Status of CMS GEM Projects

Archana Sharma
CERN

RD 51 Mini week
Dec 7 - 9, 2015

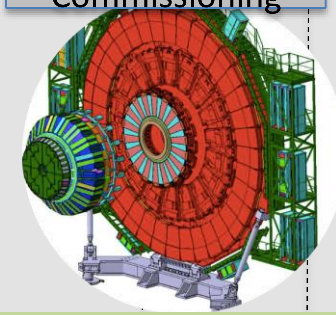
Phase 2 Scope and Schedule Muons : GEM

LS2 | LS3

2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025

GE11 Installation & Commissioning

GE1/1 : 10°
Triple-GEM LS2



TDR

Eng. and Preprod.

Production/Assembly

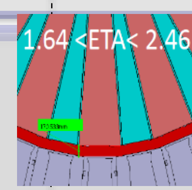
40º Slice in YETS

10.1.2017 – 31.3 March 2017

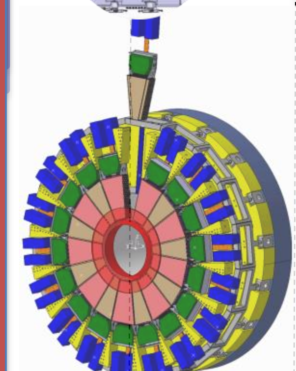
Testing & Preparation in UXC

Short SC
eta=1,61-2.18
Long SC
eta=1.55-2.18

Week 15 onwards – until Ready for beam minus 30 weeks)



GE21 ME0 Installation & Commissioning



GEM21

Design and Prototyping

MUON TDR

Prototyping

Engineering and Preproduction

EDR

GE2/1 Production

Testing and preparation

ME0

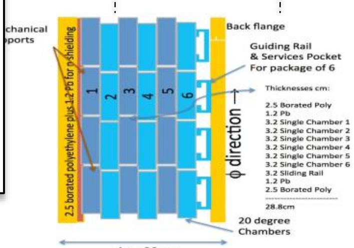
Design and Prototyping

Prototyping

Engineering and Preproduction

EDR

ME0 Production



New technologies are being investigated.

- back-to-back triple GEM permitting six layers of detection, as a backing calorimeter for muon tagging
- Second possibility is based on newly patented devices – fast timing micropattern (FTM) detectors https://cds.cern.ch/record/2000150

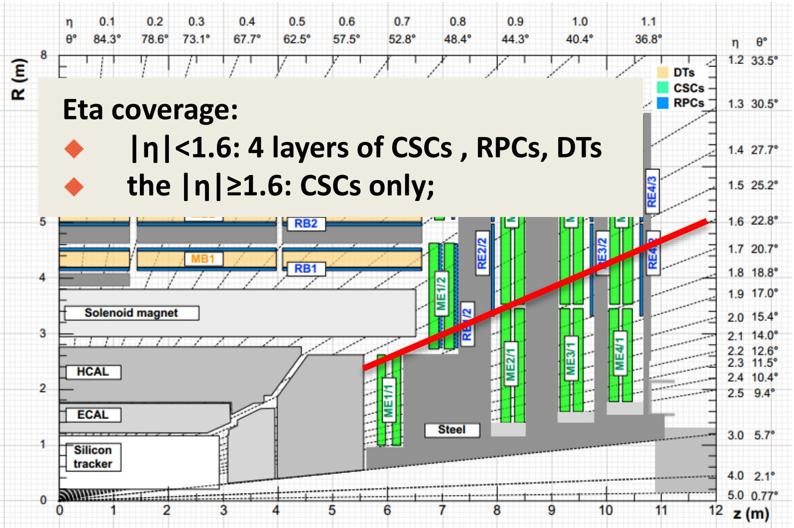
CMS: Forward muon system challenges

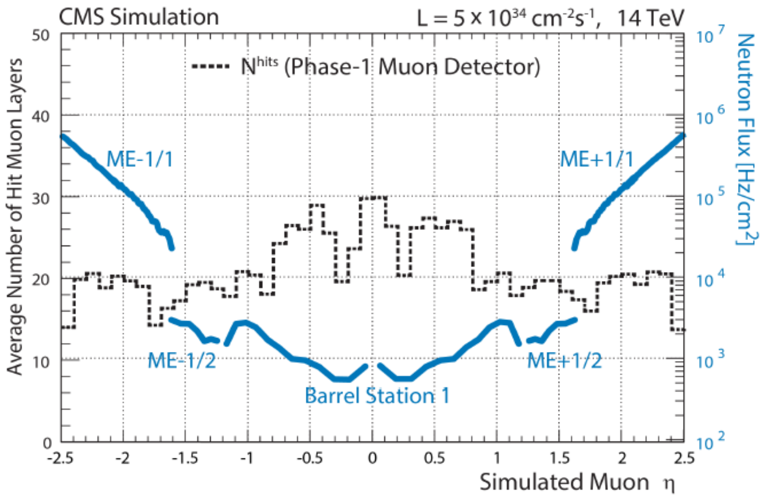
The forward region |η|≥1.6 is very challenging

- **Redundancy**: the highest rates in the system vs fewest muon layers
- **Rate** : in 100's of kHz/cm^2 and higher towards higher eta and worse momentum resolution

  → already a challenge post LS2.

- **Longevity:** Accumulated charge ~C/cm after many years of LHC operation
- **Electronics:** High occupancy/rate and latency increases exceed capabilities of the existing electronics



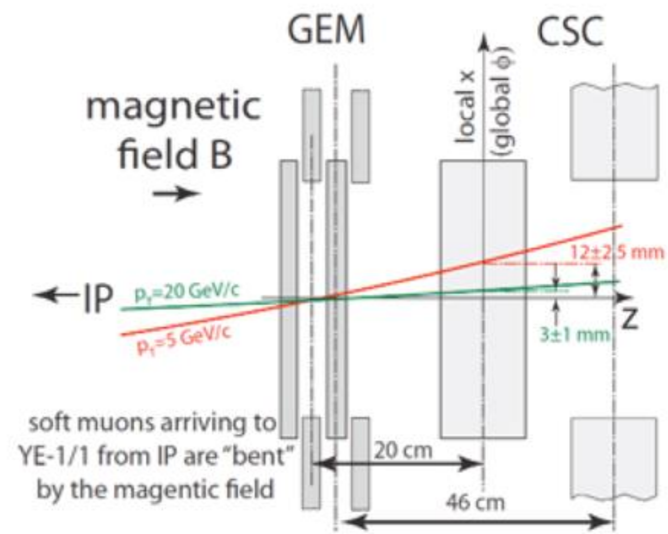


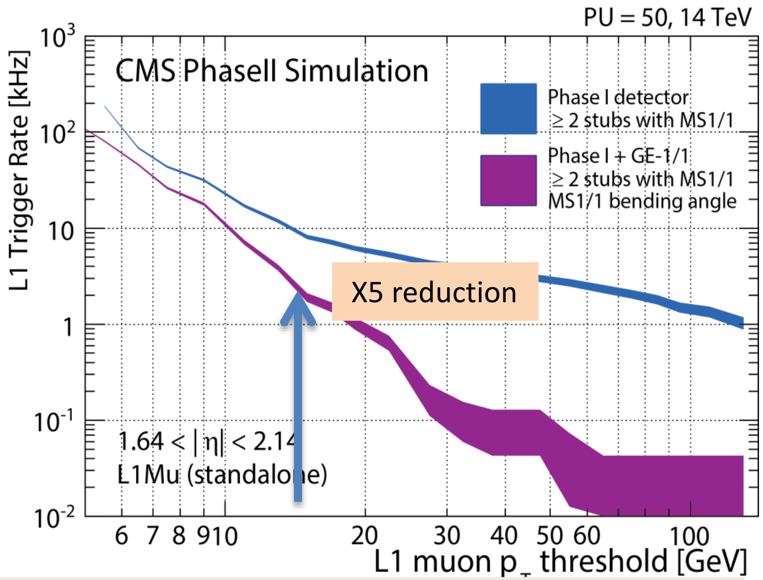
Performance: forward Muon Trigger

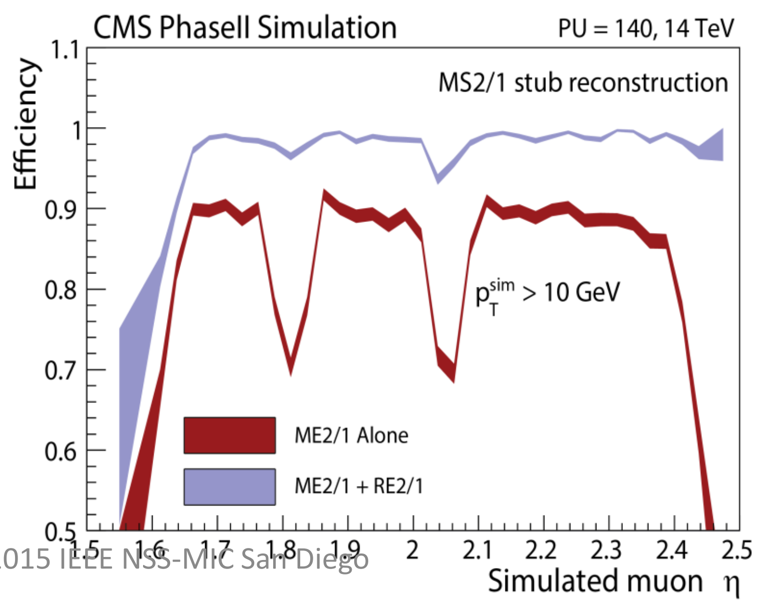
Forward trigger for |η|>1.6 relies entirely on the CSC system:

Adding detector in front of CSC to measure the muon bending angle in magnetic field in the each station, keeps the rate under control and adds redundancy:
Large improvement from GE1/1 and GE2/1 stations

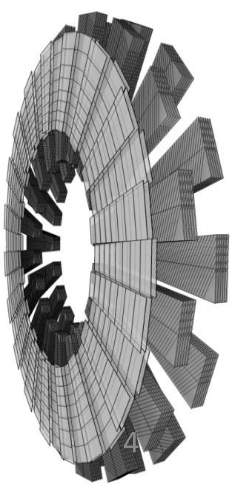
✓ Requirement precise Δϕ meas.→spatial resolution







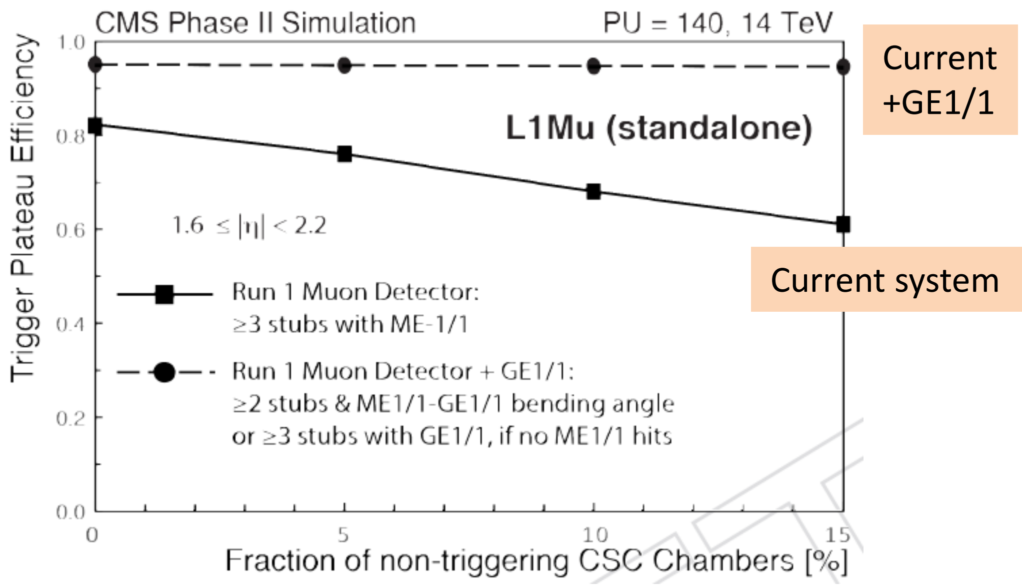
Lever arm – trigger

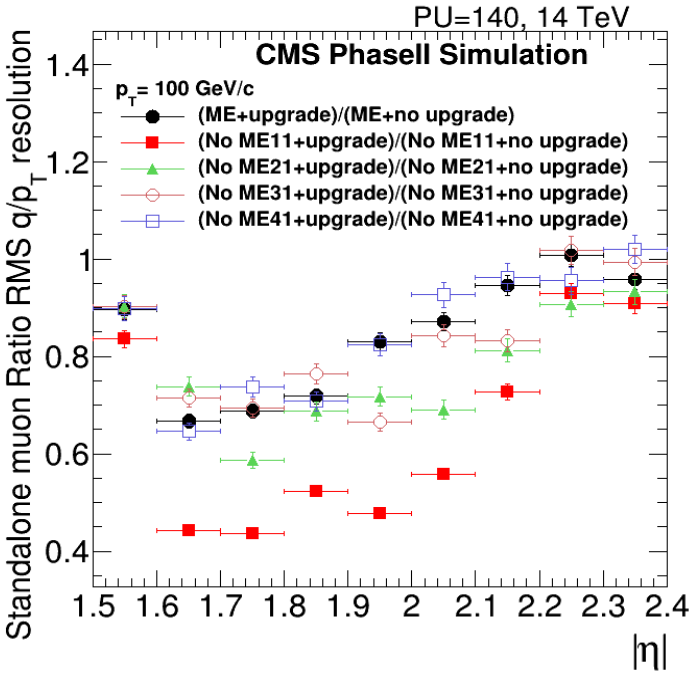


maintain 15 GeV online threshold, keep < 5 kHz rate, high efficiency

Longevity vs redundancy

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



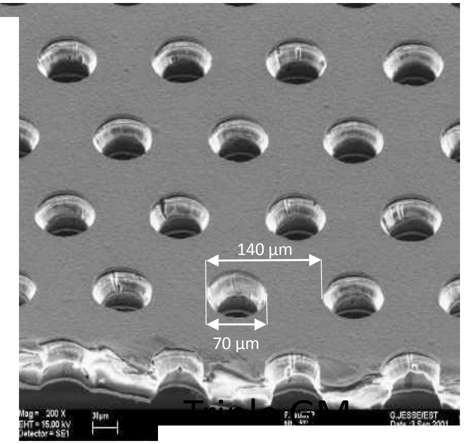


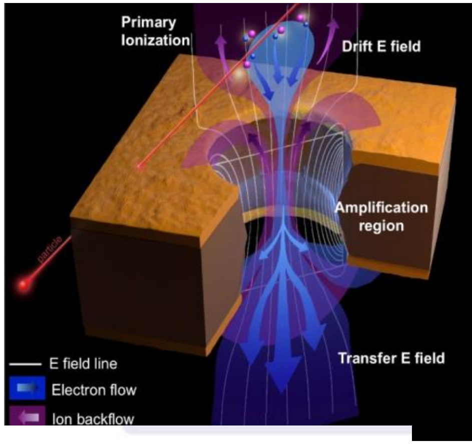
Redundancy assured by the GEM helps in:

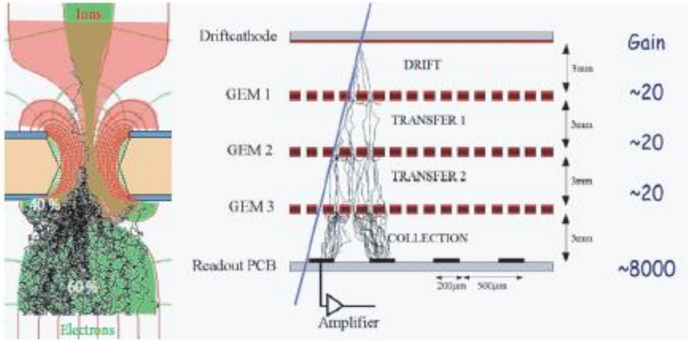
- Reducing the deterioration of Level-1 muon trigger performance
- Reducing the large degradation in momentum resolution
- Mitigating otherwise large efficiency losses if a sizeable fraction of CSC chambers becomes partially or fully irresponsive

Detector requirements

- Maximum geometric acceptance within the given CMS envelope :
- Rate capability 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:

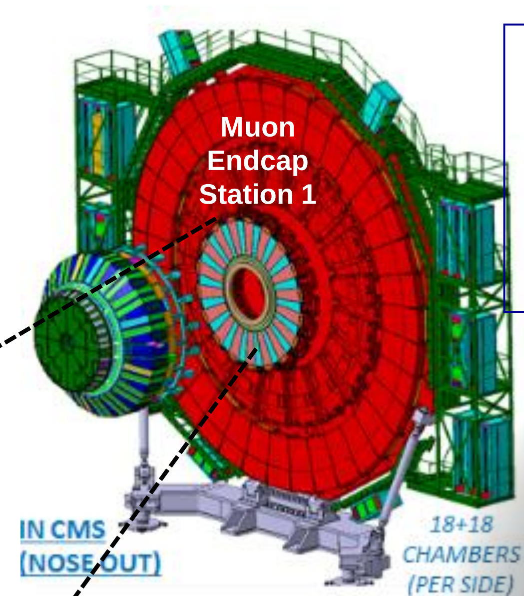
The GE1/1 design

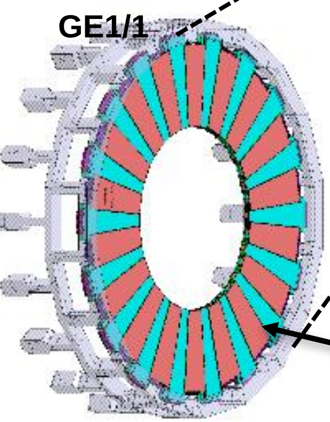
GE1/1 in high-η region 1.5<|η|<2.2

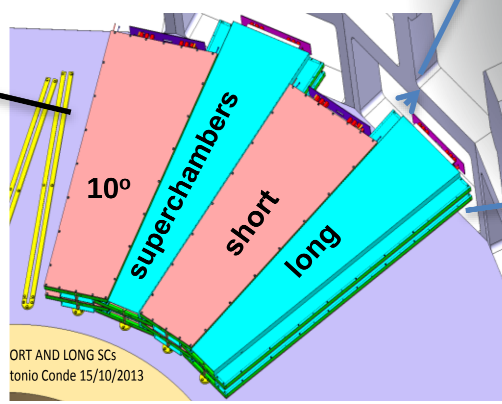
10^0 trapezioidal triple-GEM Superchambers

