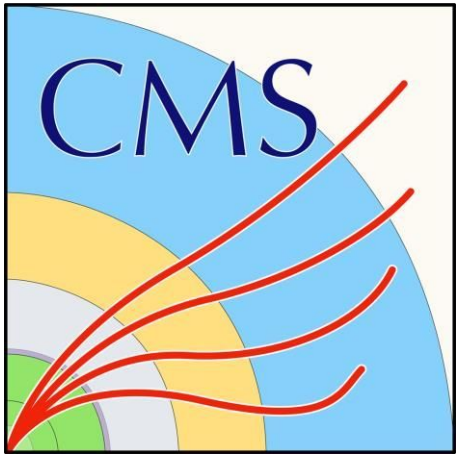


HGCAL's SiPM-on-Tile

APS - DPF Meeting, 071321

Suho Kim

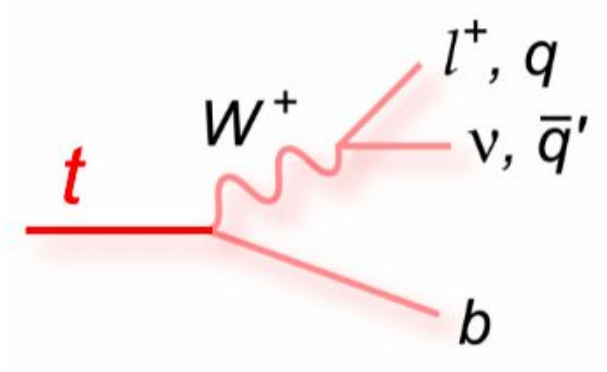
Outline

I. The goal of CMS's HL-LHC upgrade and its High Granularity Calorimeter (HGCAL)

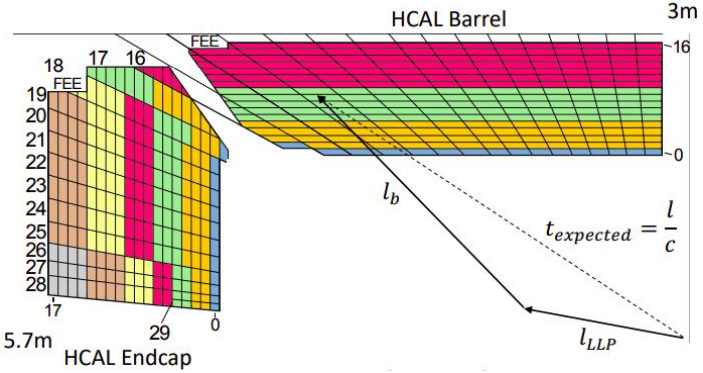
II. Scintillator Tile, SiPM, and the Tile module

III. Importance of MIP reconstruction

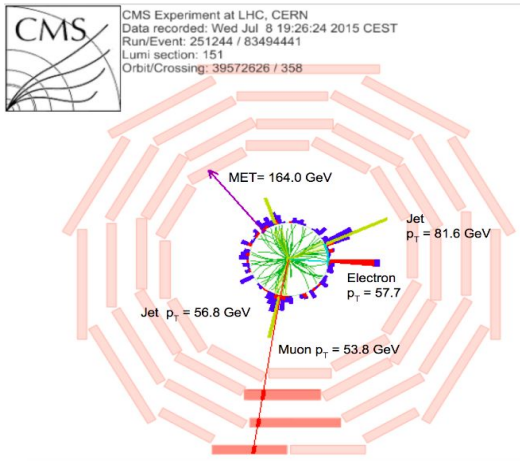
The Role of Calorimeter in CMS



Final state with b-jets, multi-jets (Physics of interest (Λ_{EWK}) mostly have multi-jet final states)



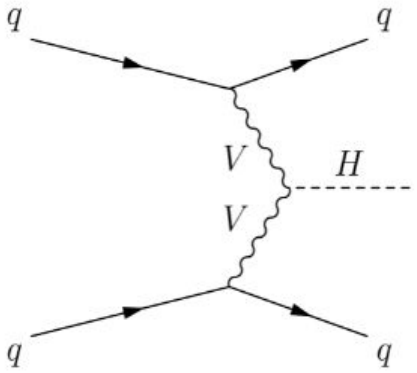
Final state with Long-Lived Particles (LLPs)



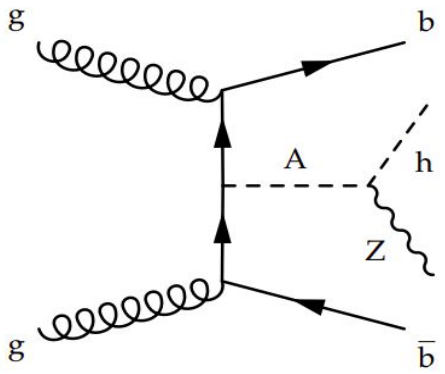
Final state with MET, Leptons (ν, SUSY Physics)

Plenty of signatures in the Calorimeter!!

