Recent developments in calorimetry for Linear Collider

Lucia Masetti
Johannes Gutenberg University Mainz
PRISMA Cluster of Excellence

Terascale Detector Workshop
Berlin - March 4th, 2015

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

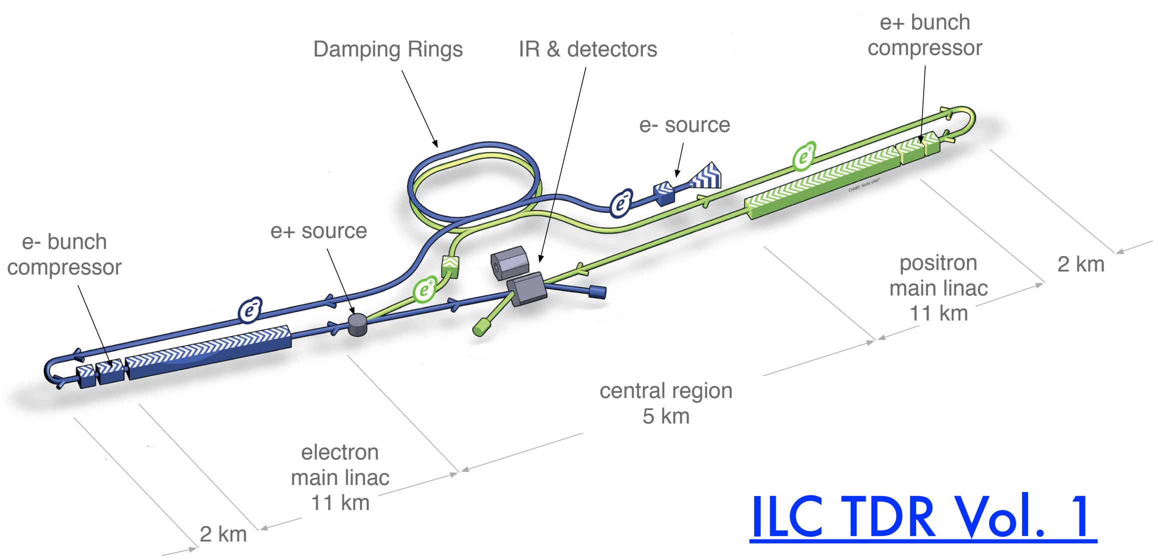
PRISMA

Outline

- Introduction
  - Calorimeter designs for ILC and CLIC
- Recent developments
  - ECAL
  - HCAL
  - Forward
- Conclusions

Introduction

ILC and CLIC



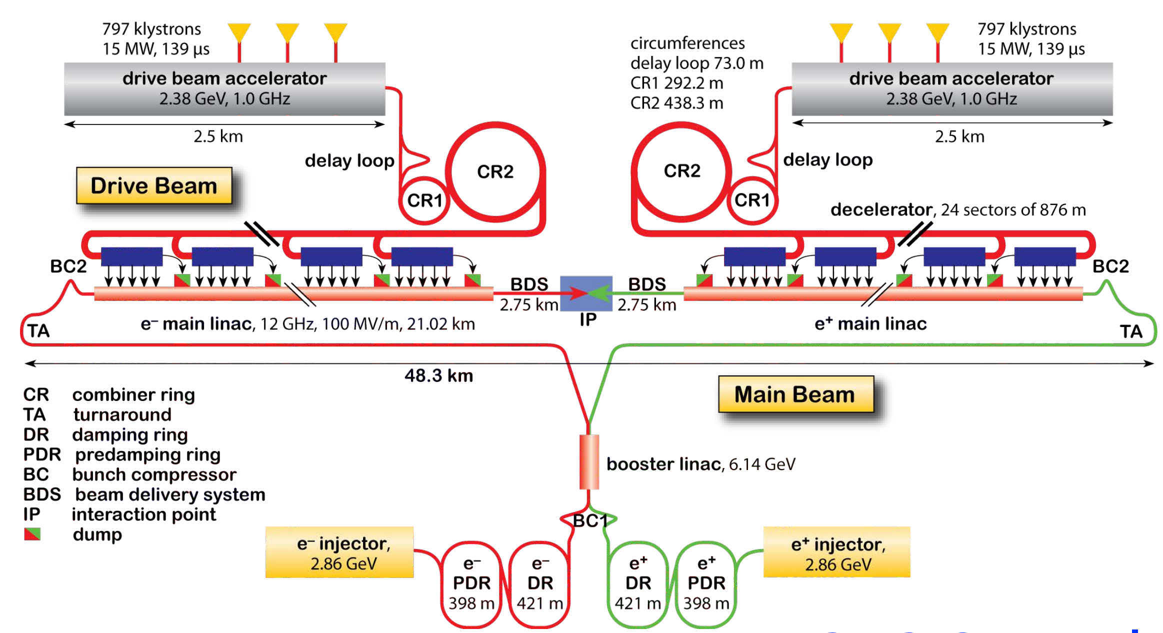
ILC TDR Vol. 1

ILC

Energy: 250 GeV - 1 TeV
Luminosity: $10^{34}/cm^2/s$
Total footprint: 31 km
Polarised beams
"Standard" technology

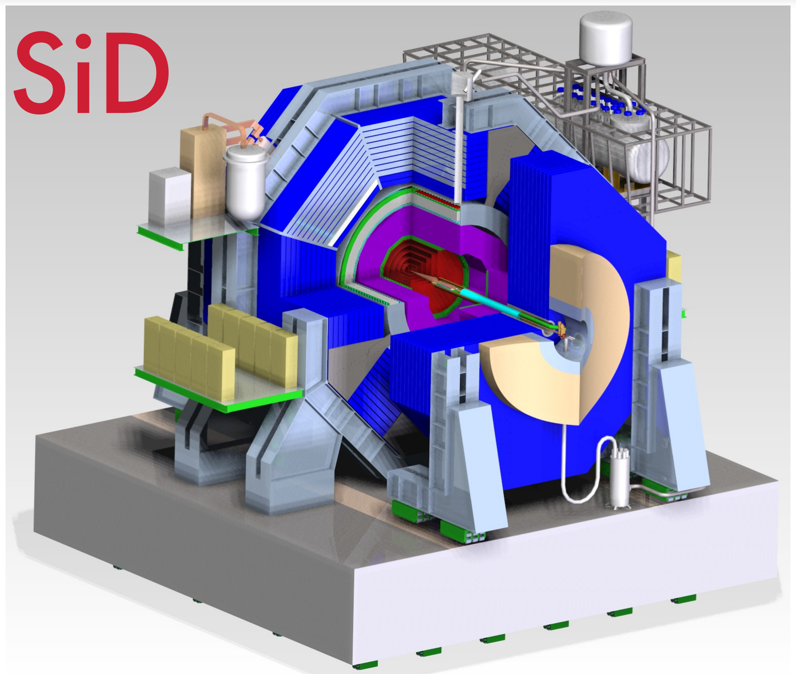
CLIC

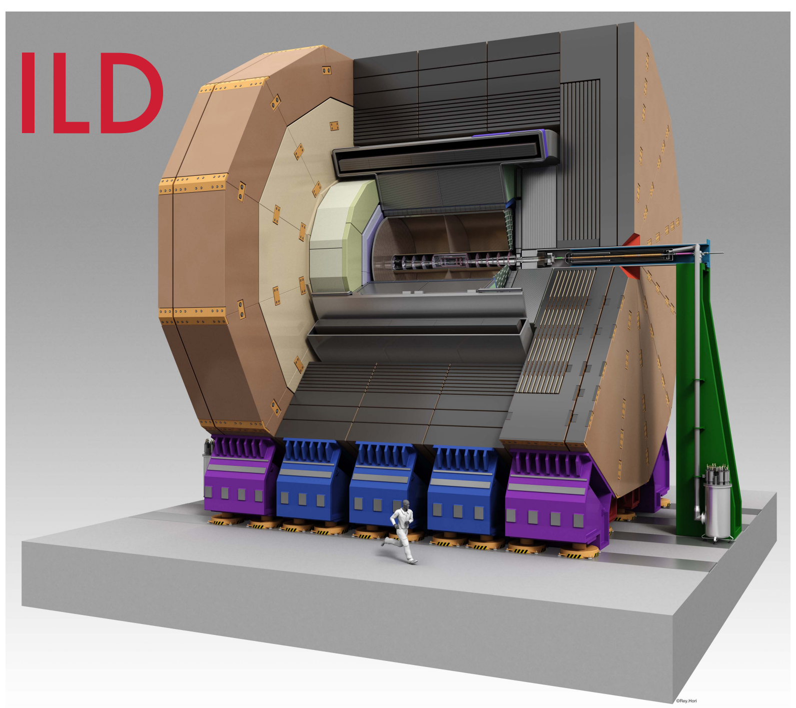
Energy: 500 GeV - 3 TeV
Luminosity: $5x10^{34}/cm^2/s$
Total footprint: 48 km
Polarised electrons
Two-beam acceleration



CLIC CDR Vol. 1

Detector designs





Two experiments sharing one interaction point with push-pull approach

SiD: compact detector with silicon tracking
ILD: larger detector with silicon+TPC tracking

Concept	ILD	CLIC_ILD	SiD	CLIC_SiD
Tracker	TPC/Silicon	TPC/Silicon	Silicon	Silicon
Solenoid Field (T)	3.5	4	5	5
Solenoid Free Bore (m)	3.3	3.4	2.6	2.7
Solenoid Length (m)	8.0	8.3	6.0	6.5
VTX Inner Radius (mm)	16	31	14	27
ECAL r_{min} (m)	1.8	1.8	1.3	1.3
ECAL Δr (mm)	172	172	135	135
HCAL Absorber B / E	Fe	W / Fe	Fe	W / Fe
HCAL λ_I	5.5	7.5	4.8	7.5
Overall Height (m)	14.0	14.0	12.0	14.0
Overall Length (m)	13.2	12.8	11.2	12.8

ILC TDR Vol. 4

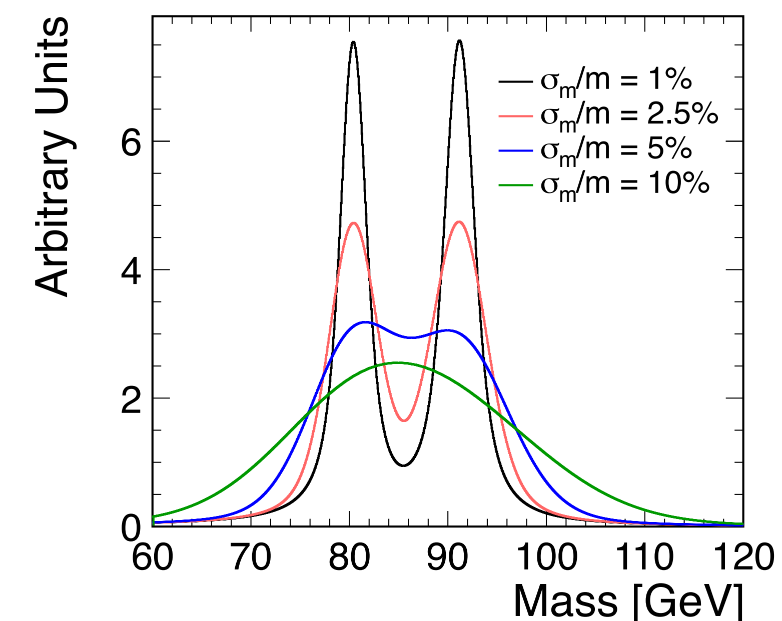
CLIC CDR Vol. 2

Calorimetry requirements

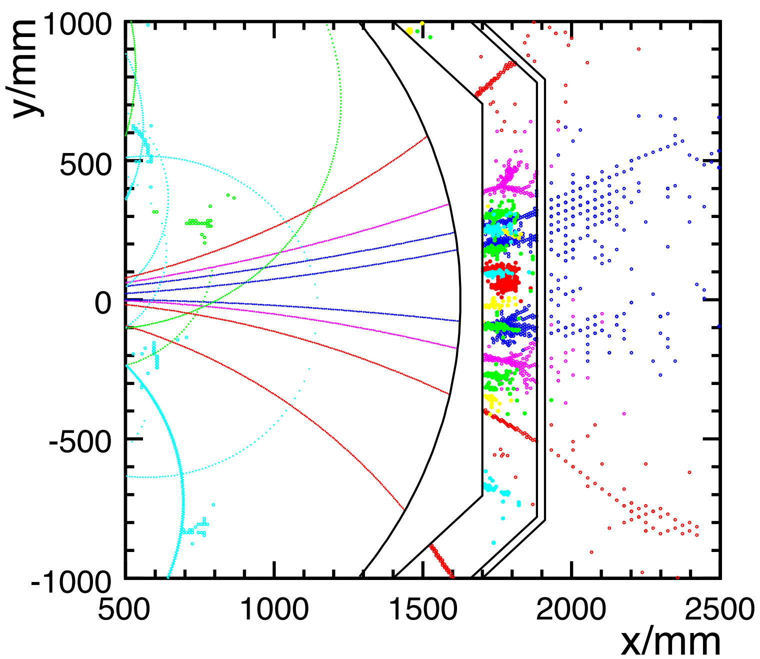
Requirement: Jet energy resolution of few %, allowing to separate W and Z decays

Solution: Jet Reconstruction with Particle Flow Algorithm
Charged particles in tracker (65% of jet energy)
Photons in ECAL (25% of jet energy)
Neutral hadrons in HCAL (10% of jet energy)

