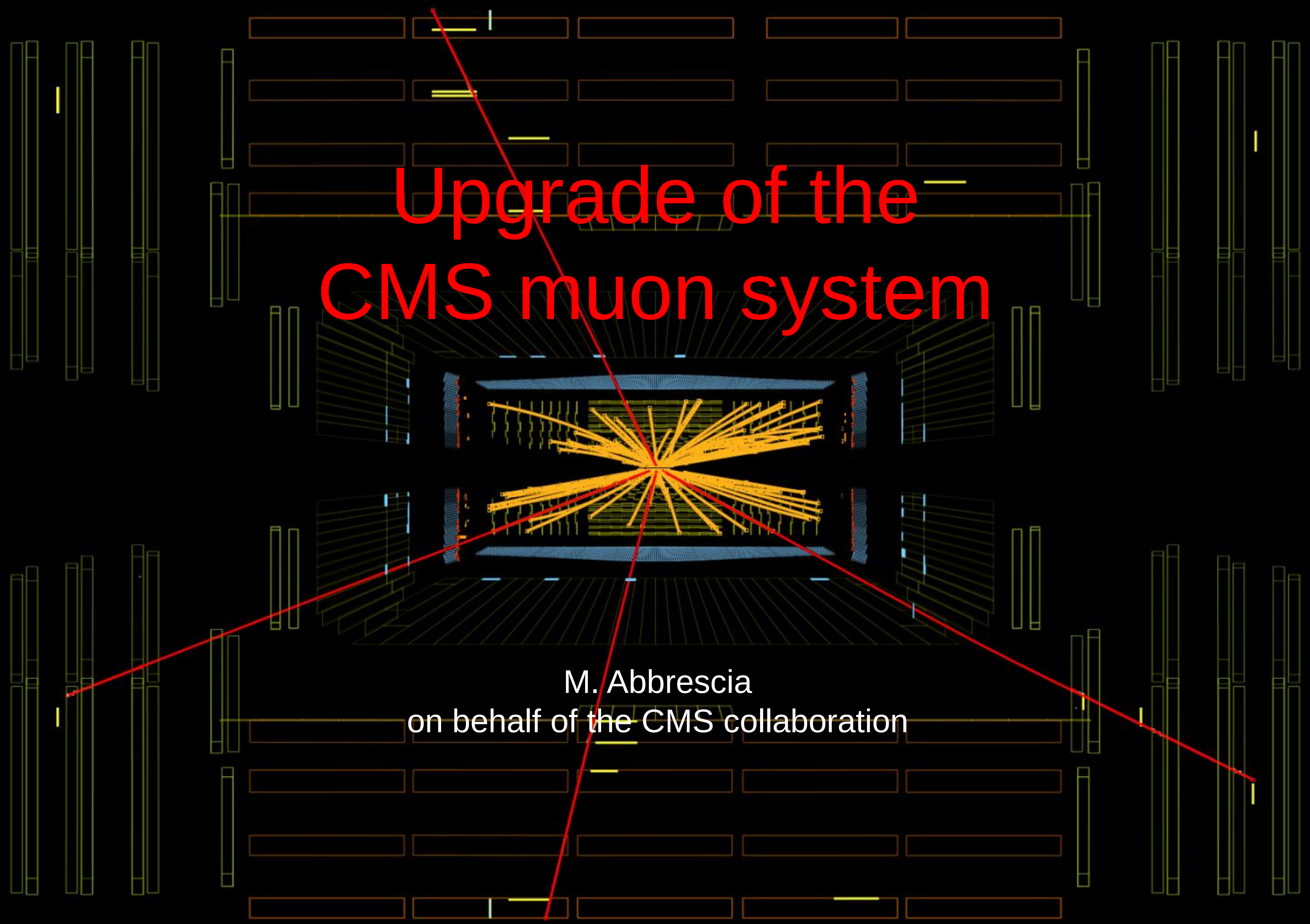


Upgrade of the CMS muon system

M. Abbrescia
on behalf of the CMS collaboration

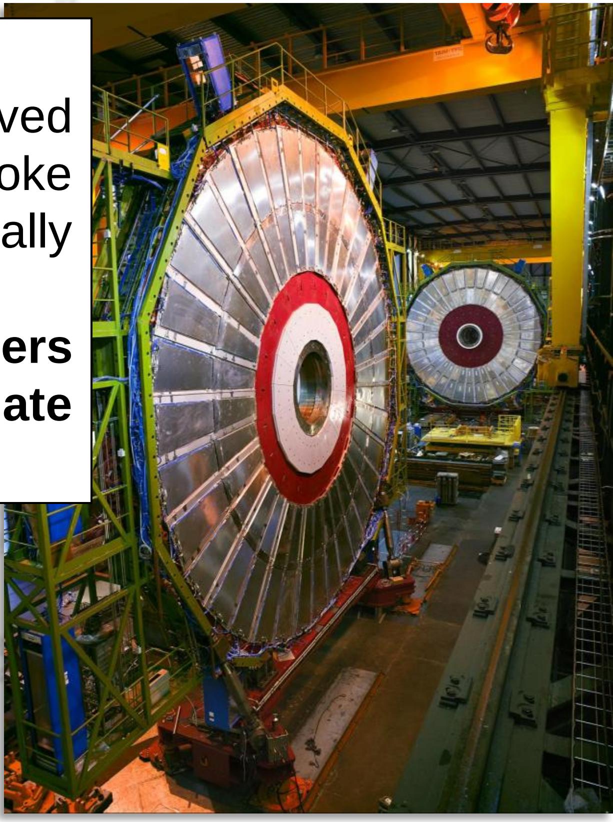
The muon system

A robust, efficient and redundant muon system

- ✓Muon identification
- ✓Measurement of muon transverse momentum
- ✓Bunch crossing (BX) assignment

Planar endcap region:

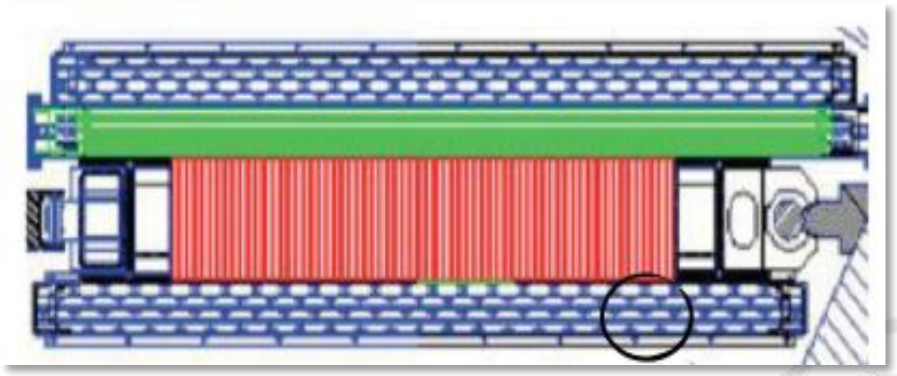
- ✓**4 planar stations** interleaved with the iron return yoke plates (the 4th is partially descoped).
- ✓**Cathode Strips Chambers and Resistive Plate Chambers**



Cylindrical barrel region:

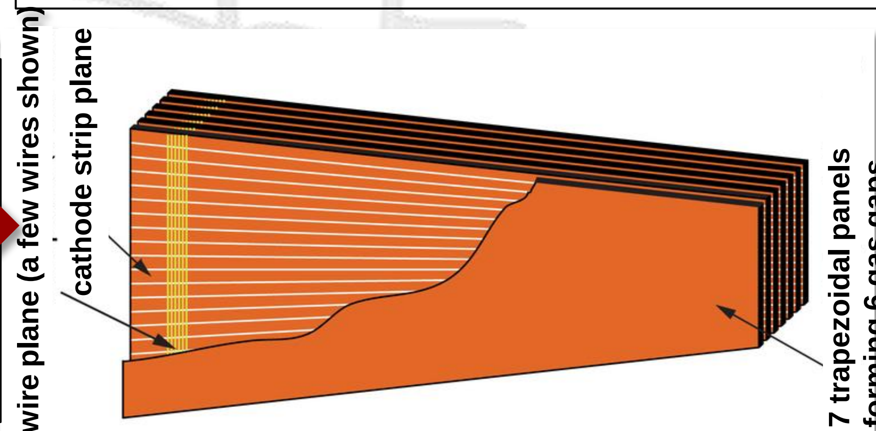
- ✓**4 coaxial stations** interleaved with the iron return yoke plates. The stations are grouped into **5 wheels** around the beam line
- ✓**Drift Tubes and Resistive Plate Chambers**

