CALICE

Status report to the DESY PRC

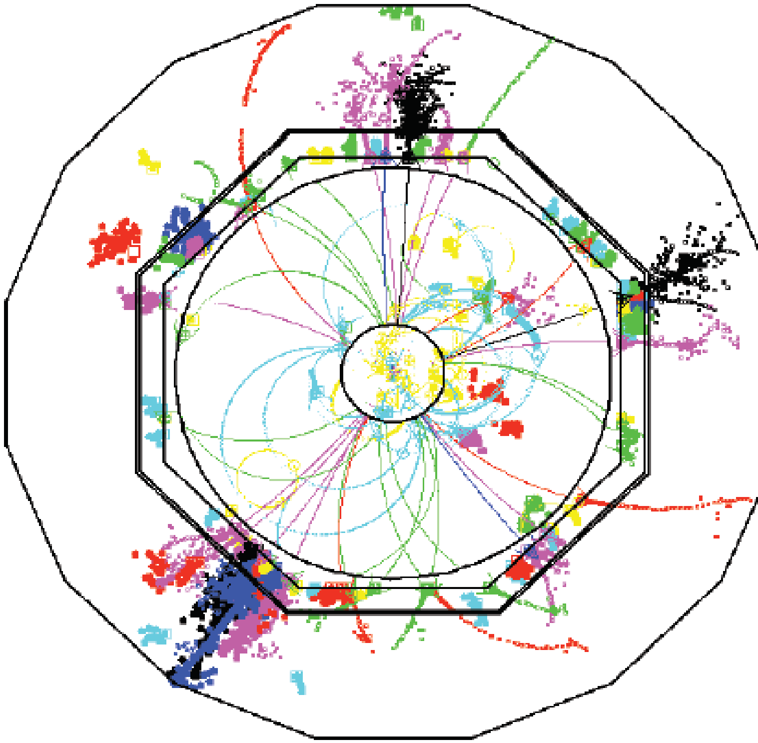
David Ward

- Introduction
- Recent analysis results
- Highlights from recent test beams
- Future plans

CALICE

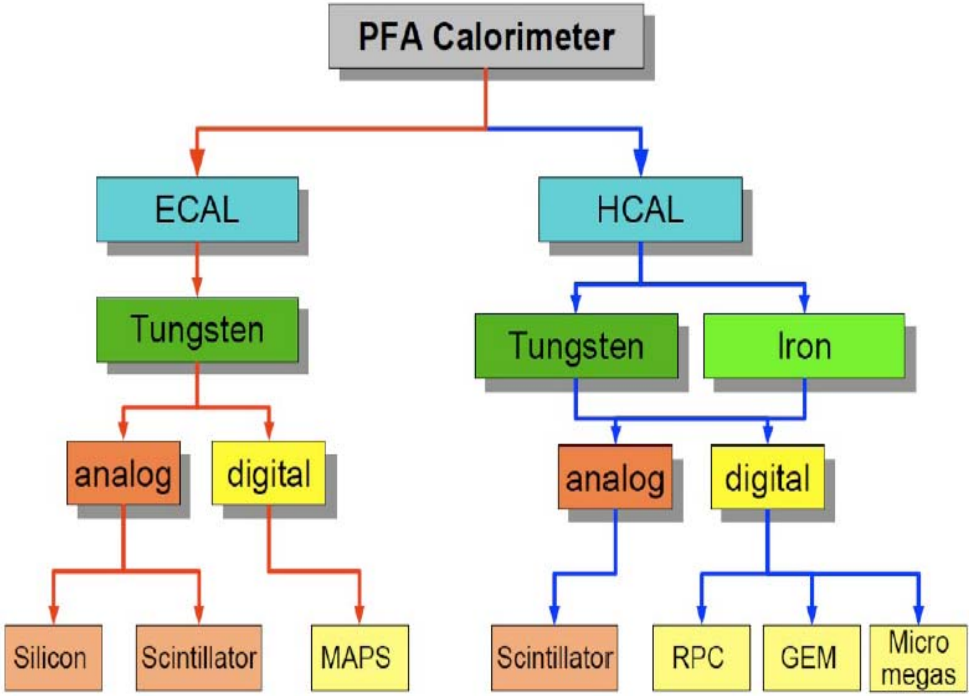
- CALICE ~350 people/57 groups/17 countries/4 continents
- Various projects aimed towards aspects of highly segmented calorimetry for a future Linear Collider detector, motivated by Particle Flow for jet reconstruction.
- Given focus by common test beams, combining ECAL/HCAL/tail catcher (TCMT); common DAQ/analysis.
- First round – small "physics prototypes"
  - Evaluate technologies; identify problem areas.
  - Validate Monte Carlo simulations, especially for hadronic showers, so that results can feed into full detector simulations.
  - Still sizeable systems with ~20K channels.
- Second phase – "technological prototypes" (mainly under aegis of EUDET).
  - More realistic technological solutions; module dimensions etc. Should be scalable.
  - e.g. minimise thickness of sensitive layers; power pulsing.

PFA and calorimetry



Various technologies under study

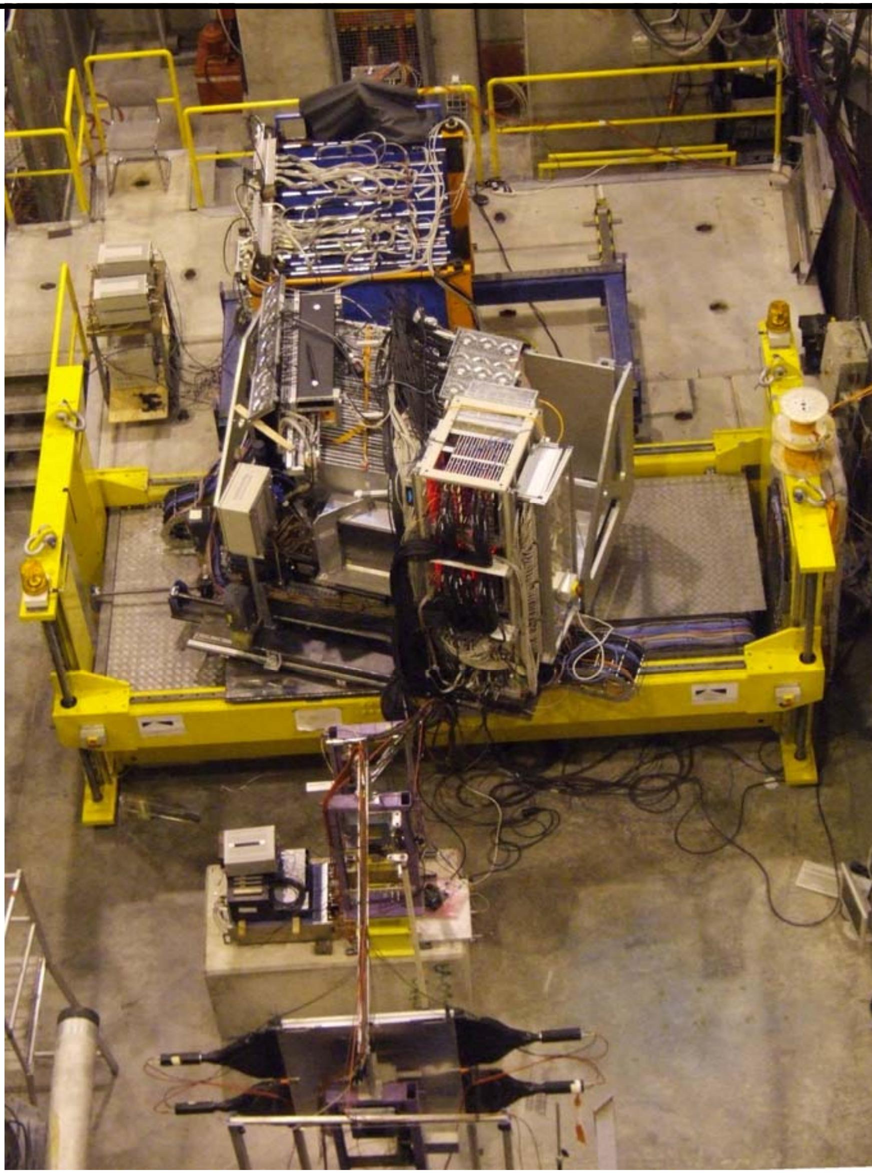
Discuss most of them *briefly* today



- **Basic PFA paradigm**
- Charged energy (65%) measured in tracking
- Photons measured in ECAL
- n/K_L measured in ECAL+HCAL
- Granularity more important than resolution in calorimeters

CALICE test beams

- **Main beam tests, using π, μ, e beams:**
- 2006-7
  SiW ECAL + AHCAL + TCMT @ CERN
- 2007
  DHCAL vertical slice test @ Fermilab
- 2008
  SiW/Scint-W ECAL + AHCAL + TCMT @ Fermilab
- 2009
  Scint-W ECAL + AHCAL + TCMT @ Fermilab
  Standalone RPC and Micromegas tests @ CERN
- 2010
  DHCAL + TCMT @ Fermilab
  WHCAL @ CERN
- 2011
  DHCAL + TCMT ($\pm$ SiW ECAL) @ Fermilab
  WHCAL @ CERN
  SDHCAL @CERN



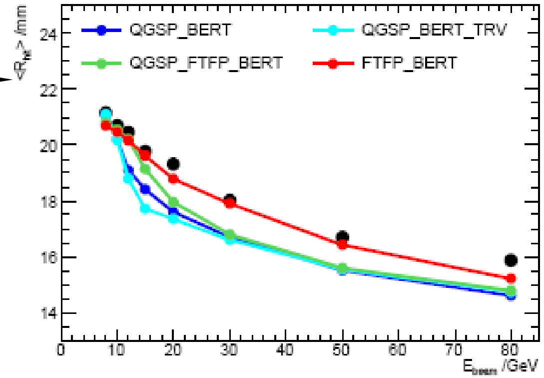
Publications, talks etc.

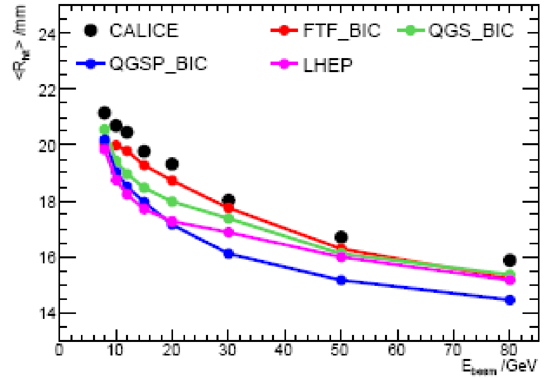
- Since the start of 2010:
  - 6 papers submitted for publication
    - **Study of the interactions of pions in the CALICE silicon-tungsten calorimeter prototype** 2010_JINST_5_P05007
    - **Effects of high-energy particle showers on the embedded front-end electronics of an electromagnetic calorimeter for a future lepton collider** Submitted to NIM ; e-print arXiv:1102.3454
    - **Construction and Commissioning of the CALICE Analog Hadron Calorimeter Prototype** 2010_JINST_5_P05004
    - **Electromagnetic response of a highly granular hadronic calorimeter** 2011_JINST_6_P04003
    - **Environmental Dependence of the Performance of Resistive Plate Chambers** JINST 5 (2010) P02007
    - **Beam test of a small MICROMEGAS DHCAL prototype** 2010 JINST 5 P01013
  - + 2 more imminently.
  - 11 new Calice Analysis Notes (preliminary results)
  - >100 Conference talks given
- See https://twiki.cern.ch/twiki/bin/view/CALICE/SpeakersBureau

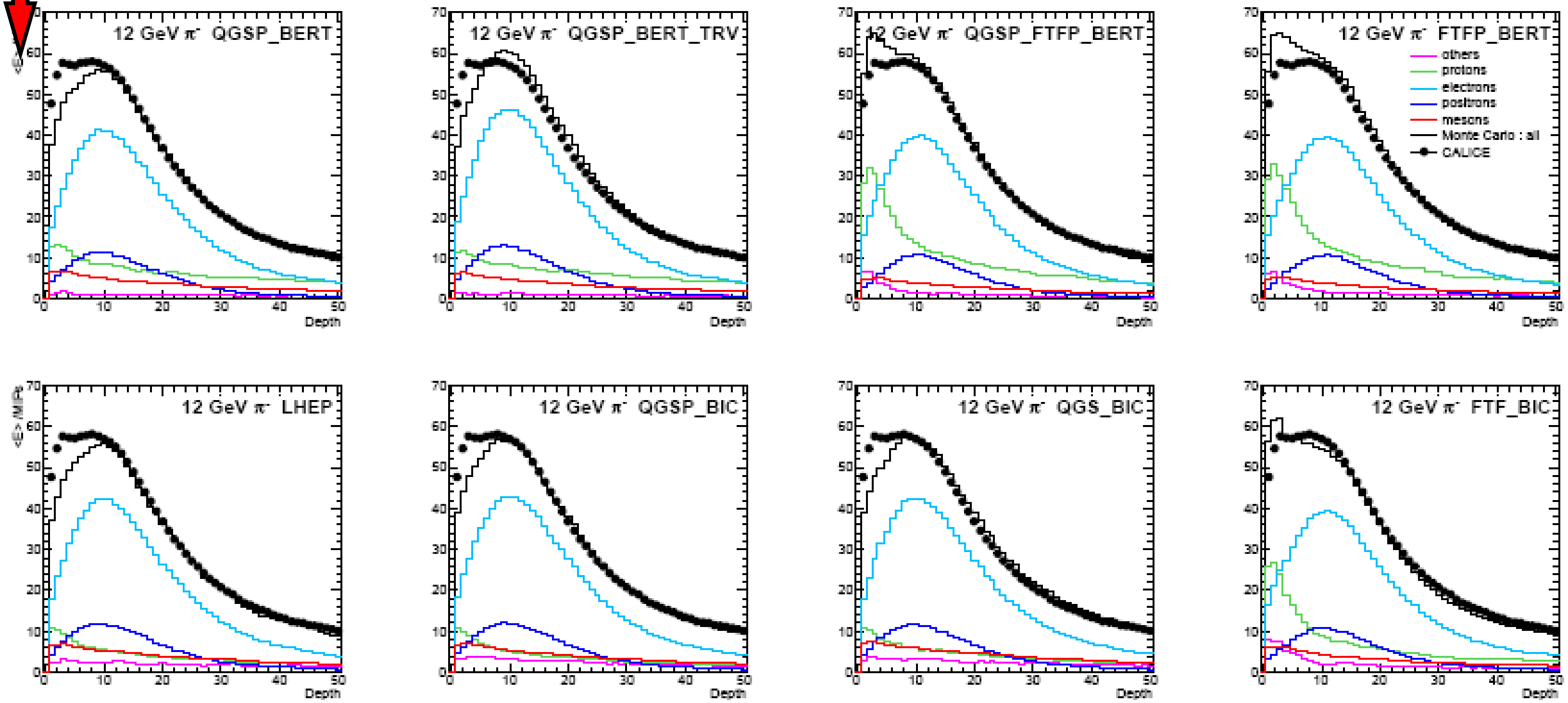
Analyses of data from older test beams (up to ~2009)