Design: high-granularity "imaging" calorimeters



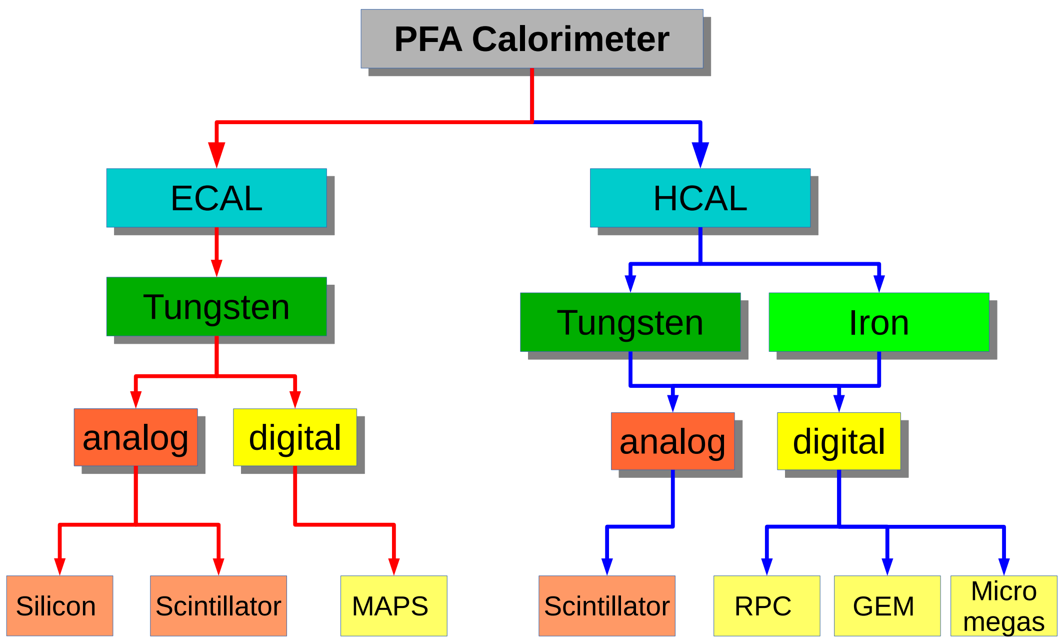
CLIC CDR Vol. 2



PandoraPFA

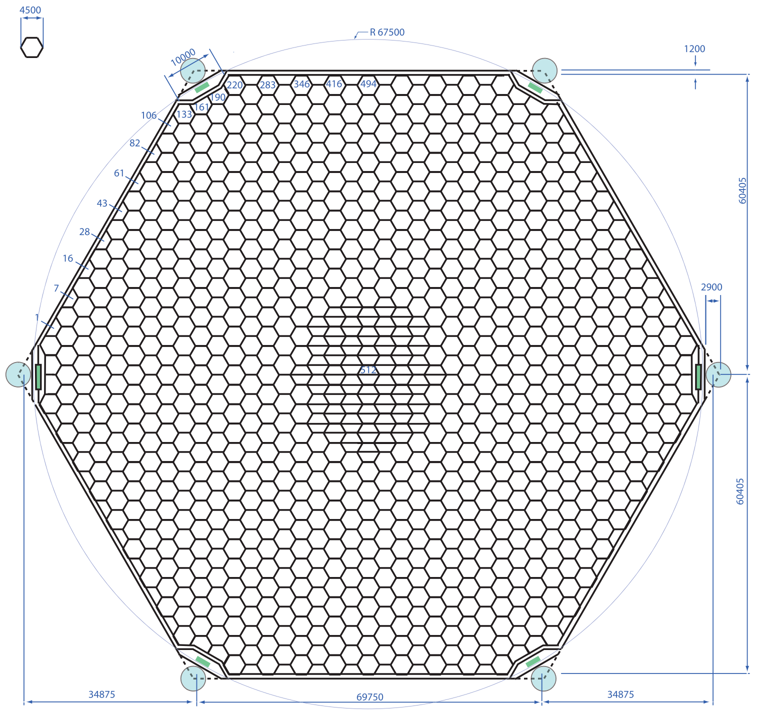
Common R&D within the CALICE collaboration

Many **German institutes** involved:
DESY, MPI Munich, Hamburg, Heidelberg, Mainz, Wuppertal



ILC TDR Vol. 4

ECAL



ILC TDR Vol. 4

SiECAL

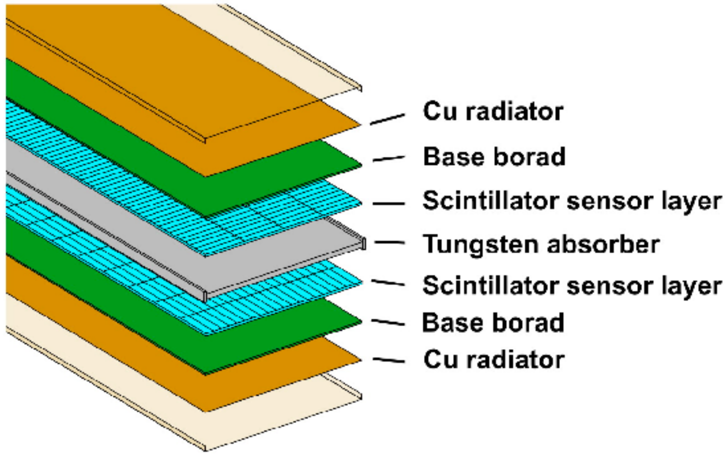
SiD: 13 mm^2 pixels bump-bonded to read-out chips
20 thin + 10 thick W layers (26 X_0 total)

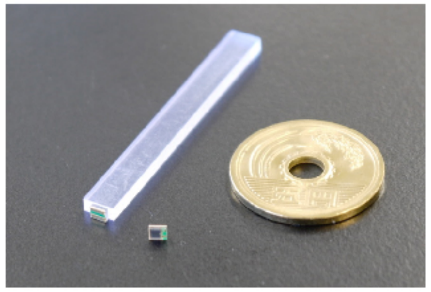
ILC: 5x5 mm^2 pixels
30 W layers (24 X_0 total)

ScECAL: cheaper option
5x45 mm^2 scintillator strips with MPPC

Sc+Si option under study

T. Suehara, LCWS 14





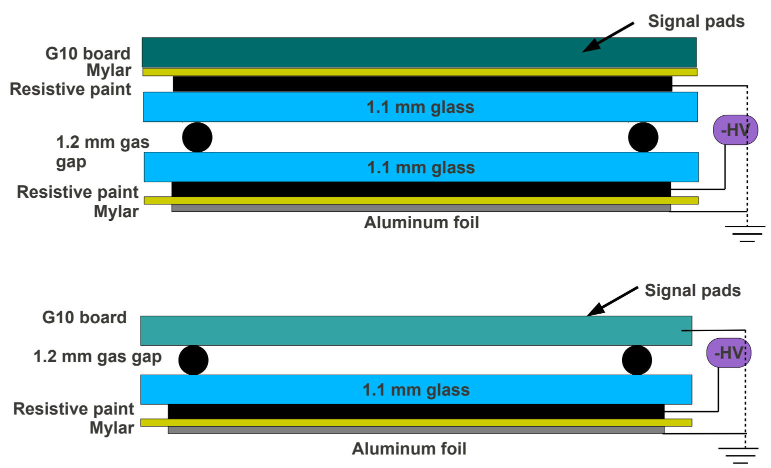
K. Kotera, LCWS 13

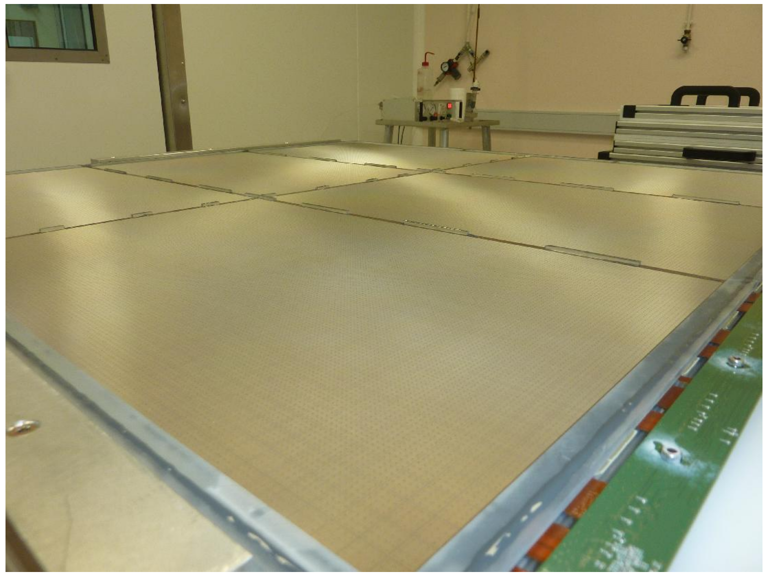
HCAL

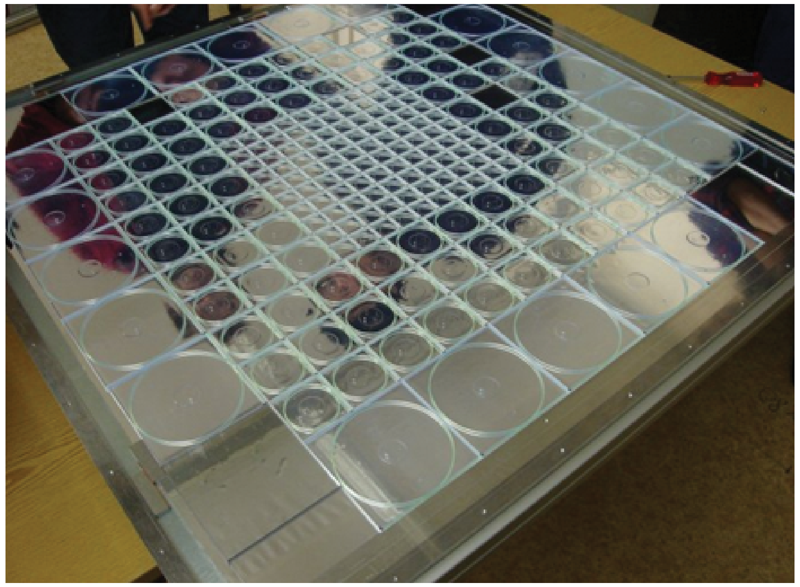
Absorber: stainless steel (preferred for ILC) or tungsten (preferred for CLIC)
Many options for active materials under investigation

AHCAL: 3x3 cm^2 scintillator tiles with SiPM
analog readout

(S)DHCAL: gaseous detectors with 1x1 cm^2 segmentation
Glass RPCs as baseline, GEM and Micromegas also considered
digital or semi-digital (3 thresholds) readout







ILC TDR Vol. 4

Forward

LumiCal

Aim: measure luminosity to better than 10^{-3}
Bhabha scattering as reference process

Cylindrical sandwich with tungsten absorber and silicon sensor planes

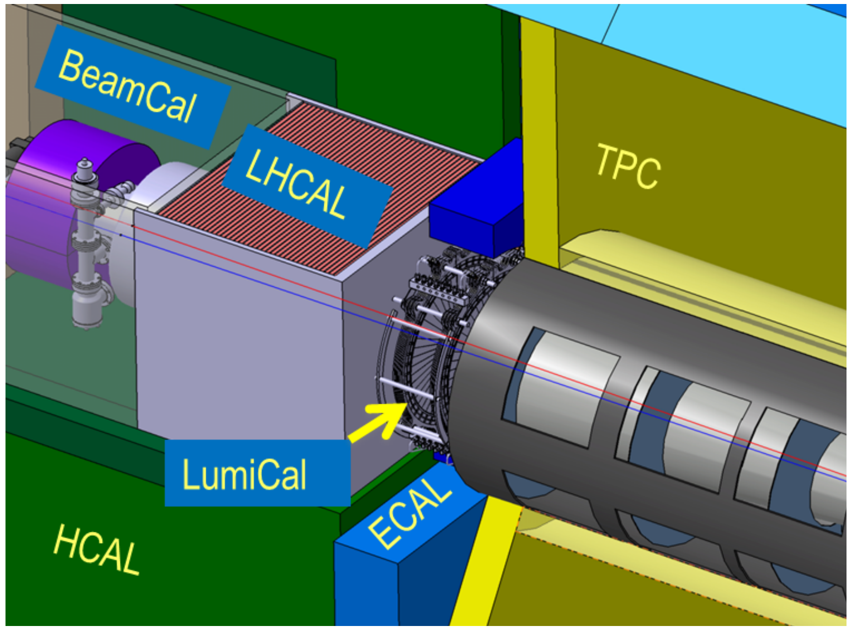
BeamCal

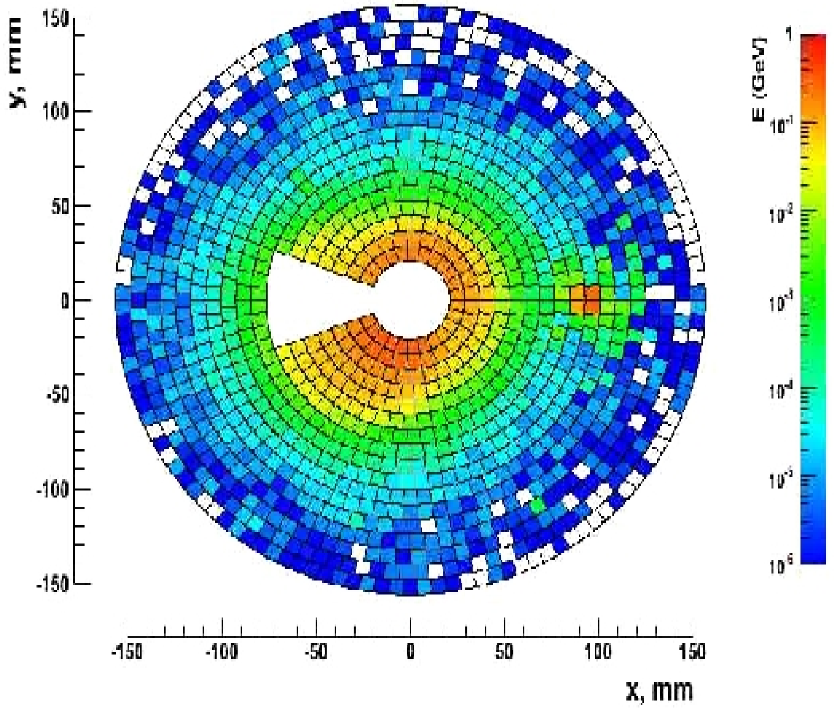
Aim: bunch-by-bunch luminosity estimate
determination of beam parameters

