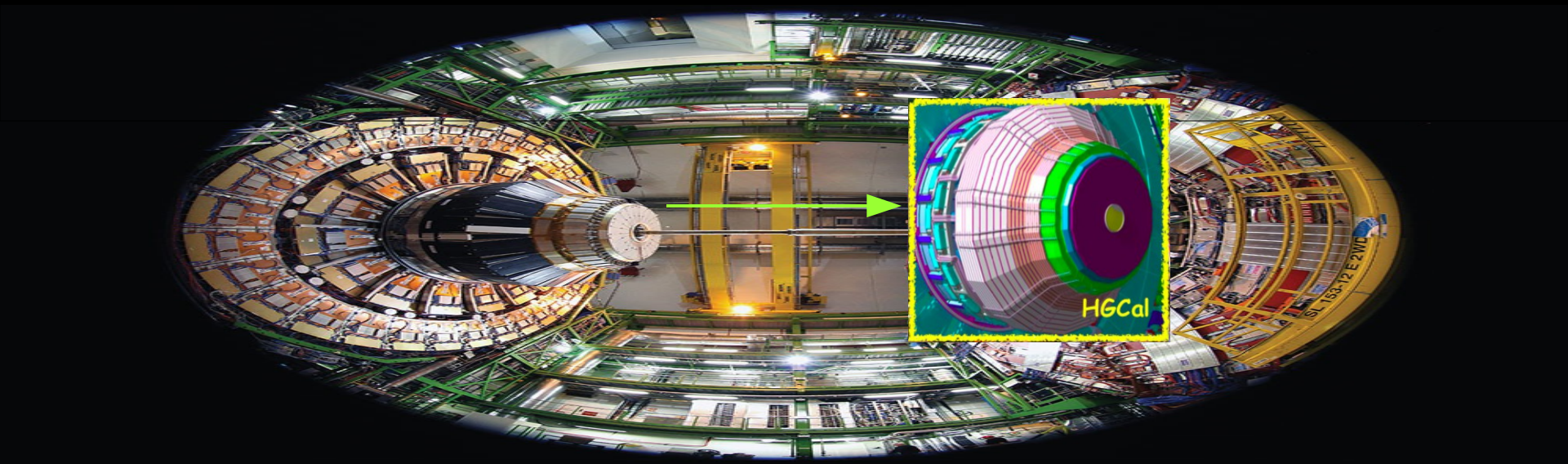
The CMS High Granularity Calorimeter (HGCAL) for the HL-LHC Upgrade



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Adiyaman University
PARTICLEFACE 2020: WG Meeting and MC Meeting
Krakow
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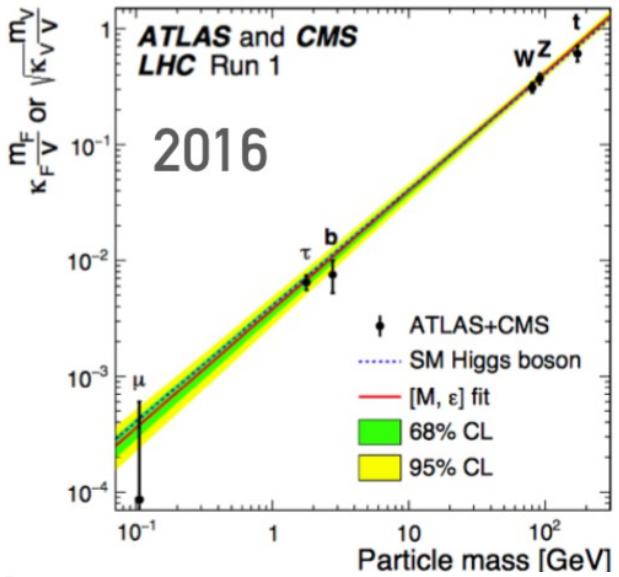
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Outline

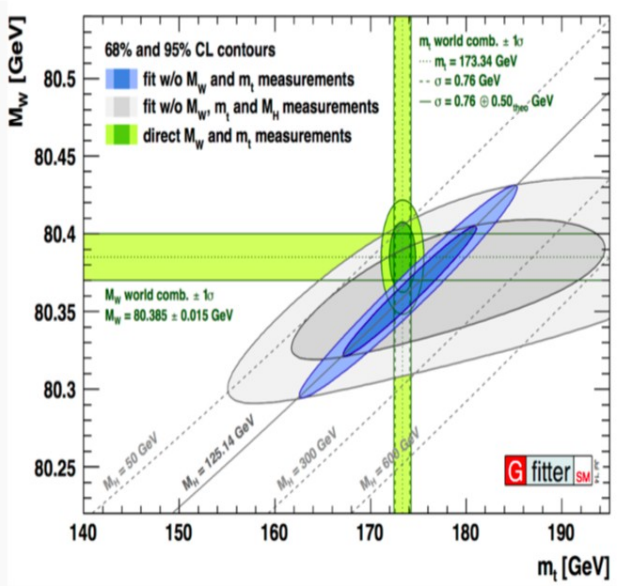
- Introduction
- High Luminosity LHC (HL-LHC)
- High Granularity Calorimeter (HGCAL)
- Test beam results
- Summary

Why High Luminosity LHC (HL-LHC)?

- **Huge success for the Standard Model of High-Energy Physics: Higgs**
  - LHC is a Higgs factory!

