CMS Muon Upgrade: R&D and Electronics

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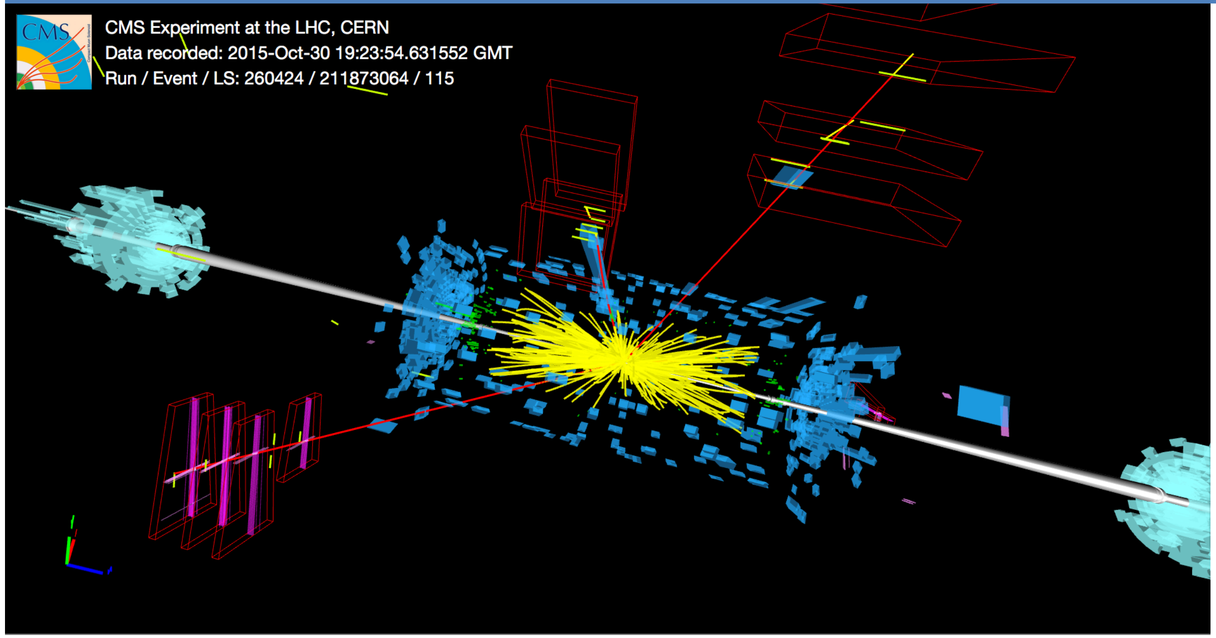
Northeastern University

Outline

- Overview of CMS Muon Upgrades
- Chamber R&D
  - Existing chambers
    - Aging and alternative gas studies
  - New Chambers
    - Resistive Plate Chambers
      - R&D for high rate chambers
    - Gas Electron Multiplier (GEM)
      - Triple GEM baseline
      - μRWELL R&D
      - FTM R&D



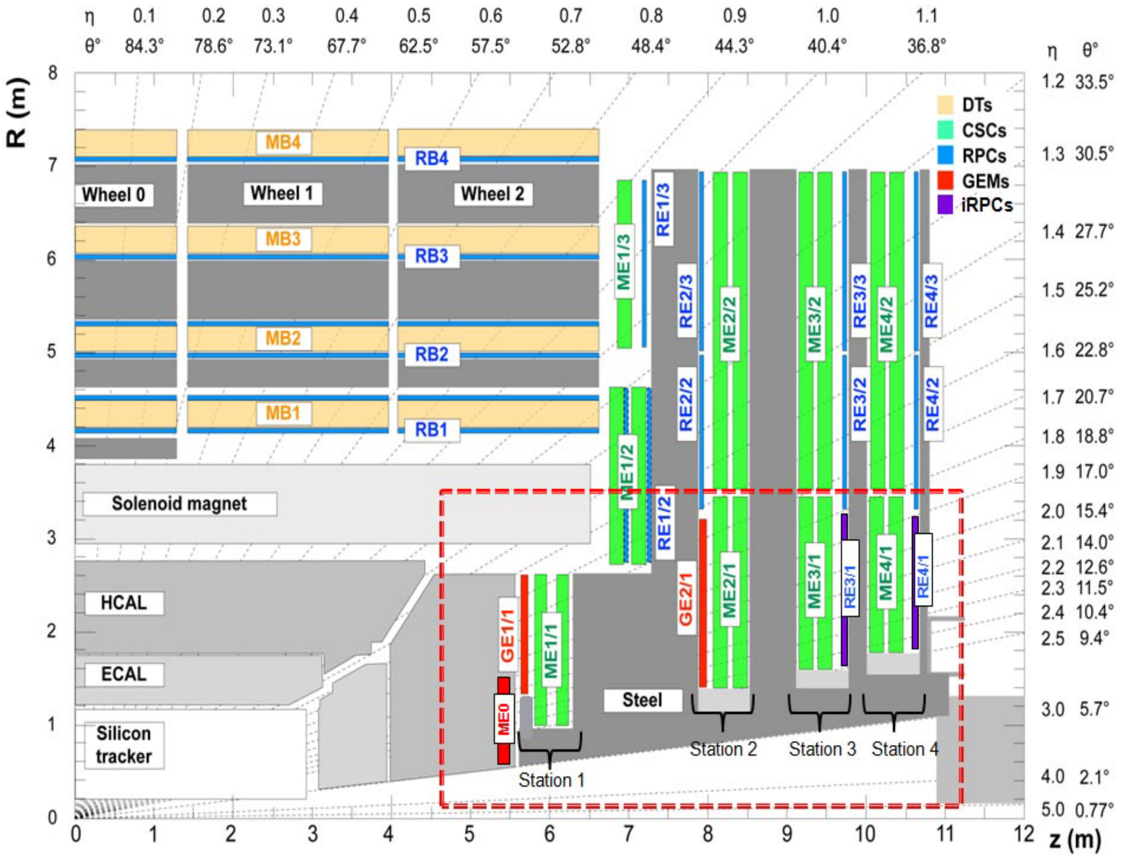
- Electronics
  - DT electronics upgrade
  - CSC electronics upgrade
  - RPC electronics
  - GEM electronics R&D
- Summary

CMS Muon Upgrade Scope

More details in Anna Colaleo's talk

- CMS Phase-2 upgrade scope:
  - Barrel electronics upgrade
  - Forward muon upgrades: maintain trigger, increase offline coverage

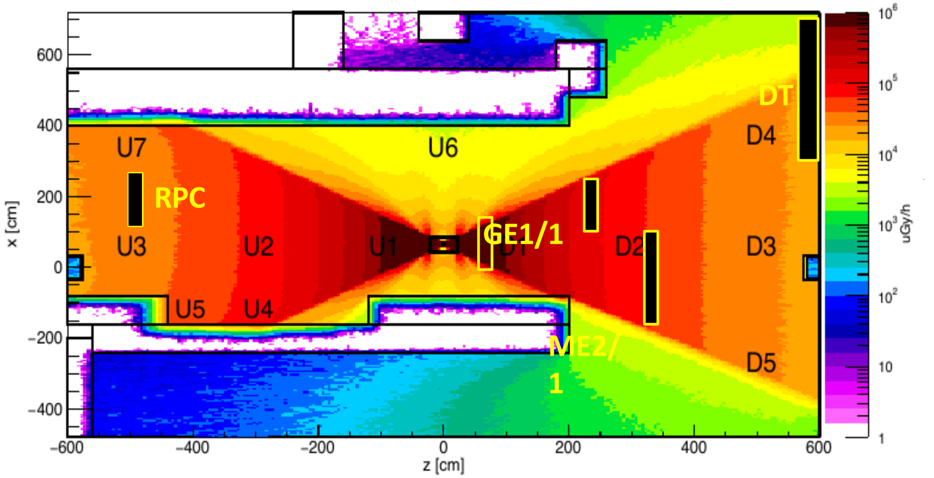
- Endcap Muon Cathode Strip Chambers (CSC):
  - Upgrade MEX/1 electronics to cope with data volume/bandwidth
- New Improved RPCs (iRPCs) in ME3/1 and ME4/1
- New Gas Electron Multiplier (GEM) detectors:
  - GE1/1 and 2/1 work with CSC ME1/1 and ME2/1 to maintain muon trigger
  - ME0 works with ME1/1 to maintain trigger and extends offline coverage η=2.4 → 2.9



Chamber Aging and Gas Studies

More details in Anna Colaleo's talk

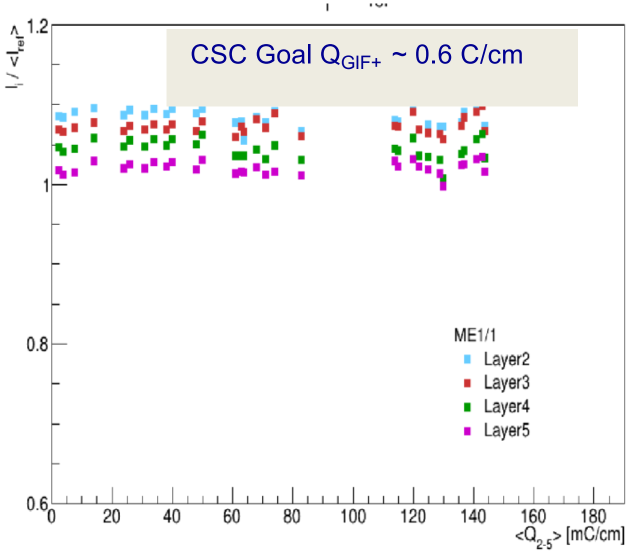
- Existing chambers in CMS: DTs, CSCs, RPCs
  - Remain and continue to provide the core muon detection
- Important to understand how they will respond to HL-LHC integrated exposure of 3000 fb^{-1}
  - Also true for new chambers
- All detectors profit from the CERN gamma irradiation facility, GIF++:
  - 662 keV photons emitted by an intense 14 TBq 137Cs source
  - + high momentum particle beam
- Also study alternatives to greenhouse gases, particularly CF4 (GWP=4950) and C2H2F4 (GWP=1430)
  - Current use: CSCs: CF4 (10%), RPCs: C2H2F4(95.2%), SF6(0.3%)
  - need to confirm both performance and aging



