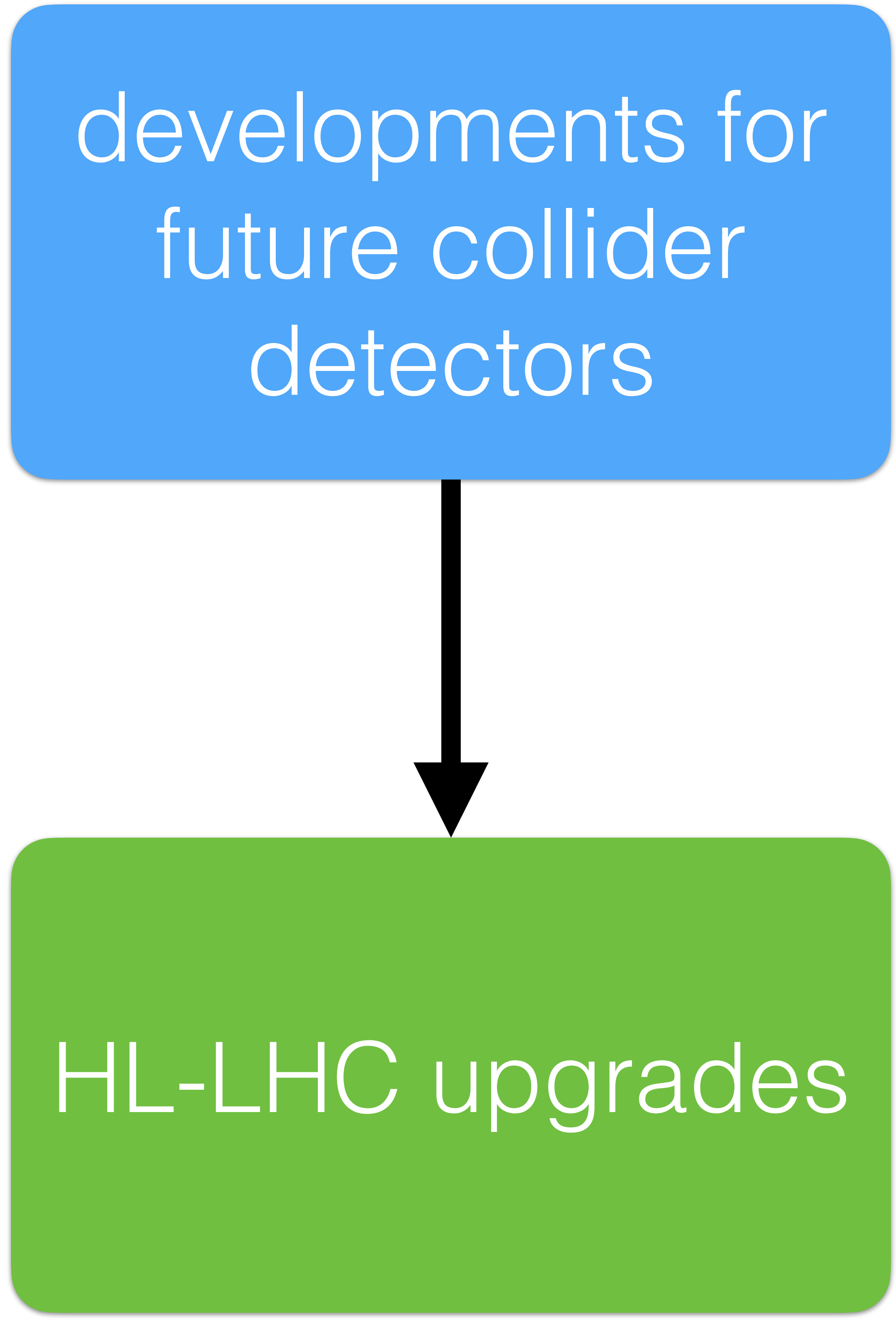
Experience in design and prototyping of CMS HGCAL

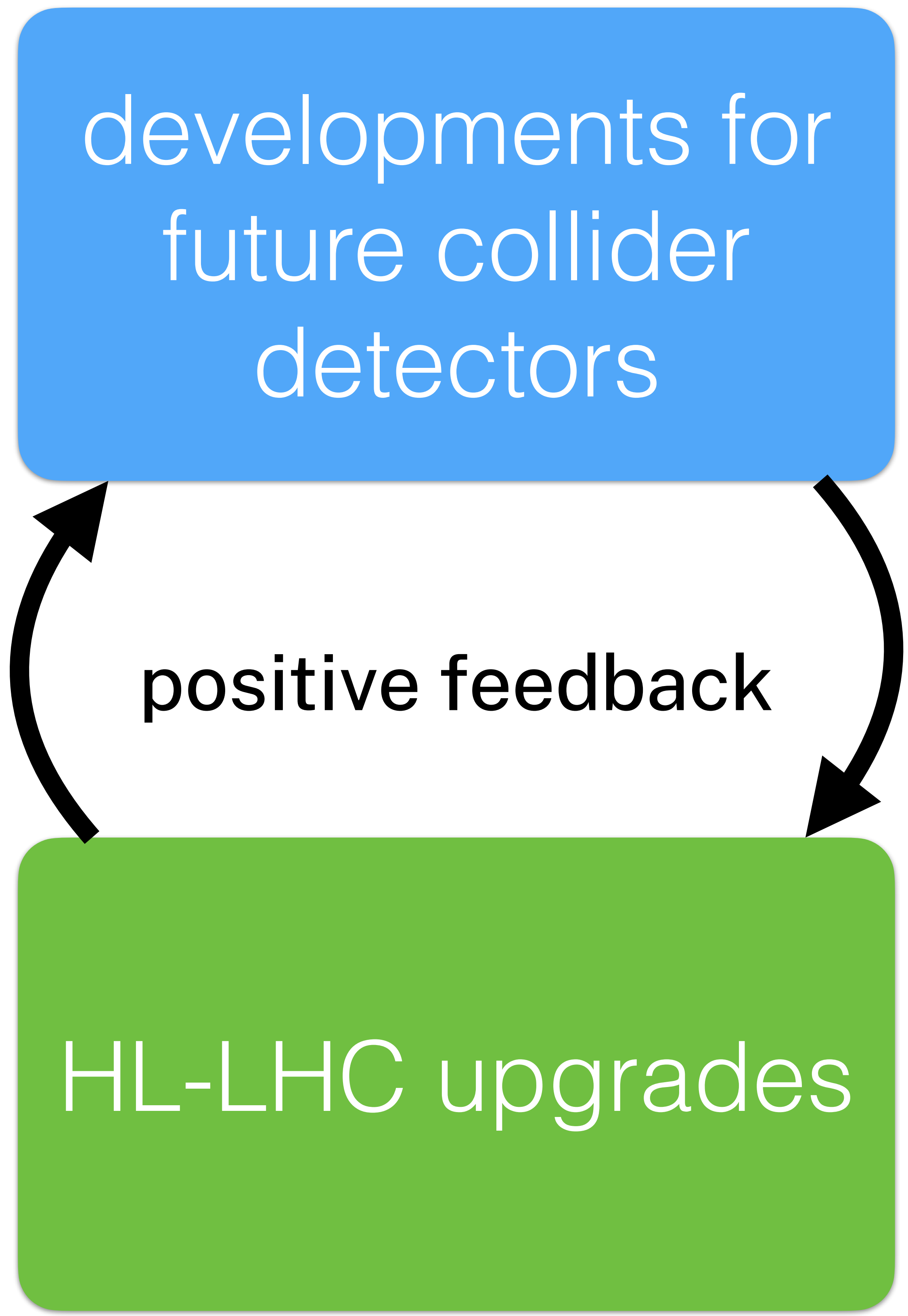
Ted Kolberg (FSU) on behalf of CMS collaboration

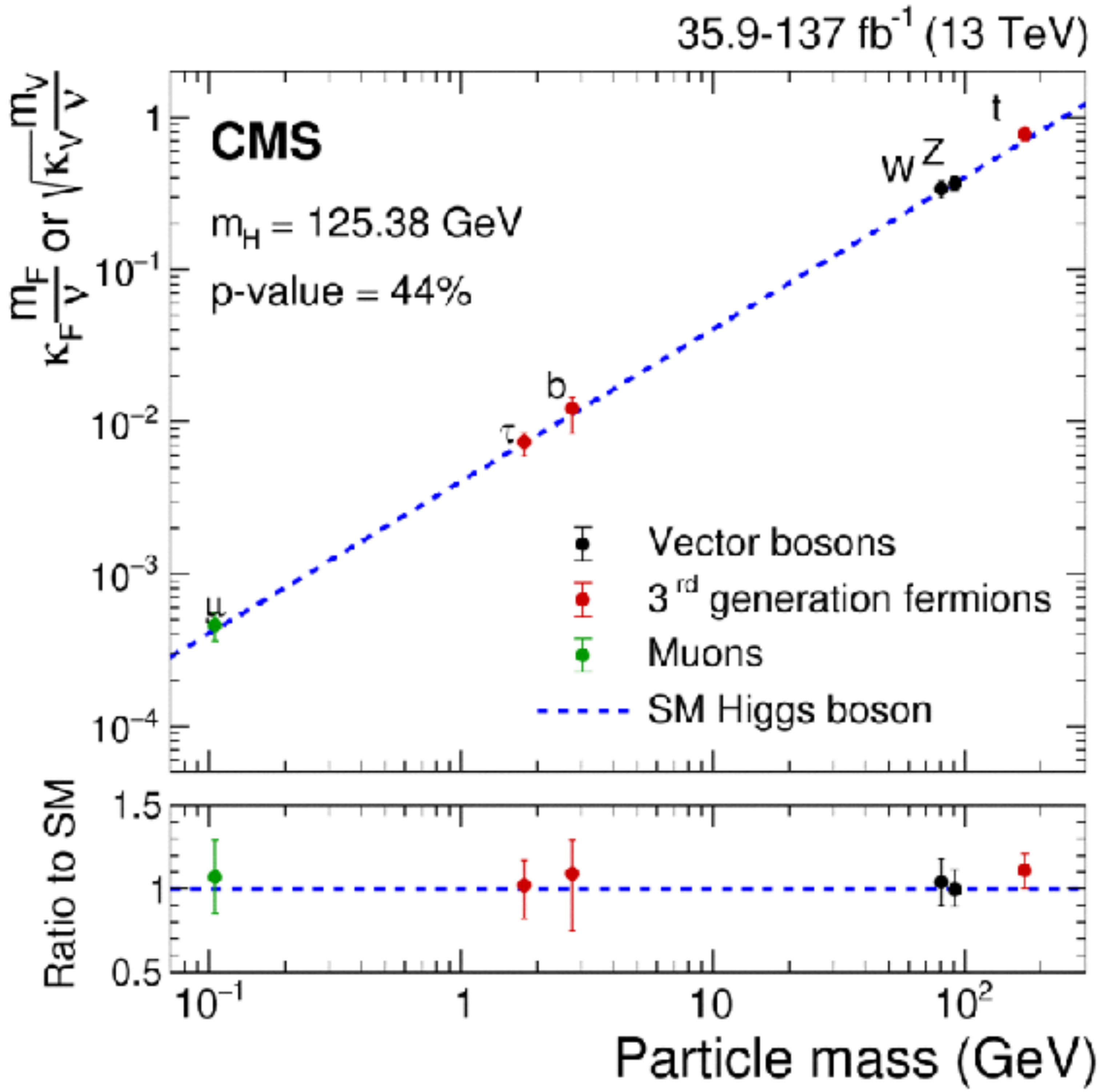
CPAD 2021, Stony Brook

18 March 2021

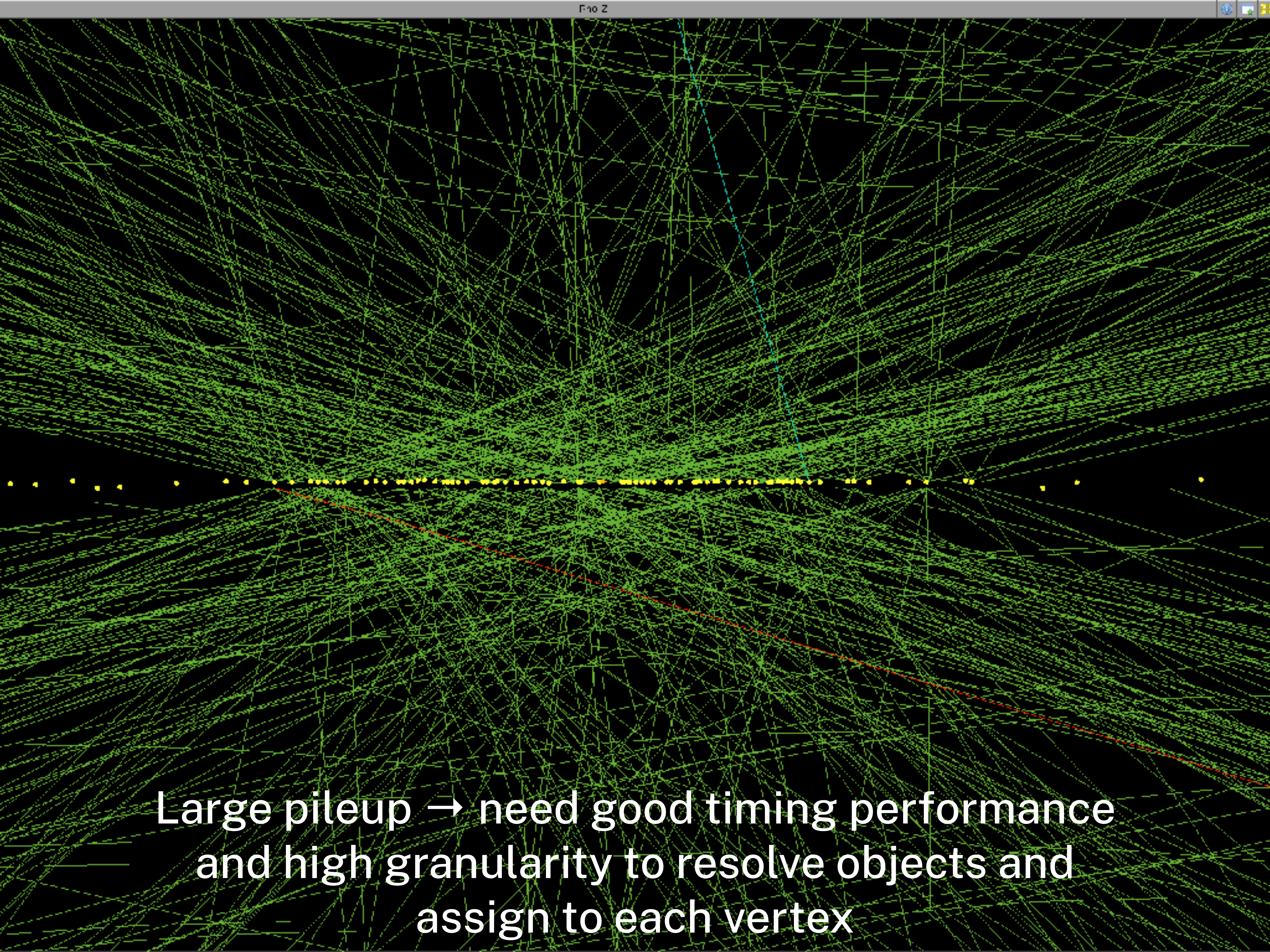
developments for future collider detectors


