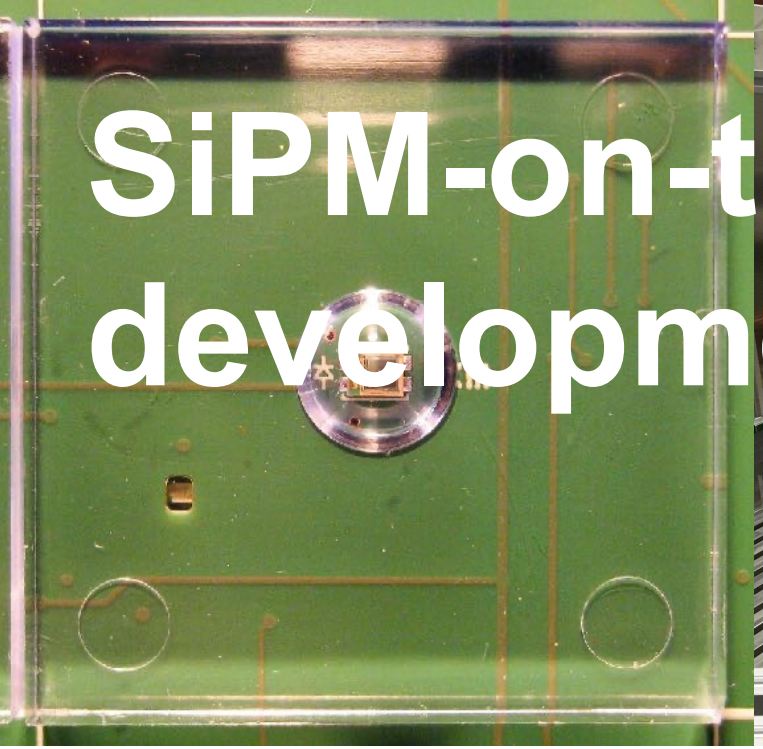
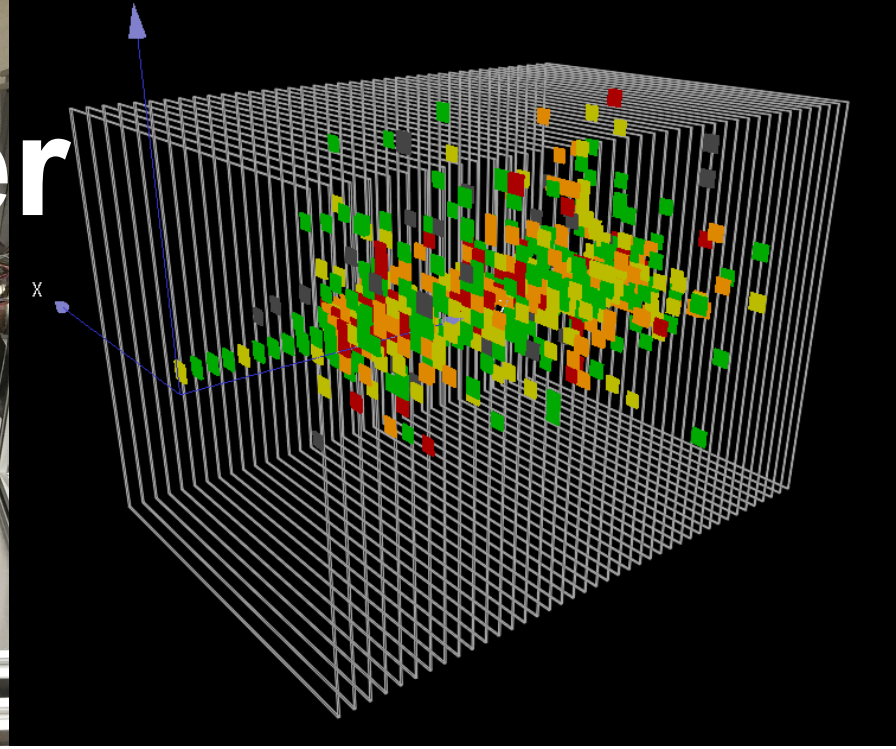




SiPM-on-tile calorimeter development

Katja Krüger (DESY)

Joint DESY/UHH perspectives in detector research
1 June 2023

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

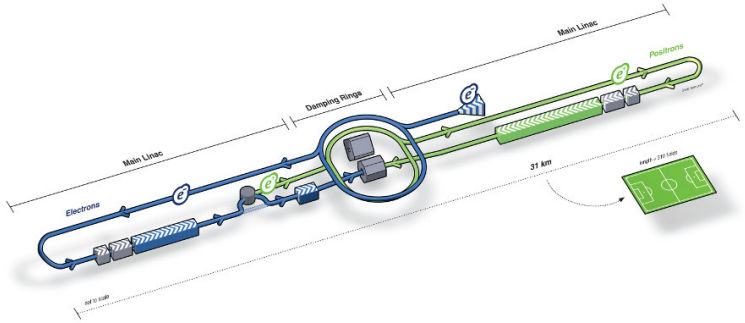
CALICE

DESY.

Motivation

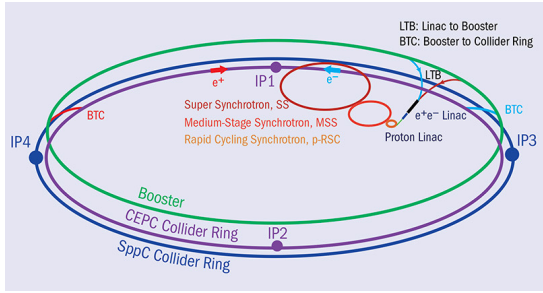
Higgs Factories

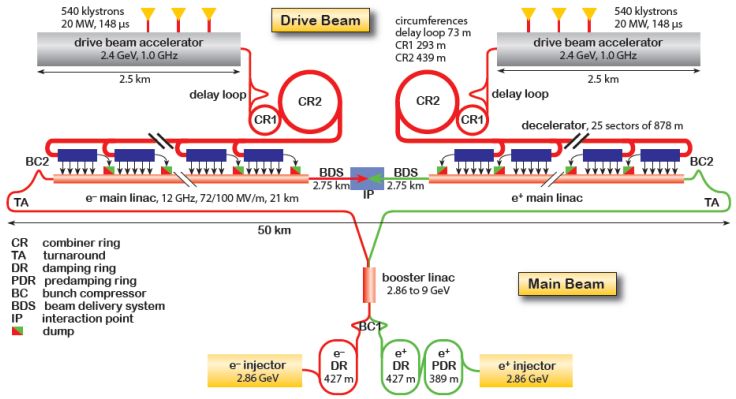
- European Strategy Update identified Higgs Factory as high priority
- Linear & Circular Proposals



