CMS Muon Upgrades for HL-LHC

Gilles De Lentdecker
Université Libre de Bruxelles (ULB)
Brussels, Belgium

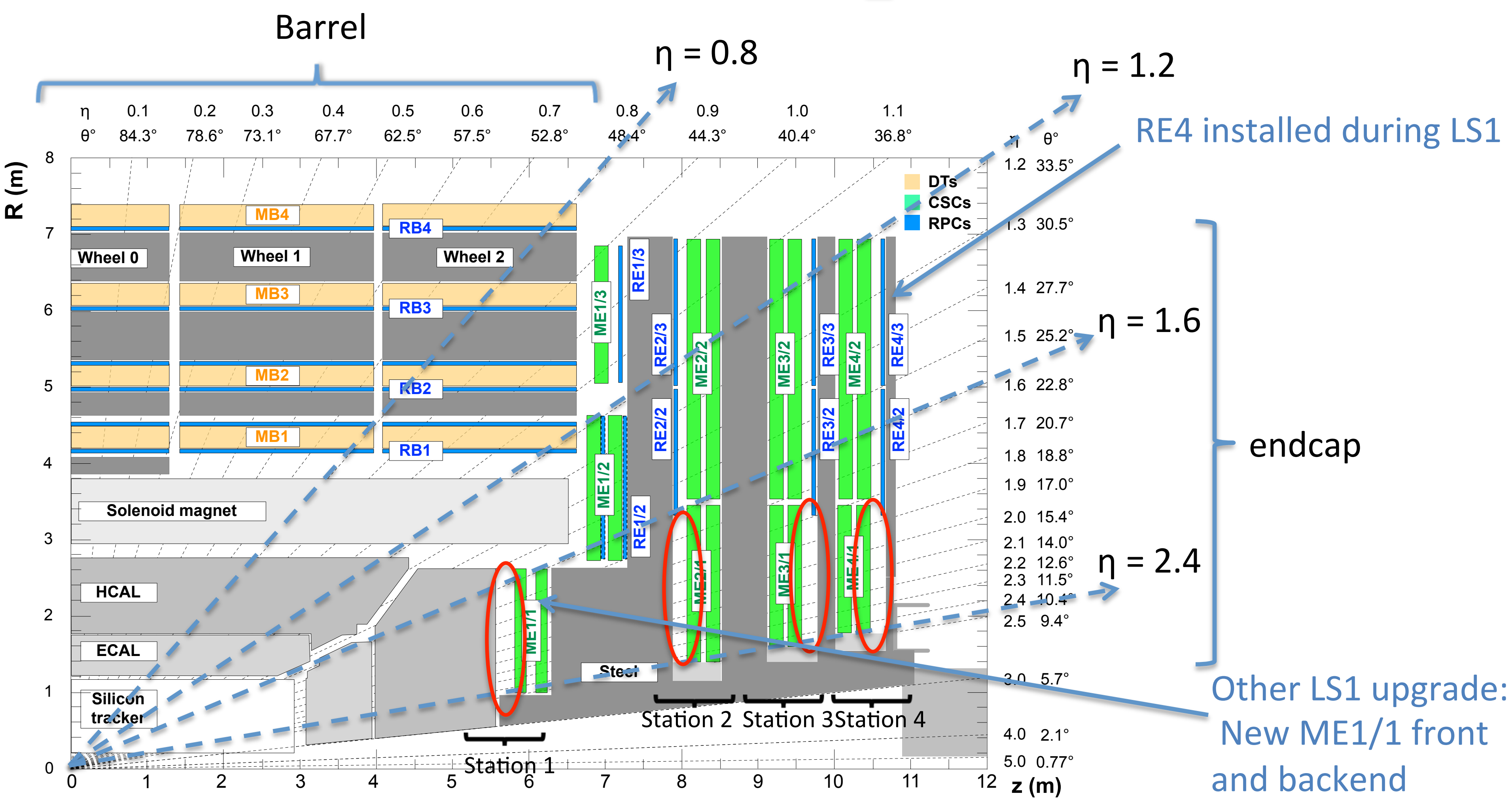
Overview

- The CMS muon system post LS1
- Requirements to the Muon system
- Radiation conditions
- Barrel Drift Tube electronics upgrade
- Forward Muon Upgrades
  - GE1/1
  - GE2/1
  - ME0
- Conclusions

The CMS muon system post LS1

- CMS muon system built to be redundant for high performance tracking and triggering

Drift Tube (DT) – Barrel only
Cathode Strip Ch. (CSC) – Endcap only
Resistive Plate Chamber (RPC)

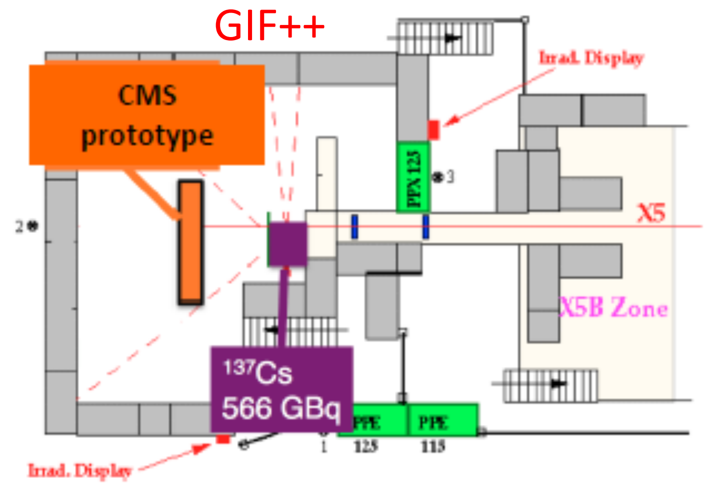


Requirements

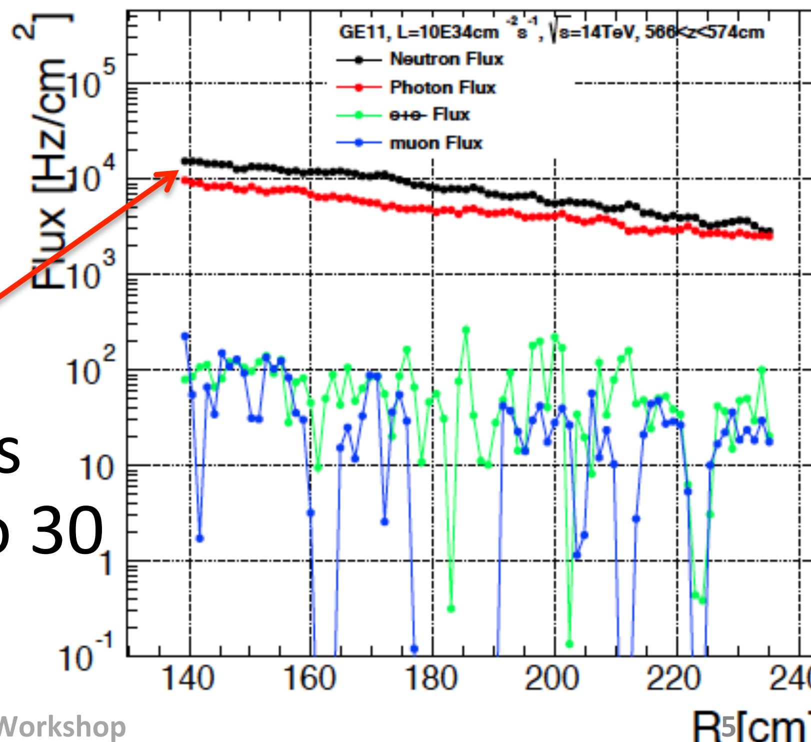
- Aging and longevity
  - The present muon system installed in 2007 must continue to operate w/o significant degradation after higher irradiation and longer operation time than expected
- Trigger
  - At high luminosity the L1 muon trigger in the forward region is compromised
  - This problem can be addressed by the addition new forward muon stations.
- η-coverage
  - If tracker and endcap calorimeter are extended up to $\eta = 4$, the coverage for muon identification can be greatly extended with the addition of a small but precise muon detector built into the back of the new endcap calorimeter

Radiation conditions

- Detector and electronics longevity is a concern:
- Past irradiation studies for DTs, CSCs and RPCs need to be repeated at higher doses at GIF++ facility



- HL-HLC rate expectations (5 E34)
  - DT: 50 Hz/cm^2
  - RPC background rate:
    - barrel ~ 50 Hz/cm^2
    - endcap ~ 100 Hz/cm^2
  - CSCs and GEMs: a few kHz/cm^2



- Note: CSC ME1/1 new electronics have been exposed to dose up to 30 krad (30 years of HL-LHC)

