HEP Division Seminar, Argonne National Lab, July 24, 2012

GEM Detectors for a CMS Muon Endcap Upgrade & Other Uses

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Florida Institute of Technology
(for the CMS GEM Collaboration)

Overview

- Premise for CMS GEM Upgrade
- Benefits for CMS Muon Physics & Trigger
- Gaseous Detectors at LHC
- Micro-Pattern Gas Detectors & RD51
- Gas Electron Multipliers (GEMs)
  - The Basics
  - Current Uses at LHC
- GEM Detectors for CMS Upgrade
  - Overview
  - Detector R&D
  - GEM foil production
  - GE1/1 production design
  - Electronics design
  - New strip readout
  - Plans, Summary & Conclusions
- "Other Uses:" GEMs for Homeland Security → Muon Tomography

PREMISE & MOTIVATION

Premise for CMS GEM Upgrade

- CMS was designed with a "hermetic and **redundant** muon system" – Joe Incandela, CERN "Higgs Discovery" Event 7/4/12

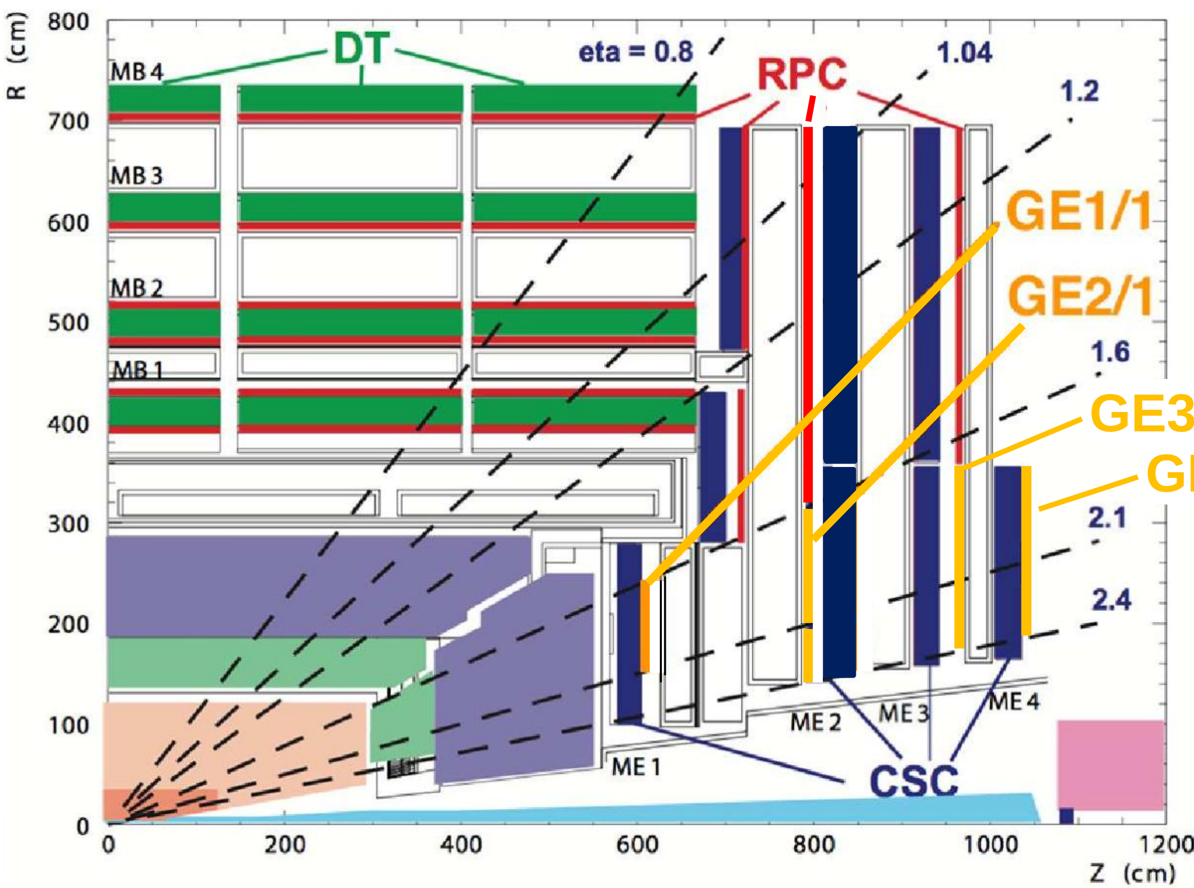
- **But: CMS currently has the least redundancy in the most challenging muon region at |η| > 1.6** (RPCs descoped)

- Long-term functioning of the muon system into LHC Phase II (beyond Long Shutdown 3) is of vital interest for C**M**S
- The **high-η** muon region in particular needs **robust and redundant tracking and triggering** due to higher rates

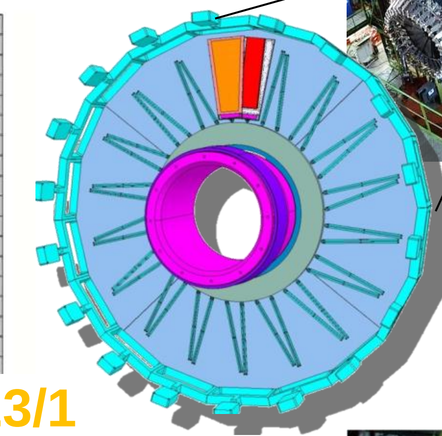
⇒ **Additional muon detectors with high spatial and temporal resolution in the high-η endcap region could bring benefits in muon triggering, reconstruction, and ID**

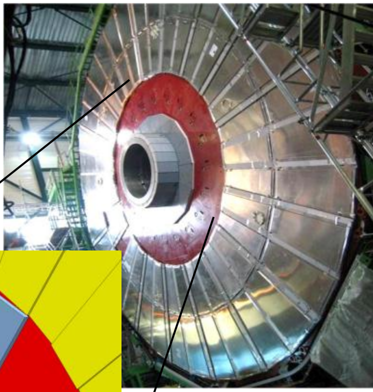
GEM Endcap Chambers

The currently un-instrumented high-η RPC region of the muon endcaps presents an opportunity for instrumentation with a detector technology that could **sustain the radiation environment long-term** and be suitable for operation at the LHC and its future upgrades into Phase II: **GEM Detectors**

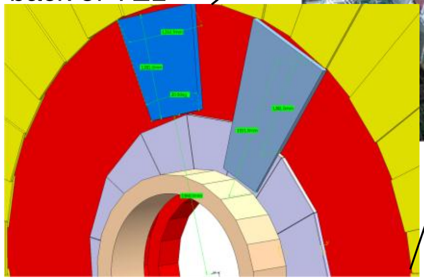


GE1/1 in YE1 nose





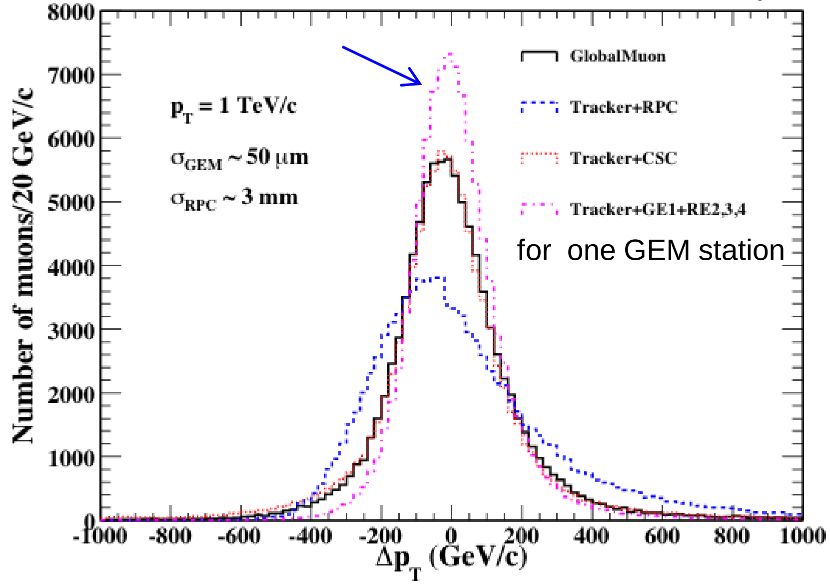
GE2/1 on back of YE1



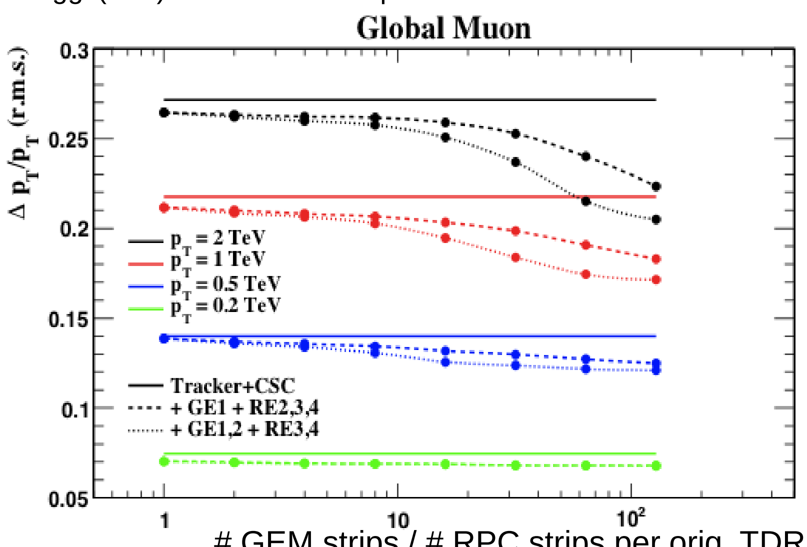
BENEFITS FOR CMS MUON PHYSICS & TRIGGER

Initial Reconstruction & Trigger Studies

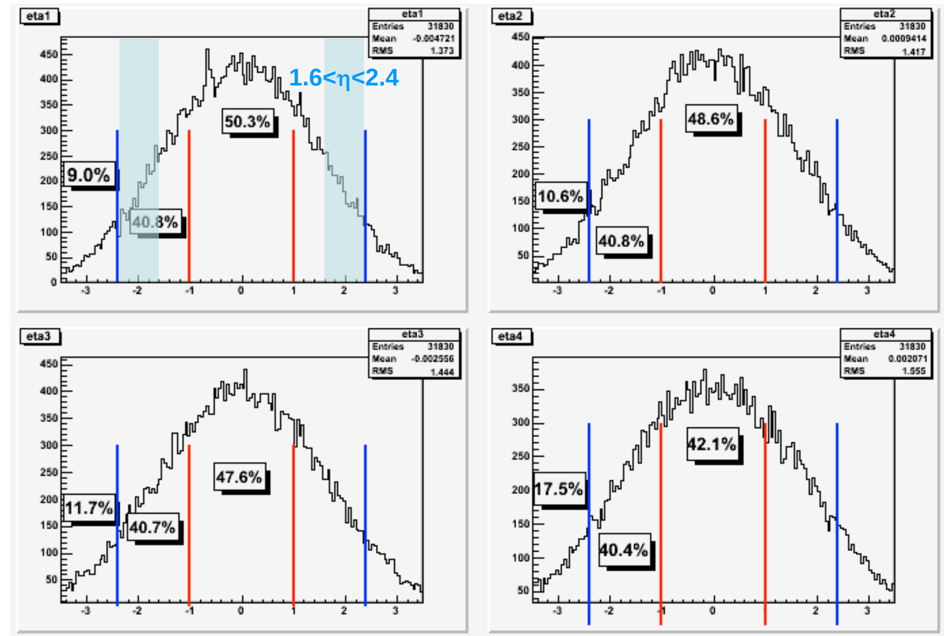
Expected gains in momentum resolution at high-p_T



M. Maggi (Bari) – GEM Workshop 3

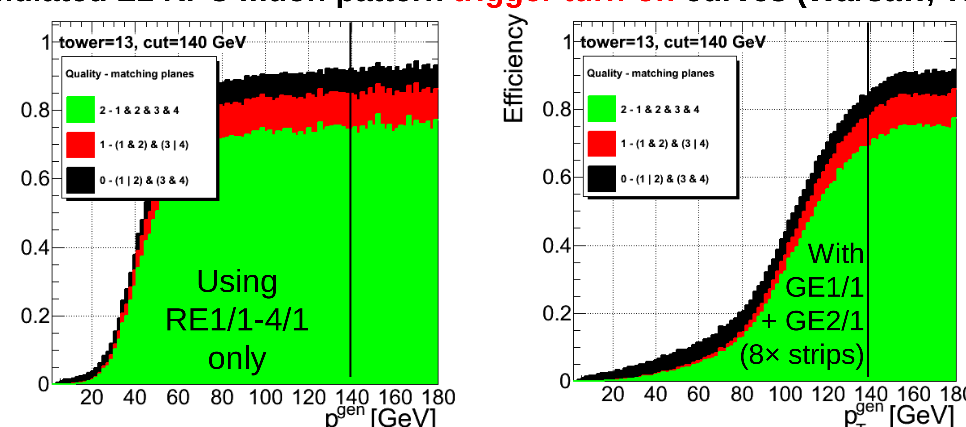


Acceptance impact: η distribution of 4 muons in H → ZZ → 4μ



Paolo Giacomelli (Bologna) & Markus Klute (MIT) – GEM Workshop 3

Simulated L1 RPC muon pattern trigger turn-on curves (Warsaw, TP)

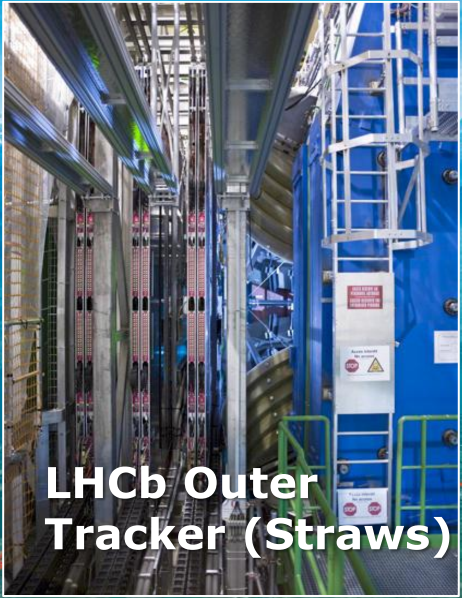


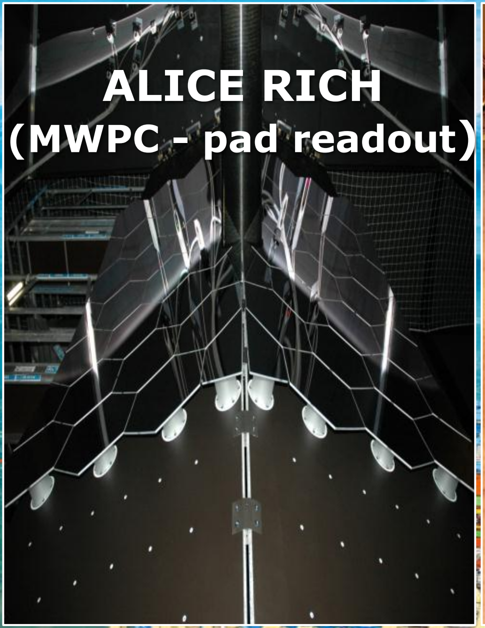
GASEOUS DETECTORS AT THE LHC

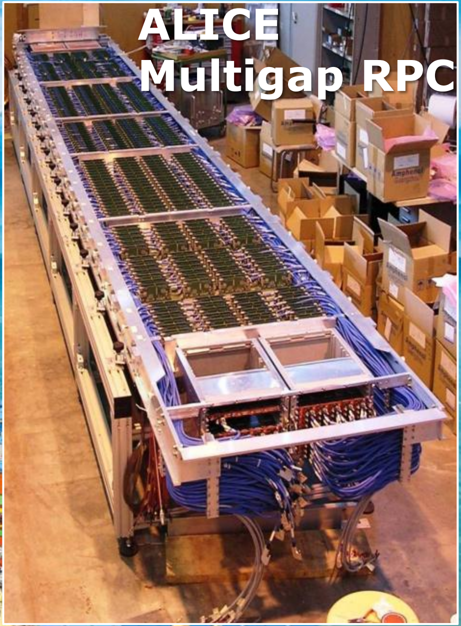
Gaseous Detectors in the current LHC experiments

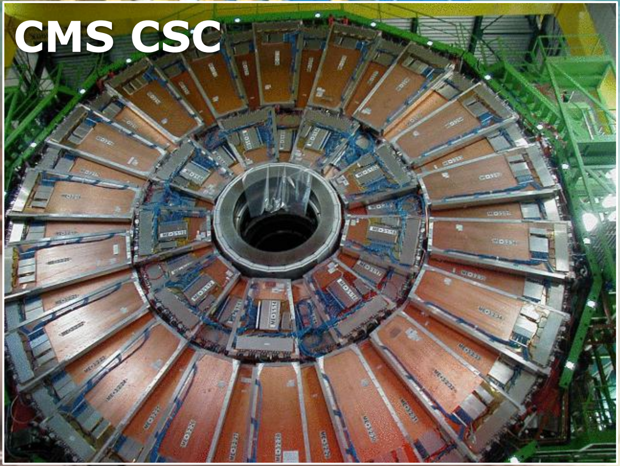
	Vertex	Inner Tracker	PID/ photo-det.	EM CALO	HAD CALO	MUON Track	MUON Trigger
ATLAS	-	TRT (straws)	-	-	-	MDT (drift tubes), CSC	RPC, TGC (thin gap chambers)
CMS	-		-	-	-	Drift Tubes, CSC	RPC, CSC
TOTEM	-	GEM	-	-	-	-	-
LHCb	-	Straw Tubes	-	-	-	MWPC	MWPC, GEM
ALICE	-	TPC (MWPC)	TOF(MRPC), RICH pad chamber, TRD (MWPC)	-	-	Muon pad chambers	RPC

Examples for Gaseous Detectors at the LHC





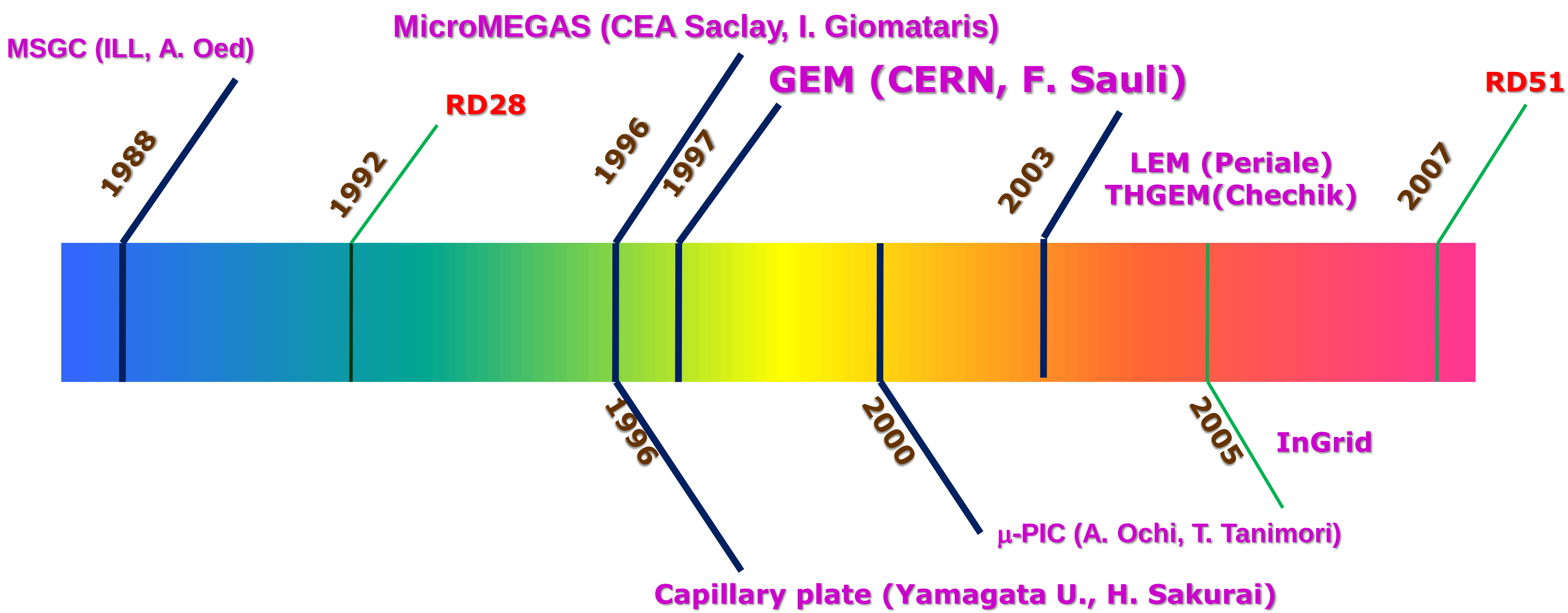




Overview

MICRO PATTERN GAS DETECTORS & RD51

MPGD Development Timeline

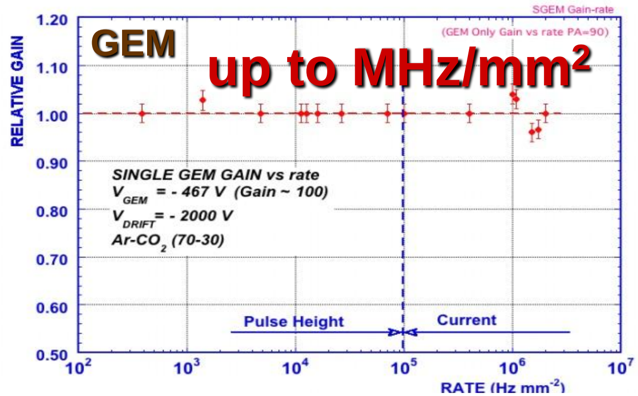


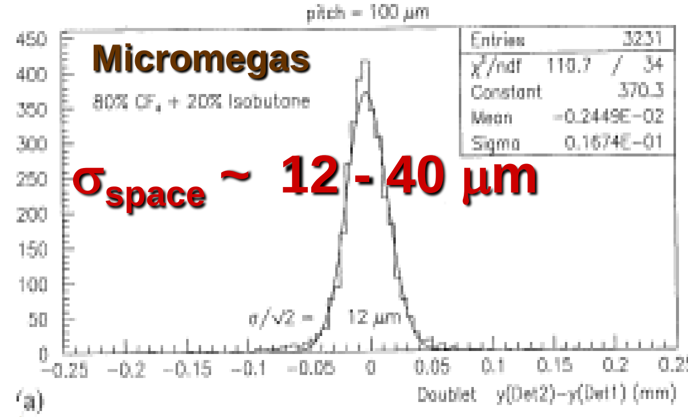
(Many more micro-pattern structures were developed)

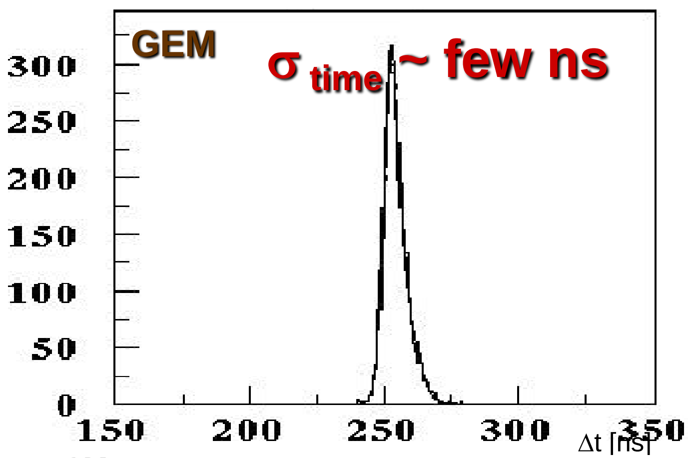
From A.Ochi ADA2012@Kolkata (updated)

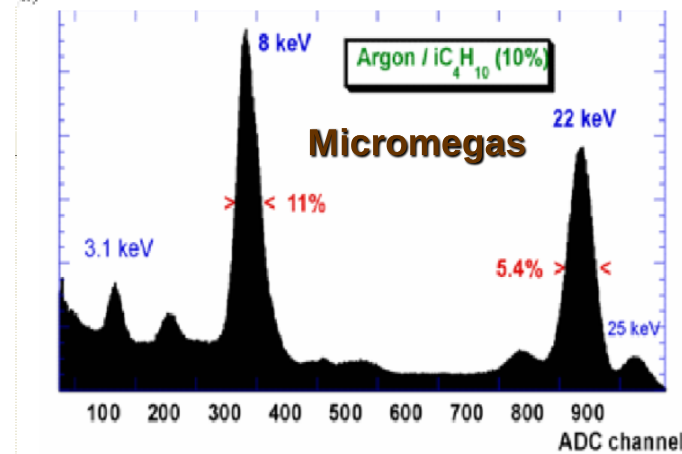
MPGD Performance Overview

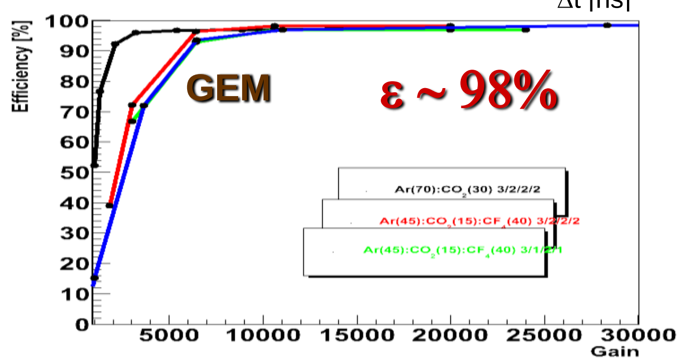
- **High Rate Capability**
- **High Spatial Resolution**
- **Decent Time Resolution**
- **High Efficiency**
- **Excellent Radiation Hardness**
- **High Gain**
- **Good Energy Resolution**
- **Ion Backflow Reduction**

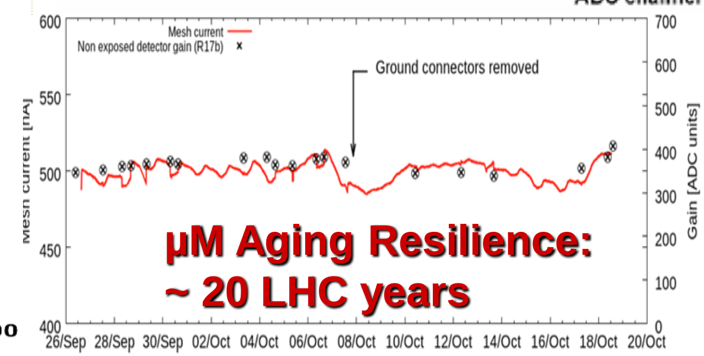












2007: RD51 Collaboration for “Development of MPGD Technologies”

- **80 institutes worldwide**
- **~ 450 people involved**
- **hosted by CERN**
- **Participation from Europe, Asia North/South America, Africa**

Mission: “RD51 aims at facilitating the <u>development of advanced gas-avalanche detector technologies</u> and associated electronic-readout systems, <u>for applications in basic and applied research”</u>

RD51 contributes to the LHC upgrades, BUT <u>the most important is:</u>

- **RD51 serves as an access point for MPGD “know-how” for the world-wide community**

M. Titov (Saclay), CERN Detector Seminar, 4/12

RD51 Working Groups

Consolidation around common projects: Large-area Micromegas, GEM, THGEM R&D; Software Tools; Common Electronics Developments (SRS), CERN/MPGD production facility, Industrialization, RD51 test beam facility

	WG1 MPGD Technology & New Structures	WG2 Characterization	WG3 Applications	WG4 Software & Simulation	WG5 Electronics	WG6 Production	WG7 Common Test Facilities
Objectives	Design optimization Development of new geometries and techniques	Common test standards Characterization and understanding of physical phenomena in MPGD	Evaluation and optimization for specific applications	Development of common software and documentation for MPGD simulations	Readout electronics optimization and integration with MPGD detectors	Development of cost-effective technologies and industrialization	Sharing of common infrastructure for detector characterization
Tasks	Large Area MPGDs Design Optimization New Geometries Fabrication Development of Rad-Hard Detectors Development of Portable Detectors	Common Test Standards Discharge Protection Ageing & Radiation Hardness Charging up and Rate Capability Study of Avalanche Statistics	Tracking and Triggering Photon Detection Calorimetry Cryogenic Detectors X-Ray and Neutron Imaging Astroparticle Physics Appl. Medical Applications Synchrotron Rad. Plasma Diagn. Homeland Sec.	Algorithms Simulation Improvements Common Platform (Root, Geant4) Electronics Modeling	FE electronics requirements definition General Purpose Pixel Chip Large Area Systems with Pixel Readout Portable Multi-Channel System Discharge Protection Strategies	Common Production Facility Industrialization Collaboration with Industrial Partners	Testbeam Facility Irradiation Facility

= most relevant for CMS GEMs

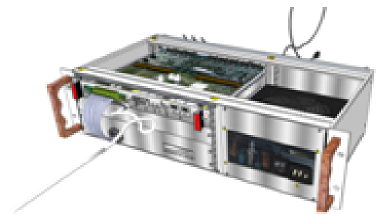
http://rd51-public.web.cern.ch/RD51-Public

M. Titov (Saclay), CERN Detector Seminar, 4/12

Scalable Readout System

CERN experiments

- ATLAS CSC upgrade MMegas (8kch APV-SRS systems, 1st SRS testbeams, MMDAQ developer)
- ATLAS CSC upgrade MMegas, (VMM1 readout chip developer, SRS Adapter by Arizona Univ, MMDAQ)
- ALICE EMCaL + FOCAL, SRU-based backend (50 kHz upgrade via SRS, DATE, new: Focal readout via SRS-Beetle ?)
- ALICE TPC upgrade, SRS readout electronics with DATE backend ?
- NA62 ref. tracker with Micro-Megas (1kCH-SRS Minicrate, MMDAQ)
- CMS high Eta (VFAT hybrid and VFAT SRS adapter, in prep.) ←
- Totem upgrade R&D , SRS VFAT readout, DATE ?



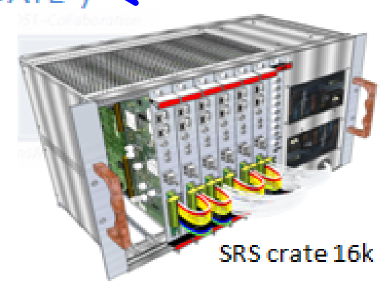
SRS Minicrate up 4k ch.

HEP experiments

- NEXT Coll., dual Beta decay, SiPM, PM (Collaboration on SRS HW & FW, FEC cards, DATE)
- BNL GEM detector readout (2kCH. APV Minicrate, PHENIX SRDAQ porting to SRS)
- Jeff. Lab Virginia Univ. GEM prototyping, (Minicrate , Offline Data evaluation via AMORE + DATE)

Applications with Cosmic Tomography

- FIT Florida, Muon **Tomography** for homeland security, GEMs (1st 16K SRS application, DATE) ←
- Geoscienes CRNS- Waterquality in Rocks, MMegas (5kCh SRS Crate , DATE , Labview)



SRS crate 16k ch.

R&D with MPGD's (small systems)

- Bonn/Mainz Univ, Timepix readout (SRS- Timepix adapter card)
- Helsinki HIP, GEM-MMega (SRS evaluation, Trigger pickup box via CSP)
- MEXICO UNAM, THGEM 2x (SRS Minicrate, DATE)
- C.E. Saclay, Micromegas (2k Ch SRS Minicrate , MMDAQ)
- WIS Israel, THGEM 3x (Minicrate, Beetle hybrid, SRS- Labview Beta tester
- INFN Naples (Minicrate, Labview for SRS developer, CTF card , Zero-supression code

Teams waiting for commercial SRS delivey via CERN store)

- RD51 lab, Radcore, WIS, USTC, SAHA, INFN Bari, INFN Napoles, Stony Brook, Freiburg Univ
- Yale Univ, J-Parc-RIKEN, East Carol. Univ., Jeff-Lab, Tsinghua Univ, Univ Texas,

4/2012

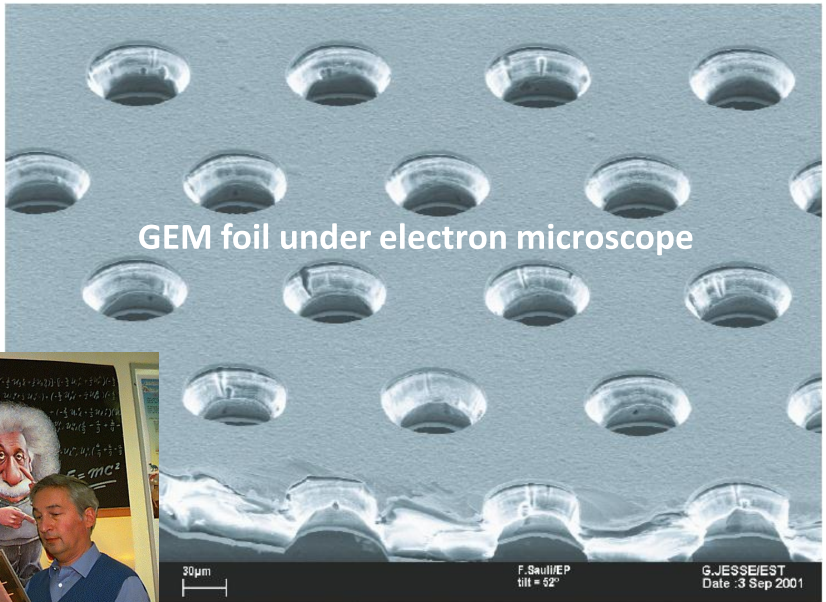
*** in red: SRS developers in green: to be confirmed in blue: USER**

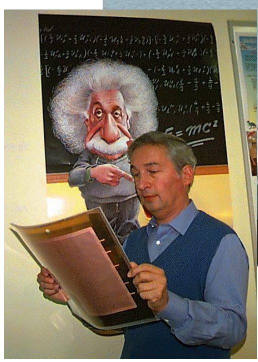
H.Muller CERN PH, 2012

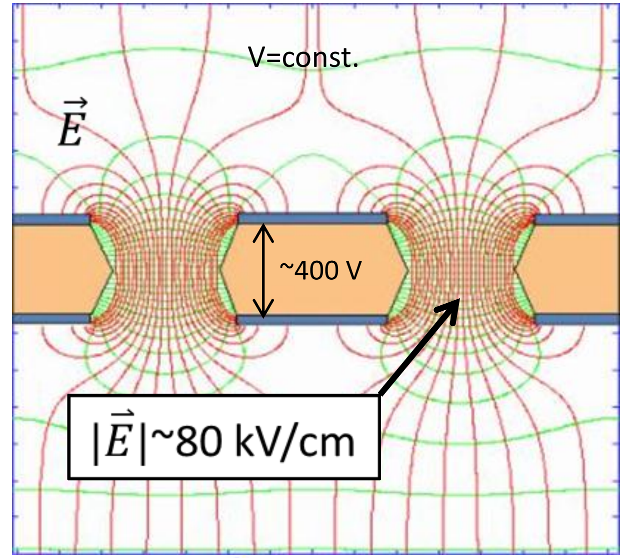
GEM BASICS

Gas Electron Multiplier

GEM detector is a Micro Pattern Gaseous Detector (MPGD)

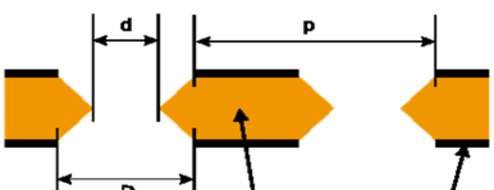


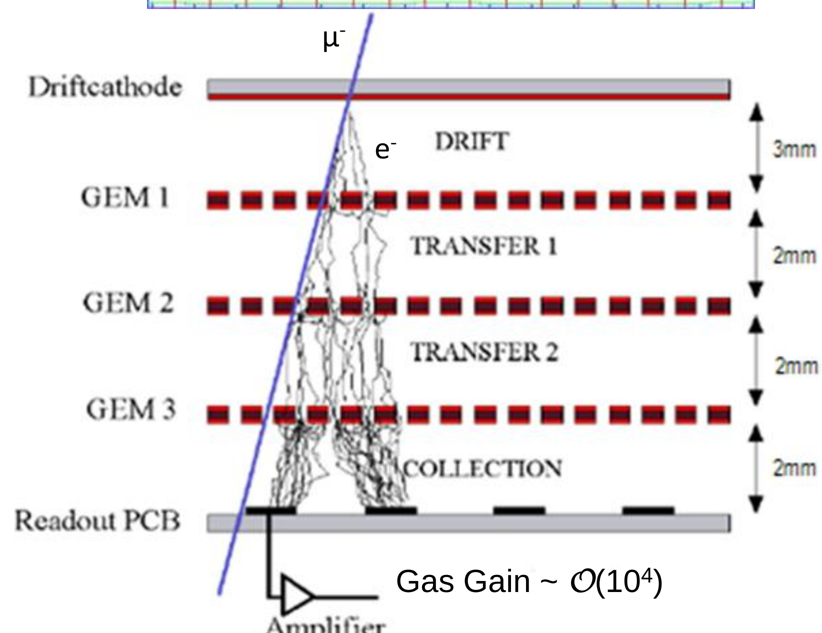




$$D = 70\ \mu\mathrm{m}$$
$$d = 60\ \mu\mathrm{m}$$
$$p = 140\ \mu\mathrm{m}$$

Handout !





