Micro-pattern Gaseous Detectors GEM for Upgrade of the CMS Muon System

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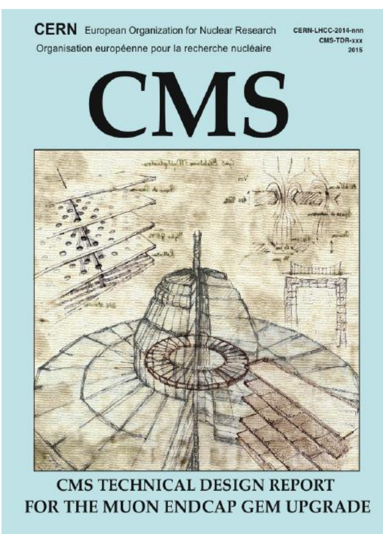
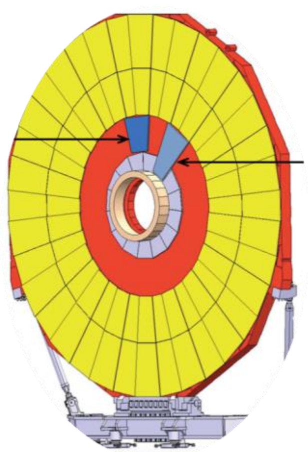
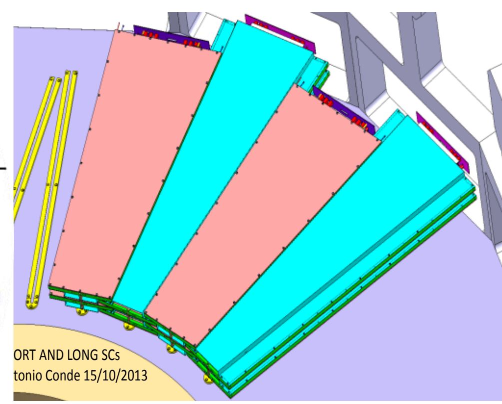
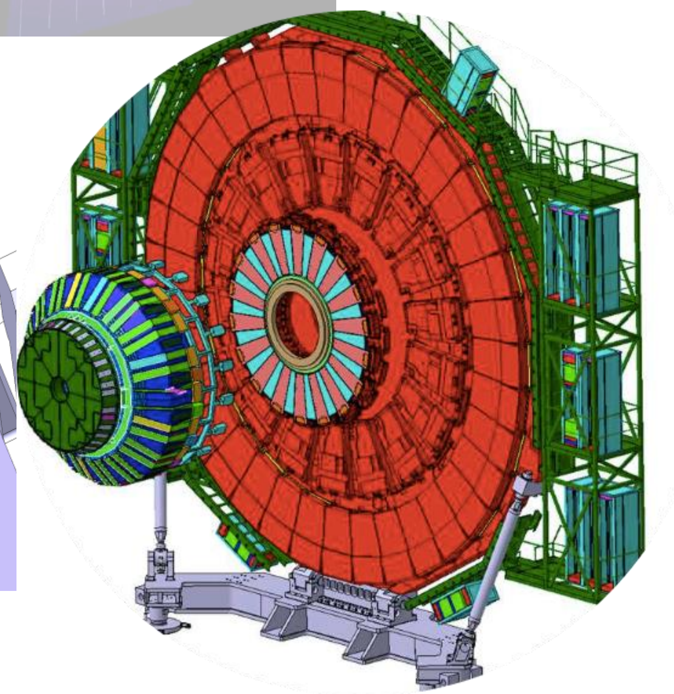
14-12-2016

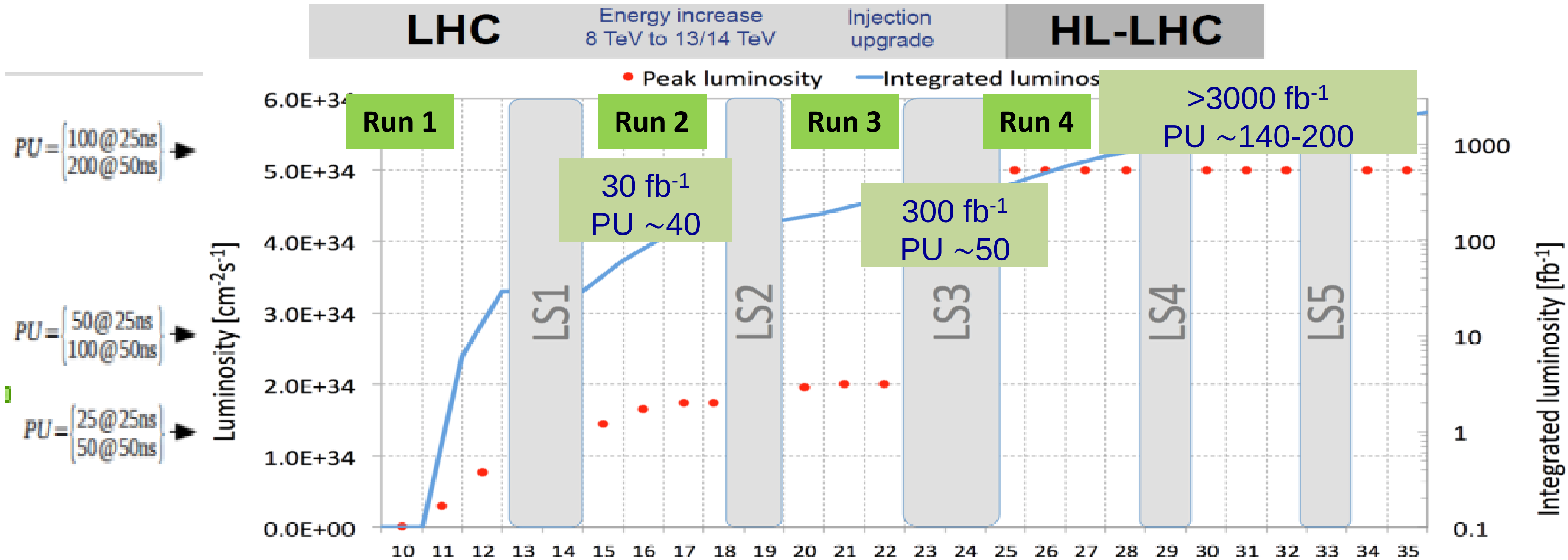








LHC future scenarios



CMS Upgrade — Phase I Upgrade → Phase II Upgrade →

LHC:

Run2:

- L=1.7e34, PU 40→factor 2 increase wrt 2012
  L=1x design lumi by LS2

Run3:

- L=2x design lumi by LS3, and integrate 300fb-1 by 2022

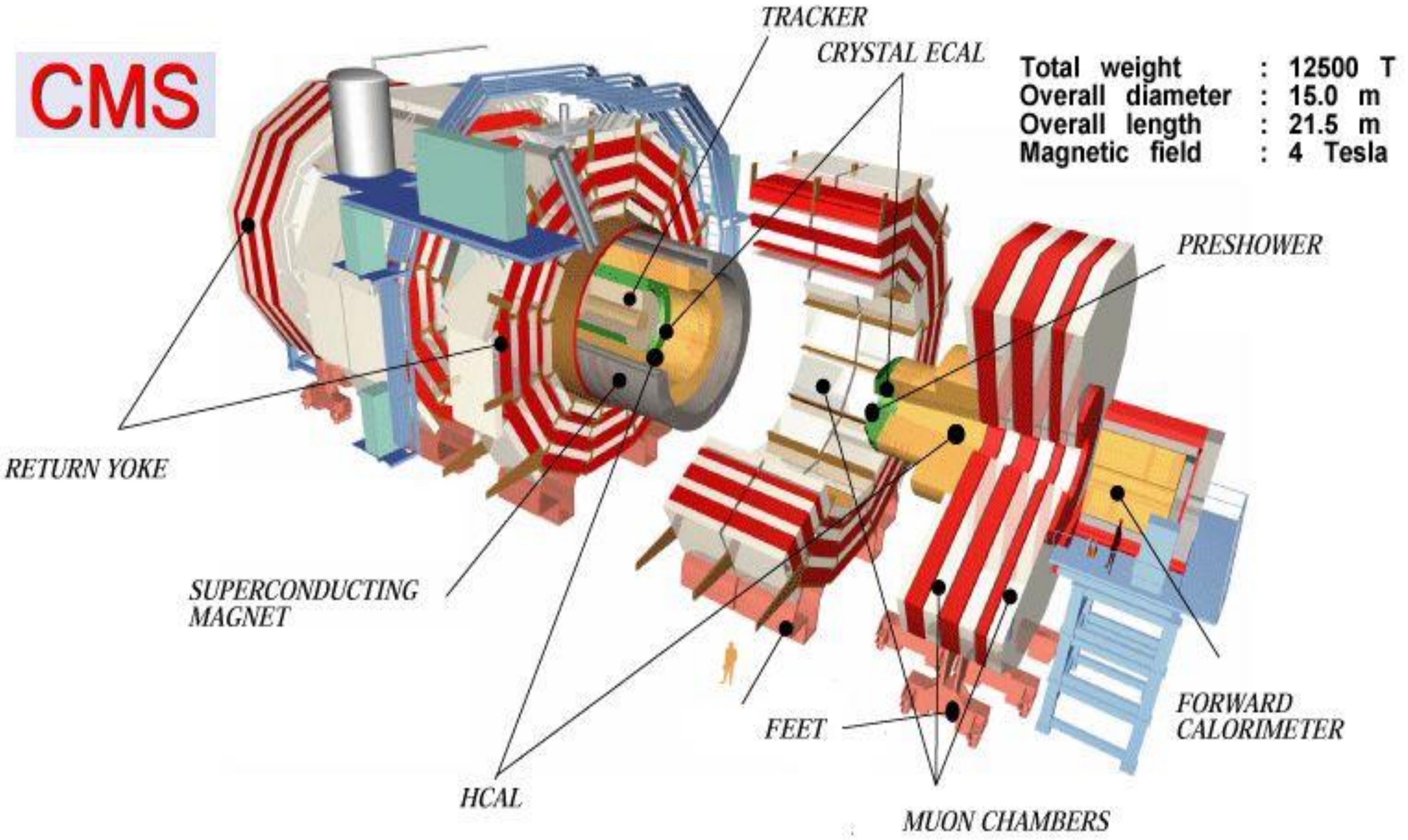
Use PU=50 for upgrade studies

HL-LHC:

- Lumi-level at 5x design and integrate 3000 fb-1

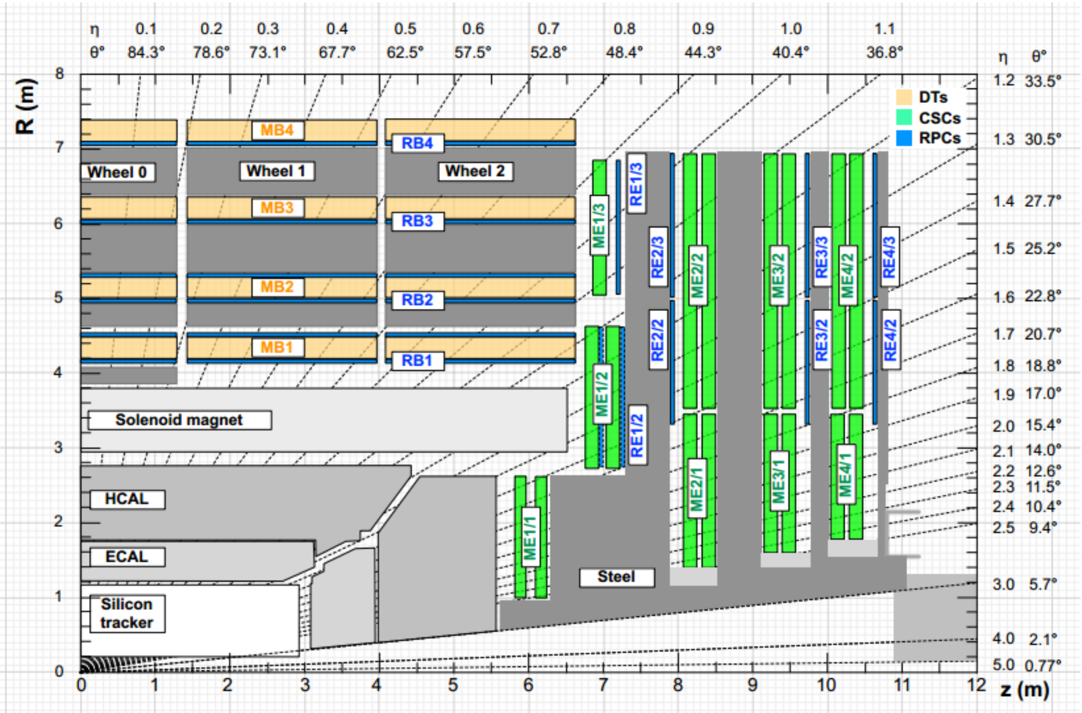
PU=140 for upgrade studies

Compact Muon Solenoid



The CMS Muon system

Highly hermetic and redundant muon system, with 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).

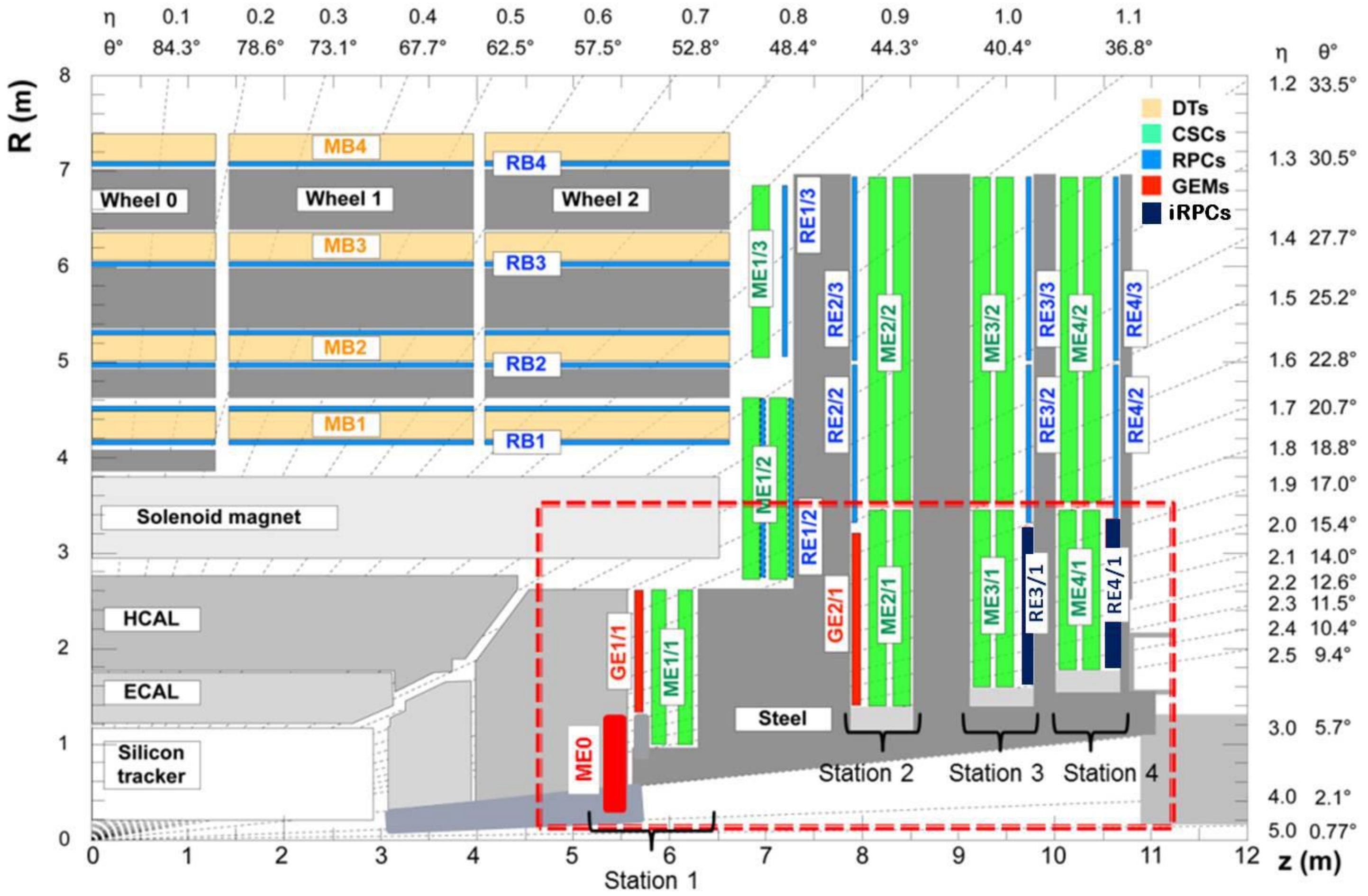
Eta coverage:

- |η|<1.6: 4 layers of CSCs and RPCs, DTs
- the |η|≥1.6: 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)

High η region upgrade with MPGD for Phase 2



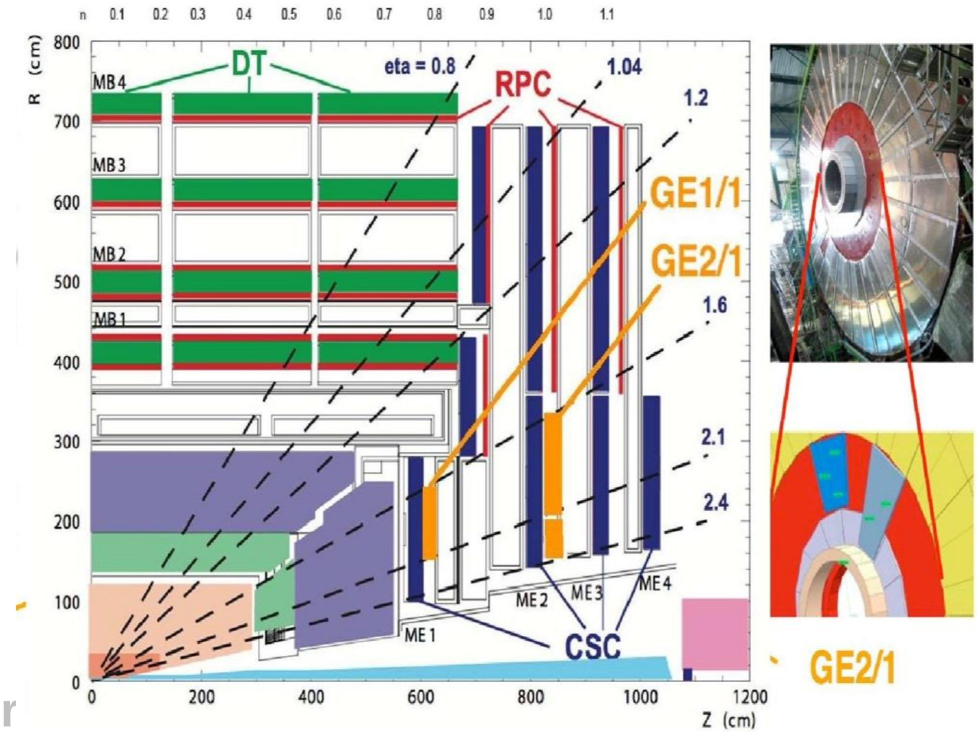
- Objectives:
  - Sustain triggering at current trigger thresholds
  - Increase offline muon identification coverage
  - Maintain existing envelope by mitigating aging effects