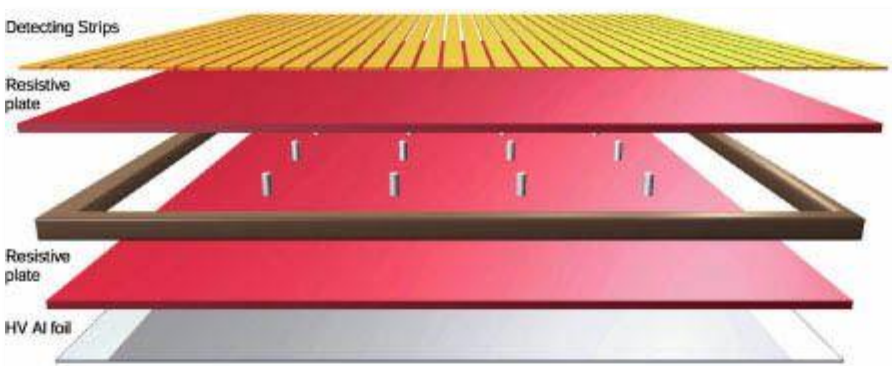
The detectors



- **250 Drift Tube Chambers**
  - Barrel region, for |η|<1.2
  - 4 stations, 5 wheels, 12 sectors
  - (4+4) layers measuring *Φ*
  - 4 layers measuring z in stations 1-3
  - Local segment per chamber
  - Spatial resolution ~ 250 μm

- **540 Cathode Strip Chambers**
  - Endcap region, for 0.9 <|η| < 2.4
  - 2×4 stations, 1-3 rings, 18-36 sectors
  - 6 layers of strips per chamber measuing *Φ*
  - 6 layers of anode wires per chamber measuring *r*
  - Local segment per chamber
  - Spatial resolution ~ 150 μm





- **480 + 432 Resistive Plate Chambers**
  - Both regions, for |η|<1.6
  - Barrel: 4 stations, 1-2 layers, 5 wheels,12 sectors
  - Endcap: 2×3 stations, 2 rings, 36 sectors
  - Local hit per chamber
  - Time resolution < 3 ns

…and their excellent performance

DT average local trigger efficiency

93.5 % in 2011 and 93.7 % in 2012

✓lower efficiency points due to the crack between W+1 and W-1

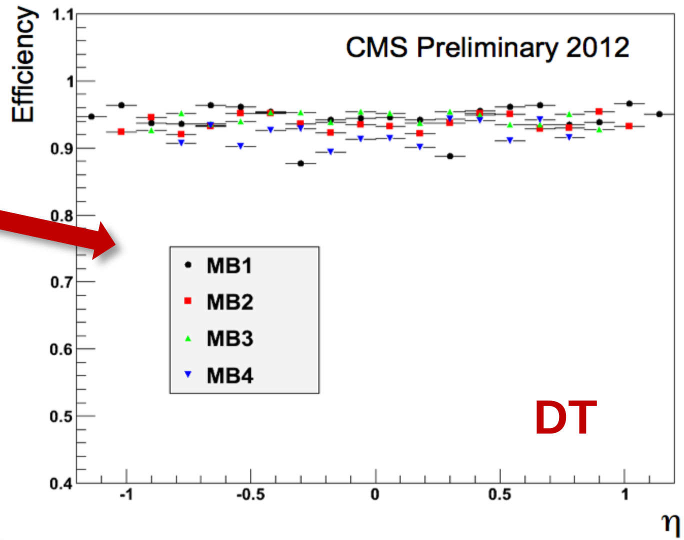
CSC efficiency for ME1 trigger primitives