The Role of Endcap Calorimeter in CMS



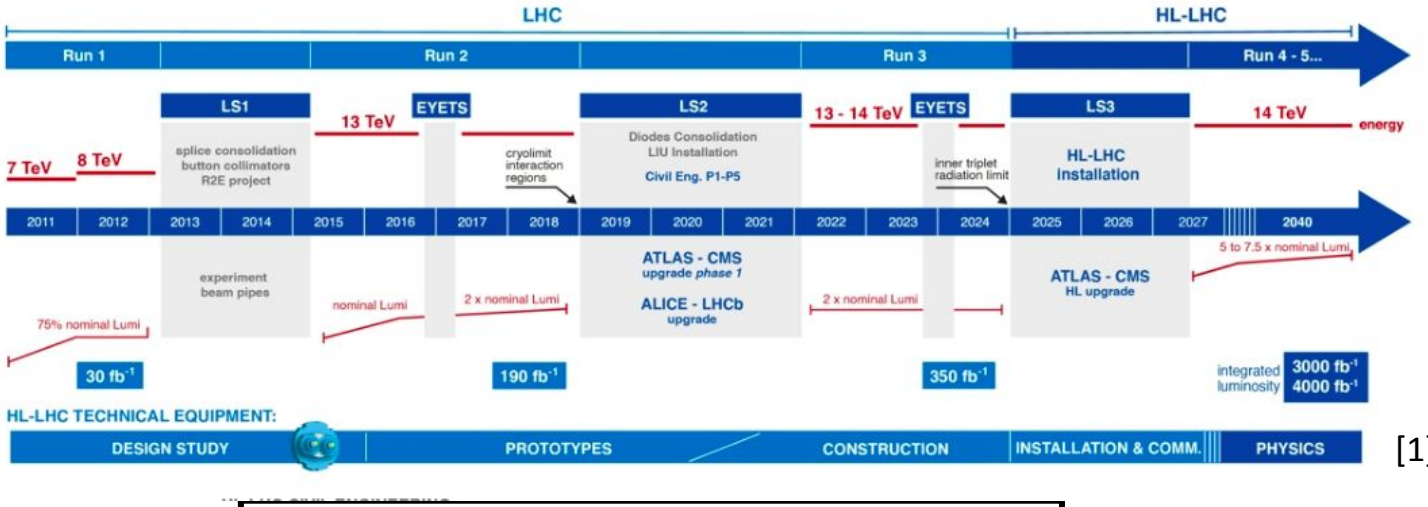
Vector Boson Fusion of Higgs Production



Heavy Resonance decaying into Vector boson

Jets with high energy towards to the endcap

HL-LHC and its Challenge

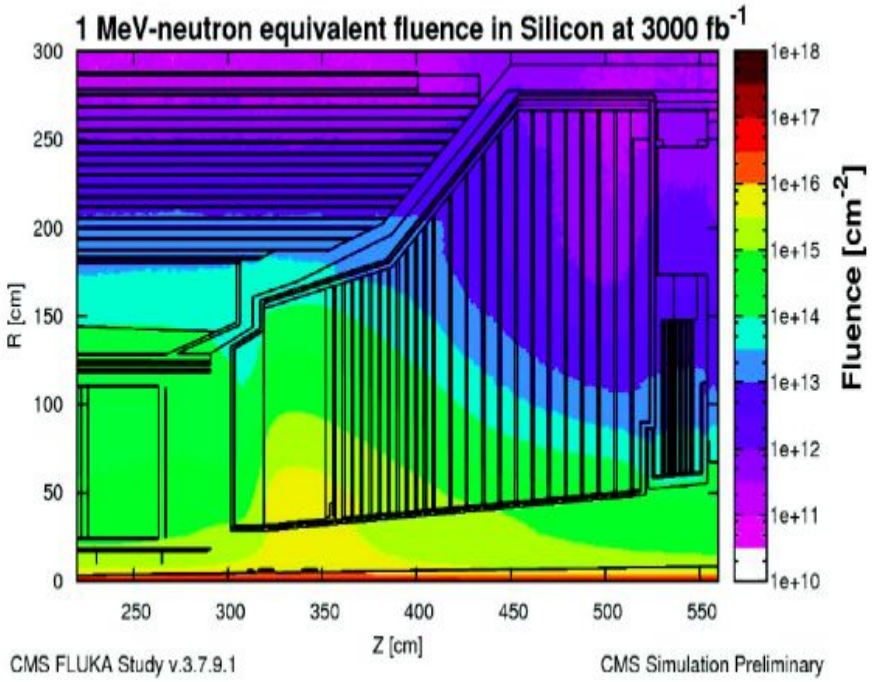


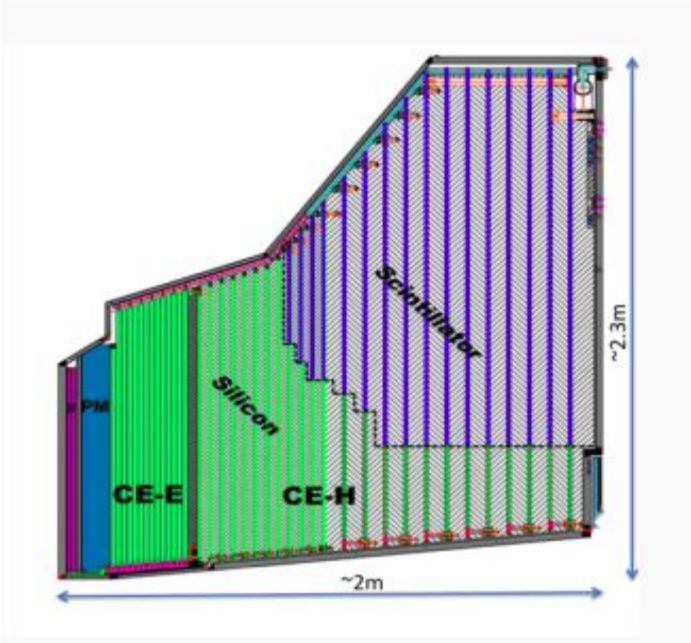
[1]

Challenge
• Unprecedented Radiation dose level • Up to ~200 Pile-up (PU)

[1] https://hilumilhc.web.cern.ch/content/hl-lhc-project

Upgrade for the (Endcap) Calorimeter





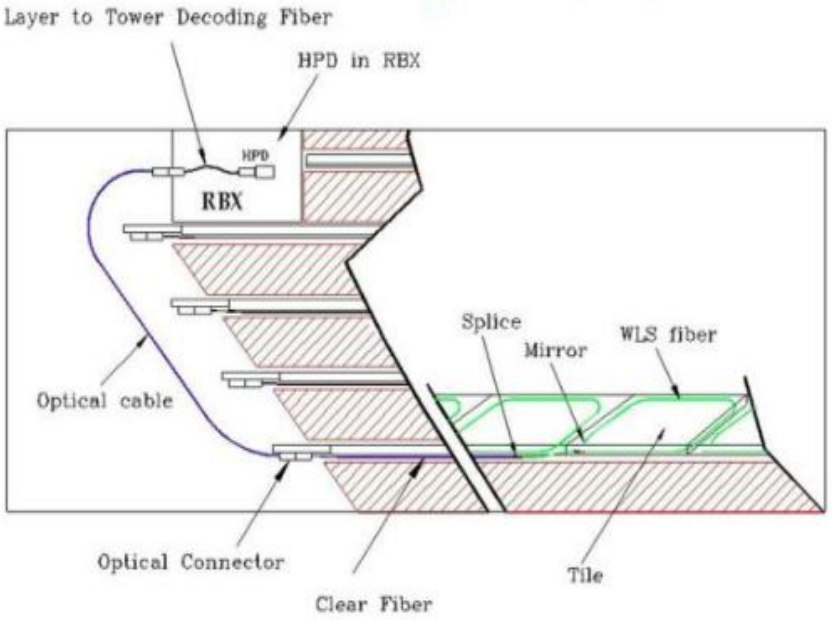
[2]

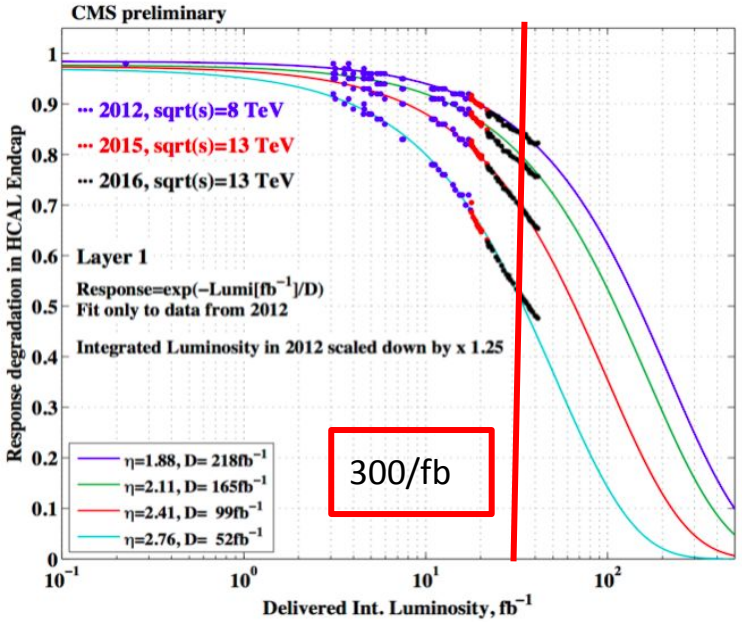
- Silicon in the highest radiation area (Fluences of up to 10^{16} neq/cm^2)
- Scintillator in lower radiation area (Fluences of up to 10^{13} neq/cm^2)

- Scintillator will still be used for HGCAL in lower $|\eta|$ high |z|

[2] hhttps://cms-docdb.cern.ch/cgi-bin/DocDB/ShowDocument?docid=13251

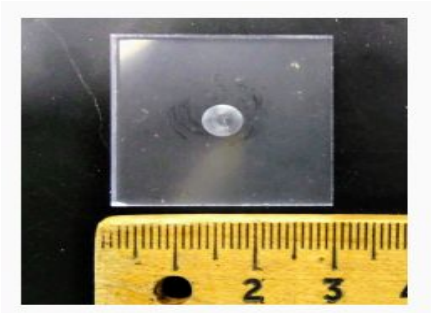
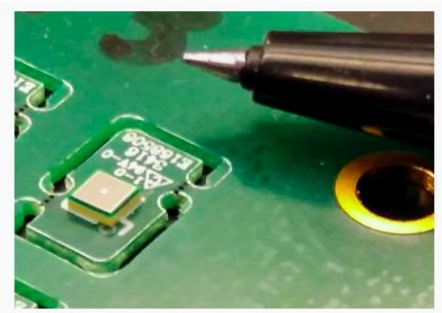
Phase 1 HCAL extrapolated to HL-LHC scenario





