Status Report on the Upgrade of the CMS muon system with triple-GEM detectors

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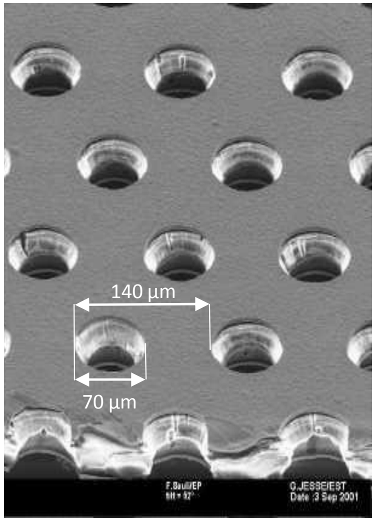
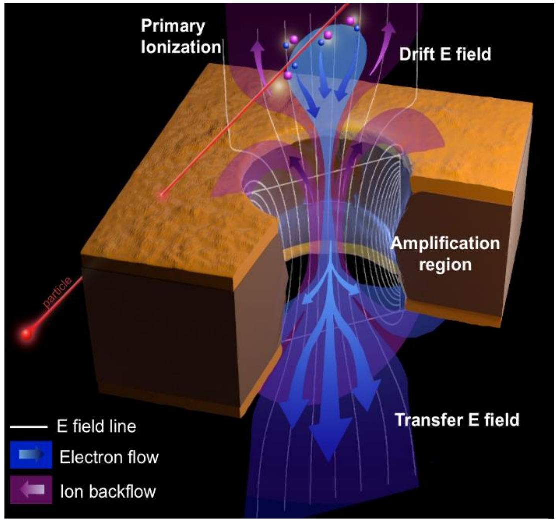
On behalf of the CMS Collaboration

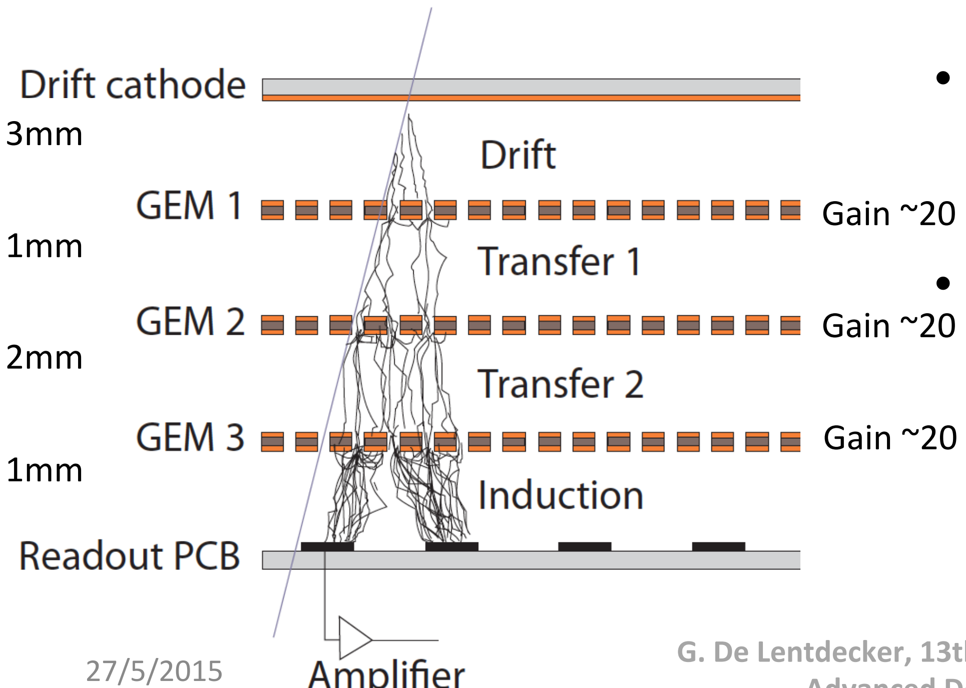
Overview

- Triple-GEM detectors
- The CMS GEM project
  - System design
  - Impact on CMS muon trigger performance
- CMS triple-GEM detector performance
- Preliminary results on ageing
- CMS triple-GEM Electronics
  - VFAT3 front-end chip
  - Readout chain
- Up-coming activities
- Summary

CMS requirements

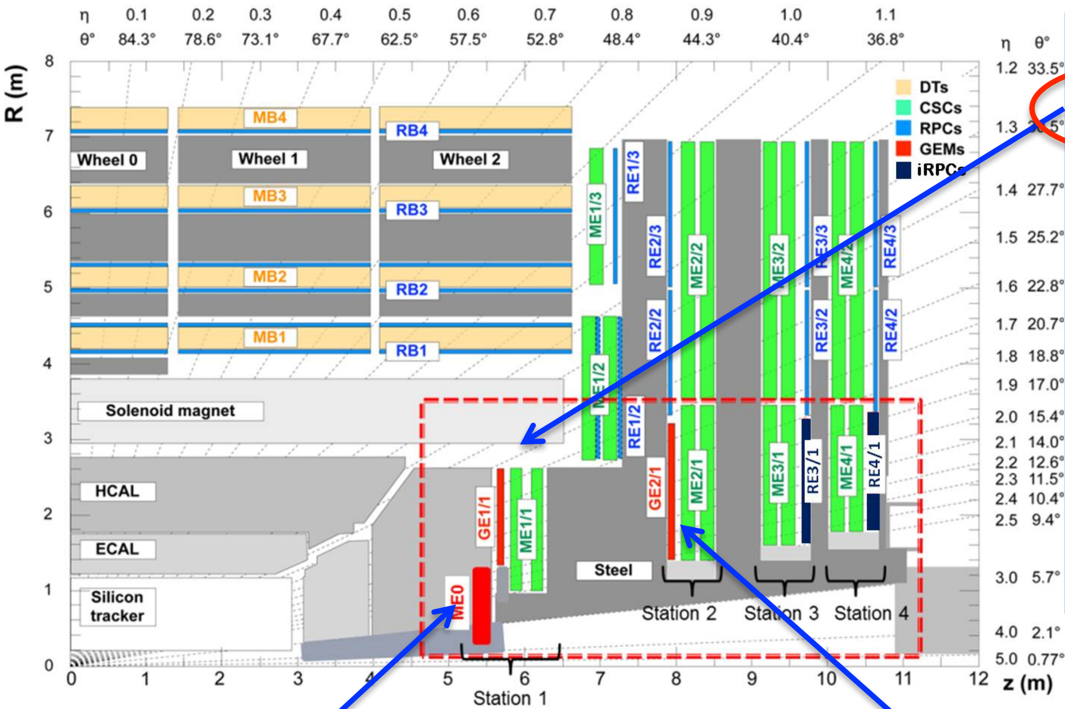






- Maximum geometric acceptance within the given CMS envelope
- Rate capability of 1-2 kHz/cm^2
- Single-chamber efficiency > 98 % for MIP
- Angular pitch of 460 mrad.
- Timing resolution of 10 ns or better for a single chamber.
- Gain uniformity of 10% or better across a chamber and between chambers.
- No gain loss due to aging effects after 200 mC/cm^2 of integrated charge

The CMS GEM project



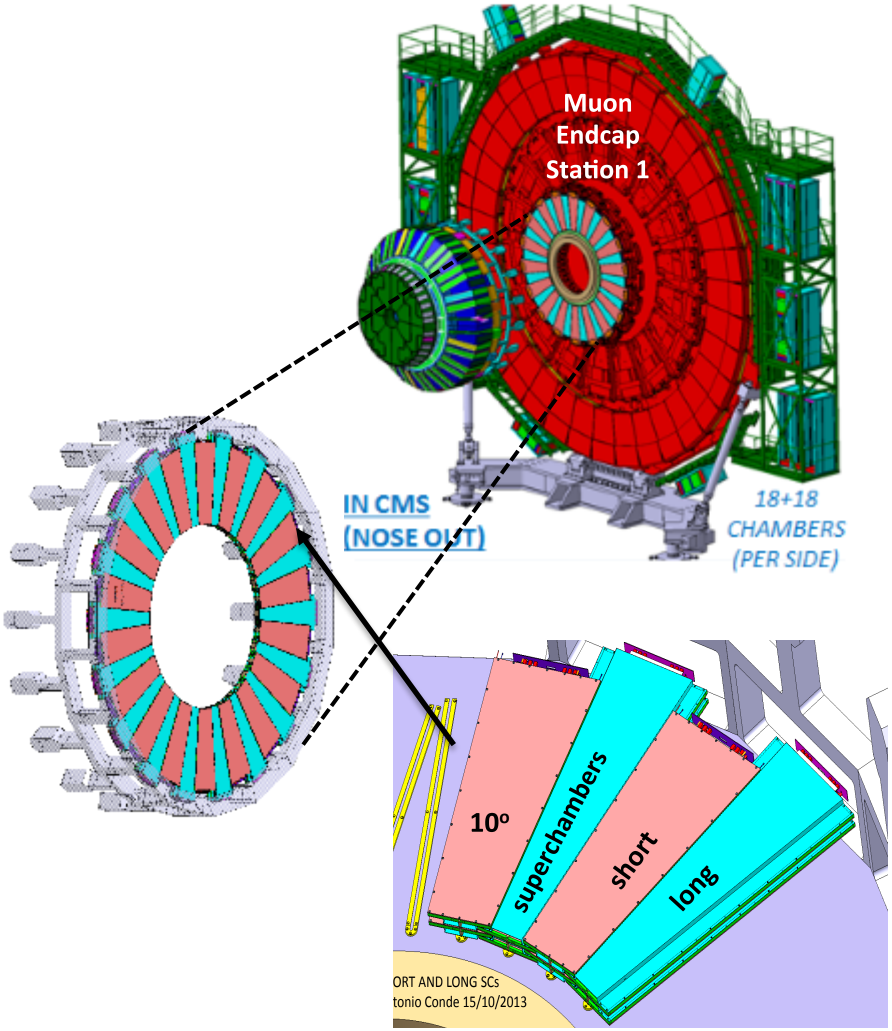
- $1.55 < |\eta| < 2.18$

GE1/1:
- baseline detector for GEM project
- 36 staggered super-chambers per endcap, each super-chamber spans 10°
- One super-chamber is made of 2 back-to-back triple-GEM detectors
- Will guarantee high trigger performance during late Phase I and throughout Phase II
- Installation: LS2 (2018-19)

