Azimuthal asymmetries in coherent photoproduction of J/ψ with ALICE

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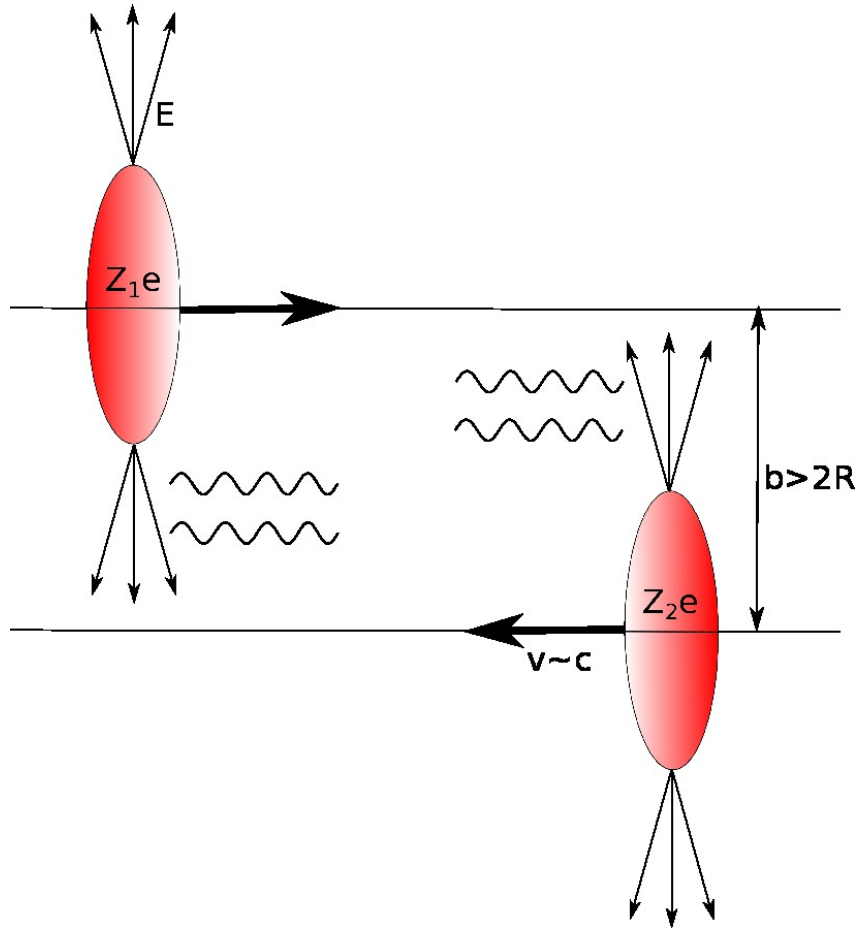
September 15, 2021

Content

Ultra-peripheral collisions

- Collisions with impact parameter larger than the sum of the radii of nuclei.
- Electromagnetic fields of accelerated nuclei get Lorentz contracted.
- Electromagnetic fields are considered to be a source of quasi-real photons.
- $\gamma\gamma \rightarrow l^+l^-$
  - Interaction between photons from each nuclei.
- $\gamma + Pb \rightarrow \mathrm{VM} + \mathrm{Pb}$
  - Photon fluctuates into $q\bar{q}$ pair that scatters off a nucleus.



Vector-meson photoproduction

- The process of vector-meson photoproduction is sensitive to the gluon content.
- It is a clean process from the experimental point of view.
- By measuring the scattering angle of the J/ψ we can study the evolution in Bjorken-x of the structure of hadrons with Bjorken-x in the scale $Q^2 \sim M^2_{J/\psi}$ that allows for the use of pQCD.

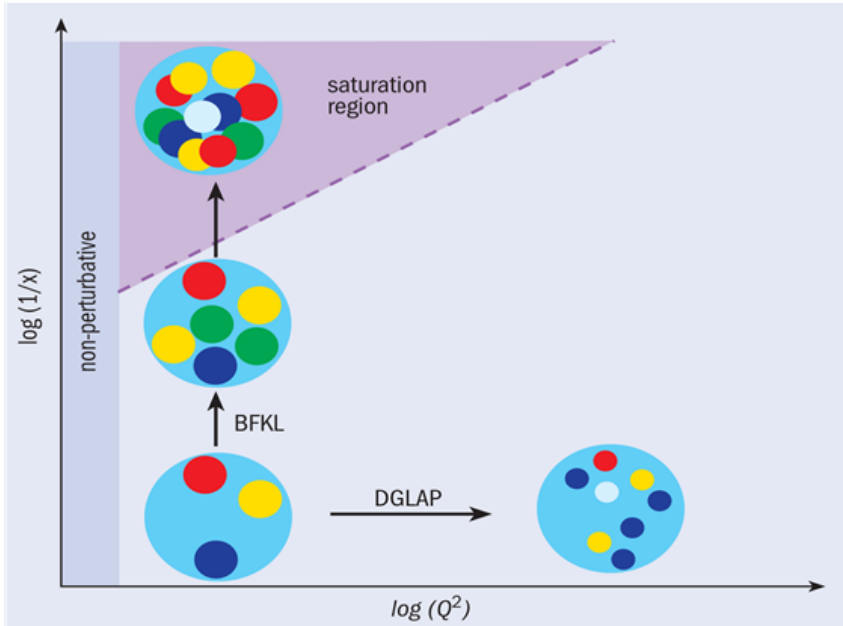


Figure 1: Hadron structure for different transfered momenta and Bjorken-x. [1]

[1] CERN Courier **50** (2010) no.6, 24-27, [https://cds.cern.ch/record/1734540].

