# Phase II Upgrade plans of the CMS Muon System

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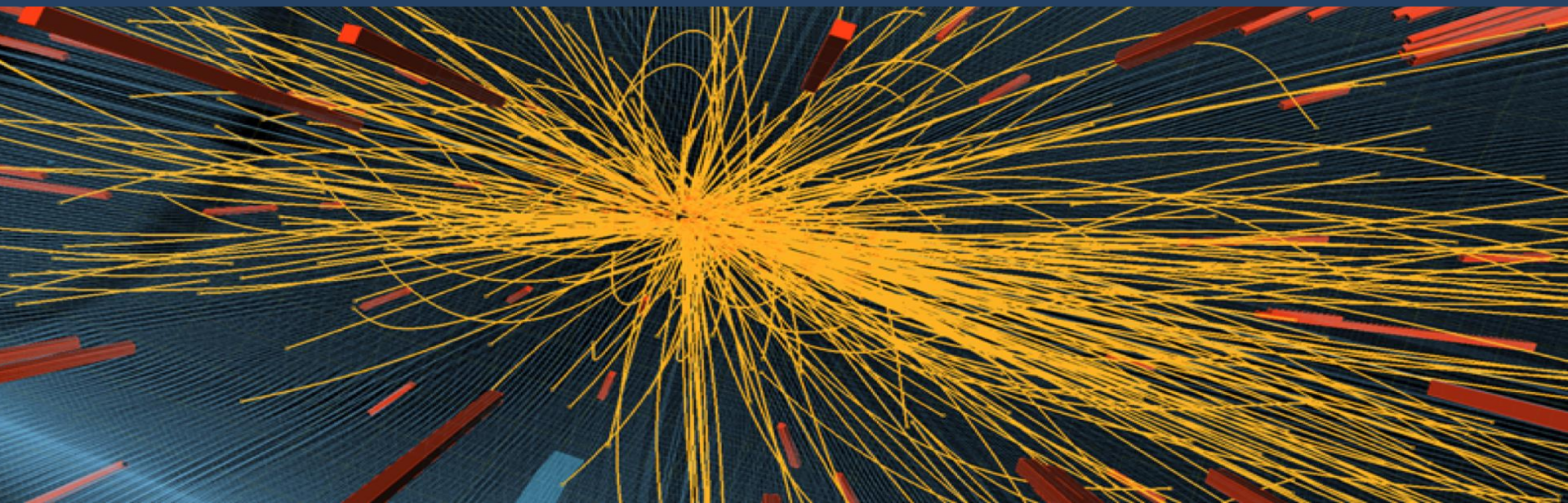
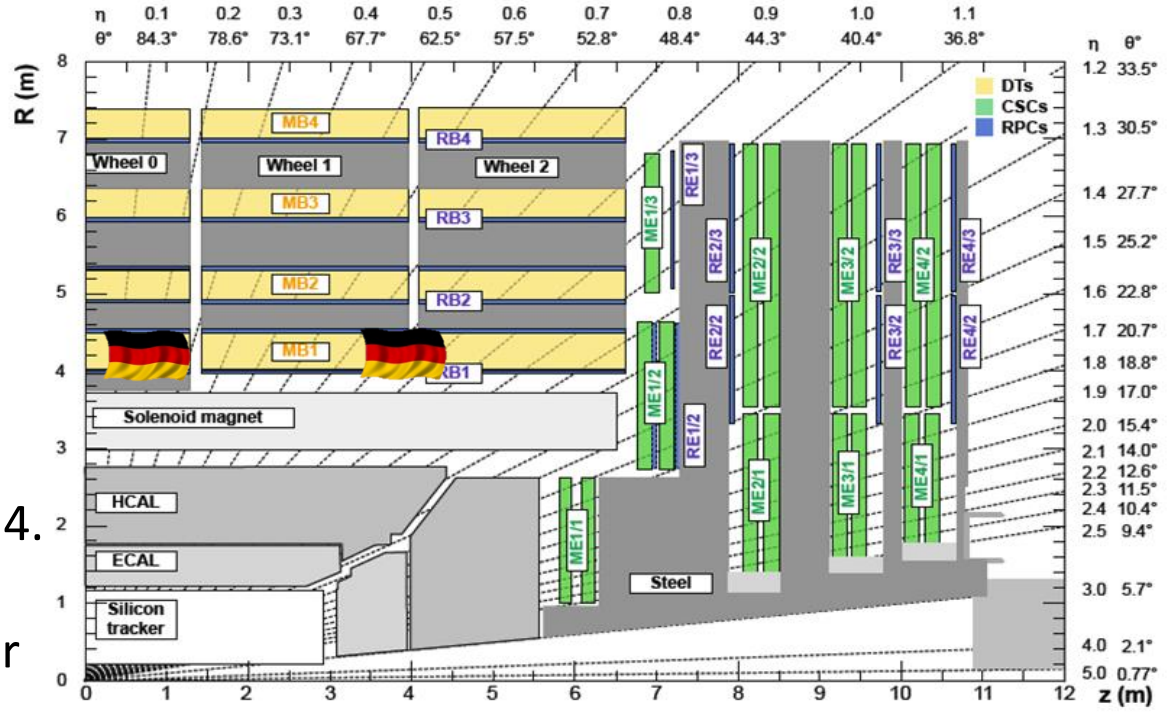
7th Annual Workshop of the Helmholtz Alliance, 2-4 December 2013

