Muon Tracking and Triggering
GEMs for CMS at High Eta

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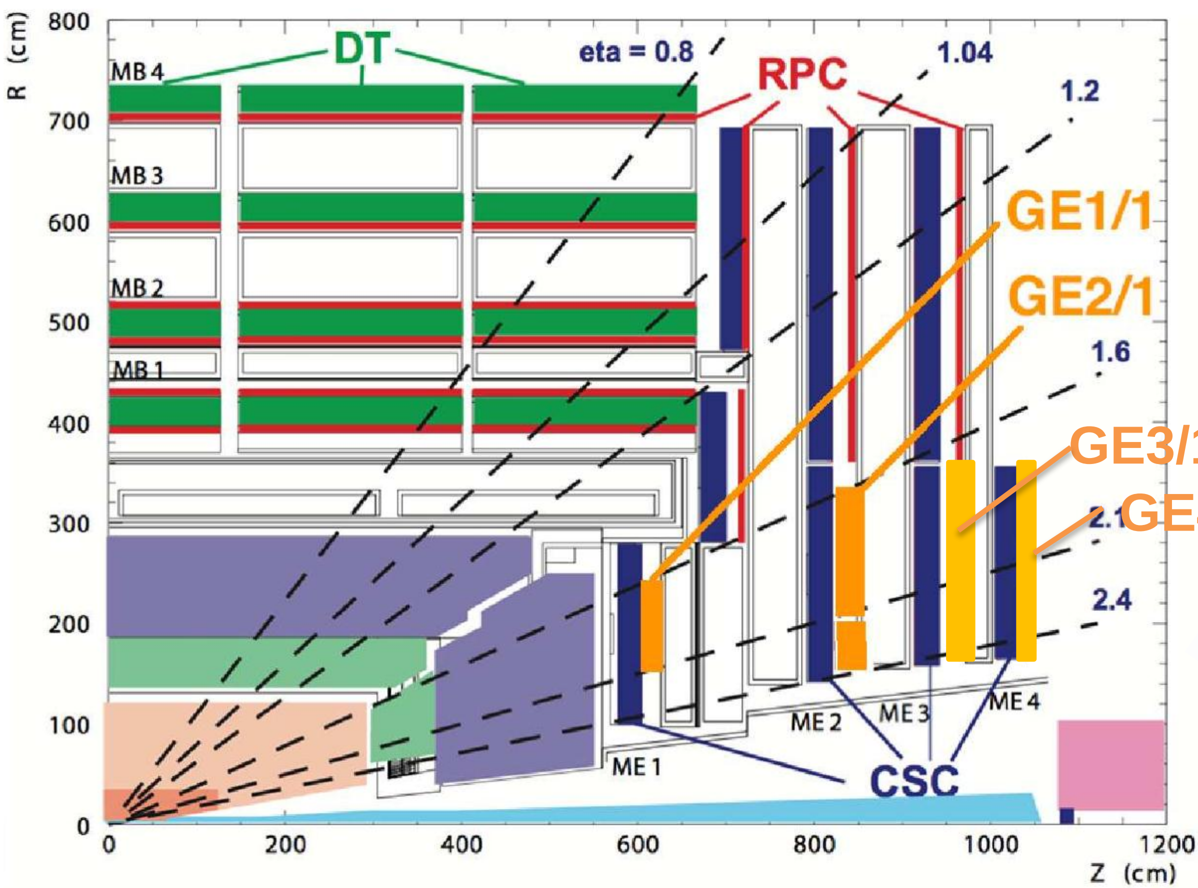
on behalf of the GEMs (GEM for CMS collaboration)

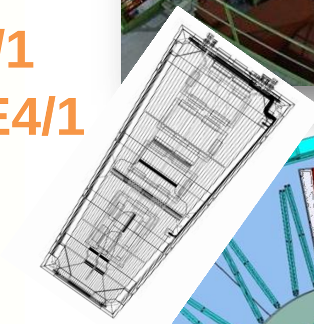
Technical Proposal Submitted February 10th 2012 to Upgrade Committee
https://twiki.cern.ch/twiki/pub/MPGD/CmsGEMCollaboration/GEM_technical_proposal.pdf

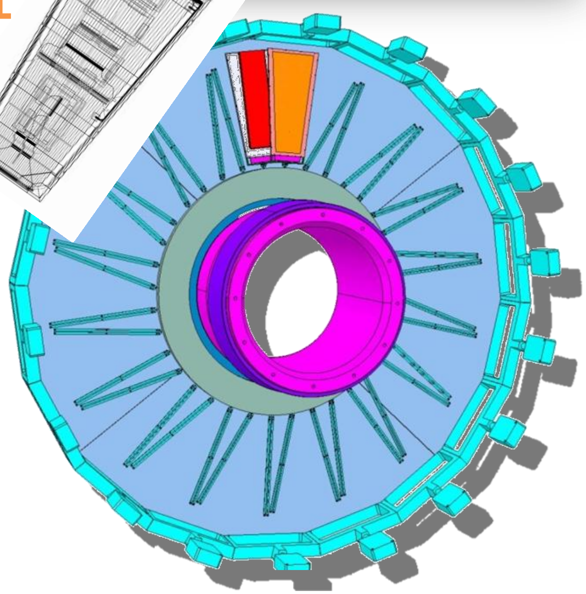
Outline

- Introduction
- Triple-GEM detector for high eta CMS
- Detector Performance, Large-scale chamber production
- Integration and installation studies, services
- Initial design of on- and off-detector electronics
- Project, Schedule and feasibilities for LS2
- Conclusion and Outlook

High Eta GE Stations: Focus 1.6 > η > 2.1



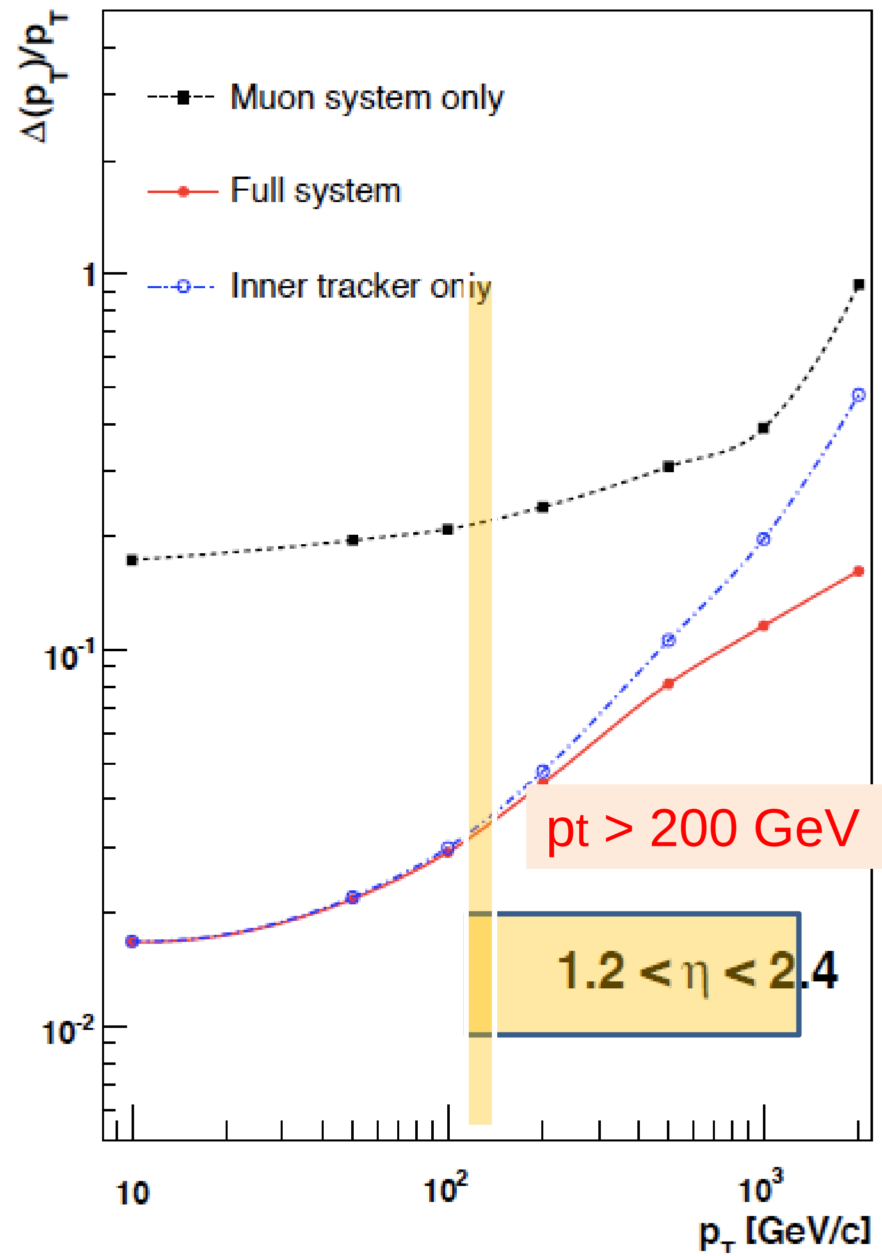




The high η region presently vacant presents an opportunity to instrument it with a detector technology that could **sustain** the environment and be suitable for operation at the LHC and its future upgrades.

The Key Points

- CMS was designed to have a highly Redundant Muon system
- CMS is missing redundancy in the most difficult region : The high η region
- ME1/1-2/1 in particular needs robust and redundant tracking capability
- Poor momentum resolution at high momenta ; Point resolution still dominant w.r.t. multiple scattering ; Important for acceptance and Muon Id
- Detectors with high resolution would bring additional benefits in Muon HLT, Reconstruction and Identification

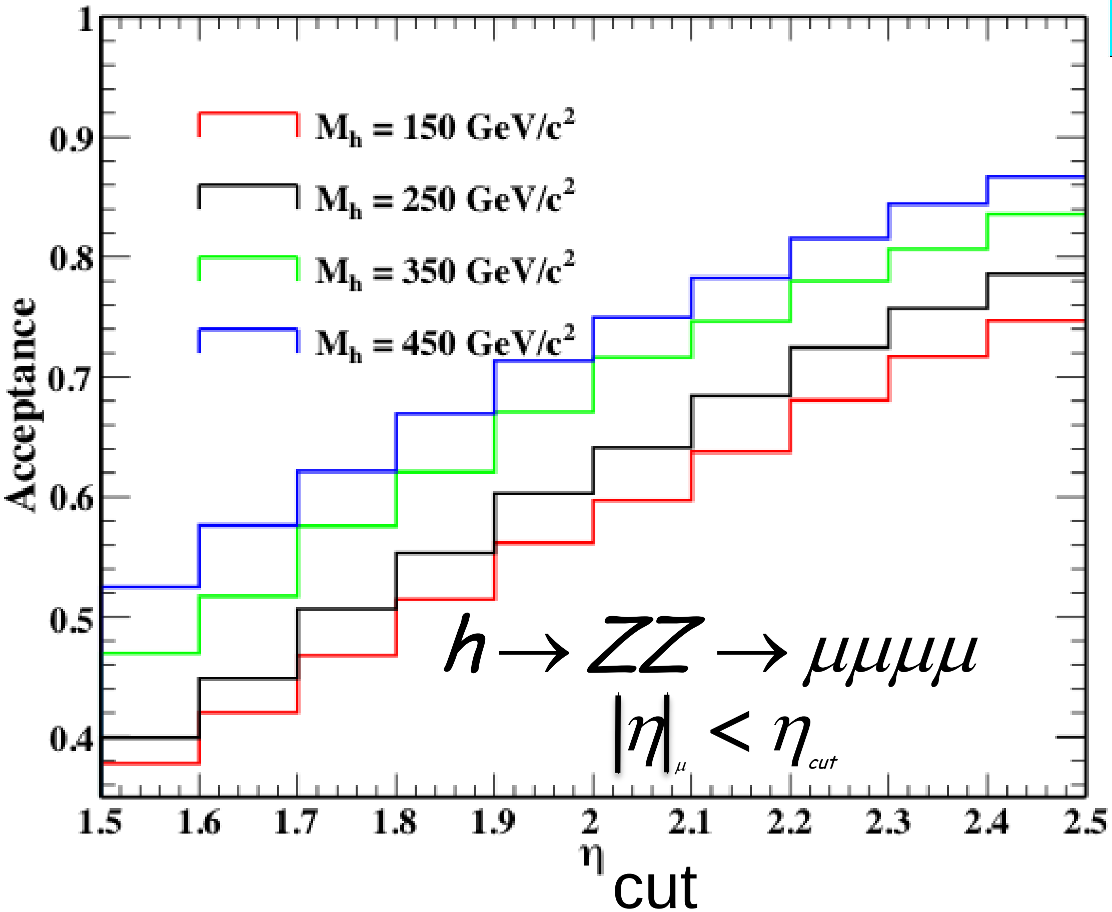


CMS TDR
M. Maggi

M. Maggi

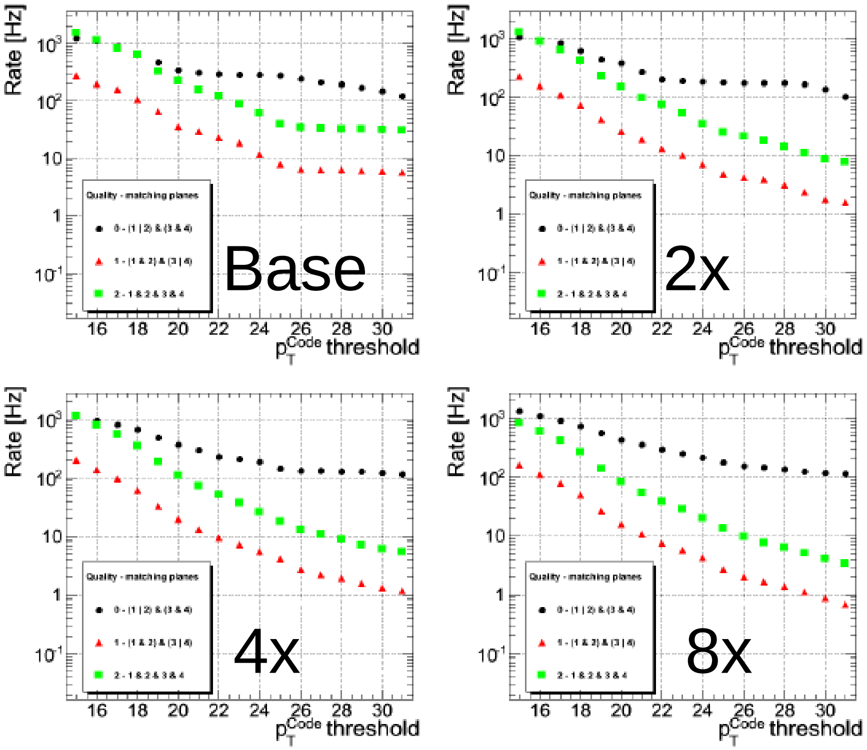
Acceptance benefits nearly linear at “low” mass

Hermeticity: ~ 4π essential to avoid fake E_T



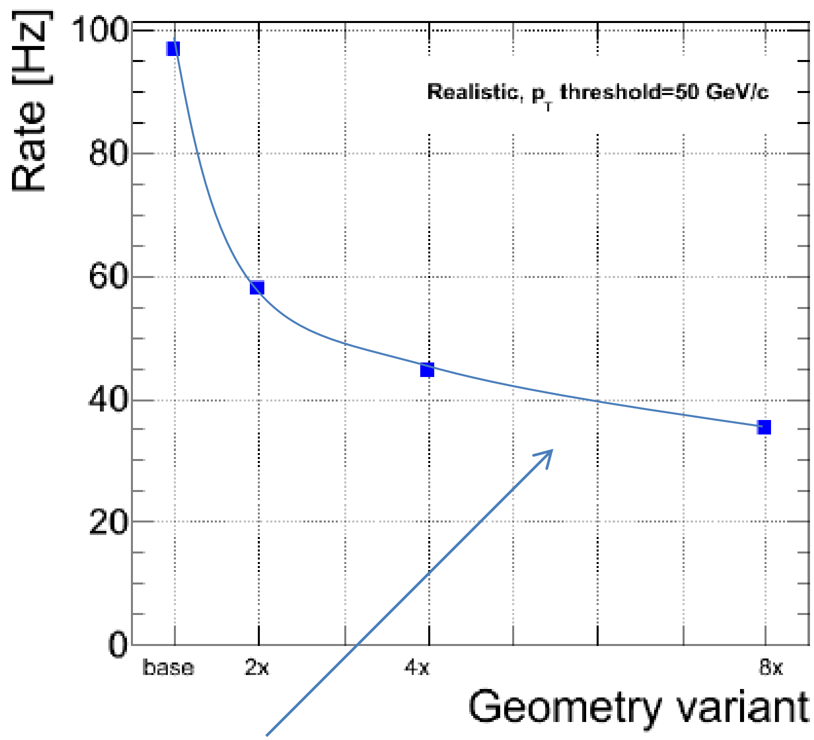
Proposed **GE system** plays a crucial role in the low p_T region where improved STA in HLT allows decrease in feed through rates and permits to lower p_T thresholds

Reduction of (PAC) Trigger Rate Level 1 in 1.6 < |η| < 2.1



Rate vs pT cut distribution for realistic chambers model

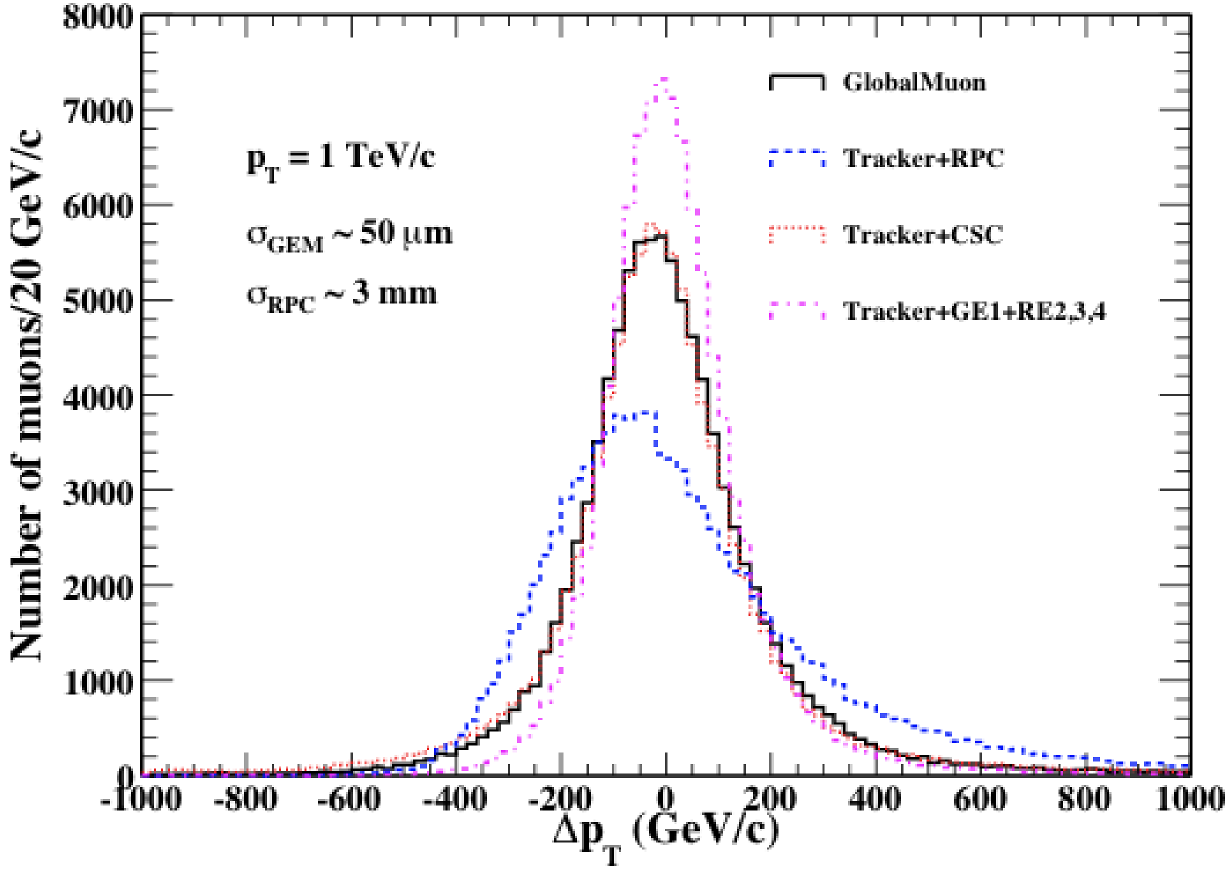
PtCut = 50 GeV



Rate reduced by factor ~4

K. Bunkowski; T. Frueboes 2011

Resolution with an ideal layer of GEM in the first station



M. Maggi; Tupputi

Benefit to Physics

1μ	**W, t, W’, HSCP, etc**
2μ	Z, t, Z’, HSCP, HWW, etc
3μ	WZ, SUSY, etc
4μ	ZZ, HZZ, etc A. De Roeck; M. Maggi

Upgrade foreseen by >2017-18 : ~300 fb^{-1} will be already collected by CMS …

- Standard Model precision measurement
- High-η Z production for backward-forward asymmetry studies (important for PDF)
- Precise measurements of electroweak processes where barrel is not enough (low-pT J/ψ, ϒ)
- Exotica (new physics at 7-8 TeV mass scale)
- Heavy-resonances (with possible multi-muon/lepton signatures)
- New (HSCP) Heavy Stable Charged Particle
- May have an environment of very high-pT muons (hundreds of GeV/c)

Wide acceptance, redundant and robust triggering become even more crucial for CMS

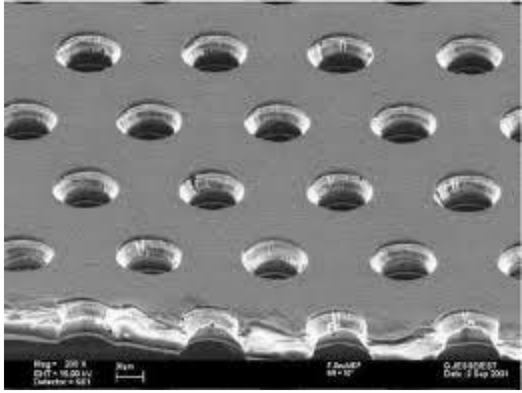
Detailed evaluation requires time and resources: GE Stations provide robustness and redundancy

The environment

Forward Region	Rates Hz/cm^2 LHC (10^{34} cm^2/s)	High Luminosity LHC 2.3 x LHC	(10^{35}cm^2/s) Phase II
RB	30	Few 100	kHz (tbc)
RE 1, 2, 3,4 $\eta < 1.6$	30	Few 100	**kHz (tbc)**
Expected Charge in 10 years	0.05 C/cm^2	0.15 C/cm^2	~ C/cm^2
RE 1,2,3,4 $\eta > 1.6$	**500Hz ~ kHz**	**Few kHz**	**Few 10s kHz**
Total Expected Charge in 10 years	(0.05-1) C/cm^2	few C/cm^2	Several C/cm^2

P. Bhat; Upgrade Plots ME1/1 Rates

CMS GEMs: Introduction



Enhance and optimize the readout (η-φ) granularity by improved

rate capability ~ $10^5/cm^2$

Spatial/Time resolution: 100-200 μm / ~ 4-5 ns

Efficiency > 98%

Gas Mixture: Ar-CO_2-CF4 (non flammable)

