An engineering prototype for a highly granular hadron calorimeter for a future linear collider

Oskar Hartbrich

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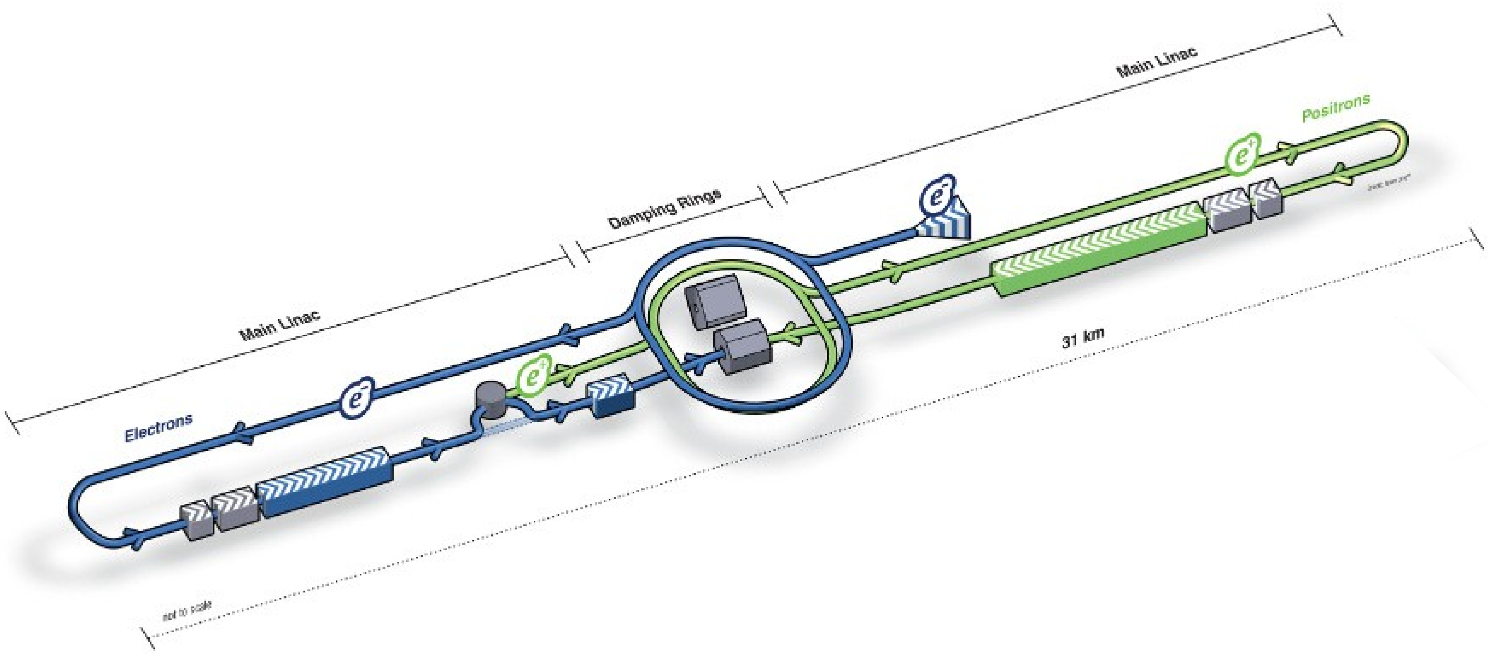
Overview

- International Linear Collider
  - Accelerator
  - Physics
- International Large Detector
- Calorimetry at a future linear collider
  - Particle Flow Algorithms
  - Calorimeter Design
- The CALICE collaboration
- The CALICE AHCAL
  - Scintillator tiles / Silicon Photomultipliers
- Current status of the AHCAL prototype
  - Design
  - Electronics
  - Current Results

International Linear Collider

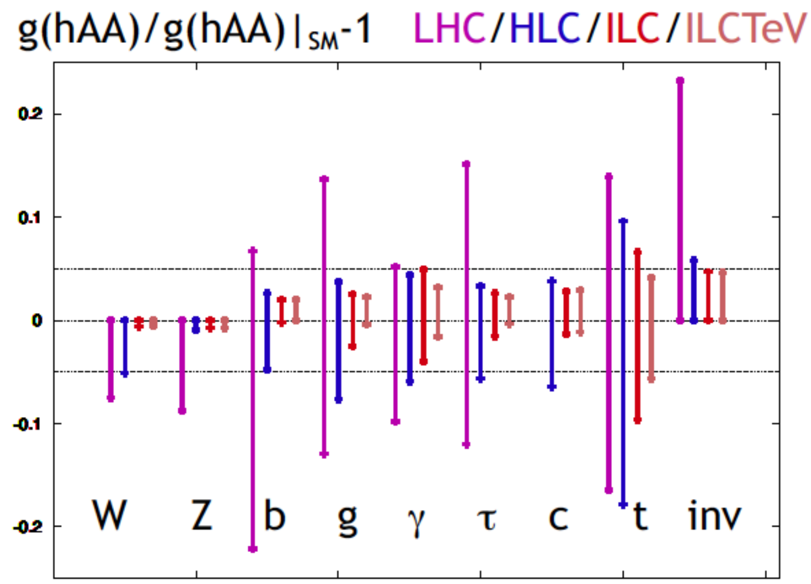
The International Linear Collider (ILC)

- e+e- linear collider, √s = 500 GeV (1 TeV upgrade included in designs)
- 31km superconducting cavities
  - DESY development (TESLA)
  - Market-ready (e.g. XFEL)



Physics at the ILC

- Higgs Boson found at LHC
- Really SM Higgs?
  - Coupling proportional to mass?
  - Absolute branching ratios
- ILC is the perfect tool for precision Higgs measurements!
- Capabilities in BSM searches, W, Z and top precision measurements...



LHC: 3000 fb^{-1} pp at $\sqrt{s}$ = 14 TeV
HLC: + 250 fb^{-1} e^+e^- at $\sqrt{s}$ = 250 GeV
ILC: + 500 fb^{-1} e^+e^- at $\sqrt{s}$ = 500 GeV
ILCTeV: + 1000 fb^{-1} e^+e^- at $\sqrt{s}$ = 1 TeV

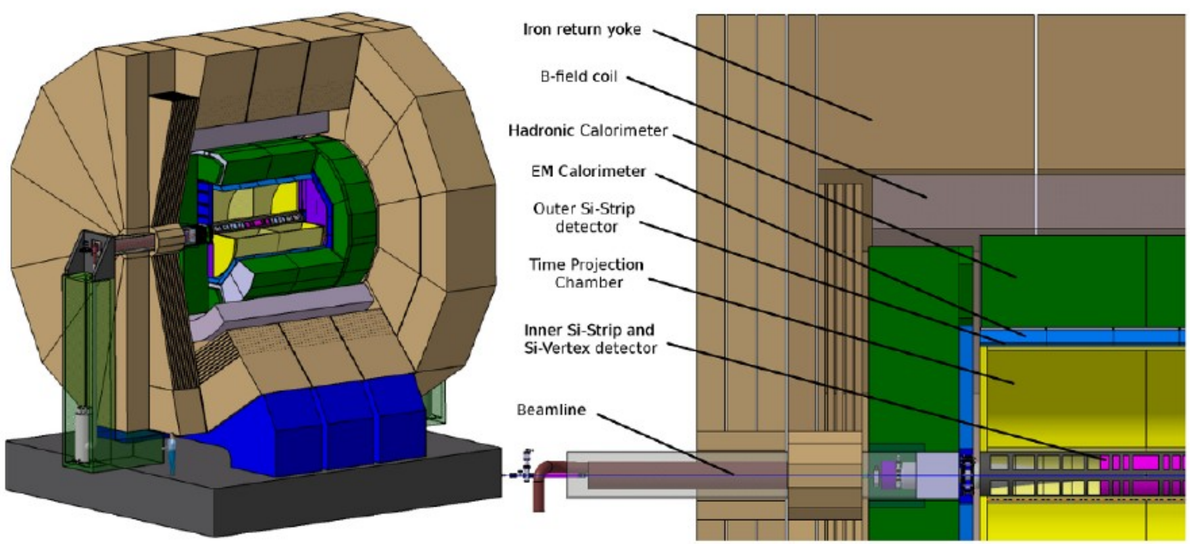
The International Large Detector

- Two detector concepts for ILC, SiD & ILD
  - Only one interaction point in linear collider

