THE HIGH-GRANULARITY CALORIMETER FOR HL-LHC

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MOTIVATION FOR BUILDING THE HIGH GRANULARITY CALORIMETER

Physics Motivation of the HL-LHC:

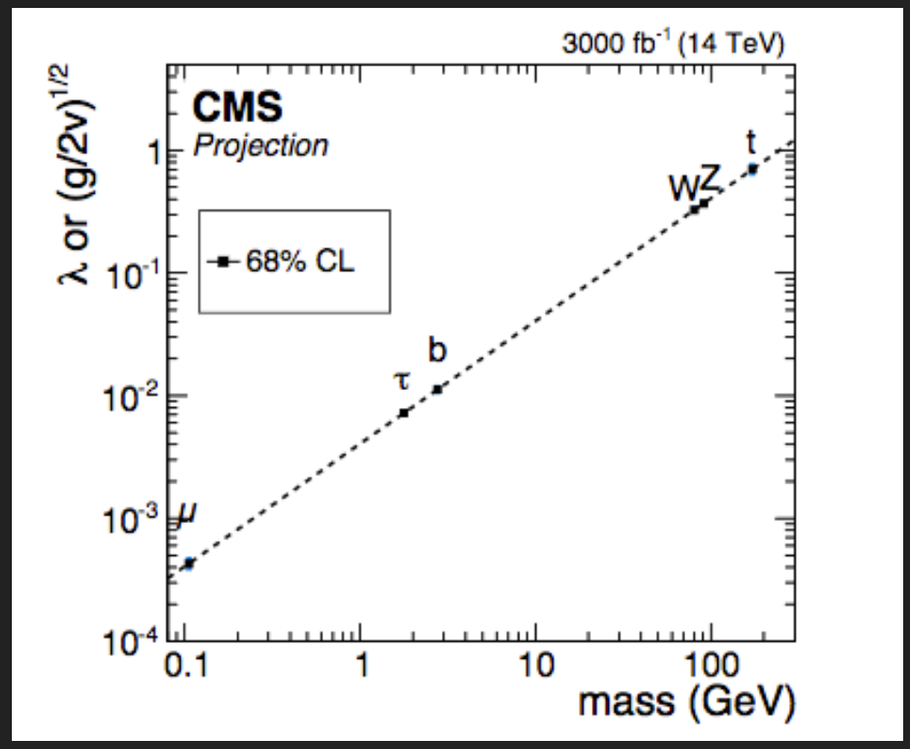
- Studying properties of the Higgs boson is central to the physics program at the LHC
- High precision measurement of the Higgs boson coupling (including to second generation fermions and self coupling) is a goal of the HL-LHC
- Study direct detection of dark matter (Run I results show considerable sensitivity)

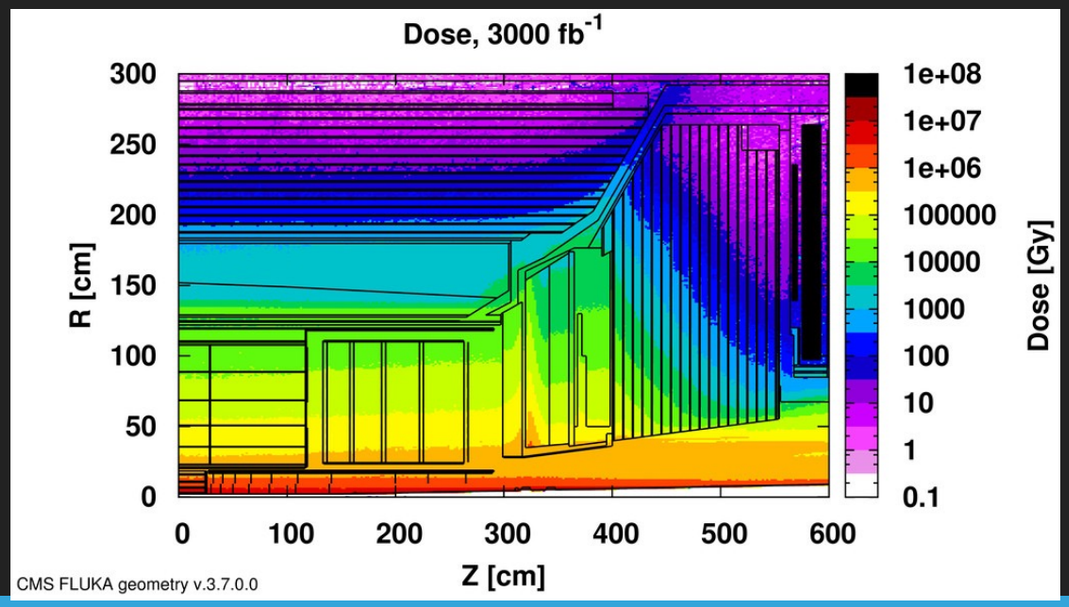
Challenges of the HL-LHC environment:

- Radiation changes by a factor of ~100 between η = 1.48 and η = 3
- Current endcap detectors cannot survive the radiation damage introduced after collecting 3000 fb^{-1} of data

Detector Requirements:

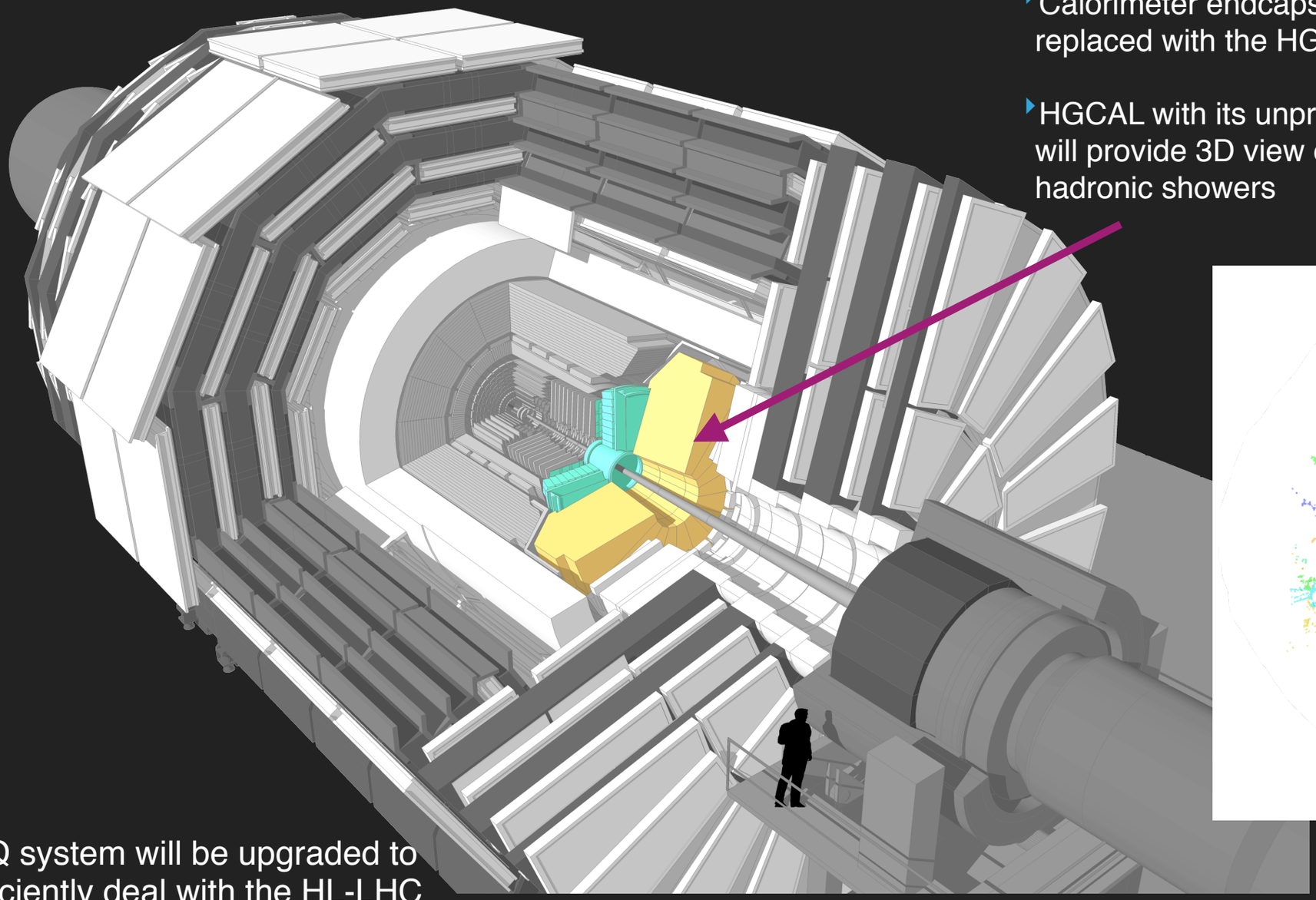
- The active layers of the HGCAL are made up of Si/scintillator, due to their radiation tolerance