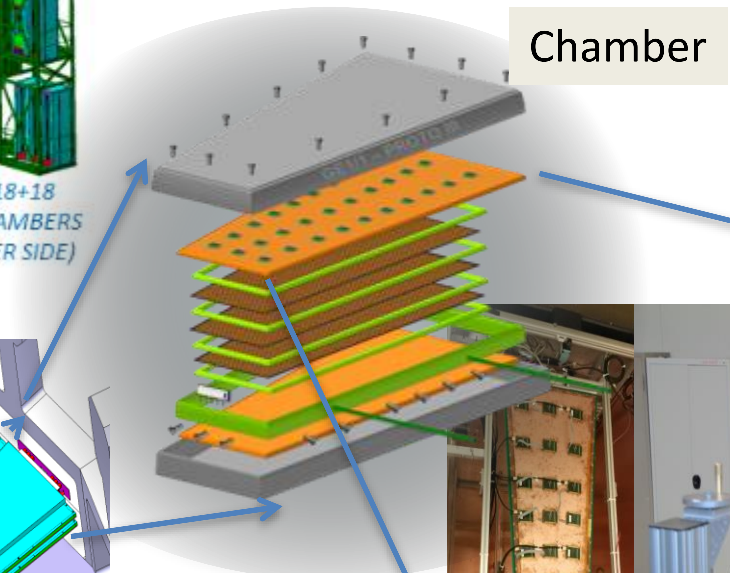
Long (1.5<|η|<2.2) and short (1.6<|η|<2.2) version

36 superchambers in each endcap



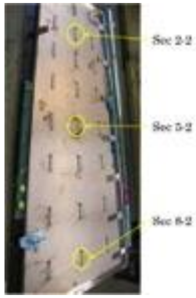


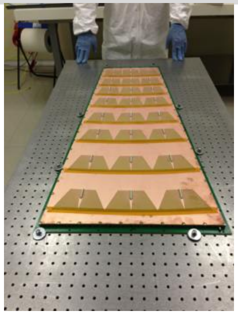


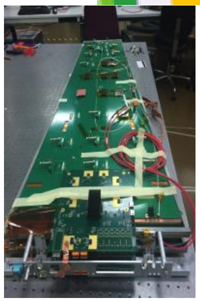


Installation in LS2

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
First suuperchamber In test beam campaign with V2 electronics, Optohybrid and GEB

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.

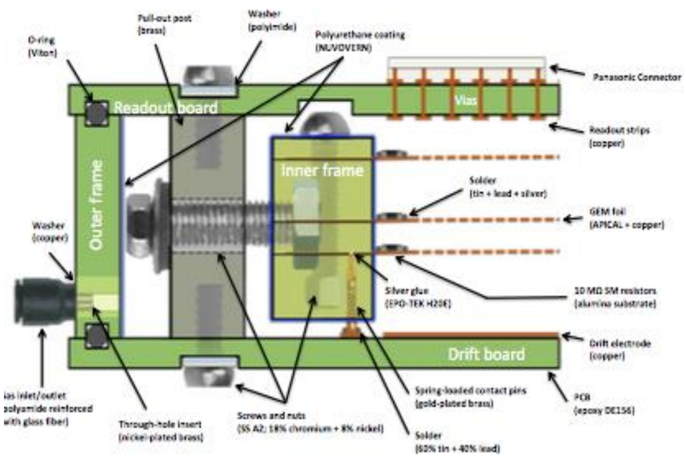
2017/18: Production GE1/1 chambers with final electronics

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

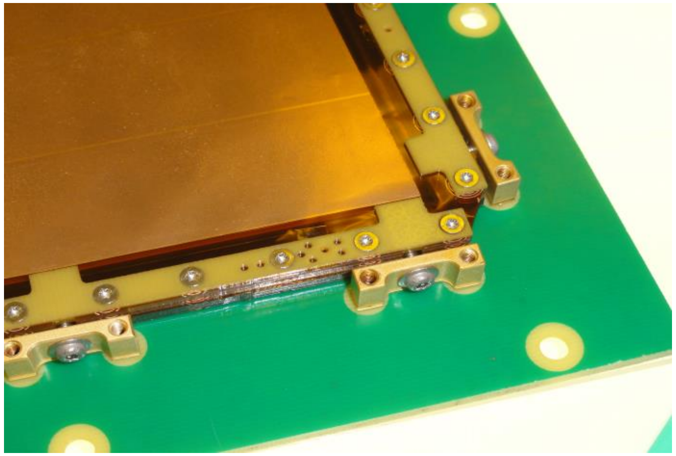
TDR Approved: 30.9.2015

Full-production of chambers and electronics started

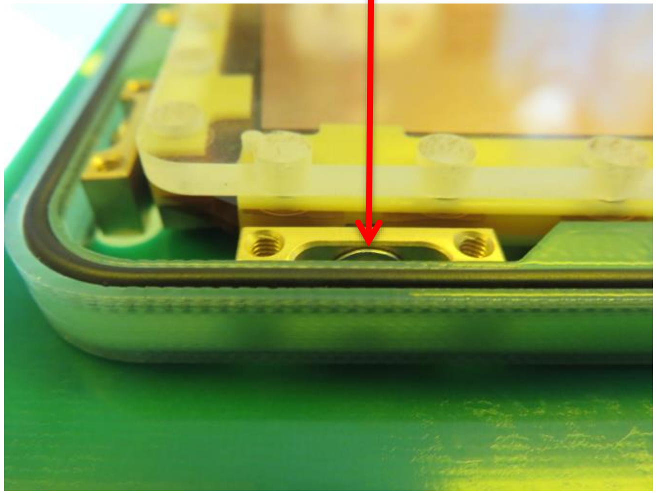
Some details ….

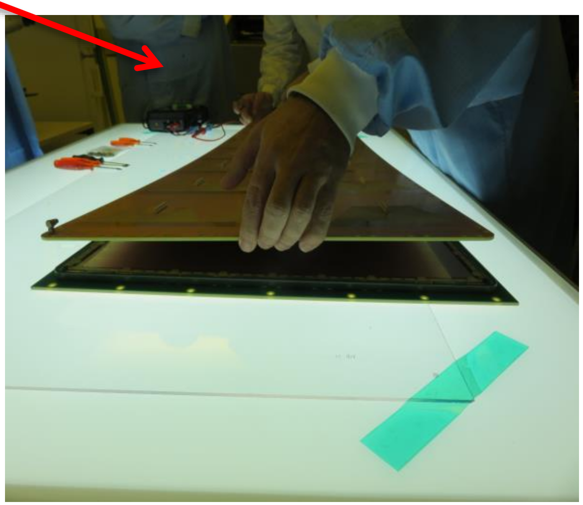


GEM Pull out system and his implementation



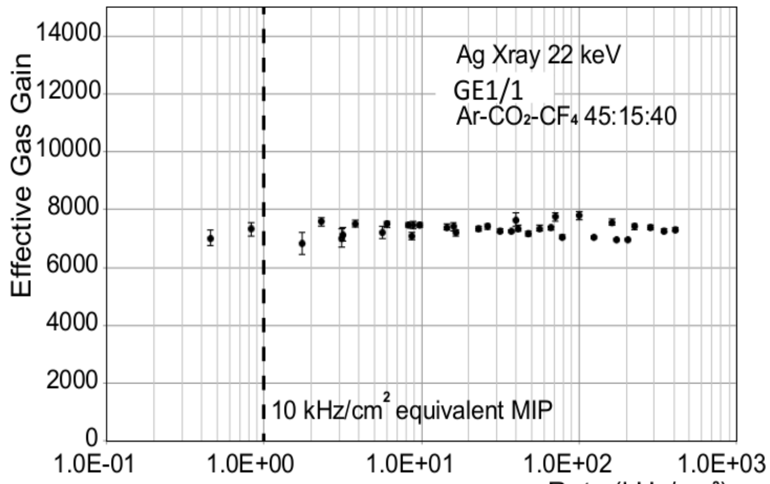
External frame, O-ring and chamber closure



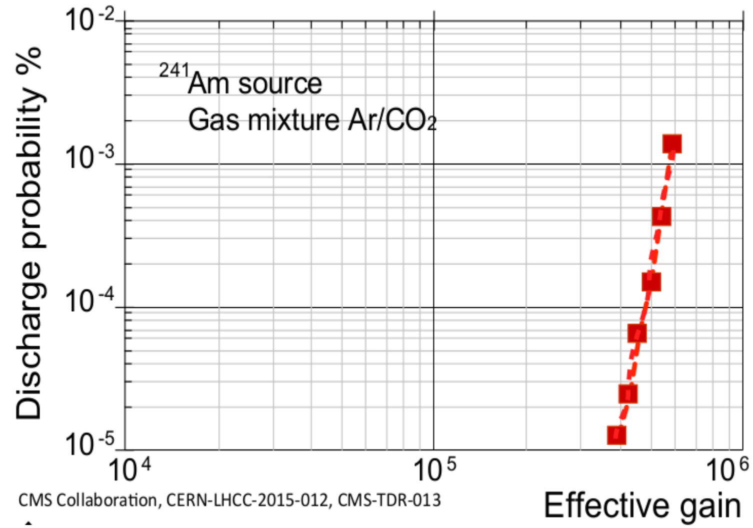


Performance of large prototypes

Triple-GEM technology perfectly meets the requirements imposed by the HL-LHC

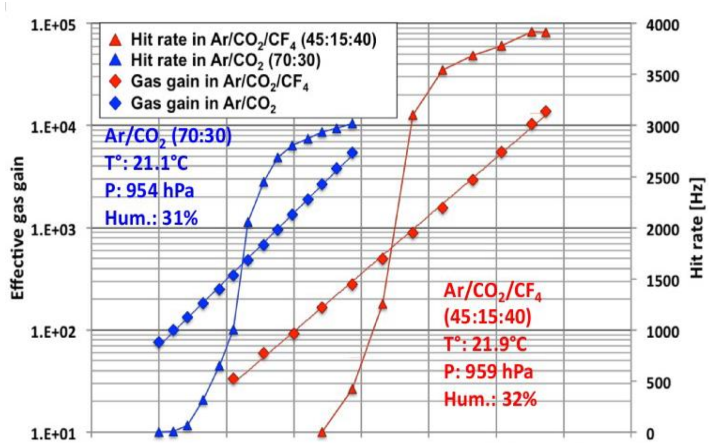


CMS Collaboration, CERN-LHCC-2015-012, CMS-TDR-013



CMS Collaboration, CERN-LHCC-2015-012, CMS-TDR-013

Effective gas gain is constant up to 1e5 kHz/cm^2 with low discharge probability; high spatial resolution



