June 2013 - photo by Michael.Hoch@CERN.ch

The CMS Upgrade program

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on behalf of the CMS Collaboration

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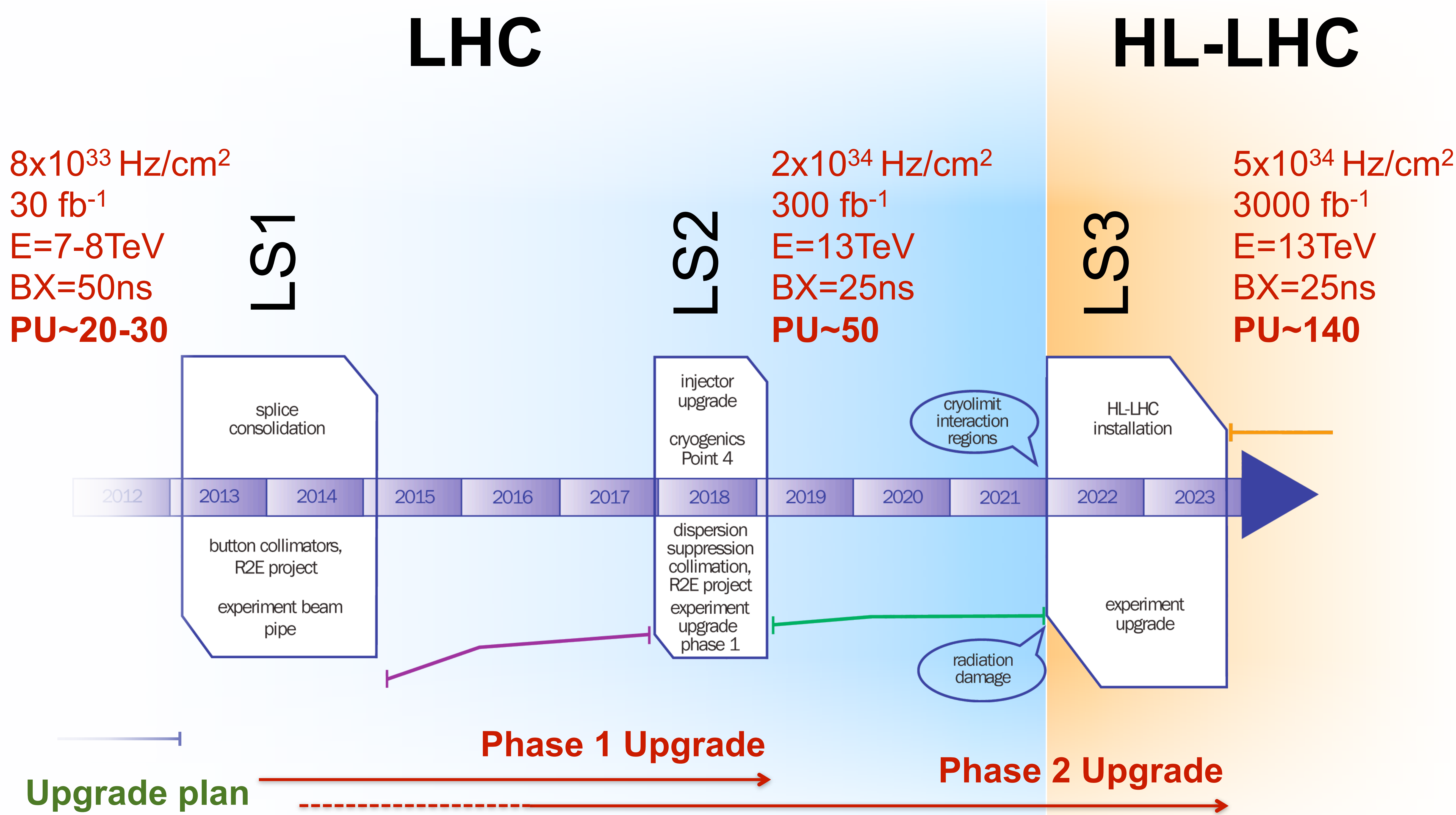
Table of contents

- LHC program and timeline
- Motivations and directions
  - Radiation effects and subdetector lifetime
  - Physics object performances (Particle Flow)
  - Pile Up mitigation
  - Rates and trigger requirements
- Overview of the CMS upgrade program
- Tracker Detectors
- Calorimeters
- Muon system
- Trigger system
- Conclusions

Much more details specific talks during the Workshop

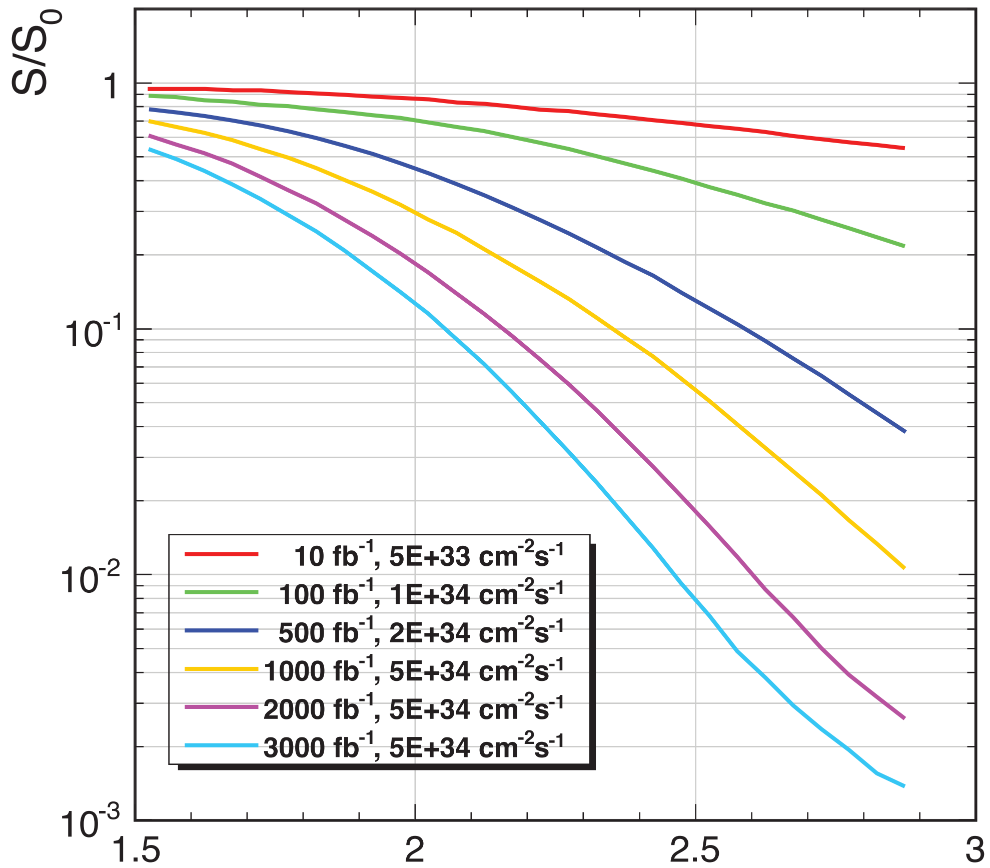
The LHC timeline



Motivations and directions

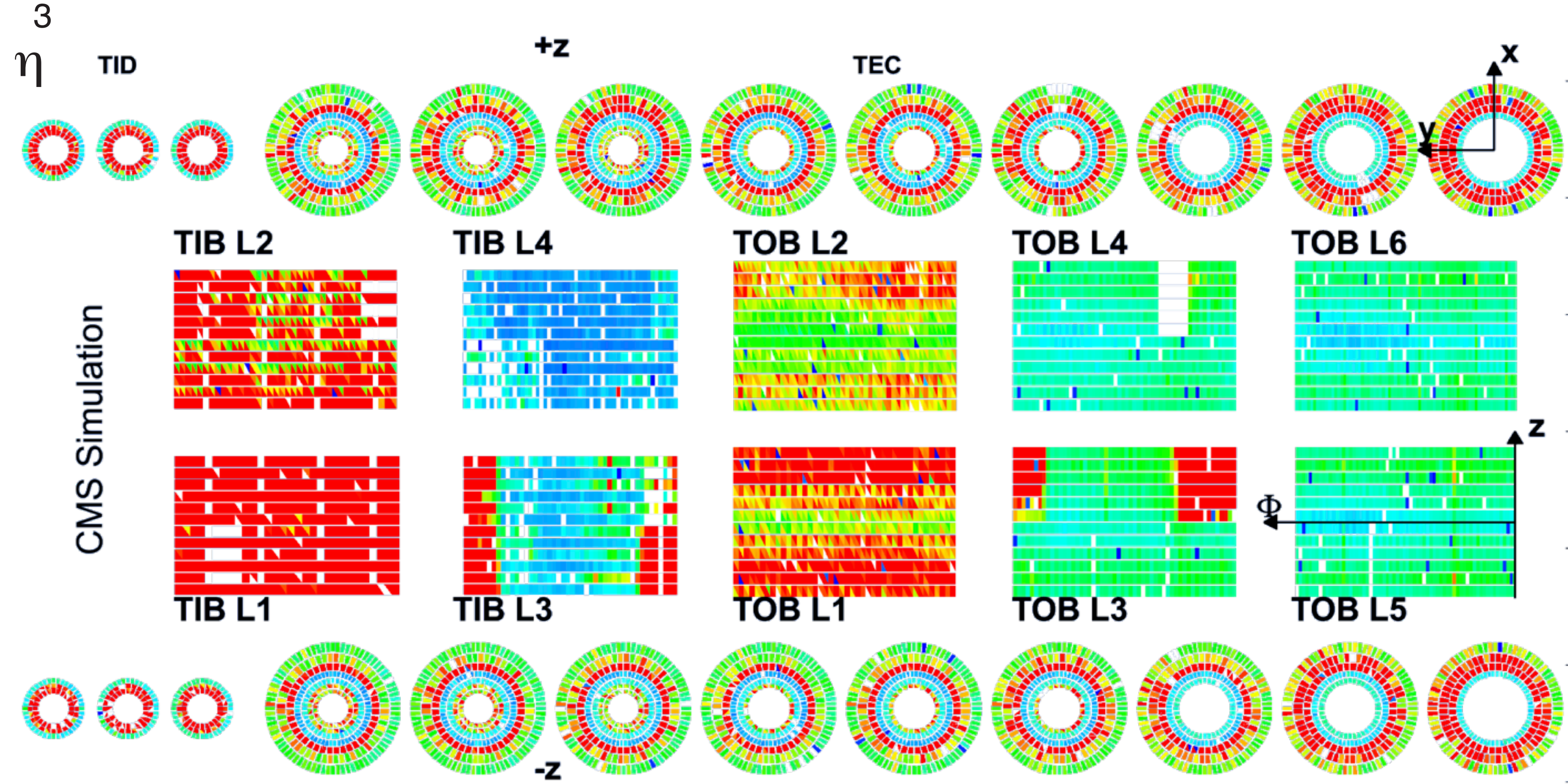
- Radiation effects and subdetector lifetime
- Physics object performances (Particle Flow)
- Pile Up mitigation
- Rates and trigger requirements

Radiation effects



- $L=5\cdot10^{34}cm^{-2}s^{-1}$; L_{INT}=3000/fb; PU~140
  - Radiations levels **~6× the design ones**
- The entire detector (but muons) is contained in the magnet (larger radiations)
- Tracker and Endcap Calorimeters need to be replaced

Fraction of ECAL response

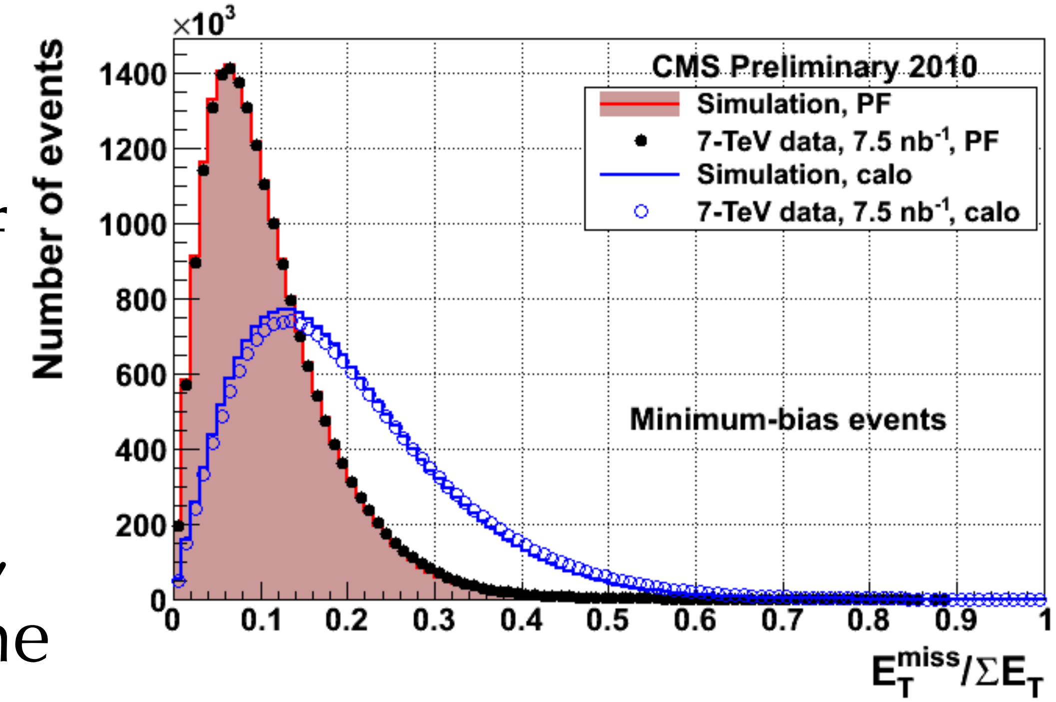


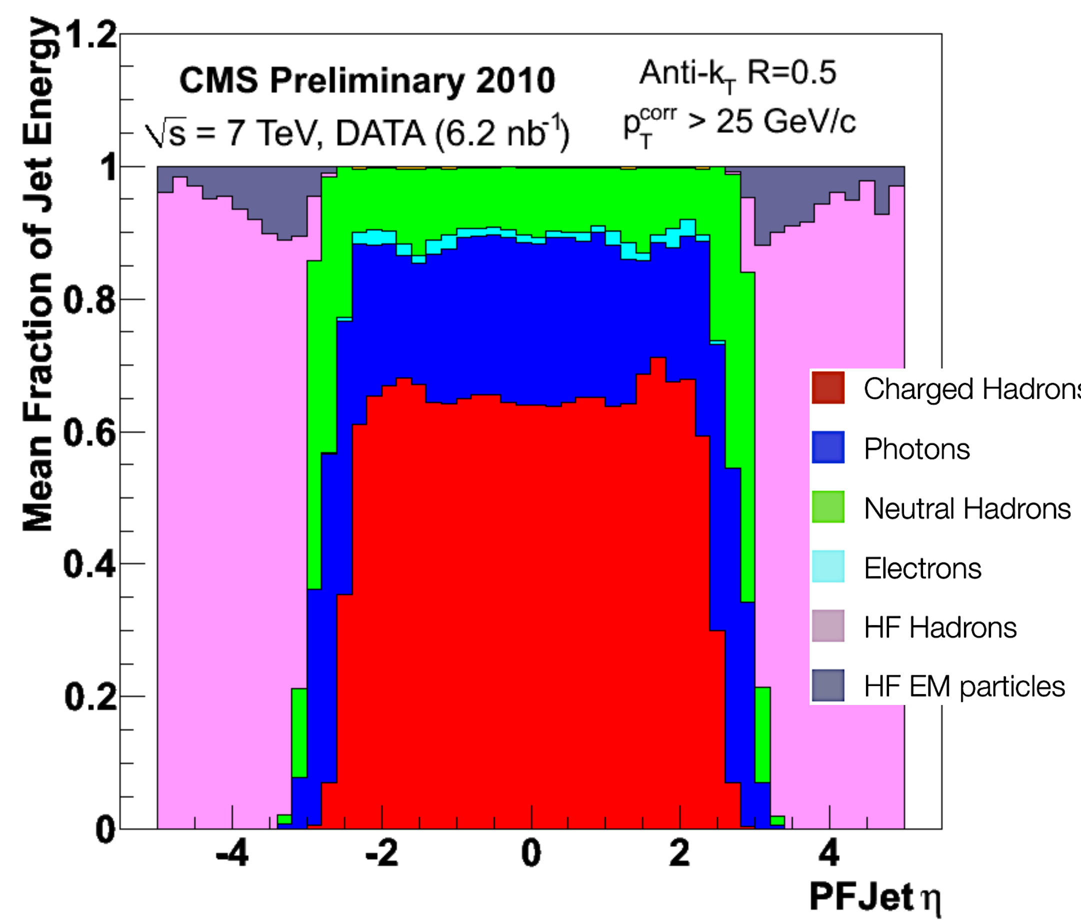
TRACKER module leakage current (1000/fb, -20°C): **red (~3mA)** module is lost

Physics object performances (Particle Flow)

CMS aims to maintain high precision experiment performances throughout the entire LHC to HL-LHC physics program.

