Developments and Performance of ATLAS Electron and Photon Triggers in Run 3

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On behalf of the ATLAS Collaboration

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ATLAS EXPERIMENT

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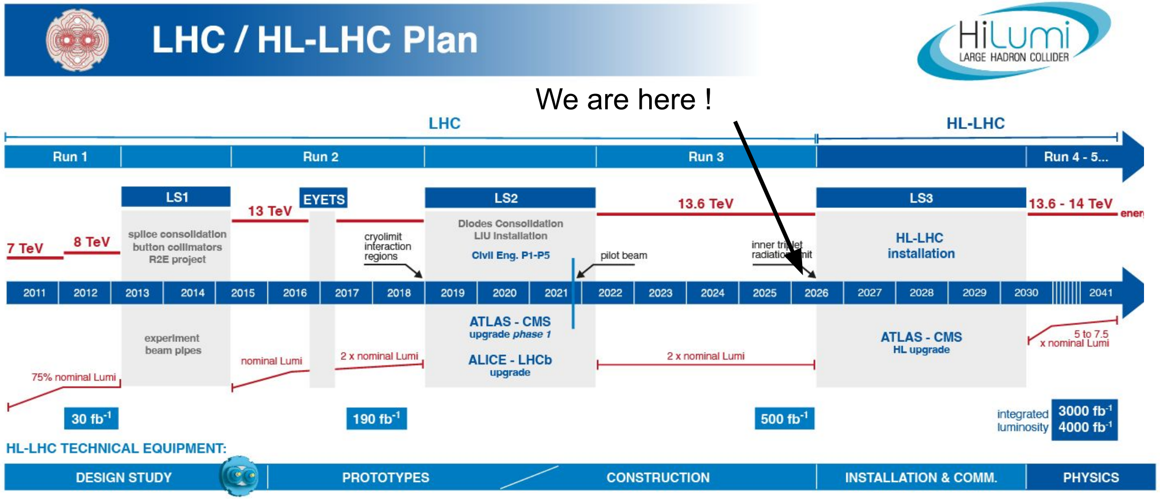
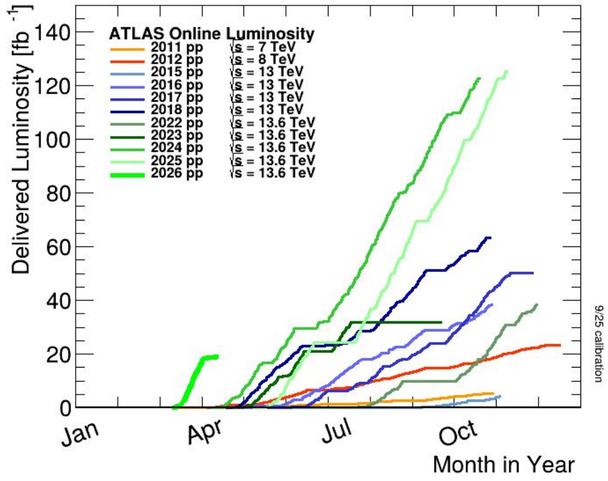
LAPP

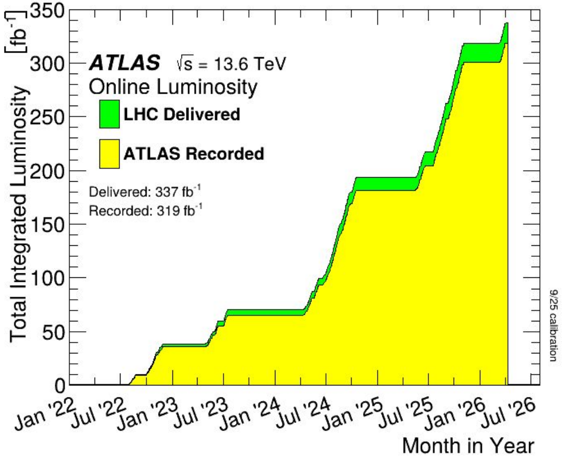
ATLAS data taking in Run 3



	Run 2	Run 3
Quantity of pp data	$147\ fb^{-1}$	$\sim\ 319\ fb^{-1}$
Center of mass energy	13 TeV	13.6 TeV

- Running at peak luminosity of $\sim 2.6 \cdot 10^{34} cm^{-2} s^{-1}$ and an average number of interactions per bunch crossing $< \mu >= 63$





The ATLAS Trigger system

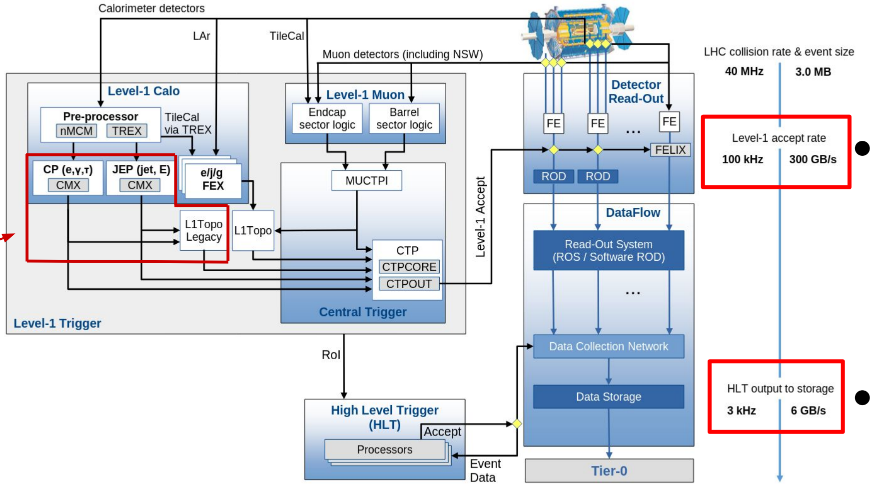
- Over a **billion** particle interactions take place in the ATLAS detector every second
  Data rate → x20

- Obvious need to be
  selective on what is saved !

