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Measurements of elliptic azimuthal anisotropies in γp interactions in pPb collisions with the CMS experiment

Subash Chandra Behera for the CMS Collaboration*

Indian Institute of Technology,
Madras, Chennai, India

E-mail: subash.chandra.behera@cern.ch

A wide variety of measurements suggest the existence of strong collectivity in collisions of small systems such as proton-proton (pp) and proton-nucleus (pPb) with hydrodynamic models or gluon saturation in the initial state as two theory alternatives showing consistency with the observations. These results raise the question as to whether such phenomena may be present in even smaller systems. Just recently ATLAS, ALEPH, and ZEUS collaborations have extended the studies to photon-Pb, electron-electron (ee), and electron-proton (ep) systems respectively. This talk will summarize the latest CMS results on the study of long-range particle correlations extended to photon-proton interactions using pPb collisions at 8.16 TeV. Such interactions provide unique initial conditions with event multiplicity lower than in pp and pPb systems but comparable with electron-positron and ep systems.

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1. Introduction

The existence of collectivity has been extensively studied and well established in large collision systems like lead-lead (PbPb) and gold-gold (AuAu) collisions. These collisions involve heavy nuclei at high energies, creating conditions where the formation of a quark-gluon plasma (QGP) is expected [1, 2]. Several key measurements and observables have been used to study collective behaviour. One of the attention is the presence of the long-range correlation that manifests as an enhanced yield of particles at small relative azimuthal angles, typically within a few units of pseudorapidity, even when the particles are far apart in rapidity, which is commonly referred to as the "ridge" [3, 9]. The results from the studies in small collision systems have shown intriguing observations for high-multiplicity events. Evidence of a ridge-like structure has been reported recently by CMS, suggesting the presence of collectivity [9]. The emergence of collectivity in small systems like proton-proton (pp) and proton-lead (pPb) collisions has spurred theoretical investigations to explain its origin. Possible explanations include the role of initial-state effects, such as gluon saturation and the color glass condensate, and the presence of hydrodynamic-like behaviour in these systems.

The Fourier components of two-particle azimuthal correlations, denoted as $V_{n\Delta}$, provide information about the azimuthal anisotropy in the system. The Fourier components characterize the magnitude of the correlation at a particular azimuthal angle difference ($\Delta\phi$) and for a specific harmonic order (n). The single-particle azimuthal anisotropy Fourier coefficients (v_n) may be obtained from the Fourier components of the two-particle correlations if the two-particle correlations can be factorized into the product of the corresponding single-particle azimuthal distributions. The relationship between the Fourier components and the single-particle azimuthal anisotropy coefficients is given by $v_n = \sqrt{V_{n\Delta}}$. The second harmonic coefficient (v_2) corresponds to the elliptic flow, while the third harmonic coefficient (v_3) corresponds to the triangular flow [3].

In ultraperipheral collisions, the impact parameter is larger than the sum of the radii of the nuclei, meaning that the colliding particles (proton and lead nucleus) nuclear interactions are suppressed, as they are of a shorter range [5, 6]. On the other hand, nuclei are more likely to interact electromagnetically, since the electromagnetic force is of longe range. In the case of pPb ultra-peripheral collisions, one of the lead nuclei emits a virtual photon that interacts with the proton. These interactions can result in various processes, such as exclusive vector meson production (e.g., ρ, ϕ), elastic photonuclear scattering, or diffractive dissociation of the proton [5]. Studying long-range correlations in photon-proton collisions offers a new perspective and expands our understanding of collective phenomena in different collision systems [7].

2. Data analysis

Two-particle correlations in photon-proton (γp) interaction were analysed in ultra-peripheral pPb collisions using data recorded by the CMS detector [8] during the pPb run at the LHC in 2016. The data used for the analysis corresponds to an integrated luminosity of 68.8 nb^{-1}, representing the amount of data collected during that run. The use of the trigger system allows for the selection of relevant events that exhibit characteristics of interest, such as γp interactions in the ultra-peripheral pPb collisions. These selected events are then used for the subsequent analysis of long-range correlations and the measurement of the $V_{\mathrm{n}\Delta}$ coefficients. In the analysis of the γp-enhanced selection, a rapidity gap is defined as a continuous region with low detector activity [10].