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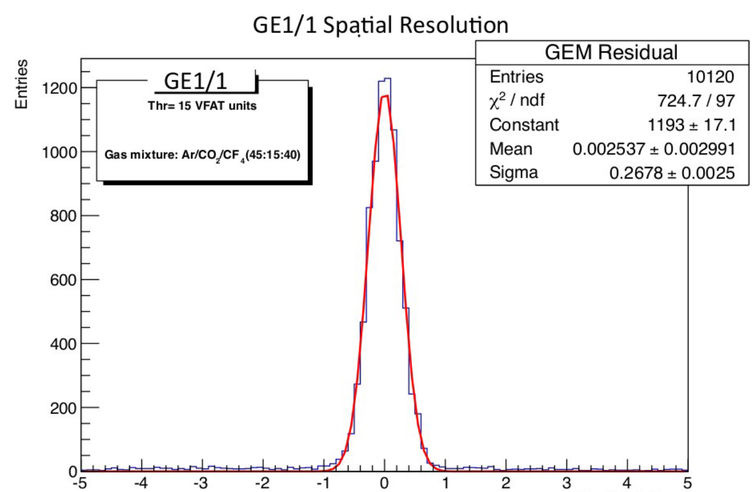
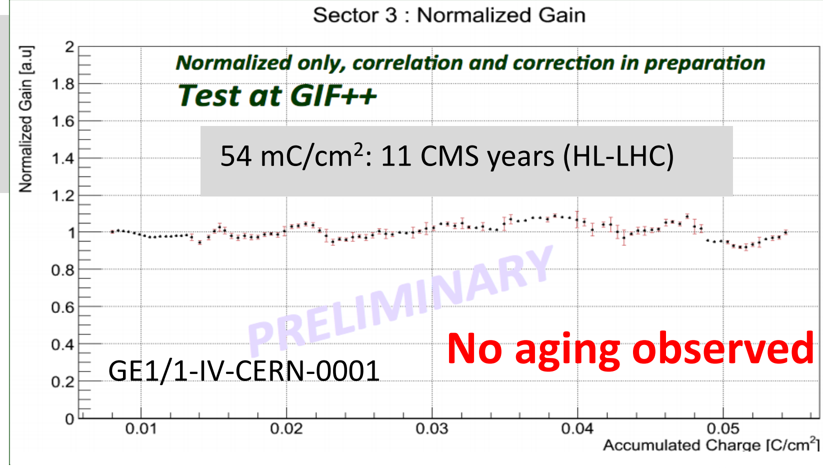


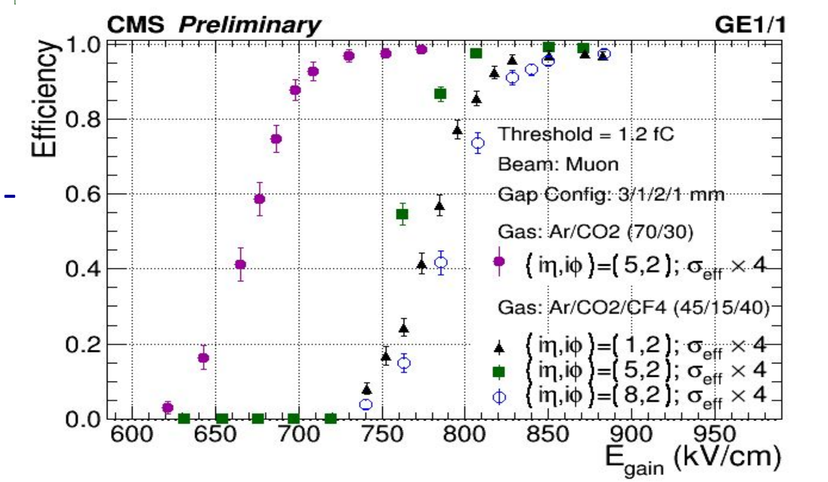
CMS Collaboration, CERN-LHCC-2015-012, CMS-TDR-013

GE1/1

Gearing up for production of chambers

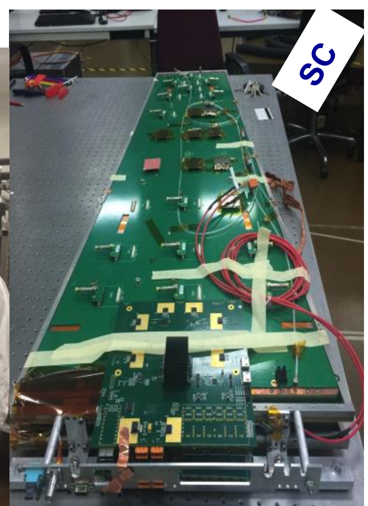
- GE1/1 Two Generation VI-L chambers constructed
- First Super Chamber tested successfully at beam
- GIF++ tests and test beam ongoing
- Cosmic Stand readiness for QC ongoing
- Lab at bd. 904 being equipped
- Clean room for assembly: tech specs complete, order on-going
- Foil production: 2 FTE technicians dedicated
- Assembly : CERN 2 sessions scheduled: Dec 3rd and 9th
- Electronics and DAQ integration on-going in bd. 904



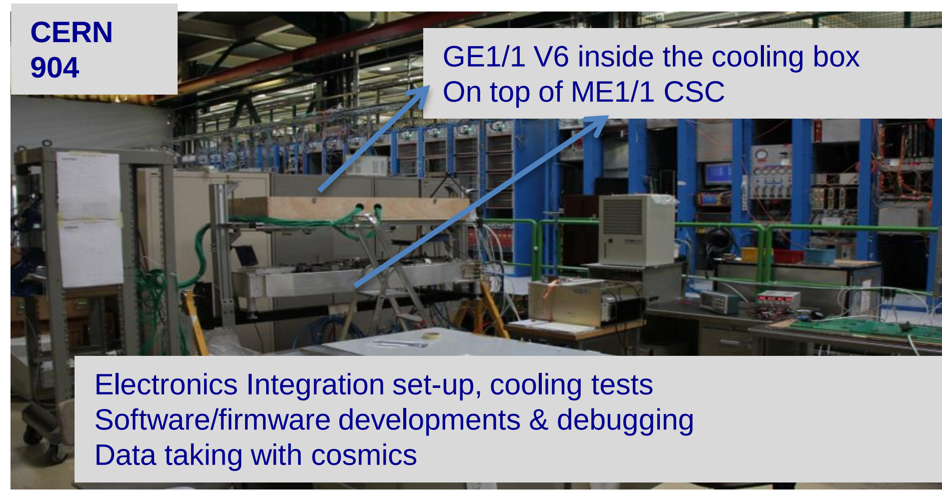


CERN 186

GE1/1 Two Generation VI-L



CERN 904



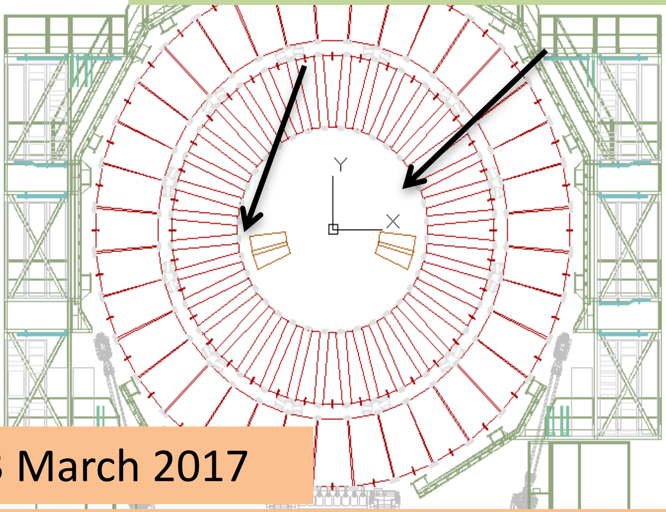
Electronics Integration set-up, cooling tests
Software/firmware developments & debugging
Data taking with cosmics


GE11
GEM Lab at Building 186

Slice test in YETS2016

Installation of 4 SuperChamber during 2016 YETS

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



- 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.

