The ATLAS TRT FastOR Trigger For Ultra-Peripheral Heavy Ion Collisions

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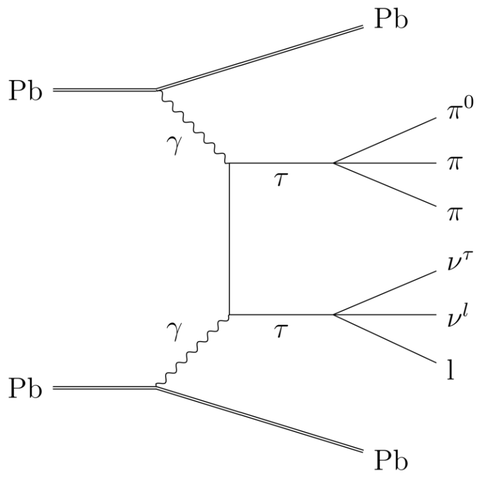
ATLAS EXPERIMENT

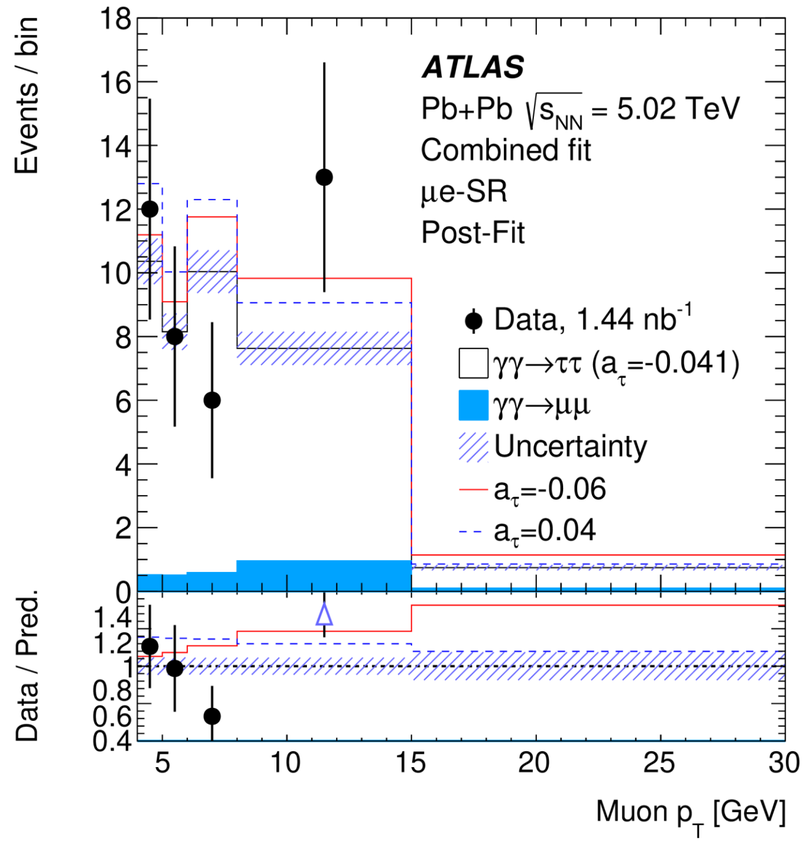
Motivation

- Ultra-peripheral collisions (UPCs): The electromagnetic clouds surrounding the ions interact → rare processes like di-tau production
- Studies mainly constrained by statistical uncertainty, especially at low lepton p_T



Feynman diagram showing the $\gamma\gamma \rightarrow \tau\tau$ process

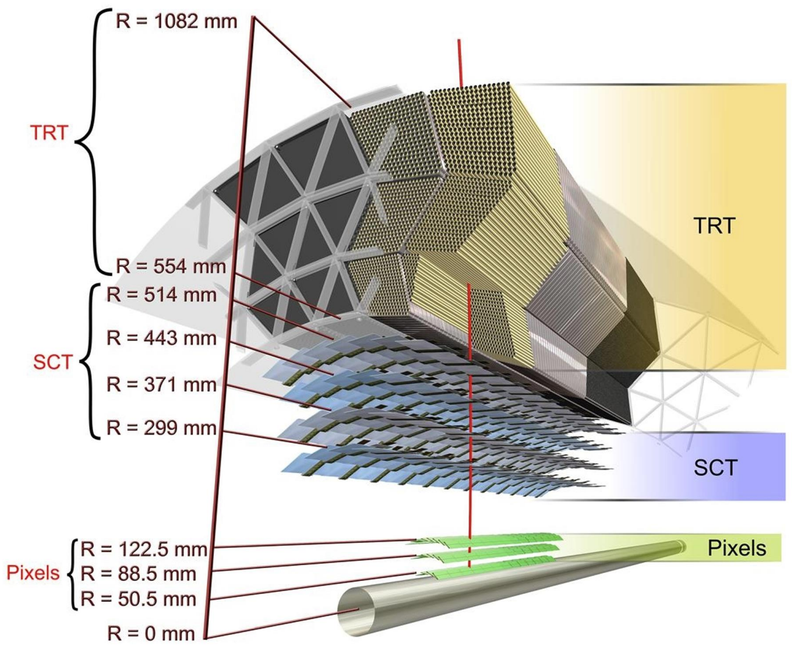
- UPC events in Run 2 were selected by random triggers at level 1 and later filtered for the presence of tracks. Highly inefficient!
- Using a trigger sensitive to the presence of tracks would increase the number of events containing physics information by a few orders of magnitude.



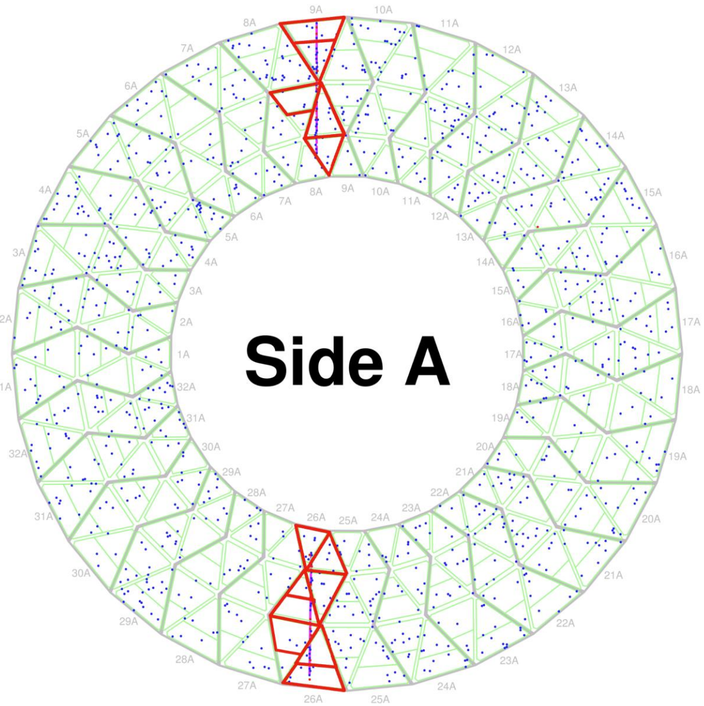
Results from the recent observation of $\gamma\gamma \rightarrow \tau\tau$ from the 2018 HI runs [3]

ATLAS TRT and Fast-OR

- The Transition Radiation Tracker: outermost inner detector, consists of ~300k straw drift tubes
- Hits classified using Low Threshold (tracking) and the High Threshold (electron identification).
- TRT Fast-OR trigger:
  - Developed as a cosmics trigger
  - Uses fast trigger generation circuit to produce L1A when a certain number of FE boards show hits exceeding a configurable HT value.



