Gaseous Detectors-Part 2
Muon Upgrades

IPMLHC2013: Second IPM Meeting on LHC Physics

TEHRAN Oct 7-11, 2013

Archana SHARMA

CERN Geneva Switzerland

CMS Upgrade Program

Consolidation

Upgrades

LHC Upgrade
LS = Long Shutdown

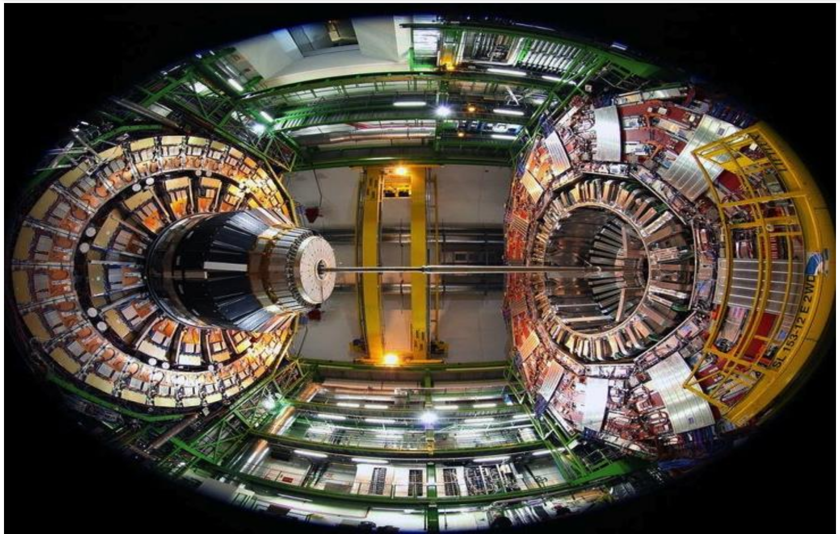
30 fb^{-1} PU ~40	300 fb^{-1} PU ~50	3000 fb^{-1} PU ~140	

LS1 — RUN 2 — LS2 — LS3

2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 year

CMS Upgrade

RUN 1 — Phase I Upgrade — Phase II Upgrade



STRATEGY:

LS1 - Consolidation:

Approved Projects still to be completed

Maintenance

LS2 - Work on R&D

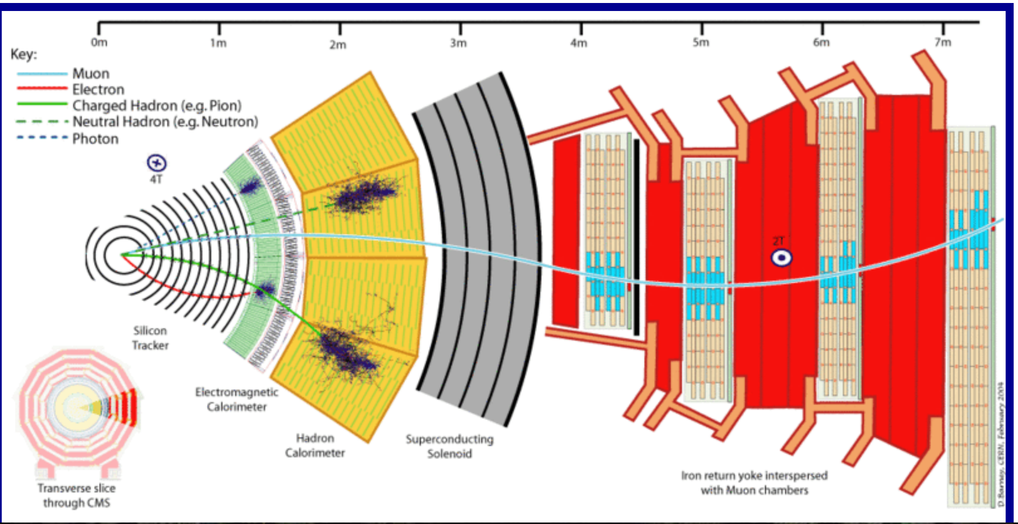
Choose Upgrade Technology; Physics driven

Develop Collaboration and Partners

Get Project Approved

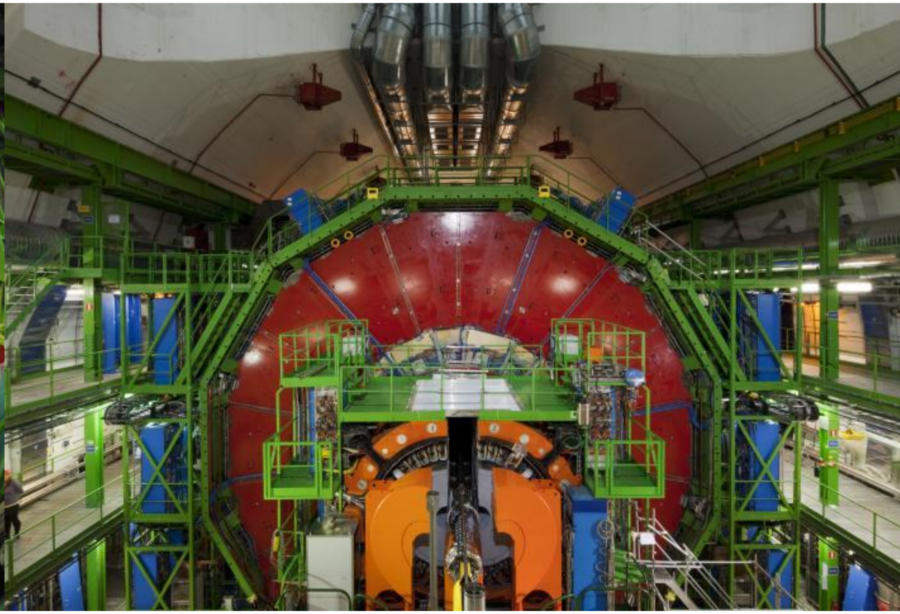
Do it !

Muon Stations: 4 in Barrel and 3 in Endcap

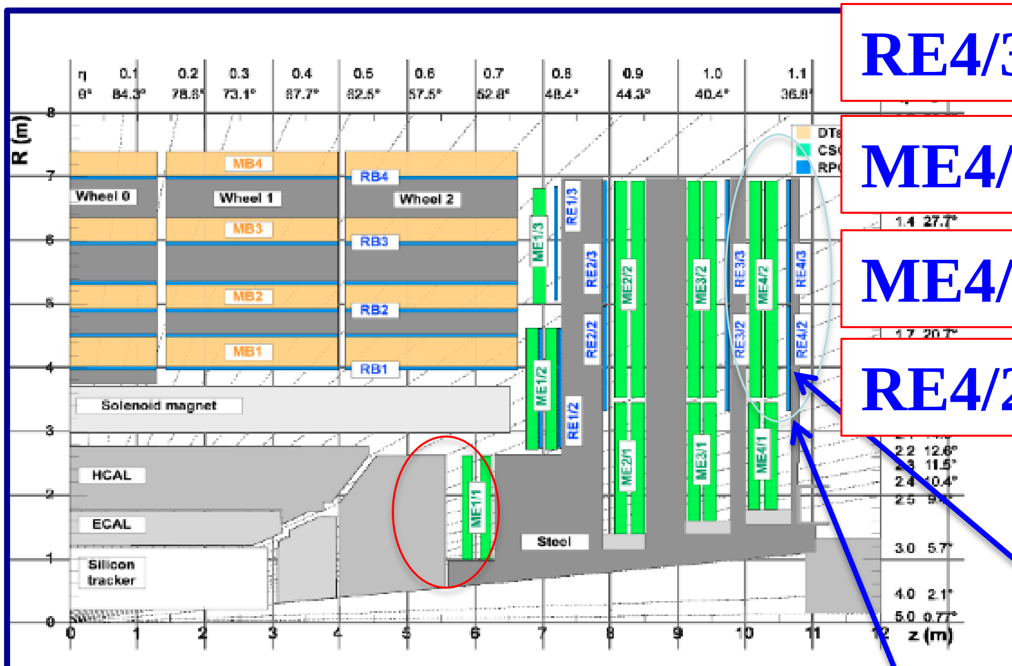


OUTLINE:

- Consolidation example
- Potential Technologies for Muon Upgrades
- Upgrade Projects
- Horizon Phase 2



Consolidation: Muon projects for LS1

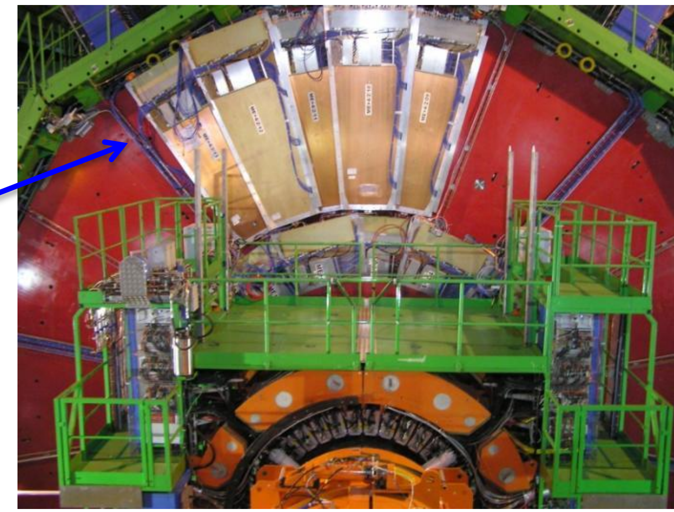


RE4/3

ME4/3

ME4/2

RE4/2



Completion of the 4th station..

..build, install and commission..

67 ME4/2 chambers

Maintenance and consolidation of existing detectors..

..to fix pending problems encountered during Run 1 and recover the highest operation efficiency for Run 2

Completion of the 4th station..

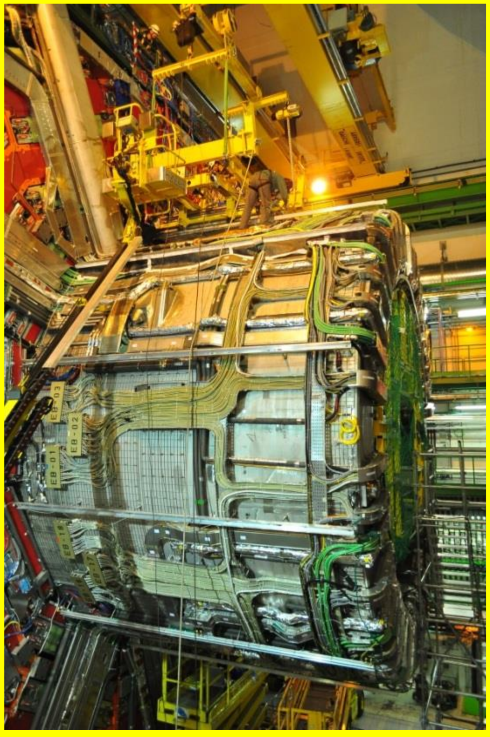
..build, install and commission..

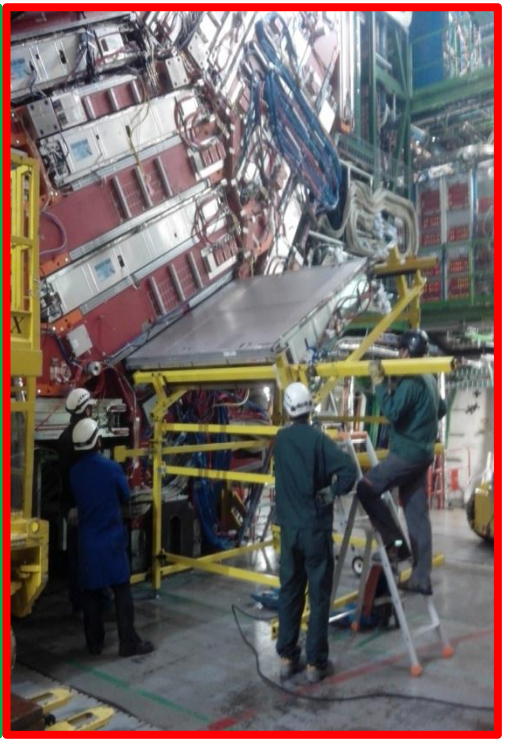
144 RE4 chambers

Updating Barrel Muon System

YB0 interventions (August): any intervention in YB0 requires a fair amount of preparation

- HV side is not accessible due to fixed services, so full extraction from the opposite side is needed for chamber opening. This required un-cabling and cabling of the involved sector.
- Special tools for extraction used….





Endcap CSC (ME4) status

GOAL: Build, install and commission 67 CSC chambers to complete the station ME4/2

- ME4/2 Chamber factory in building 904 operational since summer 2011
- **89% of chambers assembled**
- 75% passed long-term HV training and testing
- cables and fibers installed on the + endcap

Production on track, ME4/2 factory completion as March 2014

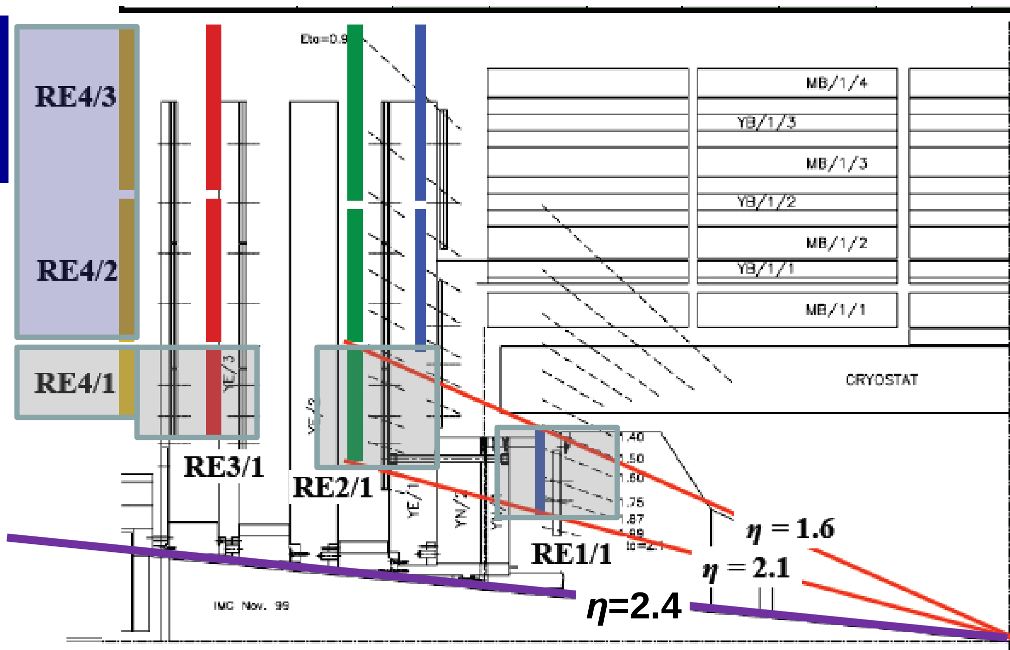

B904 CSC Factory view

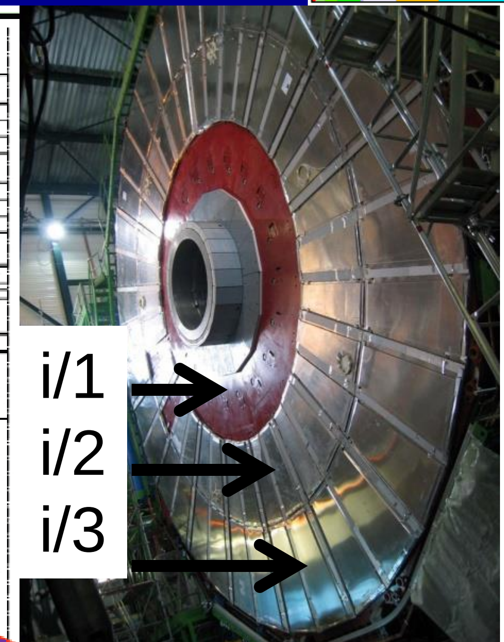

Chamber testing


Chamber storage

RPC system – what's missing?

Reduced RPC endcap system |η| < 1.45



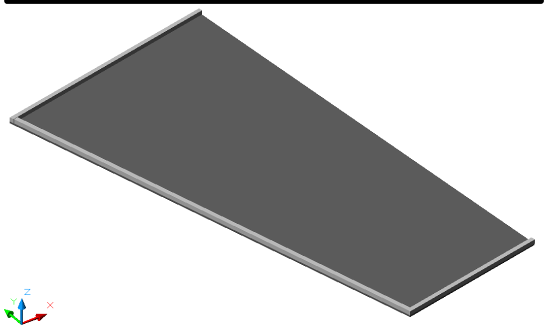


The CMS Forward Muon RPC system consists of 3 endcap disks and is equipped with chambers up to |η|=1.45, while the original CMS Muon Technical Design Report describes a system with 4 stations and a detector up to |η|=2.1.

