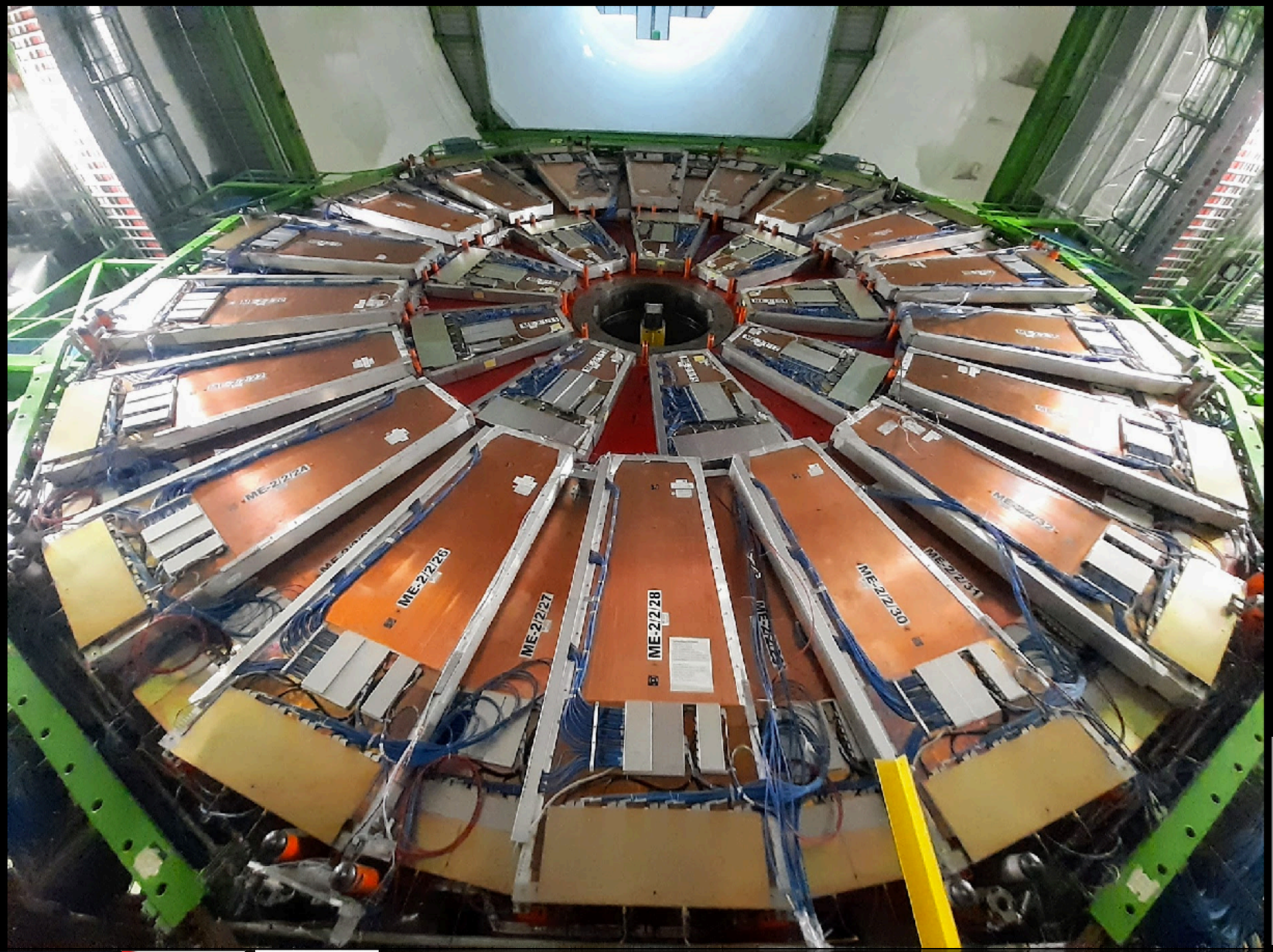


CMS Cathode Strip Chambers

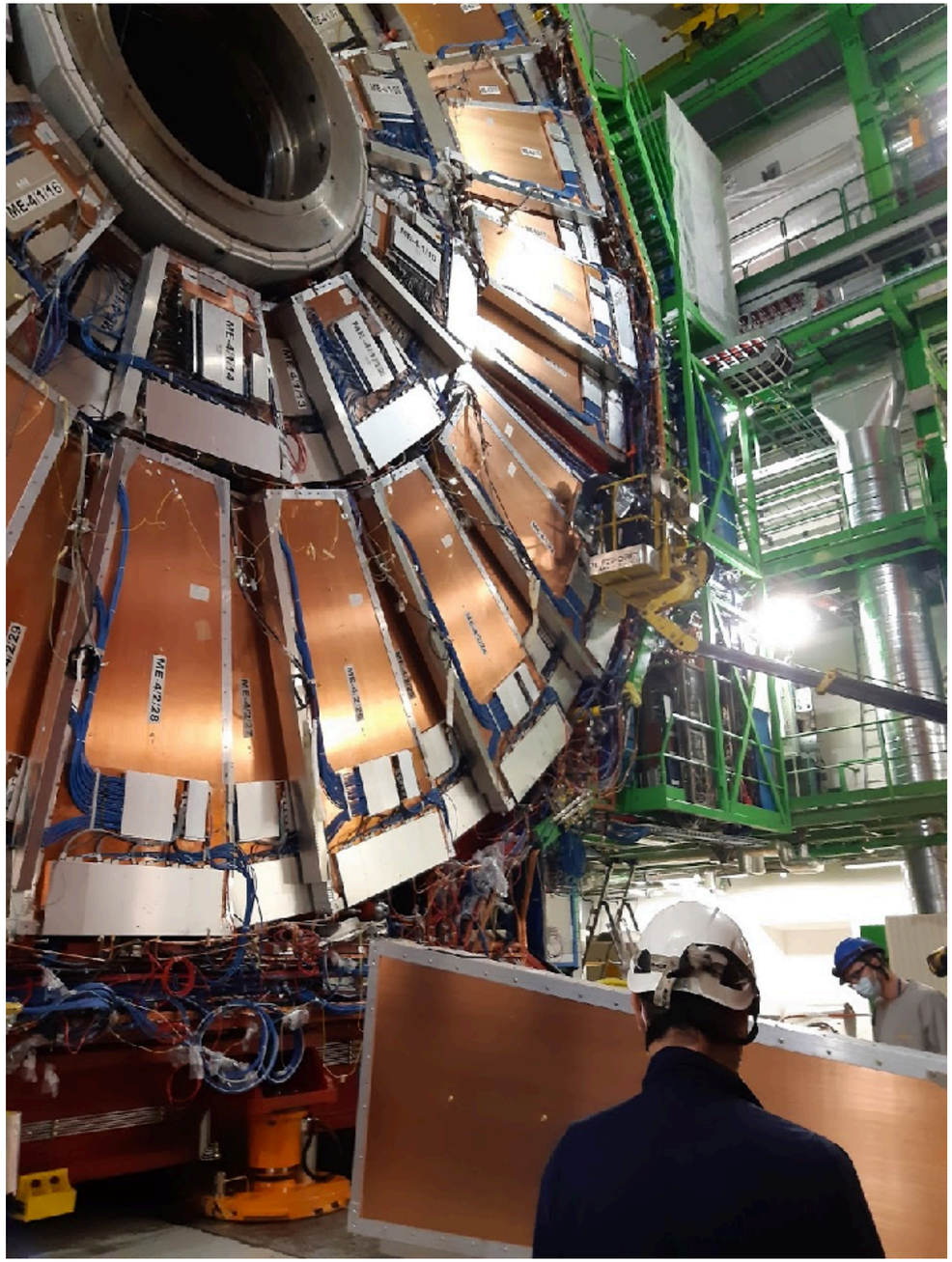
Upgrades for the High Luminosity LHC

Johan Sebastian Bonilla Castro
They/Them Pronouns
On behalf of the CMS Collaboration
2 December 2020

