Commissioning and Integration Testing of the DAQ System for the CMS GEM Upgrade

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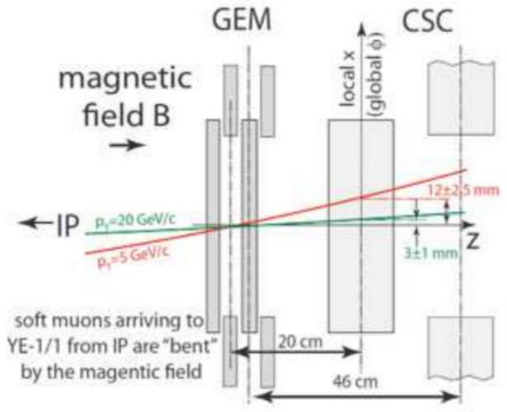
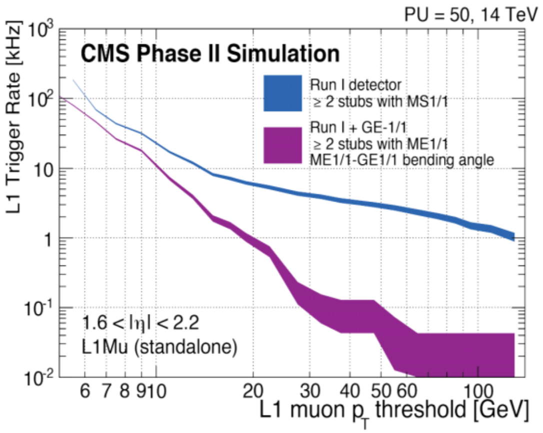
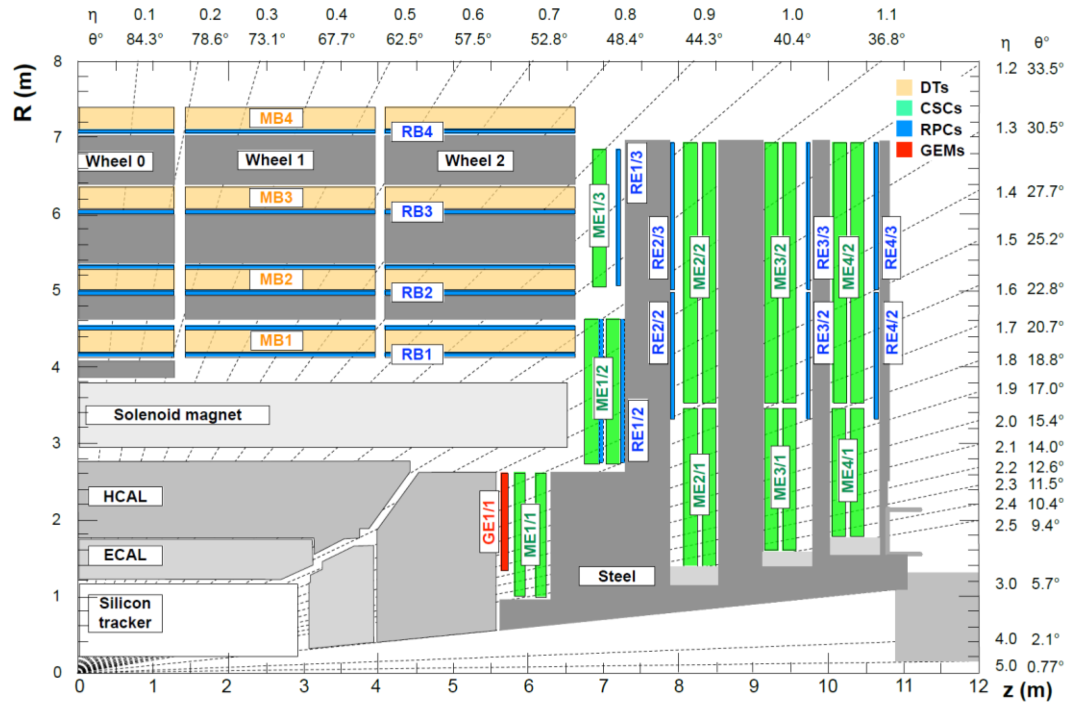
Project Motivation

- Integration of new detector technology in order to enhance muon reconstruction capabilities in the forward region of the CMS experiment (GE1/1 project)

- Main goals:
  - Maintain an excellent muon reconstruction performance during the high-luminosity LHC scenario (most intense particle flux)
  - By combining information with other CMS muon subsystem (CSCs) reduce trigger rate to allow for low muon transverse momentum thresholds in order to increase sensitivity for several SM and beyond-SM processes