Phase 1 HCAL	Phase 1's HCAL endcap in HL-LHC
• Scintillator Tile • WaveLength Shifting Fiber (WLS) • SiPM	***Not usable*** • Degradation in response function • Low granularity in <PU> ~ 200

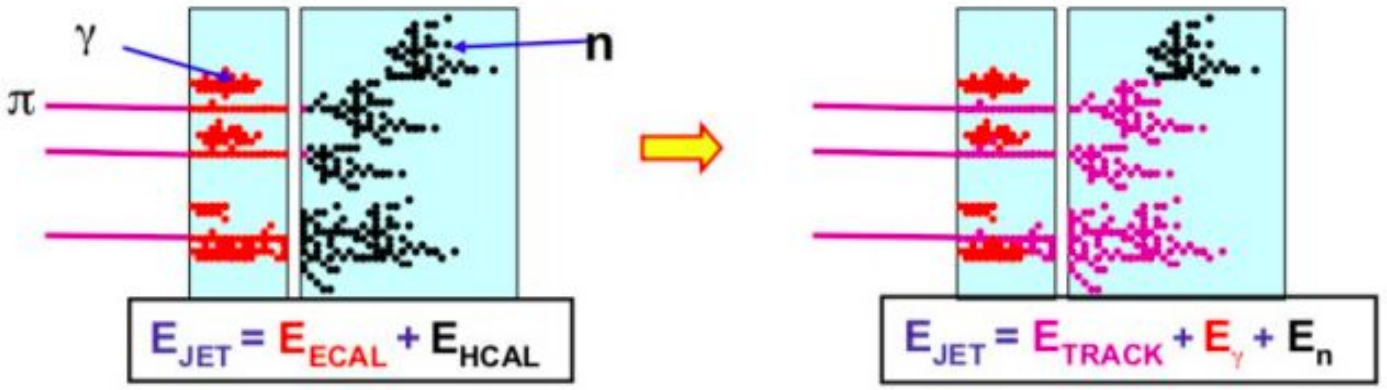
Scintillator and SiPM-on-Tile

Scintillator Tile	PhotoDetector
	
• Small size tiles (3mm thick), (20 x 20 mm^2 to 60 x 60 mm^2)	• All SiPMs on the Scintillator Tiles
By Going from HCAL to HGCAL	
• Resolves PU issue • Shorter distance between light and SiPM	• Compact space usage

High-Granularity Calorimeter's SiPM-on-Tile

Impact of SiPM-on-tile on PF reconstruction

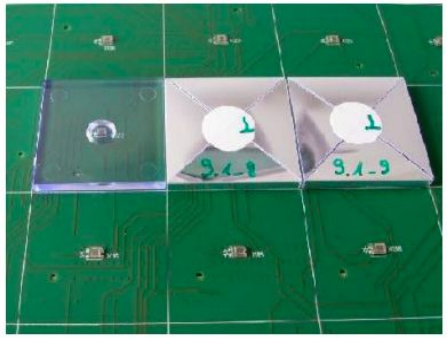
At the end

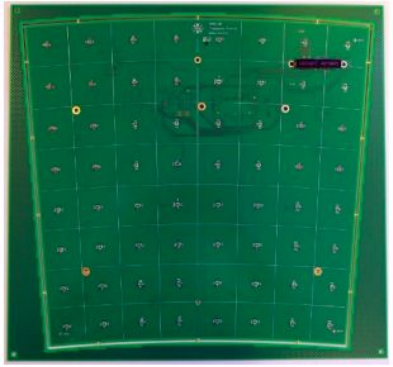


With Radiation tolerance

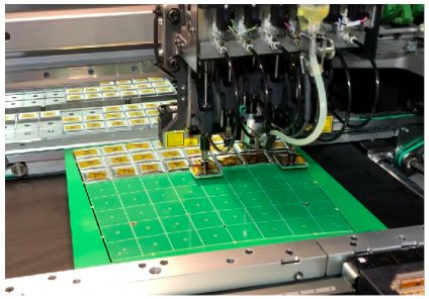
- Better handling of pile-up interaction
- Better imaging for particle flow (PF)
- Precision on timing

Tile Modules





- SiPM-on-Tiles with fine granularity

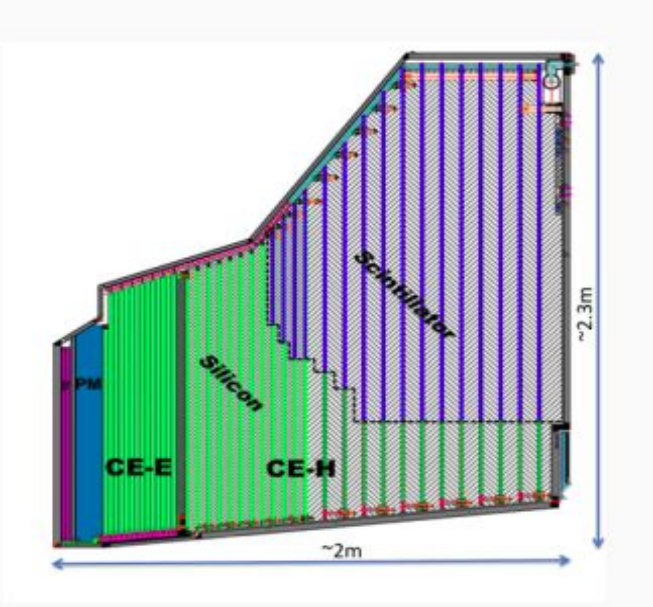


- Tile Module:
- HGCal Read-out-Chip (HGCROC)
- GBT-Slow Control Adaptor (GBT-SCA)

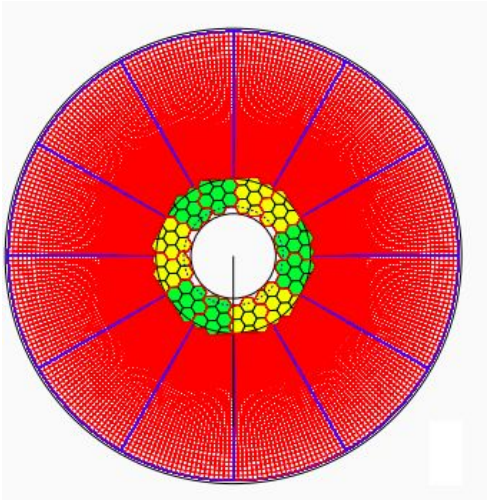
SiPM's dark noise
↓
Maintained at
-30°C
with Cu cooling plate