10 MGy radiation hardness required

GaAs or CVD diamonds considered as sensors

R&D within FCAL collaboration
German participation: DESY



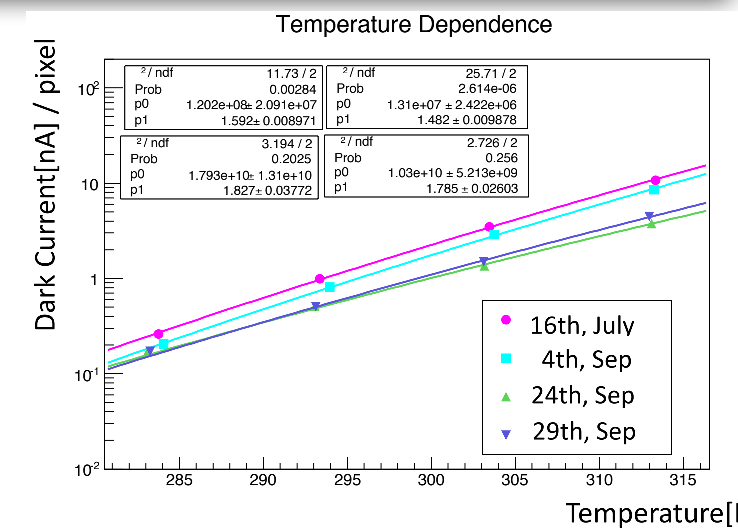


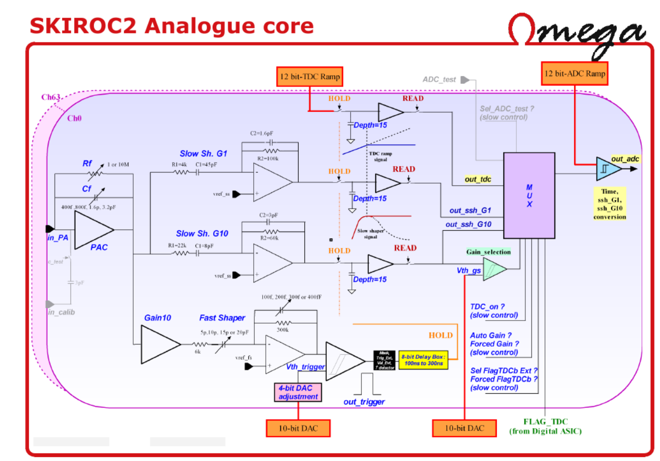
ILC TDR Vol. 4

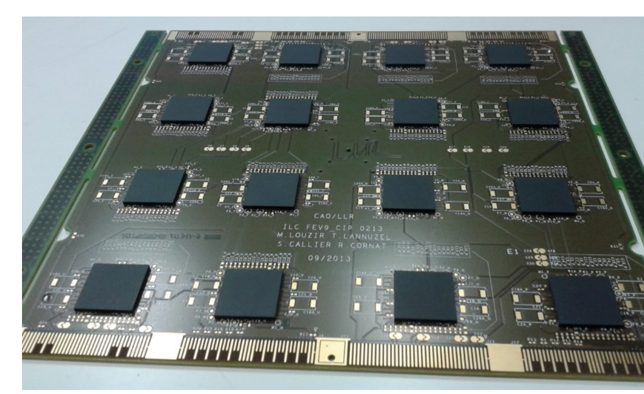
Recent developments

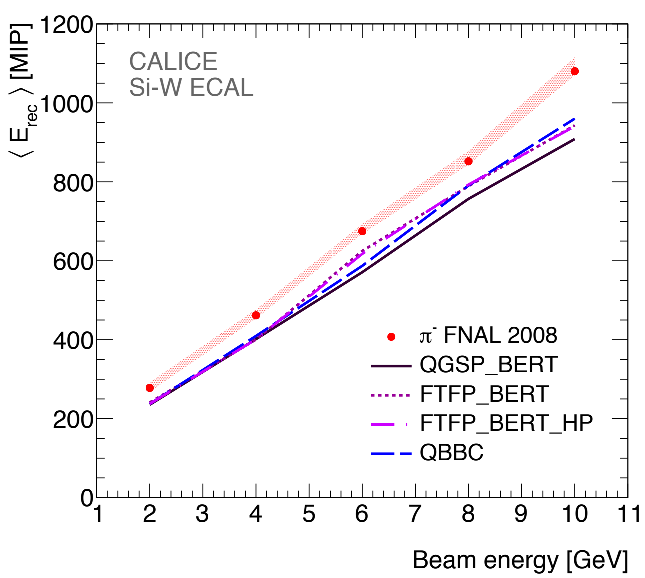
SiECAL: results and news

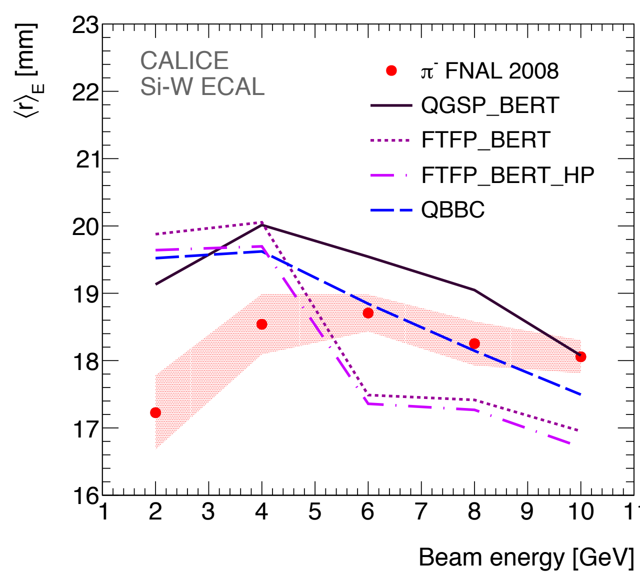
- Analysis of pion testbeam data from 2008
  - Comparison with hadron shower models
- Detector development
  - Silicon sensor studies [S. Takada, LCWS 14]
    Temperature and humidity dependence, laser injection
  - Readout electronics, mechanical design [V. Balagura, LCWS 14]

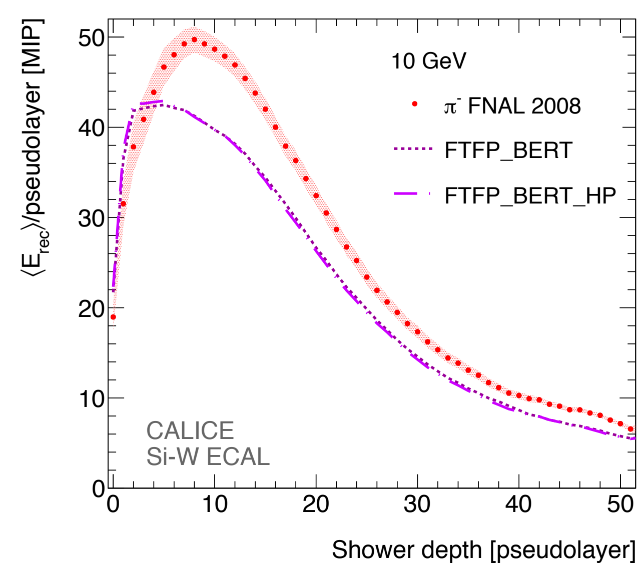








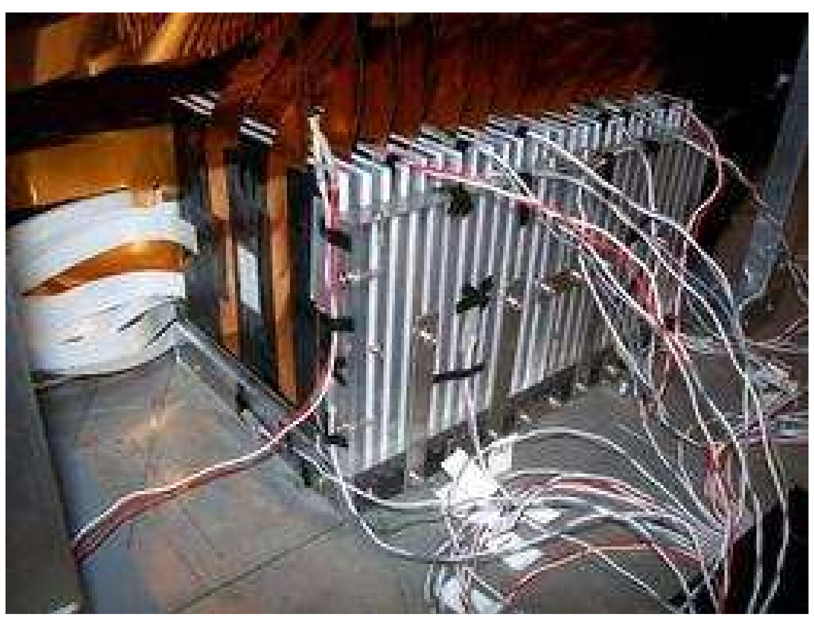




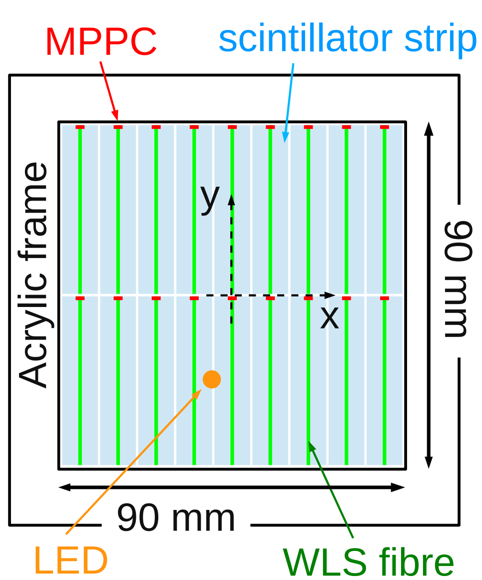
arXiv:1411.7215

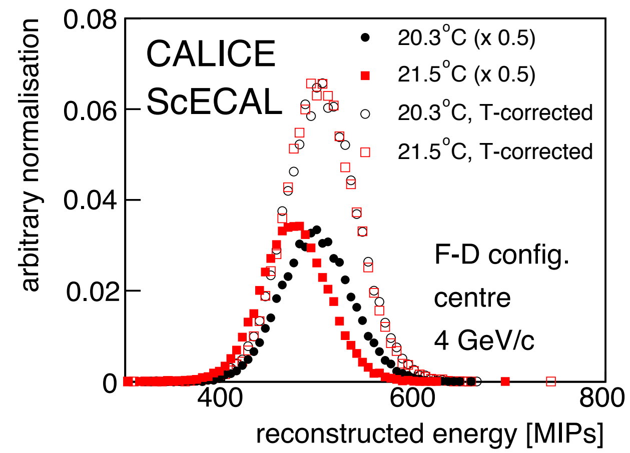
ScECAL: latest results

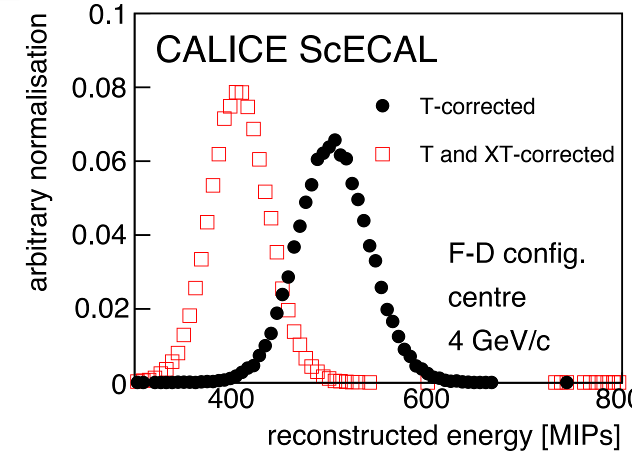
- Results from **ScECAL testbeam in 2009**
  30 layers with 1 cm wide scintillator strips w/ and w/o WLS fibre
  - Temperature dependence, cross-talk
  - Comparison of detector configurations
  - Energy linearity and resolution

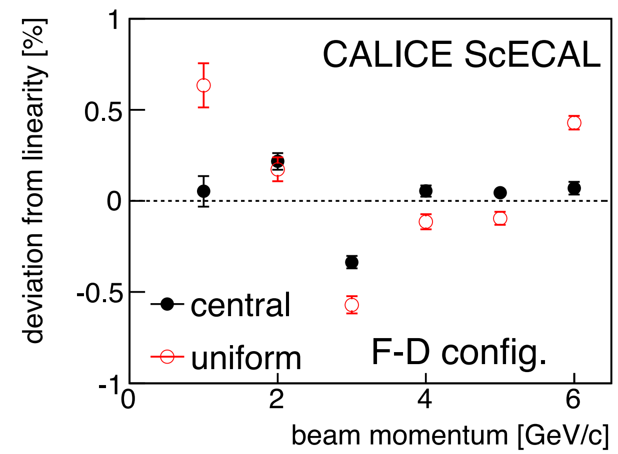


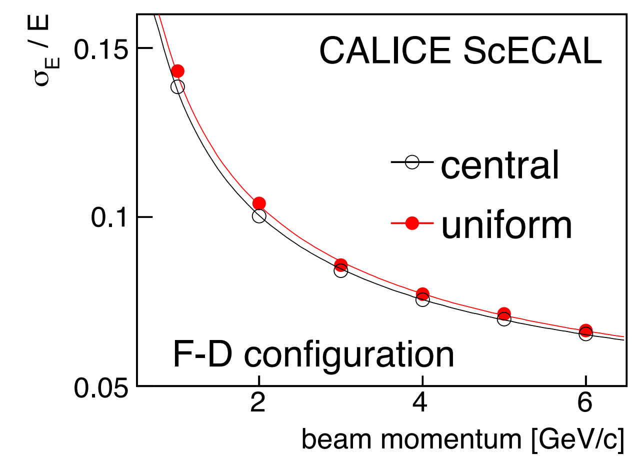
[arXiv:1311.3761](https://arxiv.org/abs/1311.3761)