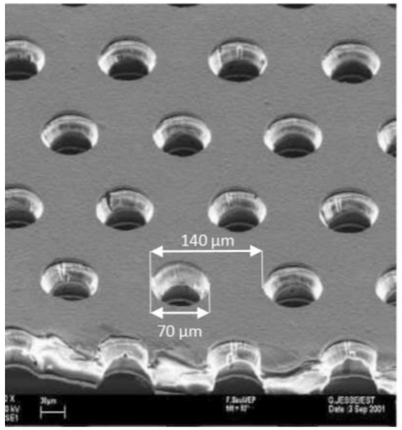


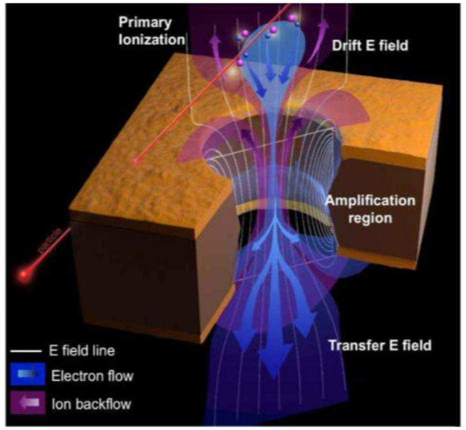


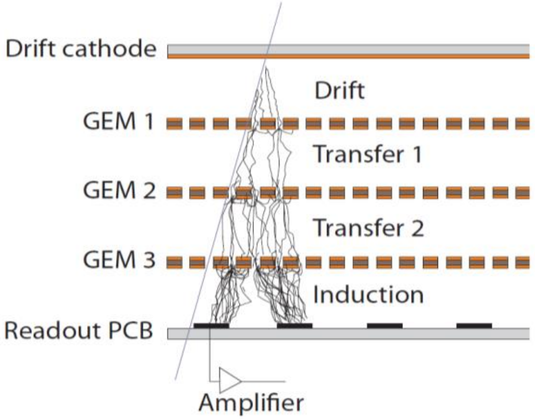


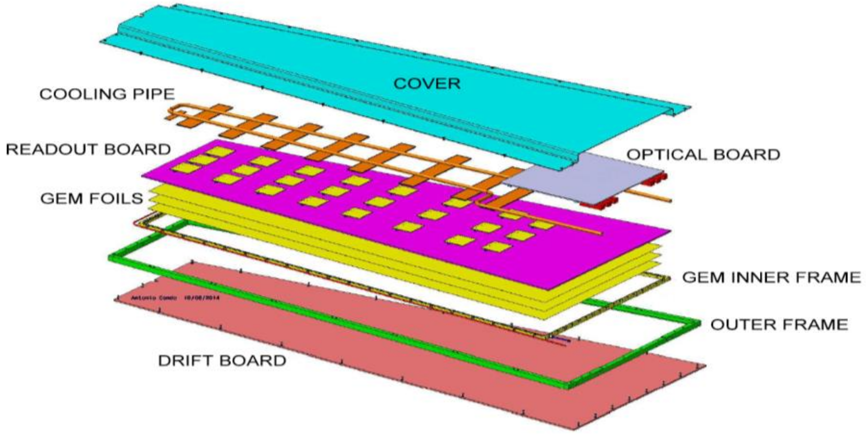
CMS Technical Design Report for the Muon Endcap GEM Upgrade https://cds.cern.ch/record/2021453?ln=en

Gas Electron Multiplier (GEM) Operation Principles

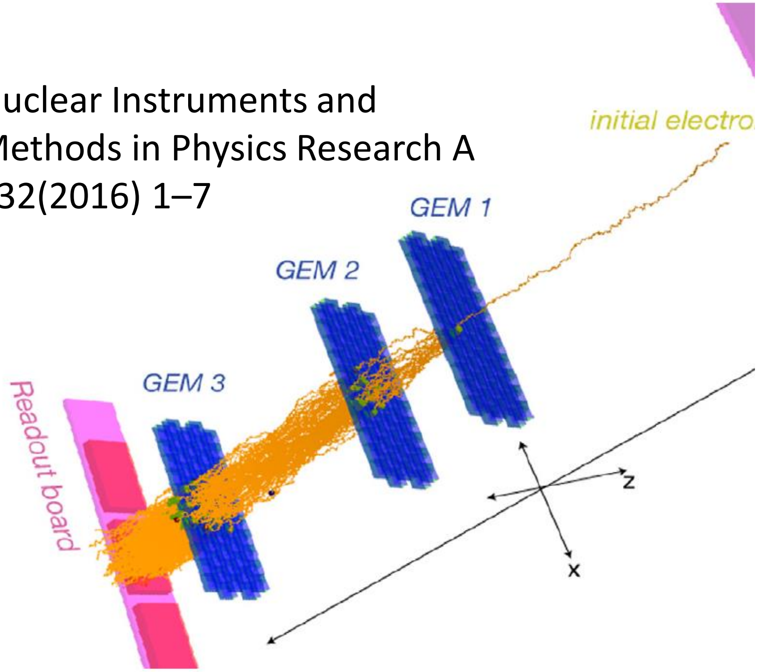








Nuclear Instruments and Methods in Physics Research A 832(2016) 1–7



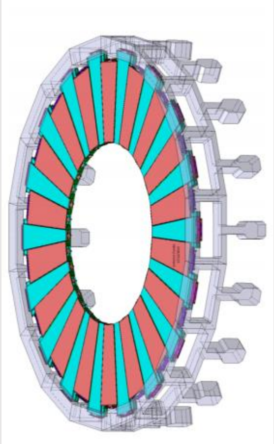
- A GEM is a thin metal-clad polymer foil perforated with high density of microscopic holes (chemical etching)
- A stack of gas gap layers and three gem foils (triple-GEM) was selected as the optimal design (signal amplification)
- Muons interact with the medium and release electrons from the atoms (primary ionization)

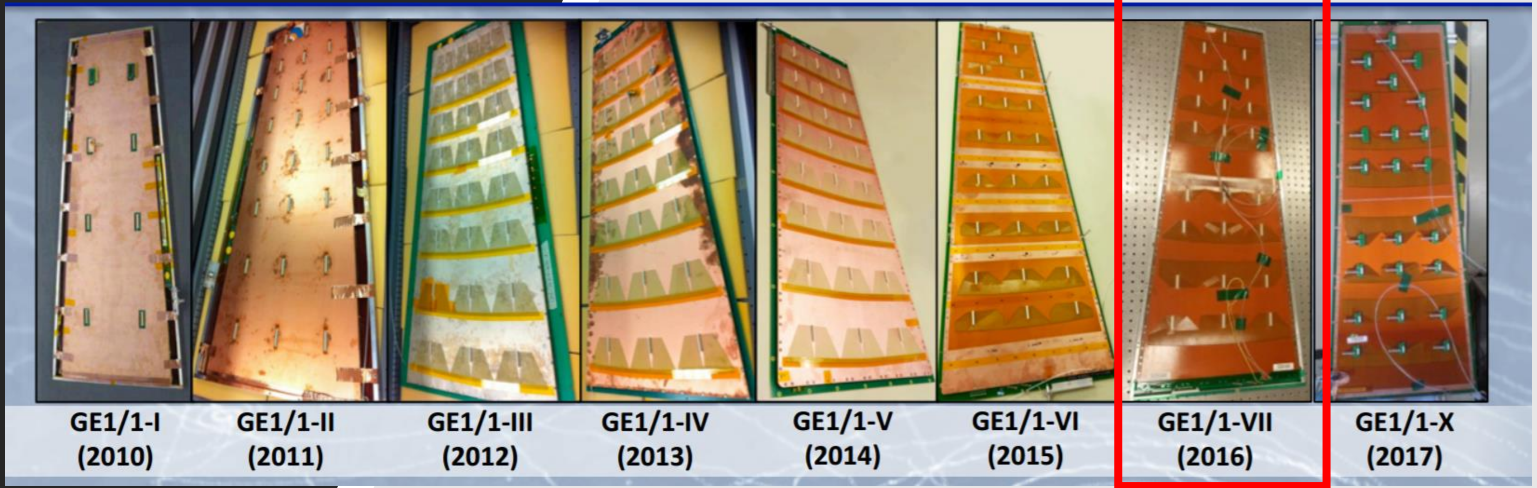
- Free electrons are transported and further multiplied (second ionization) by the action of an electric field (more intense in the GEM holes)
- Total number of electrons are collected (charge) in the readout strips from where muon information can be inferred

