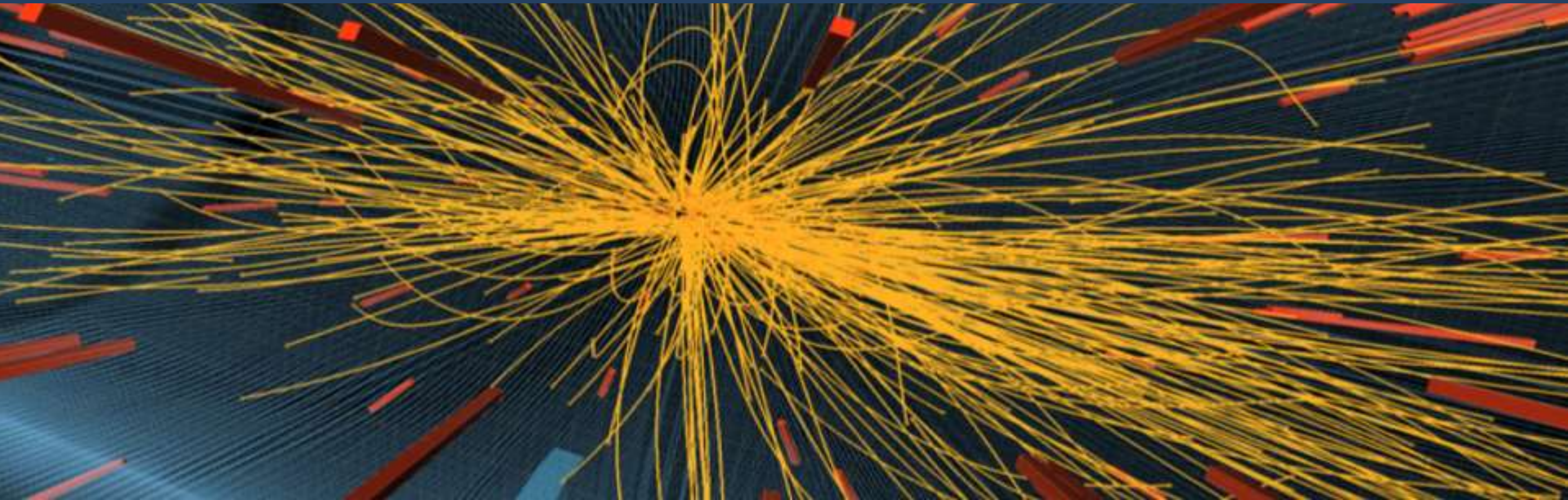
Upgrade plans of the CMS Muon System

Kerstin Hoepfner, RWTH Aachen, III. Phys. Inst. A

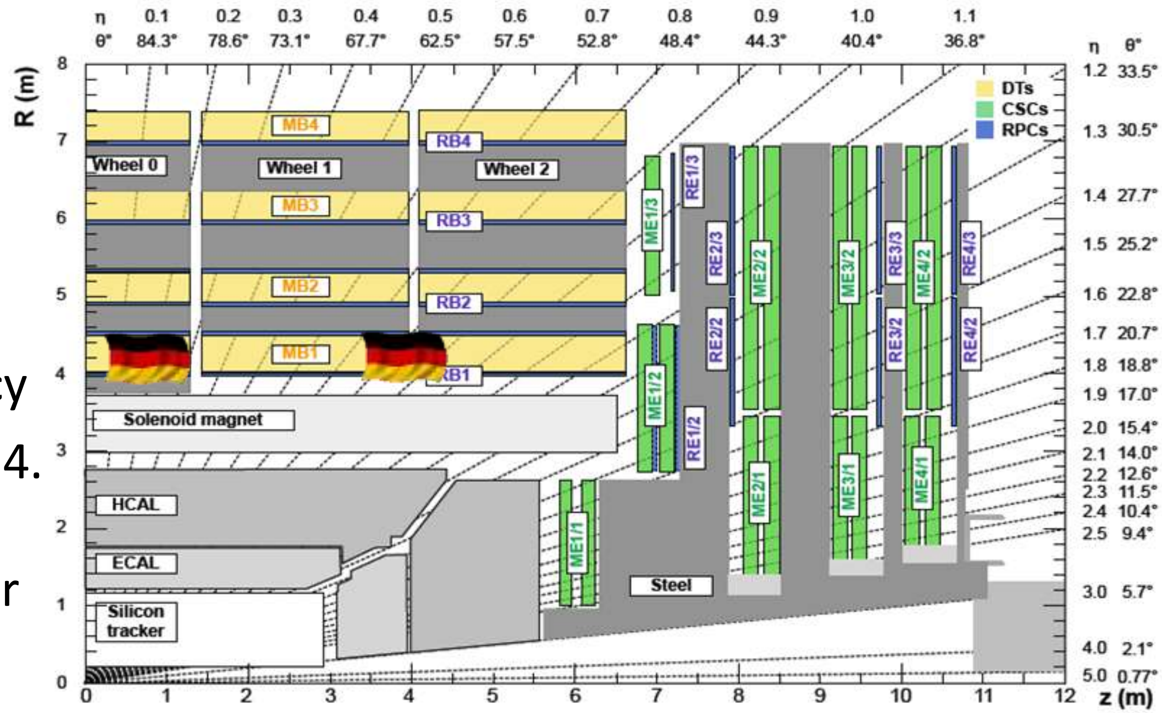
Terascale Detector Workshop, 4 April 2016



Upgrading the CMS Muon System

Highly hermetic and redundant muon system

- Drift tubes (DT) to η~1.2
- CSC Endcaps $1.0<|\eta|<2.4$
- RPCs for adequate redundancy
- Trigger coverage up to $|\eta|=2.4$. Typical threshold of p_T~20-25 GeV for inclusive muon trigger



Excellent performance with present conditions

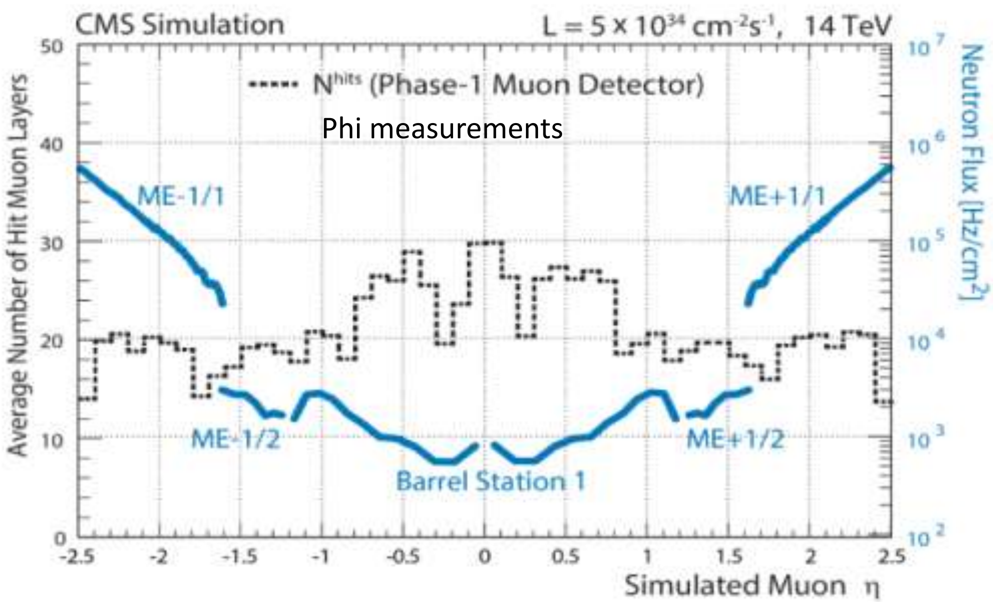
$\Delta p_T/p_T$ global 1% (10 GeV) - 10% (1 TeV), STA 10% (10 GeV) - 40% (1 TeV)

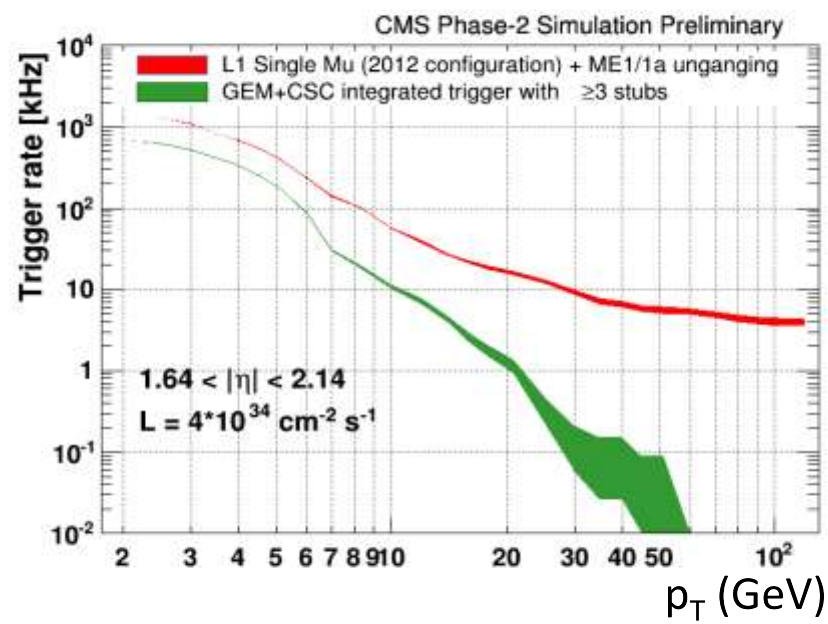
Chambers: No indications of aging at phase-2 conditions. GIF++ tests.

Upgrade: No plans to rebuild muon (large area gaseous) chambers. Upgrade concentrates on **additional detectors** for weakly instrumented areas and **trigger & readout electronics.**

Challenges of the high η region (η>1.6)

- ***Redundancy***: this is the muon system region with the highest rates but the fewest muon layers.
- ***Rate***: is increasing towards higher η, where there is also the worst momentum resolution .





High lumi affects performance. Forward region |η|≥2.0 especially challenging.

