HFCC Calorimetry 2025 R&D Projects

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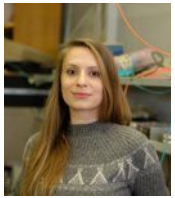
L3 coordination (Calorimetry)

Calorimeter (us-hfcc-calorimetry@cern.ch)

- Dual Readout: Grace Cummings
- Nobel Liquid: Erich Varnes
- Si-W: Jim Brau
- Tile-Scint: Vishnu Zutshi

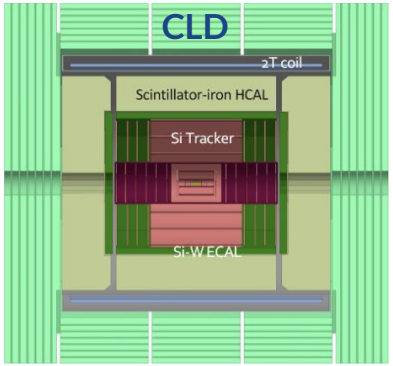


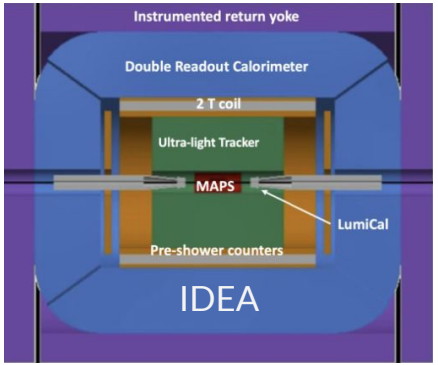

US HEP has demonstrated expertise and leadership across multiple calorimeter technologies, e.g.

- **DR Calorimetry**
  - Calvision, DREAM/RD52
- **Noble Liquid**
  - ATLAS ECAL, D0
- **Silicon-Tungsten**
  - CMS HGCAL, CALICE
- **Tile-Scint**
  - ATLAS Tile CAL, CMS HCAL/HGCAL

Many inputs were received, including generic and RAD hard tech R&D. Below we summarize only those closely related to FCC-ee calorimetry.

Proto detector concepts



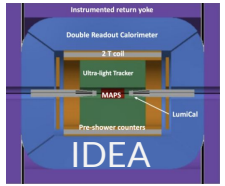


ECAL: Si/W, 5×5mm2, 22 X0
HCAL: Sci/steel, 30×30mm2, 5.5

ECAL: dual-readout crystal
HCAL: Copper with S/C fiber for

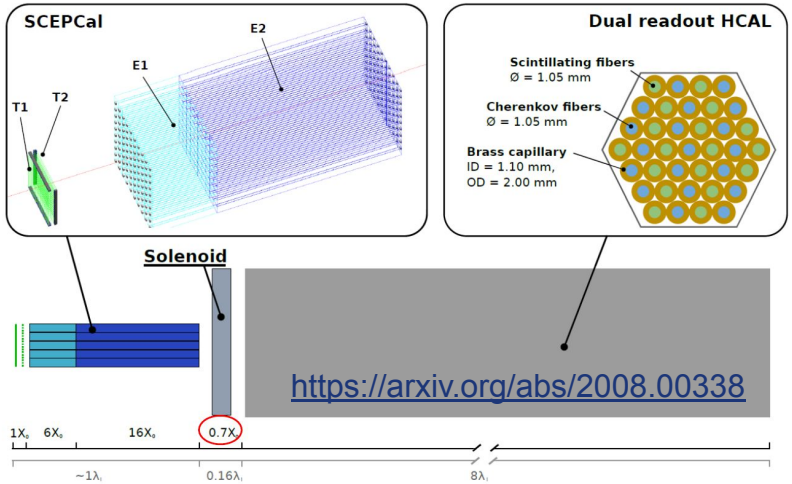
ECAL: LAr/LKr with Pb/W absorber
HCAL: CALICE- or TileCal-like

