Gas Detectors (GEM)

THE 6TH EGYPTIAN SCHOOL FOR HIGH ENERGY PHYSICS

DECEMBER 3-8, 2016

THE BRITISH UNIVERSITY IN EGYPT

BY

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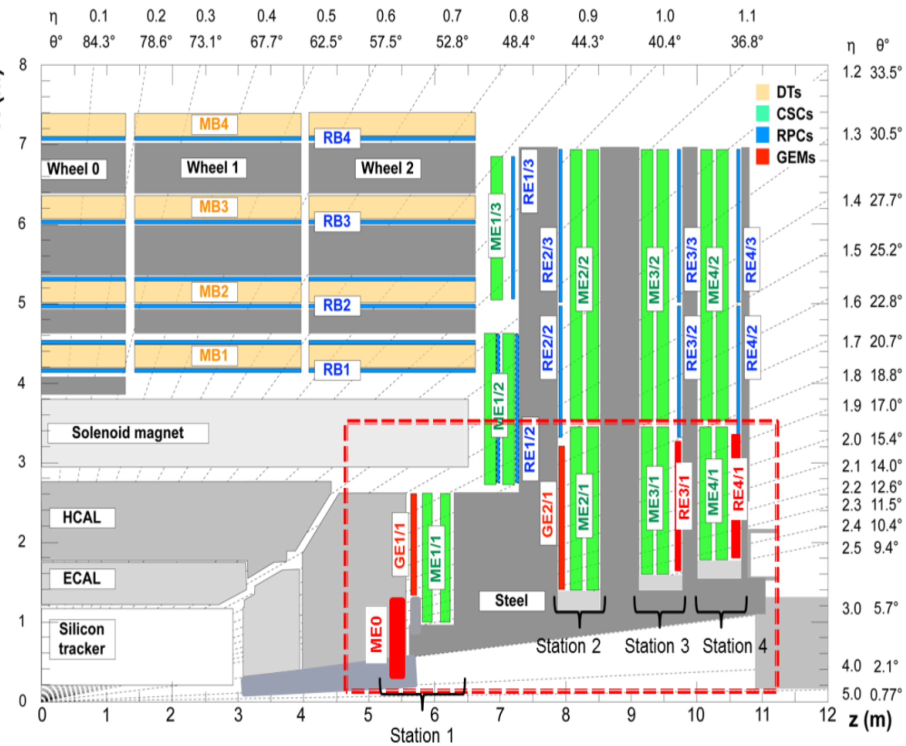
The Muon Upgrade

Phase-II CMS needs handles to cope with high rate between LS2 and LS3
– Tracking trigger won't be installed until ~2023

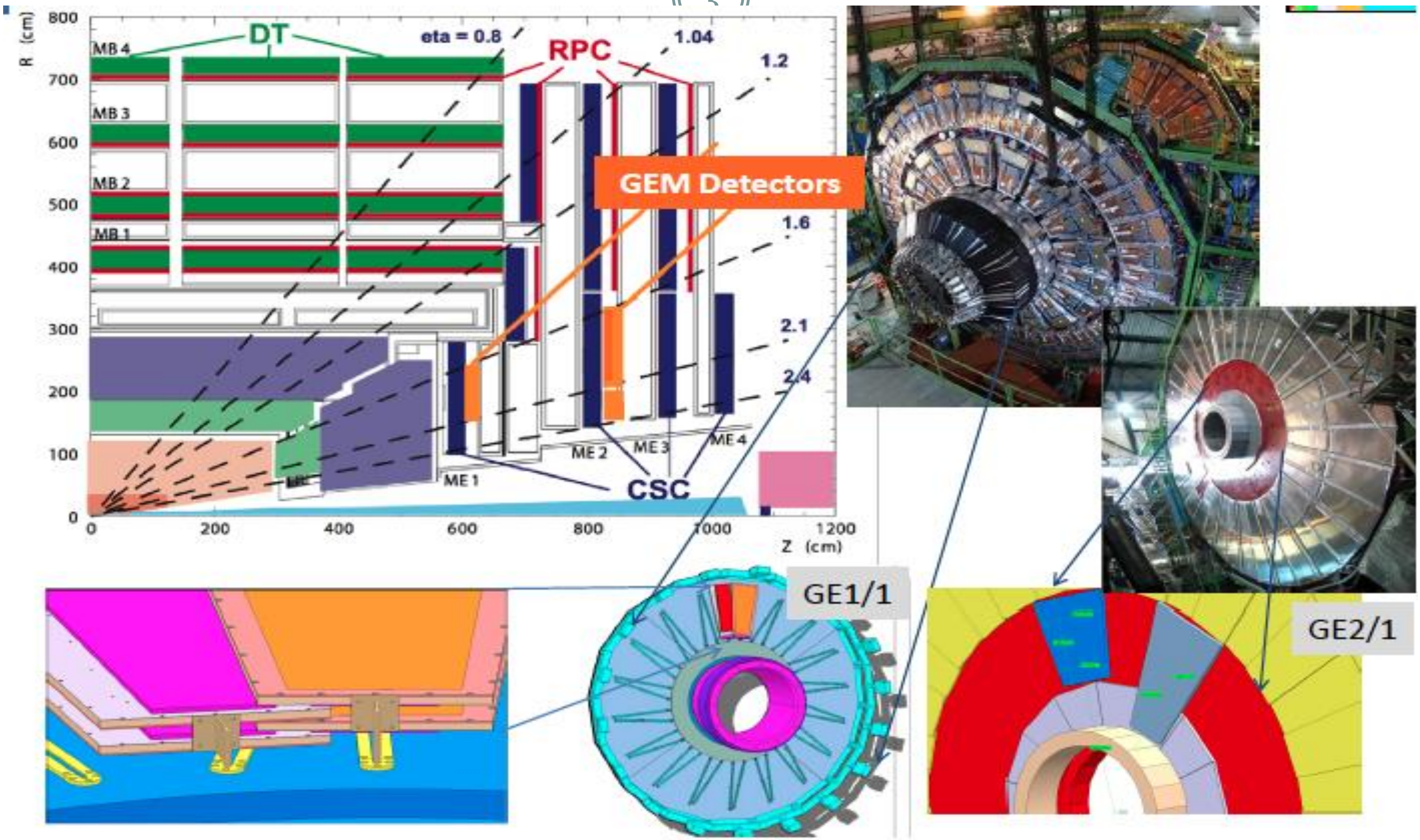
High eta region has vacancies after LS1: good opportunity to install new detectors
– Current CMS RPC design is not sustainable at high rates



High eta region requires
a new and mature technology
that satisfies requirements:

- High rate capability (MHz/cm^2)
- Good time resolution: triggering
- Good spatial resolution (100μm): tracking

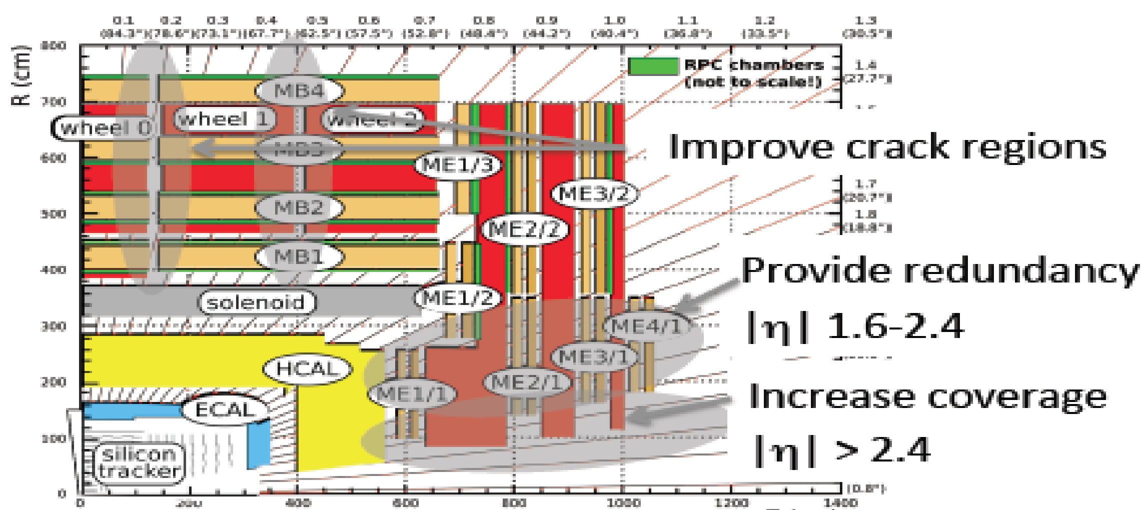
The Muon Upgrade



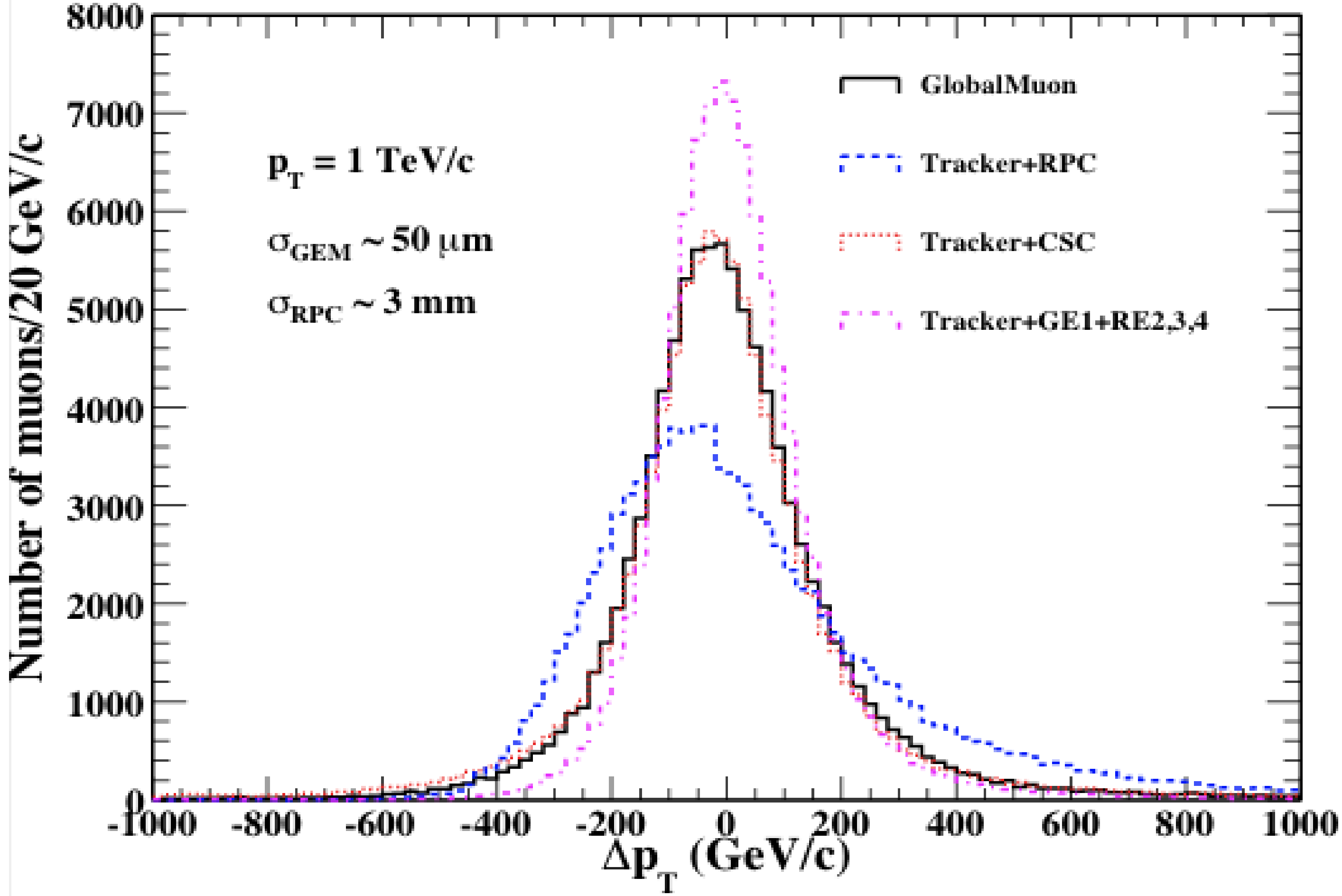
Motivations

Phase 2: Muons

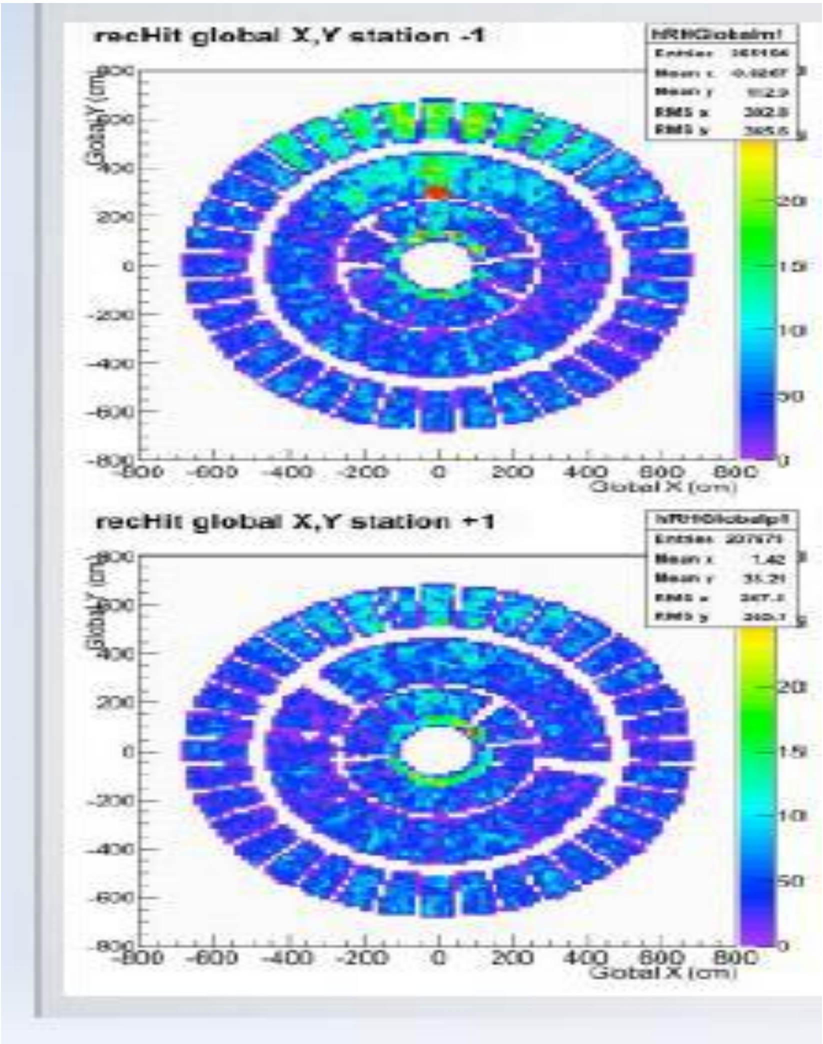
- Muon chambers are expected to survive beyond LS3
  - Muon strategy group organized by IB for long-range muon planning to deliver an initial report (questions to be addressed?) in July and more complete plan in Dec.
  - Simulated rate increase with luminosity compares well to data
  - Barrel DT and RPCs should sustain 75Hz/cm2 at 5e44 with some margin, no know radiation dose issues for detector and electronics
  - CSCs designed for 30 years of LHC – need re-evaluation - full exposure of M1/1 chambers to be foreseen – rates capabilities being investigated
  - RPCs should sustain rates up to η=1.6 – investigate hot spots
  - Investigate technology opportunities for η>1.6 – GEM – Glass RPCs
  - Investigate current trigger performance and possible improvements