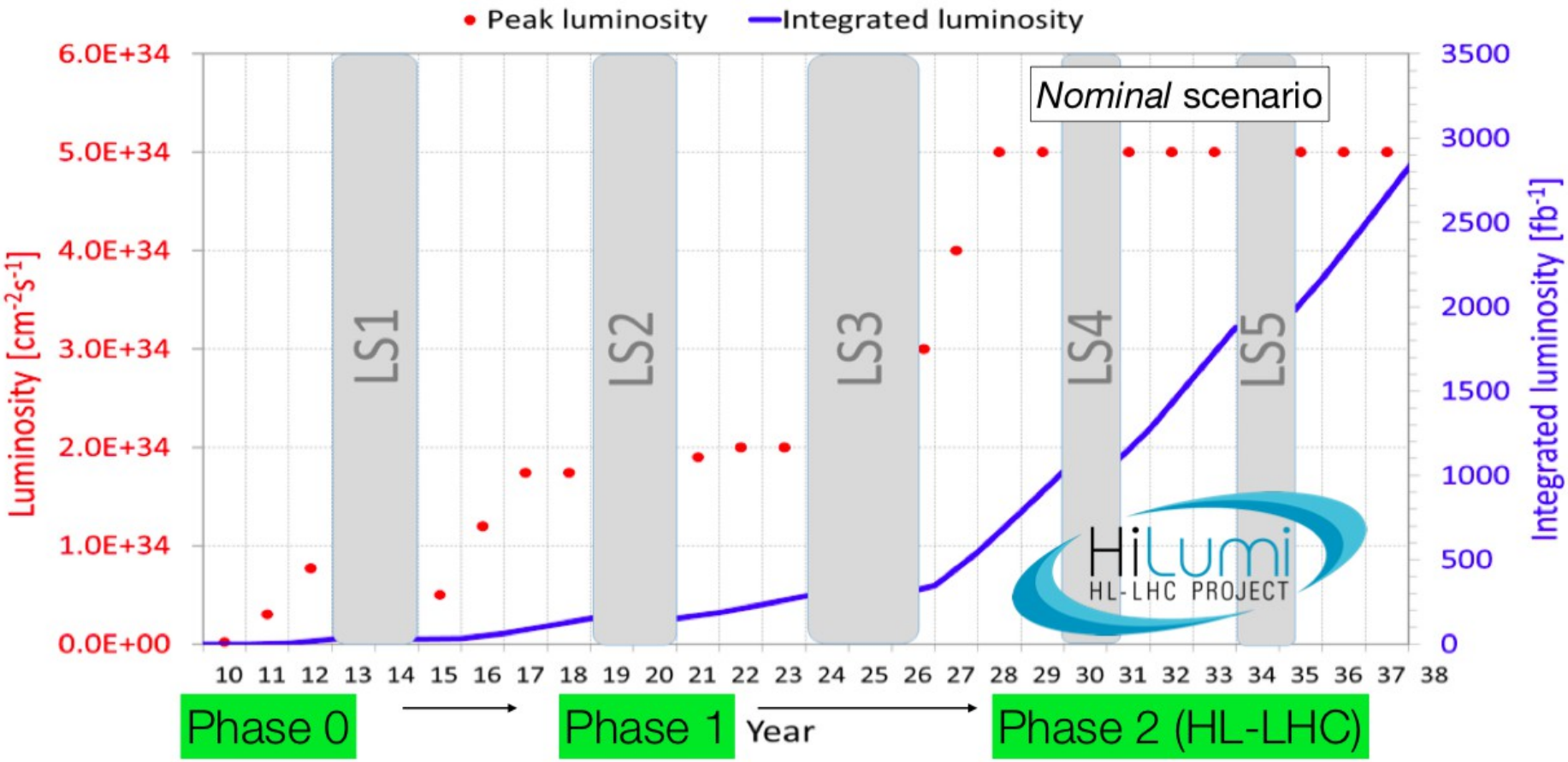


- **But many questions remain unanswered!**
- **Improve precision of SM measurements:**
  - Higgs properties and couplings, flavour physics, etc.
- **Continue search for new physics beyond the SM:**
  - SUSY, dark-matter, resonances,
- **The detector and infrastructure are available**
  - Fast way to explore electroweak landscape
- **All of these need higher luminosity!**



HL-LHC

- **Starting from 2026 onwards**, the **HL-LHCs** instantaneous luminosity
  - increase by a factor **5 to 7 compared to LHC**
  - will result in up to 200 collisions per bunch crossing.

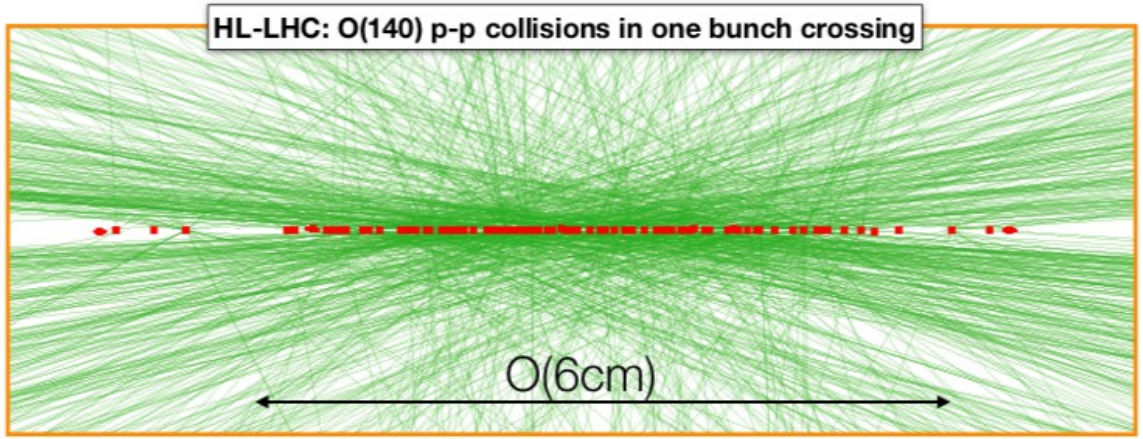


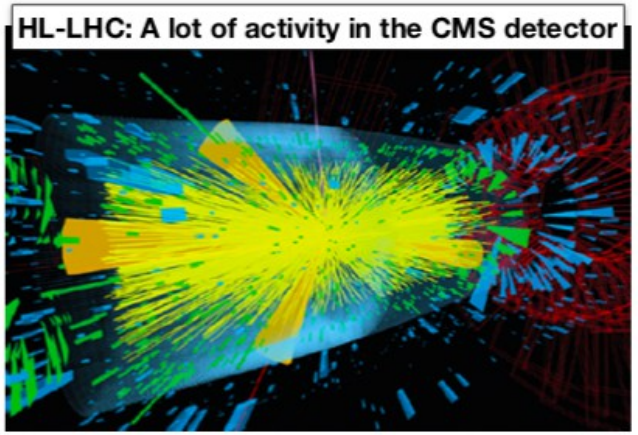
CMS detector in HL-LHC

- The current CMS detector was designed for operation at 25 collisions per bunch crossing and up to 500 fb^{-1}

- Integrated luminosity ~ 3000 fb^{-1}@HL-LHC
  - 140-200 collisions per bunch crossing
  - 3-4 times larger than Run 2!
  - Vertices concentrated within a few centimeters

