Istituto Nazionale di Fisica Nucleare
LABORATORI NAZIONALI DI FRASCATI

CMS STATUS

L. Benussi

On behalf of CMS Frascati group

54th Frascati Scientific Committee Meeting

LNF CMS STAFF

- **LNF staff**
  - Benussi L. 100%
  - Bianco S. 100%
  - Piccolo D. 100%
  - Muhammad S. 100% PhD Student
  - Raffone G. 50%
  - Primavera F. 100% (End October 2017)

- **Associated**
  - Ferrini M. 100% Roma1 Univ.
  - Saviano G. 100% Roma1 Univ.
  - Caponero M. 80% ENEA Frascati

- **Technicians**
  - Passamonti L 50%
  - Pierluigi D. 50%
  - Russo A. 50%

- GEM production coordinator (L. Benussi)
- RPC National Responsible (D. Piccolo)
- Muon Phase2 TDR RPC editorial coordinator (D. Piccolo)
- GEM Resource Manager (S. Bianco 2015-2017)

Alice Alfonsi defended her graduate thesis on Z' in July
S.Muhammad has submitted his PhD Thesis in Materials Engineering in October."

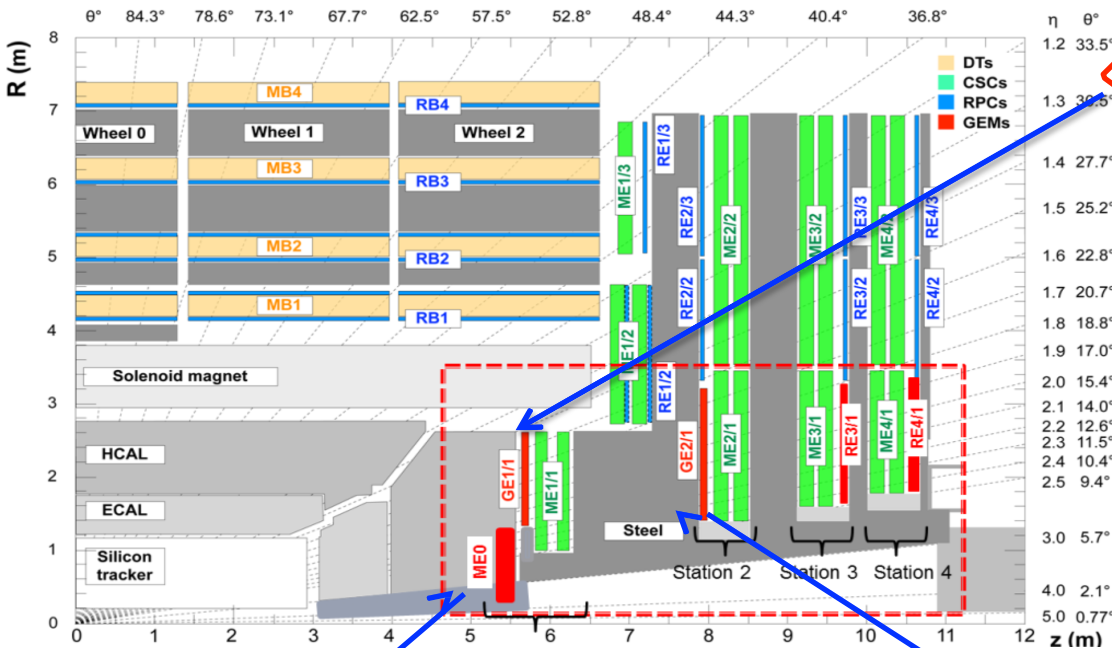
CMS LNF major activities guidelines

1. GE1/1 chamber production site and global GE1/1 production coordination
2. R&D on eco-gas and material compatibility with new gas mixtures
3. R&D GEM Phase2: study, characterization and development of a μ-RWELL detector for possible installation in CMS (GE2/1 or/and ME0)
4. Development of a FBG sensor network as temperature monitor for the GE1/1 (and GE2/1-ME0 detector).
5. Search for high mass resonances in dimuon channels
6. Editorial responsibility of Muon Phase2 TDR for the RPC detector
7. Maintenance and operation of RPC Gas Gain Monitoring system

1

GE1/1 Chambers Production Site And Global GE1/1 Production Coordination

GE1/1 and GEM R&D for Phase2



GE1/1: Embarking on productio

Trigger and reconstruction

- 1.55 < |η| < 2.18
- baseline detector for GEM project
- 36 staggered super-chambers (SC) per endcap, each super-chamber spans 10°
- One super-chamber is made of 2 back-to-back triple-GEM detectors
- Installation: LS2 (2018-19)
- 144 Chambers

GE2/1:R&D in progress

Trigger and reconstruction

- 1.55 < |η| < 2.45
- 18 staggered SC per endcap,
- chamber spans 20°
- Installation: LS3 (2022-24)
- 216 Chambers

ME0 : R&D in progress

- Muon tagger at highest η
- 6 layers of Triple-GEM
- chamber spans 20°
- Installation: LS3 (2022-24)
- 72 Chambers

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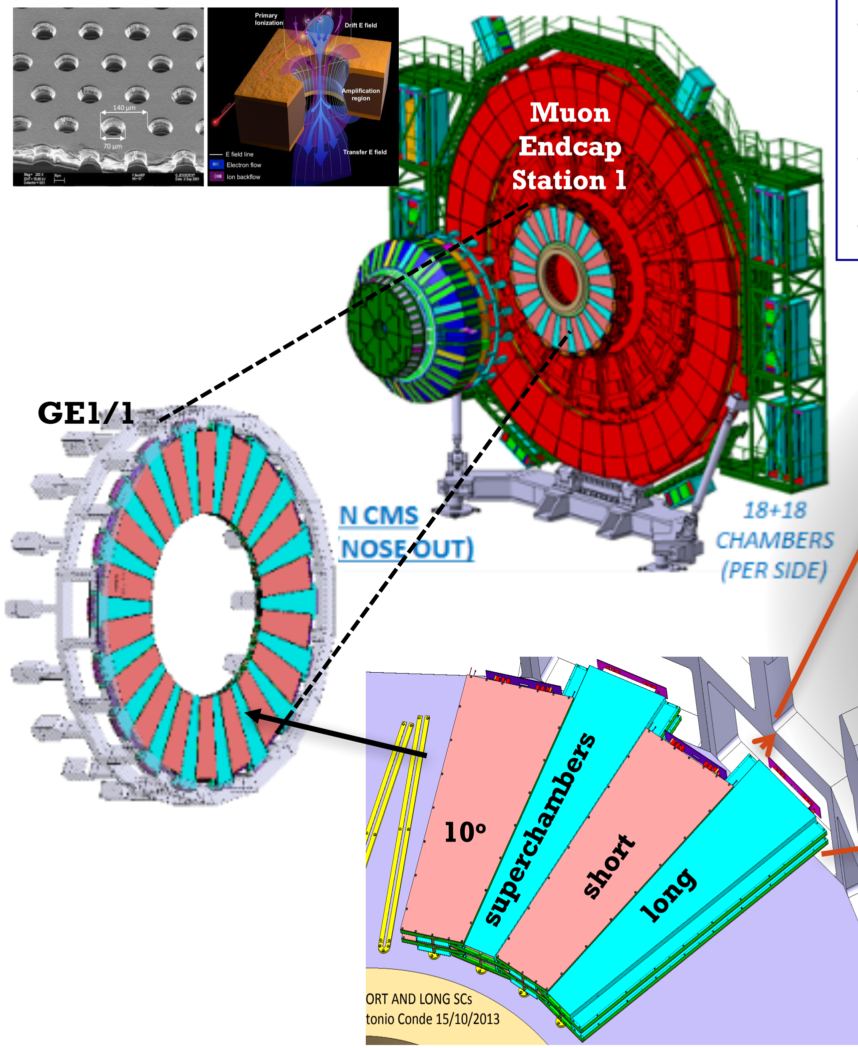
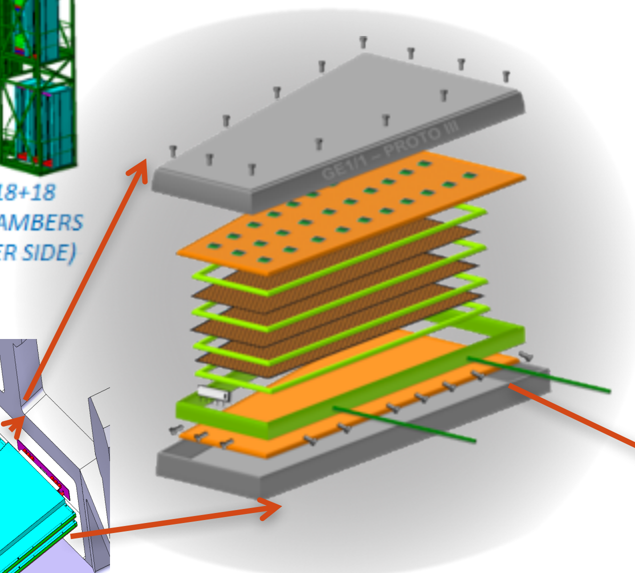
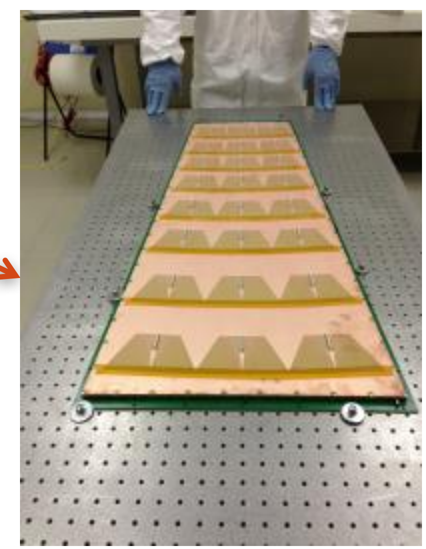
GE1/1 Detector

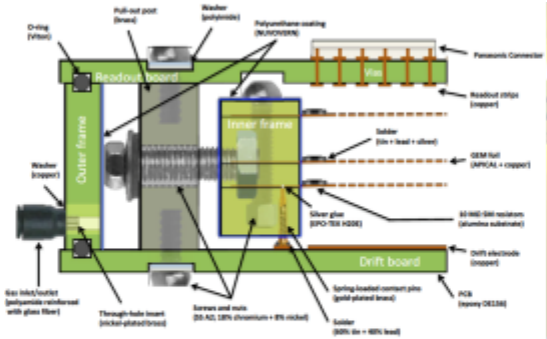
- GE1/1 in high-η region1.5<|η|<2.2
- 10^0 trapezoidal triple-GEM chambers, 144 in total
- Long (1.5<|η|<2.2) and short (1.6<|η|<2.2) version
- 36 super-chambers in each endcap.