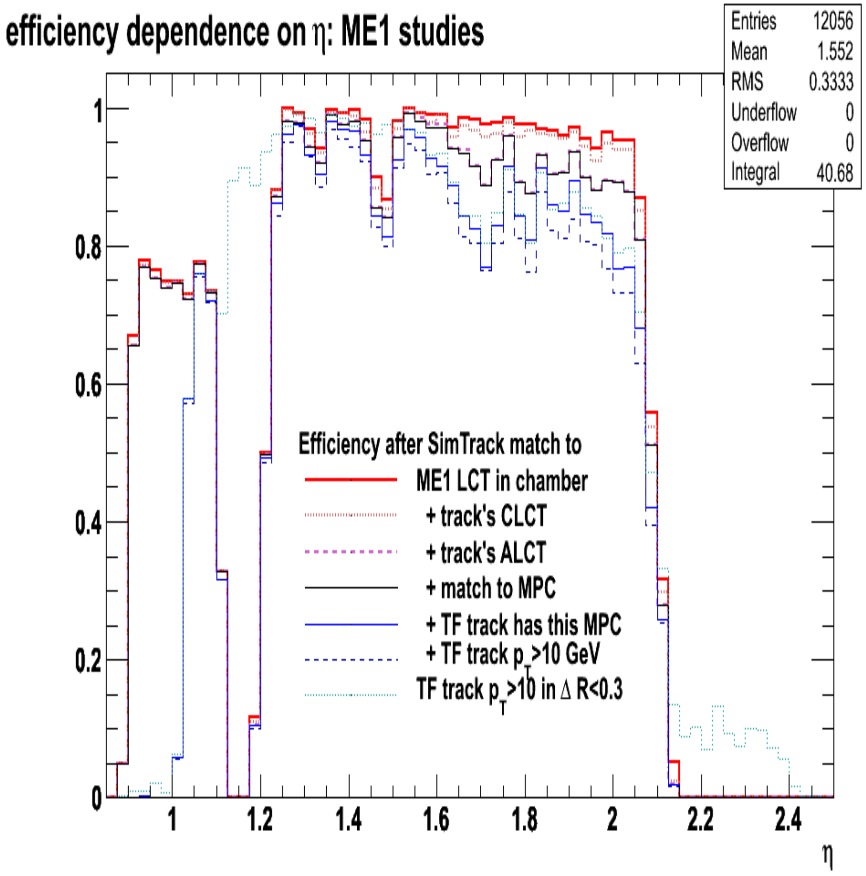


Motivations (Muon momentum resolution)

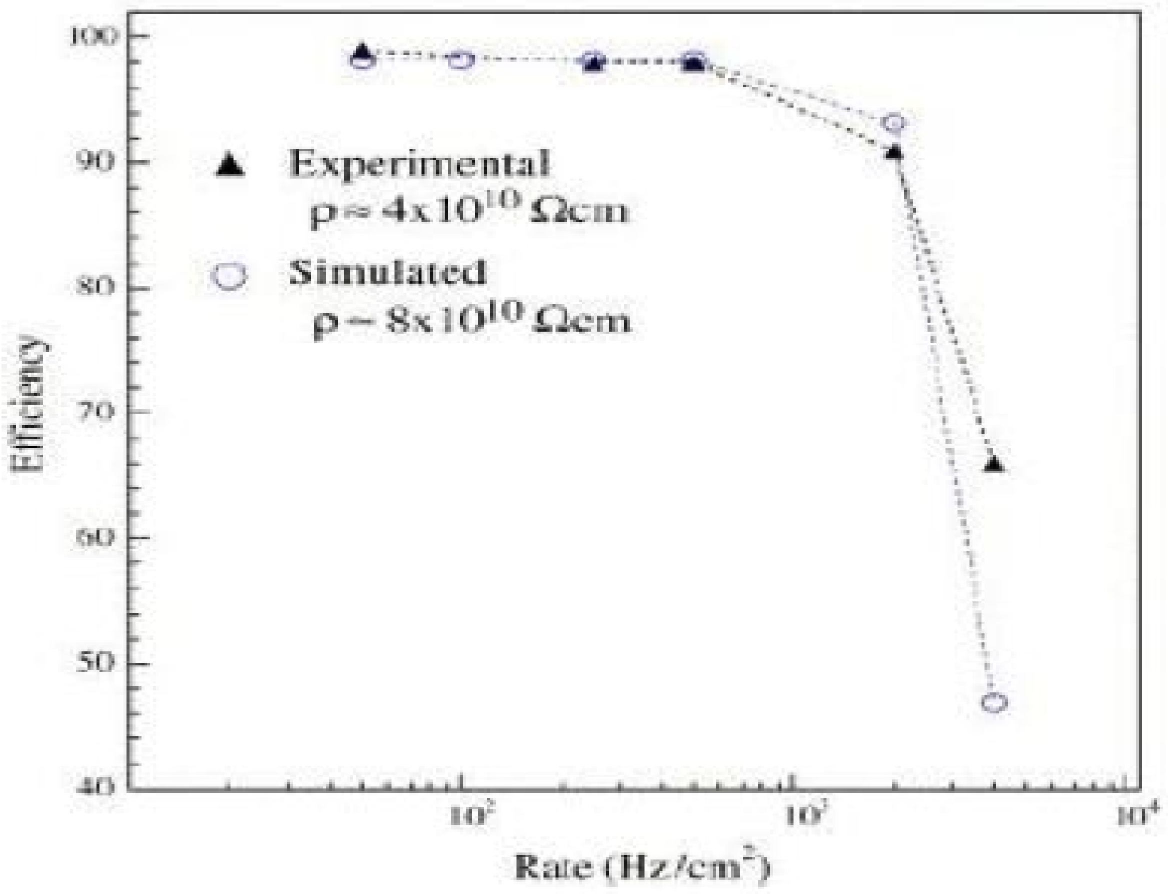


CSC Inefficiency



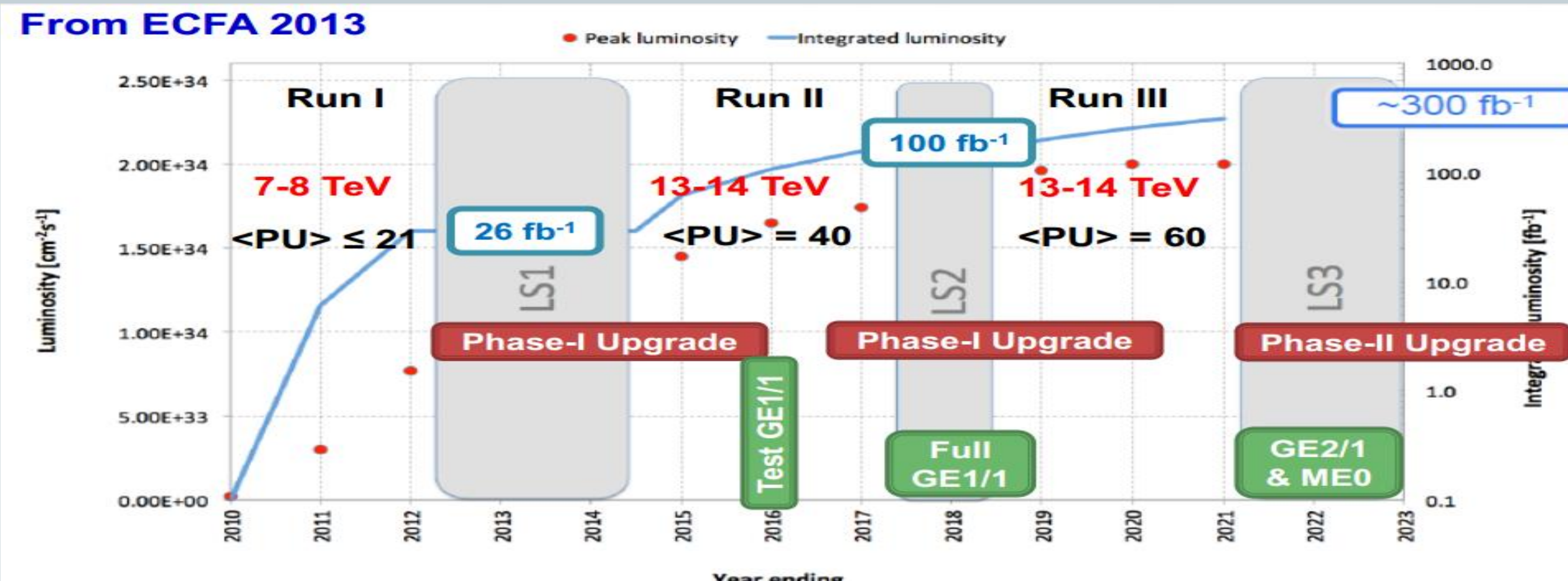


RPC Rate capability



GEM Project

- Install double-layered triple-GEM chambers in the presently vacant positions in front of ME1/1 (LS2) and GE2/1 (LS3), and a 6-layered triple-GEM near-tagger behind the future compact forward hadron calorimeter (LS3)

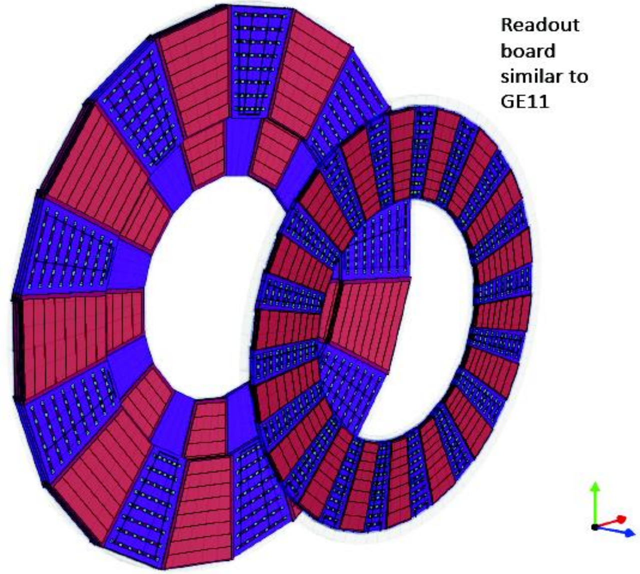


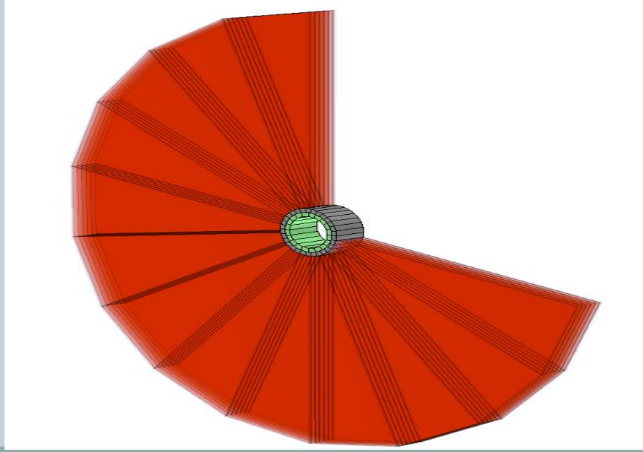
GEM Geometry

- **GE1/1: baseline detector for GEM project**
- 1.55 < |eta| < 2.18
- 36 staggered chambers, each chamber spans 10°
- Several prototype designs with different number of eta partitions
- Major conclusion from ECFA 2013: **short and long super chambers for maximum coverage in pseudo-rapidity**

- **GE2/1: station 2 upgrade**
- 1.55 < |eta| < 2.45
- Chambers spanning 20°
- Geometry details to be finalized.
- Looking into possibility of installing 2 rings of double-layered triple GEMs (1 ring with short, 1 ring with long super chambers)

- **ME0: near-tagger to be installed behind new HE**
- 2.0 < |eta| < 3.5
- 6-layers of triple-GEM detectors
- Geometry is yet to be finalized





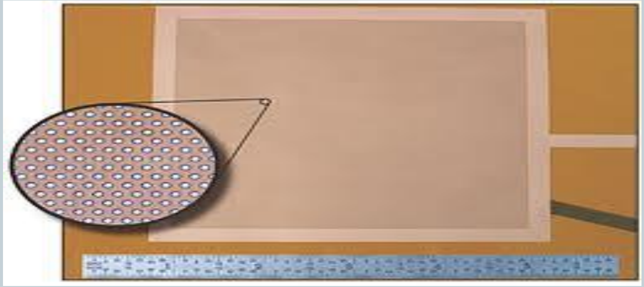
GEM Foil

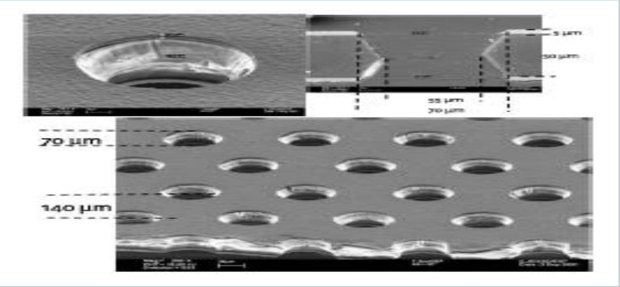
Rate capability : 10^5Hz/cm^2

Spatial/Time resolution: ~ 100 µm / ~ 4-5 ns

Efficiency > 98%

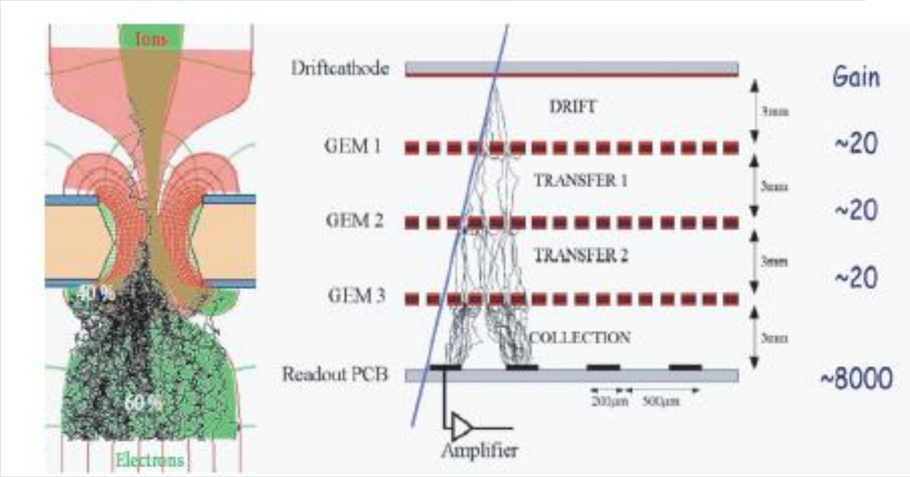
Gas Mixture: Ar-CO_2-CF_4 (non flammable mixture)

