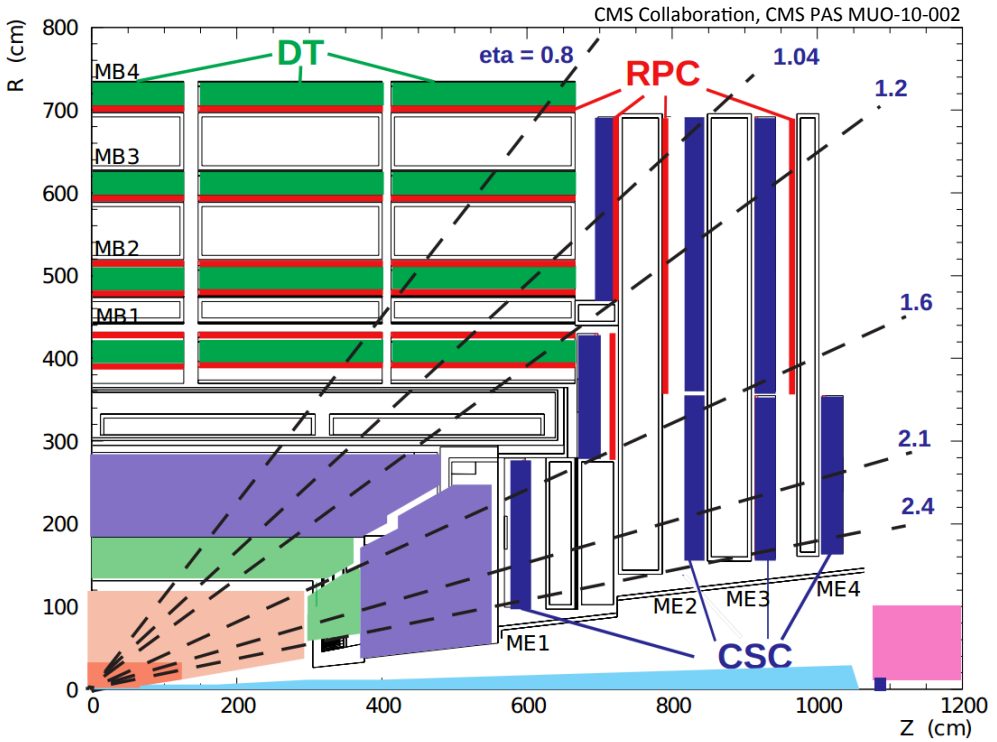
Upgrade of the CMS Muon System with Triple-GEM Detectors

B. Dorney

On behalf of the CMS Collaboration

CMS Trigger and Original Muon System Design

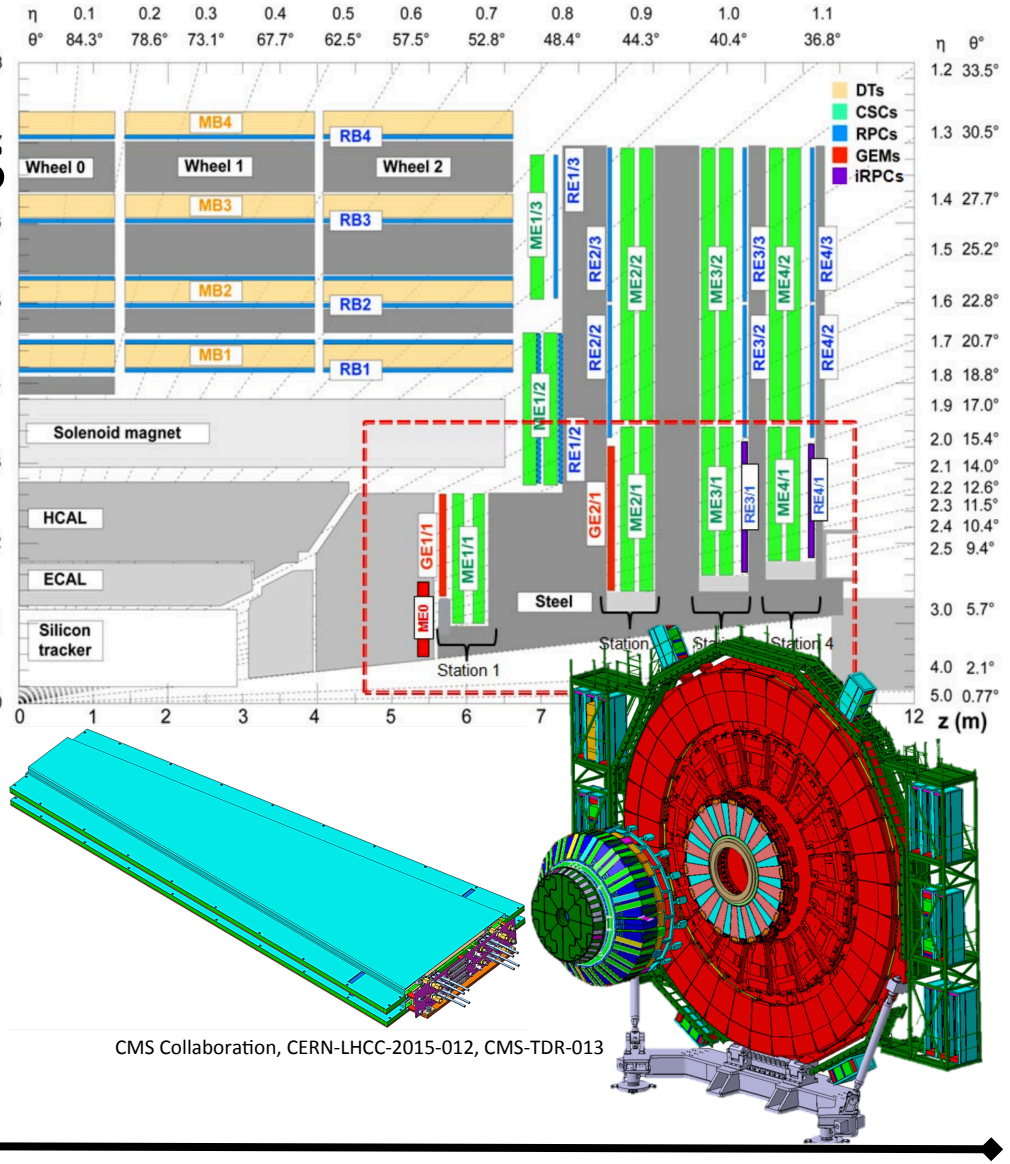
- **Redundant muon system**
  - **Drift tubes (DT); $|\eta| < 1.2$**
  - **Resistive plate chambers (RPC); $|\eta| < 1.6$**
  - **Cathode strip chambers (CSC); $1.0 < |\eta| < 2.4$**
- **Original RPC's coverage planned to extend to entire CSC range**
  - **Un-instrumented due to rate capability concerns**
- **Only CSC system provides muon information beyond $|\eta| > 1.6$**



- **Two part trigger system**
  - **Hardware: Level 1 (L1) R≈100kHz**
  - **Software: High-level-trigger (HLT) R≈1kHz**

