UNIVERSITY OF OREGON

CLD

CLD DETECTOR CONCEPT

Jim Brau (Oregon)

for the CLD team

Research partially supported by the U.S. Department of Energy

FCC PHYSICS REQUIREMENTS



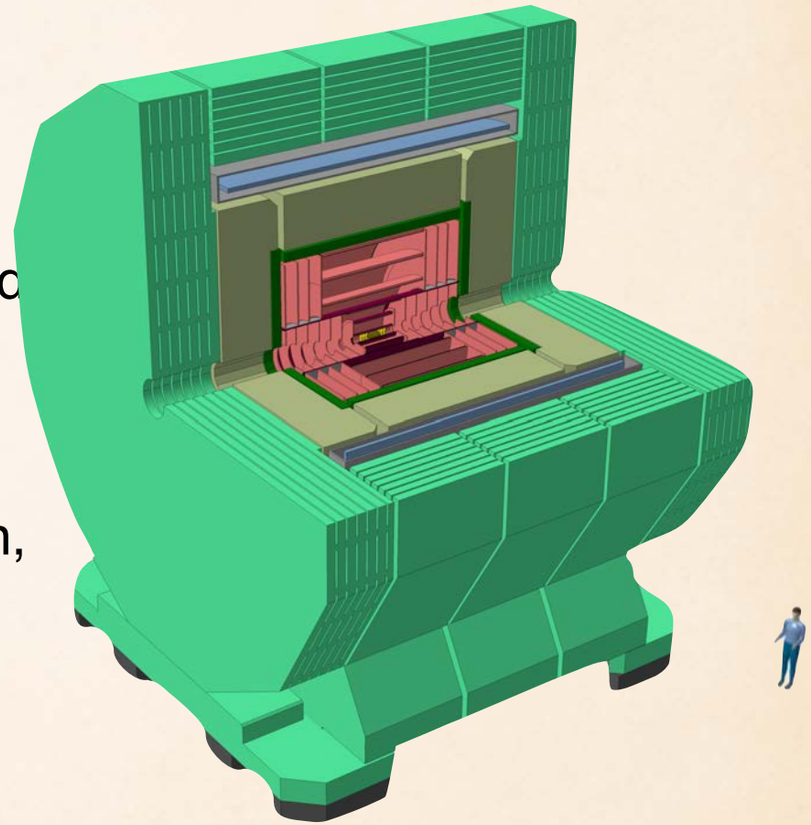
- Higgs physics goals define initial detector requirements for calorimetry and tracking:

Physics Process	Measured Quantity	Critical Detector	Required Performance
$ZH \to \ell^+\ell^- X$	Higgs mass, cross section	Tracker	$\Delta(1/p_{\mathrm{T}}) \sim 2 \times 10^{-5}$ $\oplus 1 \times 10^{-3}/(p_{\mathrm{T}} \sin\theta)$
$H \to \mu^+\mu^-$	BR($H \to \mu^+\mu^-$)		
$H \to b\bar{b},\ c\bar{c},\ gg$	BR($H \to b\bar{b},\ c\bar{c},\ gg$)	Vertex	$\sigma_{r\phi} \sim 5 \oplus 10/(p \sin^{3/2}\theta)\ \mu$m
$H \to q\bar{q},\ VV$	BR($H \to q\bar{q},\ VV$)	ECAL, HCAL	$\sigma_E^{\mathrm{jet}}/E \sim 3-4\%$
$H \to \gamma\gamma$	BR($H \to \gamma\gamma$)	ECAL	$\sigma_E \sim 16\%/\sqrt{E} \oplus 1\%$ (GeV)

- Full set of physics goals expand requirements, such as flavor tagging.

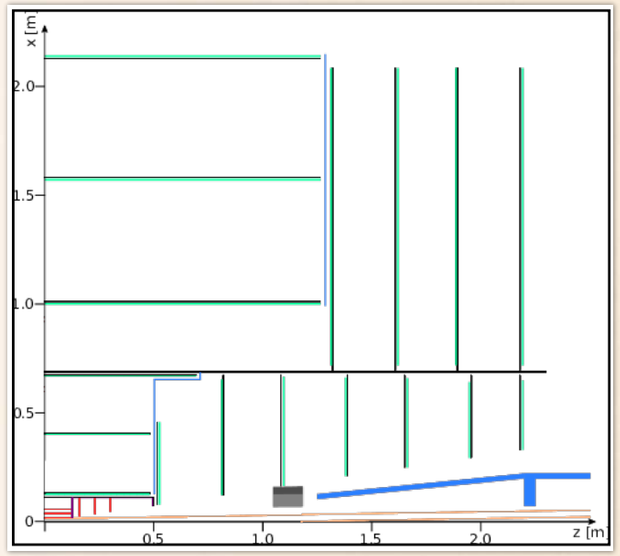
THE CLD DETECTOR

- CLD detector (CLIC-Like Detector) concept evolved from CLIC detector model CLICdet (built on earlier SiD and ILD):
  - Silicon vertex detector and silicon tracker,
  - Highly granular calorimeters (a silicon-tungsten ECAL and a scintillator-steel HCAL),
  - A superconducting solenoid with 2T magnetic field, and
  - Steel Yoke and RPCs for muon identification.
- For the full range from the Z pole (91 GeV) to the ttbar threshold (365 GeV), the same detector must have:
  - Exceptional track momentum and jet energy resolution,
  - Highly efficient flavour tagging,
  - Robust lepton identification capabilities, and
  - Full geometrical coverage down to low polar angles.
- Detector concept has benefited from early complete, full simulation, used for performance studies.