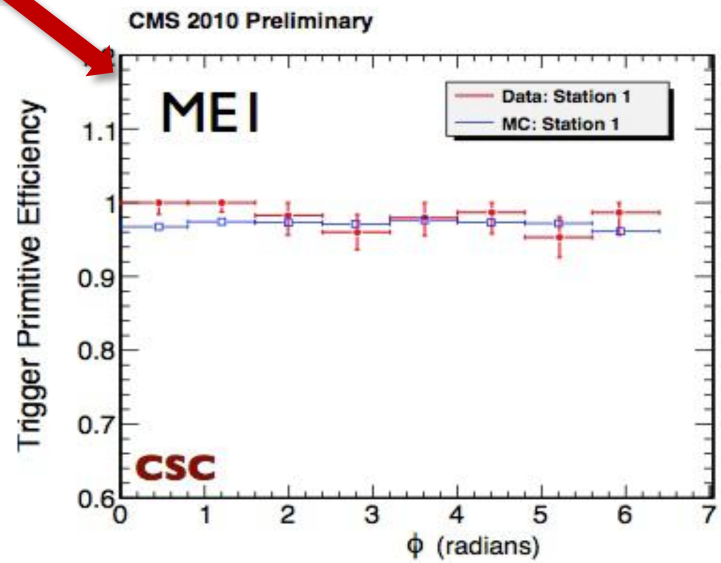
✓similar result for other stations

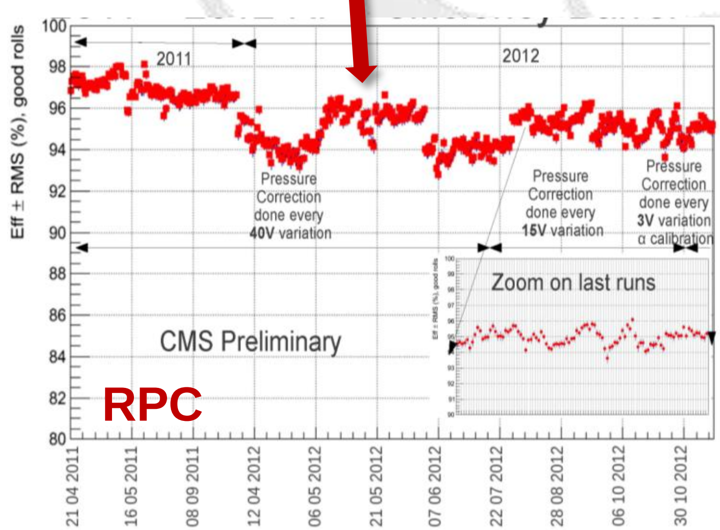
RPC efficiency, in 2011-12

✓different p correction algorithms applied

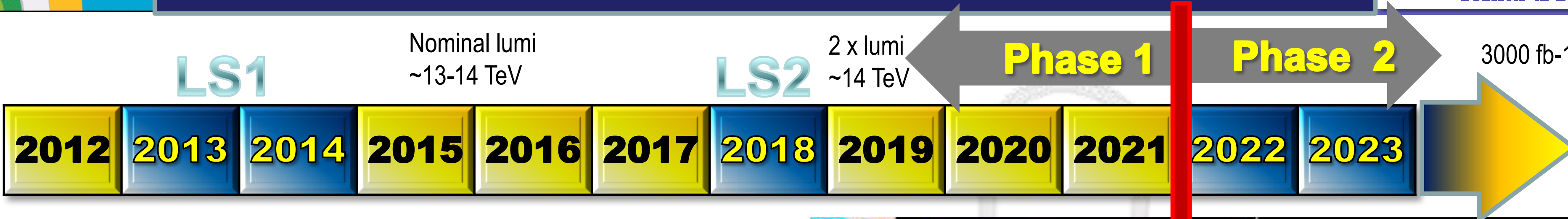
✓average efficiency in 2011: 93.97 %







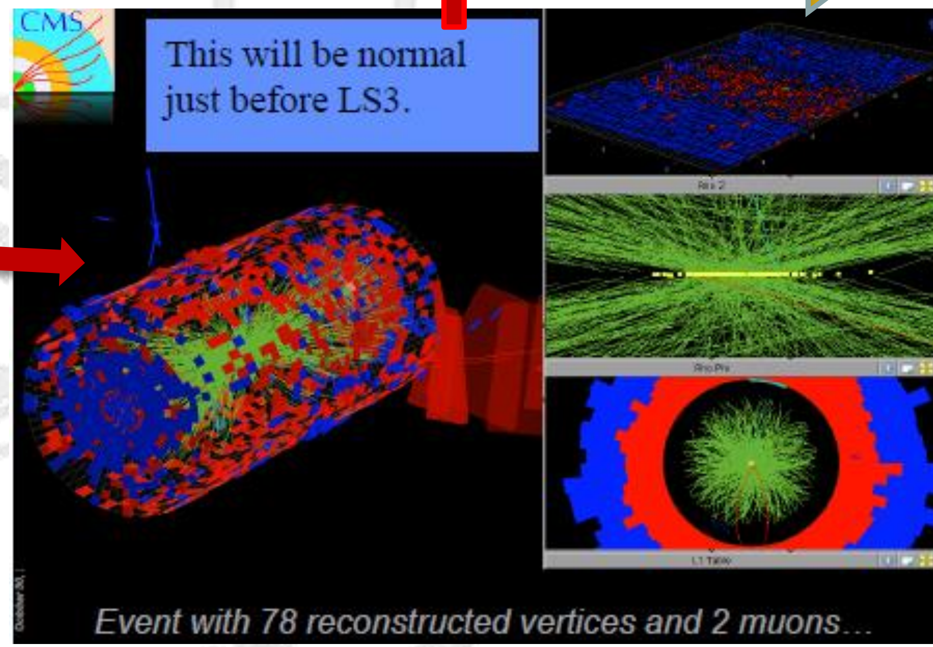
LHC luminosity evolution



LS1 → LS2:
- $\mathcal{L}$ < 2 x 10^{34}, 120 fb^{-1}@ 13-14 TeV

LS2 → LS3
- 400 fb^{-1},<μ> ≤ 70

Phase II
- 250 fb^{-1}/year
- 3000-5000 fb^{-1} in 2030s
- Peak luminosity: ~5 x 10^{34}

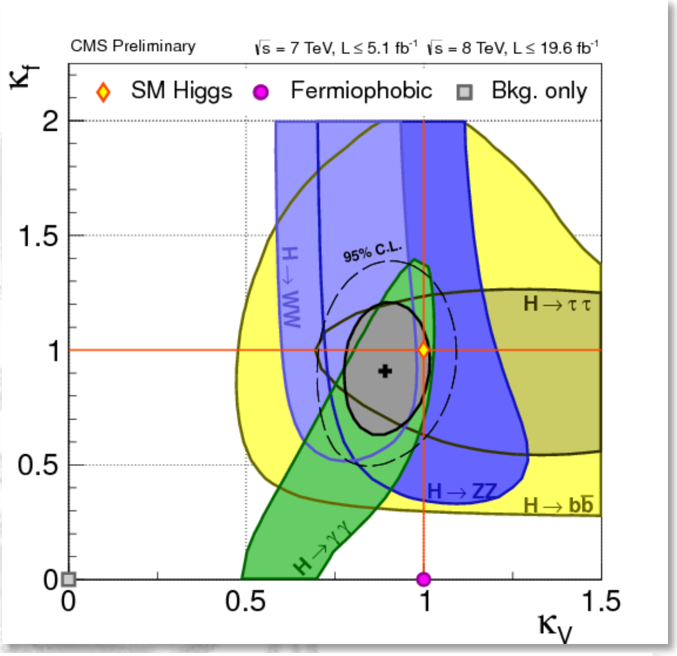


Phase II (post LS3, 2022-23) essentially means integrated luminosity, Pile Up, etc. an order of magnitude greater than the design values of the LHC experiments

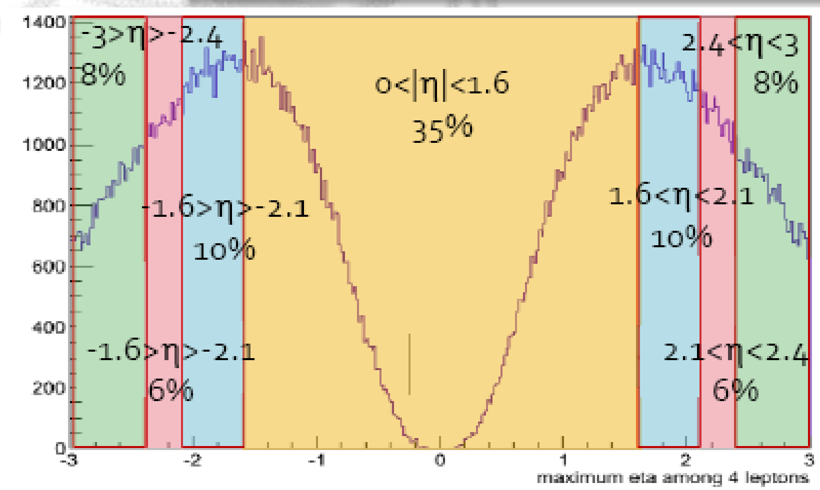
…And the detectors will be more than 10 years old!

Muon system and physics reach

- Conservative scenario: focus on precision measurements on Higgs coupling
- Muon system is critical for both bosonic and fermionic couplings:
  - ✓H → WW and ZZ are key to the precision on HVV couplings
  - ✓H → τ τ is key for measuring fermion coupling
    - ✓Muon + hadronic tau is the most sensitive channel; fully relies on muon trigger



- H → ZZ → 4μ channel:
  - ✓Acceptance increases by 30% if muon reconstruction coverage extends from $|\eta_{max}|$ 2-4 → 3.5



Need to get that "last" muon"!

Strategies for muon upgrades

- Mantain current offline and trigger coverage - especially important to strenghten the region 1.8-2.0 < |η| < 2.4 despite increasing luminosity and Pile-Up

Baseline

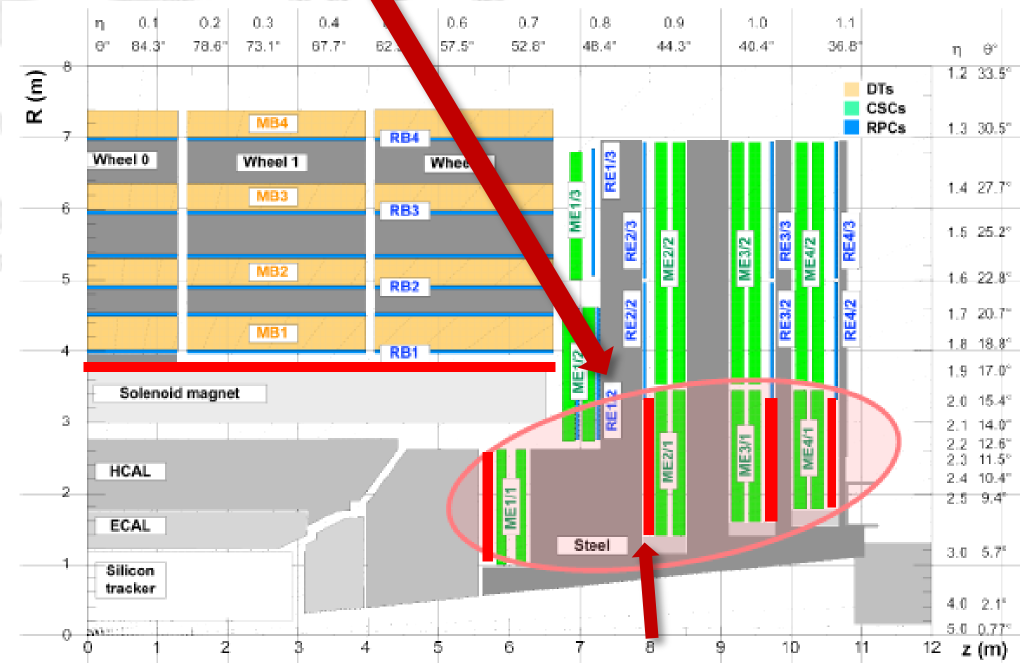
- ✓ May require additional redundancy, i.e. additional stations
- ✓ Obvious existing space where RE1/1 , 2/1, 3/1, 4/1 were envisioned
- ✓ Technologies considered: GEMs, Glass and other improved RPCs,…)

