CSC Front End Trigger Upgrades for the CMS Endcap Muon System

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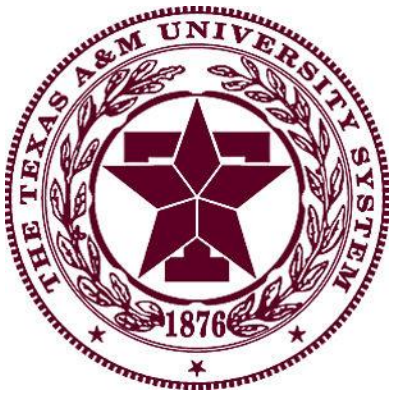

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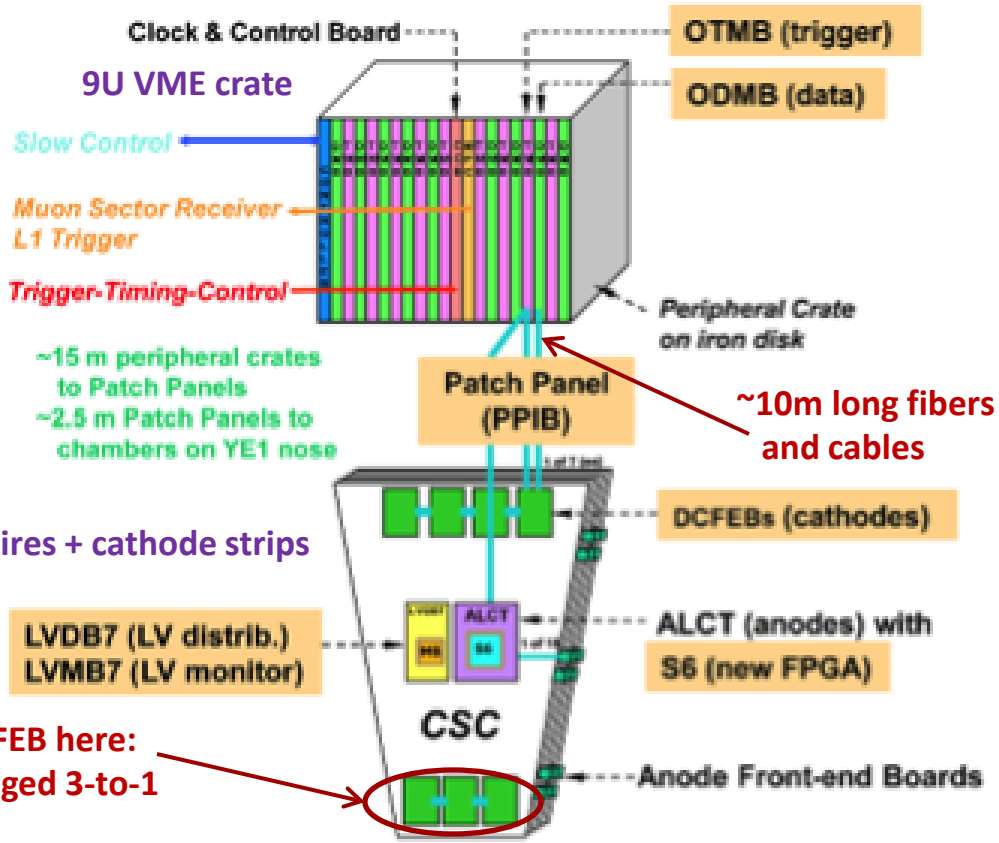
Outline

- Cathode Strip Chamber (CSC) system overview
- Newly installed trigger electronics on innermost CSCs
  - Features and capabilities of the new components in ME1/1
- New CSC trigger algorithm implementation
  - Projected efficiency and performance expectations in high-rate conditions
- Impact of new GEM detectors for the muon trigger
  - Projected performance gains from a combined GEM-CSC system

CSC ME1/1: New DAQ and Trigger Electronics



New board acronyms:

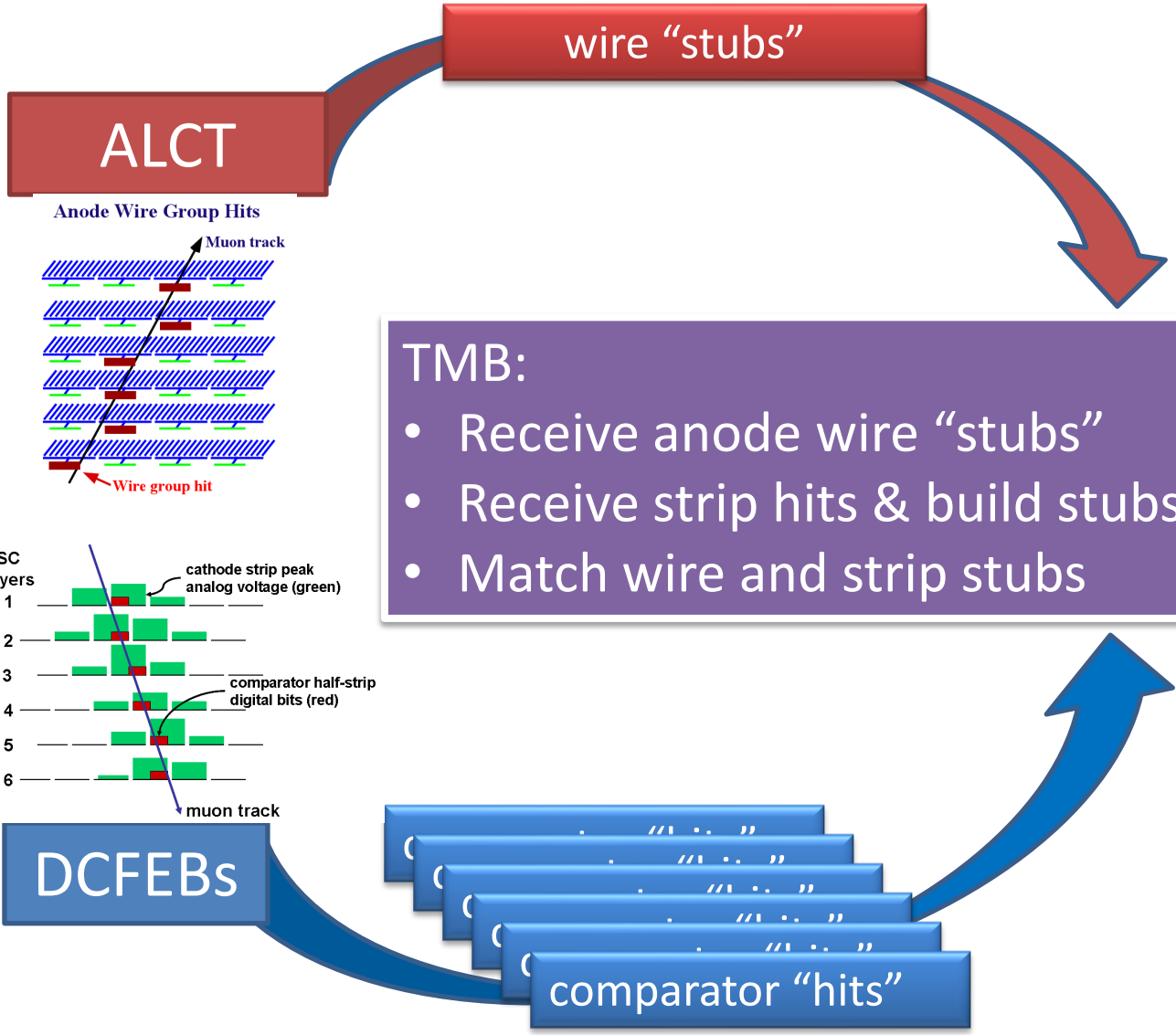
- **OTMB** Optical Trigger MotherBoard
- **ODMB** Optical Data MotherBoard
- **PPIB** Patch Panel Interface Board
- **DCFEB** Digital Cathode Front-End Board
- **LVDB7** Low Voltage Distribution Board (7 DCFEB version)
- **LVMB7** Low Voltage Monitor Board (7 DCFEB version)
- **S6** Spartan-6 mezzanine board

