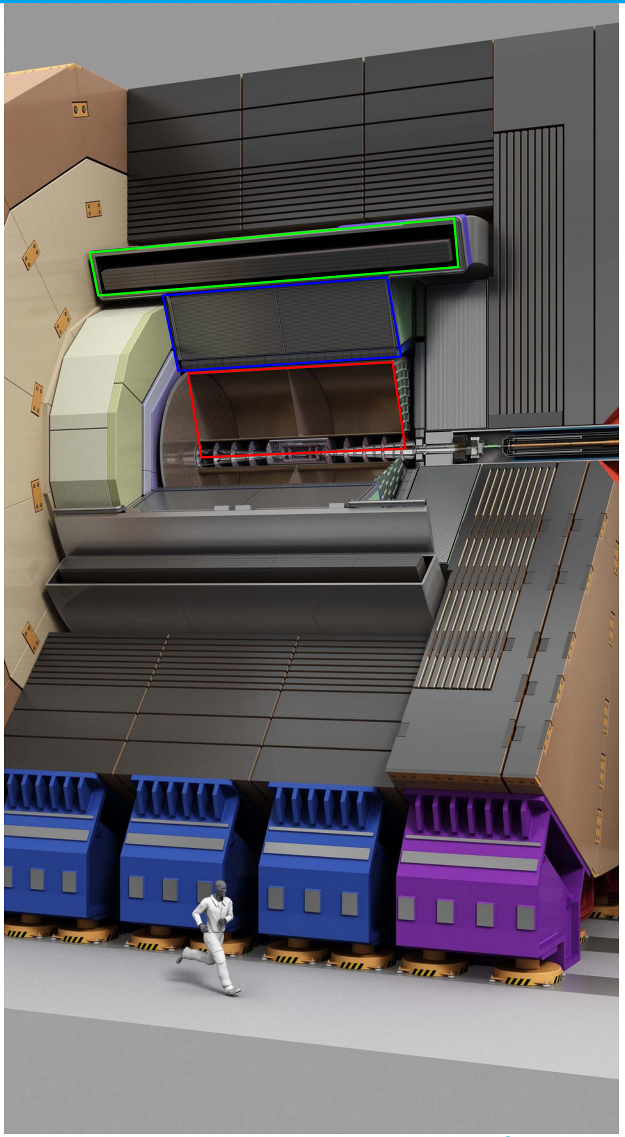
Particle Flow Calorimetry for a future Linear Collider.

Or: How to build a calorimeter for using it the least possible.

Oskar Hartbrich
READi Workshop 2014
Hamburg, 07.04.2014

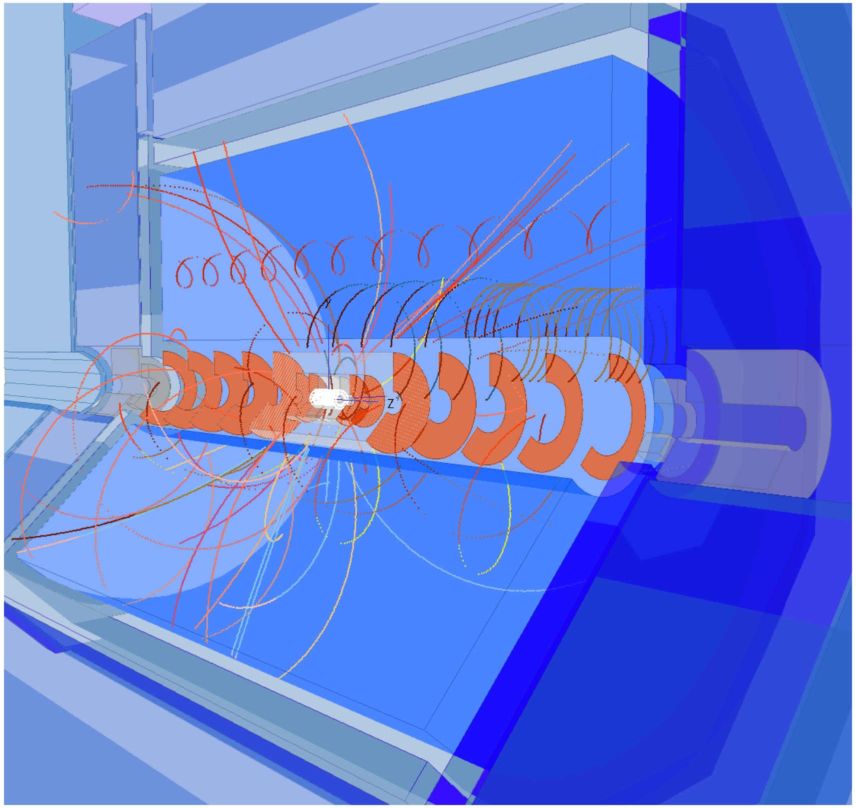
Particle Collider Experiment Detectors

- Measure all particles resulting from collision
  - Detector built around collision point
  - Maximum coverage (hermeticity)
  - Detector parts measure different properties
- Tracking system —
  - Tracks from charged particles
- Calorimeter system —
  - Particle energy determination
  - ECAL: photons, electrons
  - HCAL: hadrons
- Magnet system —
  - Field lines parallel to beam axis
  - High field strength (~3T)



Tracking

- Tracing particles with minimal interference
- Charged particle induces signal in active material
  - Reconstruct path from signals → "track"
- Magnetic field bends flight path
  - Depending on charge and momentum
  - Helical paths
- Track curvature → momentum
  - High precision (~0.1%)
  - Resolution worsens with higher momenta
- This talk is not about trackers...
  - ... but tracking is important later.



