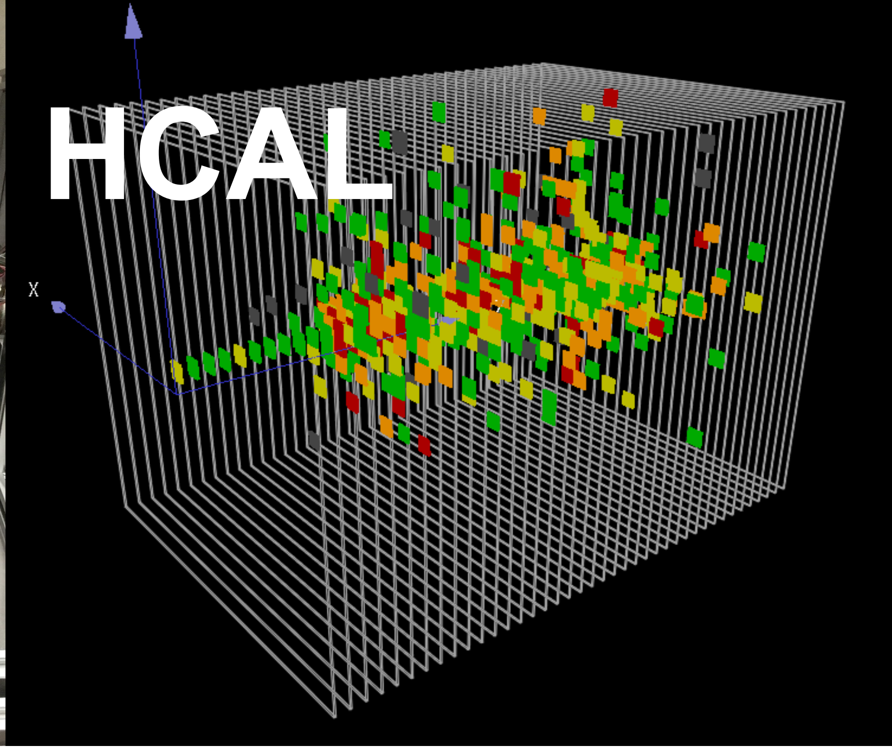
CALICE Scintillator-based HCAL overview



Katja Krüger (DESY)

CEPC workshop 2022
25 October 2022

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

CALICE

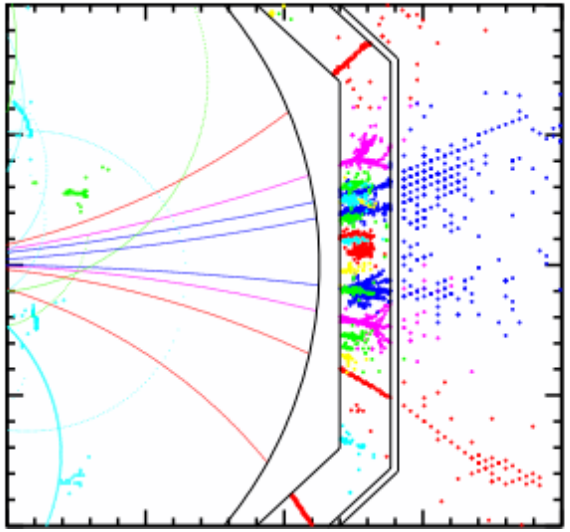
DESY.

Overview

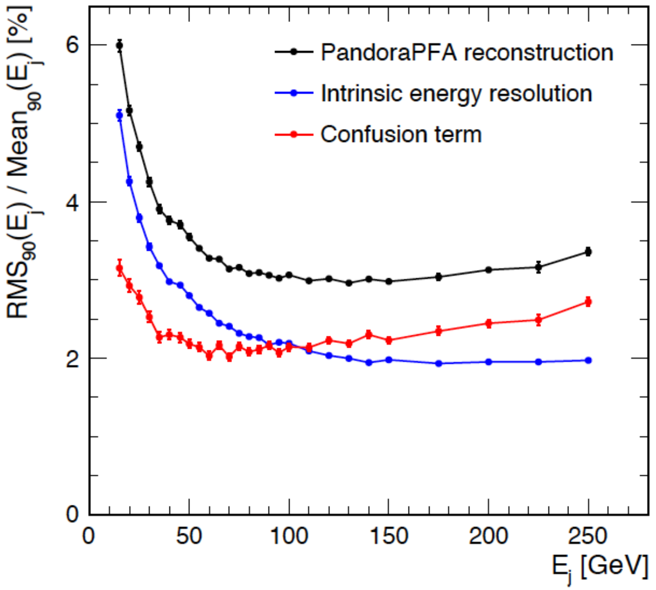
- The CALICE Analog Hadron CALorimeter AHCAL
  - Physics Prototype
  - Engineering Prototype
  - Further Developments
- SiPM-on-Tile technology beyond Higgs Factories
  - CMS HGCAL
- Summary

Calorimeters for Higgs Factories

- goal: want to distinguish Z → jet jet from W → jet jet
- requires $\sigma(E)/E \approx$ 3-4%
- can be reached by particle flow algorithms (PFA)
  - for each particle within a jet: use the subdetector with optimal resolution
  - need to avoid double counting and wrong merging
- need an imaging calorimeter!



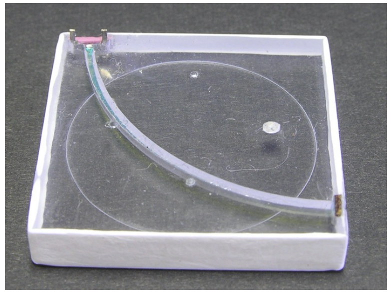
- requirements for the calorimeter:
  - highly granular
  - reconstruction of neutral particles: good energy resolution
  - calorimeter has to be within magnet coil: very compact
- Scintillator tiles are a scalable, cost effective solution

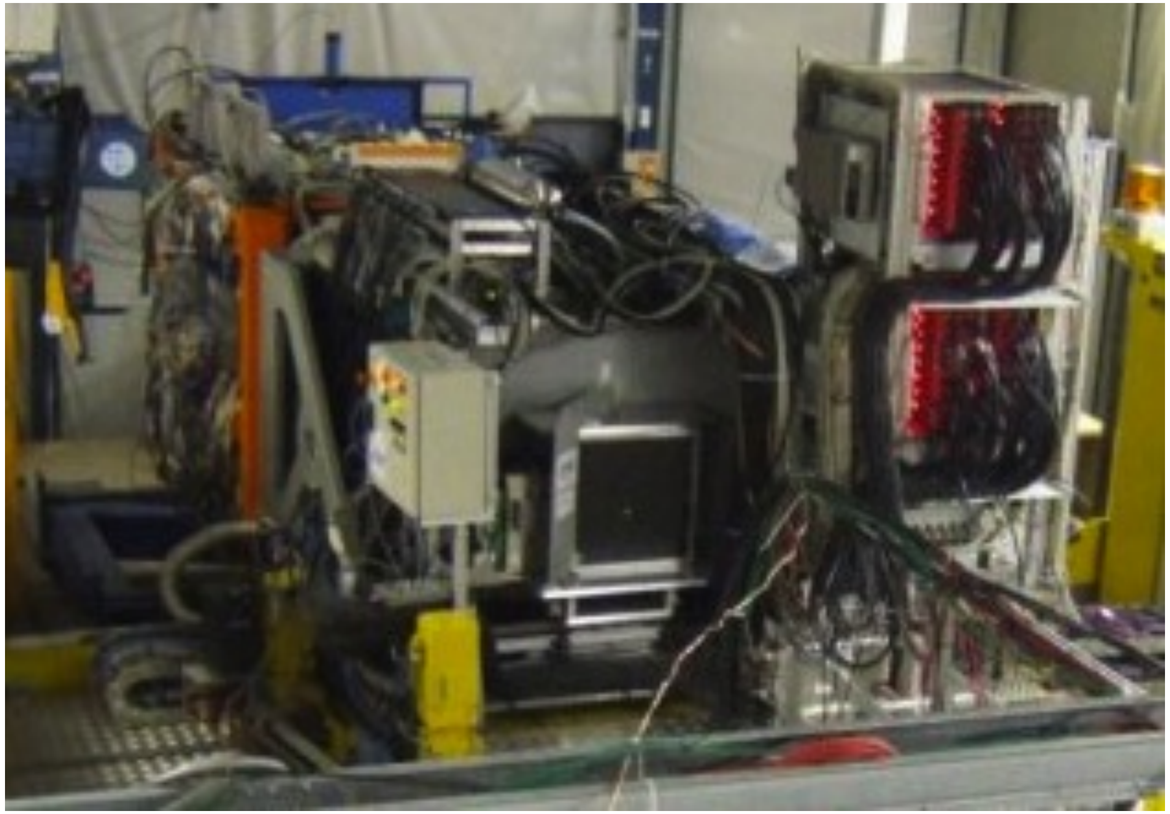


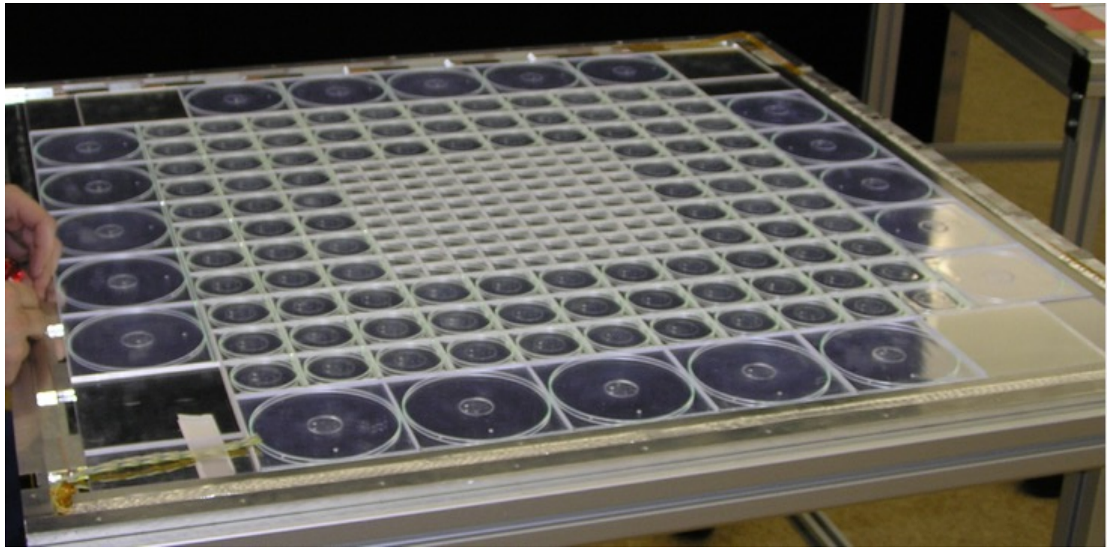
The CALICE AHCAL

The Origin: AHCAL Physics Prototype

- The first large calorimeter based on scintillator tiles read out by SiPMs
    - WLS fibers in each tile
- Tested in many testbeams 2006-2011

