Machine Learning for Particle Identification in Real Time at the ATLAS Experiment

Fourth MODE Workshop on Differentiable Programming for Experiment Design

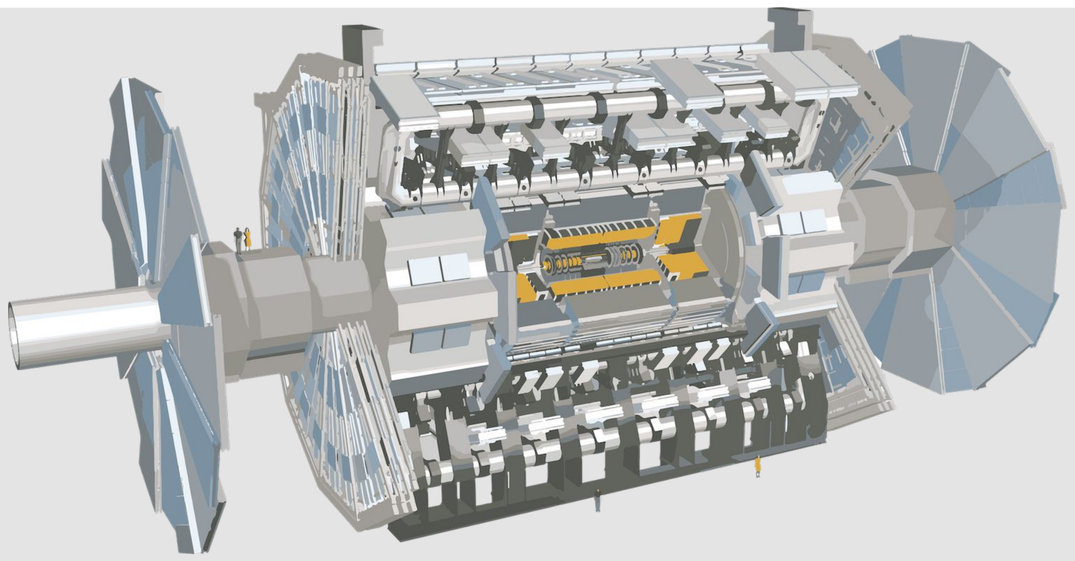
ATLAS detector

ATLAS is a multipurpose detector:

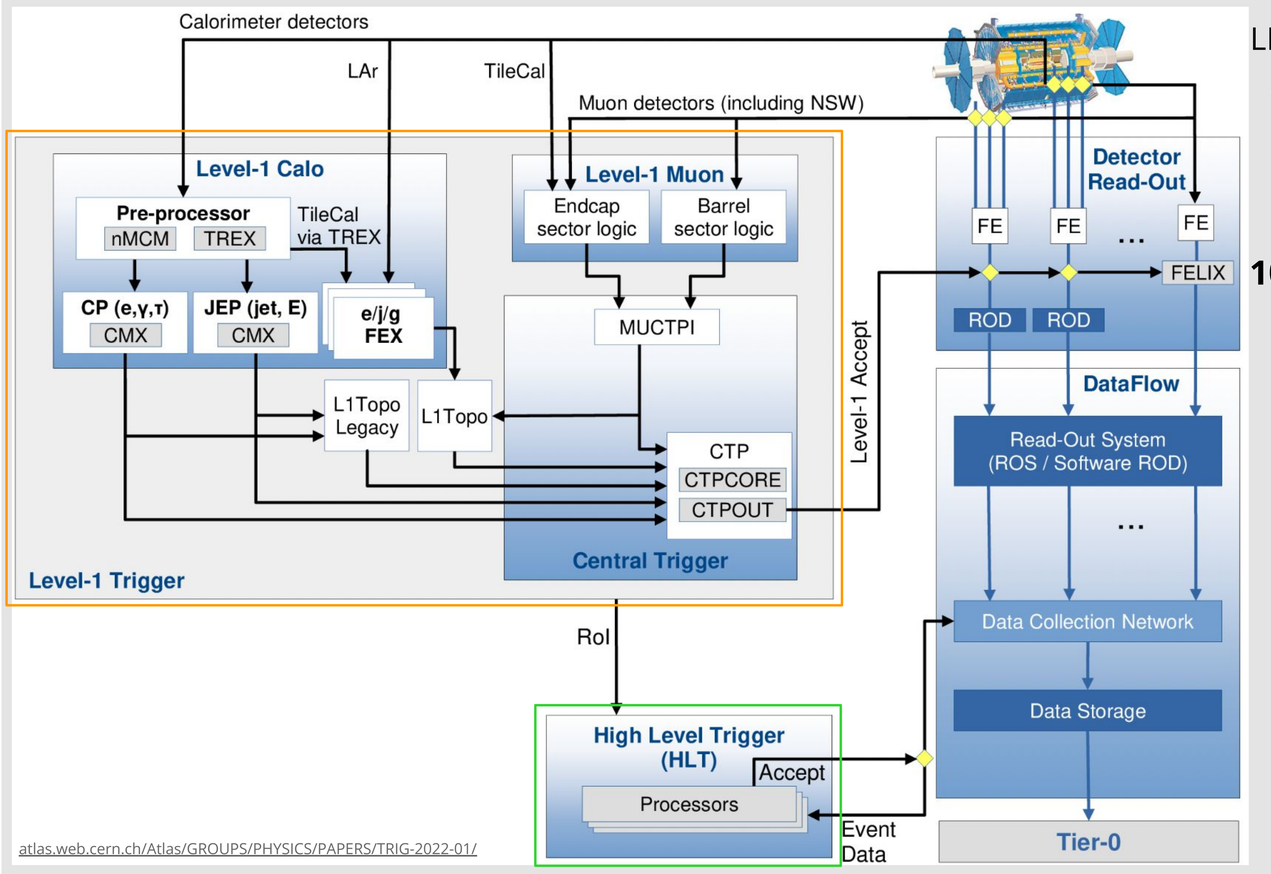
- test Standard Model (SM) predictions in the new range of energy
- study SM Higgs boson properties
- search for new physics beyond the SM

