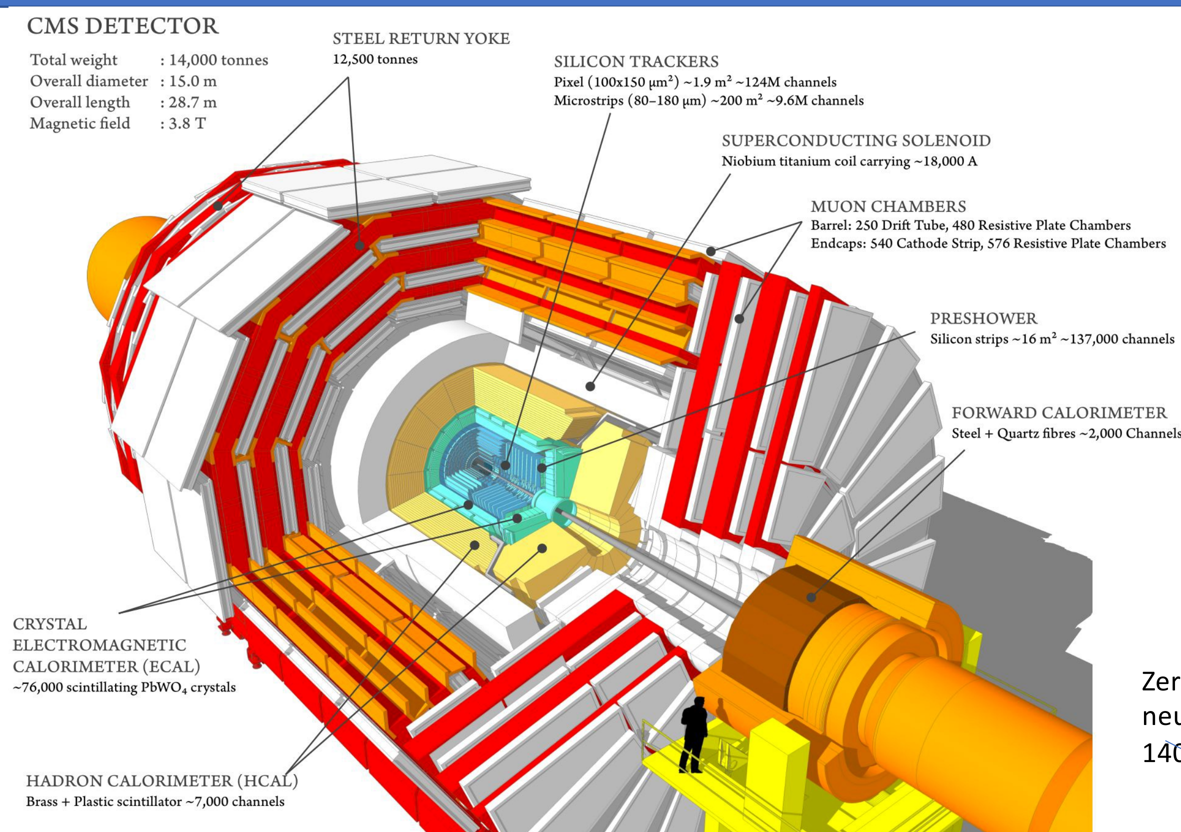
- The associated photons have small pT typically less than 10 MeV and large longitudinal momenta and energies. Due to the low pT of the photons, the leptons are produced nearly back to back in azimuth and with nearly identical momenta

Motivation

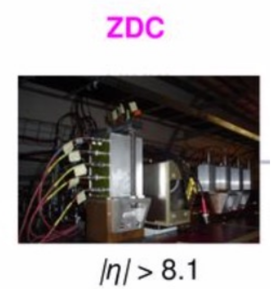
- photon-induced reactions are typically measured in UPCs, but recently have also been observed in hadronic collisions of heavy ions. In such events, the photon fluxes are largest just outside the nuclear overlap region, and it is expected that charged leptons produced in this region interact with the electric charges in the QGP that is formed. (While the effects of EM are much weaker than the strong interactions, the initial angles and momenta of the produced leptons are sufficiently well correlated to make even small modifications observable. A potential source of modification is the final-state interaction of the produced leptons with the electric charges in the QGP)

- small momentum transfers to the leptons due to EM => broadening of the momentum and angular correlations of the lepton pair
- In analogy with the picture of jet energy loss proposed by Bjorken is expected to be largest in central collisions, where the degree of overlap between the colliding nuclei is greatest and the transverse size and lifetime of the plasma are largest