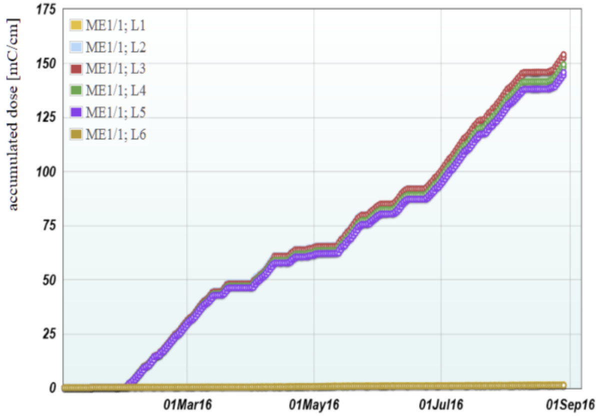
Station	Rate HL-LHC	Safety factor	T_{GIF} (months)	Q_{GIF+}
DT	50 Hz/cm^2	3	2	0.06 C/cm
CSC ME11/ME21)	4.8 kHz/cm^2	3	24	0.51 (0.55) C/cm
RPC	250 Hz/cm^2	3	24	1 C/cm^2
GE1/1	~ kHz/cm^2	3	2	0.02 C/cm^2

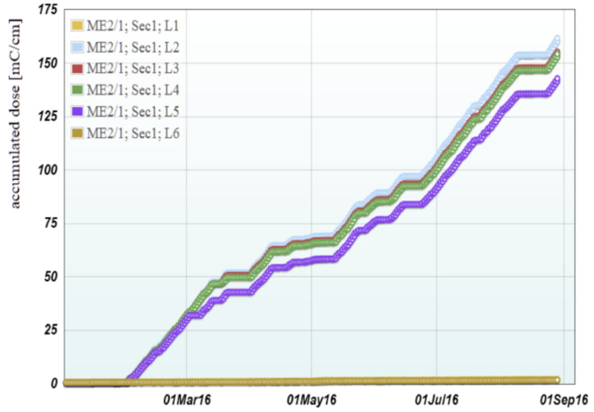
CSC Chamber Studies

- Aging:
  - Two CSCs (ME1/1, ME2/1) being irradiated at GIF++ (since ~8 months ago)
    - Monitor gas gain and current.
    - Measure trigger rates at HL-LHC condition.
    - Monitor Malter effect
  - With ~¾ the HL-LHC charge, no signs of degradation (gas gain, resolution, efficiency)
- Alternative gases
  - Constructing compact CSC prototypes at CERN and PNPI (2016-17)
  - Will allow for testing of CF4 substitutes with conditions more similar to present
  - Gas mixtures with reduced CF4 (<5%) and with no CF4
  - Closed-loop gas system, operation at lower HV
  - Will perform long term irradiation at GIF++



Irradiated CSC layer currents relative to non irradiated (reference) layers (Feb-Aug 2016)



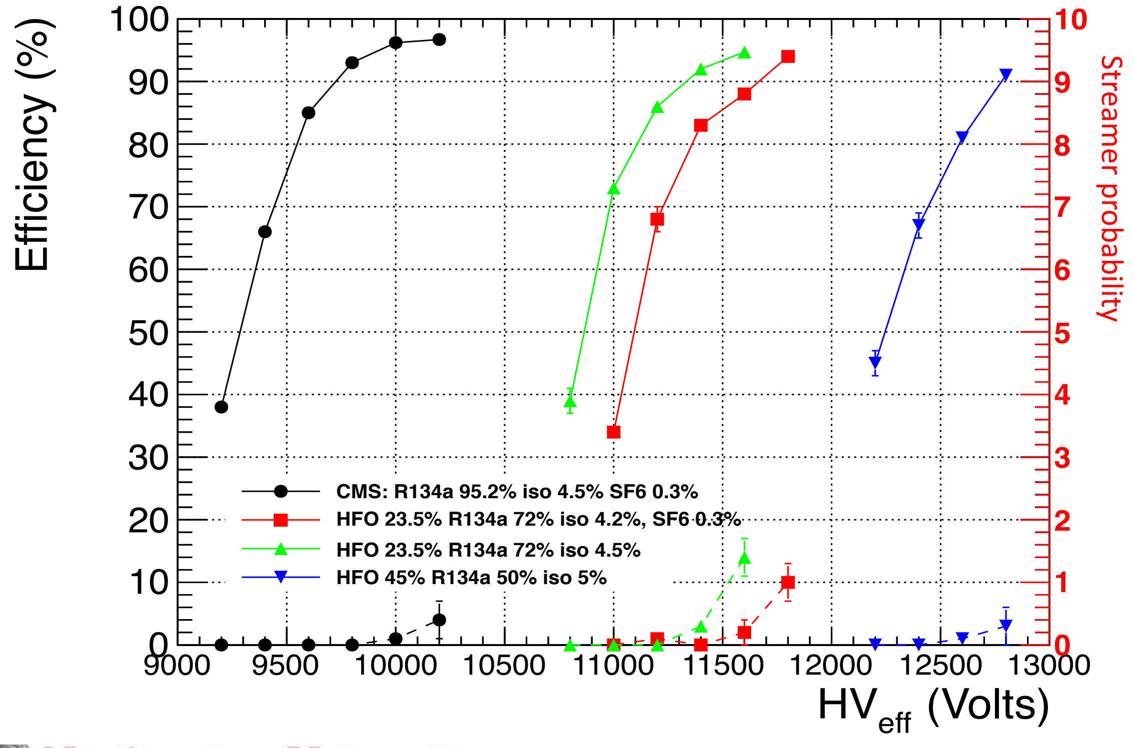


RPC gas studies and aging

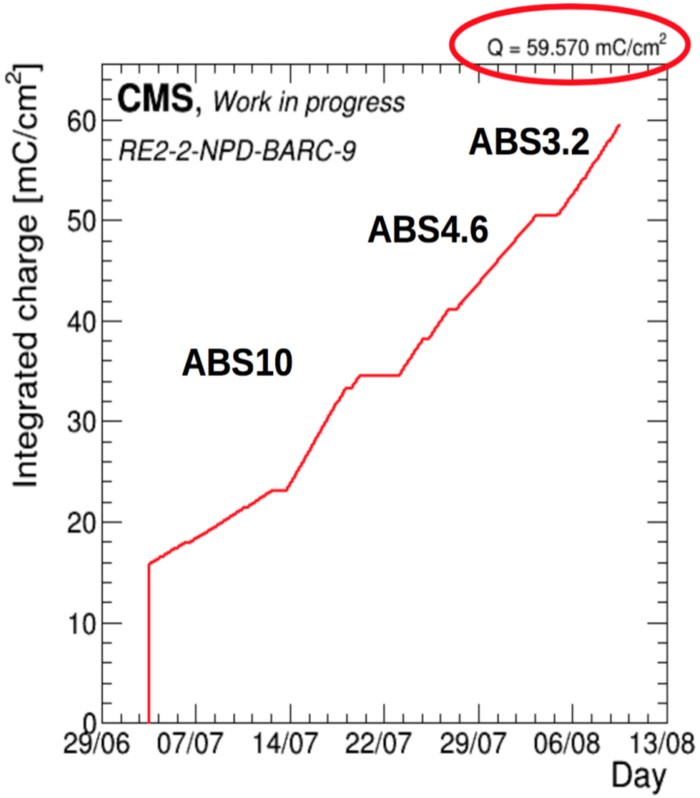
RPC Eco-gas studies :

- Replacing $C_2H_2F_4$ with $C_3H_2F_4$
- $CO_2 - C_3H_2F_4$ based gas mixtures
- $CO_2 - C_3H_2F_4$ based gas mixtures
- He – $C_3H_2F_4$ based gas mixtures
- CF_3I based gas mixtures

Good efficiency with C3H2F4 : 23 % of C3H2F4 moves the working point moves around 12 kV