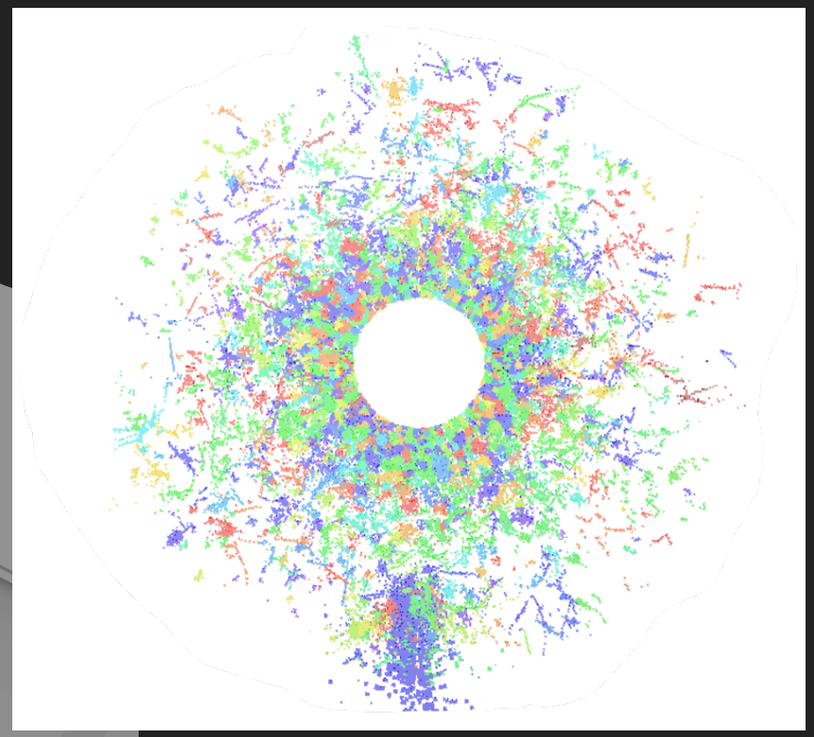


EXPECTED DOSE OF IONIZING RADIATION ACCUMULATED IN THE EB, HB, EE, AND HE AFTER 3000 fb^{-1}

HIGH-LUMINOSITY LHC PROGRAM AT A GLANCE



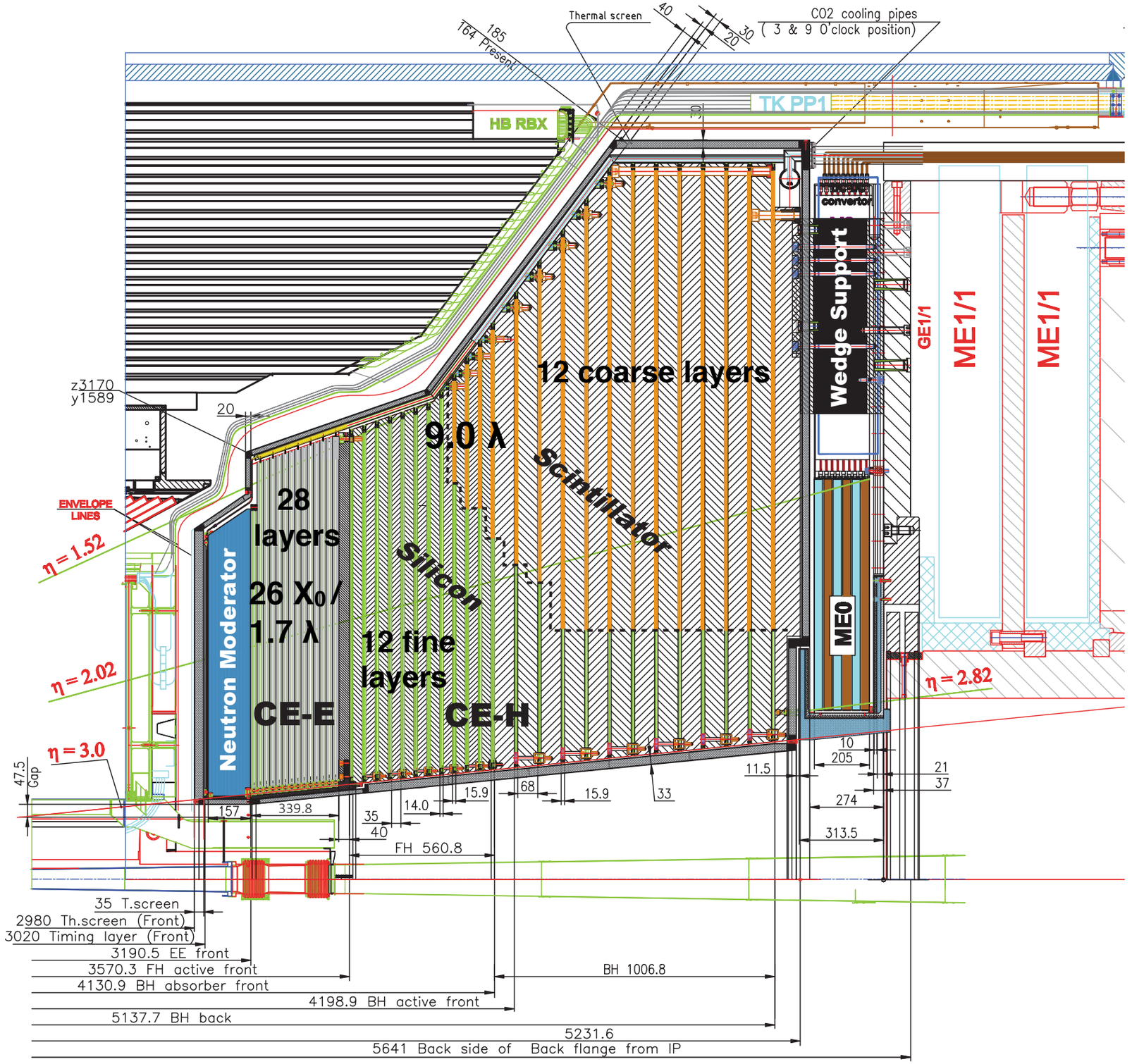
- Calorimeter endcaps will be completely replaced with the HGCAL
- HGCAL with its unprecedented granularity will provide 3D view of electromagnetic and hadronic showers



- DAQ system will be upgraded to sufficiently deal with the HL-LHC conditions
- Considerable R&D for software and computing needs and development of efficient algorithms for reconstruction

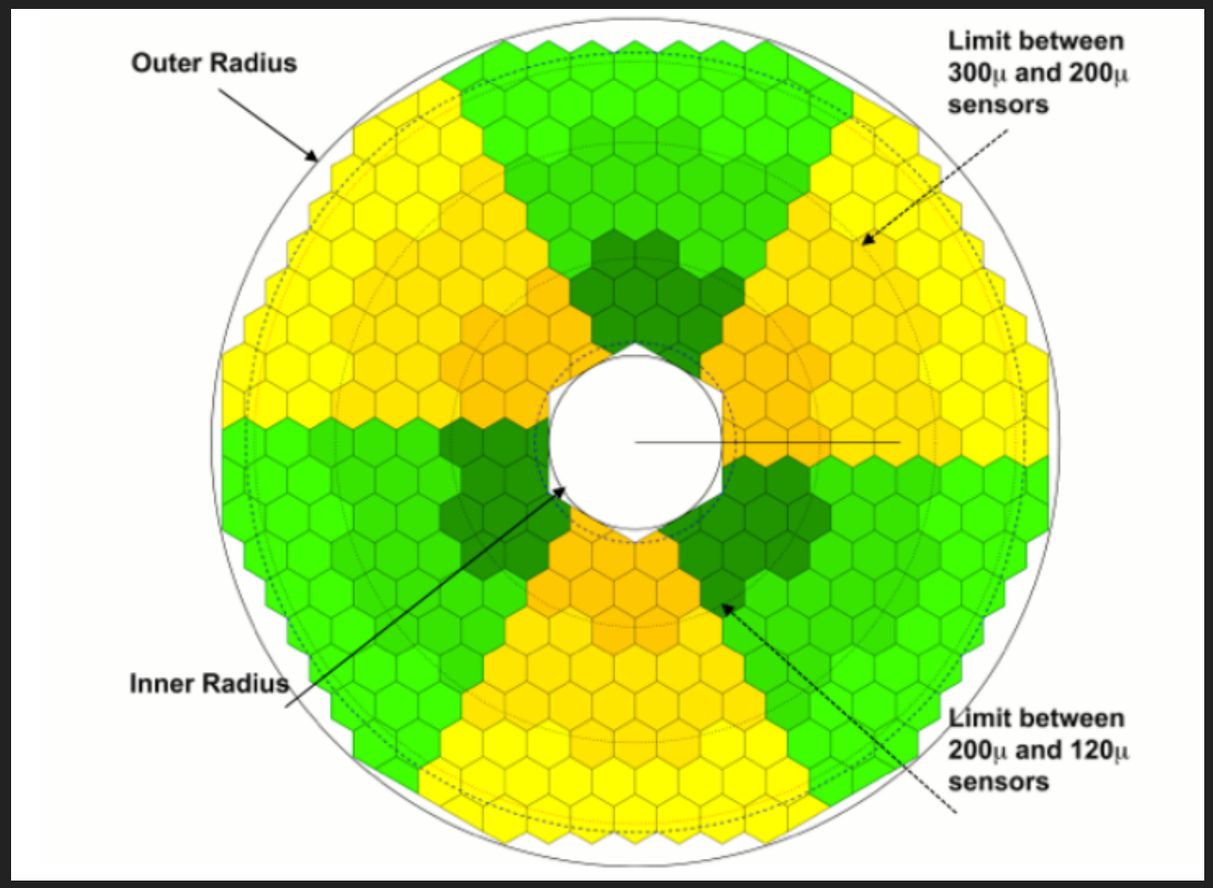
TECHNICAL DESIGN OF THE HGCAL

- HGCAL: **electromagnetic compartment** (CE-E) followed by a **hadron compartment** (CE-H)
- ECAL (CE-E) : 28 layers with Si + Lead/ Steel
- HCAL (CE-H) : Si/ Scintillator + Steel
- Si covers 600 m^2 : ~ 3 X CMS Tracker volume
- Hadronic compartment contains 500 m^2 of plastic scintillator with on-tile SiPM readout