Large scale trapezoidal triple-GEM detectors

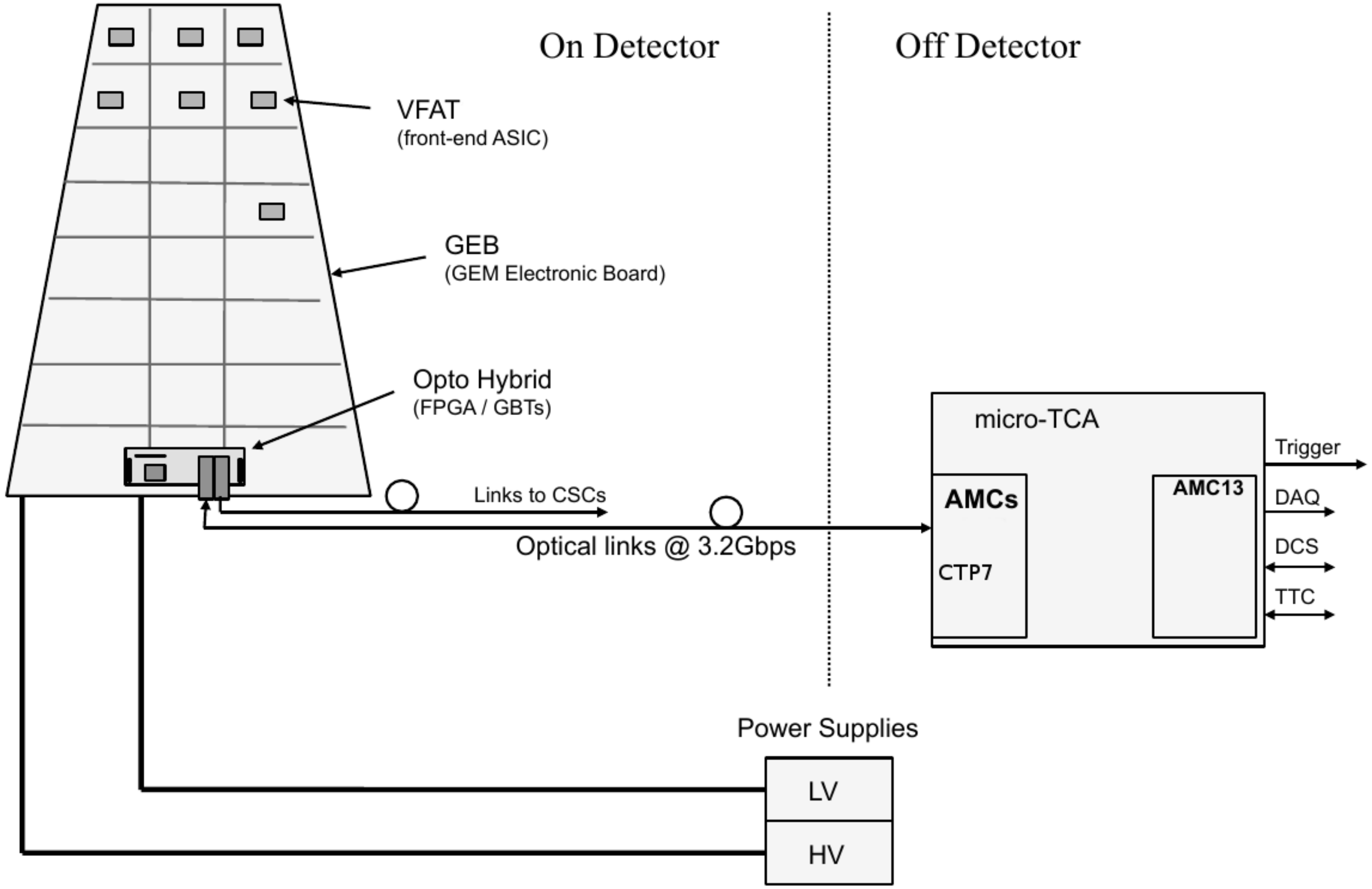
- Trapezoidal shape is needed in order to cover a whole ring in the CMS forward region (each chamber will cover 10 degrees)
- Two triple-GEM chamber modules ("GEMINIs") to be integrated in CMS
- 5 GEMINIs used for GEM Slice Demonstrator
- A big challenge was to build large scale GEM foils and preserve their properties (efficiency, uniformity, etc..)
- Few production sites all around the world

Prototype used for GEM Slice Demonstrator





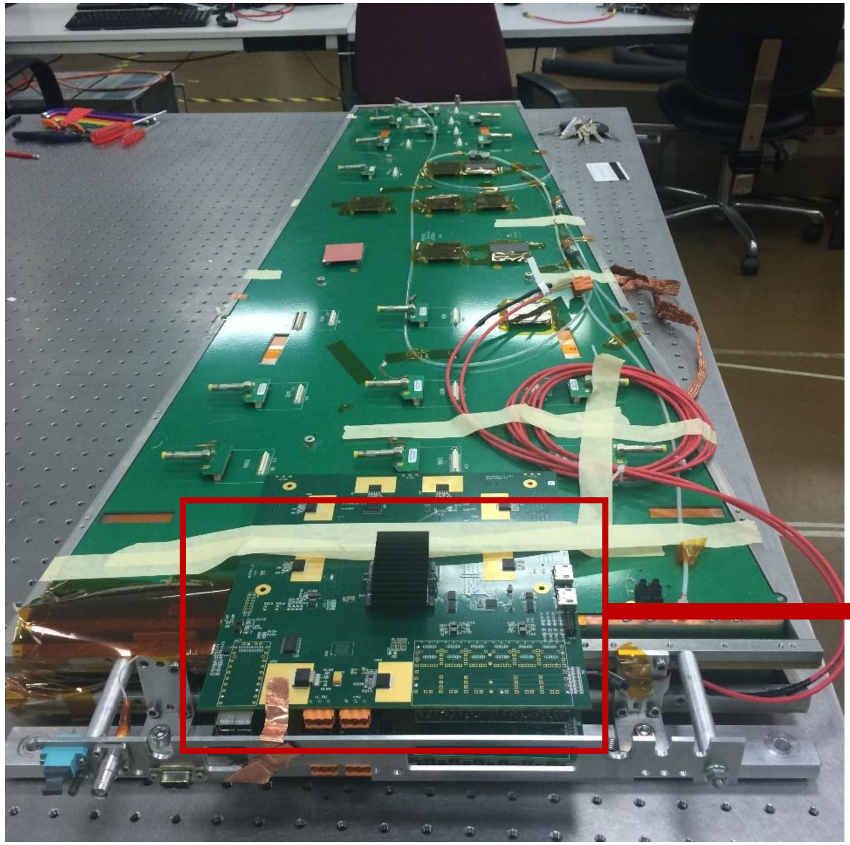
GEM DAQ system



Main hardware and software components for signal readout, data transmission and system configuration

- **On-Detector:**
  - VFAT chips (front-end ASIC)
  - GEM Electronic Board (GEB)
  - Opto-Hybrid
    - GBT chipset, FPGA
    - Optical links
- **Off-Detector:**
  - Micro-TCA
    - AMC cards
    - AMC13 (Custom AMC card)