The CMS detector



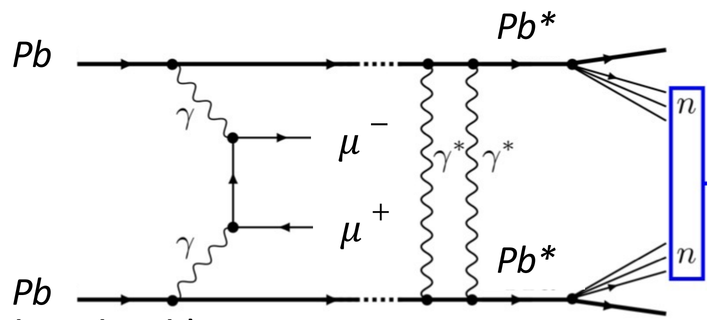
https://twiki.cern.ch/twiki/bin/view/CMSPublic/SketchUpCMS

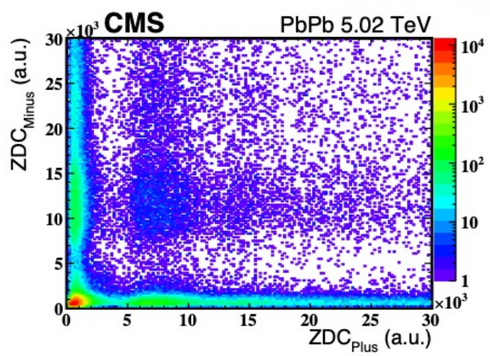


Zero Degree Calorimeter (ZDC) detects neutral particles in |η|>8.5|η|>8.5 region

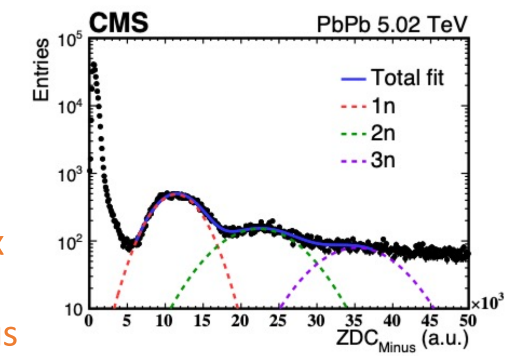
140 m

Photon-photon intereaction



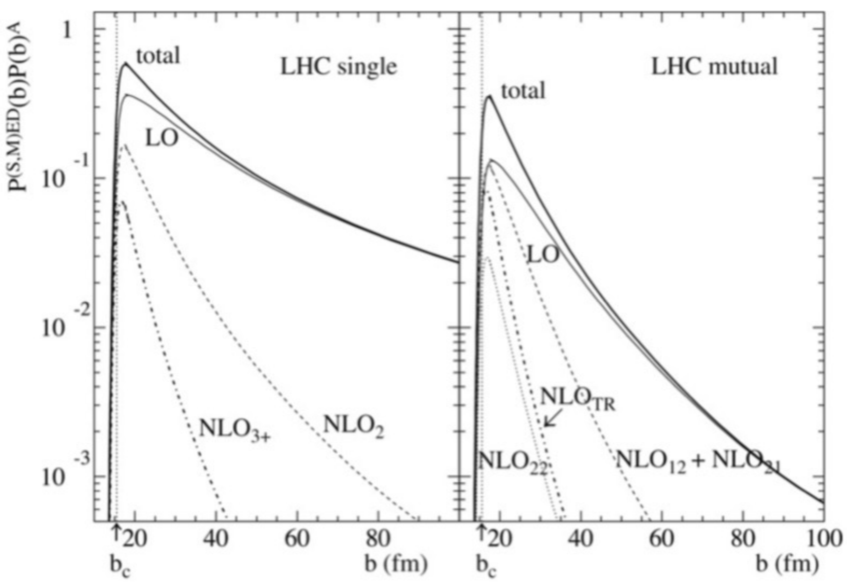


- Exclusive production
- Concentrate at low p_T (back to back)
- Smooth mass spectrum
- May followed by EM dissociation between the same ion pairs
- Also observed in hadronic collisions of heavy ions



From the combinations of the number of neutrons in each ZDC separately, a total of six neutron multiplicity classes, labeled as 0n0n, 0n1n, 0nXn, 1n1n, 1nXn, and XnXn, are used in this study. The 0n0n class corresponds to no Coulomb breakup of either nucleus and the 1nXn class corresponds to one neutron emitted from one nucleus and at least two neutrons emitted from the other nucleus