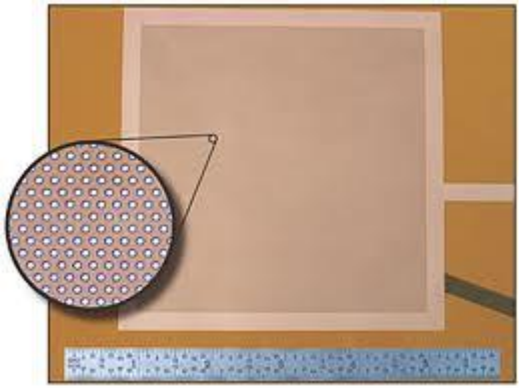
Large areas ~ 1m x 2m with industrial processes (cost effective)

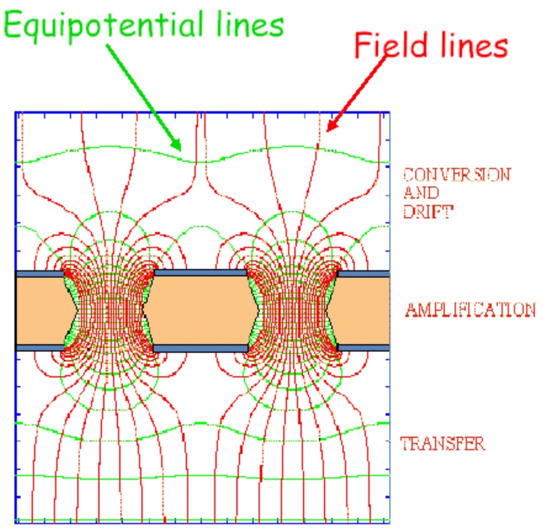
Long term (10 years) operation experience in Compass; and LHCb at CERN

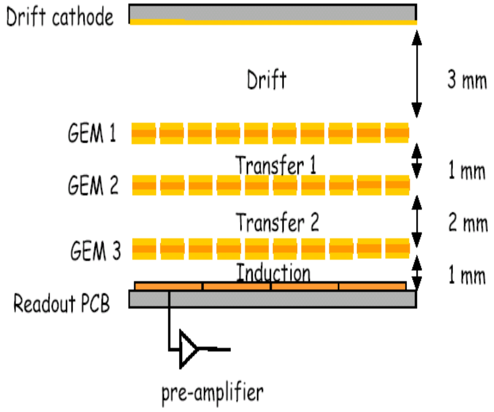
Large margins of operation at full efficiency

Long term operation experience in Compass; Recent LHCb and TOTEM at CERN

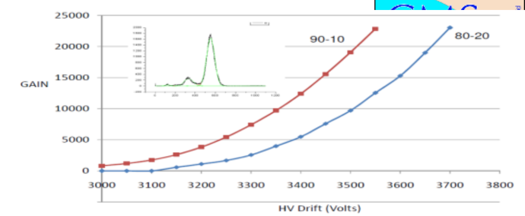
Large margins of operation at full efficiency







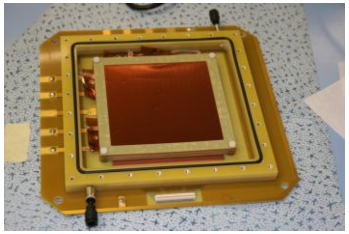
GEM Collaboration
Construction and tests 2010-11



Small prototypes

CMS_timing_GEM: Standard double mask **10x10cm^2** 1D readout (3/2/2/2); 256 channels

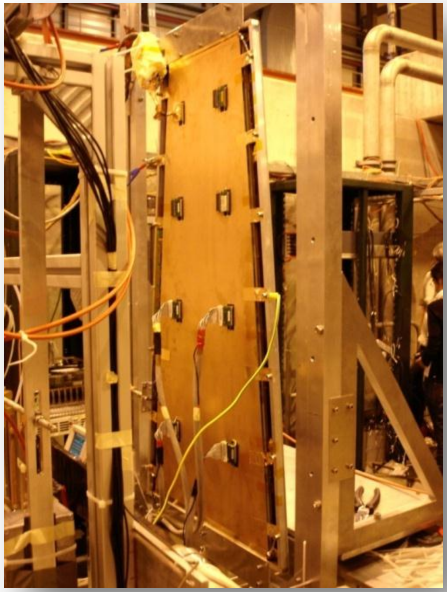
SingleMaskGEM: Single Mask **10x10cm^2** 2D readout (3/2/2/2) 512 channels



Honeycomb: Standard double mask **10x10cm^2** 1D readout (3/2/2/2); 256 channels

CMS_Proto_III Single Mask **10x10cm^2** [N2] (3/1/2/1); 256 channels

Korean_I Double Mask **7x7cm^2** (3/2/2/2); 256 channels



Full-size prototypes 2010/11

CMS_Proto_I: Single mask **FULL_SIZE** 1D readout (3/2/2/2); 1024 channels

CMS_Proto_II: Single mask **FULL_SIZE** 1D readout (3/1/2/1); 3072 channels

CMS_Proto_IV Single Mask **30x30cm^2** [NS2] (3/1/2/1); 256 channels

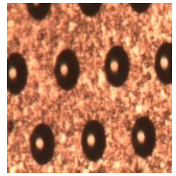
4 Production Prototypes (NS2) on the way 2012

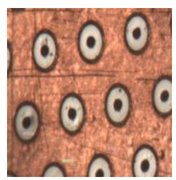
CMS_Proto_V: Single Mask **FULL_SIZE** 1D [NS2] (3/1/2/1) ~3840 channels

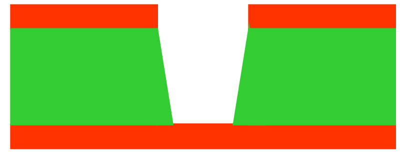
Single Mask Technology

GEM PROCESS

1. Base material 50 µm polyimide foil copper clad
2. Photoresist lamination, masking, exposure, development
3. Chemical etching of copper Top
4. Polyimide etching in 2 steps
5. Electrochemical etching of copper Bot etched
6. Polyimide etching to transform hole geometry
7. Photoresist lamination, masking, exposure, development to define electrodes
8. Chemical etching of copper Top and Bot, Cleaning and electrical test

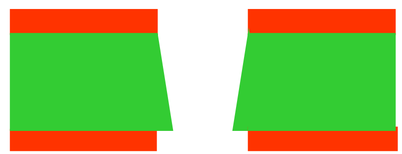




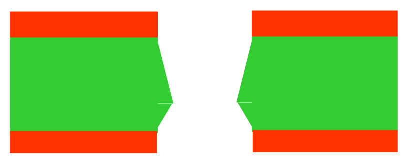


Chemical Polyimide etching

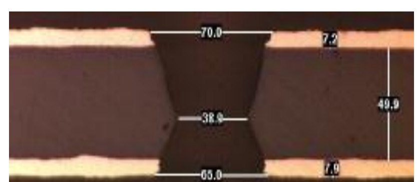
Copper electro etching



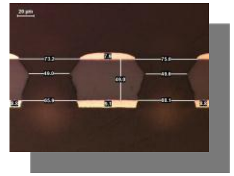
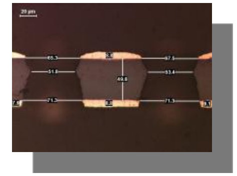
Stripping



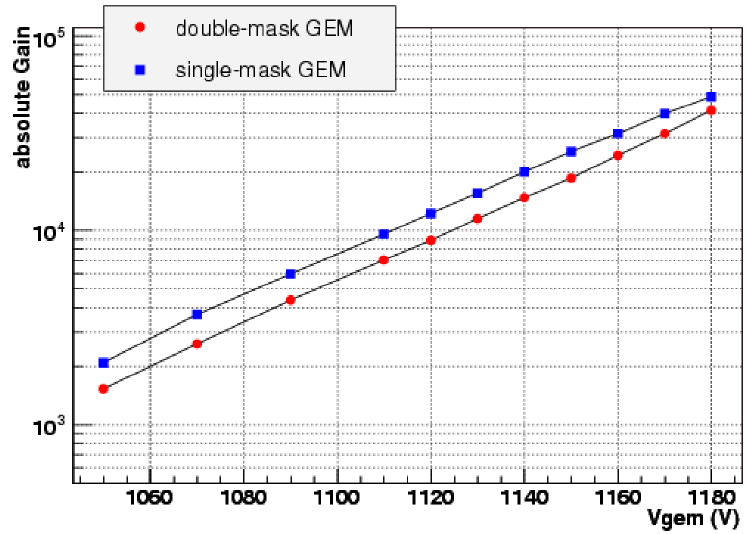
R. De Oliveira
S. Ferry

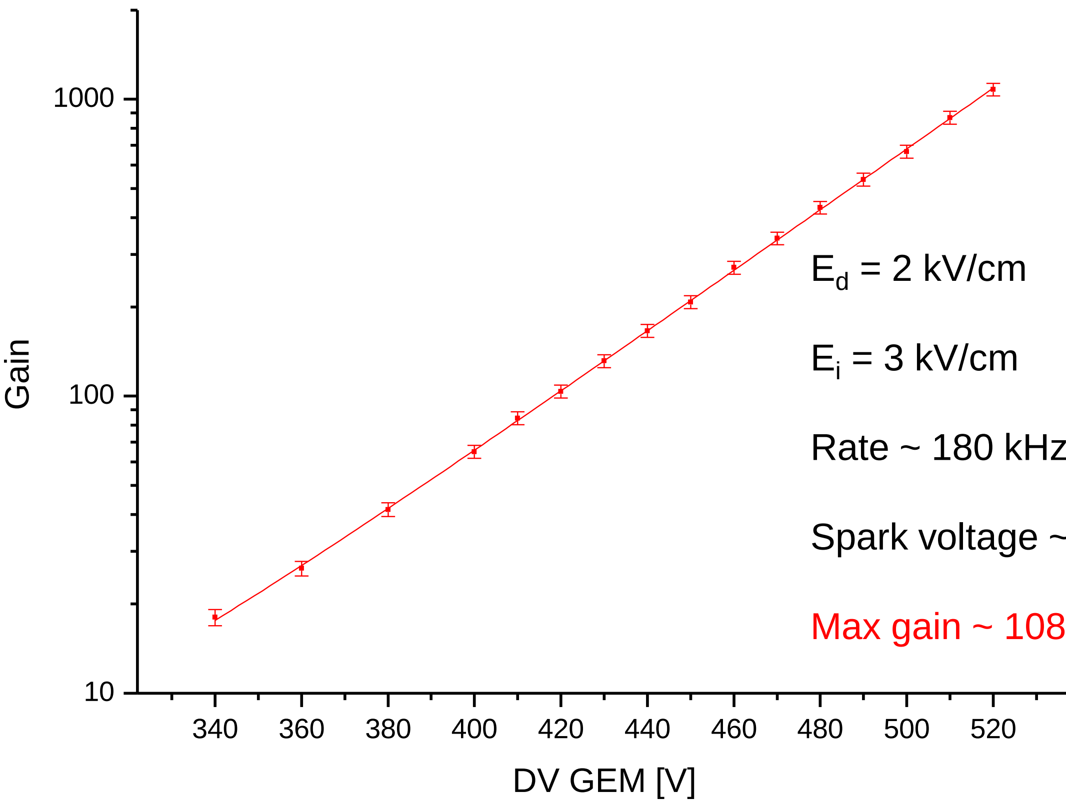


Reality

Single Mask Single GEM





E_d = 2 kV/cm

E_i = 3 kV/cm

Rate ~ 180 kHz/mm^2

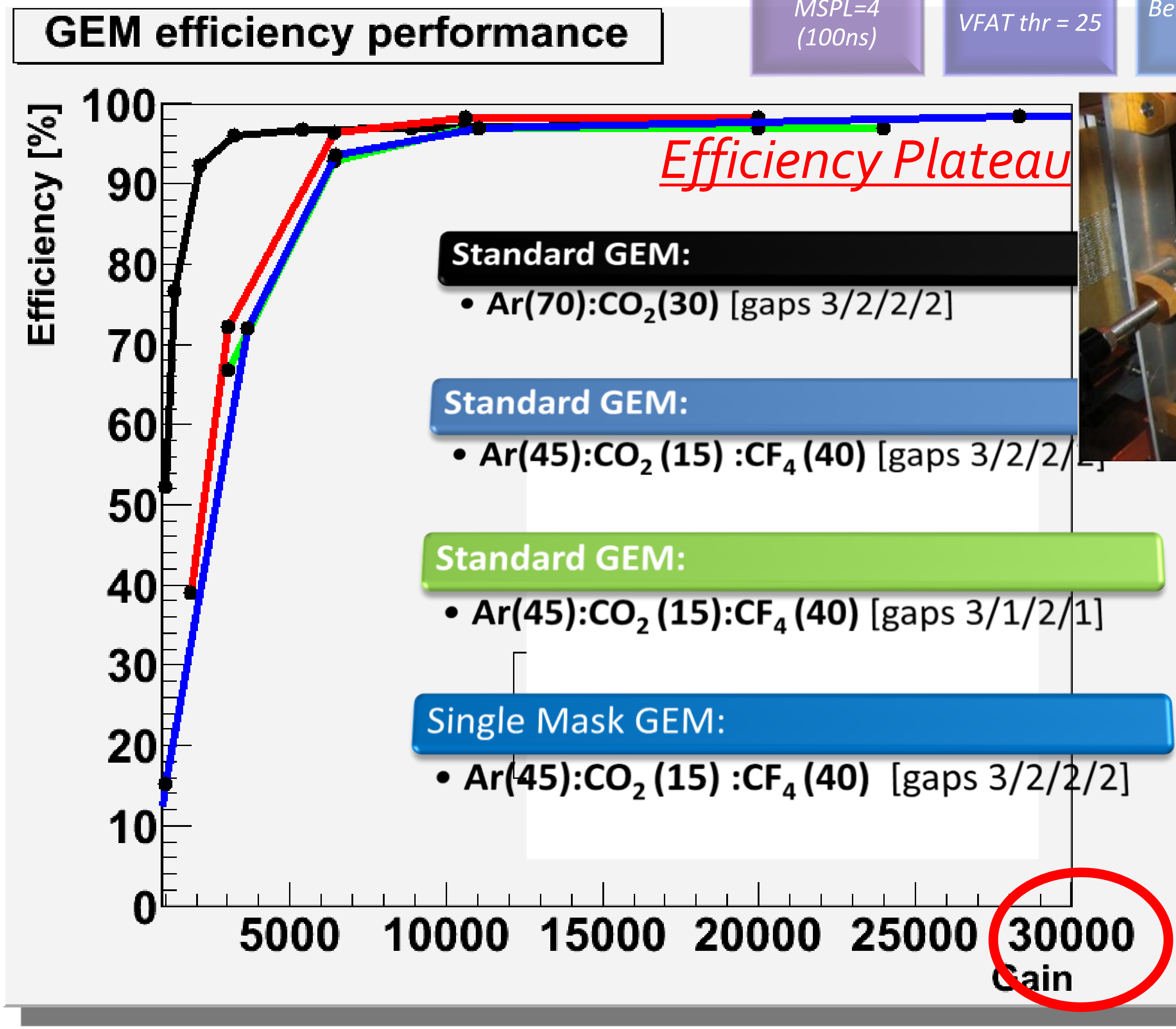
Spark voltage ~ 530 V

Max gain ~ 1080

M. Villa 2010

Construction and tests 2010-11

MSPL=4 (100ns) | *VFAT thr = 25* | *Beam = Muon 150GeV* | *25kEvt ∀run*

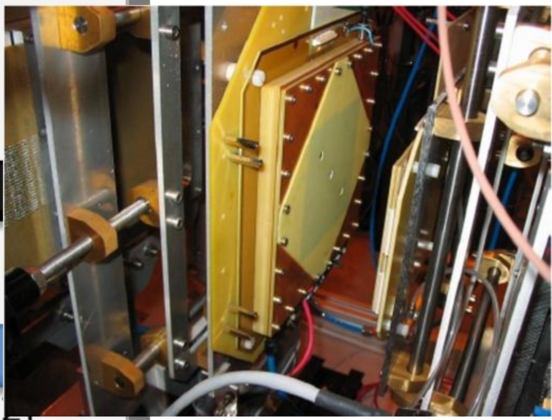


Standard GEM:
- **Ar(70):CO_2(30)** [gaps 3/2/2/2]

Standard GEM:
- **Ar(45):CO_2 (15) :CF_4 (40)** [gaps 3/2/2/2]

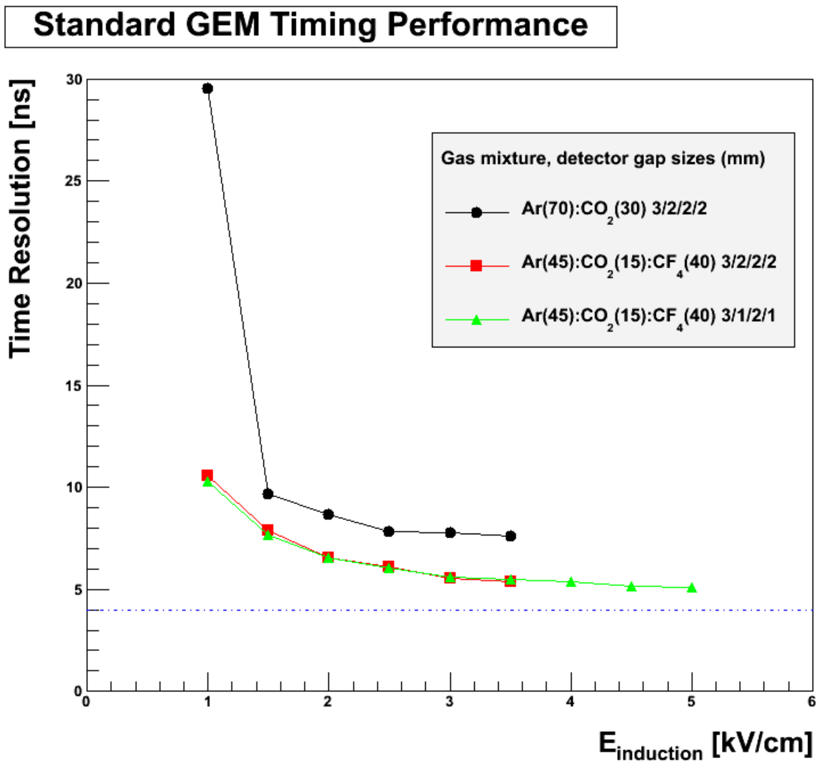
Standard GEM:
- **Ar(45):CO_2 (15):CF_4 (40)** [gaps 3/1/2/1]

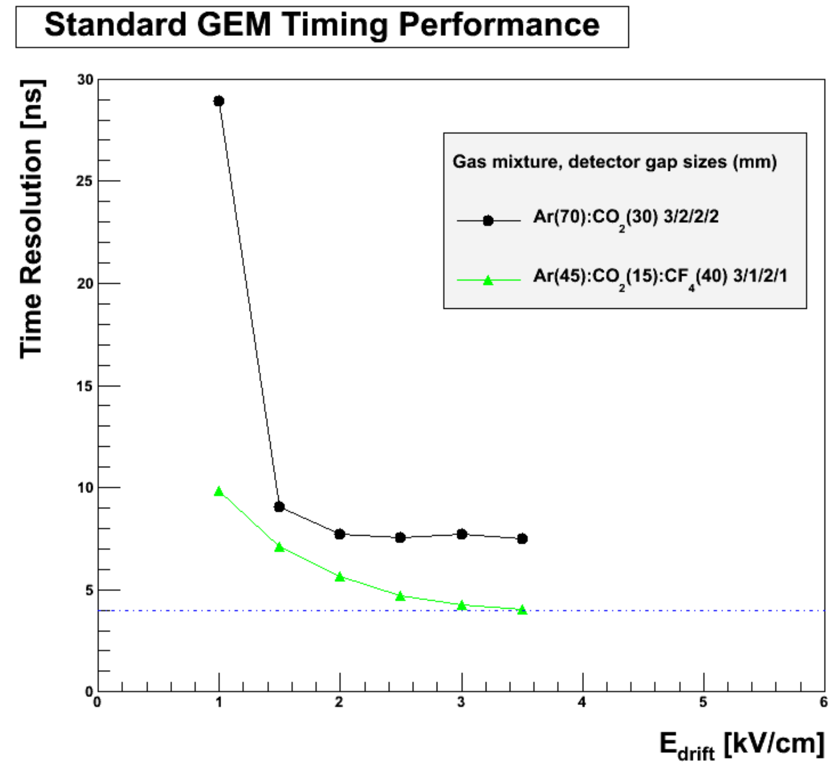
Single Mask GEM:
- **Ar(45):CO_2 (15) :CF_4 (40)** [gaps 3/2/2/2]



High achievable gain!