CSCs have 6 layers
Each layer has anode wires + cathode strips

Used to be just one CFEB here: channels were ganged 3-to-1

- New: unganged CFEBs for the high-Eta end of ME1/1
  - This is a critical step for making trigger rates manageable
    - These are by far the highest rate chambers in the CMS Endcap Muon system
- Digital CFEB: digital storage on the DCFEB replaces old analog SCA technology
- The extra channels necessitate the change to optical readout
  - Upstream boards redesigned with optical components: Optical Trigger Motherboard

CSC Trigger Motherboard Functional Diagram



- TMB Inputs:
  - "ALCT" anode wire stubs
  - DCFEB hits for all 6 CSC layers
- TMB Output:
  - "CLCT" cathode stubs
  - Local Charged Track stubs (LCTs)

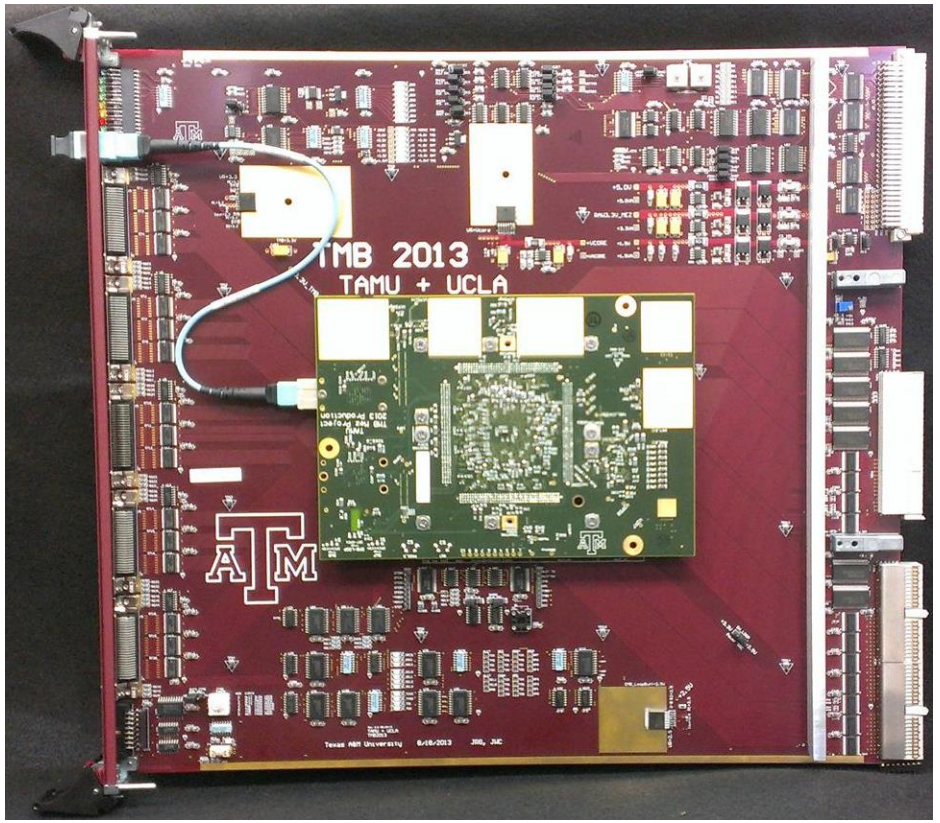
Optical Trigger Motherboard Design

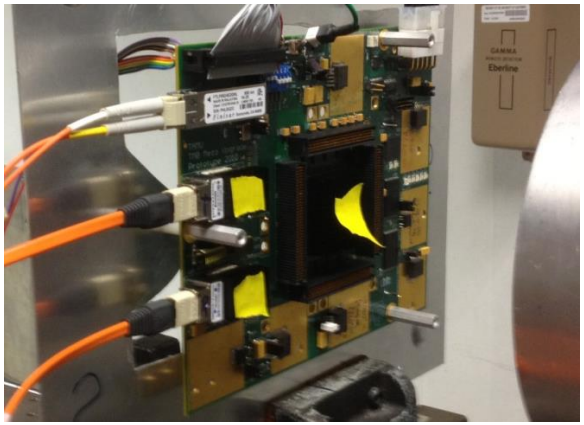
Requirements for the OTMB design

- Receive fiber optic data from 7 DCFEBs using 3.2 Gb/s links on ME1/1 CSCs
  - Optical Trigger Motherboard interface is required for the new DCFEBs
- Provide a programmable logic platform that allows for greater CSC trigger complexity
  - FPGA that is larger and faster than the old model
  - Necessary for efficient HL-LHC trigger operation
- Full backwards compatibility with the copper cable data links used on other CSCs with old CFEBs
  - OTMB could be used on any CSC in a future upgrade
- Operate reliably in the CMS endcap environment
  - Magnetic field concerns
  - Verify the system is sufficiently radiation tolerant

Optical Trigger Motherboard R&D

- OTMB Features:
  - Mezzanine is a 12-layer PCB with impedance control layers
    - Virtex-6 FPGA
    - Snap12 optical receiver
  - Baseboard is a 10-layer PCB
    - 9U VME module, 400 mm deep
    - Design very similar to old board
- Extensive Radiation Testing
  - Reactor tests for neutron exposure
    - Texas A&M Nuclear Science Center
  - SEU studies in proton beams
    - Texas A&M Cyclotron, 55 MeV
    - UC Davis Cyclotron, 63 MeV