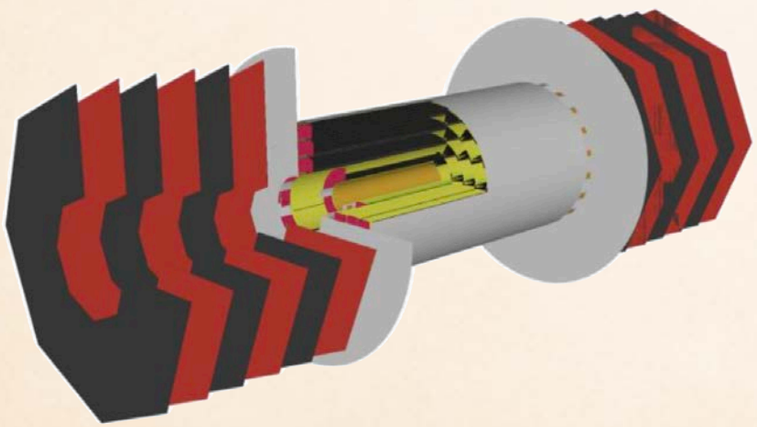
VERTEX DETECTOR & MAIN TRACKER

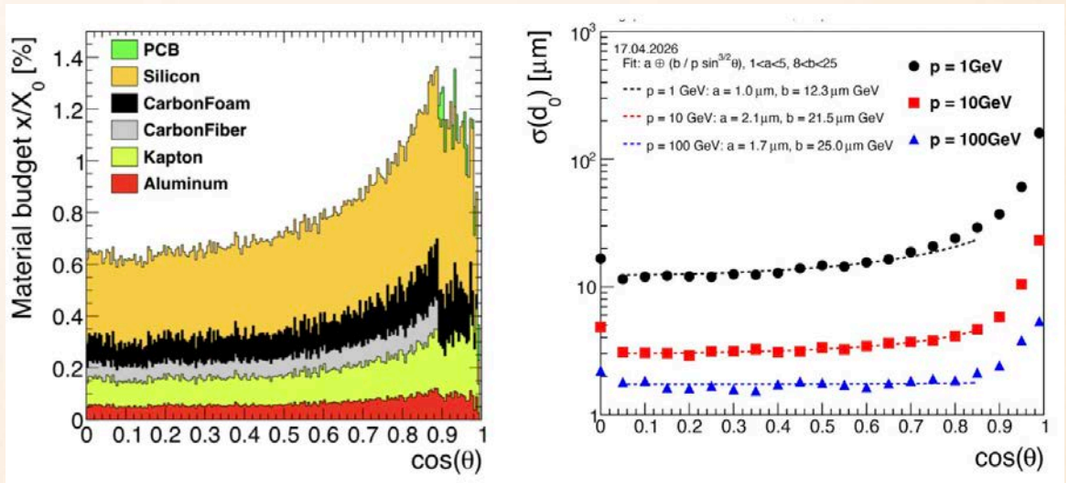
- Vertex detector:
  - 3 double layers (0.6% X_0 per double barrel layer, 0.7% X_0 per disc),
  - 25 x 25 μm² pixels, with 50 μm silicon thickness,
  - 3 μm x 3 μm single point resolution,
  - R_{in} = 13.0 mm.
- Full silicon tracker:
  - Inner Tracker: 3 short layers and 7 inner disks,
  - Outer tracker: 3 long layers and 4 outer disks,
  - 200 μm Silicon thickness,
    - 50 μm x 0.3 mm cell size,
  - Material budget: 1.1 % – 2.1 % X_0 per layer (including overlaps),
  - 7 μm x 90 μm single point resolution,
    - (except first inner tracker discs, 5 μm x 5 μm),
  - At least 8 hits for θ > 8.5°.



VERTEX DETECTOR

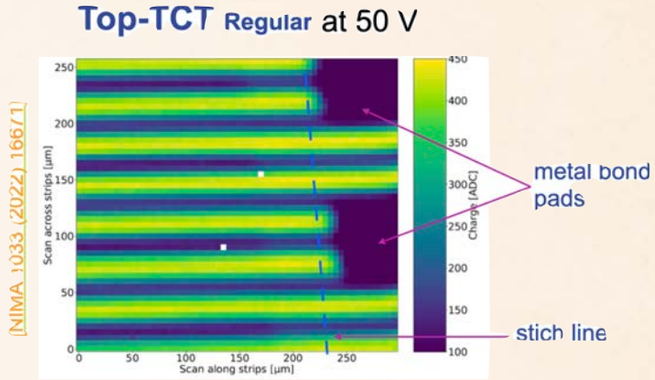
- FCC-SEED concept under development for FCC-ee:
  - Based on large size curved sensors,
    - Smallest possible radius, first hits as close as possible to the collision point,
    - Minimization of the material budget,
  - Snail-like shape, slight sensor overlap,
  - Allow for a full r-ϕ coverage.
- Full DD4hep simulation model initially for CLD, and developing for other detector concepts.
- Current design and related performance will evolve in parallel with sensor R&D, mechanics and integration studies.



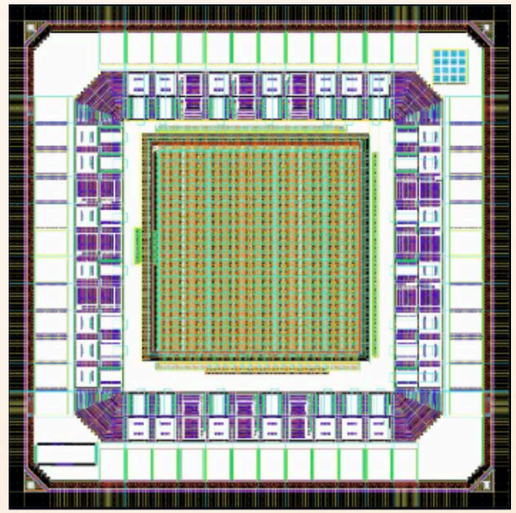


MAIN TRACKER

- Geometry compatible with ALICE ITS technology:
  - ➡ Could be sensors plus ASICs or monolithic structure.
  - ➡ Will benefit from active R&D (eg. DRD3 and other):
    - ◉ Large area CMOS strip tracker (Monstera Collaboration),
      - ✦ A R&D project that is of interest for CLD,
    - ◉ Several MAPS R&D activities down to 65 nm in DRD3, e.g., NAPA-p2 (TJ 65nm),
      - ✦ Novel Vernier delay-line TDC (core of sub-ns timing),
        - ▸ Programmable resolution to 20 ps,
        - ▸ Low-power, small-area design for MAPS integration.
- Joint effort with other concepts pursued when appropriate.