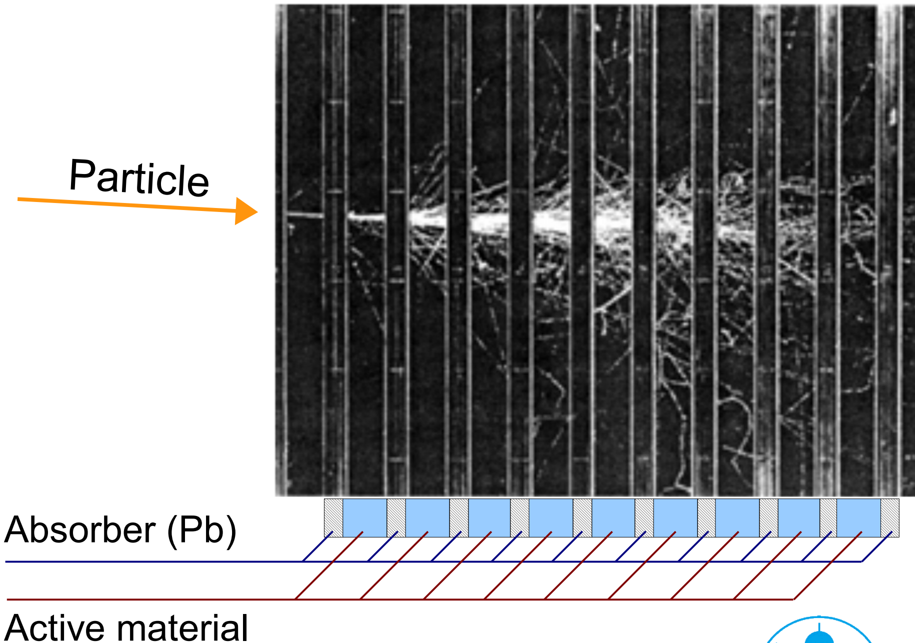
Calorimetry

- Collider detectors: energy of particles
  - Convert particle energy into measurable quantity
- Stop particle and measure ΔT
  - Very unfeasible (20GeV $e^- \rightarrow \Delta T \sim 10^{-12}$ K)
- Instead: count number of fragments
  - Need active material to detect particles
  - Good absorbtion != good detection
- Sandwich calorimeter concept
  - Interleaved absorption/detection layers

WIKIPEDIA
The Free Encyclopedia

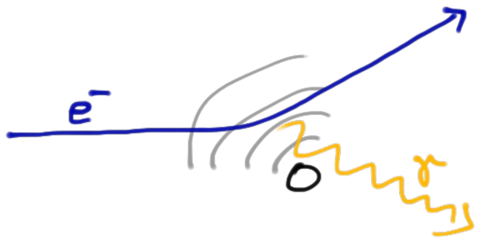
"Calorimetry is the science [...] of deriving the heat or heat transfer of [an object]."

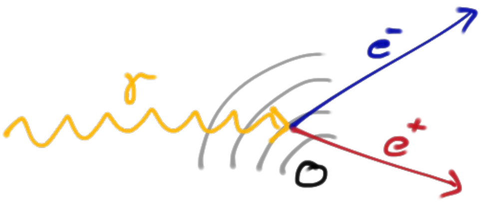
(MIT cosmic ray group)



EM Shower Mechanism

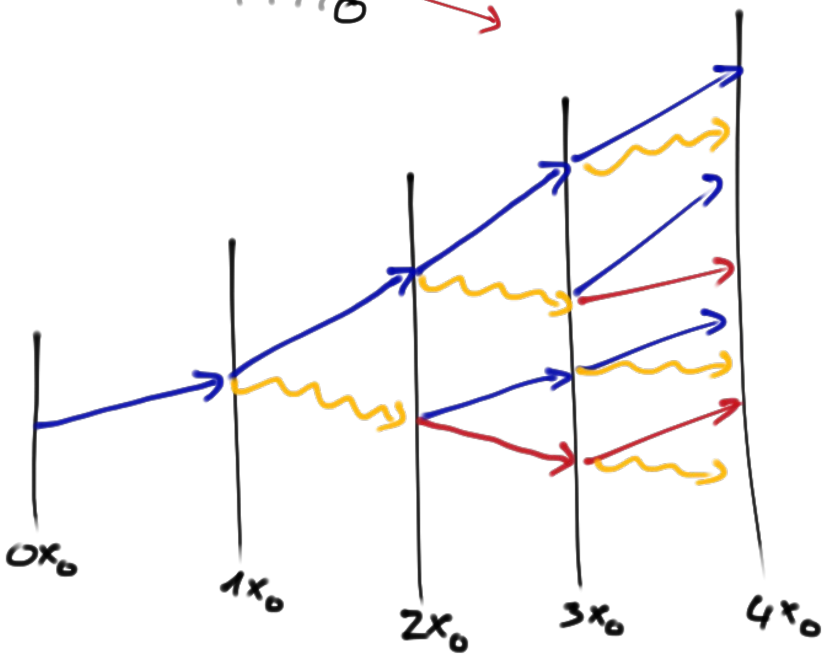
> At high energies:
  - Electrons lose energy by Bremsstrahlung
  - Photons convert to e^+e^- pairs





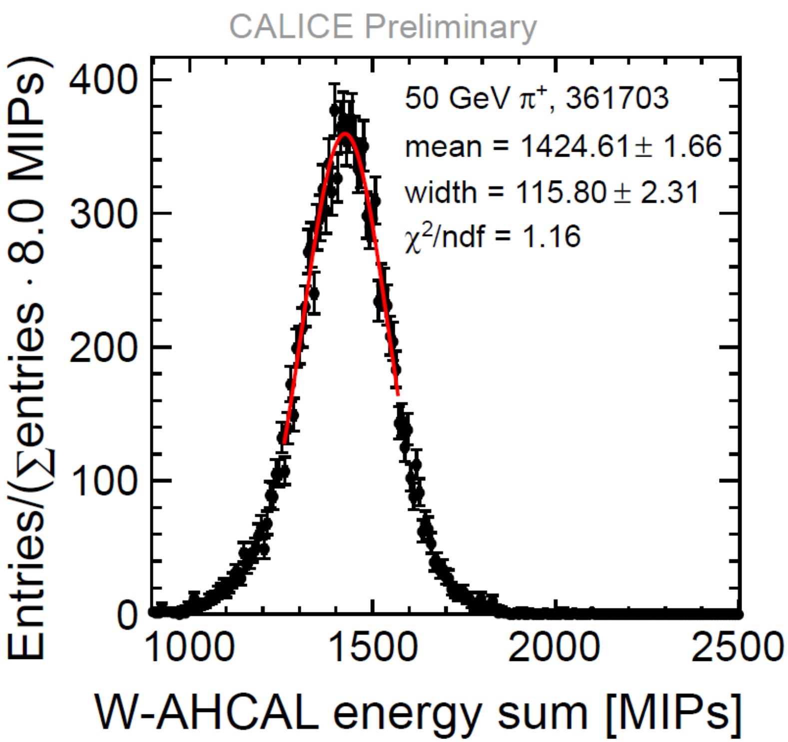
> Electron/photon cascade
  - N_p increases, E_p decreases
  - Particle multiplication stops at $E_p < E_c$
  - $N_{tot} \sim E_{tot}/E_c$ (20GeV e^- in Fe: N_{tot} ~1000)
  - Statistical process

