Calorimetry for a Linear Collider

- > introduction
- > electromagnetic calorimeters
- > hadronic calorimeters
  - analog hadronic calorimeter

PHYSICS AT THE TERA SCALE
Helmholtz Alliance

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6th Annual Helmholtz Alliance Workshop on "Physics at the Terascale"

DESY, Hamburg, 3-5 December 2012

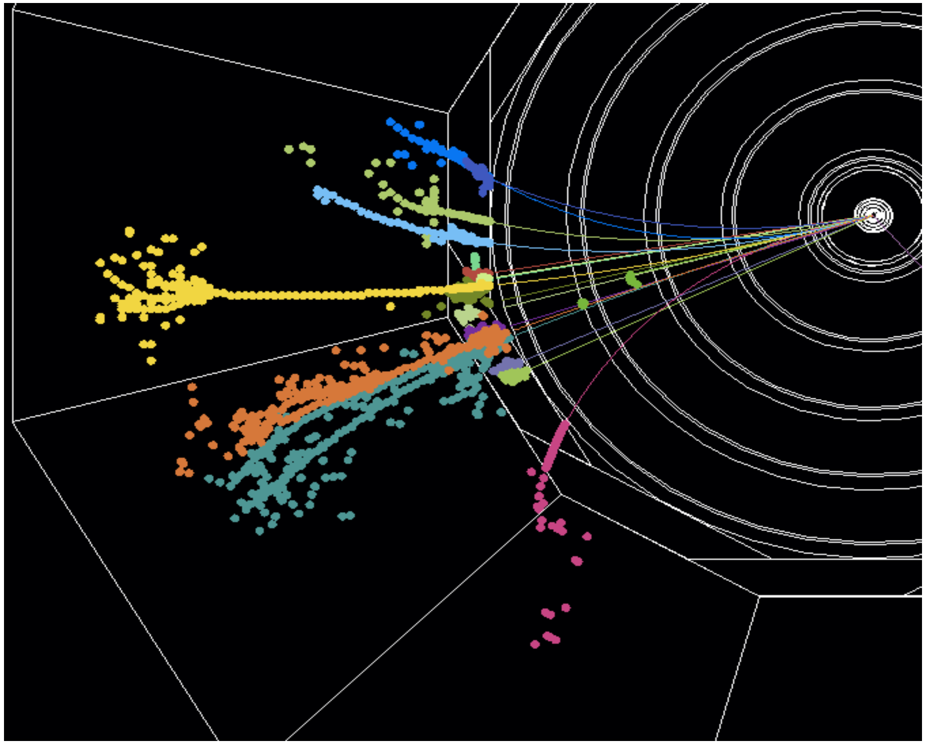
HELMHOLTZ | ASSOCIATION

CALICE
Calorimeter for ILC

UH
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

DESY

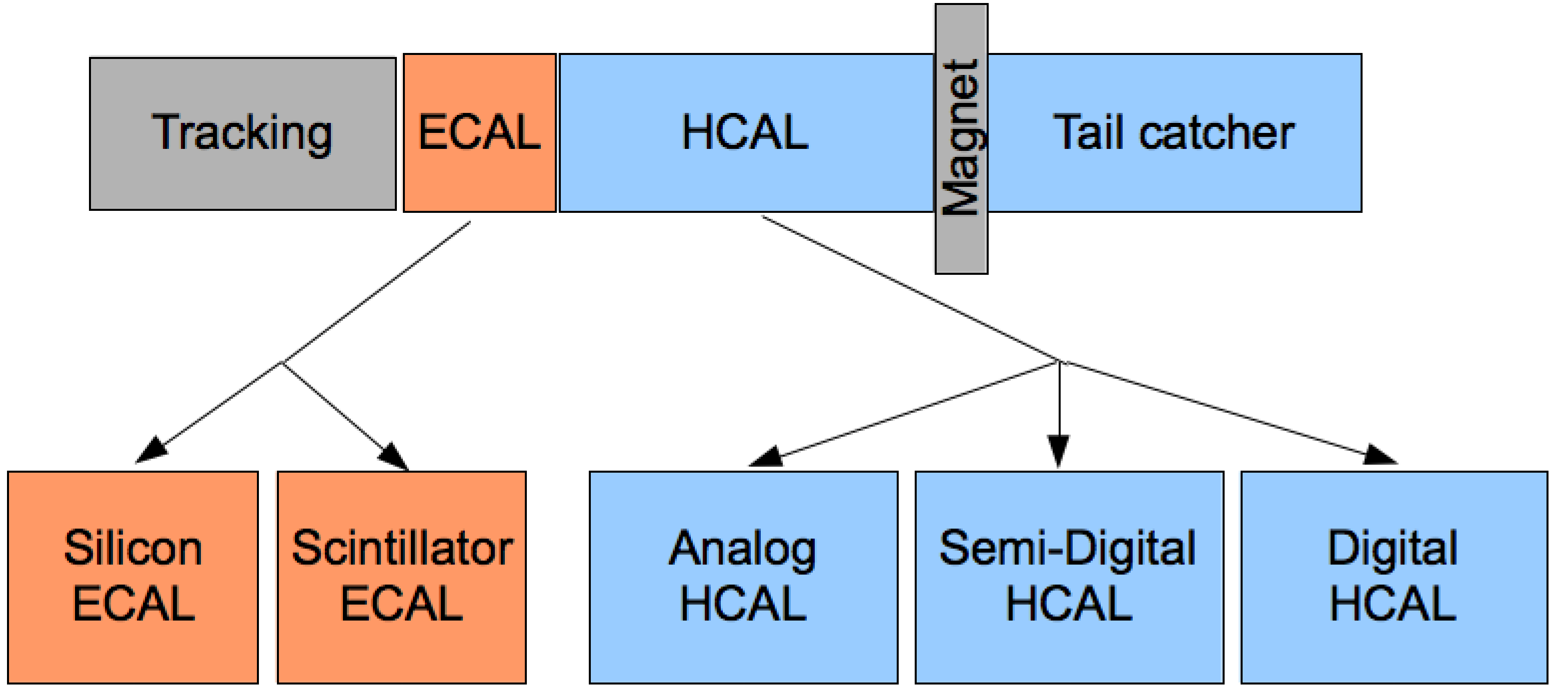
Introduction: Jet reconstruction at a Linear Collider



- goal: want to distinguish $Z \rightarrow$ jet jet from $W \rightarrow$ jet jet
- requires $\sigma(E)/E \approx 0.3 / \sqrt{E}$
- can be reached by particle flow algorithms (PFA)
  - for each particle within a jet the subdetector with optimal resolution is used
  - need to avoid double counting
- need an imaging calorimeter!

