Level-1 Muon Trigger of the CMS experiment

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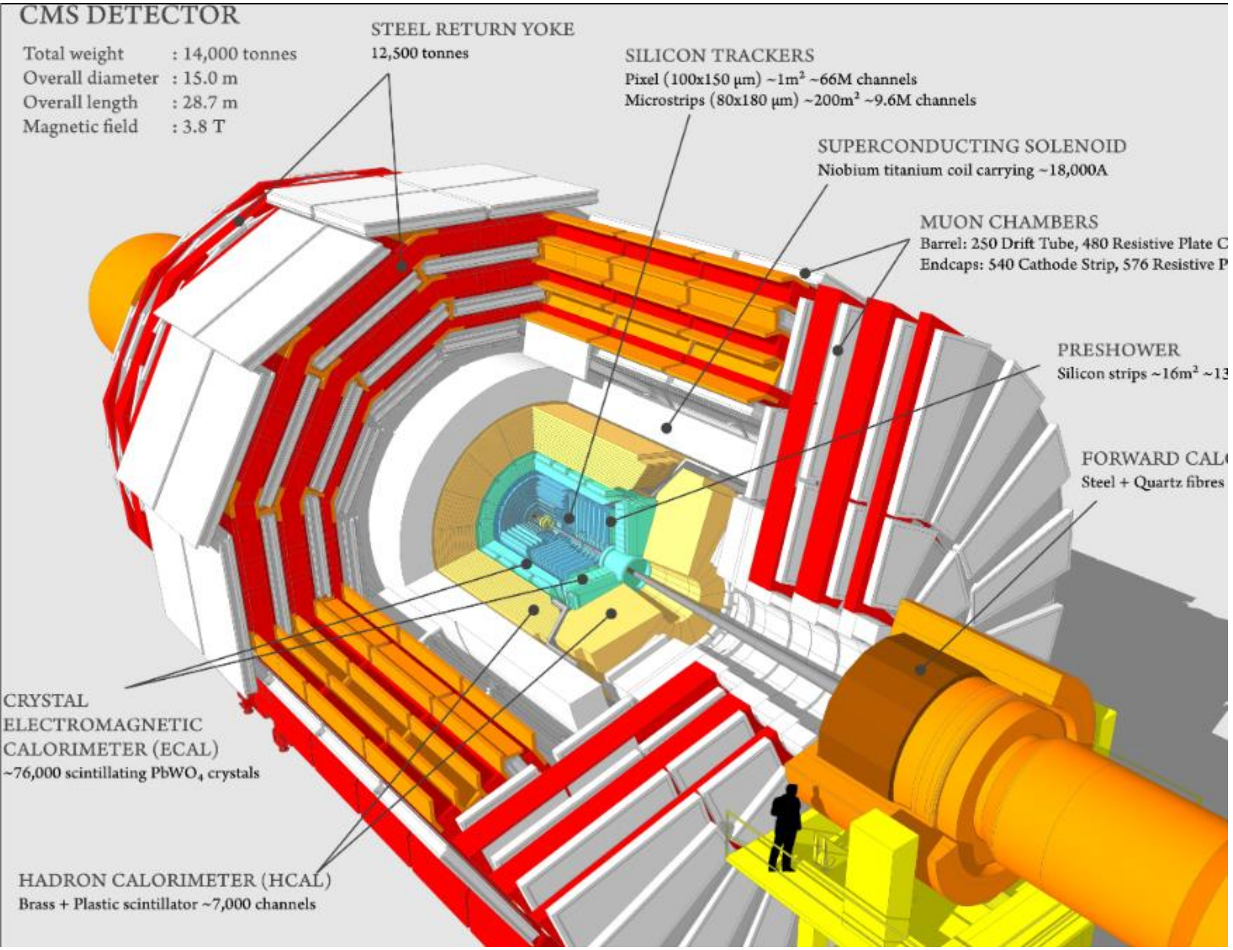
CMS experiment

p_T resolution:

- Tracker : -~1-3% for 10 GeV
- ECAL: - ~1.5% for 1.5 GeV
- HCAL: - ~40%, ~12% and ~5% for 10GeV, 100GeV and 1 TeV



Main CMS goals:

- Precise tests of standard model (very good muon system and high resolution sub-detectors).
- Electroweak symmetry breaking mechanism (led to Higgs discovery).
- Search for new physics.