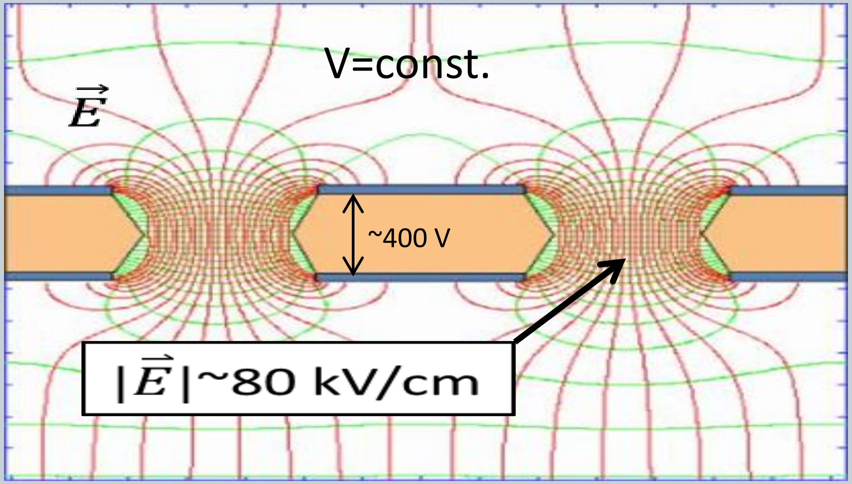




- GEM foils developed using PCB manufacturing techniques
- Large areas ~ 1m x 2m .
- Each foil (perforated with holes) is 50µm kapton sheet with copper coated sides (5µm)
- Typical hole dimensions : Diameter = 70µm, Pitch = 140µm,

Triple GEM Detector

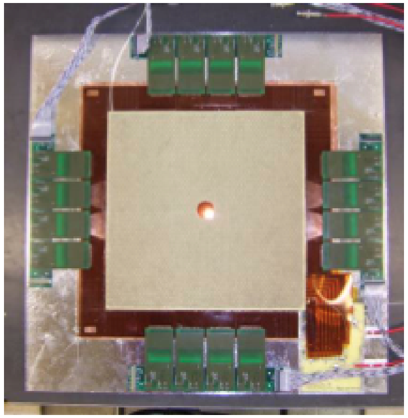




- Combine triggering and tracking functions
- Enhance and optimize the readout (η-φ) granularity by improved rate capability

GEM At COMPASS

- Overview
  - First high-luminosity experiment that used Triple-GEM detectors (running at CERN SPS)
  - 22 31cm × 31cm Triple-GEMs with 2D strip readout (400 µm pitch);
    central circular region (d = 5 cm) deactivated (beam passage)
  - 11 stations with 2 detectors each (x-y; u-v at 45° wrt x-y)
  - Low-mass tracker: 0.4 - 0.7 % X_0 per Triple-GEM
  - Operated w/ gas gain ~ 8,000 in Ar/CO_2 70:30
  - Readout with APV25 chip w/ 40 MHz sampling
    (same as for the CMS Si-tracker)

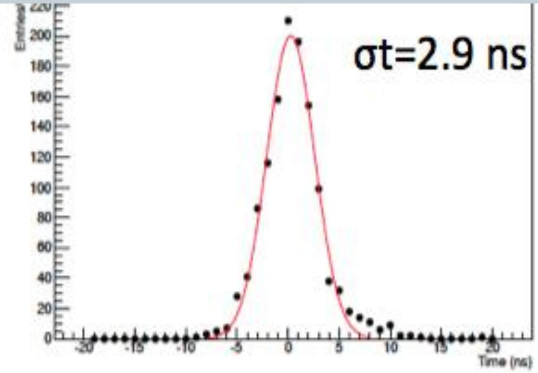


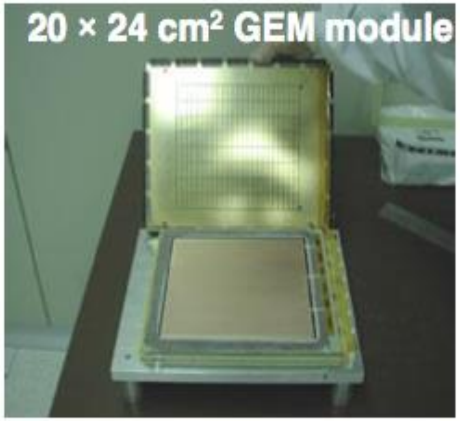
- GEM performance during running
  - Sustained rates up to 2.5 MHz/cm^2
    → corresponds to ≈1000 × est. CMS GE1/1 rate @ HL-LHC (few kHz/cm^2)
  - Uniform efficiency of 97.5% for two OR'ed detectors
  - 70 µm spatial resolution achieved (very close to normal incidences)
  - 12 ns time resolution achieved at high beam intensity using leading edge of pulse
  - Accumulated charge during 2002-2007 running: 200 mC/cm^2
    → corresponds to > 12 years est. CMS GE1/1 charge @ HL-LHC
  - No gain drop observed in this running period

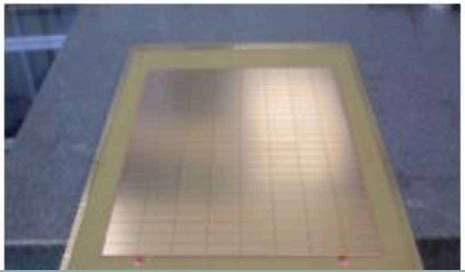
GEM at LHCB

GEMs in LHCb M1 muon station (LHCb L0 Muon Trigger):

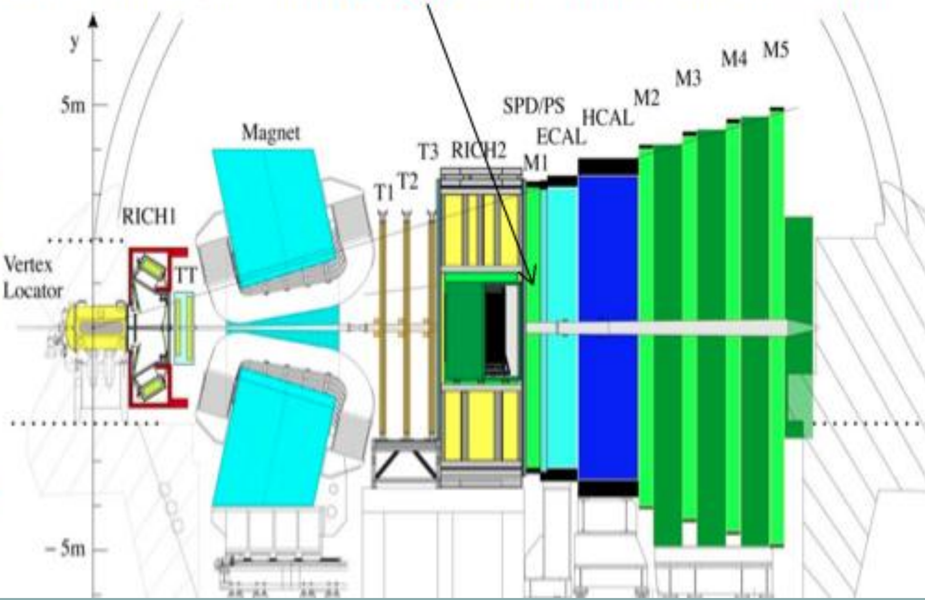
- Operating since LHC startup; rate up to 500 kHz/cm² (>> CMS)
- Gas mixture Ar/CO_2/CF_4 (45:15:40)
- Gas gain ≈ 6,000
- Efficiency ≥ 98% in 25 ns window using OR of two GEM
- Rad-hard up to integrated charge of ≥ 2 C/cm² (15 LHCb years)



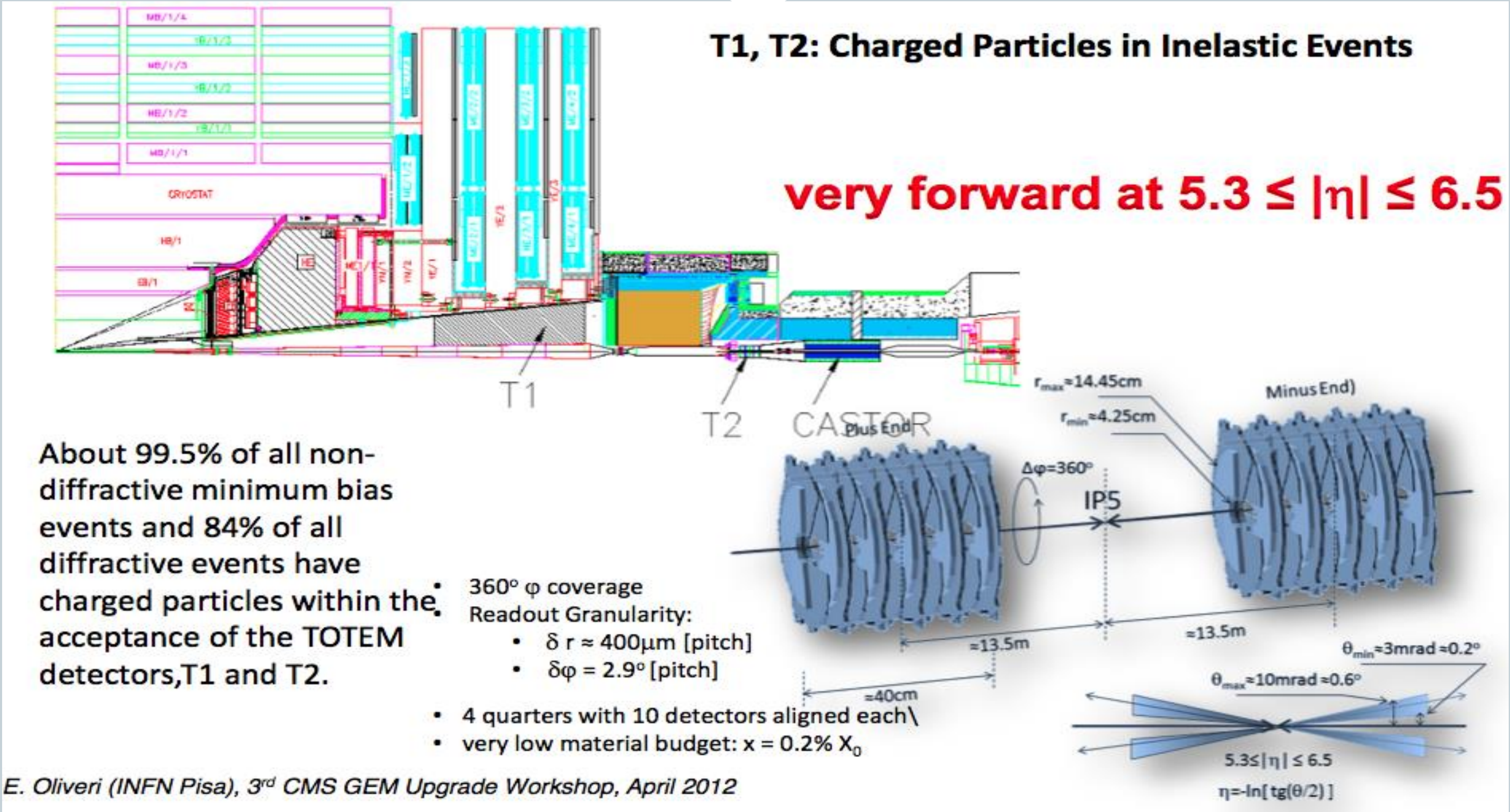




12 Double Triple-GEMs in front of calorimeter; total area 0.6 m²

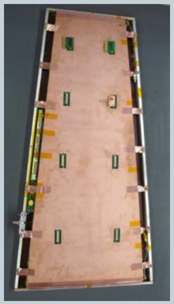


GEM at TOTEM



T1, T2: Charged Particles in Inelastic Events
very forward at 5.3 ≤ |η| ≤ 6.5
CRYOSTAT
T1
T2
CASTOR
Plus End
Minus End)
r_max≈14.45cm
r_min≈4.25cm
Δφ=360°
IP5
≈13.5m
≈13.5m
≈40cm
θ_min≈3mrad ≈0.2°
θ_max≈10mrad ≈0.6°
5.3≤|η|≤6.5
η=-ln[tg(θ/2)]
About 99.5% of all non-diffractive minimum bias events and 84% of all diffractive events have charged particles within the acceptance of the TOTEM detectors,T1 and T2.
• 360° φ coverage
• Readout Granularity:
• δ r ≈ 400μm [pitch]
• δφ = 2.9° [pitch]
• 4 quarters with 10 detectors aligned each\
• very low material budget: x = 0.2% X0
E. Oliveri (INFN Pisa), 3rd CMS GEM Upgrade Workshop, April 2012

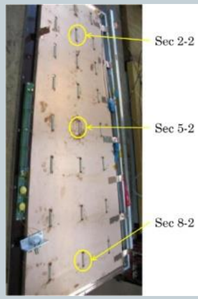
GEM Detector R&D



2010

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)**



2011

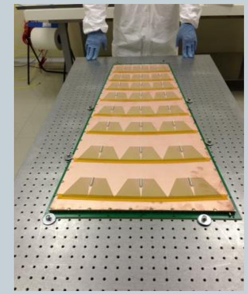
Generation II

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.**

2012

Generation III

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



2013

Generation IV

The current generation that we have built two of at CERN so far, with four more to come from the different sites. No more gluing whatsoever. **Upcoming papers from MPGD 2013;**

2013/14

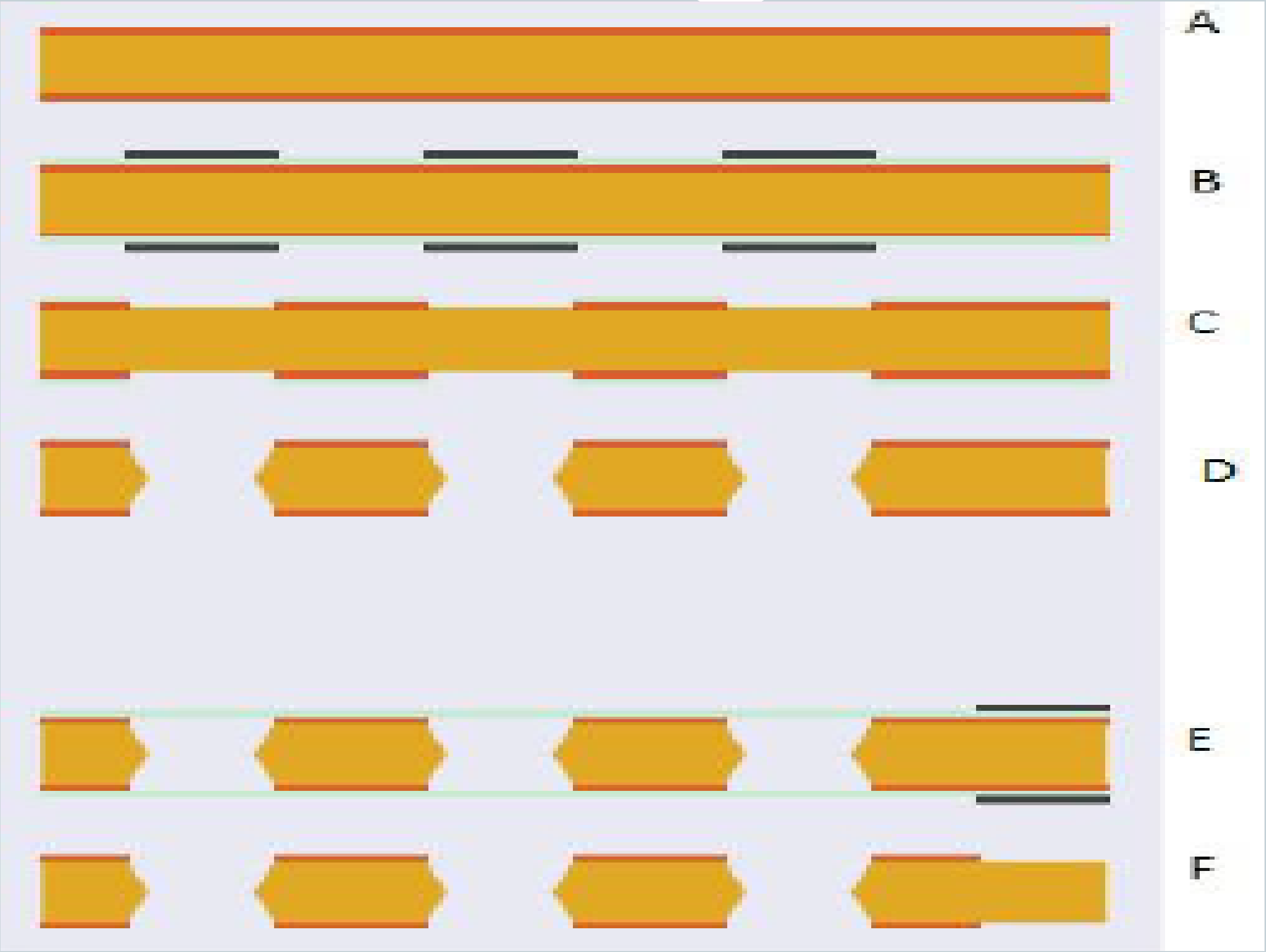
Generation V

The upcoming detector version that we will install. One long and one short version. Optimized final dimensions for max. acceptance and final eta segmentation. Installation of dummy