Drift Tube Phase II upgrade

Replacement of DT Electronics

*Present system, the **DT Minicrate:***

** aluminum structure attached to the DT chamber*

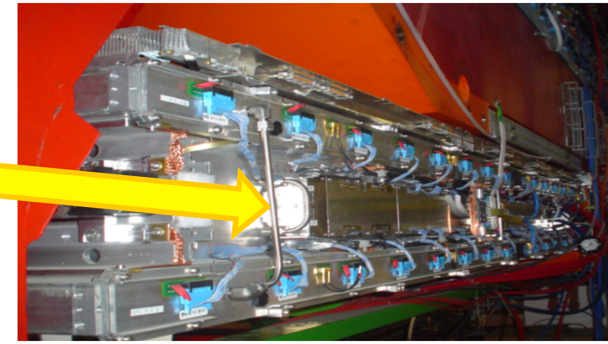
** 6 types of boards highly integrated, lots of interconnections and dense connectors*

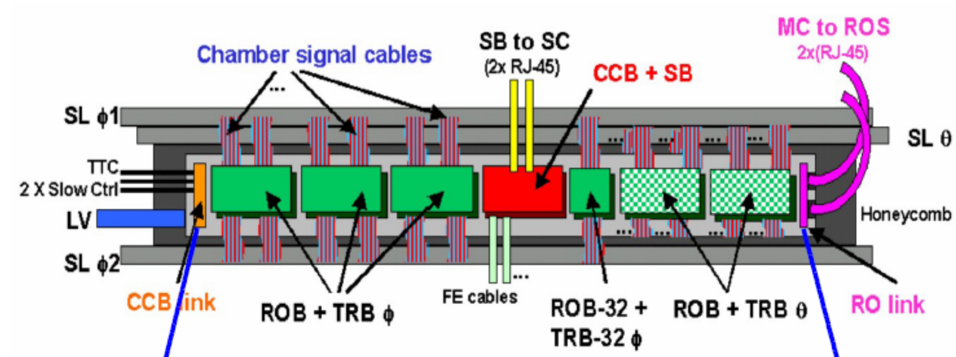
** 85 Watts through water cooling*

** Tasks:*

-Time digitization and event matching

-Trigger primitive generation at chamber level (segment matching, track correlation, BX identification, momentum measurement, etc)





Survival of this old system will require maintenance in UXC that looks very problematic taking into account the harsh environment foreseen for HL-LHC.

** Further radiation tests required (some parts showed failures in past tests at high lumi)*

** ROB will limit L1A rate to 300 kHz*

** Some reliability issues in the past force us to limit the number of power on/off cycles*

** 25% of the Minicrates intervened in LS1 (to recover only the 1% failures) => Hard to maintain*

** Large and costly power supply system to be maintained*

Courtesy of C. Fernandez Bedoya

Drift Tube Phase II upgrade

New DT Electronics

** New low cost time digitization electronics in UXC*

** Timing info from all the wires will be serialized and made available to USC using high bandwidth data link: **highest chamber resolution available for Level 1***

** Produce **improved trigger system** by using algorithms not based in on-chamber ASICs but in high performance processor systems.*

Use **off the shelf high performing devices (uTCA with powerful FPGA? ... 2023...)*

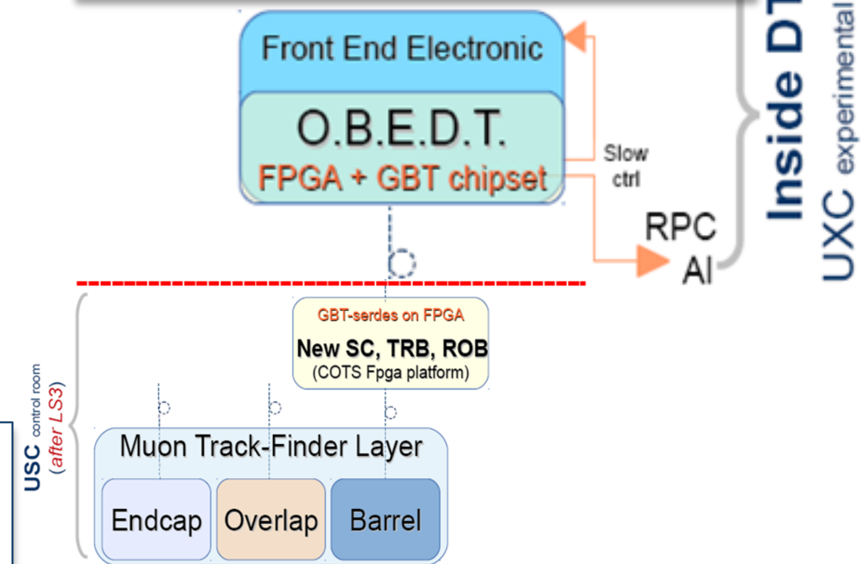
** Exercise of migration of present Bunch Crossing and Track Identifier (BTI ASIC) and Track Correlator (TRACO ASIC) algorithms*

=> 20 million gates of logic

==1 or 2 Virtex 7 biggest part 7V2000T per chamber

UXC

OBEDT **(On Board Electronics for DT)**
~800 analog FE channels
TDC temporal resolution required ~1 ns
HL-LHC barrel radiation environment

