Performance and design of ATLAS trigger in *p*+Pb and Pb+Pb collisions

General overview of the ATLAS trigger system

Design of ATLAS trigger

- The ATLAS trigger system consists of two levels, a **hardware Level-1 (L1)** trigger and a **software High Level Trigger (HLT)**.
- L1 gives fast reduction of the rate of accepted events from the bunch-crossing rate of tens of MHz to a maximum of 100 kHz.
- HLT:
  - Goal: efficient reduction in the rate of accepted events to 1-1.5 kHz, while keeping interesting ones.
  - Reconstruction in steps in regions of interest (RoI) defined by L1 or in full detector.
  - Event rejection at the end of each reconstruction step.

Design of Pb+Pb and *p*+Pb trigger menu

- Peak luminosity:
  - Pb+Pb: $2.9\times10^{27}\,cm^{-2}s^{-1}$
  - *p*+Pb: $8.6\times10^{29}\,cm^{-2}s^{-1}$
- Collision rates:
  - Pb+Pb: up to 50 kHz
  - *p*+Pb: up to 1.4 MHz
- Broad range of triggers prepared:
  - hard probes (jets, electrons, muons, photons)
  - minimum-bias events
  - ultra-peripheral collisions
  - azimuthally asymmetric events
  - very central collisions (in Pb+Pb collisions)
  - events with high multiplicity of tracks (HMT, in *p*+Pb collisions)
- In some cases trigger **algorithms** have to be **adapted to heavy-ion environment**.
- Minimum-bias triggering strategy in Pb+Pb collisions:
  - require total energy in calorimeter above 50 GeV
  - for peripheral events, require total energy below 50 GeV and minimal activity in silicon detectors and ZDC
- Minimum-bias triggering strategy in *p*+Pb collisions:
  - require minimal activity in Minimum Bias Trigger Scintillators (MBTS)
  - OR require minimal activity in silicon detectors

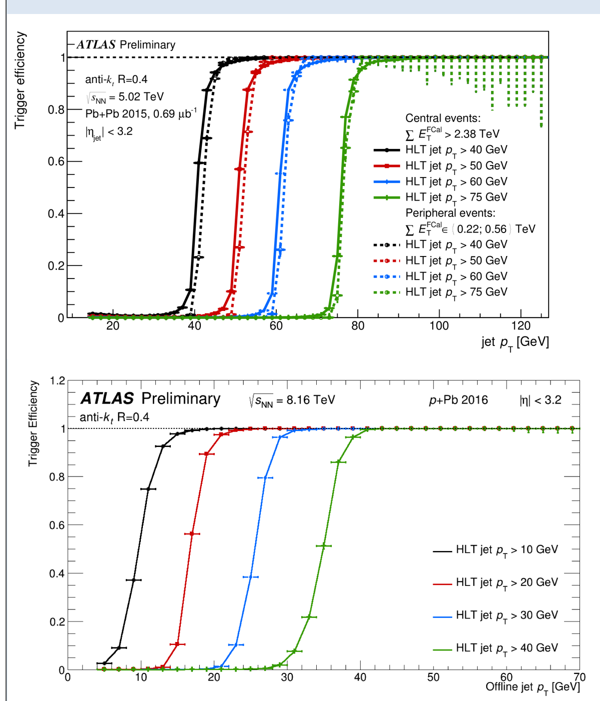
Jet trigger

- Goal: collect sample of jet events for studies of **jet quenching** and **jet fragmentation**.
- The main challenge for triggering on jets in heavy-ion collisions is the **large underlying event (UE) contribution**.
- A crucial part of the ATLAS jet reconstruction is the cell subtraction of the event-by-event UE energy density:

$$\rho_i(\eta)=\frac{1}{N_i}\sum_j^{N_i}\frac{E_{T,j}}{\Delta\eta_j\Delta\varphi_j}\frac{1}{1+2v_{2,i}\cos\left(2(\varphi_j-\Psi_2)\right)}$$

It is estimated in bins of η in each calorimeter layer and modulated in φ to account for elliptic flow.

