CMS Calorimetry at forward rapidity

20th Annual RDMS CMS Collaboration Conference

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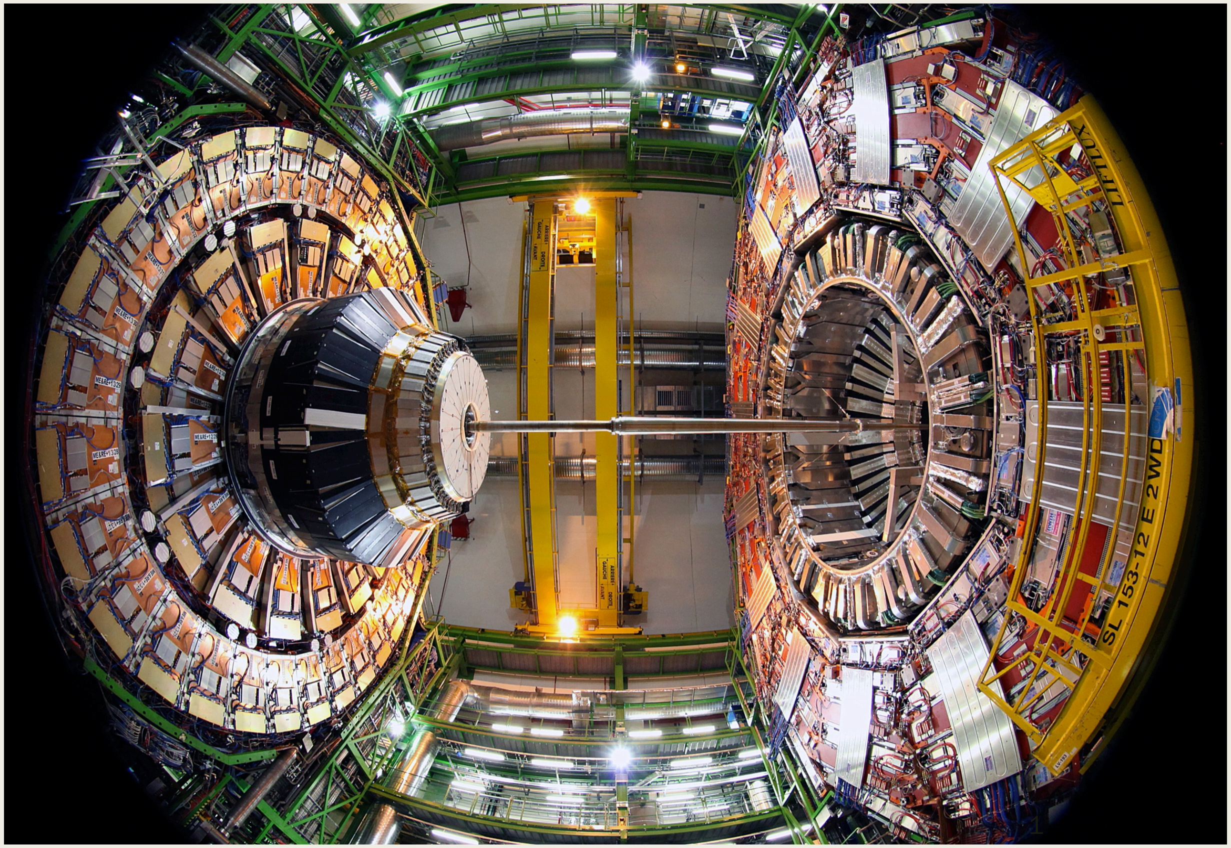
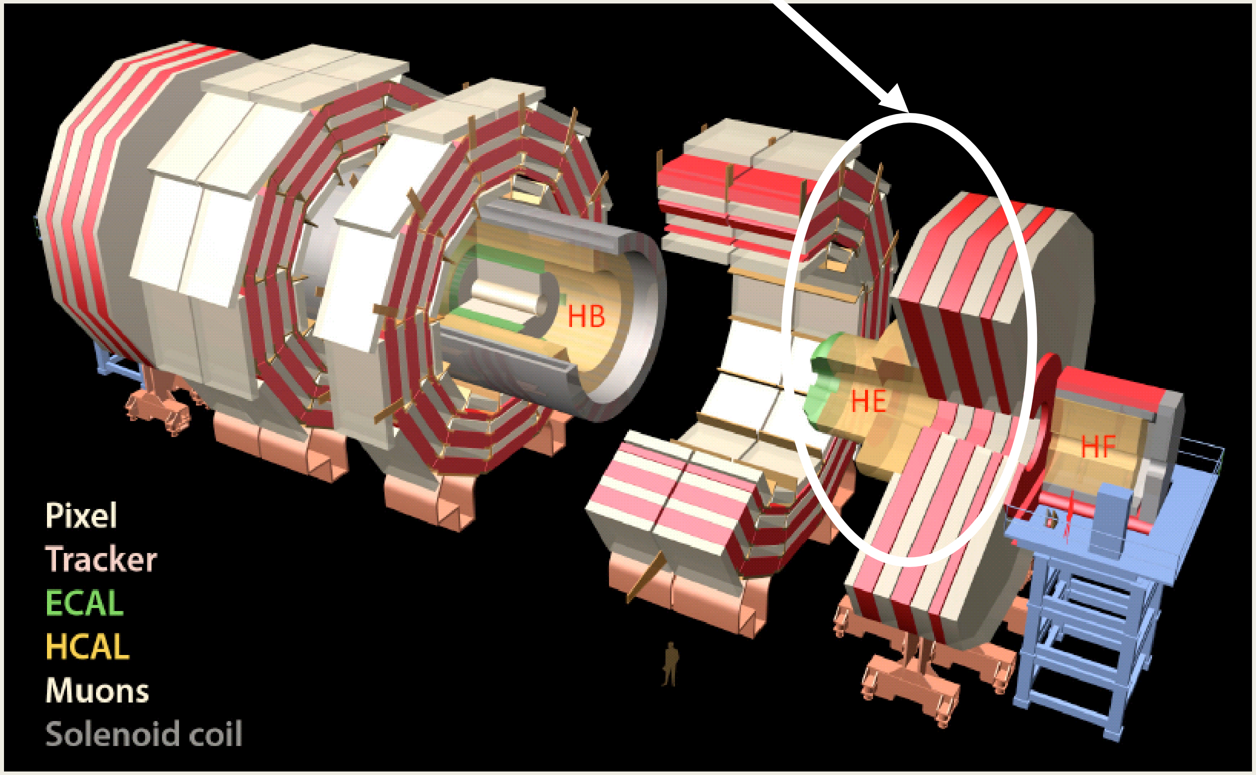
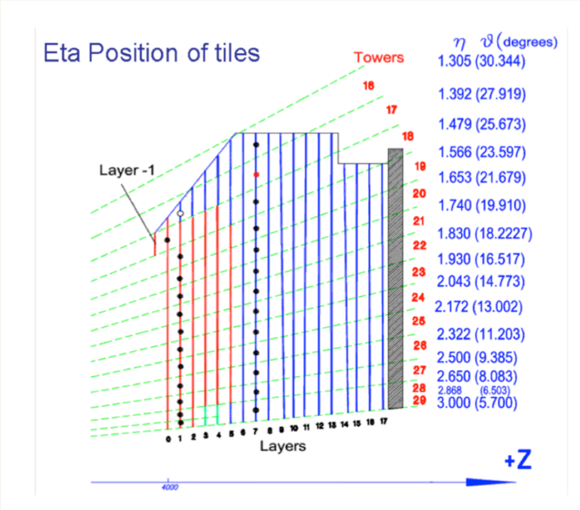
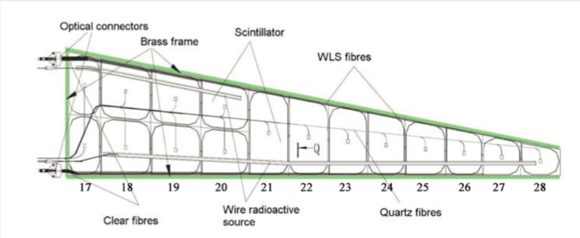


The CMS Detector and HCAL Endcap

RMDS played key role in designing and construction of the present CMS detector.
In particular, RDMS institutes, including Uzbeskistan, have made critical contributions to the design, construction and commissioning of CMS Hadron Endcap calorimeter.

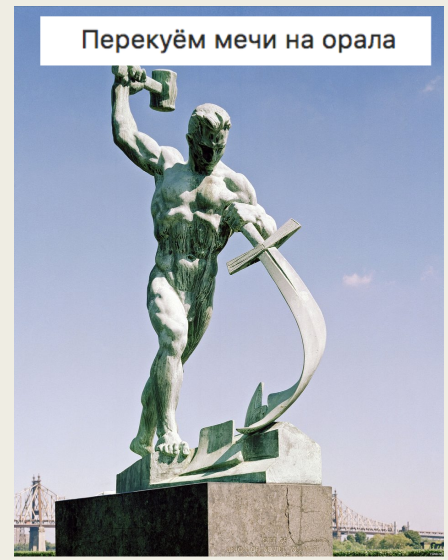






RDMS contributions to HCAL Endcap

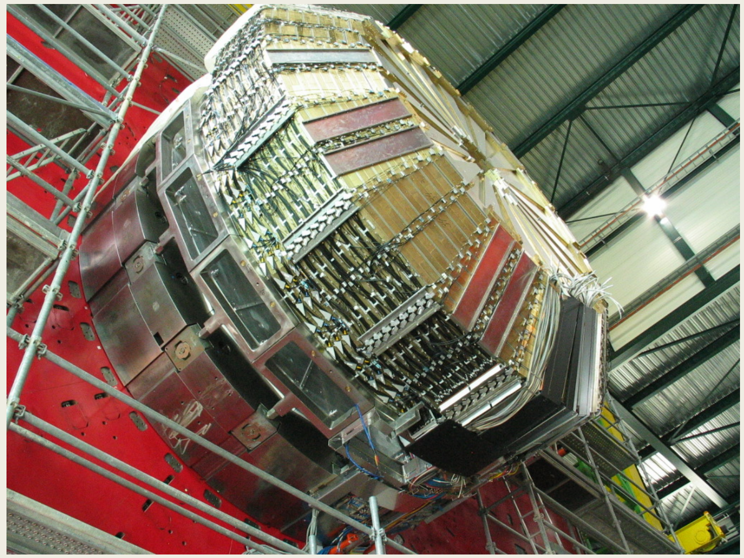
> "And he shall judge among the nations, and shall rebuke many people: and they shall beat their swords into plowshares, and their spears into pruninghooks: nation shall not lift up sword against nation, neither shall they learn war any more. (Isaiah 2:4)."