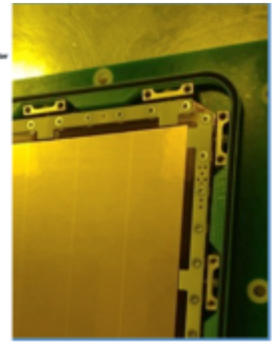






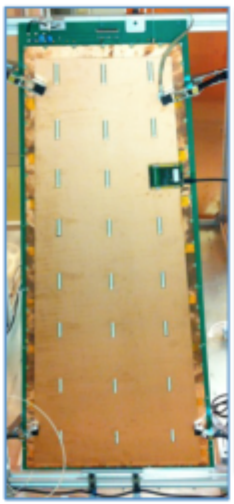
GE1/1 Detector

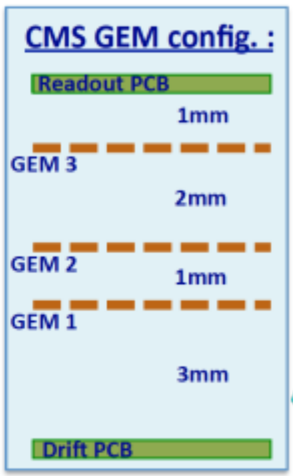


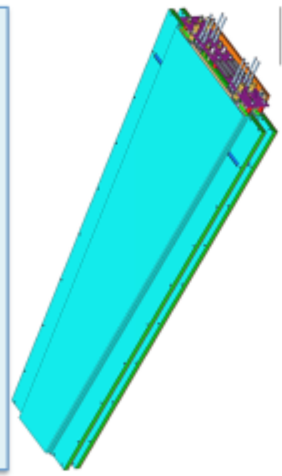


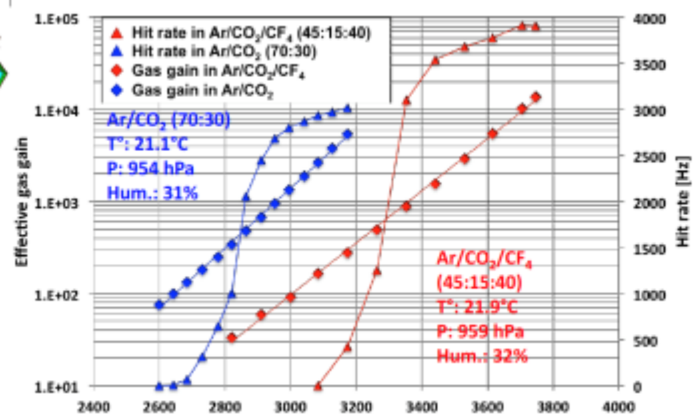
CMS Collaboration, CERN-LHCC-2015-012, CMS-TDR-013

- Size: 1-1.2 × 0.22-0.45 cm²
- Single-mask GEM foil × 3
- Gap configuration: 3/1/2/1 mm
- Readout sectors 3 × 8 in ϕη-plane
- Total channel count: 3072
- Passive resistive divider
  - All fields change *simultaneously*
- Final gas mixture still under study









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

- GE1/1 Assembly technique completely glue-free.
- Totally mechanically assembled.
- Chambers can be fully disassembled if problems during constructions
- This choice is cost effective and reduce enormously the time needed for the assembly

GE1/1 Detector final production

- Frascati has the responsibility to assemble up to 20 GE1/1 chambers
- GE1/1 chambers assembly started on November 2017
- Assembly time budget 1 chamber/working week
  - GE1/1 Assembly 1 day
    - GEM foils check
    - Chamber assembly
  - Gas Leak Test: 1 day
  - HV test and signal monitoring: 1 day
  - Gain uniformity test: 2 days

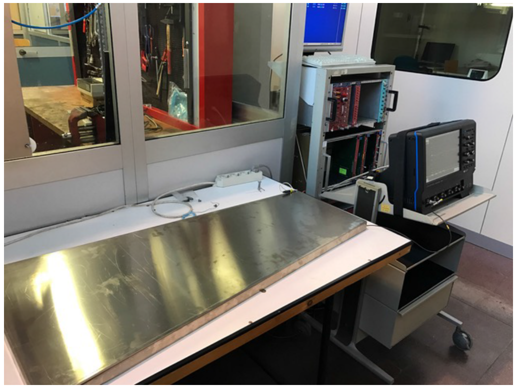
  30 weeks (20 + 10 of contingences) needed to complete 20 GE1/1 chambers in Frascati (1 Physicist & 1.5 Technicians)

GE1/1 Detector final production

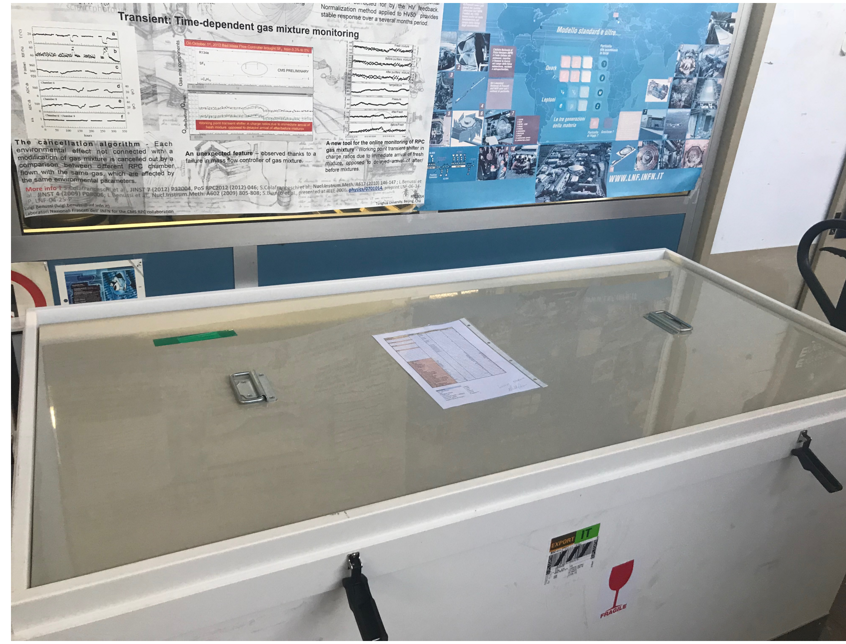
- Clean room ready and fully operational (class<1000) equipped with 2 benches for the assembly.

- X-ray station for gain uniformity test ready. X-ray gun Amptek 50keV installed in the bunker.

- Gas system ready

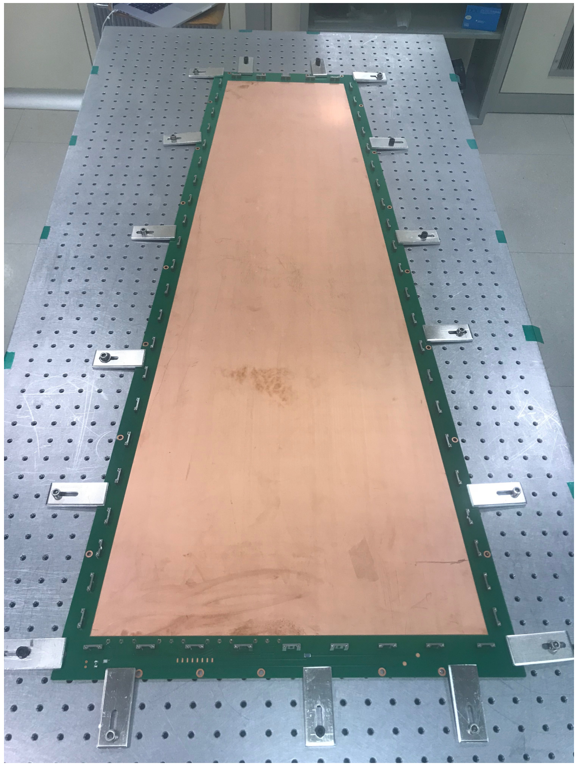


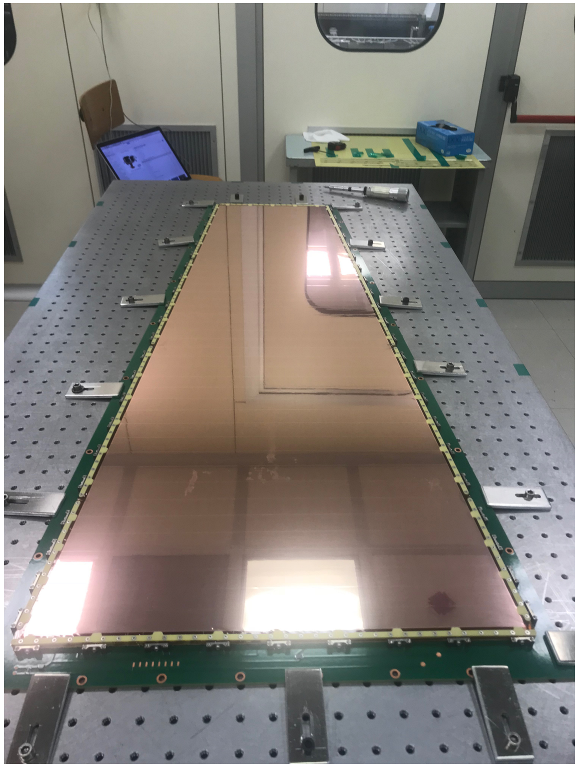
GE1/1 Detector final production

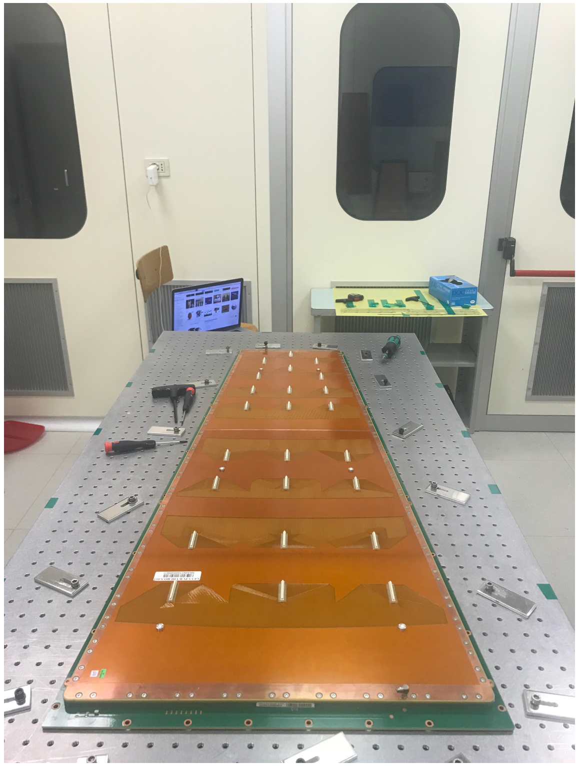


GE1/1 Started! On October 20 the first two GE1/1 kits arrived at Frascati

GE1/1 Detector final production







The first GE1/1 chamber fully assembled is now undergoing the QC test for final acceptance before being shipped back to CERN

GE1/1 Global production coordination

GE1/1 Global production plan

<table>
<tr><th></th><th colspan="7">2017</th><th colspan="12">2018</th><th colspan="5">2019</th></tr>
<tr><th></th><th>June</th><th>July</th><th>August</th><th>September</th><th>October</th><th>November</th><th>December</th><th>January</th><th>February</th><th>March</th><th>April</th><th>May</th><th>June</th><th>July</th><th>August</th><th>September</th><th>October</th><th>November</th><th>December</th><th>January</th><th>February</th><th>March</th><th>April</th><th>May</th></tr>
<tr><td>Electronics</td><td></td><td></td><td></td><td colspan="5">Production</td><td colspan="3">Test and Delivery</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2" rowspan="5">Ready for P5 installation</td></tr>
<tr><td>1st endcap production</td><td colspan="12">Production 1st endcap</td><td>OK</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>1st endcap super-chamber</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="7">S-C Assembly and cosmic test (1st endcap)</td><td>OK</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>2nd endcap super-chamber</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="6">S-C Assembly and cosmic test (2nd endcap)</td><td>OK</td></tr>
<tr><td>Production reviews</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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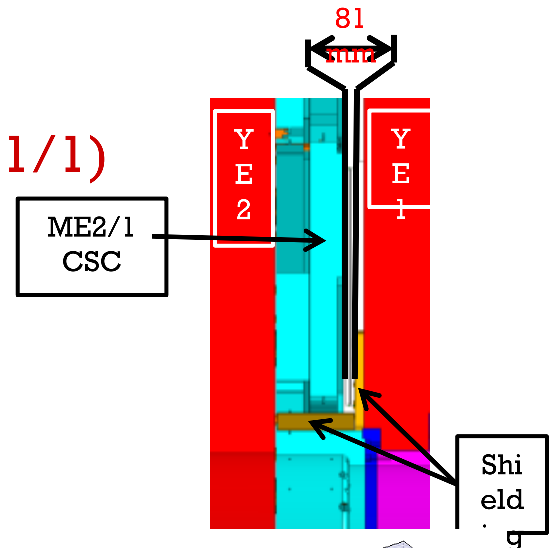
3

R&D GEM Phase2: Study, Characterization And Development of a μ-RWELL detectors for a possible installation in CMS (GE2/1 Or/And ME0)

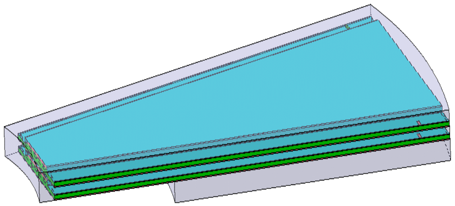
GE2/1 Detector layout

20° GE2/1, with more than 3 times the area of GE1/1, will be the largest MPGD detector ever built.

