AHCAL - A Scintillator Hadron Calorimeter For ILD

Technologies, Prototypes and Readout Considerations

Oskar Hartbrich (DESY / BUW)
Teilchenphysik Seminar BUW
15.01.2014

HELMHOLTZ
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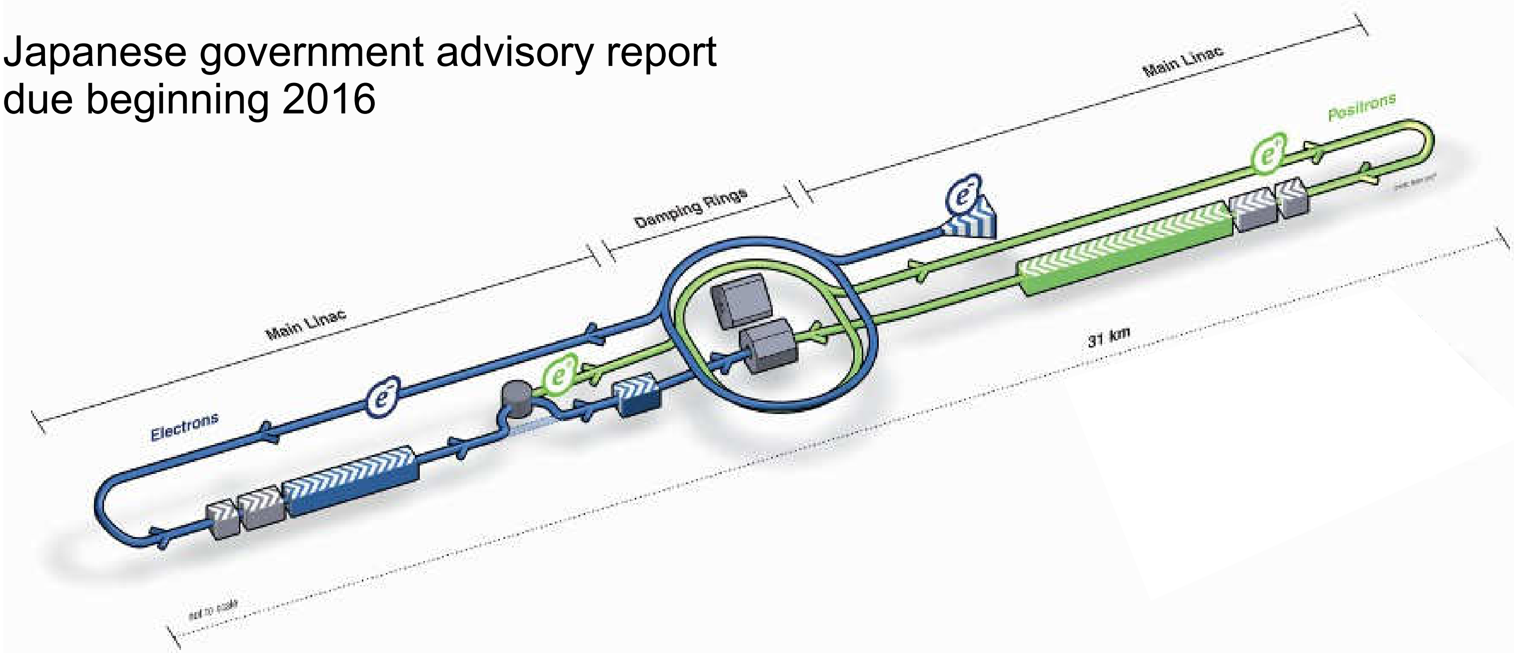
DESY

Overview

- Introduction / Motivation
  - Physics & Calorimetry at ILC
- The CALICE AHCAL project
  - Technologies & Prototypes
- Operating a High Granularity Calorimeter
  - Constraints & Consequences
- Summary / Outlook

International Linear Collider

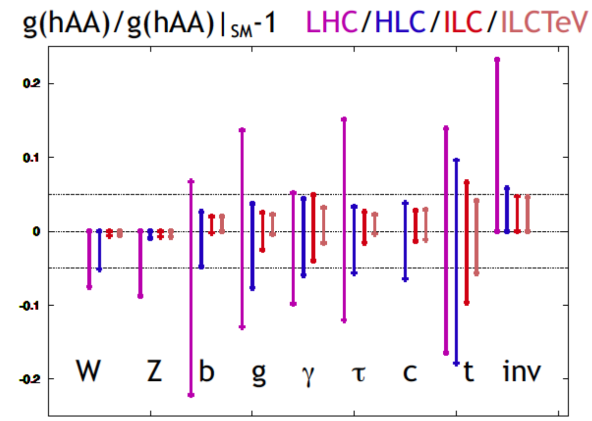
- International Linear Collider (ILC)
  - Electron-positron linear accelerator (polarization ~0.8/~0.3)
  - 250-500 GeV center of mass energy (potential upgrade to ~1 TeV)
  - Based on superconducting RF acceleration (XFEL, FLASH I&II, ...)
  - Potential location: Kitakami, Iwate pref., Japan
- Extensive technical design report published 2013
  - Japanese government advisory report due beginning 2016

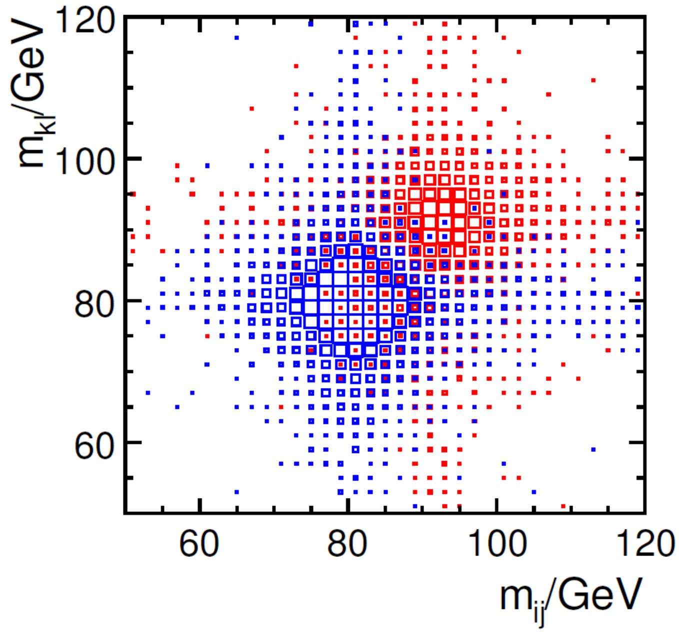


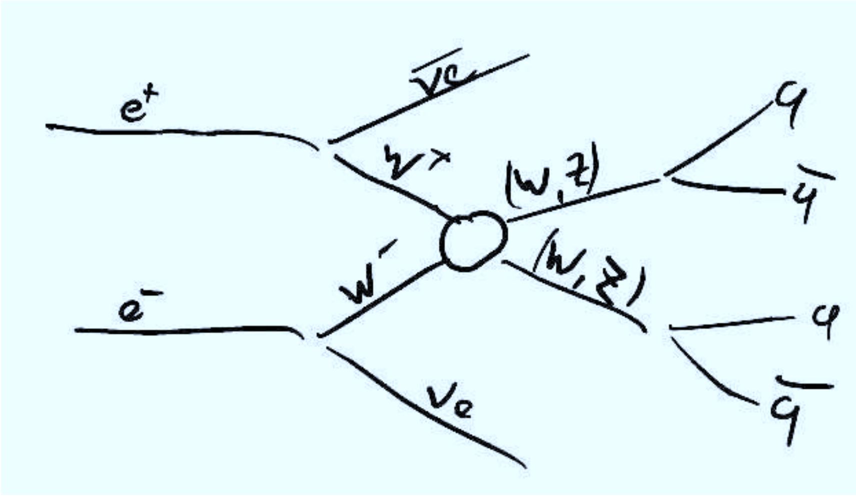
Physics at ILC

- Electroweak precision machine
  - Complementary to LHC
  - Higgs coupling measurement precision
    LHC: O(10%) ILC: O(1%)
- Example: Strong EWSB
  - Vector boson scattering: quartic gauge coupling
  - Need to distinguish hadronic W from Z in calos