developments for future collider detectors
HL-LHC upgrades

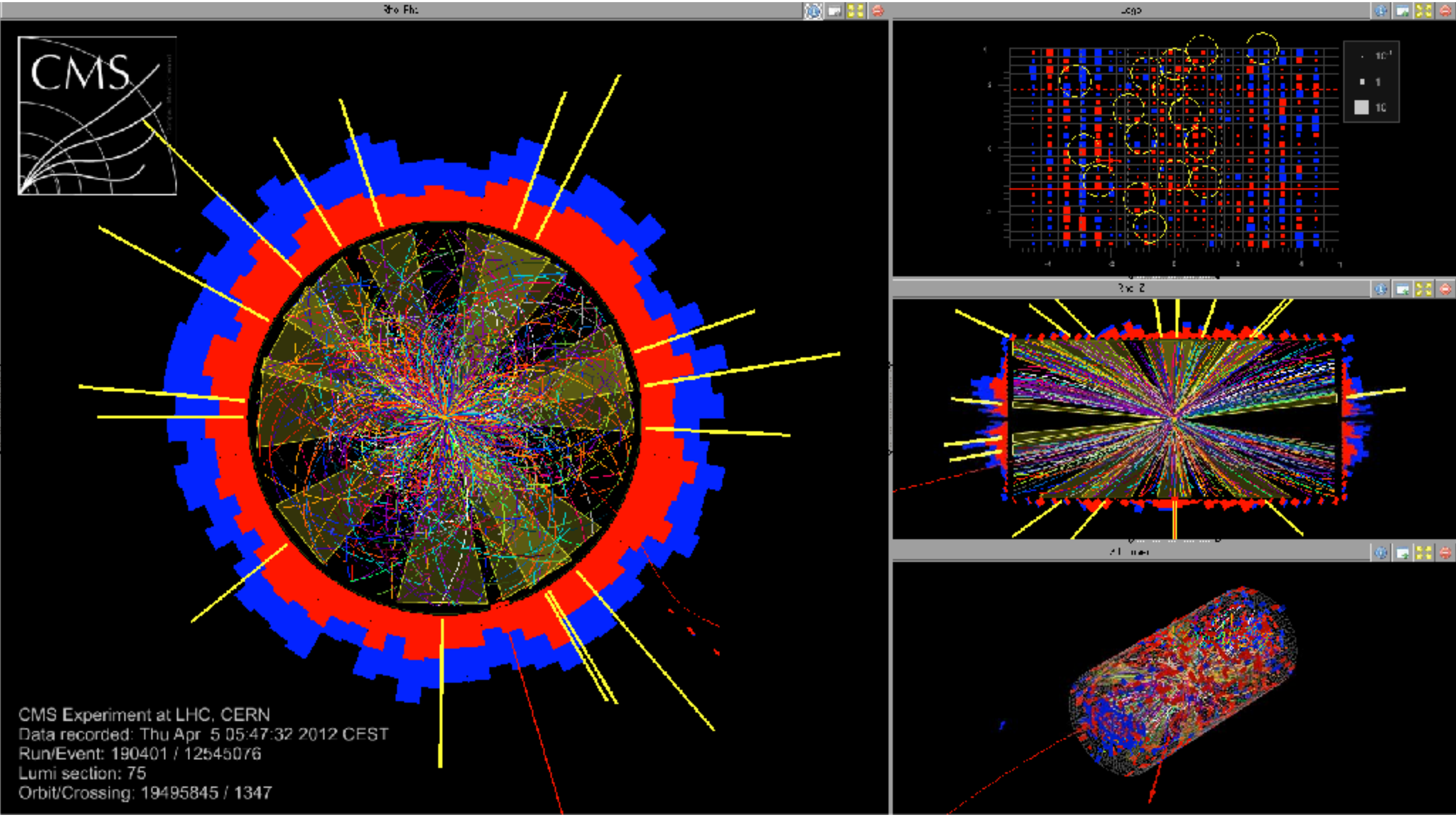

developments for future collider detectors
positive feedback
HL-LHC upgrades



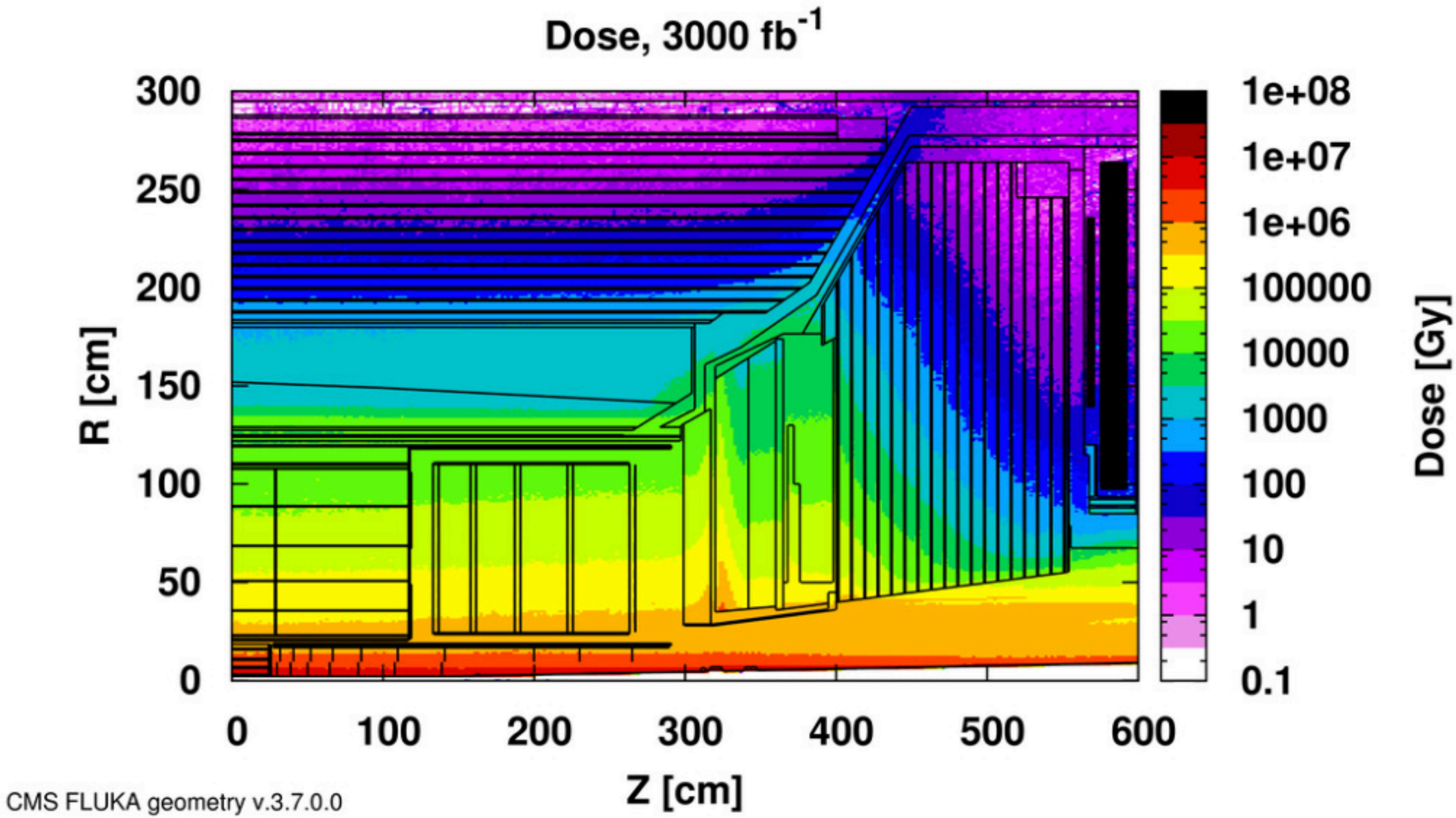
HL-LHC dataset offers the opportunity to measure each accessible coupling to O(1%)



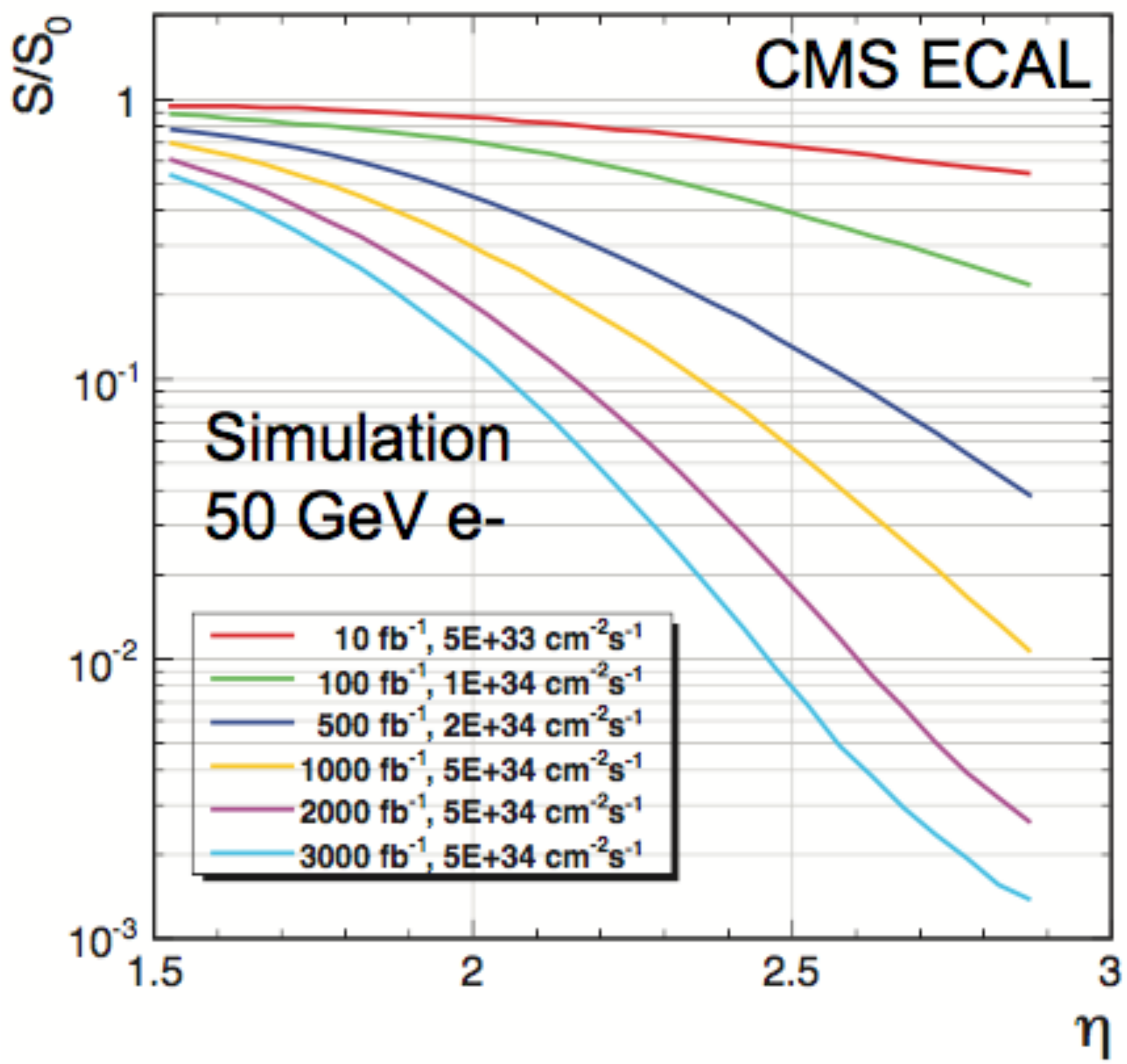
Large pileup → need good timing performance and high granularity to resolve objects and assign to each vertex

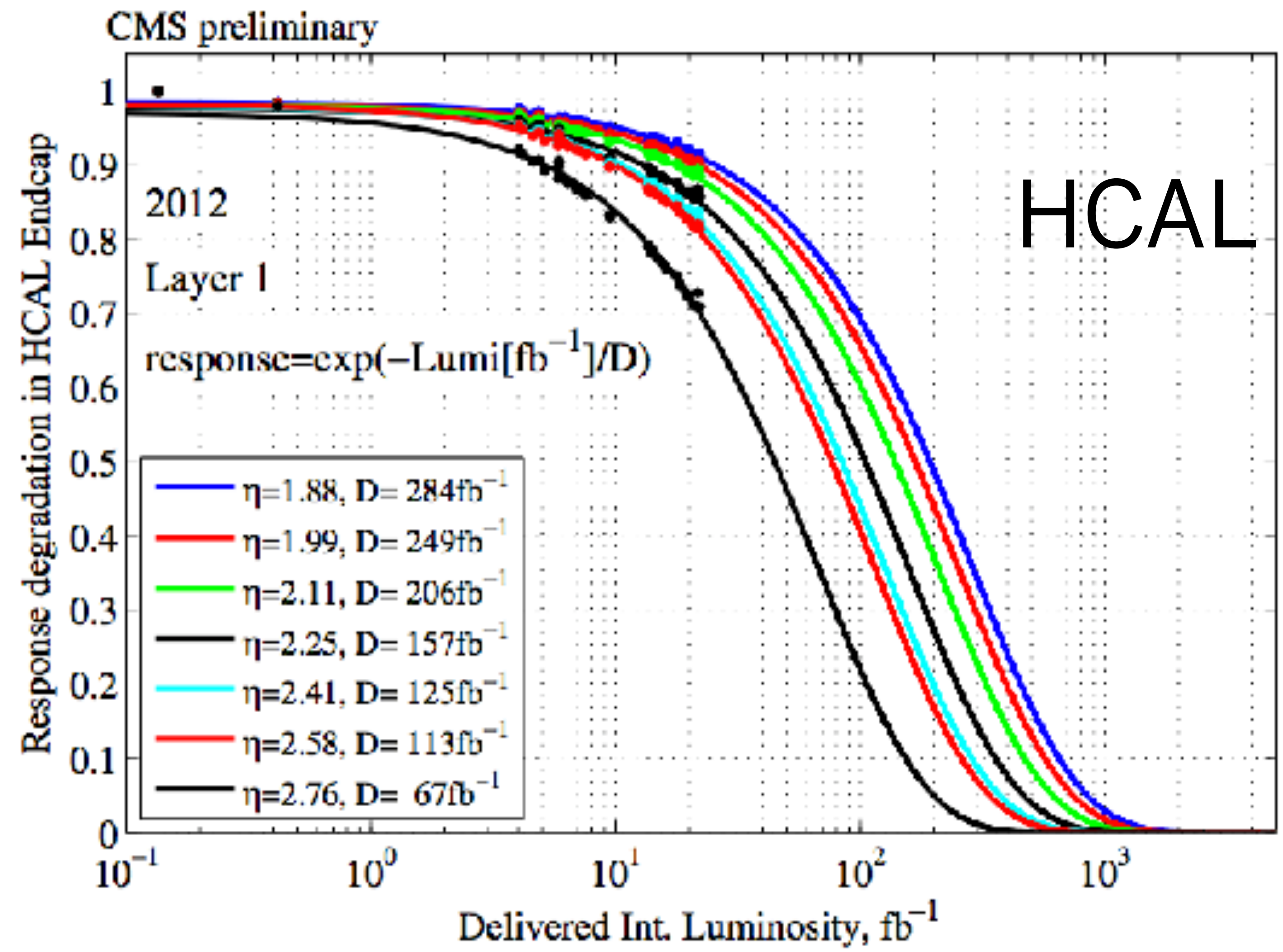


Real event from large pileup run:
occupancy approaches 100% already in the existing endcap calorimeters!



Extreme radiation field presents formidable (yet sizable) challenges.





Signal from existing ECAL, HCAL in endcap region
will be gone after HL-LHC dose;
replacement required.