CMS GE1/1 System

- GEM technology
- 36 superchambers per CMS endcap
  - Two detectors per superchamber
  - Spanning 10° in ϕ
  - Detectors per endcap: 72
- Maximum η coverage
  - 1.6 < |η| < 2.2
- Additional wheels planned for Phase II Upgrade
  - GE2/1 and ME0
  - Not covered in this talk



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Original Muon System Limitations

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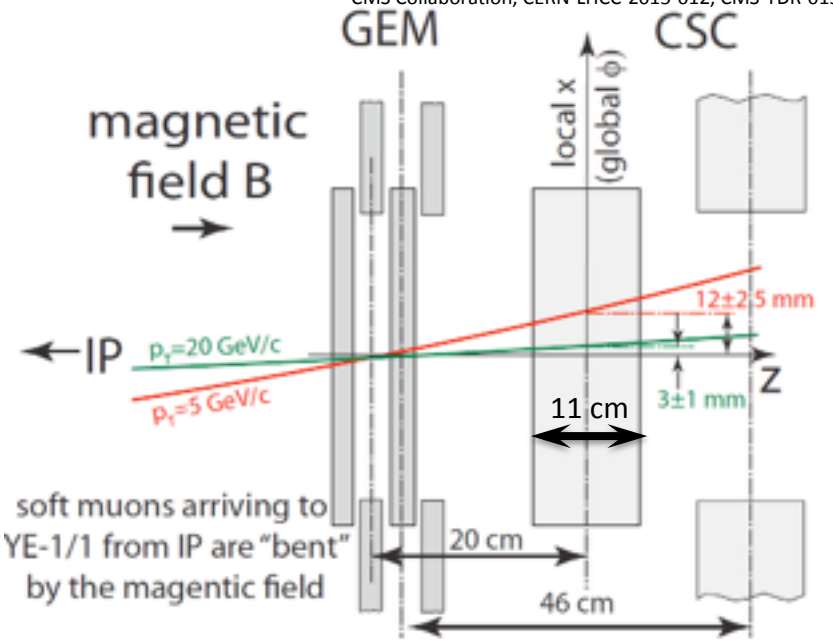
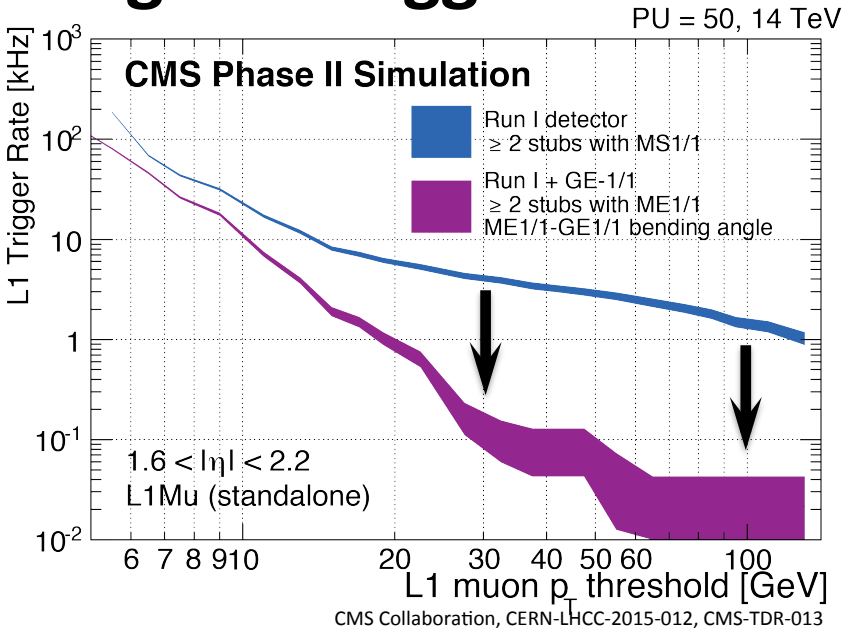
- **Cannot measure muon direction at trigger level**
  - **i.e. bending angle**
  - **Low magnetic field**
  - **Small lever arm (11cm)**

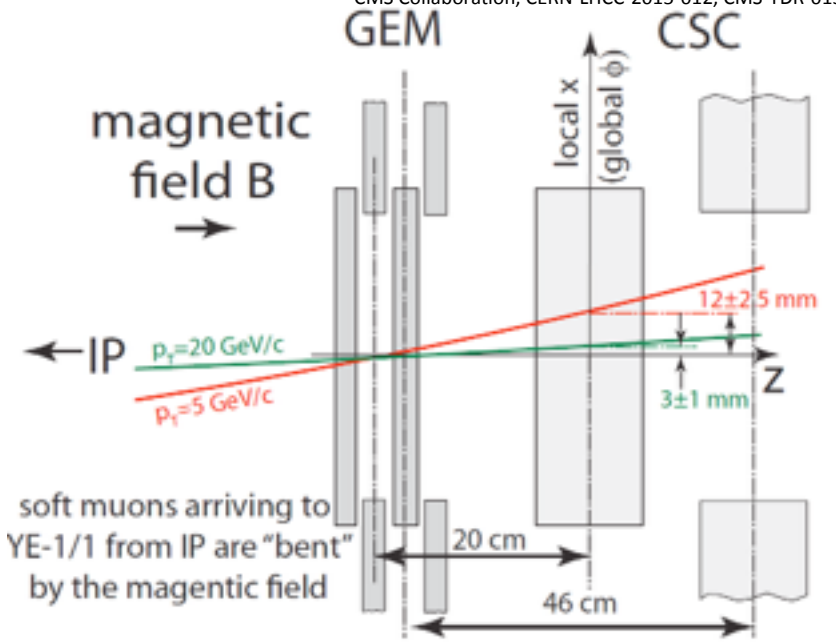


- **Challenge to distinguish between low and high transverse momentum p_T muons**
  - **Scattering in iron return yoke**

GE1/1 Improvements

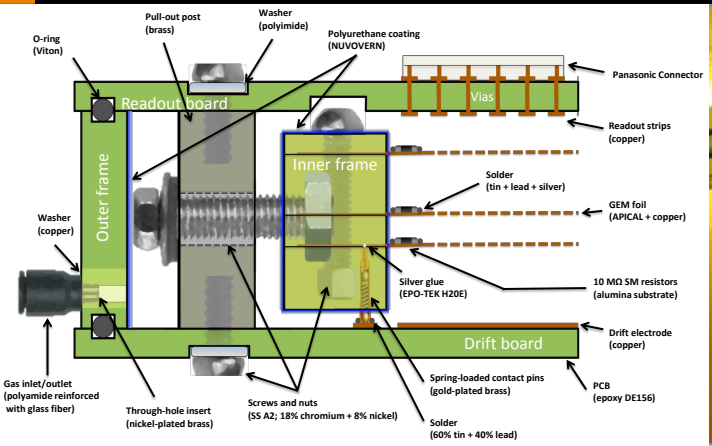
- **Improves muon p_T measurement**
- **Allows measurement of muon bending angle at trigger level**