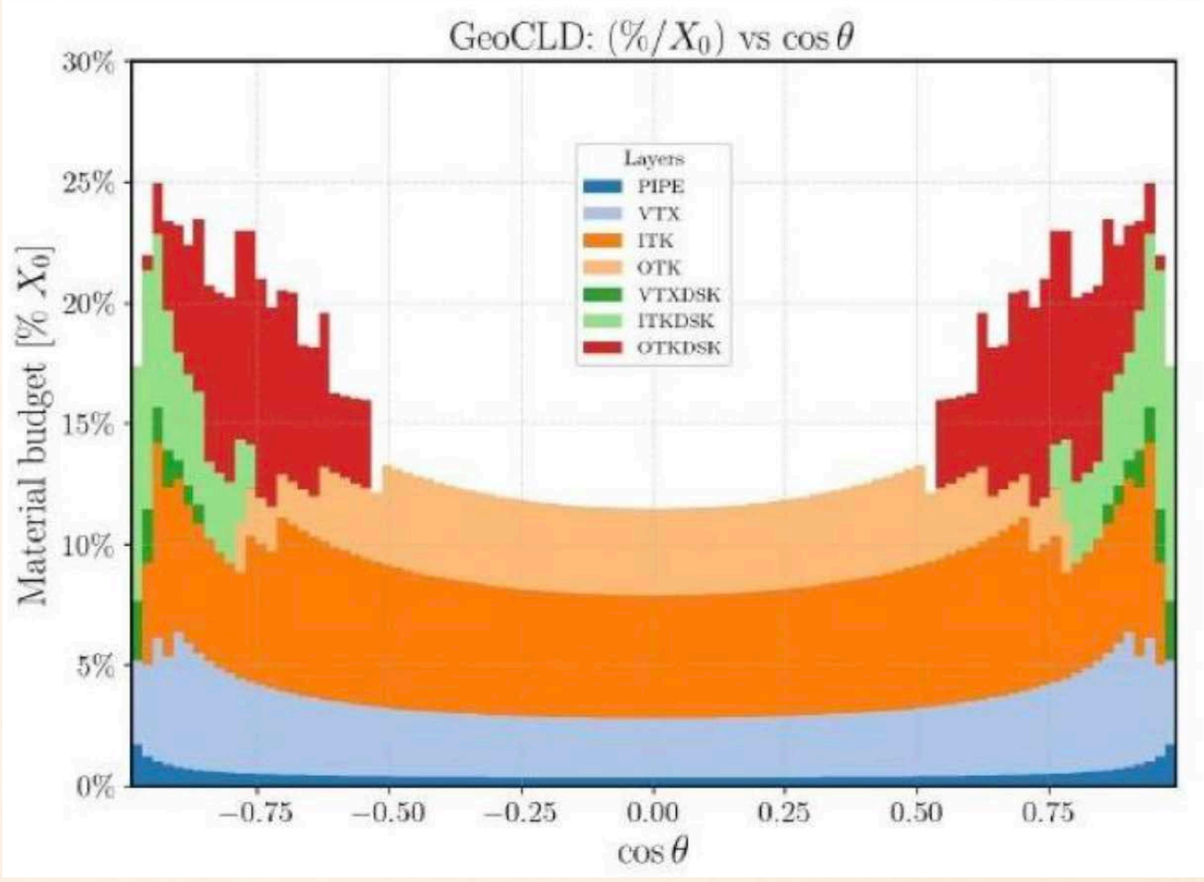
monstera



	Specification
Time resolution	1 ns-rms
Spatial Resolution	7 μm
Noise	< 30 e-rms
Minimum Threshold	200 e-
Average Power density	< 20 mW/cm^2

TRACKER MATERIAL BUDGET

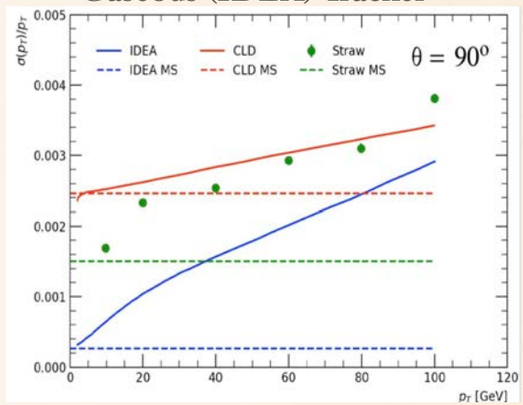
- Aim to reduce this initial material budget.
  - For example, taking advantage of ALICE ITS3 design.



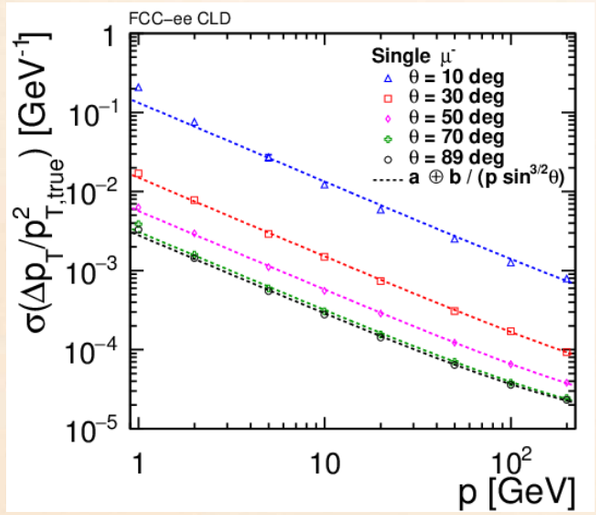
MAIN TRACKER OPTIMIZATION

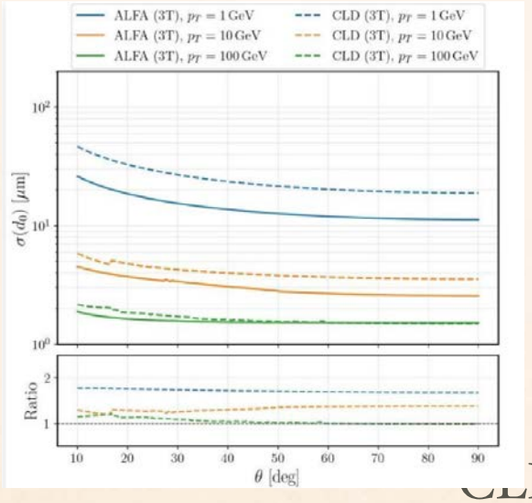
- CLD tracking performance frequently compared to other tracking approaches:
  - eg. at FCC Week 2026 - shown here.
- Layout/configuration now being refined and optimized to achieve better performance:
  - Multiple scattering limits precision,
  - All-MAPS tracker (e.g. also proposed by ALFA) demonstrated light material budget achieveable for structures+cooling - approaching gaseous tracker performance.