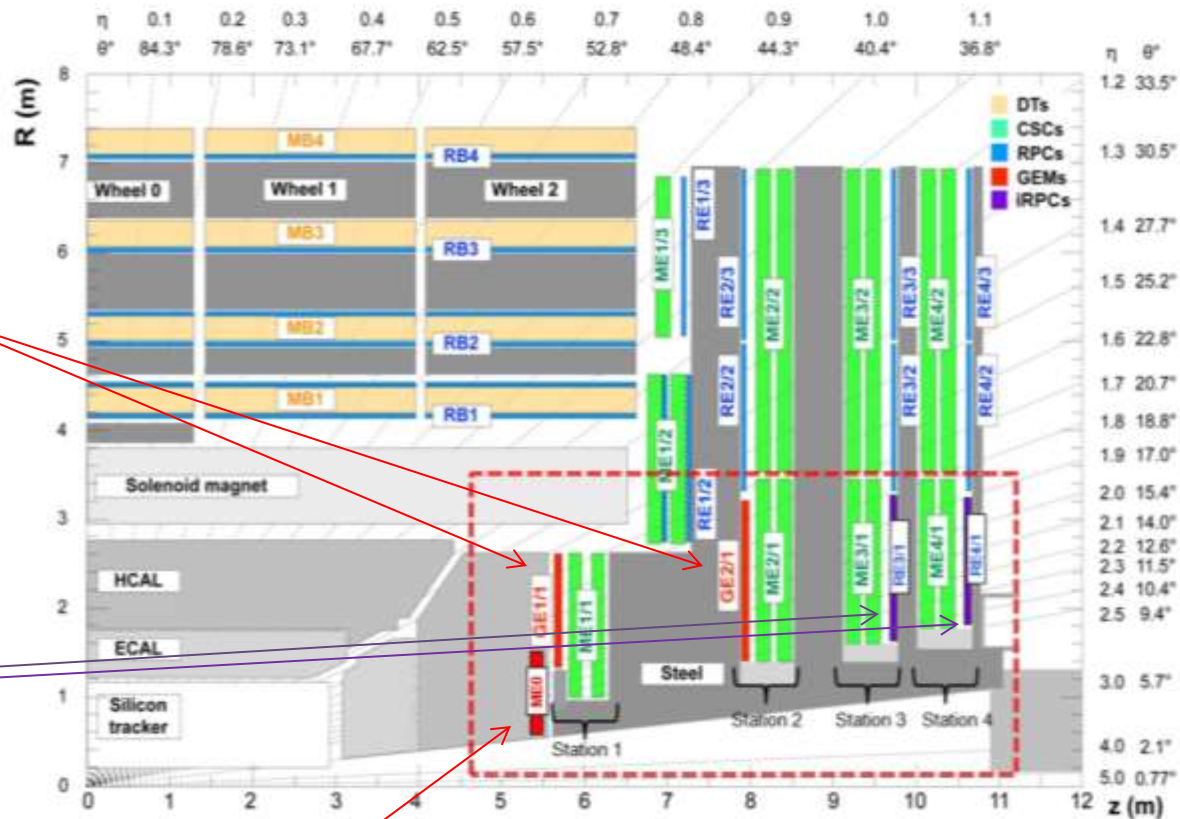
High rates = reduced resolution and longevity issues

p_T mis-measurements and multiple scattering in iron yoke cause rate flattening

CMS Muon Upgrades

Improve weakly instrumented areas:

GEM detectors for stations 1+2



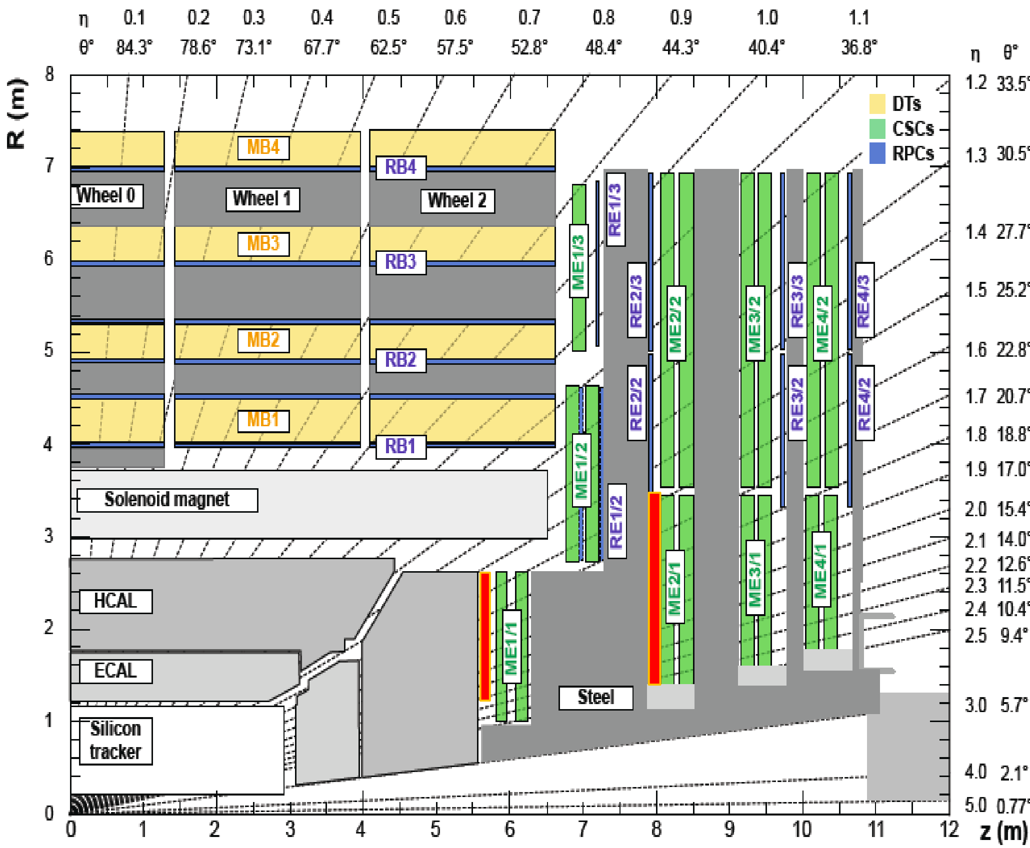
Improved RPCs for stations 3+4

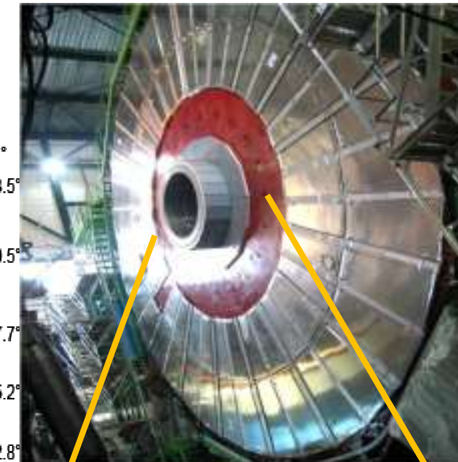
Gain acceptance:

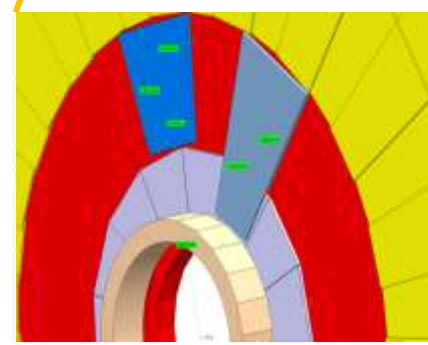
Additional muon tagger (ME0)

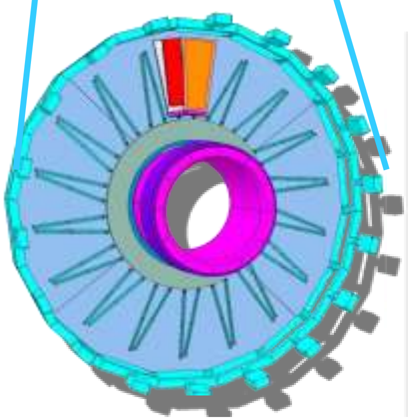
CMS GEM Extension

GAS ELECTRON MULTIPLIER (GEM)









GE1/1

Status: TDR approved. In production, installation in LS2

Technologies: double-layered triple-GEM

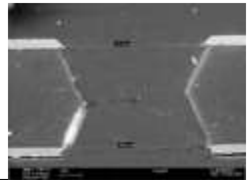
GE2/1

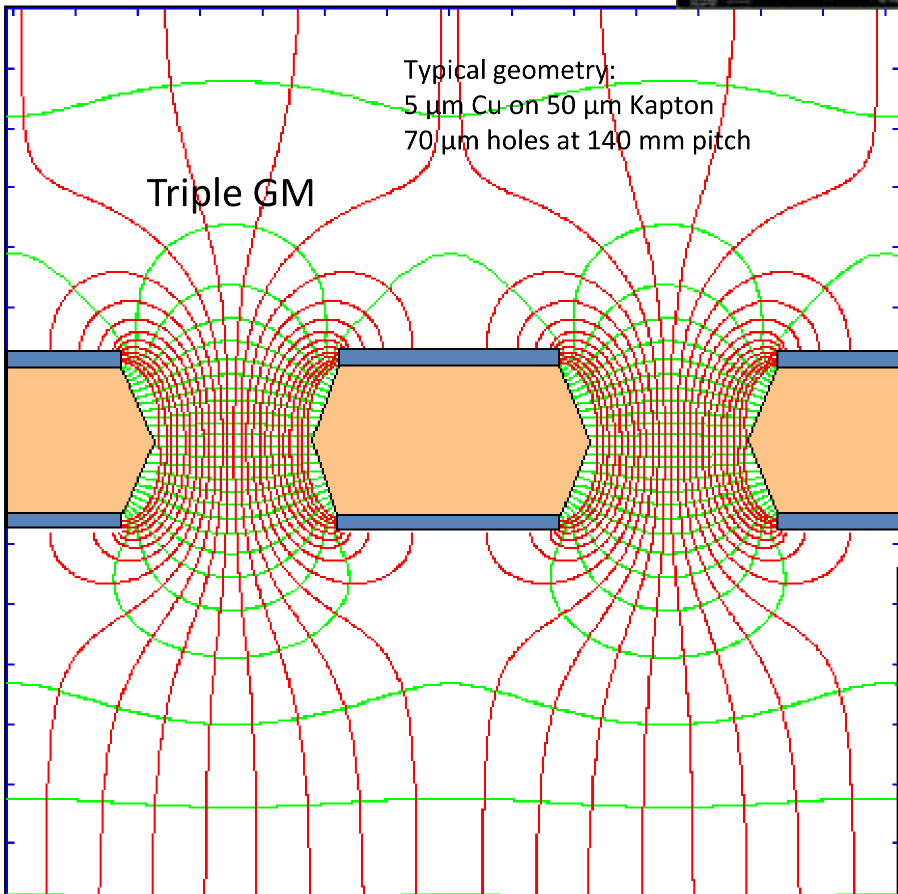
Status: Proposed in TP

Being designed

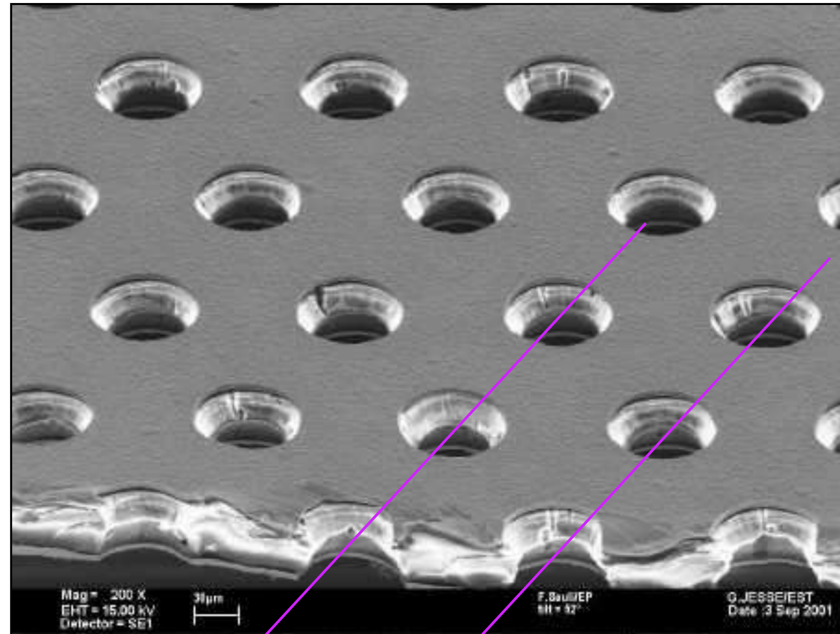
GEM Principle

Thin, metal-coated polymer foil
with high density of holes:

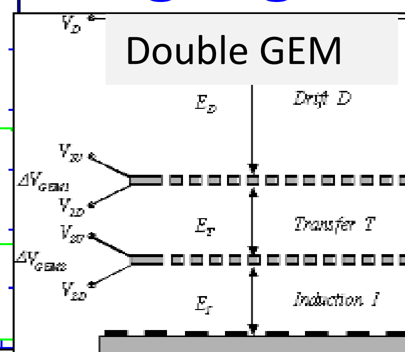


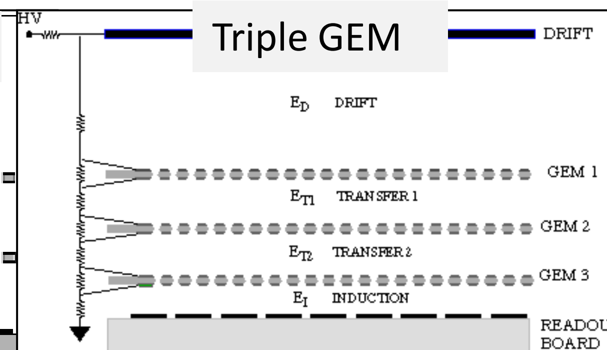


F. Sauli,
Nucl. Instrum. Methods A386(1997)531



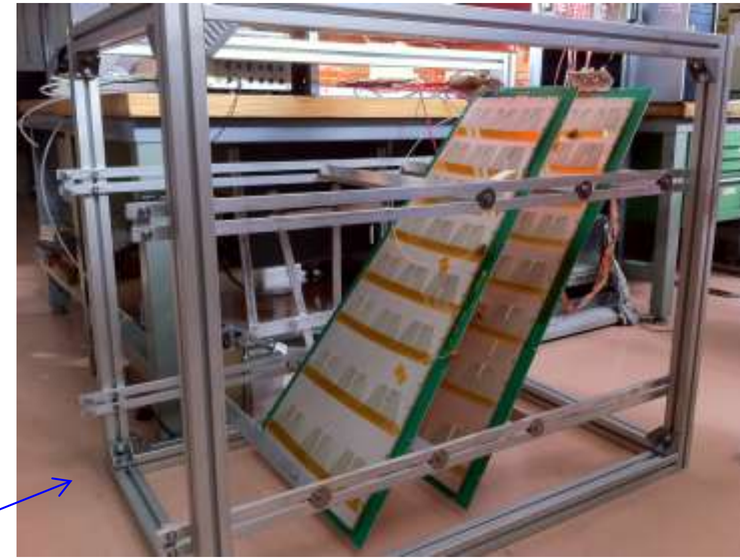
Cascaded GEMs allow much larger gains before discharge





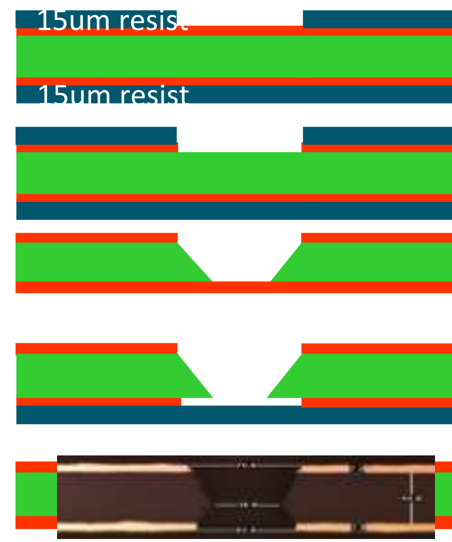
C. Buttner et al, Nucl. Instr. and Meth. A 409(1998)79
S. Bachmann et al, Nucl. Instr. and Meth. A 443(1999)464

GEMs for CMS



- GEM foil = key component, for amplification
- So far produced at CERN detector workshop.
- Detectors up to 30 x 30 cm^2 installed in several experiments. → Principle works

Challenge in CMS = the size!! GE1/1 O(1qm), GE2/1 O(2qm)



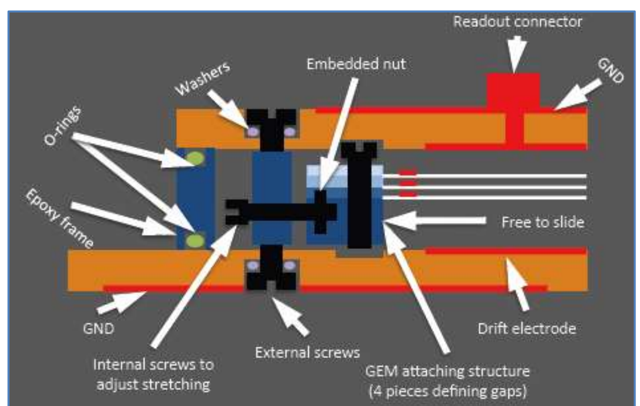
Performed R&D:

Single mask technology for wet etching

- Dramatically reduces foil production costs and allows large sizes
- Performance same as that of double mask

Foil stretching

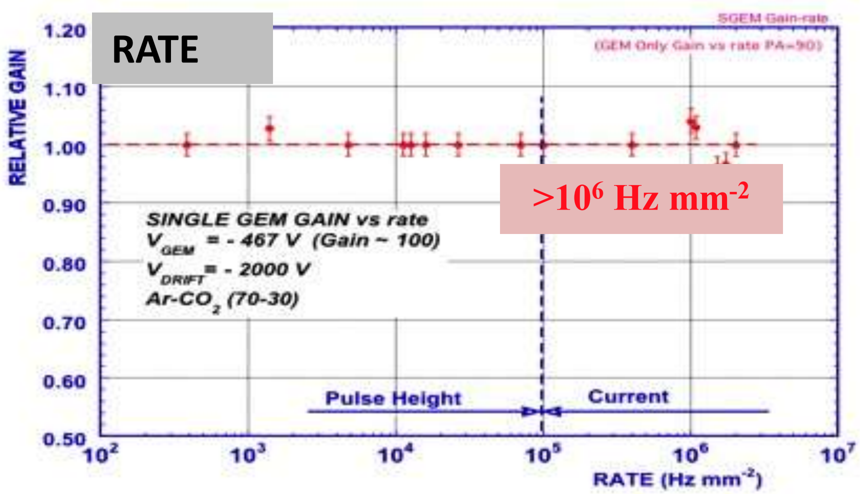
- Construction time reduced from week(s) to 2 hours/chamber



Performance

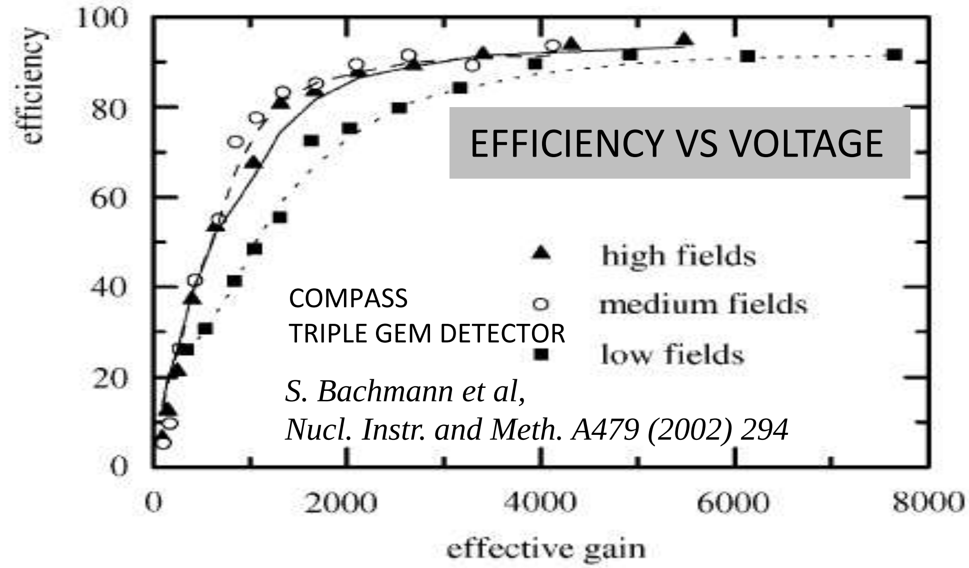
SPACE ACCURACY:
~ 50-100 μm

RATE



>10^6 Hz mm^{-2}

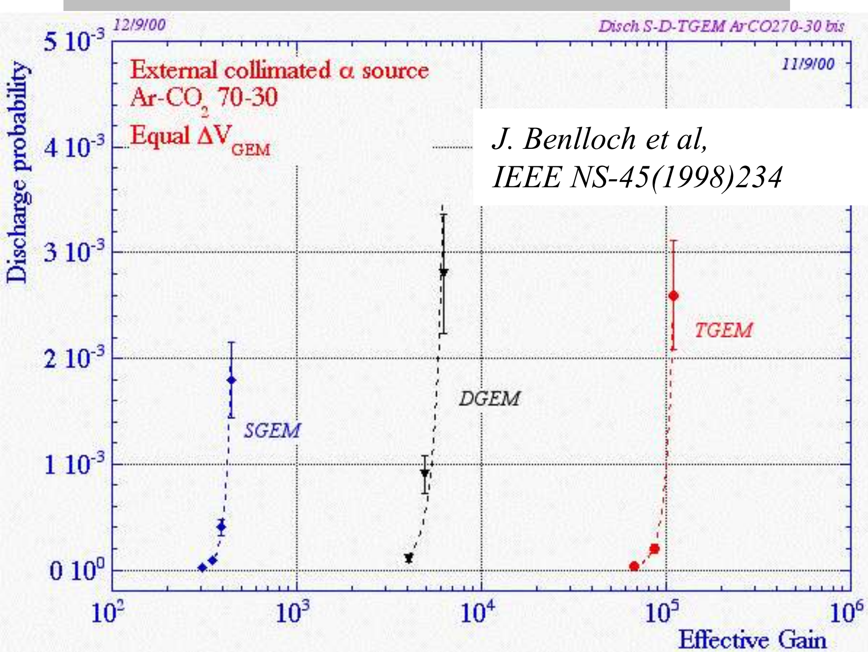
EFFICIENCY VS VOLTAGE



COMPASS
TRIPLE GEM DETECTOR

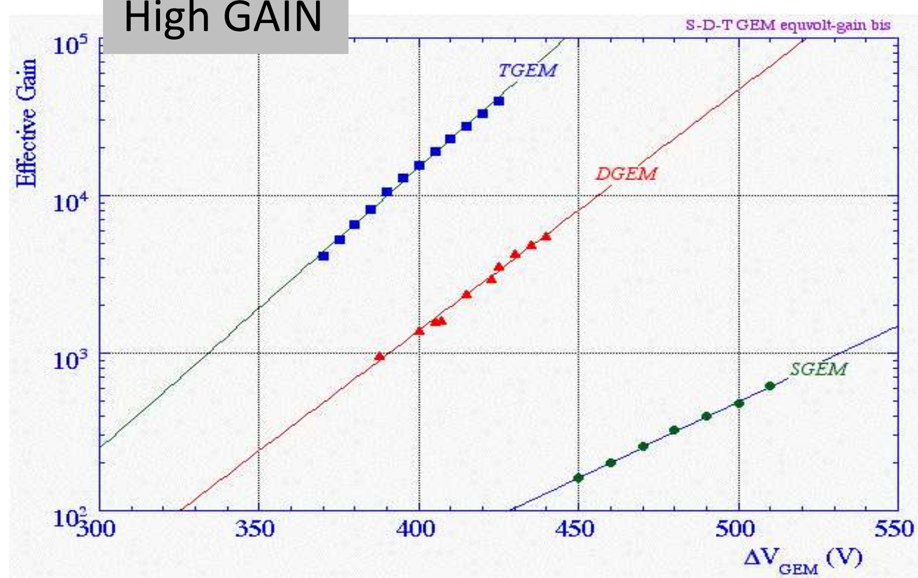
S. Bachmann et al,
Nucl. Instr. and Meth. A479 (2002) 294