Elements of the detector:

1. Tracker- silicon pixels and strips.
2. ECAL – homogenous ($PbWO_4$- lead tungstate).
3. HCAL- sampling brass/scintilator.
4. Solenoid magnet - made of superconducting material, generates a magnetic field with a strength of 3.8 T.
5. Muon system - four different types of gaseous chambers interlaced in magnet return yoke.

https://cms.cern/detector

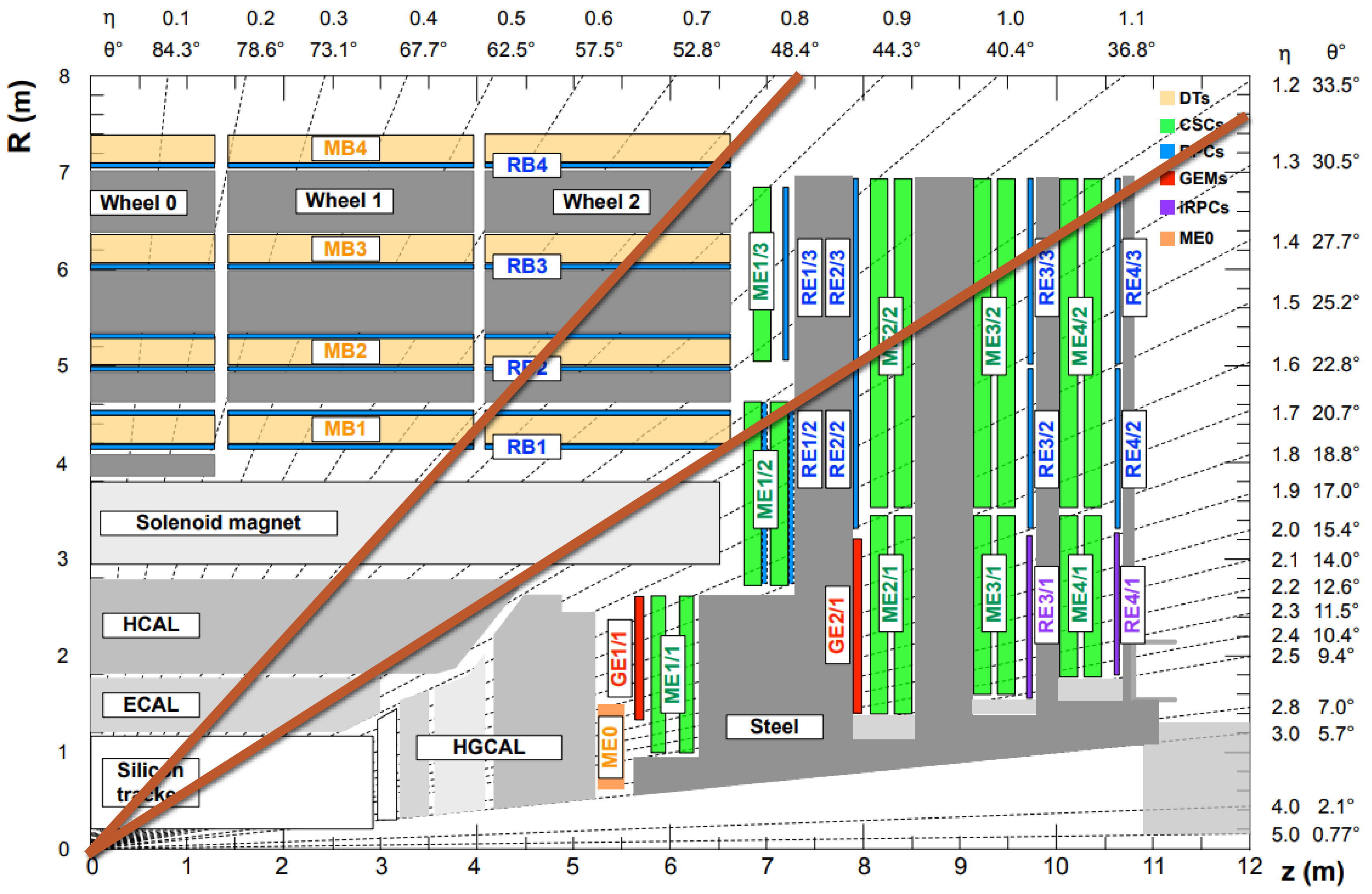
Muon system regions

Pseudorapidity:

$$\eta = -\ln[\tan\left(\frac{\theta}{2}\right)]$$

Barrel Muon Track Finder (0<| η |<0.83)

Overlap MTF (0.83<| η |<1.24)



Endcap MTF (1.24<| η |<2.4)

OMTF:

-complicated geometry

-complicated magnetic field

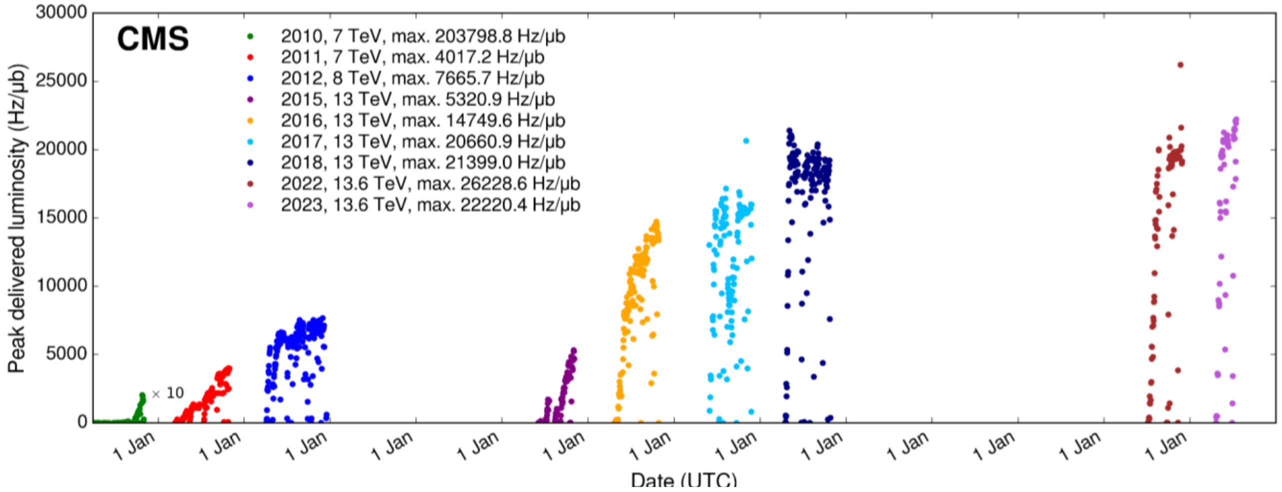
In Run 3 (2022) new gaseous chambers were added (GEM) but in this presentation they will not be discussed (they aren't used in the trigger system).

CMS-TDR-021

Luminosity

It determines the ability to produce the expected number of interactions. It is expressed by the formula:

$$L\sigma = \frac{dN}{dt}$$



~2400 bunches/beam-> ~$1.6 \cdot 10^{11}$ protons per bunch-> collision every 25 ns (40 MHz frequency)-> Luminosity $\sim 2 \cdot 10^{34} \frac{1}{cm^2 s}$.

A lot of data to process!

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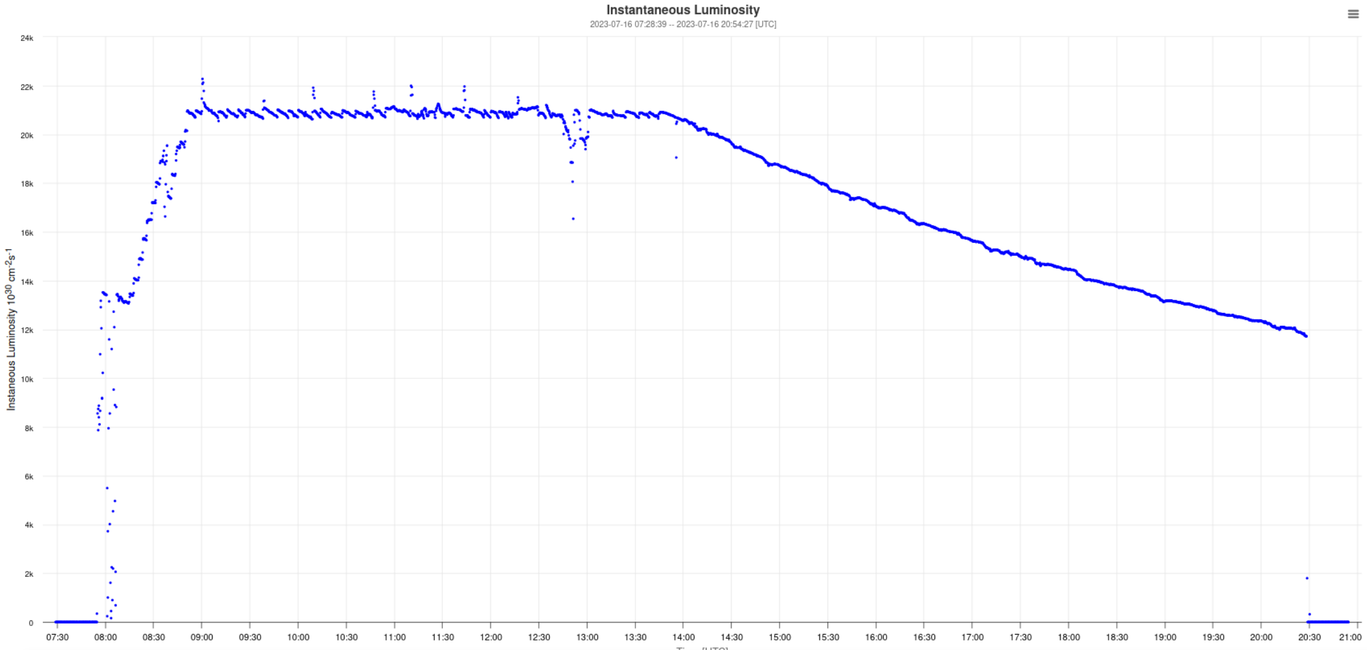
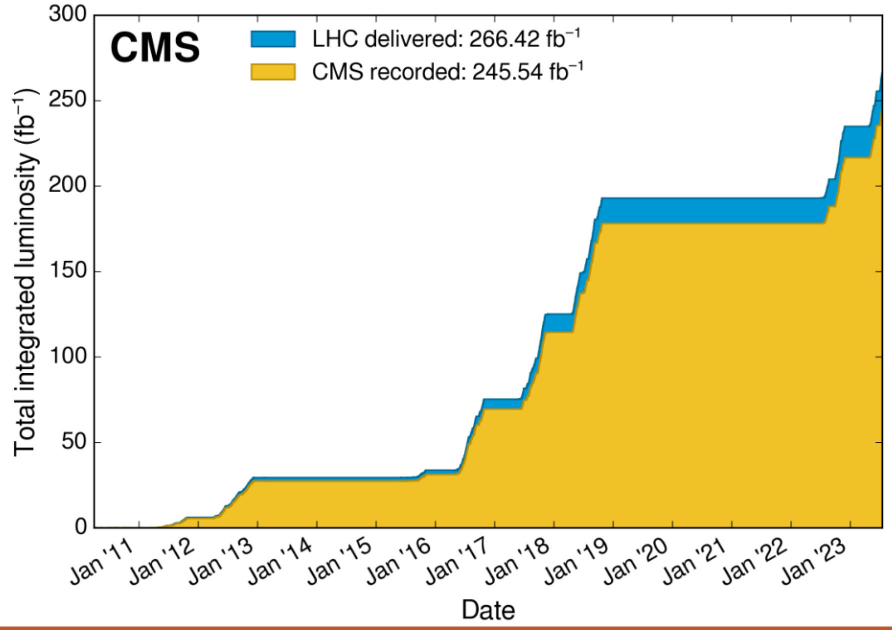
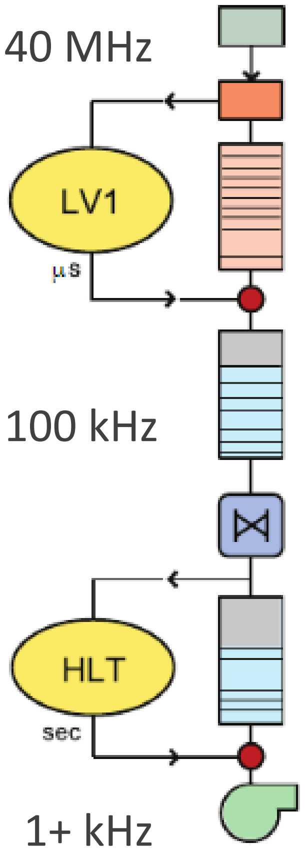