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**

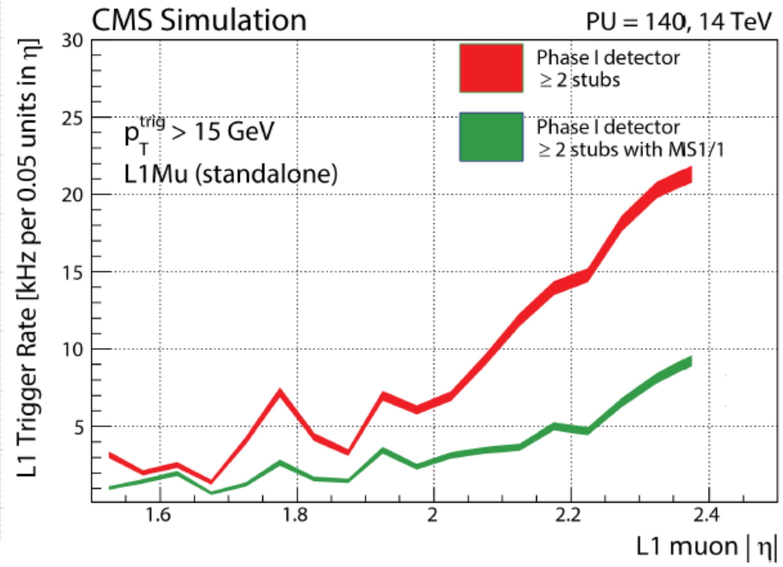
Phase-II

Forward Muon system : challenges

High luminosity can adversely affect muon system performance

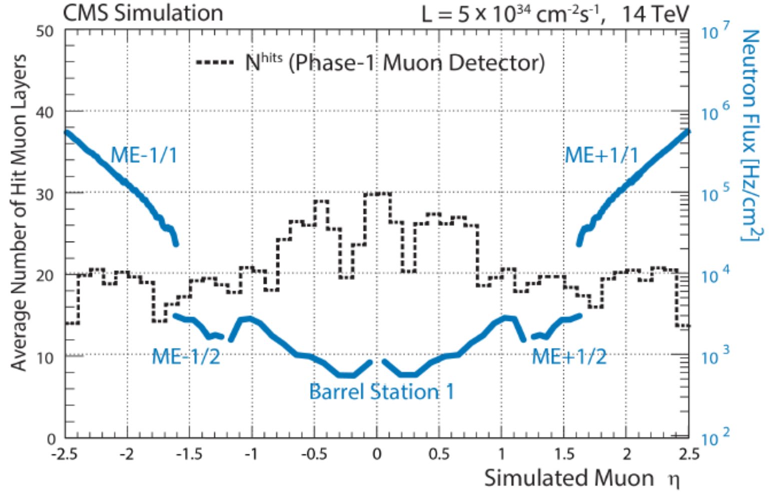
The forward region |η|≥1.6 is very challenging

- **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

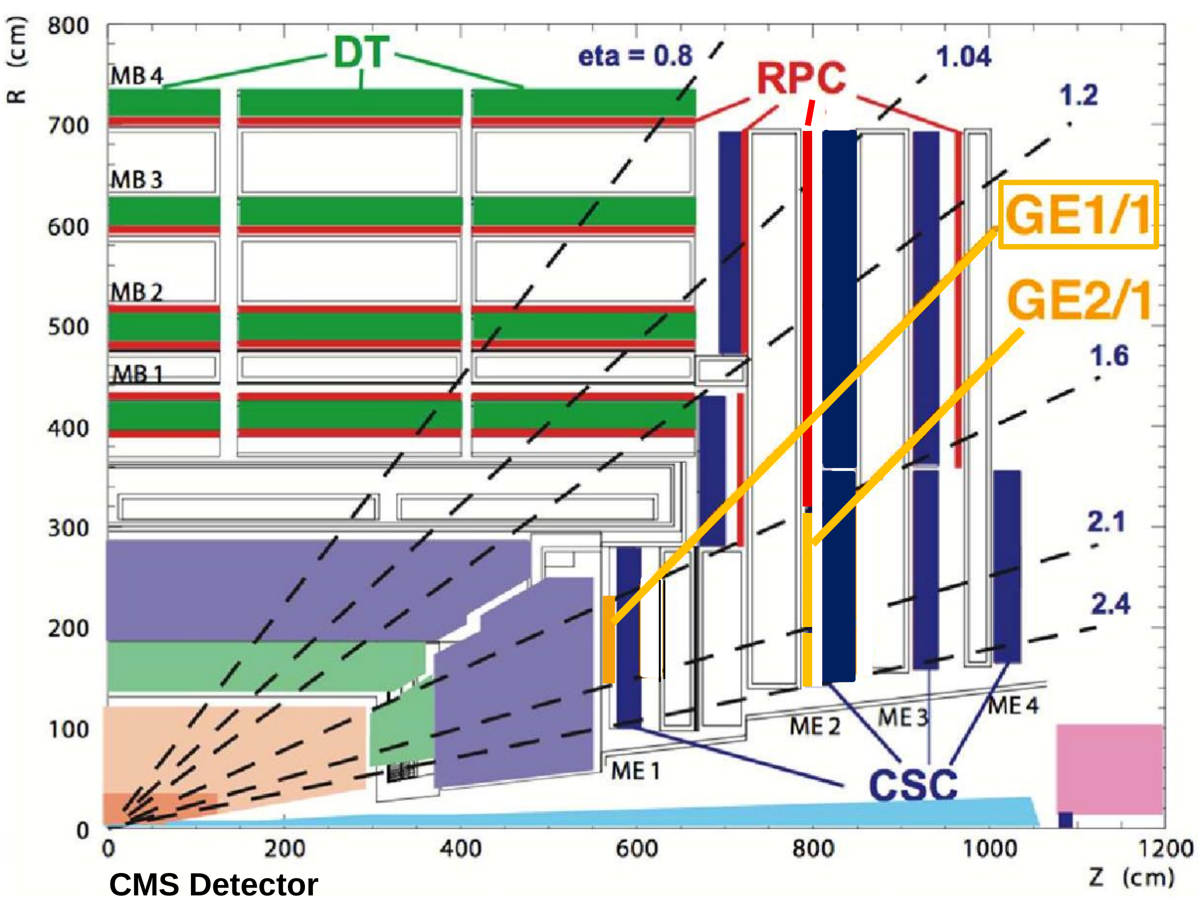


- **Electronics:** High occupancy/rate and latency increases exceed capabilities of the existing electronics

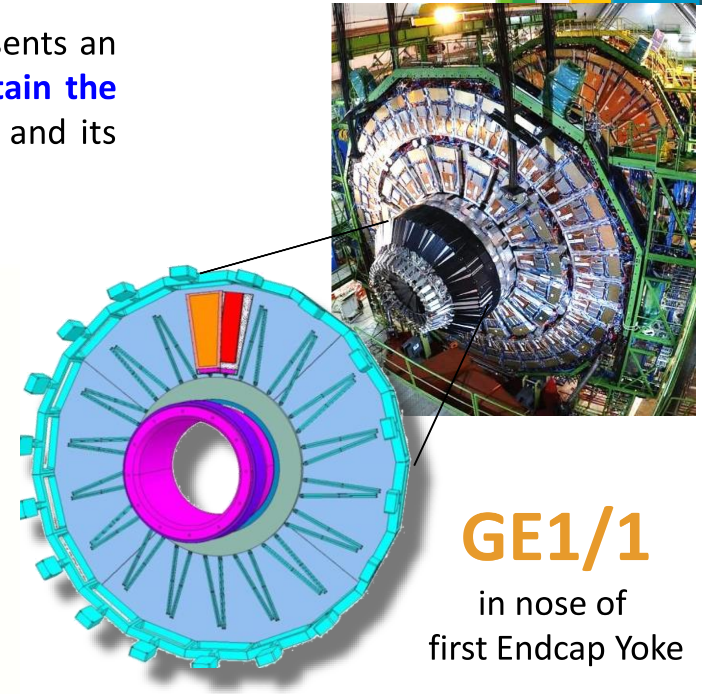
The issues affect already the postLS2 operations and will be exacerbated in Phase 2

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**



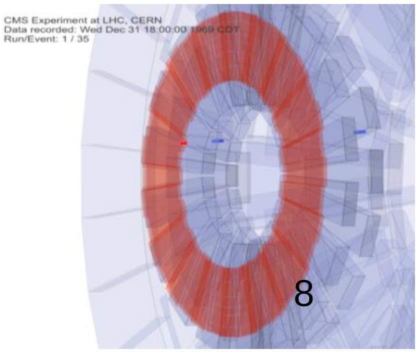
CMS Detector



GE1/1

in nose of
first Endcap Yoke

GE1/1 simulation geometry

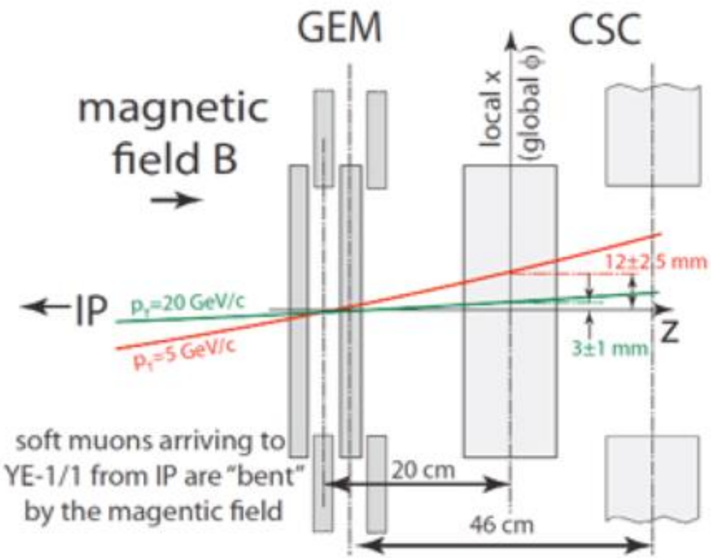


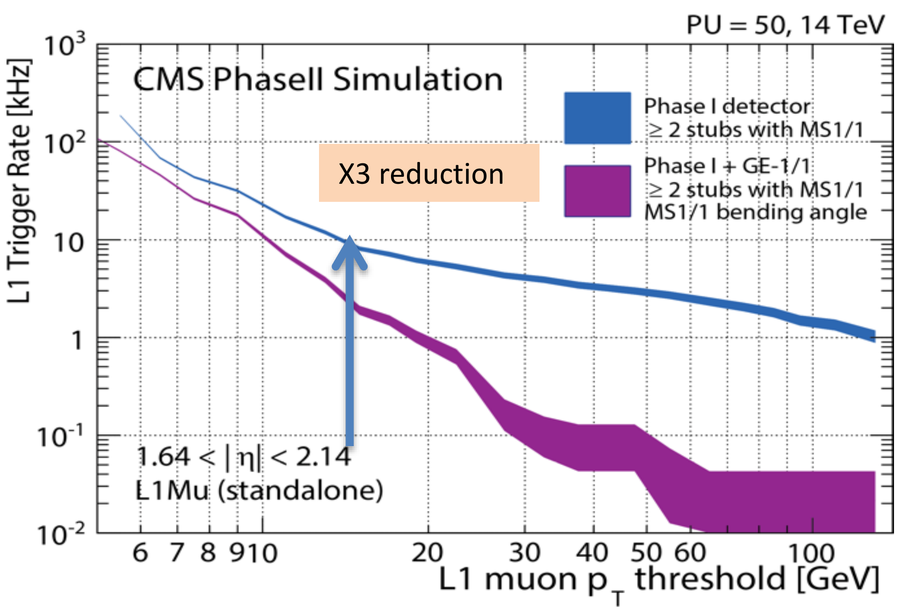
New handle: bending angle

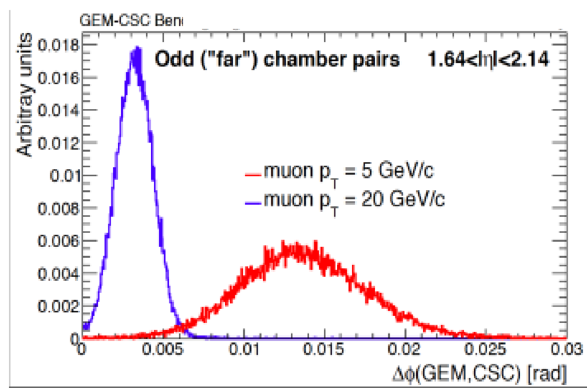
Forward trigger for |η|>1.6 relies entirely on the CSC system:

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

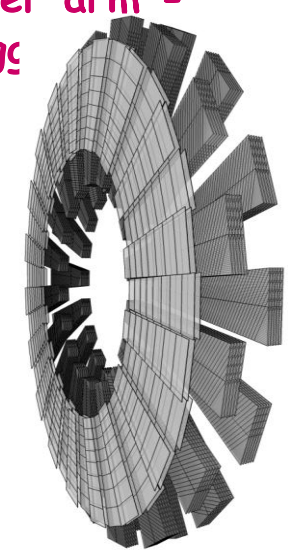
GEM detector in front of CSC can measure muon bending angle in magnetic field and add redundancy







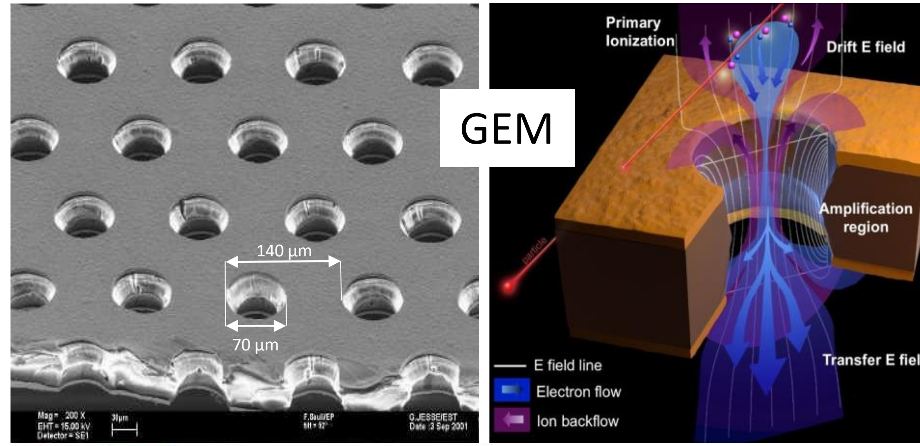
Lever arm - trigg

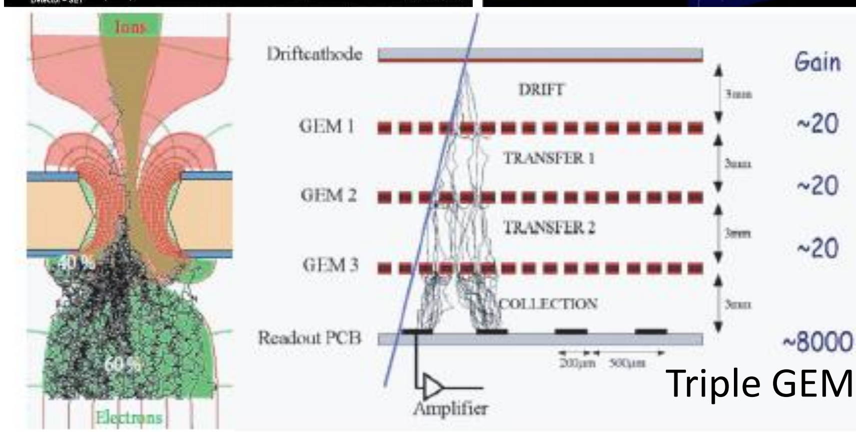


maintain 15 GeV online threshold, keep < 5 kHz rate, high efficiency

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

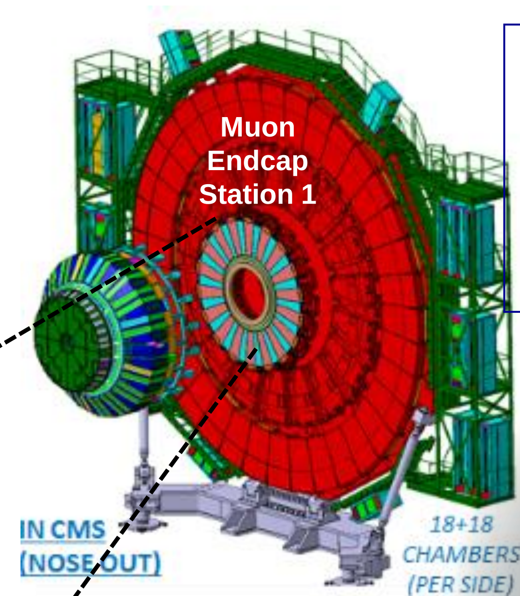


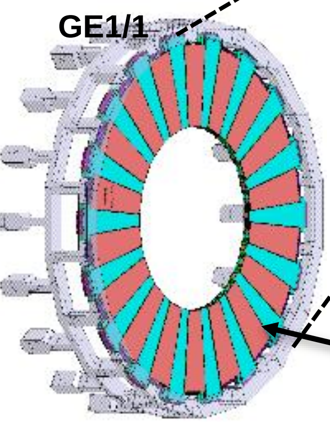


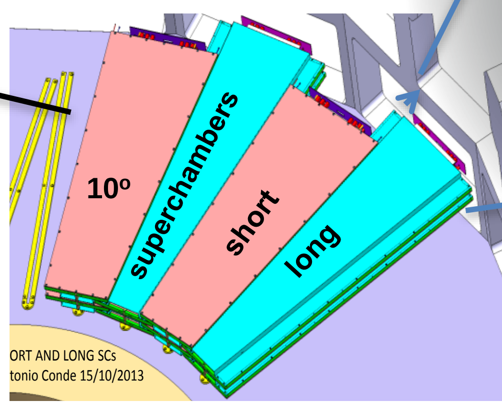
Micro-Pattern Gas Detectors (MPGD) due to their proven performance at HEP experiment (high rate capability and fine space resolution, high gain stability) are ideal tools. Dedicated studies for the large CMS detector:

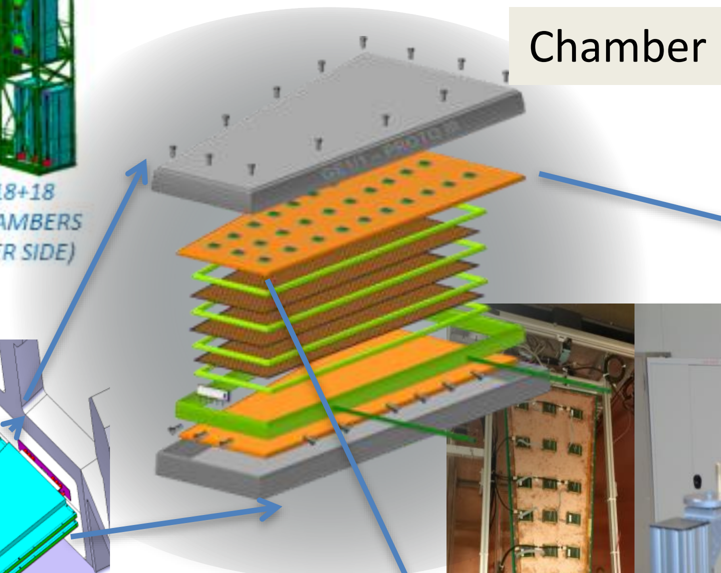
The GE1/1 design

- **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**



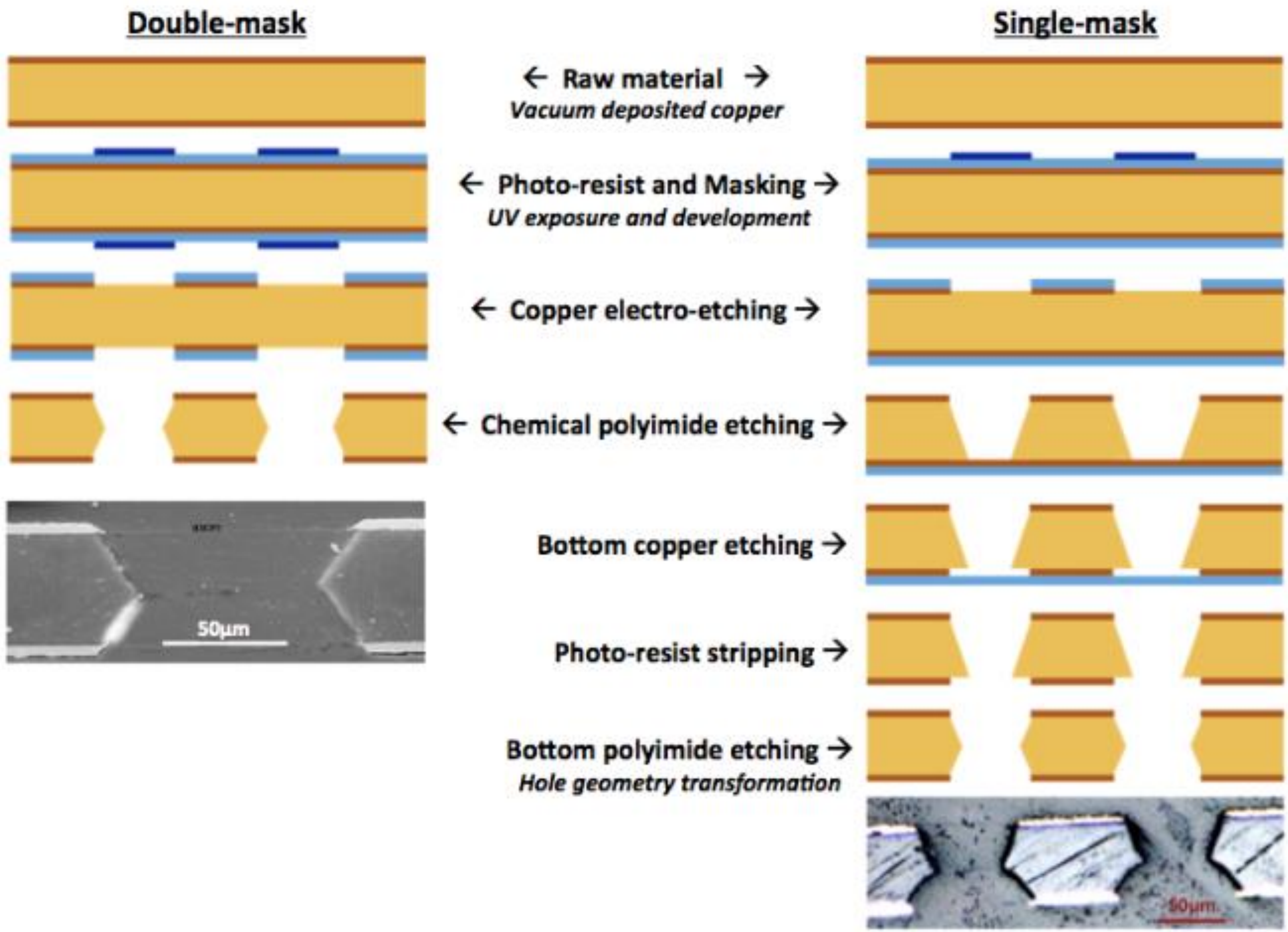




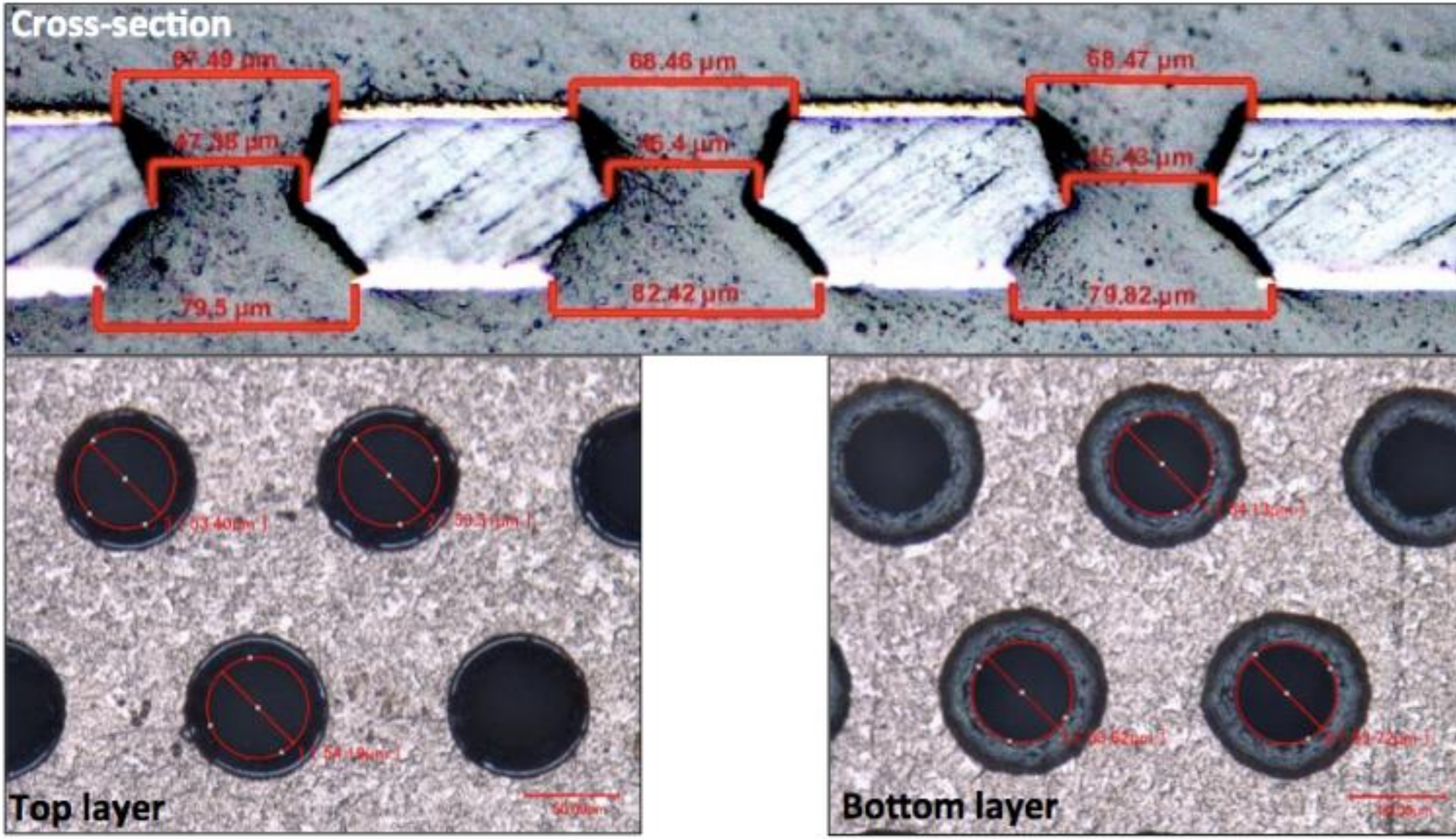


Installation in LS2

Challenge 1

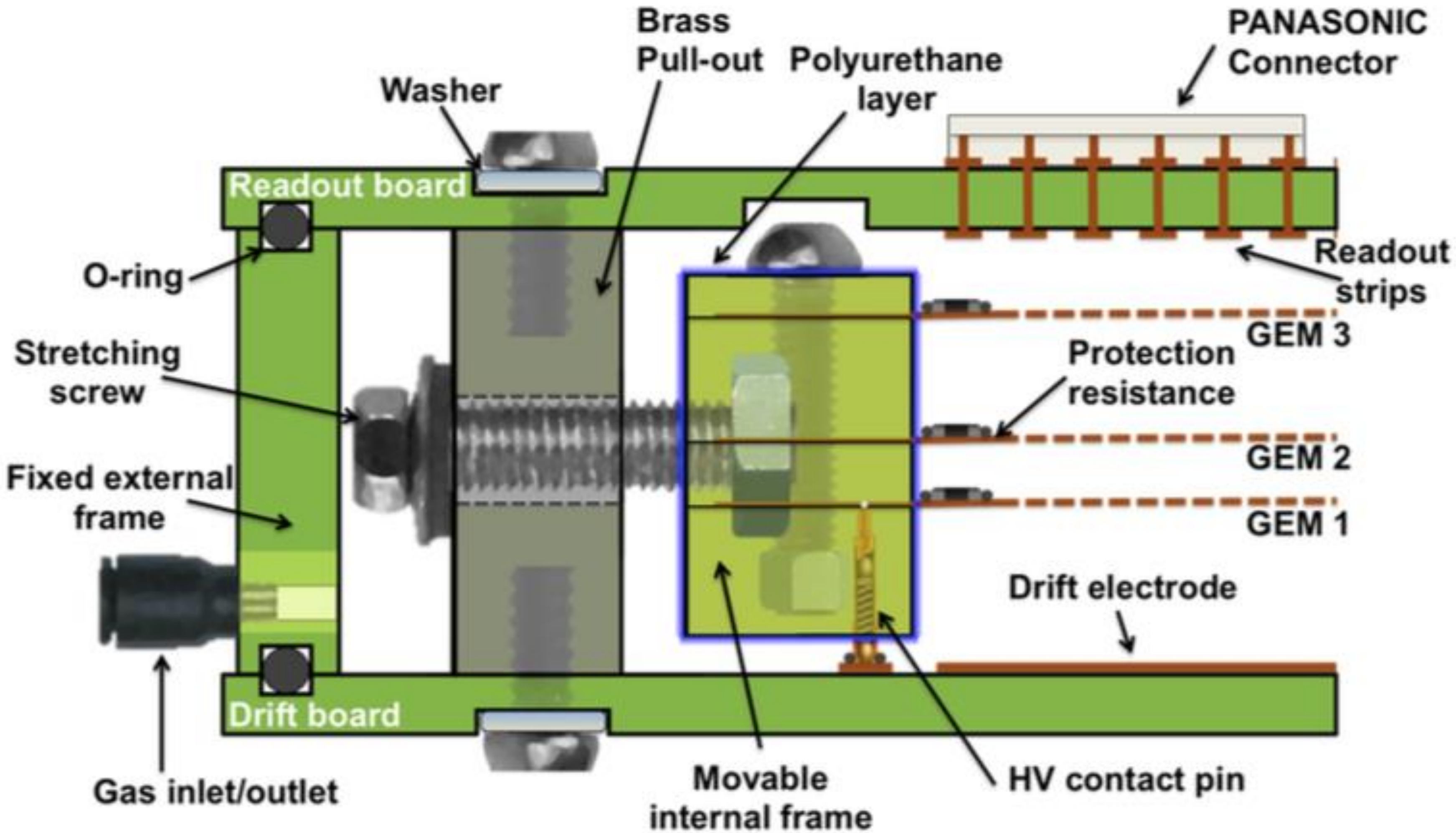

Double-mask
Single-mask
← Raw material →
Vacuum deposited copper
← Photo-resist and Masking →
UV exposure and development
← Copper electro-etching →
← Chemical polyimide etching →
Bottom copper etching →
Photo-resist stripping →
Bottom polyimide etching →
Hole geometry transformation
50µm

Challenge 1 ..



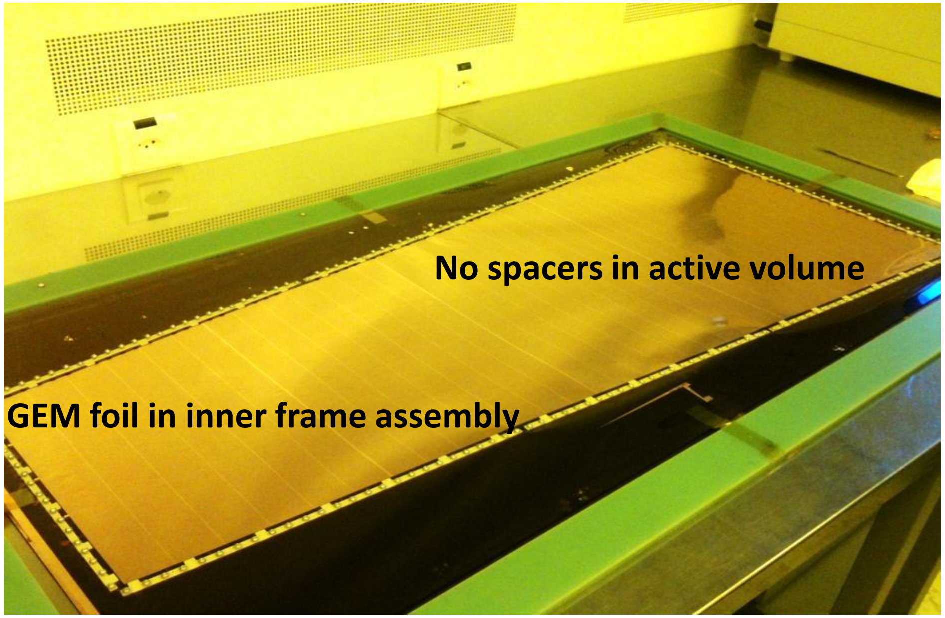
Cross-section
68.46 µm
68.47 µm
79.5 µm
82.42 µm
79.82 µm
Top layer
Bottom layer

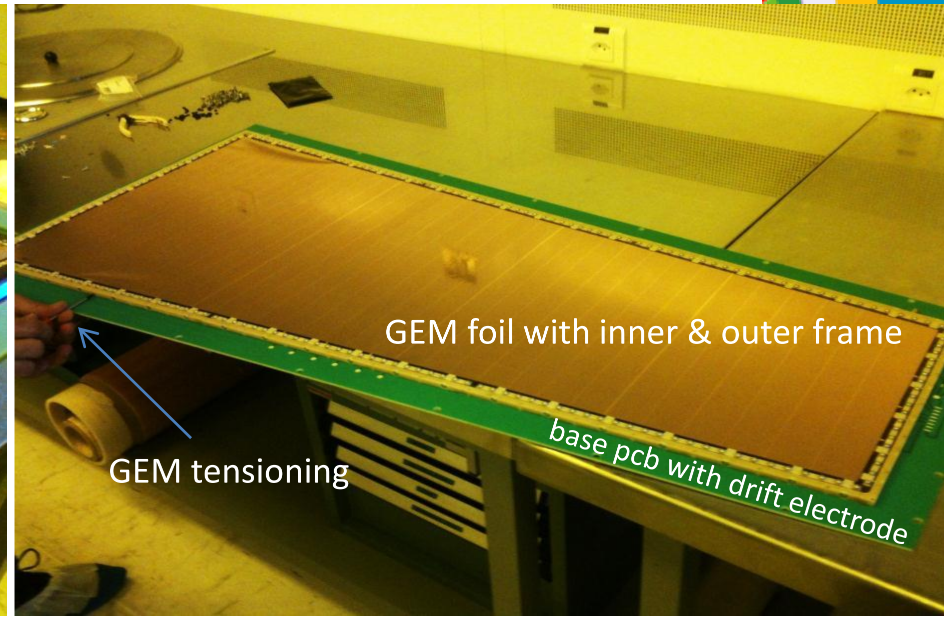
Challenge 2

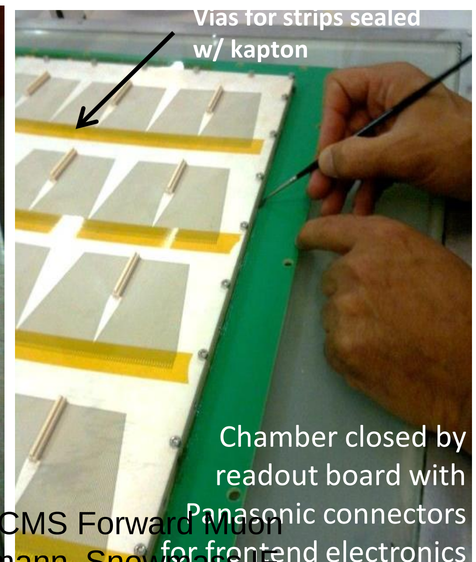


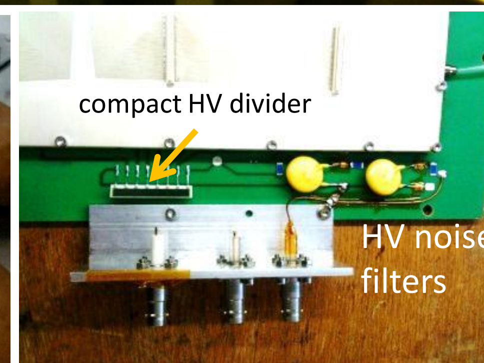
Brass
Pull-out
Polyurethane
layer
PANASONIC
Connector
Washer
Readout board
O-ring
Readout
strips
GEM 3
Stretching
screw
Protection
resistance
GEM 2
Fixed external
frame
GEM 1
Drift electrode
Drift board
Gas inlet/outlet
Movable
internal frame
HV contact pin