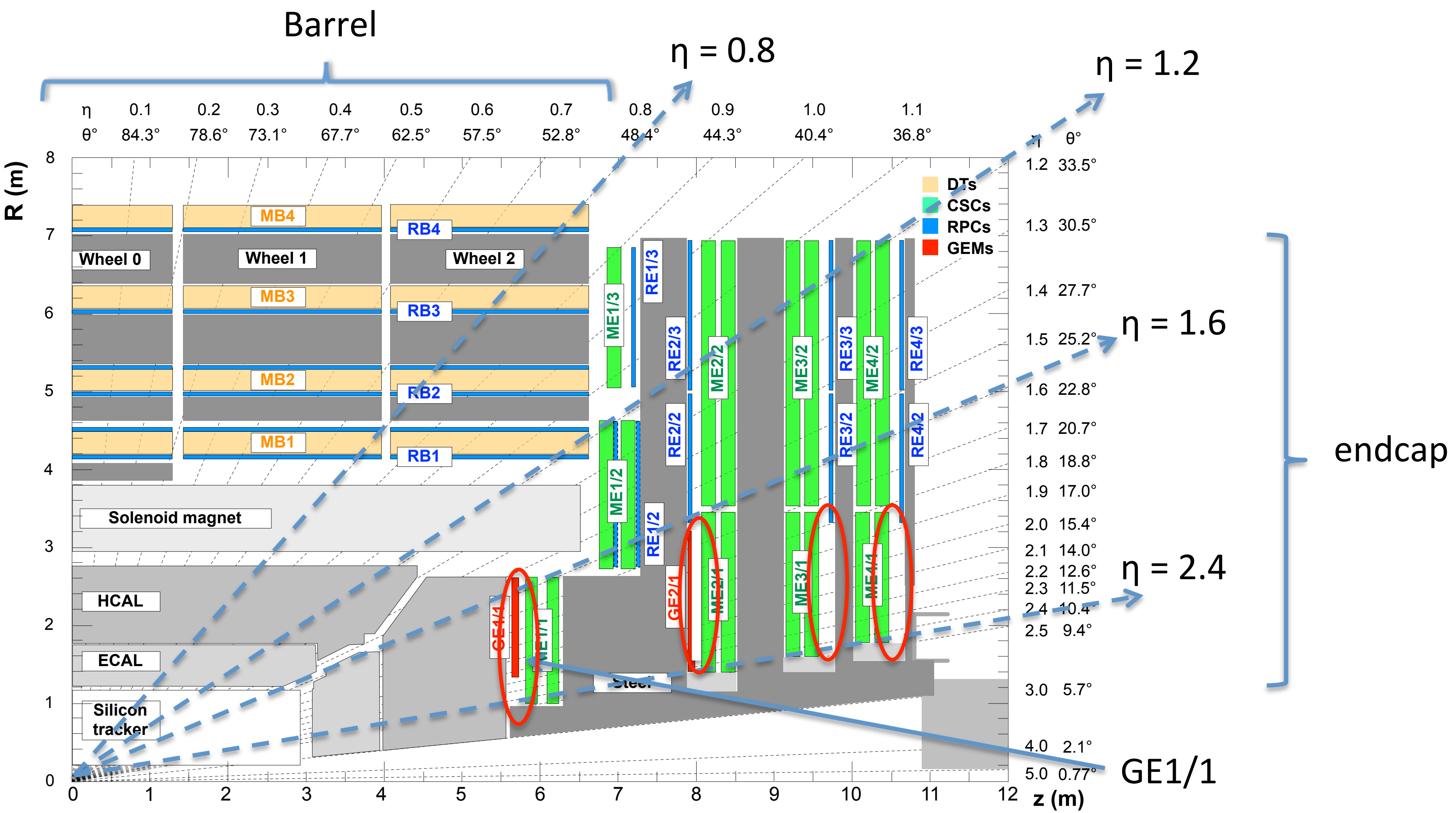


Courtesy of C. Fernandez Bedoya

The CMS muon system post LS2

- CMS muon system built to be redundant for tracking and triggering

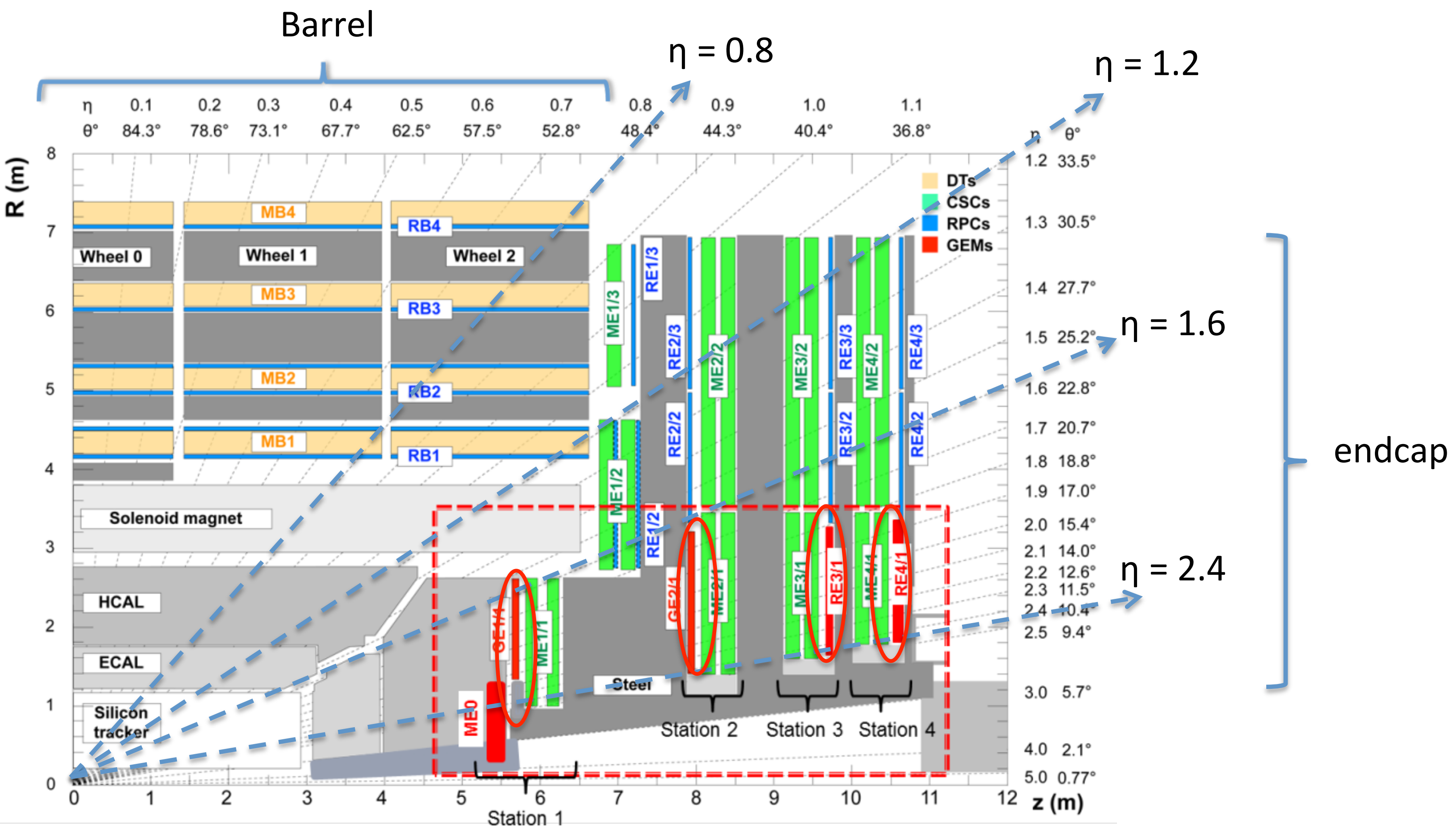
Drift Tube (DT) – Barrel only
Cathode Strip Ch. (CSC) – Endcap only
Resistive Plate Chamber (RPC)



The CMS muon system post LS3

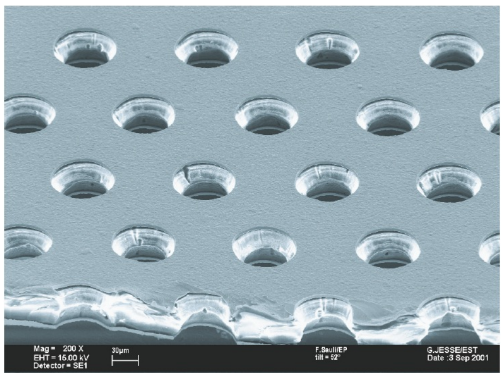
- CMS muon system built to be redundant for tracking and triggering

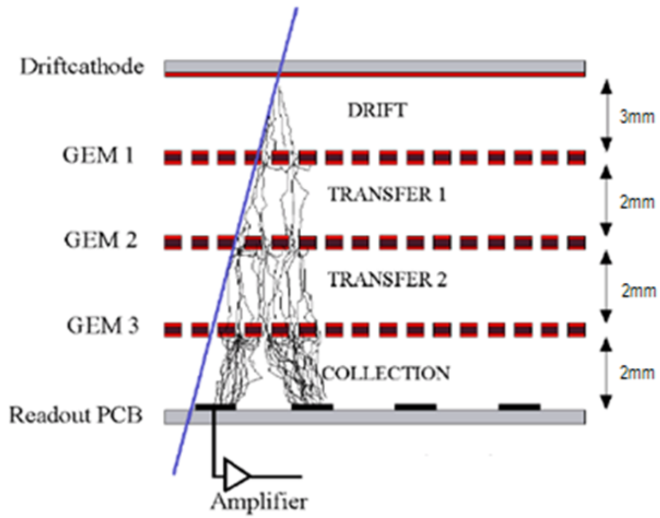
Drift Tube (DT) – Barrel only
Cathode Strip Ch. (CSC) – Endcap only
Resistive Plate Chamber (RPC)

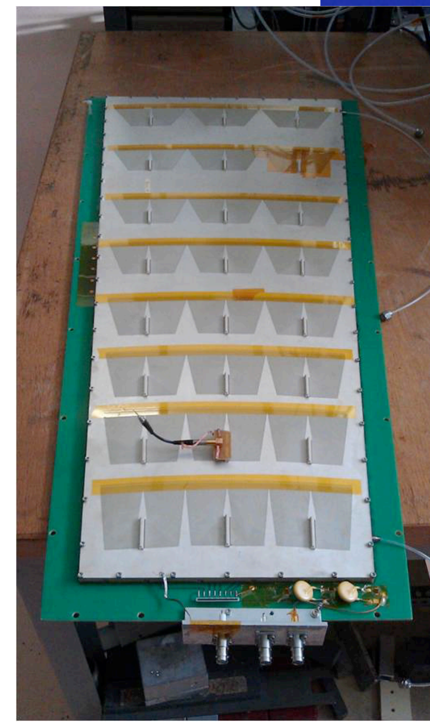


New Detector technology

- GE1/1, GE2/1 & ME0
  - Triple-GEM detectors



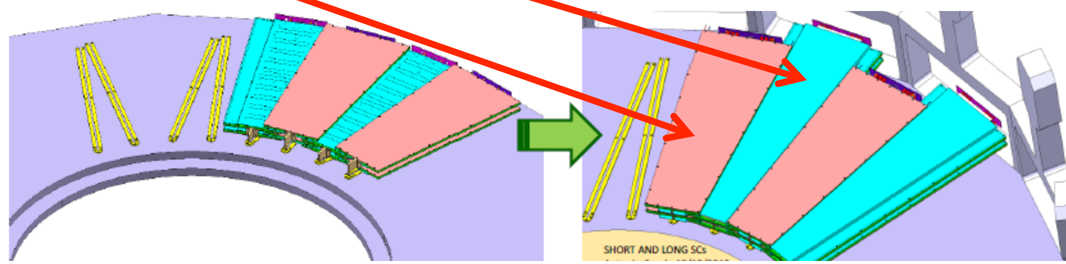




- RE3/1 & RE4/1:
  - Advanced RPC detectors to sustain rate > $1kHz/cm^2$
    - RPC with lower electrode resistivity
    - Optimizing gas gaps or electrode thickness
    - Glass RPCs, etc.