HGCAL Tile Modules

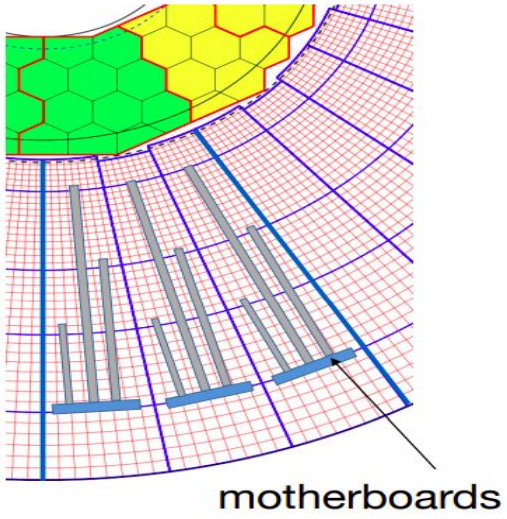
Cassettes



Transverse plane view of HGCAL layers



Z-axis view of the layer NN

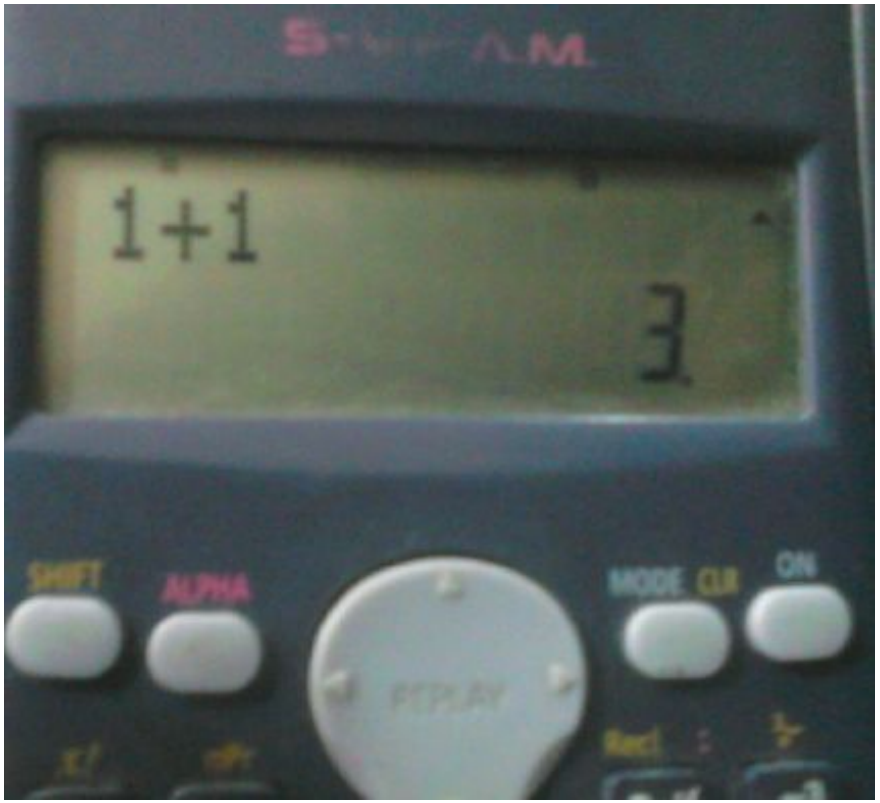


HGCAL layer NN viewed from the top

- Inner portion of cassettes : silicon sensors (High fluence zone)
- Outer portion of cassettes : scintillator tile modules
- Layers assembled from cassettes inserted into slots between absorbers

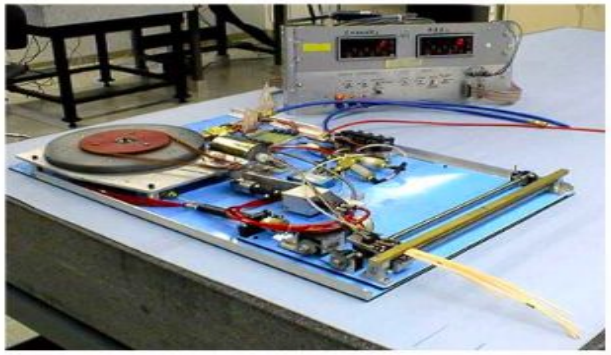
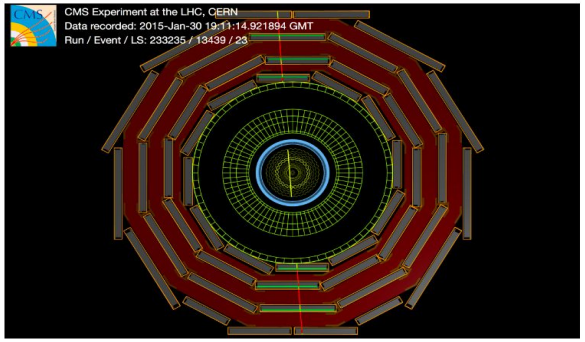
Calibration Strategy

Calibration to verify detector's accurate reading !!



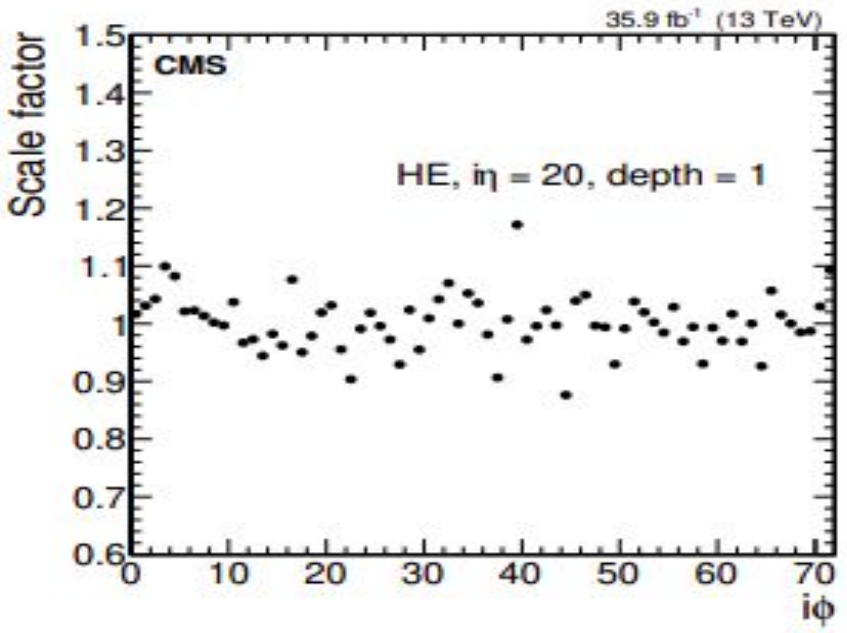
Calibration Strategy - HCAL in the past

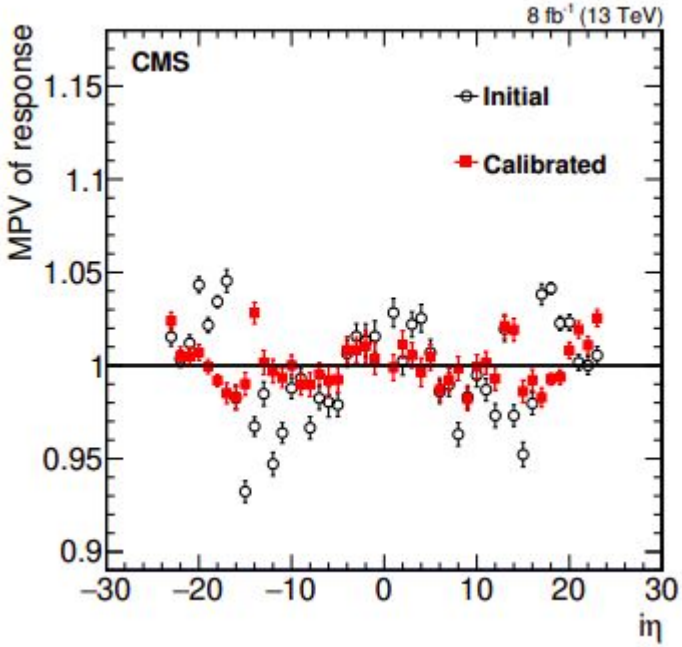
- HCAL's calibration strategy evolved with time