ILC

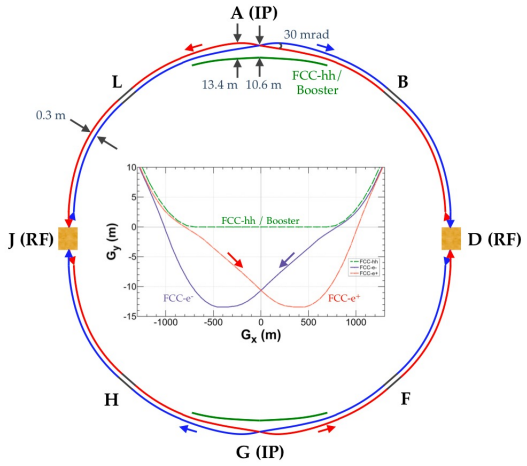
CEPC





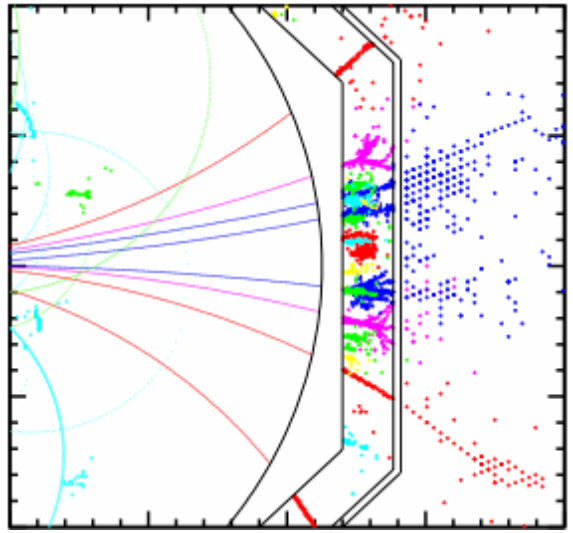
CLIC

FCCee

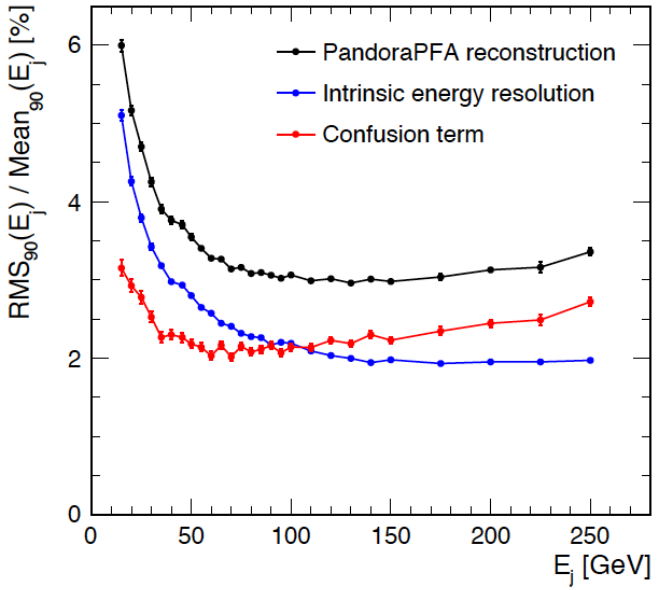


Calorimeters for Higgs Factories

- goal: want to distinguish Z → jet jet from W → jet jet
- requires σ(E)/E ≈ 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!



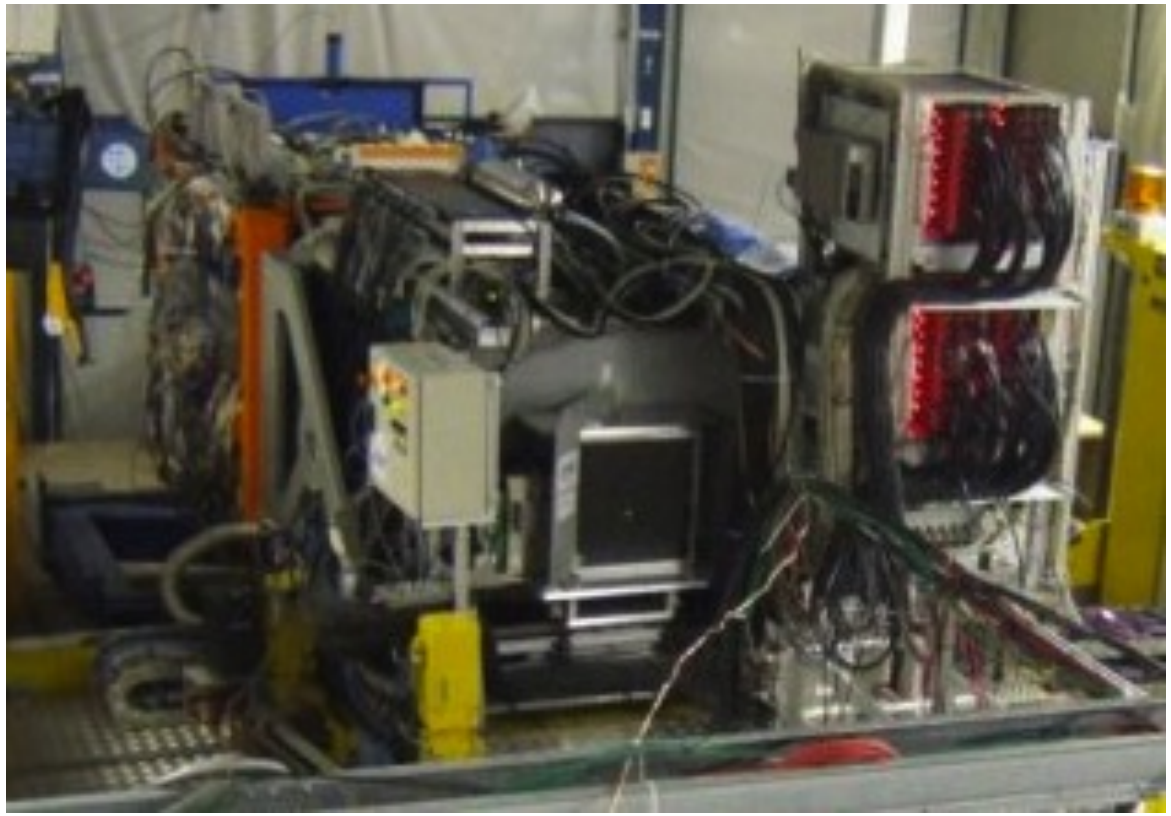
- requirements for the calorimeter:
  - highly granular
  - reconstruction of neutral particles: good energy resolution
  - calorimeter has to be within magnet coil: very compact
- Scintillator tiles are a scalable, cost effective solution

