FIRST-LEVEL MUON TRACK TRIGGER FOR FUTURE HADRON COLLIDER EXPERIMENTS

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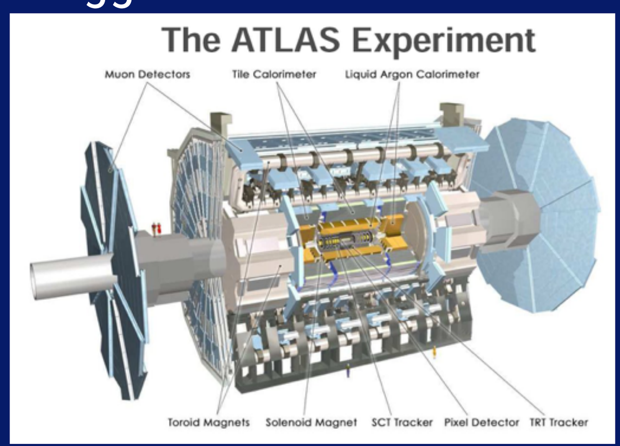
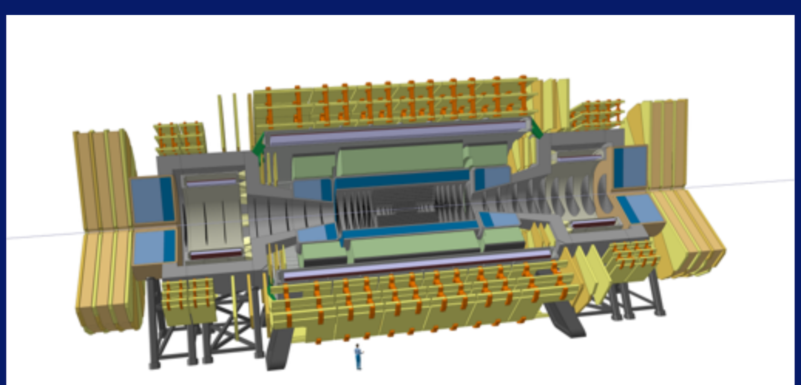
L0 Muon Trigger at future colliders

Highly selective **first level muon trigger** will still be crucial to undertake the demanding physics programme of future hadron collider experiments, like the **High Luminosity LHC** (HL-LHC) or the **Future Circular Hadron Collider** (FCC-hh). The high luinosities foreseen for these experiments place stringent limits on the L0 trigger rates. Therefore the future triggers must be able to discriminate much better high-pT from low-pT muons. This improvement in the muon pT resolution can be achieved in different ways. The **ATLAS** collaboration will upgrade its L0 muon trigger system for the HL-LHC, by including the more precise hit information coming from the **monitored drift-tube** (MDT) chambers.



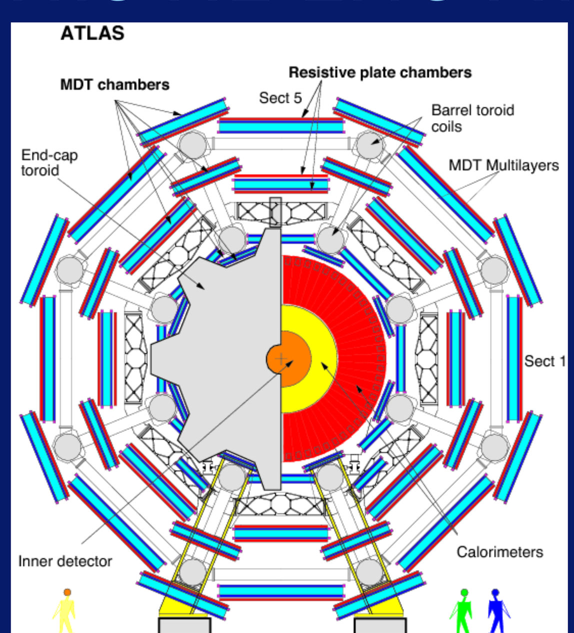
A similar approach is also undertaken by the baseline concept of a FCC-hh detector. A first level muon trigger composed by fast response gaseous detectors, RPCs, and more accurate drift-tube chambers could employ a similar approach as that for the upgraded ATLAS detector.



FCC-hh reference detector

In this poster we want to present a concept for a **lightweight L0 MDT trigger** based on the use of modern System-On-Chip technology. The presented system is designed for the future ATLAS L0 Muon trigger system, even though it could be easily applied to other hadron collider experiments.