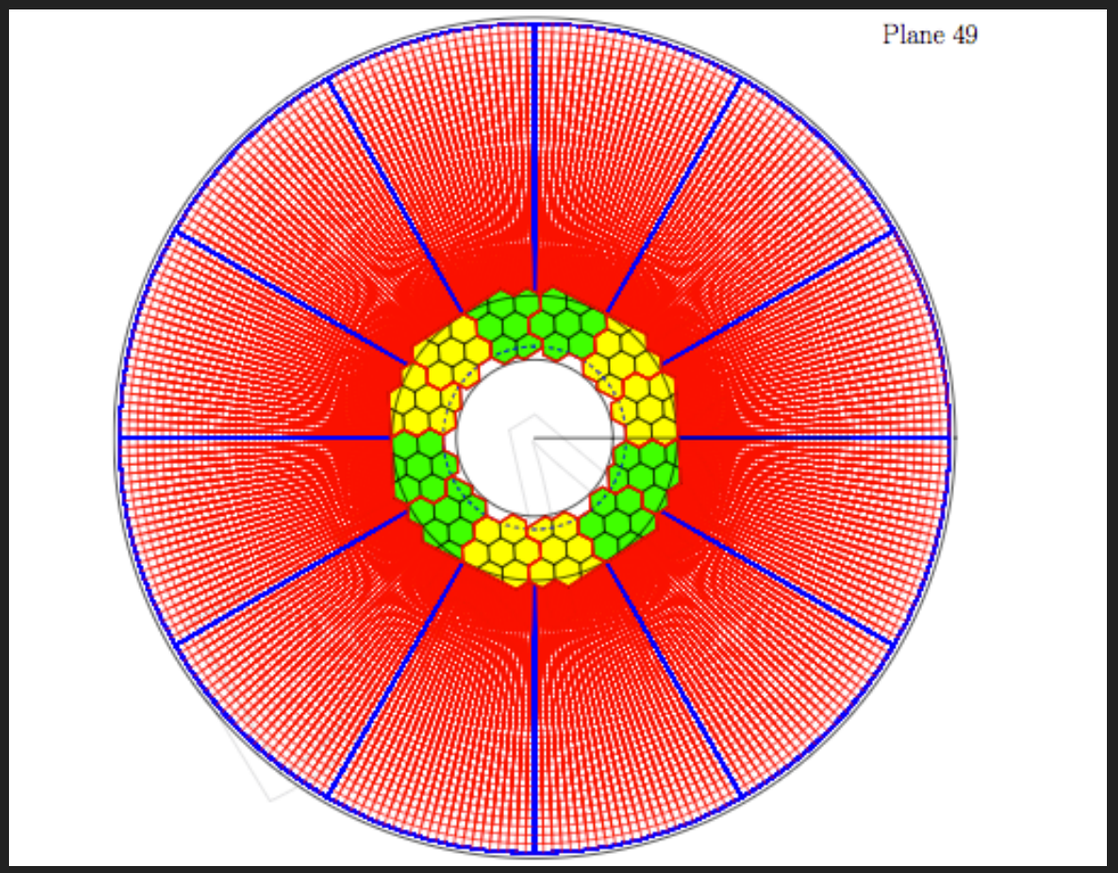


SENSOR LAYOUT

- HGCAL sensors will have 3 different active thicknesses:
  - optimized by considering charge collection and operation conditions
  - 120 µm, 200 µm and 300 µm



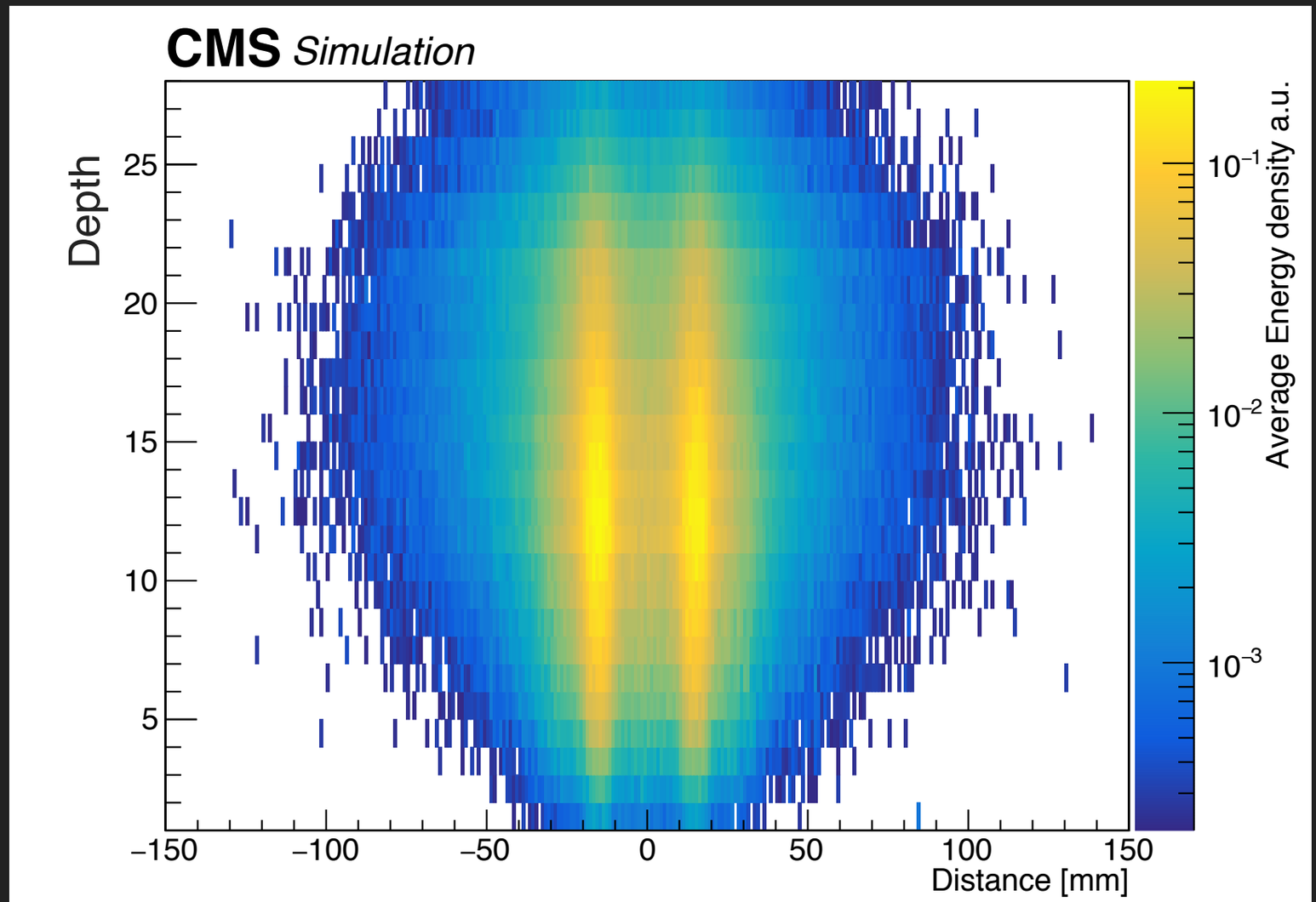
- 9th layer of the CE-E
- Layer shows layout of silicon



- 22nd layer of the CE-H
- Layer shows layout of wafers and tiles

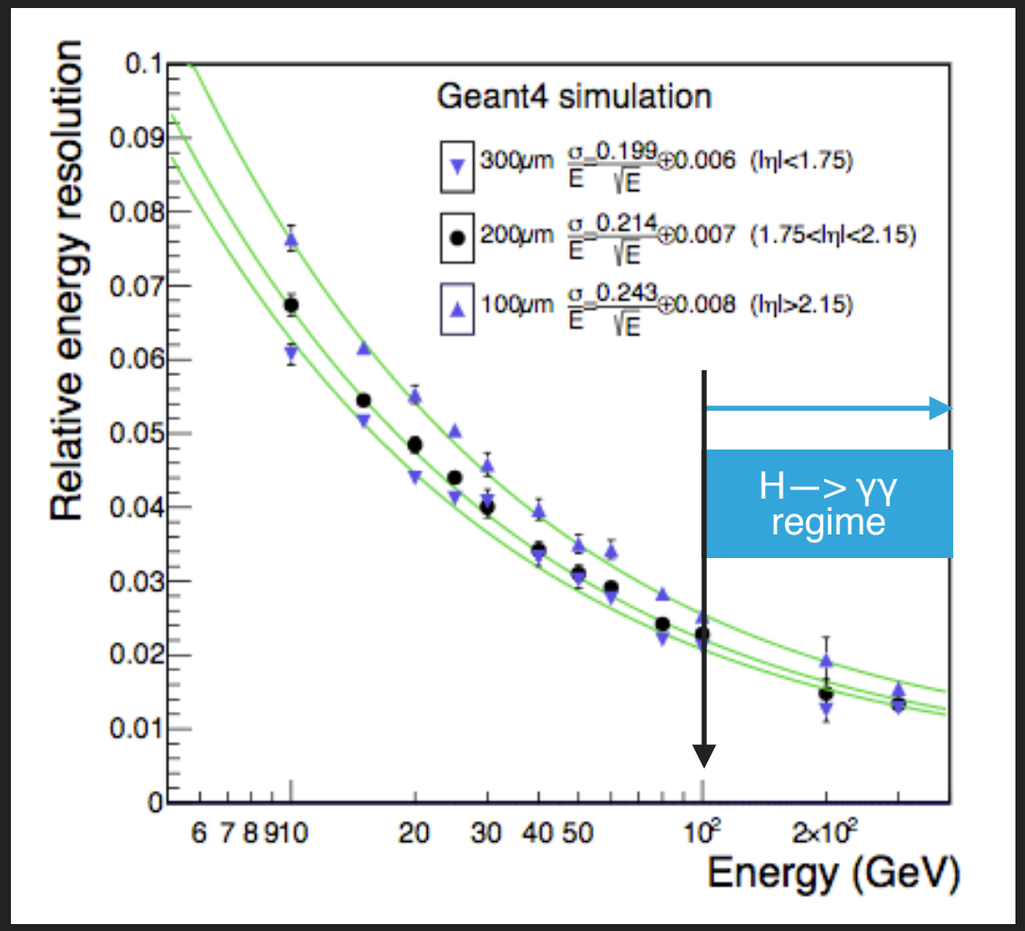
EVENT RECONSTRUCTION

- The HGCAL provides unprecedented spatial granularity for a calorimeter
- This enables excellent identification of electrons and photons
- The calorimeter also allows for the identification of muons