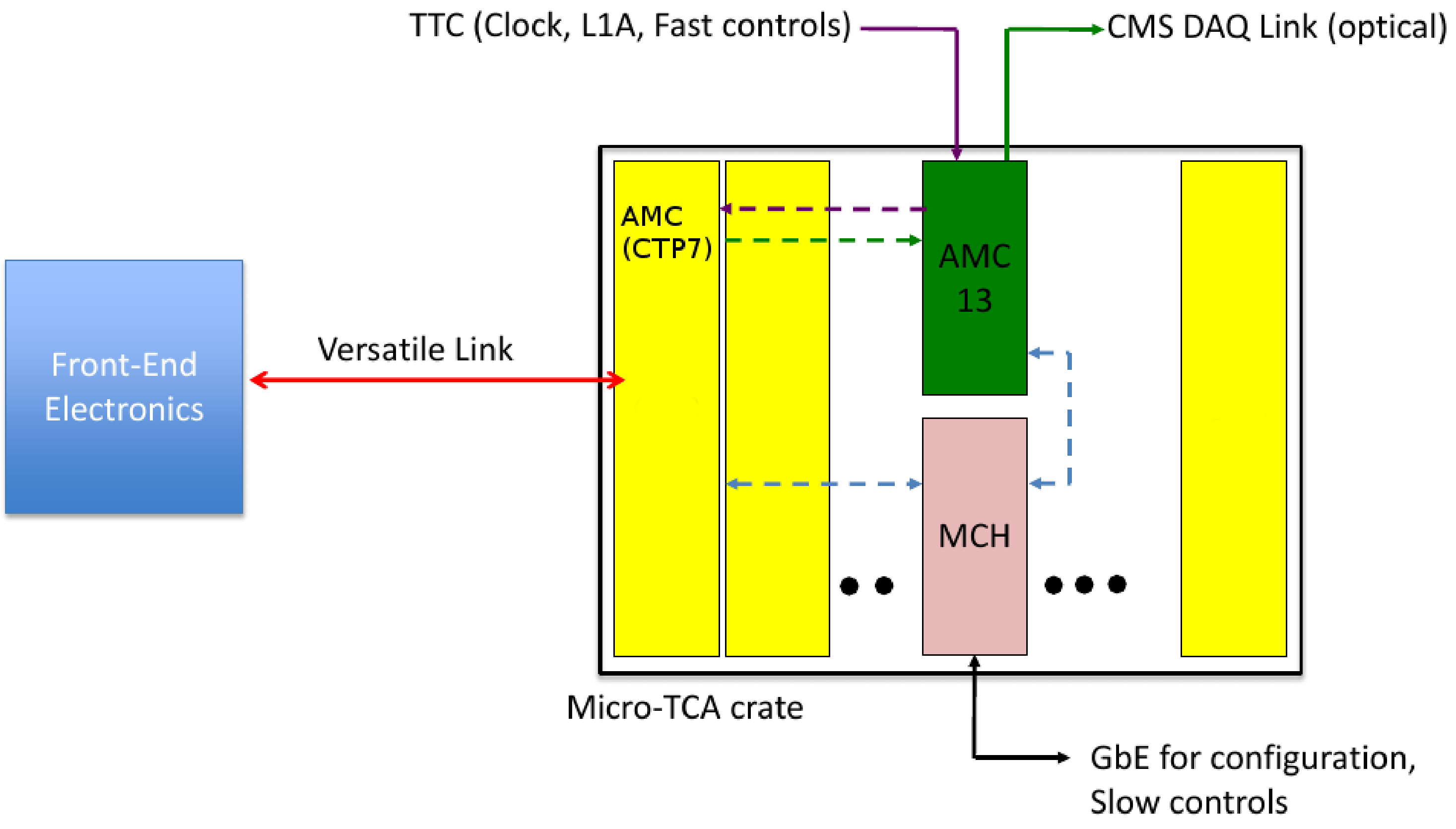
Front-End (On-detector) Electronics

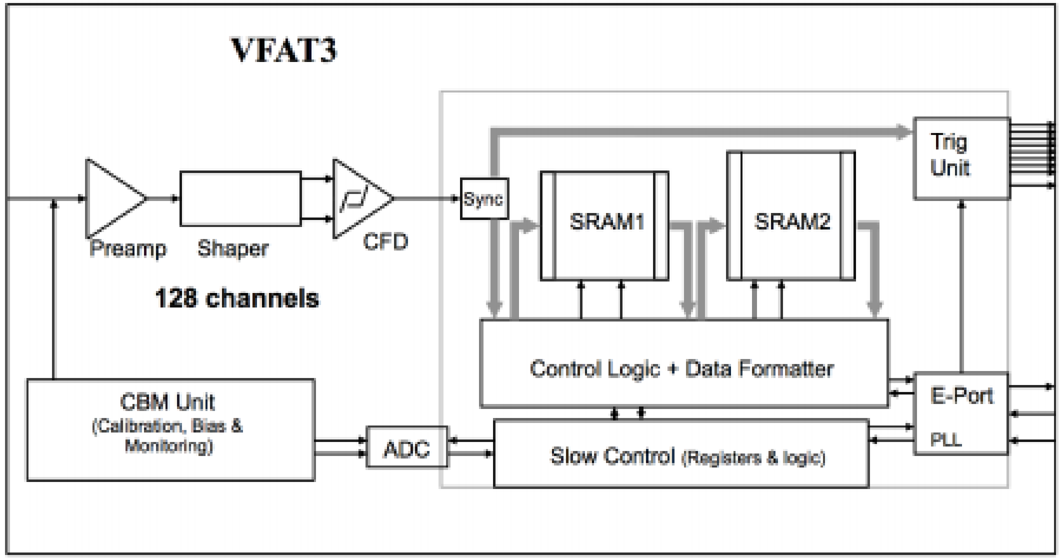


- GEM chamber divided into 24 sectors
- Each sector with 128 readout strips that are connected to a VFAT chip
- VFAT readout and control signals are transmitted via E-links running through a flat PCB known as GEM Electronic Board (GEB)
- Signals from the 24 VFATs are sent to an opto-hybrid device for further processing
- The opto-hybrid consist of a GBT chipset, a FPGA and optical receivers and transmitters for communication with the Off-detector region (including the CSC muon system)

Back-End Electronics

- **micro-TCA**
  - Support 12 AMC cards and 2 MCH
  - Data throughput of 2Tbit/s
  - Standard for all CMS upgrades
- **AMC13**
  - Standard module to interface to CMS DAQ and provide the Trigger Timing and Control (TTC)
- **AMCs**
  - UW CTP7 (University of Wisconsin Calorimeter Trigger Processor)
  - Based on Xilinx Virtex-7 FPGA
  - 1 board sufficient for GEM Slice Demonstrator
  - 12 boards needed for full GE1/1 upgrade