Si-W ECAL – pion showers

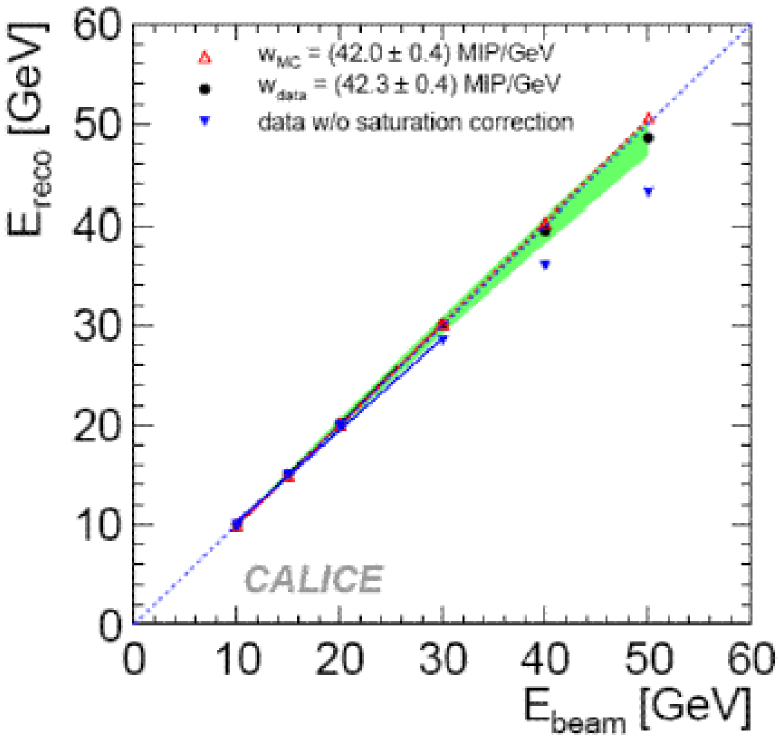
- 2010_JINST_5_P05007
- Mean radius
  - Most models underestimate data; FTF models best
- Longitudinal shower profiles w.r.t. shower start
  - sensitive to particle composition in shower
  - All models show deficiencies

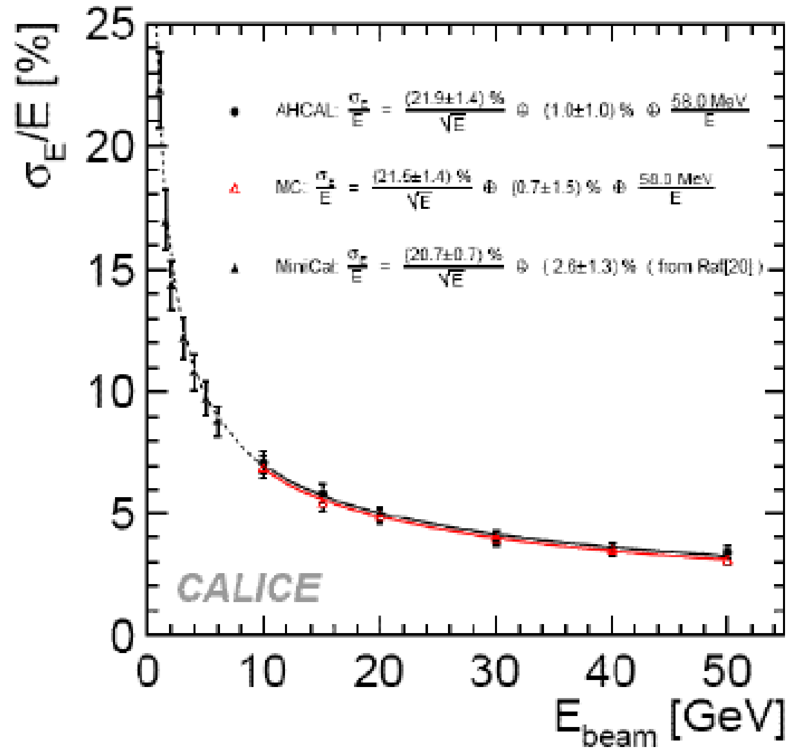






Analogue (Fe + scintillator tile) HCAL

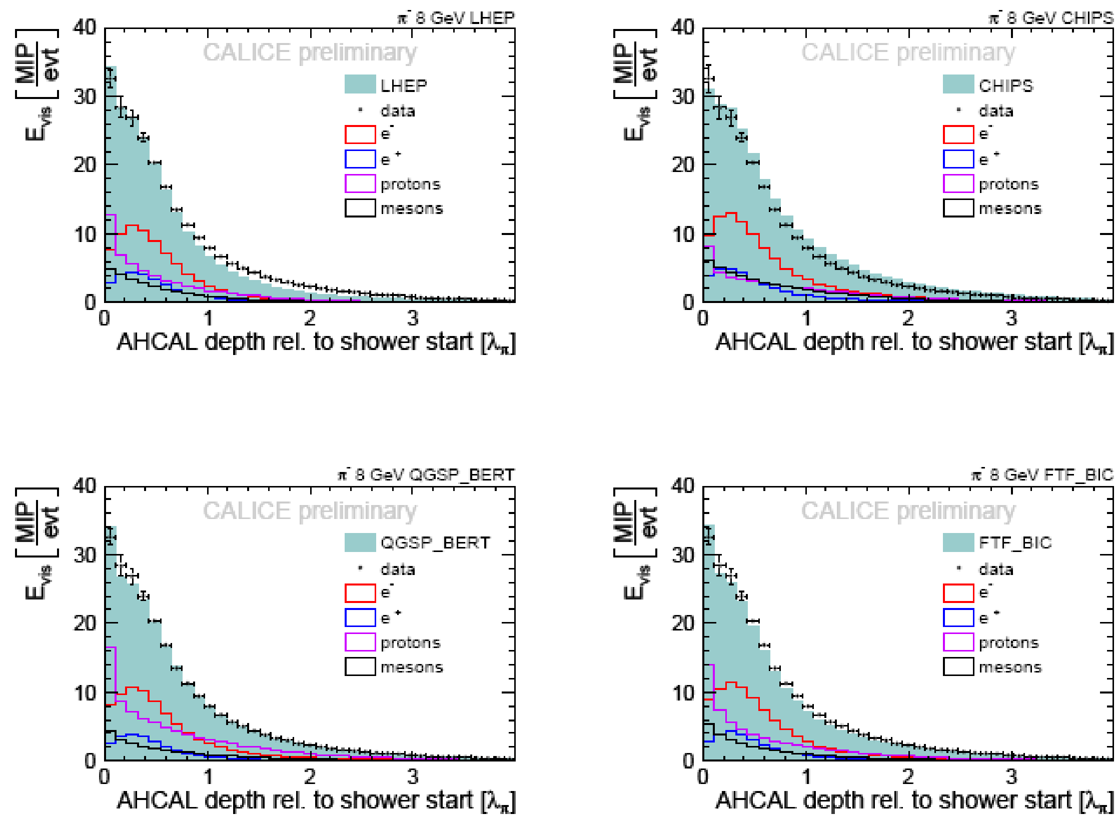


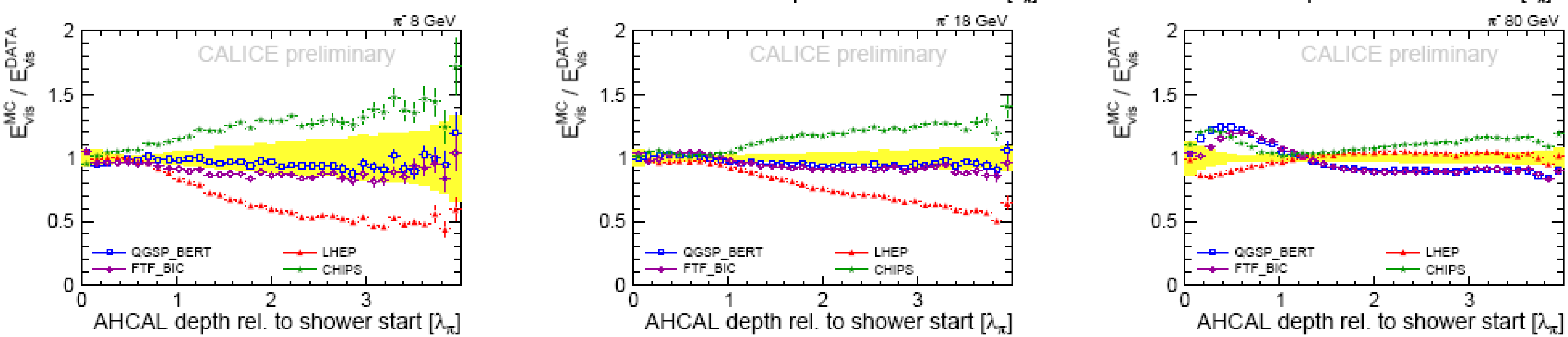


- Electromagnetic showers. 2011_JINST_6_P04003
- Important prerequisite for hadron showers – demonstrate that SiPM saturation corrections are under control. (greater energy density in e/m showers)
- Largely OK - ~2% non-linearity still at 50 GeV. Resolution well modelled.

Analogue (Fe + scintillator tile) HCAL

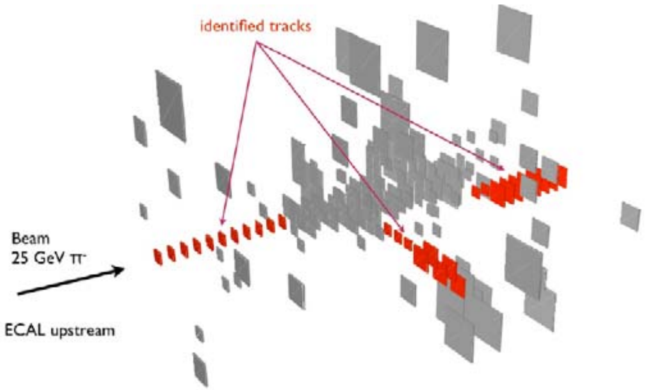
- CAN-026
- Longitudinal shower profiles for pions, w.r.t. shower staring point.
- Complementary to the ECAL study. Broadly similar conclusions

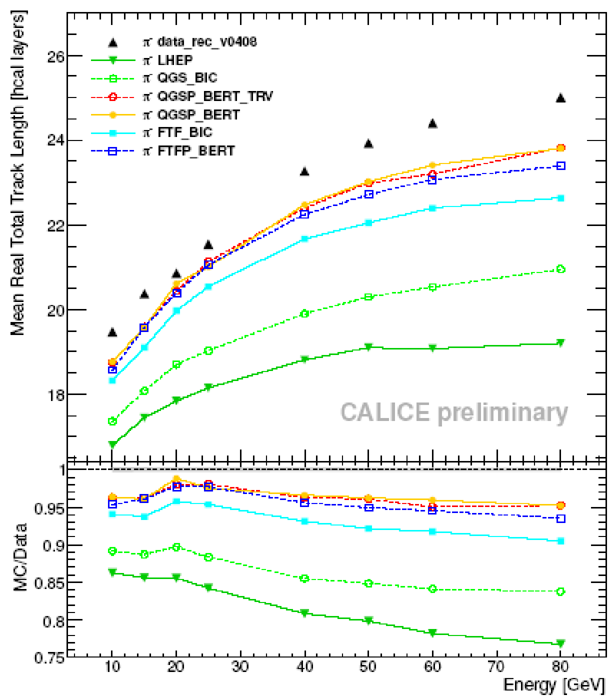


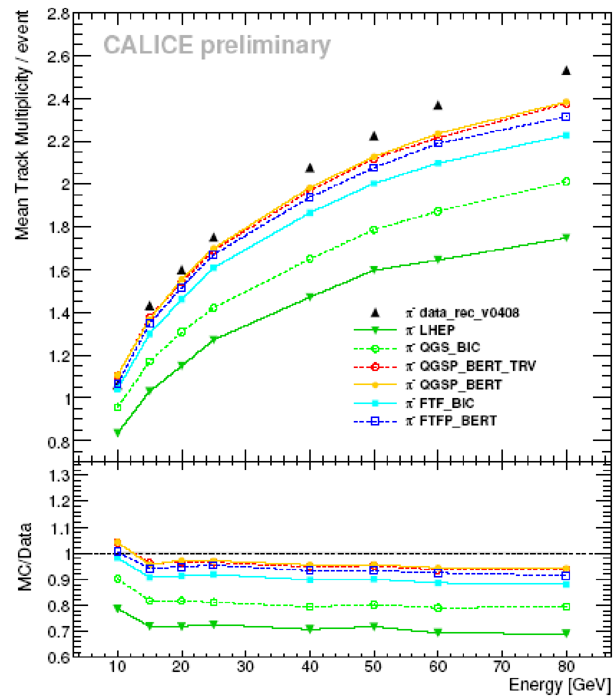


Analogue (Fe + scintillator tile) HCAL

- CAN-022 - Substructure within showers seen (“tracking calorimeter”)
- Identify MIP-like track segments within shower; compare with simulations.
- Quite discriminating between models; none is ideal, though favoured models like QGSP_BERT and FTFP_BERT not at all bad (n.b. suppressed zero).
- Valuable input for model developers.