Around 1 billion events/second are generated in the pp collisions:

- Only a fraction (~10^3 events/second) can be recorded
- Need a powerful Trigger system



Overview of the ATLAS Trigger and Data Acquisition System



atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/TRIG-2022-01/

LHC collision rate & event size

40 MHz **3.0 MB**

Level-1 accept rate

100 kHz **300 GB/s**

HLT output to storage

3 kHz **6 GB/s**

- The ATLAS trigger system decides which events to save from a given bunch-crossing for offline analysis
- Data selection is performed in two stages:
  - Level-1 **(L1)**: hardware based using custom made electronics
  - High Level Trigger (**HLT**): software based using custom algorithms to identify physics objects

Identification algorithms at the HLT

Different reconstruction algorithms are implemented in the HLT for each signature:

- ➔ Photons: cut-based selection
- ➔ Electrons: likelihood discriminant
- ➔ Taus: **Recurrent Neural Network (RNN)**
- ➔ Muons: tracks in the ID and MS
- ➔ Jets: anti-κ_t algorithm
- ➔ b-jets: **Graph Neural Networks (GNN) GN1 and GN2**
- ➔ Missing E_T: different algorithms to compute the sum of the missing energy

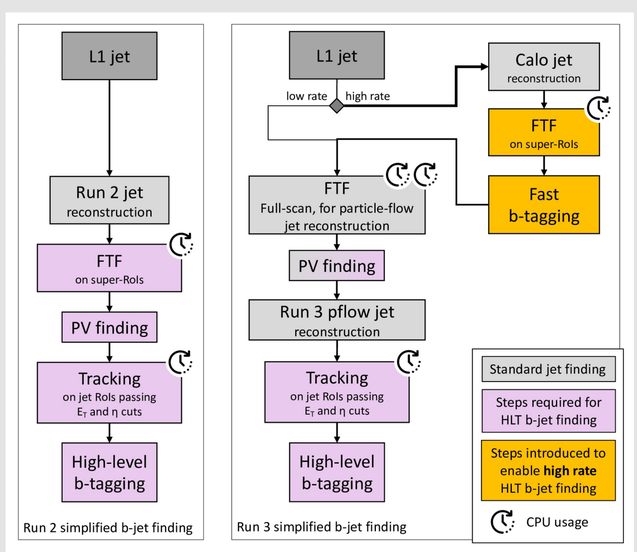
b-jets and tau leptons are reconstructed using **Machine Learning** algorithms in the ATLAS High Level Trigger

b-jet Trigger

In Run 3, ATLAS has incorporated a fast neural-network-based b-tagger that runs after L1 trigger and before the HLT reconstruction. ML is used at two stages:

- **Fast b-tagging**: deep-sets-based neural network (DIPS)
- **High-level b-tagging**: GNNs

At HLT, the b-tagging algorithm used during Run 2, MV2, was replaced by DL1 in 2022 data taking, upgraded to GN1 in 2023 and GN2 in 2024:



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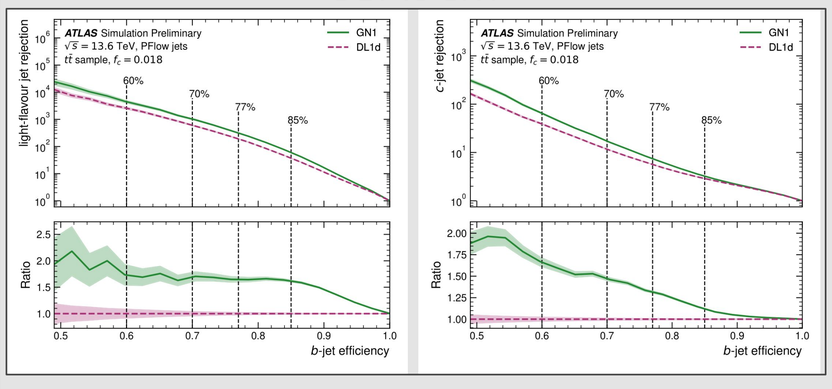
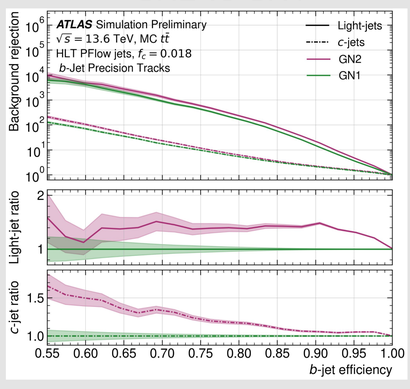
DL1 vs GN1



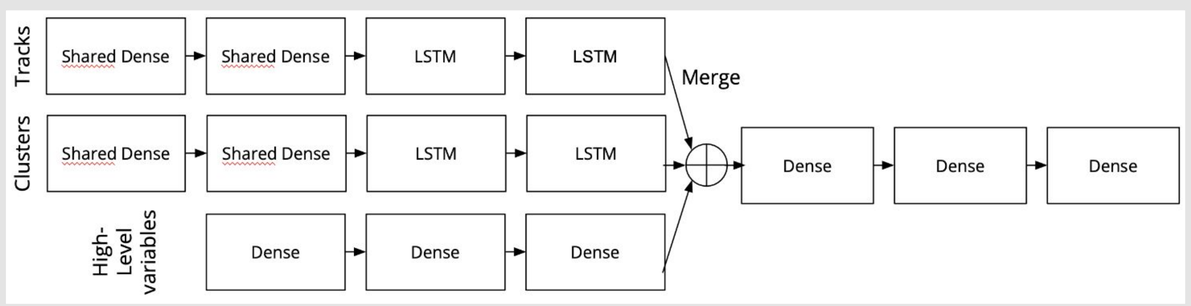
GN2 vs GN1



twiki.cern.ch/twiki/bin/view/AtlasPublic/BJetTriggerPublicResults

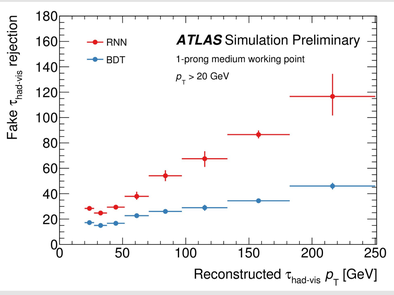
Tau Trigger

The RNN implemented at HLT for tau identification is needed to discriminate between jet-like objects and **hadronic taus**. The Network architecture:

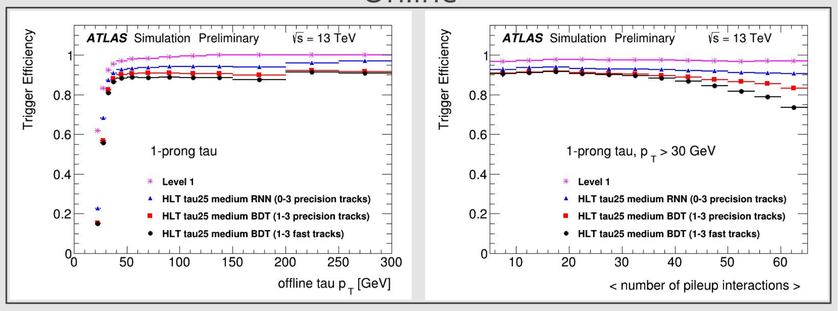


RNN performance compared to the Boosted Decision Tree (BDT) during Run2:

Offline



Online



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twiki.cern.ch/twiki/bin/view/AtlasPublic/TauTriggerPublicResults

The background rejection for jets misidentified as hadronic taus is improved by approximately 70% in a p_T range of 30-50 GeV. At higher p_T, the **improvement** in rejection, when implementing this new ML algorithm, exceeds **100%**.

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