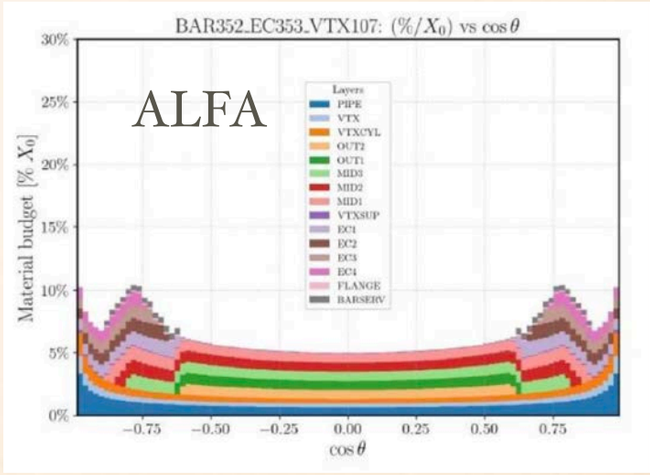
Comparison to Straw and Gaseous (IDEA) Tracker



Comparison to MAPS Tracker (ALFA)

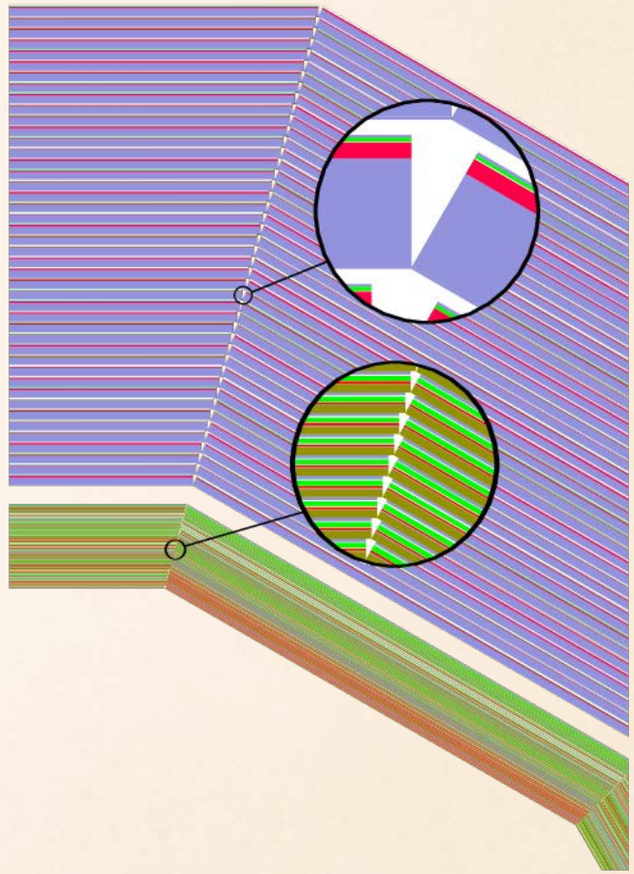






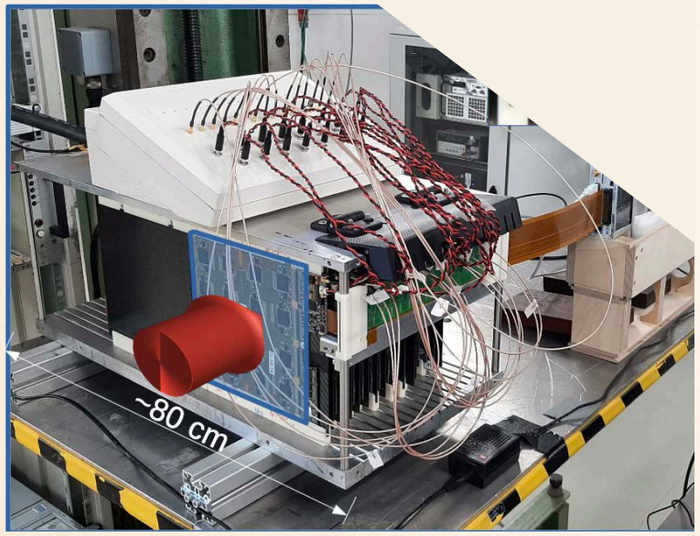
CALORIMETER

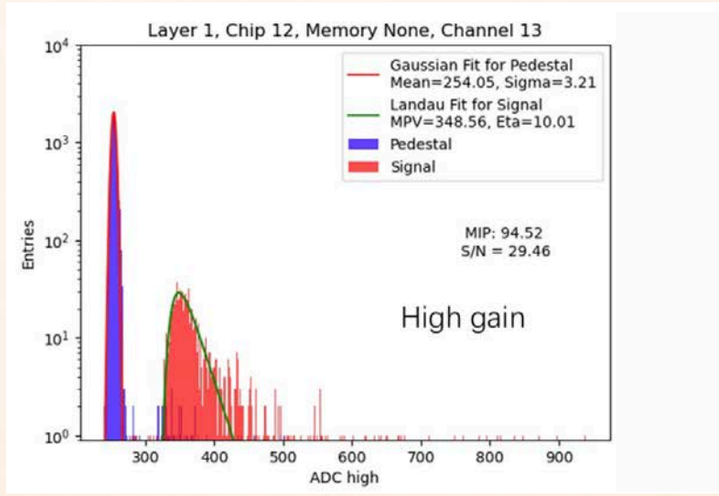
- Highly granular calorimeters optimized for particle flow:
  - Percent level jet energy resolution,
  - Excellent hit time resolution possible.
- ECal:
  - 40 layers, 1.9 mm tungsten absorber, 22 X_0,
  - 0.5 mm thick silicon sensors with 5 x 5 mm^2 pixels.
- HCal:
  - 44 layers, 19 mm steel absorber, 5.5 λ_I,
  - 3 mm thick scintillator tiles with 3 x 3 cm^2 cells,
  - Analogue readout with SiPMs.
- Technology R&D being pursued in DRD Calo, such as
  - FE for high rates and continuous ECal operation,
  - ECal cooling solution with minimized degradation.