- requirements for the calorimeter:
  - reconstruction of photons: separation ECAL/HCAL
  - highly granular
  - calorimeter has to be within magnet coil: very compact

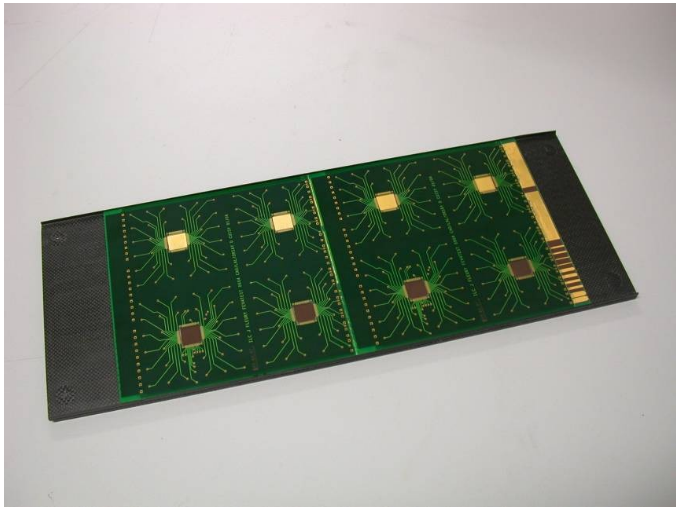
CALICE: Calorimeters for Particle Flow Algorithms



granularity	$0.5*0.5cm^2$	$4.5*0.5cm^2$	$3*3cm^2$	$1*1cm^2$	$1*1cm^2$
active material	silicon pixels	scintillator strips	scintillator tiles	RPCs or µMegas	RPCs (or GEMs)
absorber	W	W	W or Fe	Fe	W or Fe

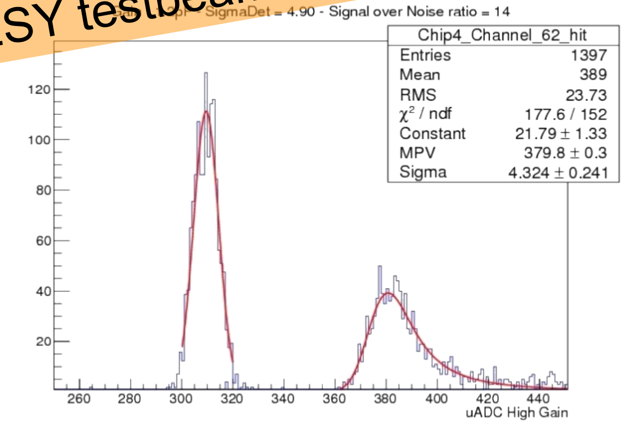
Silicon ECAL

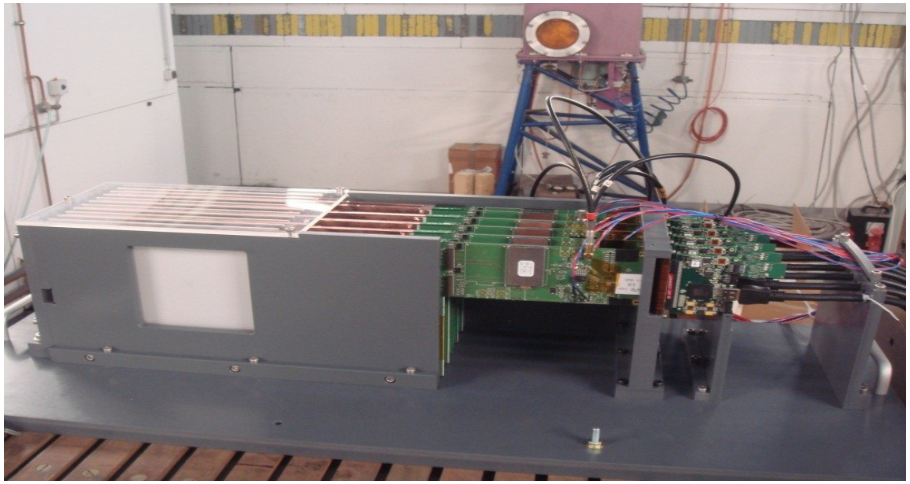
- working principle tested in 2006-2010
- test of 6-layer prototype of integrated design tested in electron beam at DESY in Summer 2012
    - calibration data
    - electron showers