-for GE2/1 (74 mm available, 20 mm less than GE1/1)



The construction of a GEM requires some time-consuming assembly steps such as the stretching (with quite large mechanical tension to cope with, 1 kg/cm) of GEM foils.
The splicing/joining of GEM foils smaller detectors–to realize large surfaces is difficult unless introducing not negligible dead zones (2÷3 mm).



Foil stretching without spacers and no-gluing (NS2 technique developed for GE1/1) should be validate for the larger area of GE2/1

CMS is currently investigating the application of the following technology for GE2/1 station :

The μ-RWELL (by G. Bencivenni et al)

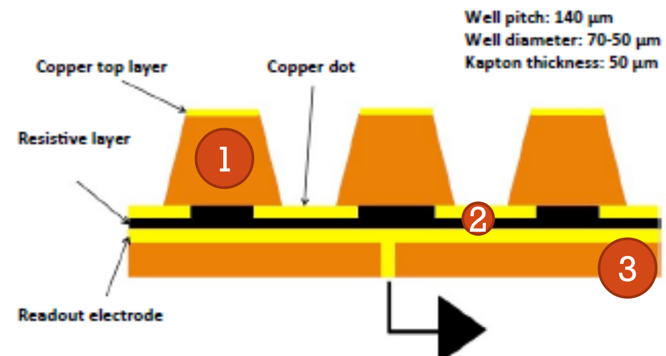
JINST 12 (2017) no.06, C06027

μ-RWELL

The goal of this study is the development of a novel MPGD by combining in a unique approach the solutions and improvements proposed in the last years in the MPGD field (RD51).

The μ-RWELL is realized by coupling:

1. a "suitable patterned GEM foil" for the "amplification stage"
2. a "resistive stage" for the discharge suppression & current evacuation
3. a simple readout PCB board



The simplest scheme of μ-RWELL detector

The detector is compact, simple to build & cost effective :

- only two mechanical components: μ-RWELL_PCB + cathode
- no critical & time consuming assembly steps: no gluing, no stretching, easy handling
- no stiff & large frames
- large area with PCB splicing technique (dead zone <0.5 mm)

The μ-RWELL is easy to operate:

- very simple HV supply: 2 independent channels or a trivial passive divider

μ-RWELL GE1/1 prototype

The first large size prototype (GE1/1 like) has been assembled and test in H8 test beam area and GIF++ (ongoing).

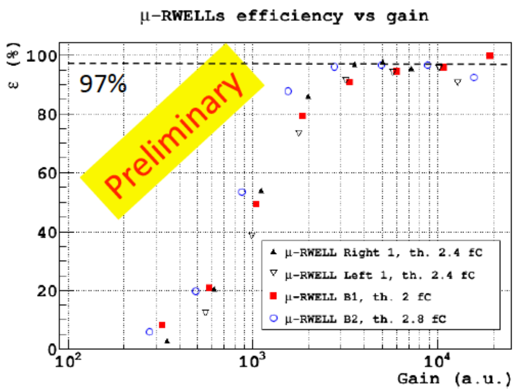
μ-RWELL in their location inside the GIF++

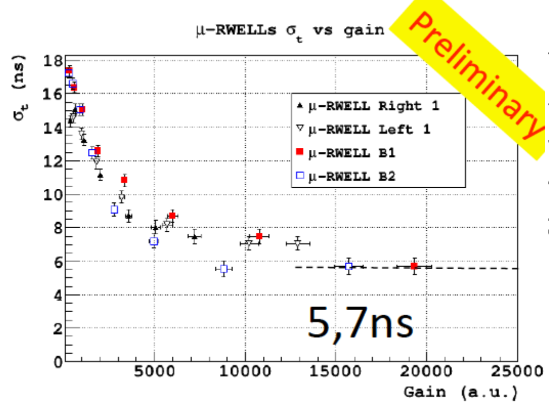
test started on begin of April, detectors running smoothly since then

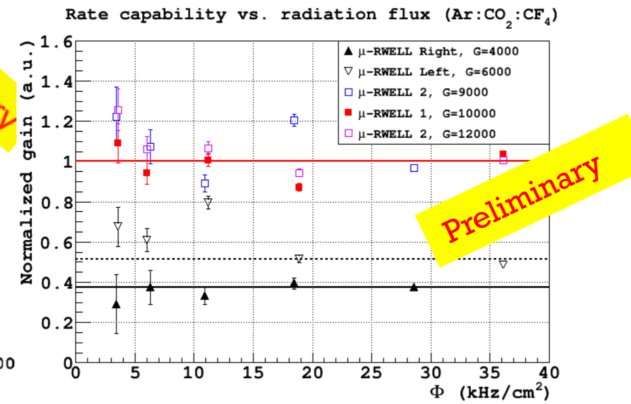
In collaboration with G. Bencivenni, G. Morello and M. Poli-Lener

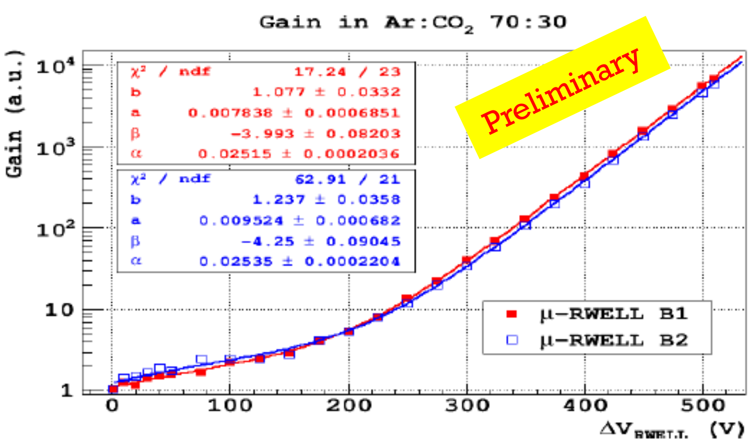
Partially funded by AIDA2020 project

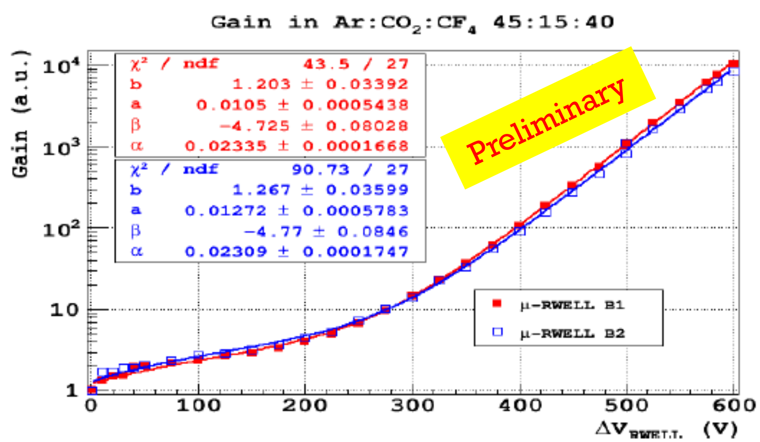
μ-RWELL GE1/1 prototype





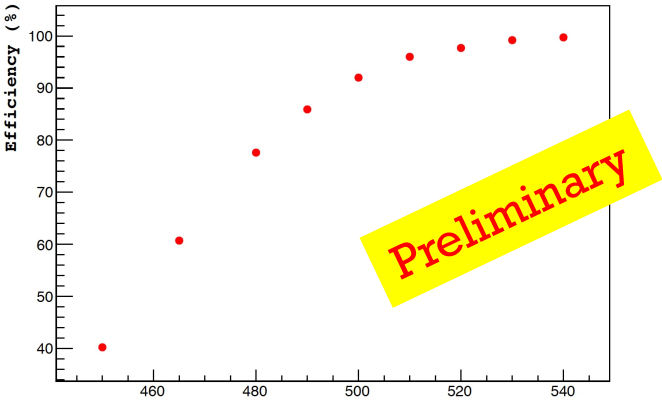


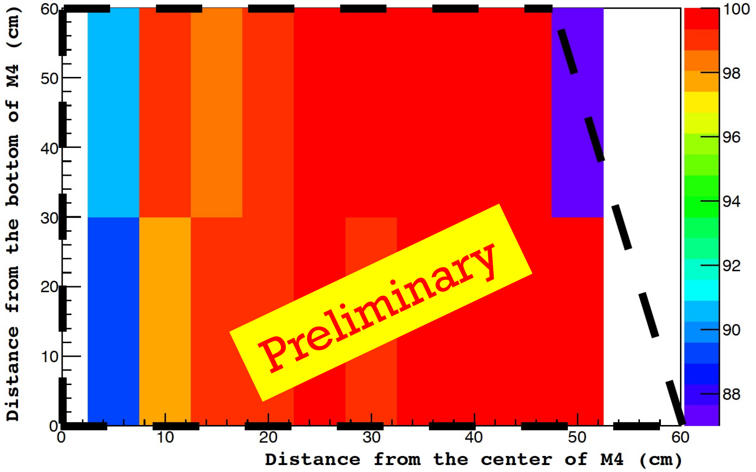


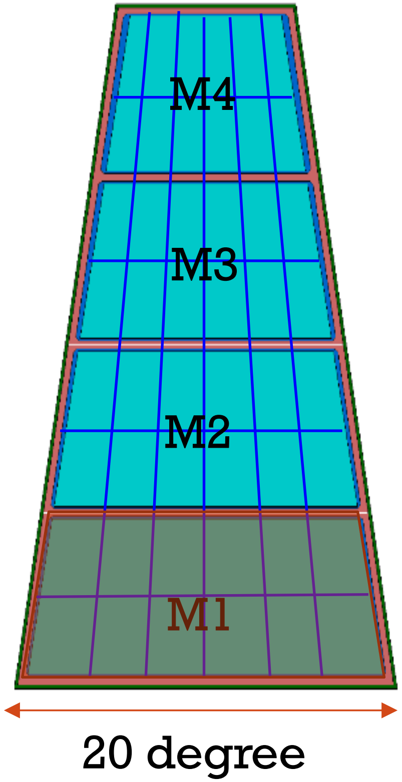


μ-RWELL GE2/1 prototype

A second prototype has been assembled of the dimensions of the M4 sector of a GE2/1 chamber and tested in H4 in July







2 R&D on Eco-gas And Material Compatibility With New Gas Mixtures

R&D phase2: Eco-friendly gas mixtures

General issues

- We are looking for an eco-gas component to replace R134a and eventually SF_6 with performance similar to present RPC and GEM system and working if possible with the same front end electronics
  - FEB threshold ~150 fC
  - Total charge per hit ~30pC (imply ~1.5 pC induced charge)
  - Cluster size ~2
- Identified Gas components
  - CO_2
  - HFO1234ze *tetrafluoreprophene*
  - HFO1234yf (warning HMIS =2 moderate flammability)