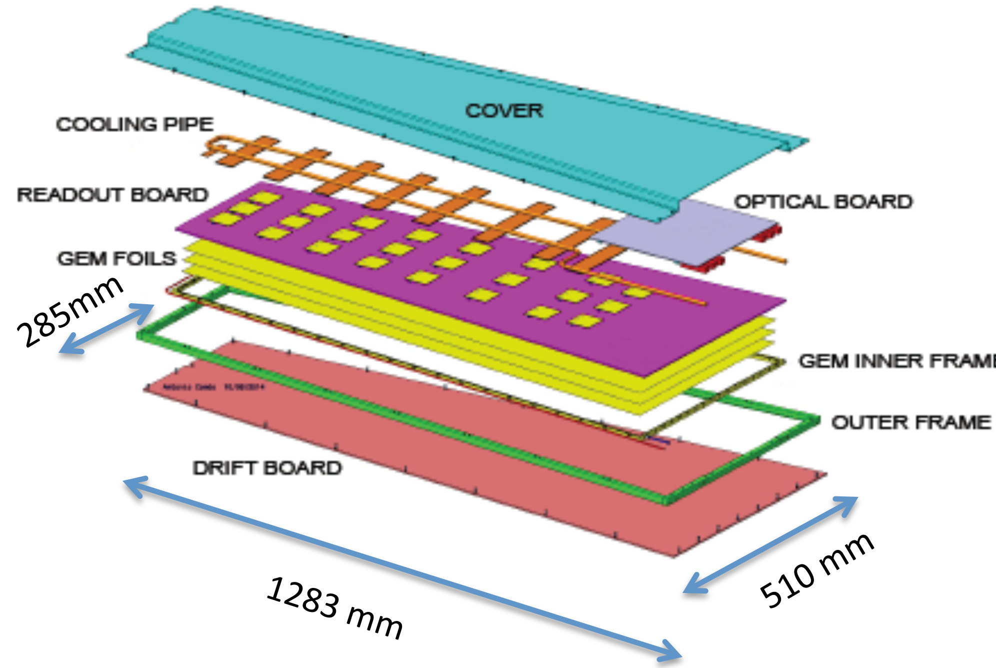
ME0:
- Muon tagger at highest η
- $2.0 < |\eta| < 3.5$
- 6 layers of Triple-GEM
- each chamber spans 20°
- Installation: LS3 (2022-24)

GE2/1:
- $1.55 < |\eta| < 2.45$
- 18 staggered super-chambers per endcap, each chamber spans 20°
- Installation: LS3 (2022-24)

CMS GE1/1

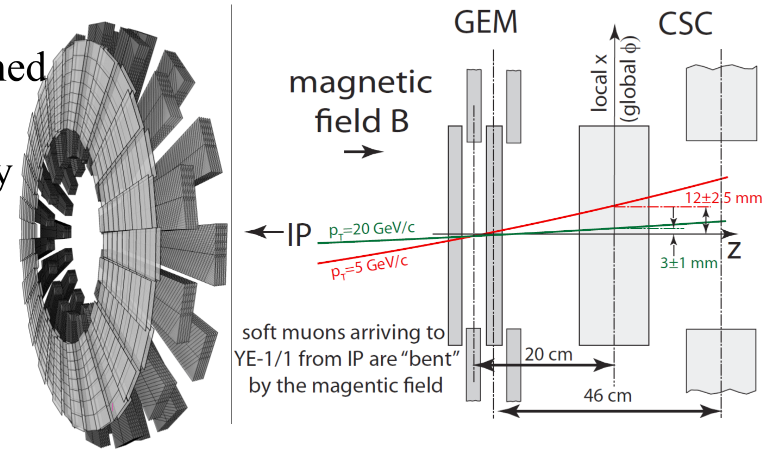


Exploded view of a long GE1/1 triple-GEM:

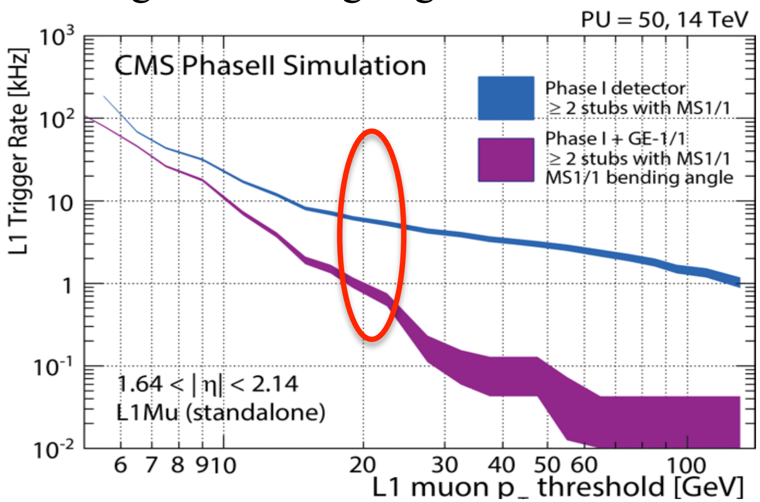


Muon Trigger performance

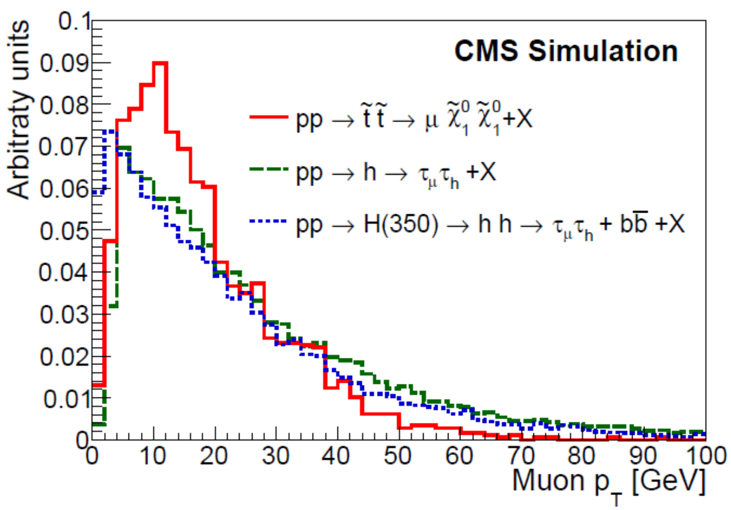
- L1 trigger rate "flattening"
  - Low-p_T muons scattering can occasionally have stubs aligned like for a high-p_T muon (rare, but lots of low-p_T muons);
  - L1 muon-trigger momentum resolution can be improved by measuring the bending angle with CSC+GEM

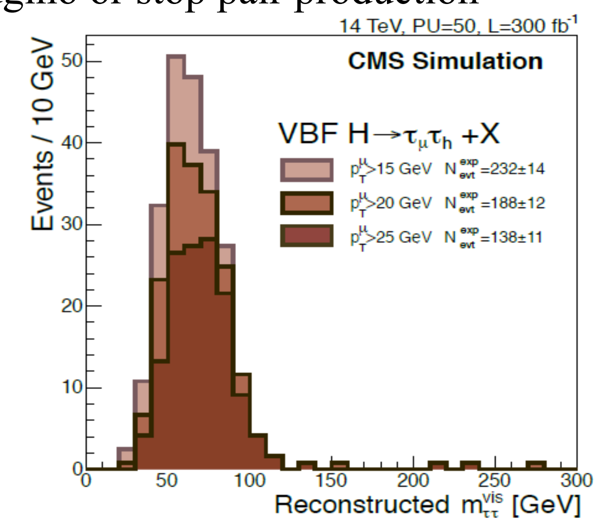


YE-1/1	p_T=5 GeV	p_T=20 GeV
$\Delta x_{Dz=30\ cm}$	12±3mm	3±1mm

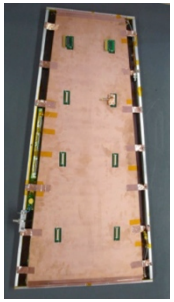


- Low thresholds have a large impact on physics that relies on a of low-p_T muon:
  - Higgs, SUSY gaugino or stop pair production

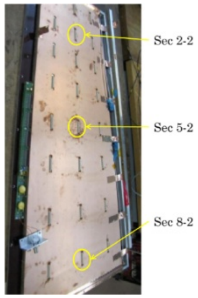




R&D: 6 generations of triple-GEMs

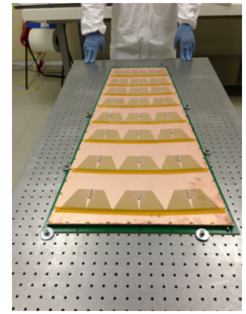


2010

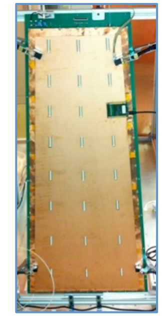


2011

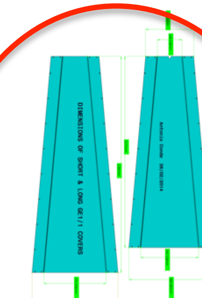
2012



2013



2014



2014/2015

Generation I

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

Generation II

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

Generation III

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

Generation IV

First detector with complete mechanical assembly; no more gluing parts together! **Upcoming papers from MPGD 2013; And IEEE2013.**

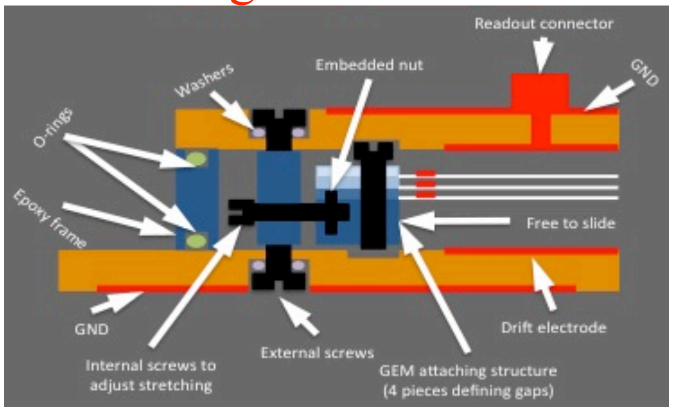
Generation V

Very close to what we will install in CMS. Features re-designed stretching apparatus that is now totally inside gas volume. **Fall 2014 test beam campaign for final performance measur-ements. Publication pending.**