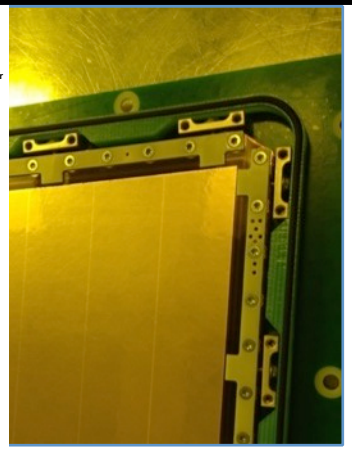




- **Overall reduction in L1 trigger rate**

GE1/1 Detector Design





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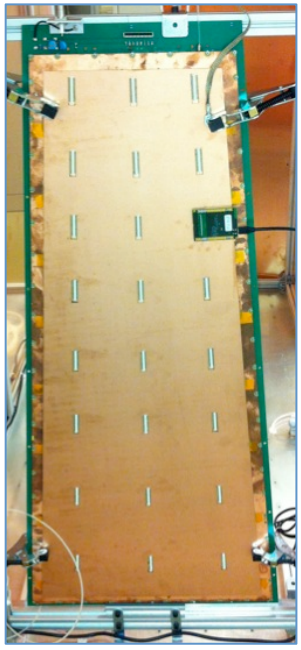
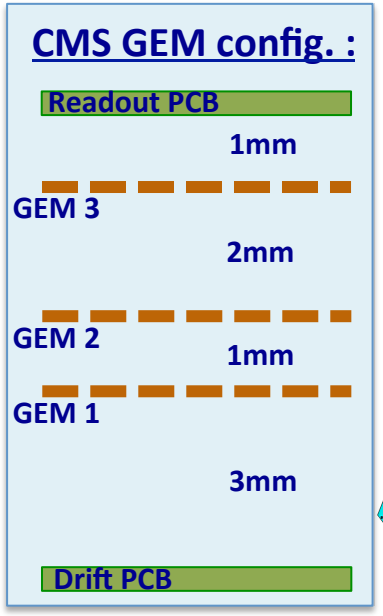
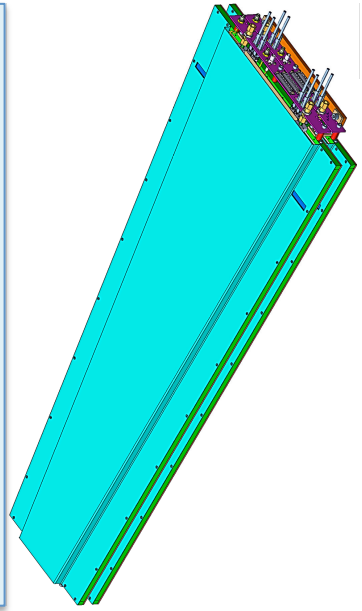
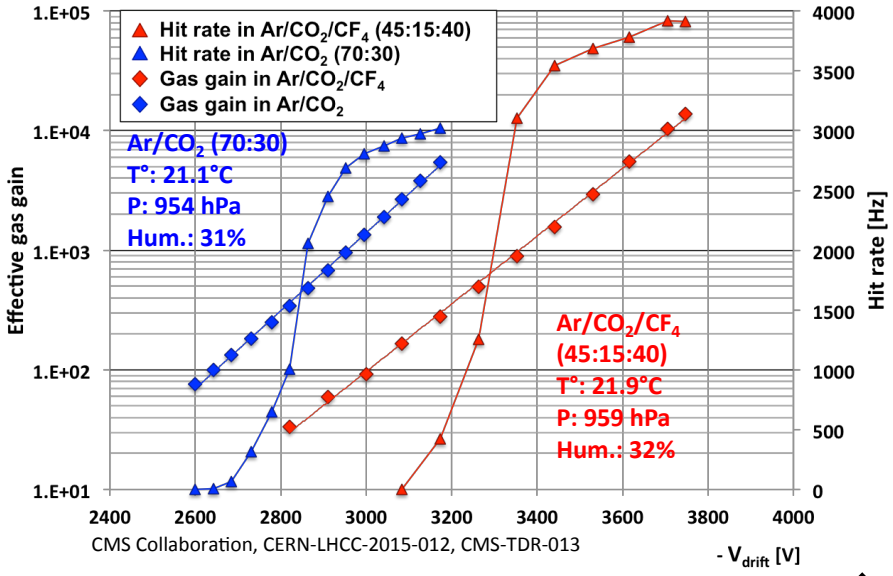
- Size: 1-1.2 × 0.22-0.45 cm²
- Single-mask GEM foil × 3
- Gap configuration: 3/1/2/1 mm
- Readout sectors 3 × 8 in ϕη-plane
- Total channel count: 3072
- Passive resistive divider
  - All fields change *simultaneously*
- Final gas mixture still under study









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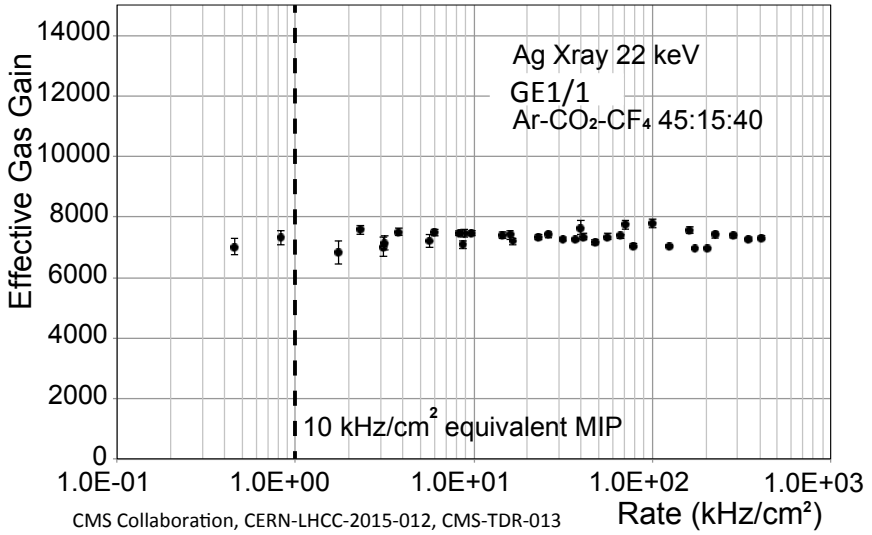
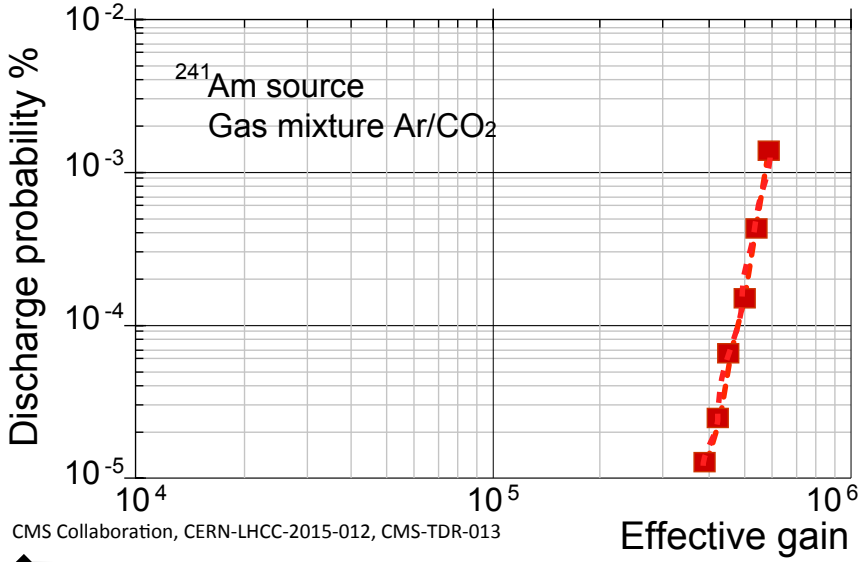
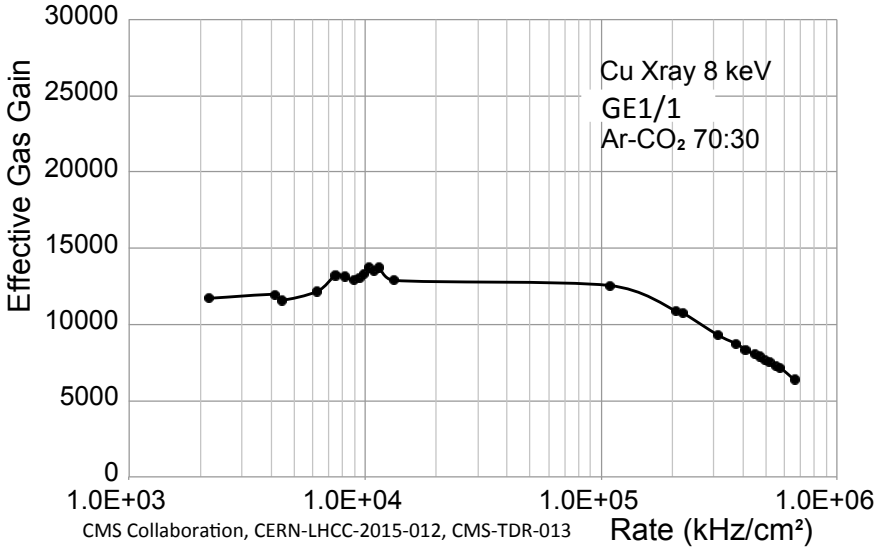
GE1/1 Detector Performance 1