Linearly polarized photons

- Electric and magnetic fields of charged particles moving at ultra-relativistic speeds are both perpendicular to the beam directions and they propagate as linearly polarized electromagnetic waves.
- Photons generated by those fields are considered to be linearly polarized.
- When the same type of particles collide, there is also an interference effect.
- This allow us to measure basic QED processes in $\gamma - \gamma$ interactions and to search for new polarisation/interference dependent observables to study the structure of hadrons in diffractive photoproduction of vector mesons.

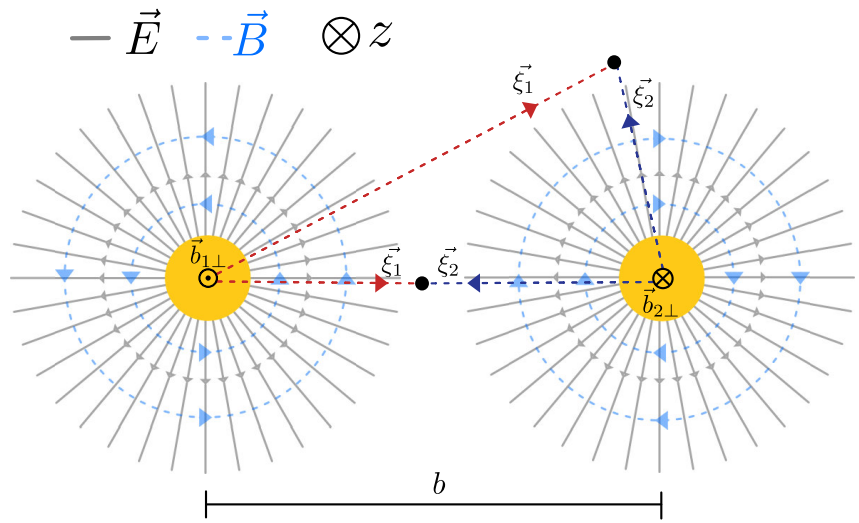


Figure 2: Photon polarization vectors. [2]

[2] J. D. Brandenburg, W. Zha and Z. Xu, [arXiv:2103.16623 [hep-ph]].

Linearly polarized photons

- We are interested in process where only two leptons are produced in the collision. They can come about for example in $\gamma\gamma \to e^+e^-$ or $\gamma + Pb \to J/\psi +$ Pb where the J/ψ decays into dilepton pair.
- The polarisation/interference dependent observable is $\Delta\phi$. It is defined as the difference between sum and difference of the track 4-momenta.
- During vector meson photoproduction the nuclei "take turns" in photon production.
- There are two interfering events.

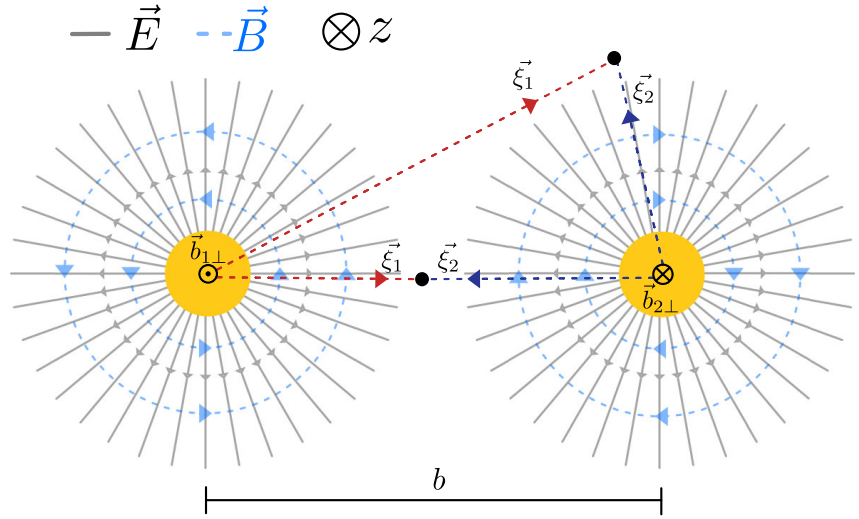


Figure 3: Photon polarization vectors in electromagnetic fields of the nuclei. [3]

[3] J. D. Brandenburg, W. Zha and Z. Xu, [arXiv:2103.16623 [hep-ph]].

Previous measurements: $\gamma + Pb \rightarrow J/\psi(\rightarrow l^+l^-) + \mathrm{Pb}$

- Measurement of coherent and incoherent exclusive charmonium photoproduction.
- Data selected from 2011 data taking
- Study of coherent and incoherent charmonium and e^-e^+ pair photoproductions in ultra-peripheral Pb-Pb collisions with $\sqrt{s_{NN}} = 2.76$ TeV.