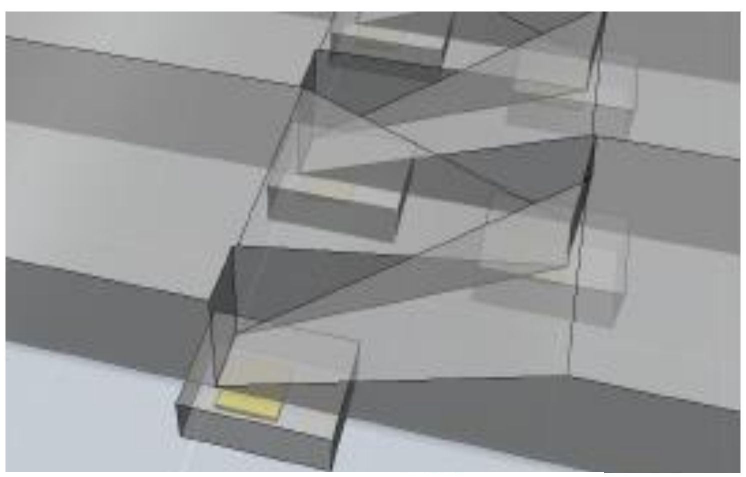


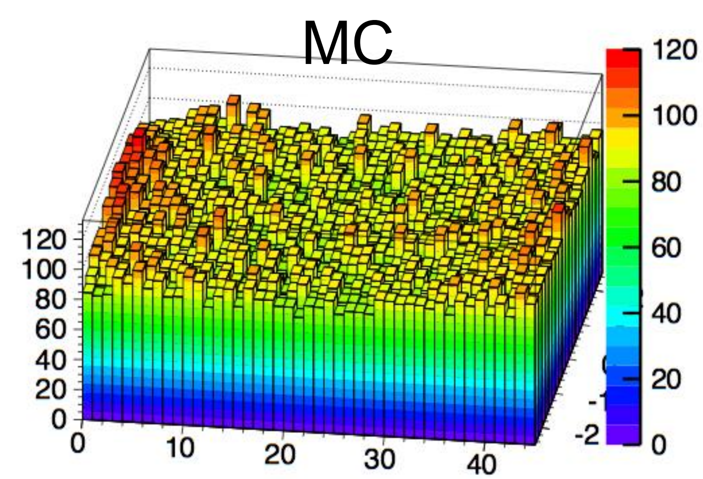
configuration	region		(%)	statistical	systematic
F-D	central	stochastic	13.24	±0.05	±0.20 $^{+0}_{-1.66}$
		constant	3.65	±0.05	±0.47 $^{+0}_{-3.65}$
	uniform	stochastic	13.76	±0.07	±0.21 $^{+0}_{-1.86}$
		constant	3.52	±0.07	±0.47 $^{+0}_{-3.52}$
D-F	central	stochastic	13.43	±0.06	±0.07 $^{+0}_{-0.80}$
		constant	4.45	±0.04	±0.22 $^{+0}_{-4.45}$
	uniform	stochastic	13.73	±0.08	±0.07 $^{+0}_{-2.34}$
		constant	3.35	±0.07	±0.22 $^{+0}_{-3.35}$

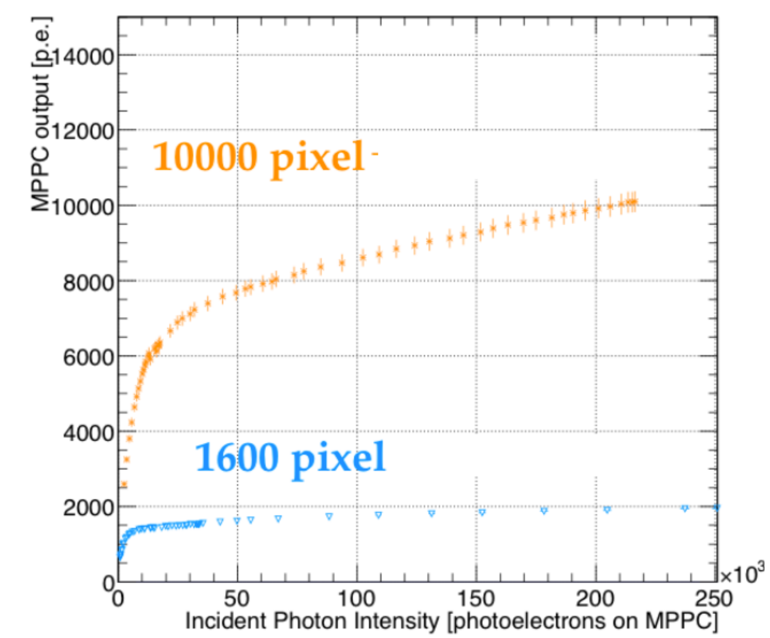
ScECAL: design improvements

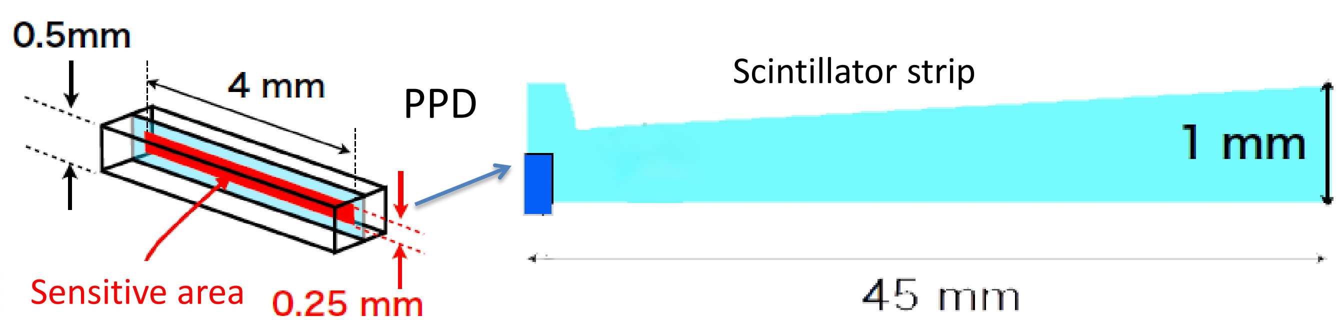
- Granularity and uniformity
  - Strip width reduced to 0.5 cm, wedge shape with bottom readout
  - Already implemented in prototype currently under test
- Ideal SiPM
  - Rectangular shape, 0.25 mm thin, with many pixels to reduce saturation effects
  - In contact with Hamamatsu

S. Uozumi, LCWS 14



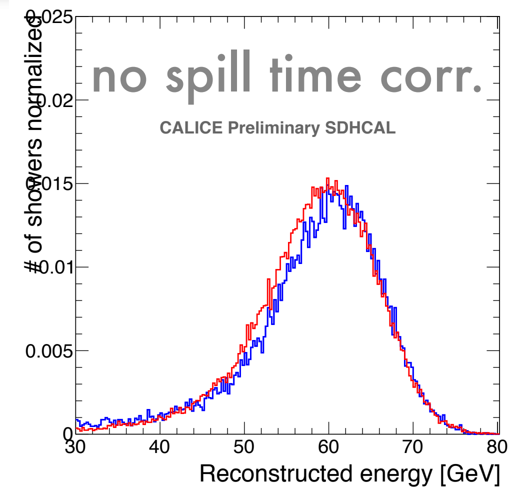


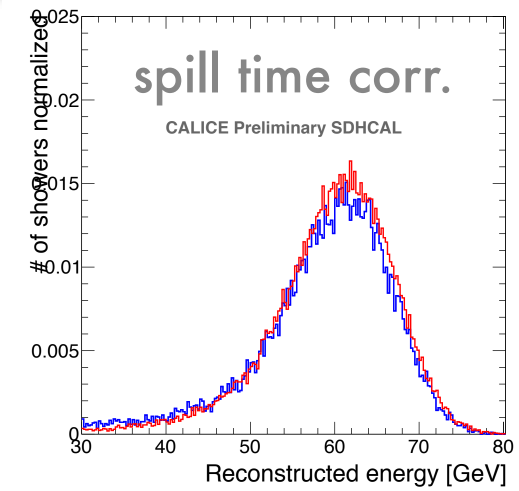


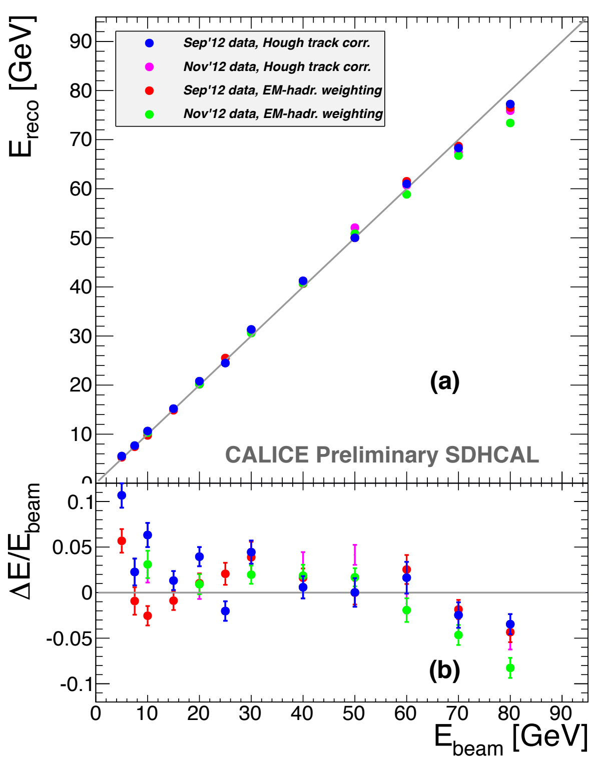


SDHCAL: latest results

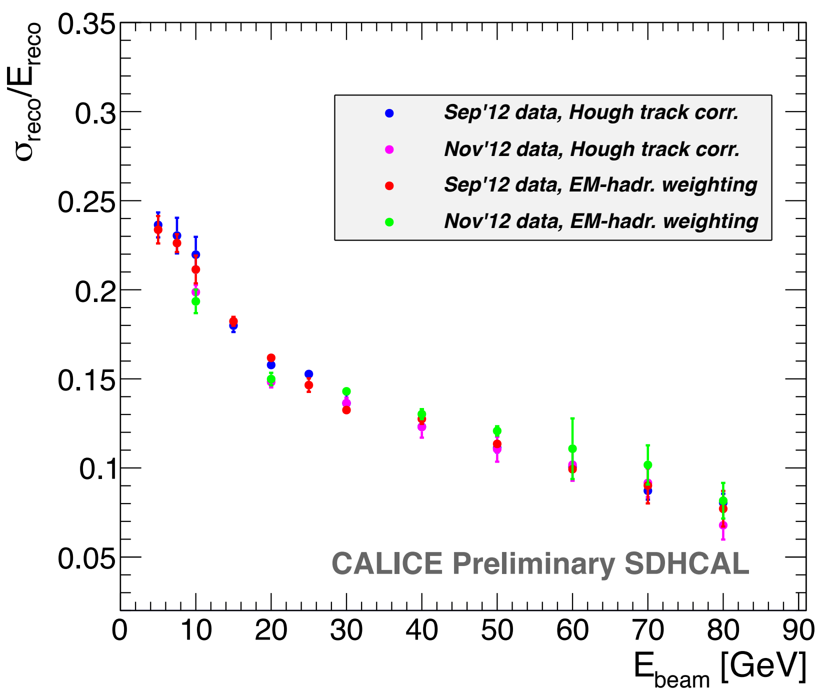
- Analysis of SDHCAL testbeam data from 2012
  48 GRPC layers with stainless steel absorber
  - Spill time correction, linearity and resolution
    [A. Petrukhin, LCWS 14]
  - Tracking within hadronic showers
    [A. Steen, LCWS 14]
  - Comparison with hadronic models

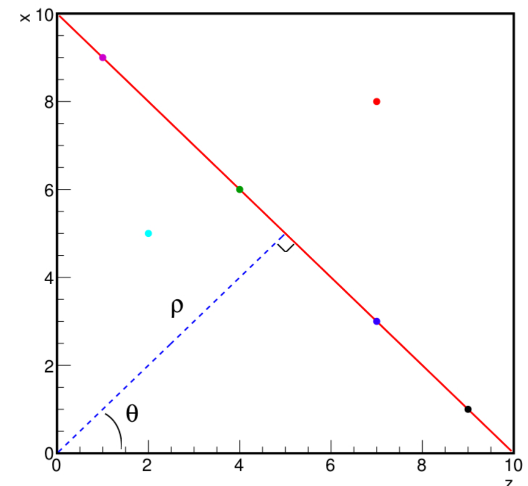


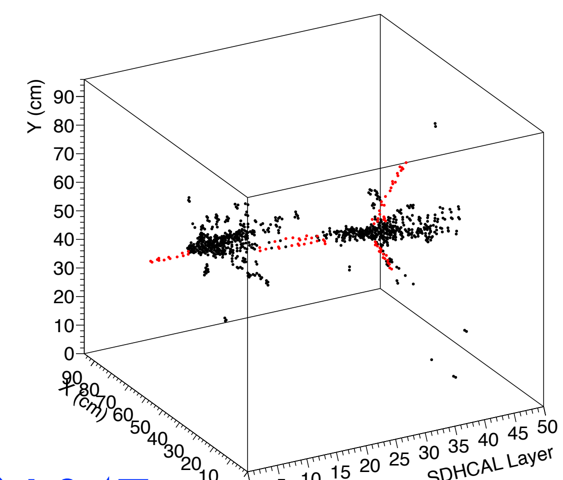




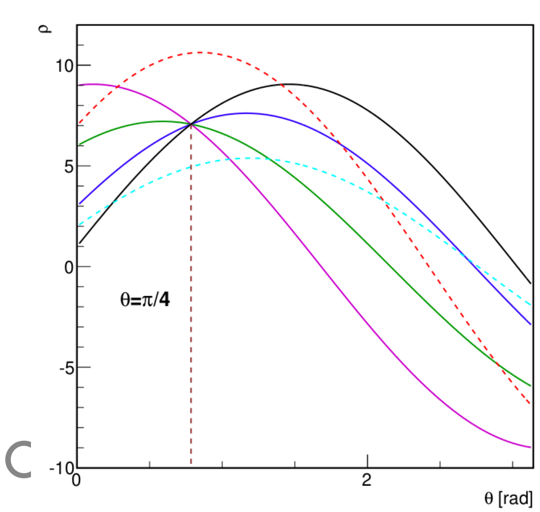
[CAN-037b]