RDMS coordinated HE design, construction, assembly and commissioning effort.

- The HE brass, supplied by RDMS, consisted of reconstituted cartridge shells.
- JINR (Dubna) had overall coordination responsibility.
- NIKIET (Moscow) had design responsibility.
- IZHORA (St. Petersburg) manufactured the plates.
- MZOR (Minsk) machined and pre-assembled the plates (under the leadership of Nikolai Shumeiko).
- Plates then shipped and assembled at CERN with final assembly performed vertically (under RDMS supervision).
- Scintillator was machined in Kharkov and assembled into megatiles, including QC and calibration in Protvino.
- RDMS led the effort of assembly and commissioning of HCAL Endcaps in SX5 prior to lowering the detectors to the UX5 cavern.

RDMS contributions to HCAL Endcap



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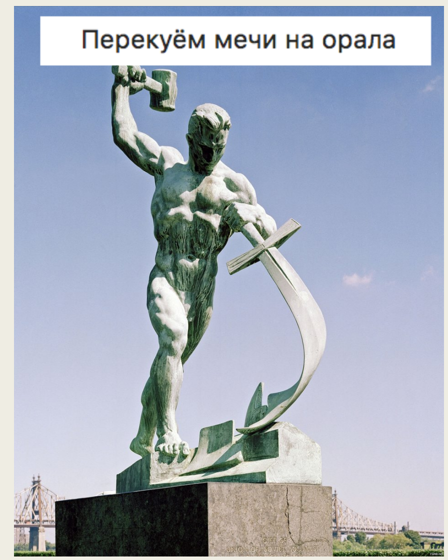

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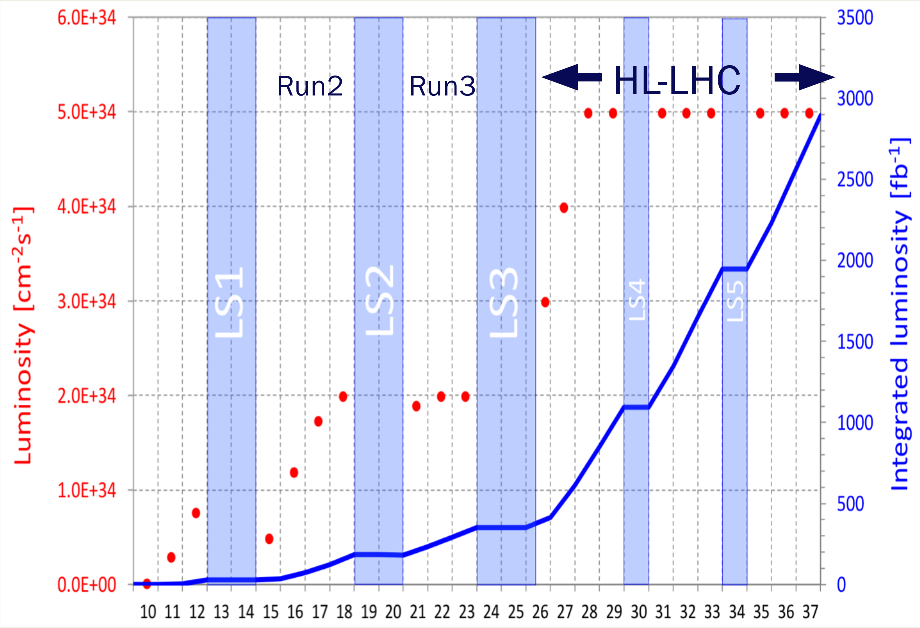
High Luminosity LHC

- Instantaneous luminosity levelled at 5×10^{34} $cm^{-2}s^{-1}$, mean pileup (PU) 140
  - potential for 50% increase over nominal values ⟶ required to handle PU 200
- Physics goals: precision SM & Higgs measurements, plus BSM searches
  - each includes vector boson fusion (VBF) events ⟶ narrow jets
  - plus boosted objects ⟶ narrow τ jets and merged jets (W/Z boson decays)



Reconstruction of forward jets in high pile-up environment is crucial for HL-LHC physics

Expected doses and fluence in CMS endcap region after 3000 fb^{-1}

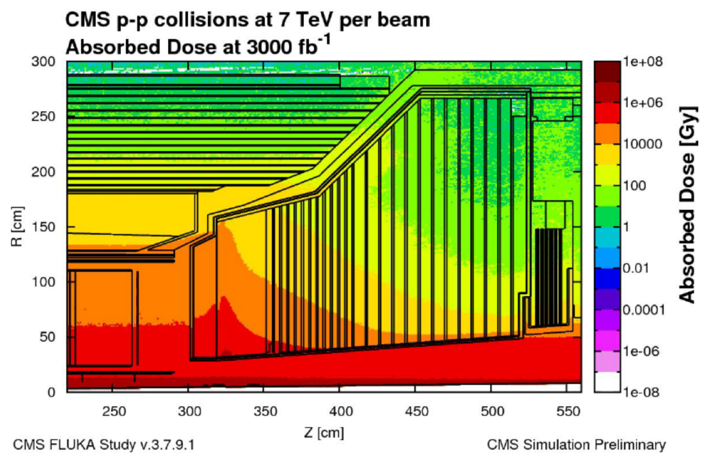


Figure 1.1: Dose of ionizing radiation accumulated in HGCAL after an integrated luminosity of3000 fb^{-1}, simulated using the FLUKA program, and shown as a two-dimensional map in the radial and longitudinal coordinates, r and z.

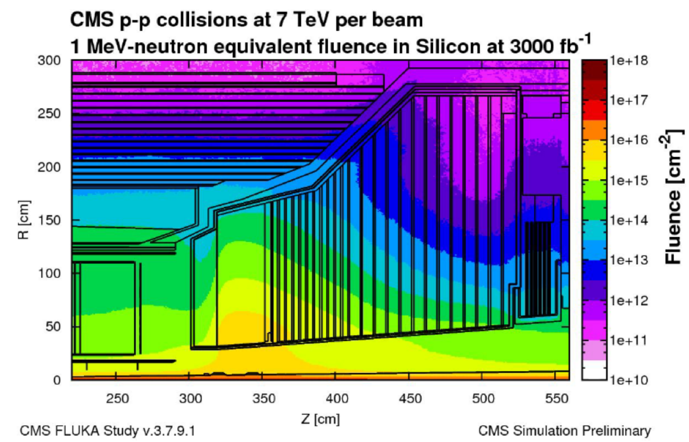


Figure 1.2: Fluence, parameterized as a fluence of 1 MeV equivalent neutrons, accumulated in HGCAL after an integrated luminosity of3000 fb^{-1}, simulated using the FLUKA program, and shown as a two-dimensional map in the radial and longitudinal coordinates, r and z.

Hadron Endcap (HE): scintillators/WLS fibers; Electromagnetic Endcap (EE): Lead tungstate crystals
Present Endcap detectors were designed for integrated luminosity of 500 fb $^{-1}$. Radiation damage to active elements of present CMS Endcap detectors much beyond this integrated luminosity would lead to performance degradation, and in effect, unacceptable loss of physics performance.
The replacement will need to tolerate up to 200 Mrad after 3000 fb^{-1}, and a fluence of 10^{16} n/cm^2.
It will also require good signal to noise ratio for minimum-ionizing particles for accurate calibration throughout HL-LHC.

Signal loss of Endcap calorimeter vs Int. Luminosity

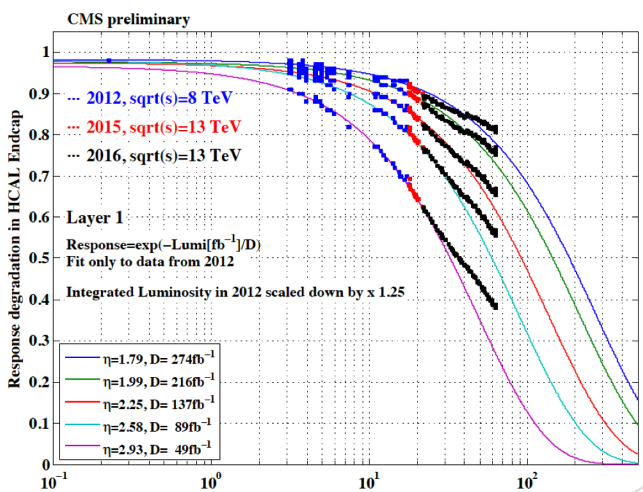
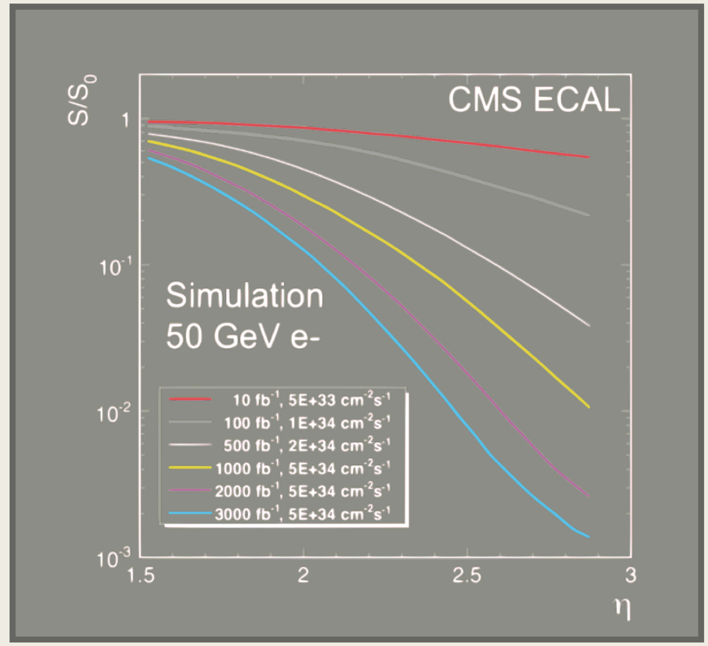


Figure 2.18: Response loss in HE Layer1 for various η towers, averaged over all ϕ towers, as a function of integrated luminosity. The response was normalized to the signal at the beginning of 2012. The normalization for Laser intensity variation was obtained using the lowest η ring.