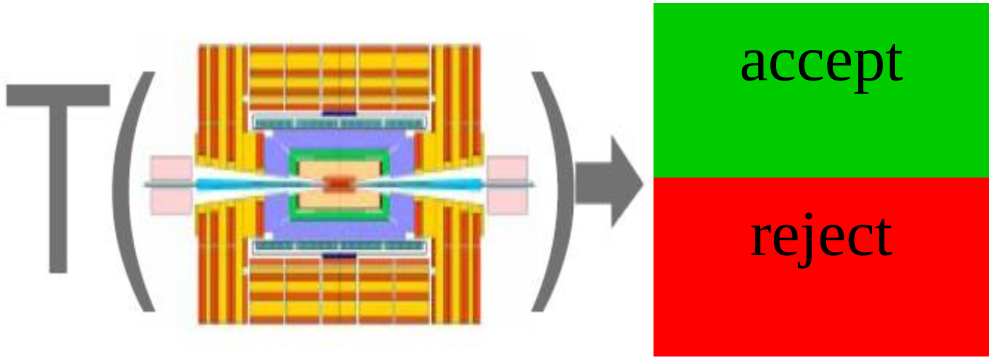
CMS trigger system



CMS PAPER CFT-09-020

Two levels of triggering:

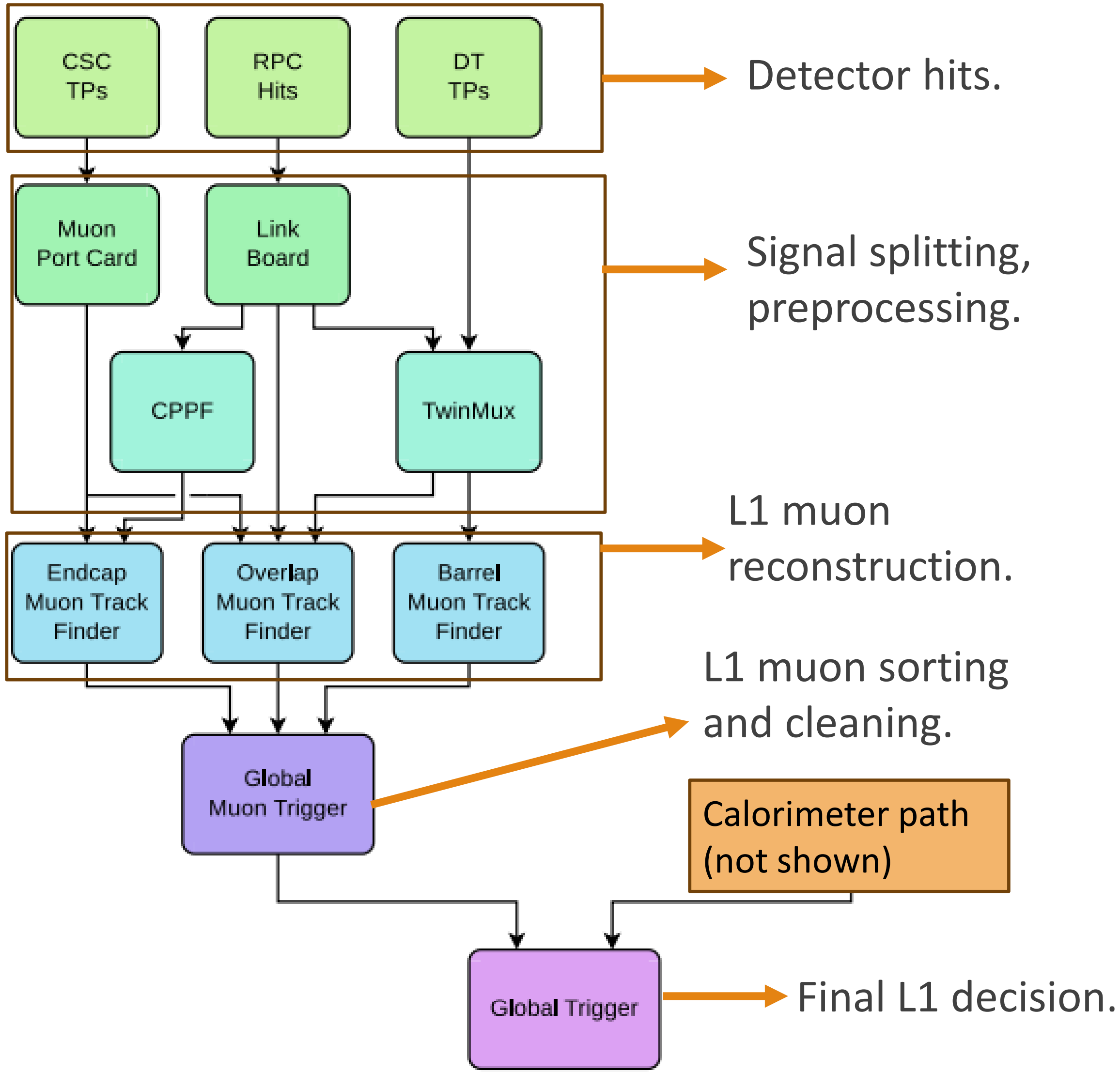
1. Level 1 Trigger:
   - Initial selection of events in dedicated trigger boards (hardware).
   - Has access to data only from muon system and calorimeters (not from the tracker).
   - Coarse reconstruction.
2. High Level Trigger:
   - Computer farm made of CPUs and GPUs (software).
   - Almost fully reconstructed events.
   - Has access to data from tracker.



Parking stream:
-reconstruction and analysis postponed (e.g. for long shutdown or when time is available)

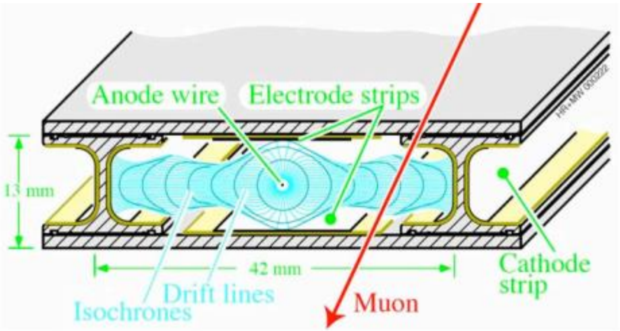
Scouting:
-more events but not reconstruted offline (only HLT information is saved)

Level 1 trigger



- It consists of two parts – muon (left) and calorimetric (right).
- Response of the muon trigger is based on hits from muon chambers:

1. Drift Tubes



Used in barrel region

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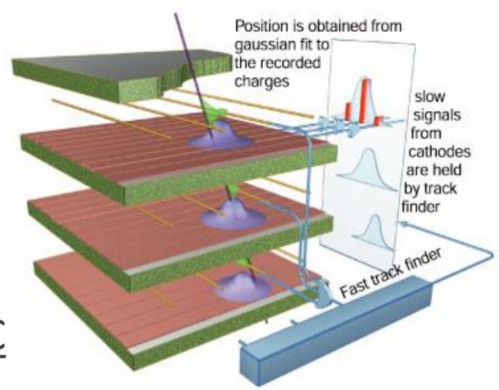
2. Cathode Strip Chambers

