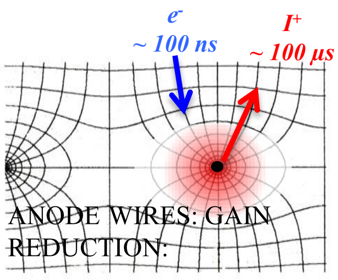
Micro Pattern Gaseous detectors

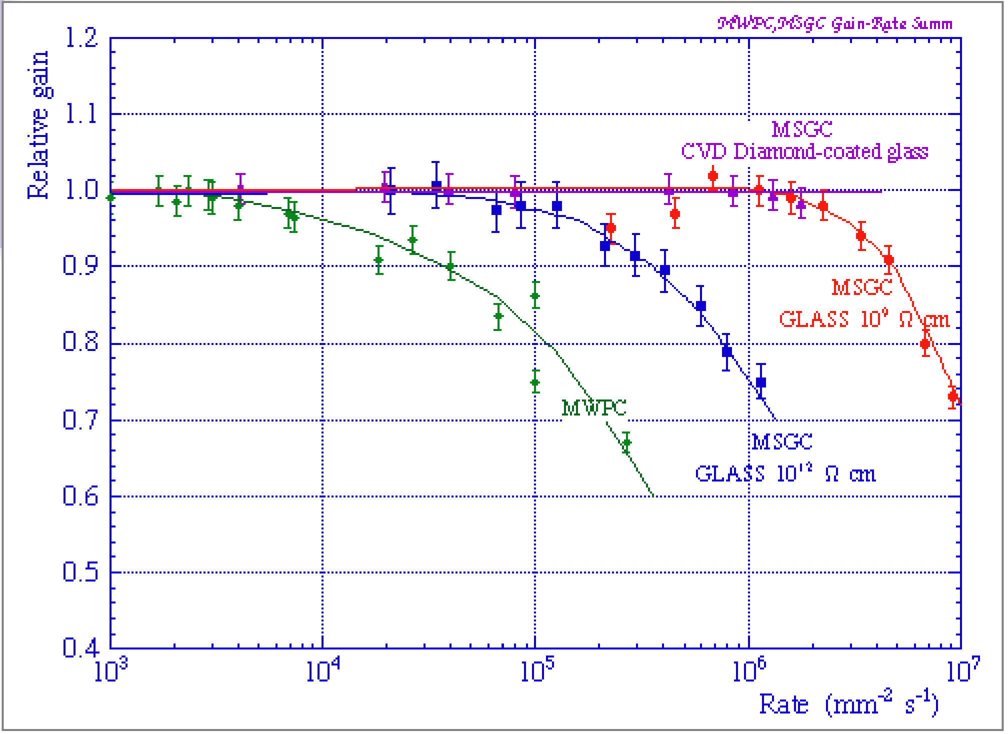
for Large Area LHC Upgrades

Archana Sharma CERN : ECFA 2014

Limitations of wire-based chambers:

- Resolution: reduction of wire spacing <1 mm very difficult
  - mechanical tolerances
  - electrostatic repulsion ⇨ wire tension!
- Rate capability: limited by build-up of positive space-charge around anode



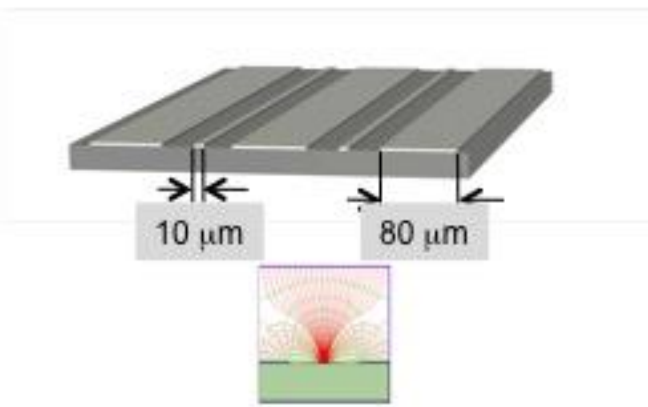


- Photolithography
- Laser & Chemical Etching
- Coating, CVD, Resistive
- Wafer post-processing

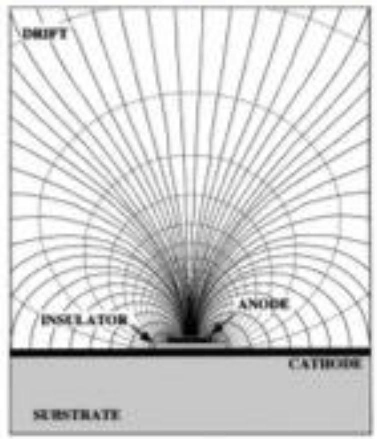
⇨ Reduction of cell size by a factor of 10

The MPGD Zoo of the 90s

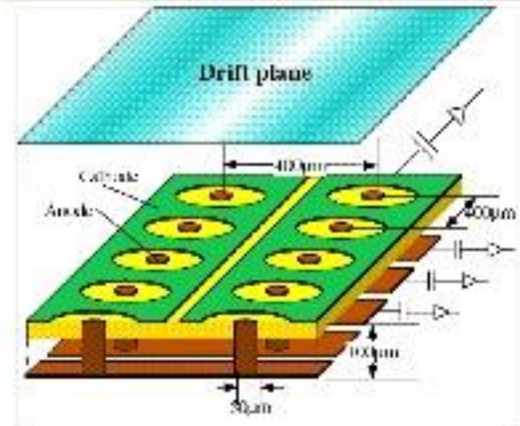
Microstrip Gas Chamber
[A. Oed, NIM A263, 351 (1988)]



Microgap Chamber (MGC)
[F. Angelini et al., NIM A335, 69 (1993)]



Microdot Chamber
[S.F. Biagi et al., NIM A361, 72 (1995)]

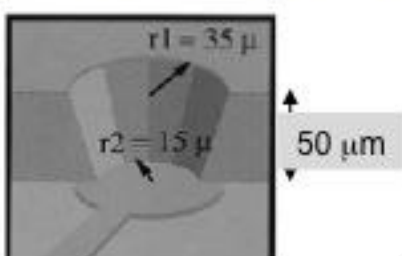


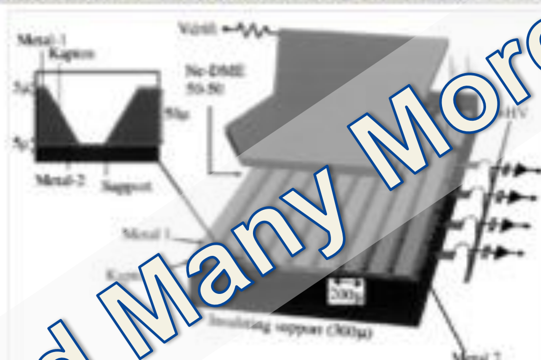
Compteur à Trous (CAT)
[F. Bartol et al., J. Phys. III 6, 337 (1996)]

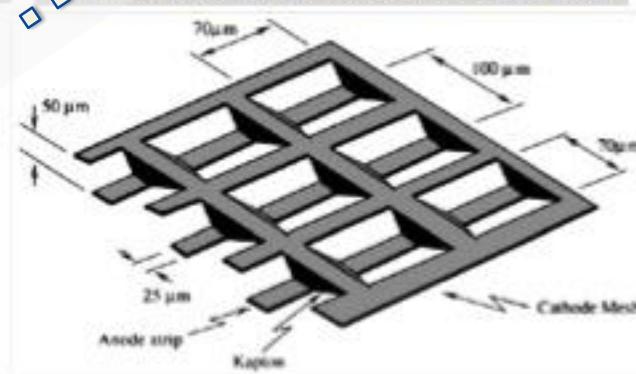
Micro Groove Counter
[Bellazzini et al., NIM A424, 444 (1999)]

Micro Wire Detector
[B. Adeva et al., NIM A435, 402 (1999)]

WELL Detector (µCAT)
[R. Bellazzini et al., NIM A423, 125 (1999)]







And Many More ....

Sauli Sharma Annual Review of Science 1999

New Challenges for LHC & Upgrades

Larger active areas
- Bulk Micromegas
- Single-mask GEMs
- Industrial Production

Rate Capability
- Pixel readout
- Ion backflow suppression

Higher resolutions
- µPixel
- InGrid

Special shapes
- cylindrical
- spherical

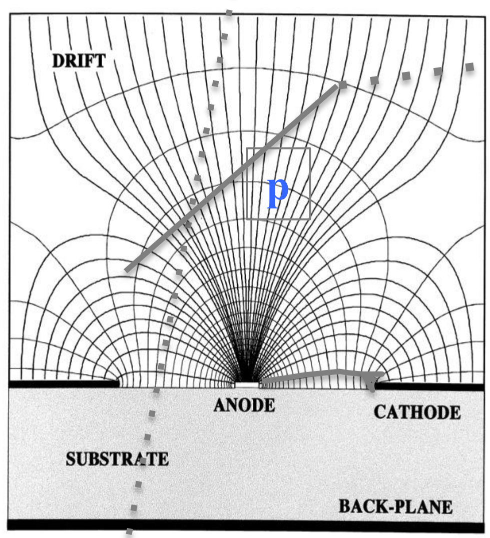
Aging, discharge protection
- Resistive Coatings
- Multi-stage amplification
- Segmentation

Gas Mixture
- Fast
- Drift & Diffusion
- B Field
- Discharges
- Aging

AVALANCHE SIZE Q= (IONIZATION)x(GAIN)

MIP: $Q = 100 \times 10^4 = 10^6$

n→ ~ MeV p $\quad Q \sim 10^4 \times 10^4 = 10^8$



Field emission from cathode edge

Q= (EDGE AMPLIFICATION)x(GAIN) $\sim 10^4 \times 10^4 = 10^8$

RAETHER LIMIT:
$Q > 10^7$----> DISCHARGE

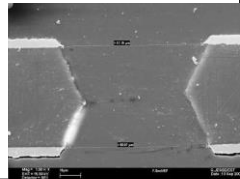
DISCHARGE POINT IN MICROPATTERN DETECTORS ~ Gain 1200

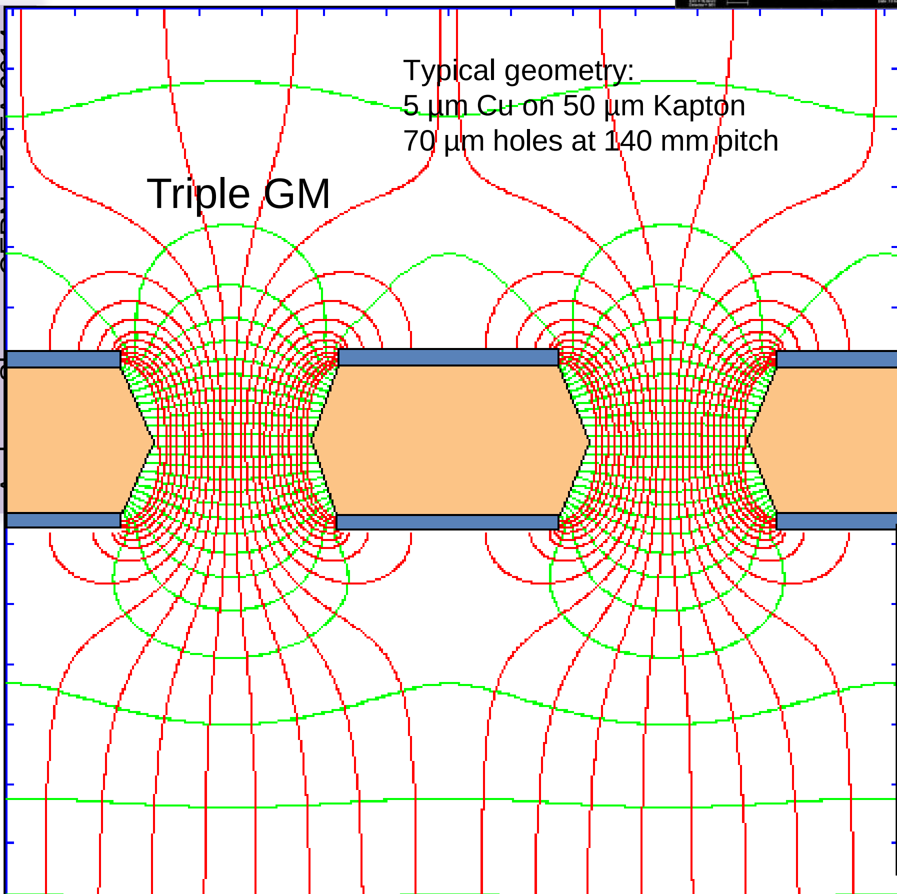
GEM

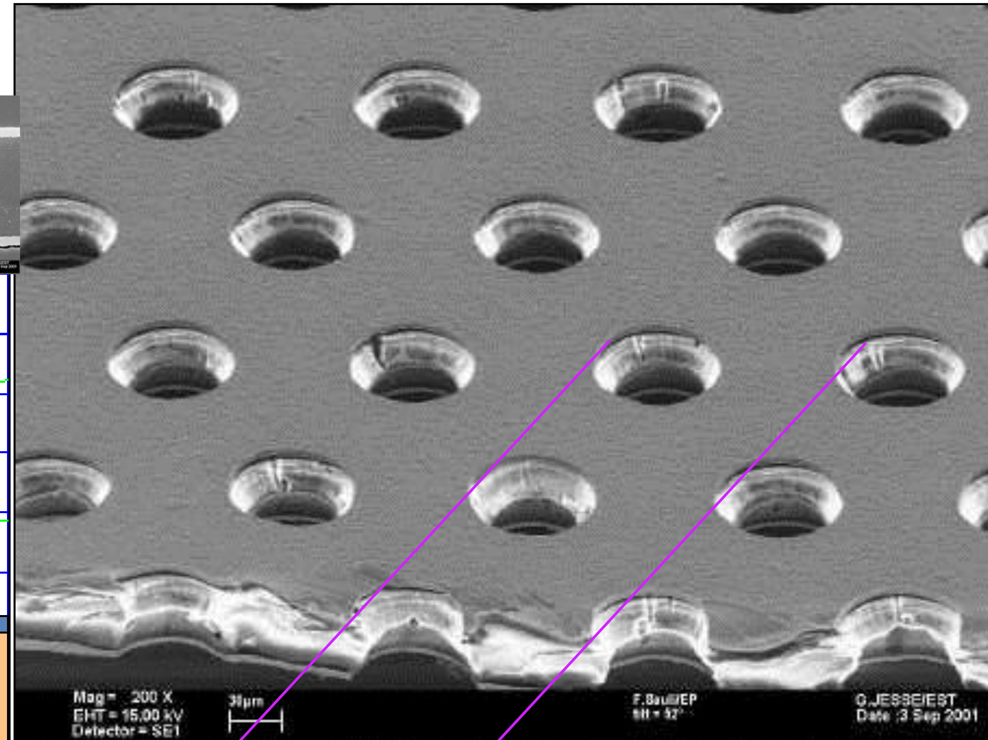
GAS ELECTRON MULTIPLIER (GEM)

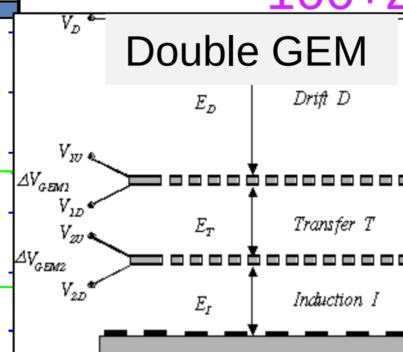
Cascaded GEMs permit to attain much larger gains before discharge

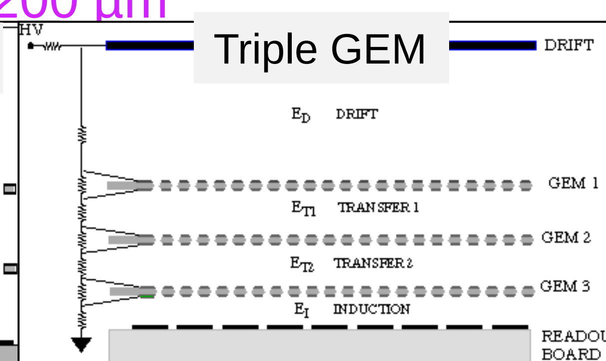
Thin, metal-coated polymer foil with high density of holes:









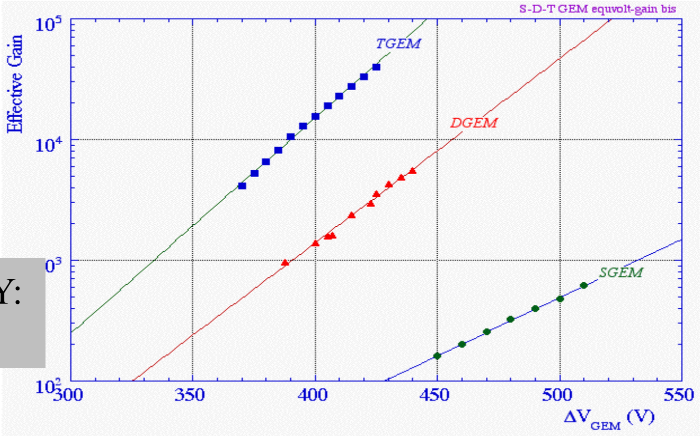


F. Sauli,
Nucl. Instrum. Methods A386(1997)531

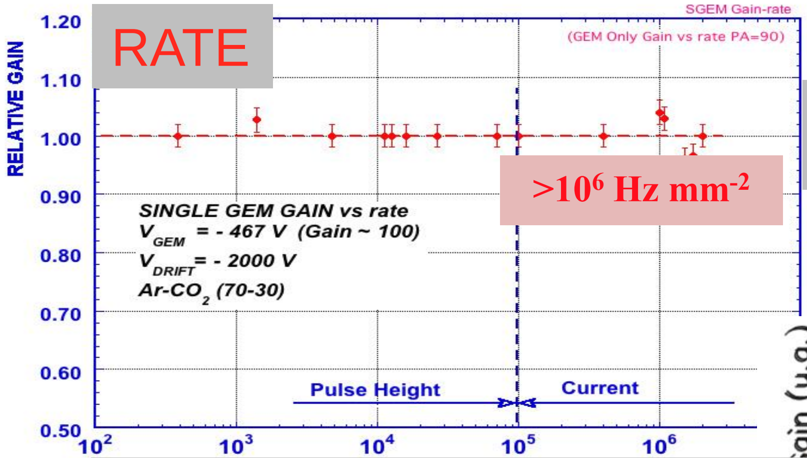
C. Buttner et al, Nucl. Instr. and Meth. A 409(1998)79
S. Bachmann et al, Nucl. Instr. and Meth. A 443(1999)464

GEM Performance

High GAIN



RATE

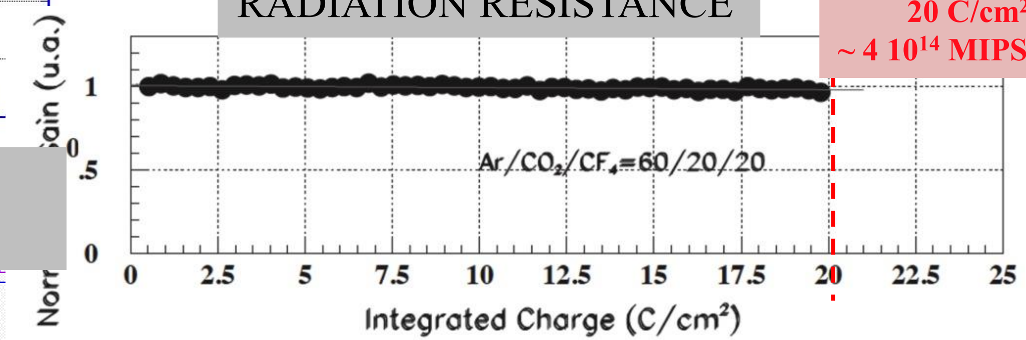


$>10^6$ Hz mm^{-2}

SPACE ACCURACY:
~ 50-100 μmx

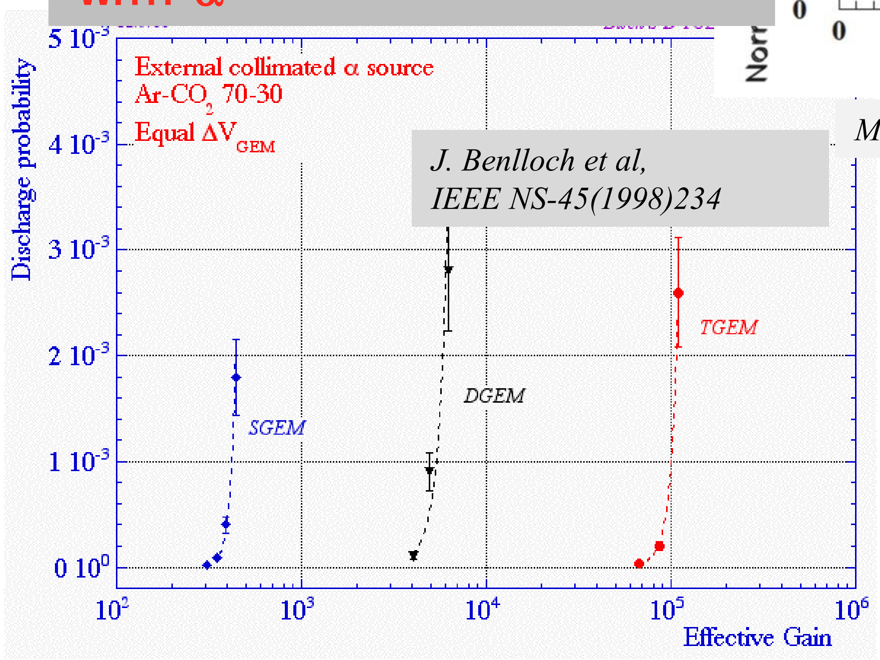
RADIATION RESISTANCE

20 C/cm^2
~ 4 10^{14} MIPS cm^{-2}



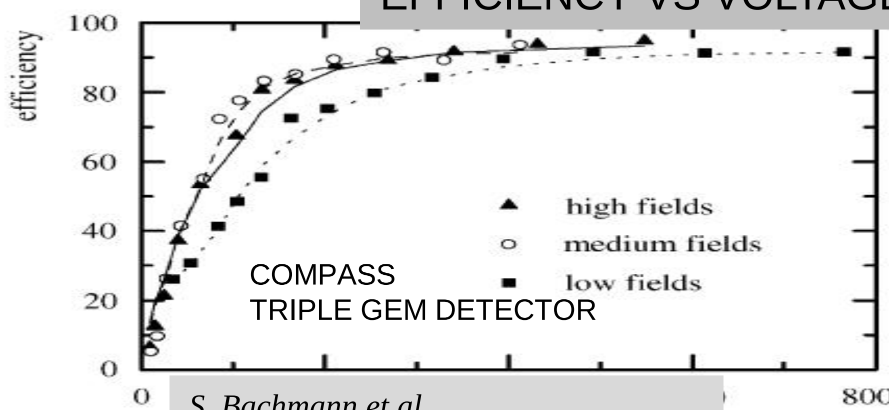
M. Alfonsi et al, Nucl. Instr. and Meth. A518(2004)106

DISCHARGE PROBABILITY WITH α



J. Benlloch et al, IEEE NS-45(1998)234

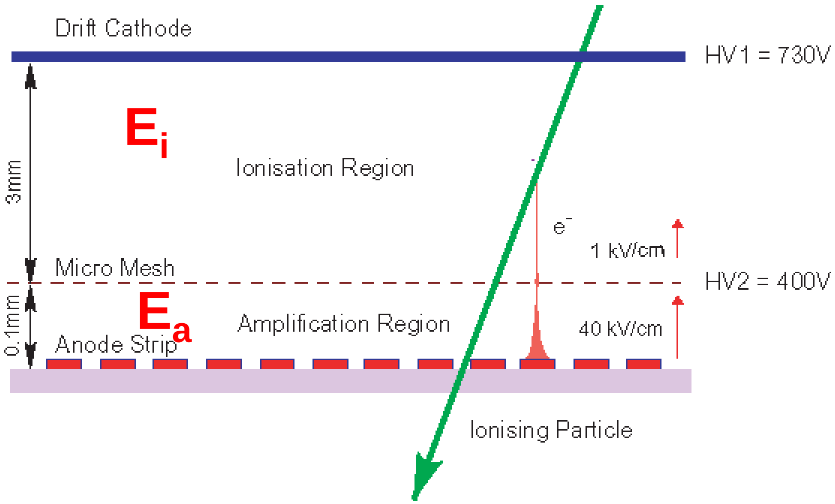
EFFICIENCY VS VOLTAGE



COMPASS
TRIPLE GEM DETECTOR

S. Bachmann et al, Nucl. Instr. and Meth. A479 (2002) 294

MICROMEGAS : Performance

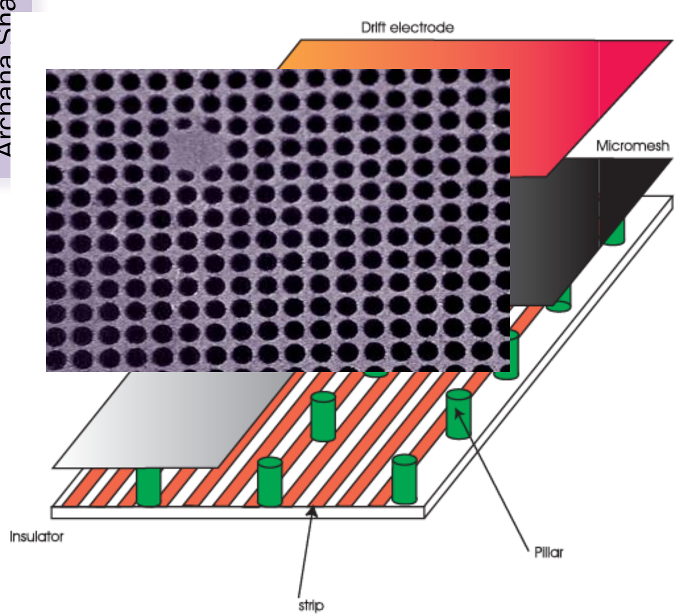


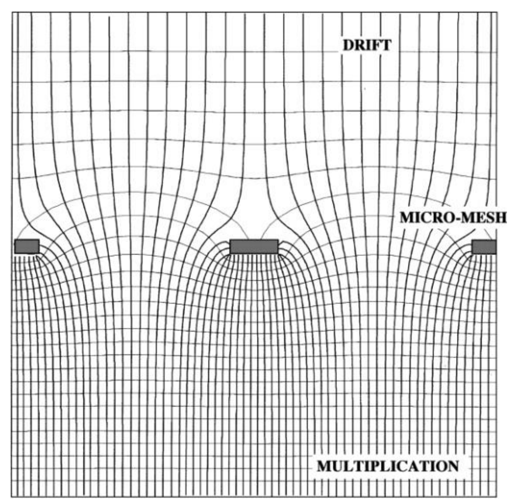
Micromesh Gaseous Structure

[G. Charpak & I. Giomataris et al., NIM A376, 29 (1996)]

- Thin gap parallel plate structure
- Fine metal grid (Ni, Cu) separates conversion (~ 3 mm) and amplification gap (50-100 mm)
- Very asymmetric field configuration: 1 kV/cm vs. 50 kV/cm

Archana Sharm





➡ Fast collection of ions (~ 100 ns)

➡ Saturation of Townsend coefficient (mechanical tolerances)

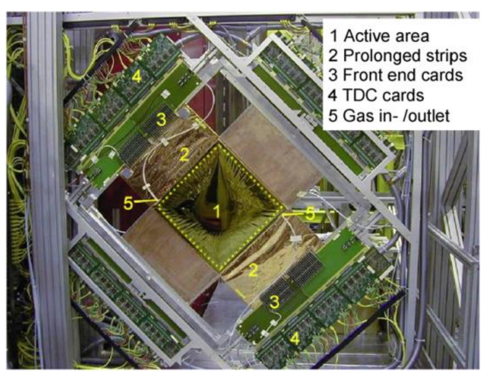
➡ good energy resolution

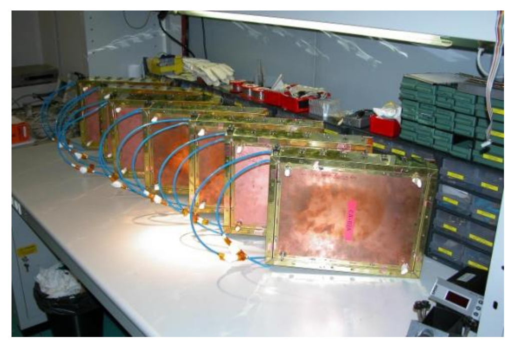
MPGD in Running Experiments

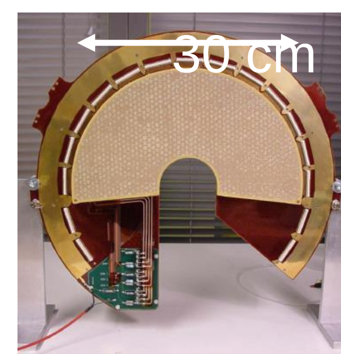
Exp.	#	Type	Readout	# of ch.	Size (cm^2)	Gas	σ_{space} (μm)	σ_{time} (ns)	ε (%)
COMPASS	22	GEM	2-D strips	1536	31×31	Ar/CO_2 (70/30)	70	12	>97
	12	MM	1-D strips	1024	40×40	$Ne/C_2H_6/CF_4$ (80/10/10)	90	9	>97
LHCb	24	GEM	pads	192	10×24	$Ar/CO_2/CF_4$ (45/15/40)		4.5	>97
TOTEM	40	GEM	pads + strips	1536 + 256	30 × 20	Ar/CO_2 (70/30)	~70 (θ)		>92