> EM showers are compact
  - Shower depth dependance ~$\log(E_{tot})$



Calorimetric Resolution

- Resolution: Spread of particle responses
  - Relative width, usually 1σ
- Particle showers are statistical process
  - Poisson statistics $\sigma_{\text{Poisson}} = \sqrt{N}$
  - Relative width $\frac{\sqrt{N}}{N} = \frac{1}{\sqrt{N}}$
- Calorimetric resolution is limited!
  - Resolution improves with higher energies
- ATLAS ECAL $\sim \frac{10\%}{\sqrt{E\ [\text{GeV}]}}$
  - CMS ECAL (non-sampling) $\sim \frac{3\%}{\sqrt{E\ [\text{GeV}]}}$

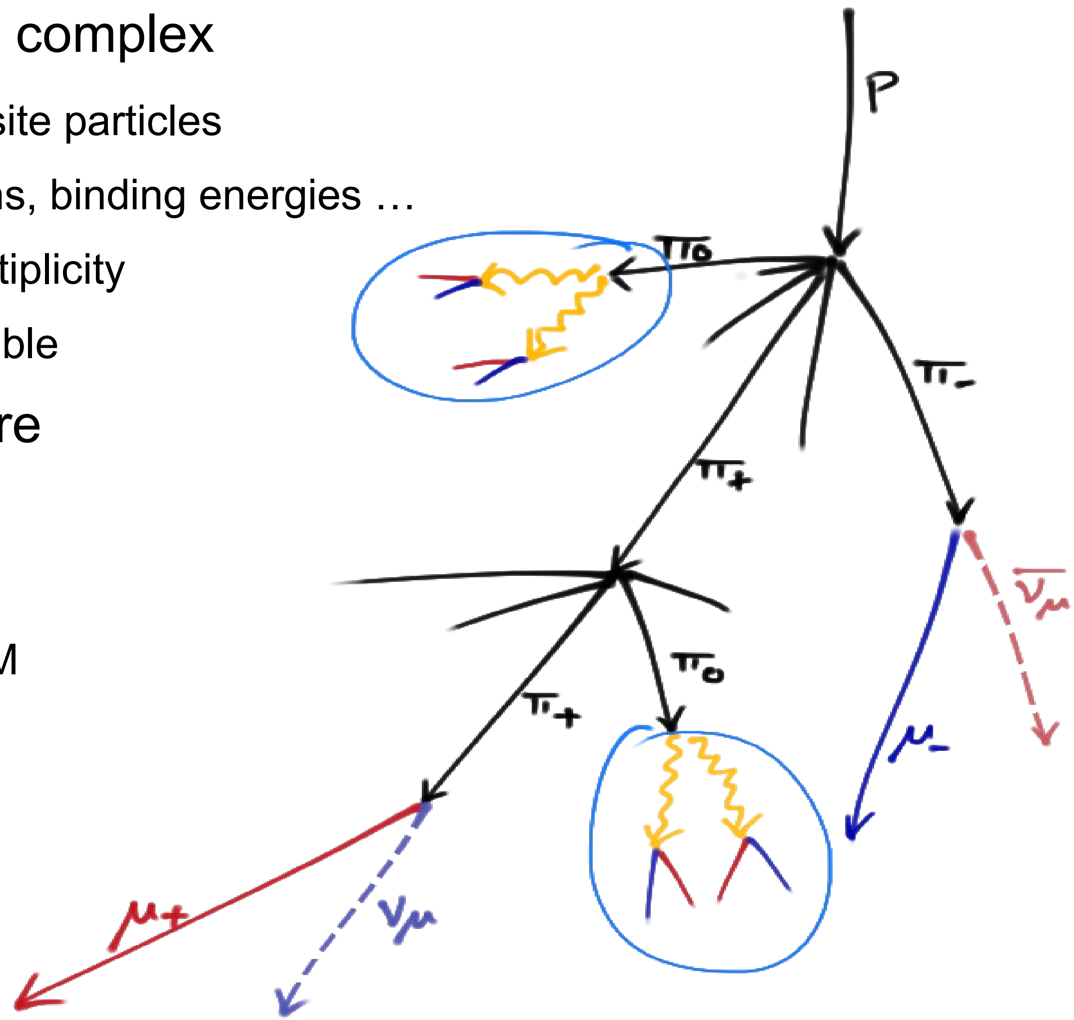


(CALICE Analysis Note CAN-044)

Hadronic Showers

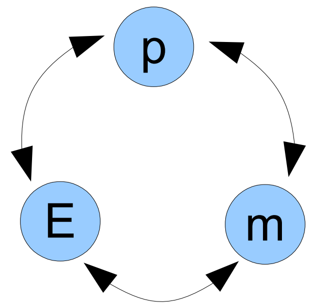
- Hadron showers much more complex
  - Elementary particles ↔ composite particles

    → Nuclear interactions, neutrons, binding energies …
  - Few hard interactions, high multiplicity
  - MC simulations not always reliable
- Large fluctuations everywhere
  - Many particle types involved
  - EM subshowers
  - Resolution much worse than EM
- Best HCAL: ZEUS $\sim \frac{35\%}{\sqrt{E\ [\mathrm{GeV}]}}$
  - ATLAS $\sim \frac{45\%}{\sqrt{E\ [\mathrm{GeV}]}}$
  - CMS $\sim \frac{75\%}{\sqrt{E\ [\mathrm{GeV}]}}$