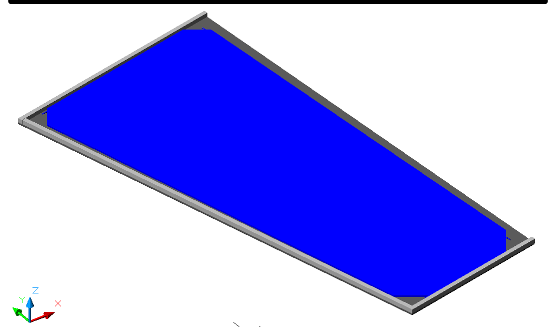
	RE 1/1	RE 1/2	RE 1/3	RE 2/1	RE 2/2	RE 2/3	RE 3/1	RE 3/2	RE 3/3	RE 4/1	RE 4/2	RE 4/3
No. of chambers	36*2	36*2	36*2	18*2	36*2	36*2	18*2	36*2	36*2	18*2	36*2	36*2

Components and QC

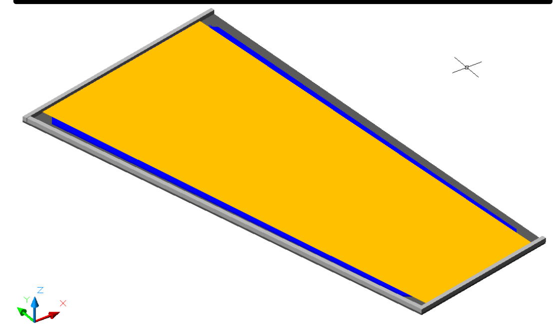
1. bottom honeycomb box



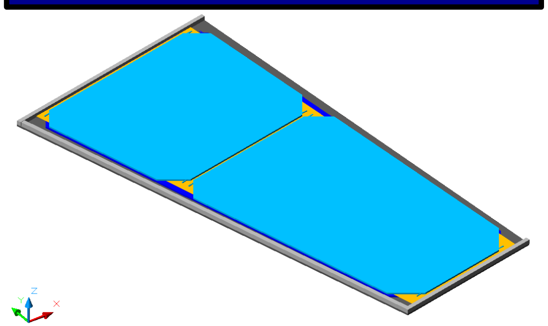
2. bottom gas gap



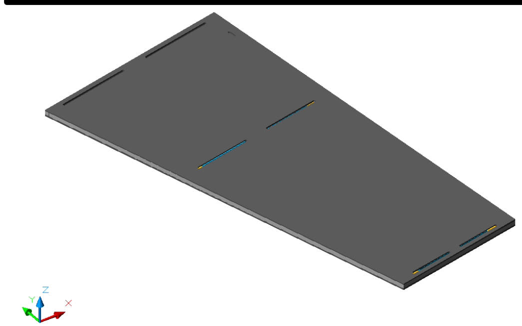
3. readout strip pattern



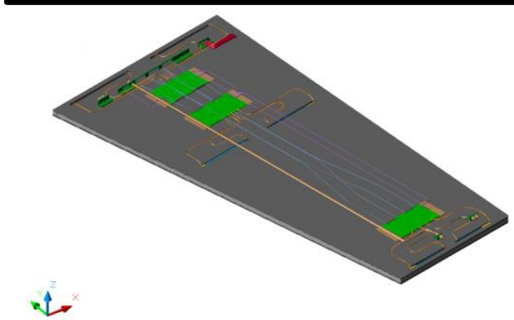
4. two top gas gaps



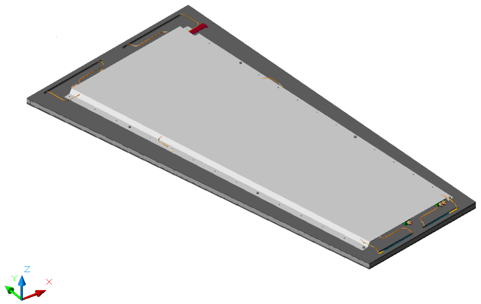
5. top honeycomb box



6. services & electronics



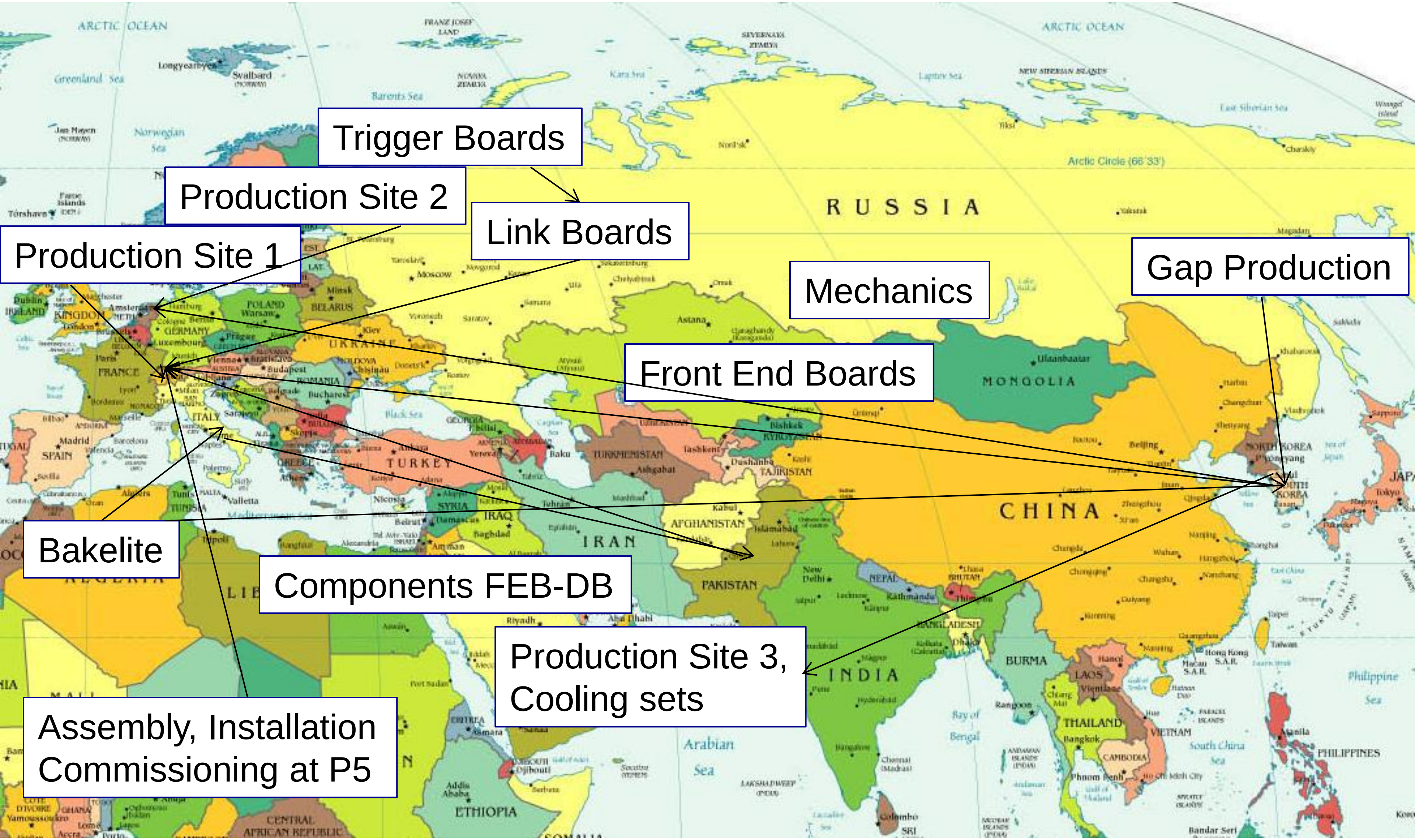
7. screen box



+

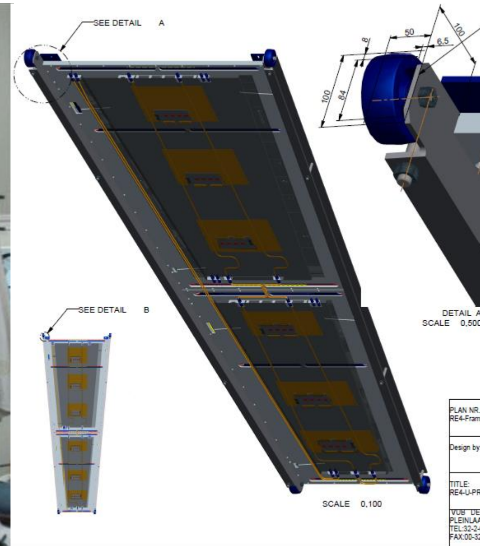
- **Quality control of all components before assembly**
- **Quality control of assembled chambers**

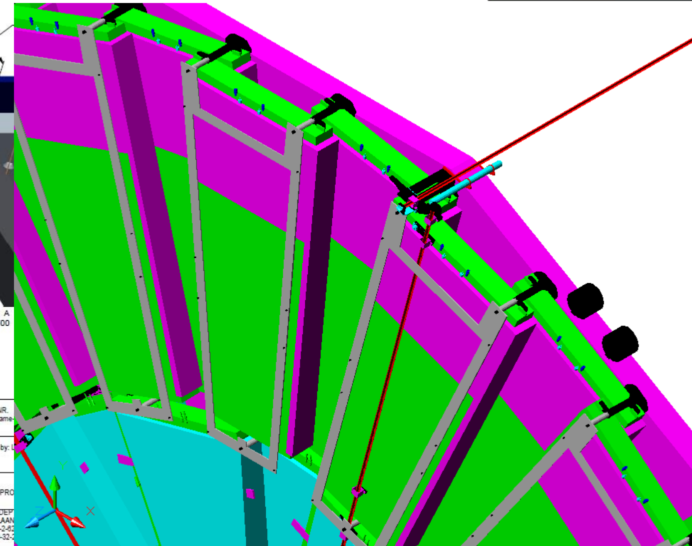
RPC "Packaged World Tour"

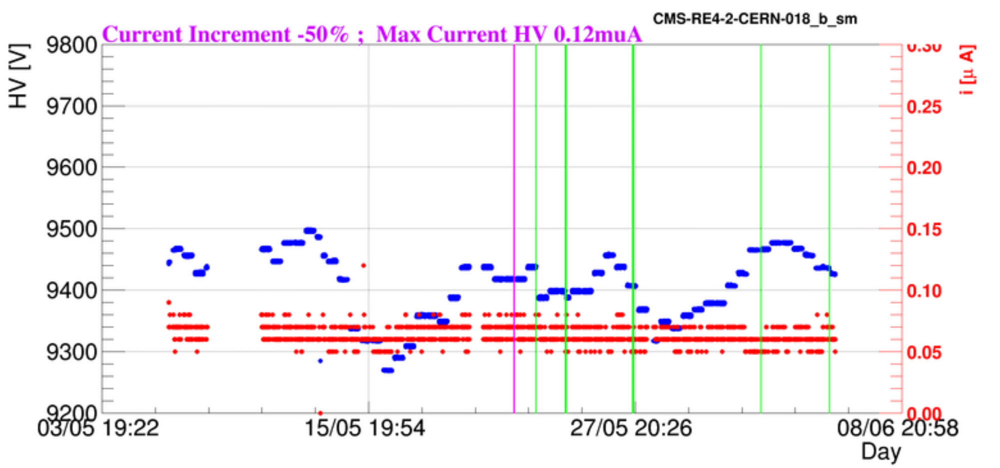


RE4 Readiness: construction

CERN 904 QC4

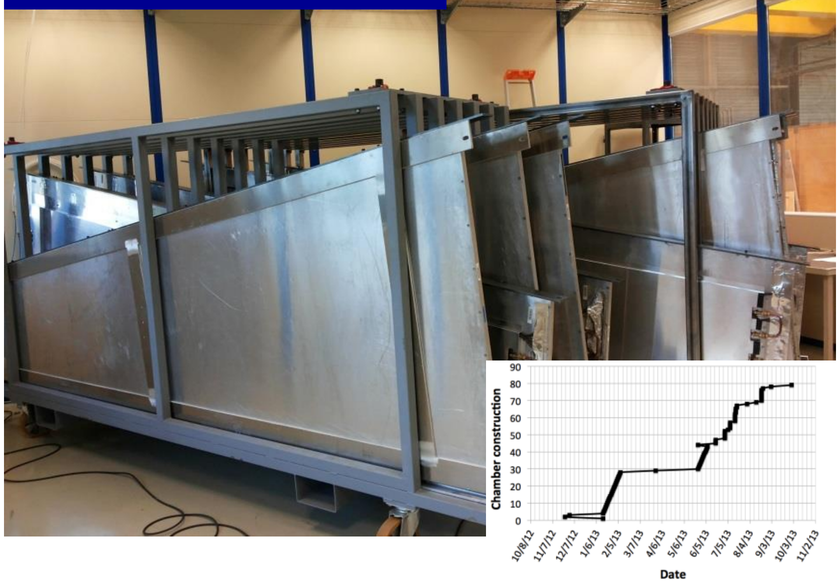






Current (and *temperature*) monitored vs time

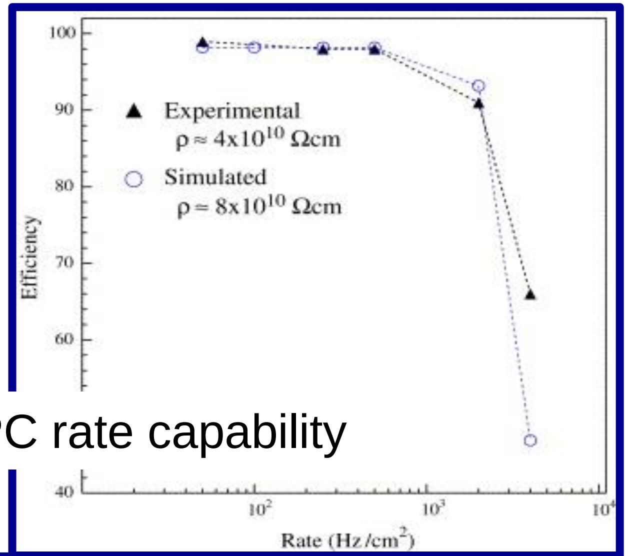
Waiting for P5



Phase II – Tour of available technologies?

- **Rate capability higher than the present**
  - Because installed in high-η regions
  - Typically endcaps, closer to the pipe
  - From 1 kHz/cm^2 → 5-10 kHz/cm^2

Accumulated Charge: higher than the present ~ C/cm^2



RPC rate capability

- In addition it could be needed to improve also:
  - Spatial resolution – from O(1 cm) → O(1-0.1 mm)
    - Mandatory in case of trigger requirements
    - Time resolution – from O(1 ns) → O(100 ps)
    - Useful for background rejection
- Given requirement on rate capability,

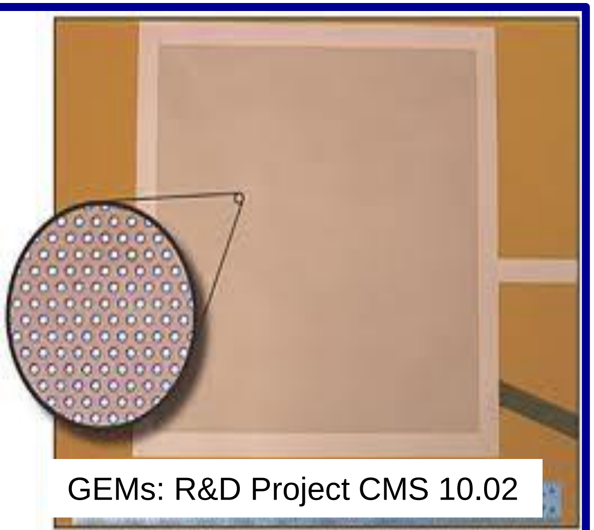
choice of the technology will be driven by the physics case:

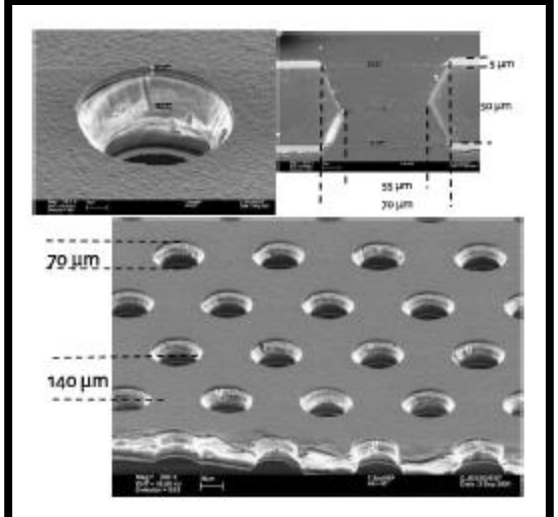
  - plus robustness, cost, ease of construction, etc.