OTMB Mezzanine Board

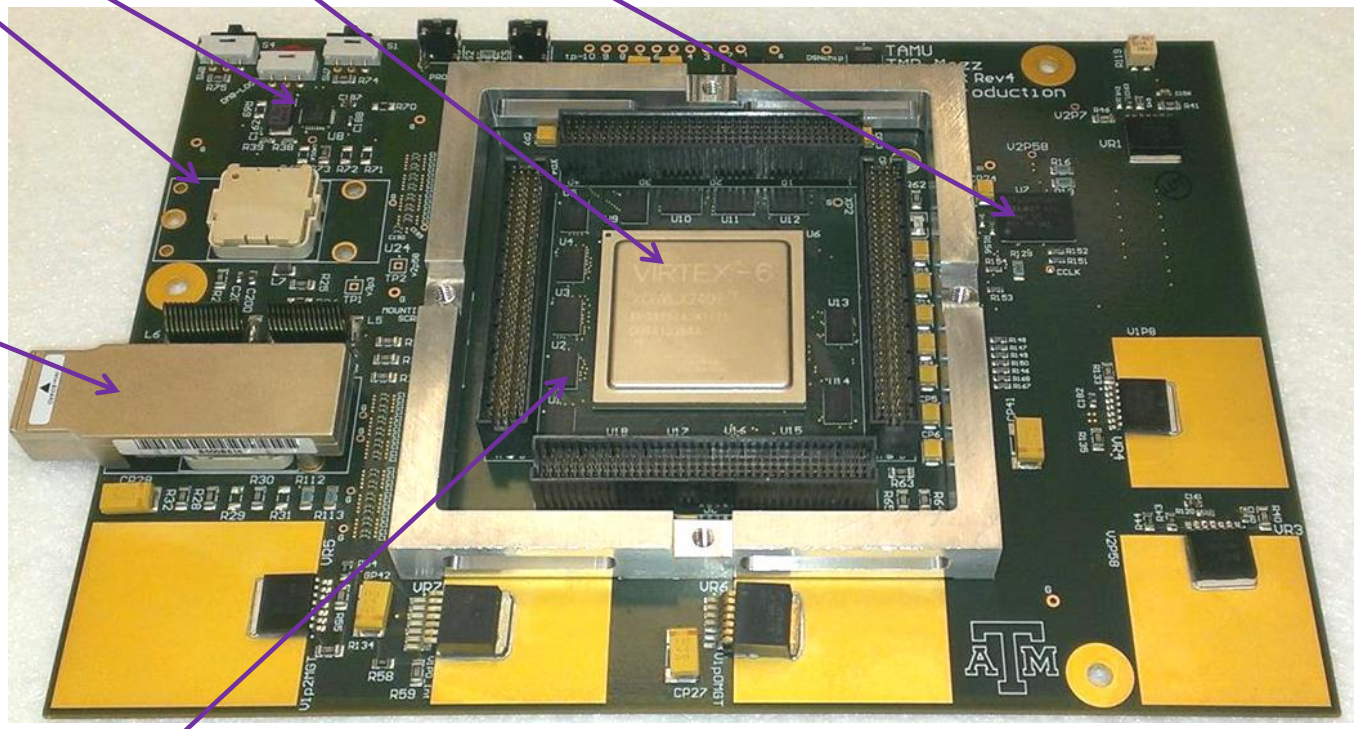
Virtex-6 FPGA + PROM

The FPGA: XC6VLX240T-1FFG1156C

Cern QPLL

Snap12 Fiber Transmitter
- an option only available for special tests

Snap12 Fiber Receiver
- rated at 3.5 gbps
- fibers from 7 CFEBs
- 5 fibers available for future plans



I/O Voltage-level shifters, 3.3 V to 2.6 V

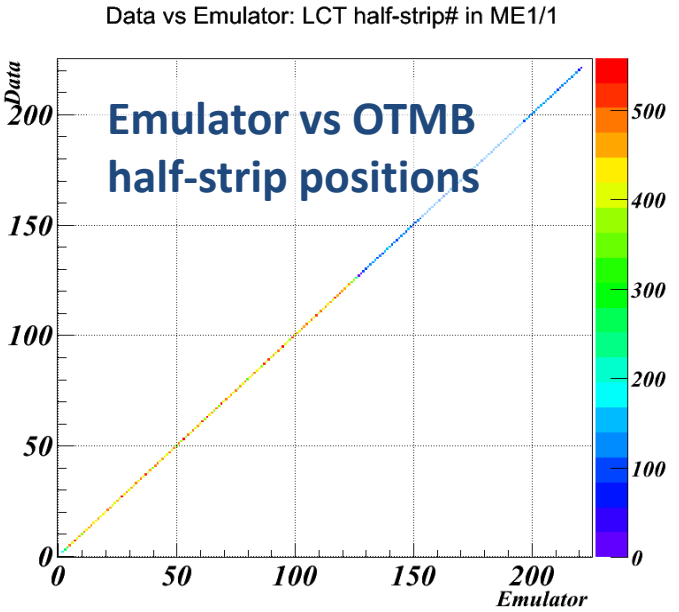
PCB Dimensions: 7.5” long by 5.25” wide
11 mm clearance from TMB base board

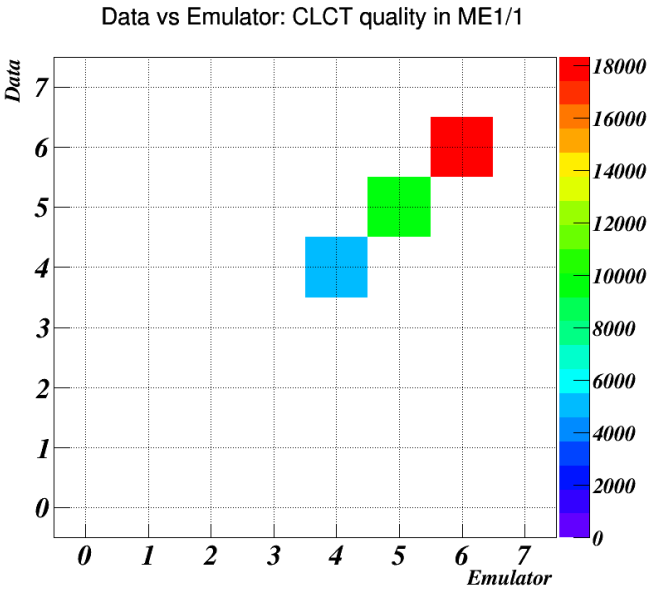
Installation & Commissioning the OTMBs

- 87 OTMBs were built, with 72 installed in CMS
  - 100% of the boards passed all production tests (after fixing a few bad solder joints)
- All of the installed boards have been commissioned
  - Validated communication with other boards in the system
  - Cosmic ray tests & timing studies are ongoing
  - Currently working to improve some monitoring features in software & firmware…
  - Plan to take advantage of speed in the faster FPGA
    - Expect new firmware will reduce trigger latency by ~100 ns
- Effort is ongoing to prepare the new OTMB trigger algorithm for phase 1

OTMB Performance Validation

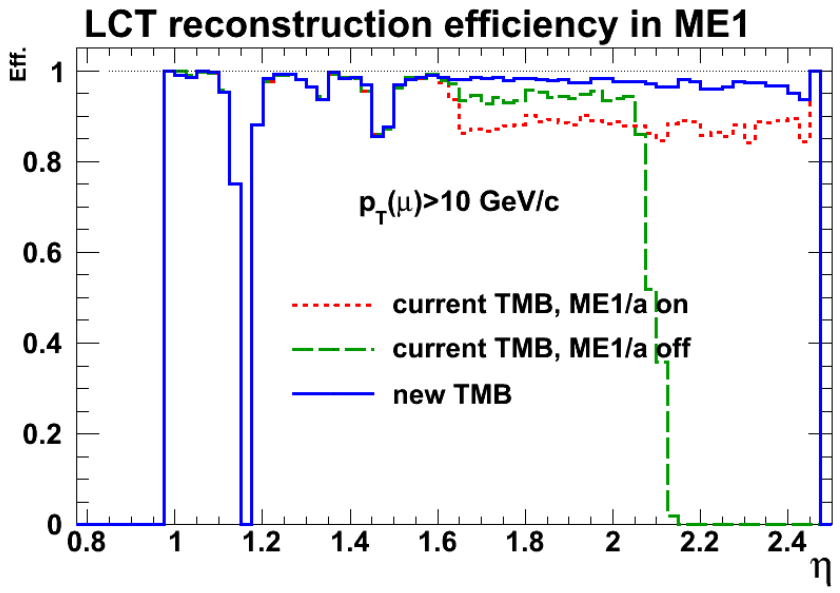
- LHC is still down… just cosmics for now
- Collect data using an ME1/1 chamber with new electronics
  - The data saved contains all the raw inputs to the trigger
- Run the TMB Trigger Emulator on raw cosmic ray data
  - Software based trigger emulation
  - Takes the same inputs used in the TMB trigger decision
  - Enables detailed comparison of trigger primitives including reconstructed positions, stub parameters, quality, etc.
  - Validation of trigger results with the emulator is an ultimate test of performance
- We see perfect agreement in the trigger emulator
  - The OTMB is working exactly as expected