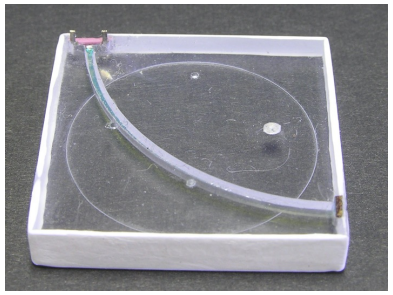


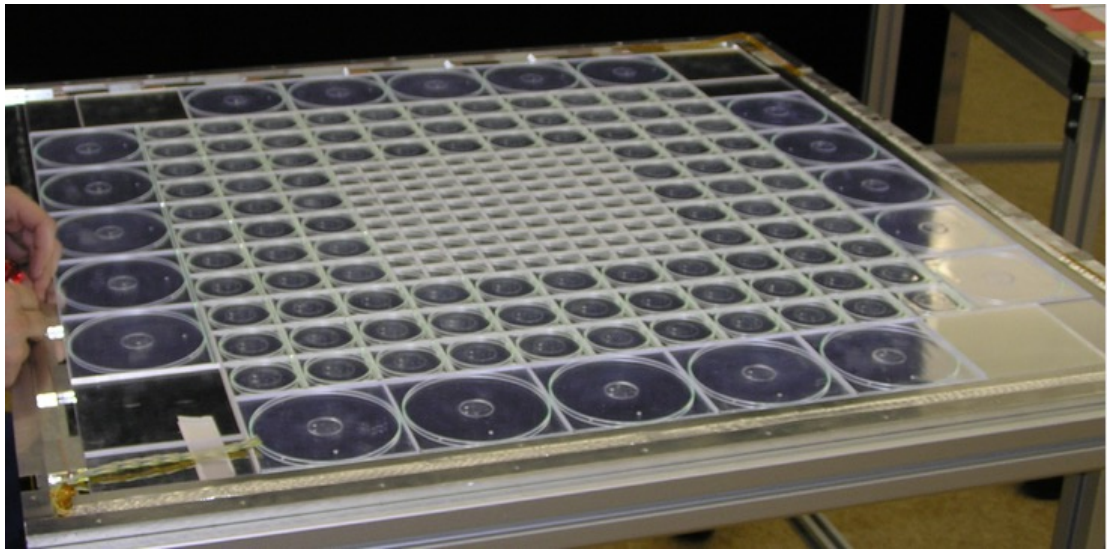
The CALICE AHCAL

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 2006-2012

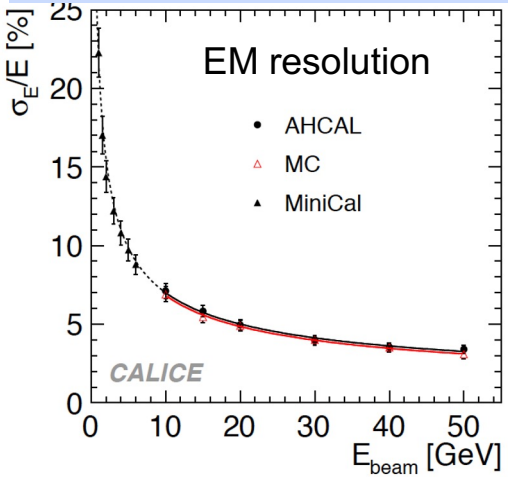






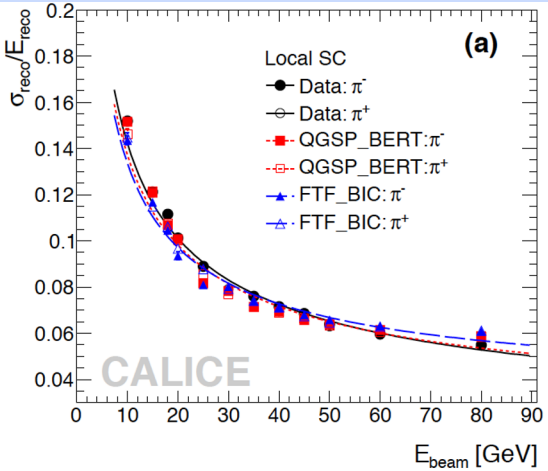
AHCAL Physics Prototype: Results

Detector validation



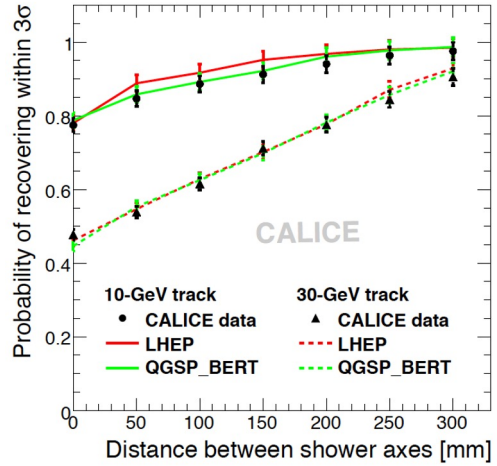
JINST 6, P04003 (2011)

