Current R&D Status of the CALICE DHCAL

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SiD Workshop
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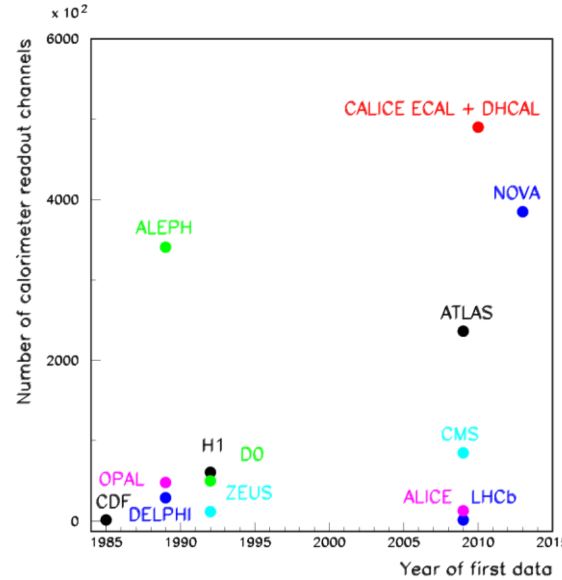
SLAC National Accelerator Laboratory

The DHCAL Project



RPC – based imaging calorimeter

DHCAL = First large scale calorimeter prototype with

Embedded front-end electronics
Digital (= 1 – bit) readout
Pad readout of RPCs (RPCs usually read out with strips)

DHCAL = World record channel count for calorimetry

Argonne National Laboratory
Boston University
Fermi National Accelerator Laboratory
IHEP Beijing
Illinois Institute of Technology
University of Iowa
McGill University
Northwestern University
University of Texas at Arlington

DCHAL Collaboration	Heads
Engineers/Technicians	22
Students/Postdocs	9
Physicists	10
Total	**41**

…and integral part of

CALICE
Calorimeter for ILC

1 m^3 – Digital Hadron Calorimeter Physics Prototype

Description

Readout of 1 x 1 cm^2 pads with one threshold (1-bit) → **Digital Calorimeter**
Layers inserted into the existing CALICE Analog (scintillator) HCAL and TCMT structures
38 layers in DHCAL and 14 in tail catcher (TCMT), each ~ 1 x 1 m^2
Each layer with 3 RPCs, each 32 x 96 cm^2
~480,000 readout channels

Purpose

Validate DHCAL concept
Gain experience running large RPC systems
Measure hadronic showers in great detail
Validate hadronic shower models (Geant4)

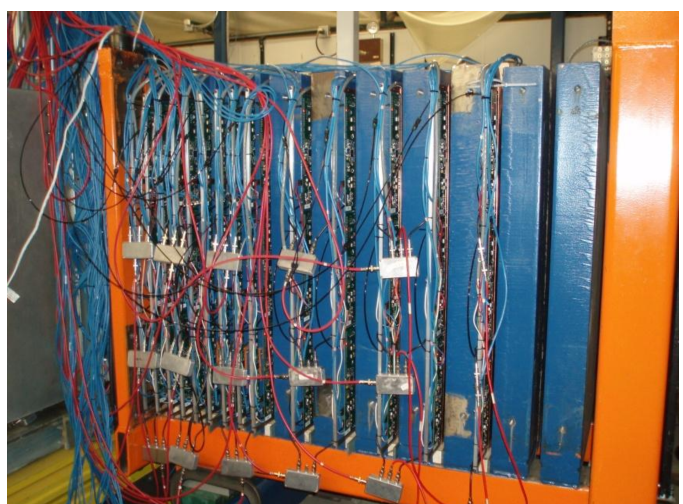
Status

Started construction in 2008
Completed in 2010
Several test beam campaigns at Fermilab

The DHCAL in the Test Beam

	Date	DHCAL layers	RPC_TCMT layers	SC_TCMT layers	Total RPC layers	Total layers	Readout channels
Run I	10/14/2010 – 11/3/2010	38	0	16	38	54	350,208+320
Run II	1/7/2011 – 1/10/2011	38	0	8	38	46	350,208+160
	1/11/2011 – 1/20/2011	38	4	8	42	50	387,072+160
	1/21/2011 – 2/4/2011	38	9	6	47	53	433,152+120
	2/5/2011 – 2/7/2011	38	13	0	51	51	470,016+0
Run III	4/6/2011 – 5/11/2011	38	14	0	52	52	479,232+0
Run IV	5/26/2011 – 6/28/2011	38	14	0	52	52	479,232+0
Run V	11/2/2011 – 12/6/2011	50	0	0	50	50	460800