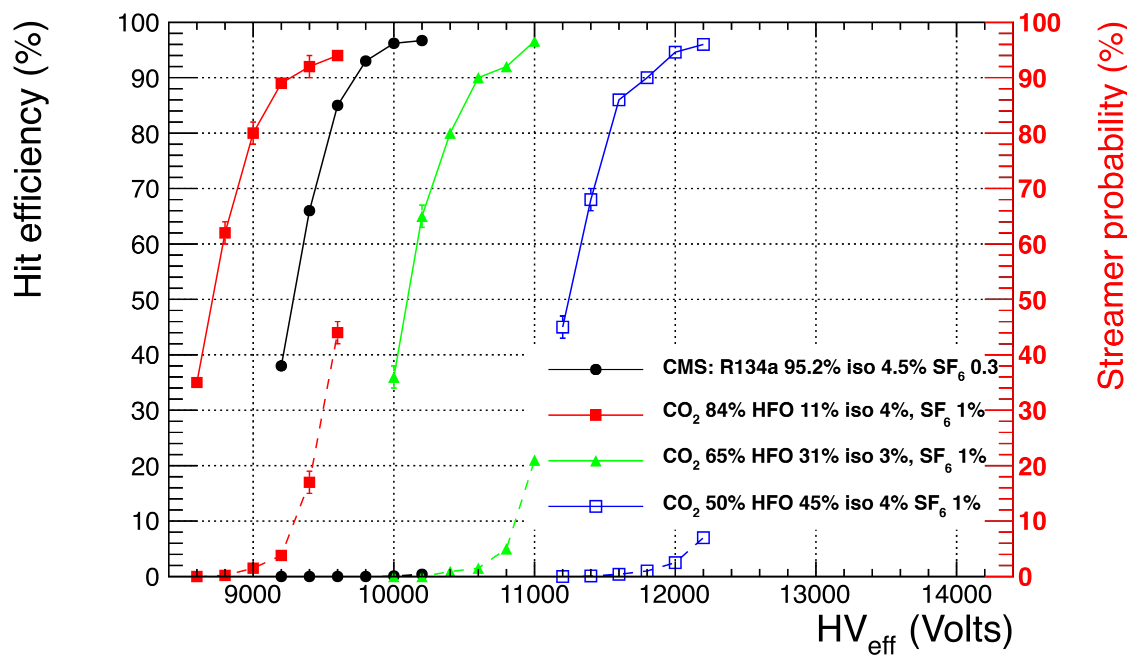
Ref:
L. Benussi *et al.*
A study of HFO-1234ze (1,3,3,3-Tetrafluoropropene) as an eco-friendly replacement in RPC detectors
E-Print: arXiv-1505.01648

L. Benussi *et al.*
Properties of potential eco-friendly gas replacements for particle detectors in high-energy physics
e-Print: arXiv:1505.00701

R&D phase2: Eco-friendly gas mixtures

- A common R&D (ATLAS+CMS) has been funded by INFN on this subject. LNF has a major role with the responsibility this task for the CMS RPC and GEM.
- Testing HFO 1234ze/Ar eco-friendly gas mixtures

L. Benussi *et al.*,
A study of HFO-1234ze (1,3,3,3-Tetrafluoropropene) as an eco-friendly replacement in RPC detectors
E-Print: arXiv-1505.01648



R&D phase2: Eco-friendly gas mixtures

- Once identified a good candidate we have to study chemical compatibility with RPC and GEM material.
- The strategy followed is two-fold, namely a static and a dynamic search.
  - The static search is performed by comparing materials properties (by means of SEM-EDS, XPS, XRD, FTIR analyses) before and after exposure to candidate ecogases in standard operating conditions.
  - The dynamic search consists of sampling and analysis (mass spectrography, F- and Cl- sensors) of candidate ecogases as exhausted by detectors after operation in electric fields and irradiation conditions.
- Activity coordinated by Associates from Sapienza and collaboration Politecnico Torino.
- Great collaboration with LNF Servizio Luce
- Joint ATLAS-CMS phase 2 R&D approved and financed by INFN

4

Development of a FBG Sensor Network as Temperature Monitor for The GE1/1 (And GE2/1-ME0 Detectors).

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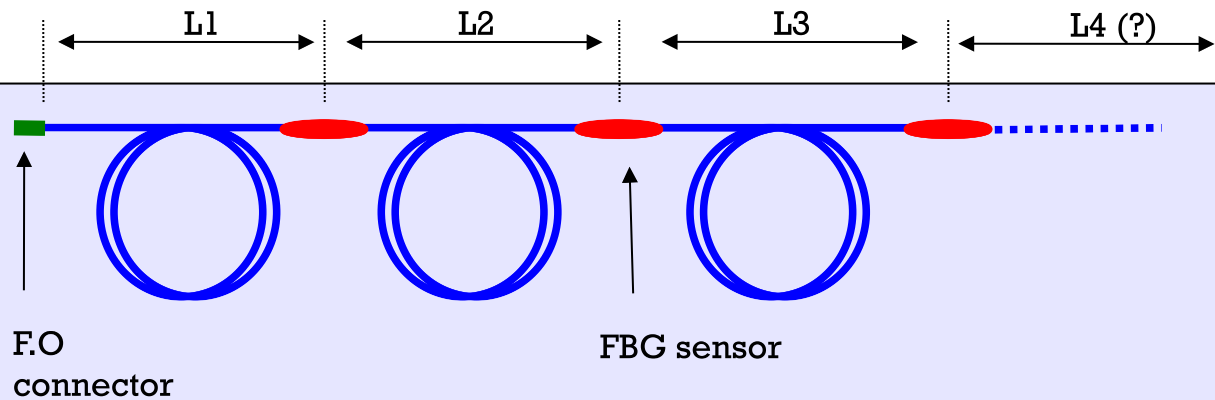
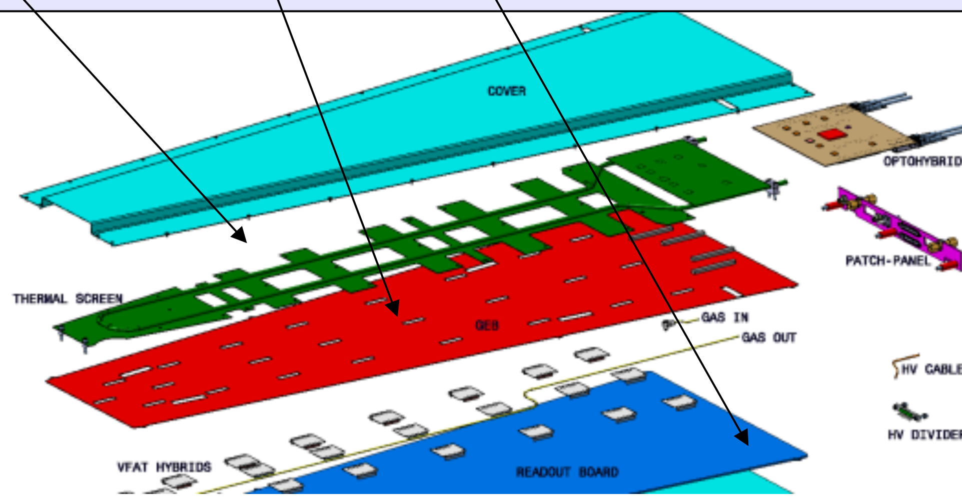
Development of a FBG Sensor Network as Temperature Monitor for The GE1/1 (And GE2/1-ME0 Detectors).

Temperature monitoring of GEM by use of Fiber Bragg Grating sensors



Production and calibration of arrays of FBG sensors, custom dimens
ready to be deployed on: Cooling Plate; GEB; Readout Board

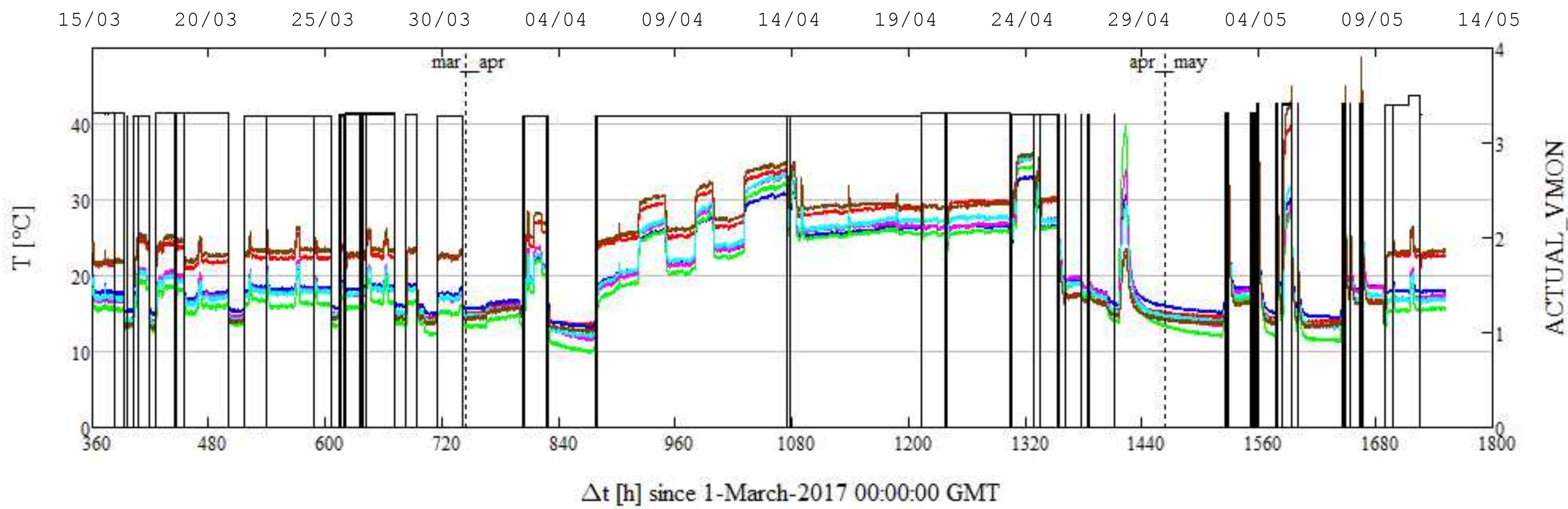


Array of FBG sensors on GEM:

- naked Optical Fibre (d=0.25mm)
- Fast response
- can fit between boards
- Activity coordinated by associates fromENEA

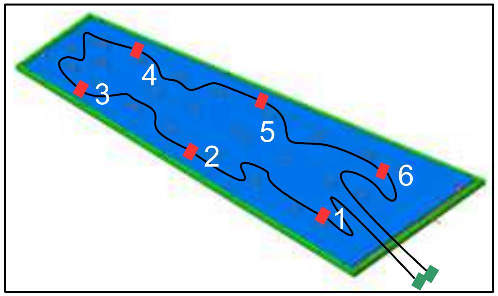
Development of a FBG Sensor Network as Temperature Monitor for The GE1/1 (And GE2/1-ME0 Detectors).

One chamber installed in the GE1/1 slice test has been already equipped with a FBG array.



Note 1:
Plot shows OptoHybid-4V series;
OptoHybrid-2V and GEB-VFAT have identical time-history

Note2:
Calibrationt on FOS data for Temperature value to be optimised.