3rd GE1/1 Prototype:: NS2

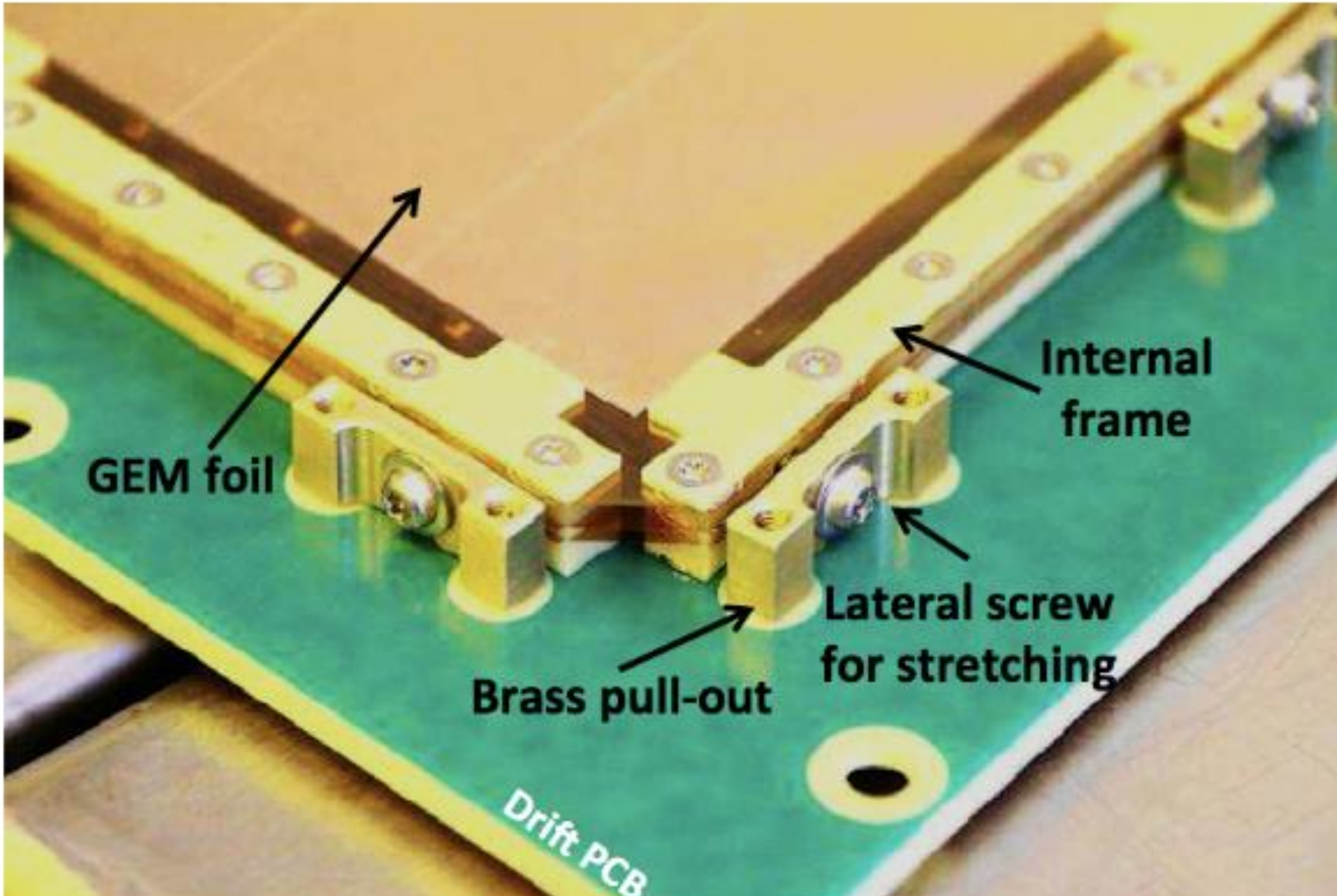






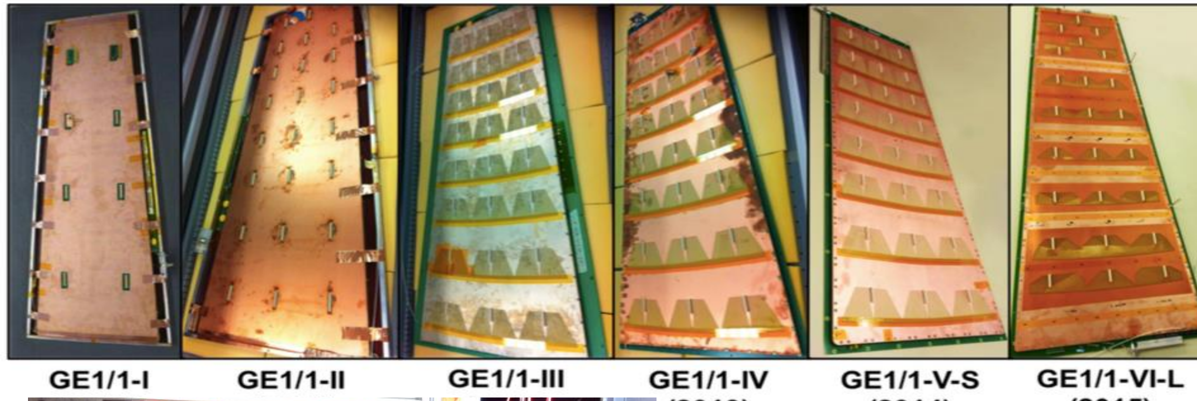


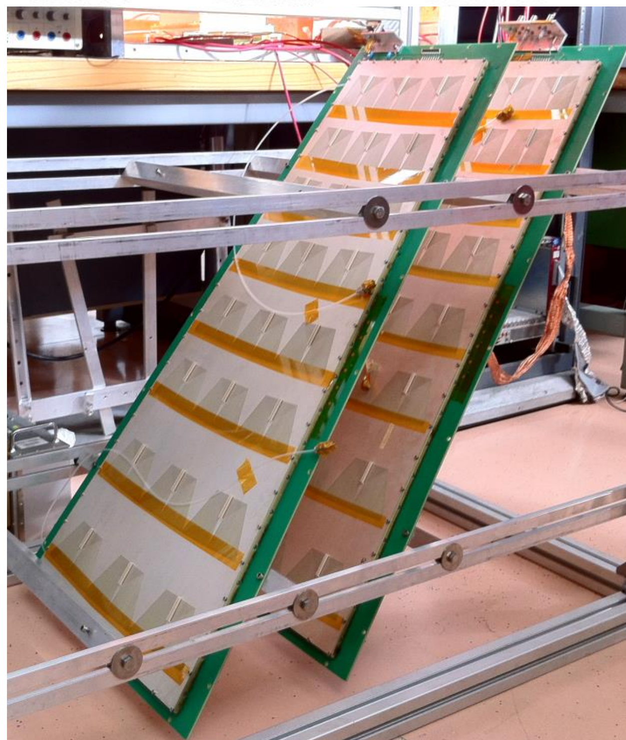
CERN 2012



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

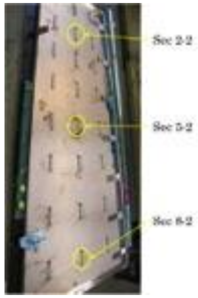
Full-size GE1/1 Detector Prototypes

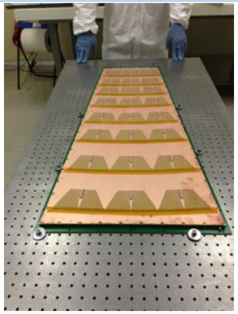


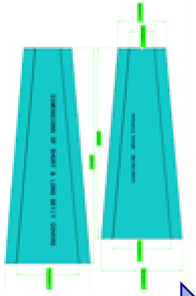


- **GEM active area: 990 mm × (220-445) mm**
- **Single-mask technology**
- **1D radial strip read-out with 3 × 8 × 128 = 3,072 channels**
- **35 HV sectors**
- **3/1/2/1 mm gap sizes**
- **Gas mixtures:**
  - **Ar/CO_2 (70:30; 90:10)**
  - **Ar/CO_2/CF_4 (45:15:40; 60:20:20)**
- **Gas flow ≈ 5 l/h**

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.

2015: Prototyping, DAQ &trigger and QC procedure of detectors. First prototype of VFAT3

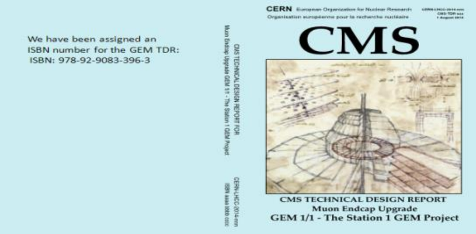
YETS 2016: electronics&chamber prototype installation-

2016/17: Slice and trigger commissioning.

2017/18: Production GE1/1 chambers with final electronics

2017/18: Full-production of chambers and electronics started

2018/19: Full installation of GE1/1 with final electronics



CHAMBERs

Project Approved 30.9.2015

2010 2011 2012 2013 2014 2015

R&D phase ***Toward production phase*** ***TDR***

GE1/1-I
-> first 1m-class GEM detector ever built
-> single-mask technology
-> 99x(22-45) cm²
-> 1024 readout channels
-> gap config. 3/2/2/2
-> use of spacer grid and glue

GE1/1-II
-> Optimization of the electric field configuration
-> single-mask technology
-> 99x(22-45) cm²
-> 3072 readout channels
-> gap config. 3/1/2/1
-> use of spacer grid and glue

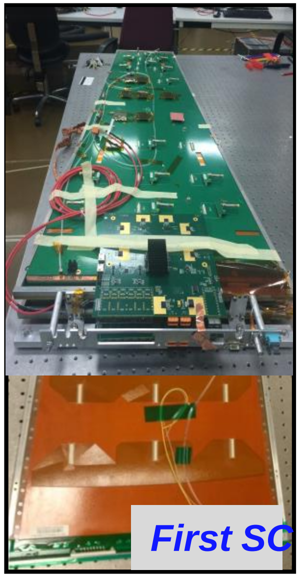
GE1/1-III
-> first use of the self-stretching technique
-> single-mask technology
-> 99x(22-45) cm²
-> 3072 readout channels
-> gap config. 3/1/2/1
-> No spacers but glue on the external frame

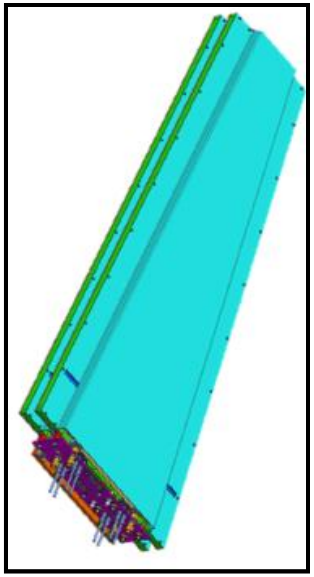
GE1/1-IV
-> Optimization of the mechanics and assembly
-> single-mask technology
-> 99x(22-45) cm²
-> 3072 readout channels
-> gap config. 3/1/2/1
-> No glue/no spacers

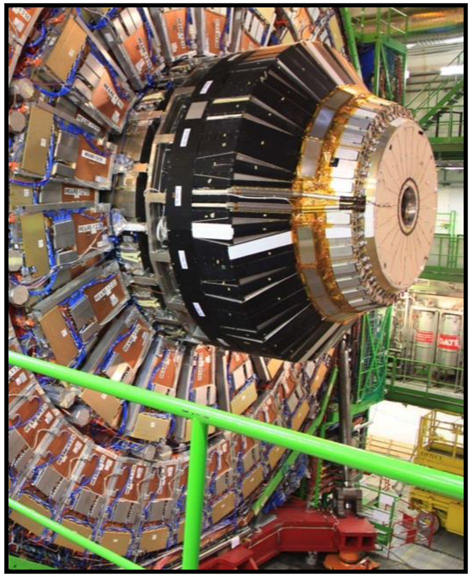
GE1/1-V
-> Optimization of the mechanics
-> stretching apparatus inside the gas volume
-> single-mask technology
-> 99x(22-45) cm²
-> 3072 readout channels
-> gap config. 3/1/2/1
-> No glue/no spacers

GE1/1-VI
-> Optimization of the mechanics
-> single-mask technology
-> design for long and short detectors
-> 99x(22-45) cm²
-> 120x(20-50) cm²
-> 3072 readout channels (new mapping)
-> gap config. 3/1/2/1
-> No glue/no

To Super CHAMBERs







2016 2017 2018 2019 2020

Slice test installation

Production phase & installation

GE1/1-VIII (LS2)

GE1/1-VII (slice test)
-> Optimization of the mechanics
-> Optimization of the grounding
Optimization of the HV distribution
-> single-mask technology
-> 99x(22-45) cm^2
-> 120x(20-50) cm^2
-> 3072 readout channels
-> gap config. 3/1/2/1

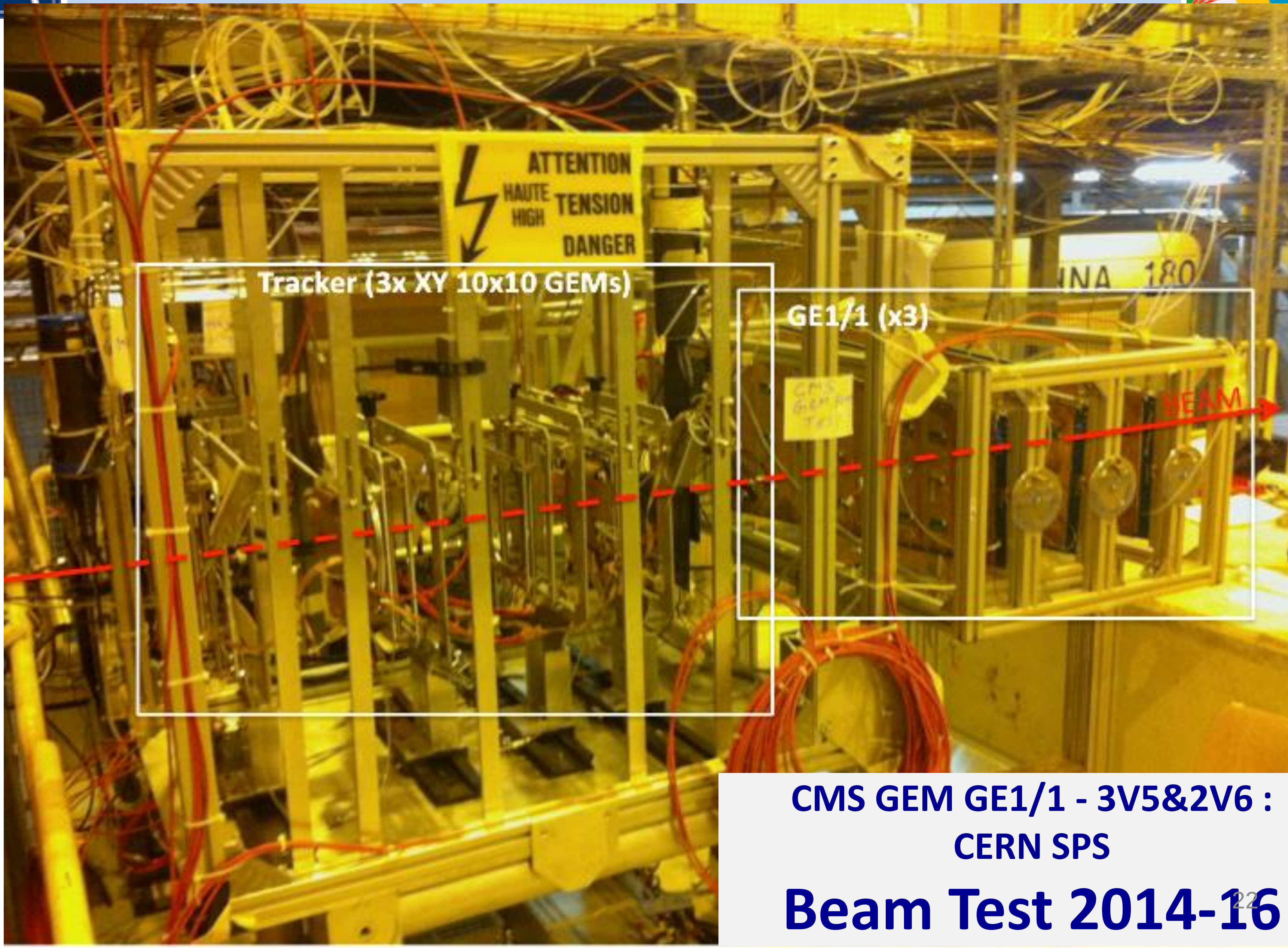
-> External (w.r.t. CERN) production sites certification and chamber components shipment
-> GE1/1 chamber assembly and certification
-> Super chamber mechanics optimization
-> First test with final

-> GE1/1 super chamber assembly and certification with final front-end electronics
-> First batch of Superchamber shipped to P5

- GE1/1 super chambers ready in P5 for installation
- Installation and cabling of all super chambers
- Commissioning in situ with cosmic muons
- Super chamber characterization in situ with cosmic muon
- First data with LHC beam