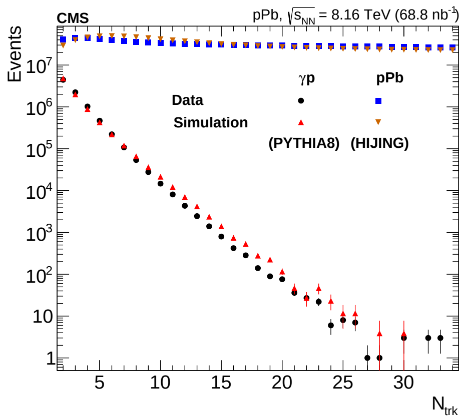

Figure 1: The N_{trk} spectra for γp and MB samples [10]. The simulated γp distribution has been normalized to the same event yield of the data γp enhanced sample.

The detector acceptance in terms of pseudorapidity is $|\eta| < 5.0$, which covers a wide range of detector coverage. This acceptance range is divided into 20 bins to characterise the rapidity gap further. Each bin in η corresponds to a specific region of the detector. the MB selection, the criteria include the coincidence of at least one tower with energy above 3.0 GeV in both HF (Hadronic Forward) calorimeters. Additionally, the MB selection requires the presence of at least two tracks within $|\eta| < 2.5$. Tracks are reconstructed trajectories of charged particles in the detector, and this requirement ensures the presence of at least two well-measured tracks within a specific η range. A γp-enhanced selection captures events with an intact Pb nucleus, particle production in the positive η region, and a large rapidity gap.

3. Results

Figure 2 (left) presents the two-particle correlation functions for γp-enhanced and minimum bias (MB) events in the specified multiplicity range of $2 \leq N_{\mathrm{trk}} < 35$, as functions of the $\Delta\eta$ and $\Delta\phi$. The $\Delta\eta$ range is limited to $|\Delta\eta| < 2.5$ for the γp distribution due to the $\Delta\eta_{\mathrm{F}}$ selection and tracker acceptance. A prominent near-side peak is centered at $(\Delta\eta, \Delta\phi) = (0, 0)$, representing correlated particle pairs from the same jet in both distributions. Additionally, there is a broader distribution from the recoiling jet centered at $\Delta\eta = 0$ and $\Delta\phi = \pi$. However, neither distribution displays a "ridge" structure at $|\Delta\phi| \approx 0$ for $|\Delta\eta| > 2$. Figure 2 (right) illustrates the correlation functions for γp-enhanced and MB events, showing the presence of jet peaks and recoiling jets [10]. These distributions are fitted over the range of $\Delta\phi$ $[0, \pi]$ using a Fourier decomposition series with terms $\propto 1 + \Sigma_{\mathrm{n}}\, 2V_{n\Delta} \cos(n\Delta\phi)$. The measured $V_{\mathrm{n}\Delta}$ coefficients are extracted from the fit. This includes only the first three terms since additional terms have a negligible effect.

