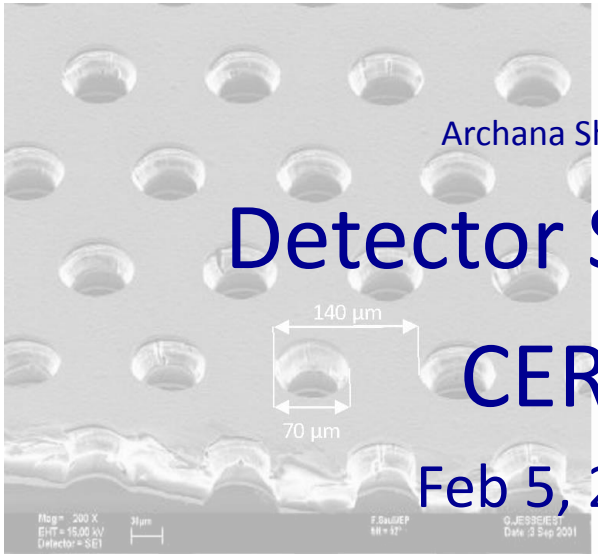
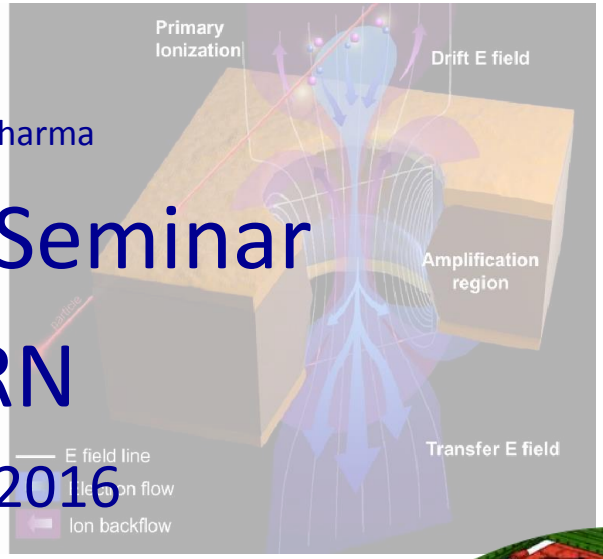
Micro-pattern gaseous detectors for Upgrade of the CMS Muon System



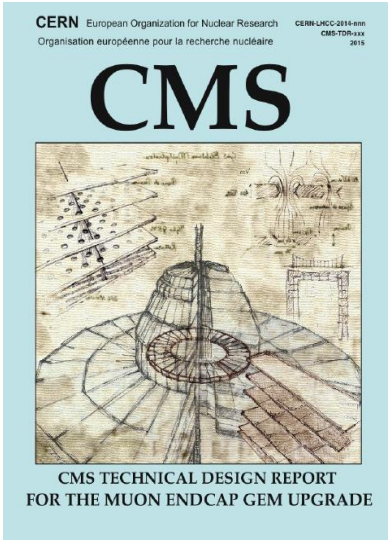


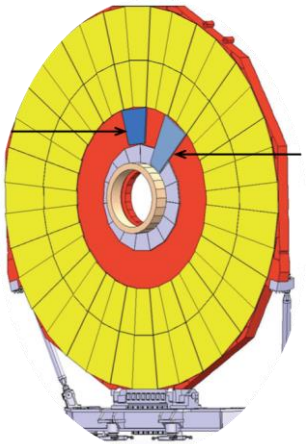
Archana Sharma

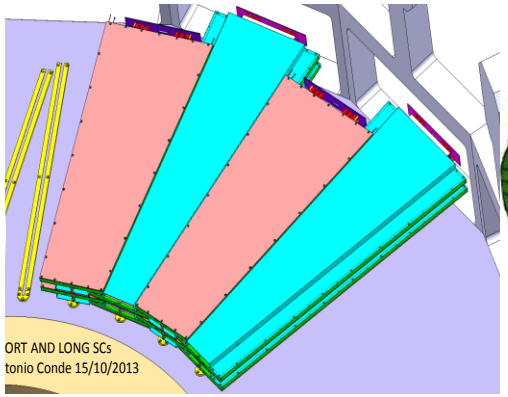
Detector Seminar

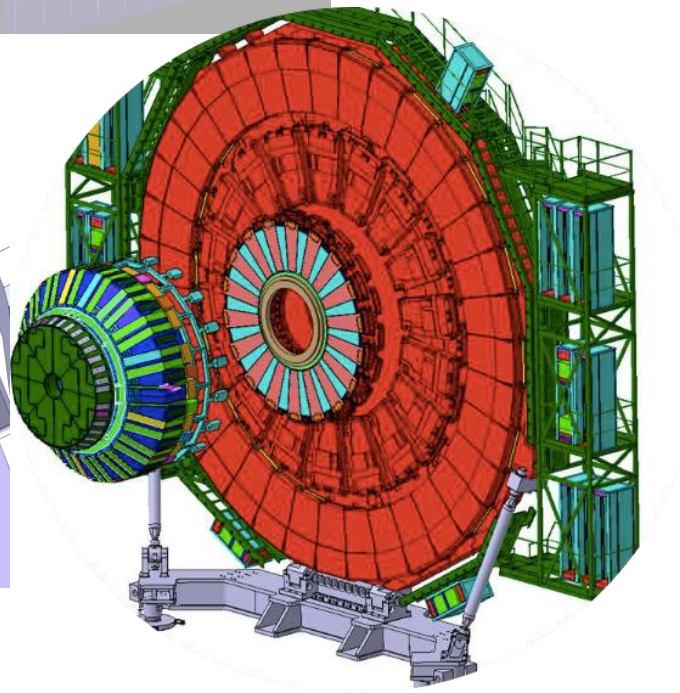
CERN

Feb 5, 2016

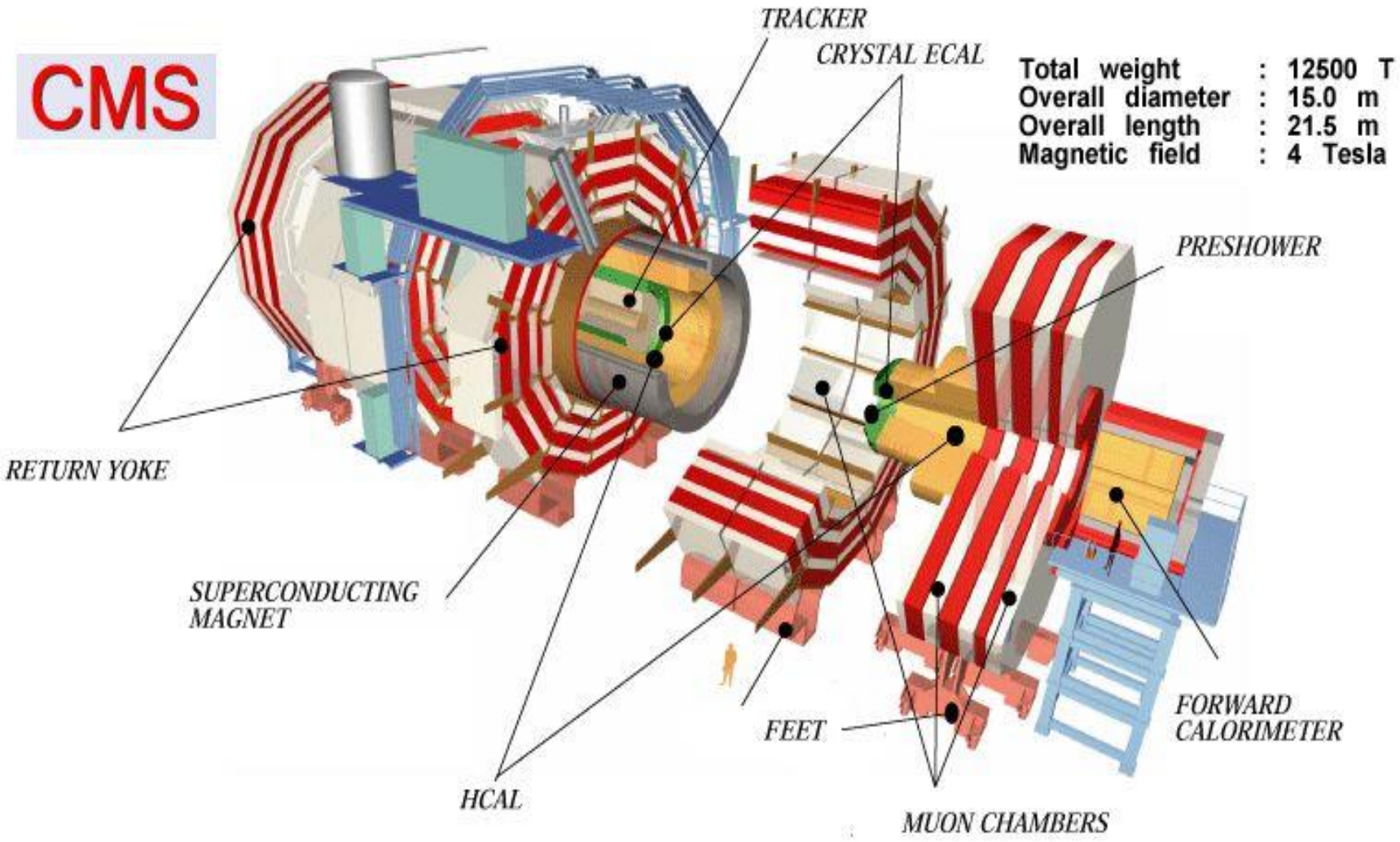






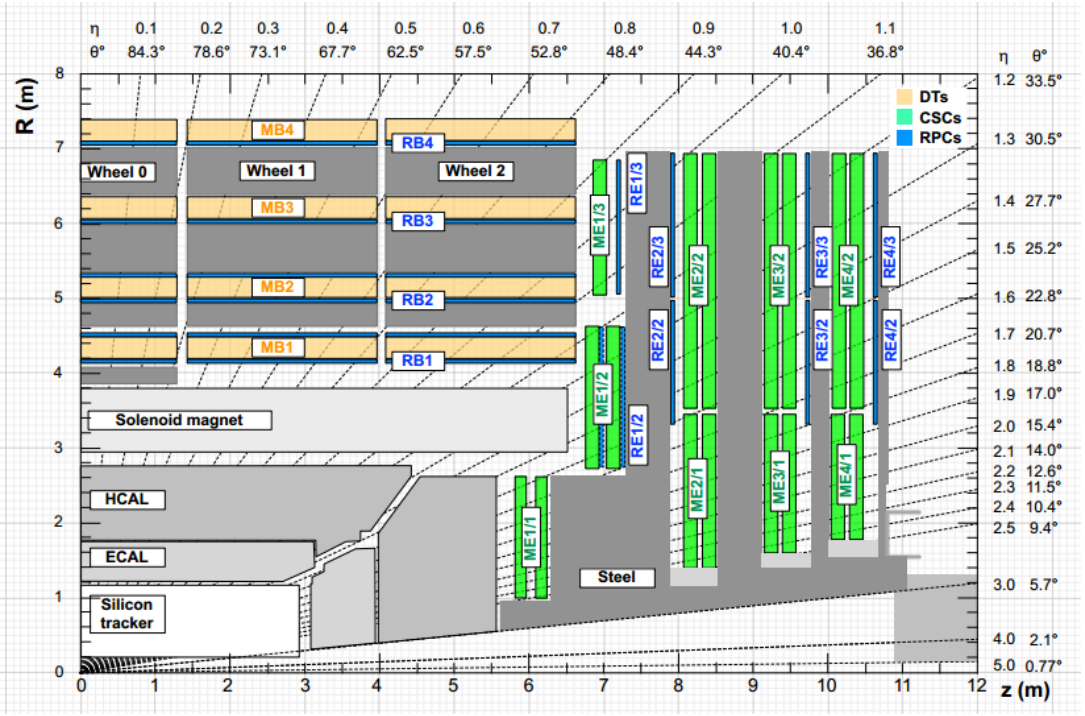


Compact Muon Solenoid



The CMS Muon system

Highly hermetic and redundant muon system, at least four stations on a muon path in all directions



3 technologies:

- **Drift Tubes** and **Cathode Strip Chambers** (for tracking and triggering);
- **Resistive Plate Chambers** (for triggering).

Eta coverage:

- $|\eta|<1.6$: 4 layers of CSCs and RPCs, DTs
- the $|\eta|\geq1.6$: CSCs only;

GOALS:

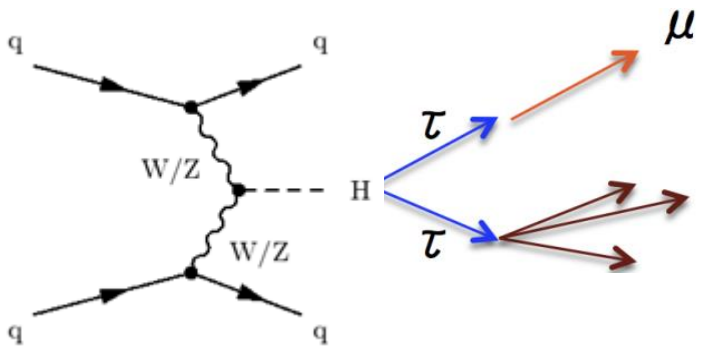
- **robust**, **redundant** and **fast** identification of the muons
- **Level-1 trigger** has access to muon information only
- **Momentum measurement**: the muon system is relevant for high pt muon (>100 GeV) and in the high η region (large lever arm of the muon system)

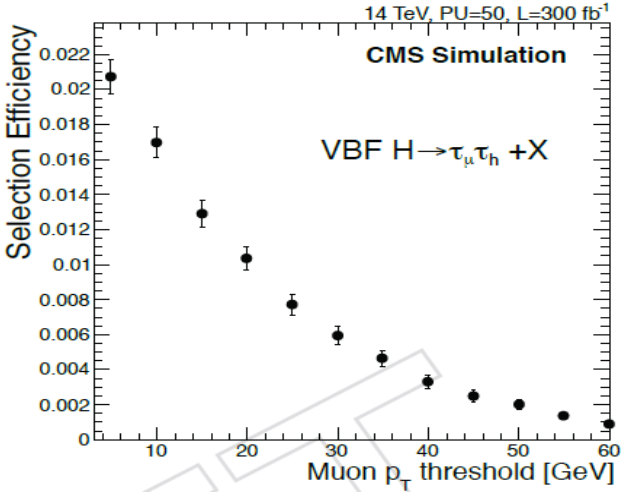
Performance Post LS2

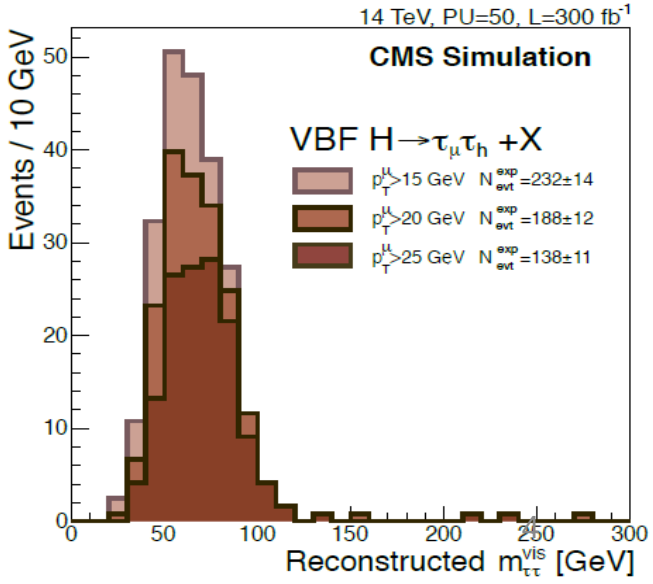
Mantain low p_t thresholds have a large impact on late Phase-1 physics that relies on triggering on soft muons

GOAL: maintain low p_t muon trigger thresholds in the endcap, comparable to the barrel

Example VBF $h \to tt \to \not{m}_X + X$



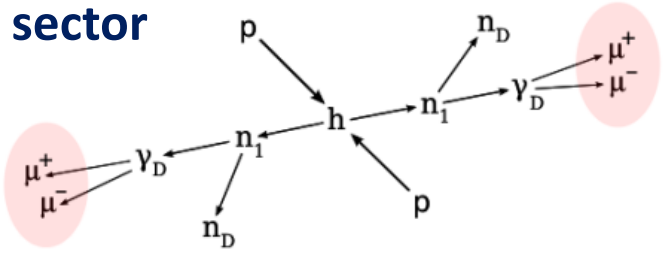


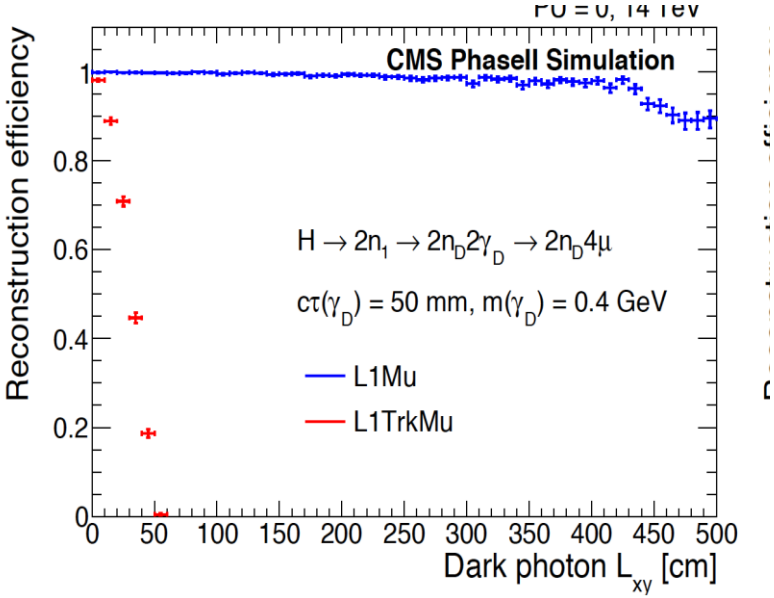


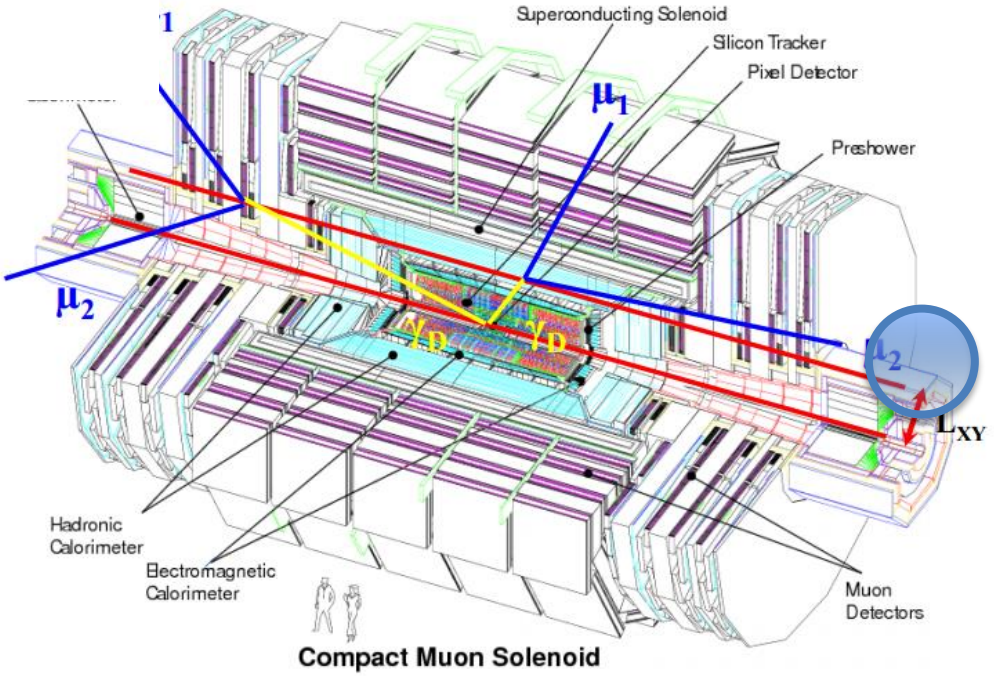
- **23% of events** has muon candidate in forward (nearly independent of threshold)
- increase in the number of final events **35%** if the threshold is reduced from **25 to 20 GeV** and **68%** if we reduce from **25 GeV up to 15 GeV**

Displaced muon scenarios

Displaced signatures frequently arise in SUSY models in search for Dark matter in the hidden sector







- **Track Trigger Muon: Fast deterioration of trigger efficiency above Lxy = 20 cm, efficiency vanishes at Lxy = 50 cm.**

- **Standalone Muon: Maintain high trigger efficiency up to very high Lxy**

CMS: Gas Detector technologies

Drift Tubes (DT)

- Central coverage: |η | < 1.2
- Measurement and triggering
- 12 layers each chamber: 8 in φ, 4 in z

Cathode Strip Chambers (CSC)

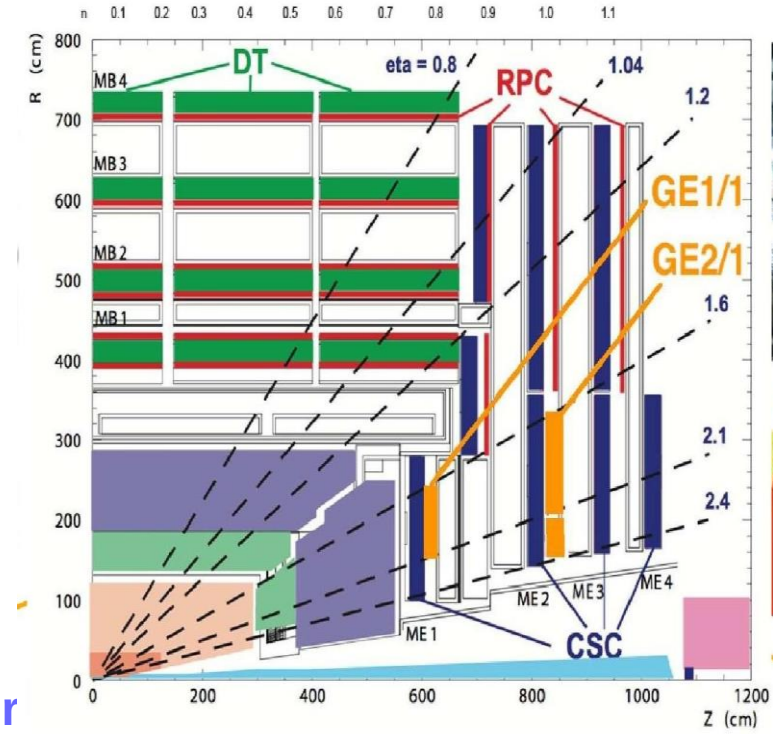
- Forward coverage: 0.9 < |η| < 2.4
- Measurement and triggering
- 6 layers each chamber: each with φ, z

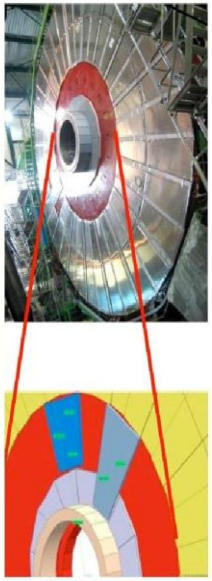
Resistive Plate Chambers (RPC)

- Central and Forward coverage:
  |η | < 2.1
- Redundancy in triggering
- 2 gaps each chamber, 1 sensitive layer

Gas Electron Multiplier (GEM)

- Fast triggering and precise tracking
- Endcap coverage : 1.6 < |η| < 2.4



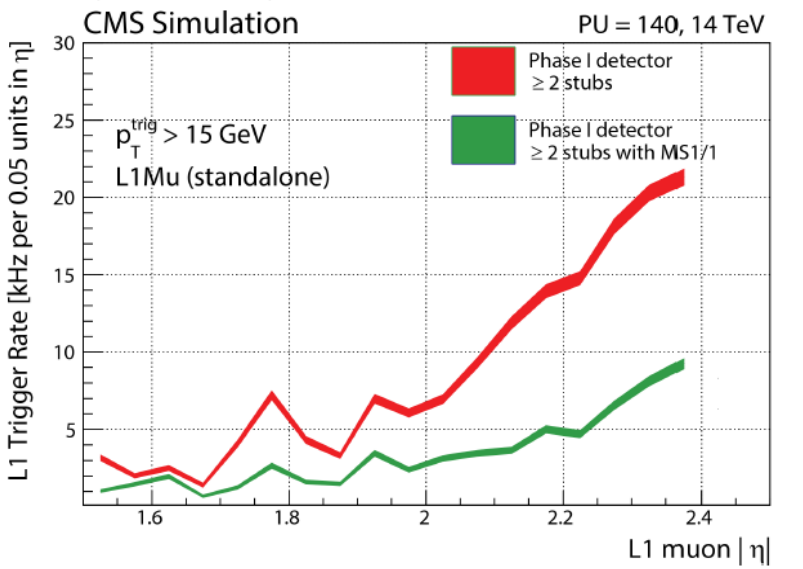


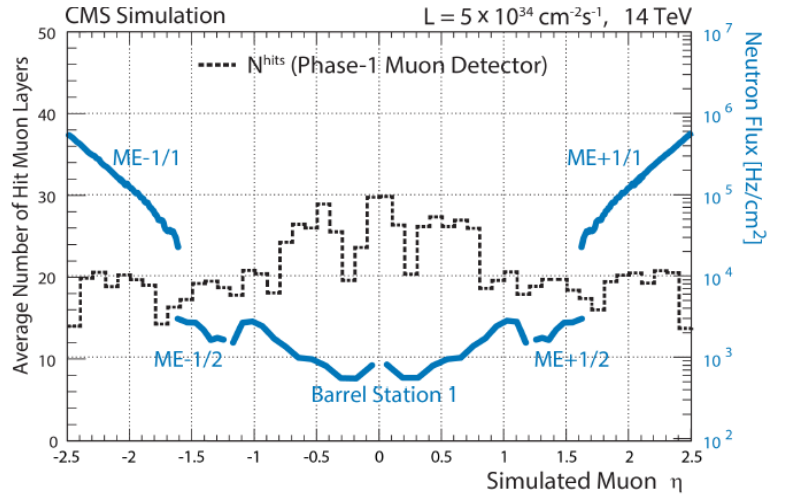
Forward Muon system : challenges

High luminosity can adversely affect muon system performance

The forward region $|\eta| \geq 1.6$ is very challenging

- **Redundancy**: the highest rates in the system vs fewest muon layers
- **Few** handles for the new Track finder postLS2 and for the track-trigger in HL-LHC
- **Rate** : in 10's of kHz/cm^2 and higher towards higher eta and worse momentum resolution
- **Longevity:** Accumulated charge after many years of LHC operation
- **Electronics:** High occupancy/rate and latency increases exceed capabilities of the existing electronics