DISCHARGE PROBABILITY WITH α

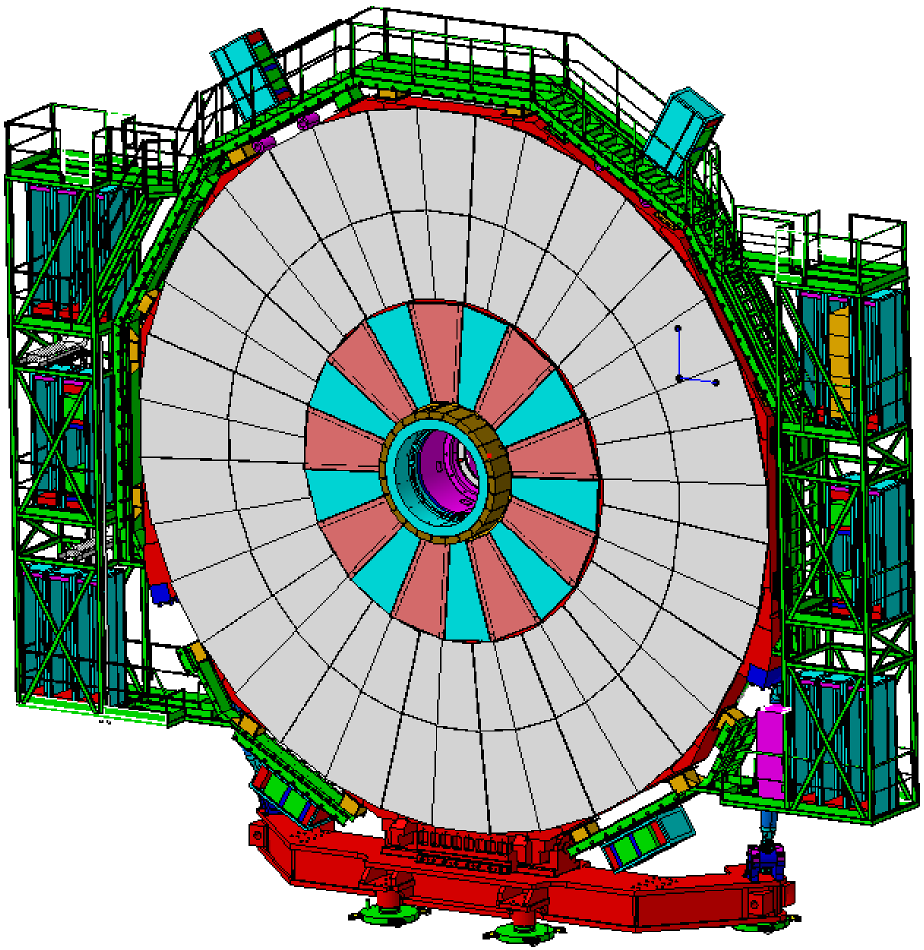


J. Benlloch et al,
IEEE NS-45(1998)234

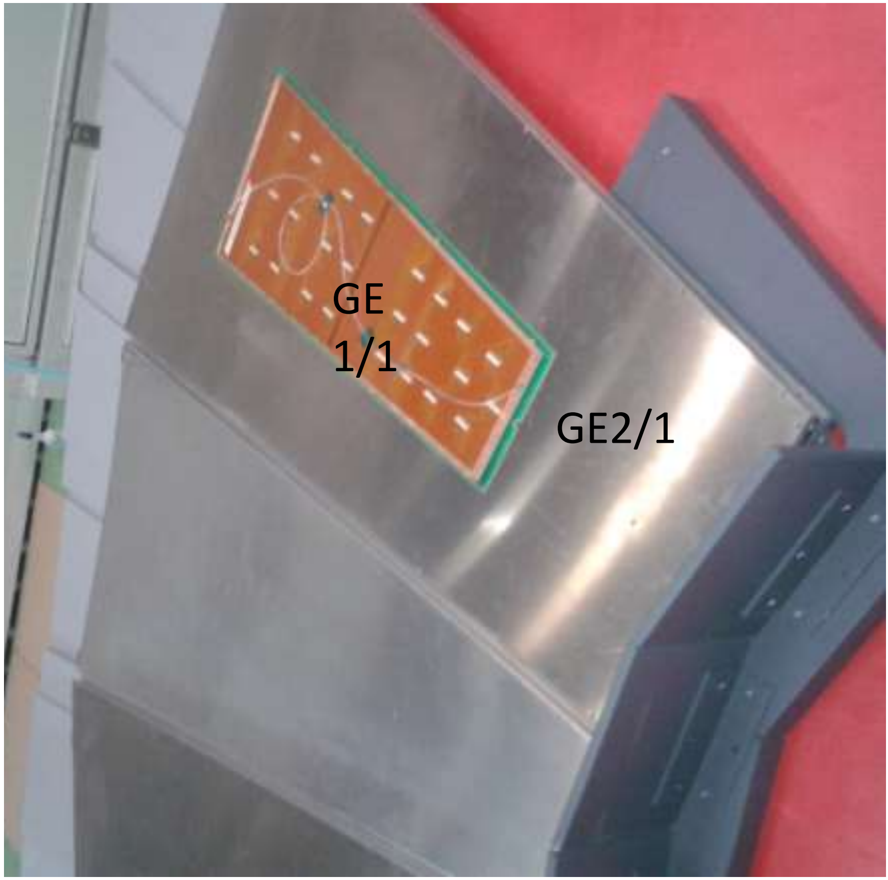
High GAIN



GE2/1 being designed



18 GE2/1 superchambers, each spanning 10 or 20° in ϕ angle

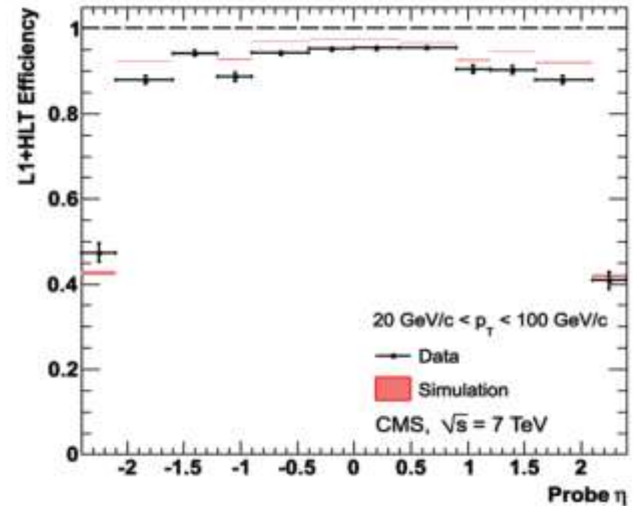


Not a single foil per chamber possible, rather 4-6 segments.
Foils from new producer(s) outside CERN detector workshop → quality control

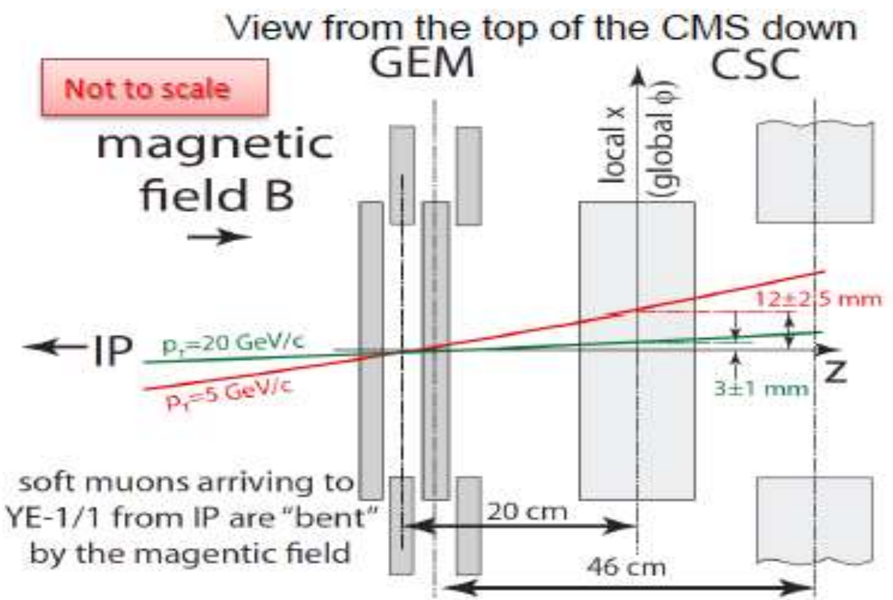
How GEMs Help the Trigger

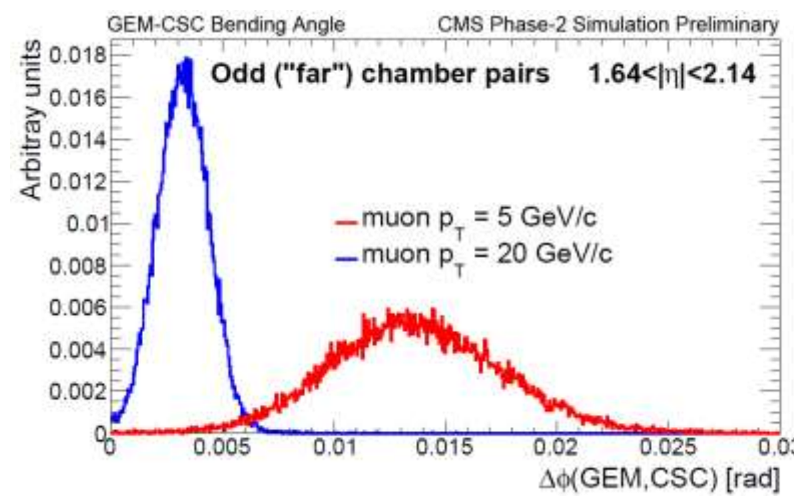
Forward region |η|>1.6 relies entirely on existing CSC

- Lower efficiency towards higher eta due to tighter cuts to compensate higher background
- Efficiency will reduce further with increasing PU
- Multiple scattering in iron yoke flattens trigger rate → raising threshold cannot lower rate



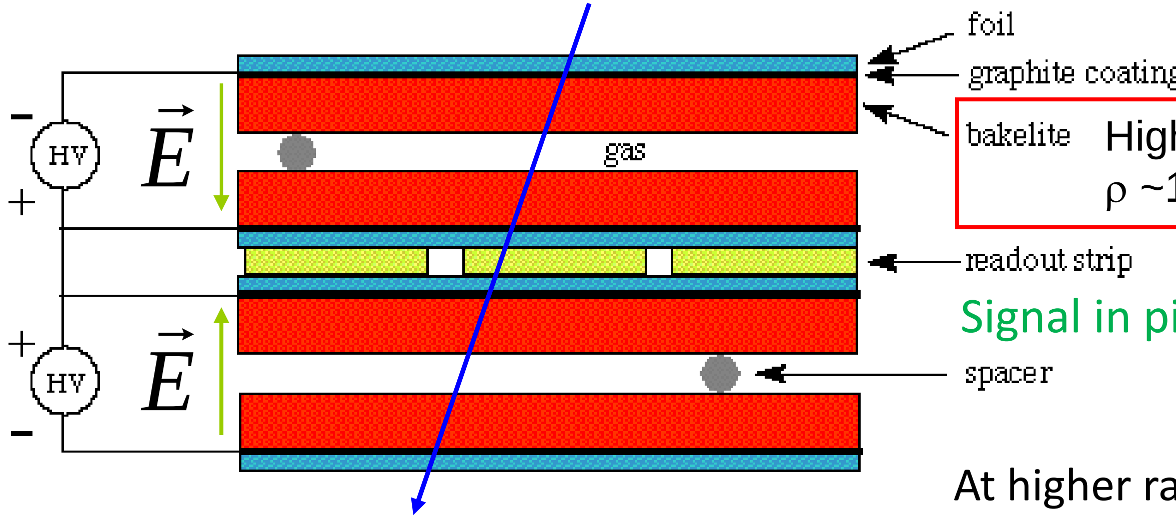
Combination of GE1/1 & ME1/1 = longer lever arm → use muon bending angle in the high B-field at local trigger level to measure p_T precisely