GEM Collaboration
Construction and tests 2010-11





Custom made HV divider for Standard triple-GEM

Clear effect of gas mixture, and induction and drift field

Timing resolution of 4 ns achieved

(Non optimal voltages due to power supply limitations)

Large GEM Sizes

Large GEM production by single mask technique

GEM Collaboration
Construction and tests 2010-11

GE 1/1 42cm x 990 cm: One piece

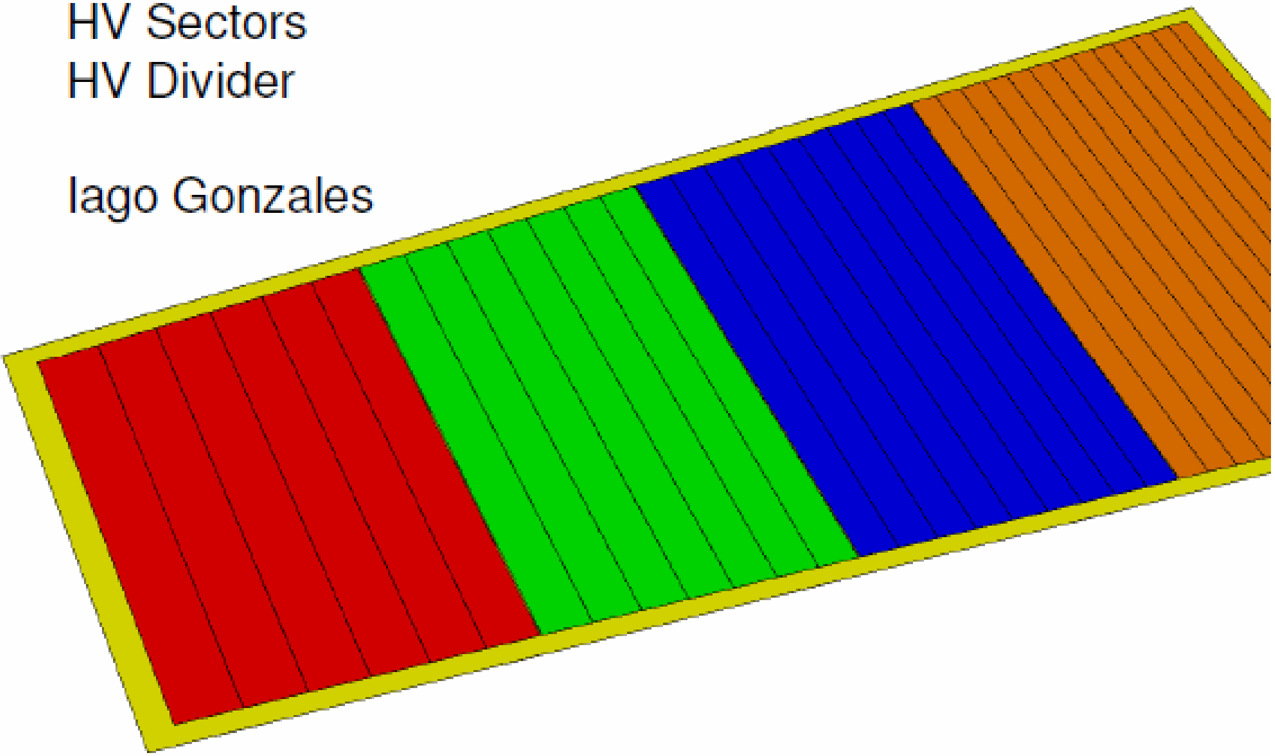
1. Base material 50 µm polyimide foil copperclad
2. Photoresist lamination, masking, exposure, development
3. Chemical etching of copper Top
4. Polyimide etching in 2 steps
5. Electrochemical etching of copper Bot + over-etched
6. Polyimide etching to transform hole geometry
7. Photoresist lamination, masking, exposure, development to define

Single-mask GEM reaches similar performance level as double-mask GEM

Single-mask technique used for large CMS-size prototypes

HV Sectors
HV Divider

Iago Gonzales

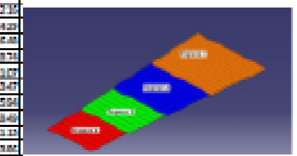


(THANKS TO IAGO GONZALEZ FOR CALCULATING STRIPS)

DIMENSION OF THE TRAPEZES

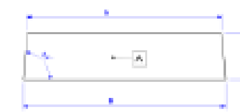
Trapeze 1

	l (mm)	A (mm^2)	b (mm)	h (mm)
1.000	419.534	9200.000	416.080	22.003
2.000	416.057	9200.000	411.168	22.218
3.000	412.143	9200.000	408.238	22.429
4.000	408.193	9200.000	404.328	22.648
5.000	404.203	9200.000	400.201	22.871
6.000	400.174	9200.000	396.131	23.107
7.000	396.105	9200.000	392.028	23.347
8.000	391.994	9200.000	387.865	23.594
9.000	387.839	9200.000	383.668	23.848
10.000	383.640	9200.000	379.438	24.113
11.000	379.394	9200.000	375.137	24.386
12.000	375.101	9200.000	370.784	24.668
13.000	370.758	9235.573	366.348	25.233



Trapeze 2

	l (mm)	A (mm^2)	b (mm)	h (mm)
1.000	365.169	9500.000	361.601	26.107
2.000	361.575	9500.000	356.948	26.448
3.000	356.921	9500.000	352.231	26.792
4.000	352.207	9500.000	347.455	27.158
5.000	347.429	9500.000	342.611	27.535
6.000	342.585	9500.000	337.698	27.938
7.000	337.673	9500.000	332.710	28.349
8.000	332.686	9500.000	327.653	28.773
9.000	327.625	9183.000	322.684	28.342



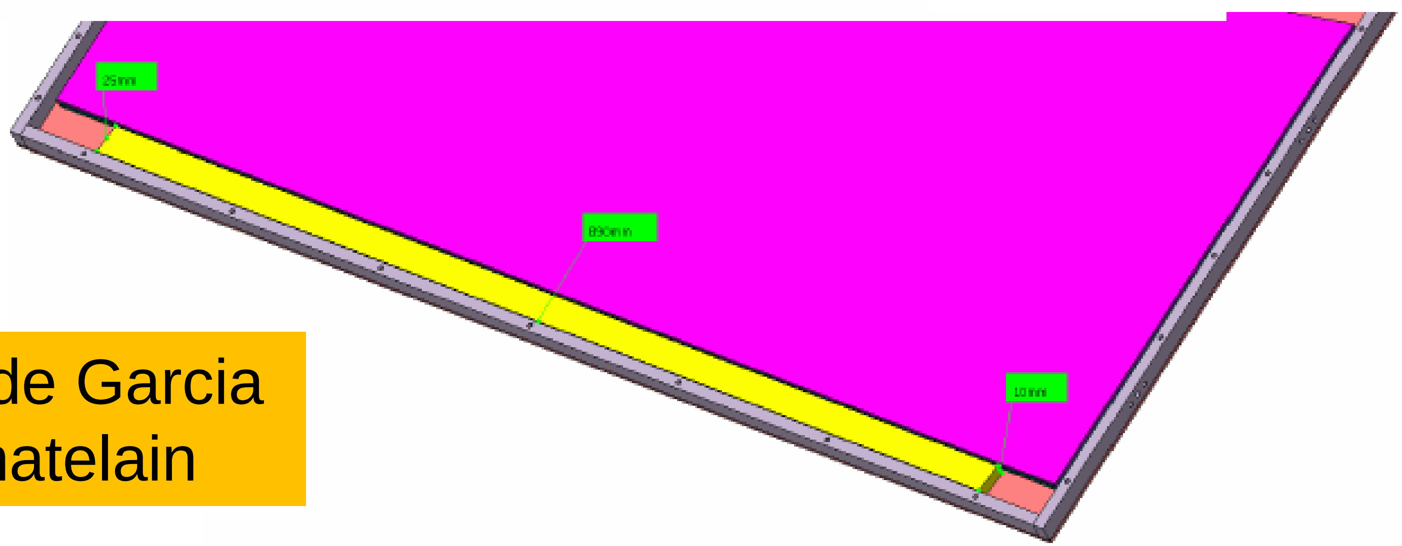
Trapeze 3

	l (mm)	A (mm^2)	b (mm)	h (mm)
1.000	322.509	9025.000	317.575	28.188
2.000	317.548	9025.000	312.538	28.647
3.000	312.510	9025.000	307.418	29.118
4.000	307.388	9025.000	302.208	29.610
5.000	302.181	9025.000	296.910	30.128
6.000	296.883	9025.000	291.518	30.678
7.000	291.489	9044.187	286.003	31.322

Trapeze 4

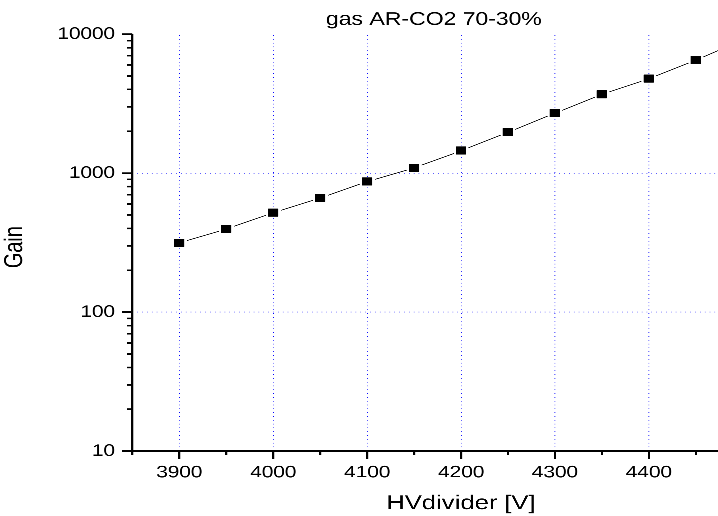
	l (mm)	A (mm^2)	b (mm)	h (mm)
1.000	285.934	9050.000	280.238	31.978
2.000	280.213	9050.000	274.504	32.628
3.000	274.477	9050.000	268.648	33.338
4.000	268.620	9050.000	262.658	34.065
5.000	262.632	9050.000	256.533	34.868
6.000	256.506	9050.578	250.278	35.640

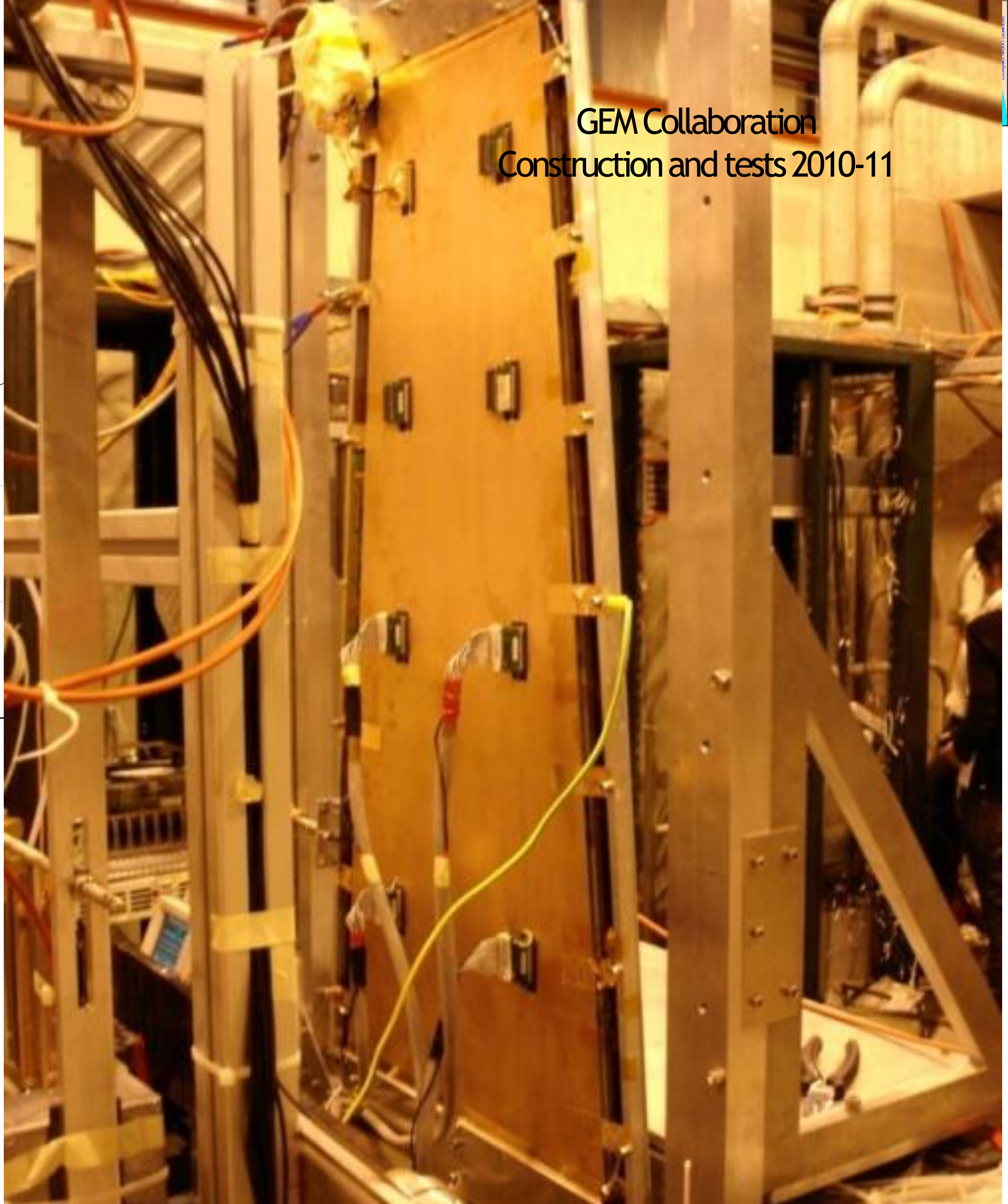
Iago Gonzalez Tabarez
PH-CMX-DS
12/1/2010



A. Conde Garcia
J. P. Chatelain

Measured in RD51 lab with x-rays



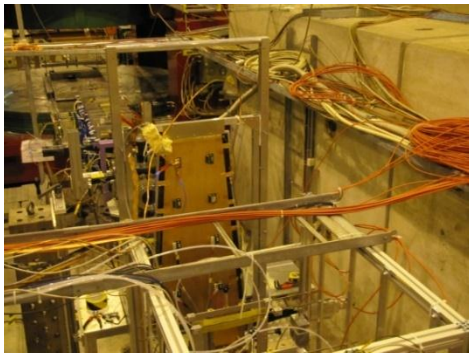


M. Zientek
A. Marinov

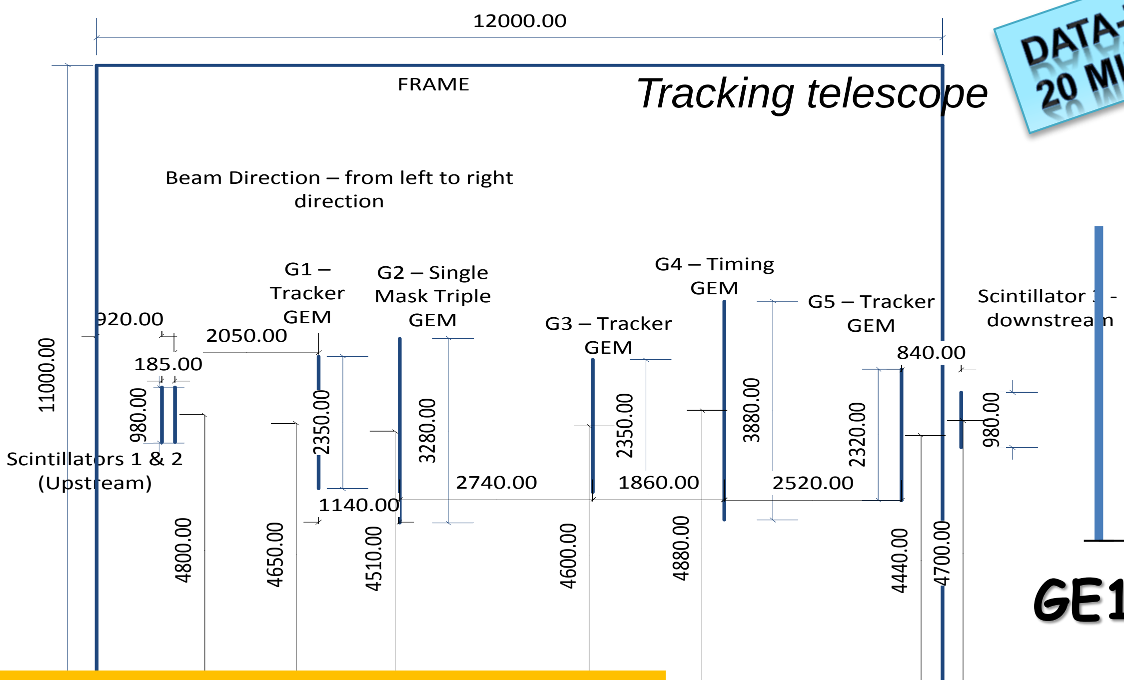
Test Beam CMS-RD51 SPS-H4

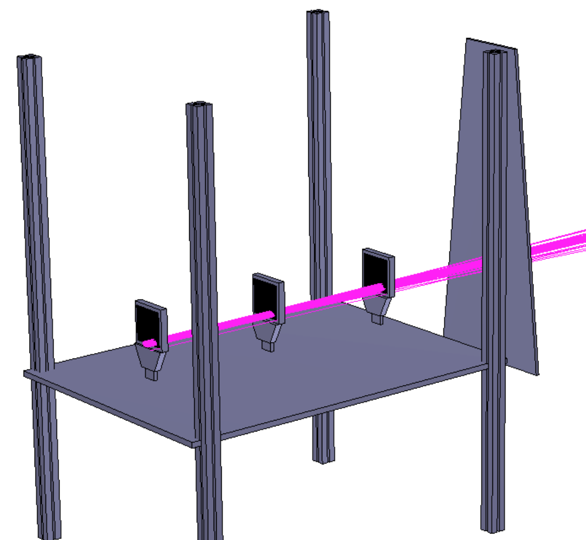
GEM Collaboration
Construction and tests 2010-11

GE1/1



DATA-TAKING:
20 MILLION EVENTS!

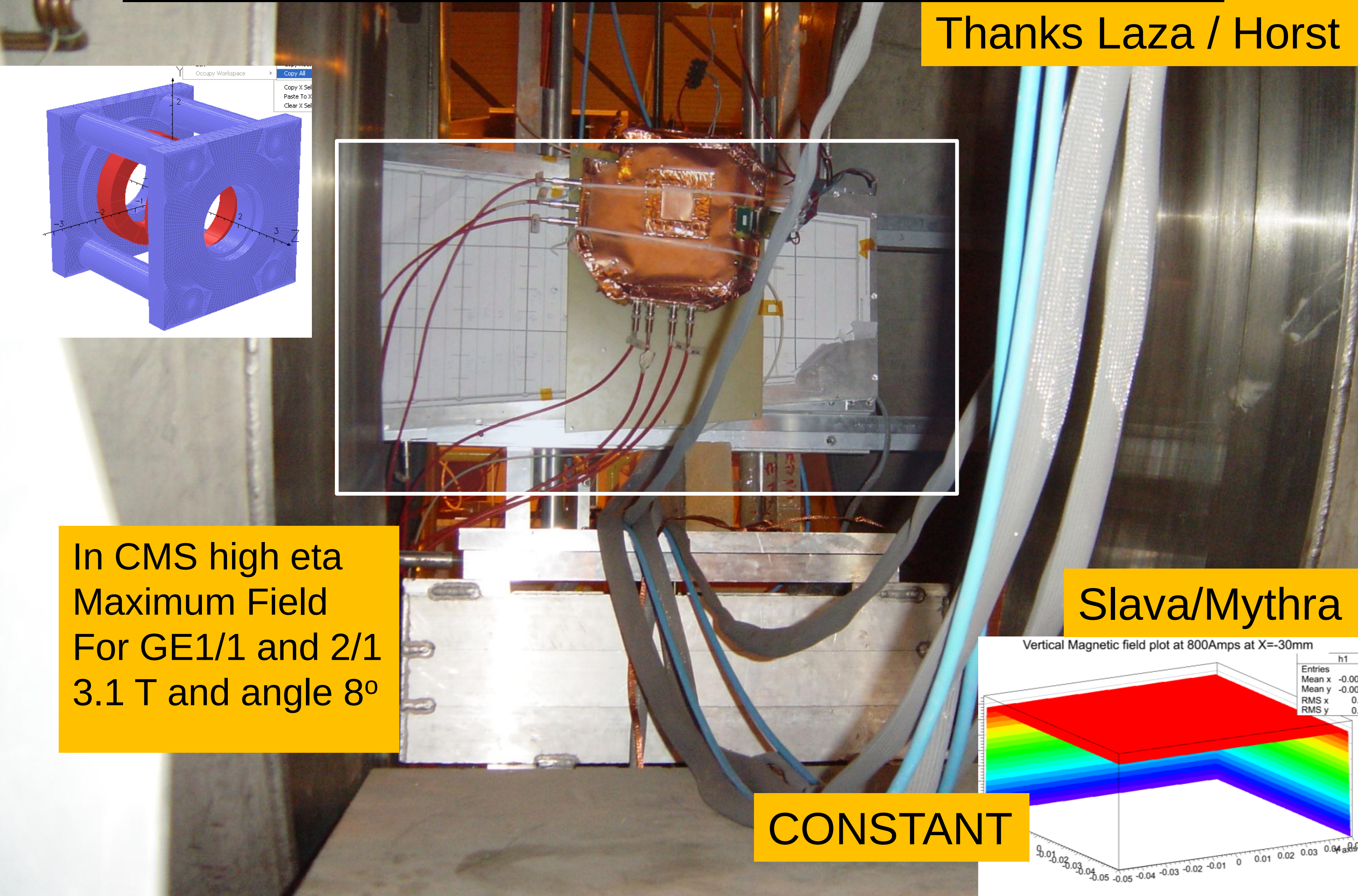




3D Event Displayer

Collab+Many Summer students

2011 Test Beam with Magnetic Field



Thanks Laza / Horst

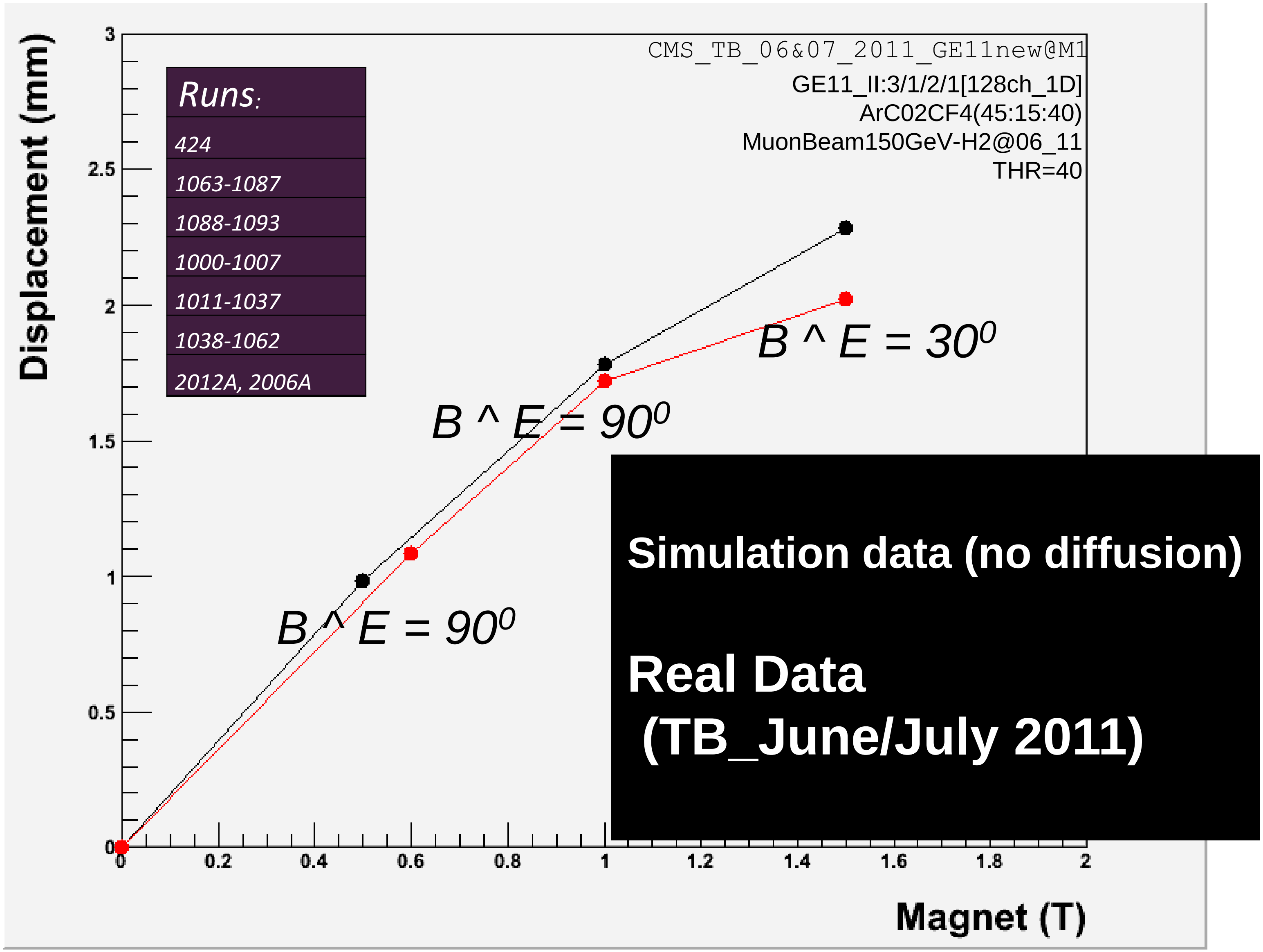
In CMS high eta
Maximum Field
For GE1/1 and 2/1
3.1 T and angle 8º