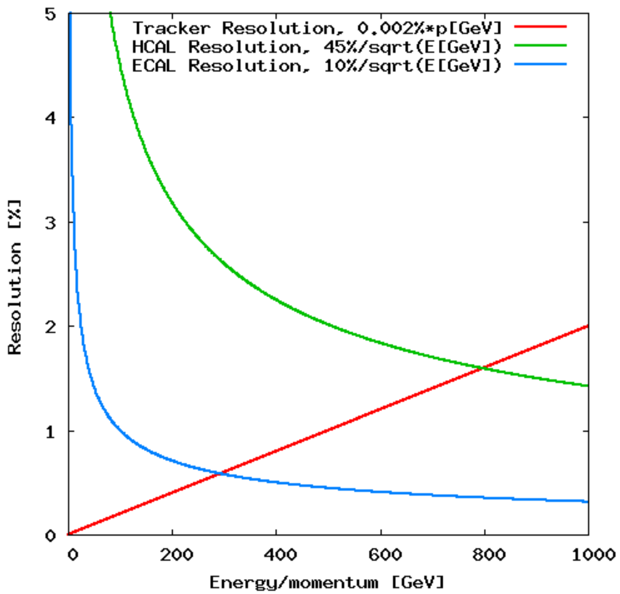


The Way Out: Particle Flow!

- Tracker resolution better than calorimeters
  - Particle mass mostly negligible → p~E
- Use momentum measurement as energy
  - Only works for charged particles
  - Still use calorimeter depositions for neutrals
  - ~27% photons → good ECAL resolution
  - ~10% neutral hadrons
- Association of tracks to calorimeter hits

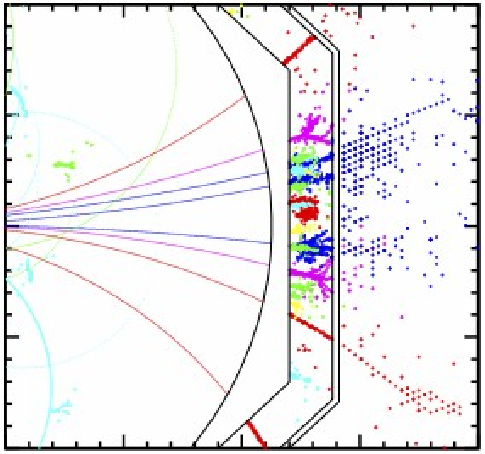


$$E^2 = p^2 + m^2$$

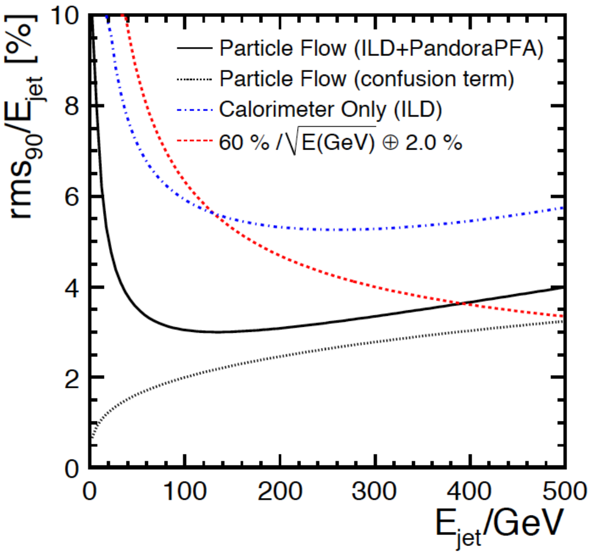


Particle Flow Algorithm Illustration

- Find tracks ending in calorimeter depositions
- Remove calorimeter depositions associated to track
  - Use momentum from track as shower energy
- Remaining calorimeter hits should be neutrals
  - Use energy measured in calorimeter

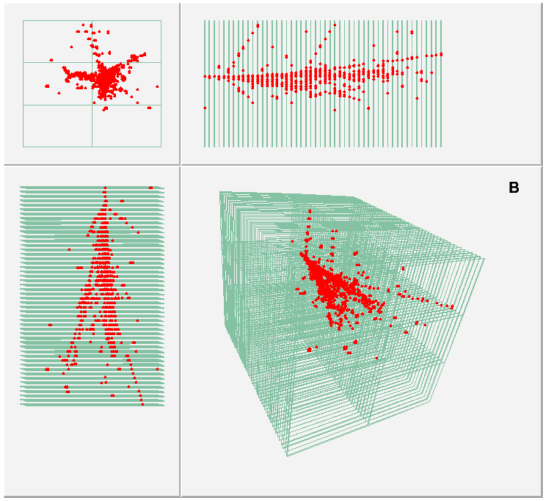


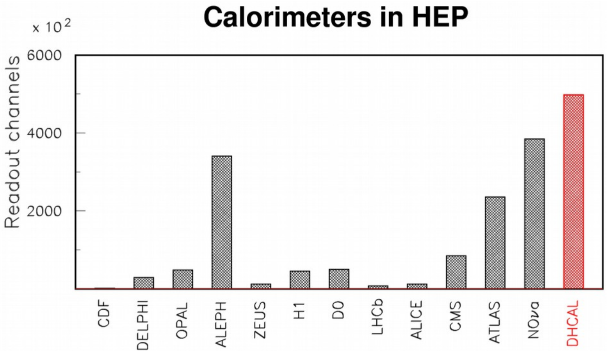
- Problem: Confusion
  - Neutral shower overlapping → lose energy
  - charged shower interpreted as neutral → double counting
- Solution: highly segmented calorimeters
  - Thousands of channels → millions of channels
  - *Imaging calorimetry*



