CALICE hadron calorimeters Test beam results, new developments

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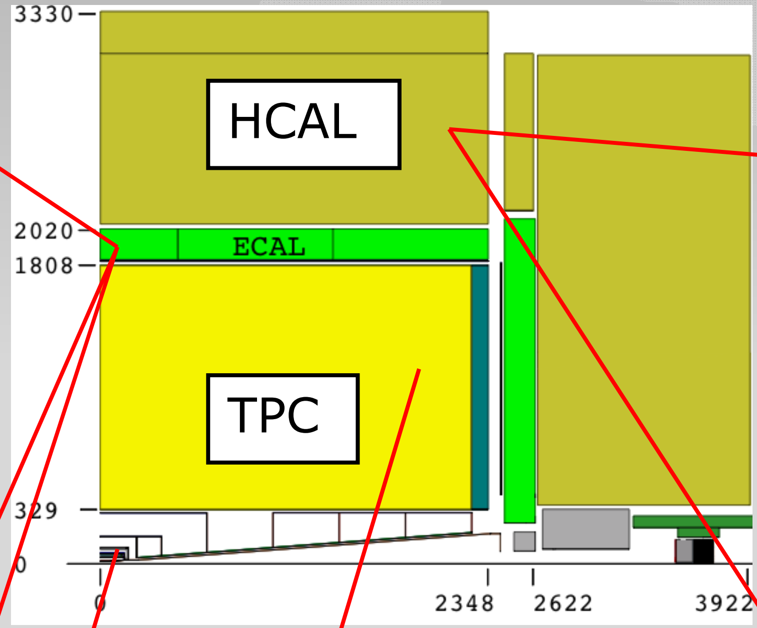
CALICE Collaboration

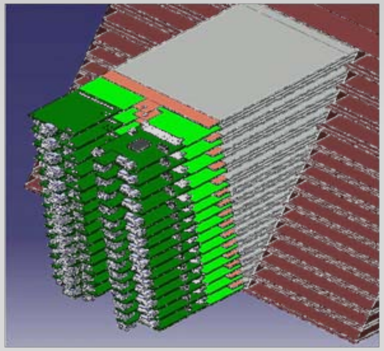
1. Introduction
2. Analogue calorimeter
3. Digital calorimeters
4. Advanced prototypes

ILD sub-detectors (LOI, March 09)



ECAL

★ SiW: 5×5 mm^2



★ ScintW: strips

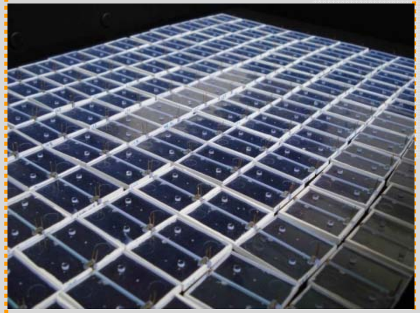
★ MAPS: digital

HCAL

★ Steel + Scint.

Analogue

3×3 cm^2 tiles

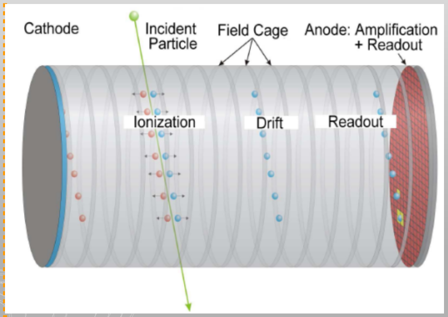


★ Steel + RPC

Semi-digital

1×1 cm^2

TPC



★MPCD Readout

★Digital

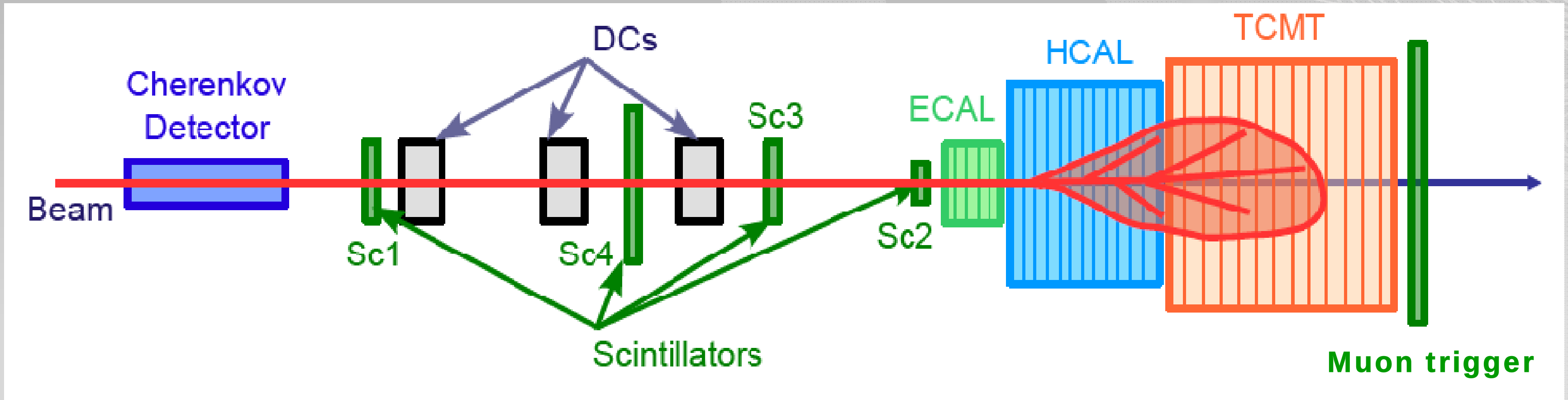
★Analog

Vertex Detector

3 Double / 5 Single Layers

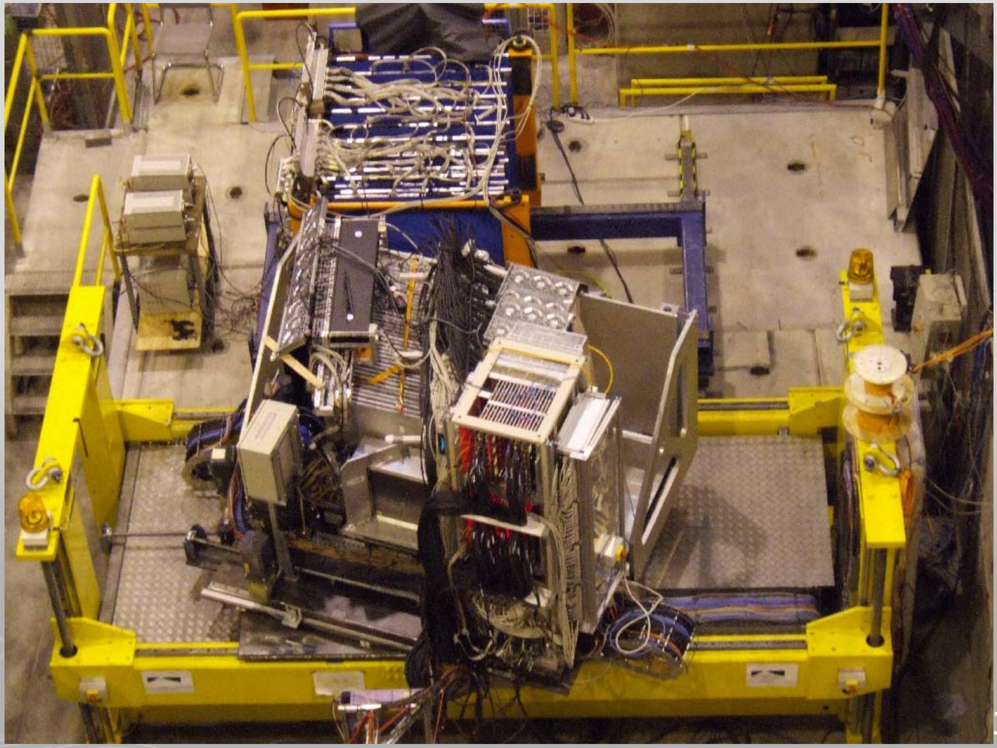
Si pads

CALICE Test Beam Program



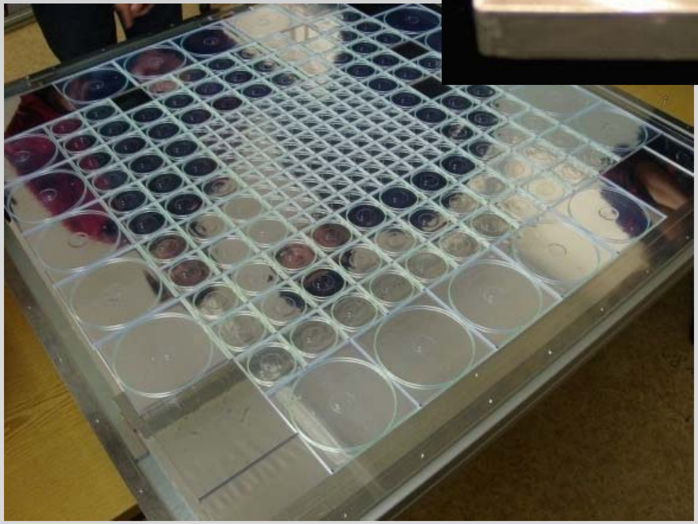
Test Beam periods:

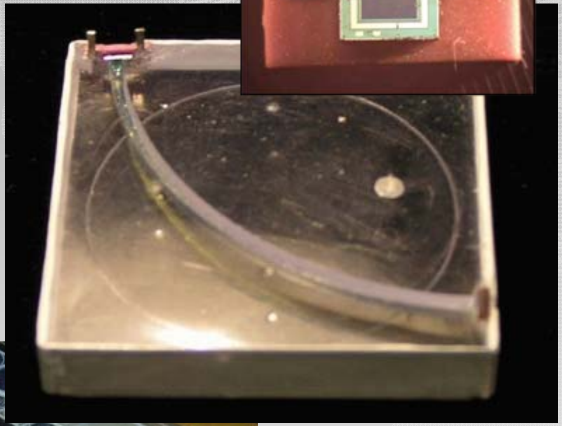
- 2006 – DESY/CERN
- 2007 - CERN
- 2008-9 – FNAL
- Si-W, Sc-Pb ECAL, AHCAL, TCMT
- $e^{\pm}$ 1-50 GeV
- $\mu^{\pm}$ (mainly for calibration)
- $\pi^{\pm}$ 2-180 GeV
- Various impact points
- Angles of incidence 0° - 45°
- stand alone runs of digital HCALs with RPCs, CERN, FNAL
- 2010 DHCALs replace AHCAL in Fermilab