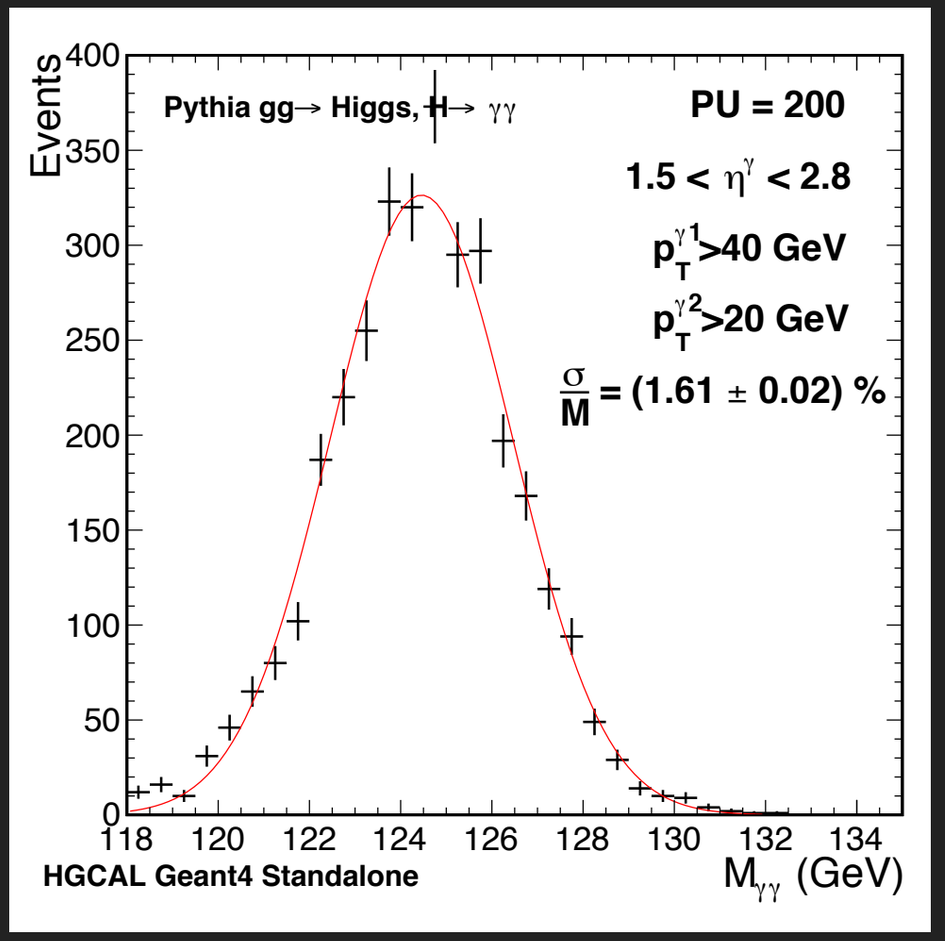


ENERGY DEPOSITED IN THE HGCAL BY PAIRS OF UNCONVERTED PHOTONS OF ENERGY = 80 GEV (PT = 14.4 AT ETA=2.4) SEPARATED BY 3 CM

PHYSICS PERFORMANCE OF THE HGCAL



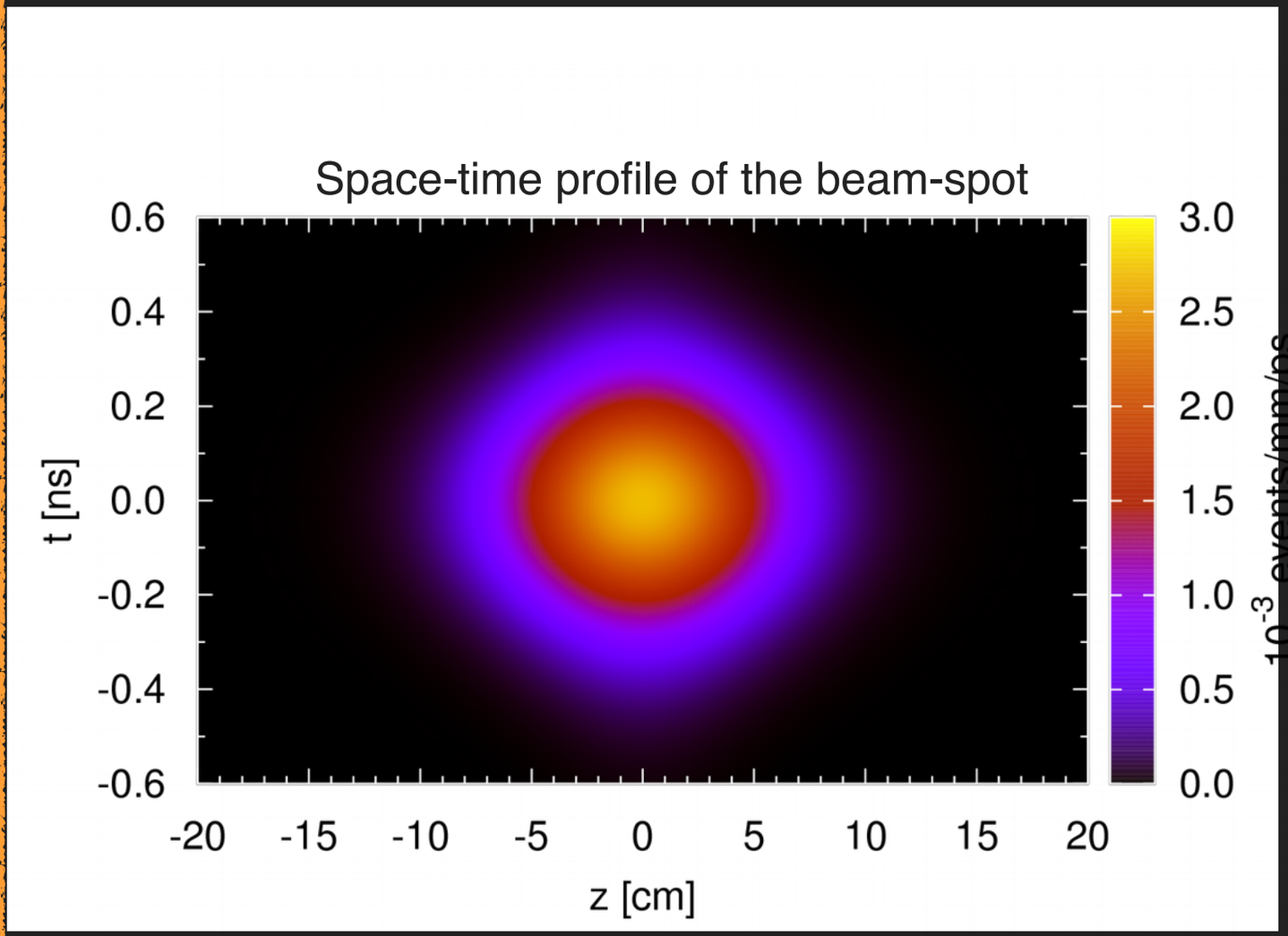
- Energy resolution of incident electrons on the HGCAL for various sensor thicknesses