The CALICE Collaboration

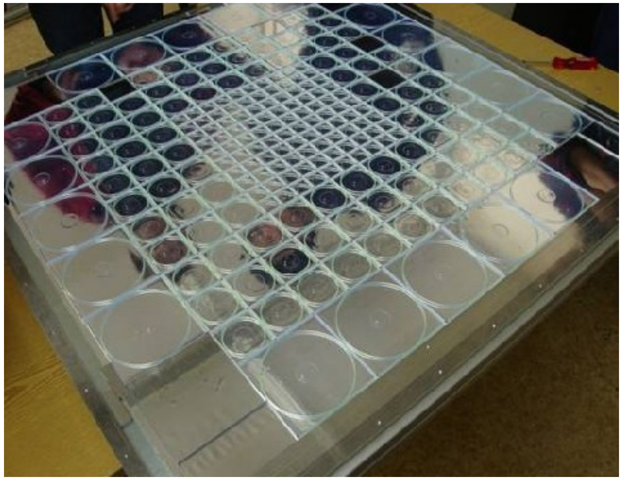
- CALICE: **Ca**lorimeters for a **Li**near **C**ollider **E**xperiment
- International collaboration effort for PFA calorimeters
  - 60 groups/institutes, ~350 people
- Different concepts under investigation
  - ECALs, HCALs
  - Readout, segmentation, digitisation options
  - Absorber materials (mainly Fe and W)
  - Devision, construction, validation of prototypes
- Extensive testbeam campaigns
  - At CERN, FNAL, DESY
  - Since 2006 and ongoing

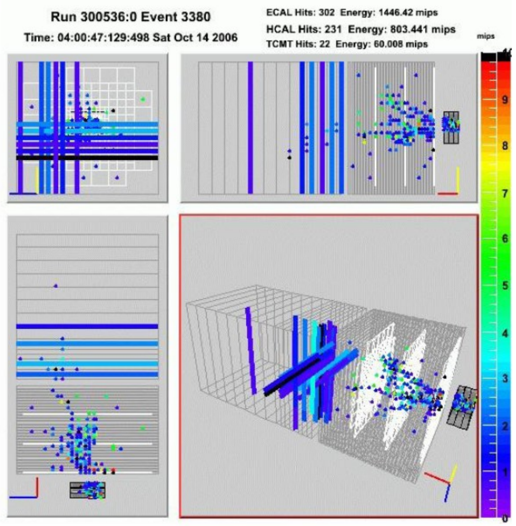




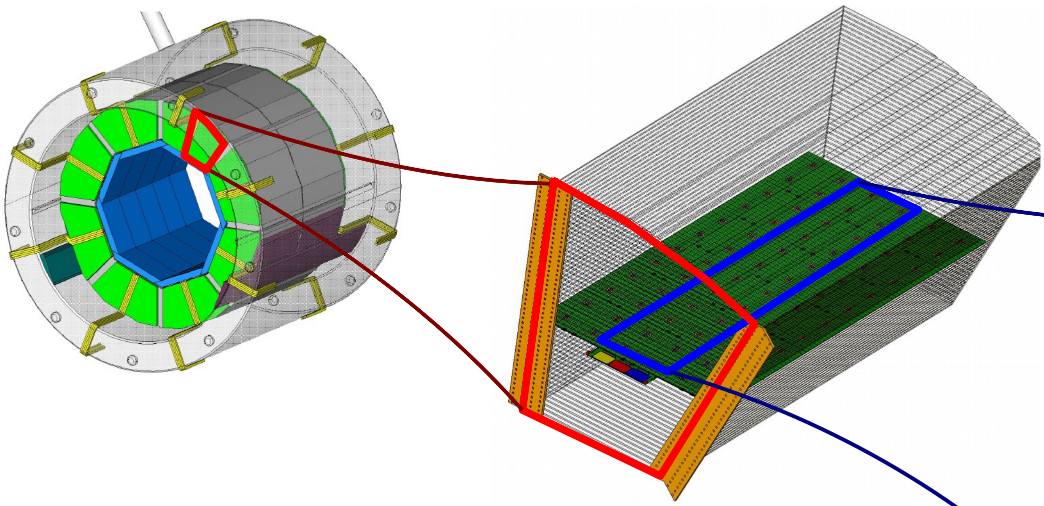
The CALICE AHCAL

- AHCAL: **A**nalog **H**adron **Cal**orimeter
- Germany centric effort
  - DESY leading institute
- Scintillator tile + Silicon Photomultiplier (SiPM)
  - 30*30*5mm^3 plastic tiles
  - First large scale SiPM detector
- 1m^3 prototype
  - Up to 38 layers
  - 8184 channels
  - Testbeams 2006-2012

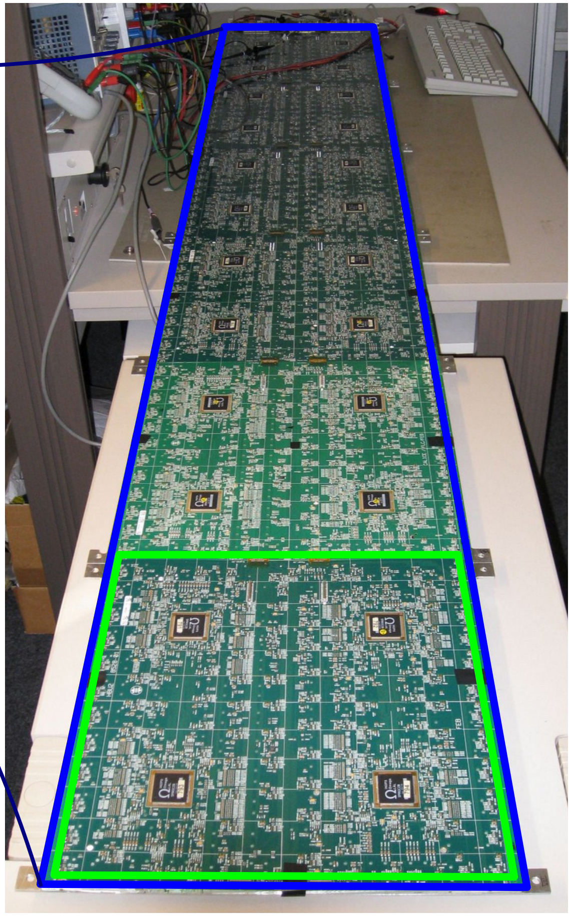




The Next AHCAL Prototype



- Scalable to full collider experiment
  - Technology
  - Production processes
- Integration!
  - ~8 million channels
  - Sensors, readout, power...
  - Minimum height