Dual Readout (DR) intro

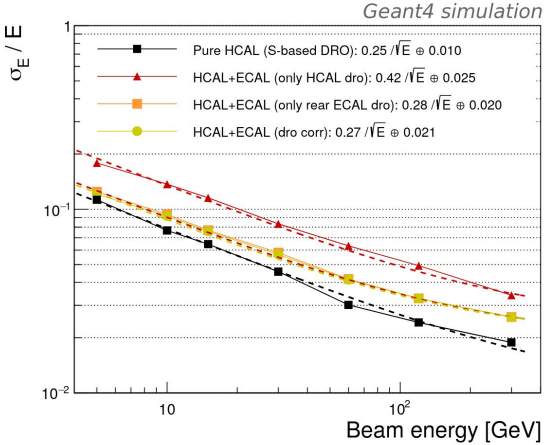


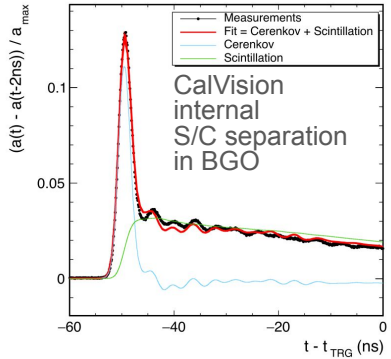
- Significant US contributions to construction, operation, calibration of CMS precision crystal ECAL
- **DREAM/RD52**: In the last decade, demonstration of DR technique in spaghetti-style (fiber) calorimeter + initial study of S/C separation in DR homogeneous crystal ECAL (DOE supported)
- **CalVision**:
  - First (and so far only) to demonstrate collection of sufficient Cherenkov signal for DR application in crystals
  - Advanced DD4HEP GEANT model
  - Innovative studies in longitudinal segmentation via timing in fiber HCAL
  - Extensive R&D program proposed to study practical detector design and bluesky materials
  - Funding via DOE HEP R&D program (7/22--3/25), $900k this year. Renewal submitted.
    - Primary goals: first demonstrations of (1) state-of-the-art EM resolution in xtal+SiPM, 2 layer ECAL and (2) DR application in xtal(EM)+fiber(HAD) hybrid calorimeter
- Building strong US collaboration in DR: ~25 university and lab groups (18 CalVision + general interests). High levels of participation.
  - US groups are already making leading contributions to detector R&D in this area
    - Complementary approaches, both targeted and blue sky, compared to international R&D (eg first results on S/C separation in heavy glass scintillators)

Hybrid dual-readout concept (new baseline for IDEA detector planning)



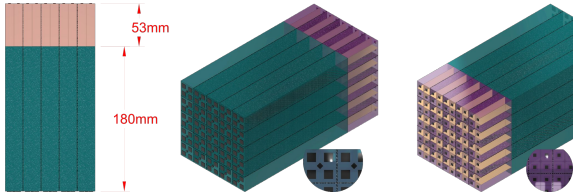
Crystal EM ~ 3%/√E + straw HAD calorimeter, Both DR, use S/C light signals for shower-by-shower hadron corrections < 30%/√E





⇐ Phase 1 proof of principle for collecting significance C signal

Phase 2 prove EM performance w/ SiPM+Xtal design and hybrid-DR performance in test beams ⇒