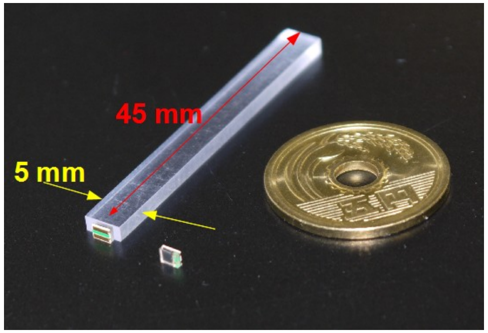
256 pixels, $9*9$ cm^2

DESY testbeam 2012 result

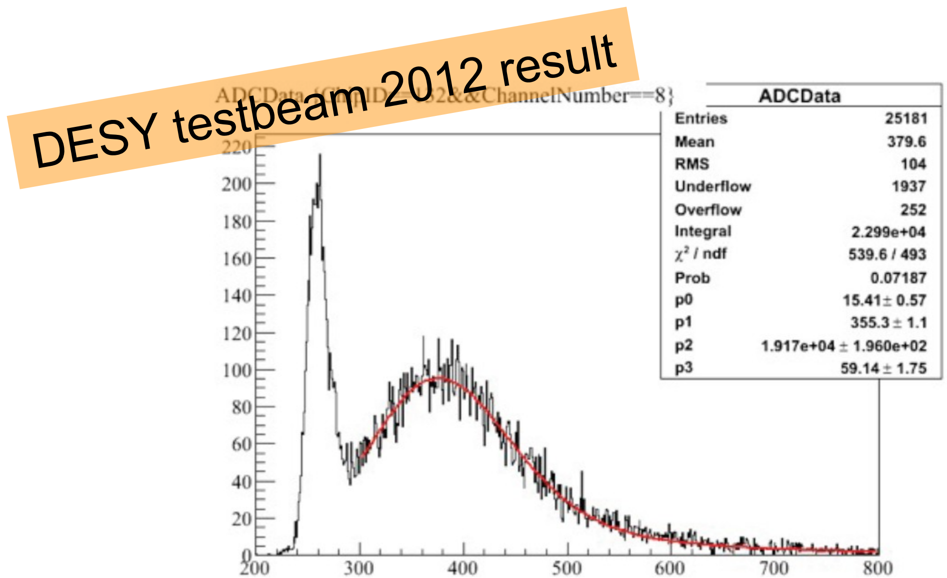




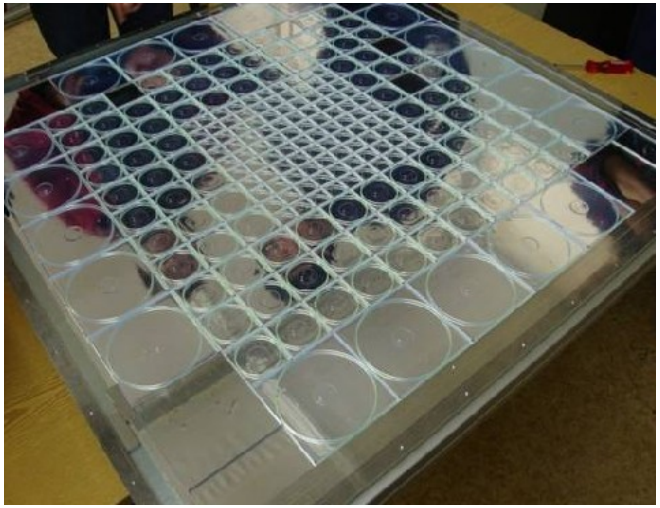
Scintillator ECAL



- working principle tested in 2008-2009
- electronics board: built at DESY, variant of analog HCAL board
- first test of one unit of integrated design tested in electron beam at DESY in October 2012
  - calibration data
  - electron showers



Analog HCAL



Physics prototype (proof of principle):

scintillator tiles of 3*3 to 12*12 cm^2,
read out by Silicon Photomultipliers (SiPMs)

38 active layers

2006-2009:
tests with Steel absorber

2010-2011:
tests with Tungsten absorber

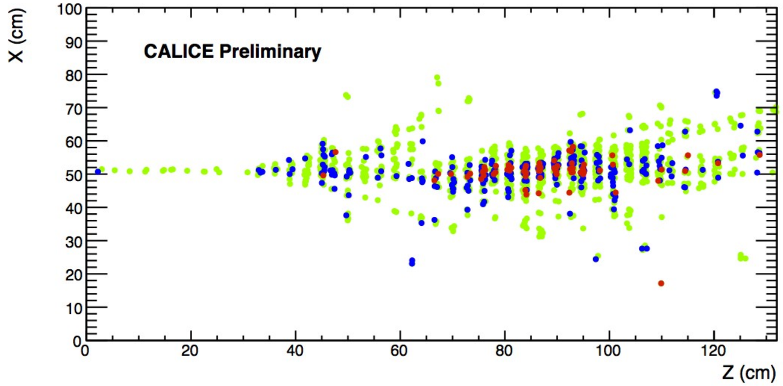
Semi-Digital HCAL

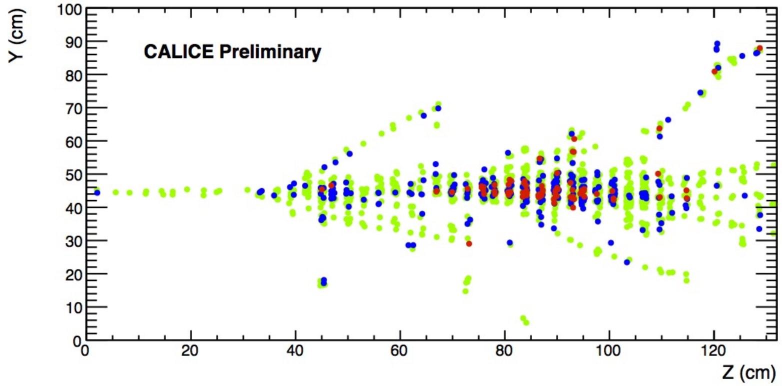
Resistive Plate Chambers, 1*1 cm^2 pads

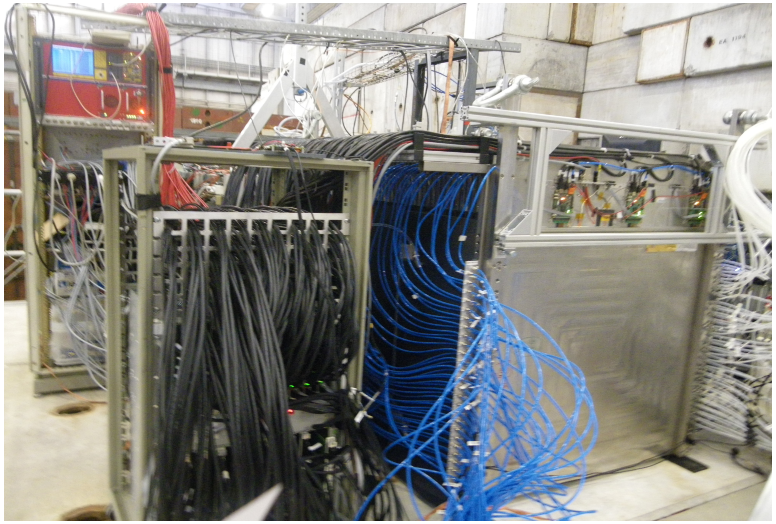
2-bit (semi-digital) → 3 thresholds
digitization embedded into calorimeter