In the past	
• External source of ^{137}Cs on stainless wire moved by computer	• Exploit Cosmic ray muons during LHC's non-operation time
	
• Even better to use copious data from pp collisions	

Calibration Strategy - current

- HCAL's calibration strategy with ϕ symmetry
  - Intercalibration : Test ϕ symmetry for each iη ring
    - Z-> ee or $\mu\mu$ events from W,Z depending on Geometry
  - Absolute Calibration : ScaleFactor for each iη ring
    - Track information of charged hadron

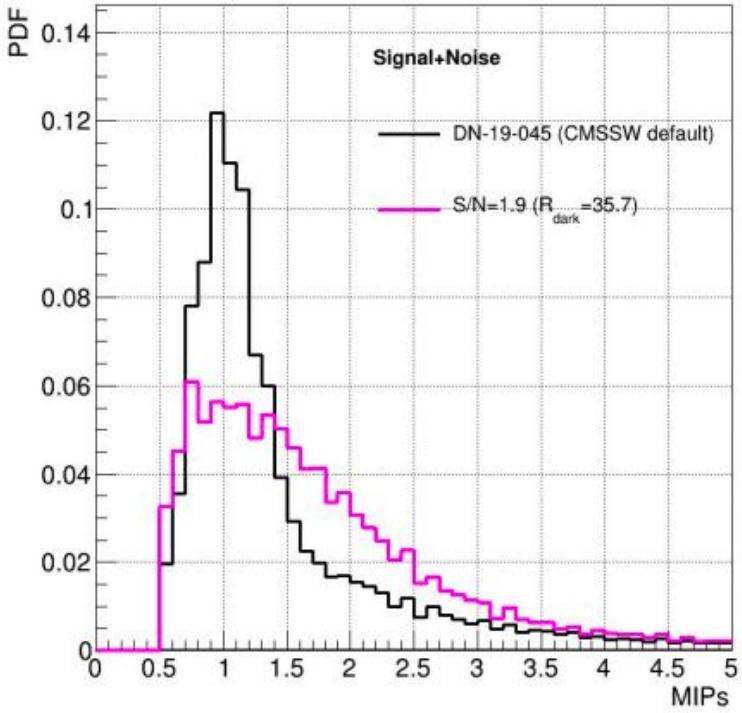




Calibration Strategy - HGCAL

- Development underway with various propositions
  - Use μs from W, Λ_{EWK} process as well?
    - 27 Isolated muons/hr from WJets process
    - Worst case scenario to S/N = 2 for End-of-Life
    - For statistics and noise condition, implementable under preliminary study

WORK IN PROGRESS



WORK IN PROGRESS

A	Inst Lumi (/pb/s)	0.05
B	WJets xsec(pb)	60430
C	WJets reco::μ per eta of 0.02	7.5E-4
D	Rechit Eff	0.95
E	Number of ring/tile	1/288
F =A*B*C*D*E	Total Muons/s/tile	0.00798

Table: Summary of Rechit and μ matching study

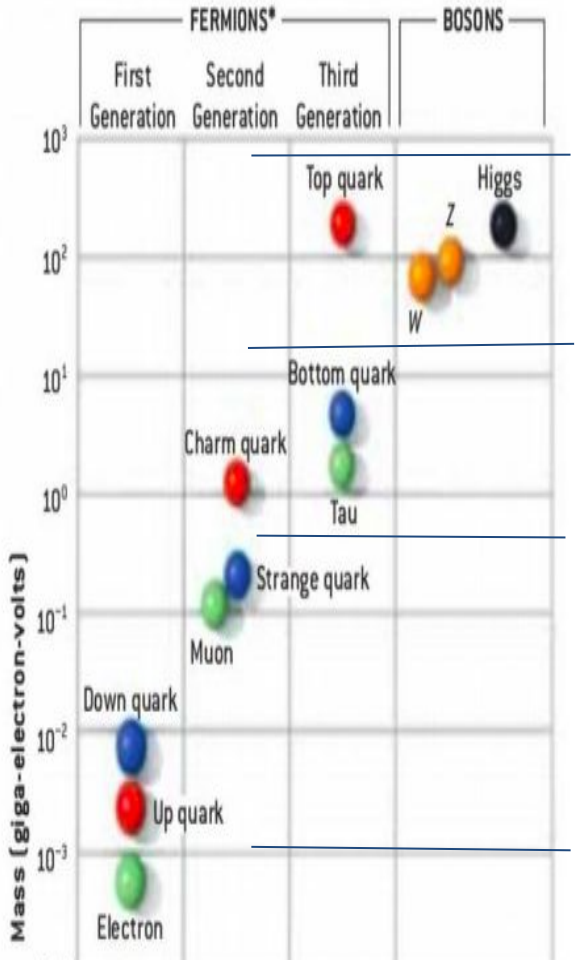
Summary

Role	Endcap Calorimeter plays a crucial role for achieving the goals of HL-LHC.
Issue	Current HCAL will not be compatible with HL-LHC environment
Solution	HGCAL's SiPM-on-Tile will be compatible and improve PF reconstruction capability
Overall Picture	SiPM-on-Tile with Silicon Sensor complete the design of HGCAL
Calibration	Usage of externally triggering muons is a competitive candidate