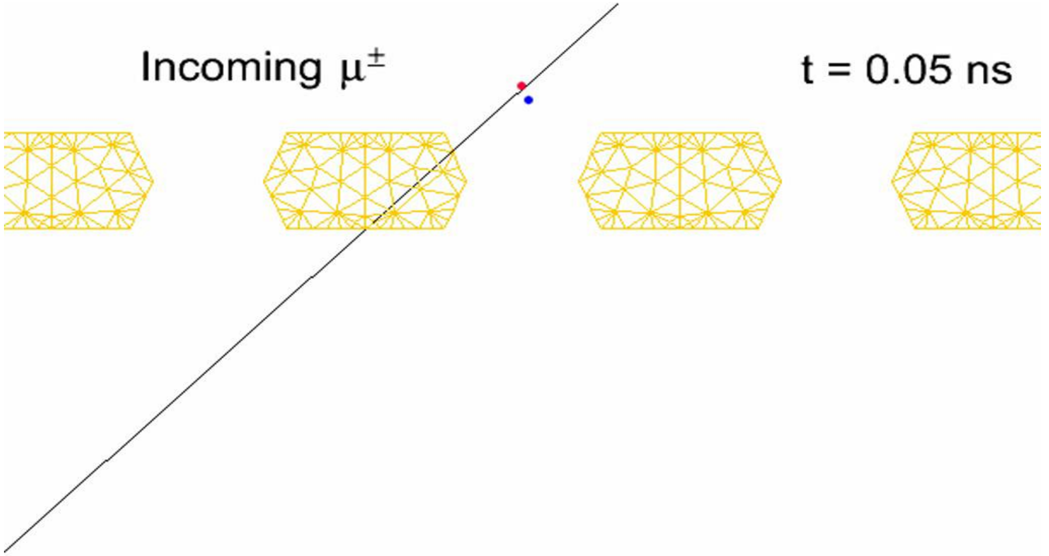
Gas Gain ~ $\mathcal{O}(10^4)$

F. Sauli, NIM A 386 (1997) 531-534.
M.C Altunbas, et al., NIM A 515 (2003) 249-254.

Electron Multiplication

- Animation of the avalanche process (electrons are blue, ions are red, the GEM is orange)
- Simulation → keep track of electron and ion drifting and ion losses at the upper GEM electrode

A voltage of ≈ 400V is applied between the two GEM electrodes. The primary electrons created by the ionizing particle drift towards the GEM holes where the high electric field triggers the electron multiplication process.



Objective: Understanding the gain in standard GEM

- **ANSYS: model & mesh the GEM**
- **Magboltz 8.9.6: relevant cross sections of electron-gas interactions**
- **Garfield++: simulate e^- avalanches**

Courtesy: Sven Dildick, Heinrich Schindler, Rob Veenhof

- Single electron-ion pair created
- Ar/CO_2 70:30

- E_{drift} = 1 kV/cm (above GEM)
- E_{induc} = 3 kV/cm (below GEM)
- V_{GEM} = 400 V (across GEM)

Developed within the framework of the RD51 WG4 Software Activities

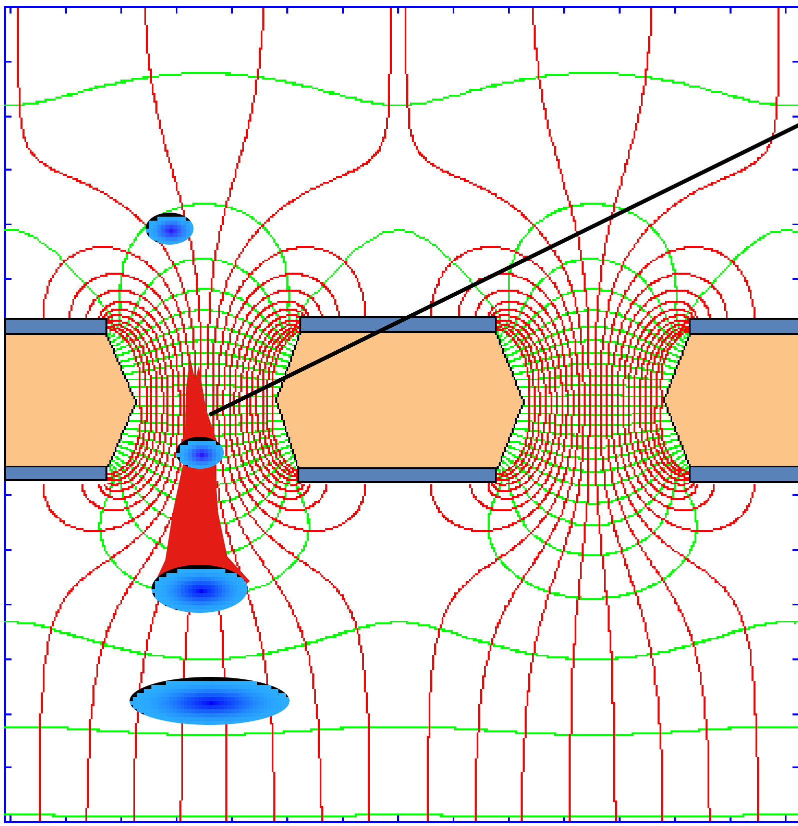
http://garfieldpp.web.cern.ch/garfieldpp/examples/gemgain

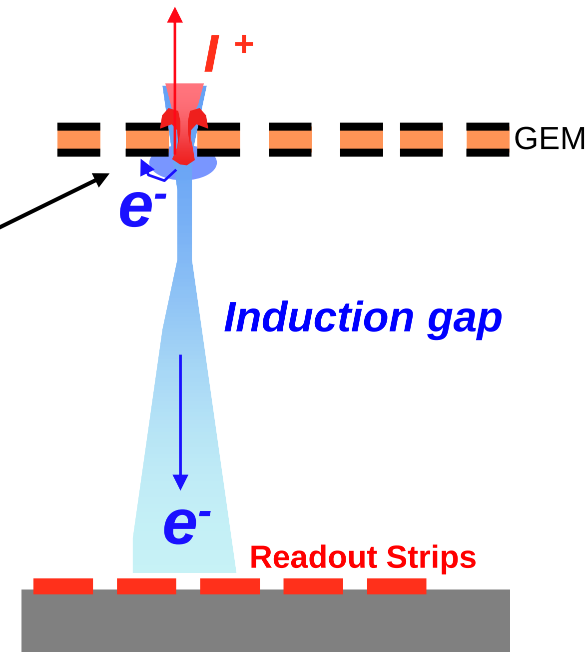
M. Titov (Saclay), CERN Detector Seminar, 4/12

Fast Signal Induction

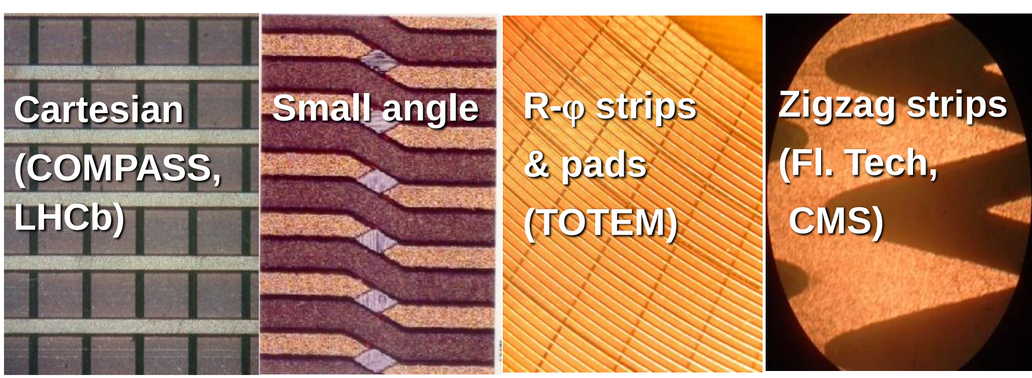
A fast signal is induced only by e⁻ on the lower readout electrode. Readout electrodes are at ground potential.

Full decoupling of amplification stage (GEM) and readout stage (PCB anode strips or pads)





Readout Strip Designs

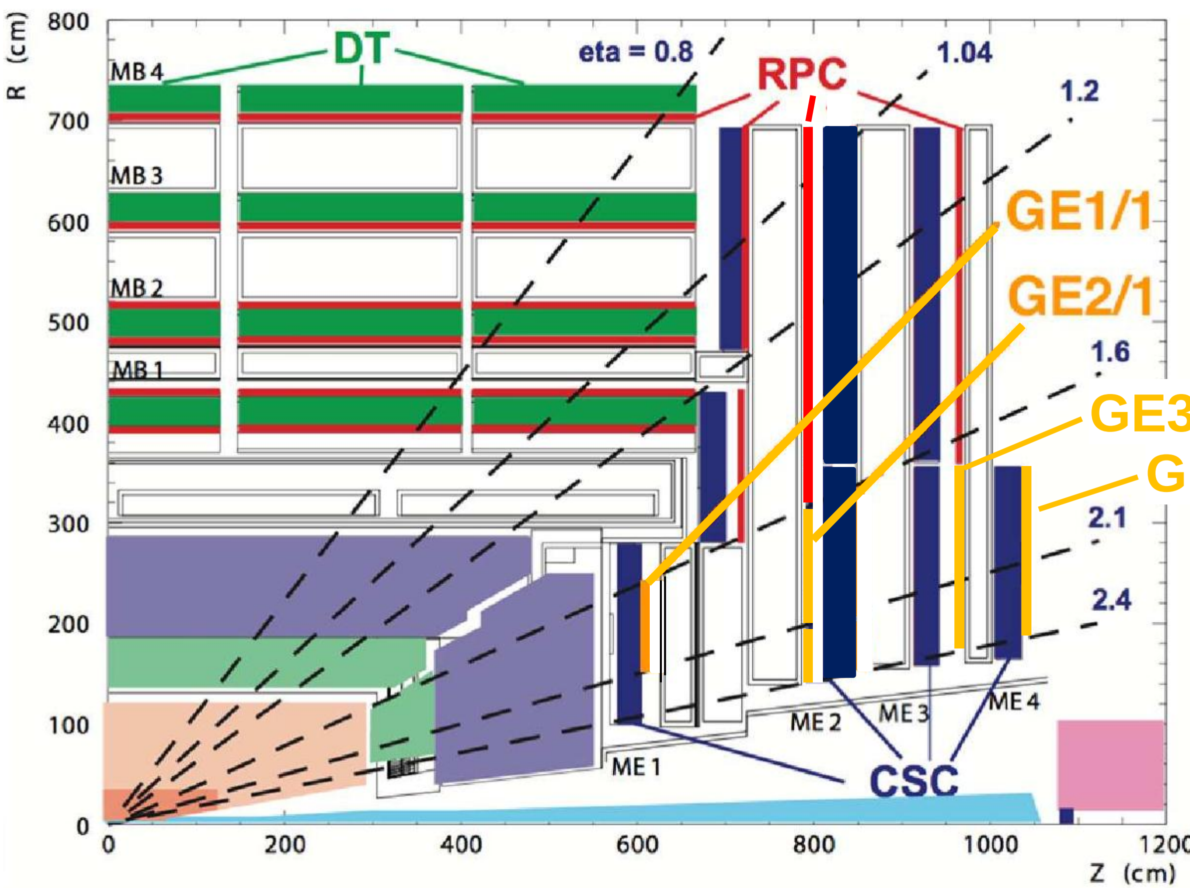


M. Titov (Saclay), CERN Detector Seminar, 4/12

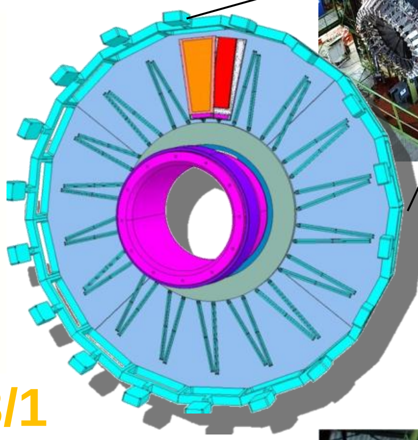
GEMS FOR CMS

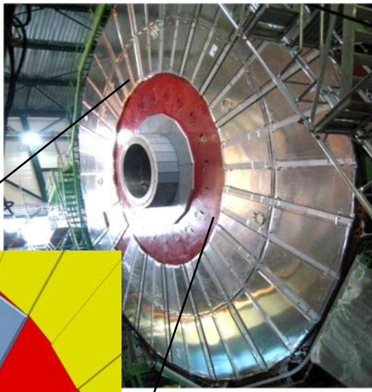
GEM Endcap Chambers

The currently un-instrumented high-η RPC region of the muon endcaps presents an opportunity for instrumentation with a detector technology that could **sustain the radiation environment long-term** and be suitable for operation at the LHC and its future upgrades into Phase II: **GEM Detectors**

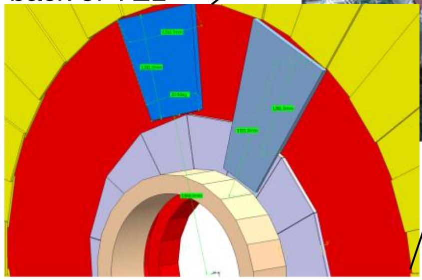


GE1/1 in YE1 nose





GE2/1 on back of YE1

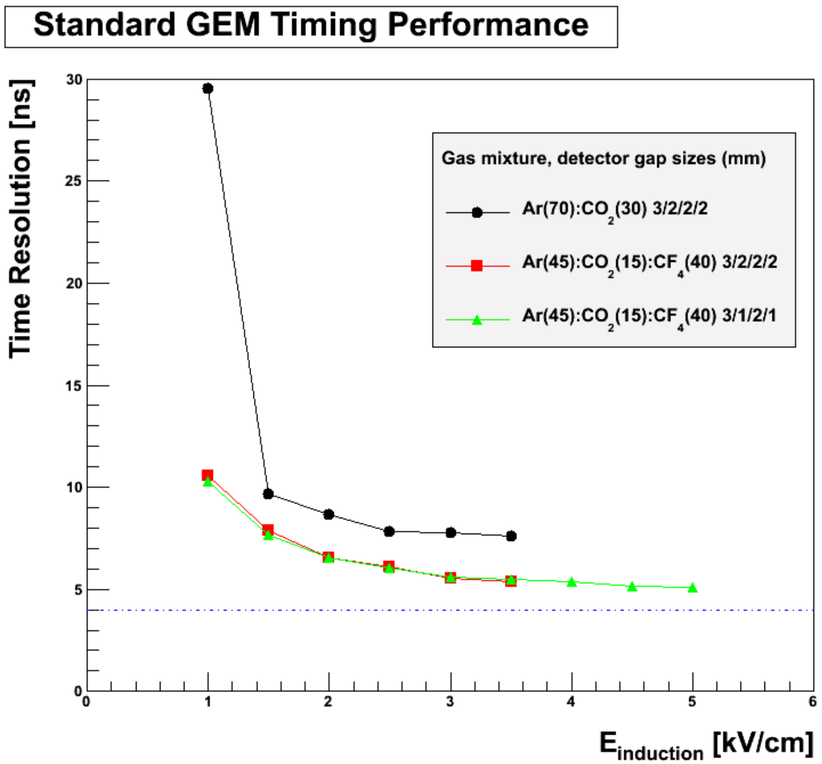


Expected Muon Rate Environments

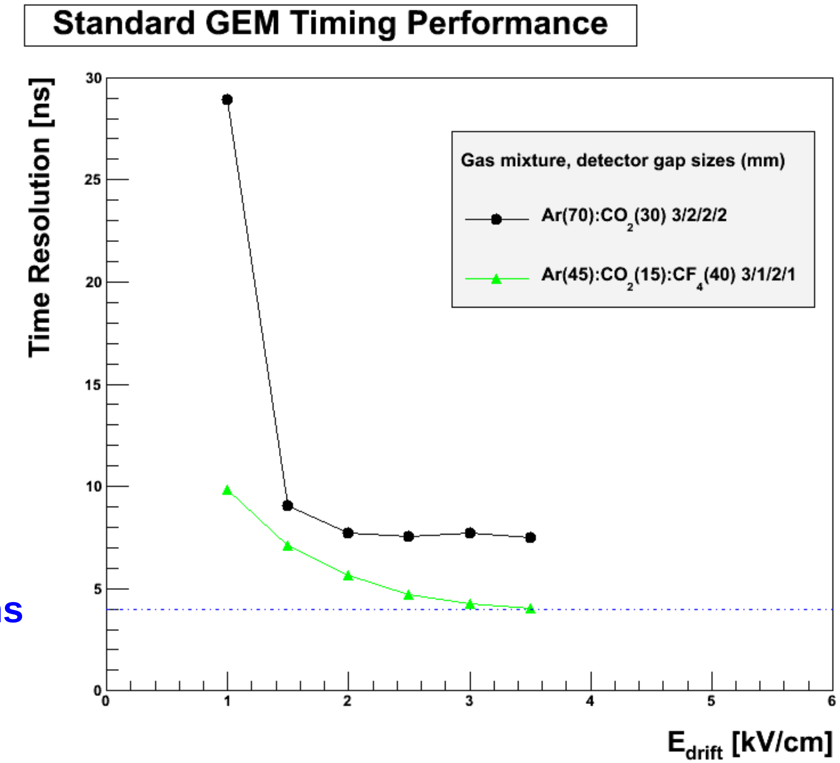
Region	LHC (10^{34} cm^2/s)	High Luminosity LHC (> LS 2) ($2\text{-}3 \times 10^{34}$ cm^2/s)	LHC Phase II (> LS 3) (10^{35} cm^2/s)
Forward Rates [Hz/cm^2] ME,RE 1,2,3,4 $\lvert\eta\rvert < 1.6$	100	Few 100	**~ kHz**
Expected accumulated charge in10 years	0.05 C/cm^2	0.15 C/cm^2	~ C/cm^2
Forward Rates [Hz/cm^2] **GE 1,2,3,4 $\lvert\eta\rvert > 1.6$**	**500 - 1000**	**Few kHz/cm^2**	**Few 10's of kHz/cm^2**
Expected accumulated charge in10 years **GE 1,2,3,4 $\lvert\eta\rvert > 1.6$**	(0.05-1) C/cm^2	**few C/cm^2**	**several C/cm^2**

GEMS FOR CMS: DETECTOR R&D

GEM Timing Studies (2010)



4 ns



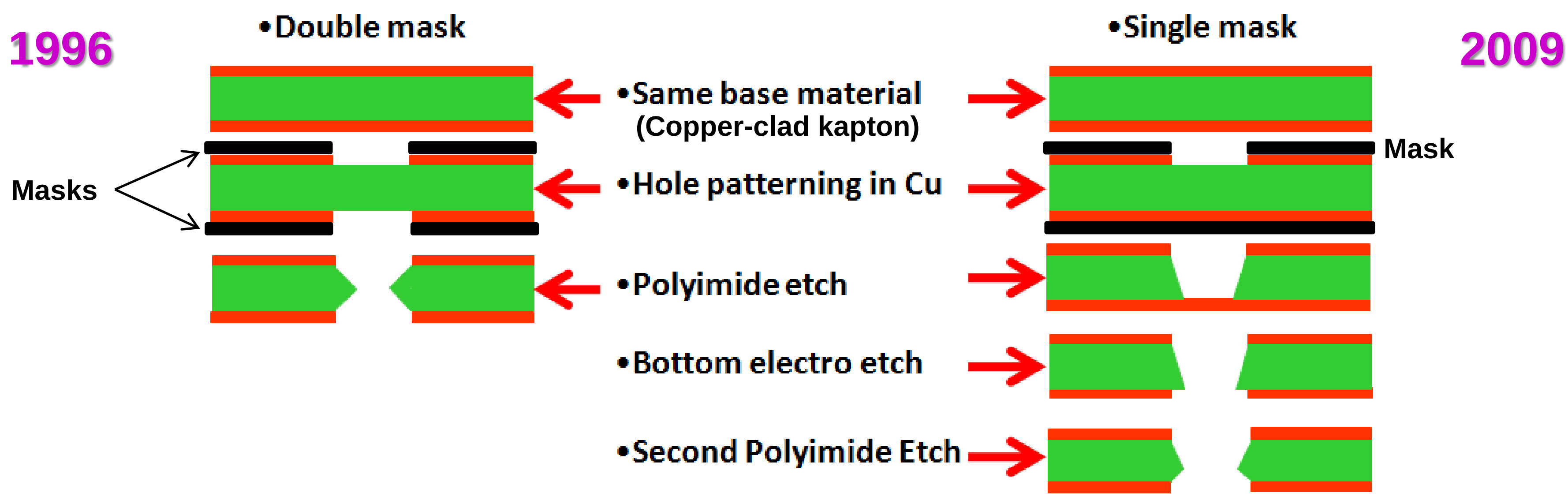
Using optimized HV divider for standard triple-GEM

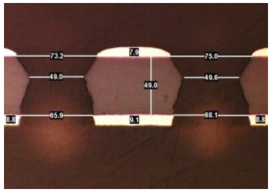
Clear effects of gas mixture, and induction and drift field

Required timing resolution of 4 ns reached

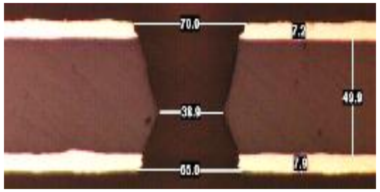
Tech. Advance: Single-mask GEM foils

Comparison of fabrication procedures for single-mask and double-mask GEM





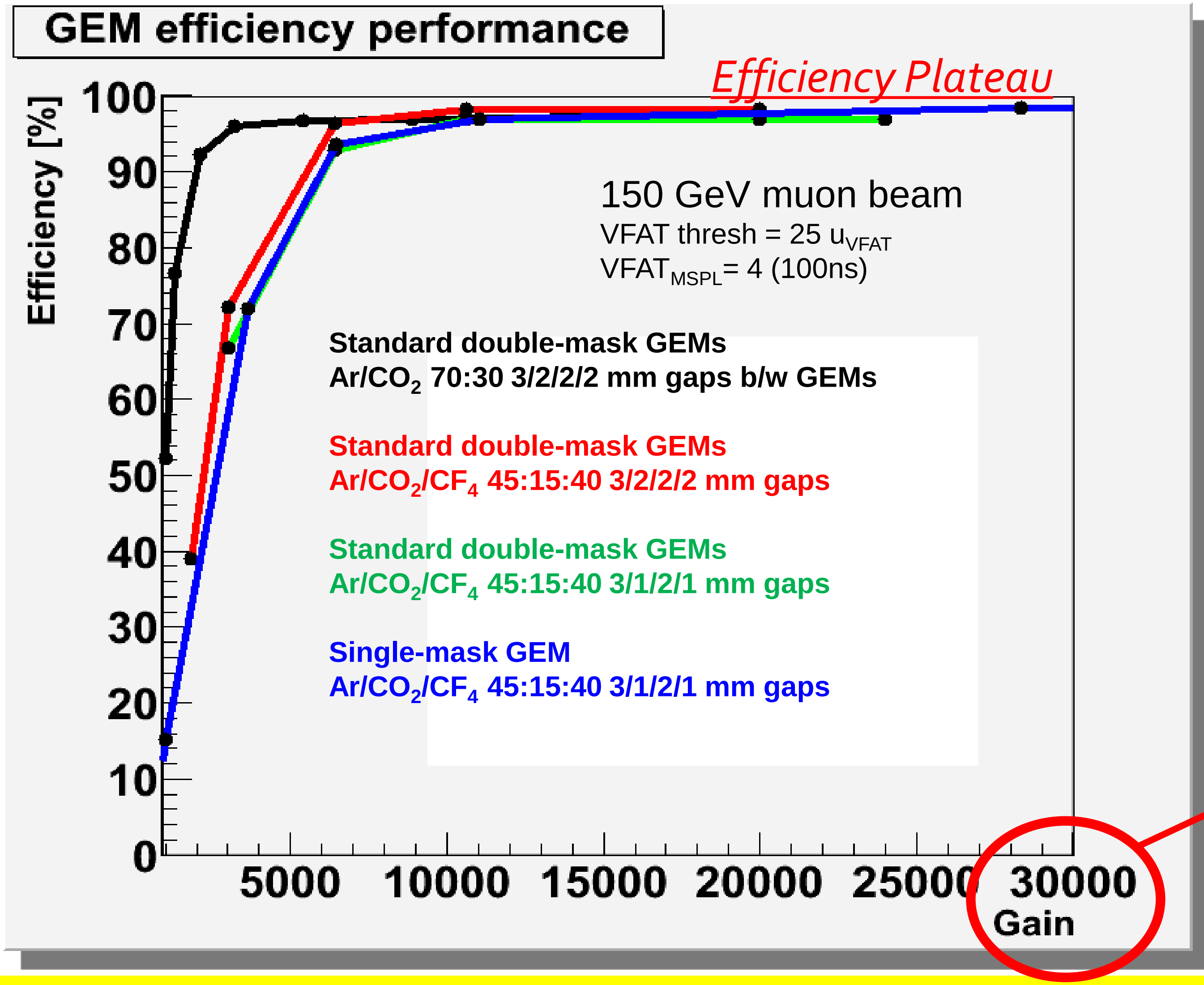
reality



Max. size **40cm × 40cm** **due to precision and alignment of top and bottom masks**

Max. size **200cm × 60cm** **limited by size of base material and machines**

Single-mask GEM performance (2010)

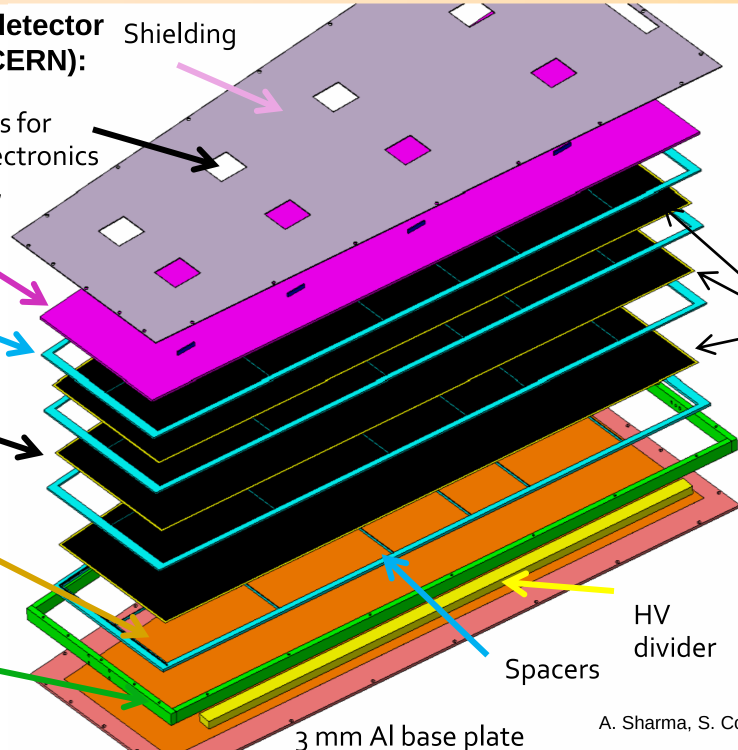


High achievable gain!

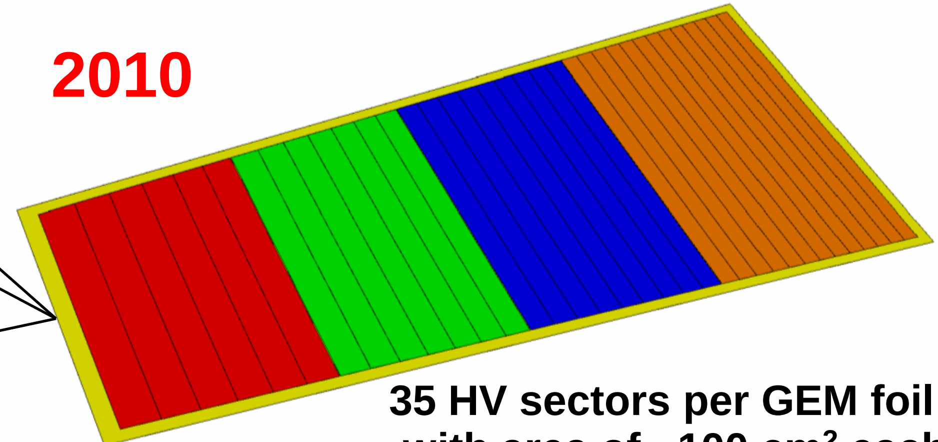
Single-mask GEM shown to achieve same performance level as double-mask GEM; used for large-area CMS GE1/1 prototypes

Design of first full-size CMS GE1/1

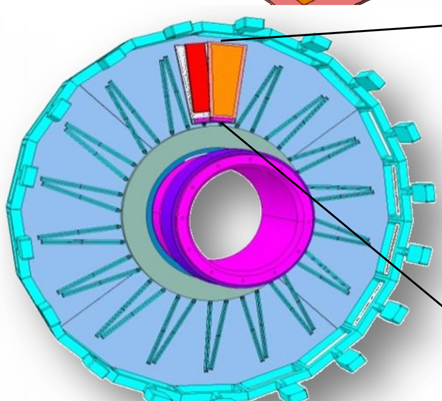
Largest GEM detector built to-date (CERN):

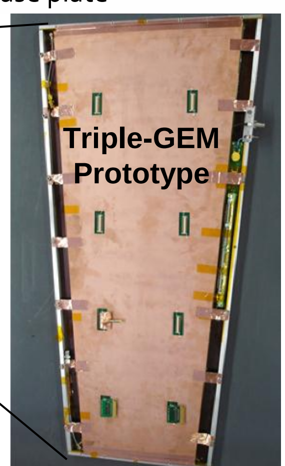


2010

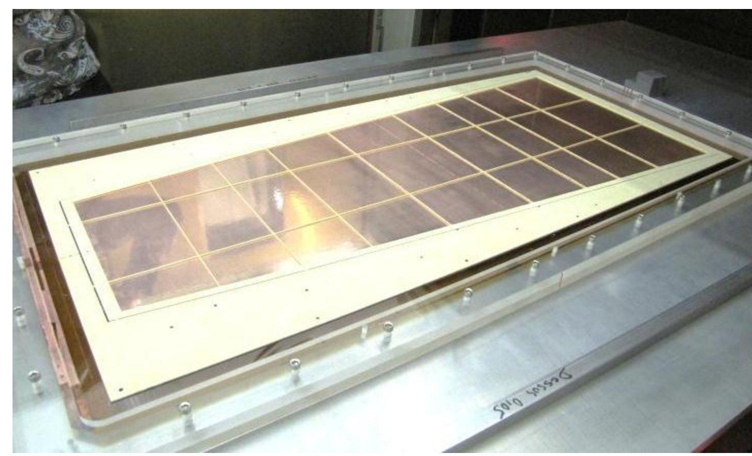


35 HV sectors per GEM foil with area of ~100 cm^2 each





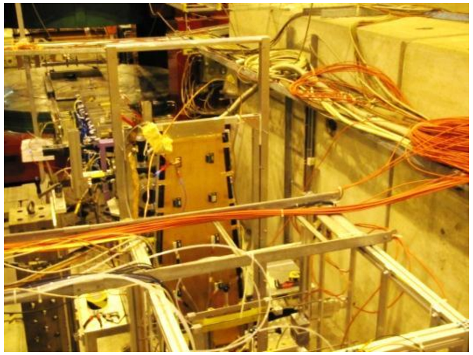
~1m

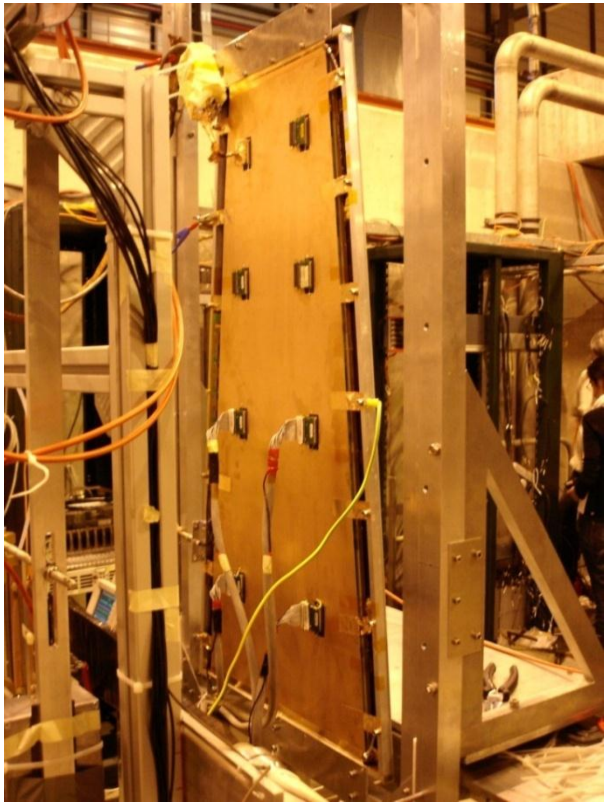


Single mask GEM foil with spacer frame at CERN (active area: 990 mm long & 220-455 mm wide)

A. Sharma, S. Colafranceschi

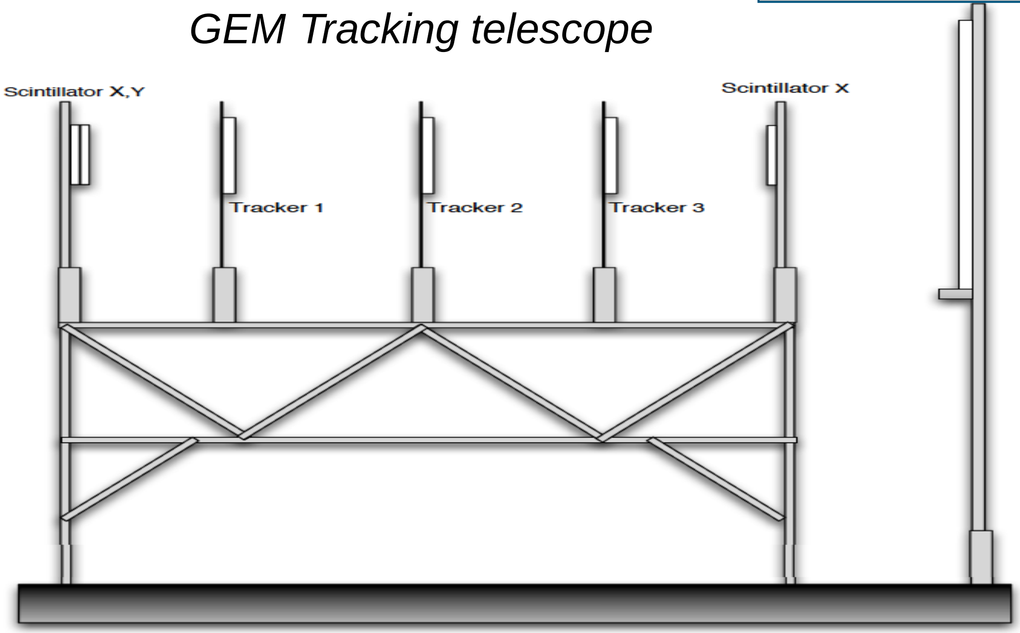
CMS-RD51 Test Beams (H4@SPS 2010)