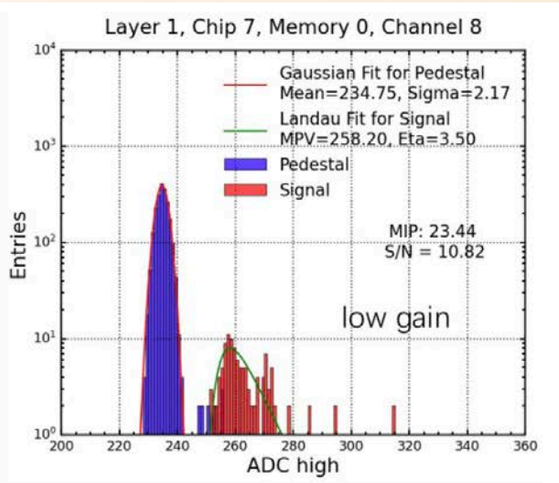


SI-W ECAL DEVELOPMENT

- A Uniform 15-layers Prototype (DRD Calo):
  - “Ultimate” design with SK2,
  - 2 layers tested in 2025 with excellent characteristics at low E (noise and MIPs),
  - High E June 2026 CERN beam test.

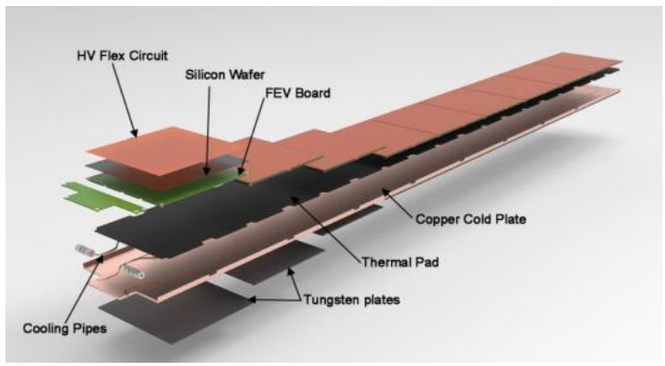


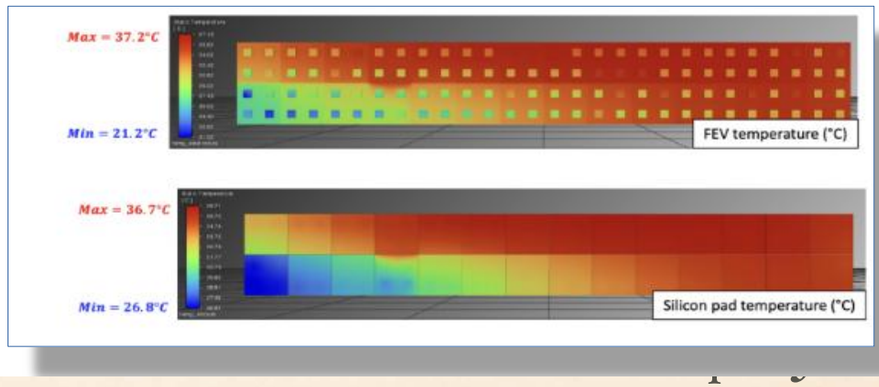




SI-W ECAL DEVELOPMENT

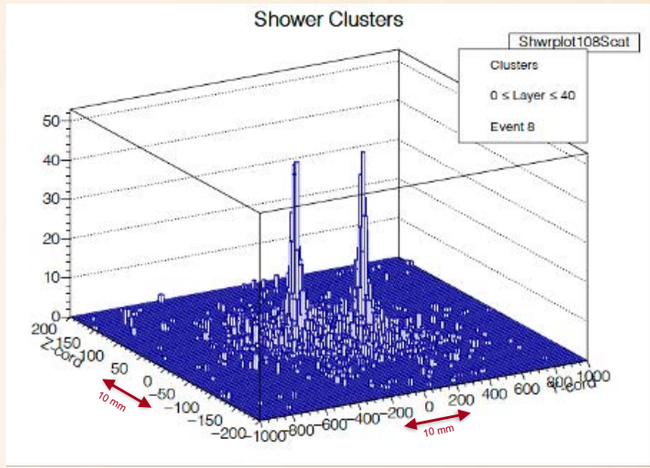
- HW Developments for the FCC:
  - CALOROC1C:
    - Technologie TSMC130nm; 1st batch imminent,
    - Excellent performances expected: power (≤ 5 mW/ch), ENC ~ 1000 e–, TDC 50ps.
  - Cooling for continuous operation:
    - Scaling checked: 13mW/ch with 0.2L/min water over 4mm Cu.
  - Design FE: just started on the basis of HKROCs (ancestor to CALOROC) + lpGBT concentrator.