Central American HEP Workshop 2020

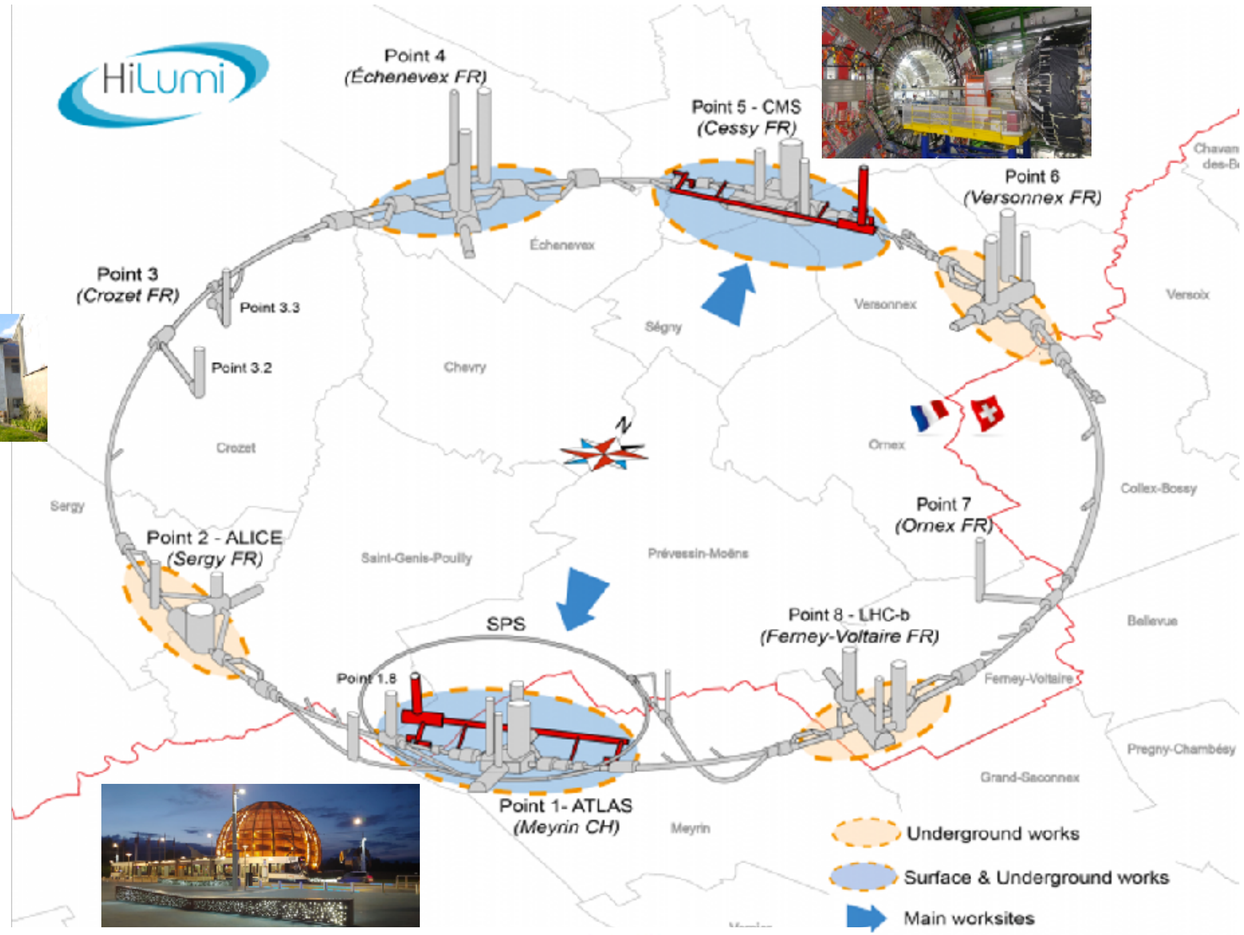
Outline

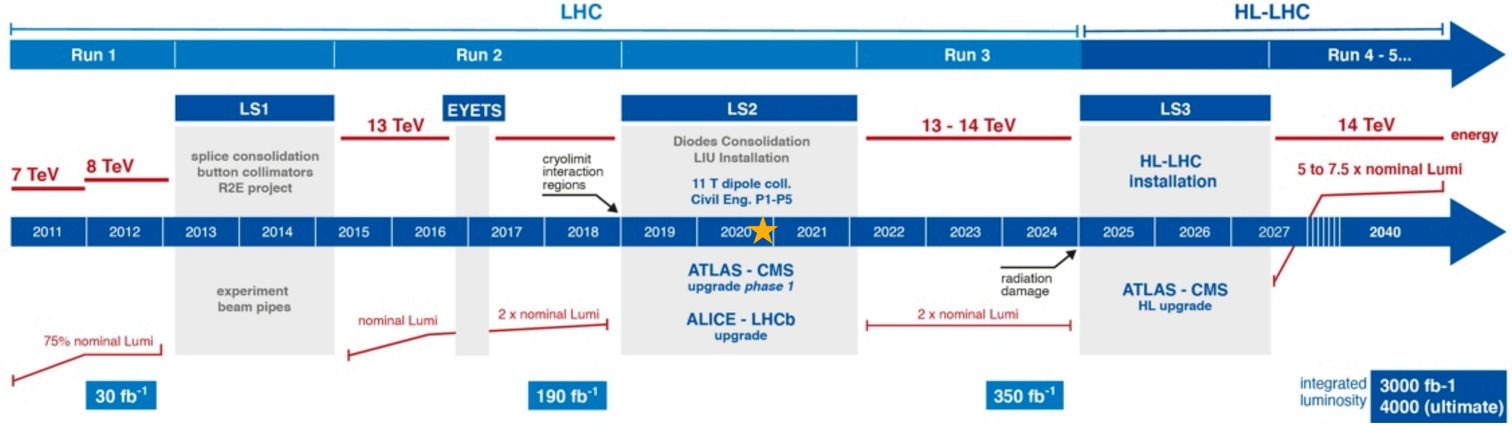
- What are CSCs?
- Why do we need to upgrade them?
- How are we upgrading them?
- Current status of upgrades
- Outlook on future upgrades



CMS at the LHC

- LHC delivers proton-proton collisions at $\sqrt{s} = 13\ TeV$
- CMS is one of four large experiments using LHC collisions
- Currently in Long Shutdown 2 (2019-2021), preparing for Run 3 (2022-2024) and High-Luminosity LHC (Runs 4+)





★ = Nov 2020

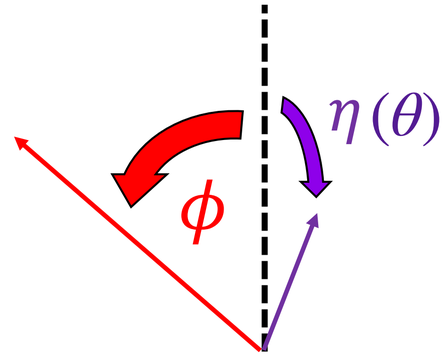
[HL-LHC Public Page]

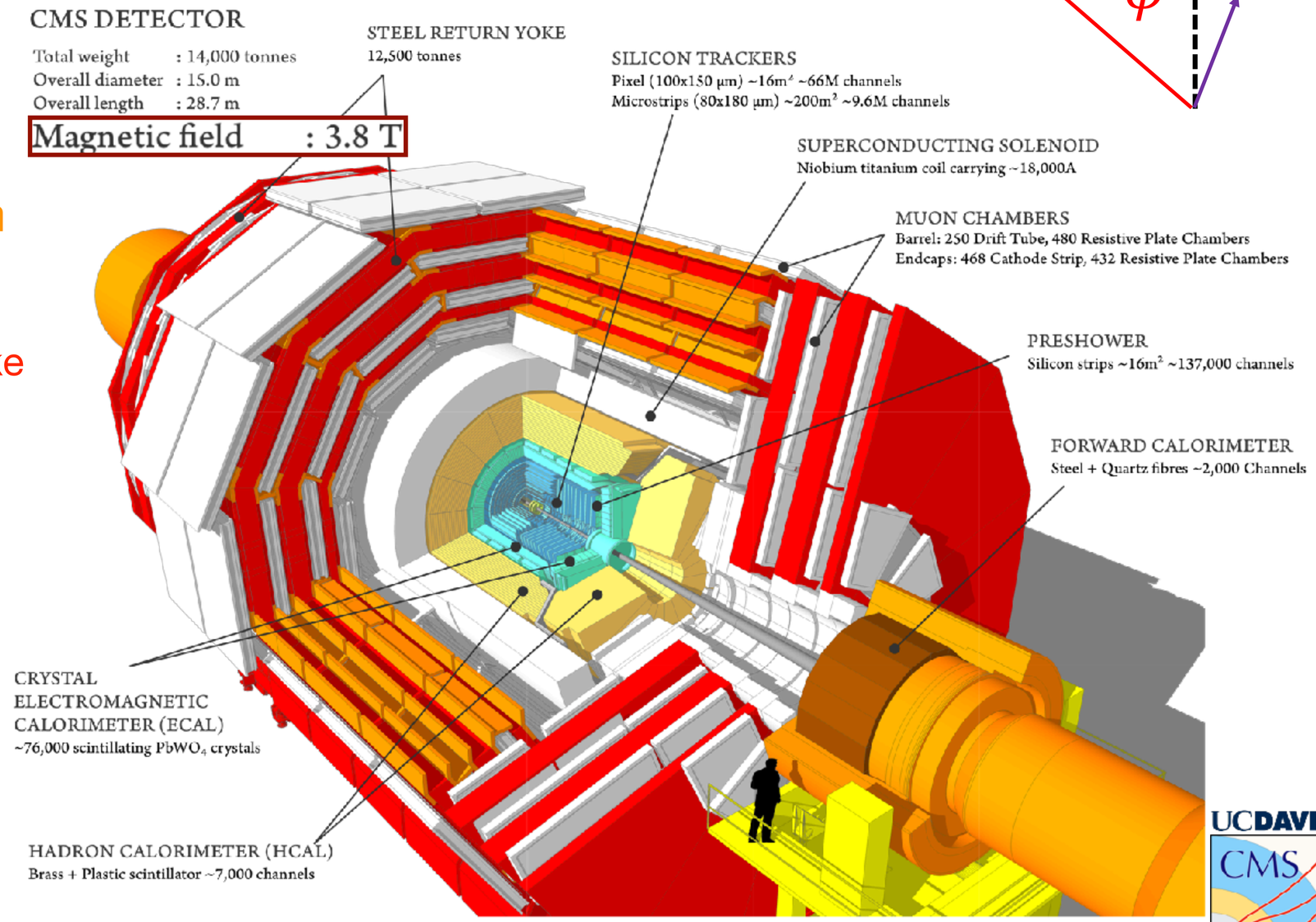
The Compact Muon Solenoid

- Hermetic detector
  - Can define missing energy to analyze invisible decays
- Excellent, robust muon system
  - Superconducting solenoid creates 3.8*T* magnetic field in tracker and calorimeters, 2*T* is steel return yoke
- $PbWO_4$ EM calorimetry
- High resolution silicon tracking in $|\eta| < 2.4$
- Cost: ~500 MCHF
  + ~200 MCHF (Upgrades)

$$\eta \equiv -\ln\left[\tan\frac{\theta}{2}\right]$$

Pseudo-rapidity





J. Phys.: Conf. Ser. 513 022032

Detecting Particles in CMS

Tracker:

Measures momentum of charged particles
$(e^{\pm}, \mu^{\pm}, \pi^{\pm}, K^{\pm})$

EM Calorimeter:

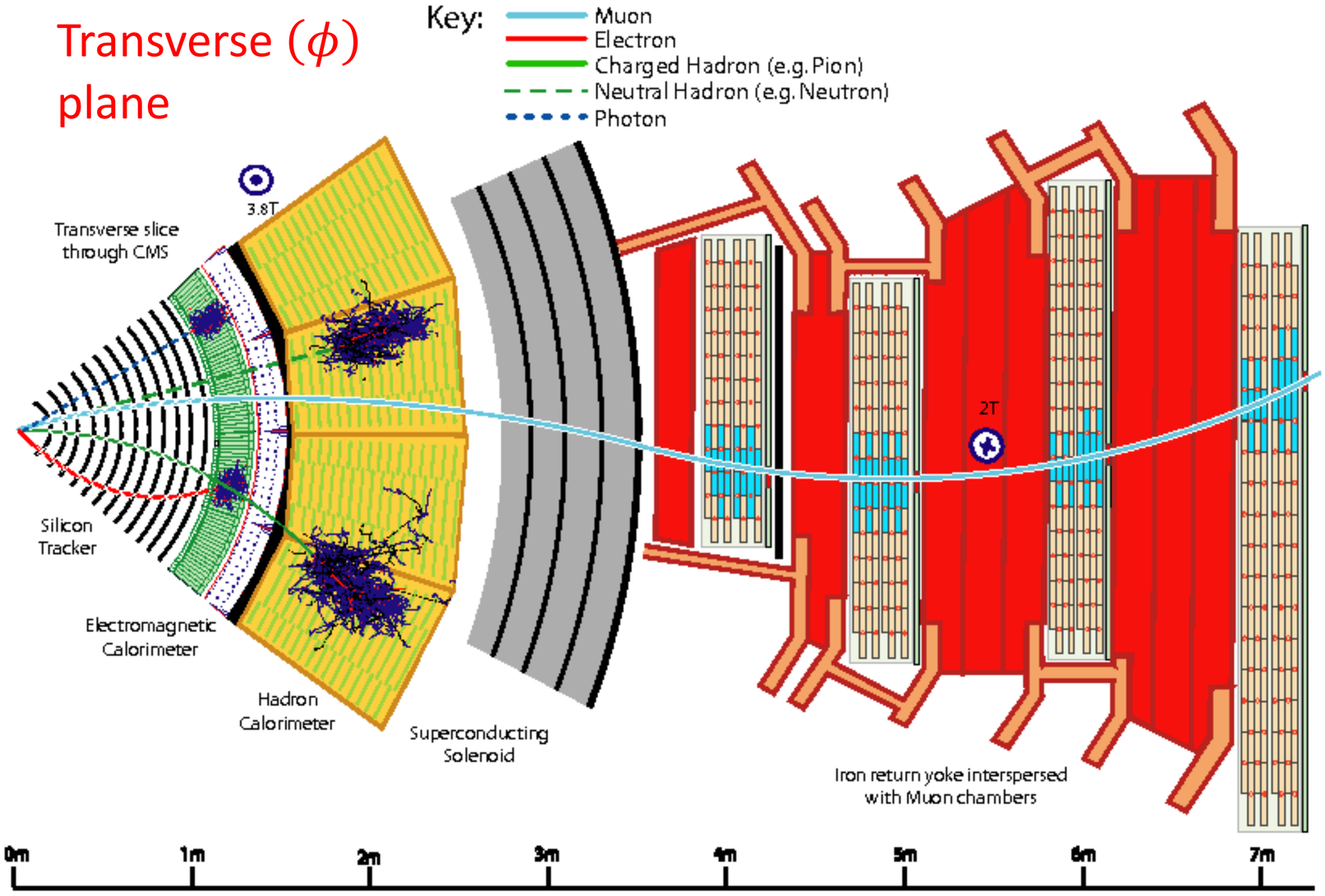
Measures energy of EM showers
$(\gamma, e^{\pm}, \pi^0 \to \gamma\gamma, K_S^0)$

Hadronic Calorimeter:

Measures energy of hadronic showers
$(\pi^{\pm}, K^{\pm}, K_L^0, p, n)$

Muon Spectrometer

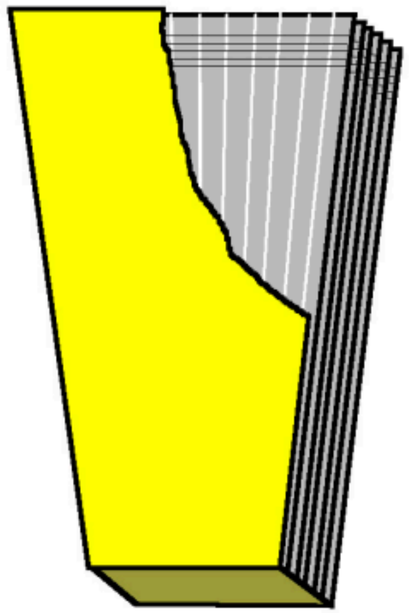
Measures momentum of surviving minimal ionizing (charged) particles, i.e. muons