    → 3-4% jet energy resolution

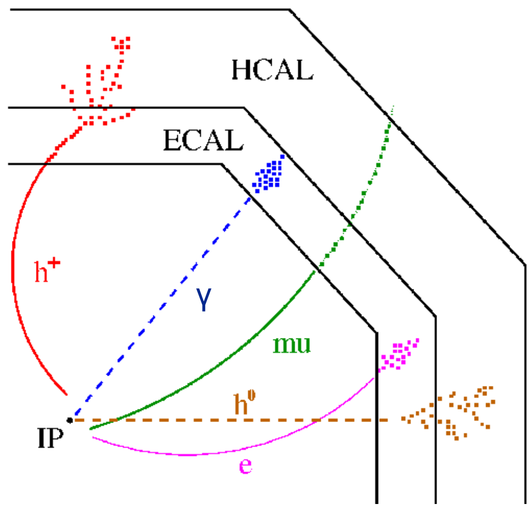


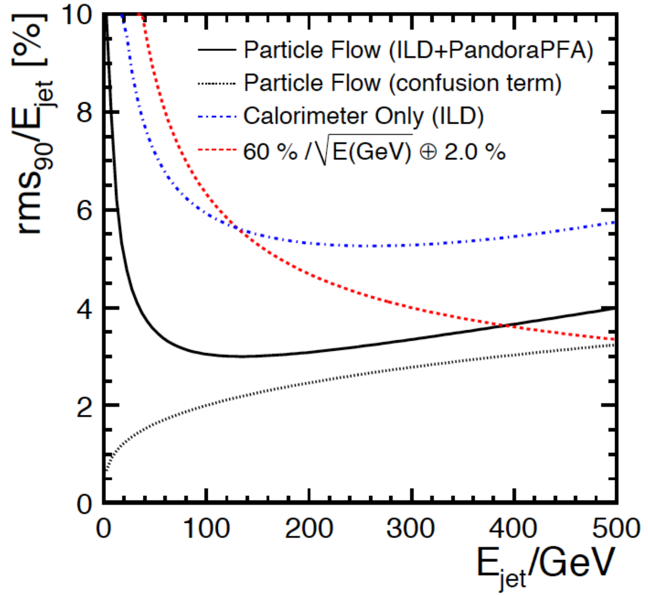




Calorimetry at ILC

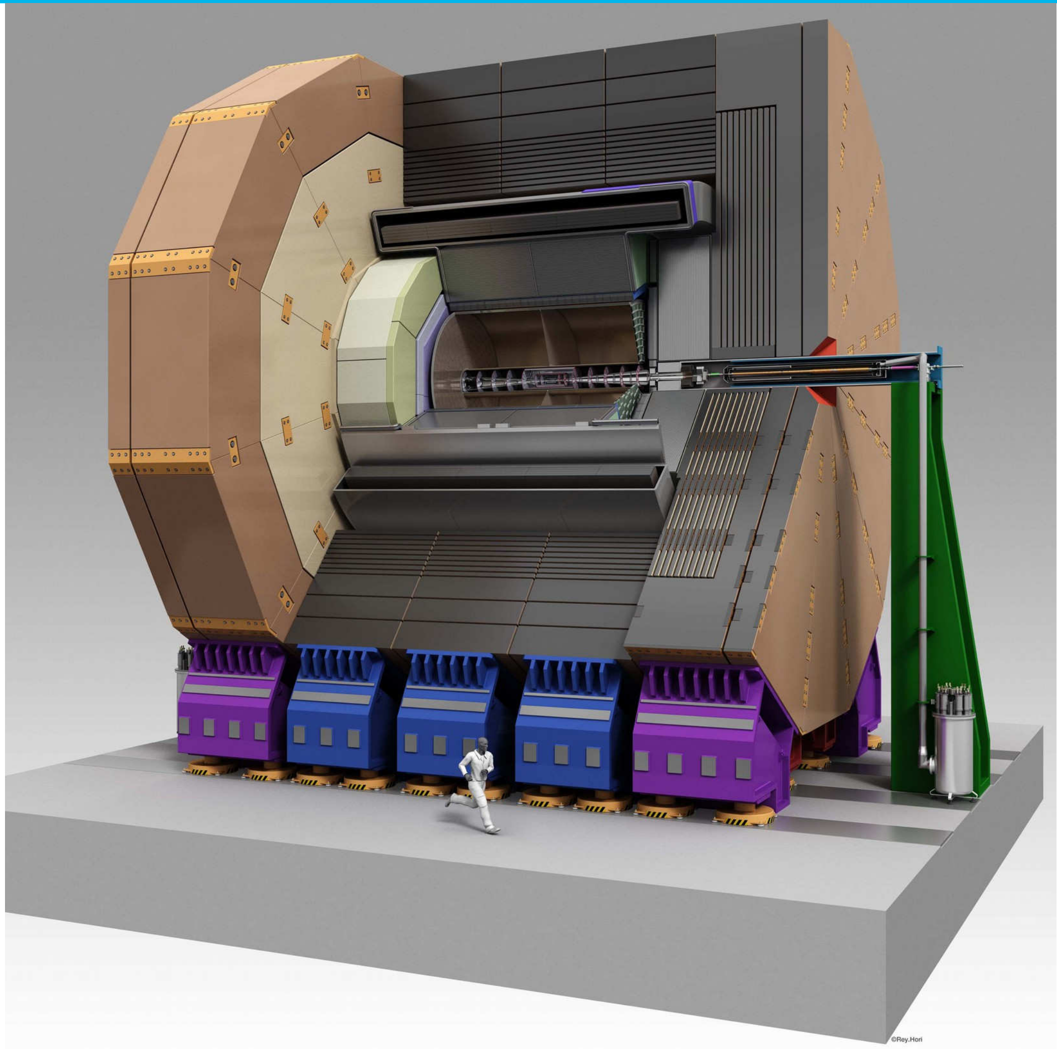
- Needed jet energy resolution not achievable by classical calorimetry
  - ZEUS: 6% width on $Z^0 \rightarrow jj$
- Particle Flow Algorithms (PFAs)
  - Reconstruct all particles in jet
  - Use track momentum for charged particles
  - Only neutral hadrons (~10%) measured in HCAL
  - Confusion: mismatching tracks and depositions
- Requirements for Particle Flow
  - Large tracker with excellent efficiency
  - High magnetic field
  - Very high granularity (all dimensions) calorimeters inside of magnet coil





International Large Detector

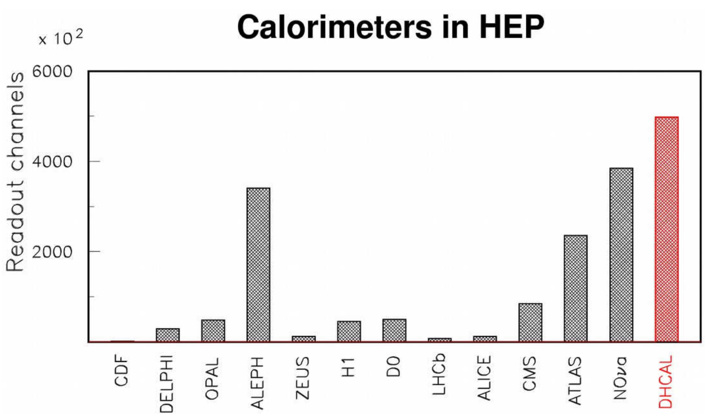
- Silicon vertex detector
- Large TPC central tracker
- High granularity calorimeters
  - 5*5mm^2 ECAL
  - 10*10-30*30mm^2 HCAL
  - Inside coil
- 3.5T magnetic field

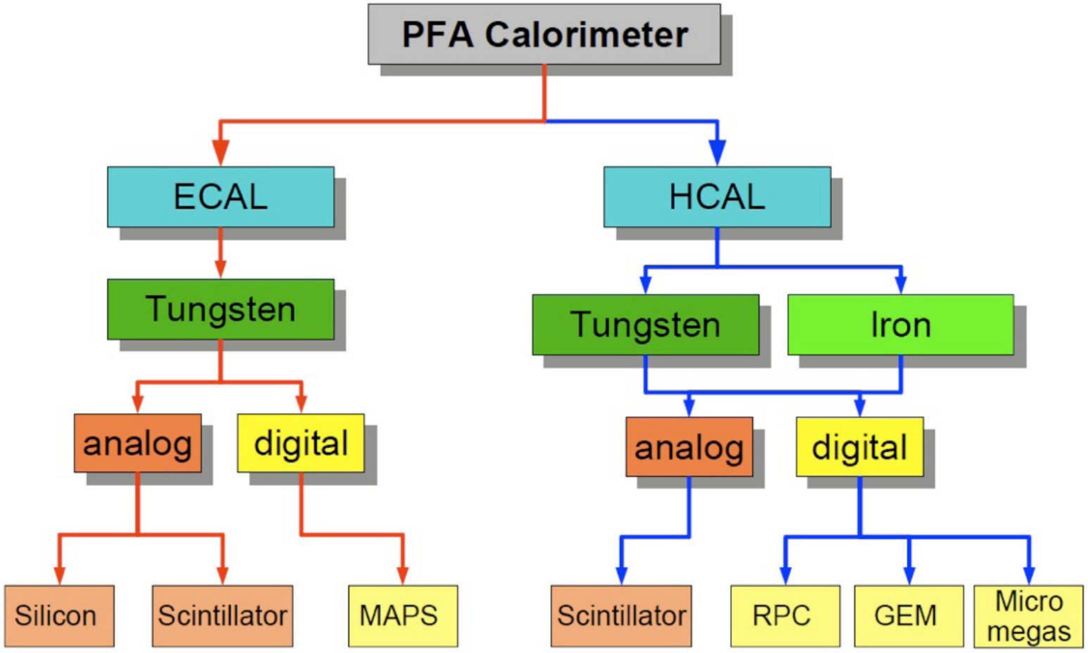


- Silicon Detector (SiD)
  - Slightly smaller
  - All silicon tracking
  - Higher magnetic field