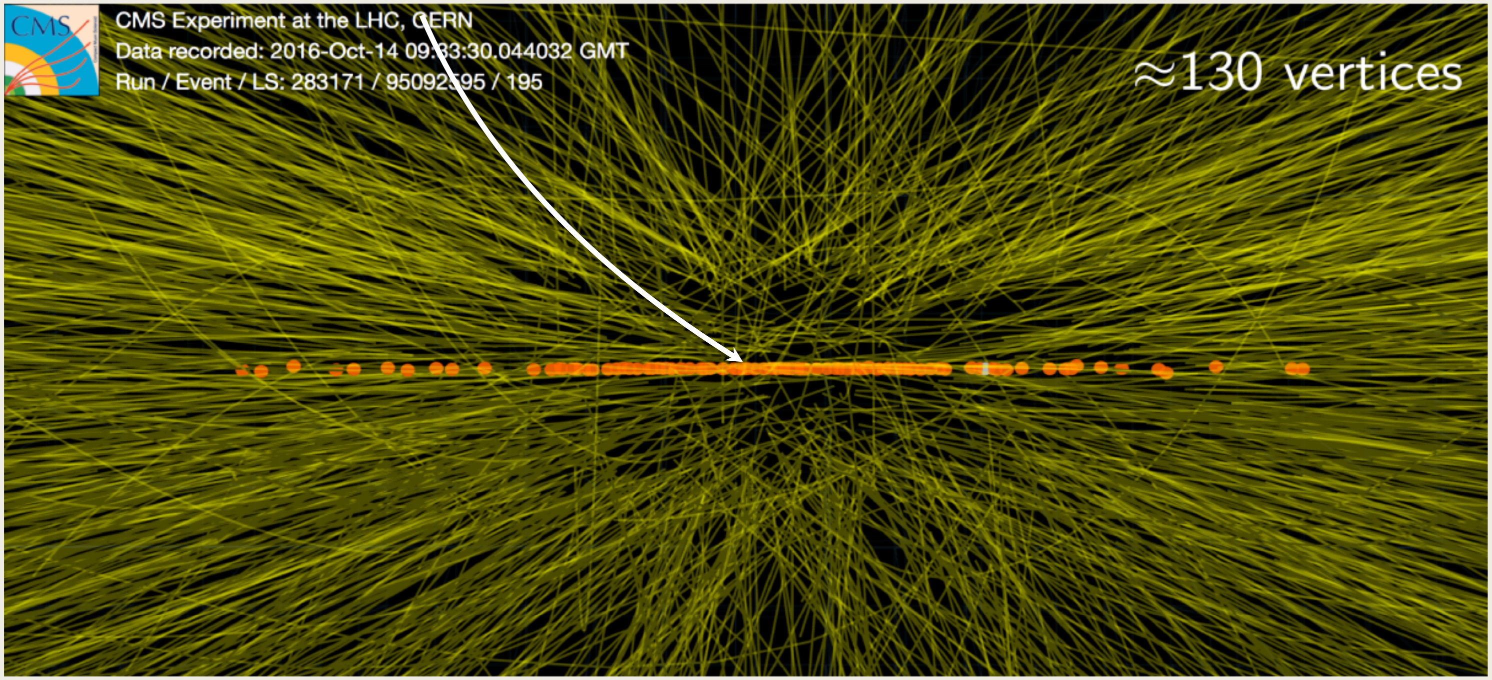


In the high eta region of HE, significant signal reduction.
HPD-> SiPM replacement (part of Phase1 upgrade)
has *reduced* rate of signal loss.

After 1000 fb $^{-1}$, in the high eta region of EE, HE, signal reduction ~ x10.

Expected pile-up in CMS at $5x10^{34}$ $cm^{-2}s^{-1}$

- Majority of 140-200 PU events end up in forward region
- Serious challenge to reconstruct events in this environment
- Example: real 2016 event with PU ~130



Reminder: Physics Questions for the LHC

1. SM contains too many apparently arbitrary features - *presumably these should become clearer as we make progress towards a unified theory.*

✓ 2. Clarify the e-w symmetry breaking sector

SM has an unproven element: the generation of mass

Higgs mechanism ->? or other physics ?

Answer will be found at **LHC energies**

e.g. why $M_\gamma = 0$

M_W, M_Z ~ 100,000 MeV!

Jim Virdee transparency from the early 90's

3. SM gives nonsense at LHC energies

Probability of some processes becomes greater than 1 !! Nature's slap on the wrist!

Higgs mechanism provides a possible solution

4. Identify particles that make up Dark Matter

Even if the Higgs boson is found all is not completely well with SM alone:

next question is "Why is (Higgs) mass so low"?

*If a new symmetry (Supersymmetry) is the answer, it must show up at O(***1TeV***)*

5. Search for new physics at the TeV scale

SM is logically incomplete – does not incorporate gravity

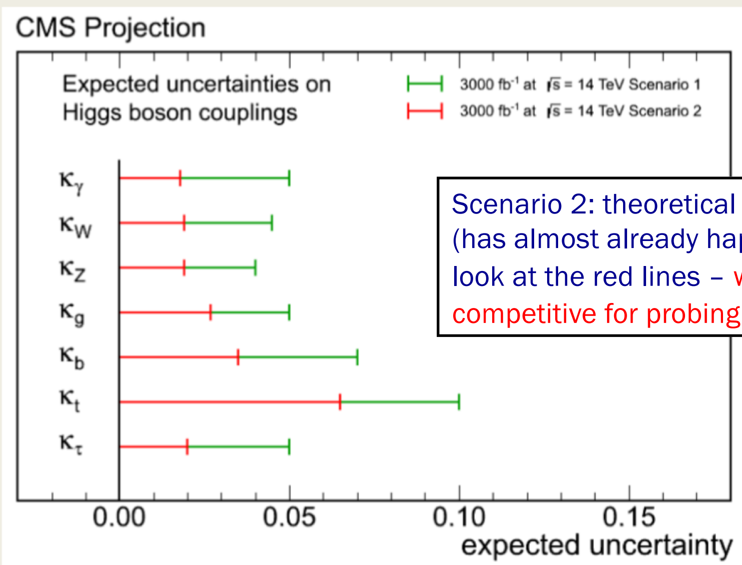
Superstring theory ⇨ *dramatic concepts: supersymmetry , extra space-time dimensions ?*

HL-LHC: Measurement of Higgs boson Parameters

HL-LHC: No. of Higgs bosons produced at √s=14 TeV for 3000 fb^{-1}

Process	No. Evts (M)
gg→ H	145
VBF	13
WH	5
ZH	2.5
ttH	1.8

- Higher statistics allows categorization of signal regions with higher S/B, regions where the systematics are better controlled,
- The balance between statistical and systematic errors changes
- e.g. VBF H→ττ: expect 200k events



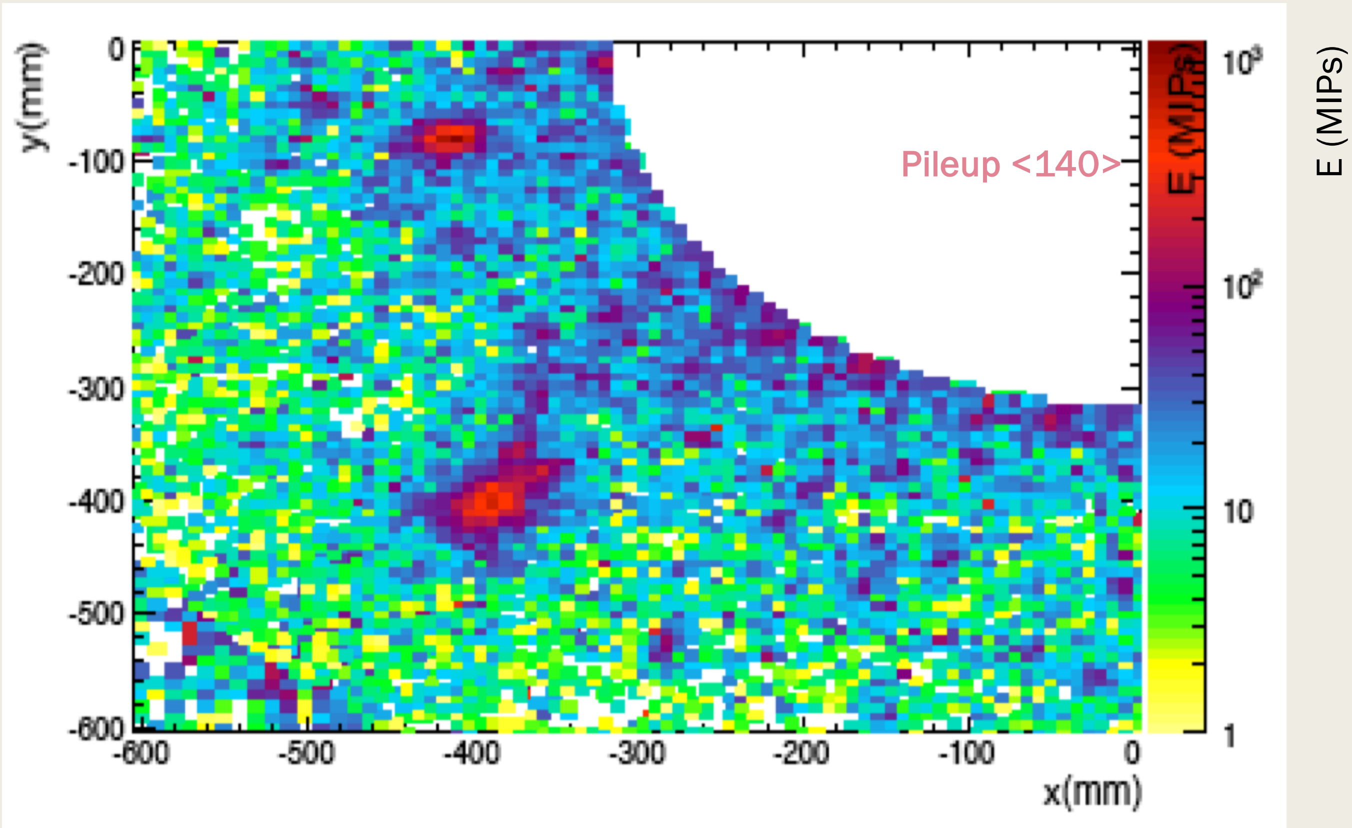
Scenario 2: theoretical errors halved (has almost already happened). So look at the red lines – will be competitive for probing BSM physics