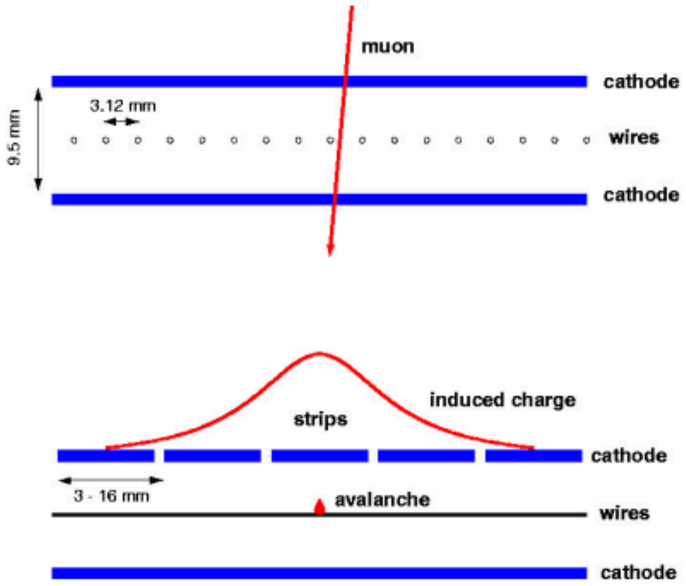


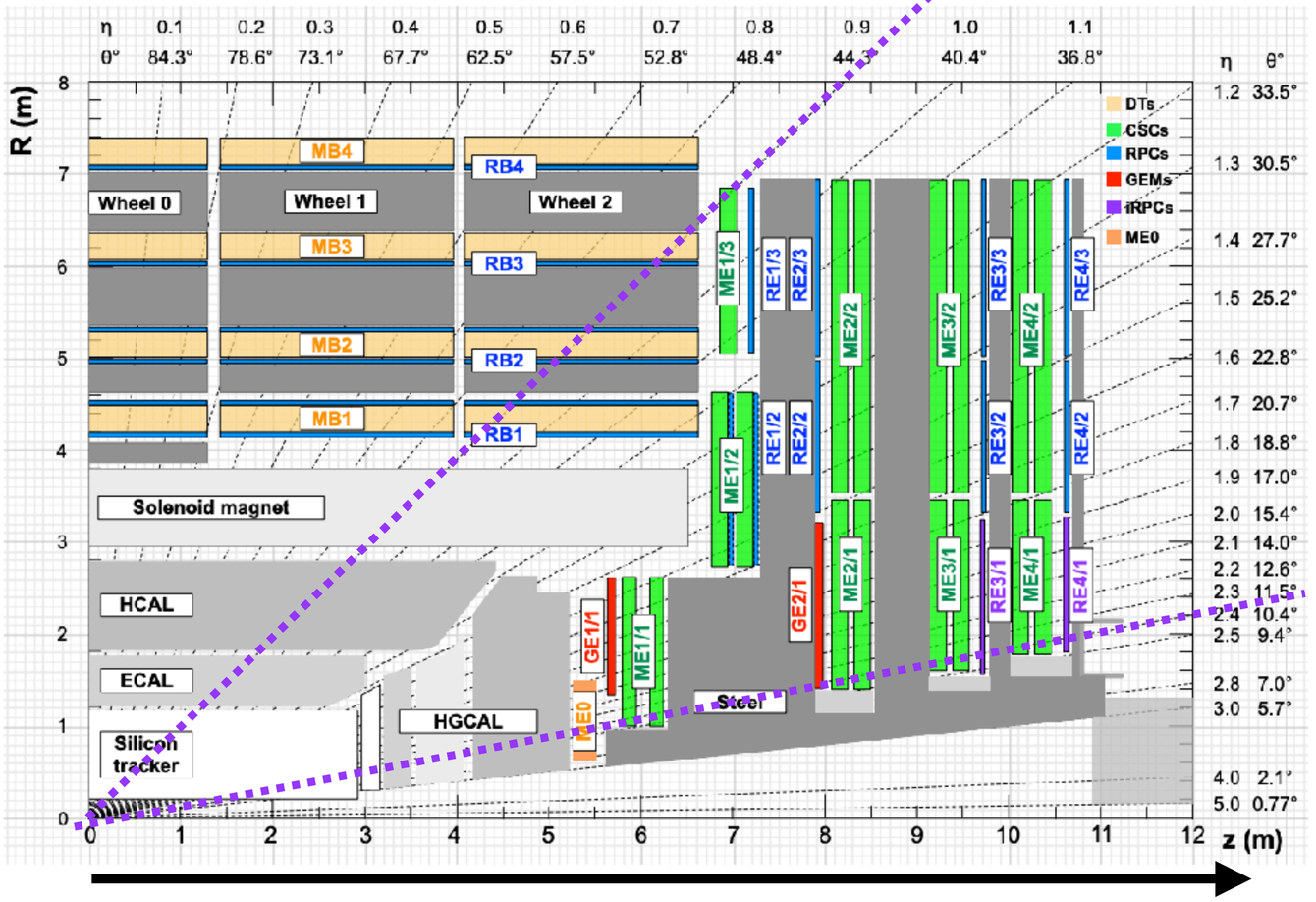
JINST 12 (2017) P10003

What Are Cathode Strip Chambers (CSCs)?

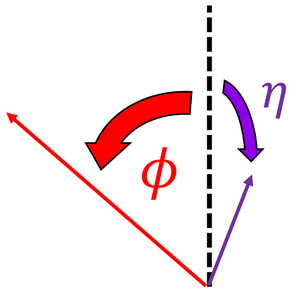
- Muon system employs different technologies
  - Barrel: Drift Tube + Resistive Plate Chamber (RPC)
  - End-Caps: CSC + RPC + Gas Electron Multipliers (GEM)
- CSCs measure 2D position, $|\eta| \in [0.9, 2.4]$
  - Work great in intense, non-uniform magnetic fields
- CSCs are 6-layers of wires (anodes) and strips (cathodes) in $Ar/CO_2/CF_4$ gas mixture
  - Traversing muons ionize gas at HV
  - Avalanche signal read by anode and cathode electronics

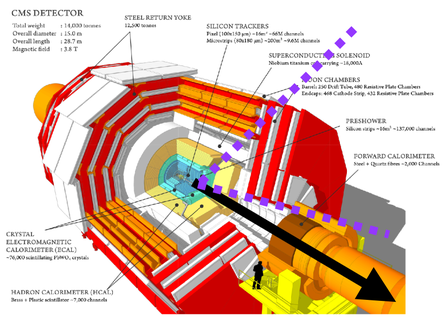






CMS-TDR-016





Electronics of CSCs

CMS-TDR-016

AFEB:
Anode Front End Board
Relays signals from wires

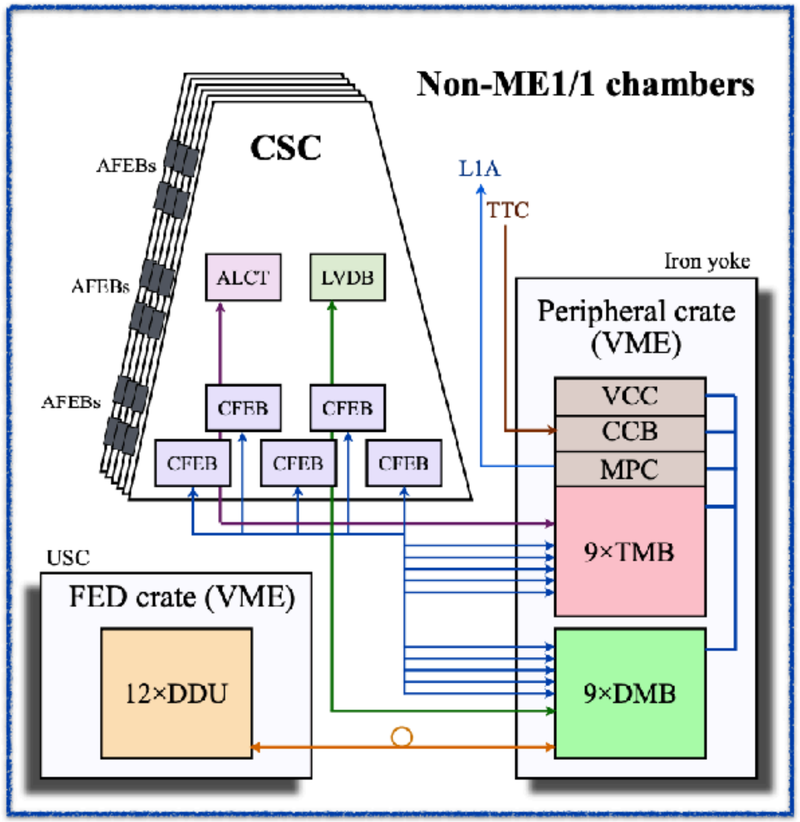
(D)CFEB:
(Digital) Cathode Front End Board
Relays signals from strips

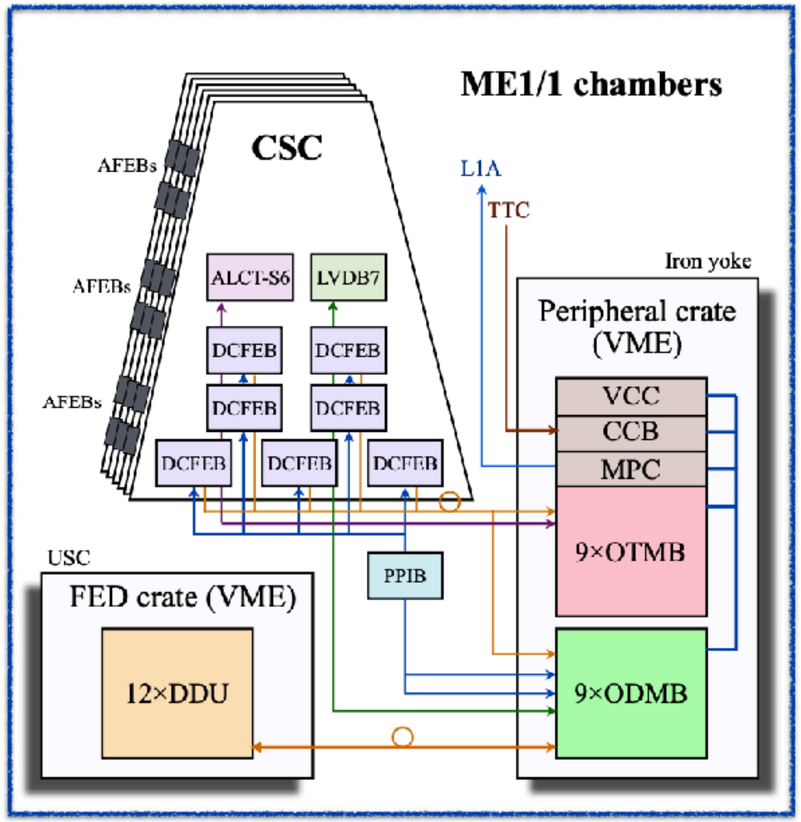
ALCT+Mezzanine:
Anode Local Charged Track
Find patterns from AFEB for trigger

LVDB/LVMB:
Low Voltage Distribution (Mother) Board
Provides power to on-board electronics

(O)TMB:
Builds patterns from ALCT/(D)CFEB to build Local Charged Trigger ‘stubs’

(O)DMB:
When triggered, exports data to Data Acquisition System (DAQ) system





ME1/1 is closest to interaction point

Why Do CSCs Need an Upgrade?