CALICE Collaboration

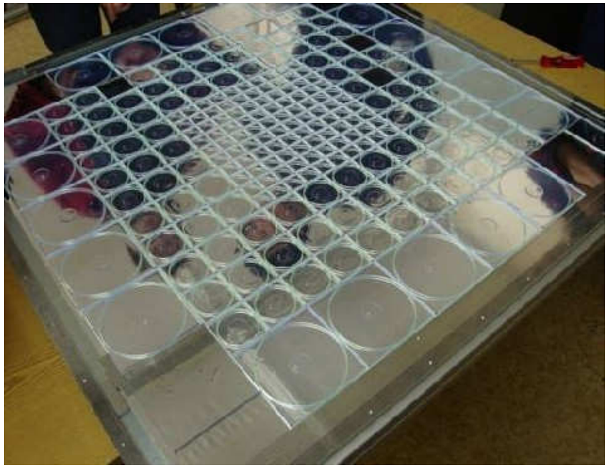
- R&D of Particle Flow calorimeters for future linear collider experiments
  - 60 groups/institutes, ~350 people
- Different absorber and detection materials under investigation
  - Sandwich calorimeter, very high granularity in X/Y/Z
  - Multiple large scale prototypes built and tested at CERN, DESY and FNAL testbeam facilities

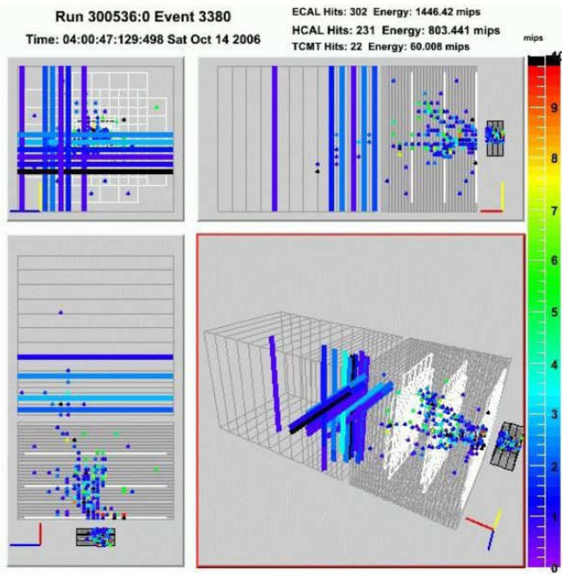




CALICE AHCAL

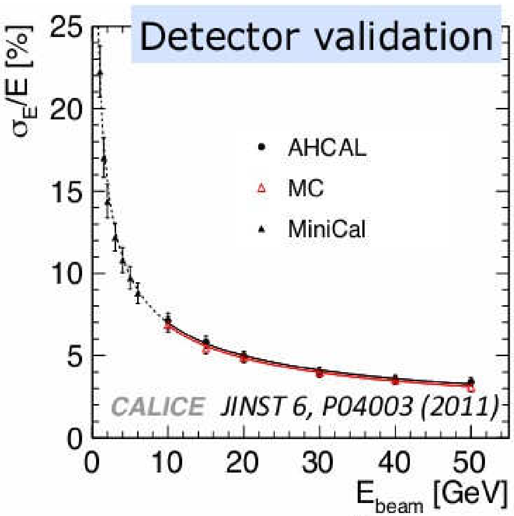
- Analogue Hadronic Calorimeter (AHCAL)
  - Scintillator tiles, 3*3cm^2 segmentation
  - Each tile read out by single SiPM
- 1m^3 AHCAL physics prototype
  - Up to 38 layers instrumented
  - 7608 channels total
  - First large scale SiPM based experiment
  - Operated in testbeams 2006-2012
  - Both Fe and W absorber structures tested
  - Analyses well progressed and published