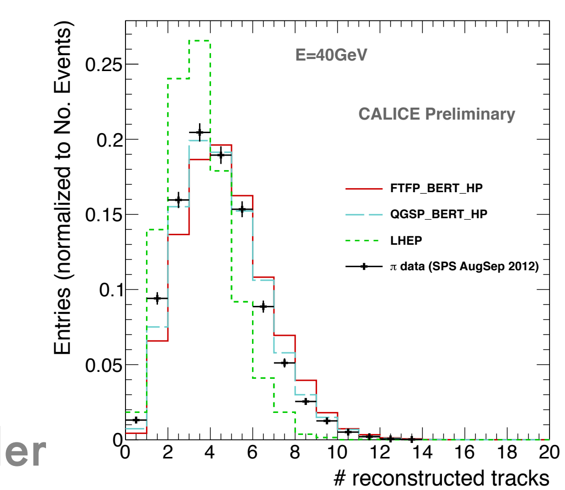






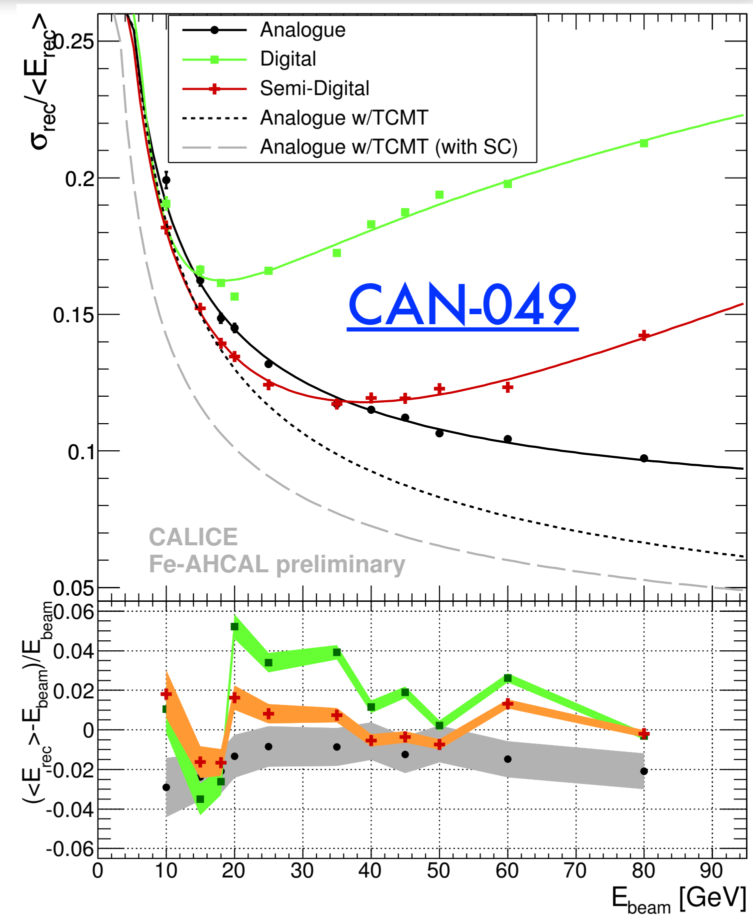
[CAN-047]



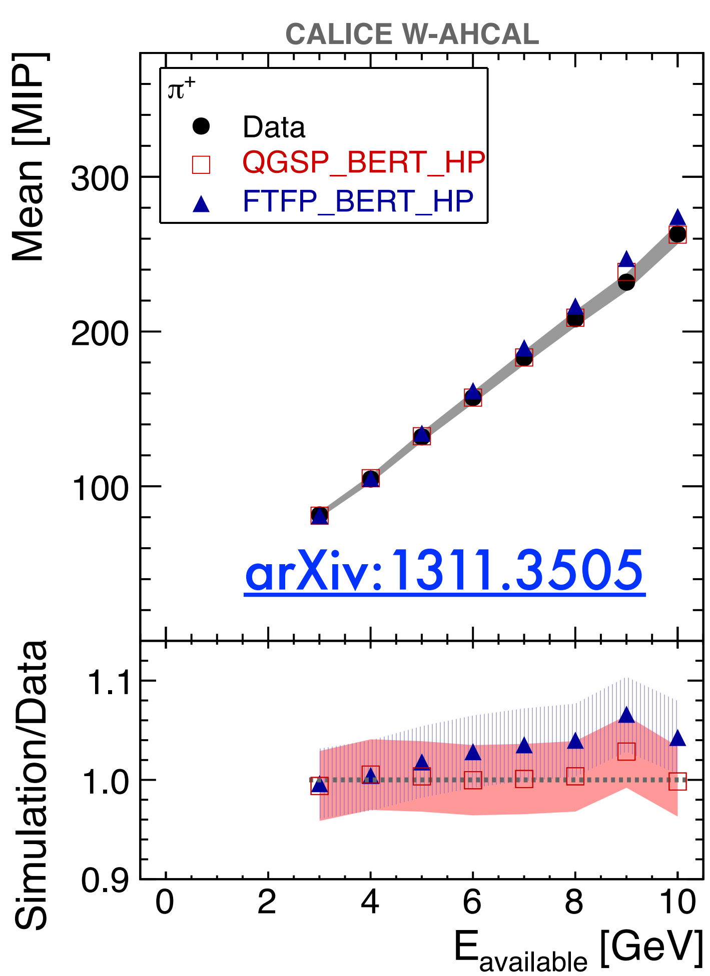


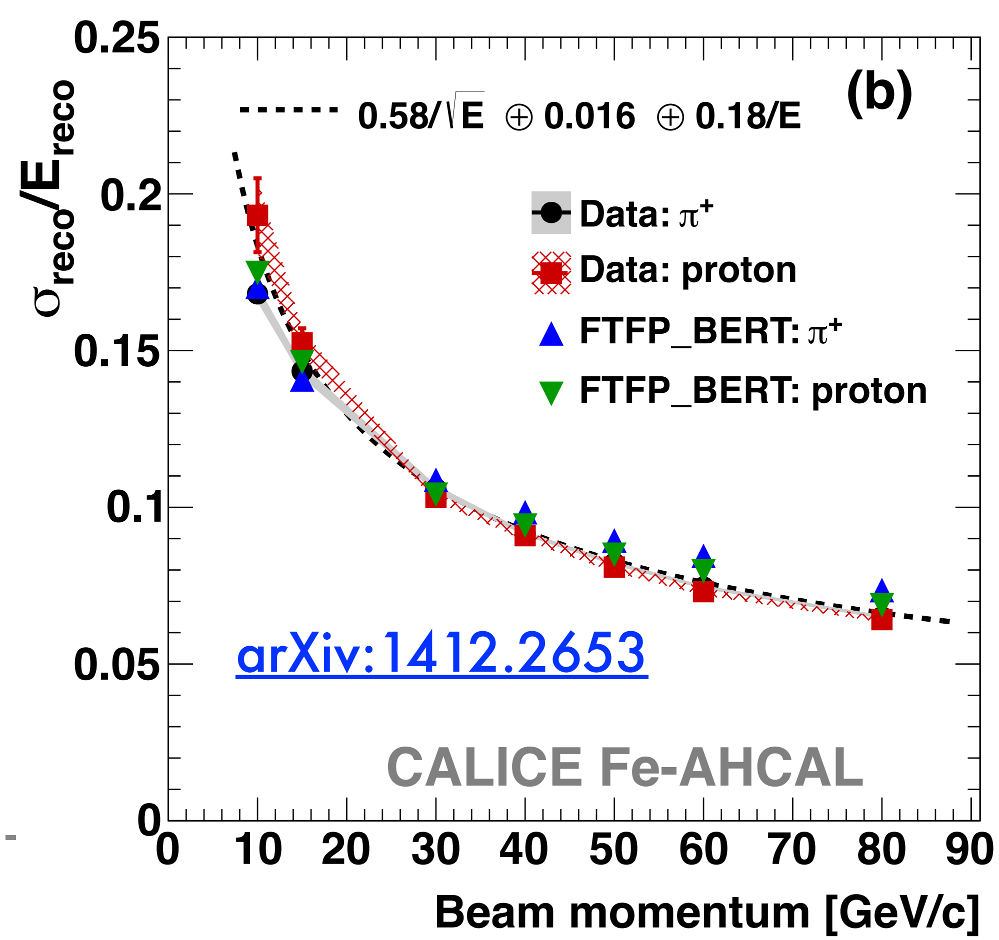
AHCAL: latest results

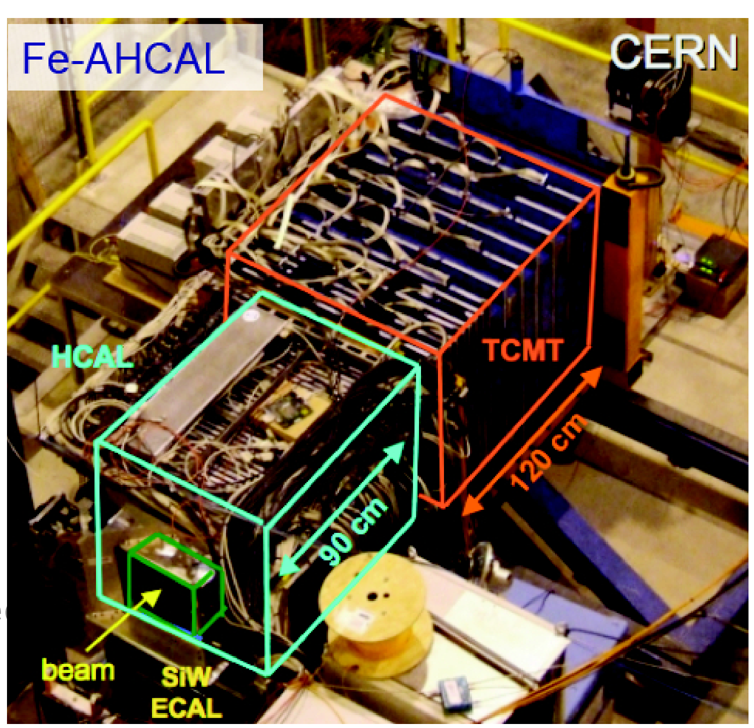
- Many new results from AHCAL testbeams in 2006-2012: 38 layers with different absorbers (Fe or W)
  - Characterisation of prototypes (linearity, resolution)
  - Measurement of particle shower evolution
  - Tests of simulation models for hadronic interactions after validation with electromagnetic processes