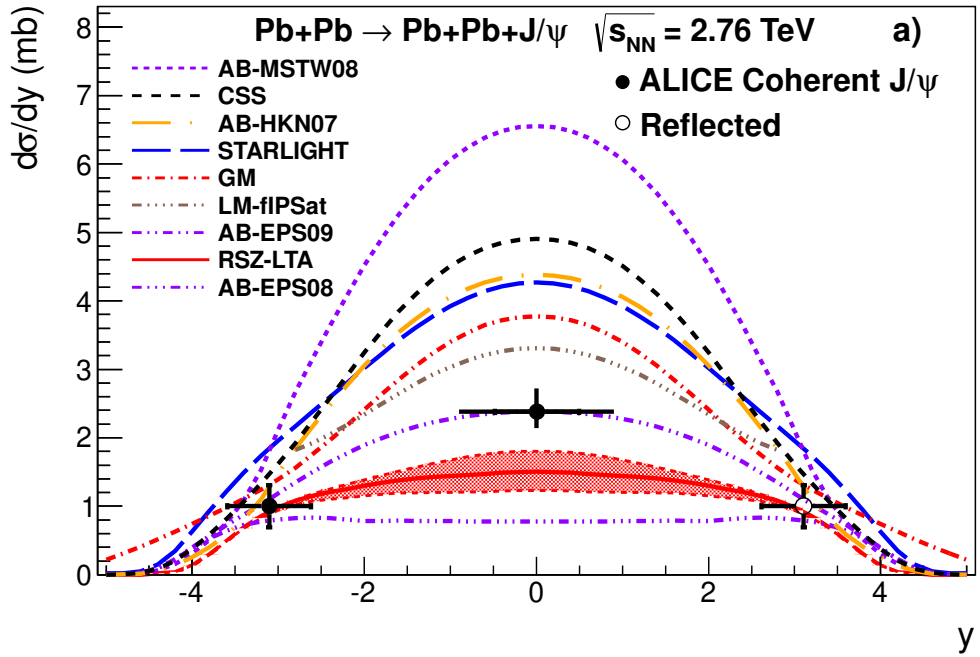


Figure 4: Comparison of theoretical models for cross sections in coherent photoproduction with measured data. [4]

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- Important shadowing effects observed at midrapidity.

[4] E. Abbaset al.[ALICE], Eur. Phys. J. C73(2013) no.11,2617 doi:10.1140/epjc/s10052-013-2617-1 [arXiv:1305.1467[nucl-ex]]

Previous measurements: $\gamma\gamma \to e^+e^-$

- Measurements of exclusive e^-e^+ pairs created by the Breit-Wheeler process in high magnetic fields.
- Measured by the STAR Collaboration at RHIC using Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV in 2010.
- $\cos 4\Delta\phi$ significance in UPC with 6.7σ significance.

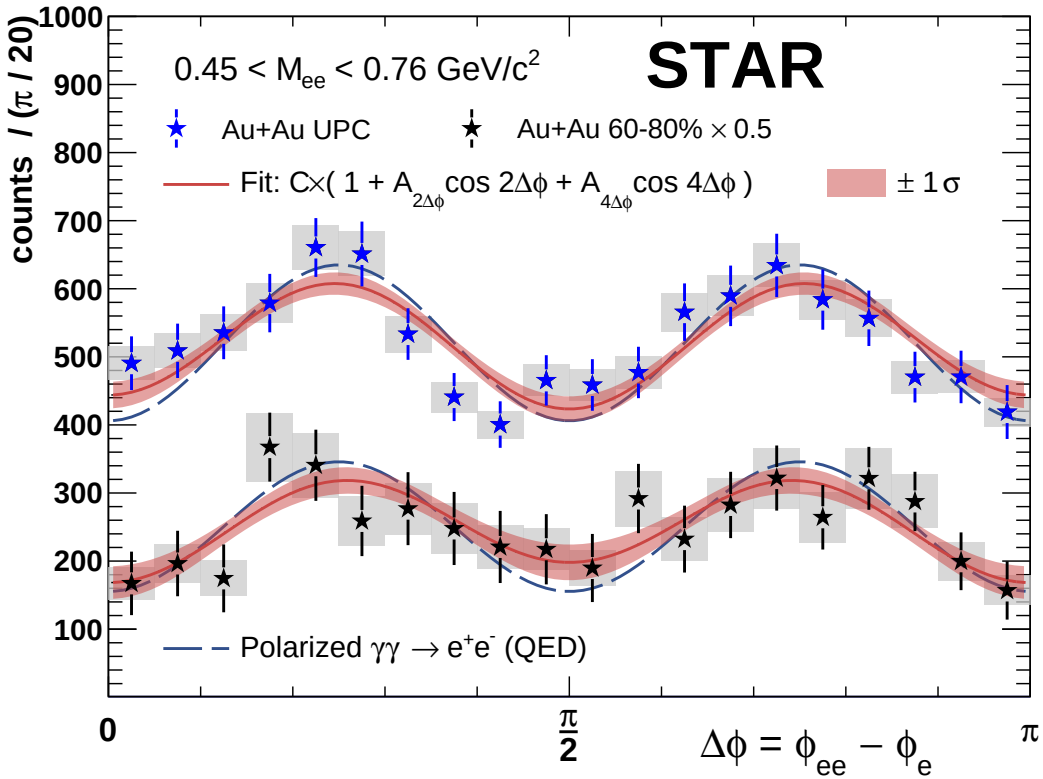


Figure 5: Comparison of observed asymmetry in UPC and peripheral collisions. [5]

- Asymmetry allows us to study the angular-momentum structure of the interaction.