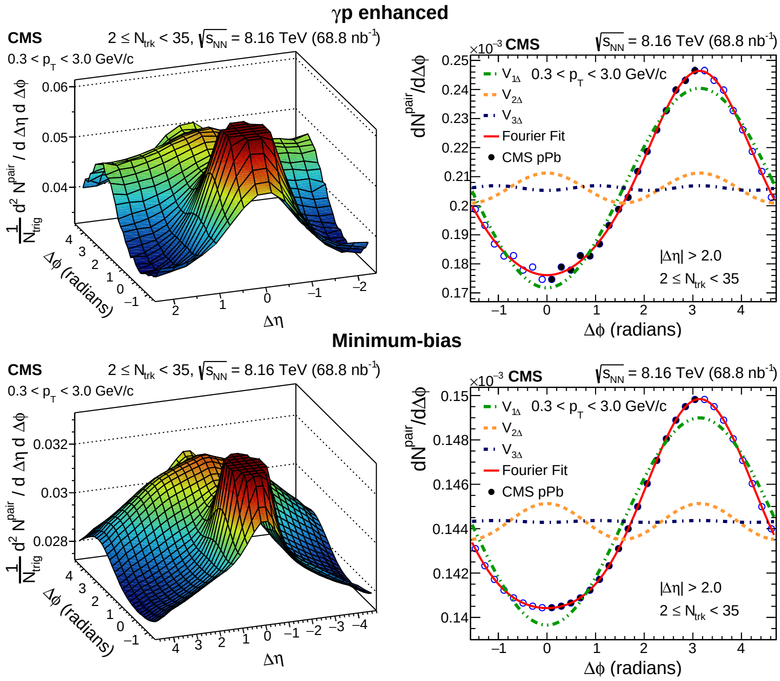

Figure 2: Two- and one-dimensional correlation plots for γp-enhanced (upper) and MB (lower) events for 0.3 to 3.0 GeV and 2 to 35 N_{trk} are shown on the left and right, respectively [10]. The jet peak with a centre at $(\Delta\eta, \Delta\phi) = (0, 0)$ is trimmed for the two-dimensional distributions to improve visualisation. The Fourier coefficients, Vn, are fitted across the range $[0, \pi]$ in the right column. By symmetrizing the points in $[0, \pi]$, points outside this range are found and shown as open circles.

Figure 3 presents the dependence of $V_{n\Delta}$ on N_{trk} (number of tracks), and the latter is studied for both γp and MB events in two different p_{T} ranges. The predictions from the PYTHIA8 generator for $V_{\text{n}\Delta}$ is calculated in γp collisions. The predictions specifically include $V_{2\Delta}$ and $V_{3\Delta}$, respectively, representing the elliptic and triangular flow. The comparison between the PYTHIA8 predictions and the γp data reveals that $V_{2\Delta}$ and $V_{3\Delta}$ from PYTHIA8 are reasonably consistent with the measured values. This consistency suggests that the model captures the observed dependencies of $V_{2\Delta}$ and $V_{3\Delta}$ on p_{T} [10].

Figure 4 presents the elliptic flow (v_2) as a function of N_{trk} and p_{T} for both the γp and MB events [10]. The figure also includes predictions from the PYTHIA8 generator for γp interactions and the HIJING generator for MB pPb interactions. Notably, neither of these models includes collective effects. Despite the absence of collective effects in the simulations, both the data and the simulations exhibit a slow variation of v_2 with track multiplicity for the γp and pPb samples [9, 10]. At a given N_{trk}, the v_2 values are larger in the higher p_{T} range. This observation is consistent with ep collision trends, where higher transverse momentum particles exhibit larger v_2 values. The simulations also demonstrate an increase of v_2 with p_{T}, but both the PYTHIA8 and HIJING generators slightly overshoot the data at higher p_{T}, indicating a discrepancy between the simulations and the measured v_2 values.