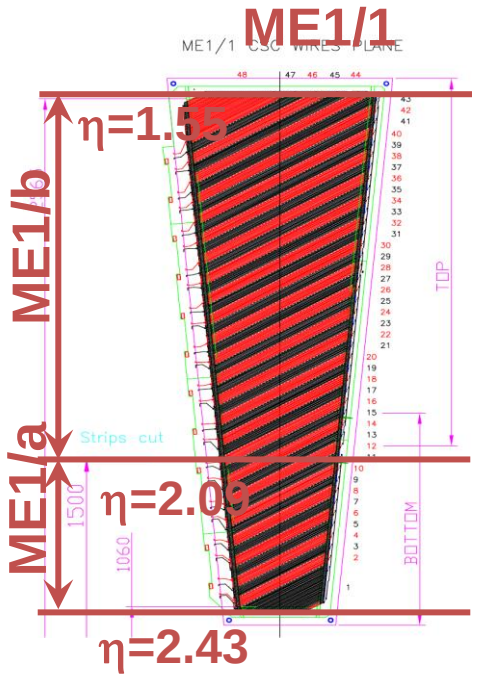




Ongoing Efforts: CSC Trigger Optimization

- Improvements in CSC efficiency already due to unganging the strips at high-Eta in ME1/1

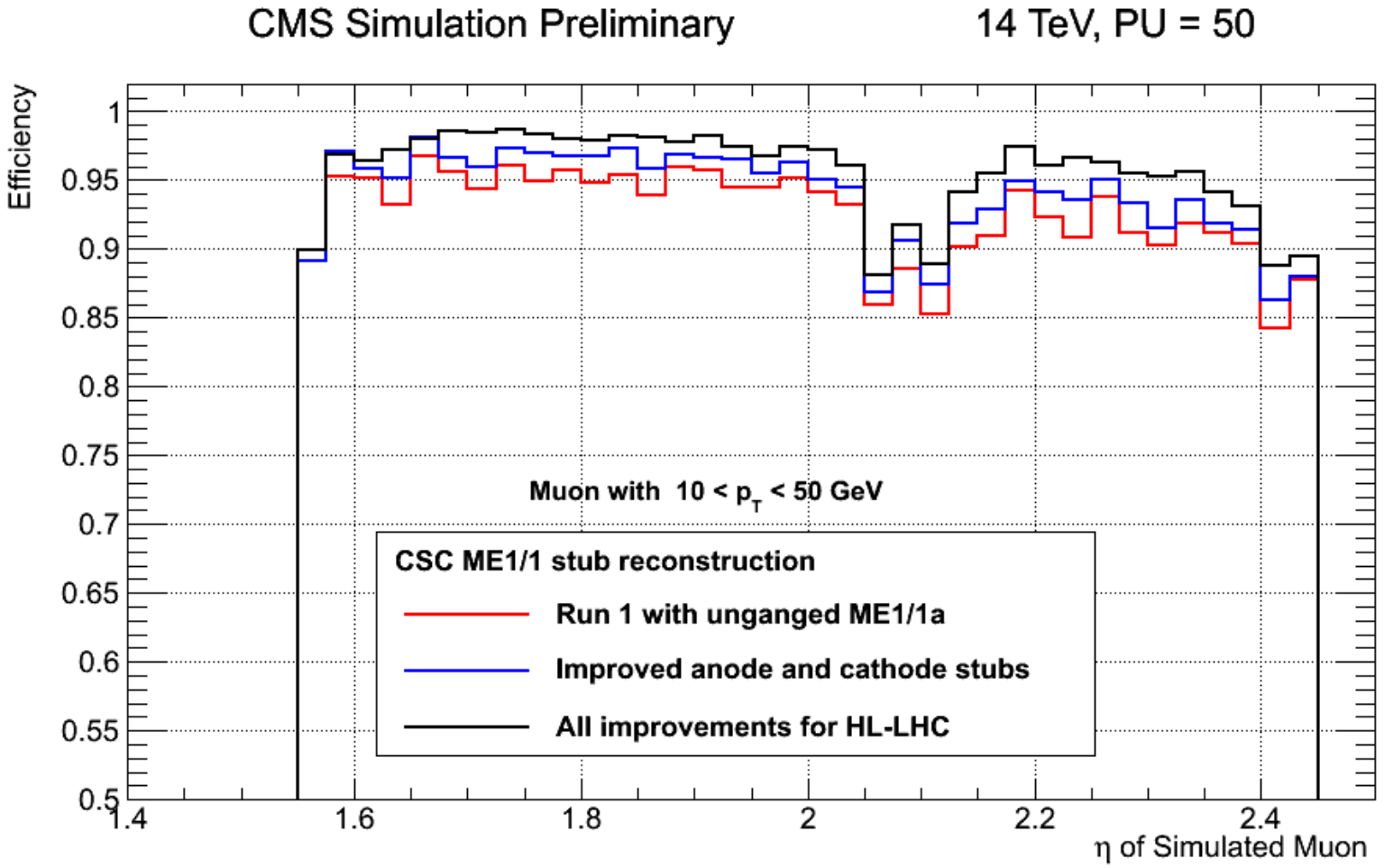




- Additional improvements are planned by changing several elements in the OTMB trigger algorithm
  - Improved ghost cancellation for anode track stubs
  - Improved handling of dead-time for cathode stubs
  - Optimized matching for anode + cathode combination