Increase of the muon tagging coverage up to 2.4 < |η| < 3.5-4.0

- ✓Offline verification of a high-Pt track being a muon
- ✓Adds acceptance for muons, could improve MET resolution and recognition

Increase muon trigger coverage into 2.4 < |η| < 3.5-4.0

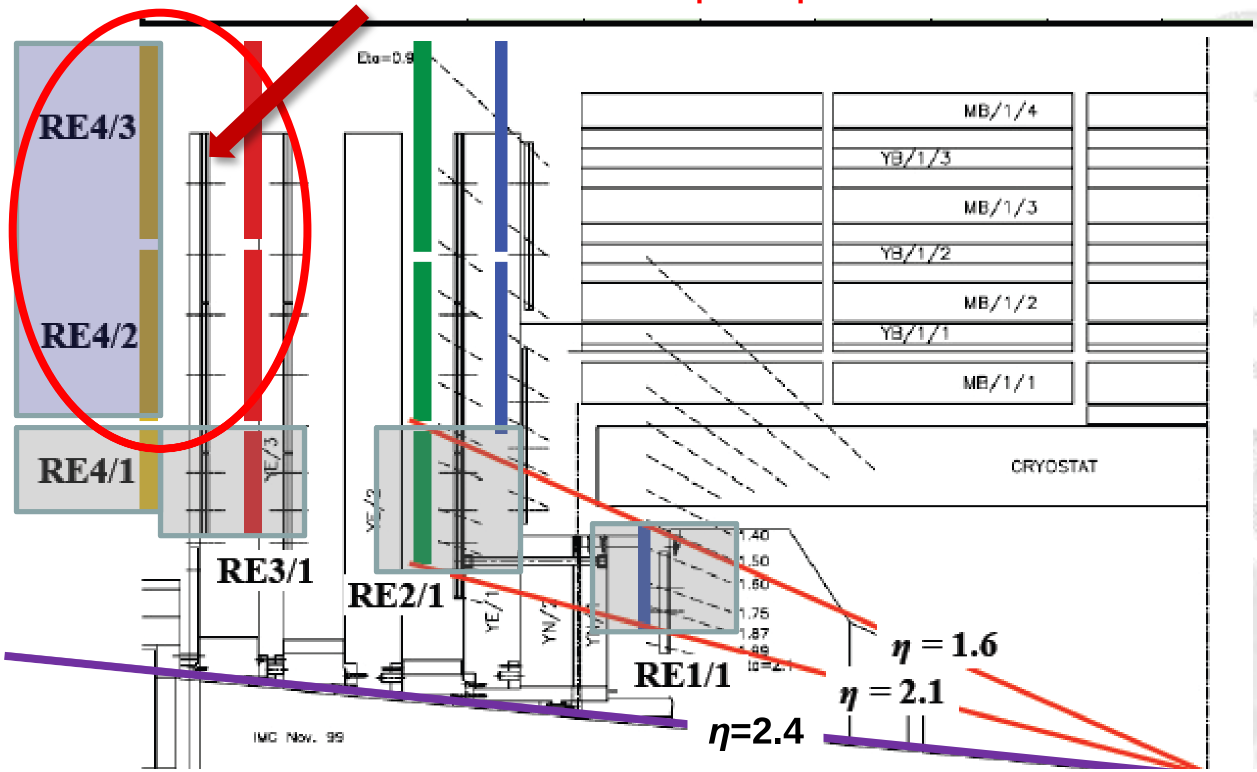
- ✓Need a new magnetic field, solenoidal is insufficient



|η| < 2.4 - highest rate and least redundancy

First step toward the "upgrade" of the muon system

RPC forward upscope

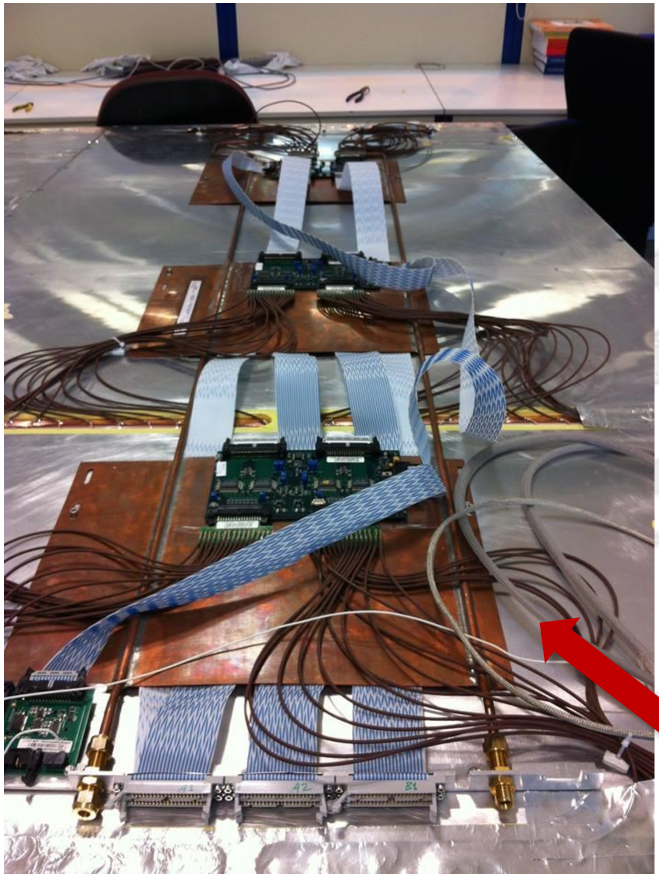


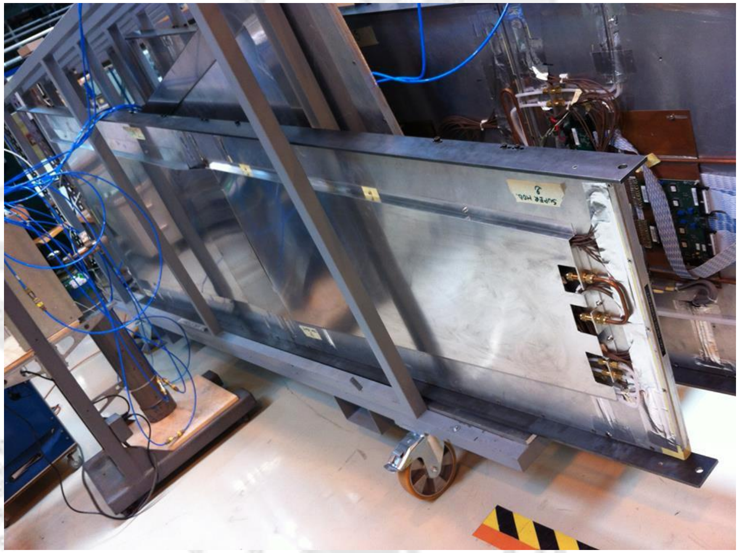
The CMS Forward Muon RPC system presently consists of 3 endcap stations and is equipped with chambers up to |η|=1.6, while the CMS Muon Technical Design Report describes a system with 4 stations and a detector up to |η|=2.1

Complete the system with the fourth station and achieve better trigger performance and robustness of the system, as it was originally designed

RPC endcap upscope

GOAL: Install the 4th layer - 144 chambers! (RE4/2-3) - during LHC LS1 (2013-2014) to complete the system up to $|\eta|=1.6$.





Construction sites: CERN, Korea, India, Belgium
Final QC and commissioning @ CERN

Huge organisational effort!