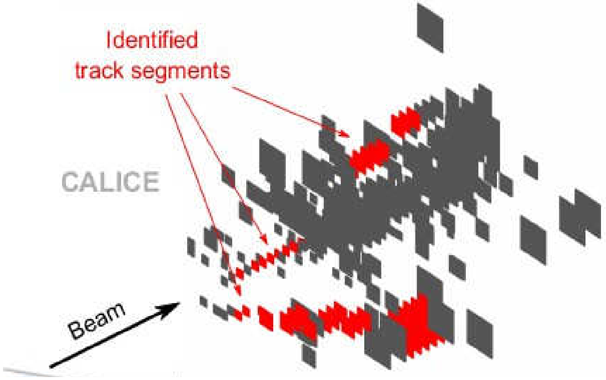


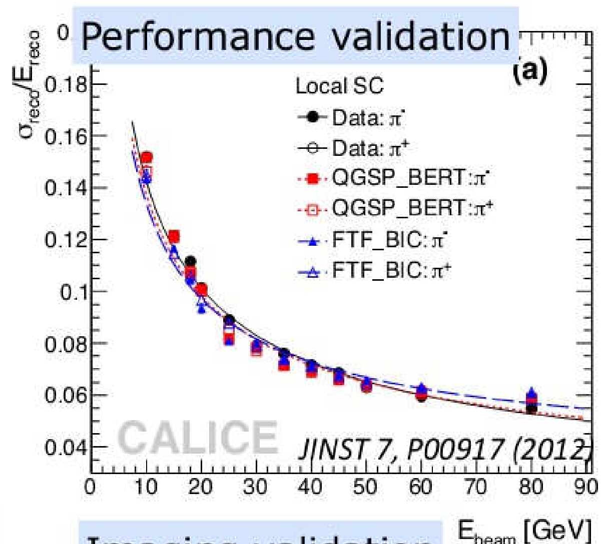


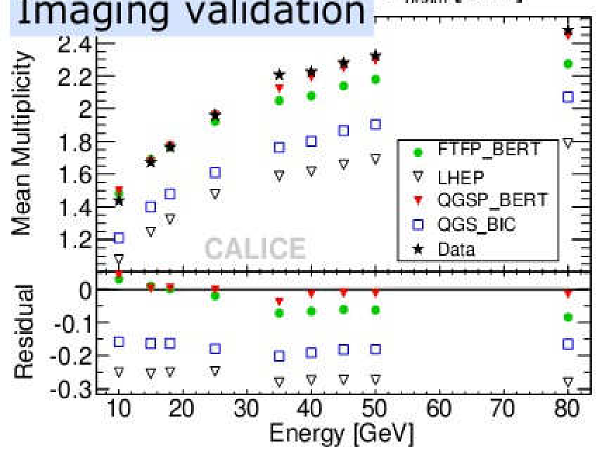
AHCAL Results

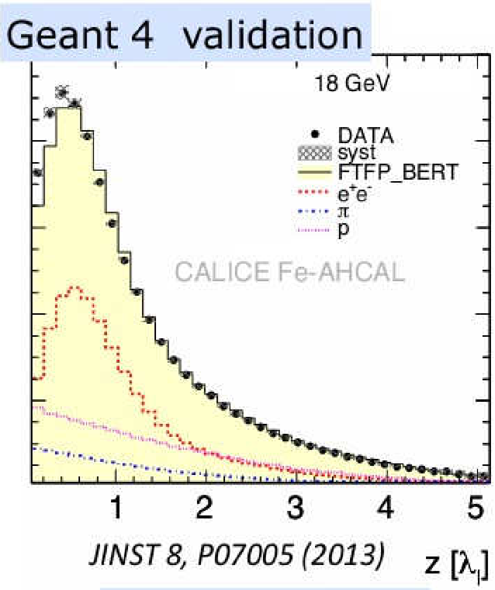
- Concept validated with prototype

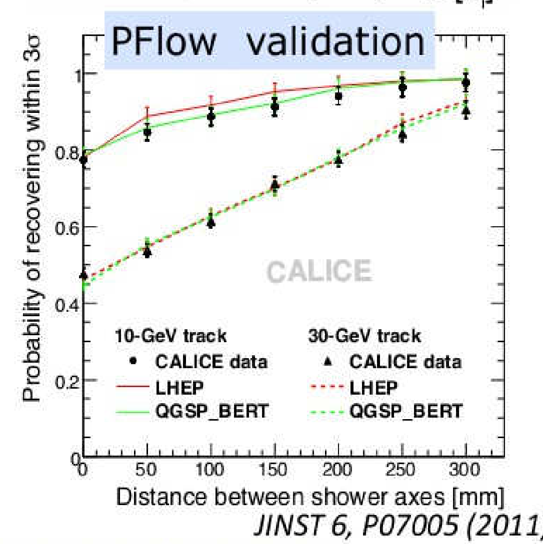






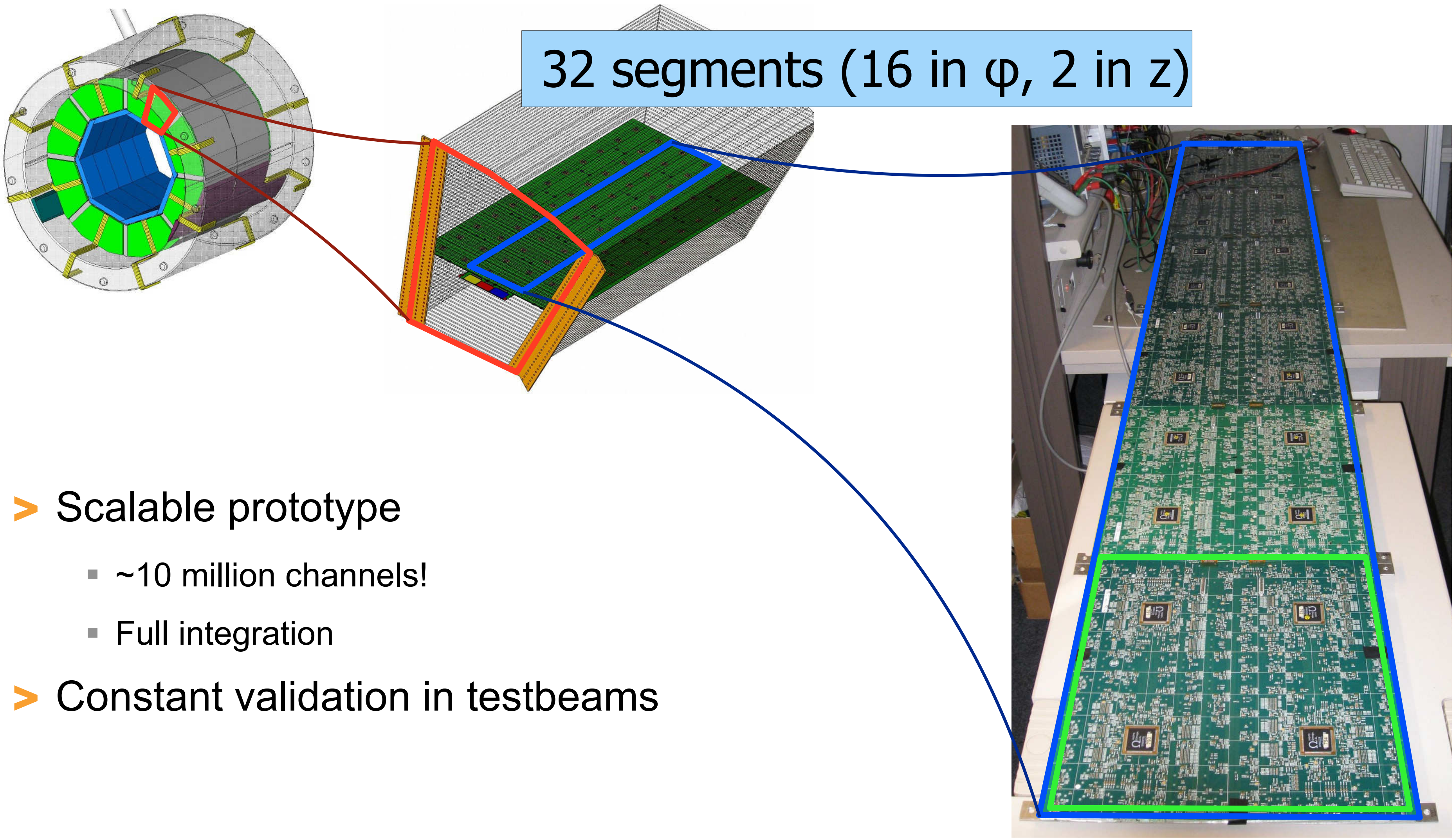






(F.Sefkow)

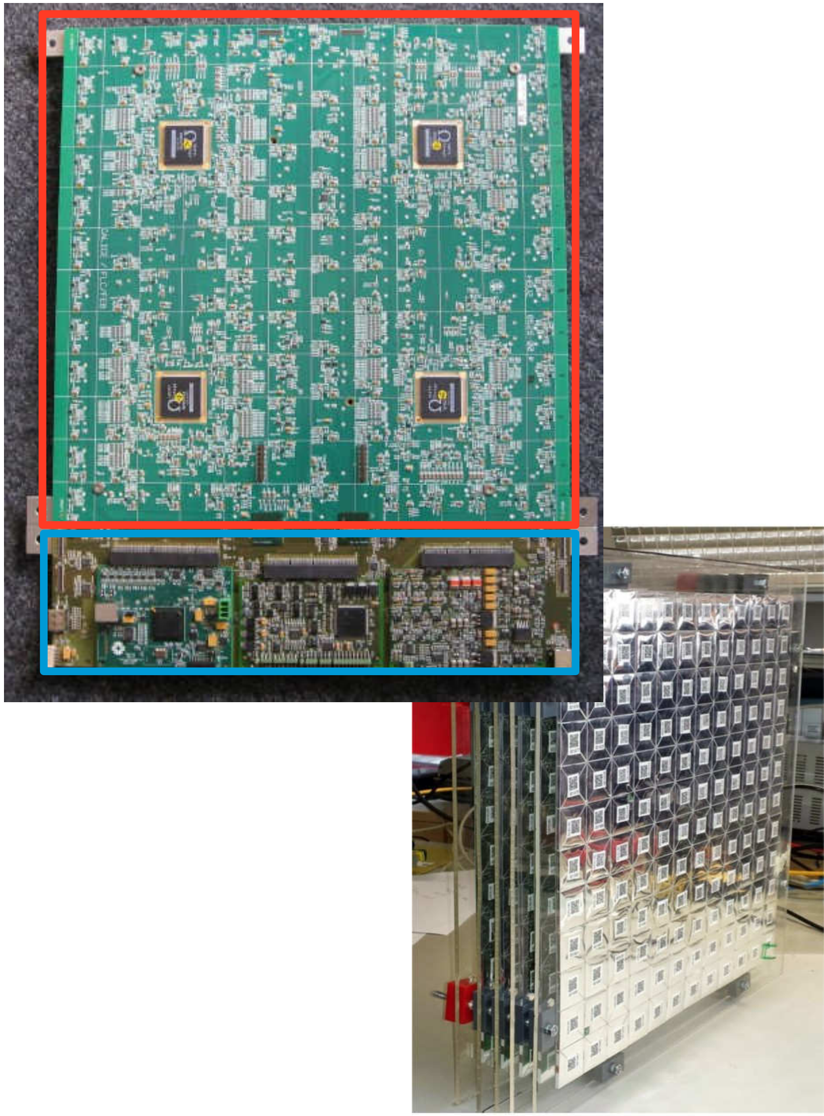
AHCAL Second Prototype



- Scalable prototype
  - ~10 million channels!
  - Full integration
- Constant validation in testbeams

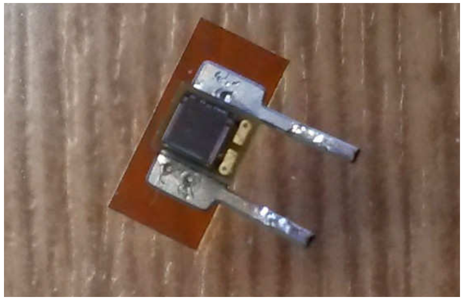
HCAL Base Unit (HBU)

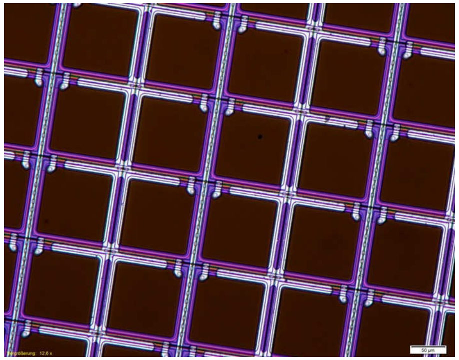
- Assembly unit of AHCAL prototype
  - 36*36cm2, 144 channels
  - Up to 6 HBUs serialisable (slab)
  - Up to 3 slabs parallel per layer
- Fully integrated
  - All signal digitisation on board
  - SiPM calibration system
  - No active cooling in layer
  - Full height including tiles 5mm
- One power/readout module per layer
  - Voltages generated locally
  - Steering calibration systems



DESY

Silicon Photomultipliers (SiPMs)

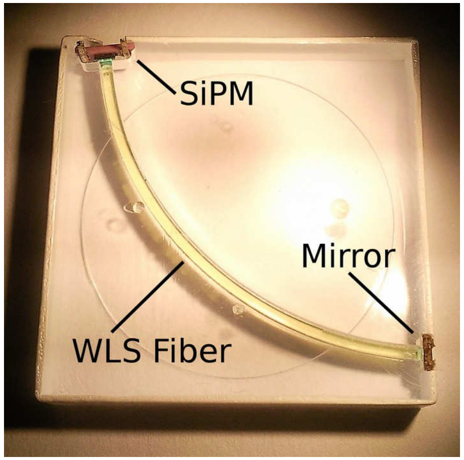




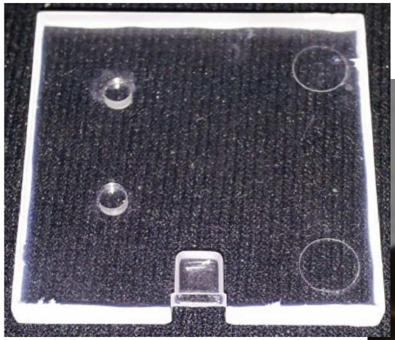
- Semiconductor based light detectors
  - Very small, unaffected by B fields, good amplification, cheap
  - Pixelated: single photon detection, saturation effects
- Wide range of manufacturers available
  - Hamamatsu, KETEK, SensL, Pulsar...
- Significant improvements since physics prototype
  - Dark noise: few MHz → few 10kHz
  - Pixel crosstalk: ~30% → ~1%
  - Spectral sensitivity: green only → up to soft UV (direct scintillation!)
  - Number of pixels : 800 → ~2000 (up to 10000!)
  - Device uniformity, photon efficiency, temperature dependence...