E. Sicking, ICHEP 14

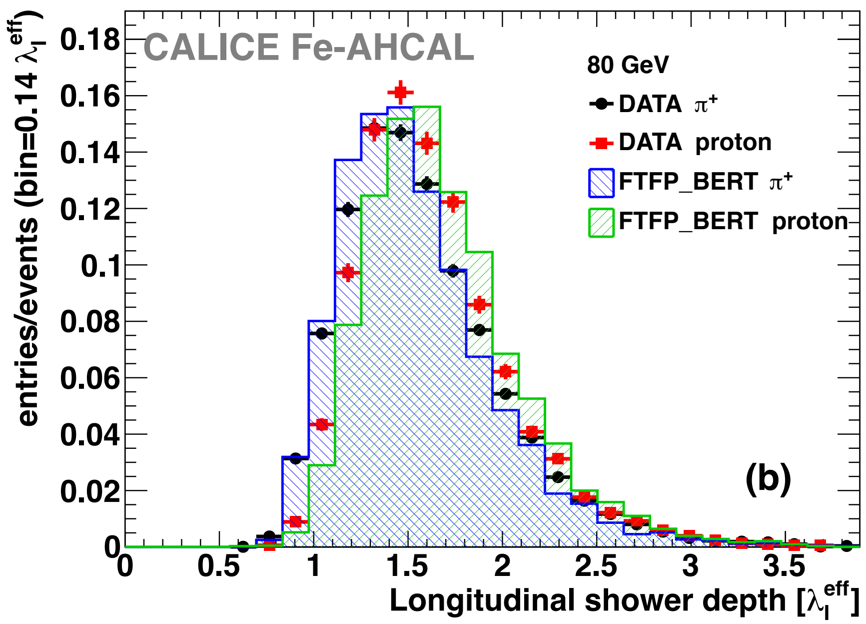


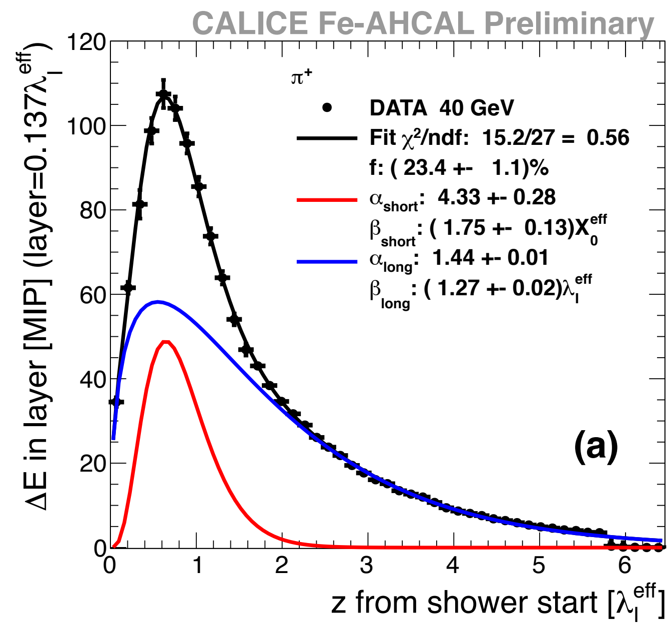


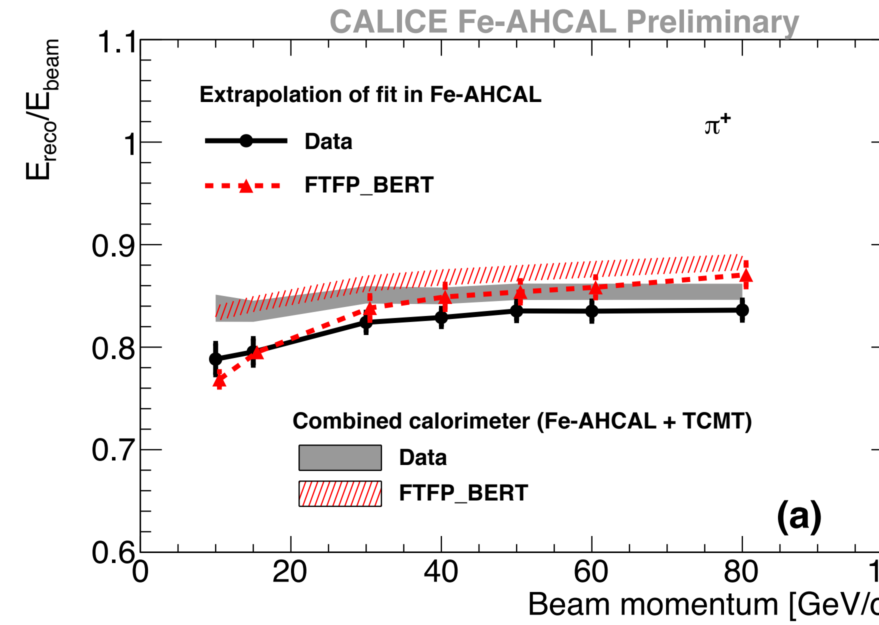


AHCAL: shower profile studies

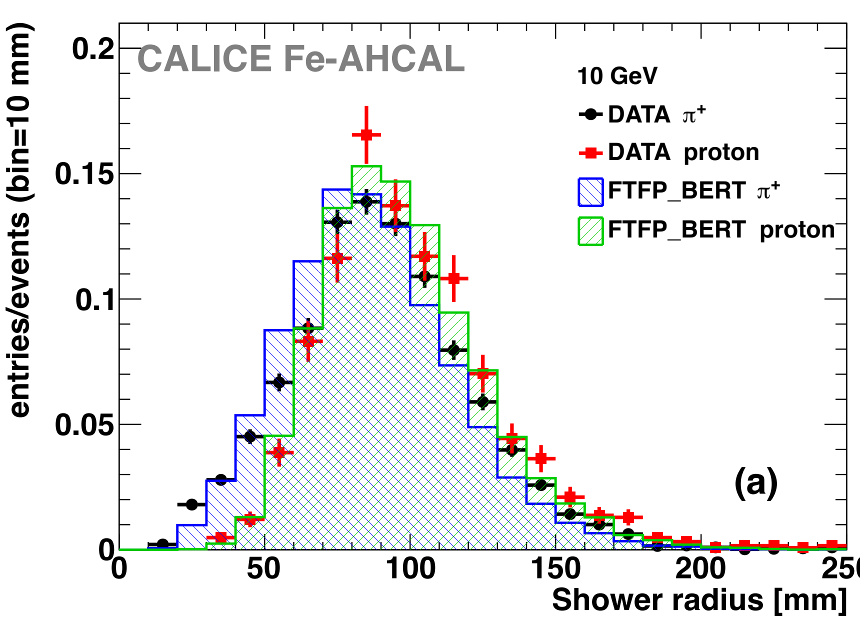
- High granularity allows for detailed study of shower profiles
  - Longitudinal and radial shape, calorimeter response, h/e

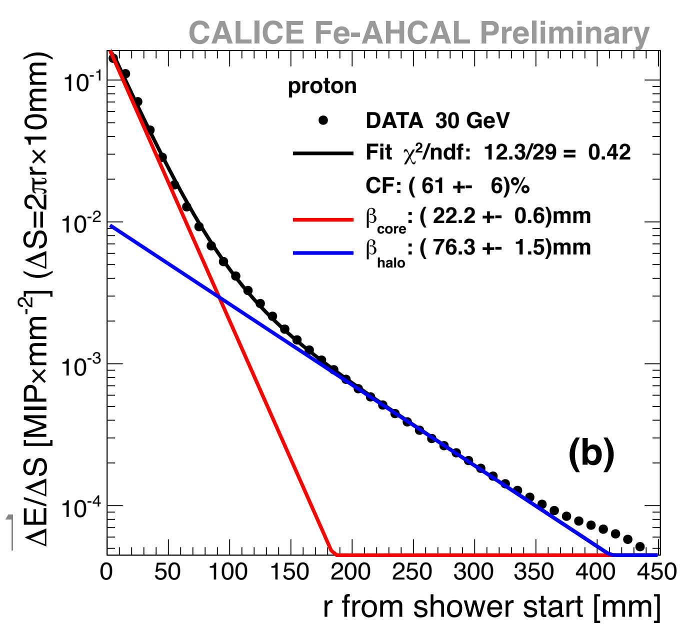


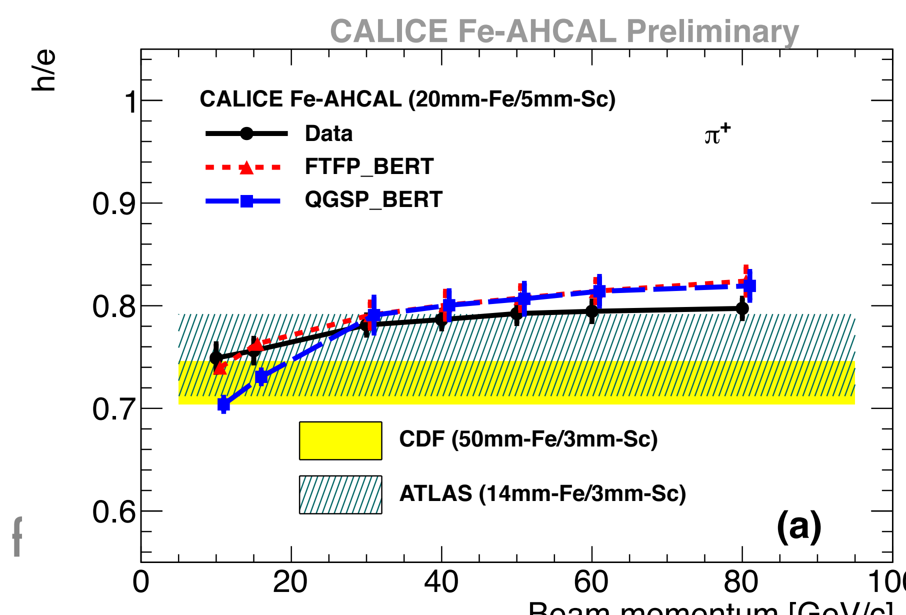




arXiv:1412.2653 CAN-048 CAN-051

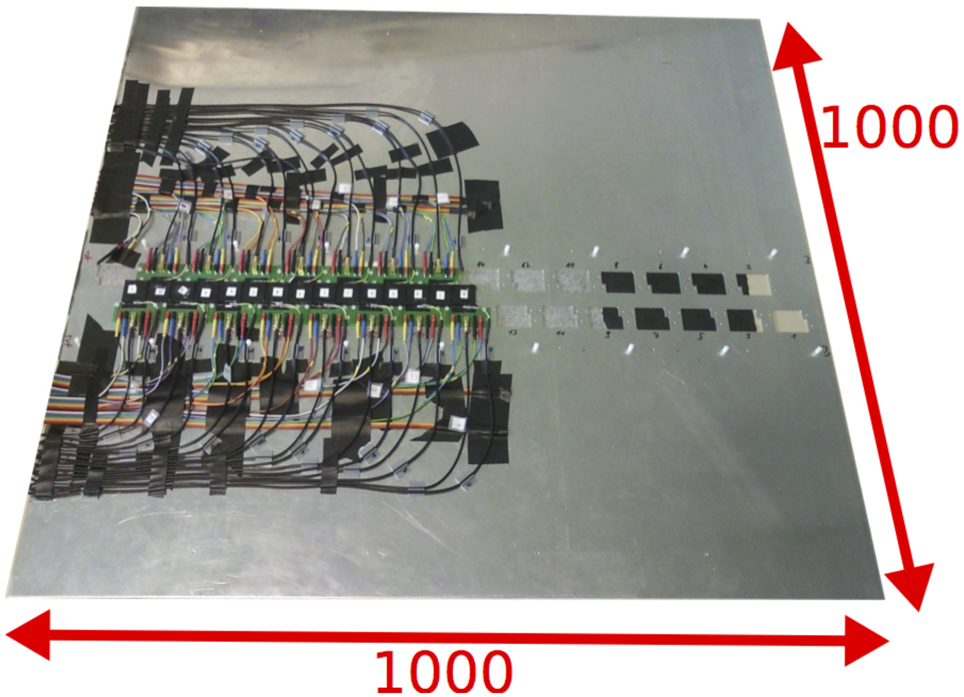




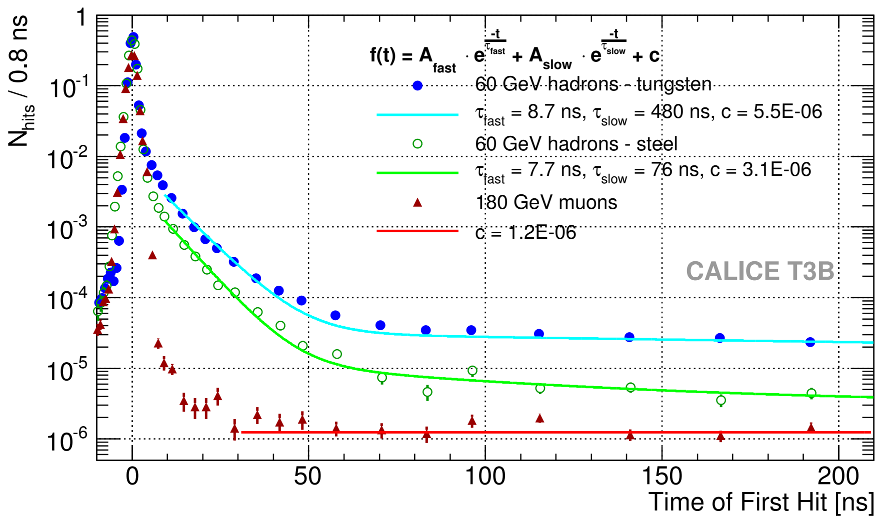


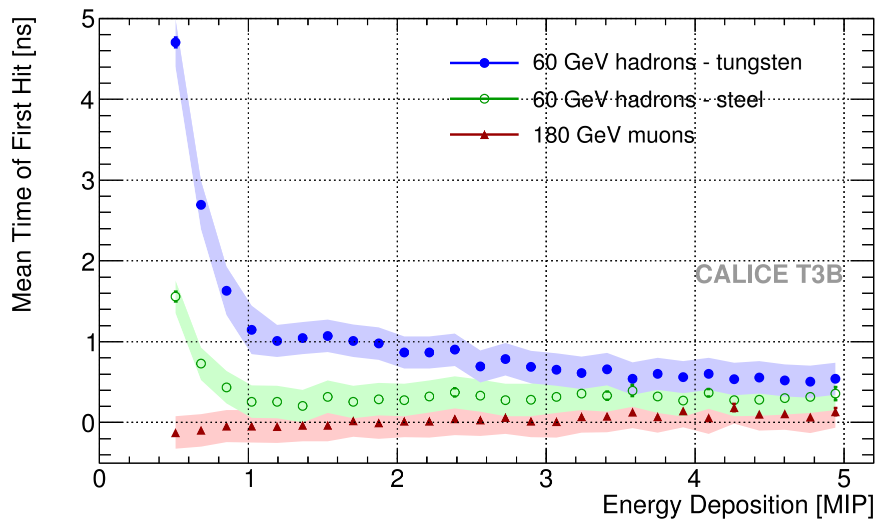
Time structure of showers (T3B)

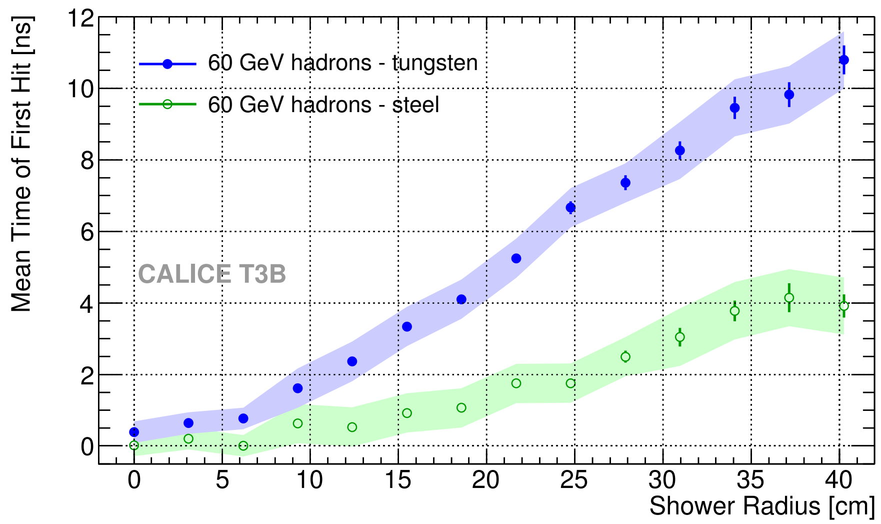
- T3B: Tungsten Timing Test Beam arXiv:1309.6143
  - Radial strip of 15 scintillator tiles behind HCAL
  - Readout with 1.25 GHz sampling rate over 2.4 µs
- Shower time structure dependence on absorber material (Fe or W), deposited energy and radius