Dual Readout: 2025 R&D proposed

- CalVision renewal submitted ~1.5M/year
  - Construct EM module 22 X_0 x 5(-7) R_M and readout for EM resolution and hybrid DR studies
  - Re-instrument DREAM module, study longitudinal segmentation with timing
  - Continue unique contributions to Generic R&D with DR in new (low cost) scintillators.
  - Research goals, particularly maintaining leading ECAL R&D + integrating ECAL with international HCAL efforts, depends on 2025 support. This will be prioritized in any funding scenario. **Missing the 2025 deliverable will likely set us back several years wrt international efforts b/c we will miss needed individual and joint test beam opportunities before beams end**.
  - Numerous groups requesting student support for analysis and simulation
- Accelerate development of analog front end for DR crystal matrix (FNAL, Virginia): Before CalVision (tentative) renewal, improve engineering design to significantly reduce risk with needed higher performance FE for matrix and very complex O(200) channel readout
  - FY25 Needs: ~$50k for 1 month FNAL EE, PCB prototyping and production
- Portable tracking and timing for calorimeter test beams w/ low mass sensors (Virginia, FNAL)
  - FY25 Needs: $20-40k in M&S for LAPPD (or potentially LGAD)-based timing/trigger, minimize e- showering
- Band-pass optical interference filters for separation of C/S light (FNAL, Univ partner): Develop custom ultra thin-film filters for Cherenkov and scintillation wavelength separation and reduce light loss. Capitalizes on Fermilab's Thin Film facility.
  - FY25 Needs: ½ graduate student, ideally ½ a postdoc.

Dual Readout: 2025 R&D proposed

- Full ECAL+HCAL Combined Detector Simulation and AI/ML Reconstruction (Princeton, MIT): Complete integration of crystal ECAL with IDEA fiber HCAL, tracker, etc., for full detector concept sim. Advance reconstruction studies with combined full sim.
  - FY25 Needs: covered in the CalVision proposal
- Developing AI/ML algorithms utilizing the timing structure of DR signals from fiber calorimeters (TTU, FNAL)
  - FY25 Needs: ~$40k for 1.0 student FTE. Partially covered in CalVision proposal
- Geant4 and TCAD simulation of precision timing photon detectors measuring DR fibers (TTU, FNAL) design and simulate the performance of future SiPMs for precision timing
  - FY25 Needs: ~$40k for 0.5 postdoc FTE, partly covered by CalVision proposal
- East coast center for crystal characterization (CUA) expand the crystal and glass characterization facilities at CUA.
  - FY25 Needs: 5k for material, 3-5k travel, ½ of graduate student salary (12.5K). Partially covered in CalVision proposal.
- On-detector intelligence for waveform processing and longitudinal shower development for DR crystal ECAL (Baylor)
  - FY25 Needs: covered in the CalVision proposal

Dual Readout: 2025 R&D proposed

- Calibration and energy reconstruction in crystal DR calorimetry (SUNY Buffalo): demonstrate realistic calibration methodology and to study optimal energy reconstruction algorithms for dual readout calorimetry, particularly CalVision
  - FY25 Needs: 1/4 postdoc (20K) and travel (5K). Supplements support requested in CalVision proposal.
- Optimized Cerenkov and Scintillation Light Collection and 3D Shower Localization with Metasurfaces for Dual Readout Calorimetry (Caltech, ORNL, U. of Utah): Design and testing of nanostructured metasurfaces and engineered diffractive filters
  - FY25 Needs: $15k M&S for test setups in the crystal lab, 20% FTE staff engineering. Covered in the CalVision proposal.
- Novel readout geometry of DR crystal ECALs (FNAL)
  - FY25 Needs: ~$20k - $50k in materials, ½ year of graduate student at partnering university. More generic R&D in nature.
- On-chip data processing for SiPM readout, fast-timing, and machine learning reconstruction (SLAC): On-chip intelligent data processing of SIPM readout for the extraction of the S/C components in the front end.
  - FY25 Needs: ½ of a graduate student to perform physics simulations and work together with the SLAC engineers defining detector requirements.
- Custom scintillator for dual readout (FNAL): Incorporation of quantum dots to tailor the scintillation spectrum and add neutron sensitivity
  - FY25 Needs covered by SBIR