Generation VI

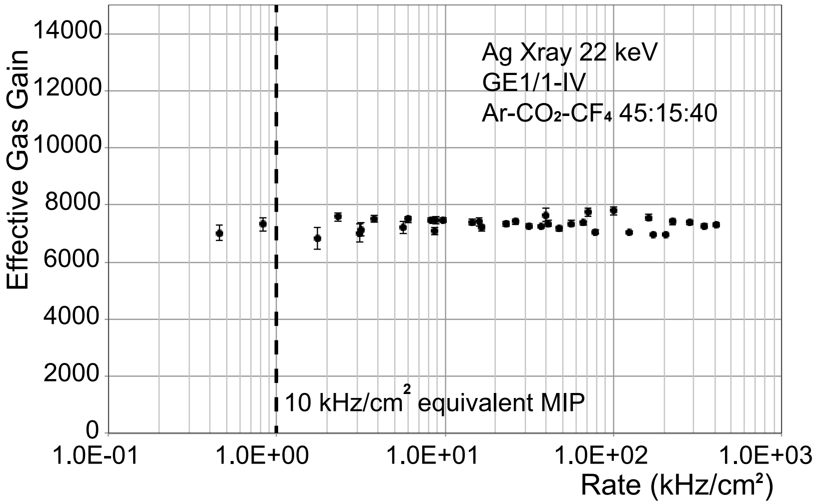
Latest detector design; **what we will install in CMS.** Optimized final dimensions for maximum acceptance and final eta segmentation. **Upcoming test beam campaign for DAQ chain stress test!**

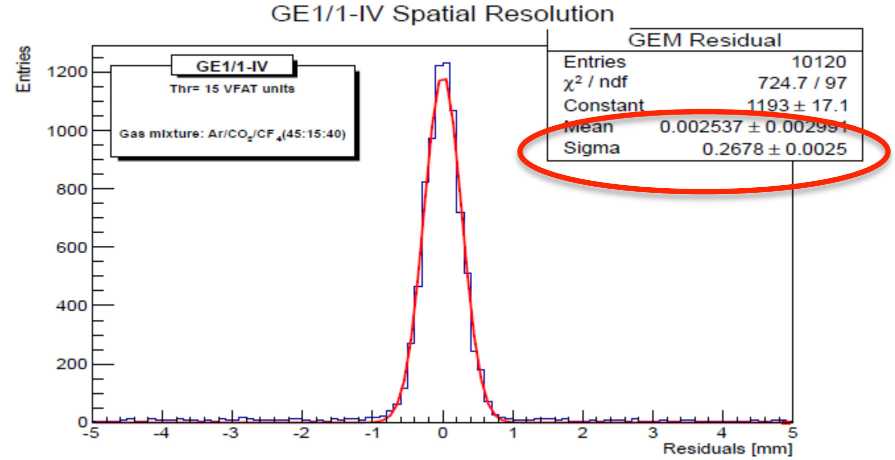
- GEM foil production uses single mask technology for wet etching
  - Dramatically reduces foil production costs and large sizes to be manufactured
  - Performance same as that of double mask
- Mechanical foil stretching procedure
  - Construction time reduced from week(s) to two hours per chamber

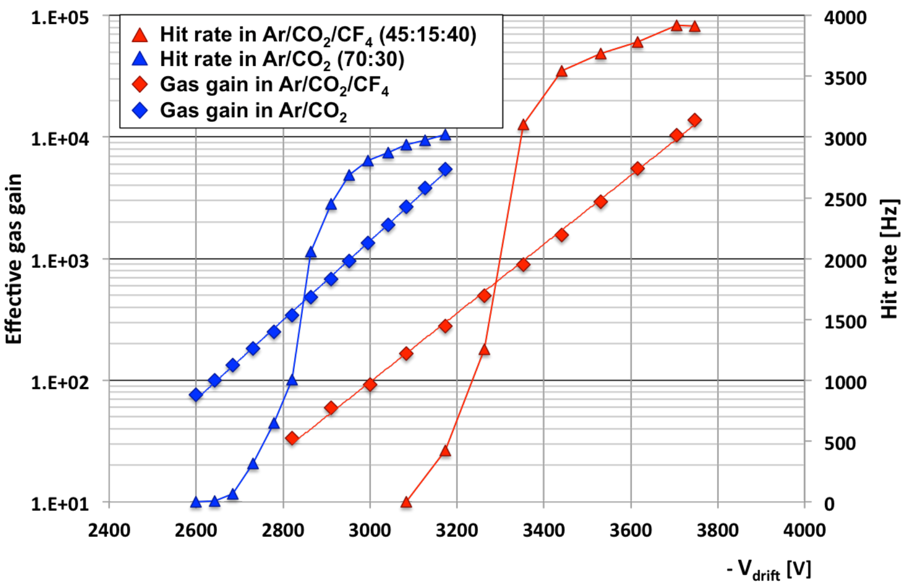


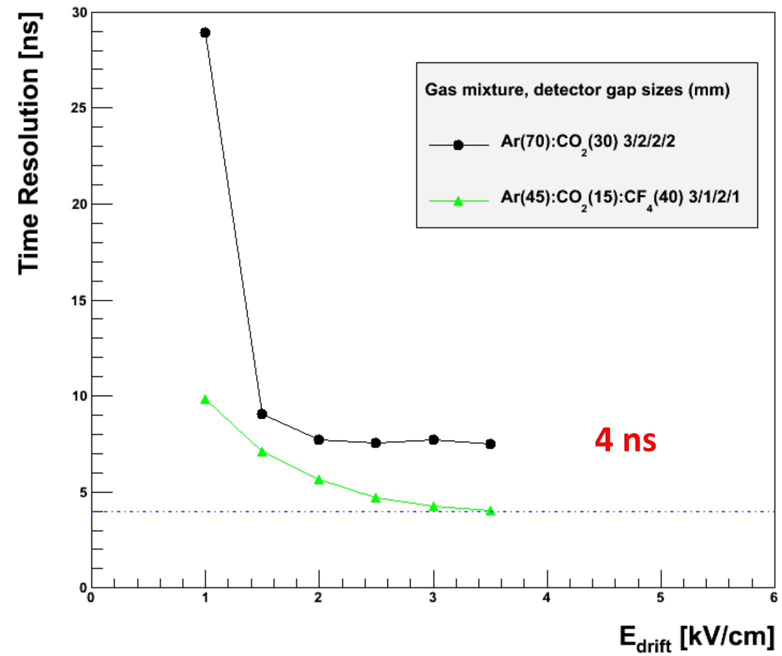
Performances

Over the years numerous tests, also with beam (CERN/FNAL), have been performed





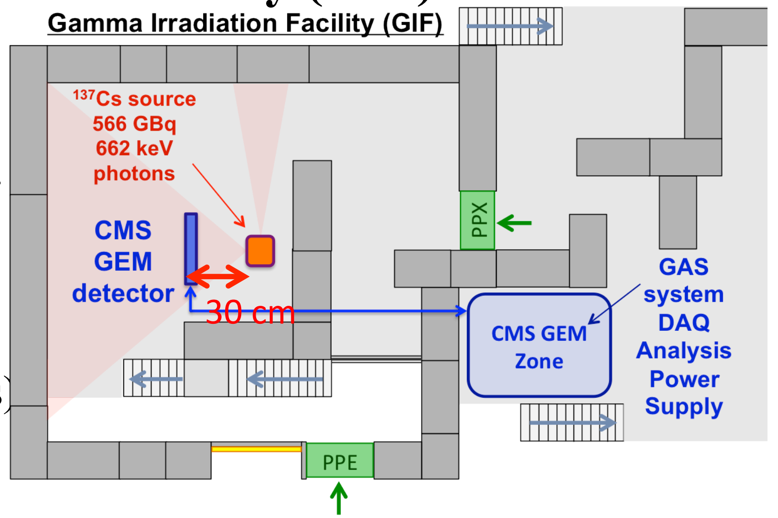




Aging studies

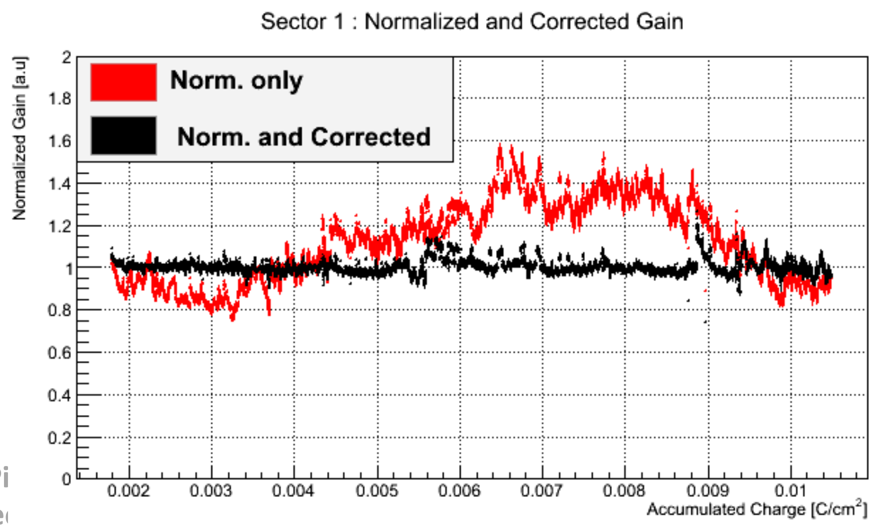
Test with GE1/1-IV at the CERN Gamma Irradiation Facility (GIF):

- ^{137}Cs source of 566 GBq
- Incident γ rate ~ 100 kHz/cm^2 → few kHz/cm^2
- $Ar/CO_2/CF_4$:45/15/40 (0.5L/h), gas gain: 2 x 10^4
- No gain drop after 10 mC/cm^2 (over 12 months)
- Next steps:
  - Move to GIF++ to reach >100 mC/cm^2 (16.7 TBq ^{137}Cs)



