Fast pattern recognition with the ATLAS L1Track trigger for the HL-LHC

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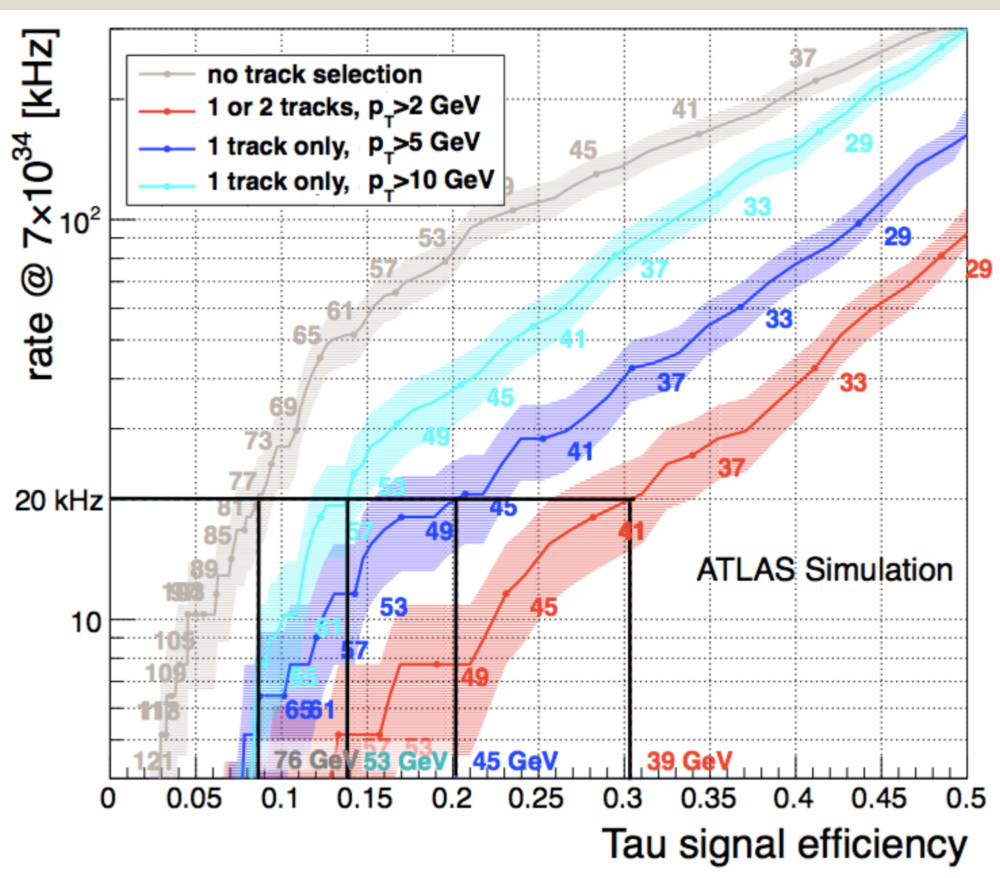
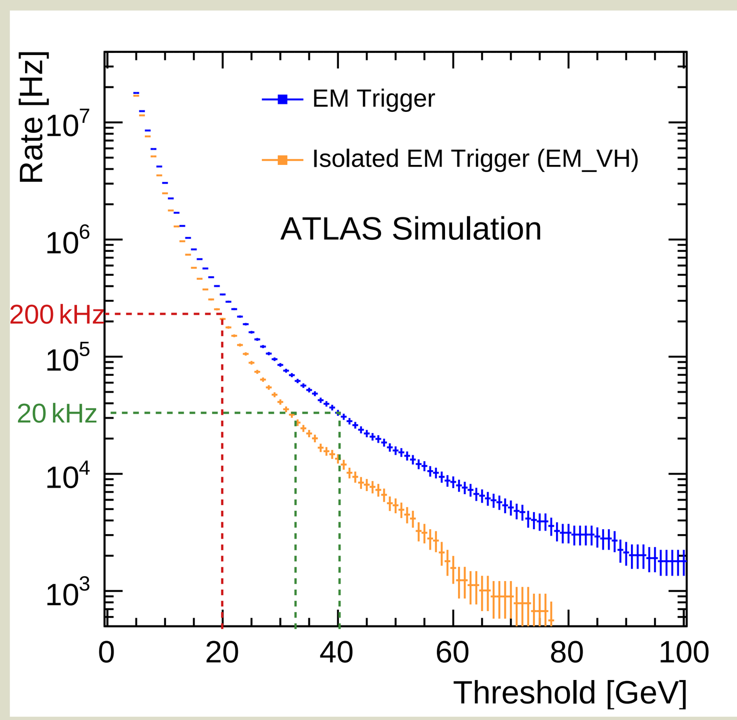
HL-LHC and the ATLAS upgrade