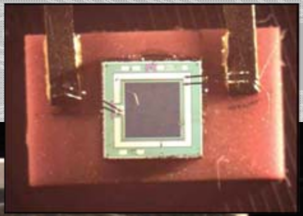


AHCAL physics prototype

- 38 scintillator planes + 38 steel layers à 2cm, 4.5 λ
- 7608 tiles, tile read by a SiPM, new photo-detector developed
- Common readout electronics with ECAL, TCM
- Stable performance over period of 3 years







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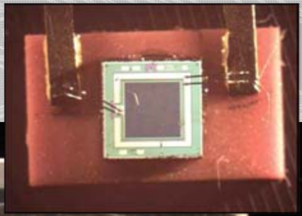
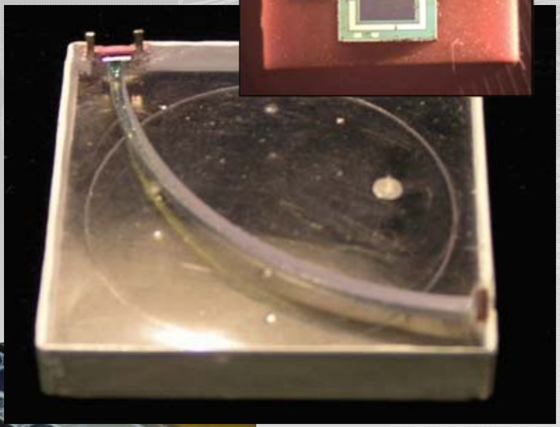
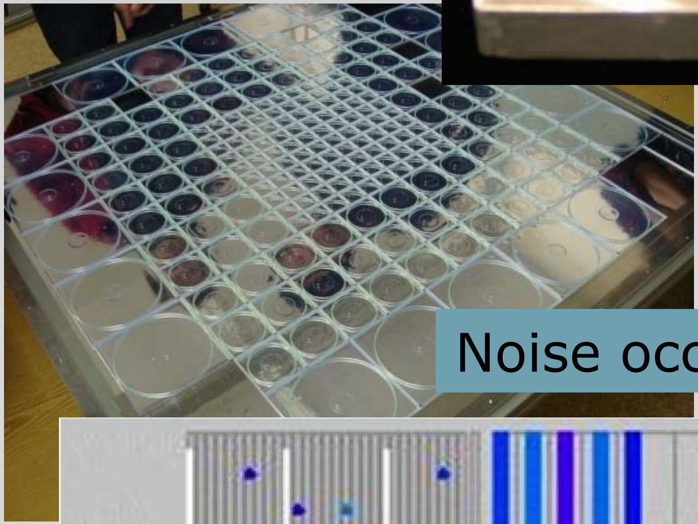
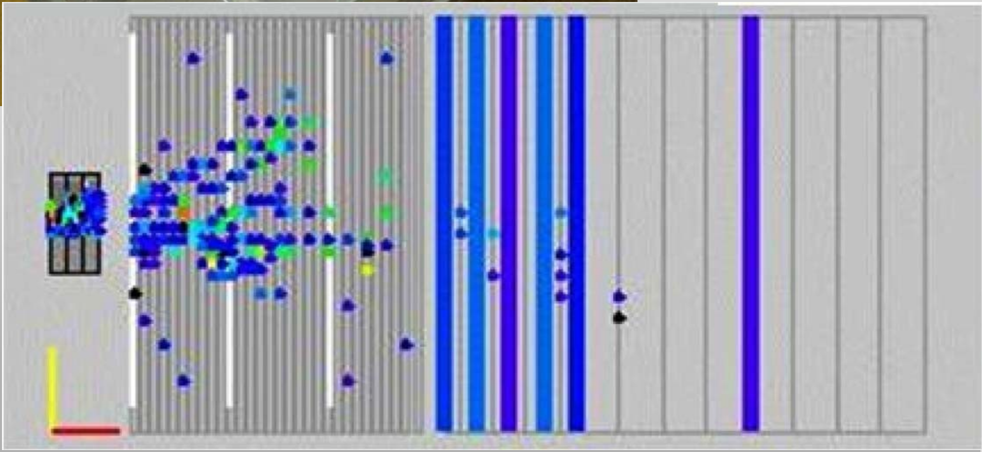






Noise occupancy 10^{-3}



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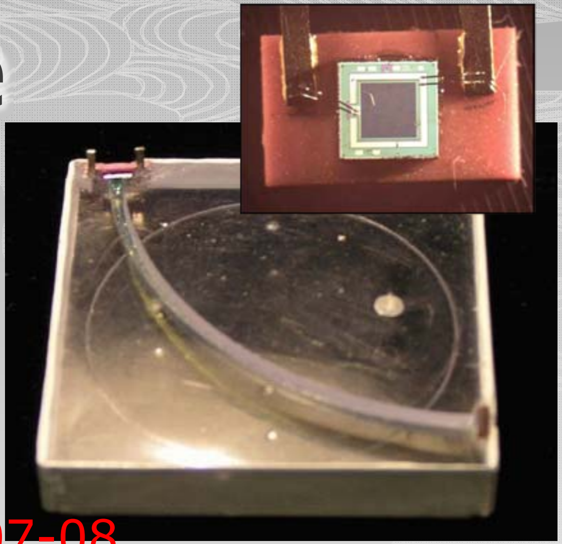

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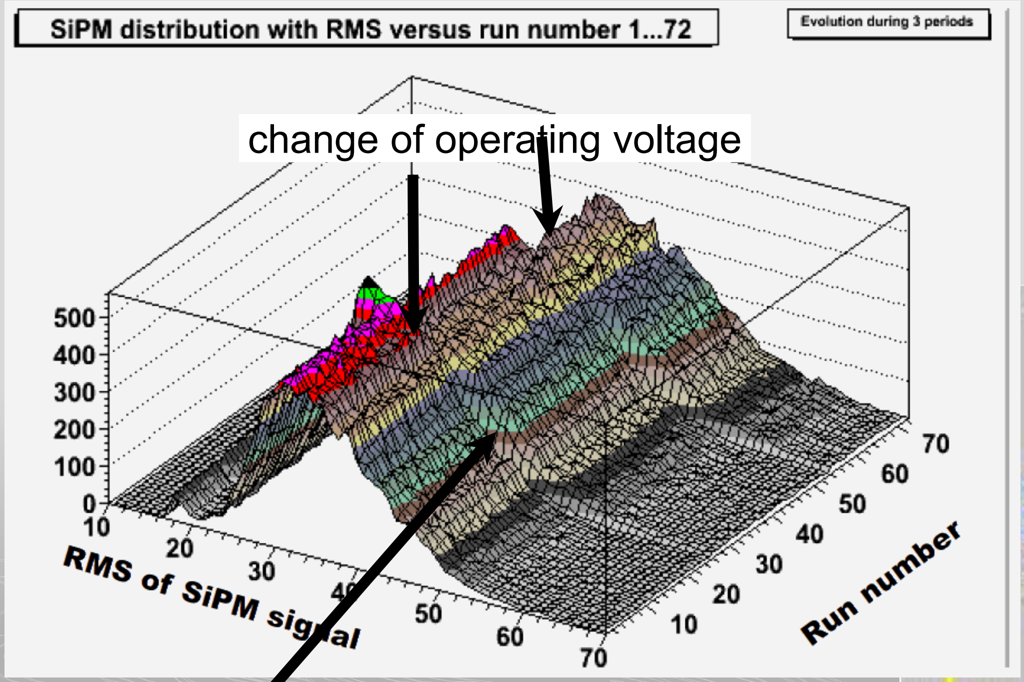
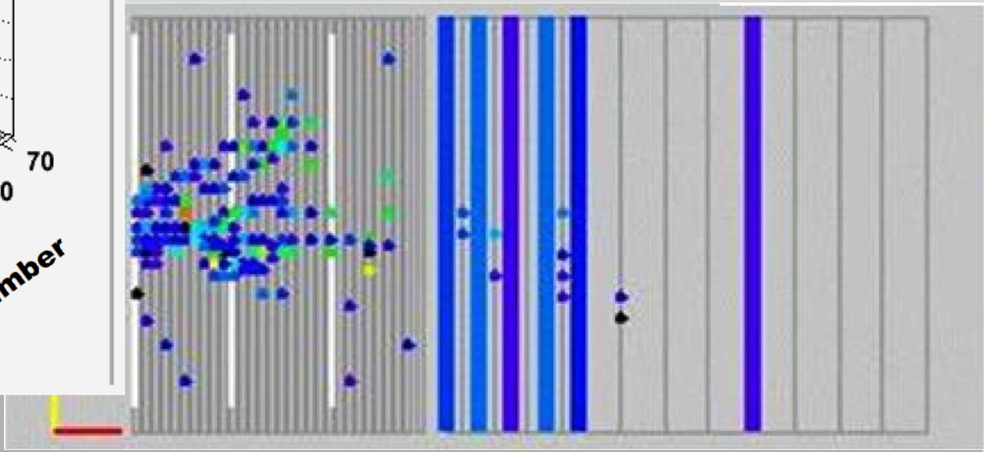
Monitoring of pedestal distribution: CERN – FNAL 2007-08