Use of neutron multiplicity to control b



- The photon-photon interactions can occur in conjunction with the excitation of one or both of the ions via photon absorption into giant dipole resonances or higher excited states.
- The giant dipole resonances typically decay by emitting a single neutron, while higher excited states may emit two or more neutrons. (These forward neutrons have very low relative momentum with respect to their parent ions and therefore approximately retain the beam rapidity).
- => Therefore, # of emitted neutrons detected in the forward region can be used to classify UPC events into different b (impact parameter) ranges.

- High excited state $\Longrightarrow$ more neutron emitted
- Small ***b*** $\Longrightarrow$ large high excited state contribution
- Bearing analogy to centrality bXnXn < b0nXn < b0n0n

A. J. Baltz et al., Phys. Rep. 458 (2008) 1

Data selection

- Data from the CMS detector during the 2018 LHC run (PbPb at $\sqrt{s} = 5.02$ TeV)
- Integrated luminosity 1.5 nb-1
- Ultraperipheral Pb-Pb collisions

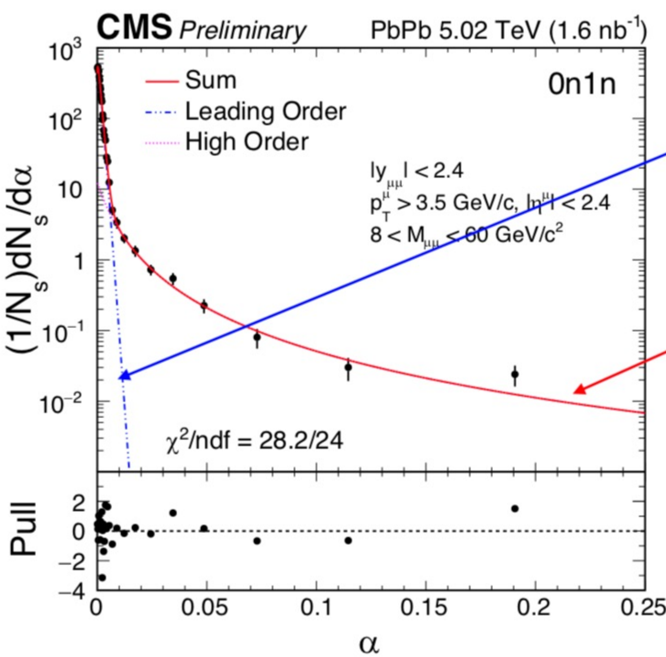
$$\gamma\gamma \to \mu^+\mu^-$$

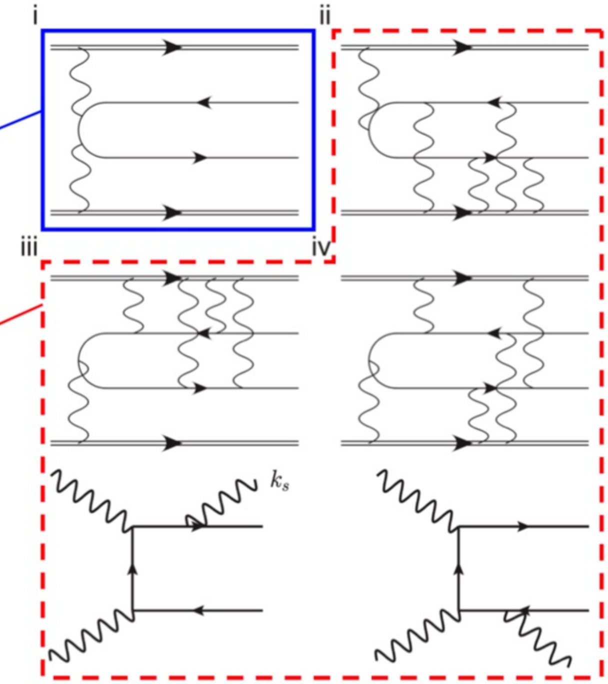
- Muon pair invariant mass region
- Muons are selected in the kinematic range $8 < m_{\mu\mu} < 60\ \mathrm{GeV}$ (suppress contribution from
- Photoproduced resonances)

$$|y^{\mu\mu}| < 2.4 \qquad |\eta^{\mu}| < 2.4 \qquad p_T > 3.5\ GeV$$

- Reconstructed combining μ μ candidates and combinatorial background estimated using events containing the same sing muons