power pulsing

48 layers







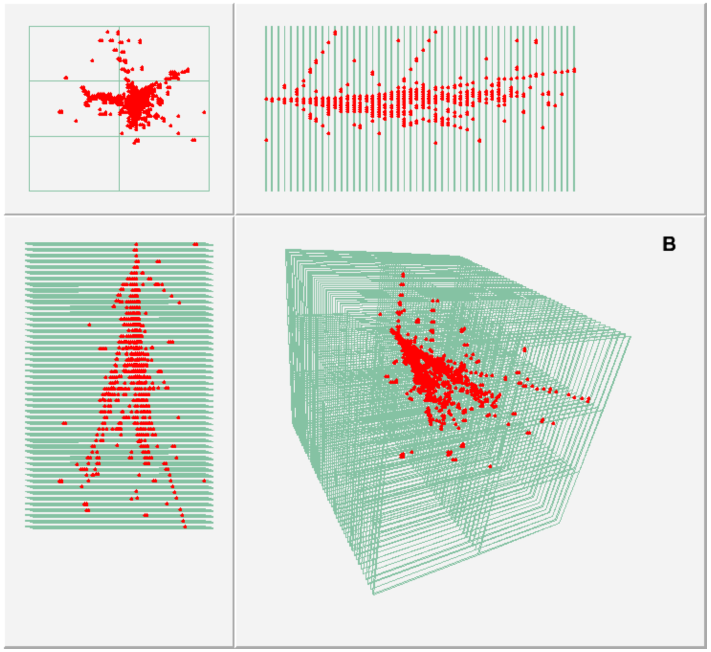
2012:
tests with Steel absorber

Digital HCAL

Resistive Plate Chambers, 1*1 cm^2 pads

1 – bit (digital)
digitization embedded into calorimeter

54 active layers

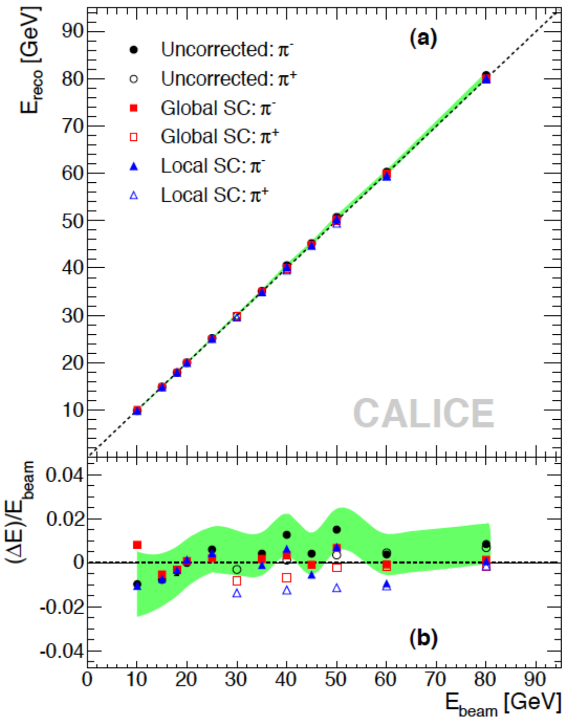


2010-2011:
tests with Steel absorber

2012:
tests with Tungsten absorber

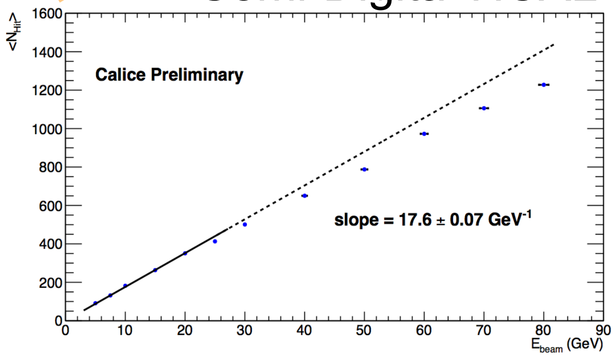
Response (Steel absorber)

Analog HCAL

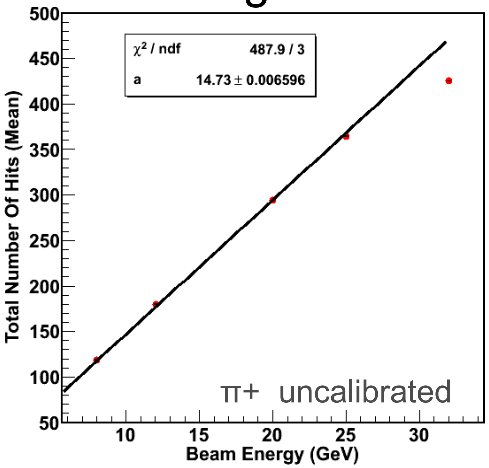


2012 result

Semi-Digital HCAL



Digital HCAL



linear response to hadrons at the <1% level

under-compensating: e/h ~ 1.2

non-linear response to both e± and hadrons

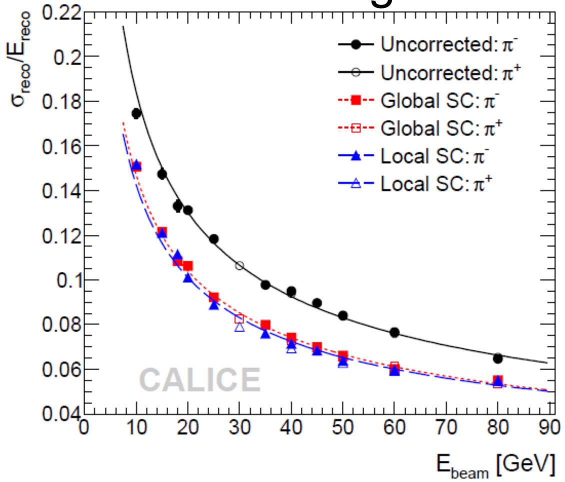
deviations from linearity due to finite readout pad size

can be improved by calibration or software compensation

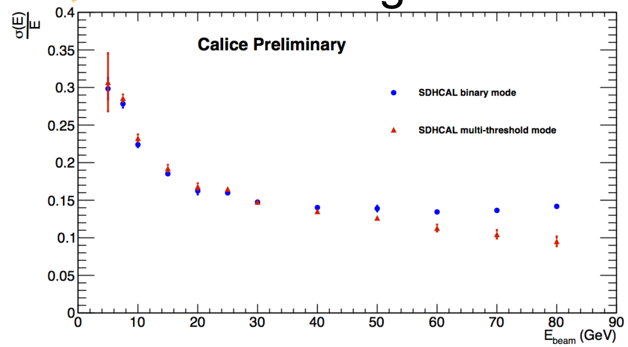
Resolutions (Steel absorber)

2012 result

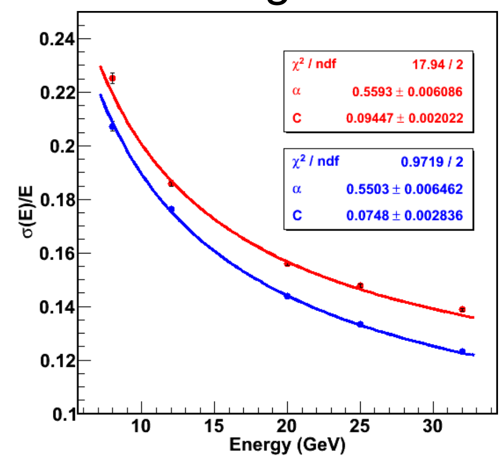
Analog HCAL



Semi-Digital HCAL



Digital HCAL



Software Compensation: apply different weights to ‘hadronic’ or ‘electromagnetic’ sub-showers