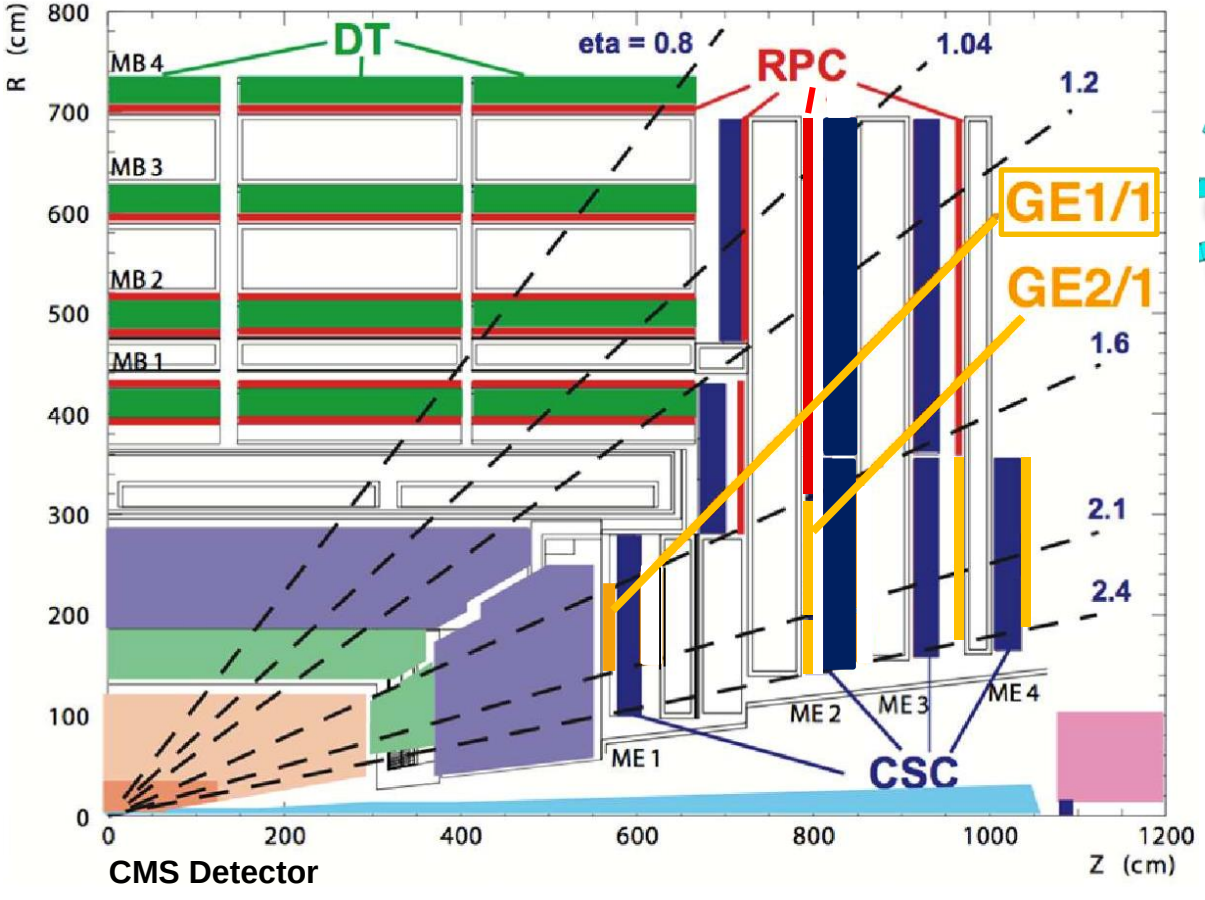




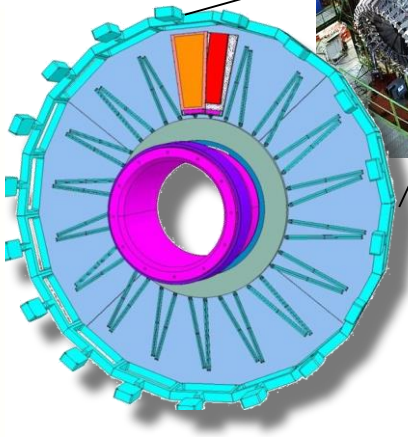
The issues affect already the postLS2 operations and will be exacerbated in Phase 2

CMS GEM Endcap Chambers

The currently un-instrumented high-η RPC region of the muon endcaps presents an opportunity for instrumentation with a detector technology that could **sustain the radiation environment long-term** and be suitable for operation at the LHC and its future upgrades into Phase II: **GEM Detectors**



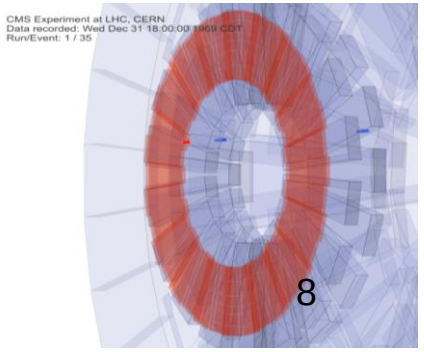
CMS Detector



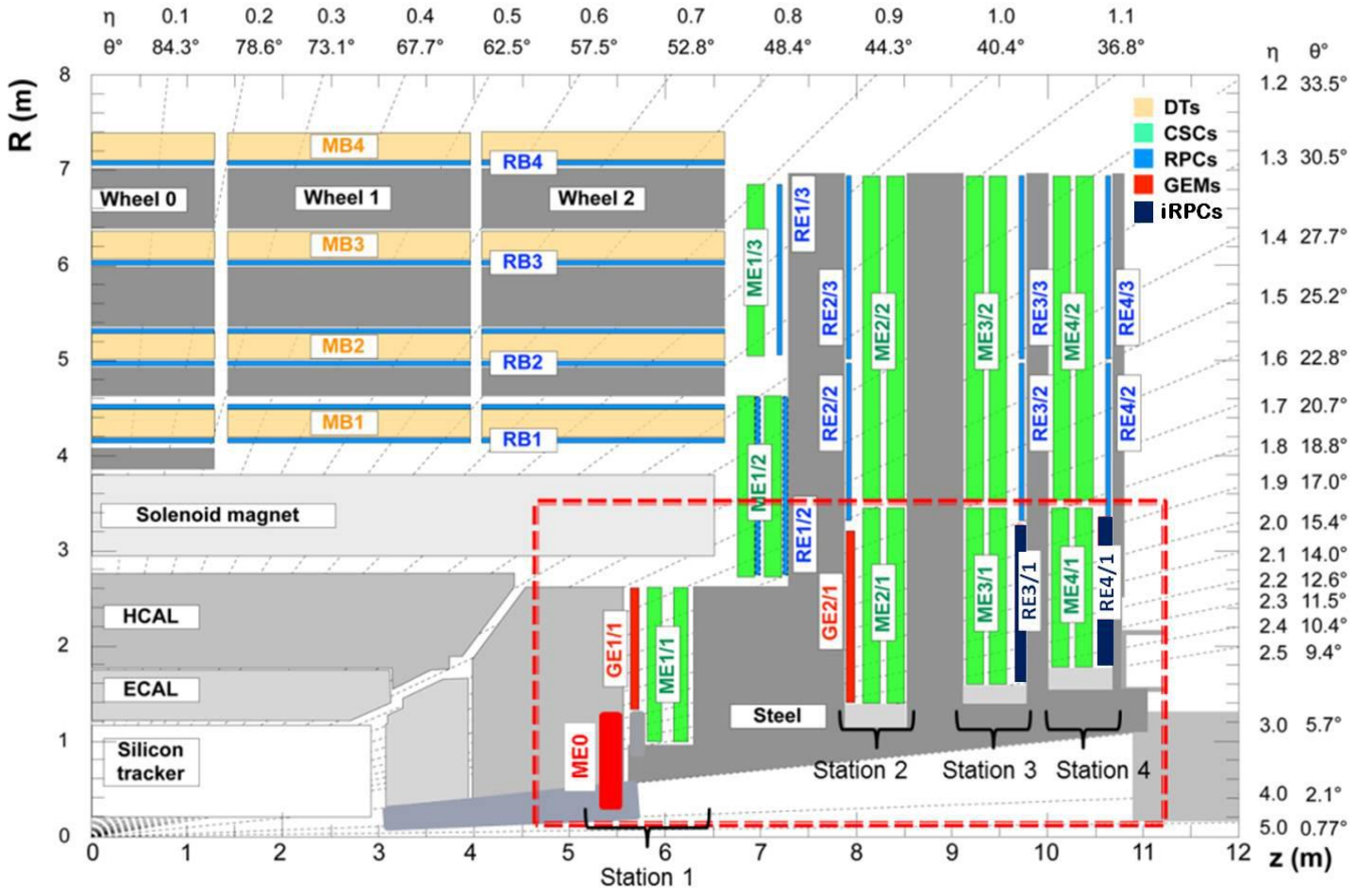
GE1/1

in nose of
first Endcap Yoke

GE1/1 simulation geometry



High η region upgrade with MPGD for Phase 2



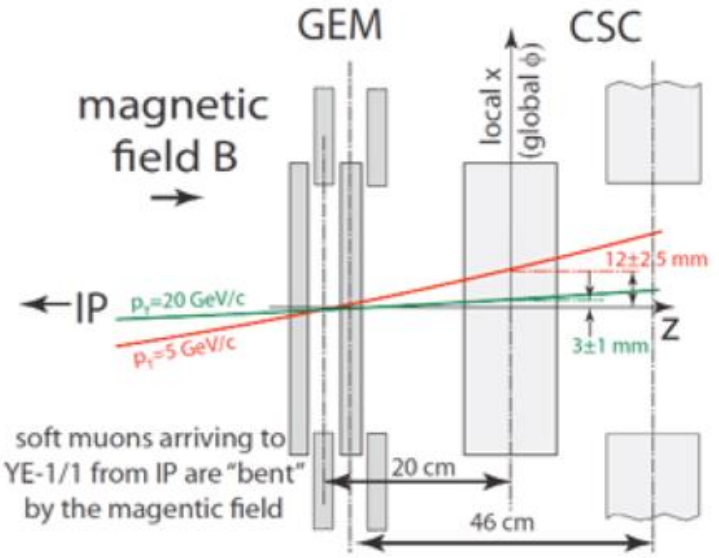
- Objectives:
  - Sustain triggering at current trigger thresholds
  - Increase offline muon identification coverage
  - Maintain existing envelope by mitigating aging effects

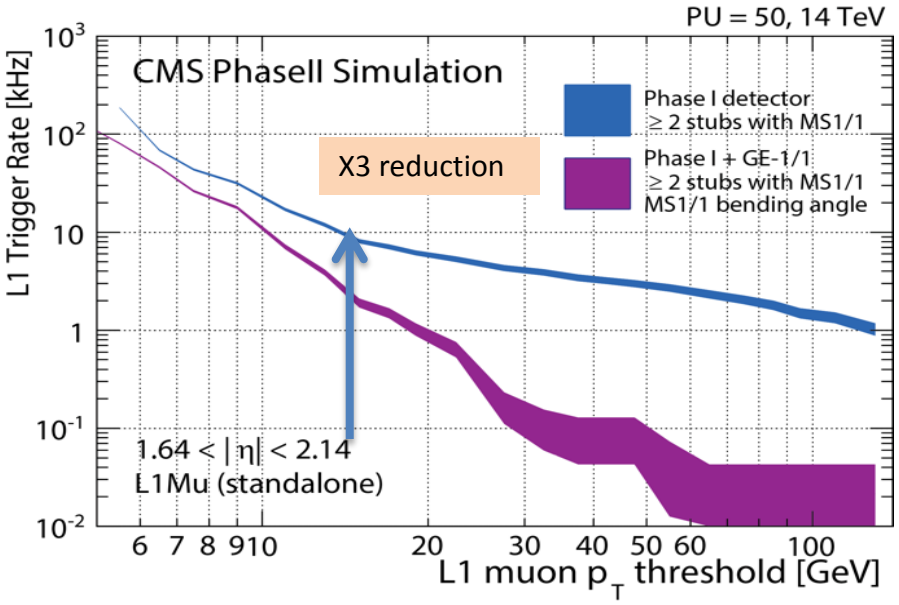
New handle: bending angle

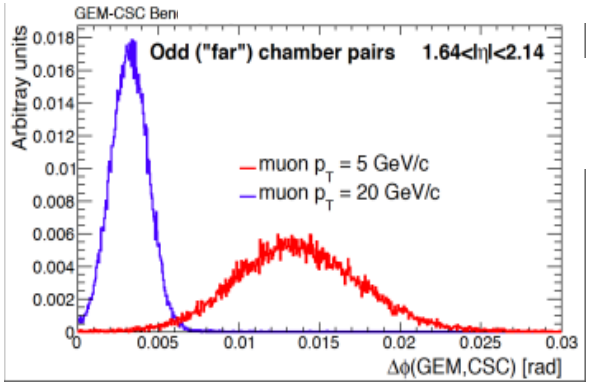
Forward trigger for $|\eta|>1.6$ relies entirely on the CSC system:

- Measurement driven by internal chambers: least scattering, strong B field.

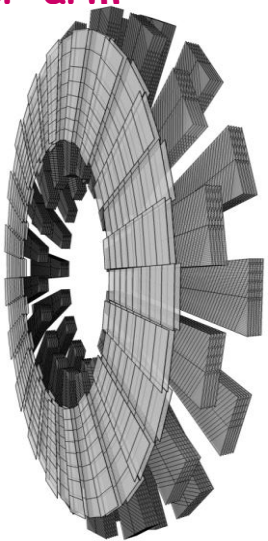
GEM detector in front of CSC can measure muon bending angle in magnetic field and add redundancy







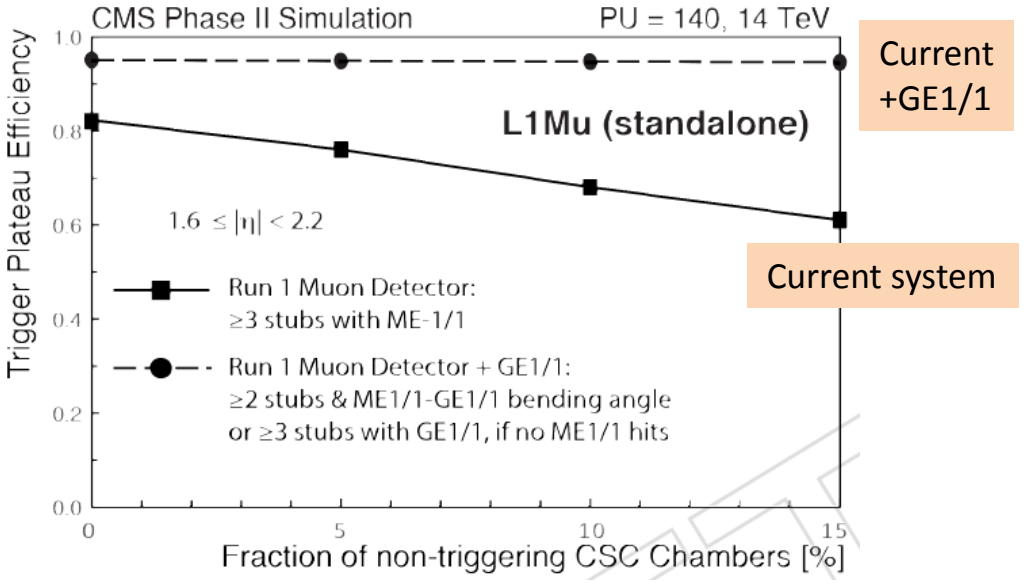
Lever arm - trigg

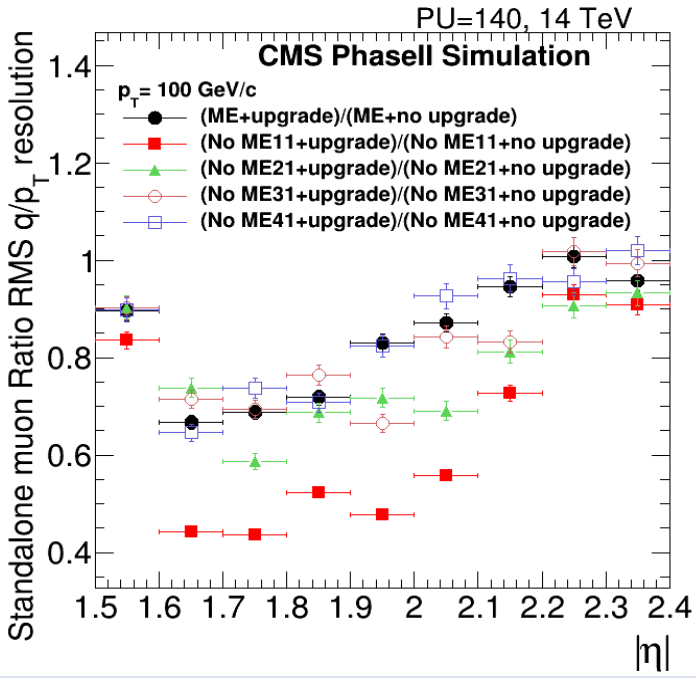


maintain 15 GeV online threshold, keep < 5 kHz rate, high efficiency

Longevity vs redundancy

Potential degradation in performance due to the aging of CSC chambers is a concern:





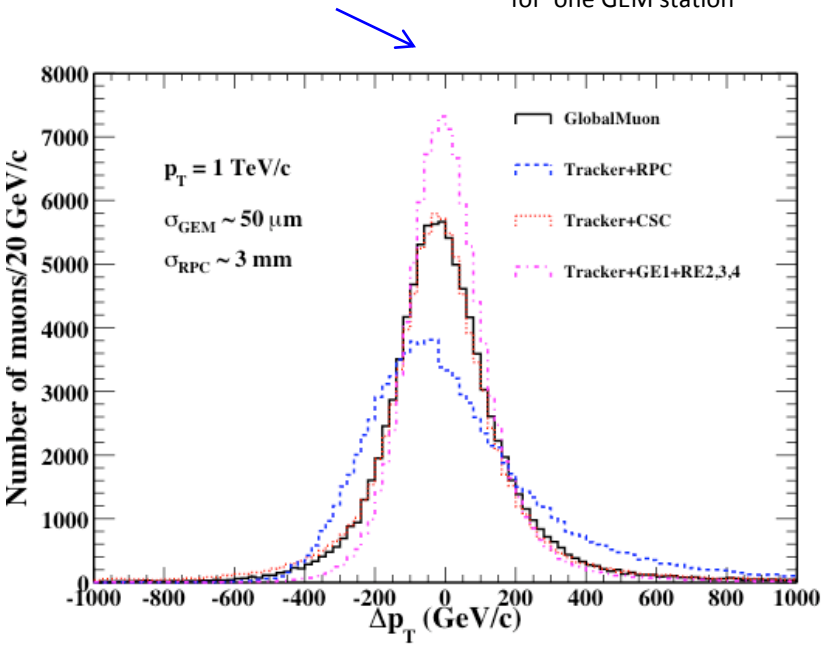
Redundancy assured by the GEM helps in:

- Reducing the deterioration of Level-1 muon trigger performance
- Reducing the large degradation in momentum resolution
- Mitigating otherwise large efficiency losses if a sizeable fraction of CSC chambers becomes partially or fully irresponsive

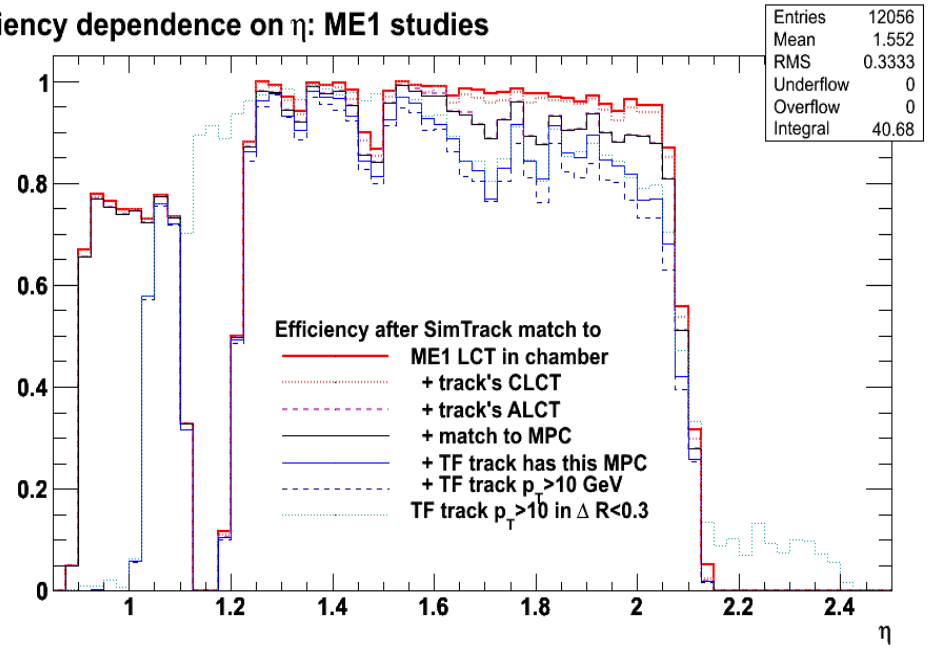
Expected Benefits for Reconstruction & Trigger

Expected gains in momentum resolution at high-p_T

for one GEM station



efficiency dependence on η: ME1 studies

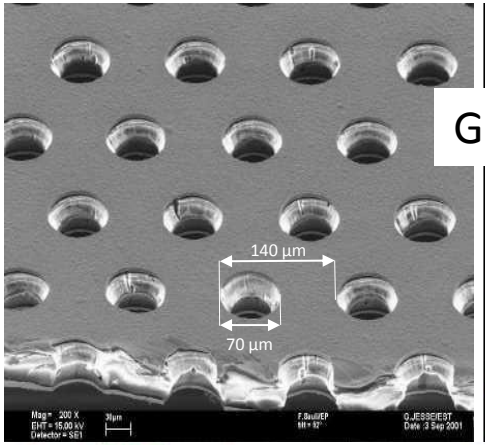


Staving off looming muon trigger inefficiencies at high-η

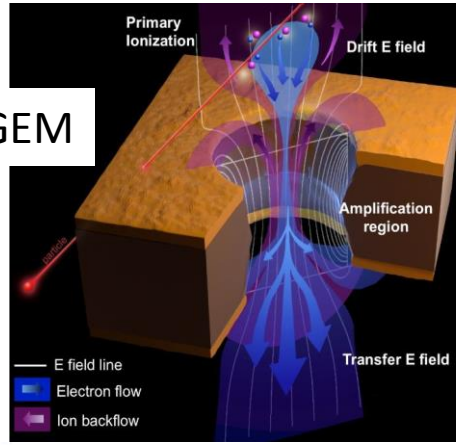
Simulation

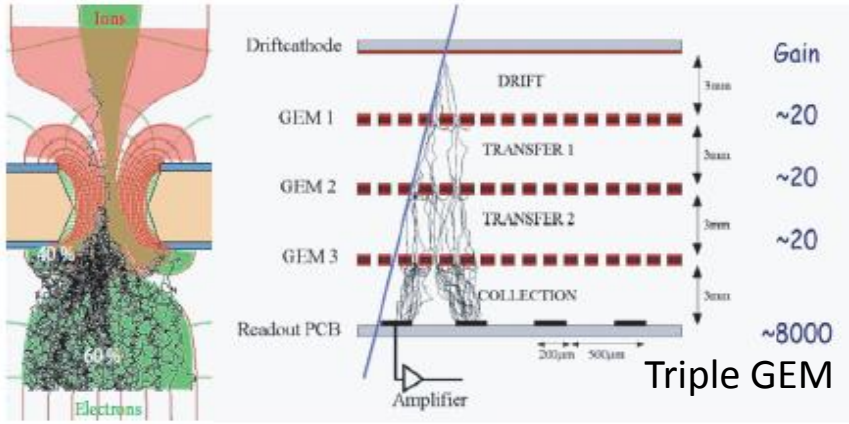
Detector requirements

- Maximum geometric acceptance within the given CMS envelope :
- Rate capabilities up to 100's kHz/cm2 .
- Single-chamber efficiency > 98 % for mips
- Gain uniformity of 10% or better across a chamber and between chambers and no loss due to aging effect after 3000 fb^{-1}
- High spatial and good time resolution



GEM





Triple GEM

Micro-Pattern Gas Detectors (MPGD) due to their proven performance at HEP experiment (high rate capability and fine space resolution, high gain stability) are ideal tools. Dedicated studies for the large CMS detector:

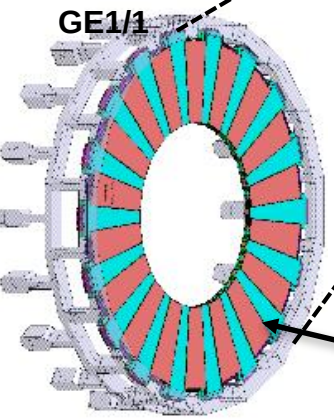
The GE1/1 design

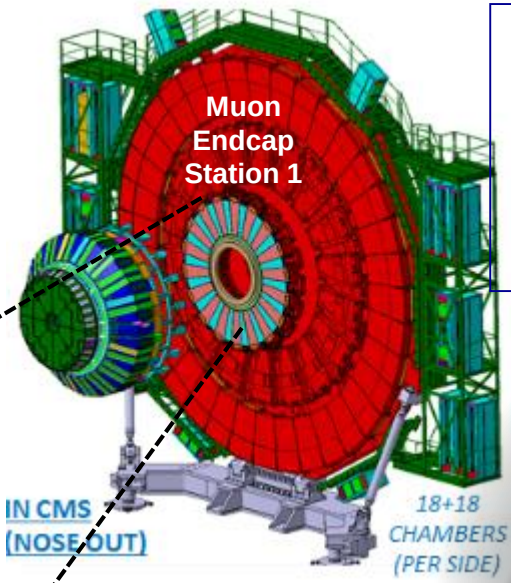
GE1/1 in high-η region 1.5<|η|<2.2

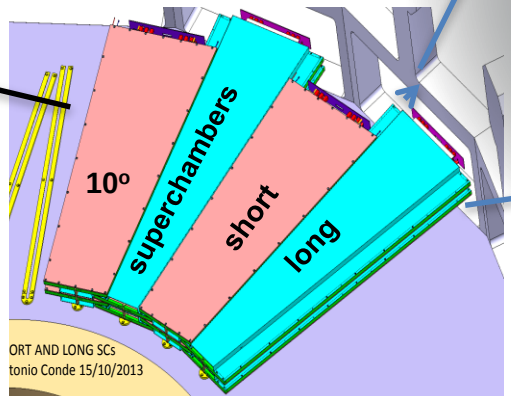
10^0 trapezioidal triple-GEM Superchambers