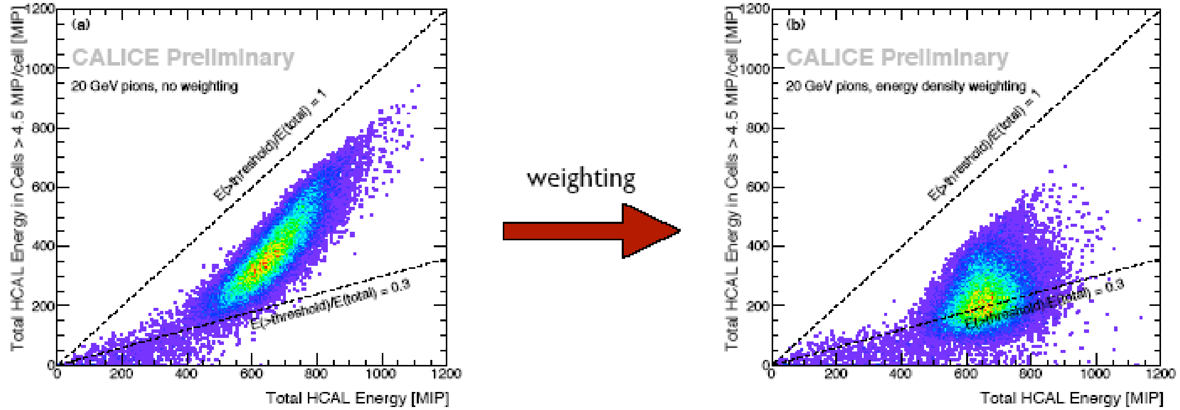


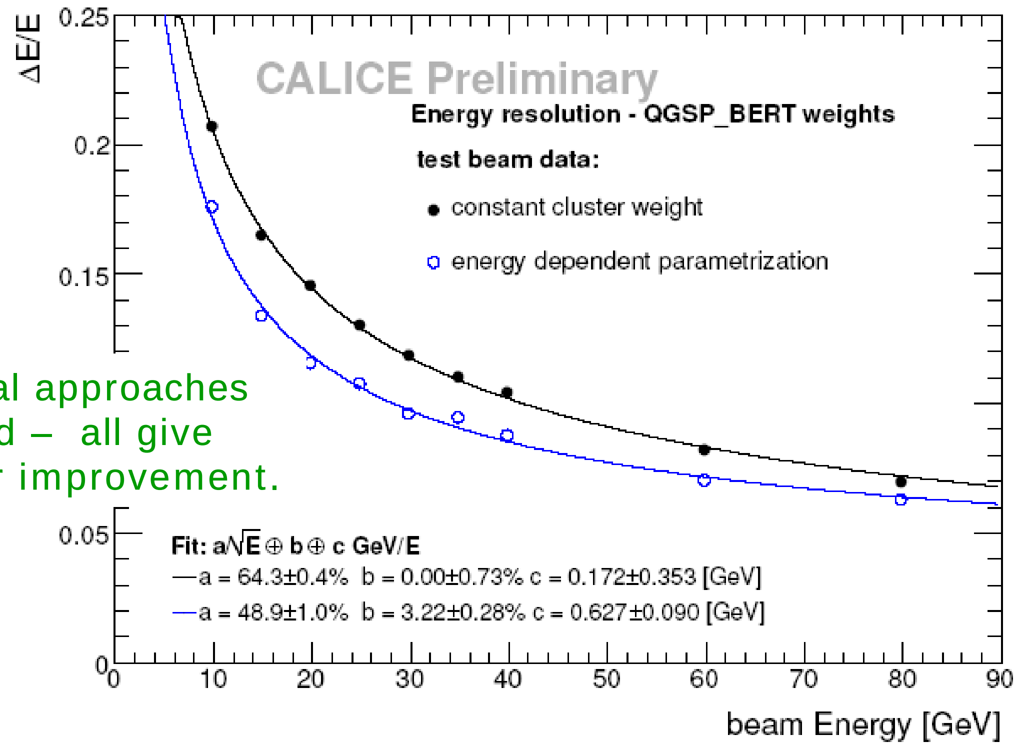




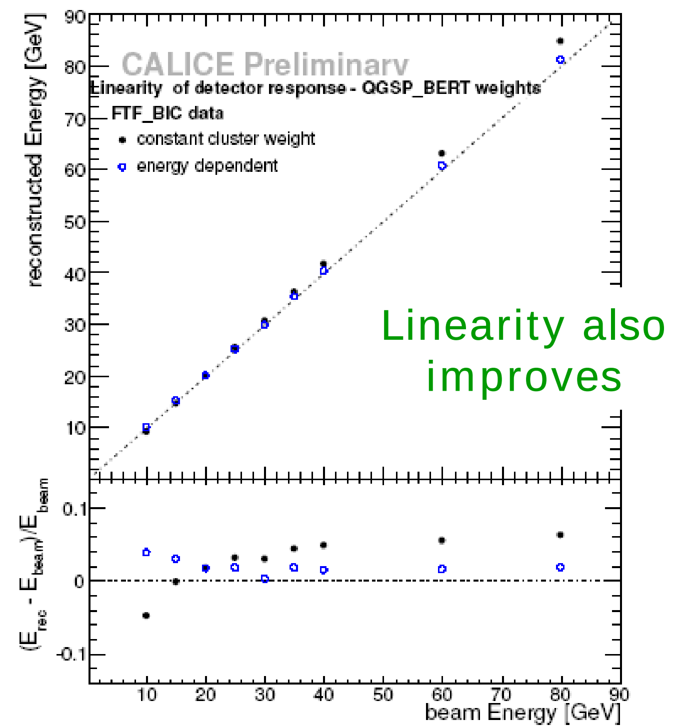
Software compensation

- $\pi/e \sim 0.8$. Non-compensating.
- Shower fluctuations contribute to resolution.
- e/m parts of showers denser typically.
- Use software weighting to improve resolution.
- [CAN-015], [CAN-021], [CAN-028]



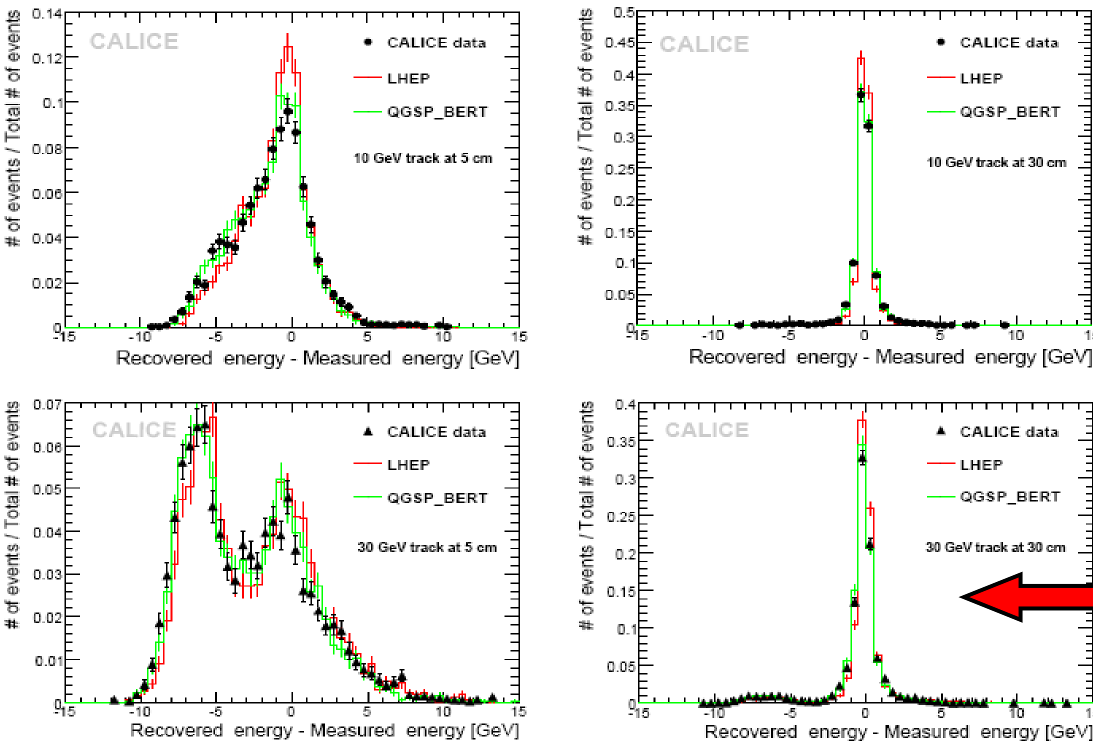


Several approaches studied – all give similar improvement.



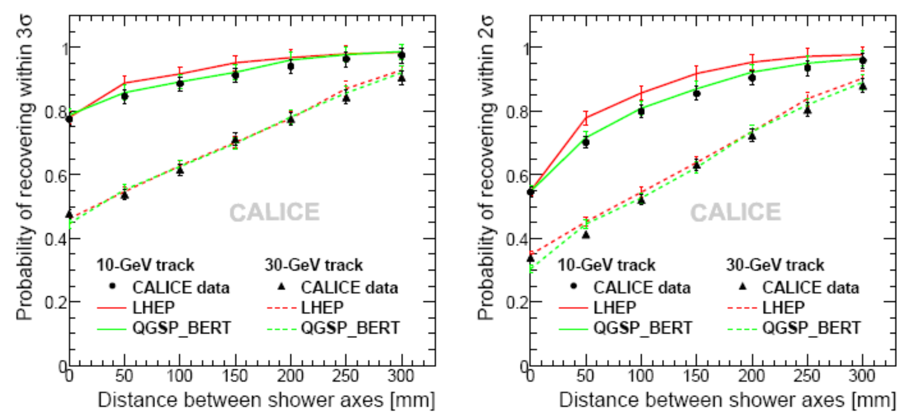
Linearity also improves

PFA tests



- Study energy reconstruction in PandoraPFA using nearby charged and neutral hadrons.
- Emulate by superposing charged π from test beam and "neutral" formed by removing incoming track. Vary transverse displacement between them.
- Look at recovered neutral energy; compare with Geant4 simulations
- CAN-024, CAN-024a

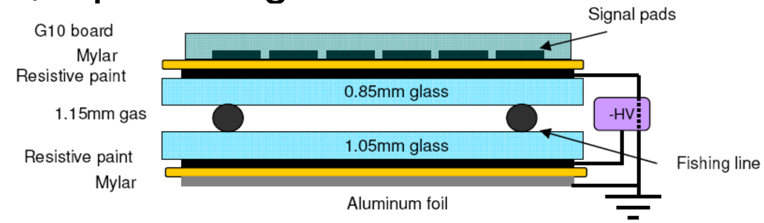
- Use these results to quantify the "confusion" introduced by imperfections in the PFA pattern recognition.
- Performance on real data, with all its deficiencies, matches MC expectations well, in the case of at least one physics list.

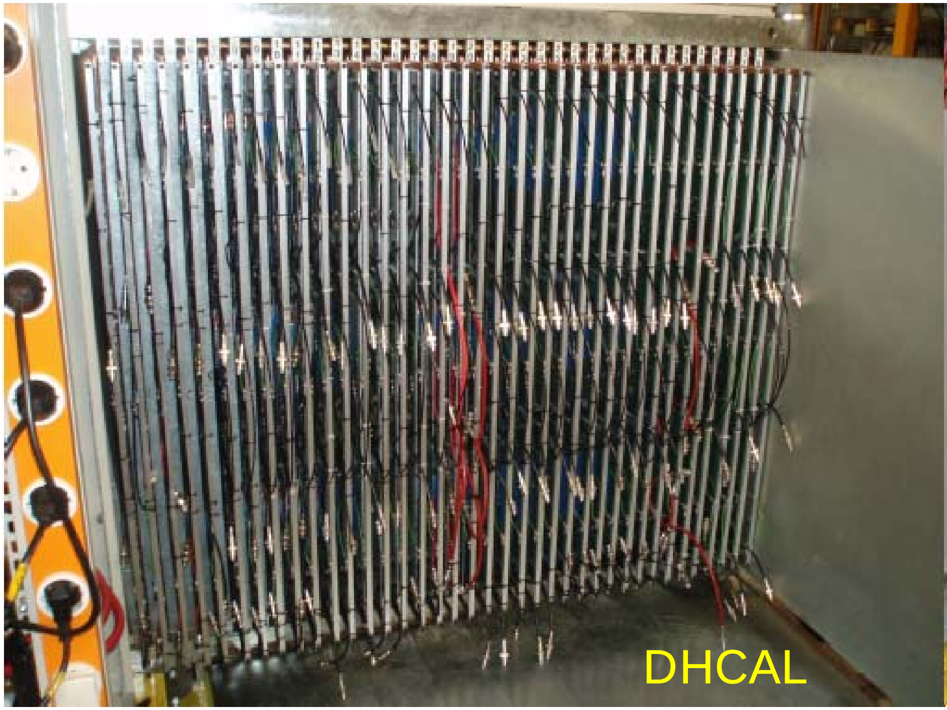


Highlights from test beams in 2010-11

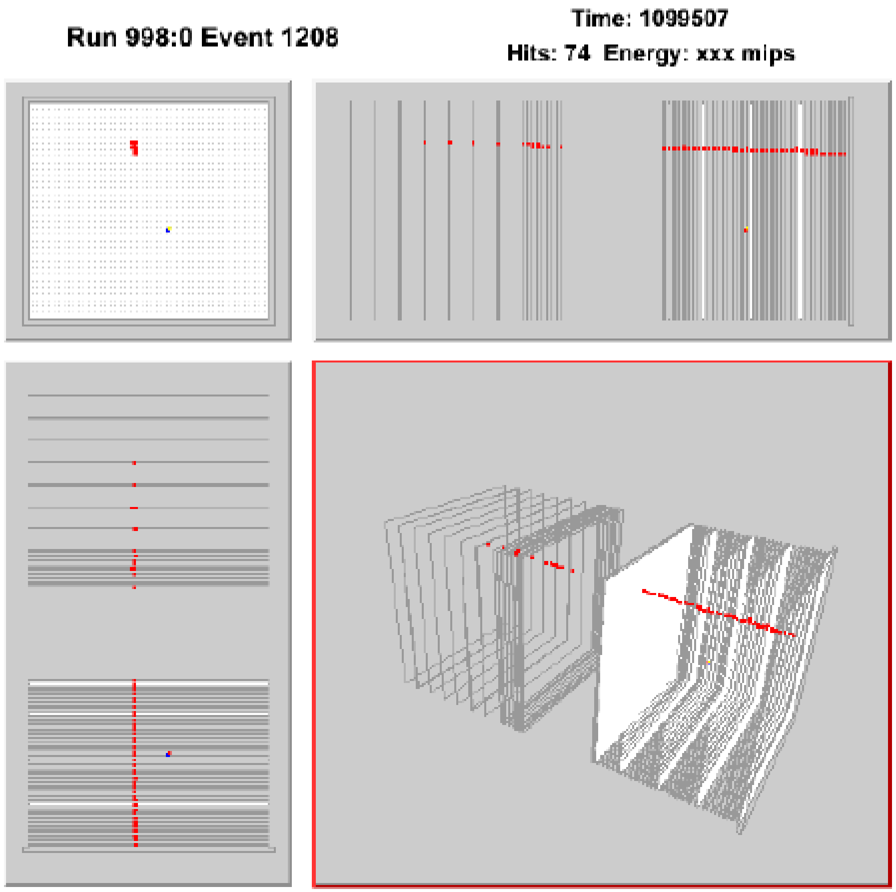
RPC 1m^3 DHCAL

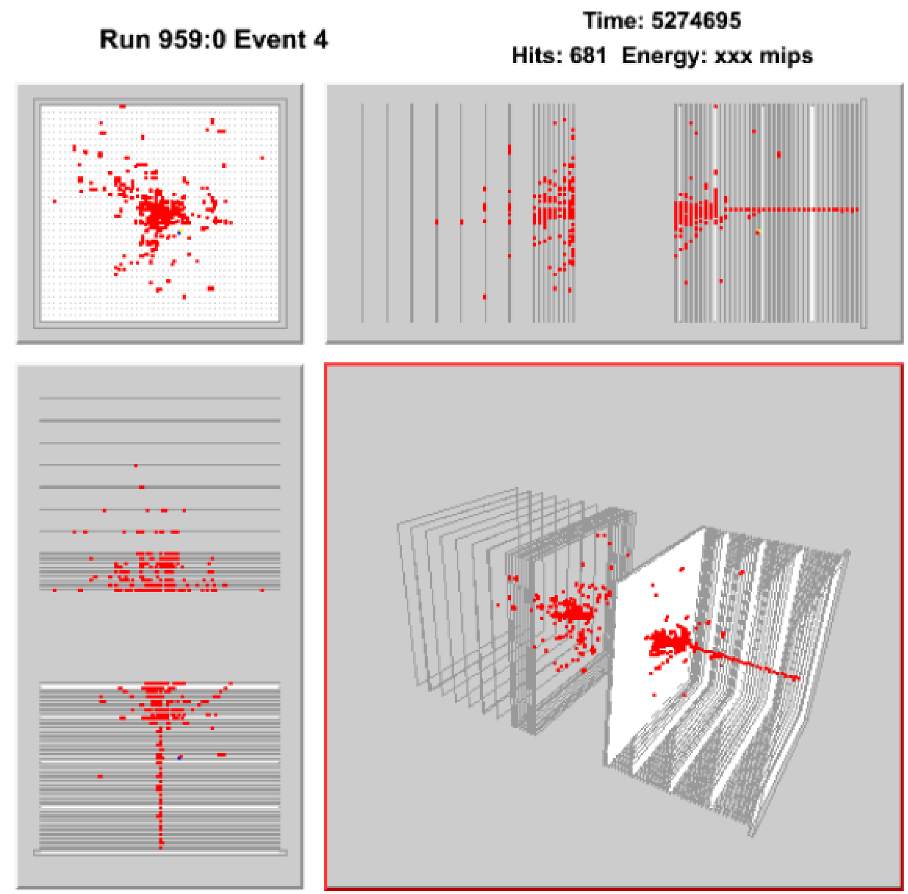
- Completed instrumentation of 1m^3 DHCAL with glass RPCs. Fe absorber.
- Each layer: three 96×32 cm^2 RPC chambers, operating at 6.3 kV.
- 1.15 mm gas gap; Readout pads 1×1 cm^2
- Now also installed RPCs in tail catcher.
- 480 000 channels, single bit readout.
- First data-taking Oct’10, Jan’11; currently running with SiW ECAL.





RPC 1m^3 DHCAL





Typical muon.

