Design and Production of the CMS High Granularity Calorimeter Mockup Modules

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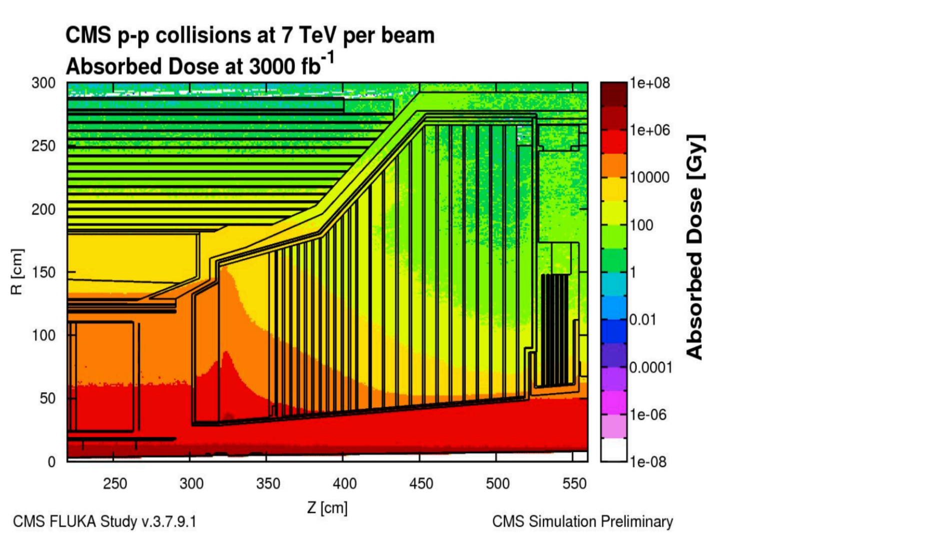
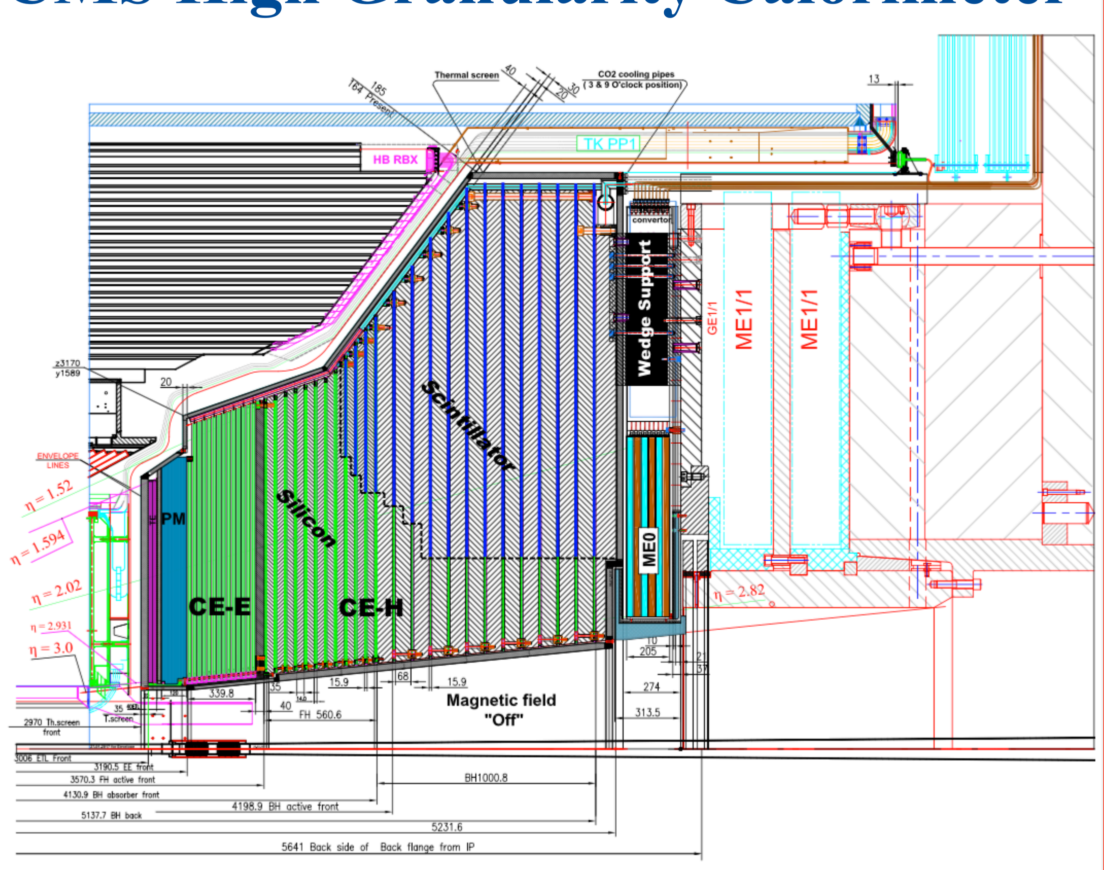
Introduction