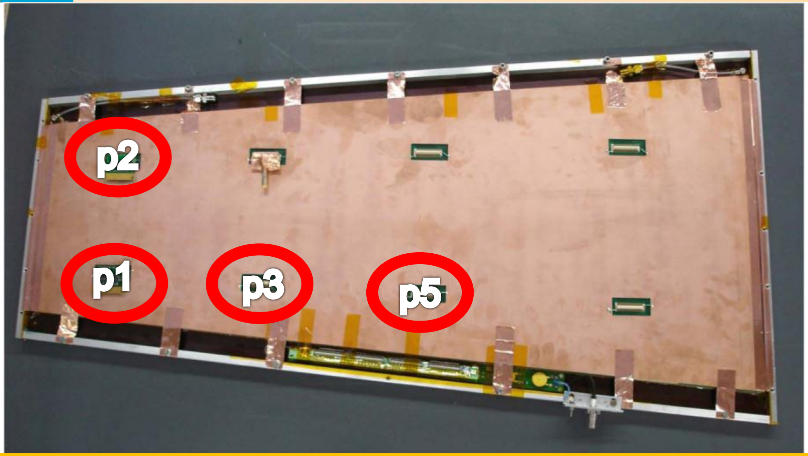
CMS full-size GE1/1 detector

GEM Tracking telescope



- **VFAT2 frontend electronics (fast binary readout)**
- **20 million events taken with CMS Prototype I**

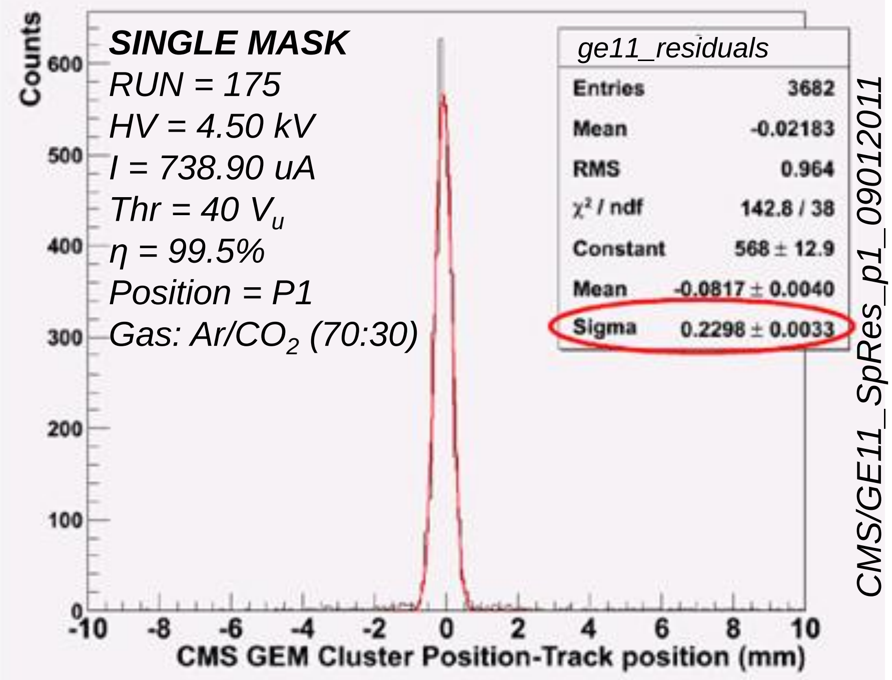
1st full-size CMS GE1/1 prototype (2010)



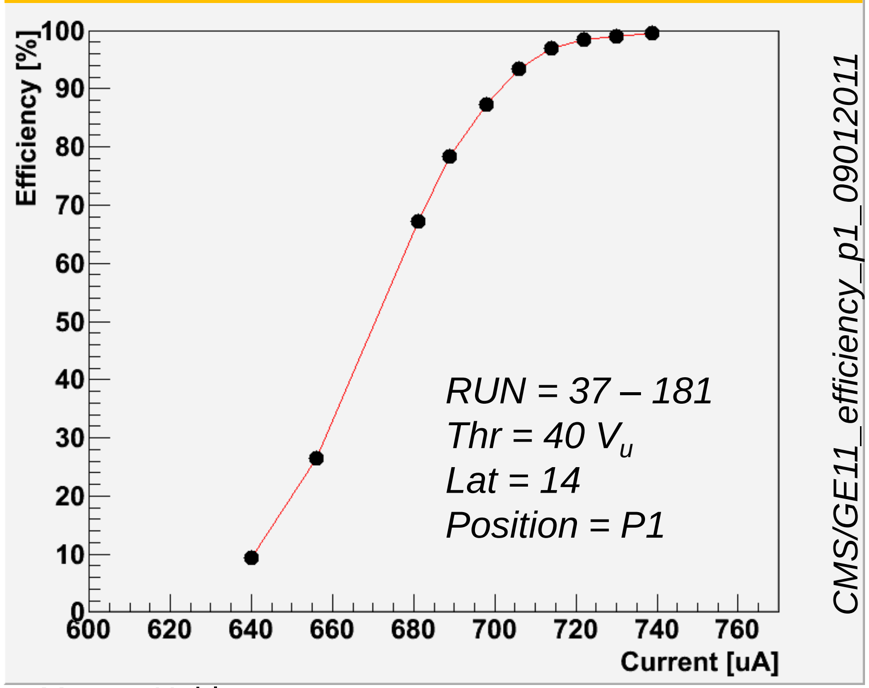
Good performance observed:

- **≥ 98% efficiency**
- **230 μm resolution (≈ pitch/√12 for binary electronics)**
- **uniform performance in different sectors**

Track residuals

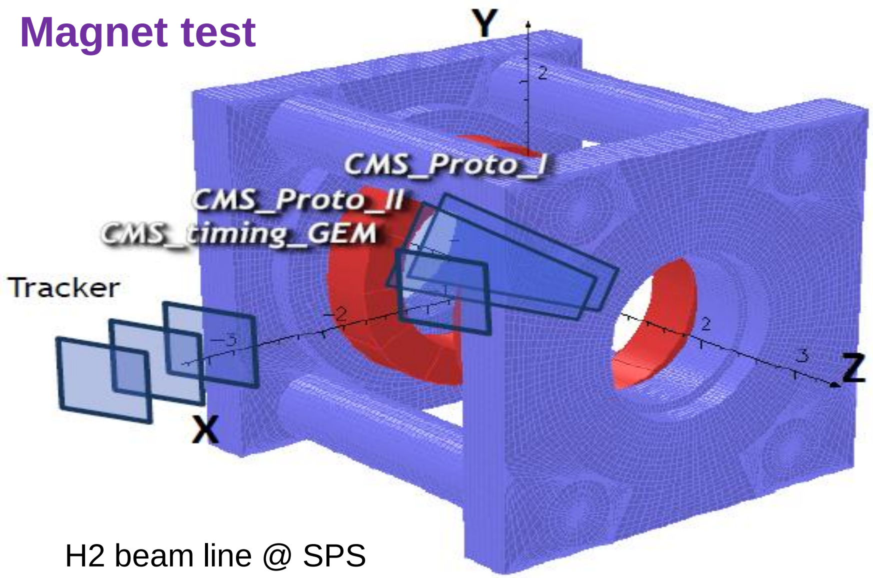


Efficiency

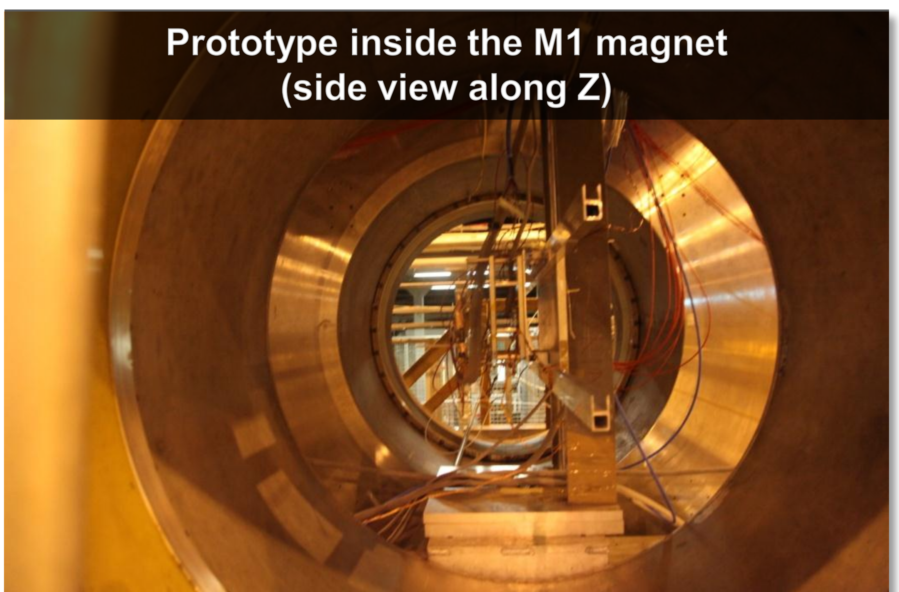


2^{nd} CMS full-size GE1/1 prototype (2011)

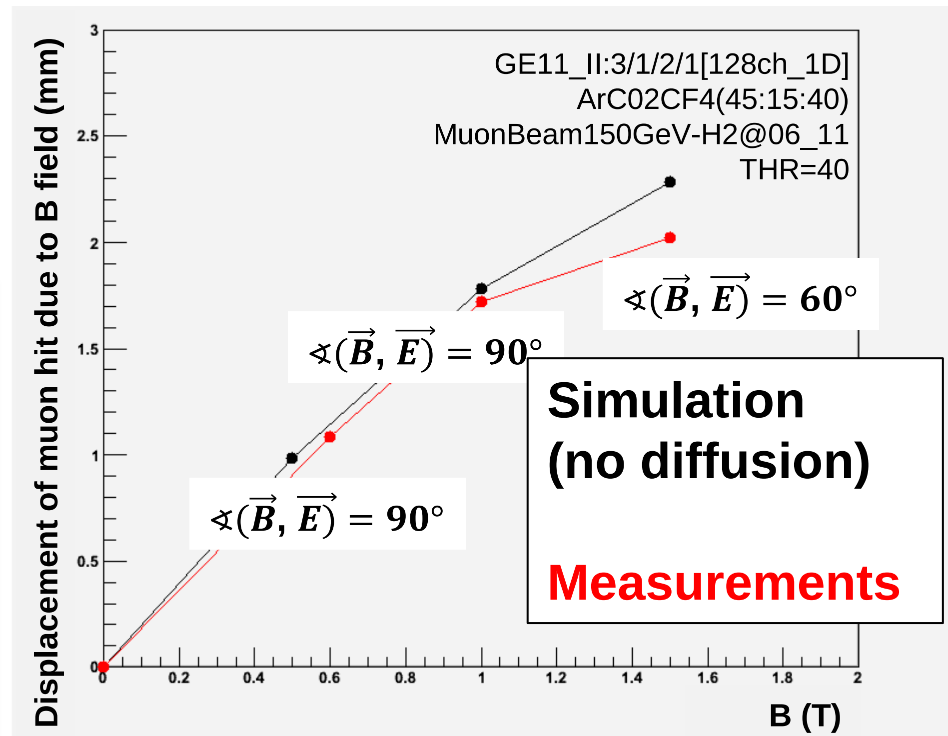
Magnet test



H2 beam line @ SPS



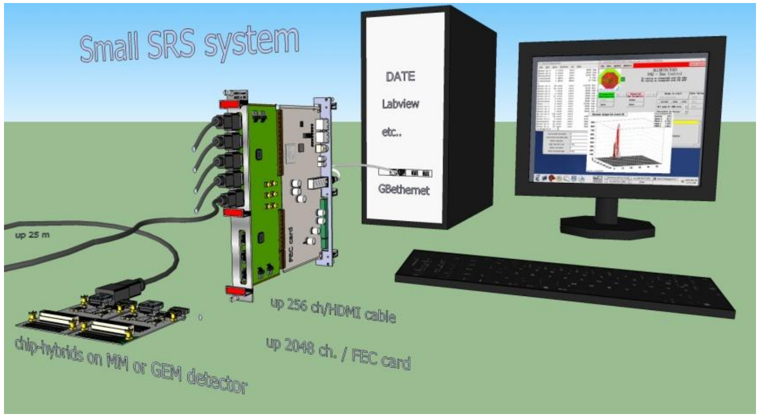
- ***Smaller GEM gap sizes: 3/1/2/1 mm***
- ***More partitions (3 columns × 8 rows)***
- ***Smaller strip pitch***
- ***At CMS we expect <u>at most</u> $B_{\perp}$ ~ 0.6T (while $B_{//}$ ~ 3T) and $\sphericalangle(\vec{B}, \vec{E})$ ~ 8°***



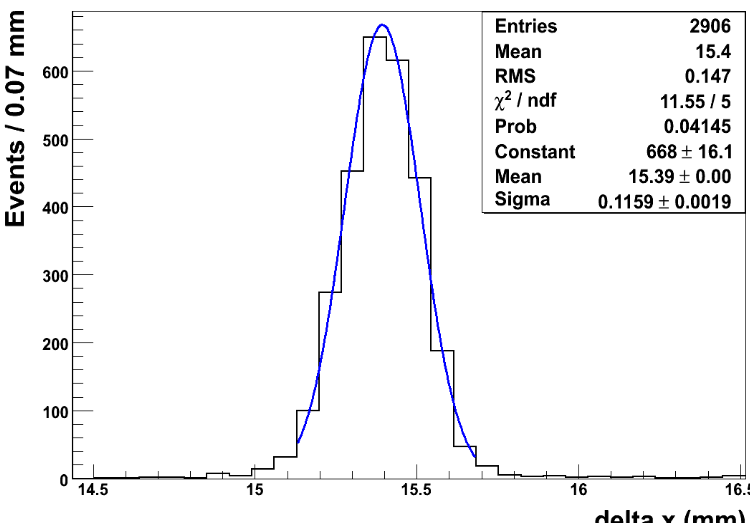
$\vec{E}$ = main direction of field in GEM

2nd CMS full-size prototype w/ SRS (2011)

RD51 Scalable Readout System (SRS)

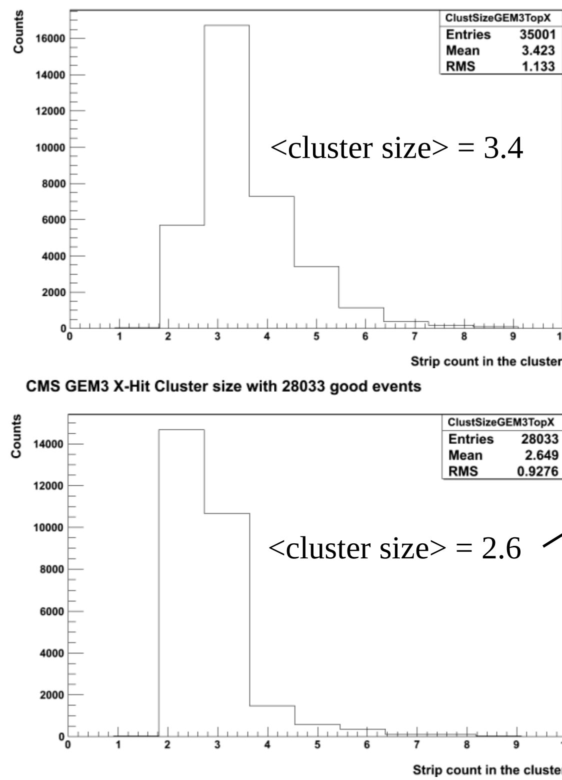


Δx_{hit} measurement : Tracker GEM vs. CMS full-size GE1/1

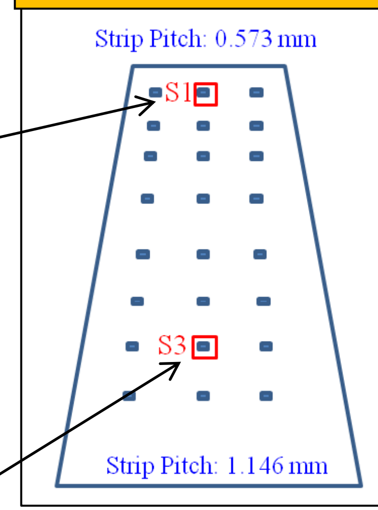


Successful data taking with **analog** APV chip and Scalable Readout System in addition to TURBO/VFAT2 DAQ system; allows cog centroid calculation for hit position using pulse heights

Strip cluster size



μ^-/π^- beams

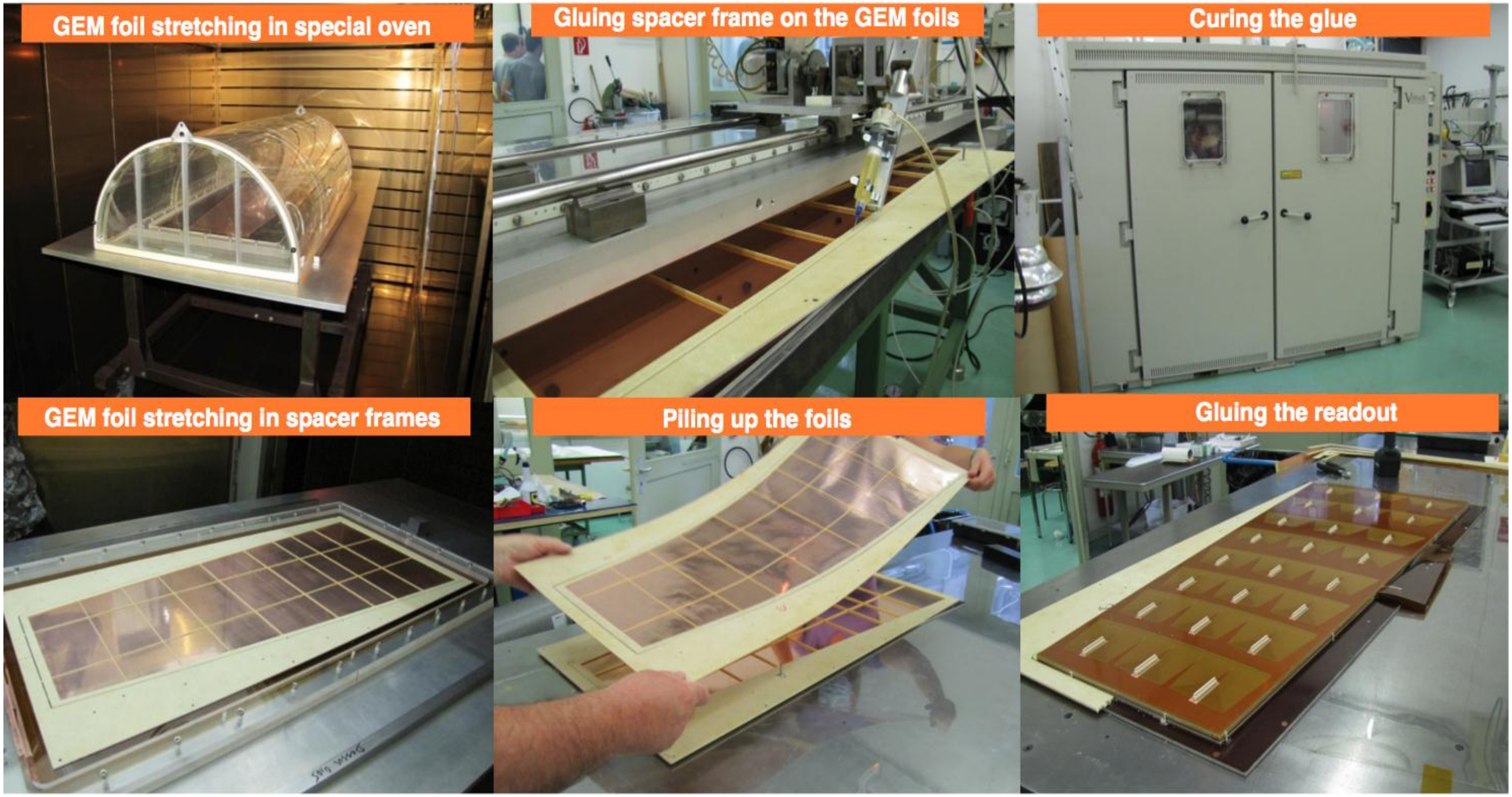


K. Gnanvo (Fl. Tech), Sep 2011

Measured GE1/1 resolution: σ_x < 103 μm in section with smallest pitch

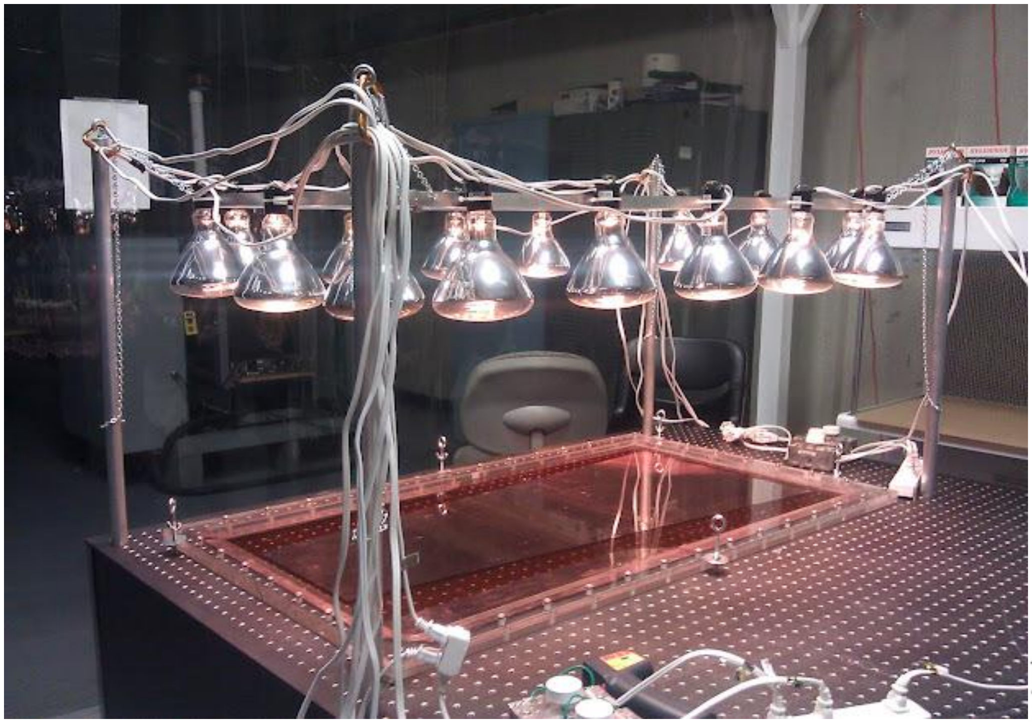
Evolution - GEM foil stretching

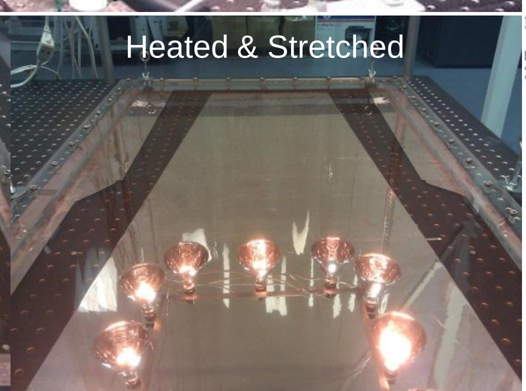
1. Thermal stretching in large oven (CERN)



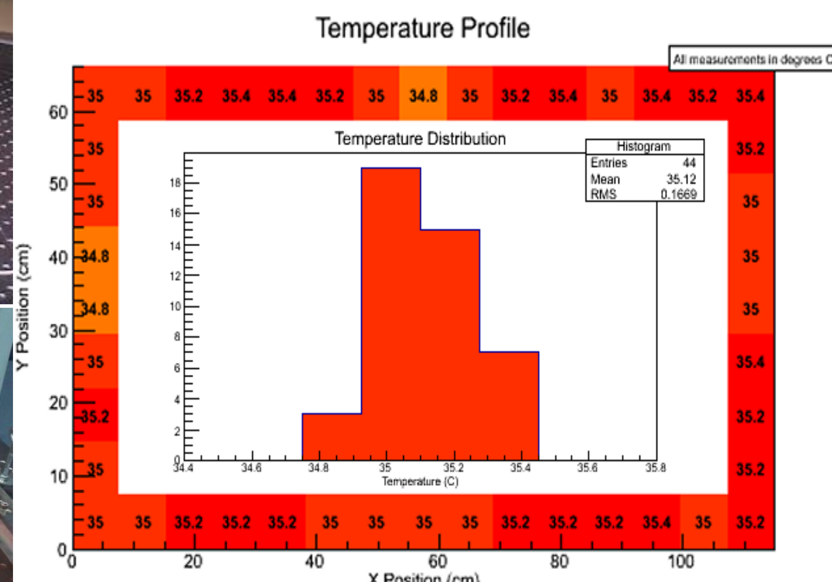
Evolution - GEM foil stretching

2. In situ thermal stretching in clean room with infrared heating lamps (Fl. Tech)



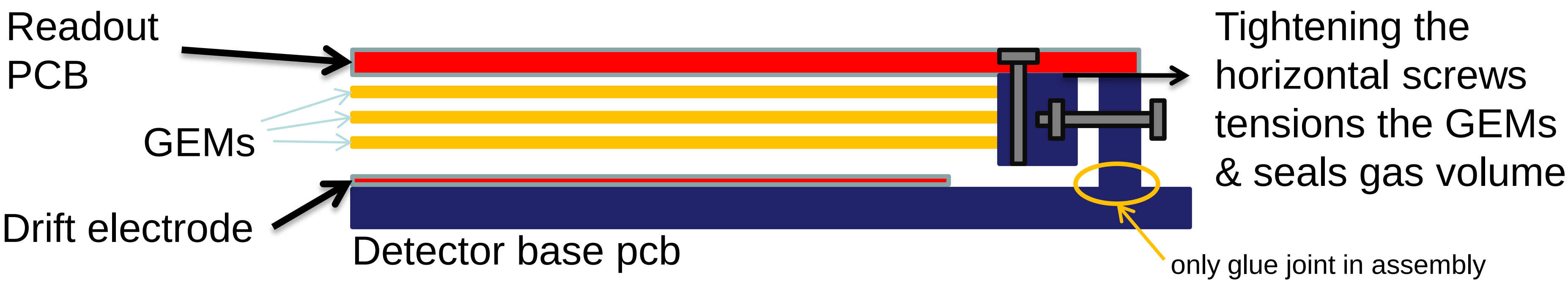


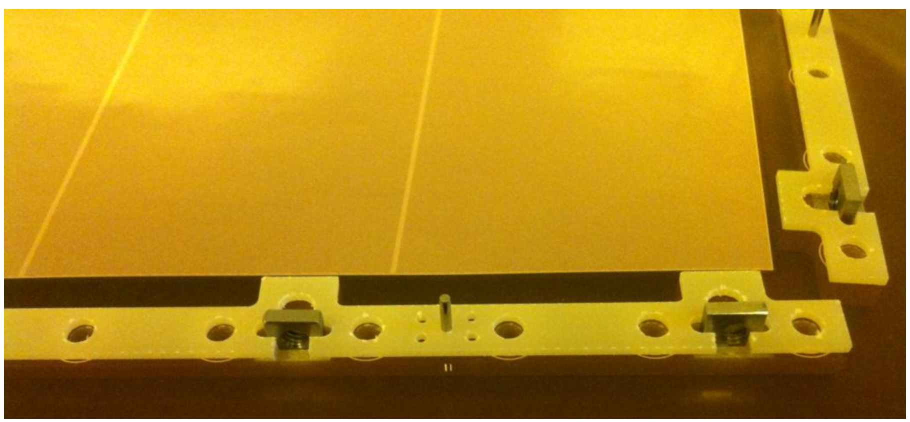
- 1”-diameter aluminum rods support the frame – allows for greater versatility and mobility. Several stations can easily be set up on the same optical table
- Sixteen 125W heat lamps; stretch foils at 35°C
- Two 30x30 cm^2 Triple-GEM built with this technique

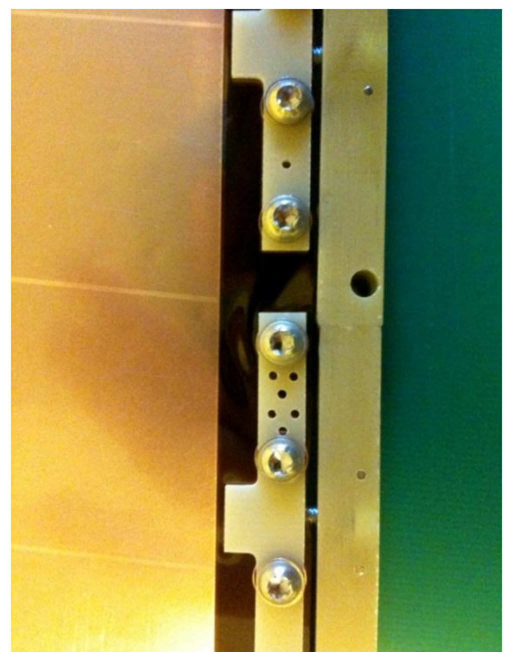


Evolution - GEM foil stretching

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





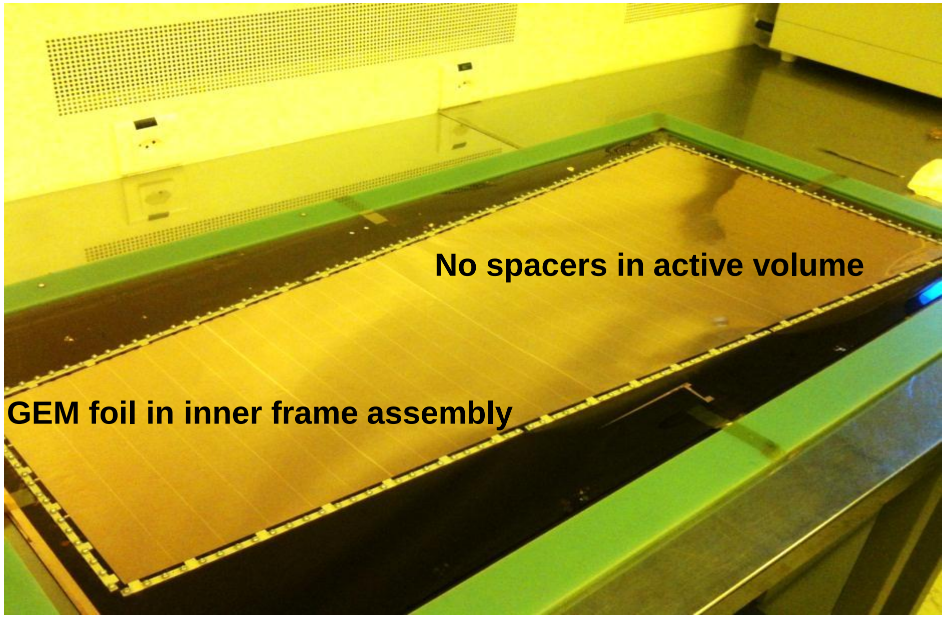


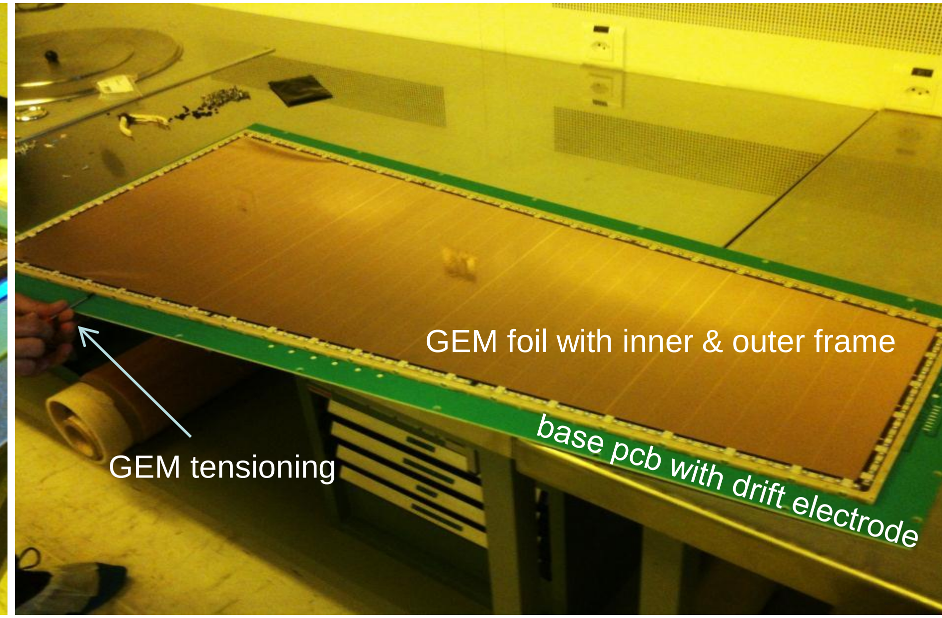
Allows re-opening of assembled detector for repairs if needed.