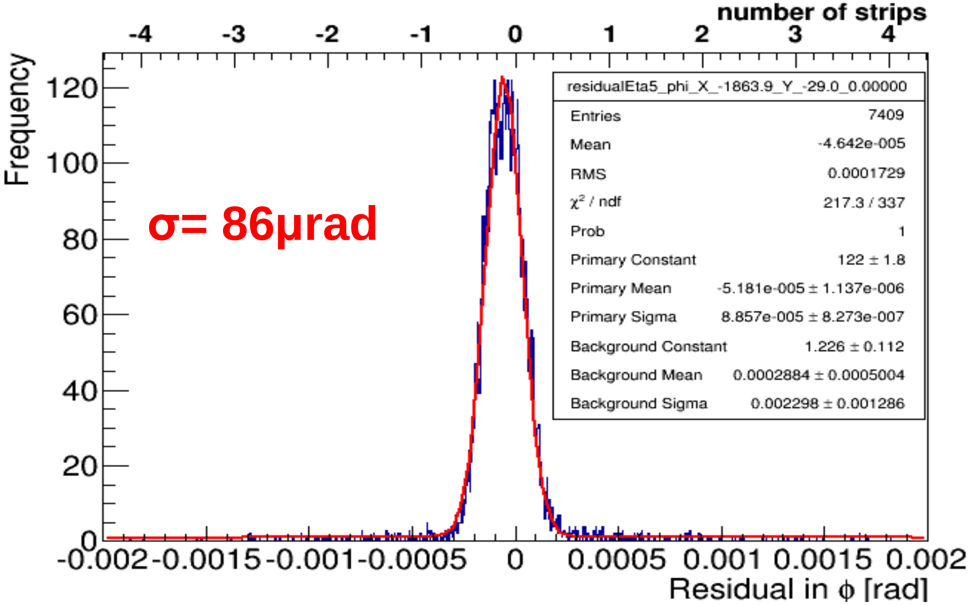
Beam Tests at CERN and Fermilab

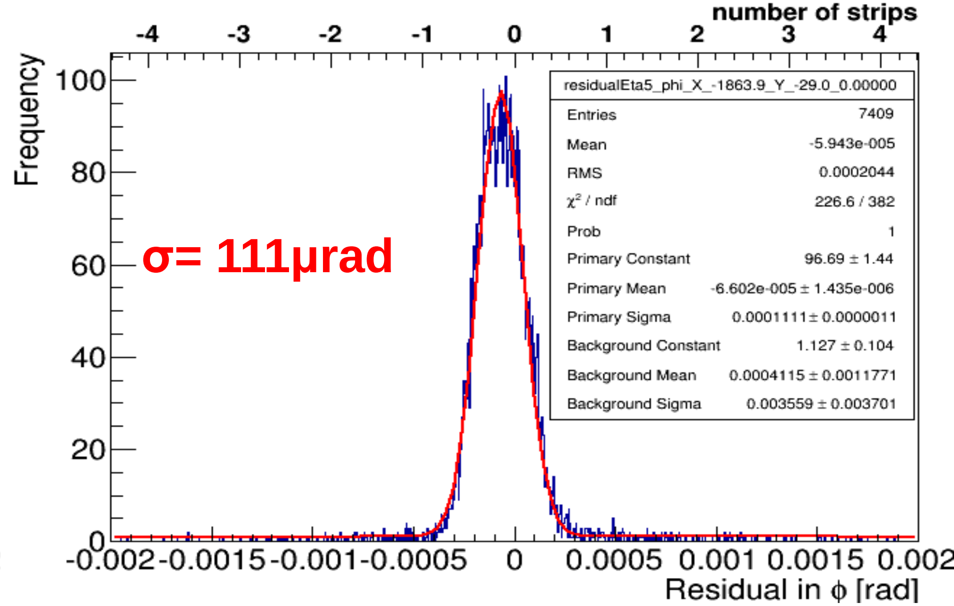


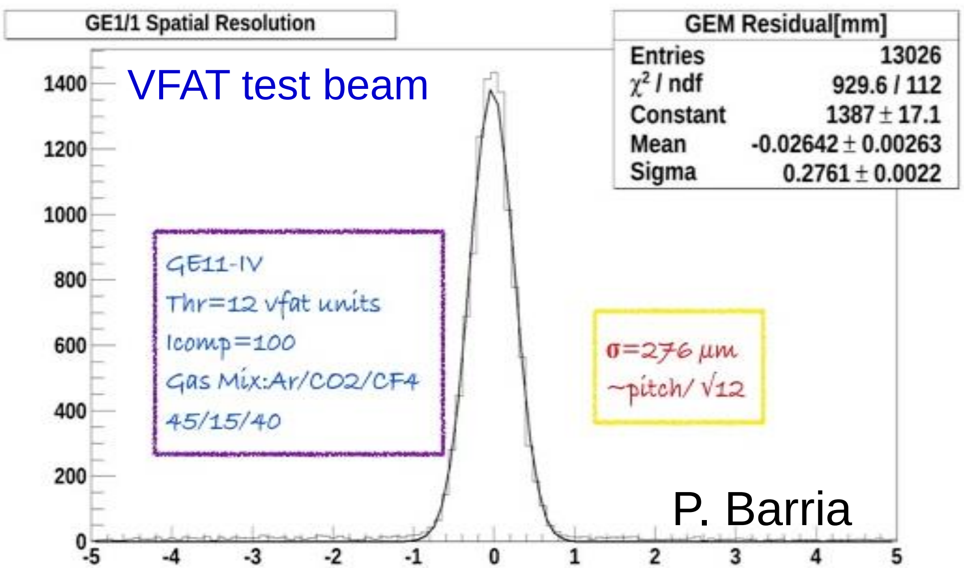
CMS GEM GE1/1 - 3V5&2V6 : CERN SPS

Beam Test 2014-16

Resolutions for CMS GEM detector

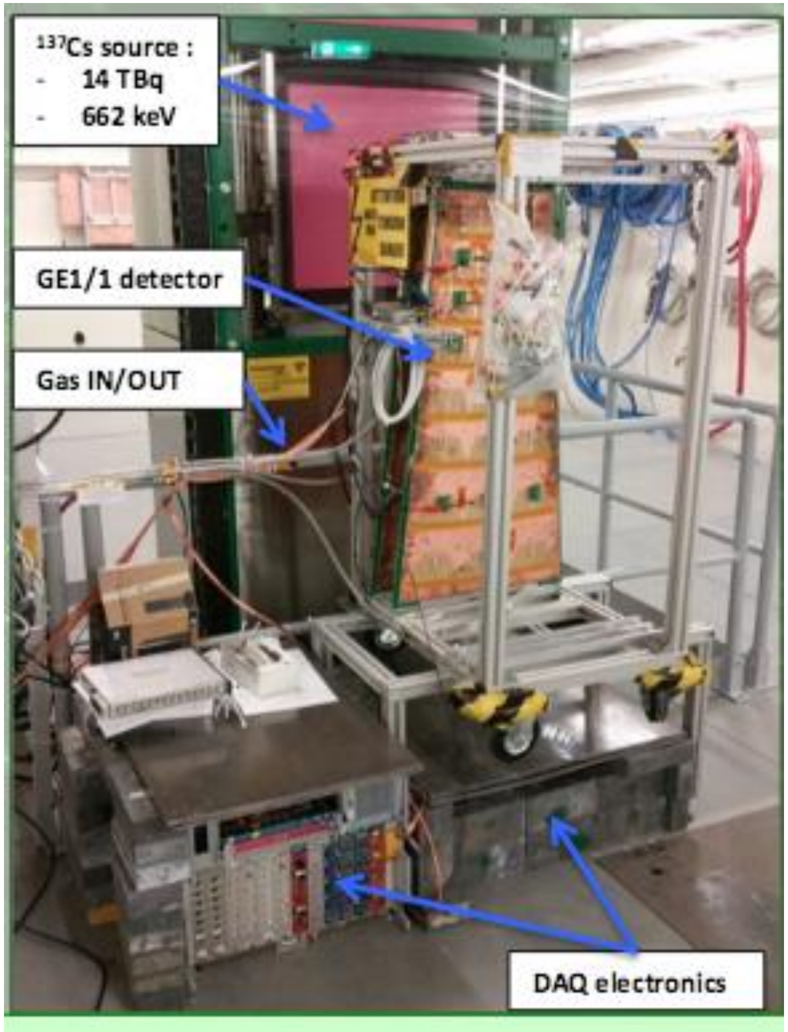






86 (111) μrad or 160 (207) μm

GEM GE1/1 Activity at the GIF++



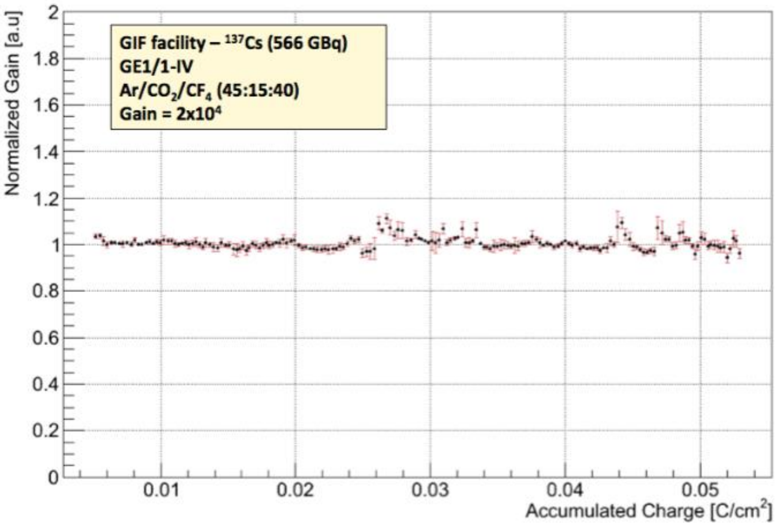


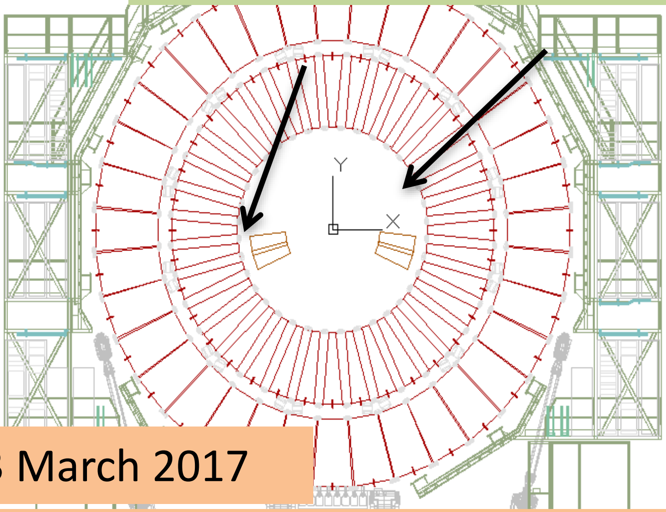
FIGURE 7.27: Normalized corrected gain of the GE1/1 detector operating in $Ar/CO_2/CF_4$ (45 : 15 : 40) as a function of the accumulated charge. The entire test represent 10 years of real operation in CMS.

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:

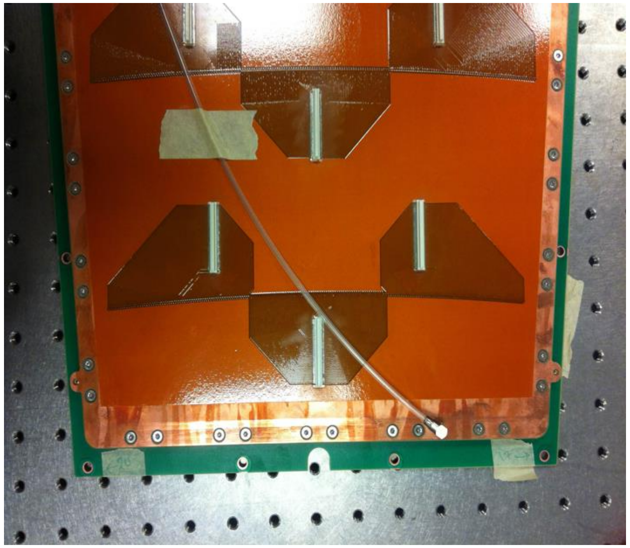
  - Back-end electronics installed and commissioned in advance of the installation of the FE electronics.

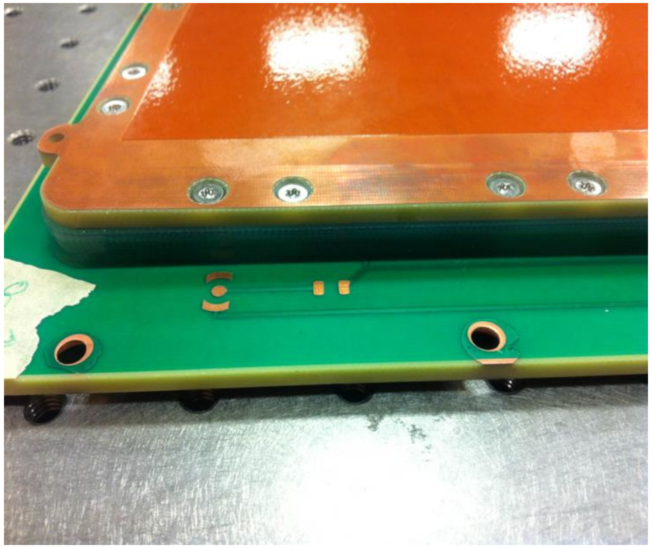
  - All components (Incl. detectors) will have been qualified beforehand at the TIF
- trigger commissioning and performance check “CSC-TF”
- background measurement.
- opportunity to cross-check with data what expected by simulation.

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

Slice Test chamber assembled

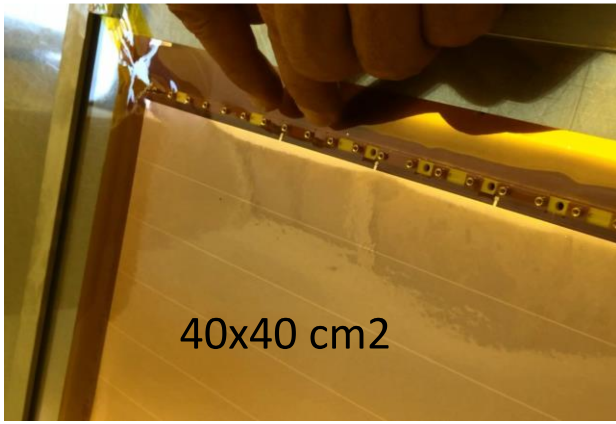


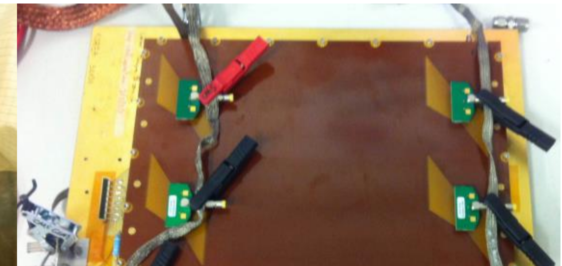


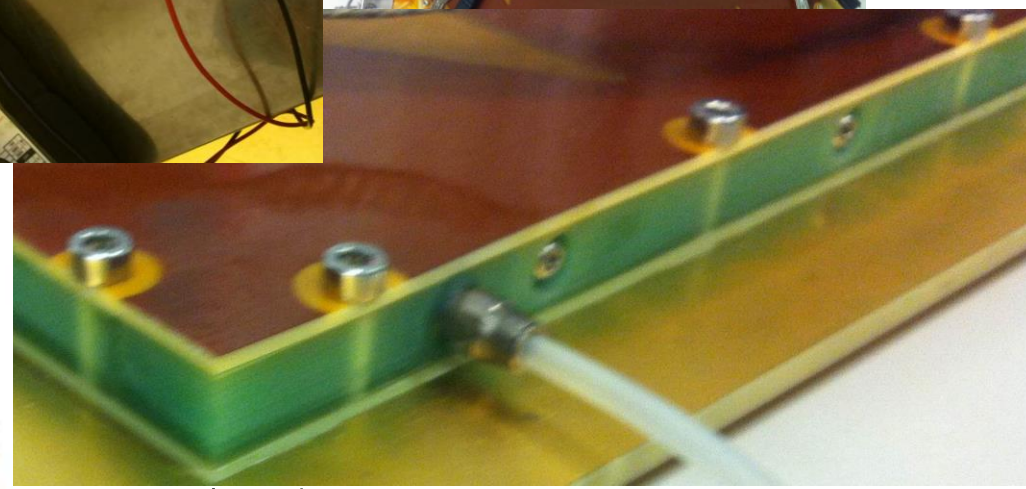
Toward the full production

Training and production site qualification

CMS: Industrialization of GEM Foils







Mecharonics: Korea M.Choi , I. Park

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

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

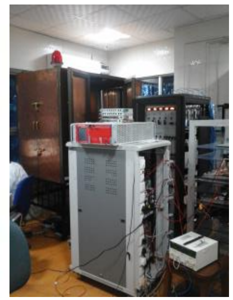
Micropack : India
L. Pant
P. Menon

A. Sharma 22092015

Production site readiness

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

Delhi University



(a) BARC

(b) INFN-Bari

Luigi Benussi
Brian Dorney
Michele Bianco
Many others !!

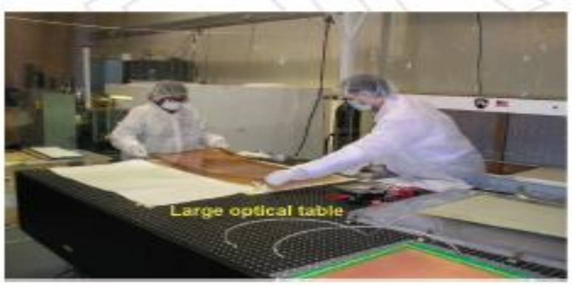
SINP

(c) CERN

(d) UGent

Site Visits
Scheduled

Panjab University



(e) FIT

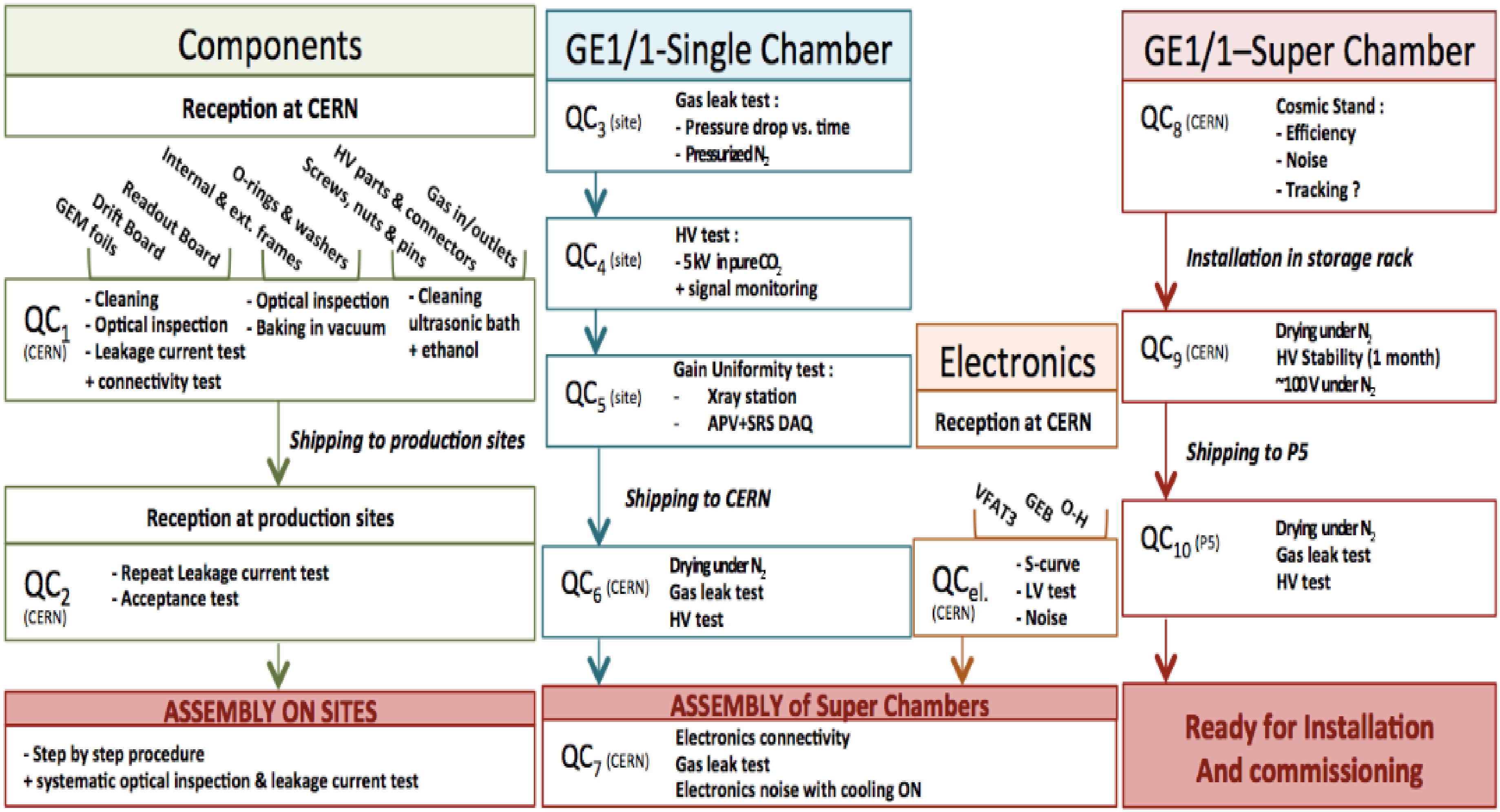
(f) INFN-LNF

Figure 5.2: Pictures from differents assembly site candidates.

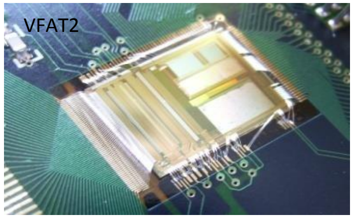
Chamber
Production Sites
QC Sites

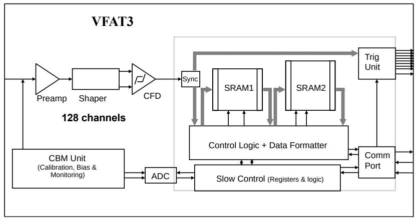
https://www.youtube.com/watch?v=Ssuqh5GAVZ4

QA and QC:


Components
Reception at CERN
GEM foils
Drift Board
Readout Board
Internal & ext. frames
O-rings & washers
Screws, nuts & pins
HV parts & connectors
Gas in/outlets
QC1 (CERN)
- Cleaning
- Optical inspection
- Leakage current test
+ connectivity test
- Optical inspection
- Baking in vacuum
- Cleaning
ultrasonic bath
+ ethanol
Shipping to production sites
Reception at production sites
QC2 (CERN)
- Repeat Leakage current test
- Acceptance test
ASSEMBLY ON SITES
- Step by step procedure
+ systematic optical inspection & leakage current test
GE1/1-Single Chamber
QC3 (site)
Gas leak test :
- Pressure drop vs. time
- Pressurized N2
QC4 (site)
HV test :
- 5 kV in pure CO2
+ signal monitoring
QC5 (site)
Gain Uniformity test :
- Xray station
- APV+SRS DAQ
Shipping to CERN
QC6 (CERN)
Drying under N2
Gas leak test
HV test
Electronics
Reception at CERN
VFAT3
GEB
O-H
QCel. (CERN)
- S-curve
- LV test
- Noise
ASSEMBLY of Super Chambers
QC7 (CERN)
Electronics connectivity
Gas leak test
Electronics noise with cooling ON
GE1/1–Super Chamber
QC8 (CERN)
Cosmic Stand :
- Efficiency
- Noise
- Tracking ?
Installation in storage rack
QC9 (CERN)
Drying under N2
HV Stability (1 month)
~100V under N2
Shipping to P5
QC10 (P5)
Drying under N2
Gas leak test
HV test
Ready for Installation
And commissioning