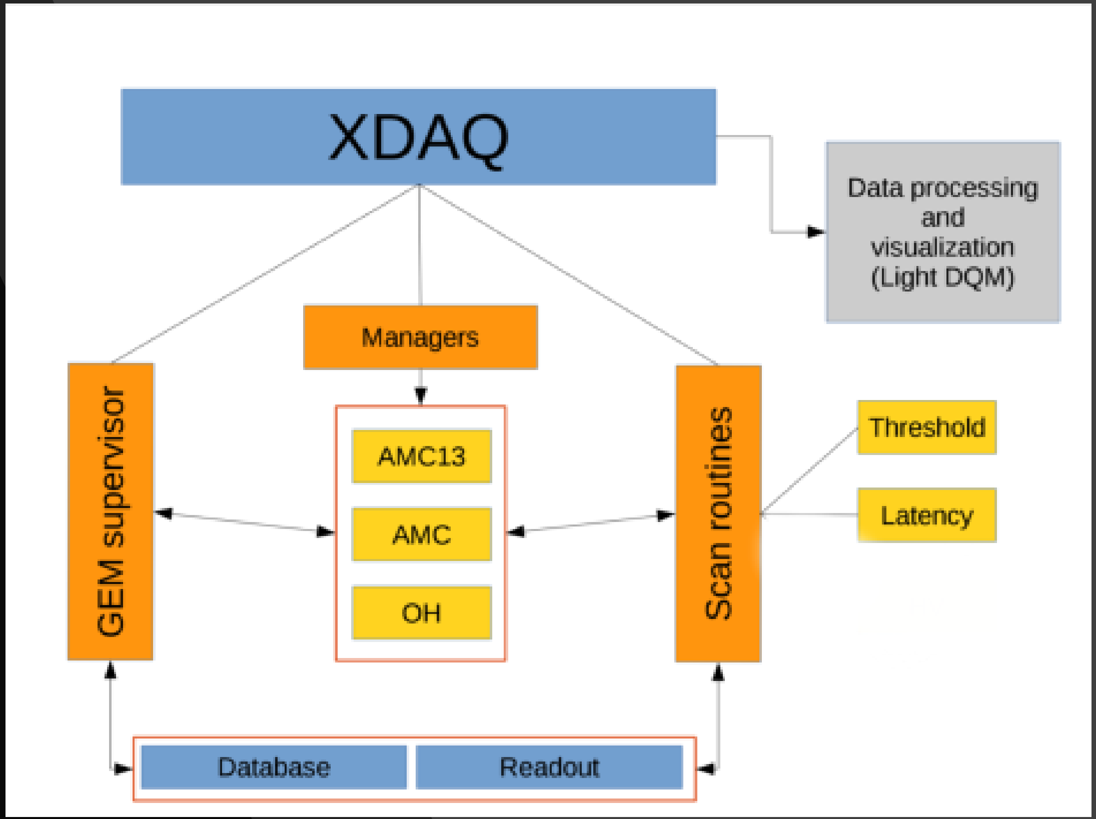


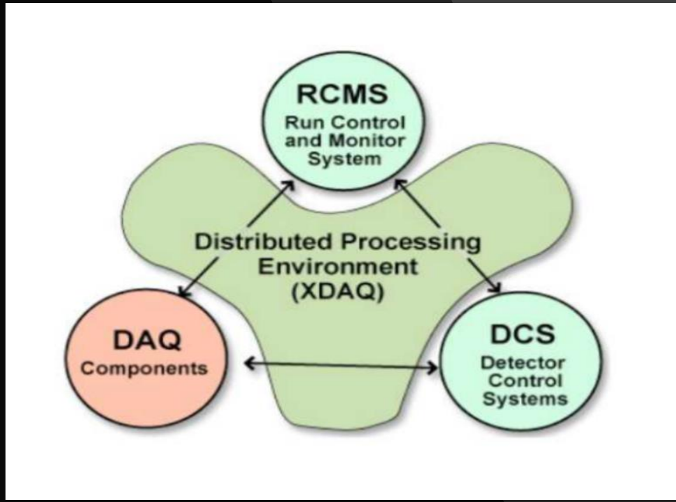
VFAT basic requirements

- 128 channels
  - Continuously sampling the GEM readout strips
  - Provide tracking and triggering information
- Time resolution of less than 7.5 ns
  - In order to cope with the duration of the signal produced during the ionization (few ns depending on the gas mixture)
- Tracking information
  - Full granularity after L1A (L1 Accepted event)
- Integrated calibration and monitoring functions
- Radiation resistant (up to 100 Mrads)
- VFAT2 prototype is used for the GEM Slice Demonstrator while for the future upgrade VFAT3 is foreseen

GEM Online Software (xDAQ)

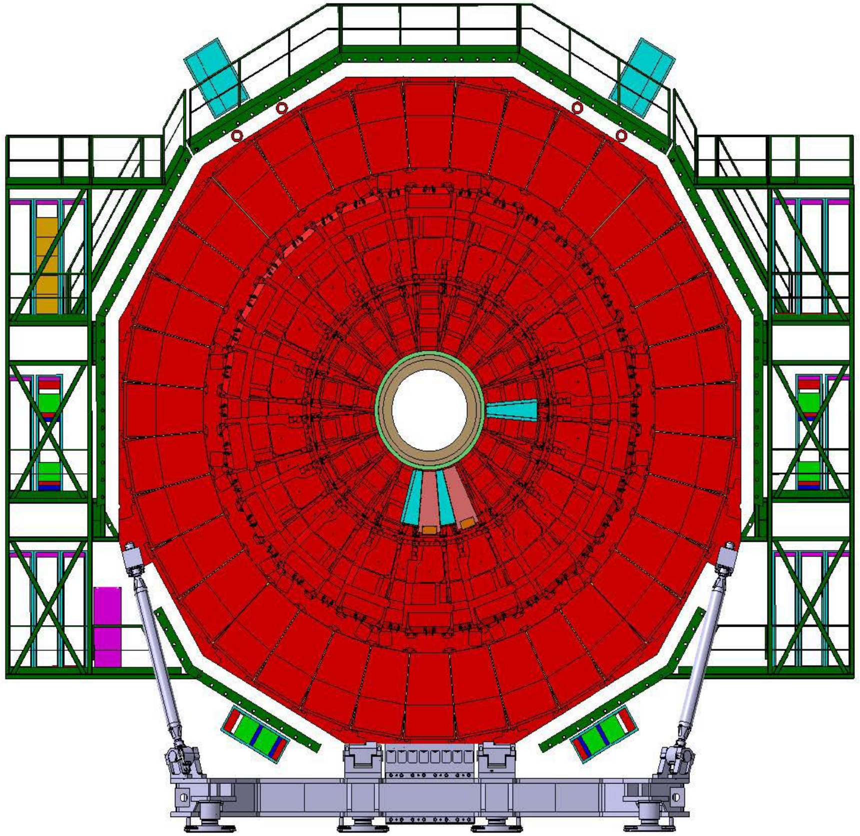
- Designed according to general CMS scheme
- Custom applications derived from standard xDAQ function
- Software is abstracted into several layers
- The software provide access to the AMC boards where the tracking and trigger data from GEM detector is received
- A Finite State Machine is implemented ensuring smooth transitions between “Halt”, “Initialized”, ‘Configured” and “Running” states
- Configurable to perform various scan routines



