# *The CMS Upgrades*

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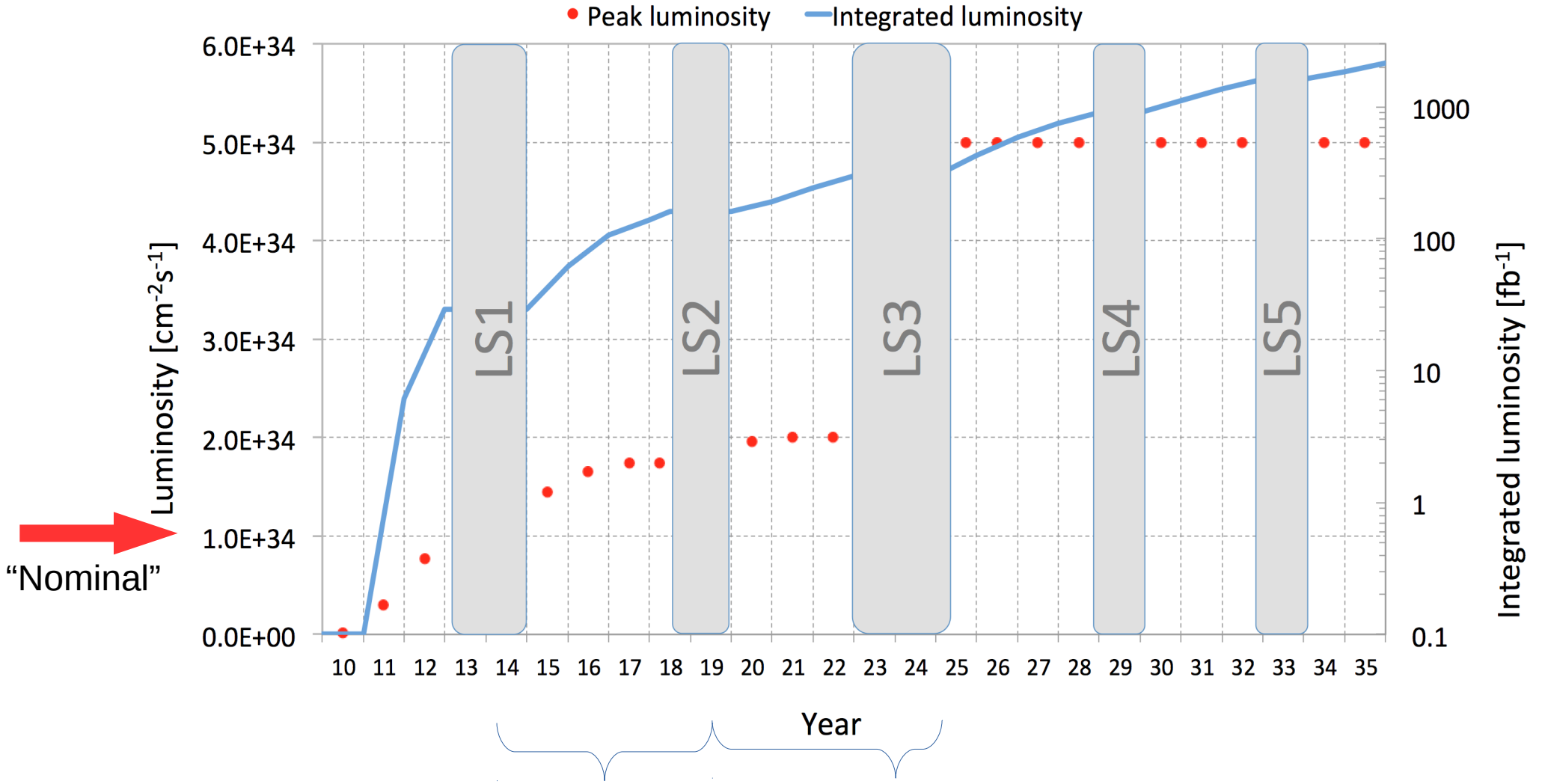
November 13, 2014

# The Coming Challenges

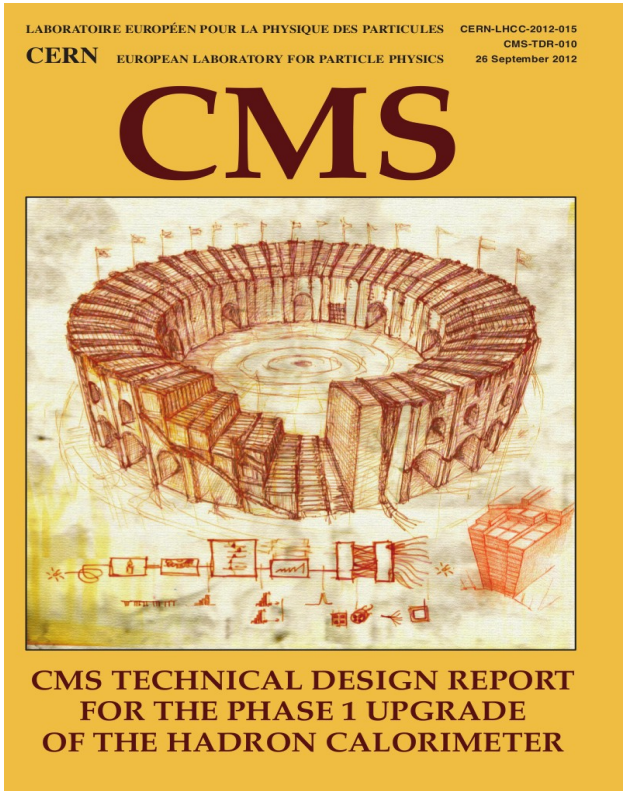


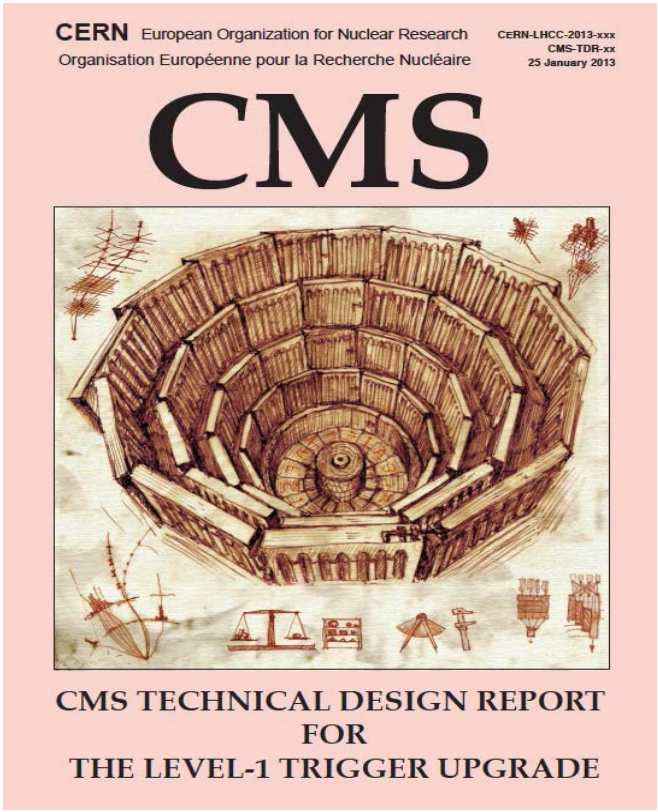

**Phase 1 Upgrades**
Targeted at managing 2x nominal pileup and integrated luminosity up to ~500 $fb^{-1}$

**Phase 2 Upgrades**
Targeted at managing 5x-8x nominal pileup and integrated luminosity up to ~3000 $fb^{-1}$

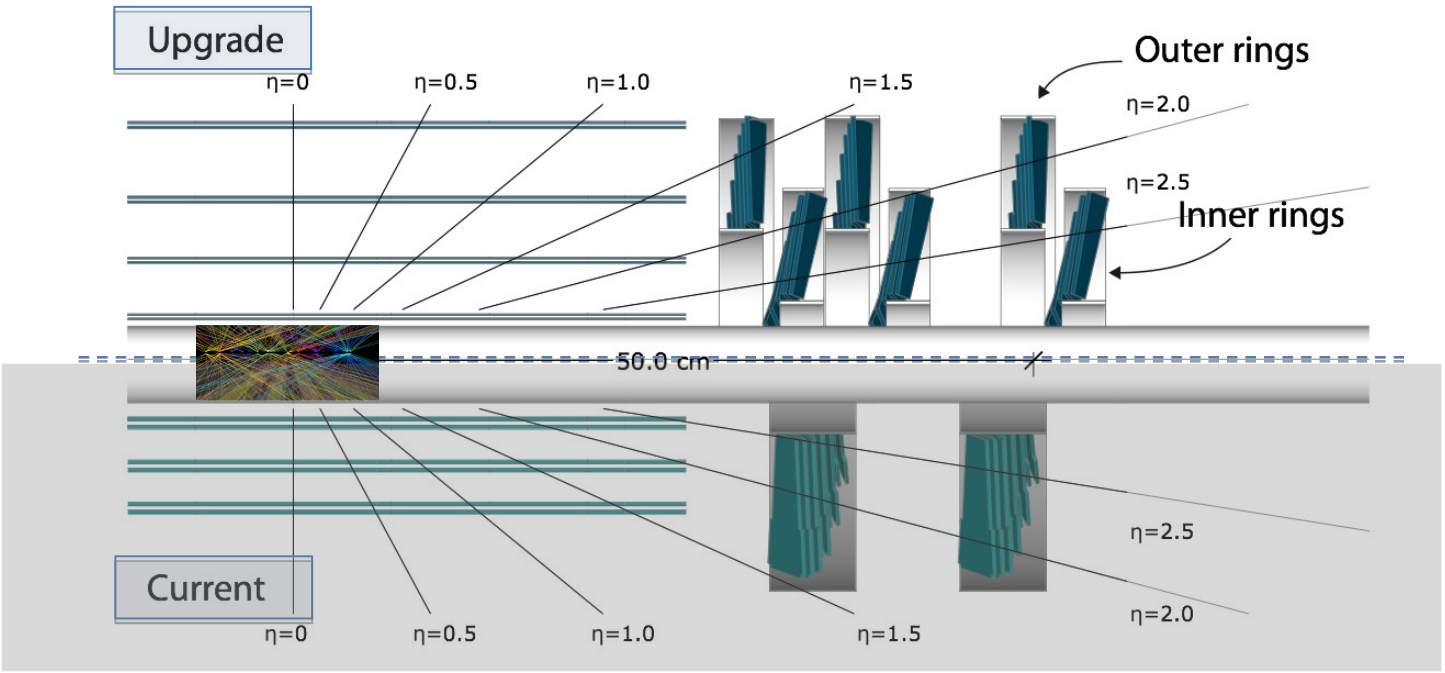
# Phase 1: Tuning Up

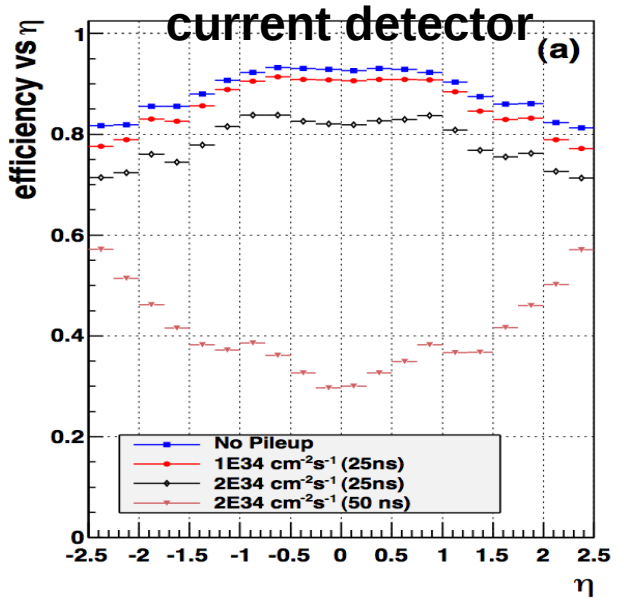
- Incremental changes to manage higher pileup and take advantage of new technologies developed since original construction
- Major US Roles in all these upgrades, successful DOE CD 2/3 review in August