The Next AHCAL Prototype

> Sensors

- SiPMs improve rapidly
- Multiple tile designs under investigation

> Electronics

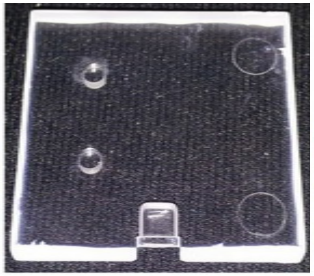
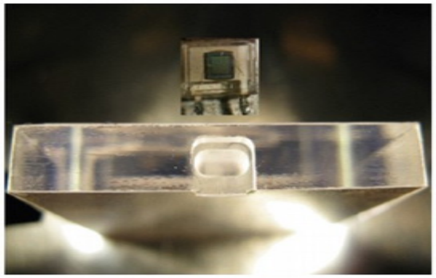
- Custom readout ASIC
- No cooling → power pulsing (45µW/ch)
- Integrated SiPM calibration system
- Readout software

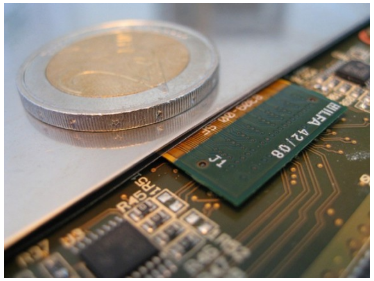
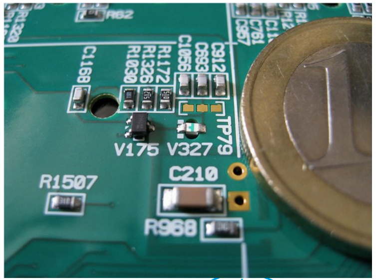
> Mechanics