Long (1.5<|η|<2.2) and short (1.6<|η|<2.2) version

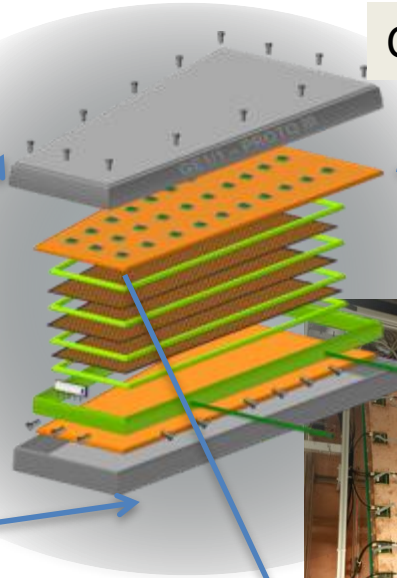
36 superchambers in each endcap







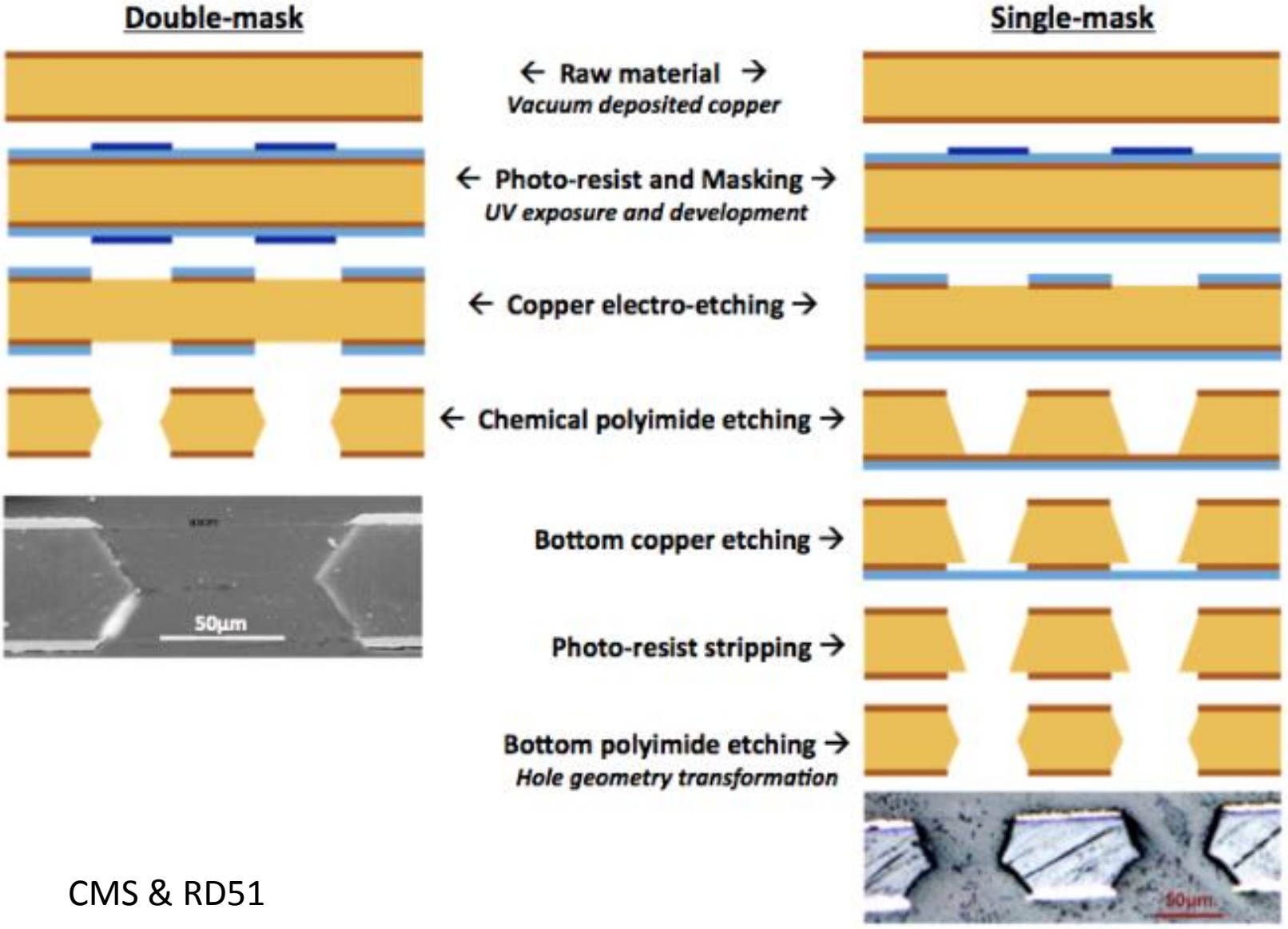
Chamber



Front-end

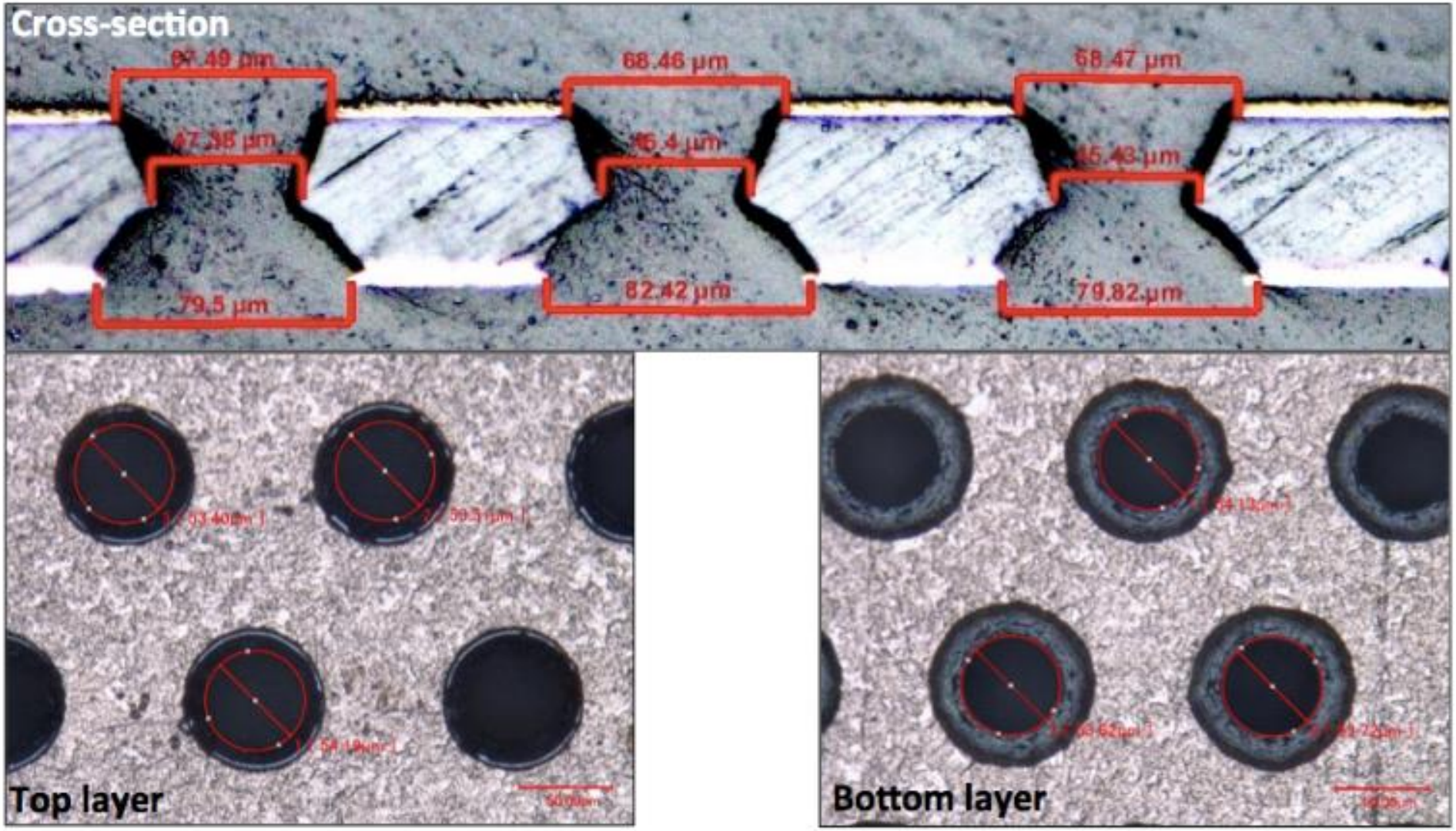
Installation in LS2

Challenge 1

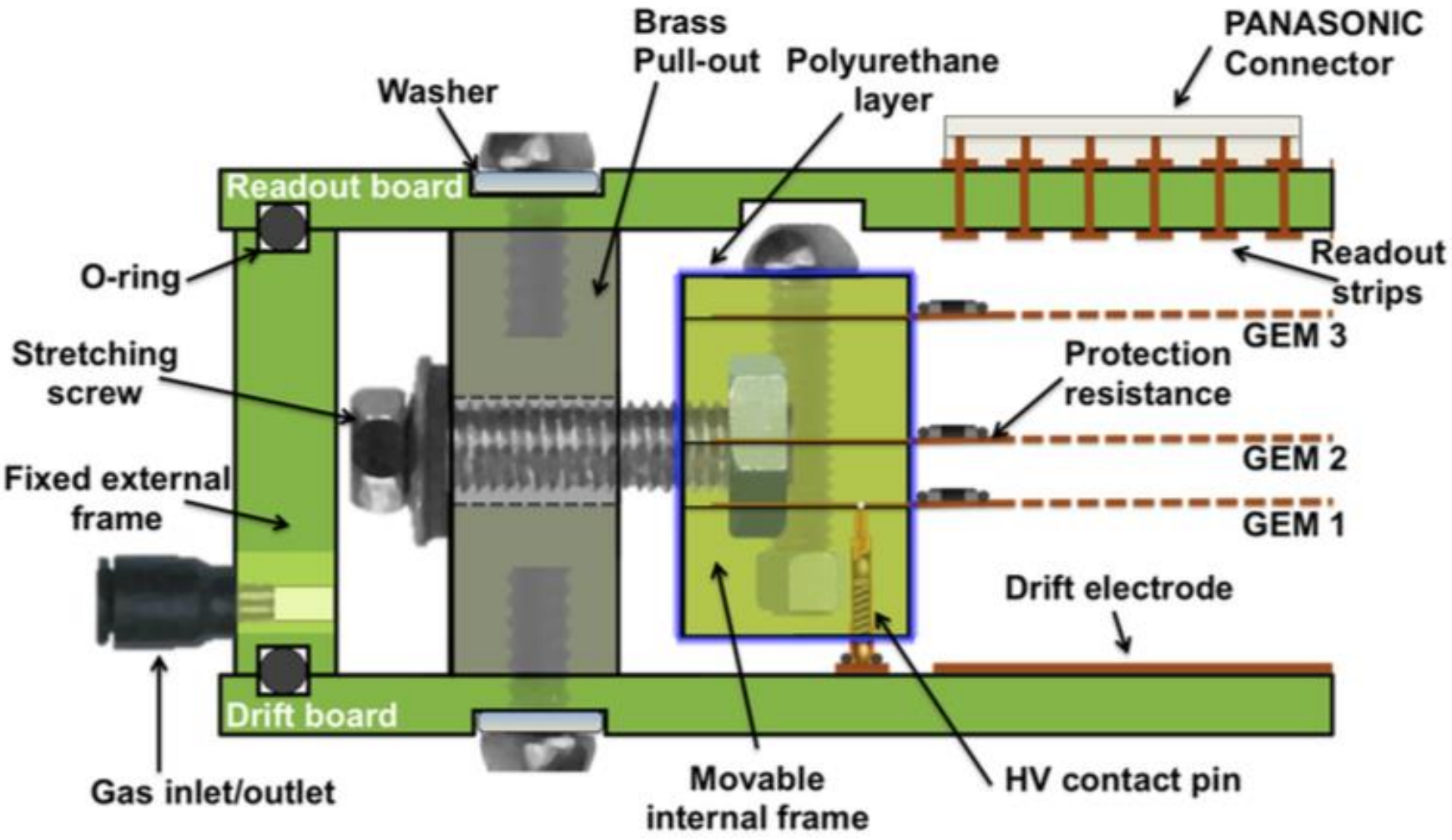


CMS & RD51

Challenge 1 ..

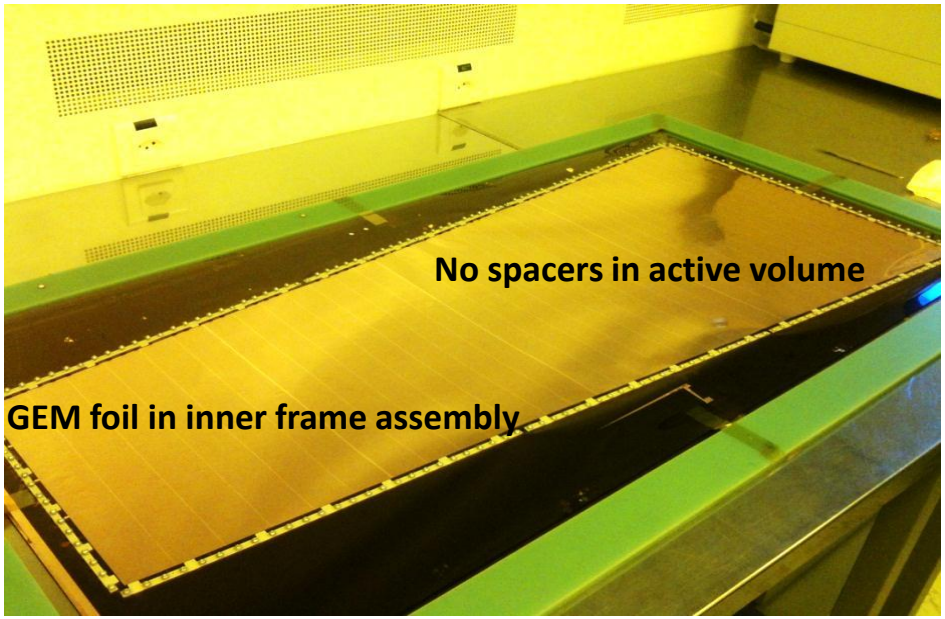

Cross-section
68.46 µm
68.47 µm
47.38 µm
46.4 µm
45.43 µm
79.5 µm
82.42 µm
79.82 µm
Top layer
Bottom layer

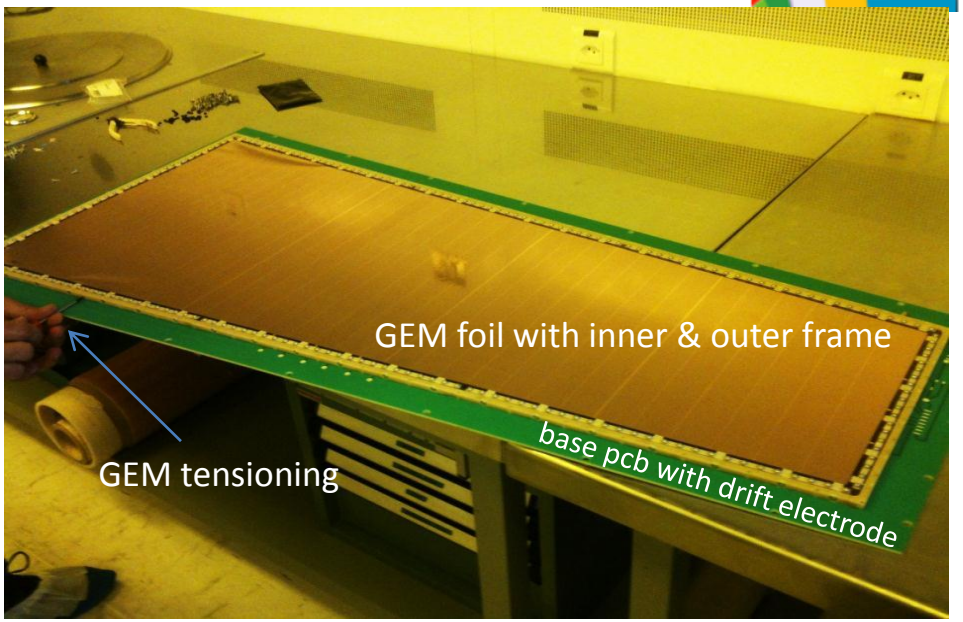
Challenge 2

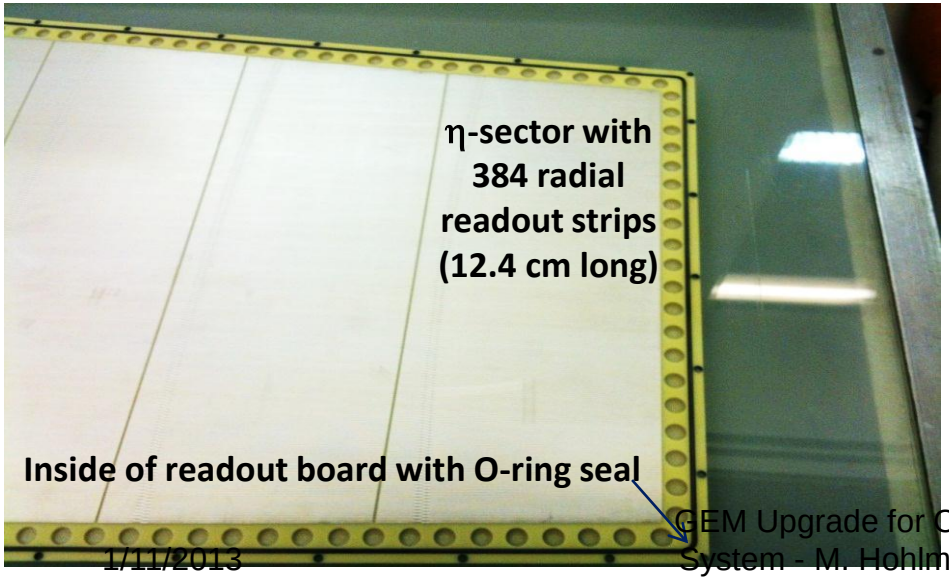


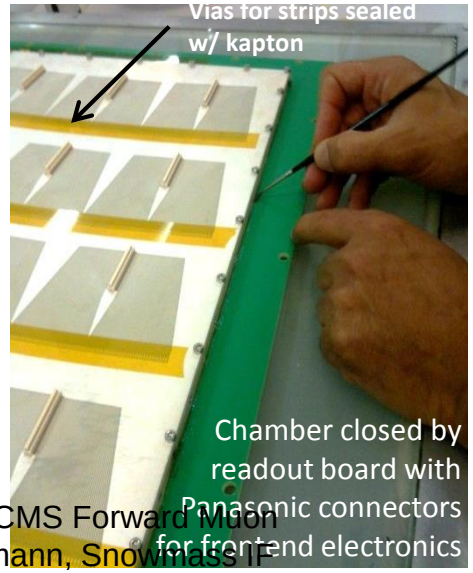
Rui, Jeremie, Brian, Alejandro, Marek, Luigi..

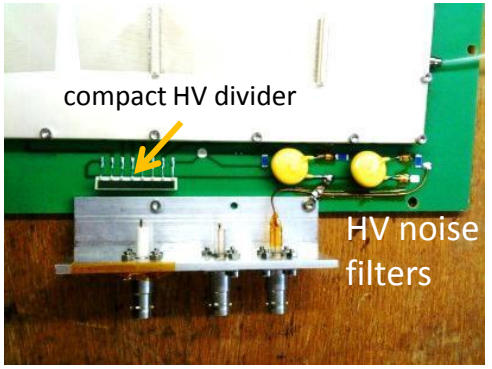
3rd GE1/1 Prototype:: NS2



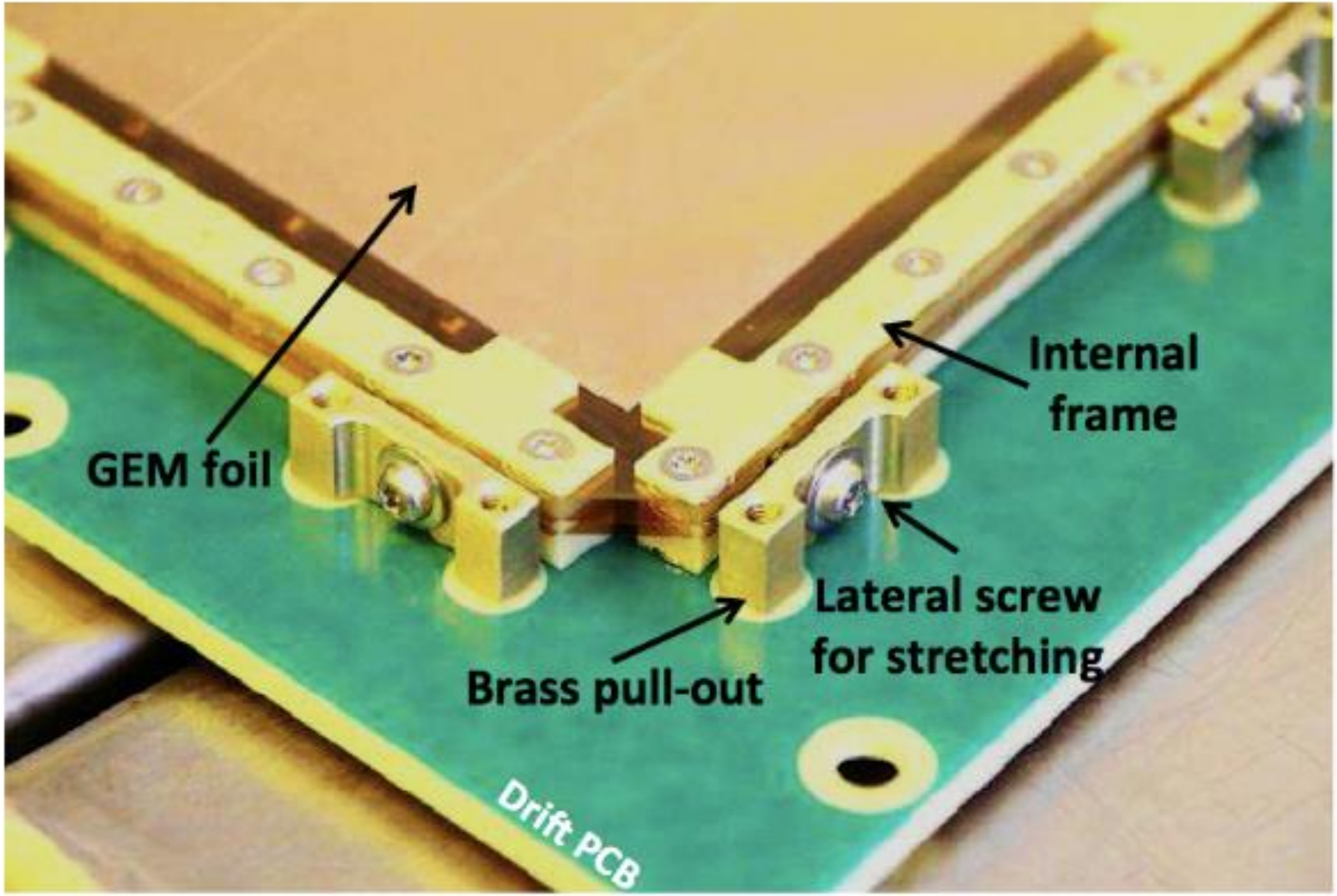




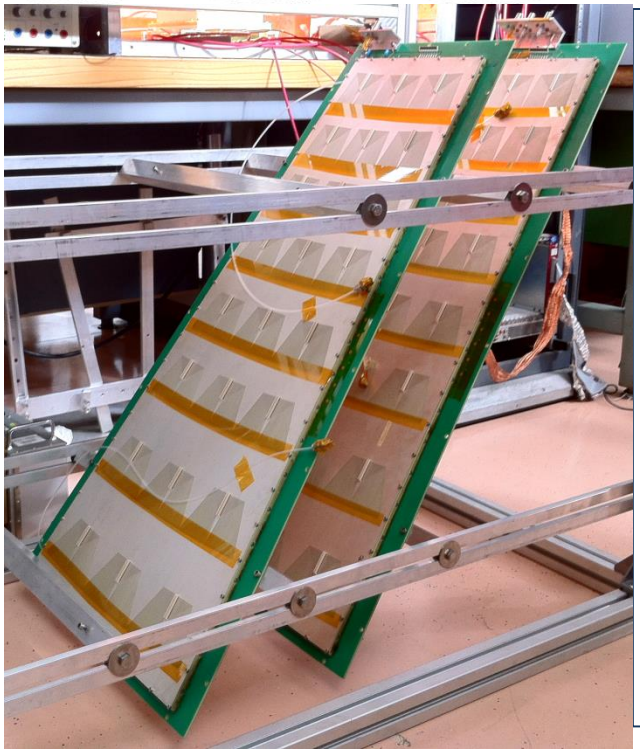




CERN 2012


GEM foil
Internal frame
Lateral screw for stretching
Brass pull-out
Drift PCB

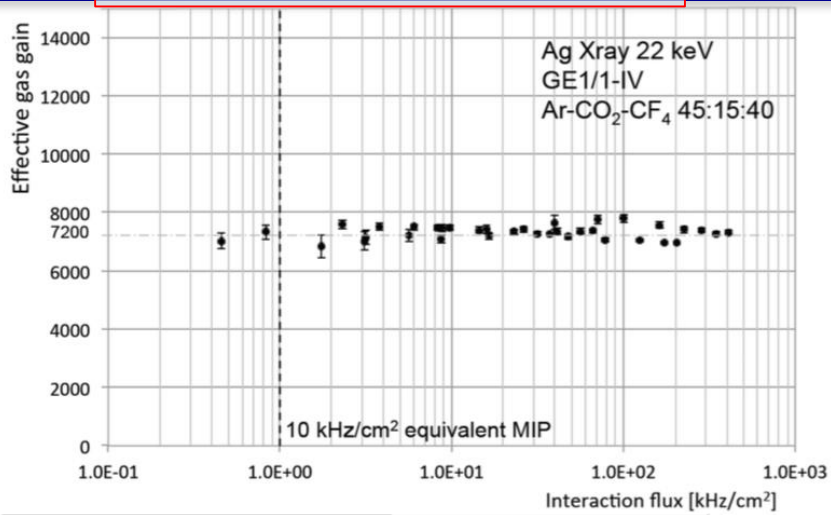
Full-size GE1/1 Detector Prototypes

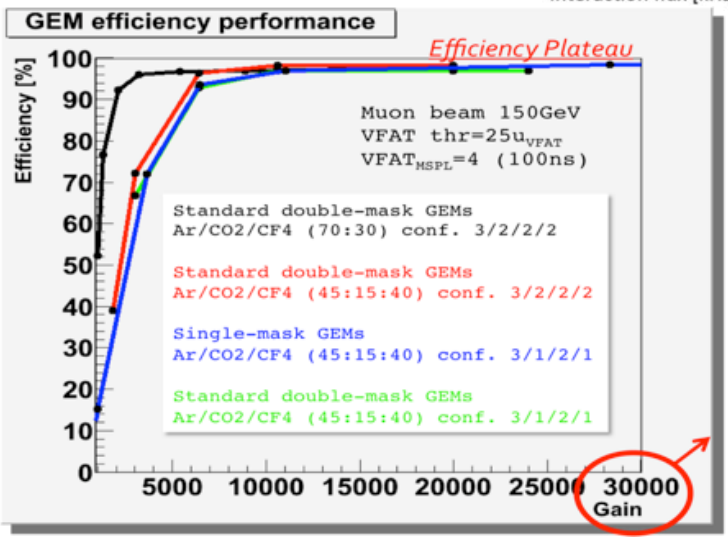


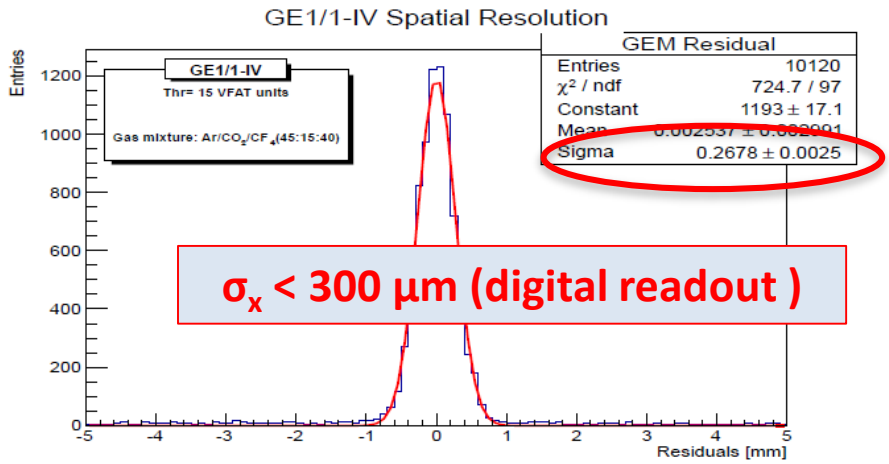
- GEM active area: 990 mm × (220-445) mm
- Single-mask technology
- 1D radial strip read-out with 3 × 8 × 128 = 3,072 channels
- 35 HV sectors
- 3/1/2/1 mm gap sizes
- Gas mixtures:
  - Ar/CO_2 (70:30; 90:10)
  - $Ar/CO_2/CF_4$ (45:15:40; 60:20:20)
- Gas flow ≈ 5 l/h

