ATLAS Trigger and Data Acquisition Upgrades for the High Luminosity LHC

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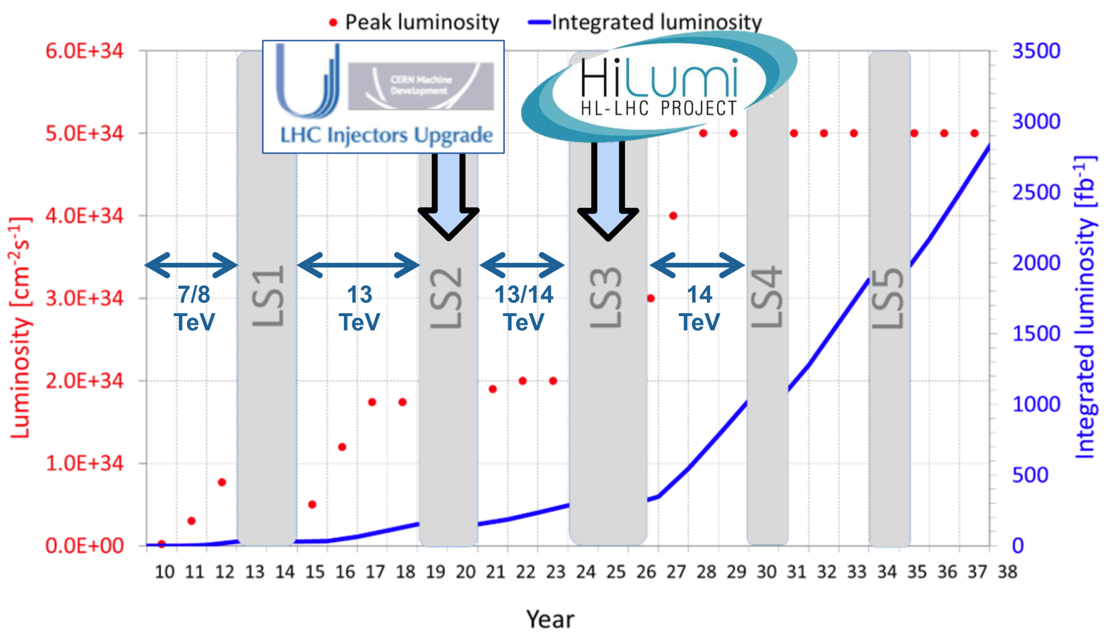
Introduction

The High Luminosity LHC (HL-LHC) is the upgrade of the LHC envisaged to be ready in 2026 targeting **instantaneous luminosities at least a factor of five larger** than the LHC design value. In order to deal with the huge amount of data resulting from this increased luminosity and to prevent the large increase of trigger thresholds, the ATLAS Collaboration will have to upgrade significantly its detector, data acquisition and trigger system [2].



Physics targets and trigger menu

The Phase II ATLAS physics program will mainly target:

- Searches for *Physics Beyond the Standard Model* (Dark Matter, compressed SUSY, Exotics, etc.);
- *Higgs boson measurements* (H couplings and self-couplings, differential distributions, Rare H decays).
- *Standard Model* (SM) and *Flavour physics* measurements.

The trigger menu determines the kinematic thresholds applied on physics objects for each physics signature [4]. The goal of the upgraded system is to **ensure thresholds as low or lower than current ones** in order to allow for EW scale physics at the HL-LHC.