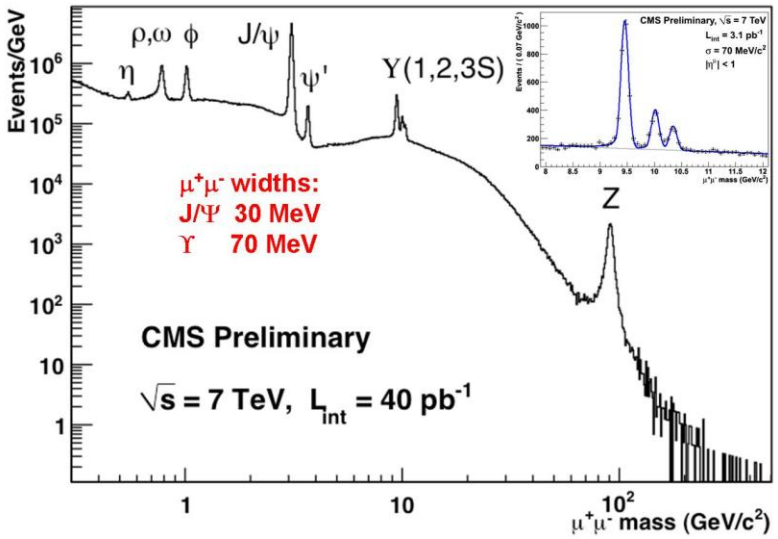


# Present CMS Muon System

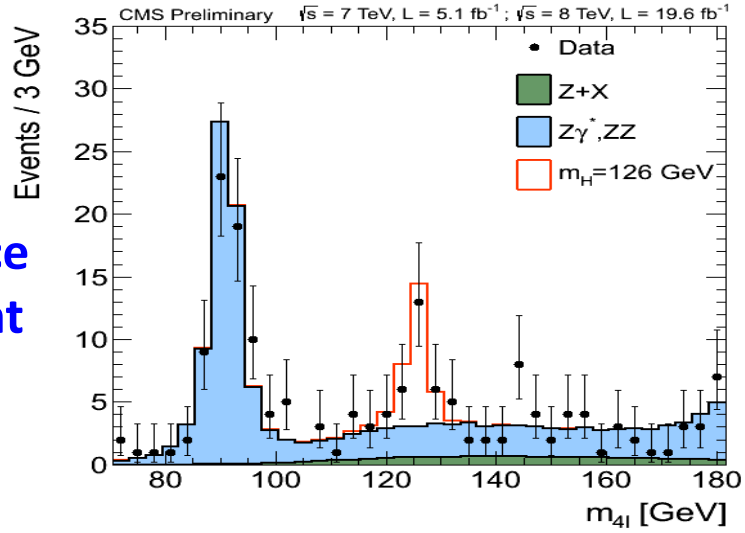
## Highly hermetic and redundant muon system

- Drift tubes (DT) to $\eta$~1.2
- CSC Endcaps 1.0<|$\eta$|<2.4
- RPCs to ensure 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**



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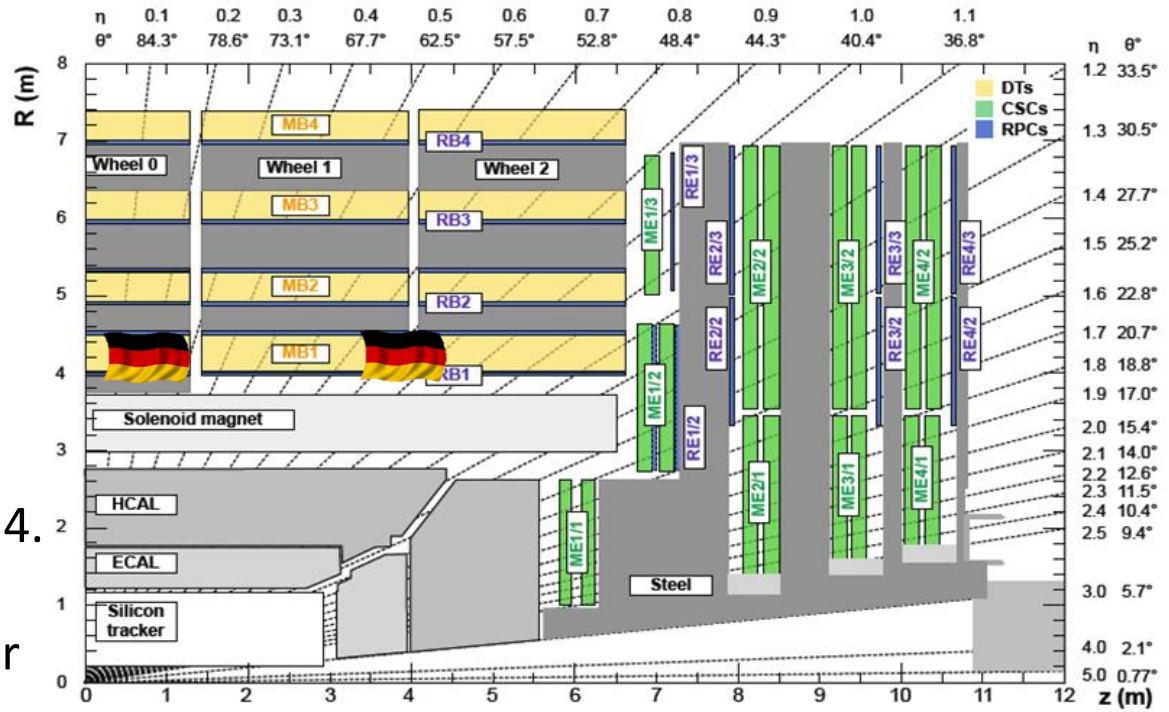



**Chambers: No indications of aging or detector performance degradation** at phase-2 conditions.

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

# HL Muon Challenges

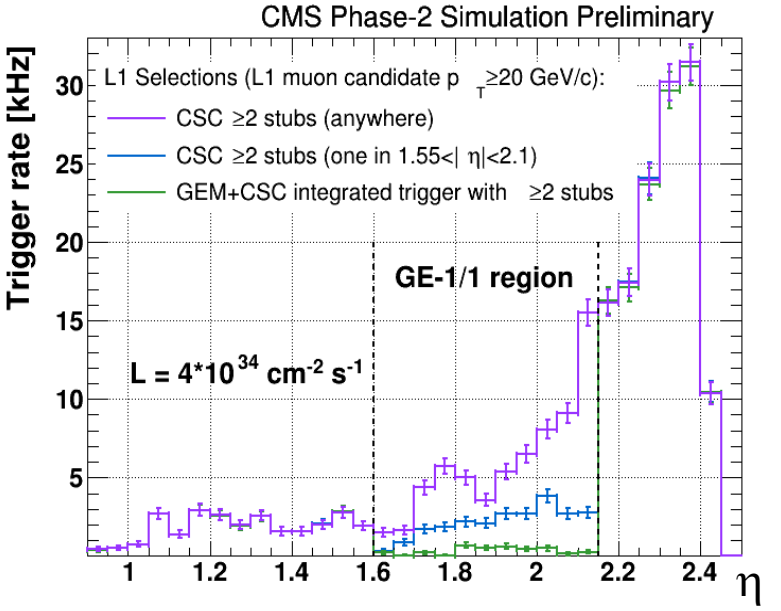
**Robust muon triggering and identification are major discovery drivers at the LHC**