LO $\gamma\gamma \rightarrow \mu^+ \mu^-$

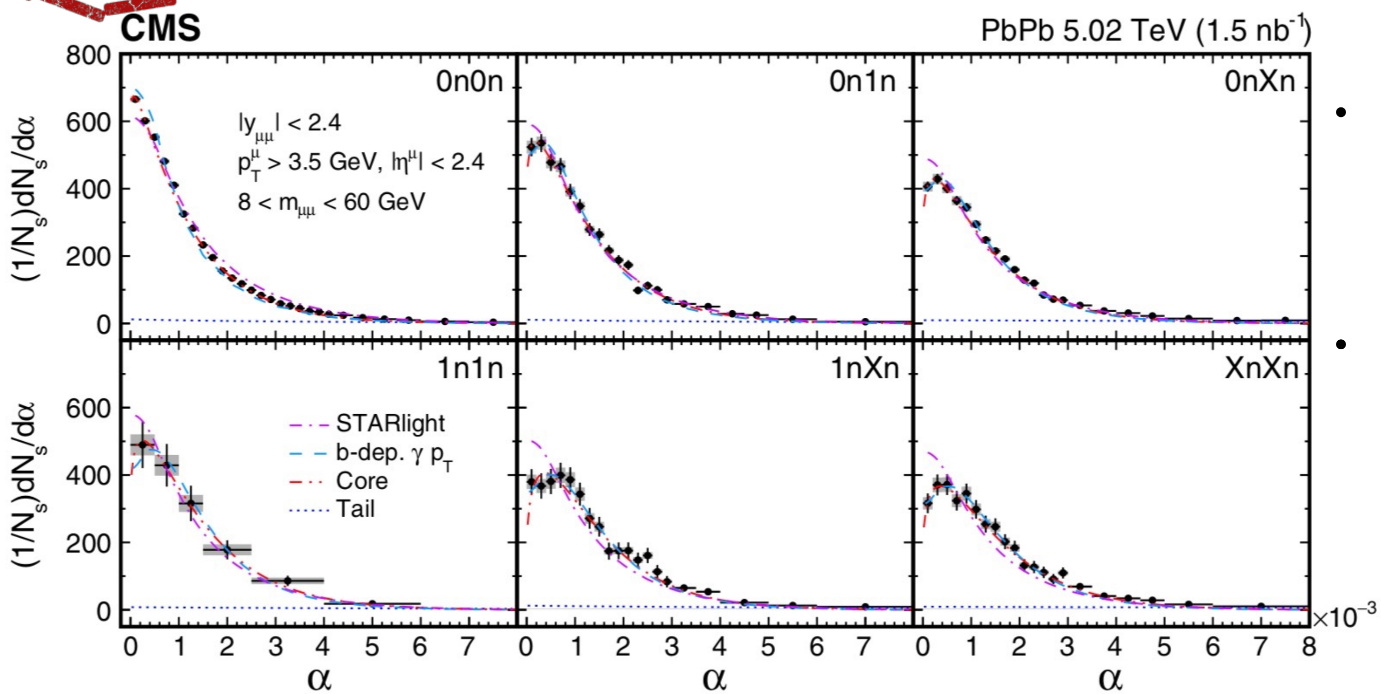




➢ ***Iterative*ly** fit α distributions:

- Leading Order: $c_0 \times e^{(-\alpha/c_1 + c_2 \times \alpha^{0.25})} \Longrightarrow <\alpha^{LO}>$
- High Order: $t_0 \times (1 + (t_1/t_2) \times \alpha)^{-t_2}$