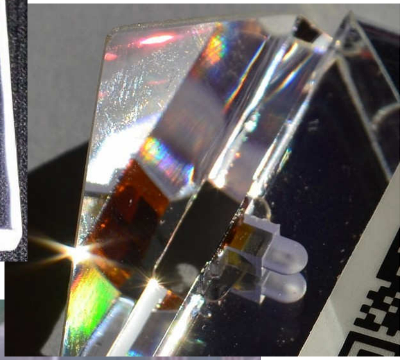
Tile types

- Physics prototype
  - 5mm scintillator
  - Wavelength shifting fiber embedded



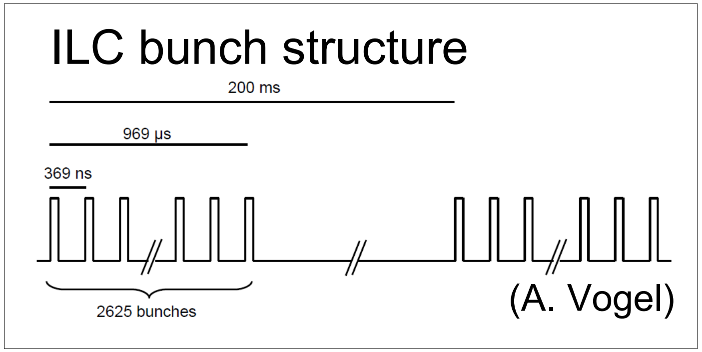
- 2nd prototype
  - 3mm scintillator
  - WLS fiber not needed anymore
  - “Dimple” needed for homogeneity
  - Faster machining, injection moulding
  - Individual foil wrapping tested
  - Alternative: surface mounted SiPMs

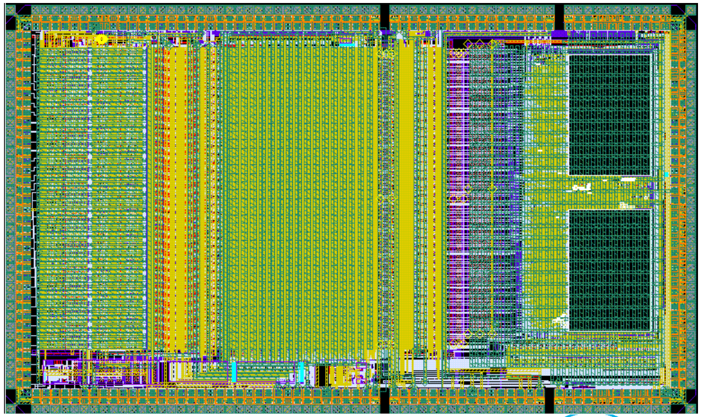




How to Read Out a High Granularity Calorimeter?

- Minimum cabling: Power in, data out
  - 1 cable per sector → 250k cells (~ATLAS calo!)
  - "Go digital as soon as possible" → zero suppression in frontend
- Buffer every hit until end of bunch train, full self triggering
  - Bandwidth not a problem (low physics occupancy)
- Buffering is expensive
  - In money
  - In power budget
- Minimise noise occupancy
- Interesting implications for test beam usage



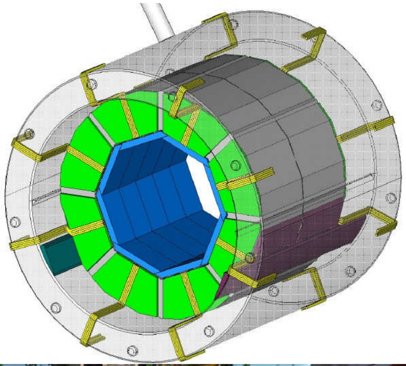


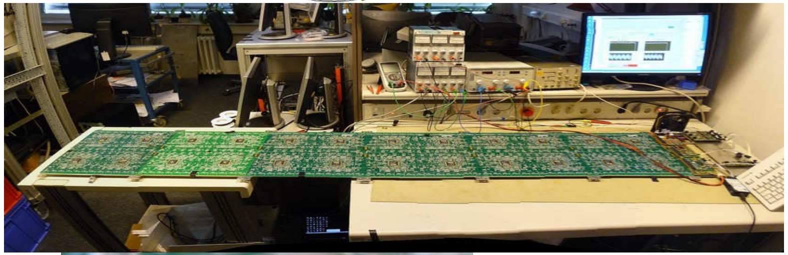
Requirements, Constraints & Parameters

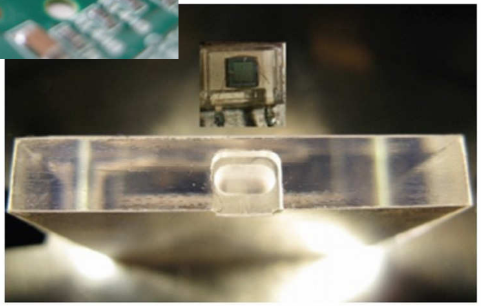
- Performance goals
  - Good S/N down to below 1 MIP (few photons)
    PFAs reconstruct MIP tracks within jets
  - Usable dynamic range up to 100s of MIPs
  - Limited noise occupancy
- Tunable parameters:
  - Tile/SiPM lightyield (in pixels/MIP)
  - Channel preamplifier setup
  - Trigger thresholds
- Efficient parameter setup
  - Which parameters to set per cell, per chip, per HBU etc. on which accuracy?
  - Automation, measurement time

Some Numbers

- The ILD AHCAL
- 60 sub-modules
- 3,000 layers
- 10,000 slabs
- 60,000 HBUs
- 200,000 ASICs
- 8,000,000 tiles





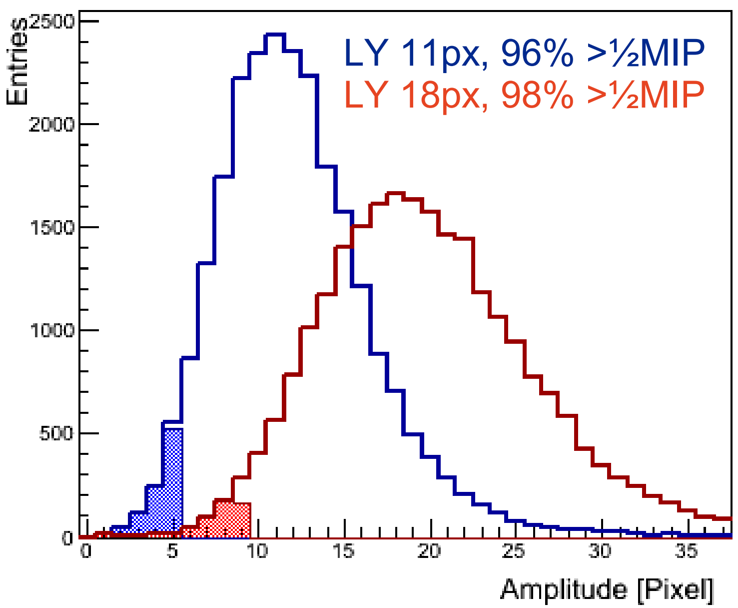


- One Year
- 52 weeks
- 230 days
- 2,000 hours
- 10,0000 min
- 7,000,000 sec

(F.Sefkow)

Tile/SiPM Lightyield

- Lightyield: mean no. of SiPM pixels fired per incident MIP
  - Depends on tile design, sensor efficiency, SiPM bias etc.
  - Elaborate setups to measure in lab (UHH: β-source, UHD: laser, JGU: cosmics)
- High lightyield
  - Good S/N, MIP efficiency
  - Large SiPM saturation corrections needed
- Low lightyield
  - Worse S/N, MIP efficiency
    (3px/MIP: ~20% 0-1 pixels fired)
  - Less SiPM saturation
- Aiming for 15px/MIP
  - >95% MIP efficiency @0.5MIP threshold