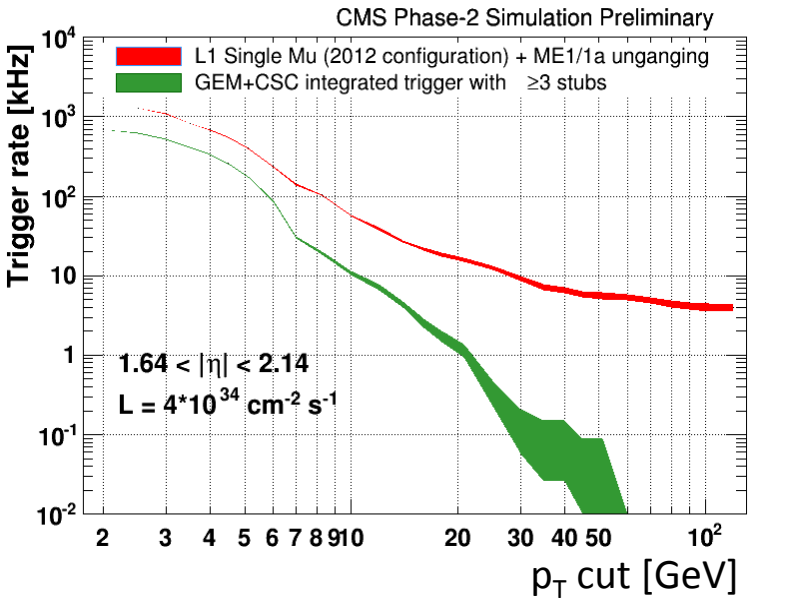
**HL affects muon system performance. Forward region $|\eta| \geq 2.0$ especially challenging.**

- Rates up to MHz/cm$^2$ and growing with $\eta$
- 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 ($\eta$, $p_T$)
- Seek acceptance gains where possible



# Phase-2 Muon Trigger Challenges

**Not loosing trigger coverage is the key**

- $p_T$ mis-measurement drives trigger rate. Increasing threshold would not help.
- Level-1 track trigger helps, but has reduced performance in high-$\eta$ "corner"

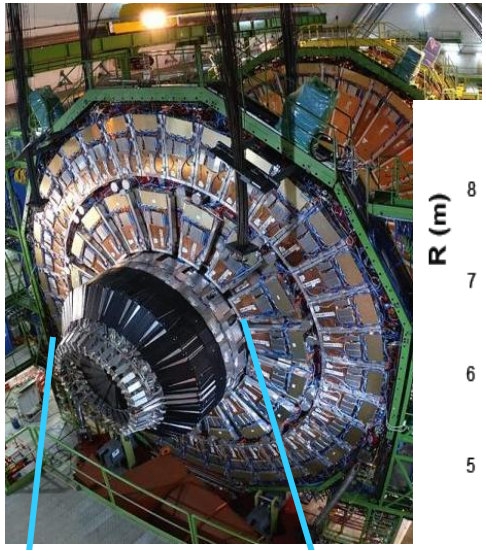
**Phase-2 objectives:**

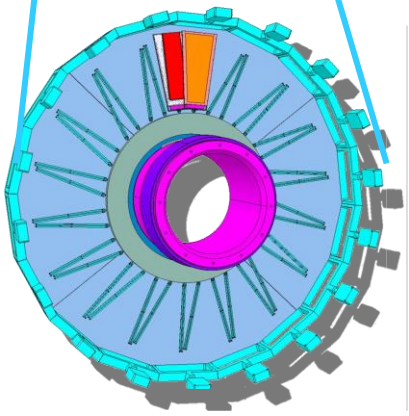
1) Increase purity, reduce $p_T$ mis-measurements
2) Sharpen trigger turn-on
3) Keep trigger threshold even at HL (Higgs physics → relatively soft leptons, e.g. H2Tau)

**Large rate reduction using bending angle in forward region** (already done in barrel)

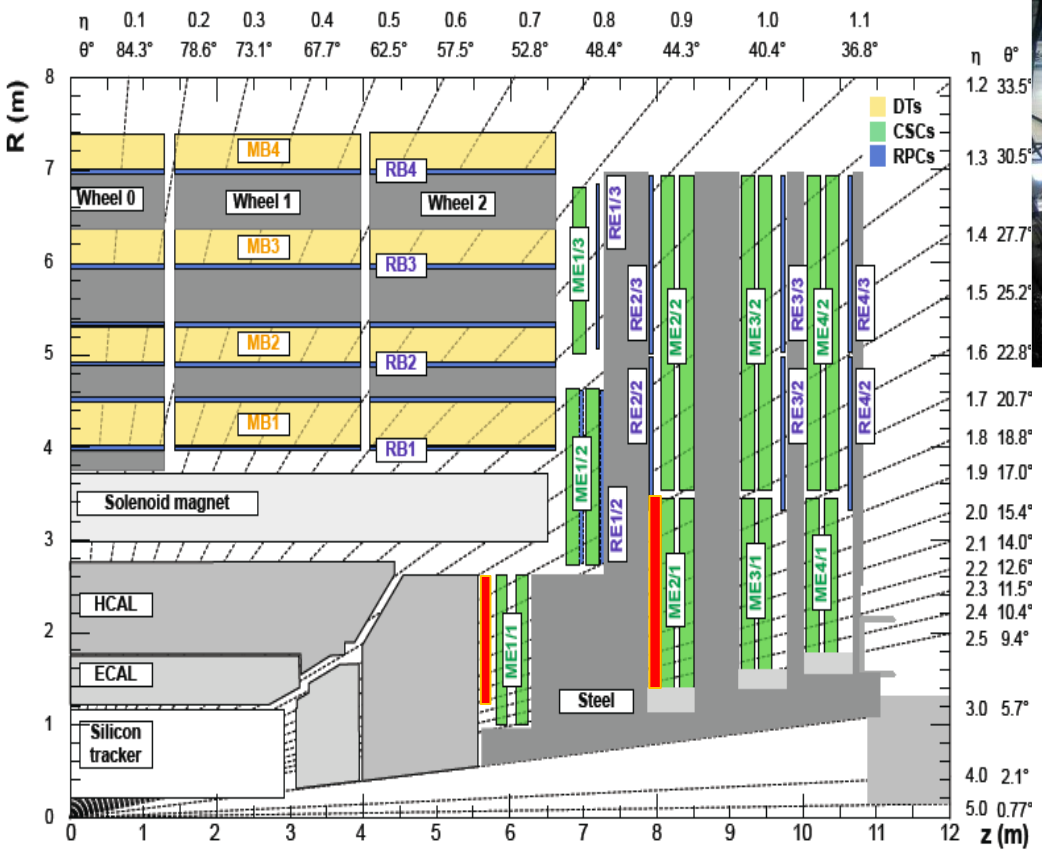
- Need good spatial resolution and rate capability
- Larger lever arms using new detectors and existing CSC chambers in the same station
- Must measure bending angle in station 1. Else radial B-field and multiple scattering quickly diminish discrimination.
- Expect x5-10 rate reduction with new detectors.