Performance validation



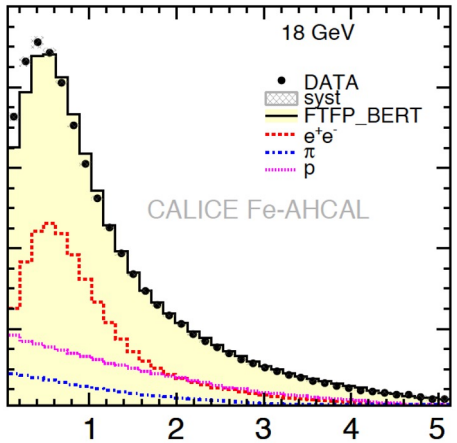
JINST 7, P00917 (2012)

Particle Flow validation



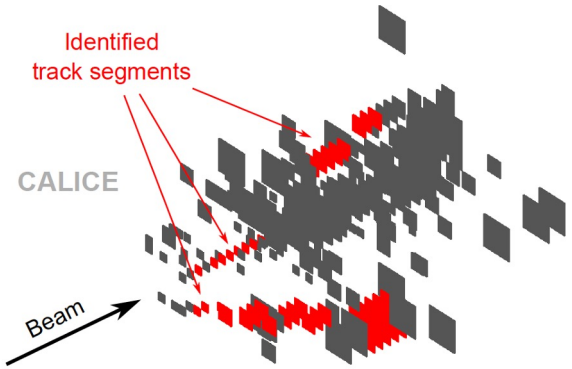
JINST 6, P07005 (2011)

Geant 4 validation

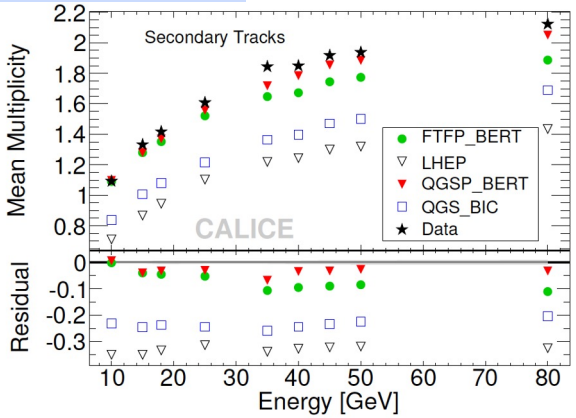


JINST 8, P07005 (2013)

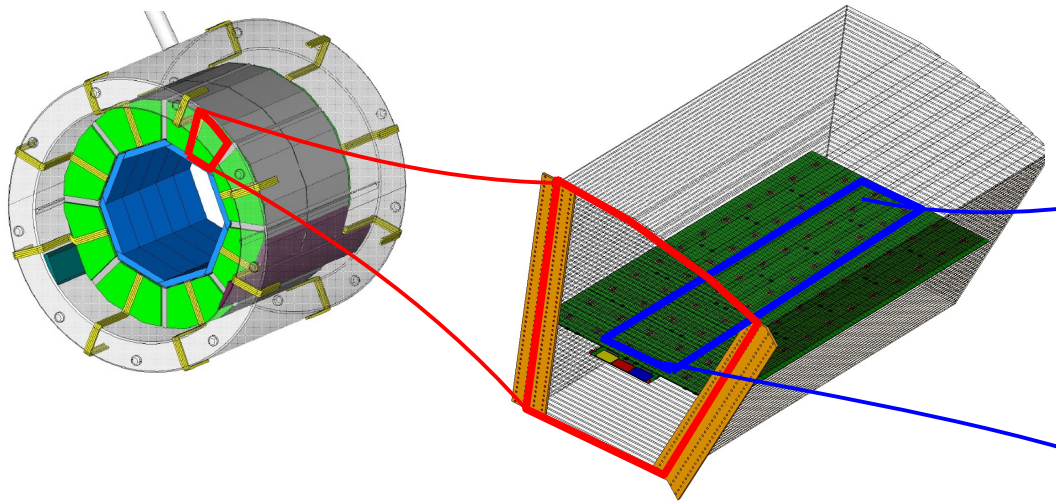
Imaging validation

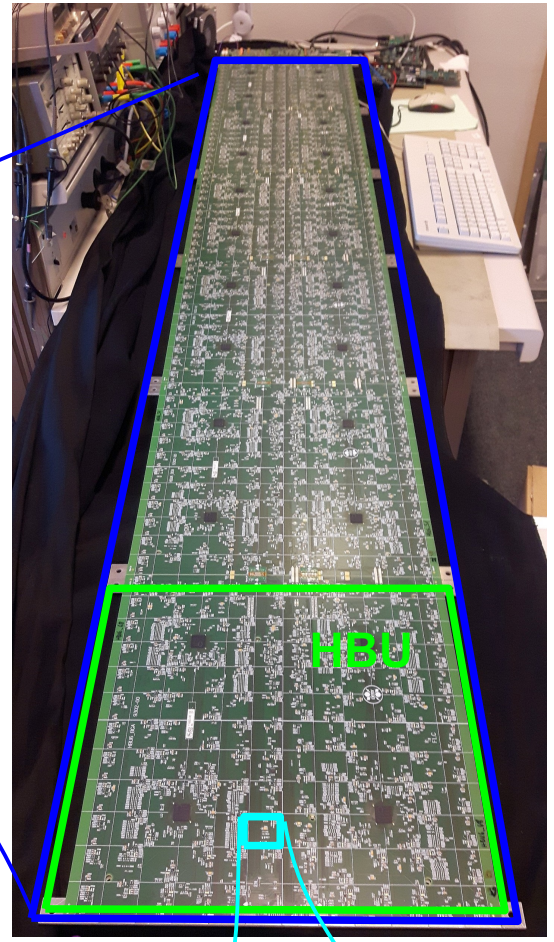


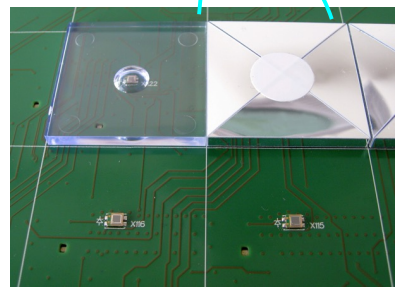
JINST 8, P09001 (2013)