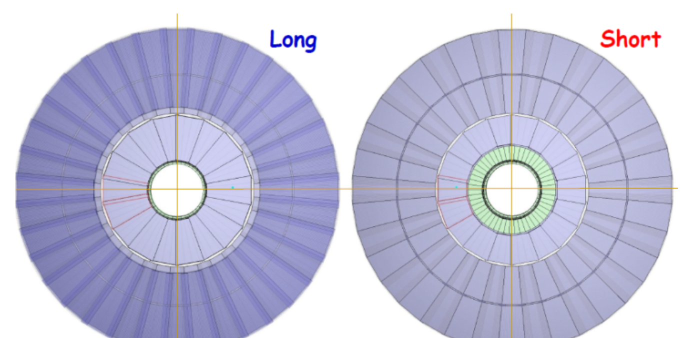
GEM project

- **GE1/1**: baseline detector for GEM project
  - 1.55 < |eta| < 2.18
  - 36 staggered chambers, each chamber spans 10°
  - Several prototype designs with different number of eta partitions
  - Major conclusion from ECFA 2013: **short** and **long** super chambers for maximum coverage in pseudo-rapidity



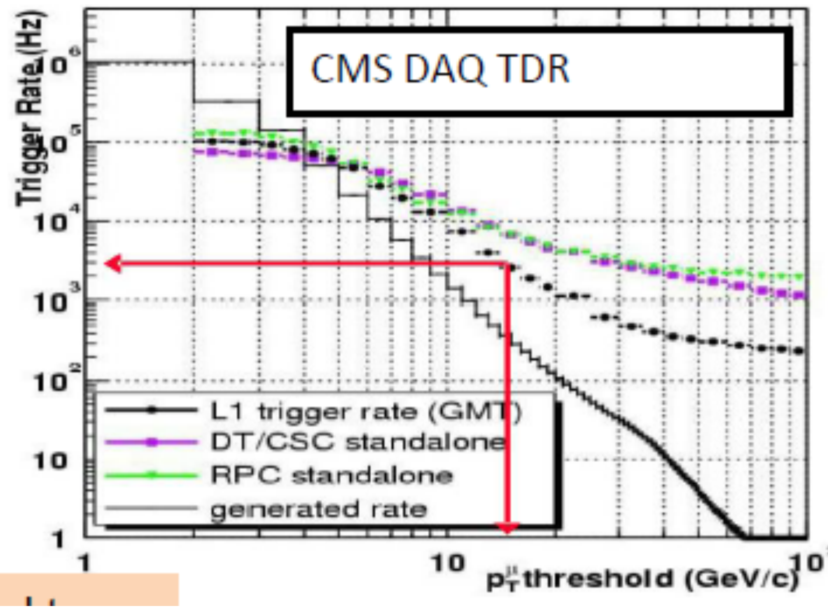
- **GE2/1**: station 2 upgrade
  - 1.55 < |eta| < 2.45
  - Chambers spanning 20°
  - Geometry details to be finalized
    - Looking into possibility of installing 2 rings of double-layered triple GEMs (1 ring with short, 1 ring with long super chambers)

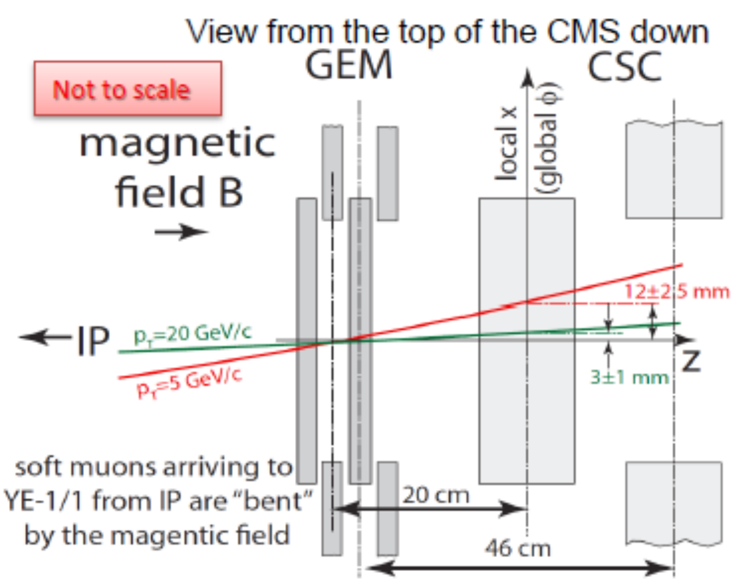
- **ME0**: near-tagger to be installed behind new HCAL
  - 2.0 < |eta| < 3.5
  - 6-layers of triple-GEM detectors
  - Geometry is yet to be finalized



Impact of GE1/1 on L1 muon Trigger

- Scattering of soft muons in the iron yoke flattens the trigger rate curve
  - Promotion of low-p_T muon to high-p_T
- Additional muons stations can help to reduce the trigger rate
- Efficiency of single muon trigger at 20 GeV is about 85% in high eta region



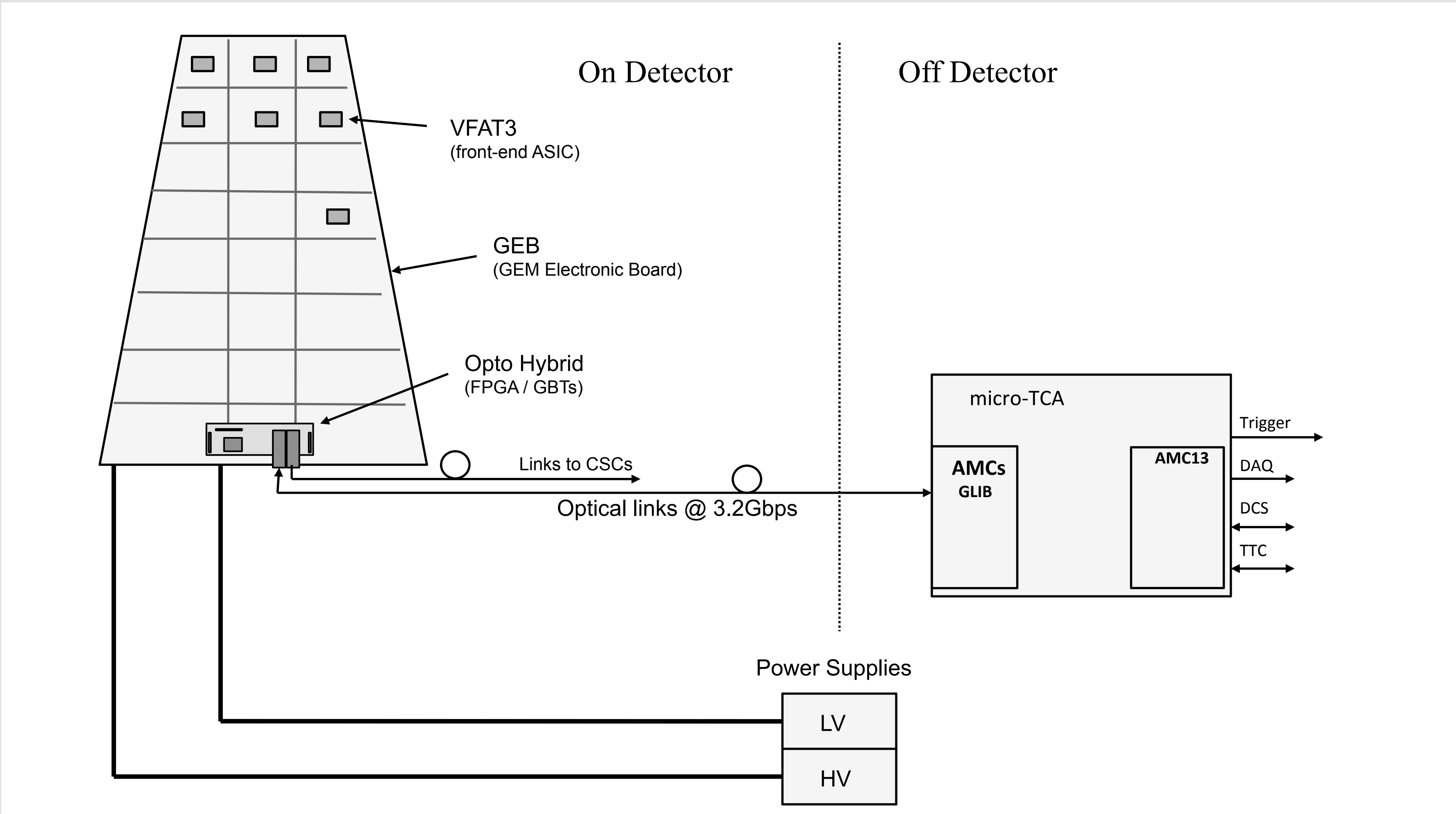


- Additional GEM detector in front of ME1/1 can measure muon bending angle in magnetic field.
- By letting the GEM and CSC **talk to each other** we get a powerful new tool
  - **Rate reduction with GEM-CSC bending angle**