Performance

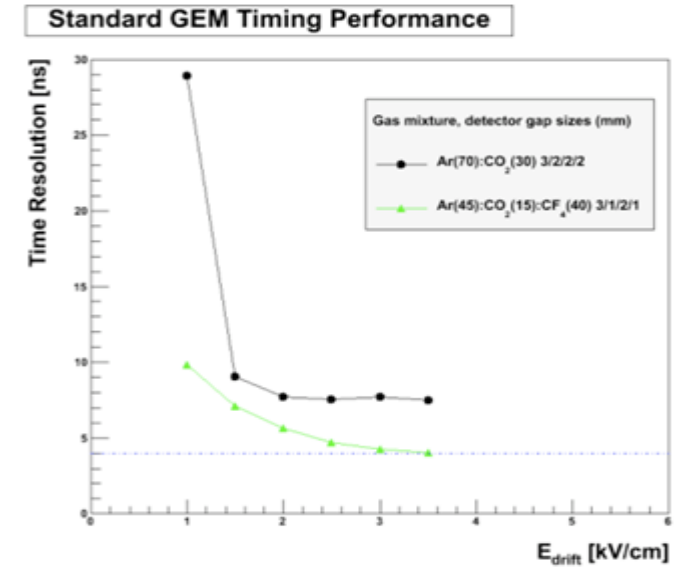
Very high rate capability







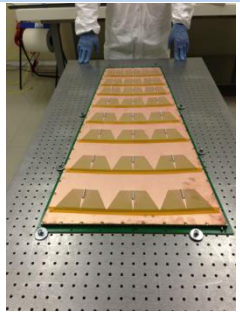
σ_x < 300 µm (digital readout)

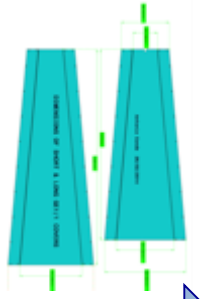


✓ Detector efficiencies above 98% in single mask technology

Reached ~4 ns with the $Ar/CO_2/CF_4$(45:15:40) gas mixture

GE1/1 Project development





2010 2011 2012 2013 2014 2015

Generation I
The first 1m-class detector ever built but still with spacer ribs and only 8 sectors total.

Generation II
First large detector with 24 readout sectors (3x8) and 3/1/2/1 gaps but still with spacers and all glued.

Generation III
The first sans-spacer detector, but with the outer frame still glued to the drift

Generation IV
First detector with complete mechanical assembly; no more gluing parts together!

Generation V
Stretching apparatus that is now totally inside gas volume. **test beam campaign for final performance measurements.**

Generation VI
Latest detector design; Optimized final dimensions for maximum acceptance and final eta segmentation.

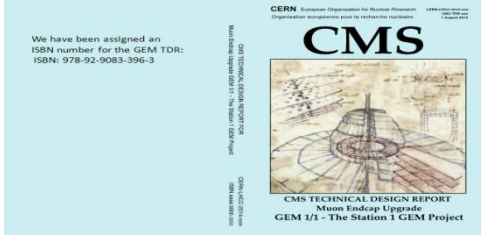
Prototyping, DAQ &trigger and QC procedure of detectors. First prototype of VFAT3

electronics&chamber prototype installation-

Slice and trigger commissioning.

Production GE1/1 chambers with final electronics

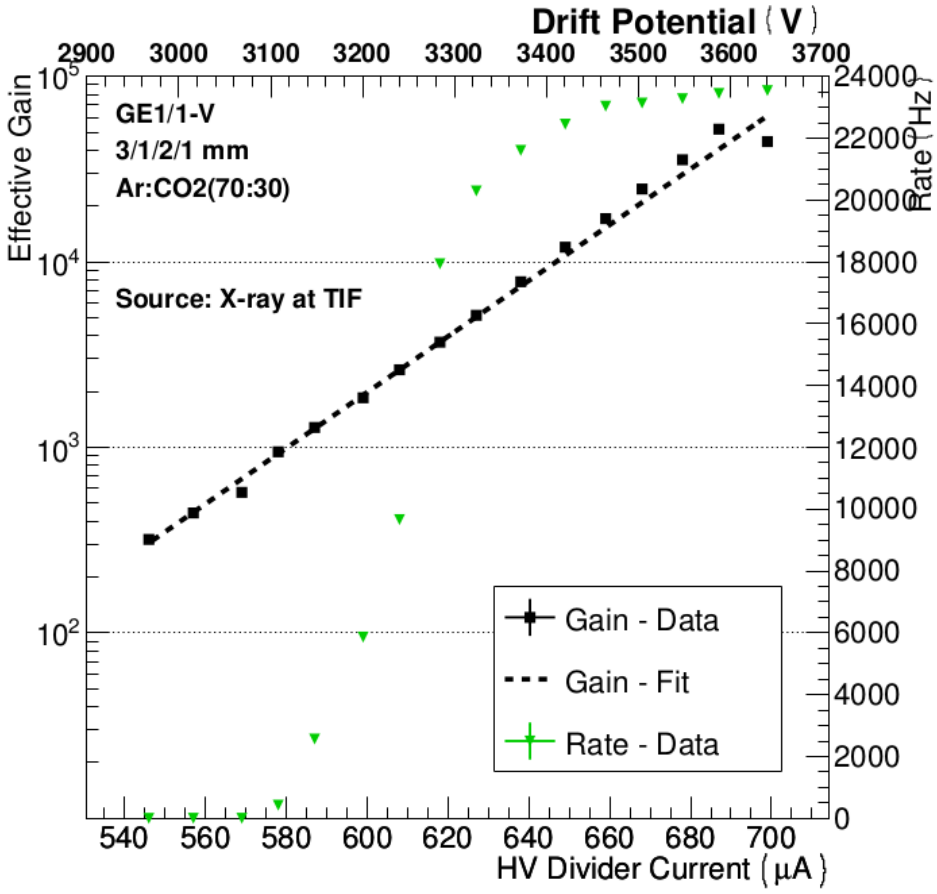
2015 YETS 2016 2016/17 2017/18 2018/19

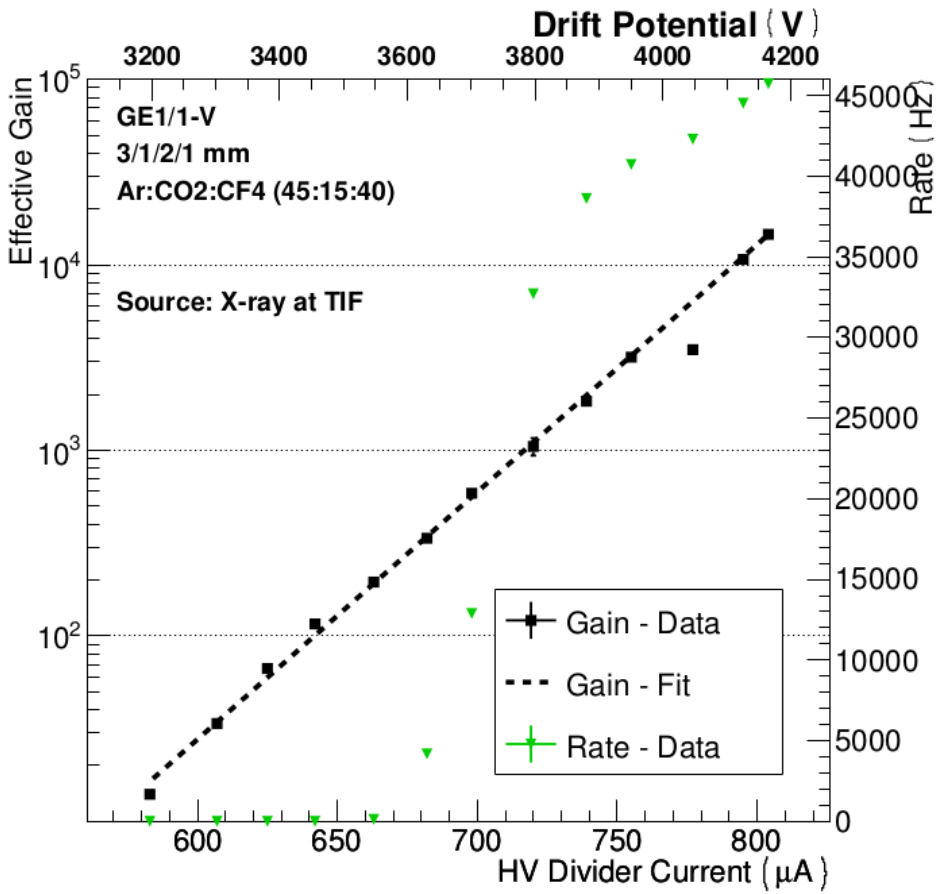


Full-production of chambers and electronics started

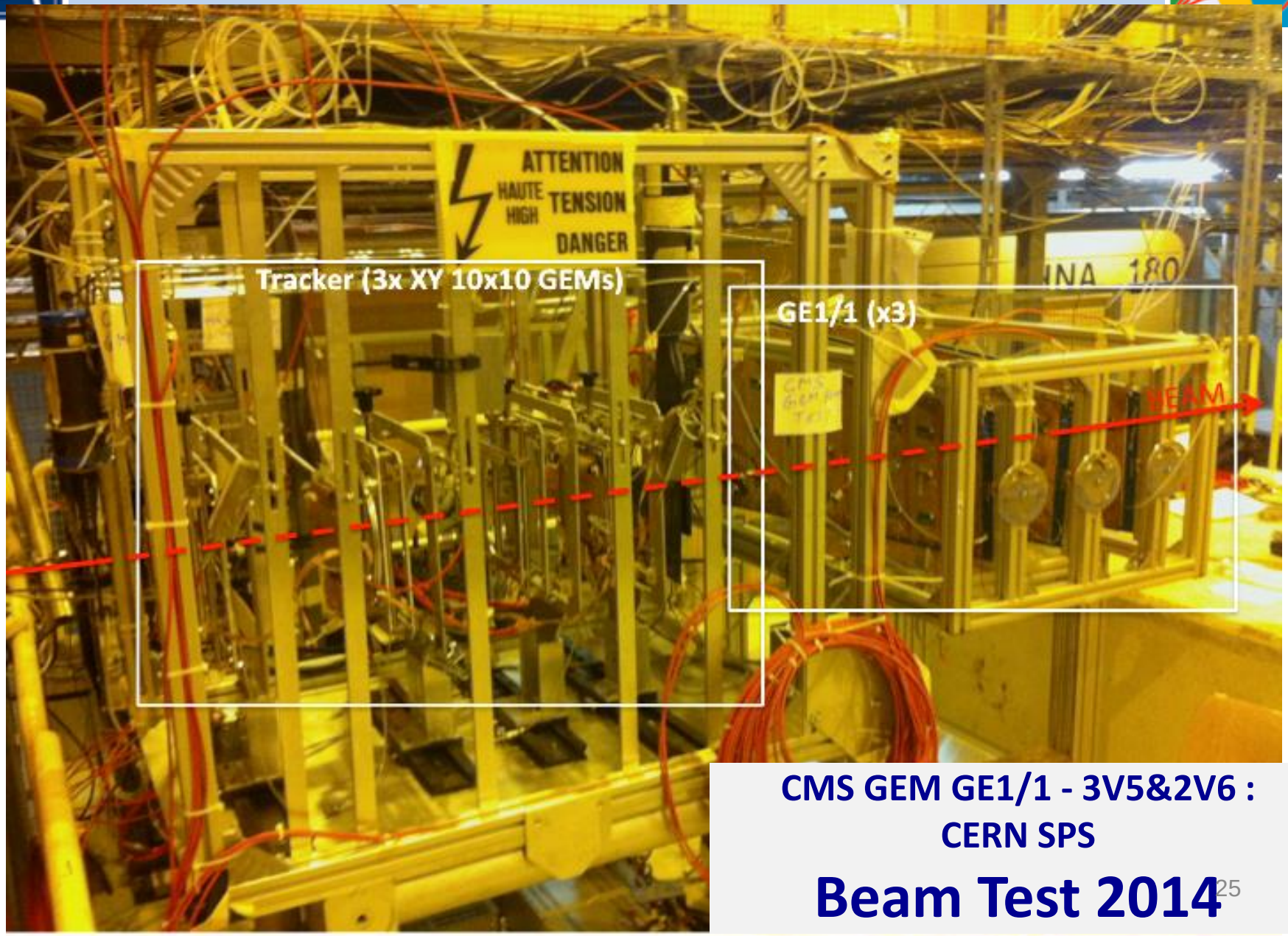
Full installation of GE1/1 with final electronics

Gain Curve For GE1/1-V





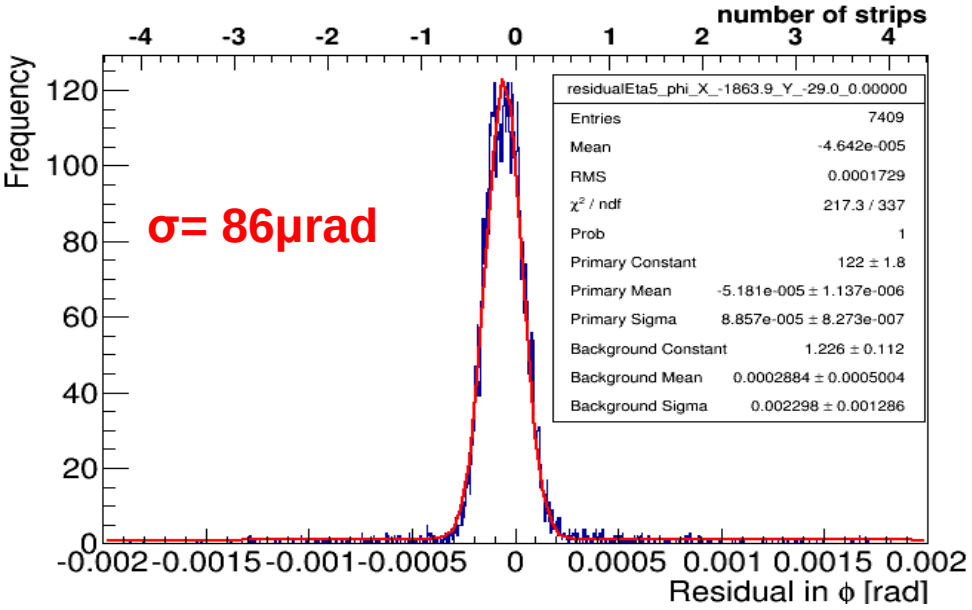
Beam Tests at CERN and Fermilab

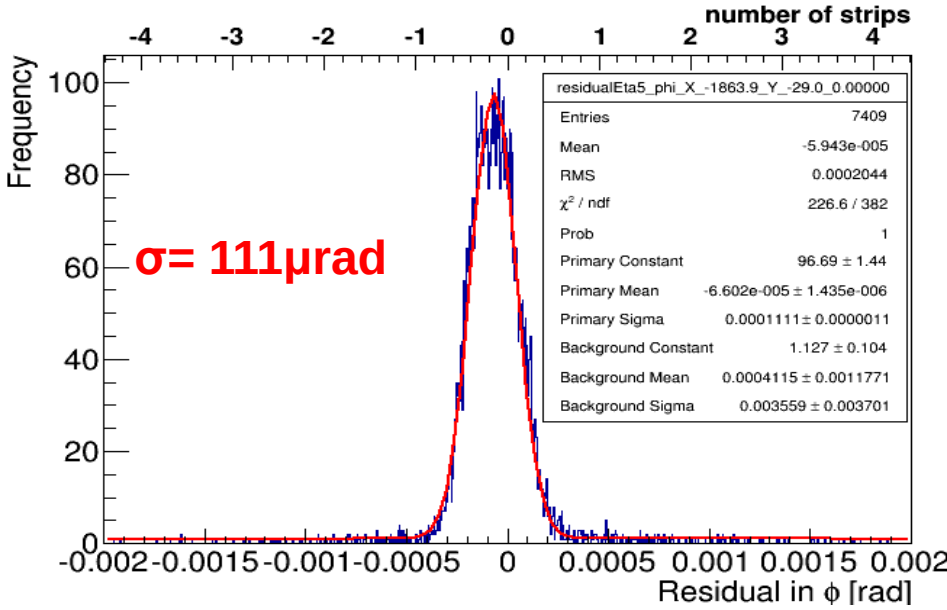


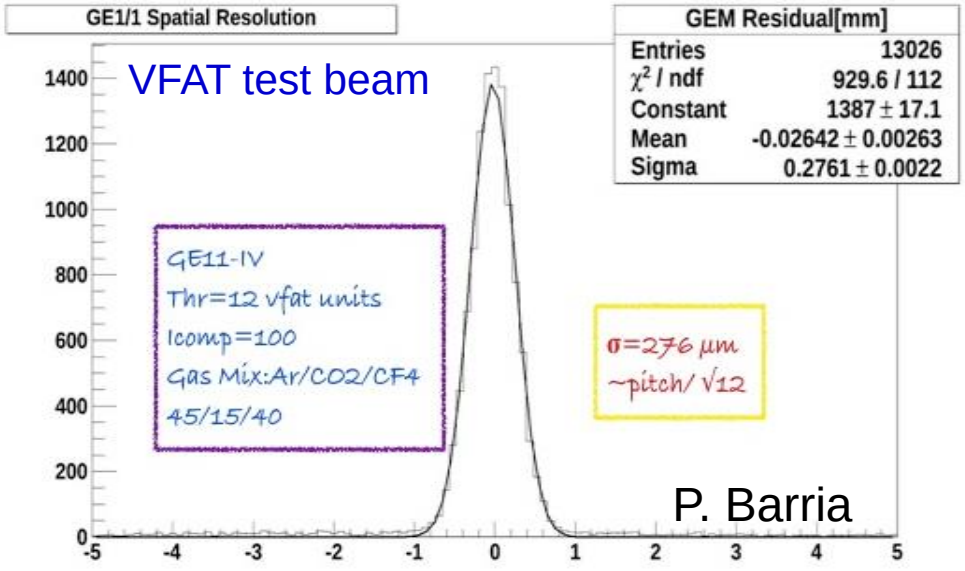
CMS GEM GE1/1 - 3V5&2V6 : CERN SPS

Beam Test 2014

Resolutions for CMS GEM detector

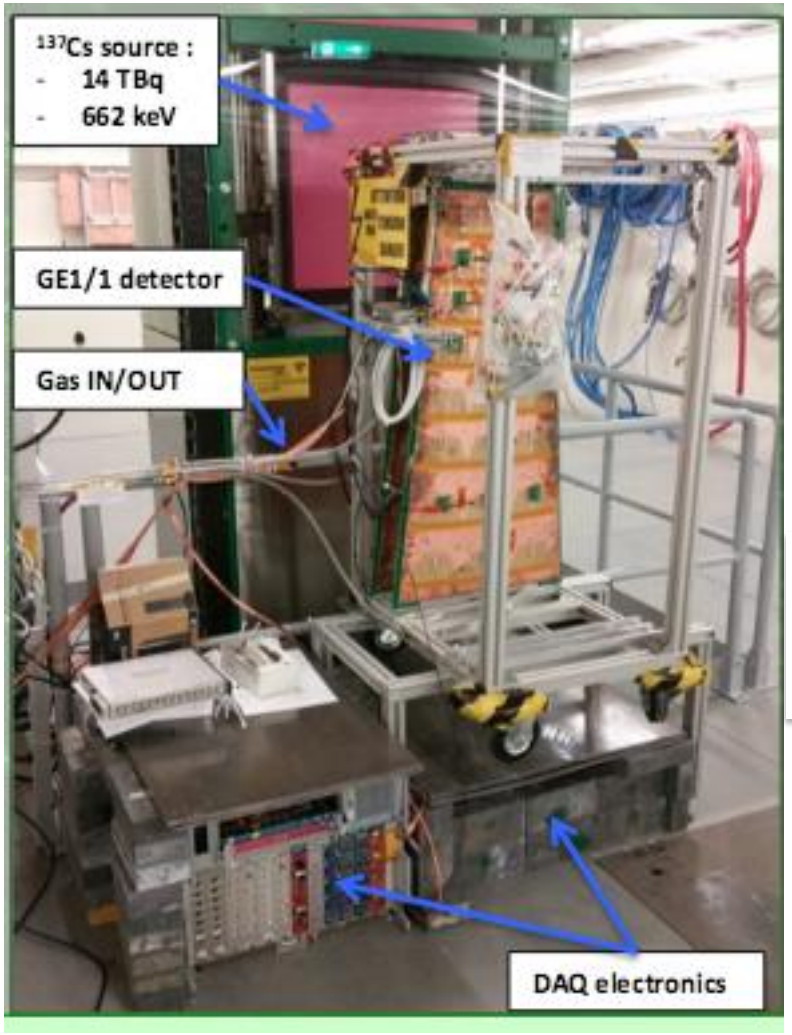


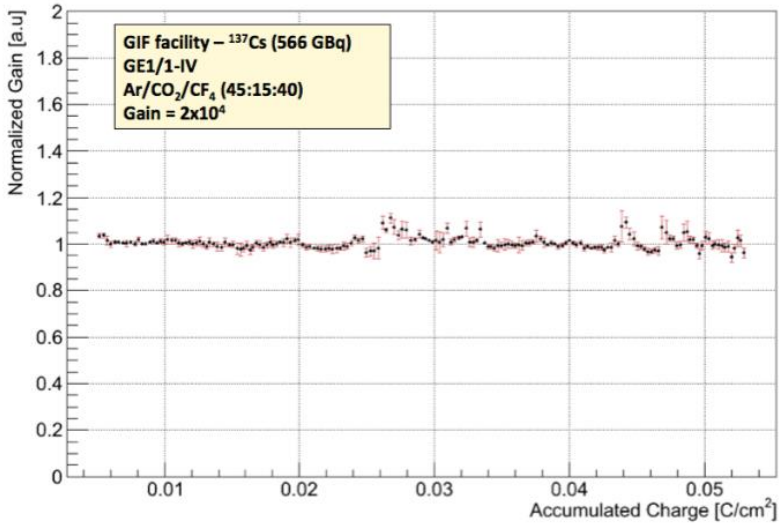




86 (111) μrad or 160 (207) μm
Well within the requirements

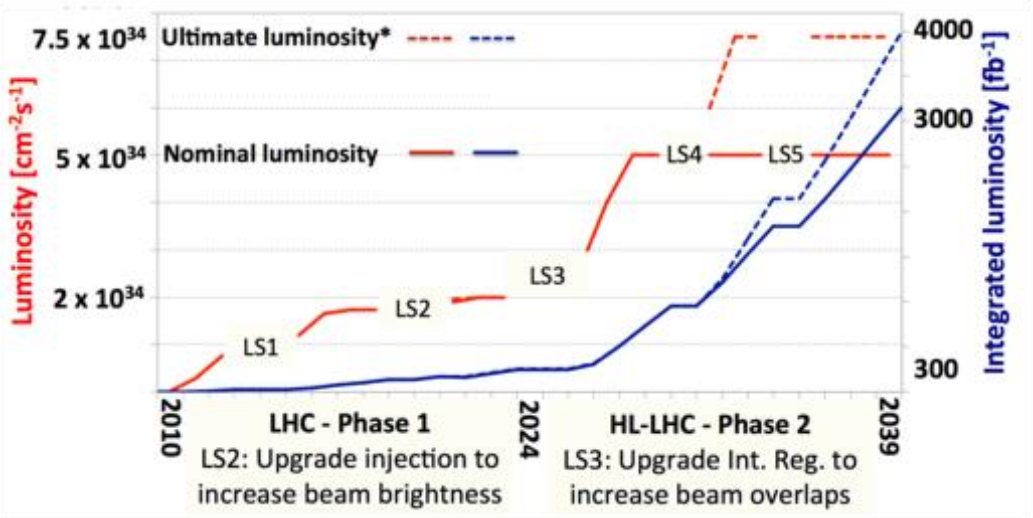
GEM GE1/1 Activity at the GIF++





Detector installed at the LHC
will collect charge up to 3000 fb^{-1} ie 20 LHC Years

Integrating Charge at GIF++



GE1/1 charge integration

$$Q_{int} = R_{max} \times n_{tot}^{ion} \times g \times e \times t_{HL-LHC}$$

Q_{int} = 1•10³ x 31 x 2•10⁴ x 1.6•10⁻¹⁹ x 6•10⁷ = 6 mC/cm²

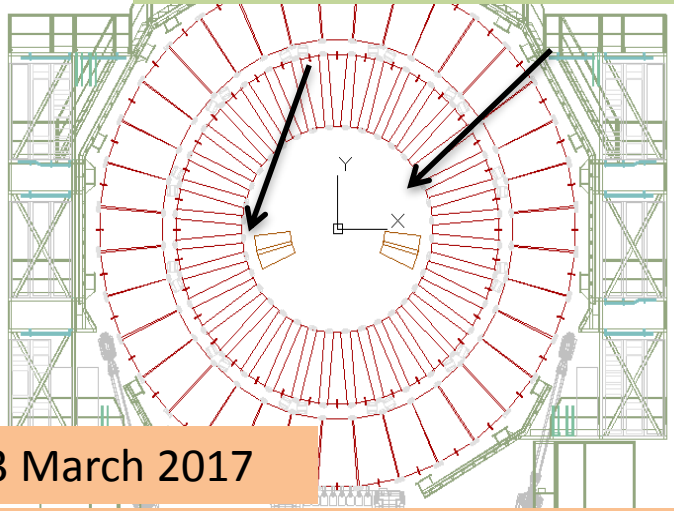
- The anode current is measured on the irradiated GE1/1 sectors (about 95 cm² each), the current is multiplied by the irradiation time to obtain the total integrated charge
- Since April 2015 GE1/1 chamber installed at the GIF++ collected ~ 75mC/cm²
- At the end of this run, we have to repeat the test with alternative gas mixture

Slice test in YETS2016

4 super chambers in slots 1,2,35, 36 on YE-1

Installation of 4 SuperChamber during 2016 YETS

- DAQ system will be integrated in CMS DAQ;
- combined CSC+GEM trigger
- Operation procedure implemented
- reconstruction included in official CMS software;
  - validation done with standard tool;
  - background and noise rate included in simulation.



