TRIGGER PRIMITIVE GENERATION ALGORITHM IN THE CMS BARREL MUON CHAMBERS DURING HL-LHC

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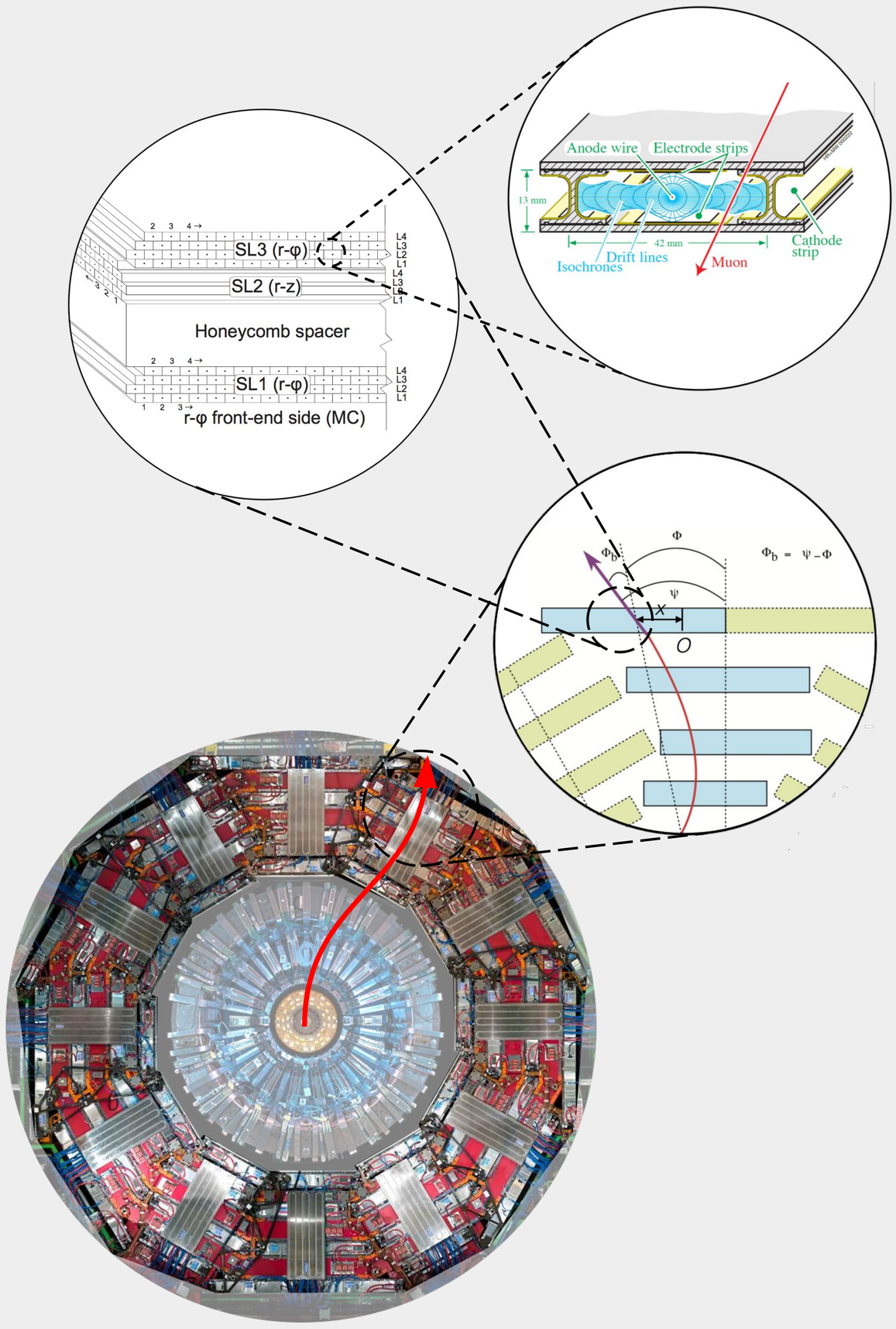
The CMS Drift Tubes Trigger System at HL-LHC

The CMS experiment presents a two-level trigger system: the Level-1 Trigger (L1), implemented in custom-designed electronics and the High Level Trigger (HLT), a simplified version of the CMS offline reconstruction software [1].

The basic element of the CMS Drift Tube (DT) detector is the drift cell, where hits are reconstructed with a left-right ambiguity in their position. Four staggered layers of parallel cells form a superlayer (SL), which provides the measurement of two-dimensional segments. A chamber is composed by two superlayers measuring the r-Φ coordinates and an orthogonal superlayer measuring the r-z coordinates [2].