PF detectors for ILC

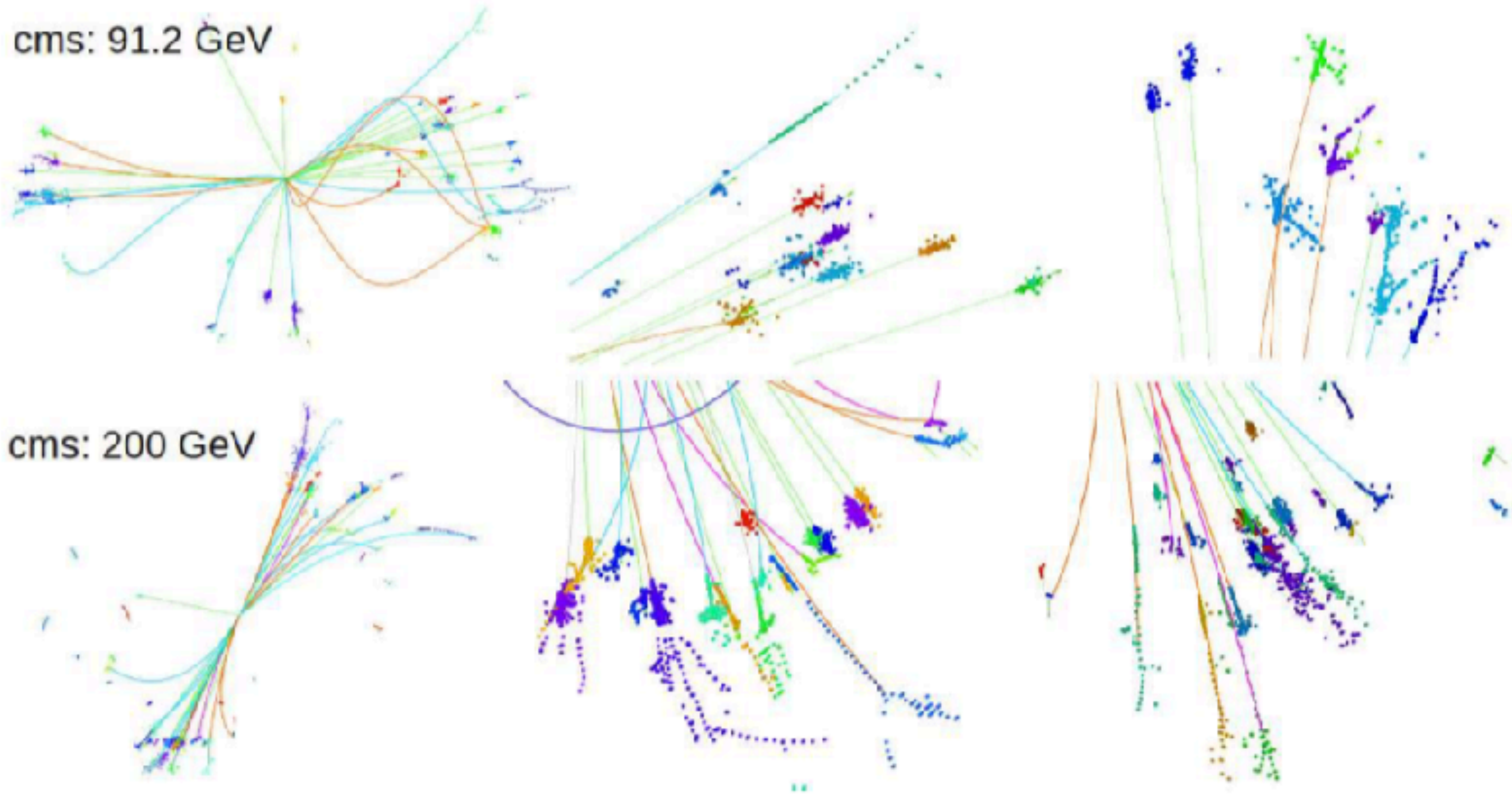
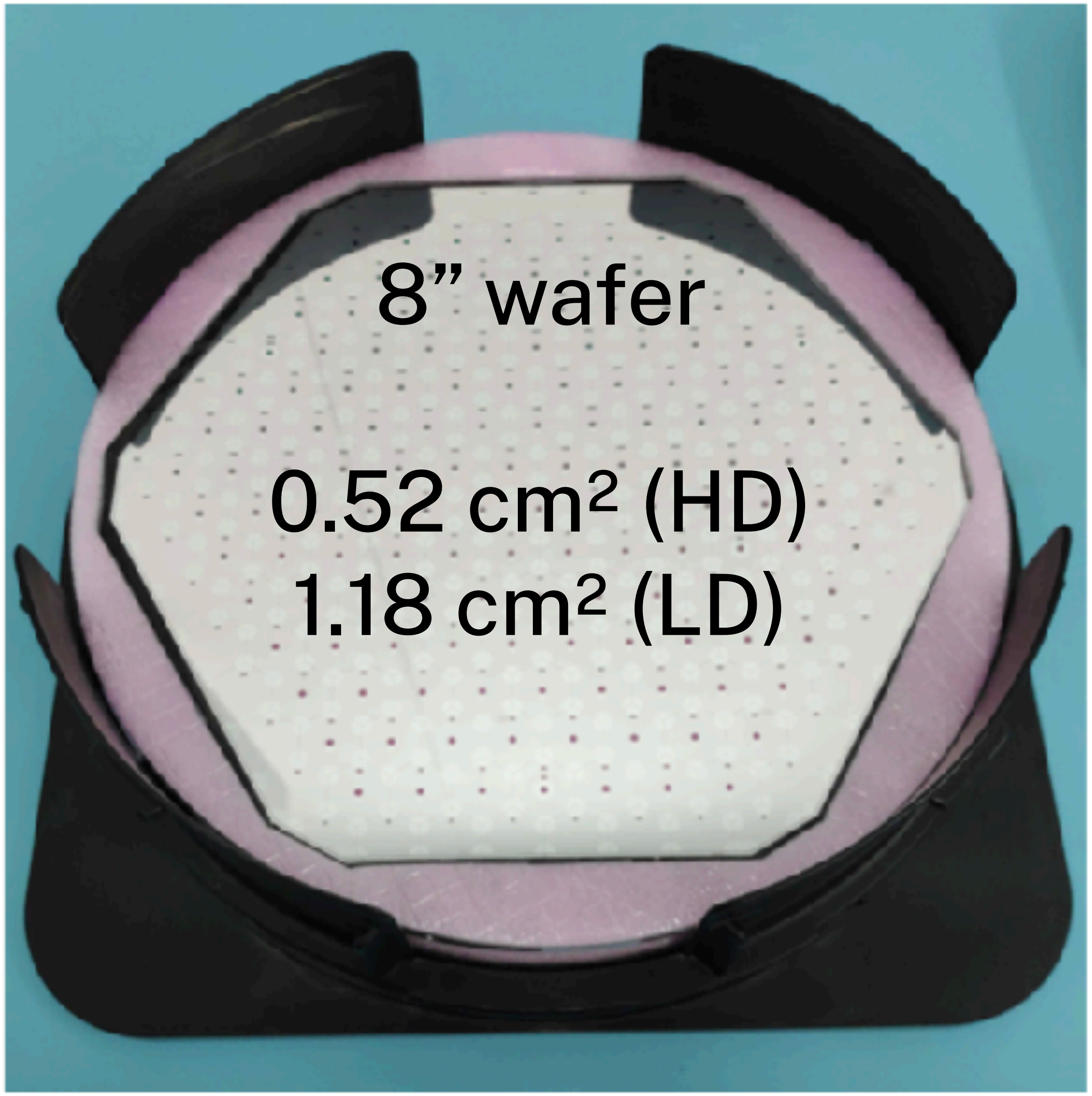
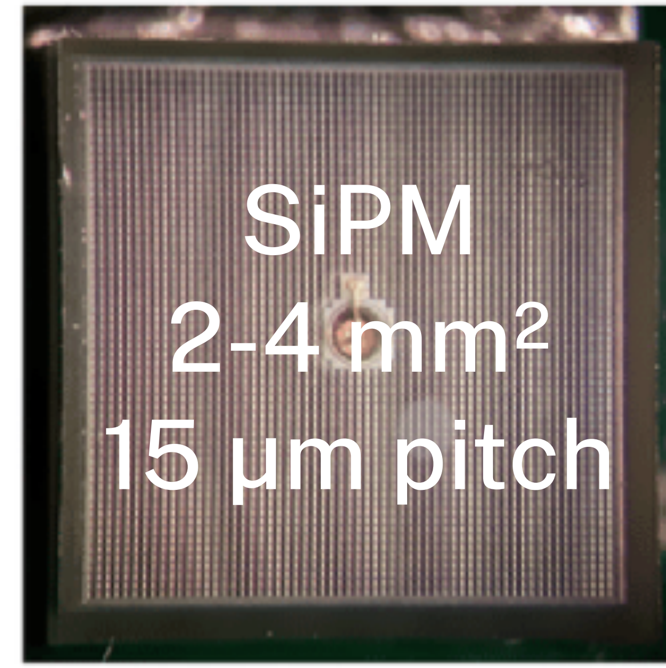


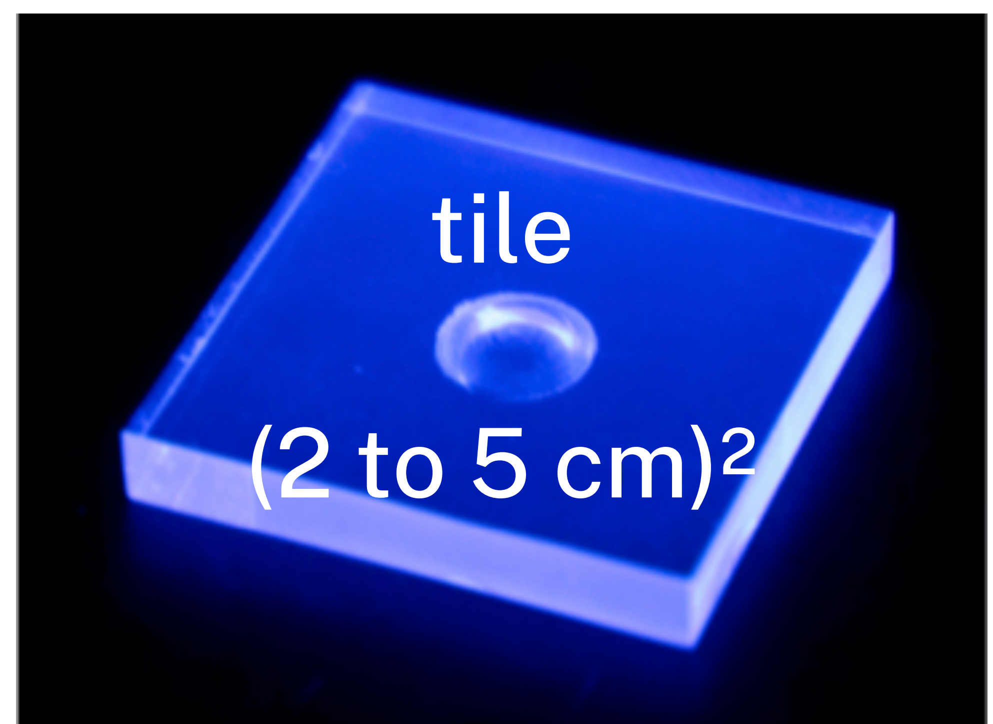
Figure 9: QQ events reconstructed with Arbor. Above plots corresponding to qq event at Z threshold, below shows that at center of mass energy of 200 GeV

PF detectors for future colliders show great promise; can a similar design work at the HL-LHC?

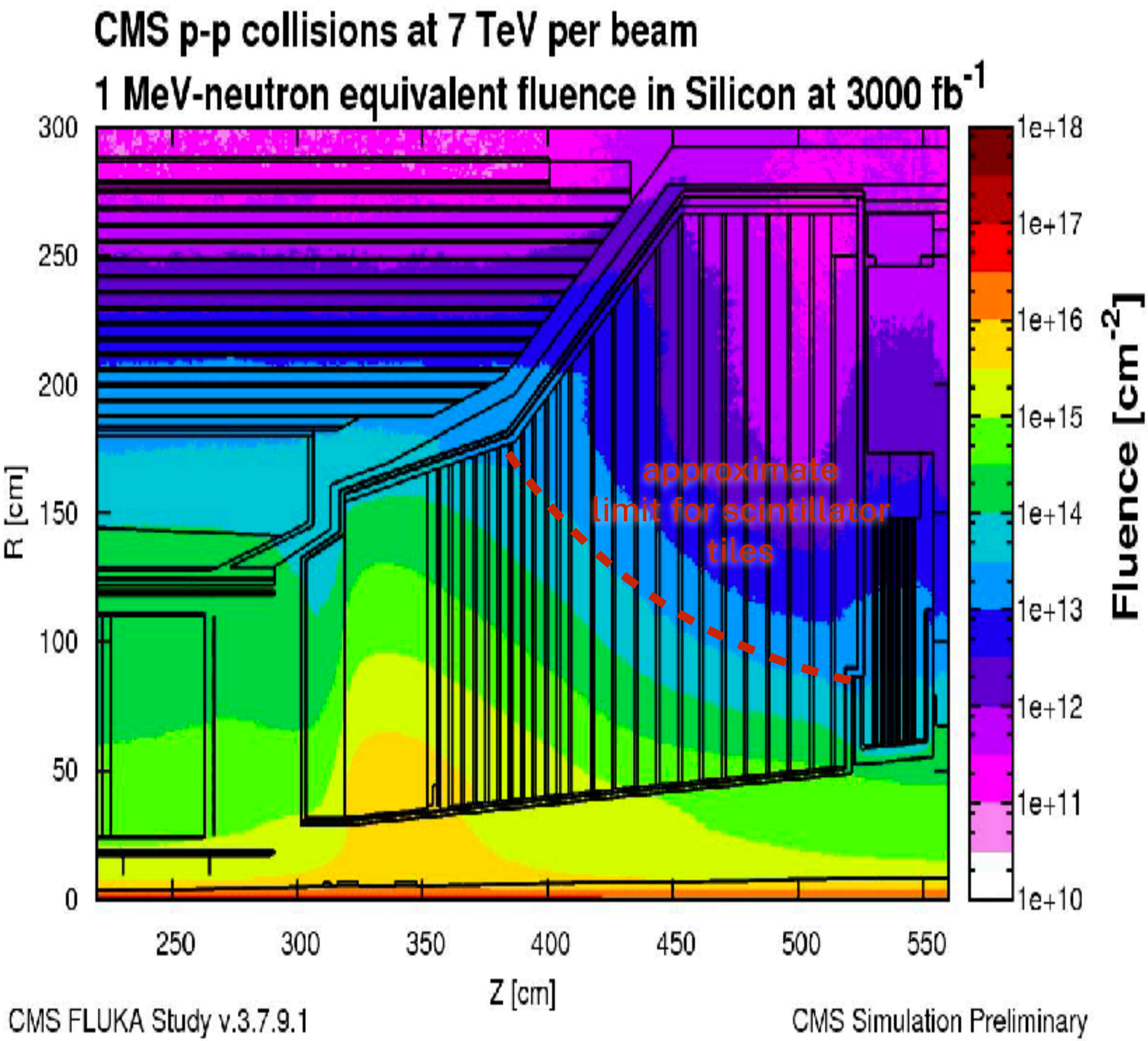
Fine segmentation
(transverse and longitudinal)
key to mitigating rad damage
and for particle flow.



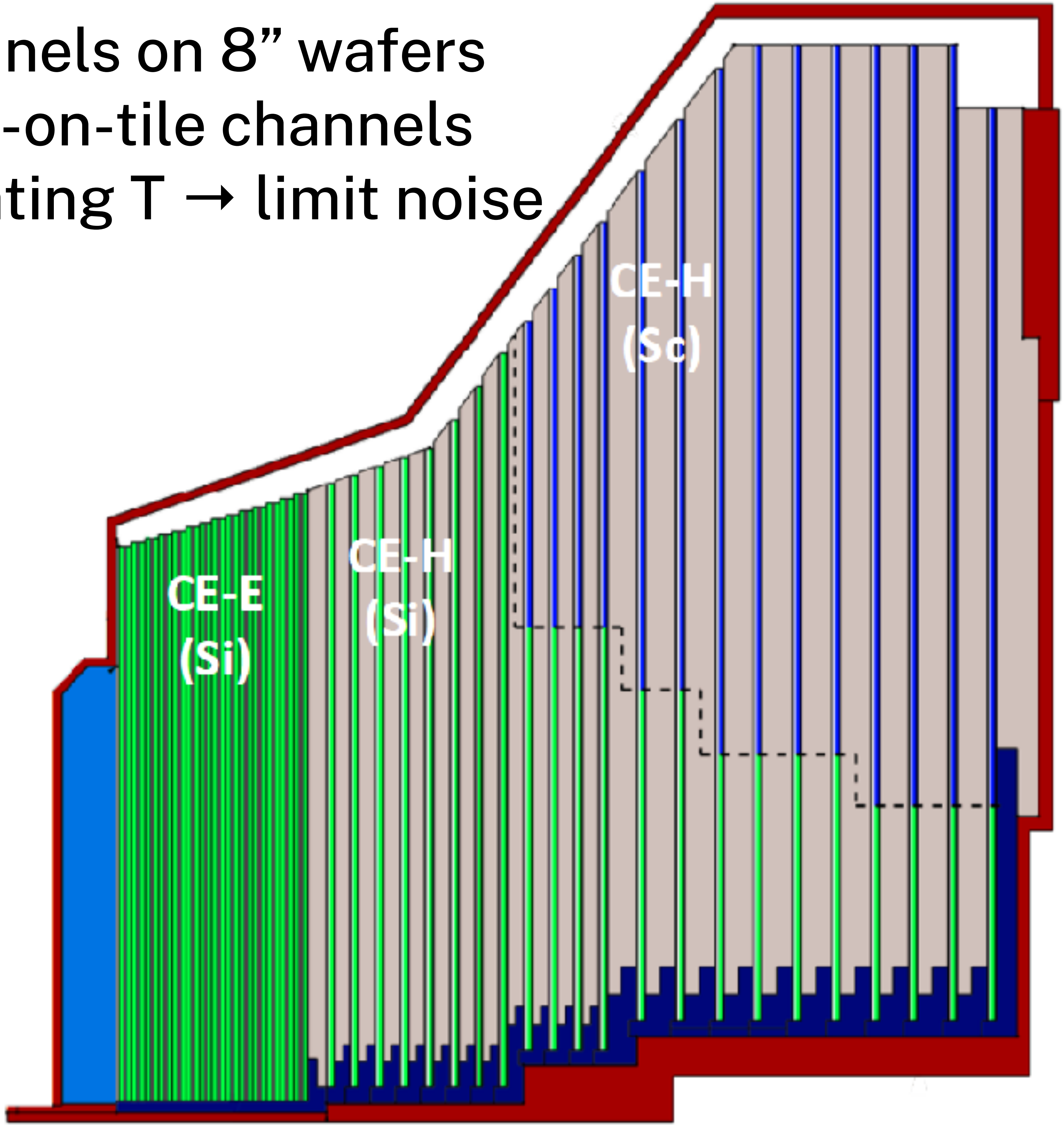




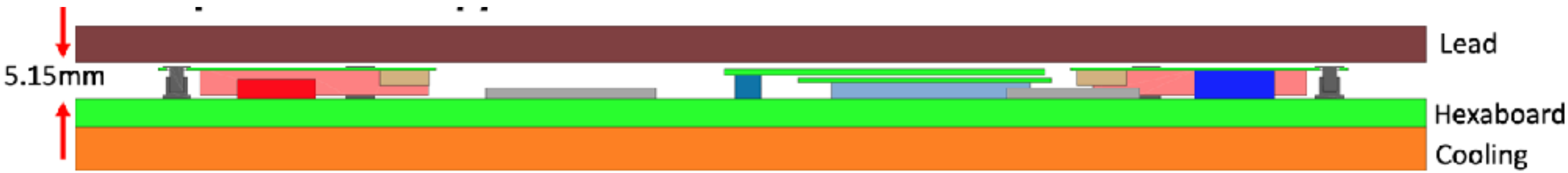
Silicon detectors can survive
the radiation with acceptable
noise levels; maintain MIP
calibration.