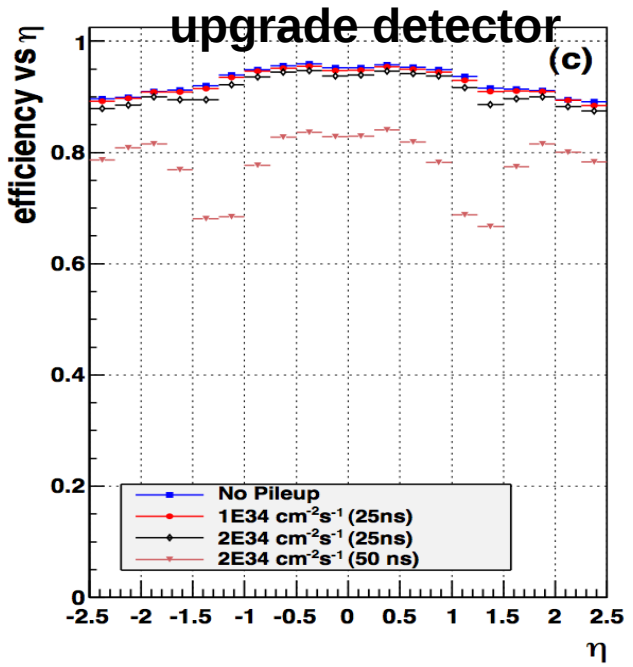



# CMS Pixel Upgrade

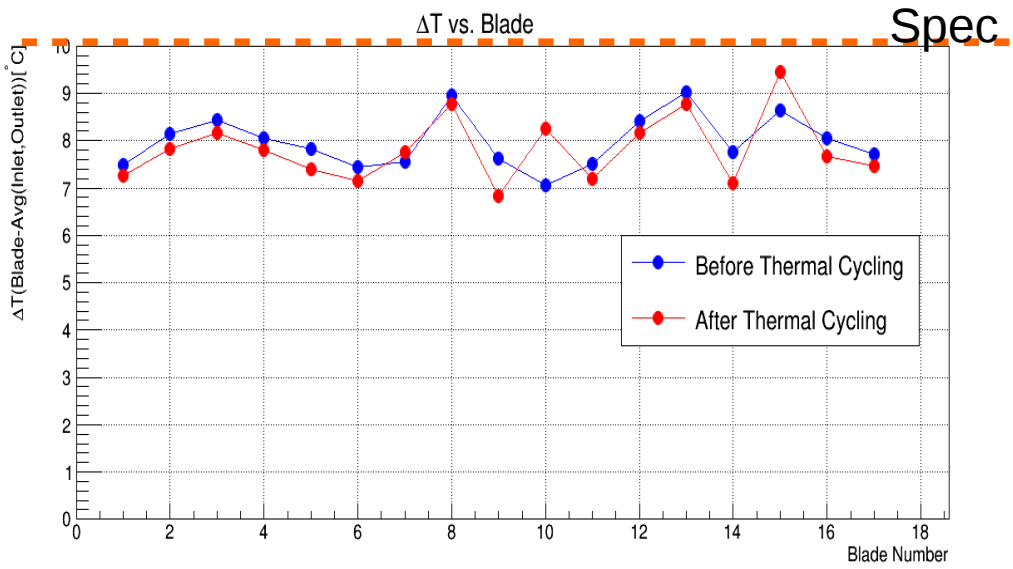


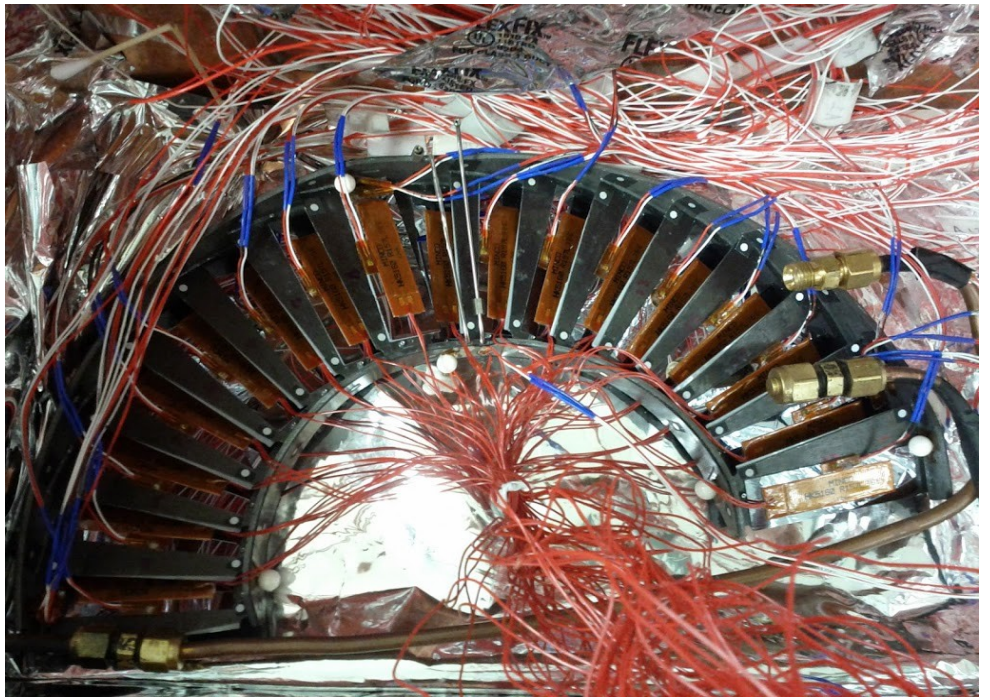



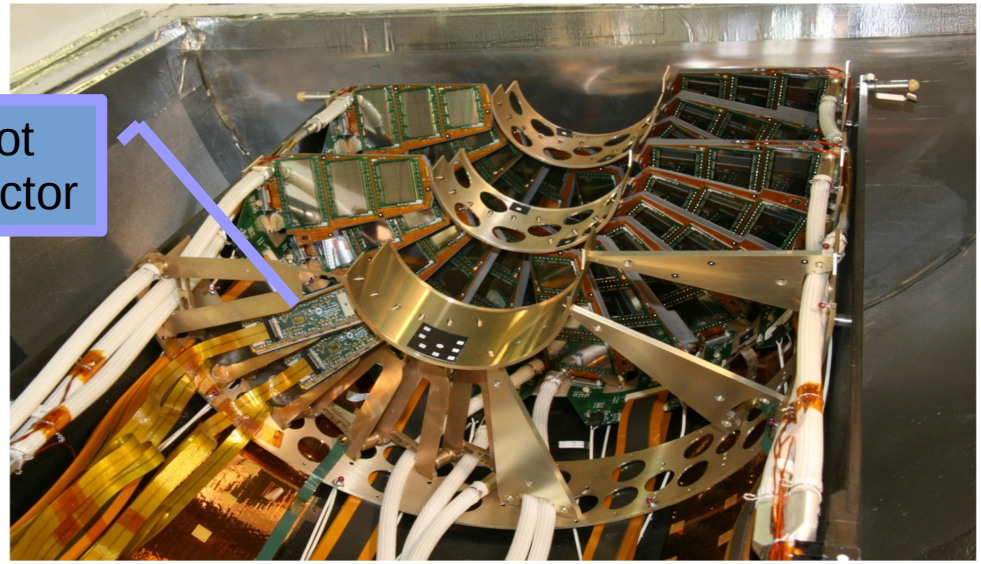

- Increase number of pixel hits from three to four within |η|<2.5
- New ROC allows operation at 50 PU/100kHz without hit loss and acceptable hit loss up to PU~100
- US responsible for construction of the forward pixel system (three stations at each end)

# Progress on the Forward Pixels

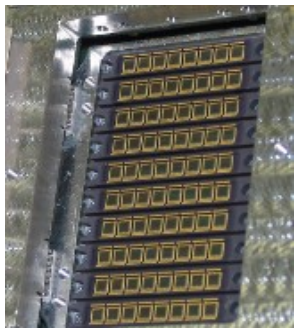


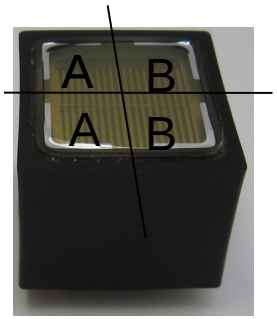



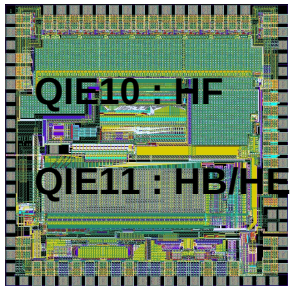
- Thermal test of cooling setup for half-disk successful
- Pilot detector (sensors, chips, powering, cables) mounted on CMS pixel assembly for Run 2



# HCAL Upgrade

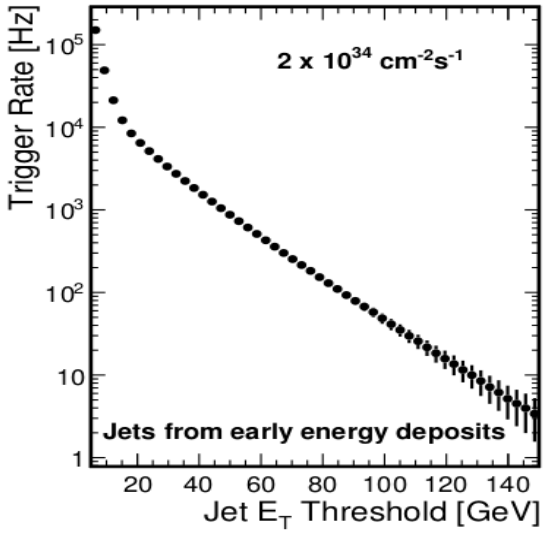


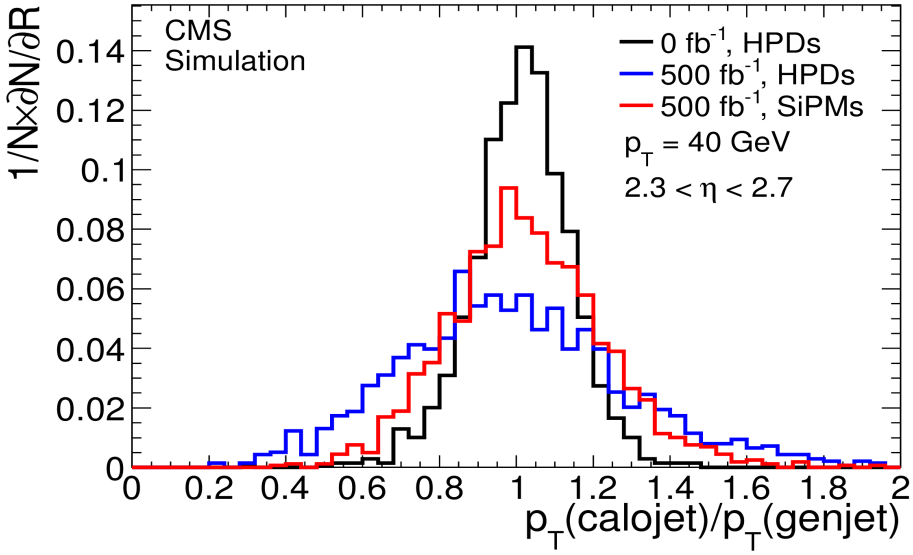


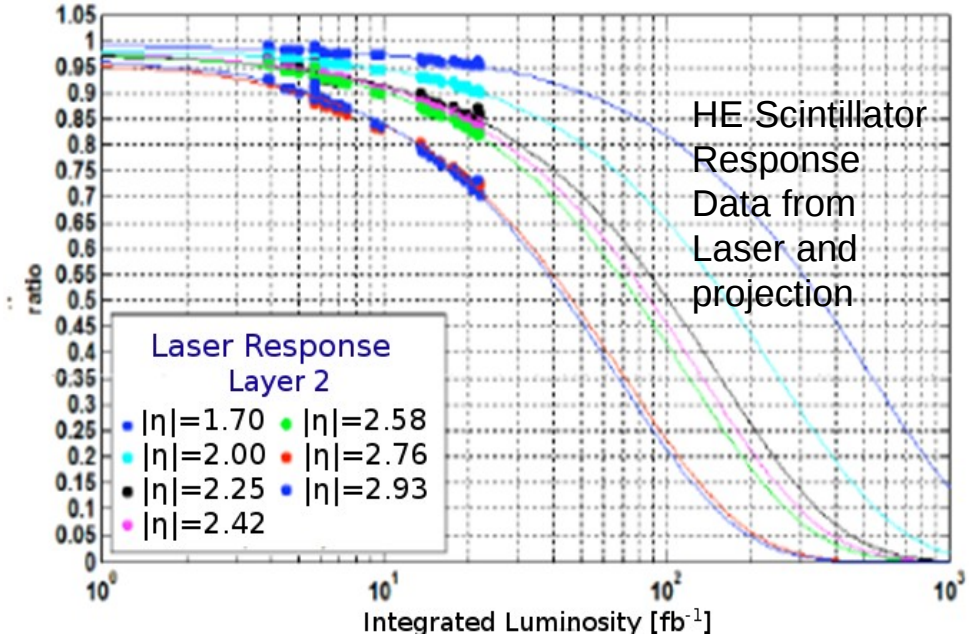




Igloo2 FPGA

- New photodetectors (SiPMs) and capabilities (TDC) to manage radiation damage and anomalous signals
- US responsible for design, much of construction