→ large improvement in stochastic term: 58%/√E → 45%/√E

Measurements using either **1** or **3** thresholds

→ improvement at higher energies with 3 thresholds

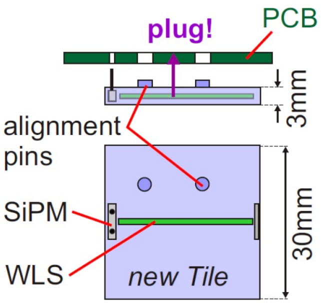
corrected for non-linearity

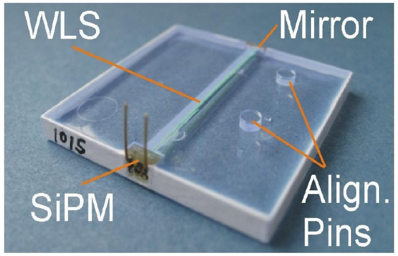
without and **with** containment cut

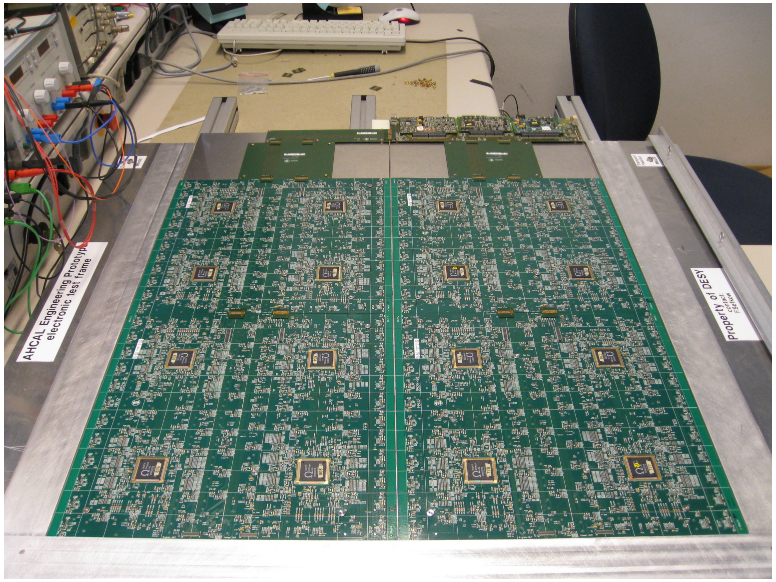
→ stochastic term: 55%/√E

not corrected for non-linearity

Analog HCAL: Towards an Engineering Prototype







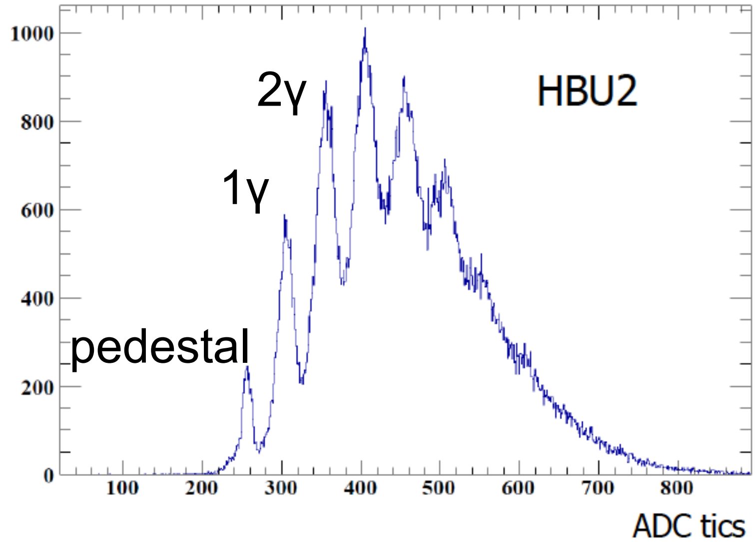
- 3*3*0.3 cm^3 tiles
- fully integrated electronics, power pulsing capability
- 1 layer with 72*72 cm^2 active area, 576 channels:
  - calibrated in DESY testbeam in 2012
  - tested in CERN π testbeam in 2012

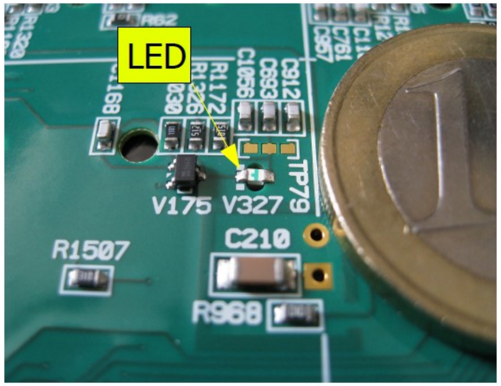
The AHCAL in CALICE

- DESY: steel structures, electronics and integration, test beam support, software, project management
- Hamburg: SiPMs and tile optimisation, test beam and commissioning w/ DESY
- Heidelberg: high gain ASICs, SiPM mass tests and characterisation
- MPI Munich: SiPM development, tile optimisation, cassettes, tungsten timing
- Wuppertal: embedded LED electronics and test stands
- Mainz: DAQ central components and AHCAL data concentrator
- LAL Orsay: SPIROC ASICs
- ITEP: tiles and SiPMs, test bench characterisation
- CERN: tungsten absorber, testbeam and Geant4 support
- Dubna: power supplies and distribution
- Prague: fibre based LED system
- NIU: alternative SiPM coupling, DAQ interface
- Bergen: calibration studies

Analog HCAL: LED calibration system

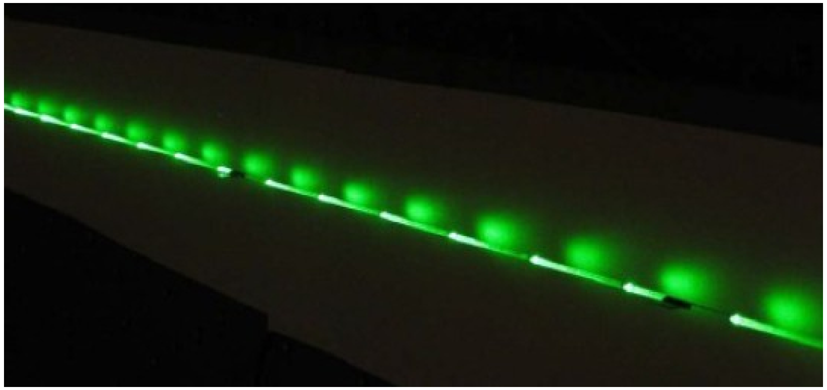
used to determine gain from single photon spectra:



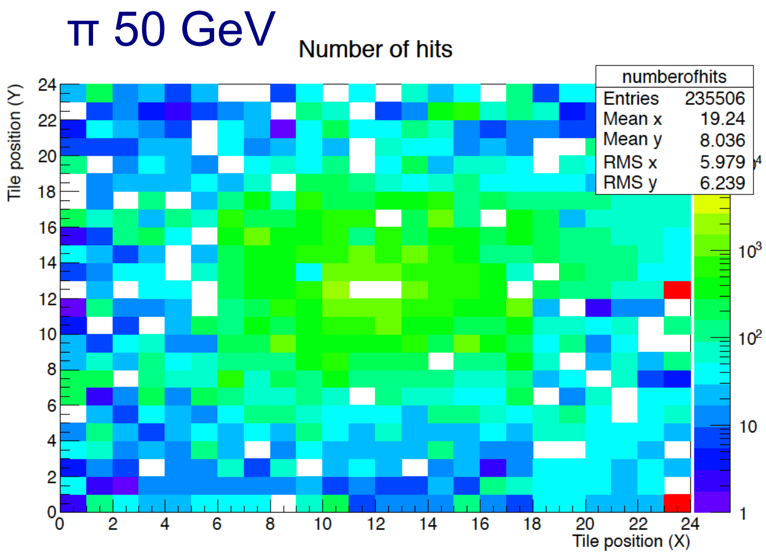


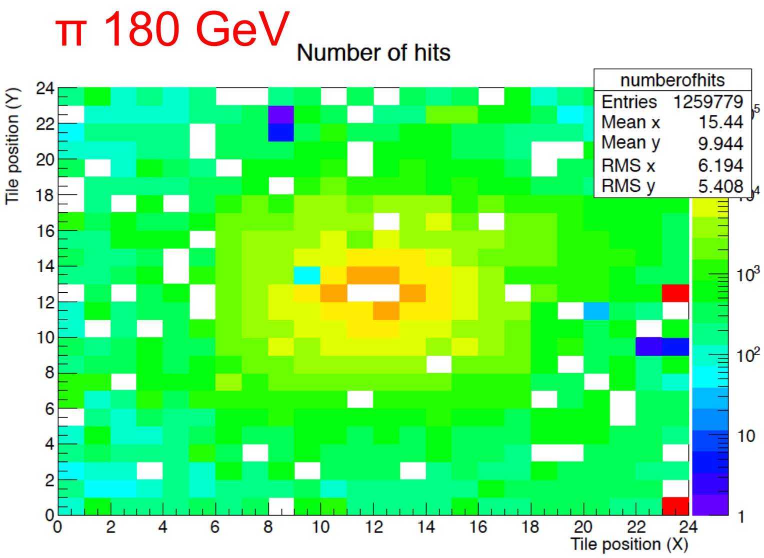
two possible solutions:

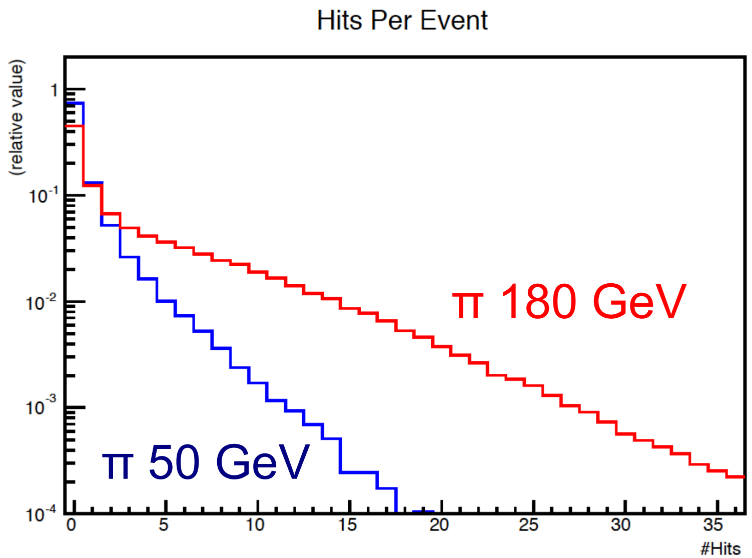
- light coupled directly into tile, 1 integrated LED per channel
  - implemented in current detector design
  - developed by Uni Wuppertal
- light coupled into tile by notched fiber
  - tests in lab ongoing



Data collected in Cern testbeam







collected data sets:

- pions at 50 GeV
- pions at 180 GeV
- muons at 180 GeV for calibration

First look into CERN data

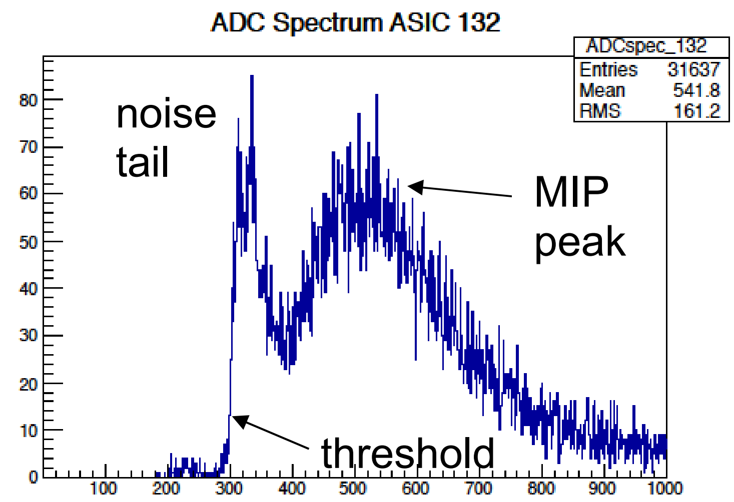
use muon data to check that gain equalization with LED data worked:

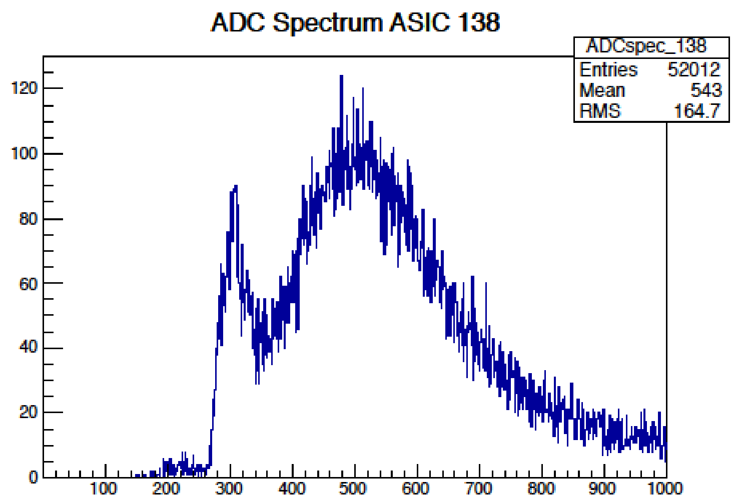
> added spectra of 36 tiles read out by 1 ASIC