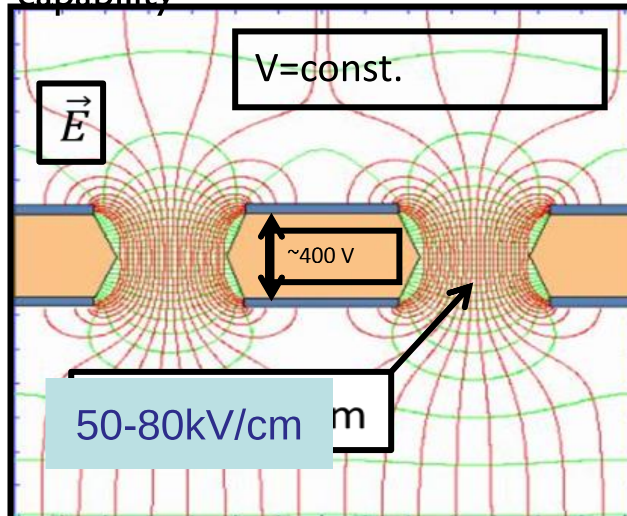
Gas Electron Multiplier (GEM)

Rate capability : 10^5Hz/cm^2
Spatial/Time resolution: ~ 100 μm / ~ 4-5 ns
Efficiency > 98%
Gas Mixture: Ar-CO_2-CF_4 (non flammable mixture)

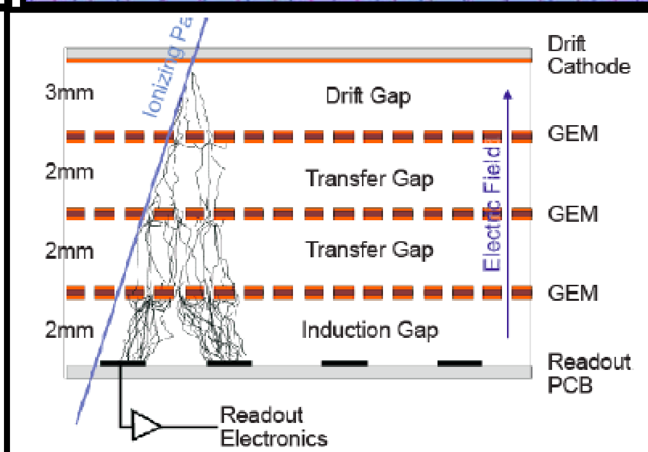
- Combine triggering and tracking functions
- Enhance and optimize the readout (η-φ) granularity by improved rate capability


GEMs: R&D Project CMS 10.02





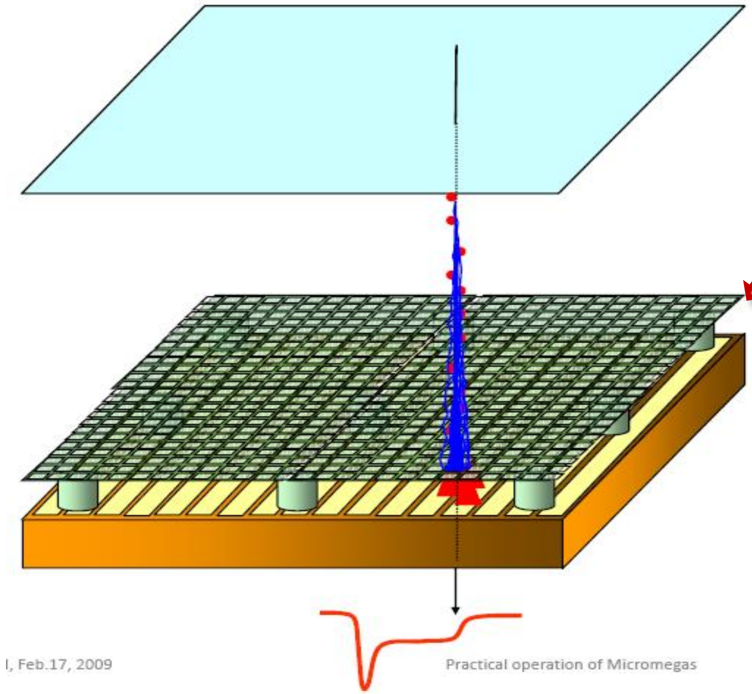
- GEM foils developed using PCB manufacturing techniques
- Large areas ~ 1m x 2m with industrial processes (cost eff.)
- Each foil (perforated with holes) is 50μm kapton sheet with copper coated sides (5μm)
- Typical hole dimensions : Diameter = 70μm, Pitch = 140μm,

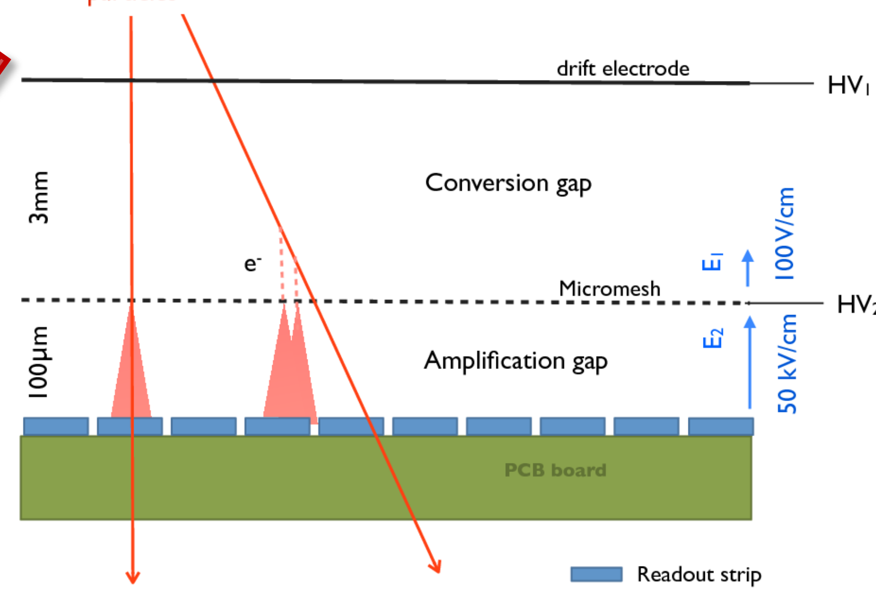


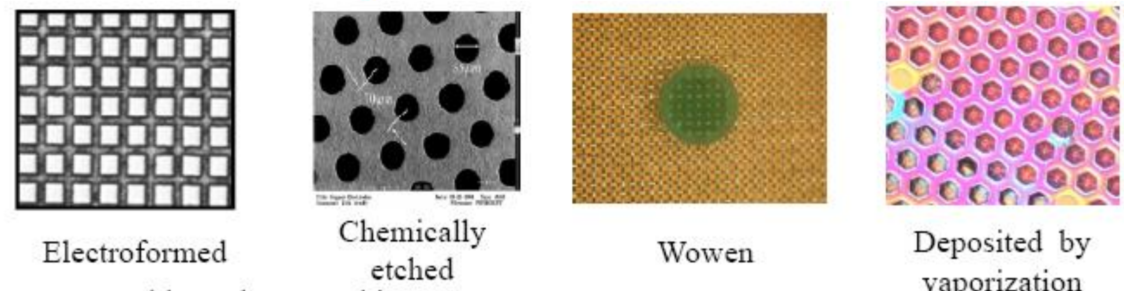
μMs: R&D ATLAS MAMMA

Y. Giomataris, PH. Rebourgeard, JP. Roberts and G. Charpak, NIM A 376 (1996) 29

Micromegas (MMs) are parallel-plate chambers where the amplification takes place in a thin gap, separated from the conversion region by a fine metallic micro-mesh, supported by 50-100 μm insulating pillars.

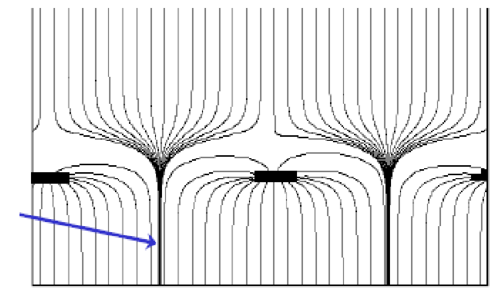






Variety of meshes

Funnel field lines: high transparency to electrons

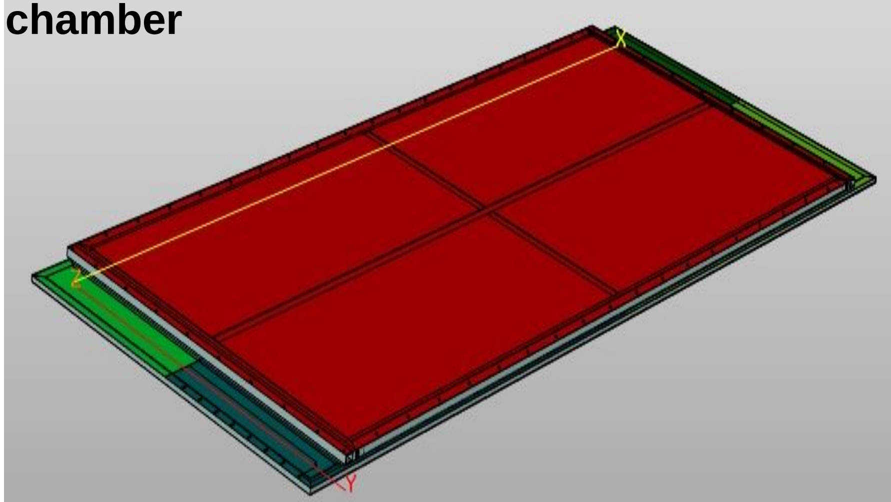


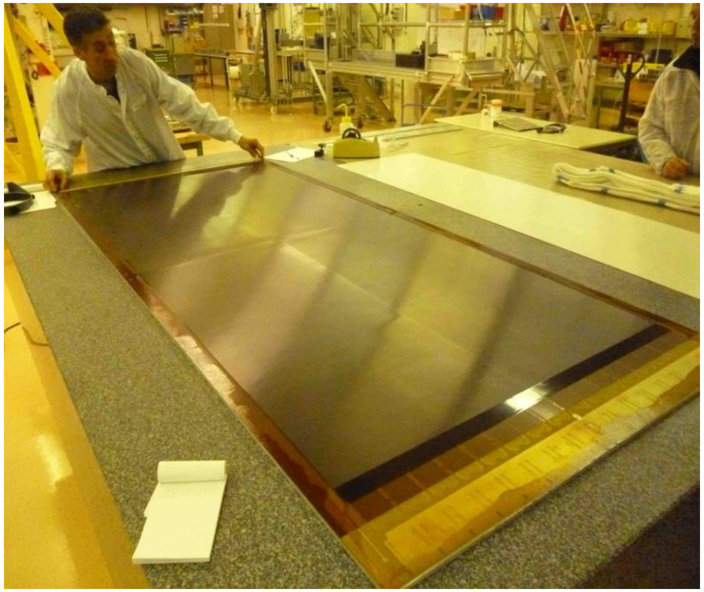
Micromegas Upgrade Project for ATLAS

Micromegas have been chosen as precision measurement detectors (but also trigger) of the New Small Wheels of ATLAS

- First large system based on Micromegas

3D view of the first large (1 x 2.4 m^2) MM chamber





✓Detector dimensions: 1.5–2.5 m^2 per detector.
✓Combine precision and 2nd coord. measurement as well as trigger functionality in a single device
✓Each detector technology comprises eight active layers, arranged in two multilayers
✓MM 2nd coord will be achieved by using $\pm$ 1.5° stereo strips in half of the planes.

- 2 M readout channels
- A total of about 1200 m^2 of detection layers

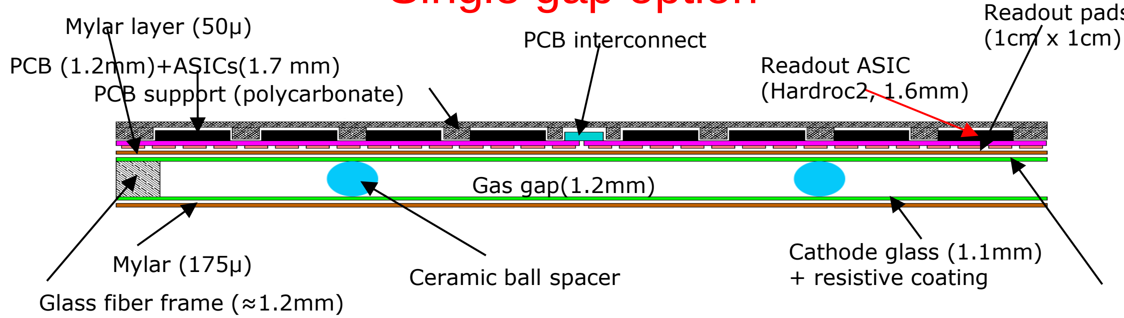
R&D on Glass RPCs for CMS

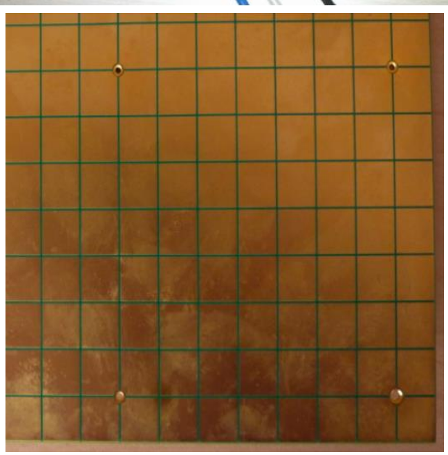
New “low” resisitivity (10^{10} Ωcm) glass used for high rate RPC

adding Aluminum, and changing the percentages of the usual ingredients

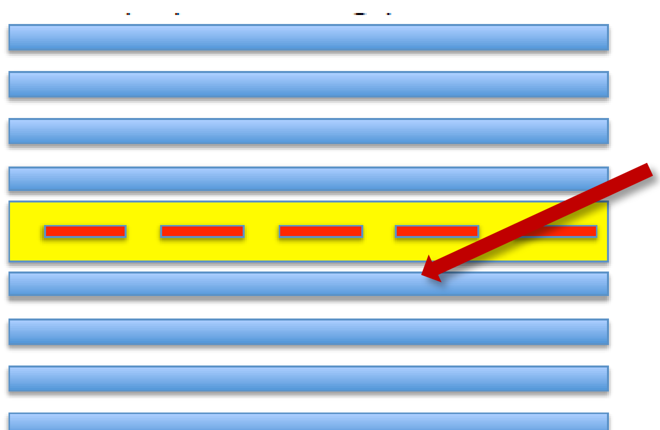
- ✓RPC rate capability depends linearly on electrode resistivity
- ✓Smoother electrode surfaces → reduces the intrinsic noise
- ✓Improved electronics characterized by lower thresholds and higher amplification

Single gap option





“Array” of small-size glass tiles to cover large surfaces



Multigap option:

- ✓a variation of the double-gap configuration used for CMS: “double triple-gaps”
- ✓High rate + high time resolution

CMS R&D #12.01

Phase II – Choice of GEM Technology for CMS Muon Upgrades

- **Rate capability higher than the present set of detectors**

From 1 kHz/cm^2 → 5-10 kHz/cm^2

Accumulated Charge: higher than the present

~ C/cm^2

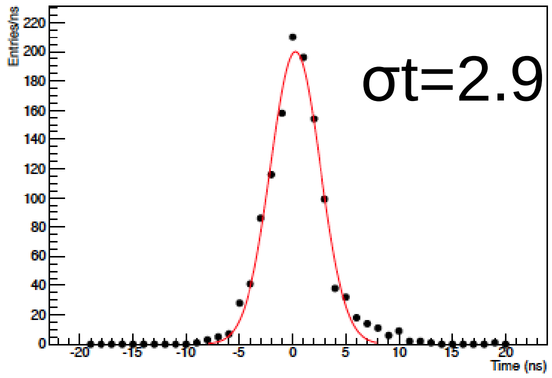
Experience in past experiments

COMPASS, LHCb, TOTEM,

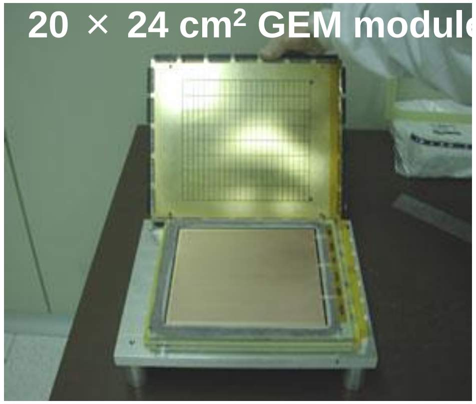
GEMs @ LHCb

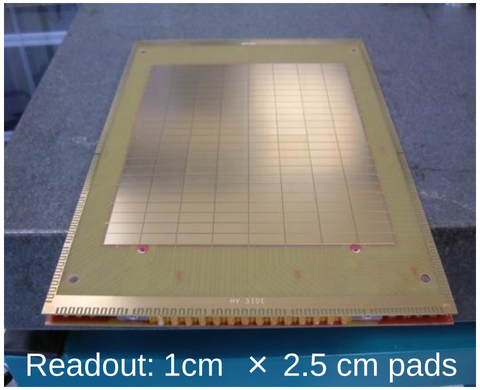
GEMs in LHCb M1 muon station (LHCb L0 Muon Trigger):

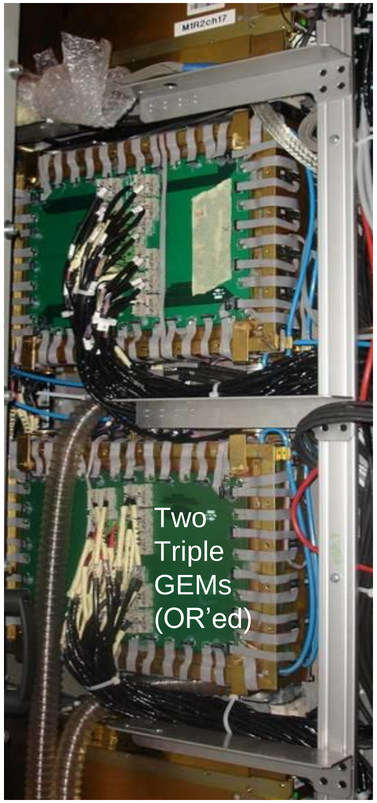
- Operating since LHC startup; rate up to 500 kHz/cm^2 (>> CMS)
- Gas mixture $Ar/CO_2/CF_4$ (45:15:40)
- Gas gain ≈ 6,000
- Efficiency ≥ 98% in 25 ns window using OR of two GEM
- Rad-hard up to integrated charge of ≥ 2 C/cm^2 (15 LHCb years)