INSTALLATION WINDOW : Early January (10.1.2017 – 31.3 March 2017

INSTALLATION WINDOW :LS2
GE1/1 Week 15 onwards – until Ready for beam minus 30 weeks)

Motivations:

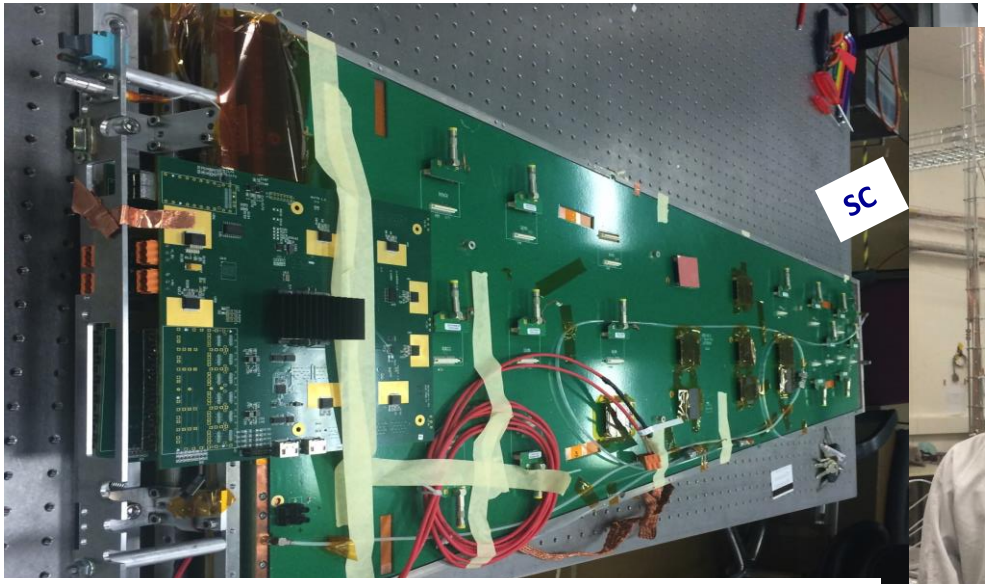
- gain integration experience
- reduce the GEM commissioning period:
  - Back-end electronics installed and commissioned in advance of the installation of the FE electronics.
  - All components (Incl. detectors) will have been qualified beforehand at the TIF
- trigger commissioning and performance check “CSC-TF”
- background measurement.
- opportunity to cross-check with data what expected by simulation.

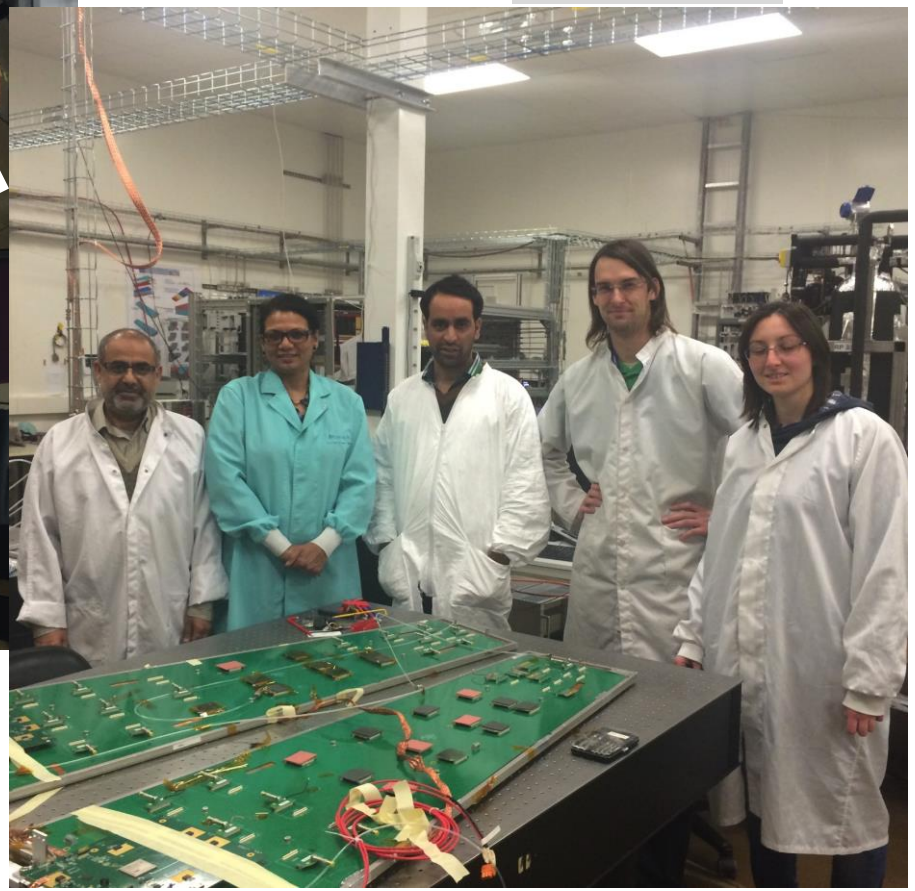
GE1/1:

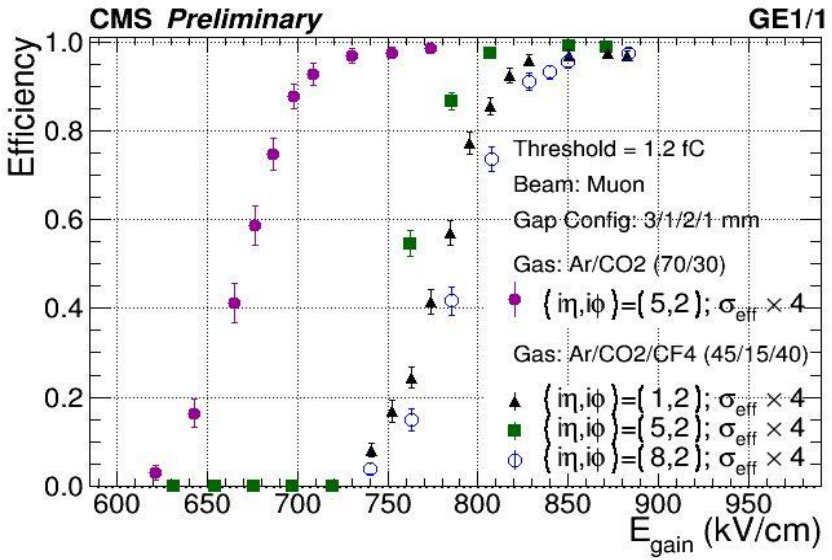
Gearing up for production of chambers
Slice test

GE1/1 2 Generation VI-L

CERN B 186





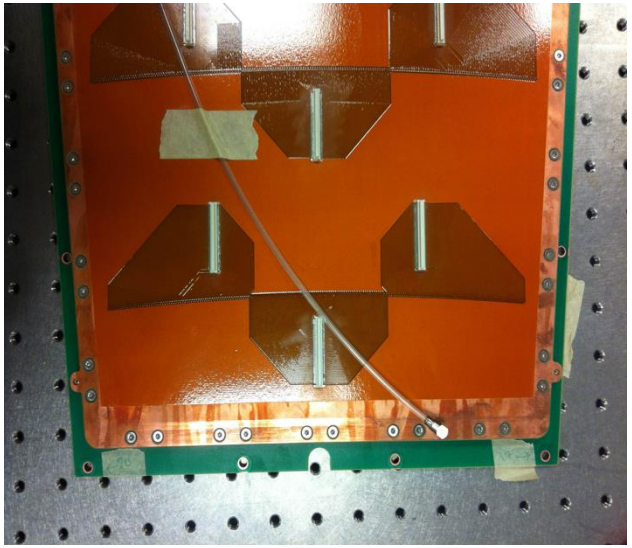
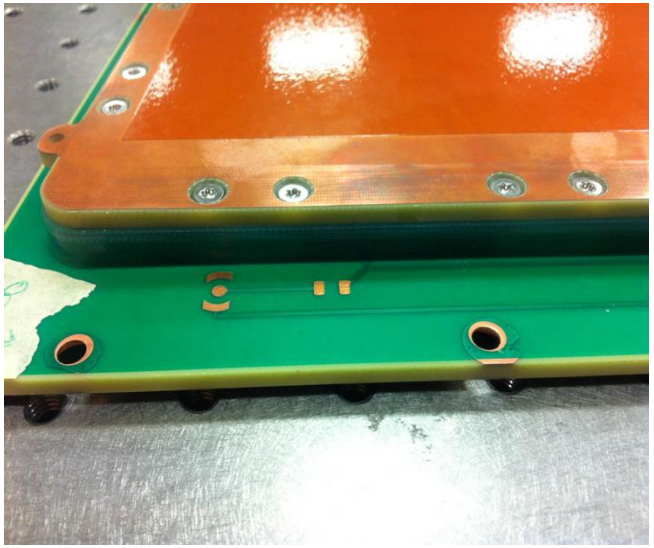


GEM Detector Production

Slice Test

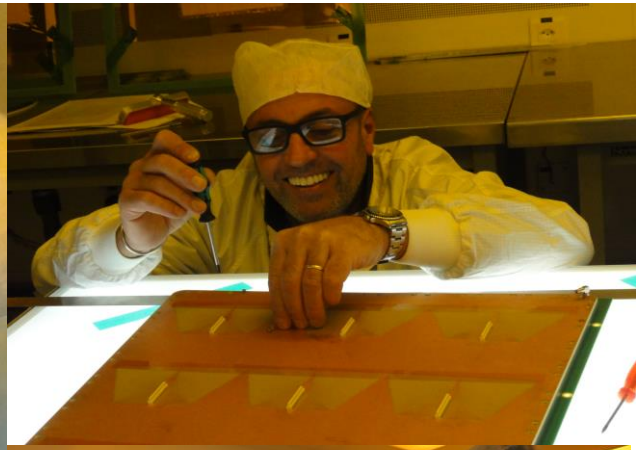
- Assembled 2 of 8 detectors for P5!
- Commissioning of quality control test stands on-going
- Price inquiries for the LS2 chambers components are running

Long Slice Test chamber assembled

Toward the full production

Training manpower and production site qualification



Production site readiness

6 production sites are ready for final production, all have assembled GE1/1-IV prototypes , QC procedures have been initiated

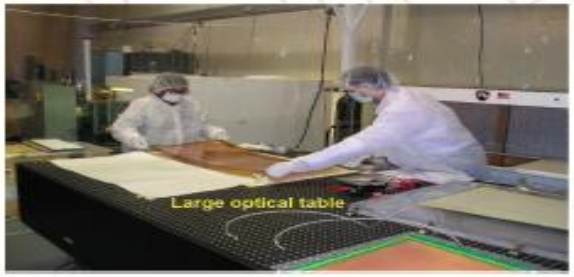
https://www.youtube.com/watch?v=Ssuqh5GAVZ4

(a) BARC

(b) INFN-Bari

(c) CERN

(d) UGent



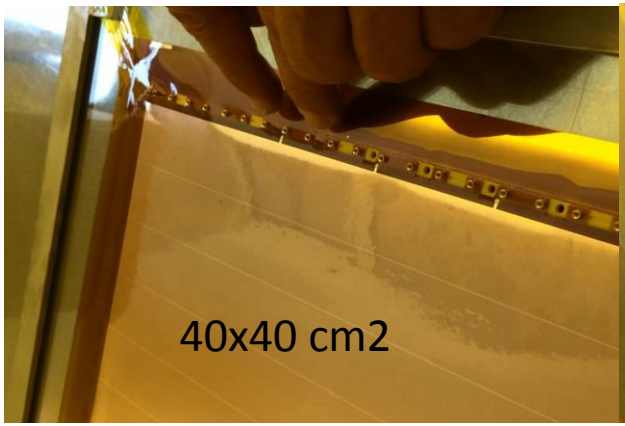
(e) FIT

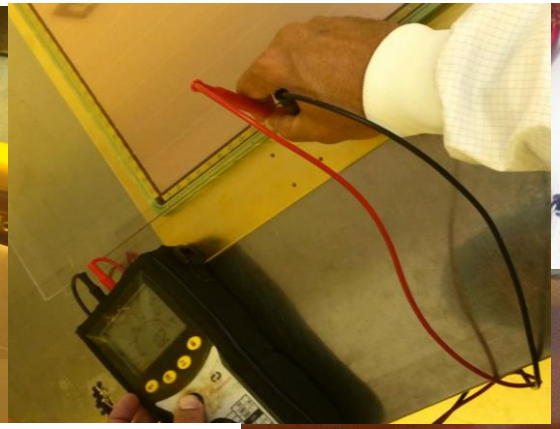
(f) INFN-LNF

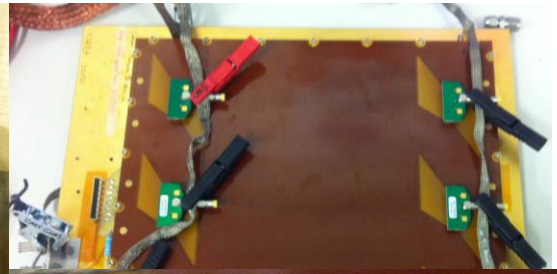
Figure 5.2: Pictures from differents assembly site candidates.

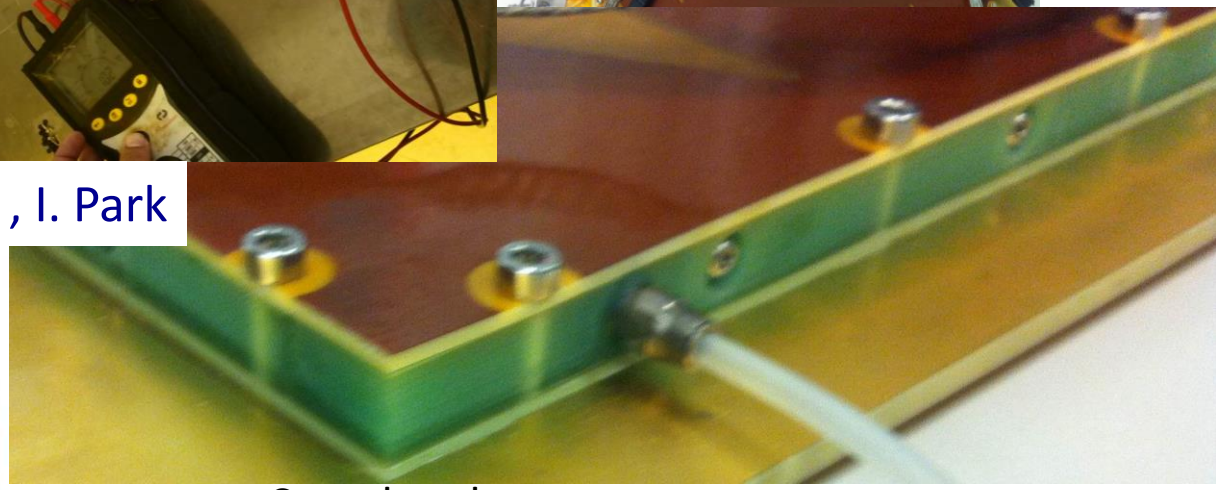
Luigi Benussi
Brian Dorney

CMS: Industrialization of GEM Foils









Mecharonics: Korea M.Choi , I. Park

- Completed:
- Technology transfer license agreement with CERN signed
- Foils made
- Detectors made
- Tests ongoing

Micropack : India
L. Pant
P. Menon

Tech Etch Florida USA : Collaboration with B. Surrow & M. Hohlmann

A. Sharma 22092015

Process stabilization in development of Single Mask GEM foils in India

L. M. Pant[1,*], A. K. Mohanty[1], Pradeep Menon[2], Archana Sharma[3], Rui De Oliveira[3]

Introduction :

The GEM foils consists of 5 μm of Cu clad on both the sides of 50 μm polyimide (PMMA/kapton) (5/50/5) produced exclusively in South Korea which is shown in Fig. 1. The Cu layer remains bound to the polyimide through 100 nm of Chromium and does not involve any adhesive glue

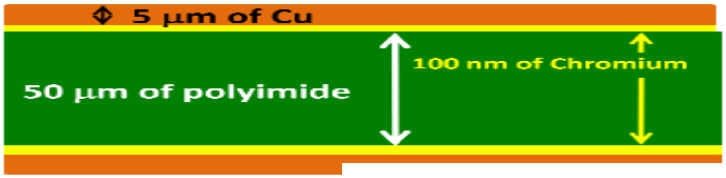


Fig.1 : Schematic of C

60th DAE-BRNS Symposium on Nuclear Physics, December 07-11, SSSIHL, Prasanthi Nilayam, Puttaparthi, Andhra Pradesh 515134, Proc.of the DAE-BRNS Symp. on Nucl. Phys. 60 (2015) 1038

The chemical etching process :

The processes involve the following four major sta

1.For removal of Cu from one side, standard perchloride, is involved as in any PCB manufacturing

2.In the second stage, the photoresist is stripped with ethanol and $KMnO_4$

3.The Cu etched foil is then moved to a different bath of ethylene diamine for anisotropic etching of polyimide. The third stage needs to be optimized, because of evaporating fumes and dissolving of polyimide in the etchant itself, in a temperature controlled environment

4. Finally, the Cu on the other side of the ploymide is removed using Galvanic Etching (reverse etching) in a different bath of chromic acid. Currents need to be optimized as per the size of the foils for the reverse etching process of Cu in the fourth and final stage

Process stabilization for Single Mask GEM foils at :

The chemical etching process has been stabilized for the 100 μm / 200 μm configuration and is being evolved for the 70 μm / 140 μm configuration in a hexagonal pattern (Fig. 2 & 3) at Micropack Ltd.

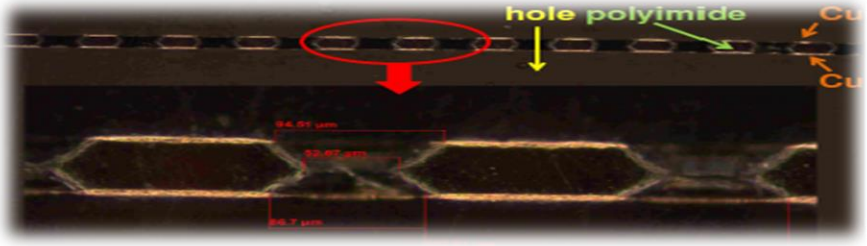


Fig. 2 : Conical shaped profile for Single Mask GEM foils (100 μm holes with a pitch of 200 μm holes)

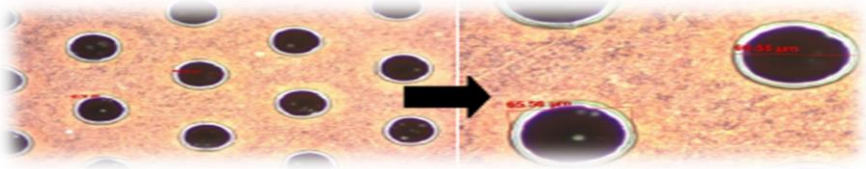


Fig. 3 : Three of the four stages achieved for developing 70 μm holes with a pitch of 140 μm in a hexagonal pattern

GEM assembly & testing facility at NPD-BARC

Fig. 4) and a class 100, LAFT (1.5 m x 2 m) is commissioned

g. 5) is also operational at NPD-BARC, which can illuminate

& VME based DAQ with 1k of TDC channels already exists in plifier

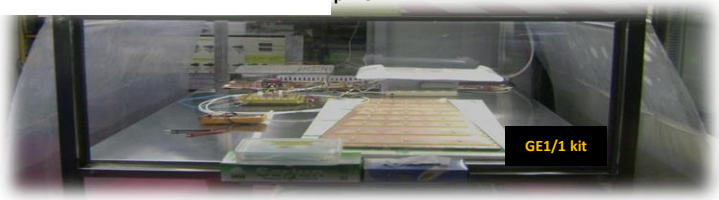


Fig. 4 : GE1/1 kit inside a class 100 LAFT (1.5 m x 2 m) with air flow from top to bottom

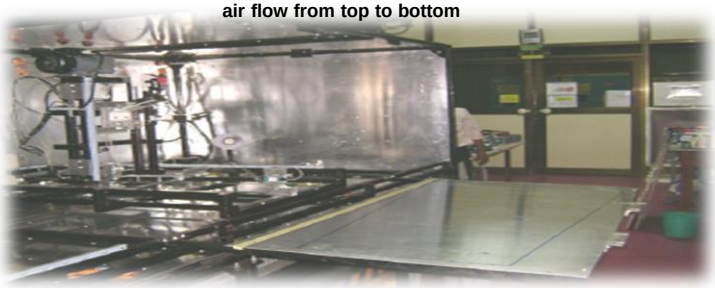
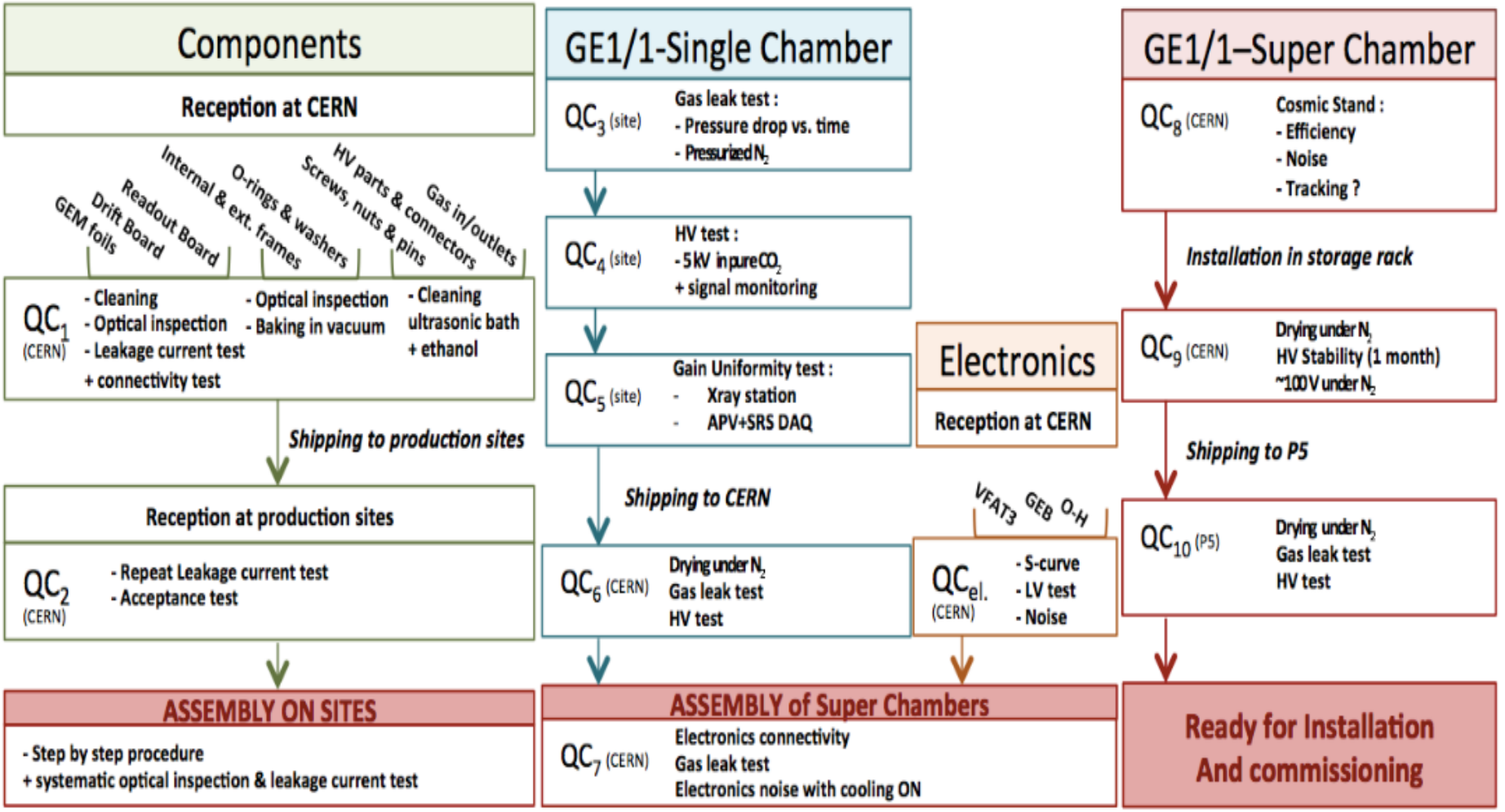


Fig. 5 : An intense x-ray source with x,y,z positioner inside a lead (1mm thick) cubicle for illuminating and characterizing GE1/1

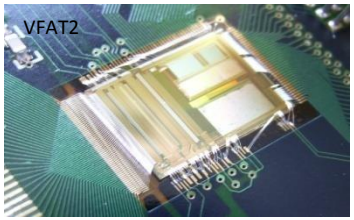
References :

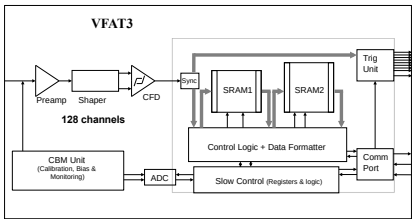
[1] [L. M. Pant et. al., Proceedings of the DAE Symp. on Nucl. Phys. 59 (2014) 844

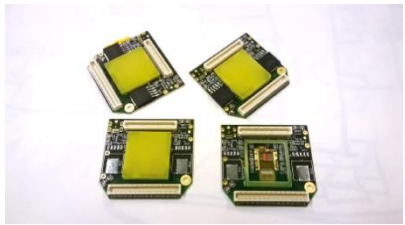
Chamber Production QA and QC:



CMS GE1/1 Electronics System







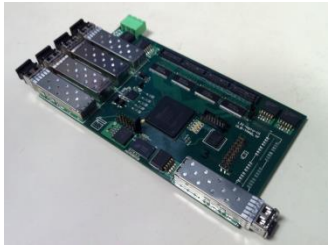
VFAT3 front-end ASIC development

Paul Aspell

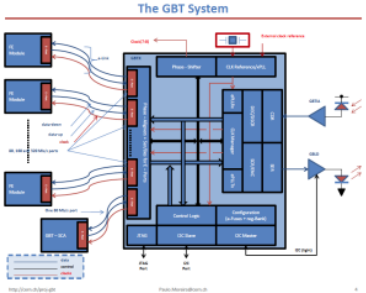
Gilles de Lentdecker

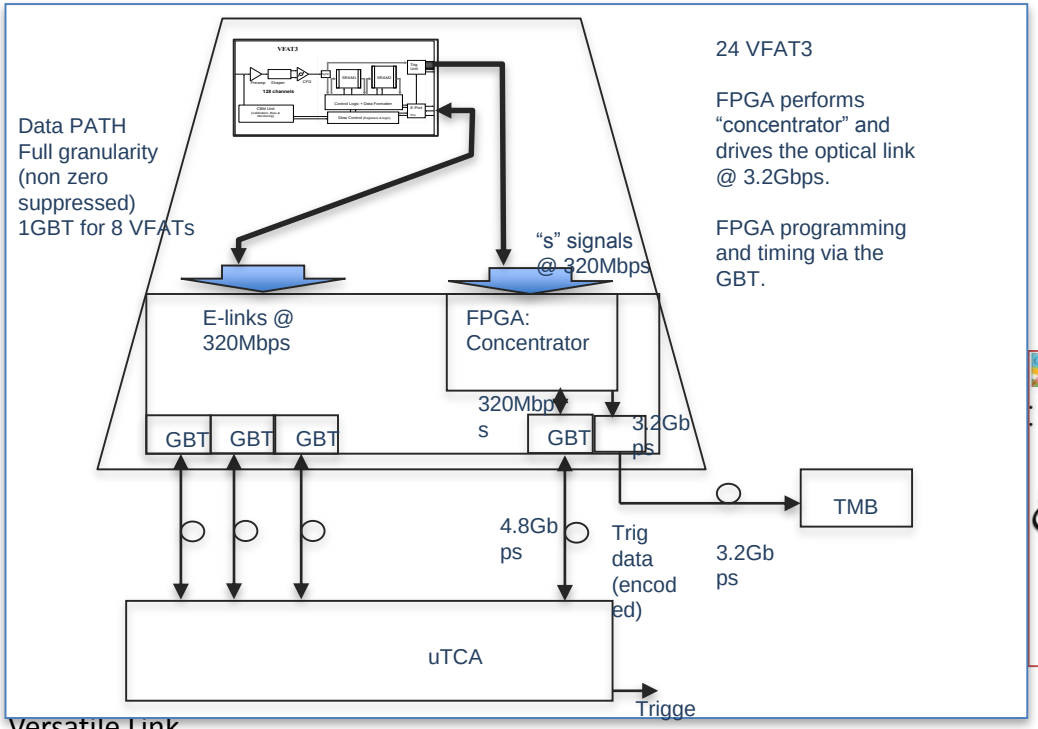
GEM Electronic Board (GEB)

Opto-Hybrid (OH)

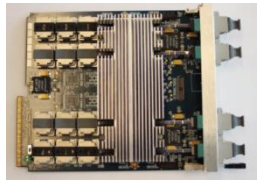


GBT



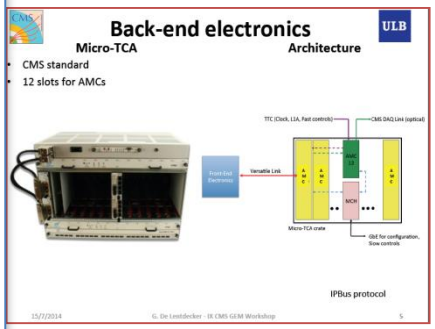


Versatile Link



µTCA

AMC13, MCH



Use of many common developments such as GBT, Versatile Link, µTCA backend

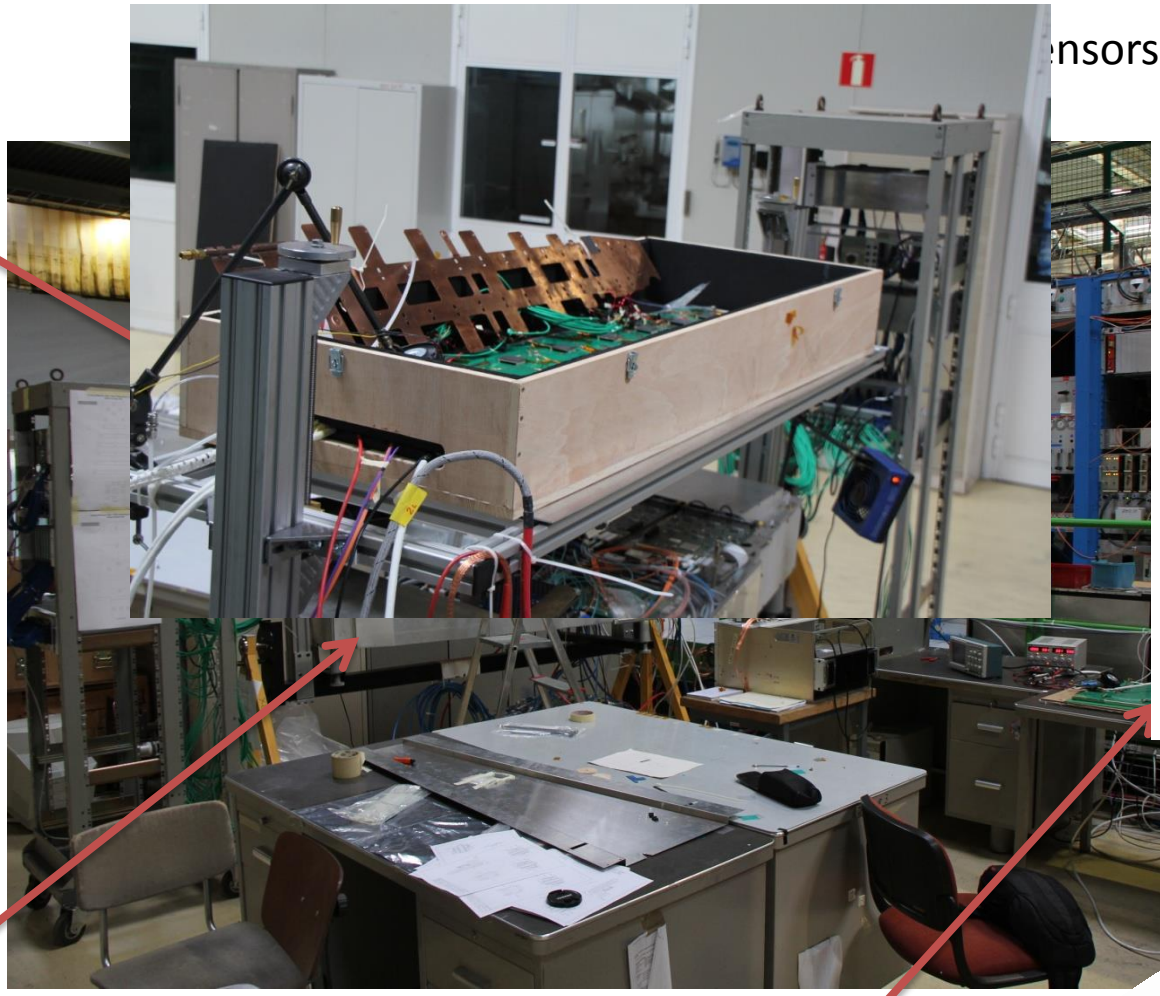
The control, readout and power to/from the VFAT3 hybrid are delivered via electrical signals (E-links) running through the GEB to the opto-hybrid.

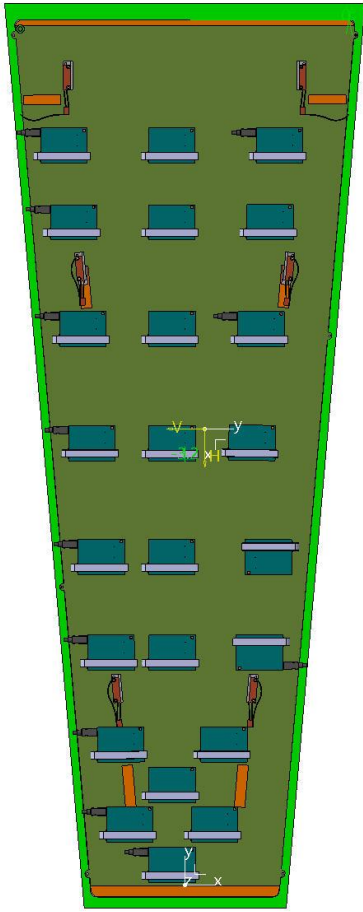
904: GE1/1 at CMS Electronics & Services Integration Center

904: GE1/1 : Integration

nsors

GE1/1 inside
The cooling box

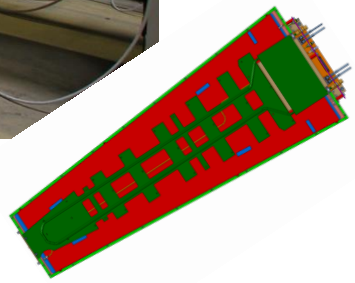




Andrey Marinov

Zoltan Zillasi

ME1/1

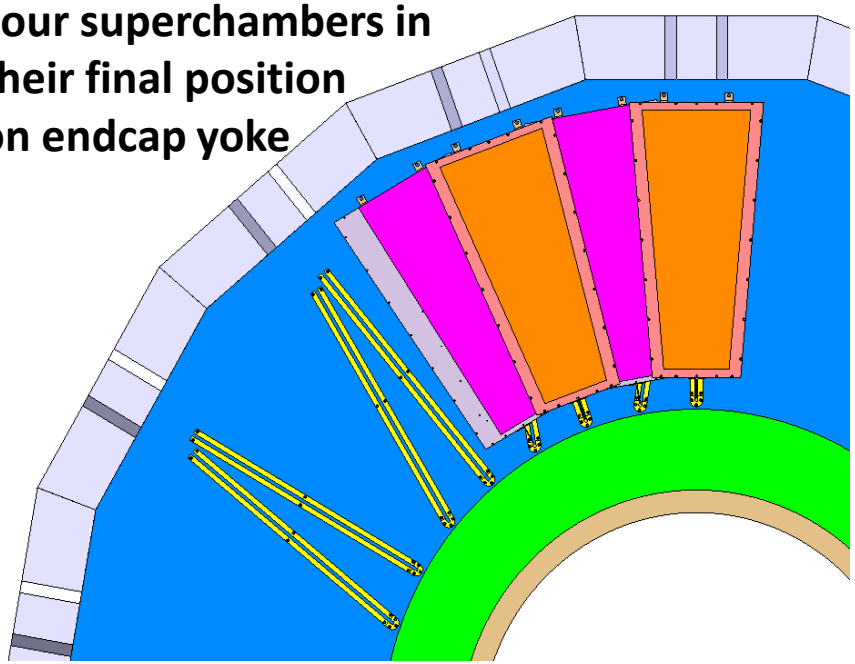


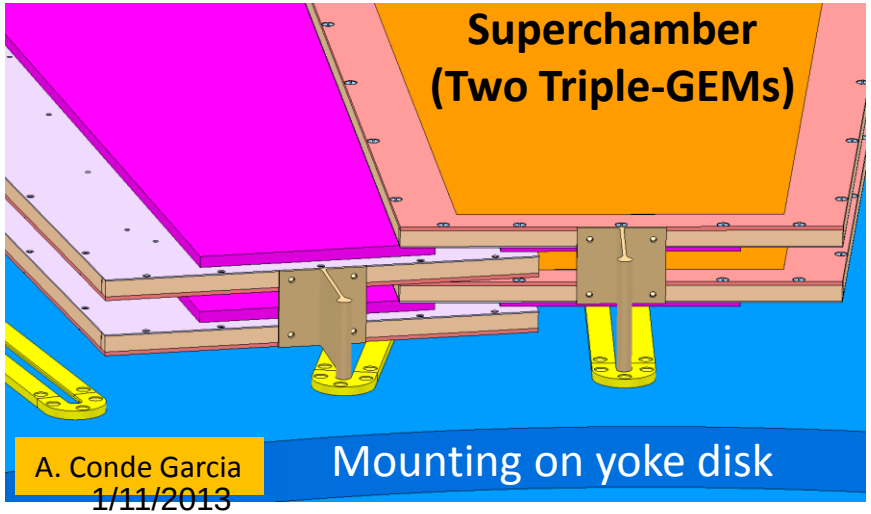
Antonio Conde Garcia

GE1/1 Setup for VFAT and GEB tests.

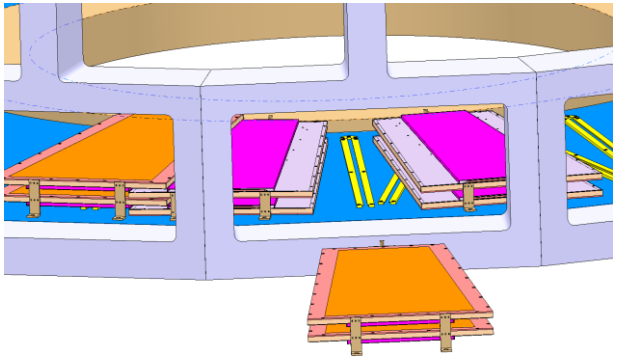
Integration into CMS

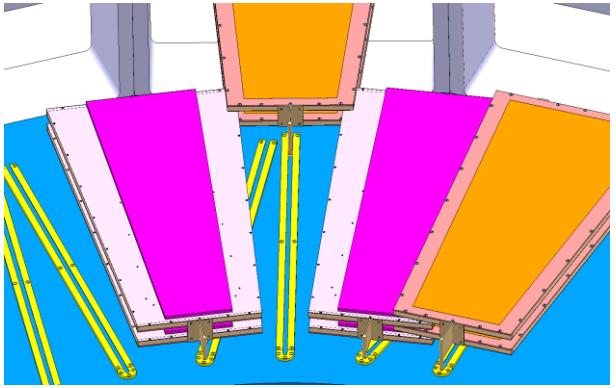
Four superchambers in their final position on endcap yoke

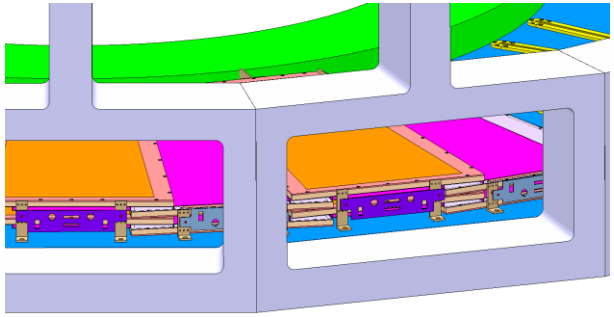




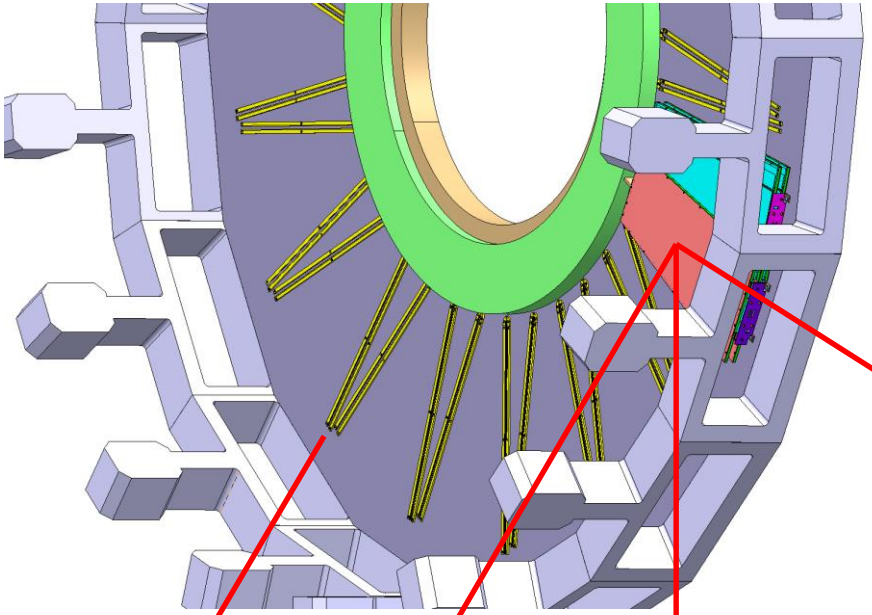
Installation sequence:

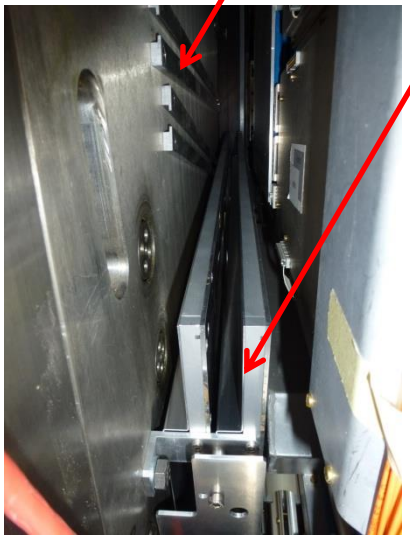


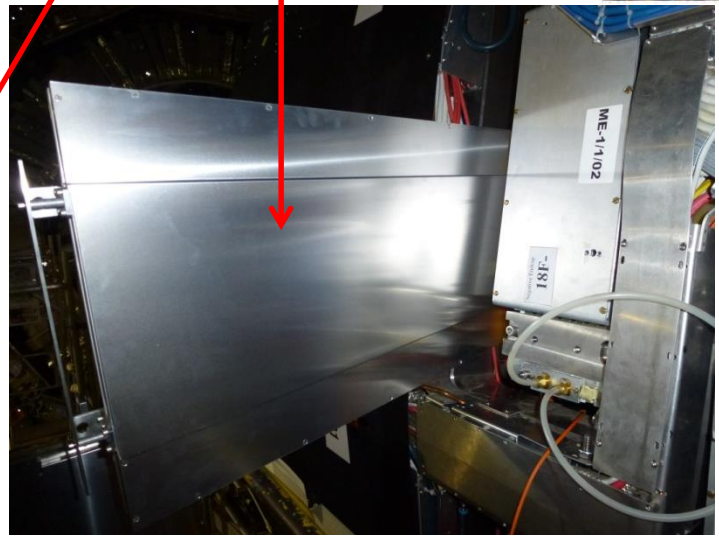


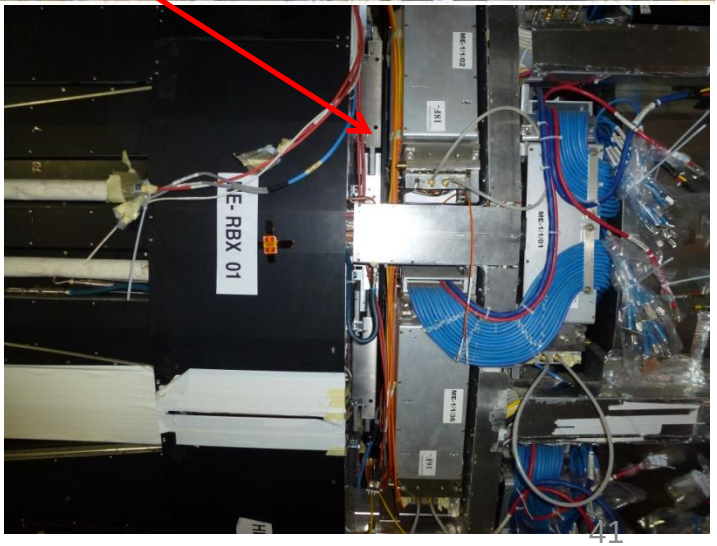


Trial Installation in CMS – 2013

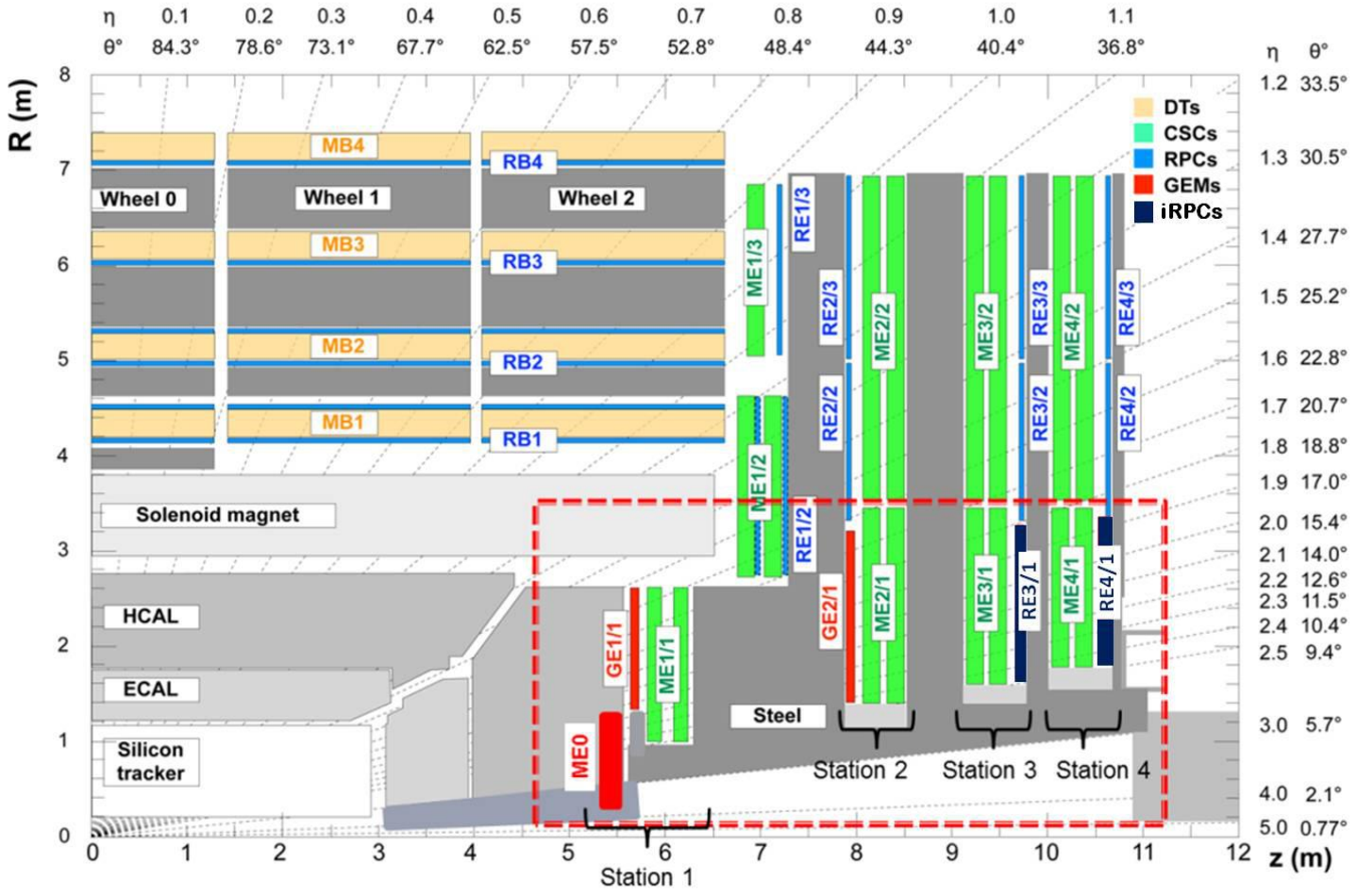








High η region upgrade with MPGD for Phase 2: ME0

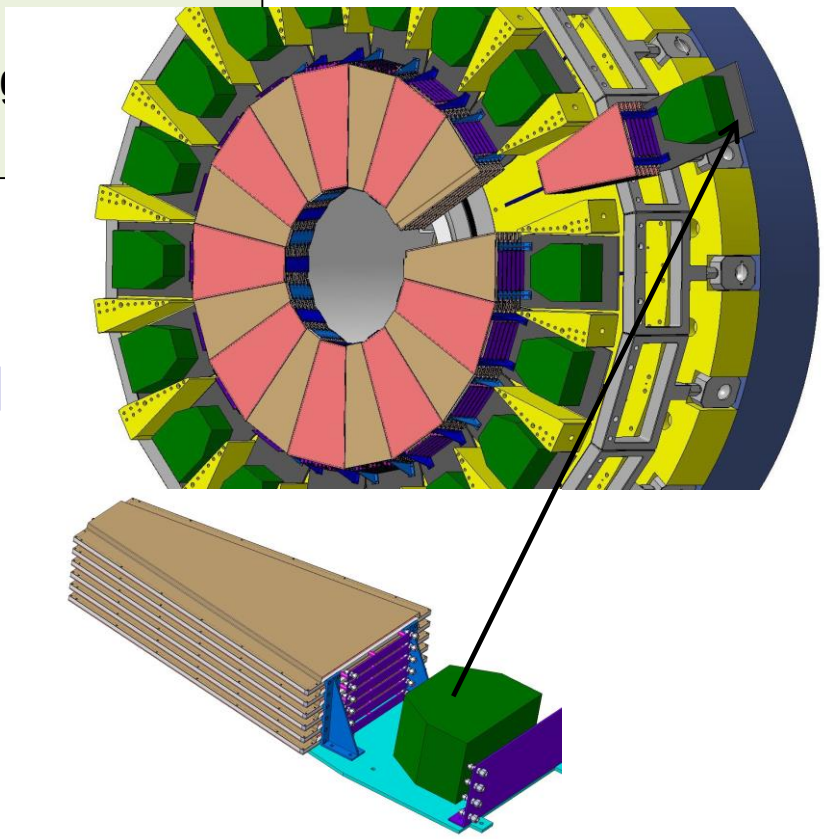


- Objectives:
  - Sustain triggering at current trigger thresholds
  - Increase offline muon identification coverage
  - Maintain existing envelope by mitigating aging effects

ME0 requirements and technical choices

Detector requirement:

- Multilayer structures
- High rate capability O(MHz/cm^2)
- time resolution for triggering
- No green house gases
- Good spatial resolution O(100 μm) for tracking triggering