- HGCAL has particular capabilities in the areas of
- H→γγ, H→ZZ*→4e, 2μ2e, H→ττ
- VBF channels (bbar, ττ, etc.)
  (lhs plot does not take account of dedicated L1-triggers)
- Di-Higgs production
- Rare decays involving photons
  (not on lhs plot)

What makes it worthwhile to run longer an HEP experiment ?

1. Higher centre-of-mass energy
2. Higher integrated luminosity
3. Qualitatively better detectors

Event Display of VBF Jets (VBF H→γγ)



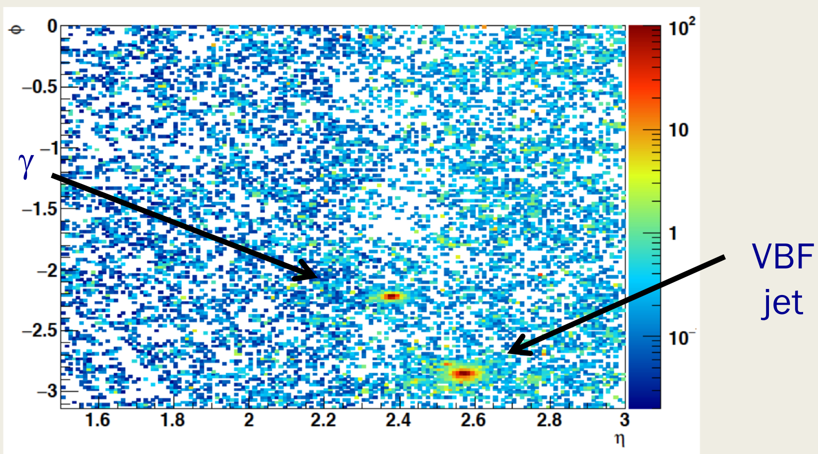
Use of Timing: One aim - Event "Cleanup"

Arises naturally from the choice of CE parameters and electronics

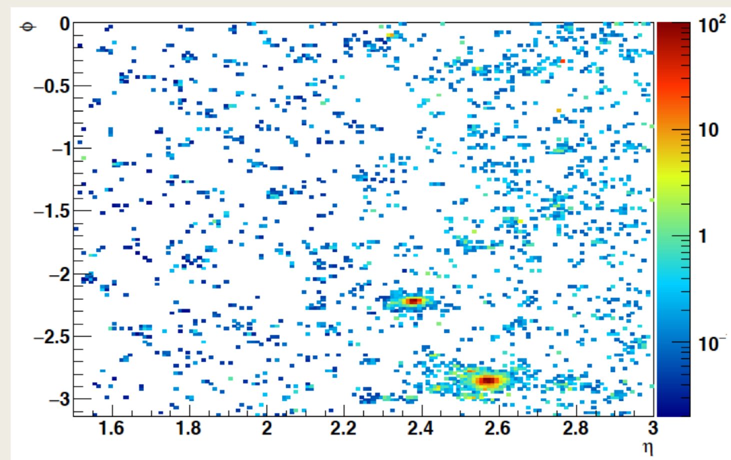
Figure of Merit: pileup mitigation (illustrative)

VBF ($H \rightarrow \gamma\gamma$) event with one photon and one VBF jet in the same quadrant,

PU=200 events: No timing cut



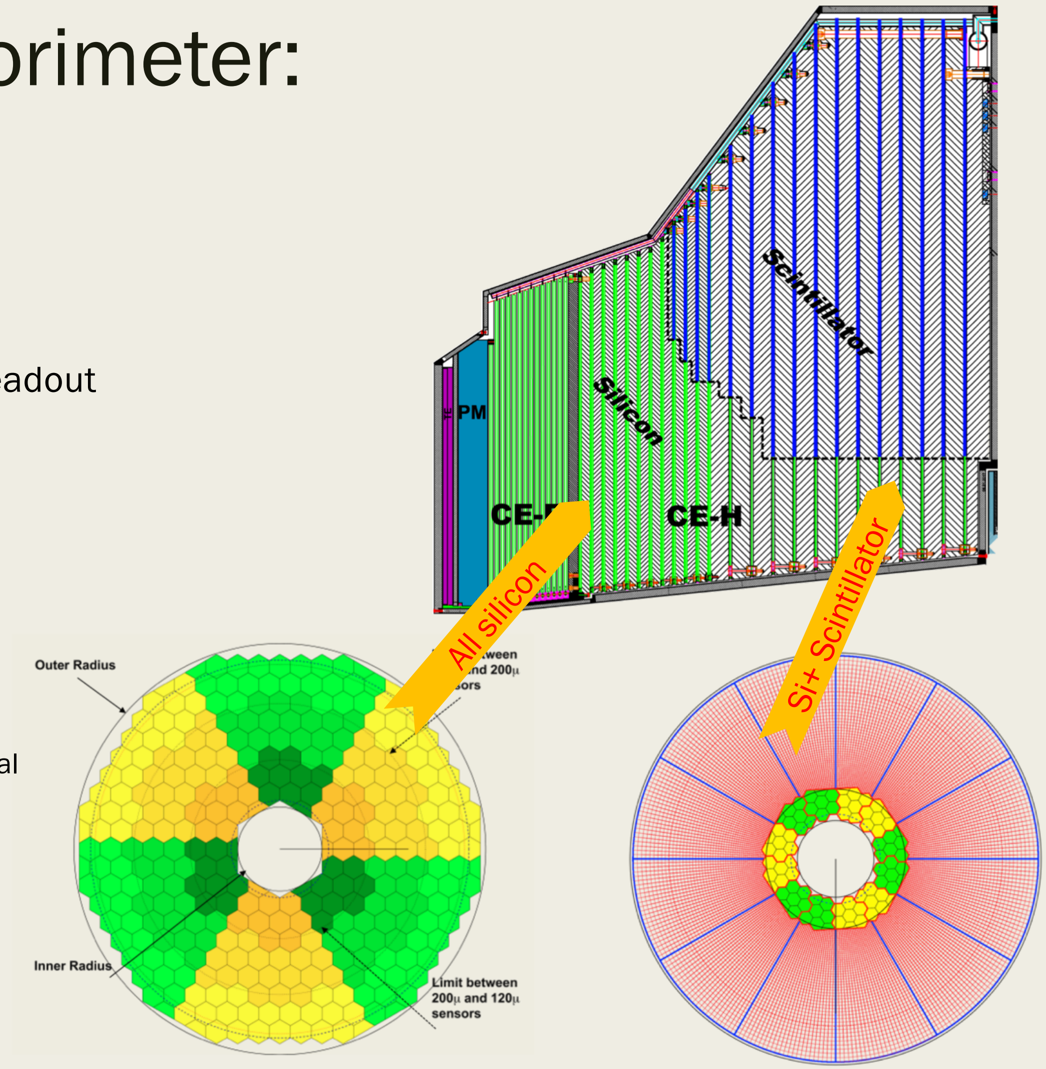
PU=200 evts: Cut Δt < 90ps (3σ at 30ps)



Plots show cells with Q > 12fC (threshold for timing measurement)
projected to the front face of the endcap calorimeter.

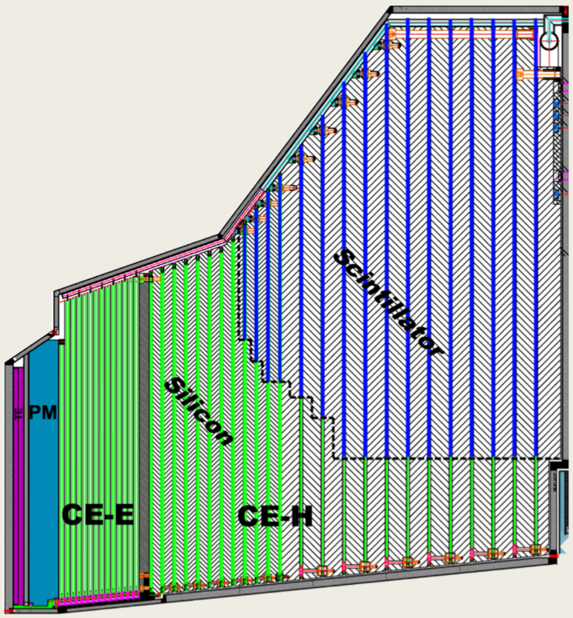
High Granularity calorimeter: key features

- Sampling calorimeter
- Unprecedented transverse and longitudinal readout segmentation
  - Silicon in high radiation areas
  - Scintillating tiles in the low-radiation region
- Covering 1.5 < η < 3.0, operated at -30 °C
- Nomenclature
  - HGCal = High Granularity Calorimeter
  - CE = Calorimeter Endcap (official CMS name) = HGCal
  - CE-E = Calorimeter Endcap - electromagnetic section
  - CE-H = Calorimeter Endcap - hadronic section