Archana

also CAST, NA48, PHENIX …







ATLAS Small Wheel upgrade project

Two new Small Wheels

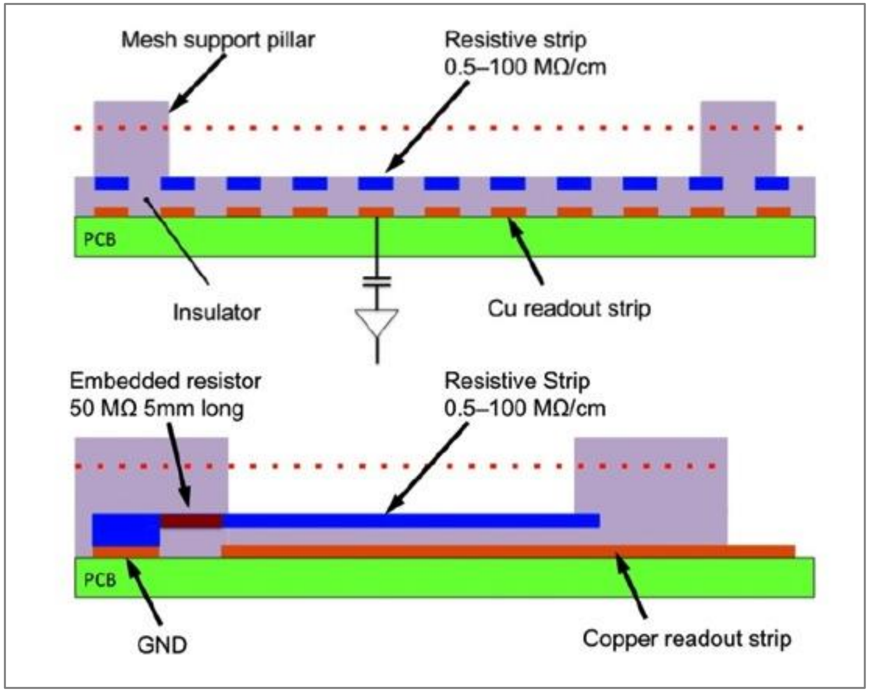
Micromegas detectors

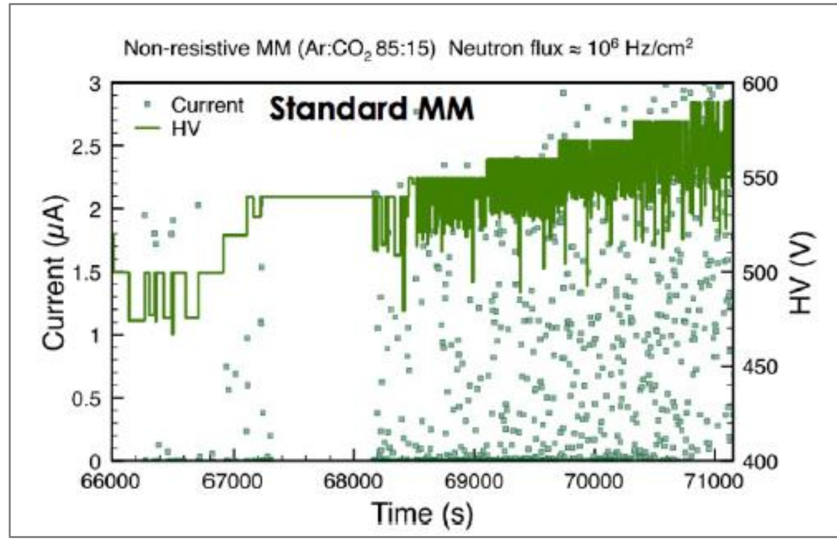
To be installed in 2018

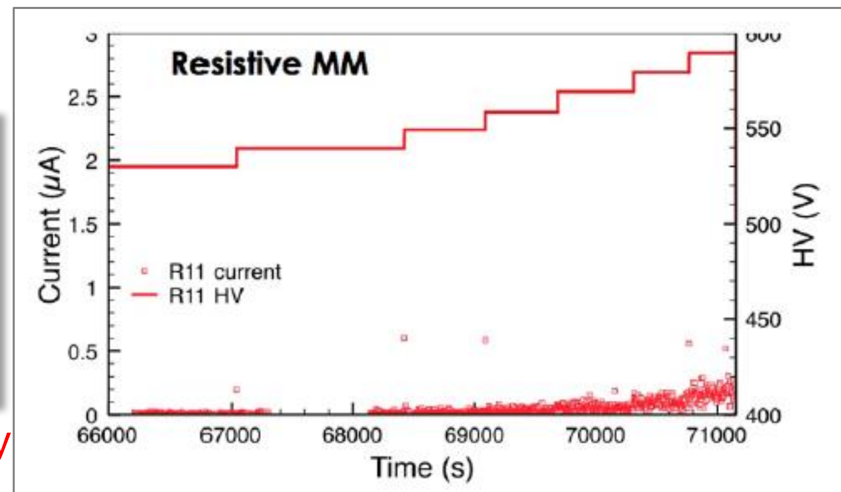
- Redundancy and Trigger
- Eight active layers per detector technology, i.e., a total of 16 measurement points along tracks
- 2M readout channels

  ⇒ 1200 m^2 of MM detectors

SPARK RATES IN NEUTRON BEAM EXPOSURE: ELIMINATED WITH RESISTIVE STRIP LAYER







Consequences of sparks:

- Complete discharge of mesh ➪ dead time ~1ms
- Huge charge ➪ protection of FE electronics necessary
- Destruction of strips, etc.

MM with resistive strips has been successfully operated during one year in front of the e/m calorimeter

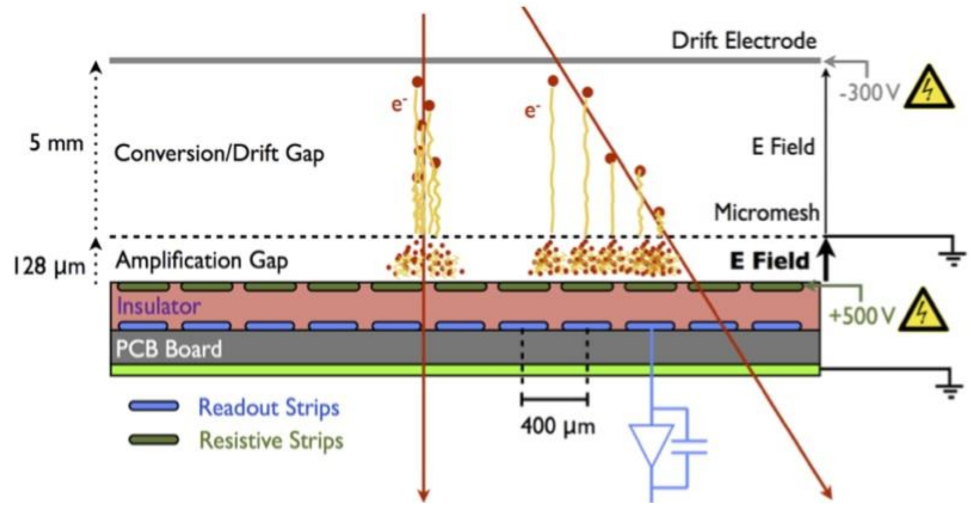
J. Galán et al, Nucl. Instr. and Meth. A732(2013)229

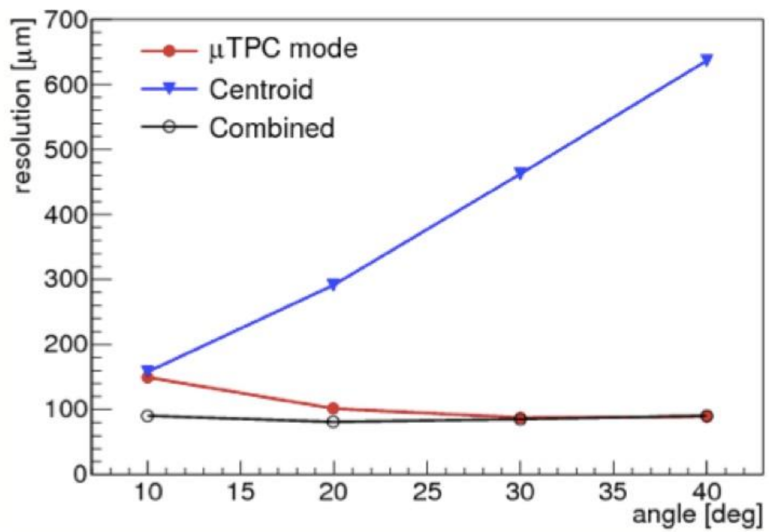
T. Alexopolous et al,
Nucl. Instr. and Meth. A640(2011)110

Micromegas as µTPC

- Detector parameters
  - Gas: Ar:CO_2 (93:7)
  - Drift region: 5 mm; E=600 V/cm
  - Amplification gap: 128 µm; E=40–50 kV/cm
  - Drift velocity: ≈5 cm/µs (or 20 ns/mm); maximum drift time for the ionization electrons is 100 ns
- By measuring the arrival time of the signals a MM functions like a TPC

  => Track vectors for inclined tracks
- Combining cluster centroid and µTPC information yields a spatial resolution of ≈100 µm over a wide range of track impact angles





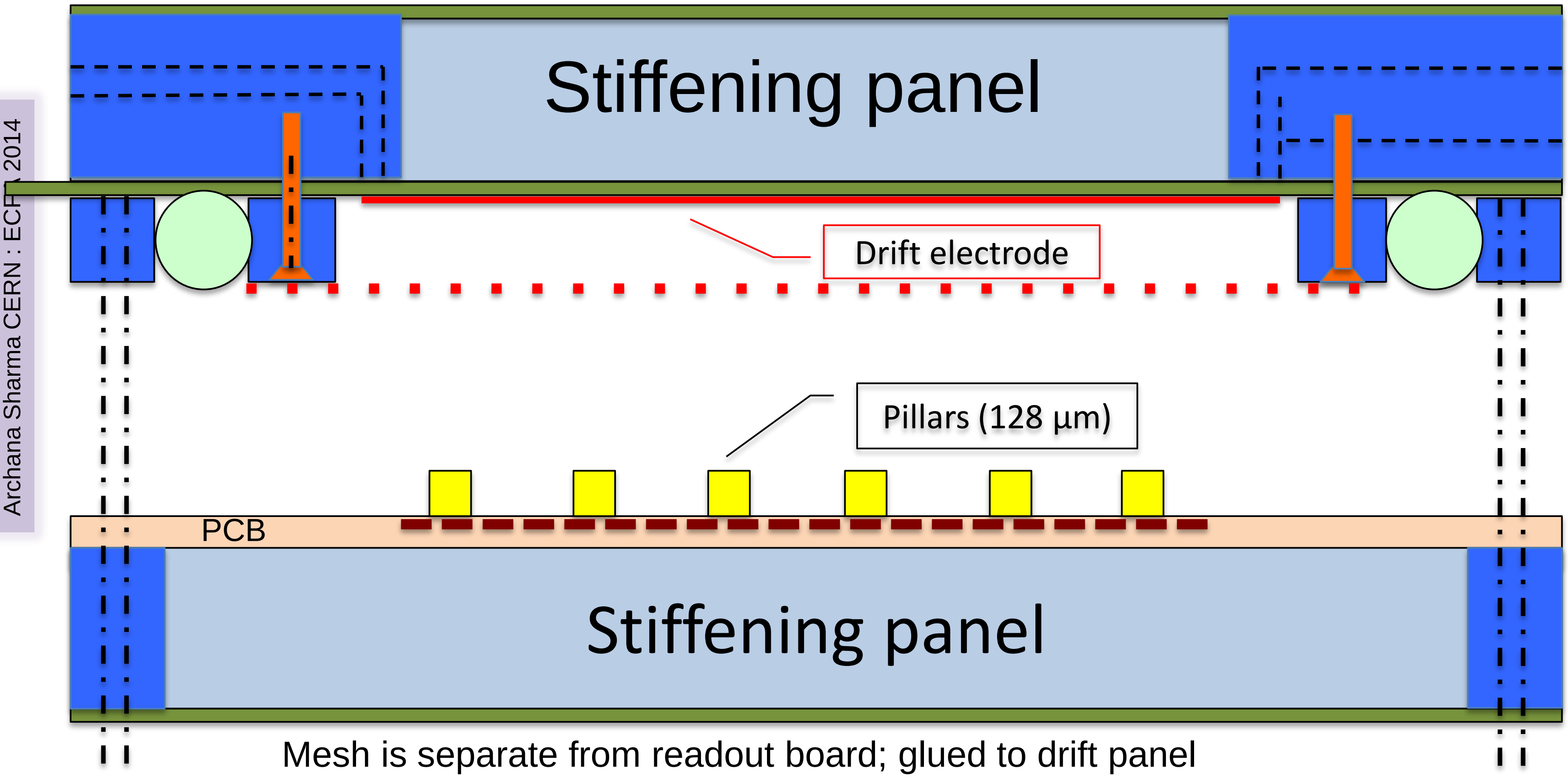
Range of track angles in NSW

MICROMEGAS : Ageing

Radiation	Energy	Integrated charge	Result
Cu X-rays	8 keV	5 years HL-LHC equivalent	No evidence for ageing
Reactor neutrons	5–10 MeV	10 years HL-LHC equivalent	No evidence for ageing
Gamma (^{60}Co)	1.17 & 1.33 MeV	10 years HL-LHC equivalent	No evidence for ageing
Alpha particles in gas	5.64 MeV	5 x 10^8 sparks equivalent	No evidence for ageing

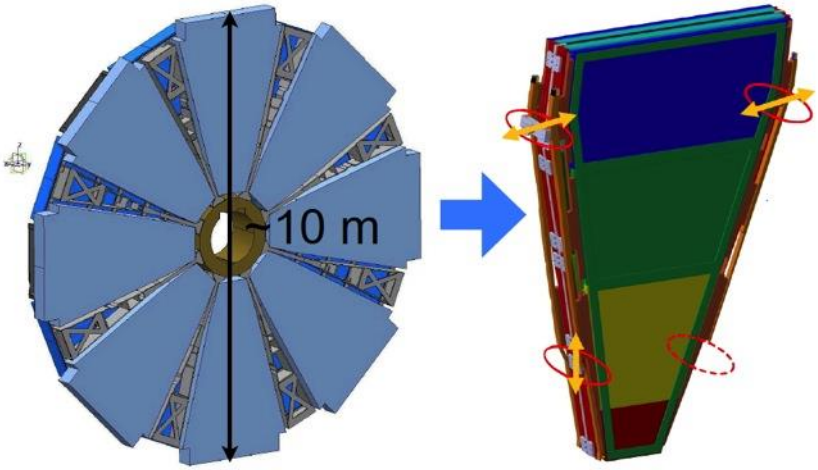
- Extensive tests at CEA Saclay with two 10 x 10 cm^2 resistive MMs
- No significant difference between irradiated and non-irradiated detector observed
- Plans: large-area exposure in GIF++
- Investigate further Rate Capability as a function of resistivity

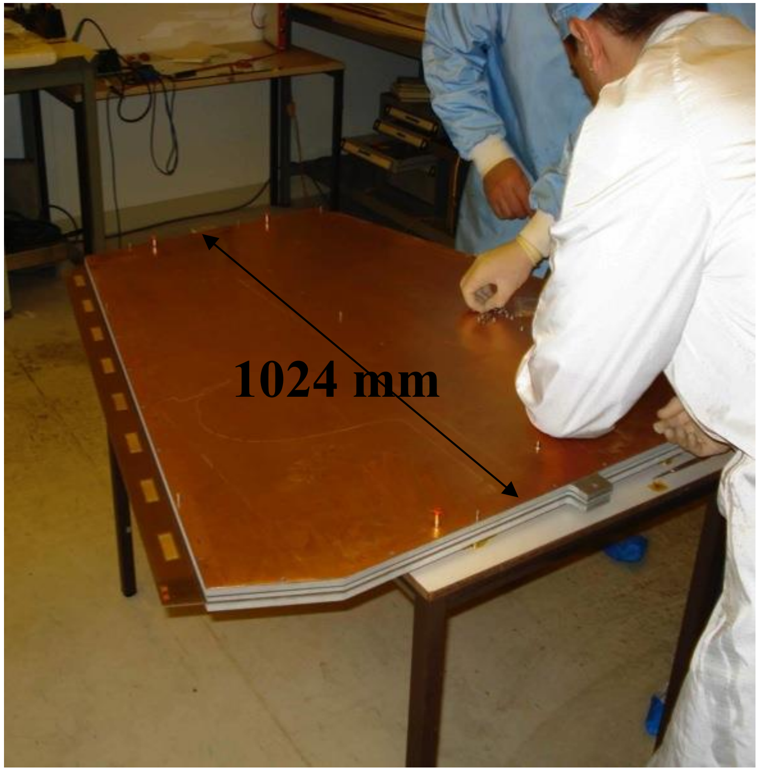
Detector Construction

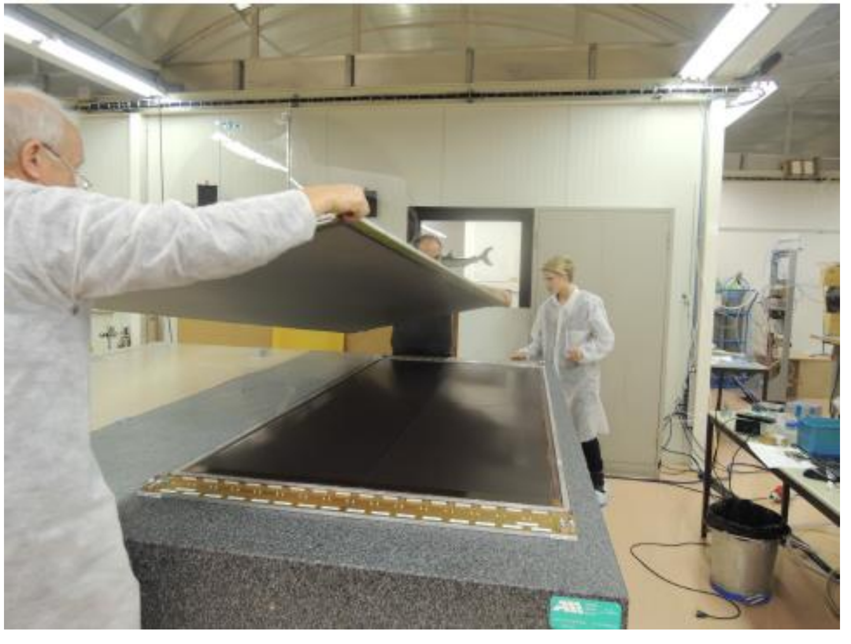


Mesh is separate from readout board; glued to drift panel
Mesh is touching readout board pillars when the detector is closed
Detector panels are kept together by bolts around the circumference
Gas tightness is achieved by an O-ring
Detector is demountable