- Two main parts :

-The Level-1 (L1) trigger
-the High Level Trigger (HLT)

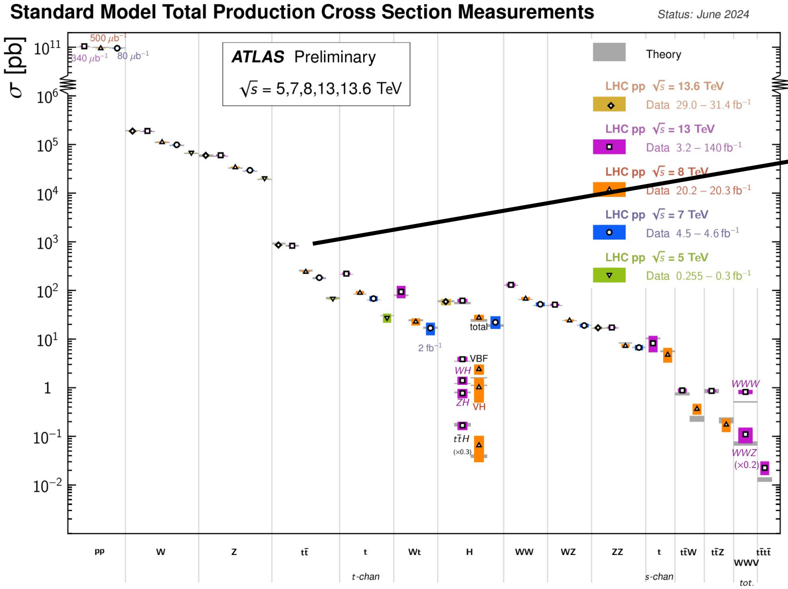
The legacy system was disabled during 2023



- The hardware based L1 trigger performs first selections and provides a Region of Interest

- The software based HLT performs more sophisticated selections on the events filtered by the L1 trigger

The trigger menu



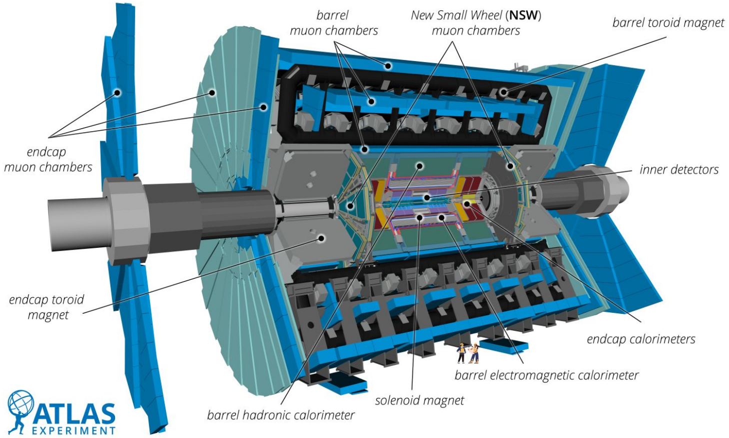
Signature	Rate per stream [Hz] Main	Delayed	TLA
Electron	270		
Photon	120		
Muon	290		
Tau	160		
Missing transverse momentum	140		
Unconventional Tracking	40		
B-physics and light states		240	
Jet	490	460	5000
Jet with *b*-hadrons	190	160	
Combined	240	50	830

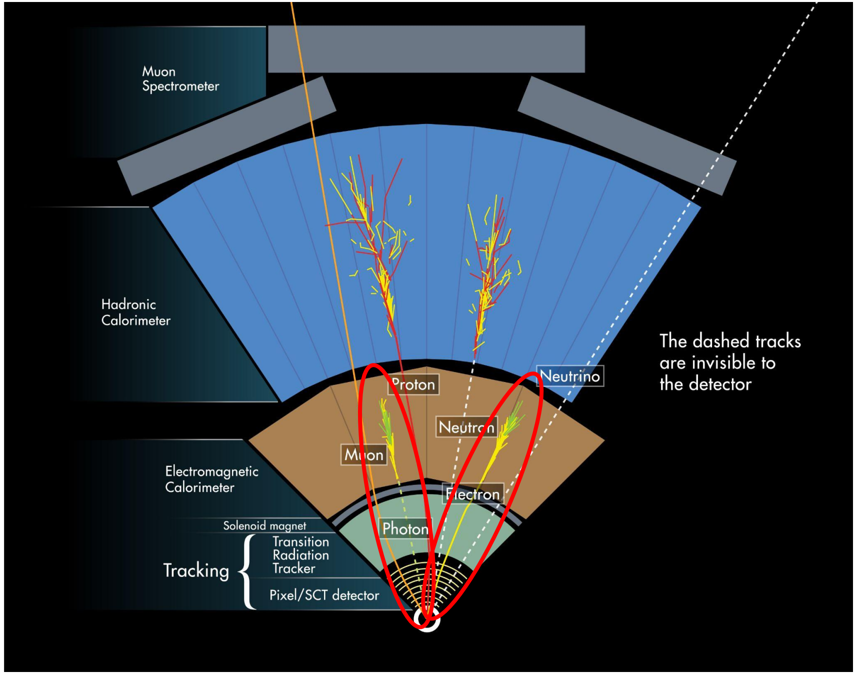
G. Aad *et al* 2024 *JINST* **19** P06029

- The trigger menu covers all signatures from electrons and photons to heavy jets and others, relevant for **physics analyses !**
- Example of electron triggers :
  - Single electrons triggers with looser identification requirement with increasing pT !