The High Luminosity upgrade of the LHC (HL-LHC), scheduled to start operation in 2024, is expected to increase the instantaneous pp luminosity to 7.5 $\times$ 10^{34} cm^{-2} s^{-1}. This increases the pile-up by a factor of 5-7 compared to current operation.



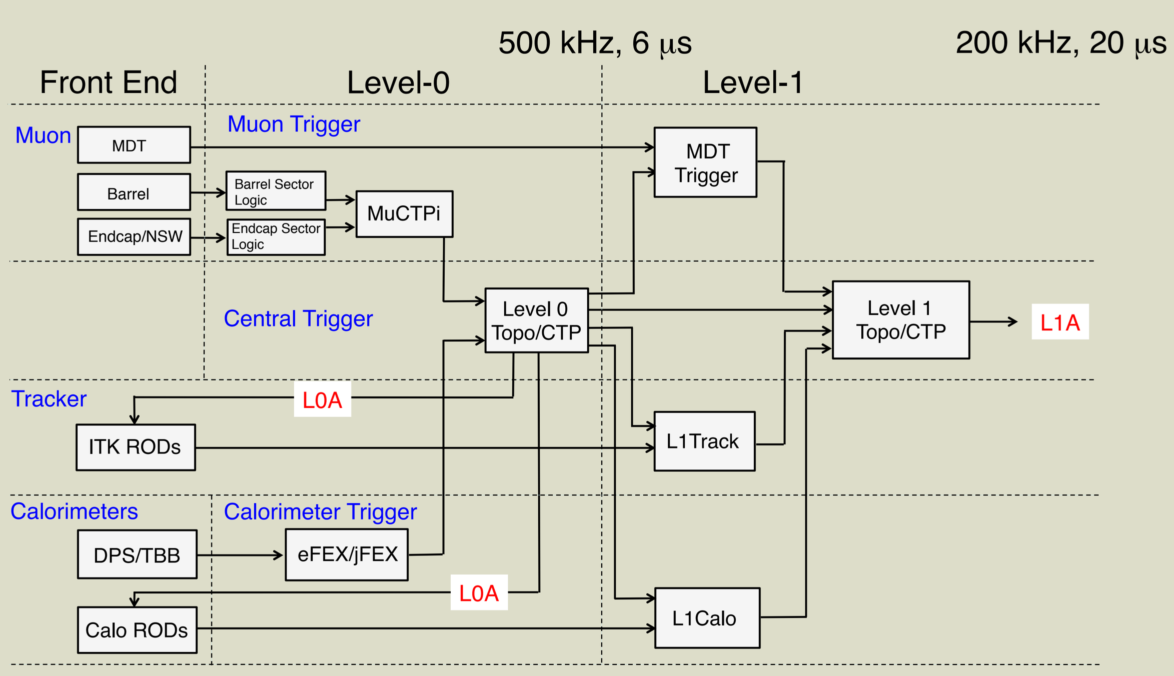
Trigger rate versus tau finding efficiency for taus from the decay of a 120 GeV Standard Model Higgs at the HL-LHC.