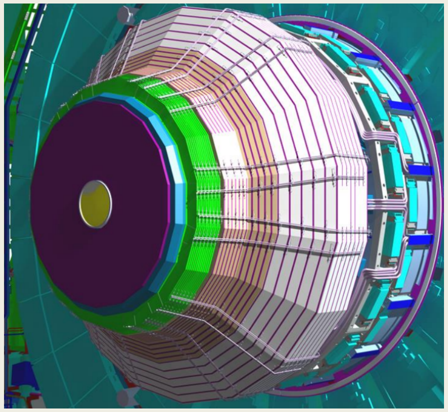


High Granularity calorimeter: absorber and active material

Per endcap	CE-E	CE-H (Si)		CE-H (Si + Scint)
Active	Silicon sensors			Scintillators
Absorber	Pb, CuW, Cu	Stainless steel, Cu		
Depth	26 X_0, 1.7 λ, 34 cm	9 λ		
Layers	28	8		16
Weight	23 t	205 t		



For both endcaps	Silicon sensors	Scintillators
Area	**600 m^2**	500 m^2
# Modules	27,000	2500
Channels Size	0.5-1 cm^2	4-30 cm^2
# Channels	6 Mio	400k
Op. temperature	-30 °C	-30 °C



HGCAL Longitudinal Structure

28 Layers | 12 Layers 35 mm SS | 12 Layers 68 mm SS

8 Layers Silicon | *16 Layers Silicon/Scintillator*

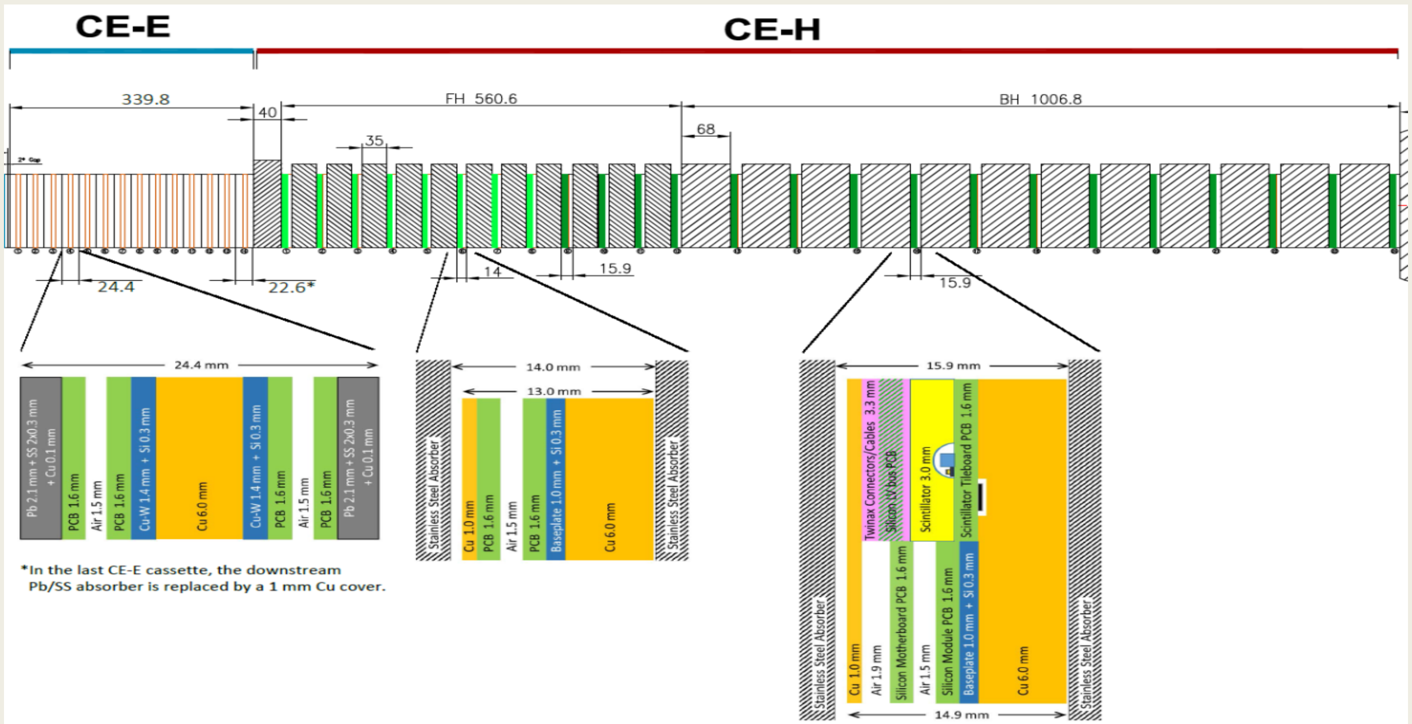
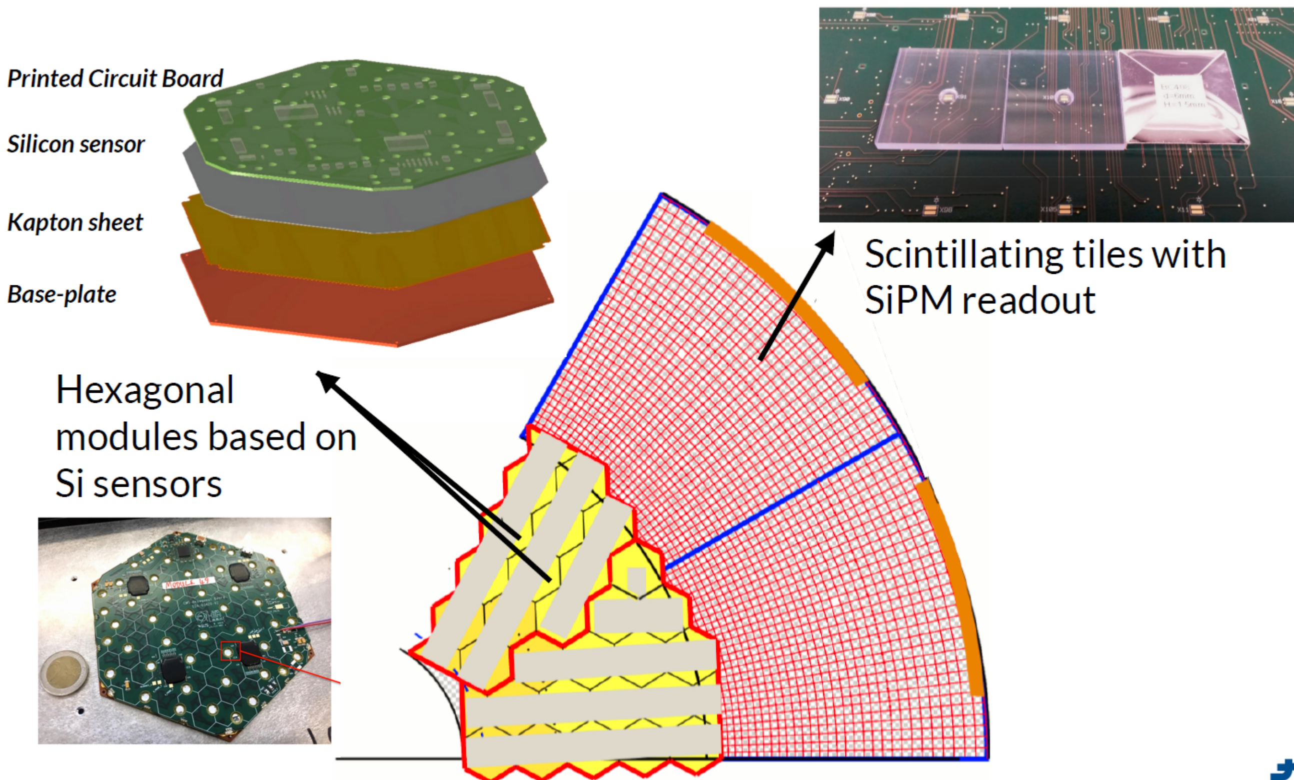


Figure 1.4: Longitudinal structure of the HGCAL, with schematic cross-sections of the three types of cassettes: CE-E cassettes, CE-H silicon sensor cassettes, and CE-H mixed silicon/scintillator cassettes. In the mixed cassettes the cross-hatched region is shared by the scintillator and silicon services in different angular regions.

HGCal Modules and Cassettes

- Cassettes provide support and cooling for the modules

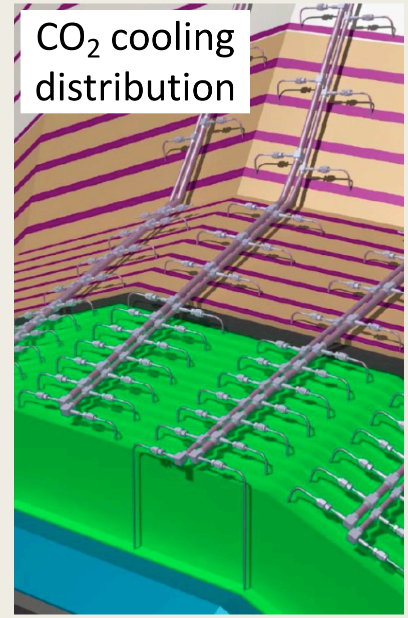


Cooling of the HGCAL

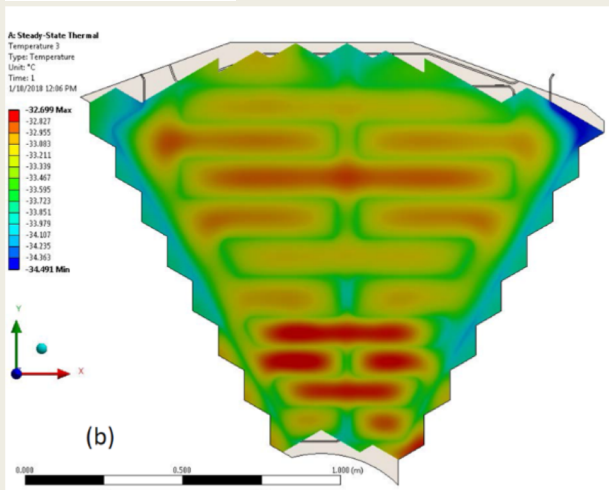
CO_2 cooling is distributed throughout the HGCAL via tubes embedded in cooling plates in each cassette.