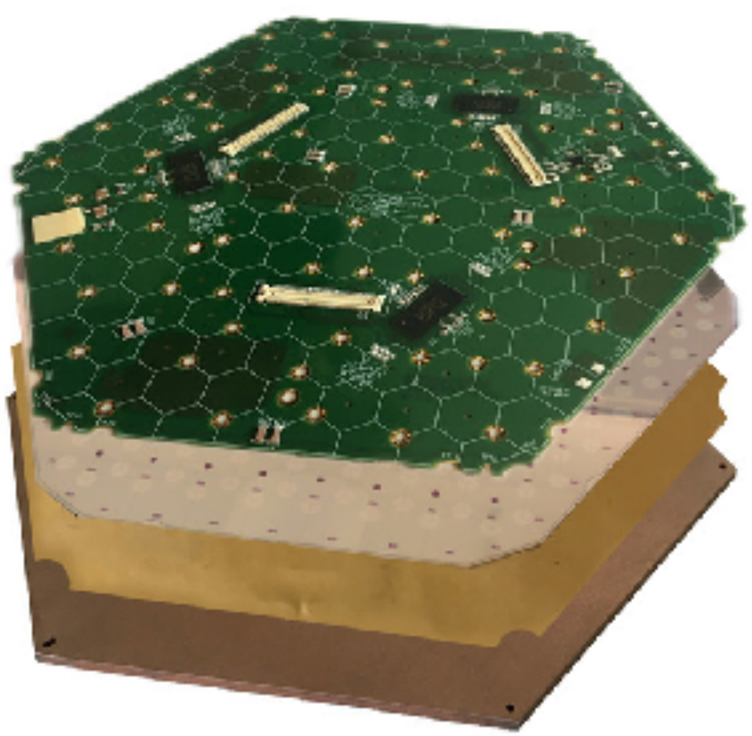

CMS p-p collisions at 7 TeV per beam
1 MeV-neutron equivalent fluence in Silicon at 3000 fb-1
R [cm]
Z [cm]
Fluence [cm-2]
approximate limit for scintillator tiles
CMS FLUKA Study v.3.7.9.1
CMS Simulation Preliminary

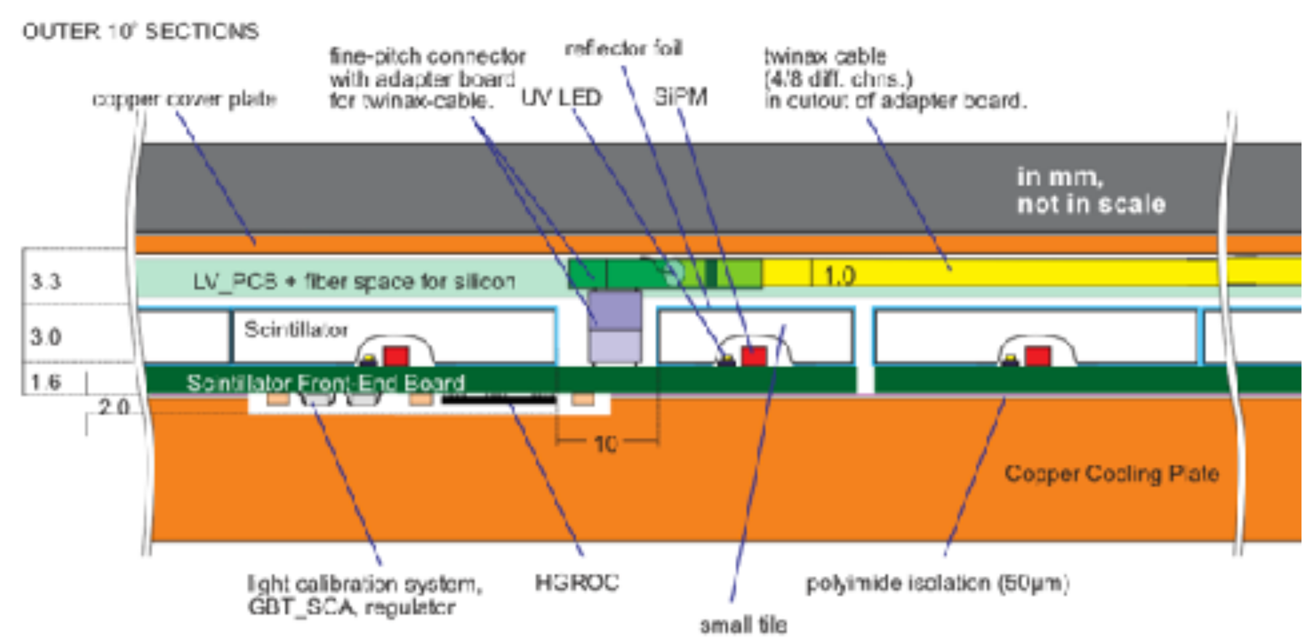
47* layers
6M Si channels on 8" wafers
240k SiPM-on-tile channels
-30C operating T → limit noise



Minimization of air gaps through careful choice of board layout and connections → maximize energy resolution

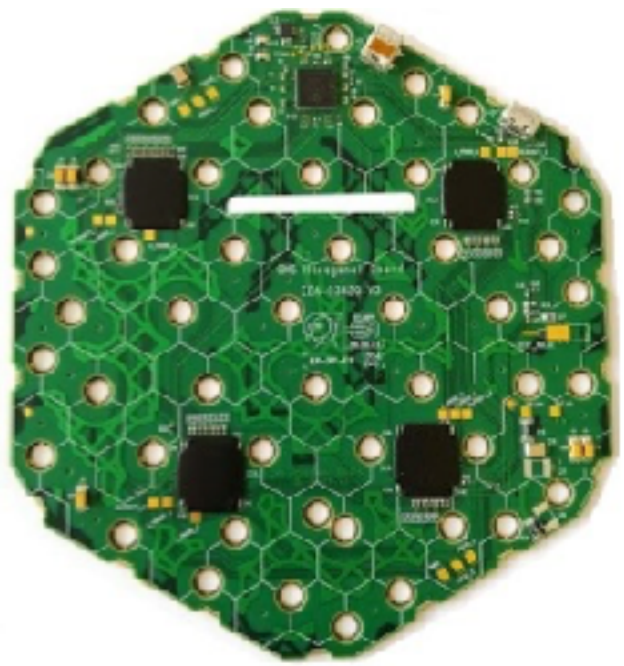


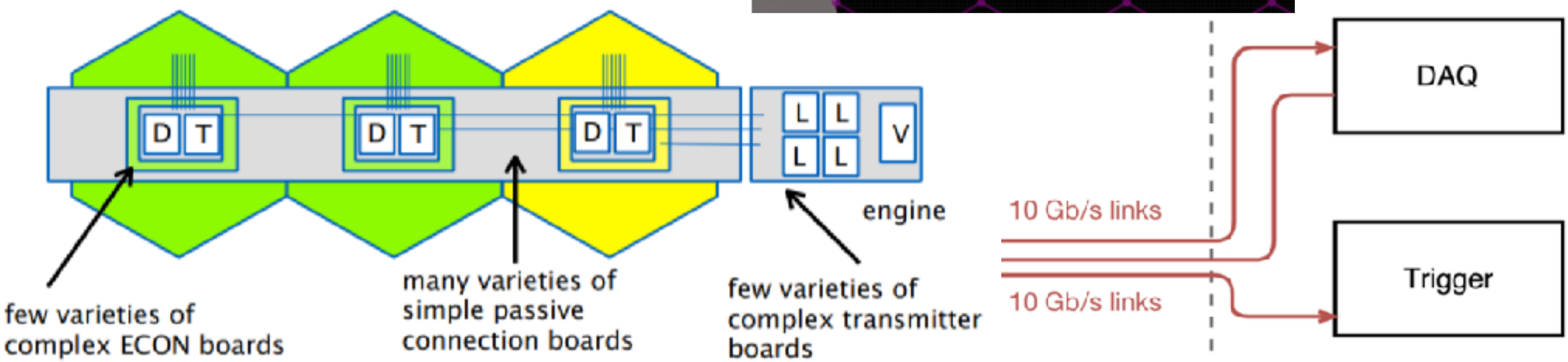




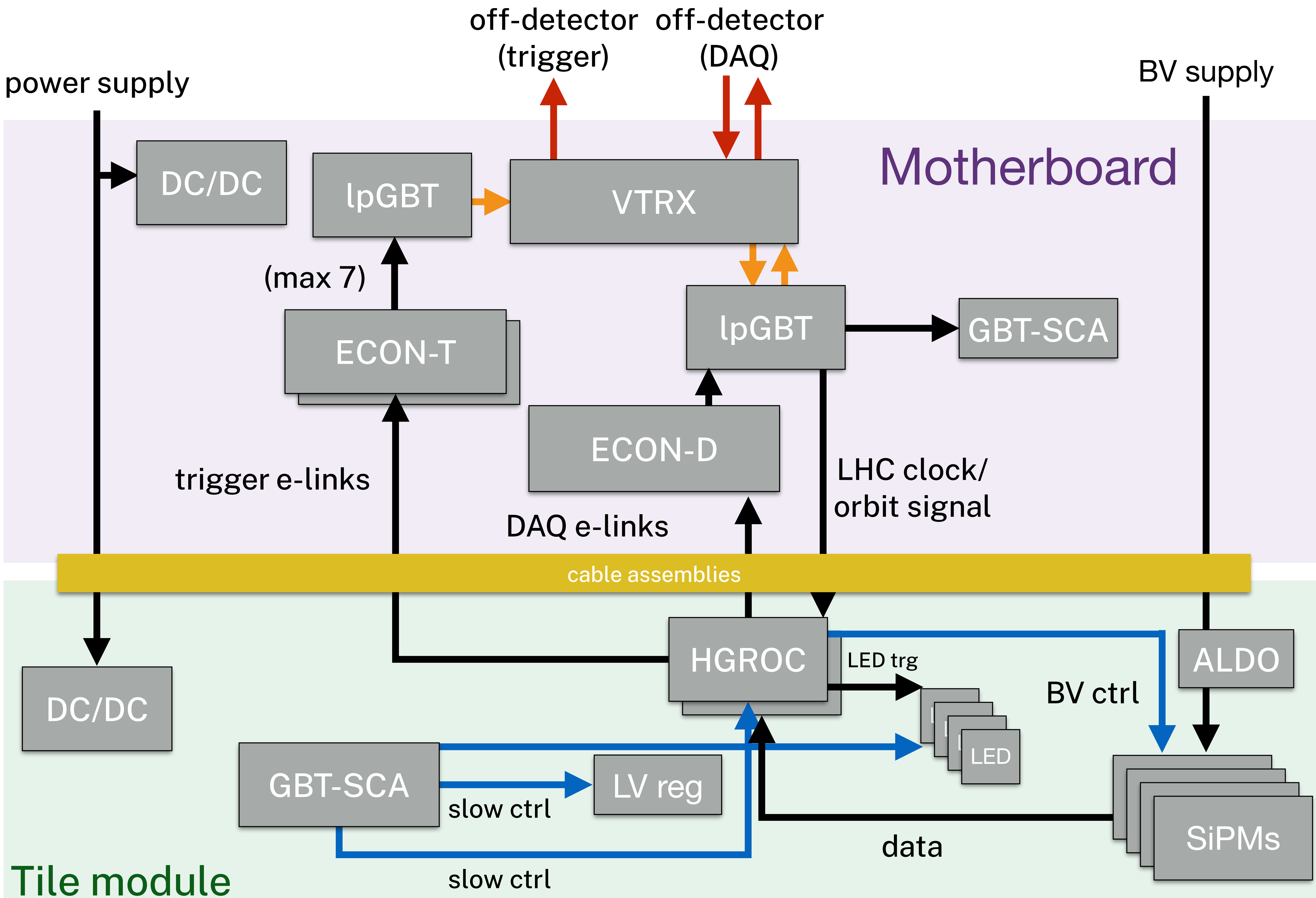
Massive challenge to fit into available space while maintaining build-ability.

ASIC engineering, always a challenge, growing more difficult due to the expense of the technology involved. Special challenges at the moment due to COVID and geopolitics...

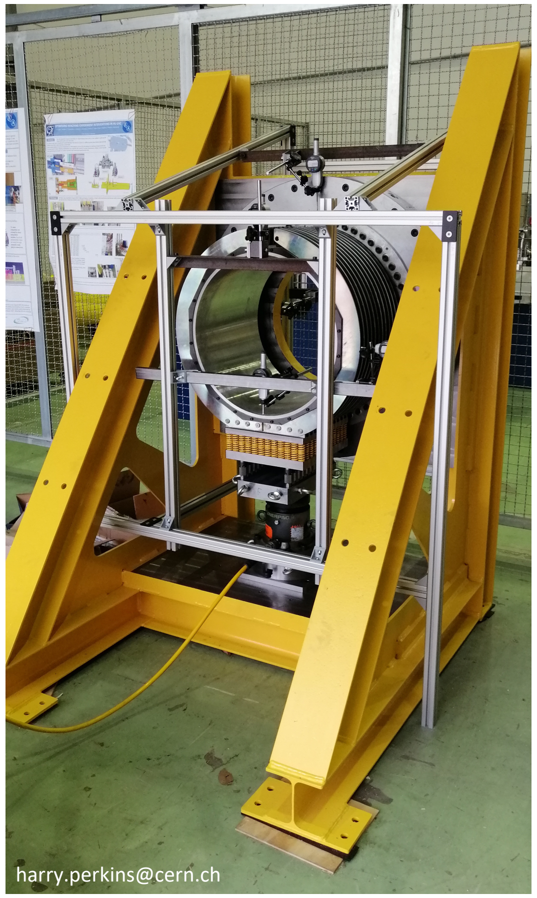


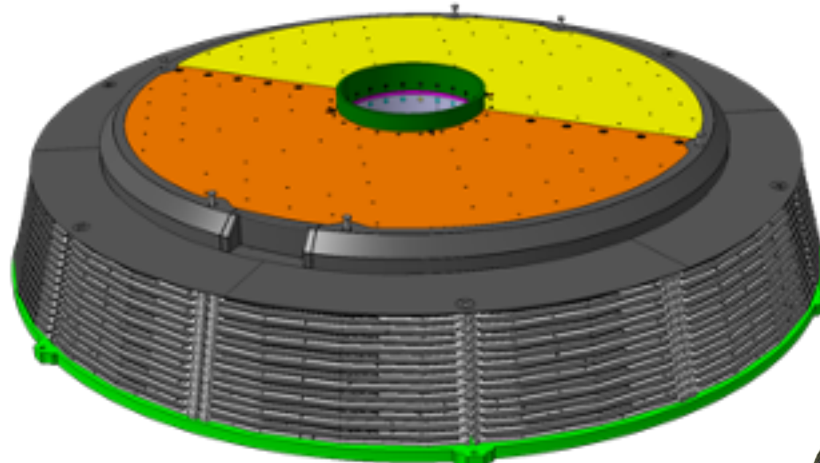


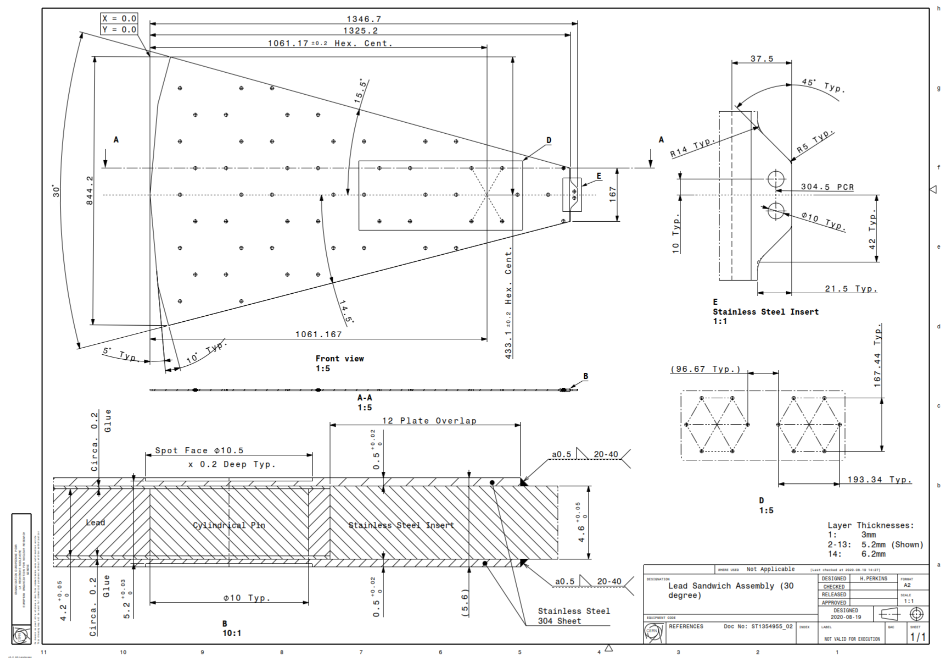
A collaborative approach using as many chips and IP as possible from LHC-wide (lpGBT) or CMS-wide (RAFAEL, ALDO) efforts helps to make the job easier.