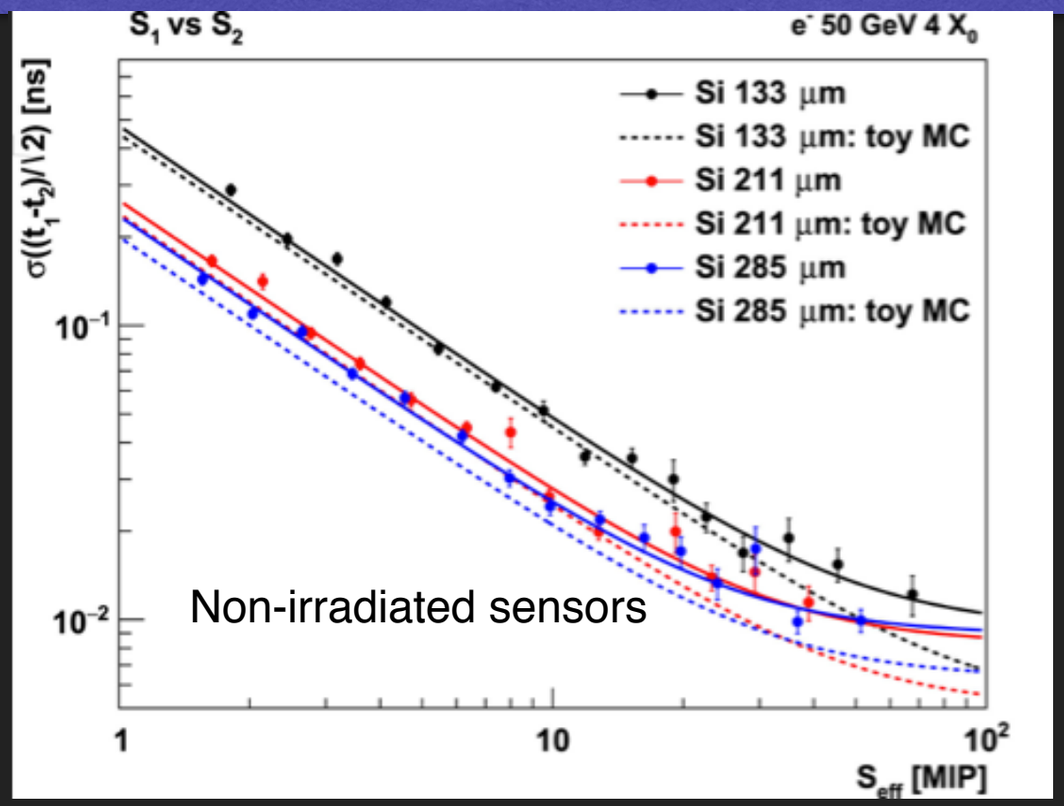
- H —> γγ mass resolution is 2 GeV

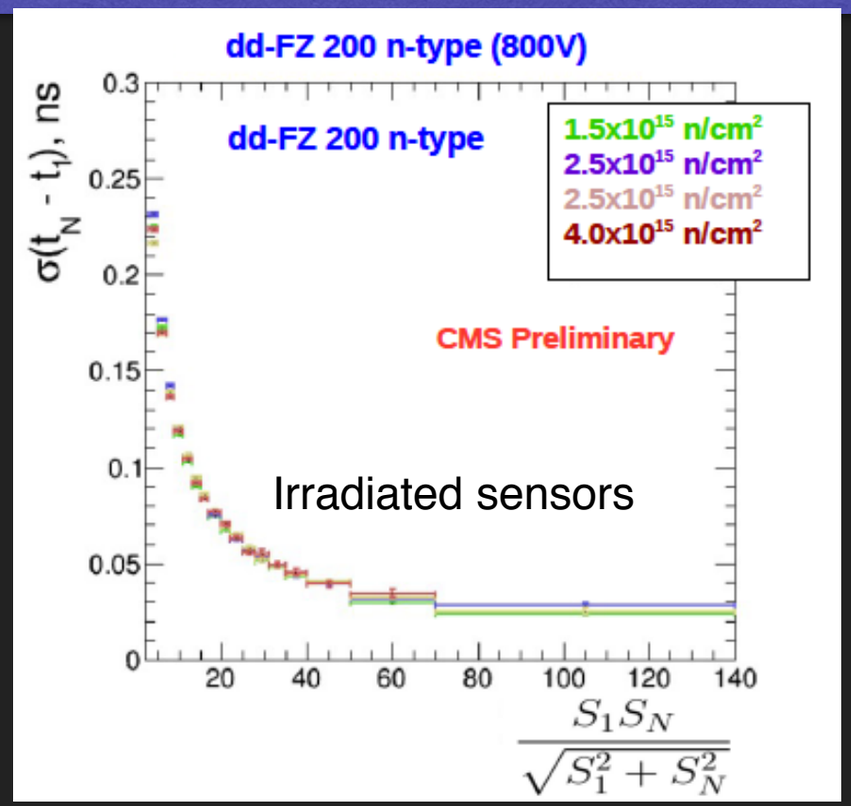
MOTIVATION FOR PRECISION TIMING

- Interactions in time are spread over 100-200 ps
- Precision timing can be used to distinguish between overlapping vertices in space
- Also to identify interactions from the shower and hence discriminate against PU
- High energy electromagnetic showers have a shower timing resolution of a few ps



PRECISION TIMING RESULTS FROM TEST BEAM STUDIES





- The timing resolution of two silicon sensors as a function of the signal strength (MIPs) and as a function of the signal-to-noise ratio were measured with the test beam
- Solid lines represent fits to a form: $\sigma = \sqrt{\left(\frac{A}{x}\right)^2 + C^2}$
- For $S_{eff} > 80$ MIP, the timing resolution is 20 ps
- Similar performance between irradiated and non-irradiated sensors

CONCLUSION

- A brief overview of the High-Granularity Calorimeter was presented
- The HGCAL provides unprecedented spatial granularity
- It enables excellent identification of electrons, photons and even muons!
- It is the first calorimeter to have precision timing capabilities, leading to the reduction of pile-up, one of the biggest challenges of the HL-LHC environment
- Most results are from the Technical Proposal and the timing performance paper:
  - https://cds.cern.ch/record/2020886/files/LHCC-P-008.pdf
  - http://www.sciencedirect.com/science/article/pii/S016890021730414X
- The HGCAL-TDR will be published by the end of the year. Stay tuned!

ADDITIONAL MATERIAL

HIGH-LUMINOSITY LHC PROGRAM AT A GLANCE

THE TRACKER

- The Tracker will be completely replaced
- Granularity of pixels and outer tracker to be increased by factor of ~ 4
- Improved pT resolution and minimize rate of photon conversions
- Improved b-tagging and hadronic tau reconstruction

THE CALORIMETERS

- Calorimeter endcaps will be completely replaced with the HGCAL
- HGCAL with its unprecedented granularity will provide 3D view of electromagnetic and hadronic showers

MUON ENDCAPS

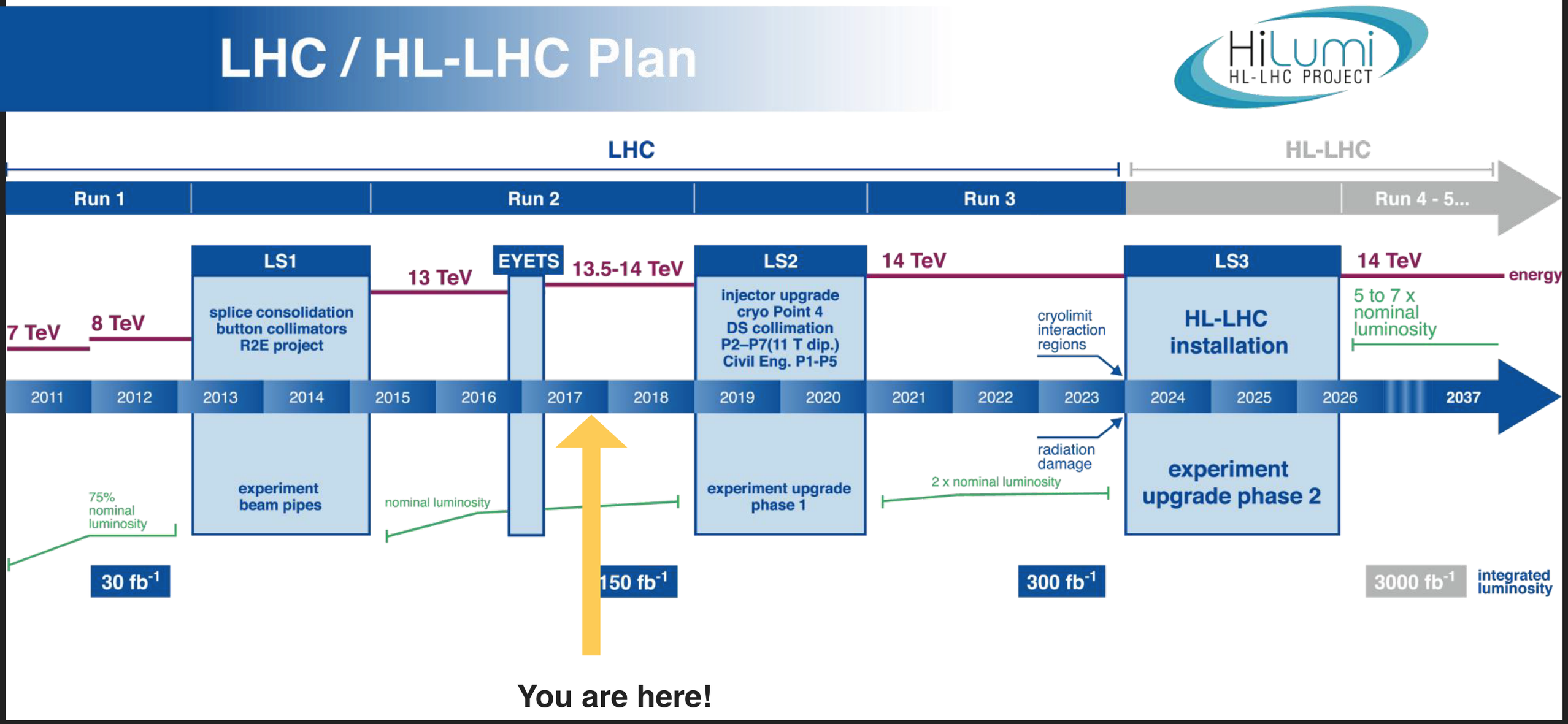
- Gas Electron Multiplier (GEM) detectors in the endcap for good position resolution
- Extend η coverage for muon detection to $|\eta| = 3$
- Include more Resistive Plate Capacitors (RPCs)