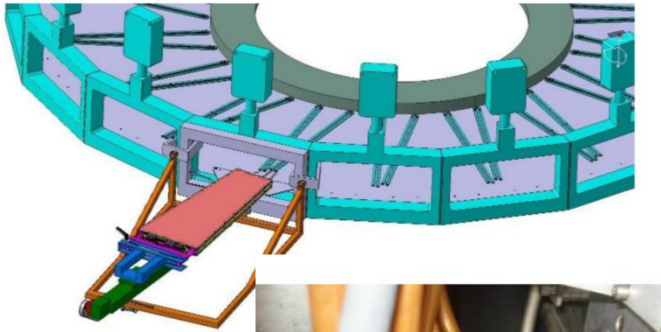


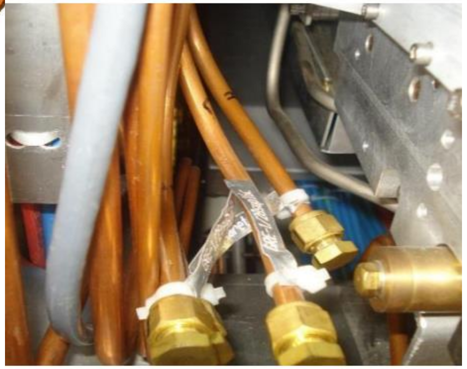
Official xDAQ webpage
https://svnweb.cern.ch/trac/cmsos

GEM Slice Demonstrator in CMS



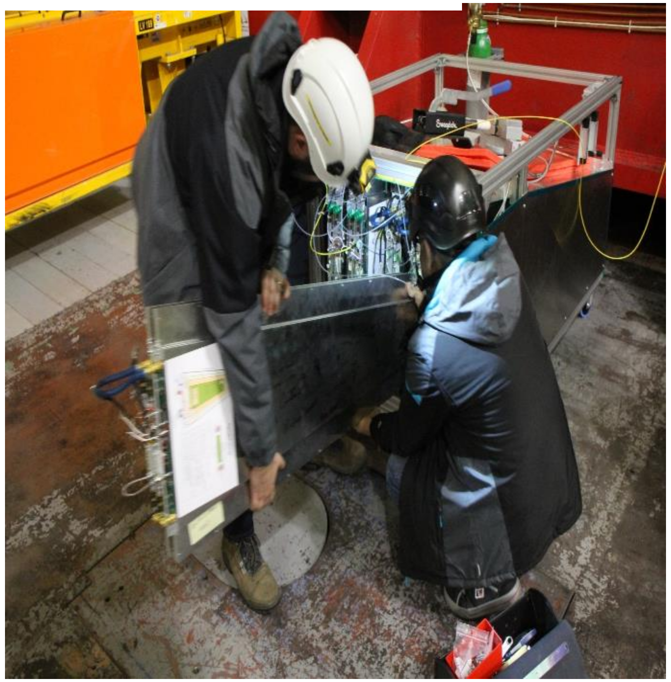
- Installation of 5 twin triple-GEM trapezoidal chambers ("GEMINIs") in CMS during the end-of-year technical stop (2016-2017)
- Main goal is to gain experience in:
  - Mechanical installation (mounting, services, cabling, etc..)
  - GEM DAQ setup
  - Testing communication with central CMS DAQ and CSC muon system





S4F03 in USC -1 level

GEM main frame with the branch controller



Mechanical Installation and services

GEM DAQ operation modes

- Local Calibration Routines: Directly from the opto-hybrid using firmware modules
- Local Run with local readout: Readout directly from the AMC13
- Local run with miniDAQ: Stripped down version of the central DAQ (cDAQ) infrastructure, mimics full path, but runs separately from the other subsystems
- Global Run: Fully integrated into the cDAQ infrastructure, events are included into the CMS data stream

VFAT Calibration Routines

- VFAT calibration routines are performed in order to identify possible malfunctioning or "noisy" channels
- Each VFAT chip comes with a calibration unit which consist of an:
    - Internal pulse generator delivered to each channel
    - Possibility to vary the amplitude of the voltage in every channel (Vcal)
- Number of counts are recorded for each Vcal step (S-curve)
- Additionally there is a 5 bit Trim DAC for each channel that can be used to adjust the slight differences between channels due to fabrication statistical fluctuations (Trimming)

VFAT2 : A front-end "system on chip" providing fast trigger information and digitized data storage for the charge sensitive readout of multi-channel silicon and gas particle detectors.

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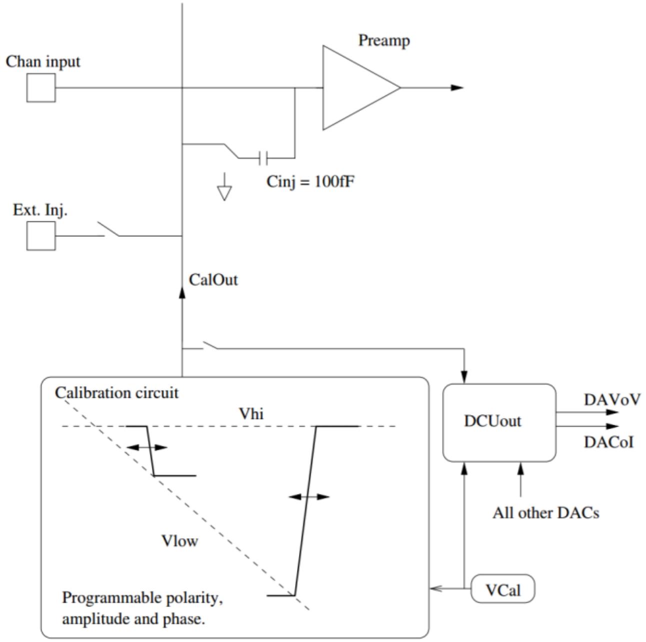
Internal test pulse generator