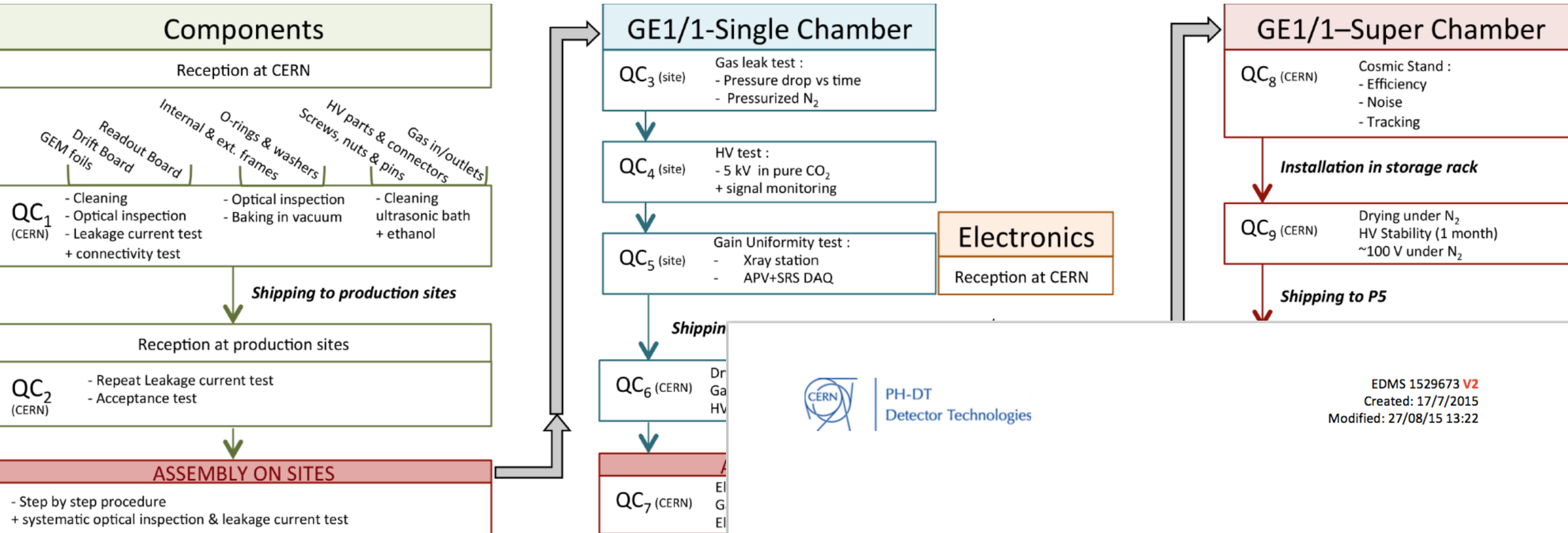
INSTALLATION WINDOW : Early January (10.1.2017 – 31.3 March 2017

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.

Quality Control – Production Flow



Sites Preparation

PH-DT
Detector Technologies

EDMS 1529673 V2
Created: 17/7/2015
Modified: 27/08/15 13:22

Collaboration Agreement between PH-DT & the CMS CERN team in the GE1/1 Muon Detector Upgrade project

This agreement describes the support of CERN PH Detector Technologies (DT) Micro-Pattern Technologies (MPT) workshop and the CMS GEM Collaboration to produce GEM foils and support the procurement of parts for the CMS GE1/1 muon detectors.

https://edms.cern.ch/document/1529673/2

Production site readiness

6 production sites are ready for final production, all have already assembled GE1/1-IV prototypes , QC procedures have been initiated and being documented as DNs

(a) BARC (b) INFN-Bari (c) CERN (d) UGent (e) FIT (f) INFN-LNF

Figure 5.2: Pictures from differents assembly site candidates.

	BARC	INFN - Bari	CERN	FIT	INFN - LNF	UGent
Cleanroom		X	X	X	X	
Leakage current setup		X	X	X	X	X
Gas system	X	X	X	X	X	X
X-ray setup	X	X	X	X	X	X
Shipping logistics	X	X	X	X	X	X
GE1/1 prototypes assembled	X	X	X	X	X	X
Past experience	X	X	X	X	X	X

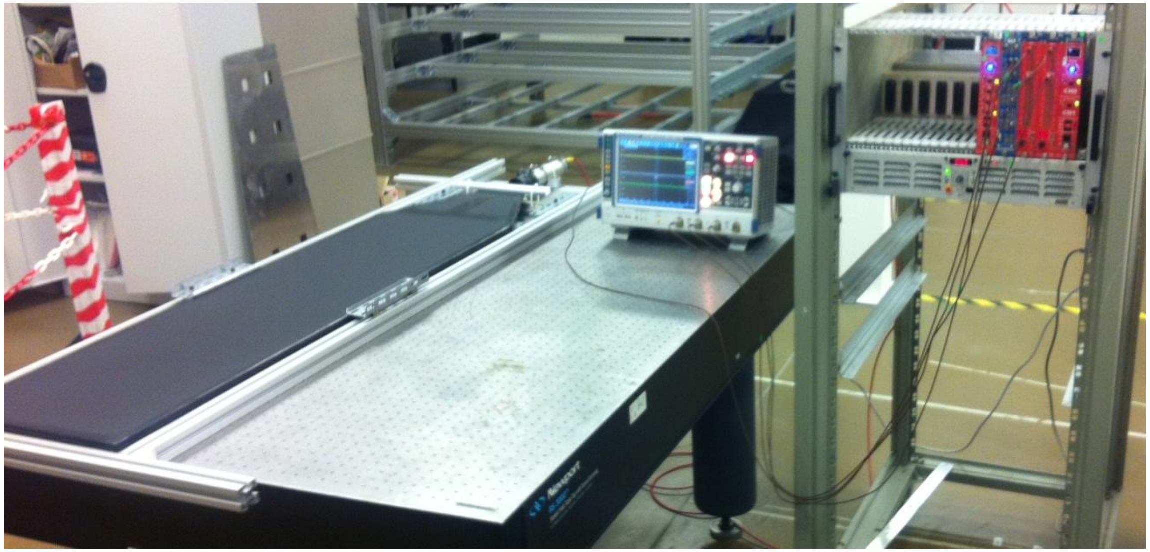
Luigi Benussi
Brian Dorney

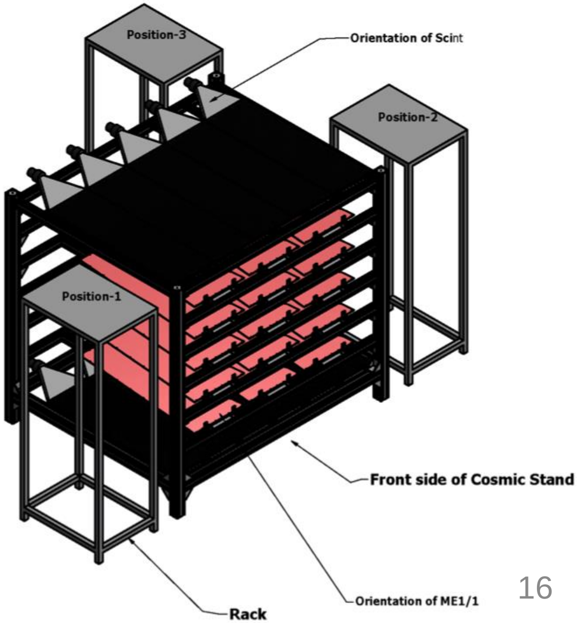
https://www.youtube.com/watch?v=Ssuqh5GAVZ4

TIF Cosmic stand : CERN

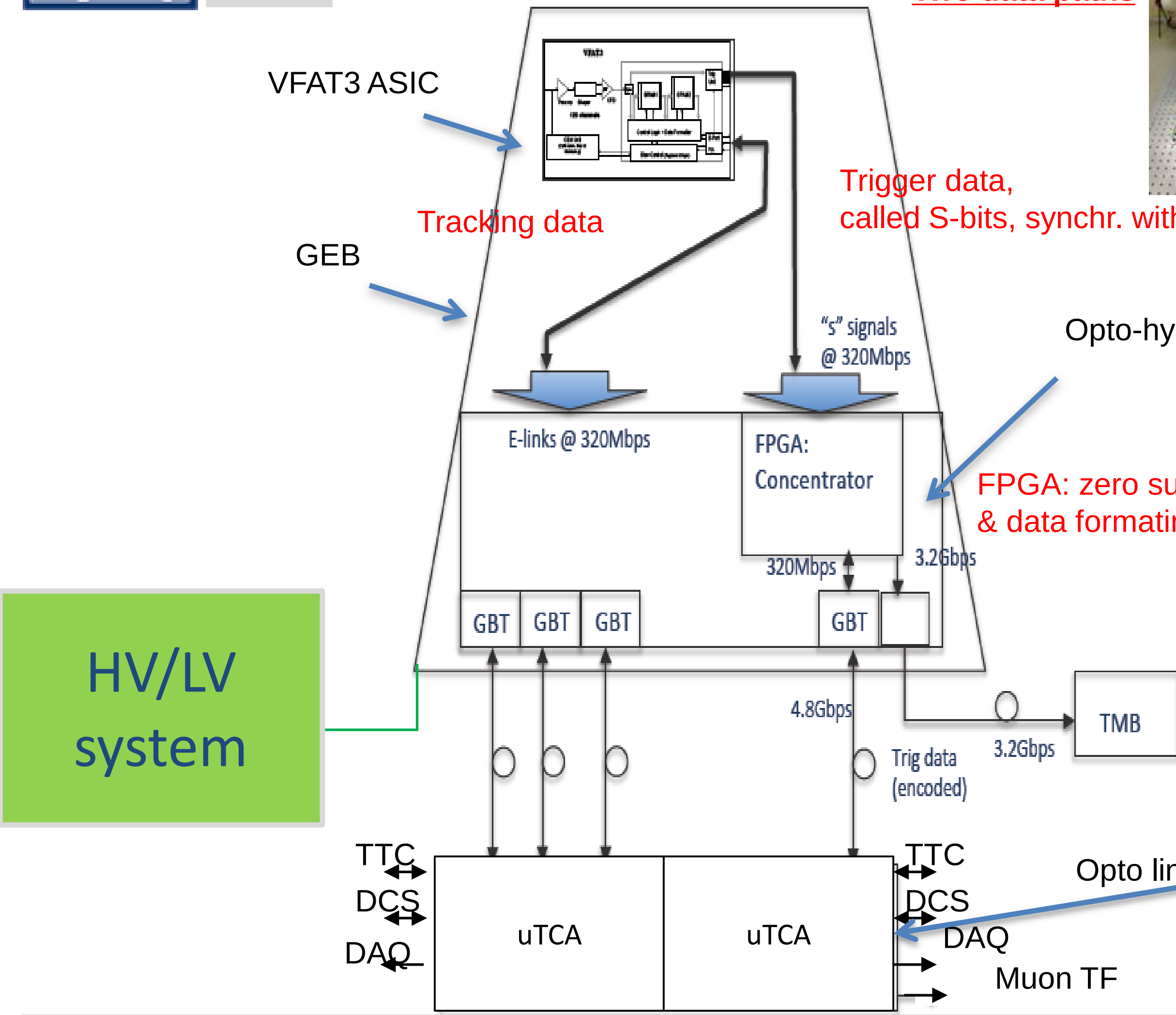
Brian Dorney

- Superchamber assembly and QC site
- Additional layer of quality control (cluster size, efficiency, etc.)
- Each chamber will have results logged in performance database
  - Reference once CMS is closed
- Aluminum superstructure completed
- Scintillators and trigger logic presently set up, DCS Operational DAQ being set up