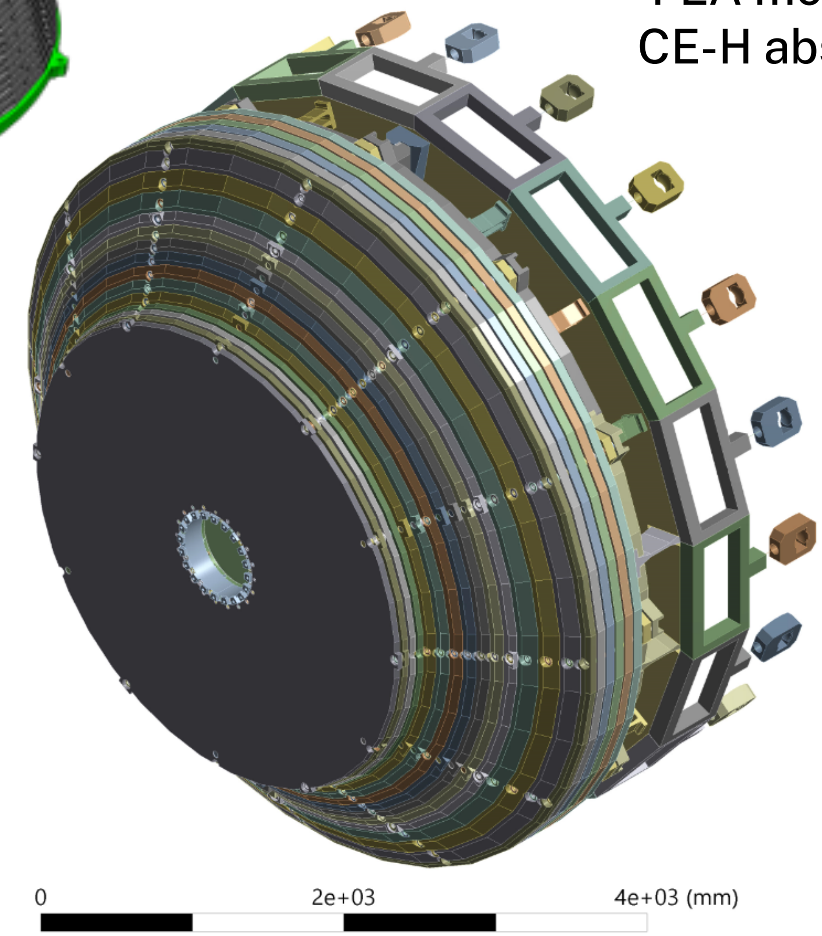
We have also been pushed to a more modular approach in many places → splitting functionality to avoid monolithic chips or boards.

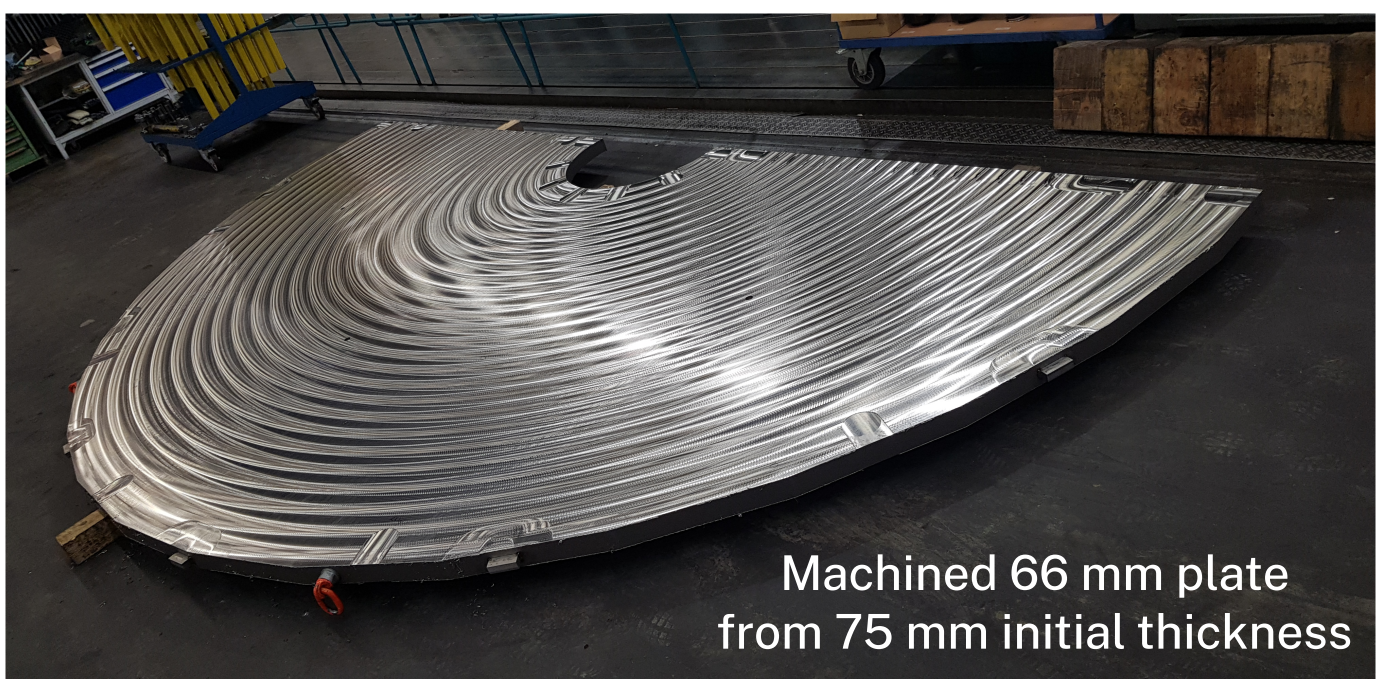


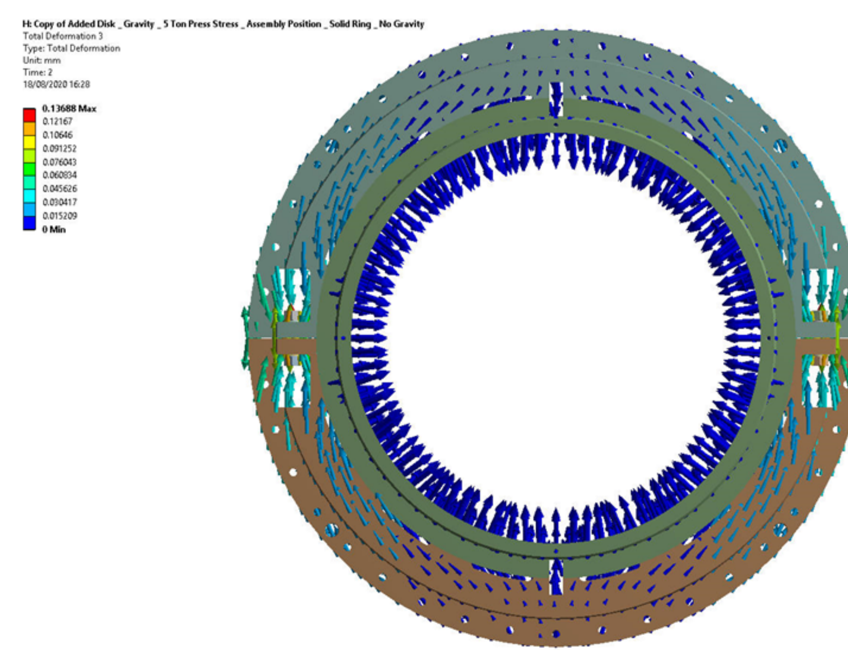




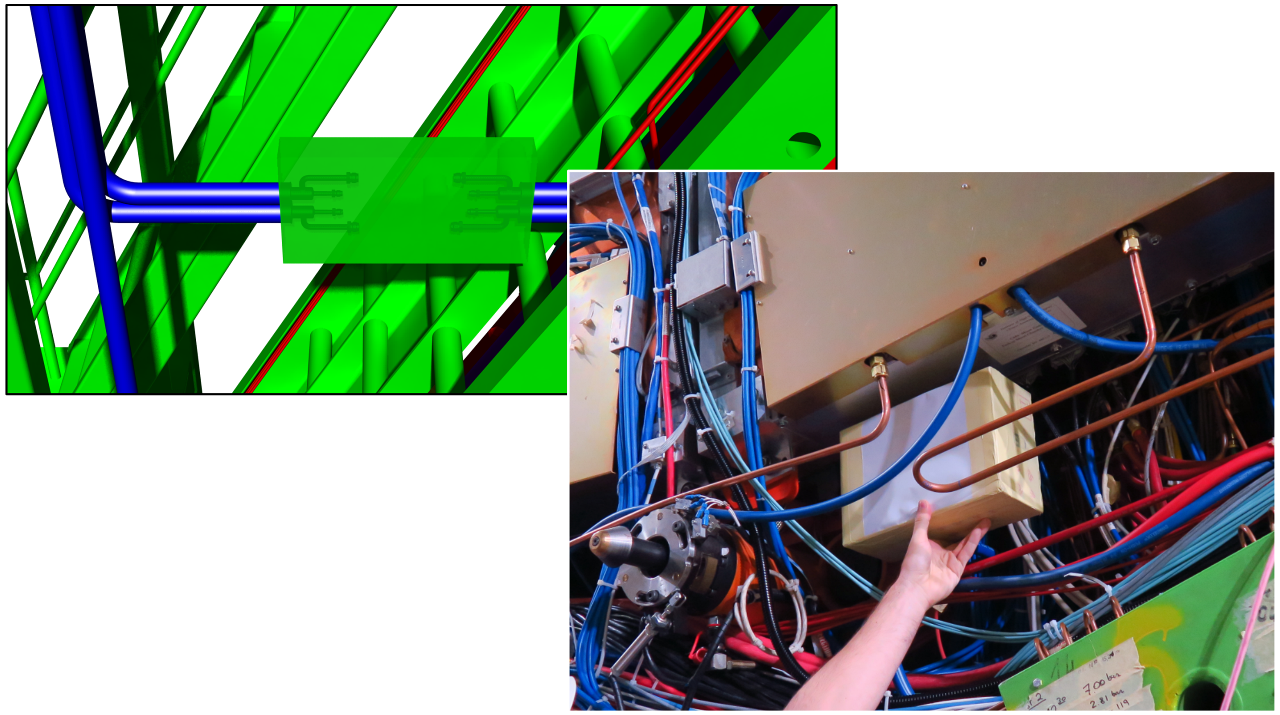
FEA model of CE-H absorber

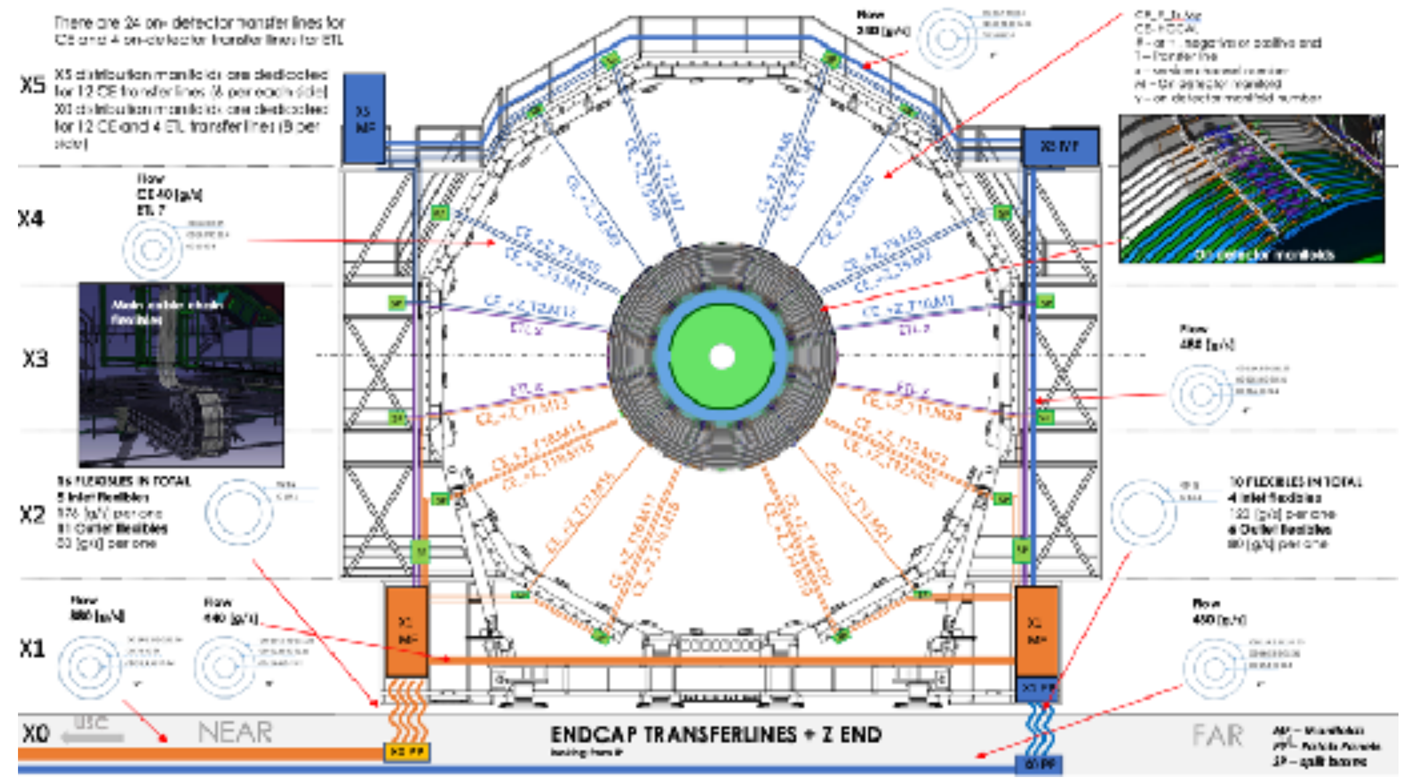


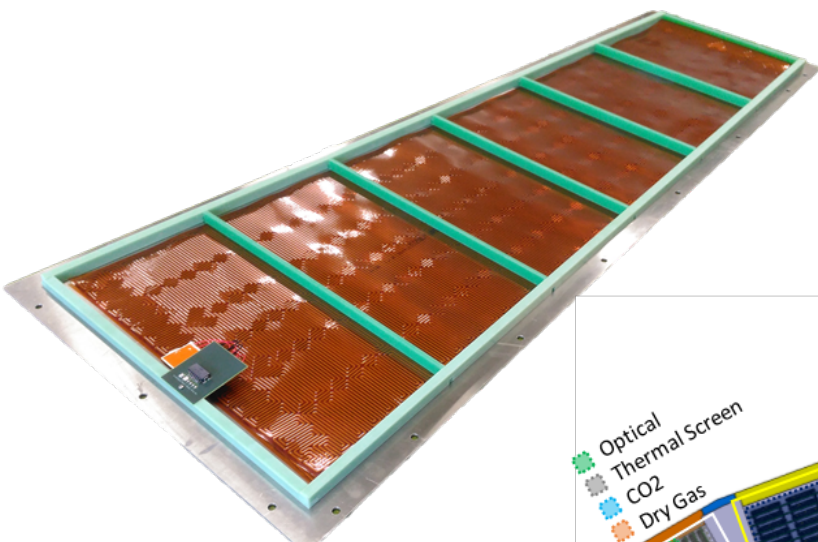


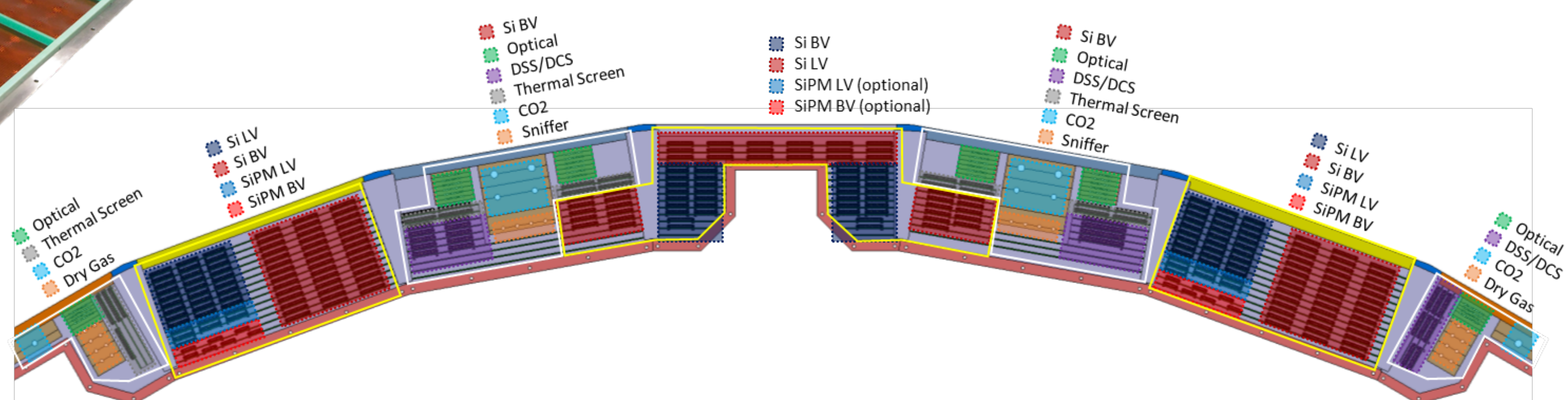


Challenging to develop robust & machinable absorbers, cooling planes and support structures with the necessary precision.