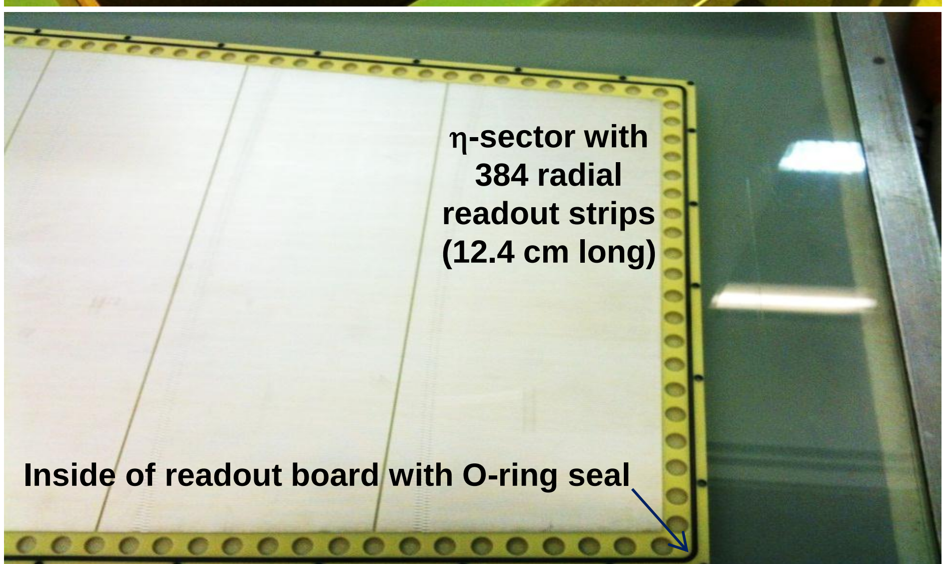
2012

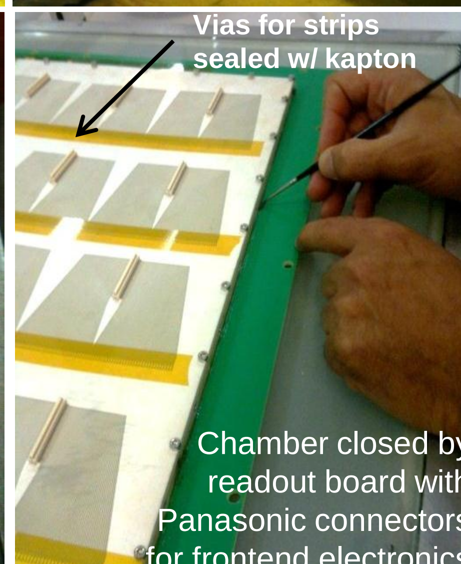
R. De Oliveira, CMS-GEM/RD51Workshops CERN & U. Gent

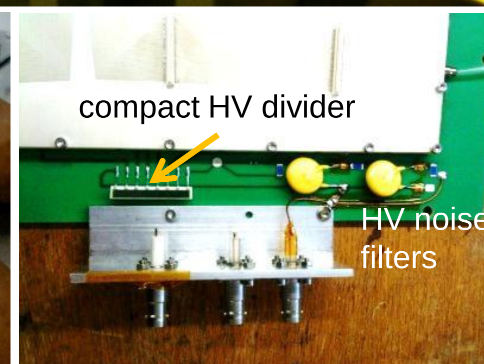
3rd CMS GE1/1 Prototype: Self-stretched











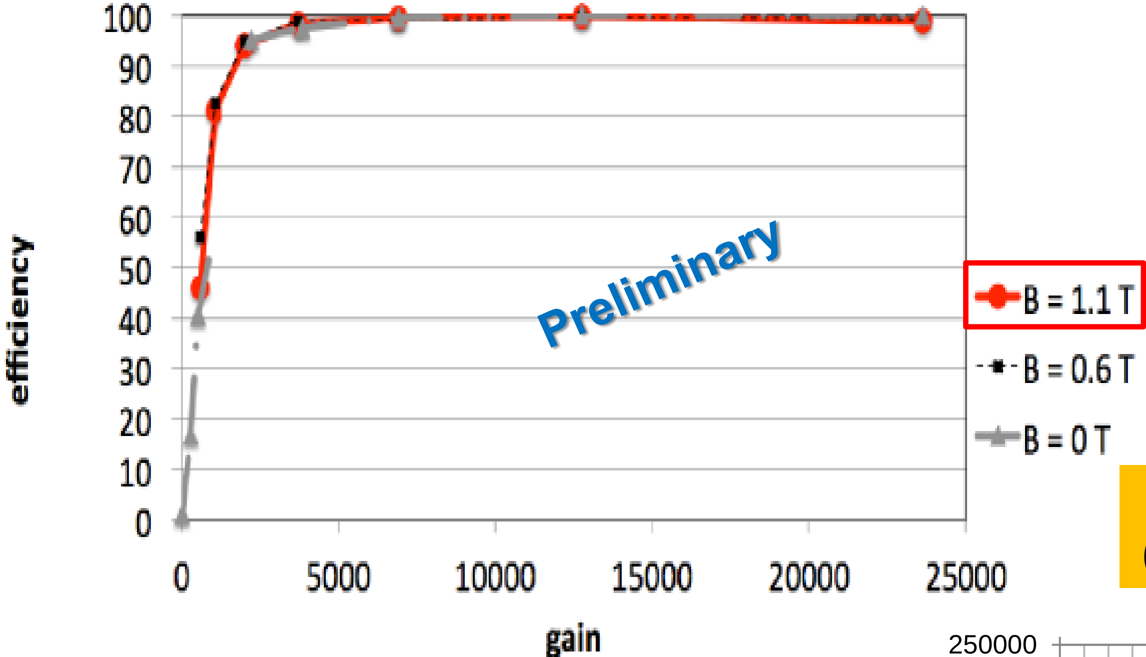
2012

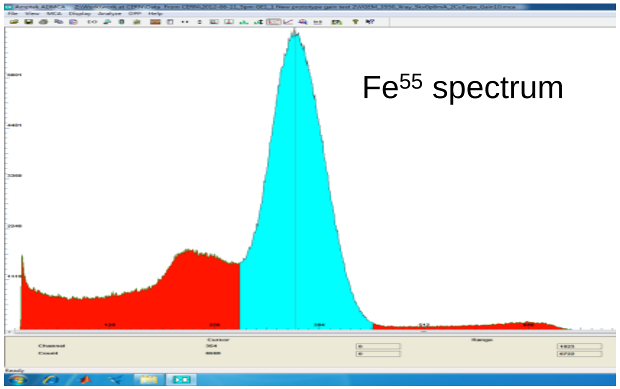
GE1/1 Production Status & Plan

- **2 chambers completed at CERN**
  - **currently in SPS test beam**
- **2 chambers in production at CERN**
  - **some issue with dust particles from fiberglass frame getting into active GEM area**
  - **investigating:**
    - **micro sand blasting & polyurethane coating of frames**
    - **change to different material (PEEK) for inner frame**
- **1 chamber to be assembled and commissioned at Florida Tech this fall**

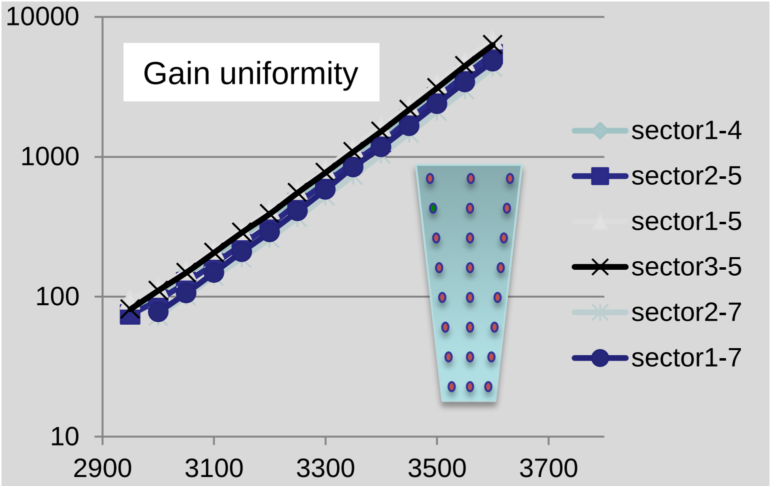
2012

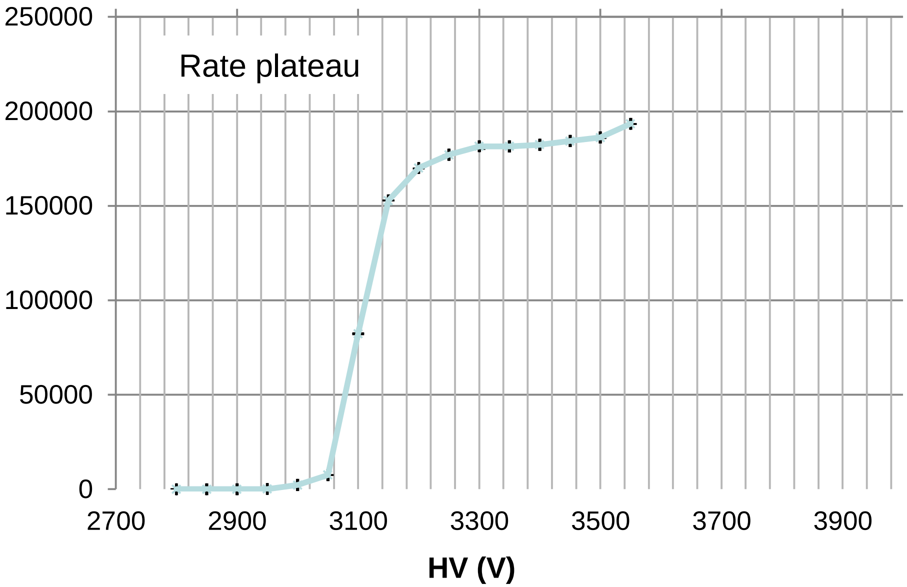
3rd GE1/1 Prototype: Self-stretched





Preliminary 2012 test results (bench tests & beam test at SPS H4)



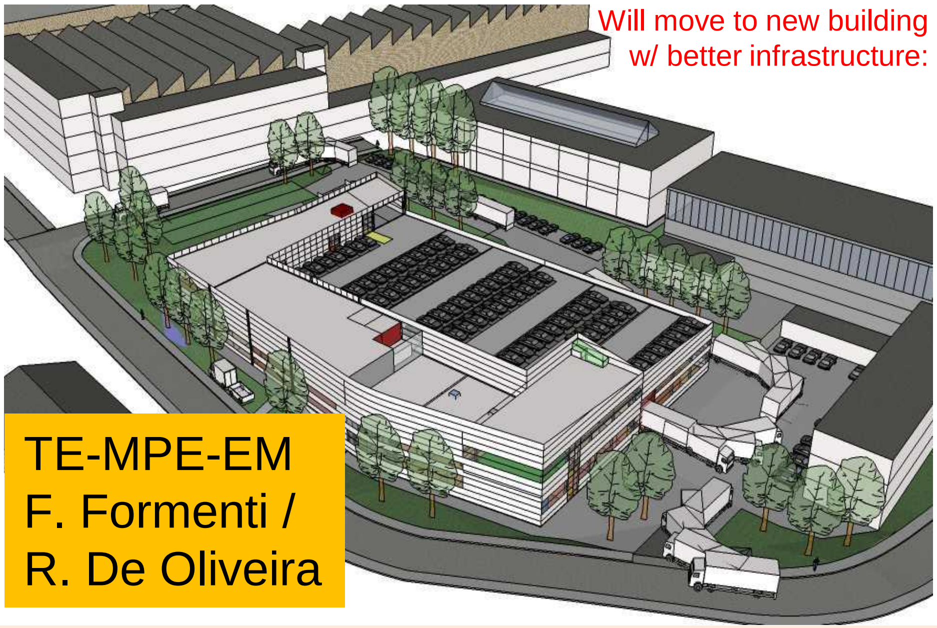


GEMS FOR CMS:
GE1/1 GEM FOIL PRODUCTION

GEM Foil Production: CERN & Industry

CERN: Currently located in building 102; well suited for prototyping & small series productions; new machines in 2011/12

Will move to new building w/ better infrastructure:



TE-MPE-EM
F. Formenti /
R. De Oliveira

Expected rate for 2012 : 250 GEMs / year

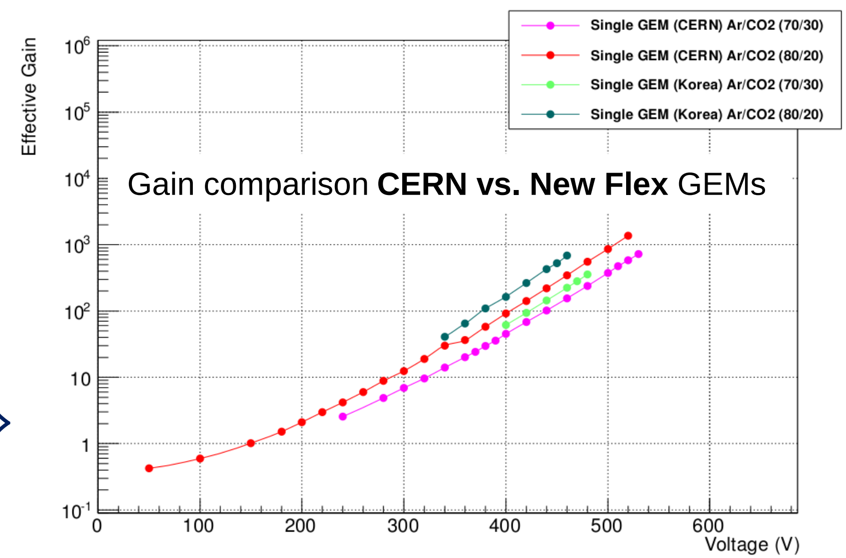
Need $\mathcal{O}$ (1000 m²) GEM foils for project ⇒

Next year the workshop will be capable of processing GEM foils of sizes up to 2m × 0.6m (0.6m imposed by raw material)

INDUSTRY: Newflex, Seoul, S. Korea

Technology transfer from CERN ongoing

- Small-size foils produced and tested with good results:



- Large-size foils being tried gradually

GEM foil production in US ?

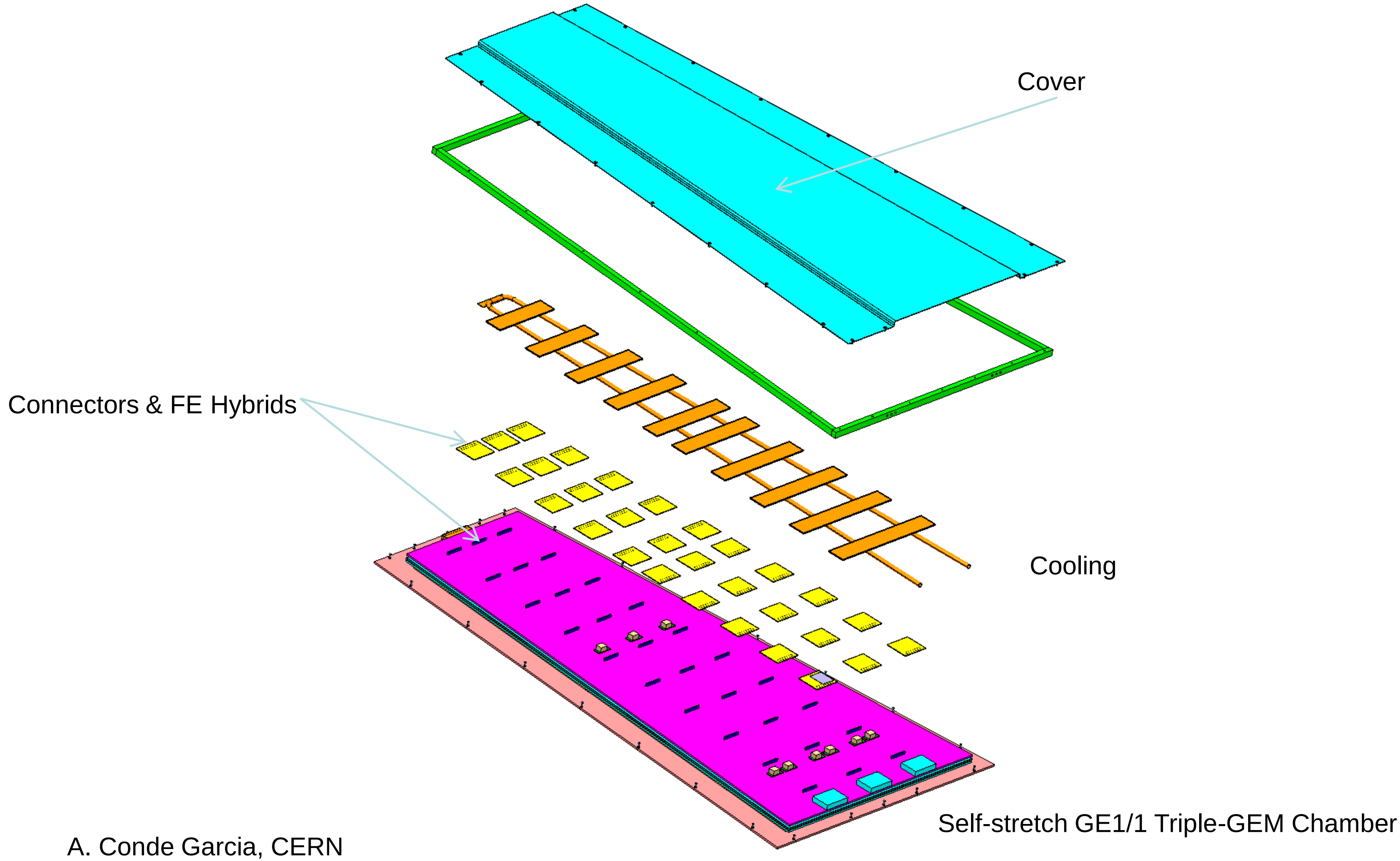
TechEtch, Plymouth, MA

- Already producing medium-size GEM foils (for STAR Forward Tracker)
- Contact refreshed by CERN in January 2012
- Declared **interest to upgrade to GEM single mask pr**ocess -> CERN to explain procedure
- Concerning large sizes (0.5 ×1.2m^2): TechEtch can’t deal with long foils, yet (polyimide etching)
- TechEtch seeking collaboration with MIT for R&D money for large -area single-mask GEMs
- Waiting for their feedback on status of this project

F. Formenti, CERN, RD51 mini-week, June 2012

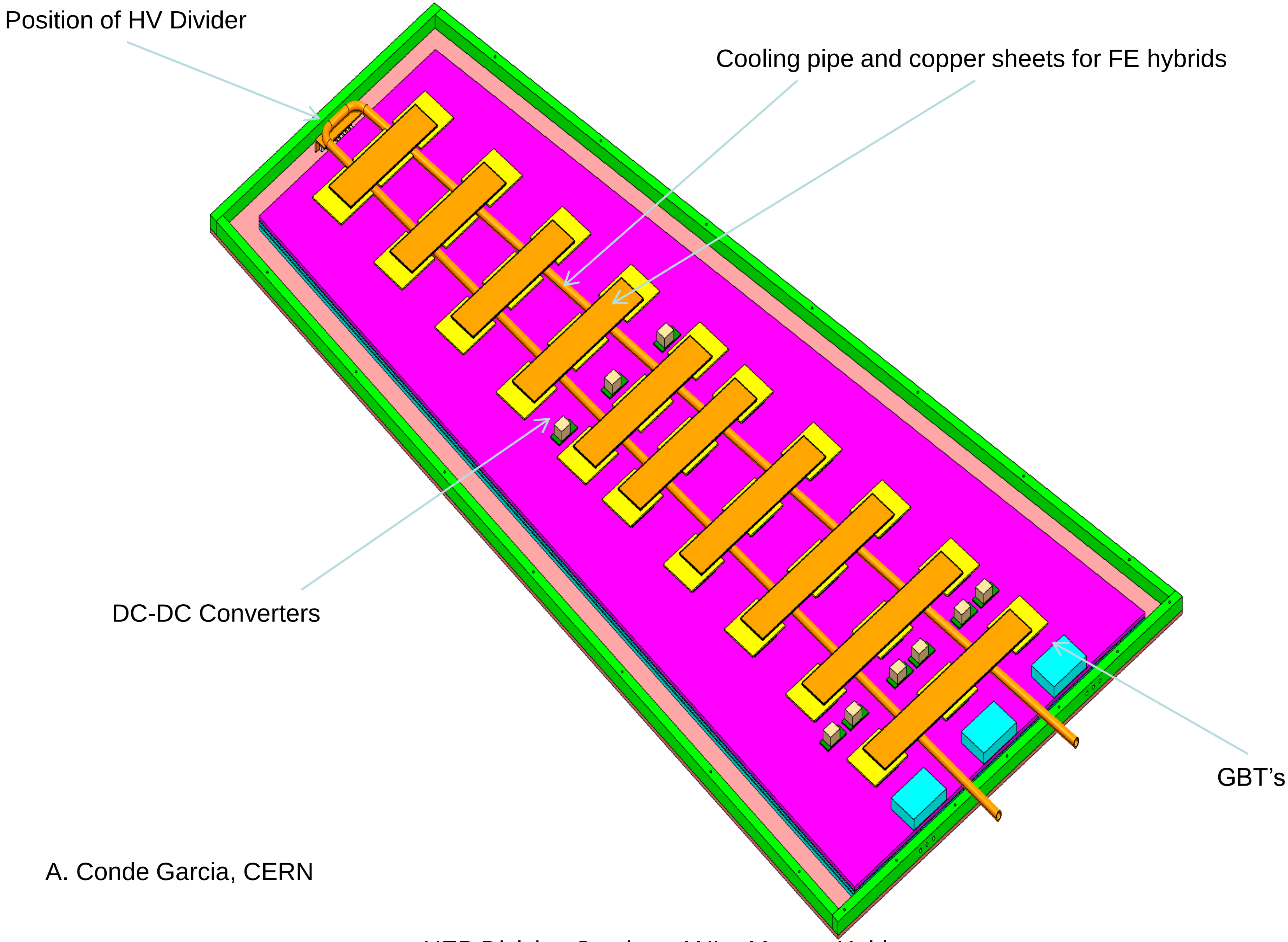
GEMS FOR CMS: GE1/1 PRODUCTION DESIGN

Exploded GE1/1 View



A. Conde Garcia, CERN

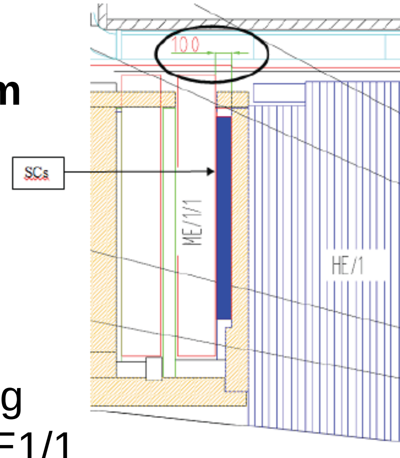
GE1/1 Mechanical Design

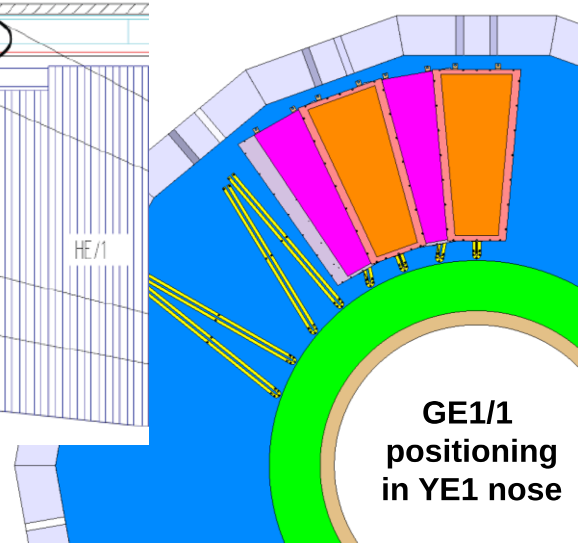


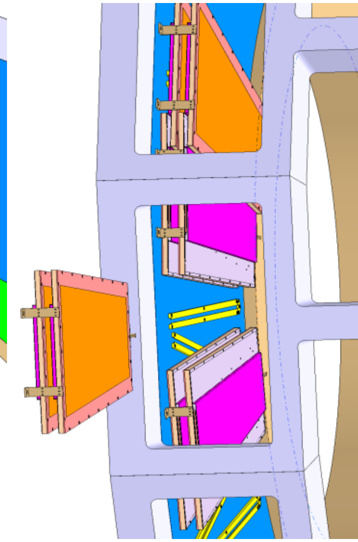
A. Conde Garcia, CERN

GE1/1 Installation

Space budget in YE1 nose: 10 cm



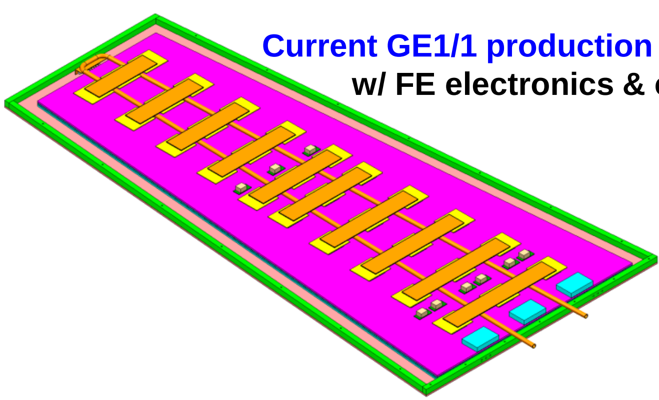




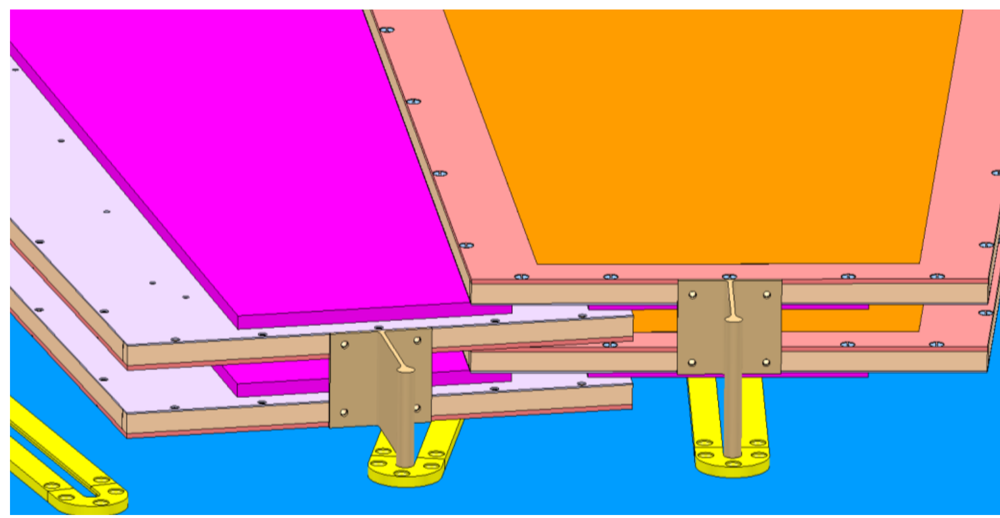
Integration studies show there is enough space to insert overlapping sandwiches of **two** Triple-GEM GE1/1 detectors (Super-Chambers)

Gives two space points ⇒ stub vector

Makes use of installation fixtures originally foreseen for RPCs

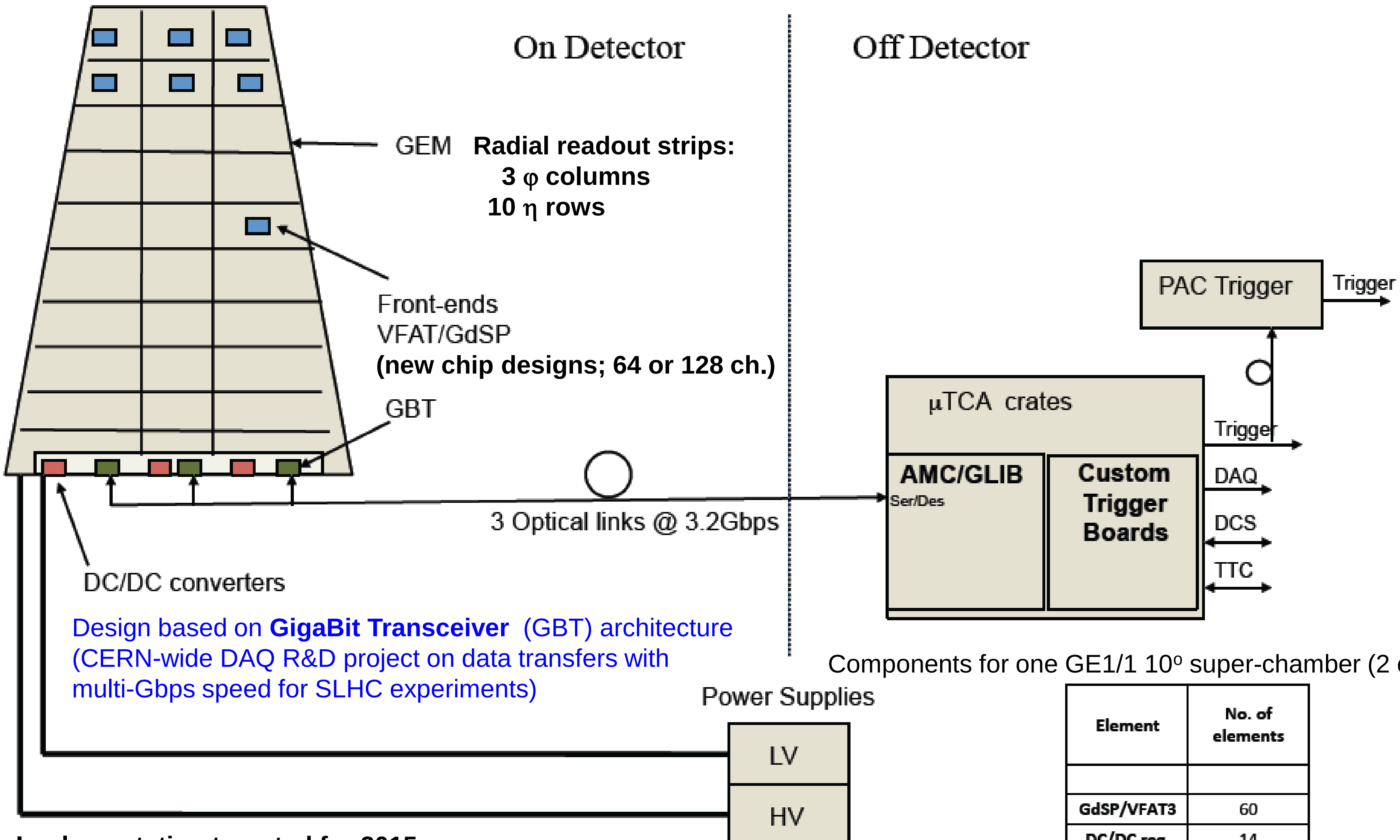


Current GE1/1 production design
w/ FE electronics & cooling



GEMS FOR CMS: ELECTRONICS DESIGN

Baseline Electronics Design



Design based on **GigaBit Transceiver** (GBT) architecture (CERN-wide DAQ R&D project on data transfers with multi-Gbps speed for SLHC experiments)

Components for one GE1/1 10° super-chamber (2 ch.):

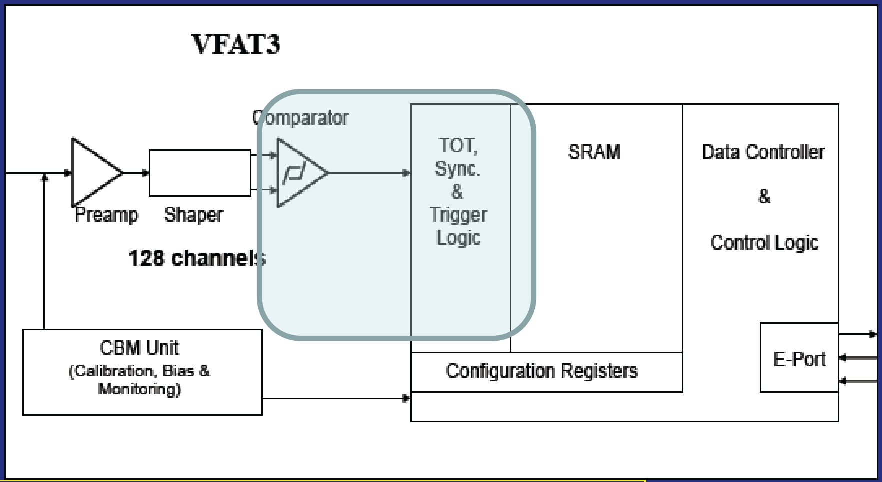
Element	No. of elements
GdSP/VFAT3	60
DC/DC reg.	14
GBT	6
Optical Link	6
Cables	2

Implementation targeted for 2015

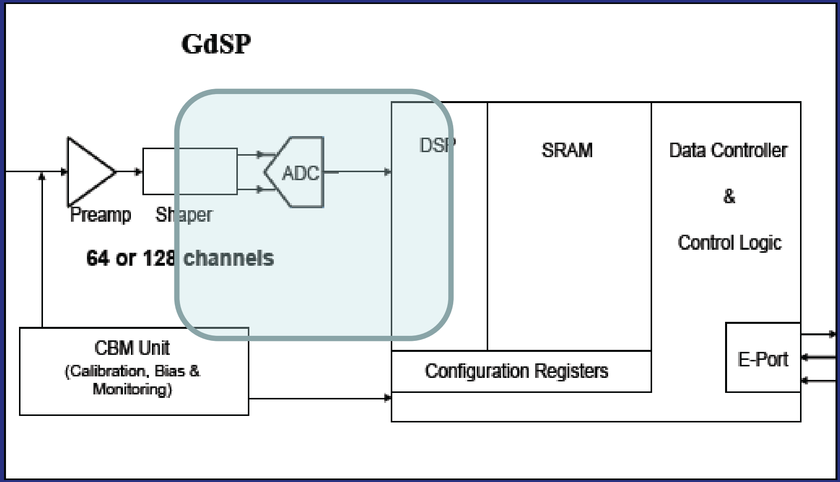
Effort led by Paul Aspell, CERN

Frontend: Two related options

2 Trigger & Tracking Front-end architectures considered.



OR



VFAT3 :

Front-end with programmable shaping time + comparator.

Internal calibration.

Binary memory

Interface directly to GBT @ 320Mbps.

Designed for high rate (10kHz/cm^2 depending on segmentation)

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

Approx. 8-10 man years of design work expected .

GdSP :

Similar to VFAT3 except has an ADC / channel instead of a comparator.

Internal DSP allows subtraction of background artifacts enabling a clean signal discrimination.

Centre of gravity a possibility to achieve a finer pitch resolution (if needed).

P. Aspell

Goals – Electronics Development

LS1 prototype

Prototype goal:

1. 30 VFAT2 front-end chips
2. Integrated GEM PCB carrying power, and signals.
3. HDMI cable readout option for SRS system
4. FPGA emulation of GBT with fibre optic readout to uTCA readout system
5. Water cooling
6. Radiation issues : total dose ~ krads, SEEs possible in FPGA (requires remote reconfiguration)

LS2 demonstrator

Ultimate goal:

1. 30 VFAT3/GdSP front-end chips
2. Integrated GEM PCB carrying power, and signals.
3. GBT with fibre optic readout to uTCA readout system
4. Water cooling
5. Radiation hard to total dose & Single Event Effects.