Very low noise ($\sim$ 0.06 hits/event);
Could be lower if better temperature control
Pad multiplicity $\sim$ 1.6
MIP efficiency $\sim$ 0.91

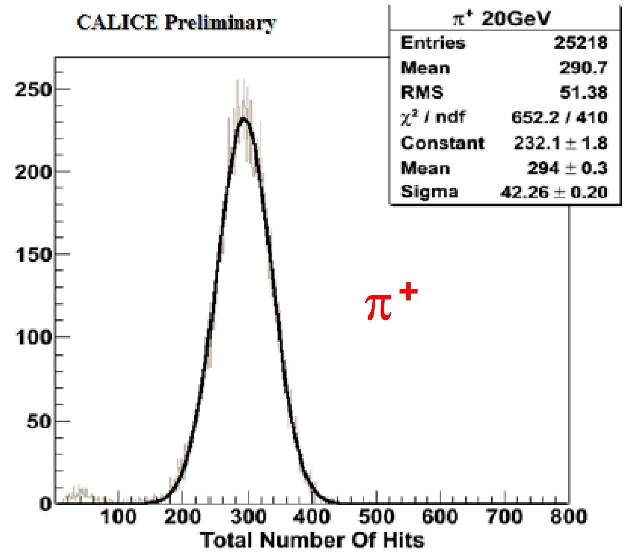
Typical pion shower.

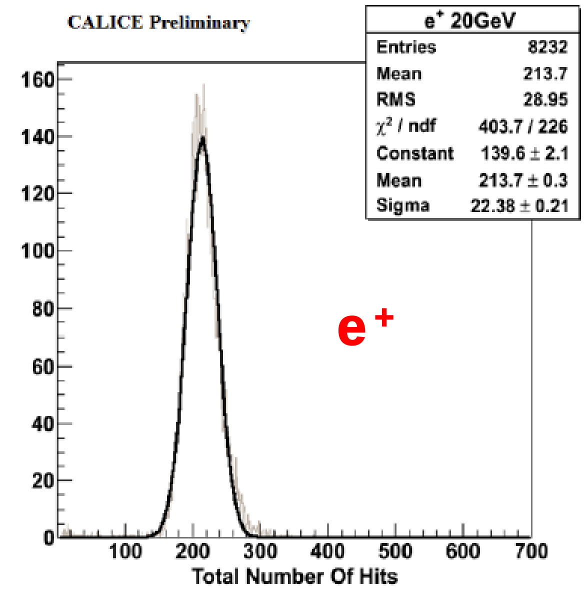
The isolated hits are shower-related, not noise

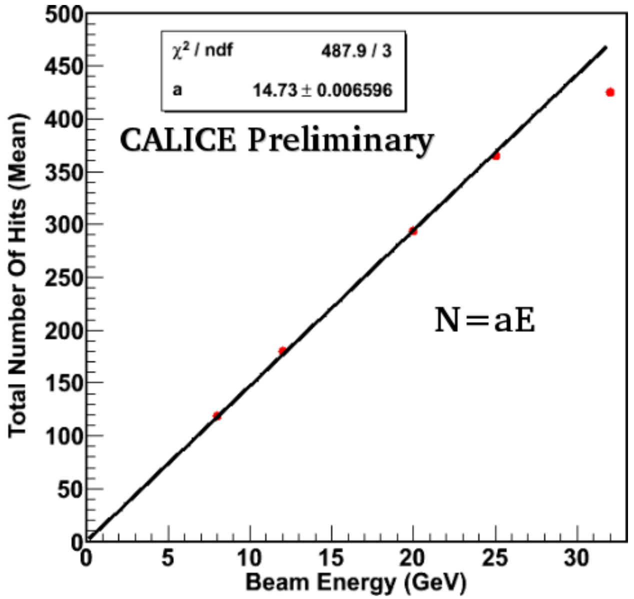
RPC 1m^3 DHCAL

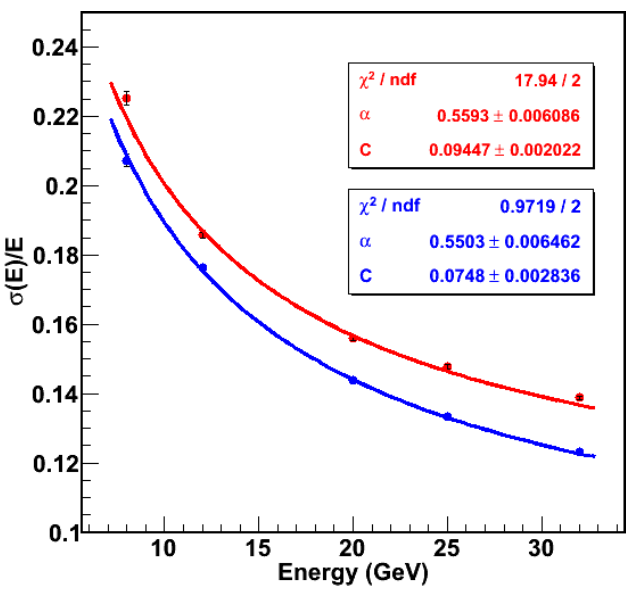
CAN-030, CAN-031, CAN-032

DHCAL Response (#hits) for 20 GeV π^+ and e^+



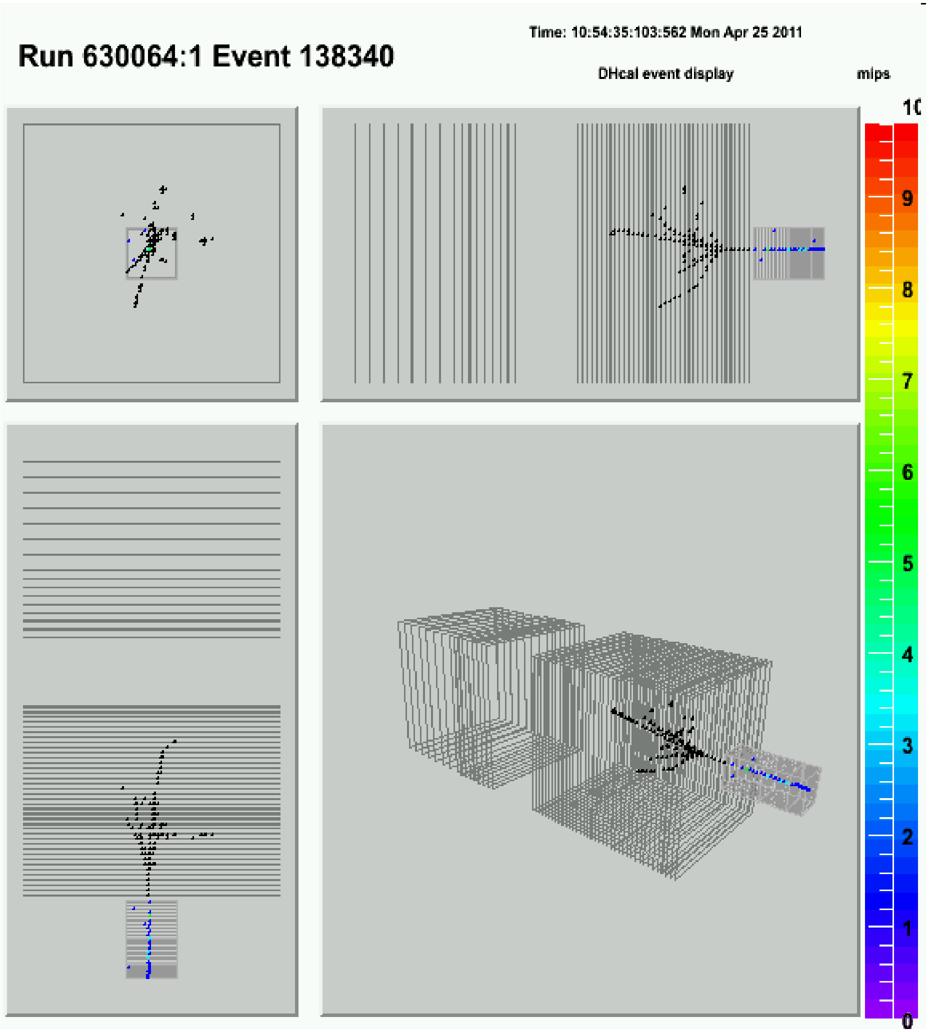




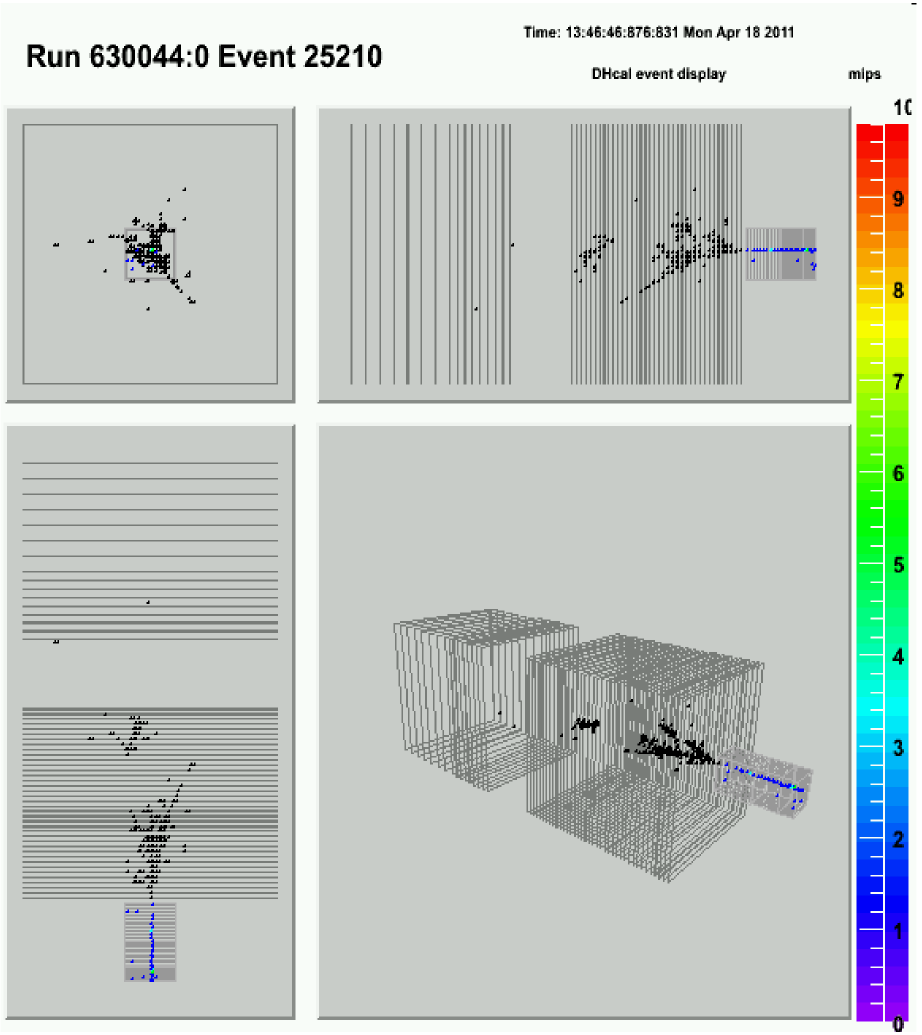


Linearity and resolution for pions.
(blue curve is after containment cut).

Latest – events from Si-ECAL+DHCAL run



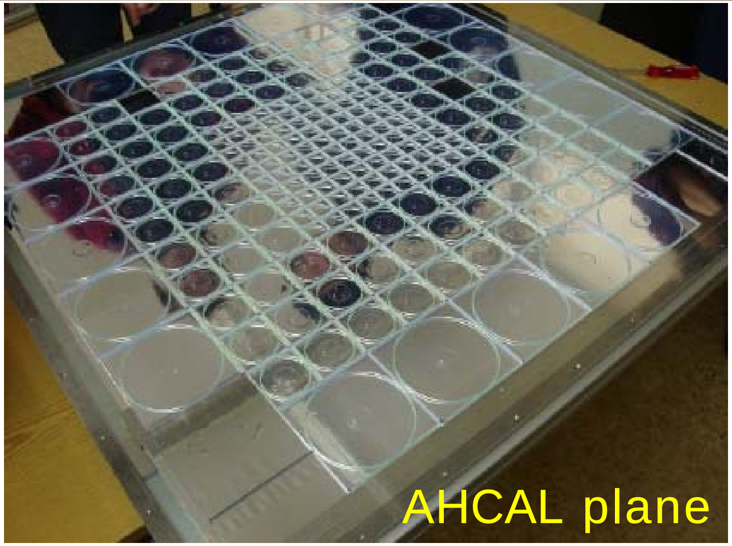
8 GeV pion



20 GeV pion

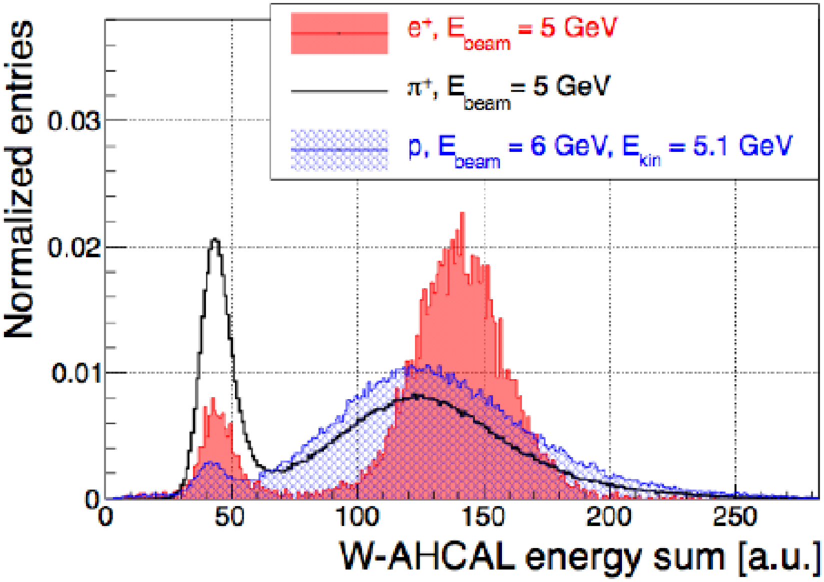
Tungsten HCAL (W-AHCAL)

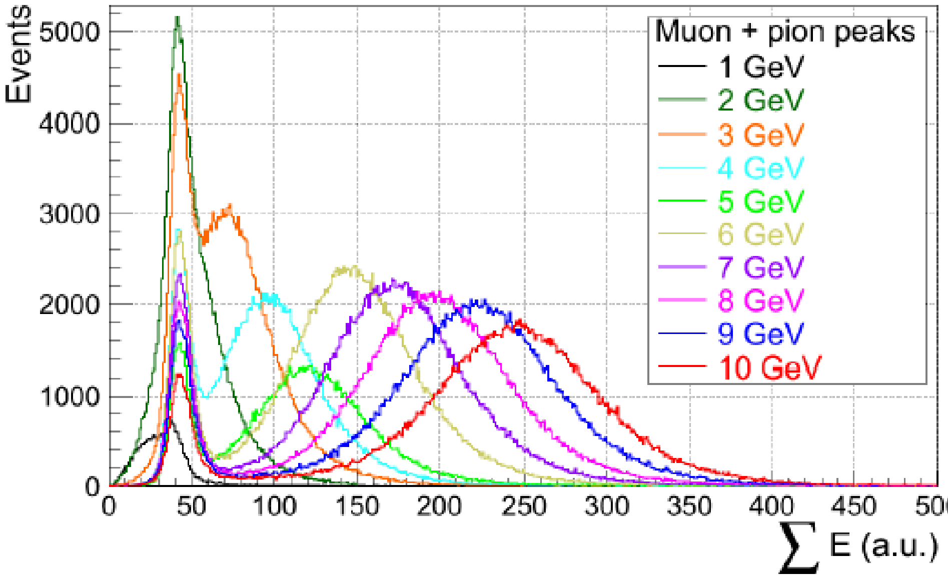
- Motivated by particle flow calorimetry for CLIC.
- To contain ~TeV jets, need ~7.5 $\lambda_{int.}$ HCAL depth; *inside the coil*.
- In order to keep reasonable coil size, replace Fe by W.
- But much less experience (and MC tuning) for hadronic showers in Tungsten.
- For example, expect nuclear breakup more important.
- Testing W absorber planes with the scintillator tile AHCAL planes.
- First runs at CERN in autumn 2010 (just 3.9λ_{int}); continuing 2011.