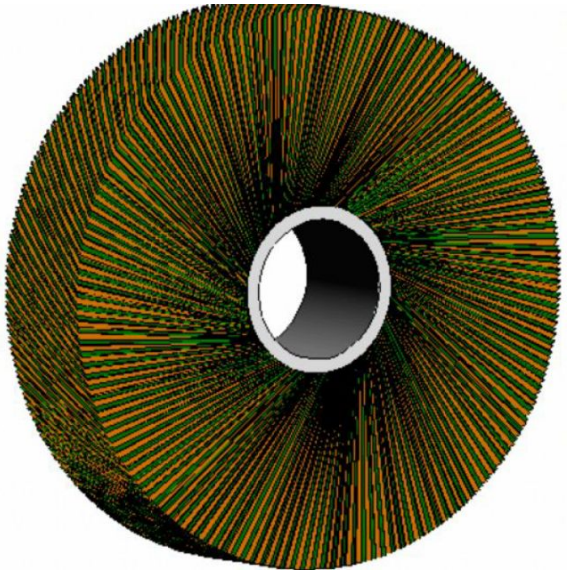
Noble Liquid R&D intro

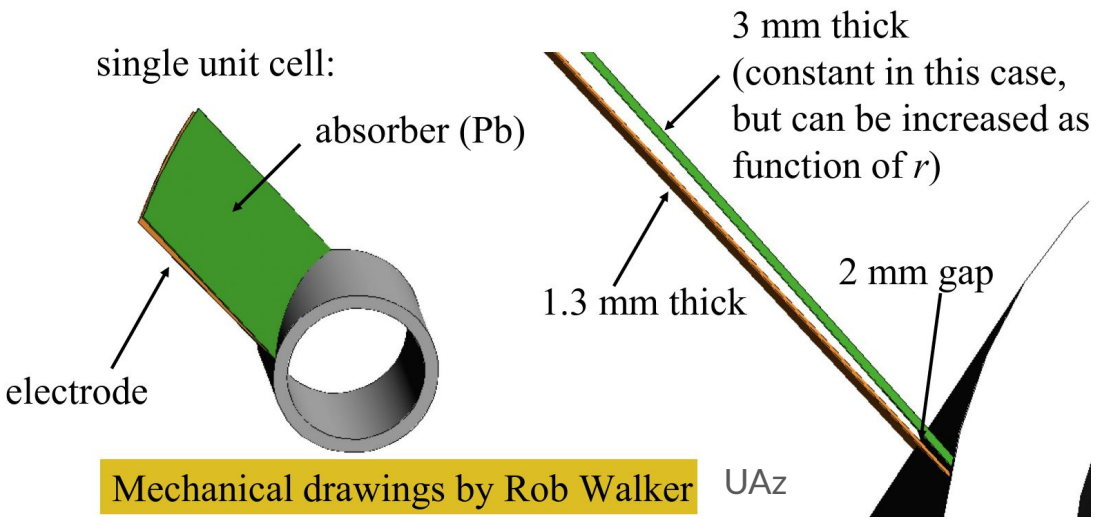
- LAr technology
  - excellent energy resolution and good timing properties with proven linearity, stability, and uniformity yielding small systematic uncertainties → crucial for precision measurements program
  - take advantage of recent developments for large LAr TPC including cold electronics (eg ASICs)
  - complementary to silicon- and gaseous-detector tracking systems [particle flow]
  - intrinsic radiation tolerance → important for FCC-hh
  - Interests expressed by: BNL,UAZ,USB,Austen,Columbia,Irvine

Example concept for ALLEGRO forward caorimeter

Turbine concept

- more similar to barrel design
- Improved symmetry
- but design optimizations needed





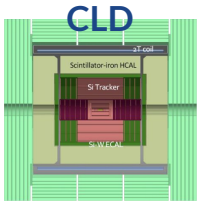
Mechanical drawings by Rob Walker

UAz

Noble Liquid: 2025 R&D proposed

- BNL-funded LDRD ($1.8M FY25-27) on new LAr calorimeter and TPC technology
  - collaboration with CERN et al towards new LAr calorimeter module [ALLEGRO]
  - additional support to US institutes would be useful to take advantage of this effort
- Design of endcap EM calorimeter for ALLEGRO (and associated readout PCBs) (Arizona)
  - FY25 needs: ~$50k engineering
- Detector simulation for physics optimization and possible joint work on module development and testing (Stony Brook Univ)
  - FY25 needs: ~$11k for summer student
- Study requirements and feasibility of including AI/ML algorithms on the readout ASICS (UT Austin)
  - FY25 needs: ~$12k for summer student