Present Double Gap RPC

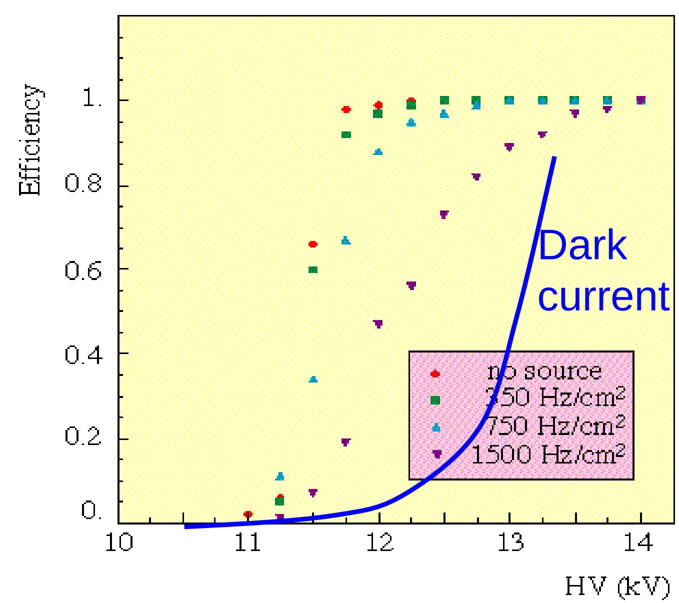
in barrel and endcaps



High resistivity
ρ ~1-5 x 10^{10} Ω cm

Signal in pick-up electrodes

At higher rates larger voltage drop requires increased HV → noise increase



[Avalanche mode]

Amplification ~10^7 e^-

High-rate capability ~10 kHz/cm² (ATLAS, CMS, LHCb)

[Streamer mode]

Higher amplification

Limited rate capability ~10 Hz/cm² (ALICE, BaBar)

Improving RPCs

At HL-LHC and in the very forward region even higher rates

Improvements possible by

1. **Decrease electrode resistivity**
   - Reducing recovery time, proportional increase in rate capability
   - New materials e.g. low-resistivity silicate glass (10^{10} Ωcm), various ceramics (10^{6}-10^{14} Ωcm), low-resistivity high-pressure laminate (~0.5 - 1 x 10^{10} Ωcm)

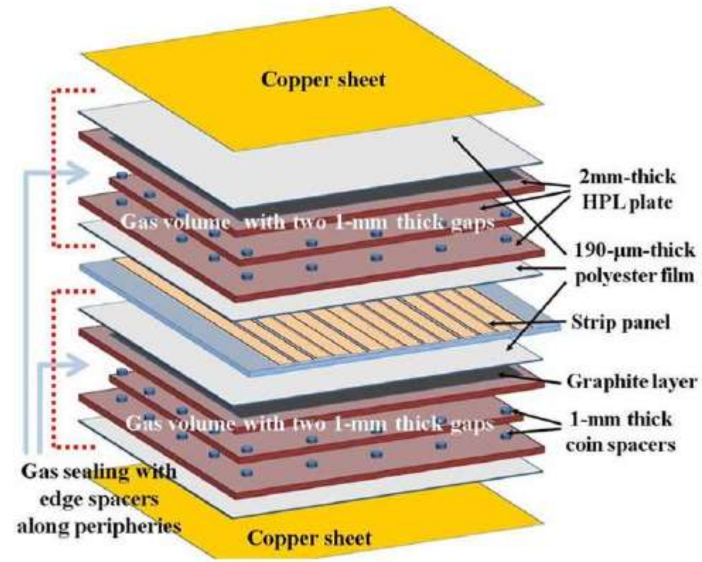
2. **Decrease average charge deposition**
   - Shift part of amplification to high amplification electronics
   - Reduced voltage drop on electrode plates
   - Shorter period of inefficiency and reduced aging

3. **Changing the detector configuration**
   - Change electrode thickness
   - Change number of electrodes

Changing RPC configuration

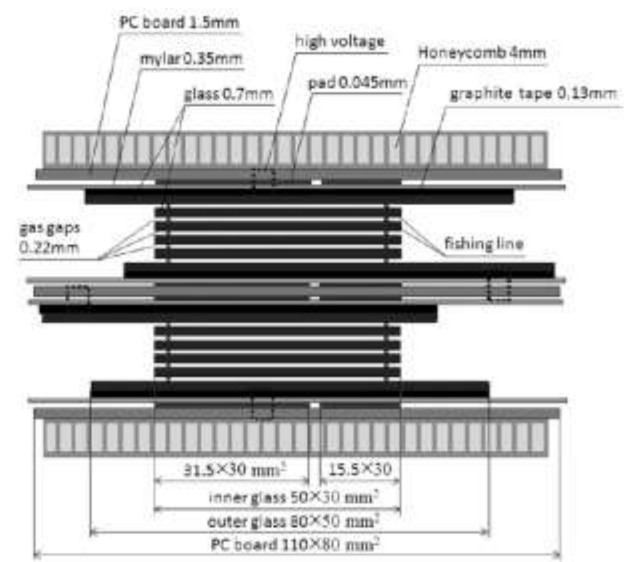
Modified standard double-gap config with additional gap on both RPCs

- Four gaps of 1 mm each
- Same electrodes and FE as standard CMS
- Full efficiency reached for HV>11.4 kV



Multi-gap glass RPC

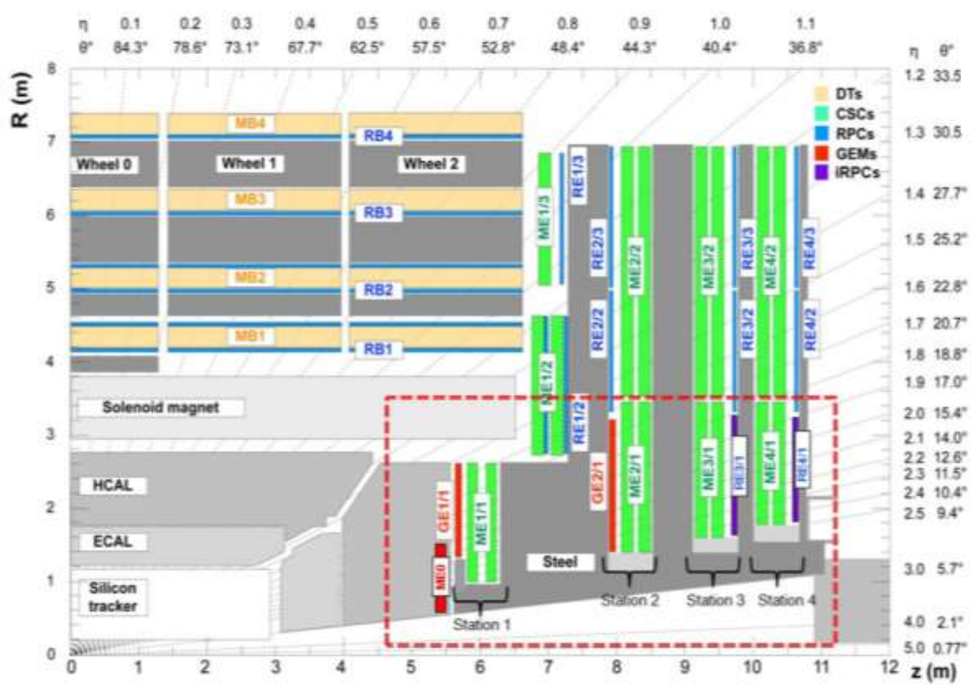
- With semi-conductive glass eff~90% for rates up to 10 kHz/cm^2
- Time resolution better than 100 ps for multi-gap configuration



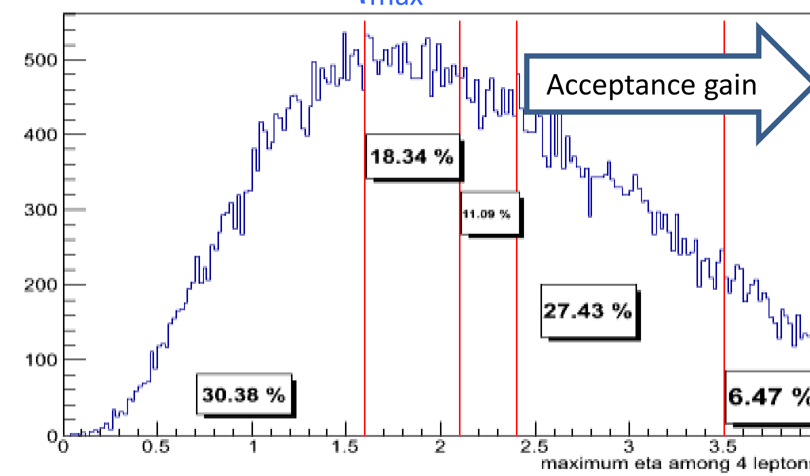
Going Beyond $|\eta|=2.4$?

Very forward region a place to gain physics acceptance

Based on tracker extension → extend muon system and match to pixel stubs (eta coverage limited by beam-pipe, services and calorimeter)



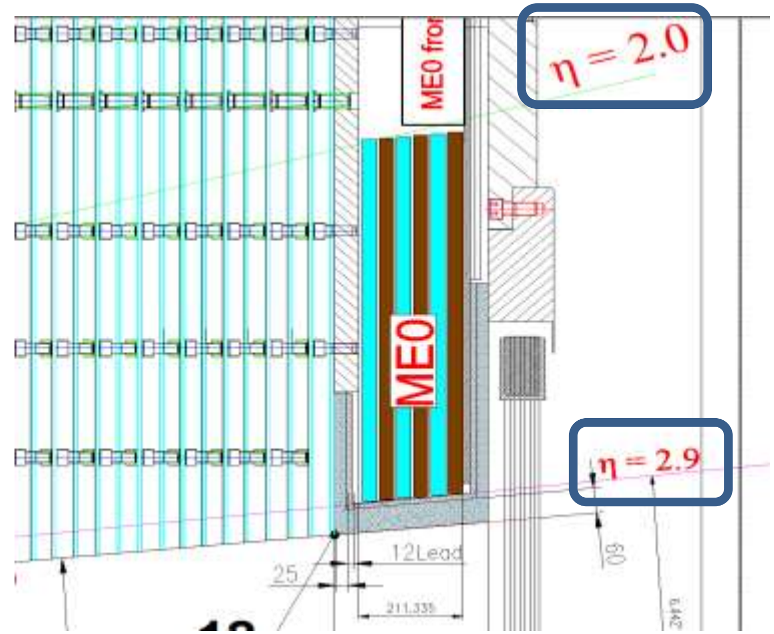
$H\to ZZ\to 4\mu$: acceptance increase
60%→94% if η_{max}=2.4→4.0



Challenges for $|\eta|>2.4$

- Nearly no B-field in muon system
- Highest background rates ~100 kHz/cm^2
- Very high PU 140-200 → backgr.
- Space, integrated in forward calorimeter

ME0 Station



Should provide muon tagging for
2.4 < |η| < 3.0

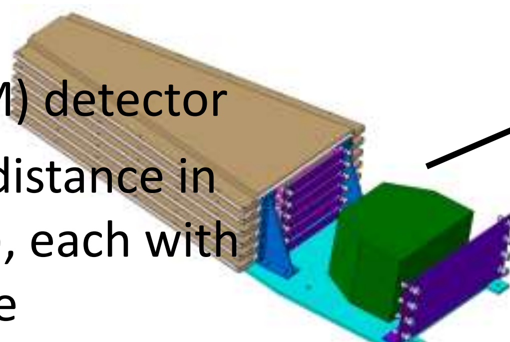
No tracking possibility (weak B-field)