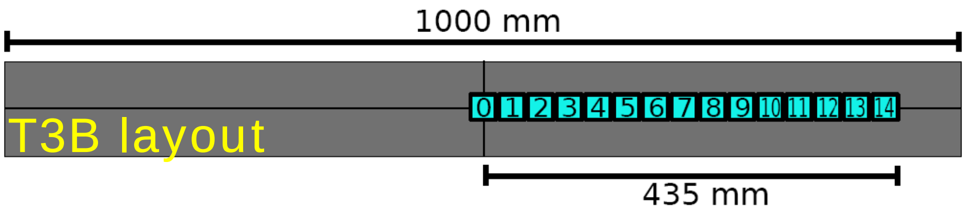
Tungsten HCAL (W-AHCAL)

- First data, π, μ, e at 1-10 GeV (CERN PS)
- Working on calibration, temperature corrections etc.
- Results below based on old (2007) AHCAL calibrations. Results already look sensible, suggesting calibrations are quite stable.
- Everything looks reasonable so far. First impressions:
  - Hadron response similar to Fe
  - e/m response worse (different X_0/λ_{int} ratio, so fewer samples)

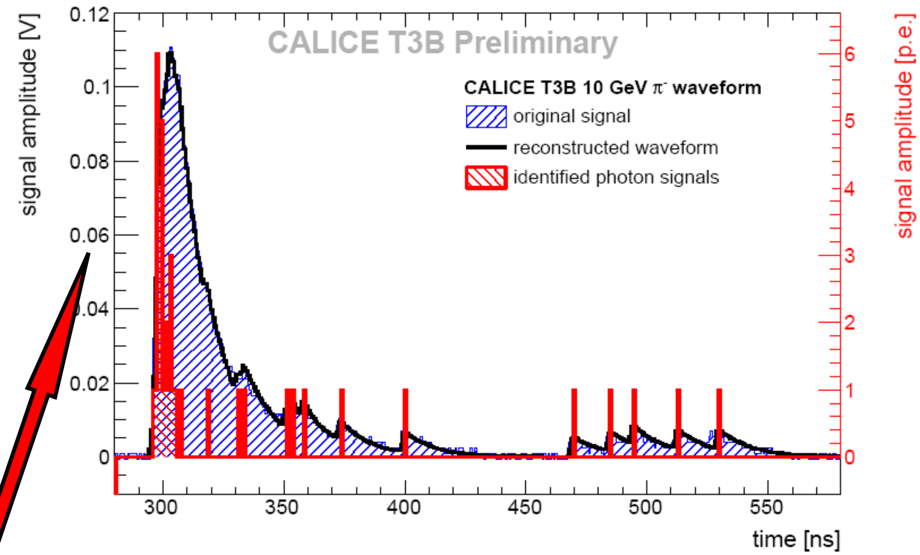


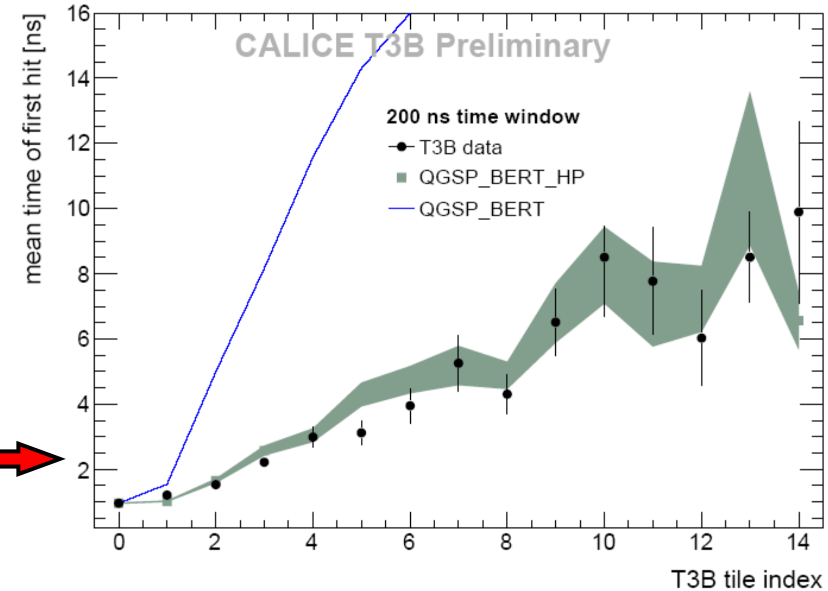


T3B (Tungsten Timing Test Beam)



- Time-stamping important at CLIC (short bunch spacing; two-photon background).
- How about intrinsic time structure of the showers?
- Introduce special timing layer after layer 30 of W-AHCAL, reading out time structure of signals.
- Fit to a sum of single photon signals.
- Compare time of first hit with GEANT4 simulations vs radius.
- CAN-033

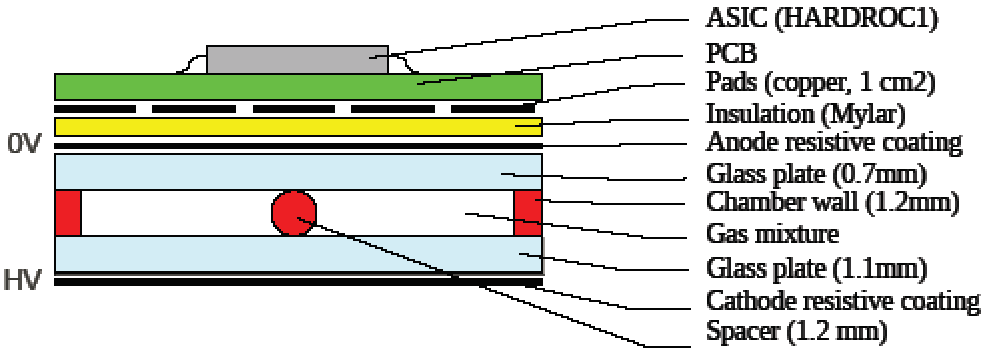


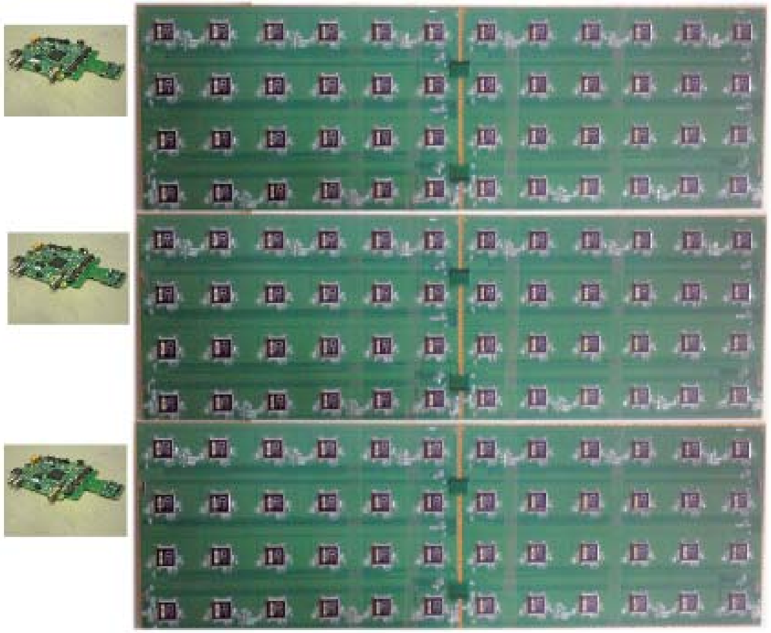


Near future plans

Semi-digital HCAL (SDHCAL)

- GRPCs with 2-bit readout (i.e three thresholds)
- Simulation studies indicate this improves linearity of response
- Two $1m^2$ cassettes built and tested in beam already in 2010.
- Moving towards full $1m^3$; to be completed ~May 2011. 35 GRPCs so far.
- Beam tests later 2011 @ CERN.
- Full test bed for 2nd generation DAQ (see later)
- 2010 – power pulsing test of a 33×50 cm^2 chamber in 3T field – no loss of efficiency seen due to field or power cycling.

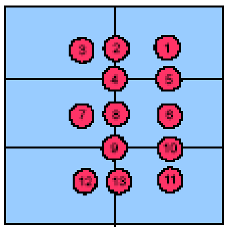


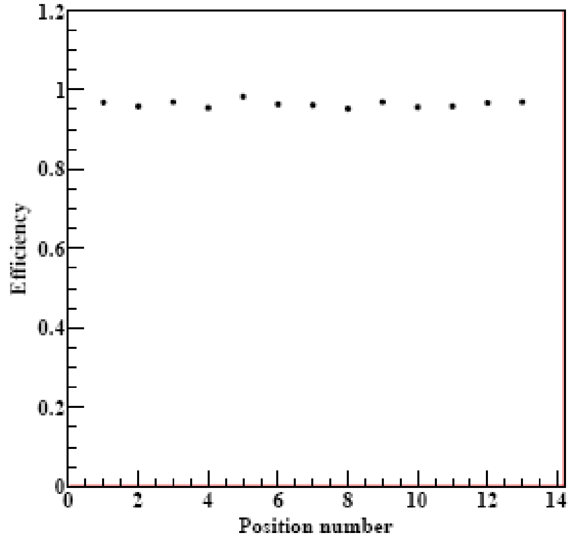


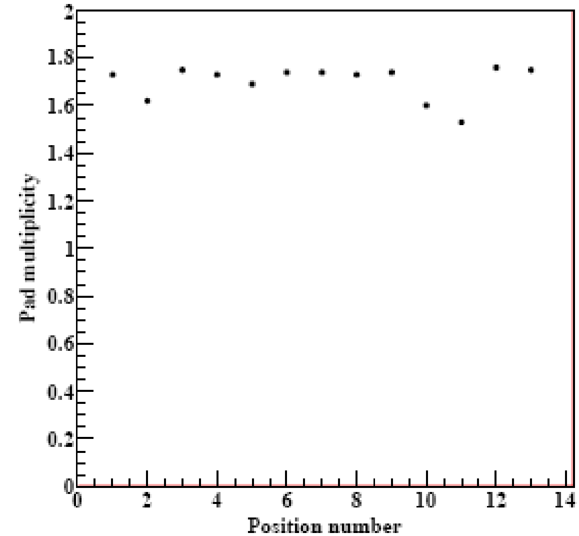
1 m^3 readout board

Semi-digital HCAL (SDHCAL)

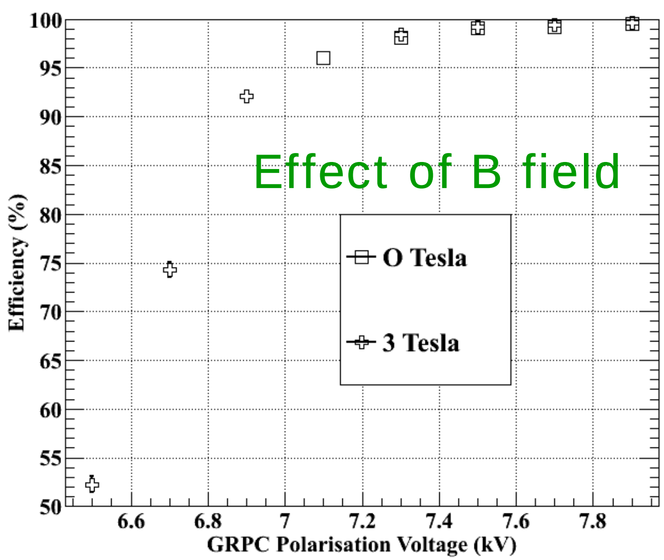
Uniformity studies



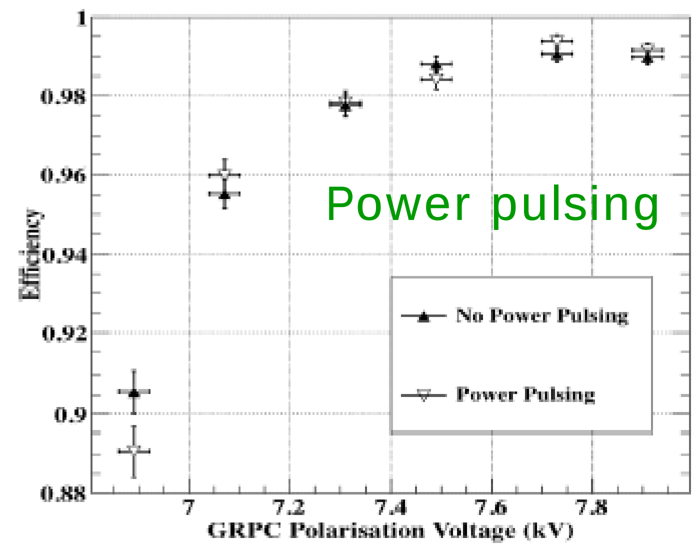




Effect of B field

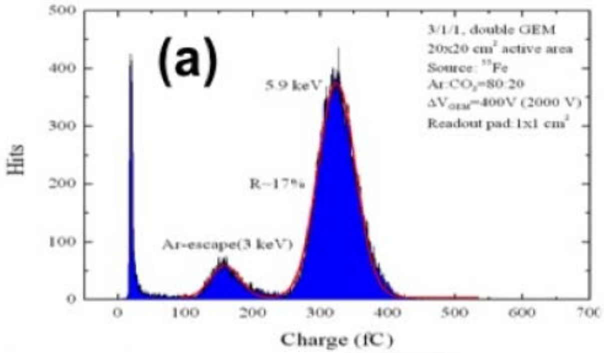


Power pulsing

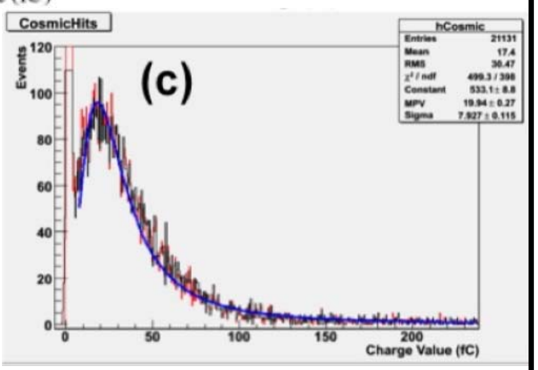


GEM, MicroMegas options for DHCAL

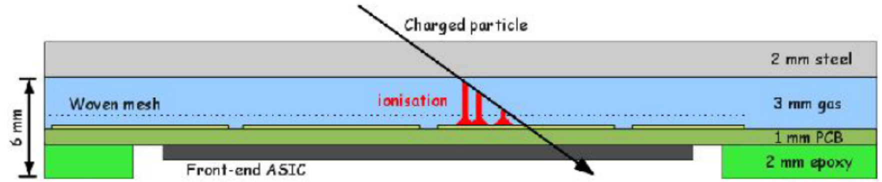
- 30×30 cm^2 **GEM** chamber under test with KPIX readout.
- Developing 33×100 cm^2 foils for 1m^2 chambers. $\Rightarrow$ Test in DHCAL
- Same electronics as DHCAL.
- Also R&D on thick GEMs



Source tests

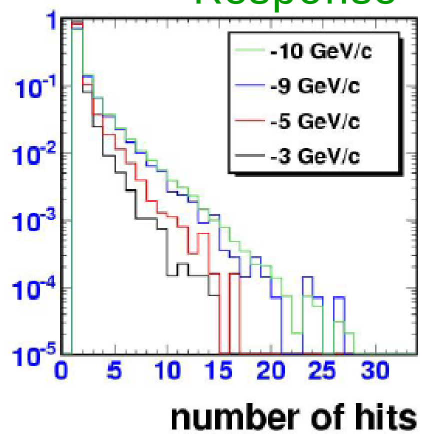


Landau in cosmic tests

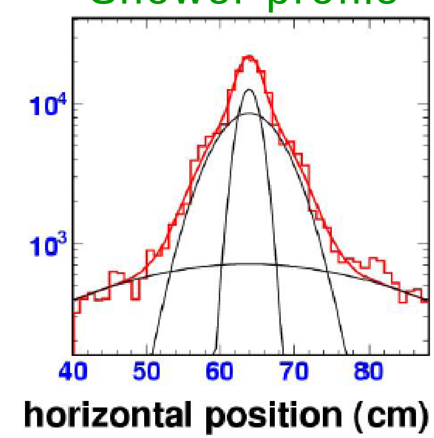


- **MicroMegas** ASUs of 48×32 cm^2.
- Beam tests of a 1m^2 module in 2010 (stand-alone and in the W-AHCAL run)
- Used HARDROC chip (as GRPC); not optimal shaping time.
  - MICROROC variant now developed, produced and tested.
- Tests in 2011 of 2 planes with MICROROC at CERN; more planes depending on funding.

