# PERFORMANCE OF THE ATLAS L1 TRANSITION RADIATION TRACKER TRIGGER IN HEAVY-ION COLLISIONS AT THE LHC*

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The ATLAS heavy-ion physics program includes the study of ultra-peripheral collisions (UPC). This gives rise to various photon-induced interactions at high energies. In order to extend the ATLAS UPC physics program, higher efficiencies at very low particle transverse momenta are required, but no suitable Level 1 trigger exists in the ATLAS detector to record such events. To provide such capabilities, the ATLAS Level 1 Transition Radiation Tracker cosmics trigger, known as the TRT FastOR, is adapted for use in a recent heavy-ion collision run. These proceedings present the achieved performance of the TRT FastOR trigger in the September–October 2023 Pb+Pb run, with data recorded at $\sqrt{s_{NN}} = 5.36$ TeV.

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## 1. Introduction

In ultra-peripheral collisions (UPC), the ions do not collide directly (hadronically), but interact through the electromagnetic fields. This gives rise to high-energy photonuclear and photon–photon interactions with typically low particle activity that may produce, for example, exclusive lepton pairs in the final state [1]. UPC events allow to study photon-induced processes, such as light-by-light scattering [2], $\gamma\gamma \to \tau\tau$ production [3], and coherent $J/\psi$ production [4, 5]. Until now, in ATLAS, the most common triggering strategy for many UPC-related analyses with muonic final states (*e.g.* for $\gamma\gamma \to \tau\tau$ analysis) was to use a Level 1 (L1) muon trigger. The limitation of the ATLAS L1 muon trigger is that it loses efficiency below muon transverse momenta ($p_{\mathrm{T}}$) of about 4 GeV, as muons loose on average roughly 3 GeV of their energy already in the calorimeters, before reaching muon trigger

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stations [6]. It is worth to emphasize that events with low-momentum leptons are abundant in two-photon UPC interactions due to an increase of differential cross section with the decreasing transverse momentum of the final-state leptons [1]. As a result, many events with low-$p_{\mathrm{T}}$ muons were not recorded, as they are not capable to fire an L1 muon trigger.

A possible solution to this problem is to use the Transition Radiation Tracker (TRT) capabilities to trigger at L1. The TRT is the outermost part of the ATLAS Inner Detector, and detects charged particles before they enter the calorimeters. Due to its closer position to the ATLAS interaction point (relative to the muon spectrometer), the TRT is sensitive to particles with low-$p_{\mathrm{T}}$ values, nominally down to $p_{\mathrm{T}} = 0.5$ GeV [7]. Particles traversing the TRT detector can produce transition radiation which gives rise to high signal amplitudes. Usually, the high threshold (HT) is calibrated to the transition radiation threshold and is used for electron identification. However, the HT signal can be instead used for the purpose of the TRT FastOR trigger. This requires lowering the HT to a sufficiently low value for which any charged particle can produce a large number of HT hits. In this way, the TRT FastOR trigger is able to record events with low-$p_{\mathrm{T}}$ tracks [8].

The TRT FastOR logic is a simple logical OR of fast electronic signals. Each TRT front-end chip can be configured to send a signal that is generated using a fast digital OR circuit ("FastOR") to the TRT trigger timing and control (TTC) board if a hit exceeding the HT is recorded in one or more of its associated straws. A logic circuit on the TTC board aggregates these signals from groups of several front-end chips. If the number of received signals within a TTC board exceeds a configurable number (multiplicity, $M$), a trigger signal is generated [9].

## 2. Material activation effect

Figure 1 shows the TRT FastOR trigger signal distribution with respect to the bunch crossing identifier (BCID), each corresponding to a 25 ns time spacing. The red/grey vertical lines shown in the plot correspond to BCIDs where the bunches are nominally crossed. The visible increase in generated TRT FastOR trigger signals with BCID indicates an accumulation of collision-induced radioactivity. The observed radioactive buildup decays roughly exponentially with a relatively short lifetime of about $\tau \approx 2$ $\mu$s.

## 3. Trigger efficiency

Figure 2 shows the TRT FastOR trigger efficiency measured for exclusive two-track events as a function of the leading track transverse momentum. Each track pair is required to pass a kinematic track quality selection. The efficiency is calculated relative to the data sample selected using alterna-

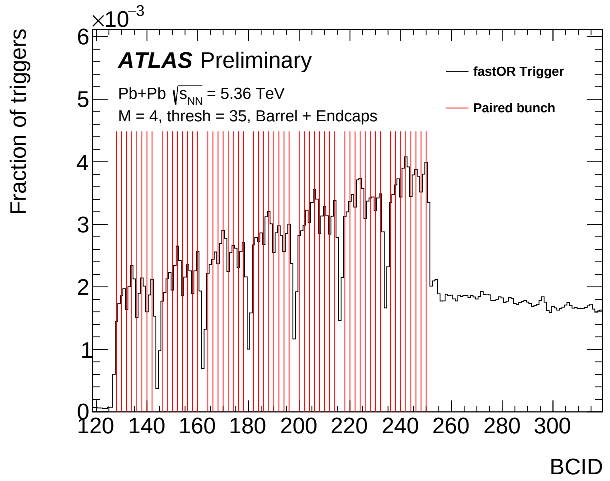


Fig. 1. (Colour on-line) TRT FastOR trigger distribution with respect to BCID. The trigger decision is formed by requiring at least 4 front-end boards ($M = 4$) to register at least one hit passing an energy threshold of 35 (in arbitrary units) that corresponds to approximately 0.67 keV of energy deposited in the active gas. Red/grey vertical lines mark the nominal BCID positions of paired bunches [10].