[5] J. Adam et al.[STAR], [arXiv:1910.12400[nucl-ex]]

ALICE

- Central barrel detectors
  - Inner Tracking System
  - Time Projection Chamber
  - Time of Flight detector
- Detectors in the forward region
  - V0 detector
  - Zero Degree Calorimeter
  - AD detector

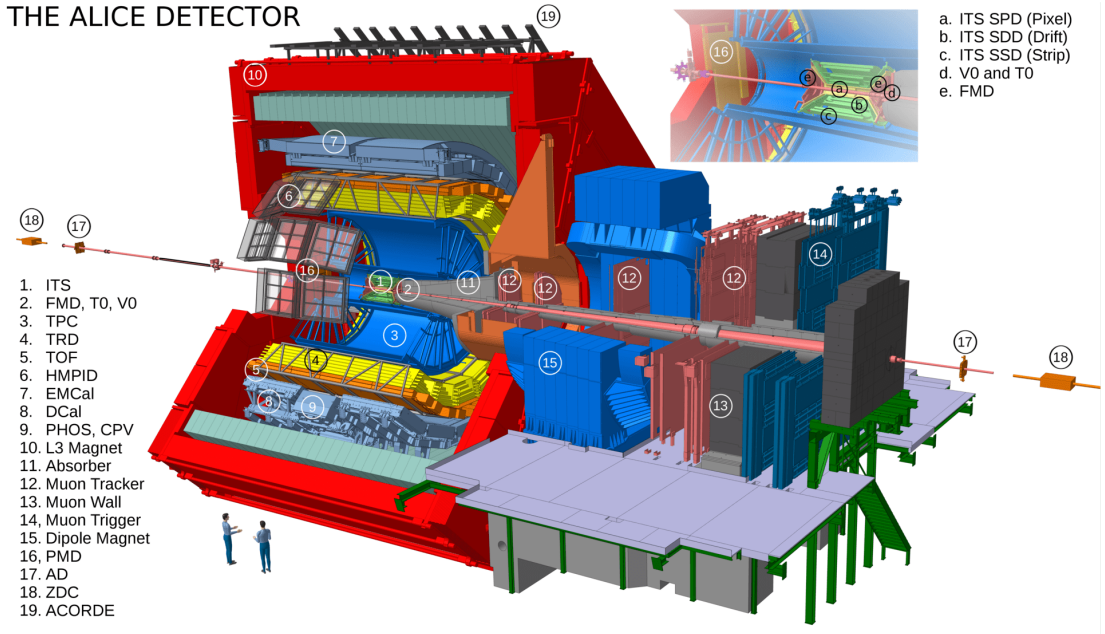
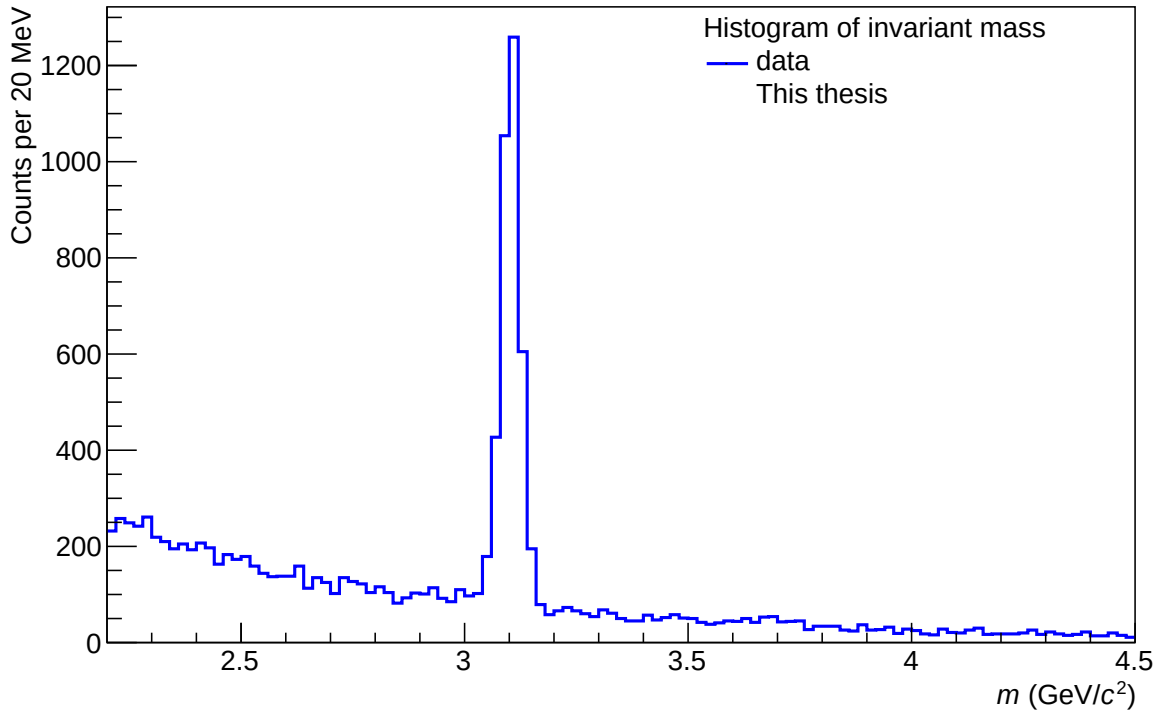


Figure 6: Scheme of ALICE. [6]

[6] ALICE Collaboration, JINST 14 (2019) no.05, P05025, [arXiv:1902.06145 [physics.ins-det]]

Data selection

- UPC Pb-Pb collisions with $\sqrt{s_{NN}} = 5.02$ TeV from 2018.
- Data selection
  - No signal in ADA, ADC, V0A, V0C detectors.
  - Dilepton rapidity $|y| < 0.8$.
  - Pseudorapidity of both tracks $|\eta| < 0.8$.
  - Only muon pairs were selected.
  - Transverse momentum cut $p_T < 0.2$ GeV/c.