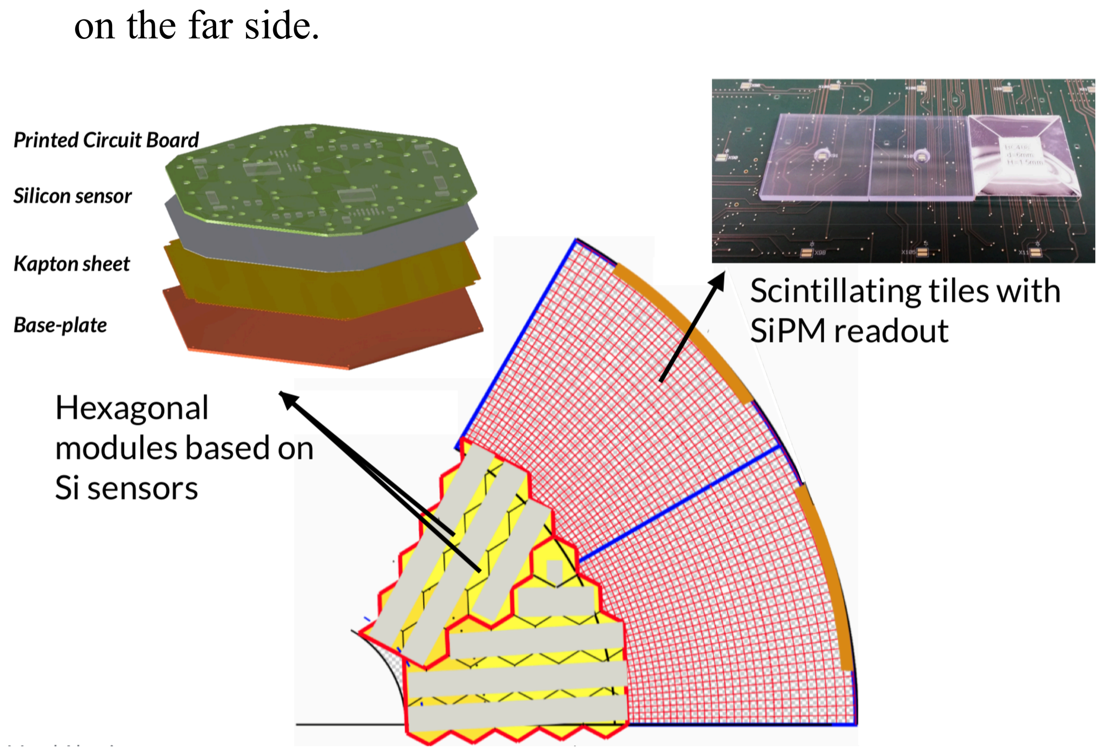
- High luminosity-LHC plans 5 x 10^{34} $cm^{-2}s^{-1}$ instantaneous luminosity and 3000 fb^{-1} integrated luminosity.
- High pile-up conditions ~200 interactions per bunch crossing and high radiation dose: ~2MGy, 10^{16} n_{eq}/cm^2. [n_{eq}/cm^2 denotes the number of 1 MeV equivalent neutrons per cm^2]
- Current electromagnetic (E) and hadronic (H) endcap calorimeter cannot stand the radiation dose of HL-LHC & can only sustain ~ 500 fb^{-1}.
- Hence, CMS plans to replace the current endcap calorimeters (CE) with HGCAL during LS3 [2024-2026].



CMS High Granularity Calorimeter



- A sampling calorimeter
- ~ 500 m^2 of scintillators
- ~ 600 m^2 of silicon sensors
  - ~ 6M channels
  - Expected to dissipate 220kW heat
- Operation ~ -30^{0}C at sensor with the supply of CO_2 at -35^{0}C
  - To reliably operate silicon sensors after irradiation, and to keep sufficiently low the energy equivalent of electronics noise from the increased leakage current & decreased charge collection efficiency after irradiation.
- Radiation damage is more nearer to the interaction point so, silicon sensor is used at the near side and plastic scintillator on the far side.