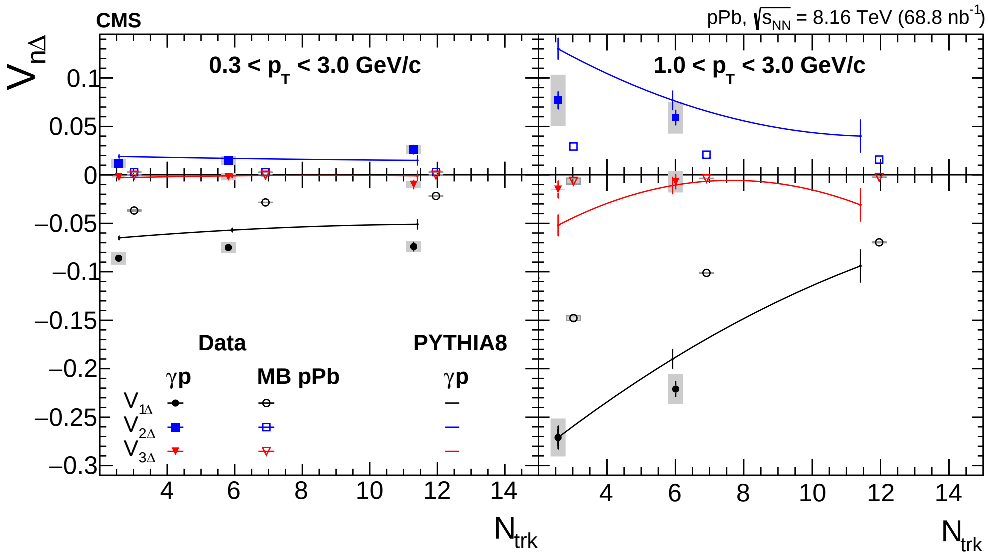

Figure 3: The dependence of $V_{n\Delta}$ on N_{trk} is studied for both γp and MB events in two different p_T ranges [10]. The results are presented in two panels, with systematic uncertainties represented by shaded bars. In the lower p_T range, the N_{trk} ranges of $2 \leq N_{trk} < 5$, $5 \leq N_{trk} < 10$, and $10 \leq N_{trk} < 35$ are used. For the higher p_T range, the N_{trk} ranges of $2 \leq N_{trk} < 5$ and $5 \leq N_{trk} < 35$ are considered. The different color lines indicate the prediction from PYTHIA8.

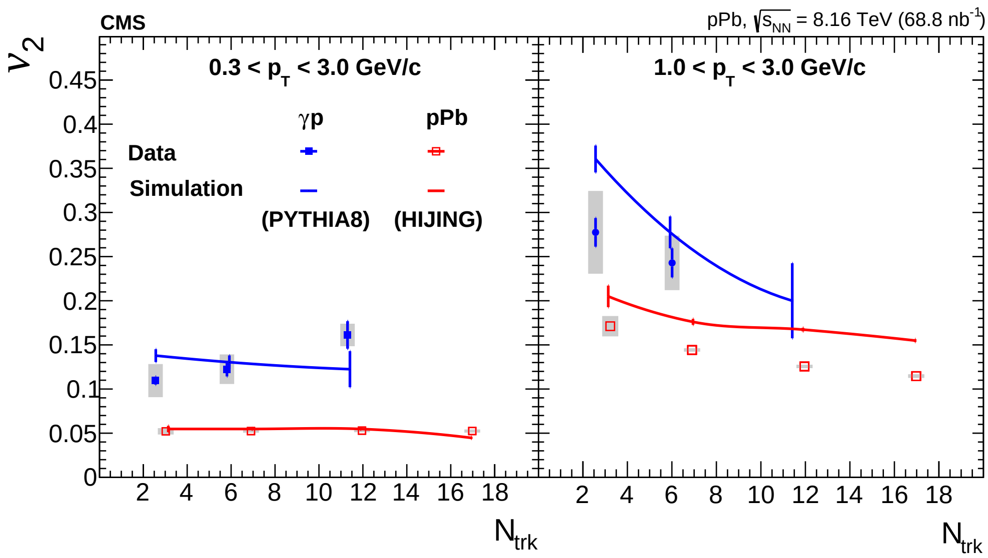

Figure 4: Shows the single-particle azimuthal anisotropy v_2 versus N_{trk} for γp-enhanced and pPb samples in two p_T regions [10]. In the figure, systematic uncertainties are represented by shaded bars, indicating the range of variation in the measured v_2 values within the given N_{trk} bin.

4. Summary

These proceeding discusses the study of long-range two-particle correlation measurements in photon-proton (γp) interactions in pPb collisions using the CMS detector. The study is focused on the two-particle Fourier coefficients $V_{n\Delta}$ and the corresponding single-particle azimuthal anisotropies v_2. These observables are examined as functions of the multiplicity of N_{trk} in two different p_{T} ranges. There is no evidence of a collectivity signal in the γp or hadronic minimum bias pPb samples within the explored multiplicity range within the sensitivity of the measurement. The measured Fourier coefficients reveal consistent features across all N_{trk} and p_{T} ranges. Specifically, $V_{1\Delta}$ is negative, $V_{2\Delta}$ is positive but with a smaller magnitude, and $V_{3\Delta}$ is consistent with zero. The predictions from the PYTHIA8 and HIJING models are found to describe the γp and pPb MB data well at low p_{T}, but slightly overestimate the data at higher p_{T}.

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