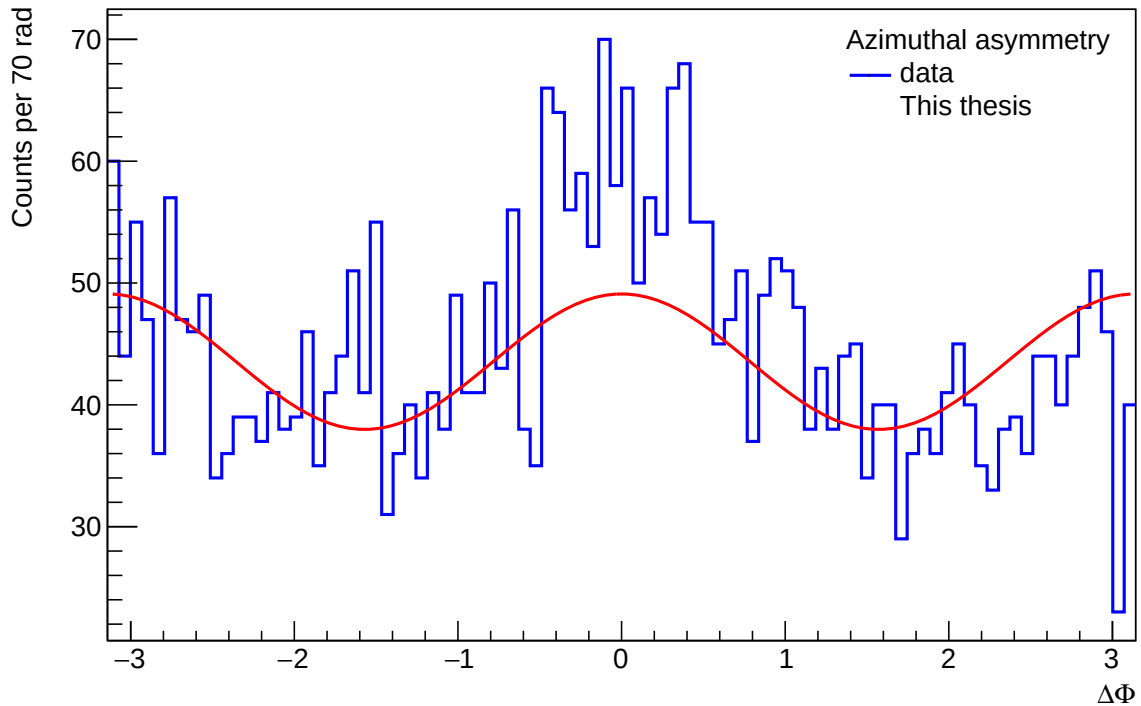


- Clear J/ψ peak can be seen with a few thousand events in the mass region of the J/ψ over a small irreducible background from $\gamma + \gamma \rightarrow \mu^+ + \mu^-$.

[7] Great thanks to Ing. David Grund for providing the input data.

Data analysis

- Values for $\Delta\phi$ were obtained by finding the difference between sum and difference of the track 4-momenta.
- The data were fitted with function $f = A(1 + B\cos(2\Delta\phi))$.
- Obtained results for parameters are
  - $B = 0.128 \pm 0.023$
- Obtained χ^2/ndf is approximately 1.5



Summary and outlook

- Ultra-peripheral collisions where a J/ψ vector meson is produced are of particular interest, because they allow us to study the gluon structure of hadrons at small Bjorken-x at a perturbative scale.
- Measurements are conducted with ALICE with Pb+Pb data from 2018 at $\sqrt{s_{NN}} = 5.02$ TeV.
- Results show possible azimuthal asymmetry in the final state.
- This result is at the raw data level; the next step is then to use Monte Carlo simulations to estimate the correction factors to see if the asymmetry is still there. Then we have to study possible systematic uncertainties. If all goes well, we can explore to repeat the analysis for different p_T ranges as suggested by theoretical predictions.[8]

Thank you for your attention!

Reference


E. Abbas *et al.* [ALICE], Eur. Phys. J. C **73** (2013) no.11, 2617 doi:10.1140/epjc/s10052-013-2617-1 [arXiv:1305.1467 [nucl-ex]].


K. Aamodt *et al.* [ALICE], JINST **3** (2008), S08002 doi:10.1088/1748-0221/3/08/S08002


J. Adam *et al.* [STAR], [arXiv:1910.12400 [nucl-ex]].


J. D. Brandenburg, W. Zha and Z. Xu, [arXiv:2103.16623 [hep-ph]].

Backup

Total Cross-section	**Measured**	**STARLight**	**gEPA**	**QED**
$\sigma(\gamma\gamma \to e^+e^-)$ mb	0.261 ± 0.004 (stat.) ± 0.013 (syst.) ± 0.034 (scale)	0.22	0.26	0.29

Differential Quantities	**Ultra-Peripheral**			**Peripheral HHICs**		
	Measured	QED	χ^2/ndf	Measured	QED	χ^2/ndf
$\lvert A_{4\Delta\phi}\rvert$ (%)	16.8 ± 2.5	22	18.8 / 16	27±6	39	10.2 / 17
$\lvert A_{2\Delta\phi}\rvert$ (%)	2.0 ± 2.4	0	18.8 / 16	6±6	0	10.2 / 17
$\sqrt{\langle P_\perp^2 \rangle}$ (MeV/c)	38.1±0.9	37.6	—	50.9±2.5	48.5	—

Figure 7: STAR data.