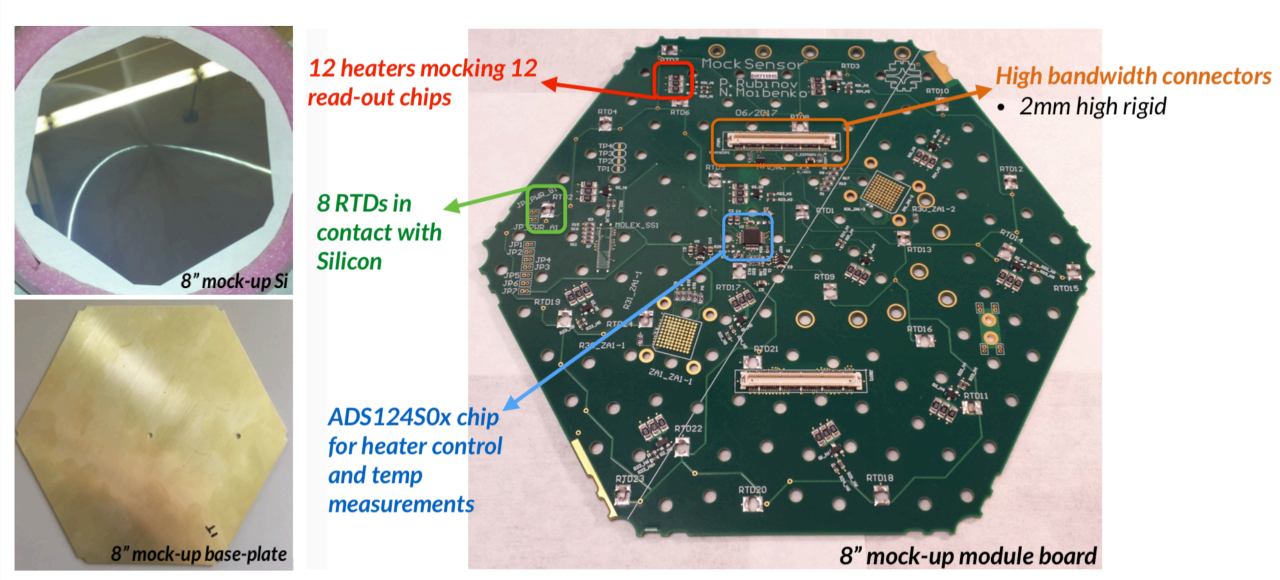
Purpose of the mockup test:

- To optimize the materials used in the construction of silicon-based modules for HGCAL.
- Thermal, mechanical prototype test.