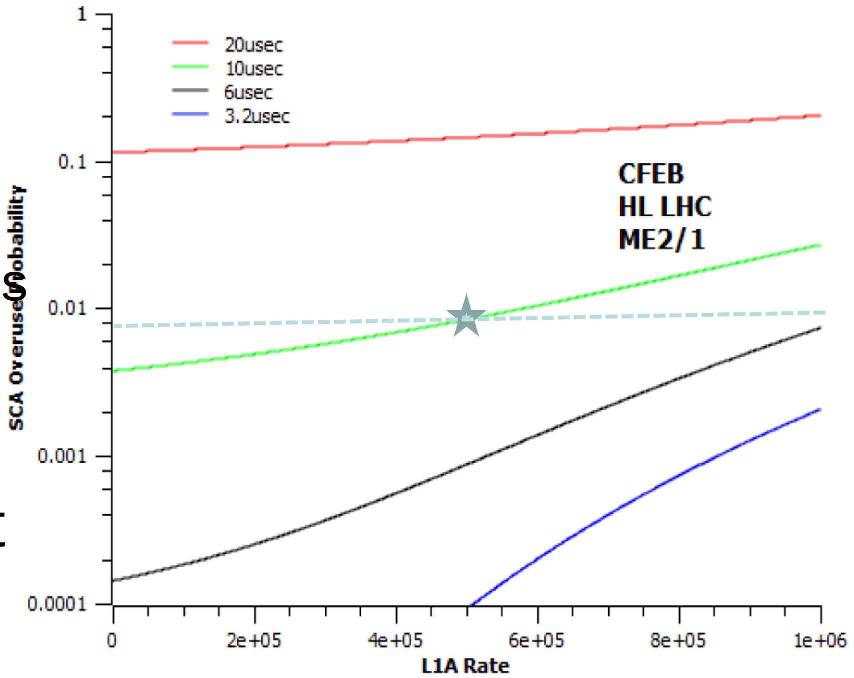
- ✓First Super-Module (pairs of RE4/2 and RE 4/3) assembled some weeks ago
- ✓53/144 chambers built so far
- ✓10/72 super-modules ready

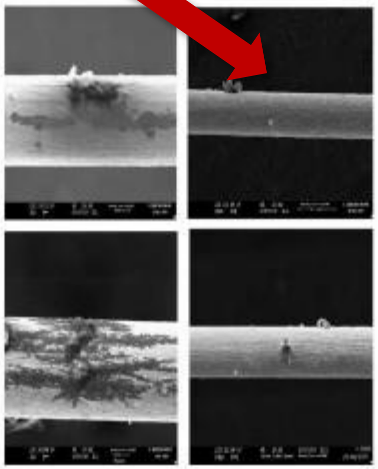
Marcello Abbrescia

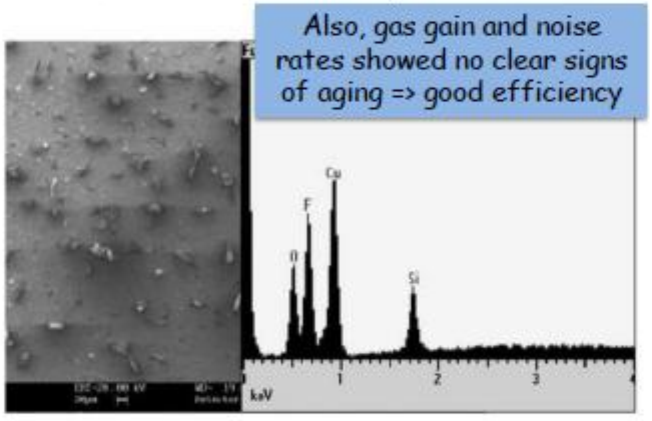
CSC upgrades phase II

1. Trigger latency and rate increase
   - At Phase 2 baseline 10 μs and 500 kHz lose ~1% of cathode data,
     - Plan to replace CFEBs if latency is to exceed 10μs
2. ME1/1 chamber aging tests
   - ✓ Aging effects measurable, but not found to inhibit chamber performance

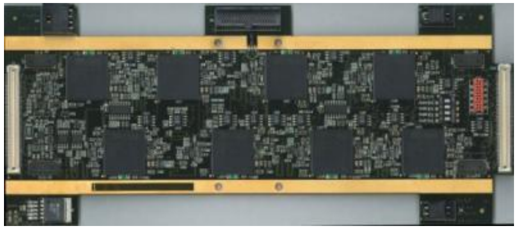
- Otherwise, no particular upgrades anticipated







DT upgrades, up to 2017



New θ TRB (Trigger board)

Sector collector re-location

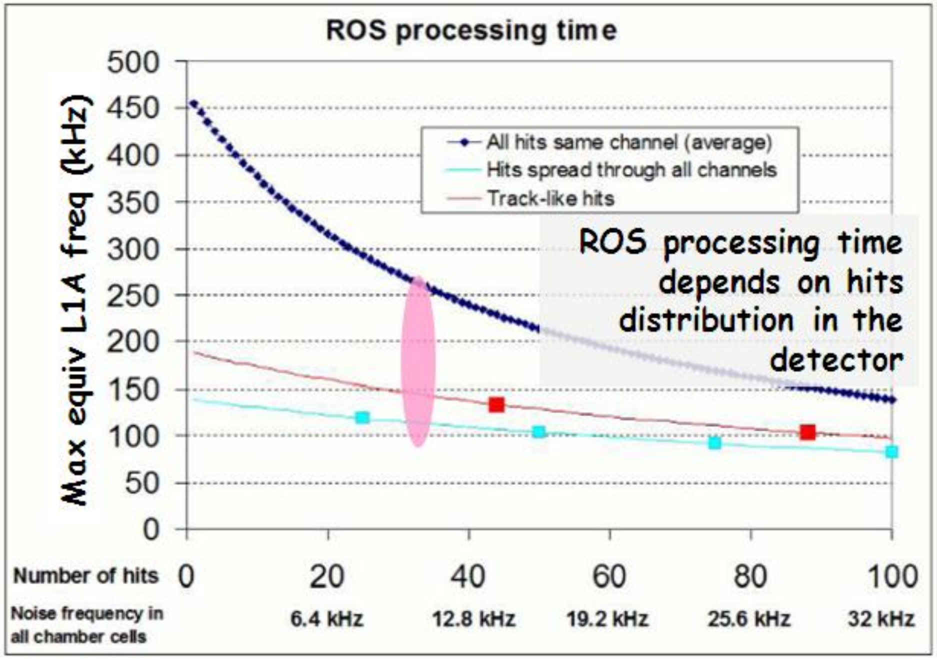
Guarantee reliable operation and allow future upgrades

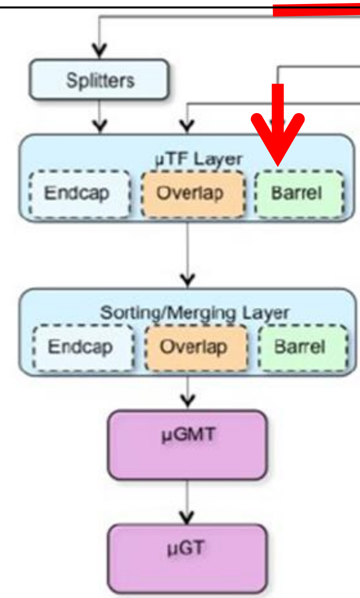
Copper links transduced to optical to cover cavern-counting room distance (65 m)

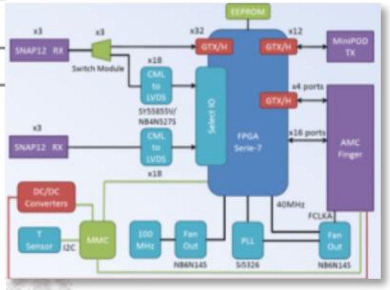
New faster Read Out server

Luminosity increase will affect processing speed of the Read-Out-Server (ROS) boards

Will reuse Twin Mux hardware (based in high speed standard uTCA)







New multiplexer (Twin Mux)

High speed data to CMS L1 Trigger Track Finder system

Full chamber trigger information forwarded

Aim to allow merging information from other subdetectors (RPC, etc)