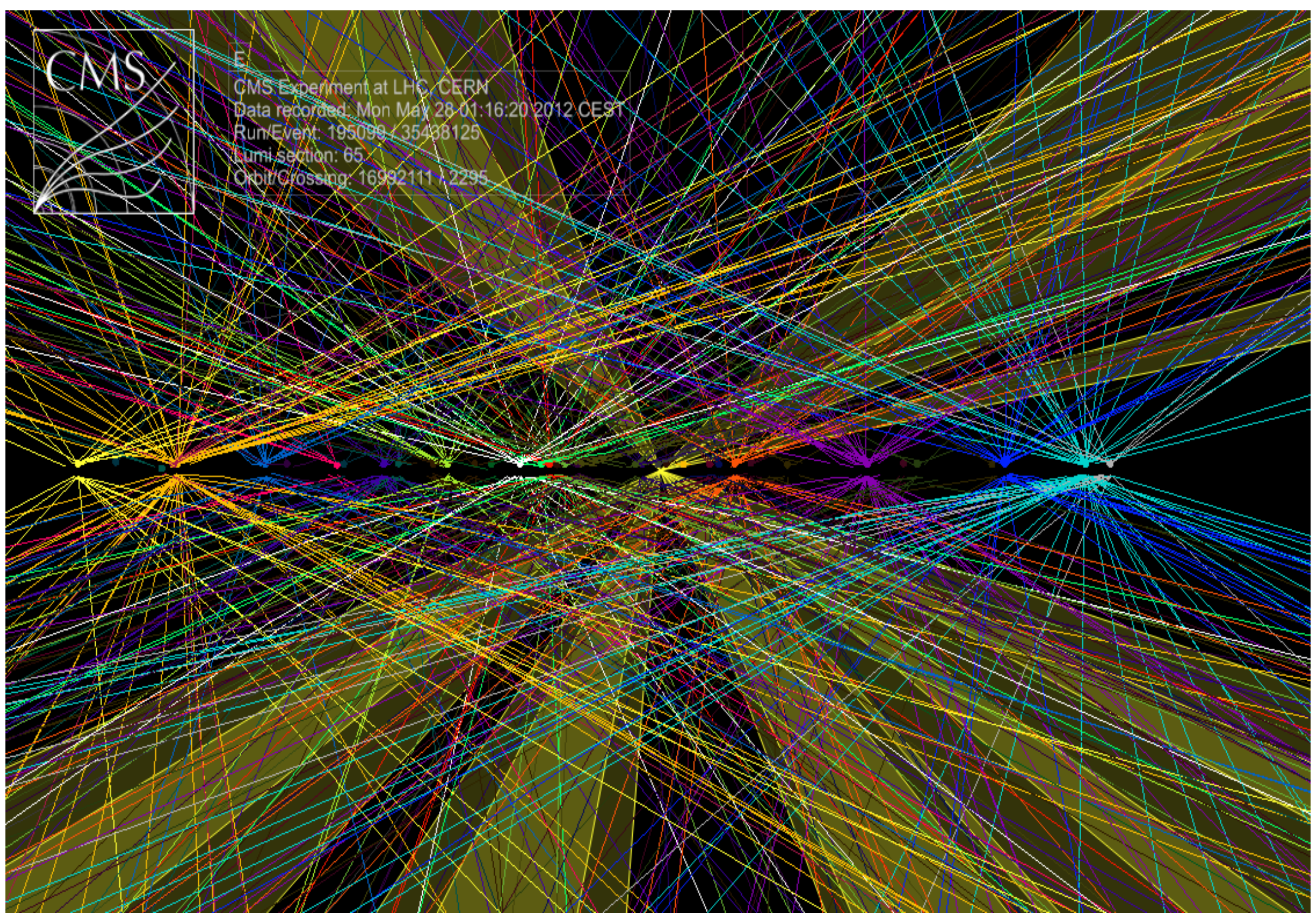
- Physics performance are driven by **object performance**, i.e. by optimal combination of sub-detectors.
- The ultimate combination of sub-detectors measurements into high level objects (μ, e, γ, charged & neutral hadrons...) is devoted to the **Particle Flow algorithm**
  - A PF-grade detector must have large coverage, excellent low-material tracker and granular, high resolution, low noise calorimeters
    - detectors need to be upgraded with object performance (PF) approach;
    - if feasible and affordable known issues or limitations should be cured (e.g. CMS is currently lacking PF capabilities beyond |η| ~2.5)

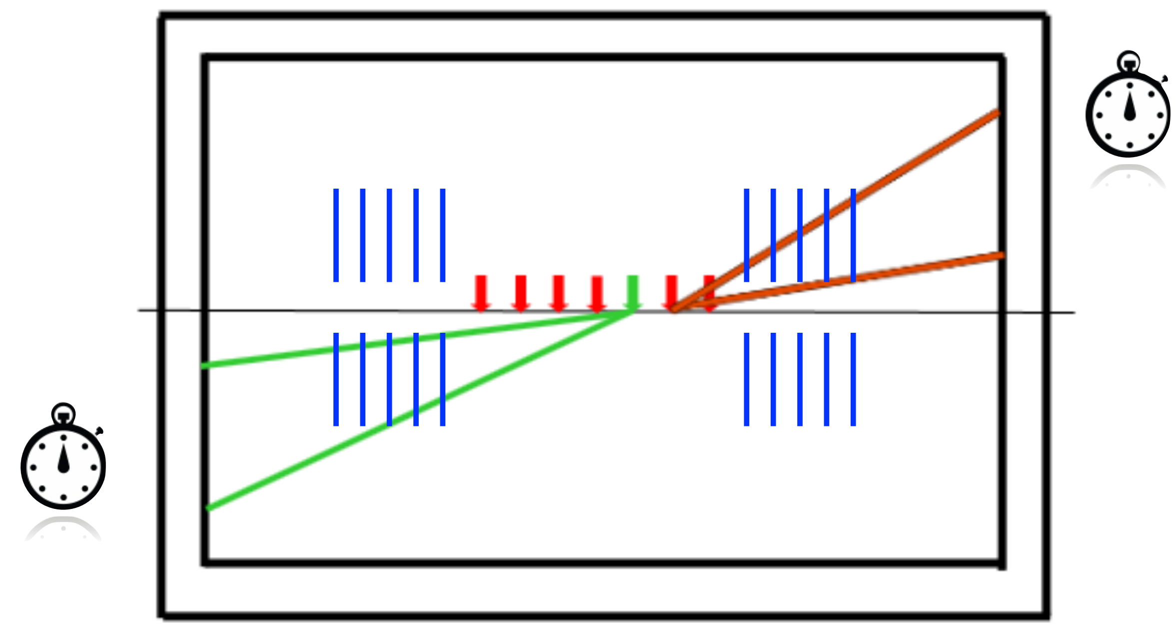




Pile Up mitigation

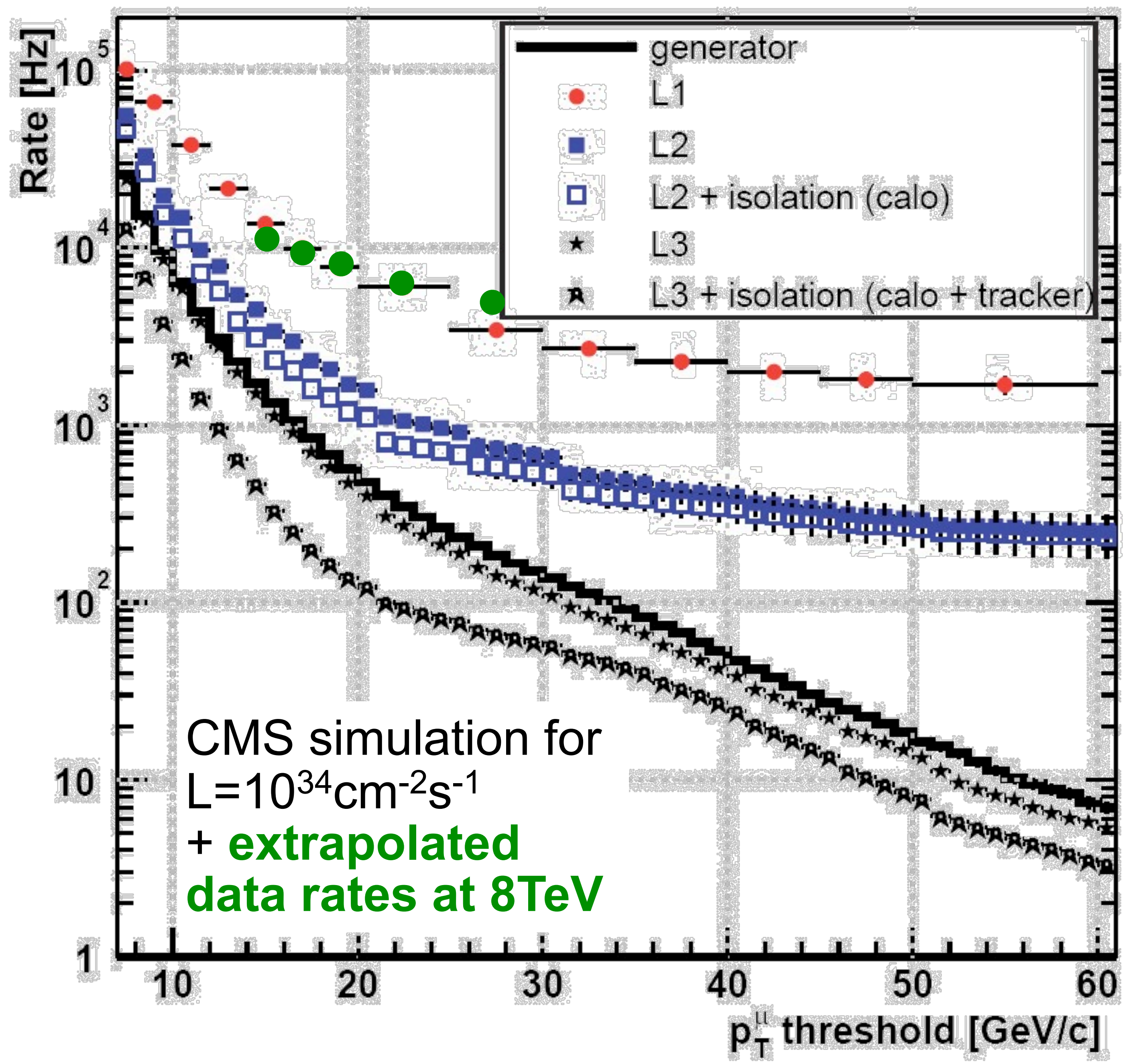
- Identification of uninteresting tracks (PU mitigation) is crucial for Particle Flow (cleaning) and correct object-to-vertex assignment
  - tagging of PU vertices (**vertex detectors with large forward extended coverage**)
  - object-to-vertex granularity and segmentation and **extreme timing capability** to associate energy deposits to a given vertex from Time-Of-Flight measurement (desired resolution is 20-30 ps)





Rates and trigger requirements

- L1 and HLT trigger capabilities will be extended to cope with the larger rates; however this is not sufficient given combinatorics induced by the PU
  - for example, in the muon case no P_T threshold is effective in reducing the rate
- Maintaining the levels of reduction rates with much worse PU condition requires more information to be used at in the trigger levels
  - Larger latency to allow for the L1 system to digest more information
  - Improved L1 systems
  - Tracker information at L1



Timeline of CMS upgrade program

LS1
2013
2014

Complete, consolidate and prepare CMS for nominal LHC beam conditions: 13 TeV, 10^{34}/s/cm^2 , <PU>~25

- Muon system (4th endcap station) and improve readout electronics
- Replace HCAL photo-detectors and backend electronics
- Operate the Tracker @-20^{o}C

Phase1 ensures running up to LS3

LS2
2018

Prepare for 1.6x10^{34}/s/cm^2, <PU>~40, 200/fb by LS2 and for 2.5x10^{34}/s/cm^2, <PU>~60, 500/fb by LS3

- New L1-trigger system ready for 2016 data taking
- New Pixels ready for installation in 2016/17 Year End Technical Stop (YETS)
- Install new HCAL readout in 2015 YETS and LS2

Phase2 ensures running for HL-LHC

LS3
2022
2023

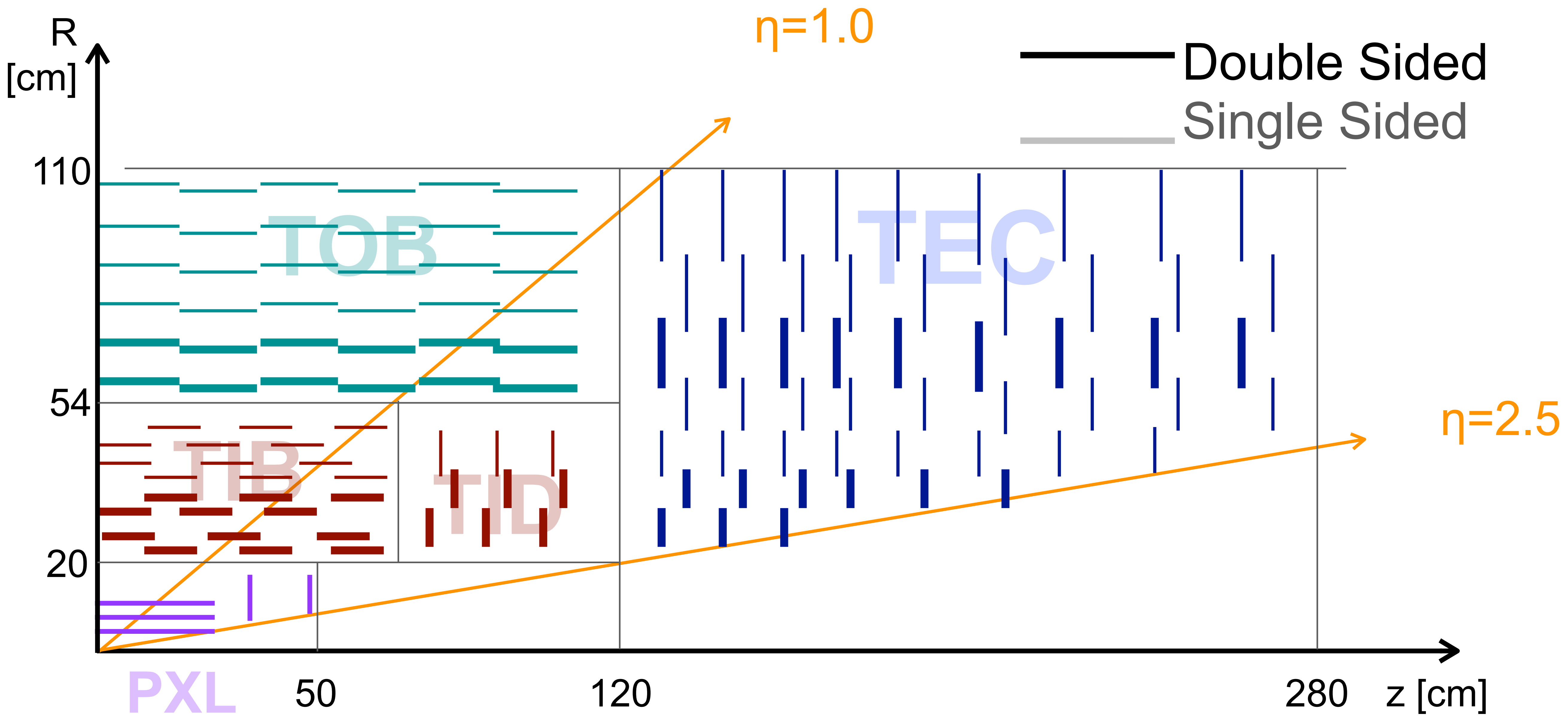
Prepare for ≥5x10^{34}/s/cm^2, PU~140-200, total of 3000/fb in ~10years operation

- Replace subsystems not surviving to radiation damage
- Tracker including Pixels, Endcap calorimeters
- Maintain physics performance at very high PU
- New Electronics and Trigger, enhanced detector coverage

Tracking detectors

Tracker evolution to Phase 2 (now)