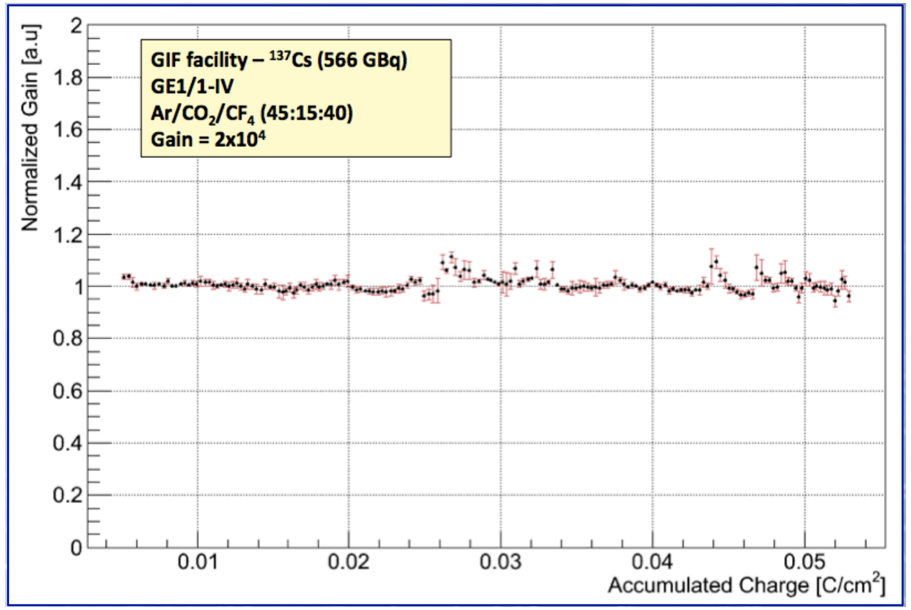


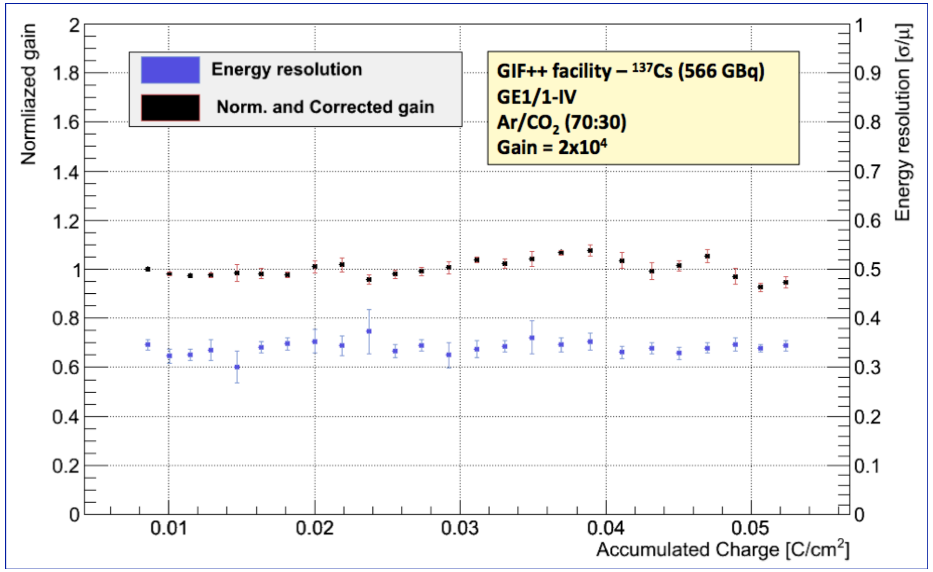
GIF++ Longevity on spare CMS RPC



RPC Goal Q_{GIF+} ~ 1 C/cm^2 for 3XHL-LHC

Triple GEM longevity





- Aging test Ar/CO2/CF4 @ GIF:
  - GE1/1 IV (close to the final design)
  - 12 months of operation
  - No aging observed up to 53 mC/cm^2
- Aging test Ar/CO2 @ GIF++:
  - GE1/1 IV (close to the final design)
  - 6 months of operation
  - No aging observed up to 55 mC/cm^2
- 55 mC/cm^2 equivalent to HL-LHC × Safety Factor ~18
- In addition "Outgassing Tests" performed to certify all components inside the gas volume

New RPC Chambers: Proposed technologies

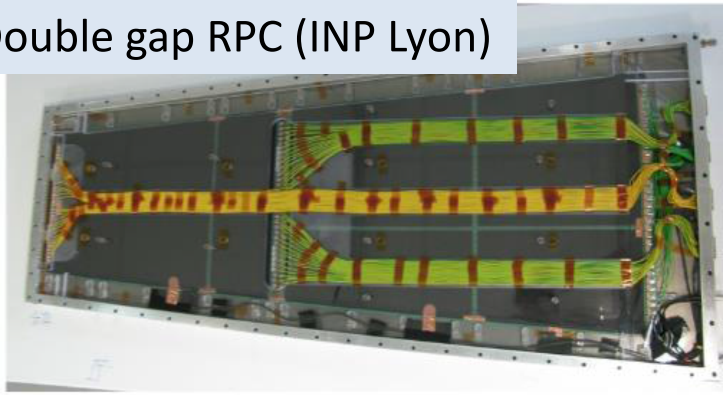
More details in Anna Colaleo's talk

- Basic requirements:
  - Increased rate capability, 2.0 kHz/cm^2 versus present 0.3 kHz/cm^2
  - Stable performance for HL-LHC requirements including dose to 3000 fb^{-1}

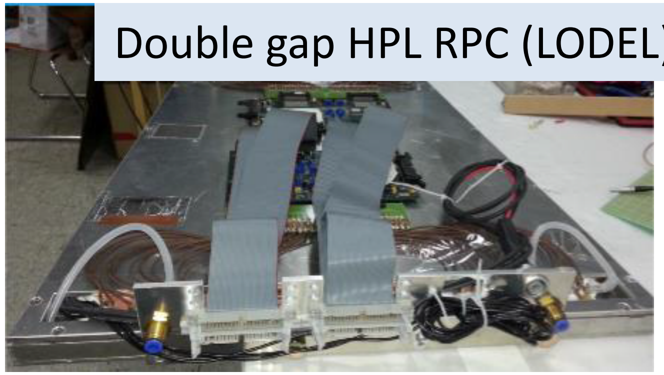
Technology	Rate Cap.	Space Res.	Time Res.
Baseline: double-gap RPC	x	x	O(ns)
Multi-gap RPC	x	x	O(<100ps)

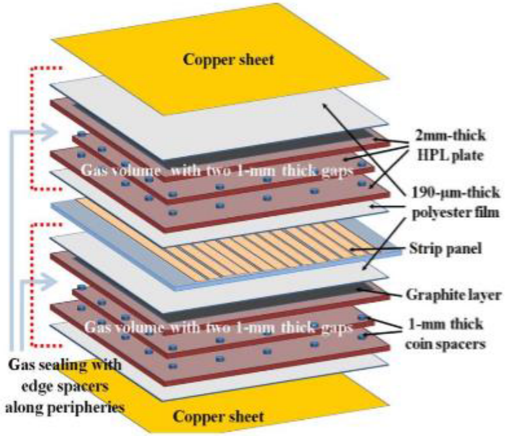
- Detector improvements planned/possible:
  - Reduced electrode resistivity: about 1010 Ωcm (HPL or silicate glass option)
  - Geometry: reduced electrode thickness 1-2 mm to improve rate capability
  - New generation low-noise front-end electronics for high efficiency, lower aging
  - Finer pitch option for improved spatial resolution: 1-2 mm vs. current ~1 cm
  - Multigap option for high timing accuracy, possible 2D if both ends of strips read out

Double gap RPC (INP Lyon)



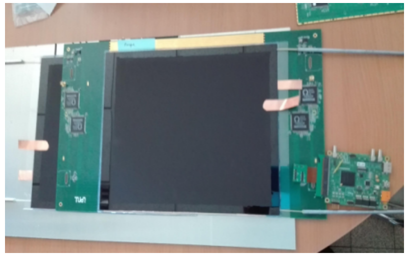
Double gap HPL RPC (LODEL)

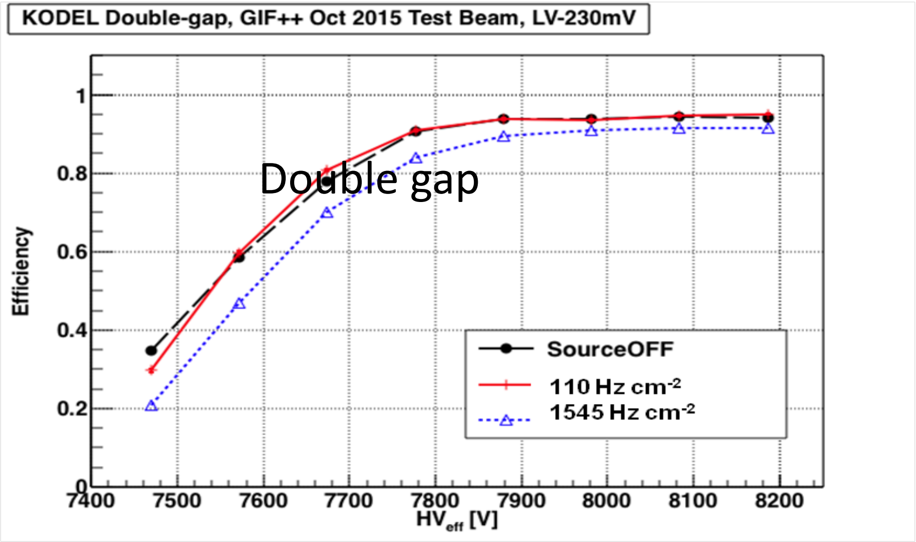


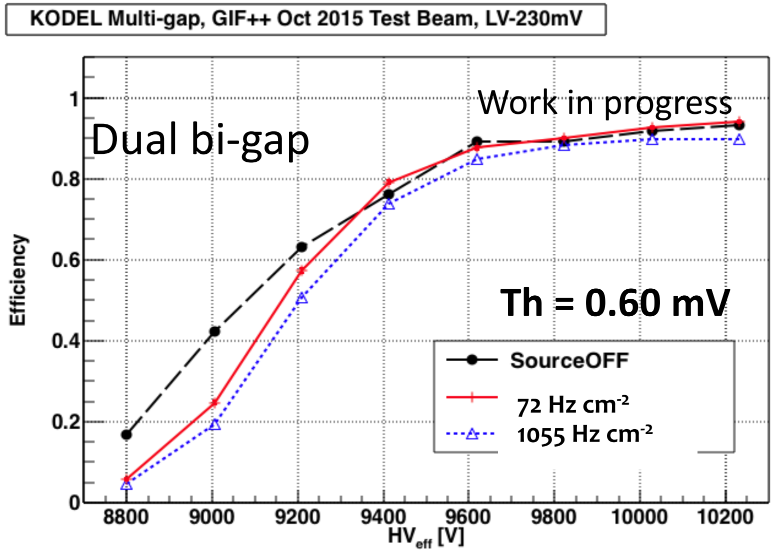


RPC Detector and FEB R&D

- Five HPL prototypes built in Korea and Italy with different gap configurations and electrodes thickness
  - arrived at CERN in August and tested during the September test beam in GIF++
  - **Rate capability under full irradiation established to be >> 1.5 kHz/cm², for both HPL and low resistivity glass RPC**
- One half size RPC (in glass) produced in Lyon
- Two double gap RPC, one glass and one in HPL, PCB's equipped with the Hardroc2 have been produced
  - detector size is 30x30 cm²
  - Plan to test them in Oct. GIF++ test Beam