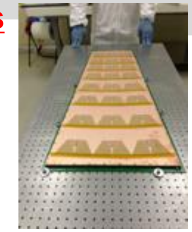




GE1/1 & GEM electronics system



Two data paths



single detector:

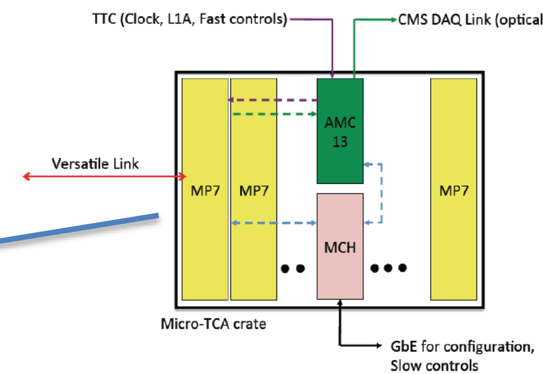
- 3 GBT
- 1 Opto-hybrid
- 4 opto-fibers

One SC 2 X single detector

LS2 : GE1/1 InstallaKon

LS3: GE2/1 and ME0

Standard CMS upgrade off detector electronics



Benefit from development for LHC wide upgrade projects: DC/DC Powering. GBT,Versatile Link, MP7, uTCA backend - minimize duplication of effort and ensure that design resources within the project are focused on the project specific designs needed.

904: Integration Stands

- 3 Set-ups:
  - GEB v2 + OH v2.a + GLIB + uTCA
  - ULBrussels
    - Mainly firmware development, debugging
  - TAMU
    - Firmware and software developments
  - CERN (bdg. 904)
    - GE1/1 v6 on top of ME1/1 CSC
    - + AMC13 + Fedkit
    - Integration set-up, cooling tests
    - Software developments, debugging
    - Data taking with cosmics

GE1/1 inside the cooling box

CERN 904

ME1/1

GE1/1 Setup for VFAT;OH and GEB tests.

Andrey Marinov
Antonio Conde Garcia
& Team

Toward the full production

Training and production site qualification

Training of our technicians/ ongoing, a V5 detector has been built, by the Italian technician, last week with the help of Rui (**THANKS Rui!!!**), a new round of training with our colleagues from Gent is foreseen for Wednesday 9th Dec.

New session to be organized in January during the assembling of the Slice Test chambers

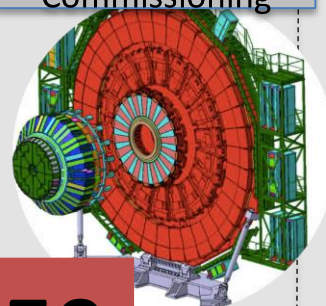
Phase 2 Scope and Schedule Muons : GEM

LS2	LS3

2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025

GE11 Installation & Commissioning

GE1/1 : 10°
Triple-GEM LS2



TDR

Eng. and Preprod.

Production/Assembly

40º Slice in YETS

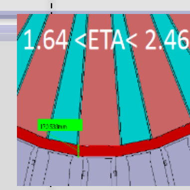
10.1.2017 – 31.3 March 2017

Testing & Preparation in UXC

Week… …eady for beam minus 30 weeks)

Short SC
eta=1,61-2.18
Long SC
eta=1.55-2.18

ME0
GE21



GE21 ME0 Installation & Commissioning

GEM21

Design and Prototyping

MUON TDR

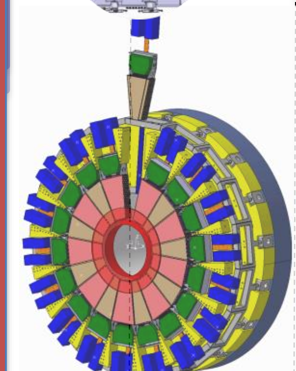
Prototyping

Engineering and Preproduction

EDR

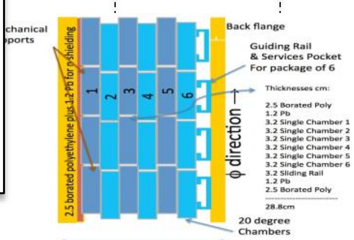
GE2/1 Production

Testing and preparation



ME0

Design and Prototyping



Prototyping

Engineering and Preproduction

EDR

ME0 Production

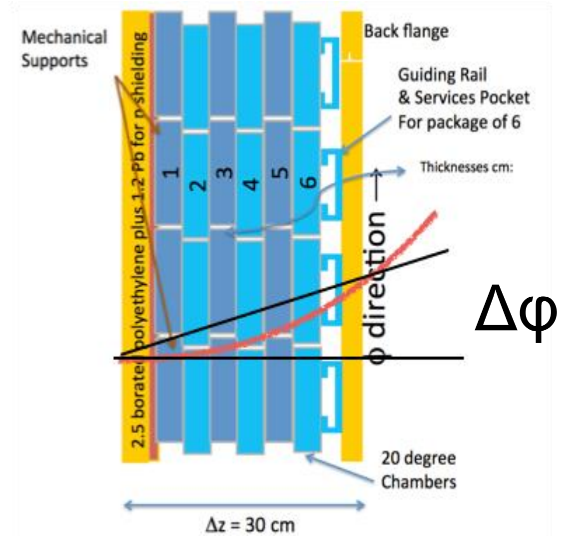
New technologies are being investigated.

- back-to-back triple GEM permitting six layers of detection, as a backing calorimeter for muon tagging
- Second possibility is based on newly patented devices – fast timing micropattern (FTM) detectors https://cds.cern.ch/record/2000150

R&D on Forward Extension: ME0

ME0 extends muon coverage behind the new endcap calorimeter for efficient muon ID with low bkg.

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

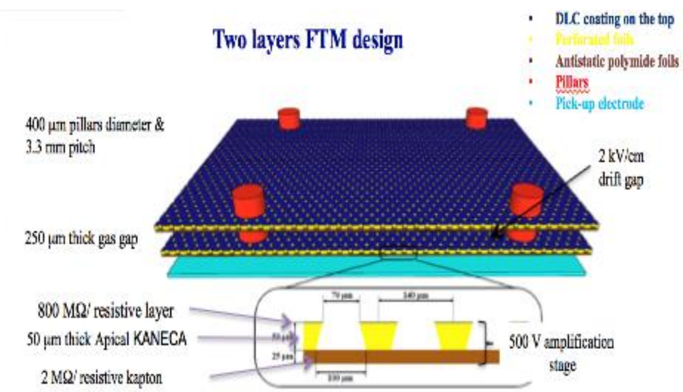


<u>On-going R&D:</u>

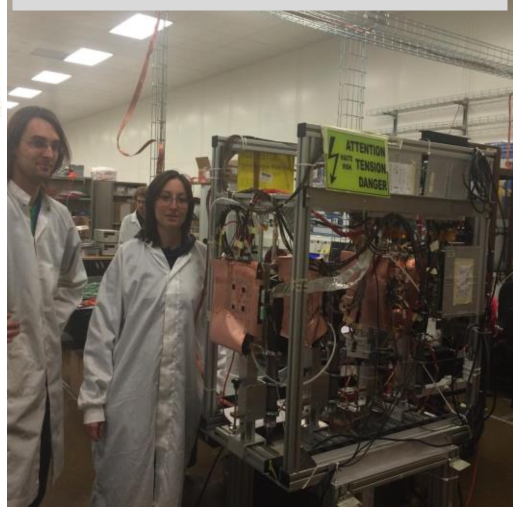
-ME0 baseline layout: 6 layers triple-GEM chambers (3 back-to-back detector)

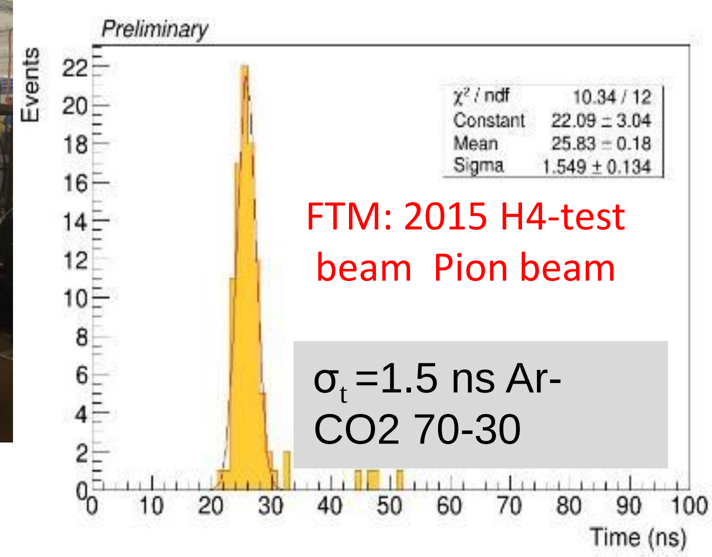
-Fast Timing MPGD (FTM): multi-gap of μ−drift and full resistive WELL amplification stages→ minimize the drift time fluctuation, no-spark.