    -> Push-pull operation

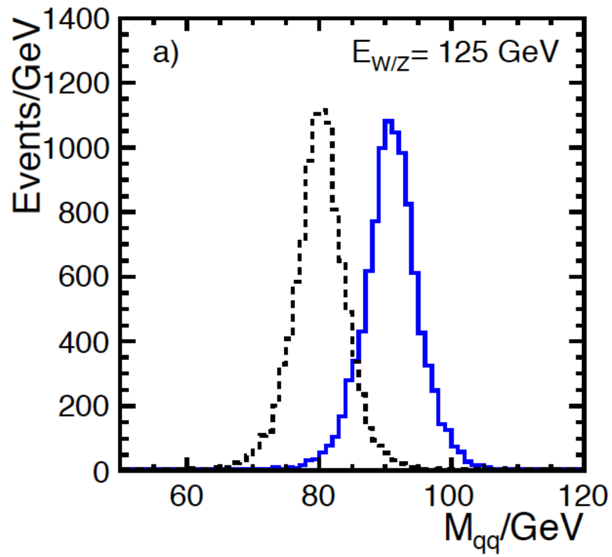
International Large Detector (ILD) design:

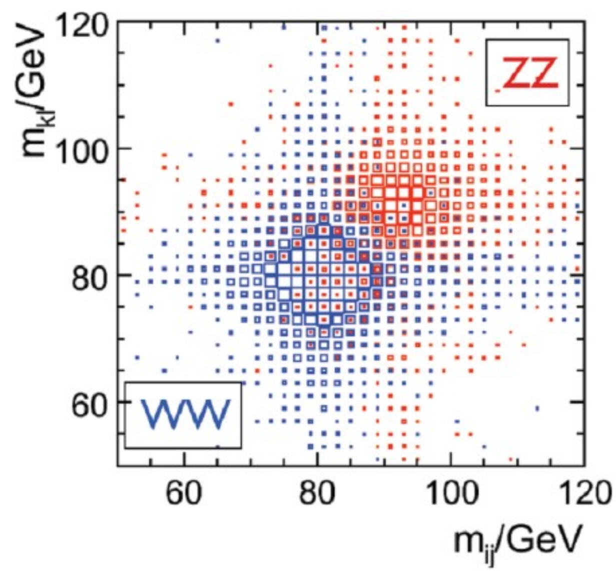
- Large central TPC + Si vertex detectors
- Calorimeters inside superconducting magnet



Calorimetry at a future linear collider

- Design goal: differentiate full hadronic W and Z decays from jet energy reconstruction
- Needs jet energy resolution $\sigma(E_{jet})/E_{jet} \approx$ 3-4% for E_{jet}=40-500 GeV
- Classic hadronic calorimeter:
  $\sigma(E_{jet})/E_{jet} \approx 60\%/\sqrt{E(GeV)}$ ->
  $\sigma(E_{jet})/E_{jet} \approx$ 10% for E_{jet} = 50 GeV
- ILD approach: **P**article **F**low **A**lgorithms

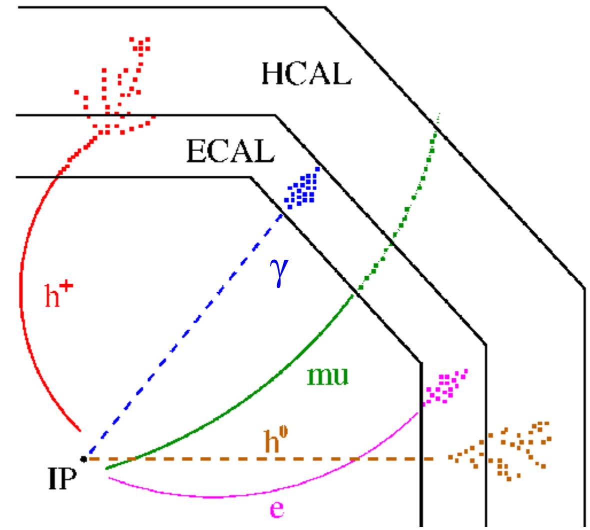


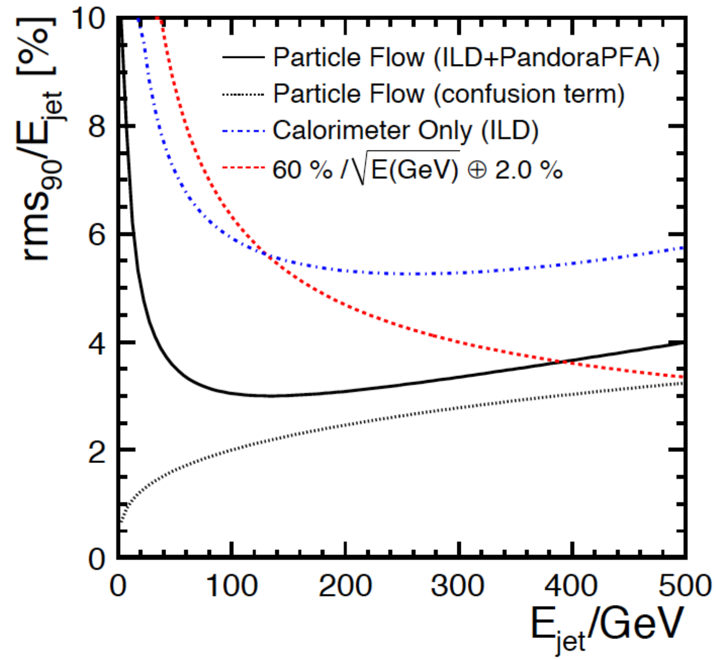


Particle Flow Algorithm

- Momentum resolution in trackers is orders of magnitude better than energy resolution in calorimeters
- Idea: Use detector with best resolution for each particle in a jet
  - Use tracks for charged particles (62% of jet content)
  - Neutral particles are measured in calorimeter (27% photons, 10% neutral hadrons)
- Problem: confusion of charged and neutral calorimeter depositions (overlapping showers)
  - Associate tracks to calorimeter hits
  - Needs very high calorimeter granularity

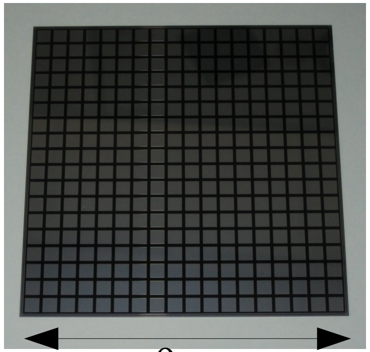
-> Imaging calorimetry



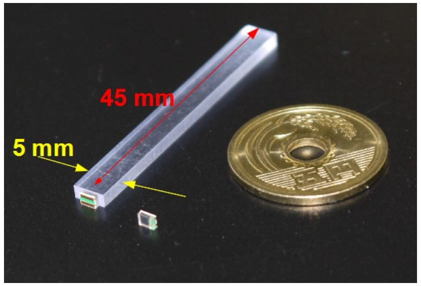


CALICE Collaboration

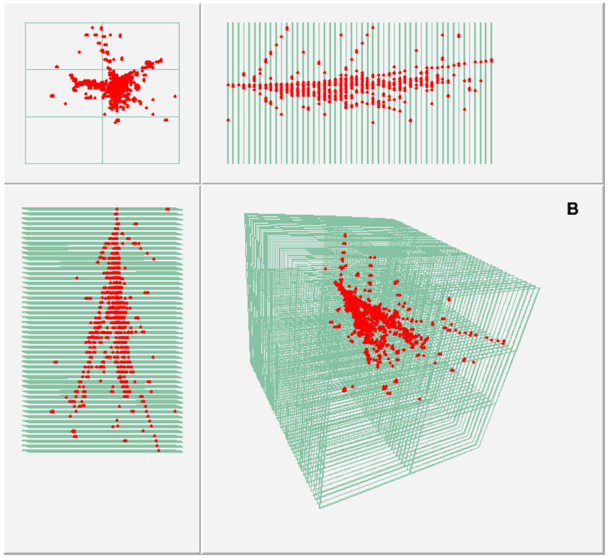
- CALICE: **CA**lorimeters for a **LI**near **C**ollider **E**xperiment
- International effort to explore different options for ILC calorimeters
- Electromagnetic Calorimeters (ECAL):
  - W absorbers
  - Readout options:
    - Silicon (5*5mm^2 pads)
    - Scintillator (5*45mm^2 strips)