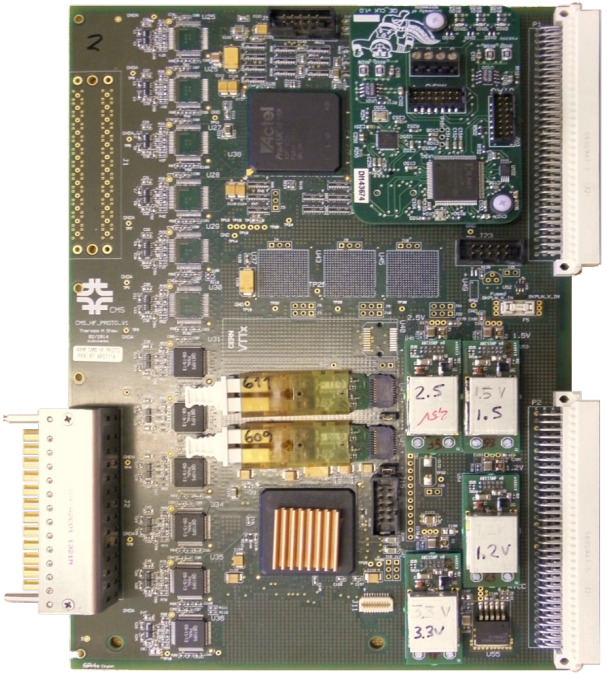



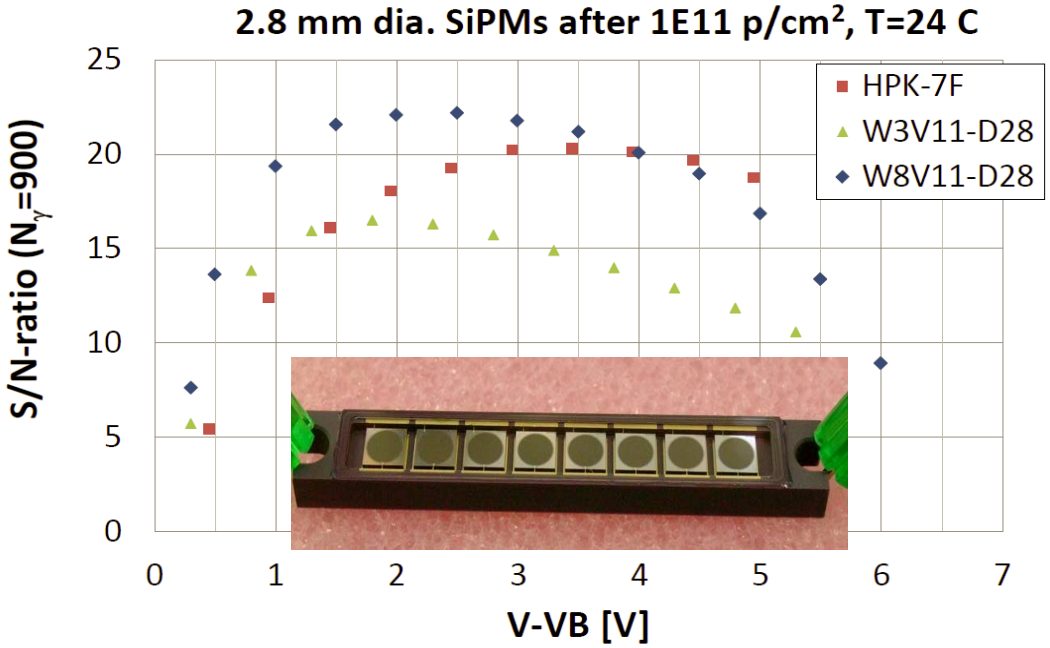



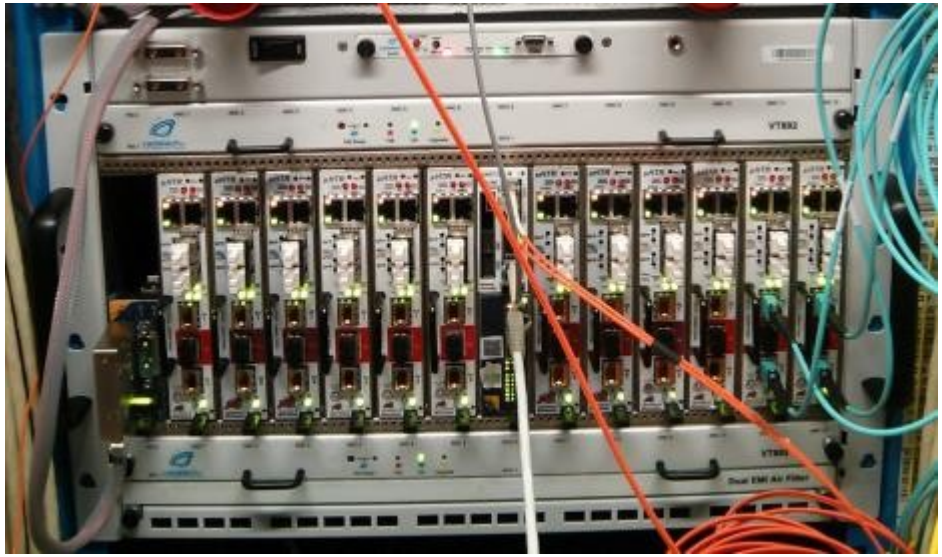

HE Scintillator Response Data from Laser and projection

# Progress on the HCAL Phase 1

- Successful QIE10/11 engineering run
- Pre-production cycles underway
  - HF front-end card
  - SiPM and SiPM packages

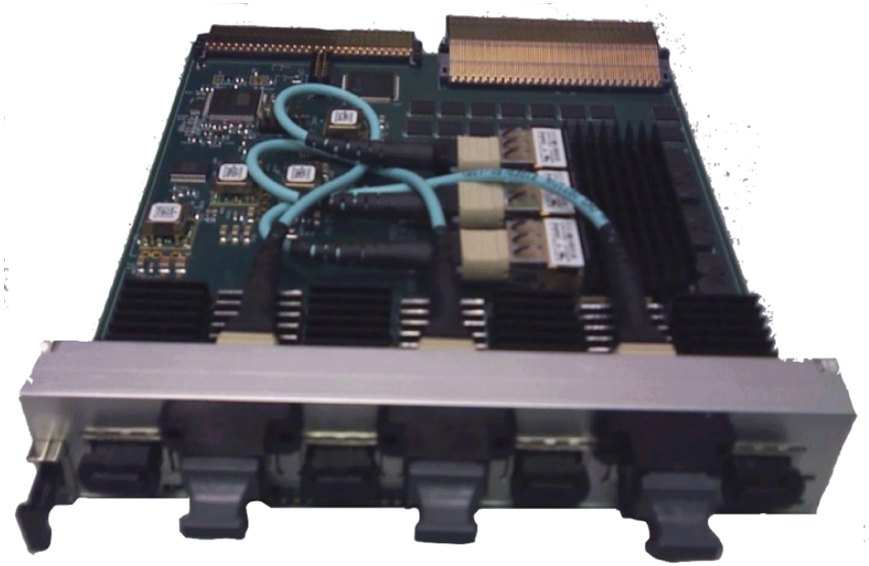




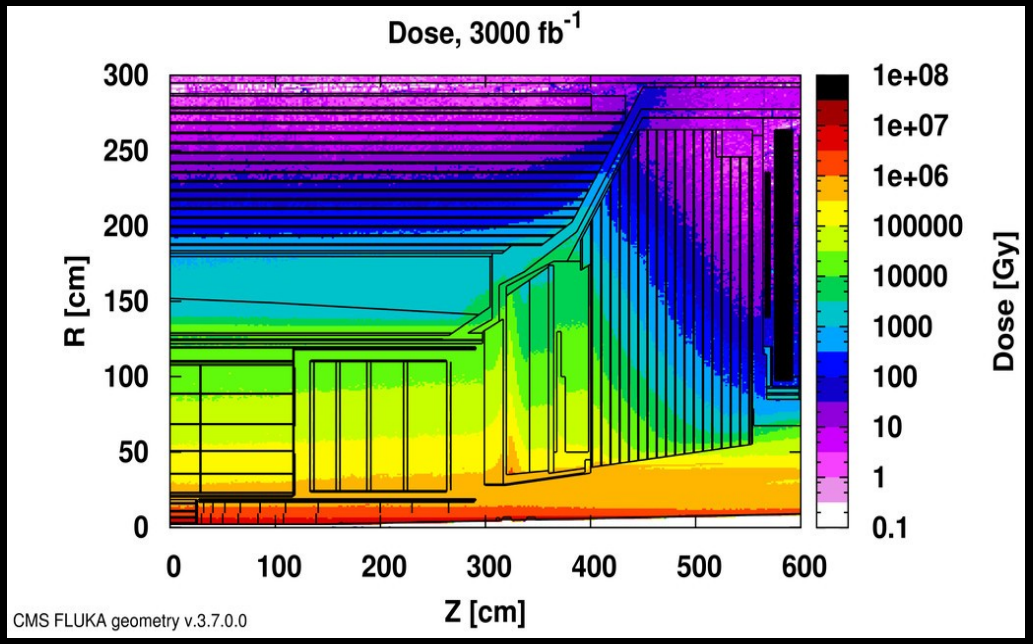
# L1 Trigger Upgrade

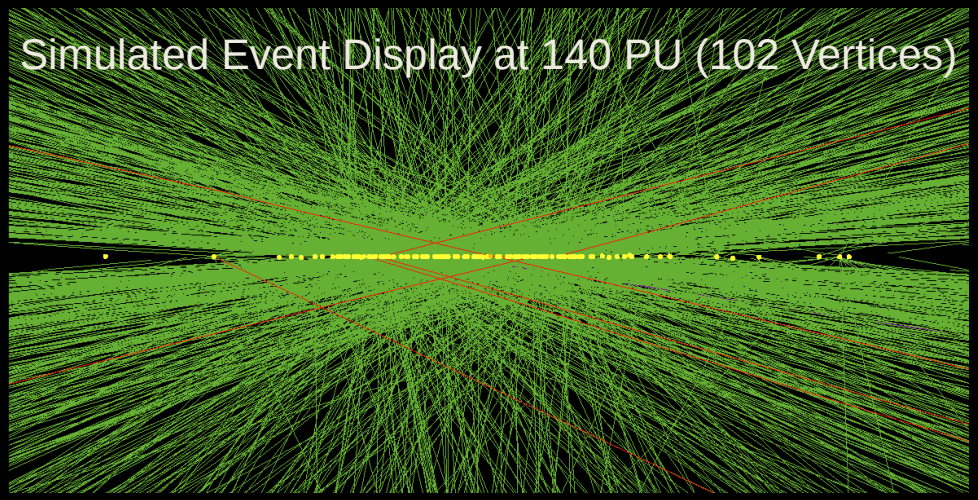
- Move to new, high-performance FPGAs to enhance both calorimeter and muon triggering with higher-granularity processing
  - Common use of uTCA architecture
- Strong US leadership in both muon and calo triggers