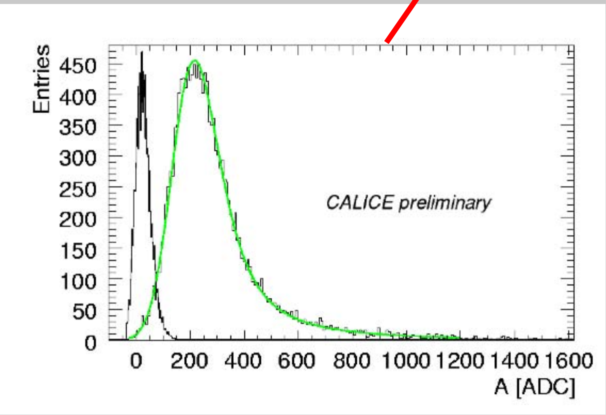
intercontinental move: CERN to FNAL

Noise occupancy 10^{-3}

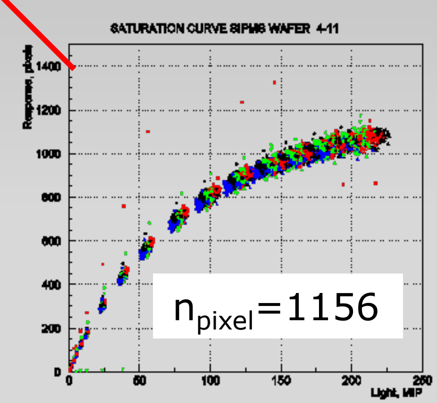


Calibration

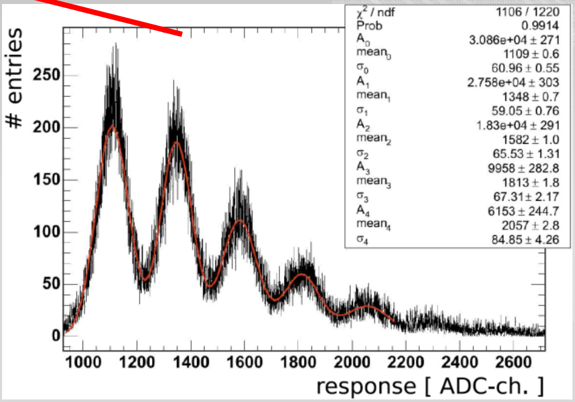
$E(MIP) = A / A_{MIP} * f\,(A/A_{pixel})$ A = signal in ADC counts



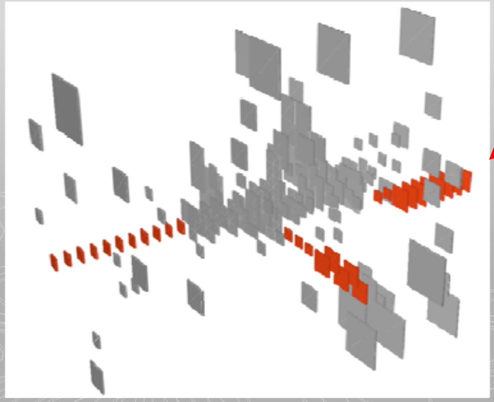
MIP calibration:
1.5 days in test beam



SiPM response function
From test bench

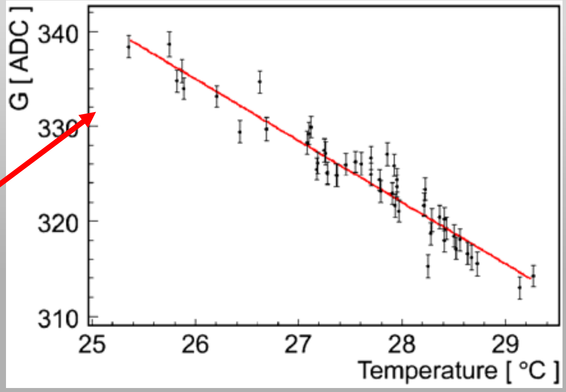


Gain auto-calibration:
Low intensity LED light
Single photo-electrons

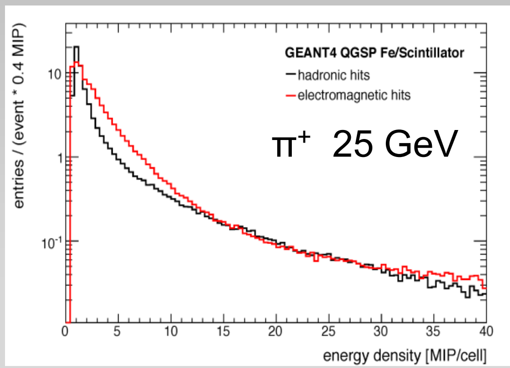


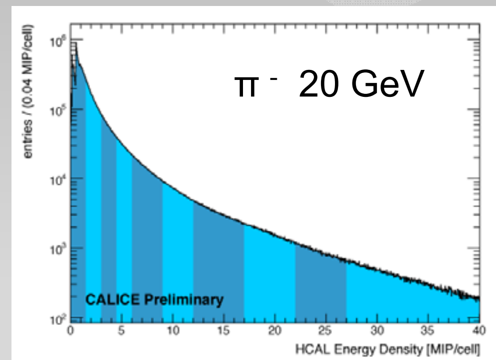
isolated tracks in
hadron showers

Temperature monitoring:
Correct MIP and gain
Future: compensate by
HV adjustment



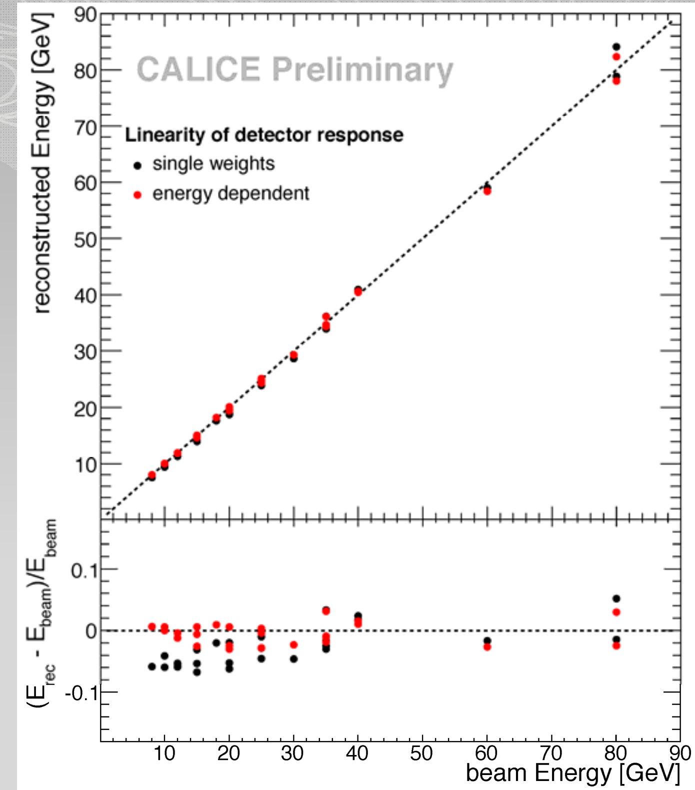
Linearity, resolution
E weighting



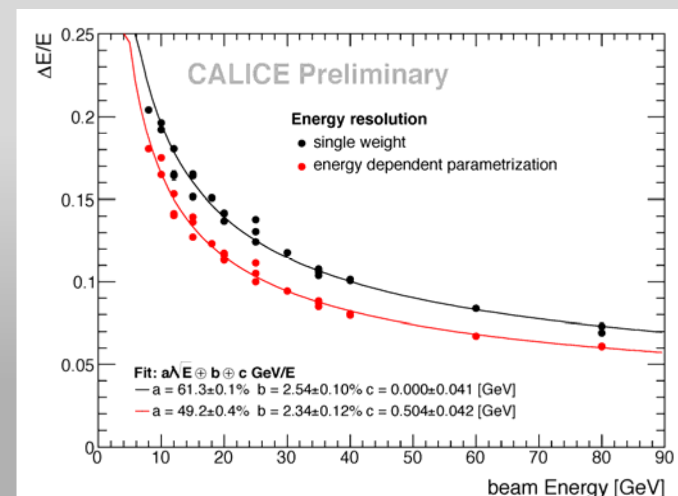


- GEANT 4 simulation of E density elmg & hadronic
- Elmg hit deposits > hadronic hits
- Slightly non-compensating: e/π~1.16
- Weighting: cells with higher *E* density get smaller weight

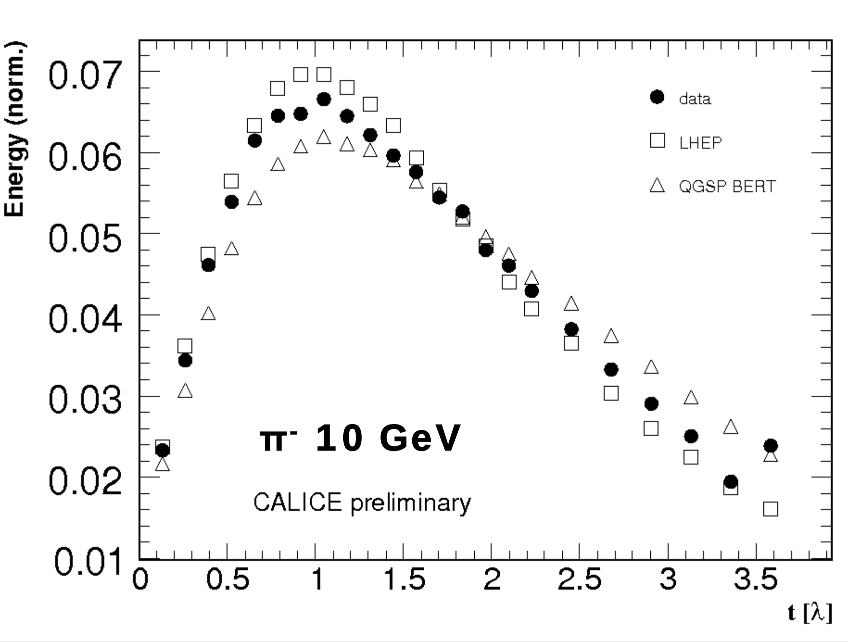
- *E* density (*E* in a cell) in HCAL
- Suitable weights ω_i minimize the sum $(\sum_i^{cells} E_i \, \omega_i - E_{beam})^2$ over all events
- Advantage of highly granular calorimeters
- Weighting improves *E* linearity and resolution