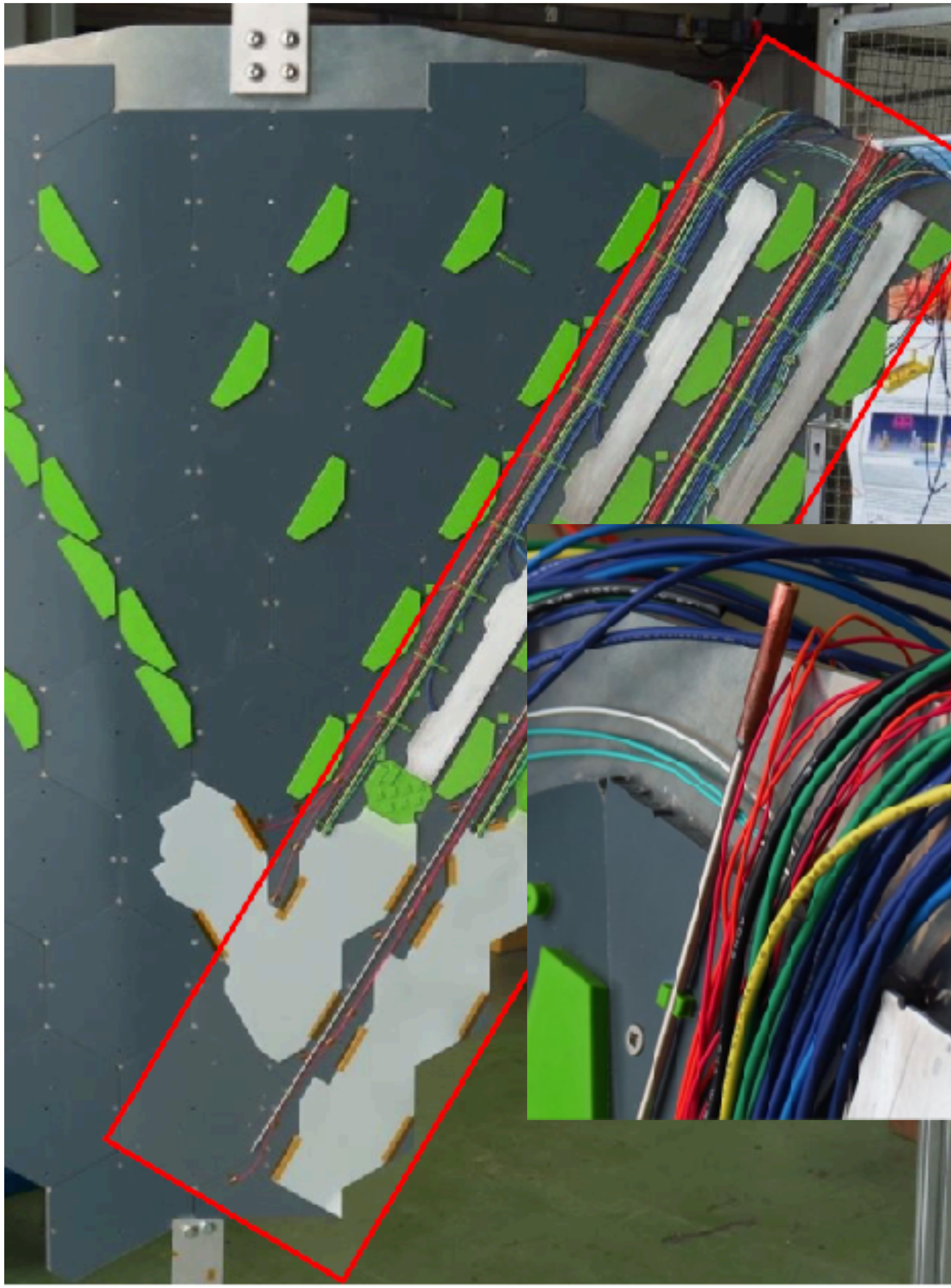


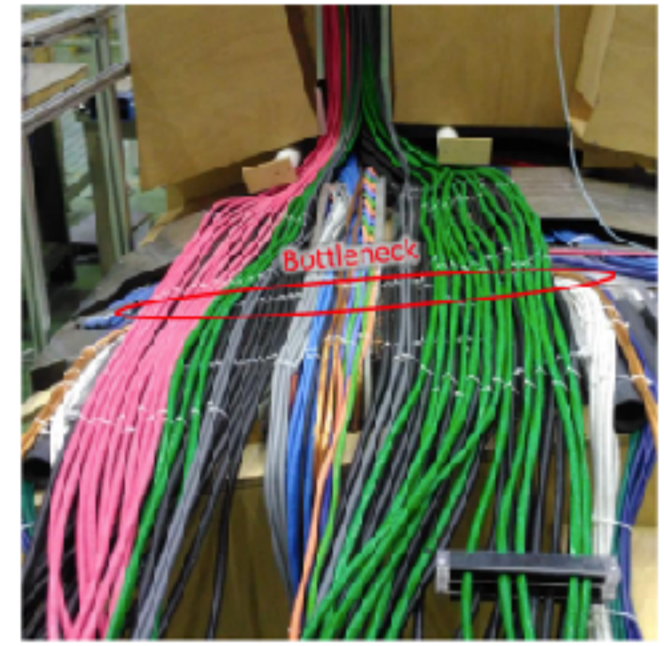




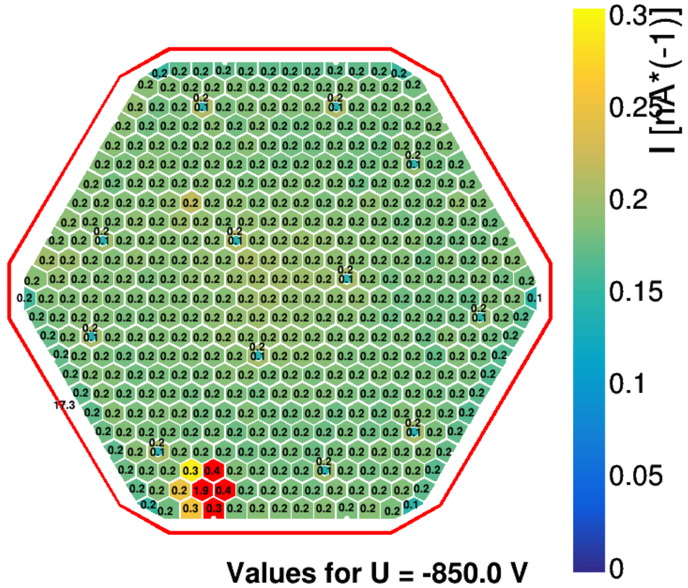


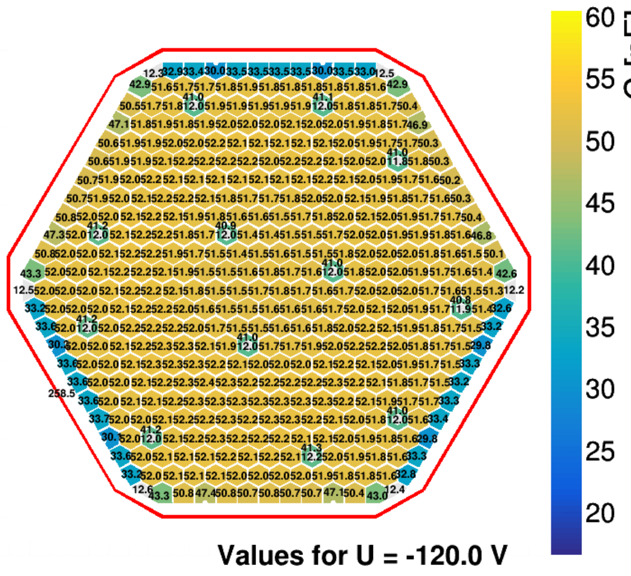
Active detector elements get most of the glory, but powering and cooling of so many layers (in a space already constrained by the existing detector) requires a lot of ingenuity.

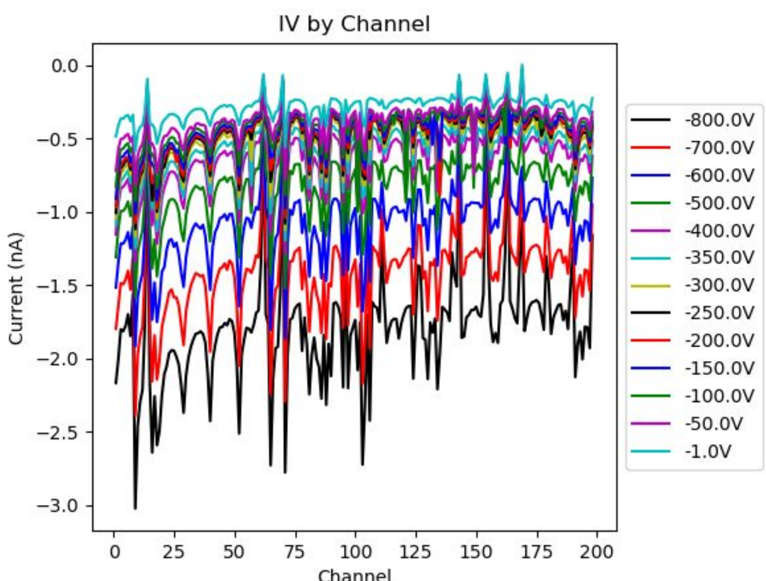


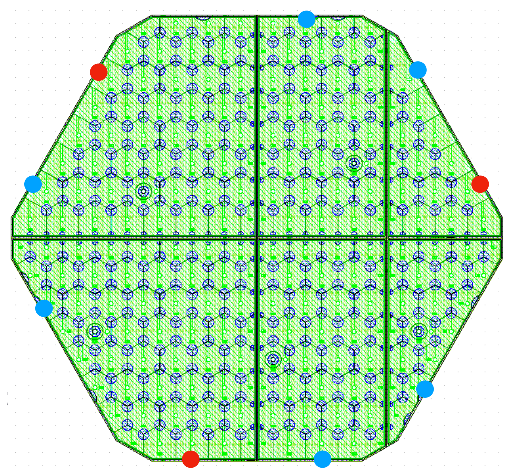


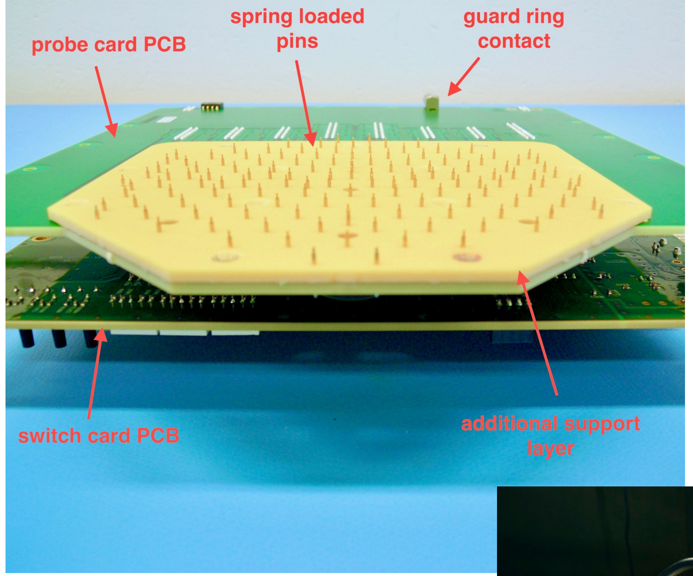
Physical mockups play an important role in connecting CAD and simulations to reality.