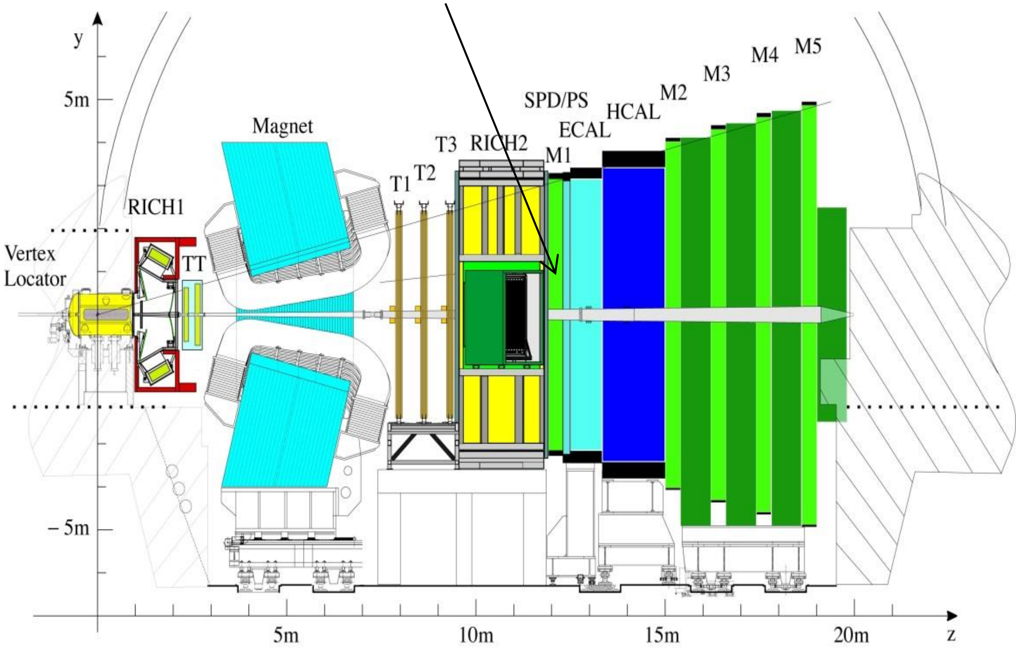
A. Cardini, et al. IEEE NSS Proc. 2012





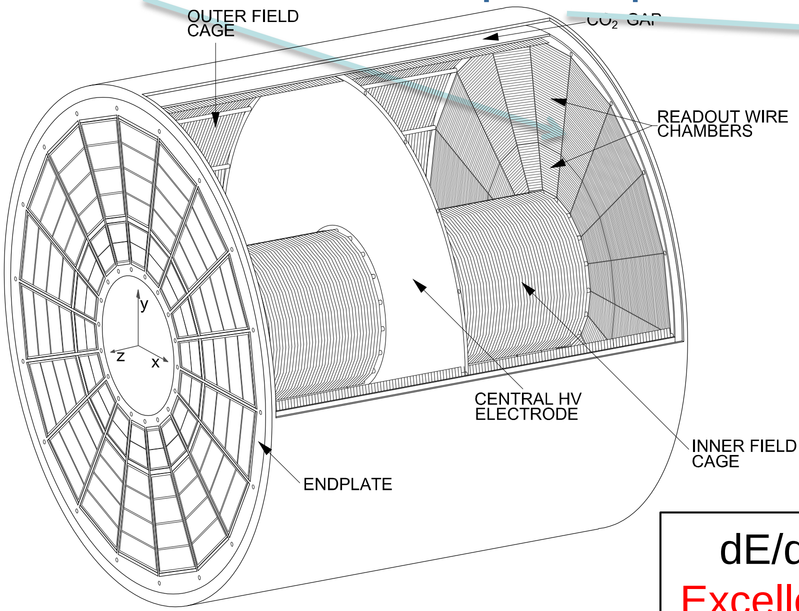


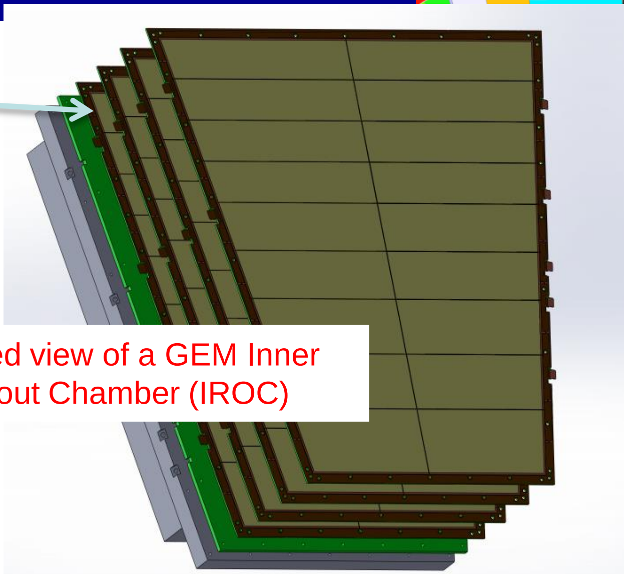
12 Double Triple-GEMs in front of calorimeter; total area 0.6 m^2



ALICE TPC upgrade with GEMS

Replace wire chambers with quadruple-GEMs



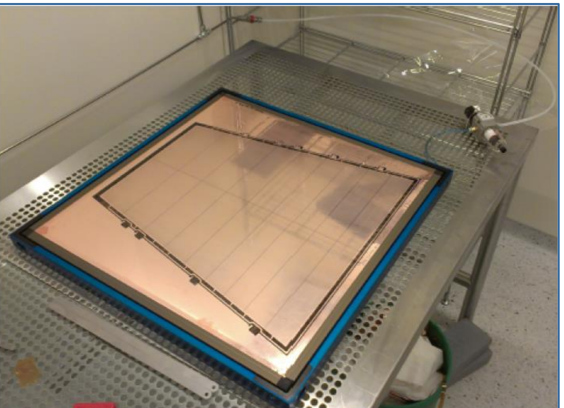


Exploded view of a GEM Inner Readout Chamber (IROC)

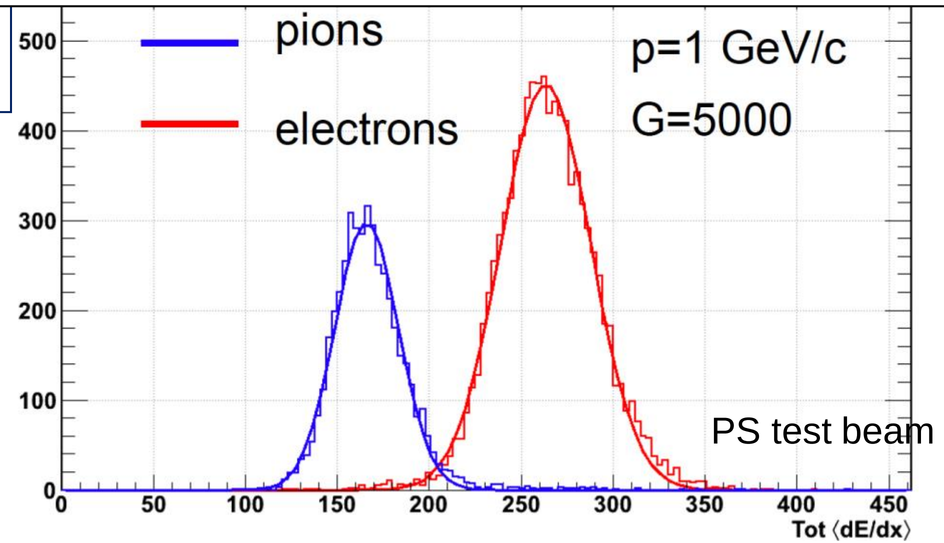
dE/dx spectrum of 1GeV/c electrons and pions

Excellent TPC performance maintained with GEMs

Because of ion backflow in the field cage MWPC not compatible with 50 kHz operation

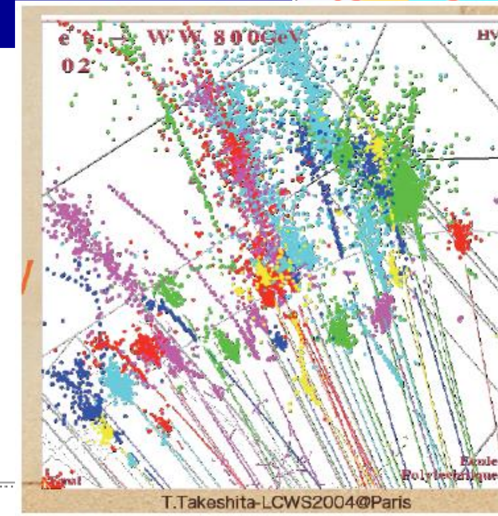


Choice of quadruple-GEM detectors to minimize ion backflow

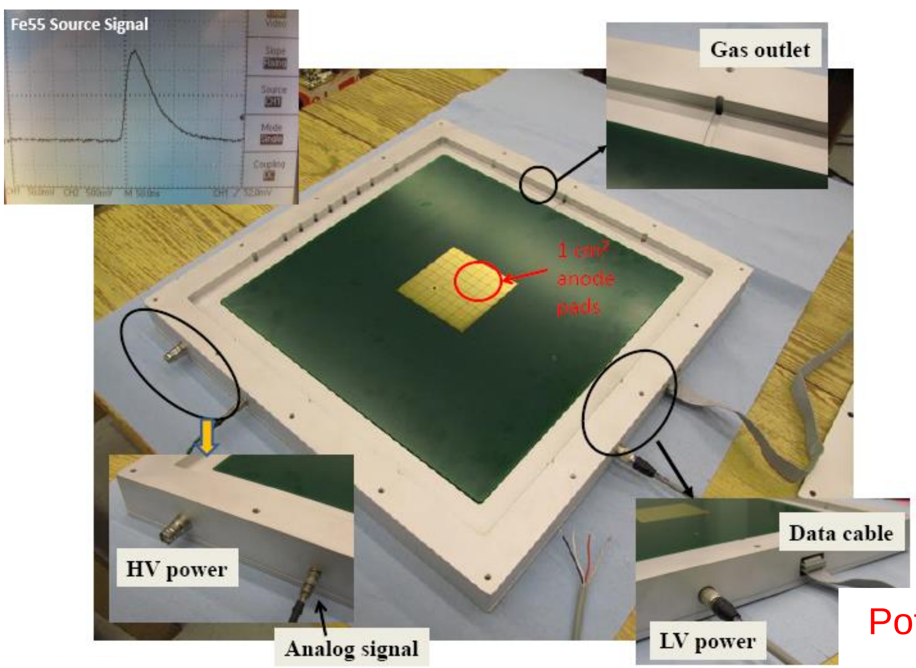


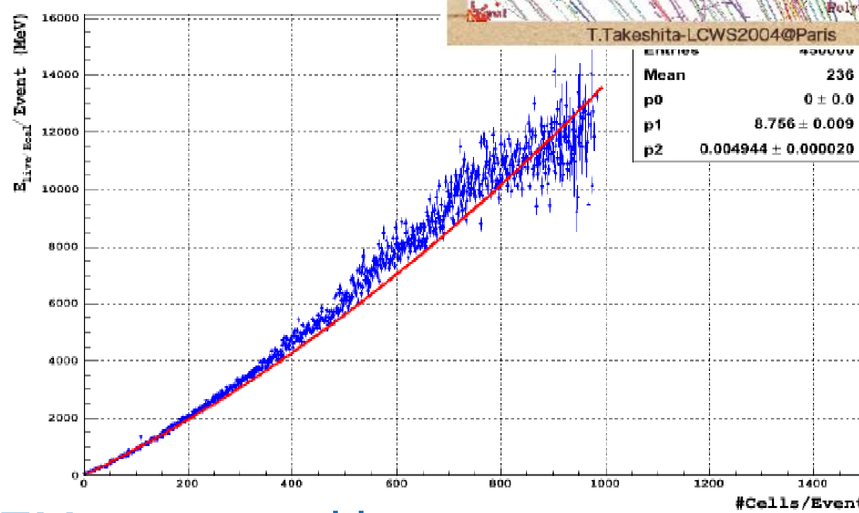
GEMs for calorimetry

Proposed a few years ago in the ILC framework



- Digital calorimetry approach:
- Cell is either ON or OFF
- High granularity for charged particle tracking
- Good correlation between particle energy and numbers of
- cells hits
- Requires development of Particle Flow
- algorithm





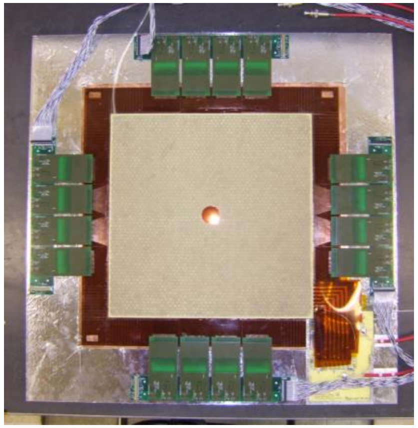
GEMs proposed because:

✓ Easy to implement small (~1x1 cm^2 cells)

Potentially quite interesting to find integrated solutions among calorimetry and muon systems

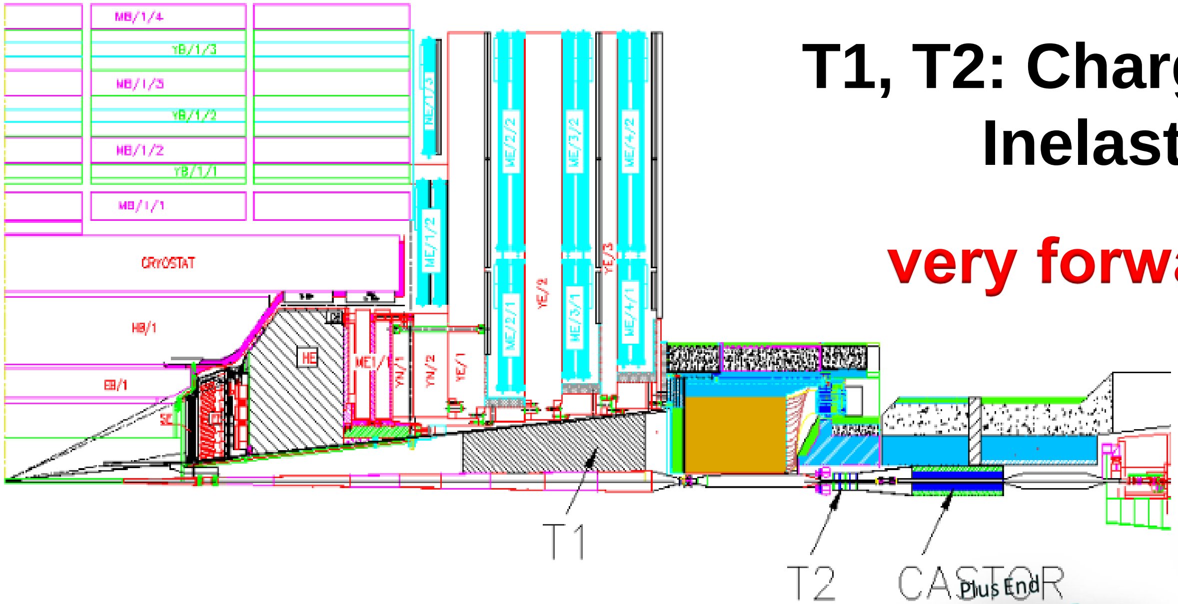
GEMs @ COMPASS

- Overview
  - First high-luminosity experiment that used Triple-GEM detectors (running at CERN SPS)
  - 22 31cm × 31cm Triple-GEMs with 2D strip readout (400 μm pitch); central circular region (d = 5 cm) deactivated (beam passage)
  - 11 stations with 2 detectors each (x-y; u-v at 45^o wrt x-y)
  - Low-mass tracker: 0.4 - 0.7 % X_0 per Triple-GEM
  - Operated w/ gas gain ~ 8,000 in Ar/CO_2 70:30
  - Readout with APV25 chip w/ 40 MHz sampling (same as for the CMS Si-tracker)



- GEM performance during running
  - Sustained rates up to 2.5 MHz/cm^2
    → corresponds to ≈1000 × est. CMS GE1/1 rate @ HL-LHC (few kHz/cm^2)
  - Uniform efficiency of 97.5% for two OR'ed detectors
  - 70 μm spatial resolution achieved (very close to normal incidences)
  - 12 ns time resolution achieved at high beam intensity using leading edge of pulse
  - Accumulated charge during 2002-2007 running: 200 mC/cm^2
    → corresponds to > 12 years est. CMS GE1/1 charge @ HL-LHC
  - No gain drop observed in this running period

GEMs @ TOTEM

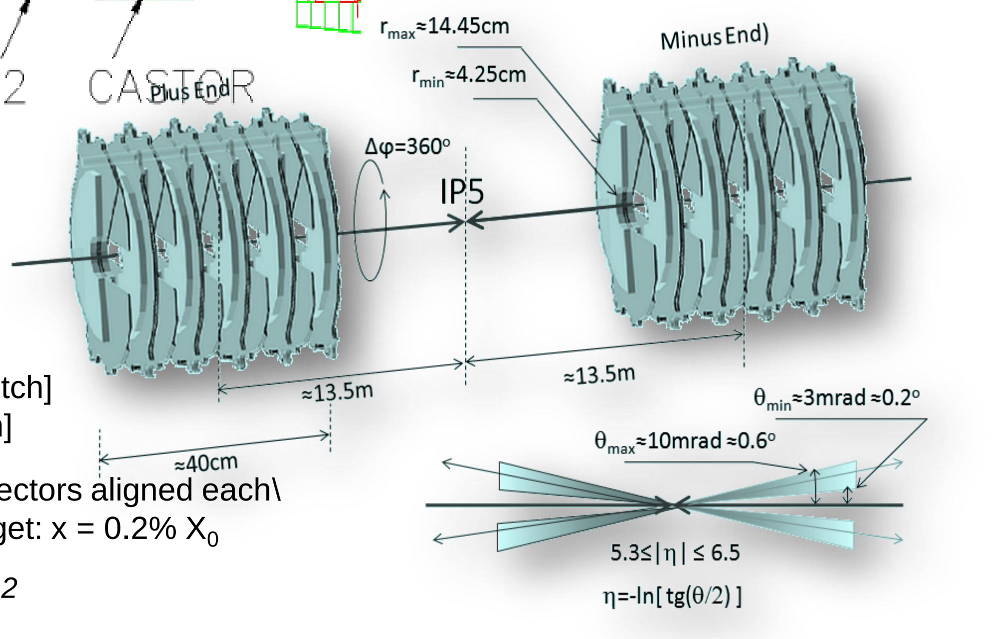


T1, T2: Charged Particles in Inelastic Events

very forward at $5.3 \leq |\eta| \leq 6.5$

About 99.5% of all non-diffractive minimum bias events and 84% of all diffractive events have charged particles within the acceptance of the TOTEM detectors,T1 and T2.