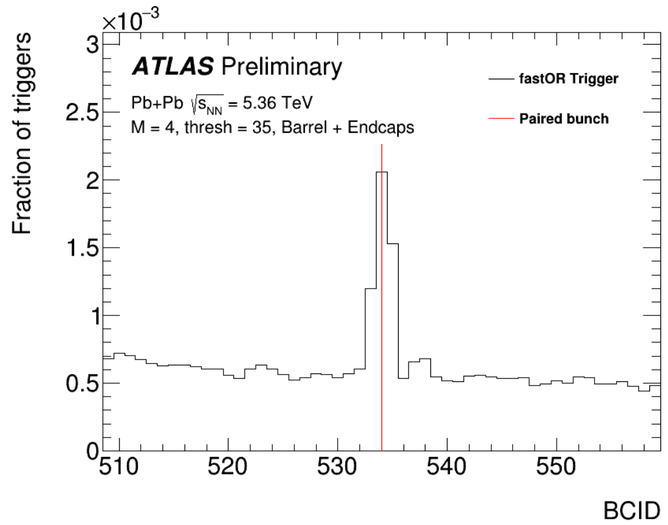
Schematic of the ATLAS Inner Detector, including the TRT.



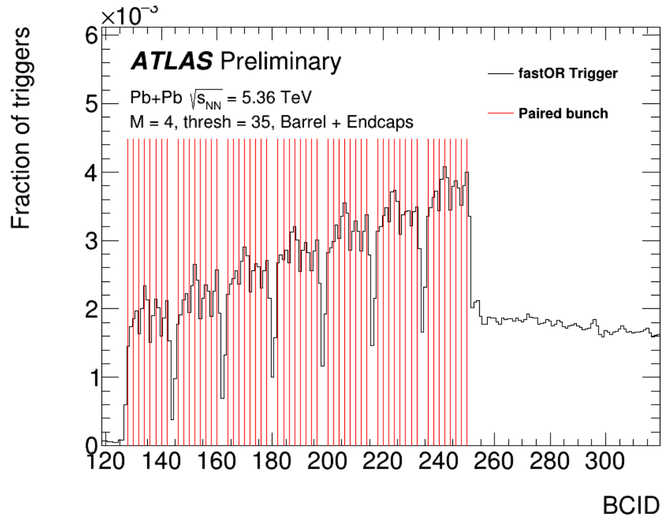
Cosmic event triggered by the Fast-OR. Boards contributing to the trigger decision are outlined in red.

Implementation for Heavy Ions

- Fast-OR has timing jitter of ~2 BC due to:
  - Leading edge depends on drift time of ionization particles in TRT straw (~40 ns)
  - Granularity of delays on lines to the FE boards (~8 ns)
  - Timing spread in chips on each FE board cannot be accounted for (~5ns)
- Output signal width of ~2 BC was chosen to maximize the efficiency in the paired BCID
- Each signal followed by ~4 BC of "deadtime" generated by a series of discriminators to ensure only one signal generated per collision



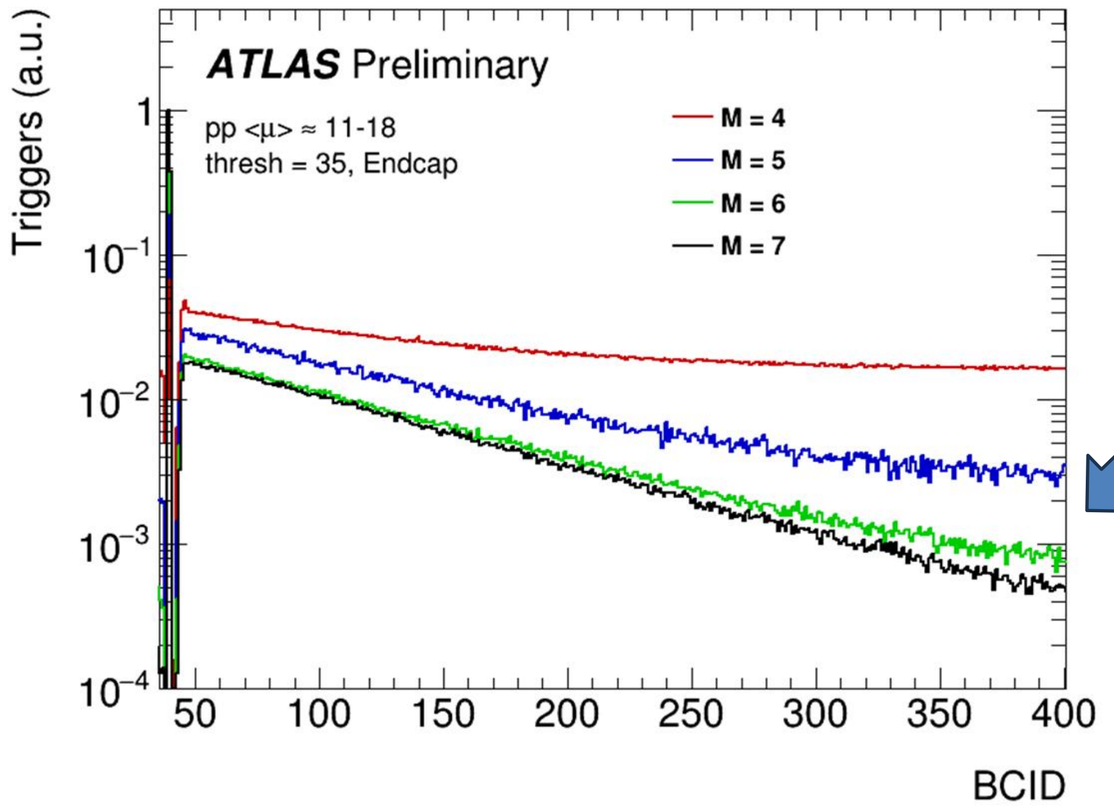
Isolated paired bunch: middle bin has ~100% signal efficiency



Bunch train: Triggers outside of paired bunches associated with induced radioactivity.