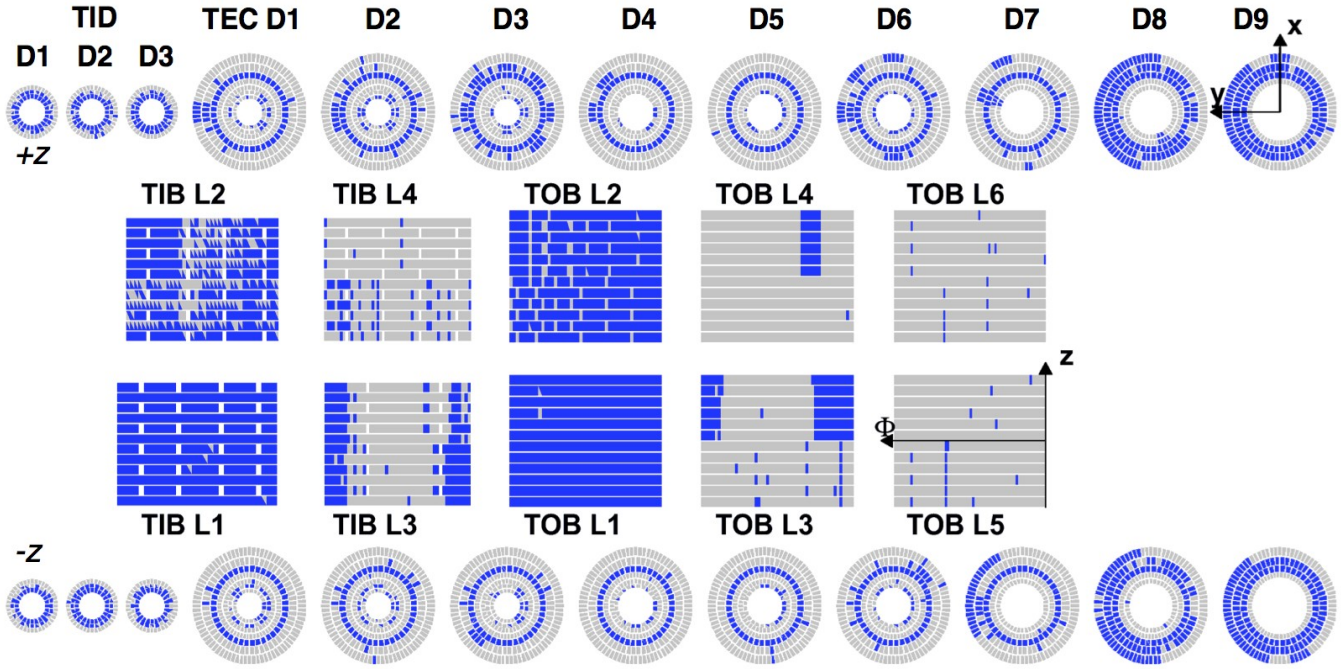
# HL-LHC: Phase 2

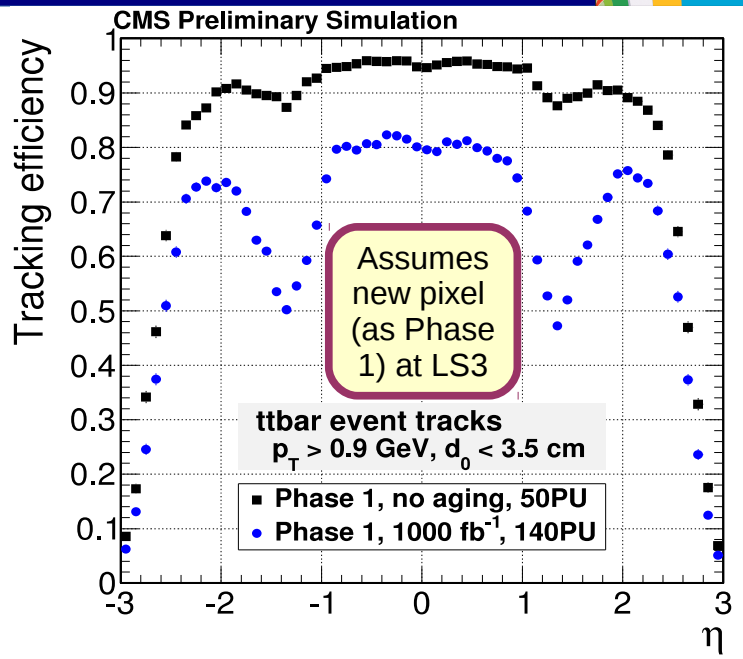
# Bright Light, Big Challenges

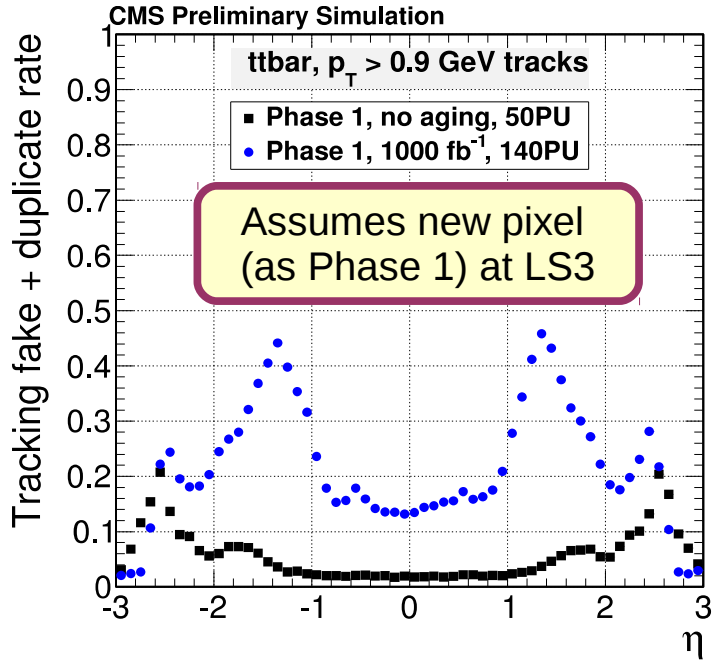


# “Bleaching” of the Tracker

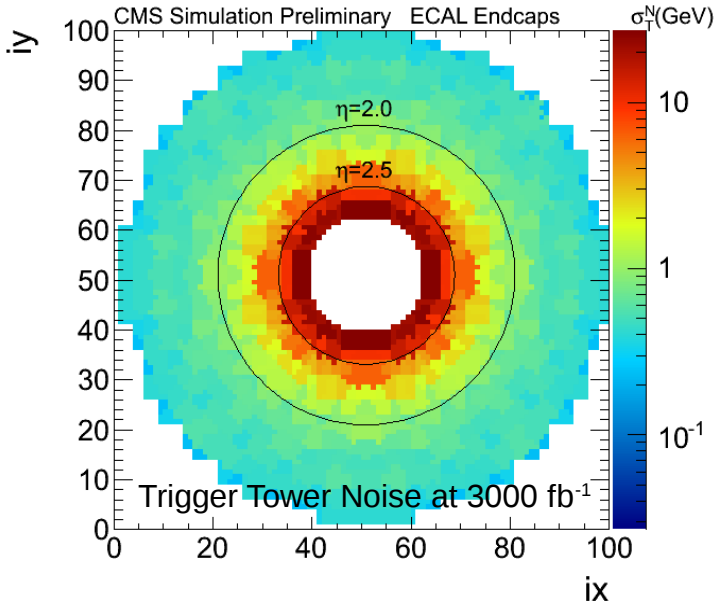


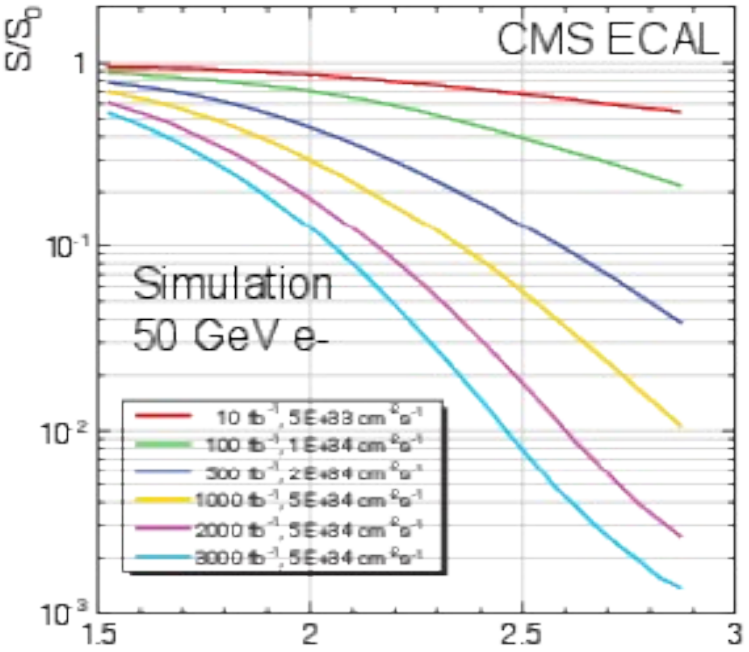



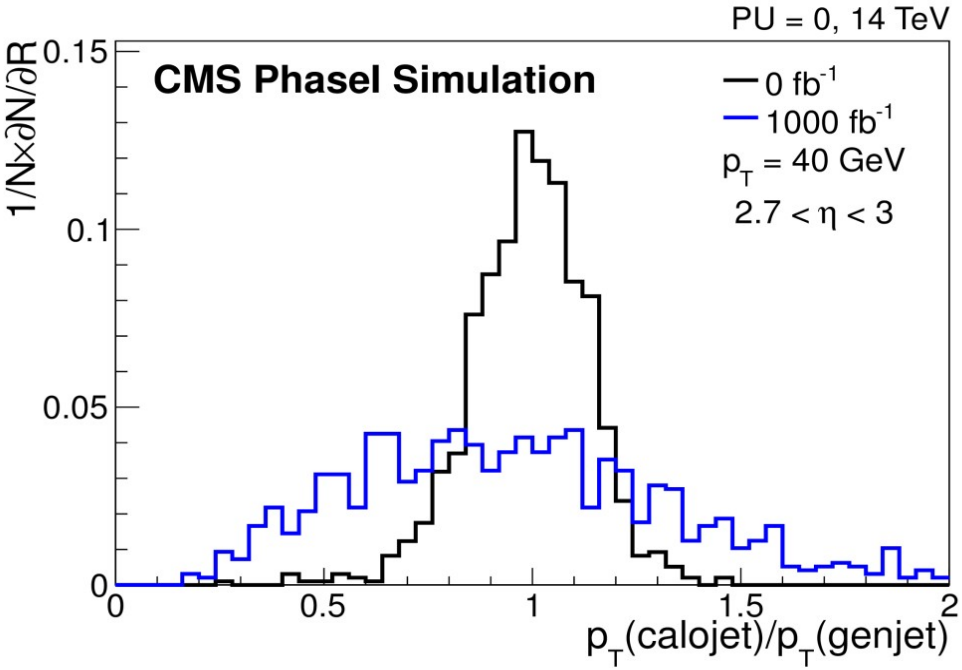



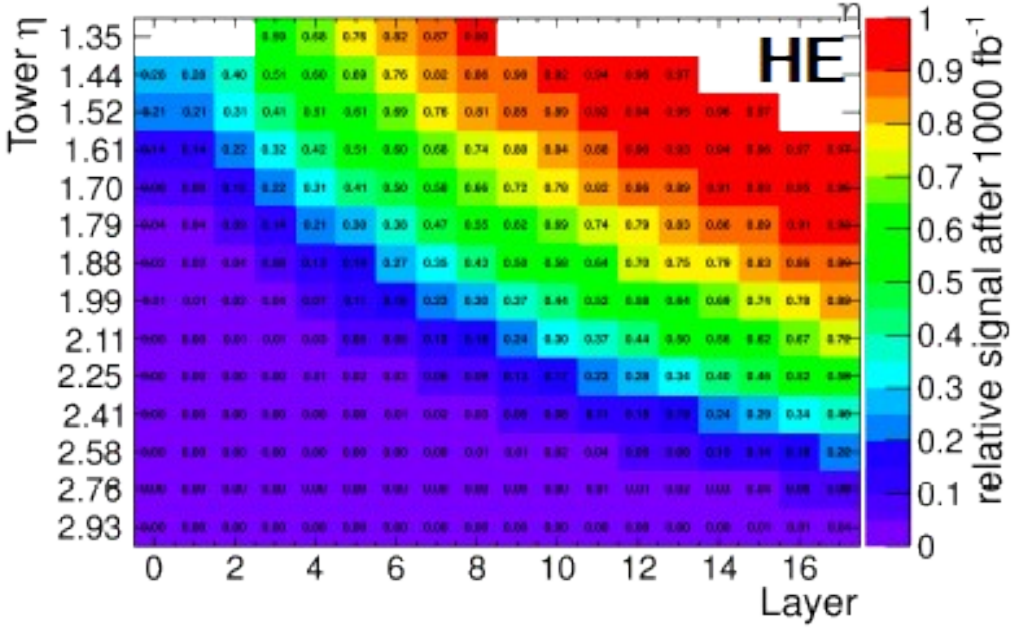

Blue tracker modules are inactive after 1000 fb$^{-1}$ due to very high leakage currents induced by hadron fluence.