Acoplanarity (α) distributions

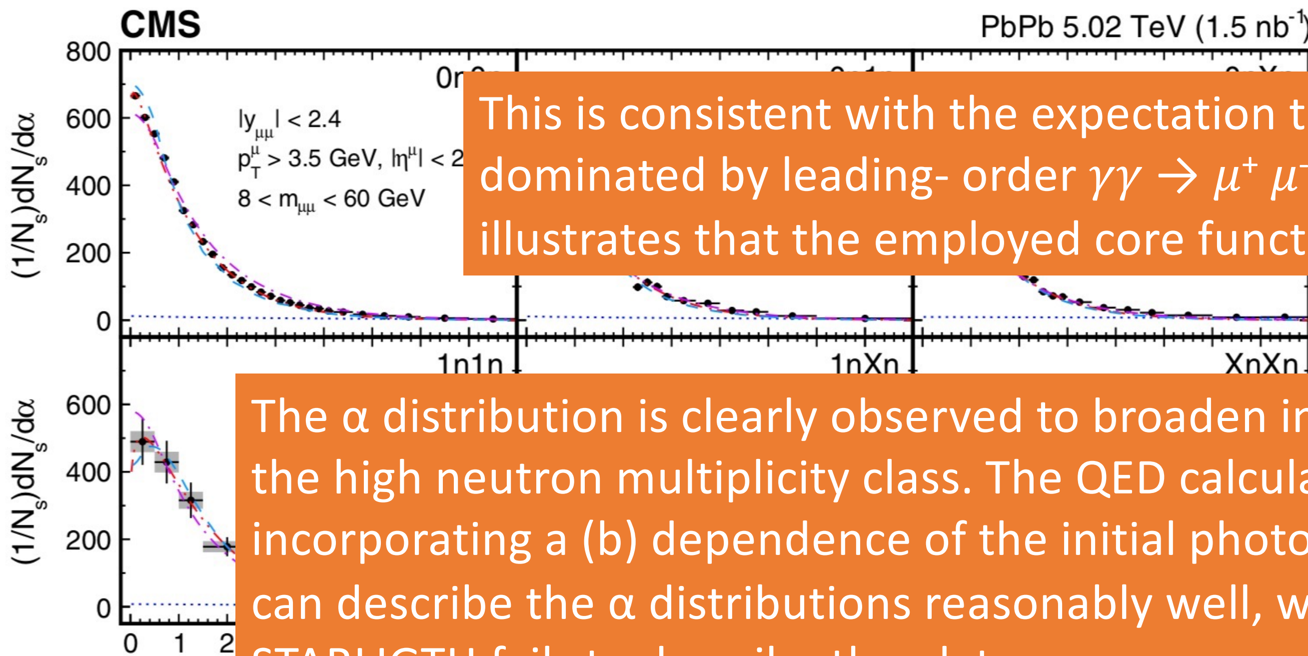


- STARLIGHT prediction and the dashed line corresponds to the LO QED calculation [J. D. Brandenburg, et. al, arXiv:2006.07365.].
- The dot-dot-dashed and dotted lines indicate the core and tail contributions, respectively. The vertical lines and shaded areas represent the statistical and systematic uncertainties, respectively.

Model calculations with $\alpha < 0.008$

Observation of Forward Neutron Multiplicity Dependence of Dimuon Acoplanarity in Ultraperipheral Pb-Pb Collisions at √sNN=5.02 TeV, CMS Collaboration, Physical Review Letters **127**, 122001 (2021)

Acoplanarity (α) distributions



This is consistent with the expectation that the <α^{core}> is dominated by leading- order $\gamma\gamma \rightarrow \mu^{+} \mu^{-}$ scatterings and illustrates that the employed core functional form is robust

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- The dot-dot-dashed and dotted …s indicate the core and tail …ributions, respectively. The …ical lines and shaded areas …esent the statistical and …ematic uncertainties, …ectively.

The α distribution is clearly observed to broaden in the high neutron multiplicity class. The QED calculation, incorporating a (b) dependence of the initial photon p_T, can describe the α distributions reasonably well, while STARLIGTH fails to describe the data