DETECTOR CONSTRUCTION:



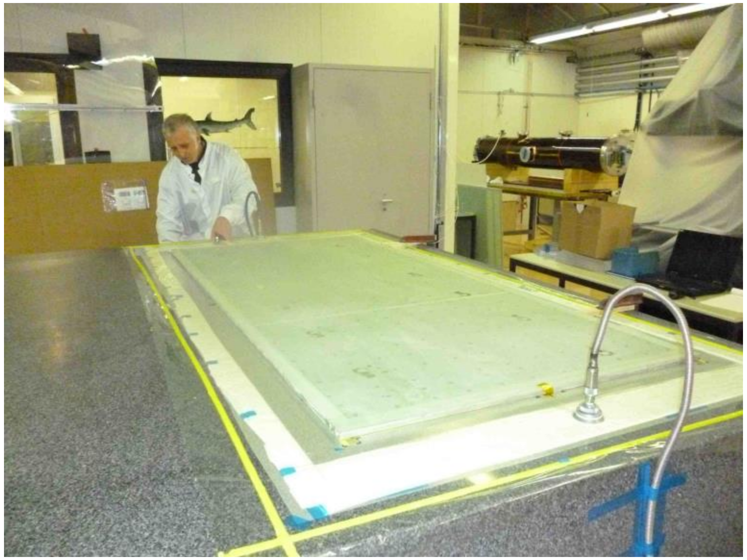




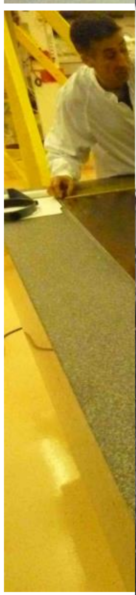
J. Wotschack, RD51 Meeting (CERN 2013)

J. Wotschack, JINST 7, C02021 (2012)

Chamber Construction: electrodes

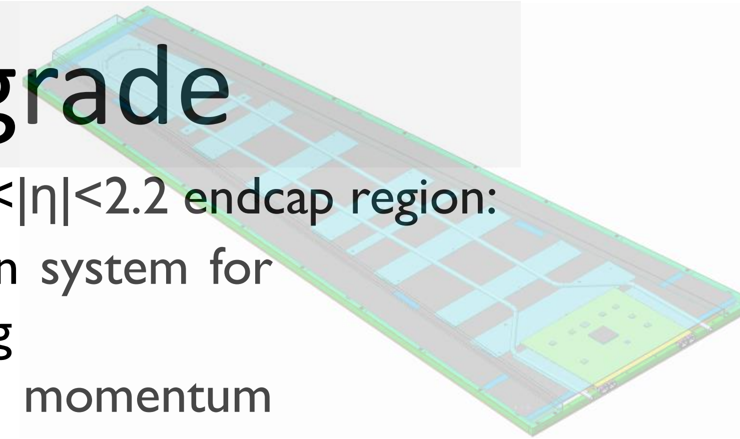


Chamber Assembly: Towards Production



Chamber after assembly in clean room

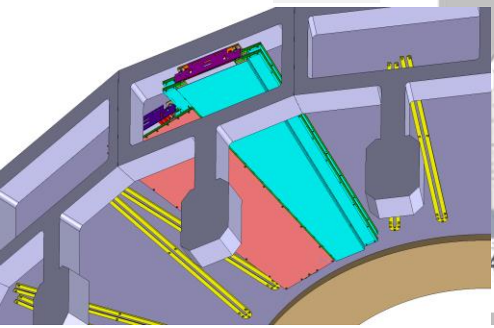
CMS GEM Upgrade



Install triple-GEM detectors (double stations) in 1.5<|η|<2.2 endcap region:

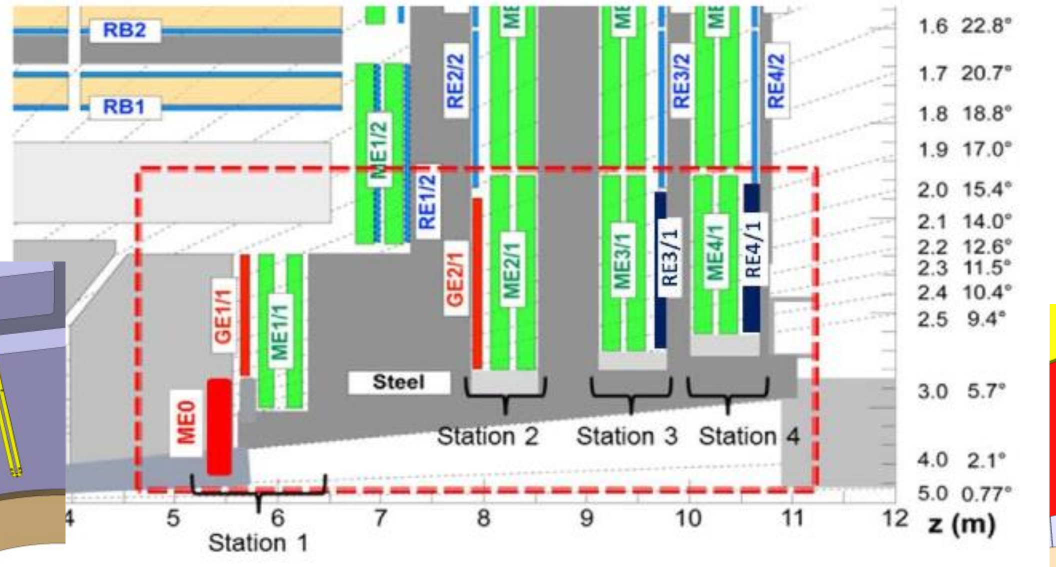
- ✓ Restore redundancy in muon system for robust tracking and triggering
- ✓ Improve L1 and HLT muon momentum resolution to reduce or maintain global muon trigger rate
- ✓ Ensure ~ 100% trigger efficiency in high PU environment **for RUN III**

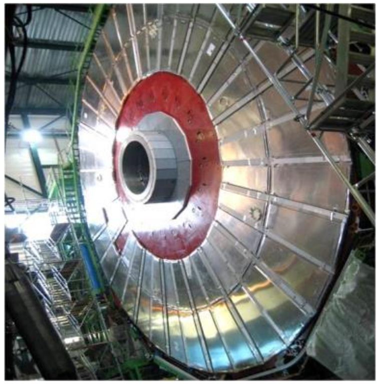
Archana Sharma CERN · ECFA 2014



GE1/1

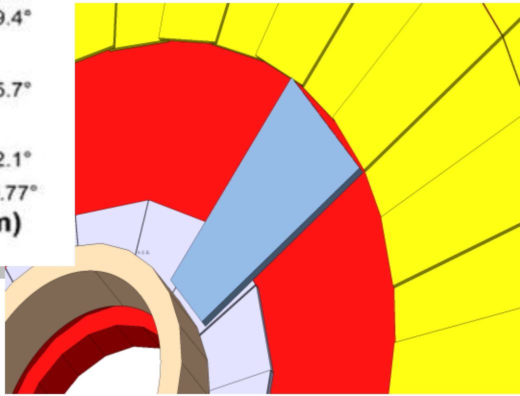
LS2



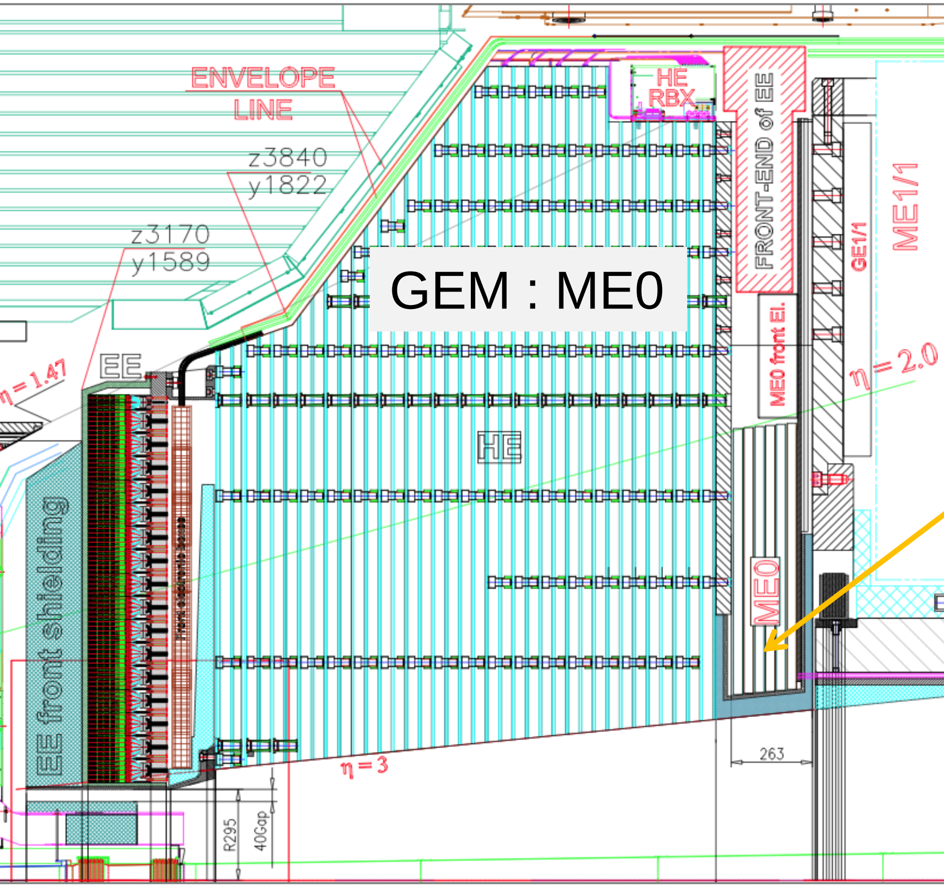


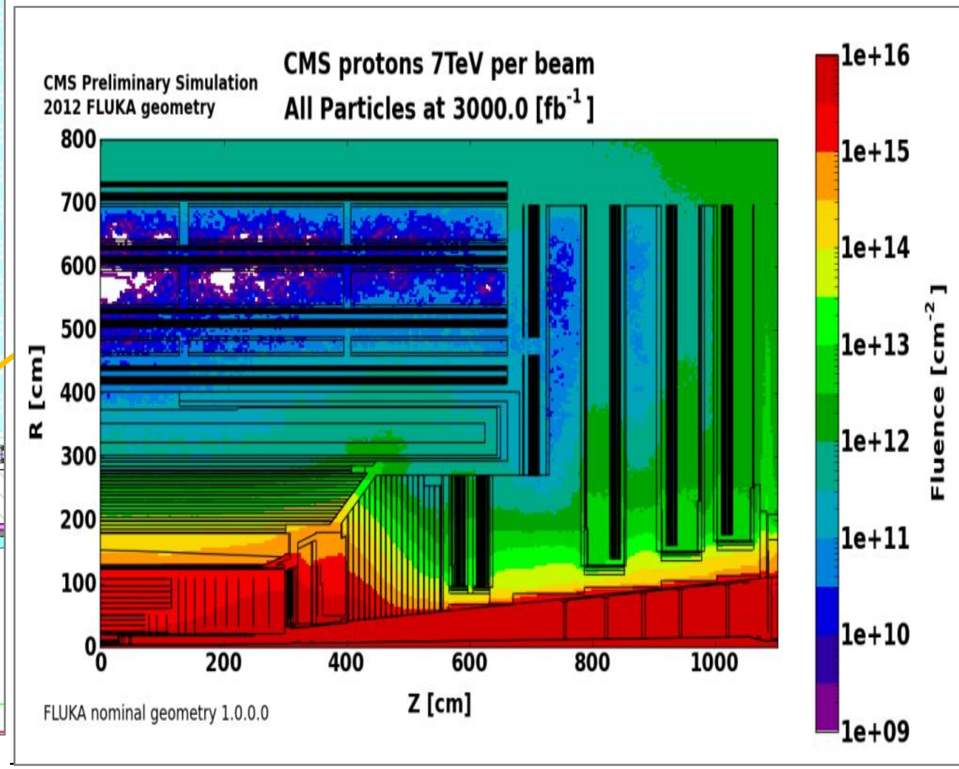
GE2/1

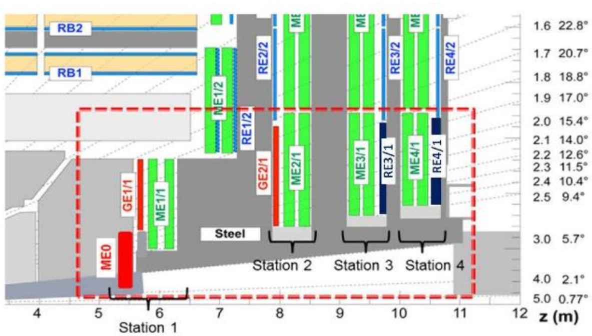
LS3



The CMS GEM Project : ME0





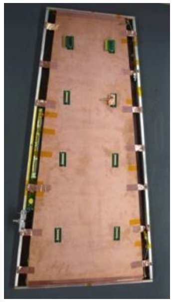


Detector has to operate in very high background environment and high PU:

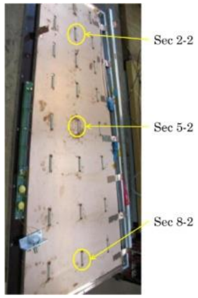
- Need high performance detectors
- GEM Performance Commensurate
- R&D Ongoing

https://twiki.cern.ch/twiki/bin/view/MPGD/CmsGEMCollaboration

Current focus: GE1/1 & GE1/1-v5 proto

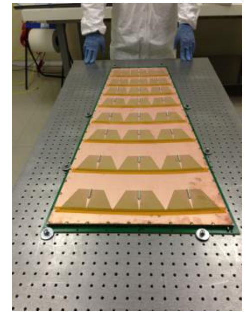


2010

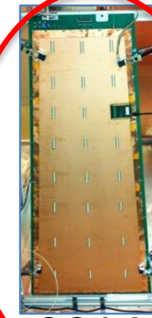


2011

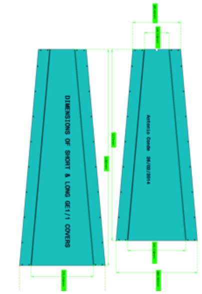
2012



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-**

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.**

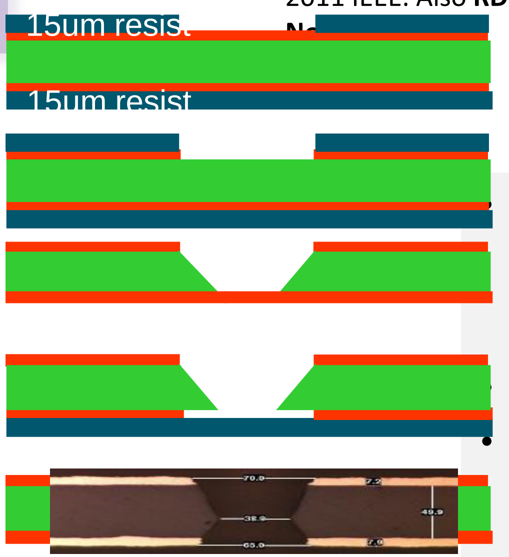
Generation V

Very close to what we will install in CMS. Features re-designed stretching apparatus that is now totally inside gas volume. **Ongoing test beam campaign for final performance measurements.**