- **Effective gain constant up to 1e5 kHz/cm²**
  - **CMS only requires 10 kHz/cm²**
- **Discharge probability P_D measured to be 10^{-3} to 10^{-5}**
- **Effective gain in CMS is 5×10^3; extrapolating gives $P_D = 9 \times 10^{-10}$**

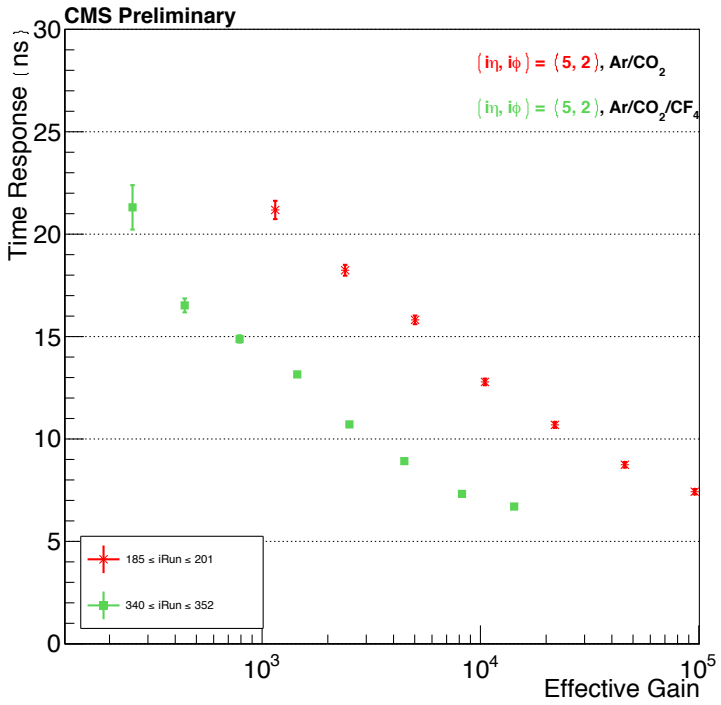


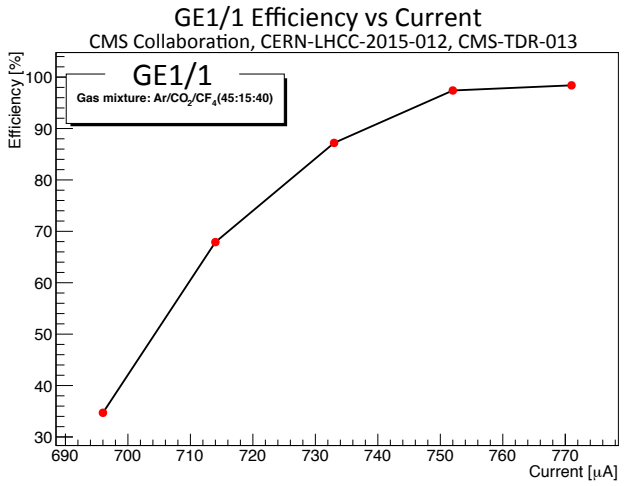


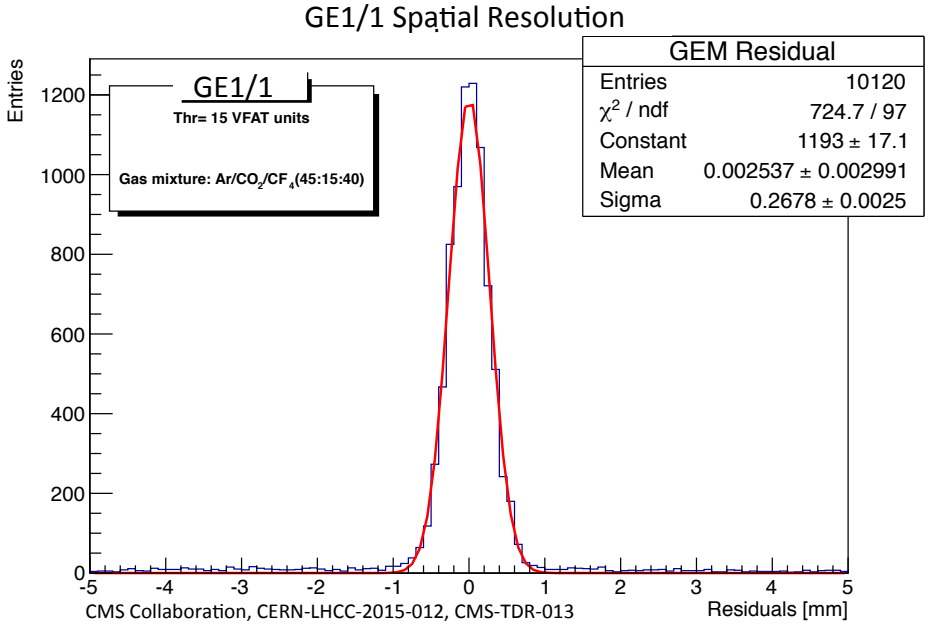


GE1/1 Detector Performance 2