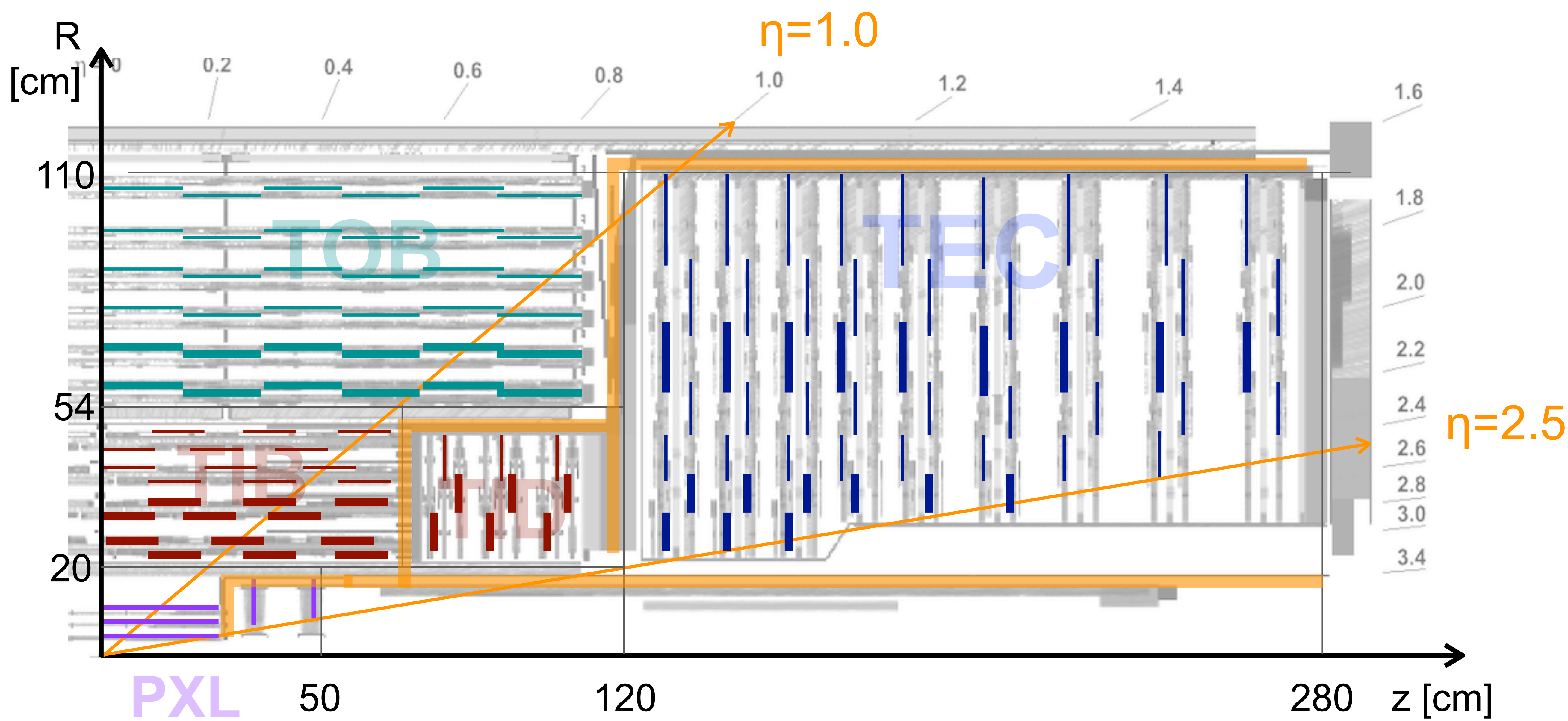
Outer strip tracker: 10 barrel layers, 9 endcap disks
with **double sided (stereo)** and **single sided** (rφ) modules.



Pixel: **3 barrel layers**, and **2+2 disks**.

Tracker evolution to Phase 2 (now)

The present tracker layout with overlay of
passive material and main **routing of services**

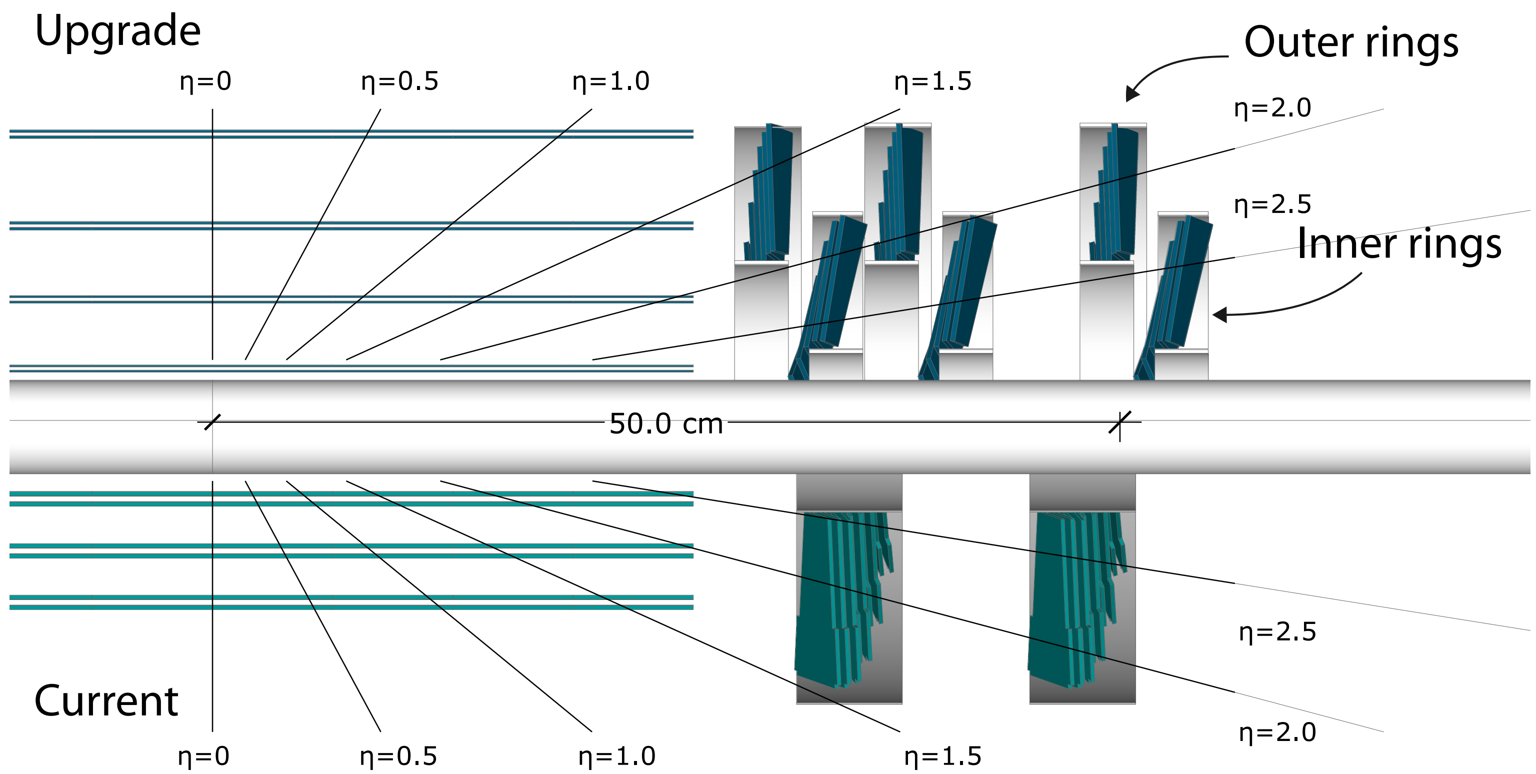


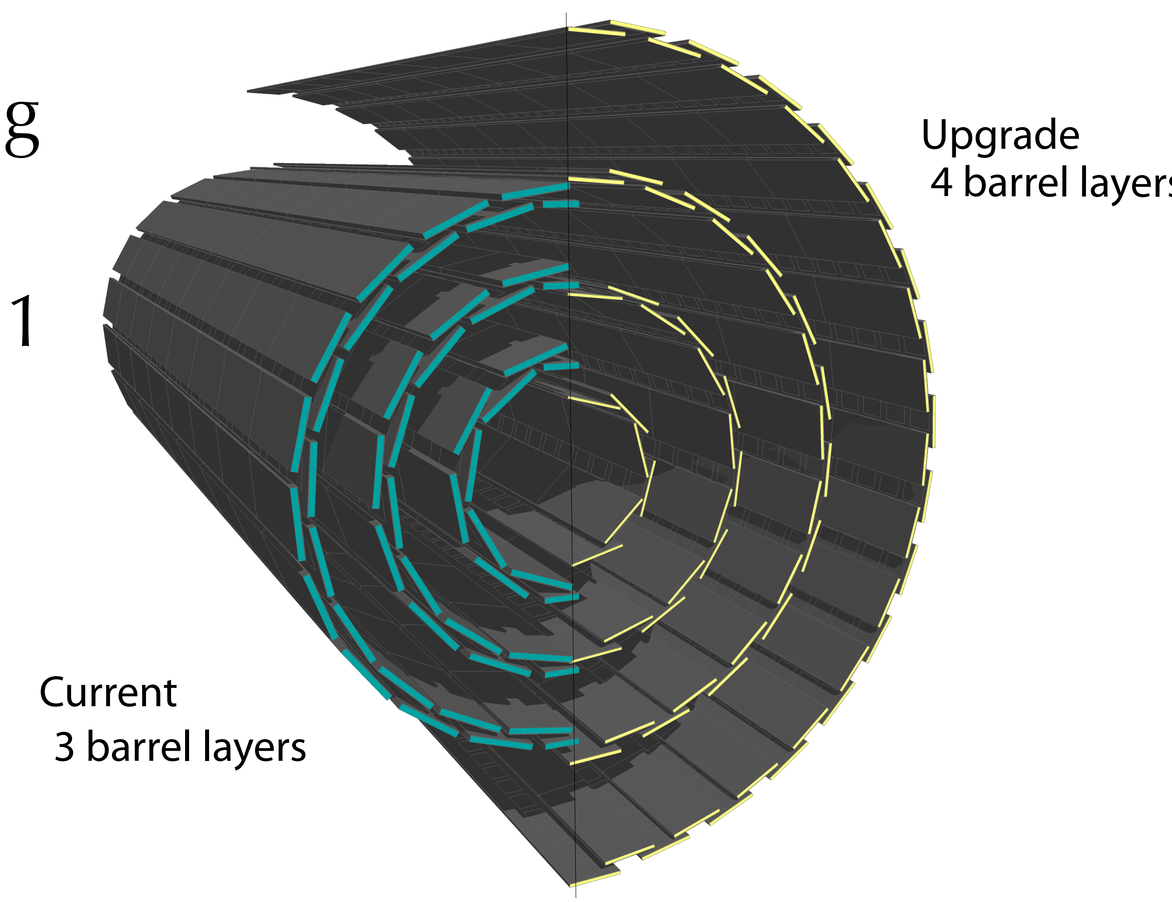
The |η|>0.9 is critical because tracks intercept several times power cables, fibers and cooling pipes. Downstream effects on ECAL are visible.

Phase 1 - 2016 TS - New Pixel Detector

The Phase1 pixel detector is an improved version of the current pixel detector.

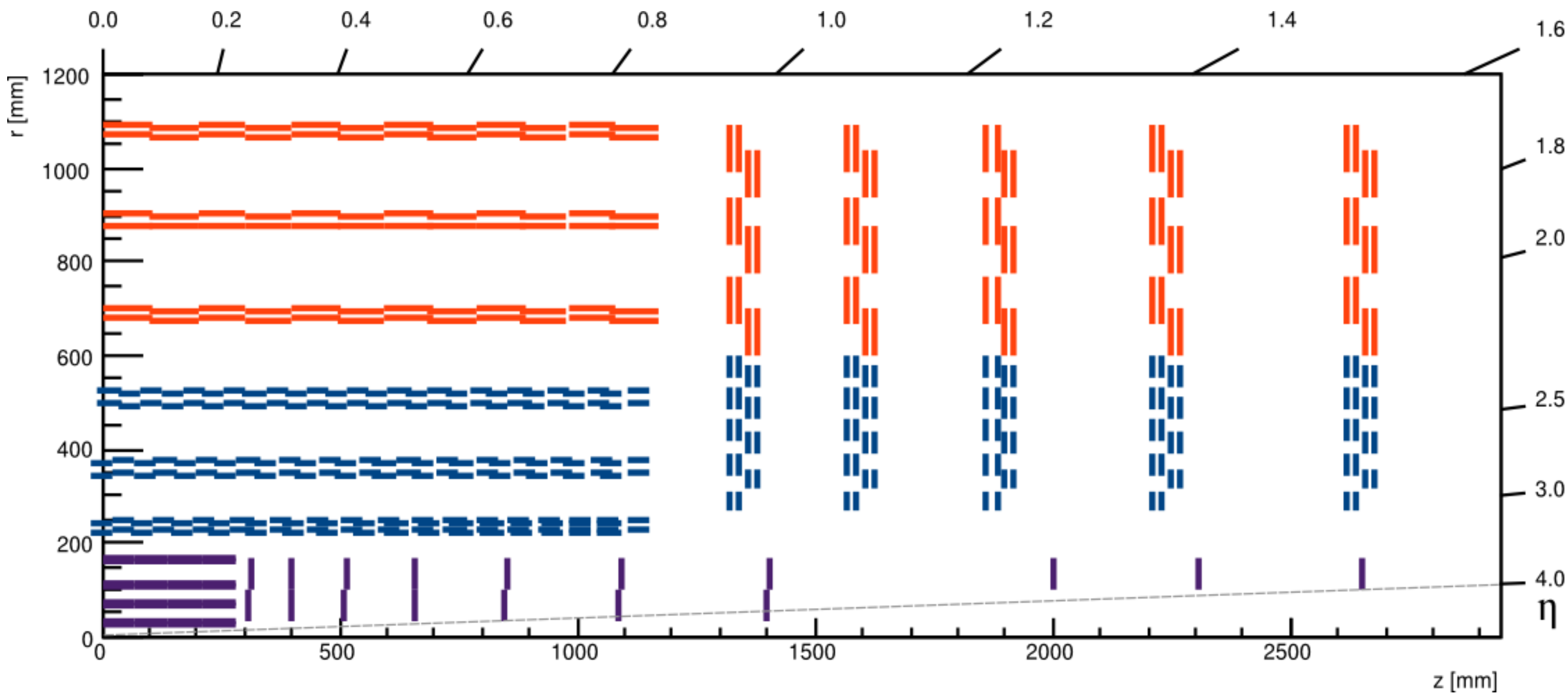
- 4 layers / 3+3 disks (100×150 μm², n⁺-in-n): improved track resolution and efficiency
- New readout chip: reduced dynamic inefficiency at high rate and PU
- Reduced material: CO_2 cooling, new cabling and DC-DC powering scheme
- Can survive up to LS3 by exchanging Layer 1
- Will be installed during the 2016 Technical Stop; a pilot disk 3 blade will be installed for 2015 for testing





Tracker evolution to Phase 2

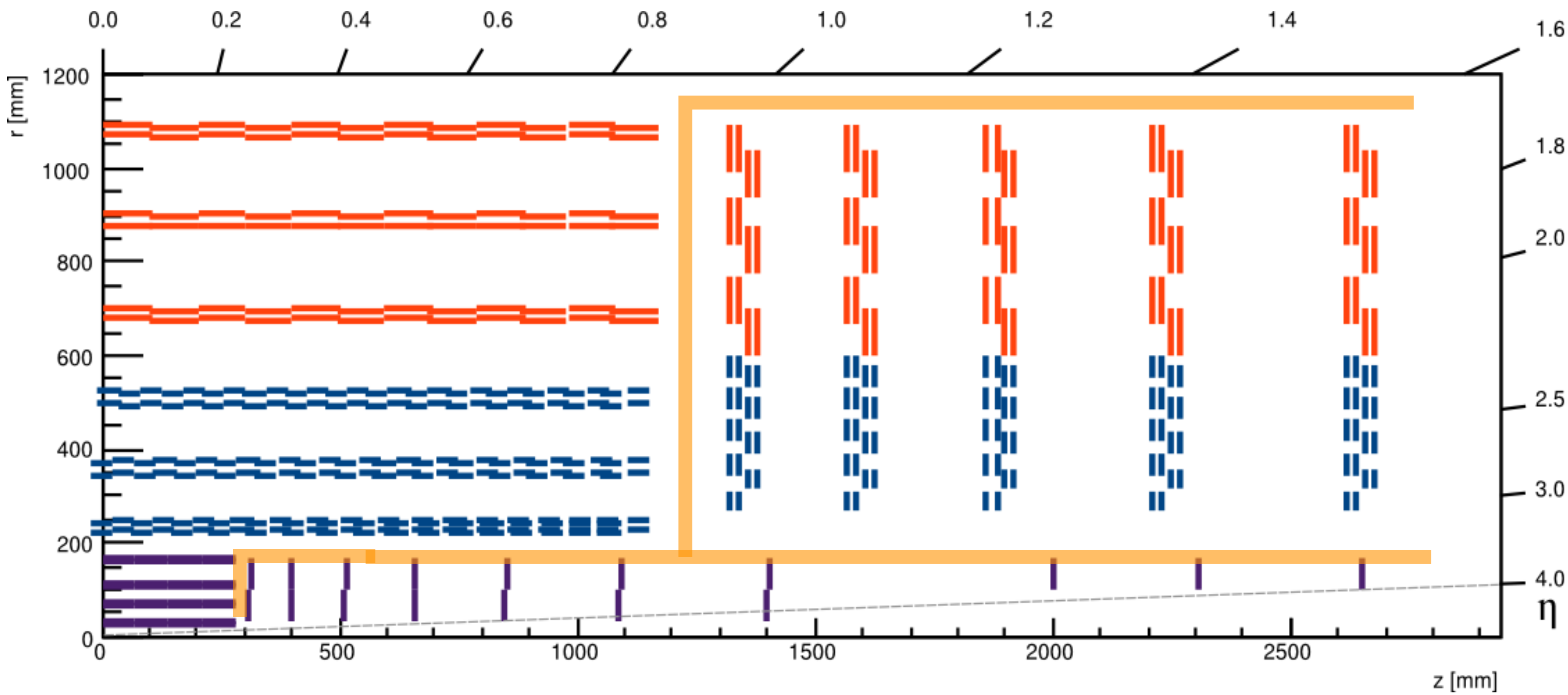
Outer tracker: 6 barrel layers, 5+5 endcap disks
with **PS (pixel+strip)** and **2S (strip+strip)** modules.