P. Aspell

R&D Effort at Fl. Tech

GEMS FOR CMS:
ZIGZAG STRIP READOUT

Motivation

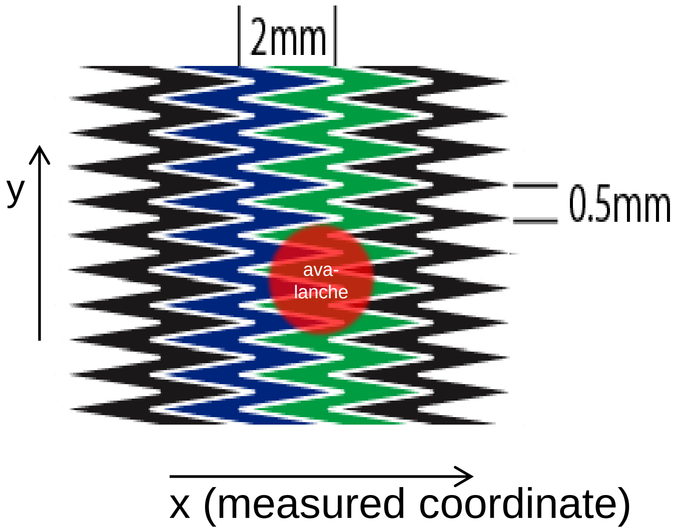
- **Cost** is one of the biggest current issues for the CMS GEM upgrade project
- The **single-largest** budget item in the original GEM budget estimate is **electronics:**

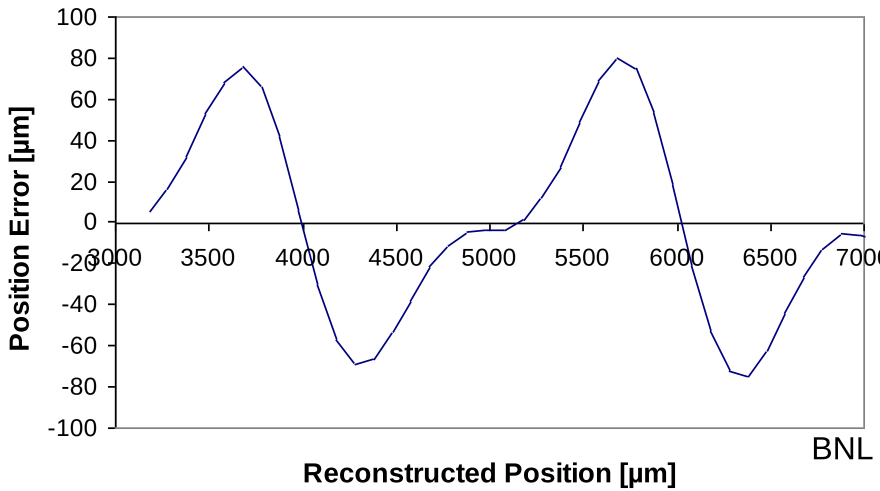
  ~3M out of 6.4M total (TP CMS IN 2012/001)
- Clearly, we should seriously look for ways to reduce the electronics cost if possible
  - One potential real cost saver would be the **significant reduction of readout channels**

$\Rightarrow$ **Can a zigzag strip readout help with that?**

Previous Work @ BNL

Zigzag strips: Previous exp. studies show <100 μm resolution with **2 mm** strip pitch is possible:



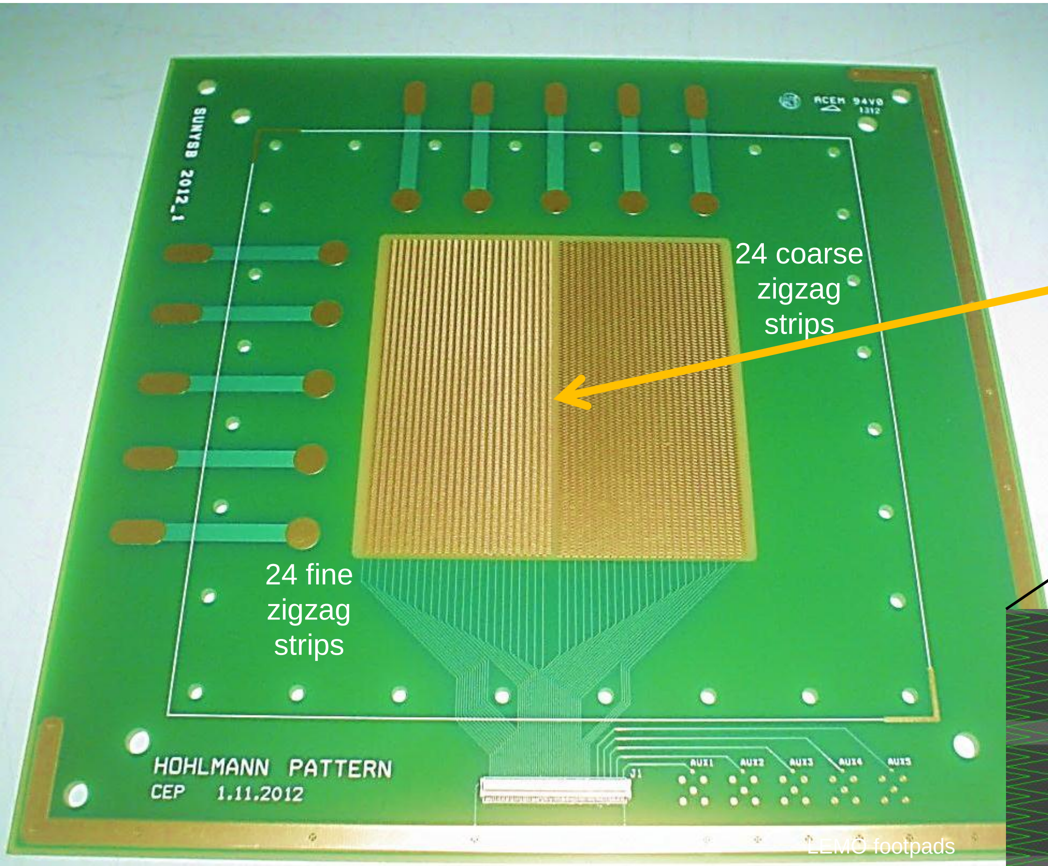


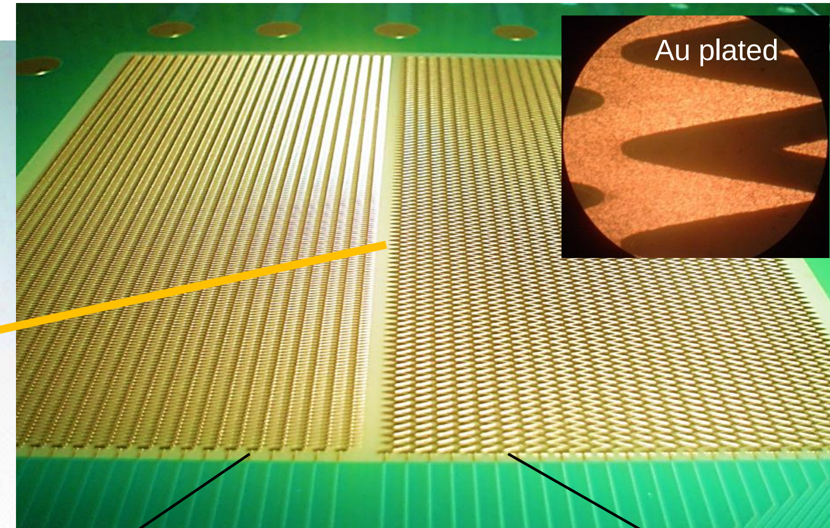
Concept:

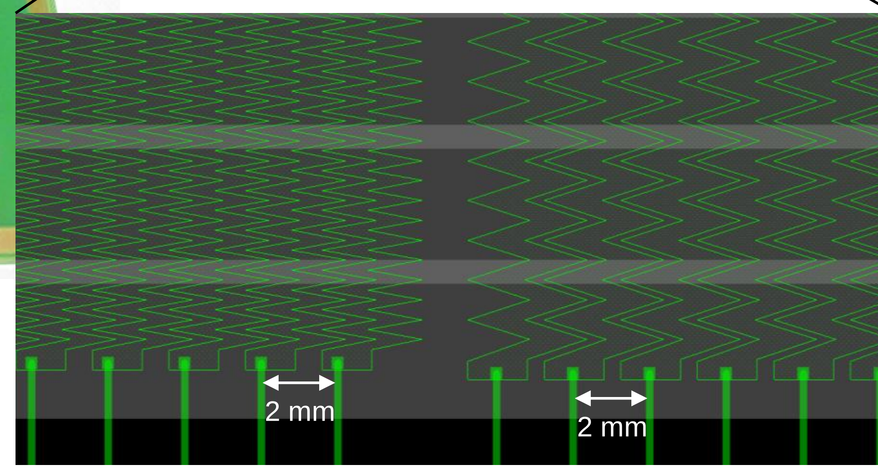
- Charge sharing among adjacent strips allows quite sensitive **position-interpolation** in x-direction
- We are sacrificing the measurement of the 2^{nd} coord. (y) to gain precision in the 1^{st} coord. (x)
- CMS GE x/1 detectors are currently intended for **1D-coordinate** measurements, so the zigzag approach is applicable to these detectors

Zigzag Strip Readout Board

2 sets of 10cm zigzag strips with different zigzag pitch (along strip)

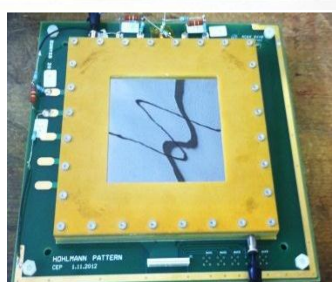






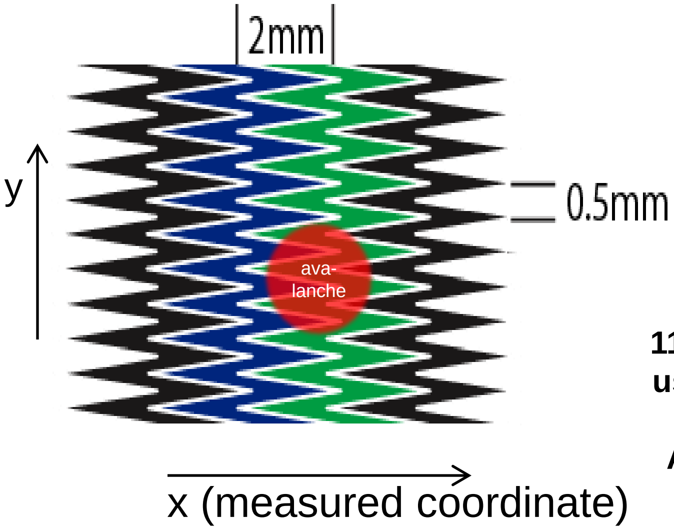
CAD Design by C. Pancake, Stony Brook

Readout Board for std. CERN 10cm×10cm Triple-GEM Det.



BNL / Fl. Tech / Stony Brook Collaboration

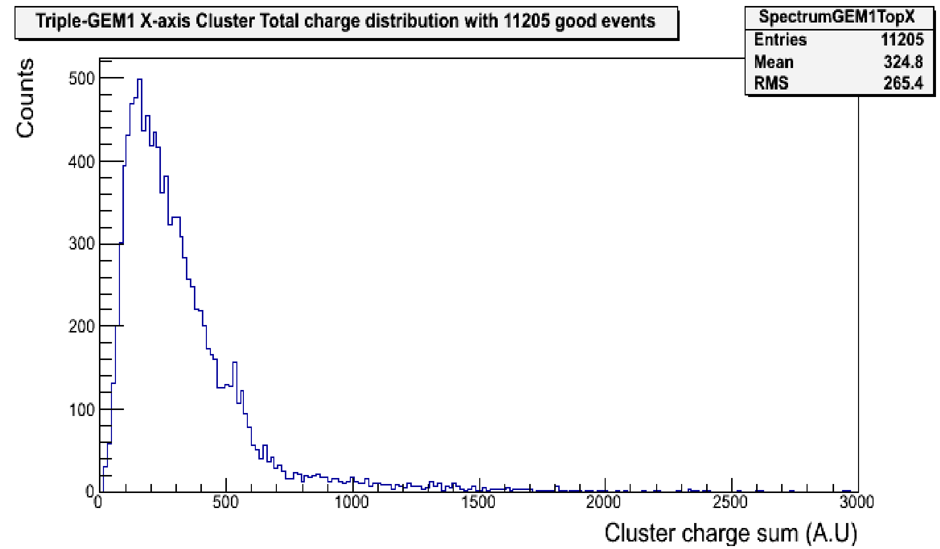
Strip Cluster Characterization



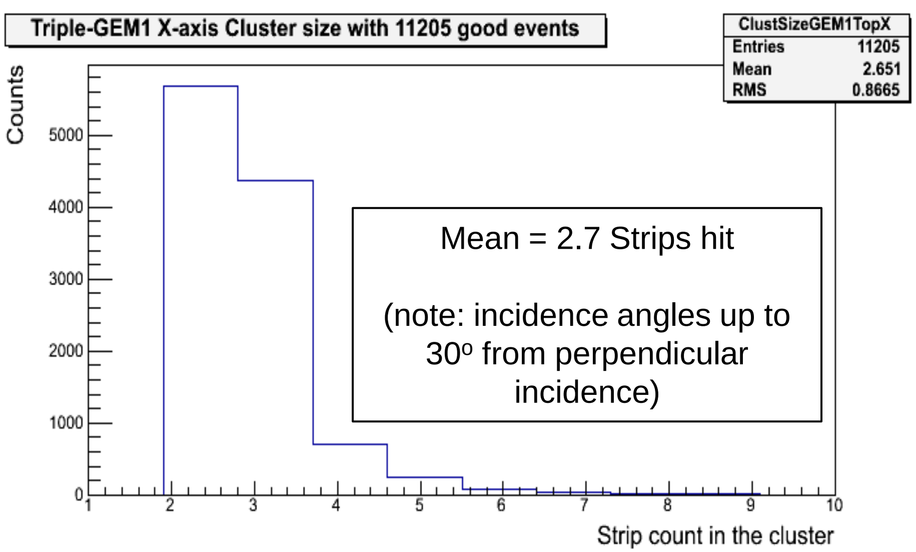
Sample of 11k mip pulses using cosmics

Ar/CO_2 70:30

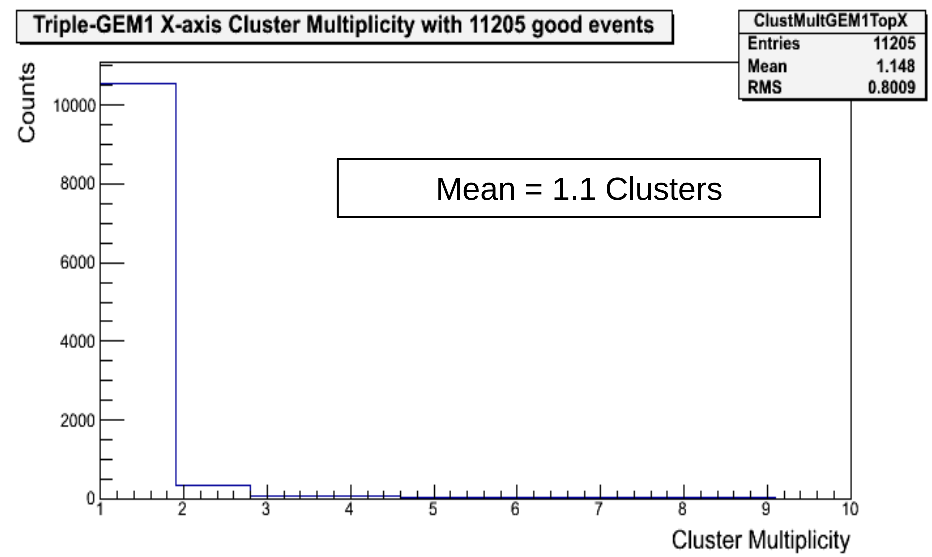
Cluster Charge Distribution



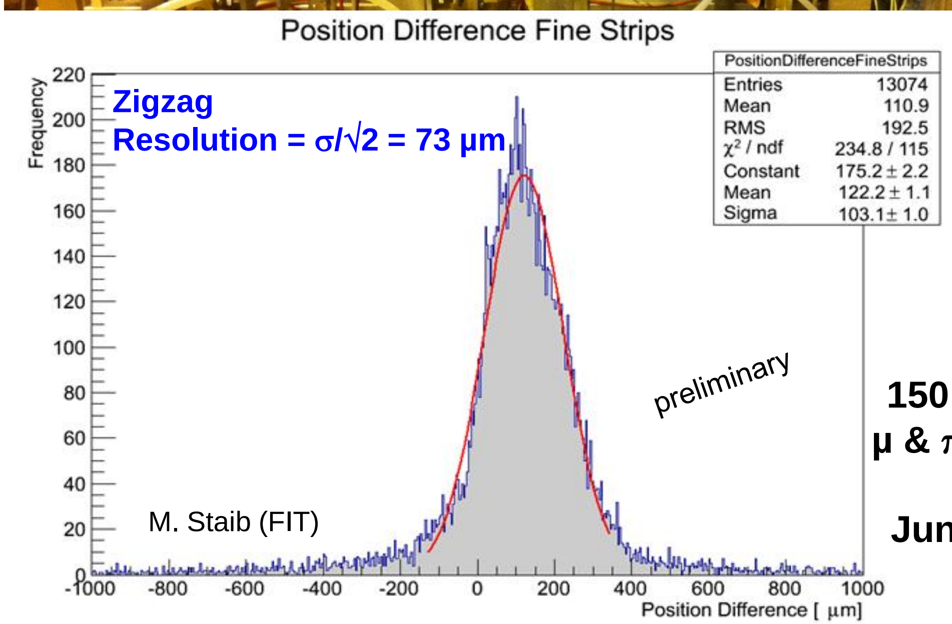
Strip Cluster Size Distribution



Strip Cluster Multiplicity

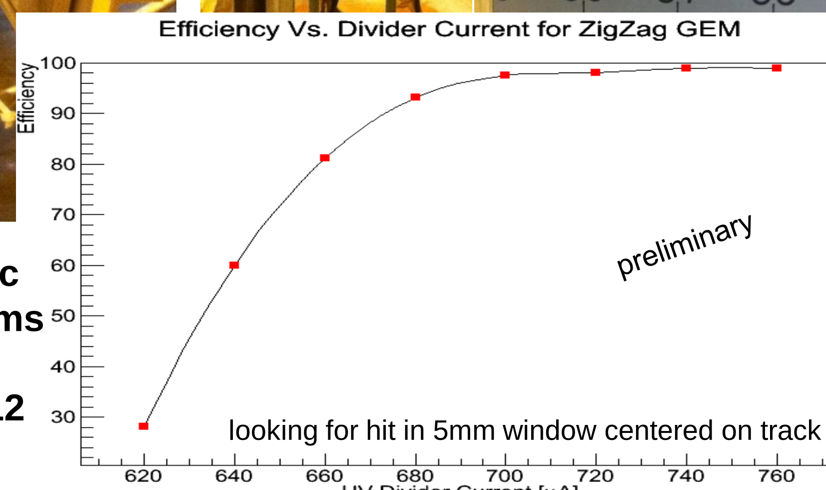


2012 CMS beam test @ SPS



150 GeV/c
μ & π beams

June 2012



Zigzag strips vs. straight strips

	Pitch [mm]	Typical Resolution [μm]
Zigzag strips & analog r/o	2.0	80
Straight strips & VFAT (current design, short end)	0.6	300
Improvement factor w/ zigzag strips	**3.33**	**3.75**

Can reduce # of readout channels (and electronics cost) **by 70%** of current design **&** Improve resolution by factor 3-4

A "figure of merit": $3.33 \times 3.75 = 12.5$

~ Potential for order of magnitude improvement over current design

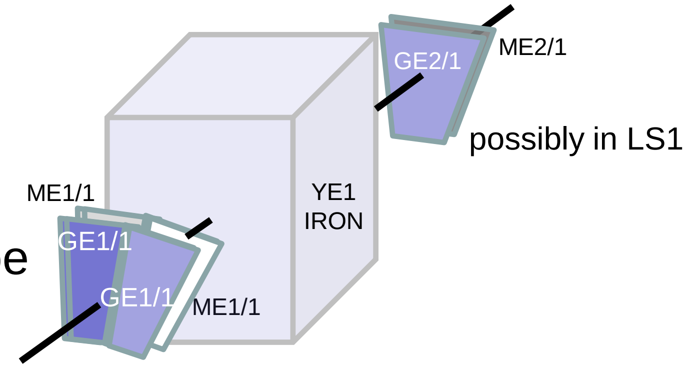
⇒ Well worth a try!

GEMS FOR CMS: PLANS, SUMMARY, CONCLUSIONS

CMS GEM Plans

Hardware

- **Now:** To be established with summer 2012 beam test data:
  - full viability of self-stretched, spacerless, large-area GE1/1 chambers
  - 4ns time resolution in large-area GE1/1 chambers with optimized E-fields
- **Medium-term**:
  - Installation of **4 GE1/1 production chambers** (2 super chambers) in CMS during **LS1**
  - Targeting electronic readout using first prototype of final DAQ using µTCA



- **Long-term**: Installation of a **demonstrator system in LS2**
  - ~ 90^{o} sector in one endcap with all 4 muon stations instrumented: **9×2 GE 1/1, 4×2 GE2/1, 4×2 GE3/1, 4×2 GE4/1** (pending CMS decisions)

Software

- Develop G4 simulation tools for GEM system and integrate into CMSSW
- Detailed muon reconstruction and physics studies of expected performance

Summary & Conclusions

- Detector development
  - In-depth detector R&D program has demonstrated large-area GEM detectors that perform well
  - Positive implications for future mass production efforts
    - Chamber construction techniques being continuously improved and simplified
    - Industrial GEM foil production appears achievable
- Electronics development
  - FE and DAQ design well underway; in synch with other CMS and LHC electronics projects
  - potential cost saving designs under study (zigzag)

We gratefully acknowledge here the RD51 Collaboration for its strong support of our detector construction, testing and data-taking and for the many fruitful discussions

- Integration and services in CMS
  - studied in sufficient detail
  - no show stoppers found
- GEMs have promise of improving CMS muon tracking and triggering substantially for Phase 2
  - High-η redundancy and robustness would increase muon acceptance × efficiencies
  - Hardware input of GEM information to CSC L1 track-finding garnering interest
  - GEMs will improve muon momentum resolution for high-pT muons

And now for something different…

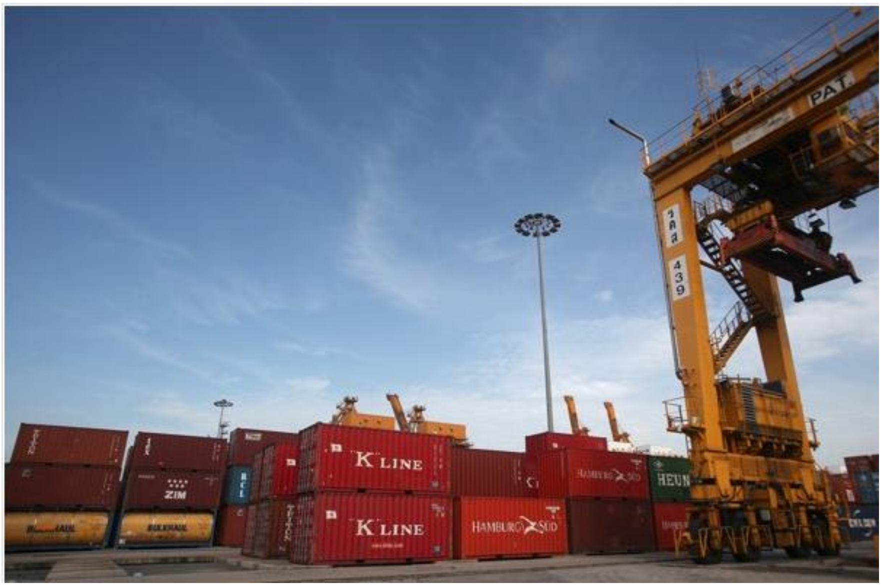
GEMS FOR MUON TOMOGRAPHY

Recent news…

National Security

In the News   Island dispute   Britain pushes back   Clinton in Egypt   Afghan lawmaker

Port security: U.S. fails to meet deadline for scanning of cargo containers



By Douglas Frantz, Updated: Sunday, July 15, 4:05 PM

The Obama administration has failed to meet a legal deadline for scanning all shipping containers for radioactive material before they reach the United States, a requirement aimed at strengthening maritime security and preventing terrorists from smuggling a nuclear device into any of the nation's 300 sea and river ports.

The Department of Homeland Security was given until this month to ensure that 100 percent of inbound shipping containers are screened at foreign ports.

But the department's secretary, Janet Napolitano, informed Congress in May that she was extending a two-year blanket exemption to foreign ports because the screening is proving too costly and cumbersome. **She said it would cost $16 billion to implement scanning measures at the nearly 700 ports worldwide that ship to the United States**.

Instead, the DHS relies on intelligence-gathering and analysis to identify "high-risk" containers, which are checked before being loaded onto ships. Under this system**, fewer than half a percent of the roughly 10 million containers arriving at U.S. ports last year were scanned before departure.** The DHS says that those checks turned up narcotics and other contraband but that there have been no public reports of smuggled nuclear material.

…

The DHS says monitors scan 99 percent of the containers for radiation after they arrive at U.S. ports. But experts say the monitors at U.S. ports are not sophisticated enough to detect nuclear devices or highly enriched uranium, which emit low levels of radiation.

…

… on an old problem

Colorado Sen. Eugene Millikin pressed Oppenheimer about **how to find a bomb hidden in a city:**

Sen. Millikin: **"***We... have mine-detecting devices, which are rather effective... I was wondering if anything of that kind might be available to use as a defense against that particular type of use of atomic bombs."*

Dr. Oppenheimer: ***"If you hired me to walk through the cellars of Washington to see whether there were atomic bombs, I think my most important tool would be a screwdriver to open the crates and look. I think that just walking by, swinging a little gadget would not give me the information."***

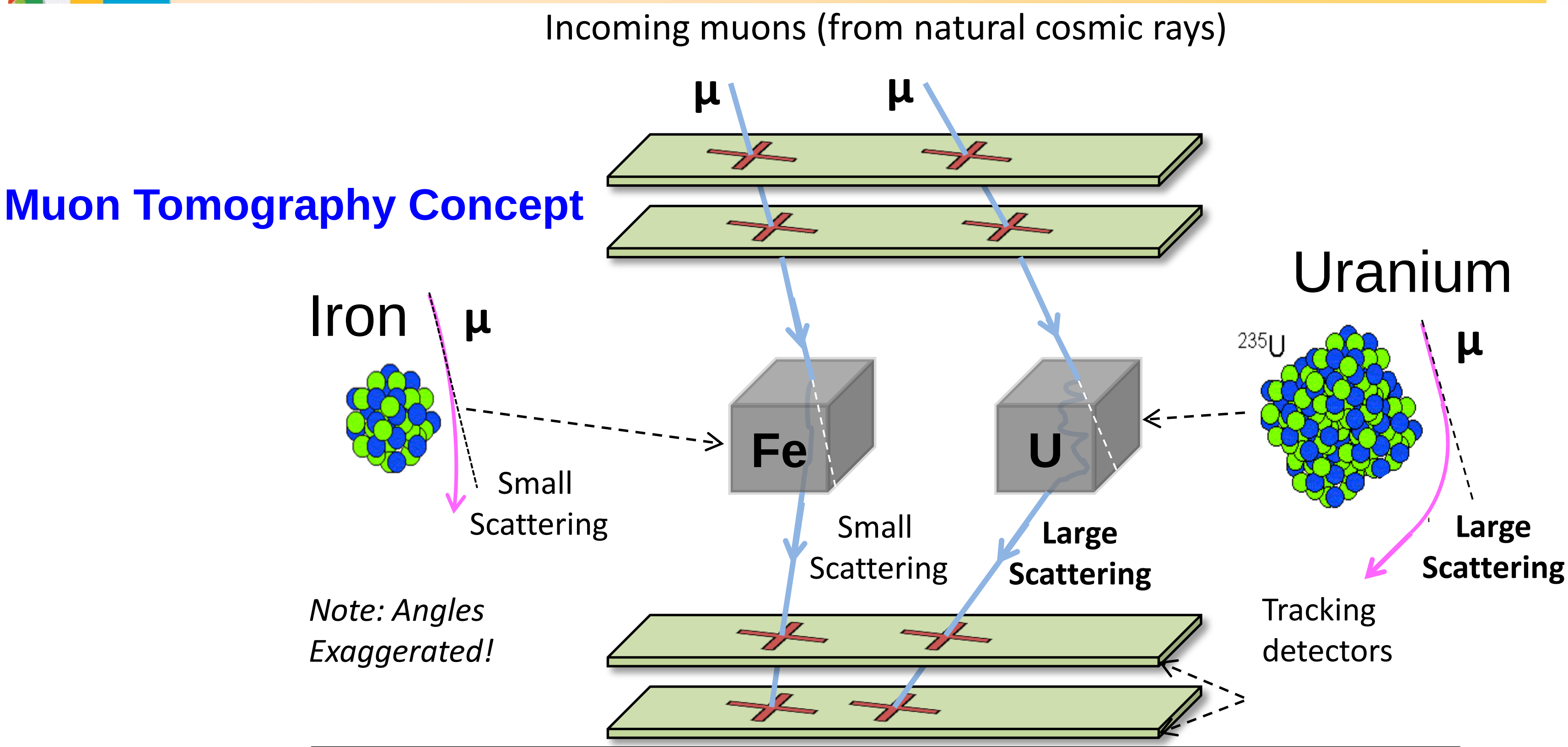
Transcripts from the National Archives

That candid assessment shocked the senators, who then asked the Atomic Energy Commission to examine the problem**. Robert Hofstadter and Wolfgang Panofsky**, a veteran of the Manhattan Project team that built the atomic bomb, produced a **still-classified assessment, which came to be known as the Screwdriver Report**.

Panofsky, now the director emeritus of the Stanford Linear Accelerator Center, says the assignment was to detect **1 cubic inch of highly enriched uranium or plutonium hidden inside a crate and smuggled across a land border**. "The conclusions of that report are still valid because the laws of physics have not changed one bit," Panofsky tells *U.S. News*. "You still can't detect a nuclear device unless you are, say, 10 feet away from it - and even then it can **be quite easily shielded**."

US News & World Report, 2/18/07

Towards a solution…



Multiple Coulomb scattering to 1st order produces Gaussian distribution of scattering angles θ with width $\sigma = \Theta_0$:

$$\Theta_0 = \frac{13.6\,\mathrm{MeV}}{\beta c p}\sqrt{\frac{x}{X_0}}\left[1+0.038\ln(x/X_0)\right]$$

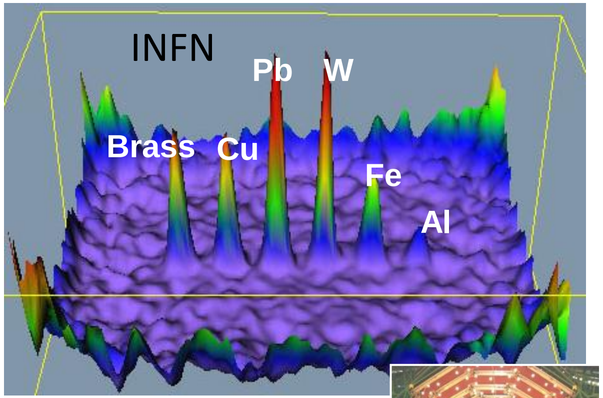
$Z \rightarrow$ Charge Number
$\beta c \rightarrow$ Velocity
$p \rightarrow$ Momentum
$X_0 \rightarrow$ Radiation Length
$x \rightarrow$ Width of Medium

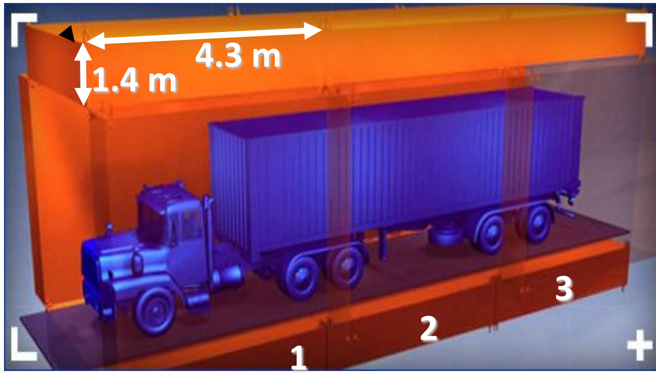
Where X_0 may be approximated by

$$X_0 = \frac{716.4\ \mathrm{g\ cm^{-2}} \cdot \mathrm{A}}{\mathrm{Z(Z+1)\ln(287/\sqrt{Z})}}$$

Drift Tube Muon Tomography

Reconstruction of 1 inch thick Pb letters

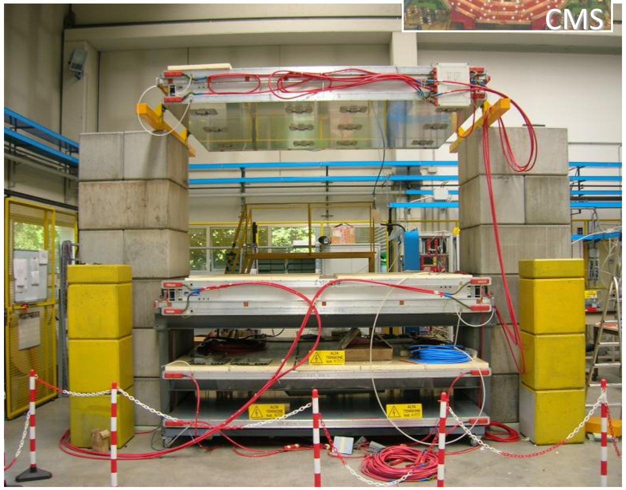




Decision Sciences Corp.: Multi-Mode Passive Detection System, MMPDS™

Original idea from Los Alamos (2003): Muon Tomography with Drift Tubes

J.A. Green, et al., “Optimizing the Tracking Efficiency for Cosmic Ray Muon Tomography”, LA-UR-06-8497, IEEE NSS 2006.



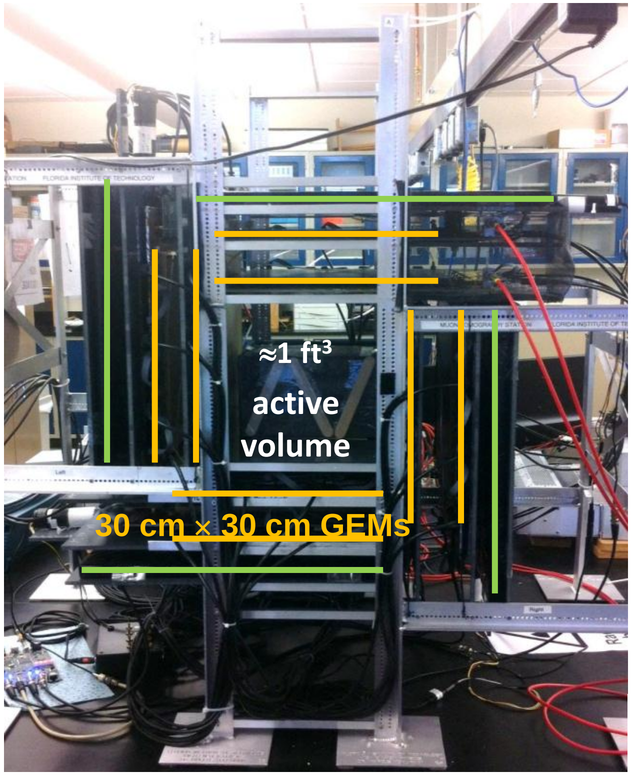
INFN : Muon Tomography with spare CMS Muon Barrel Chambers (Drift Tubes)

S. Presente, et al., Nucl. Inst. and Meth. A 604 (2009) 738-746.

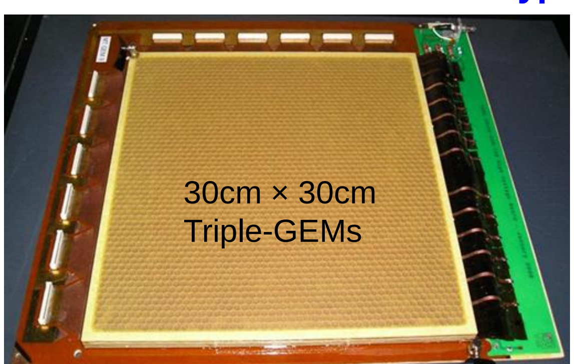
Decision Sciences prototype using drift tubes large enough to scan a vehicle.

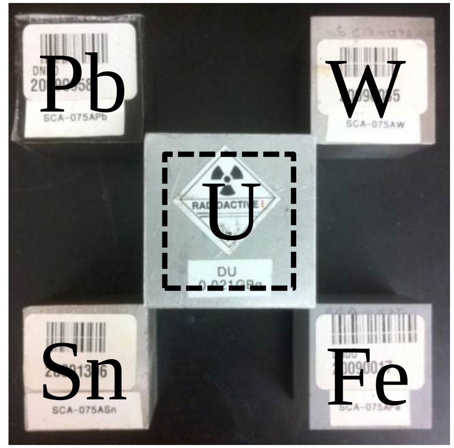
C. Milner, et al., “Non-Invasive Imaging of Reactor Cores Using Cosmic Ray Muons”, SMU Physics Department Seminar, March 2012.