AHCAL Technological Prototype





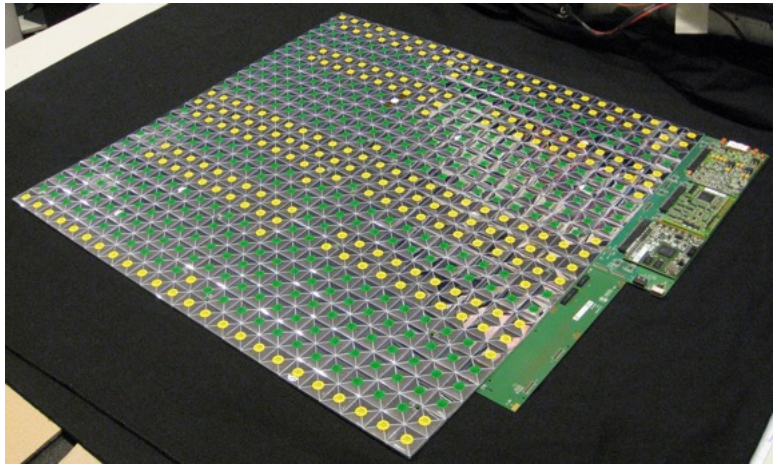


- highly granular scintillator SiPM-on-tile hadron calorimeter, 3*3 cm² scintillator tiles optimised for uniformity
- **fully integrated design**
  - front-end electronics, readout
  - voltage supply, LED system for calibration
  - no cooling within active layers -> **power pulsing**
- **scalable** to 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

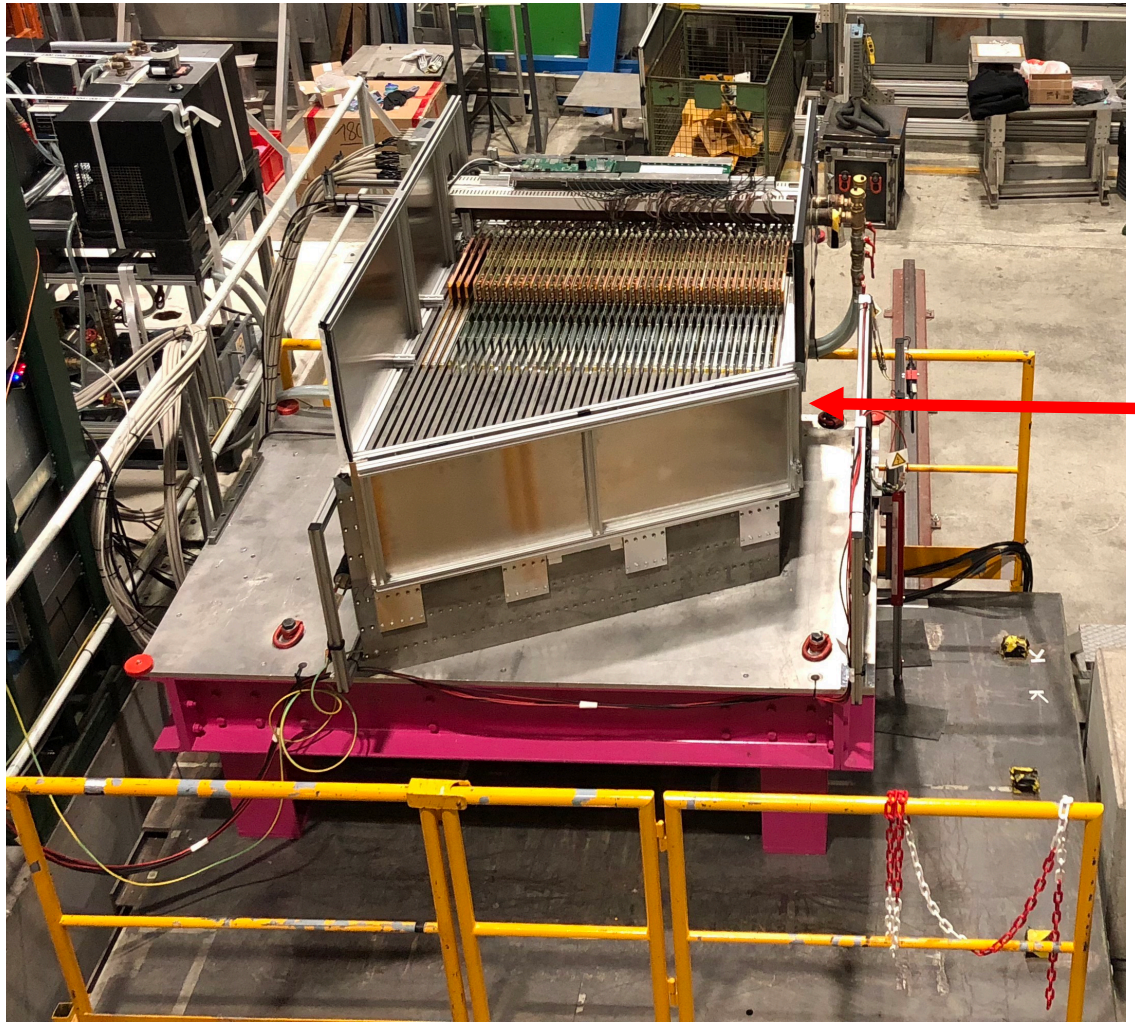
AHCAL Technological Testbeam Prototype

- 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
  - Collected O(100) mio events
  - Very stable running
  - Nearly noise free
  - < 1 per mille dead channels
- Combined beam test together with SiW ECAL in 2022

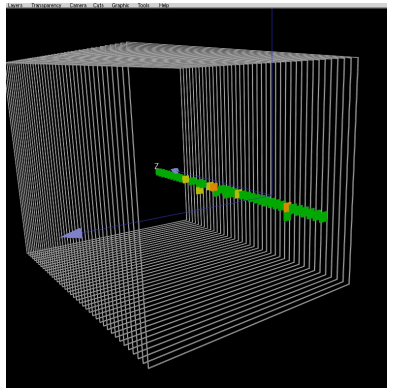
- Plan: adopt the design to the needs of a circular e+e- collider