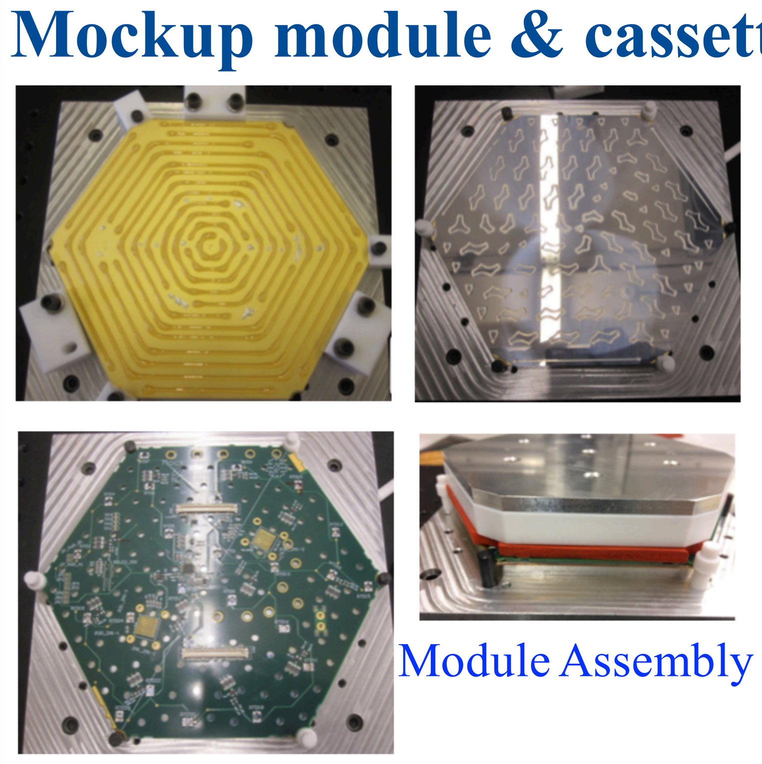
HGCAL mockup module

- Base-plates (1 mm thick):
  - Provides support for the Si & enables mounting to cassette.
  - Design: Carbon fiber (H), Copper/Tungsten (E);
    - To have the coefficient of thermal expansion (CTE) as close to silicon as possible and good thermal conductivity.
  - Investigating other choices also: brass, stainless steel, ceramics.
  - Mock-up test are so far done on brass plates.
- Kapton sheet (110 µm thick):
  - Coated with a thin layer of gold: to provide the HV bias connection to the sensor back-plane through a conductive epoxy.
  - Kapton itself provides electrical insulation to the sensor back-plane from the baseplate.
- Mockup Silicon (Si) sensors:
  - cut from 8" Si wafers & 750 um thick [design: 320 µm]
- Mockup module board (PCB):
  - 432 channel
  - Designed to apply heat loads & measure the Si temperature.
  - Enables performing thermal studies.

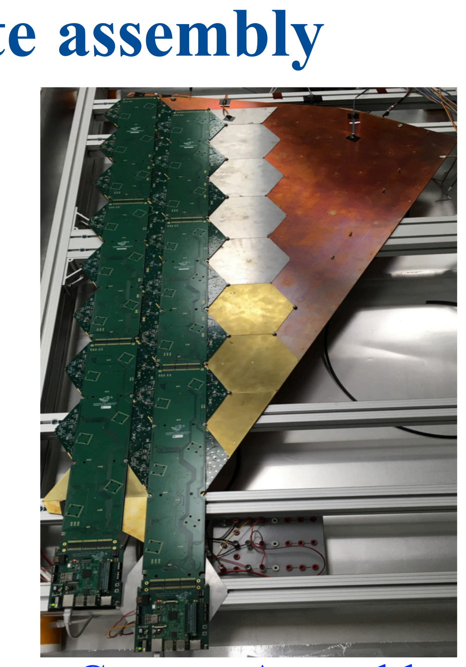
** Glue (Araldite 2011) layer is ~100 µm thick in each subsequent attachment.



Mockup module & cassette assembly



Module Assembly



Cassette Assembly
- 16 full modules
- 6 mother boards

Thermal test

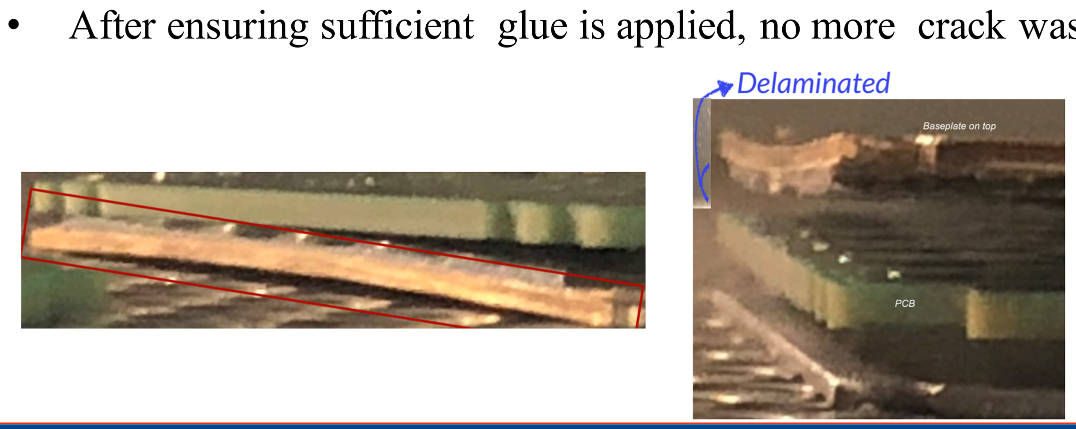
Temperature Readout:

We are reading 8 RTDs (4-wire connection) per module with ADS chip:

- 0.1^{0}C temperature measurement precision; no need of calibration.