The HL-LHC ATLAS Muon Trigger



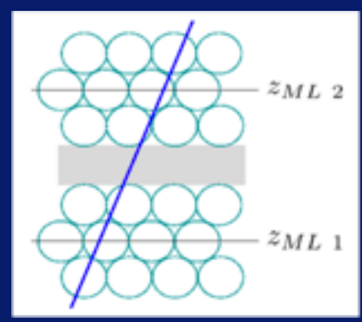
The upgraded L0 Muon Trigger of the ATLAS [0] detector will be divided into **two subsystems**. The first makes use of Resistive Plate Chambers (RPC) and Thin Gap Chambers (TGC), which have **excellent time resolution** (~ns), to identify possible high-pT muon candidates compatible with the considered *pp* **bunch crossing** (BX). Since these detectors have a moderate spatial resolution, they will limit to select a **region of interest** (RoI).

The second trigger system exploits data coming from the MDT chambers (L0 MDT Trigger). Because of the longer drift time of the MDT with respect to the RPCs and TGCs detectors, the RoI and BX will have already been identified before the generation of the MDT hit signals.

The **L0 MDT trigger** matches therefore the MDT hits with the current RoI and BX, and utilises the selected hit to perform the **pattern recognition**. The MDT trigger requirements ask for segment reconstructed with an angular resolution less than 1 mrad.

Histogram Pattern Recognition

The L0 MDT Trigger processes independly the hits from the three MDT chambers (inner, middle, outer), reconstructing **track segments** in each chamber. The segment finding is performed using a 1D Hough Transform.

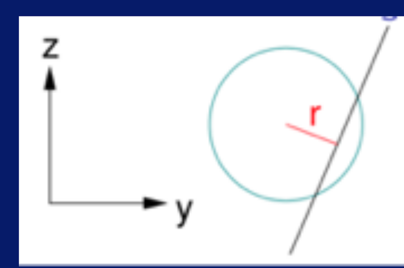


The trajectory of a high-pT muon in the *yz* plane can be approximate to a **straight line** within a single MDT chamber.

$$y = mz + b$$

Each tube in the MDT chamber will measure the **drift radius** *r*, which corresponds to the distance between the tube anode from the muon track.

$$r = \frac{|mz_t + b + y_t|}{\sqrt{1+m^2}}$$



The RPC/TGC trigger will provide an estimation of the **slope parameter**, therefore we can compute for each hit the two possible intercept values.

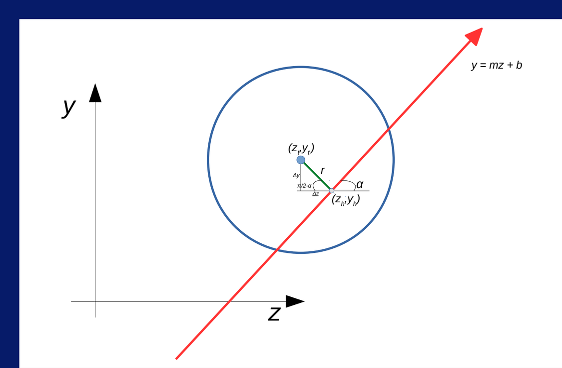
$$b_{\pm} = \pm\sqrt{1+\bar{m}^2}\cdot r - (\bar{m}z_t - y_t)$$

Each MDT chamber is composed of two **multilayers** (ML). For each ML we fill an **histogram** of *b±*, hits belonging to maxima in the histograms are selected and used for the segment fitting.

The Linear Regression Fitter

The segment fitting is performed using a **simple linear regression** technique. The first step is to calculate the exact hit coordinates in the yz plane, using some simple trigonometry.

$$y_h = y_t \pm \Delta y$$
$$z_h = z_t \mp \Delta z$$



Then we calculate the slope-intercept fit parameters.

$$\hat{b} = \frac{(\sum_h y_h)(\sum_h z_h^2) - (\sum_h z_h y_h)(\sum_h z_h)}{n_{\text{Hits}}(\sum_h z_h^2) - (\sum_h z_h)^2}, \qquad \hat{m} = \frac{n_{\text{Hits}}(\sum_h z_h y_h) - (\sum_h y_h)(\sum_h z_h)}{n_{\text{Hits}}(\sum_h z_h^2) - (\sum_h z_h)^2}$$

The algorithm reconstructs always a segment, when there are at least 2 hits per multilayer. The **average resolution** of the reconstructed segments is about 0.5 mrad, largely satisfying the trigger requirements.