> peak from MIPs and noise tail nicely visible, so all channels are similar

> MIP peaks for different ASICs have same position

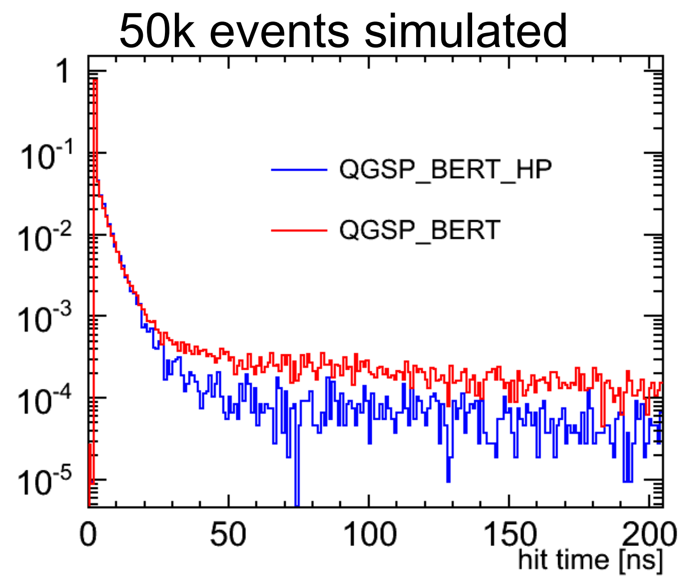
➔ equalization worked ☑



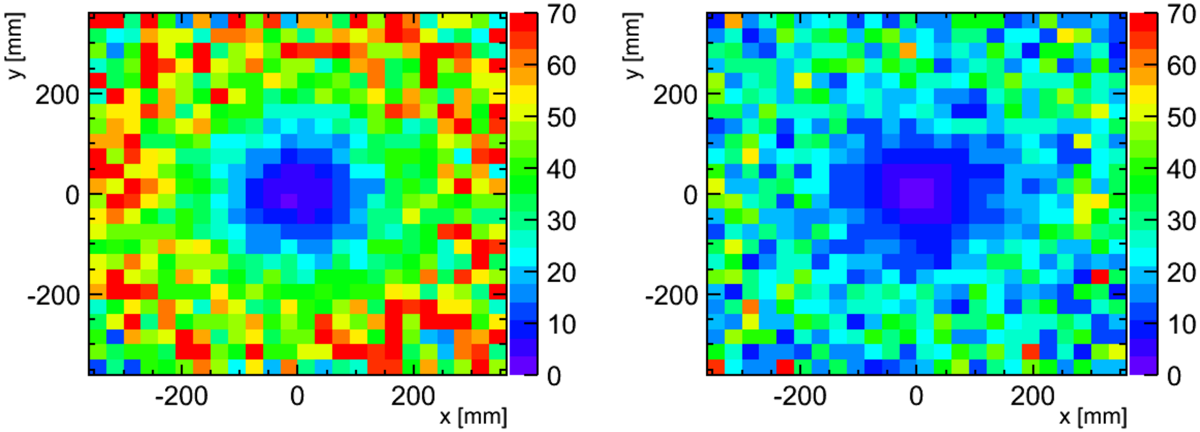


Goals for Analog HCAL testbeam at CERN

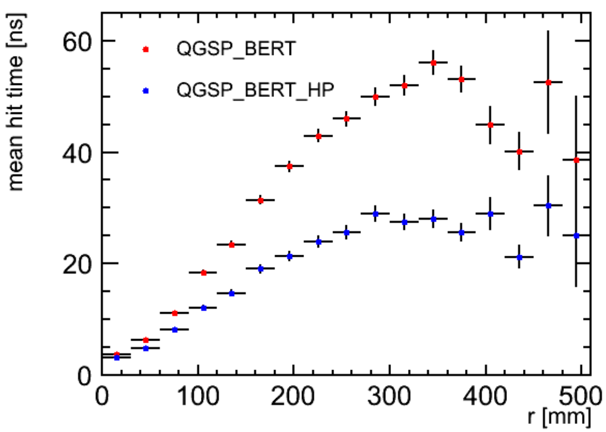
- System test of one-layer prototype
  - ➔ successful ☑
- Study time structure of hadron showers
  - differences in the time development of showers between hadron shower models
  - differences especially in the shower tail
  - ➔ analysis started



mean hit time [ns]

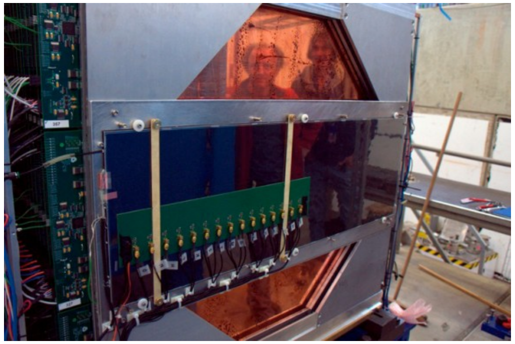


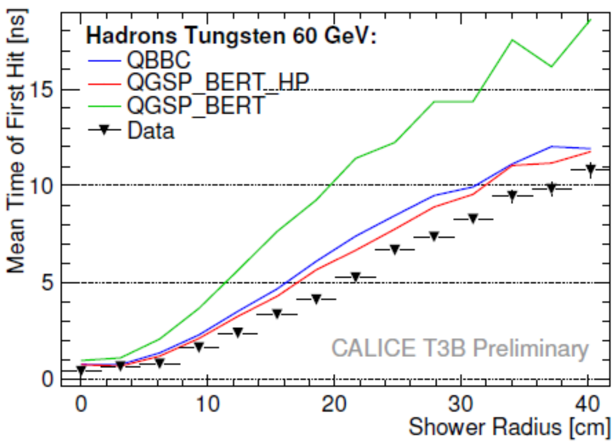
QGSP_BERT QGSP_BERT_HP



T3B: Measurements of hadron shower timing

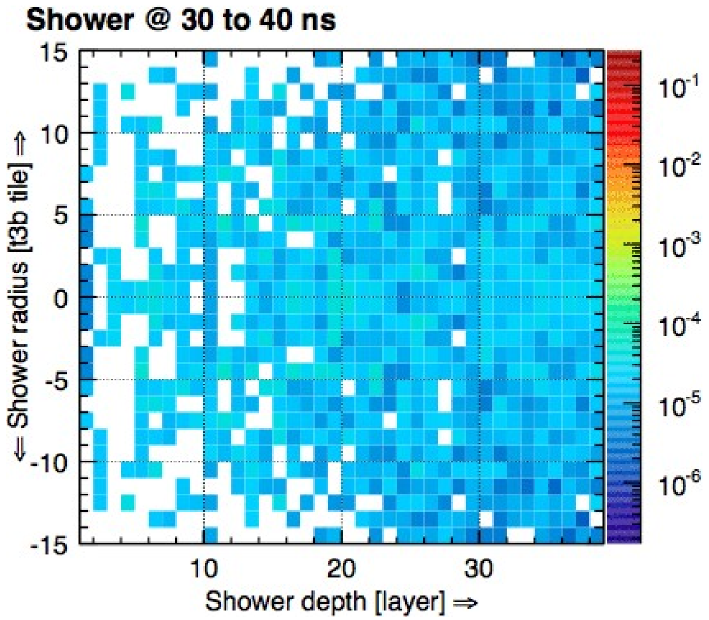
- dedicated measurement of shower timings:
  - 1 row of 15 scintillator pads or RPC with pads
  - downstream of steel or tungsten HCAL stack
  - developed by MPI München





comparison to shower models: some models give reasonable description at all radii