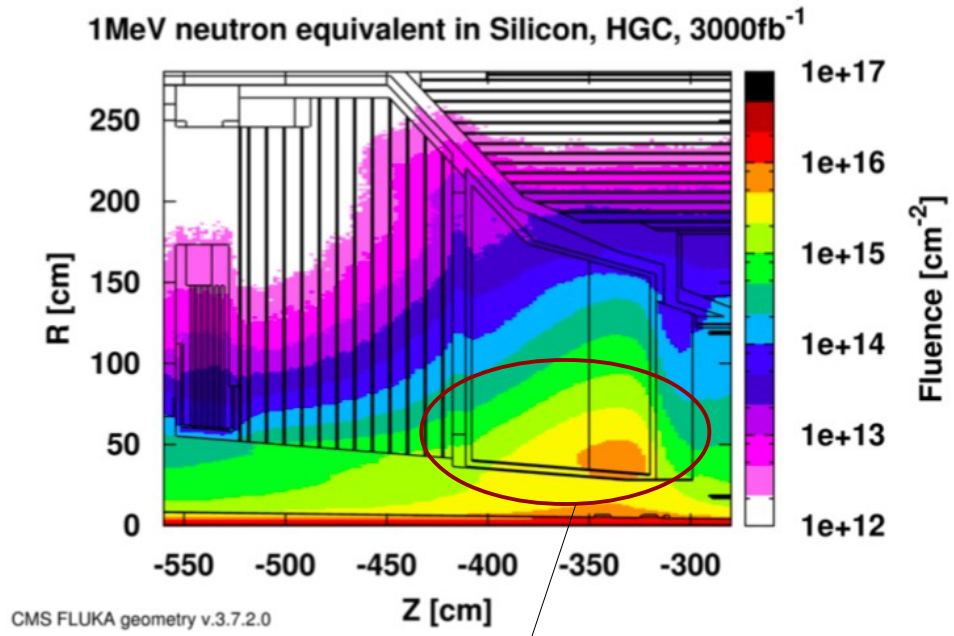
Collisions every 25 ns --> Pile-up

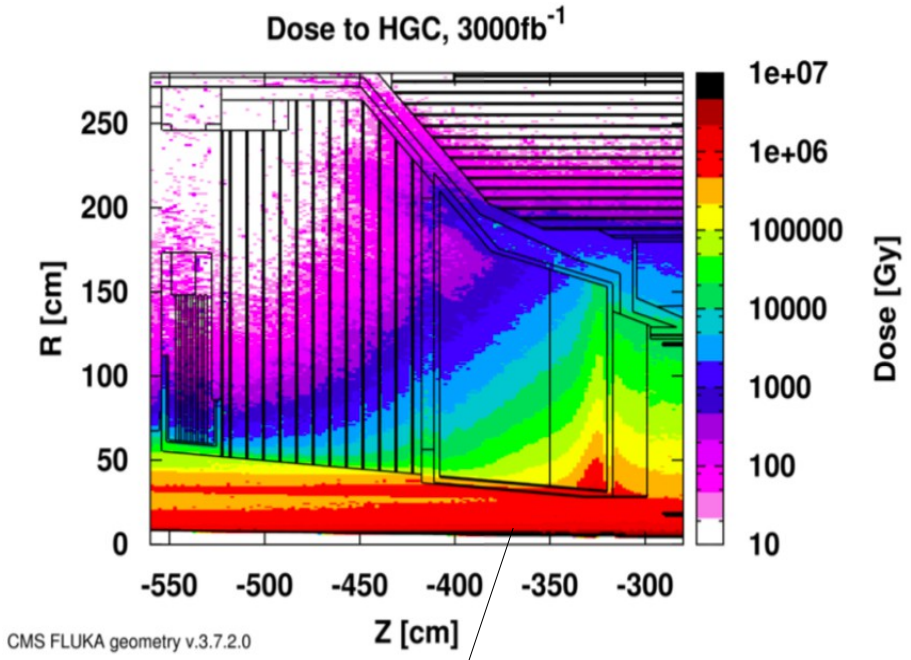




CMS in HL-LHC: increased radiation

- The endcap calorimeters are among the subdetectors that will be most exposed to high radiation levels.



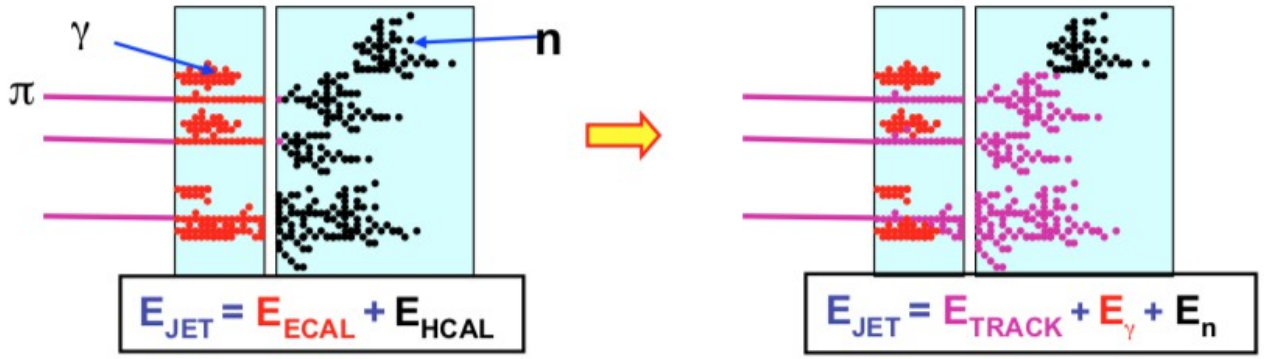


- High radiation on electromagnetic (ECAL) crystals and hadronic (HCAL) scintillators during HL-LHC

- Detail of the fluence in the pixel volume
- The expected fluence has a strong dependence on radius, while it is almost independent of the *z* coordinate.

Developments for High Granularity Calorimeters

- **Better imaging for particle flow (PF) reconstruction and removal of pile-up events!**
  - due to the great progress on micro-electronics integration (silicon sensors, SiPM-silicon photomultiplier tubes) over the last two decades and
  - precision on timing ---> essential for pile-up



- **PF reconstruction**
  - Combine information from all sub-detectors
  - Provide description of events in the form of reconstructed particle candidates

- **In order to meet the requirements of the HL-LHC PF calorimeters require high granularity!**