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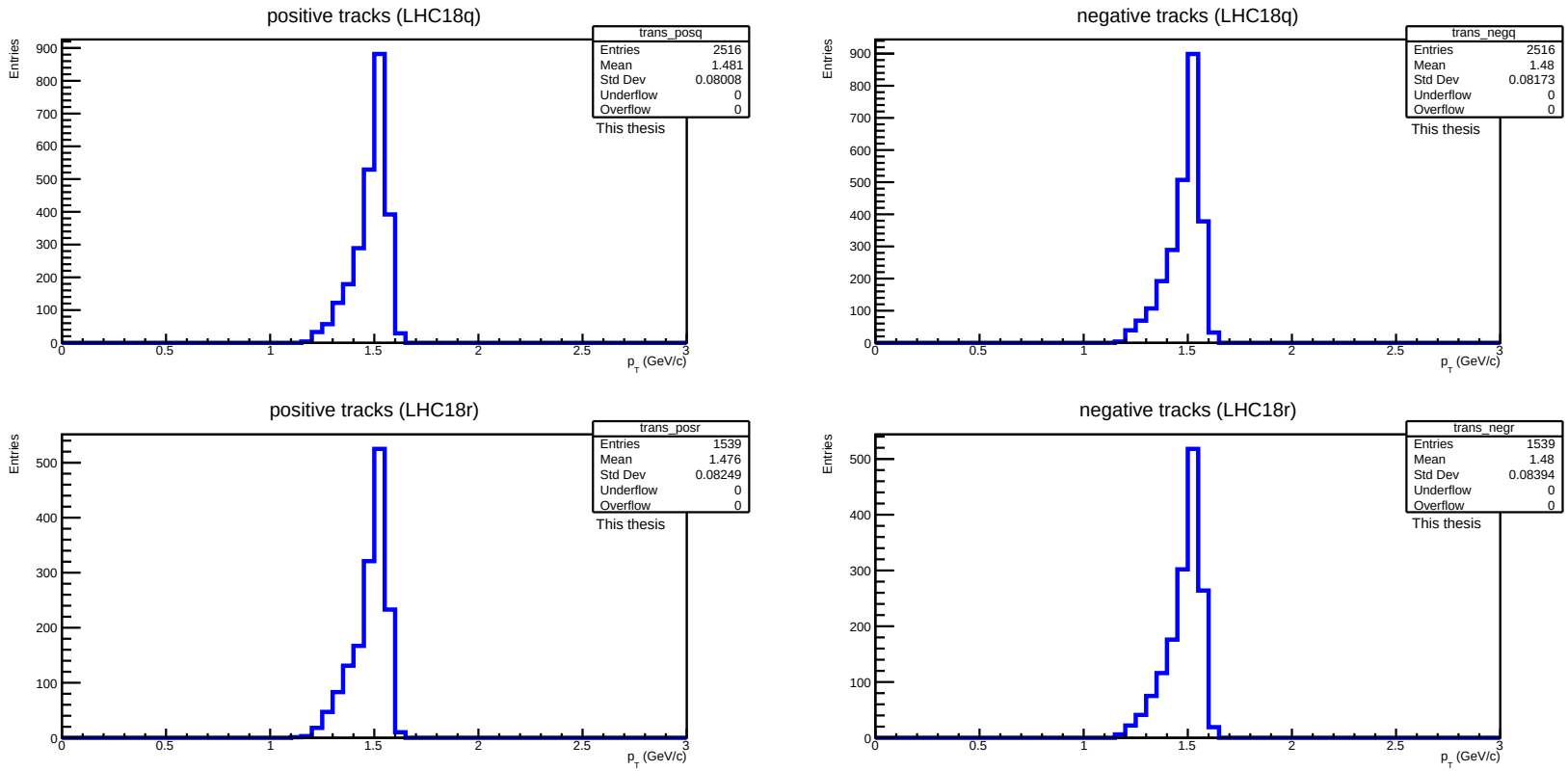

Figure 8: Comparison of the two periods for p_T.