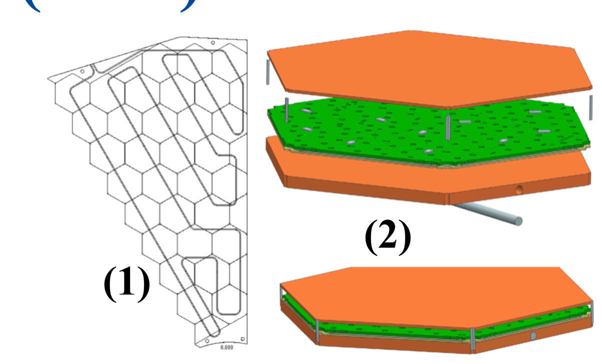
Initial gluing challenges in module construction:

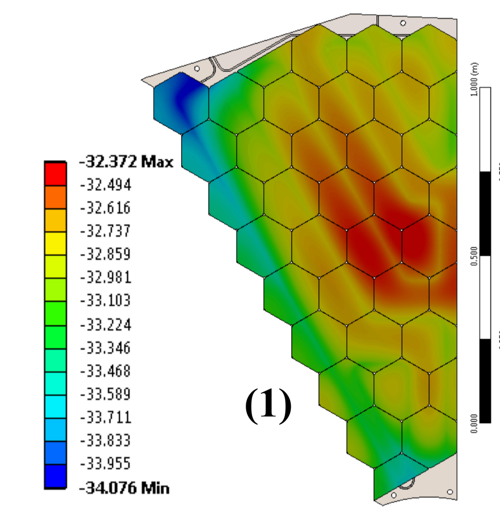
- CTE ($10^{-6}K^{-1}$) of brass baseplate, PCB, and Silicon: 12, 19, and 2.8.
- At -30^{0}C, the brass baseplate and PCB are pulling the silicon sensor in opposite directions, & the glue has to resist the stress.
- 3 modules with insufficient amount of glue had the PCB delaminated & the sensor got cracked.
- After ensuring sufficient glue is applied, no more crack was observed.



Finite Element Analysis (FEA) Simulation

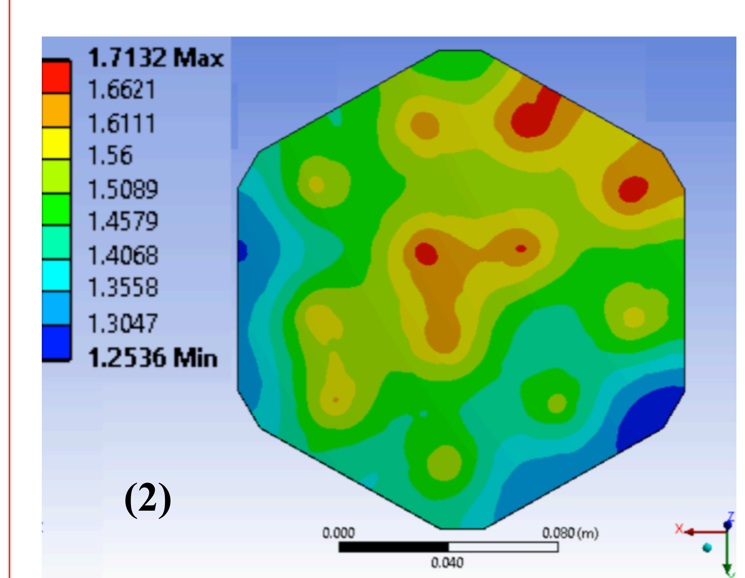
- Two categories:
  - Full size Copper cooling plate and CO_2 (1)
  - Single Si module and Copper cooling plate (2)





Copper cooling plate & CO_2 parameters:
- 200W of uniform heat load
- 6.8 meter long tube
- 2.197 gm/sec CO_2 mass flow
- Pressure drop = 0.8 psi