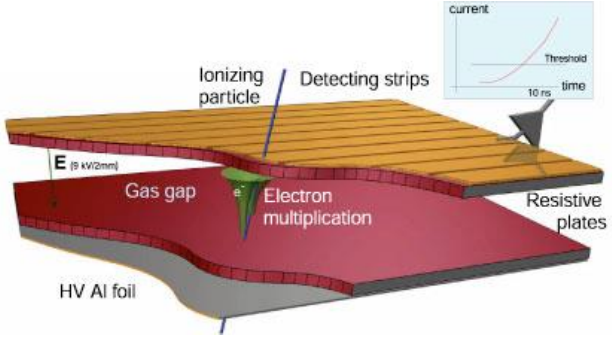


Used in endcap region.

CSC

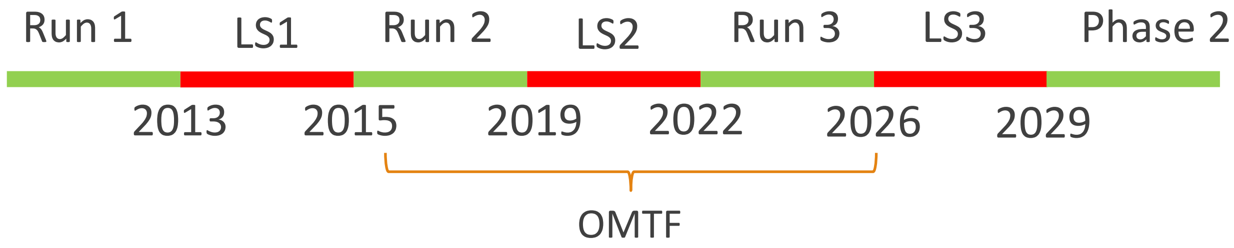
3. Resistive Plate Chambers

Designed for L1T.



RPC

OMTF



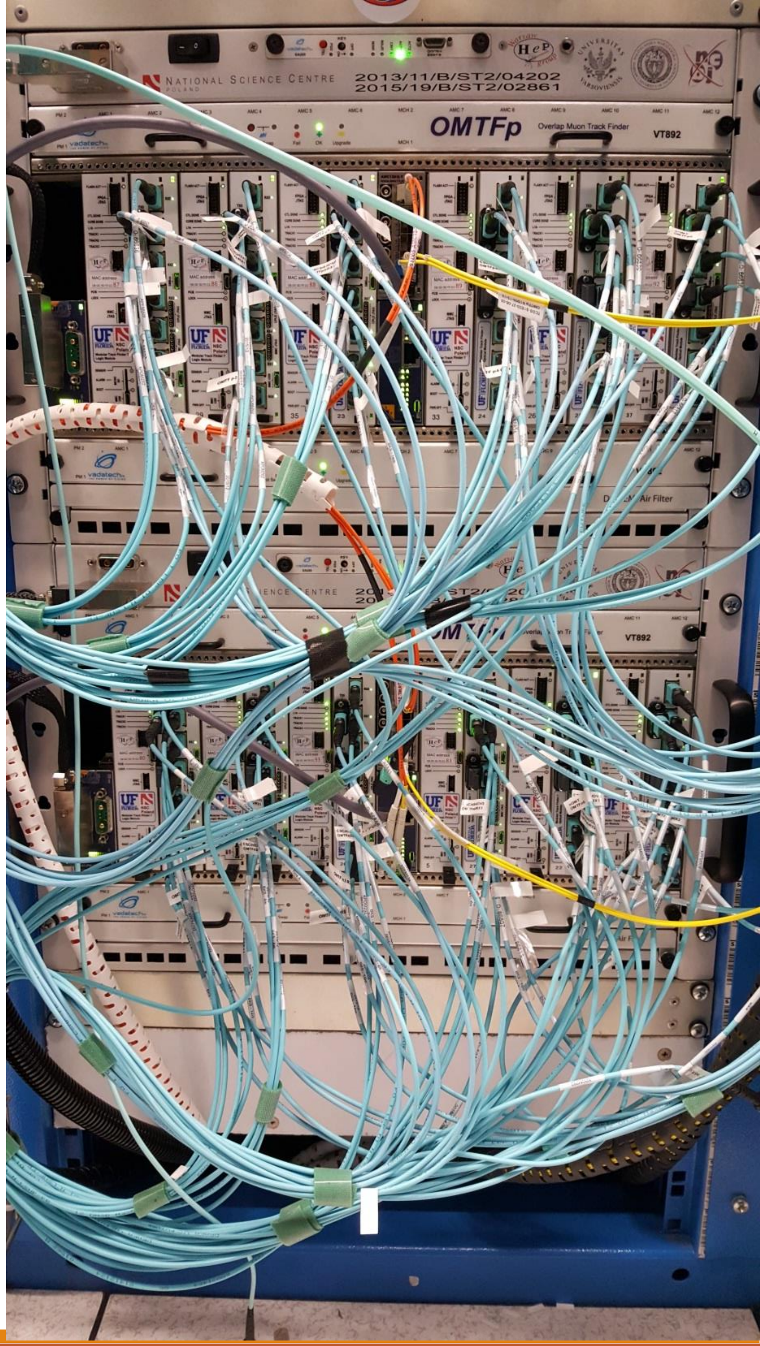
LHC timeline
LS = long shutdown

Warsaw group (UW, NCBJ, WUT):