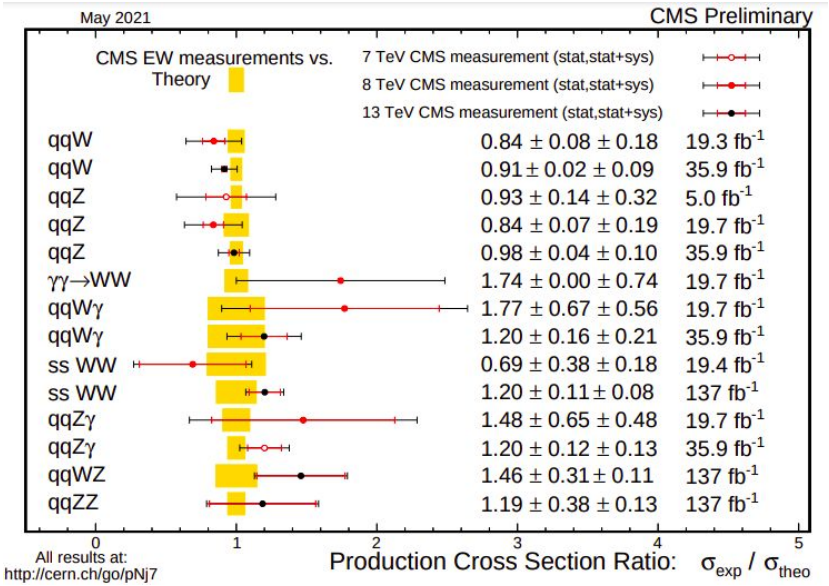
Back-Up

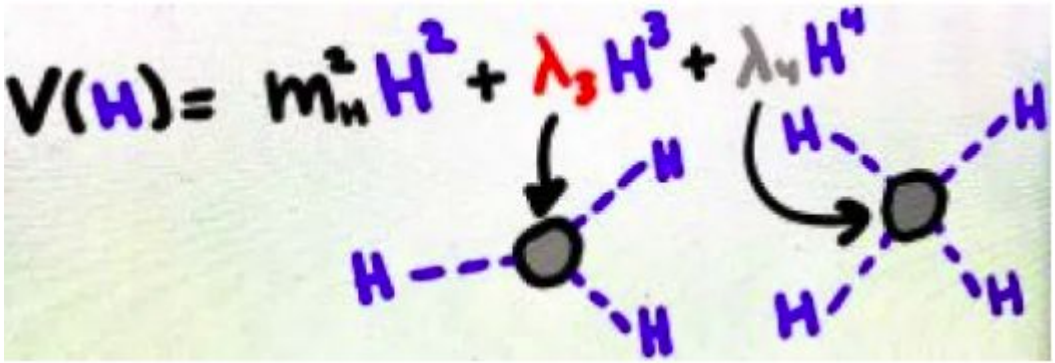
Today's High Energy Physics

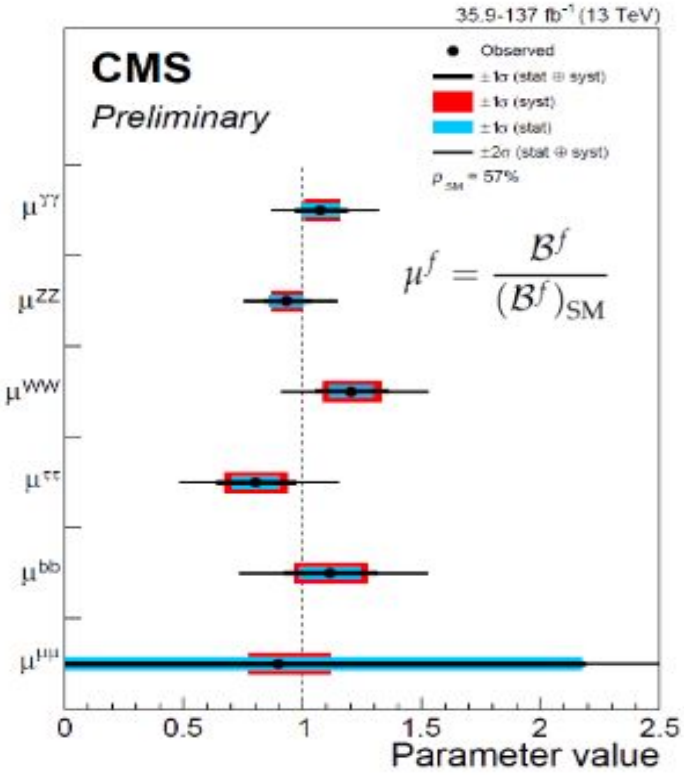
- LHC achieved the goal with discovery of the Higgs
- Moving into the precision physics of the Higgs
- Moving into the precision physics of the other Electroweak particles (Top quark mass, Diboson cross-section).
- TeV scale objects predominantly decay into final states with jets and need to be identified on the basis of their invariant mass



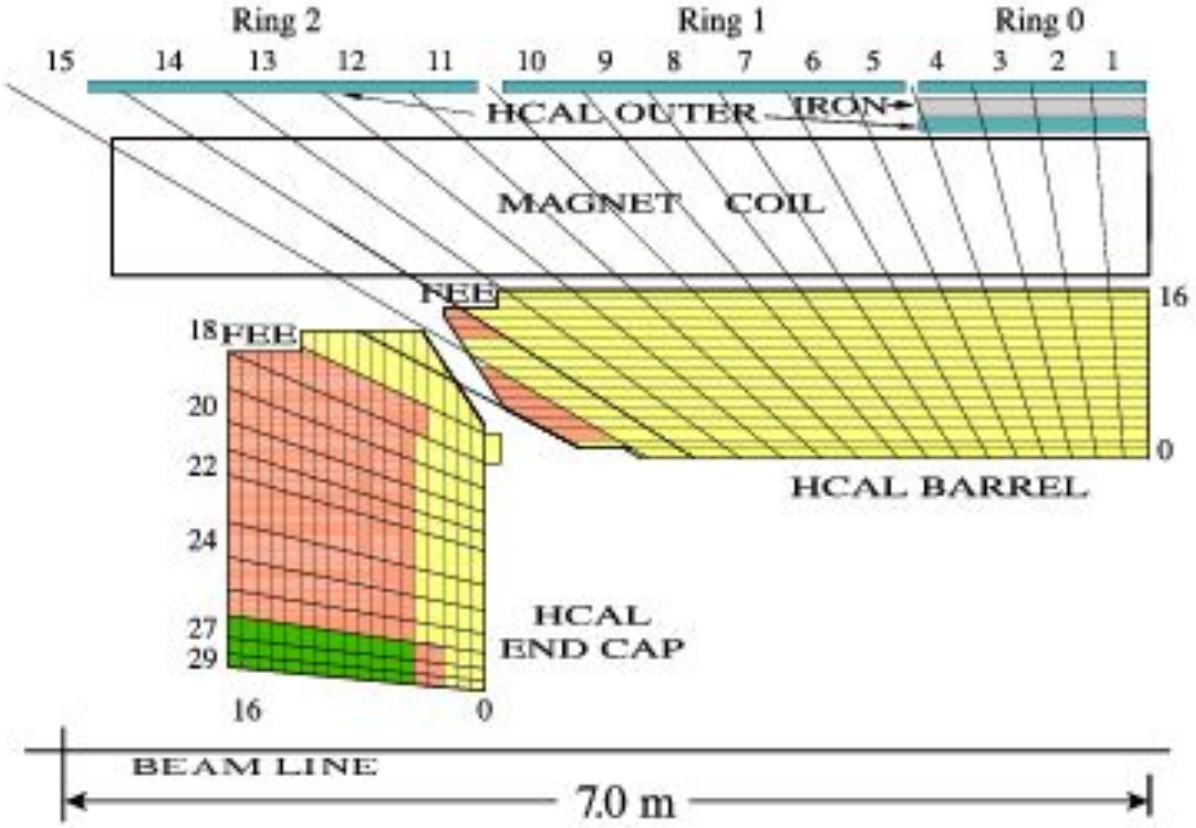
High Luminosity - LHC's goal





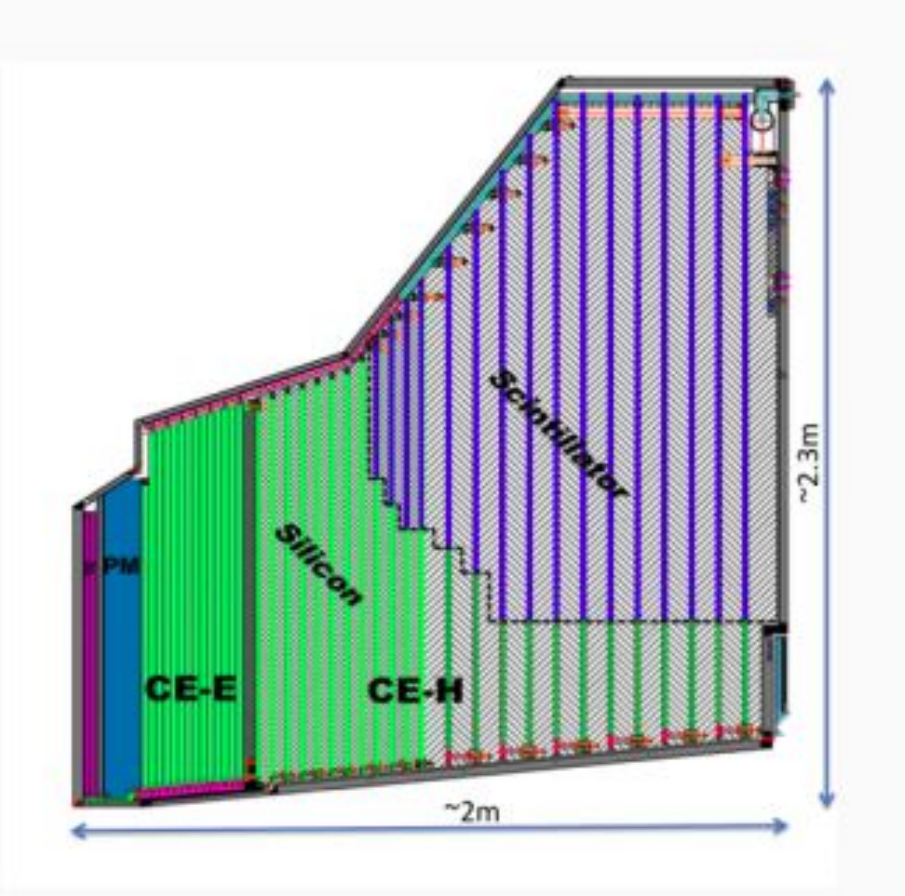


Hadron Calorimeters



- Measures
  - Positions
  - Time
  - Energy
- Scintillator tiles
  - Good Granularity for position measurement
  - Covering $|\eta|<3.0$