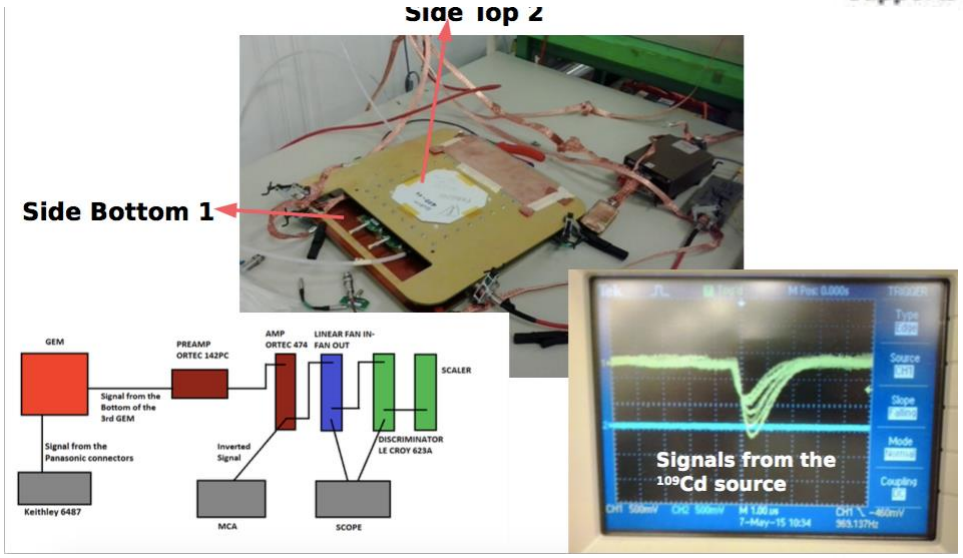
- Baseline : Six layers of triple-GEM
- Option : Fast Timing Micropattern gas detector (FTM)

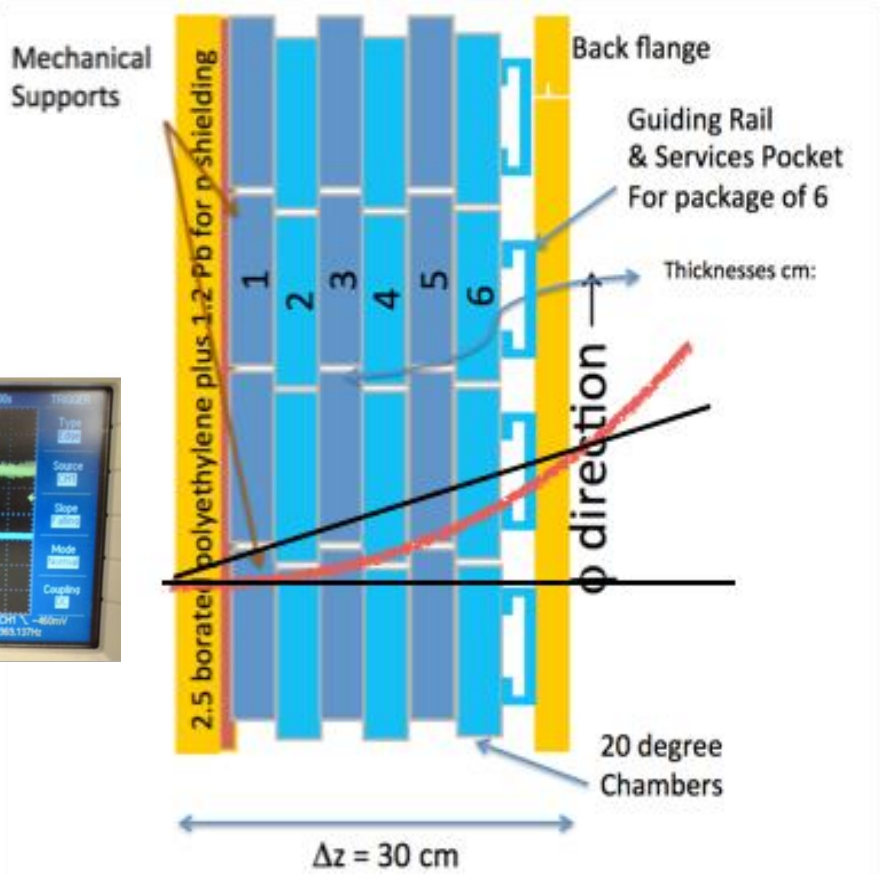
Sinem Salva, Ilaria Vai

The very forward extension: ME0

Multi-layered structure to improve local muon track reconstruction, neutrons background rejection

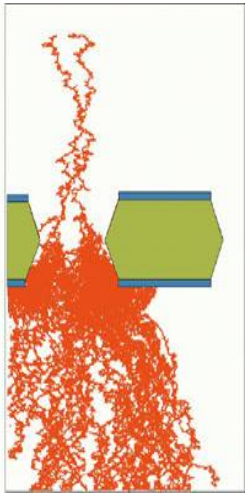
ME0 baseline layout consists of 6 layers triple-GEM chambers



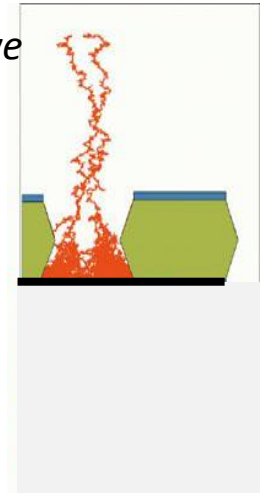


ME0 Option:
New generation of MPGD:FTM

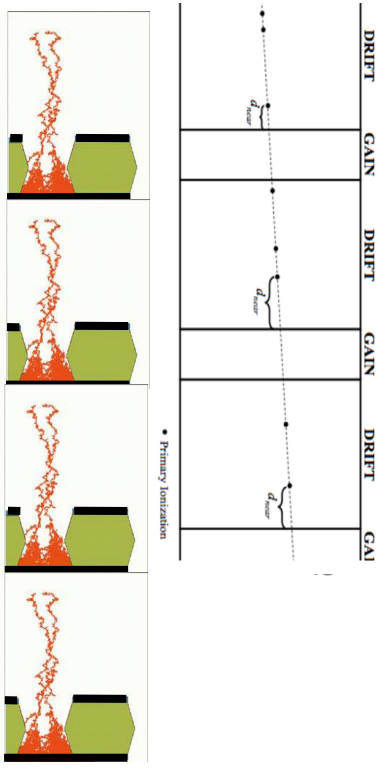
Standard MPGD



Resistive MPGD



Multi-layer Resistive MPGD



The overall structure is **transparent** to the signal
Signal can be extracted in each amplification stage

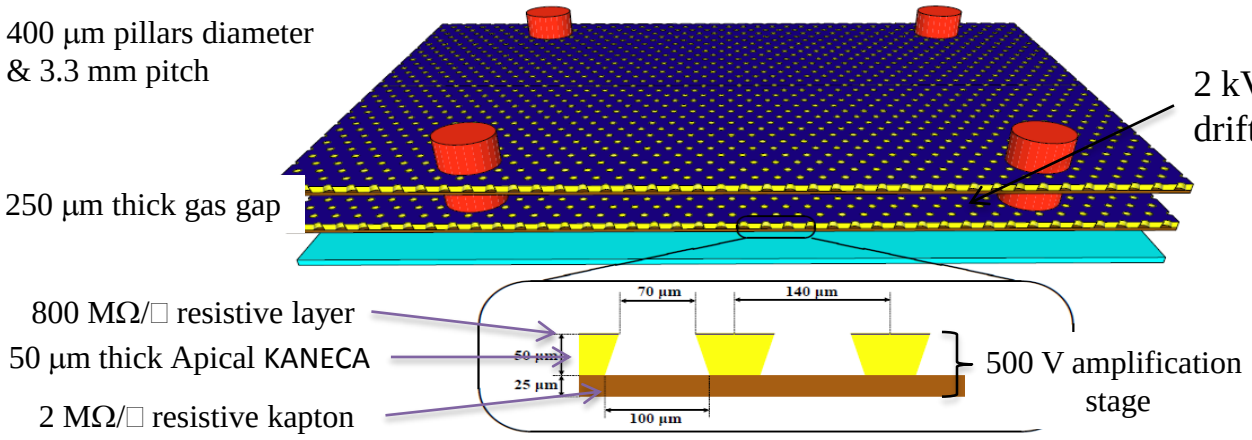
Time resolution a function of No. of layers

Beat the drift volume limitation !

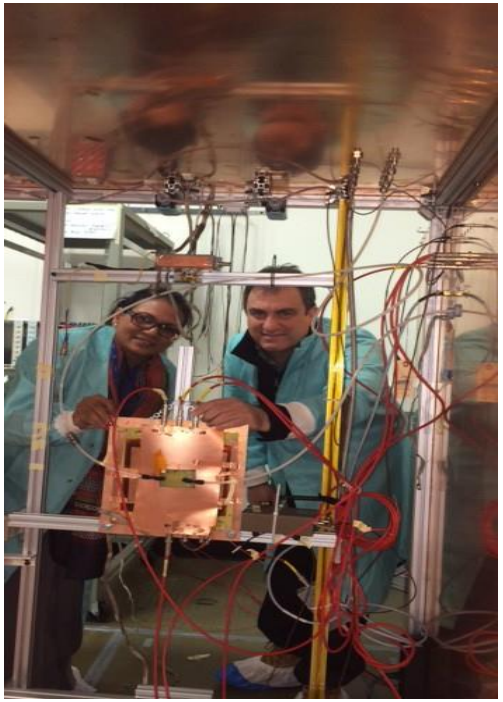
Reference:arXiv:1503.05330v1
European Patent Application 14200153.6
M. Maggi, A. Sharma, R. De Oliveira

Structure of the FTM detector

Detector Layout & Parameters



- **DLC coating on the top**
- **Perforated foils**
- **Antistatic polymide foils**
- Two layers separated by **Pillars**
- **Pick-up electrode**

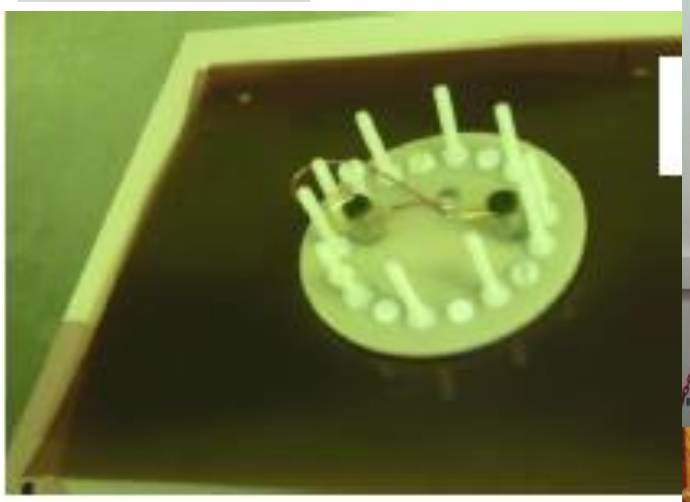


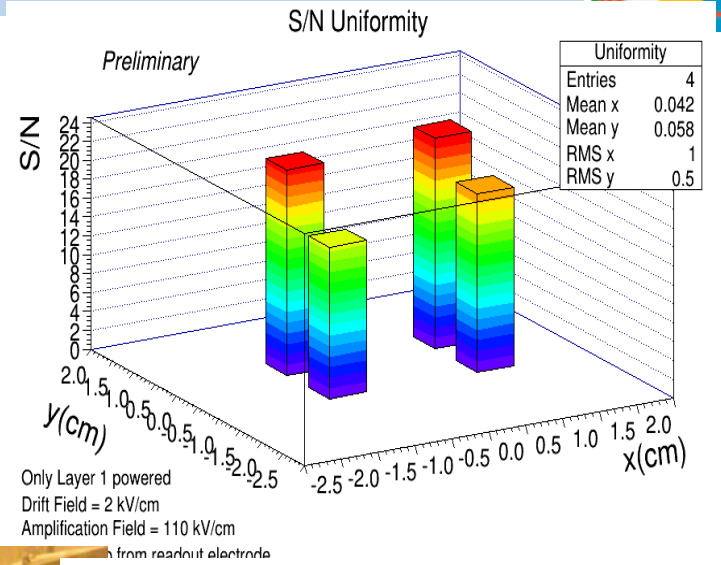
Fullly resistive amplification stage:

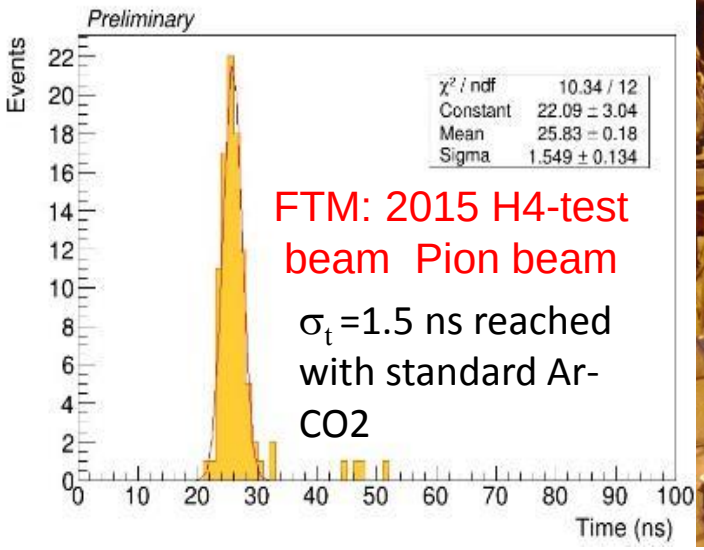
- Signals picked up by the external electrodes;
- High rate capability;
- Sub ns time resolution with several gaps in cascade;

Tests at B 186 CMS GEM Lab & Test Beam

Preliminary !

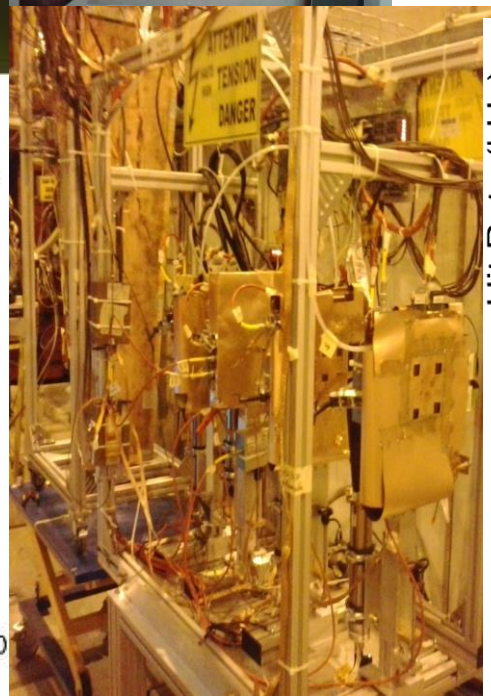


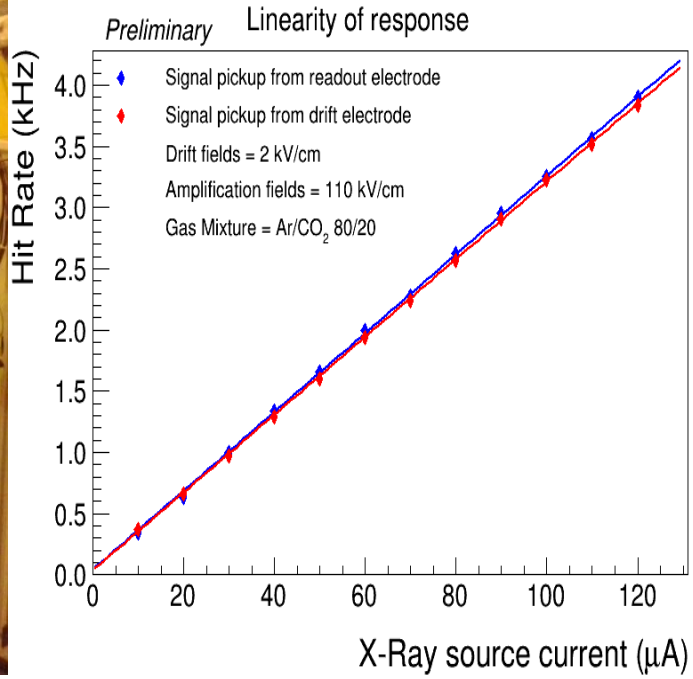




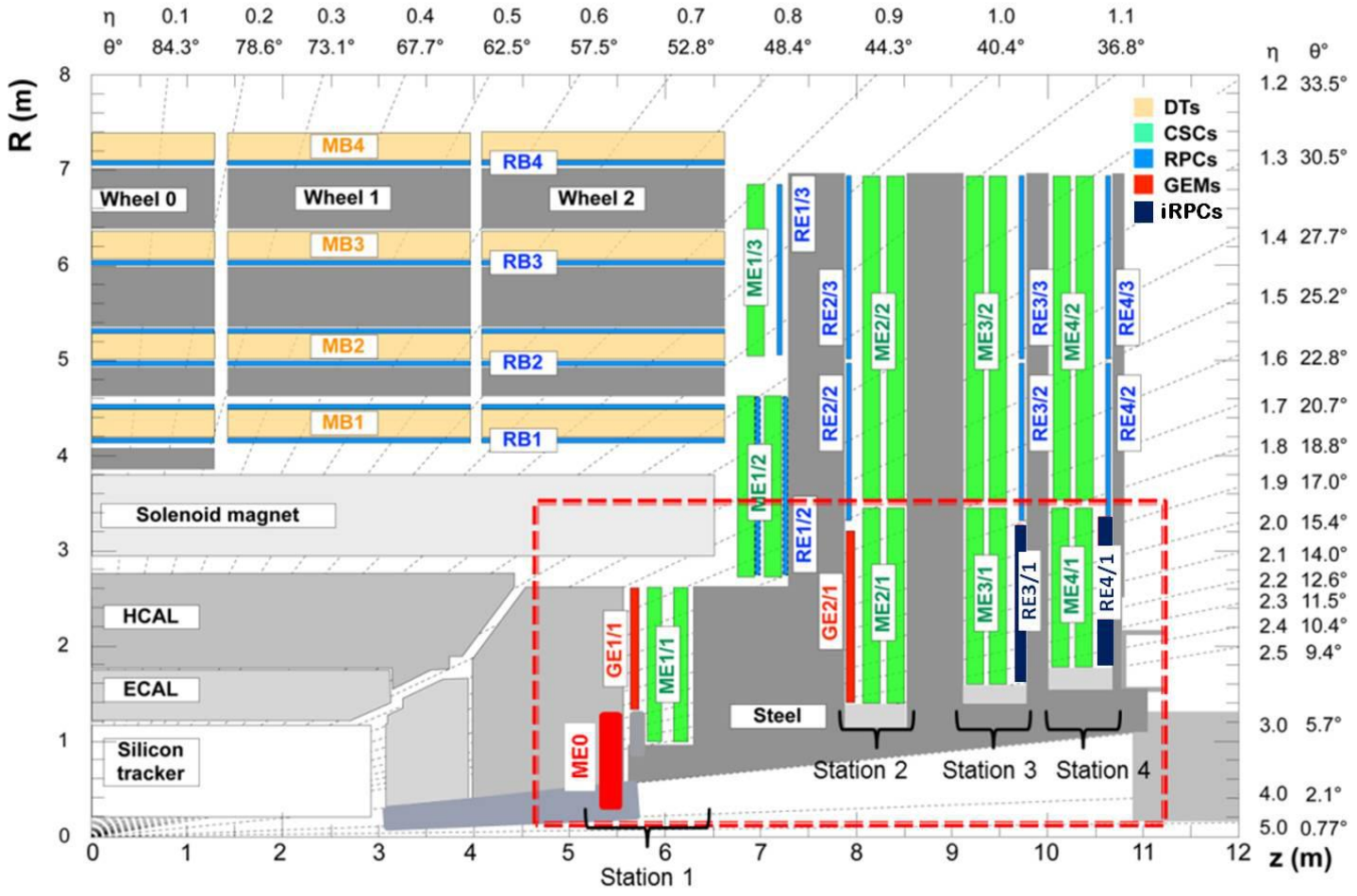
FTM: 2015 H4-test beam Pion beam

σ_t =1.5 ns reached with standard Ar-CO2





High η region upgrade with MPGD for Phase 2: GE21

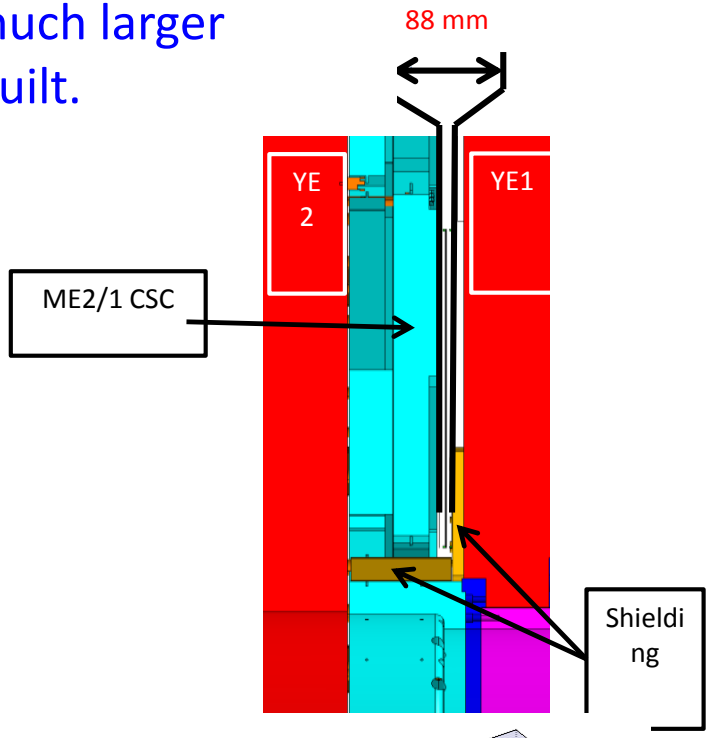


- Objectives:
  - Sustain triggering at current trigger thresholds
  - Increase offline muon identification coverage
  - Maintain existing envelope by mitigating aging effects

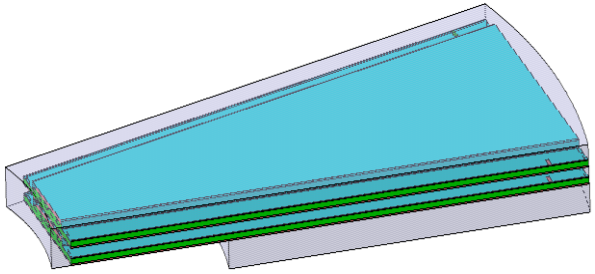
GE2/1 Detector requirements

The baseline GE2/1 station consists of 36 20^0 SuperChambers with the layout will be similar to GE1/1, but covering much larger surface. It will be the largest GEM detector ever built.

For GE21 (only 88 mm available)

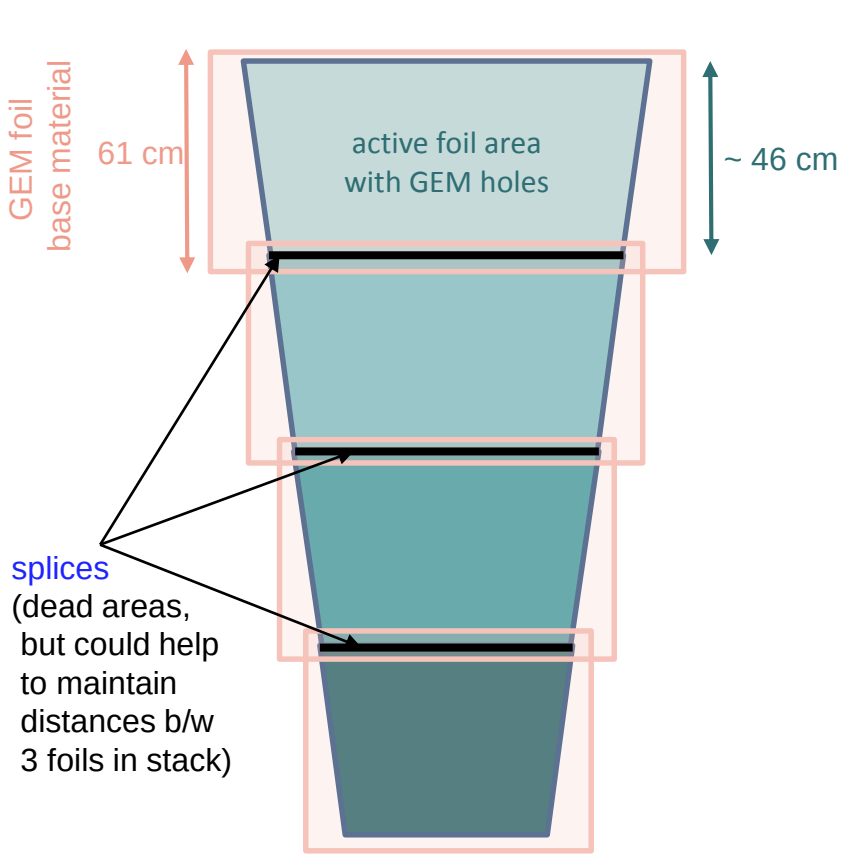


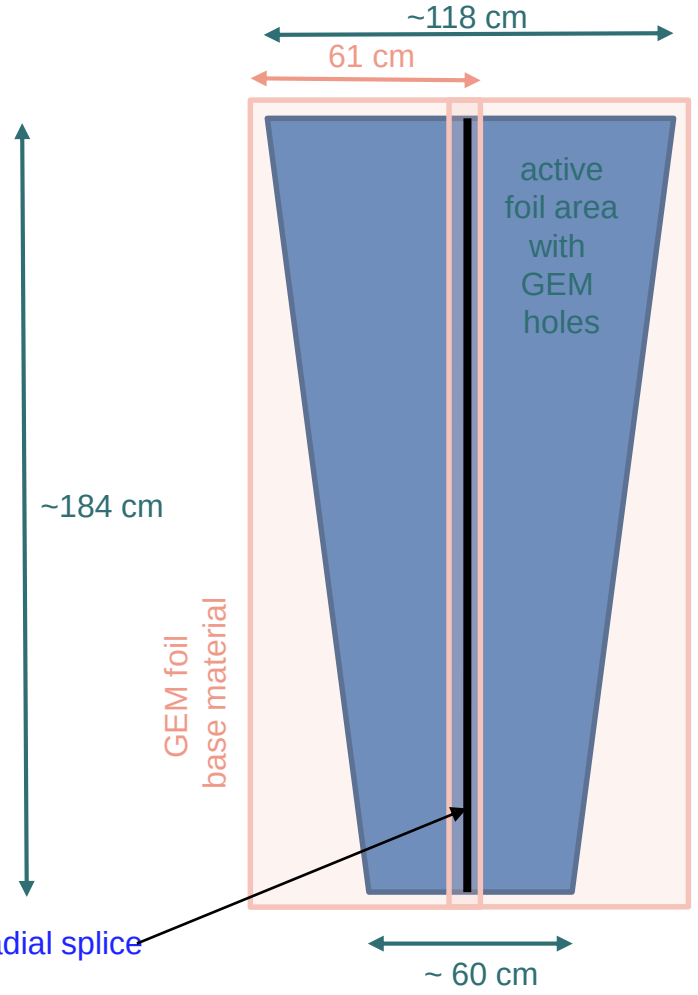
Challenge:
Foil stretching without spacers and NS2 technique developed for GE1/1 should be validated for the larger area of GE2/1



GEM Foil Splicing Challenge

20° design requires splicing together of 2-4 GEM foils by heat & pressure or by placing internal spacers:





Either method will create some dead area within the detector along the splices…

Zigzag strips vs. straight strips

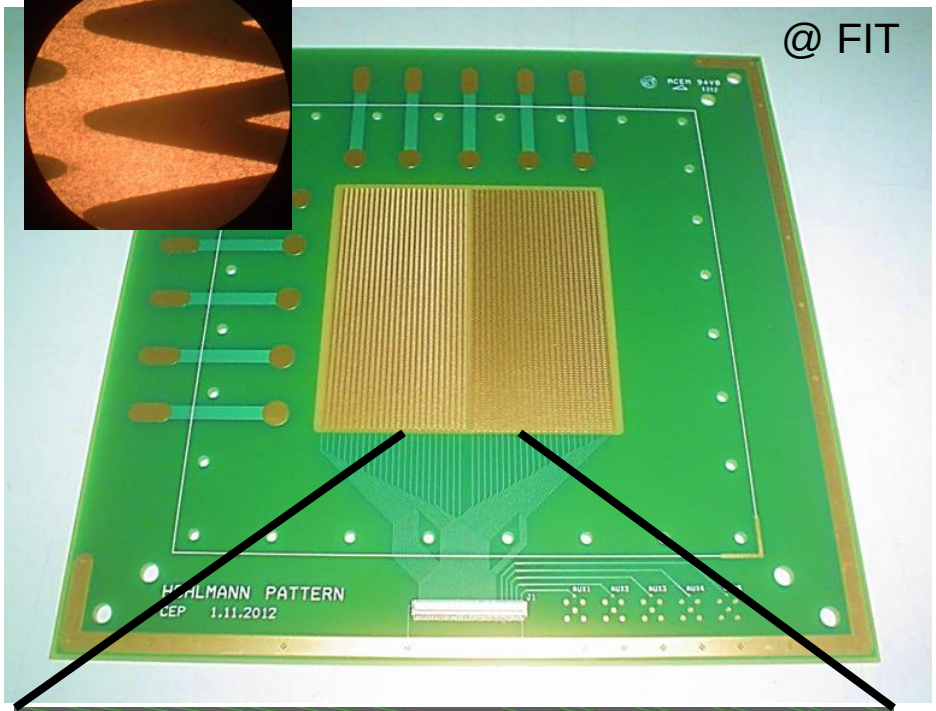
	Pitch [mm]	Typical Resolution [μm]
Zigzag strips & analog r/o	2.0	80
Straight strips & VFAT (current design, short end)	0.6	300
Improvement factor w/ zigzag strips	3.33	3.75

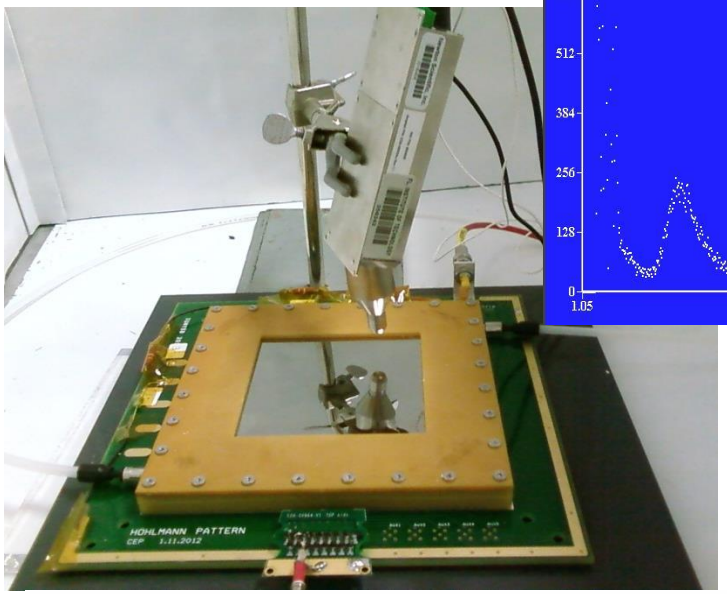
Can reduce # of readout channels (and electronics cost) **by 70%** of current design **&** Improve resolution by factor 3-4

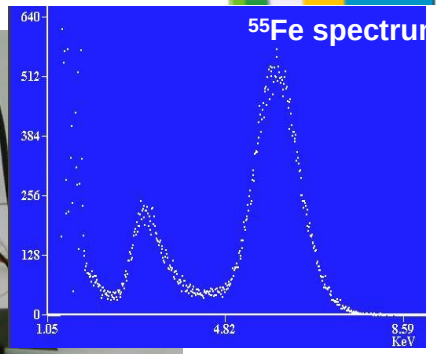
A "figure of merit": 3.33 × 3.75 = 12.5

~ Potential for order of magnitude improvement over current design

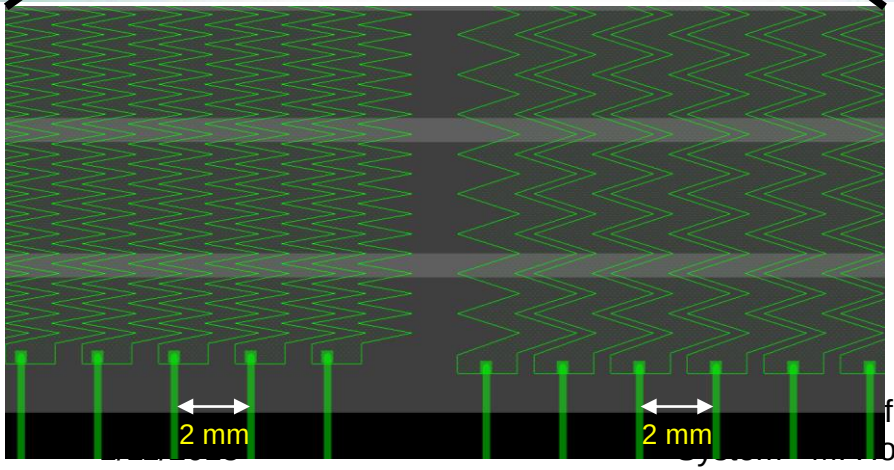
R&D: Zigzag strips to reduce readout channel count while maintaining high spatial resolution



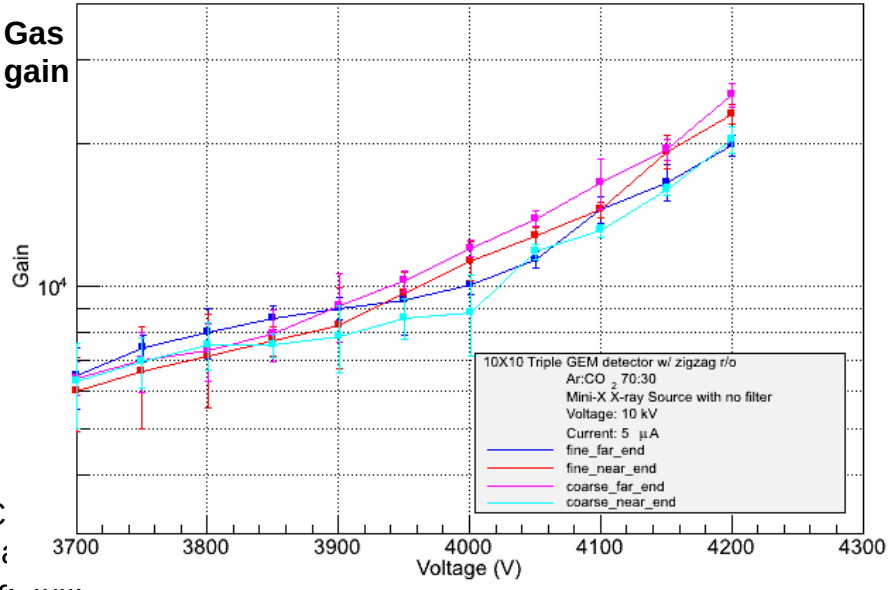




Stand. CERN
10cm × 10cm
Triple-GEM



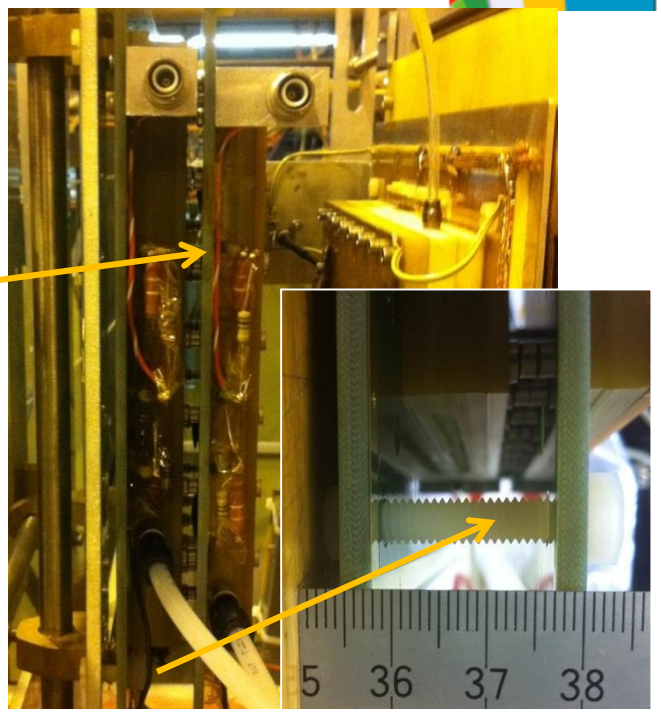
CAD Design by C. Pancake, Stony Brook

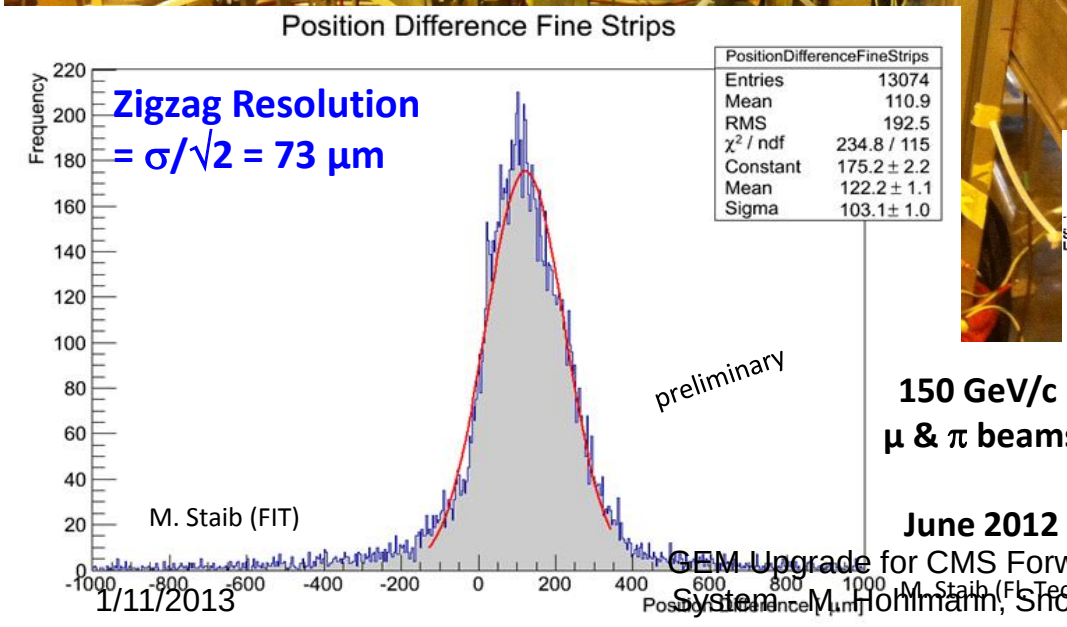


for C
Hohlma

meeting, ANL

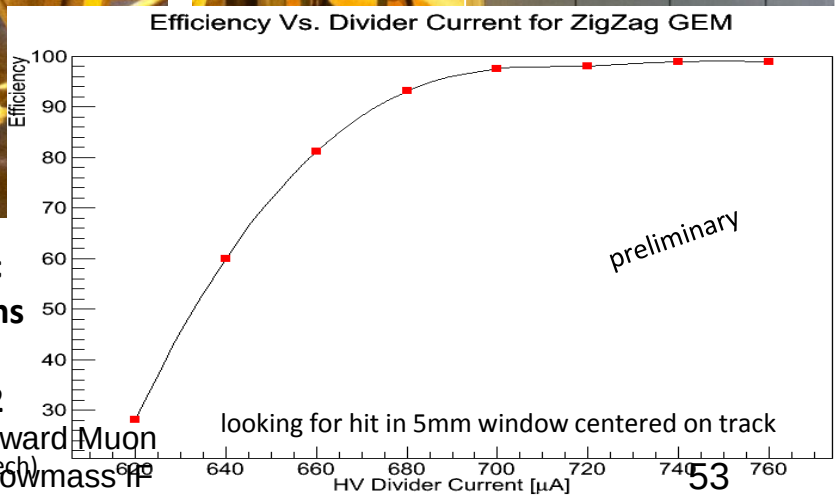
CMS/RD51 beam test @ SPS



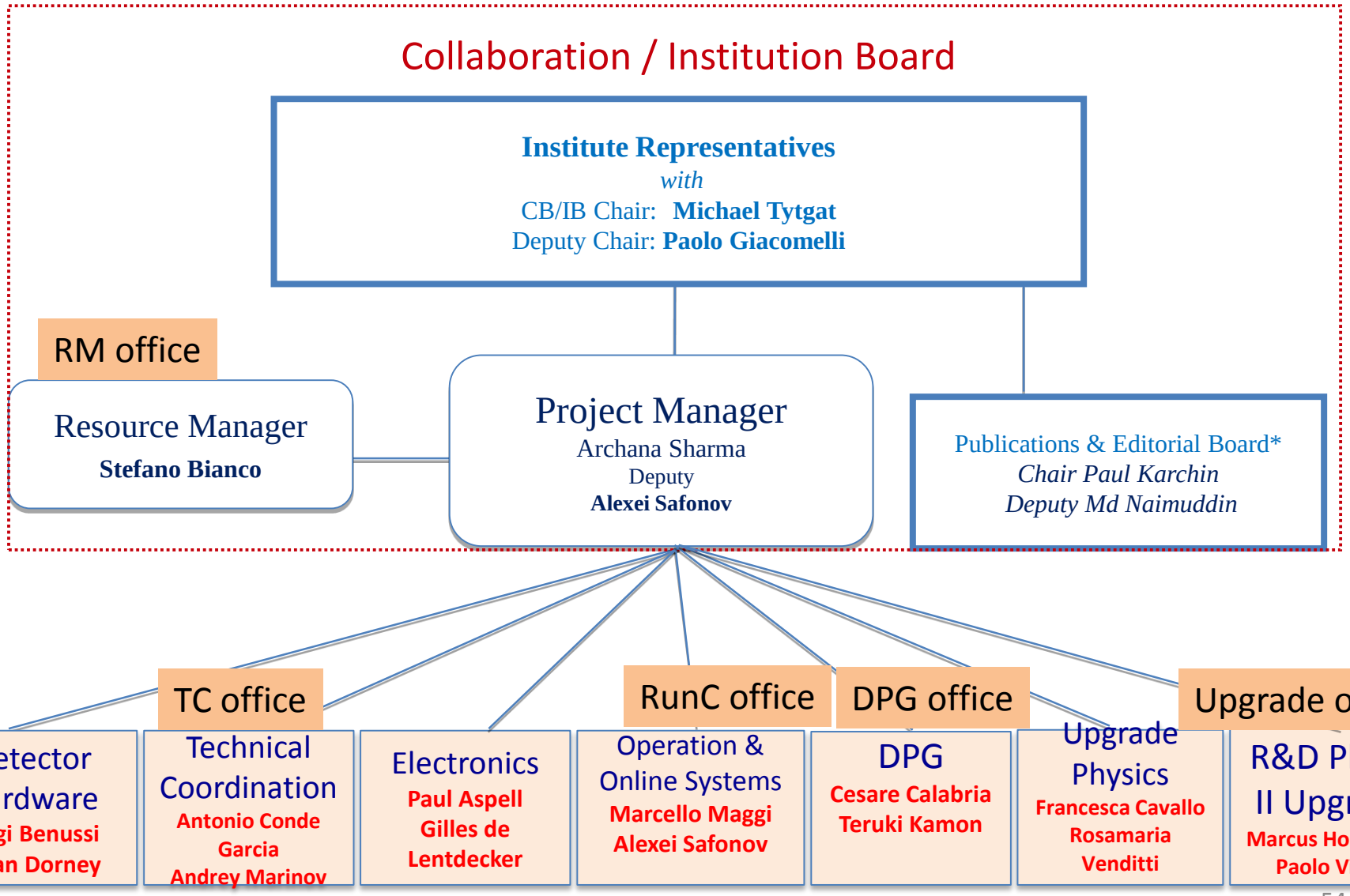


150 GeV/c
µ & π beams

June 2012



GEM Construction
Phase 2 R&D
Project Organization (approved Oct 9, 2015)



Acknowledgements

- Special mention ALL team members at the TIF/904
  - And constantly visiting collaborators
- The full CMS GEM collaboration which started in 2009…. 40 Institutions from 14 countries
- RD51 and Rui's team
- Many others

Summary

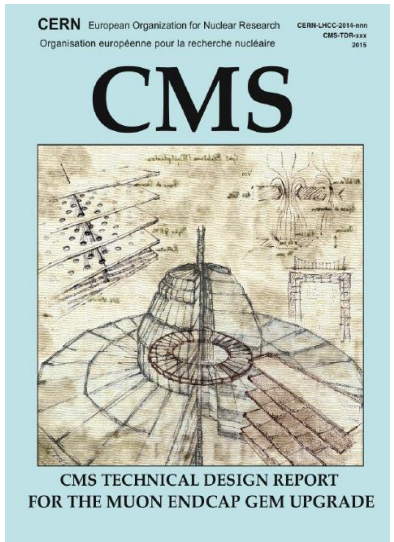
Several projects in the pipeline

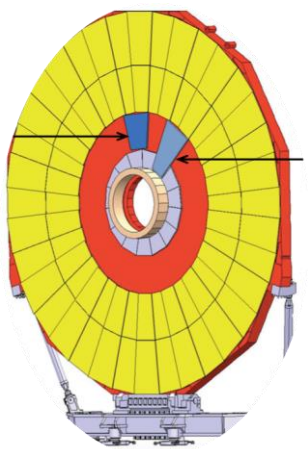
GE11 to be delivered for LS2

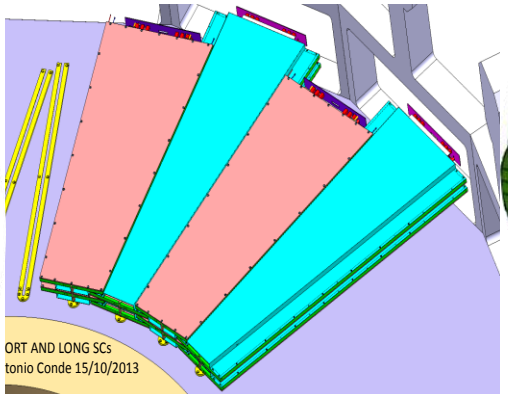
GE21 & ME0 TDR in ~ 2 years

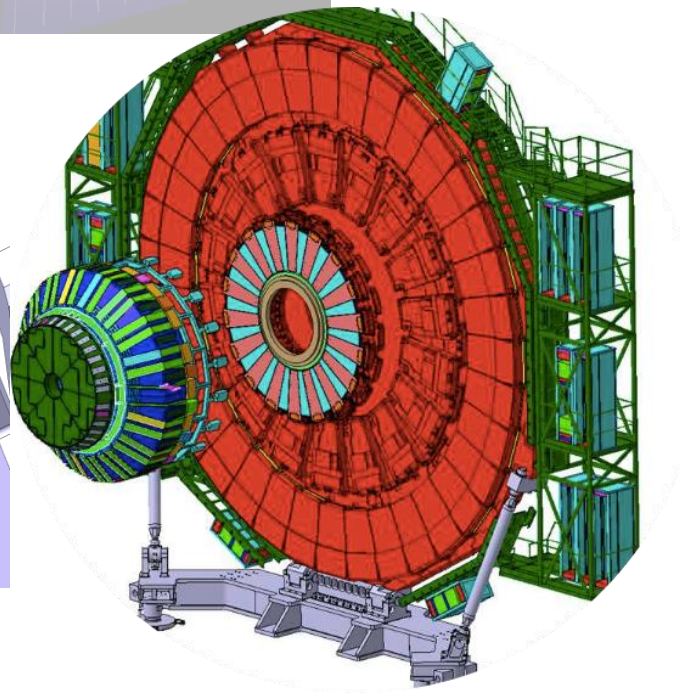
Promising outlook for a lot of work….

By the collaboration





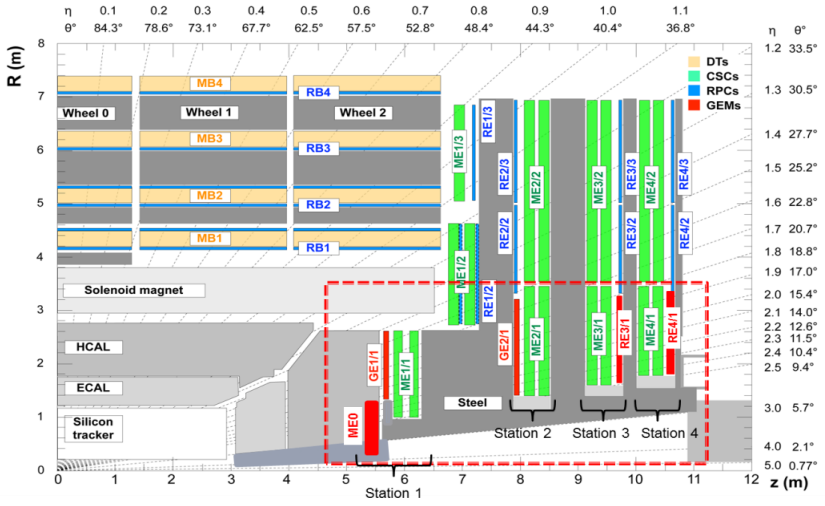


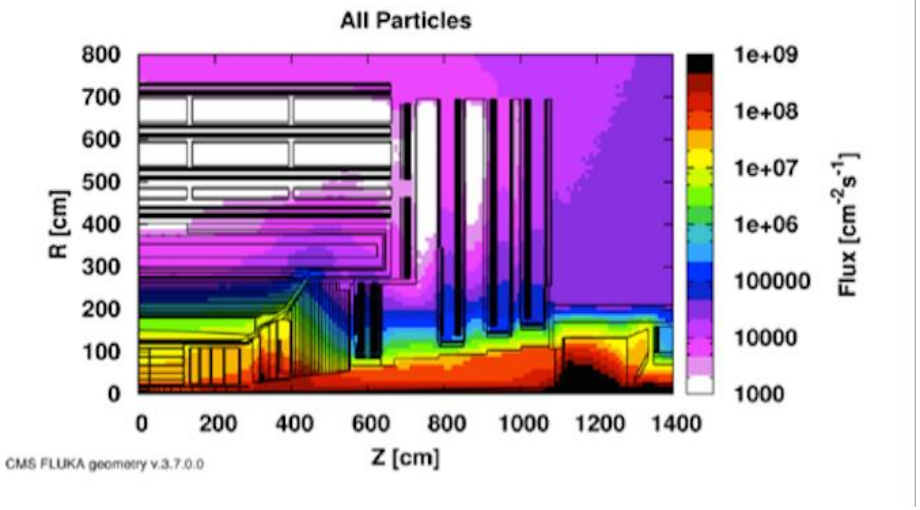


BACKUP SLIDES

Radiation: dose and fluxes

Flux of all particles at instantaneous luminosity of $5x10^{34}cm^{-2}s^{-1}$ and integrated luminosity 3000 fb-1

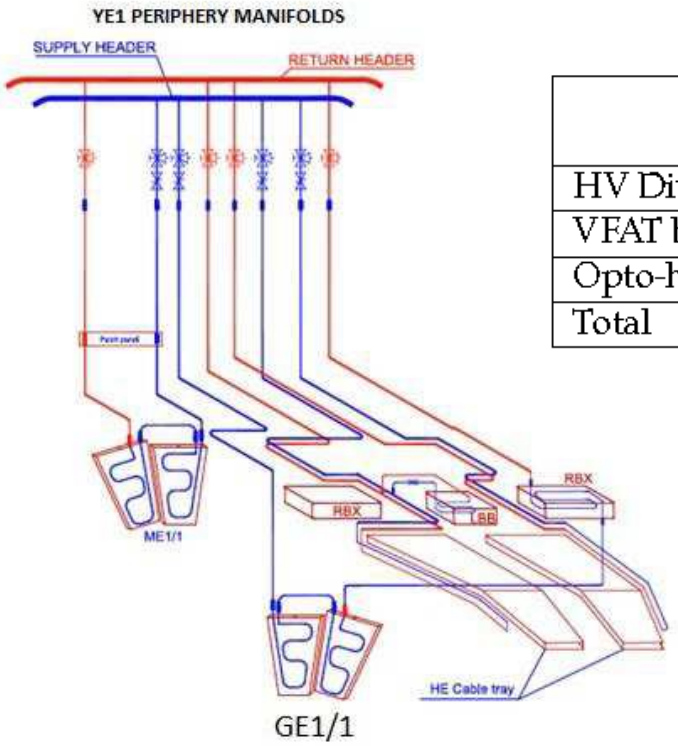




GE1/1 ~ 1-10 kHz/cm^2
(the most recent simulations = 1.6kHz/cm^2)

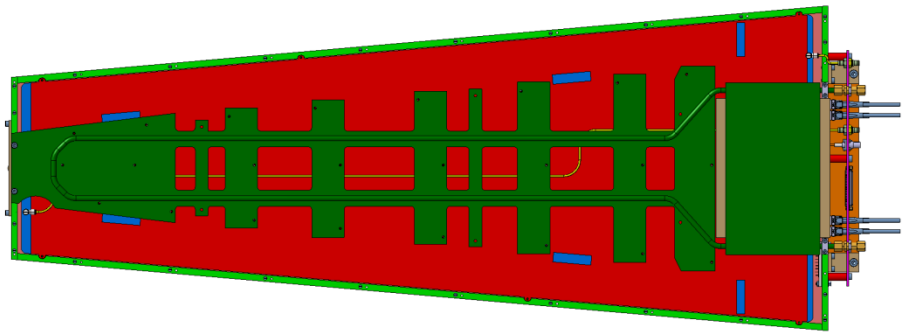
ME0 ~ 10-100 kHz/cm^2
(the most recent simulations = 55kHz/cm^2)

Power Budget and Cooling



GE1/1

	Power consumption for GE1/1			
	Single chamber	superchamber	Endcap	Total
HV Divider	4 W	8 W	288 W	576 W
VFAT boards	24 W	48 W	1.7 kW	3.5 kW
Opto-hybrid	50 W	100 W	3.6 kW	7.2 kW
Total	78 W	156 W	5.6 kW	11.2 kW



The GE1/1 Super-chamber will take cooling from the RBX loops. It will give an negligible impact to the cooling system in the YE1

The cooling circuit is designed such to provide direct thermal contact with all heat sources in the GE1/1 chamber.