Will focus on electron/photon signature in the following

Object reconstruction in ATLAS



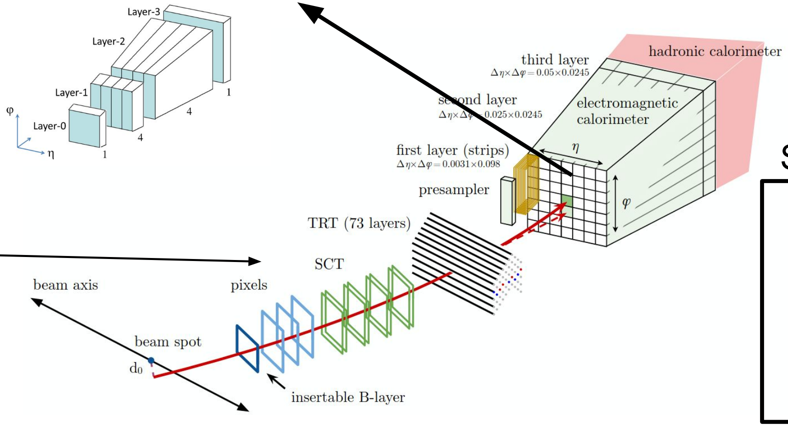


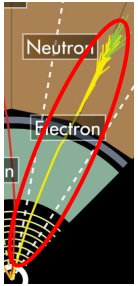
- We don’t detect particles but their interaction with our detector !

Electrons and photons reconstruction in ATLAS

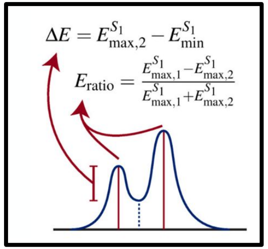
The electron/photon **L1 trigger** doesn't use the full granularity but **Supercells** Sum of 4 to 8 Calorimeter cells

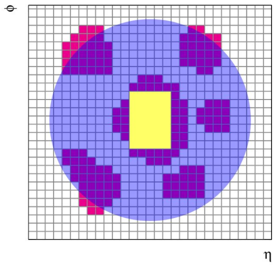
Only 3 shower shapes for the electron/photon **L1 trigger**





Shower Shape !





Reconstruction:

Energy deposit in the calorimeter (**Cluster**) + **Tracks** (trajectory in the inner detectors)

Identification:

More specific calorimeter informations like **Shower shapes**

(Isolation)

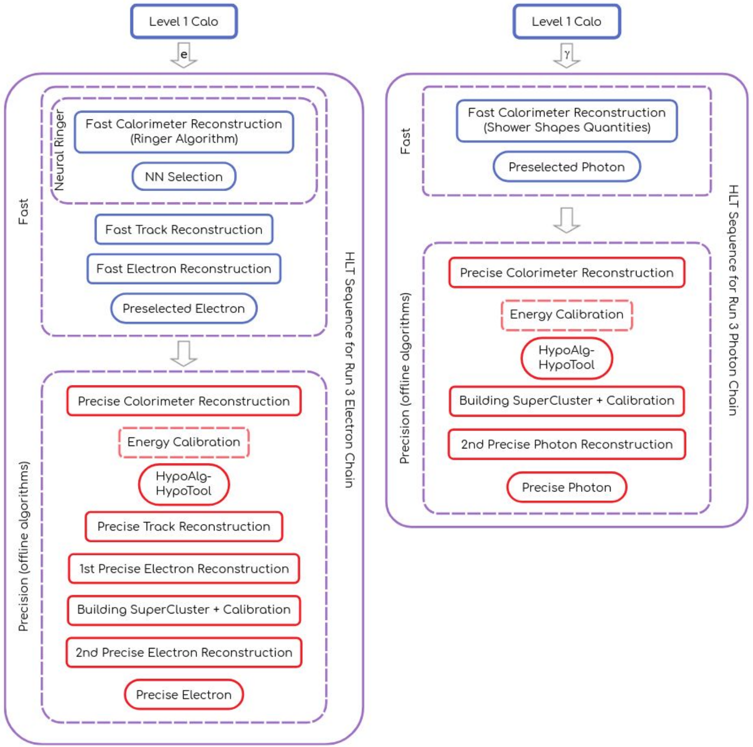
"Offline" objects **used in analyses**

The Electron/Photon trigger sequences

- Level-1 trigger **L1**
- The **HLT** trigger with :
    - A **Fast step:** early background rejection which allows the subsequent algorithms to run at a reduced rate
    - A **Precision step:** algorithms very close to those used in analyses; includes precise reconstruction and Identification
- Example of a single electron trigger:

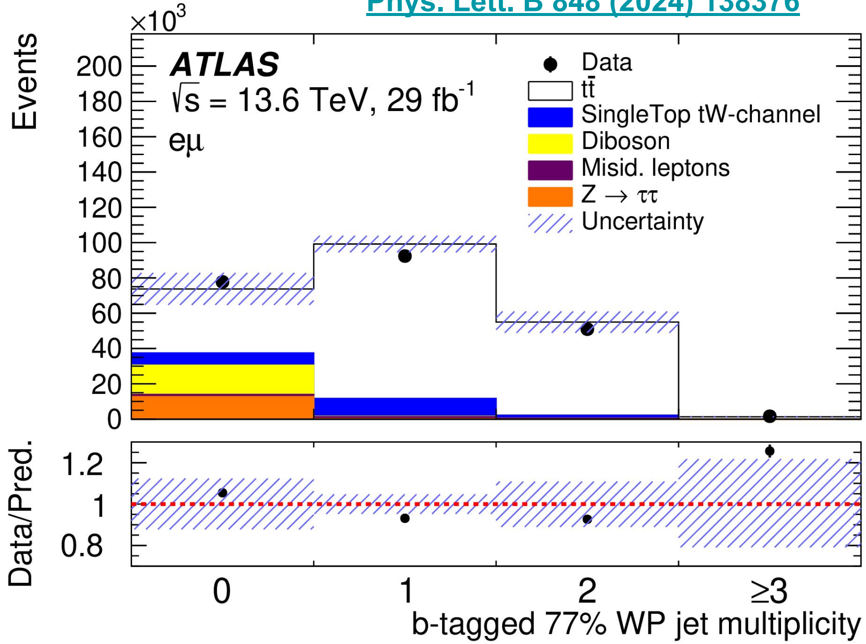
HLT_e**26**_**lhtight**_**ivarloose**_L1eEM26M