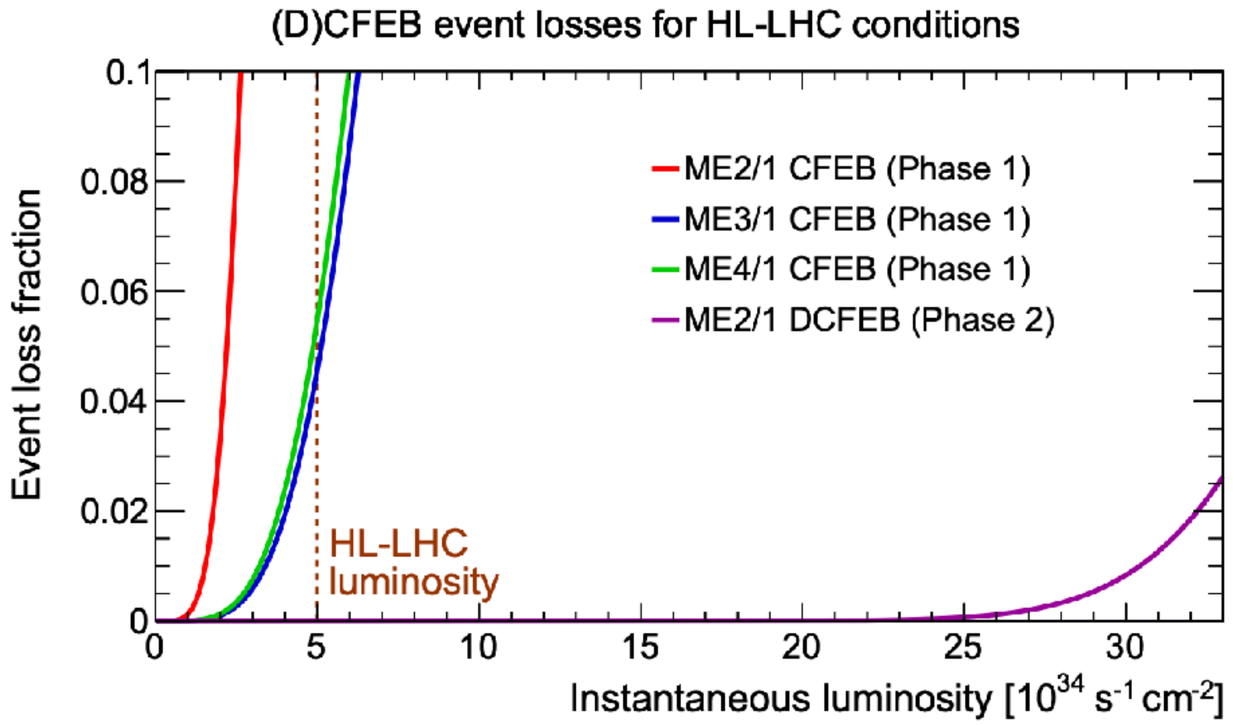
- LHC Upgrade for Run 3
  - Collision energy may increase $\sqrt{s} = 13 \rightarrow 14\ TeV$
  - Luminosity expected ~2x Run 2 nominal
  - Detectors should handle Run 3 easily

- LHC Upgrade for HL-LHC (Runs 4+)
  - Luminosity to reach 5-7.5x Run 2 nominal
  - Expected rate: 200 collisions/crossing @ 40 MHz
  - Current electronics will have readout problems due to higher detector occupancy and bandwidth limits

- CSC Need Upgrade for HL-LHC
  - Trigger latency requirement: $3.6 \rightarrow 12.5\mu s$
  - Cathode Front End Boards need more memory, analog storage replaced with digital (flash)
  - Anode readout need more memory and bandwidth, install cards with better buffer and optical readout
  - New electronics increases power consumption, replace Low Voltage supply system
  - Off-detector upgrades will continue after Run 3

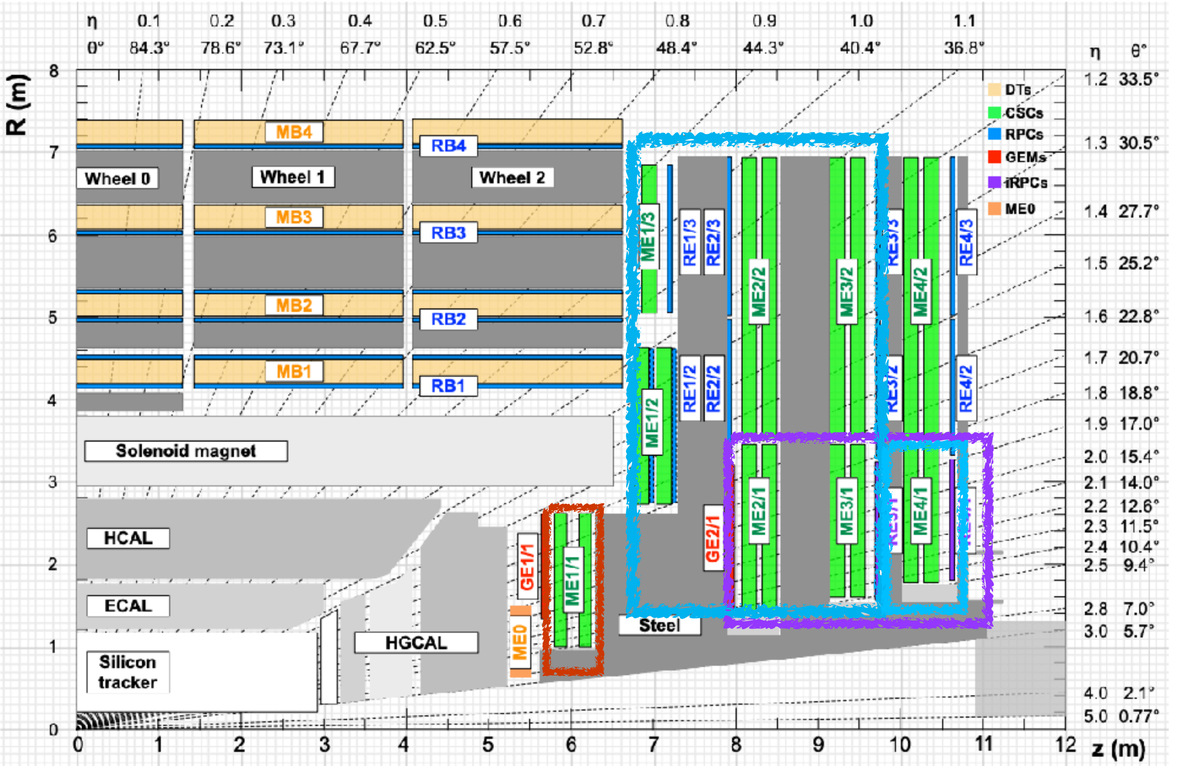
CMS-TDR-016

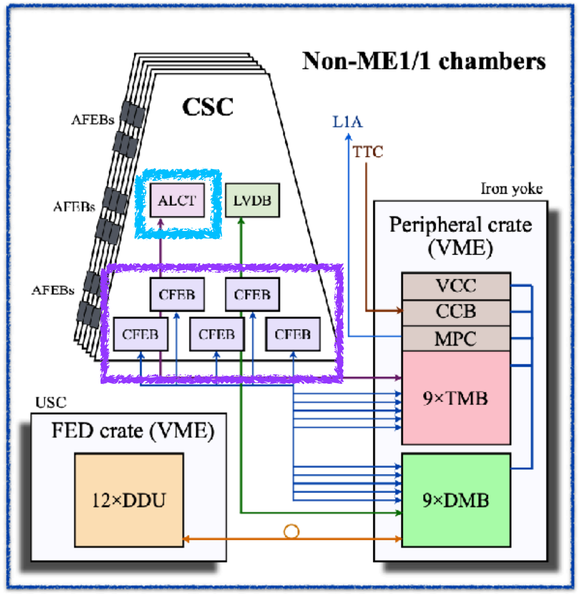
	HL-LHC needs	CMS 2017	CMS upgraded
Level-1 trigger accept rate (kHz)	500	DT: <300 CSC: <250	DT: $\gg 500$ CSC: 4000
Level-1 latency (μs)	12.5	DT: 20 CSC: 3.6	DT: $\gg 12.5$ CSC: 28.8
Total DAQ data transfer rate (Gbit/s)	DT: 1082 CSC: 1026	DT: 42 CSC: 230	DT: 3600 CSC: 2764

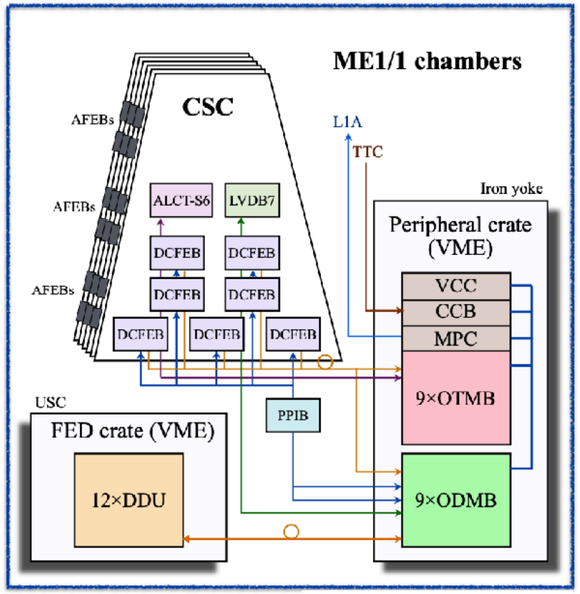


Phase-2 Upgrade Summary

- On-Detector Upgrades
  - ME234/1: CFEBs -> Digital CFEBs
  - ME1/1: Cooling Loop Swap
  - All*: New ALCT mezzanine cards
    (*except ME1/1 and ME4/2, done in LS1)
- Peripheral Crate Upgrades
  - Low Voltage power supply and distribution
  - Data/Trigger Mother Board -> Optical Comm.
    (to be done in LS3)
- Service Cavern Upgrades
  - Front End Driver, links (O)DMB to CMS cDAQ, needs boards to handle higher data rate
  - HV supply and distribution to be modified in LS3, no on-detector work needed