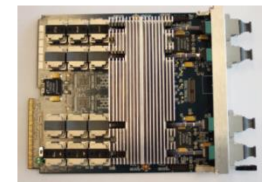
CMS GE1/1 Electronics System



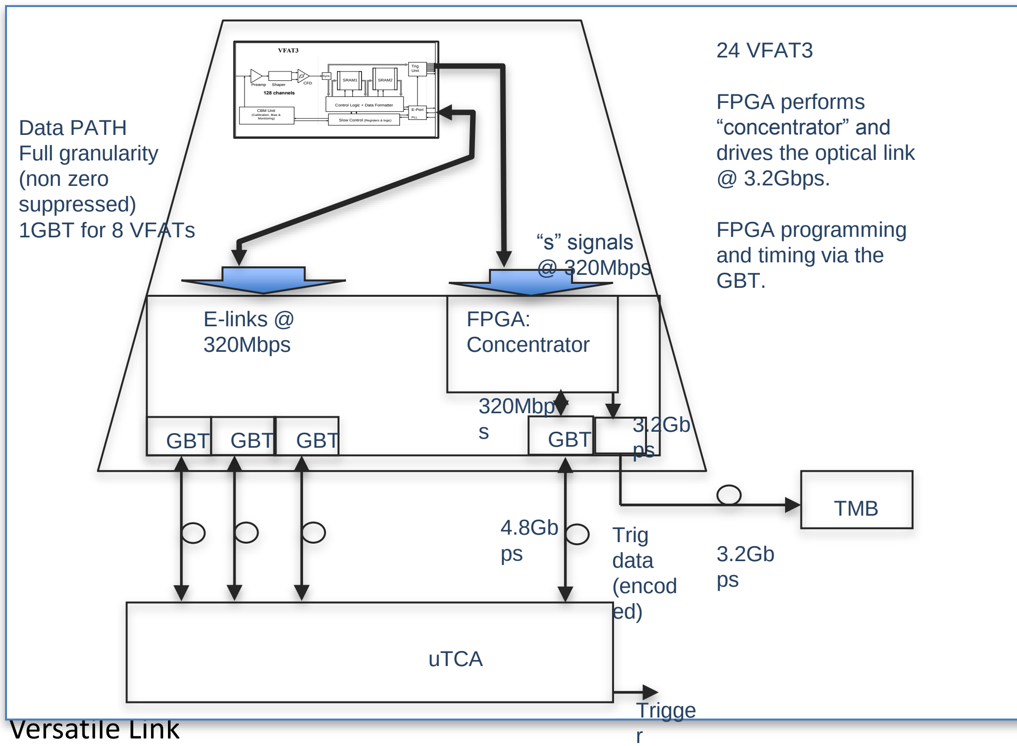


VFAT3 front-end ASIC development

MP7



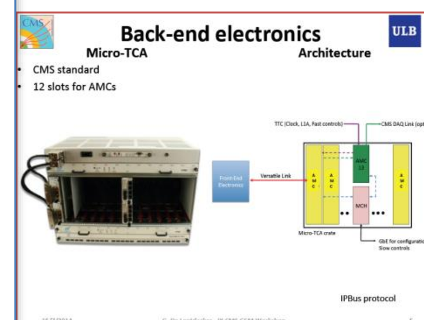
GEM Electronic Board (GEB)



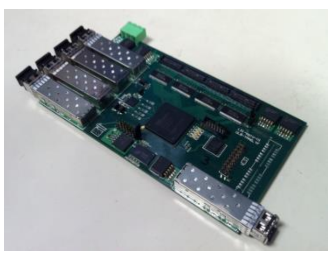
Versatile Link

µTCA

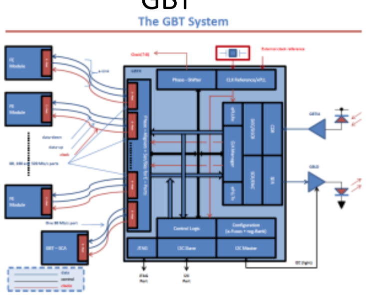
AMC13, MCH

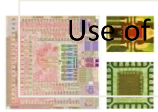


Opto-Hybrid (OH)



GBT



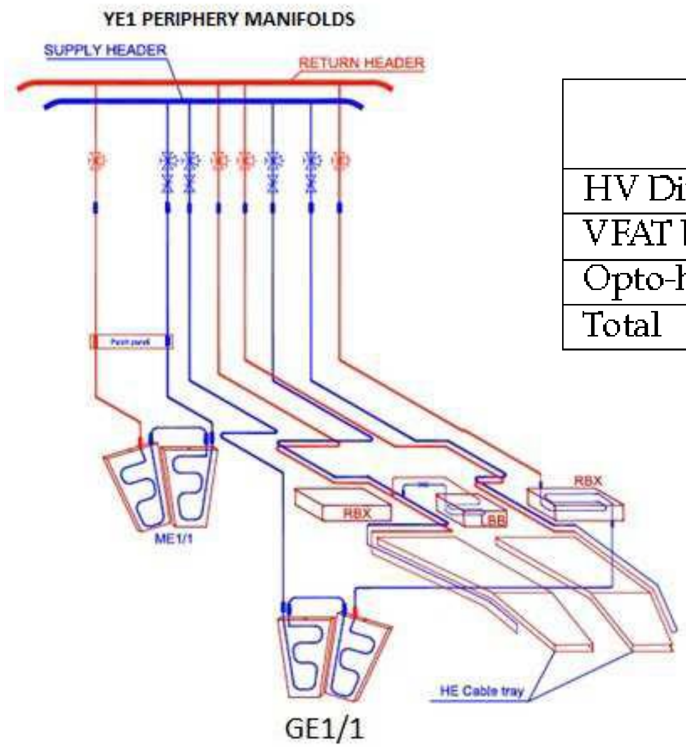


Use of many common developments such as GBT, Versatile Link, µTCA backend

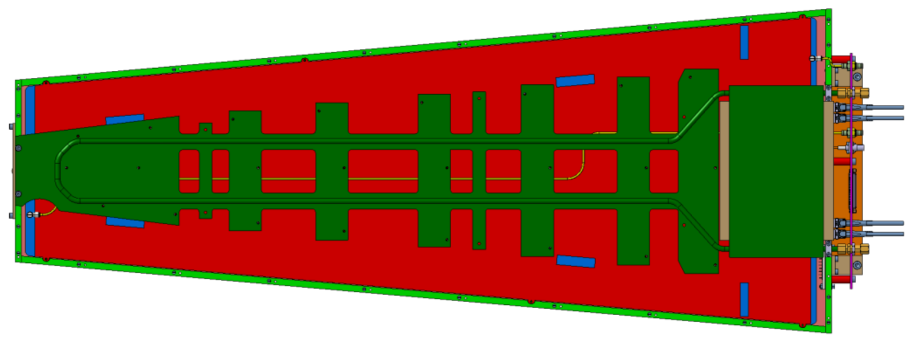
The control, readout and power to/from the VFAT3 hybrid are delivered via electrical signals (E-links) running through the GEB to the opto-hybrid.

904: GE1/1 : Integration

Power Budget and Cooling



	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

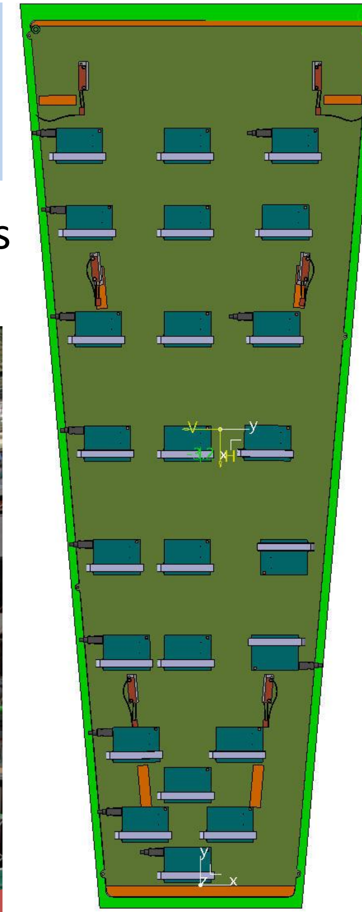


The GE1/1 Super-chamber will take cooling from the RBX loops. It will give an negligible impact to the cooling system in the YE1

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

904: GE1/1 : Integration

Alignment sensors



GE1/1 inside
The cooling box

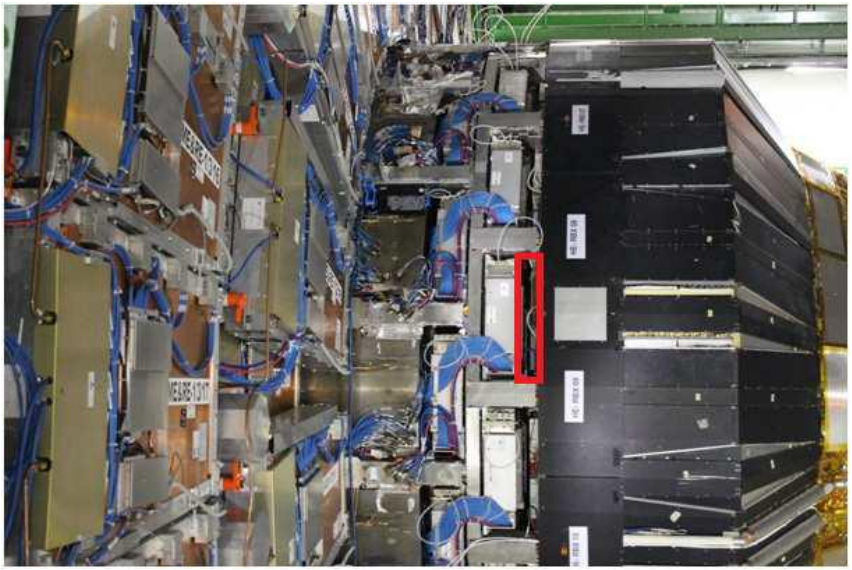
Andrey Marinov

Zoltan Zillasi

ME1/1

GE1/1 Setup for VFAT and GEB tests.

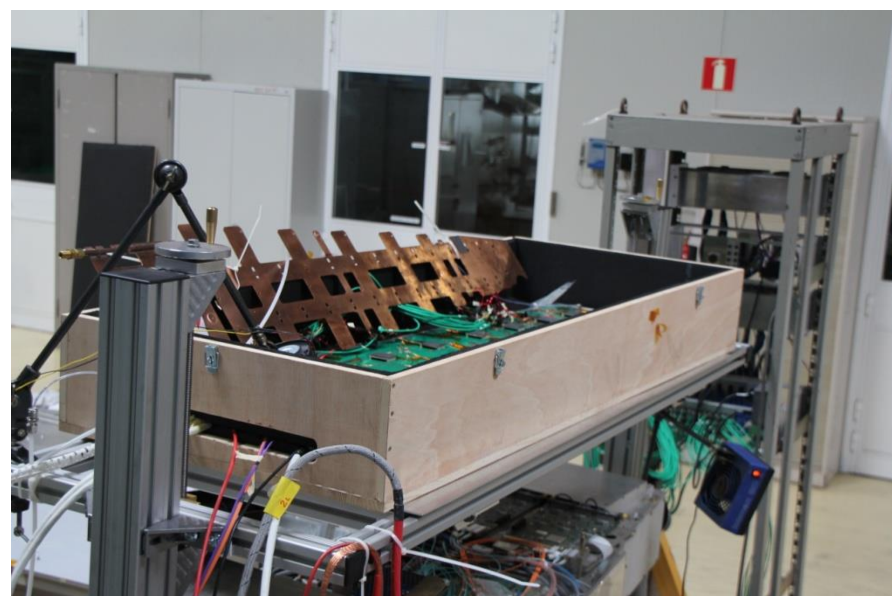
Cooling Tests Ongoing



In CMS

• The physical space of the GE1/1 Installation slots in YE1 is very compact.

• No air flow or convection can be used for evacuating the heating power of the detector and the electronics.



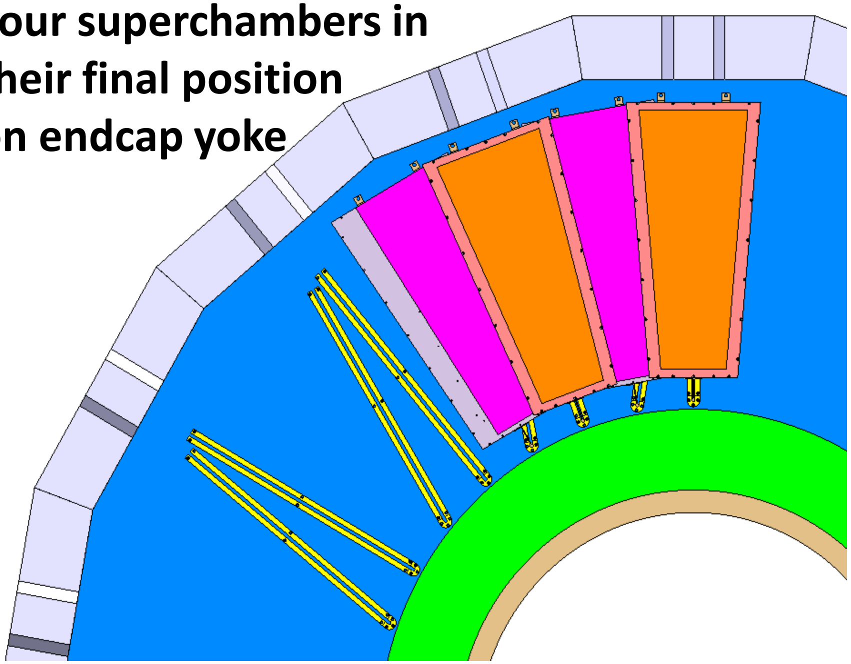
In b 904

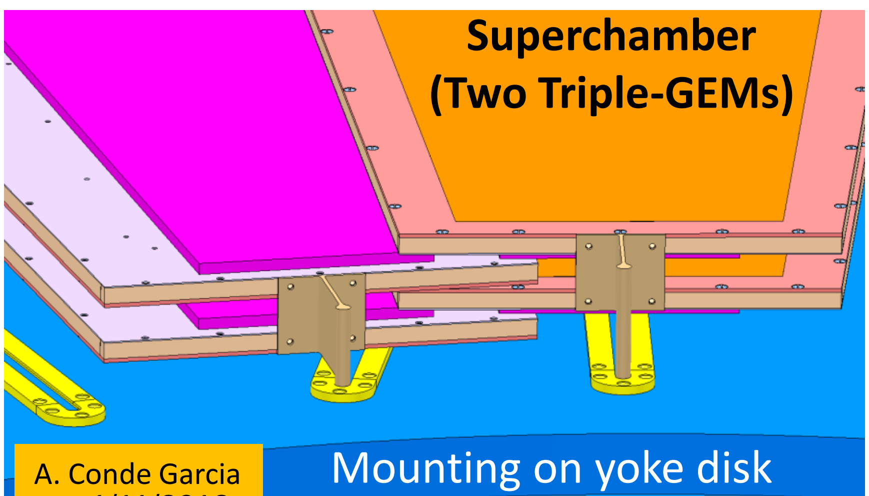
The GE1/1 chamber is placed in wooden box with cover to stop any airflow. It should simulate the same ambient conditions as it will be in CMS

The flow of the water trough the cooling pipe will be the same as in CMS – 2liters per minute.