ET threshold Identification Isolation Level-1



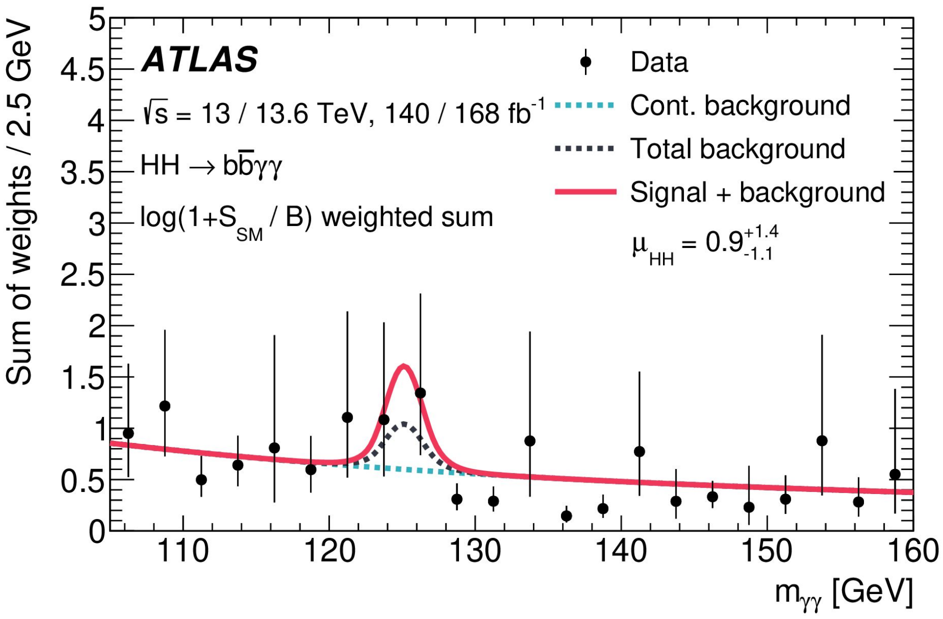
Electron/photon triggers in physics analyses

Phys. Lett. B 848 (2024) 138376



Single lepton triggers for $t\bar{t}$ cross-section measurement with 2022 data

Phys. Lett. B 876 (2026) 140280

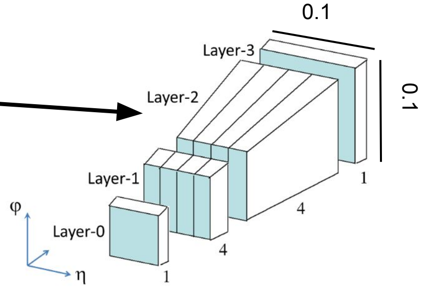


Di-photons triggers for $HH \to b\bar{b}\gamma\gamma$ measurement

The Level-1 calo upgrade in Run 3

- In Run 3 the Level-1 Calo can receive finer-granularity input data from the Liquid Argon calorimeter, using ***SuperCells*** instead of ***trigger towers*** in Run 2.

- One ***trigger tower*** is equivalent to 10 ***SuperCells*** !



- New ***F***eatures ***EX***tractors e***FEX***, j***FEX*** and g***FEX*** using this finer granularity information !

  Each with different reconstruction purposes :
  - Isolated electron/photons and hadronic taus for e***FEX***,
  - jets, E_T^{miss} and hadronic taus for j***FEX***
  - Large jets (large R=0.9) for g***FEX***

- Multiple working points for e***FEX*** (tight, medium and loose) trading off purity (tight) for statistics (loose) obtained by changing selections on Shower Shape variables

$$\begin{cases} R_\eta = 1 - \dfrac{E_{T,3\times 2}}{E_{T,7\times 2}} \\ R_{had} = \dfrac{E_{T,had}}{E_{T,EM} + E_{T,had}} \\ w_{s,tot} = \sqrt{\dfrac{\sum E_{T,i} \times (i - i_{max})^2}{\sum E_{T,i}}} \end{cases}$$

- In 2024 the legacy L1 was completely replaced by the upgraded L1 for all signatures

Tag and Probe method for electron trigger efficiency calculation

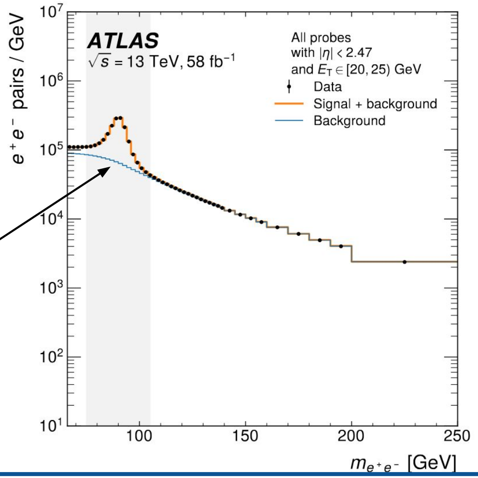
$$Z \to e^- e^+$$

Tag electron

Probe electron

e^+

e^-



1. Look for tag electron with strict requirements

2. Take the other **probe** electron from the Z decay pair **only** using the invariant mass of the two electrons to obtain an unbiased sample to calculate efficiencies