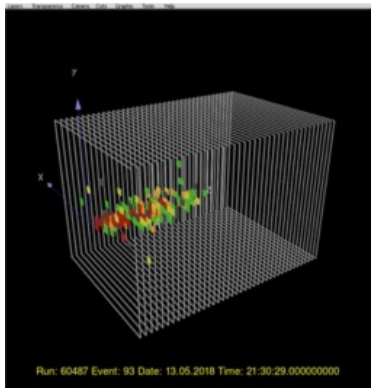


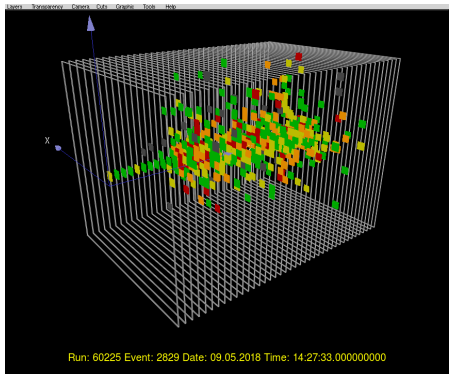
AHCAL Technological Trototype at SPS Testbeam



beam



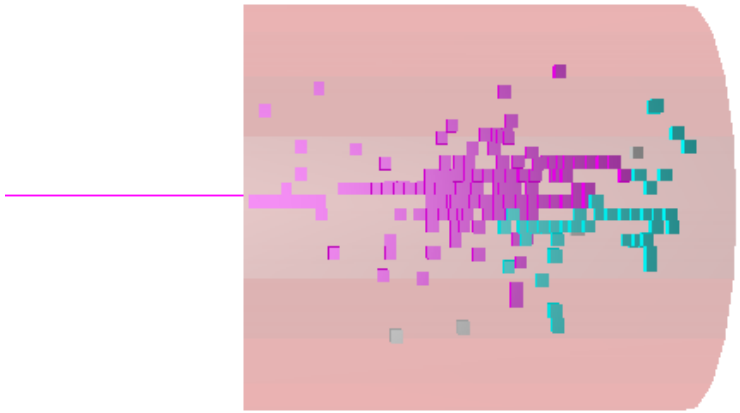




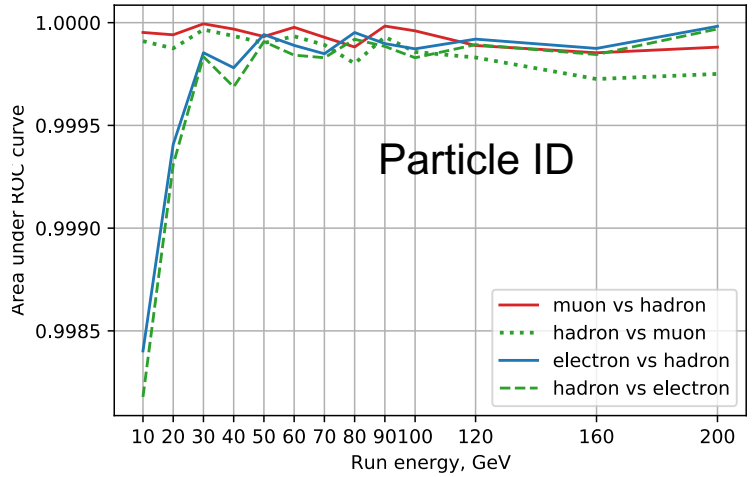
AHCAL Technological Prototype: Analyses

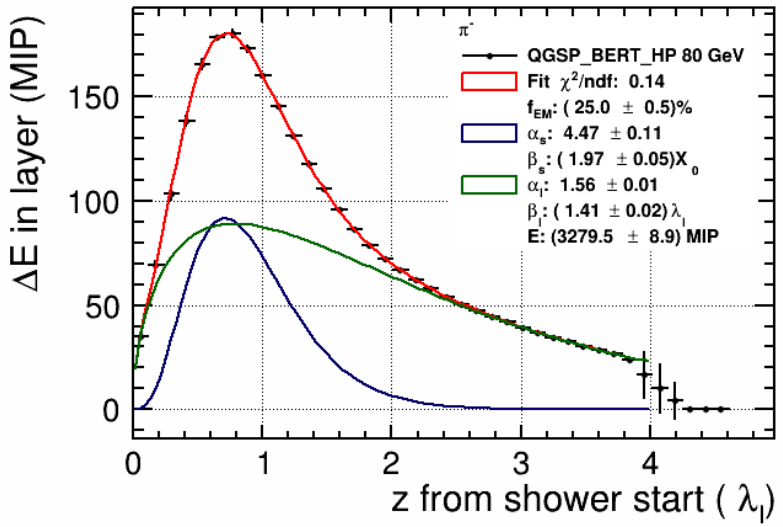
High granularity offers detailed look into hadron showers

- Used in particle ID based on Boosted Decision Trees
- Studies of shower shapes
- Application of the PandoraPFA Particle Flow Algorithm
- Hit time measurement (resolution ~1ns)