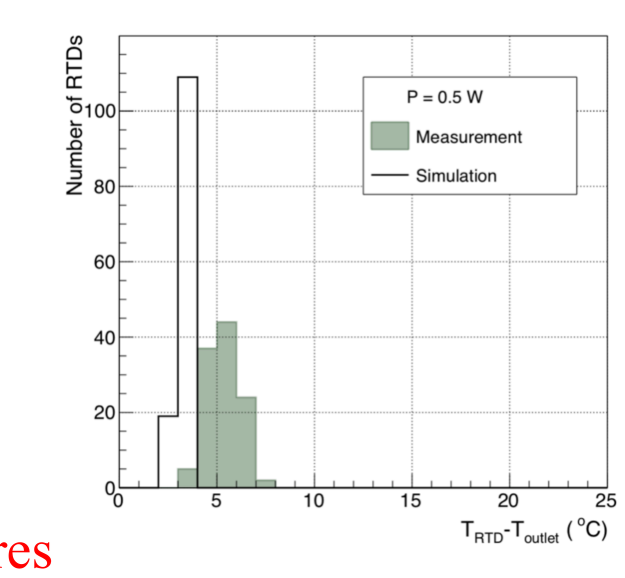
At most the Copper plate is expected to be 2.5^{0}C warmer than the CO_2 (-35^{0}C)



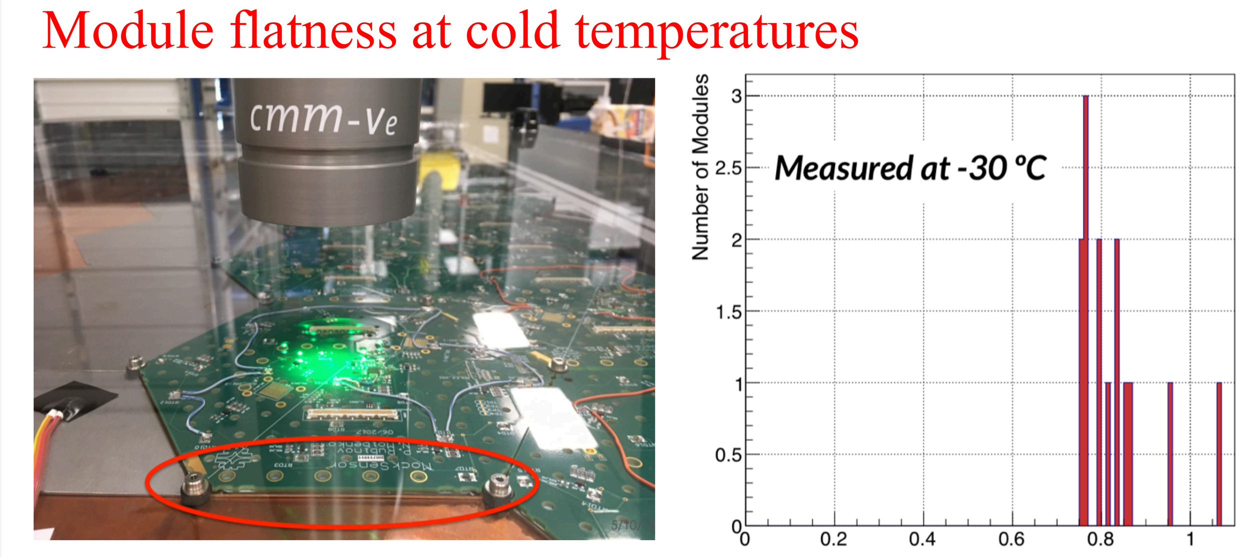
At Silicon level (Copper cooling plate and Silicon)
- 6 W of heat load is applied through 12 heaters (0.5 W each)
- On average the Si is expected to be 1.5^{0}C warmer than the Copper cooling plate.
- *Hence, all the Silicon sensors remain colder than -30^{0}C.*

Measurement vs simulation

- 6 W of heat load is applied through 12 heaters (0.5 W each)
- On average the measured temperature for Si was ~5.2^{0}C above CO_2 outlet.



Module flatness at cold temperatures



- Coordinate Measurement Machine is used to measure the height of the center & 6 corners of the modules at cooling plate at -30^{0}C.
- Center of the modules is found to be ~800 µm higher than the corners.
- *The air gap below the warped modules explains why the temperatures are larger than expected (simulation).*
- Other base-plate material is being investigated that can prevent modules from warping.

Conclusions

- First milestone i.e. first thermo-mechanical prototype test (28-Aug-18) is very well within the reach.
- The first mockup modules & cassette for thermo-mechanical study are produced:
  - Various base-plate material is being investigated to safely accommodate the large differences in CTE compared to that of the Silicon sensors.
  - An extensive set of detailed simulations and tests with full scale realistic mock-ups is currently under way to further optimize this design and arrive at a fully engineered solution.

References

- CMS-TDR-019: The Phase-2 Upgrade of the CMS endcap calorimeter