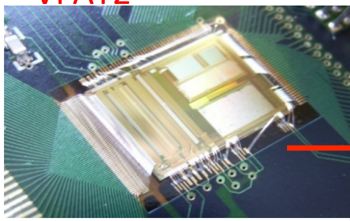
Outgassing studies:

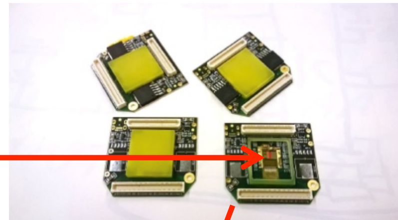
- At room T° and at 50°C
- Being performed on all materials in contact with gas
- Outgassing box-SWPC-10x10 cm^2 triple-GEM
- Chomatograph to identify impurities
- Viton O-ring : Ok
- Polyurethane Cellpack : ~~Ok~~
- Polyurethane Nuvoverne: Ok

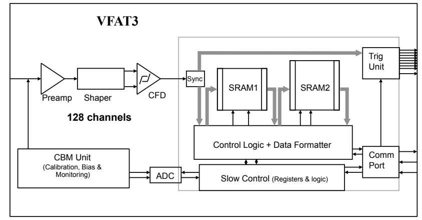


GE1/1 readout system

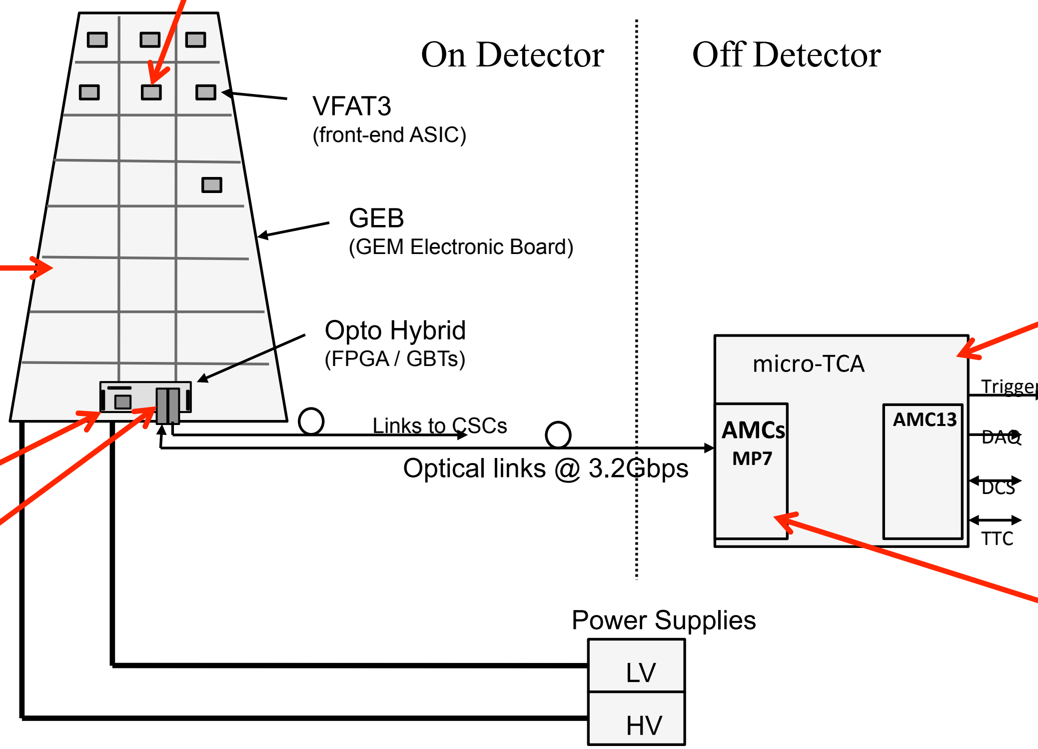
VFAT2



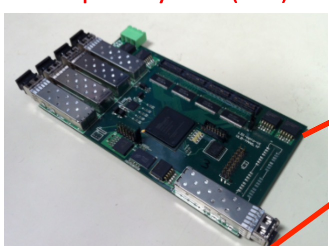




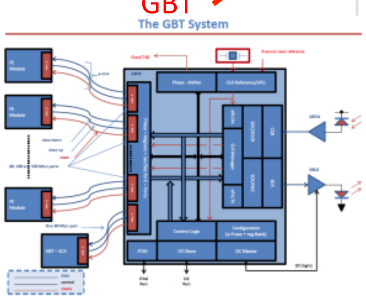
GEM Electronic Board (GEB)



Opto-Hybrid (OH)



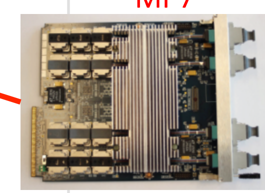
GBT



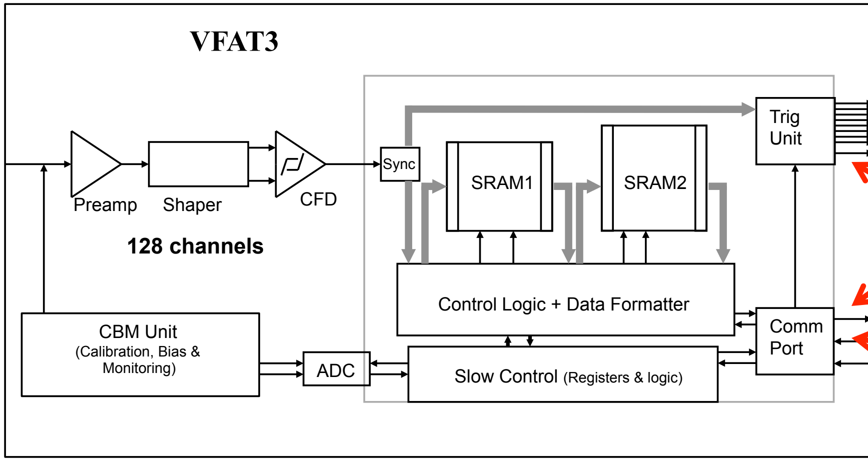
µTCA

AMC13, MCH

MP7

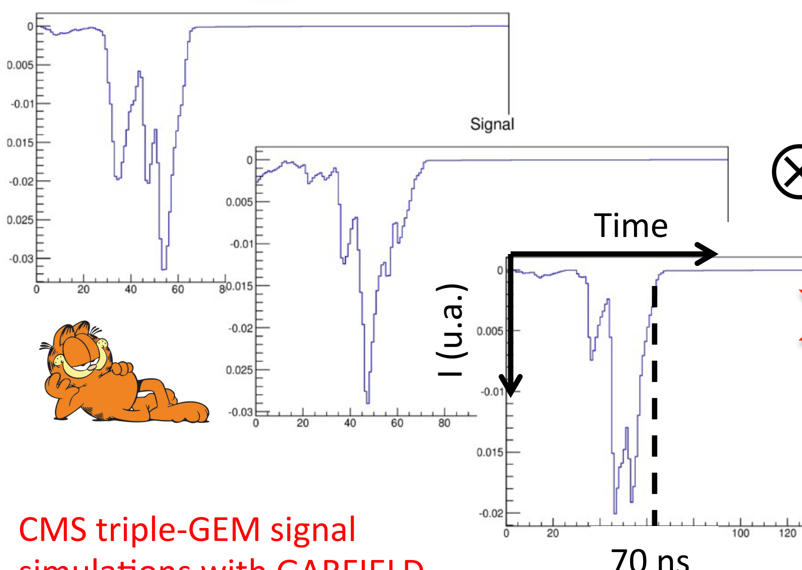


VFAT3 design

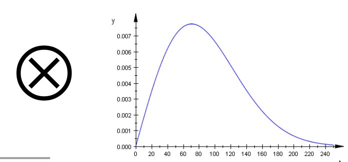


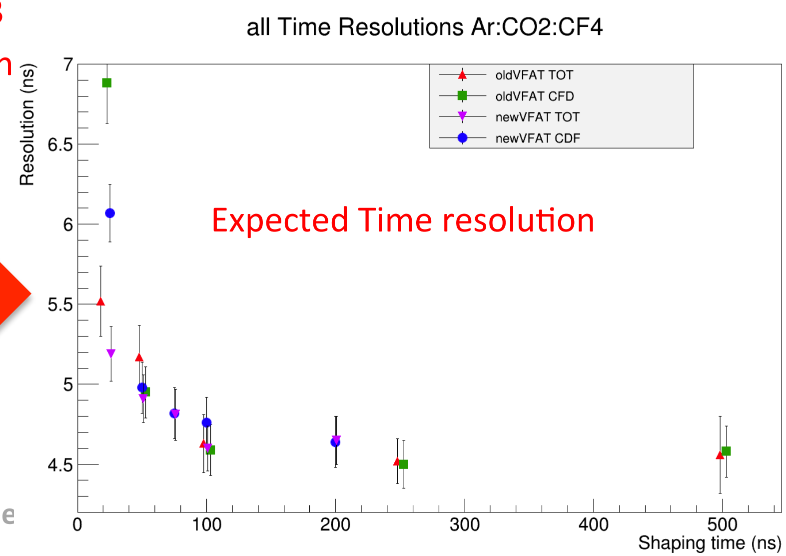
- Evolution of TOTEM VFAT2 chip
- 128 channel chip,
- Both polarity
- Provide tracking and trigger data
- LV1A latency up to 20μs
- Interface to and from GBT @ 320 Mbps
- Rad. tolerant up to 100 Mrad (radiation hardness of up to 1MRad is sufficient for the GE1/1 application through Phase-II)
- First submission : end of 2015 (TSMC 130)

A lot of simulations have been done to study the expected time resolution:



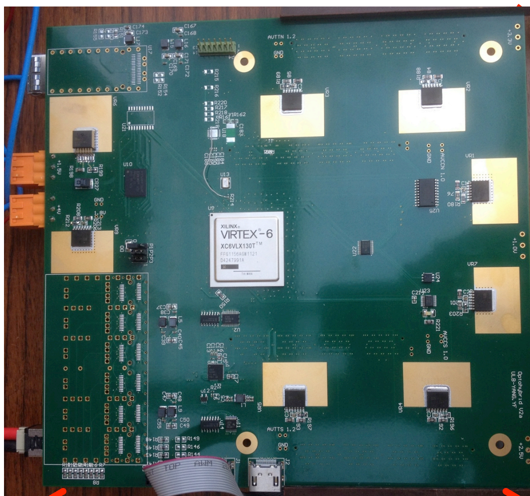
CMS triple-GEM signal simulations with GARFIELD