Implementation for Heavy Ions

- Induced radiation after each collision produces ionization signals in the TRT.
- Soft tracks from UPCs are indistinguishable from detector irradiation at the Fast-OR level → significant background trigger rate
- Scanned two parameters (board multiplicity and threshold) to determine the optimal working point



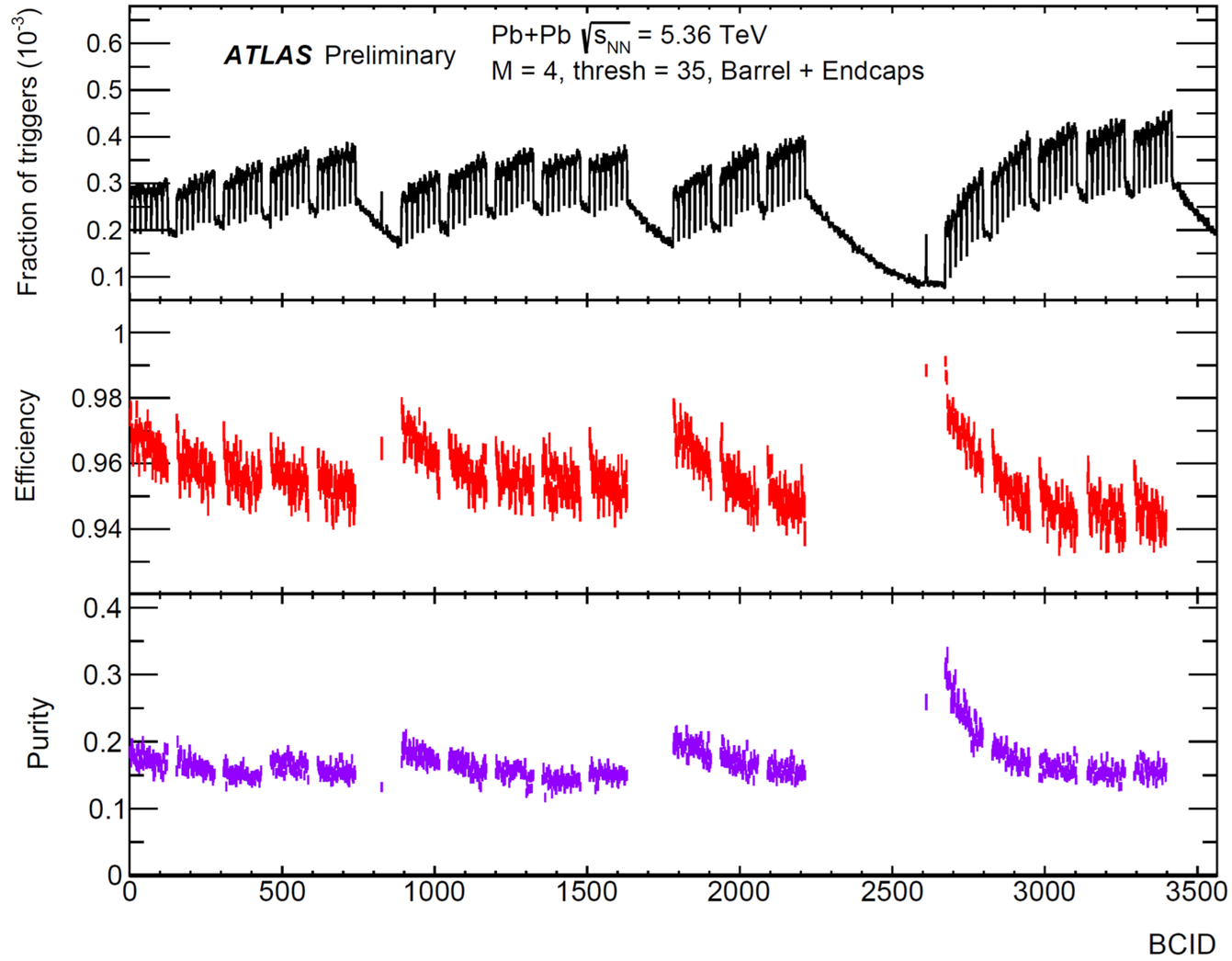
Increasing M suppresses the background, but at some cost to efficiency.

Fast-OR distribution following isolated paired bunch, showing effect of board multiplicity (M) on radiation-induced trigger rate. Normalized such that the paired BCID peak (BCID 39) integrates to 1.

Results

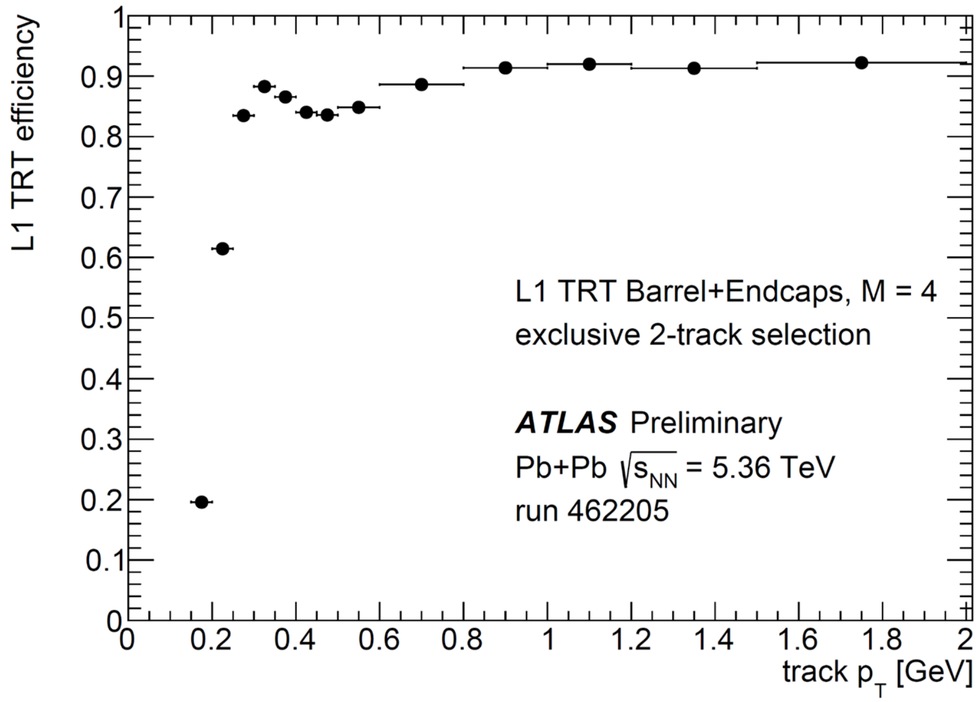
- Final parameter scans done at the beginning of 2023 run → chose optimized operating point (M = 4, threshold = 35, or ~660 eV).
- Fast-OR incorporated in ATLAS data-taking throughout the 2023 HI run (with calorimeter veto of 20 GeV)
- We expect at least a factor of 100 increase in statistics for UPC events characterized by low p_T tracks.

