L1 Track Finding for a Time Multiplexed Trigger

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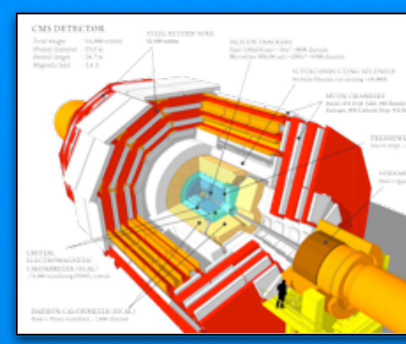
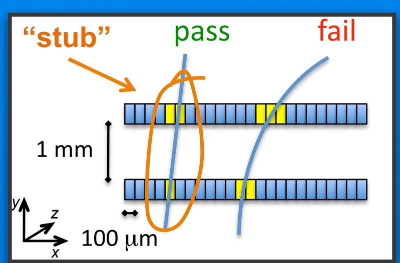
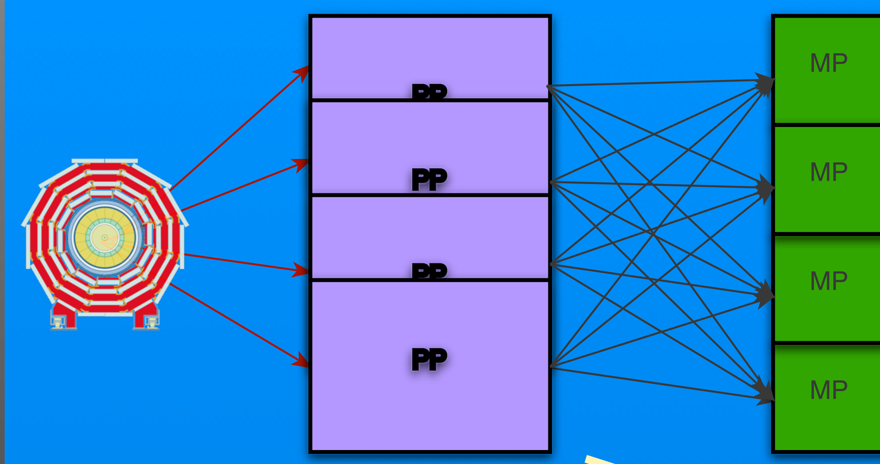
The CMS Phase II Upgrade

The **High Luminosity (HL-LHC)** upgrade to the Large Hadron Collider will allow an ultimate integrated luminosity of 3000 fb^{-1} to be collected in the decade following 2023. At the HL-LHC proton bunches will cross each other every 25 ns, producing up to an average of **200 collisions** per bunch crossing (BX). To work in such an environment the CMS experiment will be upgraded (CMS Phase II Upgrade). In particular, for the first time, data coming from the **Outer Tracker** will be used in the **L1 Trigger**. The new tracker will adopt double sensor modules. Making use of the correlation between hits in two sensors consistent with a high-p_T track (**stub**), it will be possible to reject tracks under a certain p_T threshold. The architecture that will be used to handle the tracker data is still under discussion. Our proposal is based on a **Time Multiplexed** approach.