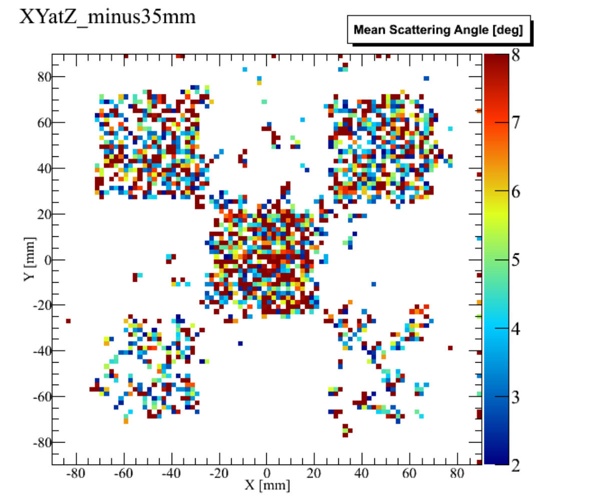
GEM Muon Tomography



Fl. Tech Cubic-Foot MT Prototype



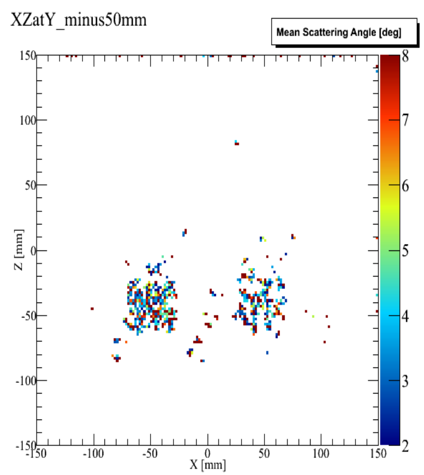


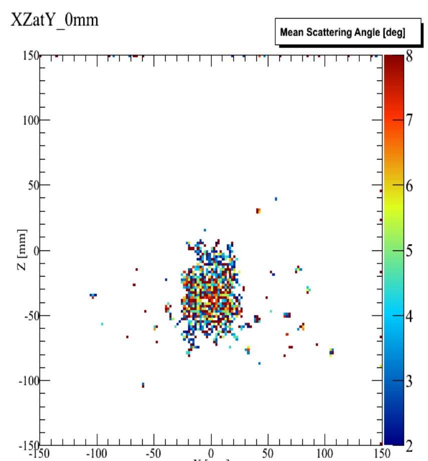


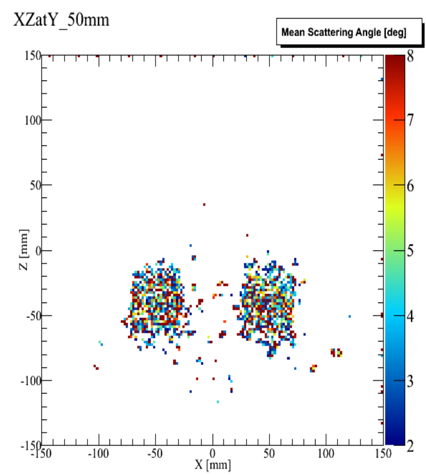
Top View

Point-of-closest-approach reconstruction for incoming & exiting track

Side views

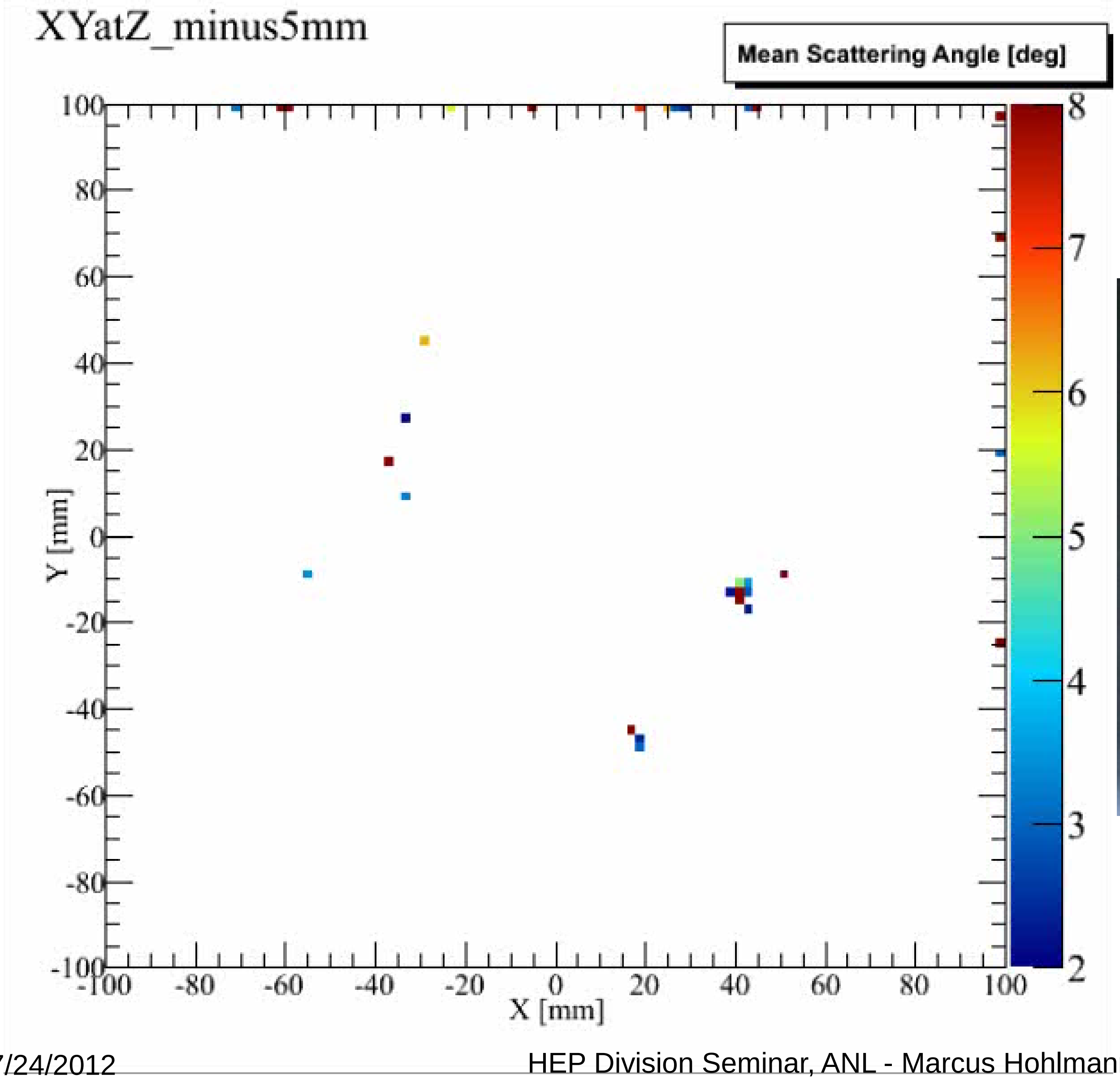




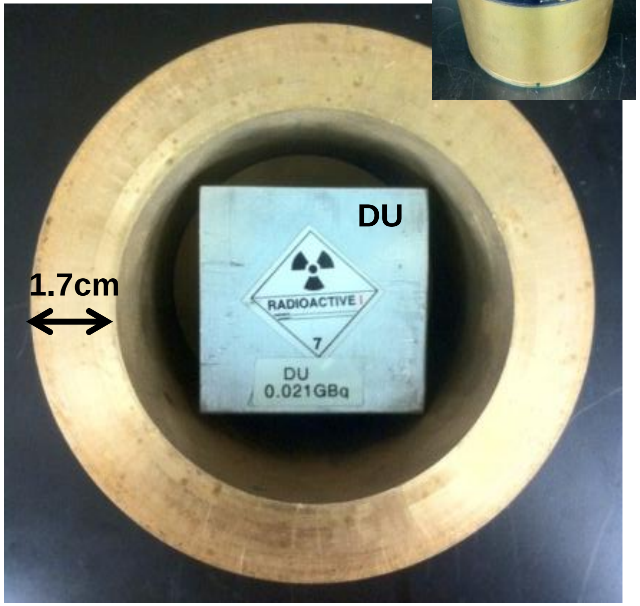


Uranium Shielded w/ Bronze

40 mm XY slices descending in Z by 5 mm per frame

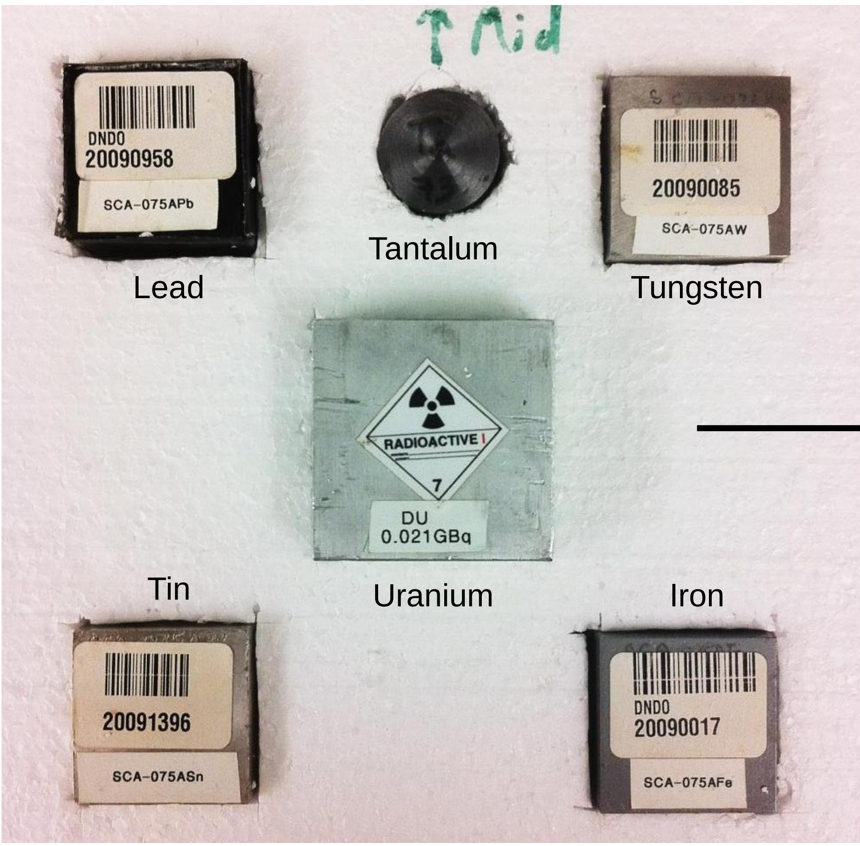


Tin-bronze shielding
(83% Cu, 7% Sn, 7% Pb, 3% Zn)
with X_0 = 1.29 cm & 1.7 cm walls

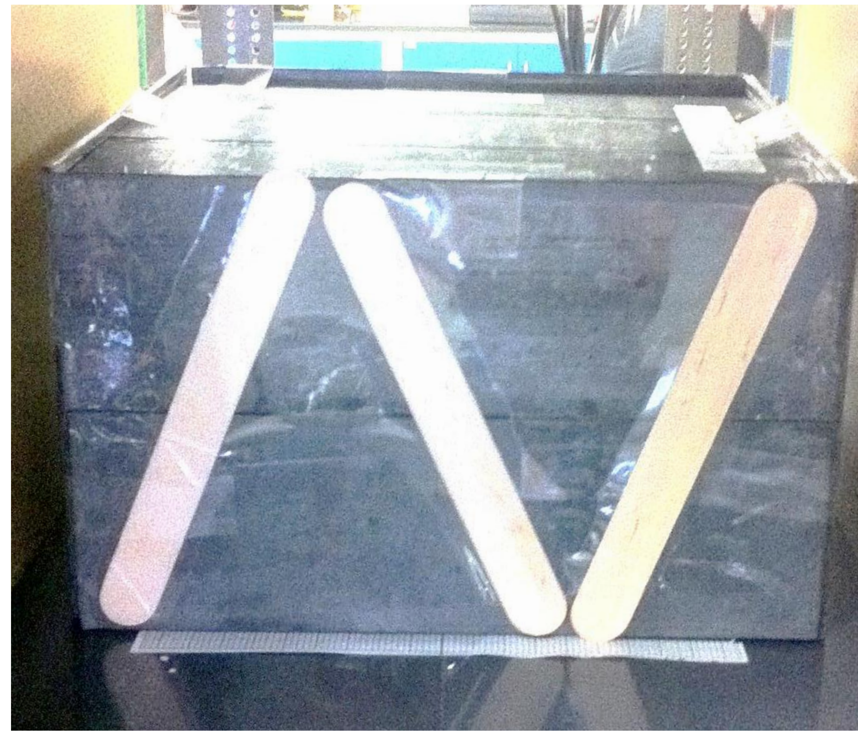


- Mixed track selection
- 187,731 reconstructed tracks
- NNP cut = 10
- 2 mm x 2 mm x 40 mm voxels

With Lead Shielding

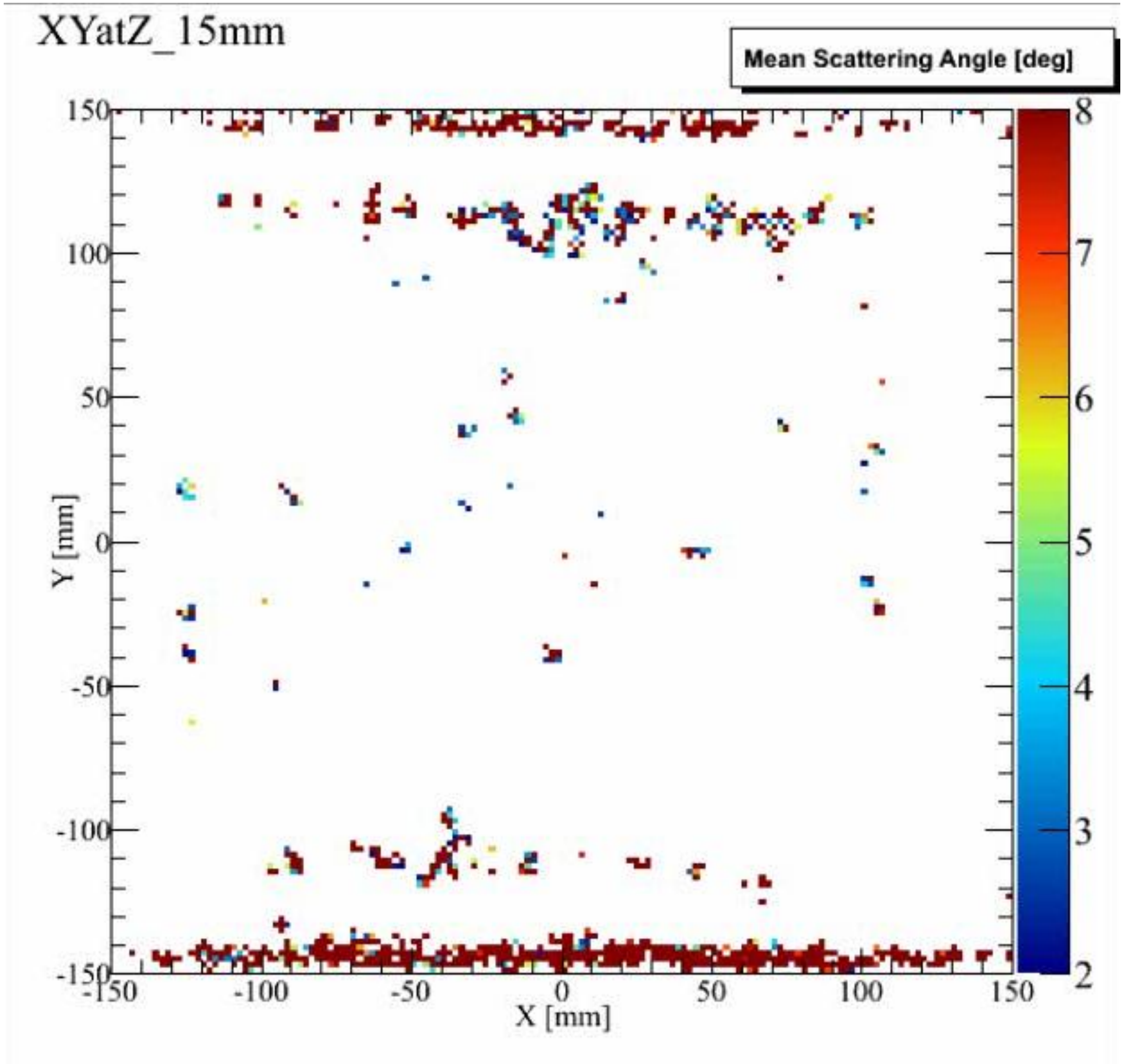


Lead box with 3.4mm thick walls

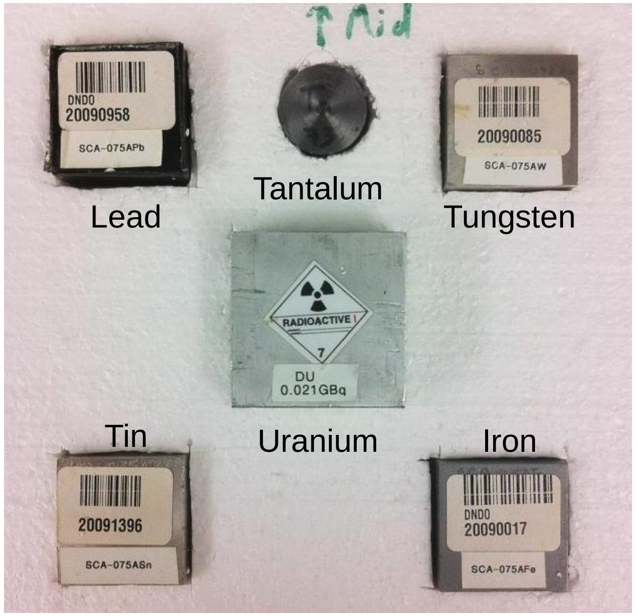


Muon Tomogram

40 mm XY slices descending in Z by 5 mm per frame



The shielded targets are **clearly visible** in the reconstruction



- Combinatoric track selection
- 292,555 reconstructed tracks
- NNP cut = 5
- 2 mm x 2 mm x 40 mm voxels

Thank you for your time!

Acknowledgments:

Many thanks to Paul Aspell (CMS GEMs, CERN), Eraldo Oliveri (Pisa), Archana Sharma (CMS GEMs, CERN), Mike Staib (Fl. Tech), Maxim Titov (RD51, Saclay) for making slides available for the preparation of this presentation.

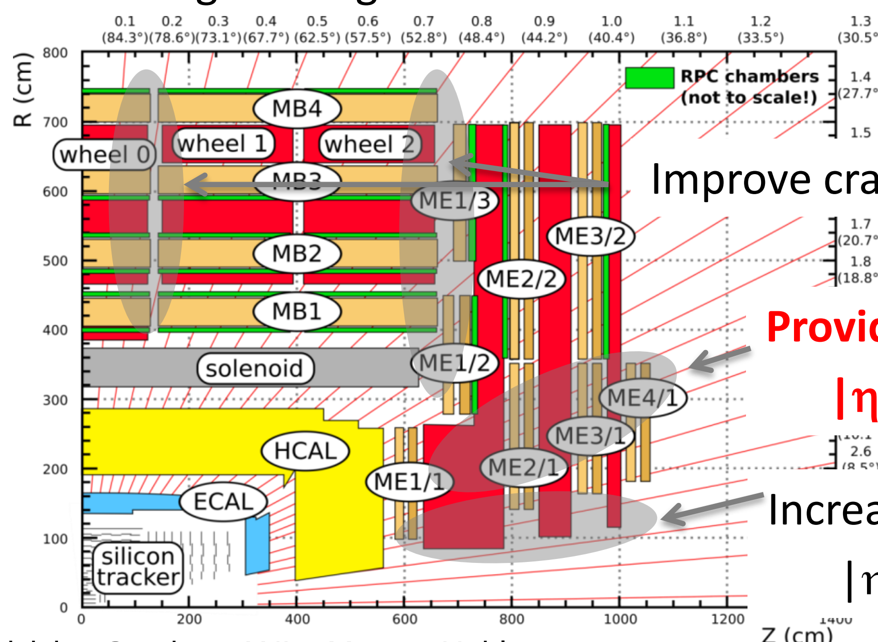
BACKUP SLIDES

LHC Phase 2: CMS Muon Issues

- New *Muon Strategy Group* organized by Muon IB for **long-range muon planning** to deliver an initial report in July and more complete plan in Dec 2012:
  - Detector longevity, trigger sustainability & evolution, **new muon detectors**

- Muon chambers are generally expected to survive into LHC phase 2 (= beyond LS3)
  - Simulated rate increase with luminosity compares well to data
  - Barrel DT and RPCs should sustain 75 Hz/cm^2 at 5 × 10^{34} with some margin; no known radiation dose issues for detector and electronics
  - CSCs designed for 30 years of LHC (needs re-evaluation) - full exposure of M1/1 chambers to be foreseen – rates capabilities being investigated
  - RPCs should sustain rates in $|\eta| < 1.6$ – investigate hot spots at GIF++, though!

- **Investigate new technology opportunities for $|\eta|>1.6$:**
  - **GEMs**
  - Glass RPCs (recent)



Improve crack regions

Provide redundancy

$|\eta| = 1.6 - 2.4$

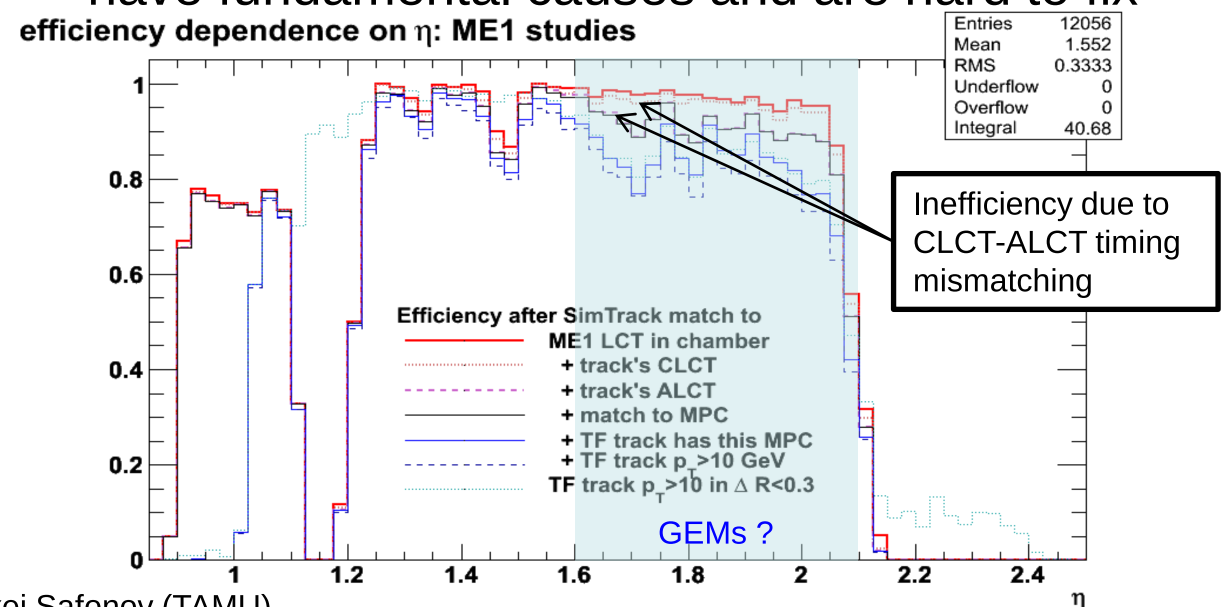
Increase coverage

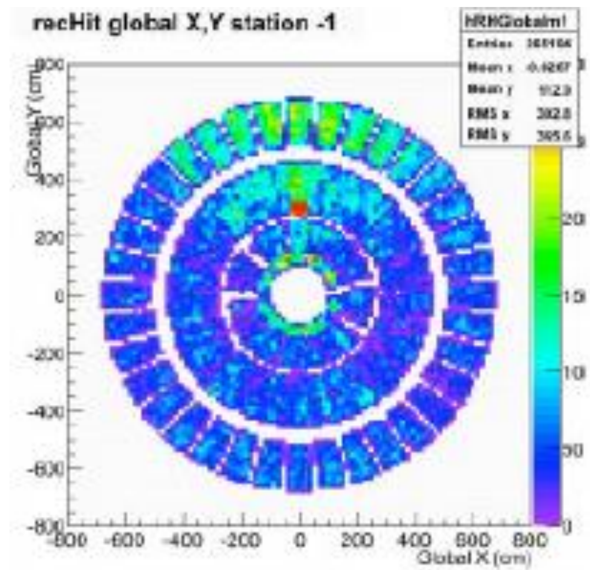
$|\eta| > 2.4$?

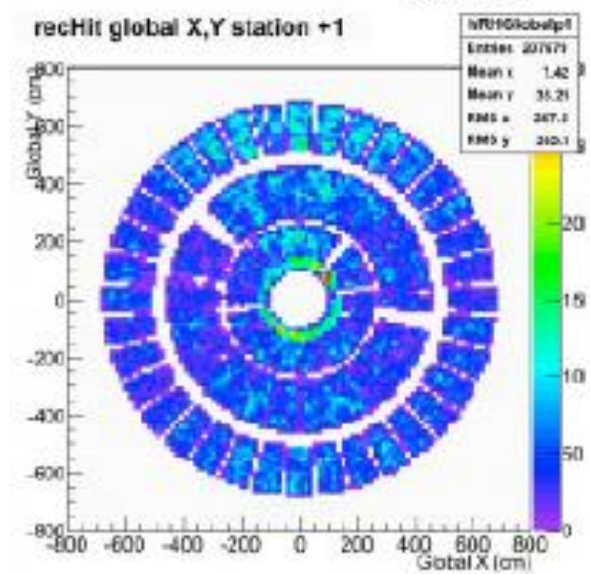
D. Contardo, J. Spalding, CMS week 06/25/12

Importance of Redundancy

- ME1/1 data:
  - White spaces are dead on-chamber electronics (currently lost due to lack of redundancy)
- **CSC ME 1 trigger stub finding inefficiency** (2009 studies @ **PileUp=400**)
  - Track finding algorithm has since improved
  - Losses due to stub timing mismeasurements have fundamental causes and are hard to fix



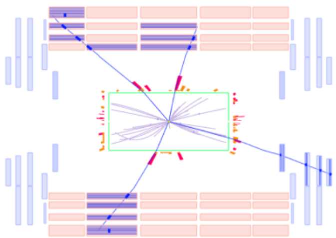




Alexei Safonov (TAMU)

Full Physics Studies to come

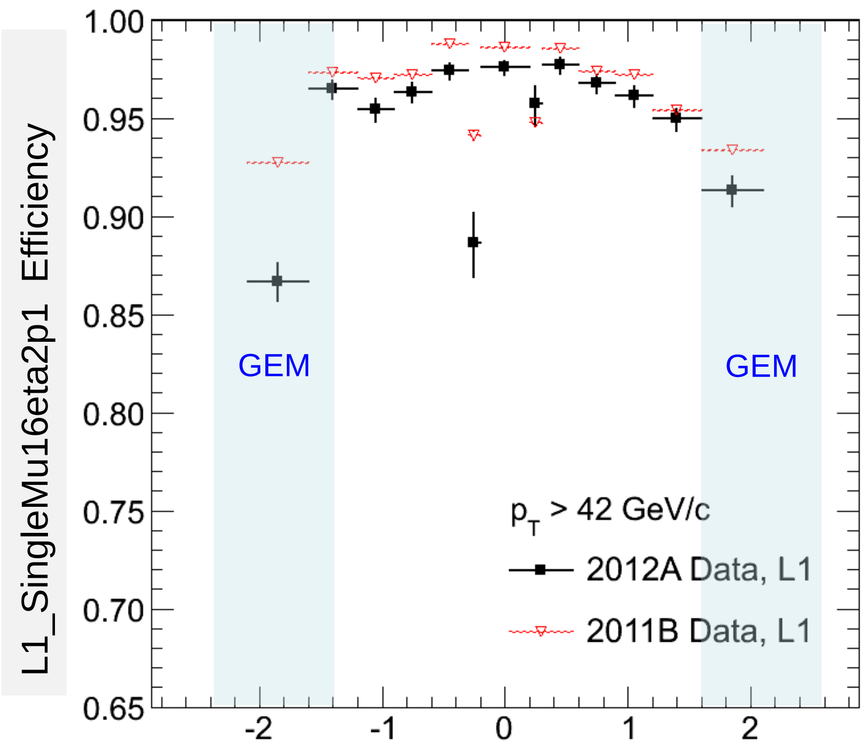
- Plan to develop GEANT & CMSSW tools for full simulation of GEM system within CMS upgrade
- Study potential benefits for physics with muons
  - Multi-muon final states, e.g. $H \to ZZ \to 4\mu$
  - Exotica high priority analyses, e.g. $Z' \to 2\mu$
  - Boosted topologies with muons, e.g. $Z' \to t\bar{t} \to 2\mu + X$
  - Forward-backward asymmetries
  - Low rate channels, e.g. $H \to 2\mu$
  - B-physics using semileptonic decays (?)
  - …



- Effort started recently (K. Hoepfner, M. Maggi, M. Schmitt, et al.)

Muon trigger efficiency issues

- Example: L1_SingleMu16eta2p1 (seed of HLT_Mu40eta2p1)
- One may ask:
  - Is it good enough?
  - Will it degrade at higher luminosity?



Jay Hauser (UCLA), Muon Strategy Meeting, CMS Week June 2012

Main CSC challenge @ HL is triggering:

- **High background rates** in forward region
  - Trigger rate is dominated by junk muons reconstructed as high p_T muons
- **Muon trigger stub losses** drive inefficiency
  - Dead electronics, spaces between chambers, but also algorithmic losses
  - Especially undesirable in station ME 1, which is key for momentum resolution
- Inefficient for events w/ **3+ nearby** muons
  - Predicted in new physics models; we don't want to miss our next discovery due to electronics limitations

Alexei Safonov (TAMU), 2-day GEM Electronics meeting, July 2012

→ Use GEM hits as additional input for CSC trigger stub generation at L1

Tech. Approach - GEM Physics Study

- Identify reference analyses for comparison with present CMS geometry
- Provide GEM input, geometry, and digitization
- Generate samples
  - Smaller signal samples to verify performance (private production)
  - Single muon gun with fixed muon p_T (private production possible)
  - Larger background samples
- Run existing analysis with present selection (non optimized for high lumi scenario). Compare performance with new geometry against 2011/12 physics analyses.
- Optimize analysis for higher Pile-Up (e.g. ~50 PU, now ~20 PU) and HL-LHC conditions, e.g. different triggers, muon ID, etc.

K. Hoepfner (Aachen), GEM software meeting, May 2012

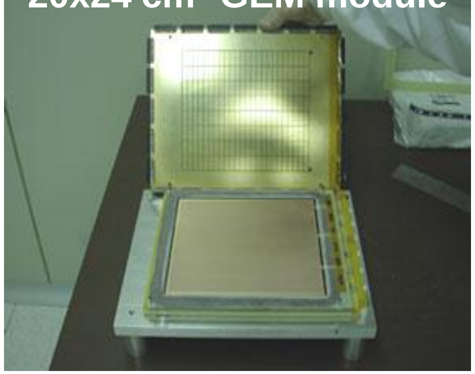
CURRENT GEM USES @ LHC

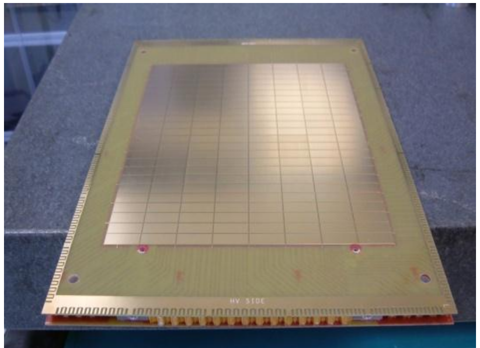
GEMs @ LHCb

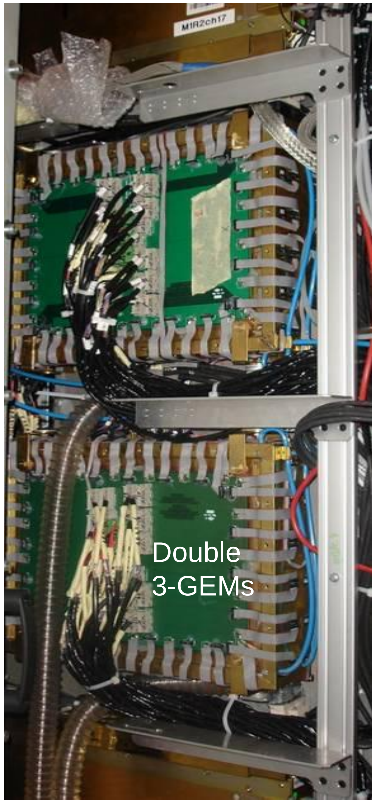
GEMs for LHCb L0 Muon Trigger:

- **Operating since LHC startup**
- **Rate up to 500 kHz/cm^2**
- **Efficiency > 96% in 25ns window (using OR)**
- **Time resolution 4.5 ns (rms)**
- **Rad-hard up to integrated charge of ≥ 2 C/cm^2 (15 LHCb years)**

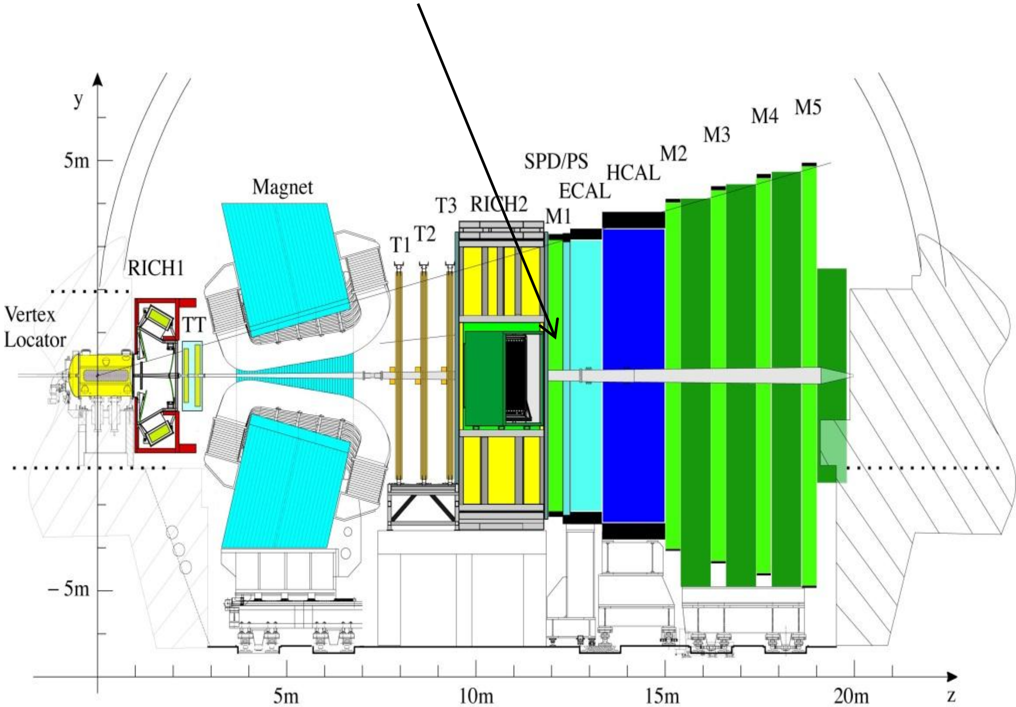
Parameter	Design value
Gas Mixture	$Ar/CO_2/CF_4$ (45:15:40)
Gas Gain	$\simeq 6 * 10^3$
Radiation Hardness	1.6 C/cm^2 in 10 years
Chamber active area	20x24 cm^2


20x24 cm^2 GEM module


Readout: 1cm × 2.5 cm pads

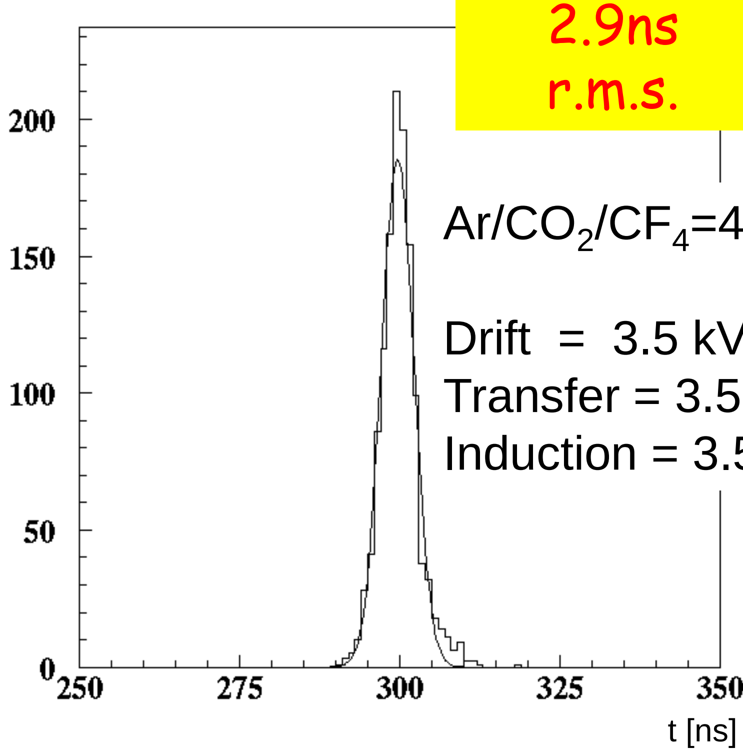

Double 3-GEMs

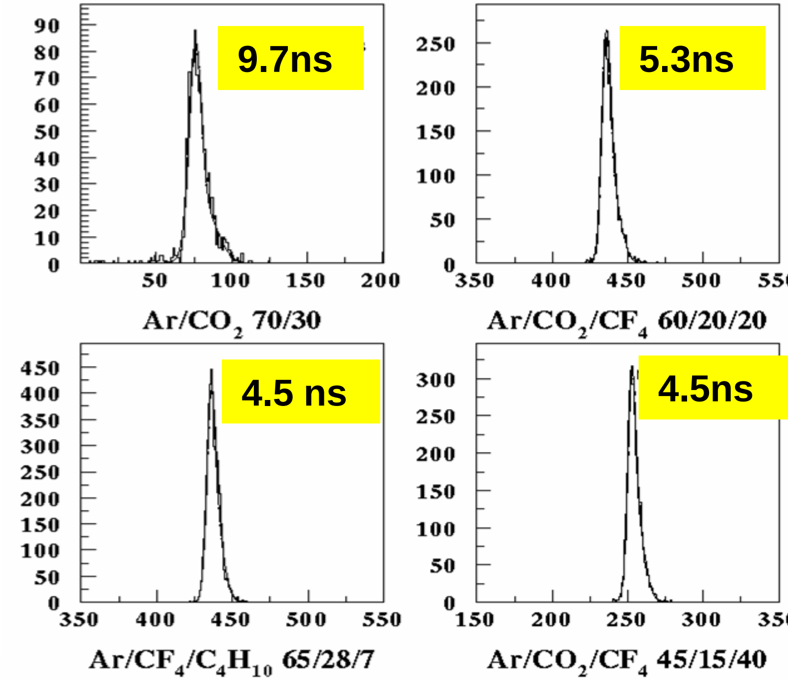
12 Double Triple-GEMs **in front** of calorimeter; total area 0.6 m^2