Fast-OR distribution, efficiency, and purity for LHC fill with 1080 paired bunches.

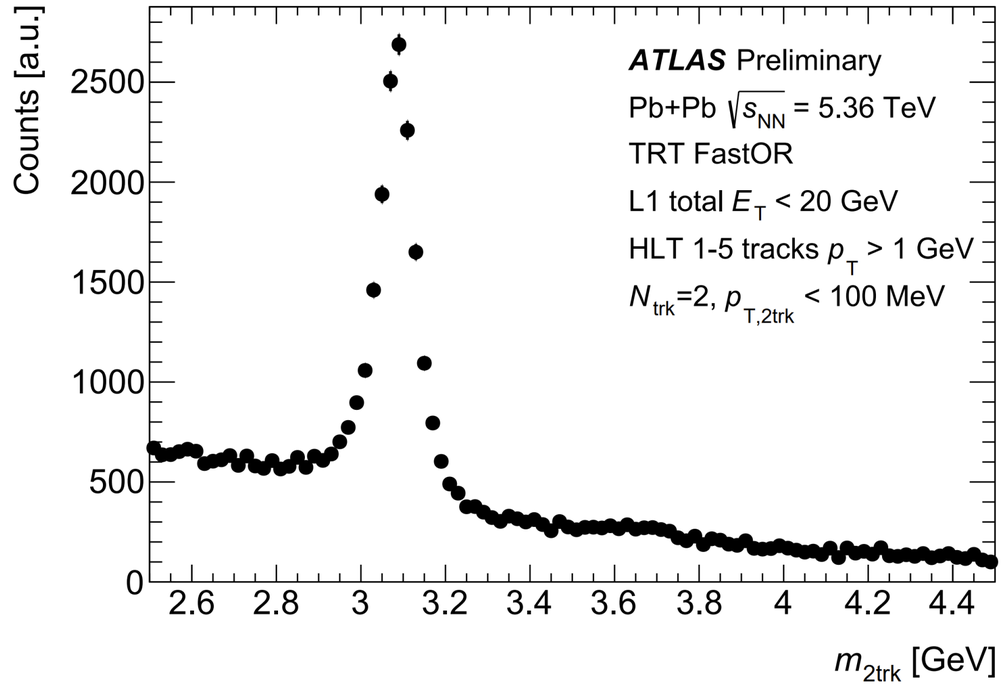


Results

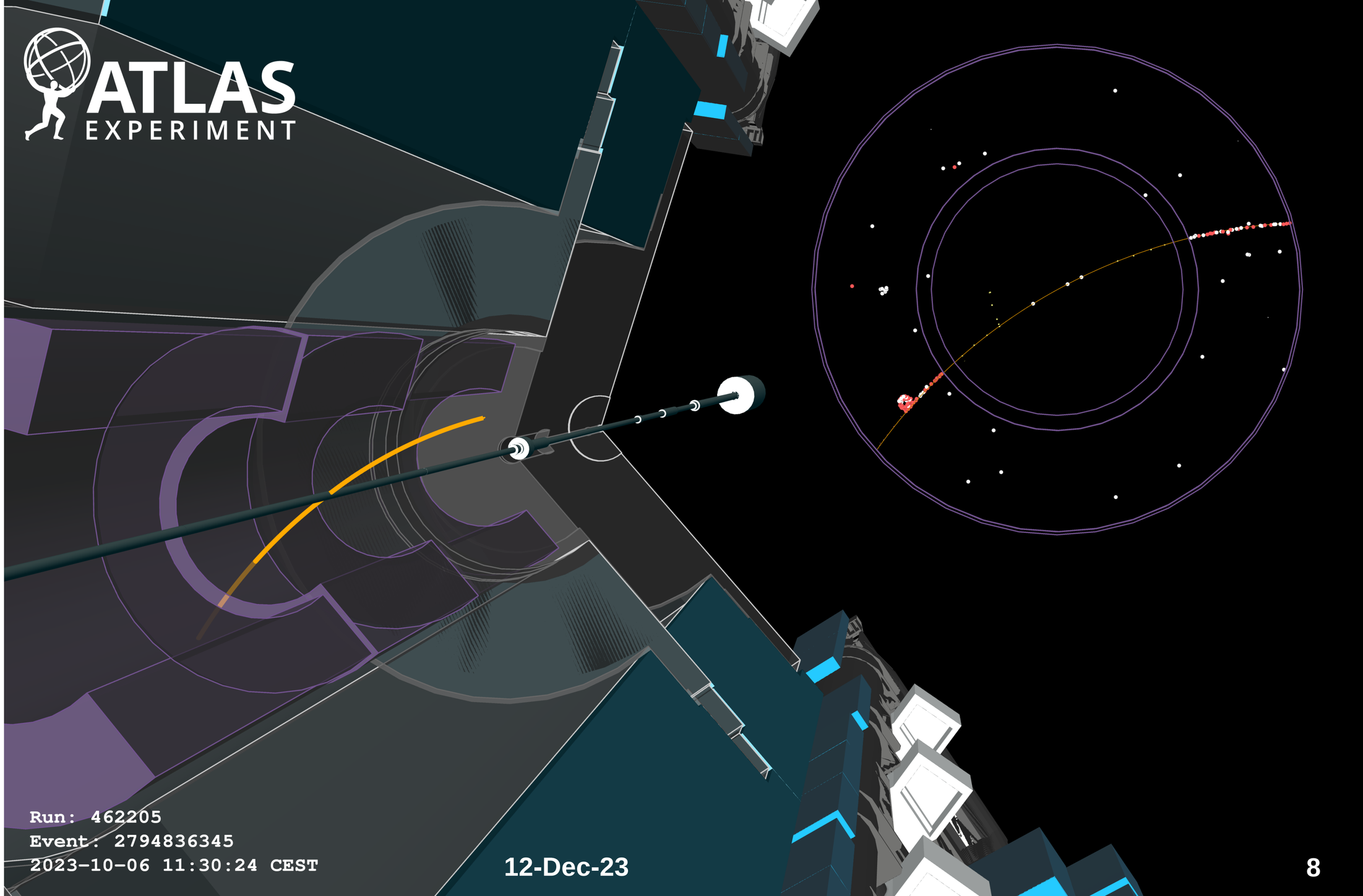
Fast-OR efficiency for exclusive 2-track events as a function of leading track transverse momentum.