- For data background subtraction needs to be applied so that efficiency measurement are compared fairly with simulations

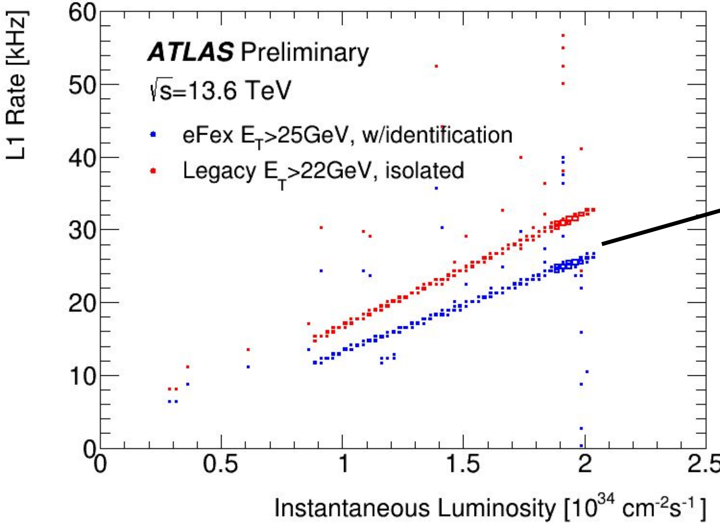
$$\epsilon_{Total} = \frac{N_{offline}}{N_{All}} \times \frac{N_{trigger}}{N_{offline}}$$

Probes passing the trigger

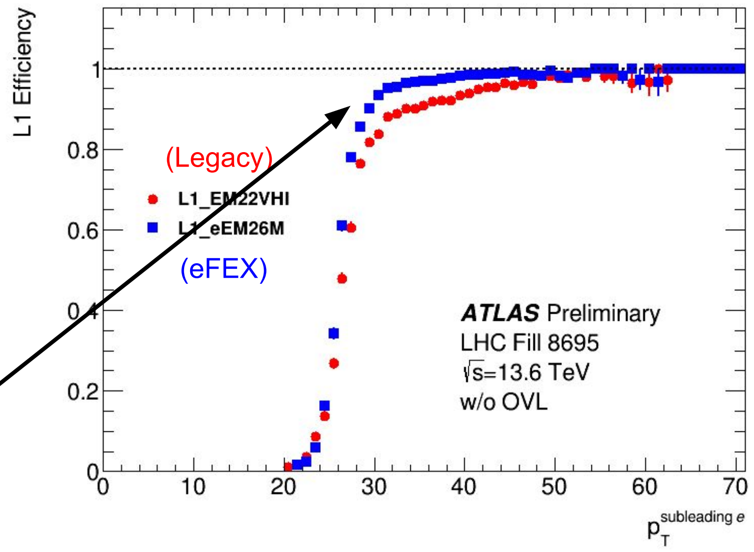
All probe electrons

Efficiencies are computed as a function of kinematic variables like p_T and η

Performances of the upgraded Run 3 L1 Calo system for electrons

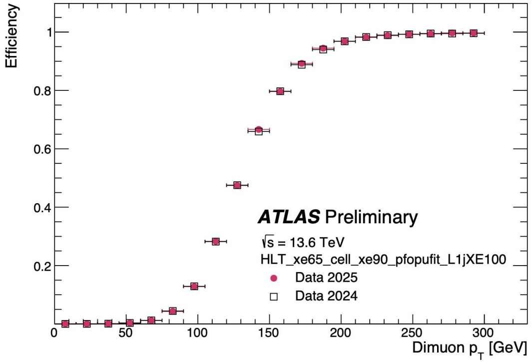


- Level-1 trigger rates for Legacy L1 and new L1 with eFEX
- L1 trigger rates for isolated object deceased by 10 kHz with eFEX compared to the Legacy system
  -> Improved background rejection !

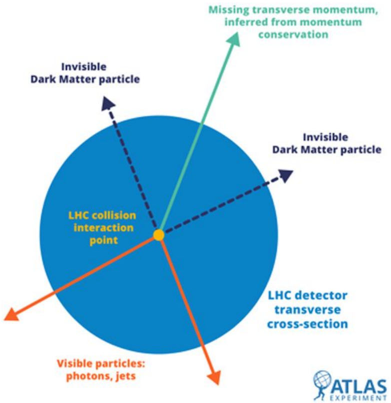


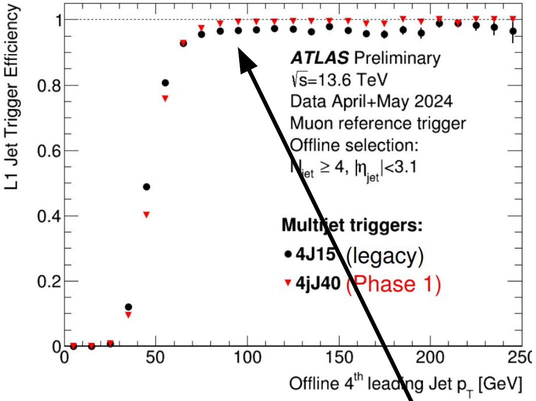
- Trigger efficiencies calculated on Z->ee events with the Tag&Probe method
- Efficiencies are also higher with the new eFEX L1 !
- These are equivalent triggers with different implementations -> these improvements make sense !