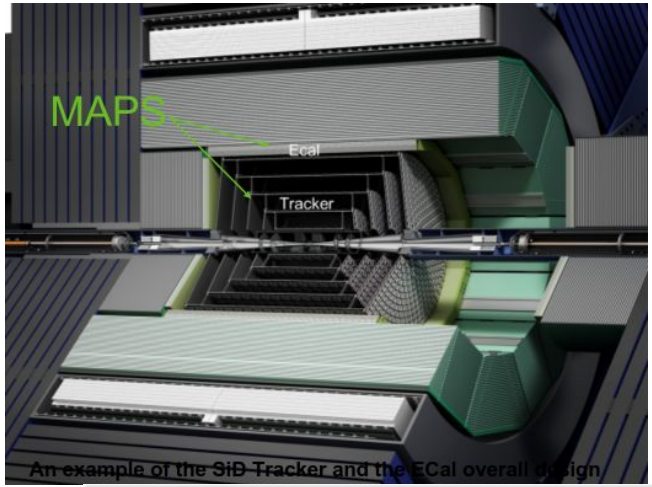
Si-W R&D intro



- Strong use efforts of the years including contributions to CALICE collaboration and CMS HGCAL design and construction
  - Supports highly granular readout for 3D shower imaging
  - Well suited to particle flow algorithms
  - Can have fast timing capabilities
  - Interests expressed by: Oregon, Kansas, SLAC

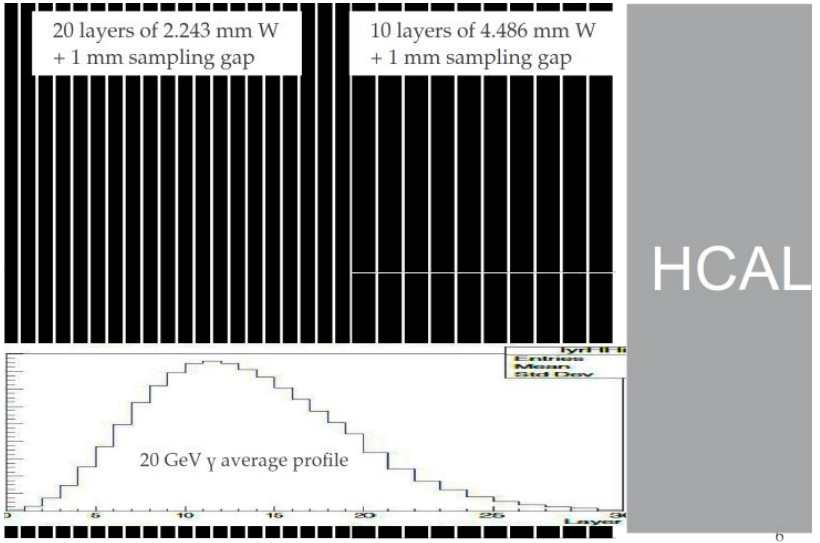
SiD MAPS + Tungsten concept

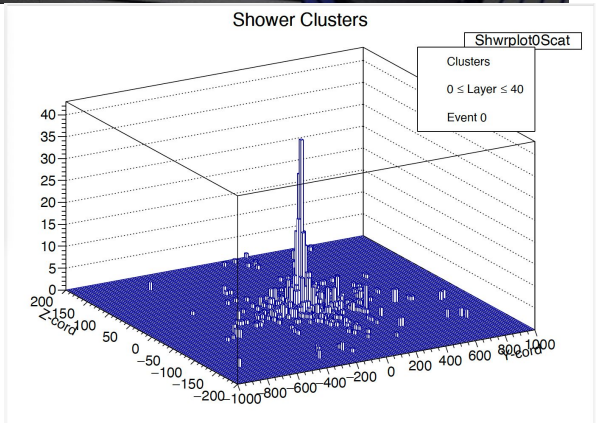
Digital ECal Based on Monolithic Active Pixel Sensors