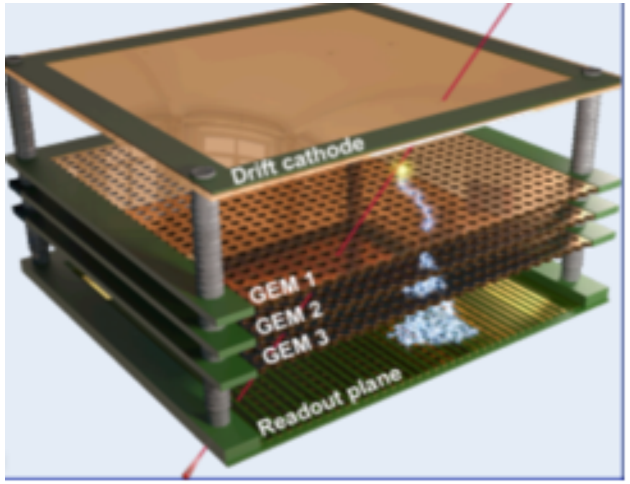






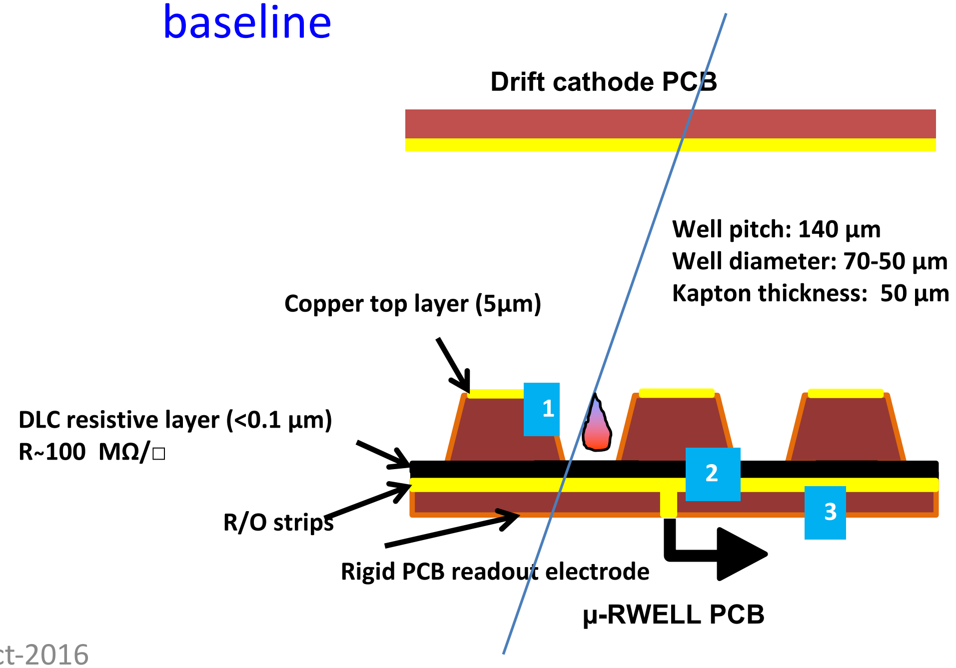
GE2/1 baseline and beyond

- Baseline: Triple GEM detector with the same operational layout adopted for the GE1/1
  - Well-known mature technology
  - Easy to be implemented
  - Match the detector requirement (GE1/1 even more demanding)
  - Time resolution of 8ns is adequate from simulation studies, (97% of single chamber hits associated to the correct)
  - Eco-friendly gas validated



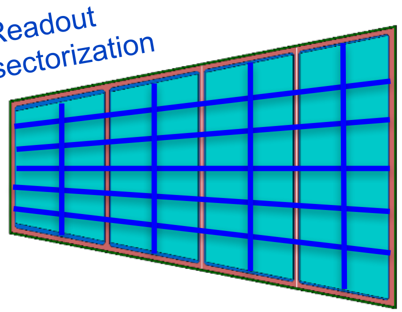
More details in Anna Colaleo's talk

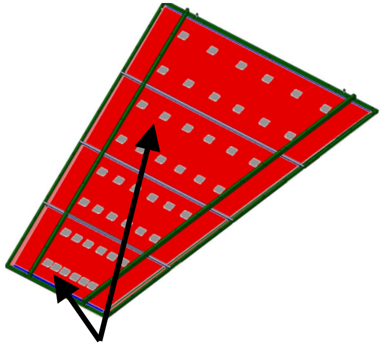
- Beyond baseline: Micro Resistive Well Chamber (μ-RWELL)
- Motivations
  - Simplified construction compared with a Triple-GEM (no foil stretching needed)
  - Thinner detector to address severe space constraints for GE2/1 installation
  - More efficient tiling of several modules in 20 degree GE2/1 chamber; less dead space than baseline



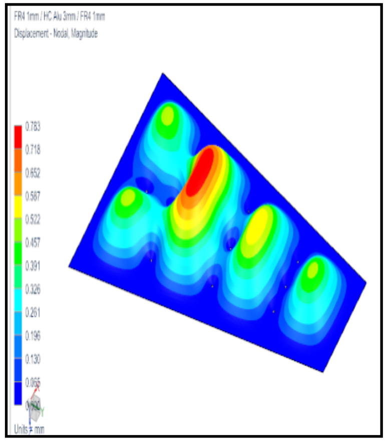
GE2/1 R&D progress and plans

- GE2/1 baseline (Triple-GEM)
  - Strip granularity of readout board for first prototype module defined
  - 6 ϕ-sectors × 2 η-sectors per module; 6 ϕ-sectors × 8 η-sectors per chamber
  - Mechanics of first full-size prototype chamber being designed
  - Introducing various reinforcement elements to ensure mechanical chamber stability
  - First prototype: one active module w/ GEM foils and three dummy modules:
  - finish design 10/16; procure parts by 12/16; construct first prototype chamber Q1/2017
- GE2/1 option (μ-RWell)
  - First large prototype (GE1/1-size) currently under construction. To be test at CERN Oct/Nov test beam
  - Mechanical design & assembly of full-size detector on-going
  - 1 gas volume, 4 PCB modules + only one cathode PCB closing entire chamber
    - finite element simulations for PCB deformation and mechanical rigidity on-going
    - optimization of FEE housing/cooling/services
  - Assembly of 2 full size μ-RWell by Q4 2017



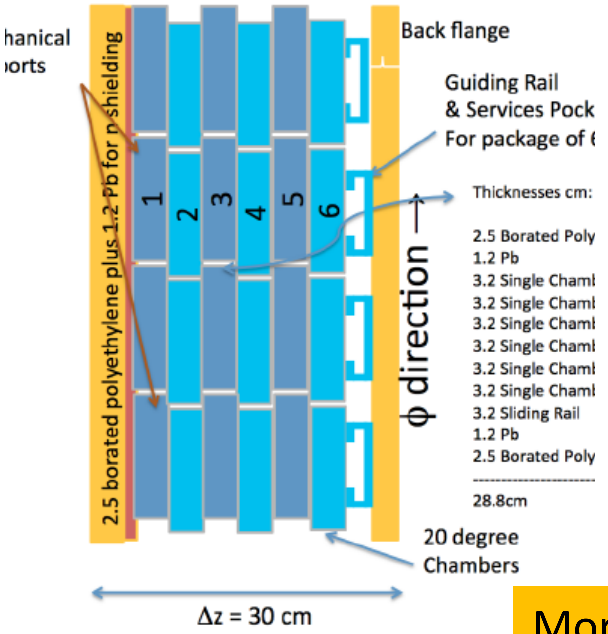


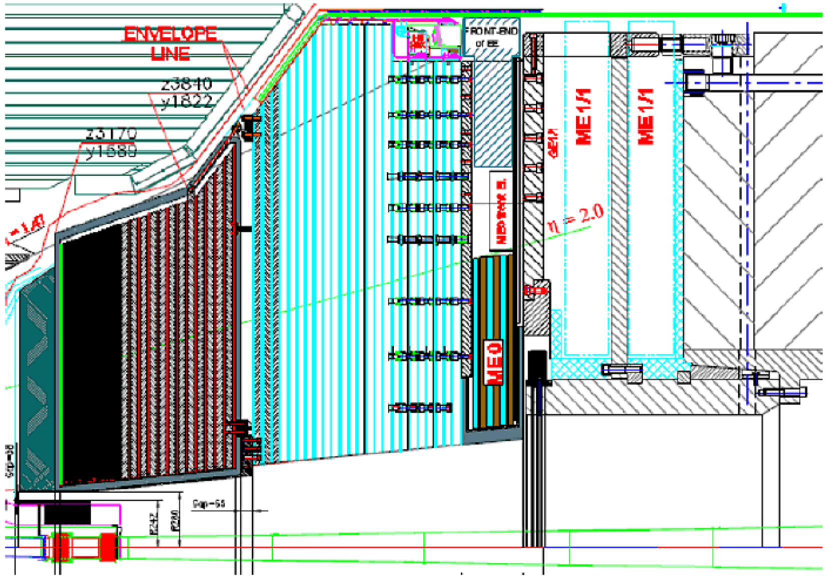
Reinforcement elements



ME0 Detector Baseline

- Extend muon tagging coverage to η~2.9
  - Also enhance trigger coverage up to η~2.4 range
- Take advantage of the space available in the back of the new endcap calorimeter
- ME0 baseline layout consists of 216 triple-GEM chambers arranged in 36 20^0 super-module wedge each consist 6 layers of triple GEMs covering 2.0<|η|<2.9