Trigger Selection offline threshold (GeV)	Run 1	Run 2	HL-LHC
Isolated single e	25	27	**22**
Isolated single μ	25	27	**20**
Di-γ	25, 25	25, 25	**25, 25**
Di-τ	40, 30	40, 30	**40, 30**
Four-jet w/ b-jets	45	45	**65**
H_T	700	700	**375**
MET	150	200	**200**

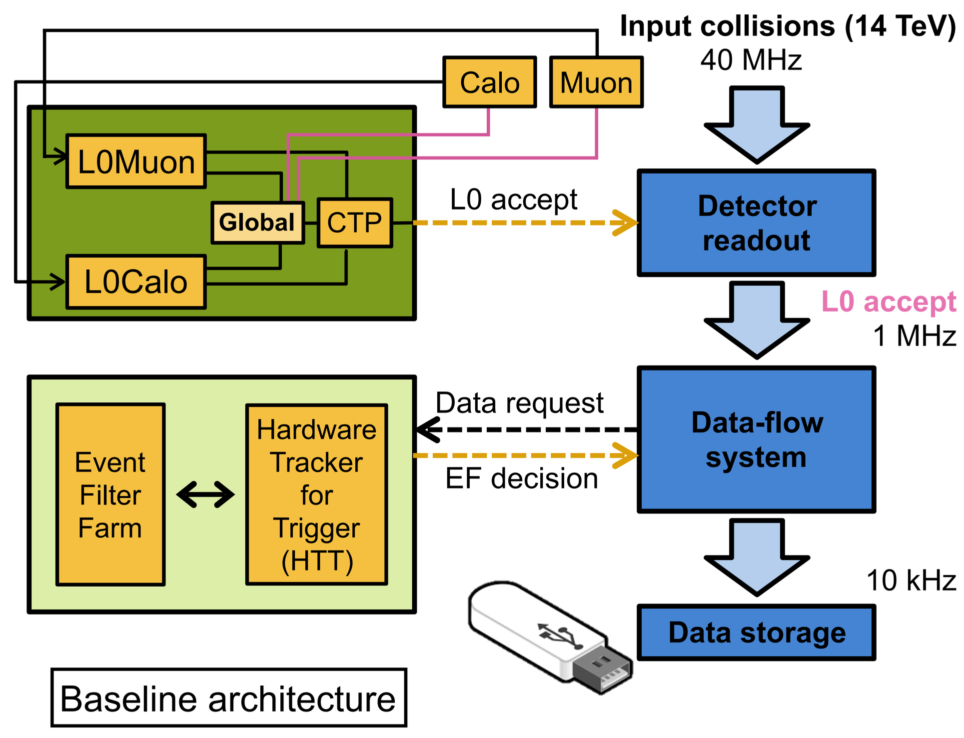
Table 1: Indicative HL-LHC trigger menu, compared to Run 1 and Run 2.

The ATLAS Phase II Trigger Upgrade

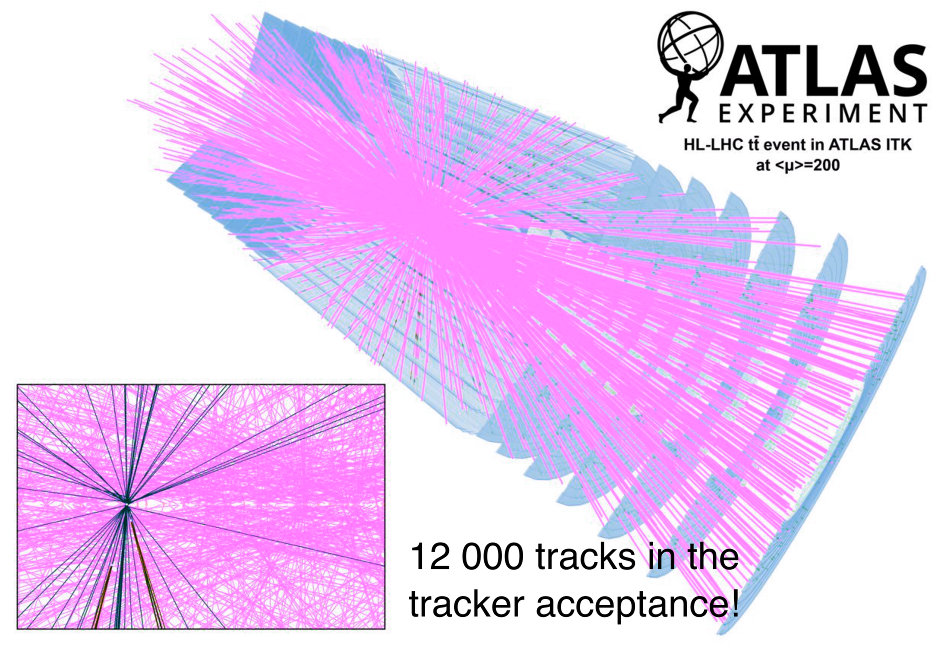
Currently, two possible architectures are considered:

- **Baseline architecture:** composed of a hardware-based *L0 Global trigger* (40 MHz input) and a CPU farm-based *Event Filter* (EF) with available tracking information (1 MHz input).
- **Evolved architecture:** composed of a hardware-based *L0 Global trigger* (40 MHz input), a subsequent filtering level (L1) with tracking capability (up to 4 MHz input) and a CPU farm-based *Event Filter* (EF), providing additional tracking information (600-800MHz input).

Both architectures plan 10 kHz output rate.



Increased Latency	Allowing for more complex objects with better selection conditions and algorithms (including ML-based algorithms in FPGAs). For lowest level trigger latency increases from 2.5 µs to 10 µs.
Higher data granularity	At L0, full calorimeter granularity and precise MDT information will be available.
Enhanced processing capabilities	New *Global* trigger improves calo and muon triggers providing offline-like reconstruction. Possibility to include tracking information in the evolved architecture.
Key technologies	• Latest class FPGAs with High-Bandwidth Memory and large DSP capability. • ATCA crates, multi-gigabit transceivers/optics. • GPUs considered and evaluated for the software trigger farm.
Challenges	• Power delivery and thermal management. • System integration.



L0 Global trigger

The Global Trigger is a new subsystem of the Level-0 Trigger system, which will perform **offline-like reconstruction on full-granularity calorimeter and muon data** as input.

This subsystem will provide the necessary objects for refined e/gamma, tau, muon and jet selections. Jet selections will particularly benefit from the utilisation of offline-like clustering [1] and jet finding algorithms [3].

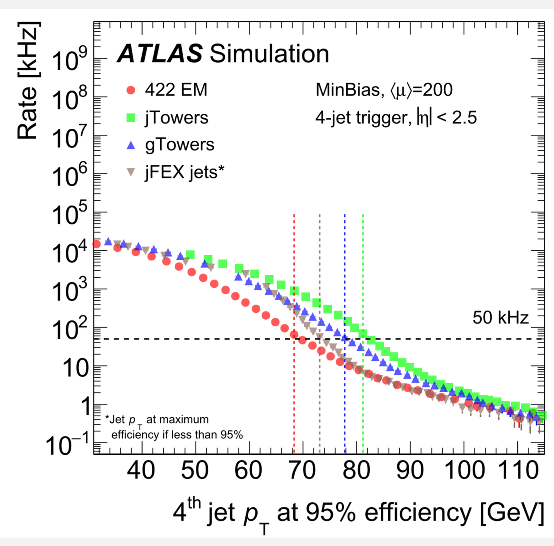


Figure 1: Background rate vs. 4th jet p_T for different jet reconstruction algorithms

Hardware Track Triggers (HTT)

Making tracks quickly available at the EF is one of the most important and challenging tasks for the reduction of trigger rates due to the pileup conditions. The utilisation of pre-built patterns and the combination of latest class FPGAs and Associative Memory (AM) ASICs make the **track reconstruction extremely fast and efficient for the ATLAS trigger system upgrade**. This will be very beneficial for hadronic trigger selections.

TDAQ upgrade effects on key physics signatures

Single lepton triggers (single e, single μ)

Single-electron and single-muon signatures play a central role in ATLAS data analyses. Main workhorses for both **new physics searches and SM measurements**.