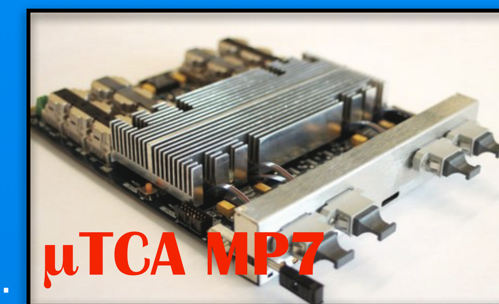




The Time Multiplexed Trigger



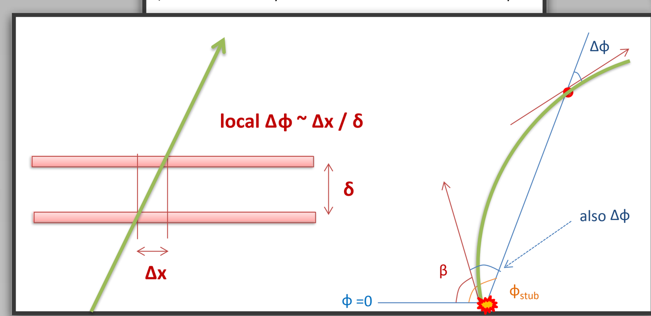
In a Time Mutliplexed Trigger (TMT) **all data** from one event flow to a **single node**. To achieve this **two processing layers** are required (Pre-processors & Main-Processors). The PPs take data directly from the Front-end modules and then buffer them into the MPs, where the Track Finding algorithm is implemented. Each MP receives data from the entire tracker. The MP7 board, which is used in the L1 calorimeter TMT, will be used to demonstrate our Track Finding concept works in hardware.



- FPGA Virtex 7
- 72 I/O Optical Links (12.5 Gbps)
- Tot. bandwitdth ~1 Tbps

DATA ORDERING

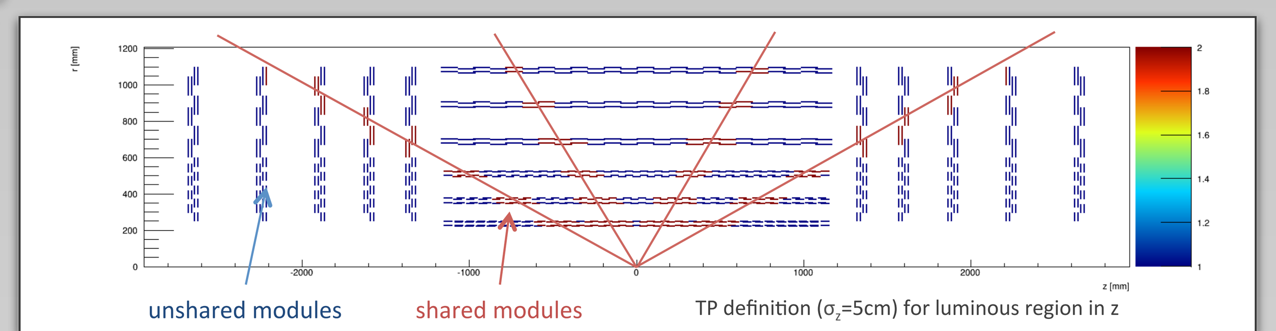
$$\beta = \phi_{\text{stub}} - \Delta\phi$$



For ease of processing, the tracker has been divided into **5 trigger regions** in pseudo-rapidity ($\Delta\eta$~1.0).

Data are then ordered according to the estimated **production angle β**.

In this way less data needs to be transmitted to the MP before a track can be found.



One trigger region

- ~ 40 unshared PPs
- ~ 15 shared PPs
- 24 MPs required (1/24 BX clock cycle)
- Subdivided into 64 β segments

TRACK FINDING

To build track candidates an approach based on the **Hough Transform** (HT) has been proposed. The HT sorts stubs into track candidates before the selection and the final fitting stages.

Stubs are collected into **β segments** and then binned into the track finder array based on a HT (m,c) using the r,ϕ projection.

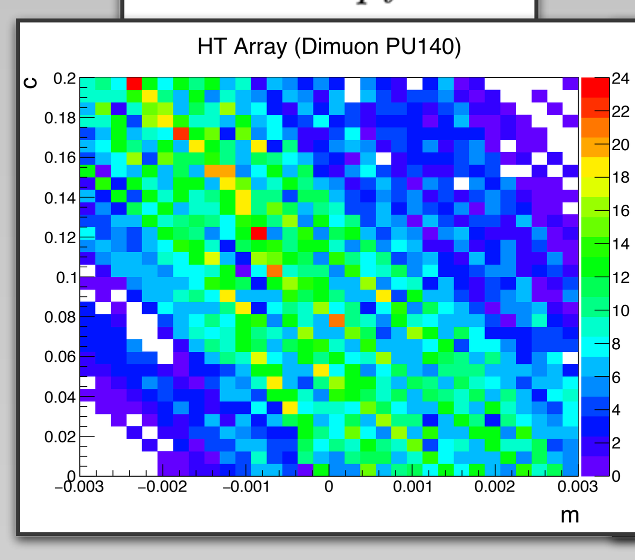
A track is found where there is a local peak in the 2-d histogram.