- Covers the full radial extent of each layer
- Heat is dominated by electronics; removed as close to the source as possible.
- Large-area contact => low thermal impedance between silicon sensors and cooling plate.
- SiPMs well anchored thermally to the cooling plate.

CO_2 cooling distribution

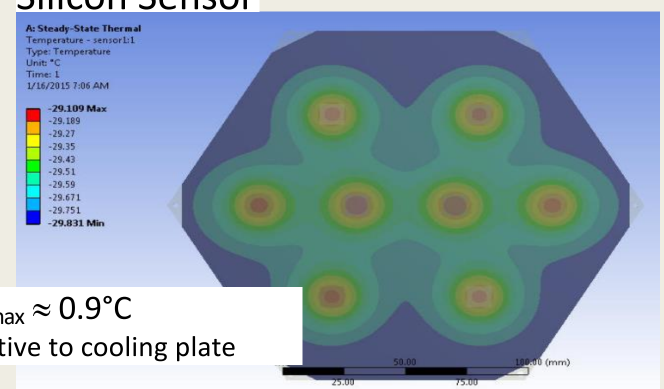


Cooling Plate



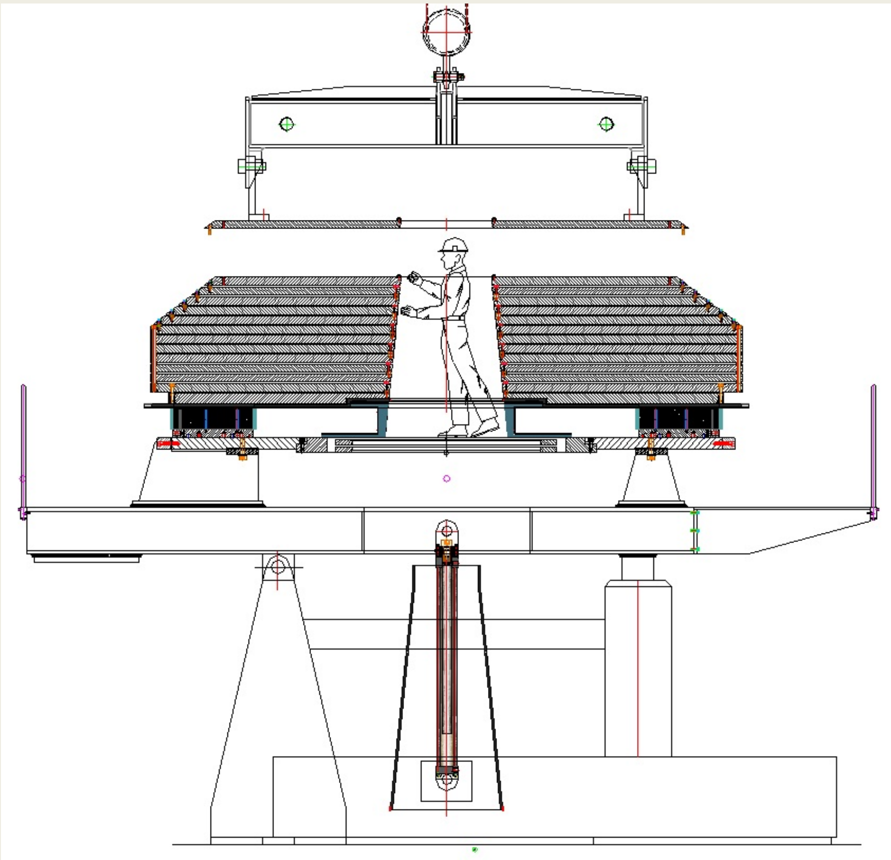
$\Delta T_{max} < 1.8$°C
highest power cassette

Silicon Sensor

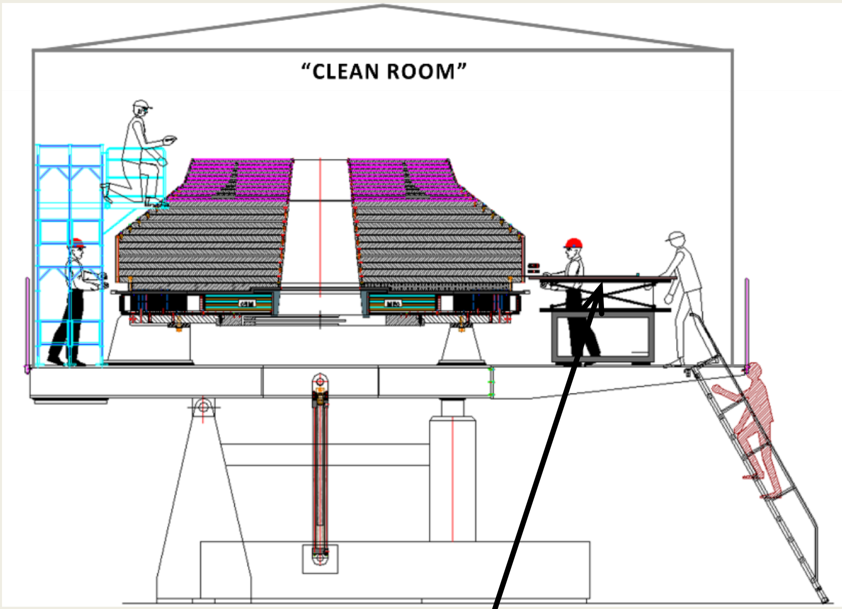


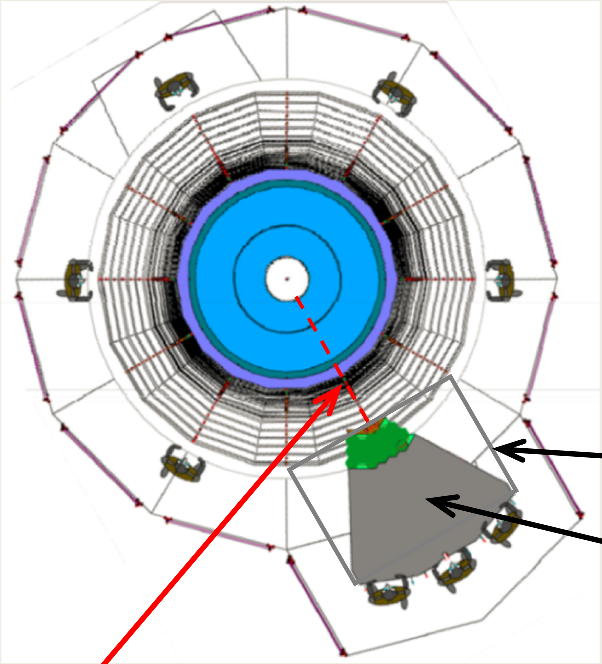
$\Delta T_{max} \approx 0.9$°C
relative to cooling plate