Pixel: **4 barrel layers**, up to **10+10 disks** for coverage up to |η|~4 in connection with extended muon system and endcap calorimeters.

Tracker phase 2 service routing

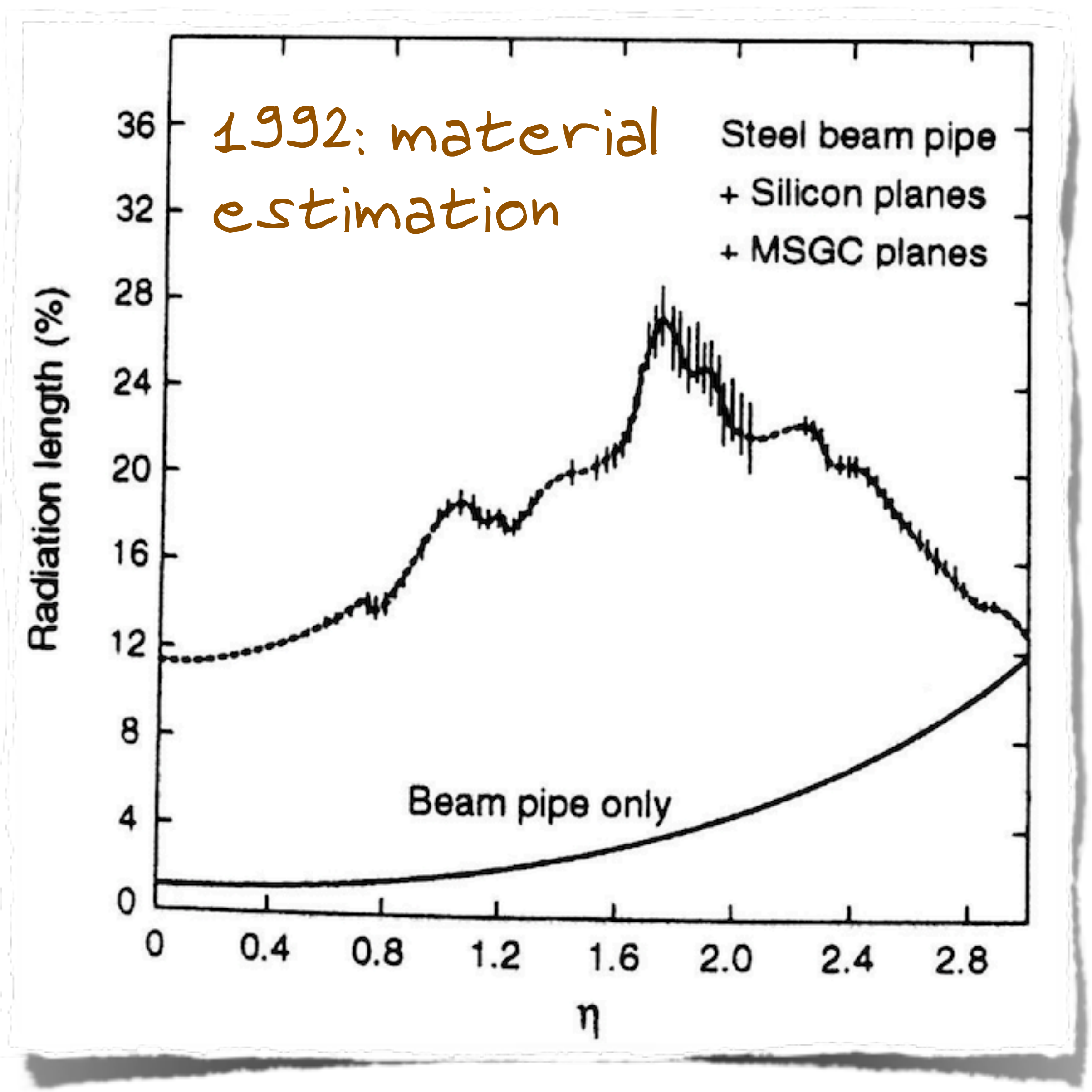
More rational routing with respect to actual tracker

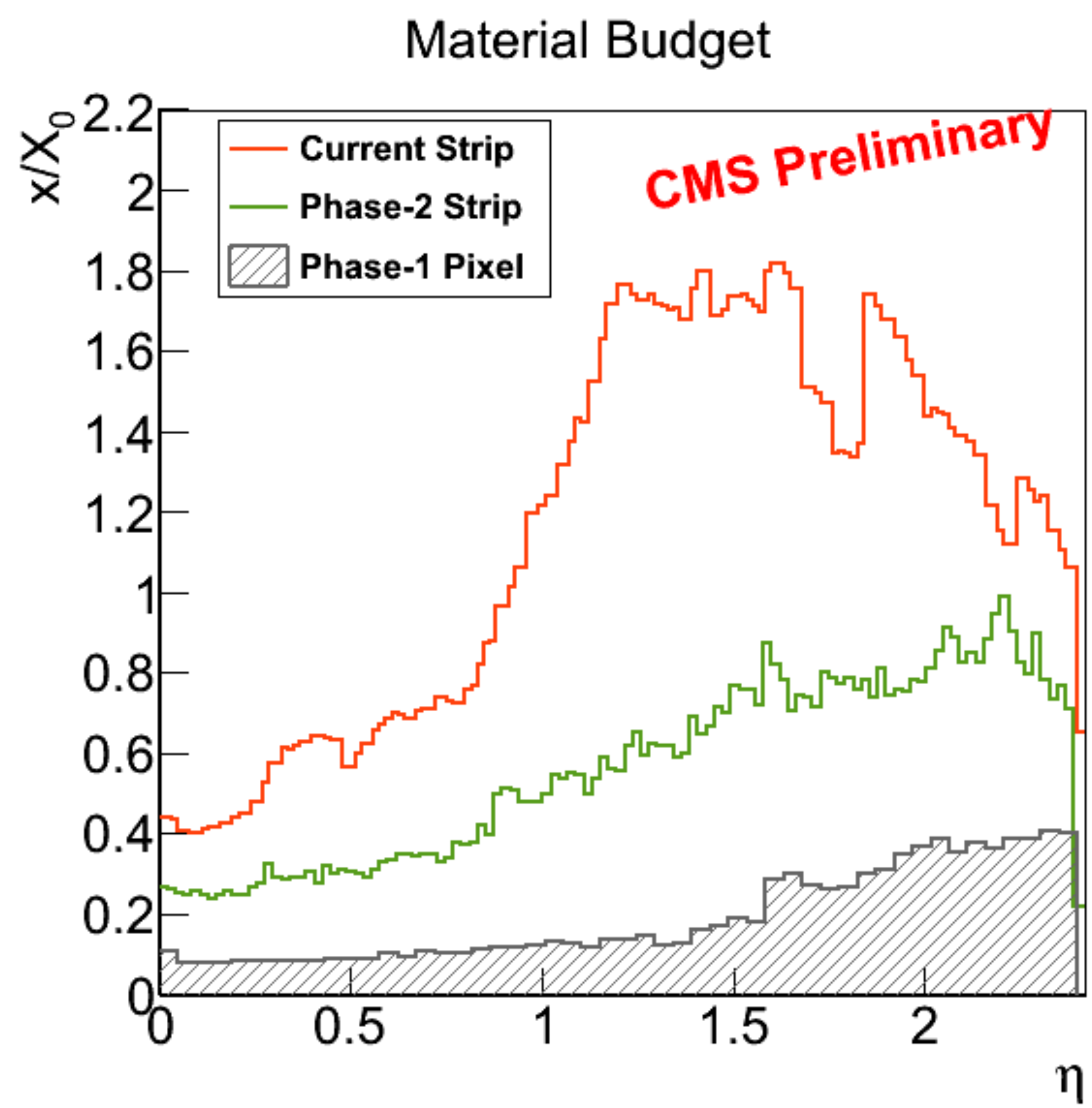


Large η region could be critical (need to route all pixel services in a region that is now active)

Tracker Material

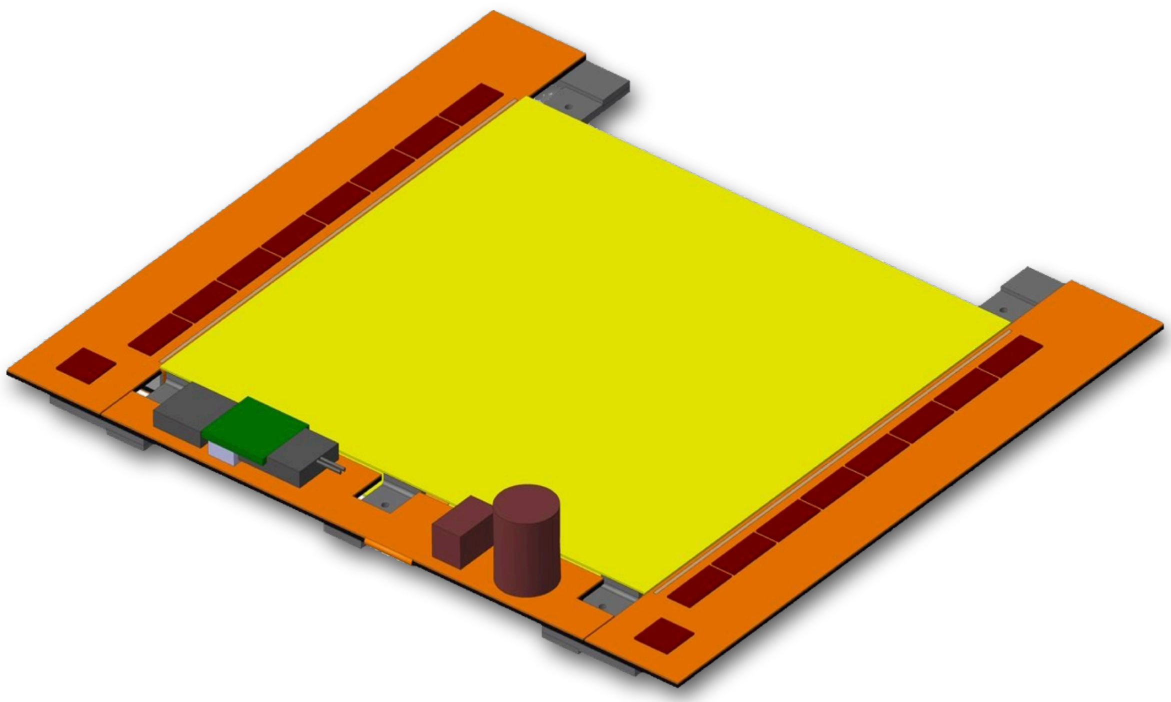
Many lessons have been learned building the current tracker. We can be confident in the reduction of the material budget in the Phase2 tracker.



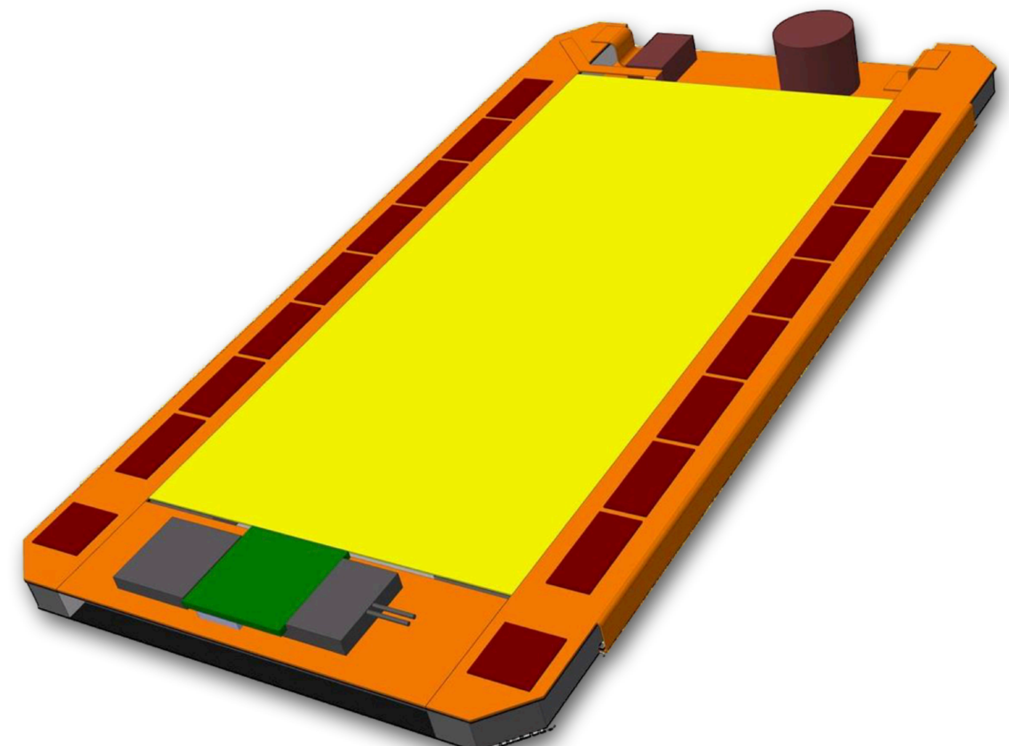


P_T Modules for track trigger

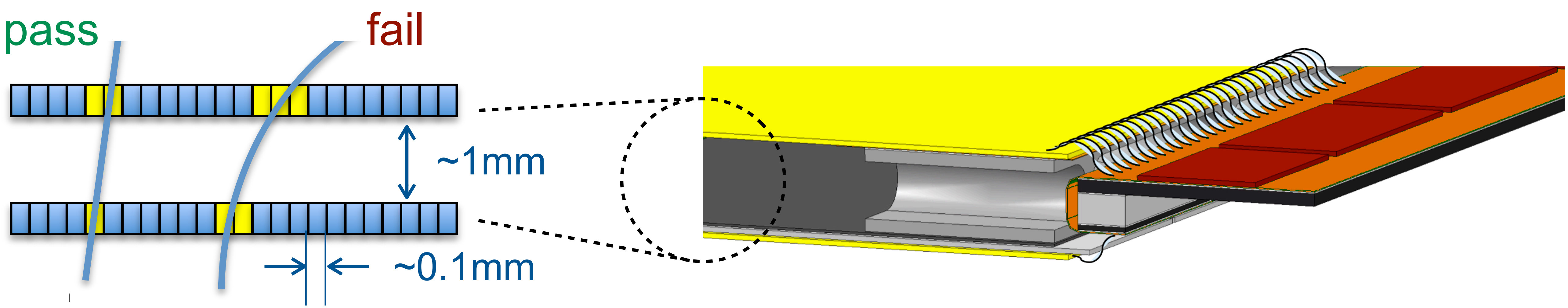
2S module 5cm long strips (both sides) 90μm pitch, P~2.7W, ~92cm² of active area