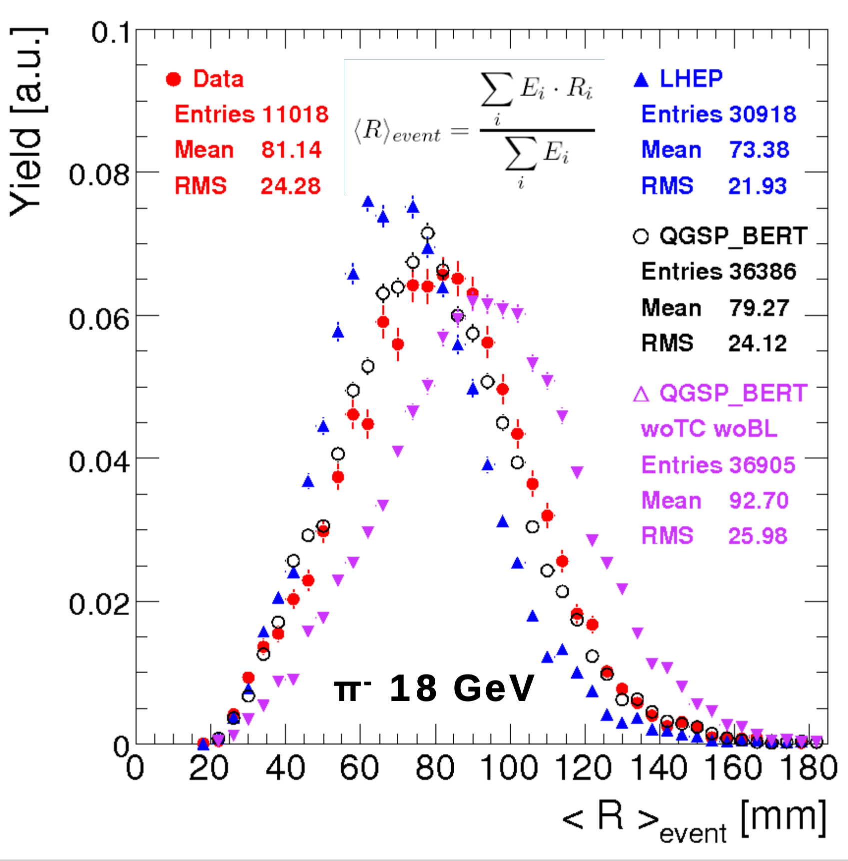


ECAL+HCAL+TCMT



Shower shape – data and GEANT4





Longitudinal profile

- 2006 data – only 23 HCAL layers avail.
- Profile with respect to HCAL front face
- Last layer, higher noise, low efficiency
- LHEP – faster rise and drop
- QGSP BERT opposite behaviour

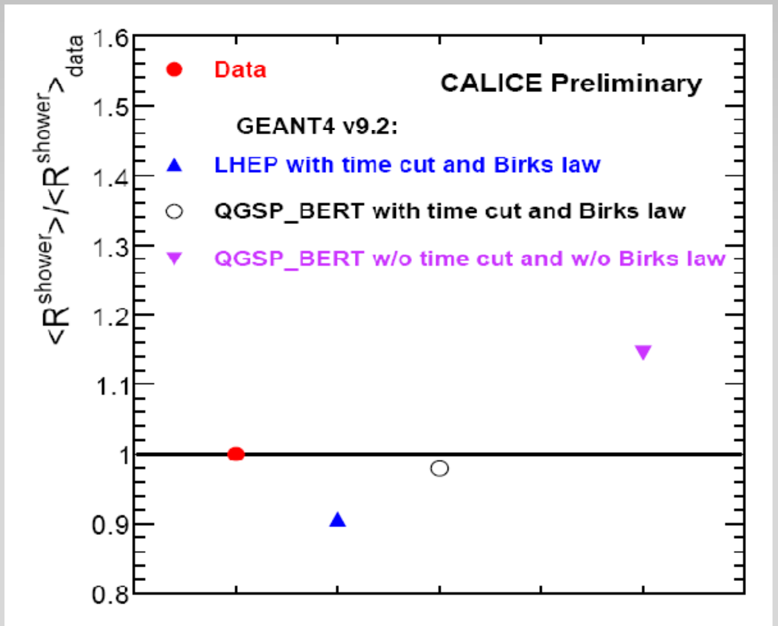
Mean event radius – *E* weighted

- Best reproduced by QGSP BERT
- Sensitive to neutrons in the cascade

Test beam data – test ground for tuning hadronization models in GEANT4

Transversal shower properties

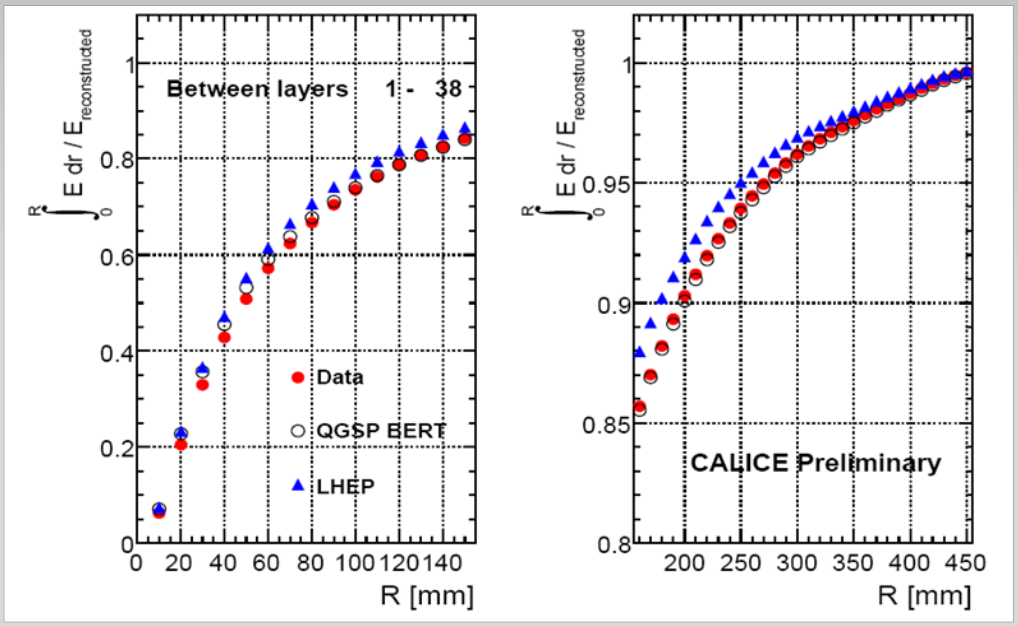
Mean shower radius



Mean shower radius data / MC

- Sensitive to differences in shower development in MC
- Sensitive to corrections for detector effects (Birks' law, signal shaping in readout)

Lateral shower containment

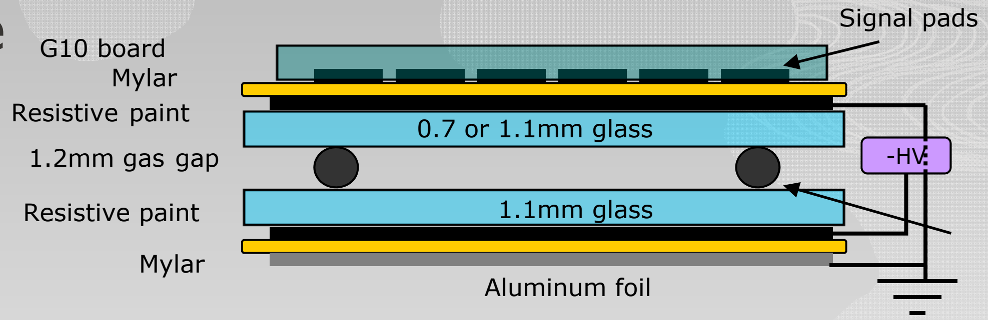


Integrated lateral energy fraction, 18 GeV π^-

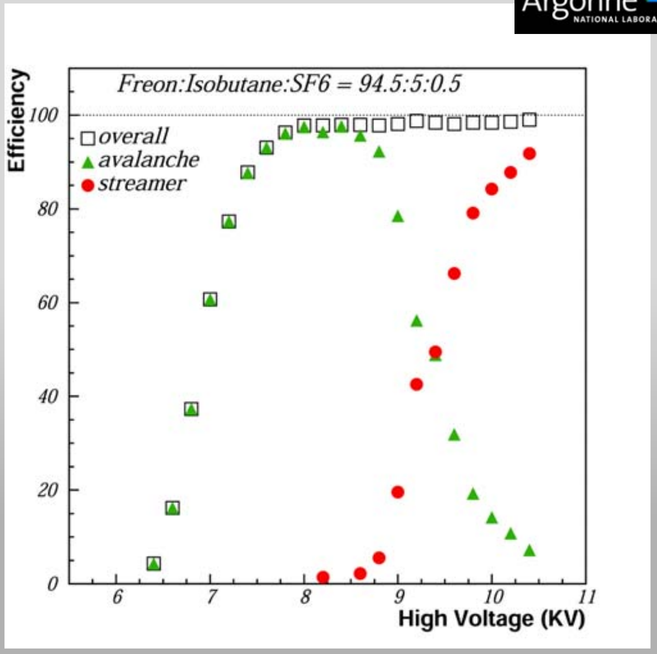
- Core and tails: reasonably well reproduced by QGSP-BERT
- Next steps:
- Lateral profiles, profiles with respect to the start of shower
- Other specific beam & detector effects