Model calculations with $\alpha < 0.008$

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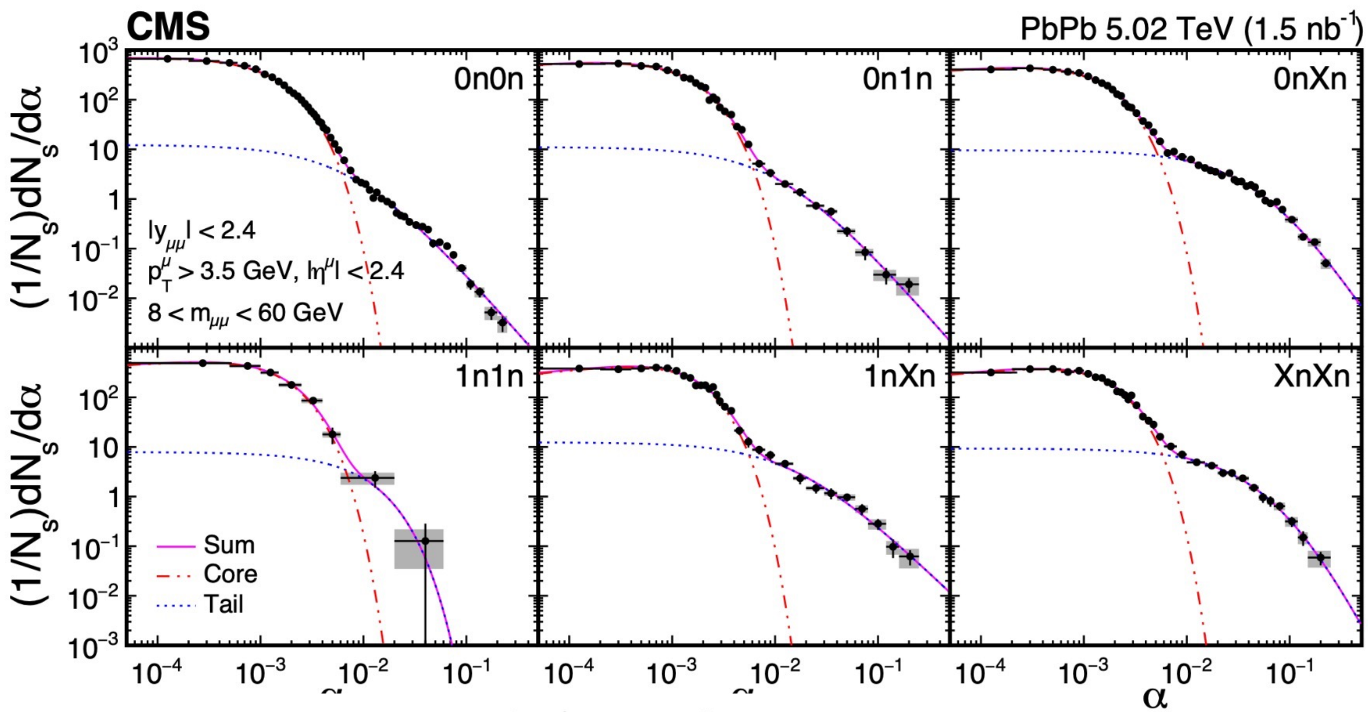
Azimuthal correlations of muon pairs



- The α distributions are normalized to unit integral over their measured range $\frac{1}{Ns}dNs/d\alpha$
- The dot-dot-dashed and dotted lines indicate the core and tail contributions, respectively, found using a fit to core $c_1 e^{-\frac{\alpha}{c2}+c3\alpha^{.25}}$ tail: $t_1\left[1+\left(\frac{t2}{t3}\right)\alpha\right]^{-t_3}$
- The vertical lines on data points depict the statistical uncertainties, while the systematic uncertainties and horizontal bin widths are shown as gray boxes