~ 480K readout channels
~ 35M events



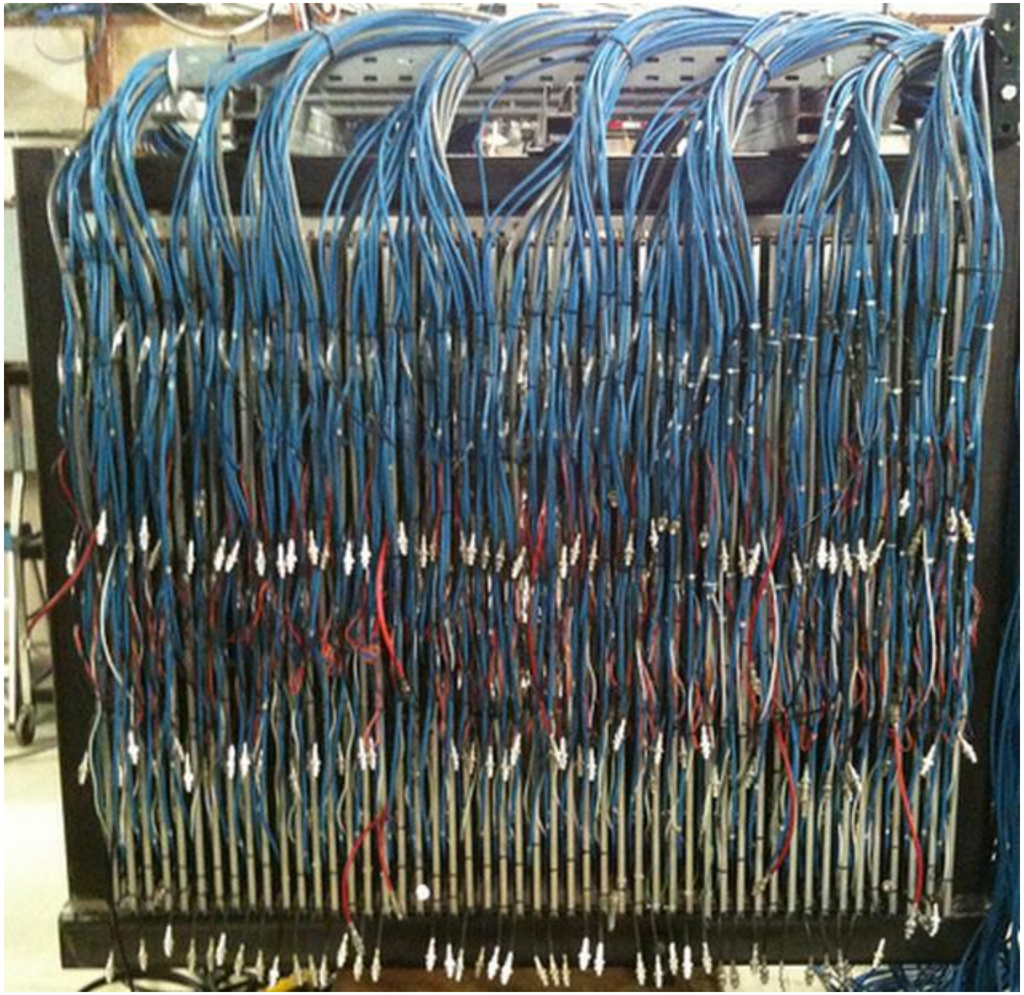
The Latest Test Beam Campaign

November 2, 2011 – December 6 2011

50 layers, no absorber

→ **13 X_0**
→ **1.3 λ_I**

460800 readout channels



Well prepared for the tertiary beam: 0.2 – 2 GeV/c

→ The tertiary beamline did not work
→ Took a lot of positron data

General DHCAL Analysis Strategy

Noise measurement

- Determine noise rate (correlated and not-correlated)
- Identify (and possibly mask) noisy channels
- Provide random trigger events for overlay with MC events (if necessary)