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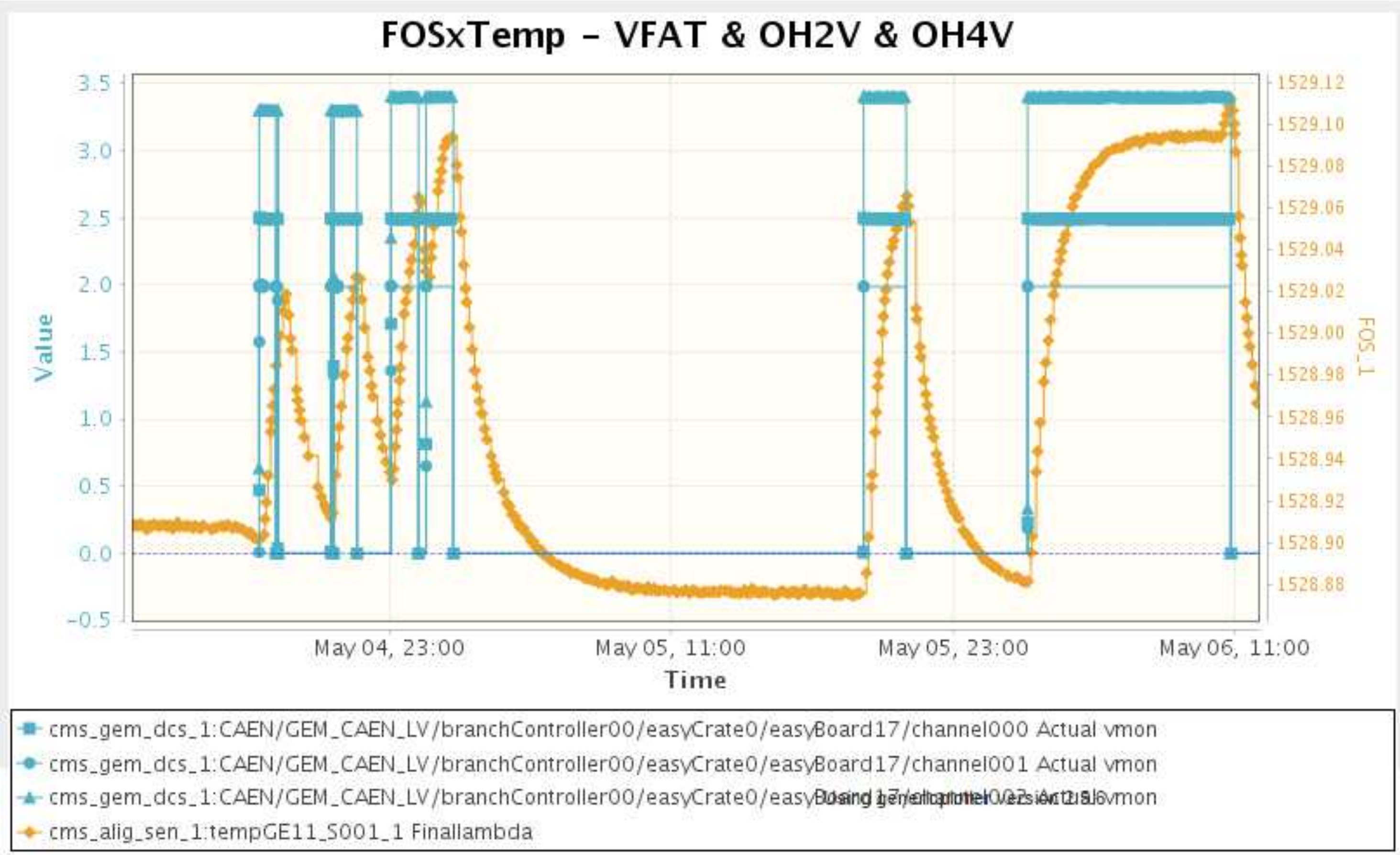
Development of a FBG Sensor Network as Temperature Monitor for The GE1/1 (And GE2/1-ME0 Detectors).

Clear correlation between FBG sensors and LV ON/OFF



5 Search For High Mass Resonances In Dimuon Channels

Search for high mass resonances in dimuon channels

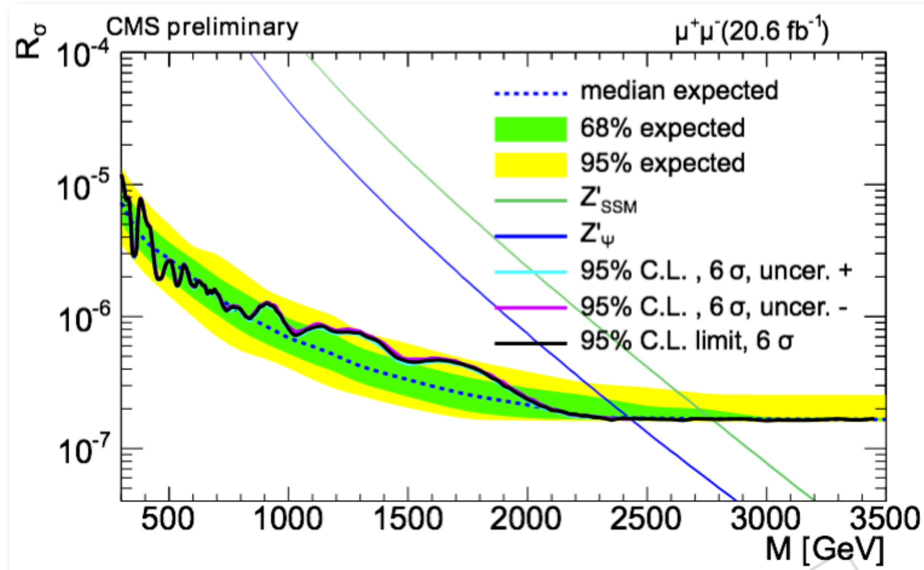
Run 1 results using 20.6/fb of data at $\sqrt{s}$ = 8 TeV:

excluded Z'_{ψ} (Z'_{SSM}) with mass up to 2.4 (2.8) TeV

Perspectives for Run2:

for resonances with mass between 2 and 3 TeV we can reach the same sensitivity of Run1 with ~1 fb^{-1} of data collected at 13 TeV

The search for Z' decaying into di-lepton pairs is one of the CMS "early analysis".



LNF contribution:

- Hotline analysis (using the Official Package developed since Run1 and modified for Run2)
- Background estimation
- Trigger studies
- Plan is to use the present analysis expertise to study the impact of muon upgrade on Z' for HL-LHC
- Assegno di ricerca ended in 2017, request a new in 2018 (two candidates available) to not stop this important analisys line.
- Ref. AN-15-061, AN-15-223 AN-16-391 and PAS EXO-16-047

Conclusions

- The group play a primary role inside the CMS muon detector
- CMS Frascati group leads the GE1/1 production as production site and as global production coordination
- Relevant contribution to R&D in progress for Muon upgrade
- Both construction plan and R&D plan fit well with the group size and skills
- R&D and Construction timelines well synchronized
- Relevant Z' analysis activity finalised in three AN. Assegno di ricerca ended in 2017, request a new in 2018 (two candidates available)

List of publications 2016-2017

1) Overview of large area triple-GEM detectors for the CMS forward muon upgrade
By D. Abbaneo et al..
10.1016/j.nima.2016.05.127.
Nucl.Instrum.Meth. A845 (2017) 298-303.

2) R&D on a new type of micropattern gaseous detector: The Fast Timing Micropattern detector
By D. Abbaneo et al..
10.1016/j.nima.2016.05.067.
Nucl.Instrum.Meth. A845 (2017) 313-317.

3) The Triple GEM Detector Control System for CMS forward muon spectrometer upgrade
By CMS muon Collaboration (W. Ahmed et al.).
10.1088/1748-0221/12/02/P02003.
JINST 12 (2017) no.02, P02003.

4) Gas Electron Multiplier foil holes: a study of mechanical and deformation effects
By L. Benussi et al..
10.1088/1748-0221/11/08/P08002.
JINST 11 (2016) no.08, P08002.

5) Preliminary results of Resistive Plate Chambers operated with eco-friendly gas mixtures for application in the CMS experiment
By M. Abbrescia et al..
arXiv:1605.08172 [physics.ins-det].
10.1088/1748-0221/11/09/C09018.
JINST 11 (2016) no.09, C09018.

6) Eco-friendly gas mixtures for Resistive Plate Chambers based on Tetrafluoropropene and Helium
By M. Abbrescia et al..
arXiv:1605.01691 [physics.ins-det].
10.1088/1748-0221/11/08/P08019.
JINST 11 (2016) no.08, P08019.

7) Status report on the CMS forward muon upgrade with large-size triple-GEM detectors
By D. Abbaneo et al..
10.1109/NSSMIC.2014.7431236.

8) Design of a constant fraction discriminator for the VFAT3 front-end ASIC of the CMS GEM detector
By D. Abbaneo et al..
10.1088/1748-0221/11/01/C01023.
JINST 11 (2016) no.01, C01023.

9) Impact of the GE1/1 upgrade on CMS muon system performance
By A. Magnani et al..
10.1393/ncc/i2016-16260-7.
Nuovo Cim. C39 (2016) no.1, 260.

10) Performance of a Large-Area GEM Detector Prototype for the Upgrade of the CMS Muon Endcap System
By D. Abbaneo et al..
arXiv:1412.0228 [physics.ins-det].
10.1109/NSSMIC.2014.7431249.

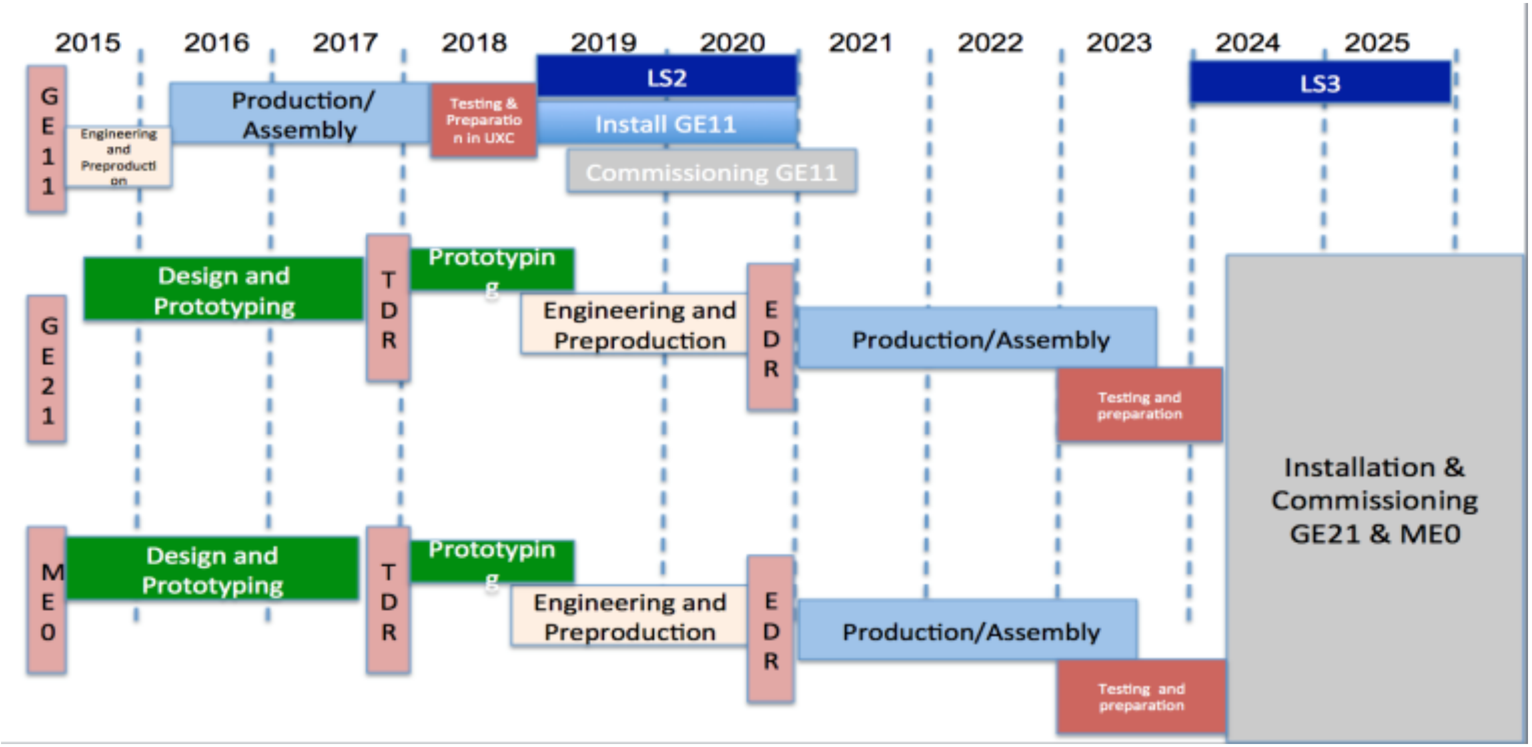
SPARES

SPARES

Table 9.1: Major milestones of the GE1/1 LS2 construction project.