- L1 seeds for HLT jet trigger algorithm:
  - Pb+Pb: events with total energy deposited in the calorimeter above a given threshold (TE triggers)
  - *p*+Pb: L1 jet RoIs
- Jet trigger types:
  - Pb+Pb: single-jet (wide range of p_T thresholds), multi-jet, b-jet, forward-jet
  - *p*+Pb: same as above and in addition asymmetric forward-jet and HMT+jet

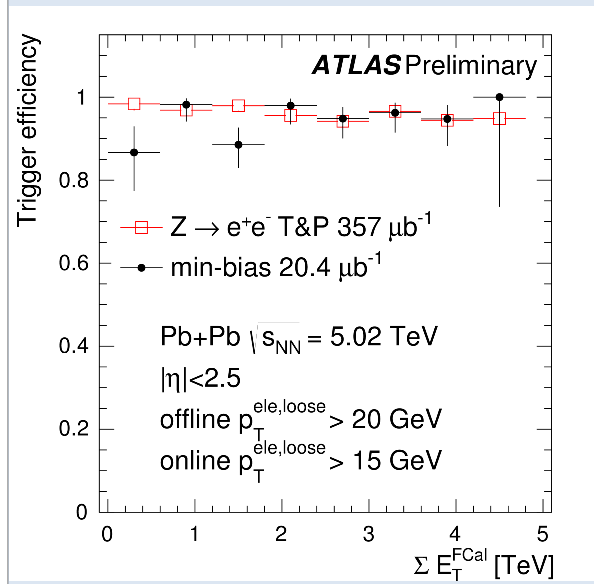


Single-jet trigger efficiency in Pb+Pb (upper plot, [1]) and p+Pb collisions (lower plot, [3]) evaluated with respect to offline jets. In Pb+Pb collisions, the UE subtraction clearly improves performance in central events.

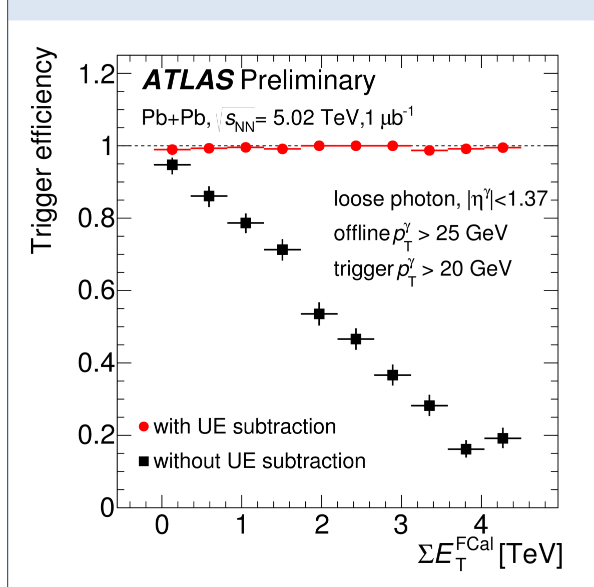
Plots available at https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/:
[1] HION-2015-001/
[2] HION-2016-001/
[3] HION-2016-002/
[4] HION-2016-003/

Electron and photon trigger

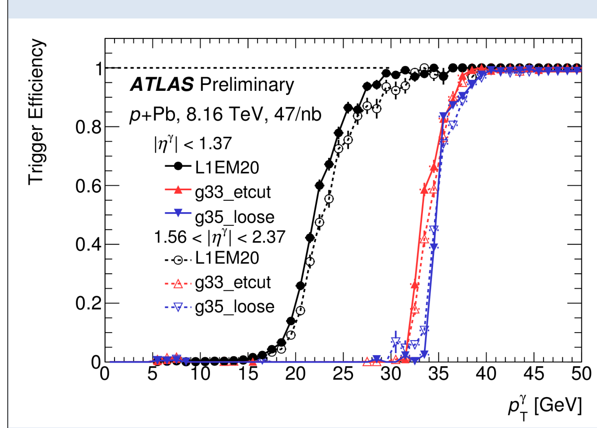
- Goal: provide sample of electrons for **W/Z boson** measurements and photons for studies of **photon-jet correlations** which is unbiased in centrality.
- Electron and photon triggers are seeded from L1 RoIs in the electromagnetic calori-meter.
- In Pb+Pb collisions, HLT algo-rithms use **calorimeter cells corrected for the UE contribution** as in the jet trigger in order to reconstruct electrons and photons.