Measurements with muons

- Geometrically align layers in x and y
- Determine efficiency and multiplicity in ‘clean’ areas
- Simulate response with GEANT4 + RPCSIM (requires tuning 3-6 parameters)
- Determine efficiency and multiplicity over the whole 1 x 1 m^2
- Compare to simulation of tuned MC
- Perform additional measurements, such as scan over pads, etc…

Measurement with positrons

- Determine response
- Compare to MC and tune 4^{th} (d_{cut}) parameter of RPCSIM
- Perform additional studies, e.g. software compensation…

Measurement with pions

- Determine response
- Compare to MC (no more tuning) with different hadronic shower models
- Perform additional studies, e.g. software compensation, leakage correction…

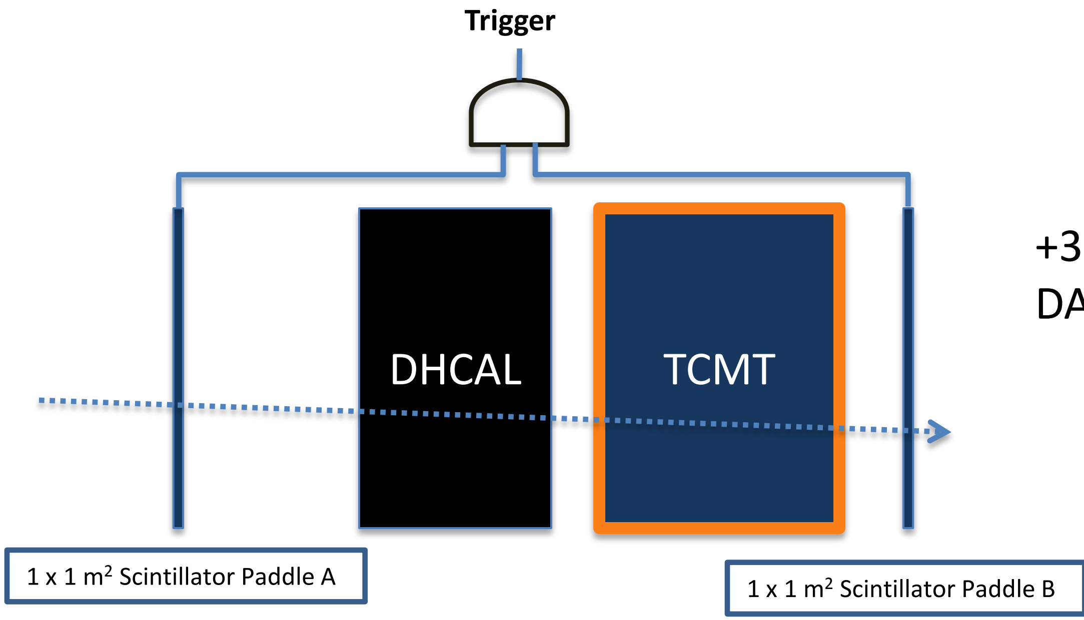
Noise Measurement

7 event categories in noise (self triggered) runs (in/out of spill):

1. Low multiplicity random noise
2. High multiplicity random noise
3. Cosmic rays & beam muons
4. Ground connector related noise
5. Board noise
6. Ground connector & board noise
7. Beam events

- Number of 'dead' asics is very small
- RPC's are in good shape after several beam tests
  - Average noise level is stable
  - Absolute noise level fluctuates with temperature
- Noise contribution to triggered beam data is extremely small (~0.1 hit/event for entire DHCAL+TCMT – 480K channels)
  - This noise level corresponds to ~6MeV/event
  - RPCs contribute negligible noise hits to beam data
  - Correlated noise level needs more study
- Noise 'hot spots' are due to unclean surface
  - Not a problem if temperature is low

Beam and Trigger for Muon events



+32 GeV/c secondary beam + 3m Fe
DAQ rate typically 500 - 1000/spill

Run	# of muon events
October 2010	1.4 Million
January 2011	1.6 Million
April 2011	2.5 Million
June 2011	2.2 Million
November 2011	1 Million
TOTAL	**~ 9 Million**