Trigger rates for pile-up 115 as a function of trigger threshold for isolated electron and tau triggers at the HL-LHC.

CERN-LHCC-2012-022

The current trigger will not be able to maintain reasonable trigger rates at the HL-LHC without increasing the energy/momentum threshold. The ATLAS Phase-II upgrade, which prepares ATLAS for the HL-LHC, will introduce a hardware track trigger (L1Track) which is expected to solve this issue.



The proposed L0/L1 hardware trigger architecture for the Phase-II upgrade.

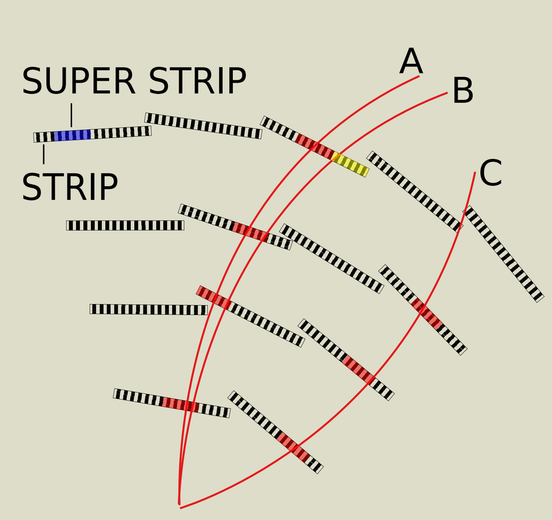
- Level-0 uses the calorimeters and muon spectrometer to define regions of interest (RoI) of maximum 10 % of the detector volume.
- L1Track looks for tracks in the RoIs in two steps.
  1. Pattern recognition to find hit candidates.
  2. Track fitting in FPGA.

L1Track using Associative Memory (AM)

ATL-UPGRADE-PROC-2011-004

The baseline approach for the L1Track pattern recognition is to use custom design AM chips to perform *pattern matching*. AM chips compares an input bit pattern from the detector with bit patterns from simulated tracks stored in its memory in parallel. In the L1Track pattern matching each bit corresponds to a hit in a detector segment.

- The pattern banks contain 10^6 sequences of hits found from simulated muons with $p_T >$ 4 GeV for each $\Delta\phi_0 = 0.2$ by $\Delta\eta = 0.2$ RoI.
- Nearby pixels and strips are grouped together into larger super strips to reduce the number of patterns.
- *Don't care* bits are used to combine similar patterns (tracks A and B).
- Missing hits in one or two layers are handled using *wild card* layers (track C).