Digital calorimeter with RPCs

- Active elements – Resistive Plate Chambers in steel absorber (same as for AHCAL)
- Readout
  - Longitudinally – every layer individually
  - Laterally 1x1 cm^2 pads
- Resolution
  - 1bit/pad – digital HCAL (ANL, Boston Univ., FNAL, Univ. of Iowa, Univ. of Texas at Arlington
  - 2-3 bits/pad semi-digital HCAL (IPNL, IHEP, LLR, CIEMAT, Tsinguha, LAL)



1. Detailed studies of RPCs with analog readout



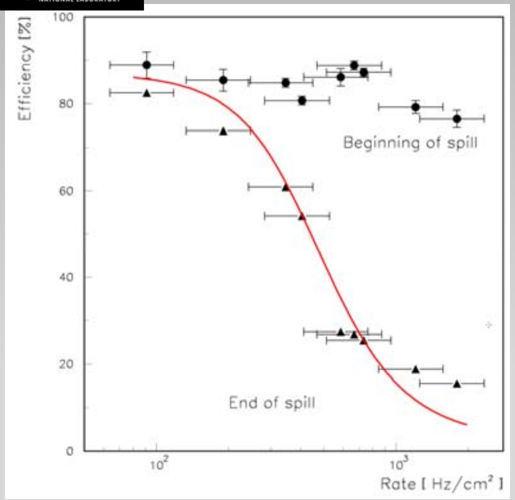
G. Drake et al., Nucl. Inst. Meth **A578** (2007) 88
I. Laktineh, J. Phys. Conf. Series **160** (2009) 012030

Tests with Cosmic Rays and Beams

- Vertical slice test of entire readout chain
  - 20 x 20 cm^2 RPCs (based on two different designs)
  - Up to 10 chambers → 2560 readout channels
  - Complete readout chain as for larger system
- Detailed tests with cosmic rays at Argonne
- Fermilab test beam (muons from 120 GeV protons, 1 – 16 GeV pions/positrons)

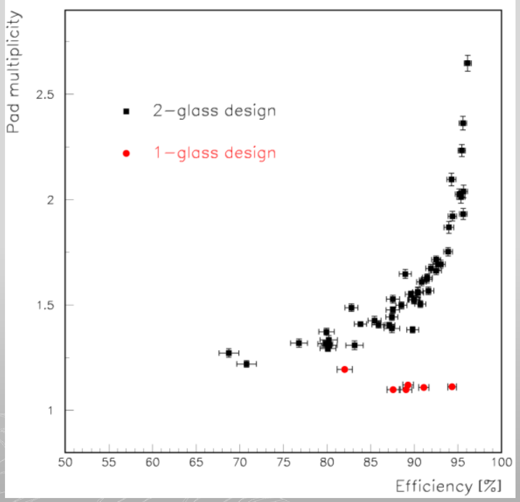
- Validation of the semi-digital electronics readout system in beam conditions
  - 1-gap, 4-gap 33 x 8 cm^2 GRPCs
  - 4 - 5 chambers, different high-resistive coating of HV plates
  - 8-layer PCB, 800 μ with HR1 ASICs
  - Edge and inter-pad effects studied with EUDET telescope
- Test beam @ PS-CERN (1 – 6 GeV pions)
- Study of the first phase of the hadron showers (with absorbers)

RPC efficiency, multiplicity, …



- Analysis of Rate Dependence
  - Measurement of the efficiency as function of time within a spill for different beam intensities
  - Explained by analytical model: drop of surface charge with the current in the chamber

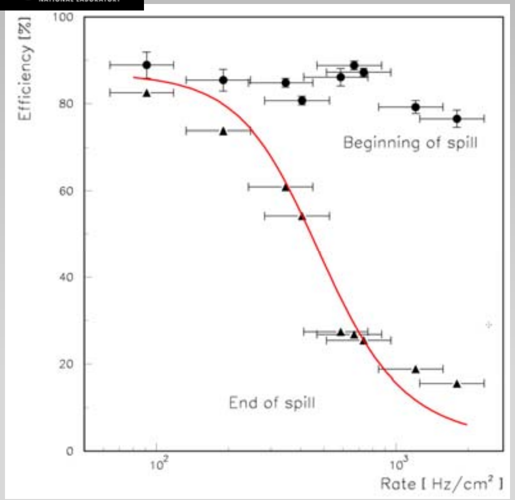
  [2009 JINST **4** P06003]

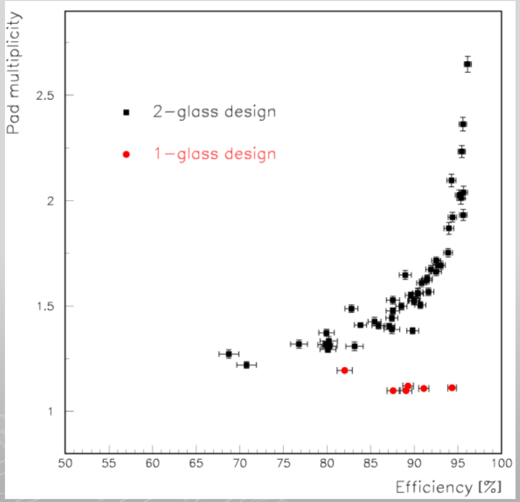


- Pad multiplicity
  - Measured for nine chamber geometries
  - Chamber with one gap shows constant pad multiplicity at 1.1

  [2008 JINST **3** P05001]

RPC efficiency, multiplicity, …





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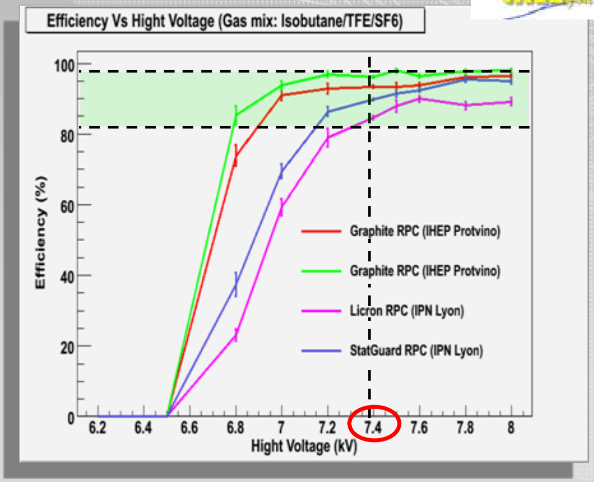
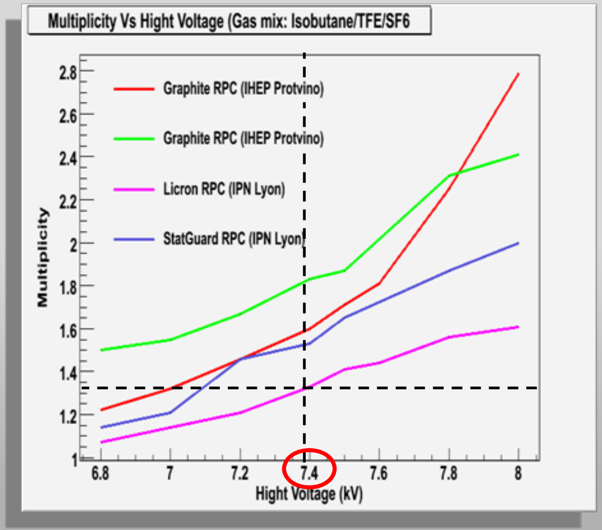
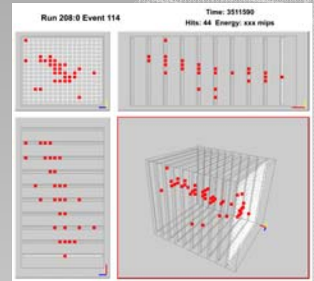
  [2009 JINST **4** P06003]
- Pad multiplicity
  - High resistive coatings (like Licron, Statguard) lead to reduced multiplicity with respect to the usually used graphite.
  - This observation agrees with similar measurement done in ANL [NIM **A578** (2007) 88]



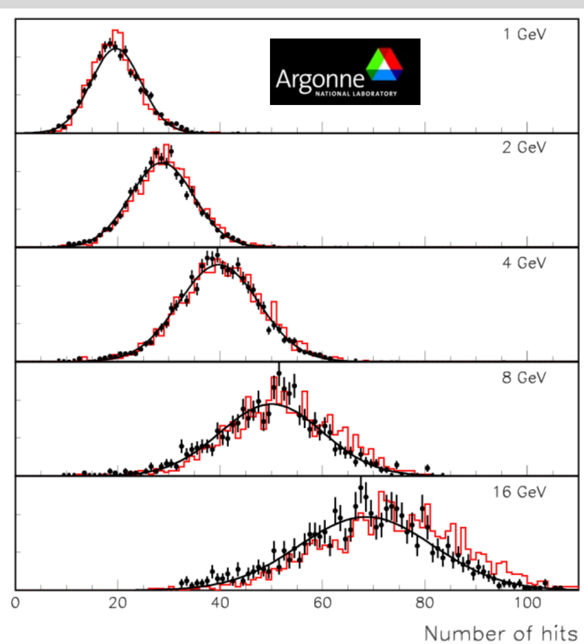


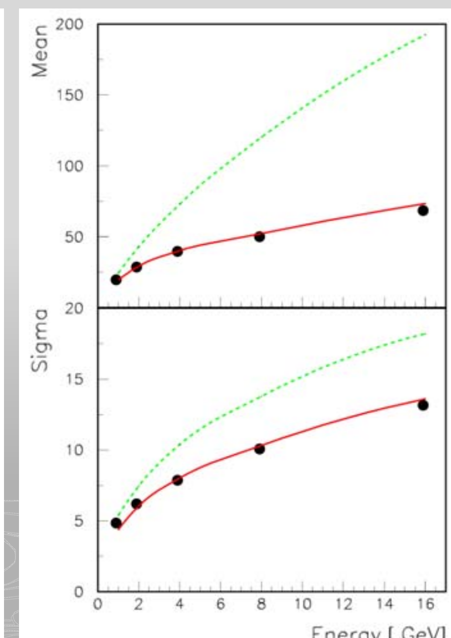
Results from the test beam



- Measurement of the response to e^+ showers
- Comparison to MC (histogram in red 6 stacks)
- Infinite stack – ideal energy response