Single-electron trigger efficiency with UE subtraction in Pb+Pb collisions evaluated with respect to offline electrons [2].



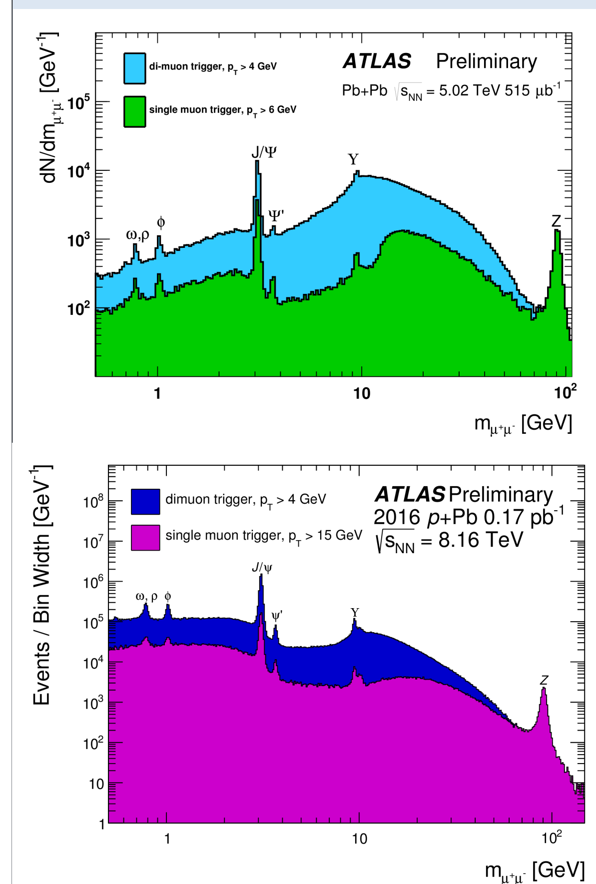
Single-photon trigger efficiency in Pb+Pb collisions evaluated with respect to offline photons [1]. The UE subtraction recovers degrading performance with centrality.



Single-photon trigger efficiency evaluated with respect to offline photons in p+Pb collisions [4]. Results are shown in two pseudorapidity regions for a L1 trigger and two HLT triggers varying in purity.

Muon trigger

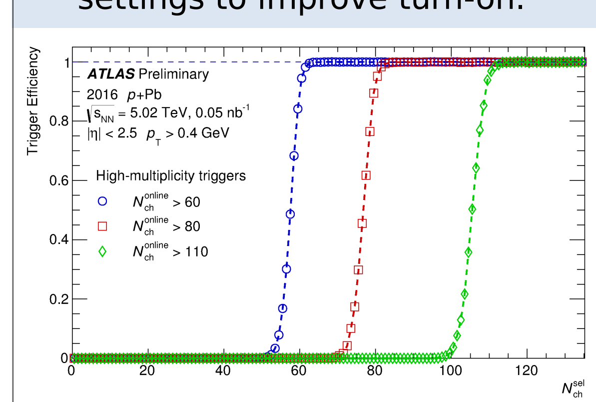
- Goal: provide single- and di-muon sample for measurements of **quarkonia** and **W/Z bosons**.
- Primary single-muon triggers require a muon with p_T:
  - Pb+Pb: p_T > 6 GeV
  - *p*+Pb: p_T > 15 GeV
- L1 seeds are muon RoIs with p_T thresholds:
  - Pb+Pb: p_T > 4 GeV
  - *p*+Pb: p_T > 6 GeV
- Di-muon triggers require two 4 GeV muons with seeds:
  - Pb+Pb: one L1 muon RoI with p_T > 4 GeV
  - *p*+Pb: two L1 muon RoIs with p_T > 4 GeV



Invariant mass distributions of oppositely charged muon pairs in Pb+Pb (upper plot, [2]) and p+Pb collisions (lower plot, [3]). Di-muon triggers enlarge the collected sample of quarkonia.

High multiplicity track trigger

- Goal: increase the number of **events with large event activity** for analyses studying long-range correlations.
- Seeded from L1 TE triggers with modified calorimeter noise settings to improve turn-on.



Efficiency of HMT triggers requiring a given number of tracks reconstructed at HLT with p_T > 0.4 GeV [3].

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