Milestone	Date
Technical Design Report	01/2015
Chamber Final Design Release for procurements	08/2015
Begin Shipment to Production Sites	02/2016
Components Reception at Production Sites	06/2016
DAQ production complete	01/2017
Electronics production complete	03/2017
Reception production chambers at CERN complete	06/2017
One endcap complete	01/2018
Second endcap complete	03/2018
Ready for installation	03/2018

GE1/1 and GEM R&D for Phase2

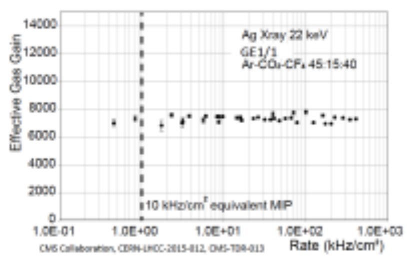


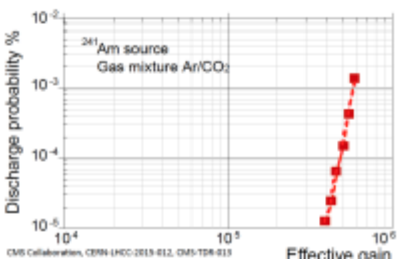
- GE1/1 timescale fully compatible with GE2/1 R&D
- GE1/1 fully approved and financed by INFN
- GEM R&D Phase2 approved and financed by INFN

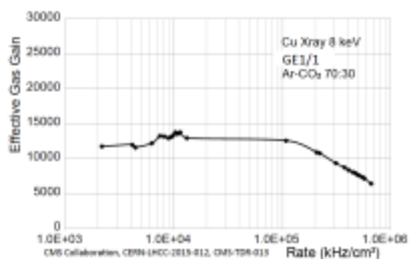
GE1/1 AND R&D FOR PHASE2

CMS GEM characteristics and performances

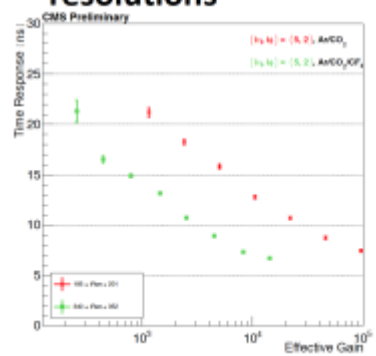
- **Effective gain constant up to 1e5 kHz/cm^2**
  - **CMS only requires 10 kHz/cm^2**
- **Discharge probability P_D measured to be 10^{-3} to 10^{-5}**
- **Effective gain in CMS is 5×10^3; extrapolating gives $P_D = 9\times10^{-10}$**

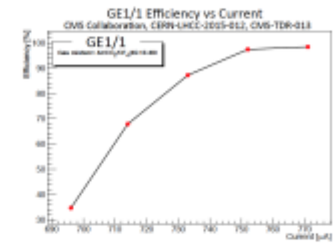


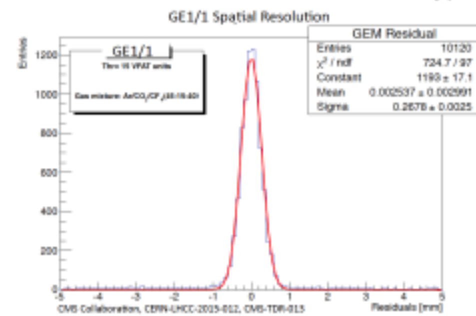




- **Test beam measurements conduction at CERN and Fermilab**
- **Detection efficiency ≈98%**
- **Excellent time and spatial resolutions**







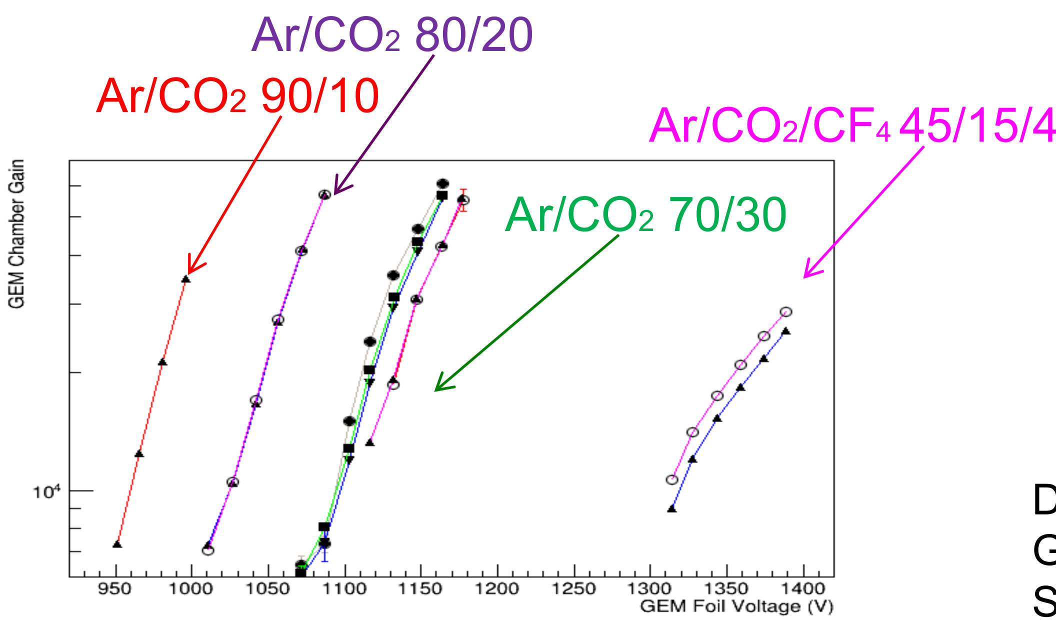
Eco-friendly gas mixtures for GEM

TEST MOLECULES SIMILAR TO BANNED BUT WITH LOWER GLOBAL WARMING / OZONE DEPLETING POWER (3,3,3-TETRAFLUOROPROPENE HFO-1234YF , 1,3,3,3-TETRAFLUOROPROPENE HFO-1234ZE, 3,3,3-TRIFLUOROPROPENE HFO-1233ZD , TRIFLUOROIODO- CF_3I)

- TEST GAS COMPATIBILITY WITH GEM AND GEM MATERIALS
- GAS GAIN MEASUREMENTS FOR DIFFERENT GAS MIXTURE. STUDIES OF GAS GAIN VS. ENVIRONMENTAL PRESSURE AND TEMPERATURE FOR DIFFERENT GAS MIXTURE, TIME RESOLUTION STUDIES

The laboratory has environmental sensors to continuously ambient Pressure, Temperature and Relative Humidity. Sensors are also located into the gas lines to monitor P,T and RH of the gas.

10X10 cm^2 triple GEM chamber (3-1-2-1) using a Fe^{55} or X-ray gun

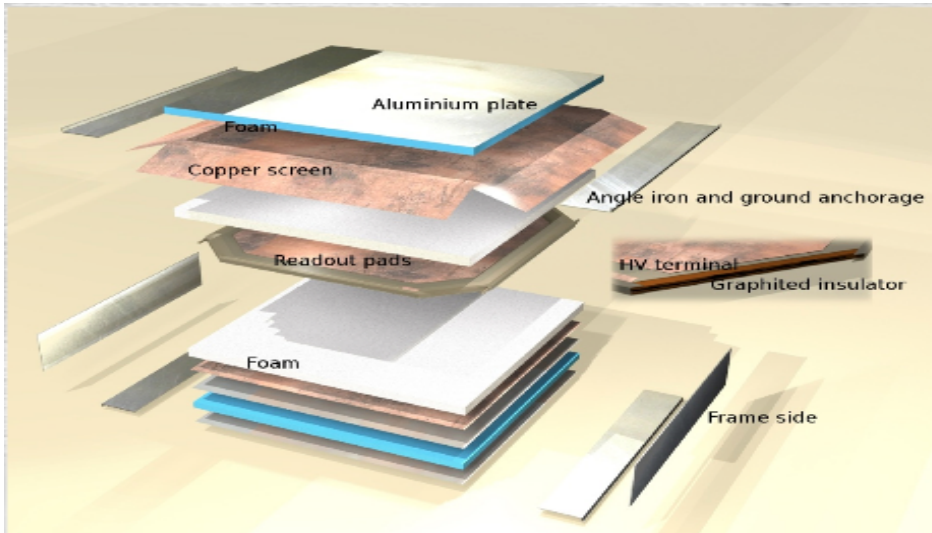


Data are acquired by means of a 10 Giga sample oscilloscope.
Signals are analyzed offline.

Measurements have been done with standard gas mixtures to validate the system

In the beginning of May 2015 started to test Ar-HFO based gas mixtures

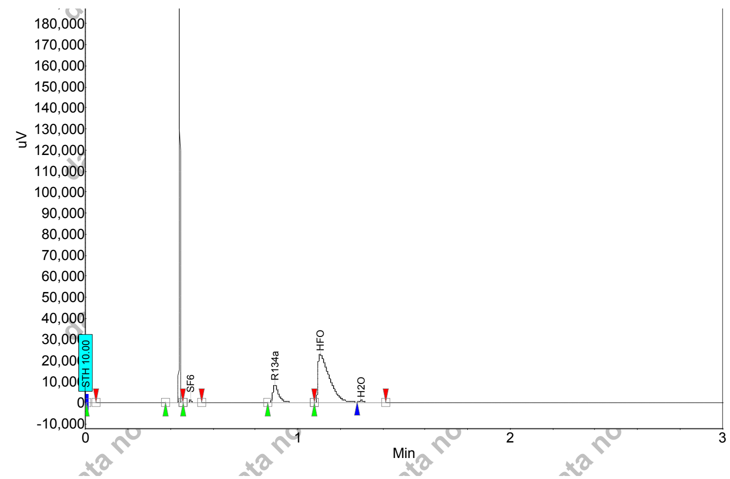
Experimental Set-up in Frascati



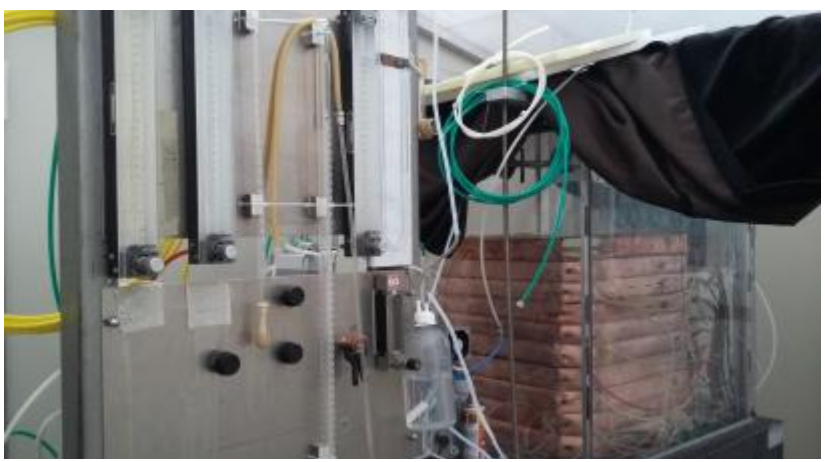
- 12 single gap RPCs, 2 mm wide gas gap
- 50 x 50 cm^2
- Double Pad readout
  - partial cancellation on single mode noise
  - Expected about x2 induced signal charge
- Scintillator layers on top and bottom for trigger