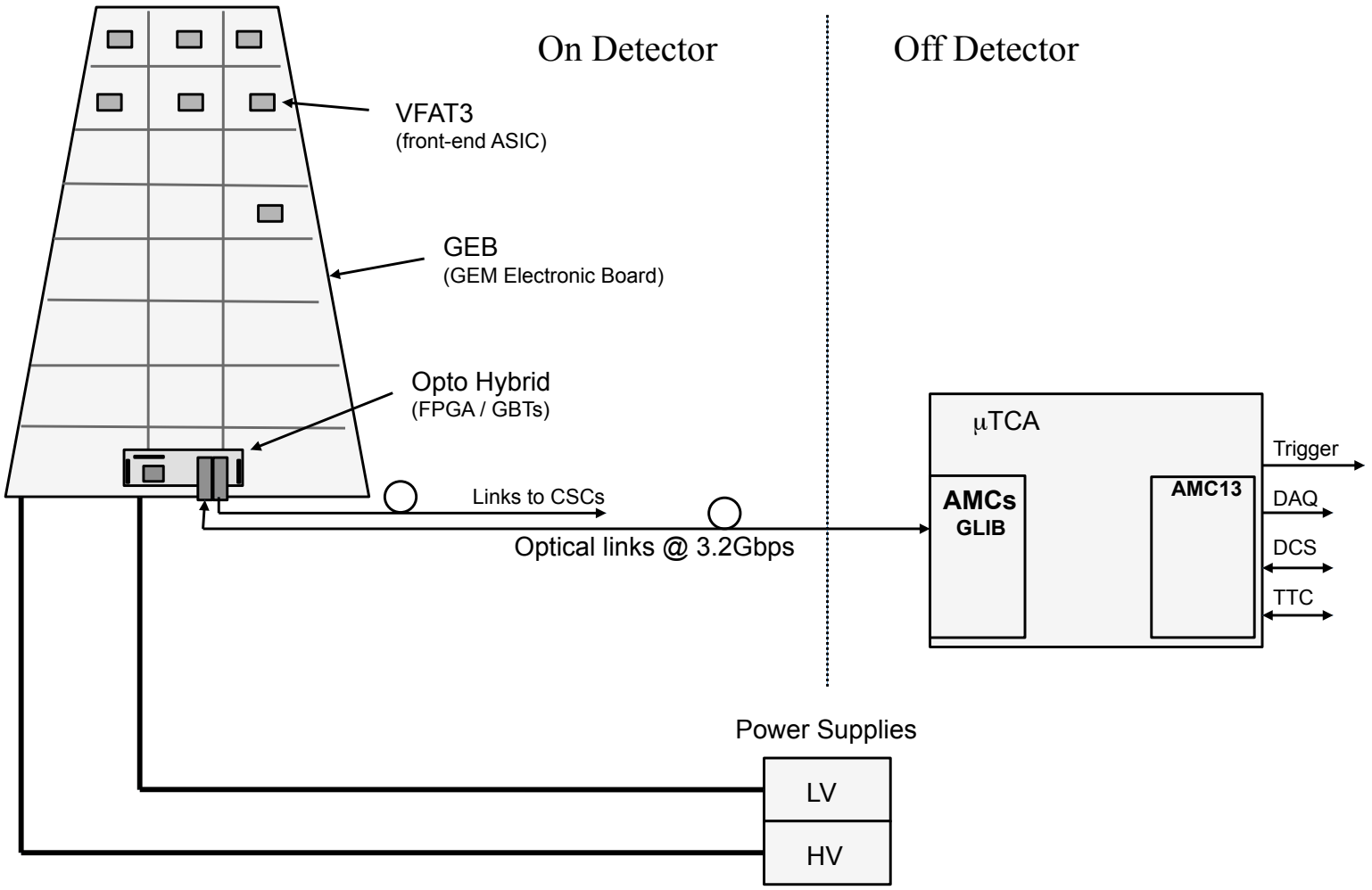
- **Test beam measurements conduction at CERN and Fermilab**
- **Detection efficiency ≈98%**
- **Excellent time and spatial resolutions**







GEM Electronics



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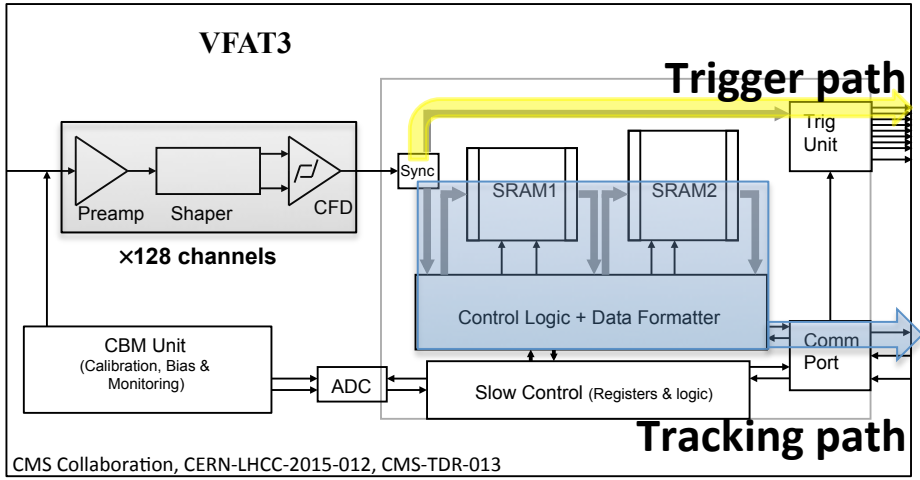
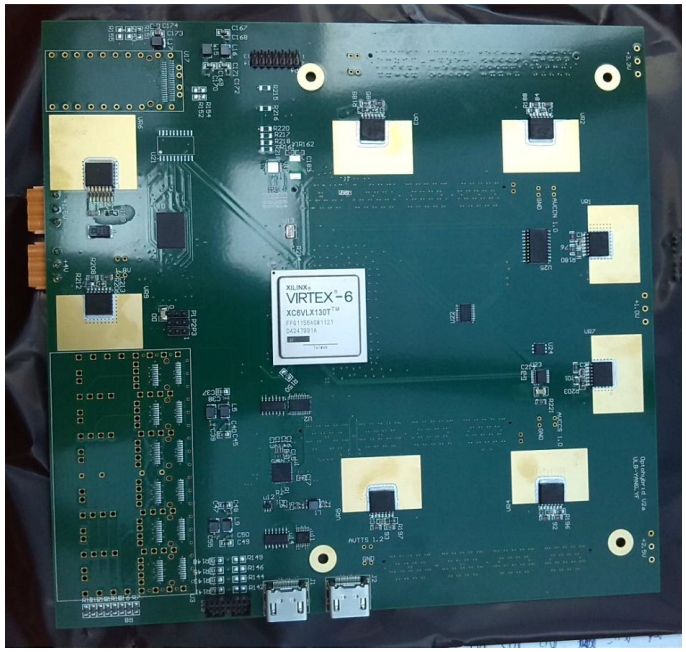
Front-End Electronics: VFAT3