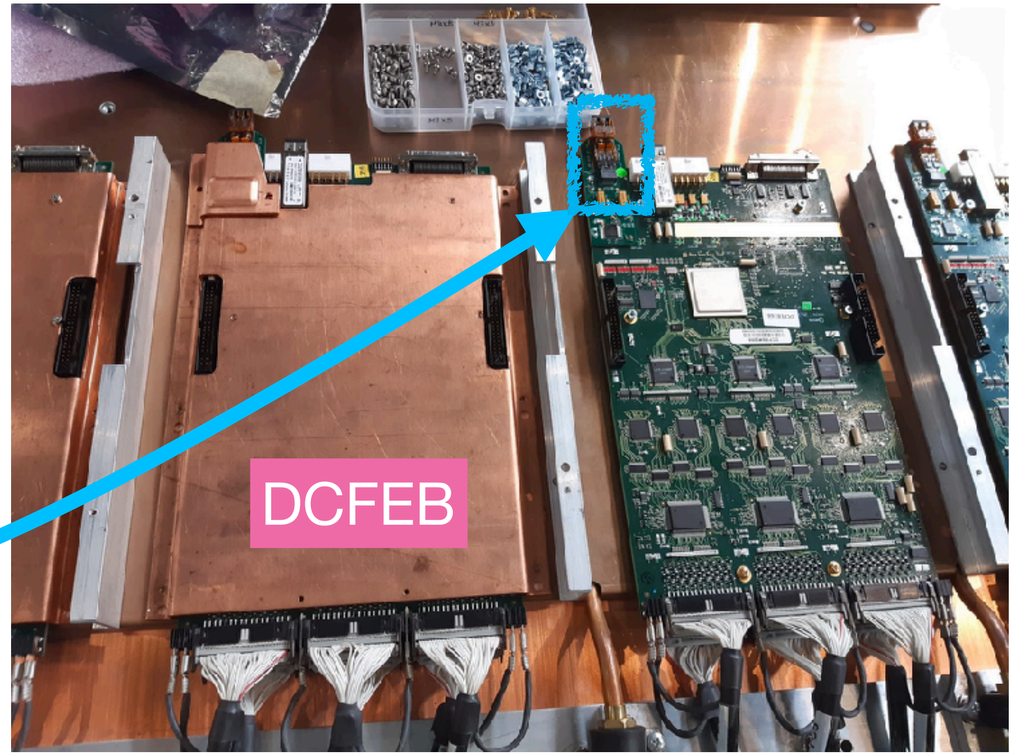


CMS-TDR-016

On-Detector Refurbishment of Electronics

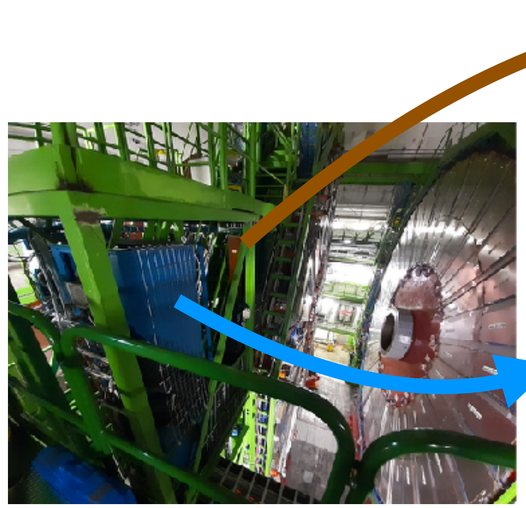
ALCT Mezzanines and DCFEBs

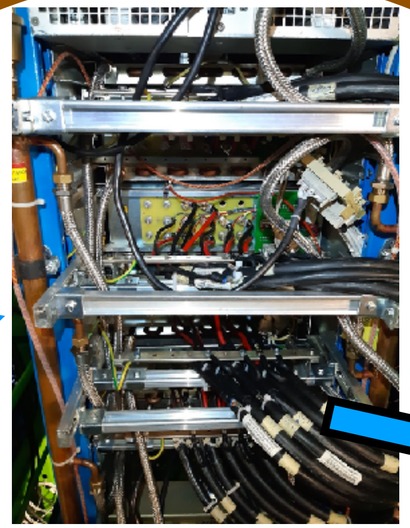
- 108 ALCT-LX150T Mezzanine boards installed in all ME234/1
- 288 ALCT-LX100T Mezzanine boards installed in ME1/1,123/2
- 504 DCFEBs installed in ME1/1 and 45 in ME+2/1
- All boards capable of optical readout



Upgrading the LV System

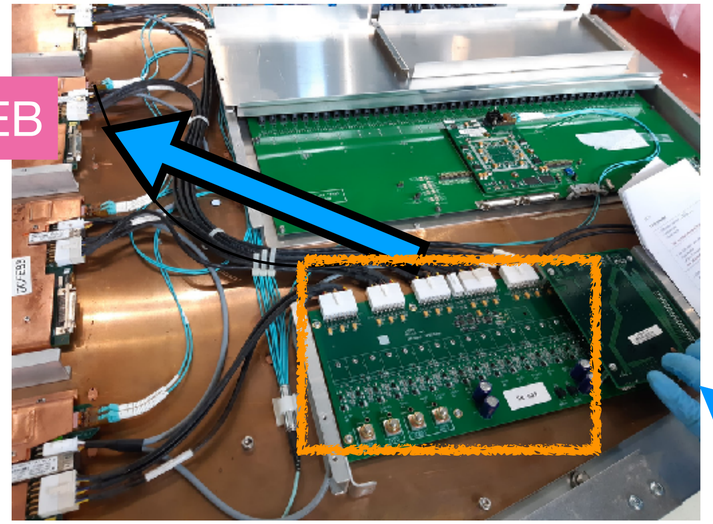
- Need to satisfy new power requirement of DCFEBs in ME234/1
  - Current 9.8/5.5 -> 22.8/13.0 Amps, increase of 144 W per chamber
- Low-Voltage Distribution Boards produced and installed on each of 18 chambers for the inner-rings (1) of ±2/3/4 stations, 108 total
- Junction Boxes distributing LV supply installed in Summer 2020
- Additional 12 Maraton power supplies installed in Summer 2020