9cm

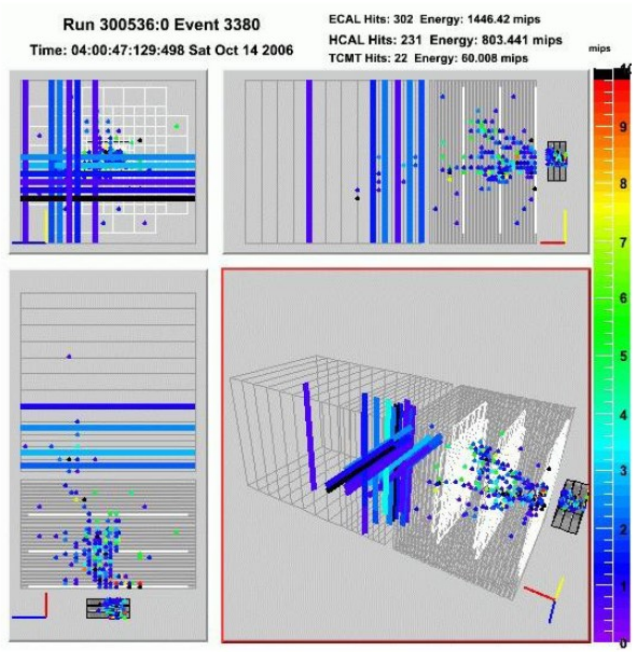


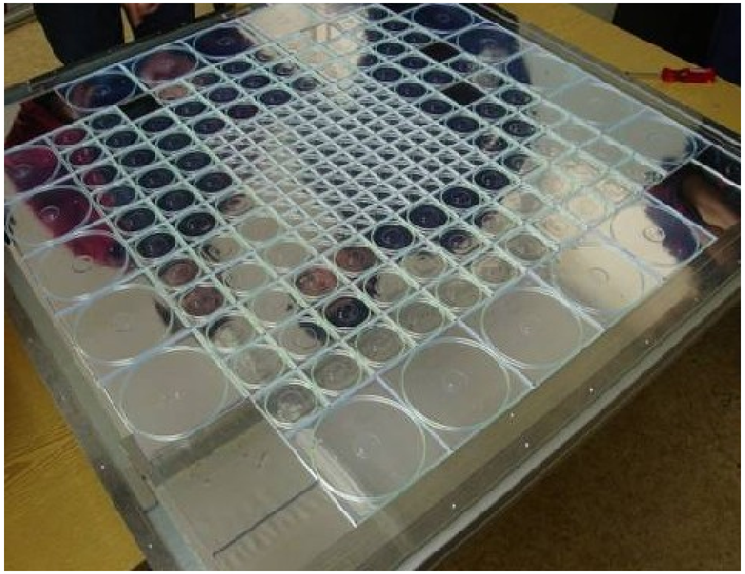
- Hadronic Calorimeters (HCAL):
  - Fe absorbers (W under consideration for higher energy collider)
  - Readout options:
    - Gaseous (1*1cm2)
      - RPCs, GEMs (1-2 bit digitization)
    - Scintillator (3*3cm2)
      - 12bit digitization



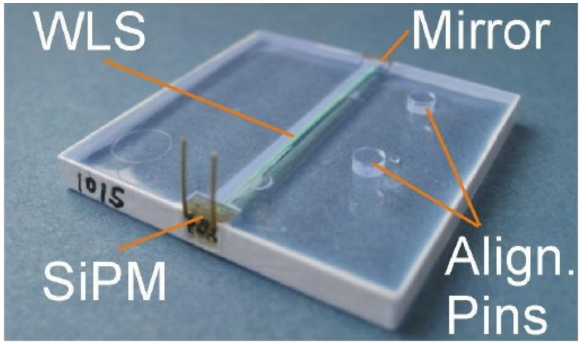
CALICE AHCAL

- CALICE **A**nalog **H**adronic **CAL**orimeter (AHCAL)
- Based on Scintillator tiles (3*3cm^2)
  - Individual Silicon Photomultiplier (SiPM) per cell
- 1m^3 physics prototype used in different testbeams 2006-2012

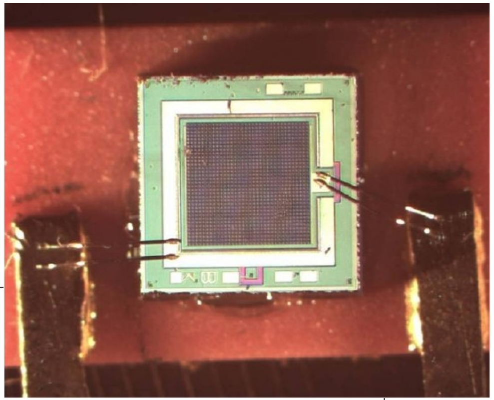




Signal Sampling

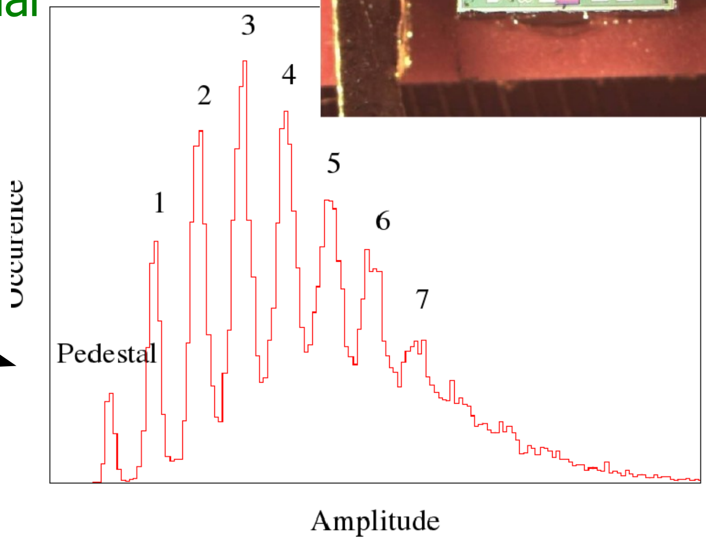


- Scintillator generates light from incident particles (ionisation)
  - Wavelength shifting fiber collects light onto SiPM



Silicon Photomultiplier (SiPM):

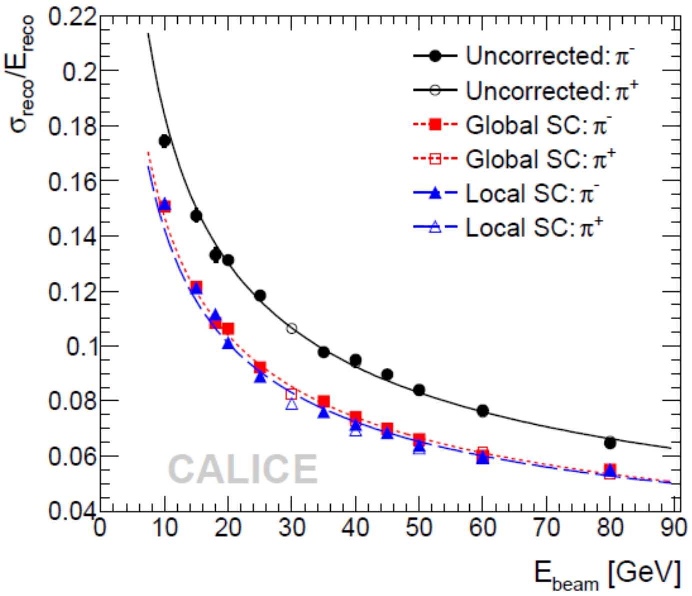
- Multi pixel array of Geiger-mode photodiodes
- Single photons can fire pixels
- Smaller, cheaper, lower bias voltage at similar gains compared to PMTs
- Non-linear, gain is temperature dependent
  - Calibration required
    -> Single photon spectra