- 360^o φ coverage
- Readout Granularity:
  - δ r ≈ 400μm [pitch]
  - $\delta\varphi$ = 2.9^o [pitch]
- 4 quarters with 10 detectors aligned each\
- very low material budget: $x = 0.2\%\ X_0$

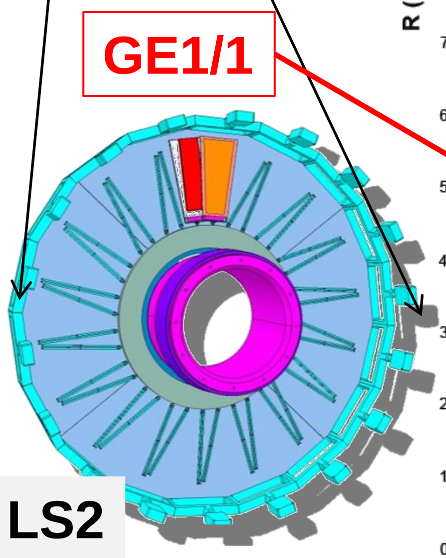


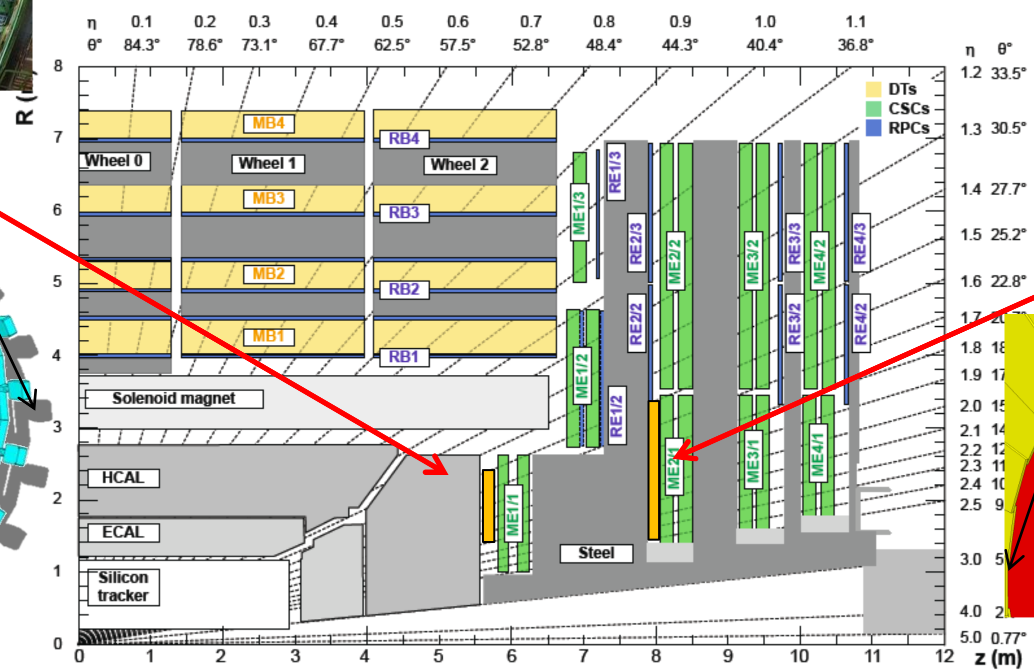
E. Oliveri (INFN Pisa), 3rd CMS GEM Upgrade Workshop, April 2012

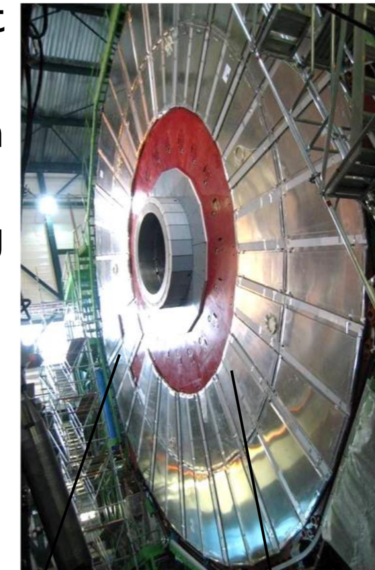
The CMS GEM Project

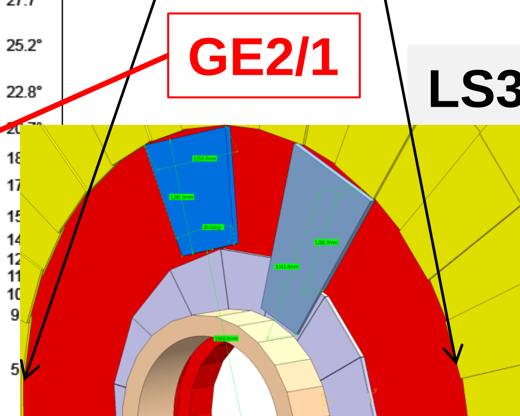
Install triple-GEM detectors (double stations) in 1.6<|η|<2.1-2.4 endcap region:

- 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









GEMs: R&D Project CMS 10.02; The LS2 Project

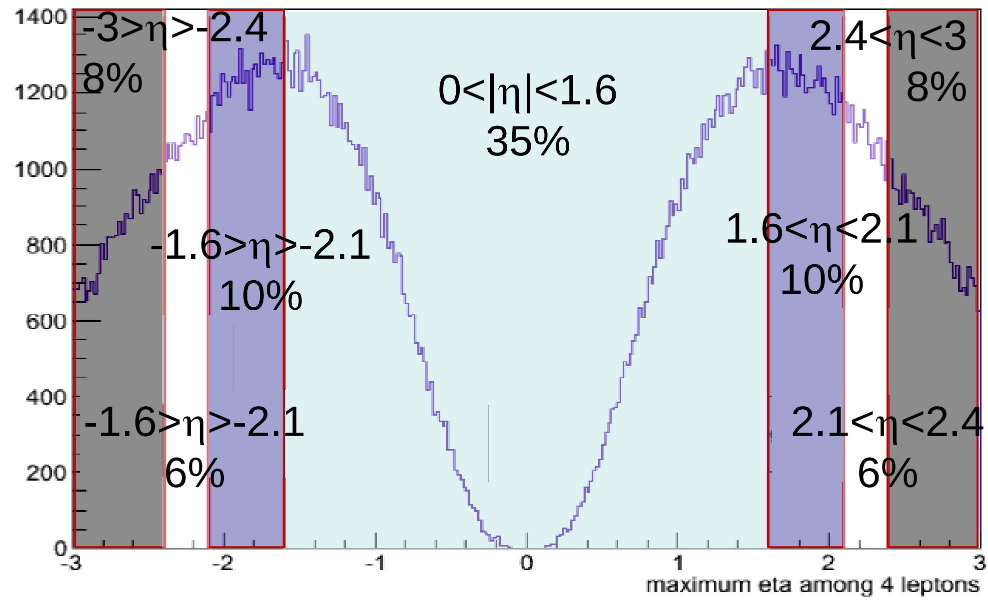
Motivations: Improving Muon System Coverage

F.R. Cavallo

Reconstruction coverage critical for multi-muon signatures

Eg. $H \rightarrow ZZ \rightarrow 4\mu$ channel:

- **Acceptance increases by 50% if muon reconstruction coverage extends from $|\eta_{max}|=1.5 \rightarrow 3.5$**



$H \rightarrow WW$, ZZ

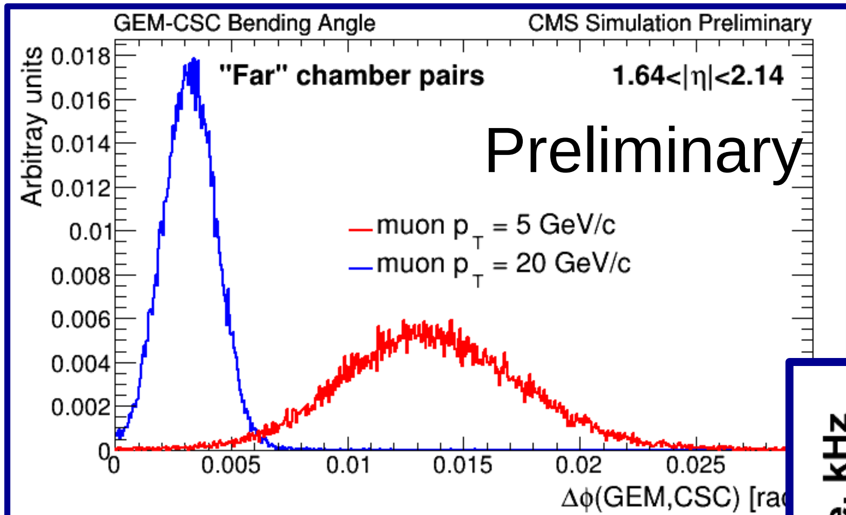
$H \rightarrow \tau\tau$ is key for measuring fermion $\mu+\tau_{had}$ is the most sensitive channel

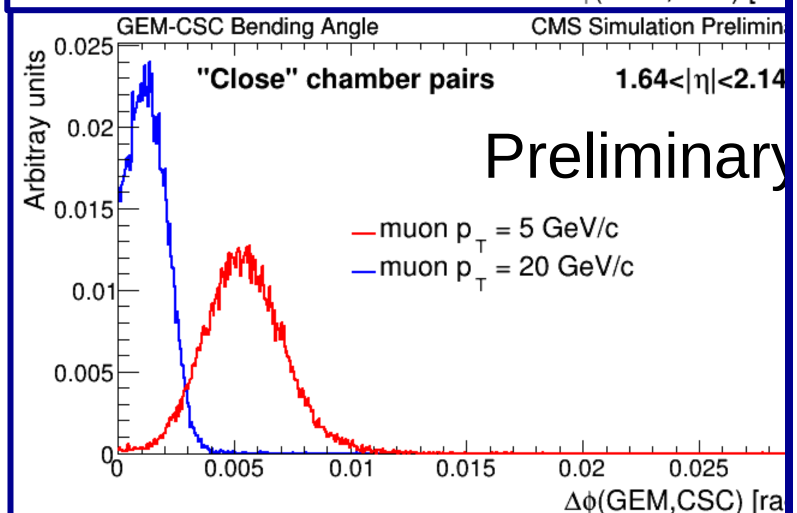
Fully relies on muon trigger

Needs

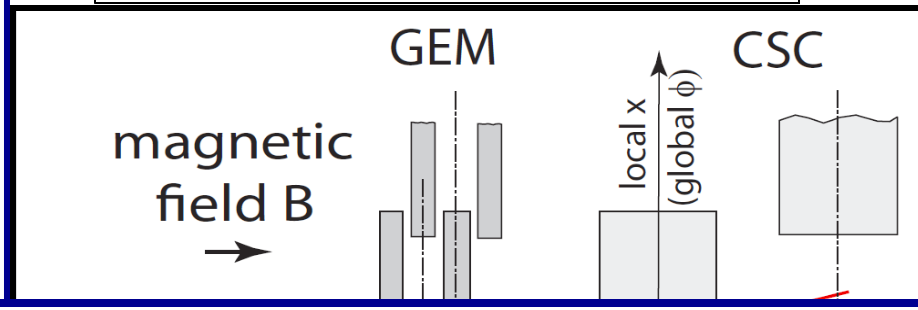
An efficient muon trigger

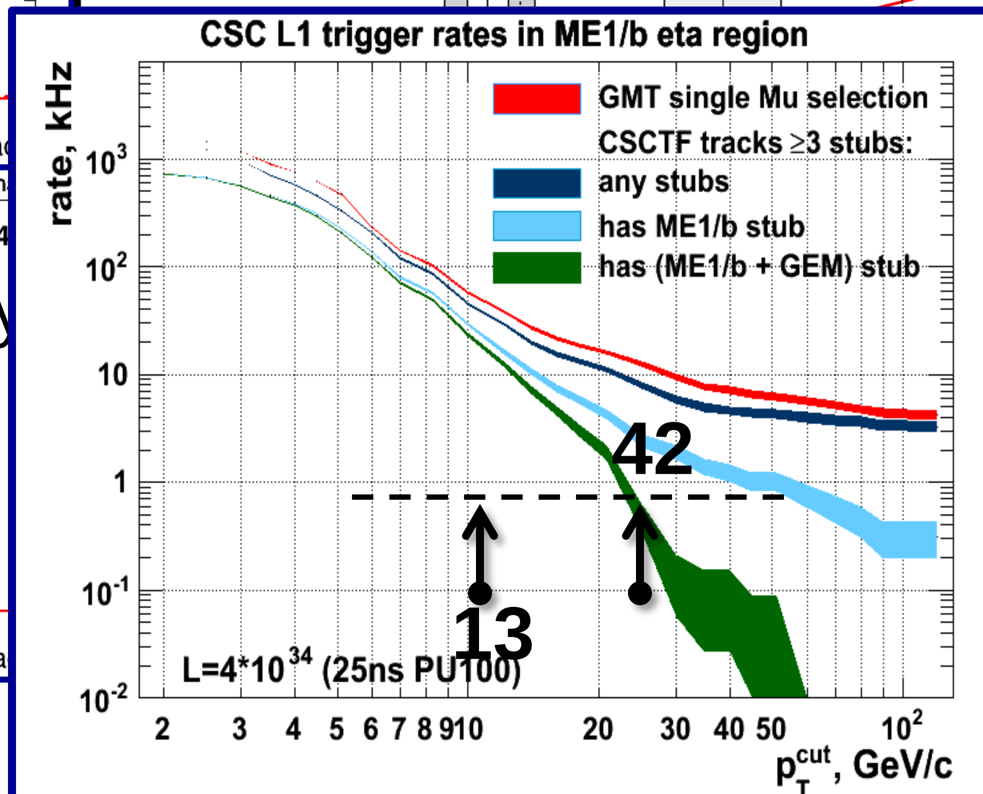
Motivation: Exploiting GEM-CSC Bending Angle