# The GEM Extension



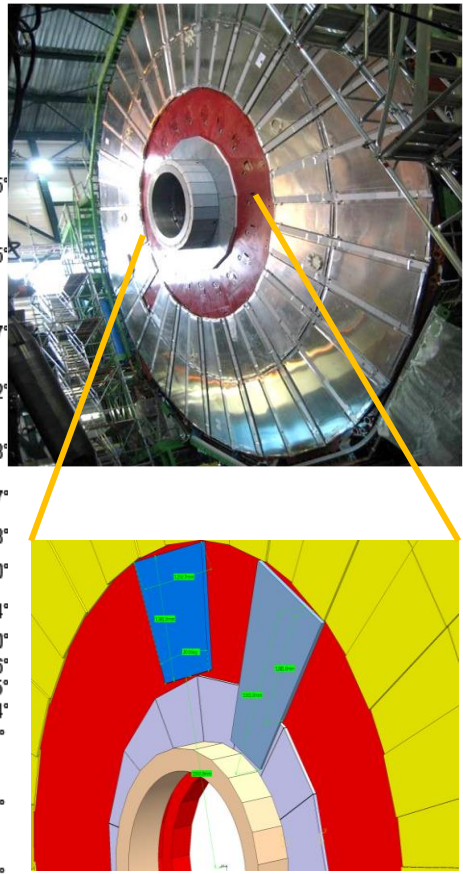


GE1/1




Proposal: double-layered triple-GEM chambers in regions GE1/1 and GE2/1

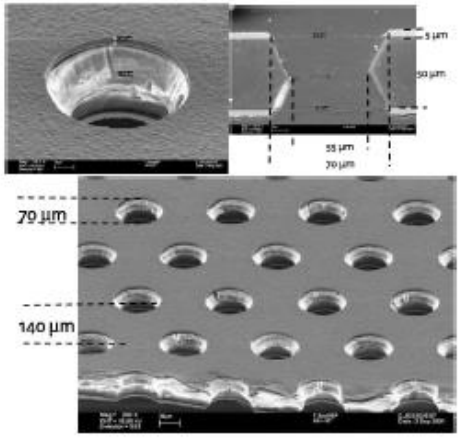
Plan: Installation of GE1/1 in LS2

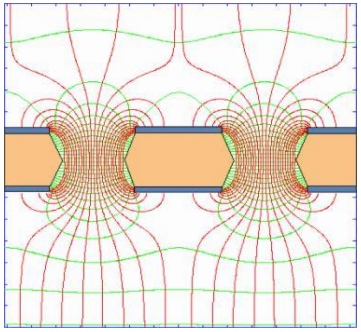


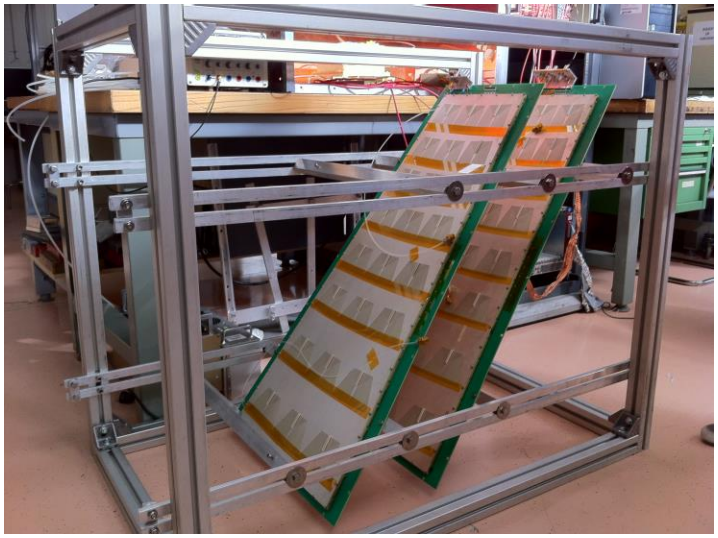
GE2/1

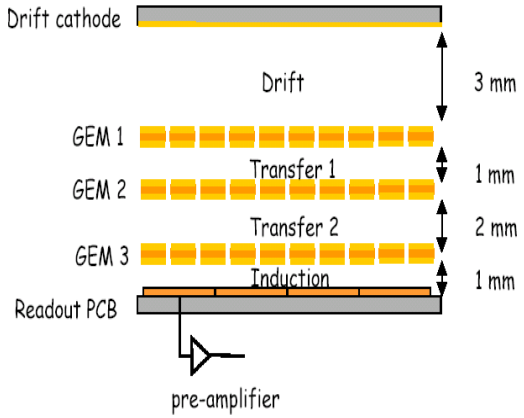
# Triple GEM Detectors for CMS

GEM foil using PCB manufactering techniques. **Large areas ~1m x 2m to be developed.** Several large-size prototypes assembled and tested in testbeams.

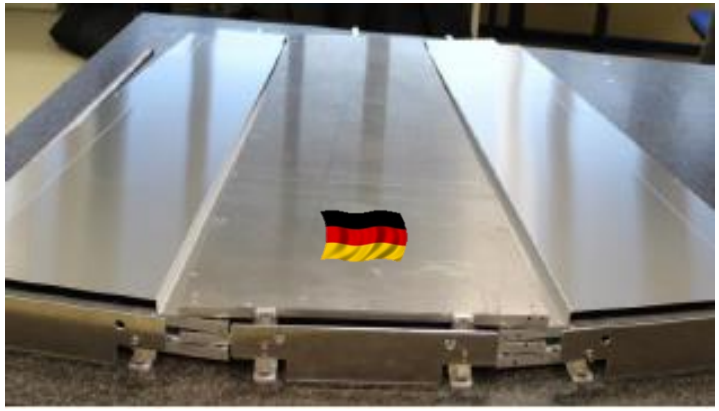






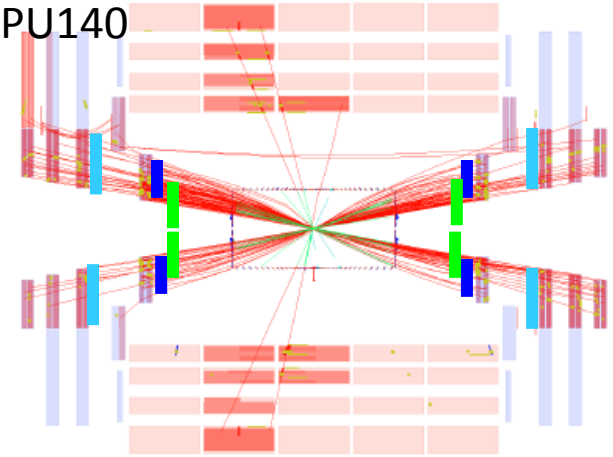

Smaller size GEM detectors operate e.g. in LHCb



For safe operation and high amplification use 3 layers to form a triple GEM.