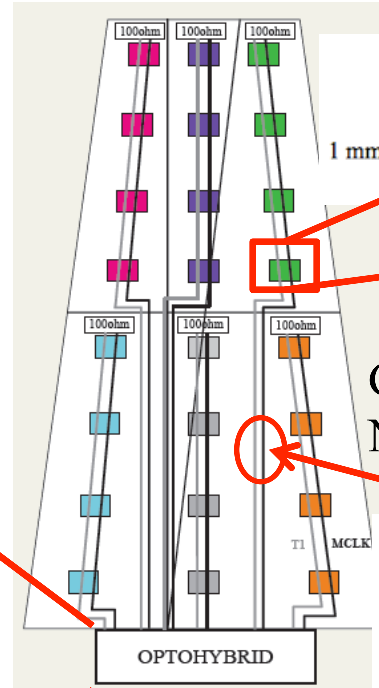


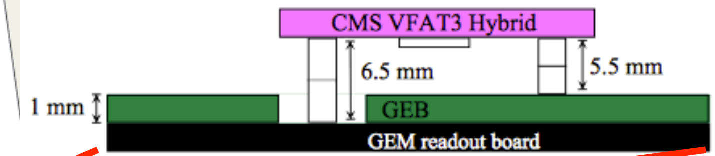
On-detector electronics

- GEB board:
  - GEM Electronics Board: large PCB to avoid cables along GEM
  - Plugged on the GEM readout board

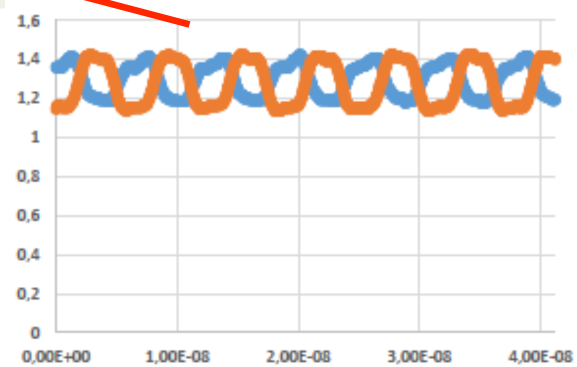


22 cm





GE1/1 GEB
Not at scale



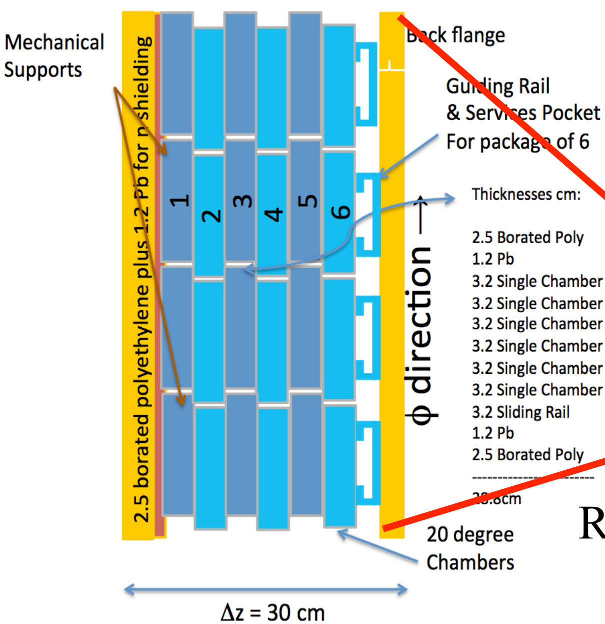
160 MHz LVDS signal over longest GEB line, within spec. for VFAT2 (40 MHz)

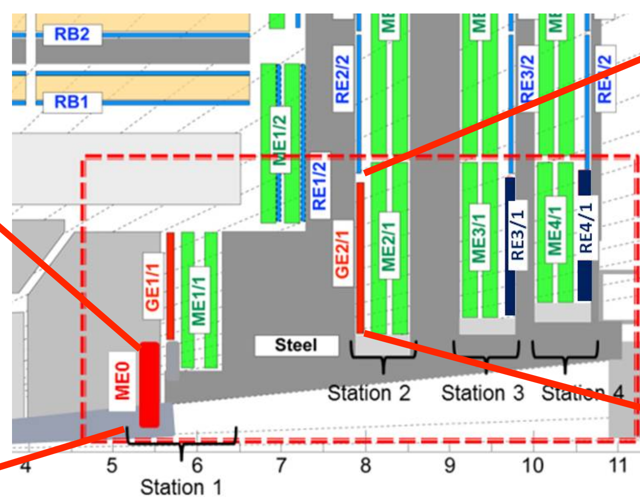
At CERN:

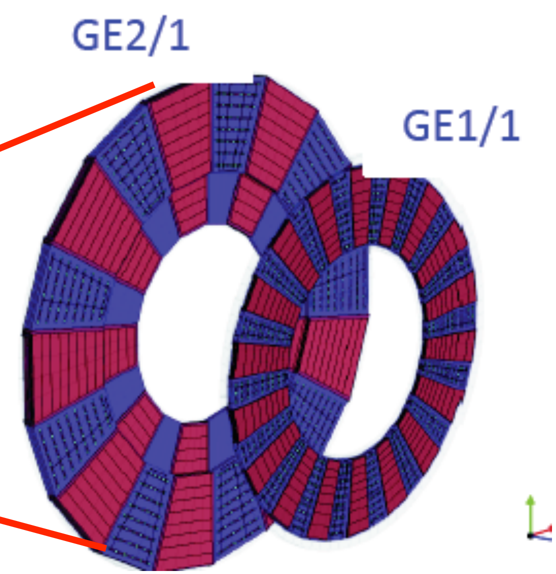
- GE1/1 electronics integration tests on-going with CSC detector and electronics
- Building a large (15 super-chambers) Quality Control cosmic test bench

Towards LS2 and beyond

- Full installation in LS2 (2018-2019)
  - 144 super-chambers equipped with VFAT3
- Slice test (YETS 2016)
  - 4 super-chambers will be installed during 2016 LHC End of Year Technical Stop
  - GE1/1 equipped with VFAT2 + OH + uTCA
  - GE1/1 data integrated to CMS DAQ
  - Goals: reduce commissioning period at the full installation, gain experience in integration
  - All components will be thoroughly qualified in the large Quality Control test bench
- LHC Phase II (LS3, 2022)
  - 2nd GE station (GE2/1) and forward tagger ME0





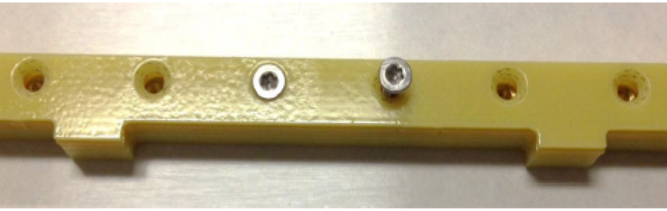


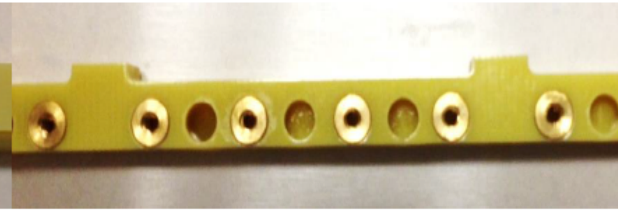
R&D ongoing: geometry, background rates, radiation hardness…

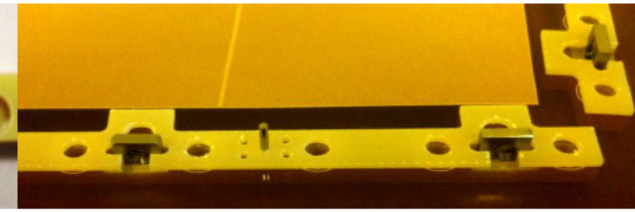
Summary

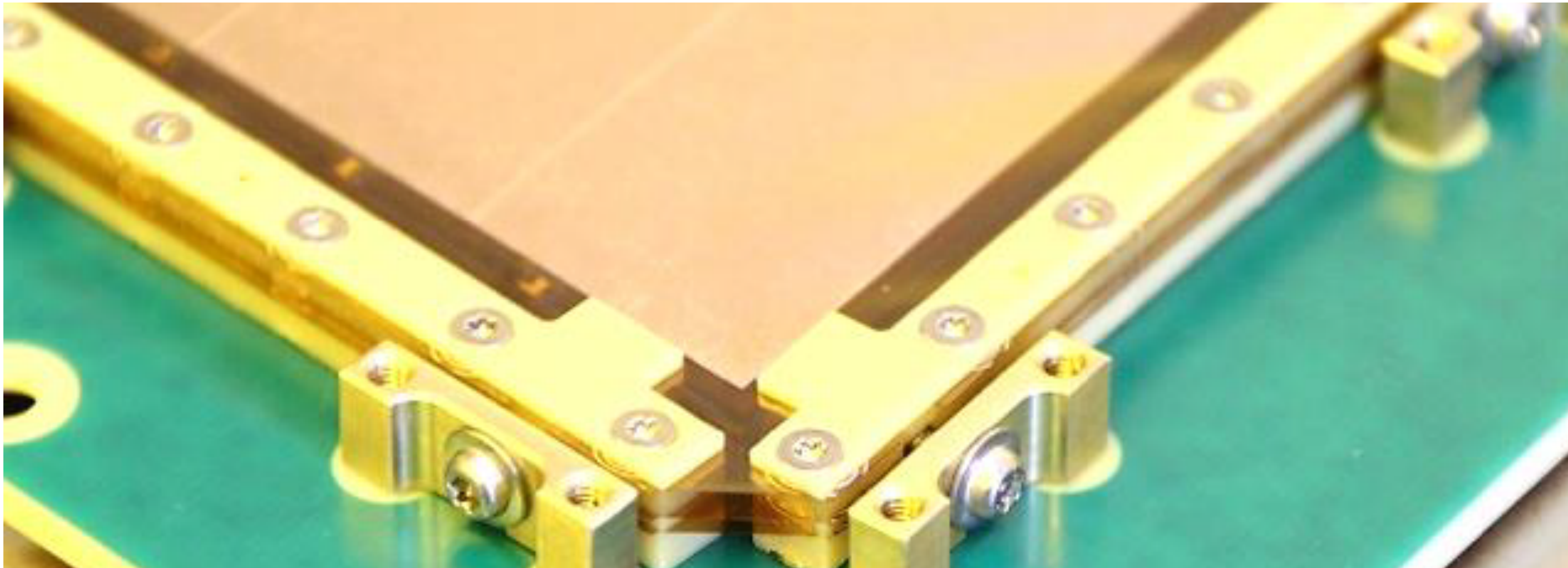
- CMS GEM project well on track
  - Technical Design Report (TDR) submitted to LHCC in March 2015
- Detector R&D :
  - 5 years of R&D has given us 6 generations of prototypes; each an improvement of the last!!!
  - GE1/1-V, test beam in fall 2014 for final performance measurements
  - GE1/1-VI, geometry changes to optimize detector acceptance in CMS
- Ageing measurements on-going (next at GIF++)
- Large Quality Control test bench being built (not shown in this presentation)
- 6 production sites ready (not shown in this presentation)
- Electronics and DAQ developments ongoing as well
  - VFAT3 analog part (incl. CFD) currently tested
  - 1st version of the new electronics (GEB, OH, uTCA, GLIB, …) tested with beam
  - 2nd version (longer GEB, OH with new FPGA,…) available and under test
  - Integration tests with CSC electronics started
- CMS GEM Community entering in production mode!