Characteristic S-curve

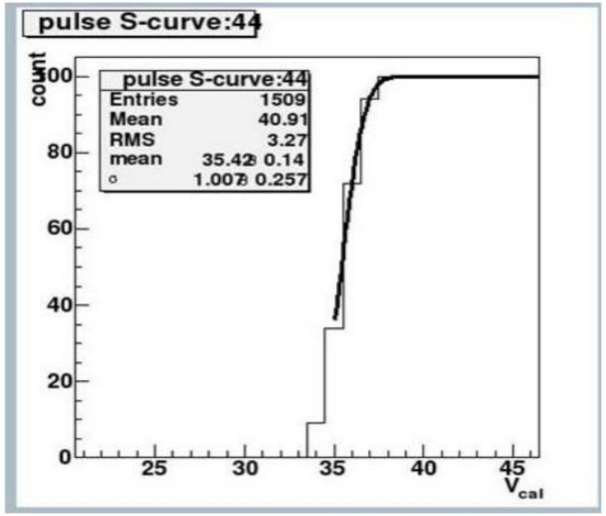
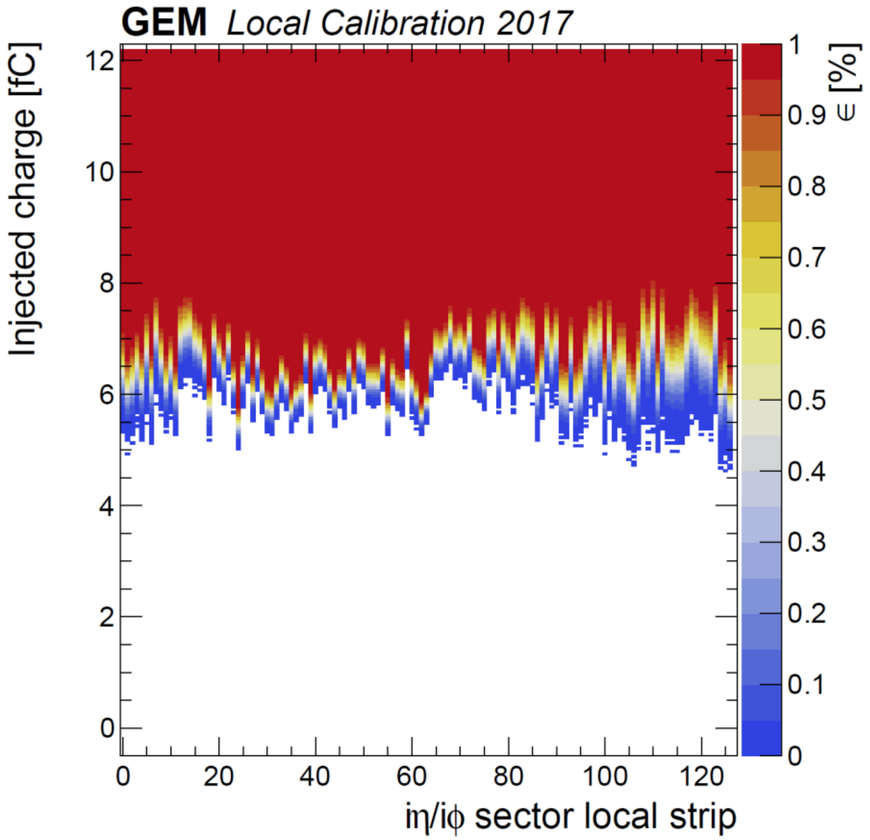


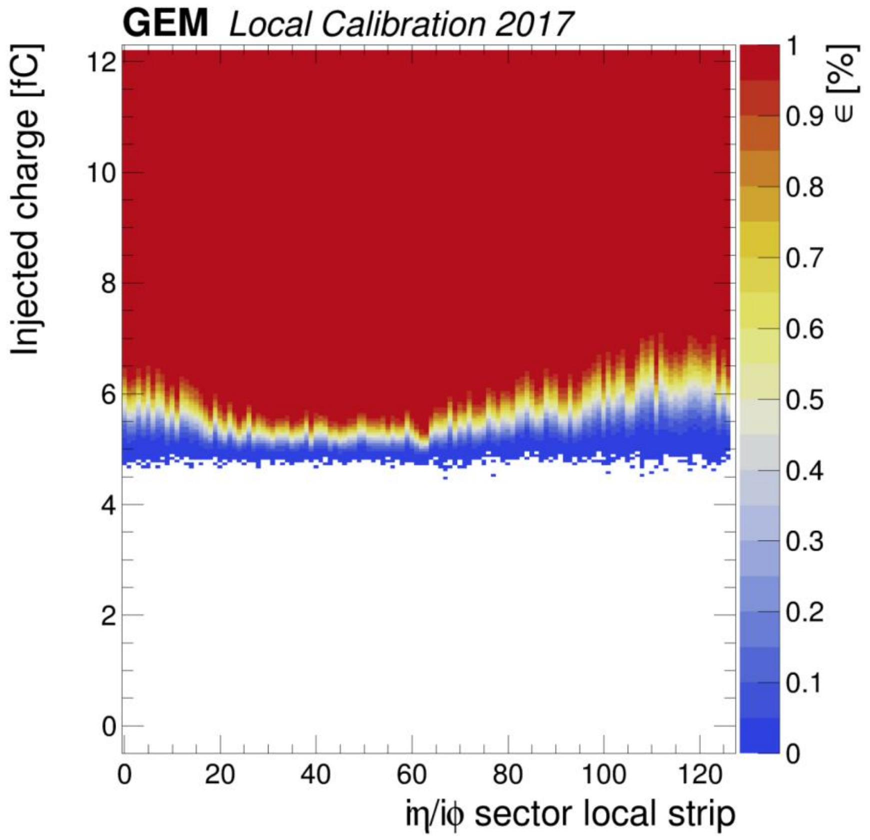
Figure 12 S-curve measurement. Sweeping the input signal amplitude (VCal) on a given channel and counting hits for a constant threshold.

GEM VFAT local calibration

Pre-trimming



Post-trimming



- VFAT Local calibration routines are performed to individual channels
- After the trimming process the resulting S-curve plots shows a smooth behavior with no dead channels identified
- S-curve is a common tool used for noise characterization

Summary and Future Perspectives

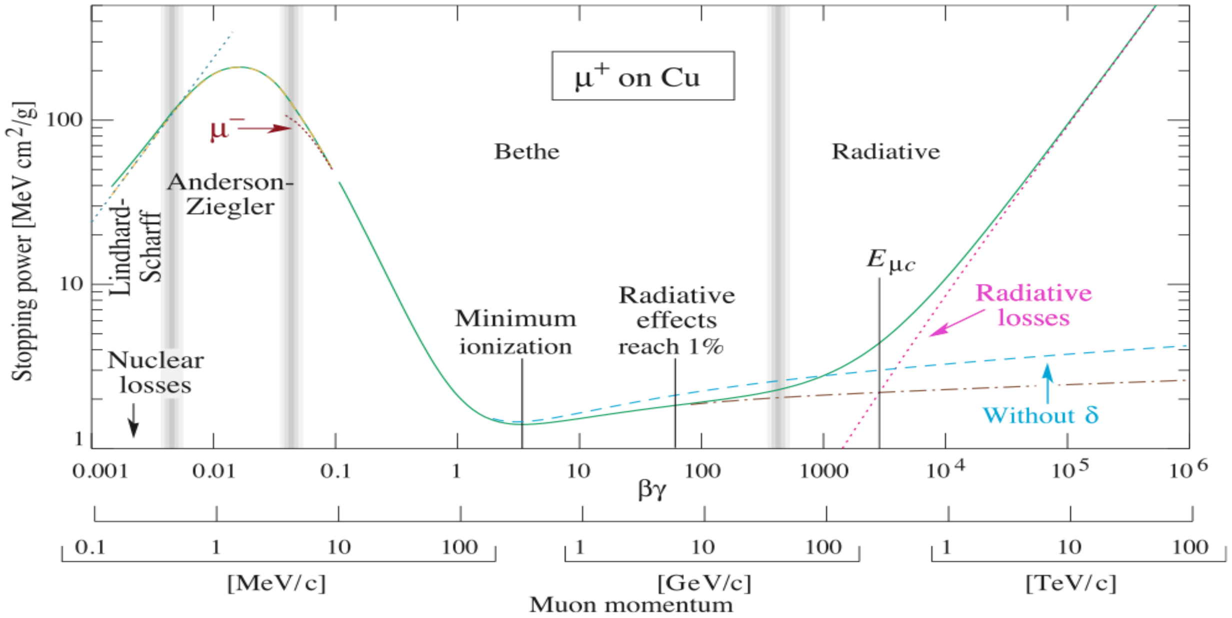
- A successful installation of 5 twin triple-GEM chambers (“GEMINIs”) into CMS was performed during the end of 2016 and beginning of 2017
- Invaluable experience gained on mechanical installation, service integration and DAQ setup that could potentially reduce and optimize the time required during the installation of the full GEM system (GE1/1) in 2019
- GEM local calibrations indicate a good system performance and provide valuable data for monitor of the system and GEM DAQ components
- GEM Slice Demonstrator commissioning work will continue during 2017 in parallel with the regular CMS collision data taking; this will allow for the system to be tested with the rest of the CMS subsystems for the first time