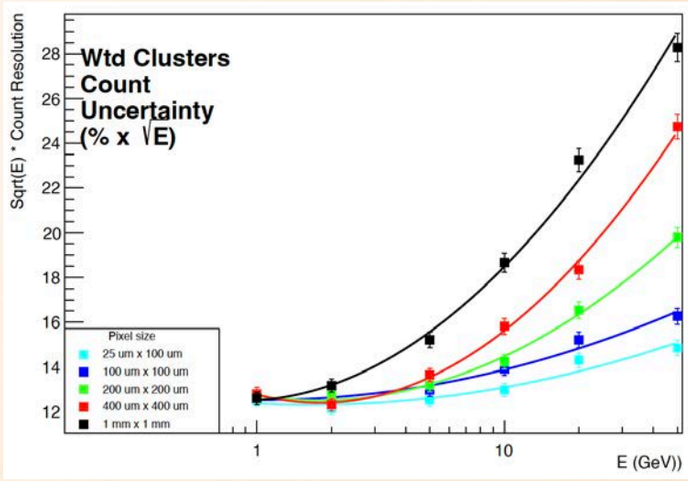




MAPS ECAL

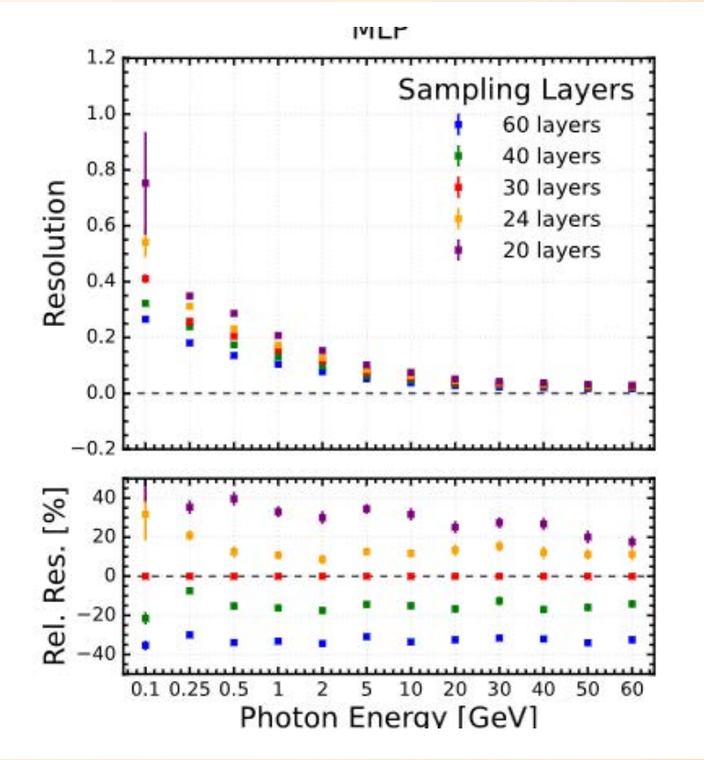
- Hardware benefiting from tracking motivated detector development, such as NAPA-p1/p2 based on 65 nm technology.
- Layout variations - advantages and disadvantages:
  - Sampling frequency and depth.
- Optimization of pixel size - investigate tradeoffs:
  - 25 um x 25 um pitch → somewhat larger.
- Design of minimal impact cooling system:
  - Minimize power to reduce cooling required.
- Study of potential timing capabilities:
  - Impact of sub-ns on event reconstruction.
- Investigate impact of multi-threshold MAPS:
  - ML/AI approaches to optimize performance.
- Physics studies with improved particle flow reconstruction.