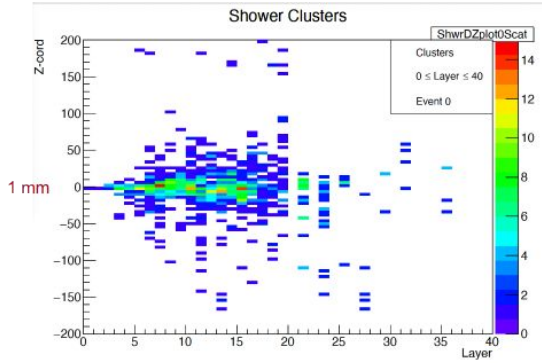
An example of the SiD Tracker and the ECal overall design

Incident Particle





10 GeV EM shower

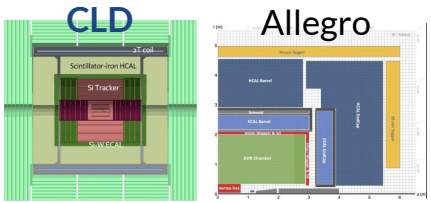


Si-W: 2025 R&D proposed

- MAPS for Future Collider Calorimetry (Oregon, SLAC)
  - SLAC National Accelerator Laboratory is leading a collaborative effort to develop MAPS for future colliders. The U. Oregon group is assuming responsibility for simulation of the performance of the MAPS applied to the electromagnetic calorimeter (ECal).
    - FY25 needs: ~$34k to Oregon for partial GS and travel support
- Si-W based e+e- collider precision luminosity measurements (Kansas):
  - New approach to the design of the luminosity calorimetry as applied to future e+e- colliders. The study is exploring the limits of precision fine sampling electromagnetic calorimetry with a focus on both energy and position.
    - FY25 needs: ~$20k for partial GS support and some travel

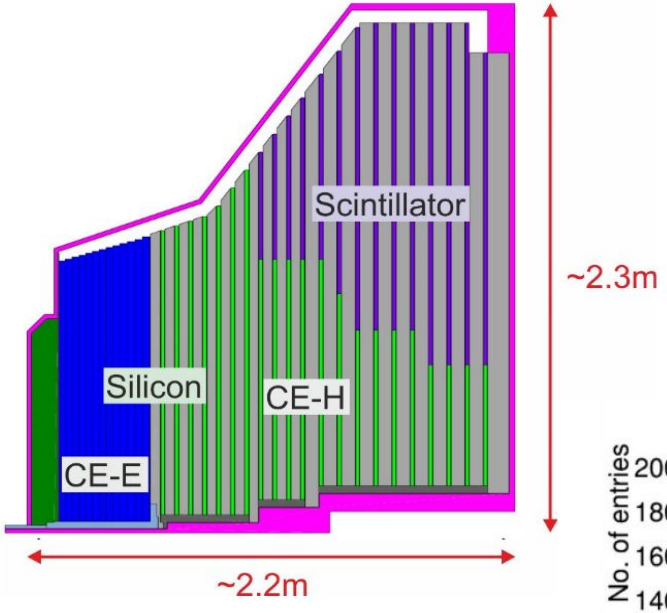
Tile-Scint R&D intro

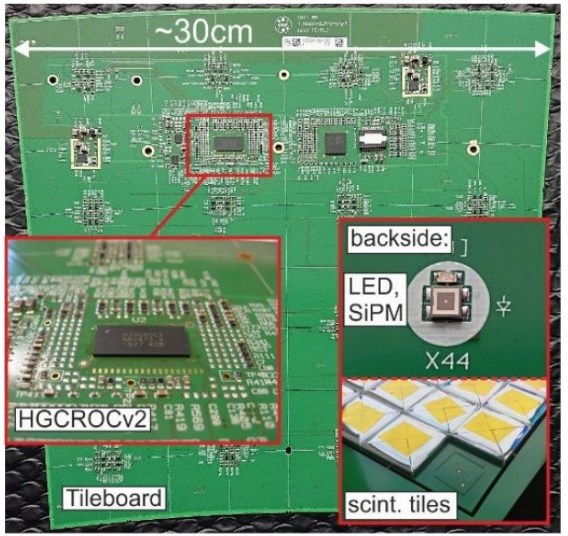
Application to: CLD/Allegro detector concepts