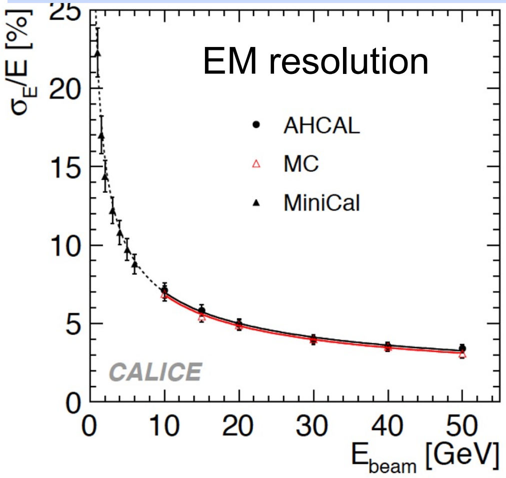






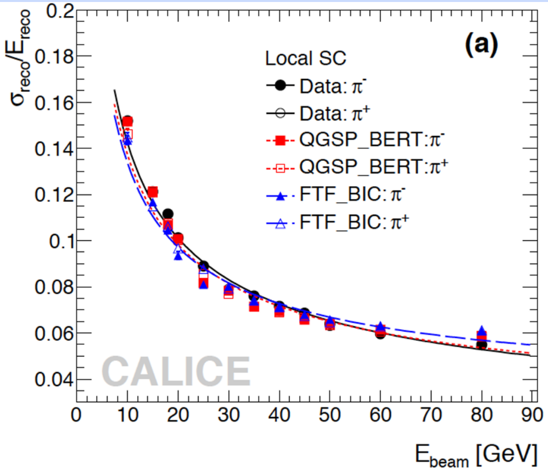
AHCAL Physics Prototype: Results

Detector validation



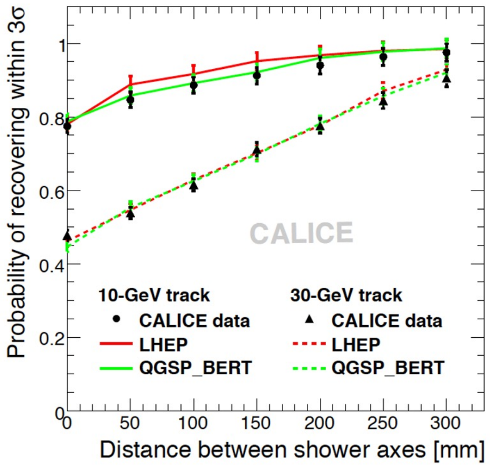
JINST 6, P04003 (2011)

Performance validation



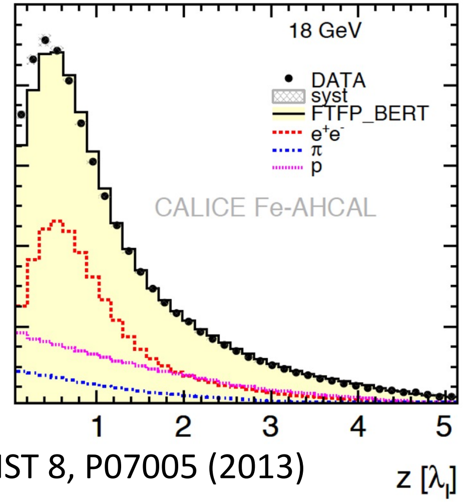
JINST 7, P00917 (2012)

Particle Flow validation



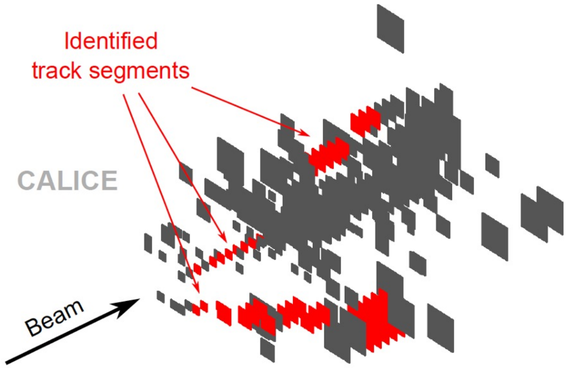
JINST 6, P07005 (2011)

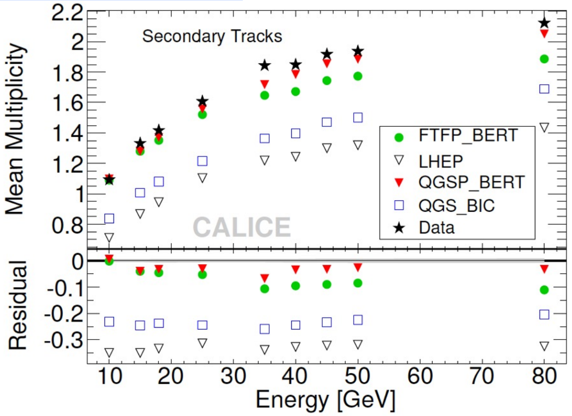
Geant 4 validation



JINST 8, P07005 (2013)

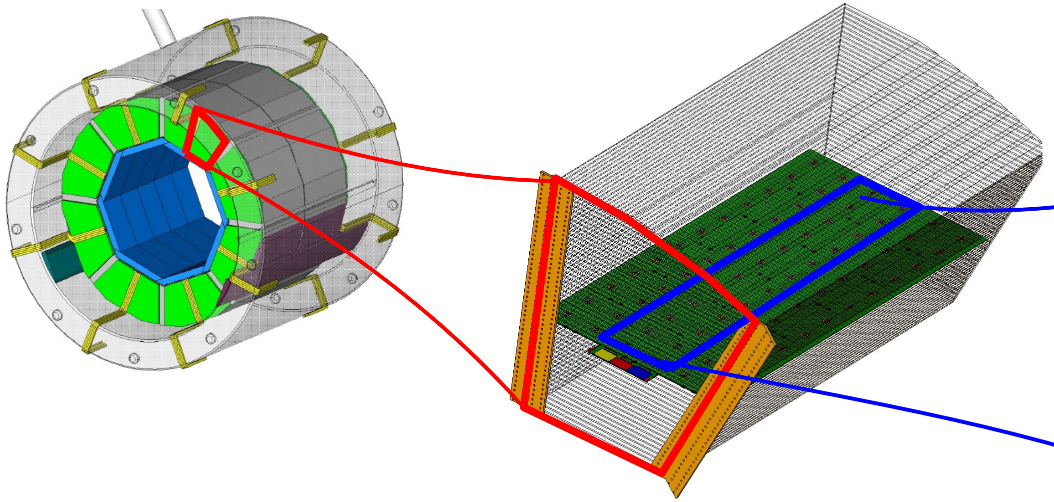
Imaging validation

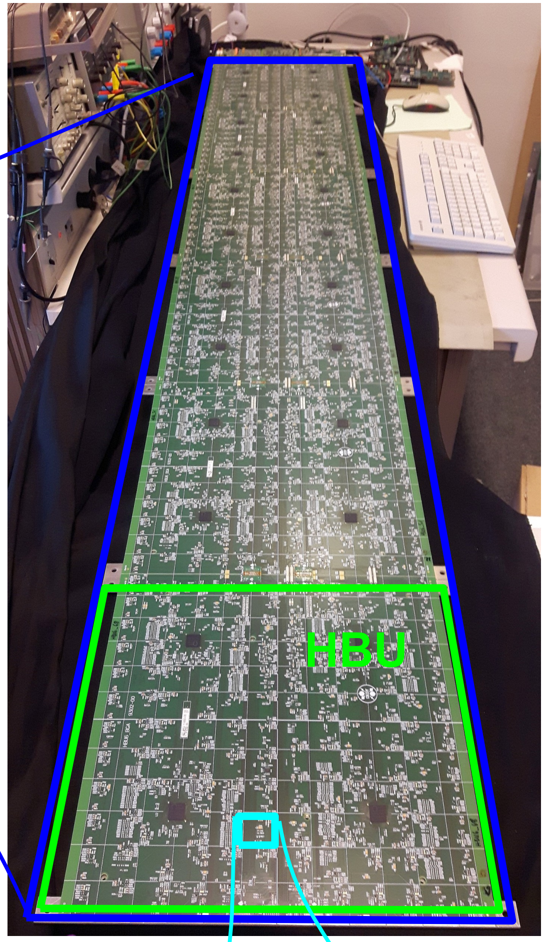


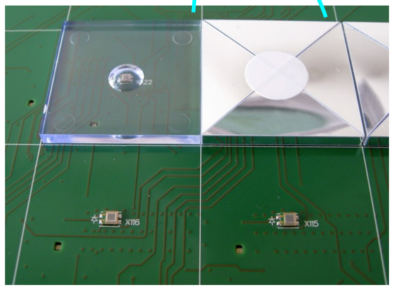


JINST 8, P09001 (2013)