- Gas chromatograph: for gas mixture analysis
- 4 channels Oscilloscope lecroy104xi (5 Gsamples, 1 GHz): for signal readout
  - Full digitization of signal
  - By hand measurement

Gaschromatograph in-line with RPC chambers



SAMPLING BEFORE AND AFTER RPC CHAMBERS



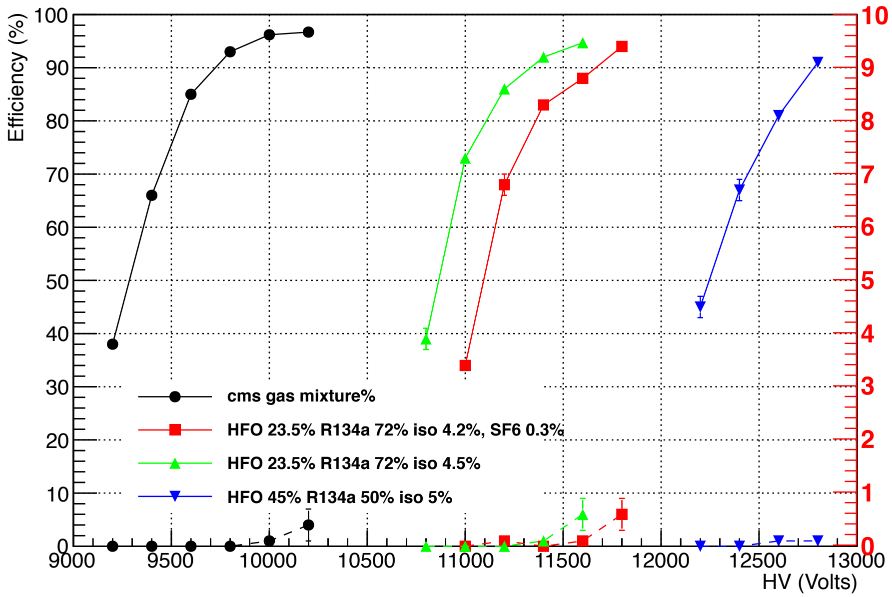
Nazionale di Fisica Nucleare
ORI NAZIONALI DI FRASCATI

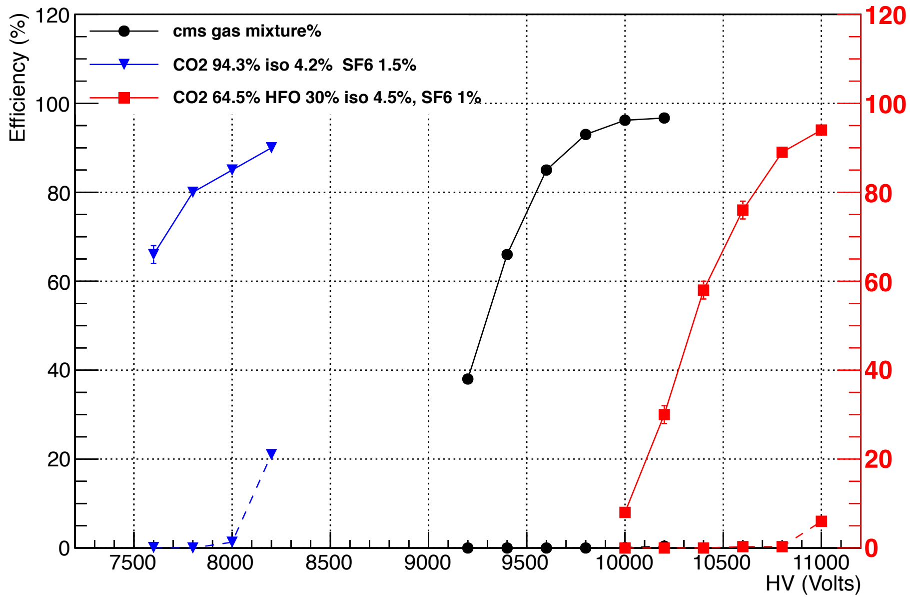
INFN Istituto Nazionale di Fisica Nucleare

Tests at LNF laboratory

From R134a to HFO1234ze

CO2- HFO1234ze Based mixtures





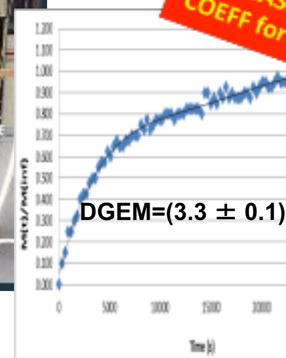
RPC Phase2 Material Studies

Joint ATLAS-CMS phase 2 R&D

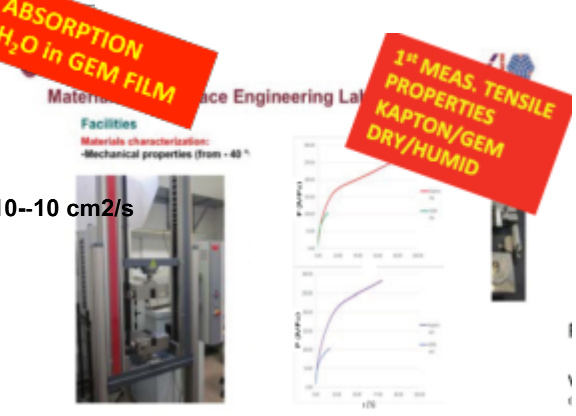
1. **WP Electrodes (up to 1-2 kHz)**
   - Lower resistivity (< 10^{10}) materials (HPL, glass) and thinner electrodes (< 2mm)
2. WP Gap and Chamber Prototypes (new configuration)
   - Double- and multi-gap, smaller gap (< 2 mm), improved time resolution (100 ps), technological improvements (mechanics, gas distribution, high voltage connector and cooling)
3. WP Low-threshold Front End Electronics
4. WP Eco-friendly gas mixtures
   - Search for replacements of $C_2H_2F_4$ (R134a) and SF_6
5. WP Irradiation studies
   - GIF++ (aging), Frascati BTF (n/γ sensitivity), Louvain & Pavia (FEE)

Monitoring of Deformation of GEM films

1) Characterize stretching of GEM, develop optical Moire' based techniques for QA/QC.
2) Characterize tensile properties of materials pre- and post- irradiation



1[st] MEAS. ABSORPTION COEFF for H_2O in GEM FILM



1[st] MEAS. TENSILE PROPERTIES KAPTON/GEM DRY/HUMID

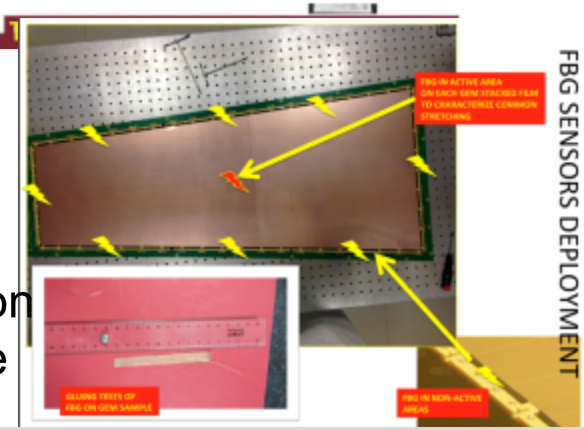
MOIRE` PRELIMINARY

CAMERA
RECEIVER LENS
RONCHI GRATING

PROJECTOR
STEPPING MOTOR
RONCHI GRATING

READY

Next step Inter-calibration between FBG and Moire



FBG SENSORS DEPLOYMENT

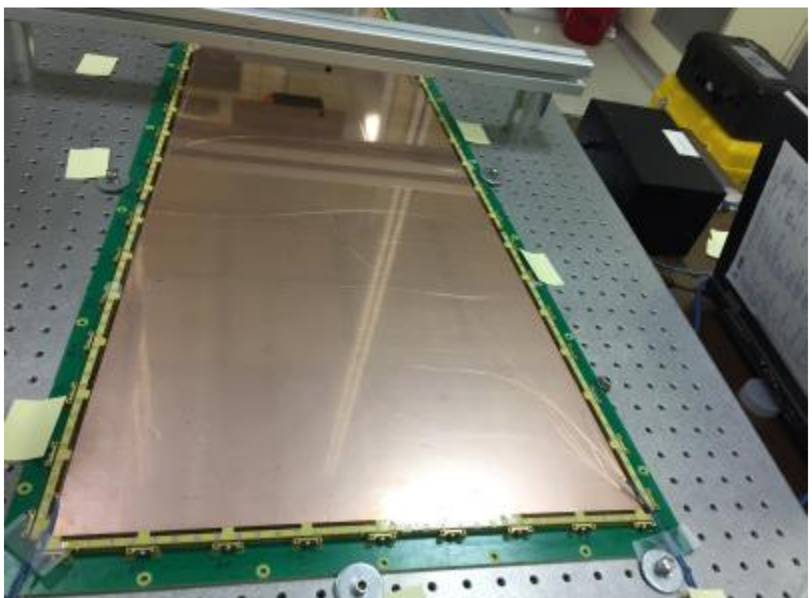
Ready to start studies of stretching monitorin&tensile load characterization on

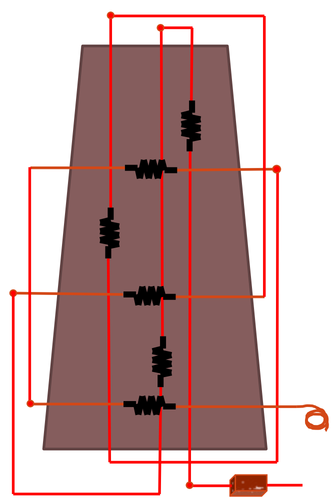
FIBER BRAGG GRATING APPLICATIONS

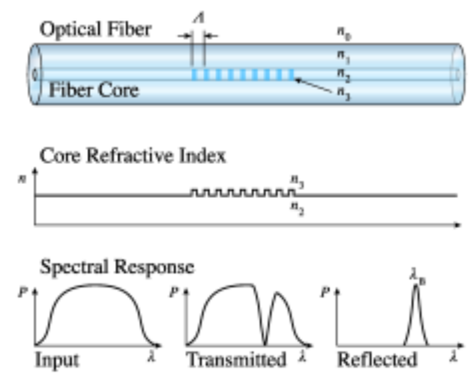
To validate the GE1/1 mechanical technology (Glue-Free assembly)
we used an FBG array glued on the GME foils of a real size GE1/1 prototype

Objectives:

1. Verify the simultaneous stretching of the foils
2. Quantify the applied force and verify that is still in the "Young" region
3. Optimization of the assembly procedure and the definition of the assembly protocol

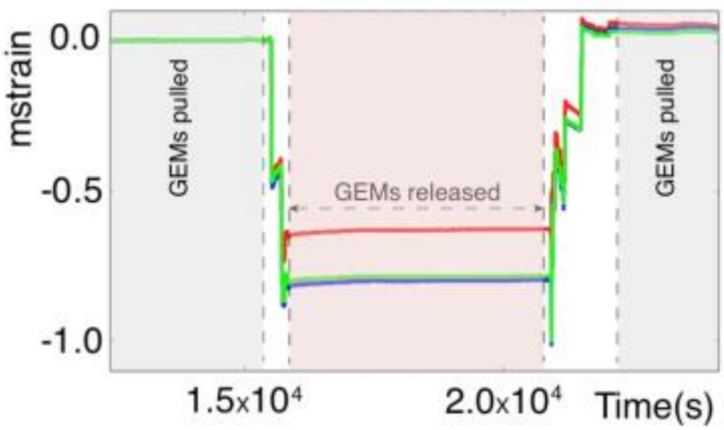


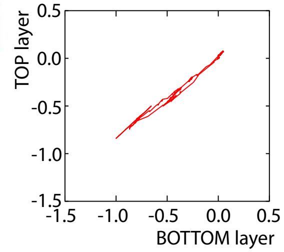




FBG working principle:
The grating reflects only its characteristics light wave-length. If the grating is deformed the wavelength shifts.