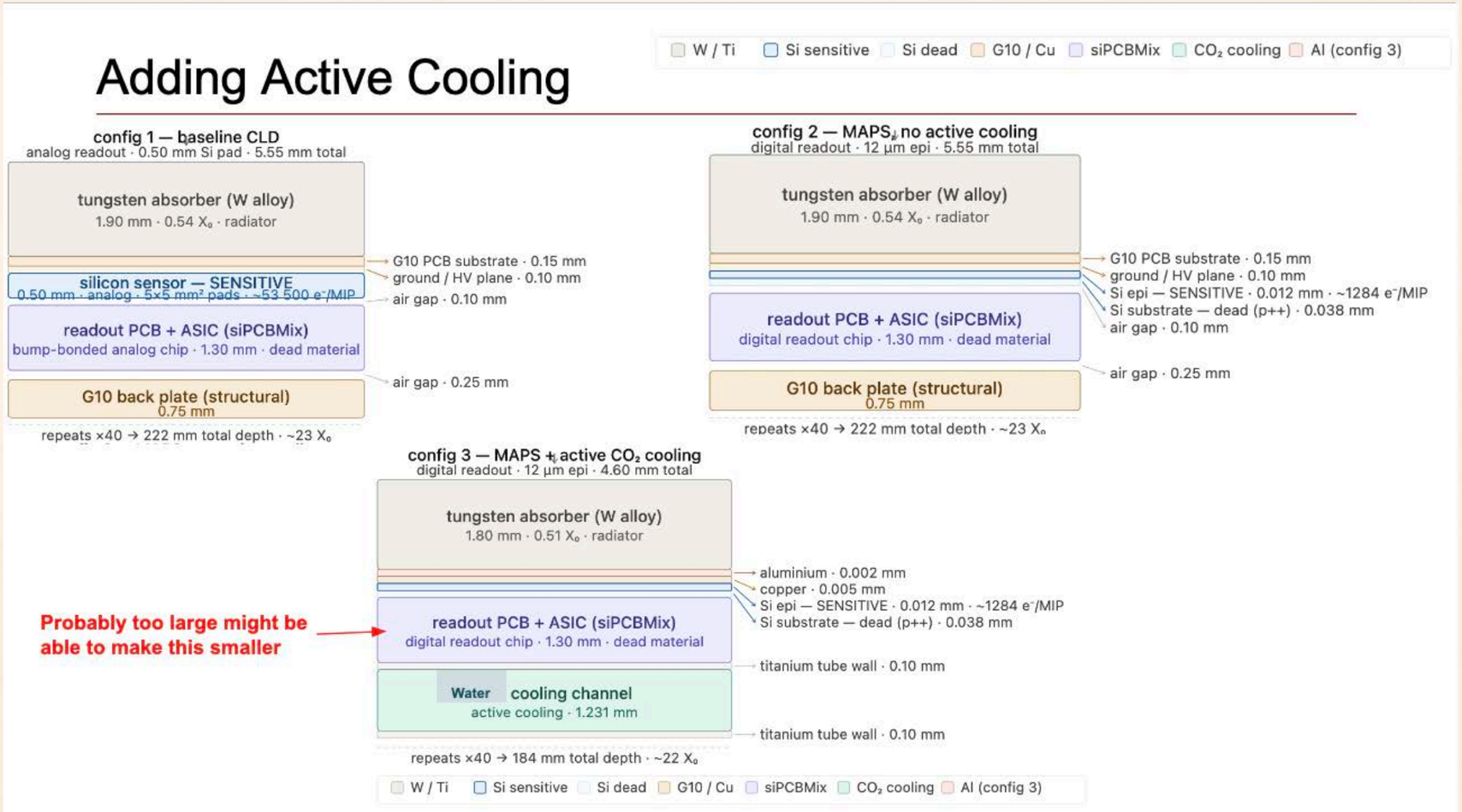


ECAL OPTIMIZATION

- R&D studies of realistic cooling (in DRD Calo) might lead to a complete redesign of the ECAL.
- Tracker size modifications would reduce the ECAL size, so reduce drastically the cost.
- Will optimize the number of layers and absorber thicknesses:
  - photon energy resolution sensitive to longitudinal segmentation (number and thicknesses of layers),
    - jet energy resolution less so,
  - 20/30 layers rather than 40,
  - two different absorber thickness for good photon energy containment and resolution.

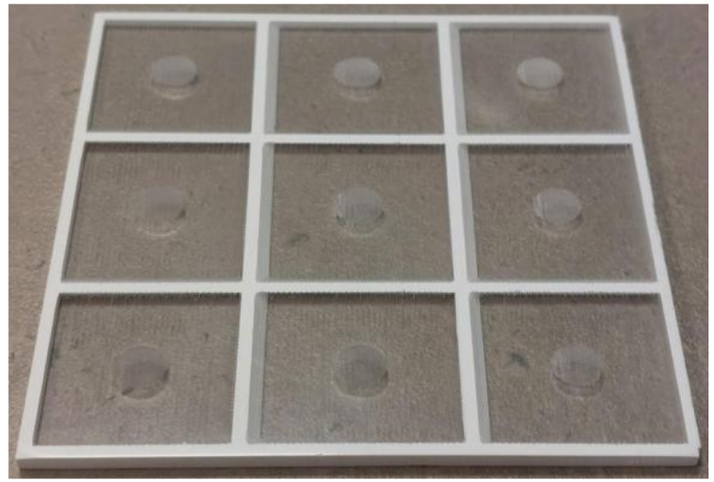


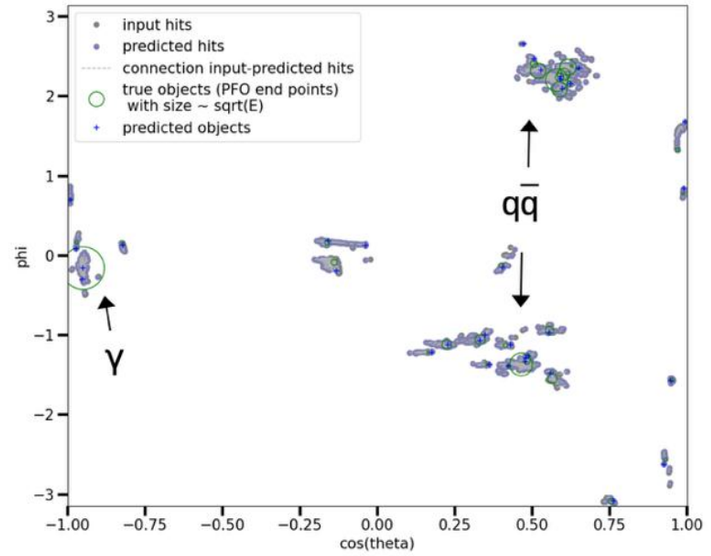
MAPS SAMPLING WITH COOLING



HCAL

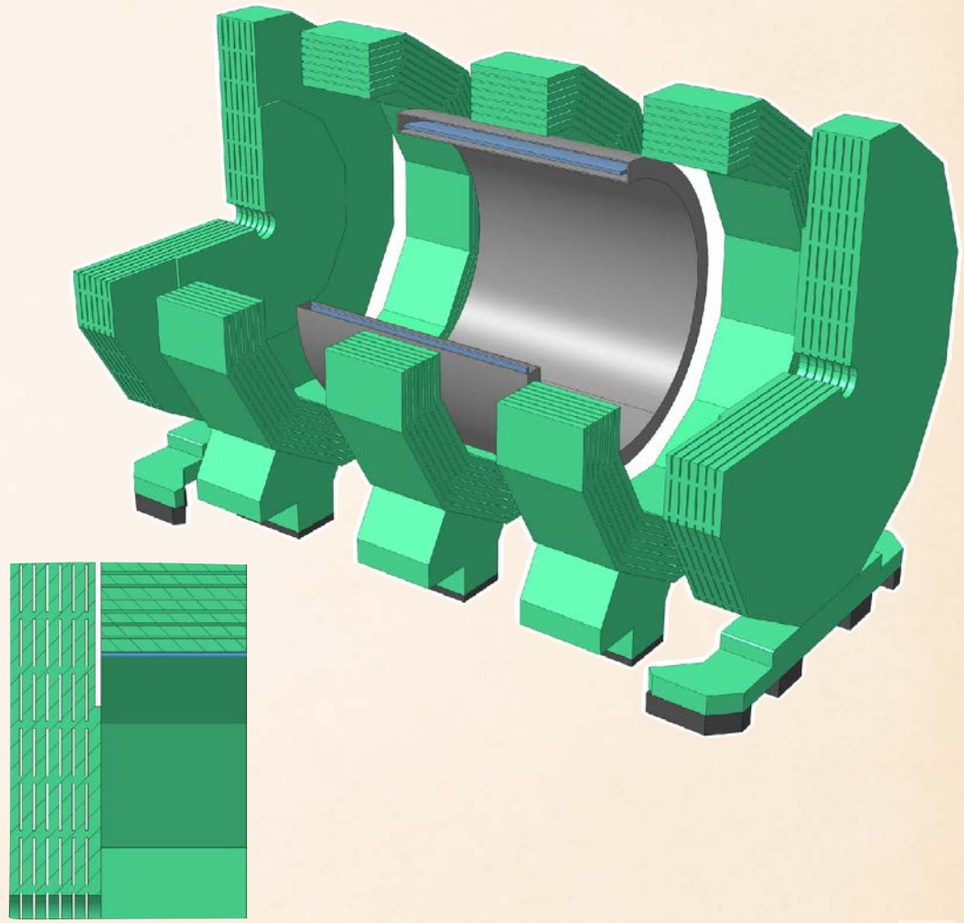
- SiPM-on-Tile technology in production for CMS HGCAL.
- Bringing technology to full readiness for FCC-ee continuous readout with highest compactness, suitable for mass production (DRD Calo):
  - Readout system: Front-end ASIC, full DAQ, powering and calibration chain,
  - Scintillator concepts (3D printing, megatiles,...), photon sensors.
- Software, reconstruction, geometry optimization (with AI/ML) in CLD concept (DRD Calo):
  - Advanced reconstruction algorithms: particle flow,
  - Detector design or parameters optimization: Timing, granularity, rates.