Alignment

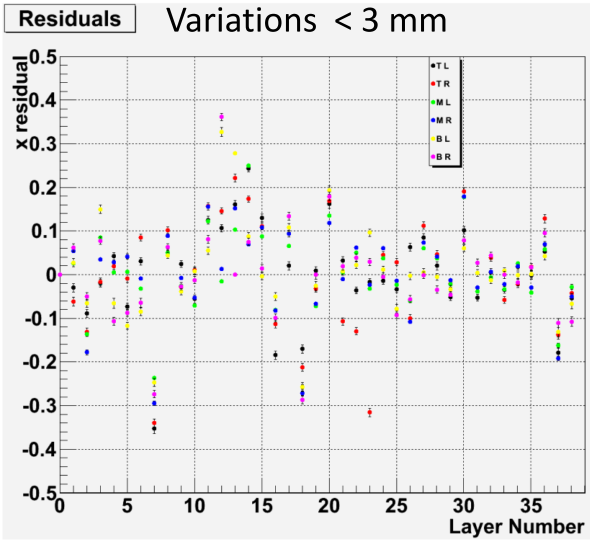
For each readout board i plot residual in x/y

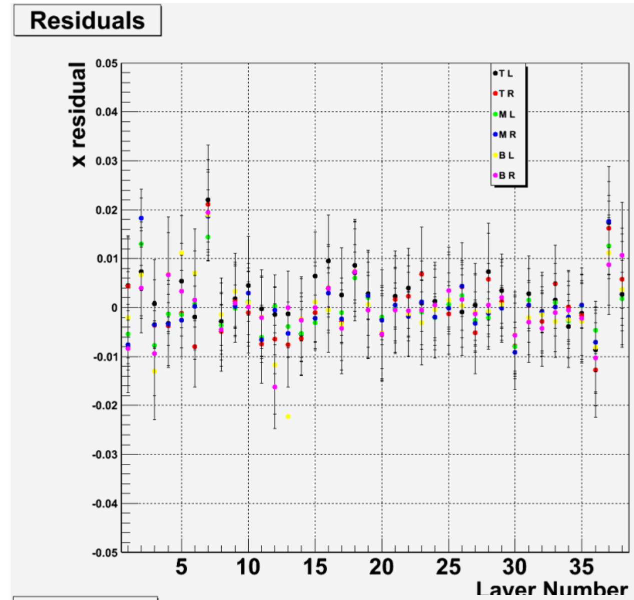
$R^i_x = x^i_{cluster} - x^i_{track}$

$R^i_y = y^i_{cluster} - y^i_{track}$

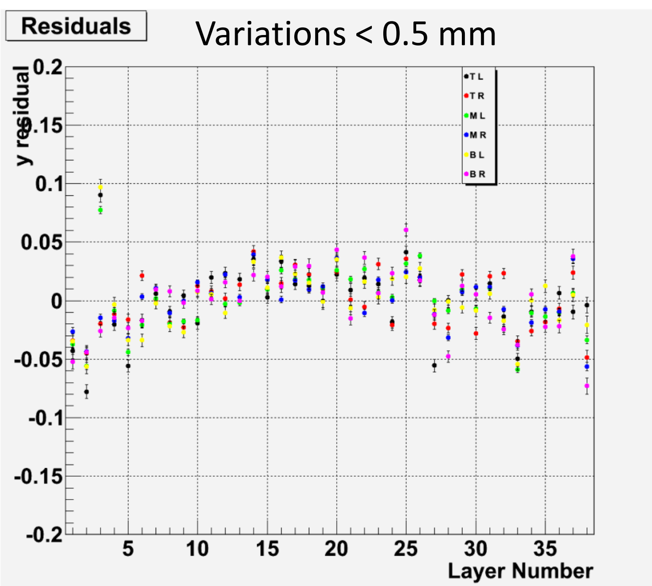
Dimensions in [cm]