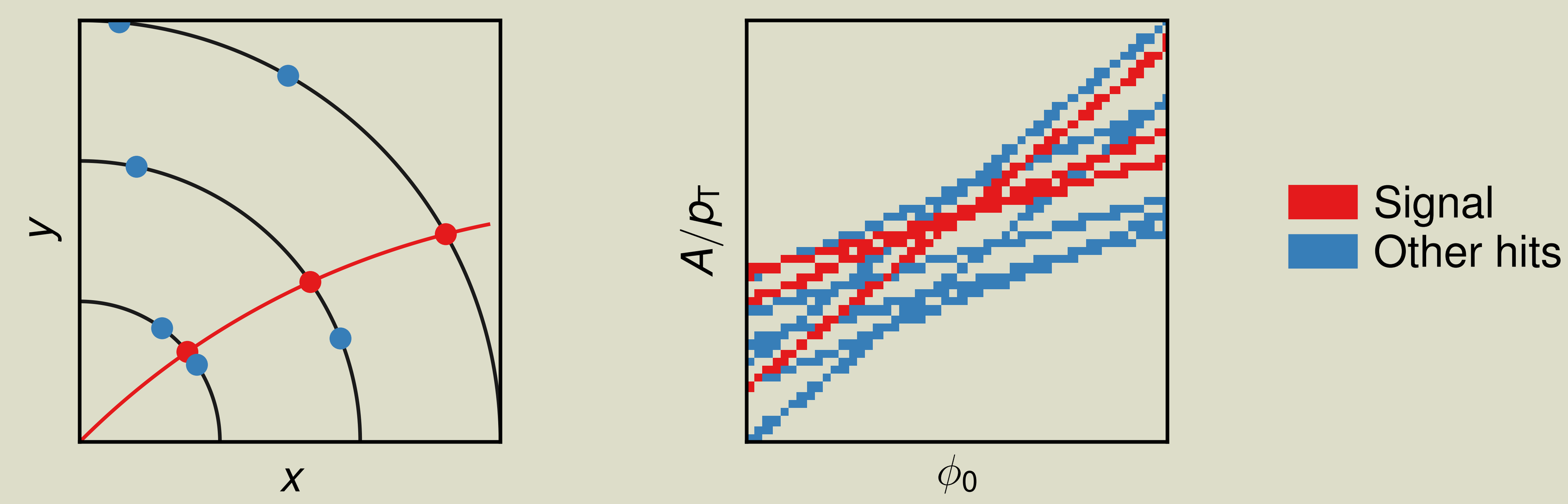


L1Track using the Hough transform

An alternative approach to pattern matching is to use the Hough transform for pattern recognition. The track of a charged particle in the transverse plane (xy-plane) of the ATLAS tracker is described by the transverse momentum p_T and its initial angular direction ϕ_0. For small angles and if a vertex constraint is imposed, each detector hit will make a line in the parameter space described by

$$\frac{A}{p_T} = \frac{\phi_0 - \varphi}{r},$$

where (r, φ) is the hit's polar coordinate and $A \approx 3 \times 10^{-4}$ GeV mm^{-1} is the curvature constant. The Hough transform uses this to map hits onto an "accumulator" of the parameter space. Hits belonging to the same track will have lines in the accumulator that intersect at the track parameter values.



In this work, a single step of the Hough transform is applied to a $\Delta\phi_0 = 0.2$ by $\Delta\eta = 0.2$ RoI. The implemented accumulator is similar to a 2D histogram, but each bin holds information about which layers have been hit and a list of all hits in that bin.

- The RoI is split into 12 parts in z to reduce the occupancy in the Hough accumulators due to the wide z-spread of the beam spot.
- An accumulator of A/p_T vs. ϕ_0 is filled for each split in z.
- A threshold is applied on the minimum number of layers hit.
- Hits from bins passing the threshold are grouped together using a simple geometric cut.
- Groups which are fully contained in other groups are removed.
- Surviving hit groups are passed on to the track fitting.

Comparison of Hough and AM

The performance of the Hough transform and the AM approach has been simulated using $p_T >$ 4 GeV muons with flat curvature parameters and minimum bias with pile-up 200 for the ATLAS Phase-II upgrade. Eight silicon strip layers (four doublet layers) have been used. The Hough transform is required to have at least six hits in unique layers.

	Efficiency		Number of fits	
Sample	Hough	AM	Hough	AM
Min. bias	-	-	344	170
Muon	98.3 %	99.2 %	2	11

Performance of the Hough transform and the AM approach for the central barrel region RoI of $0.1 < \eta < 0.3$. The efficiency of finding a muon track candidate is computed relative to the offline reconstruction. The number of fits is computed by taking all combinations of hits passing the recognition step.

Conclusion and outlook

The AM approach required fewer fits and has higher efficiency. However, the Hough transform approach can be implemented in the same FPGA as the track fitting and can include more layers to increase efficiency if needed, although this would increase the complexity of the track fitting.

Work is currently ongoing to implement the Hough transform in an FPGA to measure the execution time. The performance when including one or more pixel layers is also under investigation.

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