Performances of the upgraded Run 3 L1 Calo system for other signatures

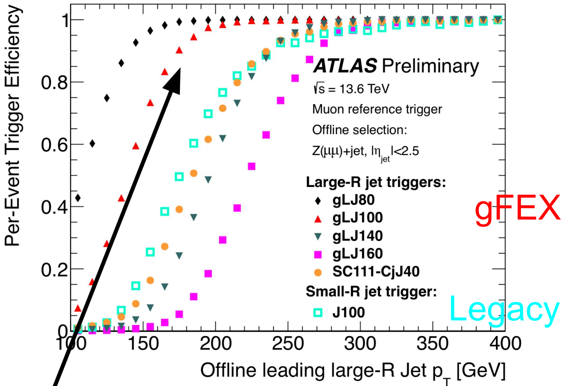


Missing transverse energy (MET) triggers efficiency based on jFEX !





Small R multijet triggers (R=0.4)



Large/Small R single jet triggers (R=0.9/R=0.4)

New FEXs systems bring better performances !

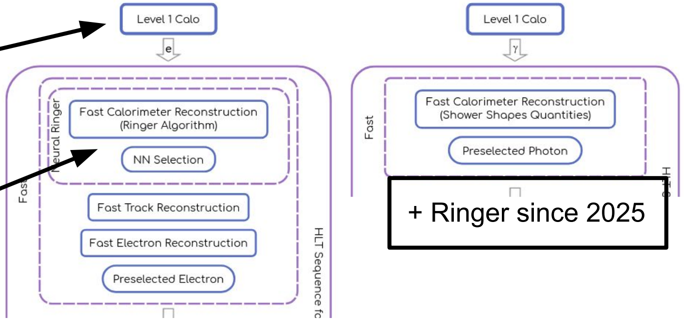
The electrons and photons triggers in Run 3 : L1 + HLT Fast step

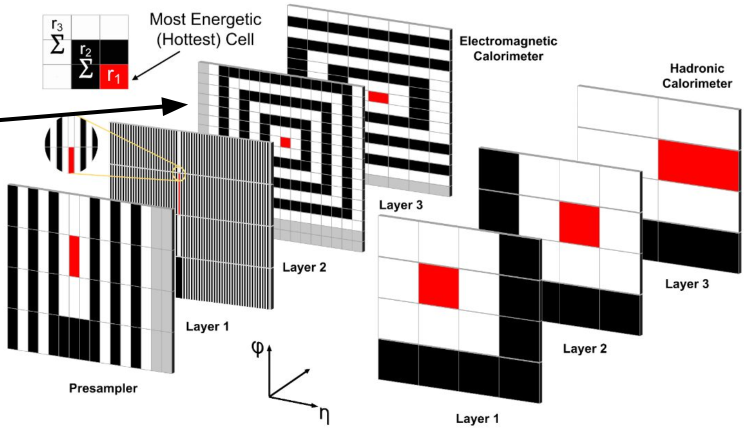
- Updated Level-1 Calo, with finer LAr granularity and eFEX systems

- The reconstruction of electron at the HLT's Fast step is done with a Neural Network based ***Ringer*** algorithm

- The ***Ringer*** algorithm uses as input energy sums of all the cells in 100 concentric rings centered around the most energetic cell in each calorimeter sampling layer

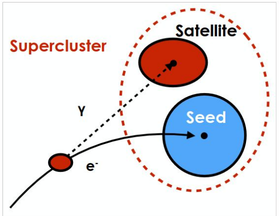
- Since 2025, the photon reconstruction at the HLT's Fast step also uses the the ***Ringer*** algorithm