AHCAL Performance

- Very successful testbeam campaigns using large range of particles and energies
  - Many published results
  - Valuable input to simulation packages

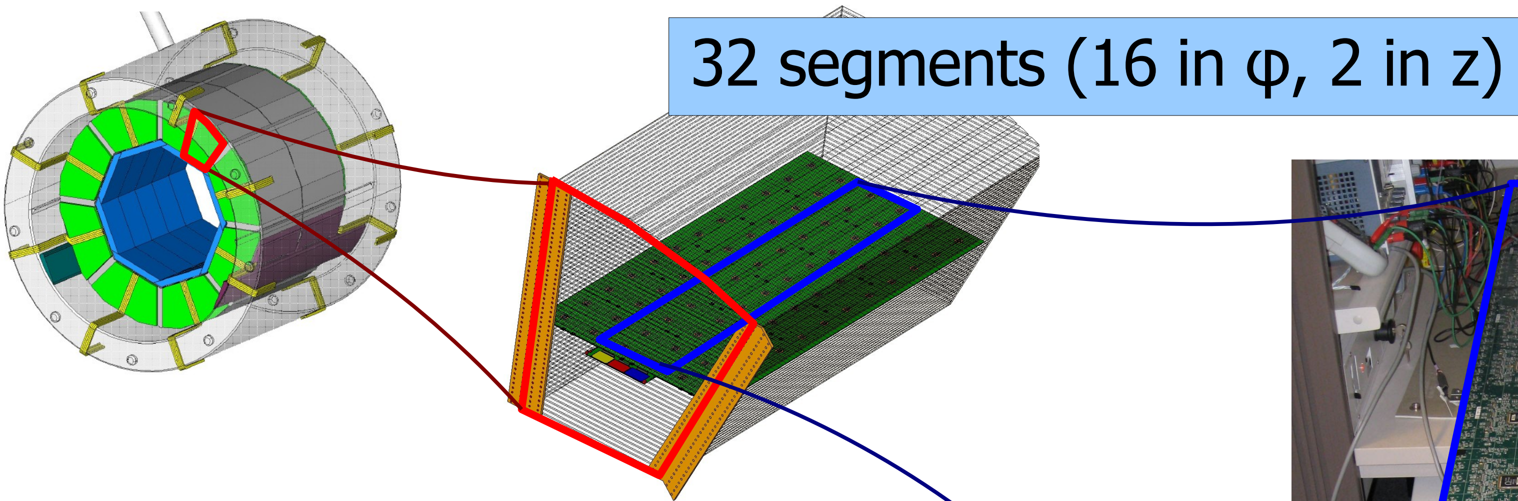
  -> Scintillator-SiPM readout is a feasible option for a highly granular calorimeter

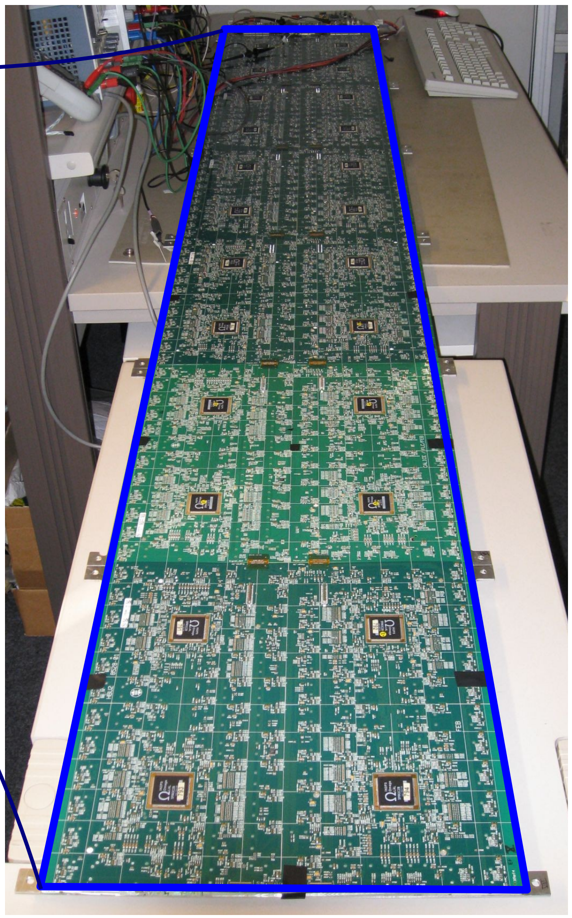


- Physics prototype not scalable to full ILD size
  - Readout and power supply electronics completely external
  - Power dissipation not optimised

- Development of an engineering prototype
  - Meeting all ILD constraints
  - Fully integrated electronics

The AHCAL Engineering Prototype





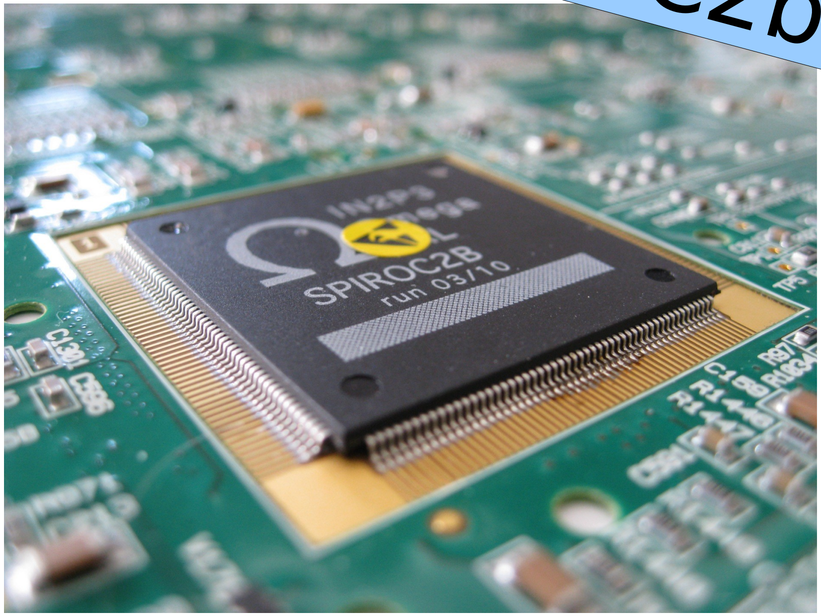
- 40 layers per half-octant
- 3 *slabs* of 6 PCBs per layer
- 8 Millions of channels! 50000 boards
- Challenge: readout fully integrated into layers
  - Readout, power, calibration etc.
  - Tight space between absorbers
  - No active cooling inside layers

Readout Chip

- SPIROC ASIC family designed by OMEGA (France)
- Provides readout for 36 SiPMs
  - Individual bias voltage per channel
  - 12bit dual gain ADC
  - Auto trigger
    - External validation mode
  - 12bit TDC (<1ns resolution)
  - Low power dissipation (25uW/channel)

    → Power pulsing (<1% duty cycle)