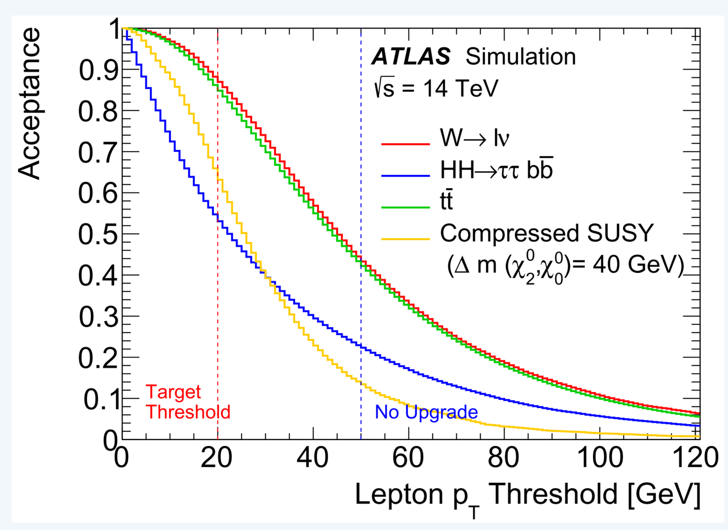


Figure 2: Impact of single lepton trigger selections to the acceptance of key physics channels.

At the HL-LHC, **single electron triggers** will be mainly improved by:

- *Increased calo acceptance and granularity* at L0 Global (background rate reduced by 1/2).
- *Extended tracker acceptance* up to $|\eta| < 4.0$ using gHTT tracks.

Single muon triggers mainly improved by:

- *Increased latency* and better *trigger coverage*.
- Improved trigger logic and p_T resolution.

MET triggers (*e.g.* Dark matter, $ZH \to \nu\bar{\nu}b\bar{b}$, SUSY)

The Missing Transverse Momentum (MET) is a key observable for invisible particles (*e.g.* Dark Matter candidates) produced at the 14 TeV p-p collisions. The access of the upgraded trigger system to enhanced tracking information allows to **largely reject the background events** while keeping the signal event acceptance stable.

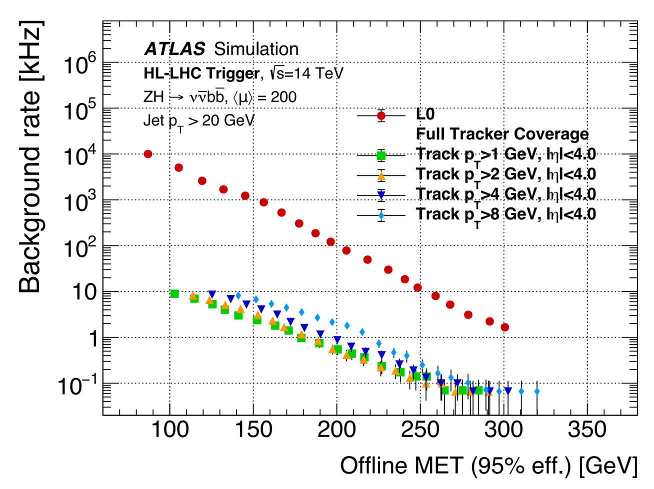


Figure 3: MET background rate vs. offline MET cut (95% signal efficiency) for full-scan track selections.

Hadronic triggers (*e.g.* 4 jet selections for $HH \to b\bar{b}b\bar{b}$)

The Higgs self-coupling represents one of the benchmark measurements for the ATLAS HL-LHC physics program. **The limits on this channel will improve significantly** thanks to the improved algorithms ensured by the upgraded TDAQ system.