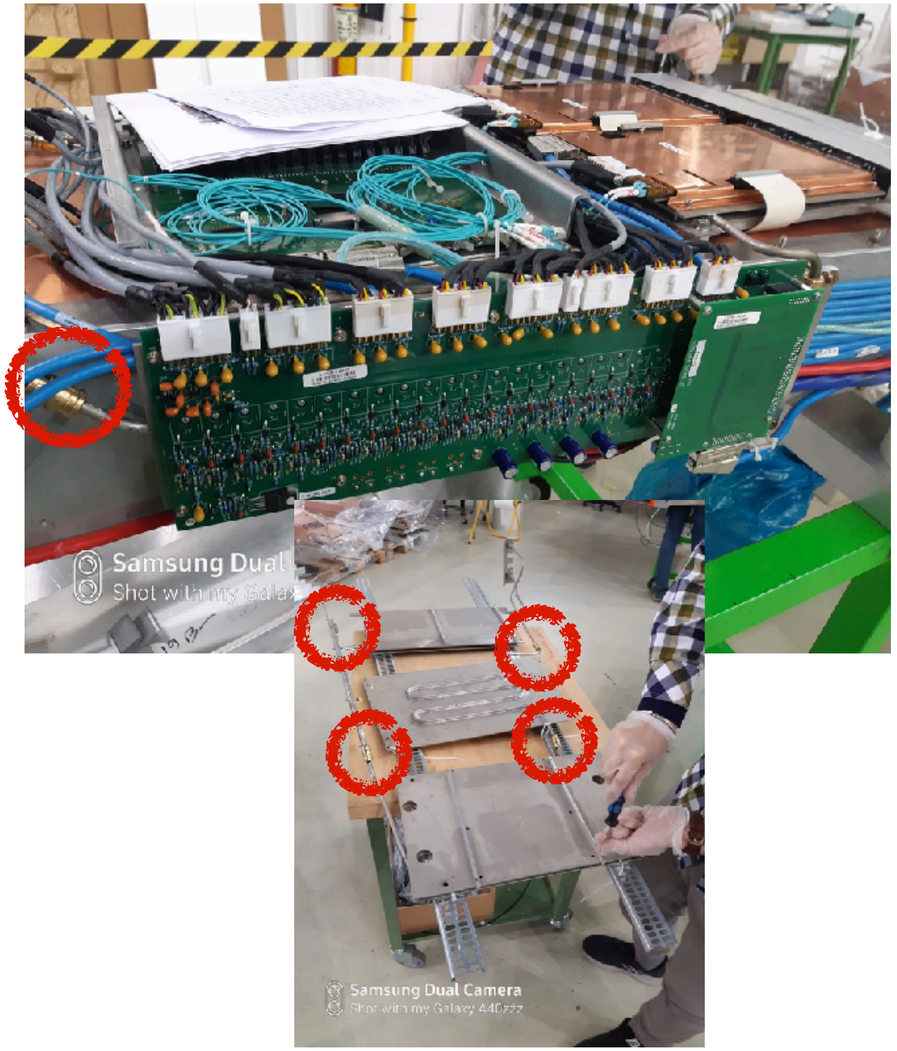
LV Supply

DCFEB



LV Supply

ME1/1 Cooling Loop Upgrade



DCFEBs, ALCT, LVDB all contact-cooled

Old cooling loop had joints, prone to leaks

New cooling loop is single-circuit

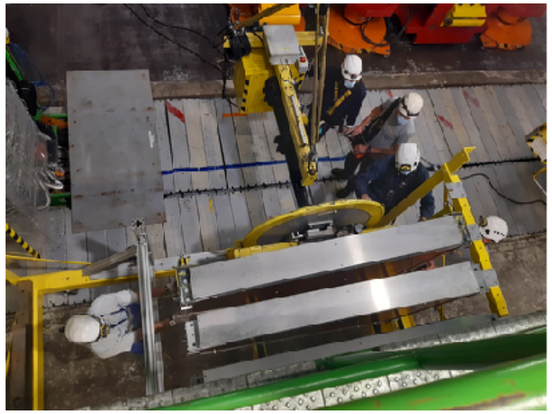
Replaced for all ME1/1

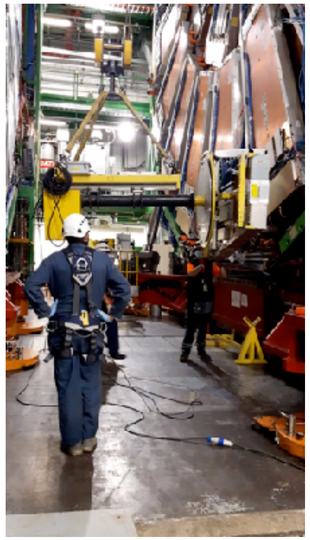
Chamber Re-Installation

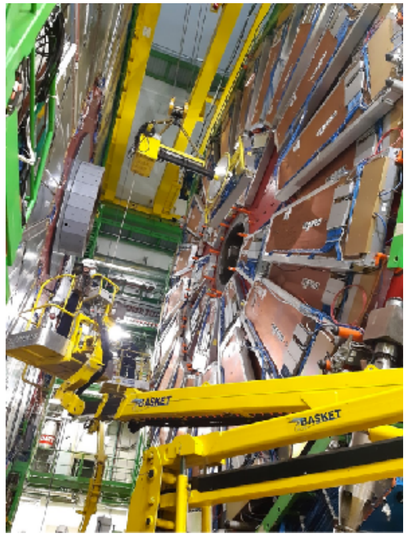
1: Refurbishment

2: Transport

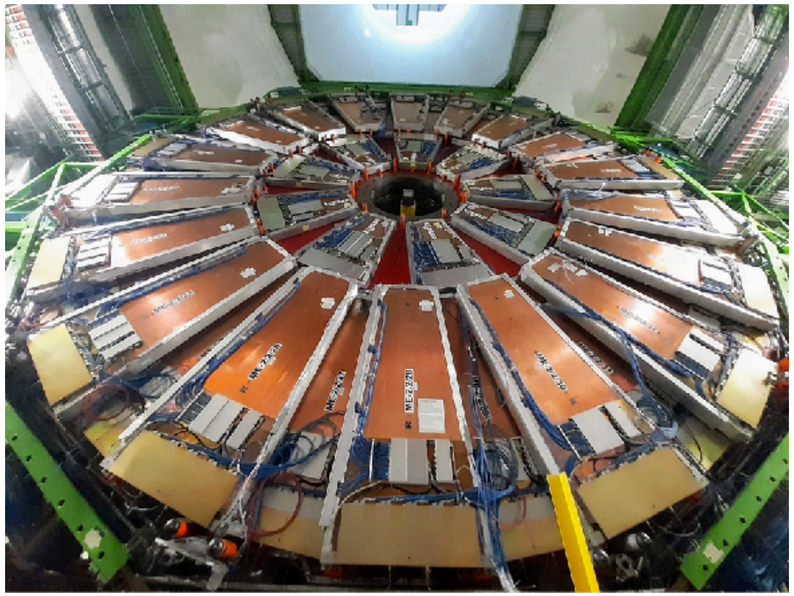
3: Load on Fixture



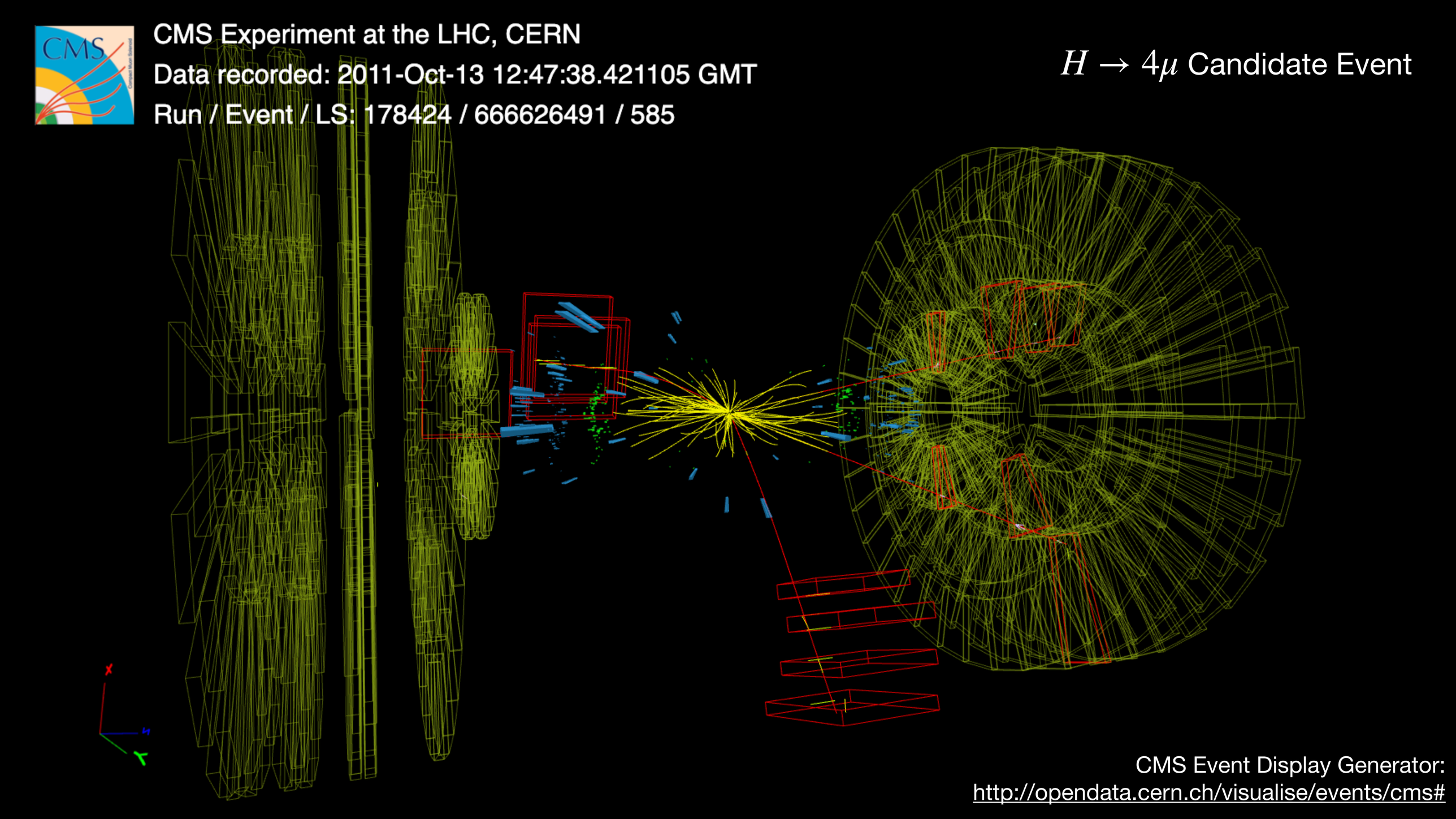




4: Hoist with crane



5: Install on CMS


CMS Experiment at the LHC, CERN
Data recorded: 2011-Oct-13 12:47:38.421105 GMT
Run / Event / LS: 178424 / 666626491 / 585
$H \rightarrow 4\mu$ Candidate Event
CMS Event Display Generator:
http://opendata.cern.ch/visualise/events/cms#

Summary and Outlook

- CSC upgrades for LS2 is complete
  - Front-End Boards replaced:
    CFEBs -> DCFEBs, ALCTs + Mezzanines, LVDB
  - Low Voltage system upgraded
  - Cooling Loops for ME1/1 installed

- Almost all chambers re-installed into CMS
  - ME234/1 already fully commissioned
  - Last ME1/1 chambers installed now

- Preparations for Run 3 and LS3 underway
  - Run 3 expected to begin early 2022
  - ODMB, Front End Driver, and HV upgrades in LS3