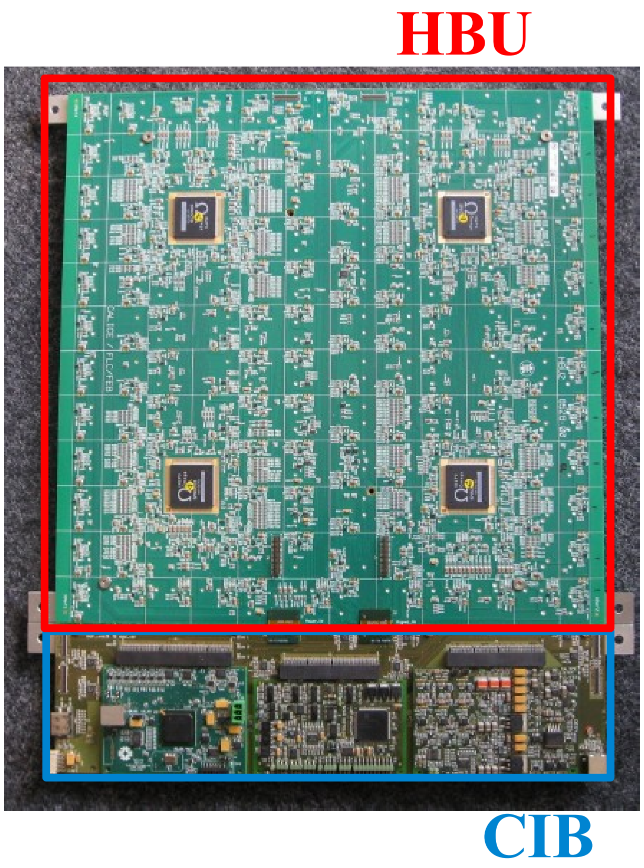
SPIROC2b



The HCAL Base Unit (HBU)

- 4 ASICs, 144 channels per PCB
- Extra thin PCB with cutouts for ASICs
- Integrated SiPM calibration system
  - Individual LED per channel
- One Central Interface Board (CIB) per layer
  - Power board
  - Calibration and trigger controller
  - DAQ interface

- 5 HBUs equipped and calibrated in DESY electron beam
  - 8 fresh HBUs to be equipped with tiles
  - Flexible in choice of tiles
    - New developments by Uni HH, ITEP
    - Rapid SiPM development progression



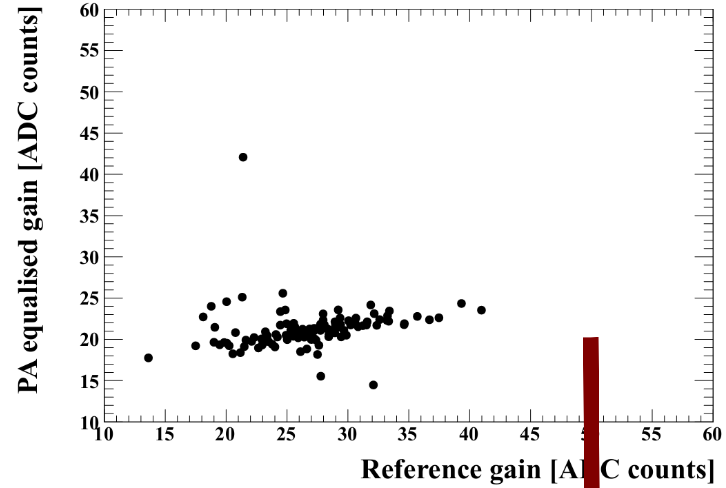
The road to a full prototype

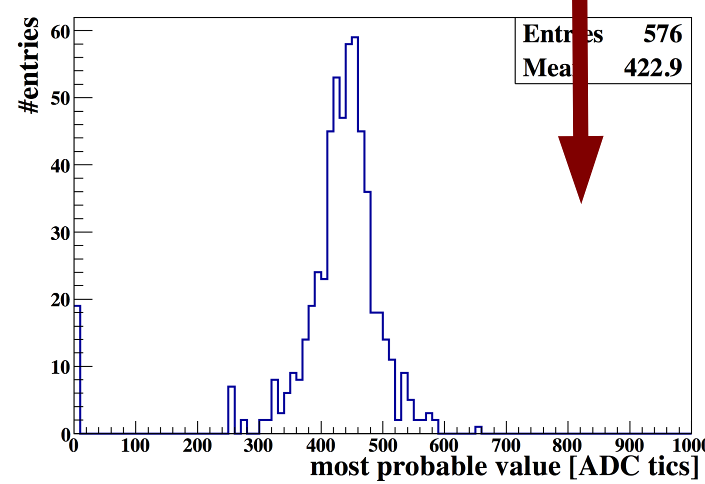
Operation modes to be tested:

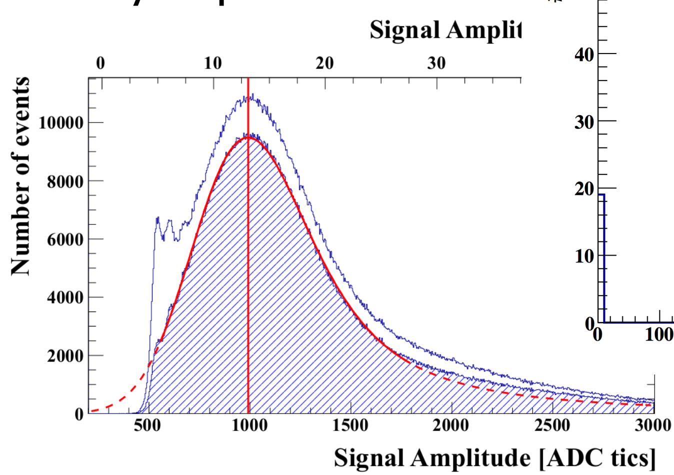
- Single HBUs in lab and testbeam
- Multiple boards in one slab (1D extension)
- Multiple HBUs in one layer (2D extension)
- Multiple layers in one detector (3D extension)

Commissioning

- Calibration and setup of bias for each channel
- Configuration of preamplifiers to equalise channel gain after digitisation
  - Should lead to homogenous MIP response on ADC scale
- Set autotrigger thresholds
  - Self triggered operation, data below threshold is lost
- MIP calibration
- Scalability of procedures is very important







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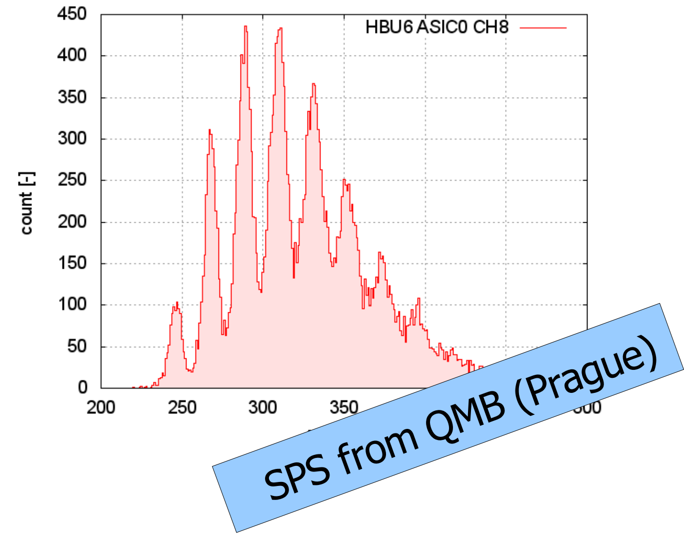
- Multiple layers in one detector (3D extension)