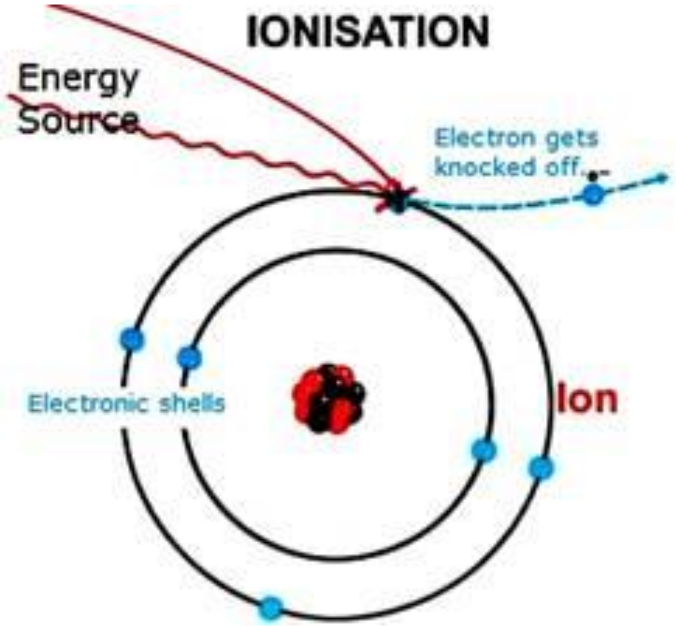
Backup

Fundamentals of Gas detectors

- Charged particles interact with the atoms in the medium
- Muon energy loss is transferred to the electrons of the atoms in the medium, if enough energy is added, the electron is ejected (primary ionization)
- If the ejected electron energy is high enough in its path can ionize other atoms (secondary ionization)
- The charge accumulated by those electrons produced in the ionization is collected in a readout to extract information from the incident muon

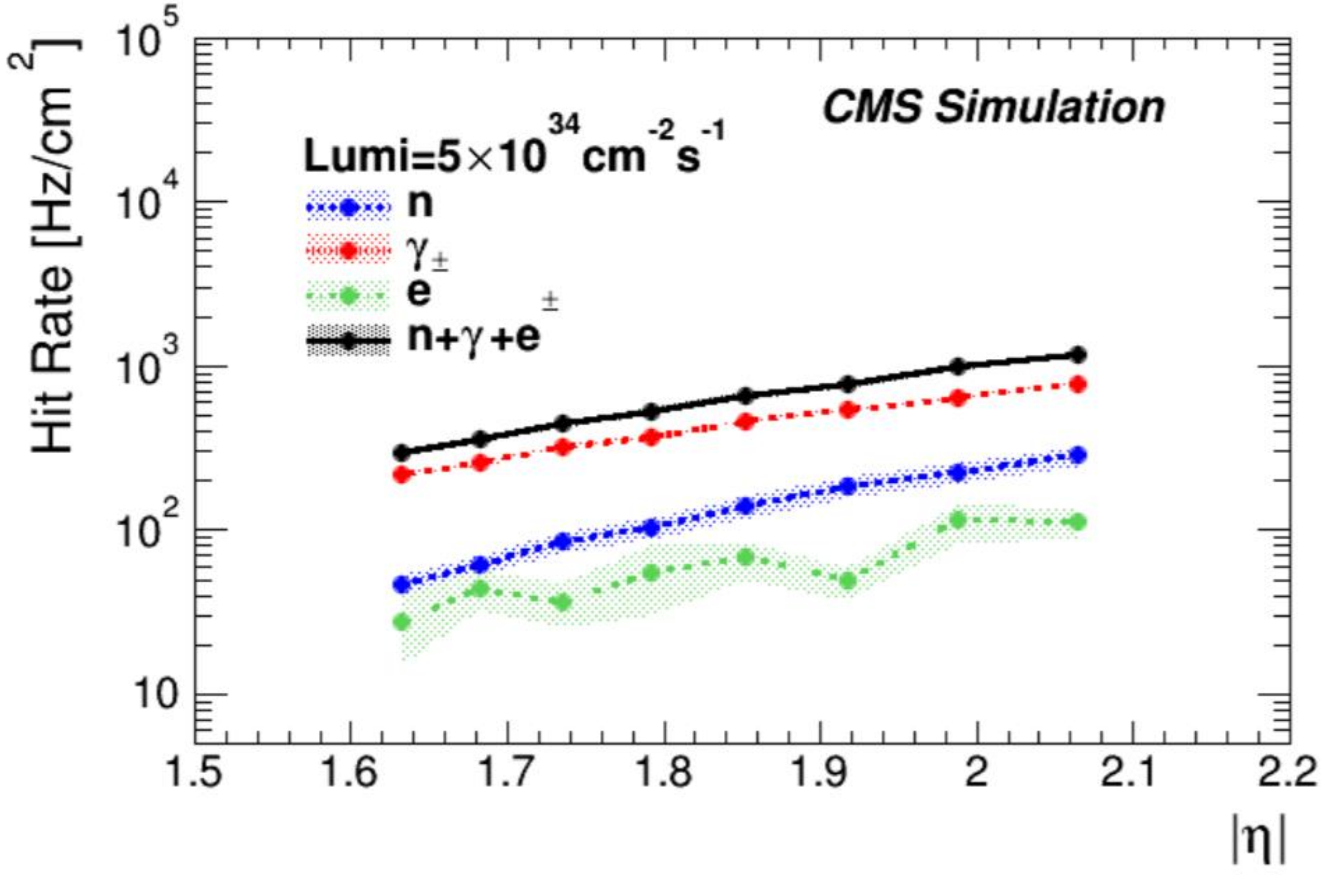
http://pdg.lbl.gov/2013/reviews/rpp2012-rev-passage-particles-matter.pdf





Expected particle rate for GE1/1

5/8/2017



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