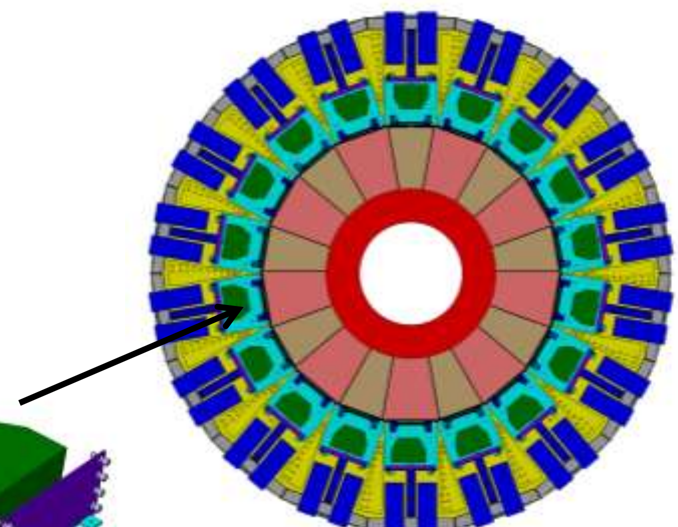
Requirements:

- ME0 as multi-layer detector to suppress neutron bkgr → 6 chambers per wedge
- Small area, low multiple scattering

Technologies:

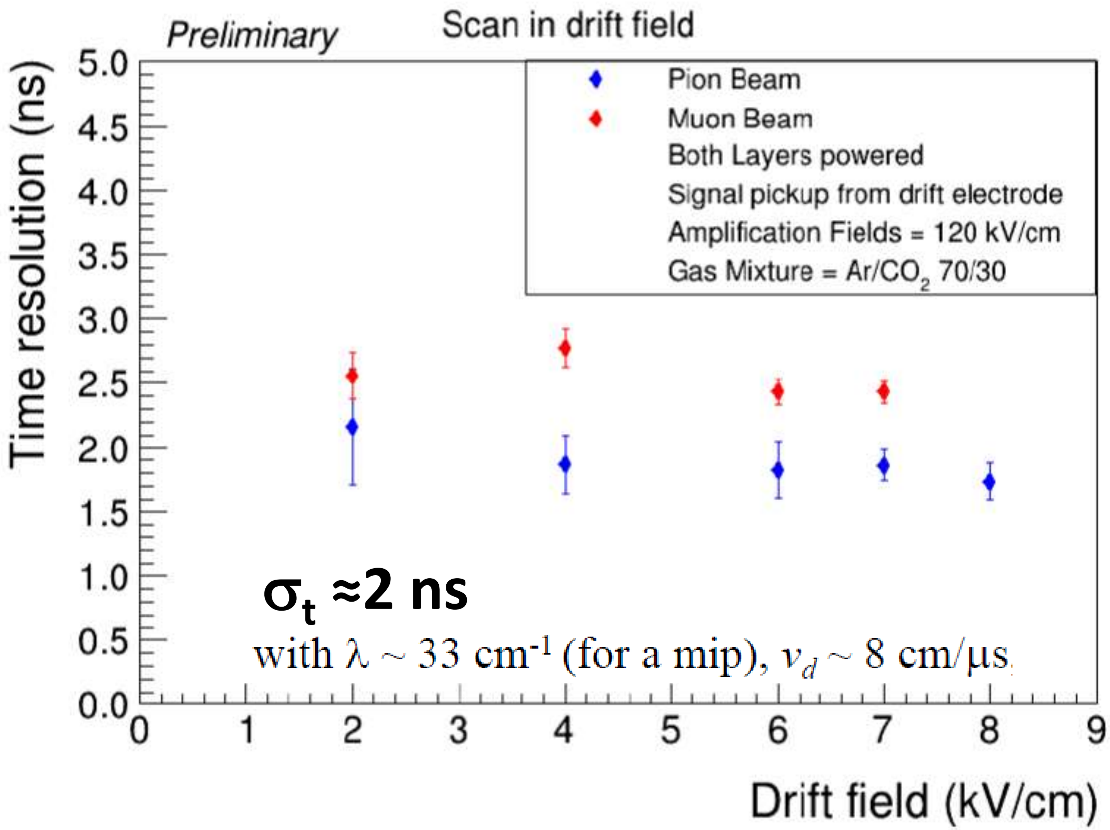
- GEM detectors (TP baseline)
- Fast timing micropattern (FTM) detector
  - Reduce single (mm) drift distance in many small gaps (250 um), each with ist own amplification stage
  - Δt from 5-10 ns → 2-3 ns





Time resolution measured with a small prototype in μ/π testbeams

Measured with a first 20 cm^2 prototype, 250 um drift gaps.
Gas mixture Ar/CO2 70/30. No CF4!!



Time resolution for different values of applied drift field, for constant amplification field

Not much affected by drift field

- Very short drift of 250 um
- Nearly constant v_D of Ar/CO2 between 2 and 10 kV/cm

Pions deposite bigger charge due to showering

Standard O(2mm) MPGD would reach 5-10 ns

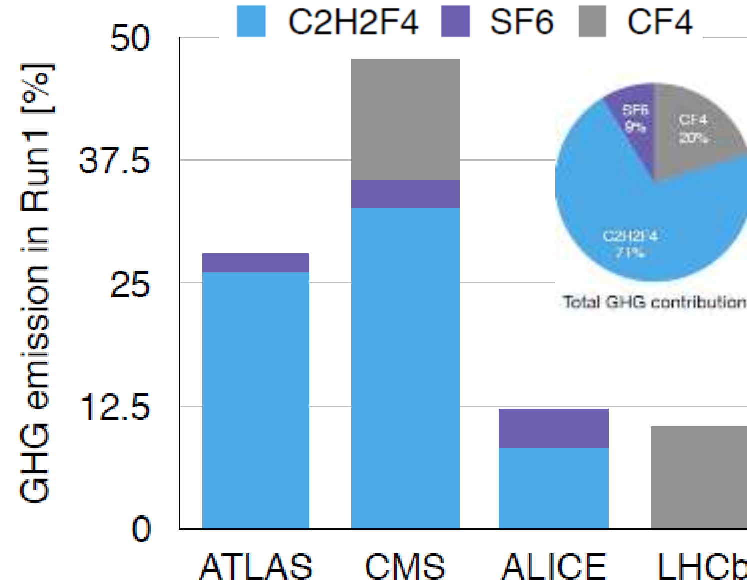
Gas Mixtures

Gas mixture is the **active element** in muon detectors → amplification, response time, operational mode (avalanche, streamer)

Typical components for **„fast“ gases are F-based**

→ Green house gas (GHG) to be faced out

- In CMS used in RPC, CSC



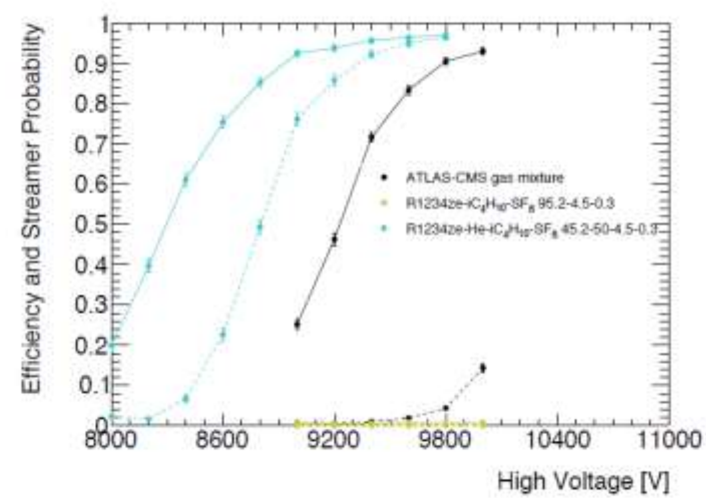
Beatrice Mandelli, CERN

Solution for **today: Recirculation & recuperation.**

Reduce leaks, closed loops, remove O_2, H_2O, not N_2

Solution for **future: find alternatives**

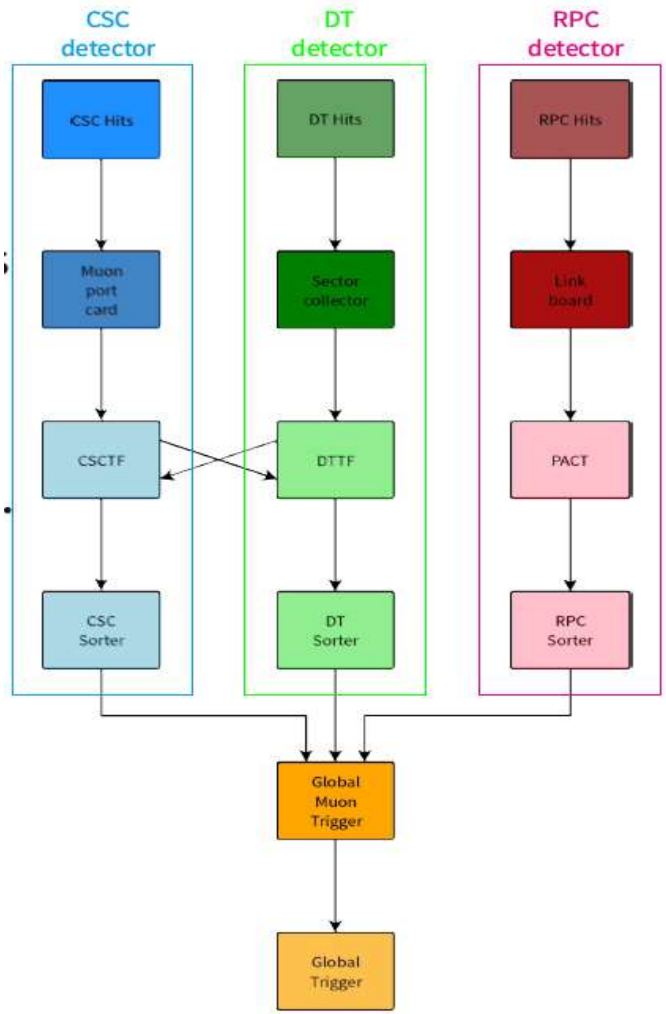
- E.g. HFO: Many are flammable or toxyc, cannot be used in experiments.
- E.g. add He: helps reducing HV working point but more difficult to be leak-tight, streamer?
- **Much more R&D needed**