- 5.4mm total thickness of active layer
- ILD absorber prototype available

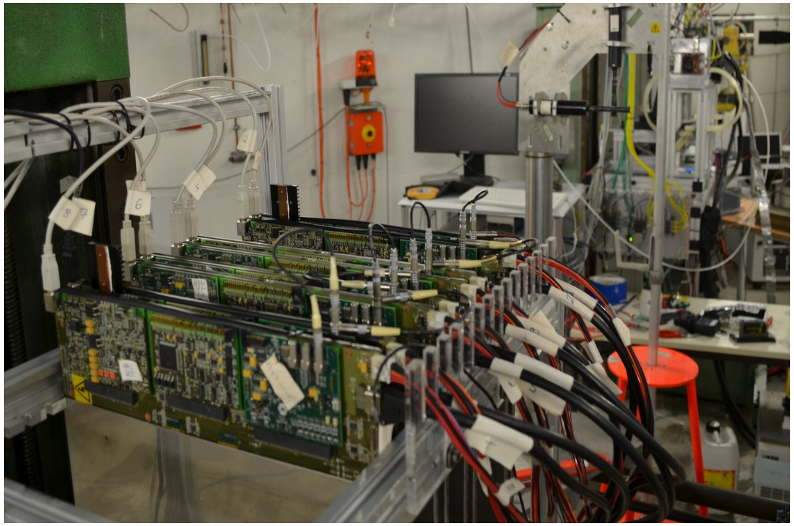
> Nine assembled units available

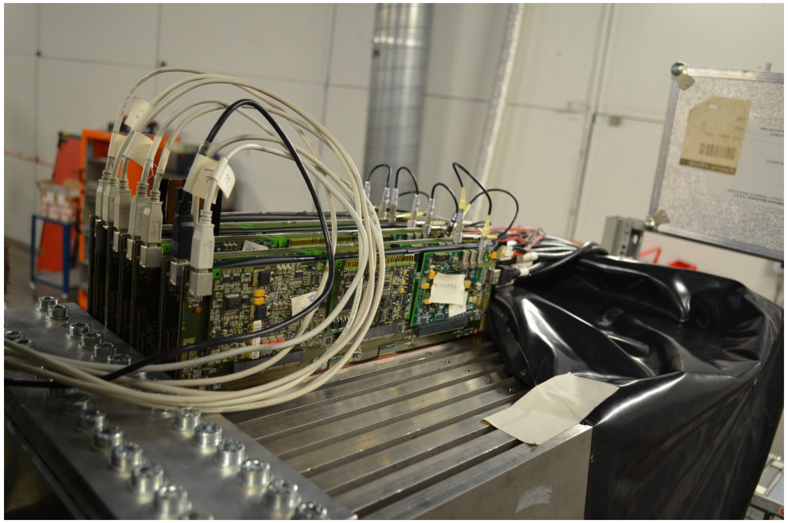
- 1296 channels

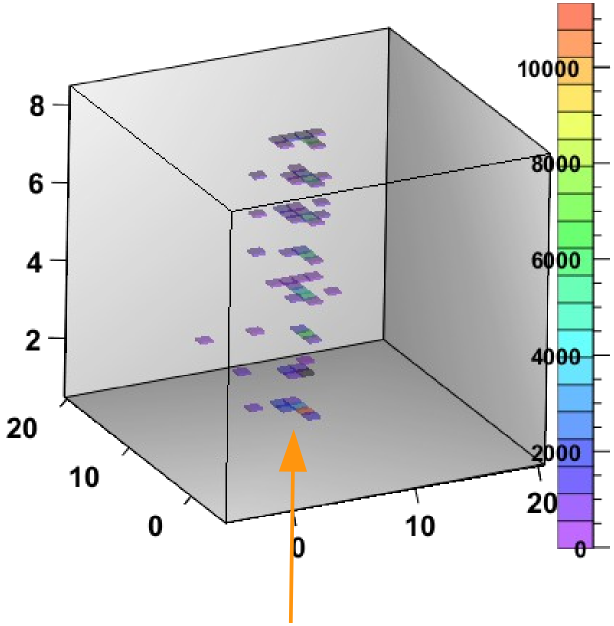



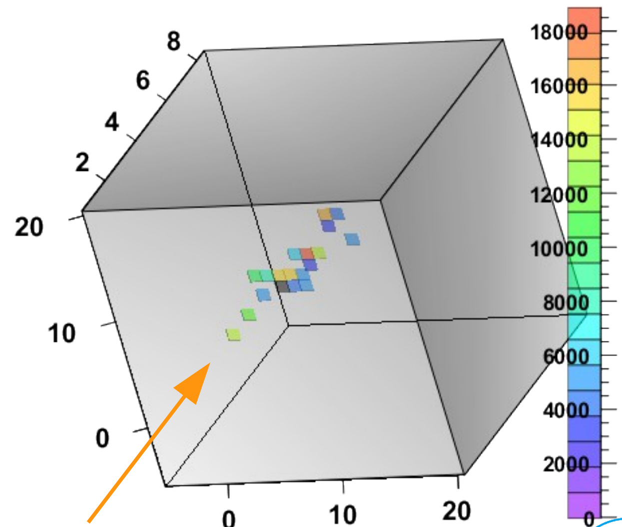




AHCAL DESY Testbeams









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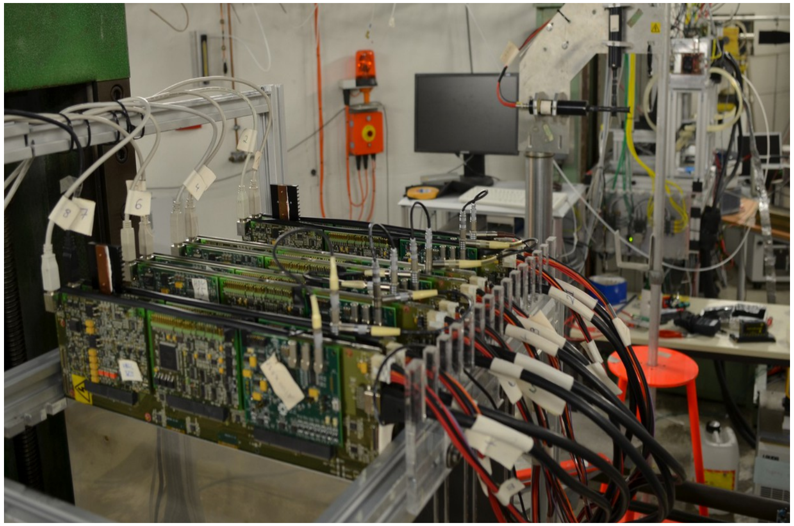
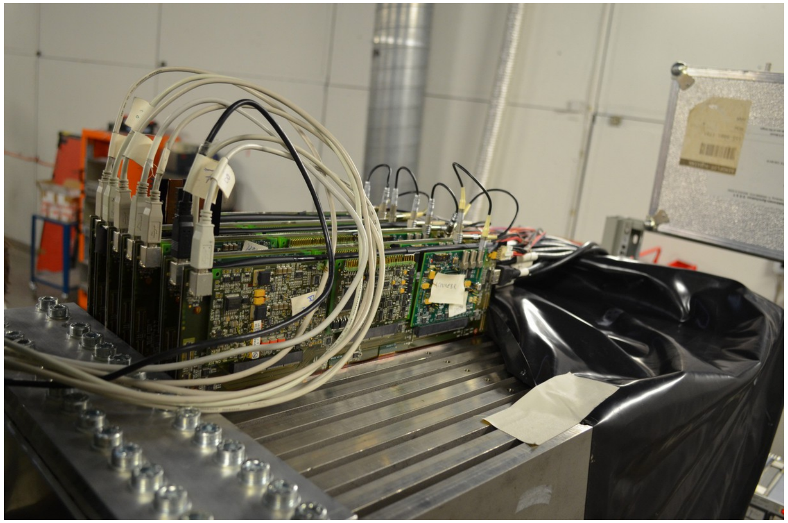
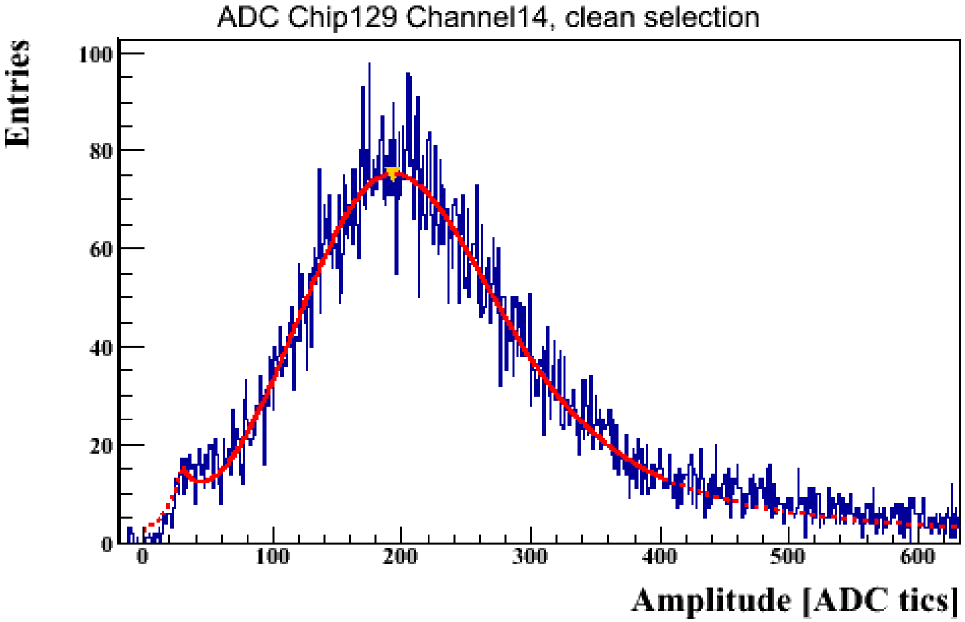
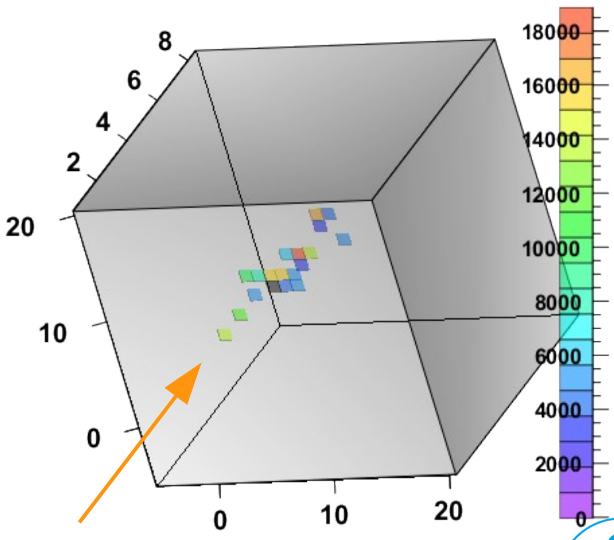