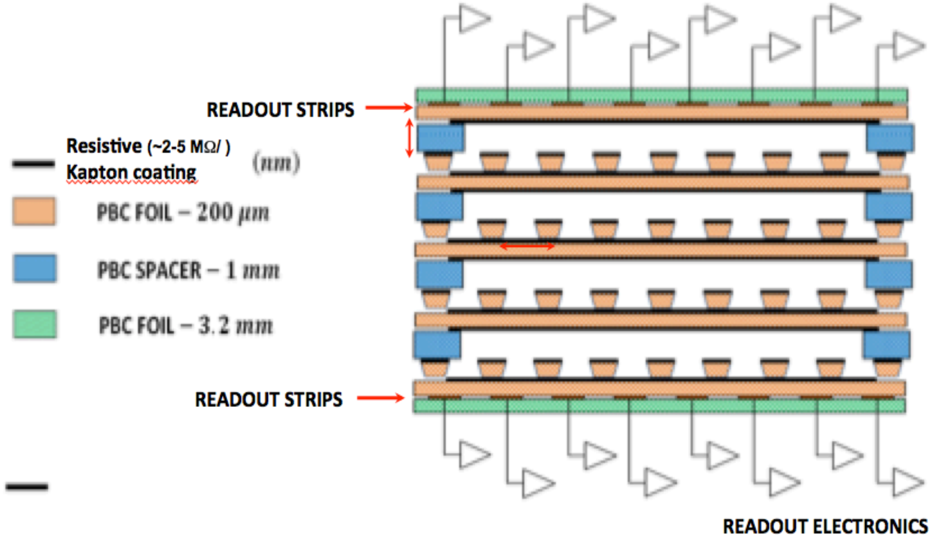


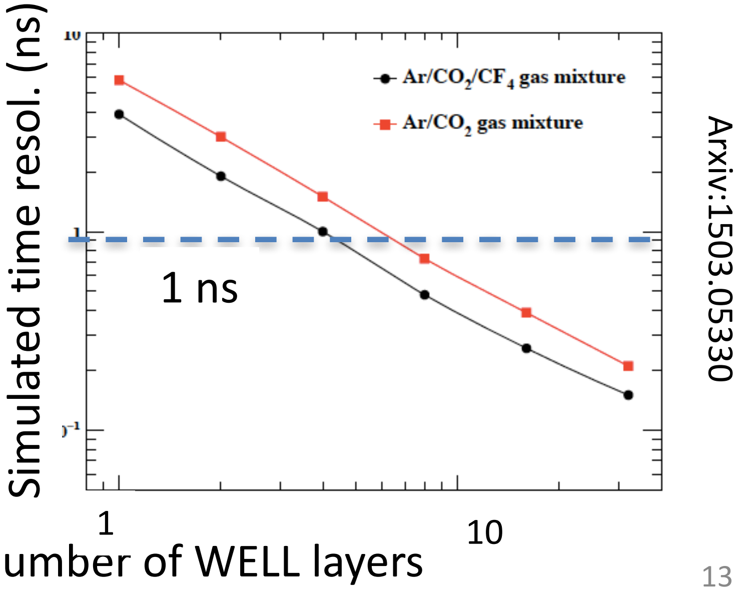


More details in Anna Colaleo's talk

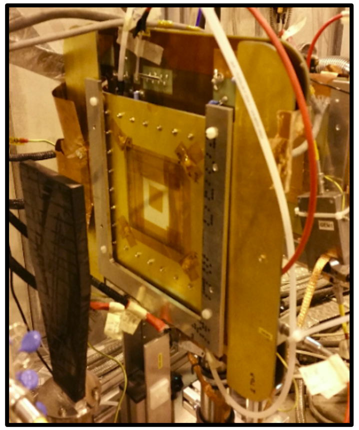
ME0 beyond baseline: FTM

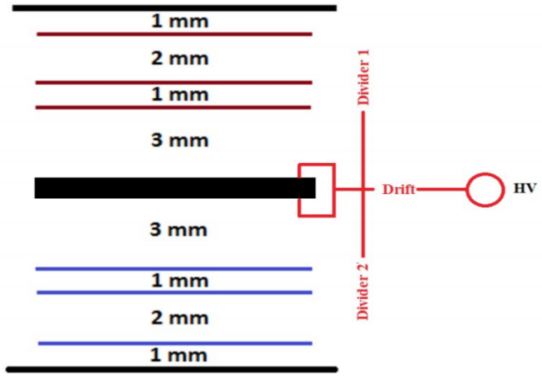
- Fast Timing Micropattern Gaseous Detectors (FTM)
  - Motivation: fast timing to reject background hits from pile-up
- Concept
  - Stack many thin (< 1mm) drift gaps each followed by an amplification structure
  - Use resistive coating in each amplification stage
- Status
  - timing and spark protection partially demonstrated on small-scale prototypes
  - Planned:
    - Large scale prototypes
    - Aging studies
    - Rate capabilities

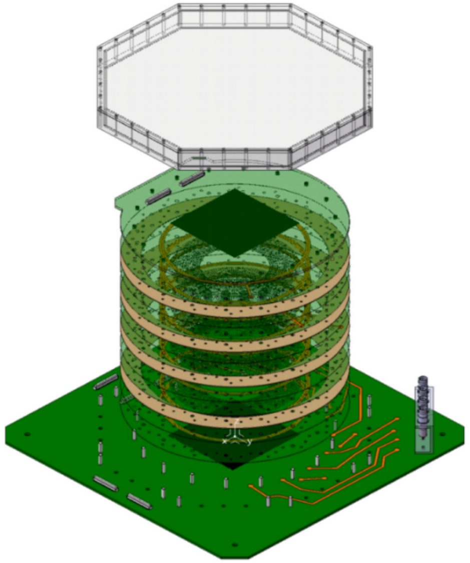




- Triple-GEM (baseline)
  - Analysis of June beam test data with first back-to-back GEM stacks prototype ongoing
- FTM prototypes
  - The design of the new small prototype, 10x10 cm^2 active region, is completed
    - can host up to 12 drift-amplification stages, with variable drift gap thickness.
  - The active layers will be made of kapton 125 µm-thick
- Baseline and FTM:
  - A test beam is planned for the end of October – beginning of November at the H8 beam line, to fully characterize the new prototypes.







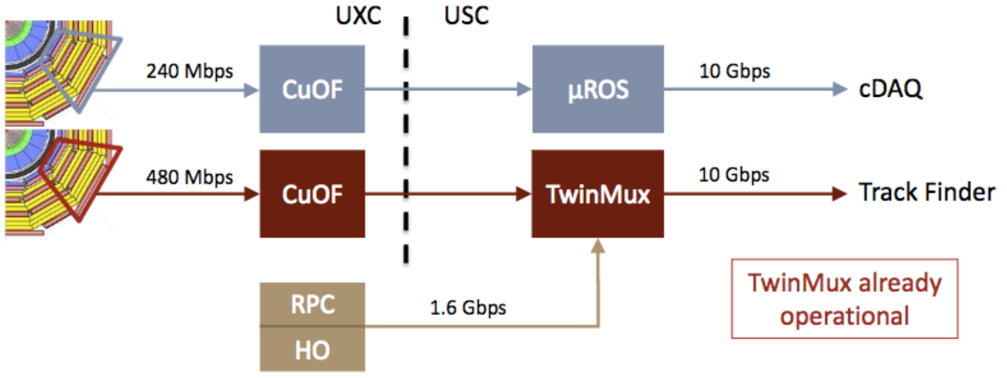
The design of the ***large size prototype***, 60 x 40 cm^2, started and should be finished by the end of the year 2016.

DT electronics upgrade

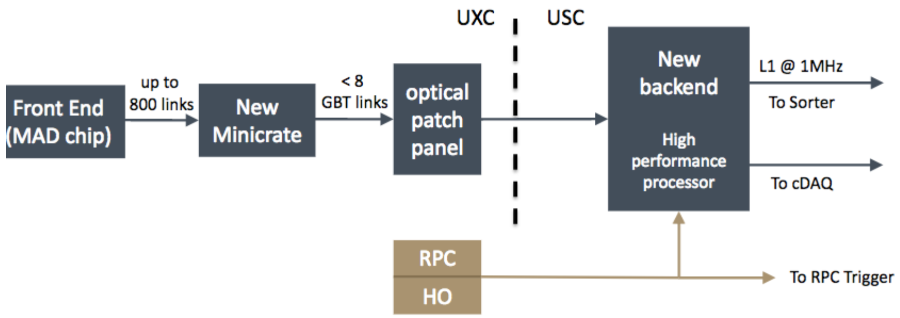
- Needs:
  - Fix legacy longevity issues
  - Meet L1 trigger rate & latency, readout bandwidth requirements
  - Enhance reliability
- Design plans:
  - Same analog front end
  - On-detector Minicrate replacement
    - Time digitization using rad-hard, Flash-based FPGAs, and CERN GBT links
    - Only one type of board vs. fourteen
    - A single data path to USC
  - Only optical patch panel and power supplies on towers
  - L1 trigger functionalities move to USC
  - Recycle much of the infrastructure