AHCAL Technological Prototype



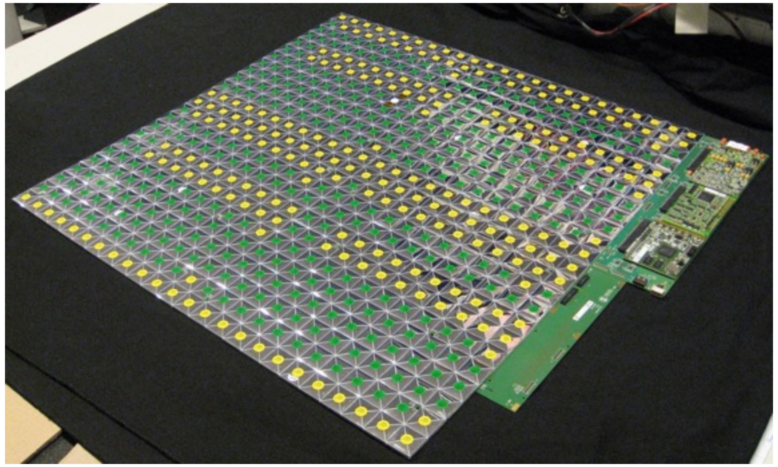




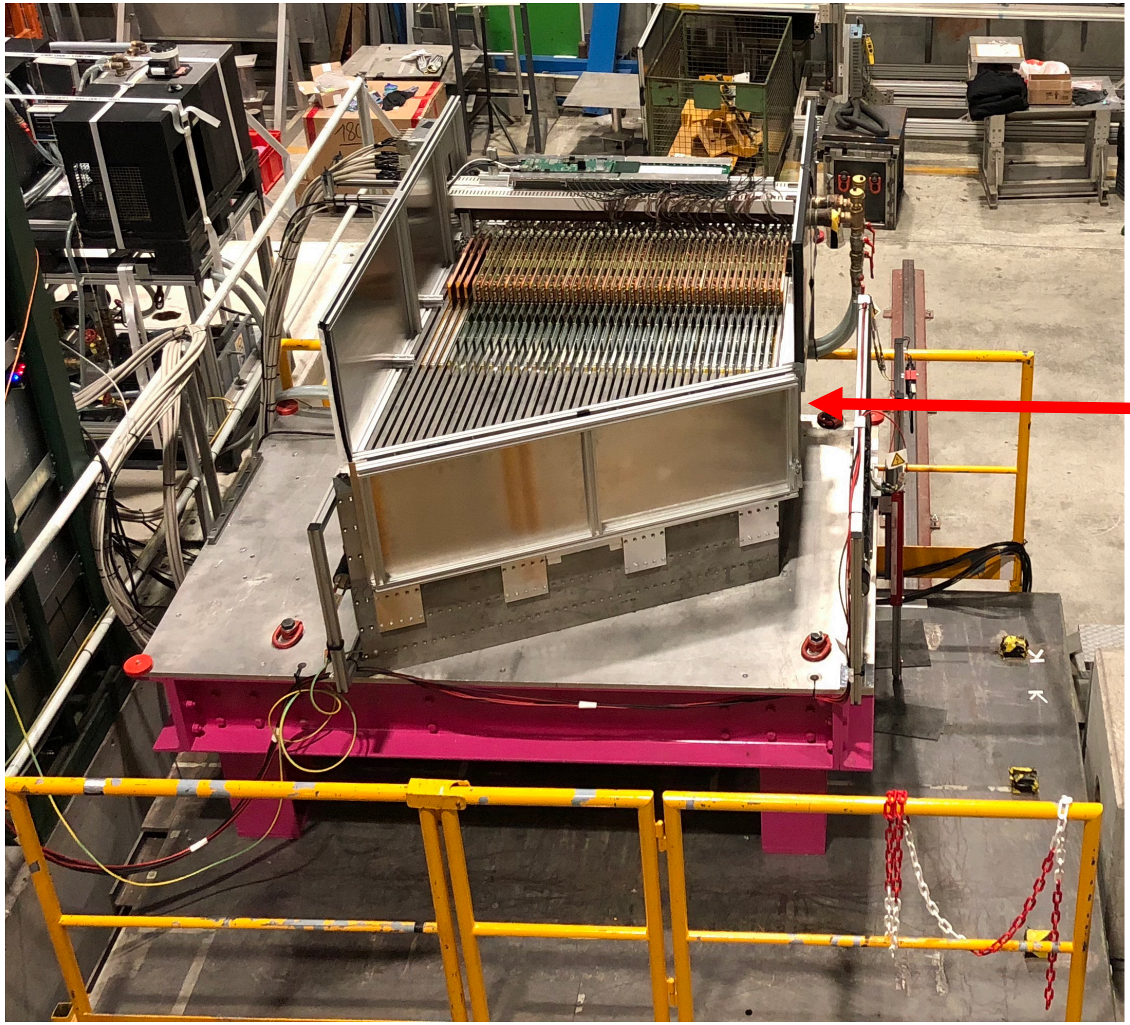
- highly granular scintillator SiPM-on-tile hadron calorimeter, 3*3 cm² scintillator tiles optimised for uniformity
- **fully integrated design**
  - front-end electronics, readout
  - voltage supply, LED system for calibration
  - no cooling within active layers -> **power pulsing**
- **scalable** to full detector (~8 million channels)
- geometry inspired by ILD, similar to SiD and CLICdp
- HCAL Base Unit: 36*36 cm^2, 144 tiles, 4 SPIROC2E ASICs
  - slabs of 6 HBUs, up to 3 slabs per layer

AHCAL Technological Testbeam Prototype

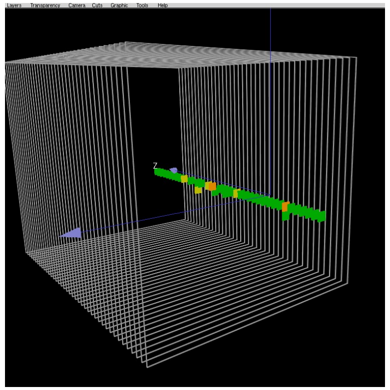
- Large enough to contain hadron showers
  - 38 active layers of 72*72 cm²
  - 4 HBUs per module
  - in total: 608 SPIROC2E ASICs, ~22000 channels
  - SiPMs: Hamamatsu S13360-1325PE
- All modules interchangeable
- Built with scalable production techniques in ~2 years
- Operated in beam tests with muons, electrons and pions at CERN SPS in 2018
  - 3 weeks of beam time
  - Collected O(100) mio events
  - Very stable running
  - Nearly noise free
  - < 1 per mille dead channels

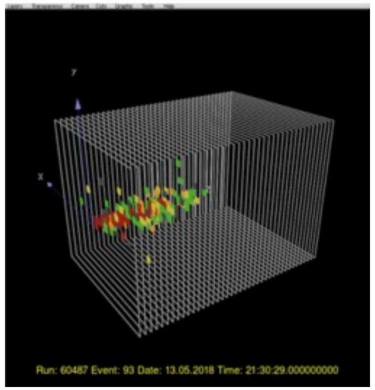


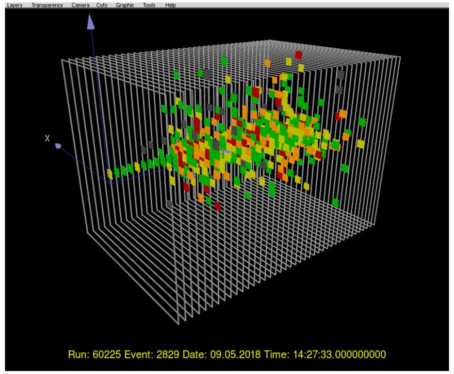
AHCAL Technological Trototype at SPS Testbeam



beam



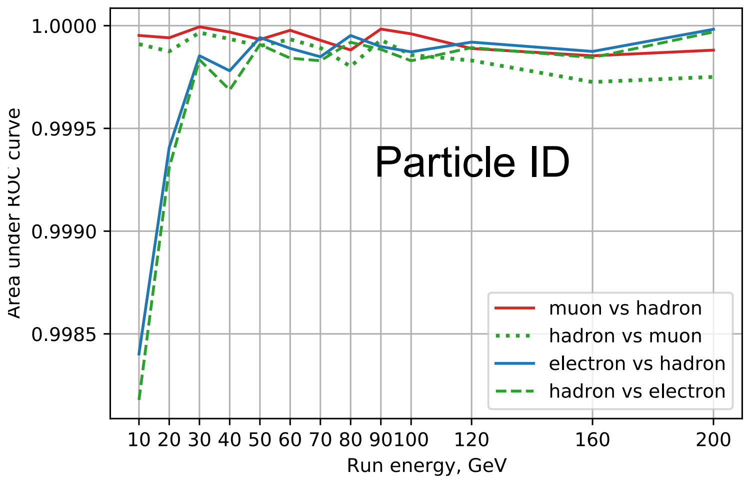


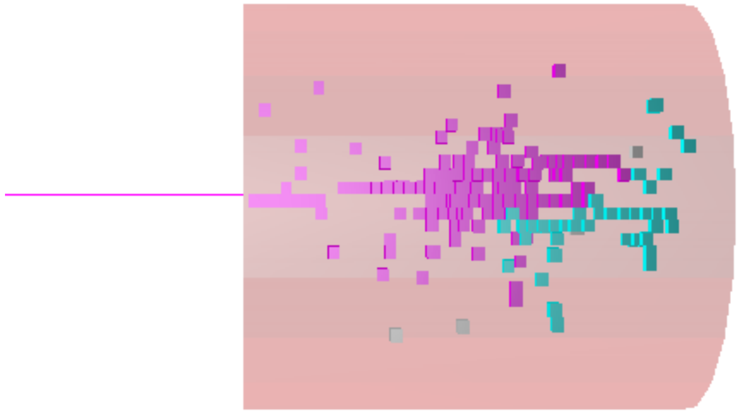


AHCAL Technological Prototype: Analyses

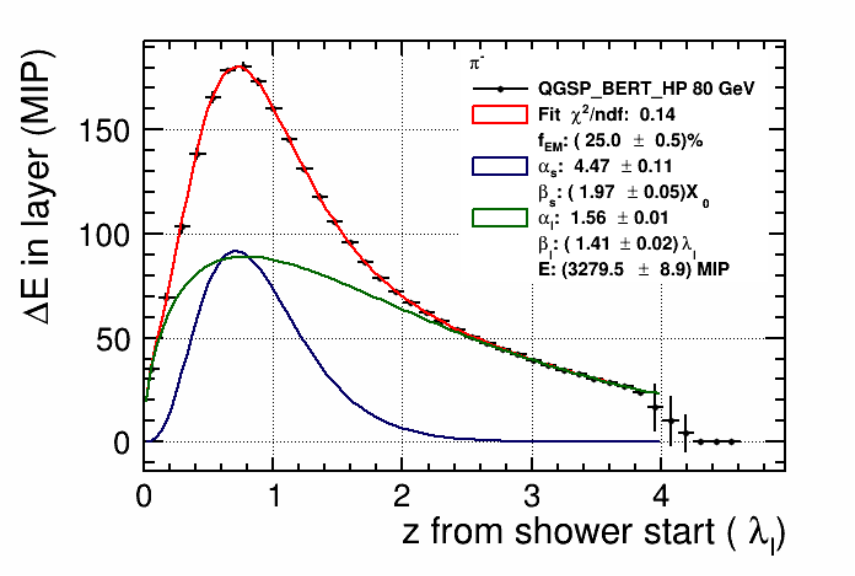
High granularity offers detailed look into hadron showers