Lightyield Setup

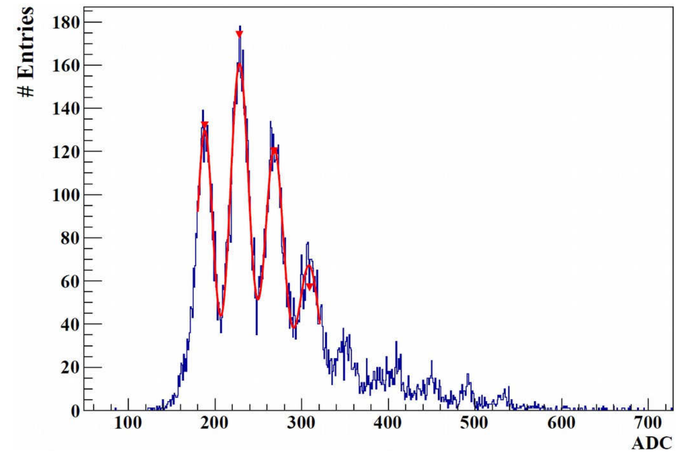
- Once tiles are at hand: Bias voltage
- Past sensor generation: Individual biasing per cell
  - Channel individual IDAC calibration (manual measurement)
  - VERY time consuming, bad reproducibility
- Current sensor generation: Uniform bias per chip
  - Expected small additional parameter spread
  - Can still use semi-calibrated IDAC to shift outliers
- IDAC calibration in future chip test setup?

Calculated for KETEK SiPMs:

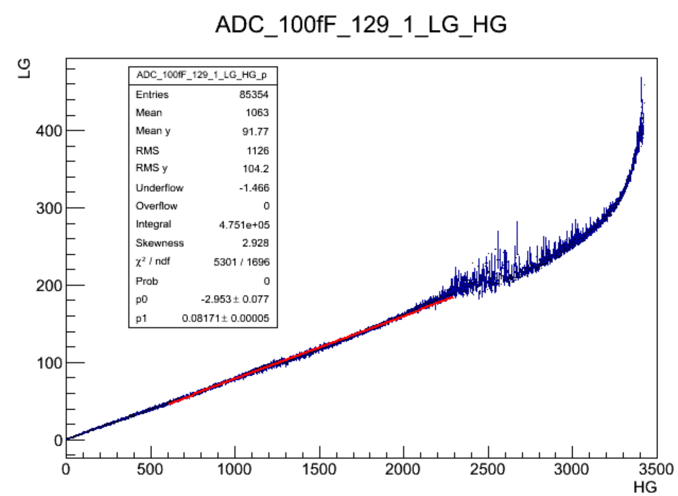
Biasing	MIP spread	Gain spread
30 V (constant)	10%	5,8%
2.5 V over bias	11%	1,8%
18px/MIP	1,5%	17,0%

Dynamic Range

- Use preamplifiers in ASIC to equalise SiPM response on ADC scale
  - SiPMs set their own scale (in ADC/pixel) → calibration system
  - Normalises MIP response as well

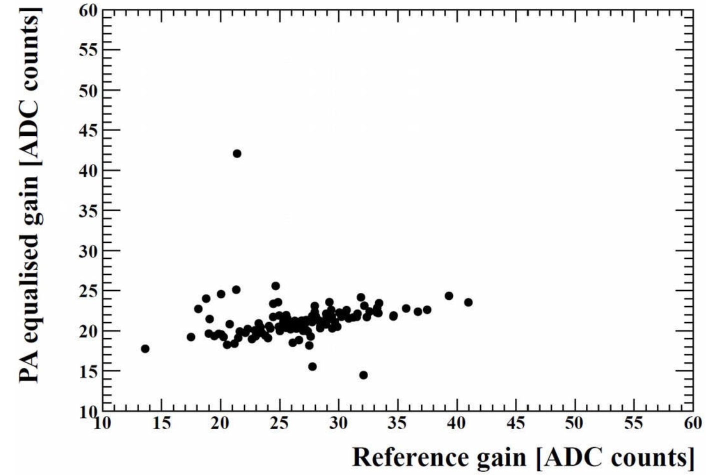


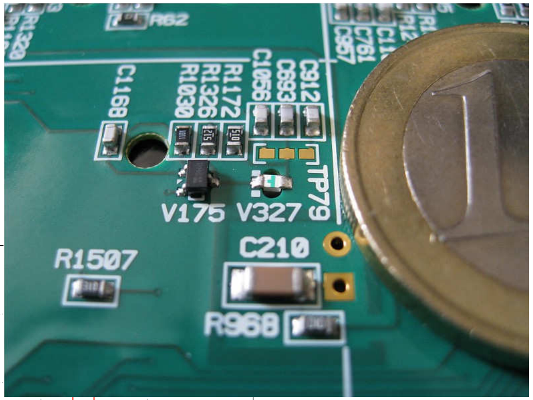
- Limiting factor: ASIC dynamic range
  - 12bit ADC → [0, 4095]
  - Standard SiPMs: ~2000pixels → Cannot resolve single pixels and full DR
- Dual gain mode
  - Automatic gain switching for higher amplitudes
  - 13bit effectively
  - Gain factor ~10 (needs measurement)

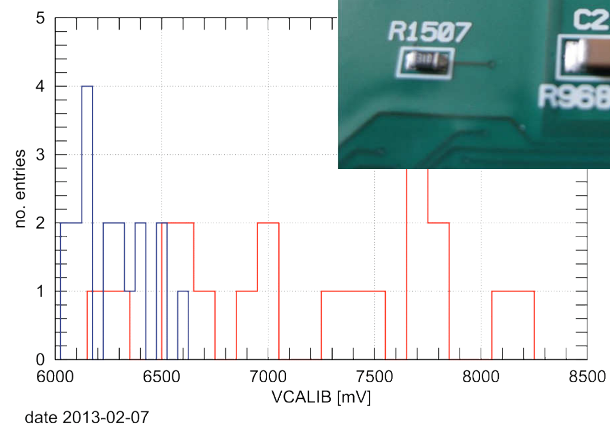


Preamplifier Setup

- Past sensor generation: wide gain spread
  - Channelwise preamp setup, time consuming
  - ~10-20% spread remaining
- Current sensors: uniform bias
  - ~15% spread with uniform preamps
  - Determine ideal preamp setup from small cell subset
- LED calibration system well integrated
  - Small, cheap, every channel equipped
  - Recently improved output homogeneity
  - Smaller VCALIB range for full coverage
  - Versatile tool for commissioning



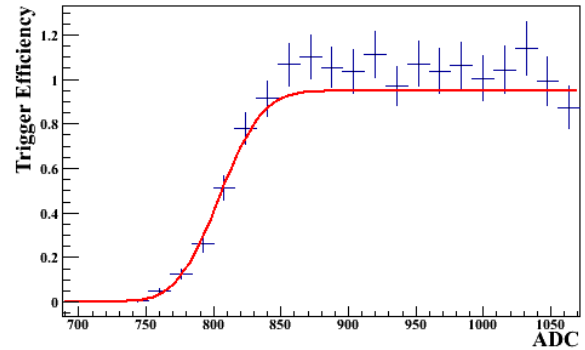


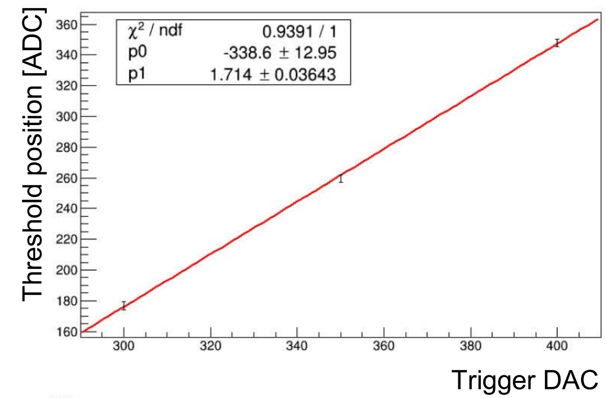


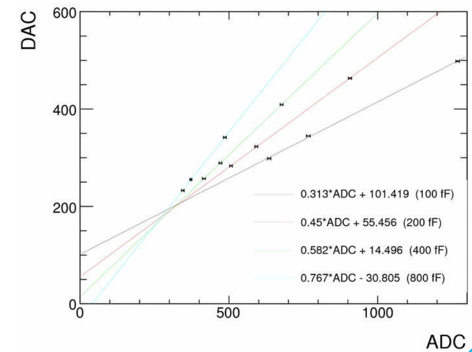
Trigger Threshold Position

- Setting thresholds correctly is crucial!
- Need to measure threshold dependencies
  - Known preamp dependency, more to come?