More details in Anna Colaleo's talk

Before LS2

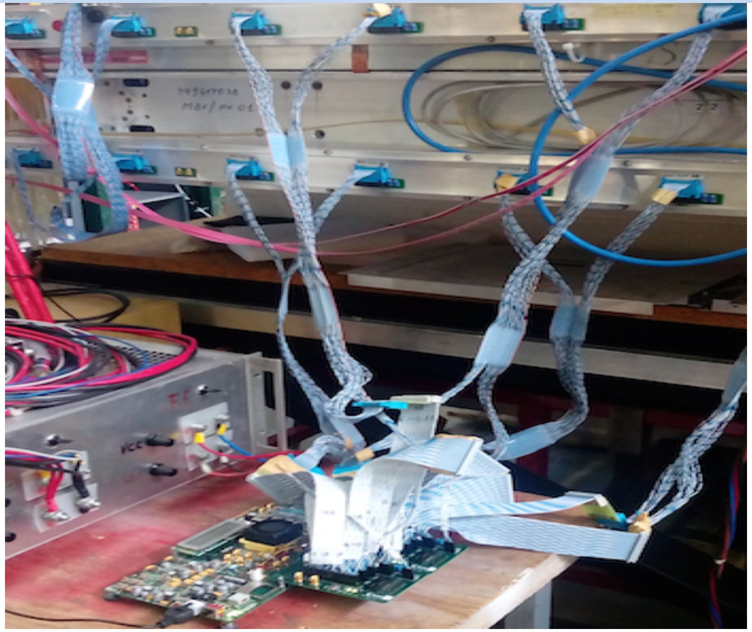


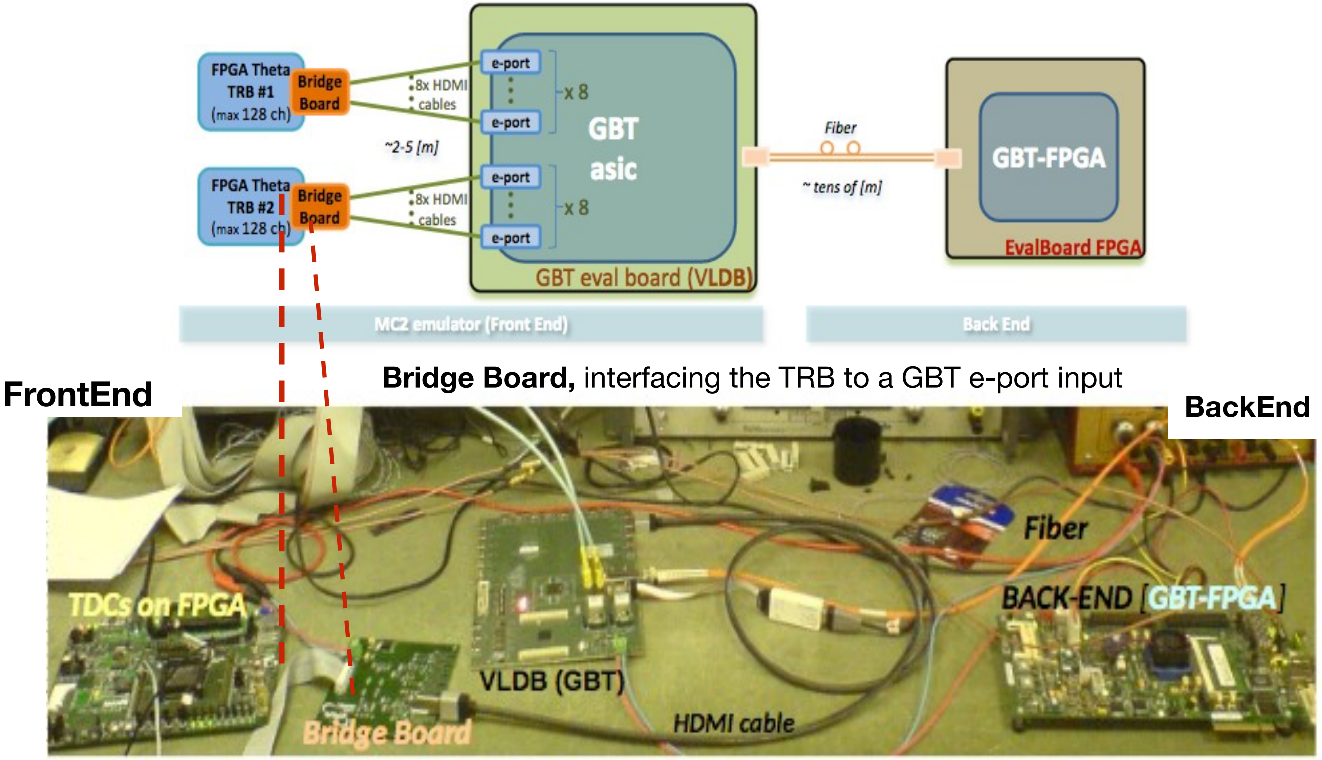
Phase 2



DT progress: Mic2 Data-path demonstrator

Chamber in the surface area =being equipped to collect cosmic muons with the upgraded chain prototypes

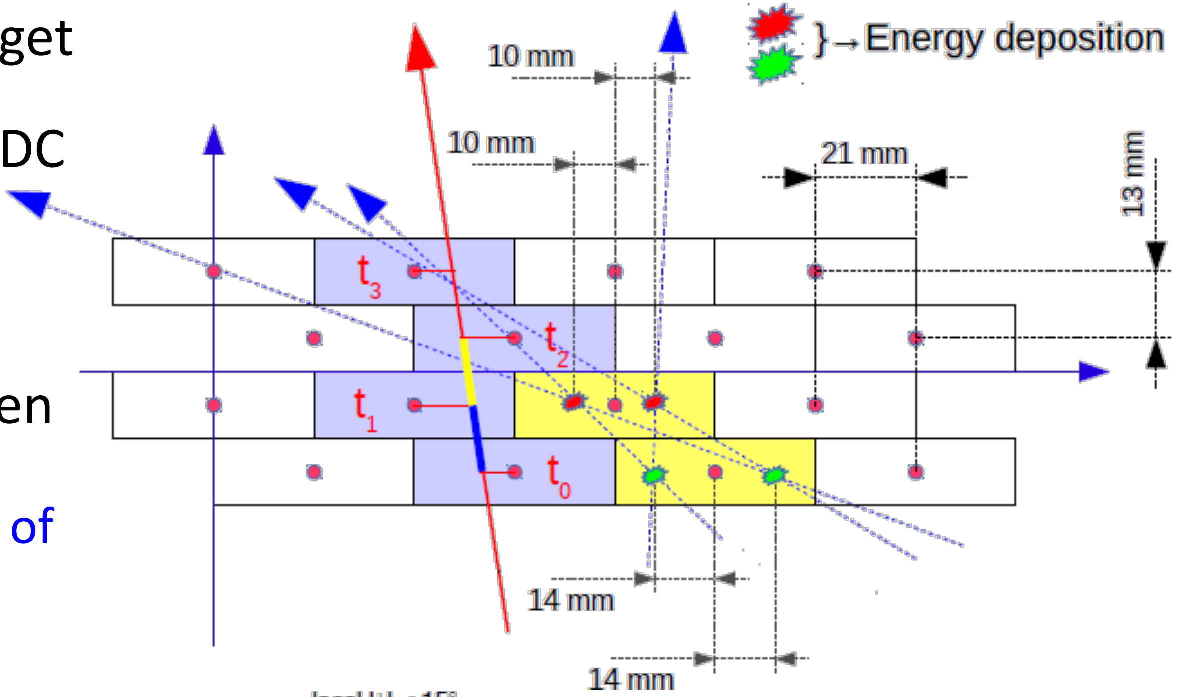


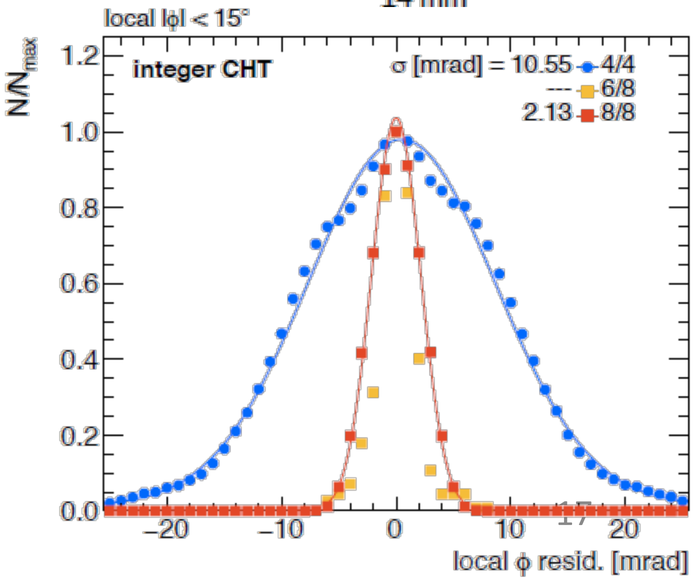


- Front end: GBT protocol running on GBT evaluation board (VLDB)
  - 2 new Theta TRB (trigger board) connected to GBT e-ports
  - Links with e-port will be tested initially in 80 Mb/s mode and then in 160Mb/s mode
- Back end: GBT protocol running on a FPGA
  - EvalBoard loaded with GBT-FPGA firmware (a CERN “off the shelf” component) recompiled for the test