The High-Luminosity Phase of the LHC (HL-LHC, or phase-2), starting in 2027, will reach an instantaneous luminosity of $7.5 \times 10^{34} cm^{-2} s^{-1}$ [3]. To cope with the new environment, the DT electronics will be replaced and trigger primitives generation will be performed using FPGAs [3].



The Analytical Method for DT Trigger Primitive Generation at HL-LHC

The Analytical Method (AM) is an algorithm designed to perform DT trigger primitive generation at HL-LHC, reconstructing the muon collision time (t_0), bunch crossing (BX), local position (x), and direction (tan(ψ)).

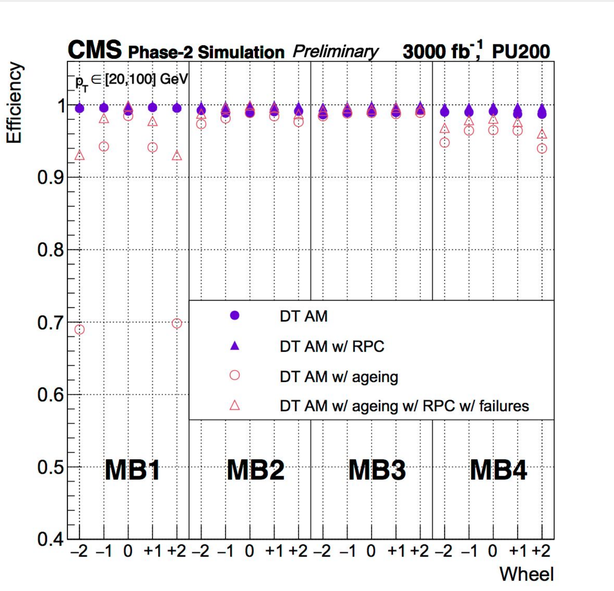
The inputs of the AM are the wire numbers and hit times with respect to the start of the LHC orbit, while assumptions have to be made on the hits lateralities (whether the signal was produced left or right of the wire). The algorithm can be separated in four steps [3]:

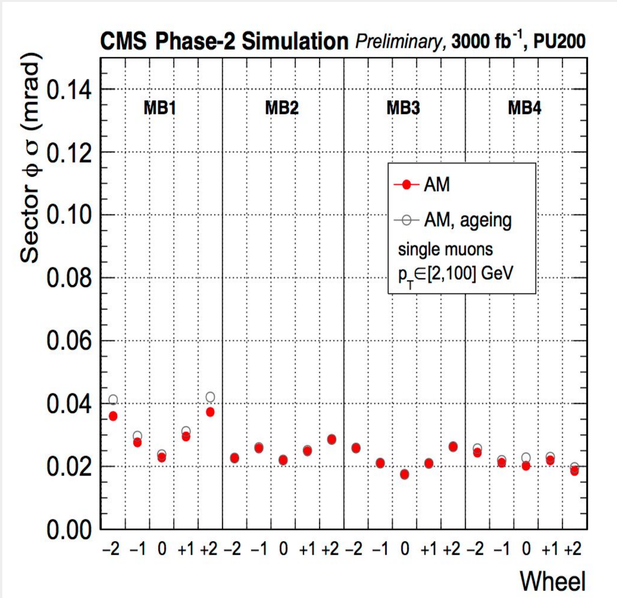
- **Grouping:** in each superlayer, selects signals in patterns of 4 cells compatible with a straight line and their sub-patterns of 3 cells. Each pattern is then assigned a set of lateralities to be considered as candidates in the fitting step.
- **Fitting:** uses analytical expressions to obtain t_0 and then the muon track parameters (x and tan(ψ)) from a χ^2 minimization fit.
- **Correlation:** patterns with 3 or 4 hits in both SL1 and SL3 can be correlated if the corresponding segment times agree within a window of ±25 ns. The track parameters are then redefined, taking into account the original positions and collision times in SL1 and SL3.
- **Cleaning:** if candidates share hits, the ones with higher quality are kept, to reduce the number of primitives returned and keep the best ones.