HT Basics

Straight lines considered in terms of slope-intercept parameter (m,c)

Point (x, y) —> Line (m,c)
Line (x, y) —> Point (m,c)

$$\phi(r) = \pm\frac{cB}{2p_t}r + \beta$$

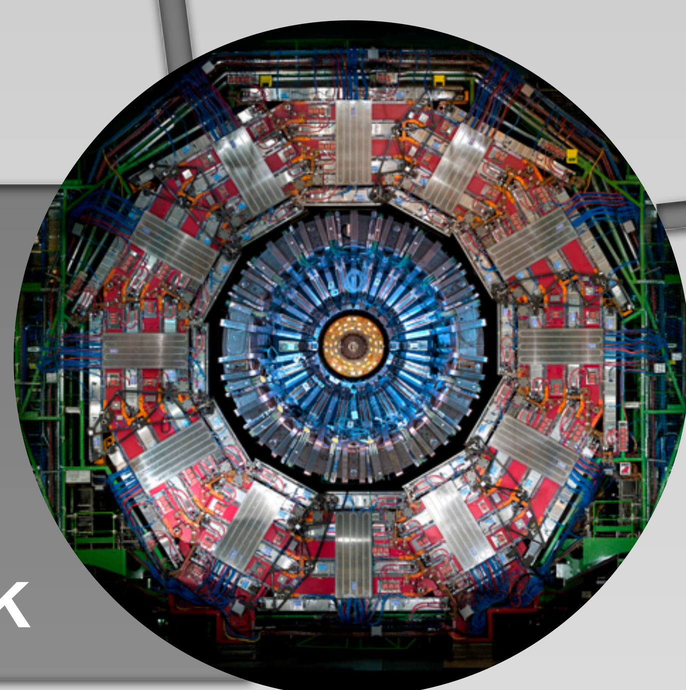


HT Parameters

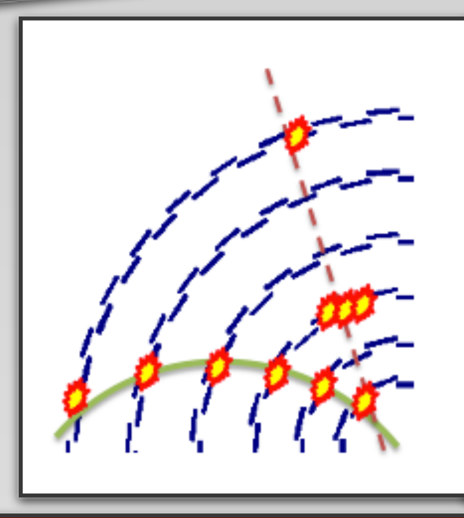
Stub Parameter from detector
Φ, r (better resolution)

Track Parameters in HT
m=0.006/pT ; c= β
Valid for p_T > 3 GeV/c

Single β segment Array Content
~ 120 stubs
90% occupied cells (av. 3 stubs/cell)