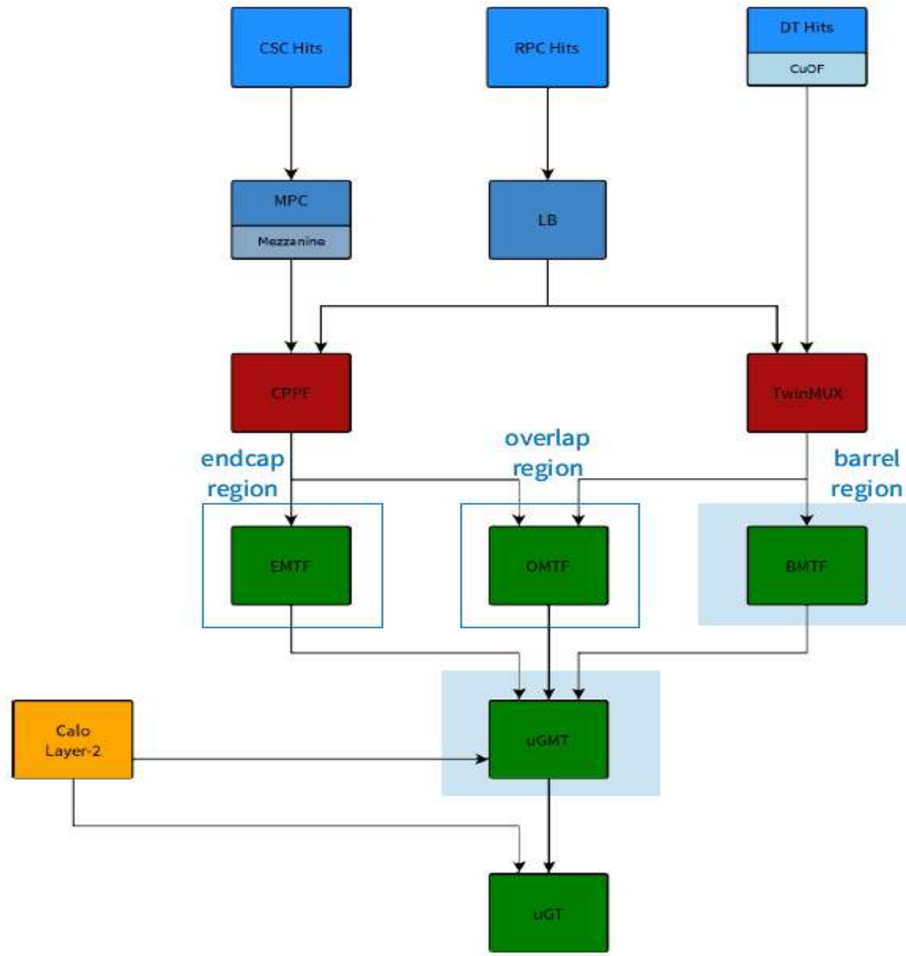


Trigger Upgrade

Present: subsystem oriented, one TF each. 4+4 tracks to GMT, selects four best by comparison, and sends to GT.

New: region-centric, each TF covers assigned region. Dedicated TF for overlap. Sorting and ghost suppression in GMT.
8 muons send to uGT.   uTCA standard.





Impact of CMS Trigger Upgrade on Muon Electronics

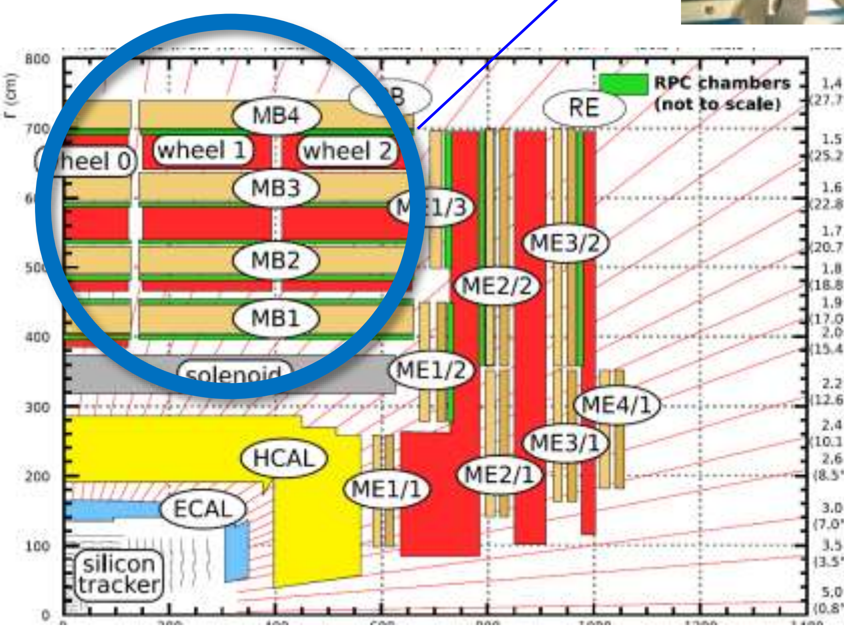
Concept of tracking trigger impacts needed latency and rate

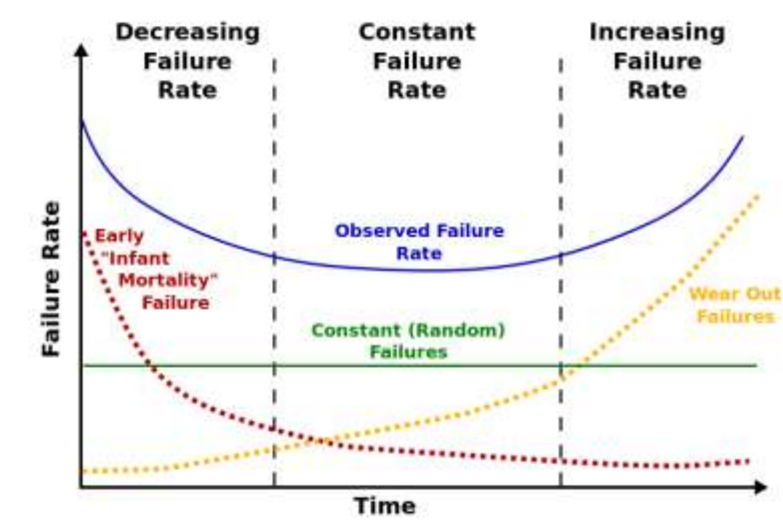
Level 1 Latency from 3 μs ⇒ 10 μs

Level 1 Rate from 100 kHz ⇒ 1 MHz

L1 rate needs replacement of the DT on-chamber RO and trigger electronics

Another argument: electronics is old, cannot be rebuilt. Wear-out failure may increase. High power consumption.

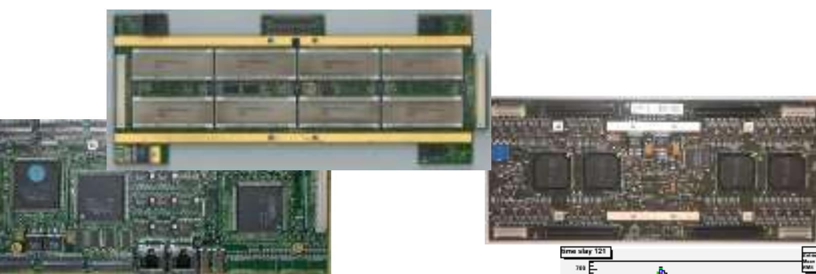


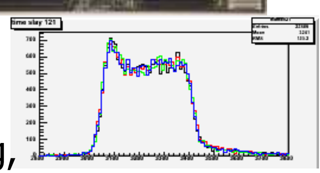


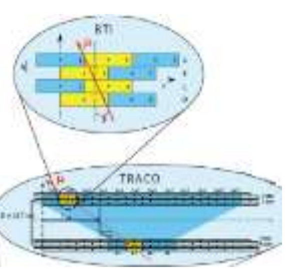
Upgrade of DT on-chamber electronics

Present Minicrates

- Highly integrated and complex system. Many boards with various ASICs for specific tasks.
- Trigger primitive generation performed inside each chamber
- Filtered information sent to counting room
- Not guaranteed to survive HL-LHC environment. Also higher trigger rates.





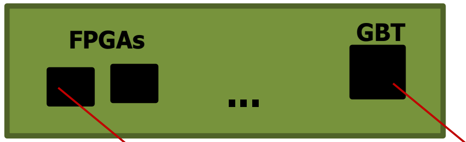


Trigger
segment finding, angle measurement=> single chamber trigger generation

Readout
Time digitization
Event matching

Phase-2 Minicrates (OBEDT)

- On-chamber electronics performs time digitization of all chamber signals
- Digital information sent through optical link to the counting room
- Complexity is brought into the counting room



Radiation tolerant FPGAs which perform 1 ns time digitization (no filtering)

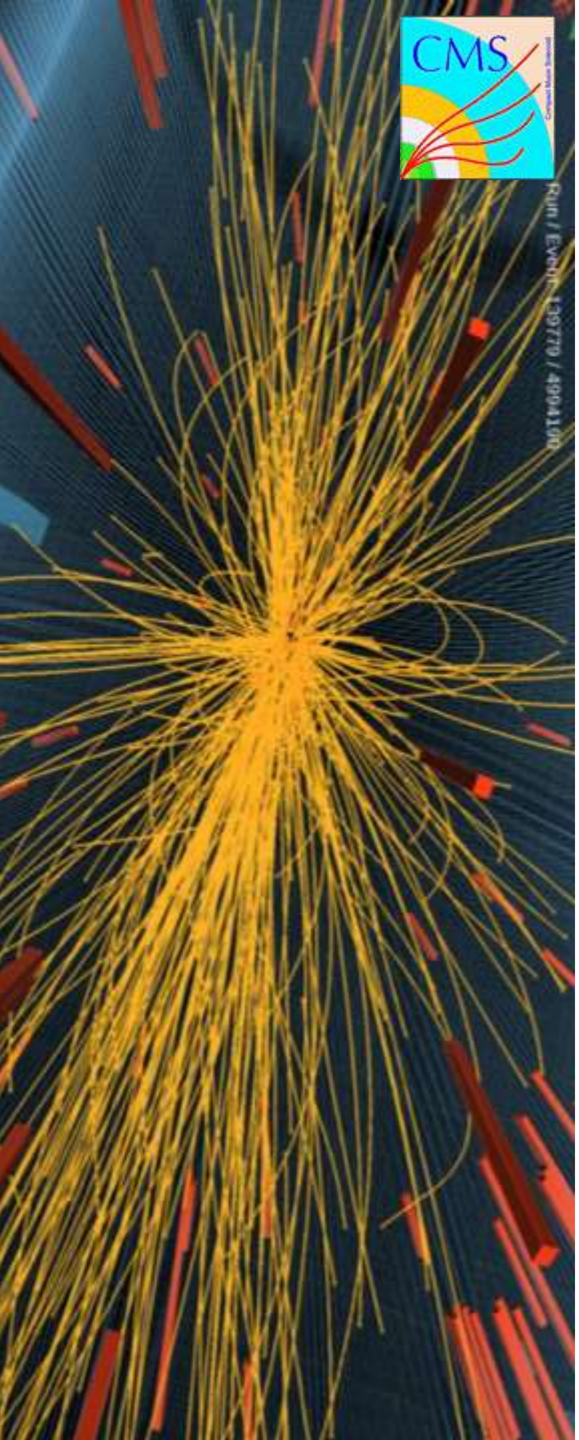
GBT link for data forwarding

*** Allows readout at 1 MHz Level-1 and 20 us latency**

*** Trigger primitive generation:**

-maximum chamber resolution

-room for pt resolution increase



Summary

HL affects muon system performance. Forward region $|\eta|\geq 2.0$ especially challenging.

- Rates very high and increasing with η
- p_T mis-measurements drives the trigger rate

Upgrade projects to improve performance

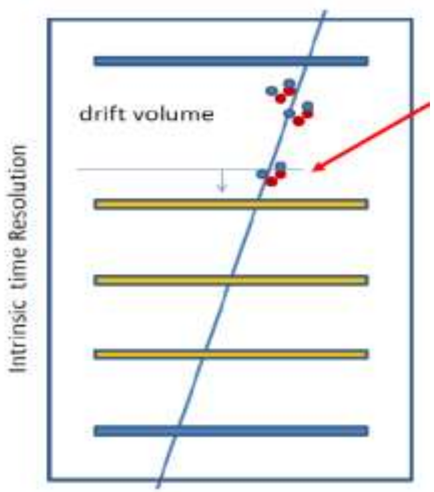
- With new GEM detectors in first station, p_T will be measured more precisely using bending angle.
- Further extension of muon coverage to $|\eta|<3$, in conjunction with tracker extension. Allows physics gain.
- Upgrade of on-chamber electronics to cope with increased latency required by tracking trigger and larger rates.