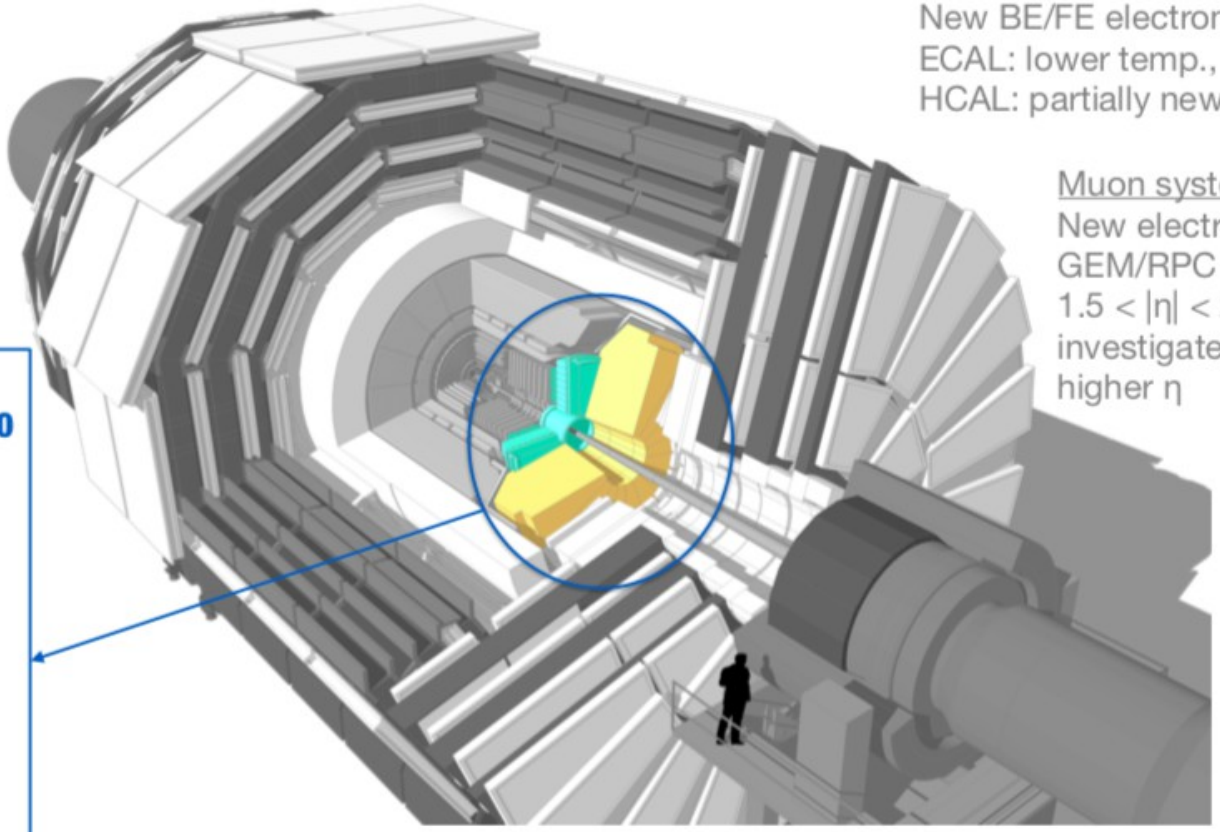
CMS Upgrade for HL-LHC

- The High Granularity Calorimeter (HGCAL) is to replacing existing CMS endcap pre-shower, electromagnetic and hadronic calorimeter, none of which would remain performant at the HL- LHC.

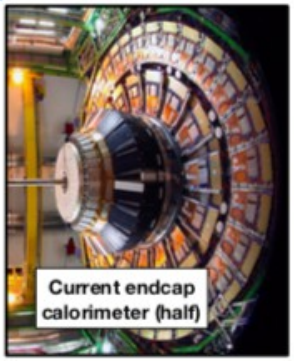
Tracker:
Radiation tolerant,
high granularity,
less materials, tracks in
hardware trigger (L1),
coverage up to $|\eta| = 3.8$

Barrel Calorimeter:
New BE/FE electronics,
ECAL: lower temp.,
HCAL: partially new scintillator

Muon system:
New electronics
GEM/RPC coverage in
$1.5 < |\eta| < 2.4$,
investigate muon tagging at
higher η

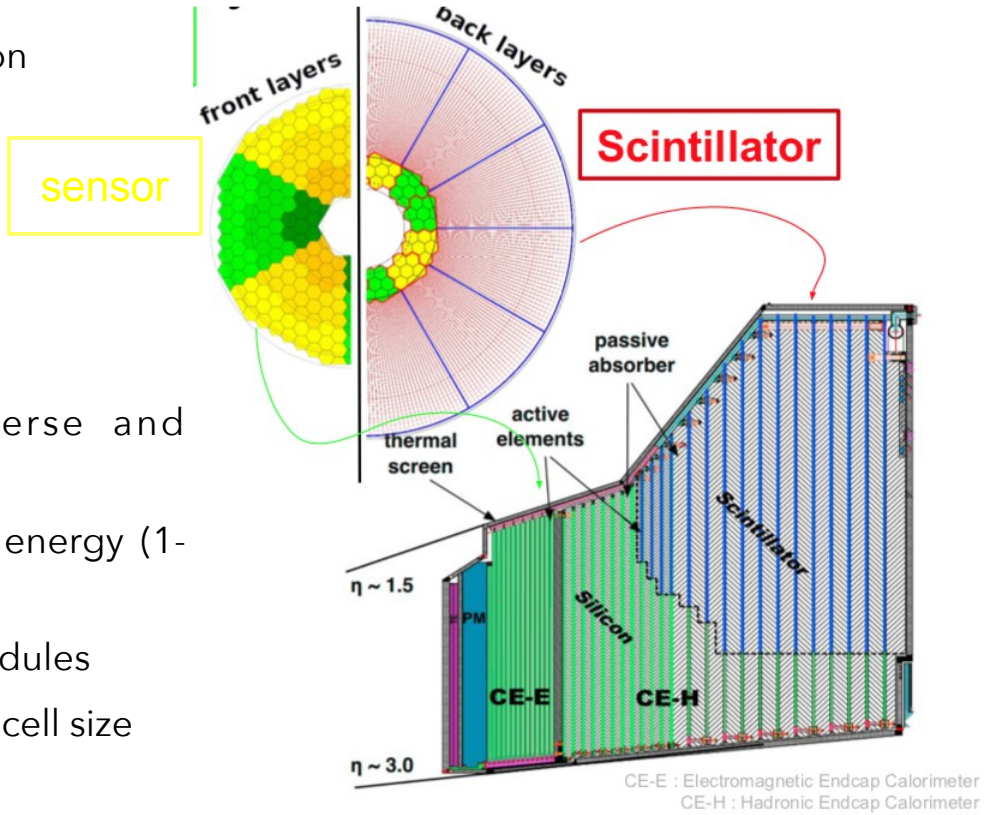


Endcap calorimeters:
Coverage $1.5 < |\eta| < 3.0$
...