B.Bilki et al., 2009 JINST **4** P04006





$1m^3$ prototype

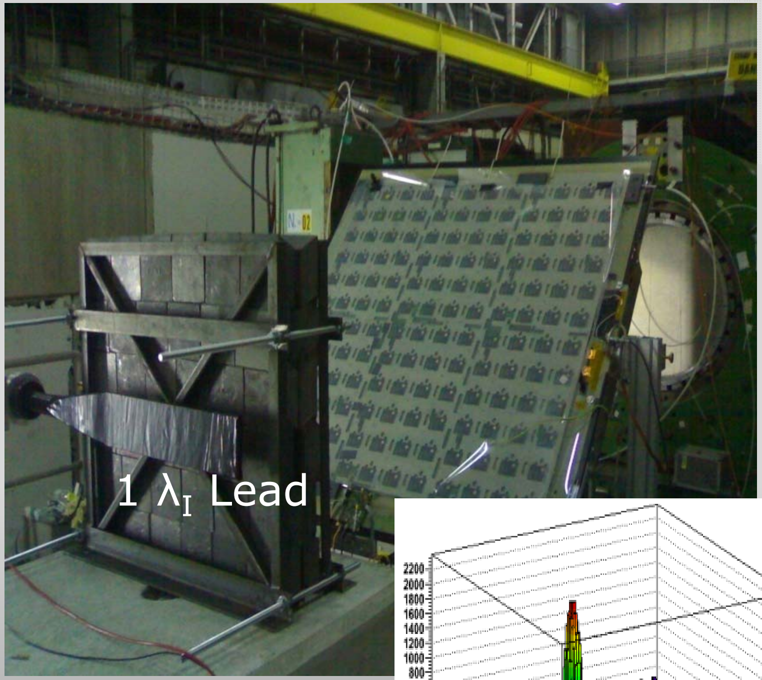
- 38 layers interleaved with ~20 mm steel plates
- Each layer 96 x 96 cm^2 → 9210 readout channels
- Each layer contains 3 RPCs with an area of 32 x 96 cm^2
- Entire calorimeter → 305,208 readout channels
- Tests in FNAL 2010

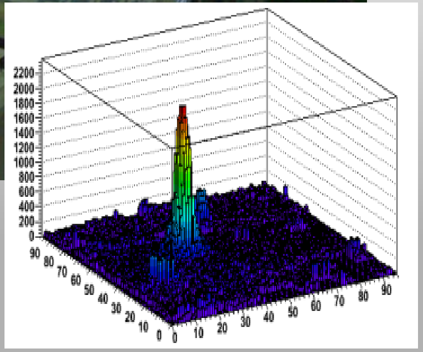
1 m³ technological prototype

Semidigital RPCs

- 40 layers of 1m² ,20 mm s. s. absorber, 6mm GRPC
- Detectors will be built by IPNL Lyon and IHEP Protvino
- New gas distribution system
- ASIC - HARDROC (Ω LAL)
  - 3 thresholds, masks, optimized power pulsing
  - controlled in a fully automatic way using a robotic system used for CMS trackers

- Thin and large PCB – 1m²
- RPCs with reduced dead zones – ceramics μ-balls instead of fishing line
- Main tests in CERN 2010
- July 2009 , test beam@PS-CERN of the fully equipped plane





Shower profile after 1 λ

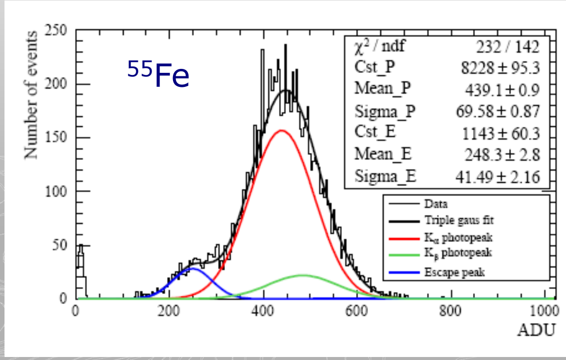
Other gaseous detectors for DHCAL

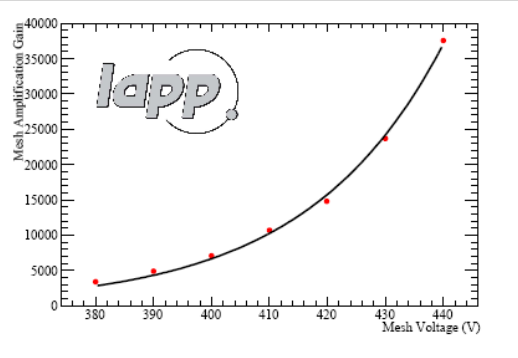
MICROMEGAS:

LAPP (Annecy-le-Vieux, France)

Digital readout prototypes:

- Embedded FE electronics
- Chips below the anode pad PCB
- Mesh laminated on the PCB
- Active Sensor Unit (ASU = PCB+ ASICs+Mesh)

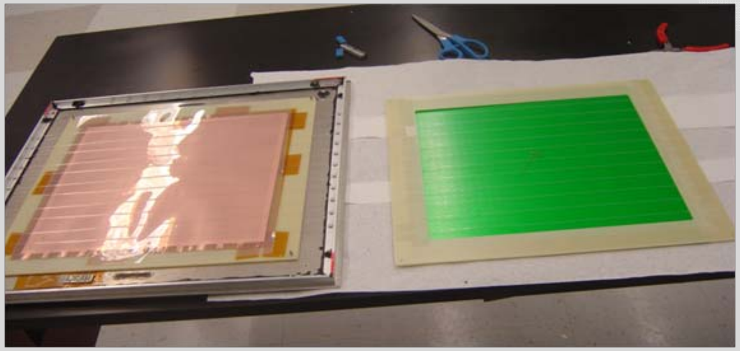




Gas Electron Multiplier

UTA (Texas, USA)

- Double GEM
- Gas mix: $Ar+CO_2$ (80%+20%)
- Gain ~ 10 000, HV < 500 V
- Robust (up to 10^{12} part/mm^2)



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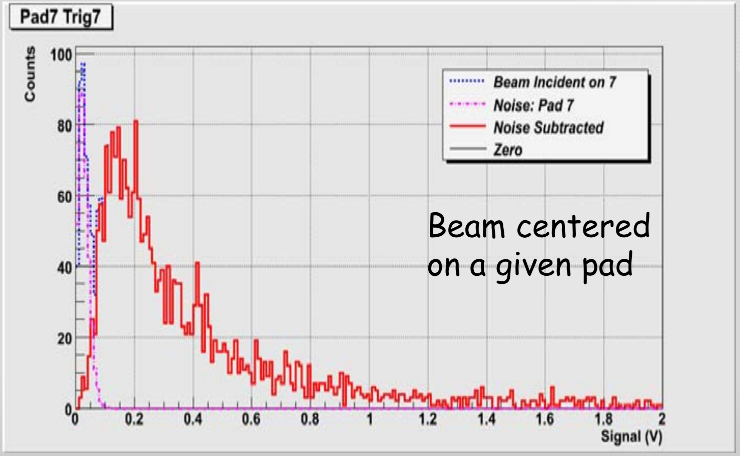
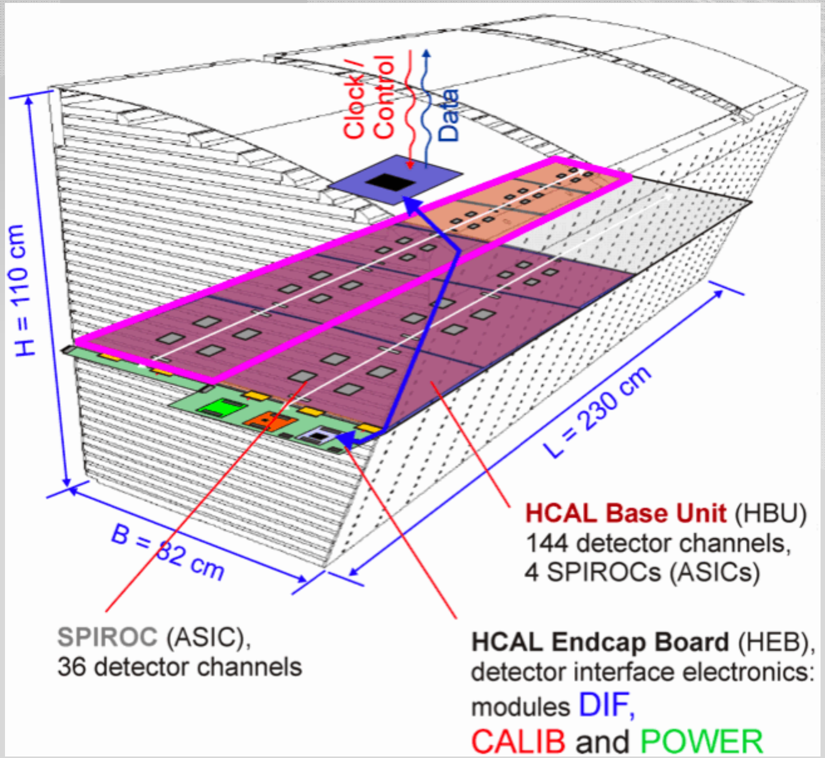


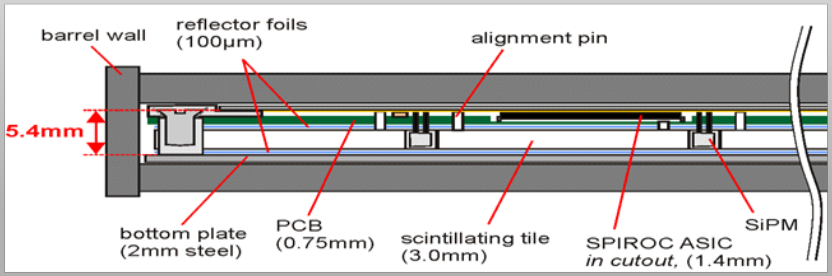
R&D strategy:

1. Small prototypes and their characterization
2. Construction and test of $1m^2$, $1m^3$ prototypes
3. Final design for DHCAL

Technical prototype of AHCAL

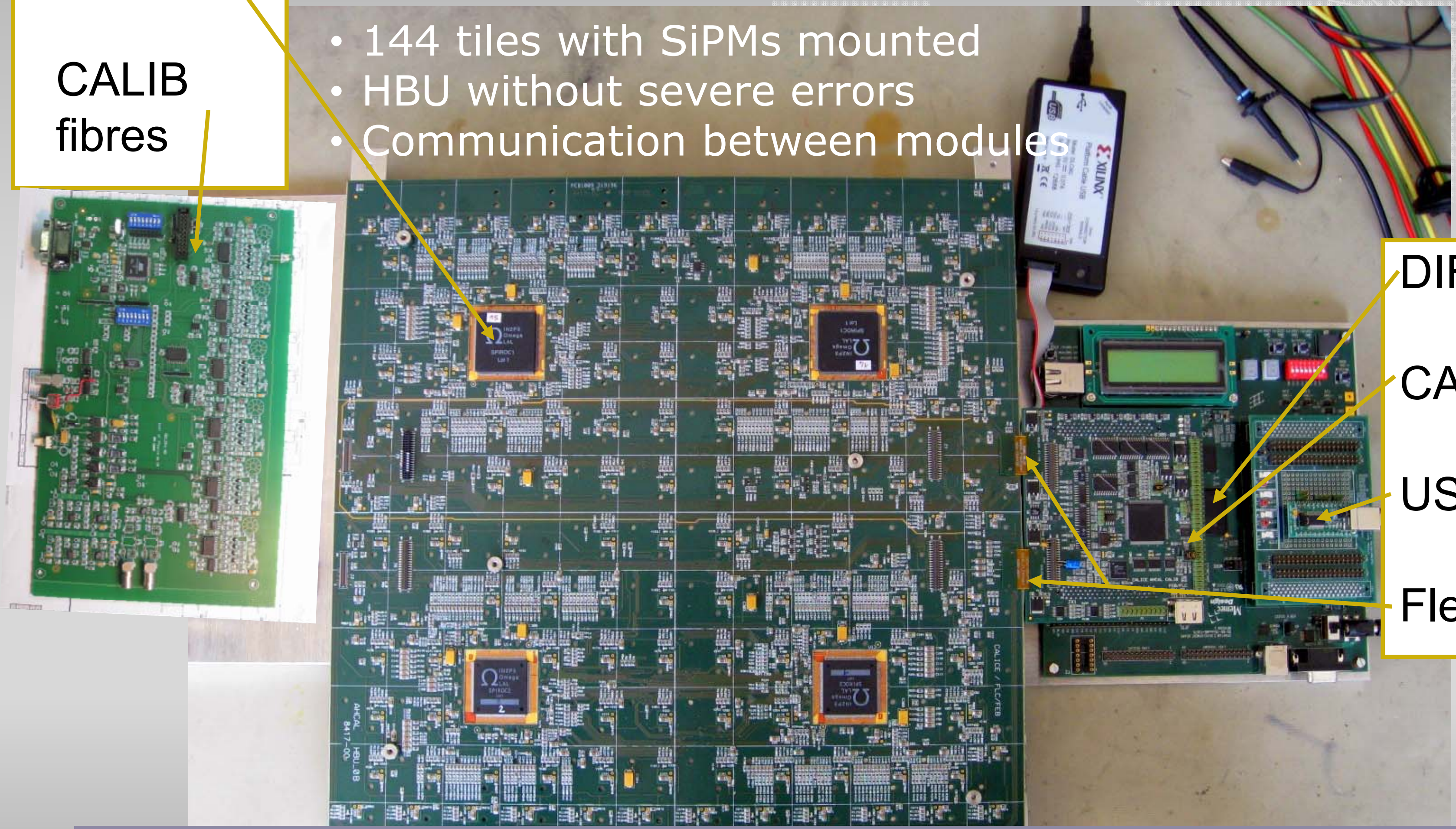
- Towards a scalable and compact detector - minimum dead space
- Embedded front end ASICS
  - Power pulsing: 40 μW / channel
  - Auto-trigger
  - Analogue pipeline
  - ADC and TDC integrated
  - Establish full readout and calibration chain
  - On-detector zero suppression requires on-line control of thresholds
- Time measurement
  - Tagging of delayed neutrons ➔ triple readout
  - Validation of simulation and exploitation for particle flow
- Larger acceptance with fine granularity
  - PFLOW studies with multi-particle events
  - Potential of an integrated test with tracking being under study
- Validation of shower models for a scintillator steel HCAL





Hcal Base Unit 0 status

- 144 tiles with SiPMs mounted
- HBU without severe errors
- Communication between modules



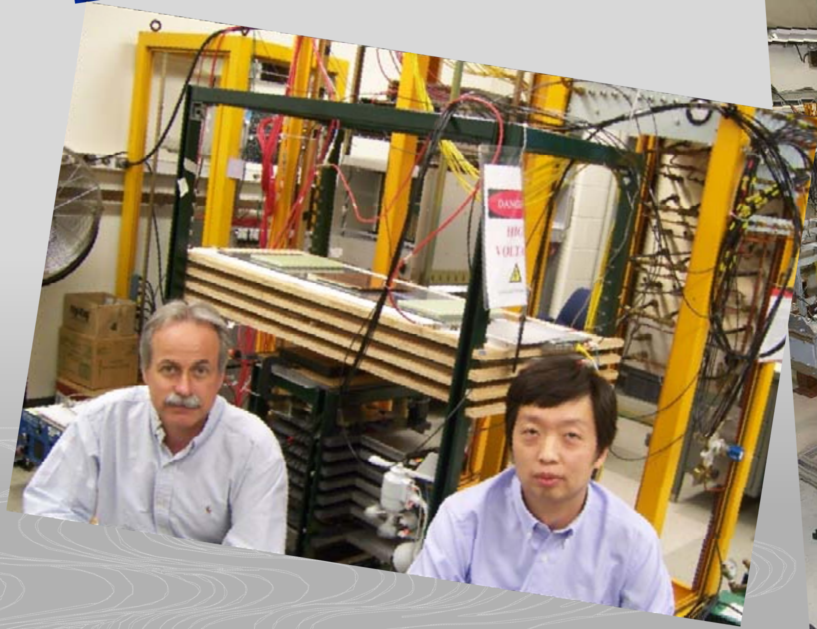
Next steps:
- Standalone tests, readout DIF → Labview
- Commissioning of calibration systems
- DESY test beam
- Switch to CALICE DAQ and use of POWER module

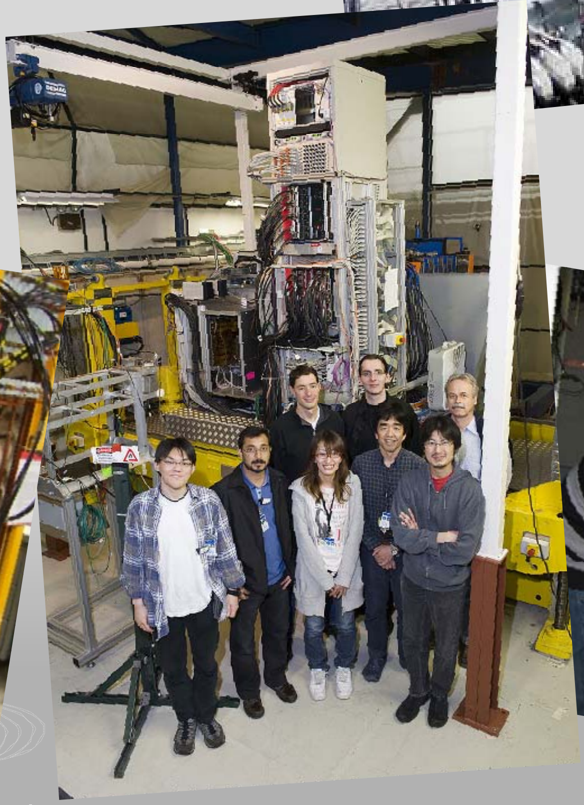
Conclusions

- AHCAL finished tests of 1m^3 physics prototype
  - The SiPM technology has proven as robust and stable
  - Calo granularity + shower substructure → laboratory for model developers of hadronic showers
  - Particle flow reconstruction with overlaid events
- DHCALs learned a lot from tests in beam of the first prototypes which provide excellent basis for construction of 1m^3 technological prototype – in progress
- AHCAL in a stage of design and construction of the technical prototype – scalable and compact
  - Minimum dead space, most of electronics integrated inside the detector volume
- HCAL Electronics
  - New generation of ASICs with ADC and TDC integrated
  - Auto-triggering, power pulsing, zero suppression
- Challenge: to establish full readout and calibration chain
- DHCALs use the infrastructure of the AHCAL in test beam and meet the similar challenges as the AHCAL with the technical prototype