Challenging… looking forward to phase-2

Spares

Fast Timing Micropattern (FTM) Det.

Goal: Improve time resolution



$$t = d \cdot v_d$$

d is the distance of the closest cluster to the first foil and it follows the distribution $e^{-\lambda x}/_{\lambda}$, where λ is the average number of primary clusters generated by an ionising particle inside the gas per unit length

Example $\lambda \sim 30\ cm^{-1}$, depends on Ion.potential of gas

v_d is the drift velocity, that depends on the gas mixture and the drift field applied.
Typically ~10 - 50 cm/μs depending on gas mixture

Time resolution: $\sigma_t = (\lambda v_d)^{-1}$ → can reach 5 – 10 ns

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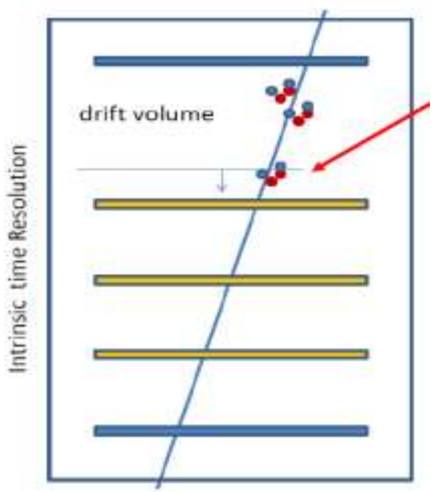

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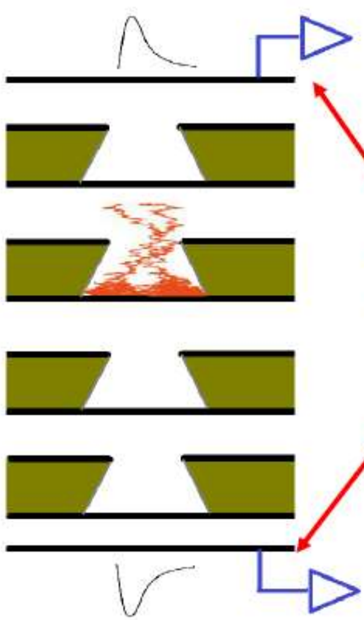
Idea: Reduce d by dividing single drift region into many small regions N_D with independent amplification stages



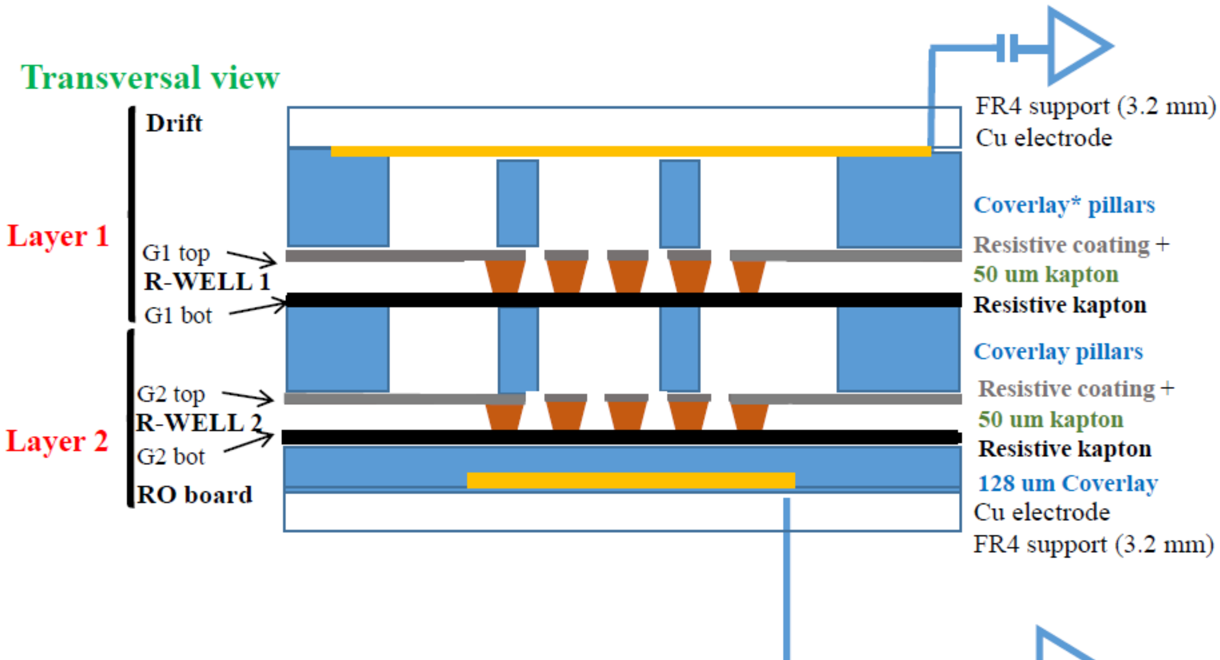
When the avalanche grows in one drift-amplification stage, the signal is induced on the top and bottom readouts.

$$\sigma_t = (\lambda v_d N_D)^{-1}$$

→ can reach O(2 ns)

The **first prototype of Fast Timing Micropattern (FTM) detector** exploits this principle using two 250 µm-thick drift gaps, each coupled with an amplification region composed by a fully resistive WELL.

FTM – First Prototype



The detector is composed by two independent drift-amplification stages (Layer 1 & 2 in the picture above).

Reference: arXiv:1503.05330v1
European Patent Application 14200153.6
M. Maggi, A. Sharma, R. De Oliveira

Drift volume 250 um thick, with planarity ensured by coverlay pillars

Each amplification region based on pair of polyimide foils stacked due to electrostatic force induced by polarization of the foils

- The first foil, perforated with inverted truncated-cone-shaped holes (bases 100 μm and 70 μm, pitch 140 μm), is a 50 μm thick Apical KANECA, coated with diamond-like carbon (DLC) technique, to reach up to 800 MΩ/□ resistivity.
- The second foil is 25 μm thick XC Dupont Kapton, with a resistivity of 2 MΩ/□.

Active area ~20 cm^2

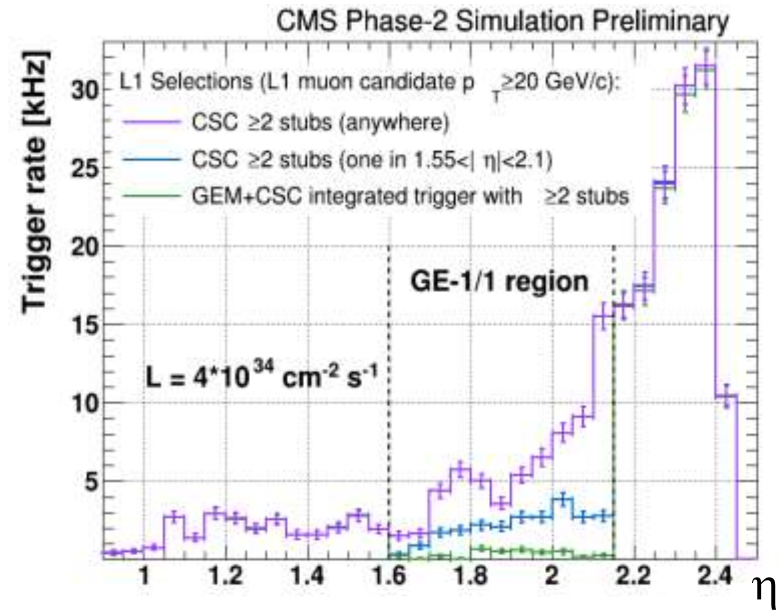
Challenge: Performance

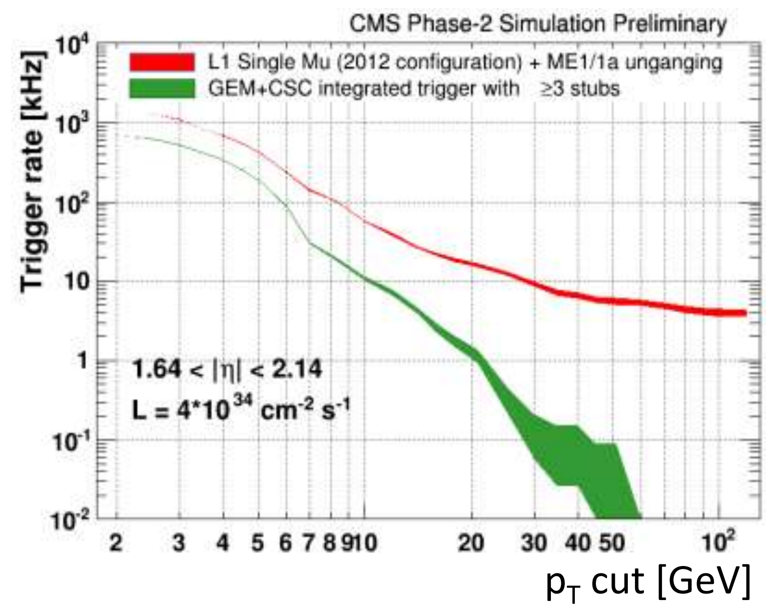
High lumi affects muon system performance.
Forward region $|\eta|\geq 2.0$ especially challenging.

- **Rates** up to kHz/cm^2 and growing with η
- **Reduced resolution and longevity issues**
- **Exceeds capabilities of existing electronics**
- **p_T mis-measurements and multiple scattering in iron yoke cause rate flattening**

Focus on maximizing the potential of large datasets to be collected at HL-LHC

- **Maintain current performance (η, p_T)**
- **Seek acceptance gains where possible**





LS1: Detector consolidation

LS2: Anticipated phase-2 upgrades

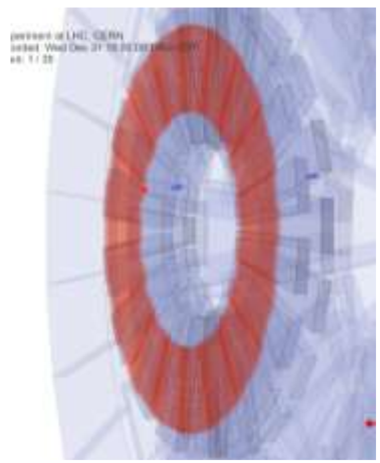
LS3: HL upgrades

Install originally planned ME4/2 + RE4/2

Partially move DT electronics from detector to cavern and redesign in uTCA technology.

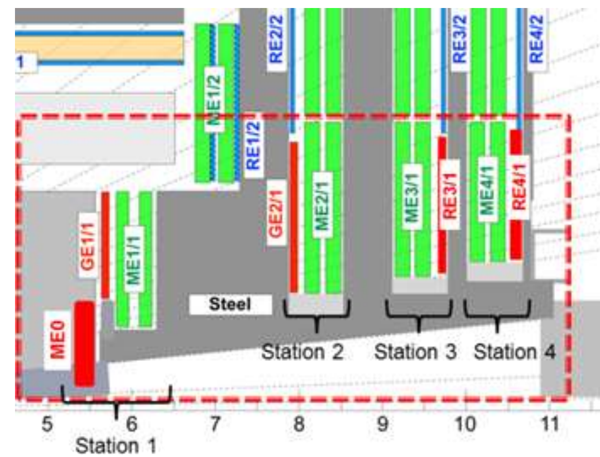
Upgrade ME1/1 electronics.

Installation of GE1/1 Combined CSC+GEM trigger



Muon trigger: Additional detectors in forward region of all 4 stations

Rapidity extension of tracker, calo, muon to $|\eta|$~4



Redesign of DT on-chamber electronics