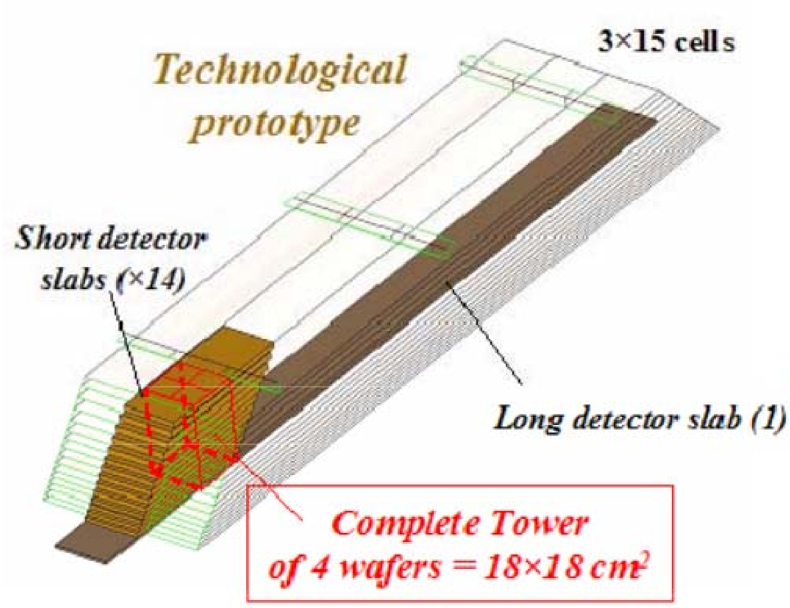
Response

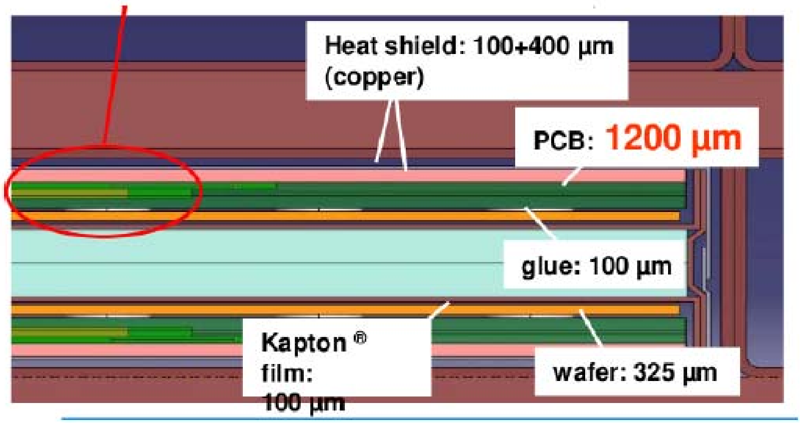


Shower profile

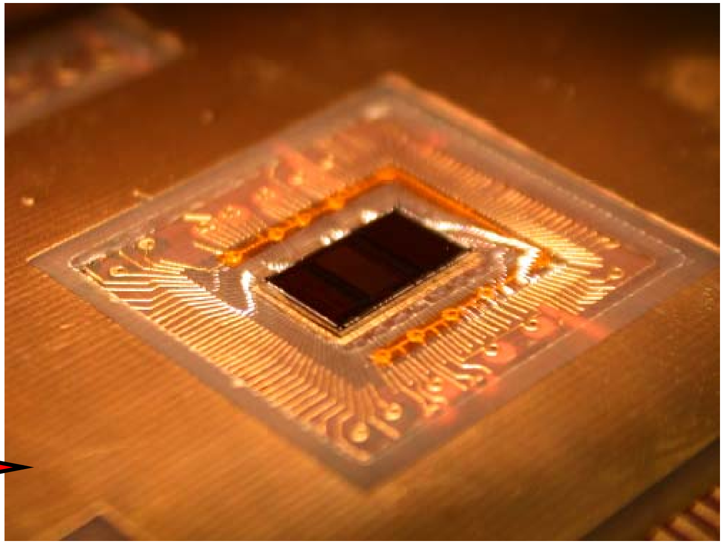


Si-W ECAL

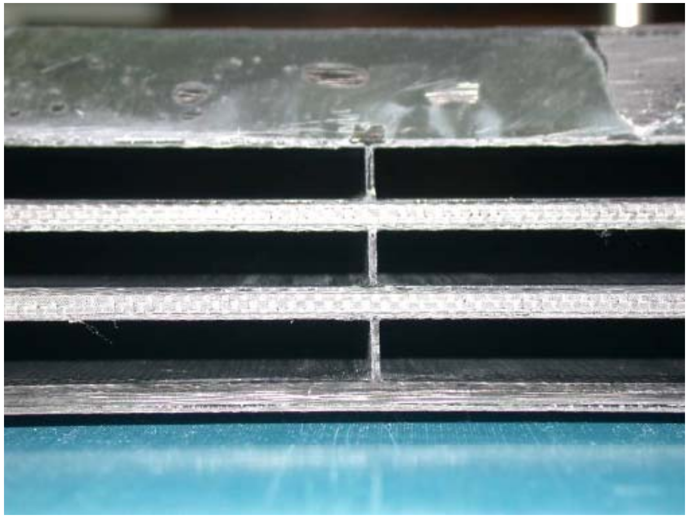




- Working towards technological prototype
- Approaching a module of a possible ILC detector
- Complete tower + 1 long (1.5 m) slab
- Sensors: 5×5 mm^2 Si pads.
- Minimise thickness of sensor layer.
- e.g. embed ASICs in thin PCB.



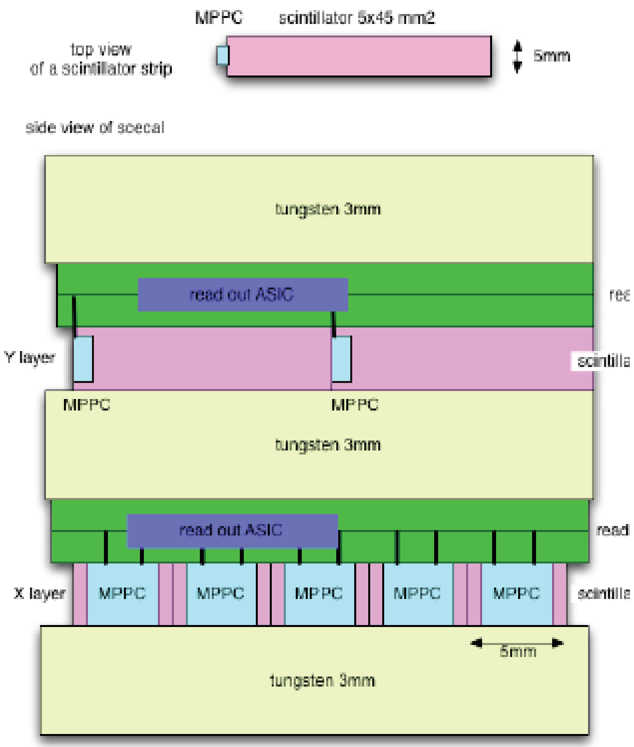
Si-W ECAL

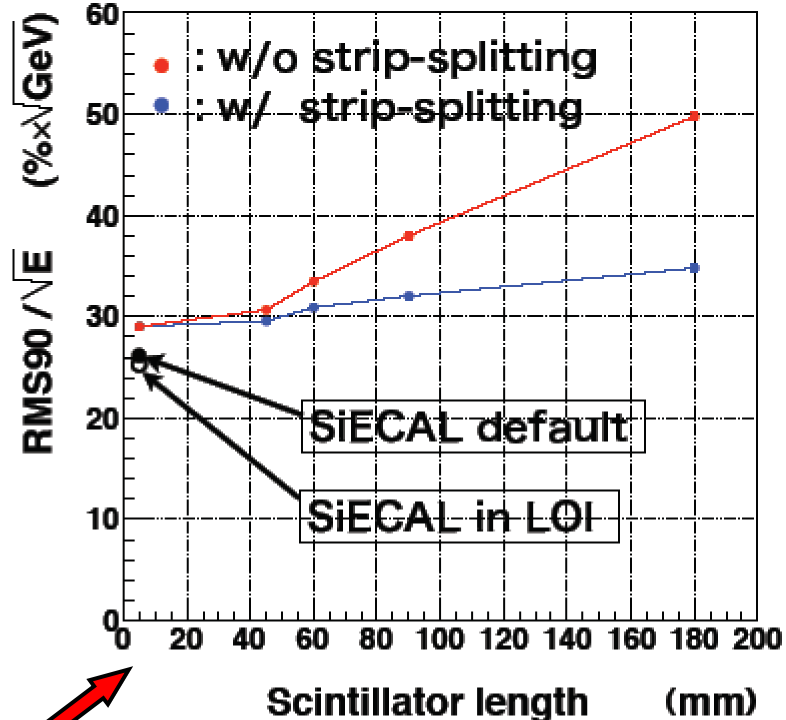


- Demonstrator module (3 alveoli) to validate assembly methods.
- Used for thermal tests to validate thermal modelling.
- One current issue is to achieve sufficient planarity in the PCBs.
- Electronics and DAQ discussed later.
- Plans – first Active Sensor Unit (ASU), 18×18 cm^2, with full DAQ in cosmics and test beam in 2011. Then build up to the full system.

Scintillator ECAL

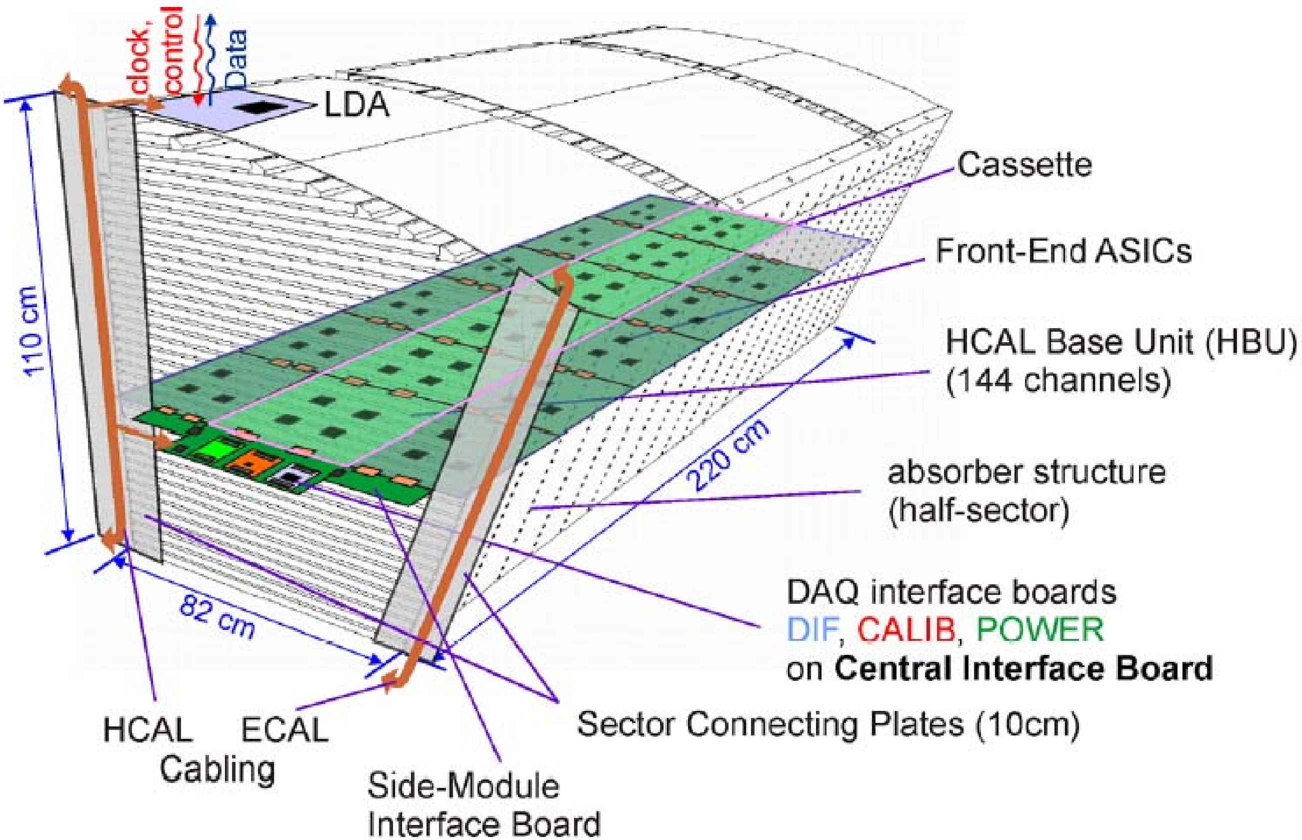
- Second generation prototype
- 5 mm strips (favoured by PFA performance). Without WLS fibre.
- Electronics based on SPIROC (same as AHCAL).
- Tested along with SiW-ECAL modules





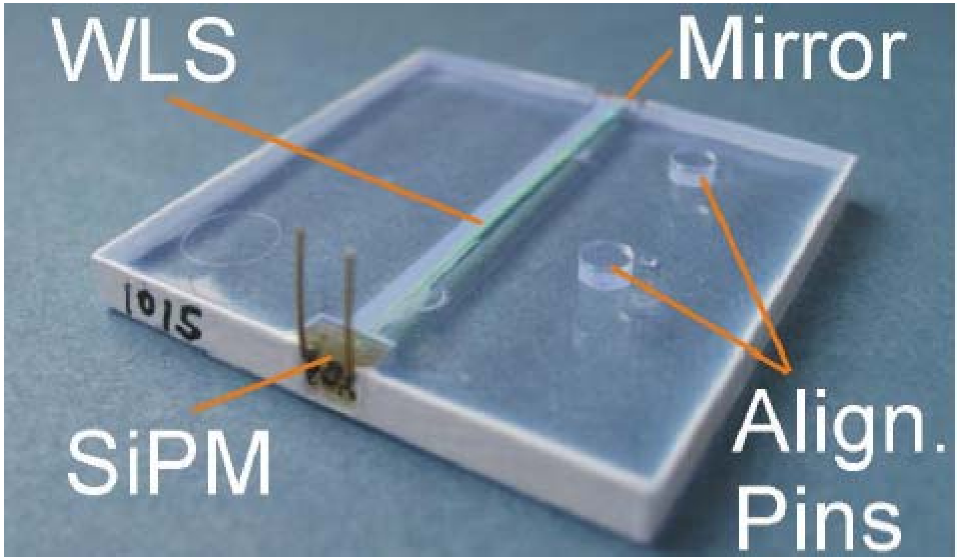
- Important developments in pattern recognition (in ILD context)
- Crossed strips – use positions in surrounding layers to localise energy
- Jet performance looks good for strips up to 50 mm length.