Reference:
arXiv:1503.05330v1



Test beam telescope with FTM





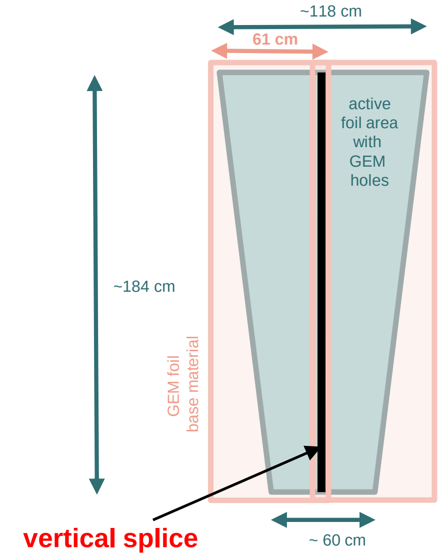
First prototype with two independent drift-amplification stages:
Fully transparent electrically, with top and bottom readout

The GE2/1 design

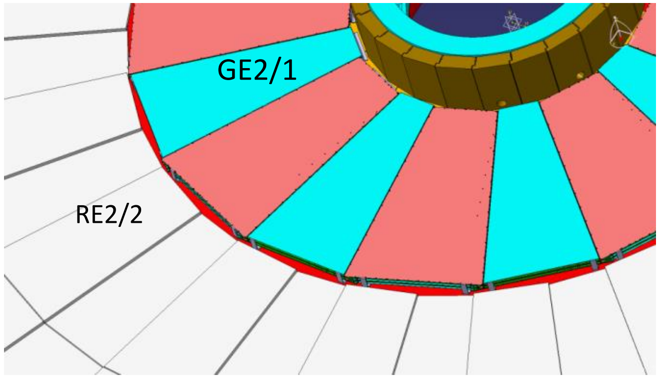
The station GE2/1 consists of 72 triple-GEM chambers arranged in 36 20^0 Super-chamber, covering $1.60<|\eta|<2.46$.

Layout is similar to GE1/1, but covering much larger surface:

- ✓ largest triple-GEM chamber ever built!

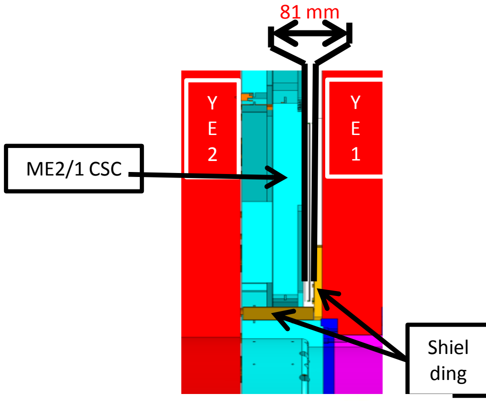


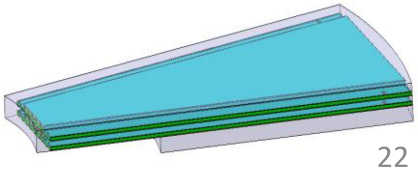
Optimization of engineering design for mass production on-going



Engineering challenges:

- Very thin: only 81 mm width
- need to **splice 2-4 GEM foils** together to build a chamber
- Also considering the 10^0 option

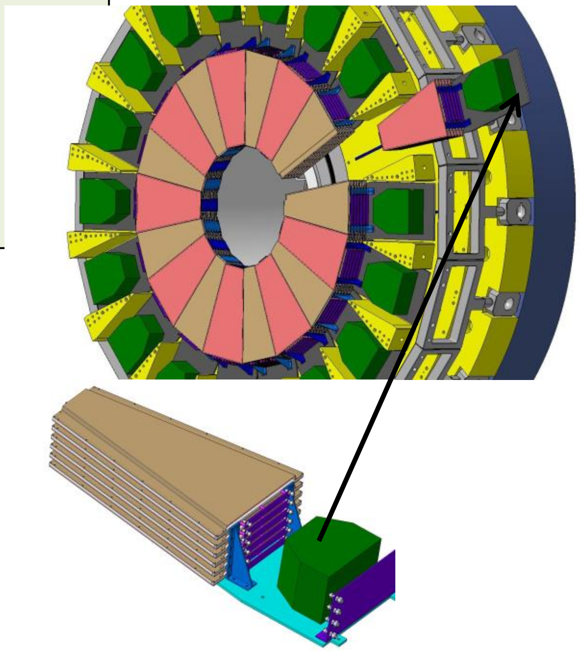




ME0 requirements and technical choices

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 and triggering



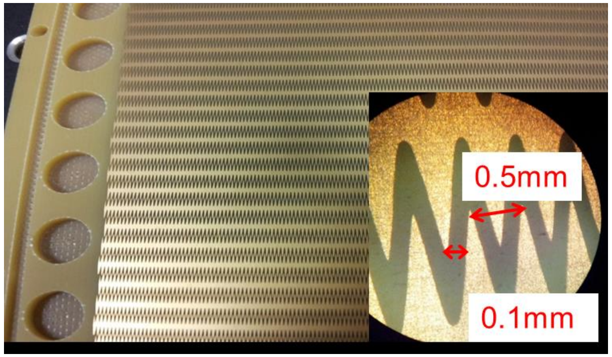
GEM group studying the application of the following technology:

- Six layers of triple-GEMs
- Fast Timing Micropattern gas detector (FTM): a full resistive multi-gap WELL detector

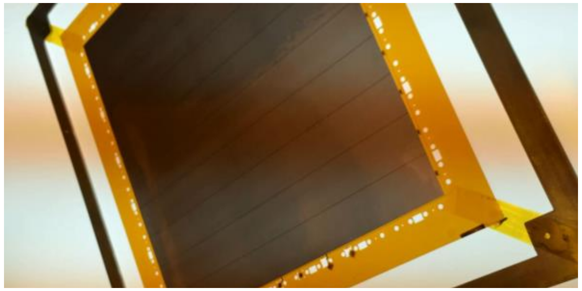
GE2/1 and ME0 Potential Cost Savings & Possible Interaction with other Projects

- **Readout with Zigzag Strips:** reduces number of electronics channels by **factor 3**
  - could eliminate expensive GEM Electronics Board (GEB) by using fibers
  - achieves similar angular resolution as standard strip readout
  - requires **readout of charges** induced on strips (pulse heights)

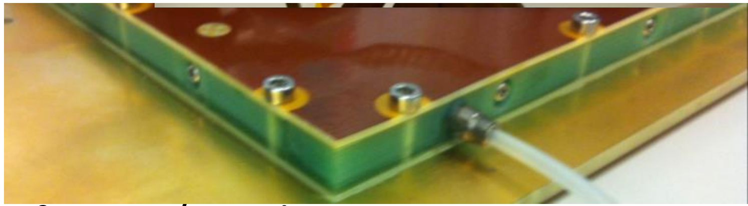
  GE1/1 successfully tested at Fermilab test beam.



- **Potential Synergy with other FEE Development (HGC/RPC)**
  - full charge readout (vs. binary r/o w/ VFATn)
  - flexible gain; fast pulse shaping, TDC
  - on-chip charge digitization
  - rad. hardness
  - serial output on GBT fiber links



Korea foil and chamber prototype: test ok

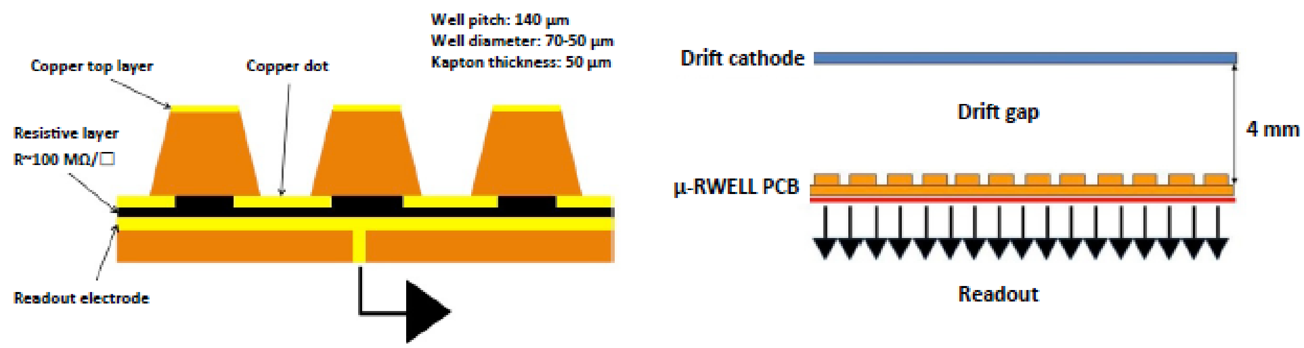


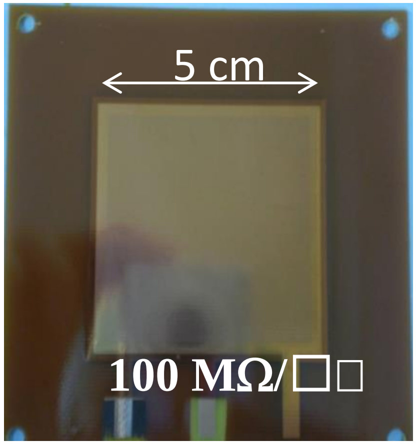
- **GEM foil production in industry**
  - Exploring the option of producing GEM foils in industry for GE2/1 and ME0 at UPLUS/Mecharonics, Tech-etch (US), Techtra (Polish), Micropack (India) : R&D on-going on production of large foils (60 cm x120 cm) with single-mask

GE2/1: A novel architecture: The μ-RWELL

-G. Bencivenni, M. Poli Lener, G. Felici M. Gatta G. Morello

A novel MPGD by combining in a unique approach the solutions and improvements proposed in the last years in the MPGD field (RD51).