Slava/Mythra

CONSTANT

GE11-II Lorentz measurements

GEM Collaboration
Construction and tests 2010-11



PERFORMANCE SUMMARY

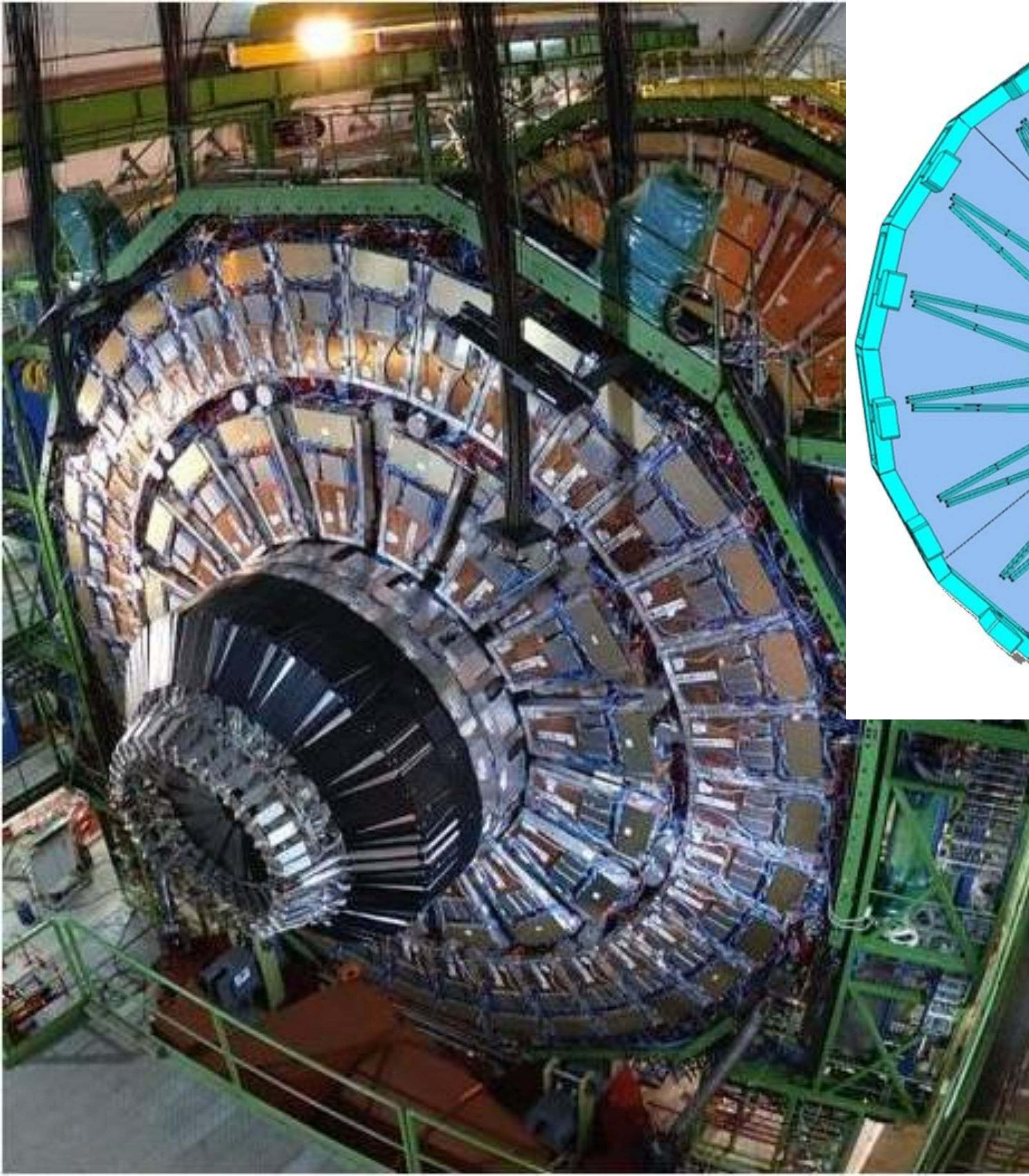
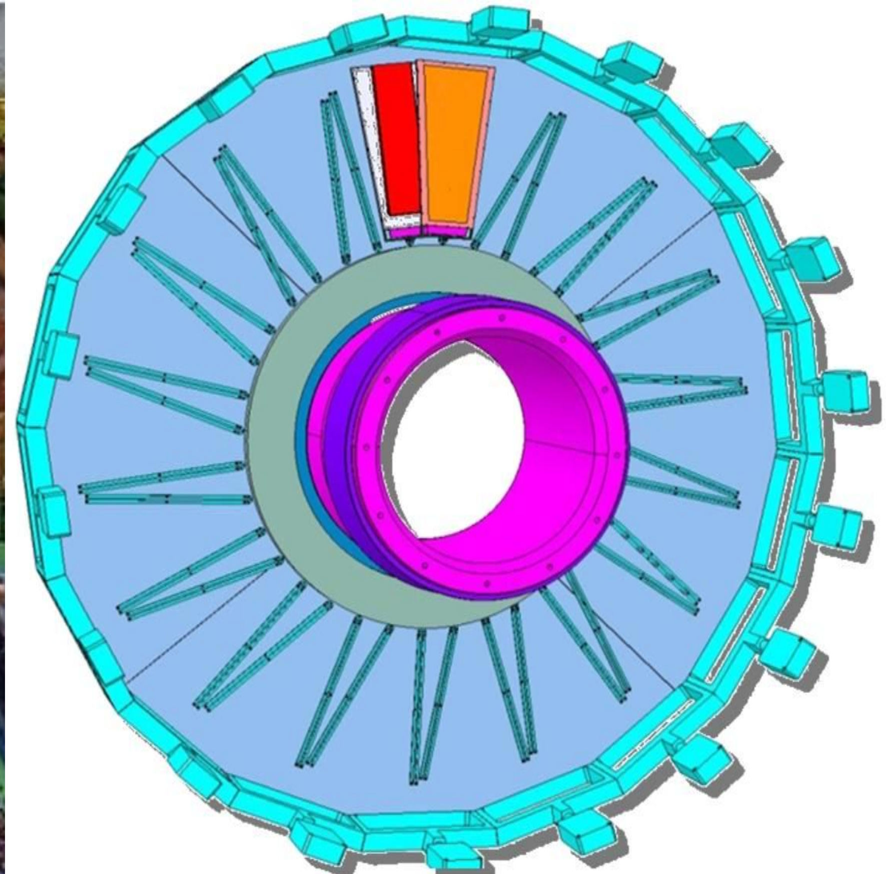
GEM Collaboration

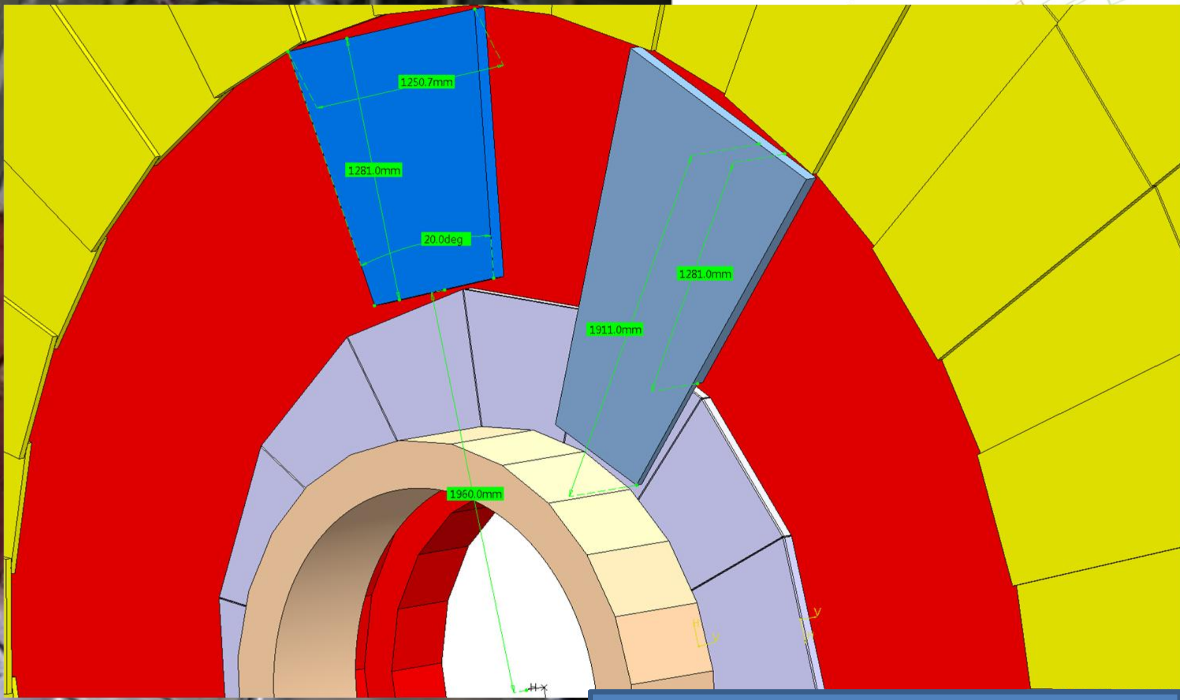
Construction and tests 2010-11

Name	Mask Type	Prod. Tech.	Active Area (mm^2)	Readout/pitch number of dimensions/mm	Gap Sizes (*drift*, *tr. 1*, *tr. 2*, *ind.*) (mm/mm/mm/mm)	#strips	Prod. Site
Timing GEM	double-mask	standard	100×100	1D 0.8	3/2/2/2&3/1/2/1	128	CERN
Single-Mask GEM	single-mask	standard	100×100	2D 0.4	3/2/2/2	512	CERN
Honeycomb GEM	double-mask	standard	100×100	2D 0.4	3/2/2/2	512	CERN
CMS Proto I	single-mask	self-stretching	$990 \times (220-450)$	1D 0.8-1.6	3/2/2/2	1024	CERN
CMS Proto II	single-mask	self-stretching	$990 \times (220-450)$	1D 0.6-1.2	3/1/2/1	3184	CERN
CMS Proto III	single-mask	self-stretching	100×100	1D 0.4	3/1/2/1	256	CERN
CMS Proto IV	single-mask	self-stretching	300×300	1D 0.6-1.8	3/1/2/1	256	CERN
Korean I	double-mask	standard	80×80	1D 0.6	3/1/2/1	256	New Flex

Name	Max Gain	Gas Mix.	Electronics	Efficiency (%)	Space resolution (mm)	Time resolution (ns)	Magnet (T)
Timing GEM	60776	Ar/CO_2 (70 : 30)	VFAT	98.3	0.24	9.8	B=0
	17943	$Ar/CO_2/CF_4$ (45 : 15 : 40)	VFAT	98.8	0.24	4.5	B=0
Single-Mask GEM		Ar/CO_2 (70 : 30)	VFAT	97.9			B=0
		$Ar/CO_2/CF_4$ (45 : 15 : 40)	VFAT	98.6			B=0
Honeycomb GEM		Ar/CO_2 (70 : 30)	VFAT				B=0
		$Ar/CO_2/CF_4$ (45 : 15 : 40)	VFAT	~~70.5~~			B=0
CMS Proto I	15889	Ar/CO_2 (70 : 30)	VFAT	98.8			B=0
		$Ar/CO_2/CF_4$ (45 : 15 : 40)	VFAT	99.0	0.32		B=0
CMS Proto II	15889	Ar/CO_2 (70 : 30)	VFAT&APV	98.9			B=1.5
	18938	$Ar/CO_2/CF_4$ (45 : 15 : 40)	VFAT&APV	97.8	0.29		B=1.5
CMS Proto III		Ar/CO_2 (70 : 30)	VFAT				B=0
		$Ar/CO_2/CF_4$ (45 : 15 : 40)	VFAT				B=0
CMS Proto IV		Ar/CO_2 (70 : 30)	VFAT				B=0
		$Ar/CO_2/CF_4$ (45 : 15 : 40)	VFAT				B=0
Korean I	4653	Ar/CO_2 (70 : 30)	VFAT				B=0
		$Ar/CO_2/CF_4$ (45 : 15 : 40)	VFAT				B=0

Large Scale Production

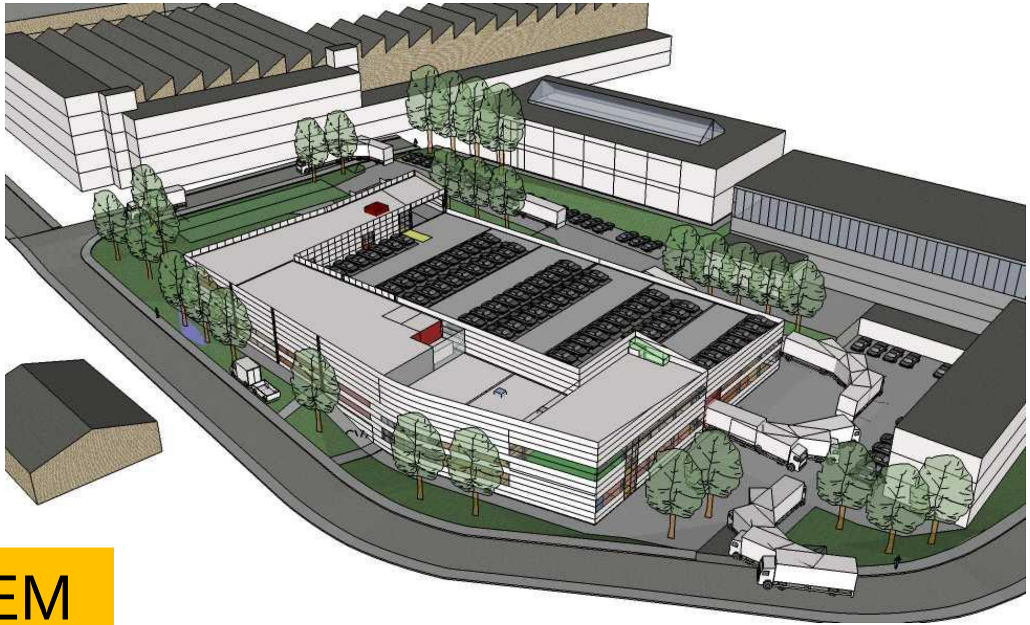





For first two stations /
4 Quarters
1000m^2 GEM Foils

Large Size and Large Scale production

TE-MPE-EM
RD-51



Presently located in the building 102
Well sized for prototyping and small series productions; New Machine

Next year the workshop will be capable to process GEM foils of sizes up to 2m x 0.6m, where the limitation of 0.6m is imposed by the availability of the raw material

F. Formenti / R. De Oliveira

Present production rate : 100 GEMs / year
Expected rate for 2012 : 250 GEMs/Year

GEM production outside CERN

Full technology transfer.. License agreement signed
Small size foils already produced and tested
Large size foils to be tried progressively

Tech – Etch USA
Techtra - Italy

30x30cm2

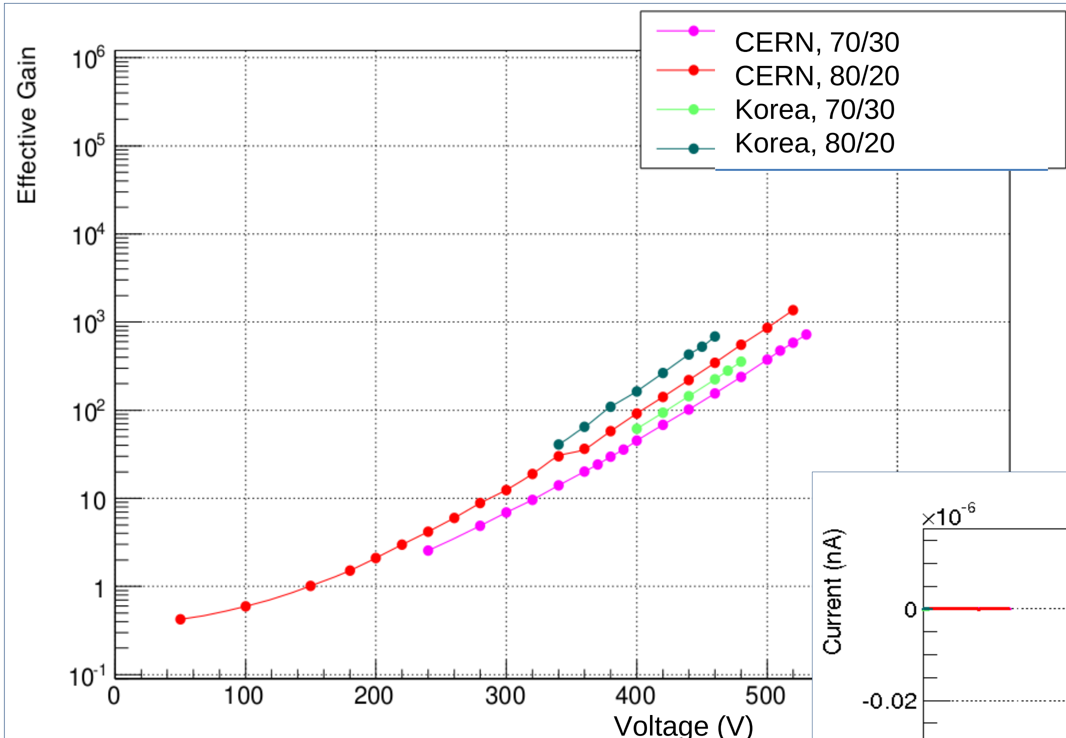
New Flex Seoul, S. Korea

Produced first 8cm x 8cm GEM August 2011

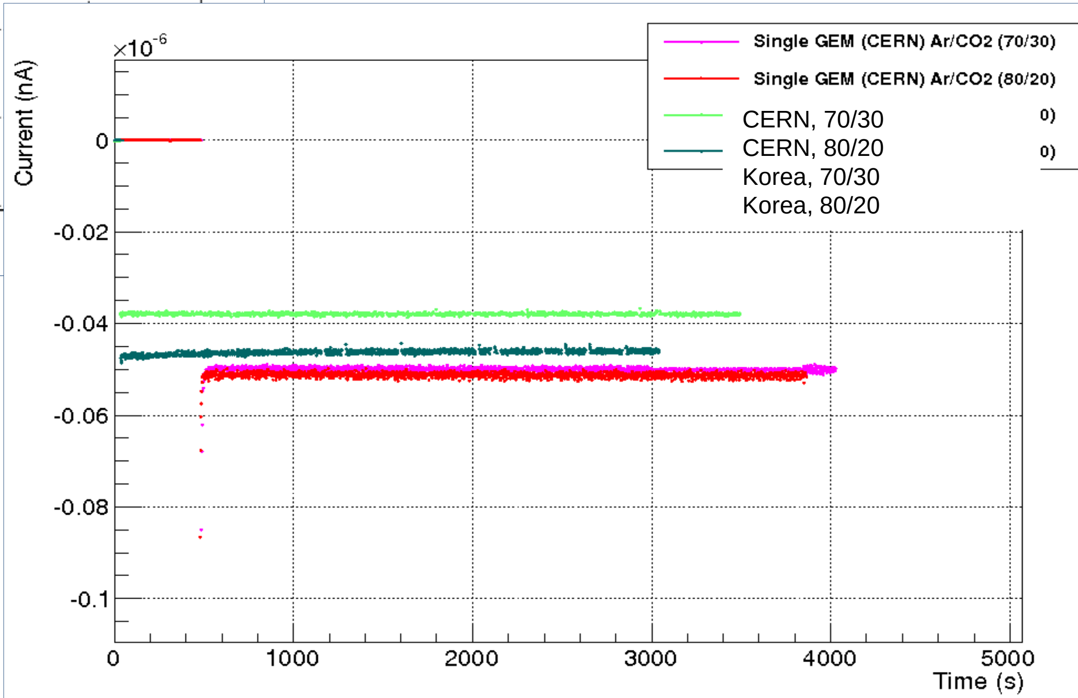
20 10x10cm2 GEMs Jan 2012

30x30 cm2 in the pipeline

Industrialization: New Flex

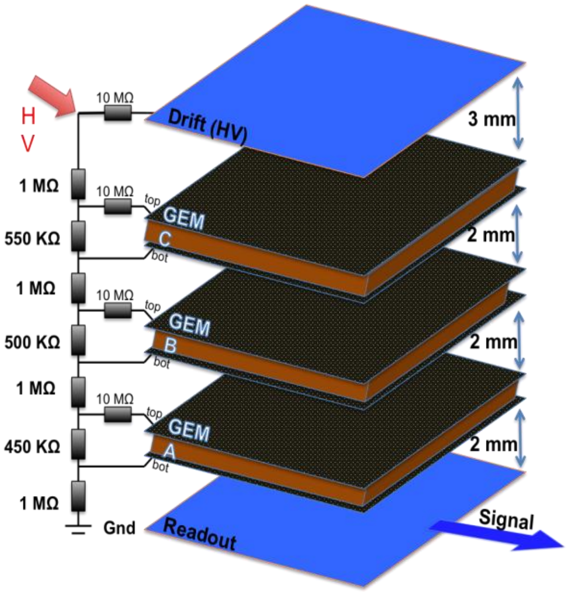


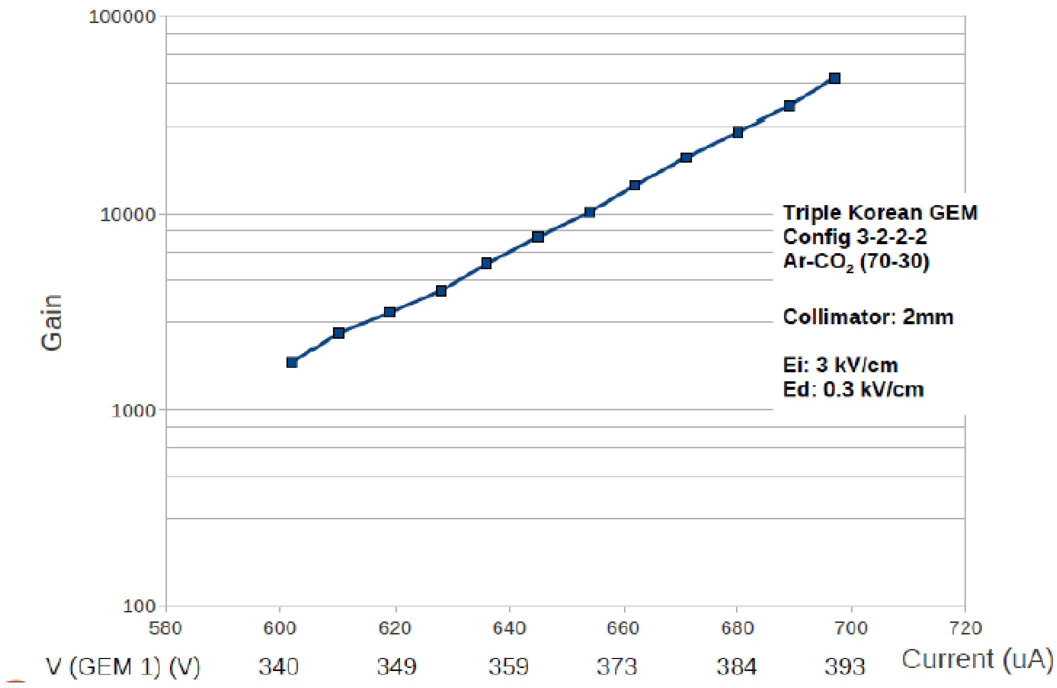
Excellent results of the Korean GEMs compared with the single mask CERN GEM detectors, in both the gas compositions.