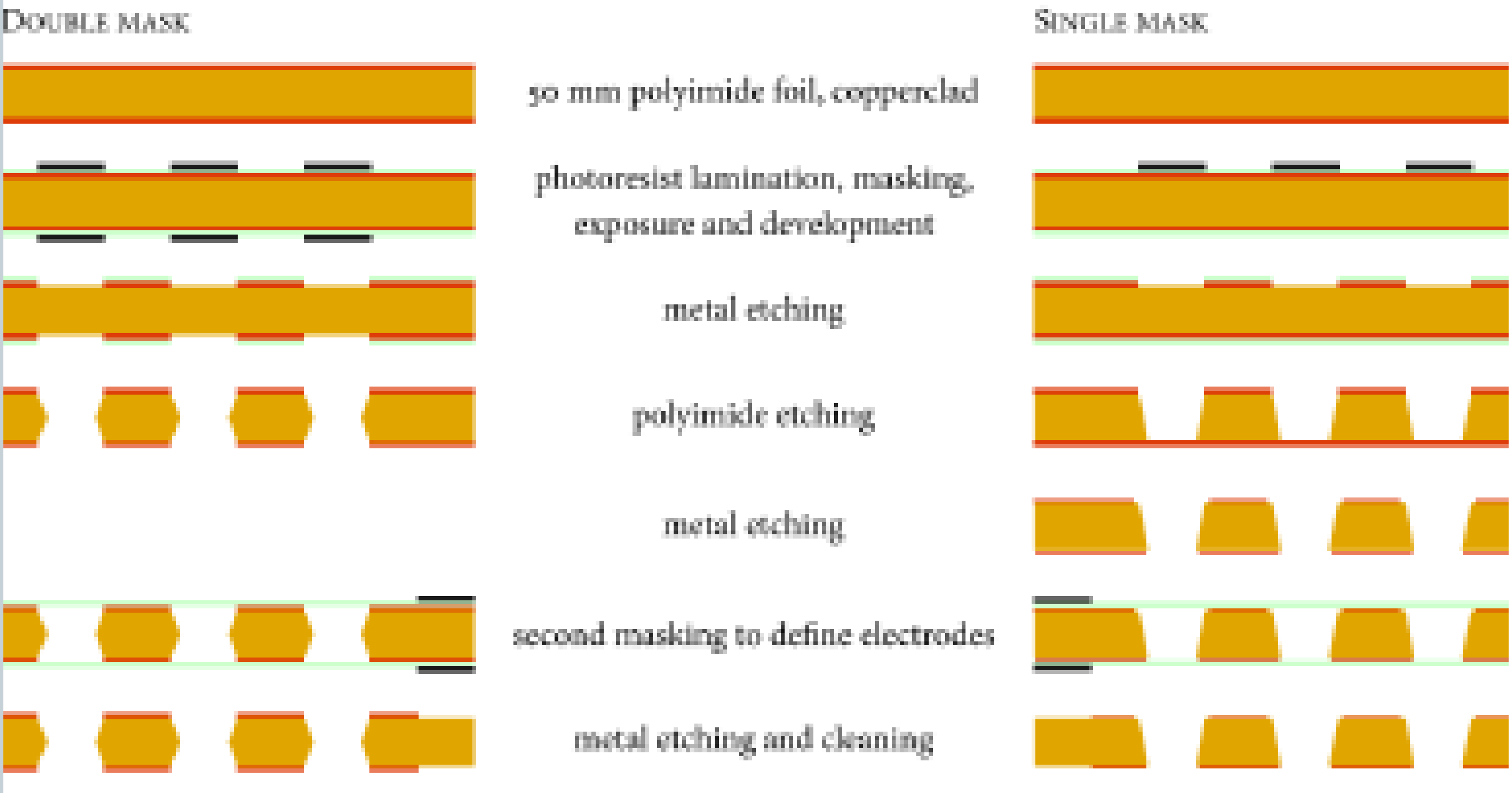
GEM foils production Single mask technology for wet etching. Effects dramatically on foil production costs and large sizes can be made. Performance same as that of double mask ; NS2 Assembly technique developed; Constructruction time reduced from week to 2 hours per chamber

New Front-end Electronics developed for GE1/1 and 2/1; continue for ME0

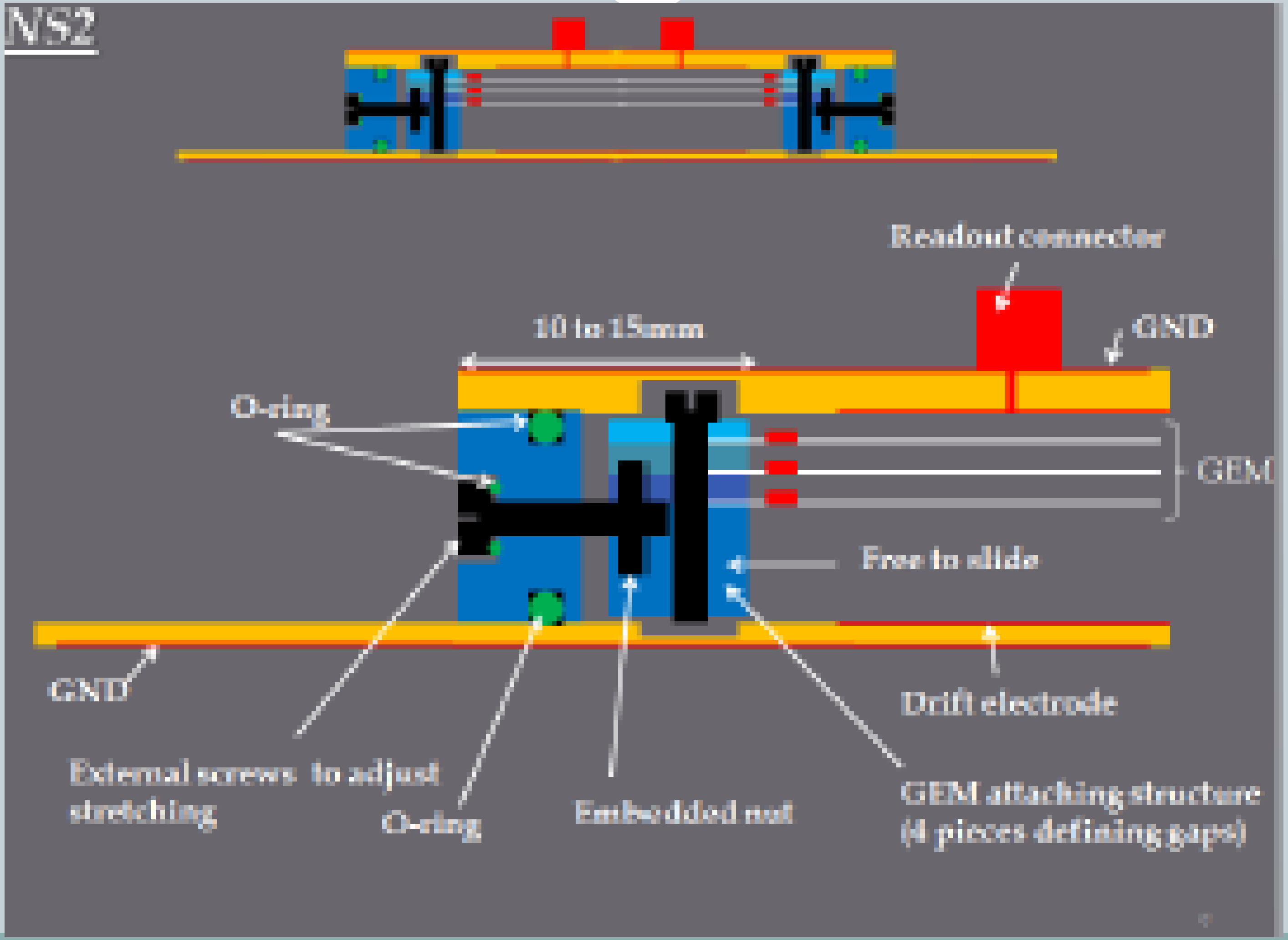
Double Mask technology



Double mask vs single mask

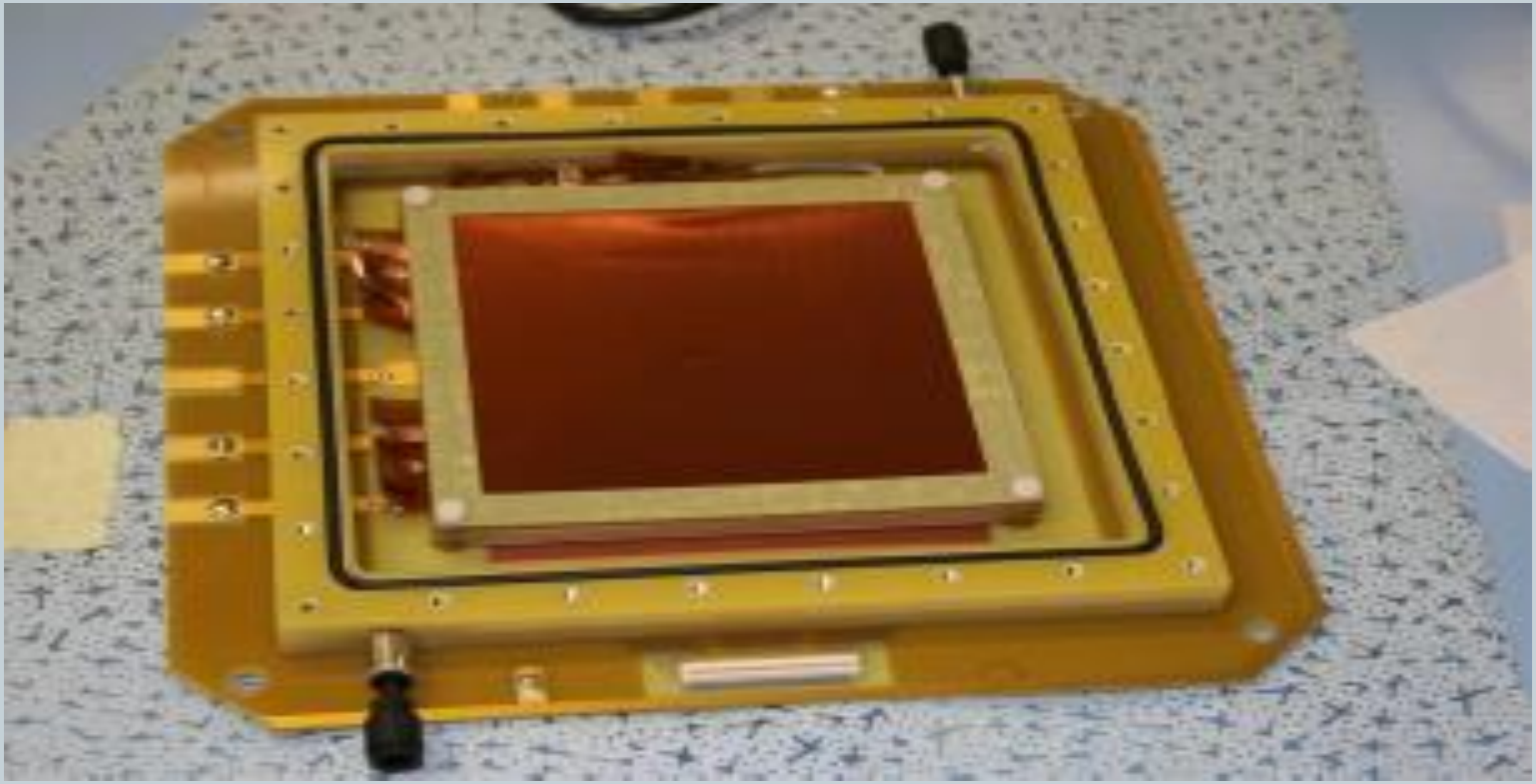


NS2 Technique

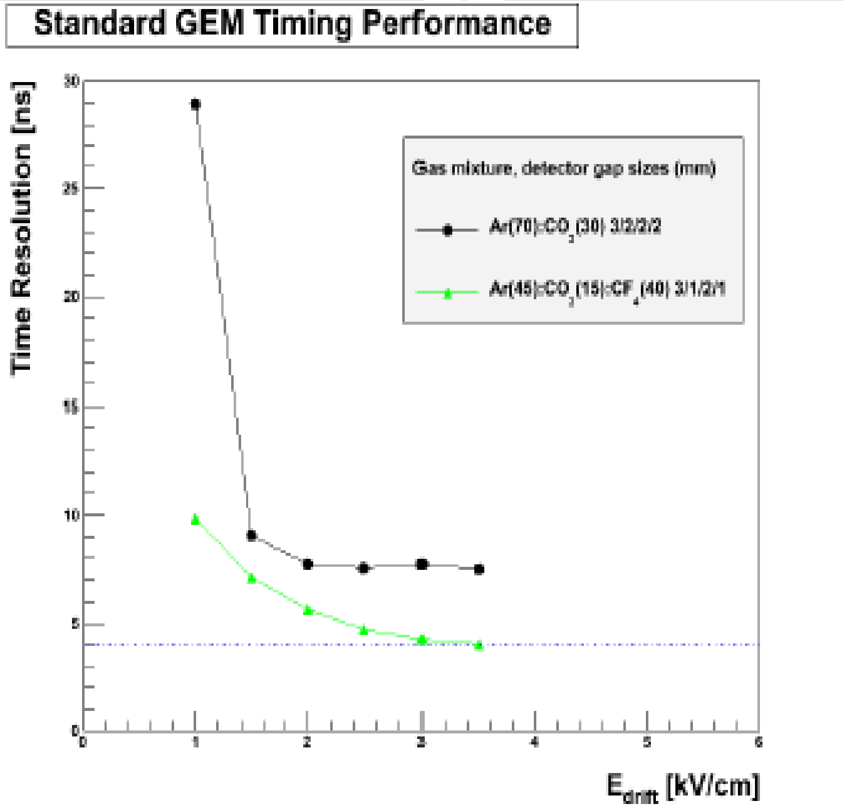


Small Prototype (2009-2010)

- 10 x 10 cm^2 triple GEM with 128 readout channels.