# Phase 2 Rates Will be High, especially in the Forward Region

PU140

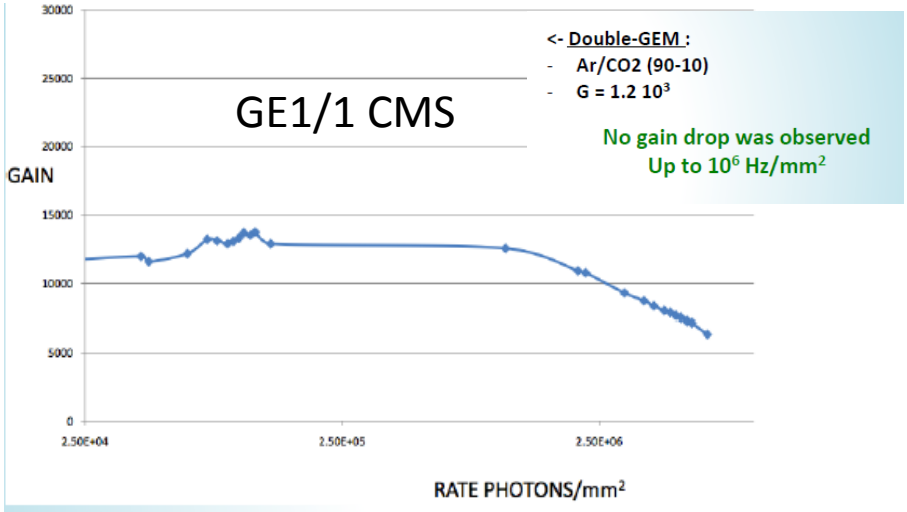


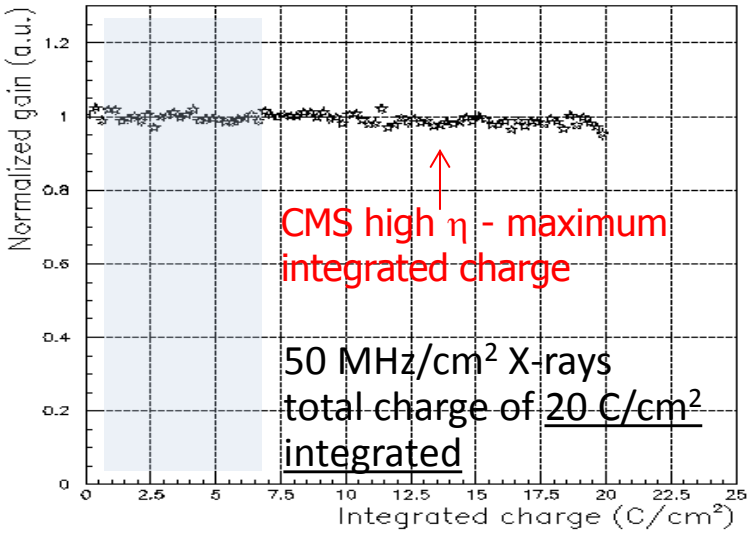
| Detector part | R (cm) | Z (cm) | Flux ($cm^{-2}\ s^{-1}$) for lumi=$10^{34}$ $cm^{-2}\ s^{-1}$ | Flux ($cm^{-2}\ s^{-1}$) for lumi=$10^{35}$ $cm^{-2}\ s^{-1}$ |
|---|---|---|---|---|
| GE1/1 | 150 | 560 | ~$1.4 \cdot 10^{4}$ | ~$1.4 \cdot 10^{5}$ |
| GE1/1 | 180 | 560 | ~$8.3 \cdot 10^{3}$ | ~$8.3 \cdot 10^{4}$ |
| GE1/1 | 250 | 560 | ~$1.4 \cdot 10^{3}$ | ~$1.4 \cdot 10^{4}$ |
| GE 2/1 | 180 | 800 | ~$1.7 \cdot 10^{4}$ | ~$1.7 \cdot 10^{5}$ |
| ME0 | 120 | 540 | ~$6.3 \cdot 10^{4}$ | ~$6.3 \cdot 10^{5}$ |
| ME0 | 20 | 540 | ~$7.2 \cdot 10^{7}$ | ~$7.2 \cdot 10^{8}$ |

← Present shielding

Flux estimates with FLUKA, neutrons (80%) + photons + charged particles. Present shielding, sqrt(s)=14 TeV. PU not included.