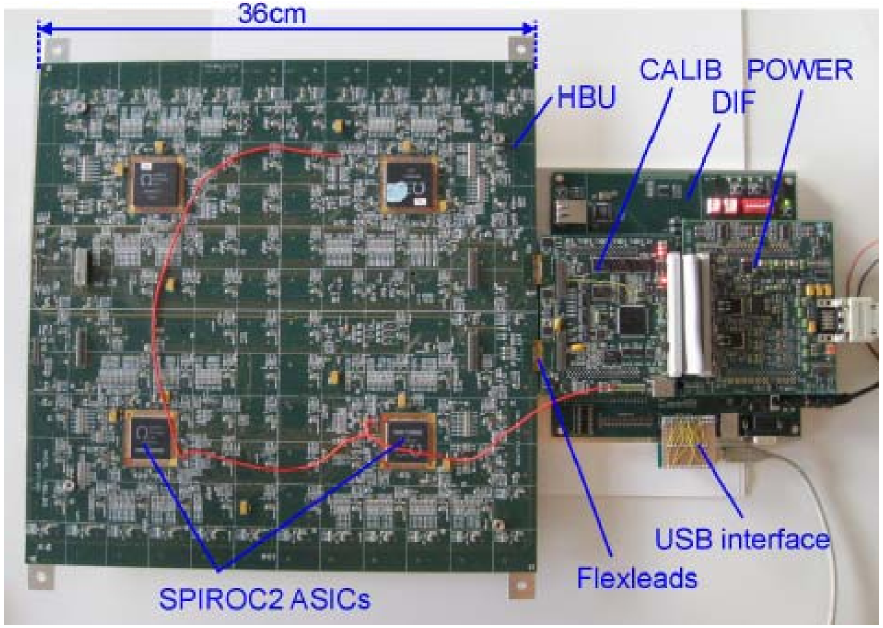
Scintillator HCAL

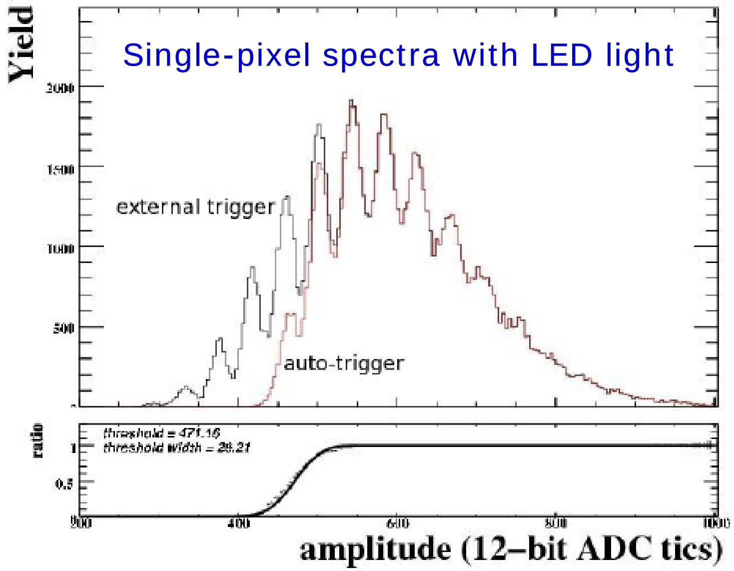


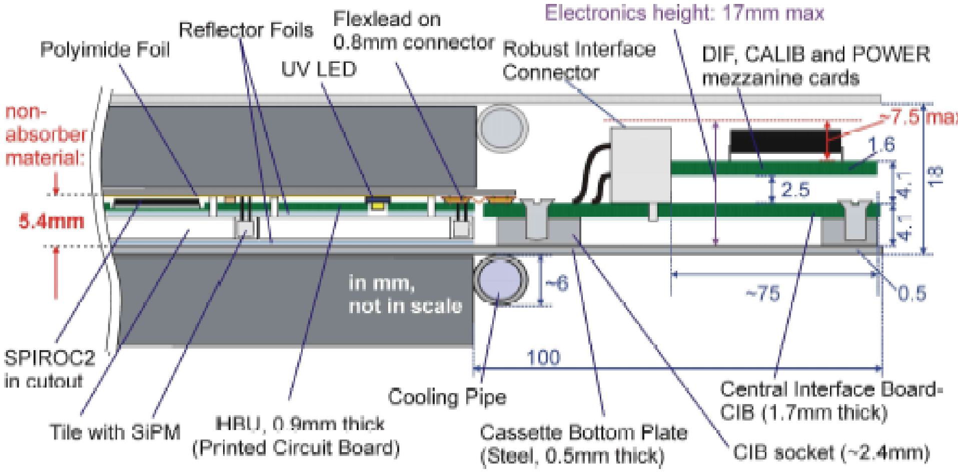
- Motivated by design of an ILD-like detector
- $3\times3\times0.3$ cm^3 scintillator tiles
- Thin sensor module of realistic size
- 3 slabs containing 6 HBUs (12×12 tiles) per layer.

Scintillator HCAL







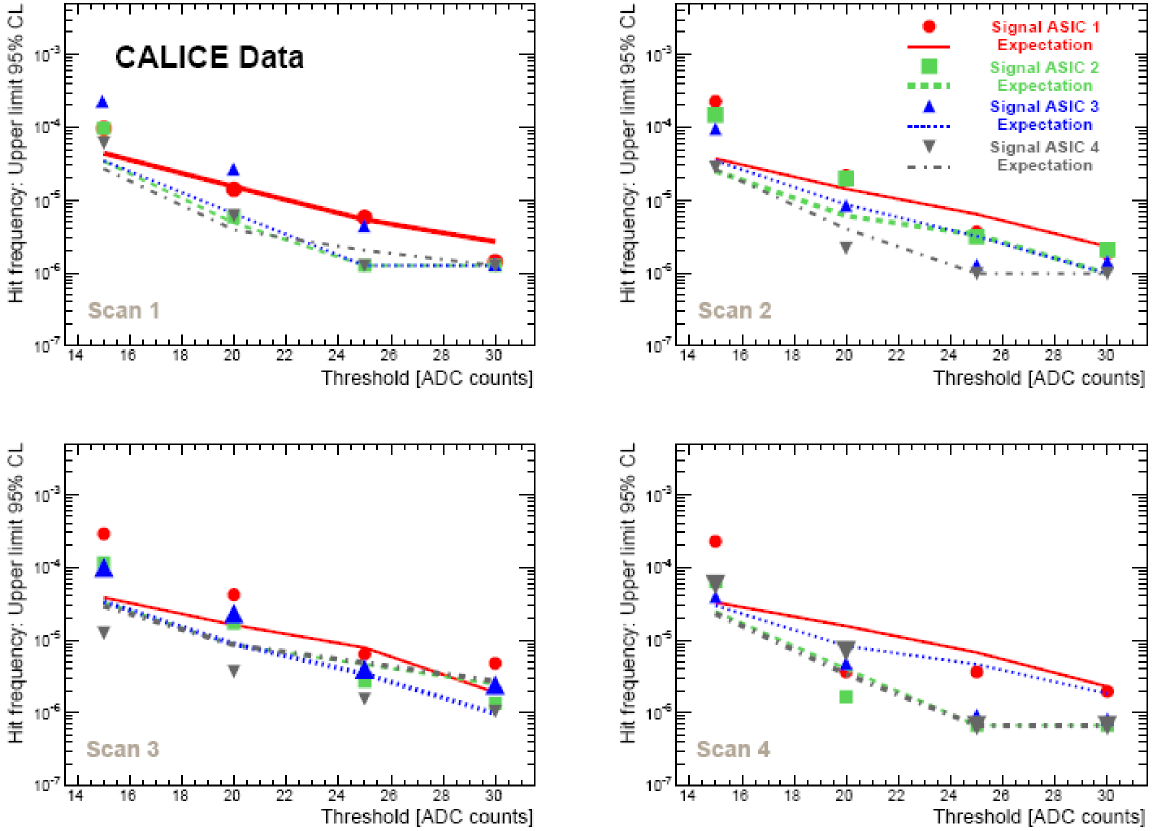


Electronics

- Second generation ASICs designed with these features:
  - Auto trigger to reduce the data volume
  - Internal digitization to allow purely digital data output
  - Integrated readout sequence and common interface to the second generation DAQ
  - Power-pulsing to reduce the power dissipation by a factor of 100
- Three chips have been designed, following the EUDET milestones:
  - HARDROC for the digital Hadronic Calorimeters, for RPCs or Micromegas chambers.
    - A new ASIC, MICROROC, has also been designed and submitted in June 2010 for 1m^2 Micromegas detectors.
  - SPIROC for analogue Hadronic Calorimeter.
  - SKIROC for the the Si-W Electromagnetic Calorimeter.
- In March 2010, sufficient numbers of these ASICs (except MICROROC) were produced.

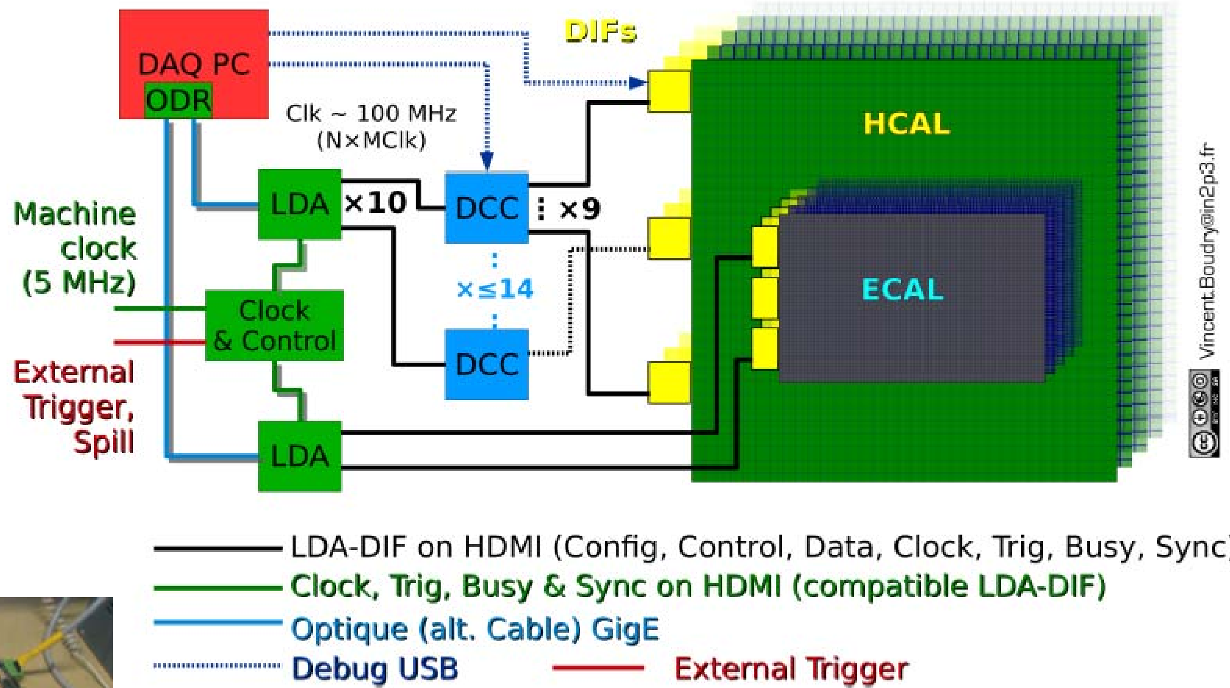
ASIC exposure test (arXiv:1102.3454)

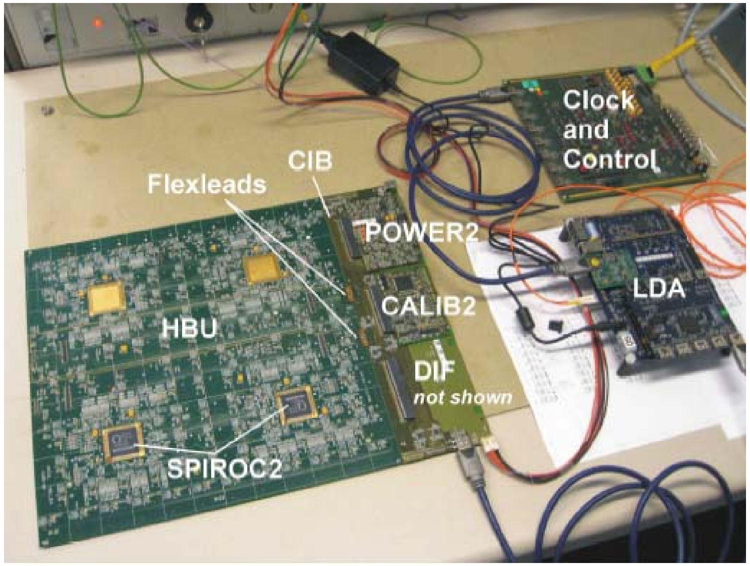
- Tech. prototypes, or full detector – embed ASICs within detector layers.
- Sensitivity to irradiation? Tested placing ECAL ASIC in shower core using SiW ECAL in a 50 GeV electron beam at CERN.
- Estimate probability to fake a signal > 0.5 MIP to be 10^{-5}
- or > 1 MIP to be 6.7×10^{-7}



DAQ

❖Modular – same for all detectors apart from DIF (DetectorInterFace) card
❖Commercial modules where possible
❖Scalable to larger system





❖Integration tests of the DAQ on test bench for the AHCAL.
❖Commissioning is ongoing
❖Combined effort of all subdetectors

Summary

- Completed beam tests of physics prototypes Si-W ECAL, Sc-W ECAL; analogue HCAL. Analysis ongoing.
  - Validation of simulation. Now seeing quite sophisticated tests of models (shower substructure; PFA tests etc).
- Started DHCAL, WHCAL and (imminently) SDHCAL tests.
- Imminent targets: CLIC CDR (end-2011), ILC BDD (end-2012).
- Important tests of second generation scalable prototypes; continue to evaluate alternative technologies.
- Test beams crucial during and after this period. Especially hadron beams @ FNAL +CERN. Availability is an issue.

Project	2011/1	2011/2	2012/1	2012/2	2013/1	2013/2
Si-W ECAL/DCHAL RPC/TCMT (π)	xx	-	-	-	-	-
DHCAL GEM (τ, π)	x	x	x	x	x	x
W HCAL / TCMT (π)	xx	xx	?	?	?	?
GRPC SDHCAL (τ)	xx	xx	x	xx	?	?
Mmegas SDHCAL (τ)	x	x	?	?	?	?
AHCAL (τ)	x	x	x	x	?	?
Si-W ECAL (τ)	-	x	x	xx	?	?
Sc-W ECAL (τ)	-	x	x	?	?	?

Rough classification

$\pi \Rightarrow$ physics proto.