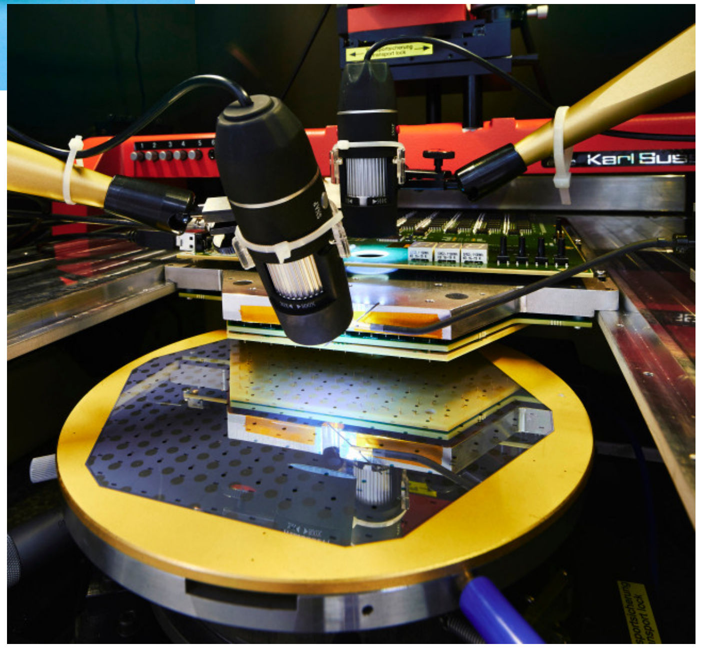


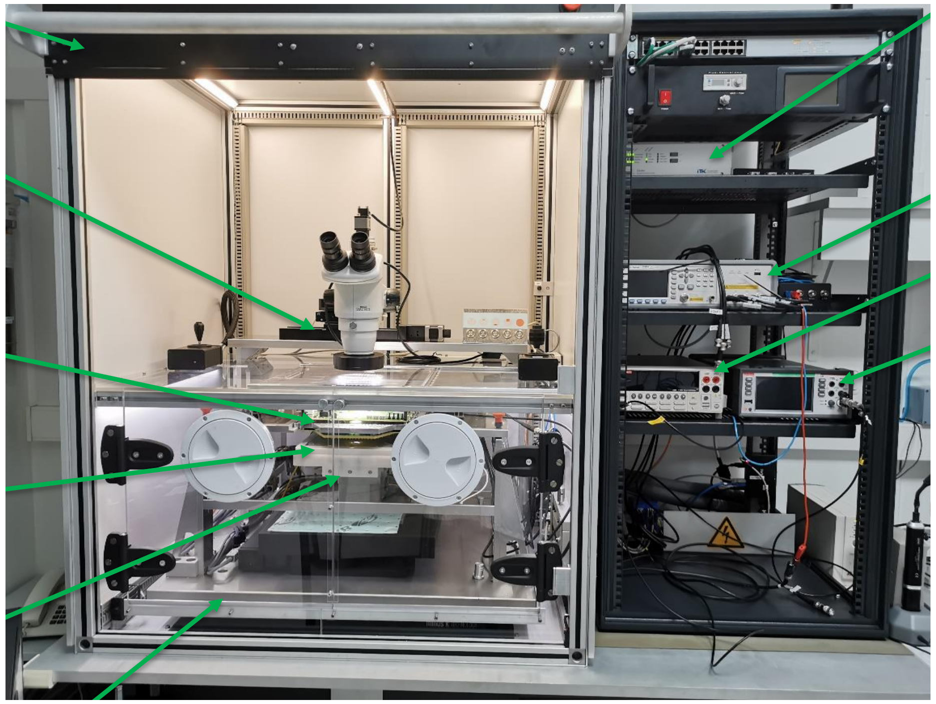




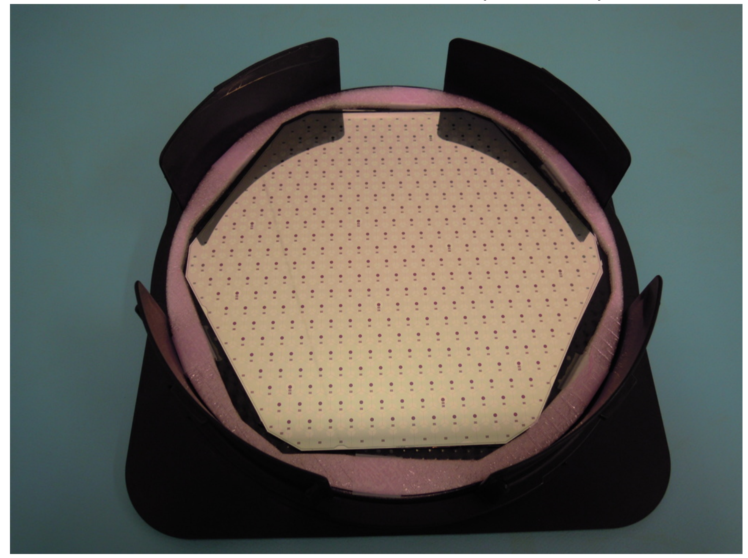




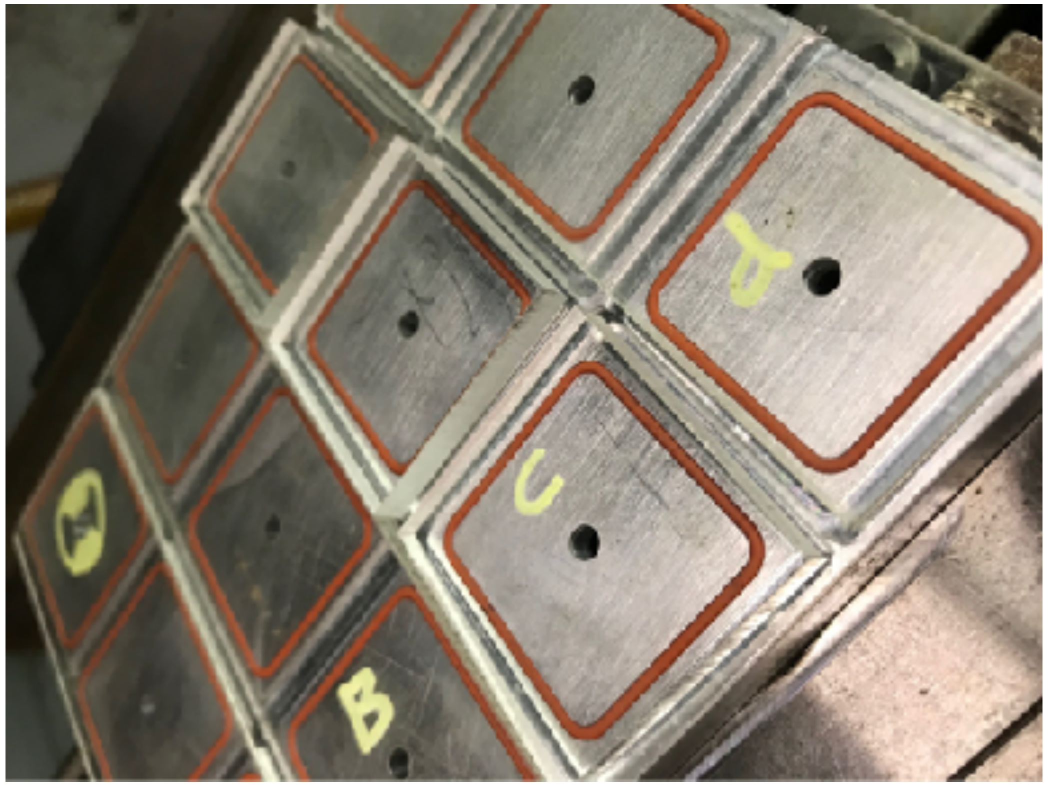


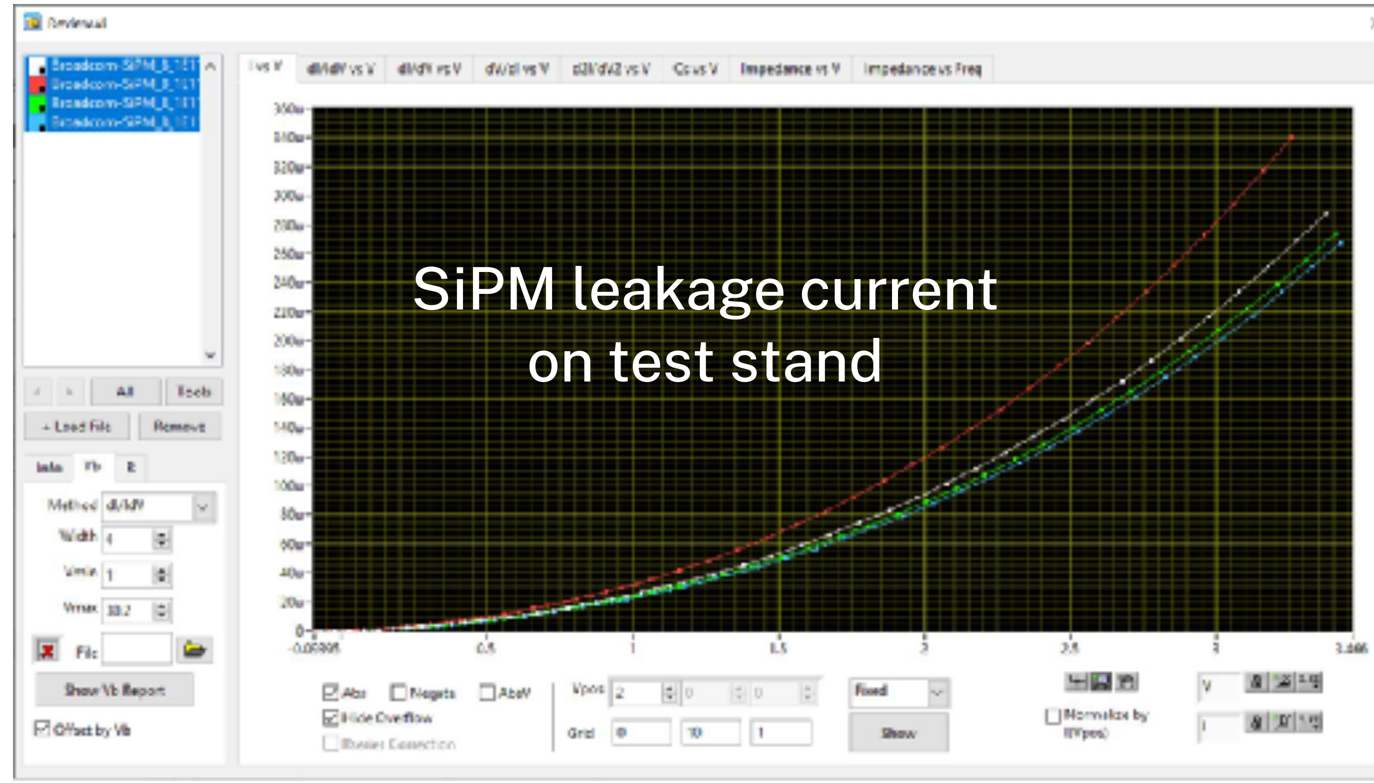


High Density: 444 cells (432+12)

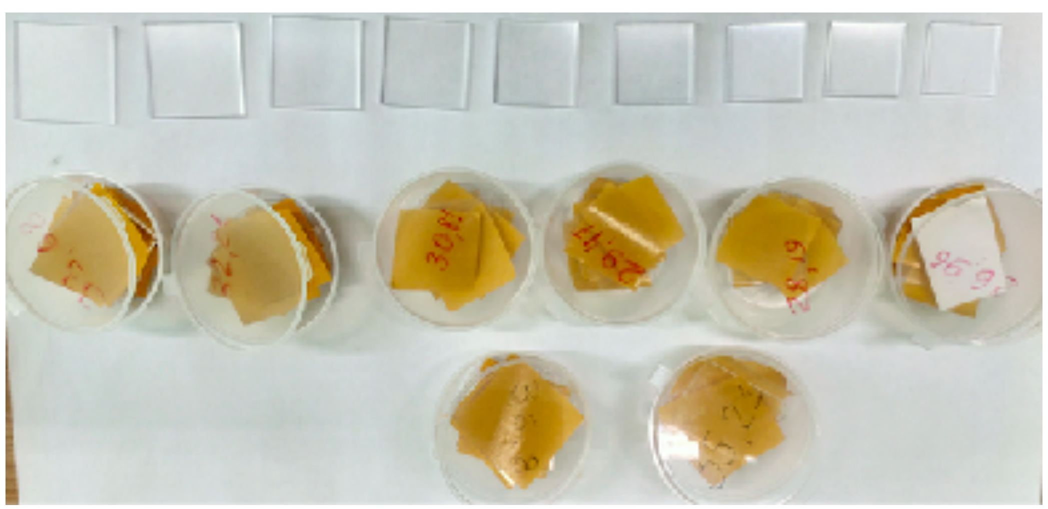


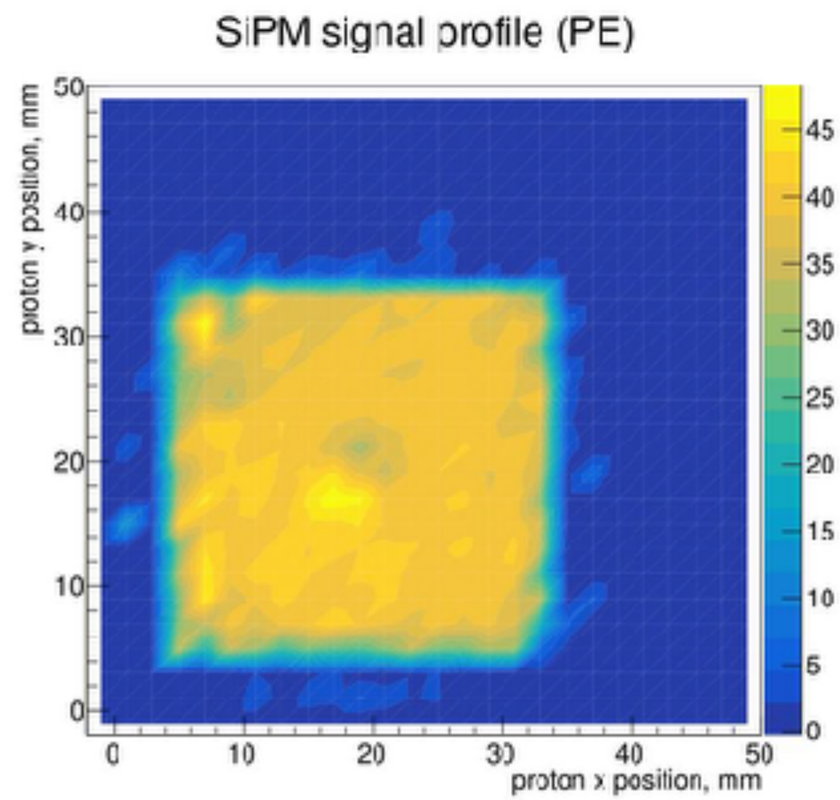
For this scale of project (6M Si channels!), resources needed for QC of all components become critical.





~30 tile variants to be machined
at 50 µm precision



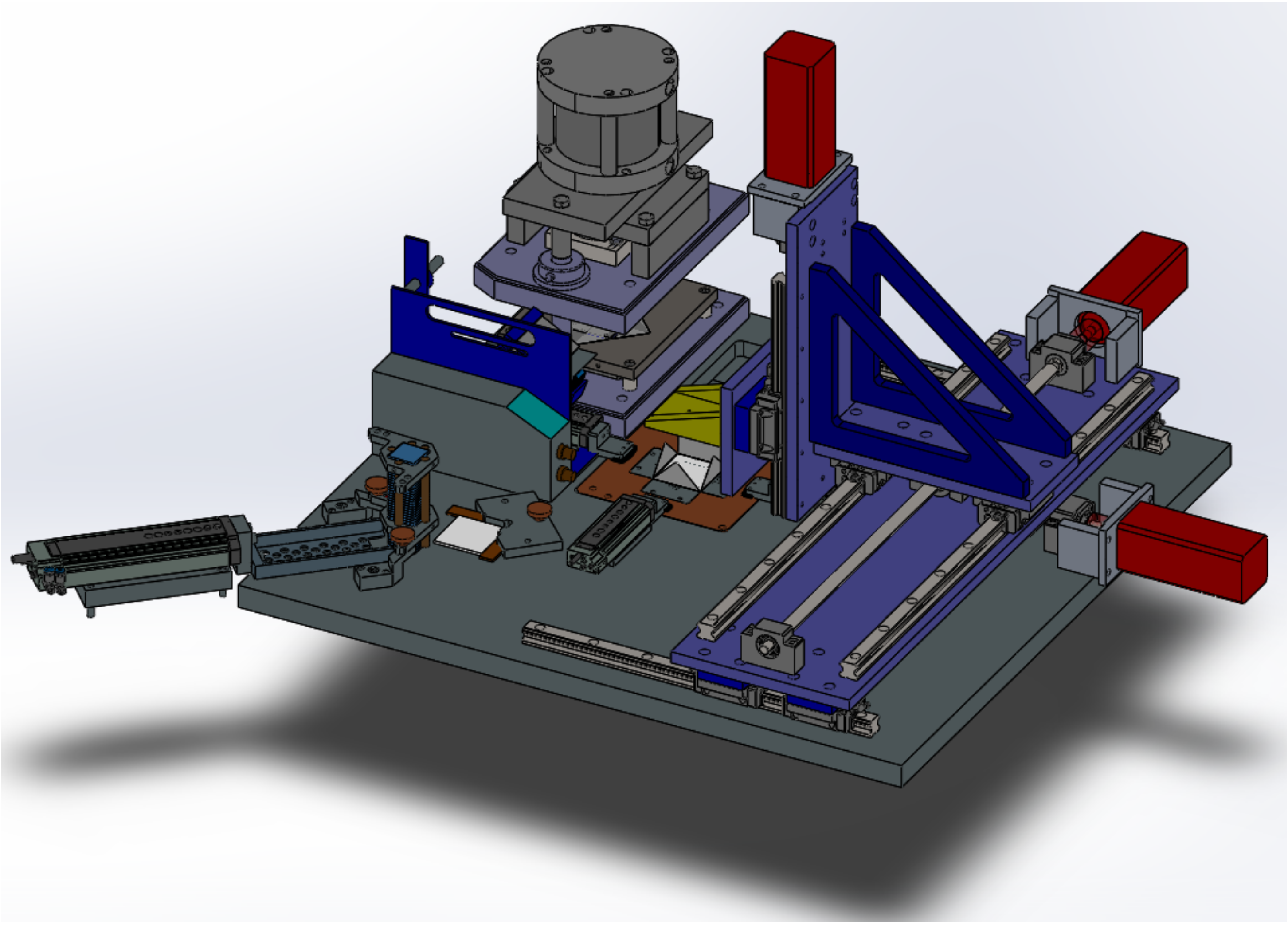


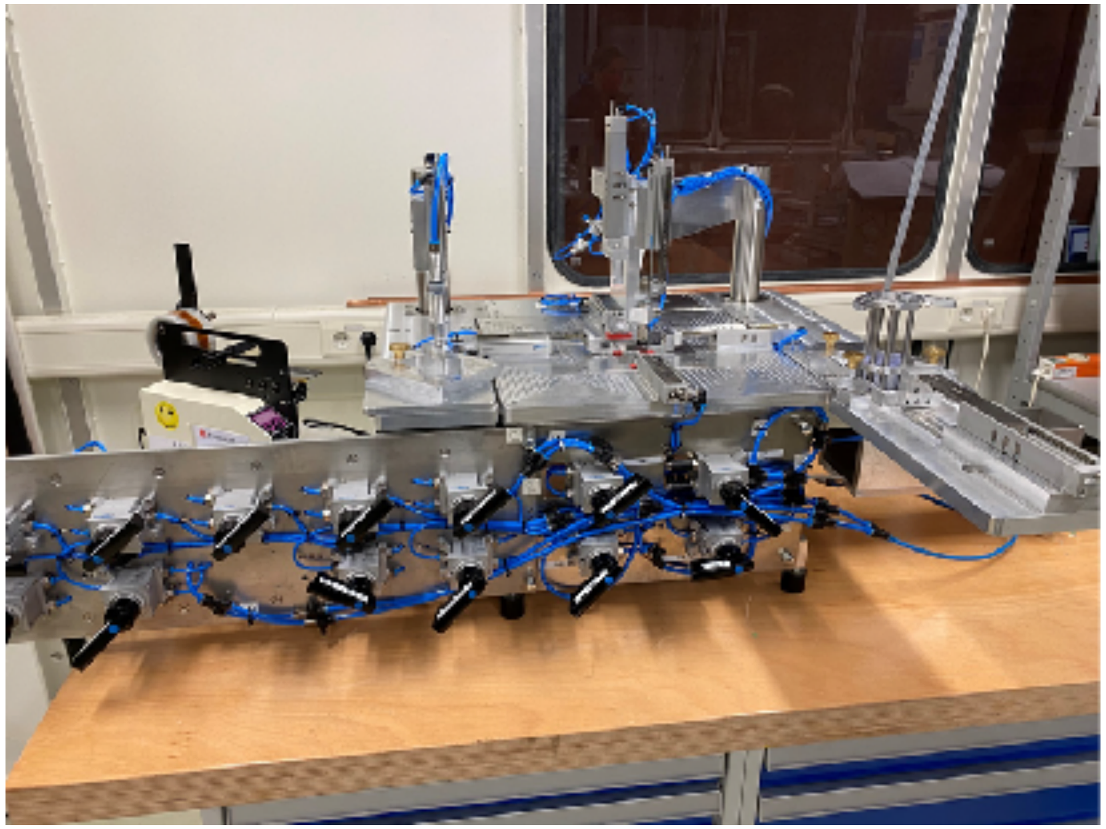
S14160 on white silkscreen,
Standard $V_{op} = 41.83V \rightarrow 3.5V$ OV