## GEM detectors tested up 1 MHz rates and 20 C/cm² integrated charge → no gain drop observed

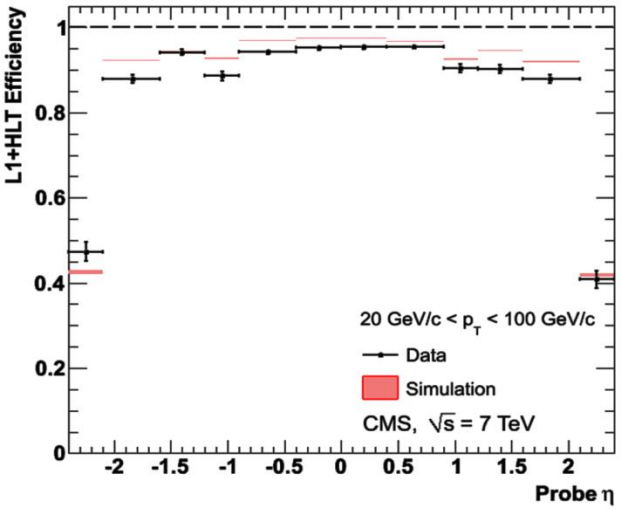


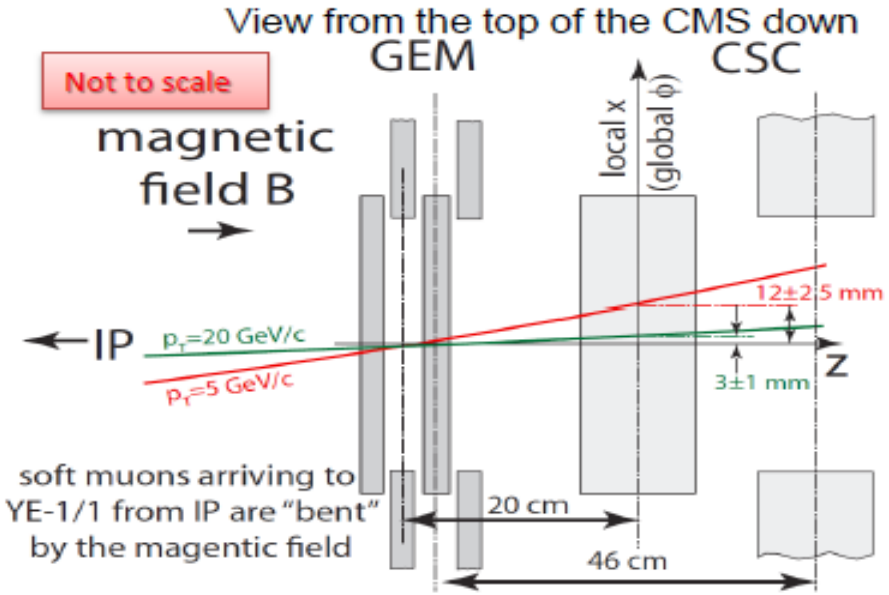
# How GEMs Help the Trigger

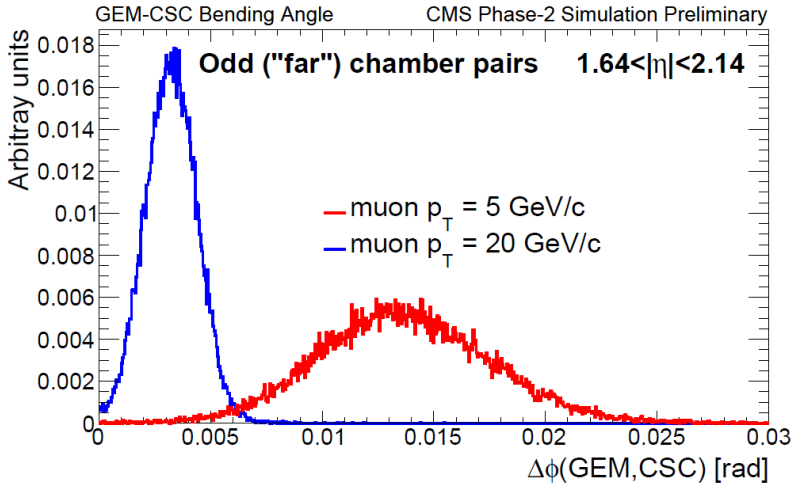
**Forward region |η|>1.6 relies entirely on existing CSC**

- Lower efficiency (by ~2%) 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**



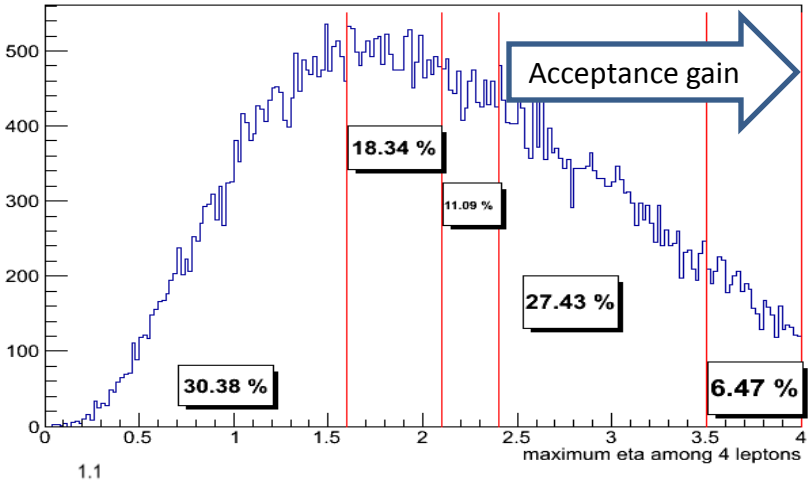



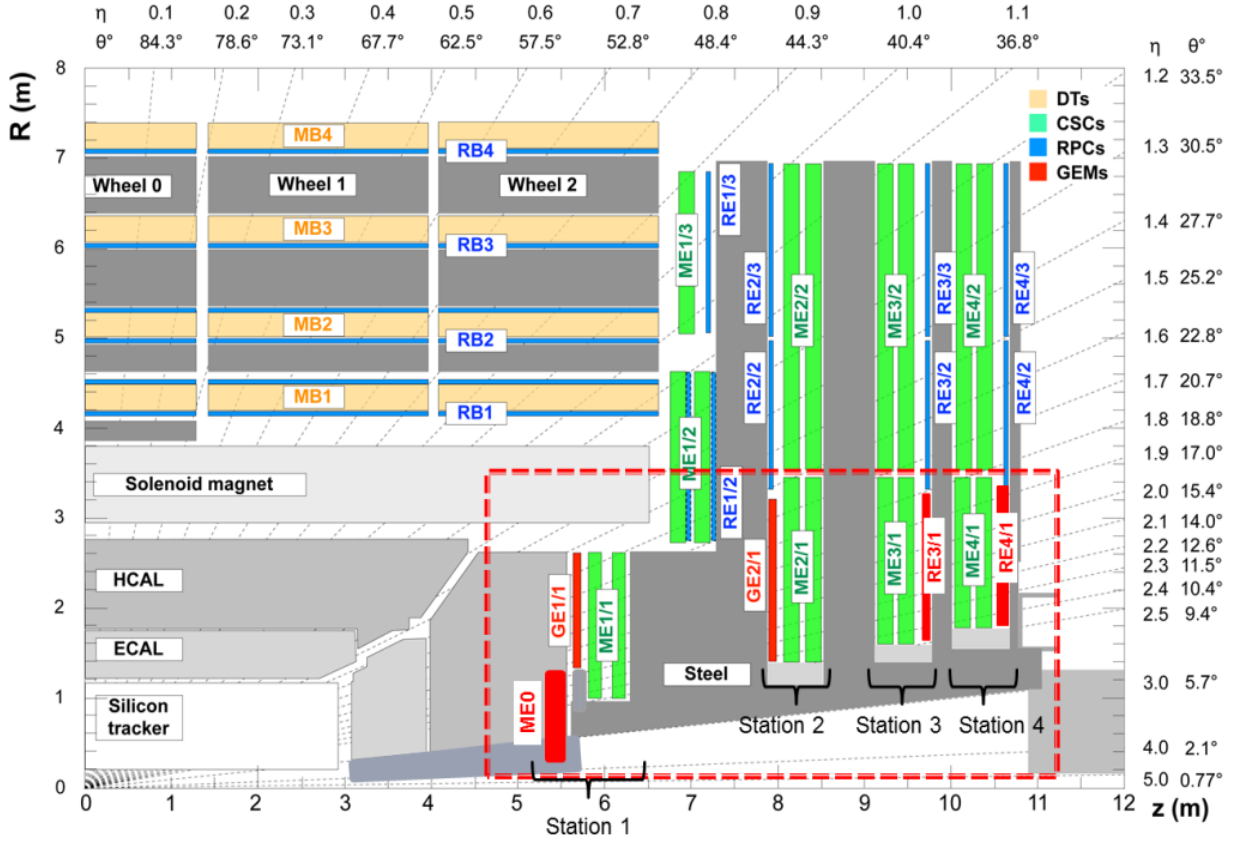
# Going Beyond |η|=2.4 ?