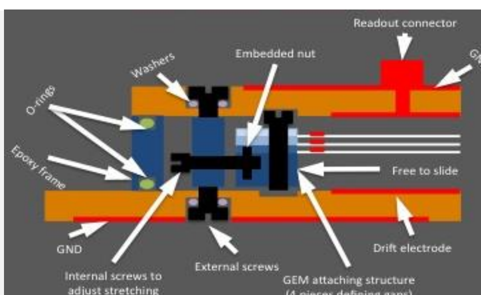
Generation VI

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

Archana Sharma CERN CFA 2014



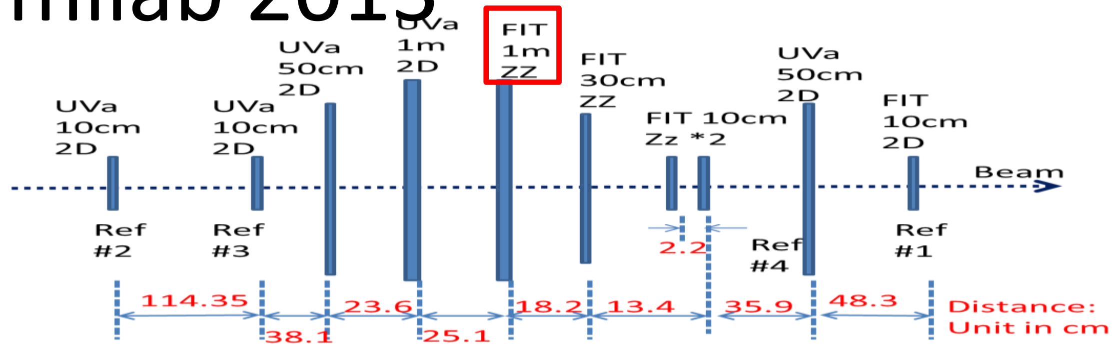
- GEM foil production uses single mask technology for wet etching
  - Dramatically reduces foil production costs and allows large sizes to be manufactured
- Performance same as that of double mask
- NS2 assembly technique developed
  - Construction time reduced from week(s) to two hours per chamber

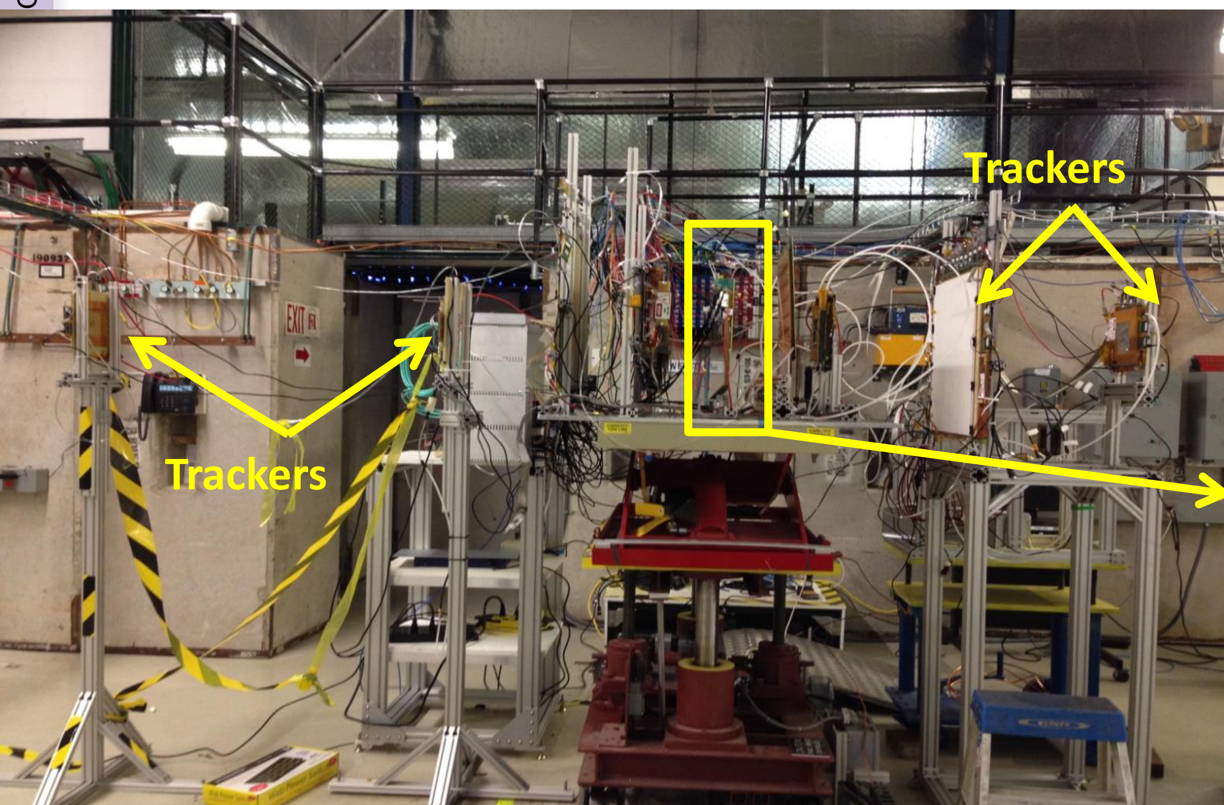


Beam Tests at CERN (2010-2012)

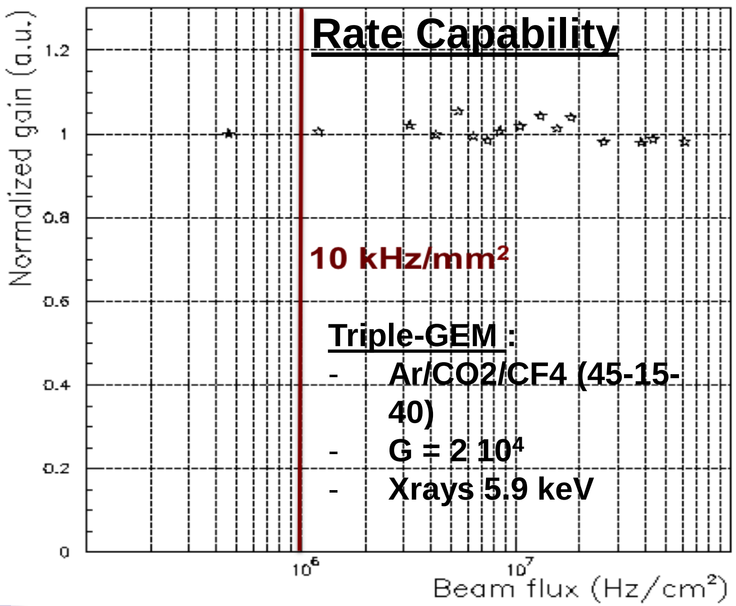
Fermilab 2013

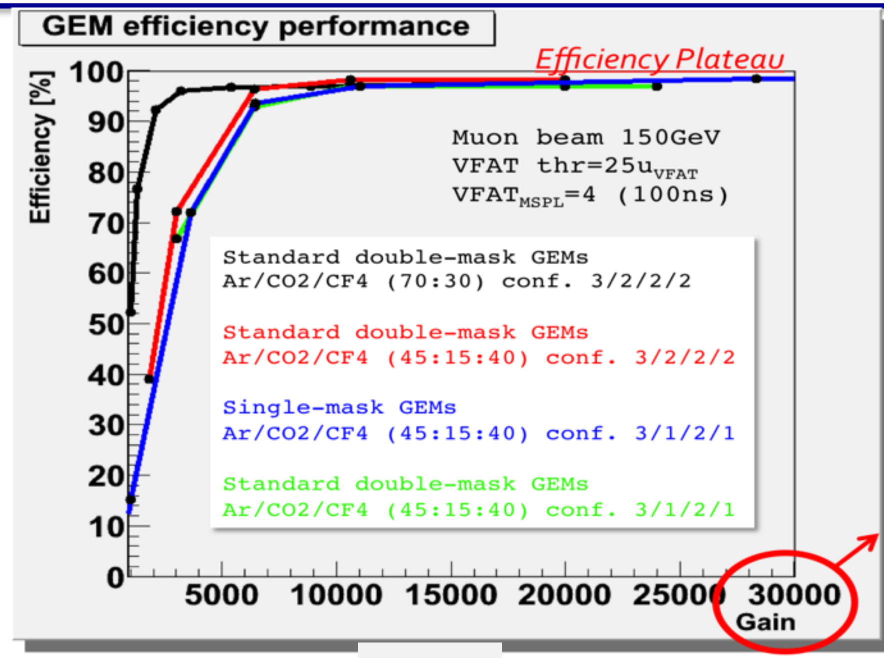
- 4 reference GEM detectors (trackers)
- Gas: Ar/CO_2 (70:30) all detectors
- Beam: 25 GeV, 32 GeV mixed hadrons (π, K) and 120 GeV protons



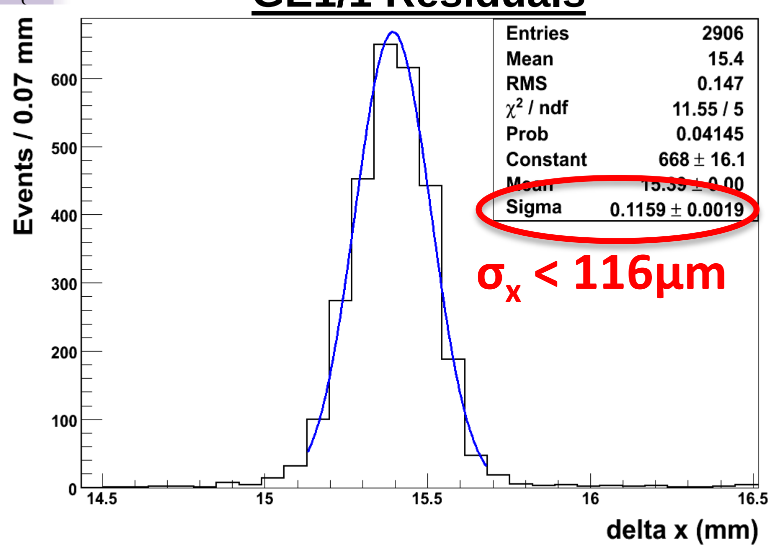


GE1/1 Performance



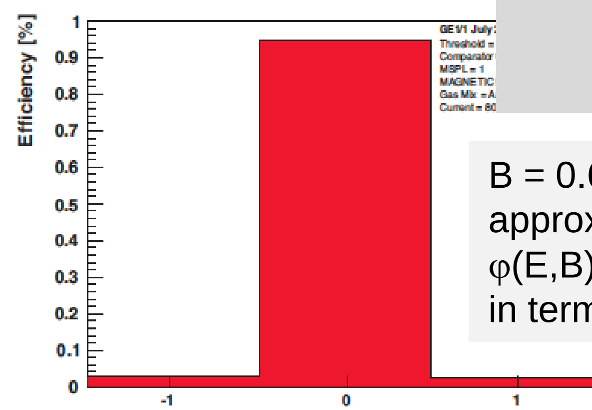


GE1/1 Residuals



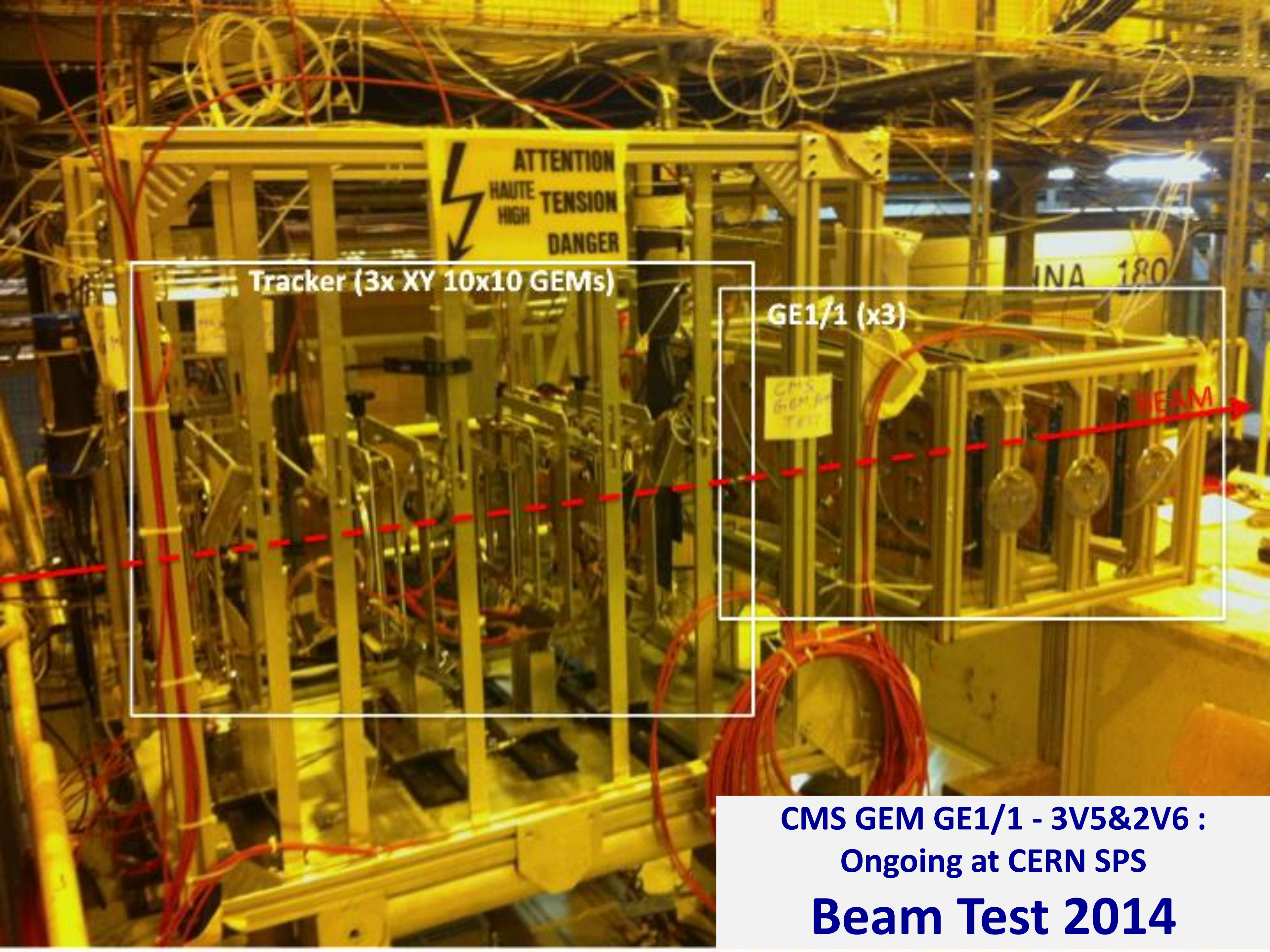
GAIN

GE1/1-III
with binary VFAT readout
at 2012 test beam



96.1%
of hits are within
correct 25 ns
clock cycle

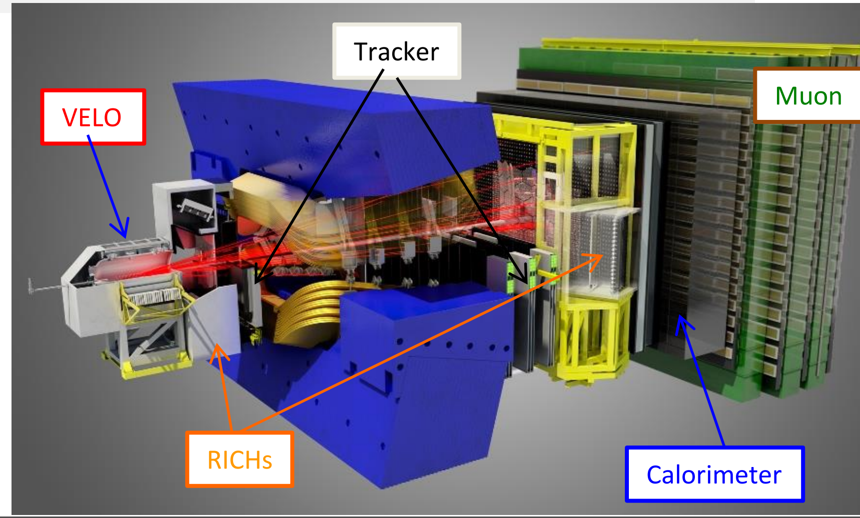
$B = 0.6T$ @ $E_{GEM} \perp B$
approx. equivalent to
$\varphi(E,B) = 6^o$ @ 3.1T
in terms of Lorentz angle