- Used in particle ID based on Boosted Decision Trees
- Studies of shower shapes
- Application of the PandoraPFA Particle Flow Algorithm





Magenta: Charged Hadron
Cyan: Neutral Hadron
Grey: Unclustered Hits



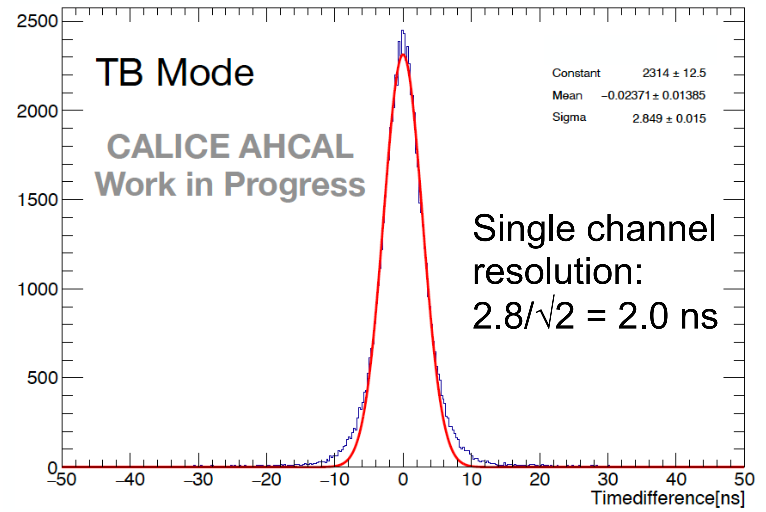
AHCAL Prototype: Hit Time Measurement

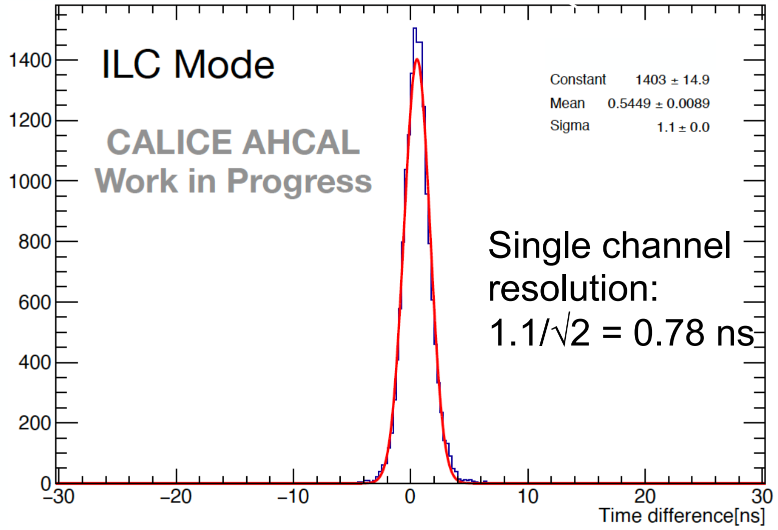
New feature in AHCAL technological prototype: time measurement for individual hits

- Design resolution: ~1 ns
- SPIROC2E readout ASIC supports 2 bunch clock speeds
    - Testbeam mode: 250 kHz clock
        - More efficient for data taking in testbeams
        - Worse hit time resolution: ~2ns
    - ILC mode: 5 MHz
        - Adapted to ILC bunch structure
        - Better hit time resolution: ~0.8 ns

- Full exploitation in data analysis just started

- Most testbeam data so far taken in testbeam mode



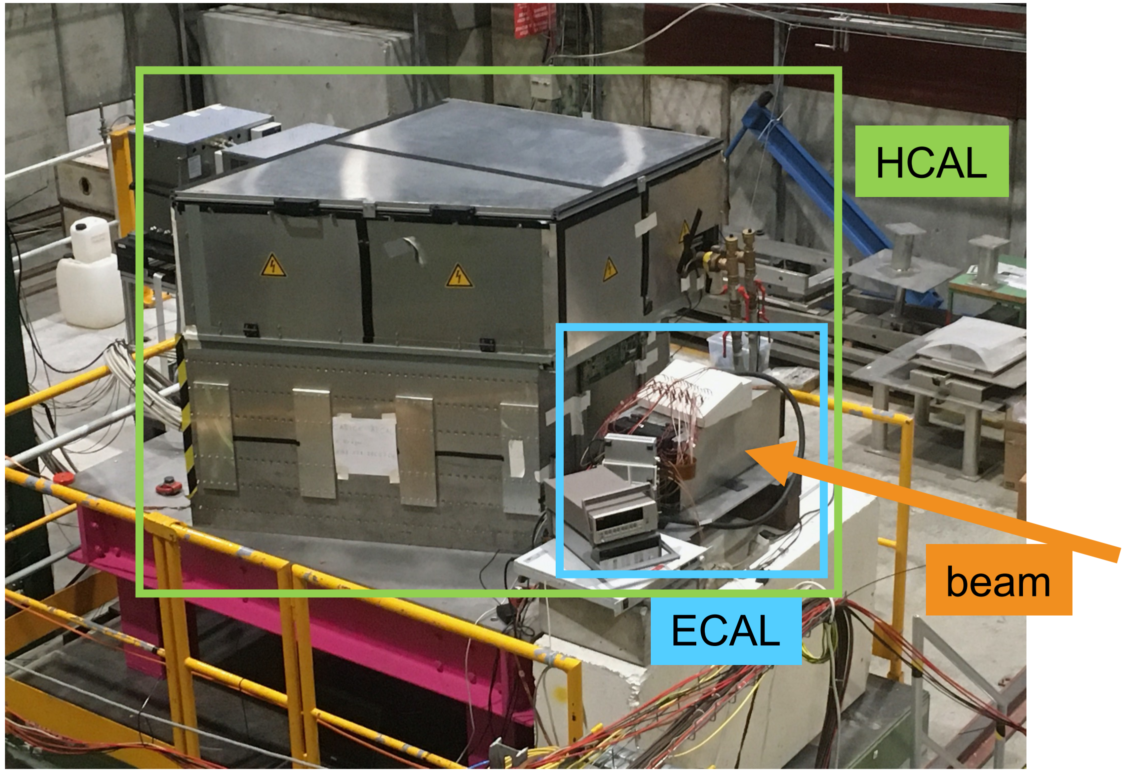


Combined testbeam with CALICE SiW-ECAL

2 weeks of beam test at CERN SPS: 8-22 June 2022

- First common running of technological prototypes of SiW ECAL and scintillator AHCAL
  - 15-layer ECAL prototype, 5*5 mm^2 cells
  - 38-layer HCAL prototype, 30*30 mm^2 cells
- Successful synchronized data taking
- Muon data for calibration
- Energy scans for electrons and hadrons

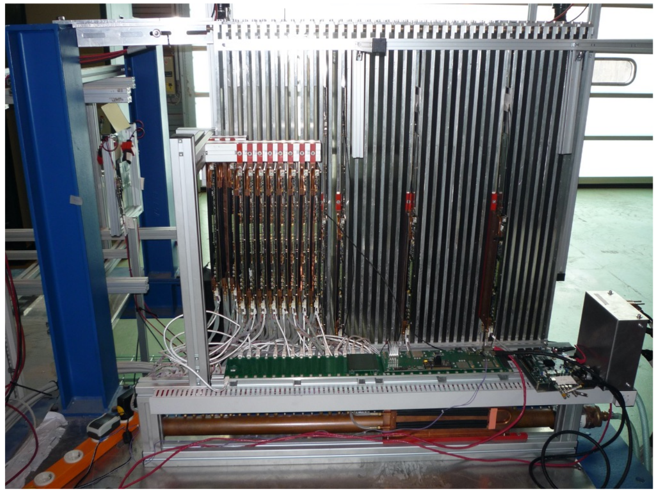
- Milestone in our program reached!
- Future beam test program to be defined
  - Tungsten stack available



AHCAL Plans: Testbeam Measurements

Fully exploit timing capabilities

- Perform full set of testbeam measurements in ILC mode
  - First tests running already
- Develop reconstruction algorithms to better use hit time information



Tungsten Stack

- Data taken so far with steel absorber stack
- Tungsten would offer shorter showers
- Valuable input for hadronic shower models (ECAL)
- Plan to re-use tungsten absorber stack already used for physics protype