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



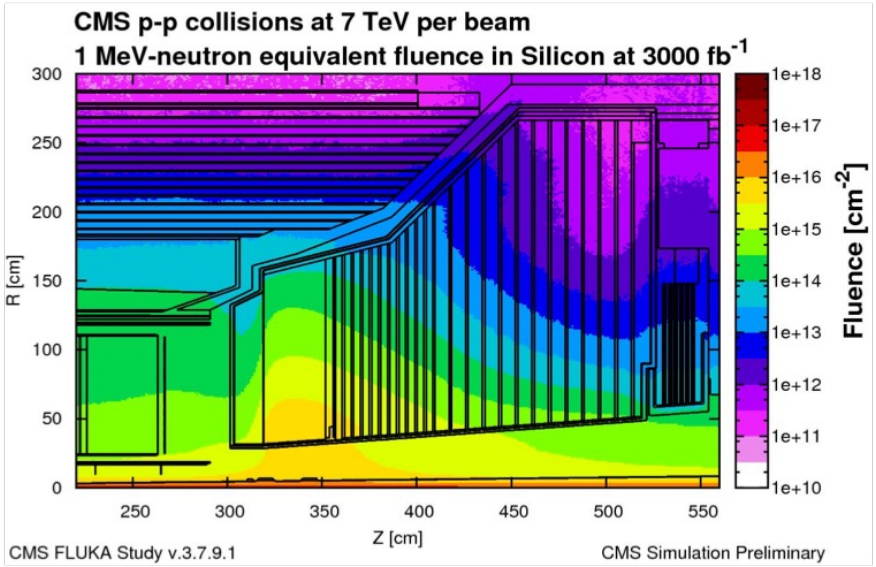


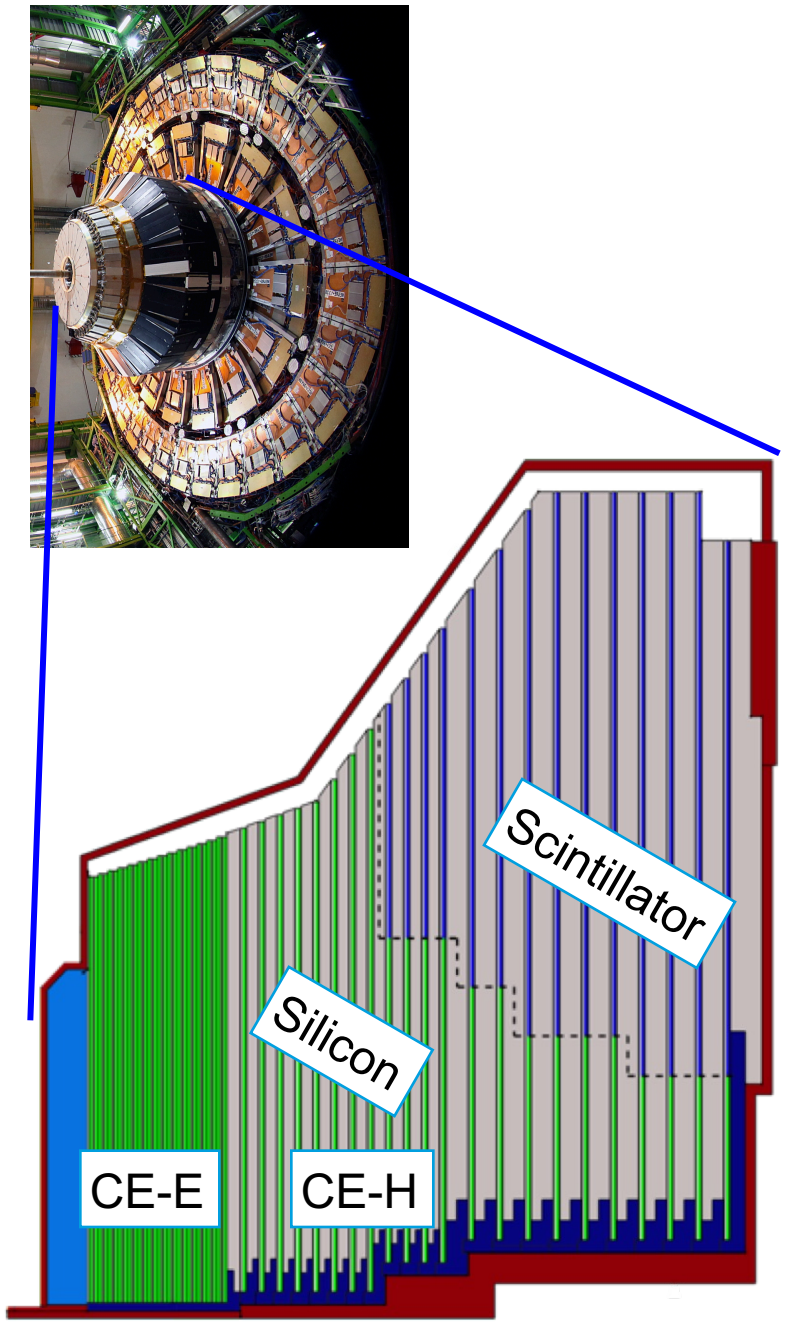
The CMS HGCAL

CMS HGCAL

Overview

- current CMS calo endcap will not survive in HL-LHC conditions
- in 2015, decided to replace it with silicon-based **H**igh-**G**ranularity **cal**orimeter
- synergy with CALICE high granularity calorimeter concepts
  - Hexagonal modules based on Si sensors in CE-E and high-radiation regions of CE-H
  - Scintillating tiles with on-tile SiPM readout in low-radiation regions of CE-H