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

Beam Test 2014

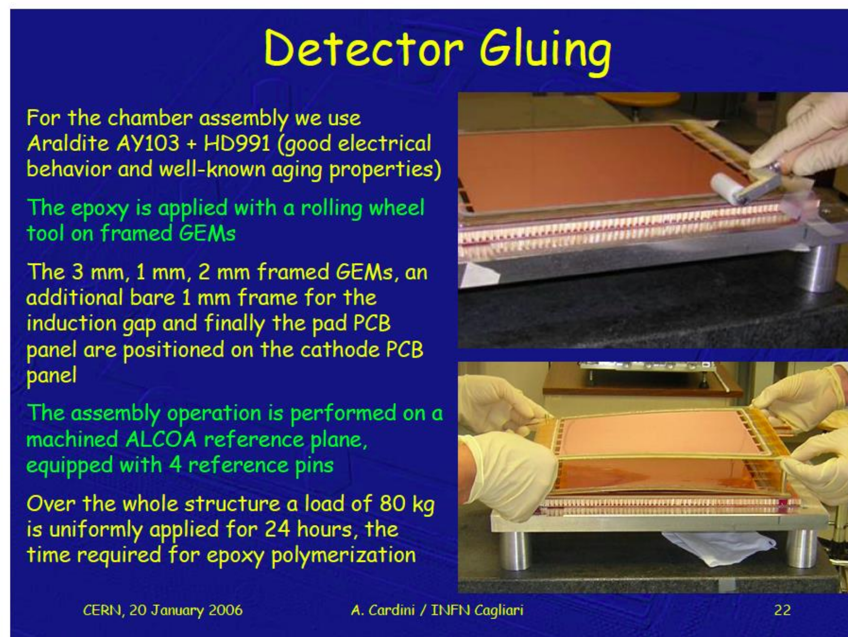
LHCb GEM Upgrade

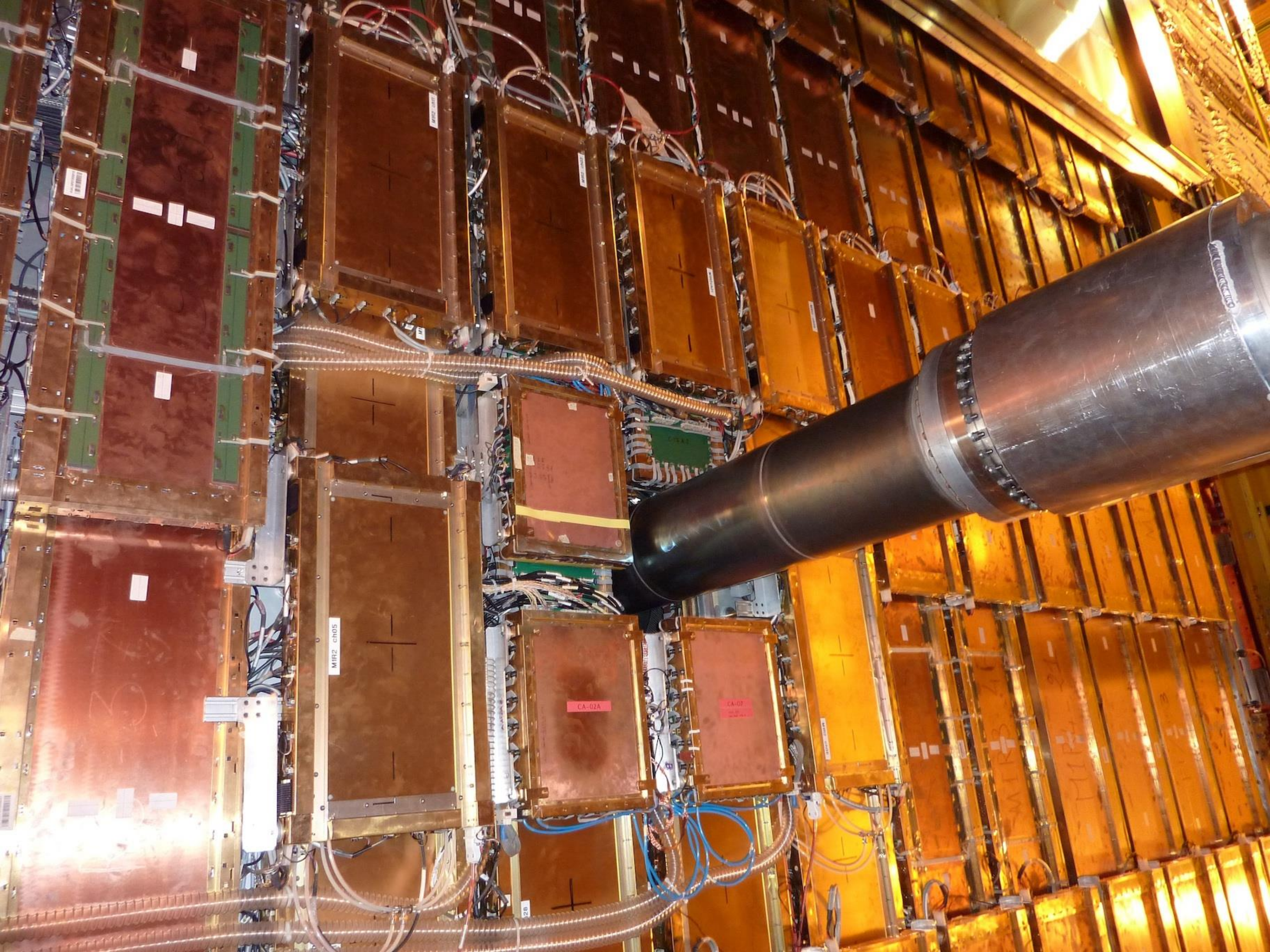


- We plan to follow a detector design similar to what is developed for CMS : embedded GEM foil stretcher

- Many advantages!
  – No gluing, no soldering during the assembly procedure
  – No special tooling required
  – The detector does not need spacers in the active area
  – Assembly is very fast and easy (~ 1/day with 2 people crew)
  – If needed, the detector can be re-opened for modifications or repairs,(or to replace a GEM foil)

- Replacing forward inner layer MWPCs with GEM Chambers
- **R&D for CF4 Replacement !**




M1R2 ch05
CA-02A
CA-07

Collective Aging experience in high rate environment

TOTEM configuration

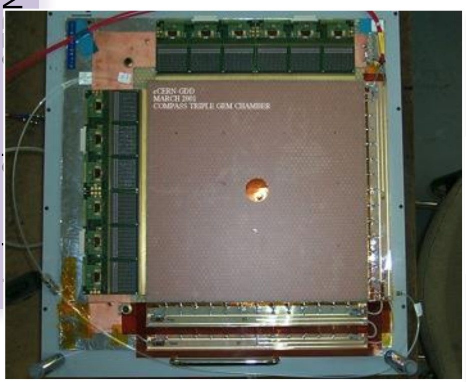
- Triple GEM Ar/CO_2 (70/30) , Position $5.3 \leq |\eta| \leq 6.5$
- **Rate up to 12 MHz/cm^2**

No aging due to polymerization

No change of materials properties

Nuc. Sci. Sym. and Med. Imag. Conf. (NSS/MIC), 2011 IEEE, 1124 – 1131

G. Croci, "Dev. and Characterization of MPGDs for HEP applications and beyond" PHD Thesis



COMPASS configuration

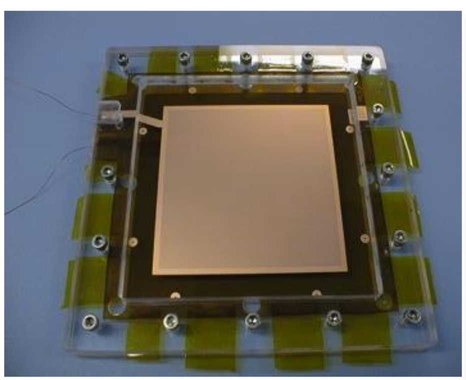
- Triple GEM @ gain : 8.10^3 in Ar/CO_2 (70/30)
- Rate up to 2.5 MHz/cm^2

No Gain drop or loss of energy resolution observed

No Loss of efficiency or time resolution until now

B. Ketzer et al., NIM A535, 314 (2004) , *P. Abbon, et al., NIM A 577 (2007) 455-518*

CERN-EP/2001 -091 & IEEE TR. On Nucl. Sci. Vol47,NO.4,AUGUST 2000



LHCb configuration

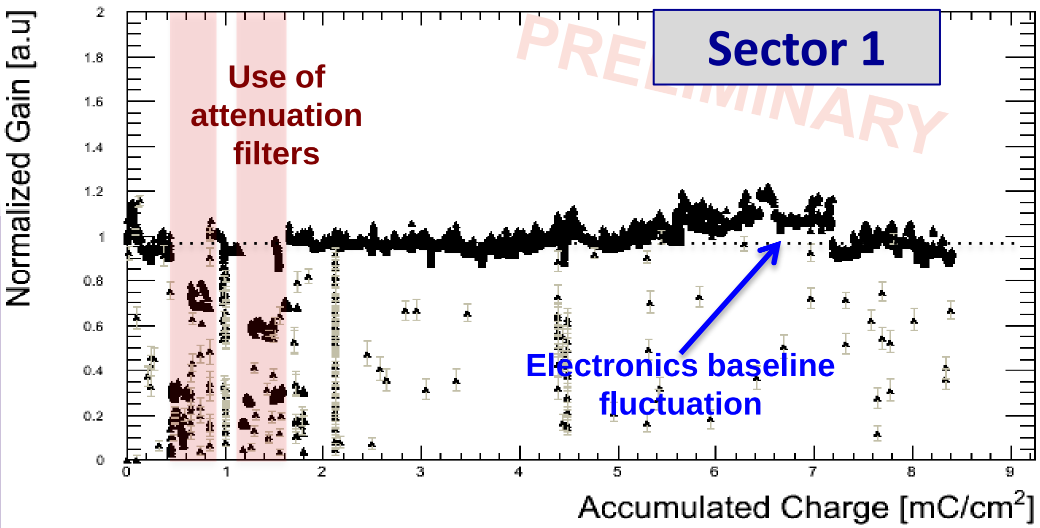
- Triple GEM @ gain : 6.10^3 in Ar/CO_2/CF_4 (45/15/40)
- Rate up to 500 kHz/cm^2

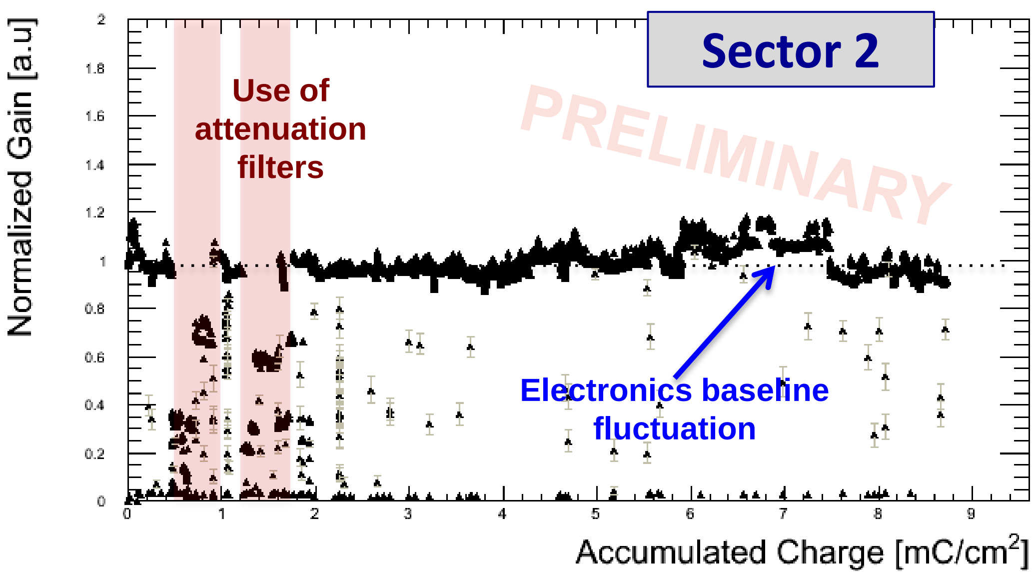
No loss of performances observed after 10 LHCb equivalent years

IEEE P. de Simone, AUGUST 2004 & S.Bachmann et al., NIM A 438(1999),376-408

Aging study of large triple-GEM detectors for the high rate environment in CMS

Archana Sharma CERN : ECFA 2014





GE1/1-IV :

Gas gain : $2x10^4$

$Ar/CO_2/CF_4$:45/15/40

Gas flow rate : 0.5L/h

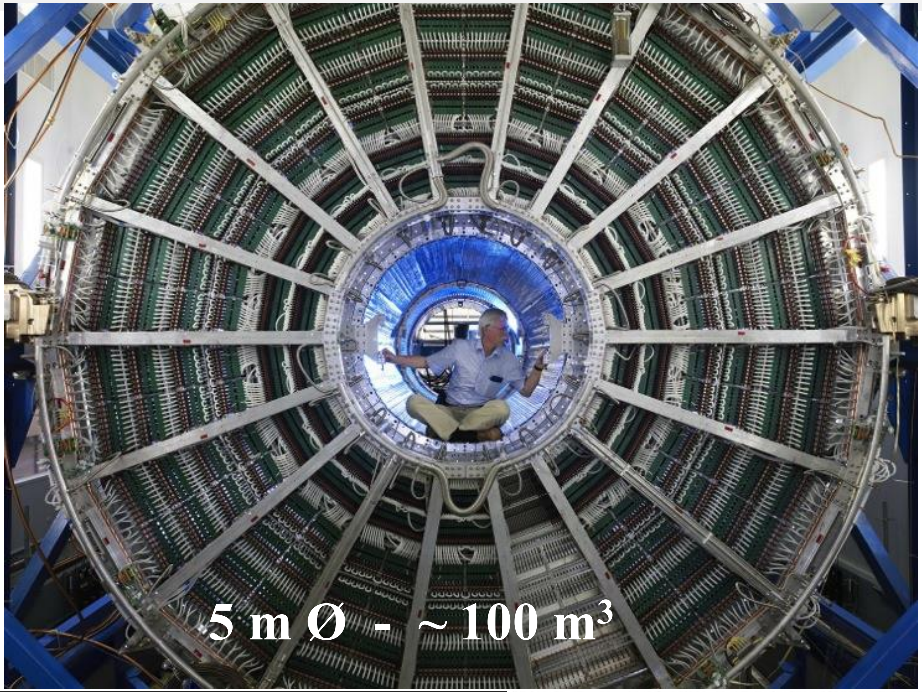
Accumulated charge : 9 mC/cm^2

No aging effect observed in the GE1/1 detector

Investigations for better corrections

J. Merlin GIF 2012-13 → GIF++ 2015

ALICE TPC UPGRADE in LS2



Operate ALICE at high rate, record all MB events

Goal: 50kHz in Pb-Pb (~10nb^{-1} in Run3 and Run4)

Operation of MWPC

w/o Gating Grid in 50 kHz Pb-Pb

Massive space-charge distortion due to back-drifting ions.