arXiv:1404.6454



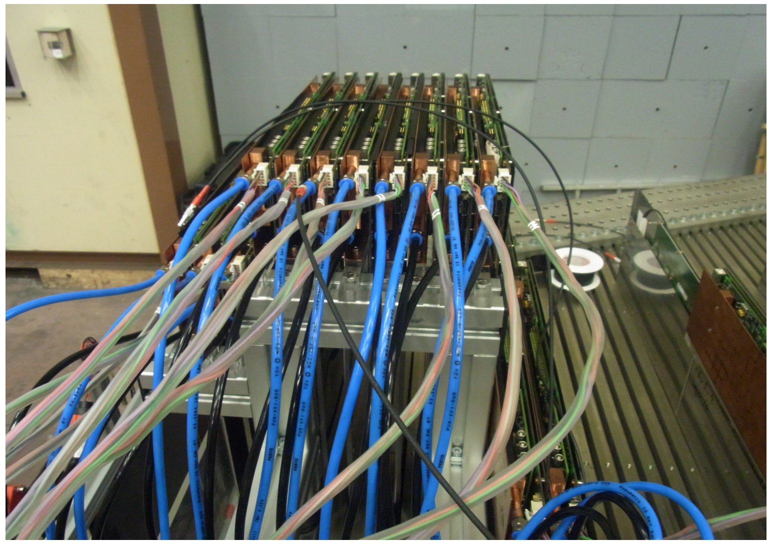


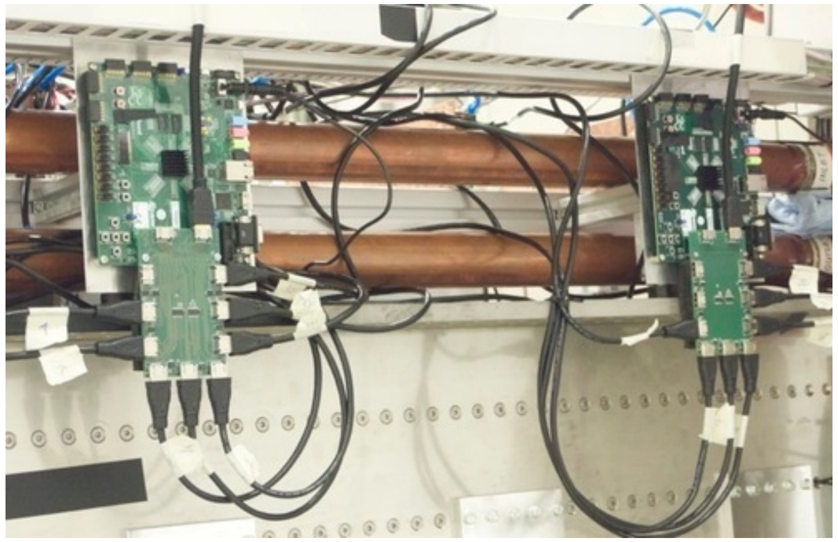


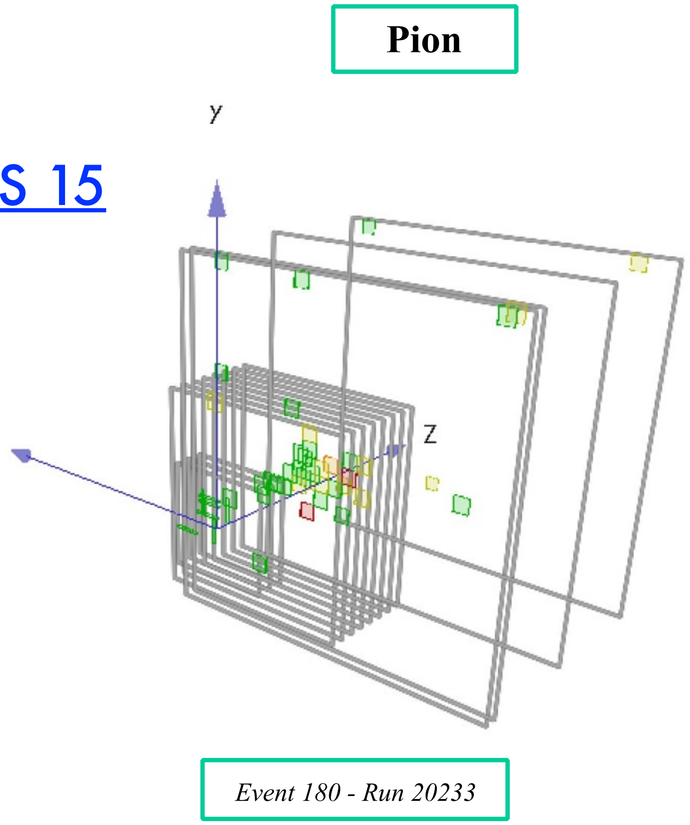
AHCAL: testbeams 2014

- EUDET stainless steel absorber structure
- Layers: 3 strip ECAL, 8 small HCAL, 4 big HCAL
- Fully HDMI-based DAQ
- Different types of scintillator tiles and SiPMs
- Scalable channel-wise power supply and distribution, water cooling for power boards
- 14+12 days at CERN PS in Oct-Dec 2014 with muon, electron and hadron beams

H.L. Tran, CLIC WS 15

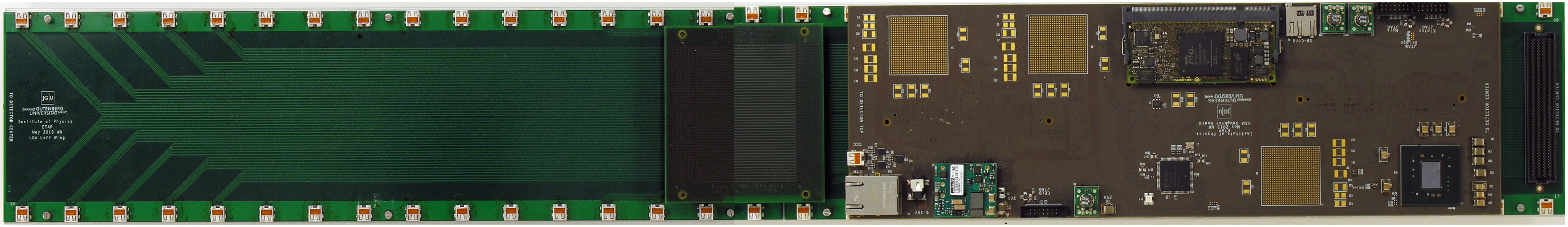






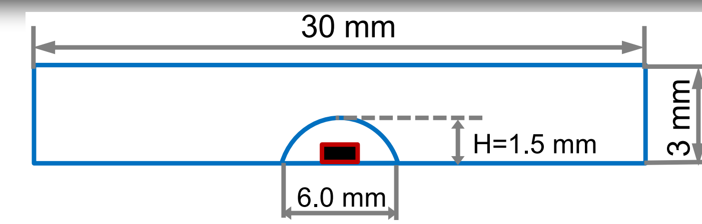
AHCAL: testbeams 2015

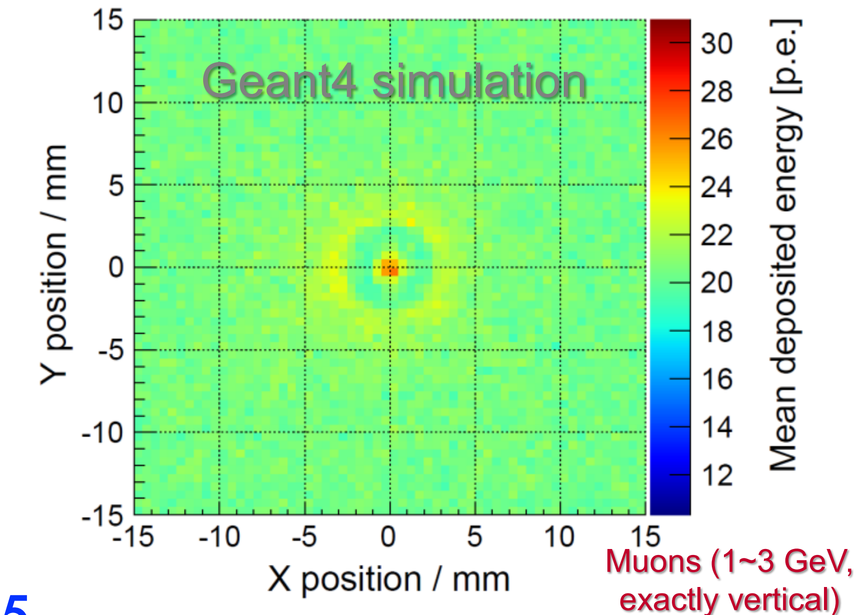
- 2 (possibly 3) weeks at DESY
  - Main goals: DAQ tests, MIP calibration, full dress rehearsal for CERN testbeams, consolidation of online software
  - First testbeam period successfully completed on Monday!
    Air stack with 5 big layers. LED, pedestal, electron beam runs.
    Stable operation with faster DAQ
- 2 periods at CERN SPS (one period with steel, one with tungsten)
- New DAQ component being commissioned:
  - Scalable data aggregator (Wing LDA) designed for one AHCAL sector in ILD geometry

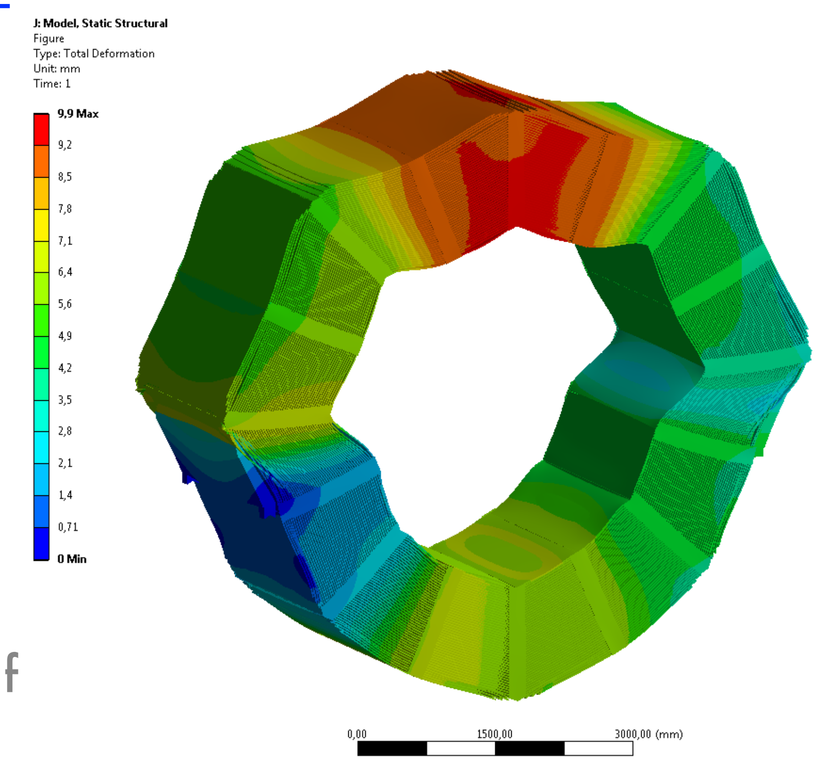


AHCAL: design optimisations

- Tile geometry [Y. Liu, IEEE 14](#)
  - SMD SiPMs convenient for mass production
  - Dimple in tiles to accommodate SiPM, different shapes under investigation
  - Single tiles and megatile under test
  - Simulation studies to optimise tile size
- Absorber [F. Sefkov, SiD WS 15](#)
  - Simulation studies to optimise material choice, thickness and number of layers
- Mechanical structure
  - Simulation of dynamical seismic stability