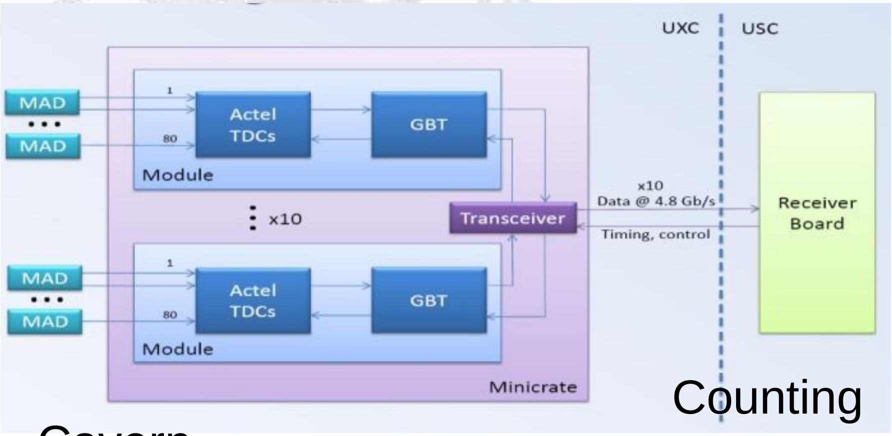
DT upgrades for Phase II

No indications of aging effects during LHC, nor in previous dedicated tests
Plan to take preventive actions (HV, gas, etc)
Perform simulations of the impact of chamber aging (efficiency loss, noise, etc)
Pile-up effects also reevaluated in complex regions

New Minicrates: chamber digitization

Evaluating radiation and longevity of present Minicrates
R&D in new design: time digitization and direct data forwarding (fundamental architectural differences)
Simple, robust and low power
A trigger primitive generator using readout data could be developed (it should provide better resolution)

Chamber longevity studies



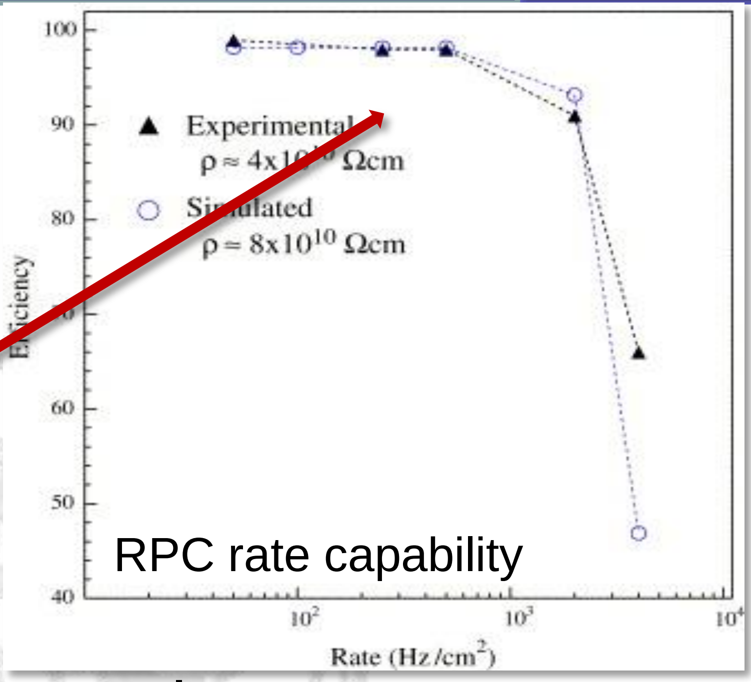
Cavern

Counting room

Basic requirements during Phase II

➢All detectors foreseen for post-LS3 with the aim of restore redundancy or increase coverage should stand a rate capability higher then the present

- ✓Because installed in high-η regions
- ✓From 1 kHz/cm² → 5-10 kHz/cm²



➢In addition we could be willing to improve also:

- ✓Time resolution – from o(1 ns) → o(100 ps)
- ✓Spatial resolution – from o(1 cm) → o(1-0.1 mm)

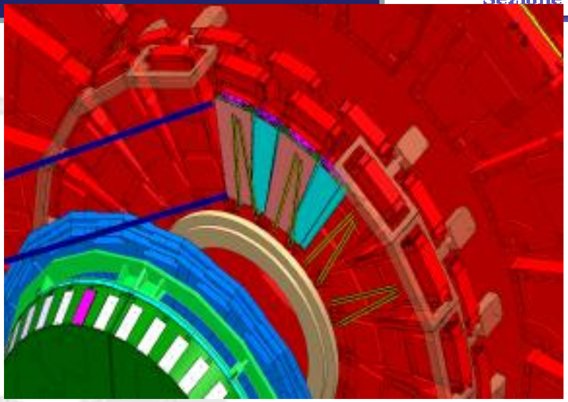
Given requirement on rate capability, choice of the technology will be driven by the physics case:

- ✓plus robustness, cost, easiness of construction, etc.

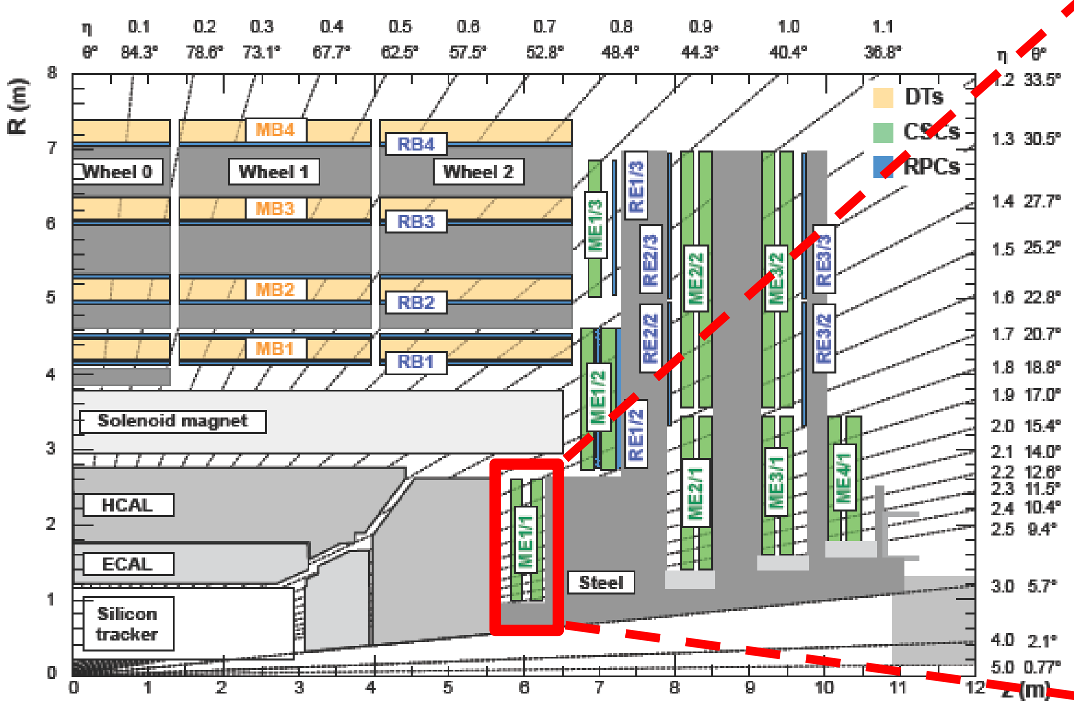
For instance, o(100 ps) would push us toward RPC multigaps solutions