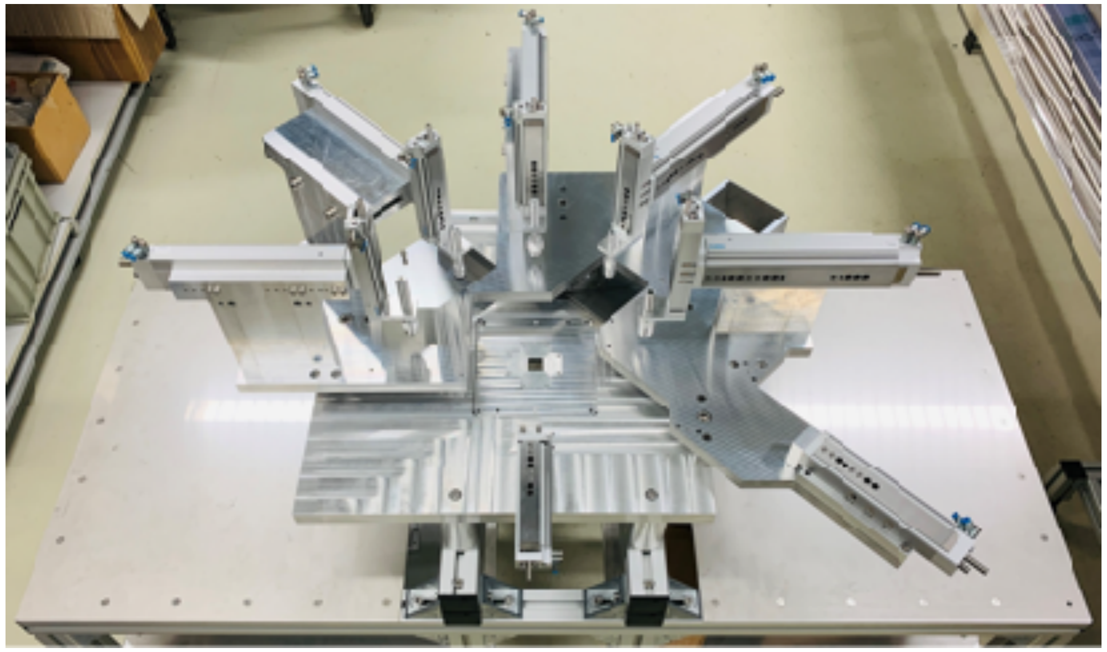
Tile	MPV
EJ208	35.3 ± 1.4
EJ200	32.1 ± 1.3
EJ262	29.9 ± 1.2
SC301	21.9 ± 0.9

Where possible, shift QC to QA. Close collaboration with vendors is of course essential. Tough decisions to be made e.g. if sampling is enough.

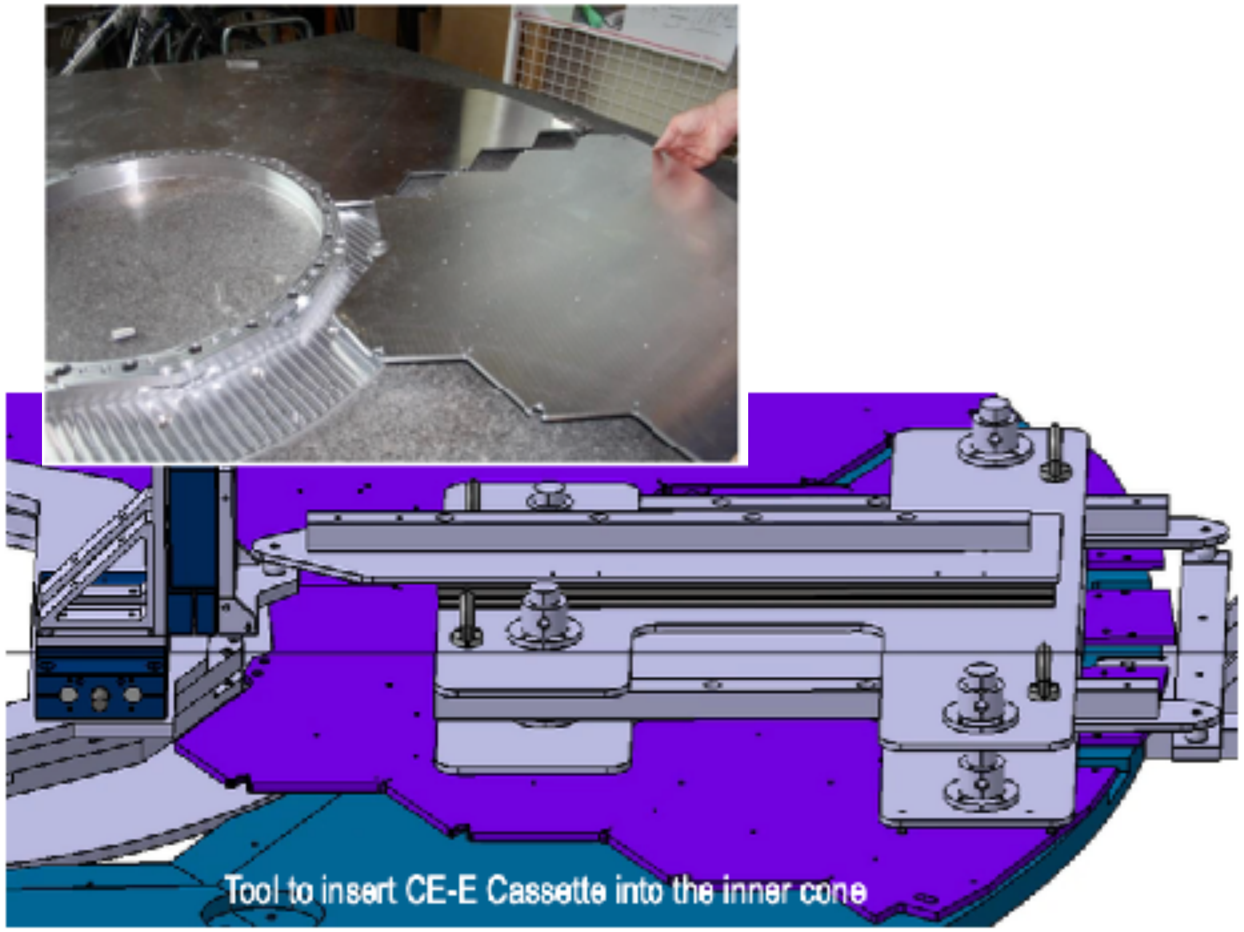
Automatic tile wrapping installation for multiple tile sizes



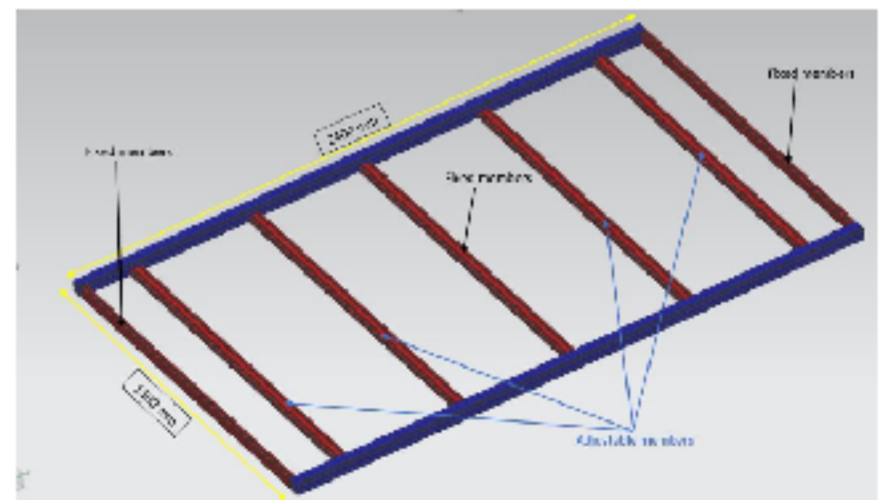




High standards for mechanical tolerances and physics performance in each module strongly favor the precision and repeatability of automated assembly.

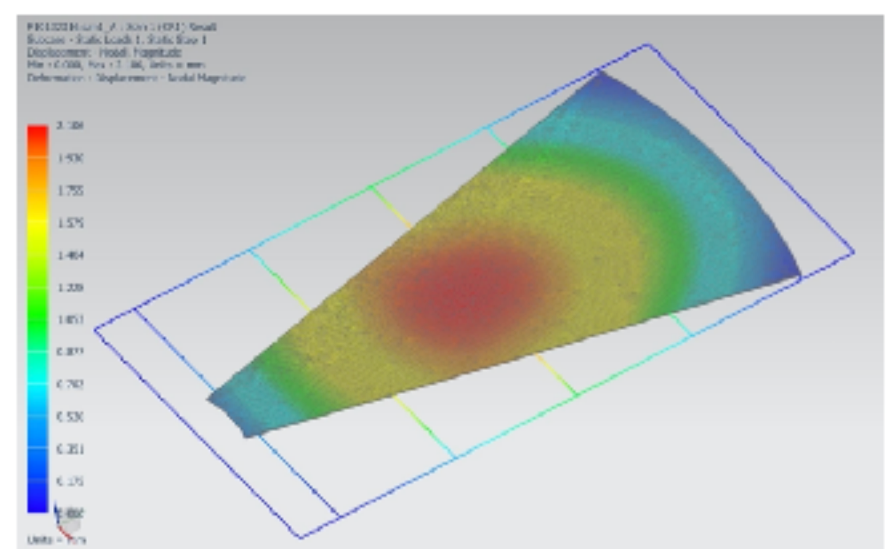


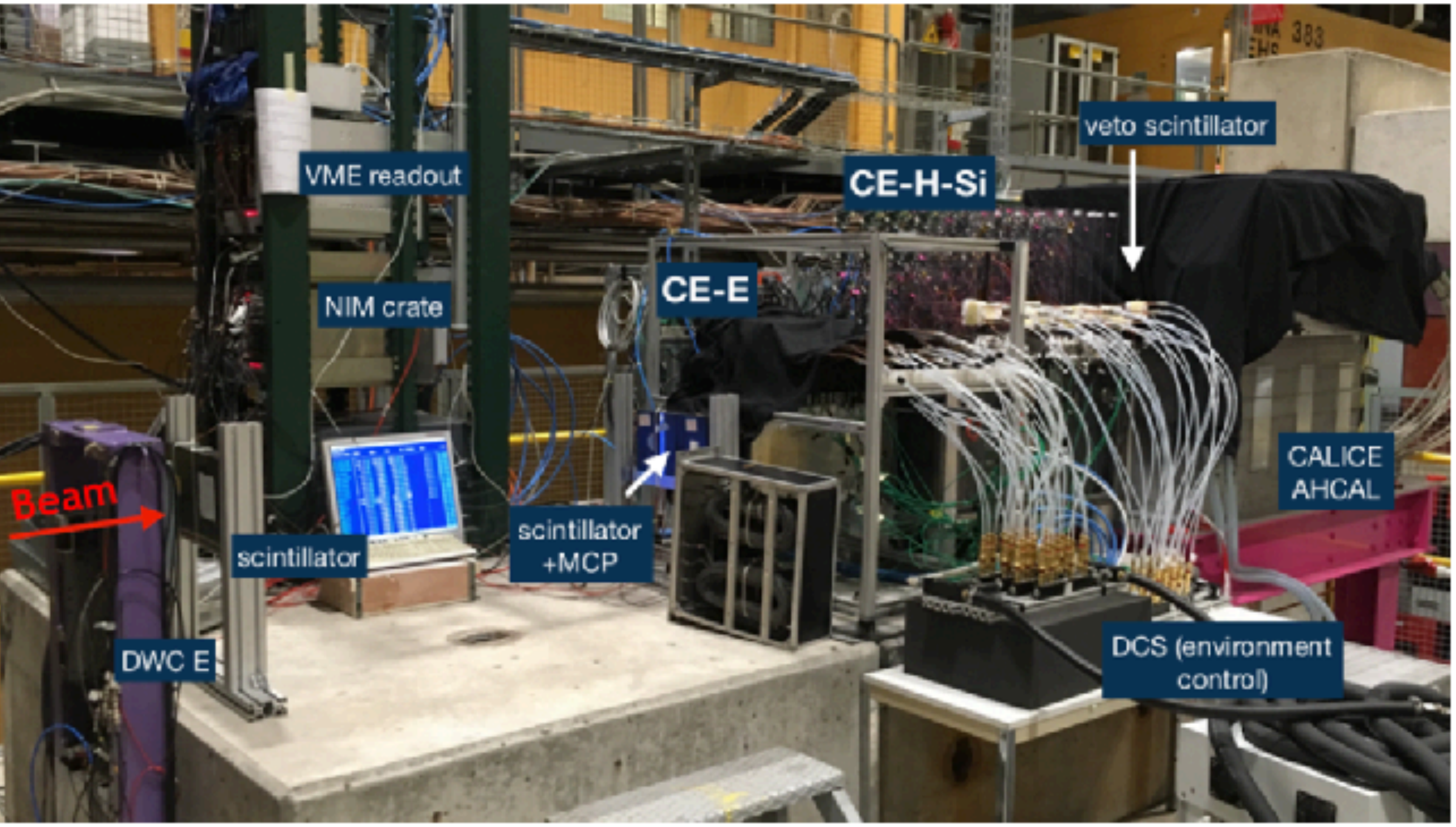
CMM for cooling plate inspection



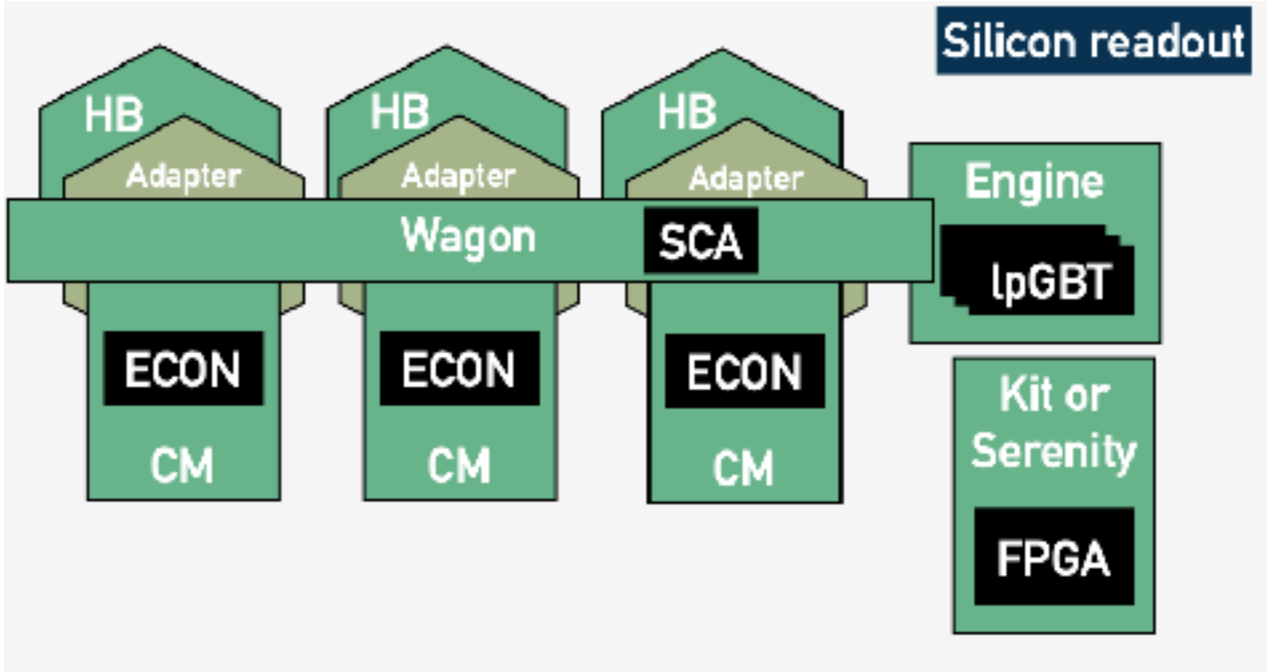
Cassette assembly particularly demanding.

Parts from many institutes and countries need to be combined and tested in a rigorous and efficient way. A multi-year effort.





Test beam system:
more channels than
existing CMS endcap!



HGCAL beam tests and test stands have a complexity comparable to whole experiments of a previous age. Close collaboration with CALICE bears fruit.

Summary

CALICE-inspired HGCAL effort will provide valuable experience to the field of constructing a PF-inspired calorimeter.

HGCAL project is moving towards production through an extensive series of prototypes and test setups.

Extensive work on managing trade-offs and challenges, including:

- Mechanical design.
- Active sensor elements (including an important QC program).
- Readout electronics and ASICs.

Lots of work ahead to complete the construction.

The HGCAL experience should increase our confidence that other calorimeters of this basic type can be successfully constructed at future experiments.