CMS High Granularity Calorimeter (HGCAL)

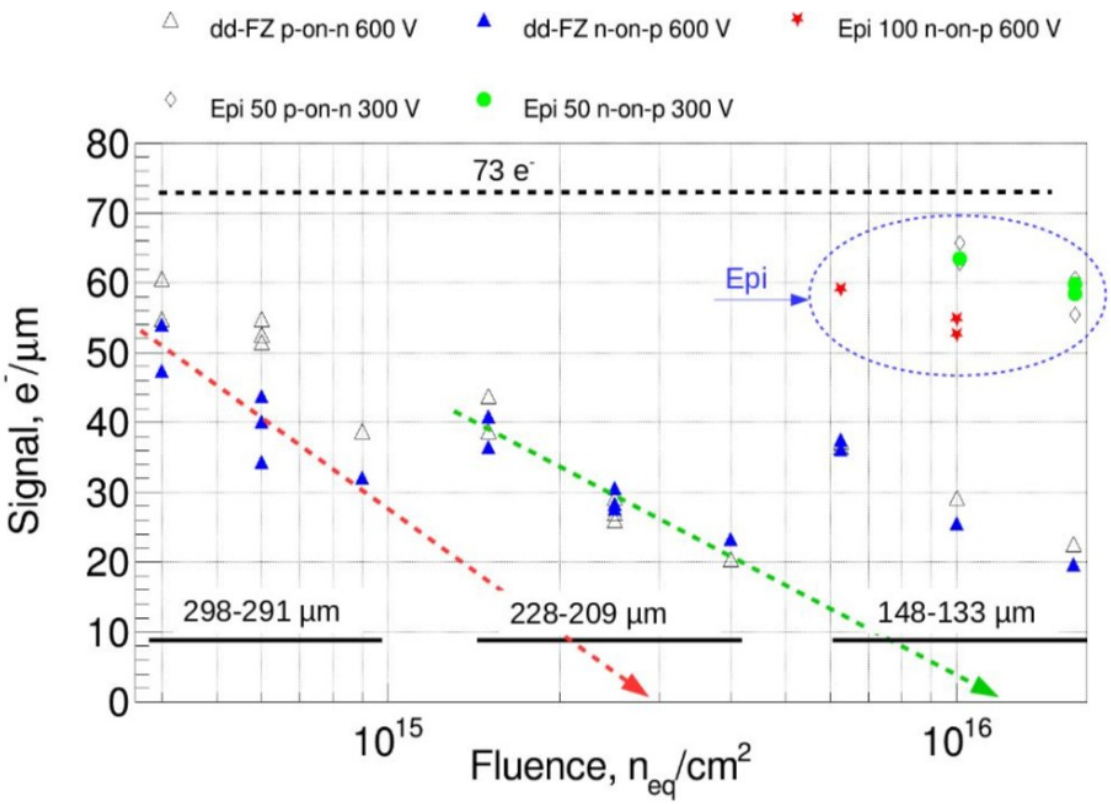
- Sampling calorimeter for CMS Phase 2
- **Active elements:** silicon sensors and silicon photomultiplier tubes (SiPM)
- **Key parameters**
  - Acceptance of 1.5 < |eta| < 3.0
  - Full system maintained at -30 °C
  - Features unprecedented transverse and longitudinal segmentation
  - Fine granularity (cell size 1-30 cm^2), energy (1-10k MIP range)
  - ~640 m^2 silicon sensors in ~31000 modules
  - ~6.1M silicon channels, 0.5 or 1.1 cm^2 cell size
  - ~370m^2 of scintillators
  - ~240k scintillator channels



Silicon sensors

- Silicon sensors fulfill the following required criteria:
  - Radiation hardness (sufficient!)
  - Good intrinsic time resolution to mitigate pileup
  - Thin sensors great for a compact system
  - Can be finely segmented
  - High signal-to-noise ratio!

Due to radiation damage signal loss is expected!

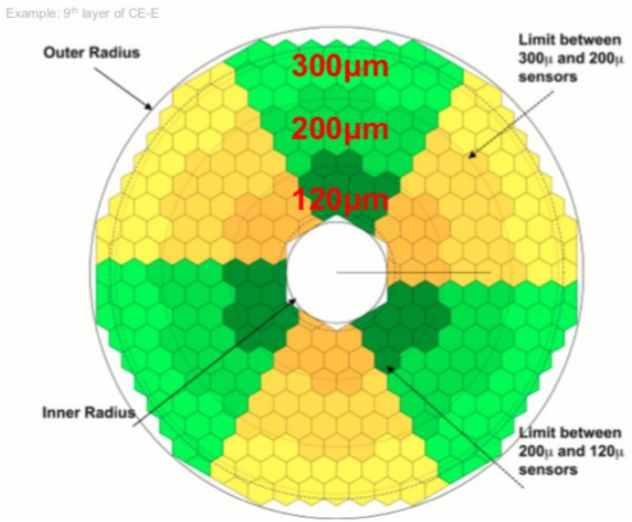


E. Curras et. al., NIM A 845 60-63 (2017)

Silicon sensors & Scintillator+SiPM

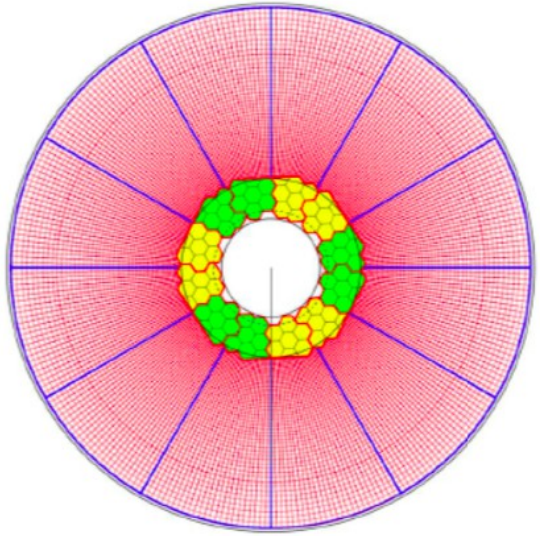
CE-E: 28 layers (Si)

- Hexagon shape maximizes usable wafer area
- Three sensor thicknesses
  - Low pseudorapidity -> thicker sensors
  - High pseudorapidity -> thiner sensors
  - 8" silicon wafer advantages:
    - Reducing the number of modules
    - Simplifies module mechanics
    - Lower cost



- At larger distances to the interaction point radiation levels are lower
  - Plastic scintillating tiles with SiPM readout will be used.
- Rely on experiences from CMS HCAL upgrade and CALICE