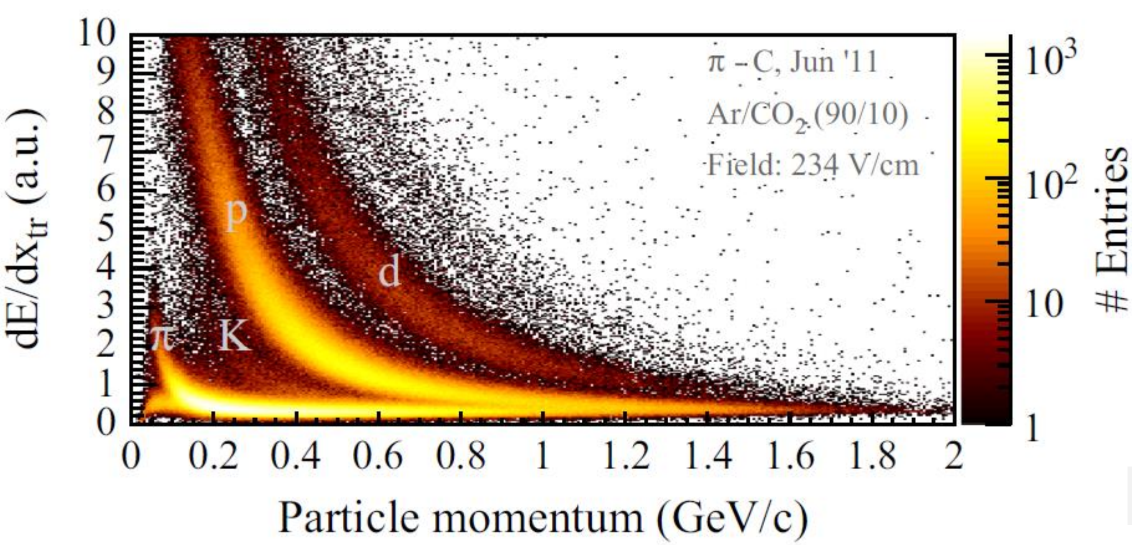
Continuous readout with GEMs

Major advantages with:

- Reduction of ion backflow (IBF)
- High rate capability
- No ion tail

Requirement

- **IBF < 1% at Gain =2000**
- **dE/dx resolution < 12% for ^{55}Fe**
- **Stable operation under LHC condition**



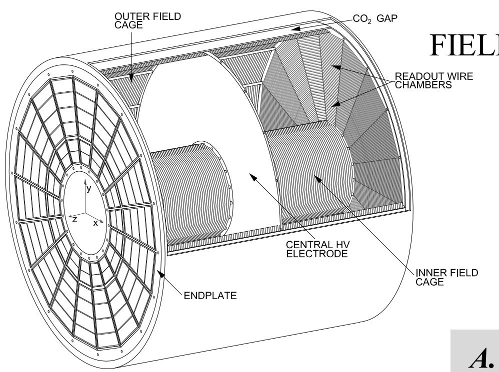
First dE/dx measurement with GEM-TPC!

[F.V. Böhmer et al., NIM A 737, 214 (2014)]

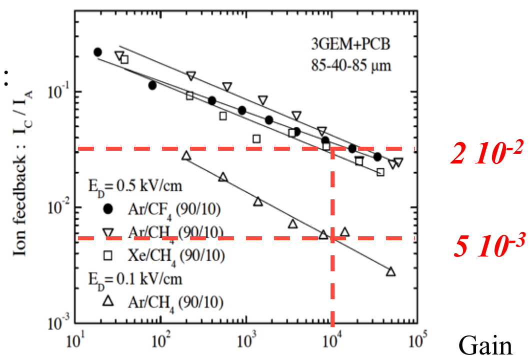
IBF PARAMETERS

Archana Sharma CERN : ECFA 2014

OPTIMIZE INTERPLAY OF GEOMETRY, FIELDS, DIFFUSION:



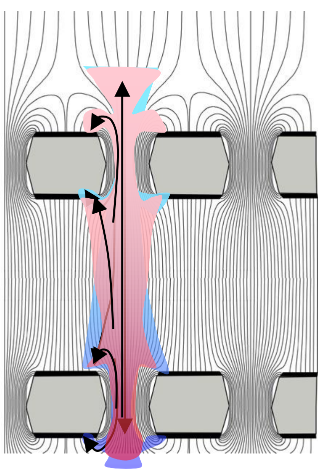
FIELDS:



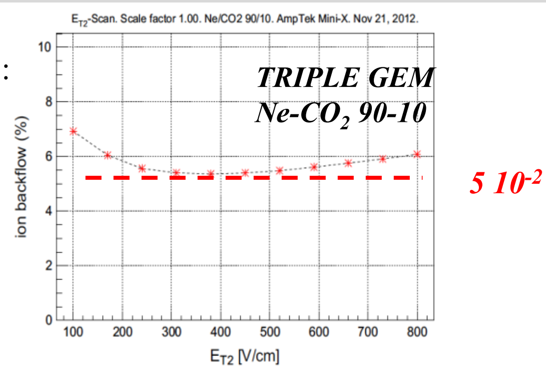
Issues:
Space-charge distortions
Discharge rate
Gain stability
QA
..

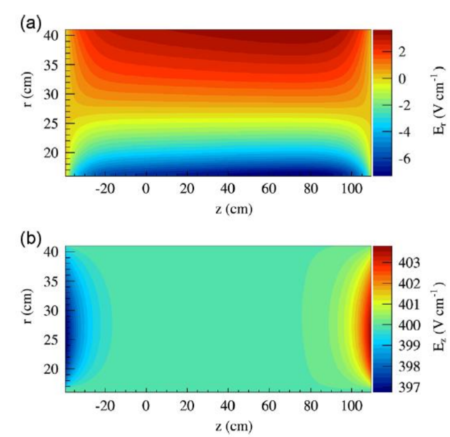
Gain: 2000
Gas: Ne-CO_2-N_2 (90-10-5)

A. Bondar et al, Nucl. Instr. and Meth. A496(2003)325



GAS:

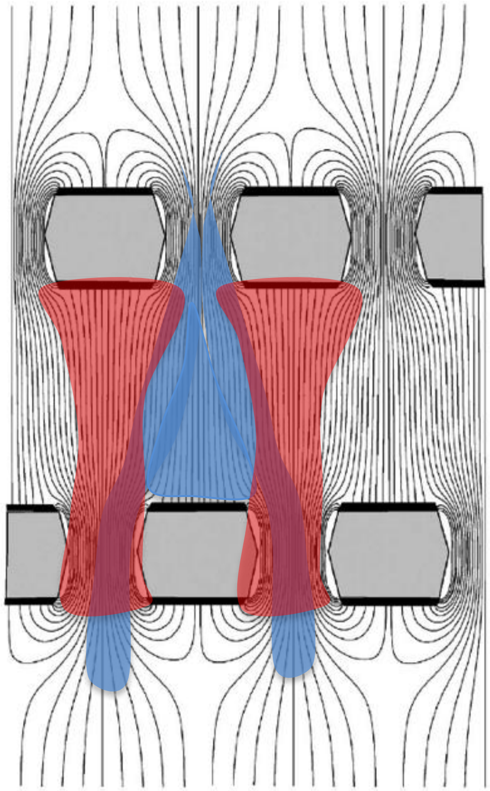




B. Ketzer, Nucl. Instr. and Meth. A732(2013)237

IBF PARAMETERS (2)

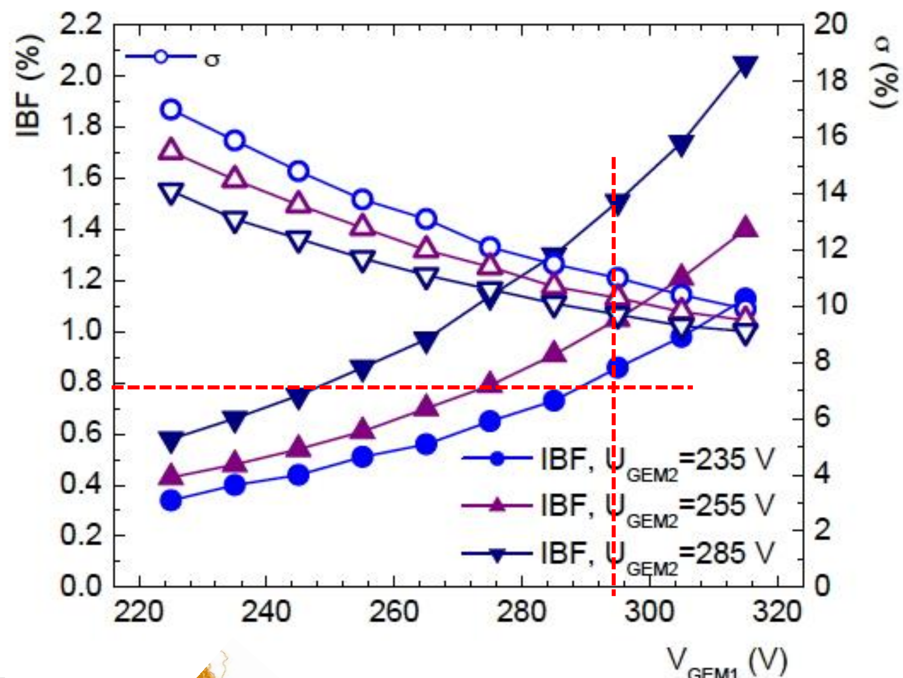
EXPLOIT THE DIFFERENCE BETWEEN IONS' AND ELECTRONS' DIFFUSION:

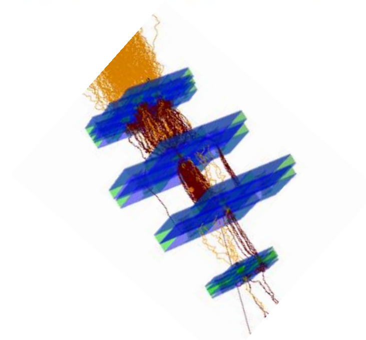


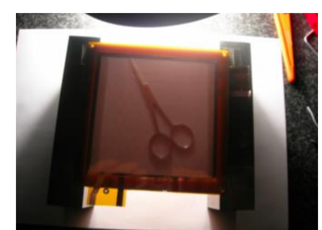
ALICE TDR CERN-LHCC-2013-020

ALICE UPGRADE: QUAD-GEM WITH ALTERNATING DIFFERENT PITCH

IBF AND ENERGY RESOLUTION VS VOLTAGE ON THE FIRST GEM:

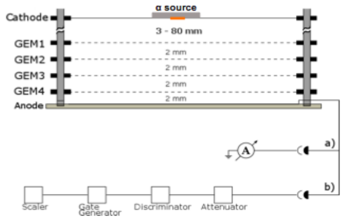






IBF and Resolution

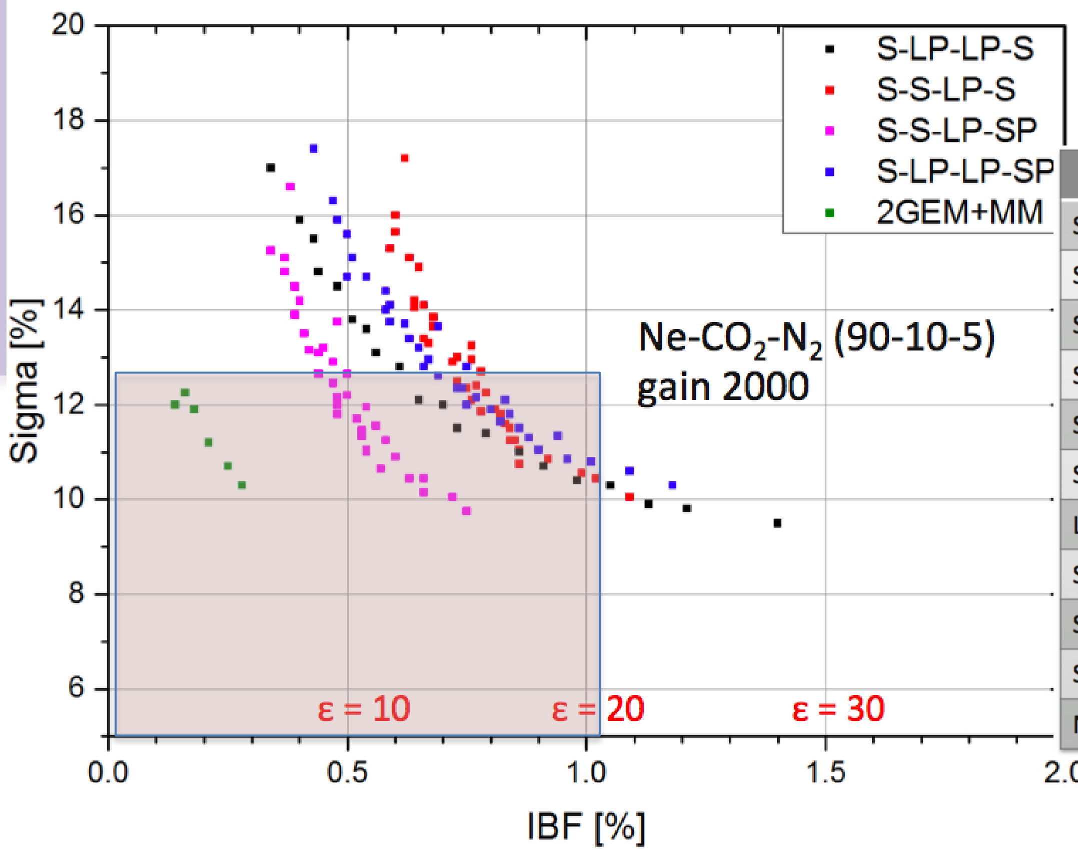
- Now more combinations with 4 kinds of GEMs
  - Measurements at CERN/FRA/Bonn/TUM



4 GEMs

2 GEM+MM results from Yale.

Cross-check is on-going at CERN

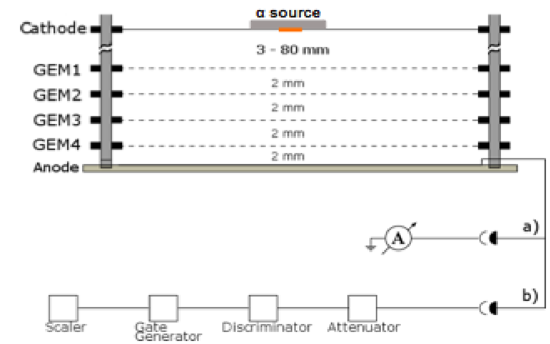


configuration	IBF	energy resolution	comment
S-LP-LP-S	0.7%	12%	TDR baseline
S-S-LP-S	0.8%	12%	
S-S-LP-SP	0.5%	12%	Best so far
S-LP-LP-SP	0.8%	12%	
S-S-S-S	<1%	>12%	
S-S-SP-S	<1%	>12%	
LP-S-LP-S	<1%	>12%	
SP-S-SP-S	>2%	?	
SP-S-LP-S	0.4%	?	
SP-S-LP-SP	?	?	
MP-S-LP-SP	?	?	

Discharge studies

- Probability is $<10^{-9} - 10^{-10}$

P. Gasik (TUM) et al



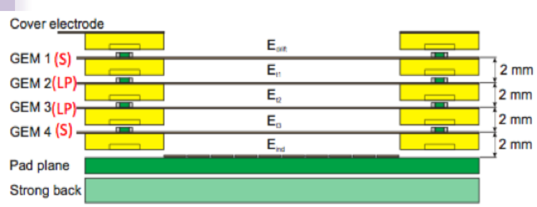
SOURCE	IBF = 0.6 % σ_E/E = 12 % G = 1000	IBF = 0.6 % σ_E/E = 12 % G = 2000	S-LP-LP-S IBF =0.6% σ_E/E=12% G =3300	IBF =0.6 % σ_E/E =12 % G =4000	IBF =0.6 % σ_E/E =12 % G =5000
^{241}Am *rate = 11 kHz* *drift gap = 80 mm*	$< 1.1\times10^{-8}$	$< 1.5\times10^{-10}$	$< 7.1\times10^{-10}$		
^{239}Pu + ^{241}Am + ^{244}Cm *rate = 600 Hz* *drift gap = 37 mm*		$< 3.1\times10^{-9}$		$\approx 5\times10^{-9}$	$(1.8 \pm 1.1)\times10^{-8}$

Beam test Preparation

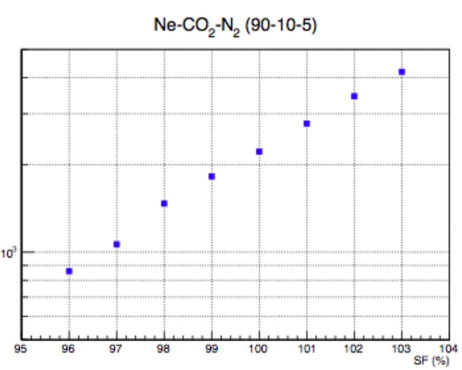
dE/dx tests at PS(21-28.11.2014) and stability tests at SPS (3-15.12.2014)

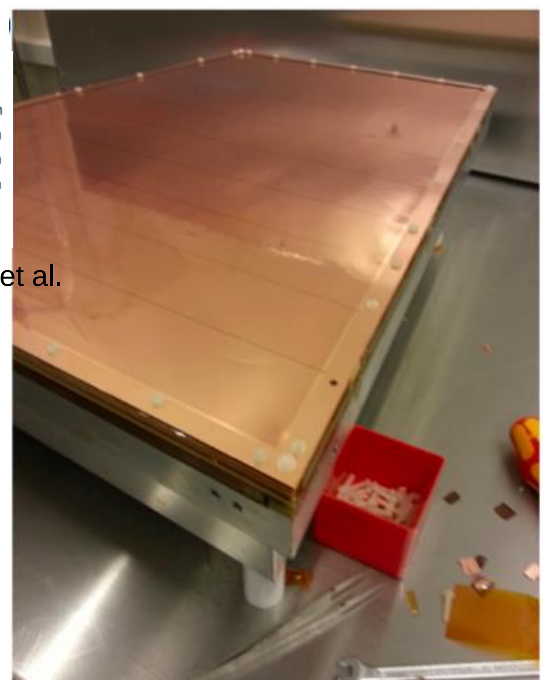
4 GEM IROC

- 4 single mask GEMs: S-LP-LP-S
- Assembly completed in Aug.
- Commissioning with Fe source
  - Gain, resolution, stability etc



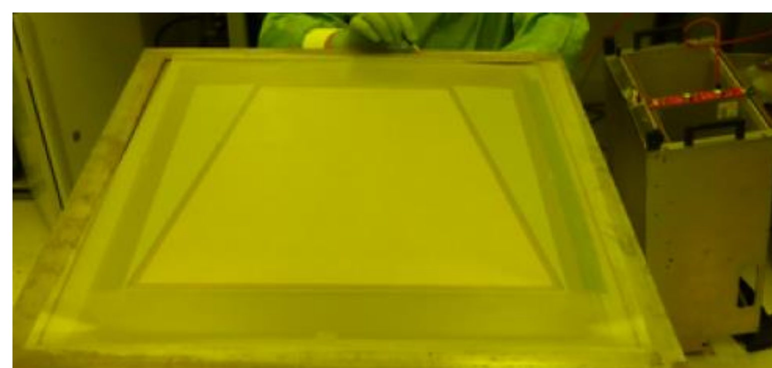
P. Gasik (TUM) et al.