  Typical trigger rate reduction for 20GeV muon: **20kHz/cm² to 2kHz/cm²**

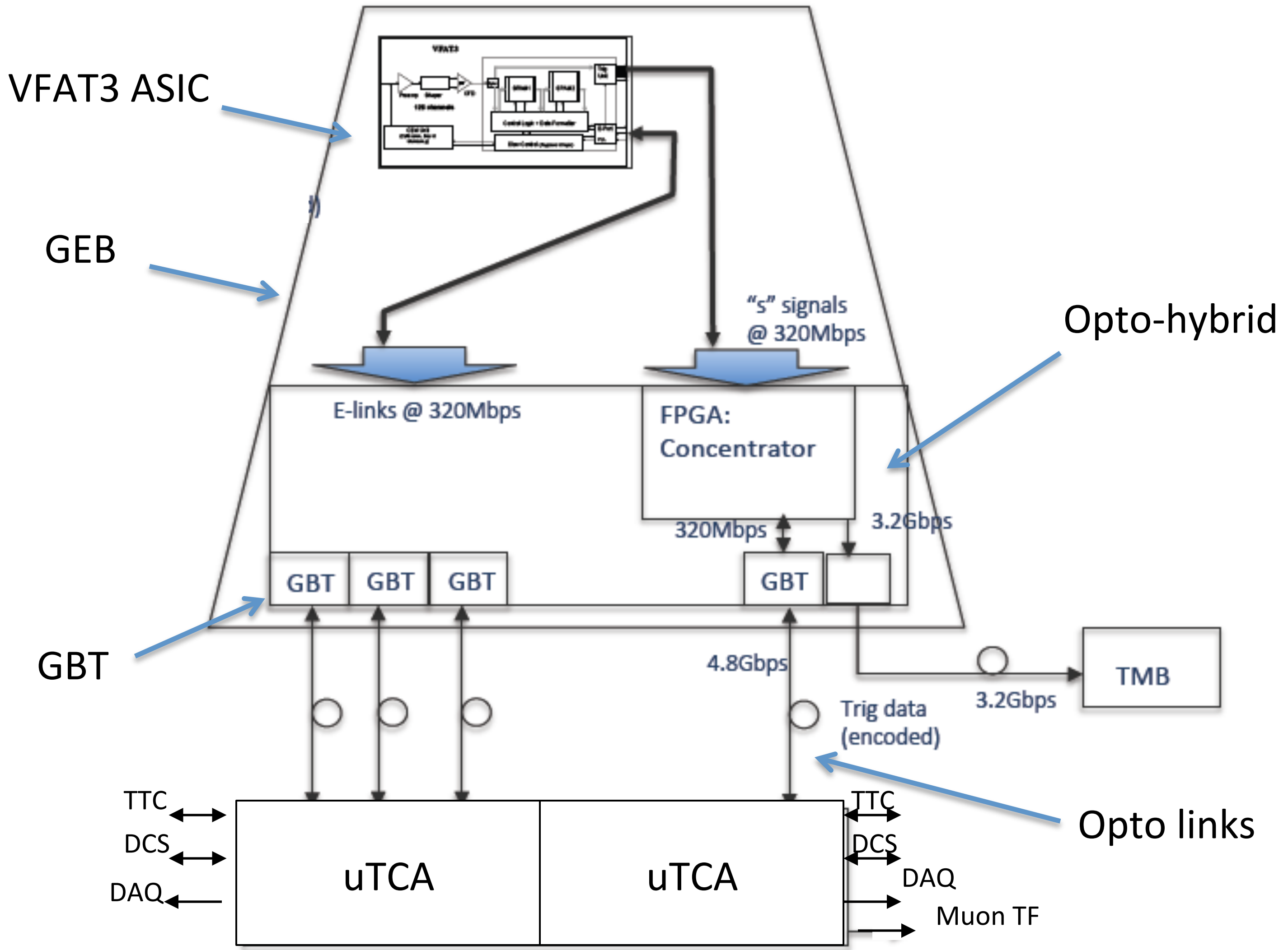
  - **Stub efficiency recovery in ME1/1 CSC TMB**

GE1/1 and GE2/1 readout system



Philosophy: intends to make full use of these generic projects as far as possible to minimize duplication of effort and ensure that design resources within the project are focused on the project specific designs needed.

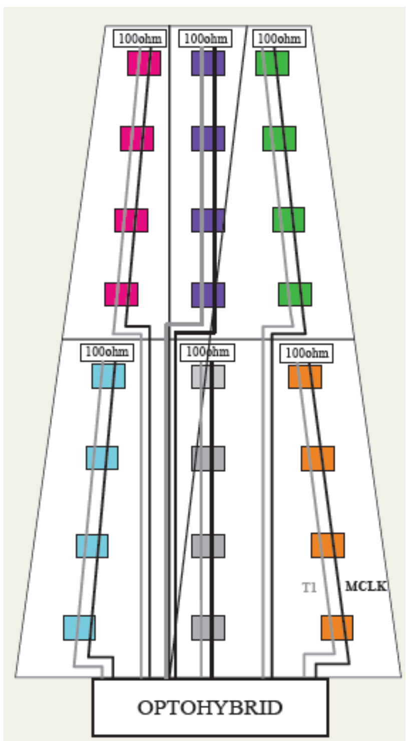
GE1/1 system



Backend electronics

On-detector electronics

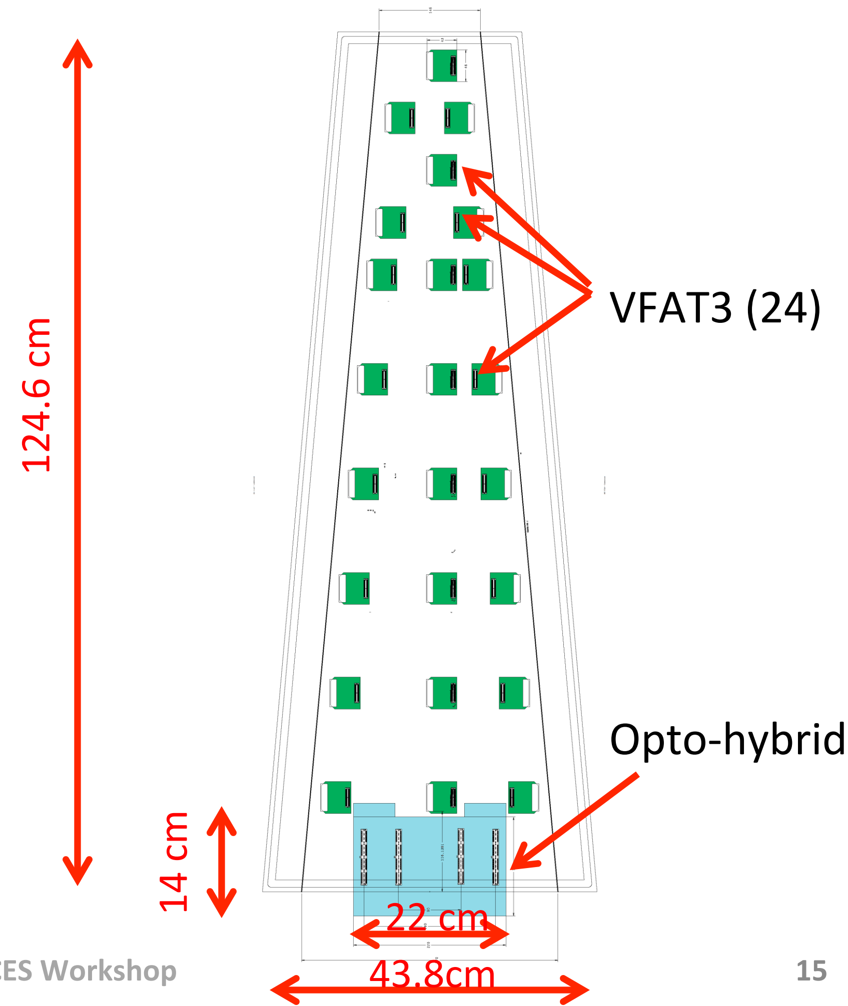
- GEB board
  - Strips segmented in 8η x 3ϕ partitions, each readout by 1 VFAT3 (see P. Aspell talk)
  - Large PCB to avoid cables along GEM



Not at scale

- Opto-hybrid

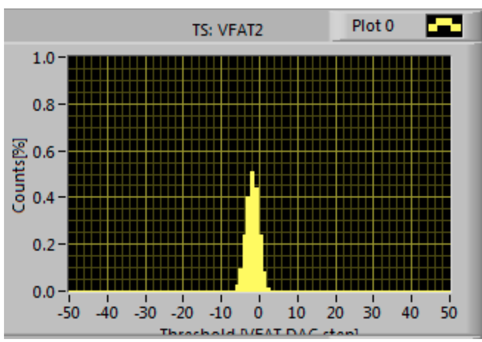
  Board equipped with concentrator FPGA, collecting signals from all VFAT3 and handling the optical links