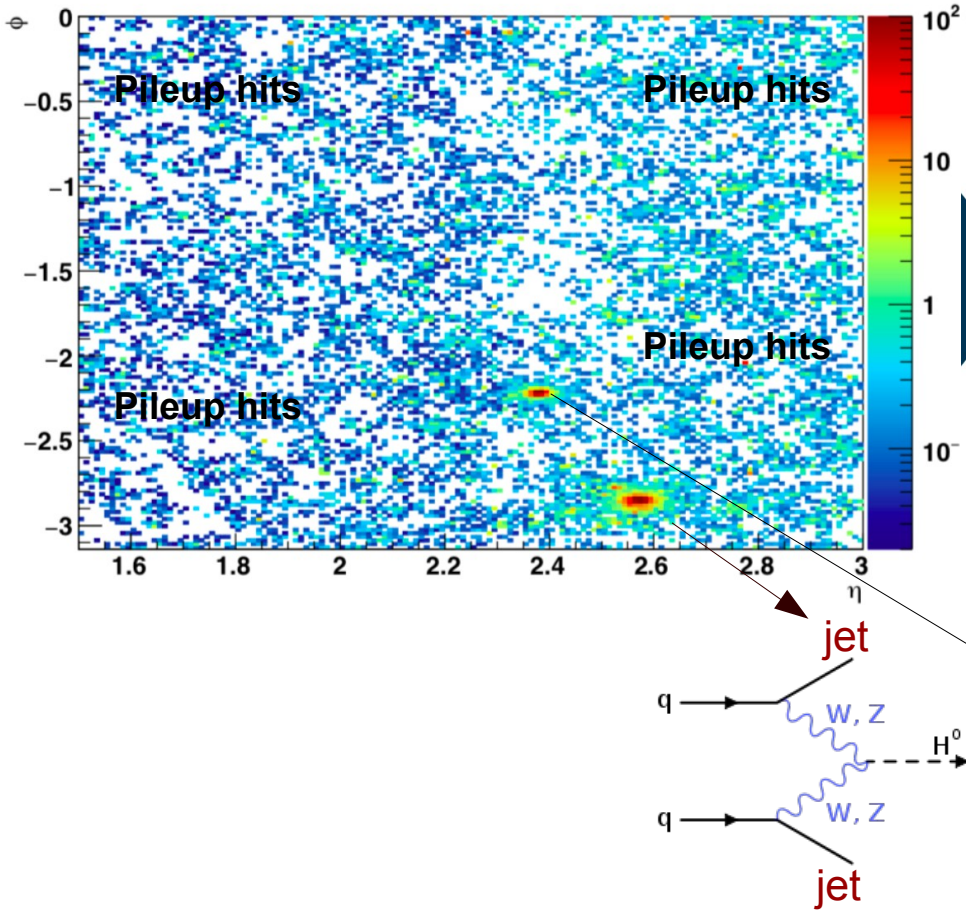
CE-H: 22 layers (Si+Si-Scint.)

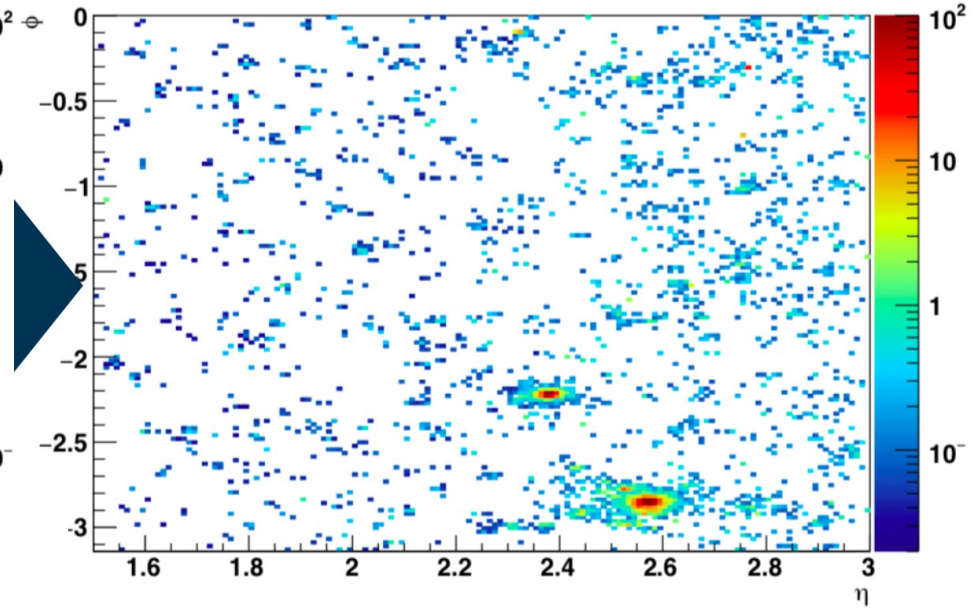


Timing capability

- Time measurement for hits > 12 fC
  - Allows imaging of showers with timing.
  - Timing information can be used in HGCAL reconstruction
  - Ambitious target: better time resolution (30 ps for clusters with p_T > 5 GeV)

Simulation of VBF H ($\gamma\gamma$) event in HGCAL **with and without timing selection (timing cut $|\Delta t|$ < 90 ps)**





• Plots show cells with Q > 12fC (~3.5 MIPs @300μm - threshold for timing measurement) projected to the front face of the endcap calorimeter.

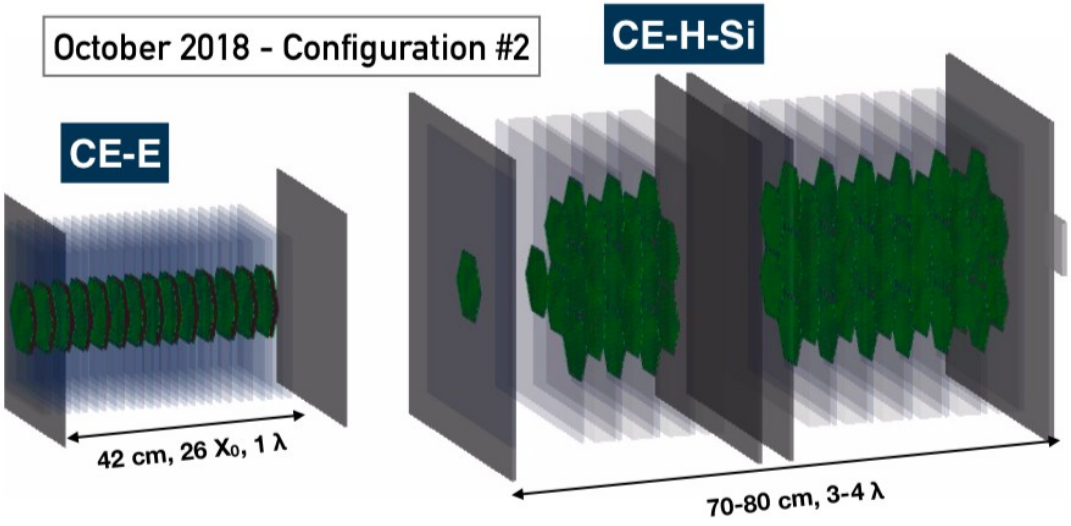
• Concept: identify high-energy clusters, then make timing cut to retain hits of interest

Test beams of HGCAL prototypes

- Beam tests of particle detectors are crucial to
  - Evaluate the physics performance: calibration, resolution, linearity, etc..
  - Identify technological or system issues affecting the performance (e.g. noise)
  - Check agreement with simulation