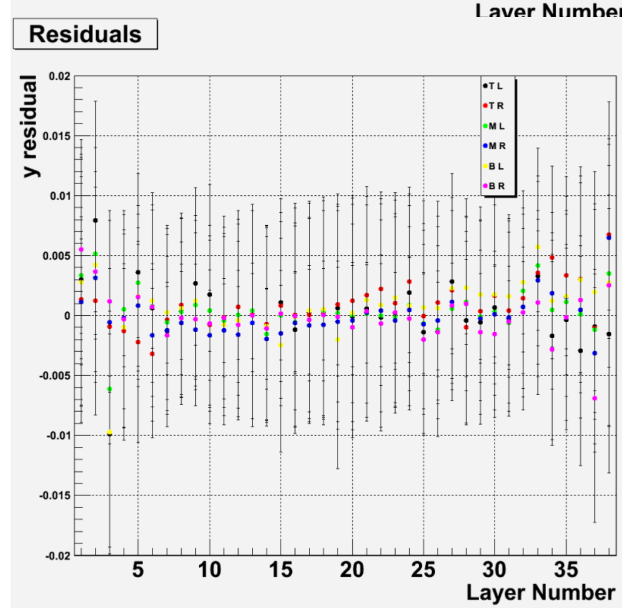
Variations < 3 mm





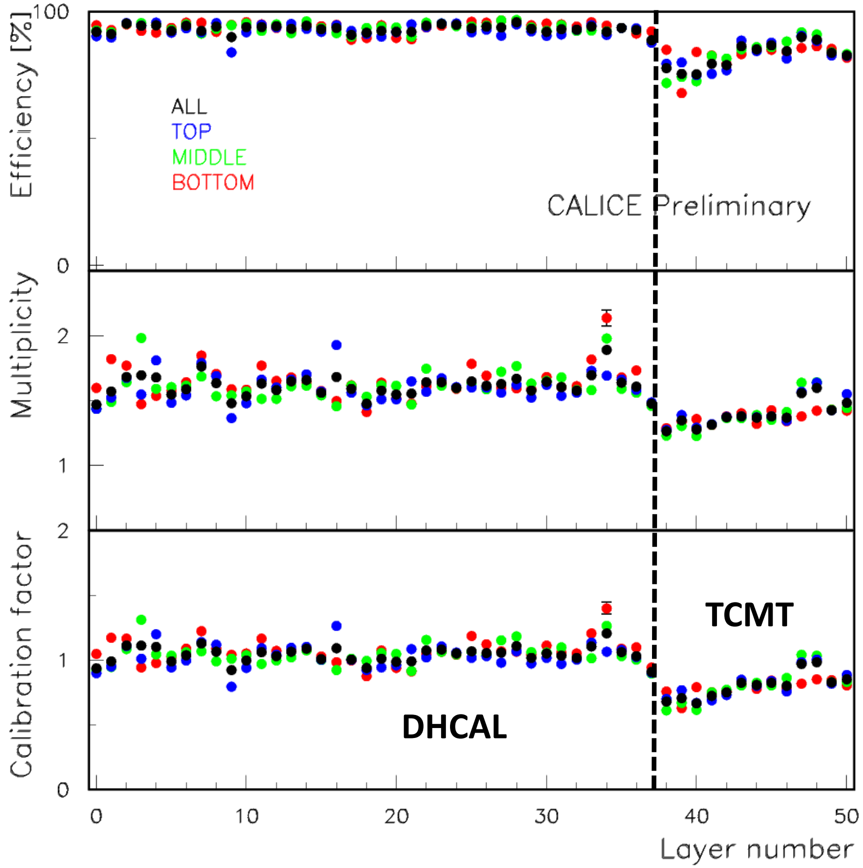
Variations < 0.5 mm

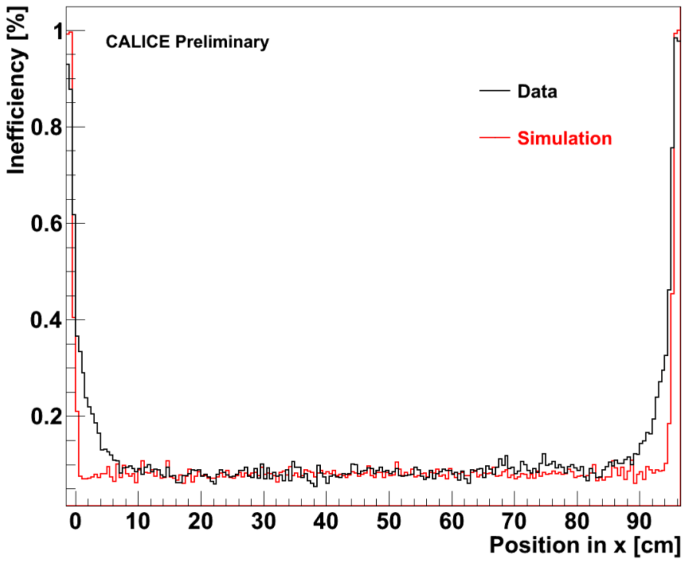


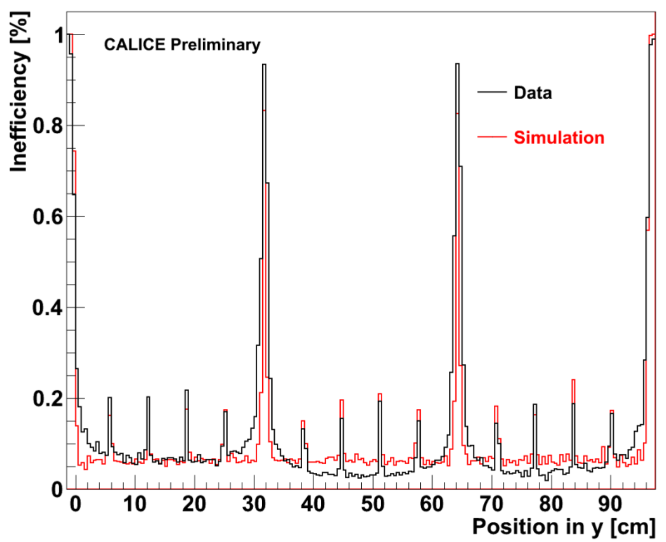


Efficiencies, multiplicities

Tail catcher is cooler
→ lower efficiency, multiplicity







Calibration factors = mean of multiplicity distribution/(average over detector) = $\varepsilon \cdot \mu / \varepsilon_0 \mu_0$

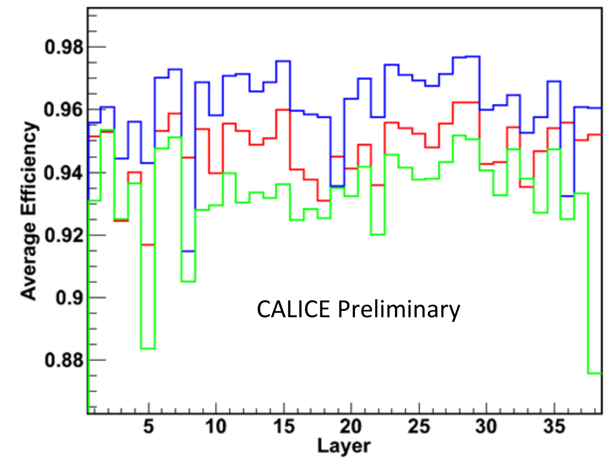