# “Blackening” of Calorimeters



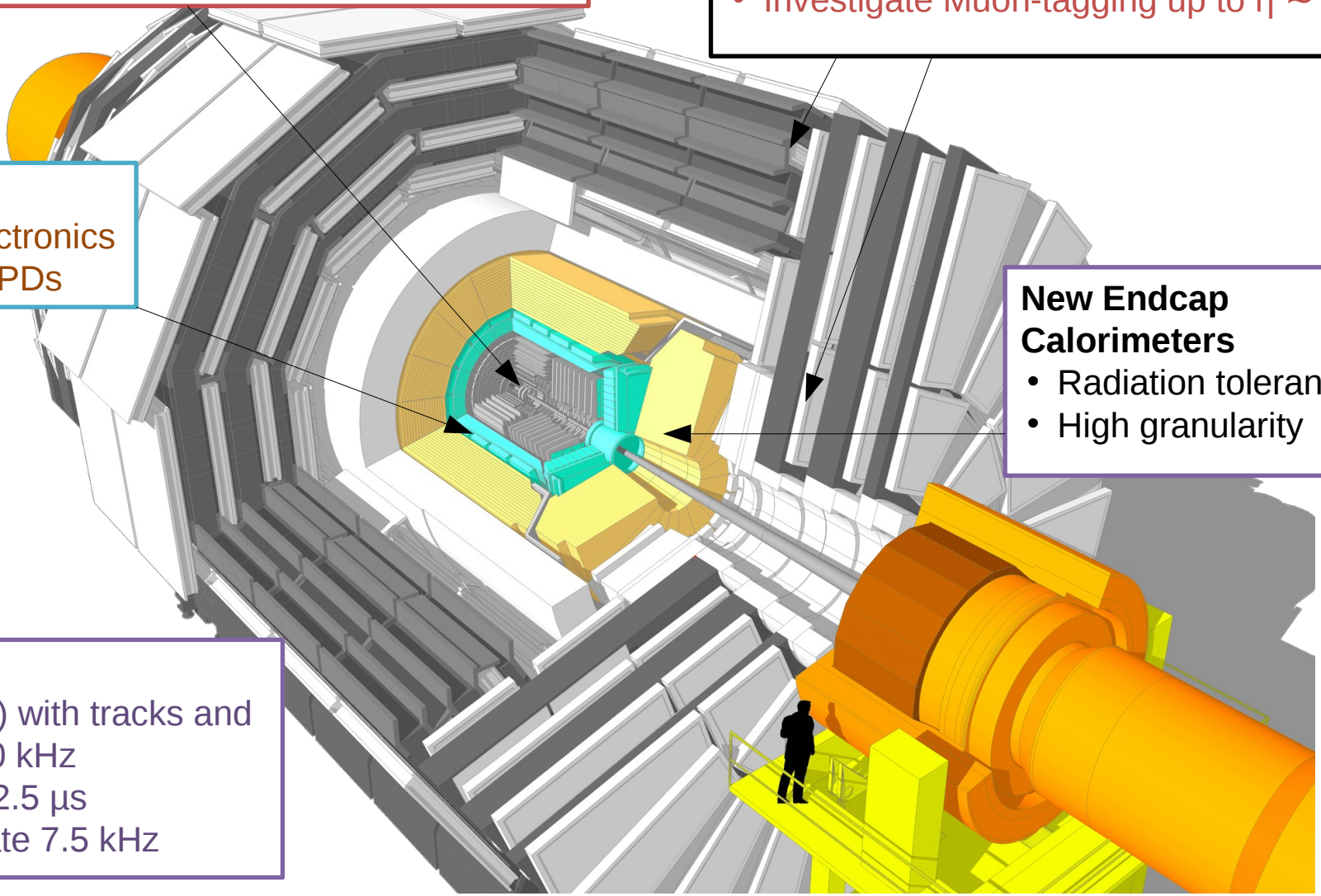



**New Tracker**
- Radiation tolerant - high granularity - less material
- Tracks in hardware trigger (L1)
- Coverage up to η ~ 4

**Muons**
- Replace DT FE electronics
- Complete RPC coverage in forward region (new GEM/RPC technology)
- Investigate Muon-tagging up to η ~ 3

**Barrel ECAL**
- Replace FE electronics
- Cool detector/APDs

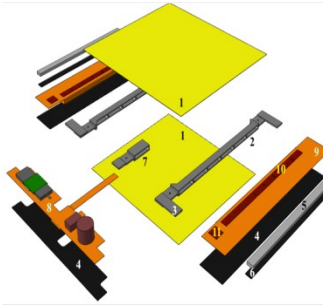


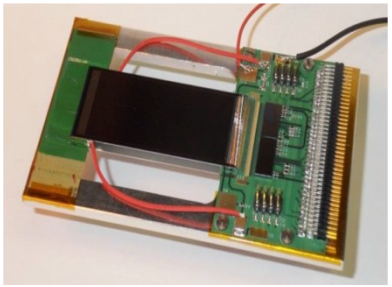
**New Endcap Calorimeters**
- Radiation tolerant
- High granularity

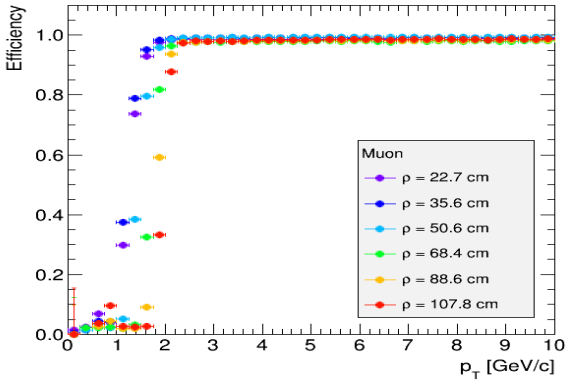
**Trigger/DAQ**
- L1 (hardware) with tracks and rate up ~ 750 kHz
- L1 Latency 12.5 μs
- HLT output rate 7.5 kHz

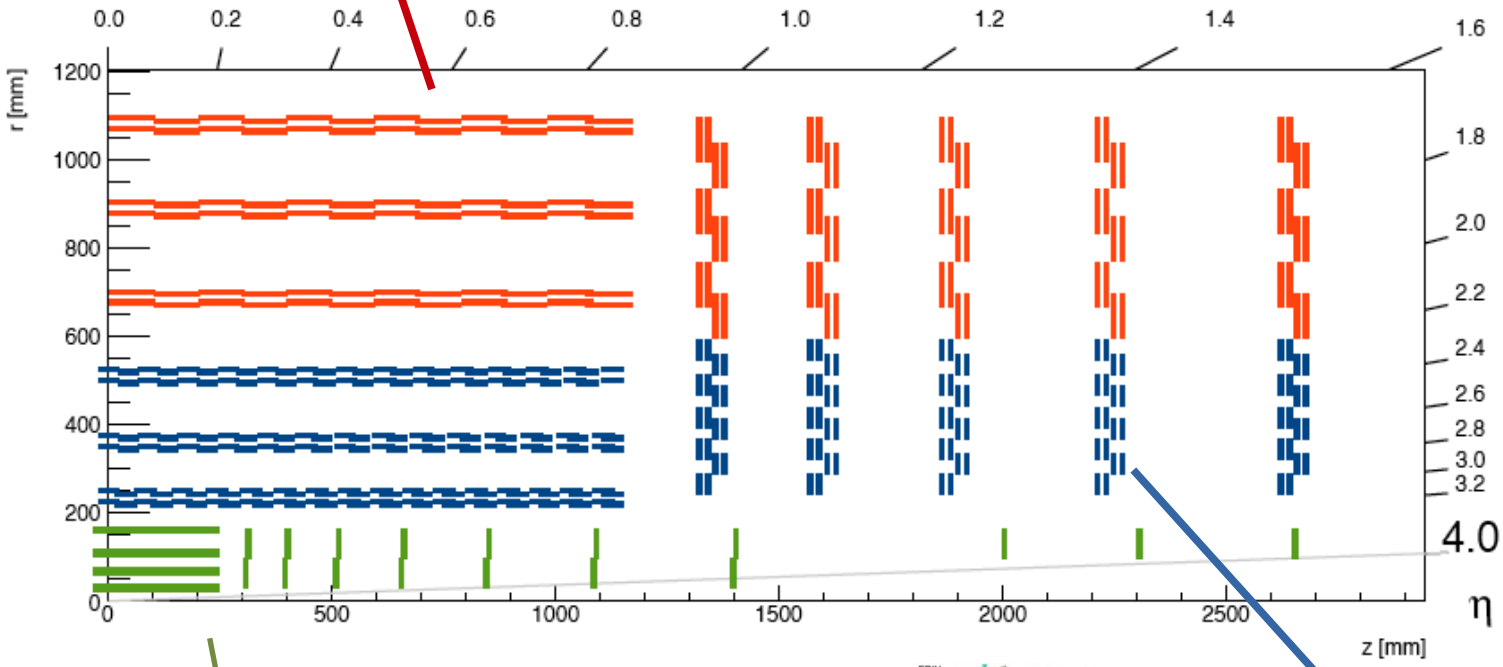
# Tracker Design with Stub Capability

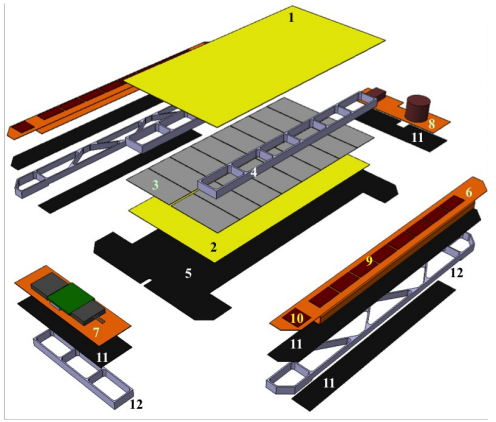
**Strip/Strip Modules**
90 μm pitch/5 cm length