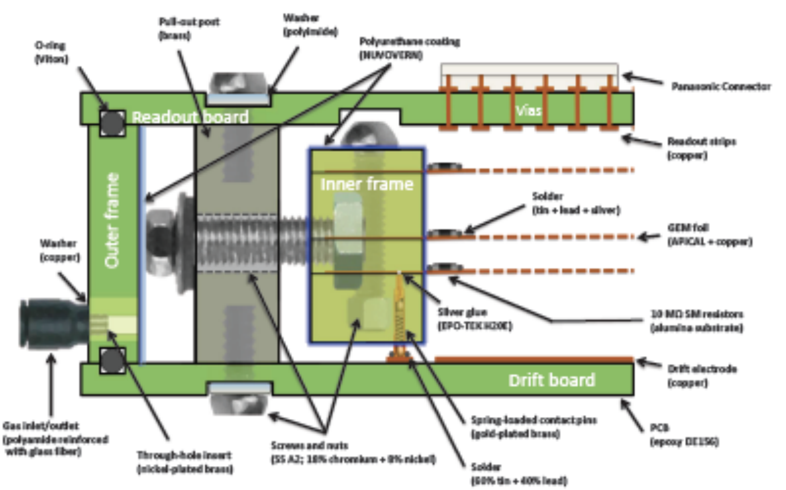
BACK-UP









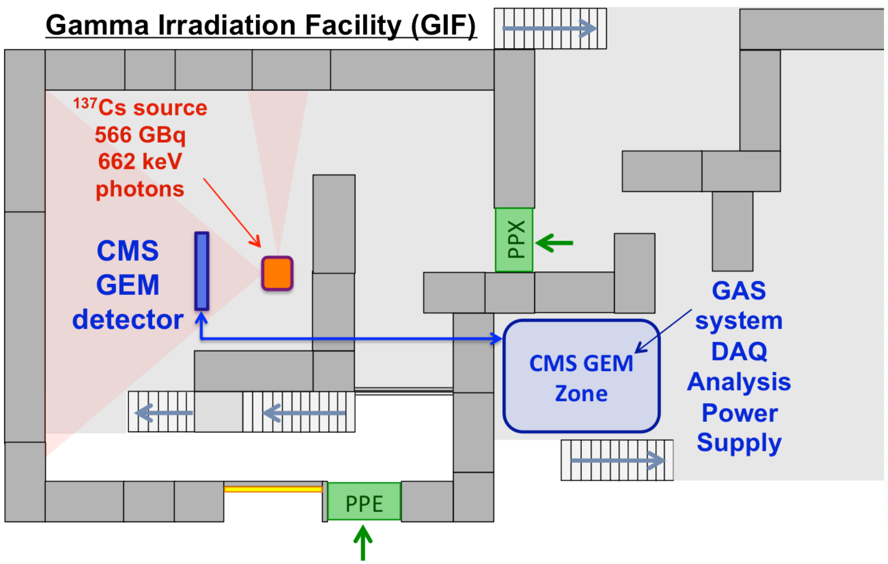


O-ring
(Viton)
Pull-out post
(brass)
Washer
(polyimide)
Polyurethane coating
(NUVOVERN)
Panasonic Connector
Readout board
Vias
Readout strips
(copper)
Outer frame
Inner frame
Solder
(tin + lead + silver)
GEM foil
(APICAL + copper)
Washer
(copper)
Silver glue
(EPO-TEK H20E)
10 MΩ SM resistors
(alumina substrate)
Drift electrode
(copper)
Drift board
Gas inlet/outlet
(polyamide reinforced
with glass fiber)
Through-hole insert
(nickel-plated brass)
Screws and nuts
(SS A2; 18% chromium + 8% nickel)
Spring-loaded contact pins
(gold-plated brass)
Solder
(60% tin + 40% lead)
PCB
(epoxy DE156)

Aging studies

Test at the CERN Gamma Irradiation Facility (GIF):

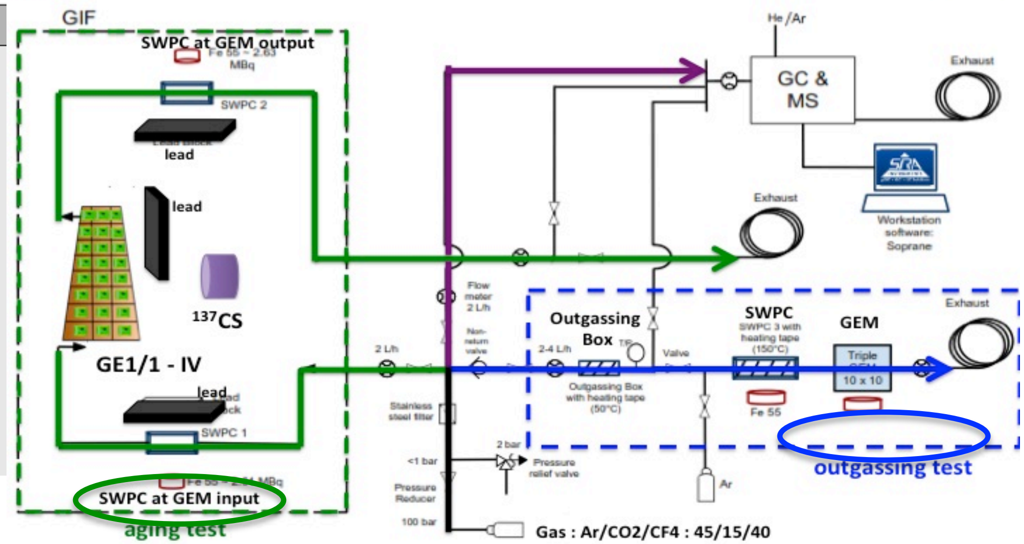
- Expected rate: few kHz/cm^2 → few 10s kHz/cm^2
- Expected charge after 10 years: 100 mC/cm^2