Acoplanarity $$\alpha = 1 - \frac{|\phi^+ - \phi^-|}{\pi}$$

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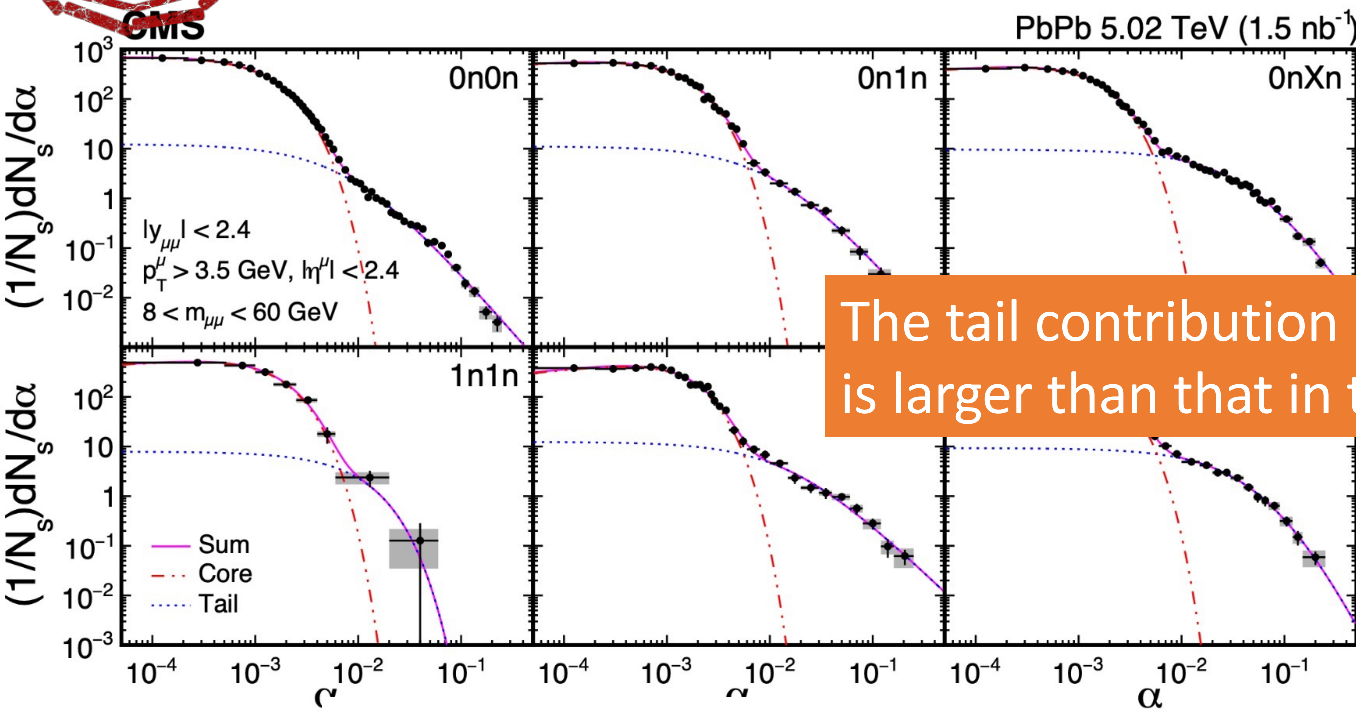

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The tail contribution in the XnXn class is larger than that in the 0n0n class

Acoplanarity $\alpha = 1 - \frac{|\phi^+ - \phi^-|}{\pi}$

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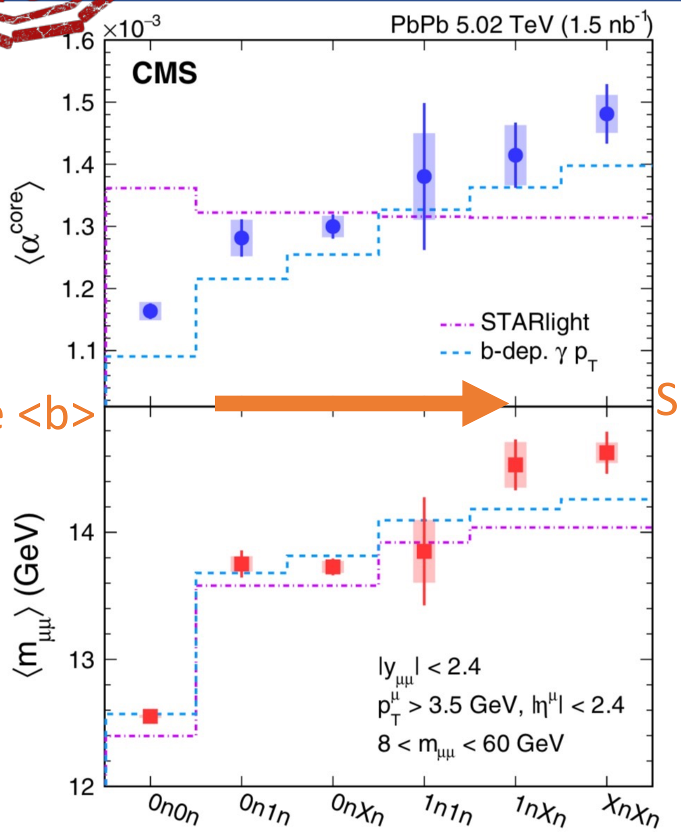
Neutron multiplicity dependence



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- Strong neutron multiplicity dependence of <αLO>
- Strong neutron multiplicity dependence of <m$\mu\mu$>

- The vertical lines on data points depict the statistical uncertainties, while the systematic uncertainties of the data are shown as shaded areas.
- The dot-dashed line shows the STARLIGHT prediction, and the dashed line corresponds to the leading-order QED calculation [J. D. Brandenburg, et al, arXiv:2006.07365.]