- ✓ L1 muon RPC based sub trigger that was used during Run 1 and 2015.
- ✓ Current (Run 2 and Run 3) upgraded muon trigger in the Overlap region (OMTF).
- ✓ Contribution to phase 2 upgrade

Two crates OMTFn, OMTFp, each:

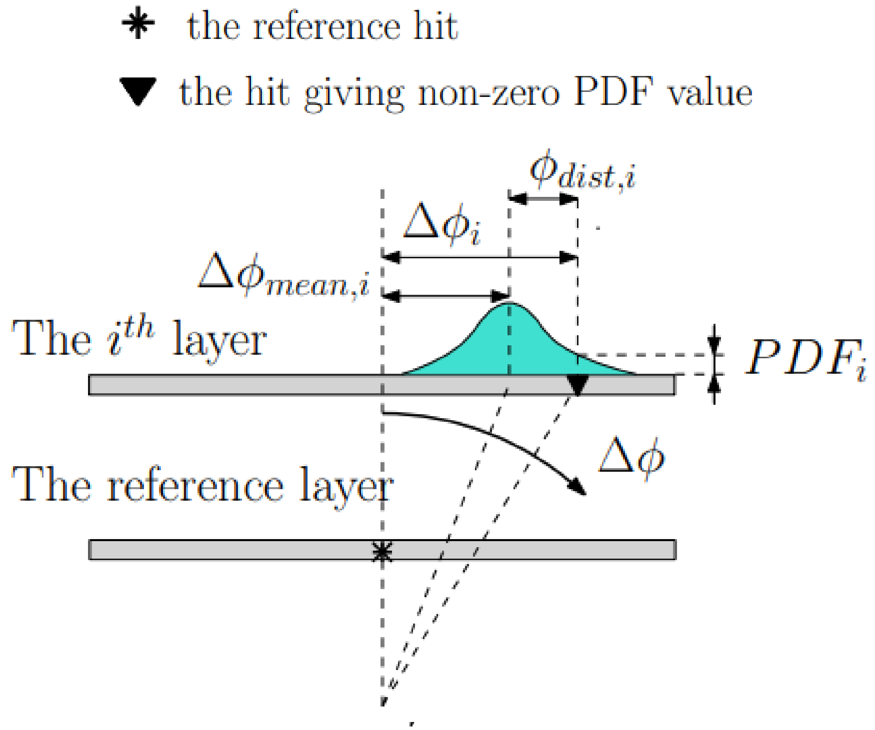
- Power module.
- MCH (µTCA Carrier Hubs).
- 6 MTF7 (Muon Track Finder based on virtex7 chip) boards (serving 60 deg each).
- AMC 13 (Advanced Mezzanine Card) - for data acquisition (DAQ) and clock distribution.



OMTF Golden Pattern algorithm

How to find transverse momentum of a muon crossing the detector in a region with complex geometry and magnetic field?

The algorithm compares the bending angle, with respect to given reference hit, between given layer and reference layer to a set of pre-computed patterns to identify the momentum of the particle.



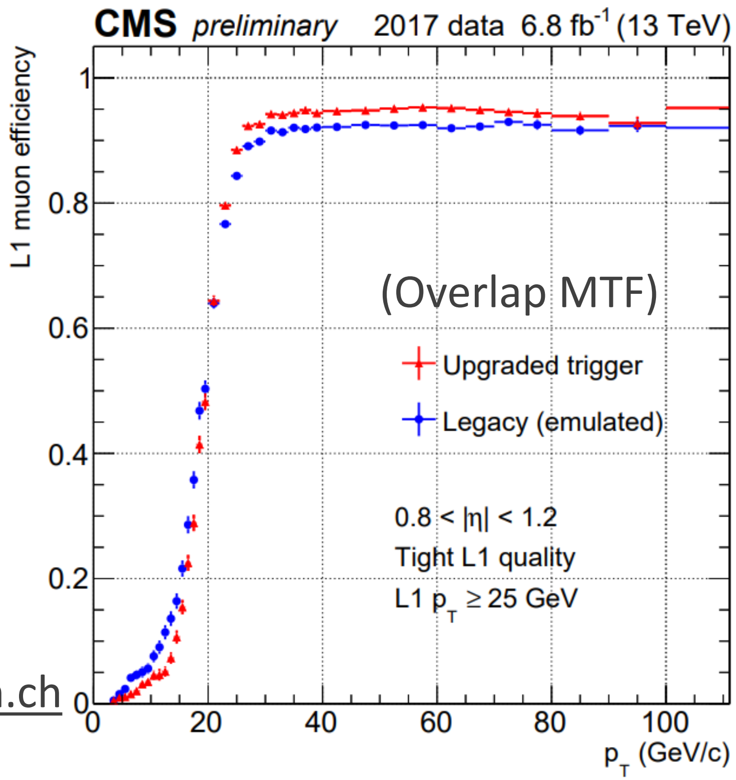
Calculation of the contribution from the i^{th} layer