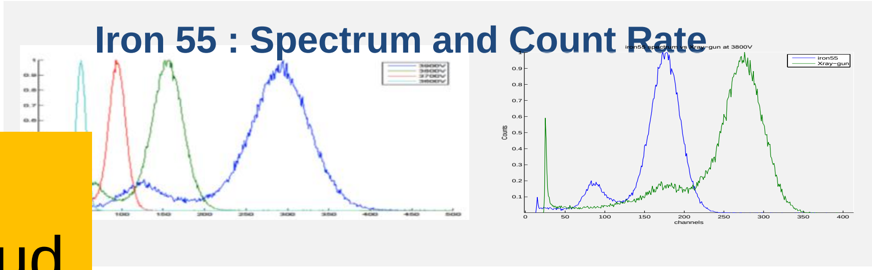


Laura Franconi
Krina Mehta
2011

Gain Calibration Triple Korean GEM



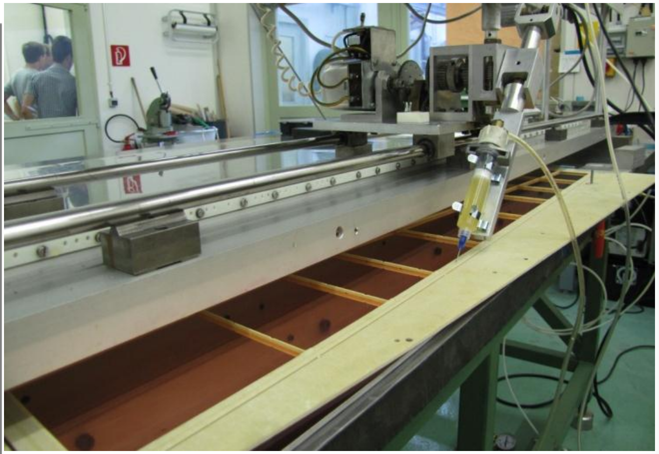


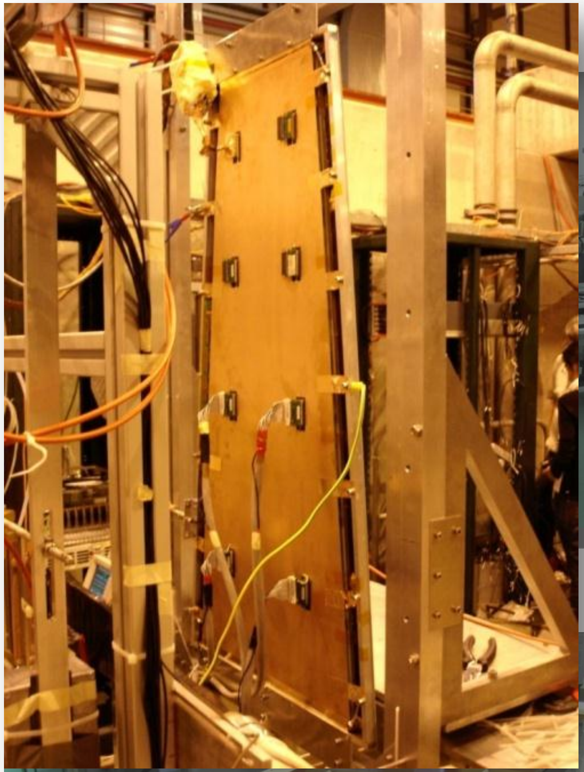


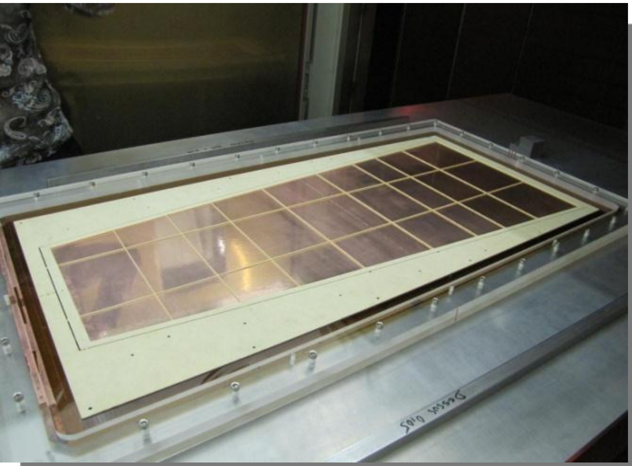
Jeremie Merlin
Christopher Armaingaud

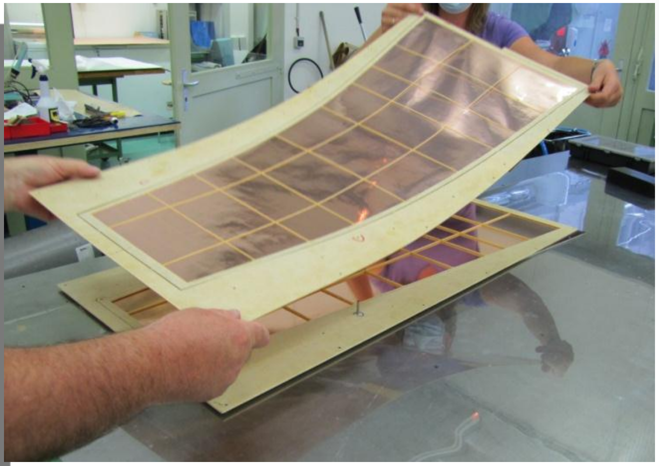
Minimising Time and Manpower for Large Scale Production

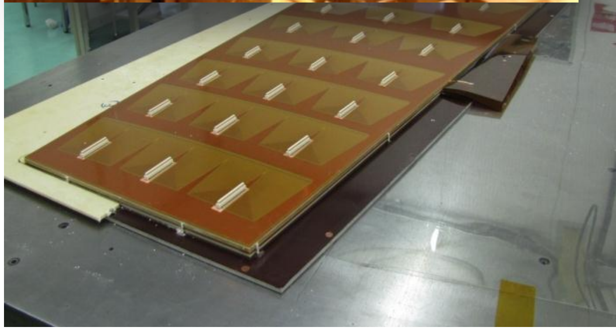
Chamber Construction – Glued Option











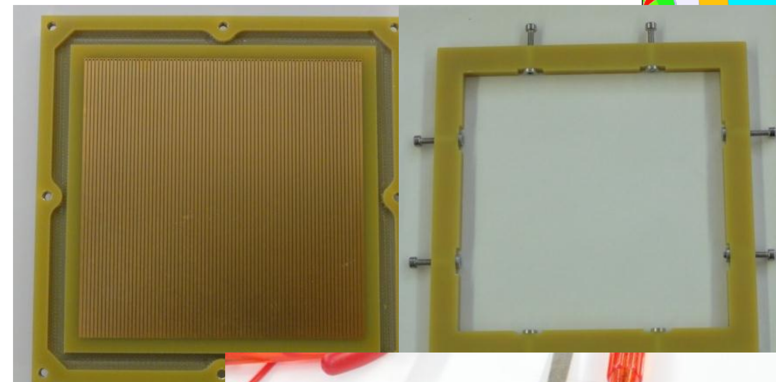
Production: New GEM stretching Technique (NS2)

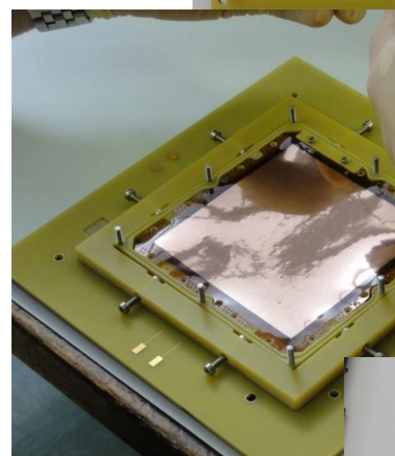
Assembly time
- ½ hour for 10cm x 10cm detector (1 technician)
- 2 hours for 1m x 0.6m detector (1 technician)

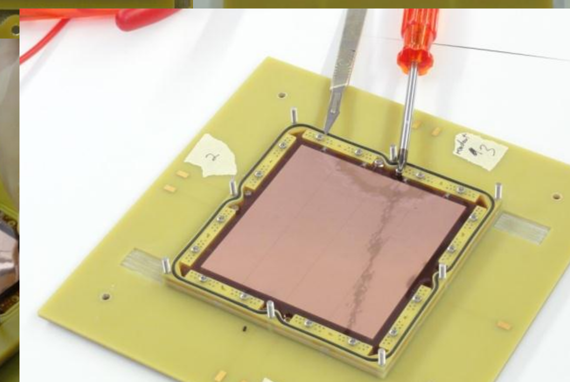
No gluing , no soldering
Re opening possible
GEM exchange possible
Frame less than 10mm
Mimimal Spacers

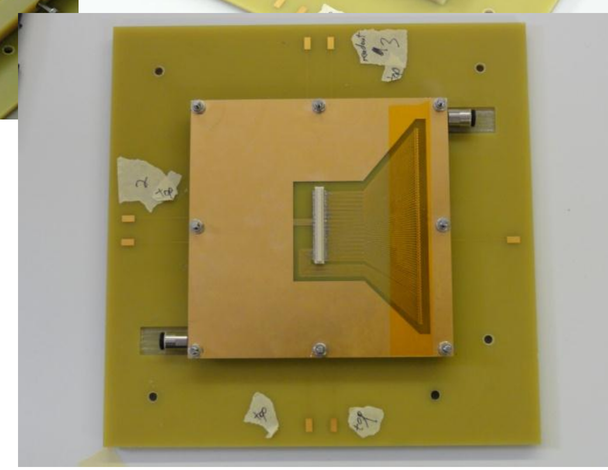
Final Gas test with detector assembled

FIRST LAB TESTS COMMENCED in August 2011 with 10x10 cm2
Subsequently 30x30 cm2 tested







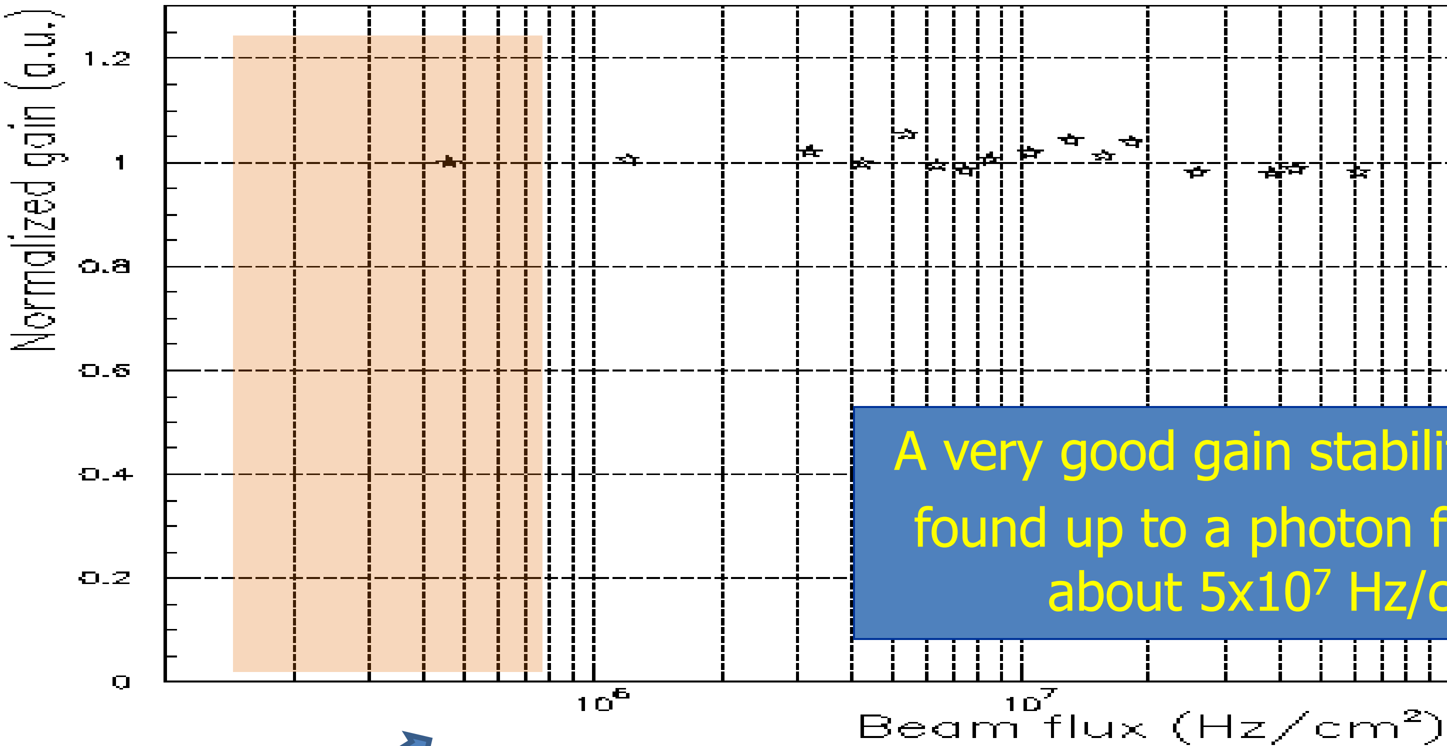


Tests performed by
Mythra Varun
Laura Franconi

GEM Collaboration
Construction and tests 2010-11

RATE CAPABILITY:

Measured with an X-ray (5.9 keV) tube;
$Ar/CO_2/CF_4$ (60/20/20)
Gain of about 2×10^4;

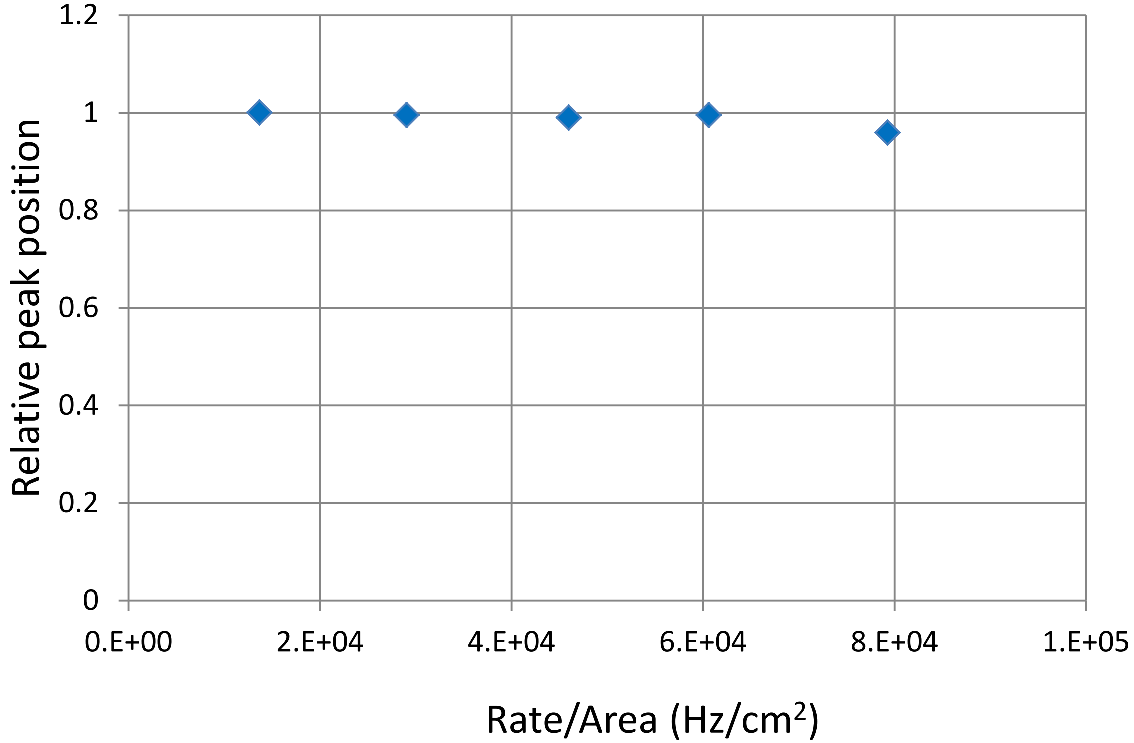


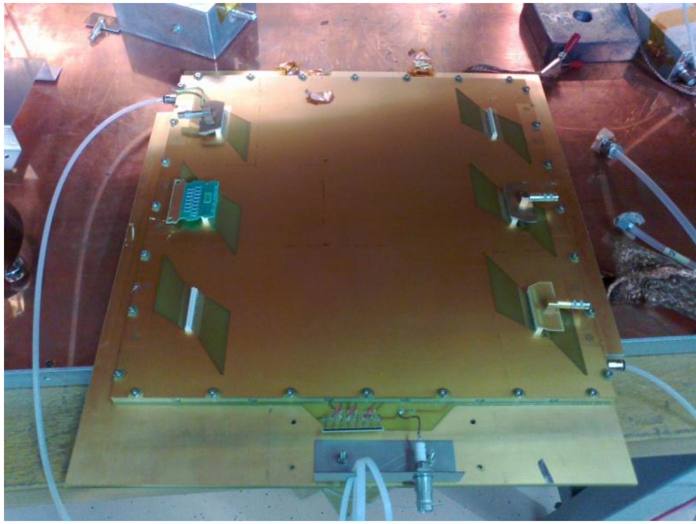
A very good gain stability was found up to a photon flux of about 5×10^7 Hz/cm^2

CMS high η - maximum rate

M. Alfonsi et al 2004

New GEM stretching Technique (NS2) : Performance





The NS2 (30x30) cm^2 triple GEM chamber shows

High gains up to $3{\cdot}10^4$

Good uniformity between different sectors

Good gain stability up to photon flux of $8{\cdot}10^4$ Hz/cm^2

4 Full size (1/1) production prototype : 2012

L. Franconi
Dec, 2011

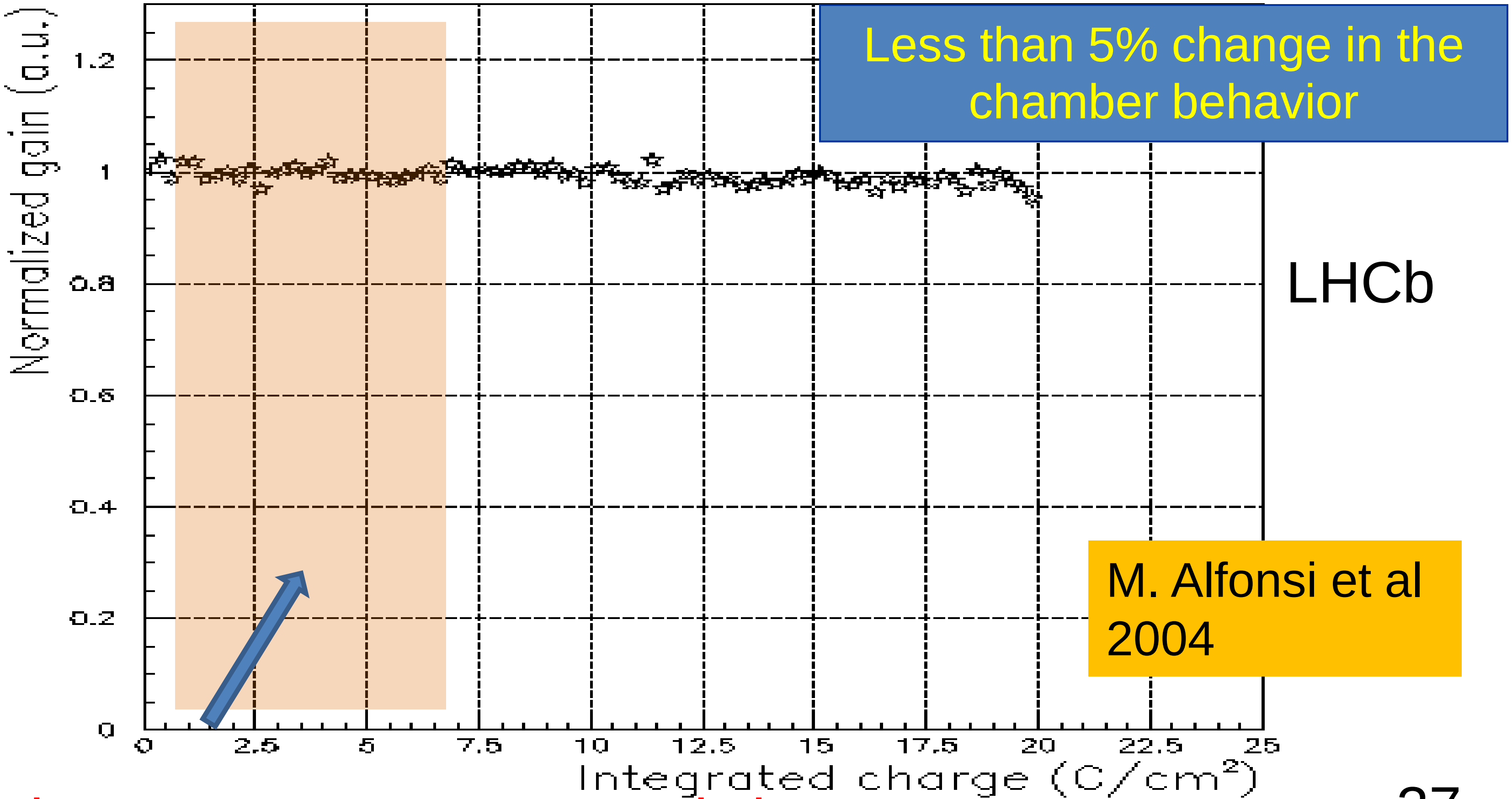
Long Term Operation tests

RATE CAPABILITY:

Gain of 2×10^4

Total integrated charge of 13 C/cm^2 is expected in 10 years of operation in LHCb

