PROCEEDINGS OF SCIENCE

Optimization of light-by-light triggers from 2022 pilot lead-lead run in ATLAS

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Light-by-light scattering (LbyL, $\gamma\gamma \rightarrow \gamma\gamma$) is a very rare and interesting phenomenon, impossible to measure in standard hadronic lead-lead collisions. Its final state consists of a low-energetic pair of photons with the absence of any other activity in the detector. These di-photon events proved to be a powerful tool for new physics searches involving axion-like particles. A new large sample of lead-lead data is collected in the fall of 2023 as part of Run-3 operations at the LHC. It will provide access to more exclusive events including the LbyL process. Trigger preparations are an important aspect of each data-taking campaign. In particular, small rates of the LbyL process in comparison with the huge activity in the detector from other processes imply the development of special triggering techniques. In this document, some ideas for efficient triggering of events with low-p_{T} electrons and photons are discussed. The first approach involves studies with a dedicated set of triggers deployed in the lead-lead pilot run recorded in November 2022 by the ATLAS experiment. In particular, the estimation of the trigger efficiency for selections based on the hardware-level trigger (so-called level 1) from the pilot run is discussed.

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1. Introduction

In addition to standard proton collisions, the ATLAS experiment [1] also collects data from lead interactions. Among these data sets, ultra-peripheral collisions (UPC) constitute a highly interesting class of events. In this case, the impact parameter between two incoming lead nuclei is greater than the sum of their radii, so they do not interact hadronically, but through their electromagnetic (EM) fields. These EM fields are equivalent to fluxes of quasi-real photons. In this approach, the intensity of the EM field from one beam is proportional to the Z^2 factor, where Z stands for an atomic number of the ion. Therefore, when two fields interact, the cross-section for the process is scaled with the factor of Z^4. UPCs may lead to the production of particles, in particular di-leptons or di-photons. Therefore, they are a powerful tool to study rare processes such as light-by-light (LbyL) scattering that are impossible to measure in standard hadronic lead-lead collisions.

LbyL is a process in the Standard Model (SM) that proceeds via virtual one-loop box diagrams involving charged fermions and $W^{\pm}$ bosons. This phenomenon was first predicted over 80 years ago, but was observed directly only in 2017 by the ATLAS experiment at the LHC based on Run-2 lead-lead data [2]. About 100 event candidates of such a process were observed in the full Run-2 data set [3]. In previous years, the LbyL process was proposed as a novel channel for exploring new physics beyond SM. One option theoretically predicted is the existence of axion-like particles (ALPs). Both ATLAS [3] and CMS [4] established first constraints on ALP production cross-sections based on Run-2 lead-lead data. ALP and other models will be investigated further in a lead sample collected during Run 3. Therefore, during Run 3, it is essential to record a large sample of di-photon events with high efficiency.

2. Trigger strategy

In preparation for heavy-ion data taking in Run 3, a pilot lead-lead run took place in November 2022. A record collision energy of 5.36 TeV was achieved. There were two LHC fills with peak instantaneous luminosities of $2.4 \cdot 10^{25}$ cm^{-2} s^{-1} and $3.7 \cdot 10^{25}$ cm^{-2} s^{-1}. Total recorded integrated luminosity of L = 0.3 1/μb was achieved with 77M events recorded in the UPC stream.

In this study, pilot data is compared with a dedicated Monte Carlo simulation. A STARlight + Pythia8 sample of 100k events for the $\gamma\gamma \rightarrow e^{+}e^{-}$ process is produced with invariant masses of $m_{\gamma\gamma}$ > 1.8 GeV reconstructed in the latest software version. Exclusive pairs of electrons ($\gamma\gamma \rightarrow e^{+}e^{-}$) have proven to provide a tool for trigger performance studies [3] as those events have a fairly similar detector signature as LbyL photons with an advantage of being copiously produced in UPC.

Before each data taking campaign, a set of triggers is defined. The main triggers, used later to select a particular process of interest, are called "primary", while those used for ancillary studies, such as determining trigger performance, are called "supporting".

For low-p_{T} di-electron and di-photon events, three items have been proposed as primary level-1 triggers: L1_TAU1_VTE200, L1_TAU1_TE3_VTE200 and L1_2TAU1_VTE200. TAU1 requires that at least one EM cluster has been registered with a minimum p_{T} = 1 GeV, 2TAU1 means at least two signals, etc. VTE200 denotes a veto for events with total transverse energy above 200 GeV and similarly TE3 cut requires a minimum transverse energy of 3 GeV in the entire calorimeter.

A supporting trigger requirement based on MBTS or TRT trigger decisions is imposed on data. The MBTS requirement means that at least one hit in the Minimum Bias Trigger Scintillators [5] has been registered and the TRT selection [6] means that at least one signal generated from tracks that cross the TRT detector was measured.