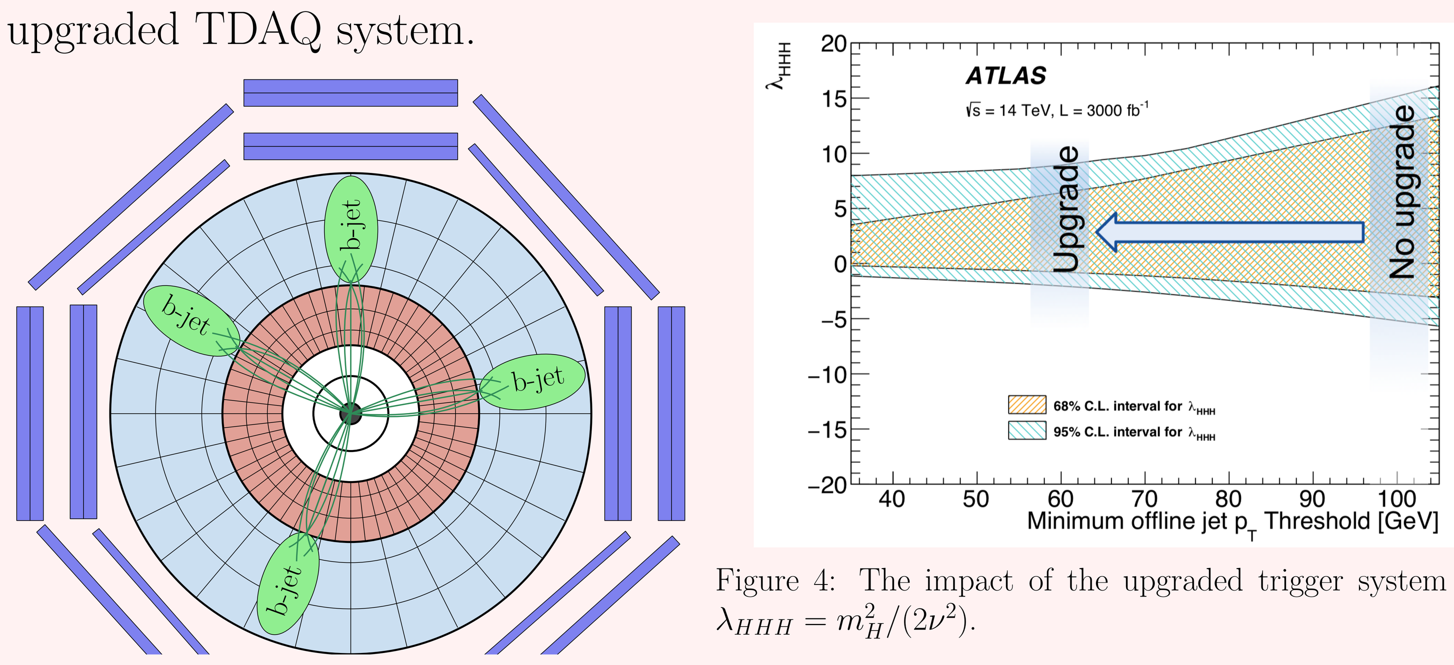


Figure 4: The impact of the upgraded trigger system on $\lambda_{HHH} = m_H^2/(2v^2)$.

Conclusions

The HL-LHC will significantly increase the physics potential of the ATLAS experiment thanks to the unprecedented data rates it will provide. In order to fully exploit this enhanced capability, major upgrades of the ATLAS trigger system are necessary. In this context, the current plans for the TDAQ Phase II upgrade will provide an important piece for the success of the ATLAS Phase II physics program. Specifications have been defined for the HL-LHC TDAQ architecture and works have started towards the construction of the first system prototypes.

References

[1] Georges Aad et al. Topological cell clustering in the ATLAS calorimeters and its performance in LHC Run 1. *Eur. Phys. J.*, C77:490, 2017.

[2] Collaboration ATLAS. Letter of Intent for the Phase-II Upgrade of the ATLAS Experiment. Technical Report CERN-LHCC-2012-022. LHCC-I-023, CERN, Geneva, Dec 2012. Draft version for comments.

[3] Matteo Cacciari, Gavin P. Salam, and Gregory Soyez. The anti-k_t jet clustering algorithm. *JHEP*, 04:063, 2008.

[4] ATLAS Collaboration. Technical Design Report for the Phase-II Upgrade of the ATLAS TDAQ System. Technical Report CERN-LHCC-2017-020. ATLAS-TDR-029, CERN, Geneva, Sep 2017.