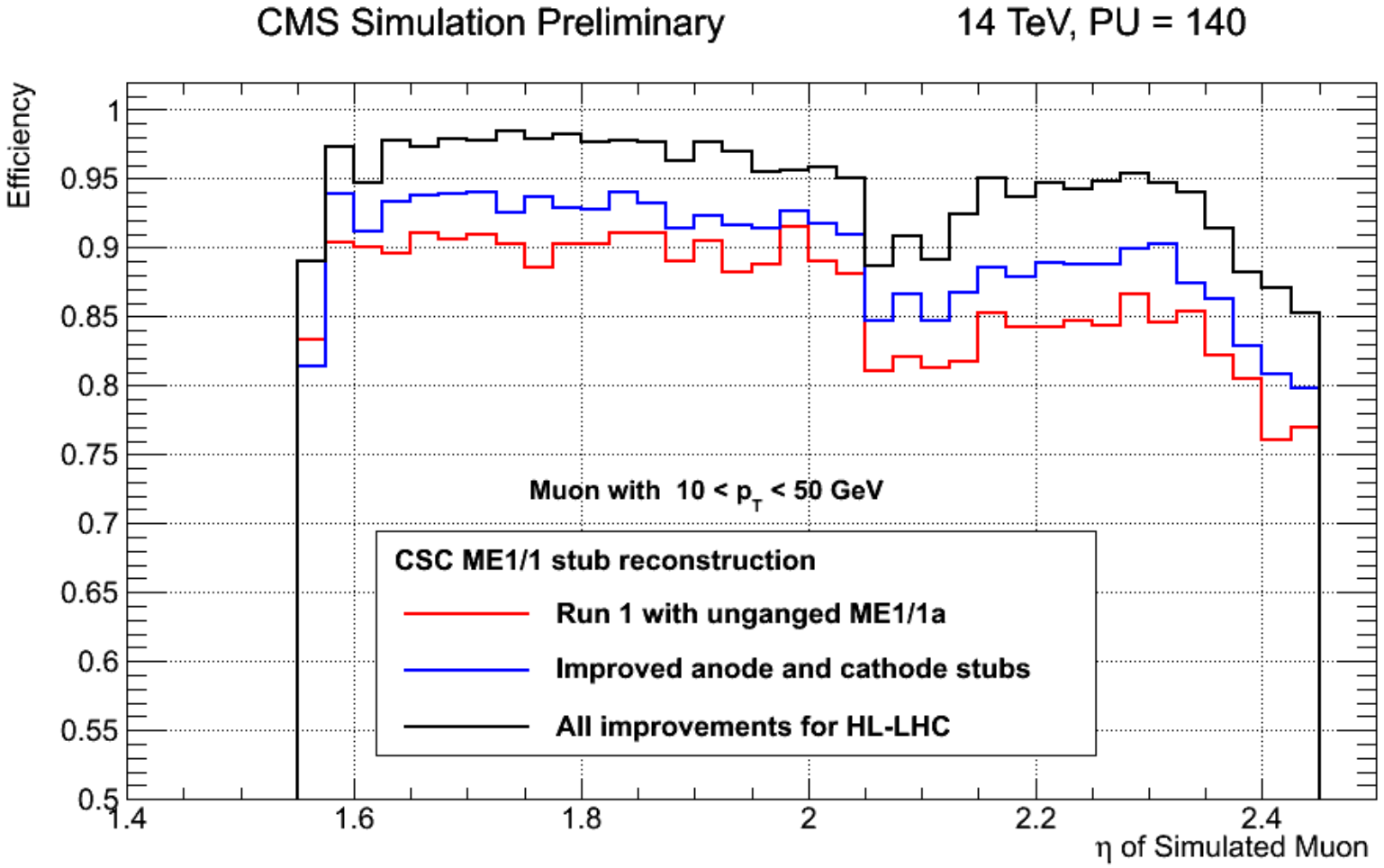
OTMB Trigger Improvements at Pileup 50

- Projected effect on CSC efficiency for different levels of trigger algorithm optimization
  - Already we see significant impact of the modifications at pileup 50



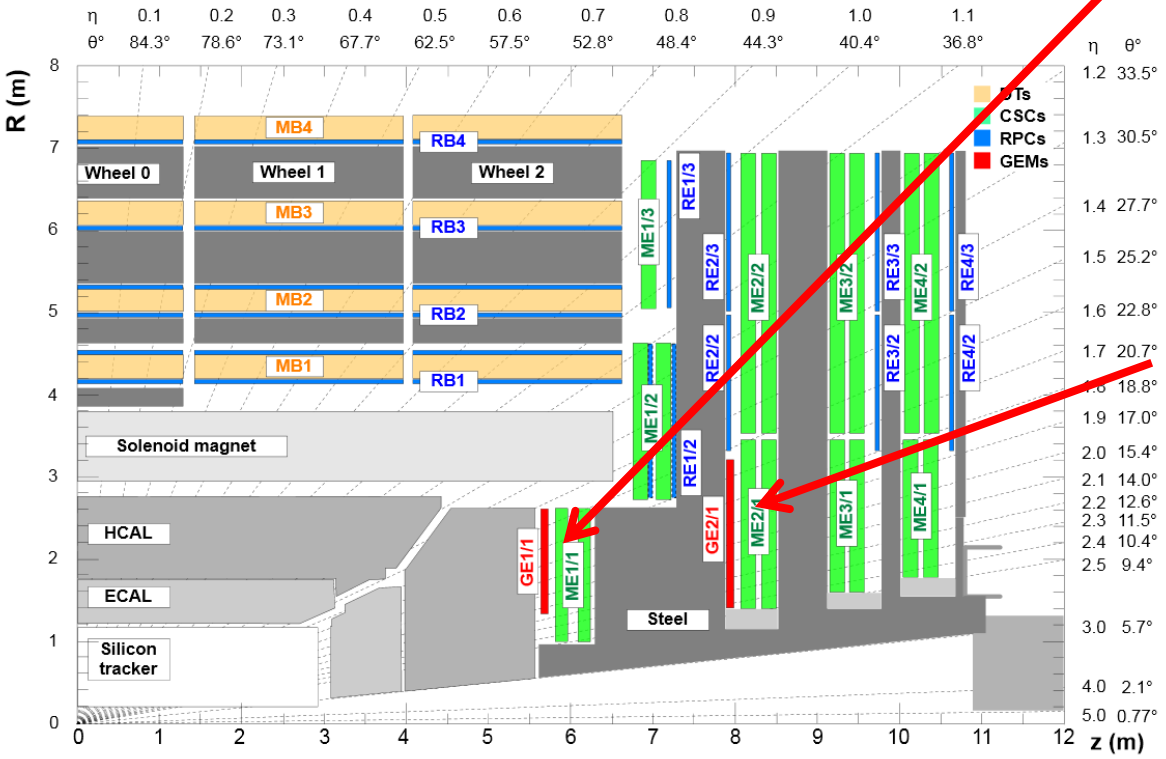
OTMB Trigger Improvements at Pileup 140

- Projected effect on CSC efficiency for different levels of trigger algorithm optimization
  - The expected impact of the new algorithm at pileup 140 is substantial



LS2 and Beyond: Integration with GEM Detectors

- GEM detectors to be installed during LS2 (and possibly LS3)
  - Redundancy to CSC in the very forward region , where especially high trigger rates expected in the future
- Possible to treat GEM + CSC as a combined system
  - Allows for an integrated “8-layer” trigger



GE1/1

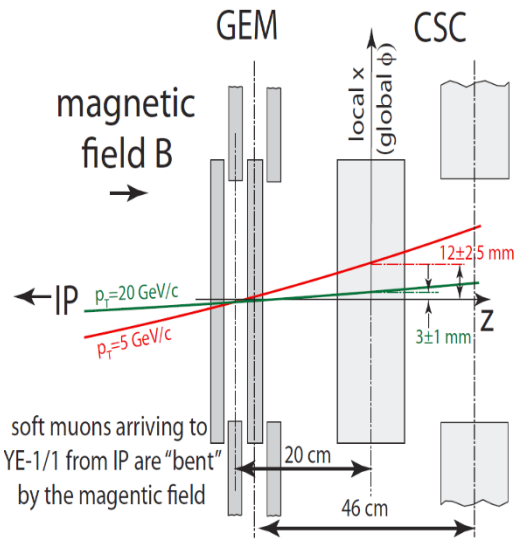
GEM GE1/1 detector planned for LS2 CMS upgrade period (2018)