Neutron multiplicity dependence

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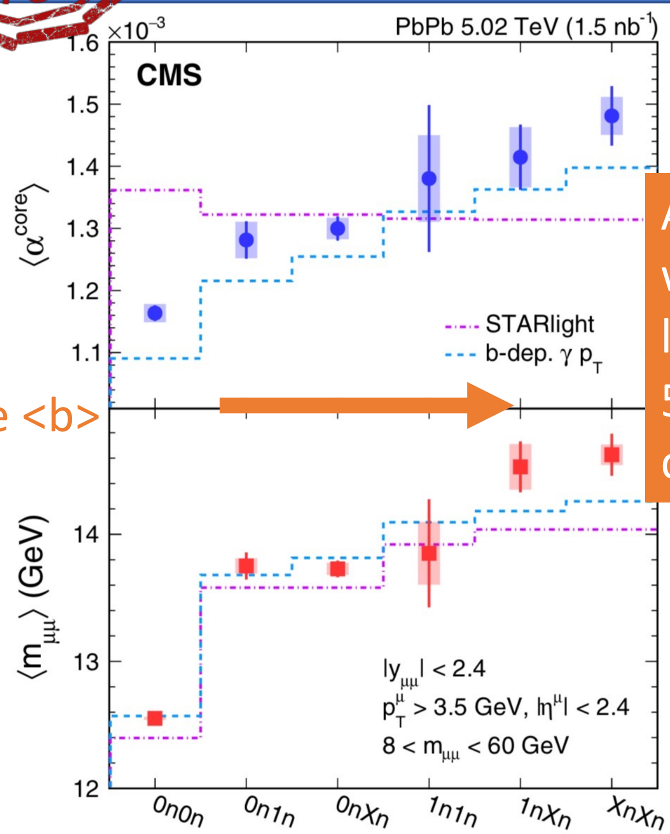

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- Strong neutron multiplicity dependence of

A clear neutron multiplicity dependence is observed, with the <mμμ> value measured in XnXn events being larger than in 0n0n events with a significance exceeding 5 standard deviations. These trends of can are qualitatively described by both model calculations

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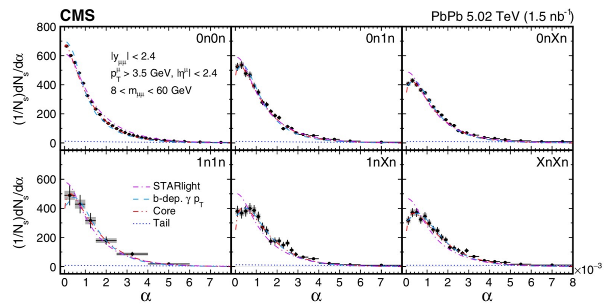
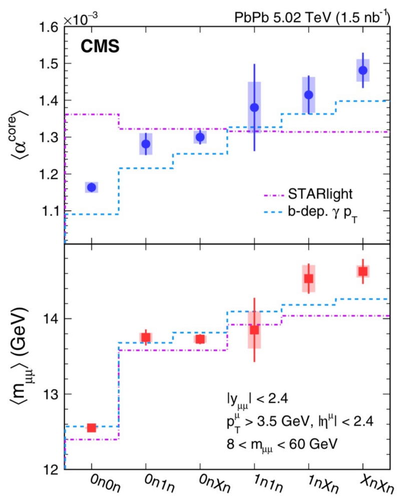
- The dot-dashed line shows the STARLIGHT prediction, and the dashed line corresponds to the leading-order QED calculation [J. D. Brandenburg, et al, arXiv:2006.07365.]

Summary

- The first measurements of $\gamma\gamma \rightarrow \mu + \mu -$ production as a function of forward neutron multiplicity in ultraperipheral lead-lead collisions at a nucleon-nucleon center-of-mass energy of 5.02 TeV.





A significant broadening of back-to-back azimuthal correlations is seen, with respect to the LO process, for increasing multiplicities of emitted forward neutrons. This observed trend is qualitatively reproduced by a LO QED calculation, demonstrating the importance of an impact-parameter- dependent photon pT .

- A similar trend of increasing average invariant mass of muon pairs with neutron multiplicity is also observed. These measurements provide the first experimental demonstration that the initial energy and transverse momentum of photons exchanged in ultraperipheral heavy ion collisions depend on the impact parameter of the interaction.

Data selection

Thank You!

More details can be found in:

Observation of Forward Neutron Multiplicity Dependence of Dimuon Acoplanarity in Ultraperipheral Pb-Pb Collisions at √sNN=5.02 TeV, CMS Collaboration, Physical Review Letters **127**, 122001 (2021)