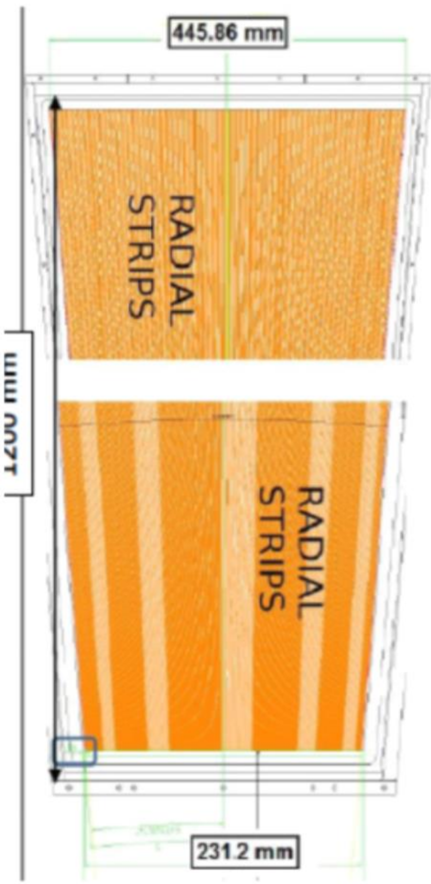
The proposed detector is:

- compact: one gap only (< 5mm thickness)
- robust against discharges: amplification through resistive coupling
- simple to build , only two components:
    - a single-amplification stage embedded with the readout
    - a cathode plane

Rif. 2015_JINST_10_P02008

GE2/1: Prototype: The μ-RWELL

The μ-RWELL 2016 proto



As a first step, the prototype will be based on the GE1/1 PCB readout:

- PCB r/o ~1.2x0.5 m divided in 8 r/o sectors
- One single resistive layer with DLC technique with edge current evacuation scheme
- One amplification stage (50 μm thick, 125 μm if available)

<u>A very simplified detector scheme</u>

Summary

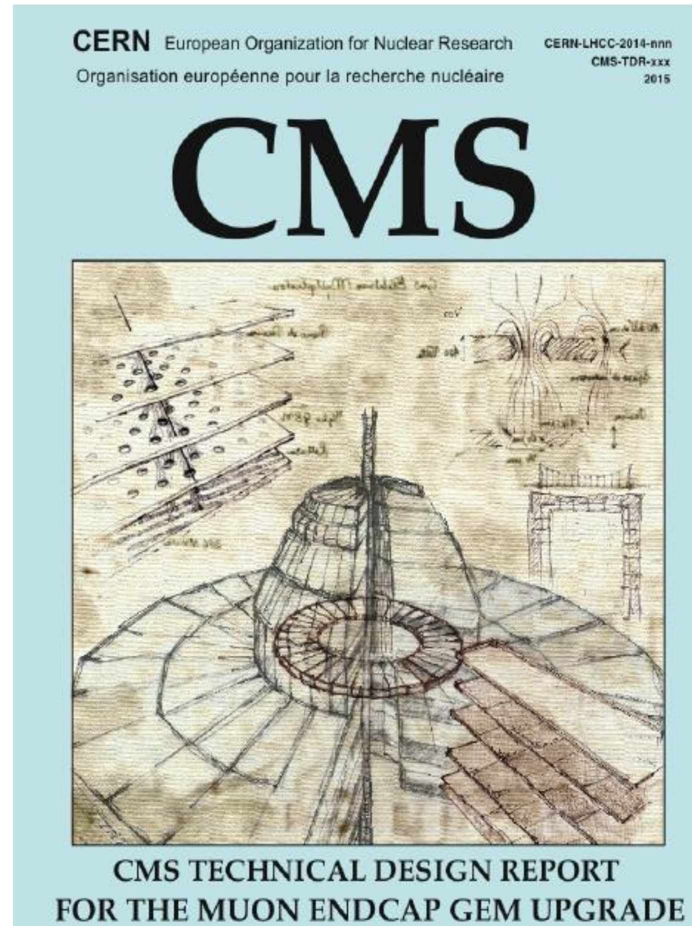
Muon Upgrade program will allow for continued excellent muon performance throughout the whole Phase 2:

1. Enhancement of the forward region $1.6 < \eta < 2.4$ in order to preserve the standalone muon trigger efficiency and reconstruction capabilities in the HL- LHC era.

2. Extension to the most forward region $|\eta| > 2.4$ with a single muon station to increase acceptance to new signals and to improve background rejection.

The triple-GEM technology is proven to be suitable solution for the CMS trigger and tracking needs in the HL-LHC era.

GE1/1 Technical Design Report (TDR) approved as being the first CMS Phase II TDR, following the need of early operation in LS2; LS3 projects to follow suit ☺

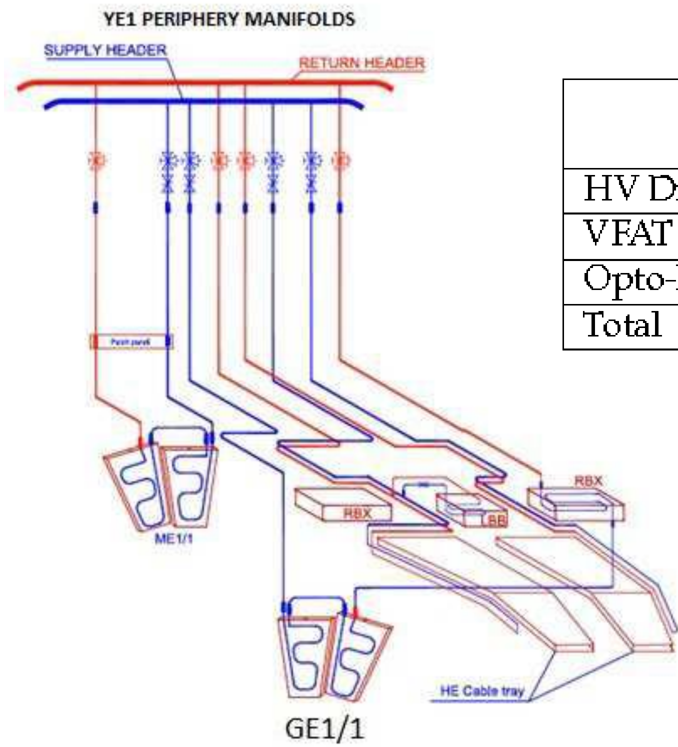


Summary (contd.)

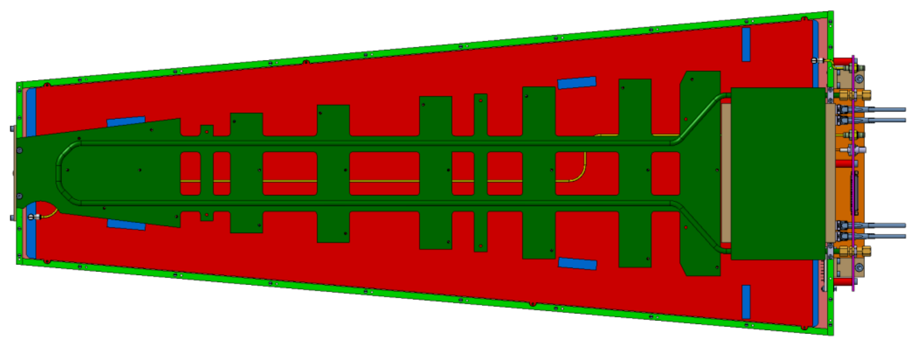
1. GE1/1 Slice test Chamber are under production
2. Full Production will be launched Spring next year
3. R&D for LS3 projects ongoing towards TDR in 2017

Spare

LV Power Budget and Cooling Setup in CMS



	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.

GEM GE11 Milestones for LS2 V1

Milestone	V0 (TDR 5.2015)	V1 (1.12.2015)	Comments
Technical Design Report	01/2015	09/2015	LHCC approval 30/09/2015
Chamber Final Design Release for procurements	08/2015	02/2016	opto-hybrid optimization (L&S)
Begin Shipment to Production Sites	02/2016	03/2016	PCB board price enquiry delay
First batch of LS2 chambers ready at CERN	12/2015	04/2016	Chambers produced @ CERN, to be qualified (milestone added)
Component Reception at Production Sites	06/2016	06/2016	no change
DAQ production complete	01/2017	01/2017	no change
Electronics production complete	03/2017	03/2017	no change
Reception production chambers at CERN complete	06/2017	06/2017	no change
One endcap complete	01/2018	01/2018	no change
Second endcap complete	03/2018	03/2018	no change
Ready for installation	03/2018	09/2018	LHC schedule shift (***)