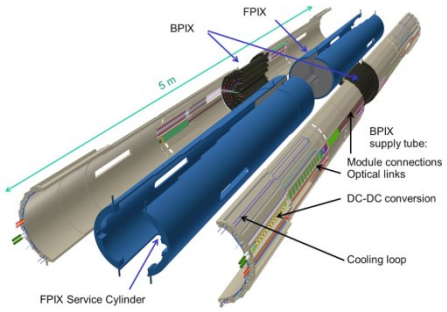




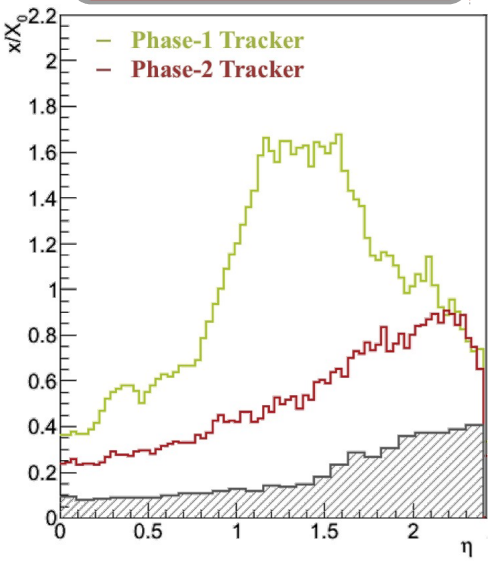
**Inner Pixel**
Covers up to η=4.0

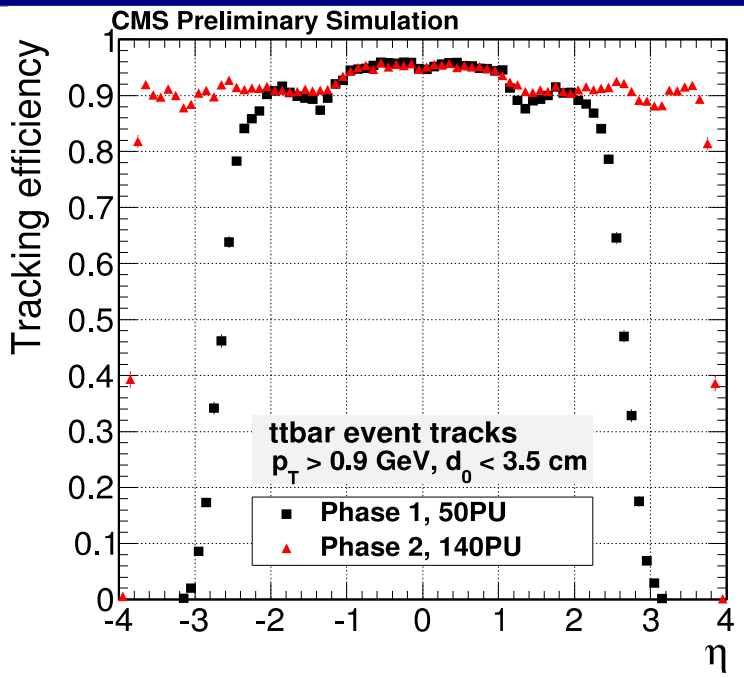


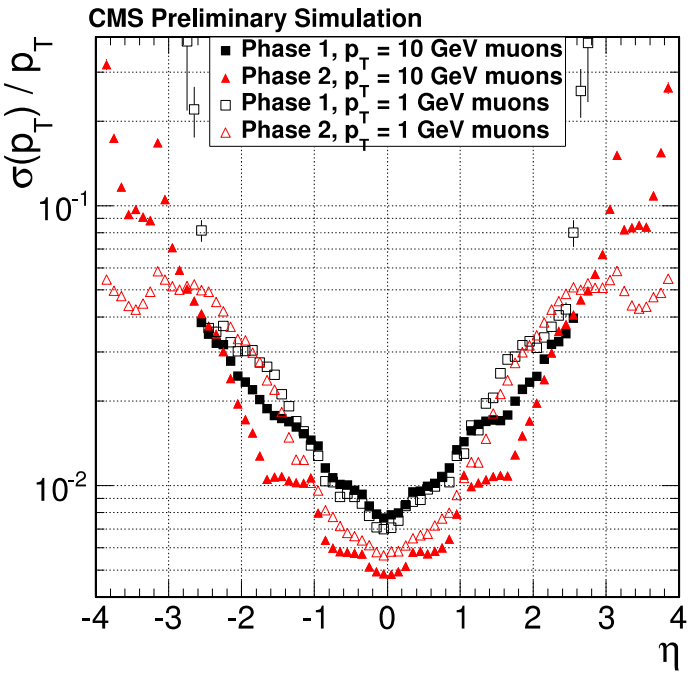

**Strip/Pixel Modules**
100 μm pitch/2.5 cm length
100 μm x 1.5 mm "macropixels"

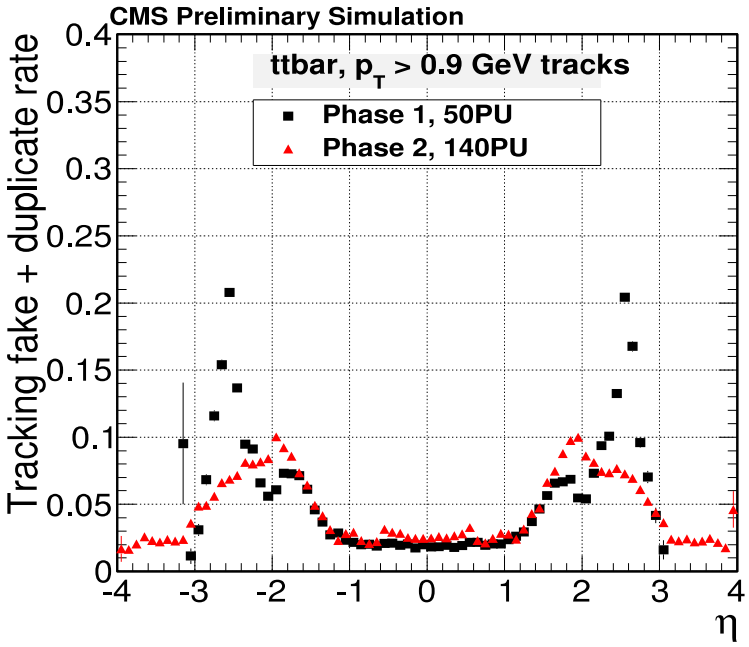
# Tracker Full Simulation Results

Outer Tracker substantially lighter!



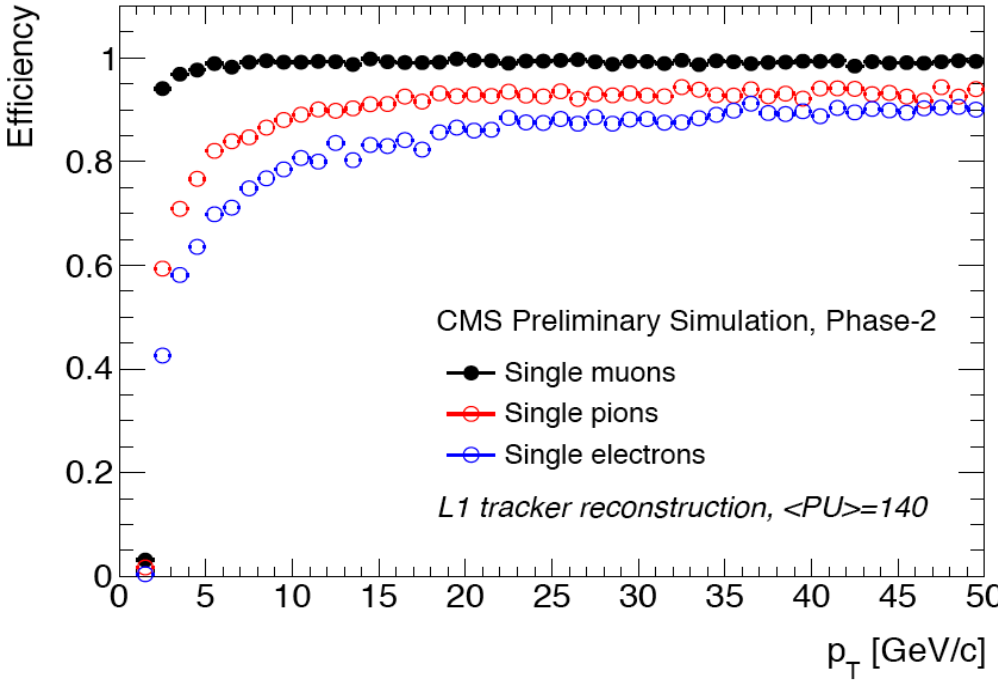



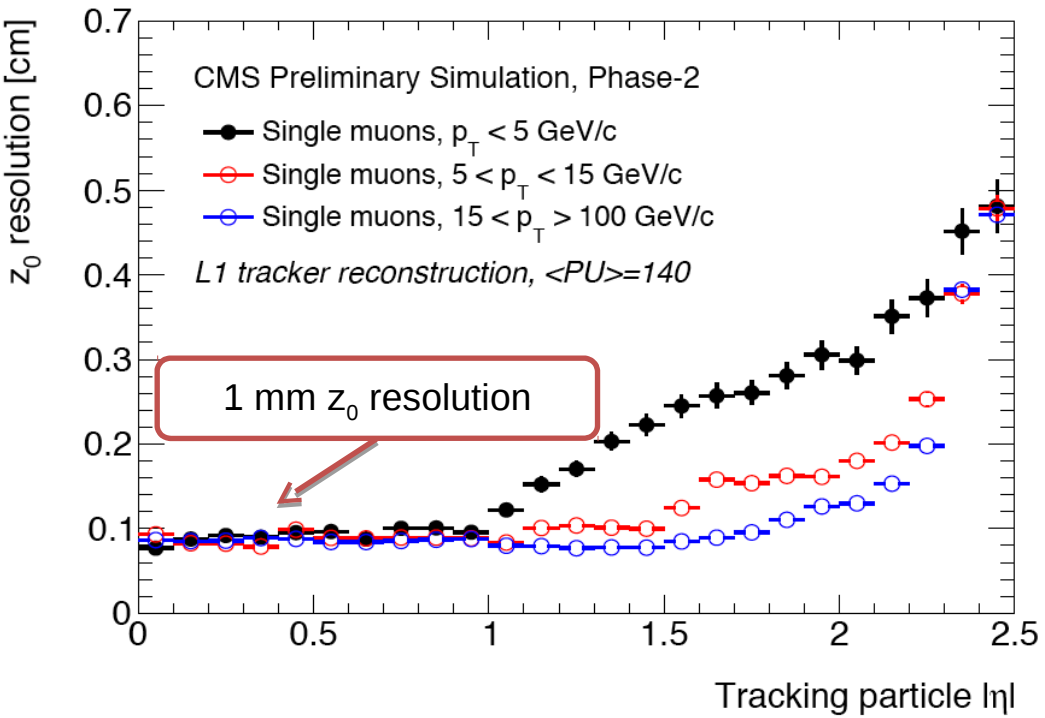




Pixel used in simulation results to date is identical to the Phase 1 Pixel detector with additional forward disks. Further optimization of pixel parameters for b-tagging and forward track parameter resolution is planned

# Tracking Performance at Level 1

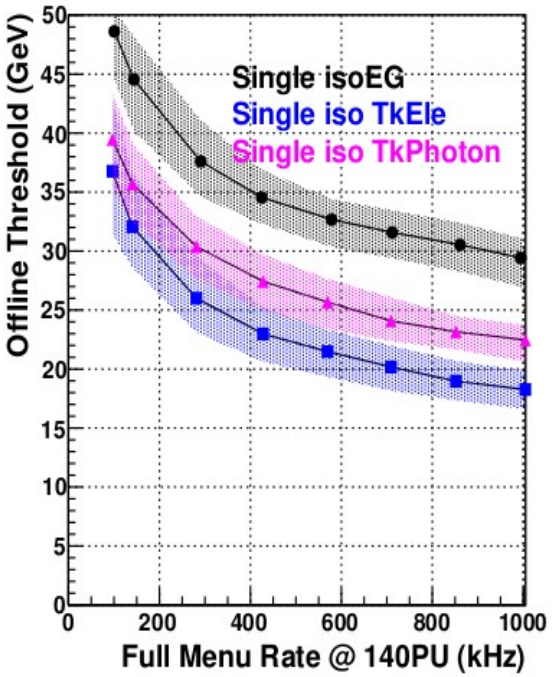


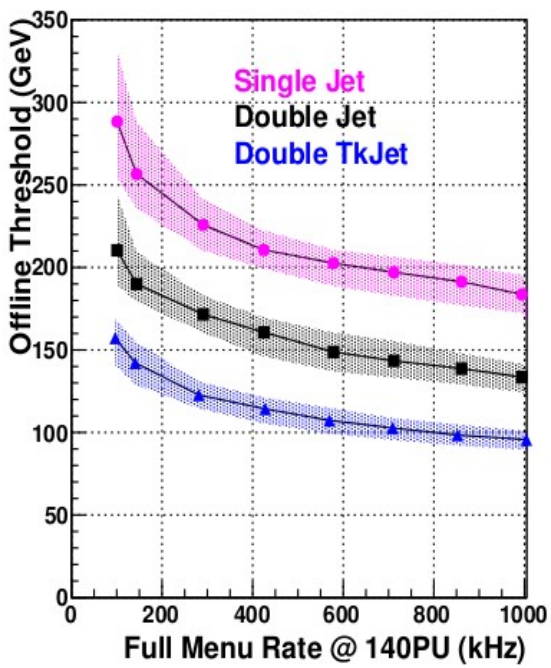



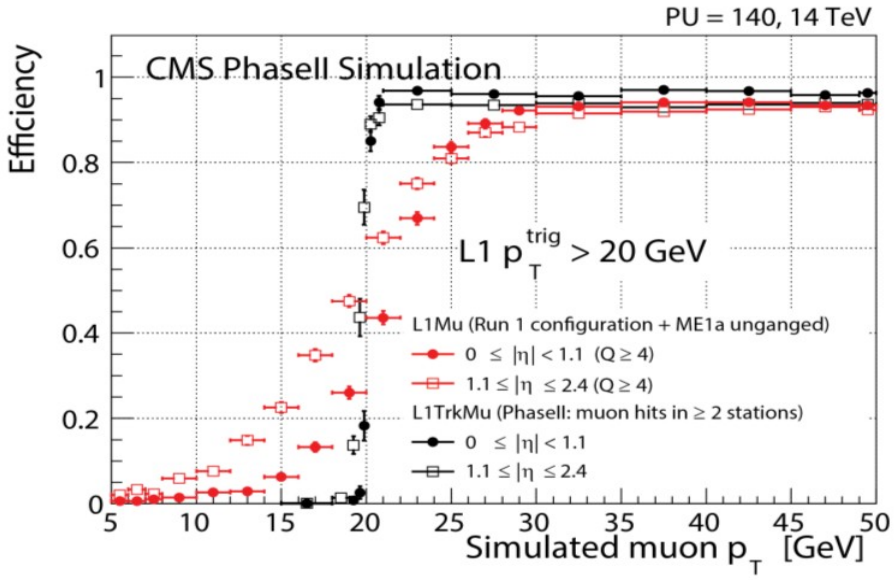

- Algorithms validated in digitized simulation
- Two hardware implementations under study
  - Associative memory (use case for 3d IC technology)
  - Tracklets in commercial FPGAs
- Requires a trigger latency of ≈10 μs compared with current limit of 3/6 μs in tracker/ECAL electronics