TRACK FILTERING

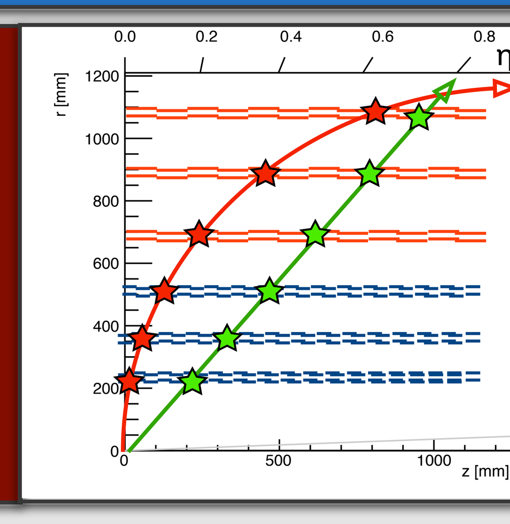


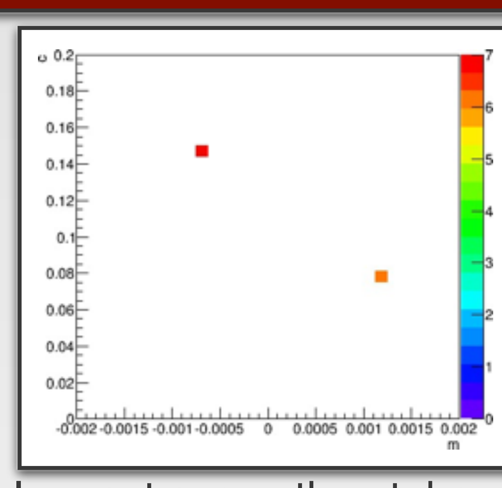
R Filter

- High p_T tracks should leave hits in all tracker layers
- Only cells with 5+ stubs belonging to 5+ tracker layers/ disks are marked for readout
- In the endcap/barrel transition region the cut is lower to 4

Eta Filter

- Tracks should have a physical r-z trajectory
- Stubs in a cell are binned in η
- Find the most populated η bin
- Remove from the cell stubs with $\Delta\eta > \sigma_{\eta,\text{stubs}}$
- R Filter applied again



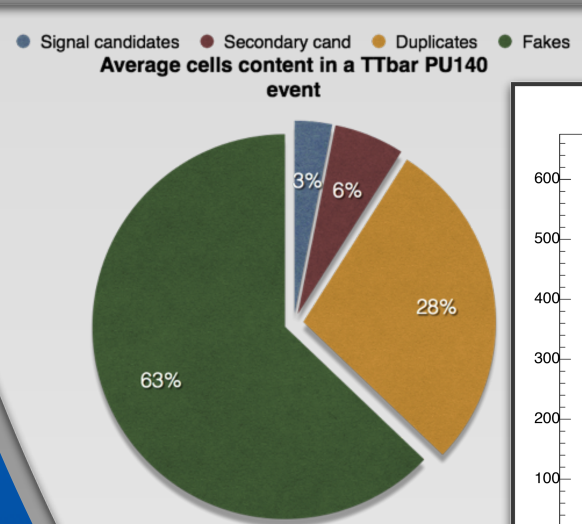


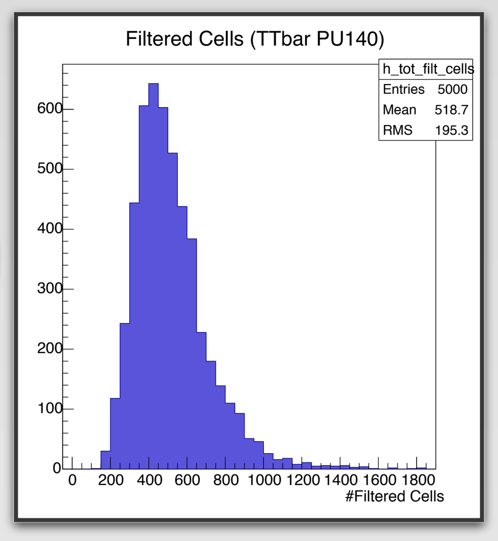
Array Readout

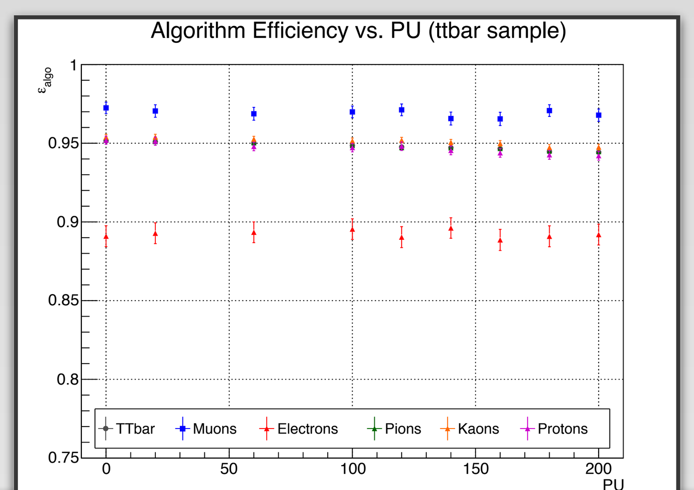
After filtering ~1.5 cells per β segment are marked for readout in a PU140 event

In most cases the stubs present in a HT cell are not consistent with real tracks. Indeed they are usually due to **random combinations** of hits belonging to pile-up tracks. In order to remove those fakes, **filter stages** can be applied to each cell in the array.