View from the top of CMS down

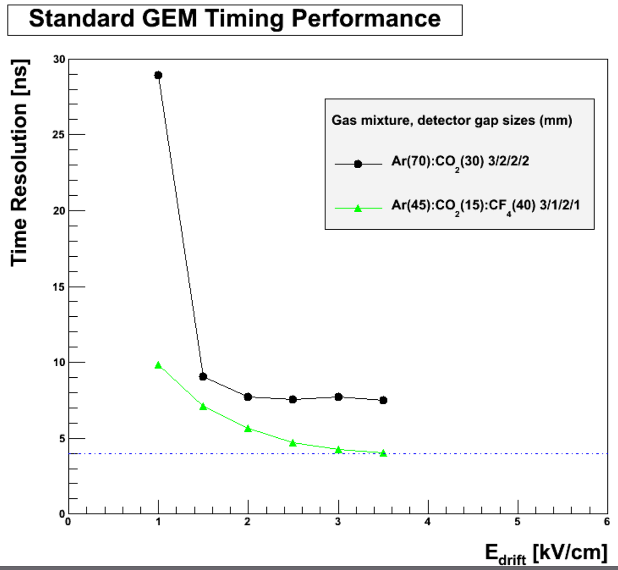


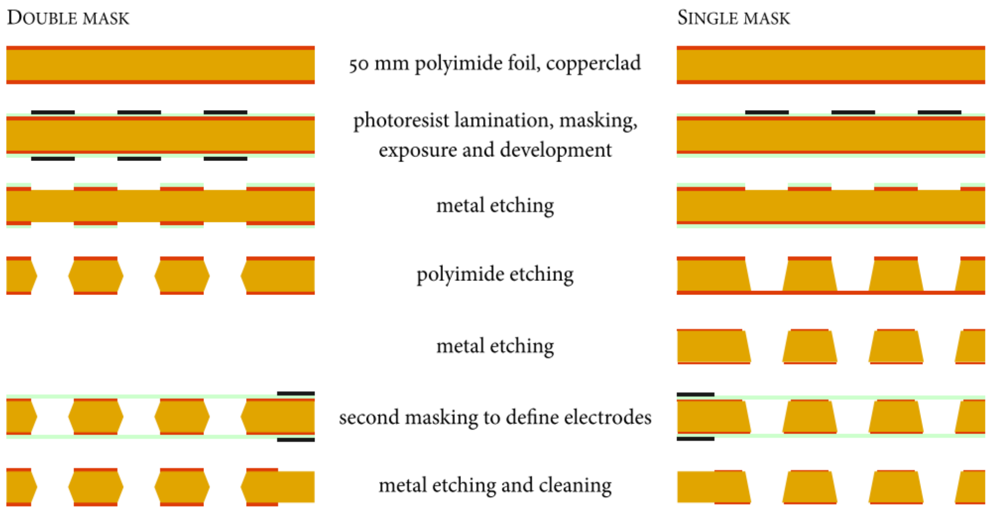


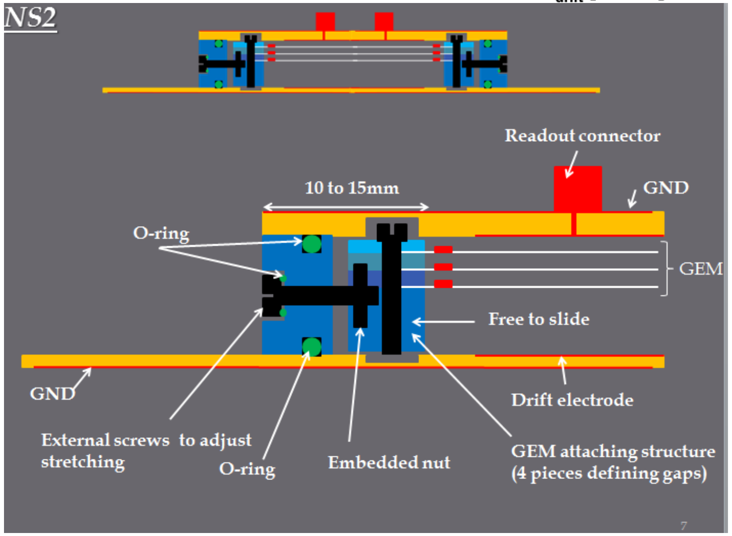
Vadim Khotilovich (Texas A&M University)

CMS GEM Project Achievements

- Detector efficiencies above 98%
- Spatial resolution of about 290µm with VFAT2 (digital) and <110µm APV (analog) readout chip
- Time resolution of 4ns
- Operation of GEMs in magnetic field
- **Validation of single-mask technology**
- **Production of large area GEM foils**
- **New self-stretching technique for GEM assembly**

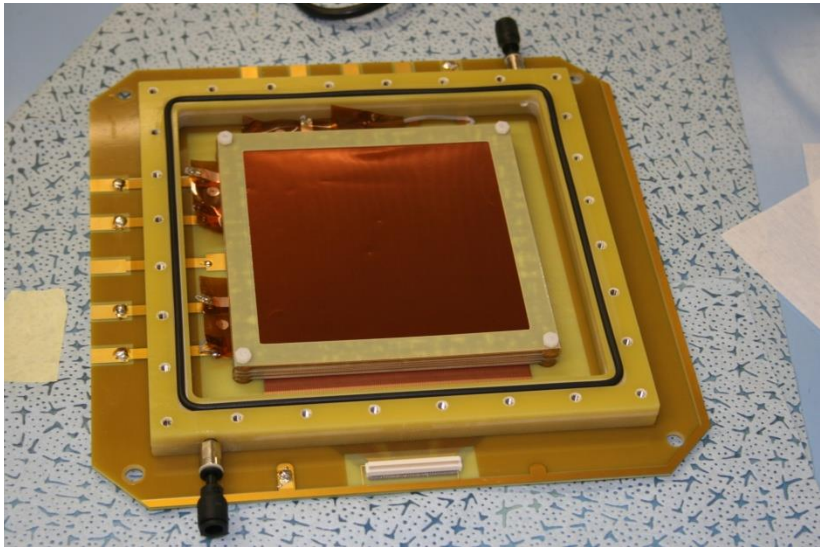


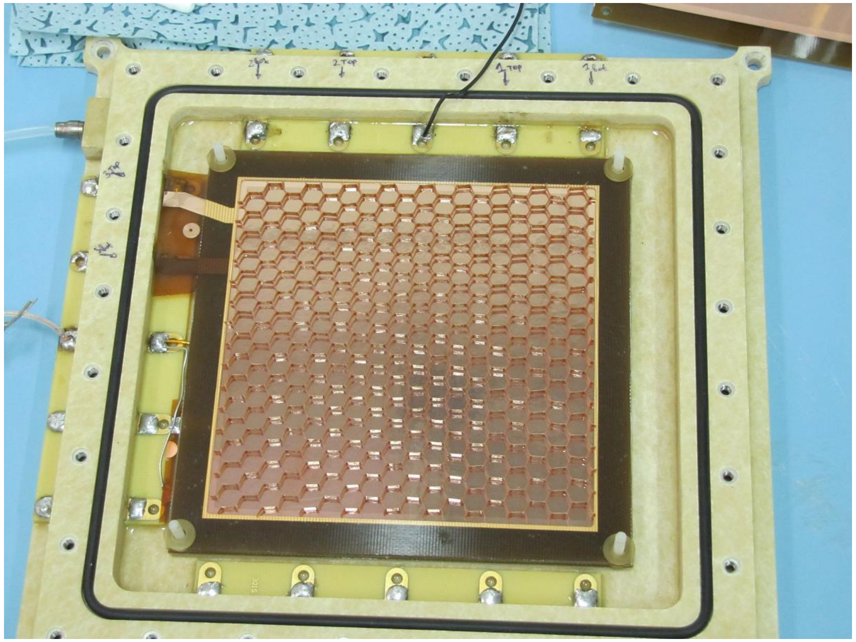




Small Prototypes (2009-2010)

- **10x10 cm^2 triple-GEMs, 1D or 2D readout, 128 or 256 channels :**
  - Standard double-mask triple-GEM - “Timing GEM”
  - Single-mask triple-GEM
  - “Honeycomb” triple-GEM

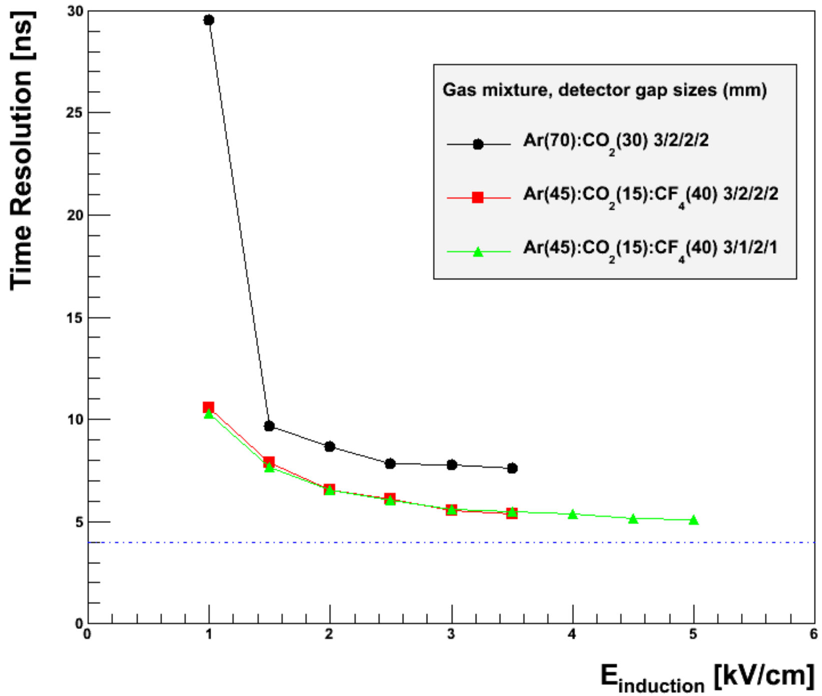




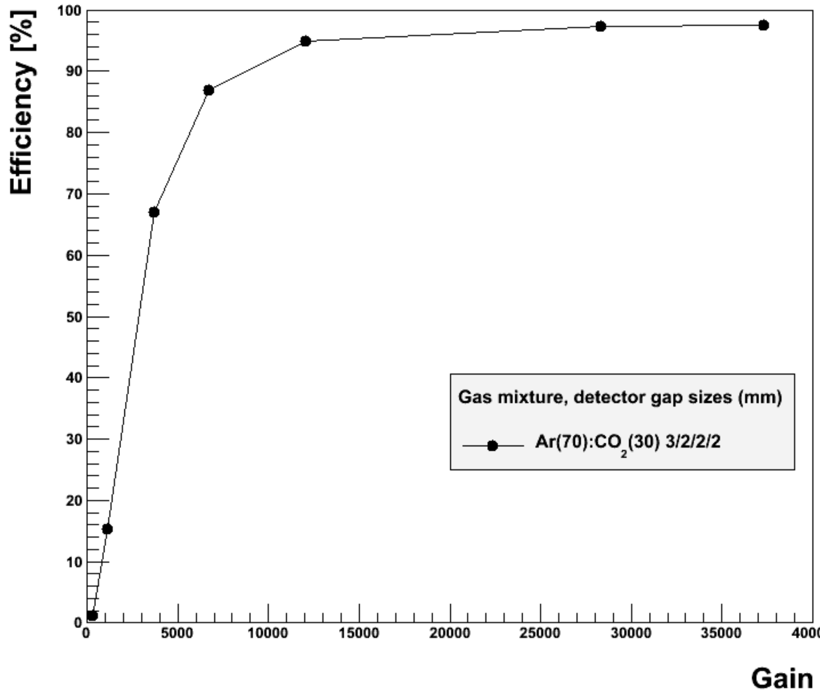
Characterization of GEM Detectors for Application in the CMS Muon Detection System
2010 IEEE Nucl. Sci. Symp. Conf. Rec. 1416-1422; RD51 Note 2010-005; arXiv:1012.3675v1 [physics.ins-det]

Validation of Single Mask Technique

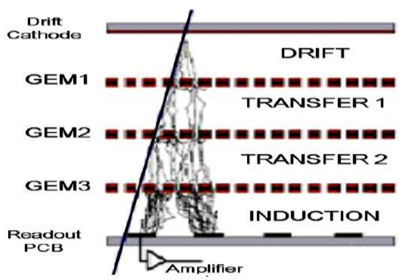
Standard GEM Timing Performance



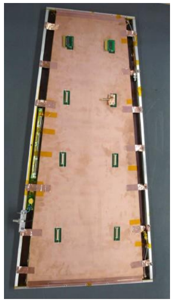
Single Mask GEM performance



- Custom made HV divider for Standard triple-GEM
- Clear effect of gas mixture, and induction and drift field
- Timing resolution of 4 ns reached



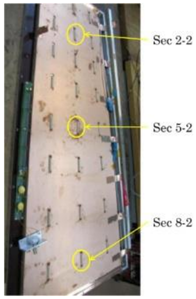
Full-size GE1/1 Detectors Developments in Time



2010

Generation I

The first 1m-class detector ever built but still with spacer ribs and only 8 sectors total. Ref.: **2010 IEEE (also RD51-Note-2010-005)**



2011

Generation II

First large detector with 24 readout sectors (3x8) and 3/1/2/1 gaps but still with spacers and all glued. Ref.: 2011 IEEE. Also **RD51-Note-2011-013.**

2012

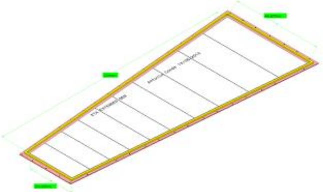
Generation III

The first self-stretched sans-spacer detector, but with the outer frame still glued to the drift. Ref.: **2012 IEEE N14-137.**

2013

Generation IV

The current generation that we have built two of at CERN so far, with four more to come from the different sites. No more gluing whatsoever. **Upcoming papers from MPGD 2013; And IEEE2013.**



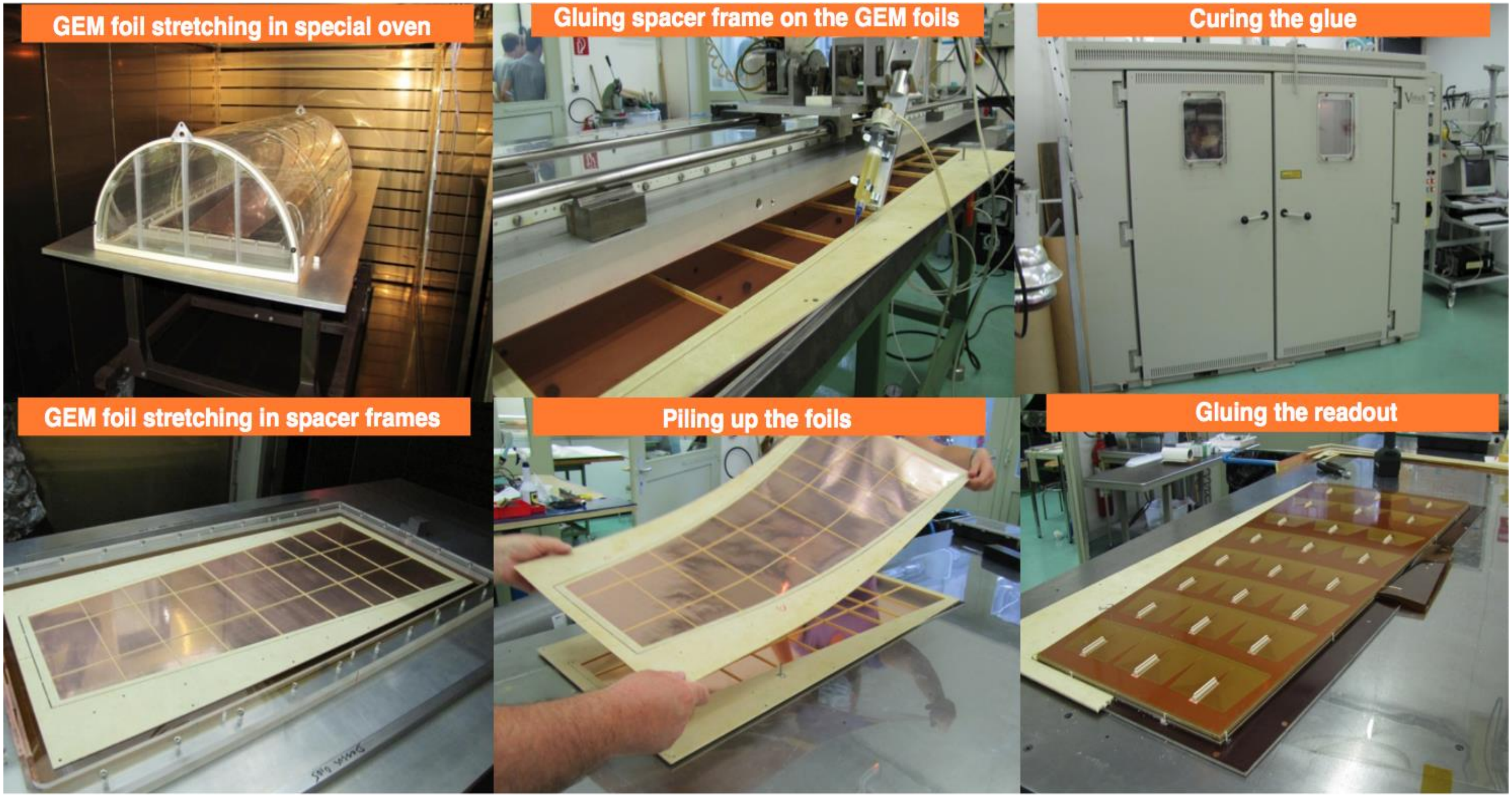
2013/14

Generation V

The upcoming detector version that we will install. One long and one short version. Optimized final dimensions for max. acceptance and final eta segmentation.