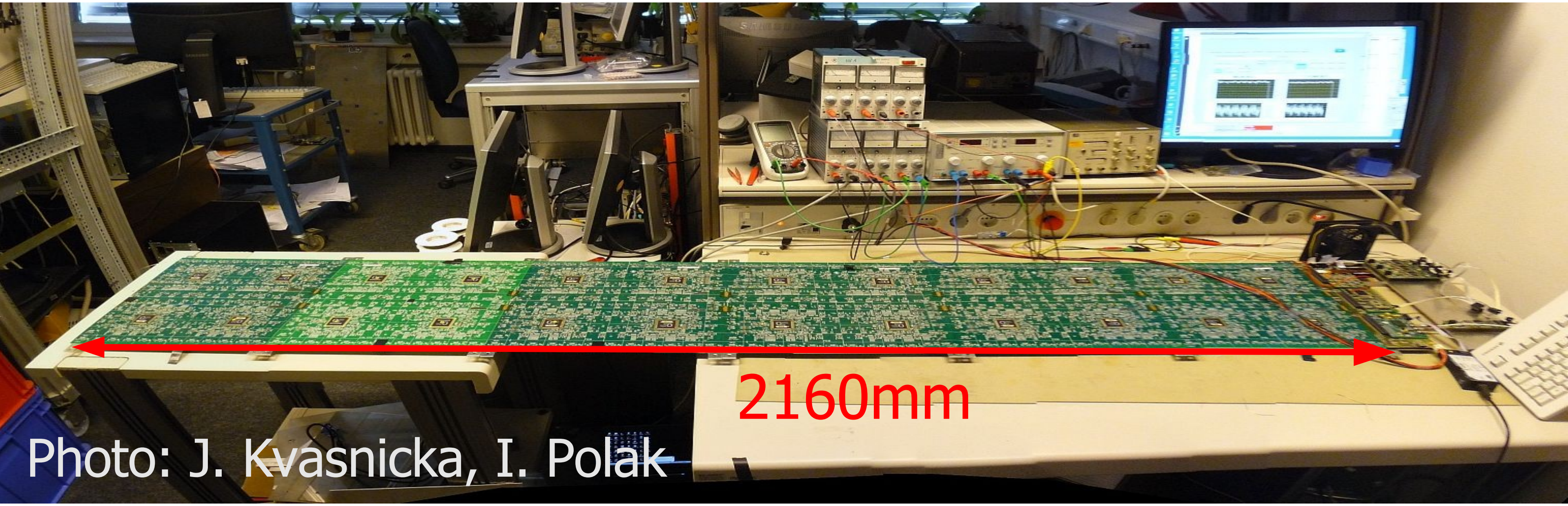
Full Slab Test

Full slab assembled in lab

- 6 serial HBUs
- Readout & calibration system tests

- Readout unhindered by 2.2m signal path





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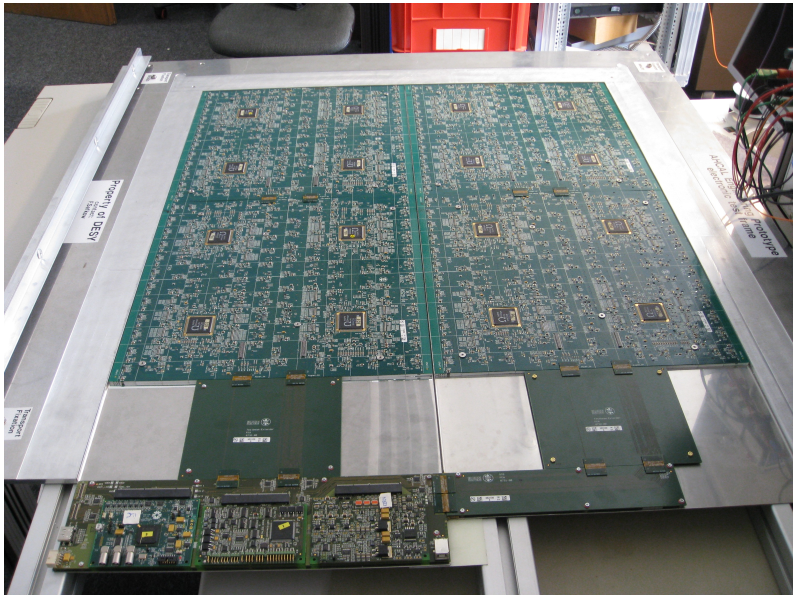
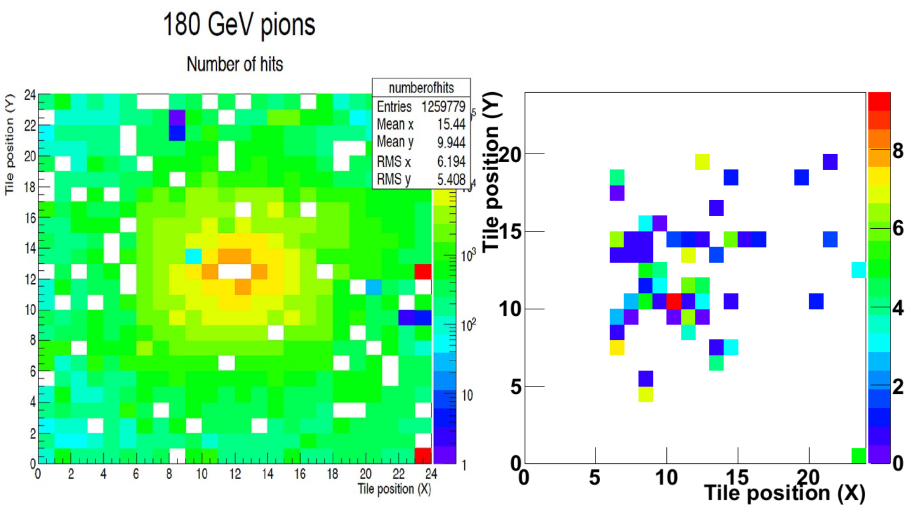
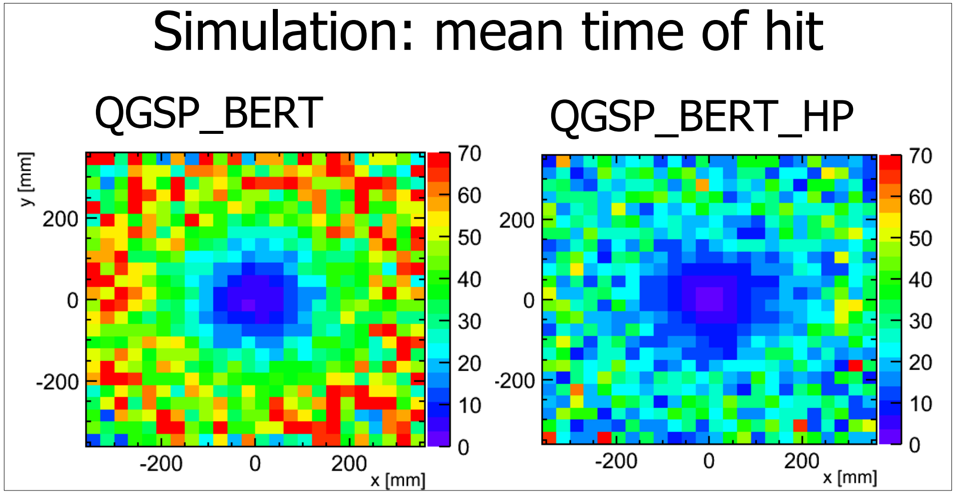
- Single HBUs in lab and testbeam ✓
- Multiple boards in one slab (1D extension) ✓
- Multiple HBUs in one layer (2D extension)
- Multiple layers in one detector (3D extension)

CERN Layer (2x2)

- First setup with parallel slabs
  - Still single layer, single CIB
  - 576 channels
- CERN hadron testbeam
  - Muons, Pions (behind $3.8\lambda_i$)
  - Physics: timing of hadron showers
    - First beam test of SPIROC2b TDC