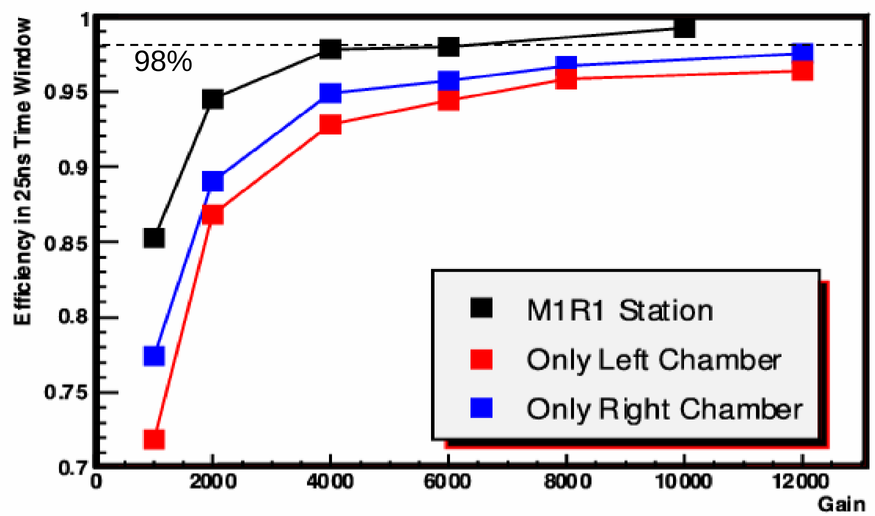
GEMs @ LHCb

Time resolution for **two OR'ed chambers**



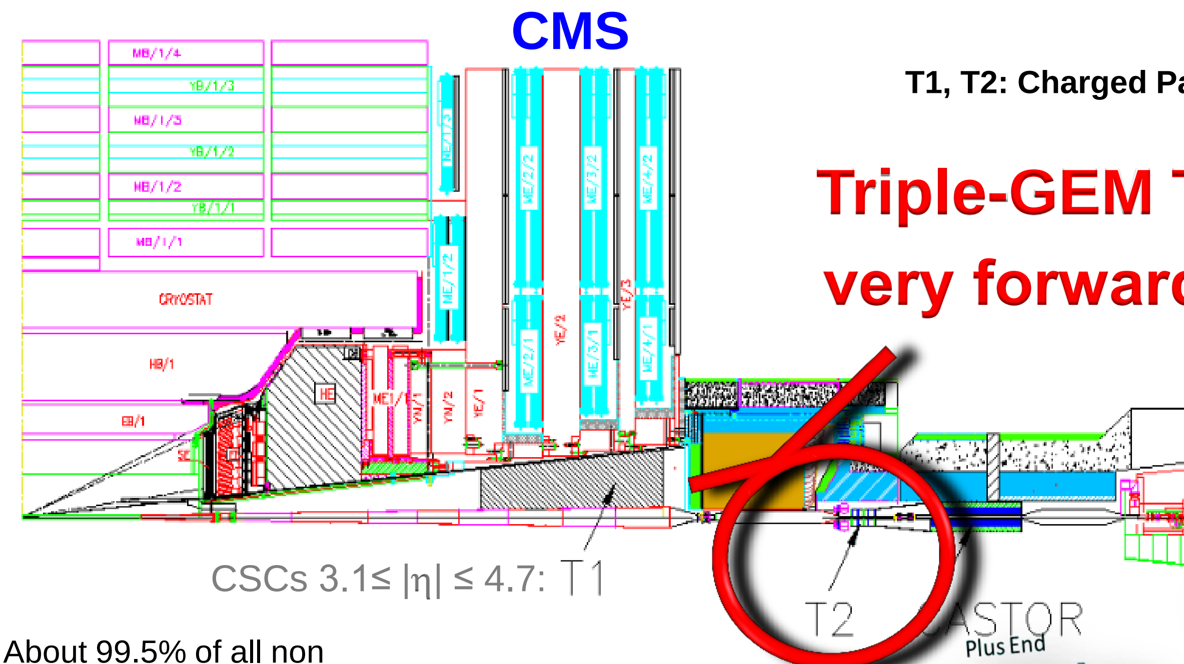


Measured efficiency in 25ns window



M. Alfonsi (Frascati), MPGD Workshop, CERN, Sep 2007

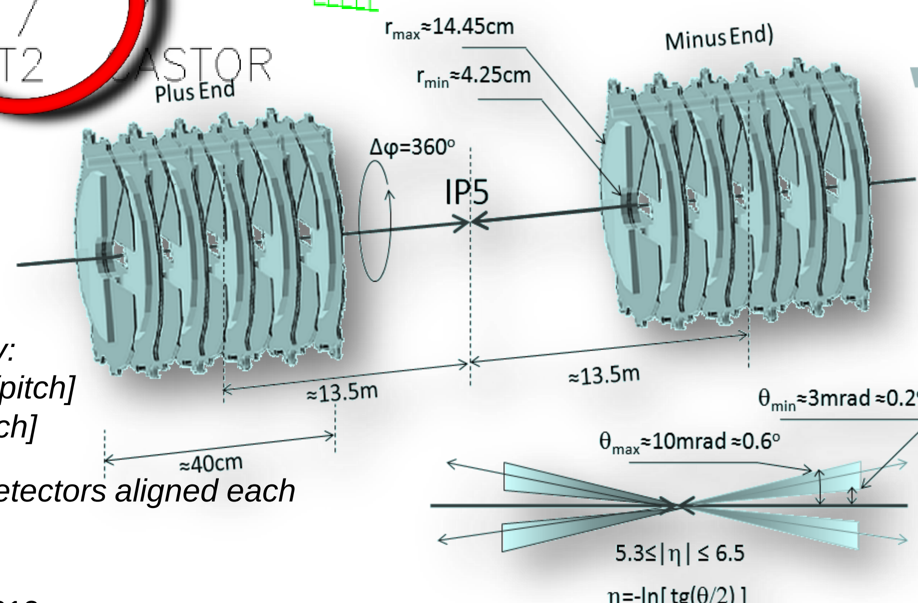
GEMs @ TOTEM



T1, T2: Charged Particles in Inelastic Events

Triple-GEM Telescope T2: very forward at 5.3 ≤ |η| ≤ 6.5

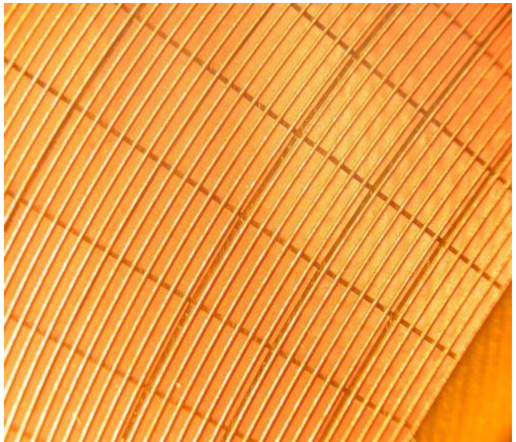
About 99.5% of all non diffractive minimum bias events and 84% of all diffractive events have charged particles within the acceptance of the TOTEM detectors,T1 and T2.



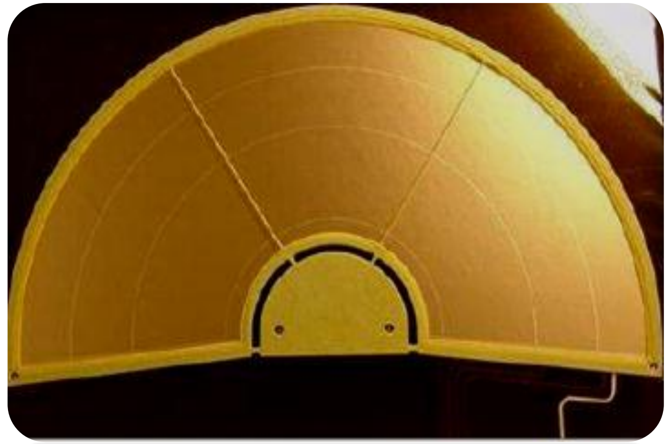
- *360° φ coverage*
- *Readout Granularity:*
  - *$\delta r \approx 400 \mu m$ [pitch]*
  - *$\delta\varphi = 2.9^o$ [pitch]*
- *4 quarters with 10 detectors aligned each*

E. Oliveri (INFN Pisa), 3rd CMS GEM Upgrade Workshop, April 2012

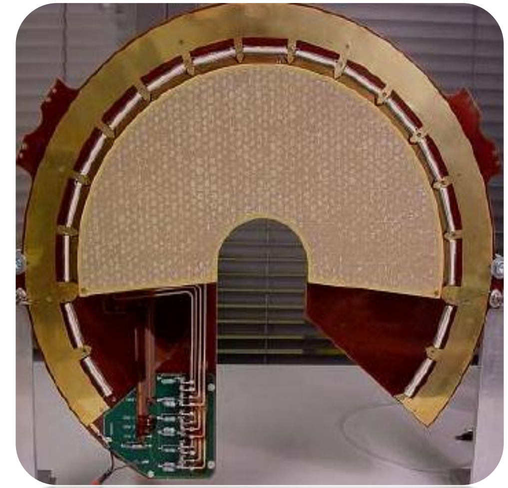
TOTEM T2 GEMs



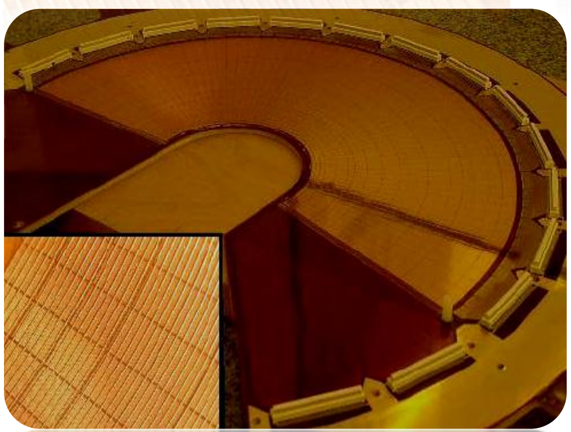
TOTEM 2D Readout Plane (strips & pads)



TOTEM GEM Foil

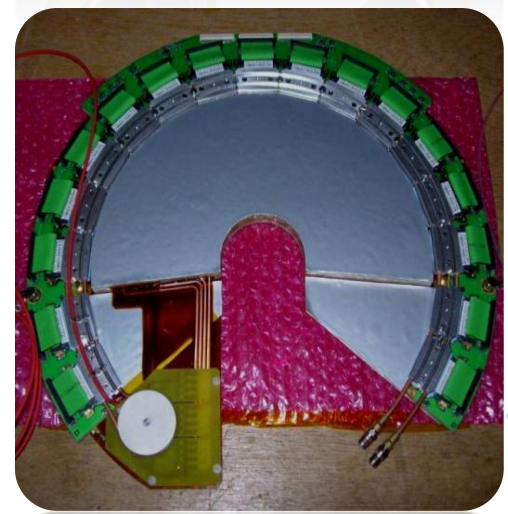


“Naked” TOTEM Triple GEM



Strips (r):
- *512 strips*
- *2 φ sectors of 256 each*
- *400μm pitch, 80μm width*
- ***mean cluster size ≈ 2.5-3***

Pads (triggering & φ):
- *1560 pads*
- *65 φ sectors of 24 each*
- *dφ = 2.9^o, dη = 0.05*
- ***mean cluster size ≈ 1.2-1.5***

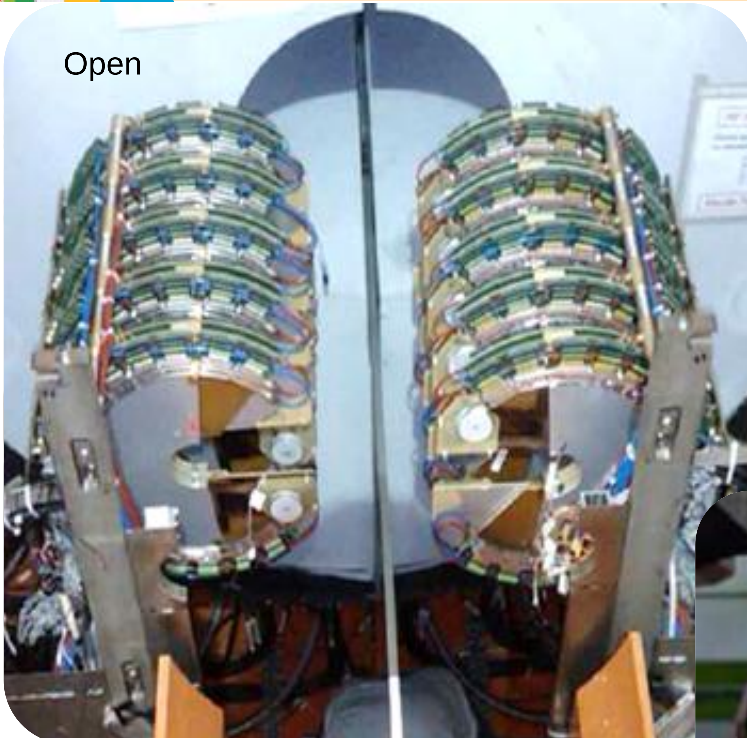


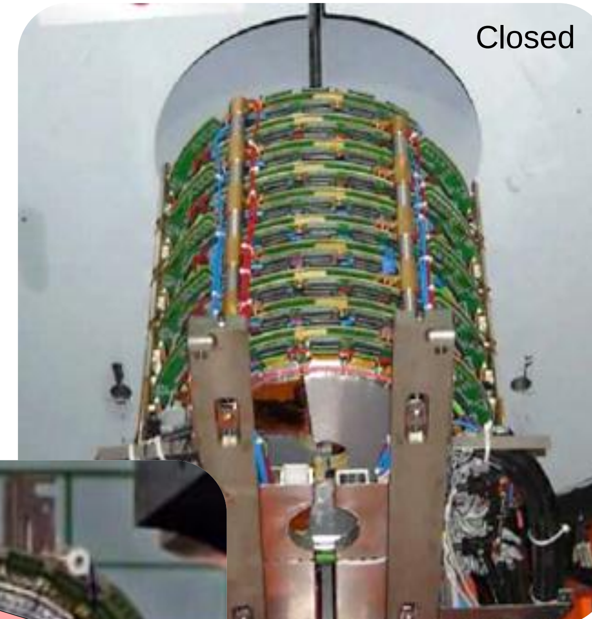
VFAT hybrids

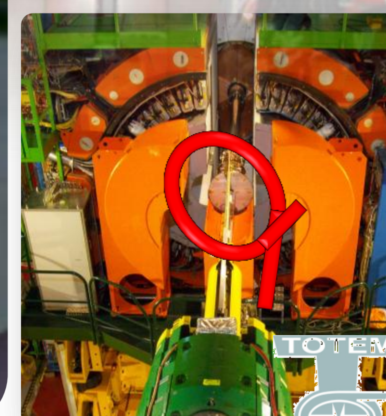
Fully Equipped TOTEM Triple GEM

E. Oliveri (INFN Pisa), 3rd CMS GEM Upgrade Workshop, April 2012

TOTEM T2 Tracker







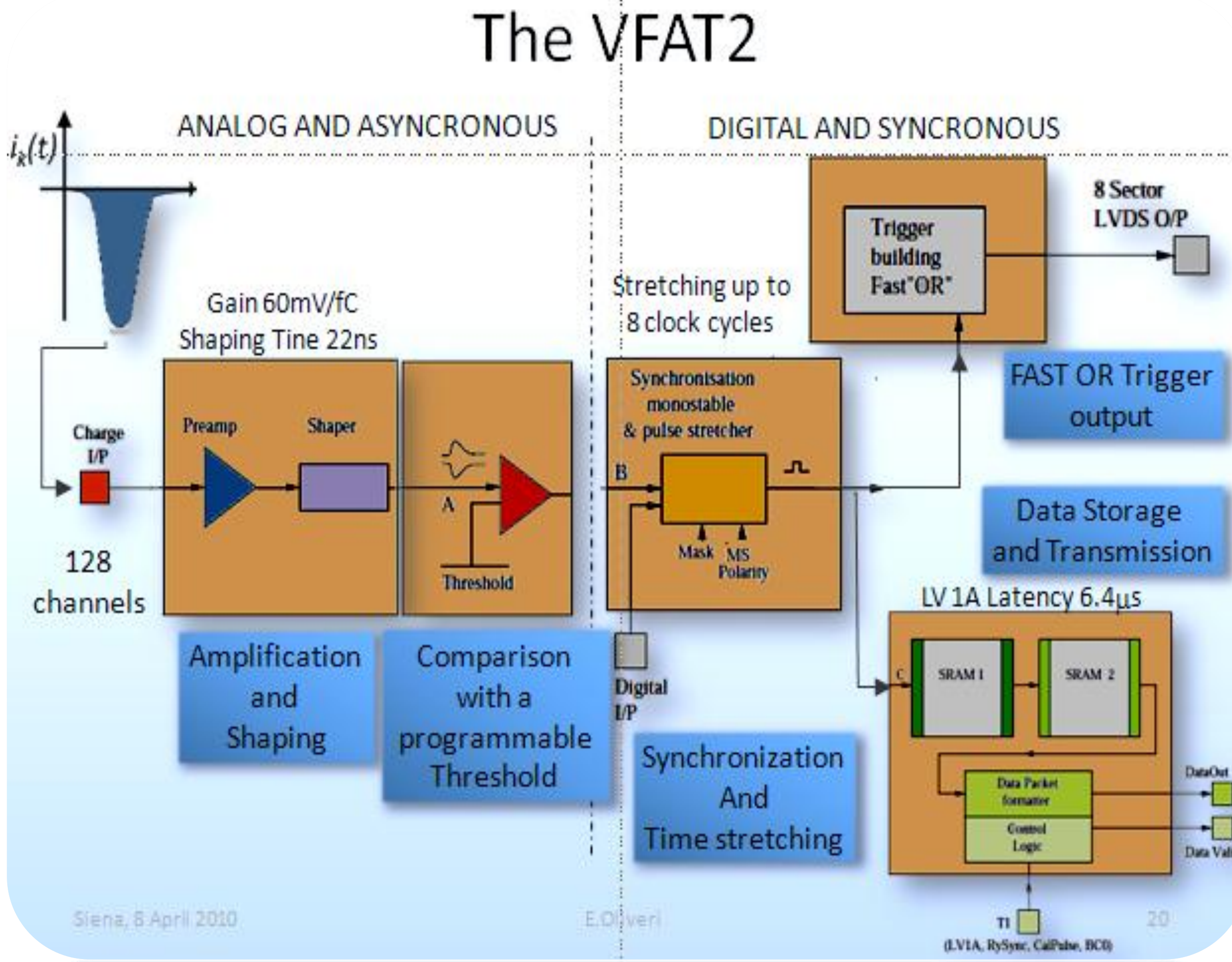
E. Oliveri (INFN Pisa), 3rd CMS GEM Upgrade Workshop, April 2012

TOTEM GEM Frontend chip

Triggering and tracking

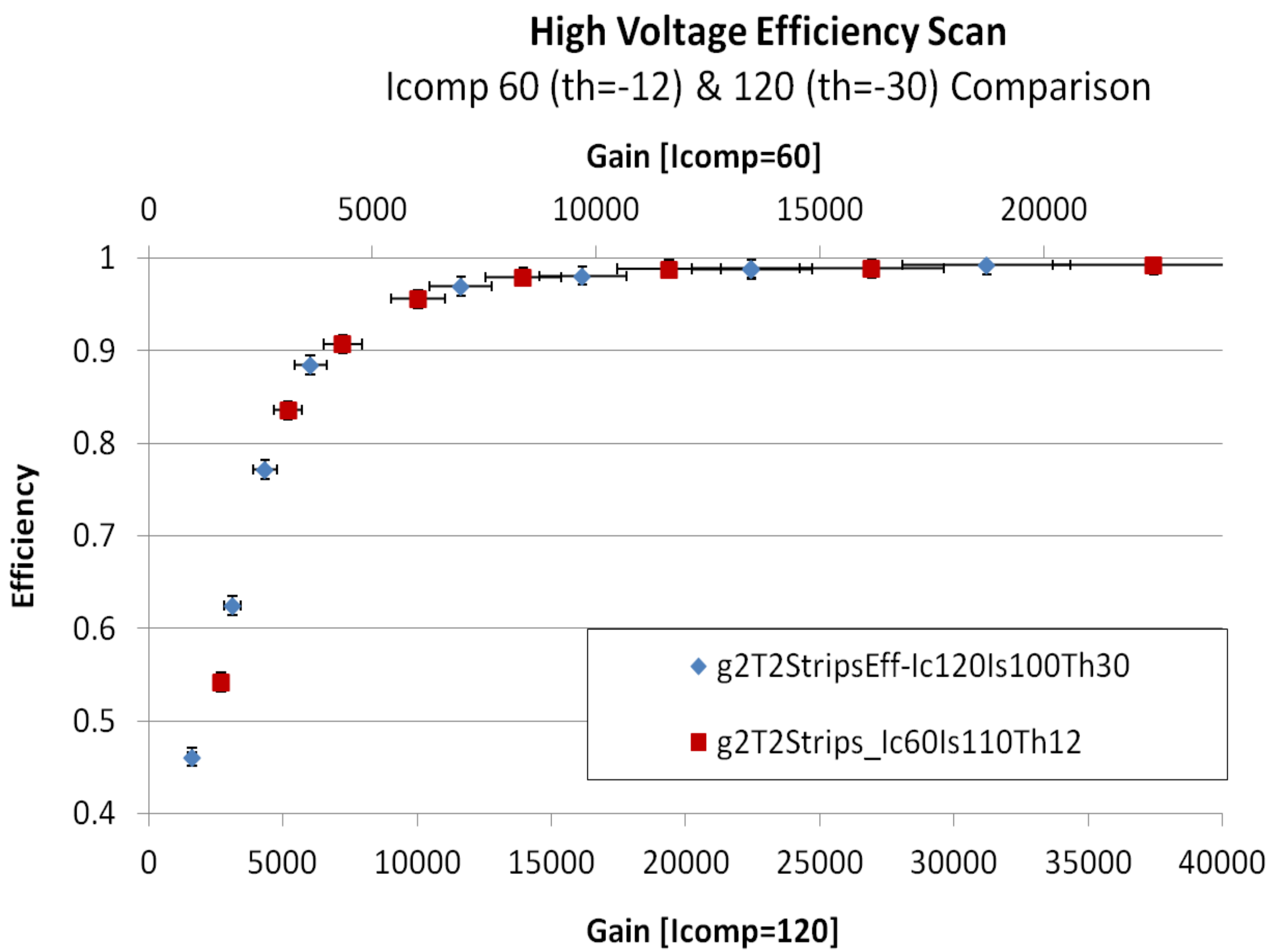
Synchronous front-end ASIC designed primarily for the TOTEM experiment and characterized by:

- *128 preamplifier-shaper-comparator readout chains to detect* ***signals above a programmable threshold***
- *Fast-OR lines (up to 8) that merge channels of programmable sectors to provide a* ***trigger signal***.



E. Oliveri (INFN Pisa), 3rd CMS GEM Upgrade Workshop, April 2012

TOTEM Efficiency w/ VFAT2

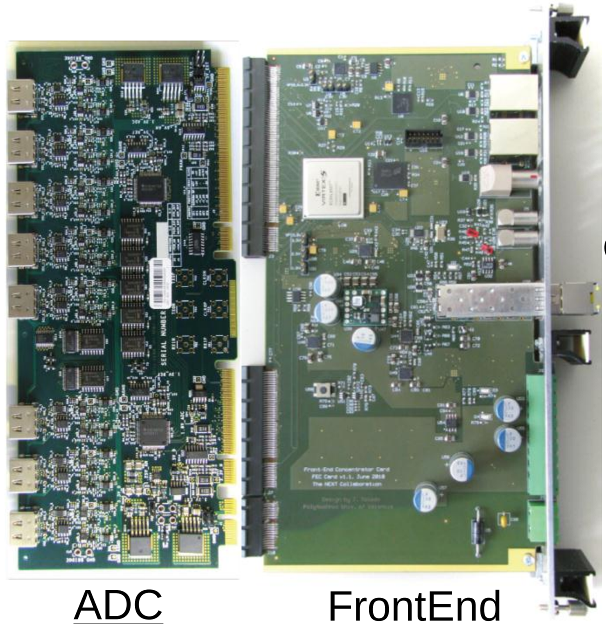


E. Oliveri (INFN Pisa), 3rd CMS GEM Upgrade Workshop, April 2012

RD51 Scalable Readout System

128 ch.

HDMI



Gb Ethernet

APV25 Hybrid

- 128 channel APV25 chip
- 192-deep analog sampling memory
- Master/slave configuration
- Diode protection against discharge
- RD51 standard 130-pin Panasonic connector interfaces to detector
- HDMI mini (type C) connector

ADC

- 2 x 12-Bit Octal ADC
- 8 x HDMI input channels (16 APV hybrids)

FrontEnd Concentrator

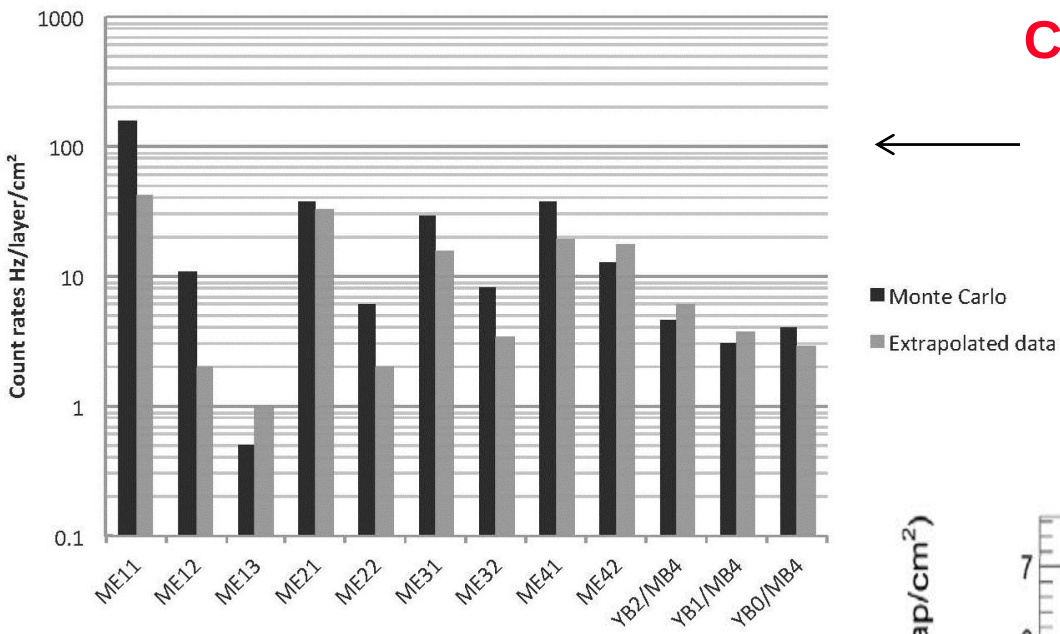
- Virtex LX50T FPGA
- SFP/Gb Ethernet/DTC interface
- NIM/LVDS GPIO (trigger, clock synch, etc.)

DAQ Computer

- Data Acquisition using DATE (ALICE @ CERN)
- Support added for data transfer via UDP
- Slow control via ethernet
- Online and offline analysis using custom package for AMORE (ALICE @ CERN)

J. Toledo, et al., "The Front-End Concentrator card for the RD51 Scalable Readout System," in *Topical Workshop on Electronics for Particle Physics*, Vienna, 2011.

Current Muon Hit Rates

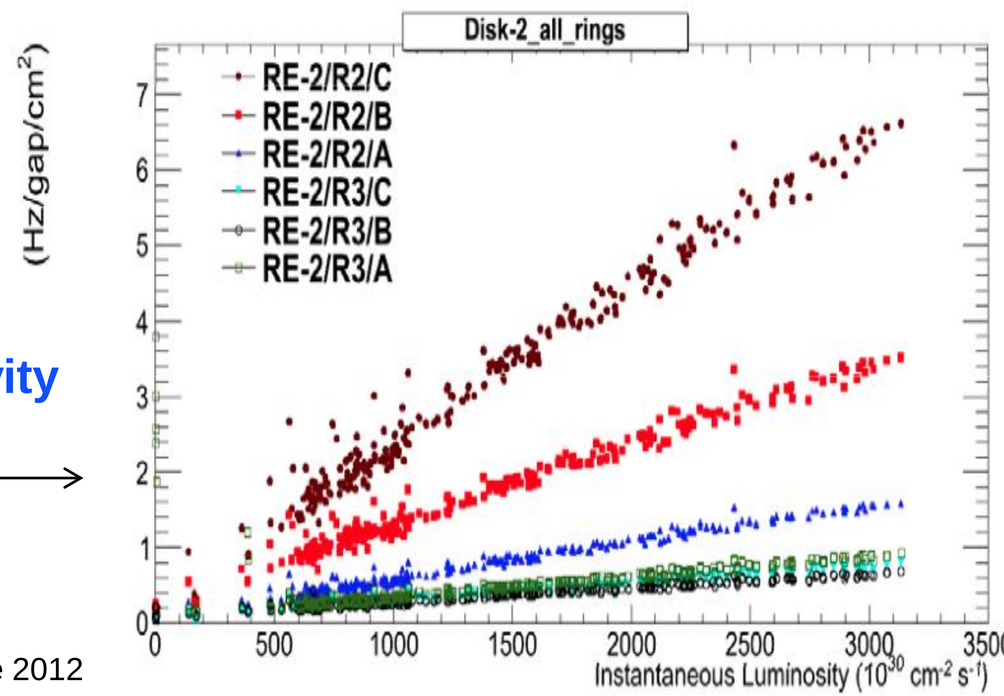


CSC and DT single-layer hit rates:

- **Highest rate in ME 1/1**
- **Scale well with luminosity**
- **Rates slightly lower than simulations in most cases**

Endcap RPC single-gap hit rates:

- **Simulation uses 0.1/1.0% sensitivity to neutrons/photons**
- **Similar to simulation**
- **Grow linearly with luminosity**

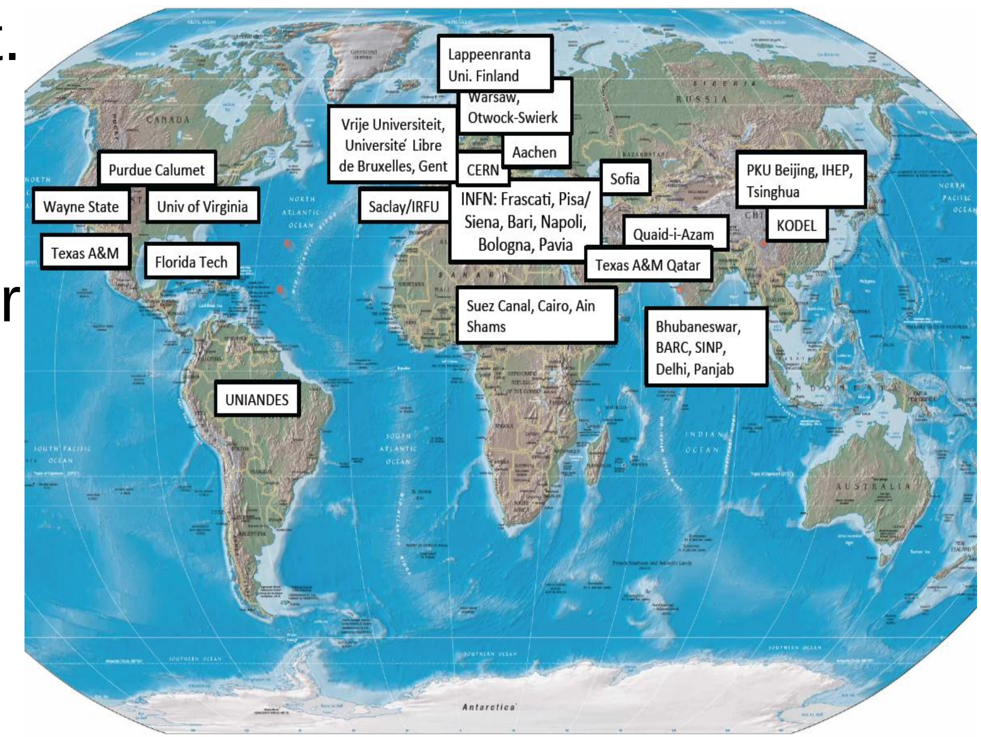


Jay Hauser (UCLA), Muon Strategy Meeting, CMS Week June 2012

Participation by USCMS groups

- **Fl. Tech:** detector R&D and production, beam tests, mgmt.
- **Wayne State:** beam tests & electronics
- **Texas A&M:** interest in trigger studies
- **Purdue Calumet:** interest in simulations
- **U. Virginia (tbc):** interest in detector R&D
- **Northwestern:** interest in muon reconstruction and physics studies

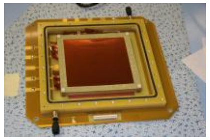
CMS GEM Collaboration (institutes signing 2012 TP)



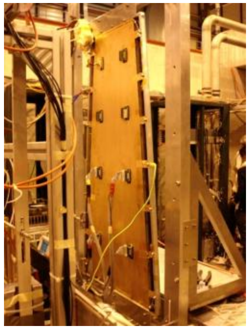
⇒ Good spectrum of tasks for USCMS institutions

R&D Project Milestones

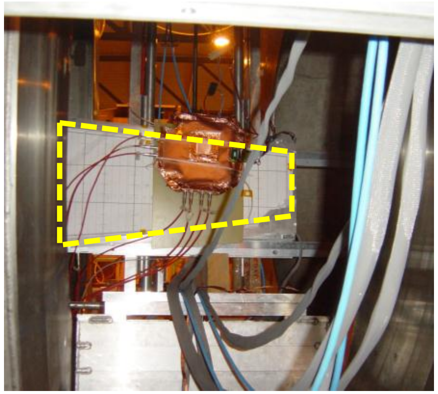
- **2009**
  - Small prototypes, bench tests; **picked GEMs** among MPGDs for further study
  - Established that **4 ns time resolution achievable**
  - **Large-area GEM foils** become available



- **2010**
  - First **large-area GE1/1 prototype**; beam test
  - **Workshop 1**
  - SLHC **R&D proposal 10.02 submitted** to CMS



- **2011**
  - Second **redesigned GE1/1 prototype** (smaller gaps b/w GEMs)
  - **"GEM Collaboration (GEMs for CMS)"** constitutes itself in May CMS week (76 collaborators from 15 inst.)
  - Summer beam tests (including first test in CMS test **magnet**)
  - Established **100µm (300µm) res.** with analog (binary) r/o chip
  - **"Self-stretch" GEM** foil assembly technique w/o spacers
  - Preliminary **electronics design starts**
  - **Workshop 2** & Project presented to Muon Institution Board



R&D Project Milestones cont'd

- **2012**
  - Internal **Technical Proposal** for two stations GE1/1 & 2/1 in LS2 submitted to Upgrade Mgmt. (Feb, CMS IN 2012-001, 104 pp., 35 inst., 176 signatories)
  - **Internal peer review** organized by CMS Upgrade Project Office (March)
    - Much interest in technology
    - Concerns raised about projected project cost (~ 6.5M CHF, mainly in electronics)
    - Suggestion: scaled-down "demonstrator system" in context of overall CMS muon upgrade strategy
  - **Workshop 3** (April; 3 days)
  - **Formally approved as R&D project of interest to CMS: RD10.02 (April 20)**

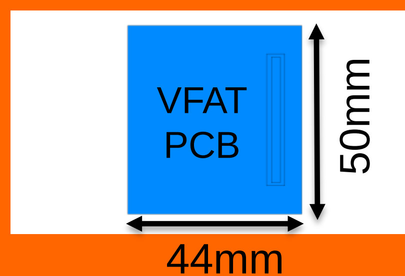
Proposal Name	Proposers	Submitted	Status	CMS SLHC RD #
…				
→ R&D for a high eta trigger and tracking detector for CMS	CERN, Frascati, Pisa, Ghent, Florida Inst. Tech, Beijing (Contact: Archana Sharma)	March 2010	Approved	10.02 ←
R&D of the Detector Systems for Stage One of the High Precision Spectrometer Project	HPS Collaboration (Contacts: Krzysztof Piotrzkowski, Marta Ruspa)	June 2010	Approved	10.03
…				

http://cmsdoc.cern.ch/cms/electronics/html/elec_web/docs/slhcusg/proposals/proposal_list.htm

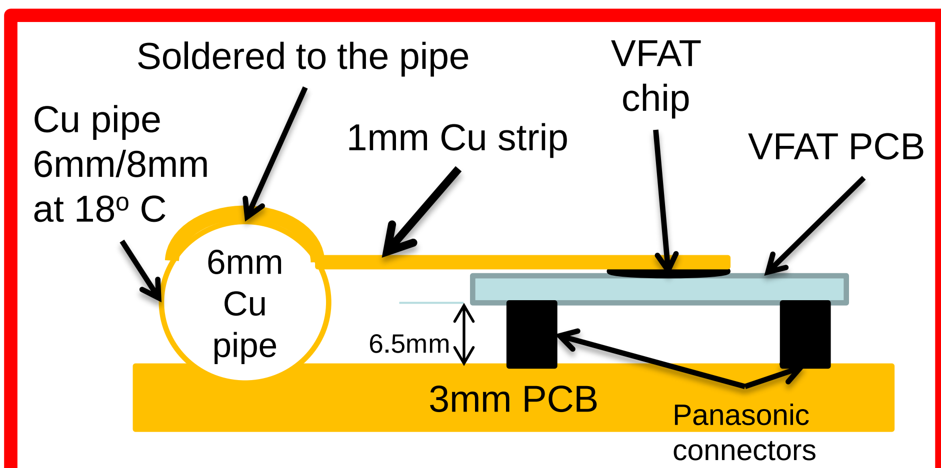
  - Construction of **5 production-style GE1/1** prototypes (May)
  - 5 weeks of **beam test** for production GE1/1 with RD51 coll. at SPS (June-July)

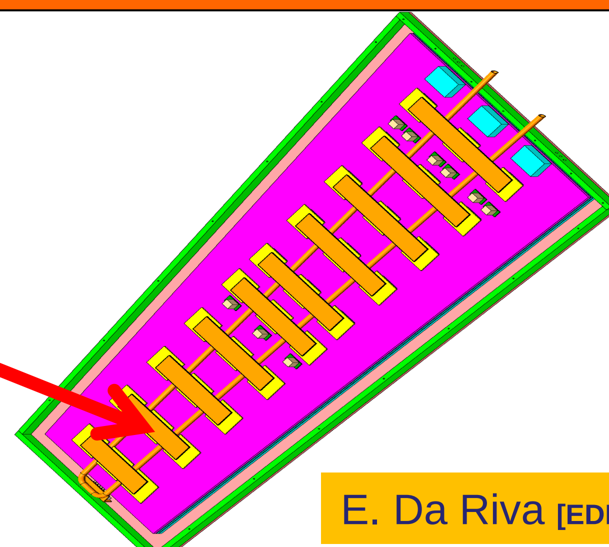
GE 1/1 Cooling System

- The cooling system has been studied/simulated taking into account electronics power dissipation (based on VFAT).
- The cooling system will ensure a chamber temp. uniformity of (20 ± 1) ⁰C.