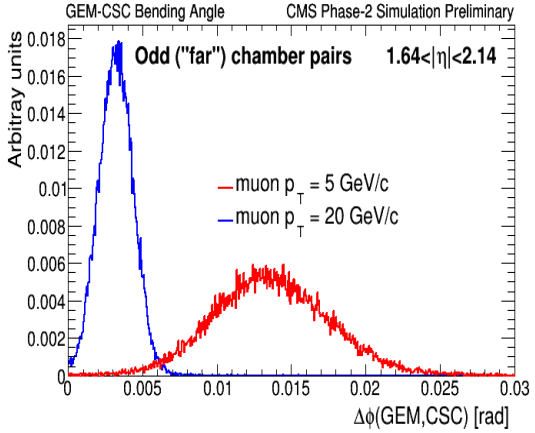
GE2/1

Possible installation of a second GEM station (GE2/1) for LS3 CMS upgrade period

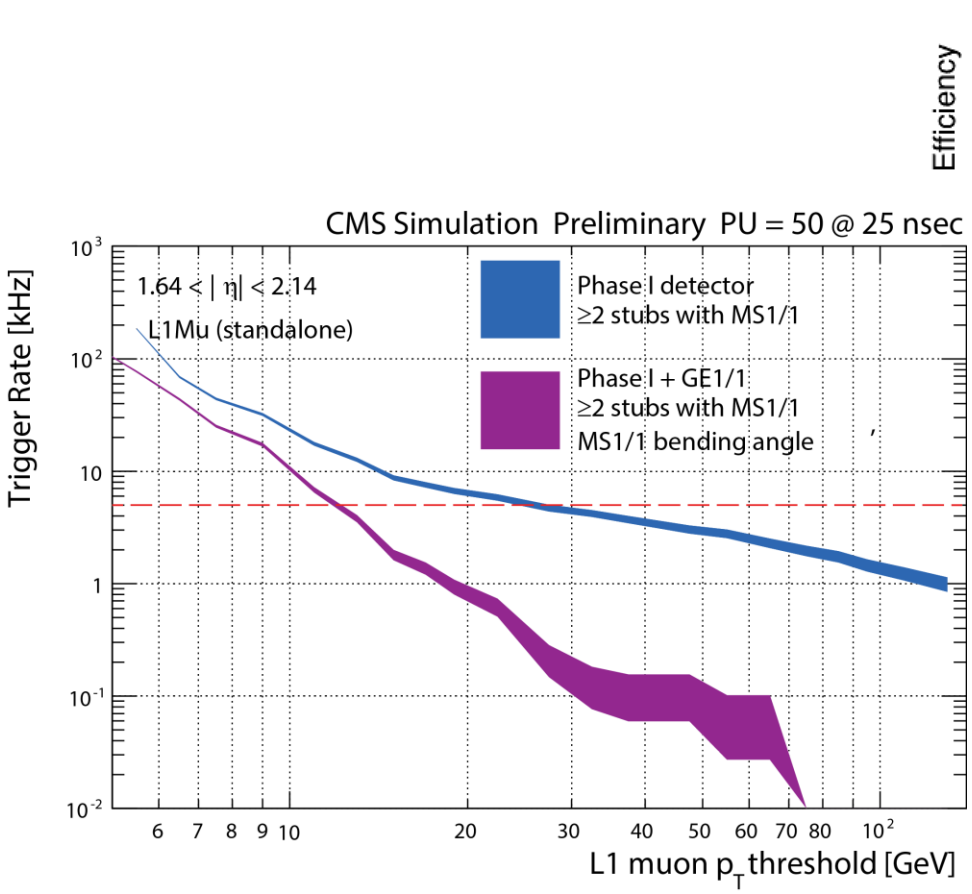
Forward Muon Trigger Challenge for HL-LHC

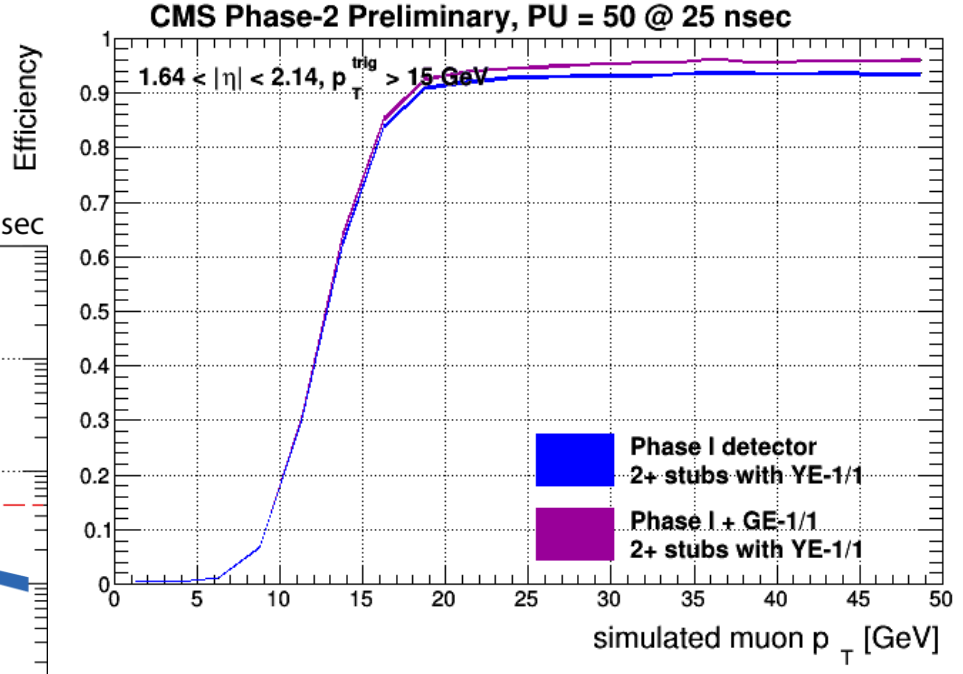
- The current system cannot suppress trigger rate without significant efficiency losses
  - p_T mismeasurements drive the rate
  - Need new handles in the trigger on momentum
- Bending angle measurement within a single station can help
  - Has been used in the barrel, but not in the forward region
    - CSC chambers are too thin, not enough lever arm to do it alone
- Have to increase the lever arm
  - Need a second detector for this
- GEM system is a great candidate
  - Good resolution and rate abilities (can get down to ~100 microns, but 200-250 will do just fine)





GEM + CSC as an "Integrated Detector"