Golden Pattern Algorithm

1. Detector ->18 logical layers with chambers of a certain type.
2. Reference hit (starting point of muon track matching)-> hit in 1 of 8 reference layers (low noise, good res.).
3. Algorithm works simultaneously for 4 reference hits and selects the one with best quality (priority for DT hits).
4. Around 50 „Golden Patterns” based on physical simulations for different transverse momenta ranges were generated to compare with real hit patterns.
5. The „Golden Pattern” handles information about average muon track propagation and hit spread.

Trigger performance- before and after upgrade

1. Legacy= Run 1+2015 (Detector based triggers)
2. Upgraded= Phase 1 upgrade (run 2 & 3)



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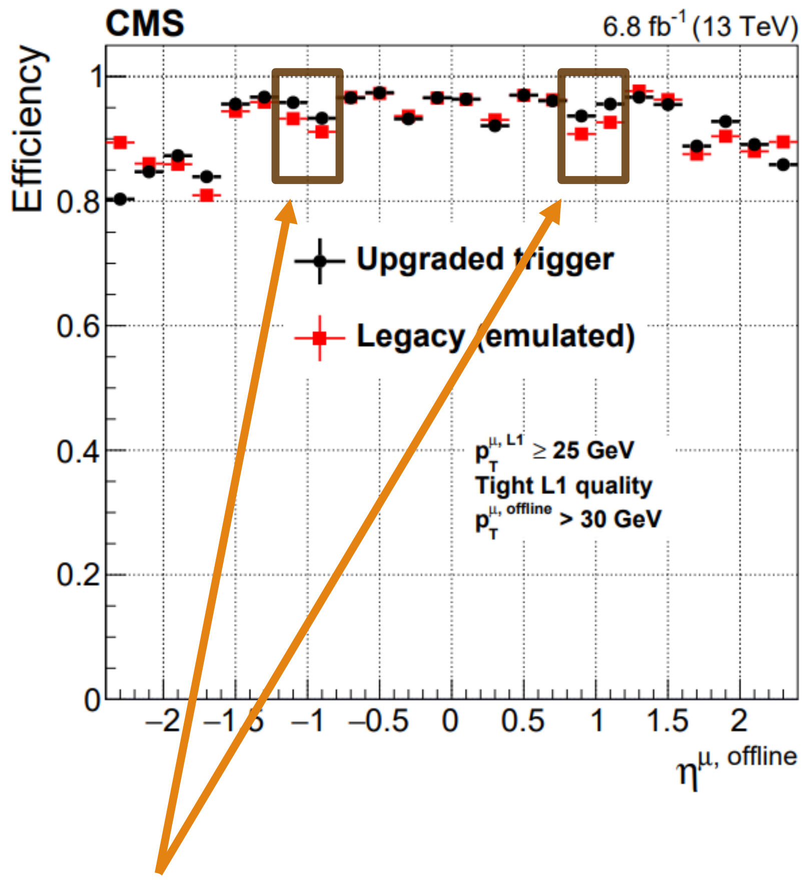

Overlap MTF

Tag and probe method is based on decays of known resonances (*Z*, J/ψ):

- Tag muon: well identified muon that gave L1 trigger.
- Probe muon: candidate that was found in the region of the detector, in which we want to calculate the efficiency for (away from the tag).

✓ **OMTF trigger is working very well.**

Prefiring- my current work

LHC works on 40 MHz clock and the unit of time is called *bunch crossing* (referred to as bx).

MY STUDY

Prefiring in OMTF region is at a minor level ($10^{-3} - 10^{-2}$). I studied an alogrithm (using veto) that could further reduce it by a factor of up to 10.

THE ISSUE

An object from a collision is identified as a one from the previous collision (e.g. a muon from bx0 is found at bx-1)-> can lead to data loss.

Trigger rule:

No more than one L1 accept in 3 consecutive bunch crossings, thus prefiring masks correct bunch crossing data.

Observation: prefiring because of hit patterns from certain gaseous chambers-> unwanted triggers-> masking based on hit pattern in 2 consecutive bunch crossings.

Transverse Momentum	Objects only at bx-1	Objects at bx-1 and bx0
$p_T \geq 22$ GeV	~8%	~92%
10 GeV $\leq p_T < 22$ GeV	~0%	~100%
$p_T < 10$ GeV	~16%	~84%

Thank you for your attention!