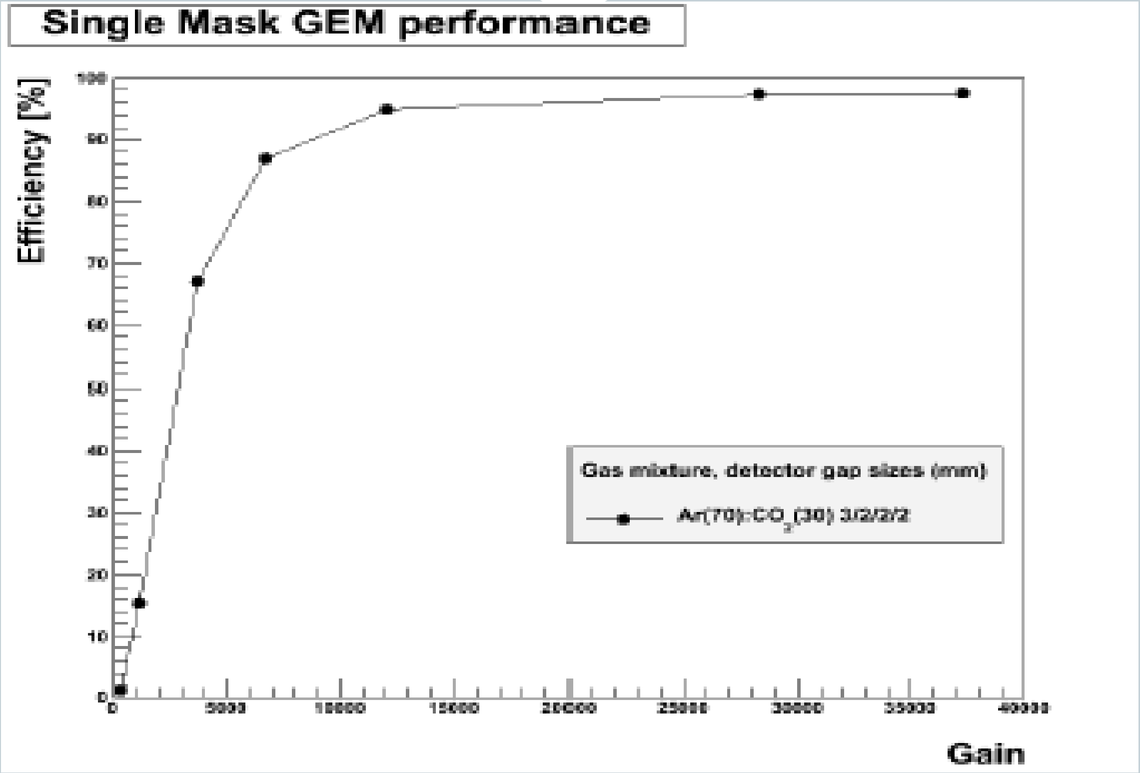


Timing study



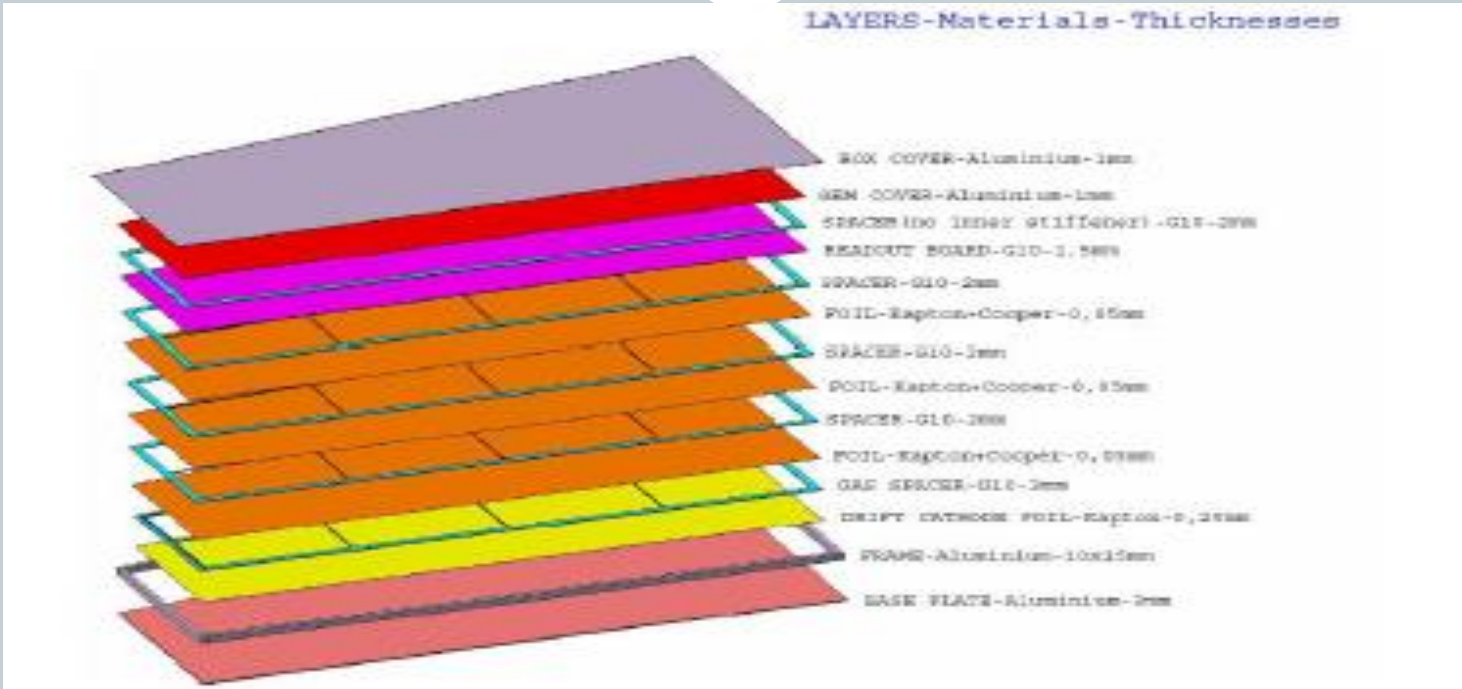
- ❑ Clear effect of gas mixture, and induction and drift field.
- ❑ Timing resolution of 4 ns reached.

Single-Mask Technique beam test 2010-2011



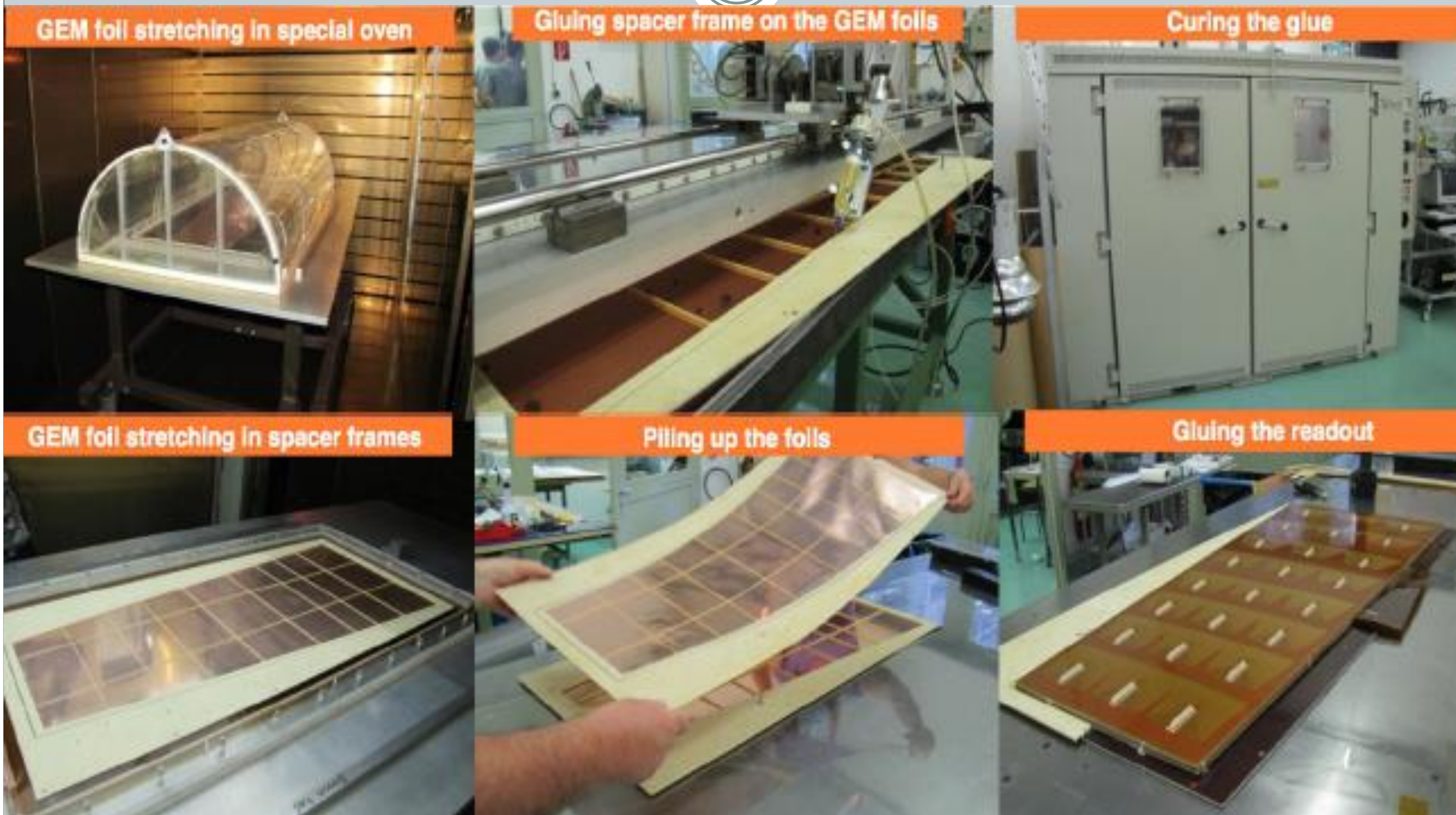
- ❑ Single-mask GEM reaches similar performance level as double-mask GEM.
- ❑ Single-mask technique used for large CMS-size prototypes.

GE1/1 Prototypes



Drift - GEM1	3mm
GEM1 - GEM2	2mm
GEM2 - GEM3	2mm
GEM3 - Readout	2mm

Foil stretching Assembly



First large prototype

October 2010

128 channel readout connector

1m

Generation I
Fully glued
Gap configuration 3/2/2/2mm
1024 readout strips

HV divider and filter

HV connector

Gas inlets

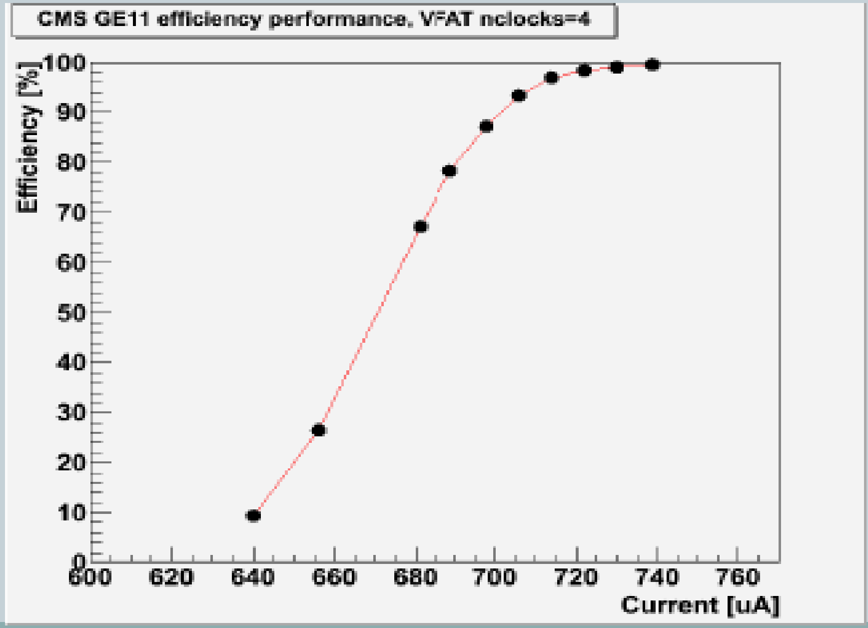
First Generation Results

- Excellent performance observed

≥ 98% efficiency

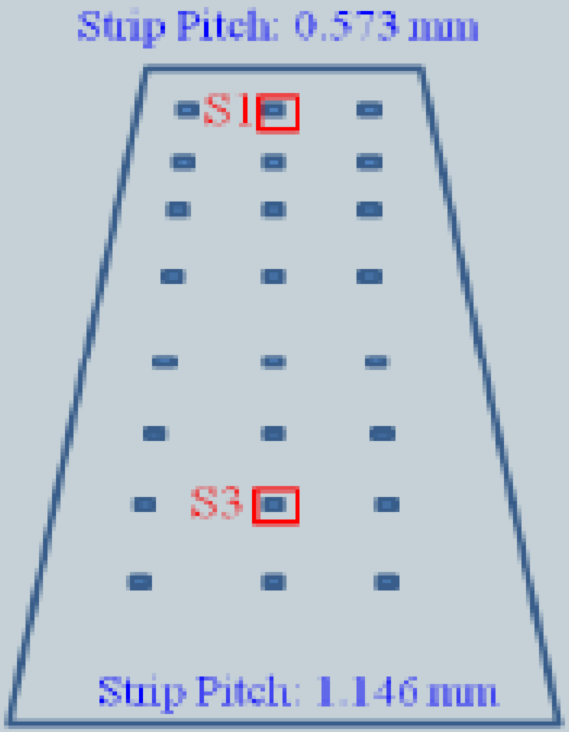
230 µm resolution

uniform performance in different sectors



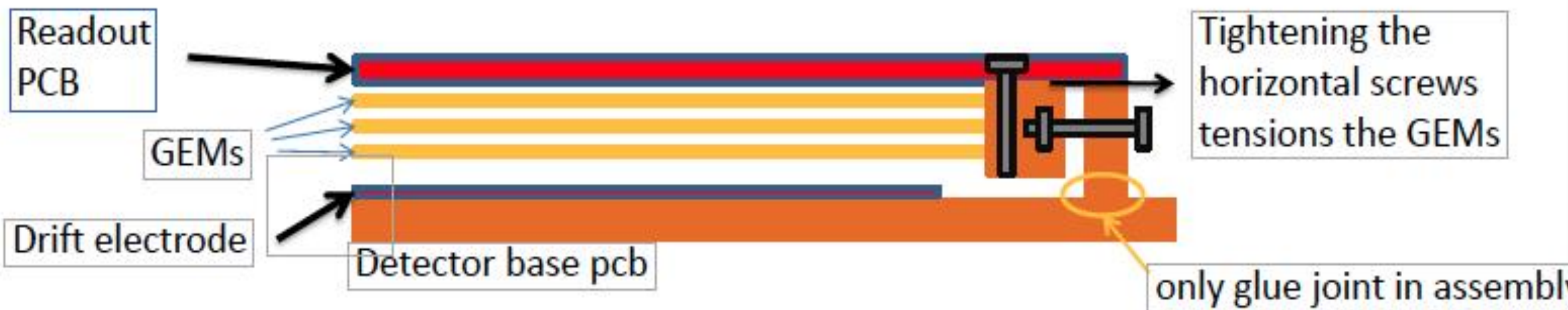
2nd GE1/1 Detector (2011)