Scintillator and SiPM-on-Tile



- CE-E (Silicon - Expensive)
  - Absorbers: Lead, Copper-Tungsten, Copper.
- CE-H (Silicon + (Plastic - Cheap))
  - Absorbers: Stainless Steel and Copper.
  - Front layers : casted plastic Scintillators
  - Other layers : molded plastic Scintillators
  - Smaller tiles, larger SiPMs optimal
- Operating Temperature −30 ◦C to minimize Dark noise

MIP energy calculation

- HGCAL Plastic scintillators with thickness of 3mm for the calculation
- For muon stopping power, with $\rho = 1.0$ g/cm^2, and dx $= 0.3$ cm

$$\frac{dE}{\rho * dx} = \frac{2MeV}{g * cm^2} \quad (1)$$

- muon's MIP in HGCAL HEB $\approx$ 0.6MeV

CMSSW Simulation of hit number > MIP

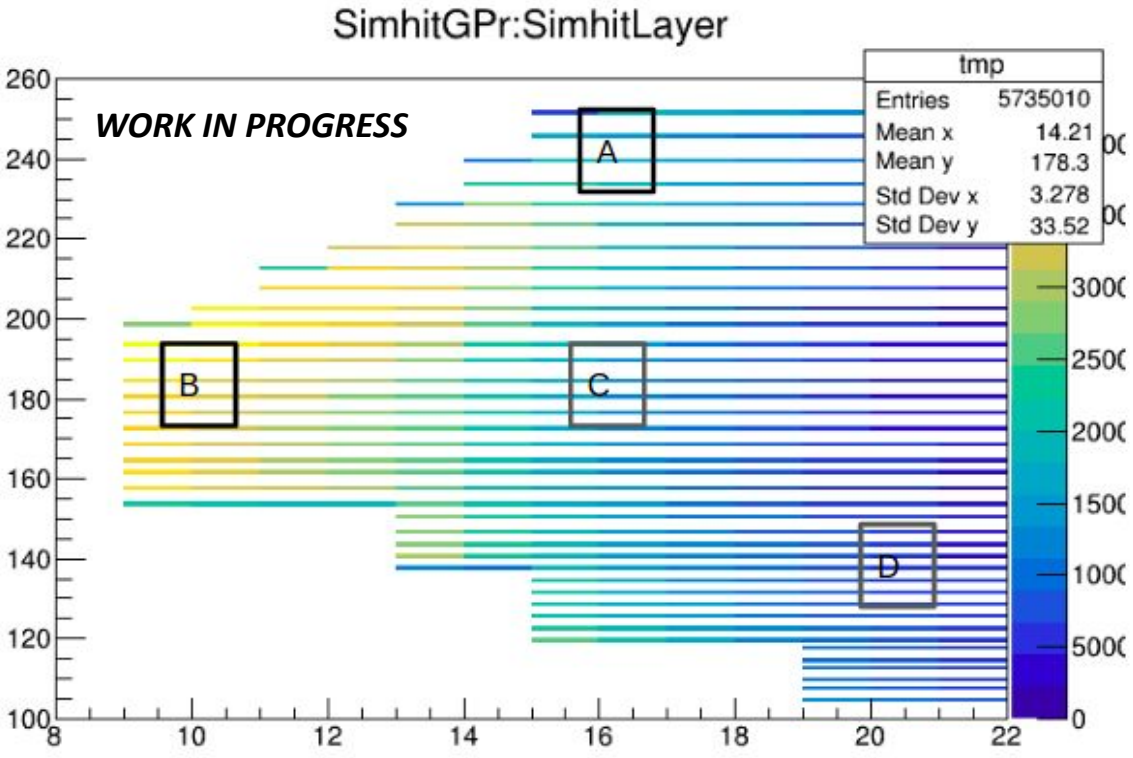


Figure. Number of rechits above 600keV for (Layer,Ring) coordinate (WJets 200PU)

Calibration Strategy - μ's MIP

- μ's Minimum Ionizing Particle (MIP)'s energy theoretically calculable
- MIP peak as landau peak

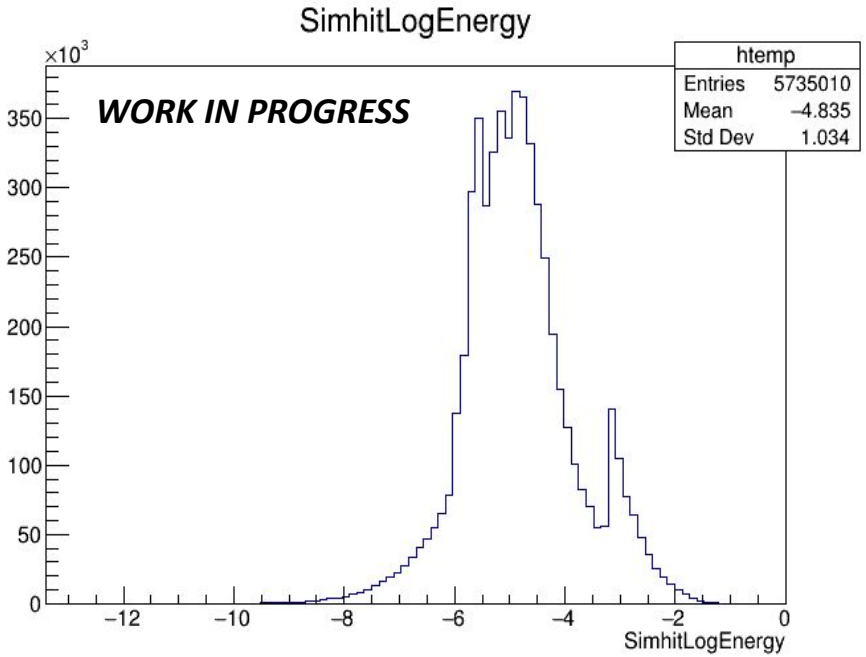


Figure. $\log_{10}$(Simhit's Energy(GeV)) (WJets 200PU)