PS module 2.4cm long strips+pixels 100μm pitch, P~5W, ~45cm² of active area

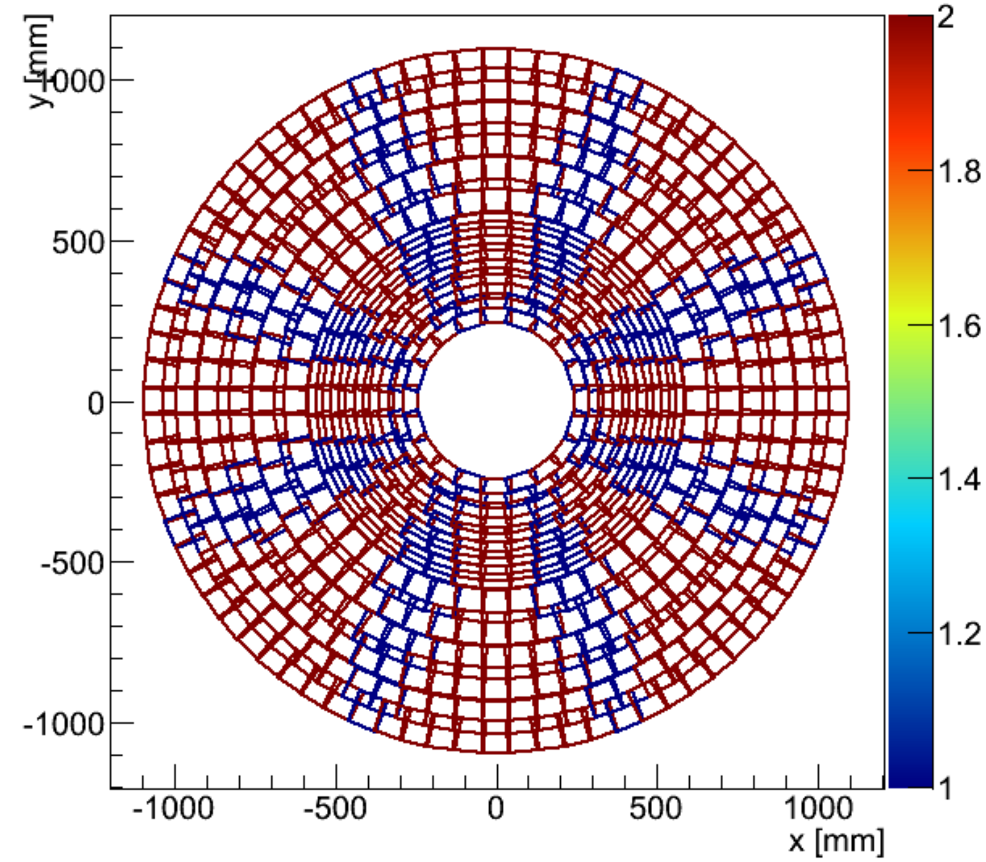


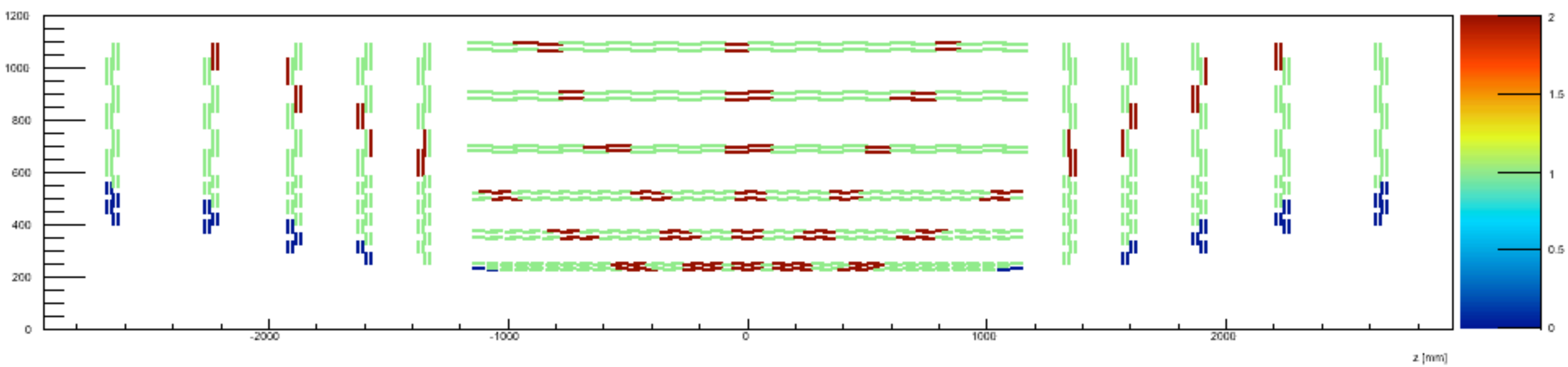
Filtering of hits originating from low P_T tracks:
local spatial correlation of the hits on the two spaced sensors is used



L1 track finding

- 8 rφ × 6 Rz trigger sectors
- Two track findings under investigation
  - Associative Memory (pattern recognition) + FPGA (track fitting)
  - FPGA boards (pattern recognition + track fitting)



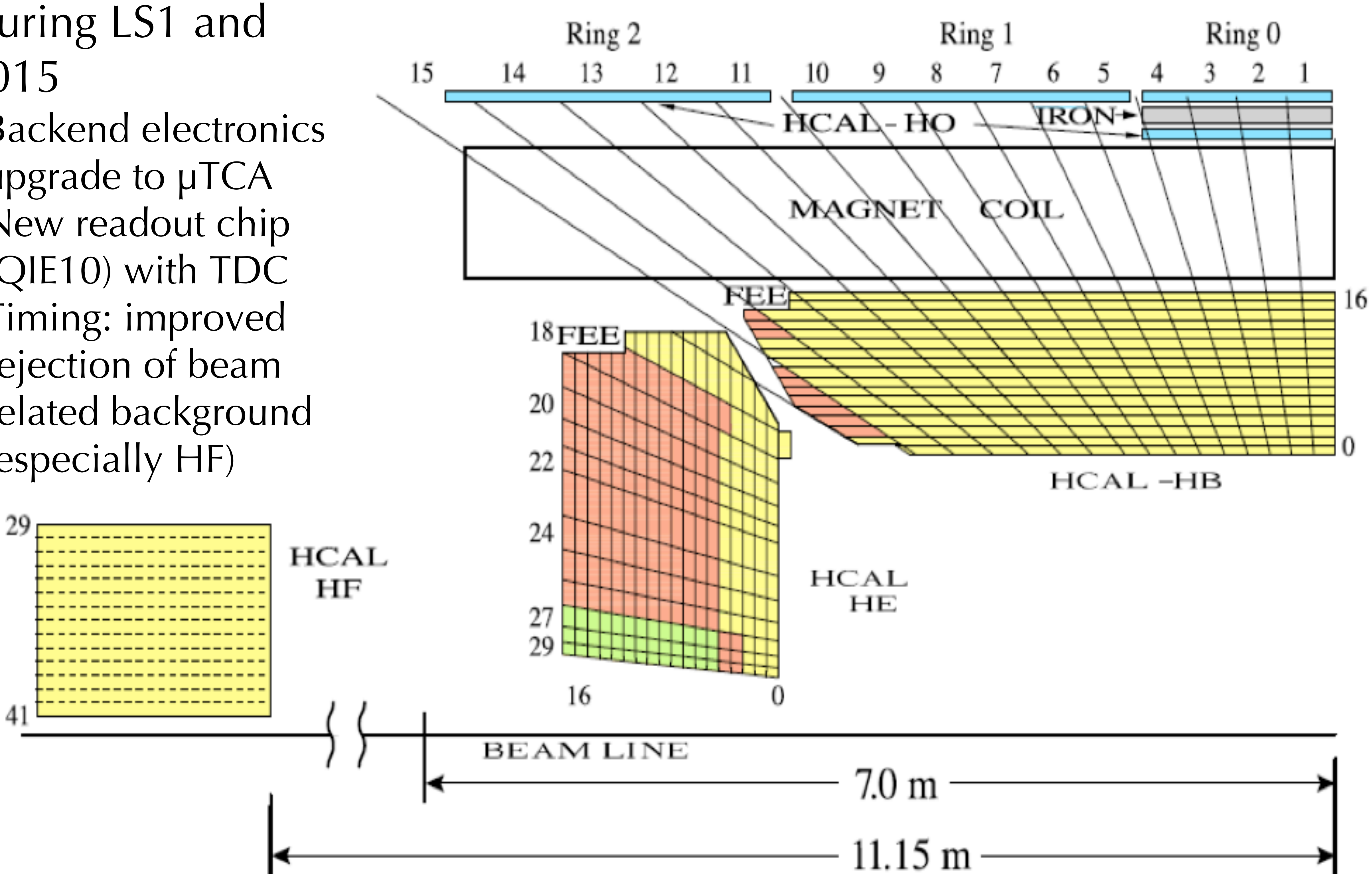


Calorimeters

HCAL Evolution (now)

The current detector has no to limited longitudinal segmentation

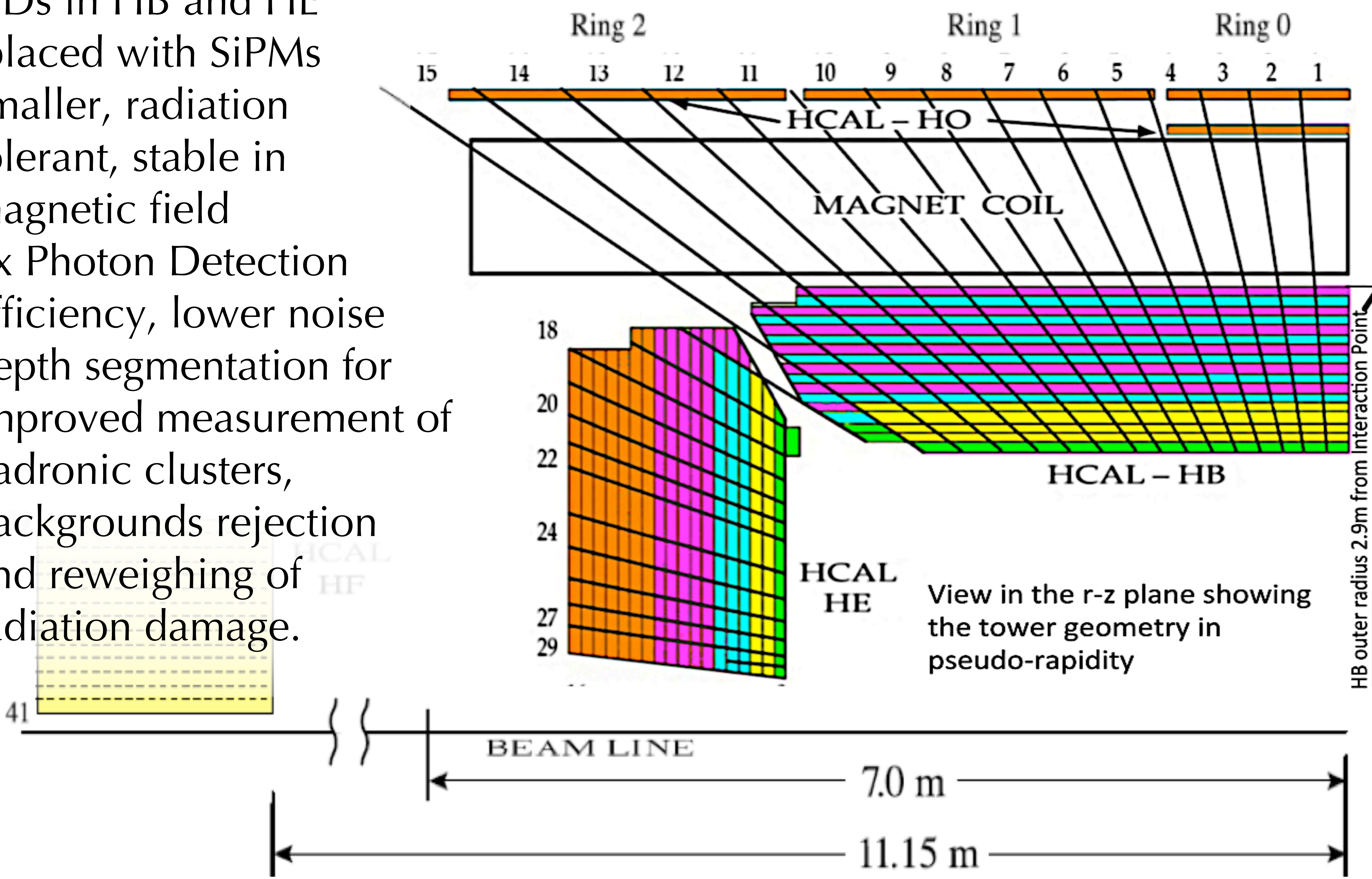
- During LS1 and 2015
  - Backend electronics upgrade to μTCA
  - New readout chip (QIE10) with TDC
  - Timing: improved rejection of beam related background (especially HF)



HCAL Evolution (phase 1, LS2)

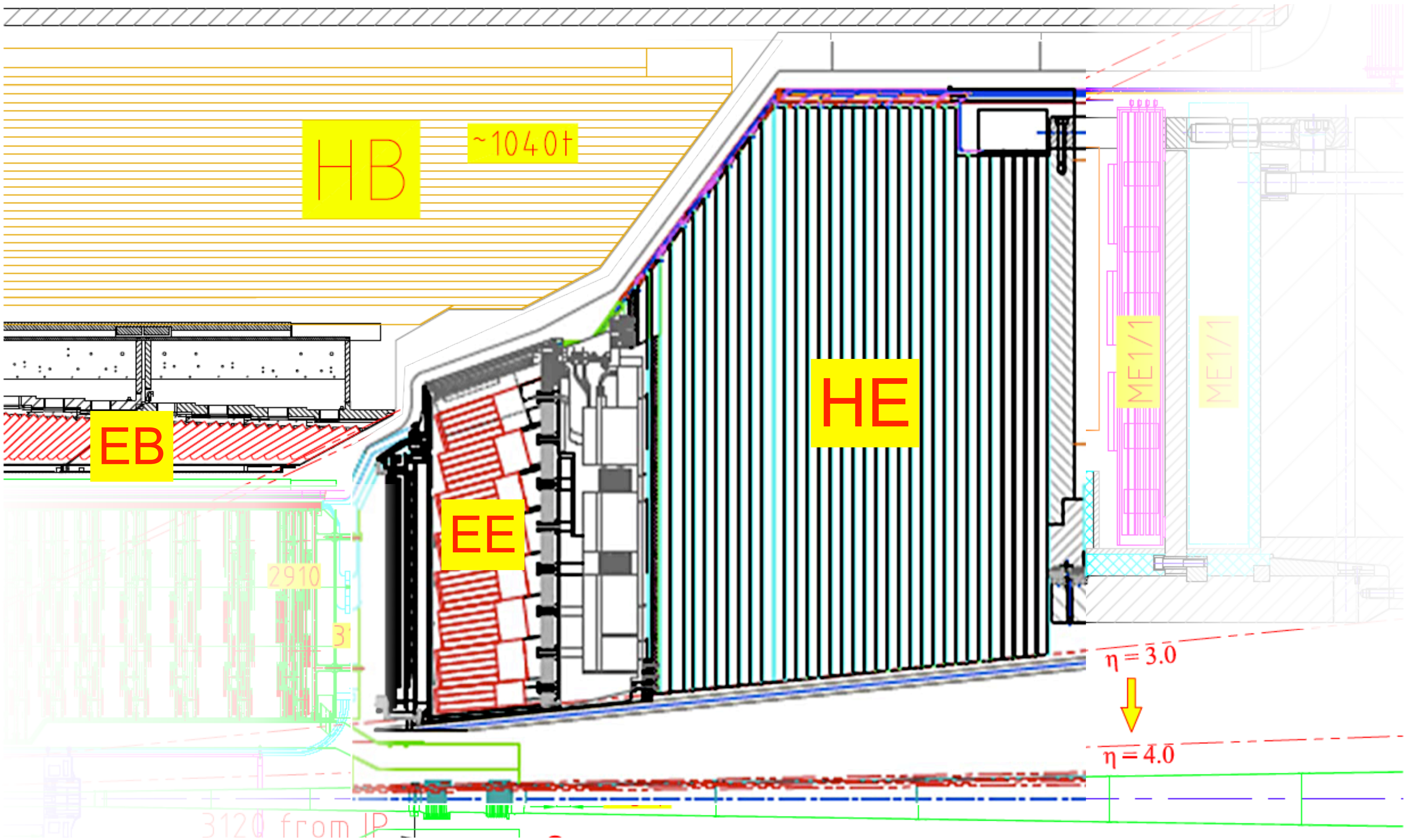
Phase1 upgrade to improve longitudinal segmentation

- HPDs in HB and HE replaced with SiPMs
  - smaller, radiation tolerant, stable in magnetic field
  - 3x Photon Detection Efficiency, lower noise
  - depth segmentation for improved measurement of hadronic clusters, backgrounds rejection and reweighing of radiation damage.