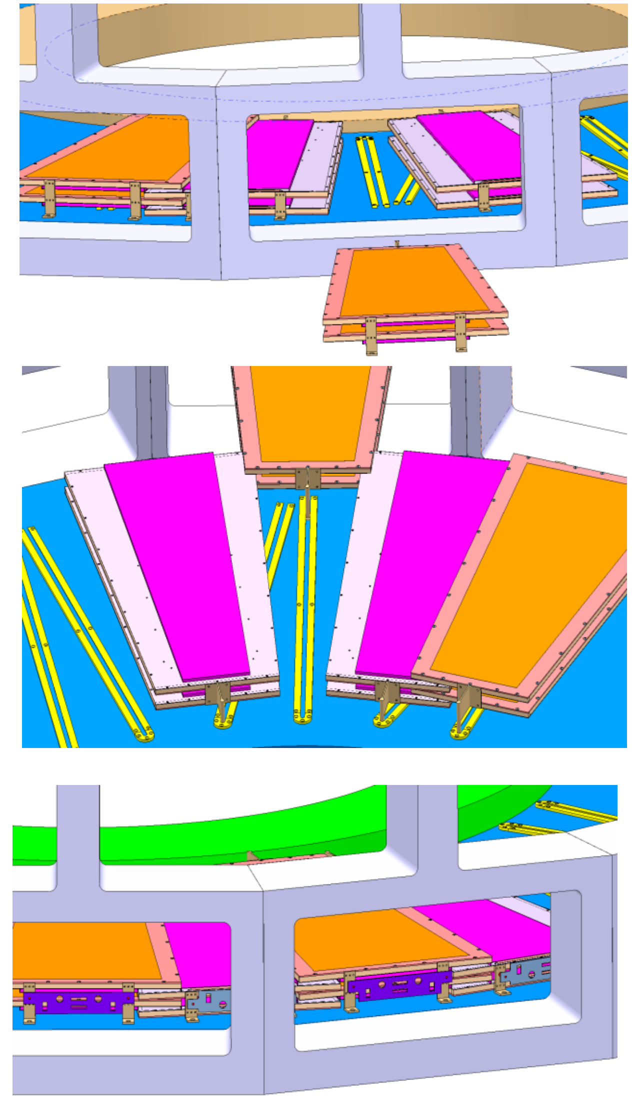
Integration into CMS

Four superchambers in their final position on endcap yoke

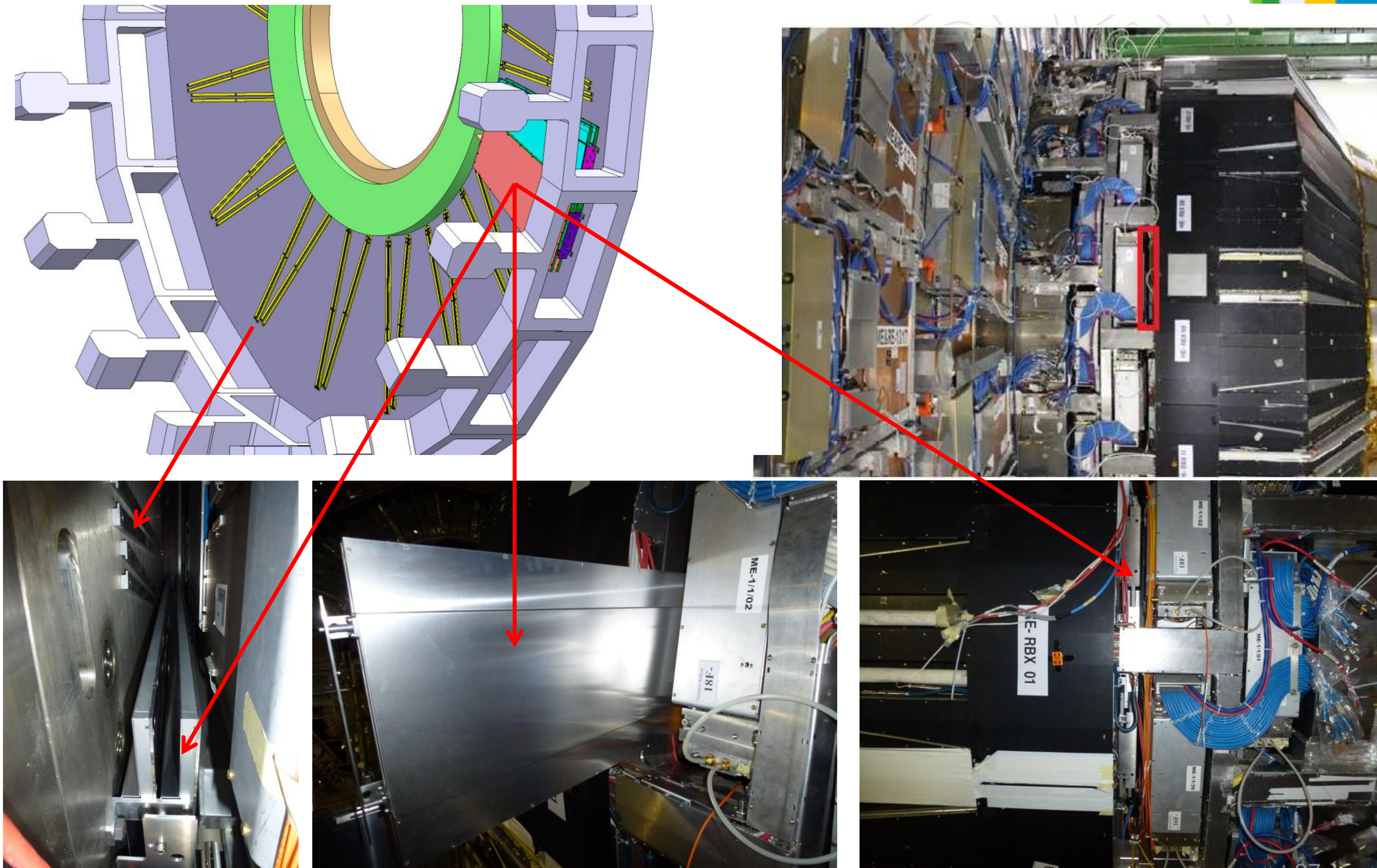




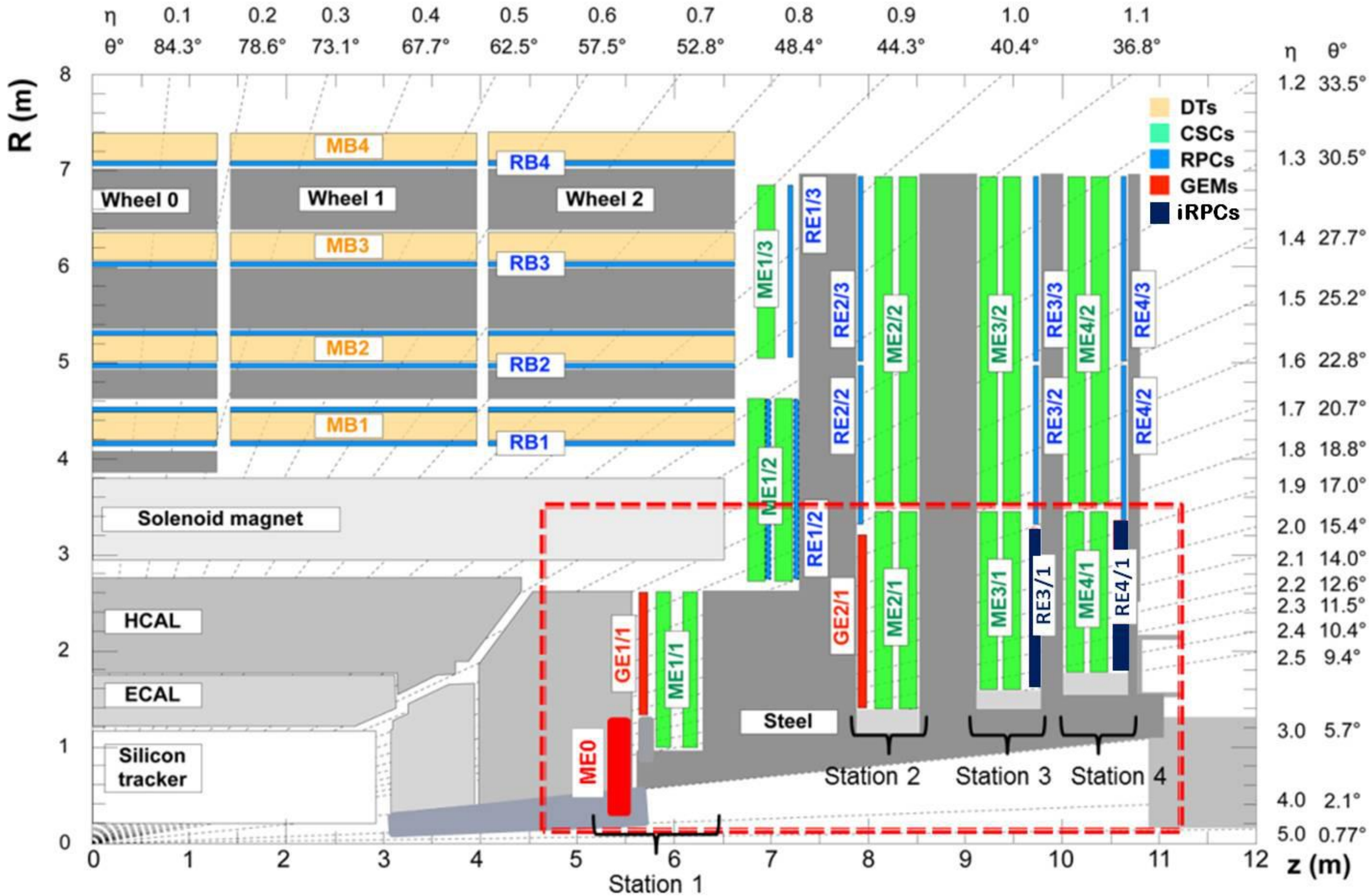
Installation sequence:



Trial Installation in CMS



High η region upgrade with MPGD for Phase 2

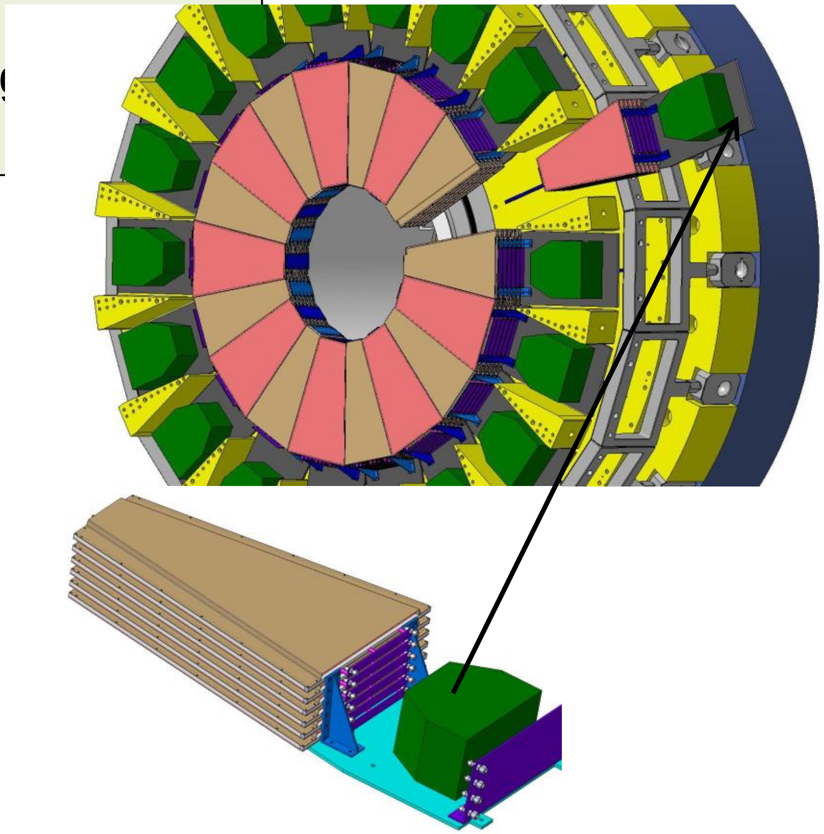


- Objectives:
  - Sustain triggering at current trigger thresholds
  - Increase offline muon identification coverage
  - Maintain existing envelope by mitigating aging effects

ME0 requirements and technical choices

Detector requirement:

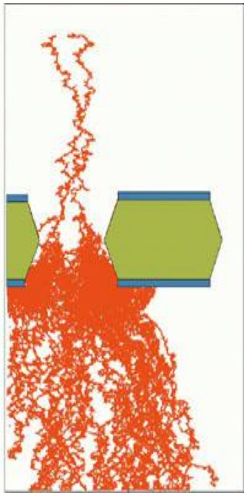
- Multilayer structures
- High rate capability O(MHz/cm^2)
- time resolution for triggering
- No green house gases
- Good spatial resolution O(100 μm) for tracking triggering



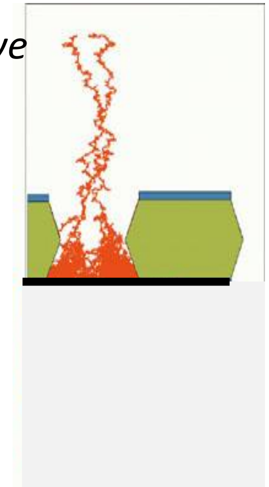
- Baseline : Six layers of triple-GEM
- Option : Fast Timing Micropattern gas detector (FTM)

New generation of MPGD:FTM

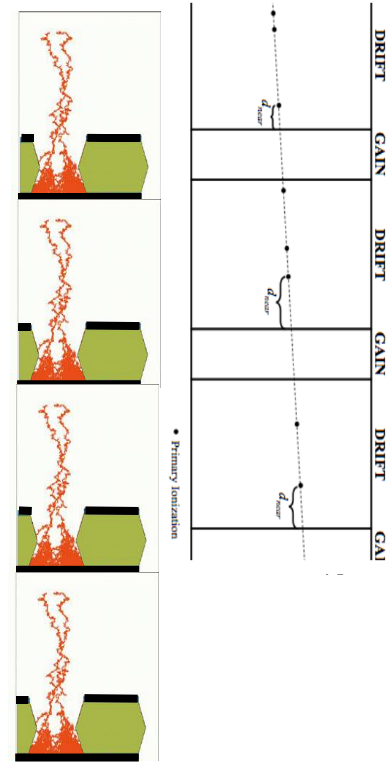
Standard MPGD



Resistive MPGD



Multi-layer Resistive MPGD

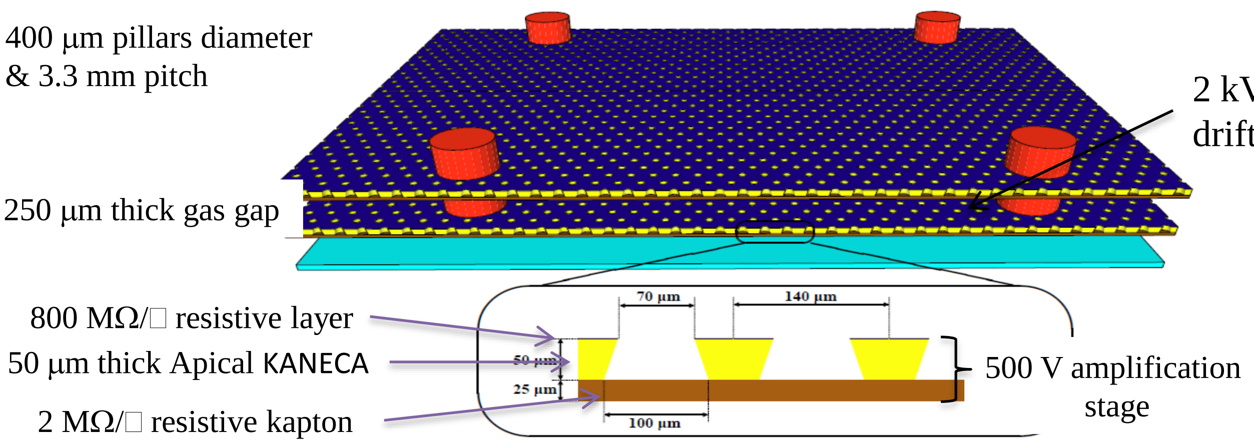


The overall structure is **transparent** to the signal

Signal can be extracted in each amplification stage

Structure of the FTM detector

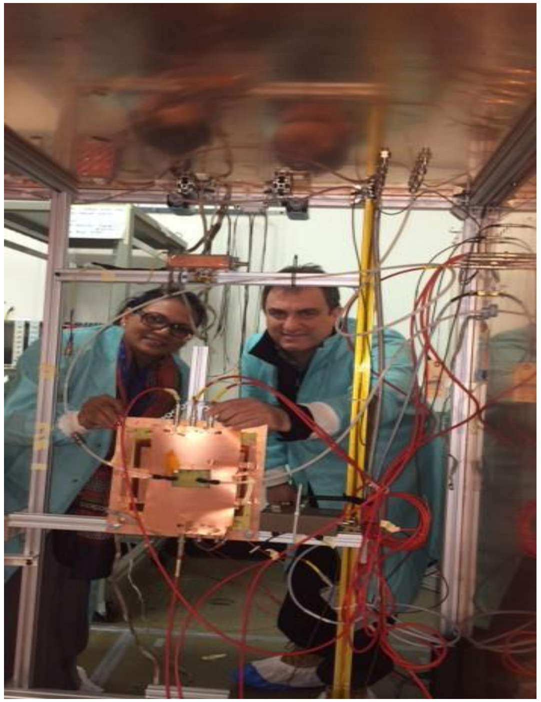
Detector Layout & Parameters



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

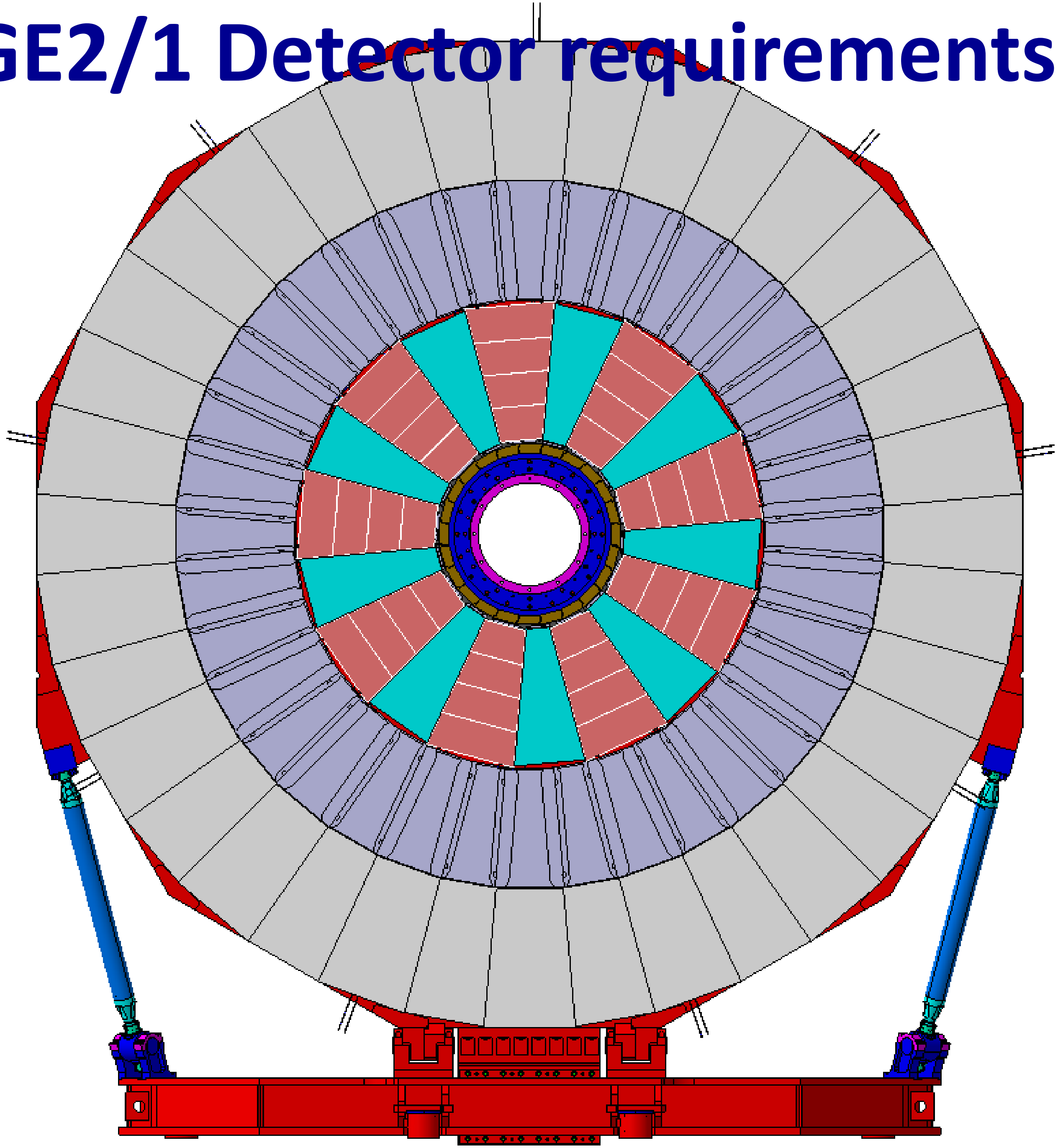
Fullly resistive amplification stage:

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



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

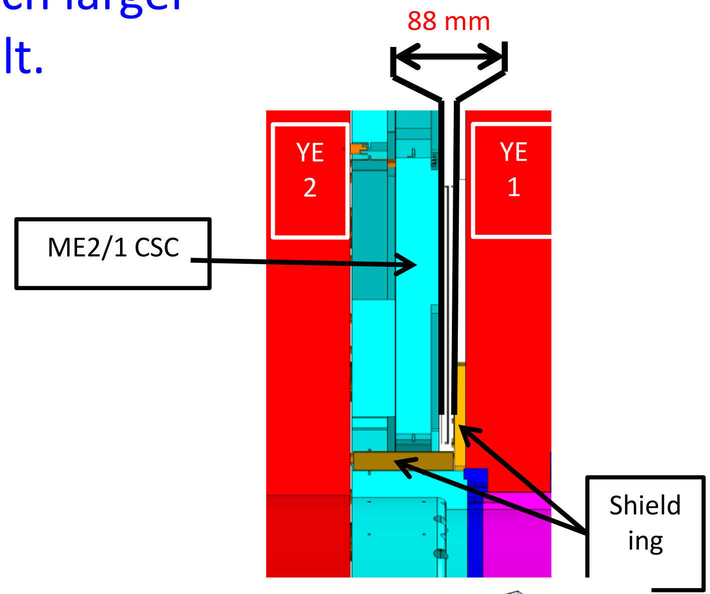
GE2/1 Detector requirements



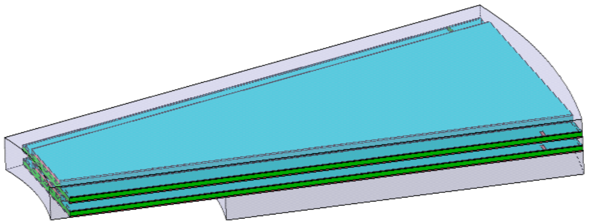
GE2/1 Detector requirements

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)



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




CMS
GEM detector
for disk 2
GE21

GEM Database Current Activities - People

Vilnius University:

- Valdas Rapsevicius: DB, DB loader, WBM framework (xfer from online to offline DB), etc.
- Andrius Juodagalvis, Vytautas Mickus: Offline DB & interfacing with DPG

ENHEP (Egypt)

- Ola Aboamer:DB GUI, DB, & WBM interface to DB
- Safaa Salem: WBM interface to DB

Delhi University

- Muhammad Hasib: DB & interface to detector construction

Texas A&M University

- Alfredo Castaneda: DB & DAQ interface

Fermilab

- Umesh Joshi: DB

Detector & DAQ Experts:

- Brian Dorney, Michele Bianco, Jeremie Merlin, Jared Sturdy, etc.