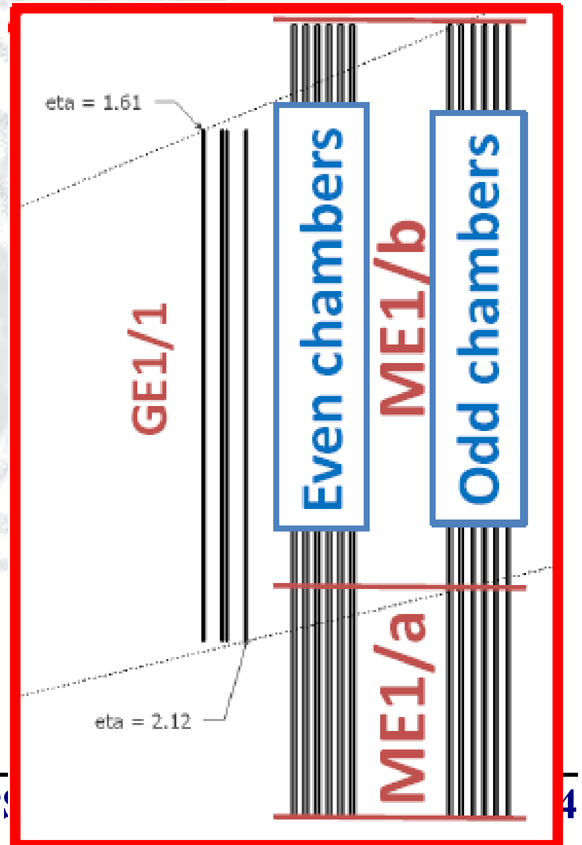
The GEM project: GE1/1

After LHC LS1 the |η|< 1.6 endcap region will be covered with 4 layers of CSCs and RPCs; the |η|>1.6 region (most critical) will have CSCs only!

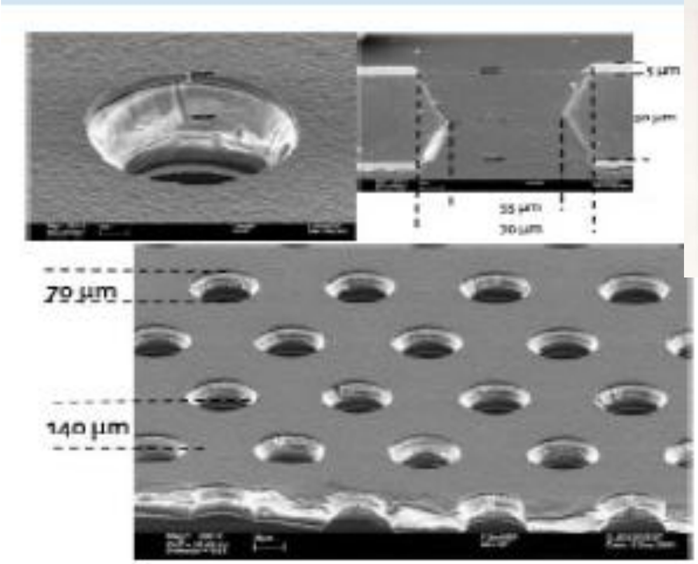


✓Restore redundancy in muon system for robust tracking and triggering
✓Improve L1 and HLT muon momentum resolution to reduce or maintain global muon trigger rate
✓Ensure ~ 100% trigger efficiency in high PU environment





The technology: Gas Electron Multipliers



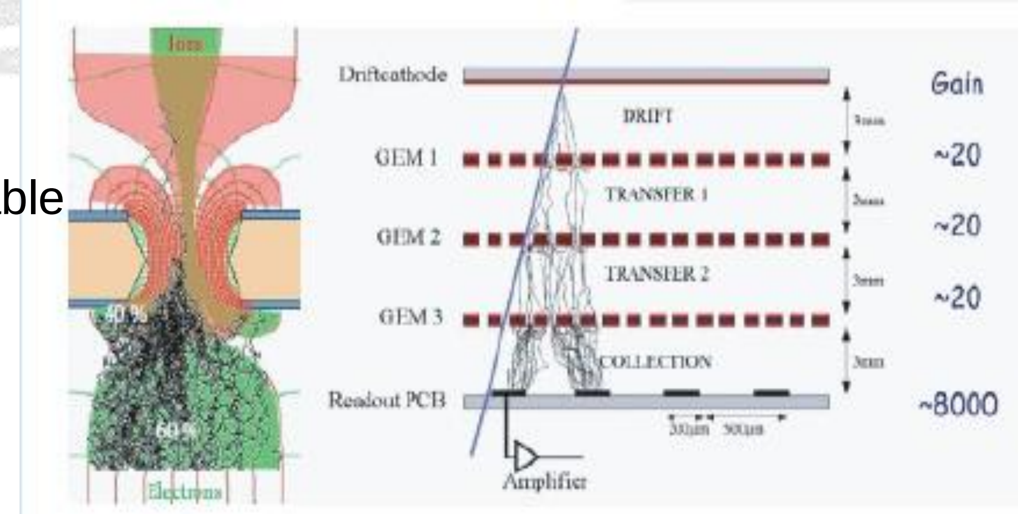
Developed by F. Sauli in 1997

Each foil (perforated with holes) is a 50 µm kapton with copper coated sides (5 µm)
Typical hole dimensions: Diameter 70 µm, pitch 140 µm

- ➢Electron multiplication takes place when traversing the holes in the kapton foils
- ➢Many foils can be put in cascade to achieve $O(10^4)$ multiplication factors

Main characteristics:

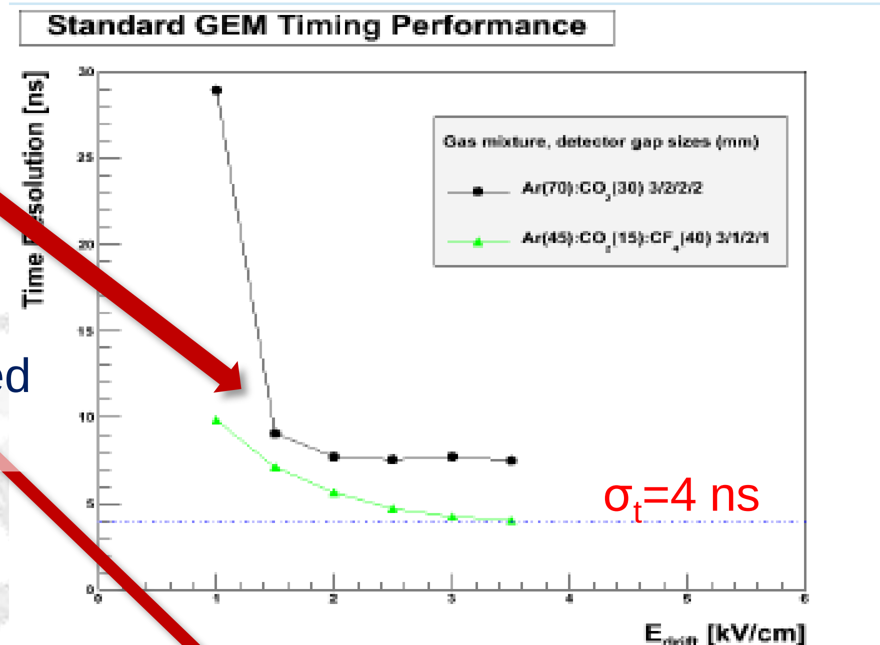
- ✓ Excellent rate capability: up to $10^5/cm^2$
- ✓ Gas mixture: $Ar/CO_2/CF_4$ – not flammable
- ✓ Large areas ~1 m x 2m with industrial processes (cost effective)
- ✓ Long term operation in COMPASS, TOTEM and LHCb