- **Successor to VFAT2**
- **Tracking & trigger data**
  - **Fixed latency trigger bits**
  - **Full granularity of track data after receipt of level 1 accept (input trigger)**
- **Improvements with respect to VFAT2**
  - **Increased S/N ratio due to programmable shaping time**
  - **Decreased time walk via CFD**
  - **Increased L1 latency to beyond 12.5 µs (up from 6.5 µs)**
  - **Communication @ 320 Mbps; 8 × VFAT2 rate!**
  - **Increased granularity at trigger level (8 × S-bits as VFAT2)**

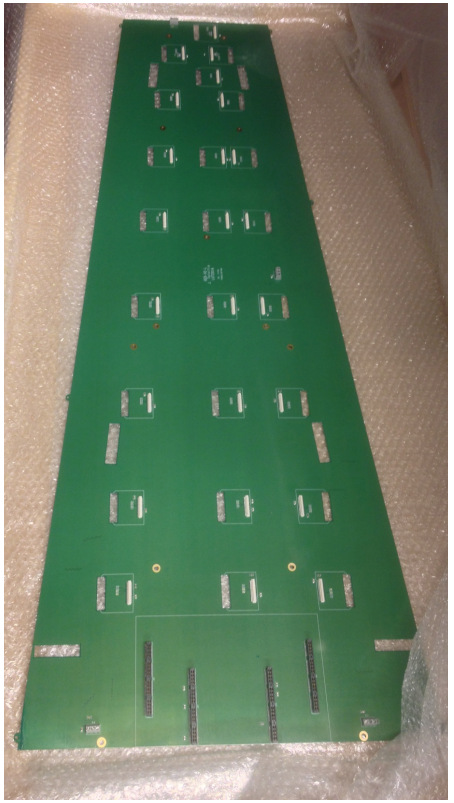
Front-End Electronics: Optohybrid (OH)

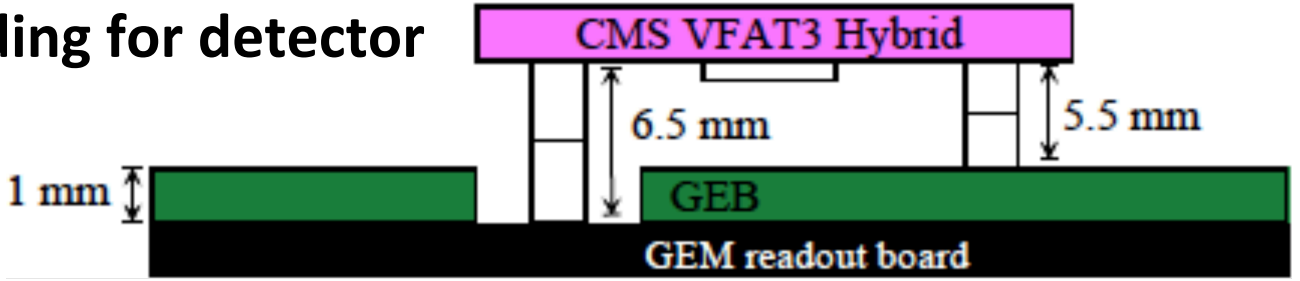


- **Xilinx Virtex 6 FPGA**
- **Two bidirectional optical link**
  - **Slow control signals**
  - **Tracking & trigger packets to back-end electronics**
- **One unidirectional optical link**
  - **Fixed latency trigger packets to CSC trigger motherboard for combined CSC-GEM L1 trigger**

Front-End Electronics: GEM Electronics Board (GEB)

- **Six layer PCB; 1mm thick**
- **Tight space requirements in GE1/1 envelope**
  - **No room for cable routing to each VFAT**
- **GEB provides:**
  - **Power to VFATs**
  - **Signal routing between VFAT3's and optohybrid**
  - **Electrical shielding for detector**





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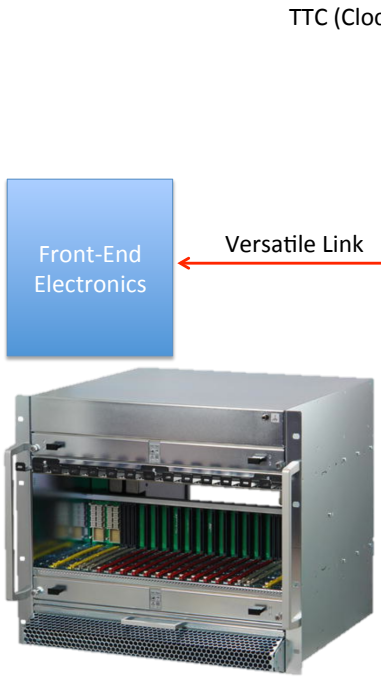
Back-End Electronics: µTCA Architecture

- **MicroTCA carrier hub (MCH) for comm. and slow control**
- **Custom MCH: AMC13**
  - **Link with CMS central DAQ**
  - **Provides trigger timing & control signals down link**



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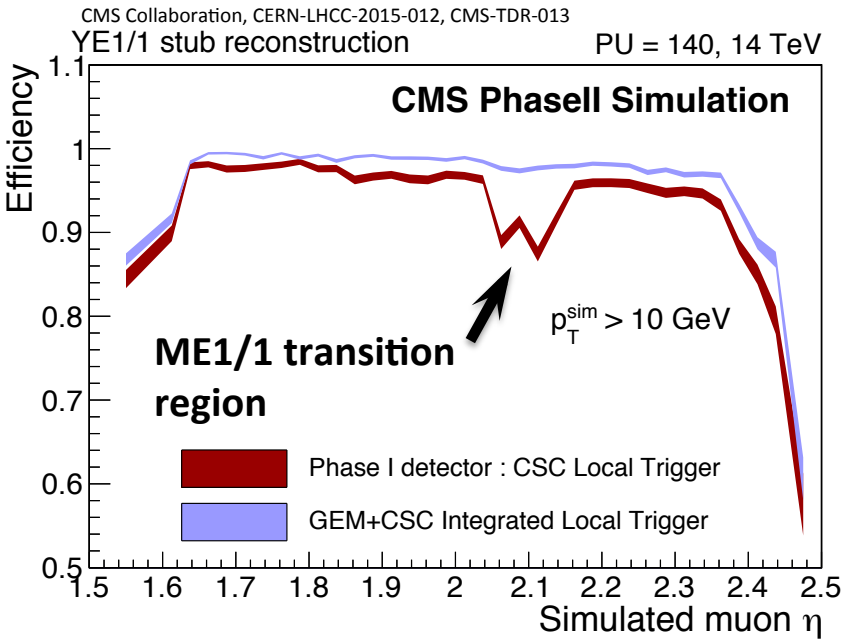
- **MP7 Advanced Mezzanine Card**
  - **Xilinx Virtex 7 FPGA**
  - **Each card provides 72 optical transceivers and receivers operating above 10 Gbps**
  - **Eight cards in 1 µTCA crate needed to readout entire GE1/1 system**