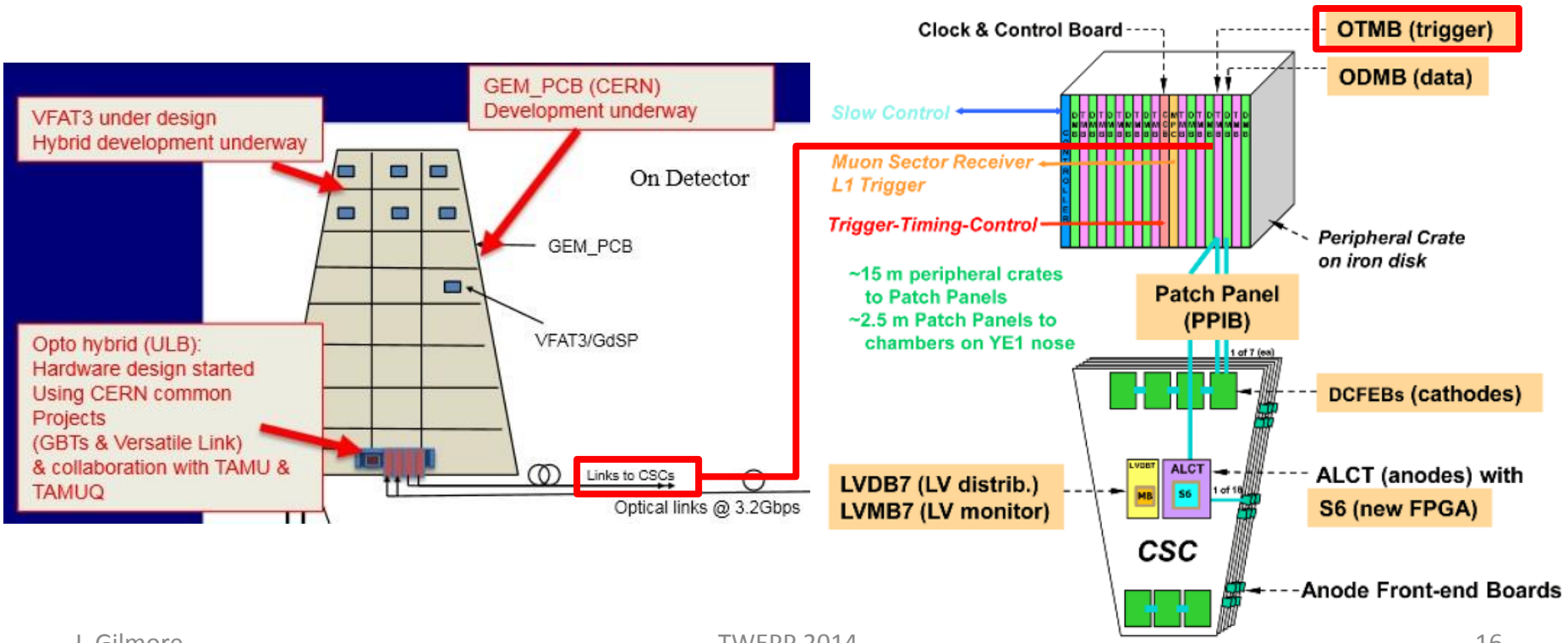


- Bending angle: dramatic improvement in trigger rate
- A bonus: better efficiency due to extra redundancy

Combined GEM-CSC Trigger

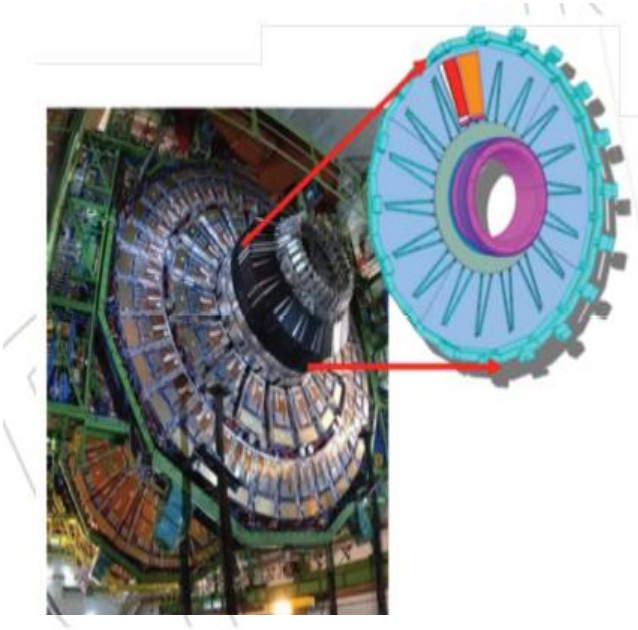
Redundancy to CSC through combined GEM-CSC trigger

- Transmit GEM data to OTMB via opto-hybrid board mounted on GEMs
  - Provides trigger hit information, formatted for CSC OTMB
    - Uses spare fiber inputs to OTMB snap12: no changes required in CSC hardware
  - Requires implementation of GEM-CSC trigger algorithm in OTMB firmware
    - Build integrated stubs that are sent to the Muon Track Finder

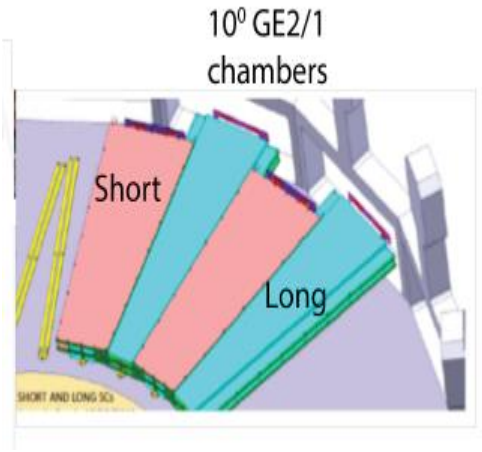


GEM Station GE-1/1: Schedule

- First install the “Slice test” chambers during 2016 LHC technical stop
  - Just four GEMs will be installed
  - Implement full trigger and readout
  - Ability to pass trigger signals to OTMB
- Goals:
  - Demonstrate performance predicted in simulation
  - Work out details and prepare for full installation



- Full GEM installation (subject to CMS approval) during LS2
  - Considered as an “early Phase-2” upgrade
  - TDR should go out later this year
- Challenge: a completely new system with a lot of development work ahead, and there is not so much time