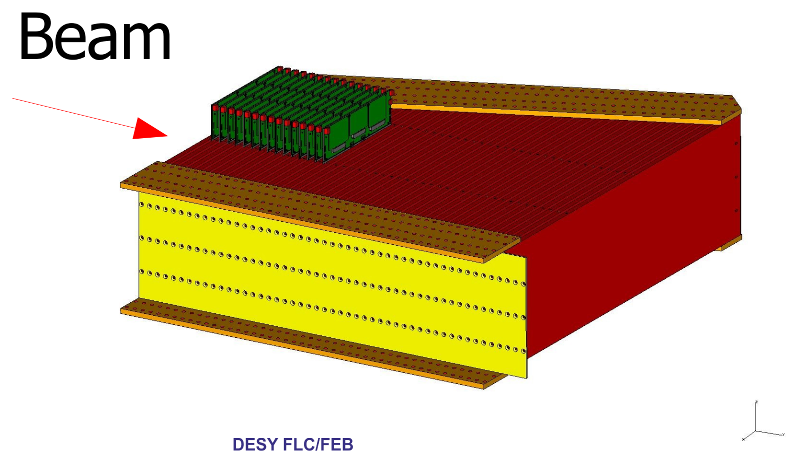
The road to a full prototype

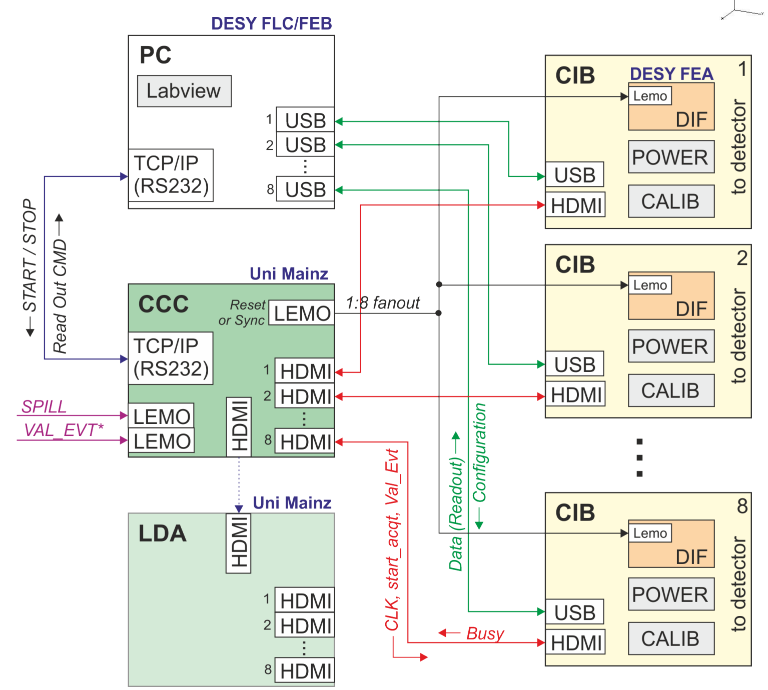
Operation modes to be tested:

- Single HBUs in lab and testbeam ✓
- Multiple boards in one slab (1D extension) ✓
- Multiple HBUs in one layer (2+1D extension) ✓
- Multiple layers in one detector (3D extension)

Multilayer Setup

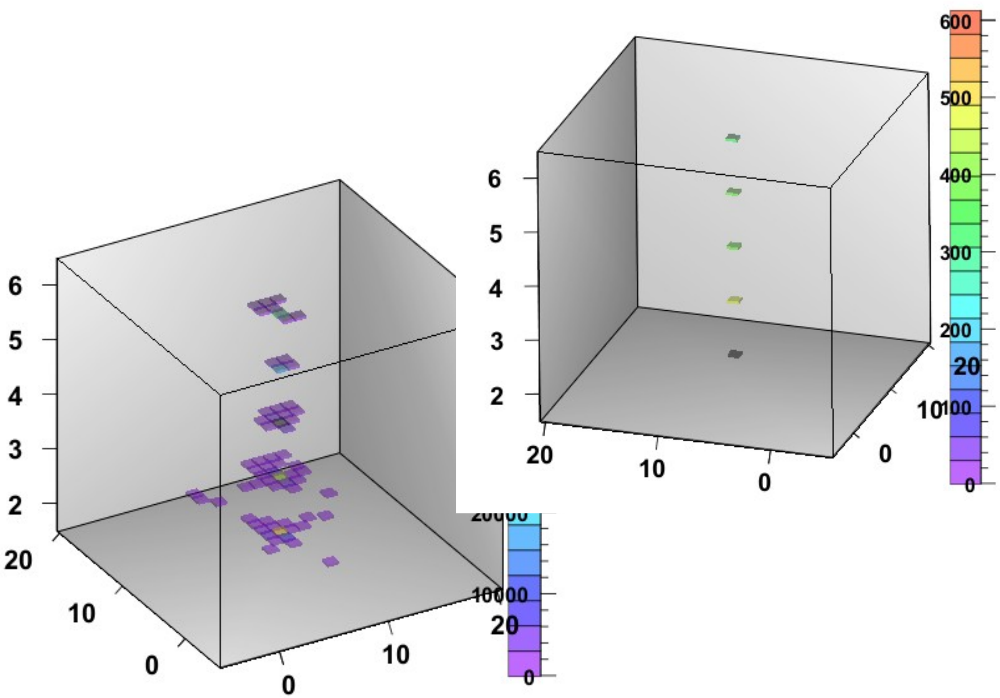
- At the moment: no hadron beams available
- Start in DESY beam (EM showers)
  - Using available ILD prototype absorber
- Synchronous operation of multiple layers requires DAQ rework
  - Single layer operated via USB and Labview
    - Local clock generated on CIB
  - Multilayer needs central clock generation
    - Needs distribution of fast signals
    - Hardware from Uni Mainz
  - First step: data via USB, fast signals via HDMI
    - Next step: Data also via HDMI, dedicated data aggregation hardware
  - New DAQ software
    - Still Labview, but modular and faster

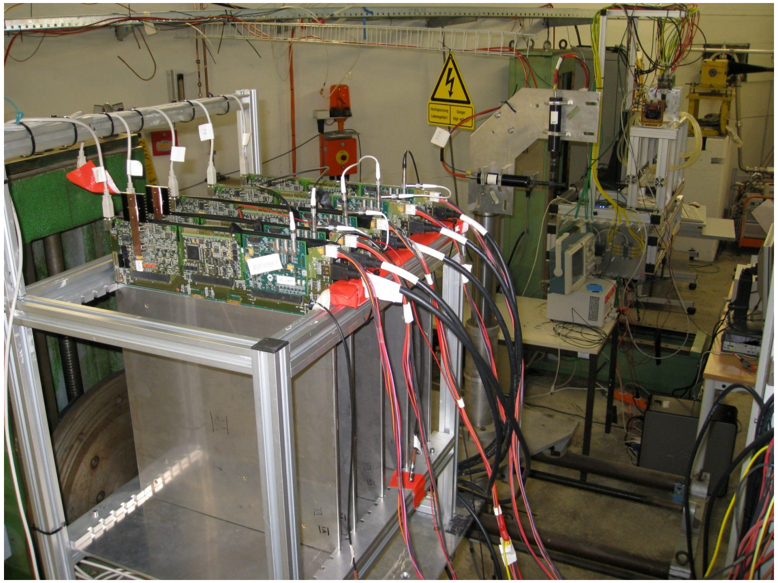


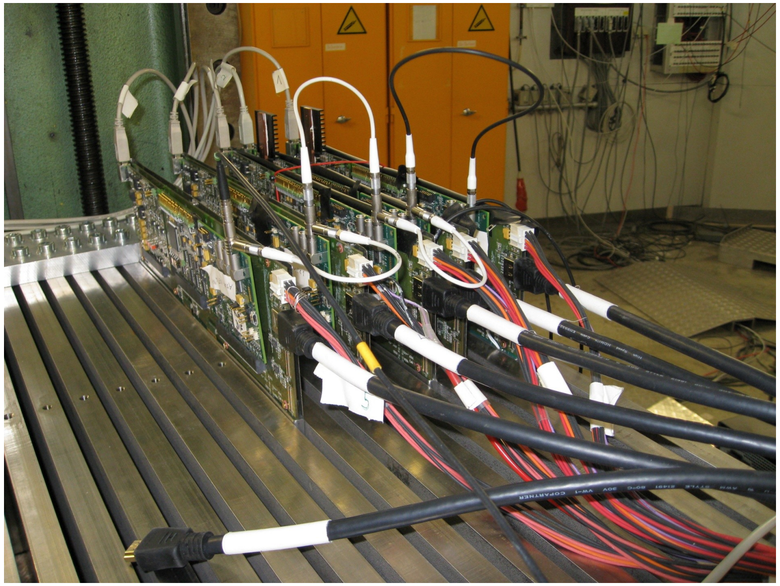


Multilayer Test Beam

- Operation of 5 synchronous layers
  - Fully self-triggered
  - Airstack for MIP calibration
  - ILD absorber for first calorimetric data
  - All mechanics already in ILD format!