Once the segments have been reconstructed in all three MDT chamber, it is possible to compute the **track sagitta** *s* and finally the muon transverse momentum

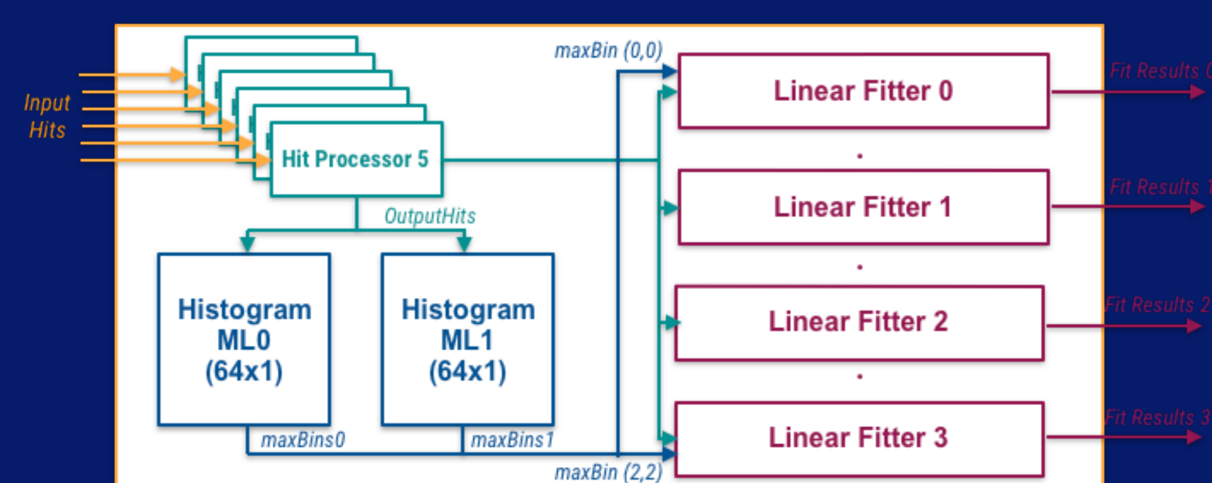
$$p_T = S(s) + P(\phi) + E(\eta)$$

where S, P and E are simple polynomial functions. [1]

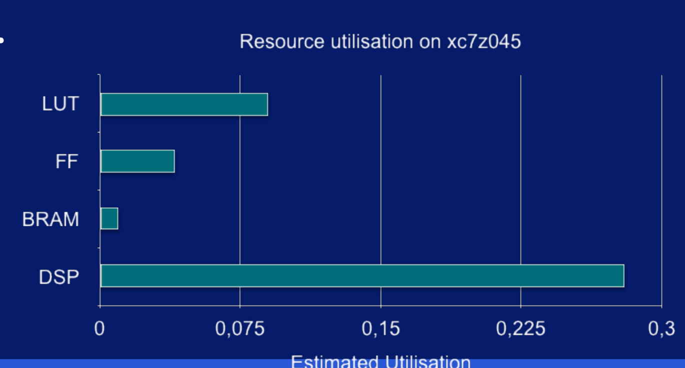
Firmware Implementation

The segment finder algorithm has been implemented in a **Zynq 7045 chip**, mounted on a Xilinx ZC706 evaluation board. The **segment finding** step is implemented on the **FPGA**, while the final **pT calculation** runs on the ARM processor. We aim to complete the whole process within less than 1 µs.

The hits matching with the RoI and the BX are first transmitted to separate **Hit Processor** modules (one per tube layer), which calculate fore each hit the *b±* values. Afterwards the hits are transmitted to the two **Histogram** blocks (one per ML), where two 64 bin histograms are filled. Once all hits have filled the histograms, maxima are identified and the corresponding hits are transmitted to the **Linear Fitter** modules. A limit of two maxima per ML histogram is imposed, in order to keep the resource usage low. Finally only the fit result with the lowest χ2 is kept and readout.



Latency ~245 ns @ 240 MHz



The implement algorithm is **fast and lightweight**. The resource utilisation on the FPGA for a single segment finder block is less than one third of the available resources. It is therefore possible to reconstruct muons in a trigger sector with a **single Zynq 7045 chip**. The algorithm runs at 240 MHz with a processing latency of only 245 ns, leaving more than enough time to transfer the data to the CPU and to perform the pT computation.

[0] ATLAS Coll., Techincal Design Report for the Phase-II Upgrade of the ATLAS Trigger and Data Acquisition System, CERN-LHCC-2017-020, 2018
[1] P. Gadow, Development of a Concept for the Muon Trigger of the ATLAS Detector at the HL-LHC, CERN-THESIS-2016-056

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