- Now: using LED system
  - Extraction of threshold not trivial (normalisation)
  - Only works in certain range, can be extrapolated
  - Summer student project 2014
  - Works for full HBU in parallel
  - >75% of channels give results
  - Compatible with previous measurements







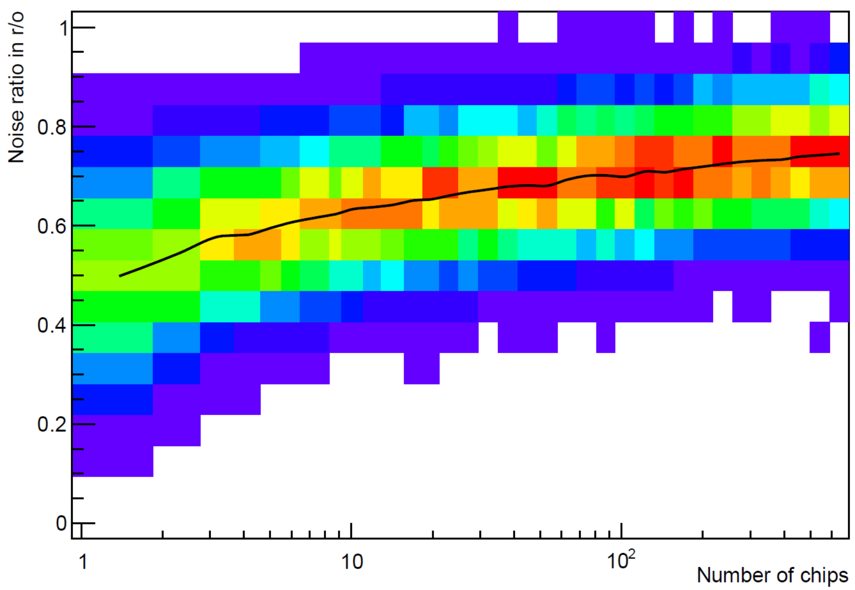
Time Efficient Commissioning

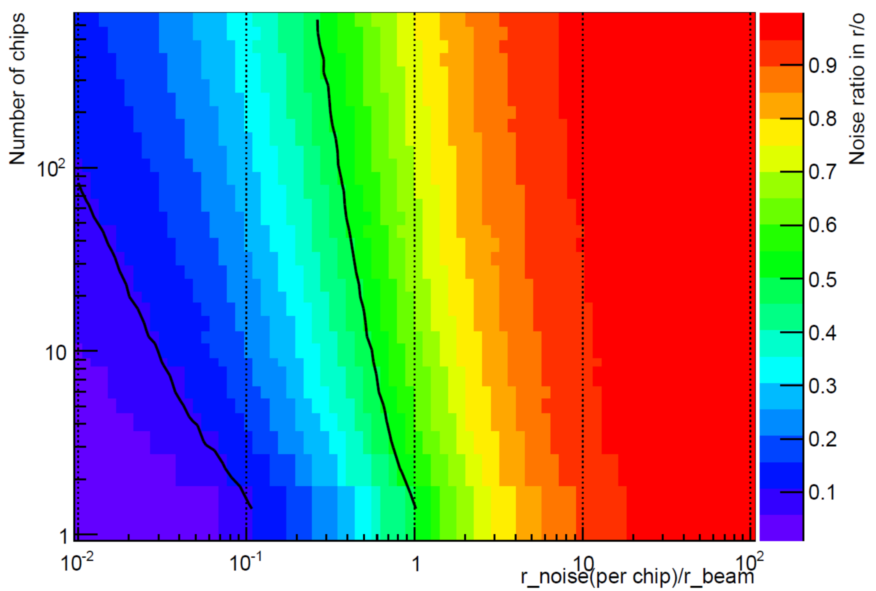
- Time optimised electronic checkup routine
  - SiPM gains, HG/LG intercalibration and threshold positions
  - Automated measurement software
  - For quality control and comparison reference

- 1 week/HBU down to few hours/HBU
  - Simplification of routines
  - Progress in DAQ software
  - All boards for CERN testbeam checked

Readout Behaviour of Large Systems

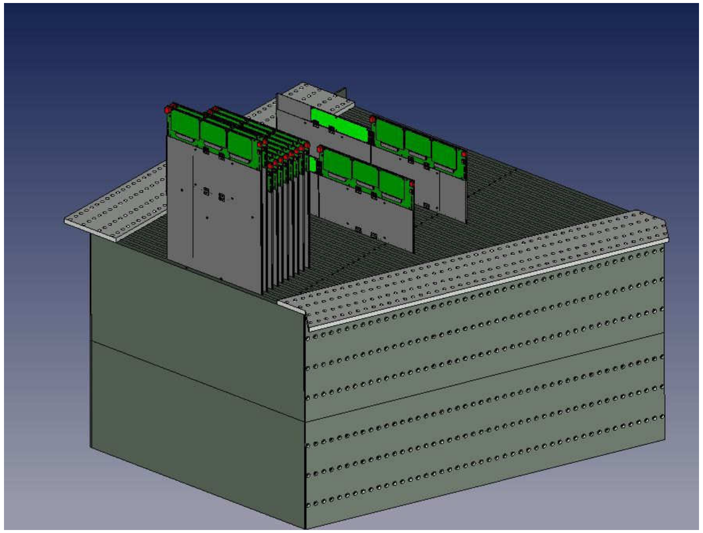
- Large system, many cells: Poissonian noise fluctuation
  - Limited buffer sizes
  - In TB: Stop acquisition and force readout once first buffer filled.
- Readout efficiency changes with total number of cells
  - Beamrate/noiserate 1:1 != 50% readout efficiency
- Usable in testbeam for now, but keep in mind when scaling