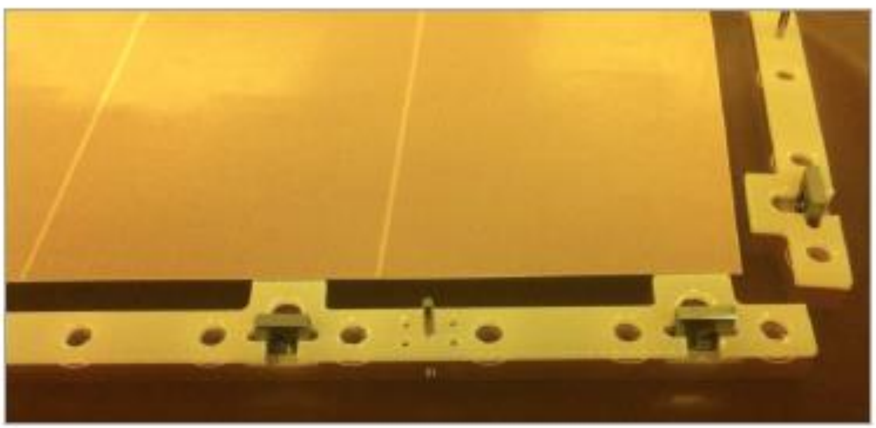
- Smaller GEM gap sizes: 3/1/2/1 mm
- More sectors: 3 columns, 8 η partitions
- Smaller strip ptich: 0.6-1.2mm
- 3072 channels, 1D readout
- Successful data taking with analog APV chip and Scalable Readout System in addition to TURBO/VFAT2 DAQ system.
- Measured resolution σx<103μm in section with smallest pitch



GEM Foil Stretching (GIII)

Current state-of-the-art: Self-stretching assembly without spacers (CERN)

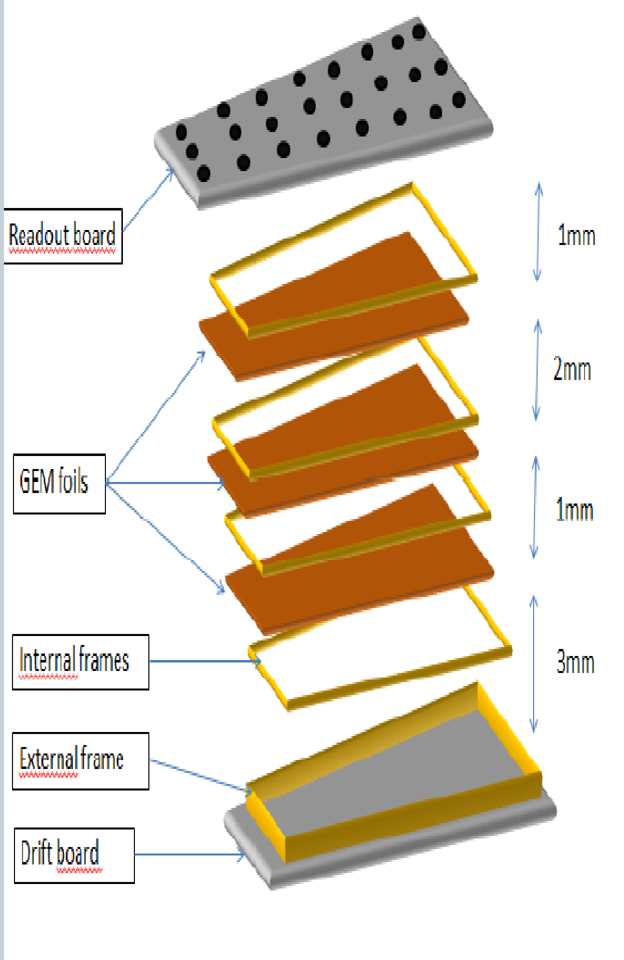




2012

Allows re-opening of assembled detector for repairs if needed

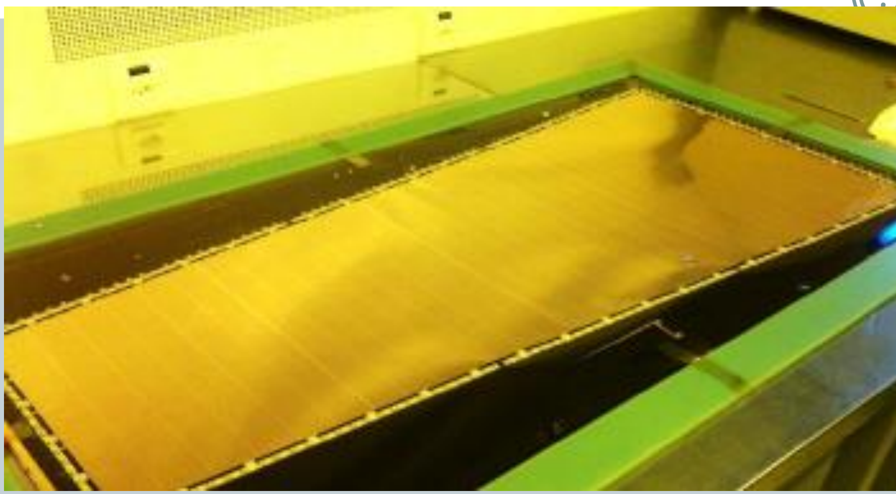
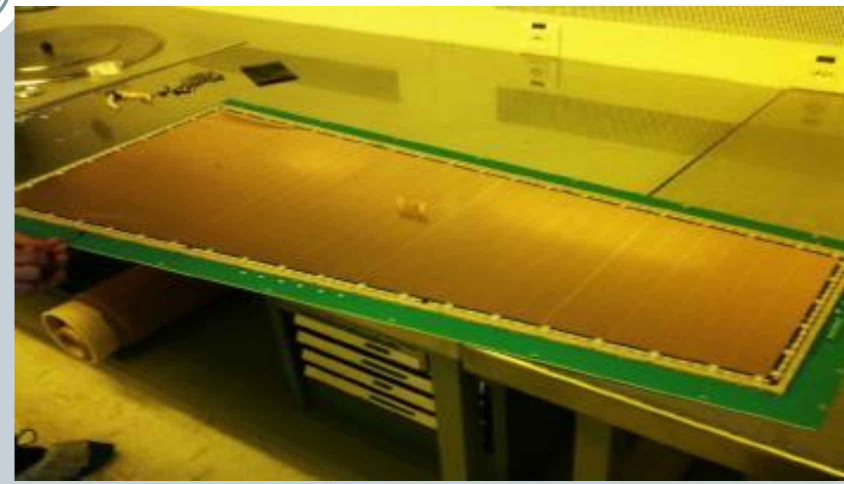
Generation IV (2012)



- Single-mask & self-stretching technique.
- Gap sizes: 3/1/2/1 mm.
- 3 columns and 8 eta partitions.
- Strip pitch: 0.6-1.2mm
- 1D readout of up to 3840 channels.
- 35 HV sectors

Generation IV GE1/1 Prototype Full-size NS2 .

Generation IV

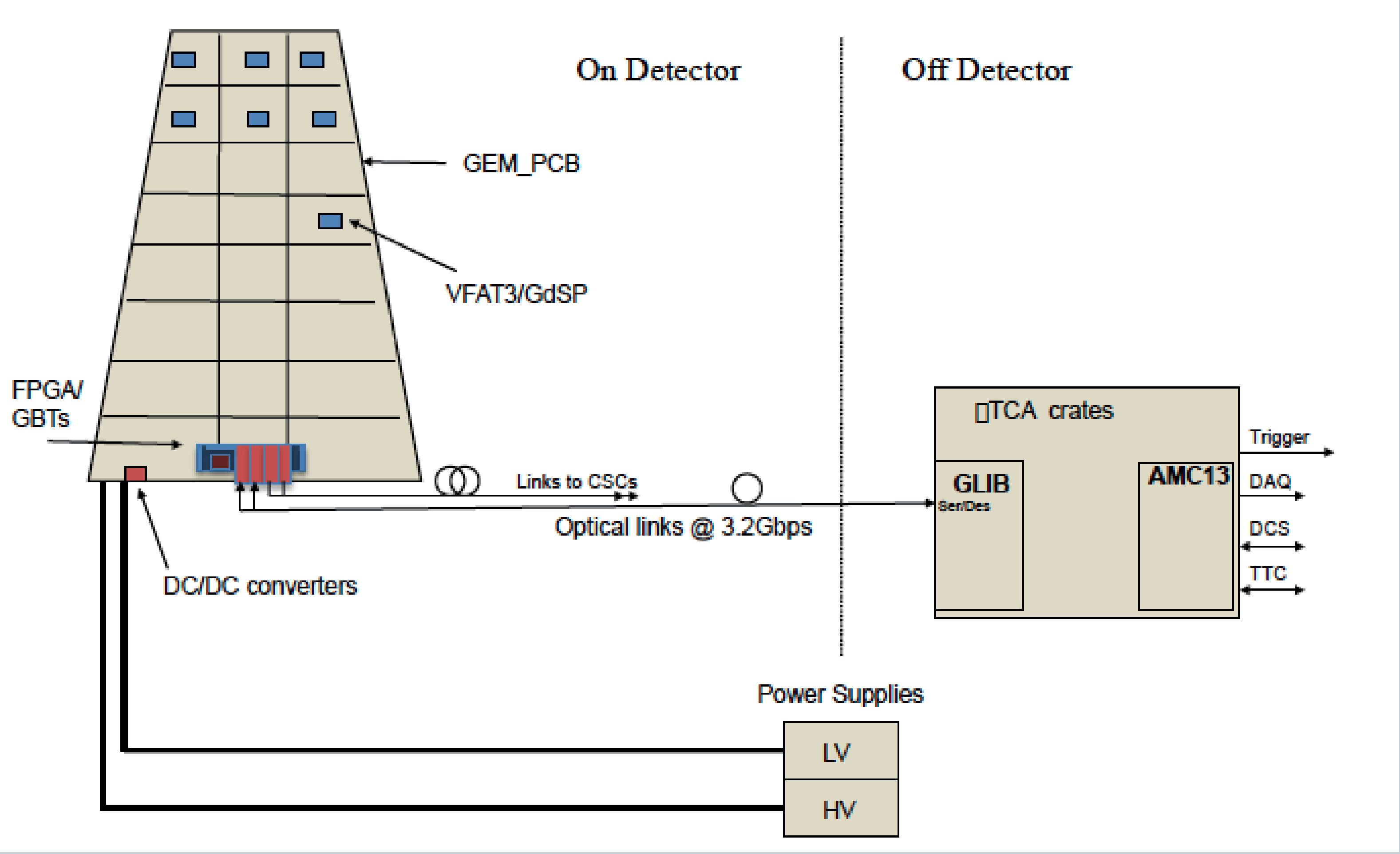


Electronics

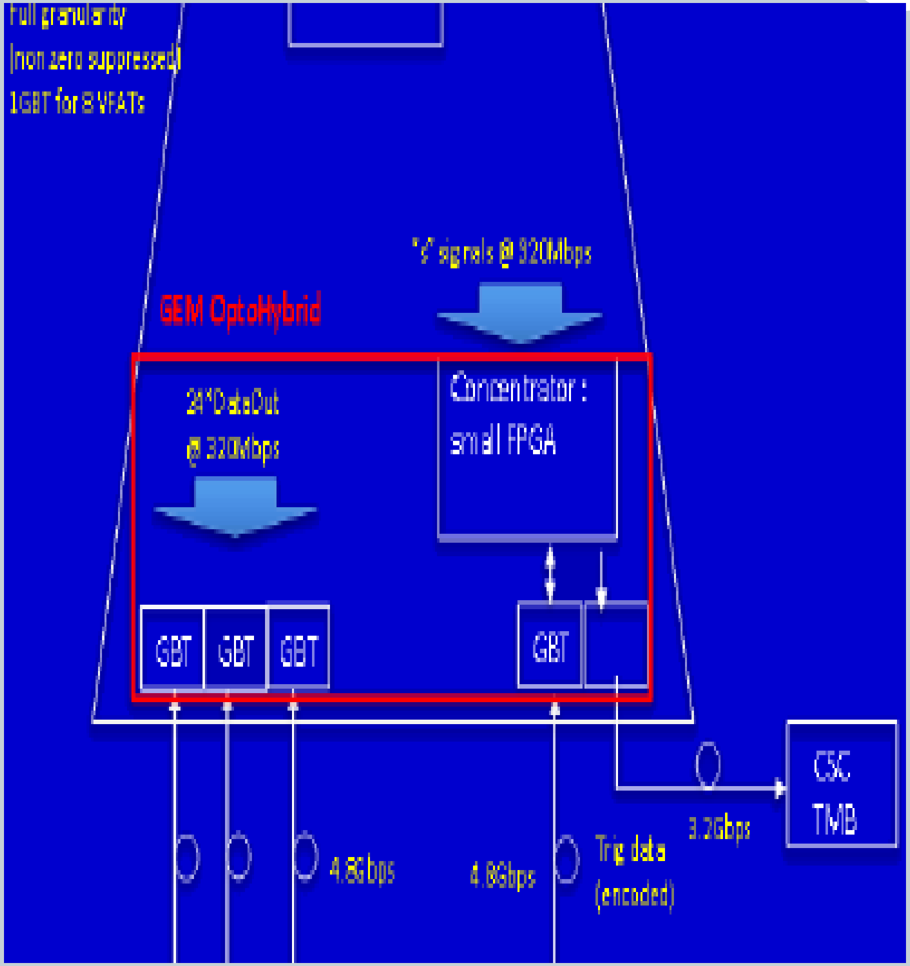
- Global Requirements on electronics: provide necessary input from all GEM detectors to Muon Triggering and Tracking.

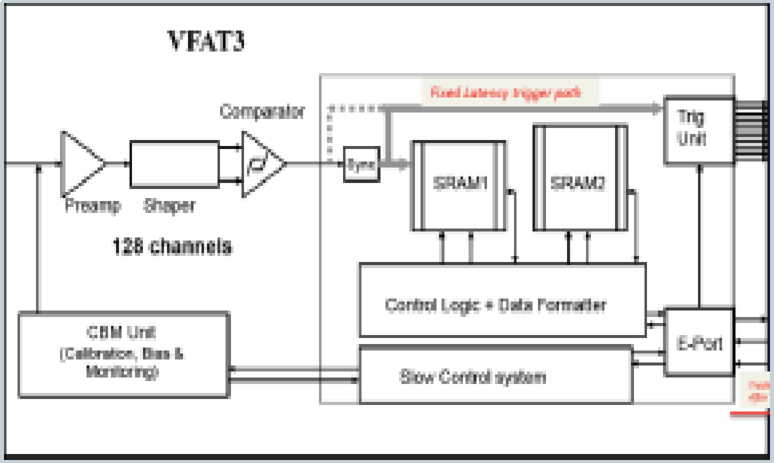
- GEM detectors:
  - Design optimized for gas detectors, in particular GEMs
- Triggering:
  - Timing resolution <8ns
- Tracking:
  - Provide full granularity tracking data on receipt of a LV1A
  - Be compatible with CMS trigger upgrade