GE1/1 Performance: Trigger Efficiency

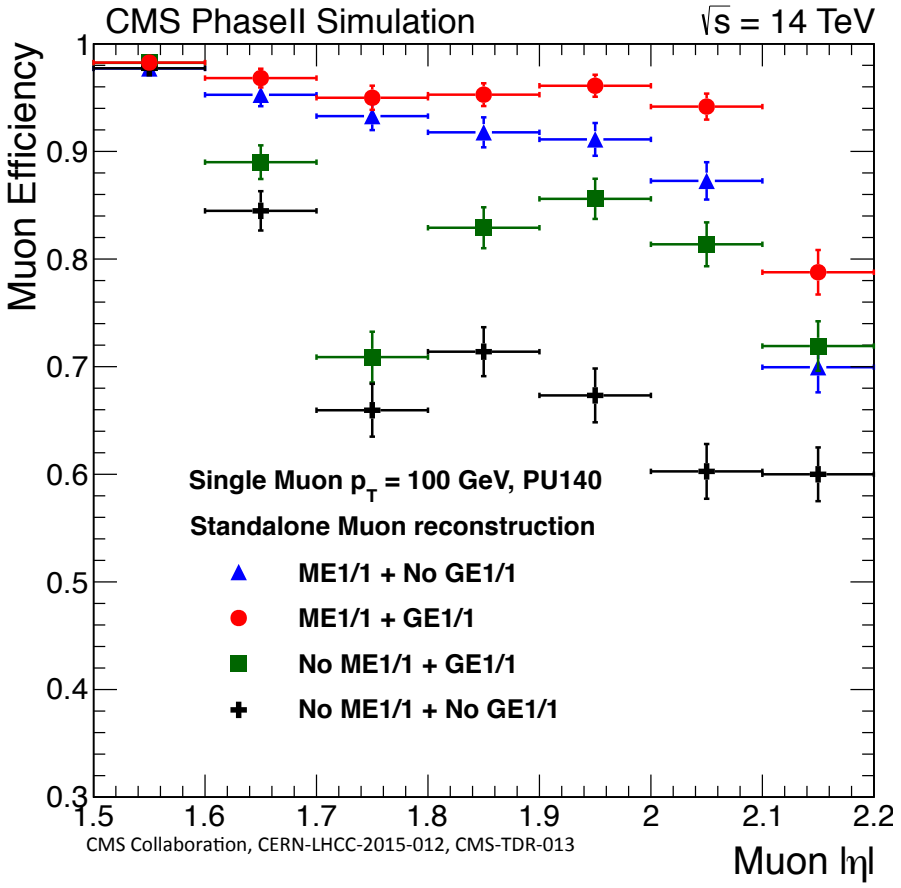
- **ME1/1 Level-1 trigger motherboard builds "local charged track" stubs**
  - **Uses GE1/1 & ME1/1 CSC hits**



- **Improvement on stub reconstruction over full GE1/1 |η| coverage observed**
  - **Added redundancy of GE1/1 system also removes dip in efficiency at ME1/1 transition region**
- **Recall L1 trigger rate is also significantly reduced!**

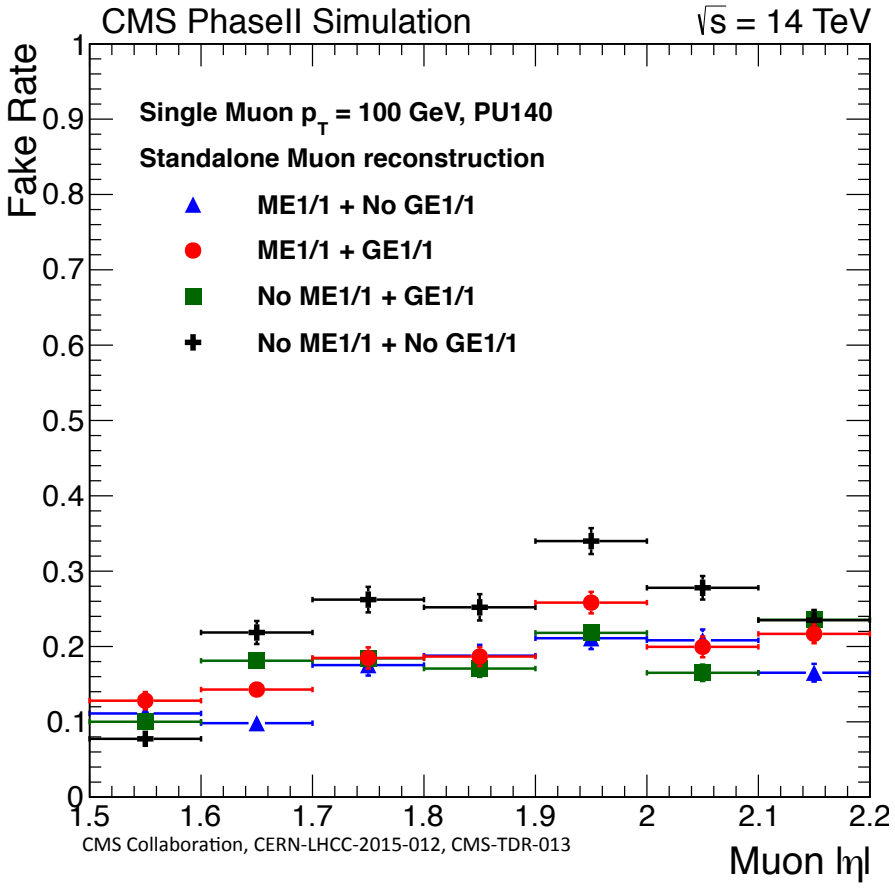
GE1/1 Performance: Muon Reconstruction – Efficiency

- **Standalone muons**
  - **Muons reconstructed with only the muon system**
- **Standalone muon efficiency is improved with addition of GE1/1**
- **Pessimistic scenario of loss of ME1/1 system due to aging was studied**
  - **Significant recovery in performance from added redundancy of GE1/1 system is observed**



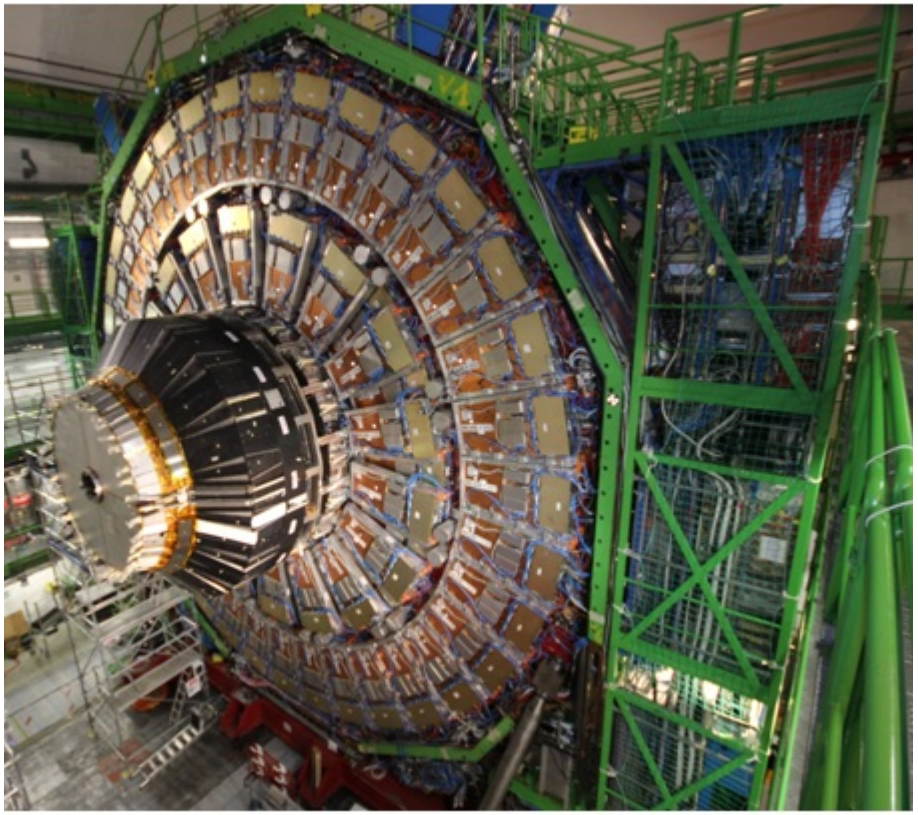
GE1/1 Performance: Muon Reconstruction – Fake Rate