L1-TRIGGER, DAQ, SOFTWARE R&D

- Upgrade the readout electronics of the L1-Trigger
- Aim to overcome latency limitations and L1- rate restrictions
- DAQ system will be upgraded to sufficiently deal with these changes
- Considerable R&D for software and computing needs and development of efficient algorithms for reconstruction

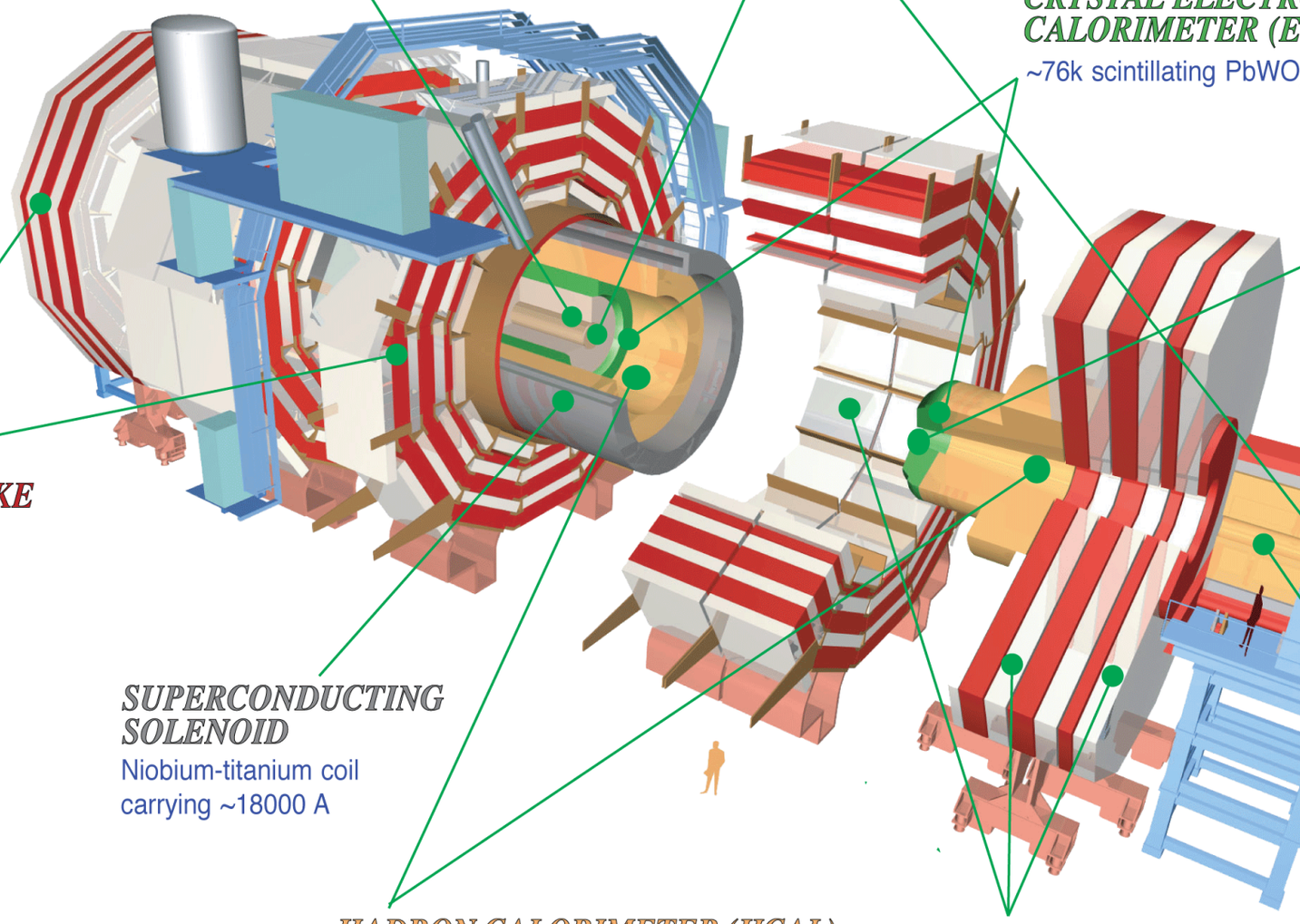
HIGH-LUMINOSITY LHC PROGRAM

LHC / HL-LHC Plan



THE CMS DETECTOR @ RUN I

BRIL
Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons



SILICON TRACKER
Pixels (100 x 150 μm²)
~1m² ~66M channels
Microstrips (80-180μm)
~200m² ~9.6M channels

BRIL
Luminosity Telescope: ~200k Si pixels (100 x 150 μm²)
Beam Monitors: 80 diamond sensors, 40 quartz counters

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76k scintillating $PbWO_4$ crystals

PRESHOWER
Silicon strips (6cm x 2mm)
~16m² ~137k channels

STEEL RETURN YOKE
~13000 tonnes

SUPERCONDUCTING SOLENOID
Niobium-titanium coil
carrying ~18000 A

FORWARD CALORIMETER
Steel + quartz fibres
~2k channels

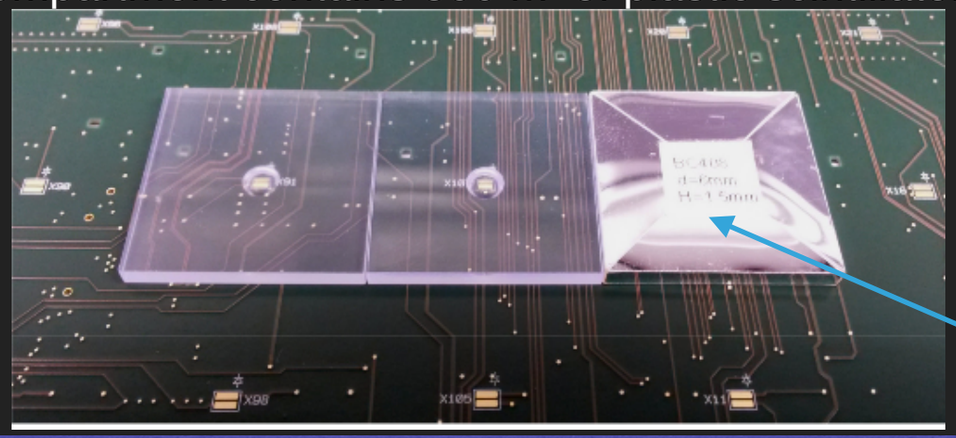
HADRON CALORIMETER (HCAL)
Brass + plastic scintillator
~7k channels

MUON CHAMBERS
Barrel: 250 Drift Tube & 480 Resistive Plate Chambers
Endcaps: 473 Cathode Strip & 432 Resistive Plate Chambers

Total weight : 14000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

SALIENT FEATURES OF THE HGCAL

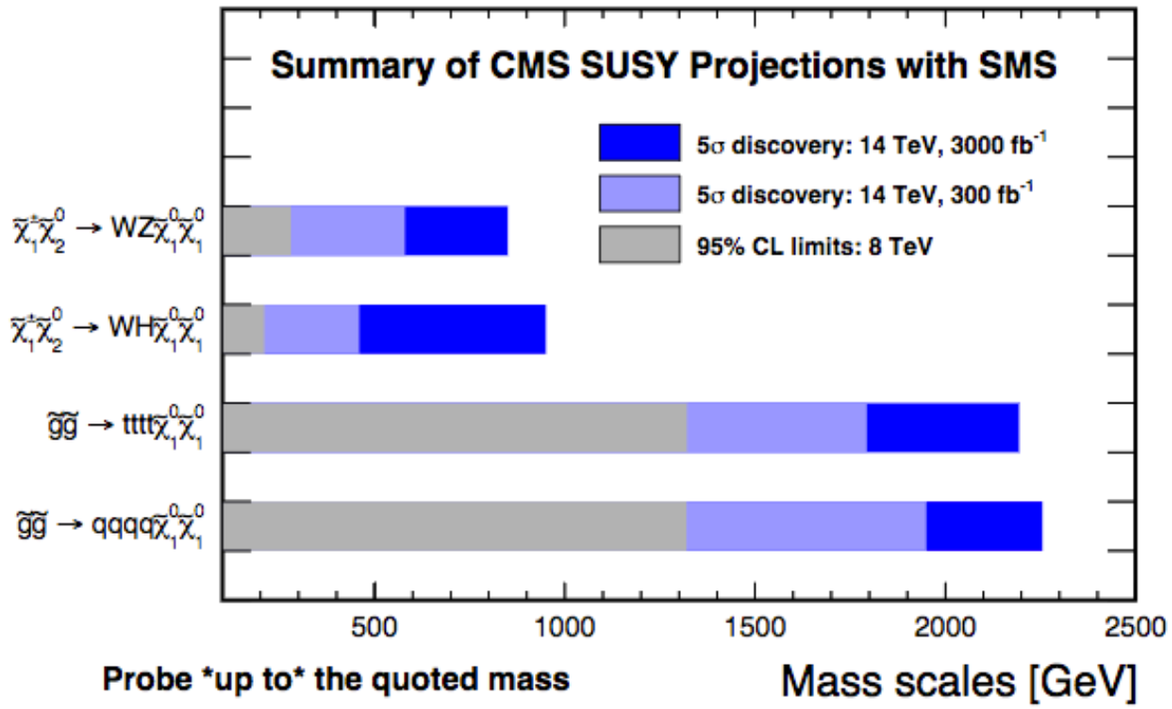
- The electromagnetic section of the HGCAL extends from |z| = 3.2 to 3.5 m:
  - 26 X_0 or 1.7 λ
  - contains 28 sampling layers
- The hadronic section extends from |z| = 3.5 to 5.1 m:
  - 9.0 λ
  - contains both finer (12 layers) and coarser sampling layers (12 layers)
    - each section covers |z| = 3.5 to 4.1 m: 3.3 λ
    - each section covers |z| = 4.1 to 5.1 m: 5.7 λ
- Contains 6 M silicon channels covering 600 m^2 : ~ 3 X CMS Tracker volume
- Hadronic compartment contains 500 m^2 of plastic scintillator with on-tile SiPM readout