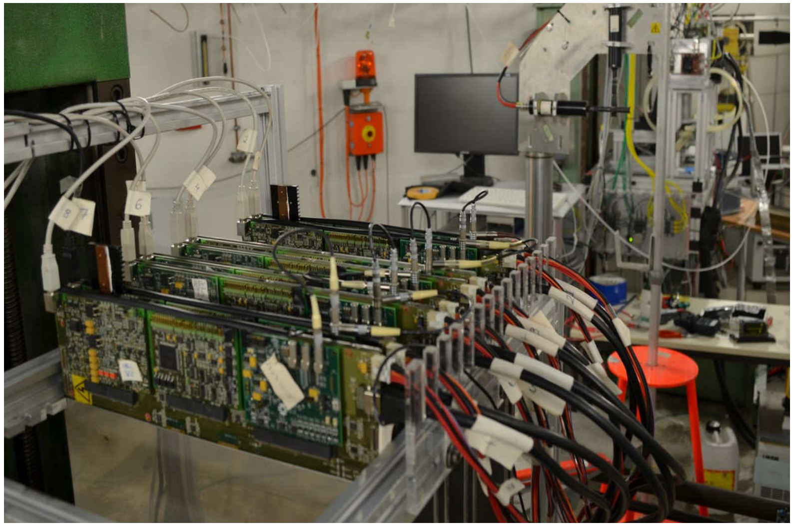


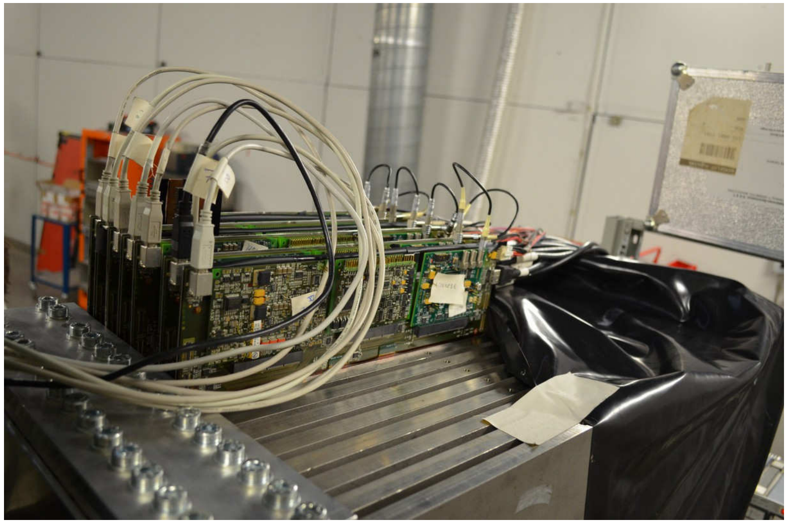
Beam Campaigns

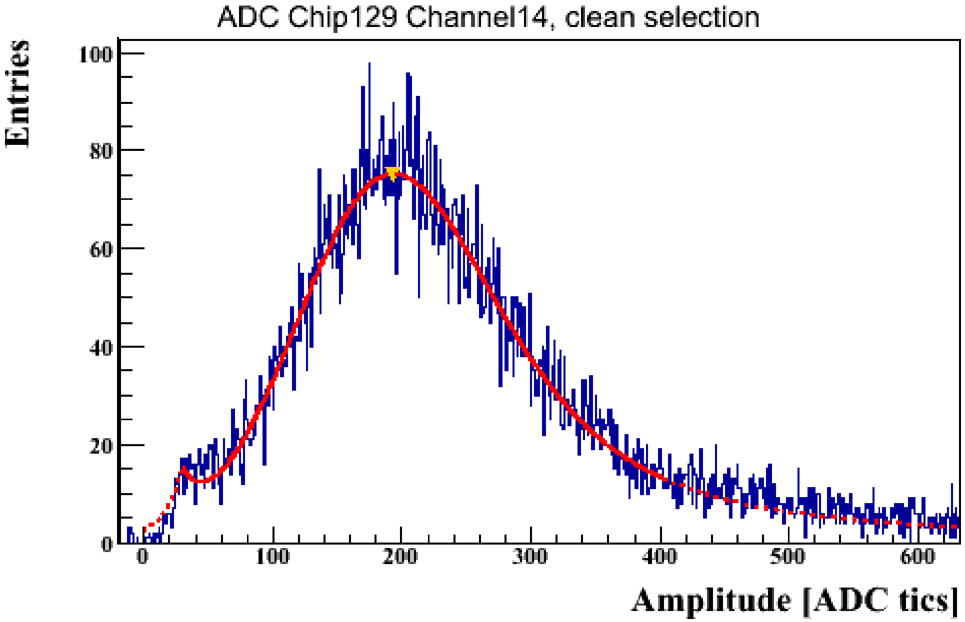
- First multi layer testbeams in summer 2013 (DESY)
  - Started with 5 layers
  - Multilayer MIP calibration, electron showers 1-6GeV
- Now: 15 layers, 27 HBUs
  - ~3500 cells, lots of different sensors, tile designs
  - Enough to do hadronic shower correlations
  - Full ILD-like mechanics: Absorber stack, HBU cassettes, cooling
  - 2*2 weeks at PS 2014
  - More beamtime at DESY and CERN SPS this year

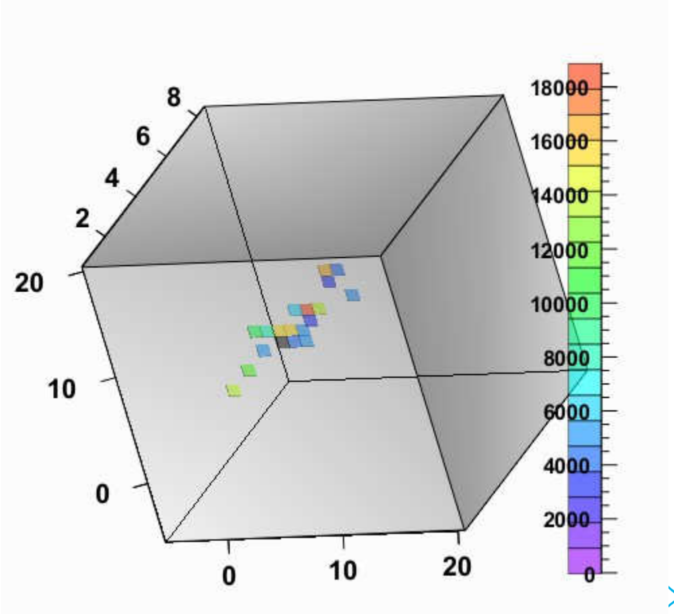


DESY Testbeam 2014



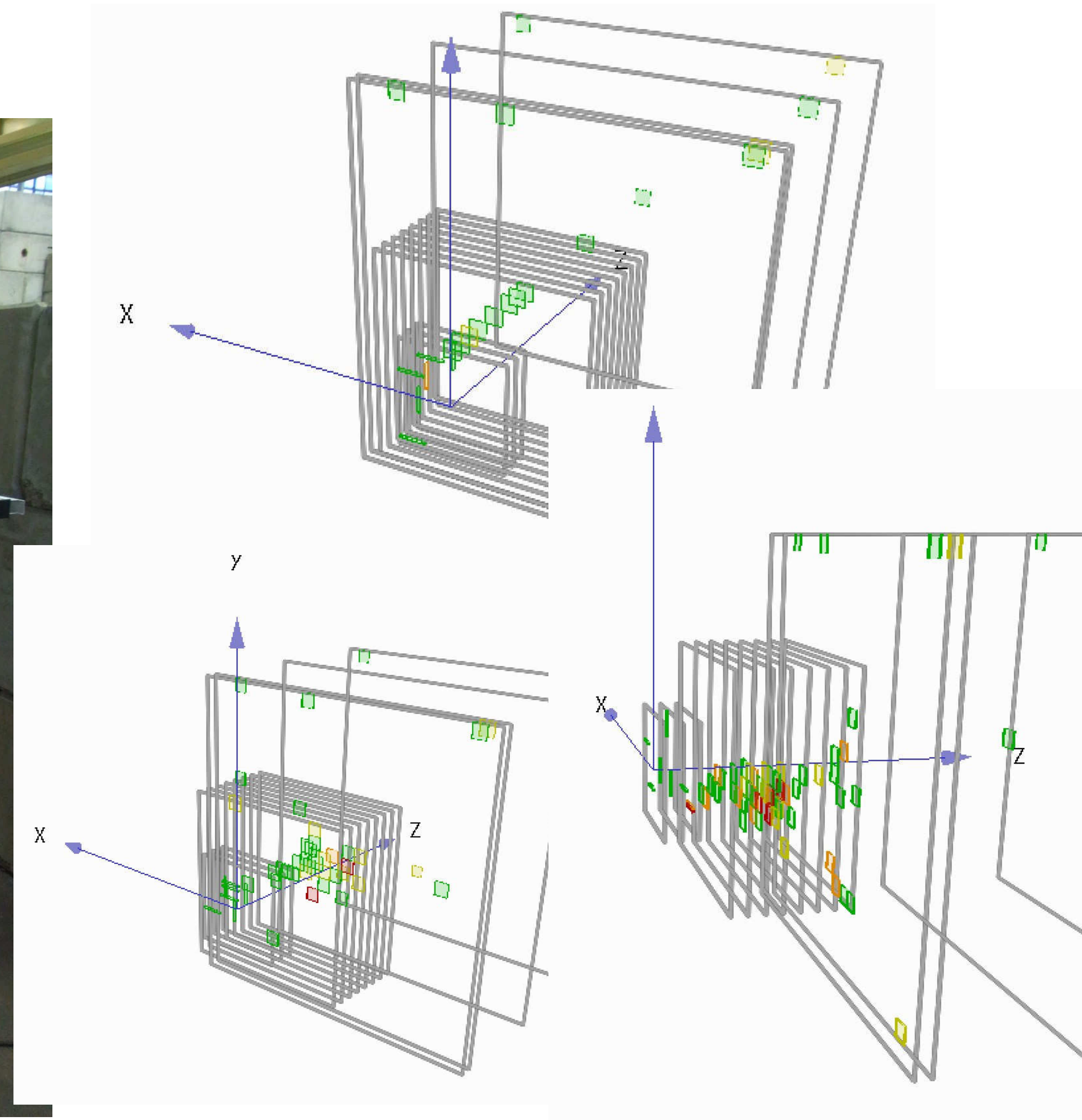






CERN PS Testbeam 2014

- ILD is getting real!



Summary & Outlook

- Particle Flow Algorithms are the future of jet reconstruction
  - Tough requirements on every subdetector
- AHCAL is a mature concept for a high granularity hadronic calorimeter
  - Based on scintillator-SiPM readout
  - Performance proven in physics prototype
- 2^{nd} generation prototype aims for full integration and scalability to ILD
  - ~3500 channels in testbeam setups already, more to come
- In any case: operation of a multi-million channel detector is not easy
  - Needs excellent understanding of operation parameters

Summer Student Programme 2015

SUMMER STUDENTS.

DESY International Summer Student Program 2015
21 July to 10 September

DESY is one of the world's leading accelerator centers for investigating the structure of matter. DESY develops and builds large particle accelerators and conducts research in the fields of photon science and particle physics. The research facilities of DESY are used by a large international community of scientists. Each summer DESY offers students in physics or related natural science disciplines the opportunity to participate in its research activities. About 100 students from all over the world take part in DESY's research and attend the lecture program.

www.desy.de/summerstudents

Photon Science
Summer students join experiments which are carried out with soft and hard X-rays using a variety of spectroscopic and scattering techniques for research in the fields of physics, chemistry, biology etc. Activities range from preparation, realization and evaluation of measurements to improvements of instrumentation.

Elementary Particle Physics, Astroparticle Physics and Accelerators
Summer students will work in the analysis, software or detector related fields of experiments in elementary particle physics (LHC, ILC, BELLE II, ALPS-II) and astroparticle physics (CTA), development of particle accelerators, theory of elementary particles or computing.

Application Deadline is 31 January, 2015.
Qualified applicants should have completed three years of full time studies on a university level by summer 2015.
All participating students will obtain financial support.

Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association