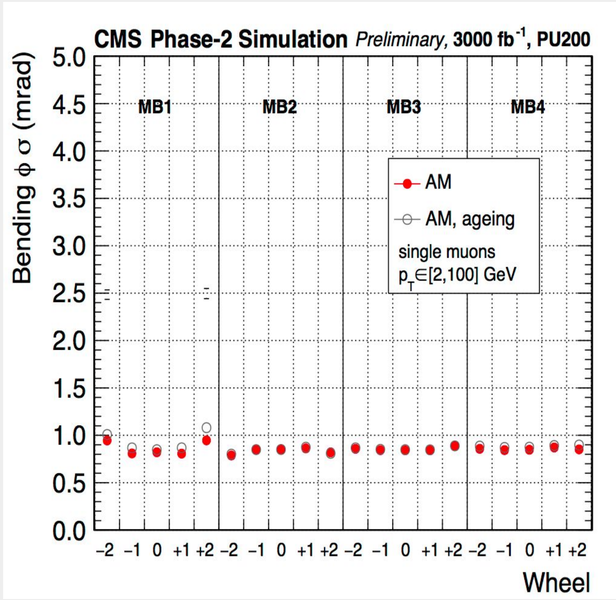
RPC information can be used to estimate t_0.

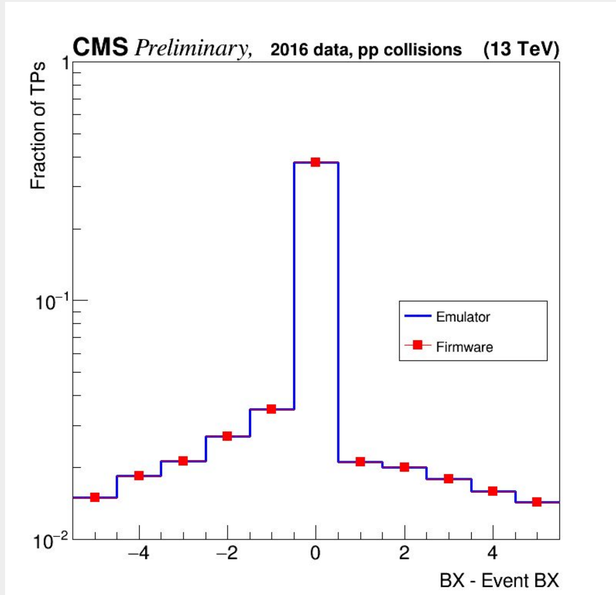
Algorithm Performance and Validation

The AM efficiency and resolutions have been evaluated using samples simulating the LHC phase-2 conditions. In both cases, the offline reconstruction is used as reference and scenarios with and without detector ageing are studied. Efficiencies are found to be very close to 1, with RPC helping in recovering performance when ageing is switched on. Resolutions on position (translated to Φ global coordinate) and slope are of the order of less than 0.05 mrad and 1 mrad respectively, significantly improving phase-1 results [3]. The algorithm has been implemented both on firmware, to run on test FPGAs, and on software, with almost perfect agreement between the two approaches [3].







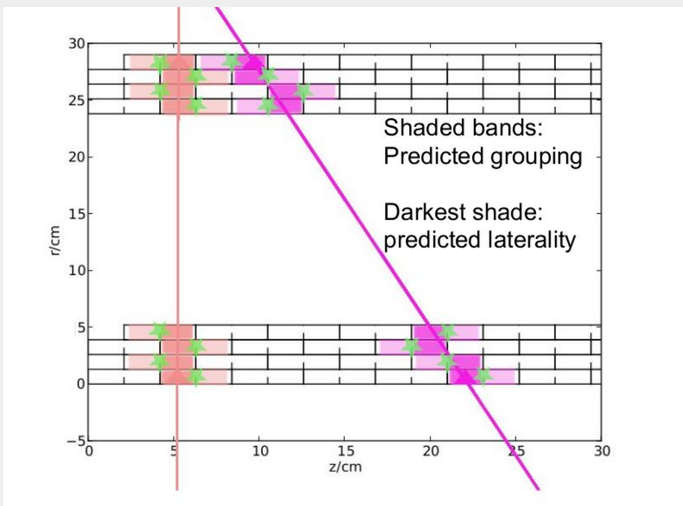


Merging of Grouping and Correlation Steps

One alternative approach to the grouping step is being studied, to consider hits from both SL1 and SL3 using a set of pre-computed patterns (straight lines) representing the possible trajectories of muons crossing the DT chambers and including information on the predicted laterality of every hit. Some possible advantages are:

- higher resilience in extreme ageing scenarios
- reduced noise due to multiple candidates
- possibly fewer combinations of hits to test thanks to longer lever arm

Patterns are then passed to the fitting step, that extracts the parameters from a single χ^2 minimization involving up to 8 hits.



References

[1] CMS Collaboration, "The CMS experiment at the CERN LHC", JINST 3 (2008) S08004

[2] CMS Collaboration, "The CMS muon project: Technical Design Report", Technical Design Report CMS. CERN (1997)

[3] CMS Collaboration, "The Phase-2 Upgrade of the CMS Level-1 Trigger Technical Design Report", CERN-LHCC-2020-001

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