50 MHz/cm^2 X-rays, in 10 days a total charge of 20 C/cm^2 was integrated;



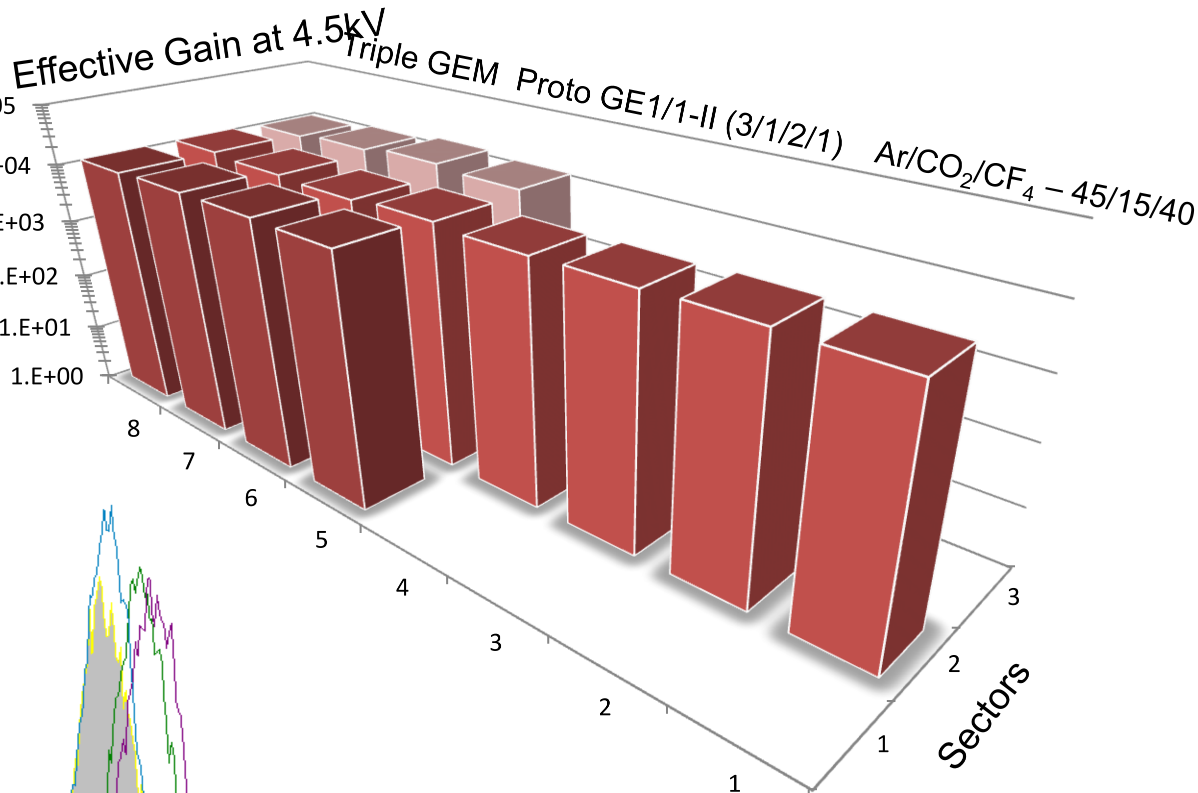
LHCb

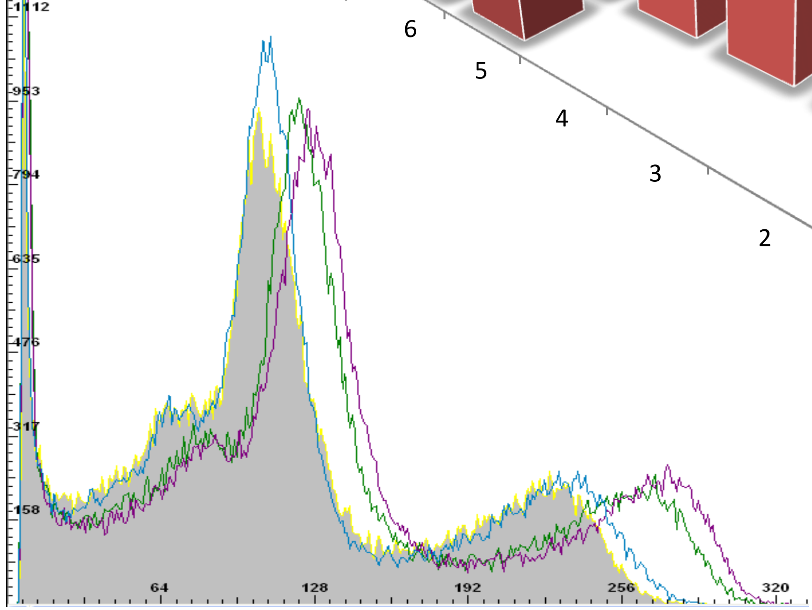
M. Alfonsi et al 2004

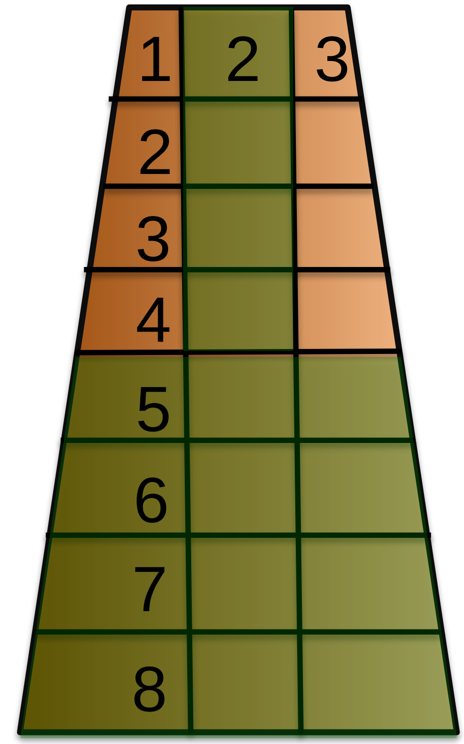
CMS high η - maximum integrated charge

GAIN CALIBRATION

Gain Uniformity







Sectors

X-rays 8 keV

Collimator 2mm

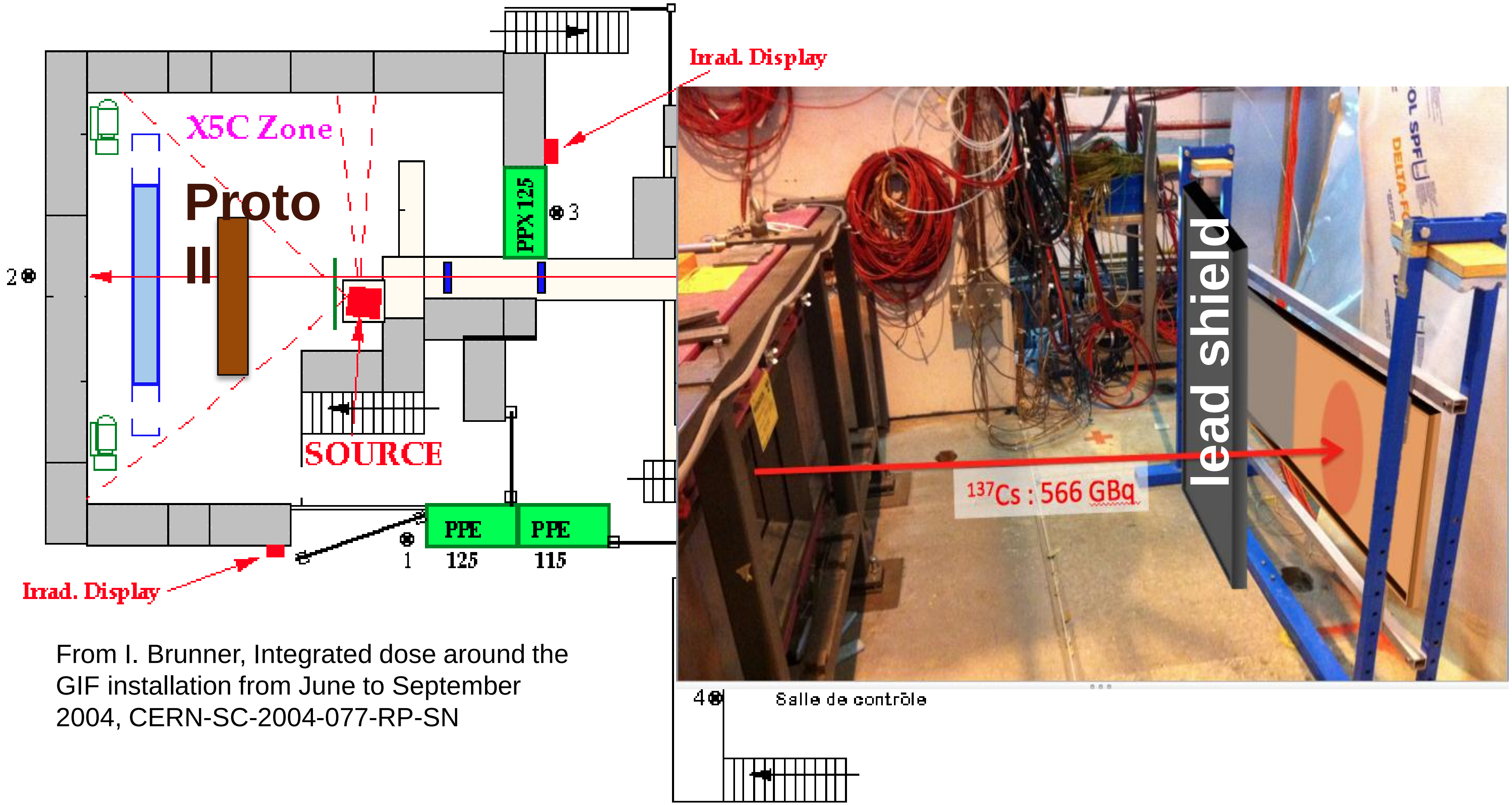
20kV-5mA

Jeremie MERLIN

Christopher ARMAINGAUD

Ageing Test

GIF and Setup



From I. Brunner, Integrated dose around the GIF installation from June to September 2004, CERN-SC-2004-077-RP-SN

Long term test installation ongoing

Jeremie MERLIN
Christopher ARMAINGAUD

Electronics

CMS High Eta Electronics System Goals

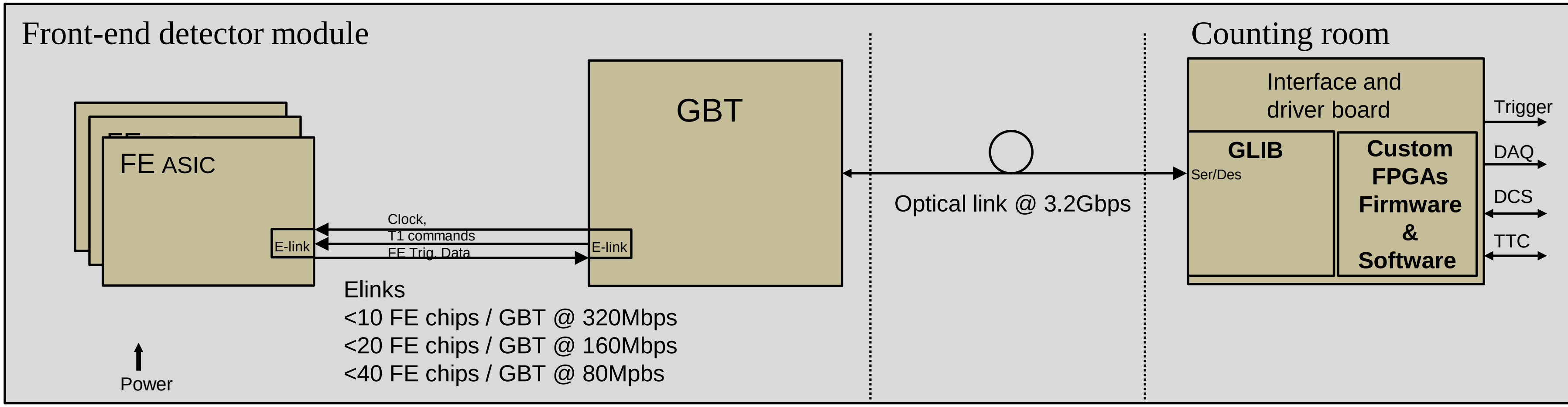
Design a system that is :

Flexible in terms of detector segmentation.

Uses generic design work as much as possible.

Paul Aspell

LHC-Upgrade style readout system

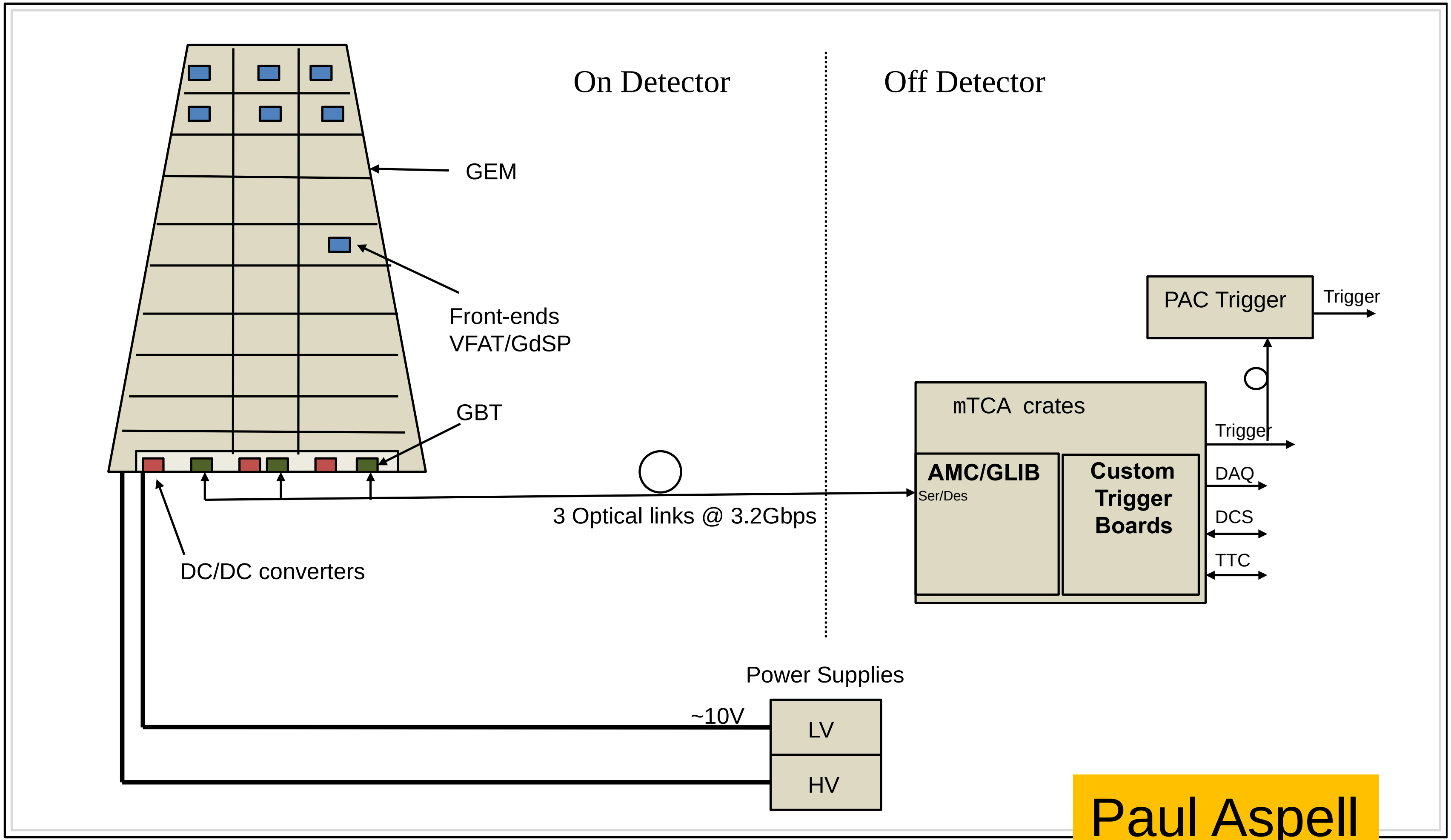


The GBT is currently foreseen for many LHC upgrades :
CMS tracker, HCAL, Atlas tracker, LHCb (all upgrades)

Generic projects in CERN for :

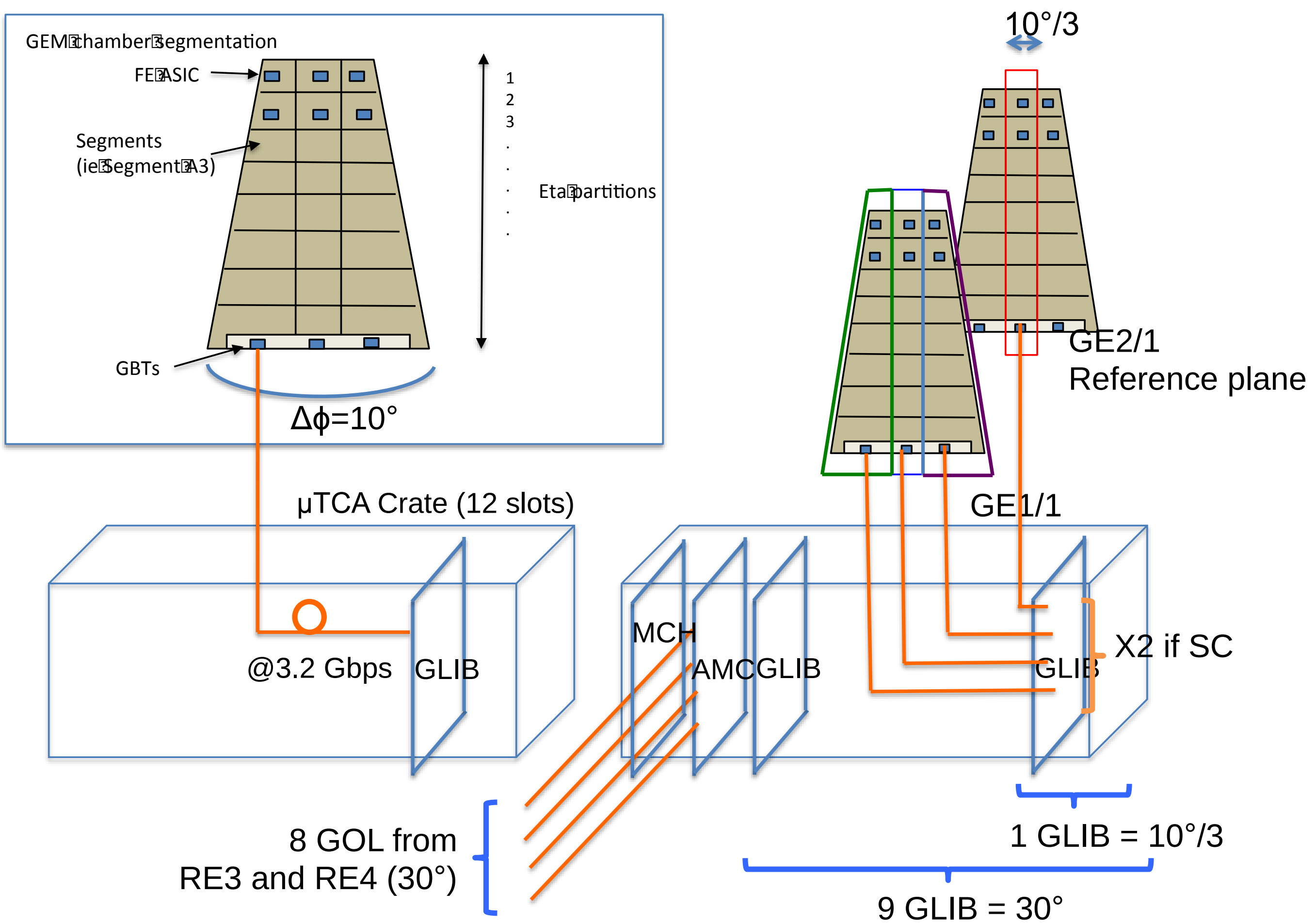
DC/DC Powering
GBT
Versatile Link
GLIB - Giga-Bit Link Interface Board

GEMs for CMS System Architecture VFAT3/GdSP ASIC design + µTCA design



Paul Aspell

Off Detecor µTCA Electronics



A possible off detector partition

1 GLIB = one phi segment ie. 10° /3

1uTCA crate = 30° degrees in phi

12 uTCA crates = 360°

24 uTCA crates for both endcaps

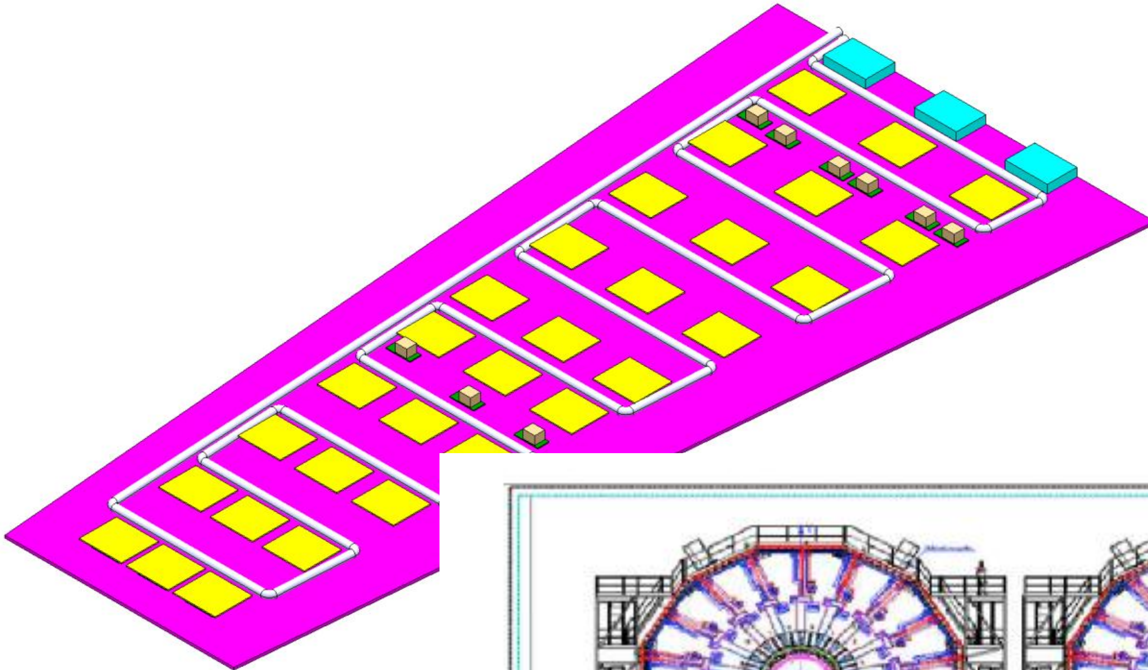
Design groups involved so far :
CERN
ULB (Brussels)
CEA Saclay
University of Bari

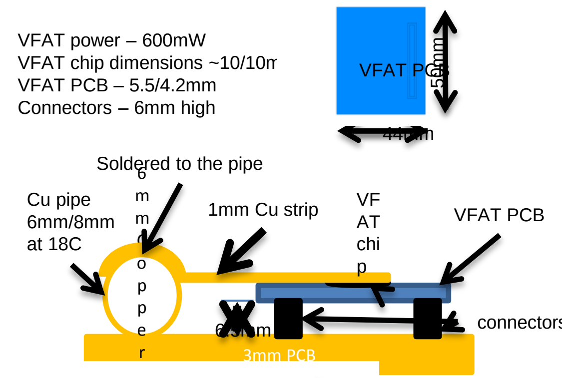
Source : G. De Lentdecker

Services, Integration and Installation

A. Gaddi
A. Conde Garcia
P. Tropea
R. Guida

Baseline Detector and services – under study





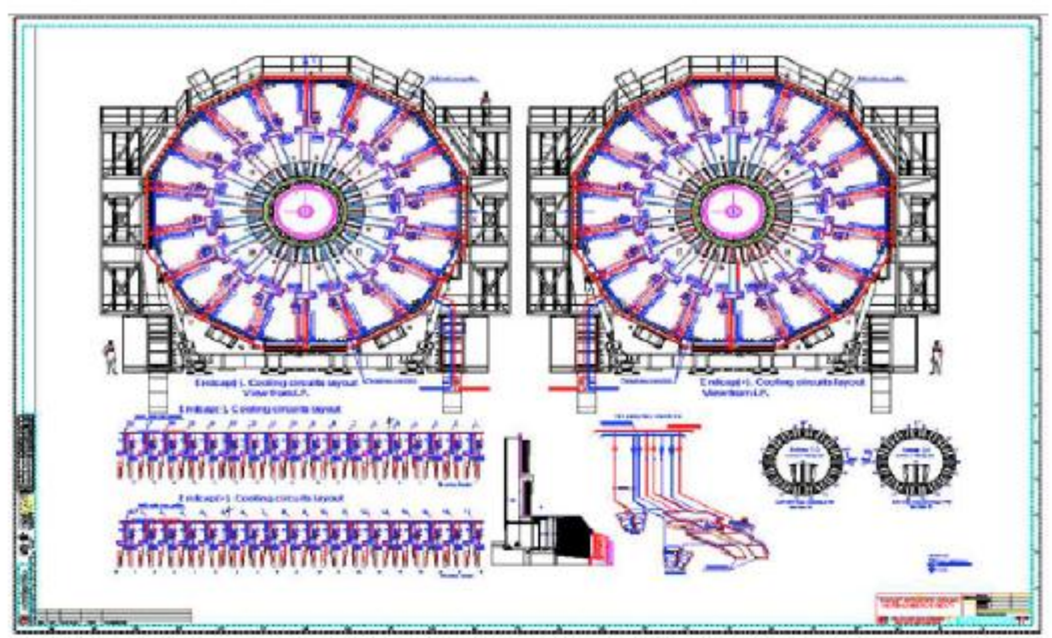
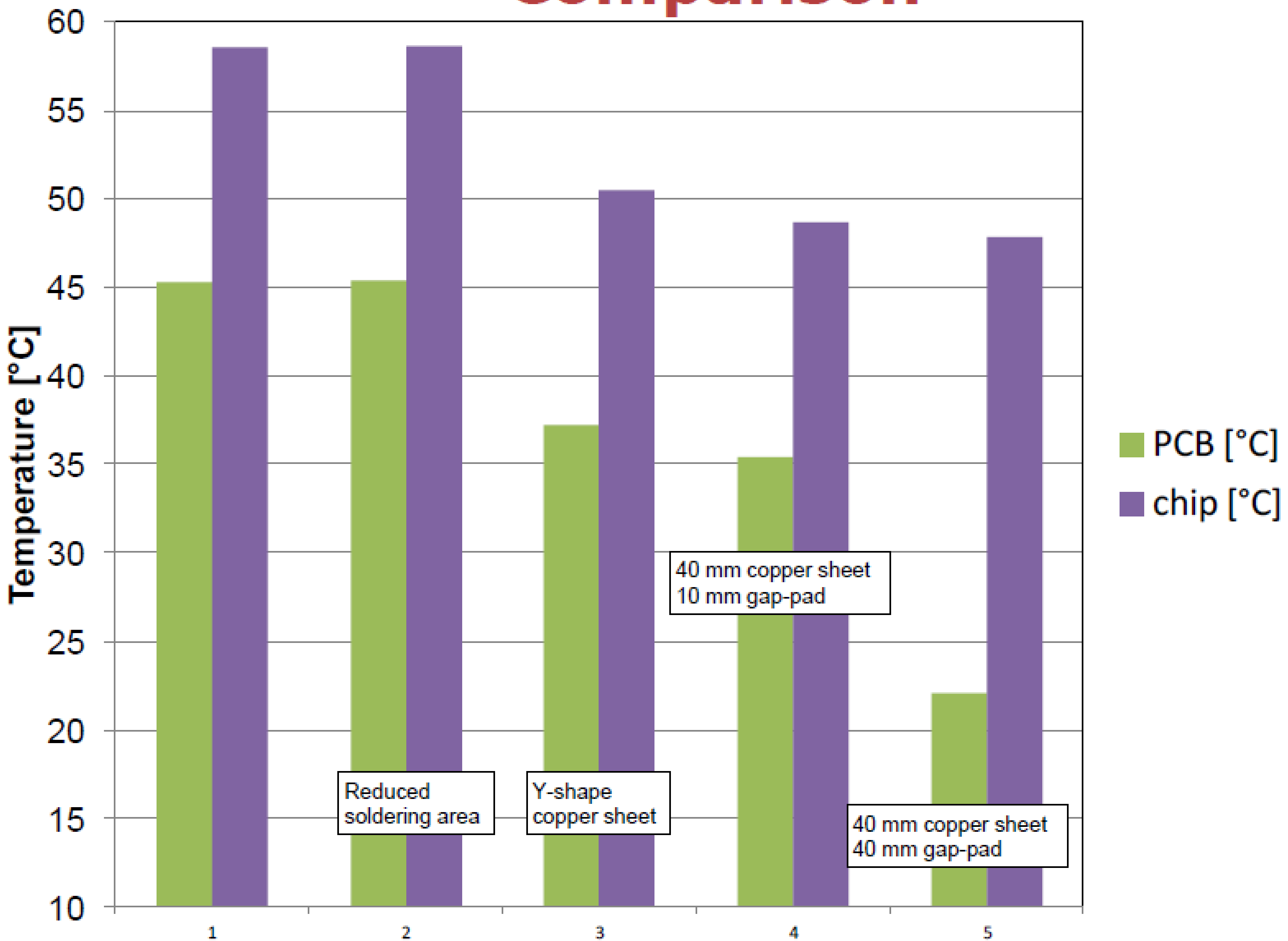


Figure 74: Endcap cooling system, main manifolds.