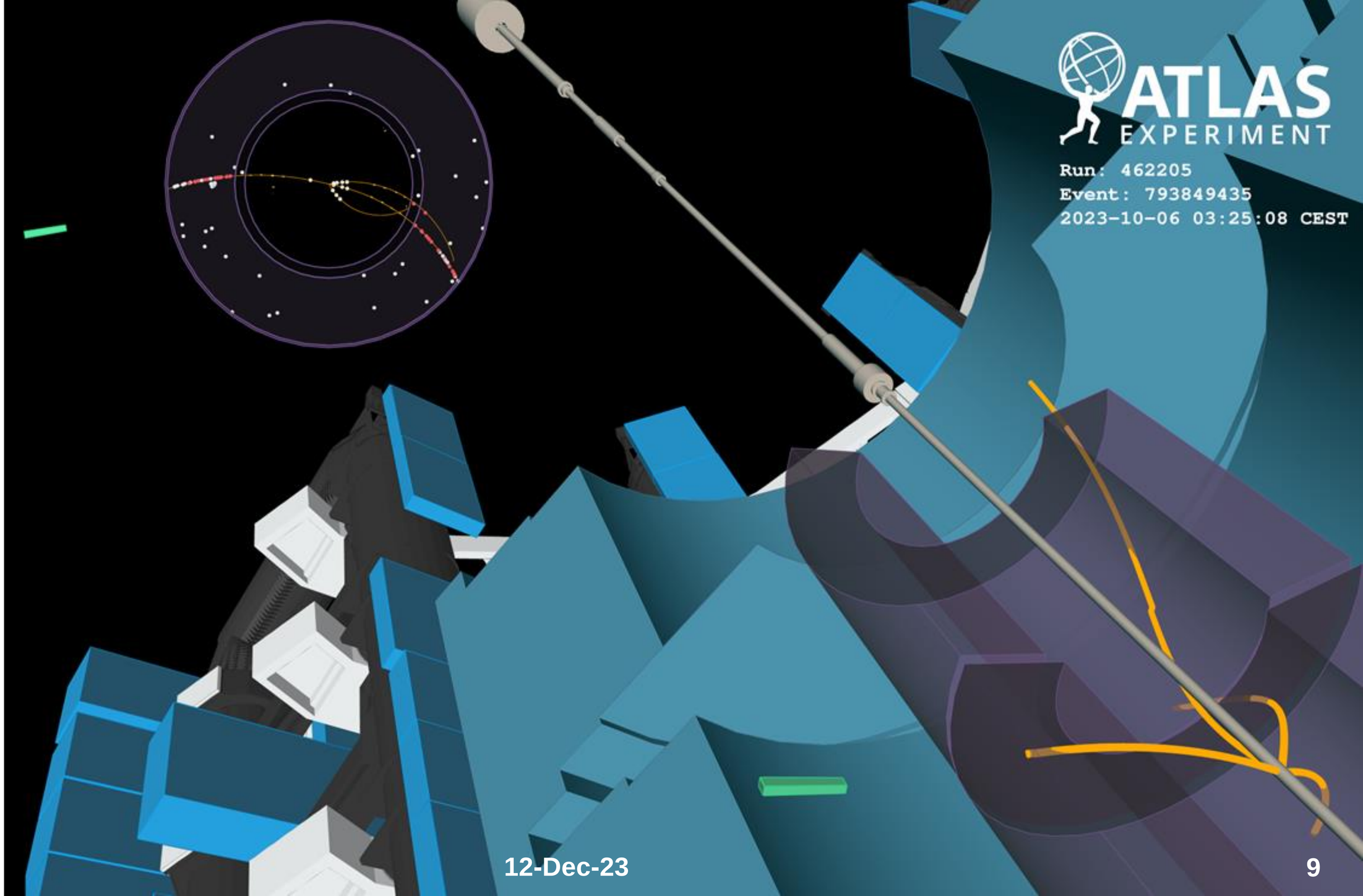
Two-track invariant mass spectrum in the J/ψ region for events triggered by the Fast-OR



J/ψ candidate event



Di-tau candidate event



References

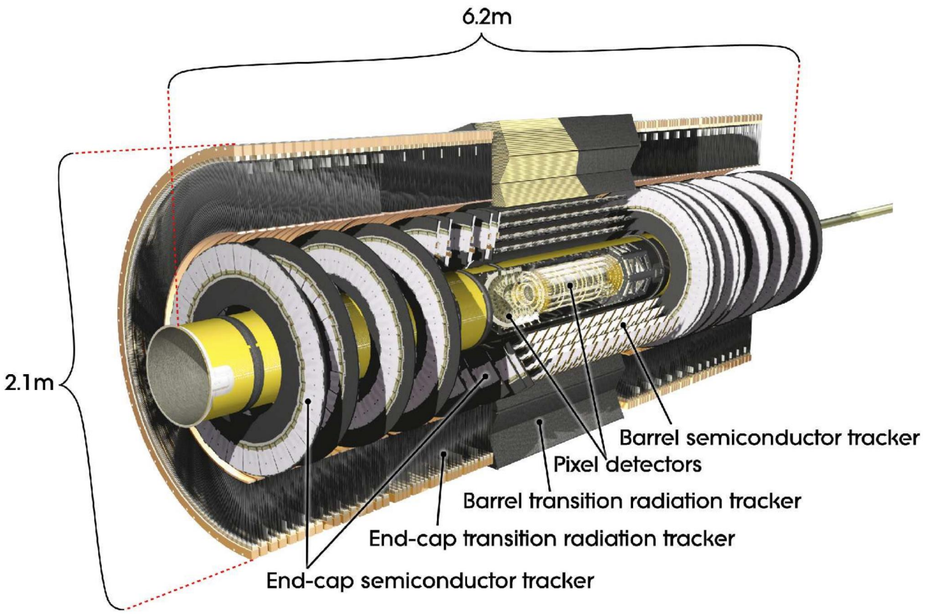
[1] S. Fratina et al., “The TRT Fast-OR Trigger,” CERN, Geneva, Tech. Rep., 2009.