# Trigger Capabilities with Tracking

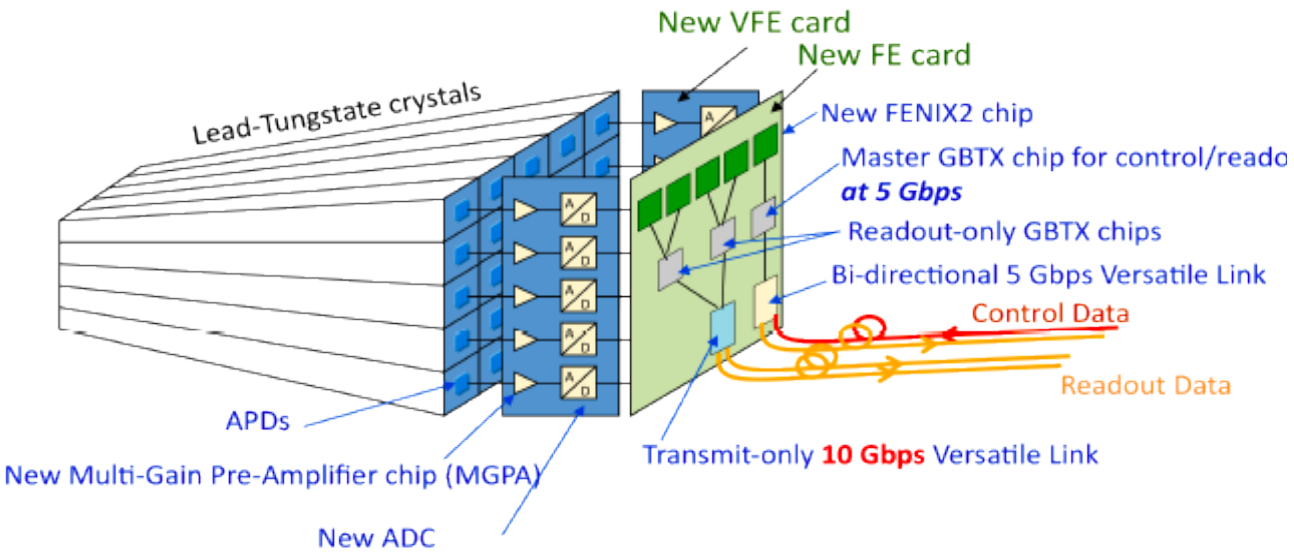
| $L = 5.6 \times 10^{34}$ cm$^{-2}$s$^{-1}$ $\langle PU \rangle = 140$ | Level-1 Trigger with L1 Tracks | |
|---|---|---|
| Trigger Algorithm | Rate [kHz] | Offline Threshold(s) [ GeV ] |
| Single Mu (tk) | 14 | 18 |
| Double Mu (tk) | 1.1 | 14 10 |
| ele (iso tk) + Mu (tk) | 0.7 | 19 10.5 |
| Single Ele (tk) | 16 | 31 |
| Single iso Ele (tk) | 13 | 27 |
| Single $\gamma$ (tk-veto) | 31 | 31 |
| ele (iso tk) + e/$\gamma$ | 11 | 22 16 |
| Double $\gamma$ (tk isol) | 17 | 22 16 |
| Single Tau (tk) | 13 | 88 |
| Tau (tk) + Tau | 32 | 56 56 |
| ele (iso tk) + Tau | 7.4 | 19 50 |
| Tau (tk) + Mu (tk) | 5.4 | 45 14 |
| Single Jet | 42 | 173 |
| Double Jet (tk) | 26 | 2@125 |
| Quad Jet (tk) | 12 | 4@72 |
| Single ele (tk) + Jet (tk) | 15 | 23 66 |
| Single Mu (tk) + Jet (tk) | 8.8 | 16 66 |
| Single ele (tk) + $H_T^{miss}$ (tk) | 10 | 23 95 |
| Single Mu (tk) + $H_T^{miss}$ (tk) | 2.7 | 16 95 |
| $H_T$ (tk) | 13 | 350 |
| Rate for above Triggers | 180 | |
| **Est. Total Level-1 Menu Rate** | **260** | |

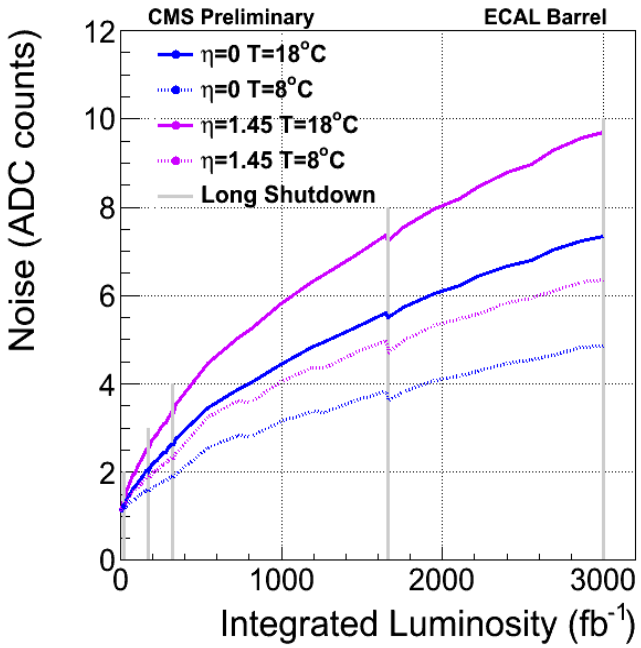


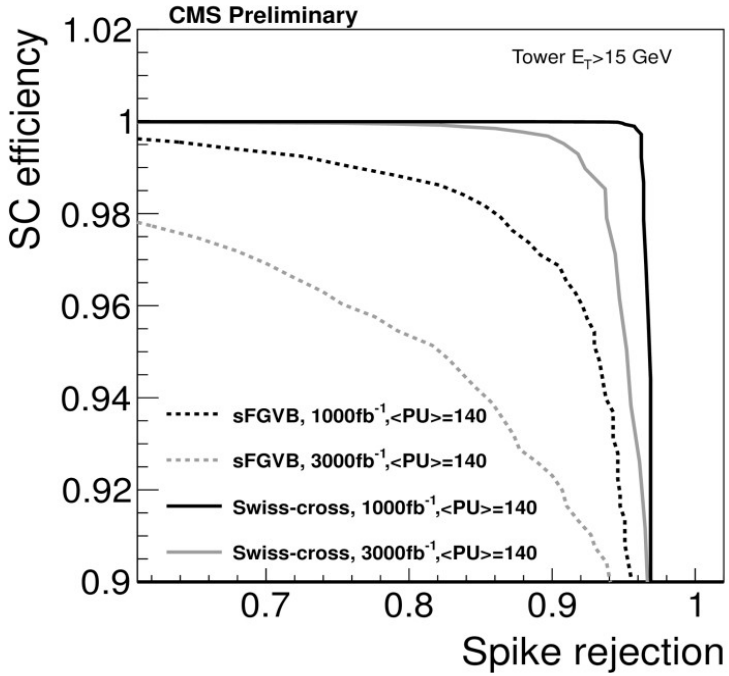



# Barrel Calorimetry



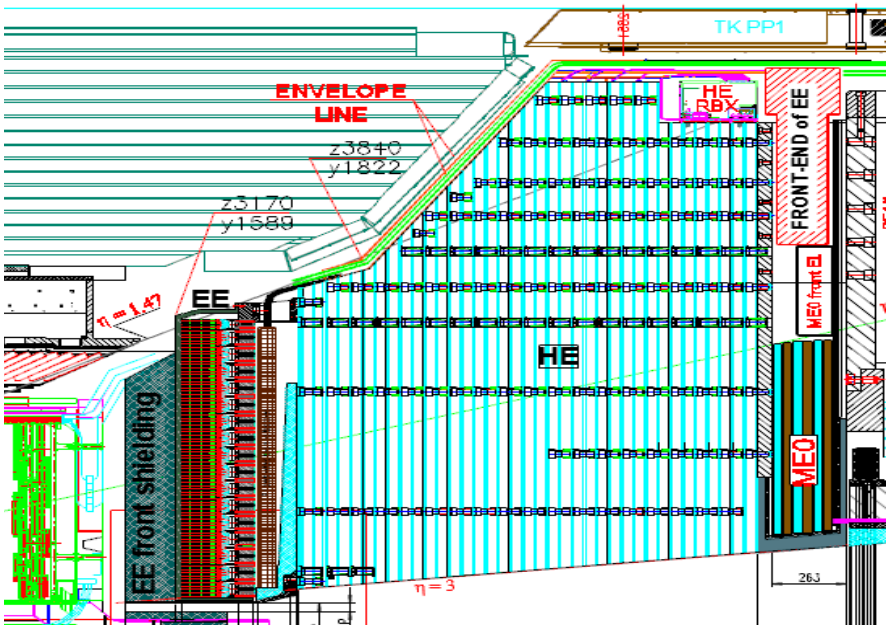



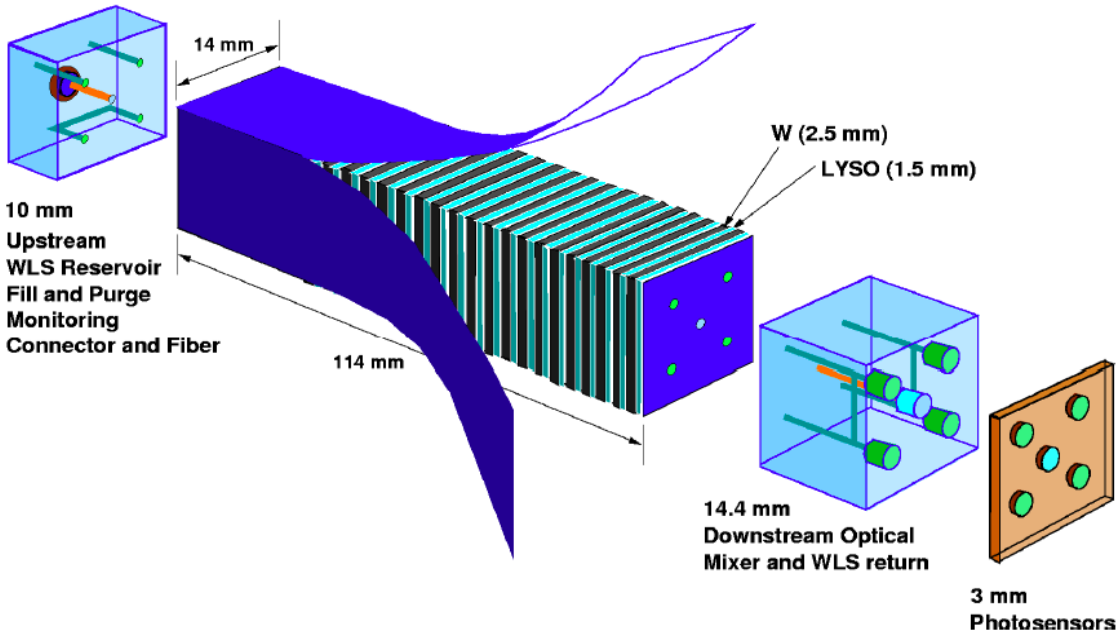



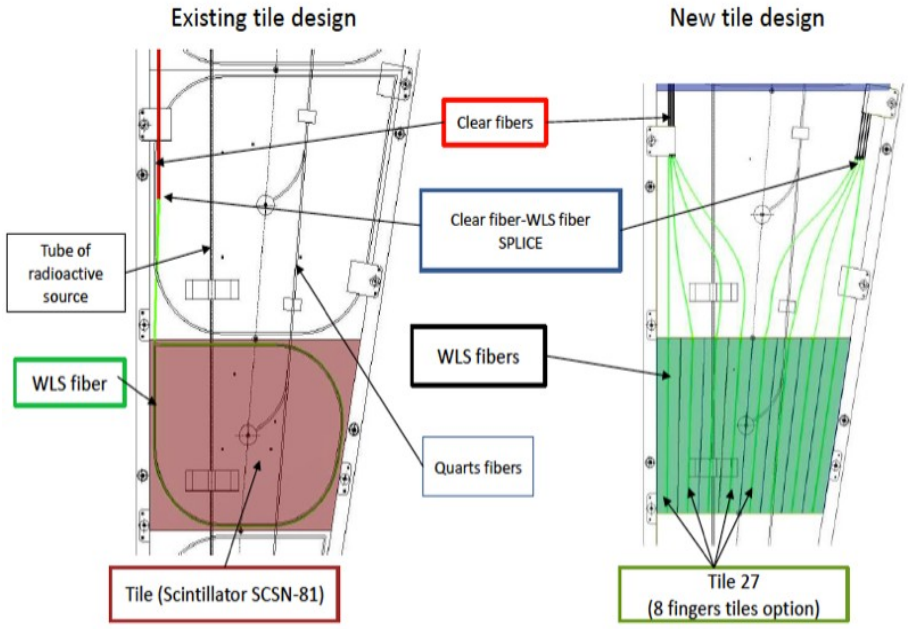

- New on-detector electronics needed to meet requirements for track trigger latency
- Replacement allows trigger-level readout of each crystal and new shaping to reduce impact of out-of-time pileup and increasing APD noise