Gas system

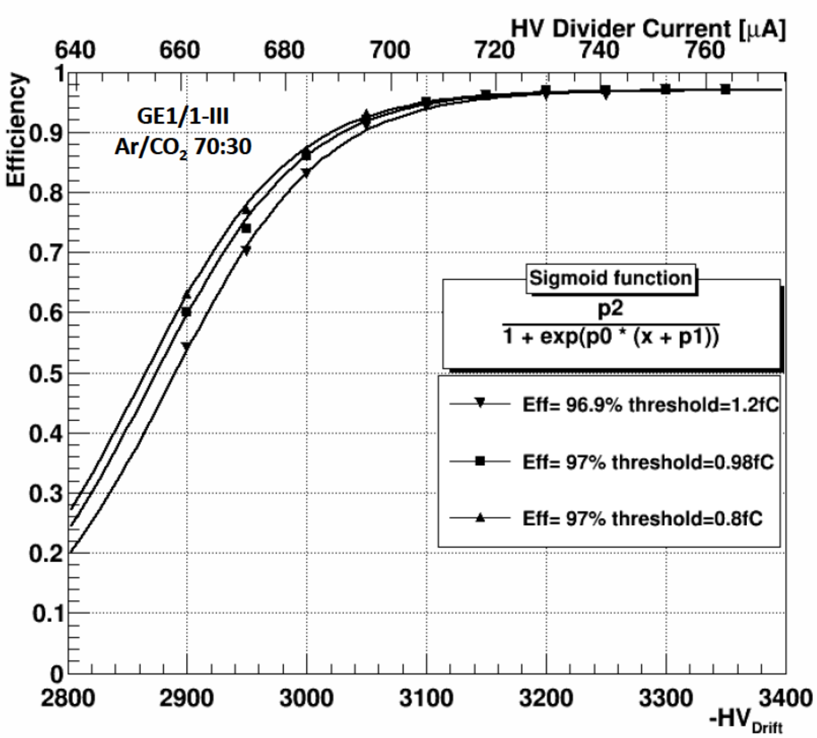
Classical aging test

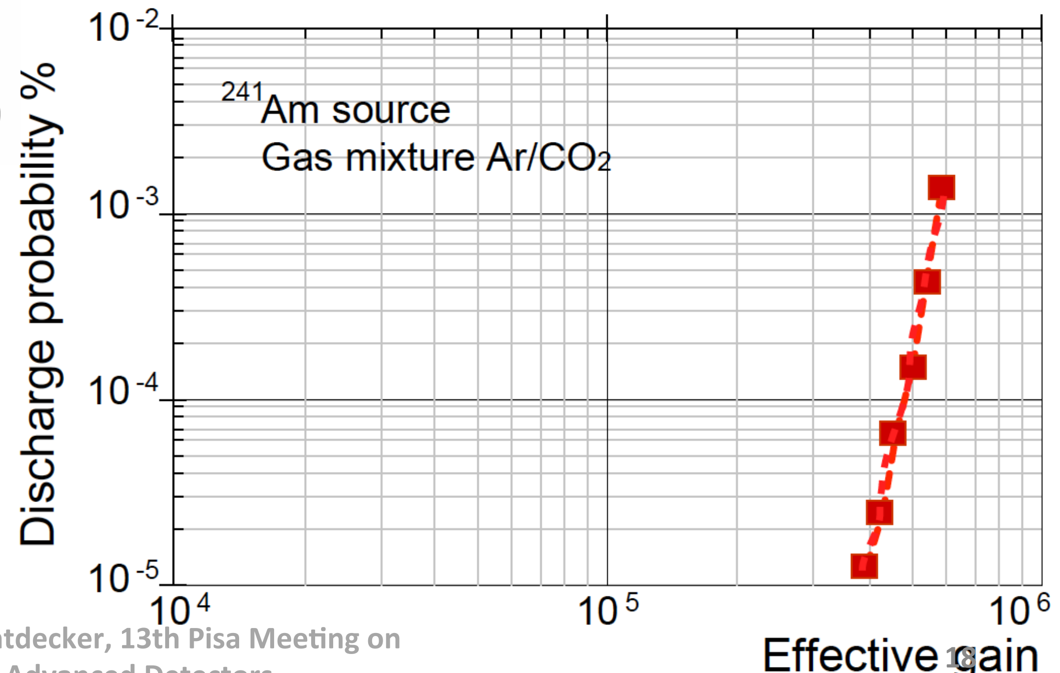
Outgassing test



- Test with GE1/1-IV (no spacer, no glue, final set of material)
- ^{137}Cs source
- ^{55}Fe sources for reference chambers
- ^{109}Cd source for outgassing study

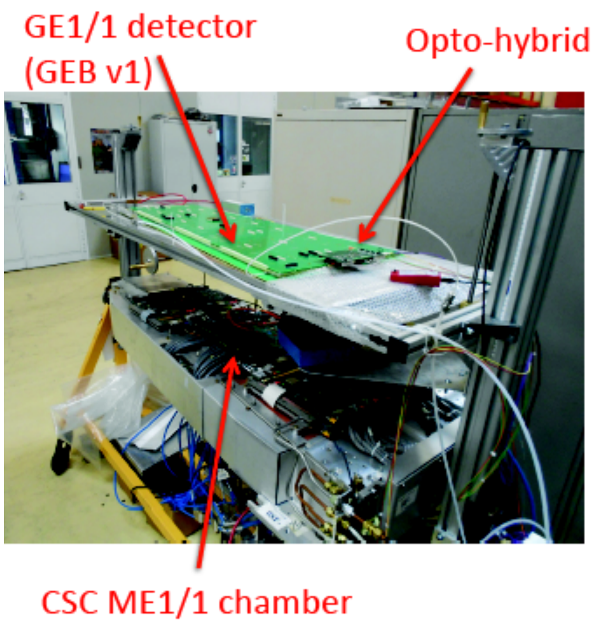
Performances



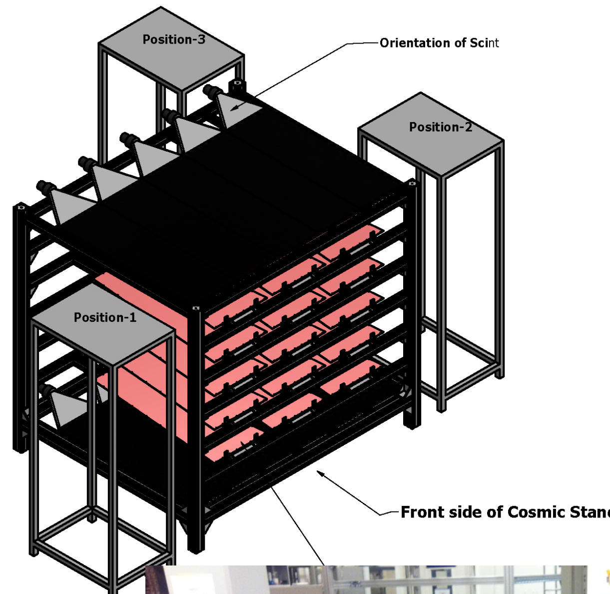


Next steps

- Integration facility:
  - 1 CMS ME1/1CSC & 1 GE1/1 detector
  - Integration of the new GE1/1 electronics
    - Get trigger signal from CSC detector and clock through the CMS TTC system
    - Use uTCA crate + GLIB + CMS AMC13



- Large Quality Control test bench:
  - 15 super-chambers at the same time
  - Efficiency & spatial resolution VS. HV
  - Results logged in performance database
  - Data taking will start in April 2016

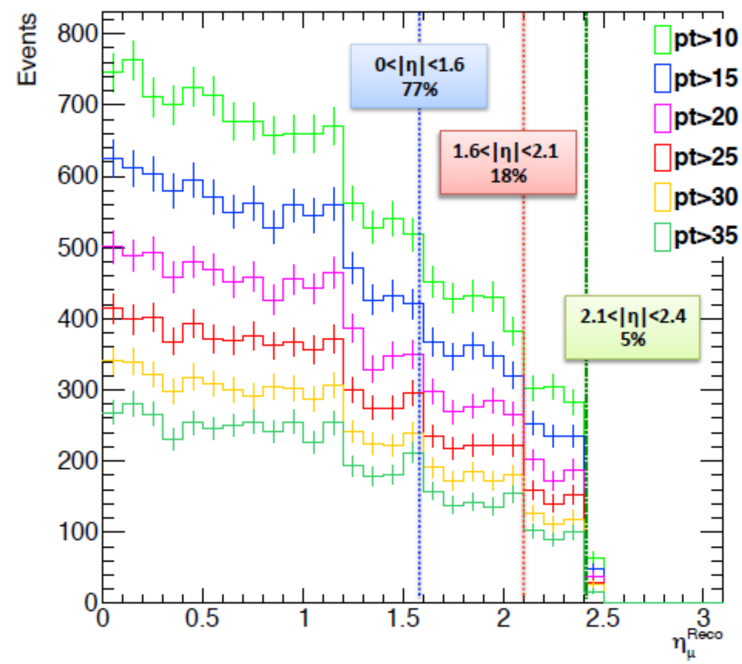


- Test beams:
  - First version of new GE1/1 electronics tested in Dec ’14
  - 2nd version will be tested in Fall 2015

GE1/1 physics

- **Redundancy** in 1.5 < |η| < 2.2 region with additional GEMs
  - ~20% of interesting physics channels (H→4μ, Z→2μ, H→ττ) in GE1/1 region
- **Lowering the trigger threshold**
  - in H→ττ yields gain in sensitivity :
    - H→ τ (μνν)τ(had)
    - H→ τ (μνν)τ(μνν)

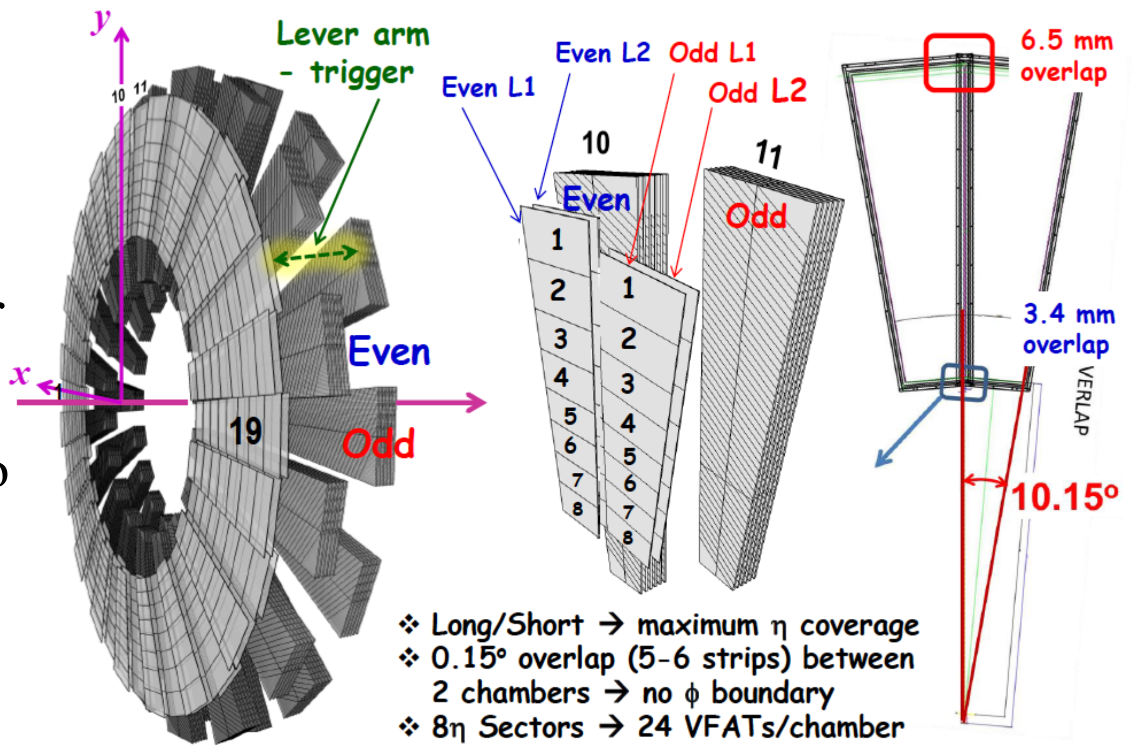
    } μ are soft, <p_T>~15 GeV
    - Lowering trigger pT from ~20 GeV (post-LS1 plan) to ~15 GeV = ~20% gain



- Challenge of **the forward region**. Impact of PU on muon reconstruction. Fraction of non-prompt muons in forward region increases dramatically with 140 PU.