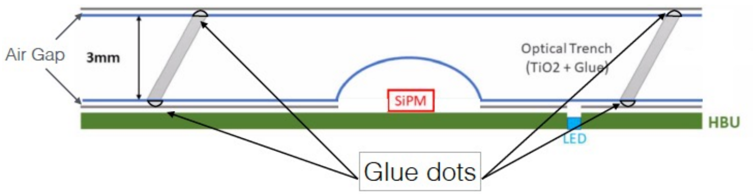
Further running with ECAL

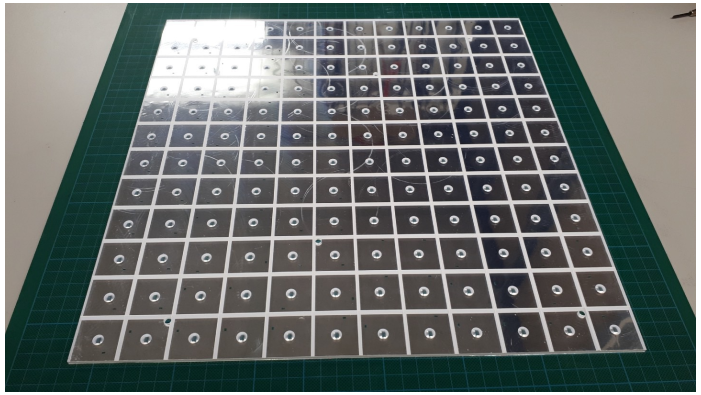
- when silicon layers are complete

AHCAL Plans: Hardware Developments

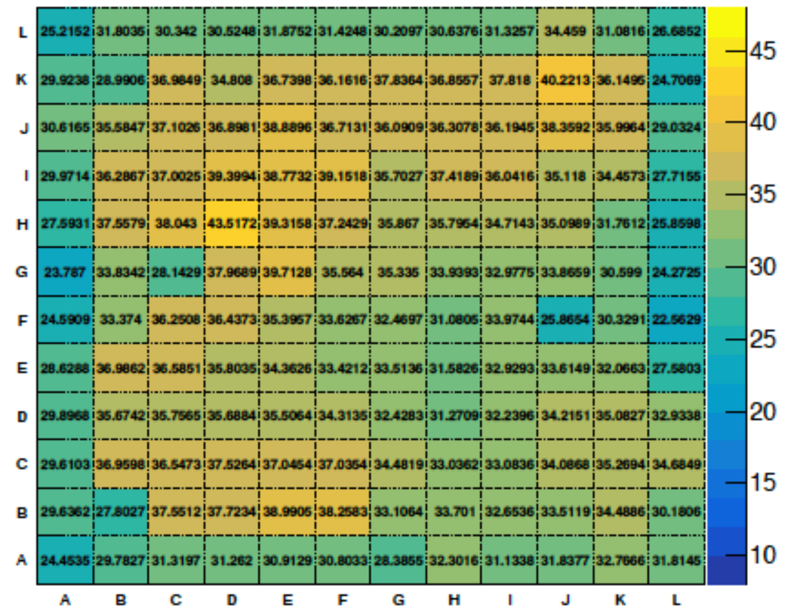
Alternative scintillator geometry

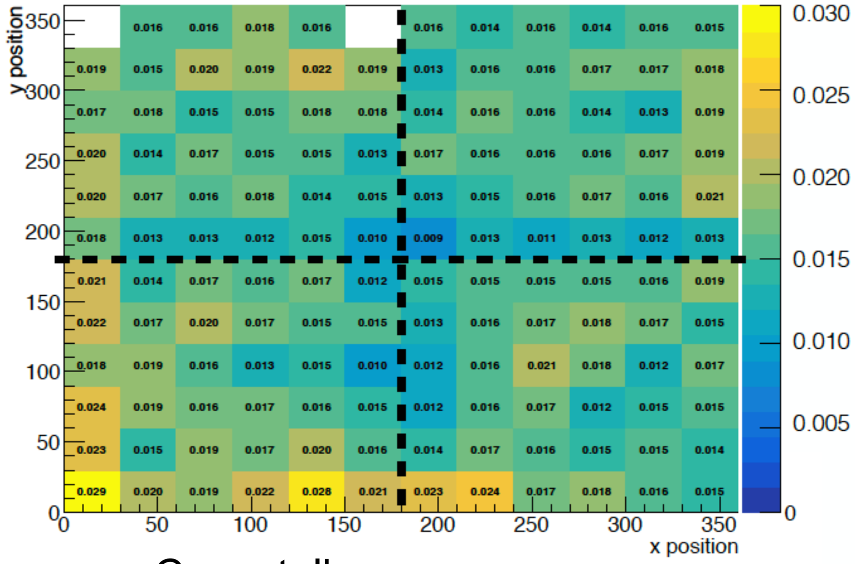
- ILD will require two orders of magnitude more tiles than AHCAL prototype, one order more than CMS HGCAL
- Megatiles would allow larger units for mechanical assembly
- Challenge: reach good uniformity while keeping the cell-to-cell light cross talk small
- Status:
  - Several generations of Megatiles produced
  - Last one shows reasonable uniformity and light yield, working on optimization of edge cells
  - One Megatile HBU included in 2022 testbeam setup
  - Plan to build a 2*2 HBU layer to study also Megatile-Megatile transition region





Light yield





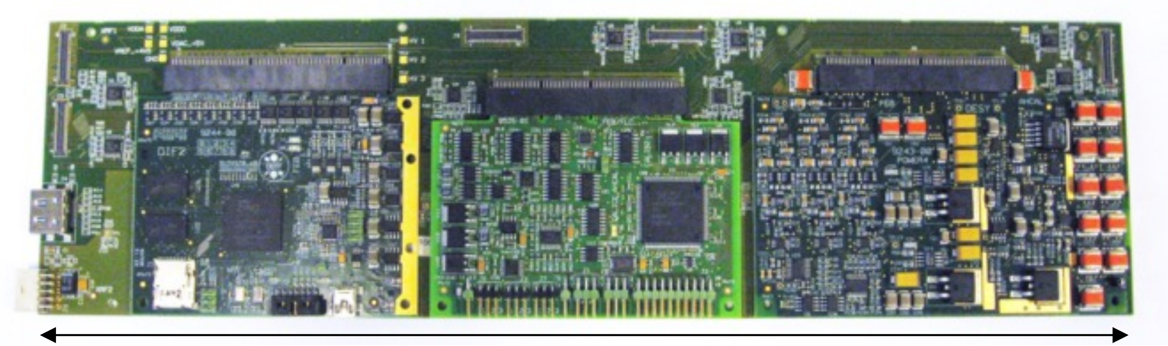
Cross talk

AHCAL Plans: Hardware Developments

Common Readout

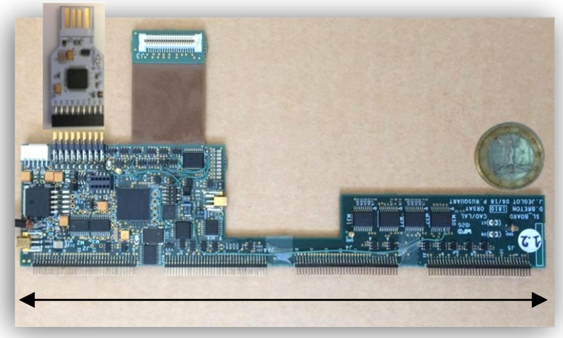
- Harmonise readout between CALICE SiW ECAL and AHCAL
- Reduce size of AHCAL interface boards
  - Current design is from 2007
  - Focus was on modularity
  - New SiW ECAL interface board (SL board) optimized for compactness
  - Plan to follow SiW design as much as possible
    - Some differences in powering concept
    - Additional LED calibration system in AHCAL
- Status: just started

AHCAL interface boards



36 cm

SiW ECAL SL board



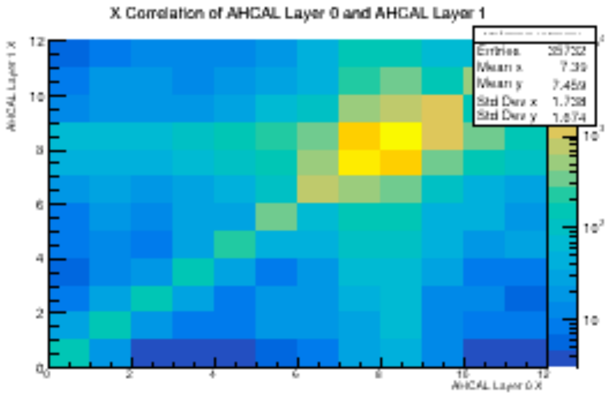
18 cm

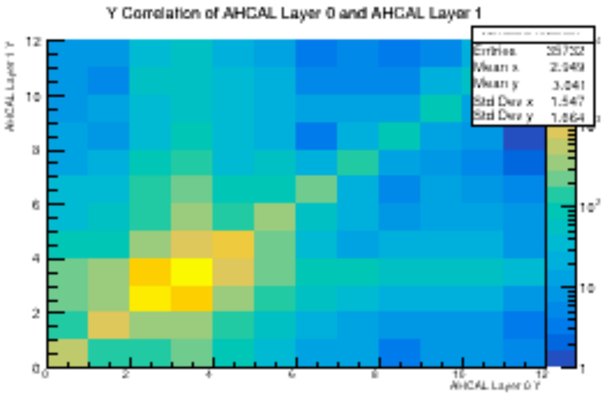
AHCAL Plans: Hardware Developments

Alternative Readout ASIC (KLauS)

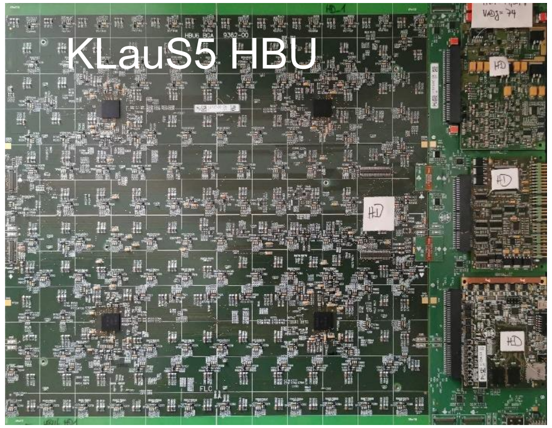
- Wide range of applications
- Possible application at circular Higgs factories
- Optimised for SiPMs with small pixels (10µm) -> possible application in scintillator ECAL
- Status:
  - First HBU with KLaus5 operated within AHCAL DAQ
  - KLauS6 with full functionality available