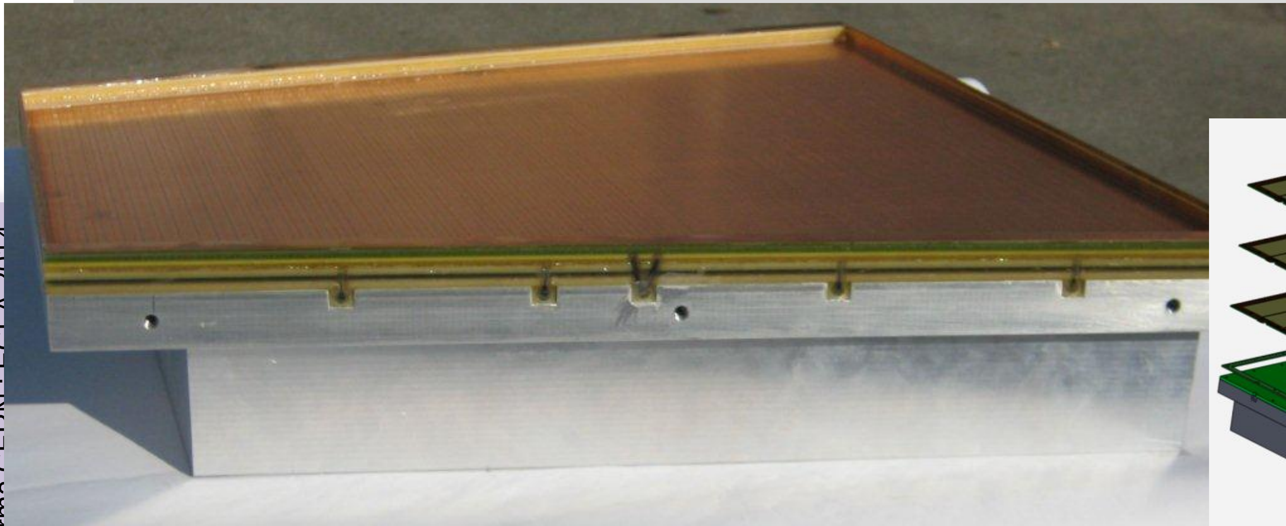


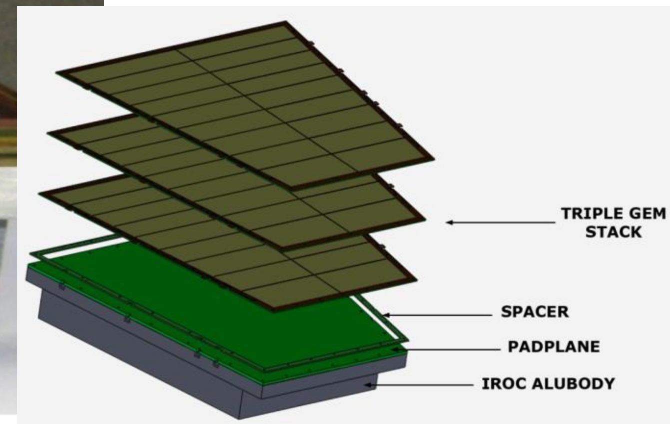
2 GEM - MMG IROC

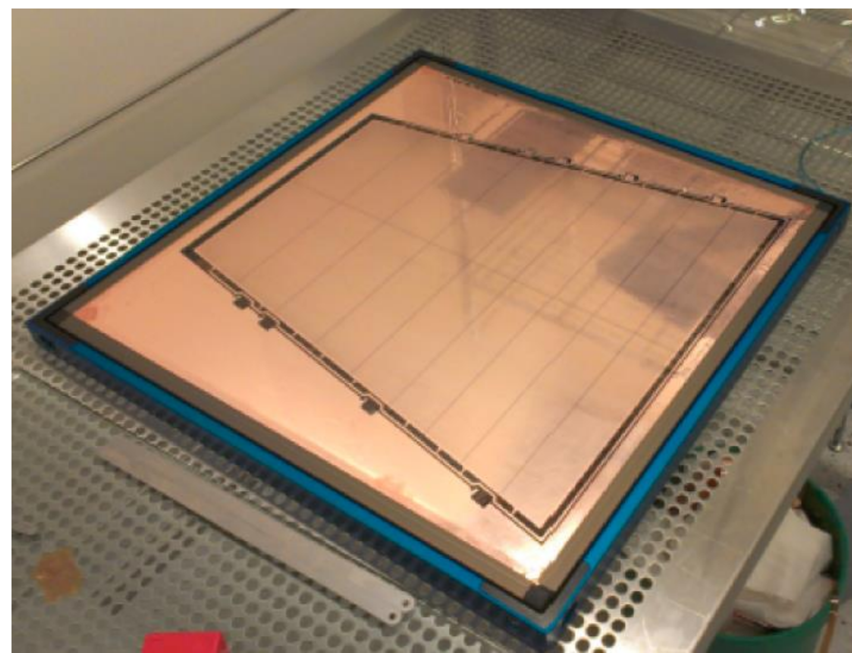
- Pre-stretched mesh (400LPI, 128um) with pillars and spacer frame glued on top of the pad plane
  - 1[st] attempt in Aug. failed. (high dark current, short developed after gluing)
  - 2[nd] attempt in Sep. Mesh is under installation. Grounding area surrounding the pad plane has been removed.
- Backup solution
  - Bulk MMG (20x25cm^2)



ALICE Full Size Prototype







- 3 large-size GEM foils: single-mask
- 18 sectors (top side), ~ $100cm^2$ each
- bias resistors 10 / 1MΩ
- 2mm frames glued on bottom side
- spacer grid: 400μm thickness
- additional frame for induction gap: 4mm

Conclusions and Outlook

Micro pattern detectors have matured over the last decade and are being well exploited for LHC Upgrades:

Innovative technical solutions for technology choices

Industrial Solutions

- ATLAS Micromegas Small Wheel Upgrade
  - TDR Approved for LS2
- CMS GE1/1
  - CMS TP possible LS2
- ALICE TPC upgrade
  - TDR Submitted for LS2
  - Prep for Review / production
- LHCb M2 wall
  - Approved for LS2
- CMS GE2/1; ME0
  - CMS TP
- LHCb
  - further stations

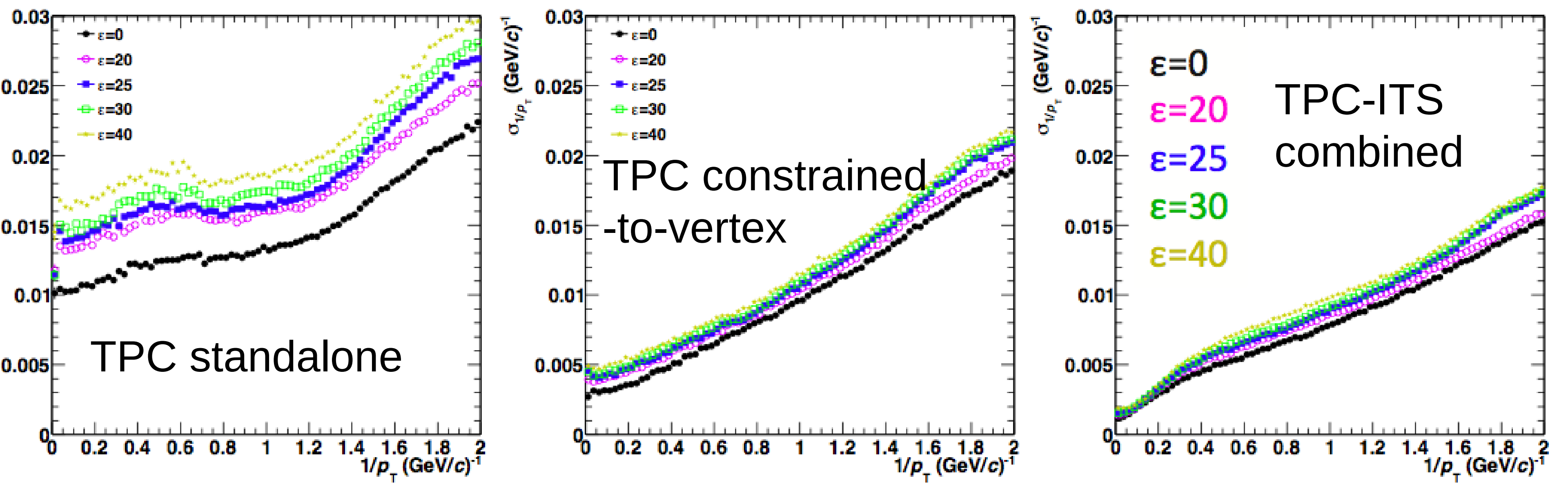
Acknowledgements: Many thanks to all members of PG4

SPARE

Simulation Studies

- Full space-charge calibration for IBF =1-2%
  - TPC standalone resolution deteriorates but can be well recovered with TPC constrained-to-vertex and TPC-ITS-combined.
  - No deterioration of TPC-ITS matching efficiency

Black – no IBF
ε=20 corresponds to 1% IBF
0.5 % in lab
1 as target
2 as margin



Micromegas – Bulk Technology

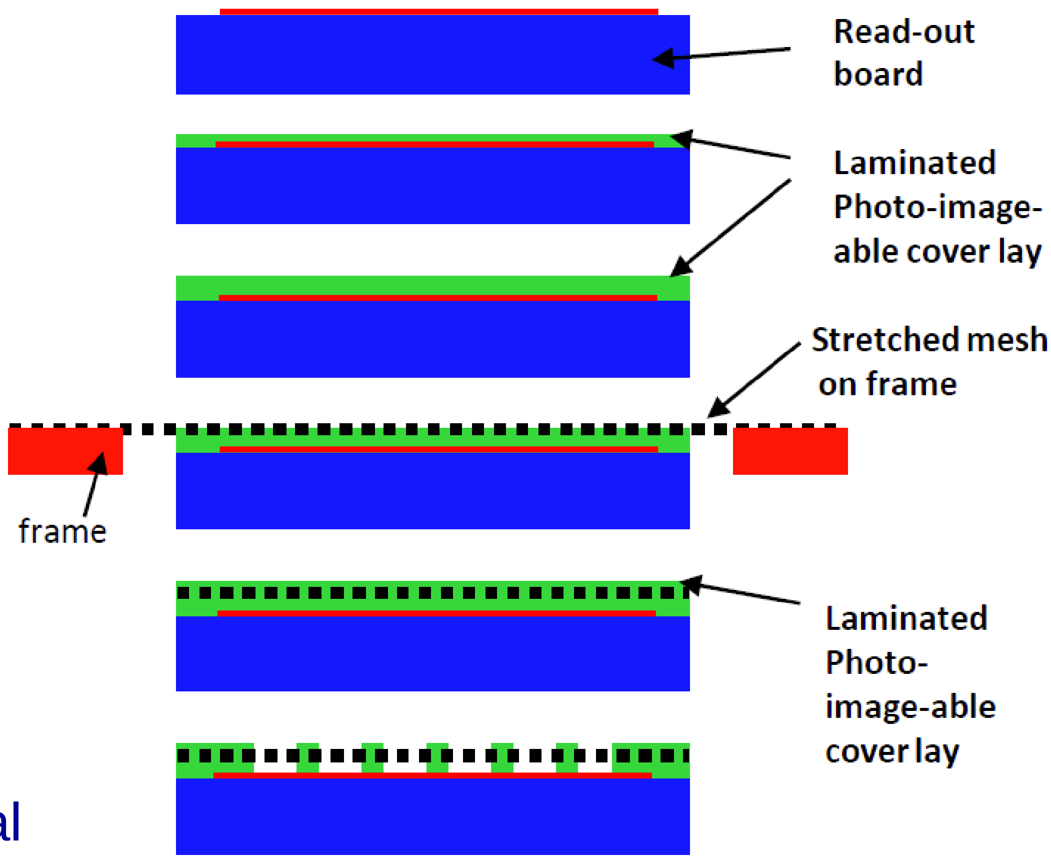
Anode PCB, e.g. FR4, with Cu

Photoresistive film, e.g. Vacrel

Woven wire mesh
- 2m × 40 m rolls
- Fe, Cu, Ti, stainless steel

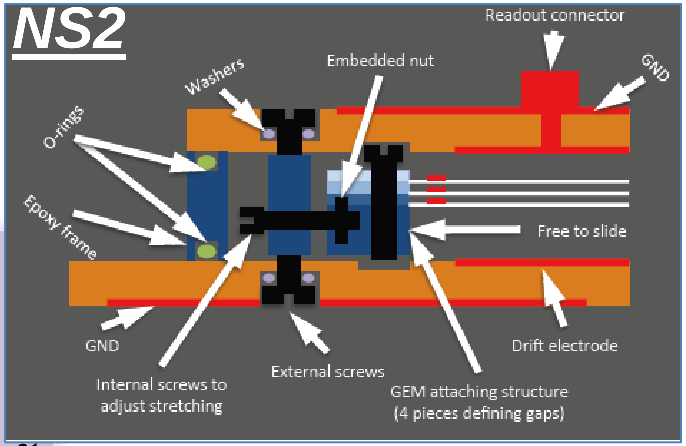
Laminated together at high temp. and pressure

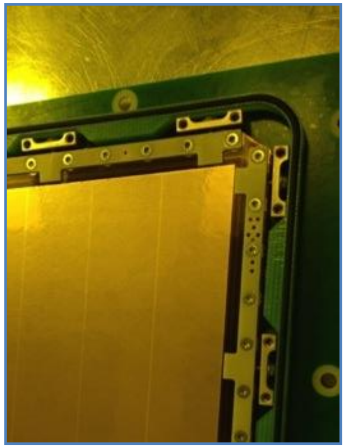
Etching of photoresistive material
⇨ pillars of 200 - 300 µm ø



[I. Giomataris et al., NIM A 560, 405 (2006)]

CMS GE1/1-V Prototype





- Size: 120 x (22-45)cm^2
- 3 GEM foils
- Gap configuration: 3/1/2/1mm
- 24 readout sectors (3072 channels)
- Time resolution (5-8ns); gives 96% BX identification efficiency
- Spatial resolution 100-200 µm
- Rate capability O(MHz/mm^2)