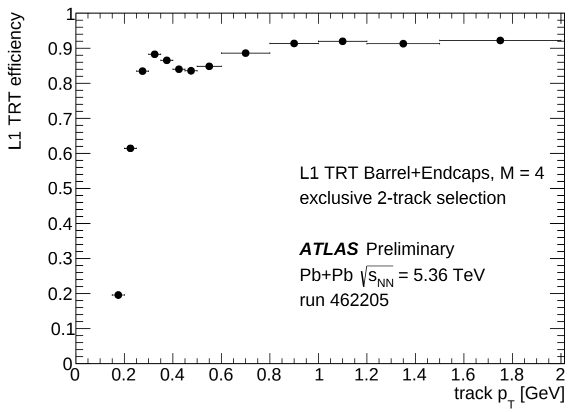


Fig. 2. Measured TRT FastOR trigger efficiency for exclusive events with 2 back-to-back tracks as a function of the leading track transverse momentum. The efficiency is calculated relative to the alternative (unbiased) control triggers. The TRT FastOR trigger decision is formed by requiring at least 4 front-end boards ($M = 4$) to register at least one hit passing an energy threshold of 35 (in arbitrary units) that corresponds to approximately 0.67 keV of energy deposited in the active gas [10].

tive (unbiased) control triggers that require the ZDC signal on one detector side at L1 and at least one track with $p_{\mathrm{T}} > 200$ MeV at HLT. It can be seen that the TRT FastOR trigger reaches the efficiency of 83% for $p_{\mathrm{T}}$ as low as 250 MeV. For higher $p_{\mathrm{T}}$ values, the efficiency saturates at about 90%.

## 4. Performance in recording coherent $J/\psi$ events

Figure 3 shows the invariant mass distribution for exclusive track pairs in the $J/\psi$ mass region for events selected by the TRT FastOR trigger at L1. Here, the TRT trigger is combined with an additional veto on the total transverse energy of 20 GeV reconstructed in the ATLAS calorimeters at L1. In addition, a high-level trigger selection for at least one track with $p_{\mathrm{T}} > 1$ GeV is applied. In Fig. 3, a peak can be observed at the two-track invariant mass corresponding to the $J/\psi$-meson mass. This shows that the TRT FastOR trigger is capable of efficient recording of exclusive UPC processes with exclusive-track topology at L1. The number of coherent $J/\psi$ candidates recorded using this trigger is about 100 times higher than the number of coherent $J/\psi$ candidates recorded in LHC Run 2 ATLAS data.

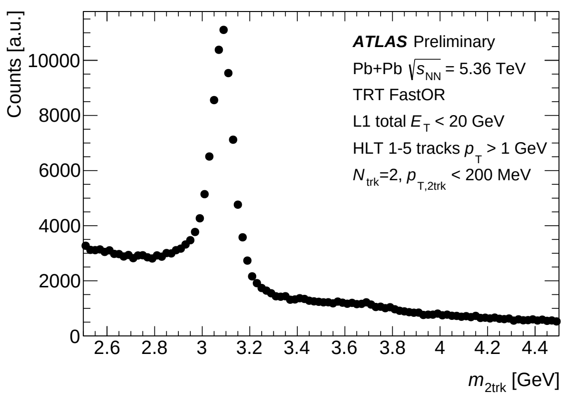


Fig. 3. Two-track invariant mass in the $J/\psi$-mass region for events selected by the TRT FastOR trigger at L1. The FastOR trigger decision is formed by requiring at least 4 front-end boards ($M = 4$) to register at least one hit passing an energy threshold of 35 (in arbitrary units) that corresponds to approximately 0.67 keV of energy deposited in the active gas. Events are selected offline to have exactly two charged-particle tracks [11].

## 5. Summary

The performance of the L1 TRT trigger is presented based on data recorded during the September–October 2023 Pb+Pb run at $\sqrt{s_{NN}} = 5.36$ TeV. During this run, for the first time, the information from the ATLAS Inner Detector is attempted to be used for triggering at L1 in heavy-ion collisions. Overall, the TRT FastOR trigger system is observed to perform well and has proven to be able to record many UPC events with low-momentum charged particles, like coherent $J/\psi \to \ell\ell$ events. The trigger reaches the efficiency of about 80–90% for tracks with $p_{\mathrm{T}}$ as low as 250 MeV. As a result, the achieved improvement in the collected coherent $J/\psi$ event yield is of the factor of $\sim 100$ relative to Run 2 ATLAS data. However, the problem with an accumulation of empty triggers, resulting from TRT material activation, is observed. In particular, this effect impacts the purity of the trigger.

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REFERENCES

[1] ATLAS Collaboration, *Phys. Rev. C* **104**, 024906 (2021).

[2] ATLAS Collaboration, *J. High Energy Phys.* **2021**, 243 (2021).

[3] ATLAS Collaboration, *Phys. Rev. Lett.* **131**, 151802 (2023).

[4] ALICE Collaboration, *J. High Energy Phys.* **2023**, 119 (2023).

[5] CMS Collaboration, *Phys. Rev. Lett.* **131**, 262301 (2023).

[6] ATLAS Collaboration, *Eur. Phys. J. C* **81**, 578 (2021).

[7] ATLAS Collaboration, *J. Instrum.* **3**, S08003 (2008).

[8] ATLAS Collaboration, Technical report, CERN, Geneva, 2009.

[9] G.L. Gardner, in: «Proceedings of 2023 IEEE Nuclear Science Symposium, Medical Imaging Conference and International Symposium on Room-Temperature Semiconductor Detectors (NSS MIC RTSD)», Vancouver, Canada, 4–11 November, 2023.

[10] https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/IDET-2023-01/, Accessed on 19.02.2024.

[11] https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/HION-2023-001/, Accessed on 06.06.2024.