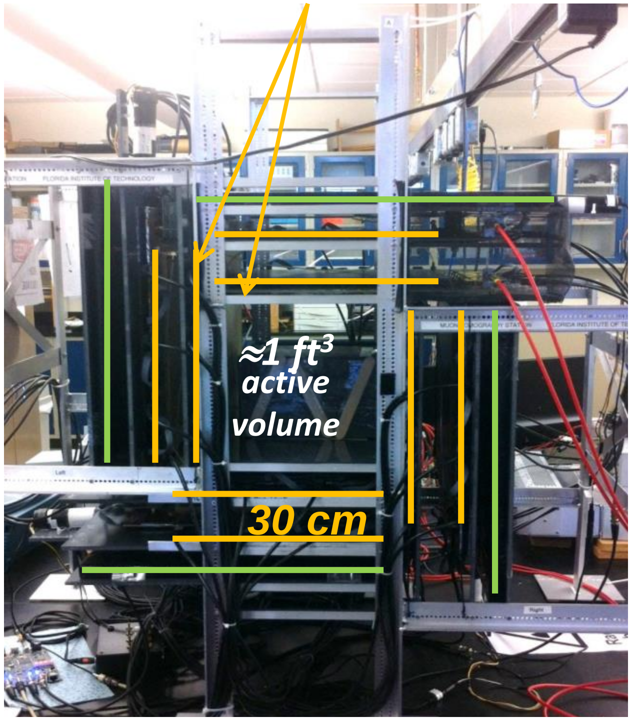
GEM DB Near Term Goals

- Store all GEM construction data of chambers for the Slice Test in DB and access & display all QC test data using WBM
  - Status
    - The DB GUI has been used to store & "build" detectors in the DB
    - All 6 super chambers have been constructed
    - In the process of storing QC data & publish using WBM interface
- Use DB to enable the DAQ system to configure the Slice Test detector using GEM DB
  - Status: The DAQ group is working on using the DB to configure the system for the cosmic test stand and Slice Test
- GEM offline conditions DB & WBM interface (developed by Valdas & his group)
  - Goal: Have this system working for the Slice Test
- Use the GEM Online DB (inP5) to store & publish all construction data from the various stations around the world
  - Goal: enable physicists in all test stations around the world to automatically synchronize & store construction & QC data in the GEM online DB in P5

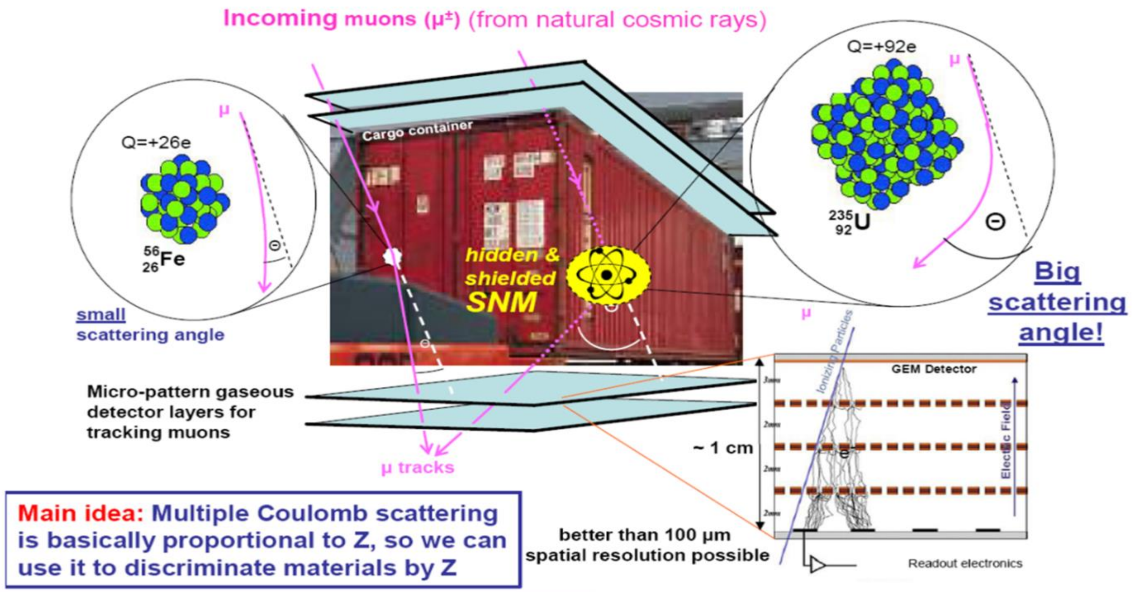
Muon Tomography for Homeland Security

http://www.economist.com/node/21552169

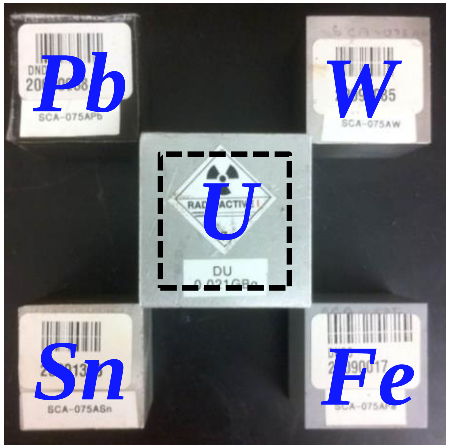
Triple GEM for Muon Tomography

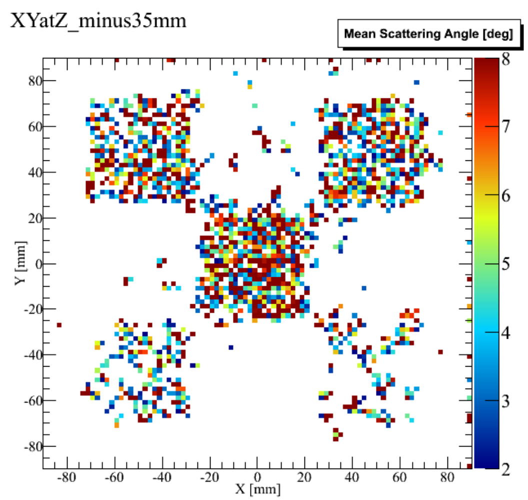


Florida Tech Cubic-Foot MT Prototype



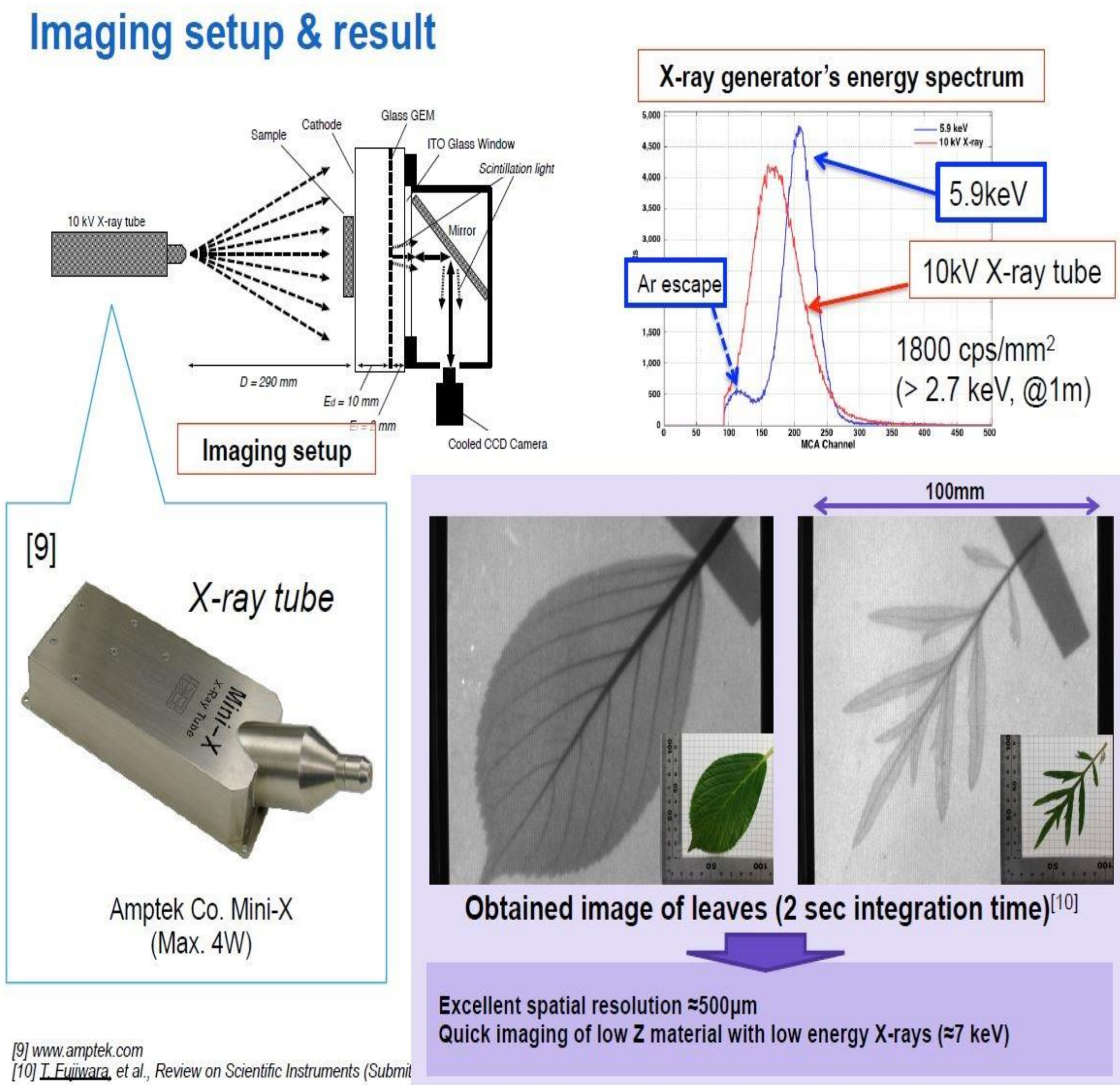
Principle of Muon Tomography (MT) based on Cosmic Ray Muons: Five targets with various Z



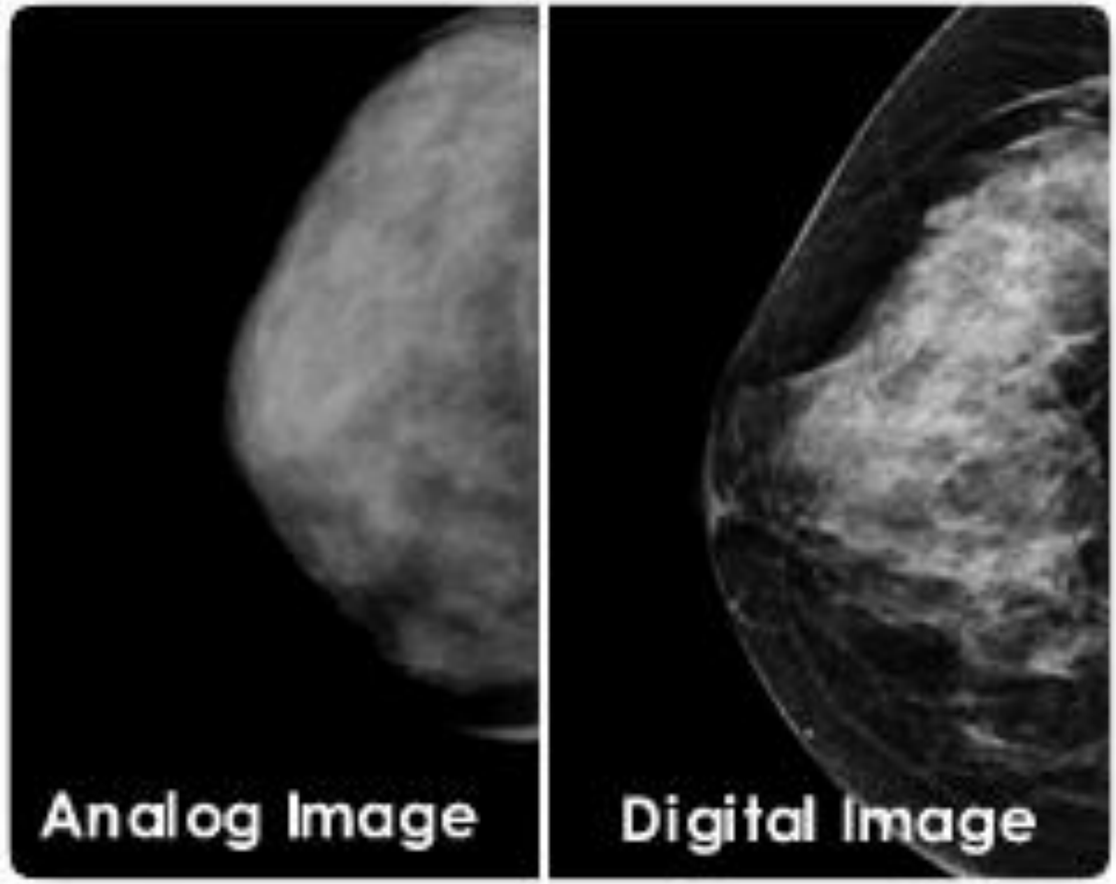


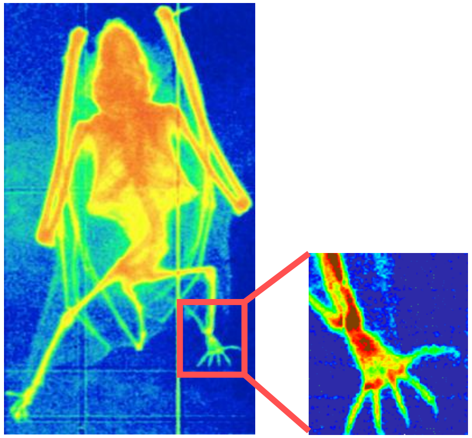
Luggage inspection, food inspection, defect scanners

- GEM combined with a scintillation gas (CF_4) is used.
- Very good spatial resolution in the method, shown on the right



Improving Digital Imaging





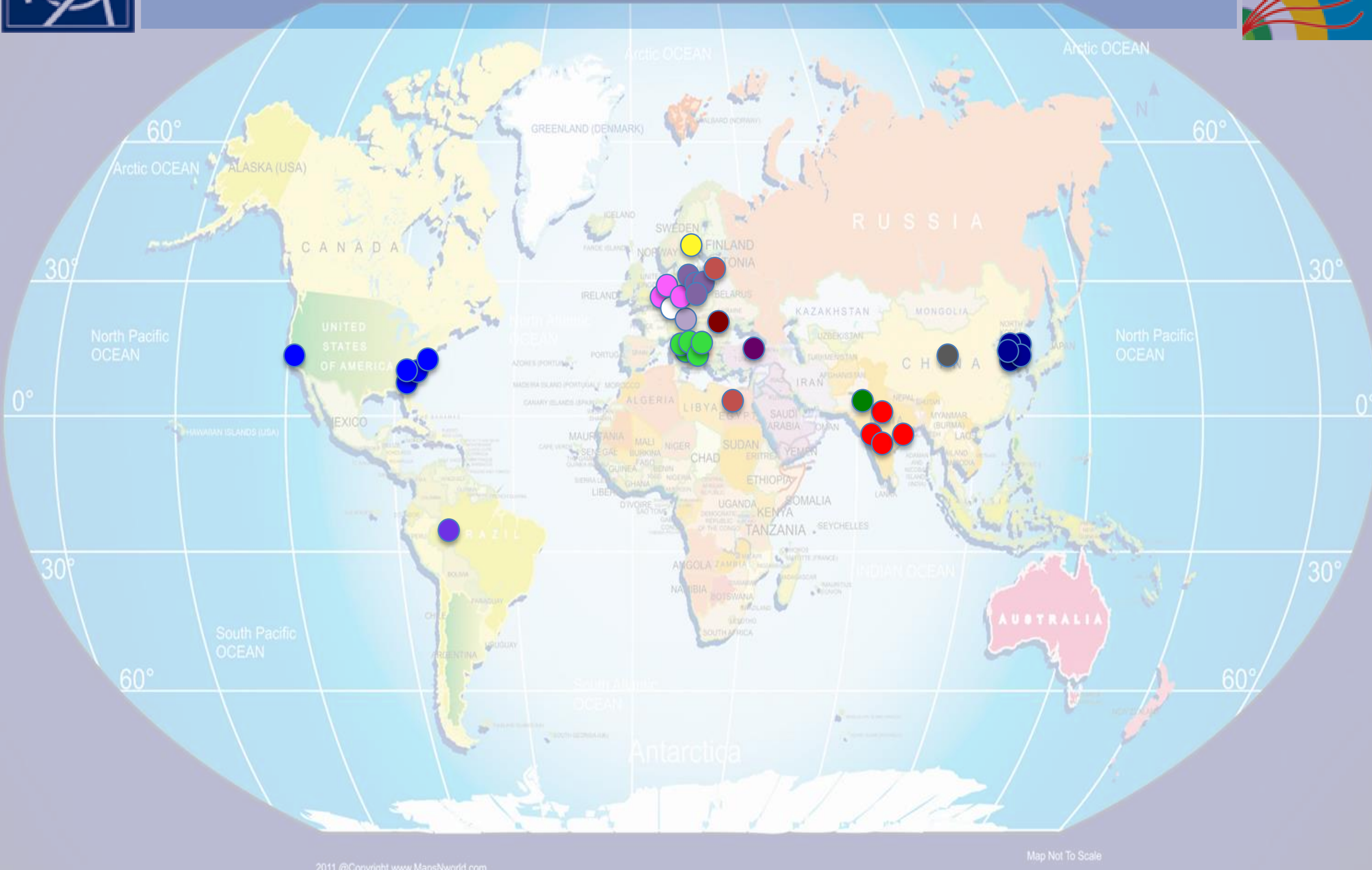
Radiography of a bat, recorded with a GEM detector

GEM Countries - 16

2011 @Copyright www.MapsNworld.com

Map Not To Scale

GEM Institutes ~ 40




A lot of students !!

Summary

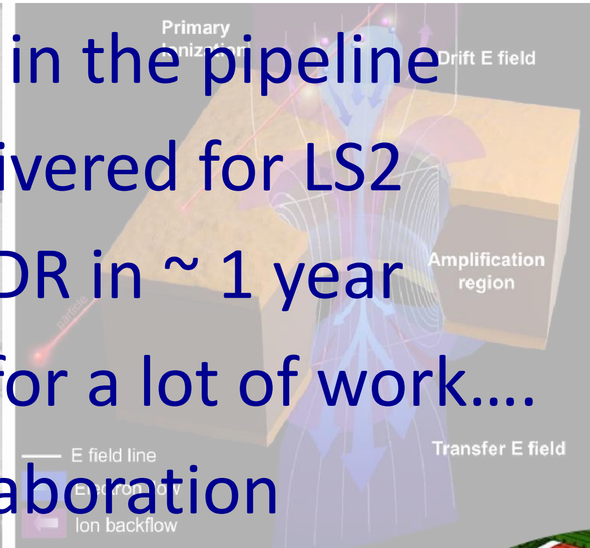
Several projects in the pipeline

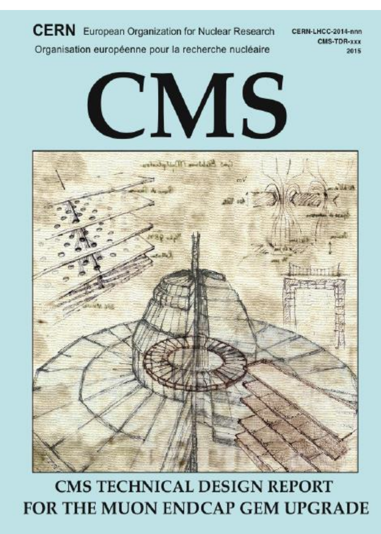
GE11 to be delivered for LS2

GE21 & ME0 TDR in ~ 1 year

Promising outlook for a lot of work….

By the collaboration




CERN European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire
CERN-LHCC-2015-nnn
CMS-TDR-xxx
2015

CMS

CMS TECHNICAL DESIGN REPORT
FOR THE MUON ENDCAP GEM UPGRADE