CMS DT: Upgraded Back-End

- Develop a new track segment reconstructor to get valid DT Primitives Algorithm to determine trajectories in a Super Layer starting from rawTDC hits
  - Solve L-R ambiguity (ghost segments)
  - Highly parallel to be implemented in FPGA
- Current Track Finder has poor performance when extrapolating at luminosity 5-7$\times10^{34}$
  - Raising threshold not effective due to flattening of rate curve
- Estimate that today's algorithms for a sector (4 chambers) would fit into two powerful FPGAs assuming 10x logic wrt current Virtex7
- Data buffering pipeline implementation (12 us L1A latency)
- DAQ integration through common CMS software and firmware



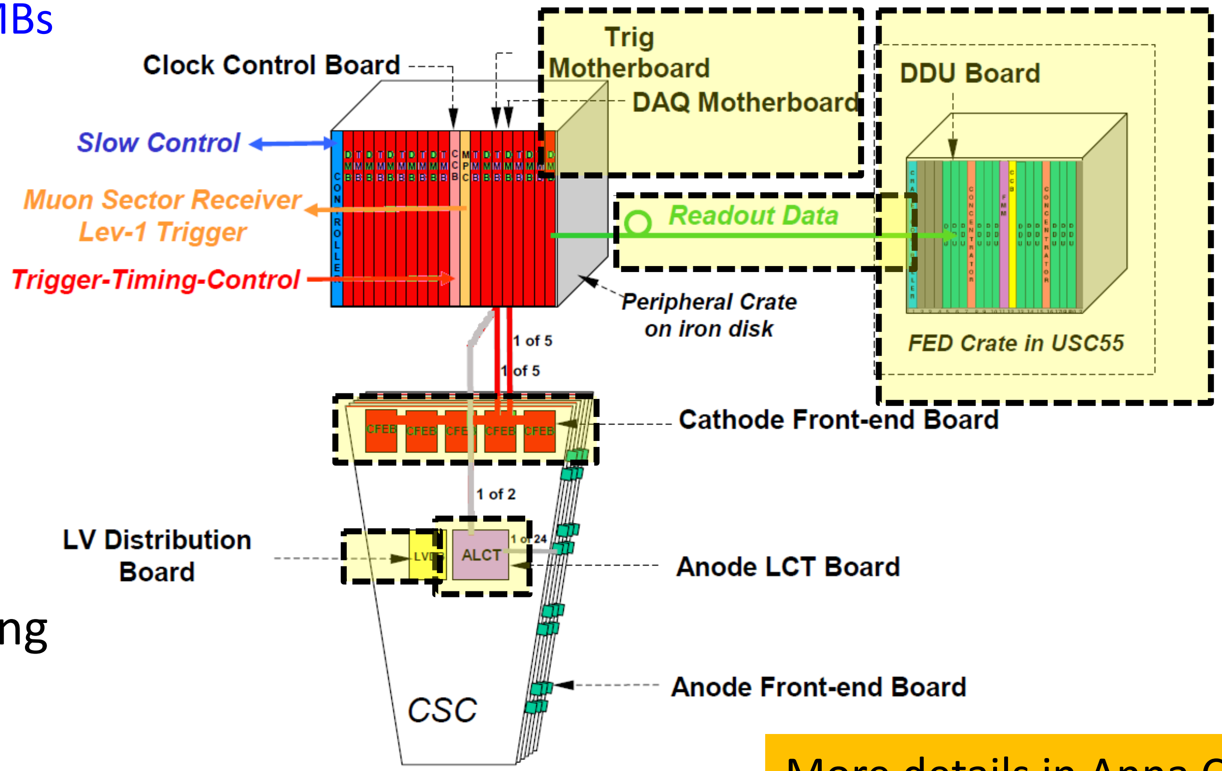


CSC Electronics upgrades

- CSC upgrades driven by latency (12.5μs) and L1A rate requirements
- Replace CFEBs with DCFEBs on ME2/1, ME3/1, ME4/1
  - Avoid SCA buffer overwrite
  - Also requires replacing TMBs with OTMBs
- Replace ALCT mezzanines
  - Accommodate latency
  - Optical output for higher bandwidth in MeX/1
- Upgrade output bandwidth
  - Replace DMBs with new ODMBs in ME1/1, ME2/1, ME3/1, ME4/1
  - Replace Front End Driver (FED) crates
    - μTCA or ATCA system
    - Additional optical fiber connections
- Other electronics are not changed during upgrade

Components to be replaced are highlighted in yellow

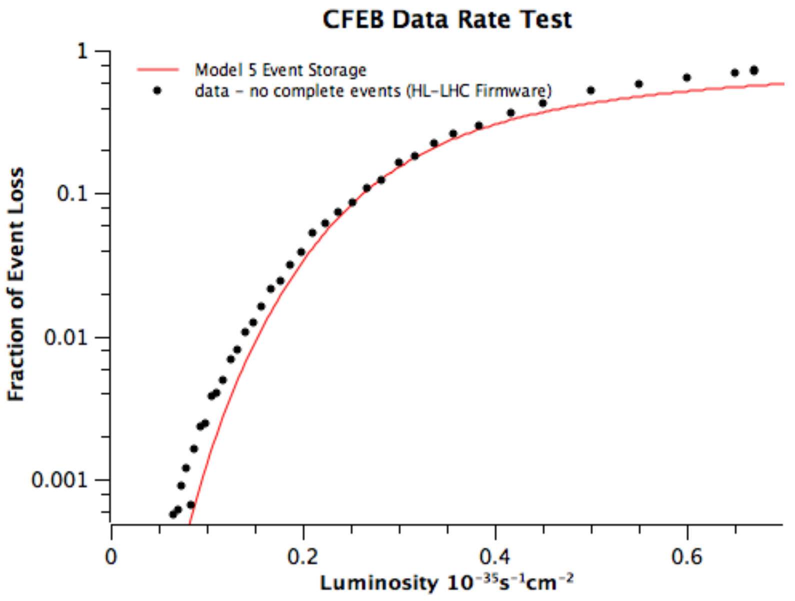
Current Electronics Configuration for CSC Readout

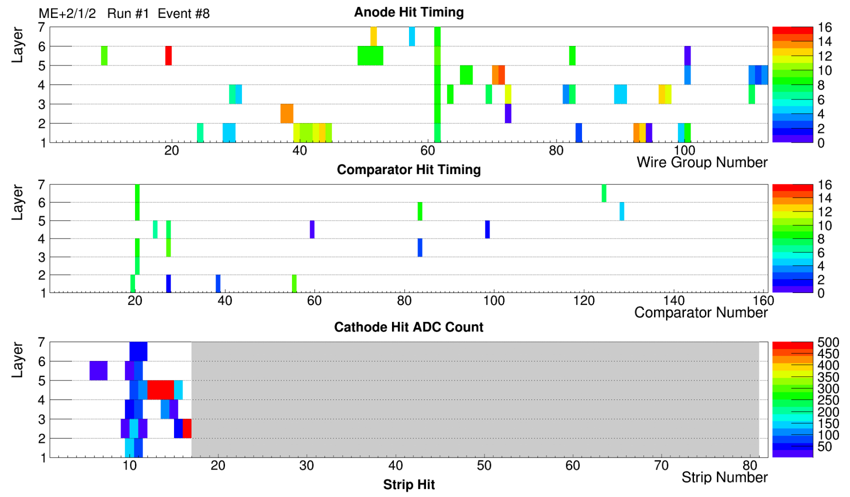


More details in Anna Colaleo's talk

CSC Electronics R&D

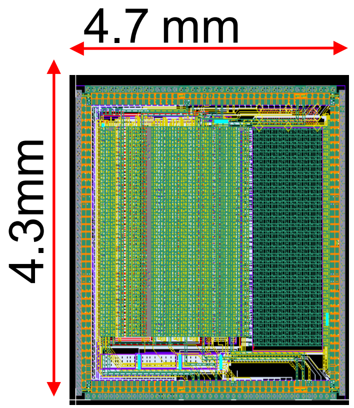
- Characterized existing electronics at high rates
  - On test stand with pulsers patterns programmed to simulate HL-LHC environment
  - At GIF++ facility with muon beam plus source
- Firmware tests
  - In cosmic ray test stand at CERN, full verification of new DCFEBs with existing DAQ motherboards (post-LS2 configuration)
  - Test stand with CTP7 as back end (FED system)





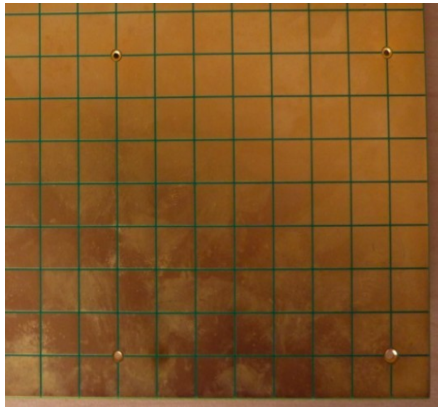
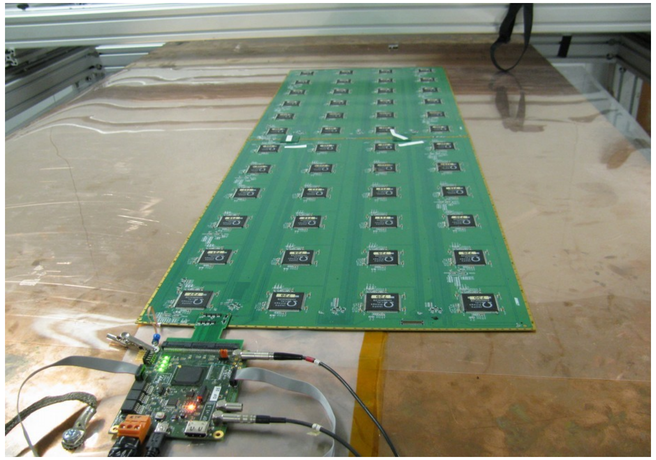
New RPC FE Electronics: HARDROC2