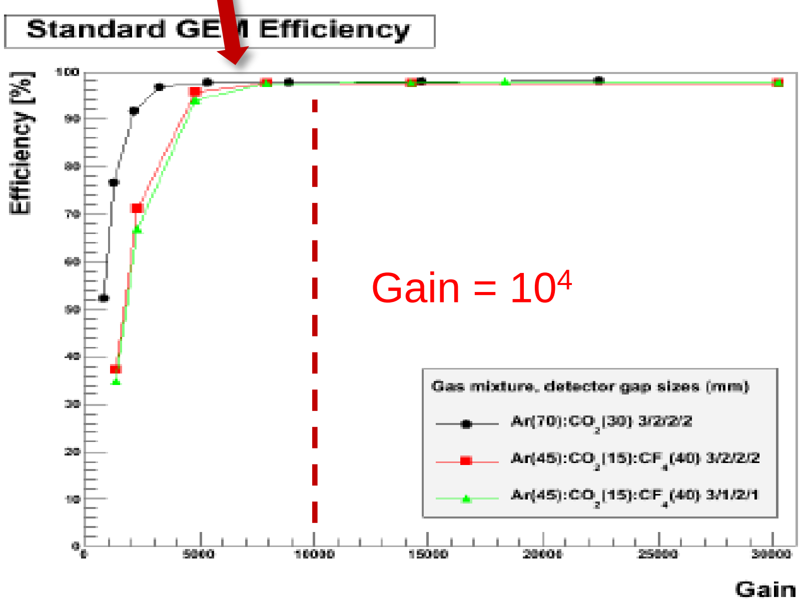


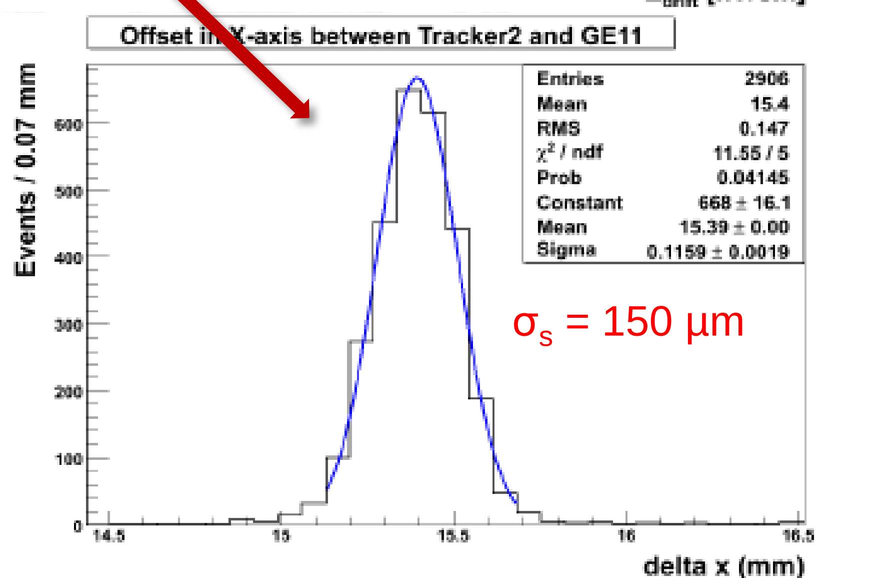
Detector performance

- ✓Very good time resolution
  - Depending critically on the gas mixture
  - Long R&D on gas (and other issues)
- ✓Excellent spatial resolution
- ✓Full efficiency at 10^4 overall gain

A new VFAT3 baFE electronics being devoped to fully profit from all these caracteristics

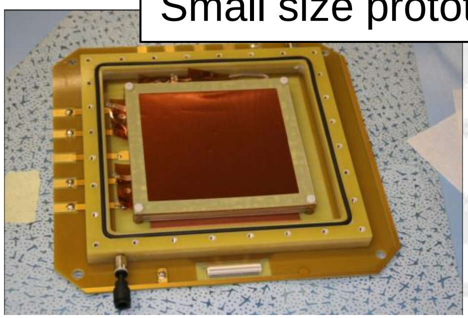




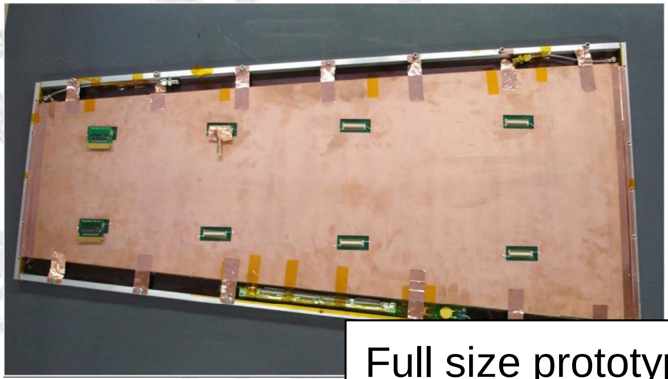


Path to approval

- Over 4 years of R&D started since 2009 in the RD51 framework
- ✓ CMS GEM Collaboration established in 2011 with about 120 people from 20 institutes; today about 40 institutes and 180 people
- ✓ R&D for a *High-η Trigger and Tracking Detector for CMS*, SLHC RD 10.02 approved in April 2012, after submission of Technical Proposal for GE1-2/1 in LS2



Small size prototype (2009)



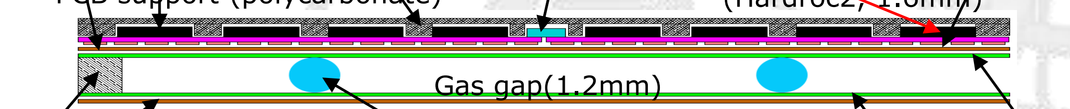
Full size prototype (201)

- Approval for developing prototype DAQ and installing slice (= GEM demonstrator) in 2016-17 to demo GE1/1 incorporation into trigger
- Current expectation is that GE1/1 will be included in Phase 2 Technical Proposal, with intent to install during LS2
  - ✓ GEM Demonstrator = 2 Super Chambers covering a 20° sector
  - ✓ LS 2 complete project: 2x36 Super Chambers (144 triple-GEMs)

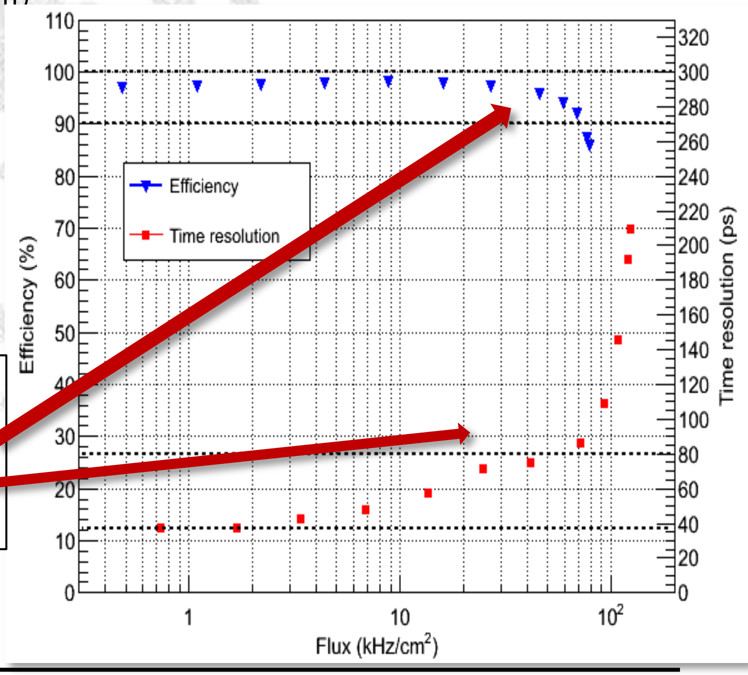
And beyond… R&D on glass RPC

New "low" resisitivity (10^{10} Ωcm) glass used for high rate RPC

✓RPC rate capability depends linearly on electrode resistivity
✓Smoother electrode surfaces → reduces the intrinsic noise
✓Improved electronics characterized by lower thresholds and higher amplification
✓Single and multi-gap configurations under study



Excellent performance at localized beam tests
✓Rate capability ~ 30 kHz/cm² (multi-gap)
✓Time resolution 20-30 ps



Conclusions

- The **CMS muon system has been operating extremely well,** delivering very good data for physics:
  - After 3 years of LHC at increasing luminosity and 6 years from the end of construction, the detector performance is within specifications both for triggering and as a reconstruction system
- Conditions after LS3, in terms of instantaneous and integrated luminosity, will pose an **incredible challenge for the system**
- CMS is developing **a strategy to cope with the new conditions**, so that the overall performance remains stable despite increased Pile Up, luminosity, background.
- **New detectors with improved performance** (GEMs, GRPC, improved RPCs) are promising candidates for the improved CMS muon system of the future

Thank you!