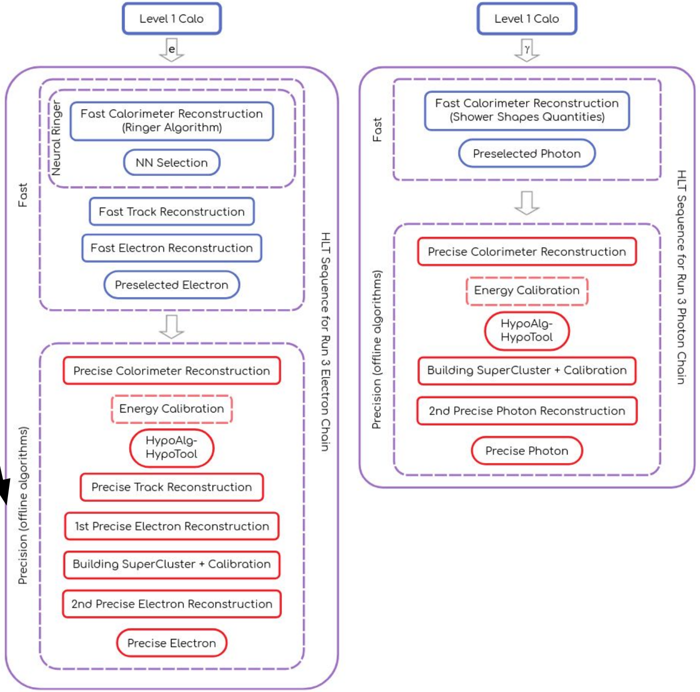


The electrons and photons triggers in Run 3 : HLT precision step

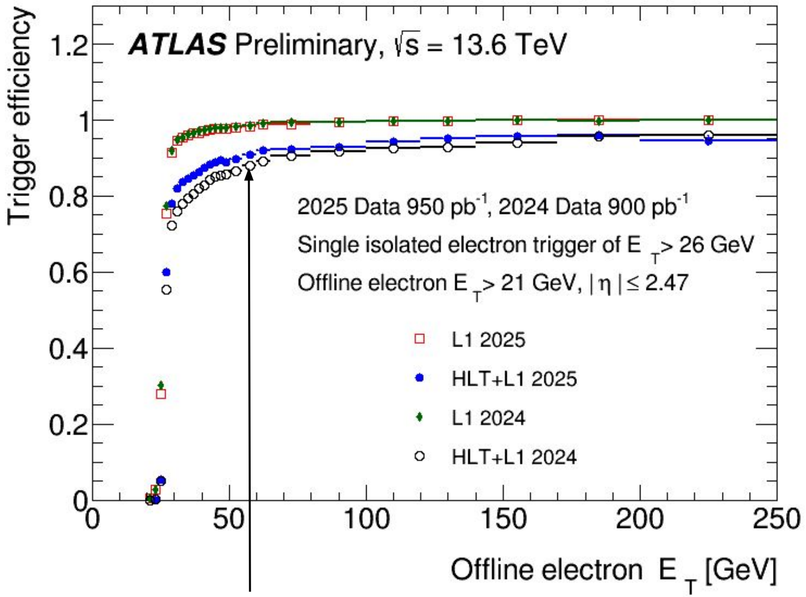
- In General, in Run 3 electron and photon precision reconstruction at the HLT became closer to the analysis level precision with additions such as :
  - Offline like improved superclustering used as inputs for a MVA-based calibration

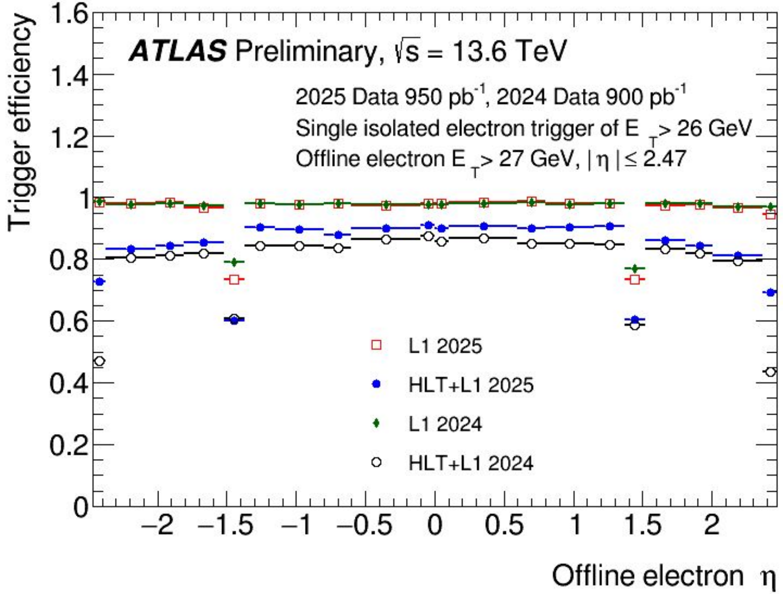


  - Gaussian Sum Filter based bremsstrahlung recovery which improves the track resolution. [G. Aad *et al* 2024 *JINST* **19** P06029]
- We need to evaluate the performances of these triggers for analyses -> **efficiency and simulation correction measurements**



Single electron trigger performances in 2025

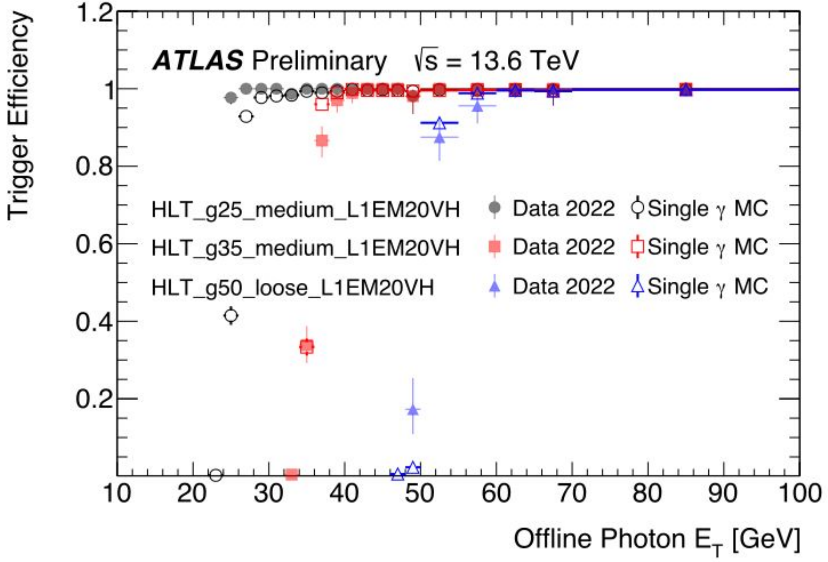


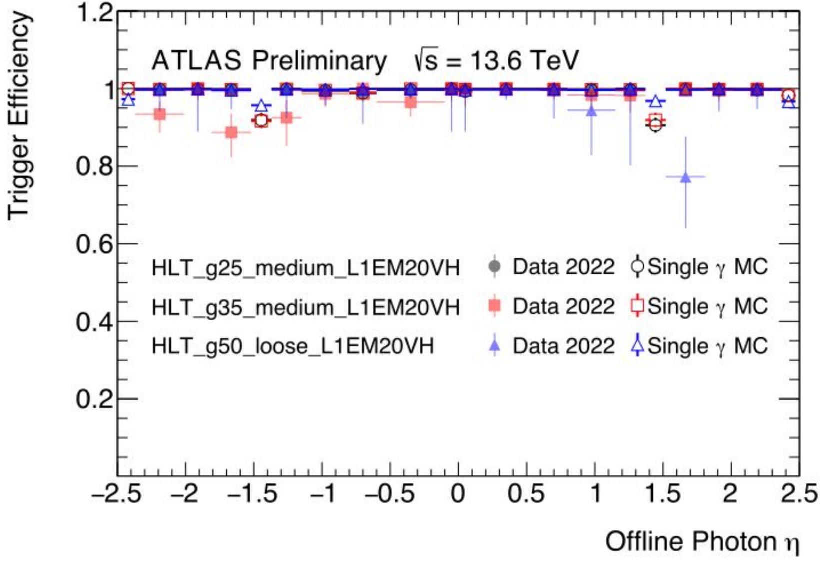


- Recovered efficiency in 2025 due to improved isolation selection and ringer selections
  HLT+L1 2025 > HLT+L1 2024 !