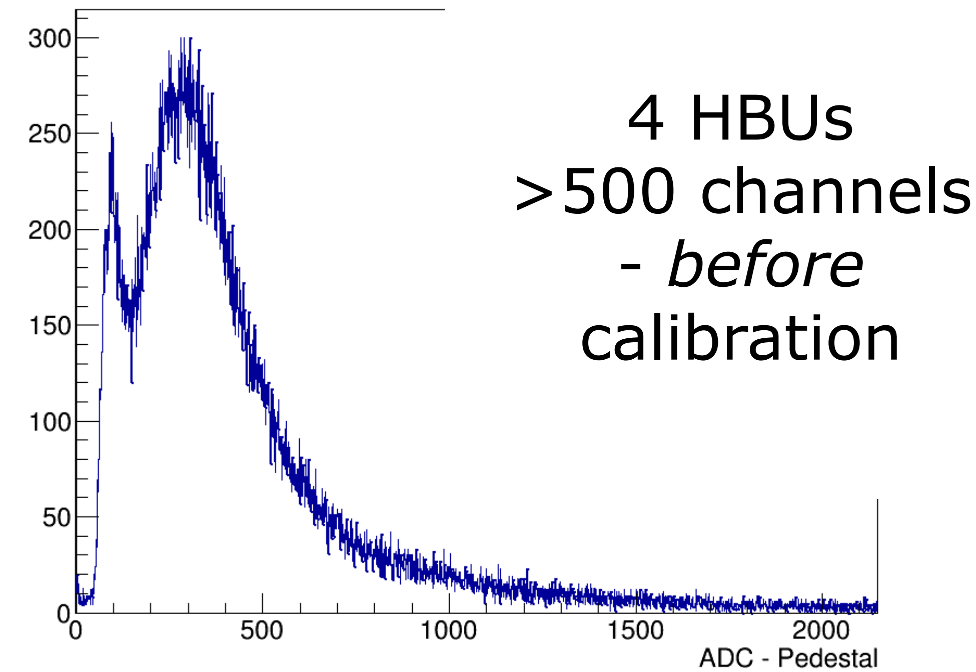


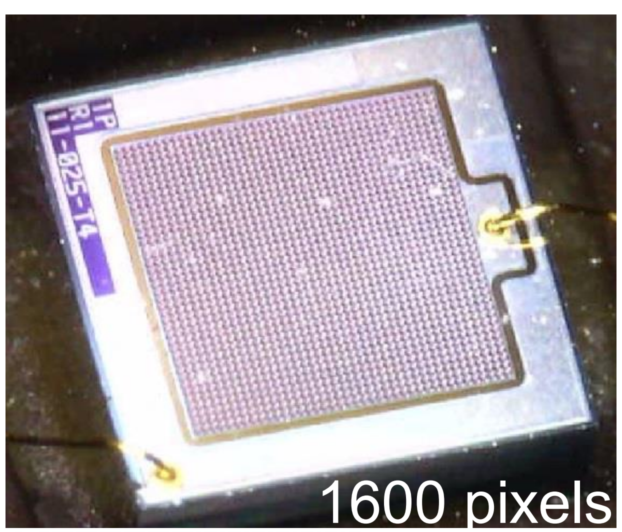


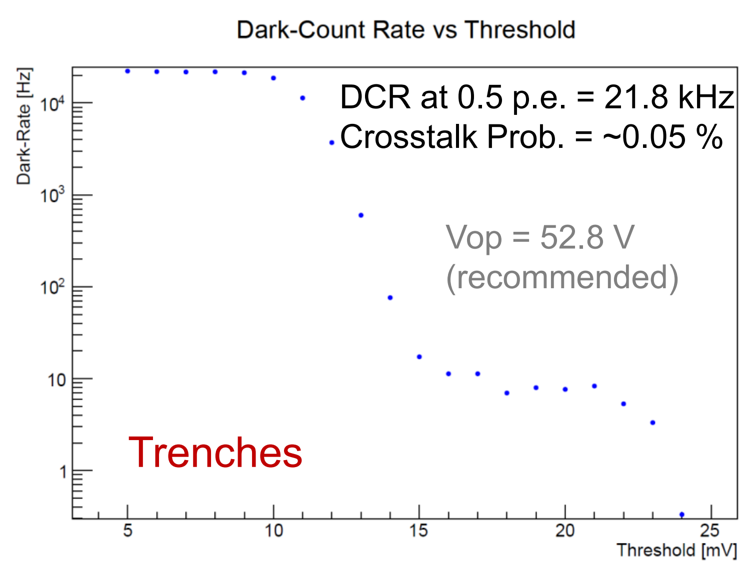
AHCAL: new sensors

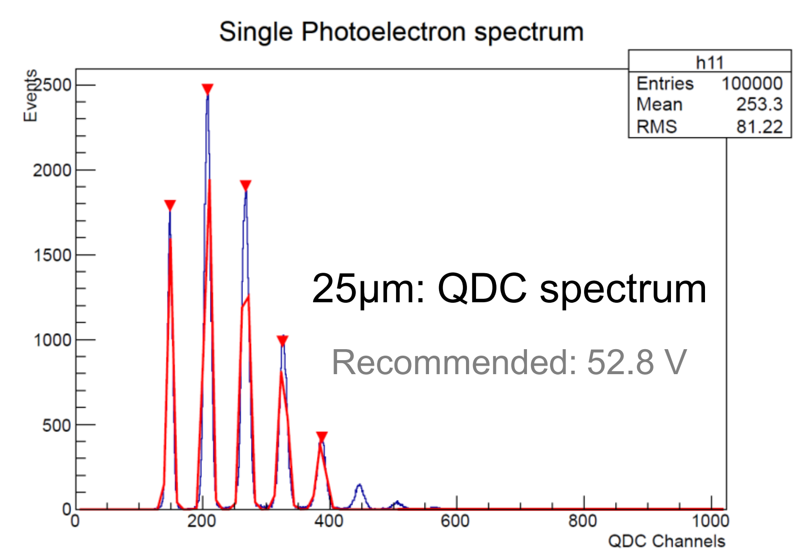
- SiPM improvements driven by medical applications
  - Very uniform performance over large batches of devices
  - Lower noise, better temperature stability
  - Easier commissioning, less parameters to be set channel-wise
- New MPPC by Hamamatsu with low inter-pixel crosstalk: first tests look very promising

F. Sefkov, LCWS 14



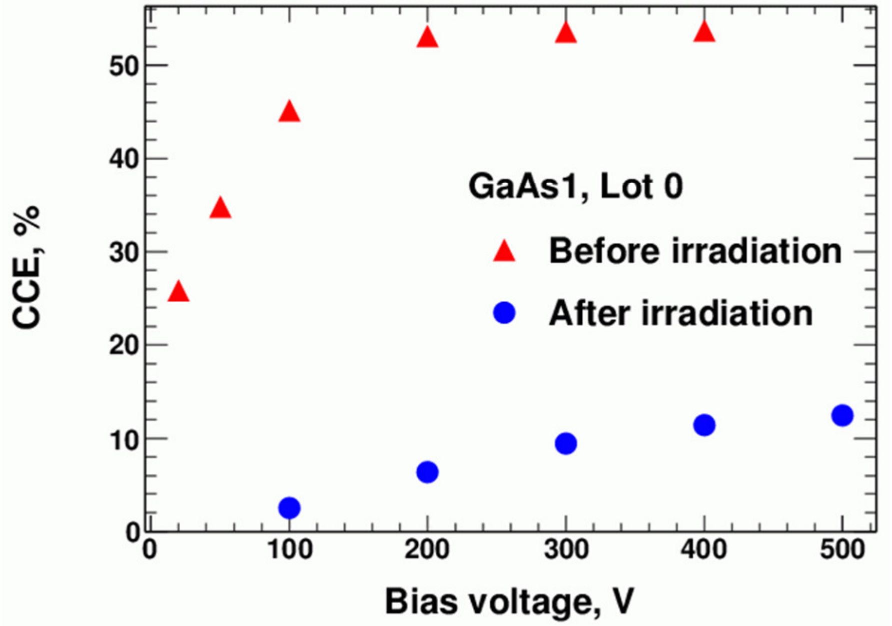






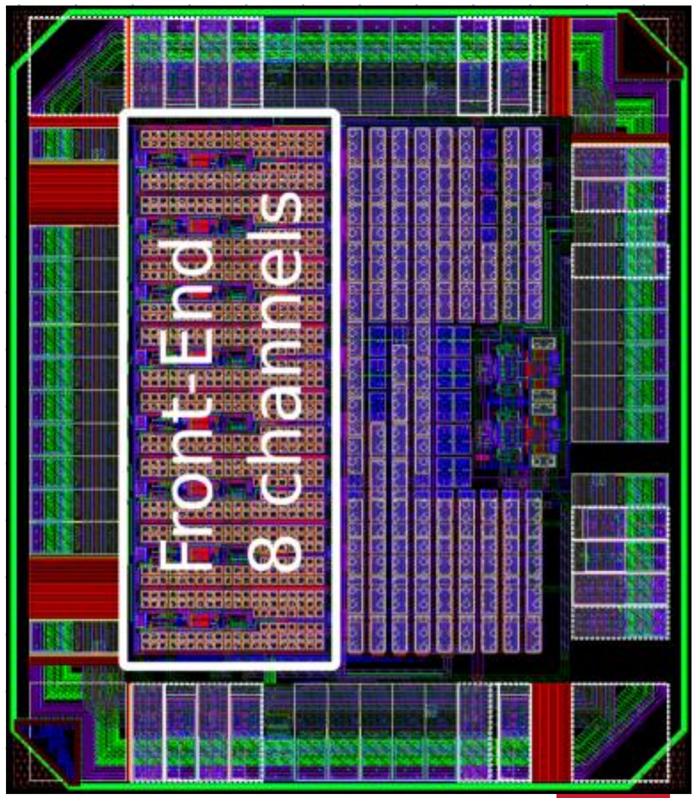
FCAL: sensors and electronics

- Different radiation-hard materials under test (also for LHC upgrade) [K. Afanaciev, CLIC WS 15]
  - Thorough comparison of silicon, GaAs, CVD diamond, sapphire
  - All show degraded performance, but are still usable after O(MGy) irradiation



[M.Idzik, CLIC WS 15]

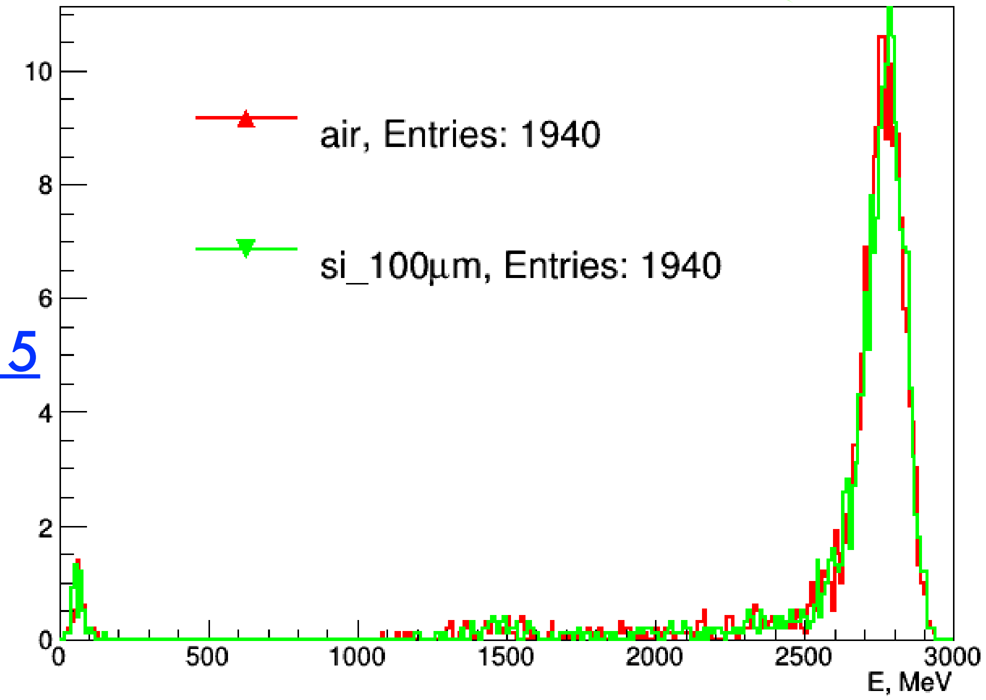
- 8-channel CMOS 130 nm chip for LumiCal read-out with front-end and ADC for each channel, data processing and serialisation to be submitted this year
- Intentionally non-linear ADC for BeamCal under study
  - ADC resolution following energy dependence of sampling term [A. Abusleme, LCWS 14]



FCAL: testbeam and simulation

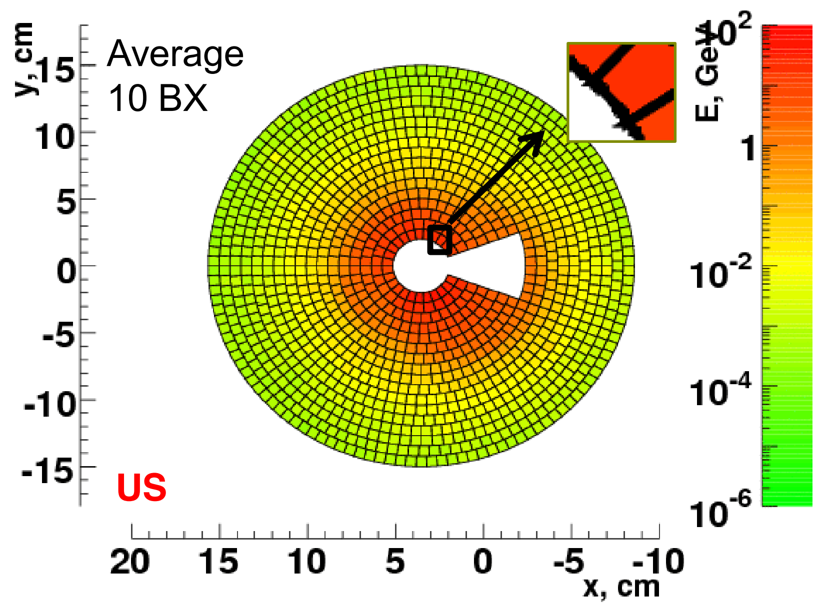
- LumiCal testbeam in October 2014 with 4 layers to study electromagnetic shower development
  - Synchronisation with telescope successful, data analysis ongoing

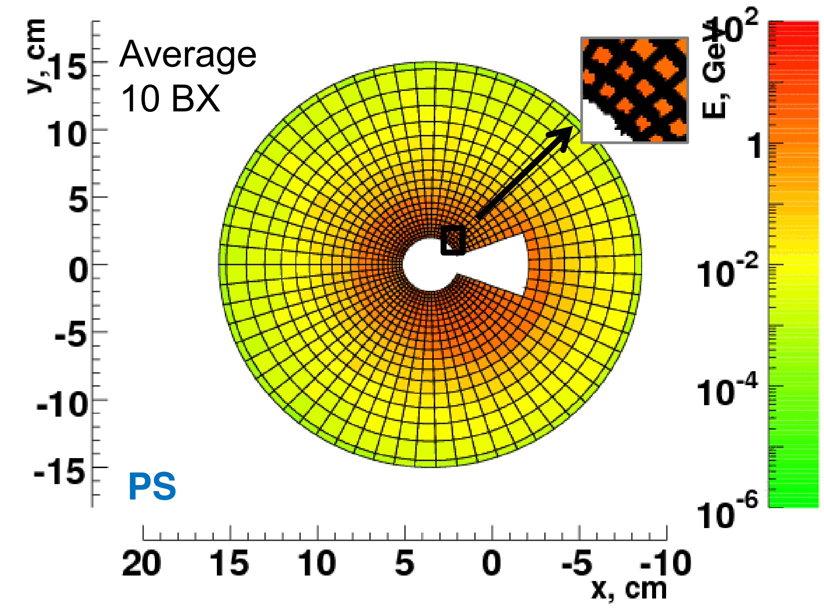
O. Borysov, CLIC WS 15



- Simulation of LumiCal response with 2x100µm silicon tracker layers in front
  - No significant degradation observed

- Optimisation of BeamCal design in simulation ongoing
  - Performance comparison of uniform and proportional sensor segmentation





L. Bortko, LCWS 14

Conclusion

Summary

- General detector designs presented in ILC TDR and CLIC CDR: highly-granular calorimeters for particle flow jet reconstruction to meet jet energy and di-jet mass resolution requirements
- Many options being throughly tested for em, had and forward calorimeters
  - Physical prototypes with different absorbers, active materials and readout have undergone several testbeam campaigns
  - Performance meet requirements
  - Detailed comparison with hadronic interaction models in simulation
    In general not so good agreement
- Strong involvement of many German institutes

Outlook

- Technological prototypes in preparation
  - Large scale production challenging
  - Mechanical structures and services getting closer to final detector
  - First tests in recent testbeams
- Design optimisation still ongoing
  - Driven by physics performance, but also by technological improvement, cost and mass production requirements
- Convergence towards common system
  - Software and DAQ electronics harmonisation