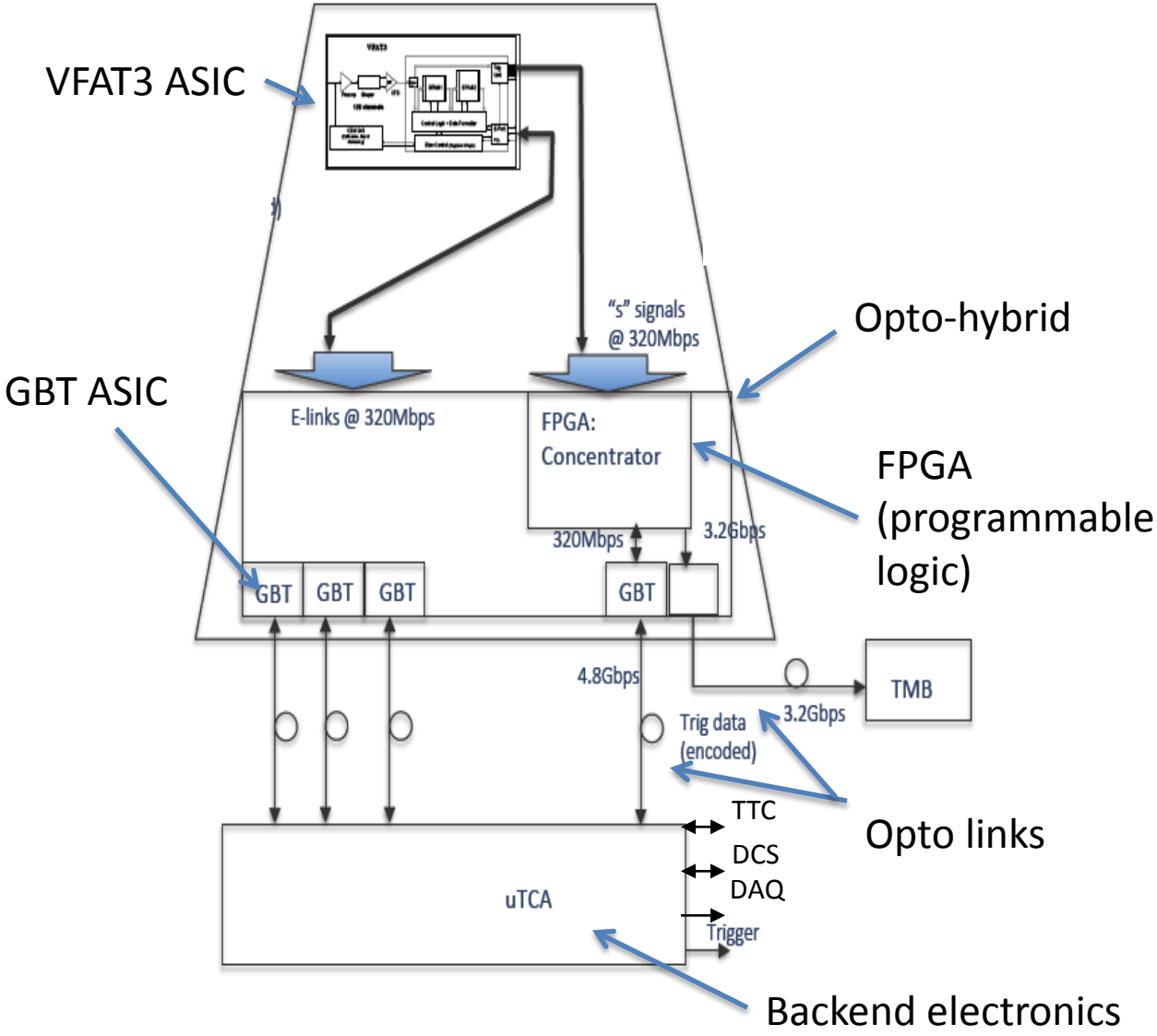
In Conclusion

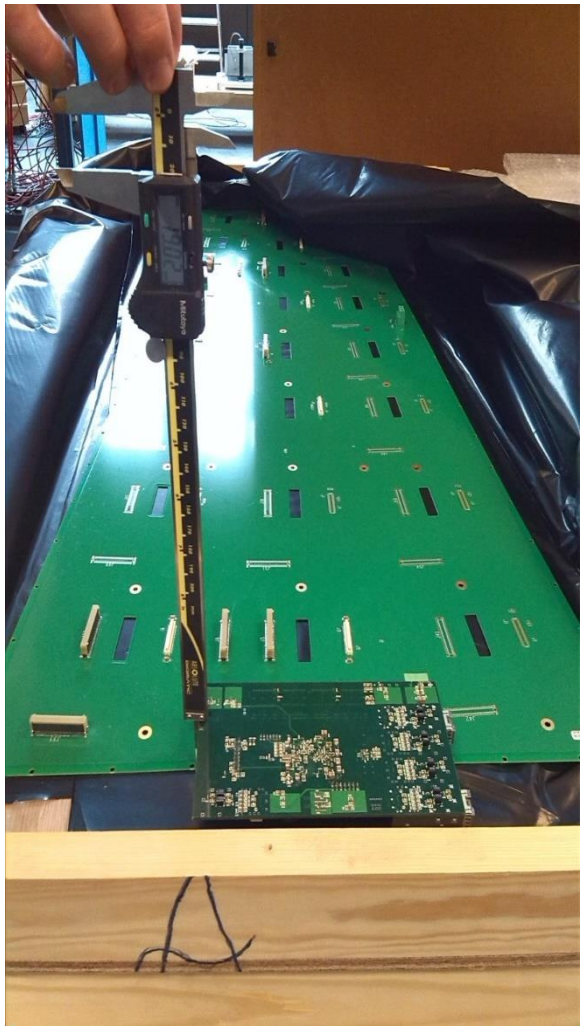
- New OTMBs are installed in CMS on ME1/1 after 2 years of development & testing
  - Commissioning is complete and functionality has been proven on ME1/1 chambers in CMS
  - A new trigger algorithm is in preparation for future HL-LHC operations
    - ➢ Plans for CSC trigger optimization look very promising
- Addition of GE-1/1 will greatly strengthen forward muon trigger
  - Effectively an extension of the CSC chambers to make a large lever arm with a combined trigger
  - Optimal way to measure the bending angle, reduce trigger rates, and improve efficiency at the same time
    - ➢ Critical for surviving through LS2 and beyond

Backup Slides

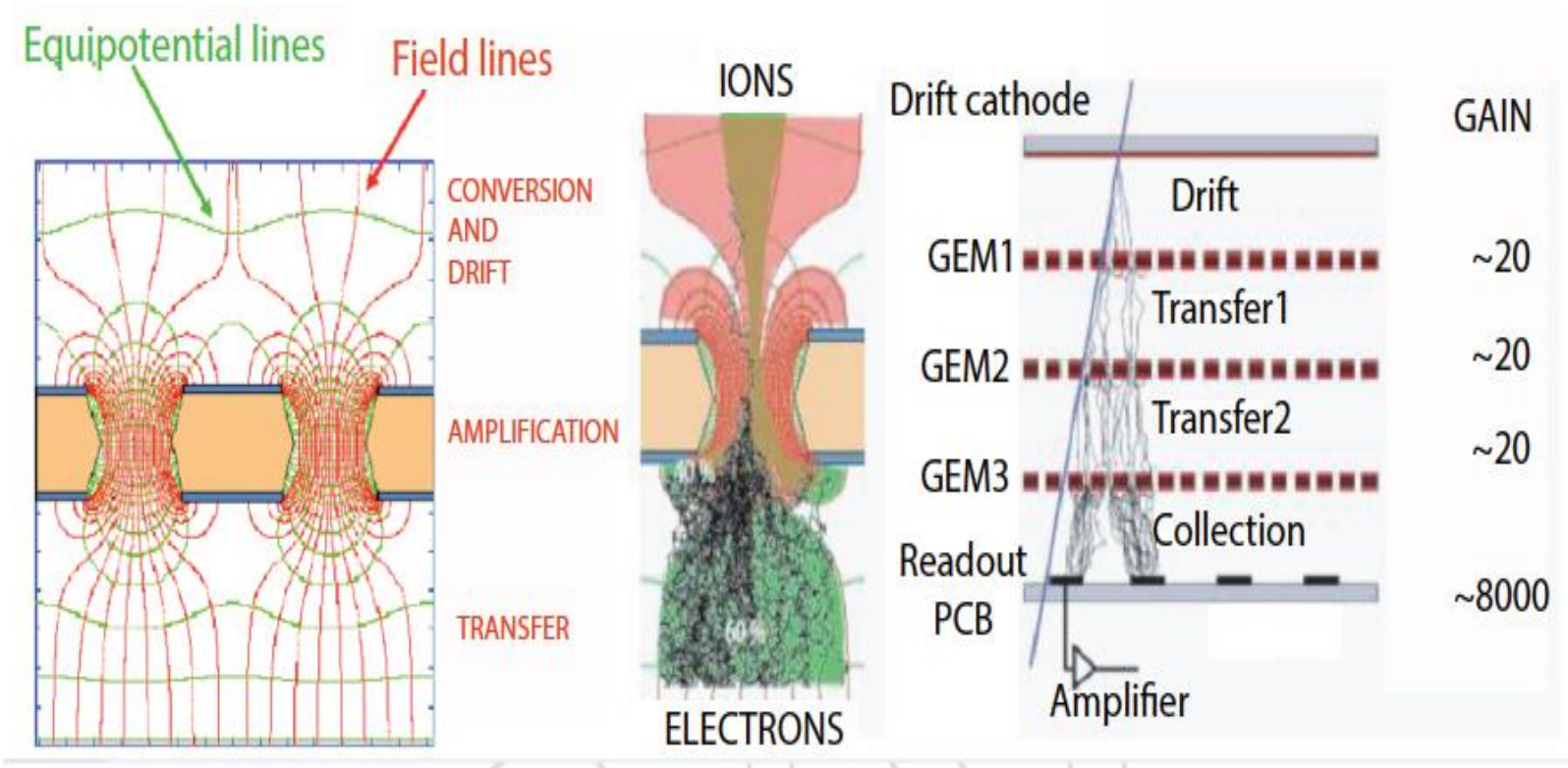
- Supporting info follows…

GEM DAQ: Current Baseline





GEM Detector Technology



- Excellent rate capability, very good special resolution and timing