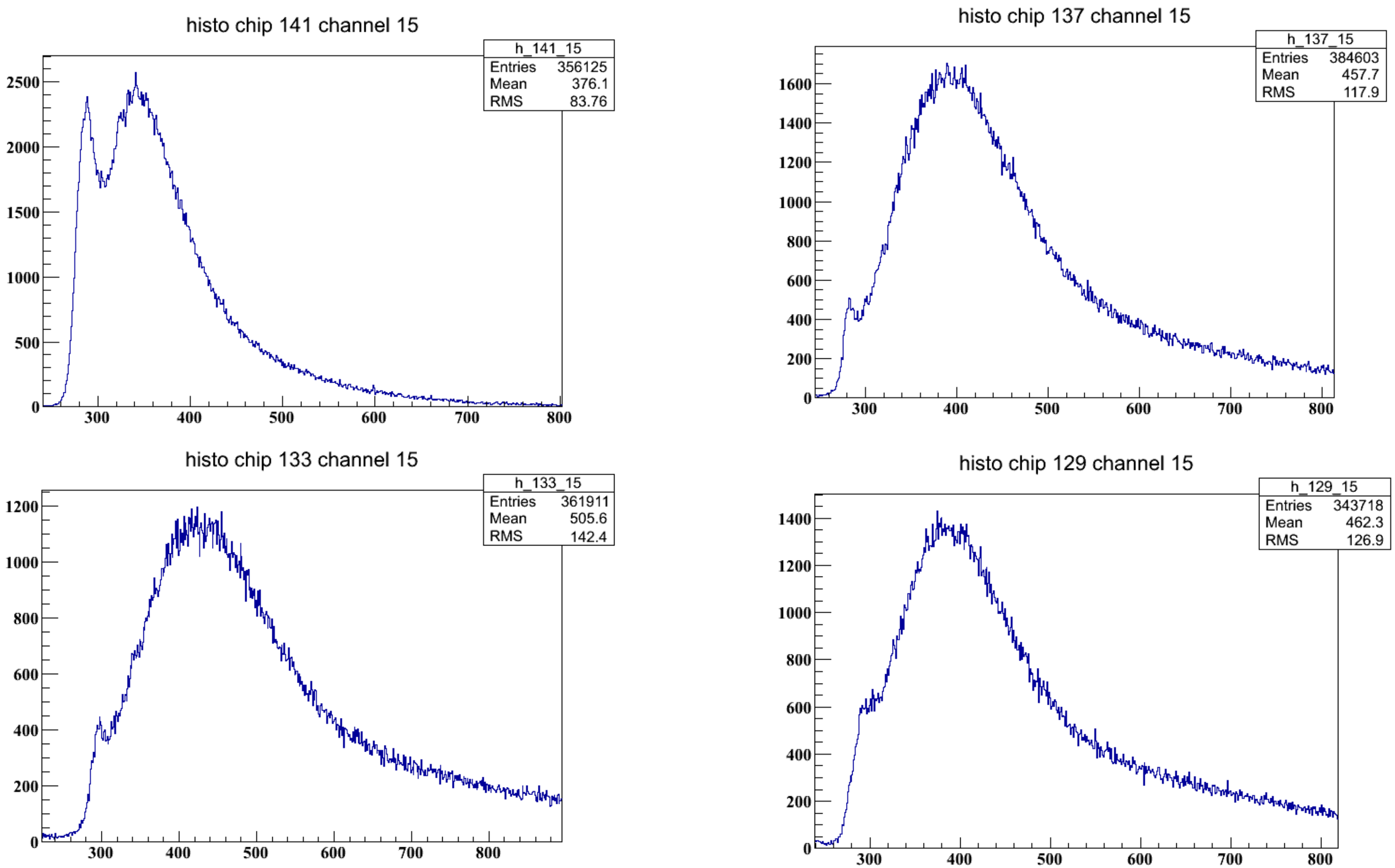






Multilayer MIPs

Synchronous MIP calibration through several layers:



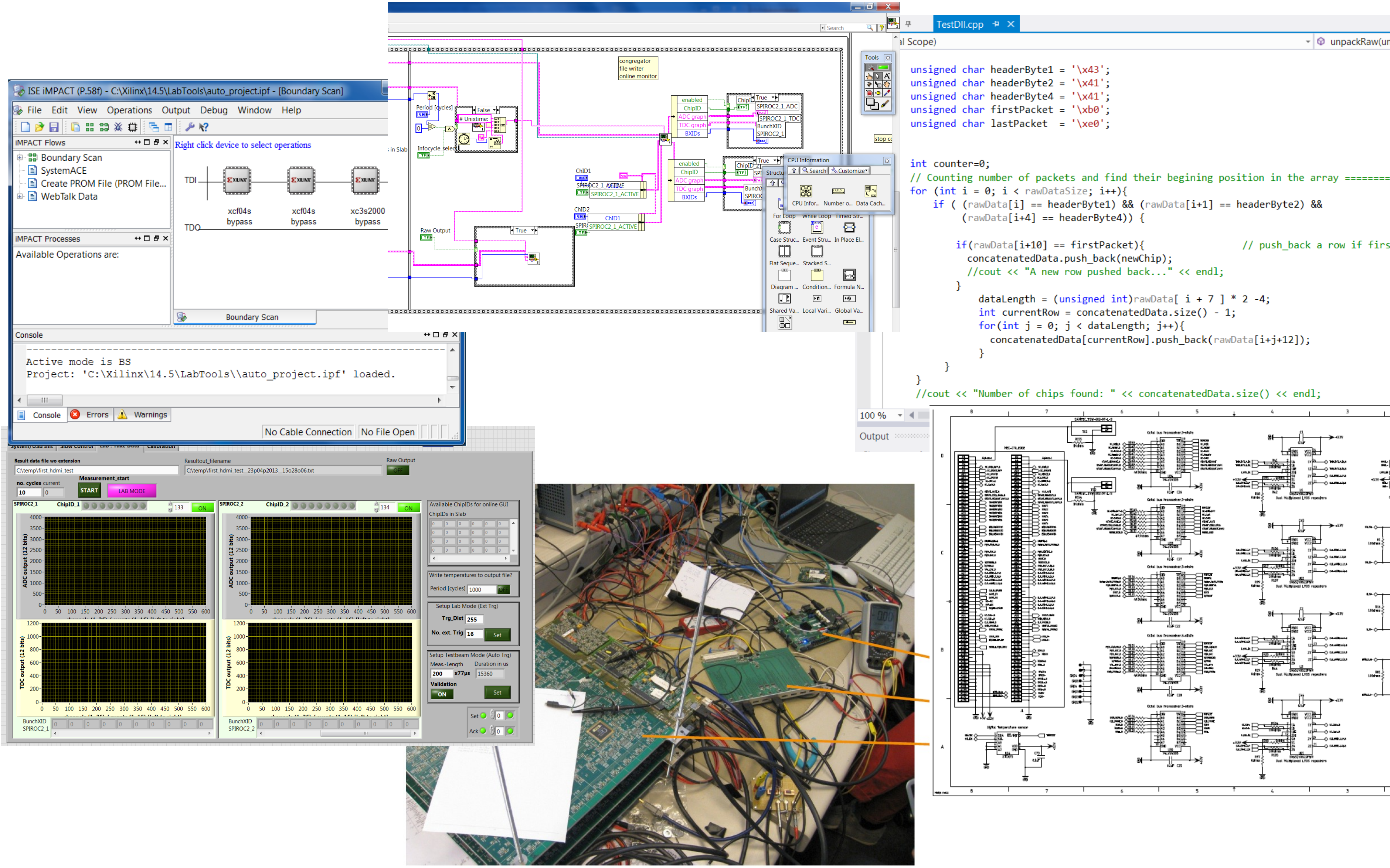
The road to a full prototype

Operation modes to be tested:

- Single HBUs in lab and testbeam ✓
- Multiple boards in one slab (1D extension) ✓
- Multiple HBUs in one layer (2+1D extension) ✓
- Multiple layers in one detector (3D extension) (✓)

Operation is established, gradually increase number of layers!

Ingredients



Summary and Outlook

Summary

- The CALICE collaboration develops calorimeters for a future linear collider
- The AHCAL is a scintillator-SiPM based concept for a hadronic calorimeter
  - Physics performance has been proven in various testbeam campaigns
- Now we are developing a prototype that is scalable to a full detector
  - The first multilayer setups have recently been tested in the DESY beams

Outlook

- Number of layers will increase until the end of this year
  - 4 weeks of beam time end of this year
  - Get first real calorimetric data
- DAQ developments will continue
- We will be ready once hadron beams are coming back!