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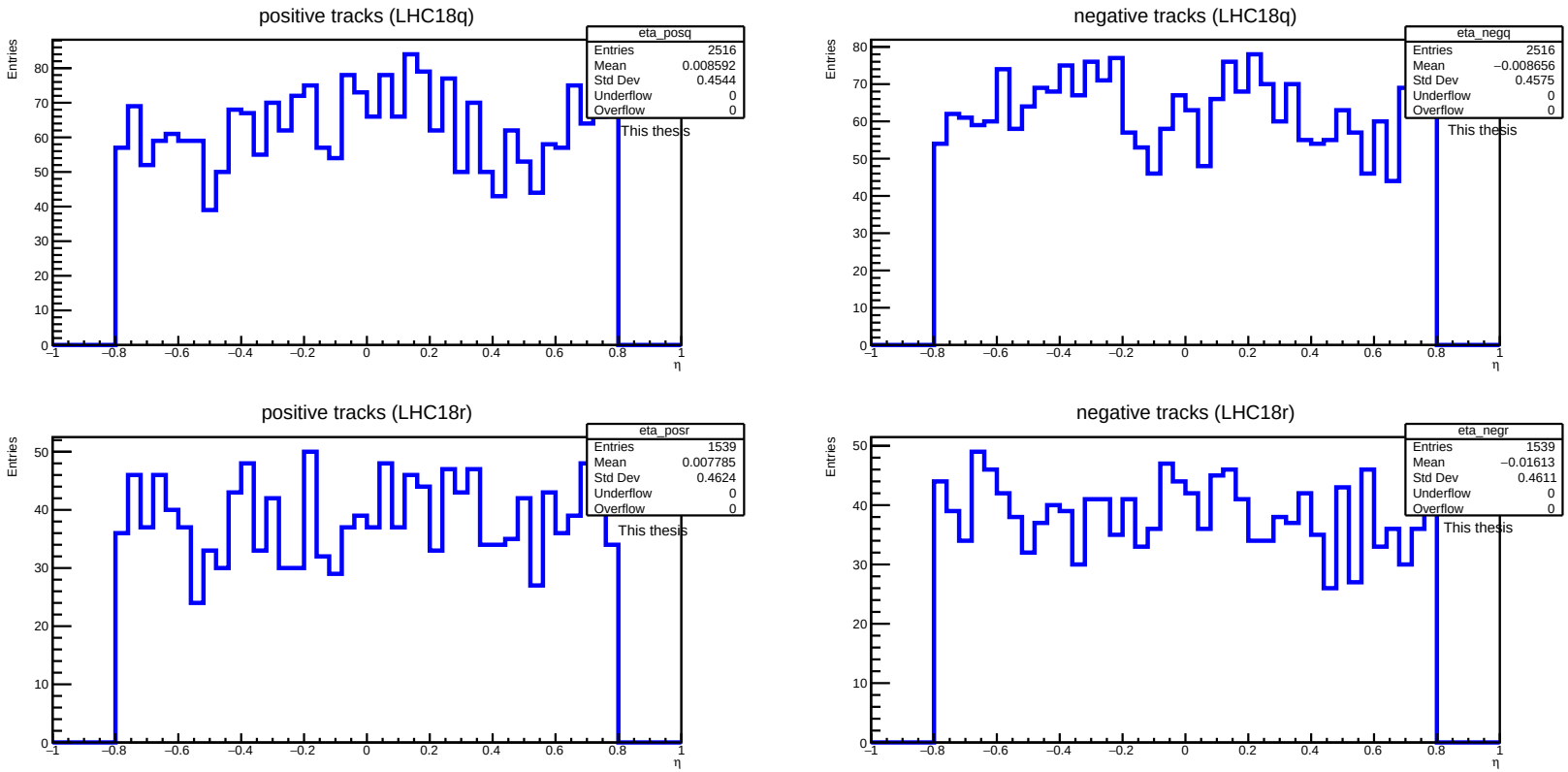

Figure 9: Comparison of the two periods for pseudorapidity

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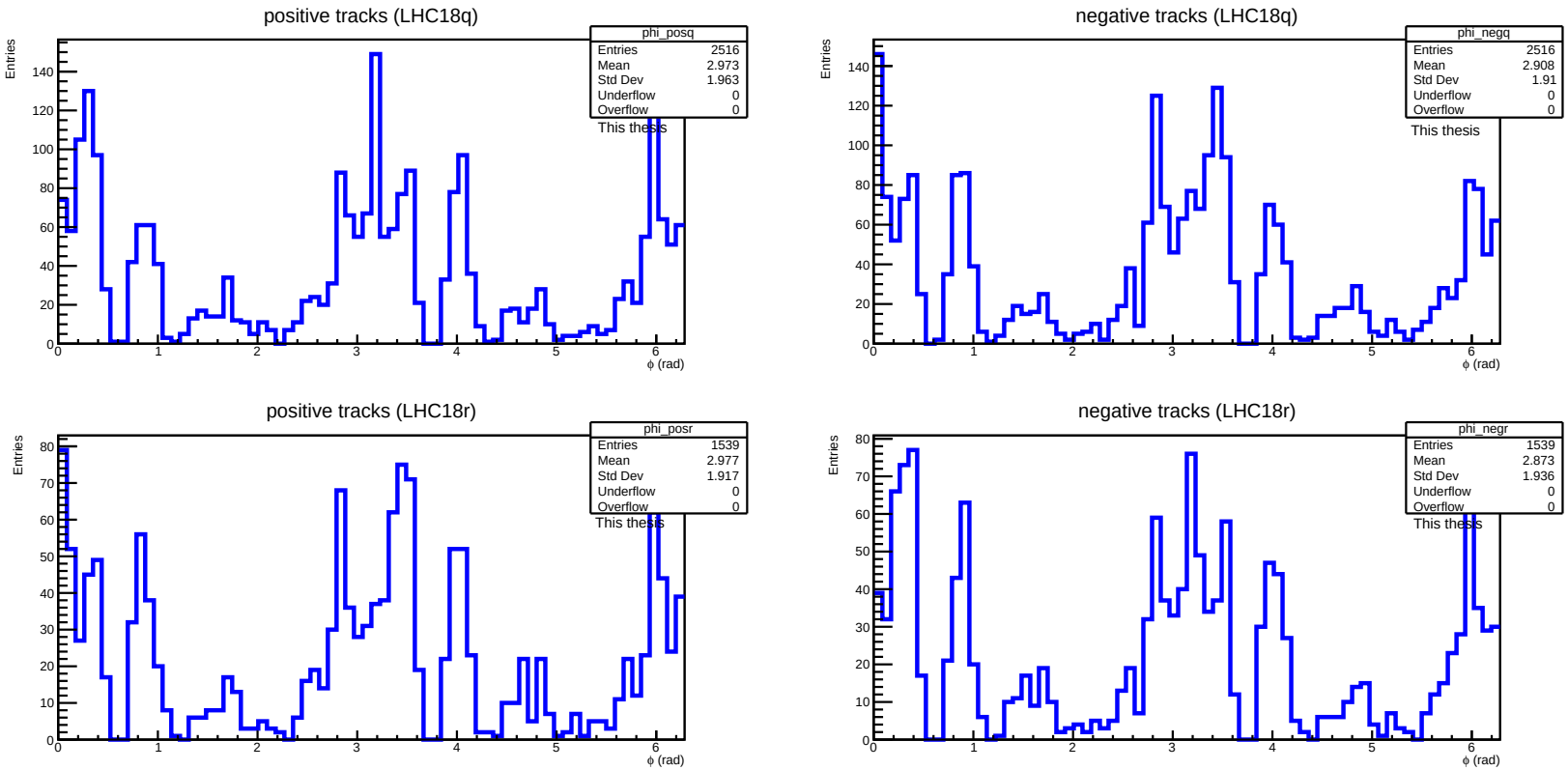