ALGORITHM PERFORMANCE

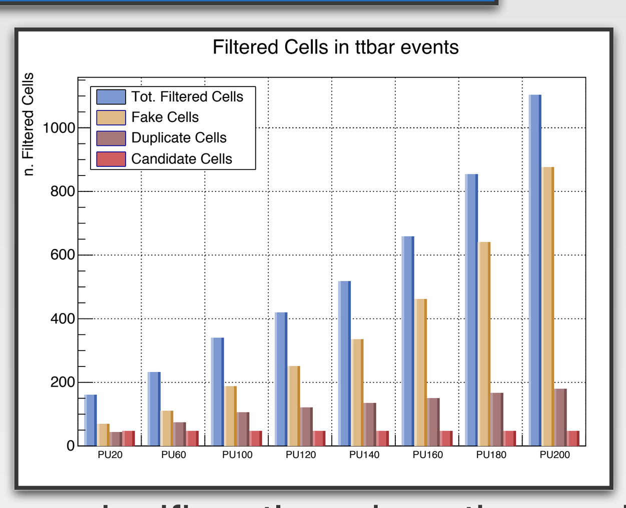






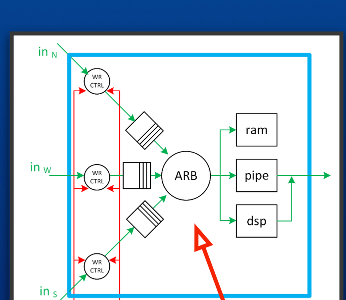
$$\varepsilon_{\text{algo}} = \frac{\text{charged signal tracks found by HT}}{\text{generated charged signal tracks passing filtering}}$$

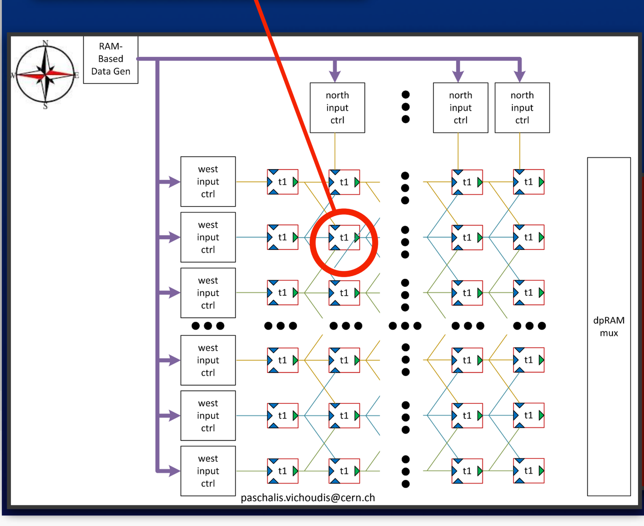
Results show a generally good **algorithm efficiency (>95%)**, except for electons. This loss is mainly due to the Bremsstrahlung effect, which changes the electron's trajectory the that which is expected.



The track filtering stages significantly reduce the number of candidate cells, even if the **majority** of tracks found by the algorithm are due to **random combination of stubs**. We are currently working to further improve the filter steps to reduce the total number of candidate cells.The remaining ones will be then removed in a later **fitting step**.

Firmware implementation





Array concept

- Eastbound traffic
- Two entry points (W-N)
- Cells readout when stub entries with 5+ different r values

The algorithm has been implemented in a **systolic array**, operating at 250 MHz.

A standalone 20x20 array is currently being implemented within the MP7, for online data processing.

Authors & References

The UK CMS Track Trigger Collaboration

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D. Cieri, K. Harder, C. Shepherd, I. Tomalin (RAL)
G. Iles, G. Hall, T. James, M. Pesaresi, A. Rose, A. Tapper, K. Uchida (Imperial College)

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