Comparison

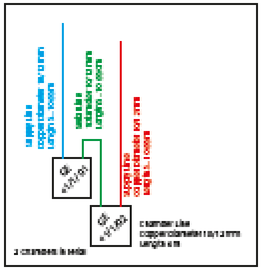

60
55
50
45
40
35
30
25
20
15
10
Temperature [°C]
1
2
3
4
5
PCB [°C]
chip [°C]
Reduced soldering area
Y-shape copper sheet
40 mm copper sheet 10 mm gap-pad
40 mm copper sheet 40 mm gap-pad

DOCUMENTATION AND DB FOR SERVICES:

The **GEM Project** interfacing with the **Detector Water Cooling** System

SB 2011 08 18 - DRAFT a.00 - EDMS XXXXXX

System Summary



Detector Water Cooling System

System Coordinator FRANK Norbert PH/CMX 162618

GEM Project

Project Cooling Coordinator SHARMA Archana PH/CMX 164875

MATERIAL AND DIMENSIONS ARE GIVEN AS EXAMPLE

PLEASE UPDATE THE DOCUMENT WITH EXISTING CARACTERISTICS OR NEW DESIGN SPECIFICATIONS

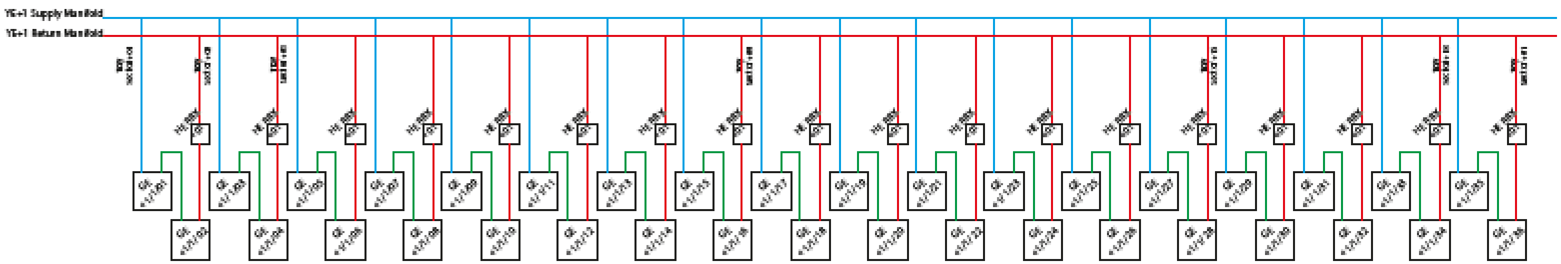
System Description

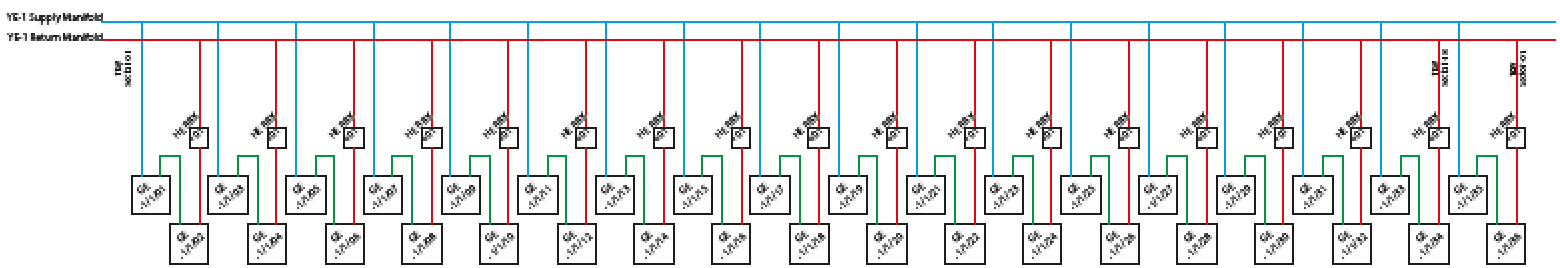
Product

72 x GEM 1/1 Chamber
36 x HE Readout Box

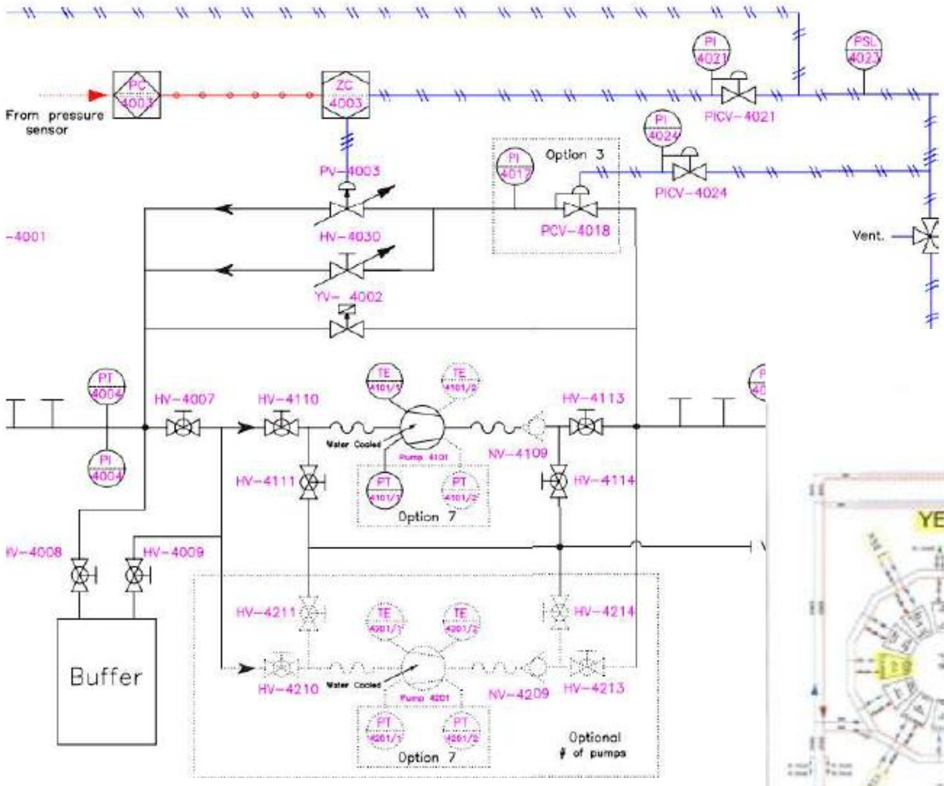
36 x Supply Radial Tube
36 x Return Supply Tube
36 x Serial Hose

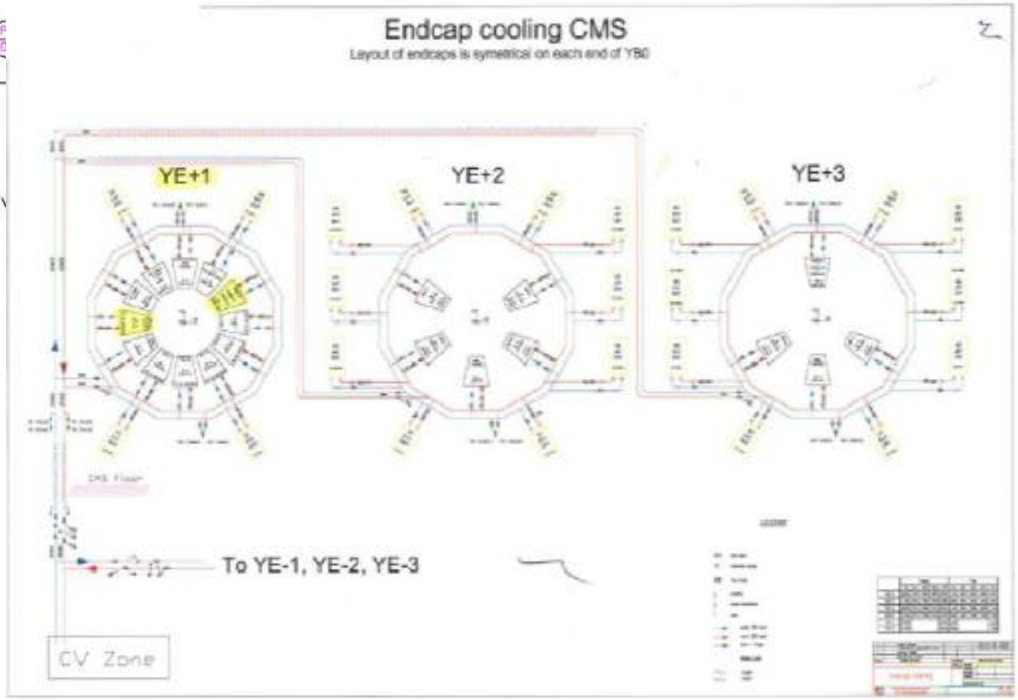
2 x Supply Manifold
2 x Return Manifo





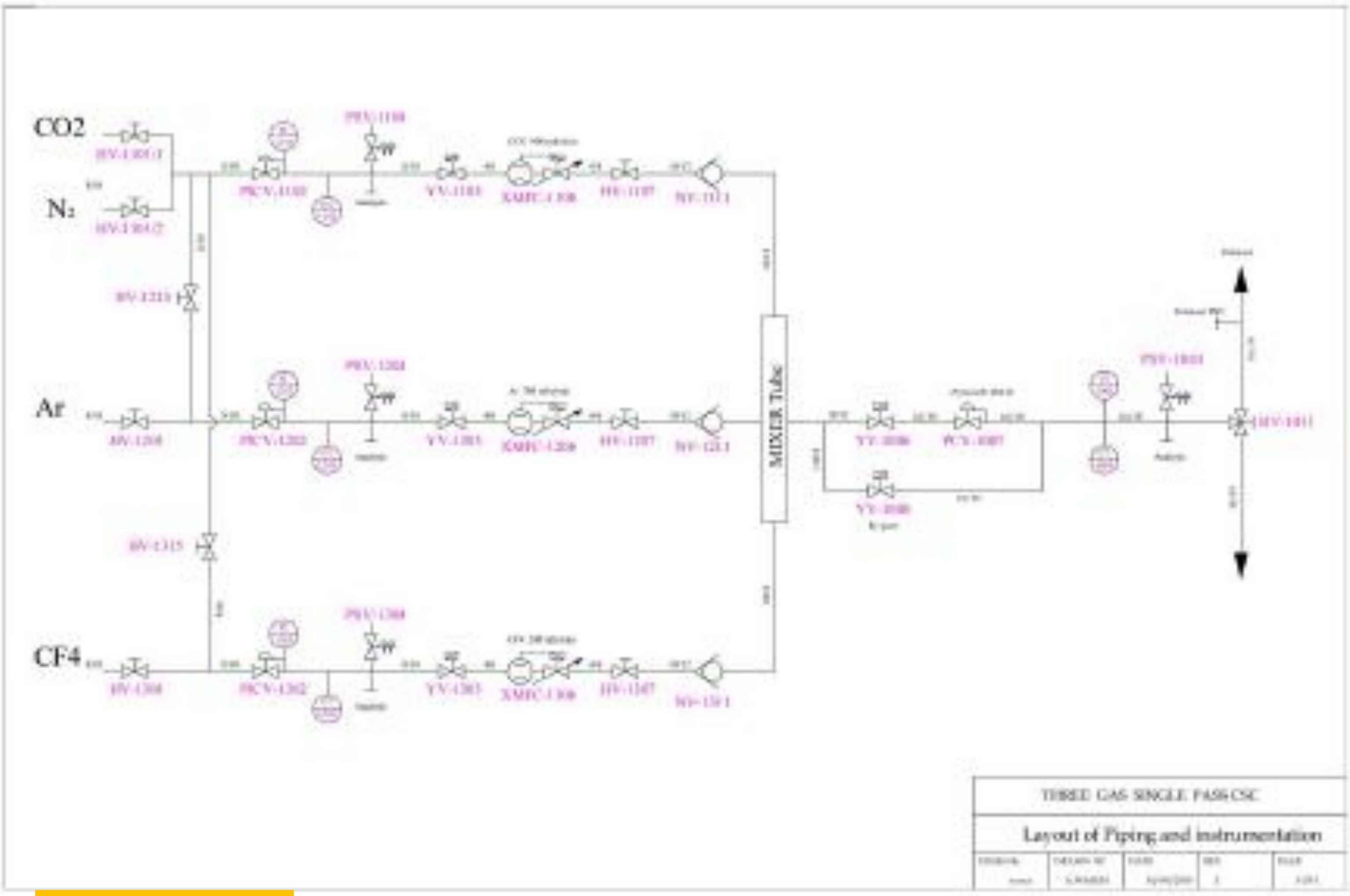
Cooling study and installation





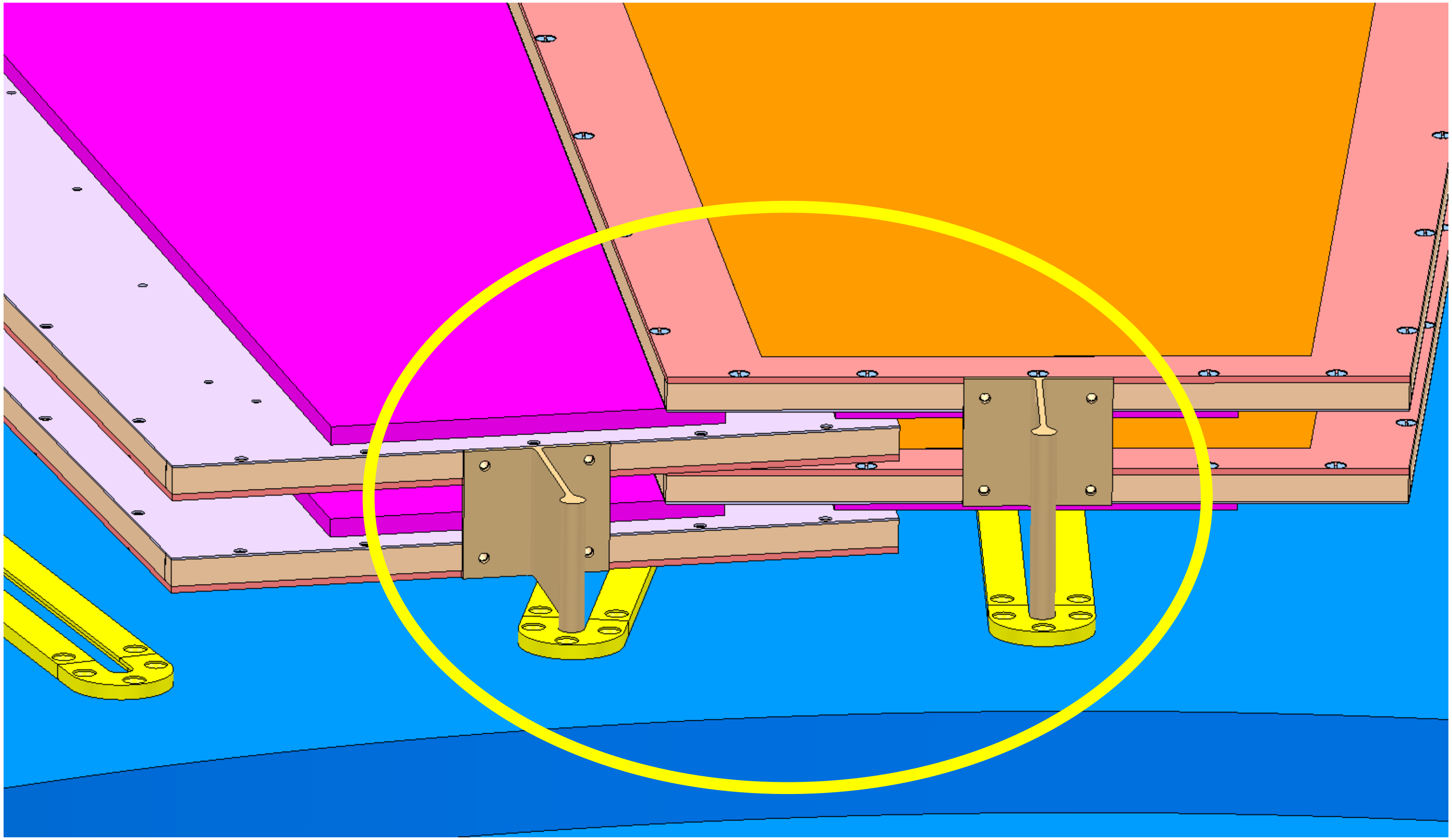
P. Tropea

Gas Installation and distribution studied by DT-gas group



R. Guida

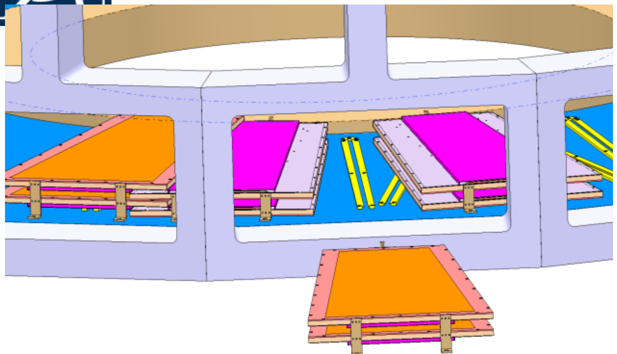
CMS Integration studies



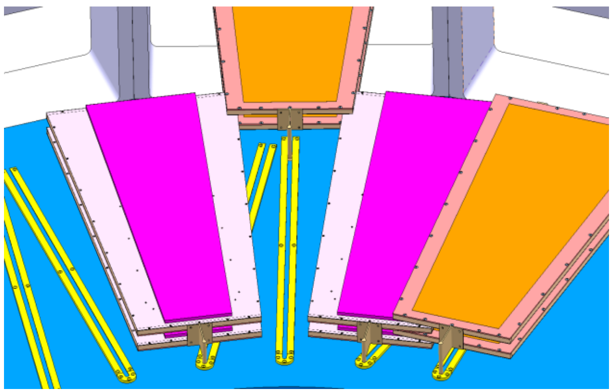
According to the integration studies there is enough space to insert a sandwich of two Triple-GEM detectors (Super-Chamber)