- **Fake rate (aka misidentification probability) caused by:**
  - **Charged hadrons transiting calorimeters into muon system**
  - **Decays in flight of kaons, pions, etc…**
- **Pessimistic scenario of loss of ME1/1 system due to aging was studied**
  - **Reduction in standalone muon fake rate observed due to added redundancy of GE1/1 system is observed**



GE1/1 Slice Test

- **During 2016-2017 year end technical stop of LHC we will install a 40° wedge of GE1/1 in CMS**
- **Invaluable operations experience before full installation in LS2**
- **Finally experience real collision data!**



Further Details This Week…

- *Jeremie Merlin's* **talk:**
  - **"Aging and outgassing studies for GEM detectors in the LHC high-rate environment"**
- *Michael Tytgat's* **poster:**
  - **"Quality Control for the first large areas of triple GEM chambers for the CMS endcaps"**
- *Archie Sharma's* **poster:**
  - **"Simulation of the CMS GEM System"**
- *Marek Gruchala's* **poster:**
  - **"Charge particle detection performance of large area triple-GEM detectors for the forward muon upgrade of the CMS detector"**
- *Luigi Benussi's* **two posters:**
  - **"A novel application of Fiber Bragg Grating (FBG) sensors in MPGD"**
  - **"Characterization of GEM foils and materials: simulation, measurements and interferometric monitoring tools"**
- *Waqar Ahmed's* **poster:**
  - **"Status of the electronics & DAQ for the Triple-GEM project for the upgrade of the CMS forward muon spectrometer"**
- *Giovanna Saviano's* **poster:**
  - **"Candidate eco-friendly gas mixture for MPGDs"**

Summary

- **GE1/1 is a mature upgrade for the forward muon system of CMS**
- **GE1/1 will maintain, and extend, the current reach of the CMS physics program**
- **We will install a 40° wedge of GE1/1 in CMS within the next 14 months**
- **And with the approval of the LHCC and the CERN Research Board *we are go for installation in LS2!!!***

BACK – UP

CMS GE1/1 System

- GEM technology
- 36 superchambers per CMS endcap
  - Two detectors per superchamber
  - Spanning 10° in ϕ
  - Detectors per endcap: 72
- Maximum η coverage
  - 1.6 < |η| < 2.2
- Additional wheels planned for Phase II Upgrade
  - GE2/1 and ME0
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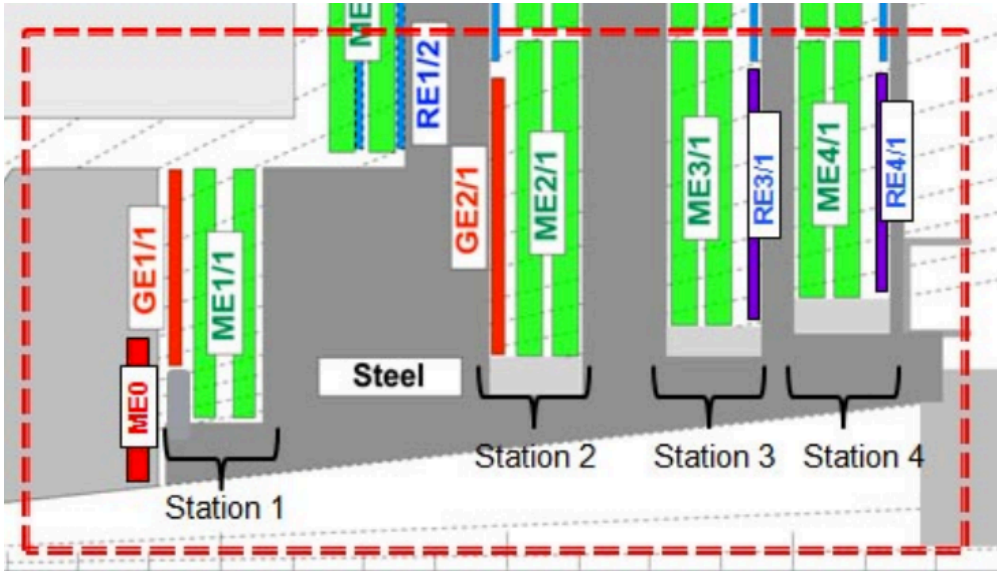

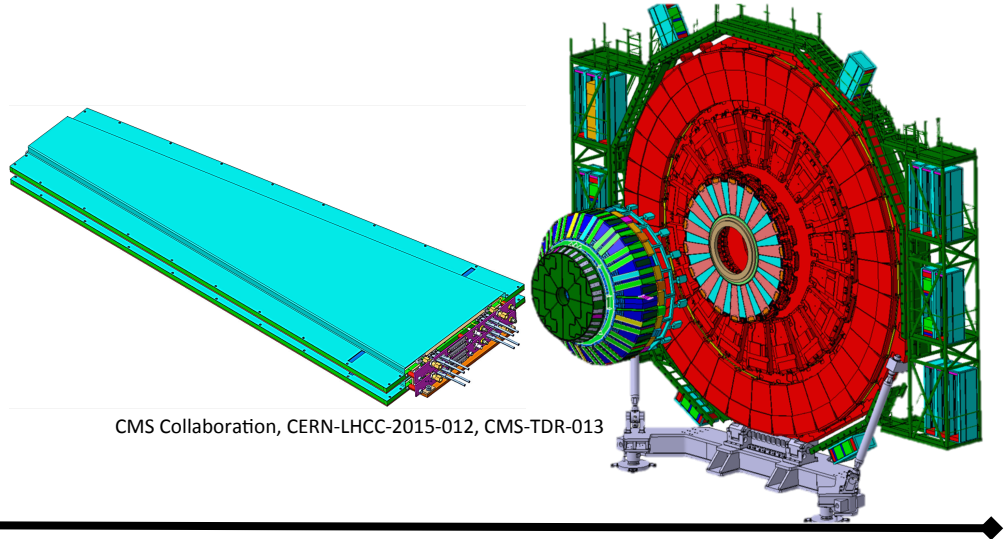

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