- HARDROC2 front end ASIC:
  - 64 inputs, current preamp with 8 bits gain correct
  - 3 shapers, variable Rf,Cf and gains, 3 discriminators
  - 3 10 bit-DACs to set the thresholds (100fC, 1pC, 10pC)
  - Auto-trigger down to 10fC up to15pC
  - 3 thresh. levels, i.e. semi-analogue readout, will improve spatial resol. beyond digital readout
- ~10 000 ASICs were already tested with a dedicated test bench for the CALICE SDHCAL project
- Successfully tested on both HPL and glass RPC; two kinds of PCB used:

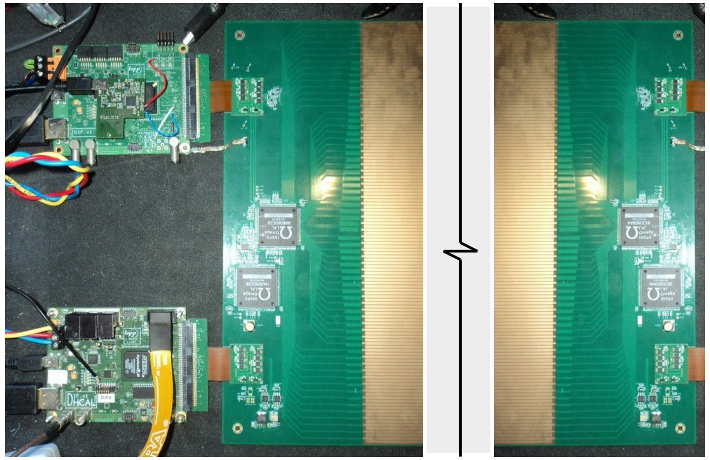


HARDROC2 and 2B:160pins

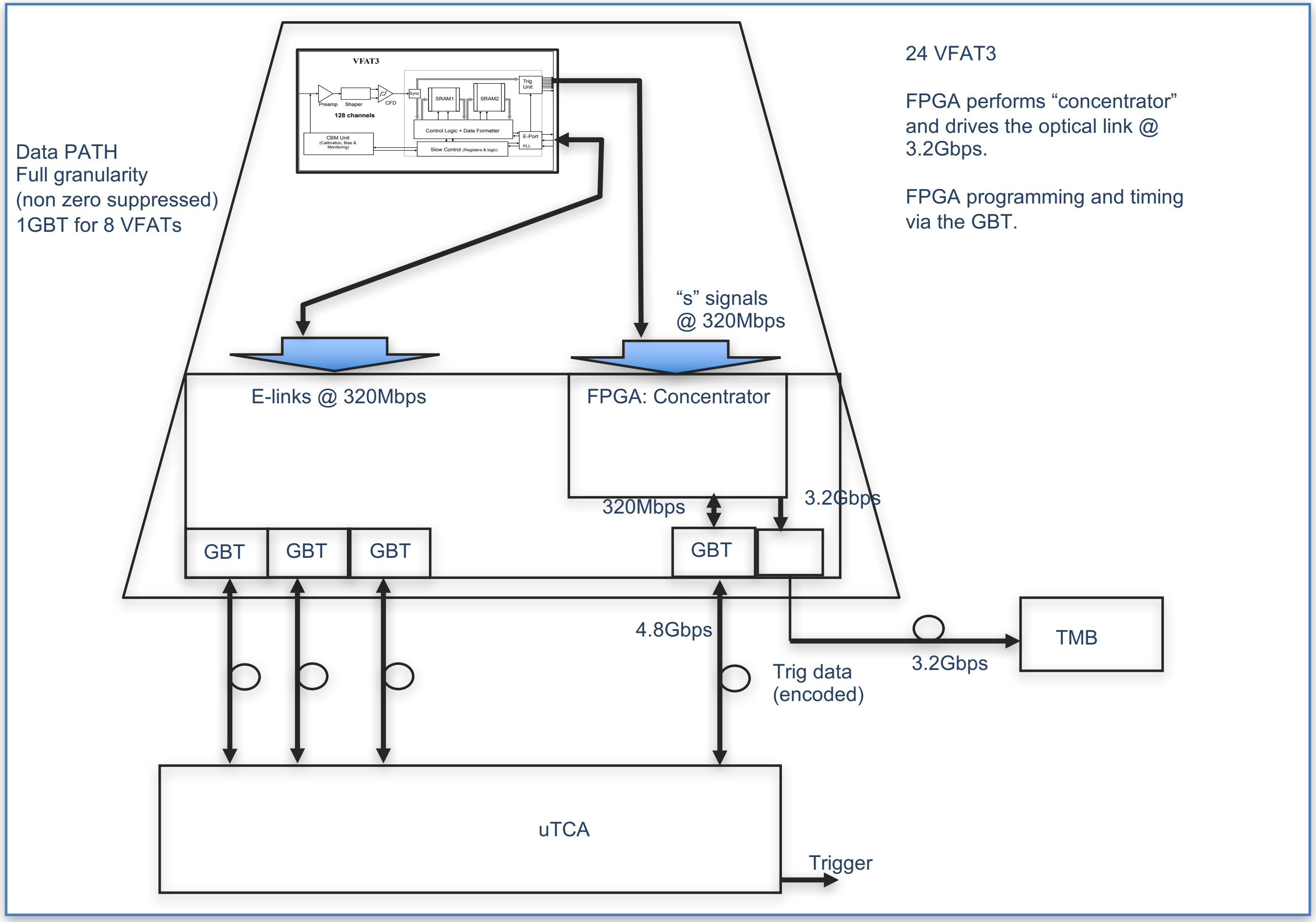
- Pads 1cm X 1cm

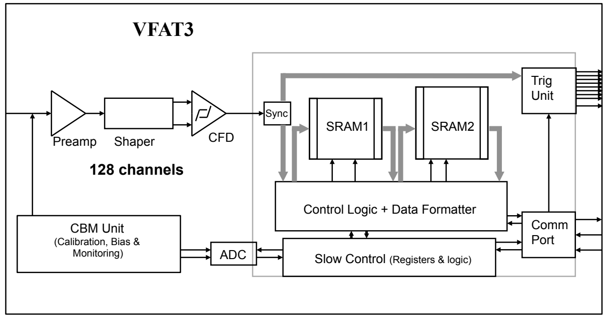
- Strips of 2.5mm pitch

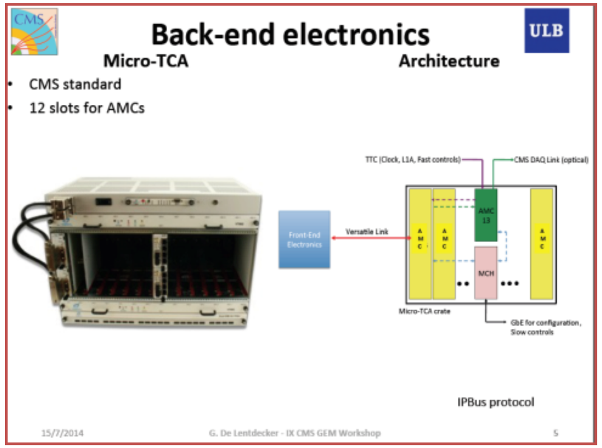


GEM Baseline Electronics System



The control, readout and power to/from the VFAT3 hybrid are delivered via electrical signals (E-links) running through the GEB to the opto-hybrid.

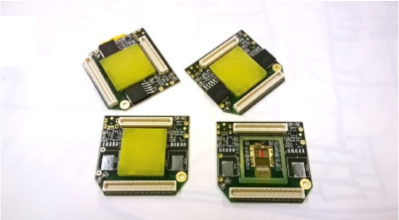


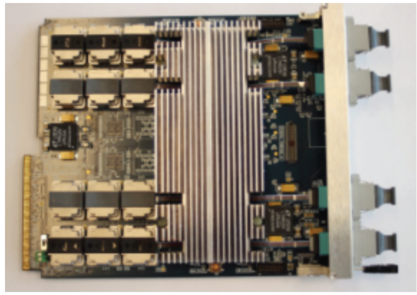


µTCA, AMC13, MCH

GEM Baseline Electronics System

VFAT2



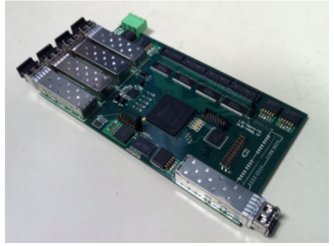


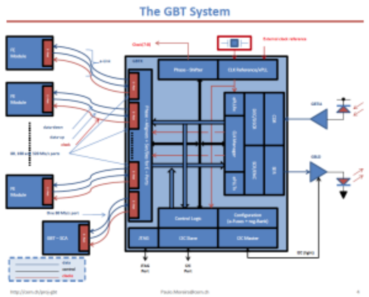
MP7 / CTP7

GEM Electronic Board (GEB)

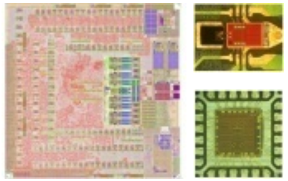
GBT

Opto-Hybrid (OH)





Versatile Link



Use of many common developments such as GBT, Versatile Link, µTCA backend

GE1/1 chamber (with electronics) in cosmic ray test stand at CERN (above CSC chamber)

Summary

- CMS muon upgrade R&D is concentrating on several areas
  - Chamber tests at radiation facility (GIF++)
    - Longevity of existing chambers and new chamber prototypes
    - Eco-gas studies
  - Assessing baseline and alternative technologies for new chambers
    - rate capabilities
    - performance of large prototypes
  - Electronics: adapting to HL-LHC conditions
    - higher hit rates and occupancies
    - Higher trigger rates
    - longer latency requirements