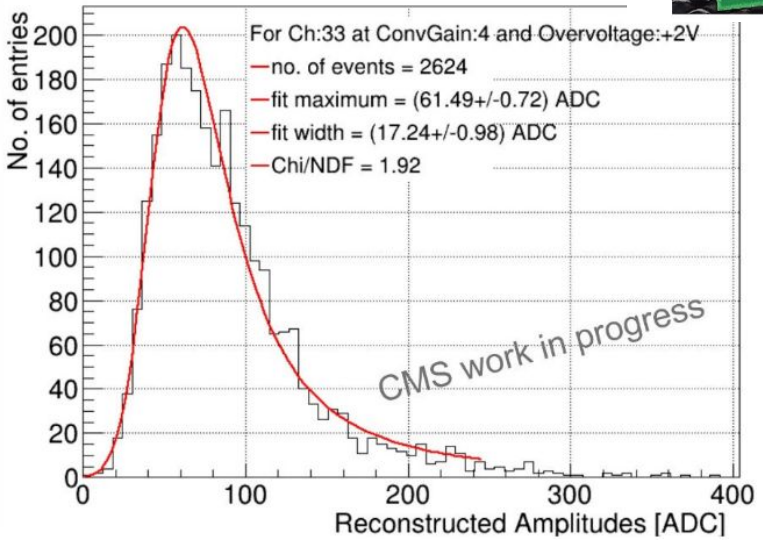


- Long history of US expertise in tile-scint Calorimetry
  - Scintillator production facility and R&D at FNAL
  - CMS HCAL construction, readout, operations
  - CMS HGCAL hadronic section
  - Interests expressed by: NIU, UTArlington, UMD, Iowa, FNAL

CMs HGC hadron tiles







Tile-Scint: 2025 R&D proposed

- NIU (Vishnu Zutshi) — Sim/design, Scintillator-based HCALs — $5k (Travel)
- UTA (Andy White) — Sim/design, Scintillator-based HCALs — $5k (Travel)
- UMD (Sarah Eno) — Sim/design, Scintillator-based HCALs — $0
- Fermilab (Jim Freeman) — Calorimetry involving scintillators (including Dual Readout)
- and scintillator-based muon systems* — $0
- Iowa (Yasar Onel) — Scintillator component R&D — $ 25k (0.25 Grad. Student + 5k M&S). Already included in CalVision/SBIR requests

This is a mature technology area in US HEP. Expect significant contributions to prototyping/design work in coming years.

Summary of R&D requests for 2025

Selected requests by L2's for relevance to Higgs Factory

Travel: $10k x 6 for travel L2/L3

$50k travel for key institute experts to attend FCC & LC workshops & meetings

$100k CalVision-adjacent efforts

$75k LAr

$55k Si-W

→ ~$340k overall

Prioritized new requests for 2025 R&D

Prioritized by potential impact on US leadership

- DR: readout electronics engineering $50k
- NL: ALLEGRO endcap design work $50k
- DR: Testbeam low mass timing/trigger instrument $30k
- SiW: Student support/travel (MAPs) $35k

- DR: Development of ultra thin optical filters $20k
- Travel for L2/L3' and key institute experts to attend FCC & LC workshops & meetings $50-100k

Some redundancy with travel above

- NL: Summer student support for simulations (Ai/ML): $12k
- NL: Summer student support for simulations (det. optimization): $12k
- SiW: Student support/travel (Lumi EM Calo) $20k
- Tile: Travel $20k
- Tile: Student+M&S for scint R&D $25k

Additional slides