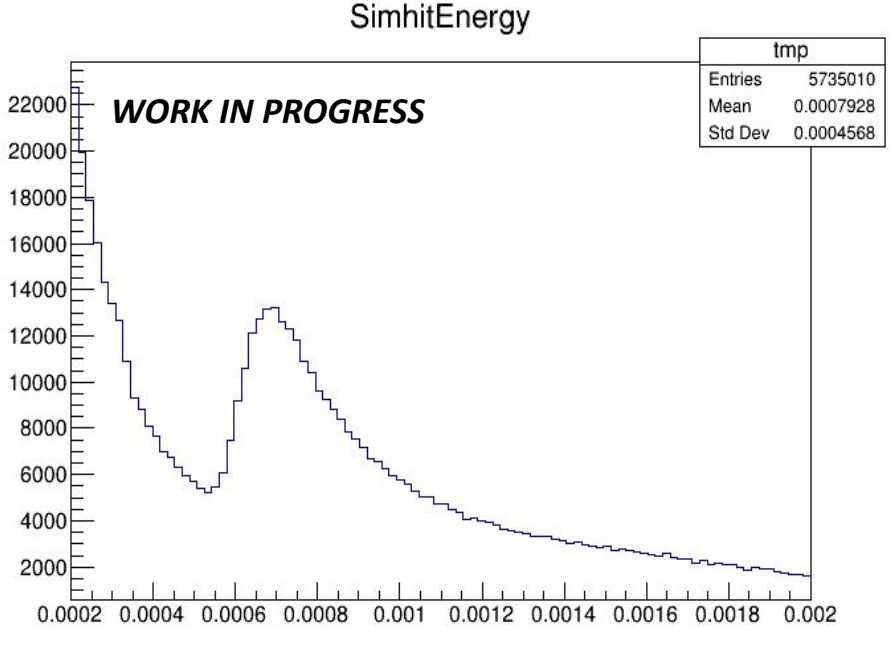
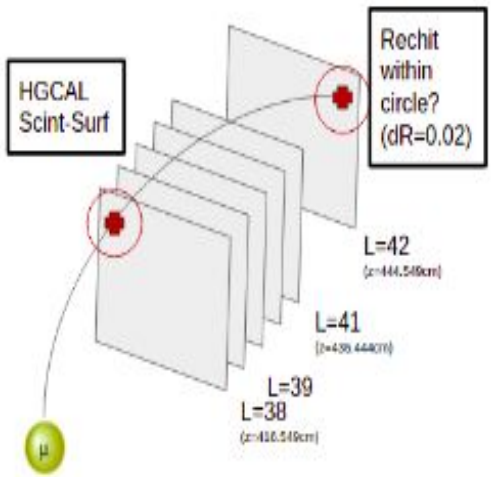


Figure. Simhit's Energy (GeV) (WJets 200PU)

Calibration Strategy - μ's rate in HL-LHC

- Well-isolated μ's copiously produced from WJets (or Top quark) in HL-LHC
- How many of such μ's are produced though? (WJets 200PU's entire dataset)
- /WJetsToLNu_TuneCP5_14TeV-amcatnloFXFX-pythia8/Phase2HLTTDRWinter20DIGI-PU200_110X_mcRun4_realistic_v3-v2/GEN-SIM-DIGI-RAW



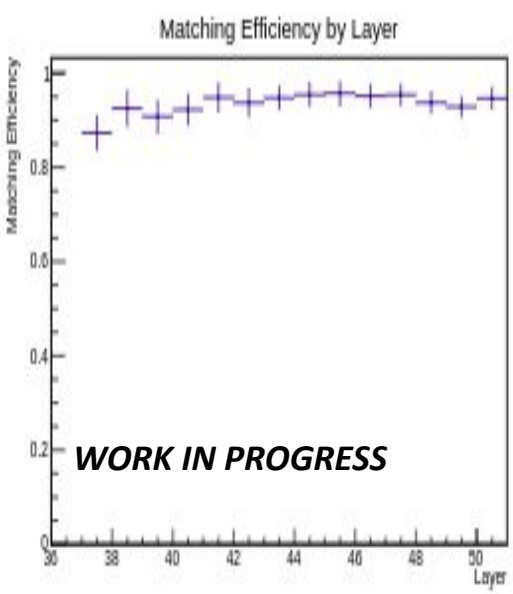


Figure. Matching efficiency by layer

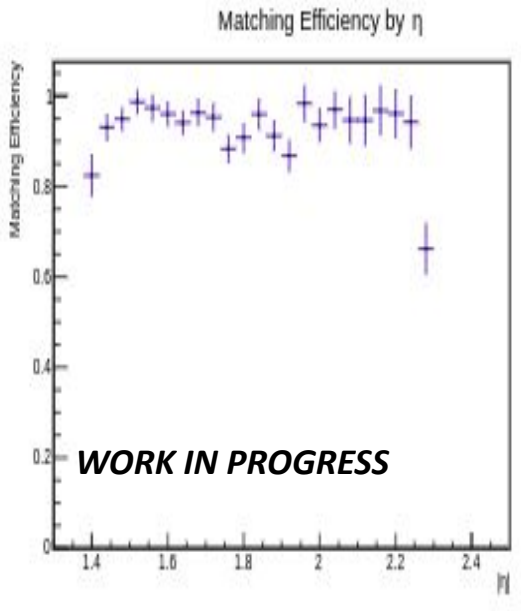


Figure. Matching efficiency by η

Matching Efficiency = Propagated muon track with rechit in dR<0.02/ All propagated muon track

Calibration Strategy - Different S/N

- End-Of-Life Signal could overlap with noise
- S/N not always optimal -> Effect on MIP μ's rate to be taken into account for its usage in calibration purpose

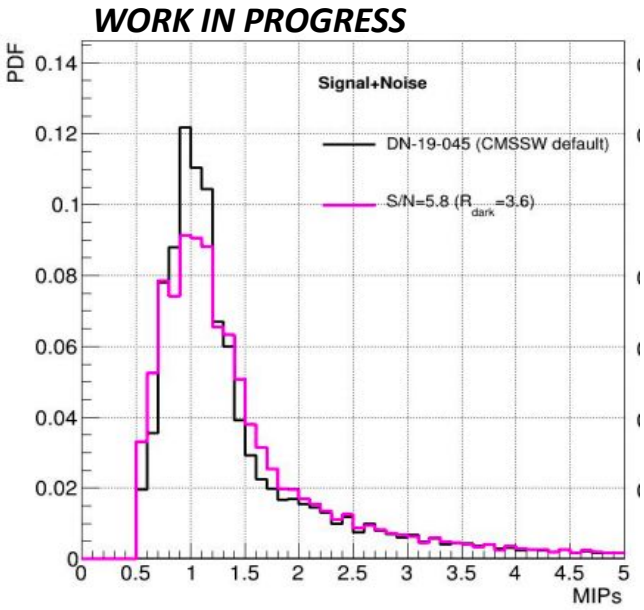


Figure. Change in MIP distribution for S/N = 5.8 with respect to Beginning-Of-Life

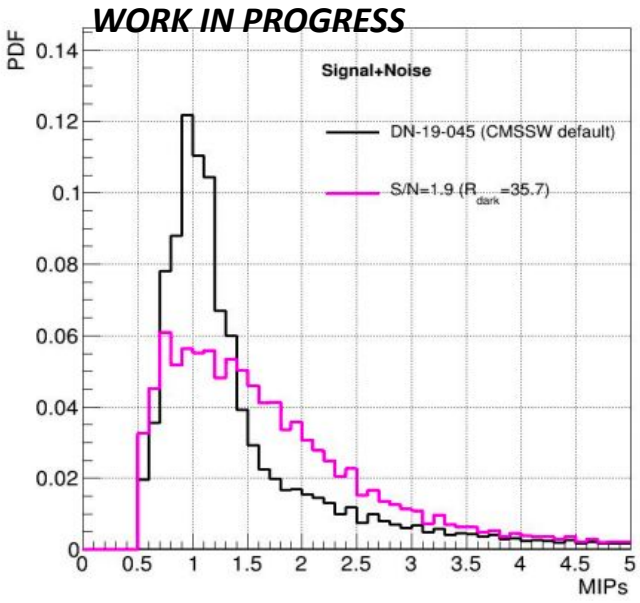


Figure. Change in MIP distribution for S/N = 1.9