SPIROC HBU





KLauS HBU



AHCAL technology for circular colliders

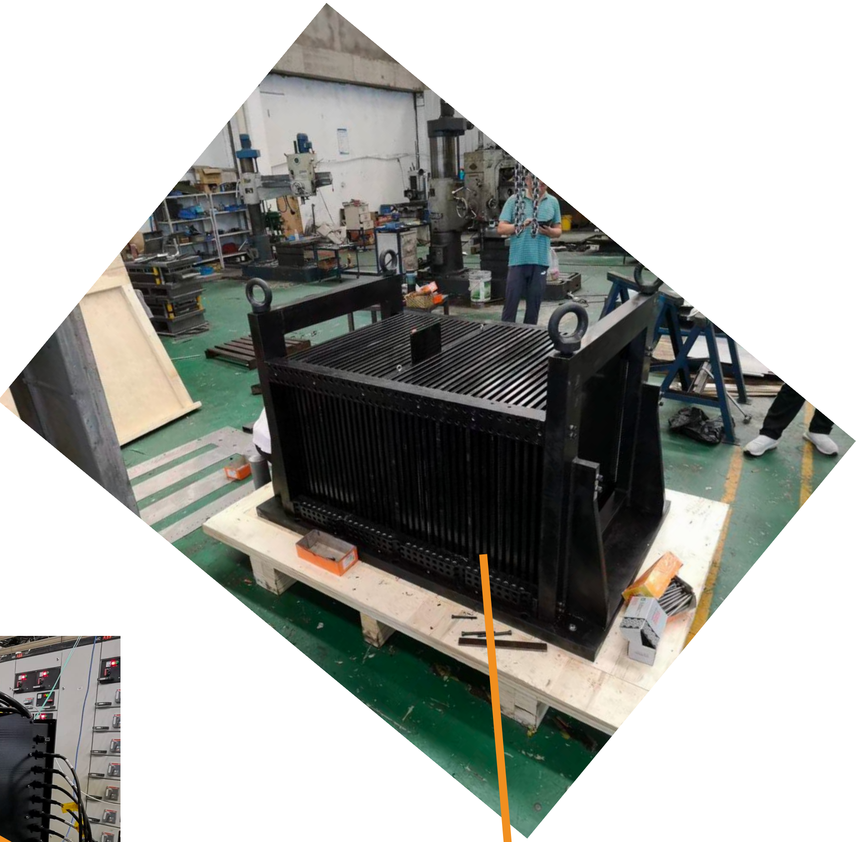
- Readout and powering concept of AHCAL technological prototype rely on beam structure of linear colliders
  - Switch between data acquisition and readout phases
  - Cell-wise auto-trigger
  - Power pulsing
  - Allows to have no cooling inside the active layers
- Continuous running at circular colliders would require significant modifications
  - Continuous readout will require higher bandwidth
  - Higher data rates may require trigger system
  - Higher power consumption will require more cooling
    - Likely: cooling within the active layers
    - Will have an impact on the homogeneity of the calorimeter
  - Depending on cooling concept, may need re-optimisation of the sampling structure

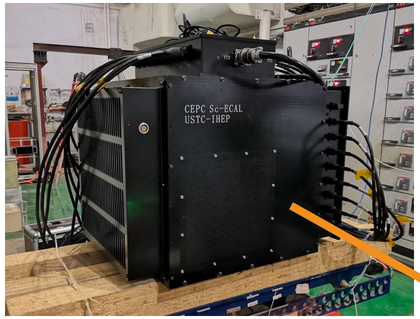
Scintillator Calorimeter for CEPC

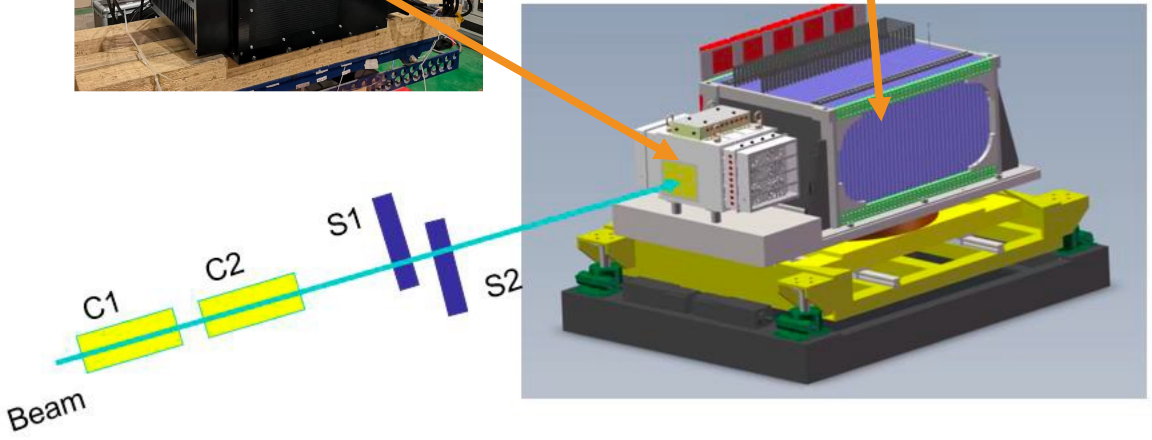
2 weeks of beam test at CERN SPS: 19 October - 2 November 2022

- System of scintillator ECAL + scintillator HCAL for CEPC
- Granularity optimised for CEPC:
  - ECAL: 5*45 mm^2 strips -> effectively 5*5 mm^2
  - HCAL: 40*40 mm^2
- Readout electronics: SPIROC2E (developed for ILC)
- 38-layer scintillator-steel HCAL prototype assembled, tested with cosmics and ready this year
- 30-layer scintillator-tungsten ECAL prototype ready since 2 years
- Plan calibration runs with muons, energy linearity and resolution measurements with electrons and pions