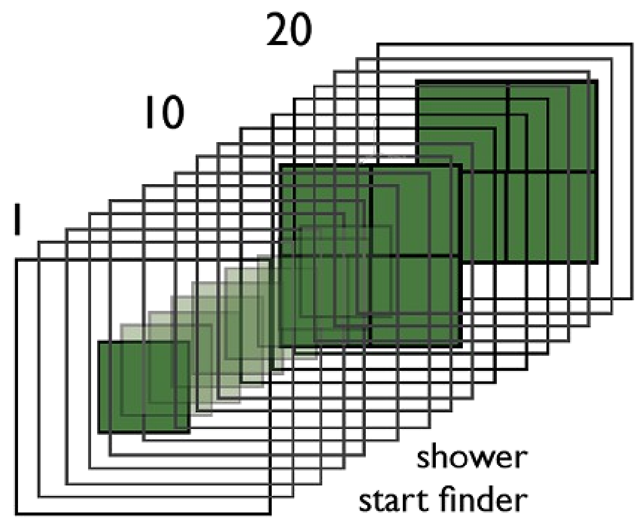


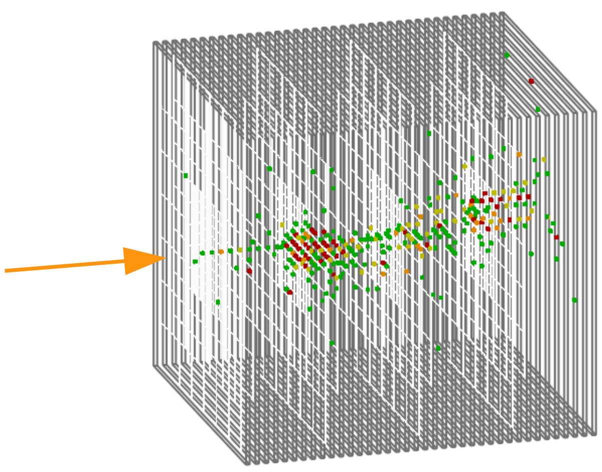




Upcoming CERN Testbeam

- Four weeks beam time Oct/Dec 2014
- Shower start finder setup
  - Less material than full instrumentation
  - Validate calorimeter performance
  - Hadron shower timing correlations
- Biggest prototype system yet
  - ~3000 channels
  - All hardware available/ordered
  - Mass production/commissioning
  - Full ILD mechanics/cabling
- Exciting times!





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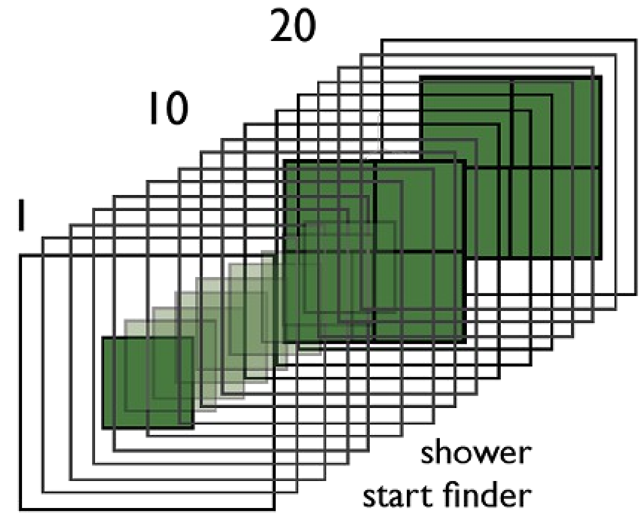

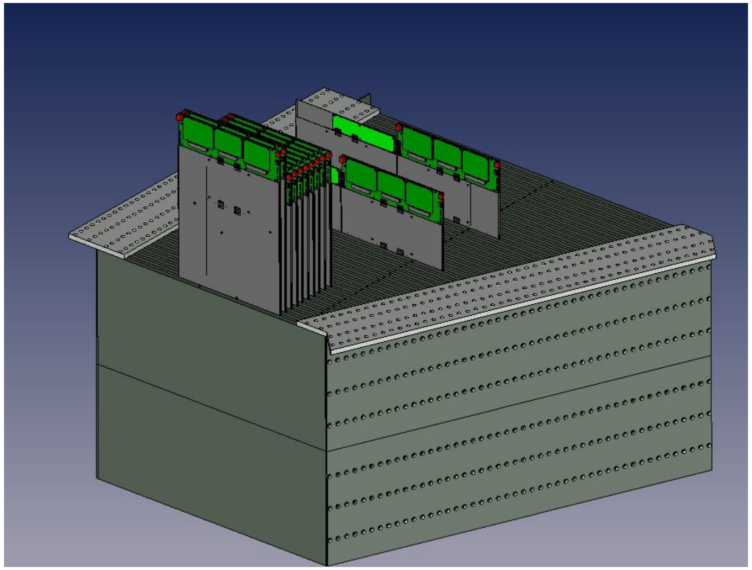

Summary

- Hadronic calorimetry is hard!
  - Classical approach hardly further optimisable
- Particle Flow Algorithms can greatly improve on this
  - Combination of tracker information into energy measurement
  - Needs very finely segmented calorimeters
- The CALICE collaboration develops such calorimeters
- The CALICE AHCAL …
  - … is Scintillator-SiPM based hadron calorimeter concept.
  - … first generation prototype has taken data 2006-2012.
  - … is now being developed into a second generation prototype to showcase full integration into a realistic collider detector.

Acknowledgements

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