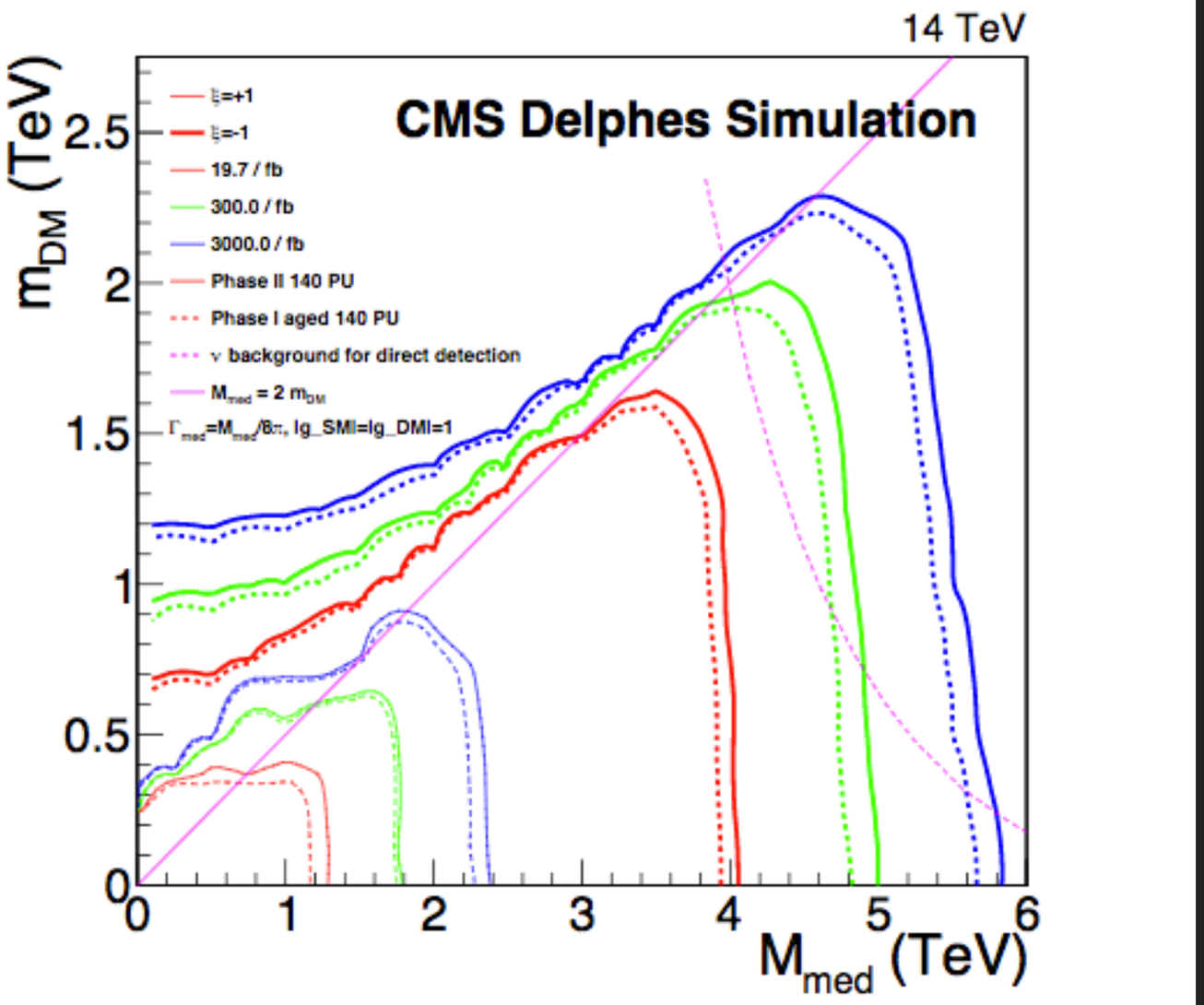
SiPM on tile readout in the CALICE detector

Wrapped in reflective foil

PHYSICS PERFORMANCE IN THE HL-LHC ERA

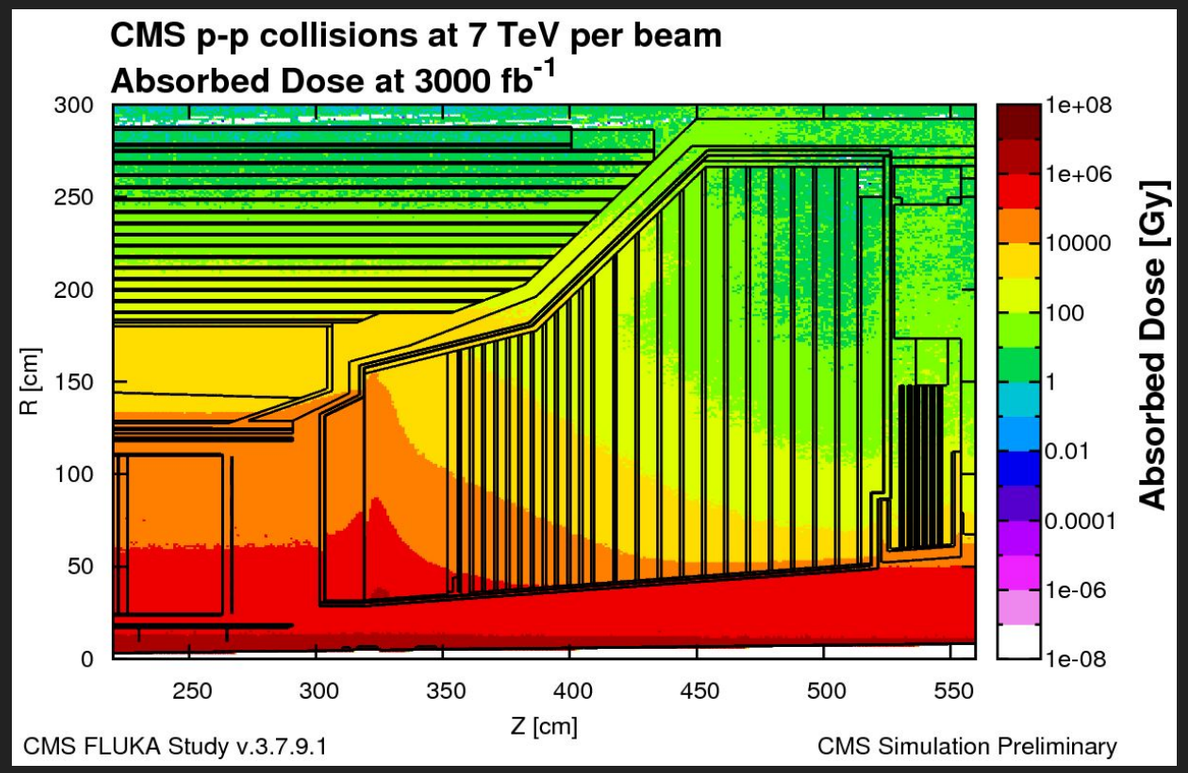


- Mass reach of SUSY searches from projections for 14 TeV run at high luminosities
- Interpreted using Simplified Models



Dark matter reach of the mono-lepton channel as a function of the DM mass and mediator mass

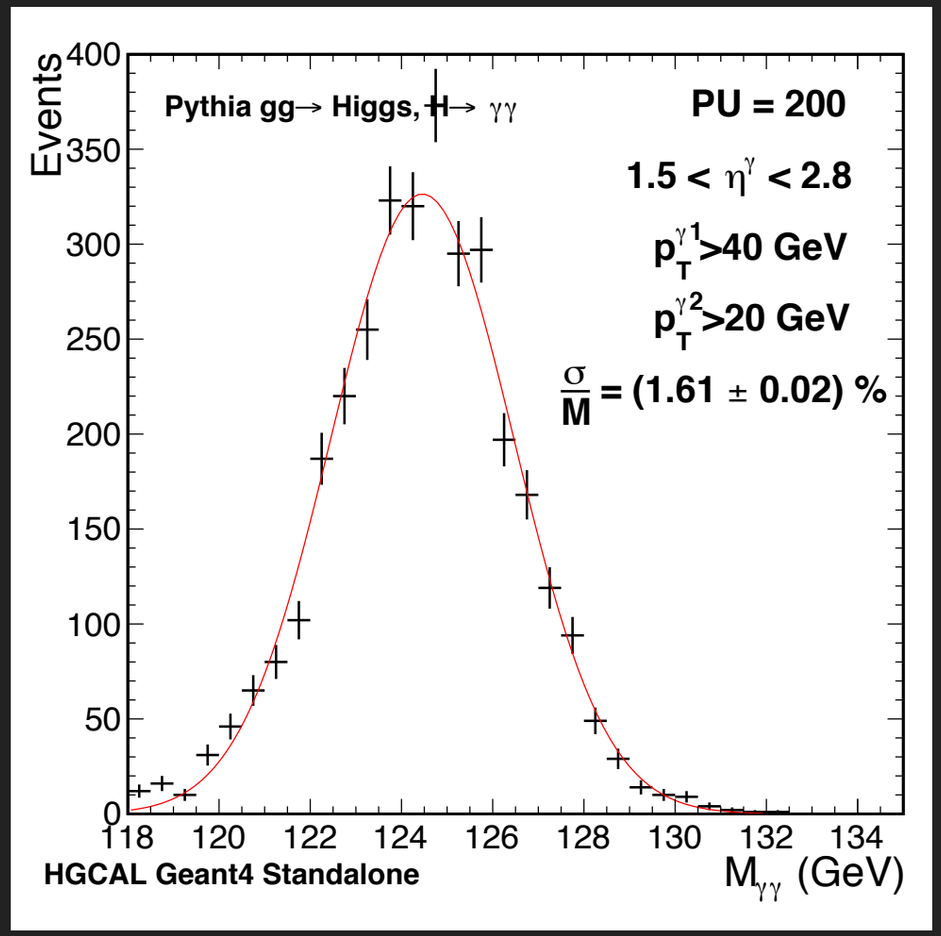
MOTIVATION FOR BUILDING THE HIGH GRANULARITY CALORIMETER