Photon trigger performances in 2022

- di-photon triggers -> trigger events with at least two photons





- These are di-photon triggers used in Higgs boson measurements. There efficiencies are measured as single photon trigger efficiencies based on the “bootstrap” method

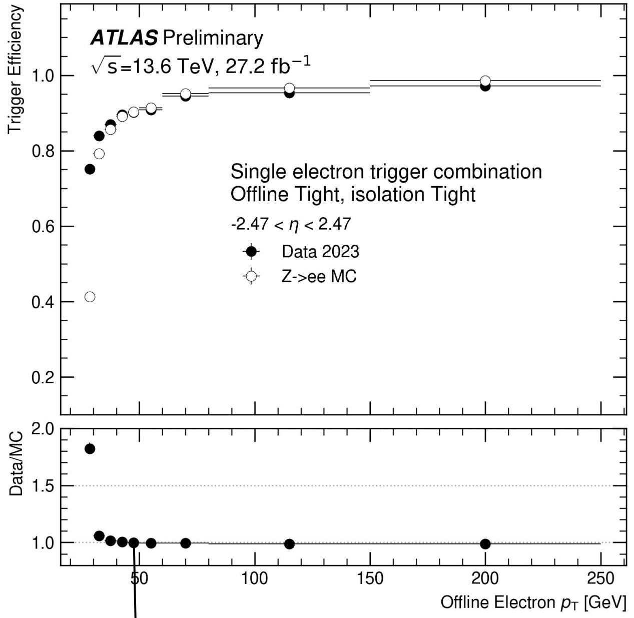
Trigger efficiency correction for electrons

- Physics analyses need to know the efficiencies of the triggers they use in **Data** and **Monte Carlo simulations** and if these **don't match** we need to **correct the MC to agree with Data** !

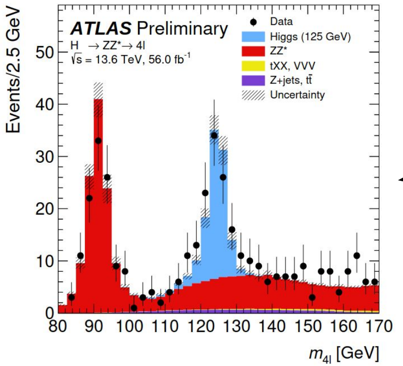
- This is done using the previously defined **Tag&Probe method**

- There is a known mismodelling in Monte Carlo simulations for low p_T electrons that results in a discrepancy between trigger efficiency in Data and MC as measured here

- These **Scale Factors** are available for analyses !



$$SF = \frac{\epsilon_{Data}}{\epsilon_{MC}}$$



ATLAS-CONF-2025-002

0.2 % error at 45 GeV !

Summary

- Trigger performance is crucial in hadron collider experiments like ATLAS, where it is not possible to record all collision events
- The Run 3 has been very successful and we have collected $319\ fb^{-1}$ of proton-proton collisions data at 13.6 TeV so far
- Improved performance of the upgraded Run 3 ATLAS trigger was presented in this talk with an emphasis on electron and photon triggers
- Run 3 triggers results already used in analyses such as **Phys. Lett. B 876 (2026) 140280** ($HH \to b\bar{b}\gamma\gamma$) , **Phys. Lett. B 848 (2024) 138376** ($t\bar{t}$) and **ATLAS-CONF-2025-002** (H->4l) were also presented
- We are preparing for HL-LHC/Run 4 with upgrades on detector systems like the LAr calorimeter and the new inner tracker, see Kazuki's talk for more details !

Thank you for listening!

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Different streams of the trigger menu

- **Physics streams:** collision events of interest for physics studies. The events contain full detector information and dominate in terms of processing, bandwidth and storage requirements.

- **Express stream:** a very small subset of the physics stream events for prompt monitoring, detector calibration, and first-pass data quality checks.

- **Background streams:** background events of interest for physics and detector performance studies.

- **Debug streams:** events for which no trigger decision could be made are written to this stream. Typical reasons are crashes, timeouts in the HLT processing, and HLT data payloads exceeding set thresholds.
- **Calibration streams:** events containing only partial detector information for calibration of specific subdetectors.

- **Trigger-Level Analysis (TLA) streams:** events sent to this stream contain only specific physics objects reconstructed by the HLT, and optionally only partial detector information. These data are used directly in the corresponding physics analysis .

- **Monitoring streams:** events to be sent to dedicated monitoring nodes for online analysis for, e.g., detector monitoring, but not recorded.

Bootstrap method for photon triggers efficiency

- The bootstrap method consist in using a bootstrap sample with triggers with very few selection (Level-1 Only triggers or loose, low pT photon triggers)

- The efficiency reads as:

$$\epsilon^{\gamma}_{trig} = \epsilon_{HLT|BS} \times \epsilon_{BS}$$

The first efficiency $\epsilon_{HLT|BS}$ is the number of photons passing the loose trigger triggers that also pass the HLT trigger in the bootstrap sample

- The efficiency ϵ_{BS} of the bootstrap sample is computed using random triggers, by comparing the number of bootstrap events with the number of isolated, identified and reconstructed offline photon candidates