See talk by Yunlong Zhang



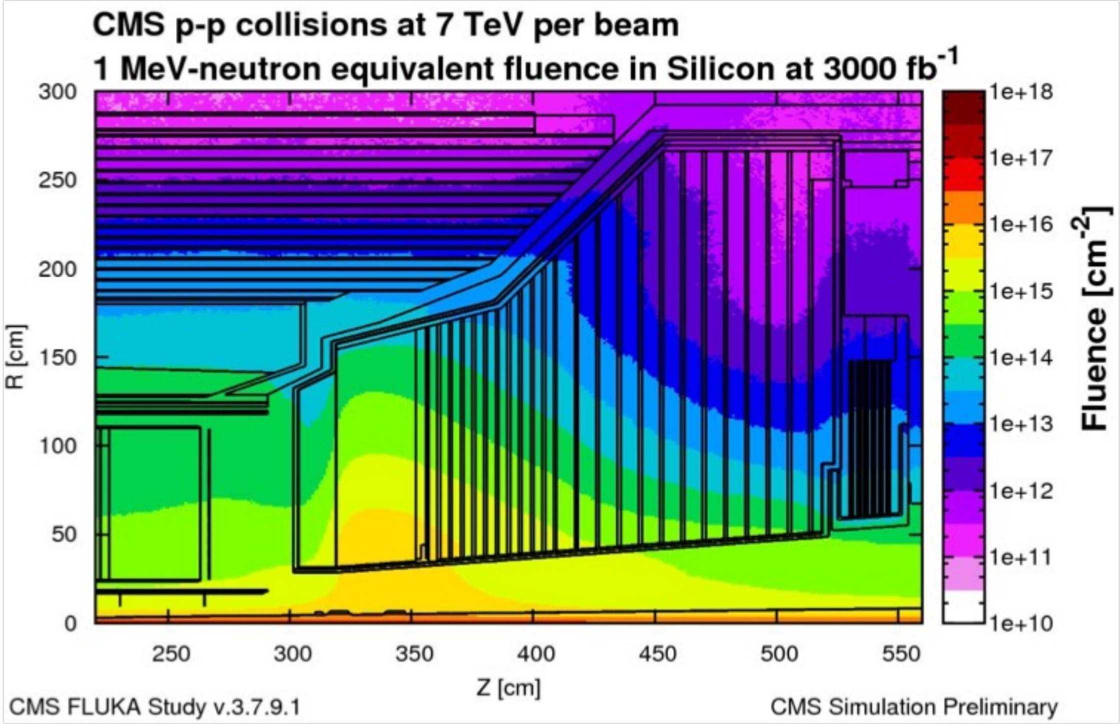


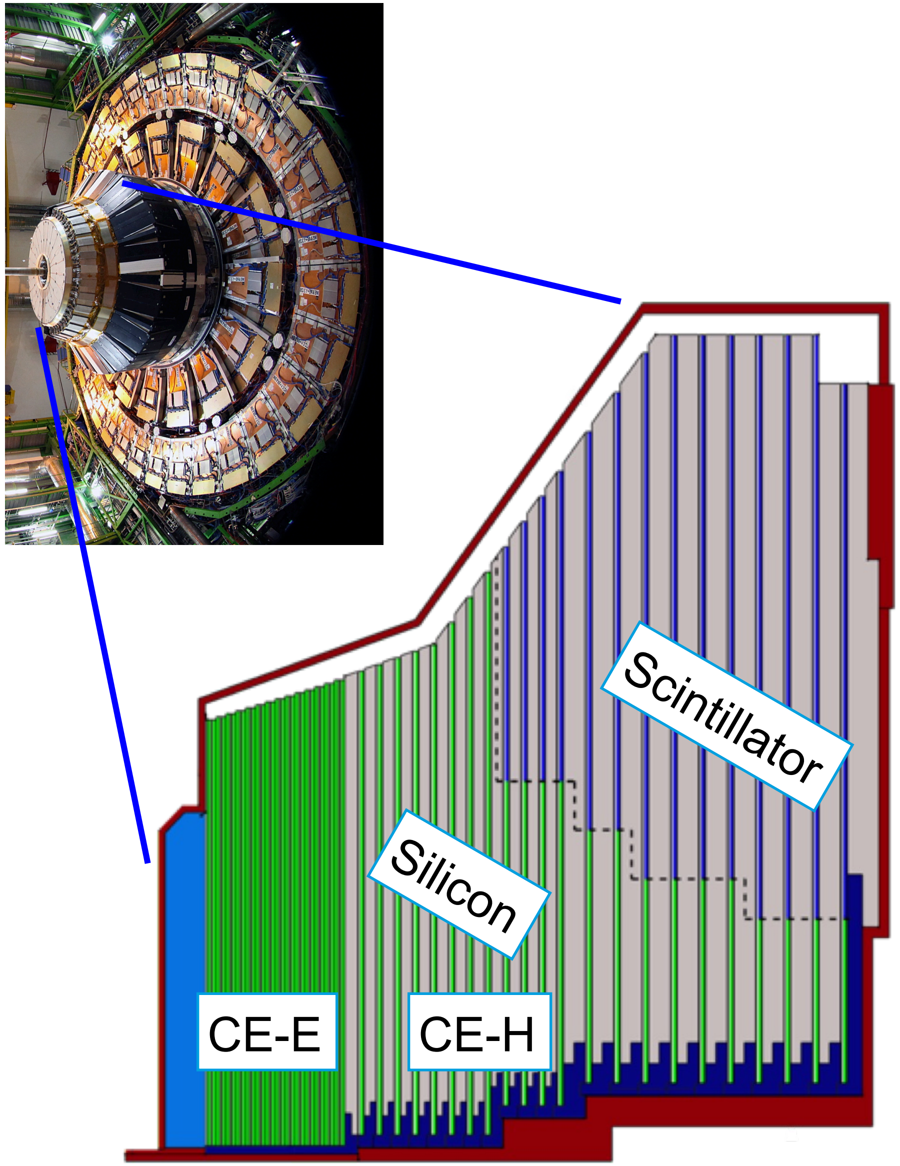


SiPM-on-Tile calorimetry beyond Higgs Factories

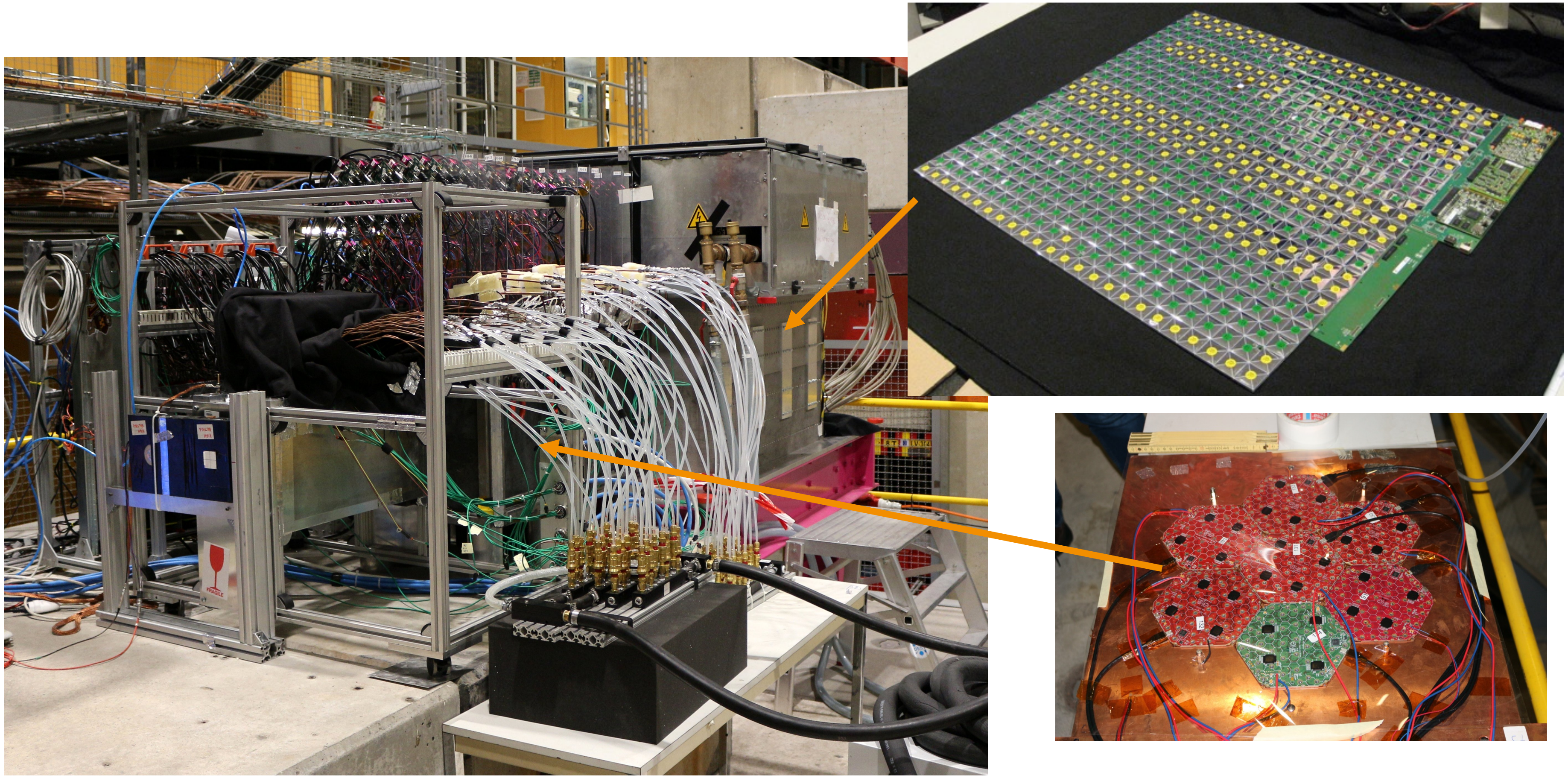
SiPM-on-Tile in CMS HGCAL

- CMS calorimeter endcap will be replaced for HL-LHC by **H**igh-**G**ranularity **cal**orimeter
- synergy with high granularity calorimeter concepts developed for electron-positron colliders
  - Use SiPM-on-tile wherever radiation levels allow





Common Running of AHCAL & HGCAL silicon prototype

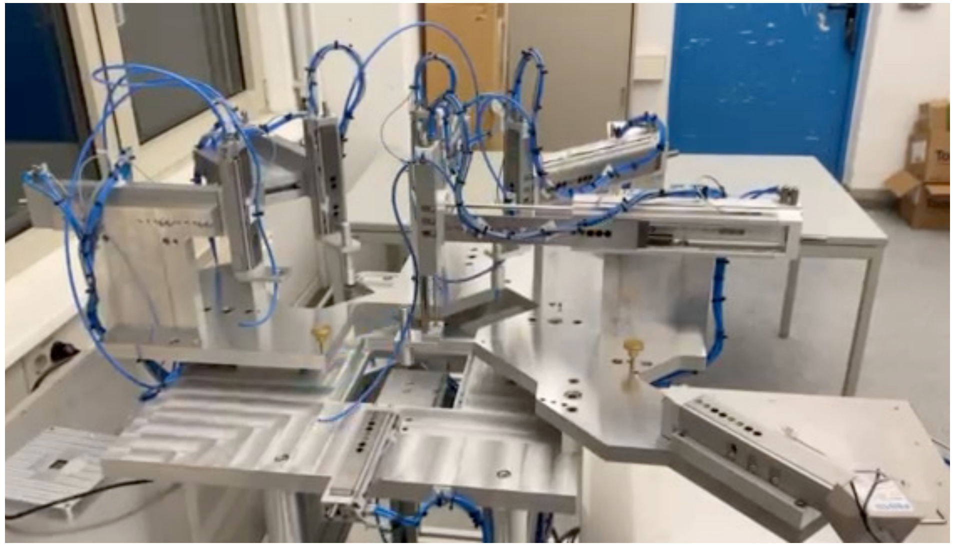


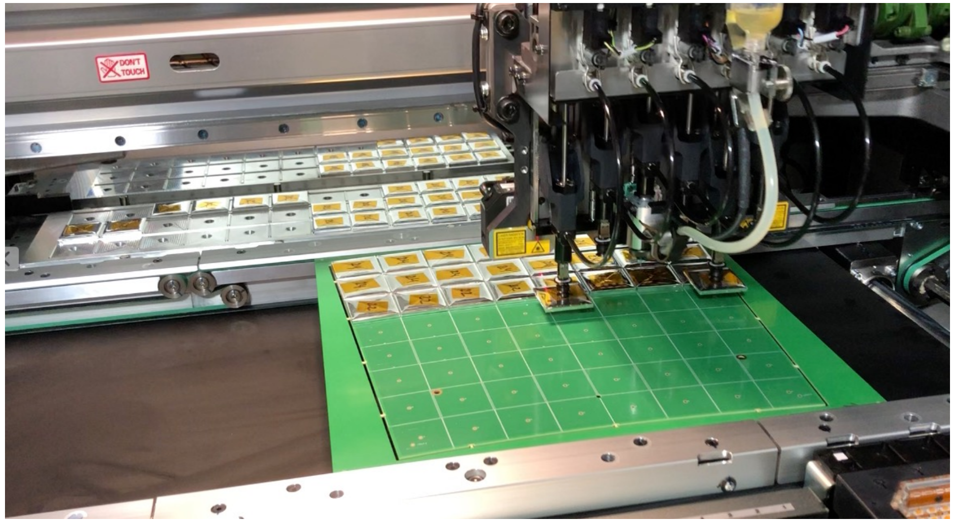
- In October 2018, collected hadron data with HGCAL silicon module prototypes and the AHCAL prototype
  - 28 layers HGCAL EE (silicon/lead), 12 layers HGCAL FH (silicon/steel), 39 layers AHCAL (scintillator/steel)
  - Comparison of simulations important to validate HGCAL performance extrapolations, publication in preparation

SiPM-on-Tile Technology for HGCAL

- New challenges:
  - radiation levels
  - data rates
  - operation at -30 degrees
  - Many different tile and board sizes