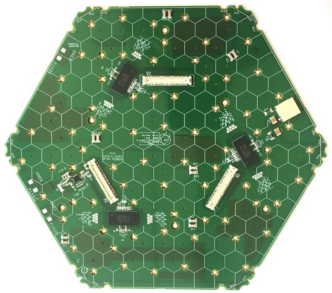


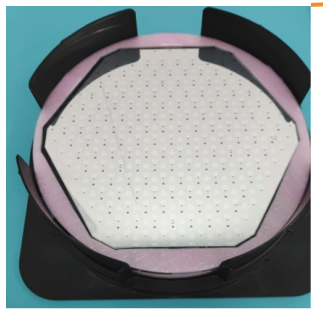


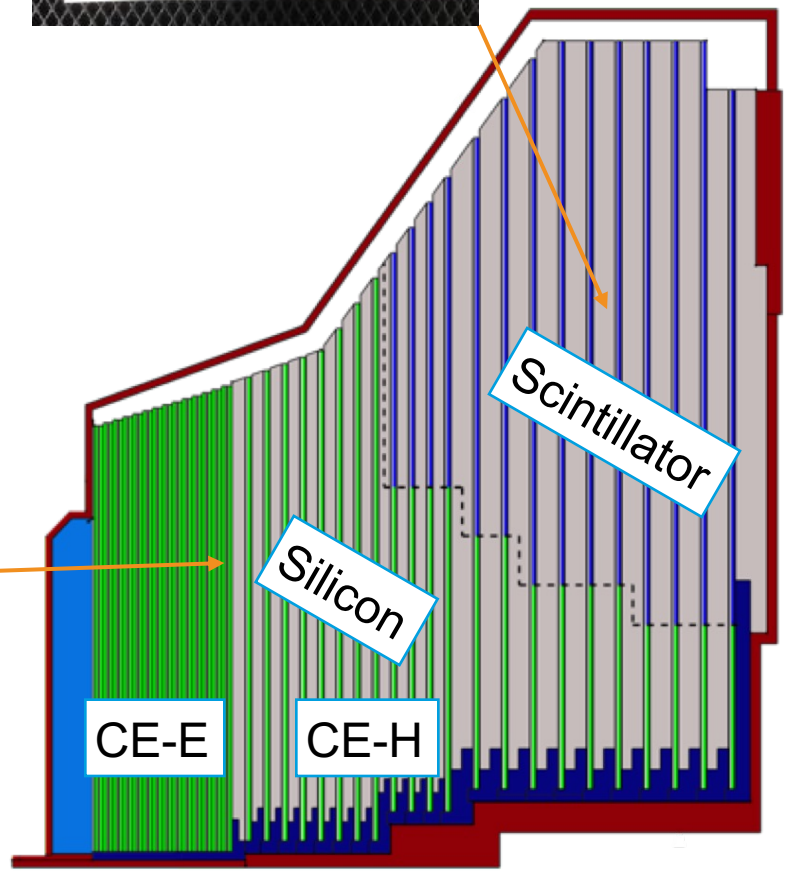
CMS HGCAL

Technology

- current CMS calo endcap will not survive in HL-LHC conditions
- in 2015, decided to replace it with silicon-based **H**igh-**G**ranularity **cal**orimeter
- synergy with CALICE high granularity calorimeter concepts
  - Hexagonal modules based on Si sensors in CE-E and high-radiation regions of CE-H
  - Scintillating tiles with on-tile SiPM readout in low-radiation regions of CE-H
- ~620m^2 Si sensors in ~26000 modules
- ~6M Si channels, 0.6 or 1.2cm^2 cell size
- ~370m^2 of scintillators in ~3700 boards
- ~240k scint. channels, 4-30cm^2 cell size





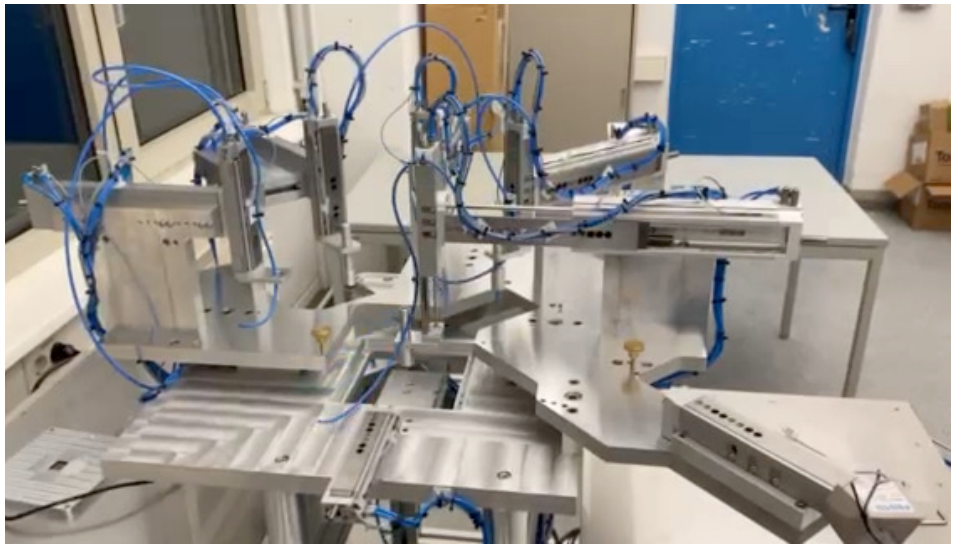


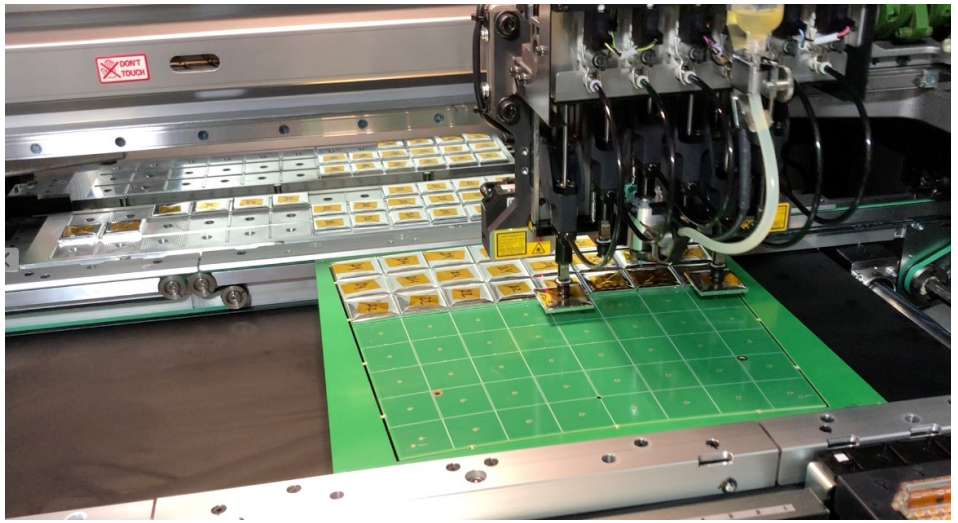
SiPM-on-Tile Technology for HGCAL

- 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
  - More flexible and robust assembly procedures
    - Tile wrapping
    - Tile glueing

DESY Contributions:

- Development of Tile-modules (board-level electronics) and production techniques (tile wrapping and placement)
- Assembly and quality control (QC) of Tile-modules, system and beam tests
- Contributions to the HGCAL low-level offline software
- Ongoing efforts in High-level reconstruction and ML





Summary

- SiPM-on-Tile calorimetry offers high granularity and good energy resolution at reasonable cost
- SiPM-on-Tile technology can be adapted to different conditions
  - Electron-positron collisions: CALICE AHCAL
  - HL-LHC: CMS HGCAL

- **Active field of detector R&D at DESY and Uni Hamburg**

Thank you!

Backup

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