**Very forward region is one place to gain physics acceptance**

Based on plans for tracker extension → also extend muon system up to 3.5….4.0

H→ZZ→4μ : acceptance increase 60%→94% if $\eta_{max}$=2.4→4.0




## Challenges in region |η|>2.4

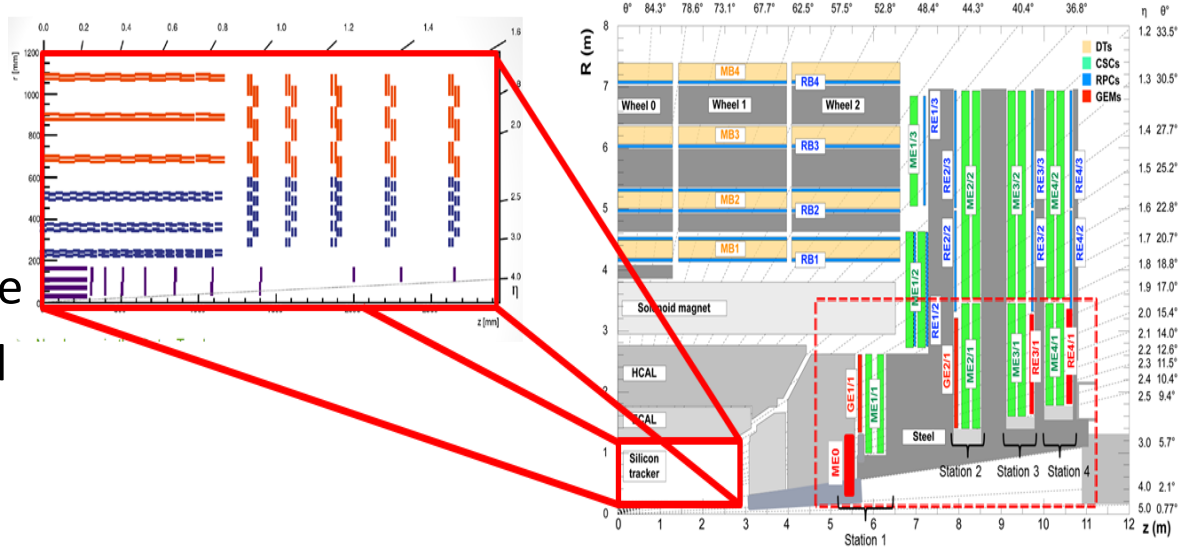
- Highest background rates
- Nearly no B-field in muon system
- Space for chambers

Timeline: TP 06/2014

# Forward Muon Extension

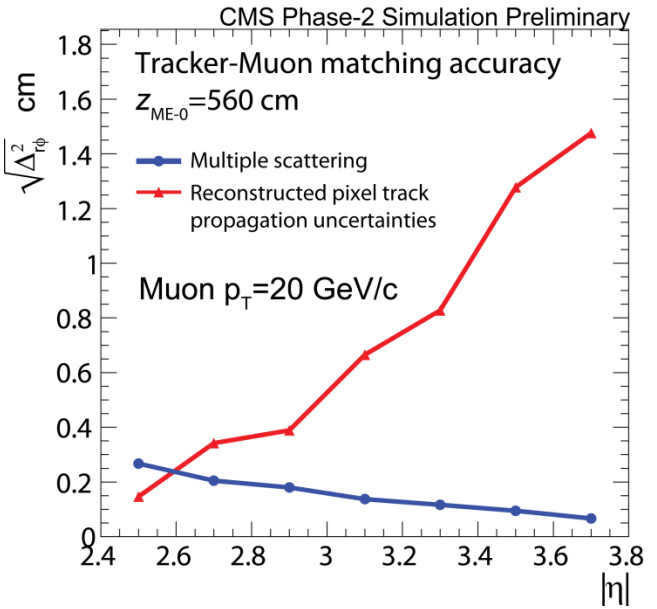
**Extend offline muon coverage to $|\eta|=4$**

- ME0: small area, but nearly doubles CMS muon coverage
- Can be optionally integrated into the new forward calorimeter




**Match muon "stubs" and forward pixel extension tracks**

- ME0 is a multi-layer detector to suppress neutron backgrounds




**High efficiency and low fake rate**

- Resolution is good enough and multiple scattering is low enough in ME0
- Ongoing studies, if muon system can improve momentum measurement

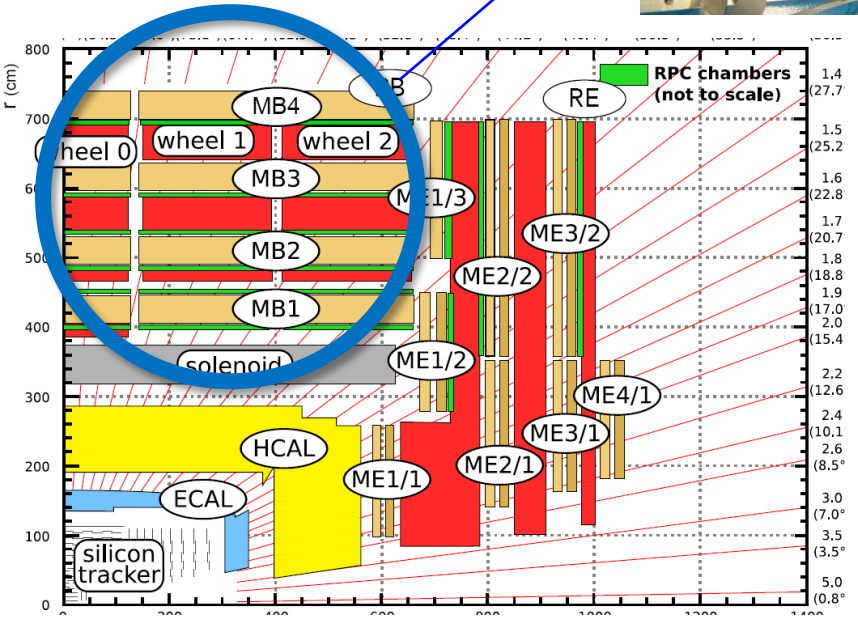
# Impact of CMS Trigger Upgrade on Muon Electronics