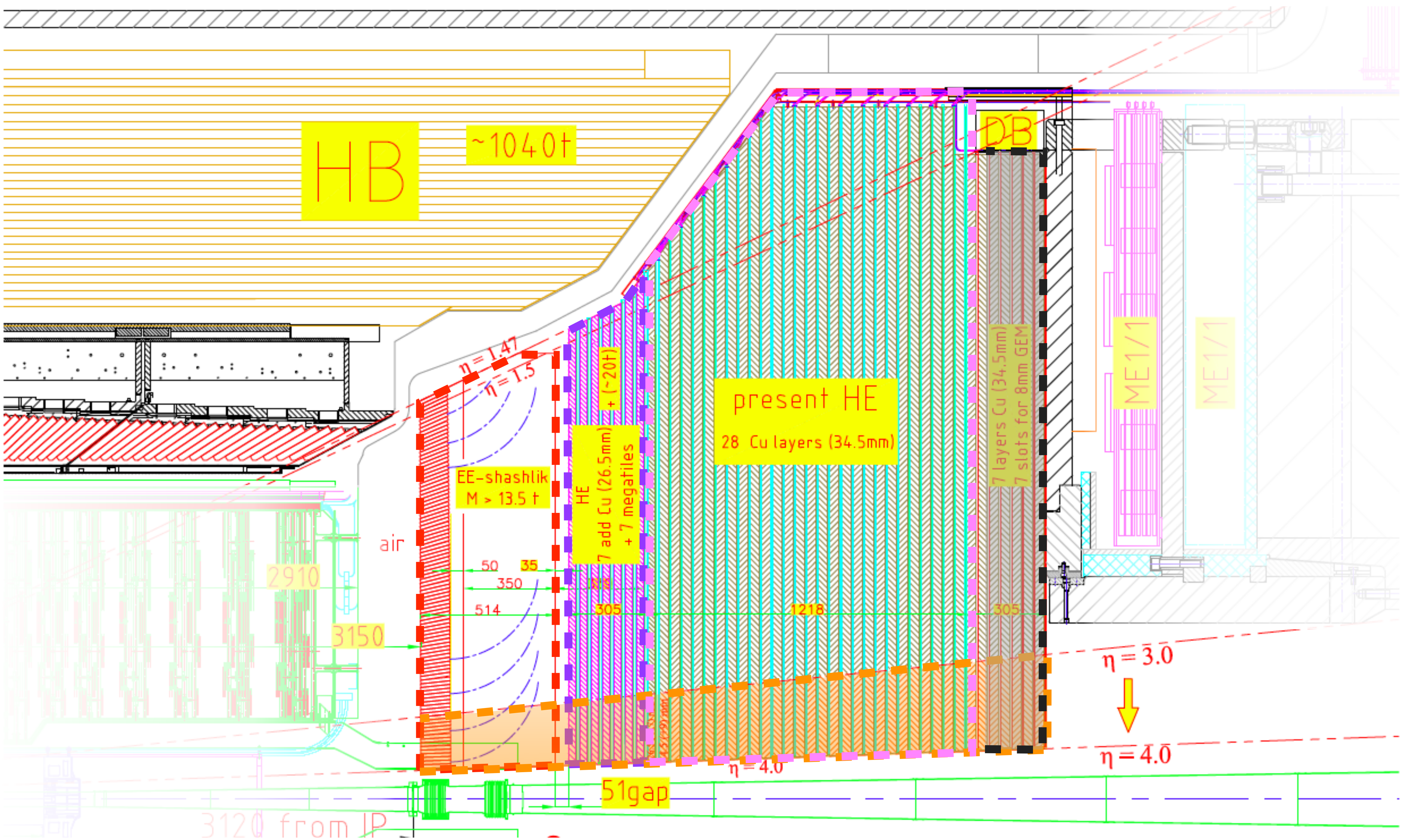
Endcap evolution (now)

Current calorimeter endcap system: PbWO crystals (ECAL, EE) + brass/ scintillator layers (HCAL, HE)



Endcap evolution (phase 2) - option 1

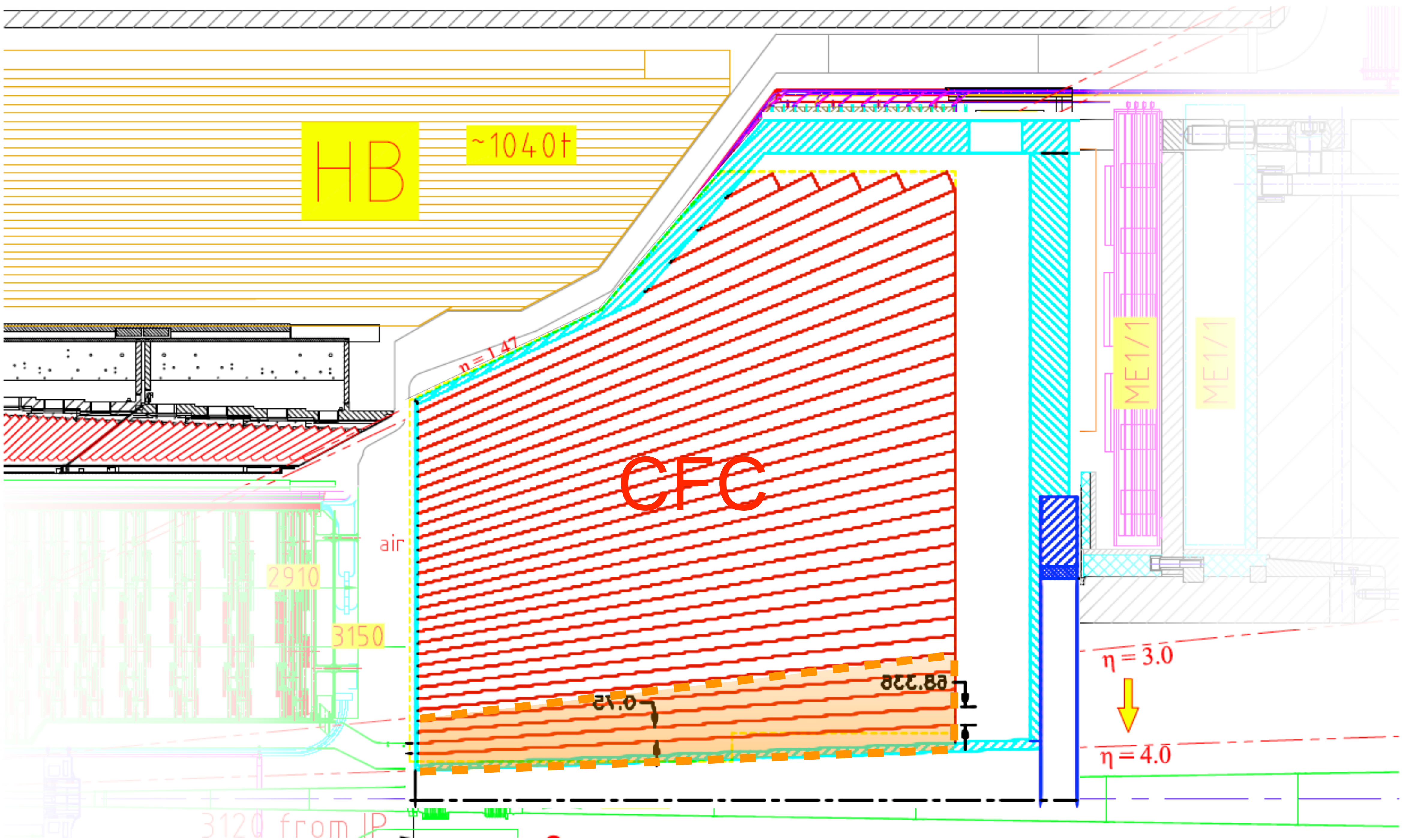
Traditional two compartment: **shashlik ECAL** + **rebuilt HCAL** (**with possible extra layers**). **Coverage up to |η|~4**. Room for the GEM muon stations.



Endcap evolution (phase 2) - option 2

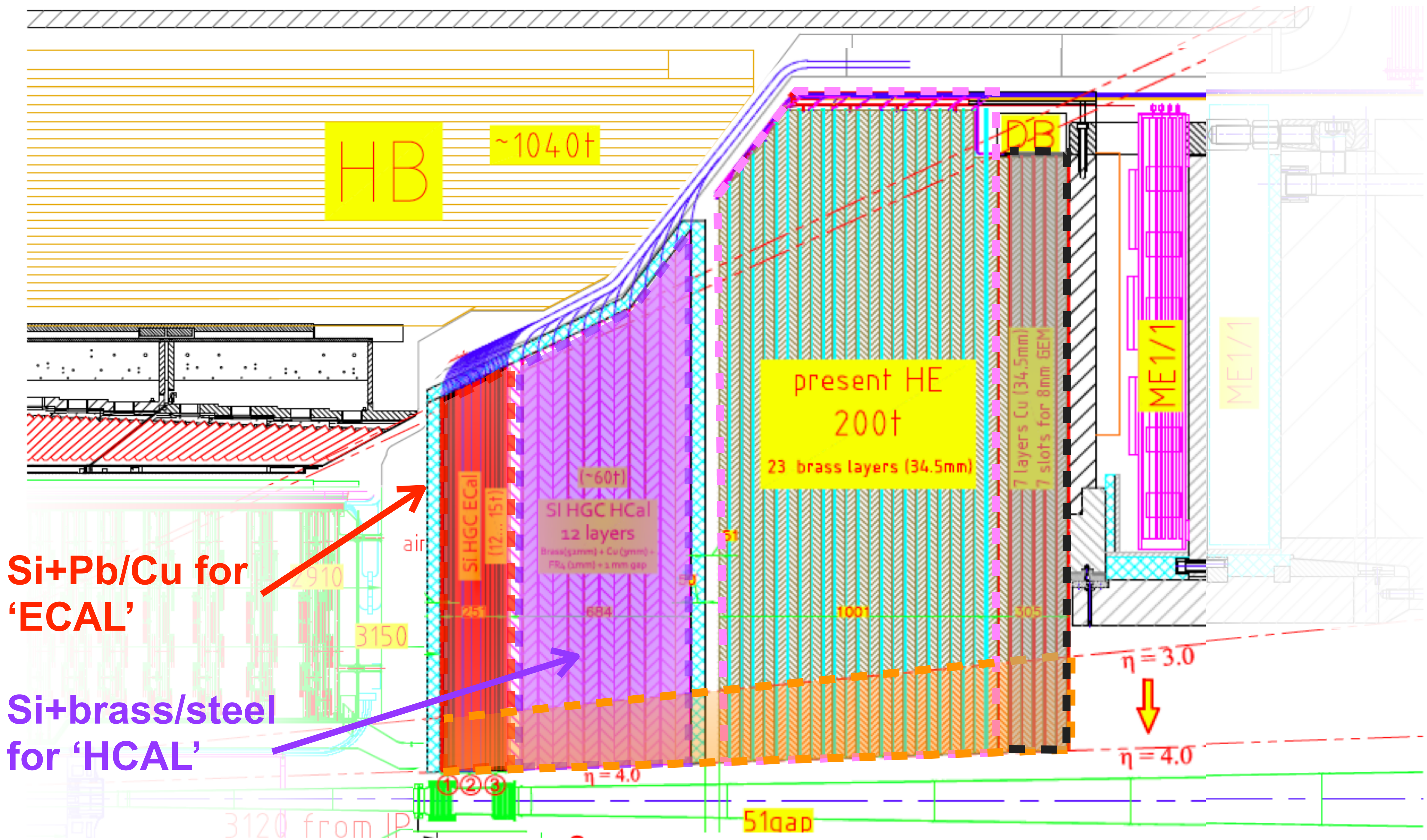
Combined Forward Calorimeter, CFC. Dual readout calorimeter.

Coverage up to |η|~4

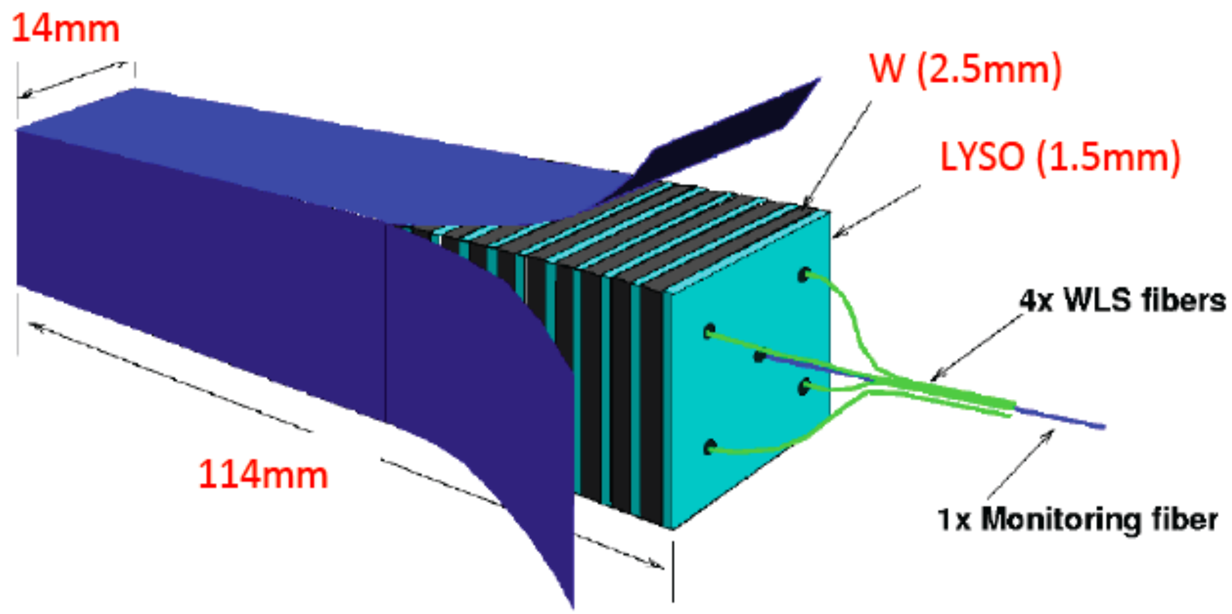


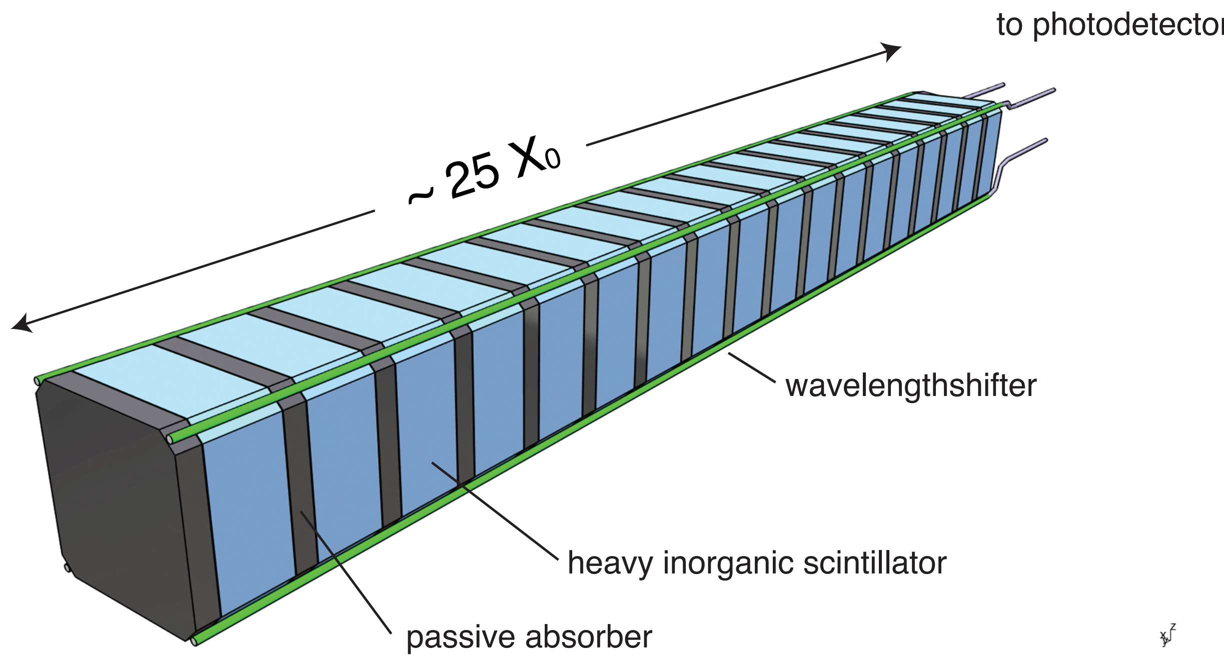
Endcap evolution (phase 2) - option 3

High Granularity Calorimeter (full imaging CALICE/PFCal concept). Backed up by *standard* rebuild HCAL. **Coverage up to |η|~4**.