Electronics



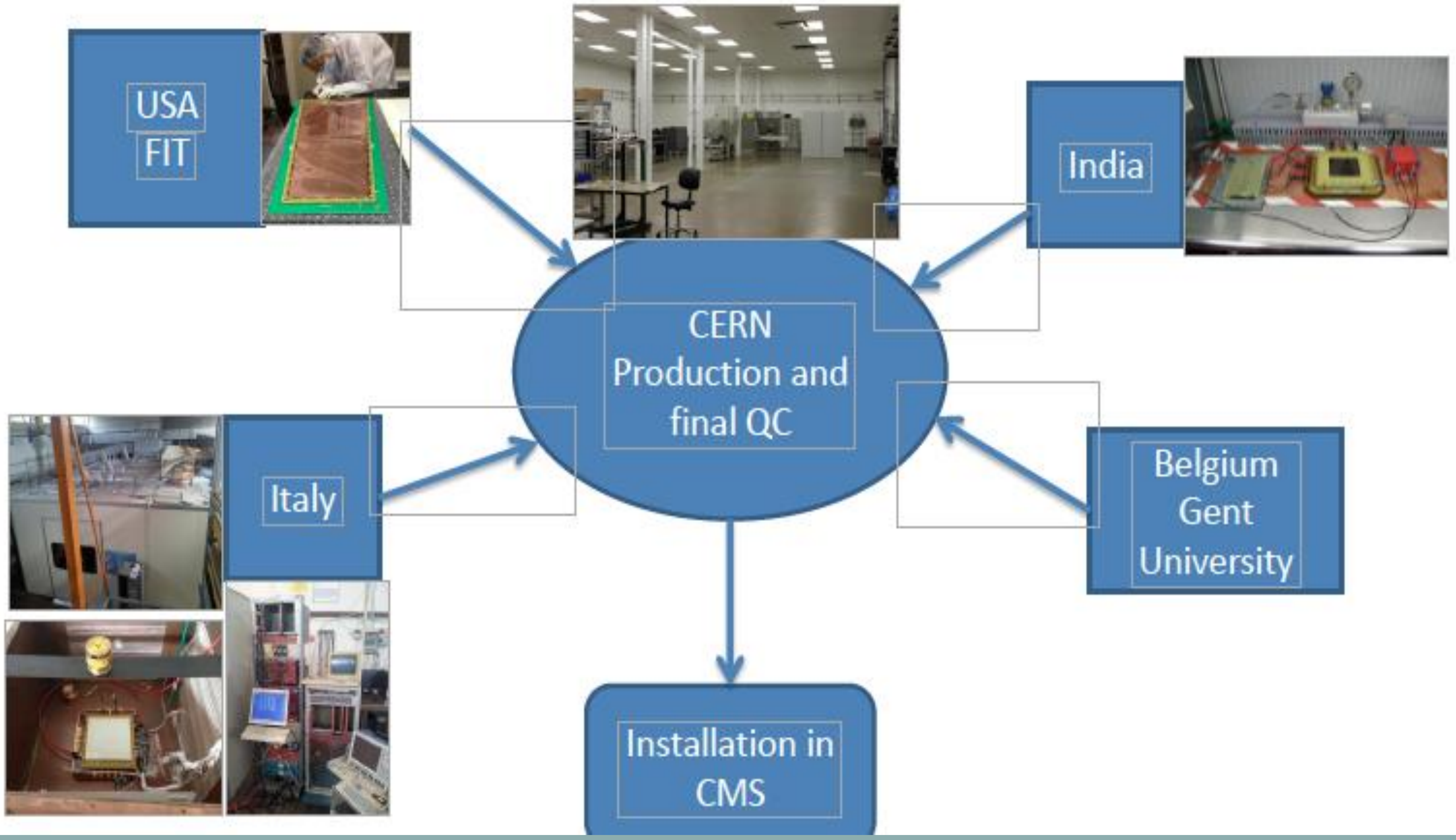
VFAT3



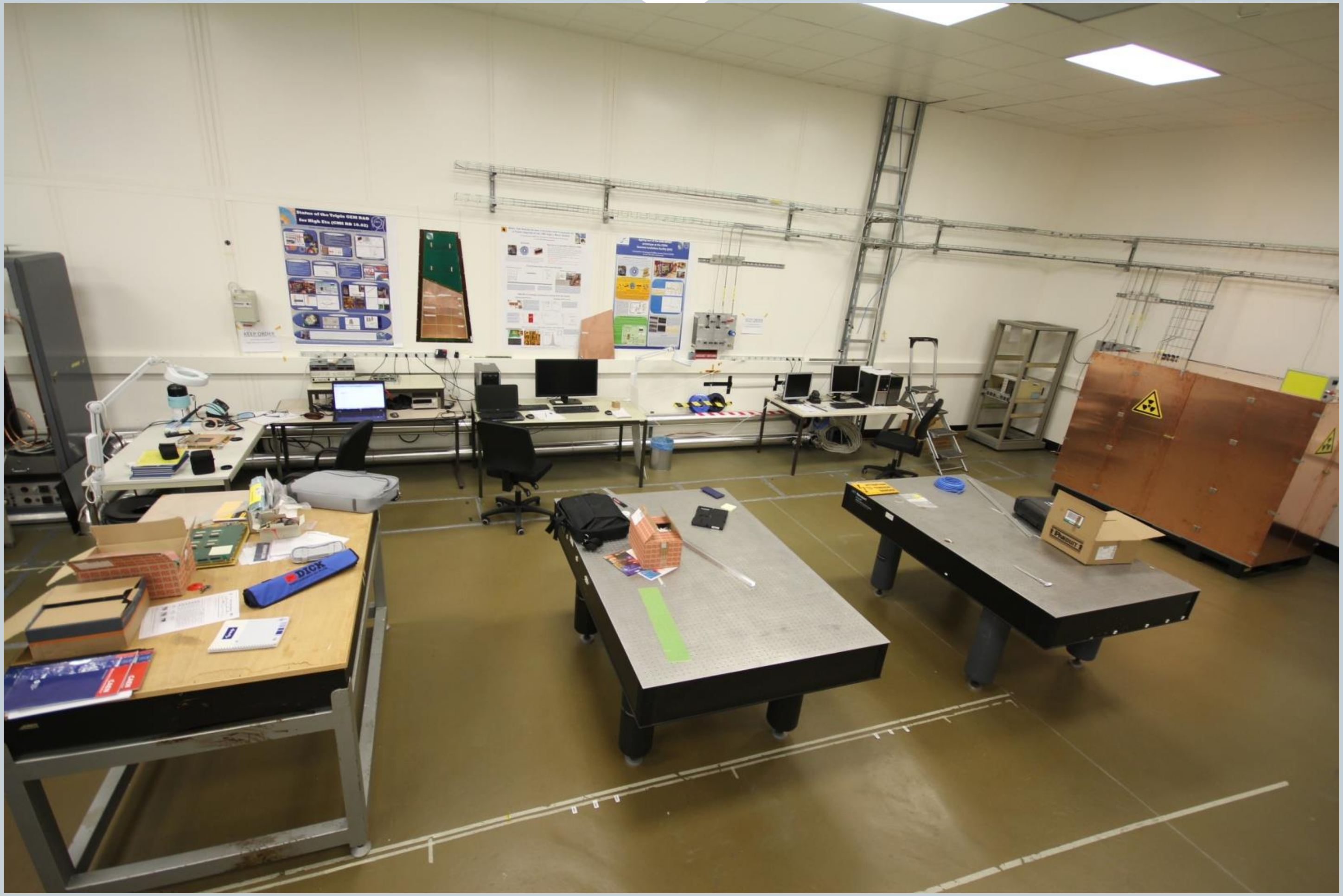


VFAT3 chosen for the 2016 Slice Test and GE1/1 full installation during LS2.

Production Sites



GEM lab.



GEM Applications

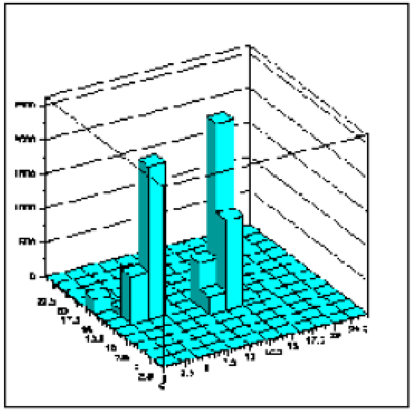
GEM For Plasma Diagnostics.

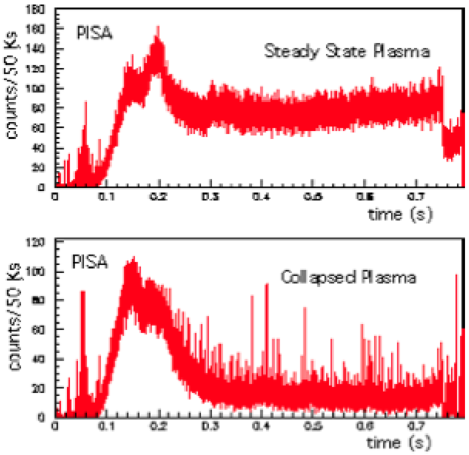
Imaging the dynamics of fusion plasmas has been attempted at the Frascati Tokamak Upgrade to exploit the sensitivity of the GEM to soft X-rays.

Time resolved plasma diagnostics are made with a GEM and individual pixel readout.

Counts integrated in 50 μs for four adjacent pixels at the Frascati Tokamak

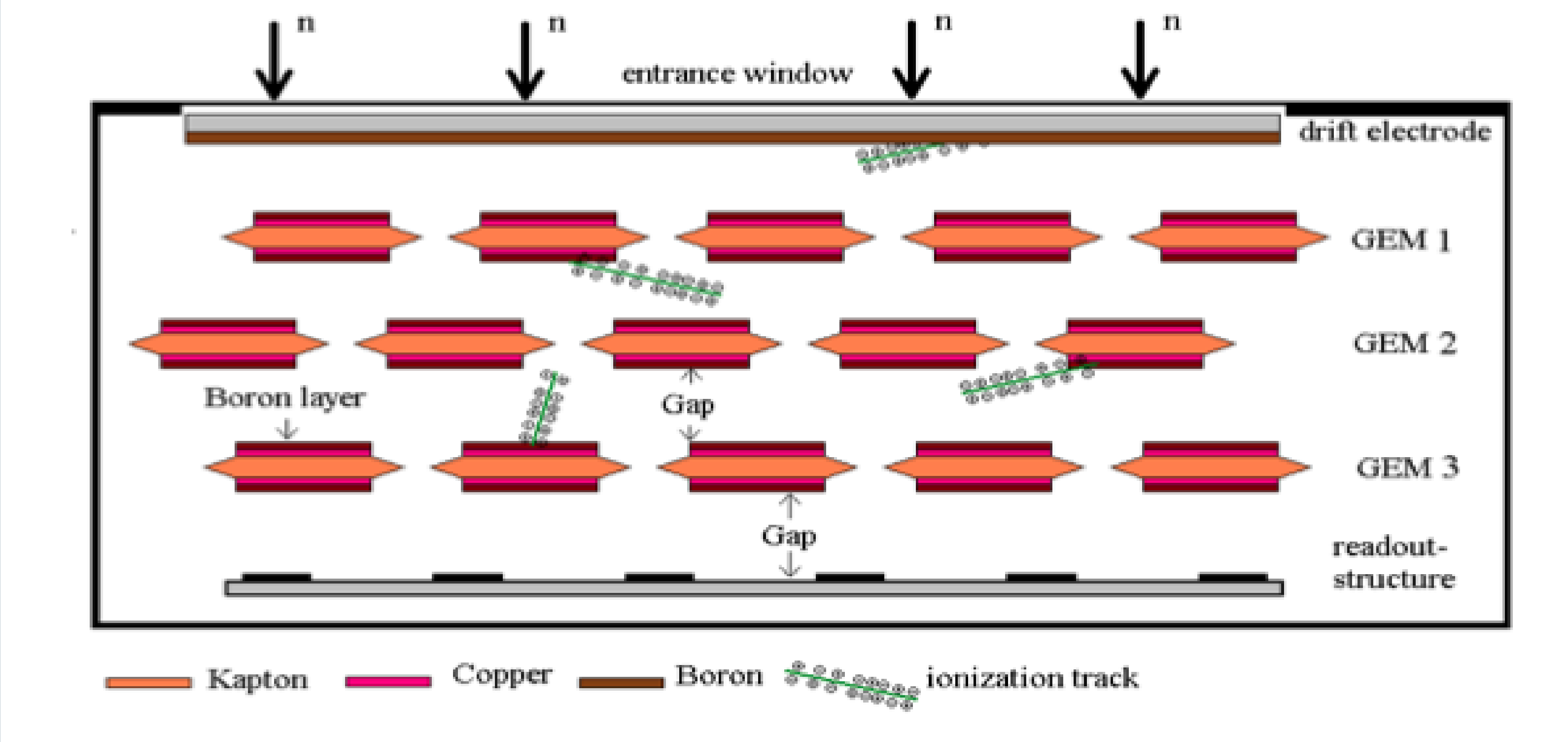
Reconstruction of photoelectrons with a GEM+ micropixel readout





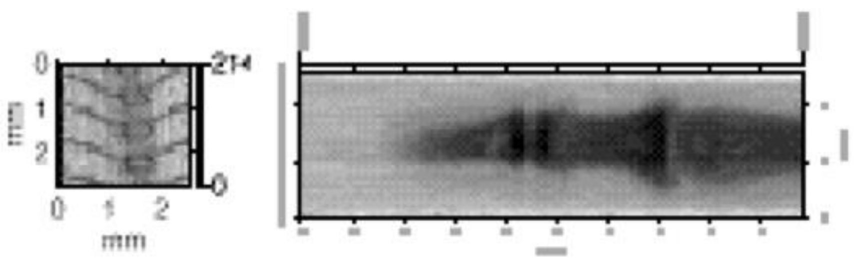
Neutron detection

- Neutrons are converted in a gas mixture of He-3 and CF4, and the resulting proton and triton tracks detected optically

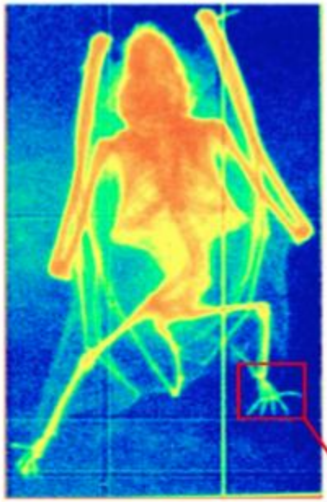


X-Ray imaging

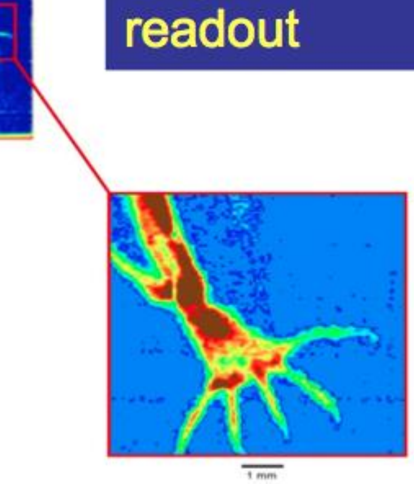
13 kV X-ray absorption radiography of a fish bone taken at 2 atm using a GEM + MSGC combination.



3 mm x 10 mm 50 kV x-ray image of a digit of a mouse.