3. Event selection and characteristics

Di-lepton events are characterized by a very clean detector signature with nothing but two reconstructed leptons in the detector. Only two electrons with opposite charges in the back-to-back topology in the transverse plane to the incoming beams are expected. In order to select $\gamma\gamma \to e^+e^-$ events and to optimize the number of events considering the small sample size of the pilot run, offline tracks and EM clusters are used. The selection criteria include exactly two tracks with opposite electric charges with $p_{\mathrm{T}} > 0.5$ GeV and acoplanarity (aco = 1 - $\frac{|\Delta\Phi|}{\Pi}$) < 0.04. There have to be at least 2 EM clusters and they have to be matched with the tracks with the $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ < 0.8. $\Delta\eta$ and $\Delta\phi$ denote the difference in pseudorapidity and azimuthal angle, respectively, between the track and the EM cluster. Data events also have to pass the L1_TAU1_VTE200 trigger requirement. 90 events pass the $\gamma\gamma \to e^+e^-$ selection in the data, while the MC simulation predicts 91 events. Good agreement is found between the two numbers. For the process, several kinematic distributions are derived and presented in Figure 1. The left panel shows the track η distribution, the middle panel shows the acoplanarity distribution and the right panel depicts correlation between the transverse energy of two EM clusters. Distributions in MC simulation are normalized to the integrated luminosity recorded in the pilot run, cross-section, and number of generated events in each sample, and moreover, are weighted with 2018 reference trigger efficiency. A good agreement is found between data and MC.

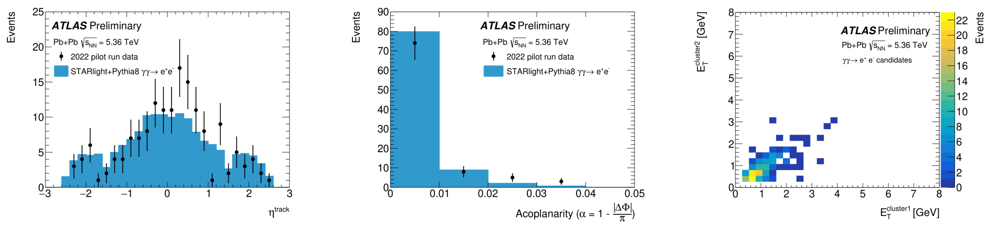

Figure 1: Track η distribution of two tracks (left), acoplanarity distribution of two tracks (middle) and correlation between transverse energy of two EM clusters (right) corresponding to the $\gamma\gamma \to e^+e^-$ process in data (markers) and MC simulation (histogram). Error bars denote statistical uncertainties [7].

4. Trigger efficiency

The trigger efficiency is calculated in a sample of $\gamma\gamma \to e^+e^-$ events for three triggers from the pilot run: L1_TAU1_VTE200, L1_TAU1_TE3_VTE200 and L1_2TAU1_VTE200. To calculate efficiency the following formula is used:

$$\epsilon = \frac{\text{events passing considered trigger}}{\text{all events passing supporting trigger}}. \quad (1)$$

Trigger efficiency is calculated as a function of the energy sum of two EM clusters ($E_T^{cluster1} + E_T^{cluster2}$). Results are compared with the fit to 2018 trigger efficiency measured in Ref. [3] for the logical OR of two level-1 triggers, L1_TAU1_TE4_VTE200 and L1_2TAU1_VTE50.

Trigger efficiencies for triggers from the 2022 pilot run are shown in Figure 2. L1TAU1_VTE200 trigger seems to be the most efficient, which is expected due to no lower cut on L1 TE. L1TAU1_TE3_VTE200 trigger is best described by the reference fit. L12TAU1_VTE200 trigger is the least efficient due to the restrictive requirement of two EM signals.

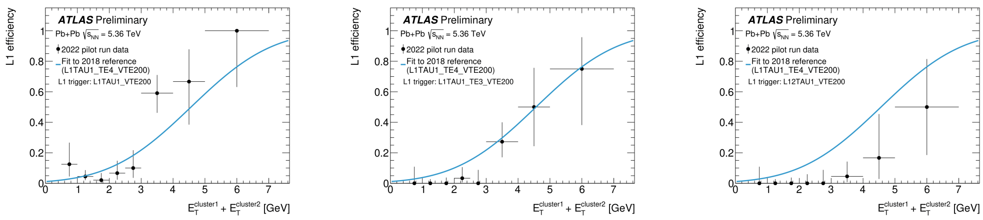

Figure 2: Trigger efficiency as a function of the energy sum of two EM clusters. Data points are compared with the fit to 2018 reference trigger efficiency derived for the logical OR of two triggers, L1_TAU1_TE4_VTE200 and L1_2TAU1_VTE50. Error bars denote statistical uncertainties [7].

5. Trigger simulation of L1_TAU1_TE4_VTE200

A level-1 item of L1_TE4 was not available in the trigger menu during data taking in the pilot run. Therefore, a direct comparison of performance between 2018 and 2022 pilot efficiencies is impossible. However, to make an exact comparison of trigger efficiency from the pilot run with the 2018 reference, a decision of L1_TE4_VTE200 is simulated based on stored L1_TE information for individual events. This is done by applying an extra requirement on a total energy (L1_TE) in a sample of events selected by the L1_TAU1_VTE200 trigger. Figure 3 shows the simulated L1_TE4 trigger efficiency with a comparison to the 2018 trigger reference. The little reduction in efficiency values with respect to the 2018 reference is noticeable. This might be explained by the fact that in the pilot run the L1 noise thresholds were slightly increased compared to Run 2.

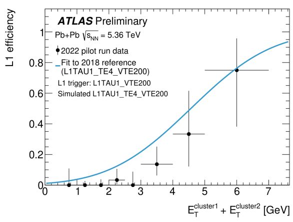

Figure 3: Simulated L1_TAU1_TE4_VTE200 trigger efficiency as a function of the energy sum of two EM clusters. Data points are compared with the fit to the 2018 reference trigger efficiency derived for the logical OR of two triggers, L1_TAU1_TE4_VTE200 and L1_2TAU1_VTE50. Error bars denote statistical uncertainties [7].

6. Acknowledges

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