Figure 10: Comparison of the two periods for azimuthal angle.

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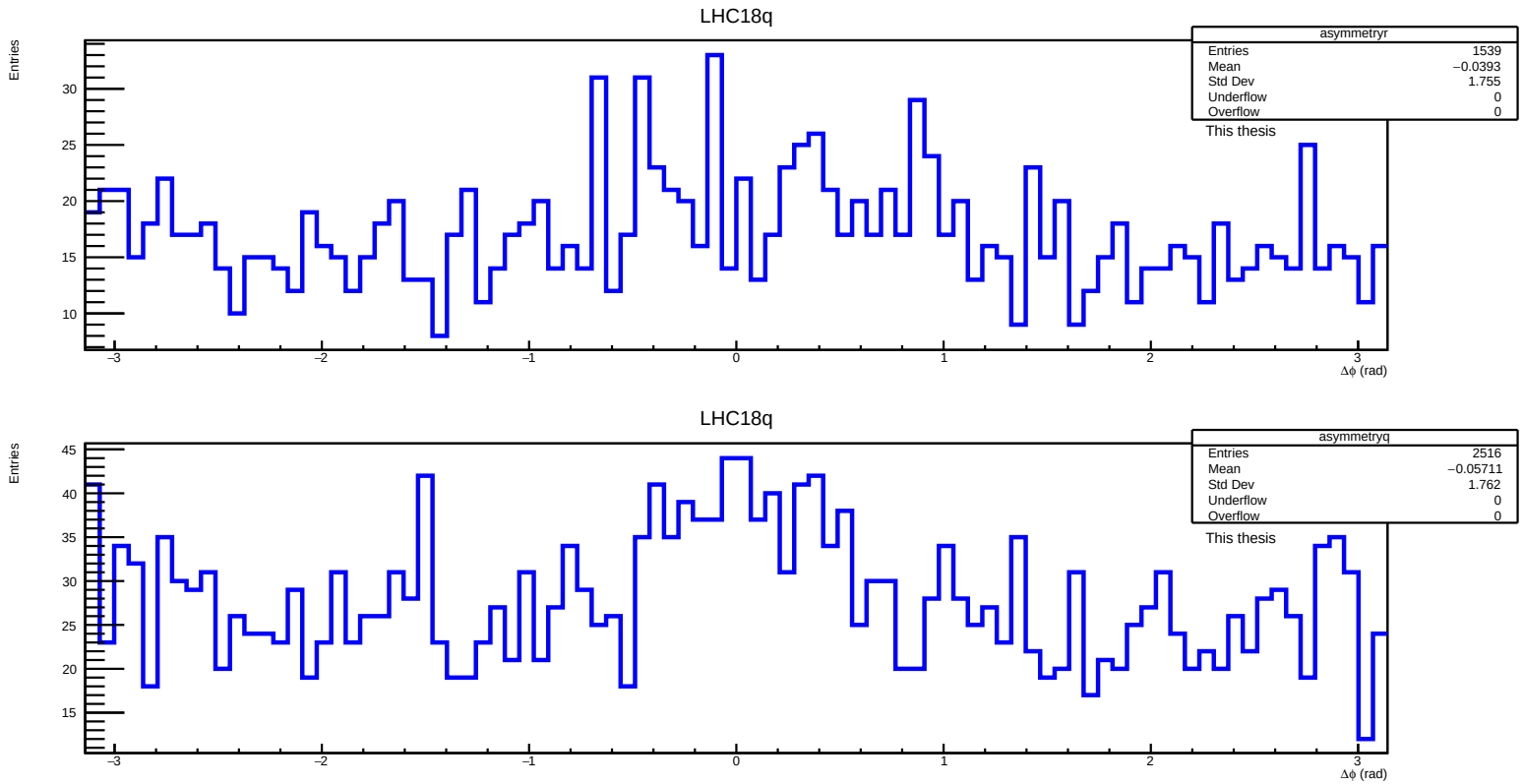

Figure 11: Comparison of the two periods for asymmetry.