Assembling the CE-H: Stacking Absorbers



Assembling the CE-H: Inserting Cassettes





Integration of CE-E with CE-H

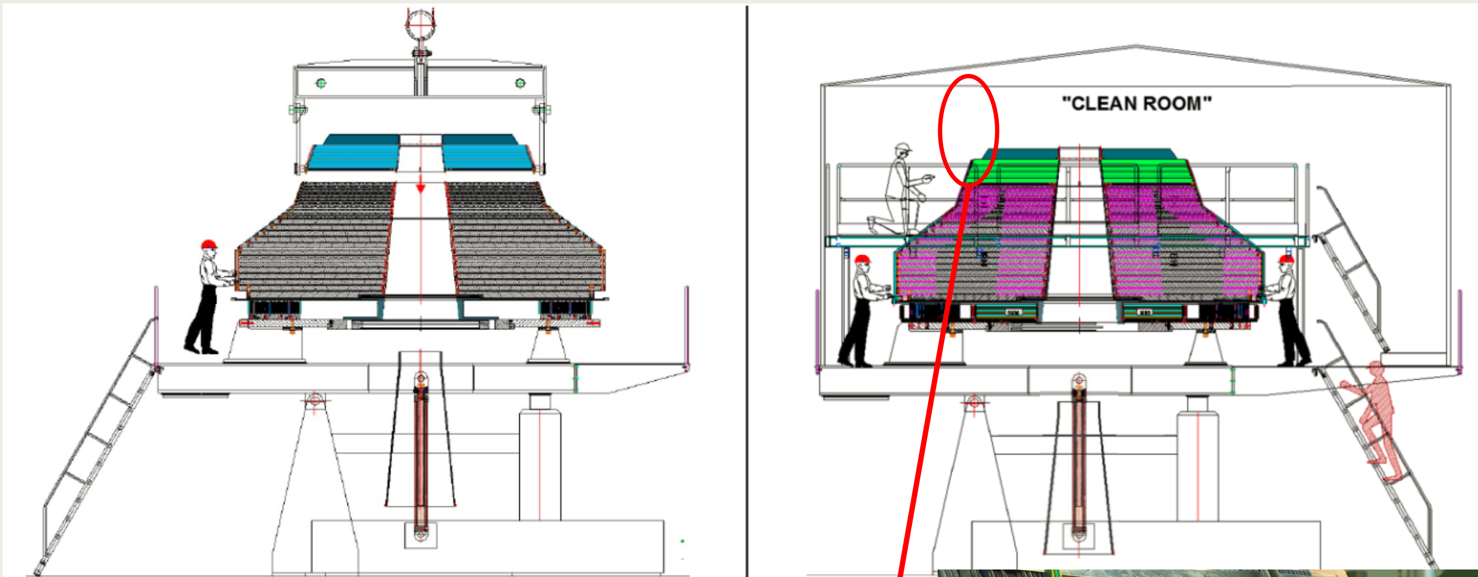
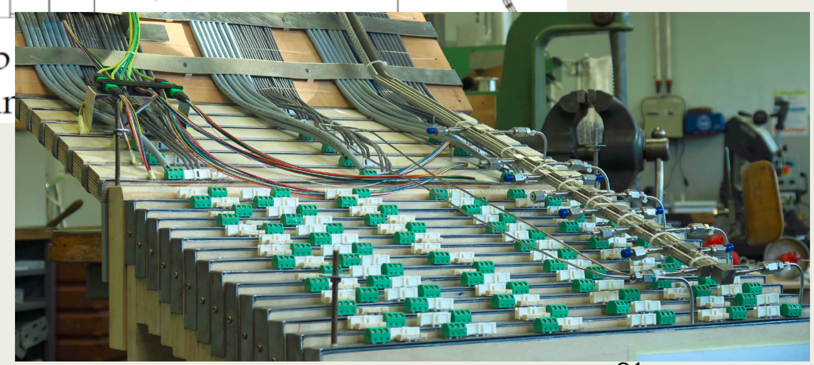
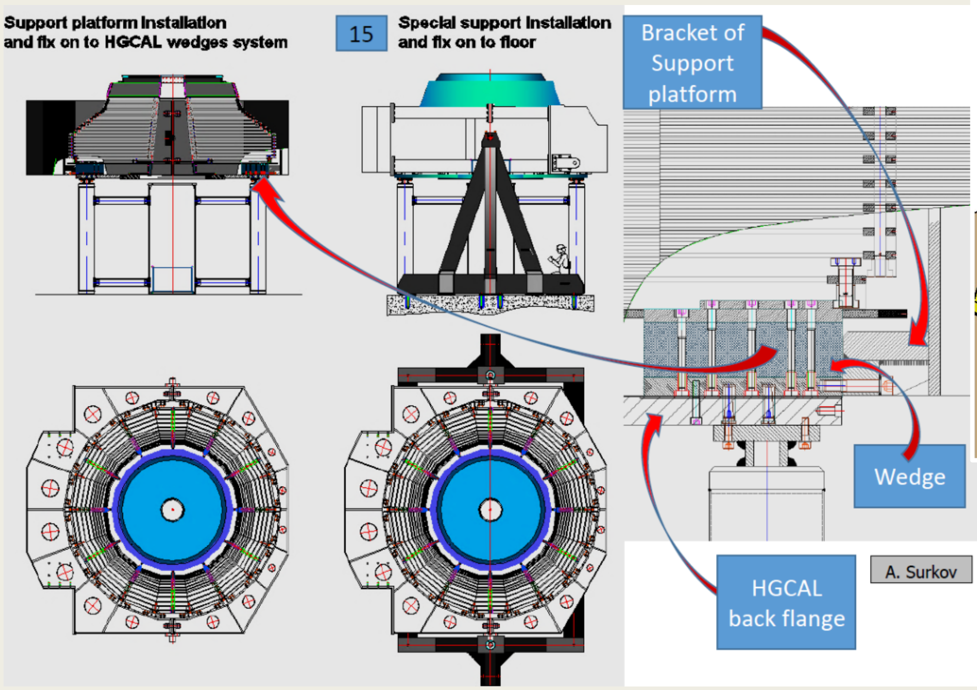


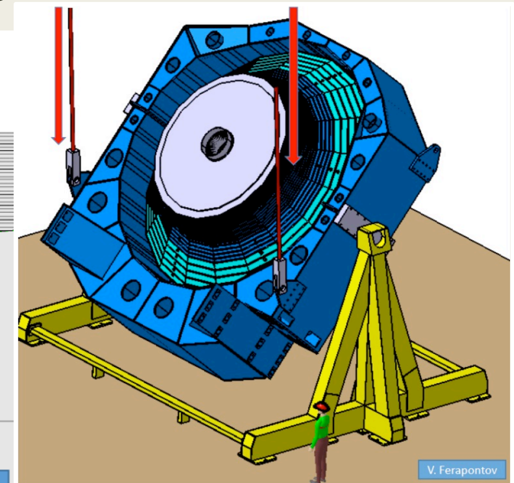
Figure 9.35: Left: Installation of the completed CE-E on top
CE-E electrical and optical services and installation of coolir