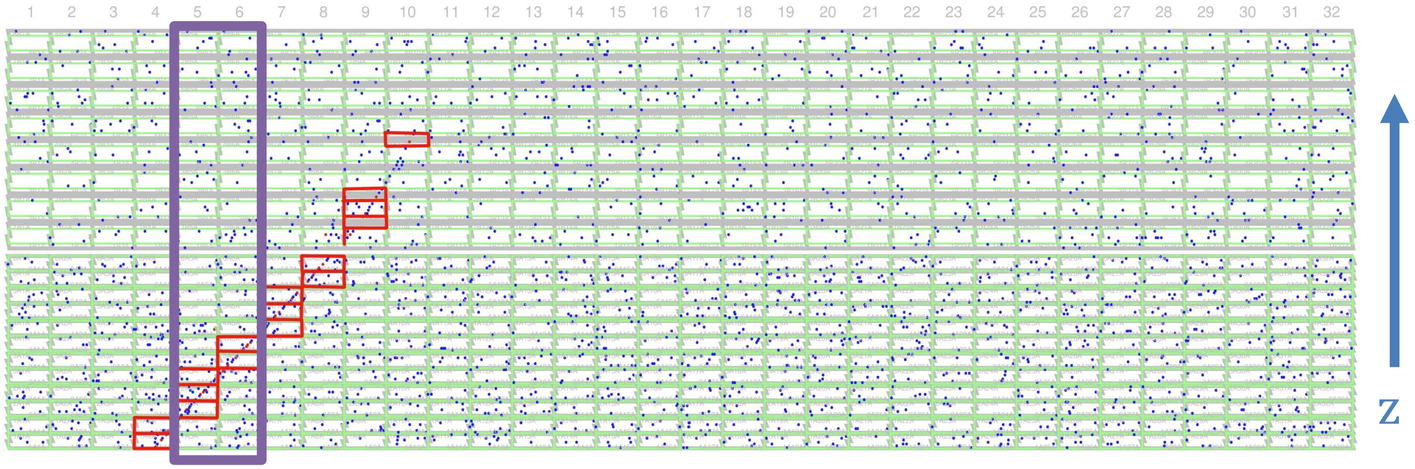
[2] E. Abat et al., “The ATLAS TRT electronics,” JINST, vol. 3, p. P06007,2008.

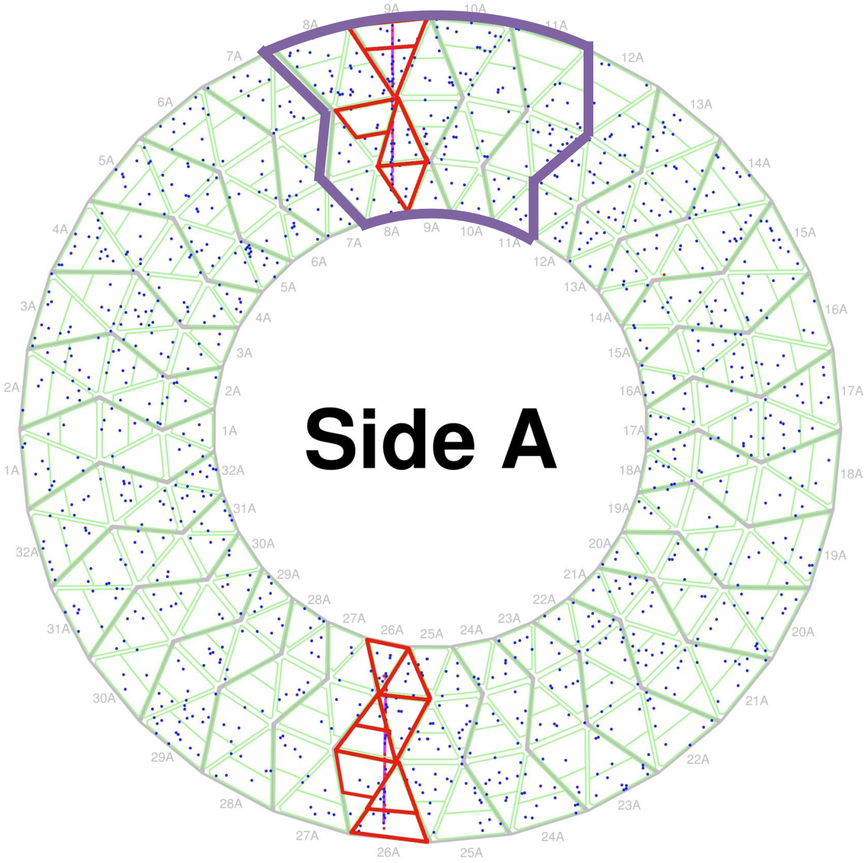
[3] “Observation of the γγ → ττ process in Pb+Pb collisions and constraints on the τ-lepton anomalous magnetic moment with the ATLAS detector,” Phys. Rev. Lett.131 (2023) 151802