**Concept of tracking trigger impacts needed latency and rate**

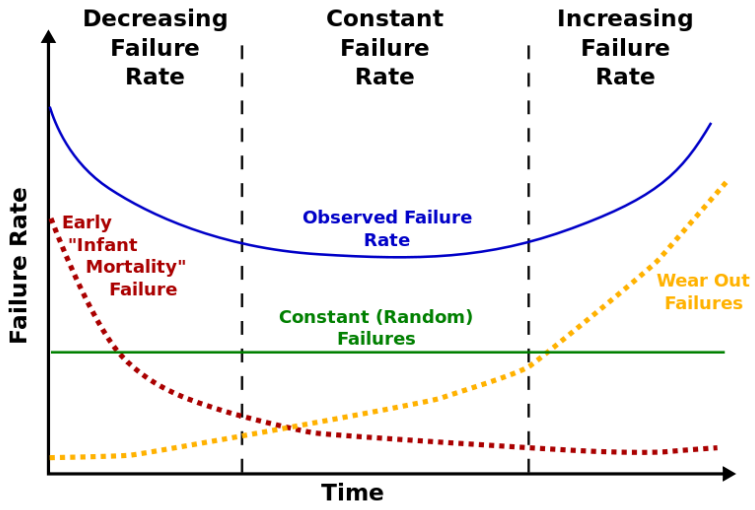
**Level 1 Latency from 3 µs ⇨ 10 µs**

**Level 1 Rate from 100 kHz ⇨ 1 MHz**

L1 rate needs replacement of the DT on-chamber electronics



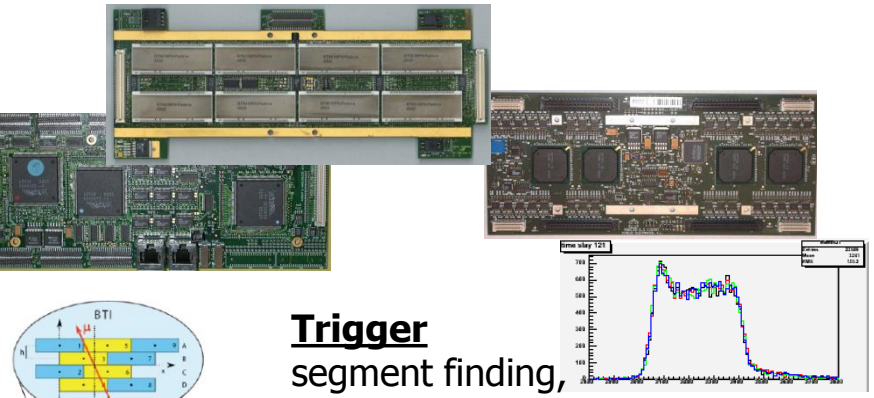

Another argument: electronics is old. Wear-out failure may increase

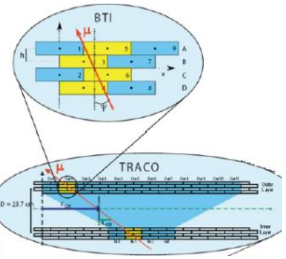


# Upgrade of DT on-chamber electronics

## 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






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

**Readout**
Time digitization
Event matching

## Phase-2 Minicrates

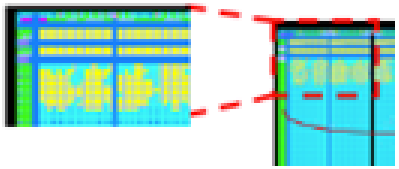
- On-chamber electronics performs time digitization of all chamber signals
- Digital information sent through optical link to the counting room
- Complexity is brought into the counting room

R&D started


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

**GBT** link for data forwarding

Zoom of first 4 TDC channels

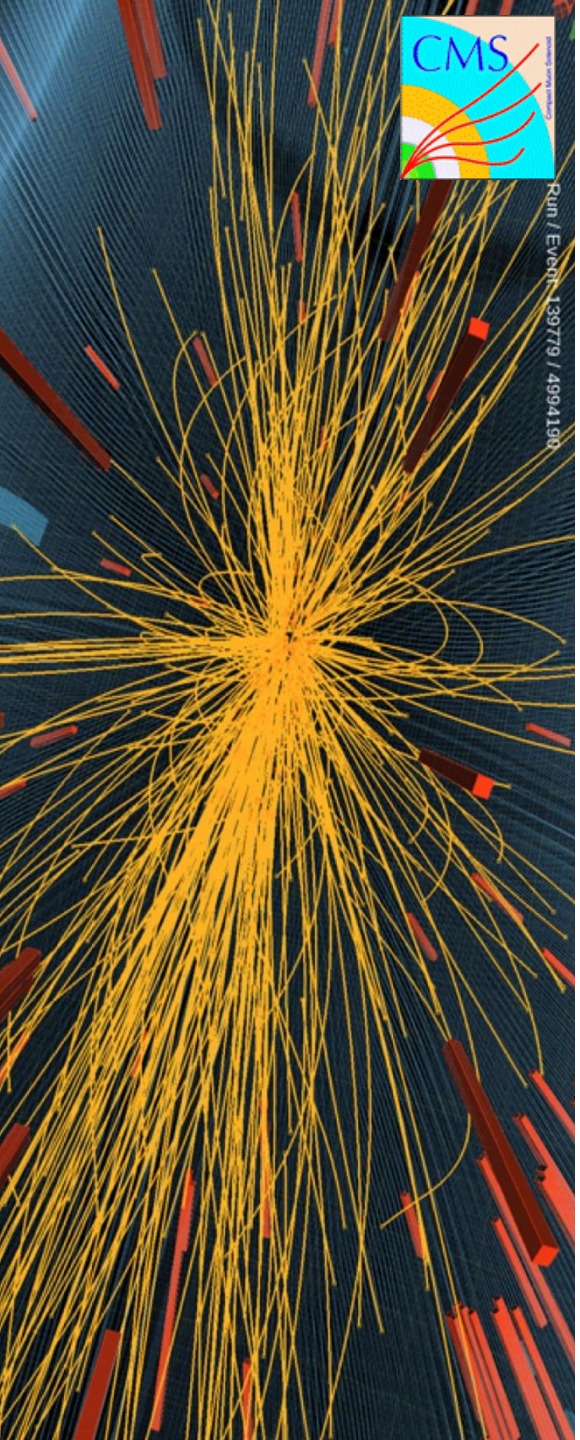


*** Allows readout at 1 MHz Level 1 and 20 us latency**

*** 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 $\eta$
- $p_T$ 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 $|\eta| < 4$ under study, in conjunction with tracker extension. Allows physics gain.
- Upgrade of DT on-chamber electronics to cope with increased latency required by tracking trigger and larger rates.

**Challenging… looking forward to phase-2**