VFAT power – 600mW
VFAT chip dimensions ~10×10mm
Connectors – 6mm high





E. Da Riva **[EDMS No. 1157976 v.2]**

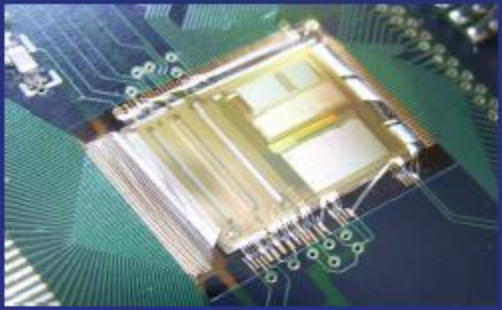
GEM Electronics Mini-Workshop

July 10 & 11; active group attracting more recruits - including CSC elec. & trigger people

Title	Speaker	Location	Time
Introduction	ASPELL, Paul	14-5-022, CERN	04:00 - 04:20
Off Detector Overview	DE LENTDECKER, Gilles	14-5-022, CERN	04:20 - 04:40
CMS Electronics Common Infrastructure	HANSEN, Magnus	14-5-022, CERN	04:40 - 05:00
CMS Software coordination	SCHWICK, Christoph	14-5-022, CERN	05:00 - 05:20
Trigger Requirements	BUNKOWSKI, Karol	14-5-022, CERN	05:20 - 05:40
Physic, Tracking Requirements	MAGGI, Marcello	14-5-022, CERN	04:00 - 04:20
GEM Detector Signal SImulations	MAERSCHALK, Thierry	14-5-022, CERN	04:20 - 04:40
Analog Front-end	GUILLOUX, Fabrice	14-5-022, CERN	04:40 - 05:10
CBM unit	LODDO, Flavio	14-5-022, CERN	05:10 - 05:30
DSP	NAARANOJA, Tiina Sirea	14-5-022, CERN	05:30 - 05:50
Experience with common mode suppression and cluster finding	TUUVA, Tuure	14-5-022, CERN	05:50 - 06:10
LS1 Goals	SHARMA, Archana	14-5-022, CERN	08:00 - 08:20
LS1 System overview	YANG, yifan	14-5-022, CERN	08:20 - 08:40
VFAT2 Hybrids	MARTOIU, Sorin	14-5-022, CERN	08:40 - 09:00
VFAT2 signals and GEM PCB	ASPELL, Paul	14-5-022, CERN	09:00 - 09:20
Coffee		14-5-022, CERN	09:20 - 09:40
FPGA + links + GLIB	VICHOUDIS, Paschalis	14-5-022, CERN	09:40 - 10:00
Mechanics constraints	CONDE GARCIA, Antonio et al.	14-5-022, CERN	10:00 - 10:20
CSC-GEMs	SAFONOV, Alexei	14-5-022, CERN	10:20 - 10:40
CSC electronics upgrade	GILMORE, Jason	14-5-022, CERN	10:40 - 11:00
CSC-GEM Alignment	PAKHOTIN, Yuriy	14-5-022, CERN	11:00 - 11:20
Experience with 130nm SRAM and dc/dc converters	ANGHINOLFI, Francis	14-5-022, CERN	08:00 - 08:15
Slow Control development	DE ROBERTIS, Giuseppe	14-5-022, CERN	08:15 - 08:35

Frontend Evolution

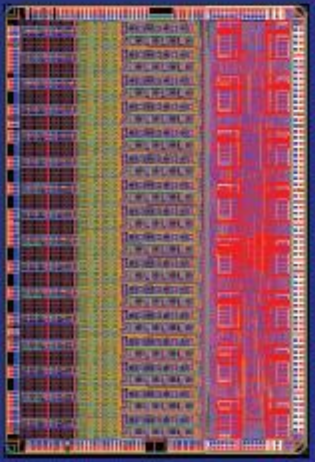
VFAT2



Existing

Used for TOTEM CSCs, GEMs and Silicon. CMS GEM prototypes

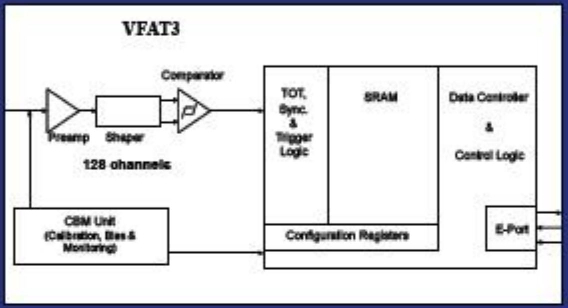
SAltro



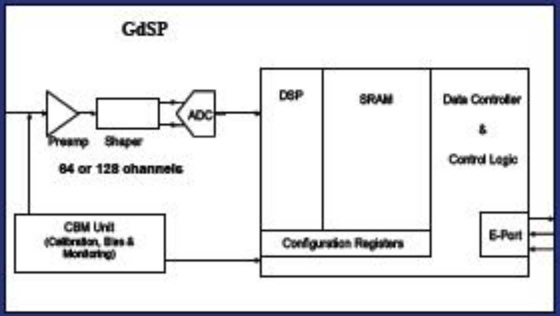
Existing

DSP 16 ch demonstrator chip, designed for ILC TPC demonstrator.

VFAT3



GdSP

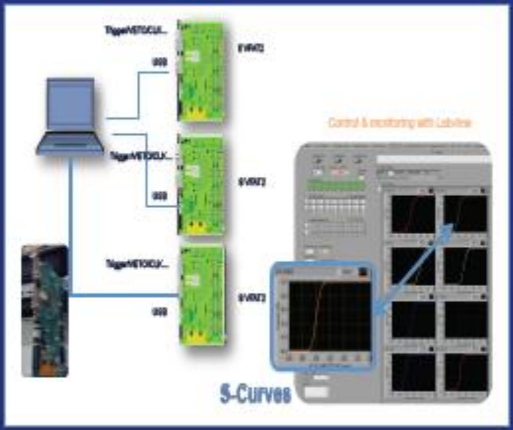


Future : design developments

P. Aspell

DAQ System Evolution

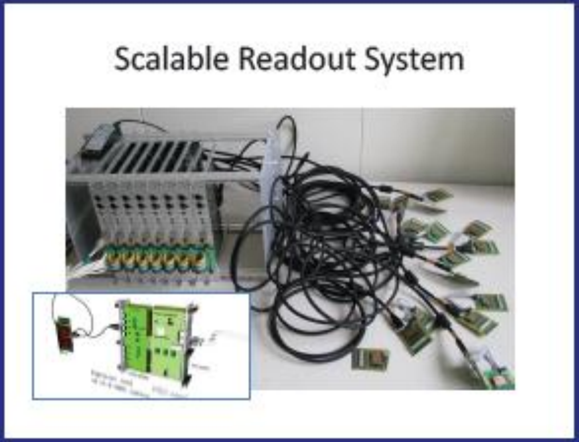
Turbo



Existing

Used with VFAT2, 2011/2012 lab tests & test beam

SRS

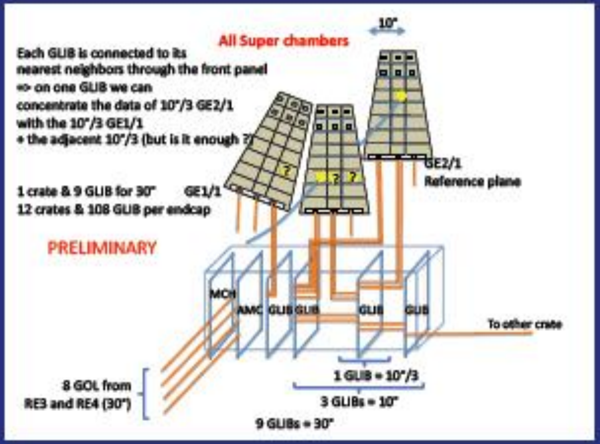


Under development.

For VFAT2, lab tests and test beam.

Could also be available for purchase by external groups.

µTCA



Under development.

Initially for VFAT2 large prototype readout.

Aim: Ultimate readout system with VFAT3/GdSP + GBT

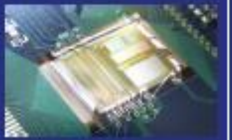
P. Aspell

VFAT2 with Scalable Readout System

VFAT2 chips:

24 wafers produced in 2011.

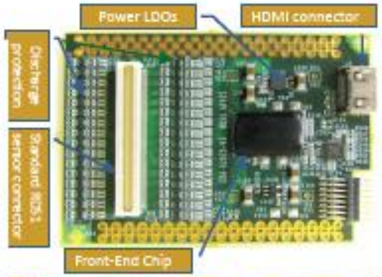
Status:
Just back from dicing.

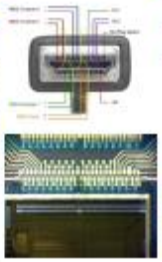


Have on order 1000 chips in hand; both types w/ and w/o diode protection

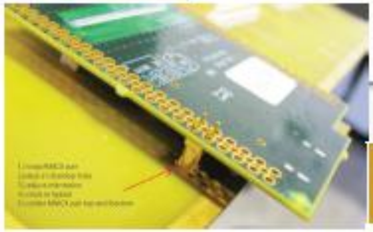
Readout & power options:
HDMI cable & Plug-in to GEM PCB

SRS Hybrids





- standard RD51 connector
- discharge protection
- micro-HDMI
  - clk & trg
  - data links
  - dcs (I2C)
- industry-ready design
- purchase through CERN store



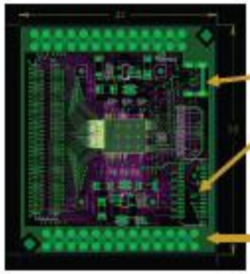
Samtec MMCX coax connector

GND connection (< 2mohm)
middle pin can be used for power
mechanical connection

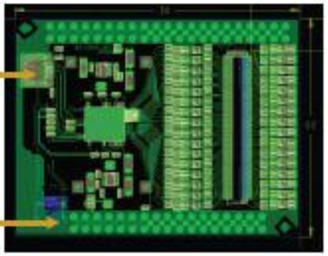
19/04/2012 Sorin.Martoiu@cern.ch 11

VFAT2 Hybrid

Short version – no input protection



Long version – full RD51 compatibility



HDMI conn. (micro)

Optional stacking conn.
for *cable-less* connection

Power option via
MMCX connectors

- schematic done
- layout under design (1 week)
- production and assembly (2-3 months (??))

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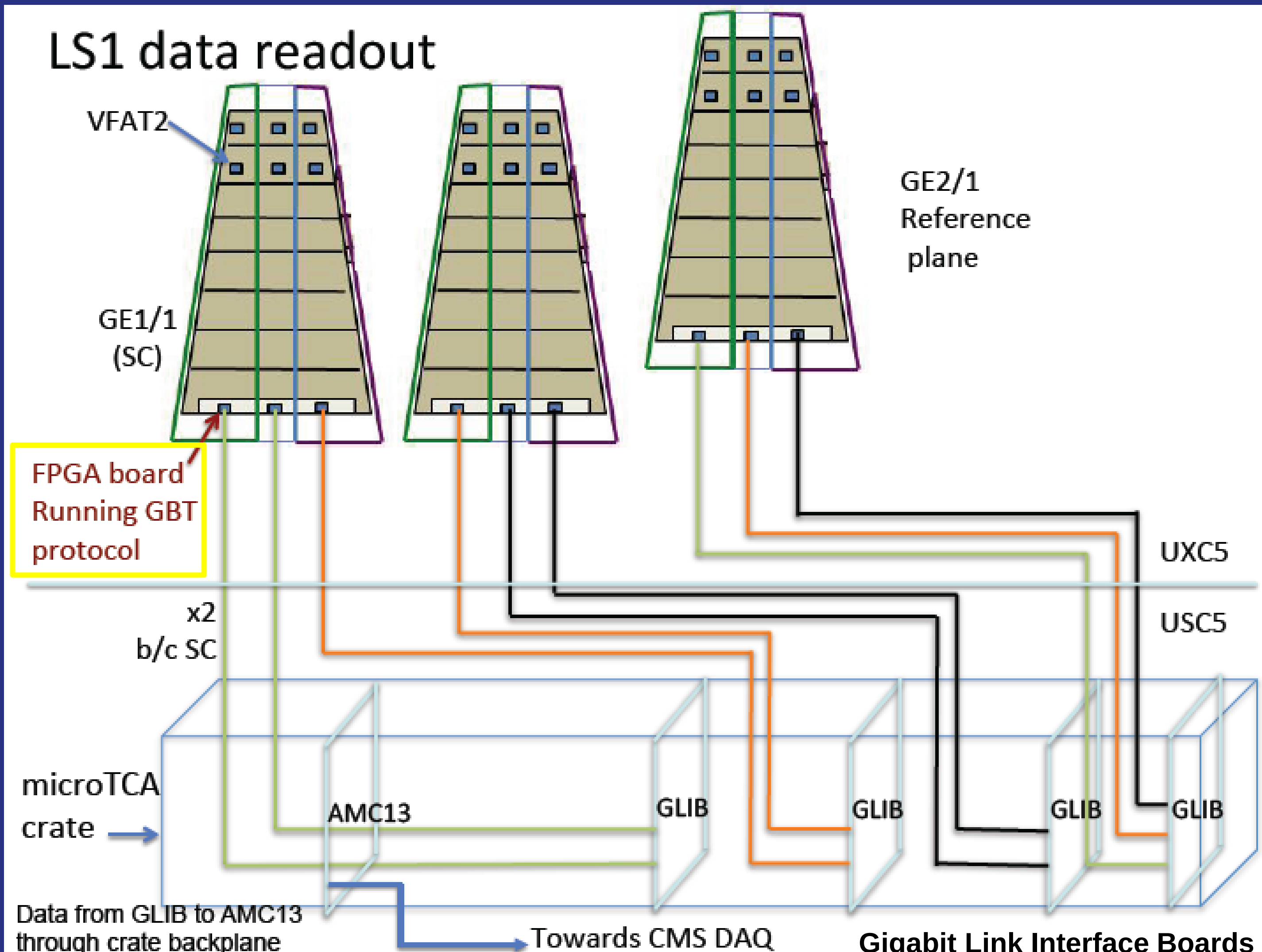
Short hybrid version to be
used with VFAT2_GEM

P. Aspell

DAQ Prototype System for LS1



FPGA also with link to new CSC Trigger Mother Board

- VFAT2 front-end chip
- FPGA instead of GBT
- µTCA using AMC13 & GLIB boards

Source: Yifan Yang (ULB)

P. Aspell

Electronics Timeline

Florida Tech

FE ASIC

Define electronics system for TP,
Formation of design teams.

ASIC design starts

FE ASIC design team
Approx. 8 man years
of design time
needed.

Submission of FE AISC (VFAT3/GdSP)

Readout systems

2011

Short Term :

VFAT2 , Turbo hardware and Labview DAQ software

2012

We are here.

Medium Term :

VFAT2 + SRS

Off Detector
uTCA development

LS1, 2 super-chamber prototypes using VFAT2 in the vicinity of CMS ?? *Currently being investigated .*

2014

Long Term :

2015

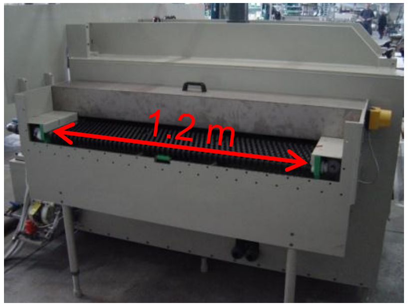
Full and final system
On & Off detector electronics.
VFAT3/GdSP + GBT + uTCA system

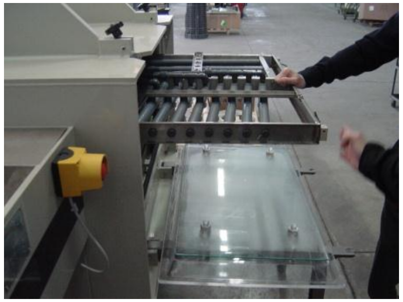
Readout of demonstrator system in LS2 (90° section)

P. Aspell

Upgrade CERN shops

Last three large PCB machines in place:





- CERN funding major upgrade of workshops
- Machines arrived May 23rd
- Some infrastructure to be updated in workshop (electricity + piping)
- 5 days planned installation time (w/ people coming from manufacturer)
- Installation planned for 3Q12 (fitting production priorities and people from manufacturer)

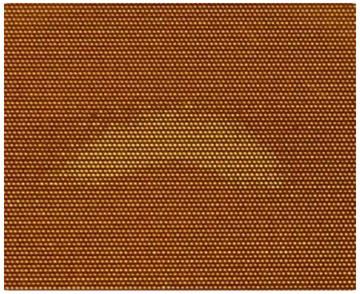
F. Formenti, CERN, RD51 mini-week, June 2012

GEM qualification procedure for Newflex

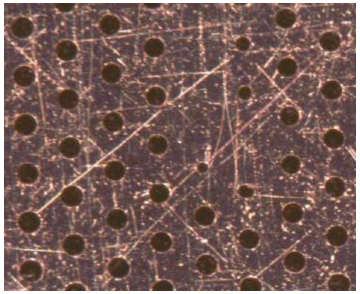
- RD51 asked Newflex to carry out a basic QC test for GEM foil validation
- Will only buy good foils from them, but would like to have a full QC report

Validation methods:

1 Visual inspection

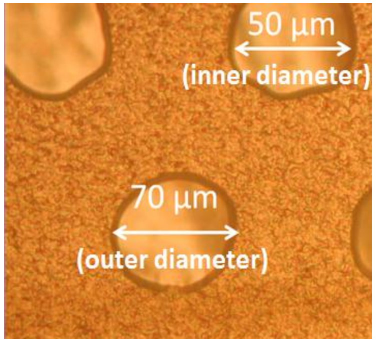


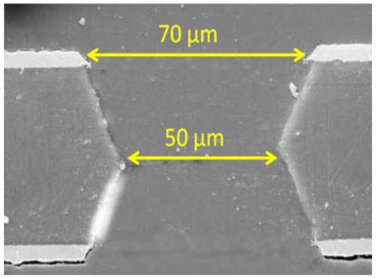
Lighter area <0.1 mm^2



2 defects max, <1 mm^2

2 Microscope inspection (few areas)





70 µm ± 2 µm
50 µm ± 5 µm

3 Open air HV test

I_{leak}<10 nA @ HV=600 V
t_r=12 s
t_{amb}, 1 amt, RH=35%
no sparks

F. Formenti, CERN, RD51 mini-week, June 2012

Quality Control for Production

Florida Tech

GEM FOIL PRODUCTION

DRIFT ELECTRODE PRODUCTION

READOUT ELECTRODE PRODUCTION

MECHANICS PRODUCTION

Electronics Production & QC

ASSEMBLY SITE

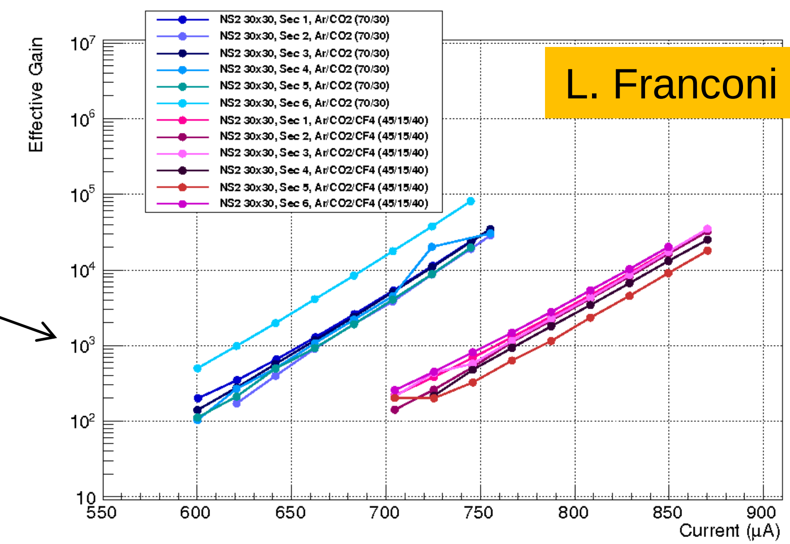
CERN?
US?
India ?

Transport to CERN

Quality Control procedures:

1. *QC-Drift Electrode*
2. *QC-GEM foils*
3. *QC frames (mechanical tolerances)*
4. *QC readout PCB*
5. *QC Gain uniformity test*
6. *QC leak test*

example



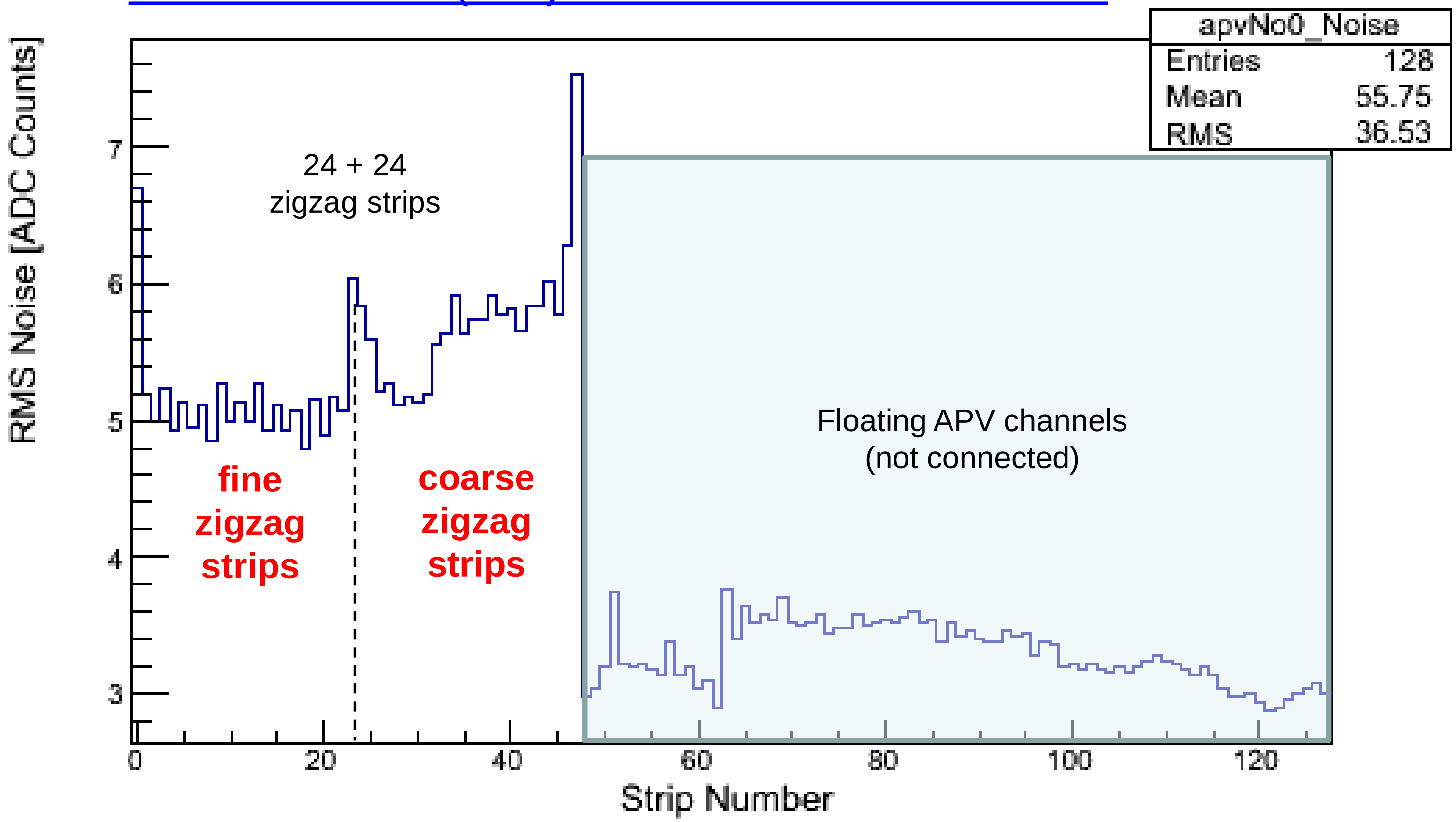
L. Franconi

Installation

Commissioning

Noise measurements

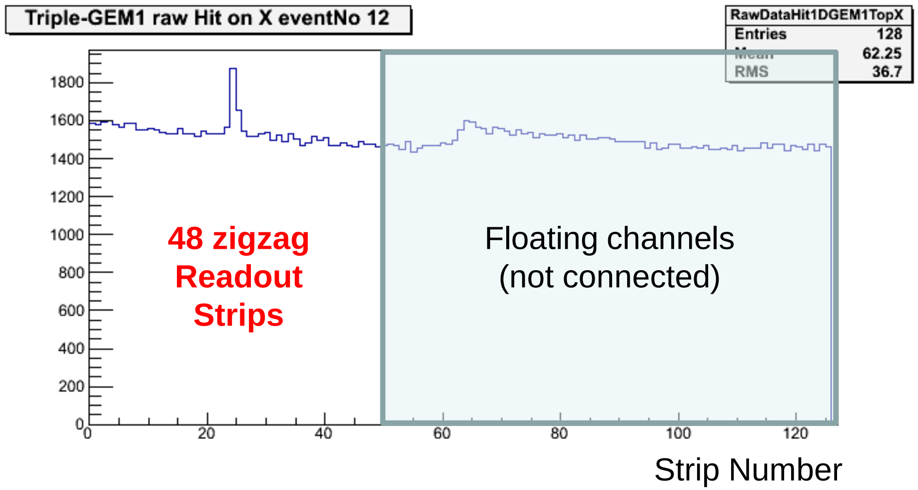
Pedestal Width (rms) recorded with APV & SRS



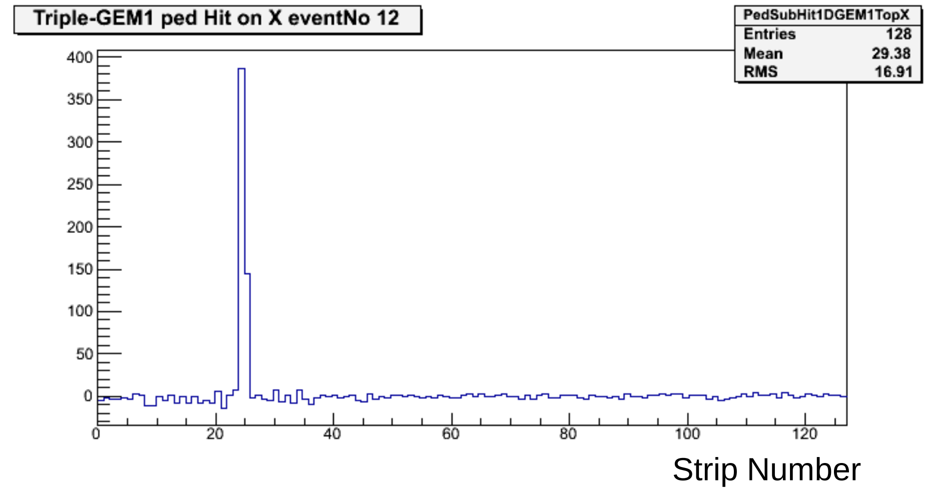
Two-Strip Cluster w/ SRS

COSMICS DATA

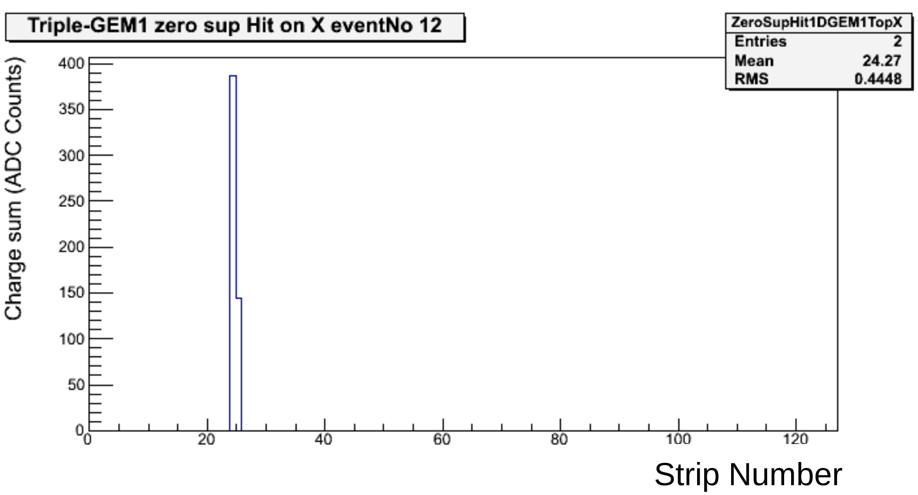
Raw Hit Data



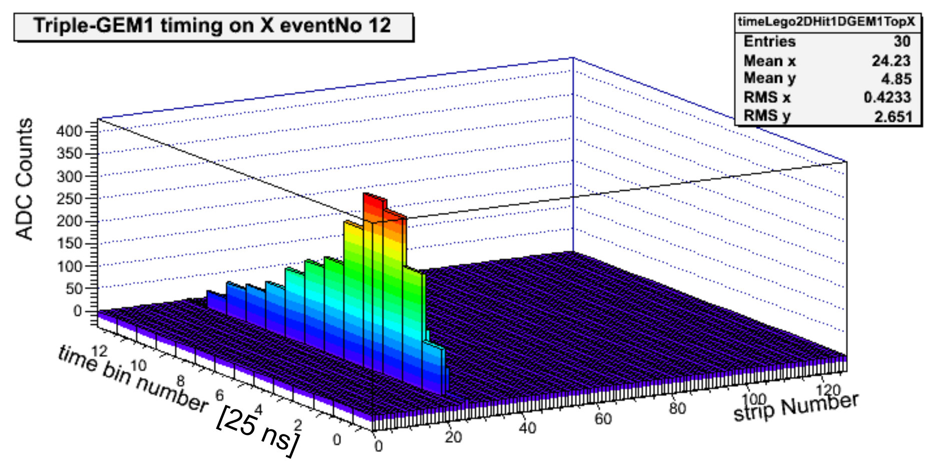
Pedestal Subtracted Hit Data



Zero Suppressed (5σ RMS) Hit Data

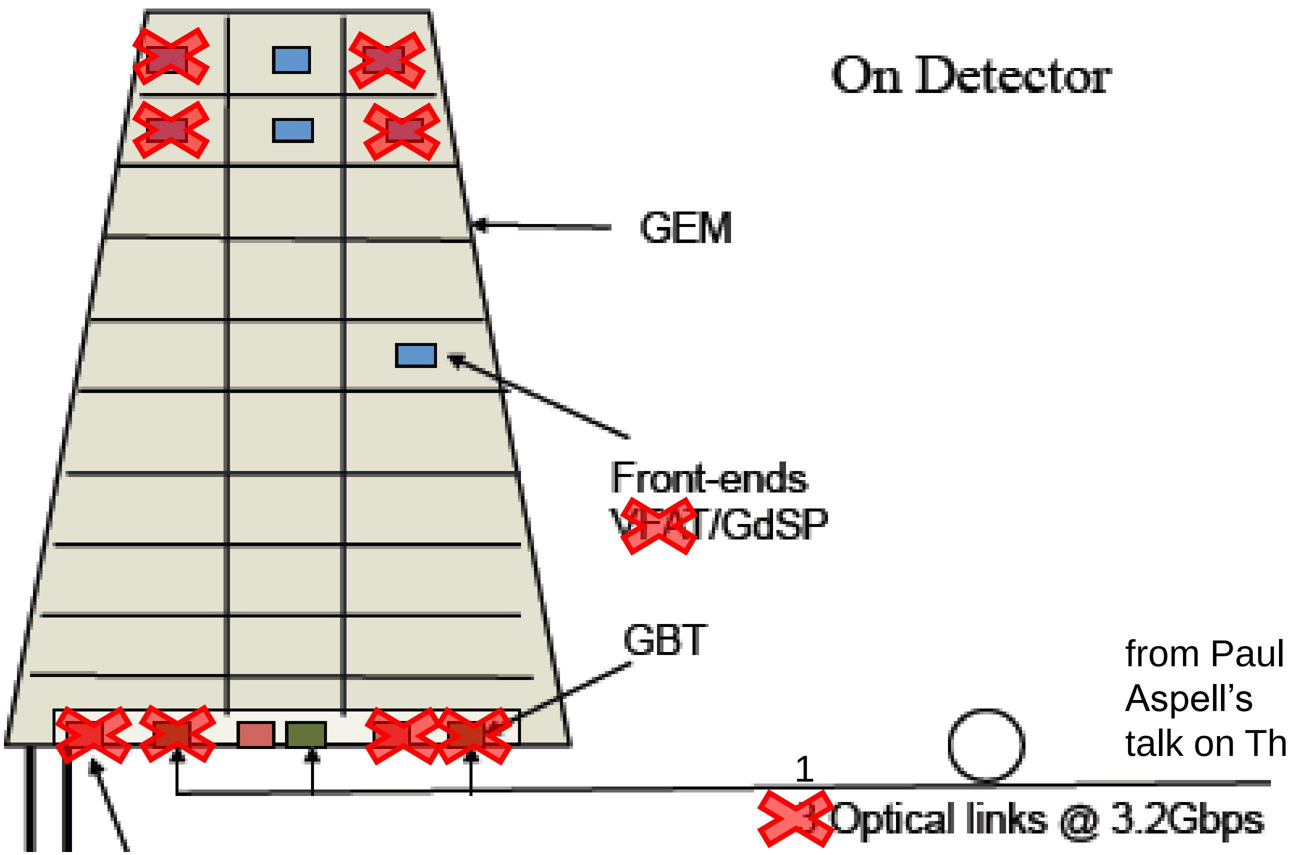


Time Evolution of Zero Suppressed Pulse Signal



Impact on electronics design

⇒ Potential for **eliminating need for 2/3 of the electronics** of current baseline design:



from Paul Aspell's talk on Thu.

Zigzag Implications

- Potential for saving 70% of readout channels and ~50% (?) of electronics cost, could mean potentially saving 1-1.5 MCHF on the project (using Tech. Proposal baseline: full GE1/1 & GE2/1)
- Simplifies cooling, cabling, power $\Rightarrow$ additional cost savings
- Total project cost < 5 MCHF possible ?!
- Analog pulse height measurement is mandatory for charge interpolation, so VFAT3 would not work
  → would need a GdSP design for front-end electronics
- Plan: Develop a full-size GE1/1 zigzag readout board & test

CMS GEM Goals for LS1

- Installation & Integration of 2 GE1/1 super chambers (possibly 1 super ch.GE2/1)
- Install new pre-production CSC TMB prototypes on chambers that overlap with GEMs

Measure: Background rates / Noise / Stability / Uniformity / Efficiency in situ

- Space & time resolution
  - In real high-η environment
  - In real magnetic field
- Provide signal to CSC and participate in L1 trigger and reconstruction
- Prove that the electronics design works and demonstrate in situ that we can operate CSC TMB with GEM input, in various operating regimes (nominal, DCFEB on/off etc).
- Test reduction of CSC X-Y ambiguity and ghost in situ
- Once we go into operations, measure muon trigger rates and efficiency in the overlap regions with and without GEMs input

Participate in CRAFT 2014