- Several test beam periods in 2016 and 2017 @ CERN, June 2018 @DESY

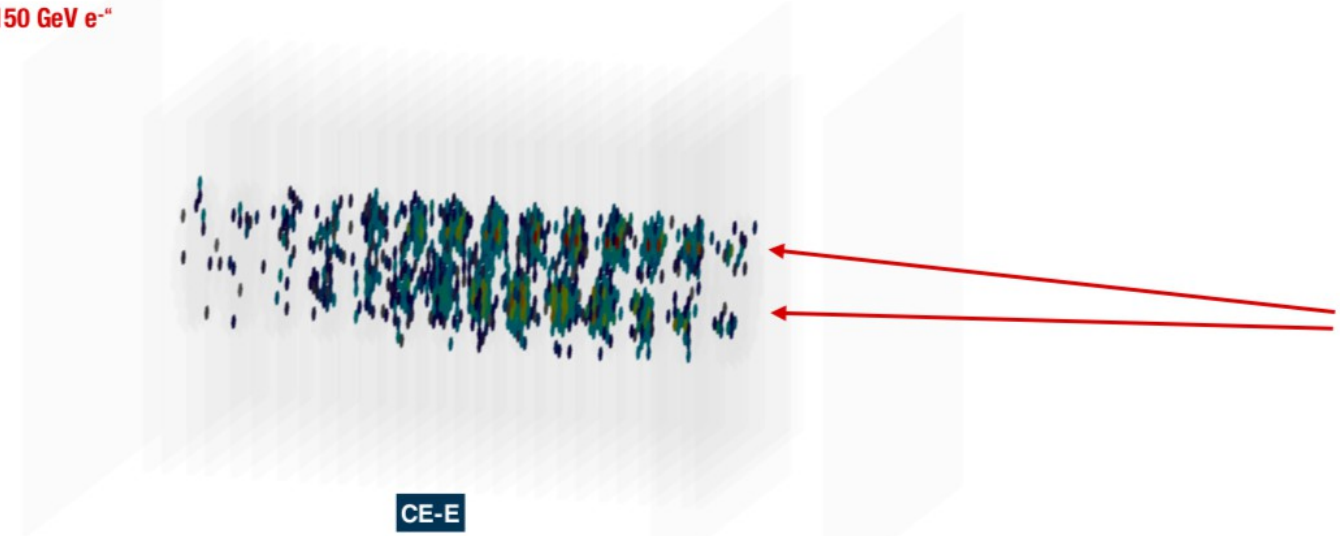
- Beam test in October 2018 @ CERN: joint efforts with Calice – AHCAL!
  - 28-layer CE-E setup
  - +12-layer CE-H-Si setup (94 modules)
  - Studied 3 different configurations in the EE/FH with electron, pion and muon beams (for calibration) up to 300 GeV



Test beams: events

June 2018 run 407 - event 1:

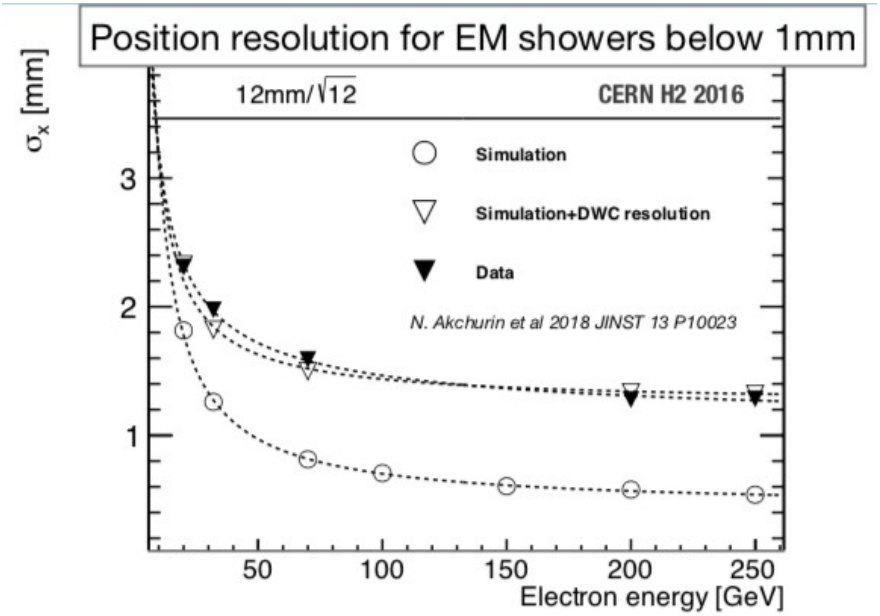
"150 GeV e-"