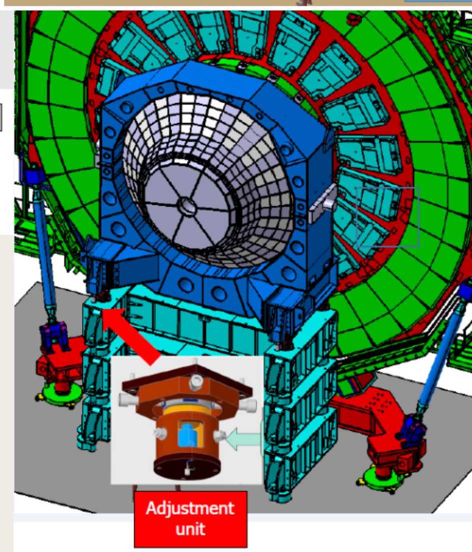


K.Rapacz

Installation Tooling Design Development

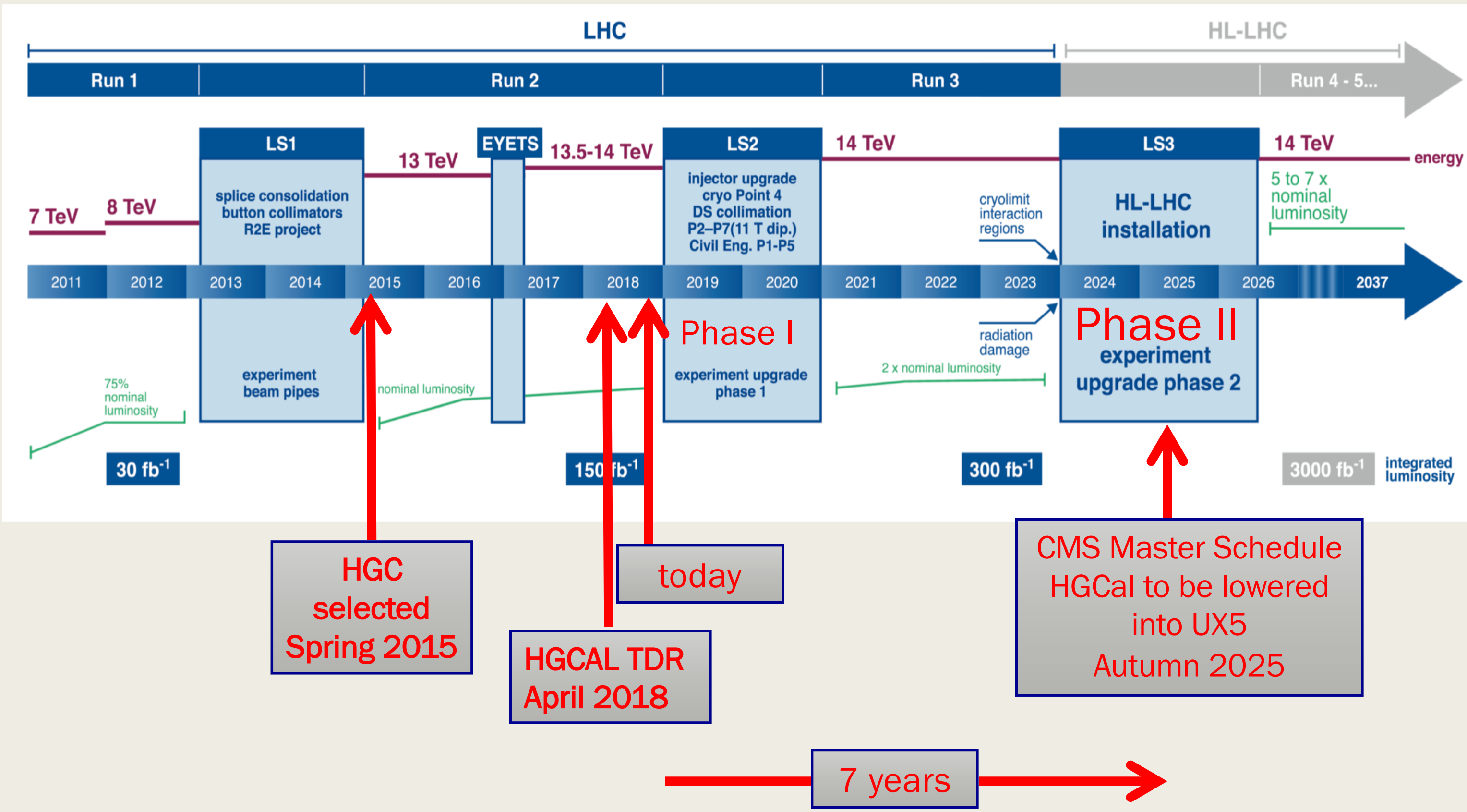






A. Surkov, V. Ferapontov

The Timeline



Synoptic View of the HGCAL Schedule

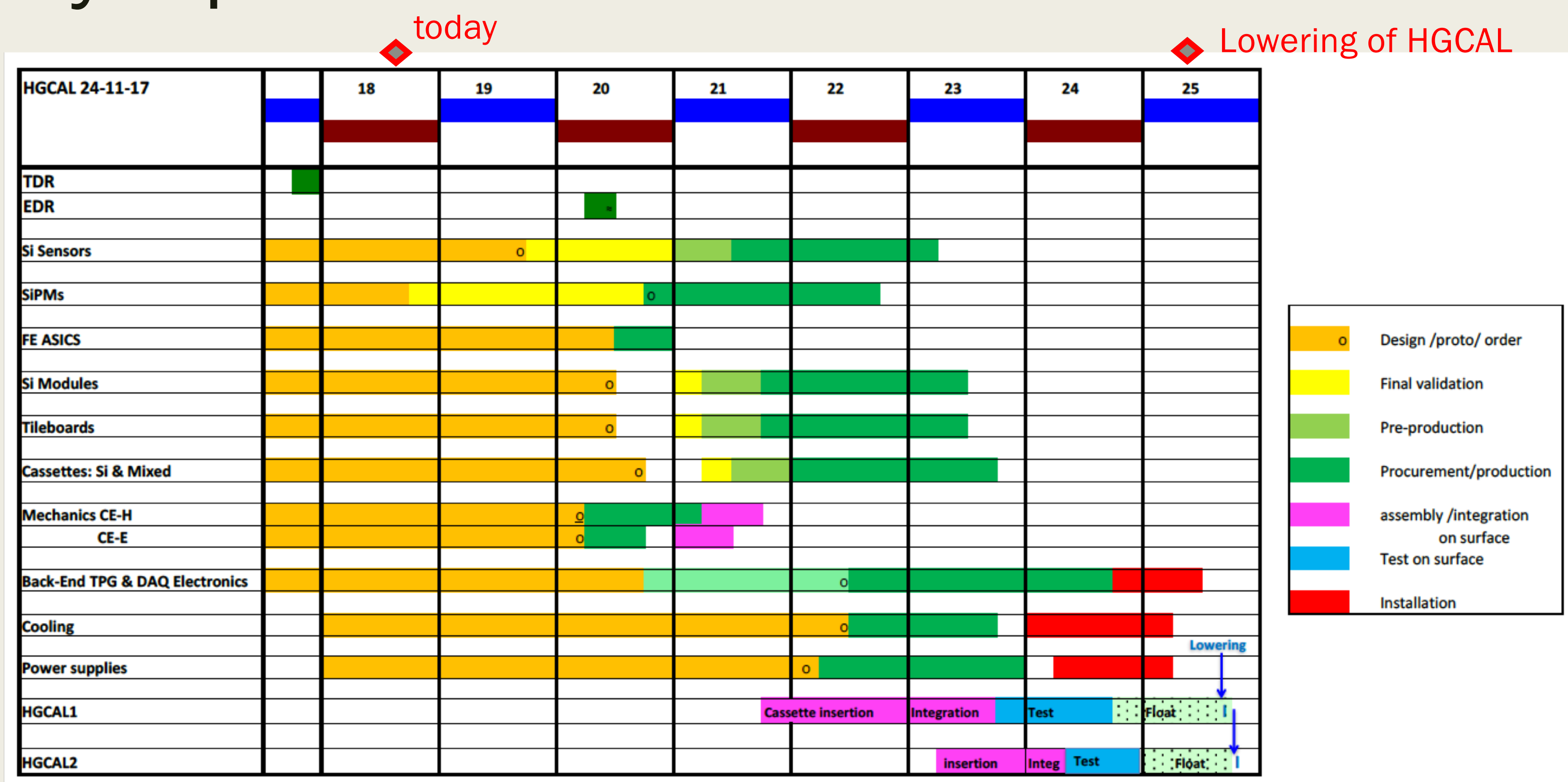


Figure 6.2: Simplified view of project timeline.

Areas of possible involvement of RDMS groups in HGCAL (1)

A: Common Purchases:

WP1	Si sensors
WP2	SiPMs
WP3	Plastic Scintillator

B: Engineering:

WP4	Design and Follow-up of CE-H absorber structure
WP5	Procurement of Cu/W baseplates
WP6	Procurement of CE-H (Si-Only) Cu cooling plates Procurement of CE-H (mixed) Cu cooling plates

Areas of possible involvement of RDMS groups in HGCAL (2)

C: Active elements:

WP7 Scintillators for outer coverage of CE-H Si-only planes

WP8 Tile Module Assembly Centre

D: Assembly Centres at CERN

WP9 Take lead responsibility or participate in Cassette Assembly Centre at CERN

WP10 Take lead responsibility or participate in Cassette Stacking and Insertion at CERN

E: CE-related Tasks under CMS-TC responsibility

WP11 Co-design and follow-up of CE-YE1 Interface and tooling (with TC and chosen manufacturer)

Two assembly tables (platforms)

Two CE-YN2 Interface rings

Four HE & CE collars;

Wedges for cold-warm transition

WP12 YE1 Services: de-/re-install

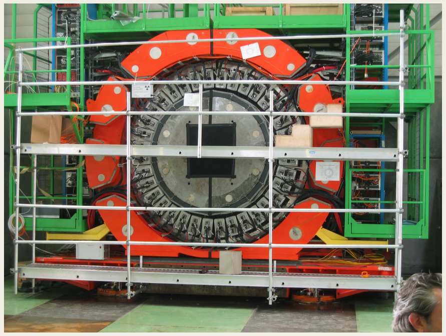
WP13 YB0 Services: de-/re-install

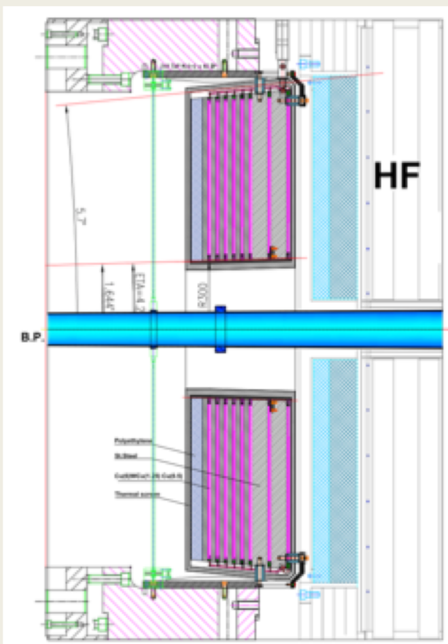
Summary

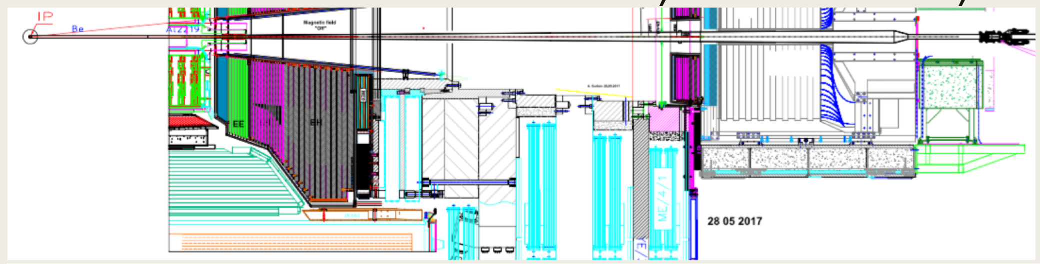
- The HGCAL will be superb detector providing an unprecedented amount of information
  - realizing the detector involves serious technical challenges
- The HGCAL Technical Design Report was approved in April 2018
  - We have to finalize design and perform prototyping over the next two years
  - Next, Engineering Design Review in 2020, with production 2021-2023
  - And finally installation in 2025
- We now enter the phase of finishing prototyping and the launch of construction of new CMS Endcap detector.
- We are very happy that this meeting in Tashkent created possibility for further discussions on participation of RDMS in design, construction and installation of High Granularity Calorimeter for the Phase-2 upgrade preparing CMS for HL-LHC era.

Back-up

HF nose for HL-LHC era: J. Virdee, June 18, 2018







Physics benefits are compelling

VBS scattering - without placing any requirement on the rest of the event - **L1 Trigger**

Get max. benefit from CMS Tracking up to |η|=4

- Extend precision timing to |η|>4.
- Help jet reco using PFlow methods.

Construction would be low risk

No new hardware development or prototyping

Use features of HGCAL (< 10% of HGCAL)

8” hexagonal sensors design with 0.5 cm^2 cell size

Same Si module assembly on a CF baseplate

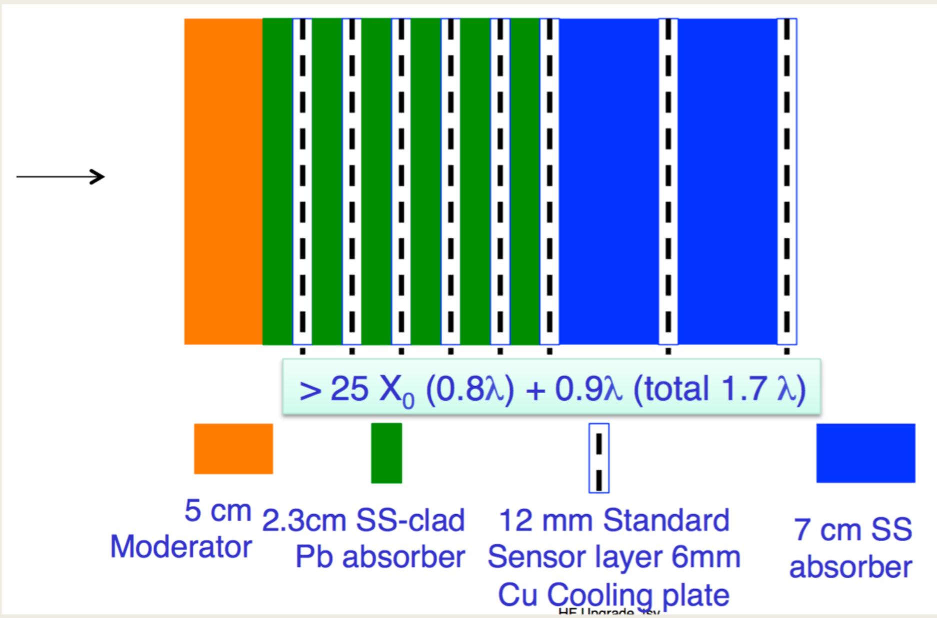
Same design of cassettes and CO_2 cooling

Same design of PCBs

Same on-detector electronics and electrical systems

Same Backend Electronics

The HF nose would be a powerful addition to the CMS Upgrade for HL-LHC



Radiation Considerations

Fluence (< 10^{16} cm^{-2})

Dose (<200 Mrad for electronics)

Key parameters:

- *50 m^2 of silicon*
- *1 M ch, 0.5 cm^2 cell-size*
- *~2200 modules (8" sensors)*
- *Power at end of life 20 kW.*

Mechanical Structure

SS-clad lead absorber for em part

SS plates for the hadronic part

em resolution ~ 60%/√E (half of current)

Had resolution – to be studied

Timing resolution (20-30 ps) to be studied