Radiography of a small bat using GEM and 50µm x 50 µm 2d-readout



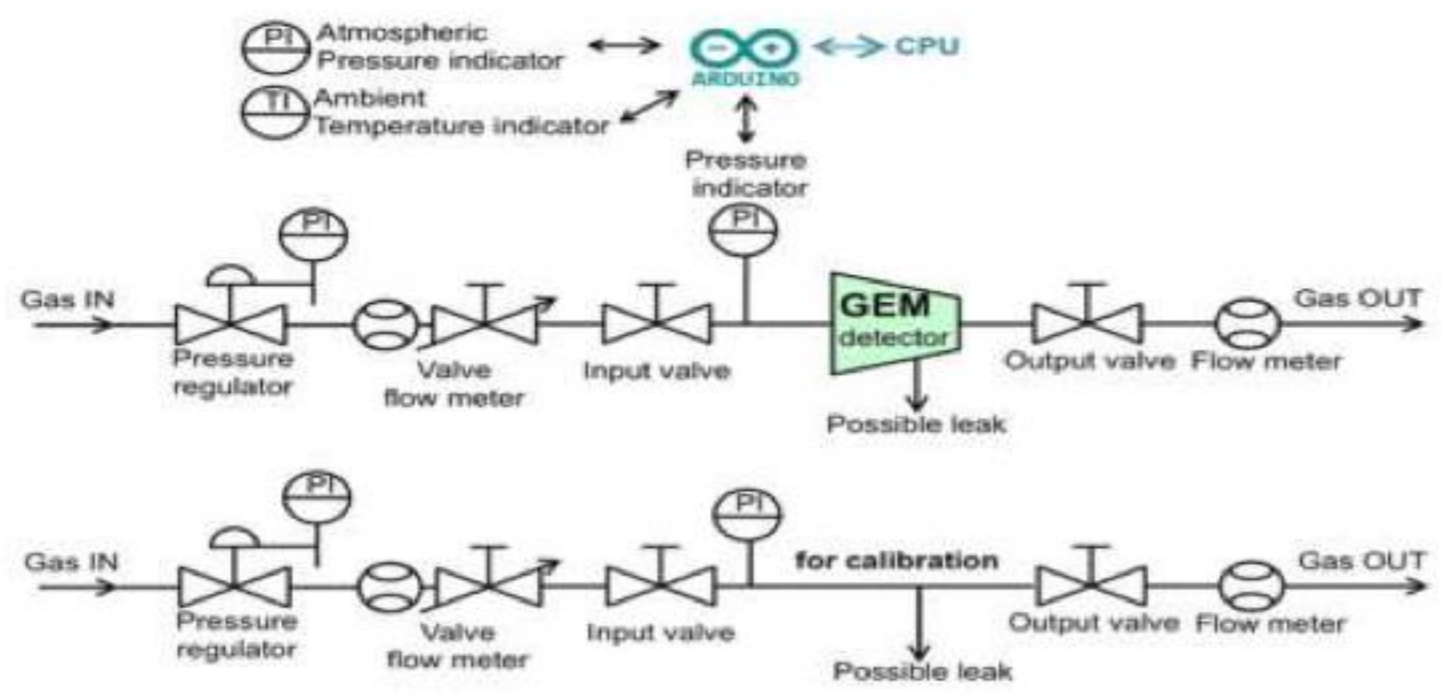
GEM LAB IN EGYPT

Egypt Participation.

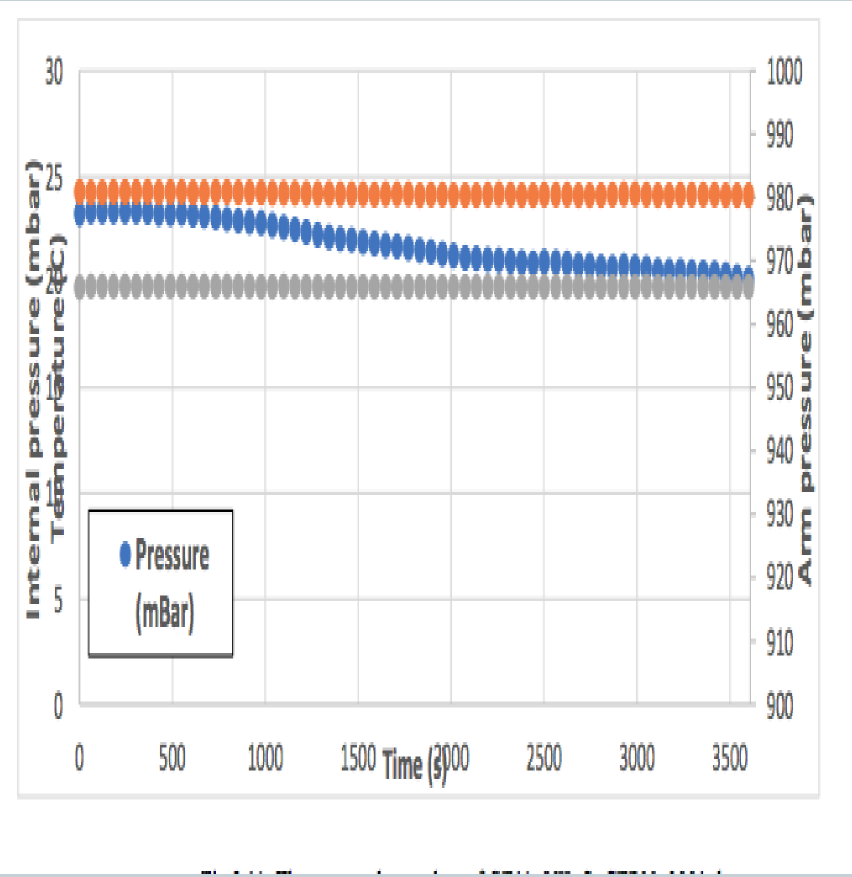
- We have two scientists at CERN during Sept-Oct work on GEM lab to collect all information about the the lab and its Structure and tests performed there.
- Egypt will participate in GE1/1 and GE2/1 production.
- Egypt will participate in GEM quality control (QC)
- A student (Salwa) works participate in QC3 and QC4 under supervision of Egyptian physicist (Dr Hassan)
- In the following slides I will present their results.

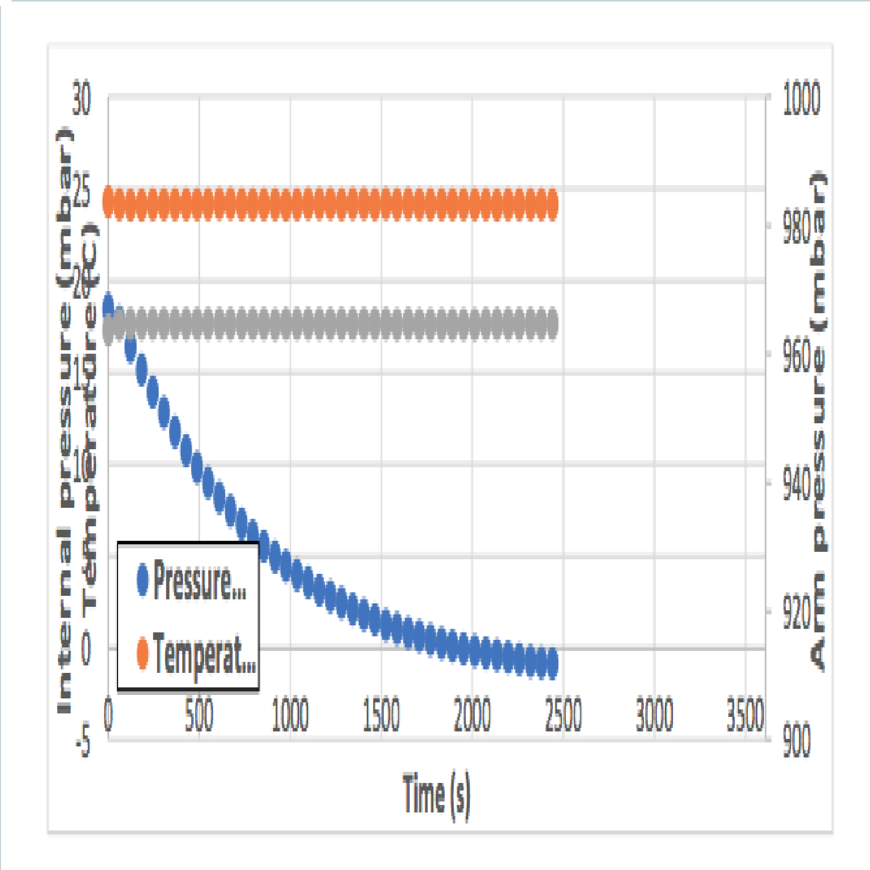
QC3

- The QC3 gas leak test aims to identify the gas leak rate of a GE1/1 detector by monitoring the drop of the internal over-pressure as a function of the time.



QC3


30
25
20
15
10
5
0
1000
990
980
970
960
950
940
930
920
910
900
0
500
1000
1500
2000
2500
3000
3500
Time (s)
Internal pressure (mbar)
Temperature (C)
Atm pressure (mbar)
Pressure (mBar)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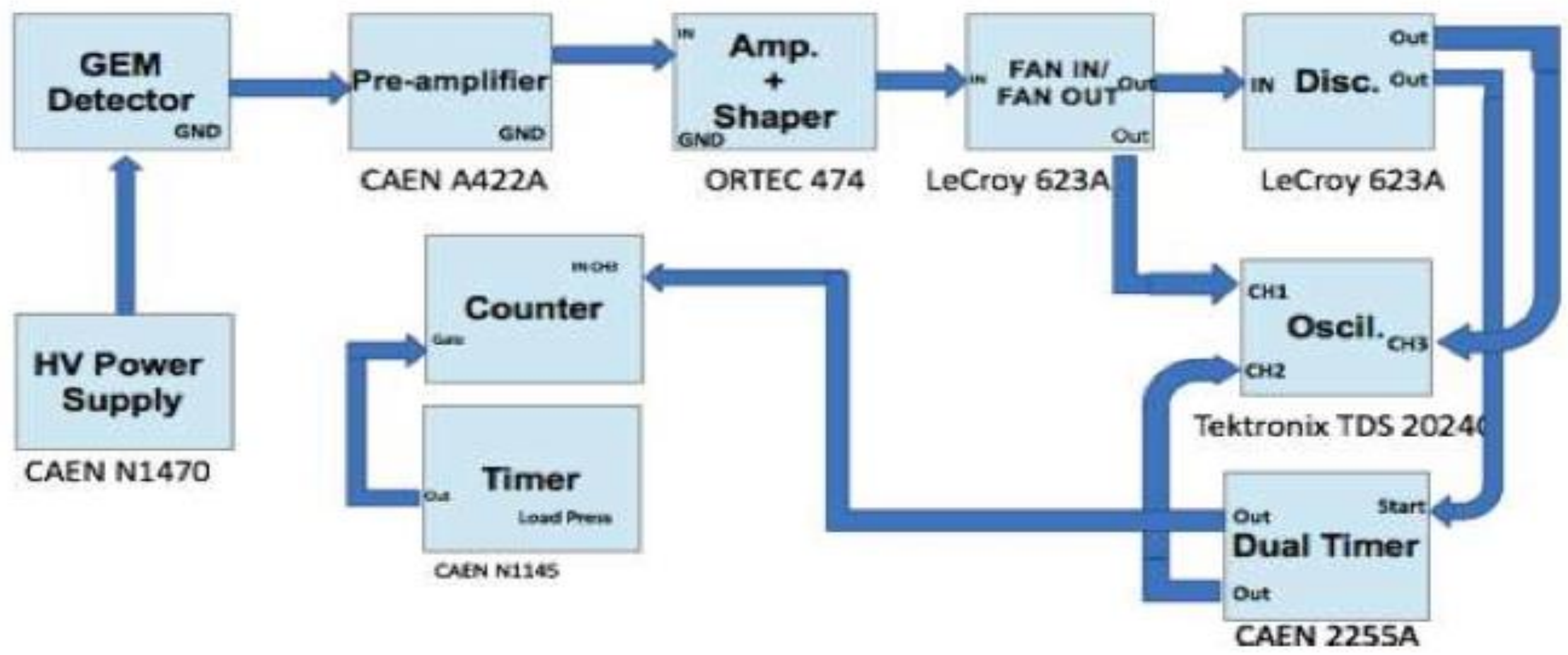
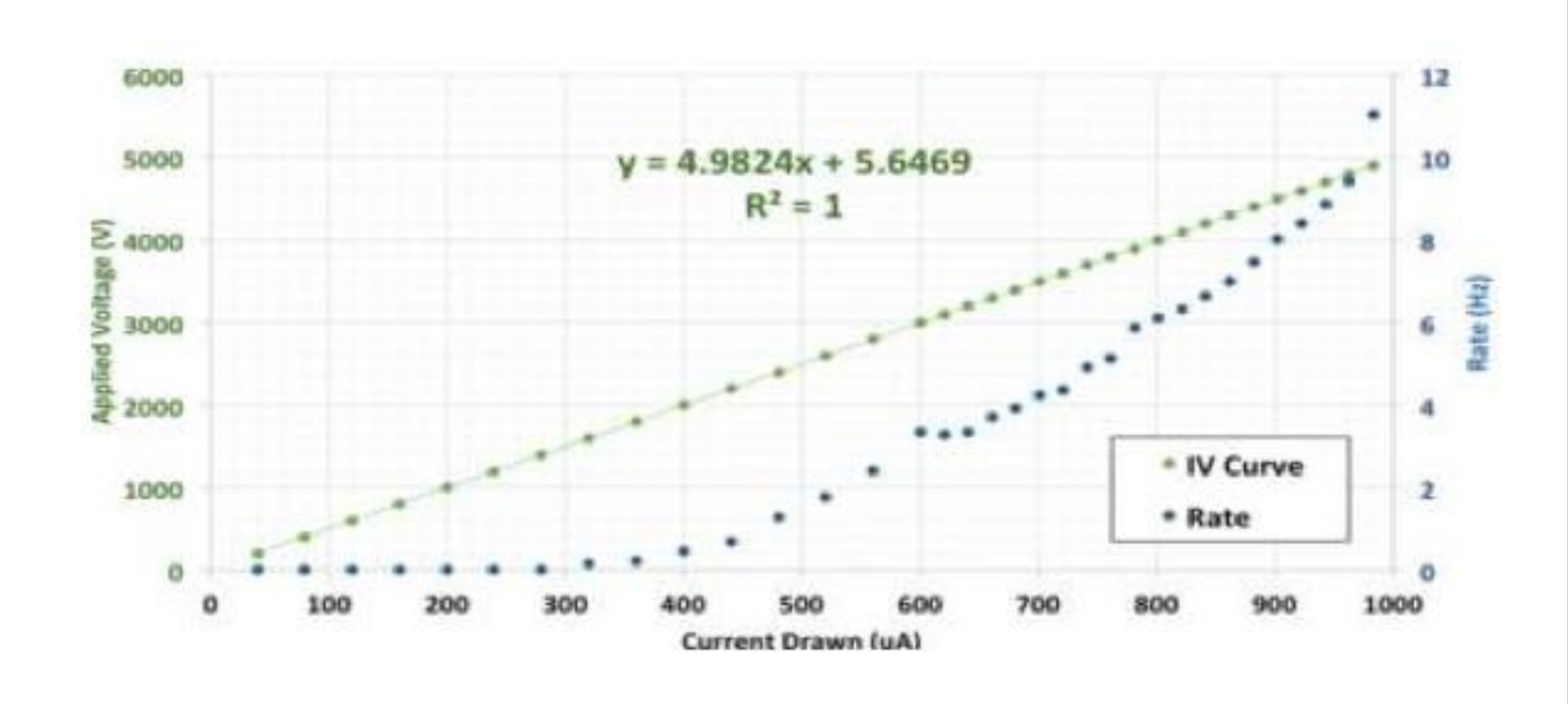
2000
2500
3000
3500
Time (s)
Internal pressure (mbar)
Temperature (C)
Atm pressure (mbar)
Pressure...
Temperat...

QC4

- The QC4 test aims to determine the V vs. I curve of a GE1/1 detector and identify possible malfunctions, defects in the HV circuit .



QC4



y = 4.9824x + 5.6469
R² = 1
Applied Voltage (V)
6000
5000
4000
3000
2000
1000
0
Rate (Hz)
12
10
8
6
4
2
0
0
100
200
300
400
500
600
700
800
900
1000
Current Drawn (uA)
IV Curve
Rate

Dear students and all,

First of all apologies that I could not come, I wanted to.

We have a lot of action ongoing at the lab in CERN.
We await much more engagement from young students physicists and engineers in our project. This is an opportunity to grow in the field, learn new techniques, bring the knowledge to your country and ignite further progress. Each one of you has
that capacity. The Egyptian impact in the GEM project, has already begun !! The best
is just round the corner.

See you soon and best wishes,

Archana Sharma
Project Manager, GEM Upgrade

Thank you!