DOSE OF IONIZING RADIATION ACCUMULATED IN THE HGCAL AFTER 3000 fb^{-1}

EVENT RECONSTRUCTION

The Higgs to gamma gamma ($m_{\gamma\gamma}$) reconstruction



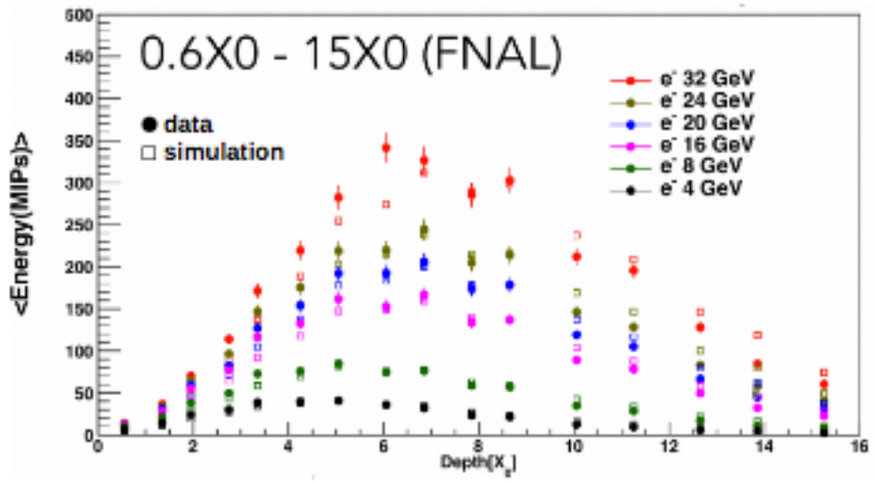
TEST BEAM

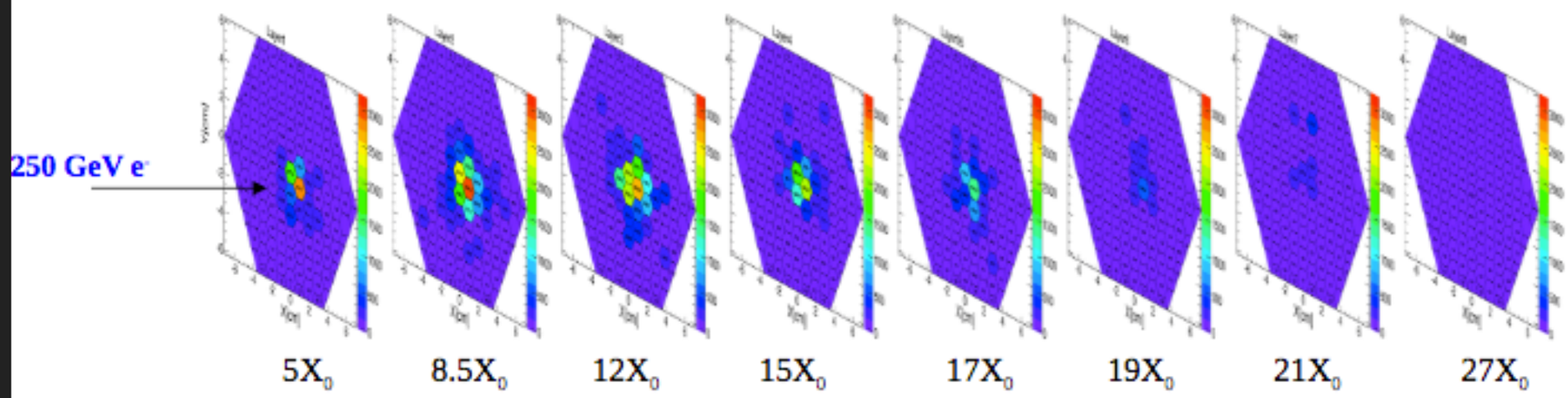
FNAL

- Up to 16 HGCAL modules tested
- e^- beam at 4-32 GeV
- Protons at 120 GeV
- 0.6-15 X_0 absorber configuration

CERN

- Up to 8 HGCAL modules tested
- π/μ at 125 GeV
- e^- beam at 20-250 GeV
- 6-15 X_0 and 5-27 X_0 absorber configurations

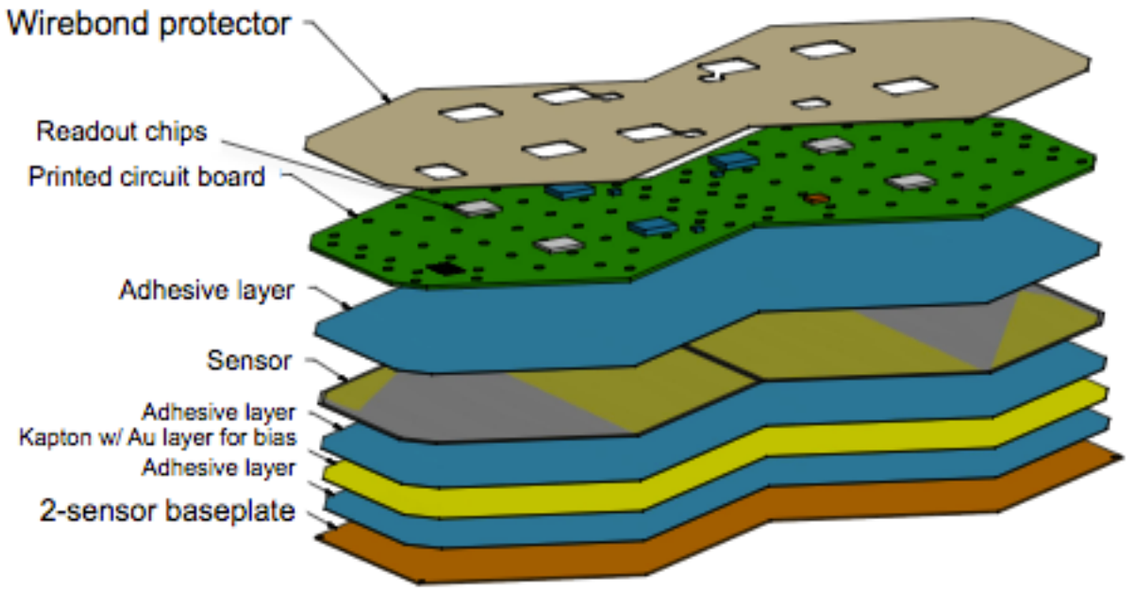




Electron showers passing through 8 layers (27 X_0)

INSTR17 at BINP, Novosibirsk 10 Andreas A. Maier

THE ELECTRONICS



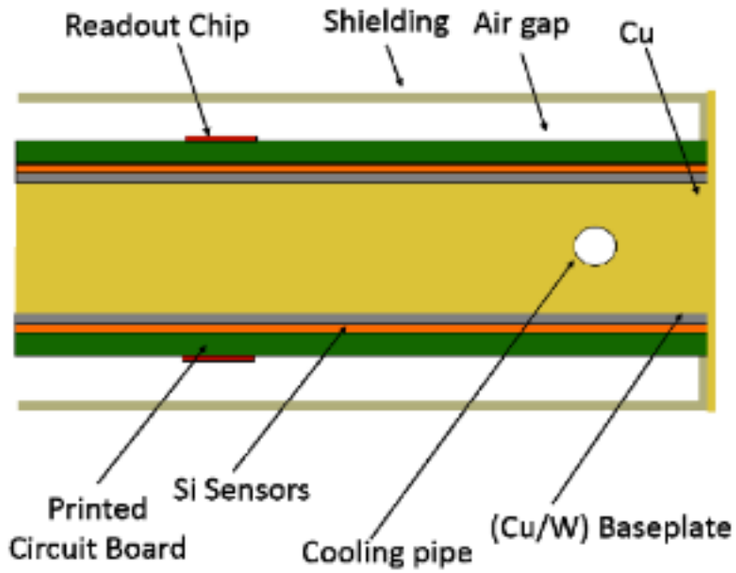


Figure 3.25: (Left) Module, consisting of printed circuit board, silicon sensors, and baseplate. (Right) Sketch of modules mounted either side of a copper and tungsten absorber/cooling plate, showing the longitudinal arrangement of a double layer.