The GE1/1 system

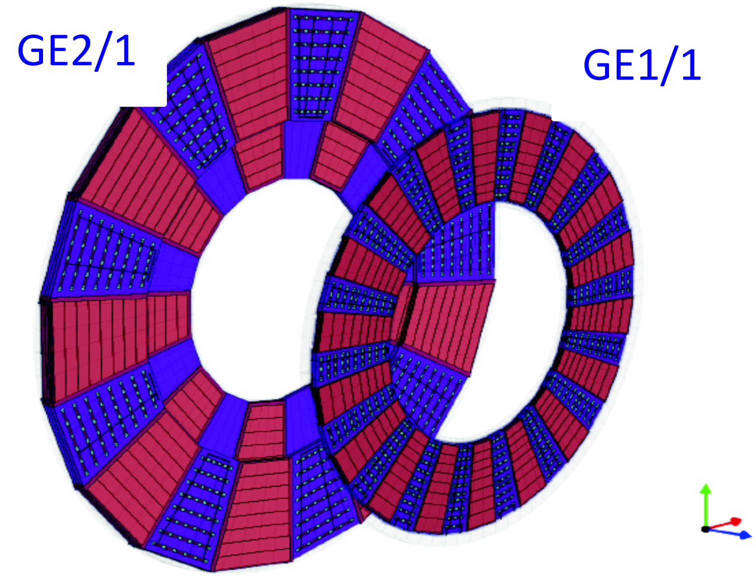
- $1.55 < |\eta| < 2.18$
  - Short and long chambers for maximum coverage
- 36 superchambers (SC) per side of CMS
  - Each chamber spans 10° in ϕ
  - 2 chambers/SC
  - 144 chambers total
- Total foil area ~140m^2



Five years of R&D has given us six generations of prototypes; each an improvement of the last!!!

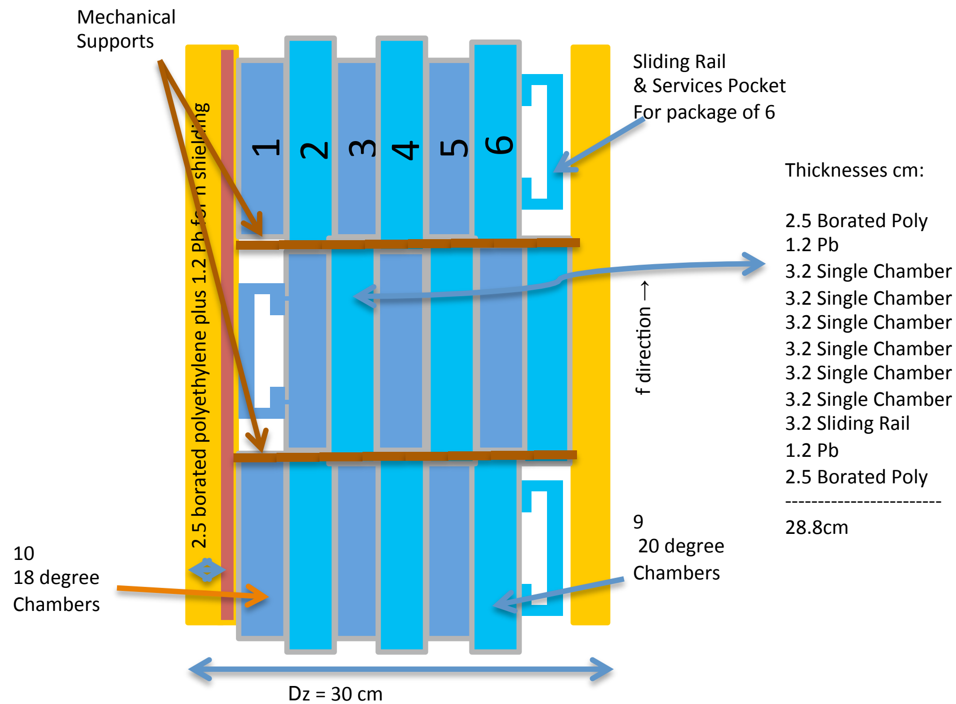
The GE2/1 system

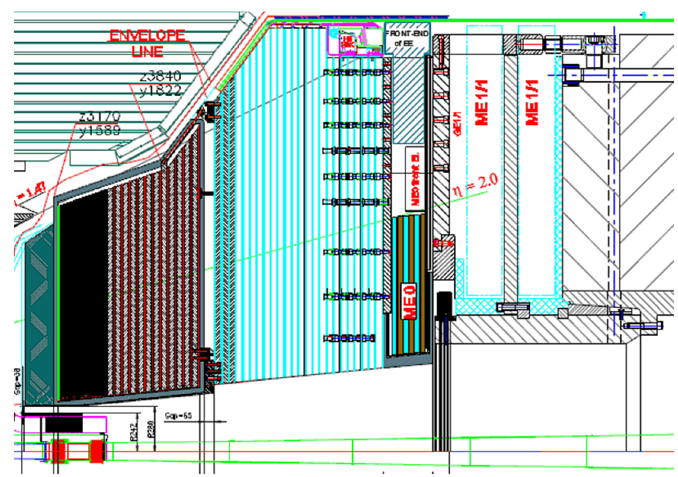
- $1.55 < |\eta| < 2.45$
  - Short and long chambers
  - Each chamber spans 20° in ϕ
  - 2 chambers/SC
  - 144 chambers total
- Targeting 2 rings of double-layered triple-GEM
  - one ring with 8 and one ring with 12 η partitions
- Total foil area ~145m^2



The ME0 system

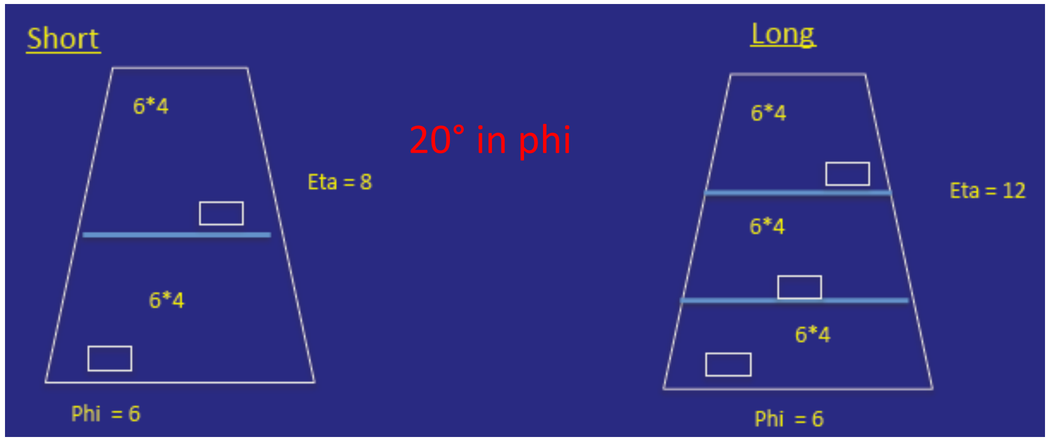
- $2.0 < |\eta| < 3.5$
  - 20° wedges affixed to back of upgraded CMS HCAL endcap
- Six layers of triple-GEM detectors
  - Design ongoing
- **Significantly increases muon acceptance for high profile analyses**
  - e.g. $H \rightarrow ZZ \rightarrow 4\mu$
- Total foil area $\sim 144 m^2$



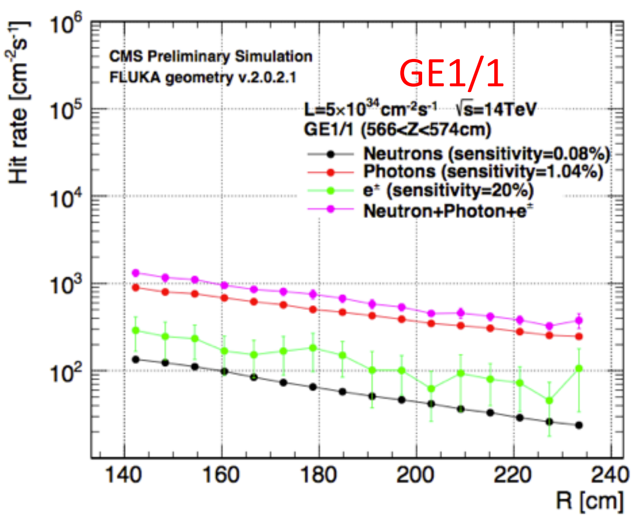


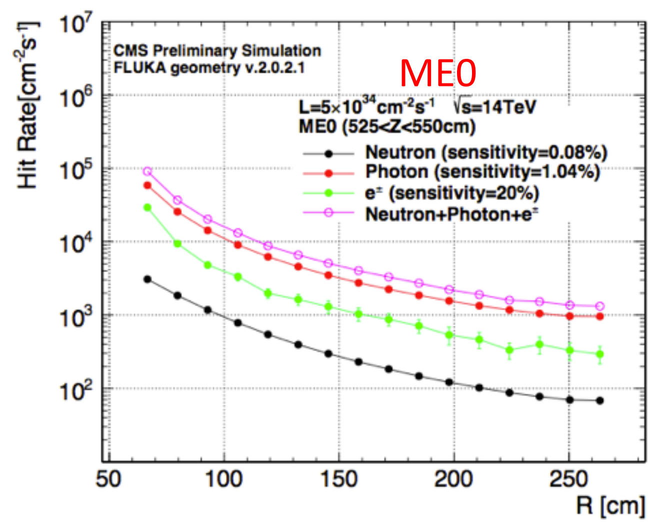
GE2/1& ME0 system considerations

- GE2/1 Long= 1816mm > manufacturer capability
  - Investigating segmentation of GEB board :



- ME0 will be exposed to rates > 10 x GE1/1 rates
  - Investigating data rates and bandwidth requirements





ME0 mean trigger & tracking rates

- Probability to hit the optical link bandwidth limit (3.2 Gbps / link):

Trigger	Data rate (Gbps)	Prob with 2 links	Prob with 3 links
Fast OR ZS	2.68	1.34%	0.02%

  - Still investigating other data format
  - Note: optical link bandwidth based on GBT. For LS3, higher speed GBT probably available

Tracking (L1A @ 1MHz)	Data rate (Gbps)	Prob with 1 links	Prob with 3 links
SPZS*	2.15	$<10^{-7}$	$<10^{-7}$

*SPZS: Sequential Zero Suppression a variant of the CMS RPC data format

- GE1/1 Probability to hit the optical link bandwidth limit (3.2 Gbps / link):

Trigger	Data rate (Gbps)	Prob with 1 links	Prob with 2 links
Fast OR ZS	0.05	$6\ 10^{-5}$ %	$<10^{-7}$