FIBER BRAGG GRATING APPLICATIONS

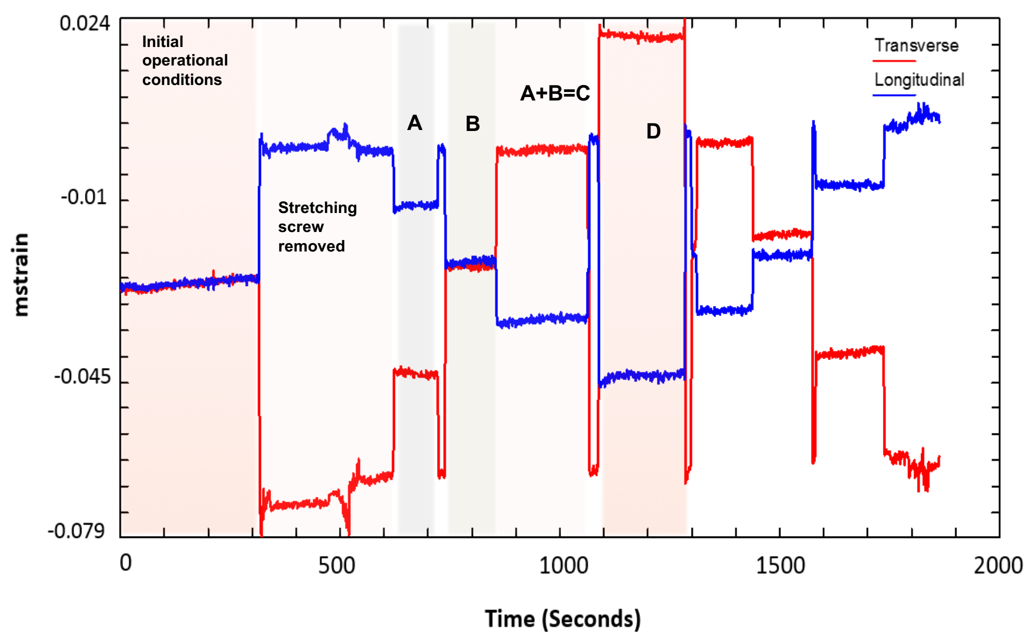




The sensors placed in the middle of the foils are monitored during the stretching procedure.
After the complete relaxation of the GEM stack the foils were stretched again up to the operational value.
The final position of "ALL" the FBG sensors reproduce almost perfectly the initial position before relaxation.
This demonstrate that the stretching procedure of the GE1/1 chambers act on each layer in the same way.

FBG as load gauge:
By applying different weights on a single screw (replaced by a eyelet) we measured the weight equivalent to the operational tensile load. This is necessary to tune the dynamometric screwdriver used during assembly

A=2.86 kg
B=5.65 kg
C=8.5 kg
D=11.3 kg

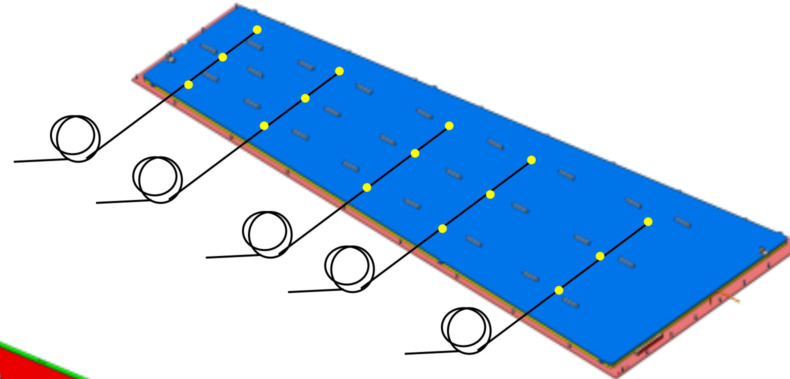


Fiber Bragg Grating applications

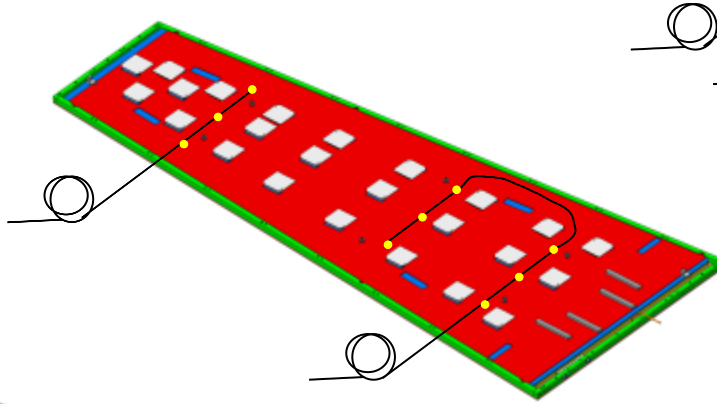
Temperature monitoring of GEM by use of Fiber Bragg Grating sensors

- Array of FBG sensors prepared @ LNF
- FBG sensors installed during GEM chamber assembly @ CERN

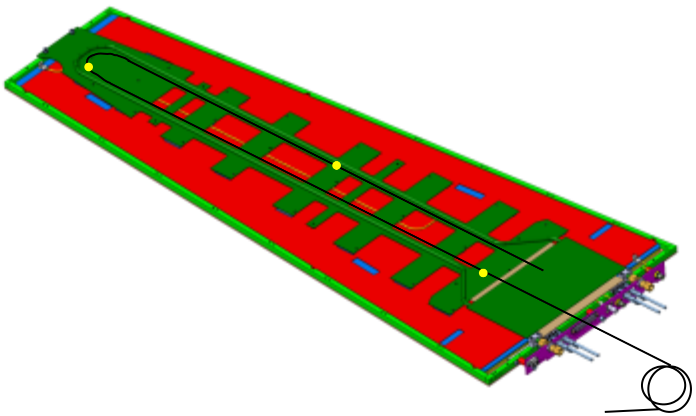
Test @ CERN ongoing



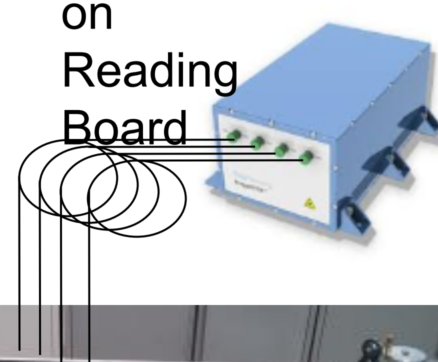
Step 1
Install FBGs on Reading Board

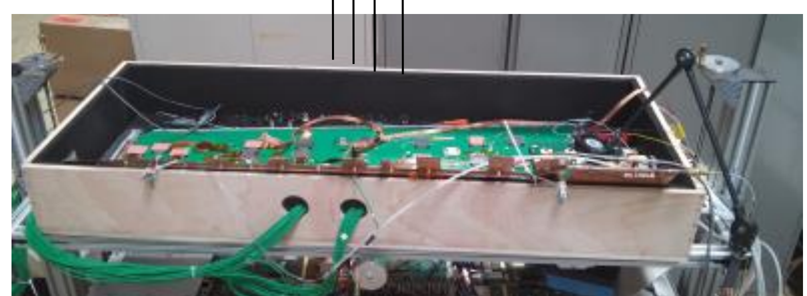


Step 2
Mount GEB and install FBGs



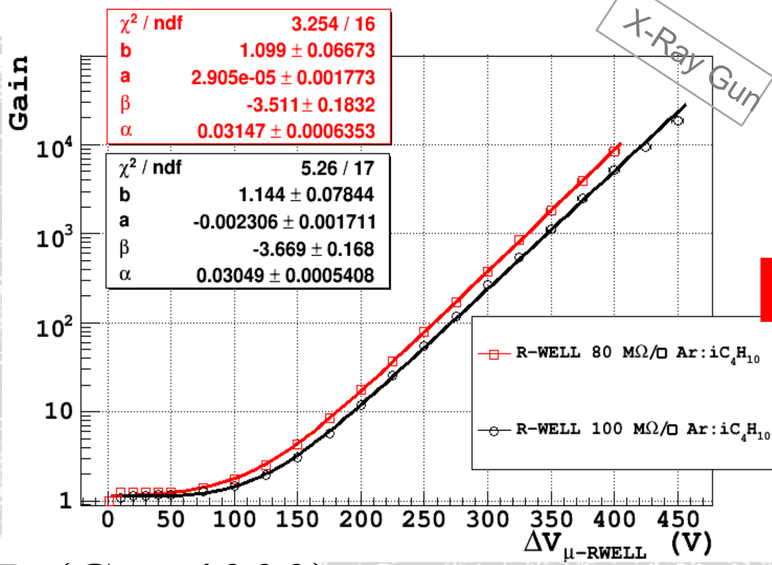
Step 3
Mount Cooling Plate
and install FBGs





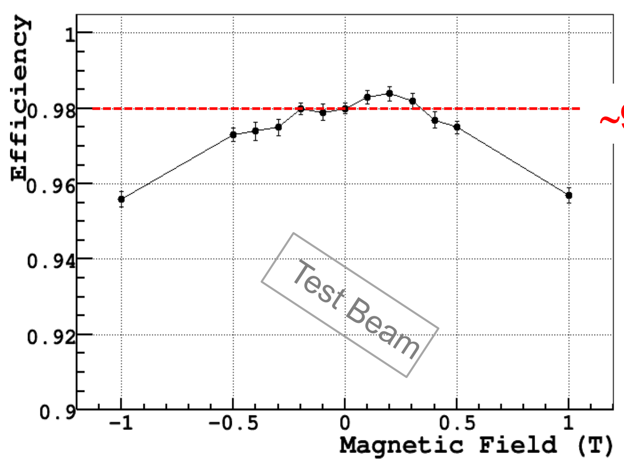
μ-RWELL performances

In collaboration with
G. Bencivenni, R. De Oliveira, G. Morello, M. Poli Lener



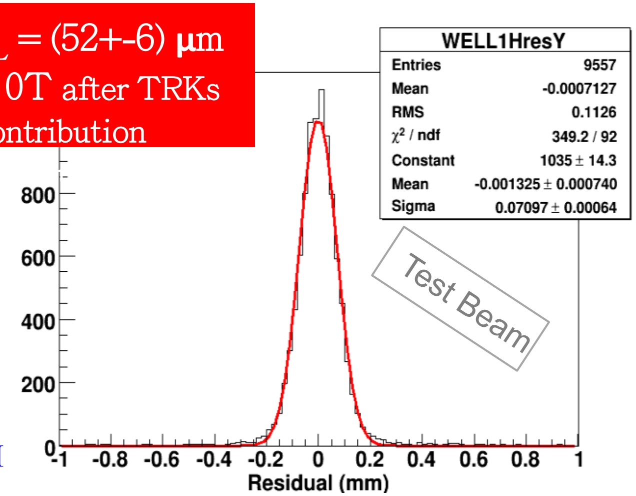
GAIN UP TO 10^4

μ-RWELL vs B (G = 4000)



~98 %

σ_{RWELL} = (52+-6) μm
@ B= 0T after TRKs contribution



Ref. To be published in NIM A, contrib ELBA conf 2015