# Concept 1: Shashlik + Scintillator HE

- EM Calorimeter
  - Compact Pb/LYSO Shashlik using WLS based on quartz capillaries and readout using GaInP “SiPMs”
- Hadron Calorimeter
  - Scintillator-based hadron calorimeter with 30% of volume replaced by “finger tiles” and 10% by a solution with higher radiation tolerance

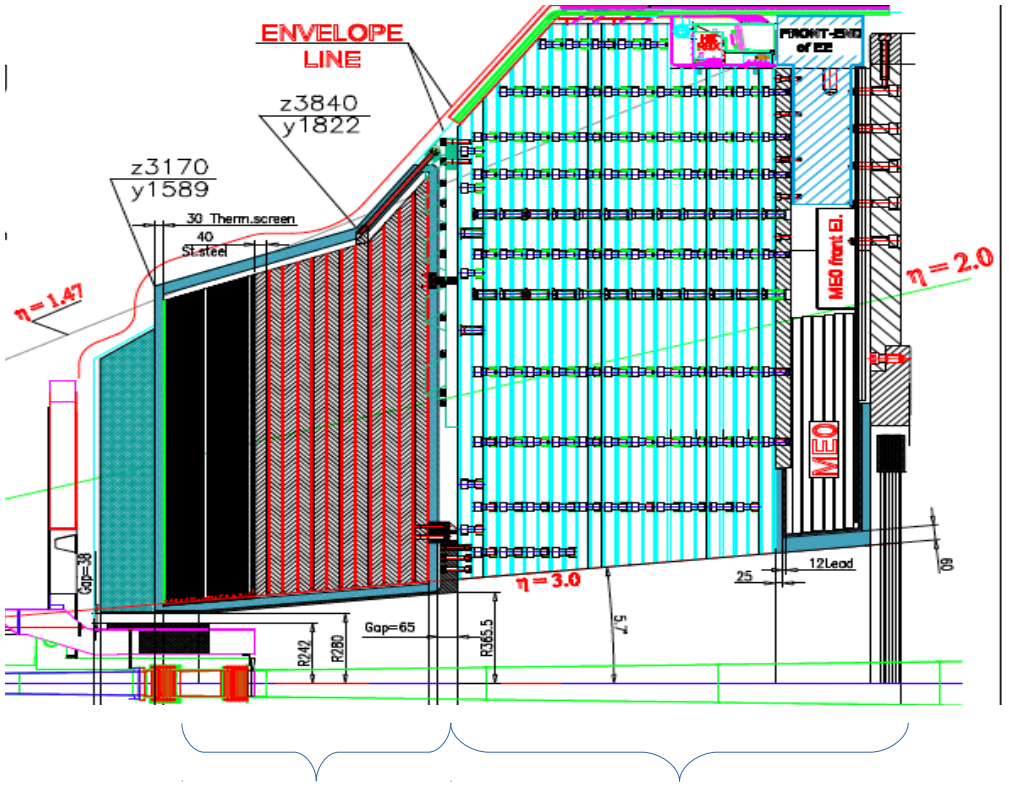


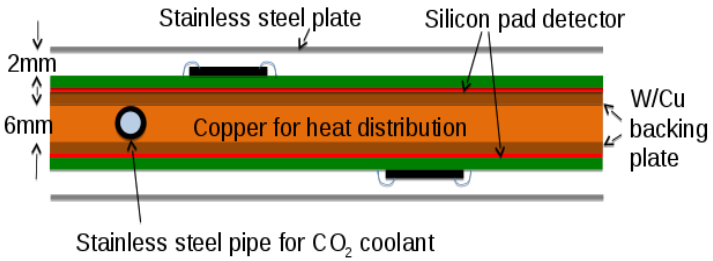



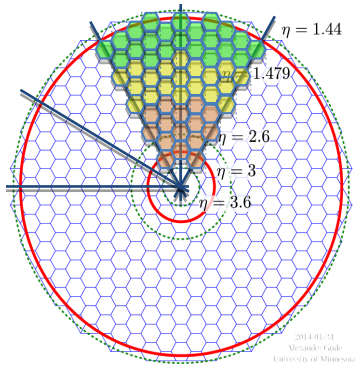



# Concept 2: Silicon Calorimeter + Scintillator backing calorimeter

- Silicon readout for front portion of calorimeter
  - Si+tungsten/copper EM calorimeter (25 $X_0$, 1λ), 30 layers
  - Si+brass front hadron (3.5 λ) calorimeter, 12 layers
  - 8.7 M channels, pad sizes 0.9 $cm^2$ or 0.45 $cm^2$ depending on η
- Scintillator-brass backing calorimeter (5.5 λ)
- Goal is to suppress pileup effects by using information on shower development provided by high level of granularity
  - Informed by experience of ILC R&D

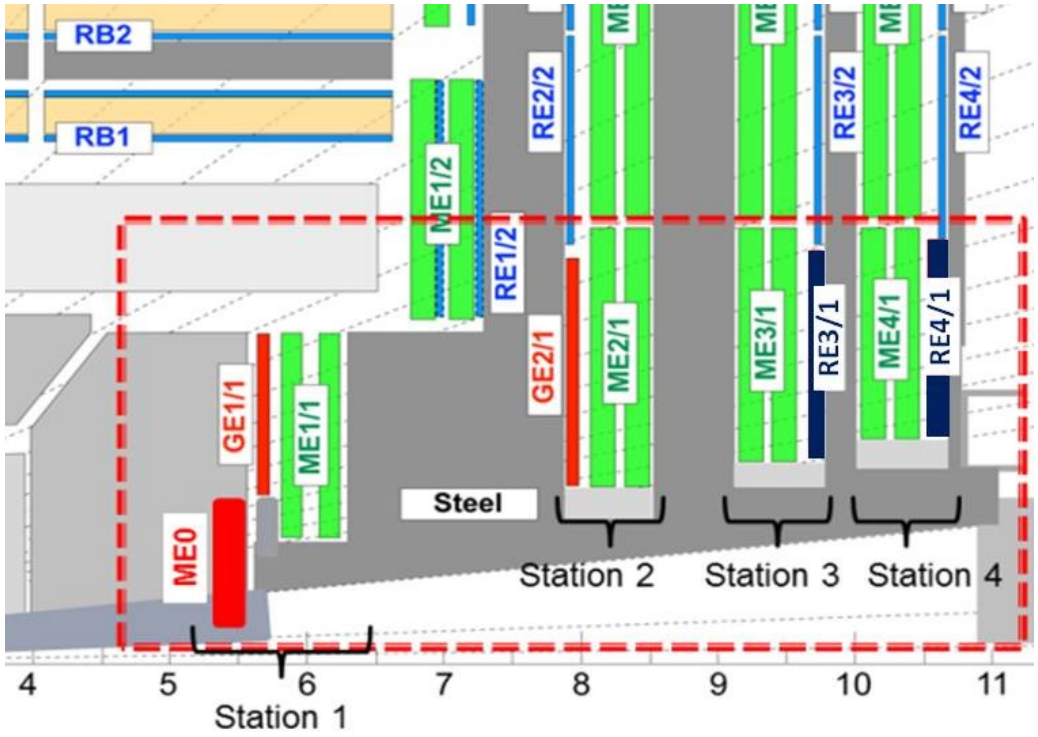


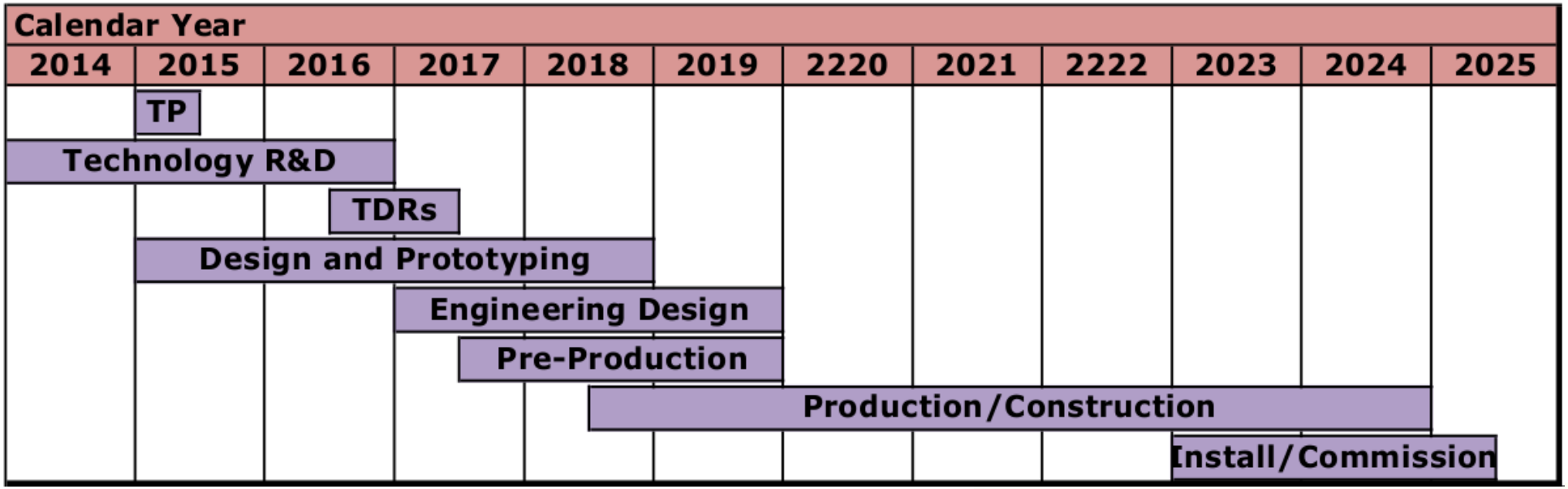



# Muon System Upgrades

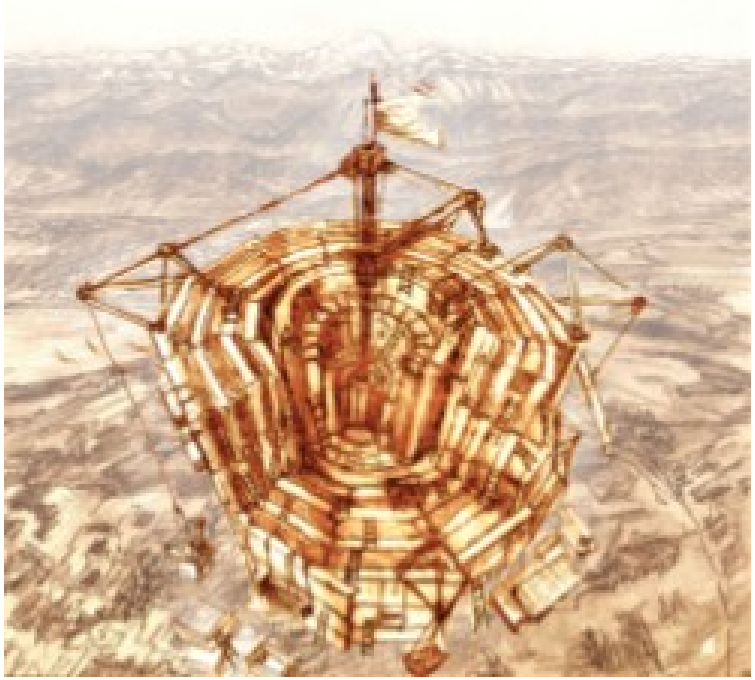
- Improvements of existing detectors
  - Electronics: DT minicrates, CSC inner MEx/1 readout
    - Both are needed for compliance with trigger upgrade
- Forward 1.6<|η|<2.4 upgrades
  - L1 trigger rate reduction, enhance redundancy
  - GEMs: GE1/1 and GE2/1
  - iRPCs: RE3/1 and RE4/1
    - Operation in higher rate
    - Technology to be selected
- Very forward extension
  - Extend muon tagging
  - ME0 with GEMs
  - 6 layer stub
  - Baseline 2.0<|η|<3.0
    - Depends on calorimetry



# Moving forward




- CMS is preparing a Technical Proposal including physics performance studies, to be completed by March 2014
  - Decision on endcap calorimeter technology planned for early 2015



# Conclusion

- Run 2 and Run 3 of LHC will open a new energy regime, hopefully leading to major new discoveries
  - The Phase 1 Upgrades of CMS will support the physics program of these LHC runs and are moving to construction: Pixels, HCAL, L1 Trigger
  - Major US leadership in all three upgrade efforts
- The HL-LHC will allow for precision studies of the Higgs as well as allowing the identification and characterization of discoveries made in Run 2 and 3.
  - CMS is preparing a technical proposal detailing the plans for upgrades allowing the same physics performance for 140 pileup and 3000 $fb^{-1}$ as CMS had in Run 1
  - US scientific and technical efforts will be critical to the success of the HL-LHC physics program