GEM Foil Stretching and Assembly (I)

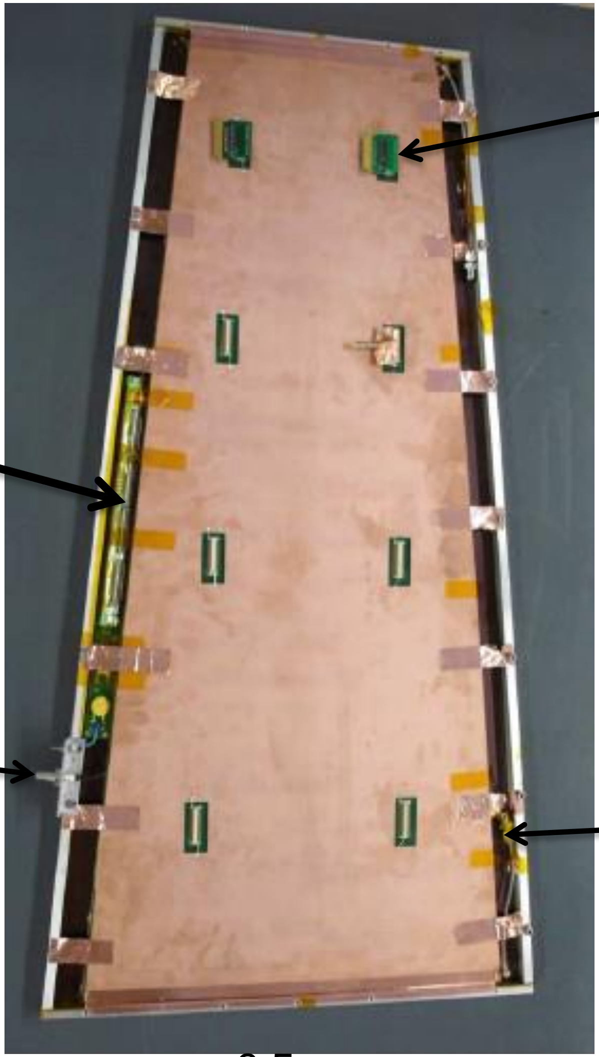
Thermal stretching in large oven (CERN) 2010



The assembly time for this detector was 1 week

Photograph of First Full-Size Detector

October 2010



0.5m

1m

128 channel readout connector

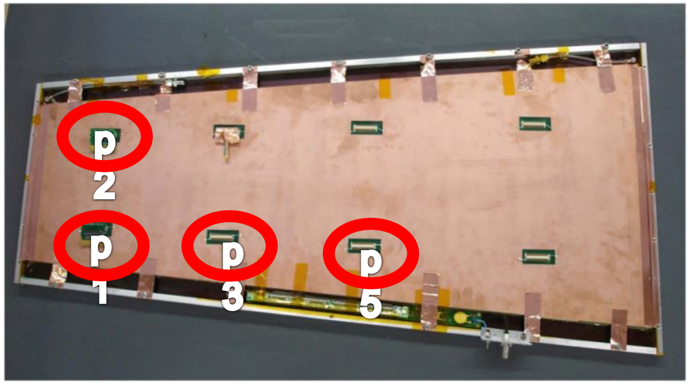
HV divider and filter

HV connector

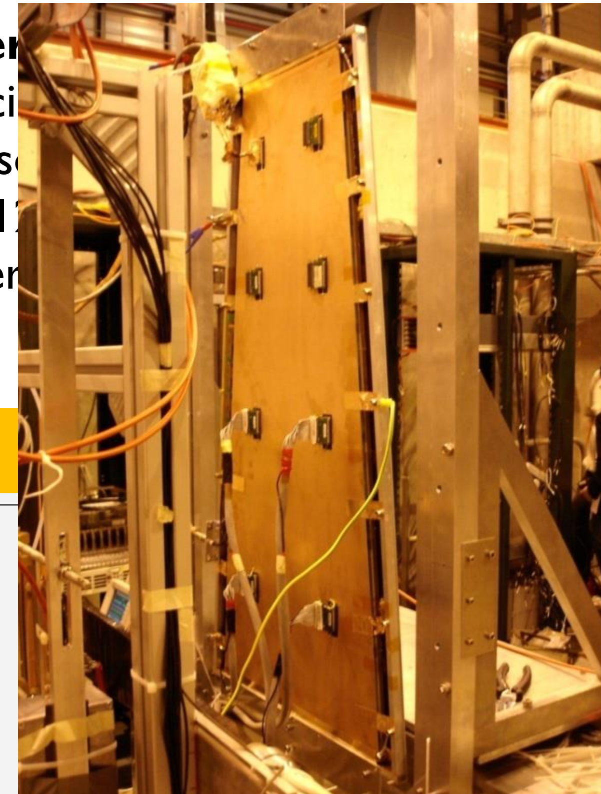
Gas inlets

Generation I
Fully glued
Gap configuration 3/2/2/2mm
1024 readout strips

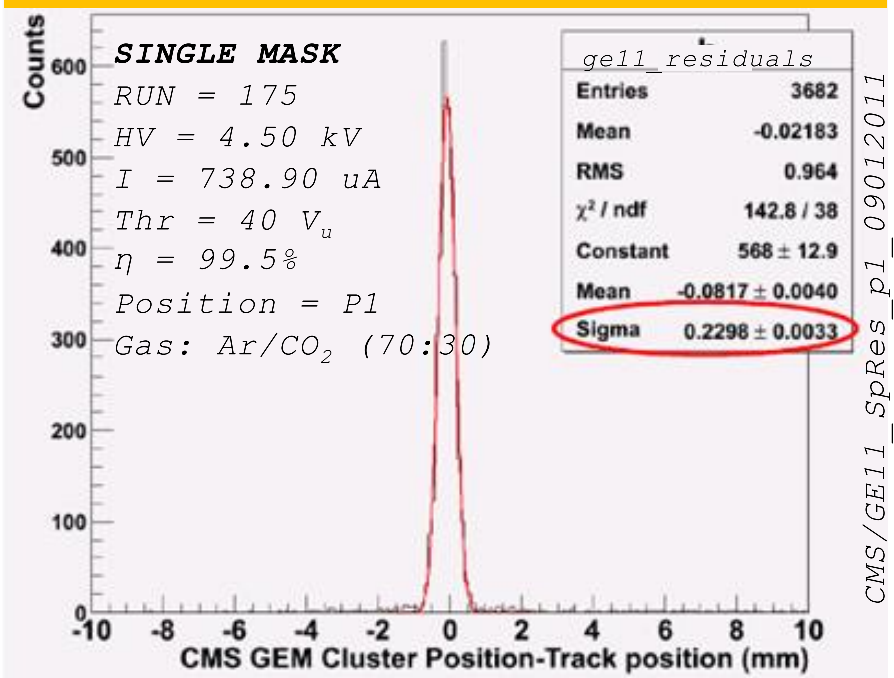
1st Generation I - GE1/1 Detector

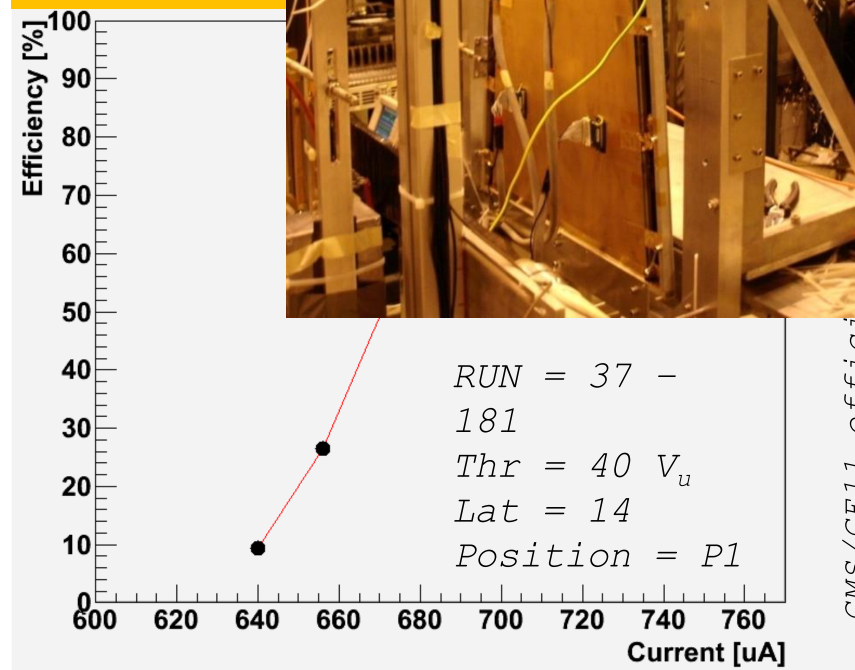


Excellent per
- ≥ 98% effici
- 230 µm res
  (≈ pitch/√1
- uniform per



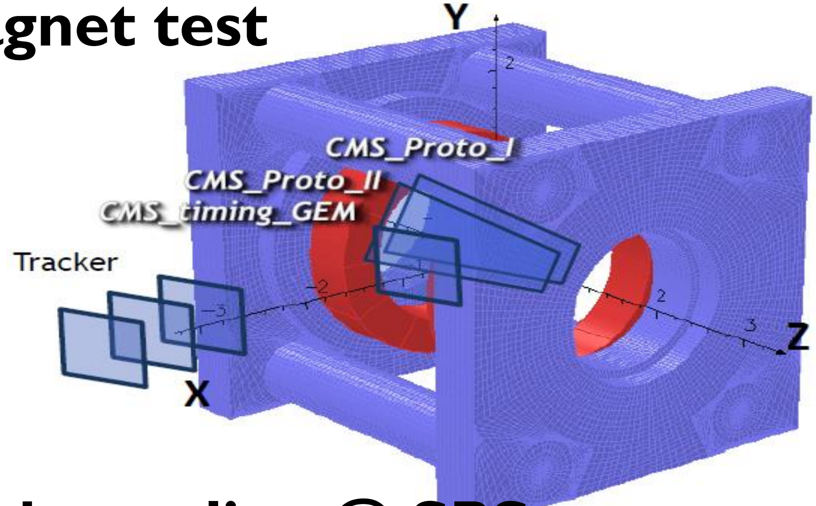
Track residuals



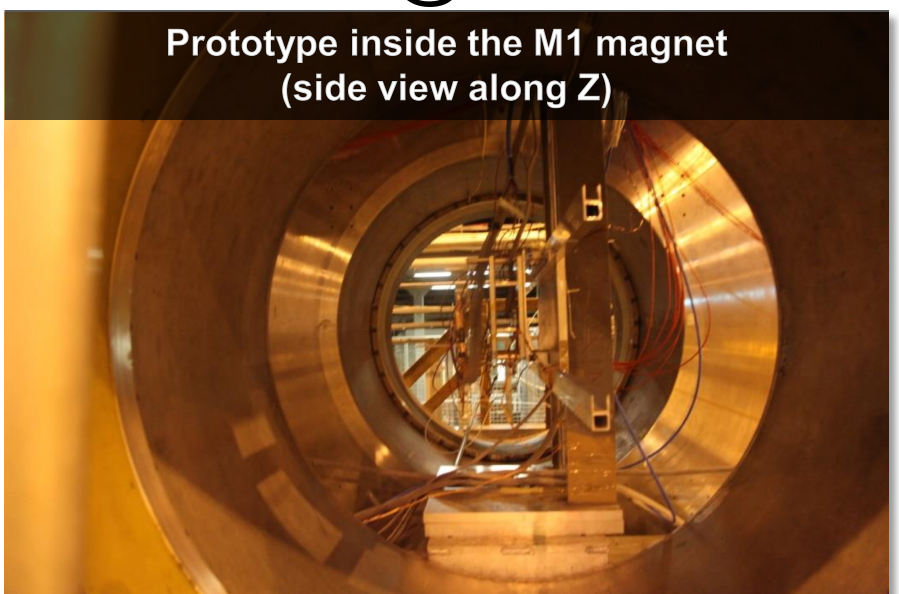


2nd GE1/1 Detector (2011)

Magnet test

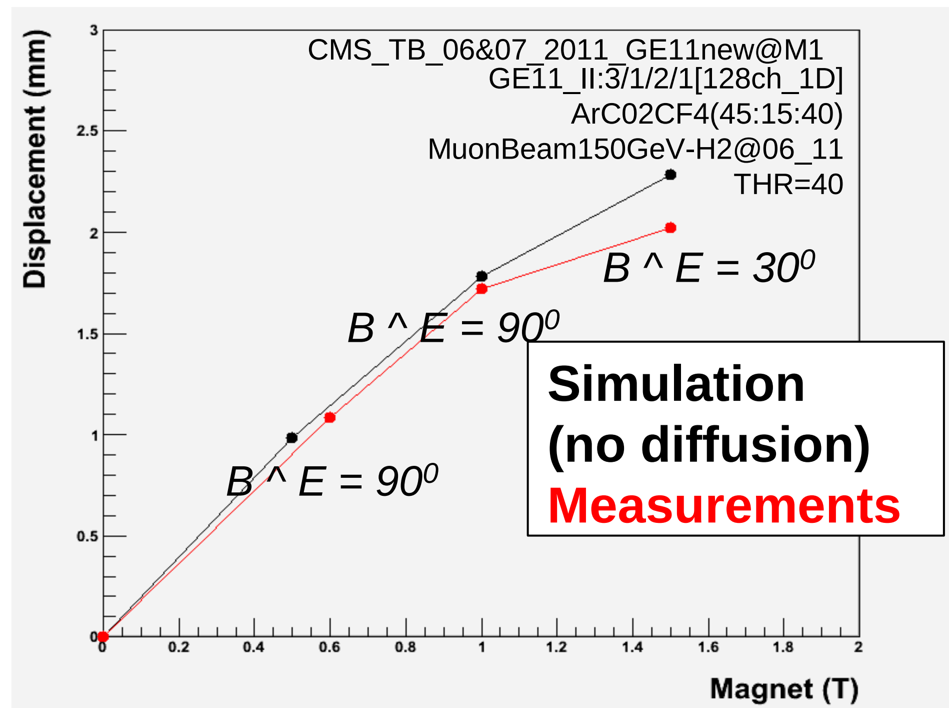


H2 beam line @ SPS


Prototype inside the M1 magnet (side view along Z)

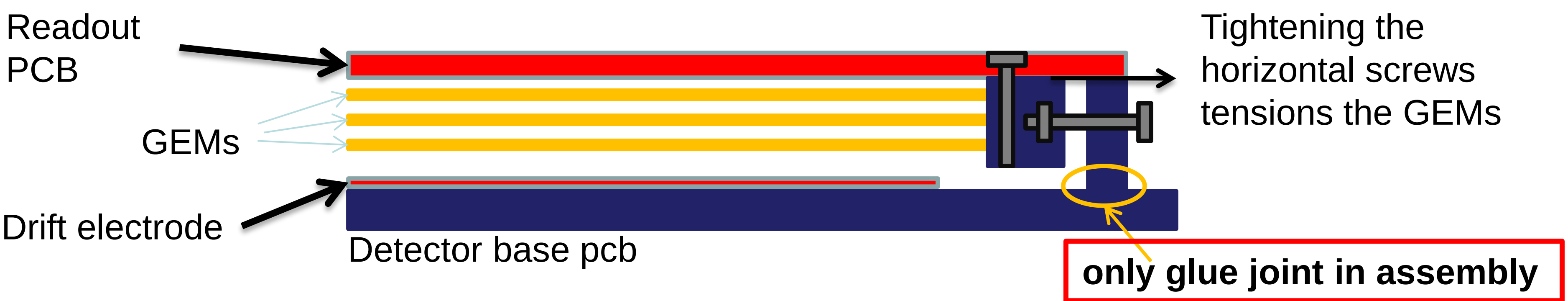
- Smaller GEM gap sizes: 3/1/2/1 mm
- More sectors: 3 columns, 8 η partitions
- Smaller strip ptich: 0.6-1.2mm
- 3072 channels, 1D readout

- Expect max. $B_\perp \sim 0.6$T, $B_\parallel \sim 3$T and B^E~8° for GE1/1



GEM Foil Stretching (III)

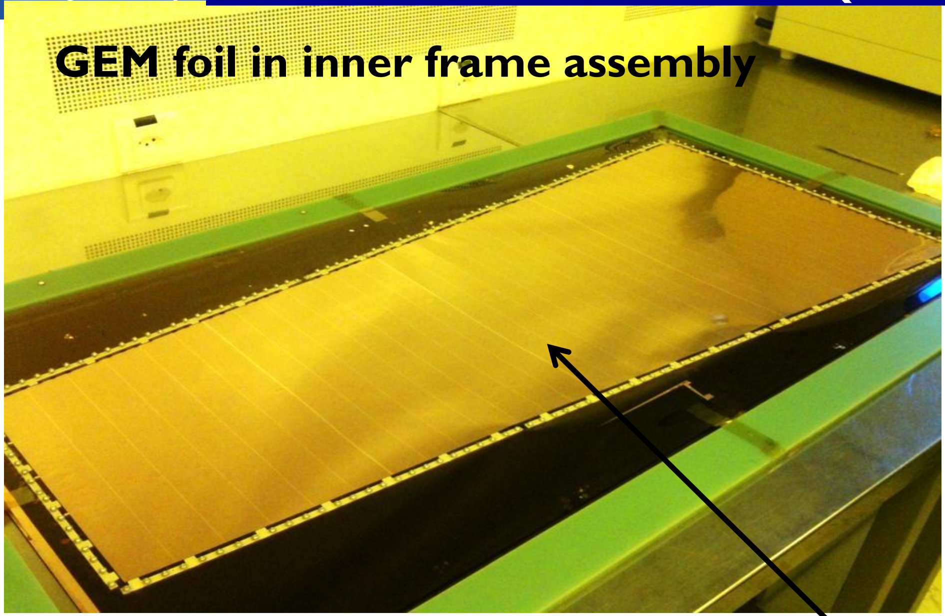
Current state-of-the-art: Self-stretching assembly without spacers (CERN)

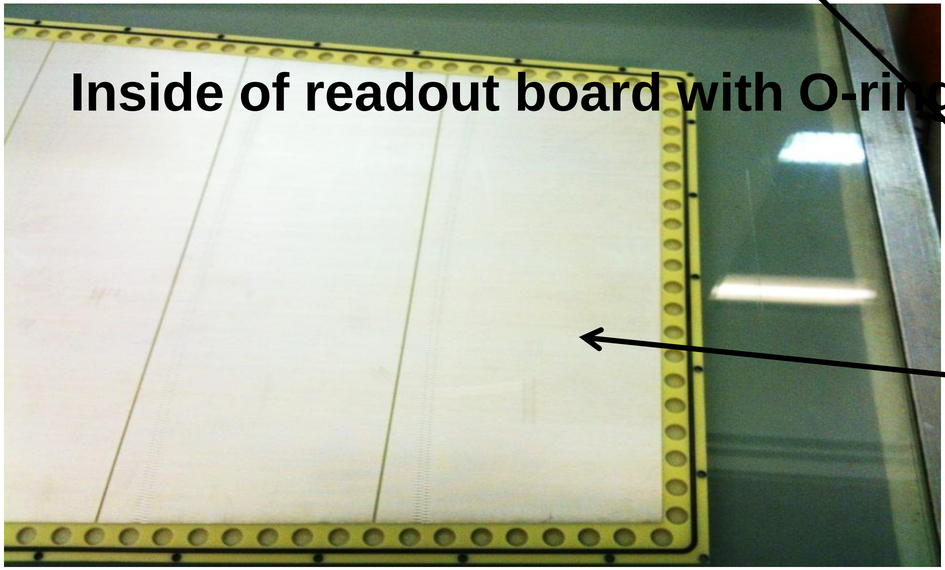


2011-12

Allows re-opening of assembled detector for repairs if needed

Generation IV - GE1/1 Detectors (2012)