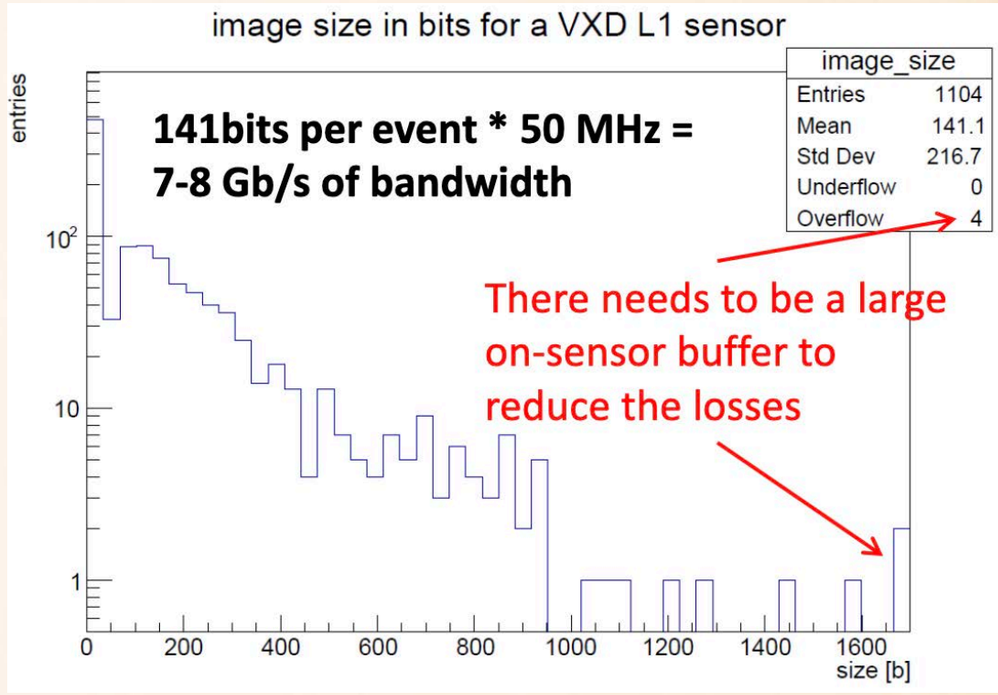
MAGNET AND MUON SYSTEM

- Superconducting 2 Tesla solenoid:
  - Critical aspects shared between FCC-ee concepts,
  - Study performance changes and configuration implications with 3T.
- Return yoke containing Muon system:
  - Slots for RPCs with cells of 30 x 30 mm^2,
  - 6 equidistant layers,
  - An additional layer after the solenoid to serve as a hadronic shower tail-catcher,
    - Reexamine the needs and optimize the layout.



TDAQ

- Data throughput under study with latest pixel digitization and beam background simulations.
- Vertex detector is the most challenging case:
  - Layer-1: bandwidth per sensor < 10 Gb/s (7-8 Gb/s), total bandwidth of 32 Gb for 32 sensors (links),
  - Other layers have less beam backgrounds and smaller total bandwidths.
- Study being extended to the other CLD subsystems.
- The triggerless readout seems possible even with the contemporary TDAQ technology. It will be more feeasible on the FCC-ee time scale.



IMPROVEMENT AND OPTIMIZATION PLANS



- New ideas and efforts are encouraged and welcome.
- Many opportunities to advance the CLD concept during the Reference Design Phase of FCC-ee.

  FOR EXAMPLE:
  - 2T (3T) superconducting solenoid,
  - Cooling for continuous operation of subsystems(vertex detector, main tracker and calorimeters),
  - Engineering details and performance of MDI,
  - Optimized design of Vertex detector for Z-pole operation,
  - Main tracker configuration and tracking performance improvement,
  - ECAL configuration optimization,
  - Optimal PID solution,
  - … …

SUMMARY

- CLD detector concept full simulation studies ongoing for several years:
  - Impressive progress by the Physics software and computing community.
- Key technology R&Ds, including within various DRDs.
- CLD team invites and welcomes participation on the CLD effort.

  Mailing list: FCC-PED-DetectorConcepts-Cld@cern.ch

  Contact persons for some key areas:
  - Vertex detector: Jeremy Andrea,
  - Main Tracker: Caterina Vernieri,
  - ECal: Vincent Boudry, Jim Brau,
  - HCal: Frank Simon, Andy White,
  - TDAQ: Sasha Paramonov,
  - Software: Andre Sailer,
  - General aspects: Jinlong Zhang.

Research partially supported by the U.S. Department of Energy

REFERENCES



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- FCCSEED_DRD8_Elba_2026
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  https://indico.cern.ch/event/1588696/
- FCC Week 2026, Jun 2026
  https://indico.cern.ch/event/1552126/