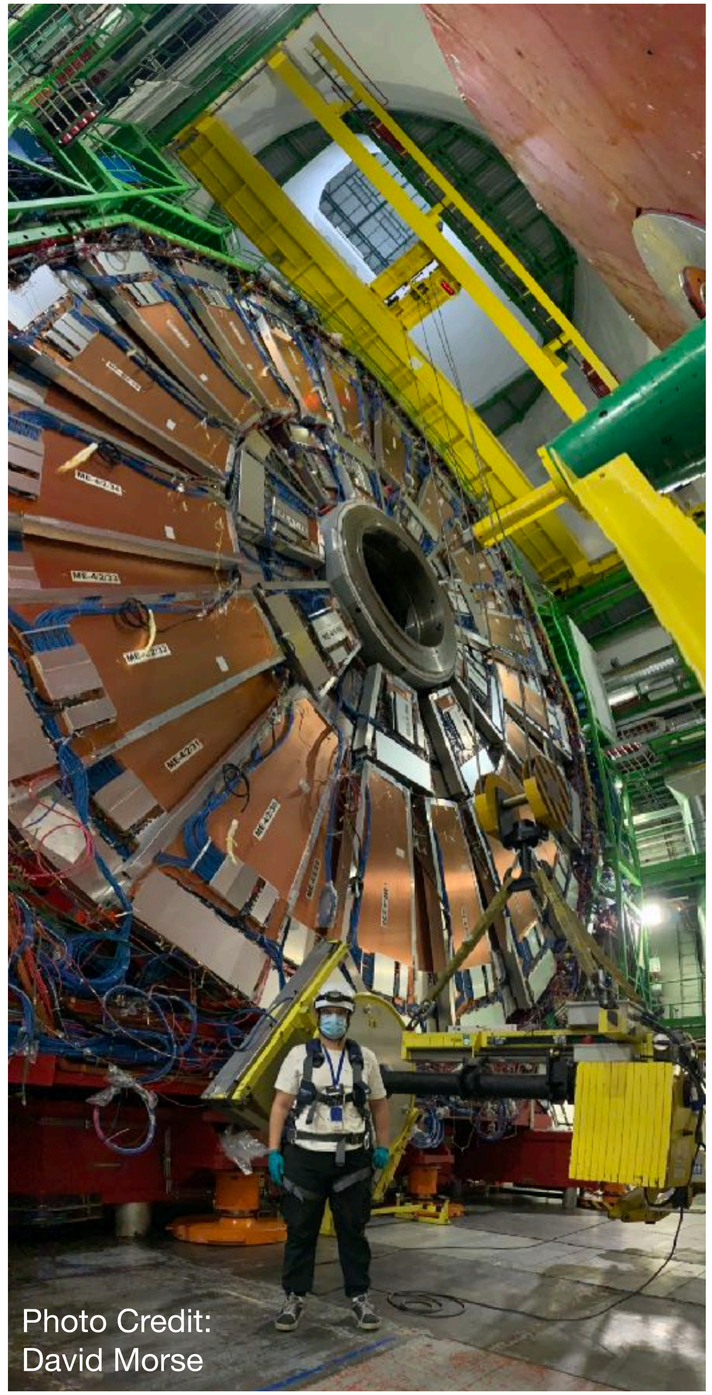


Photo Credit:
David Morse

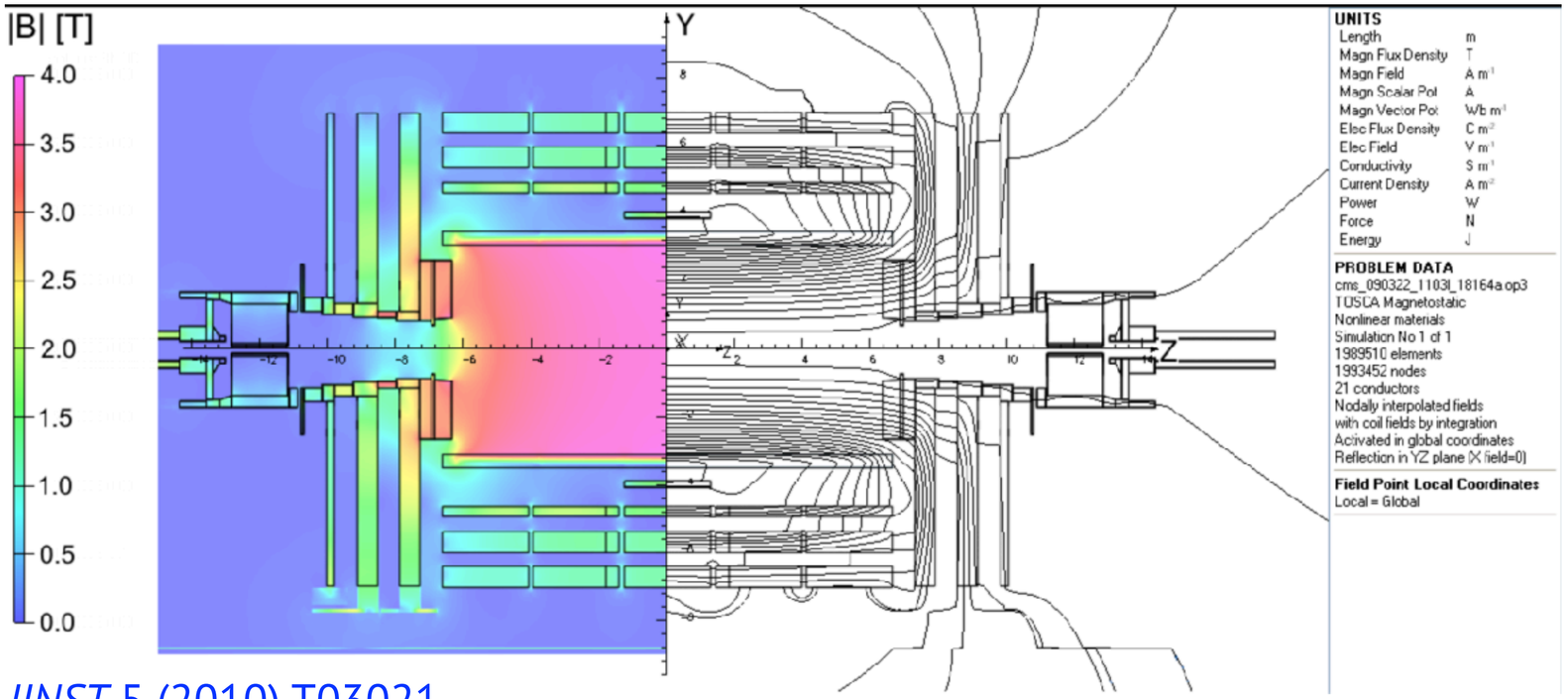
Photo Credit:
Katerina Kuznetsova

¡Gracias!

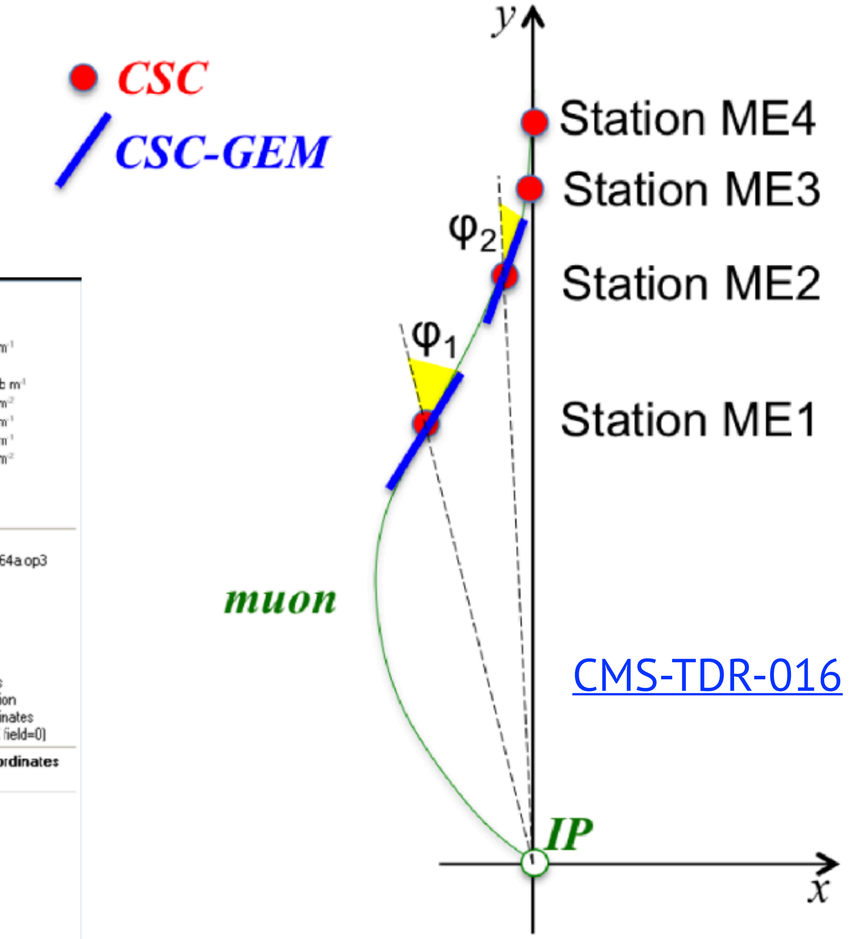
Backup

Non-Uniform Magnetic Field in Muon End-Caps

- Within barrel ($|z| < 6m$), $\overrightarrow{B} \sim B_B \hat{z}$
- In end-cap yoke: $\overrightarrow{B} \sim B_{EC} \hat{r}$
- Bending direction changes before muon exits CMS



JINST 5 (2010) T03021



CMS-TDR-016

Point of View:
Beam-axis in/out of page

References

- The Phase-2 Upgrade of the CMS Muon Detectors:
  CERN-LHCC-2017-012 ; CMS-TDR-016

- HL-LHC Public Pages:
  - voisins.cern
  - hilumilhc.web.cern.ch

- CMS Detector Figures:
  - Particle-flow reconstruction and global event description with the CMS detector:
    JINST 12 (2017) P10003
  - Cutaway Diagrams of CMS Detector:
    J. Phys.: Conf. Ser. 513 022032
  - Precise Mapping of the Magnetic Field in the CMS Barrel Yoke using Cosmic Rays:
    JINST 5 (2010) T03021

- CMS Event Display Generator:
  http://opendata.cern.ch/visualise/events/cms#