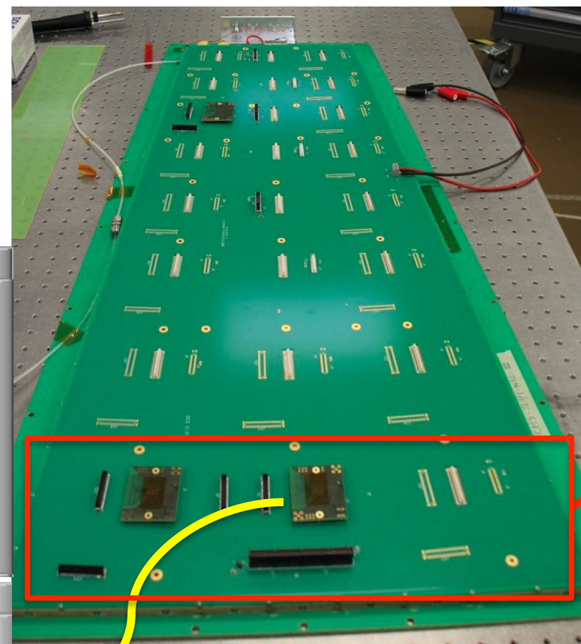


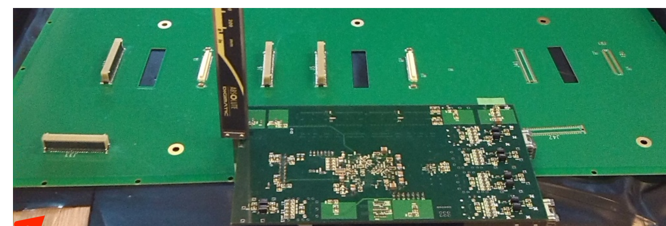
On-detector electronics II

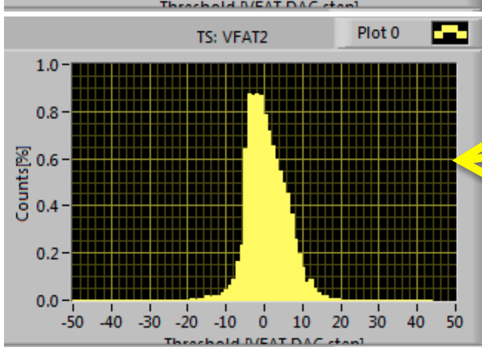
- Design of "final" GEB board (24 VFAT2s) on-going
  - 1st version (6 VFAT2s) available since beginning of 2014
- 1st version of Opto-hybrid to readout 6 VFAT2 available
  - Tests ongoing:

New VFAT2 hybrid
not connected

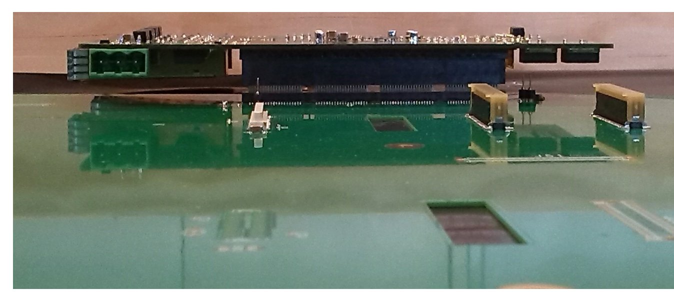








Connected but
strips floating

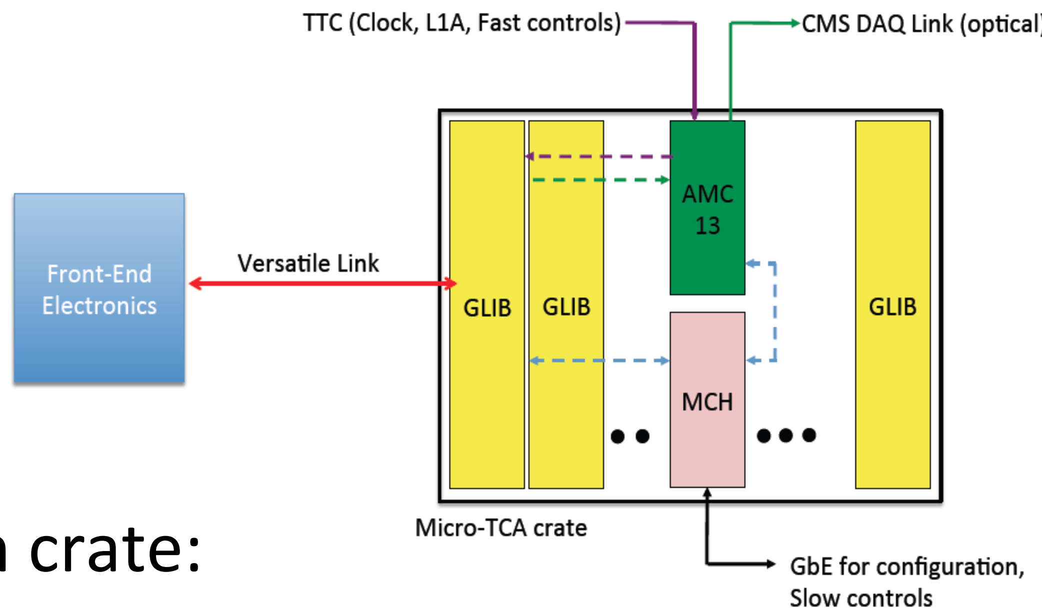


On-detector electronics III

- Constraints on the opto-hybrid
  - Need to be connected to all VFAT3s to collect trigger data and sent them to μ-TCA back-end electronics & CSC TMB→FPGA
  - 4 optical links: 4 GBT chipset + 1 to CSC TMB (~~GBT~~)
  - Space : 22 x 14 cm^2 x 1.9 cm
  - Power: targeting ~ 15 W
  - Number of lines : ~ 400 I/Os
  - Radiation environment
    - →need to implement SEU mitigation techniques
    - →Will perform irradiation tests
  - → Aiming for largest Artix 7 (500 I/Os)

Back-end electronics

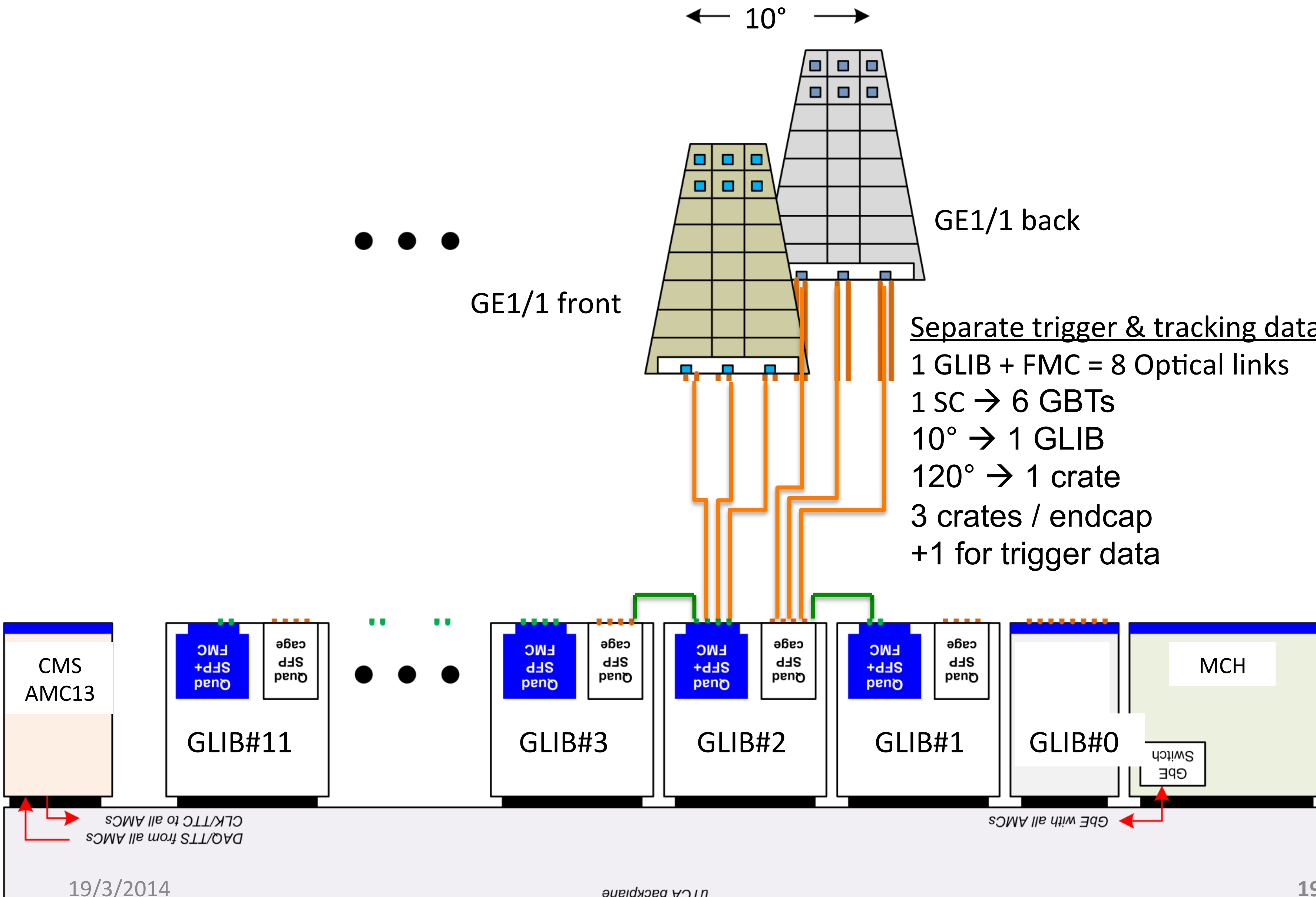
- Optohybrid-µTCA optical link: versatile link and GBT protocol
- µTCA crate:



- AMC boards in crate:
  - 12 GLIB boards
  - 1 AMC13
- µTCA crate: Vadatech VT892

Control:
use IPBus protocol based on UDP

Data sharing & links



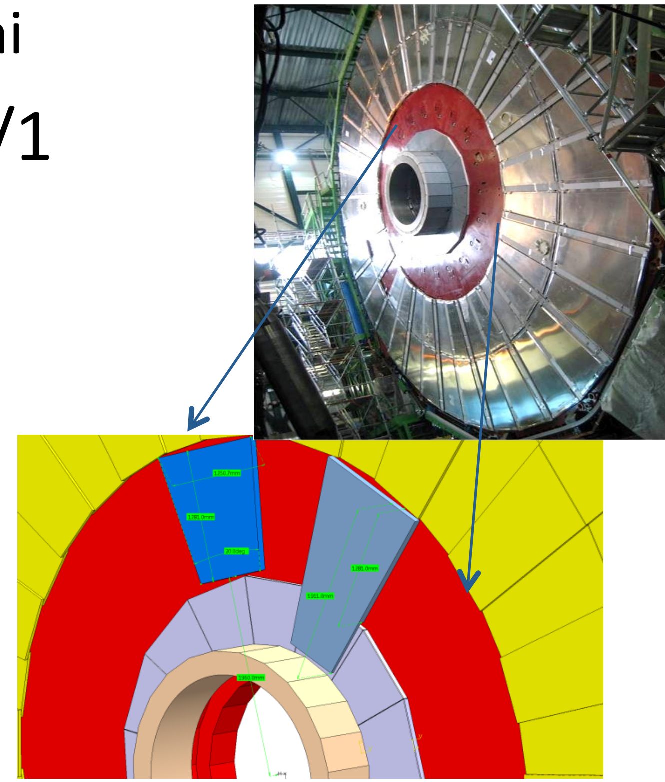
<u>Separate trigger & tracking data path</u>

1 GLIB + FMC = 8 Optical links
1 SC → 6 GBTs
10° → 1 GLIB
120° → 1 crate
3 crates / endcap
+1 for trigger data

GE2/1 system architecture

- The architecture for GE2/1 will be very similar to GE1/1
  - GE2/1 Super-chambers span 20° in phi
- Keeping same area/chip as on GE1/1
  - 120-160 VFAT3 per chamber
  - 15k-20k strips
  - 12-16 GBTs

preliminary

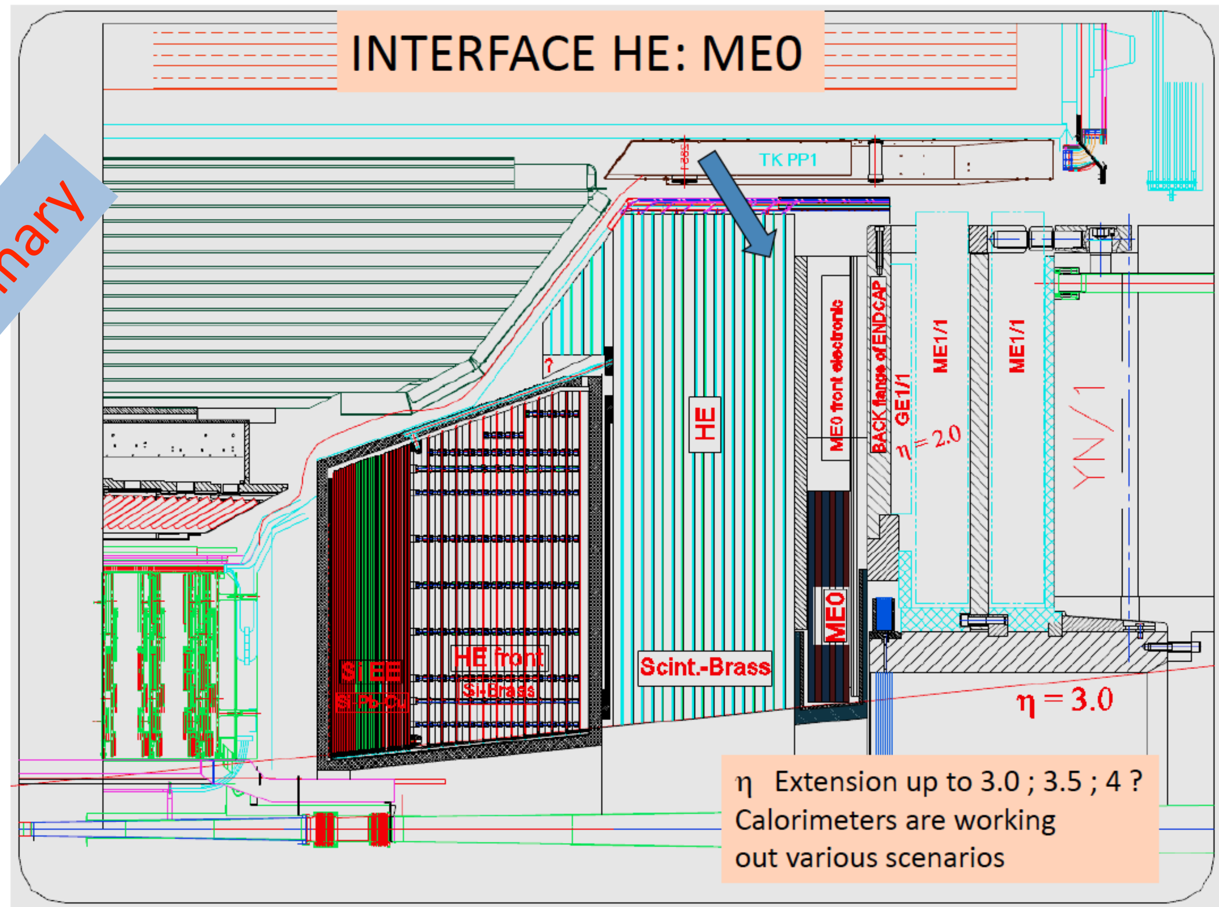


ME0 system

- ME0 would consist of a stack of 6 Triple-GEM detectors, forming a 10° super-module wedge (keeping same strip pitch as GE1/1):
  - 18432 ch
  - 144 VFAT3 chips
  - 24 GBT links
  - No CSC-TMB link

  → could avoid FPGA on-detector

preliminary



- Backend electronics: Investigating other µTCA AMCs with larger optical I/Os capability: MP7, MTF7, new one ?