Base pcb with drift electrode

No spacers in active volume

η-sector with 384 radial readout strips

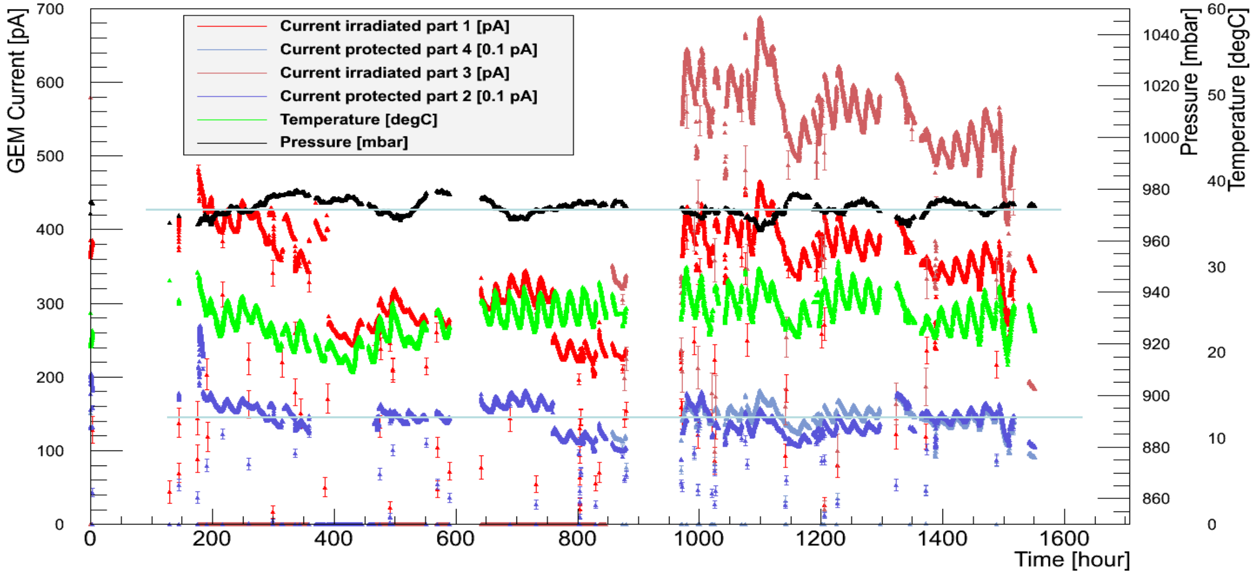
Generation IV GE1/1 Prototype Full-size NS2

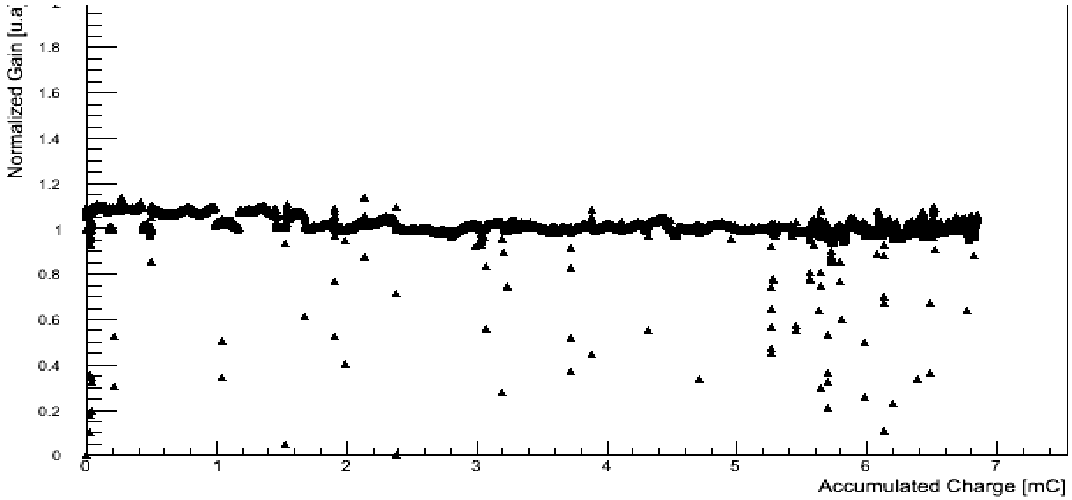
Assembling Generation IV GE1/1 at CERN

- The assembly of one single detector is about 2 hours
- All preparatory work has to be done in advance
- Clean room of class 1000 is required.
- Sites at Frascati and FIT quite advanced
- Other sites getting ready

May 2013

Normalized Corrected Gain for GE1/1 Prototype 2



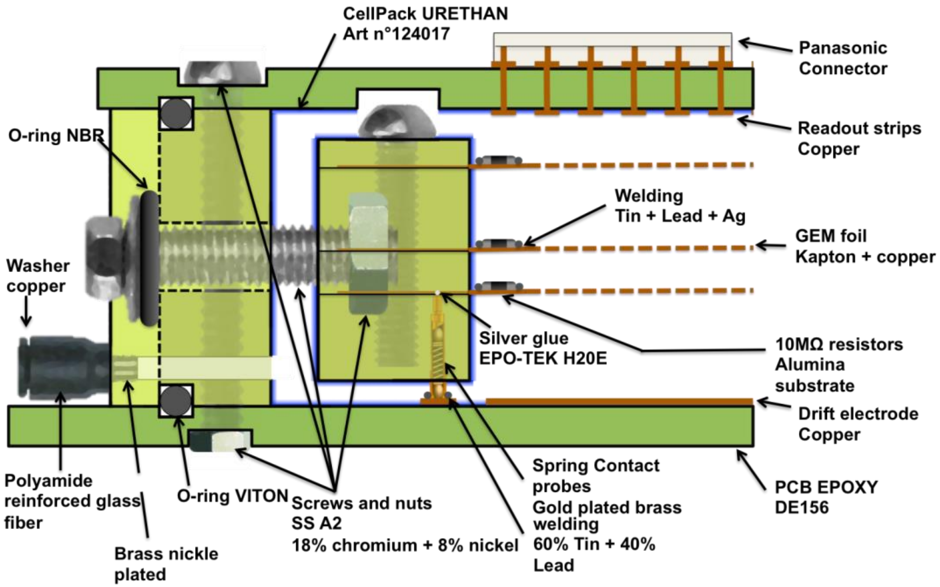


ArCO2CF4 (45,15,40%)

Ongoing Tests

J. Merlin 2013

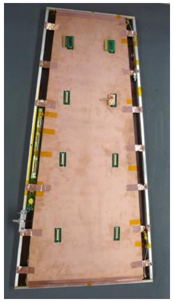
Material Outgassing Tests



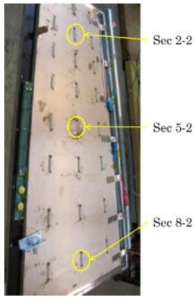
<u>Outgassing test :</u>
Started

-> most critical materials : polyurethane, O-rings …

Full-size GE1/1 Detectors Developments in Time



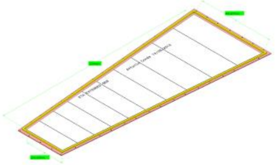
2010



2011

2012

2013



2013/14

Production and
QC of detectors
First prototype of
VFAT3

Slice installation

Slice and
trigger
commissioning

QC of
Production
GE1/1
chambers with
final electronics

2014/15

2015/16

2016/17

2017/18

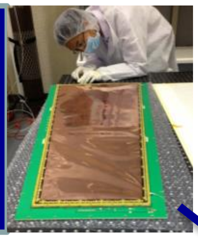
2018/19

Full-production of
chambers and electronics started

Full installation of GE1/1 with final electronics

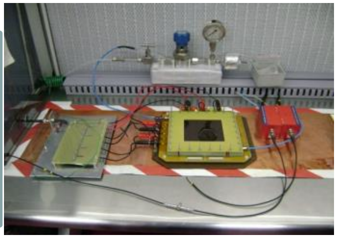
Possible Production Sites

USA
FIT



CERN: 186

India



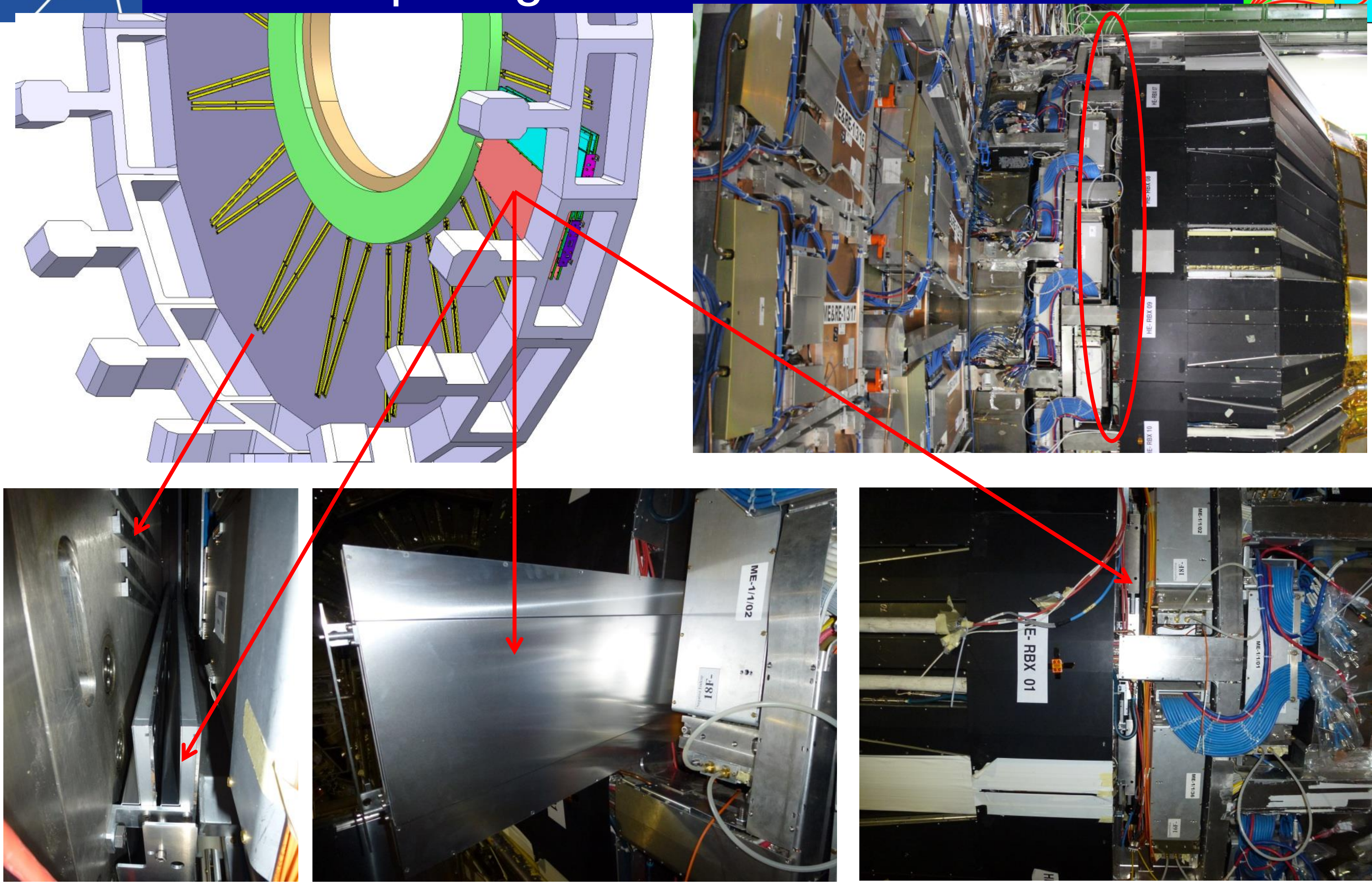
CERN
Production
and final QC

Italy

Belgium
Gent
University

Installation
in CMS

Trial Installation in CMS – 2013
Preparing for Slice Test in 2016

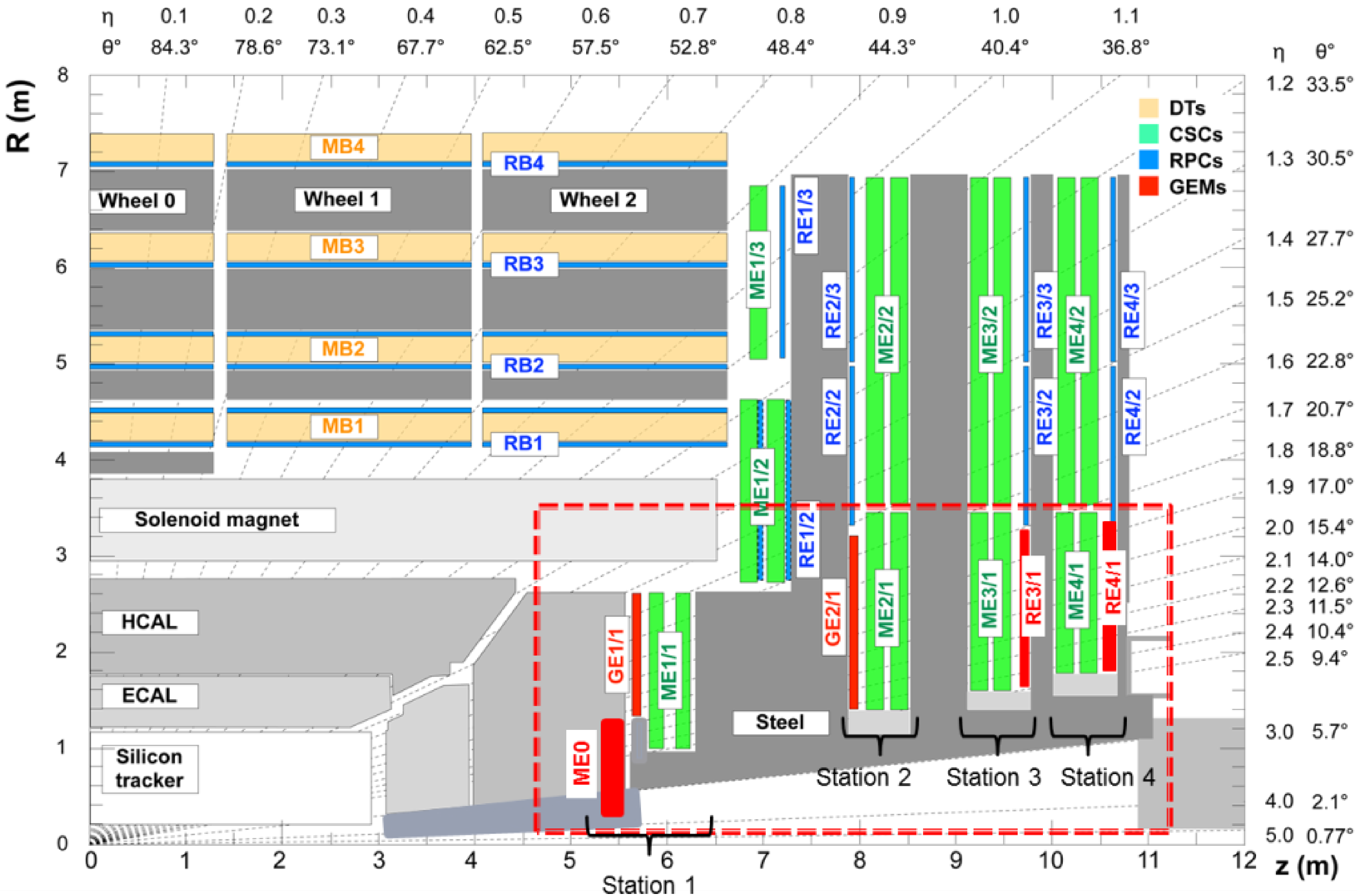


Moving forward to Phase 2 Upgrade – Post LS3

- By LS3 the integrated luminosity will exceed 300 fb^{-1} and may approach 500 fb^{-1} (use 500 for detector studies)
- We will look forward to over 5x more data beyond that, at significantly
  - higher PU (and steady throughout the fill) nd radiation
- HL-LHC with lumi-leveling at $5x10^{34}cm^{-2}s^{-1}$ will deliver 250 fb^{-1} per year

  - Performance longevity of the Phase 1 detector
  - Physics requirements for the HL-LHC program and beam conditions
  - Development cost effective technical solutions and designs
  - Logistics and scope of work during LS3

MUONS – PHASE 2



The GEM Collaboration –Oct 2013

Technical Proposal Submitted 31.10.2013
EOI: 182 Collaborators
Conference Reports & Publications ~ 40
Authors 75

CMS: It can only get better….. The best has yet to come !!