A. Conde Garcia

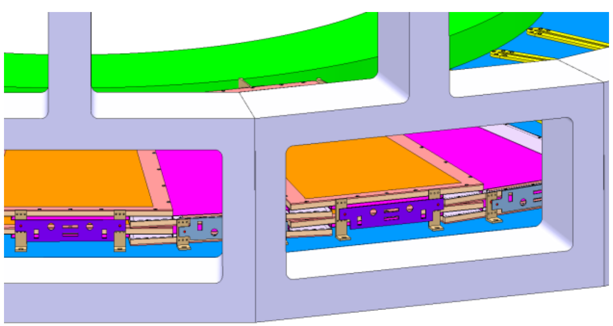
CMS Installation studies



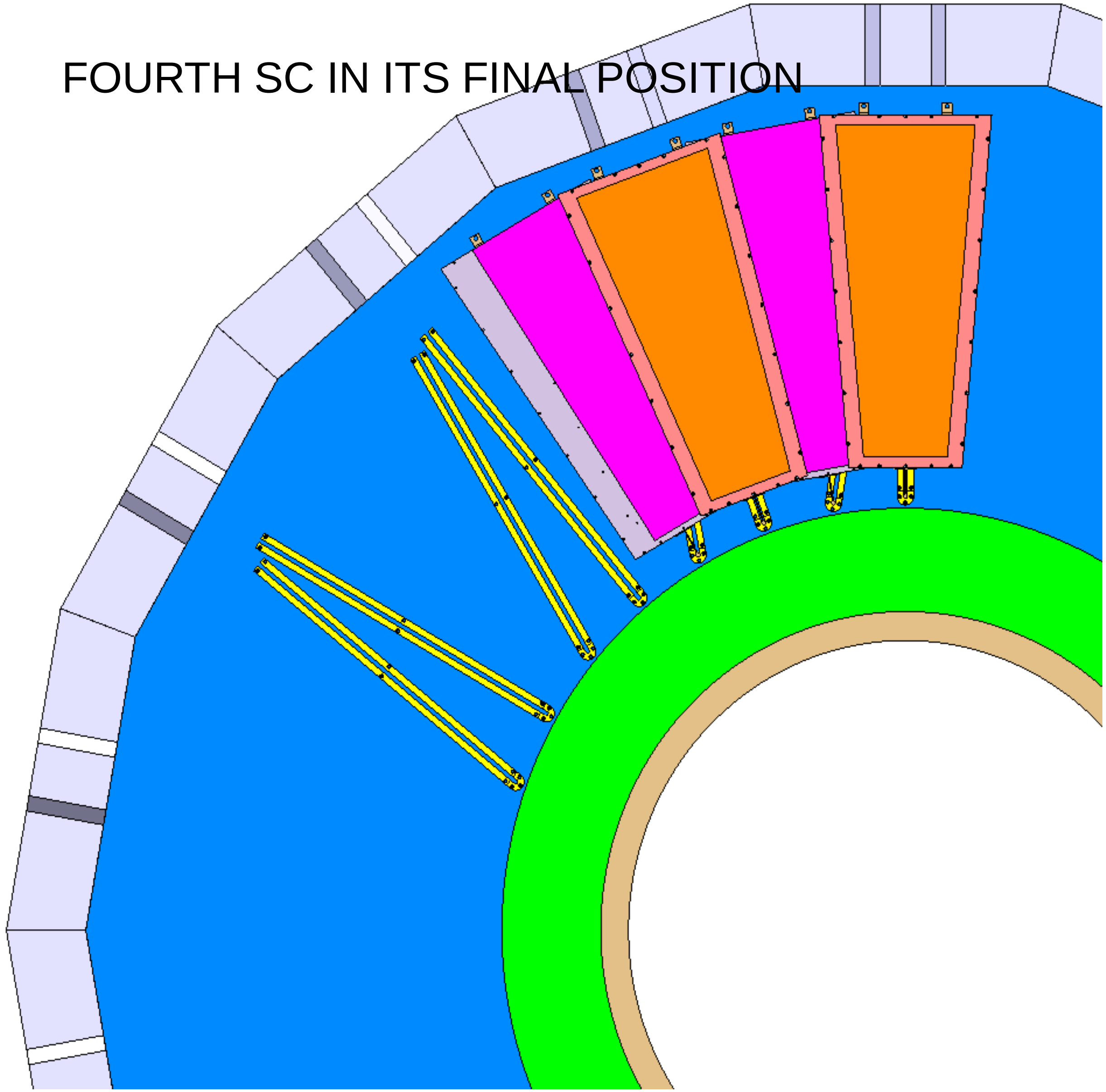
FOURTH SC TO ENTER



FOURTH SC ENTERING



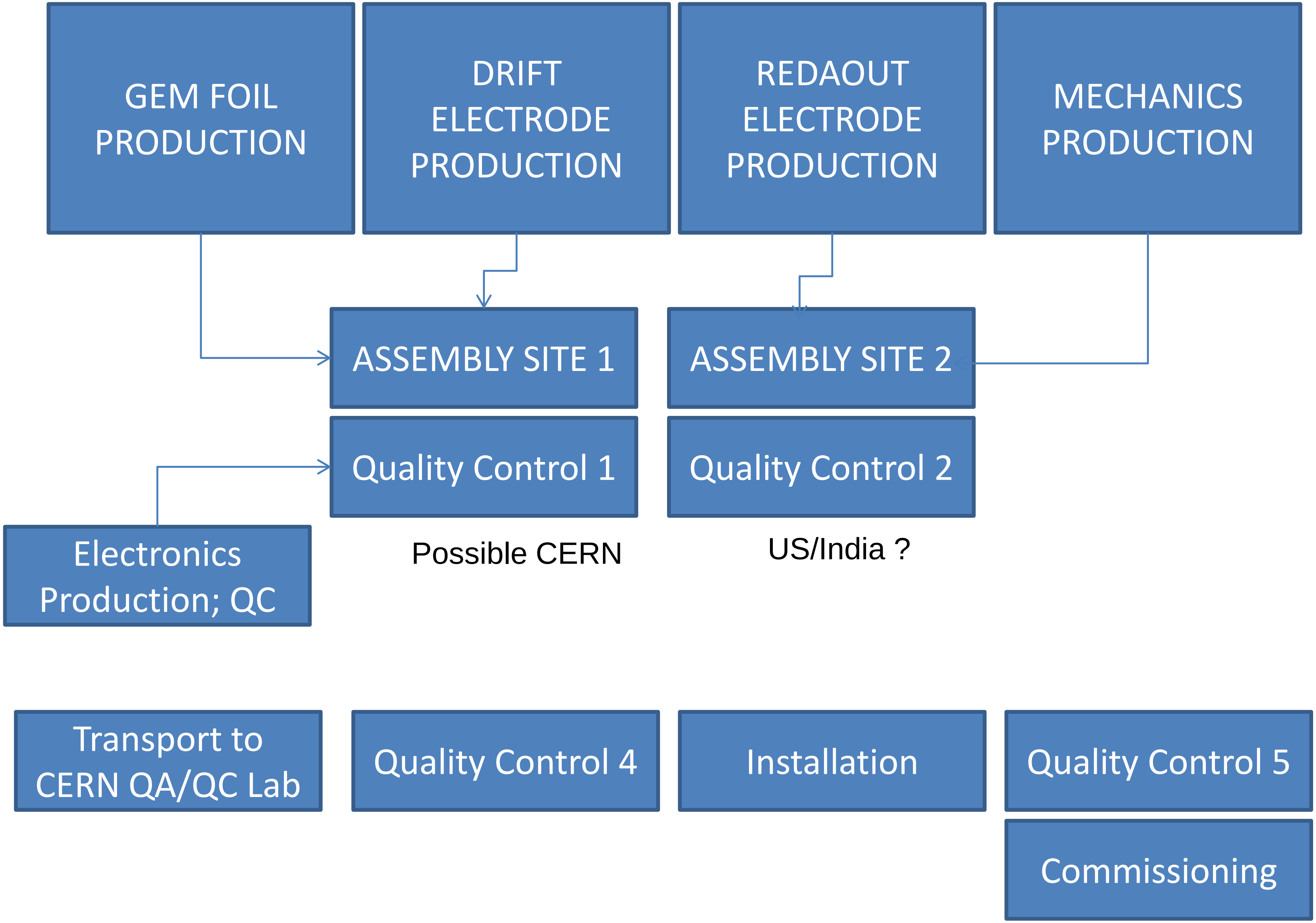
SCs PATCH PANELS



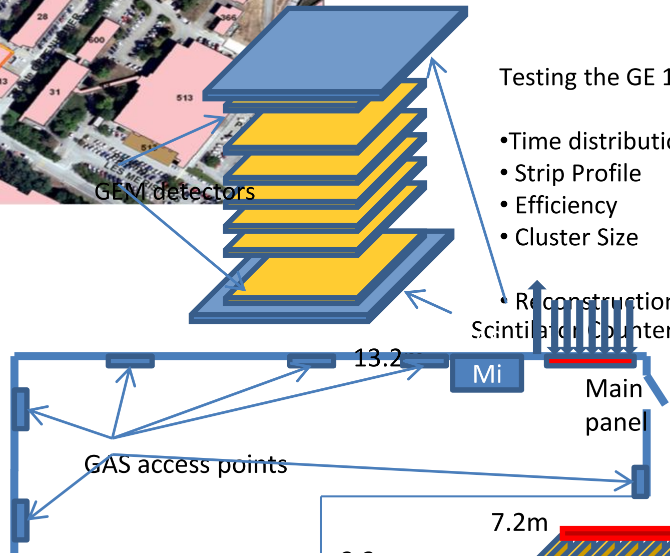
FOURTH SC IN ITS FINAL POSITION

Towards Construction

Process Flow (Draft)

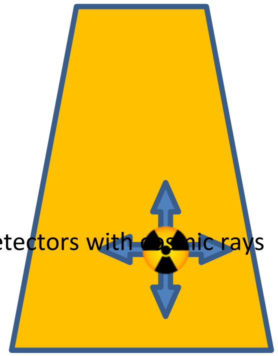


PRODUCTION QC – 186 - TIF



Testing the GE 1/1 detectors with cosmic rays

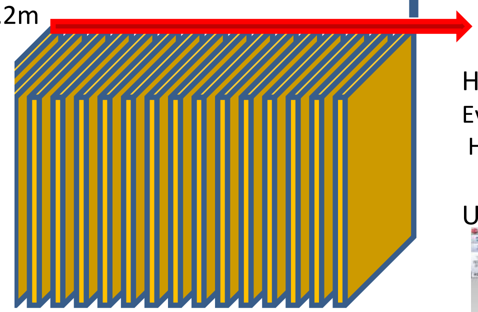
- Time distribution
- Strip Profile
- Efficiency
- Cluster Size
- Reconstruction of the tracks



Gain Calibration of the

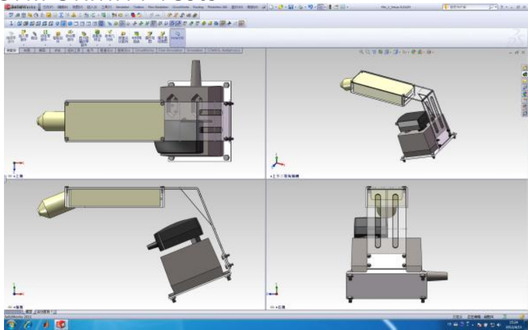
Precise Uniformity Scan

GAS Return

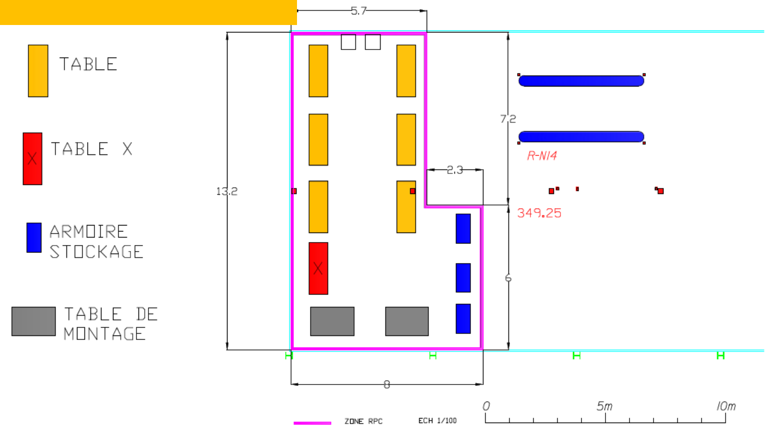


HV Supply
Every detector is on independent HV channel

UNIFORMITY Tests



JP Chatelain
A. Marinov

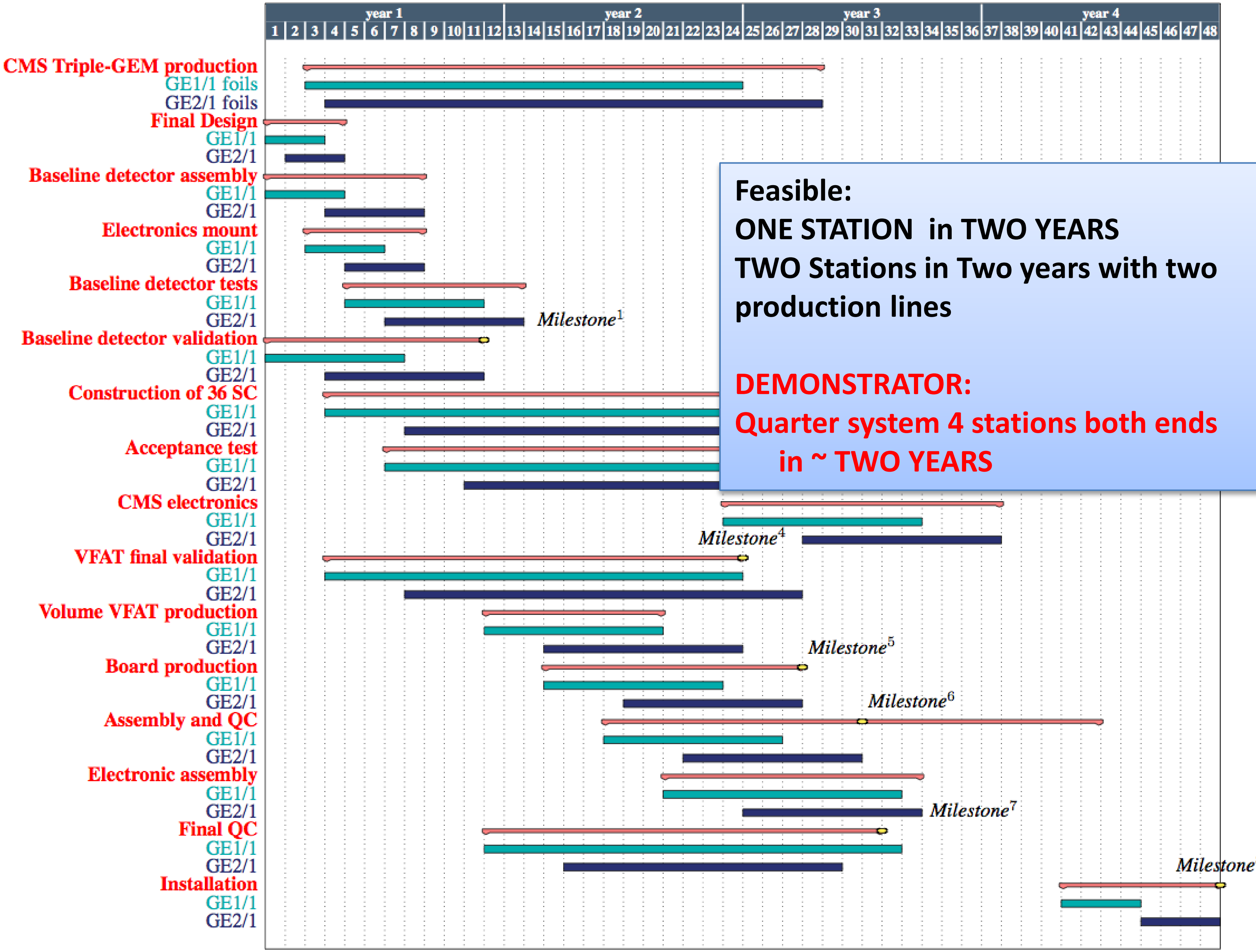


Fully monitored environment
T, H and Atmospheric pressure continuously recorded

GAS Supply

Roadmap

Construction Schedule



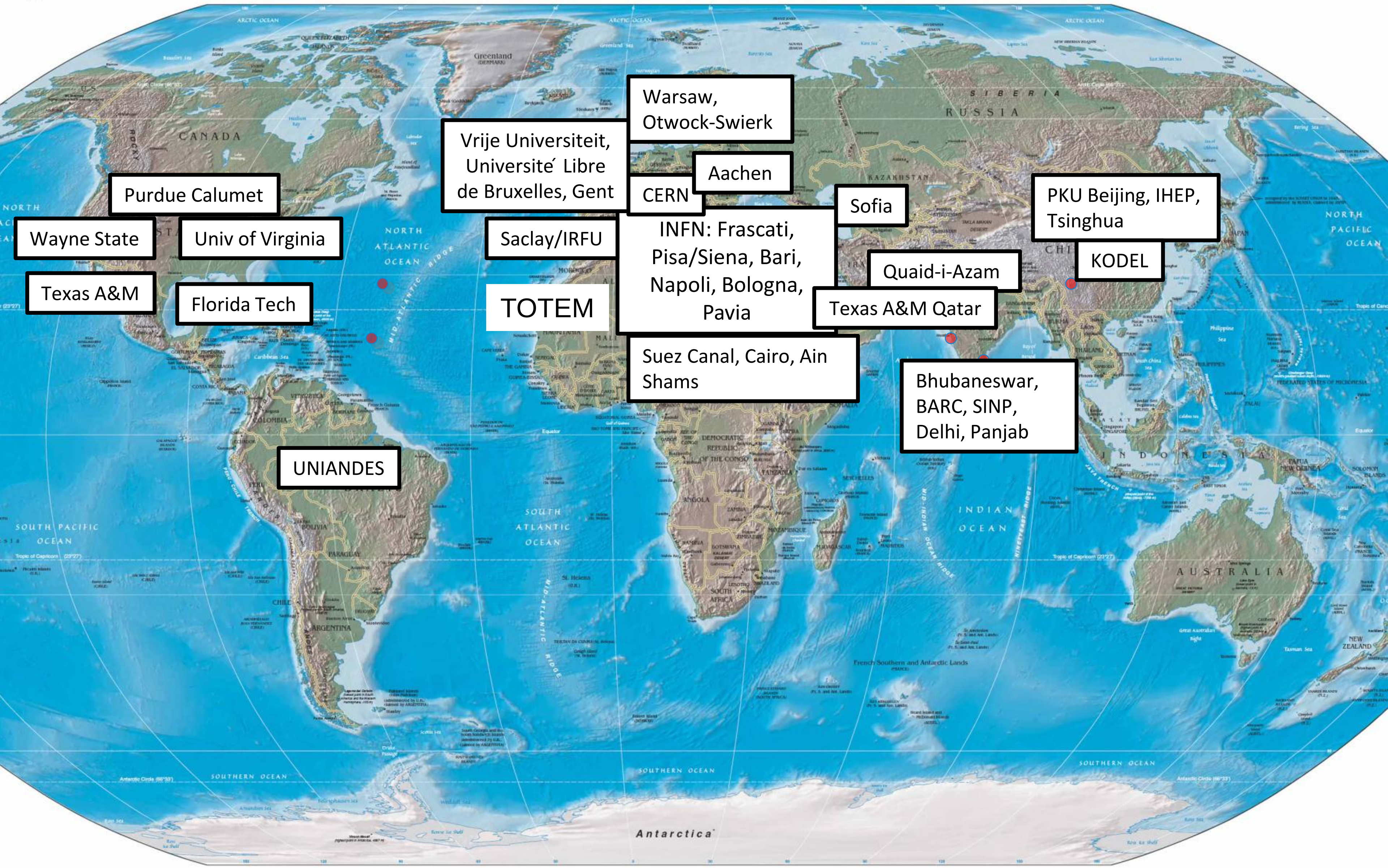
Feasible:
ONE STATION in TWO YEARS
TWO Stations in Two years with two production lines

DEMONSTRATOR:
Quarter system 4 stations both ends in ~ TWO YEARS

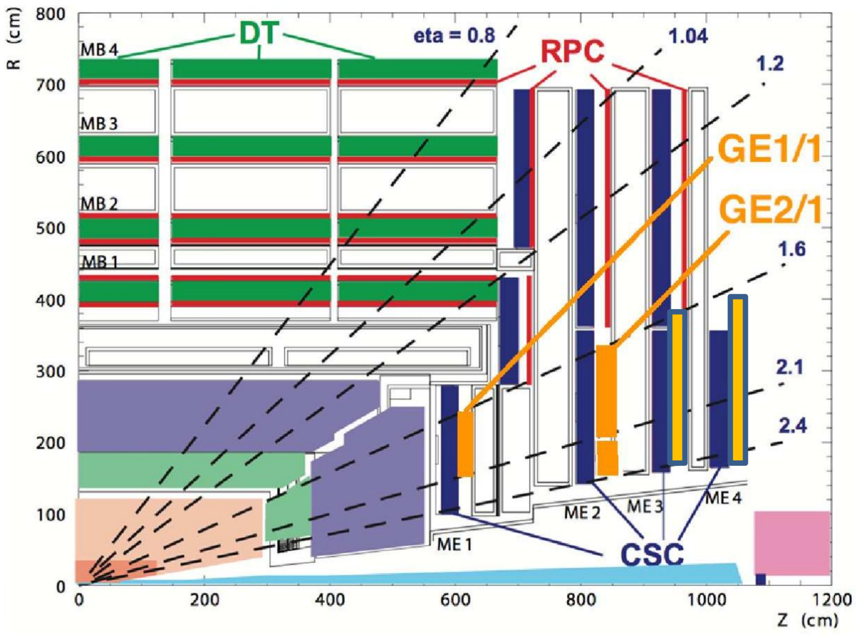
Collaboration

Collaboration

181 collaborators, 36 institutions, 14 countries



Demonstrator Feasible: A quarter of all four stations



18 GE1/1; 9GE2/1; 9 GE3/1; 9 GE3/21
Complete Services
Will be able to demonstrate
All aspects of operation
Ready For LS2

TASK SHARING – Draft
Subject to approval

	Surface treatment Workshop	Chamber Components, QC, Validation	Front-end & off-detector electronics	Chamber Cosmic Test QC	System construction, Detector assembly, QC tests	Physics studies	Students	DQM	RPC Trigger DAQ	Trigger Electronics	Lab and beam test	detector and trigger simulations	data analysis	Detector installation / commissioning	Integration with CMSSW	HV and LV electronics	Database
CERN, Geneva, Switzerland.	X	X	X	X	X	X	X										
Politecnico di Bari, Universita` di Bari, and INFN Sezione di Bari, Bari, Italy.			X		X	X	X										
Universidad de los Andes (UNIANDES), Bogota`, Colombia.					X			X									
National Center for Physics, Quaid-i-Azam University Campus, Islamabad, Pakistan.					X												
Suez Canal University, Suez, Egypt.					X												
Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Poland.									X	X							
Universita' di Siena and INFN Sezione di Pisa, Pisa, Italy.			X							X							
Peking University, Beijing, China.		X			X		X				X	X	X	X			
Saha Institute of Nuclear Physics (SINP), Kolkata, India.					X						X				X		
Laboratori Nazionali di Frascati (LNF) INFN, Frascati, Italy.					X												
Universita` di Bologna and INFN sezione di Bologna, Italy.					X	X		X					X				
Department of Physics, Panjab University Chandigarh, India.					X	X		X					X				
Bhabha Atomic Research Center (BARC), Mumbai, India.					X	X		X					X				
National Centre for Nuclear Research, Otwock-Swierk, Poland.								X		X							
Texas A&M University at Qatar, Doha, Qatar.					X							X					
INFN, Sezione di Napoli, Napoli, Italy.			X							X						X	
CEA Saclay/IRFU, Saclay, France.			X														
Department of Physics and Astronomy, Ghent University, Gent, Belgium.		X			X									X			
University of Sofia, Sofia, Bulgaria.		X				X											X
Vrije Universiteit Brussel, Brussel, Belgium.			X						X					X			
Florida Institute of Technology, Melbourne, USA.		X			X								X	X			
University of Virginia, Department of Physics, Charlottesville, USA.			X														
Cairo University, Cairo, Egypt.		X				X	X					X		X			
Purdue University Calumet, Hammond, USA.		X			X				X		X		X				
Wayne State University, Detroit, USA.			X														
Texas A&M University, Department of Physics and Astronomy, College Station, Texas, USA.			X						X			X		X			
RWTH Aachen, III. Physics Institute, Aachen, Germany.		X			X	X								X			
Institute of High Energy Physics, China.		X			X									X			
University of Pavia and INFN Pavia, Pavia, Italy.		X			X									X			
Universite ´ Libre de Bruxelles, Bruxelles, Belgium.			X					X	X								
NISER, Bhubaneswar, India.					X									X			
KODEL, Korea University, Seoul, South Korea.		X			X												
Ain Shams University, Cairo, Egypt.					X									X			
Department of Physics, University of Delhi, India.					X									X			
The Engineering Physics Dept, Tsinghua University, China.					X									X			

Summary and Outlook

Scope: instrument the vacant high-η region with detectors suitable for high rate, capable of tracking and trigger

High rate, rad hard triple-GEM technology developed and demonstrated for large area detectors

Possible due to optimising resources and expertise available at CERN and in the collaborating Institutions
RD51 ; CERN TE-MPE-EM Workshop; Electronics Group

Improvements in muon tracking and trigger promising

- Substantial increase in the acceptance
- Redundancy and robustness in high eta
- Trigger and physics groups getting involved

Electronics development underway

Integration and services in CMS studied

Project technically feasible for LS2

- Technical Proposal
  https://twiki.cern.ch/twiki/pub/MPGD/CmsGEMCollaboration/GEM_technical_proposal.pdf

Large participation: currently 36 institutes with 180 collaborators

Organisation of the GEM Collaboration in place, <u>the project is ready to move ahead</u>