Backup

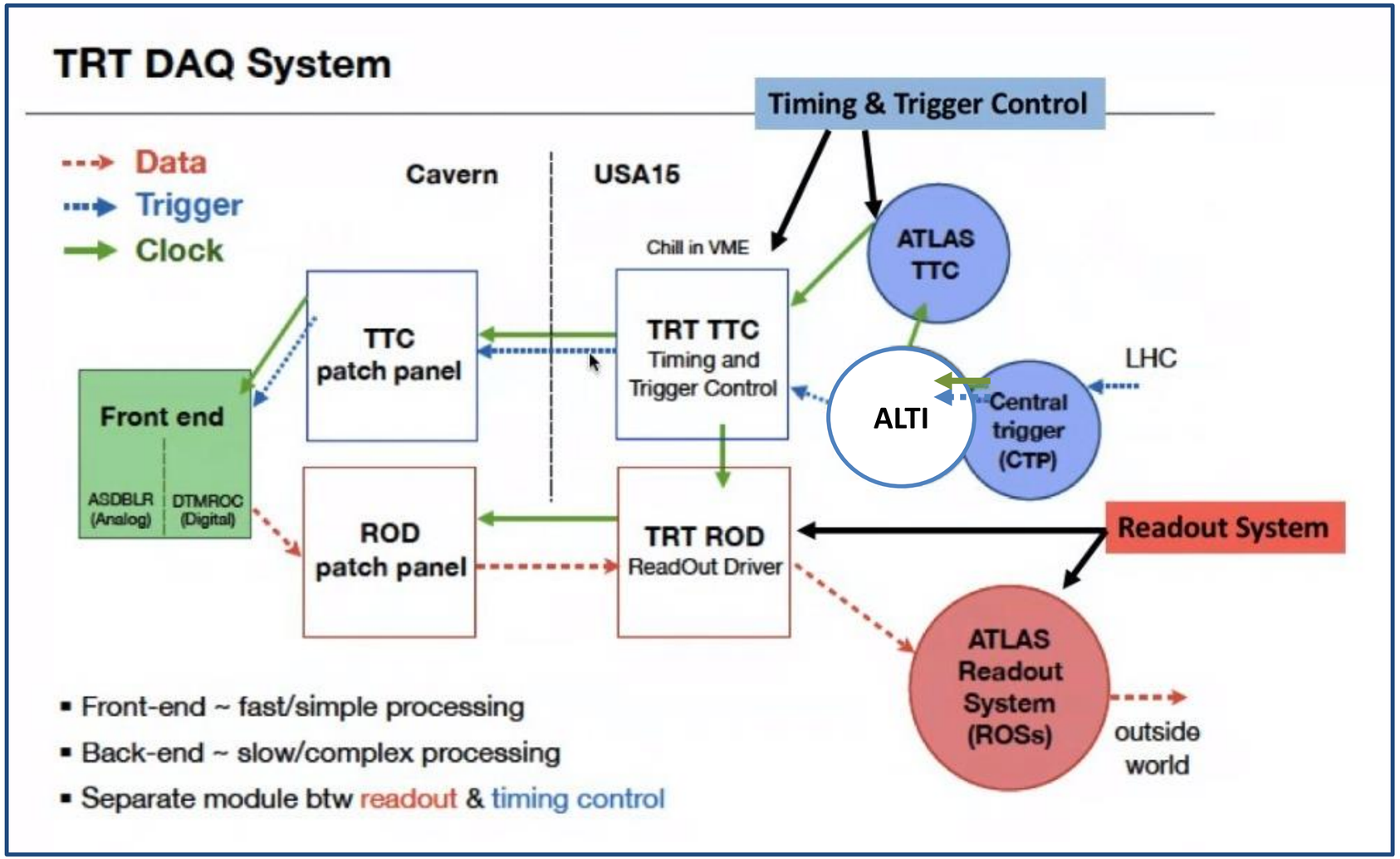
TRT and Fast-OR Geometry







TRT DAQ System



- TRT DAQ system consists of TTC and Readout Systems
- TTC system is always responsible for configuration and propagating clock and triggers.
- In normal physics running, TTC reads back FE chip registers in order to find and correct Single Event Upsets (polling)
- In FastOR mode, the readback line used for polling is hijacked for generating FastOR triggers

Fast-OR data flow

- HT hits are propagated through the Command_Out line and OR'd together on each FE board
- Signals from every FE board are propagated to the TRT-TTC
- If the TRT-TTC sees M signals arrive in coincidence, it issues a FastOR trigger.

Fast-OR data flow

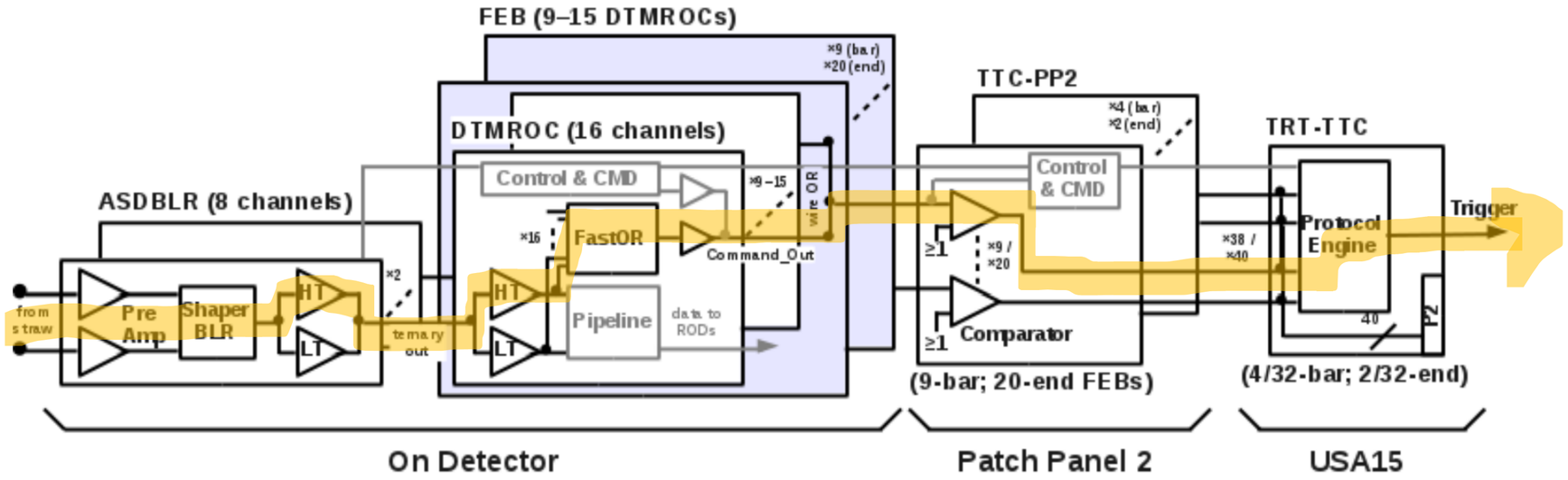
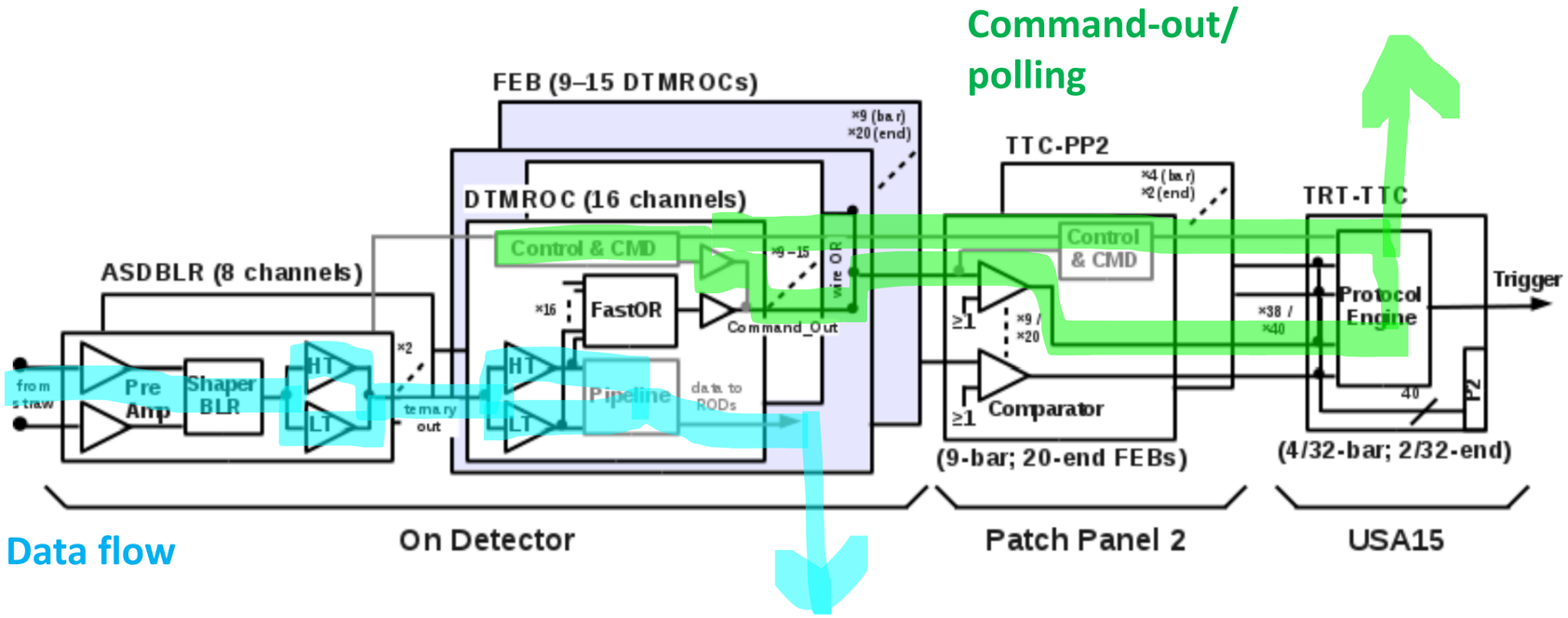


Figure 6: A simplified diagram of the path taken by signals in the FastOR branch of the TRT readout.