ECAL shashlik options





28×W (2.5mm) +
29×LYSO(Ce) (1.5mm)
[Cerium-doped Lutetium Yttrium Orthosilicate]
Readout:
WLS Capillaries (4 per module)
Calibration Fiber (1 per module)

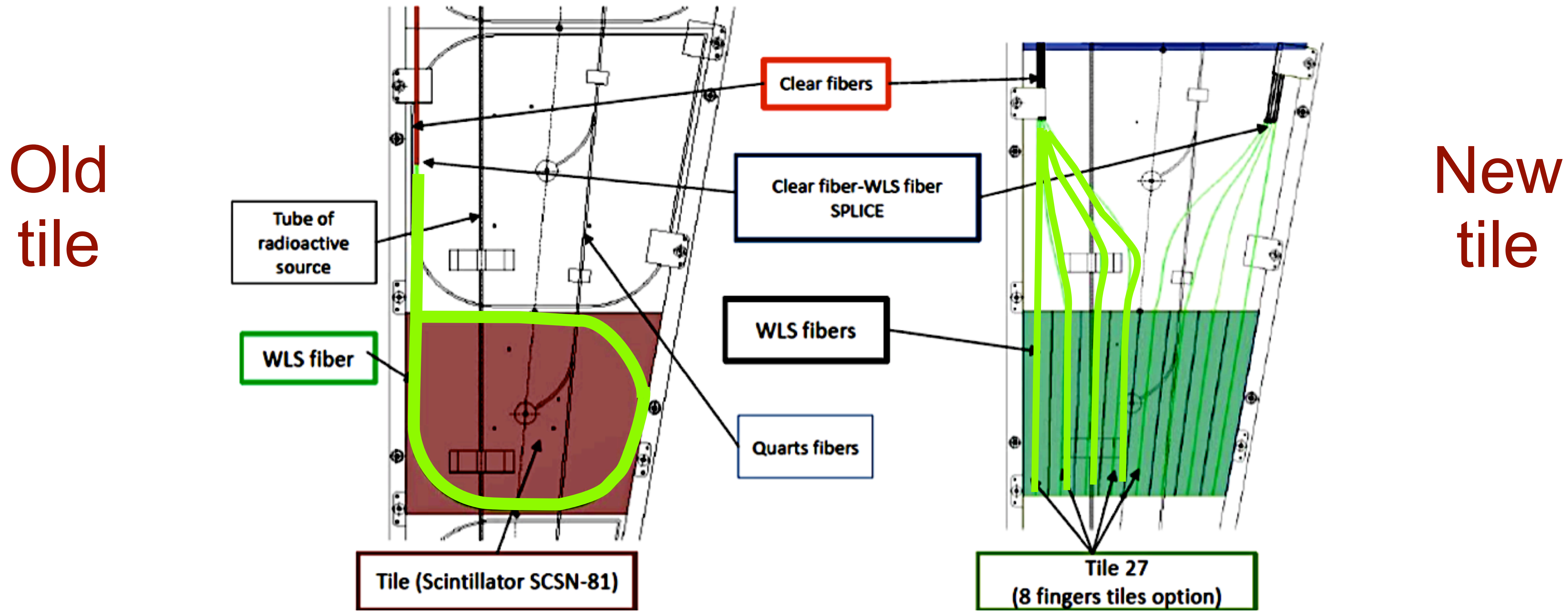
17 alternating layers of W (3mm) and CeF_3 (10mm).
[Cerium Fluoride]
Waveshifter is Cerium Doped Quartz fiber.

GaInP Photosensors (1,2 per module) - No depth segmentation

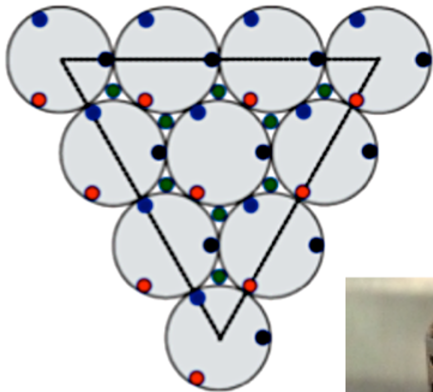
HCAL Endcap rebuild

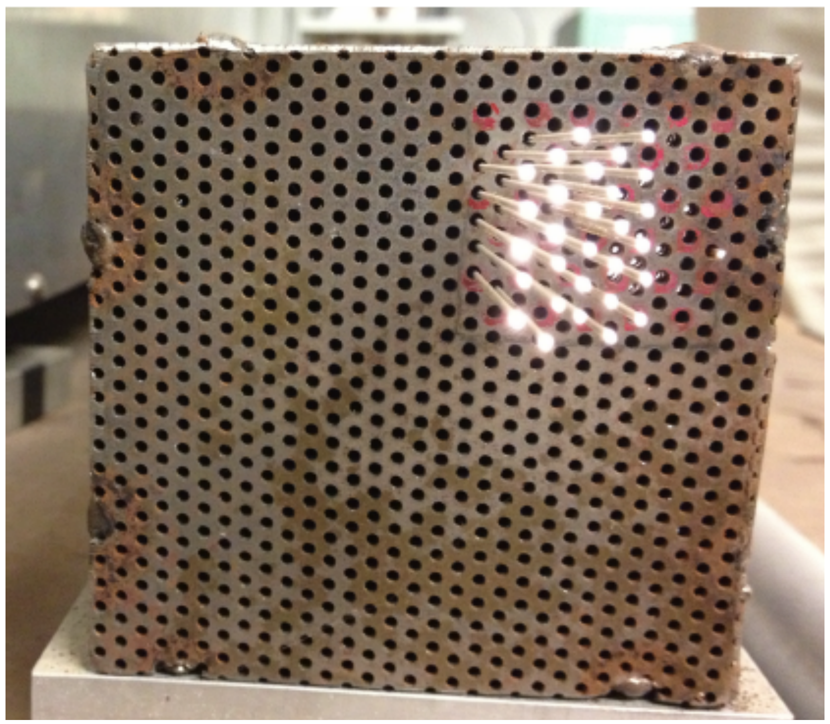
HE-rebuild option could either re-use present/existing endcap absorber, or be installed into new/similar absorber structure:

- full HCAL beyond Shashlik EE; only the back half of HCAL for HGC option
- New active material and readout (multiple, parallel WLS fiber) to mitigate radiation damage
- Increase segmentation transverse and longitudinal dimensions, to improve pile-up rejection capabilities
- Other alternatives are being evaluated

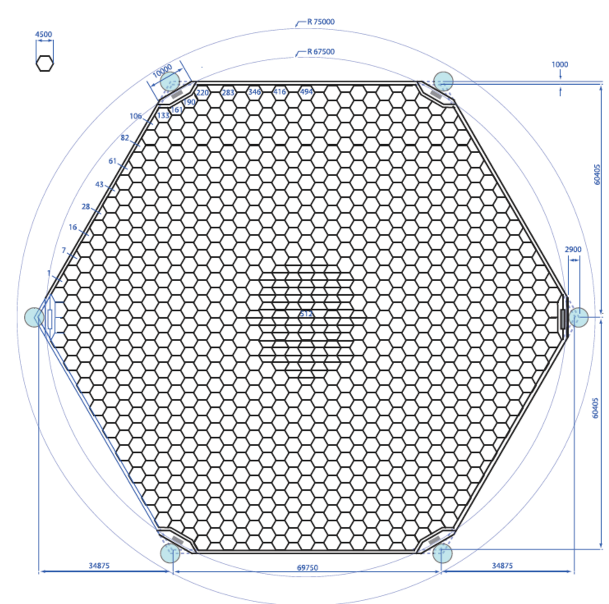


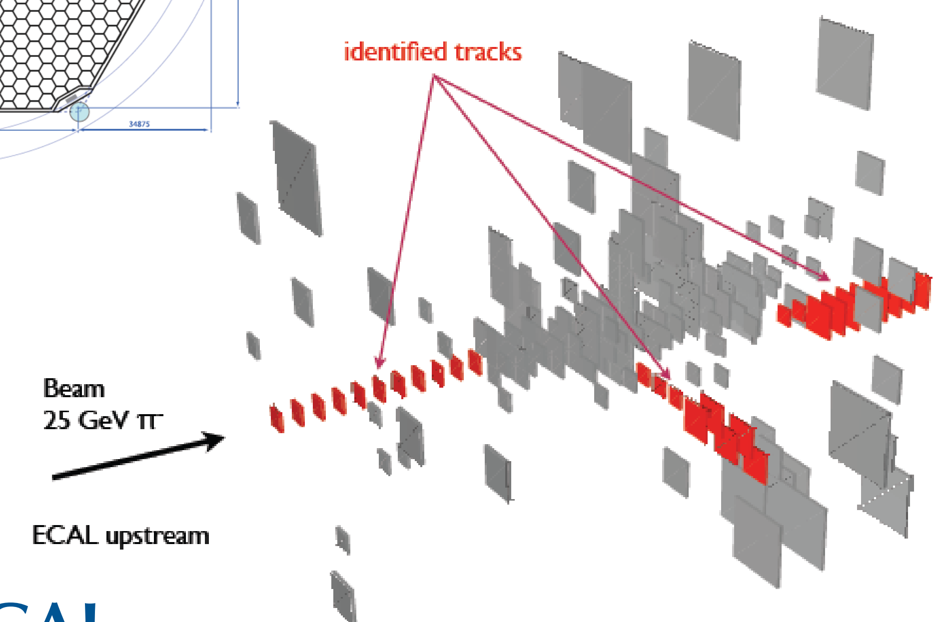
CFC and HGC concepts





6" wafer from ILC R&D





CFC

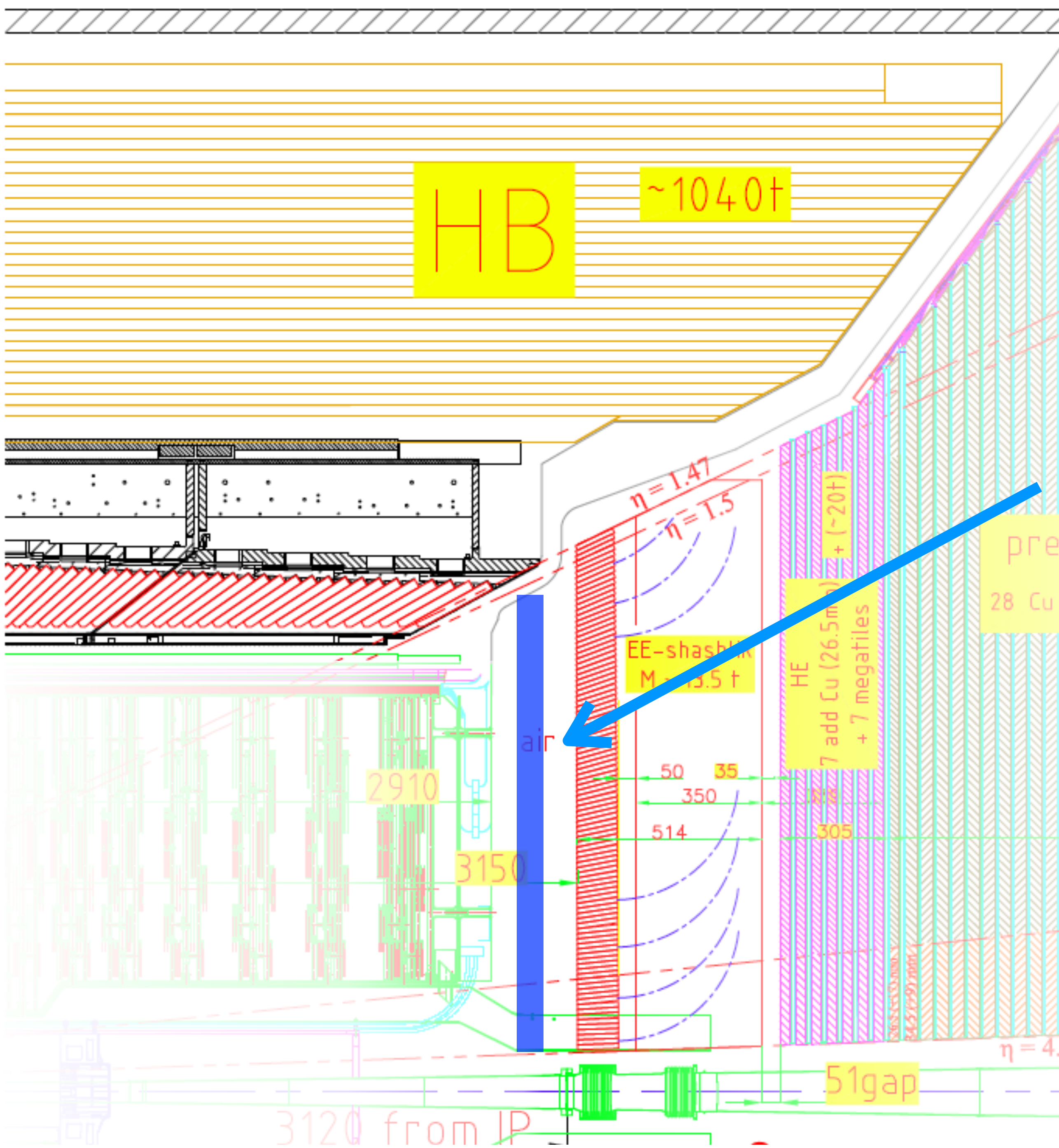
Dual fiber readout: scintillation and Cherenkov (based on DREAM concept); different doped/crystal fibers allow for e/h corrections for ultimate resolution

HGC/PFCAL

Based on CALICE concept; high longitudinal and lateral segmentation silicon detectors coupled to absorber allows for full reconstruction of the shower (sub)structure

Improving PU mitigation

Several options are evaluated to improve PU mitigation capabilities of calorimeters, especially in endcaps where the granularity is limited.



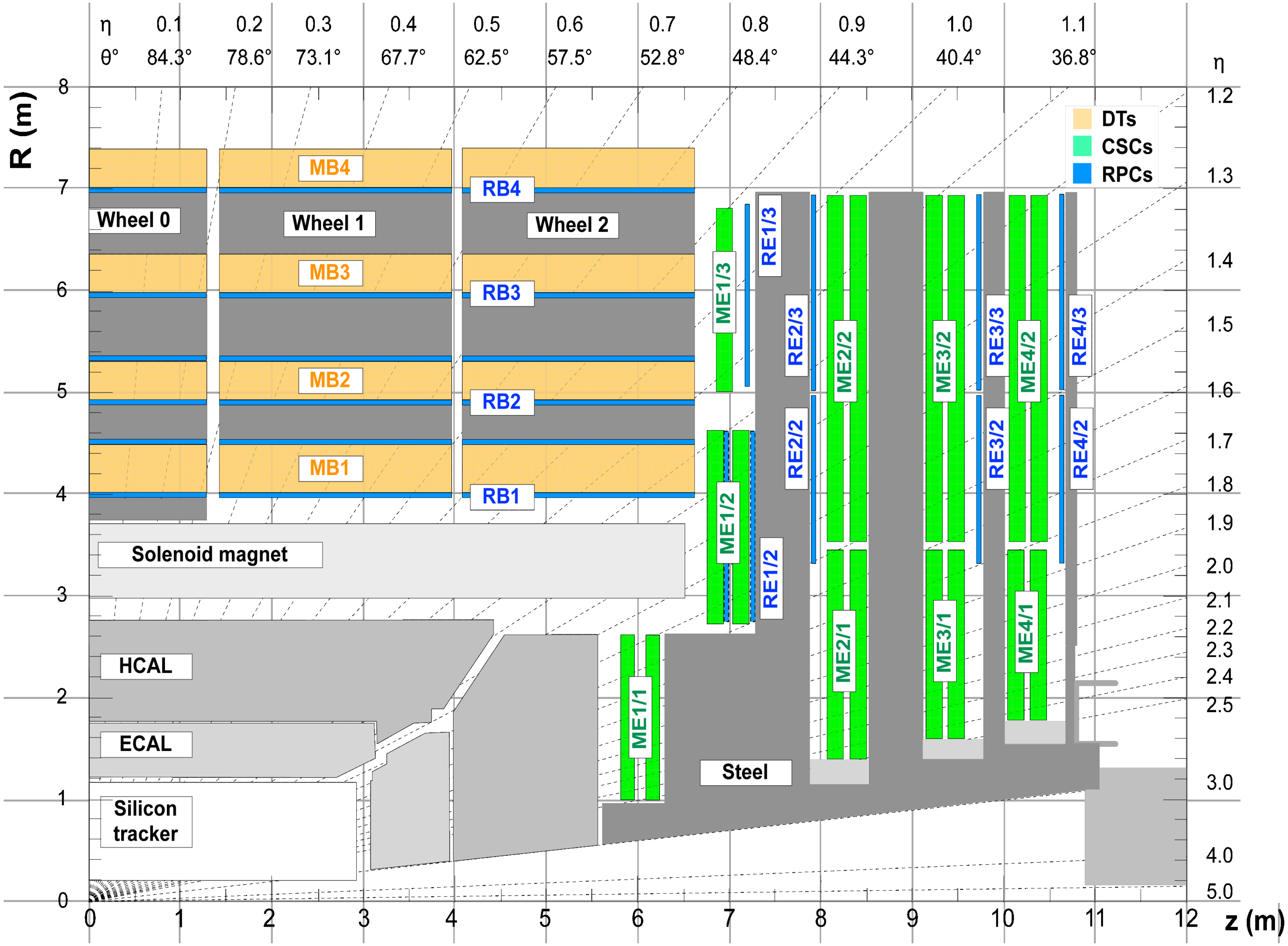
- Extract timing information from calorimeter itself (may require improved/special electronics)
- Pre-shower like configuration:
  MCP
  Micro-channel plates in various configurations under study;
  UFSD
  Ultra-fast silicon detector;

Resolutions in the 10ps-75ps range (sufficient to time tag a shower).

Muon system

Muon system evolution

Muon system layout being for 2015 data taking.