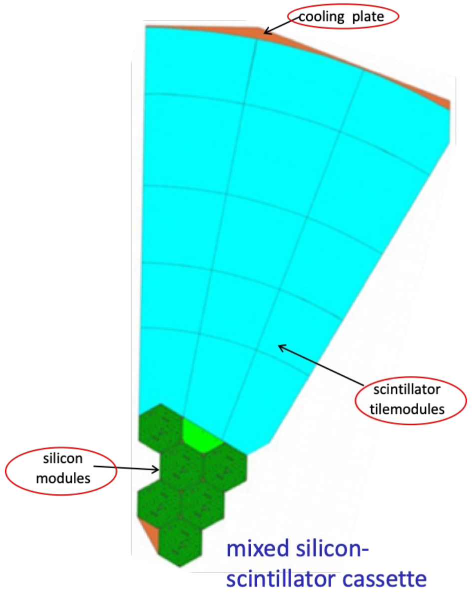
- Adaptation of AHCAL technologies to HGCAL
  - Readout with fast and rad-hard components
  - Careful design for large temperature variations (from assembly to operation)
  - More flexible and robust assembly procedures
    - Tile wrapping
    - Tile glueing





HGCAL SiPM-on-Tile Status & Plans

- Individual SiPM-on-Tile Modules have been produced and tested in the lab and with beams
  - Light yield
  - Noise of irradiated SiPMs, temperature dependence
- entering construction phase
  - engineering design, final choice & qualification of components
  - setting up of construction procedures (including quality control)
- Plans: received ~4000 pre-series SiPMs in Summer 2022
  - ~1000 for 15 tile modules of the same size
    - EM stack for beam tests
    - Validation of calorimetric performance
  - ~1000 for 15 tile modules forming a 30 degree sector
    - Cassette test
    - Validation of integration concept
- **experience & infrastructure from construction & QC will be fed back to future designs of SiPM-on-Tile calos**



Summary

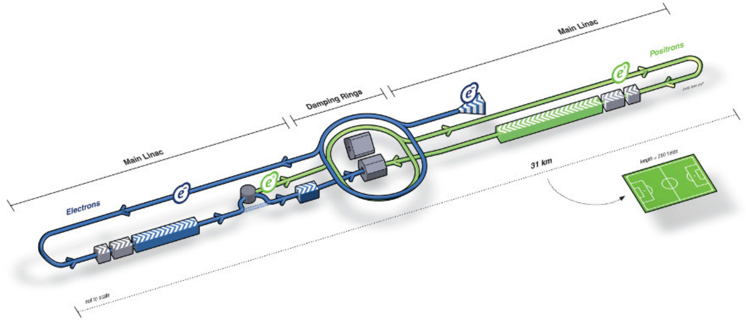
- SiPM-on-Tile calorimetry offers high granularity and good energy resolution at reasonable cost
- Performance demonstrated with CALICE AHCAL physics prototype
- Engineering design demonstrated with CALICE AHCAL technological prototype
- SiPM-on-Tile technology can be adapted to different conditions
- CMS HGCAL will be the first detector-scale application of the technology
  - Invaluable experience for future experiments

Thank you!

Backup

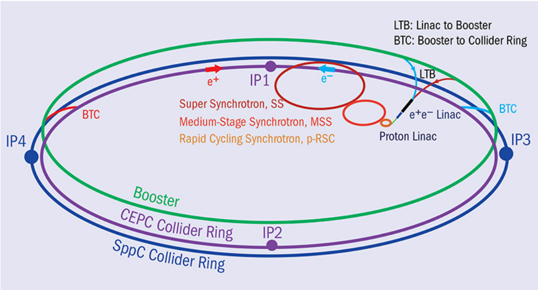
Higgs Factories

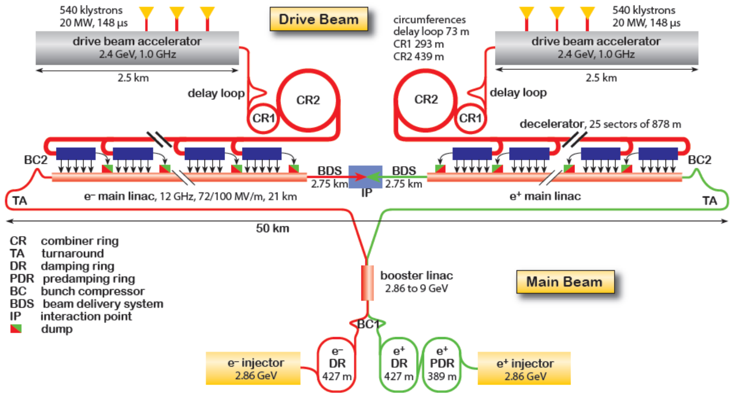
- European Strategy Update identified Higgs Factory as high priority
- Linear & Circular Proposals



ILC

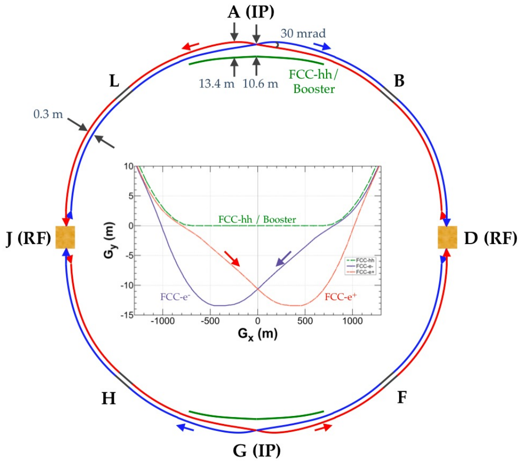
CEPC





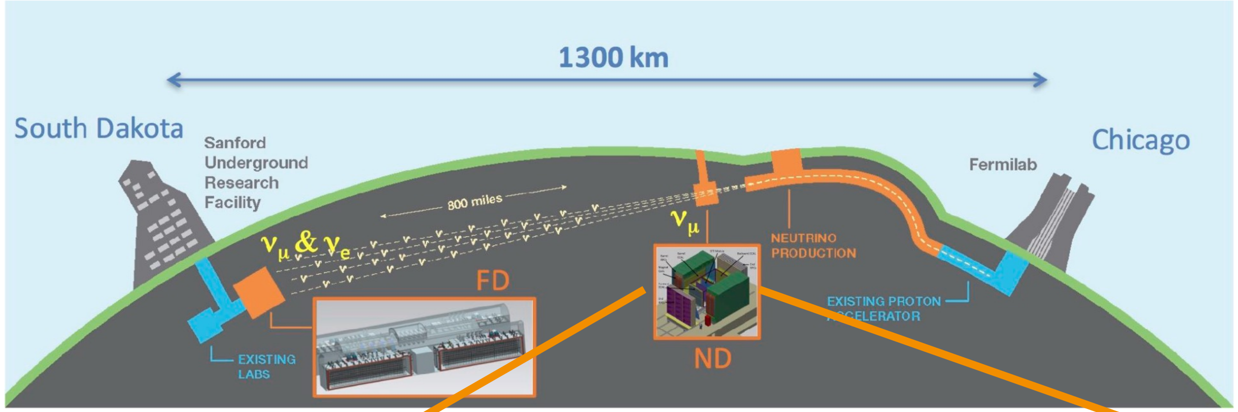
CLIC

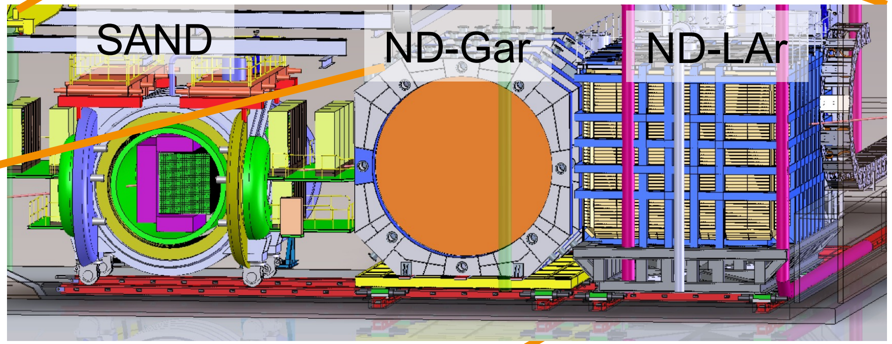
FCCee

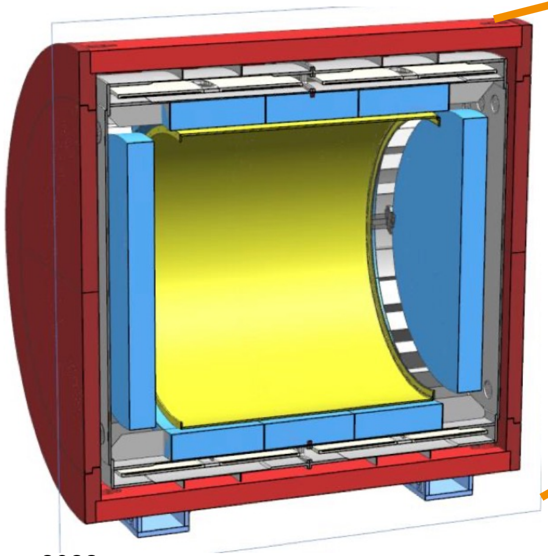


Deep Underground Neutrino Experiment

- DUNE Far Detector: Study neutrino oscillations
  - Large LAr TPCs
- Near Detector (ND): measure beam before oscillation
  - DUNE PRISM: 3 detectors of which 2 can be moved off-axis
  - ND-LAr: Liquid Argon TPC
  - **ND-GAr: High Pressure GAr TPC, surrounded by ECAL and magnet**
  - SAND: plastic scintillator target







SiPM-on-Tile for DUNE ND-GAr

ND-GAr

- Gaseous Argon TPC surrounded by ECAL and magnet
- Lower energy threshold than liquid Argon -> better to distinguish some models
- goal: detect π° from neutral current interactions and neutrons from interactions of neutrinos with Argon nuclei
    - typical energies of a few 100 MeV
    - need good energy and direction measurement

- Large sampling ECAL with good energy and angular resolution, neutron sensitivity and sub-ns time resolution
    - **Scintillator tiles and strips directly readout by SiPMs**
    - New challenges:
        - Very low energies -> very thin absorber
        - Very large area -> incorporate strips
        - Neutron sensitivity