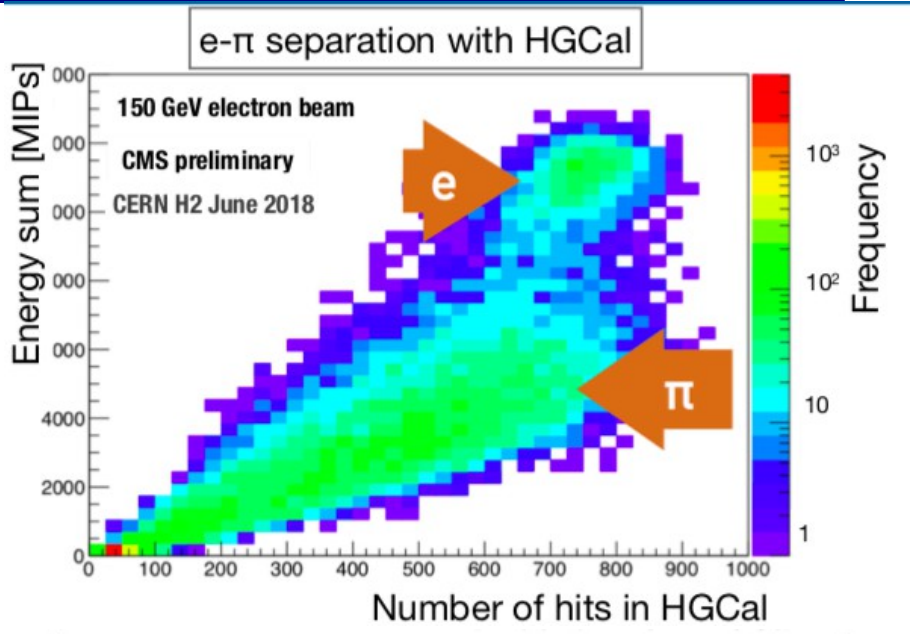


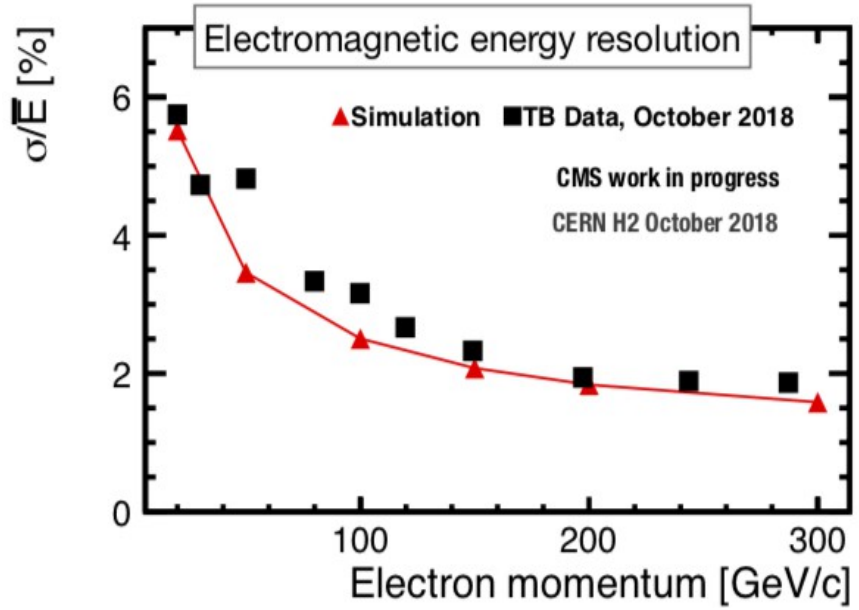
October 2018 run 517 - event 30:

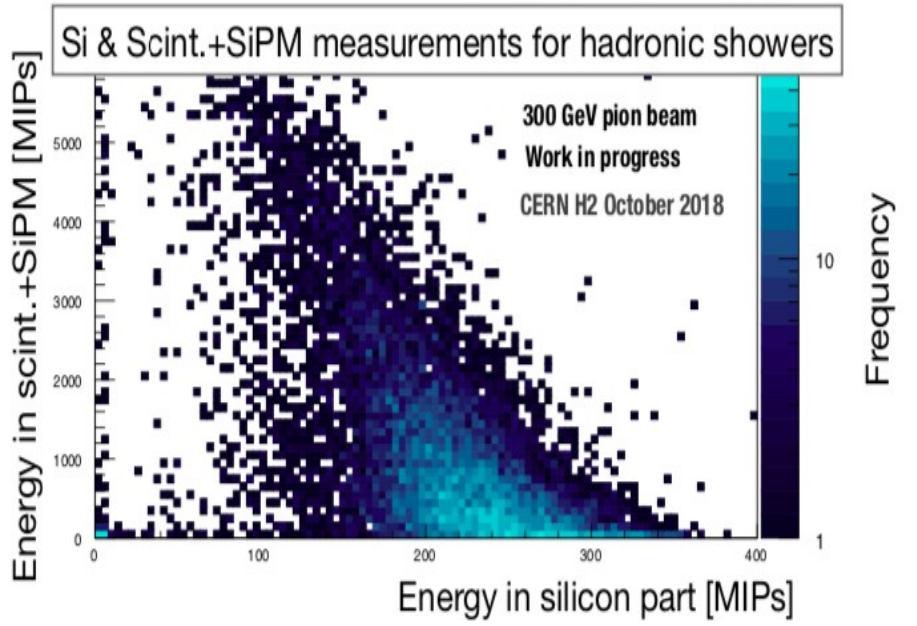
250 GeV π-

Preliminary results from test beams









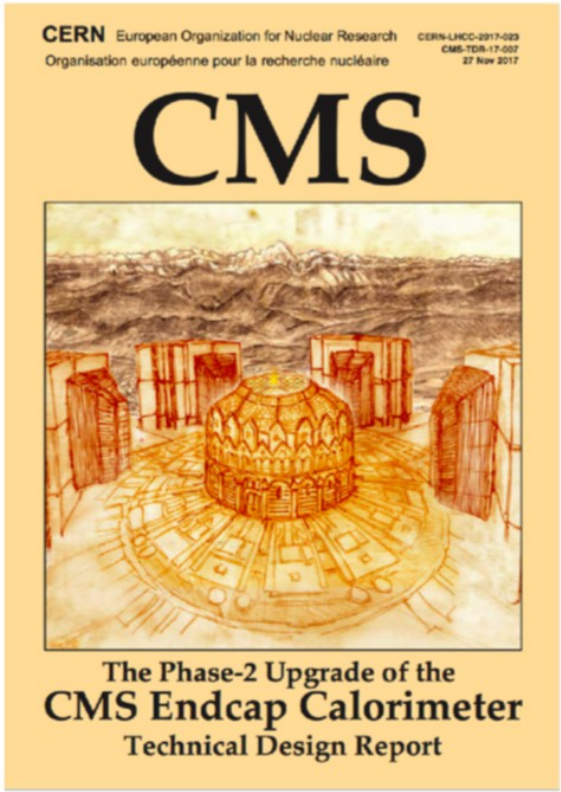
Summary

- **Radiation hard environment, high pileup and occupancy** during HL-LHC

- High Granularity Calorimeter (HGCAL) is an imaging calorimeter inspired by CALICE and HCAL @ CMS
  - will be **the largest silicon based particle detector** comes to life at the energy frontier

- Significant ongoing effort to **improve engineering design with extensive prototyping and beam tests**
  - **challenging project** in terms of mechanical and electrical engineering

- **Analyses ongoing, publications in preparation in line, stay tuned!**



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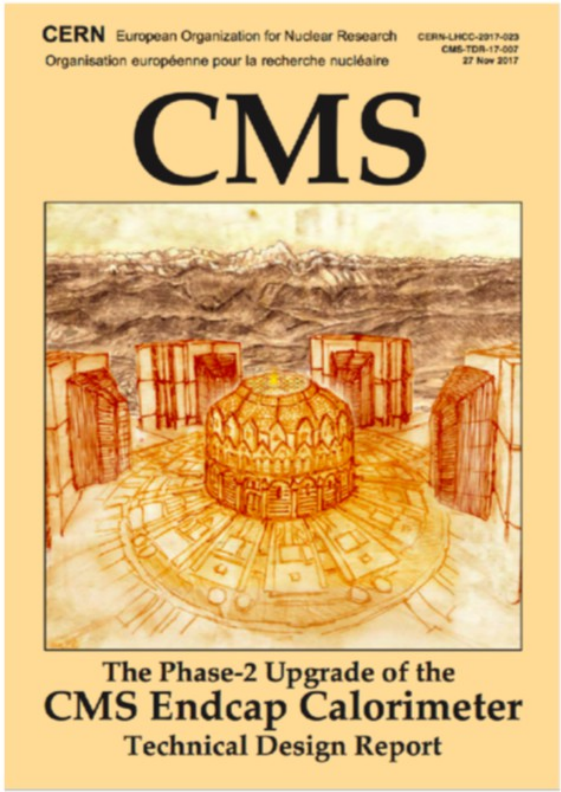

Thank you for your attention!

BACKUP