Conclusions

- Several upgrades are needed to continue to ensure good performance of the CMS muon system at HL-LHC
  - Longevity is an issue: irradiation tests of detectors and some electronics parts need to be repeated
- Barrel DT electronics need to be redesigned, optimizing the sharing between on- and off-detector electronics
- Important upgrades of the high-η region ($|\eta|>1.5$) :
  - GE1/1 during LS2
  - Addition of GE2/1 and ME0 during LS3

BACK-UP

Schedule

Prototype 1 :
VFAT2
Compatible with VFAT2 CMS Hybrid or Totem hybrids
GEB v1
OptoHybrid V1
Readout & Programming via UART or Optically to uTCA
Applications of Prototype 1 : Electrical tests – initial firmware and software development

Hardware Jan/Feb 2014

Prototype 2 : (At first 8 eta divisions, then sub versions for extended eta options)
VFAT2
VFAT2 CMS Hybrid
GEB v2
OptoHybrid V2
Readout & Programming optically from/to uTCA
Applications of Prototype 2 : Test Beam - CERN Cosmic Stand – Slice Test

Hybrids & GEB2 ~ June 2014,
OH V2 ~ August 2014
System development for TB, CS & ST

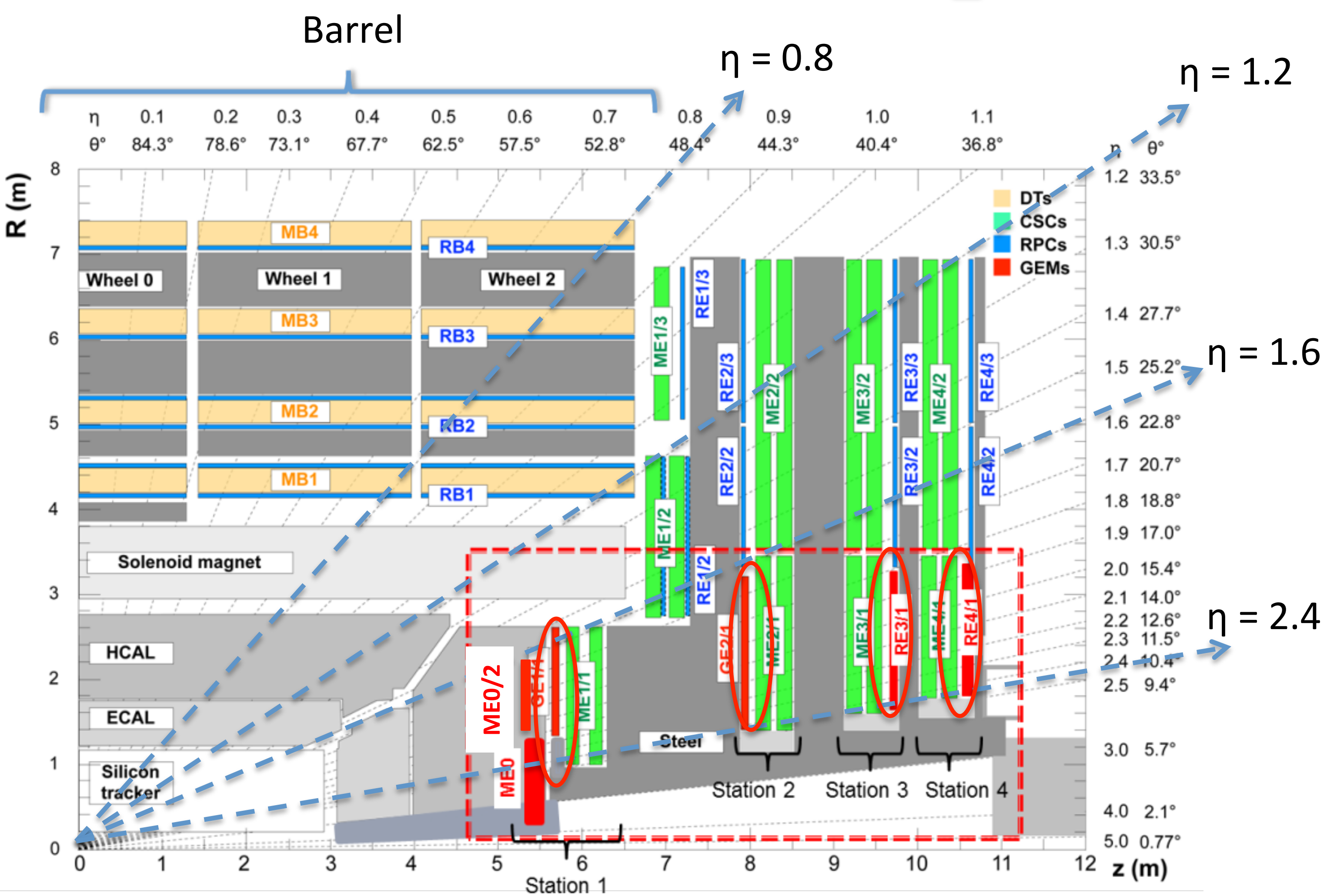
Prototype 3 :
VFAT3 (or VFAT3 emulator to start)
VFAT3 Hybrid Vx....
GEB v3
OptoHybrid V3
Readout & Programming optically via GBT from/to uTCA
Applications of Prototype 3 : CERN Cosmic Stand - Final system

VFAT3 (a) ~ Q4 2015
Initial hardware Q2-3 2015 ?
System development for CS & FS
continuous up until LS2

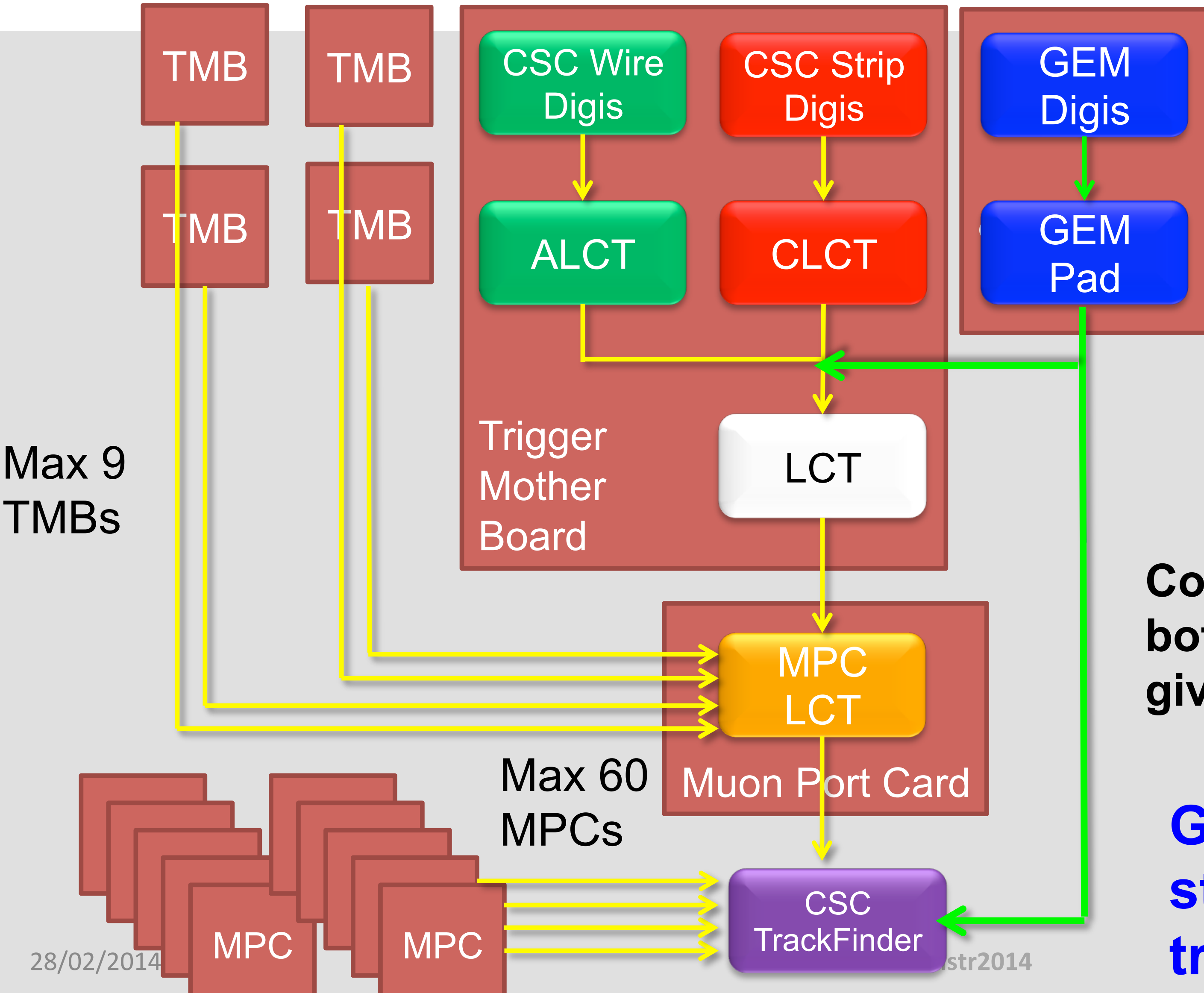
The CMS muon system post LS3

- CMS muon system built to be redundant for tracking and triggering

Drift Tube (DT) – Barrel only
Cathode Strip Ch. (CSC) – Endcap only
Resistive Plate Chamber (RPC)



GEM triggering options



GEM-CSC integrated local trigger

Combination of both paths will give best results

GEM standalone trigger