$\tau \Rightarrow$ technological

xx $\Rightarrow$ large scale

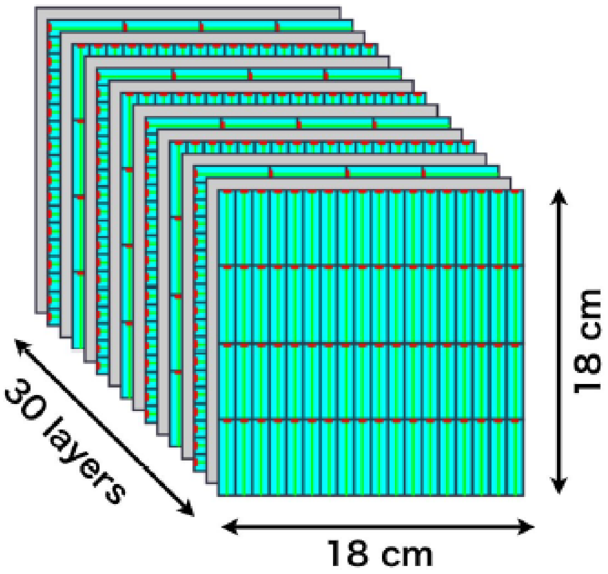
x $\Rightarrow$ few units

Backup

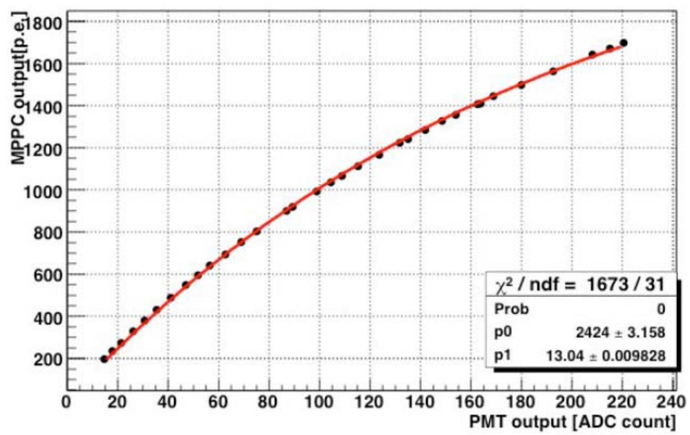
Summary of publications etc.

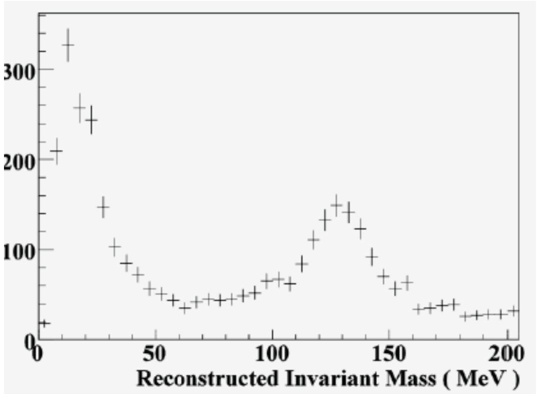
- Currently ~20 Papers
- + two very close to submission (PFA tests, TCMT paper)
- ~30 analysis notes Analysis Notes (approved preliminary results for conferences); at least 10 should turn into papers, possibly in suitable combinations. Two more currently under collaboration review.
- 15 theses listed ; almost certainly more; our records are not complete.
- Many Conference talks and posters

Scint-W ECAL results (CAN-016)

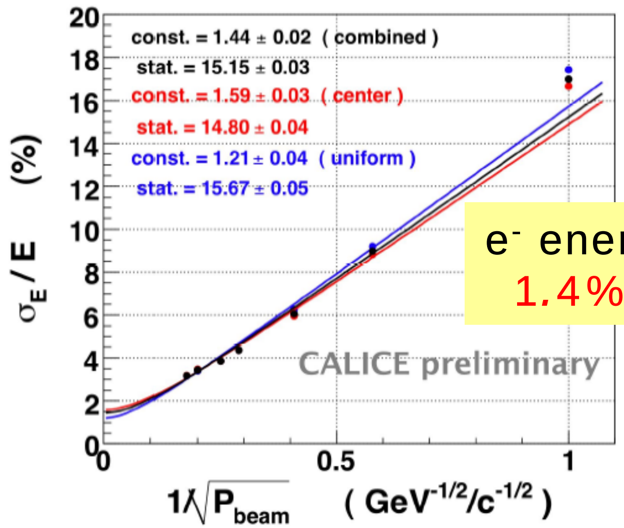


Saturation curve of MPPC

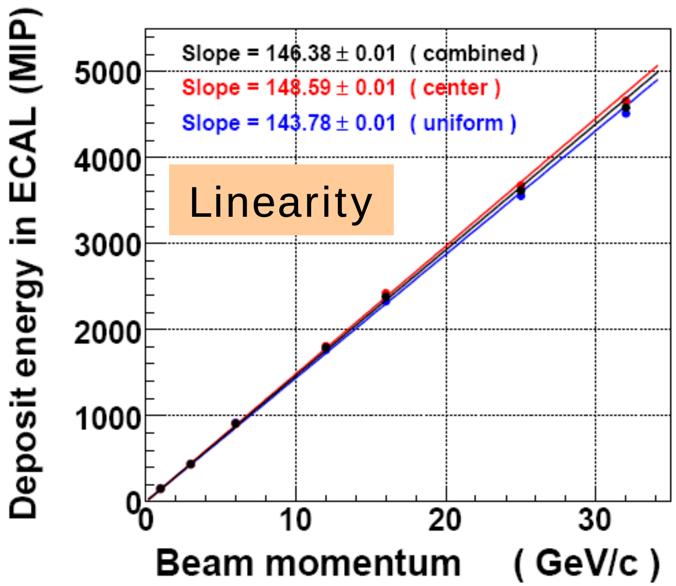




π^0 reconstruction

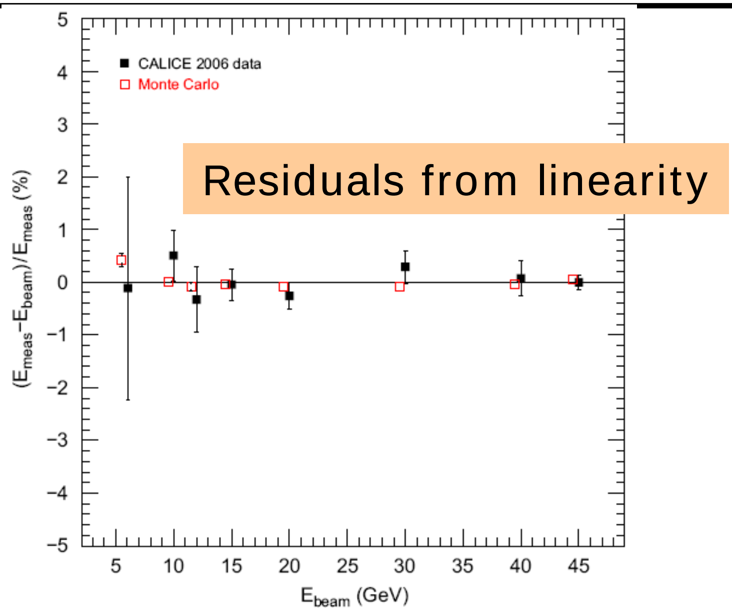


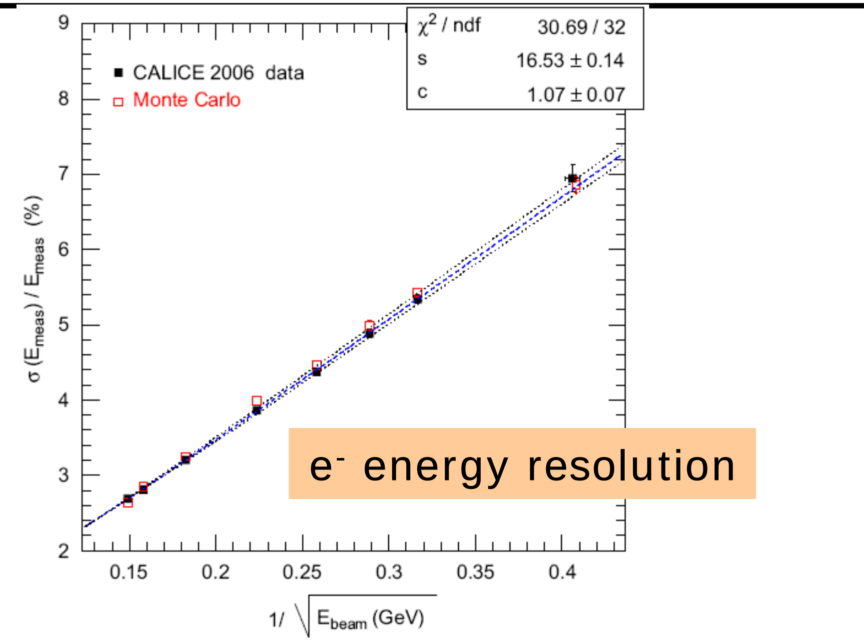
e⁻ energy resolution
$1.4\% \oplus 15.1\%/\sqrt{E}$

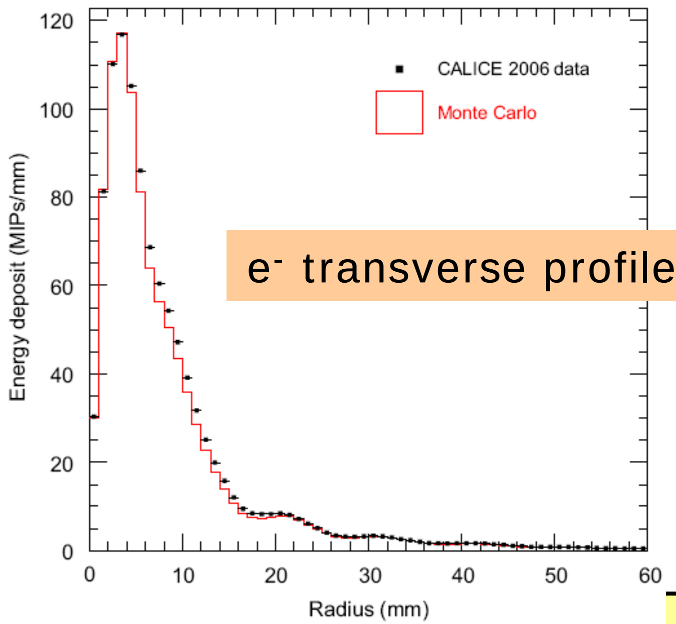


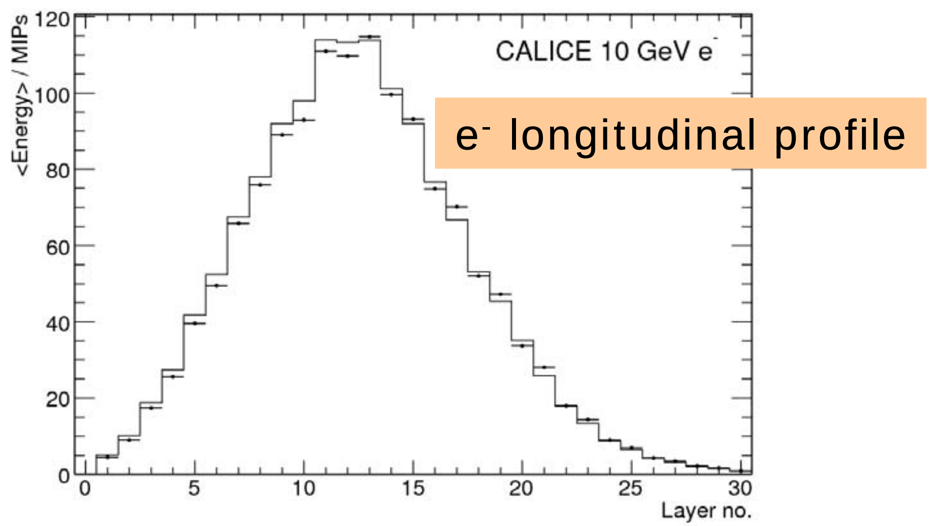
Linearity

Some electron results in Si-W ECAL

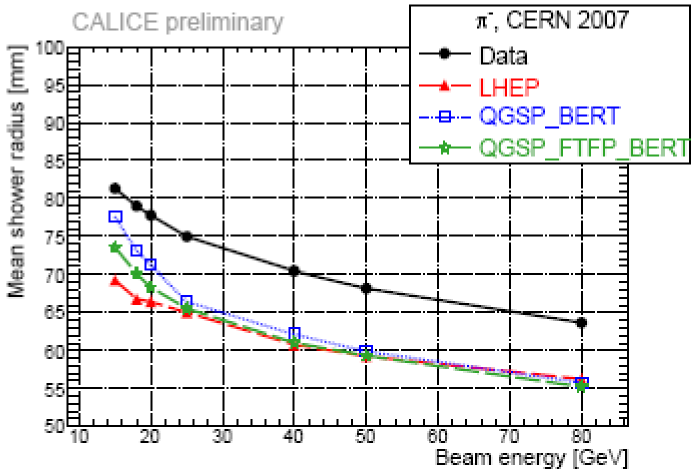




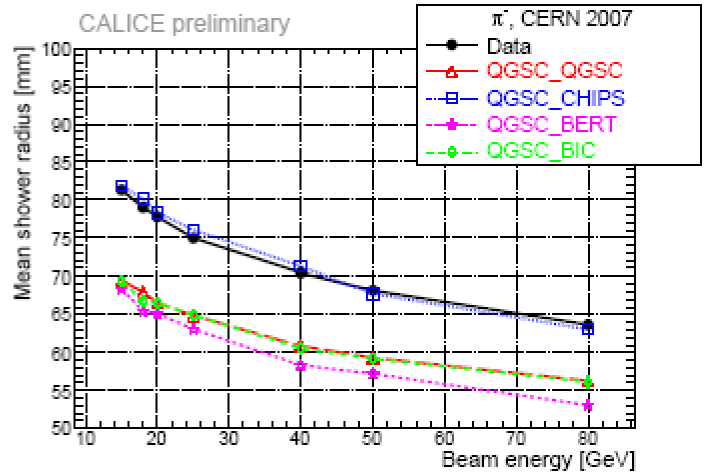




Mean shower radius in HCAL

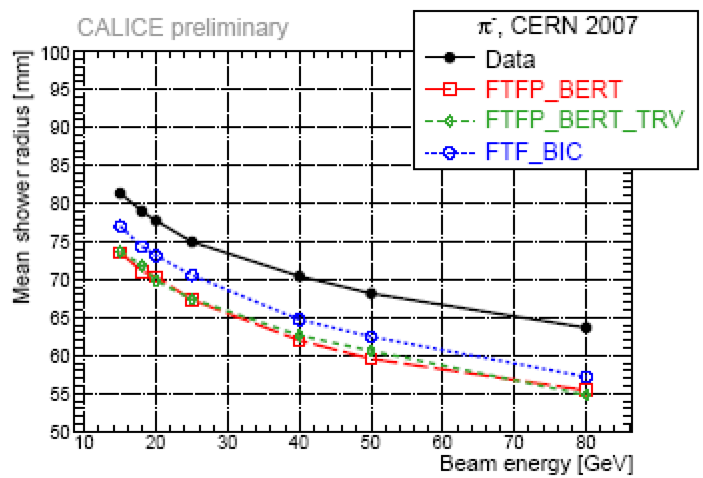


(a)



(b)

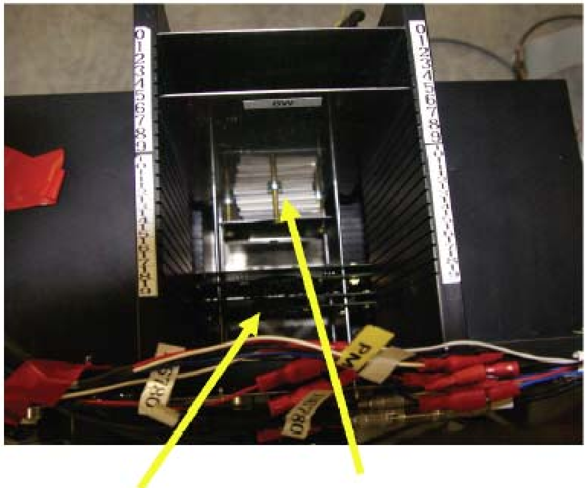
Most physics lists give too small shower radius
QGSC_CHIPS close



GEANT 4.9.2 used

DECAL

- Idea to read out ECAL in digital mode.
- Simulations suggest the idea is vialble.
- High energy density $\Rightarrow$ very small pixel size, $\sim 50\mu$m.
- Explore use of MAPS CMOS sensors
- Successful beam tests of sensors.
- Project now suspended because of funding difficulties in the UK.



4 TPAC sensors

Tungsten slab