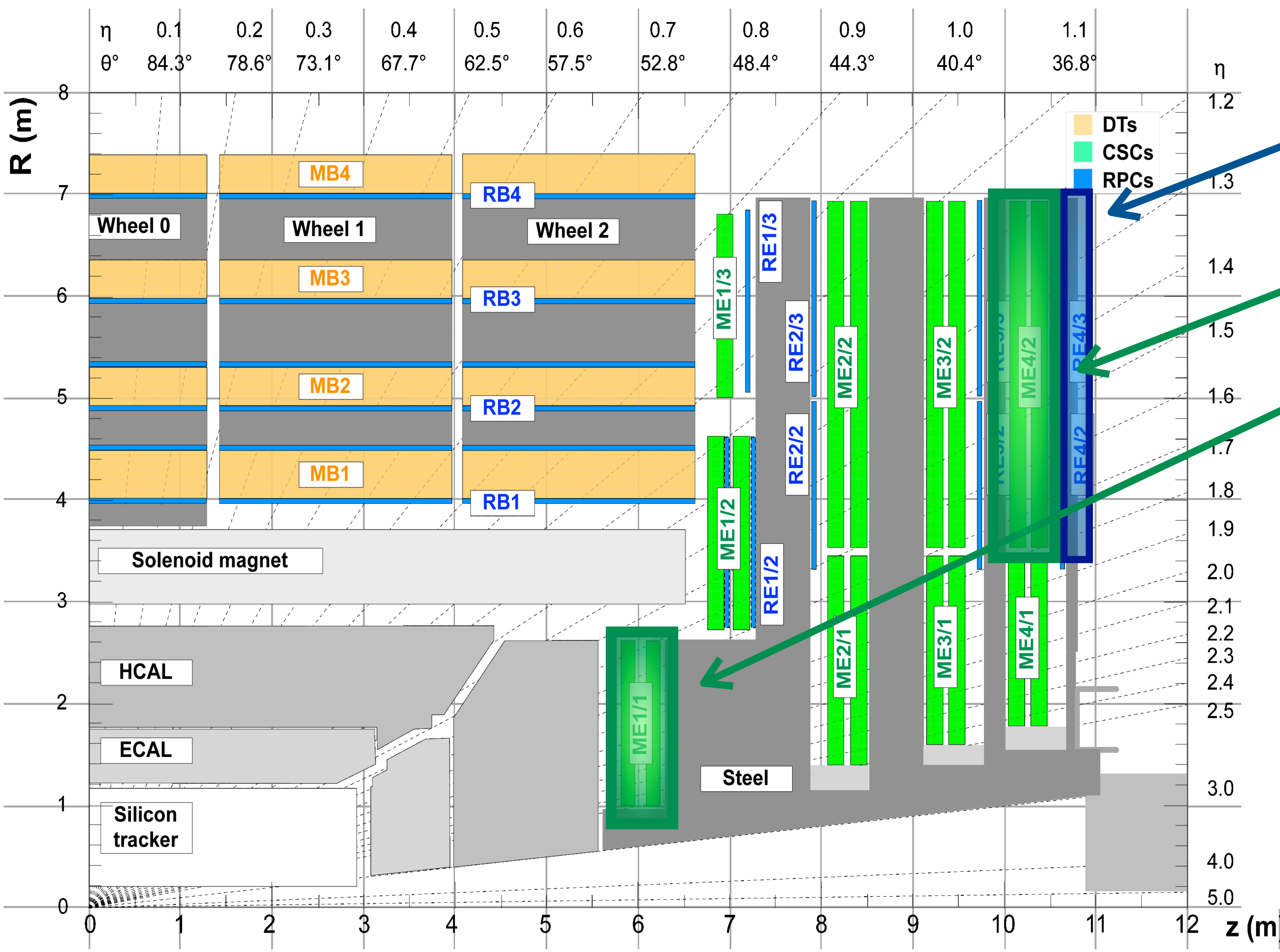
Drift Tubes (barrel)

Cathode Strip Chambers

Resistive Plate Chambers

Muon system evolution: during LS1 (now)

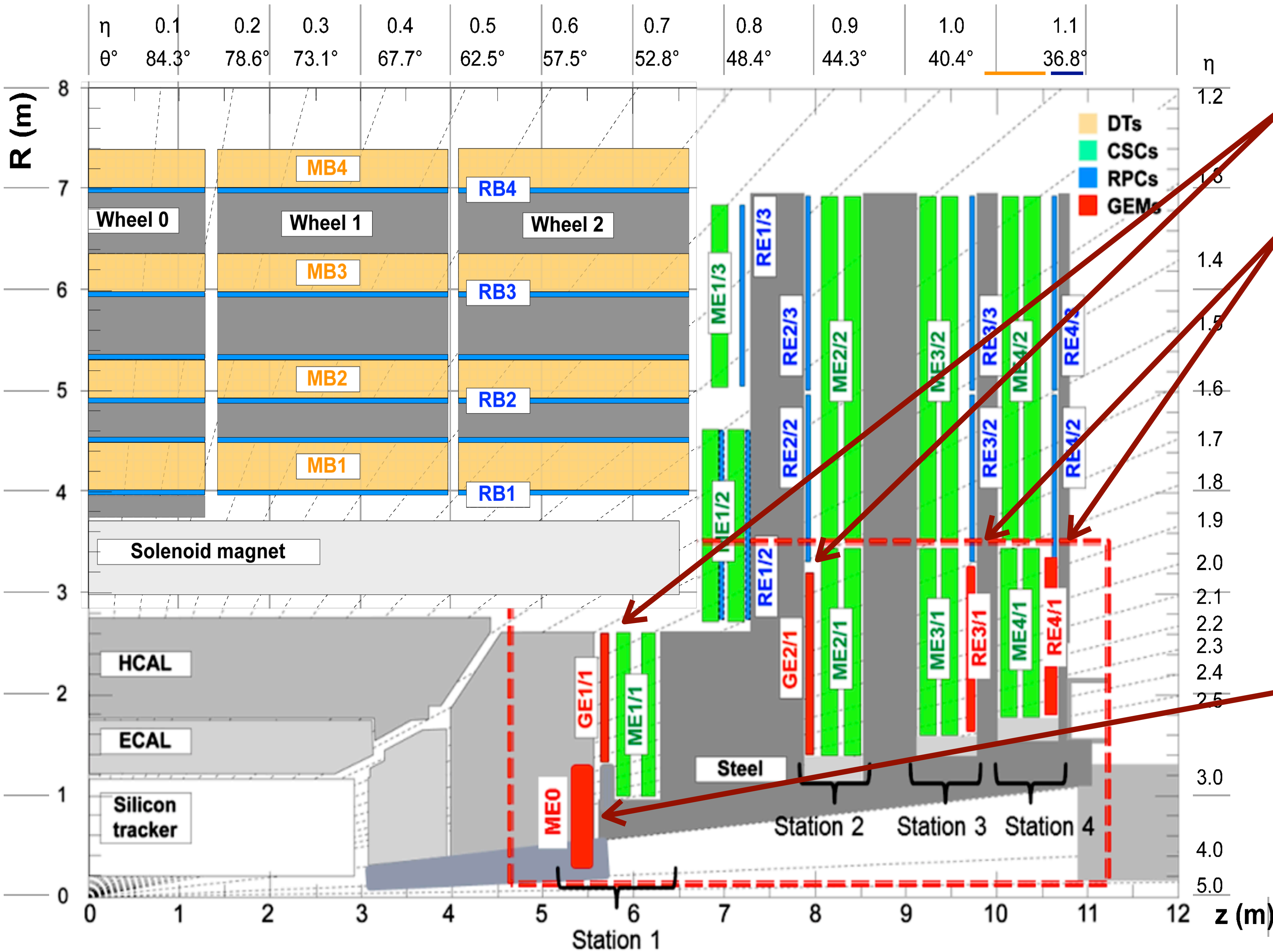
Consolidation of muon system in LS1 being finalized in the following weeks



- **RPC**:
  - RE4 installation
- **CSC**:
  - ME4/2 stations & shielding
  - ME1/1 electronics with finer granularity
- Also improving trigger electronics

Muon system evolution towards HL-LHC

Gas Electron Multiplier chambers and Glass RPC under study for performance and redundancy in high rate and high PU region

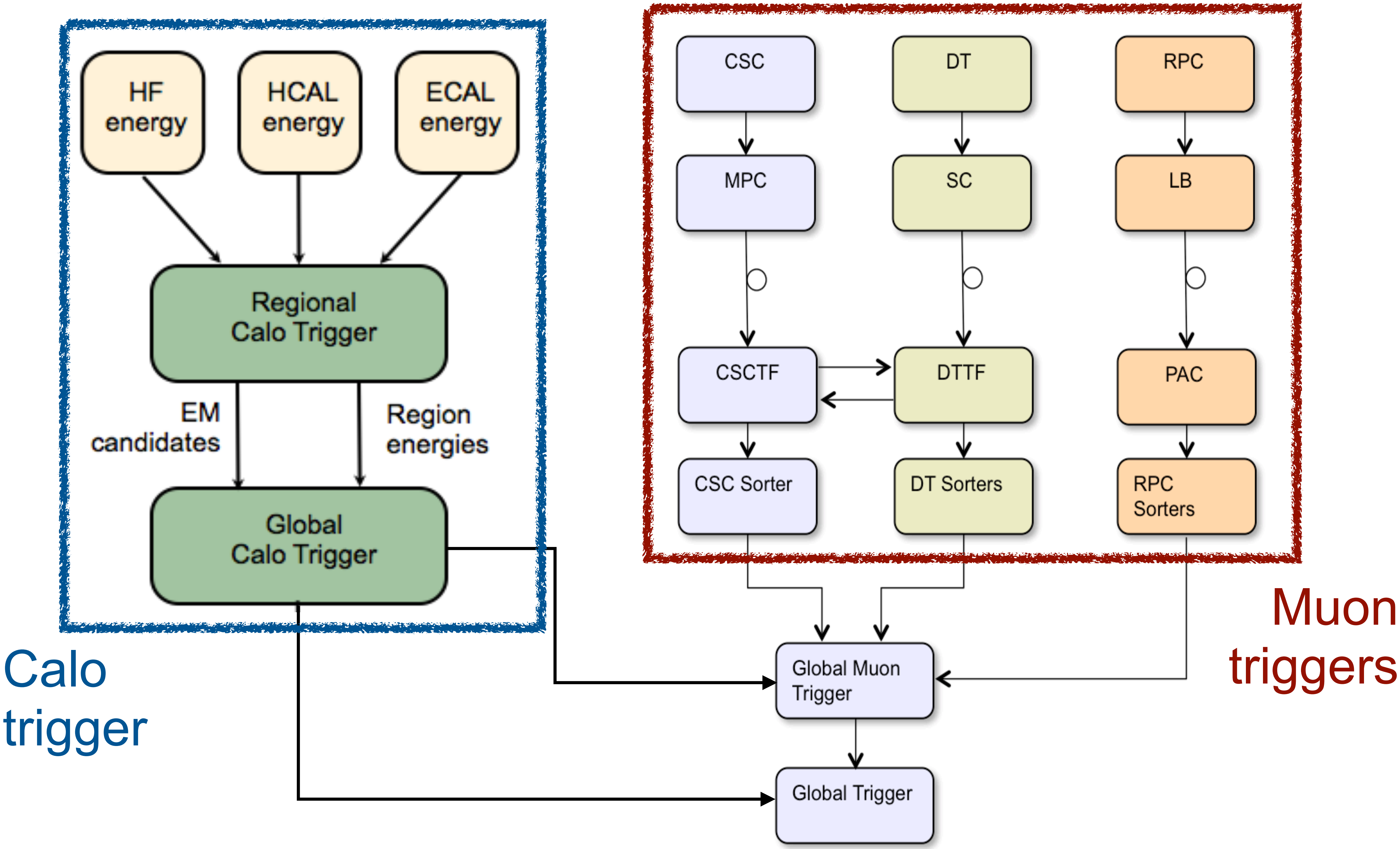


- Coverage |η|~1.6-2.4 under study
  - GEMs stations (P_T resolution)
  - Glass-RPC (timing to cut background)
  - Desirable to install GE1/1 in LS2 for early experience and fake muon rejection in trigger
- Coverage |η|<2.4
  - GEM tagging station coupled with extended pixel tracking
  - Need room from HE

Trigger system

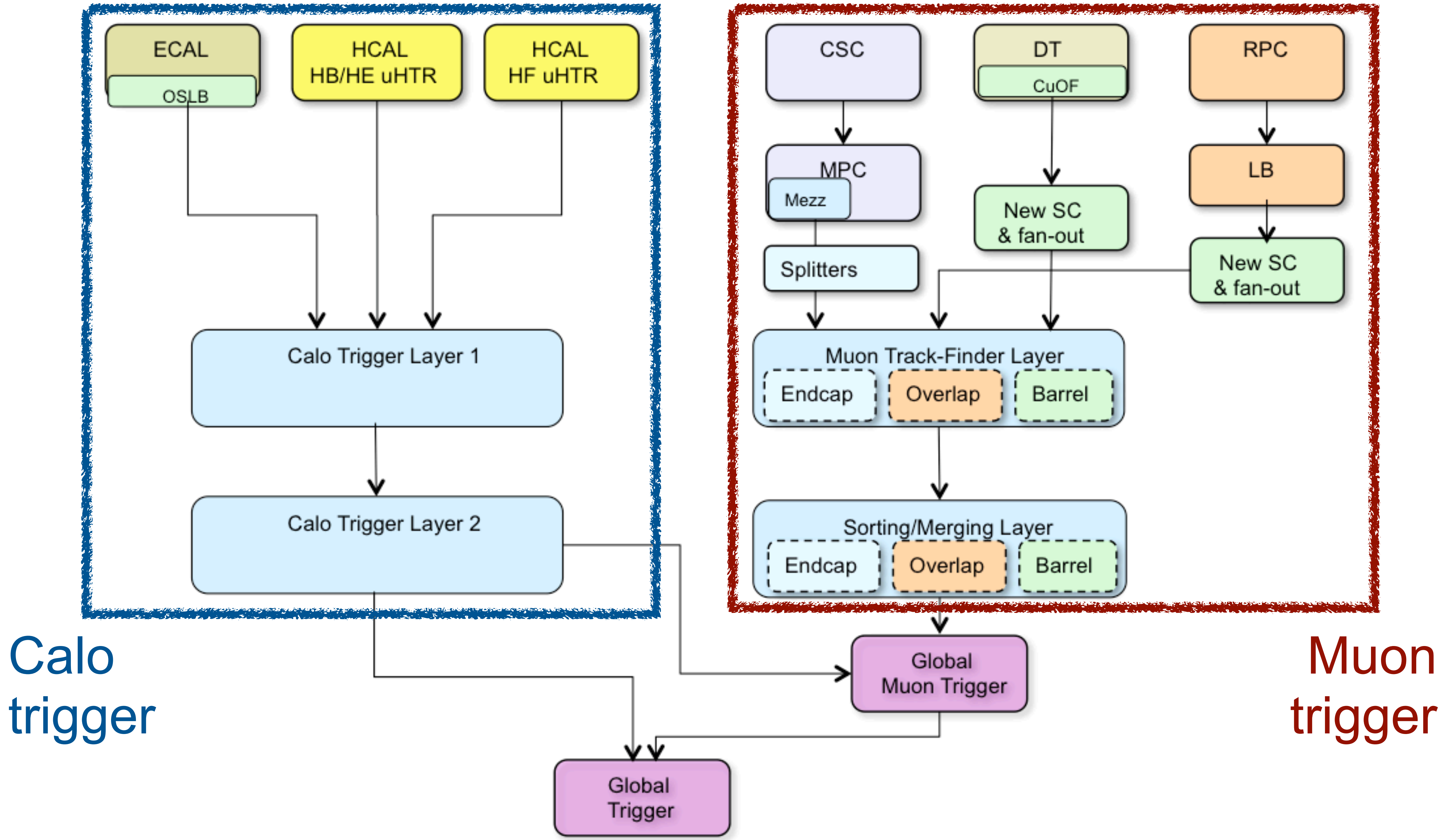
L1 trigger evolution (current)

Muon systems and calo informations combined at the very last stage (Global Muon Trigger and Global Trigger).



L1 trigger evolution (Phase 1 - 2016)

Hardware replaced; more uniform architecture; muon systems combination is anticipated and calorimetric objects are improved for better PU mitigation and isolation.



Trigger for Phase2

- **L1**: same architecture as Phase1 trigger with increased granularity (crystal level @EB) and ability to operate at 1MHz
- **HLT and DAQ**: upgraded to handle 1MHz into HLT and 10kHz output

Scenario	Input	Reduction rate	L1 output	Reduction rate	HLT output
2012	20MHz·20PU~400MHz	1/4000	0.1MHz	1/100	1kHz
HL-LHC	40MHz·**140PU**~5.6GHz	**1/5600**	**1MHz**	**1/100**	**10kHz**

- Reduction rates at 100-200PU are obtained by using more information at L1:
  - latency up to 10μs (this requires hardware upgrades)
  - track information available to all track trigger objects
- According to Moore law (computing, network, storage) this approach is technologically in the reach by LS3

Conclusions

- LHC physics program is extremely challenging
- It demands to the experiments requirements largely exceeding the design parameters
- CMS will cope with these requirements by a staged, extensive upgrade program
- Guidelines have been identified in terms of radiation tolerance, trigger performances, pile-up mitigation, physics performances
- Early upgrade steps are already in place and well advanced
- Proposals for the subdetectors that need to be replaced during LS3 for HL-LHC are actively under study
- Full performance assessment and final decisions to be taken within Summer within the preparation of the Technical Proposal.

Much more details in the specific talks during the Workshop