Normal data flow

- Straw hits are categorized as passing High and/or Low Thresholds, and data waits to be collected by trigger signal from the ROD
- Polling reads back chip registers to find and correct for SEUs

- **HT** is set to TR threshold for electron ID
- **LT** is calibrated to 2% noise occupancy level for tracking purposes



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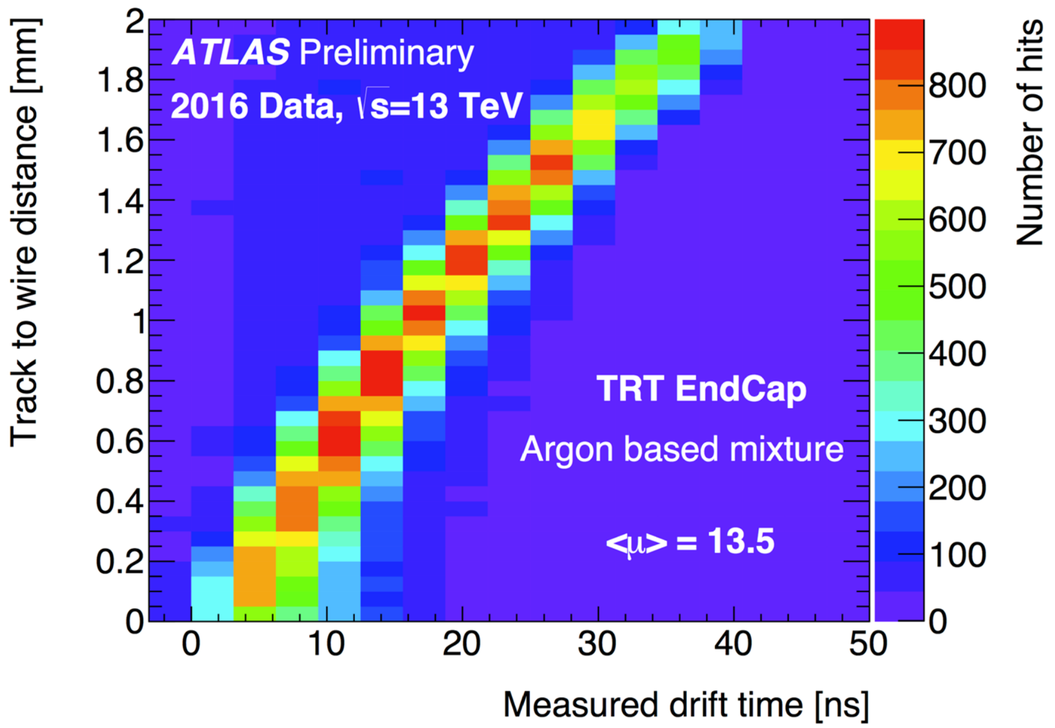
Drift time



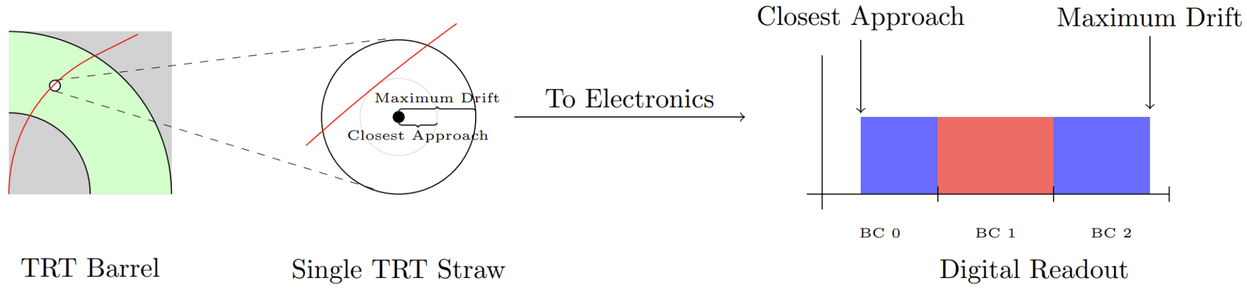


Figure 7: The passage of a charged particle through the straw ionizes gas, which causes an electron cascade into the anode. The resulting current is read out by the analog electronics and digitized by the DTMROC. The pulse at the right shows the result of that digitization. The blue regions are where the low threshold was crossed - the red region is where the low and the high threshold was crossed. The point of closest approach of the particle to the wire determines the leading edge of the digital pulse, while the size of the straw (and drift speed of the gas) determines the trailing edge.

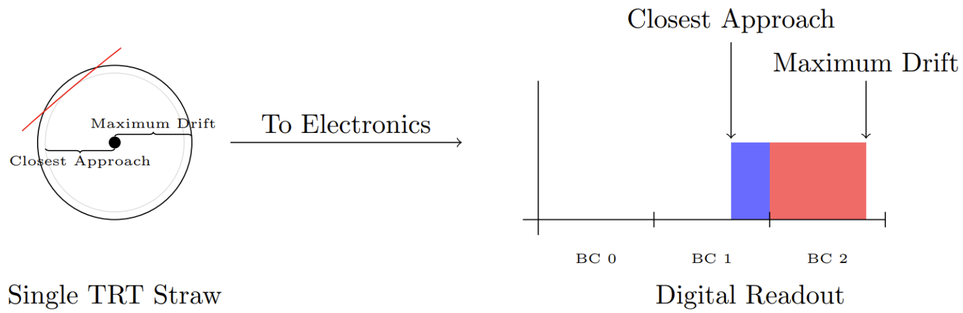


Figure 8: In this case, the straw is just barely hit by the charged particle, and the only gas ionized is near the cathode. The trailing edge of the distribution does not shift, as it is fixed by the size of the straw - the leading edge, however, moves later in time to reflect the drift radius of the track.