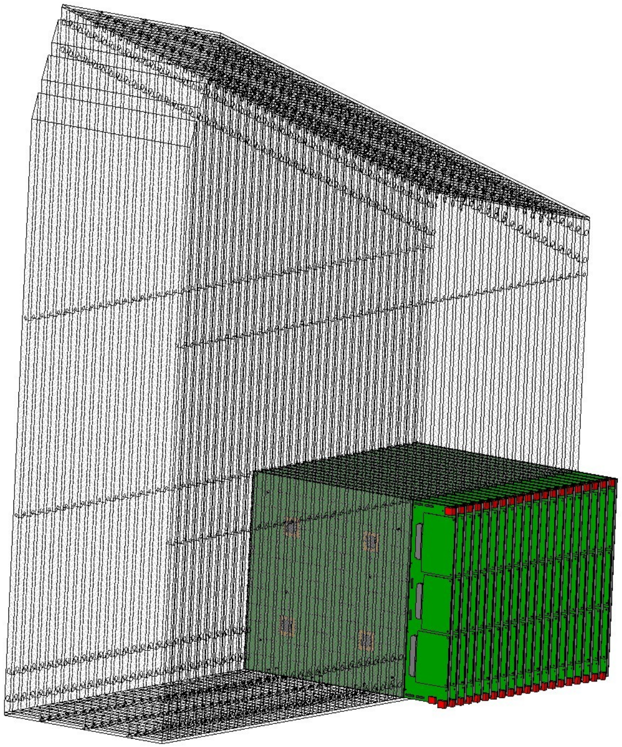
average 60 GeV shower in 4D



measured from shower start in AHCAL

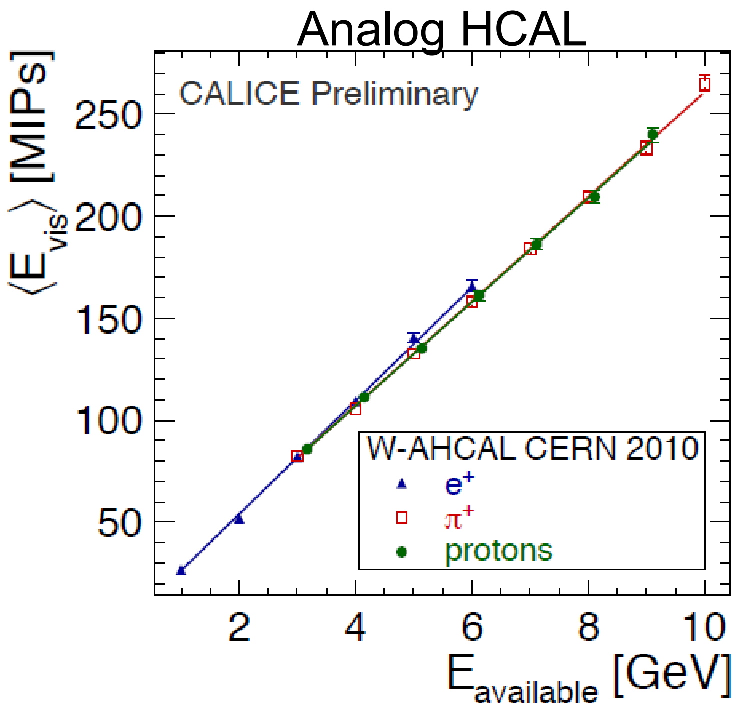
Summary & Outlook

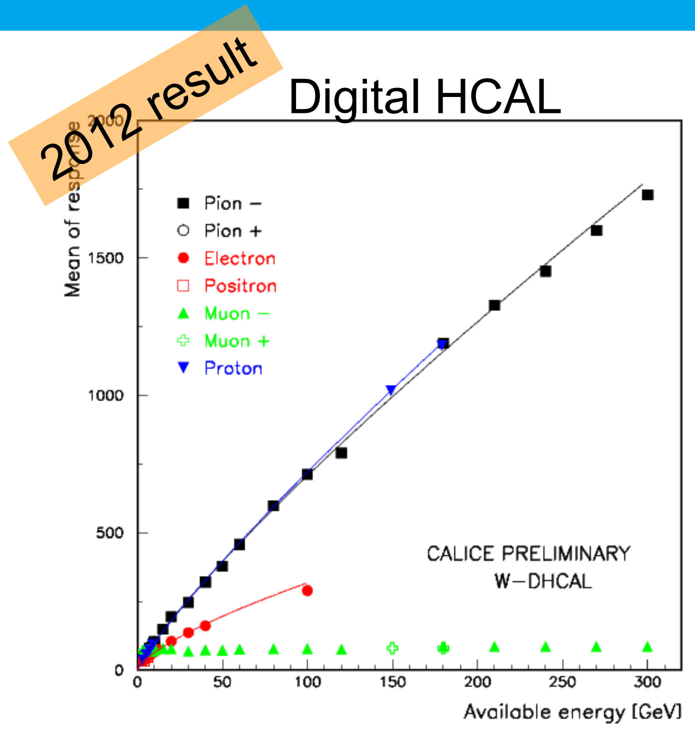
- very successful testbeam season 2012 for all detector concepts
  - DESY testbeam crucial in many areas
- working principle demonstrated for all concepts, on the way to fully integrated prototypes for LC detectors
  - analog HCAL: well established, simulation validated in great detail
  - semi-digital and digital HCAL: operation established, analysis started
  - superior resolution of analog HCAL at large energies
- plans for 2013:
  - analysis of data collected in 2012
  - next generation prototype of analog HCAL
  - further beam tests at DESY for ECALs and analog HCAL



Backup

Response with Tungsten absorber





Linear response up to 10 GeV
(higher energies still being analyzed)

5 mm scintillator + 10 mm W
→ **Compensation : e/h ~1**

non-linear response
for electrons and hadrons

e/h ~ 0.9 – 0.5
→ **over-compensating**
→ need smaller readout pads