CALICE at work

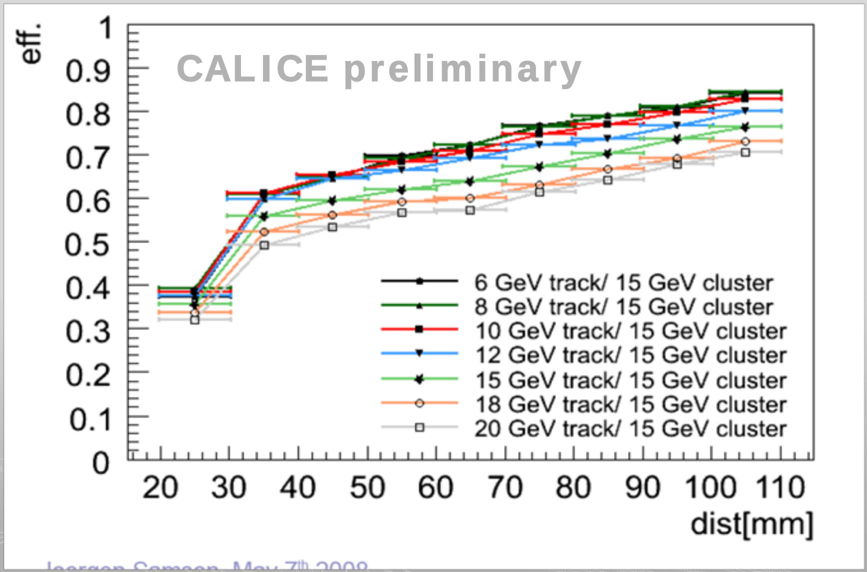
Calorimeter for ILC





BACKUP

Naïve particle flow



- Pions in the beam represent single events but with large spread over detector front face
- possible to select events with given distance and overlay offline two showers (at different energies)
- use "track-wise" clustering algorithm to reconstruct clusters, then
- assume one cluster belongs to a charged particle
- substitute energy with known momentum
- sum clusters to a Pflow reconstructed object
- quantify shower separation efficiency

$$\mathrm{eff} = \frac{\int_{-3\sigma}^{+3\sigma} E_{cluster}}{\int_{-\infty}^{+\infty} E^{1}_{calo}}$$

➔ increasing eff. at large shower separation

➔ larger eff. for low track energy

Observations for Models

8 GeV to 15 GeV

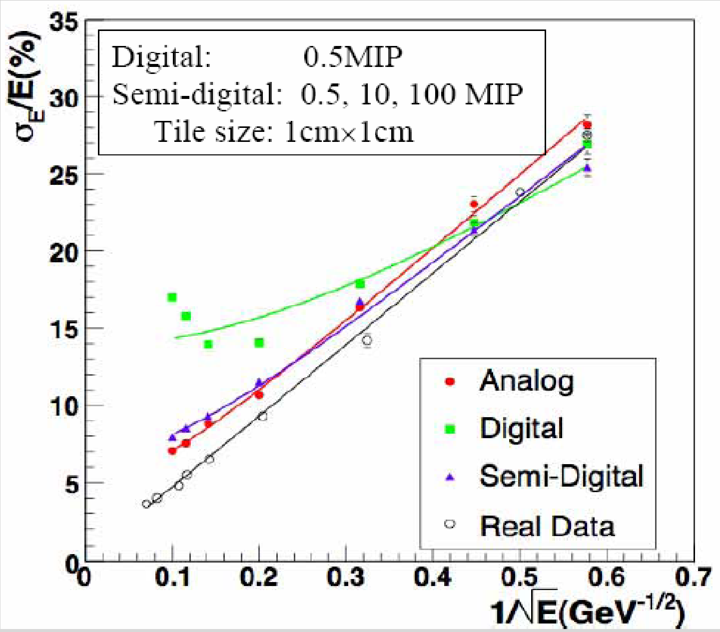
- LHEP
  - not enough visible energy
  - poor description of resolution
- FTF BIC
  - shows too much visible energy
  - gives too good resolution
- QGSP BERT
  - good visible energy description
  - perfect resolution
  - reasonable matching of profiles
  - by far best matching model

20 GeV to 80 GeV

- LHEP
  - best description of total energy
  - poor description of resolution
- FTF BIC
  - shows too much visible energy
  - resolution well described
- QGSP BERT
  - shows too much visible energy
  - resolution well described
  - still best matching model
- all
  - fail to describe shower maximum

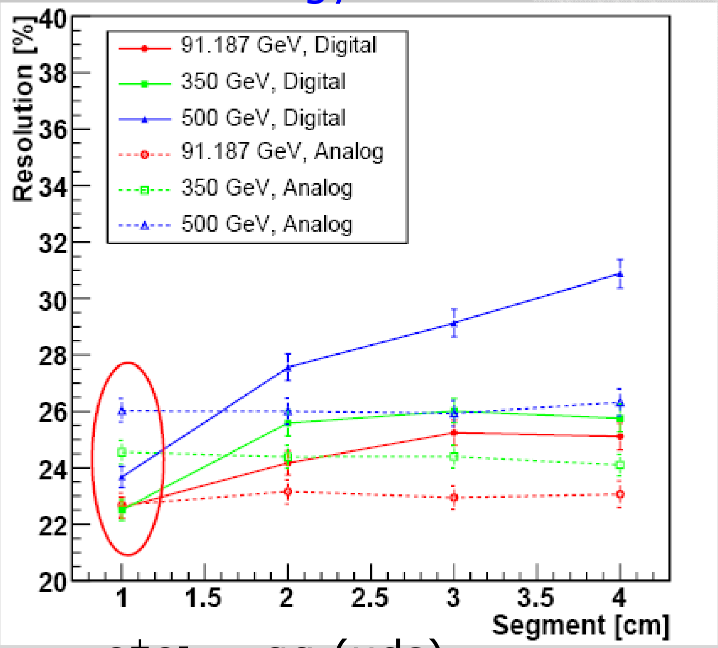
Digital or analog readout?

Hadron energy resolution



GLD HCAL study by KEK Group
(1×1 cm² scintillator tiles, Pb Abs)

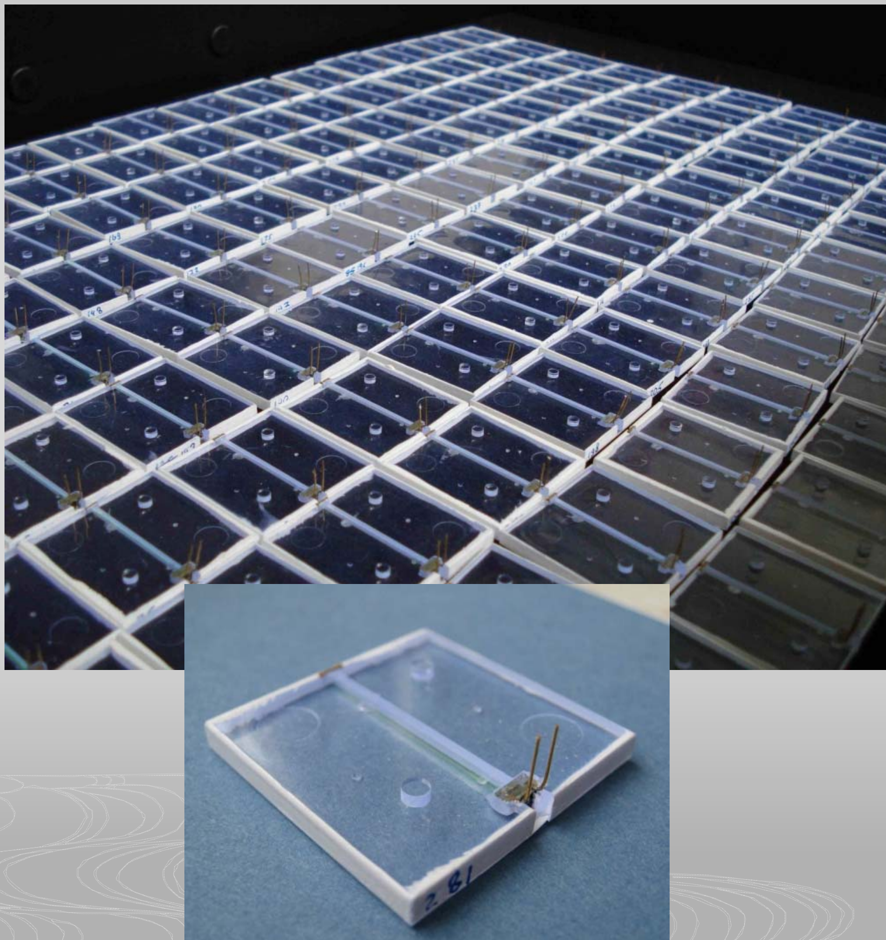
Jet energy resolution



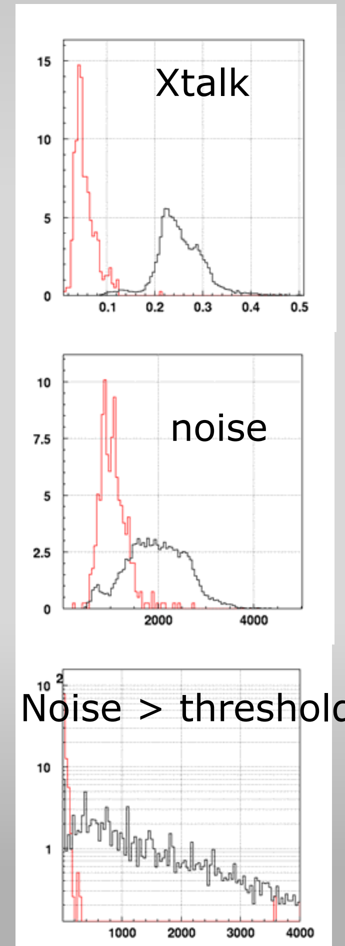
$e^+e^- \rightarrow qq$ (uds)
$\sqrt{s}$ = 91, 350, 500 GeV
Assuming Perfect PFA

New tiles and SiPMs

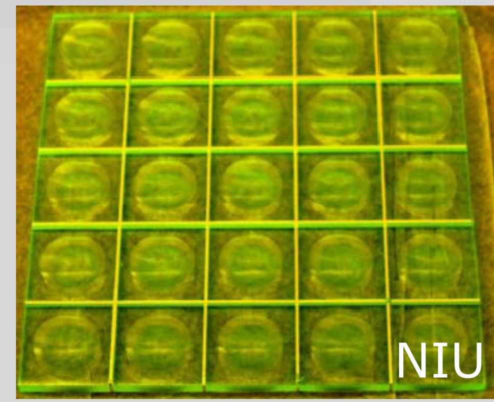
- Delivered by ITEP Moscow
- SiPMs (MRS-APDs) from CPTA



Improved properties



- Surface-mounted MPPCs
- Scintillator cells with dimple to compensate non-uniformity



Concave cell results in uniform response!