Track segment analysis

Method

Use clusters (= *source clusters*) in 2 layers to study layer in between (=*target cluster*)
e.g. use L_{i-1} and L_{i+1} to look at L_i

Source clusters

Required to have at most 3 hits
Lateral distance between source clusters at most 3 cm
No additional hits within 7 cm of source clusters

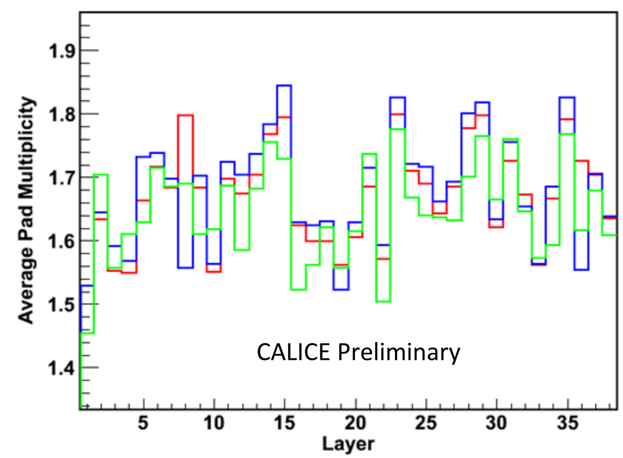


Target cluster

Searched for within radius of 2 cm from line between source clusters

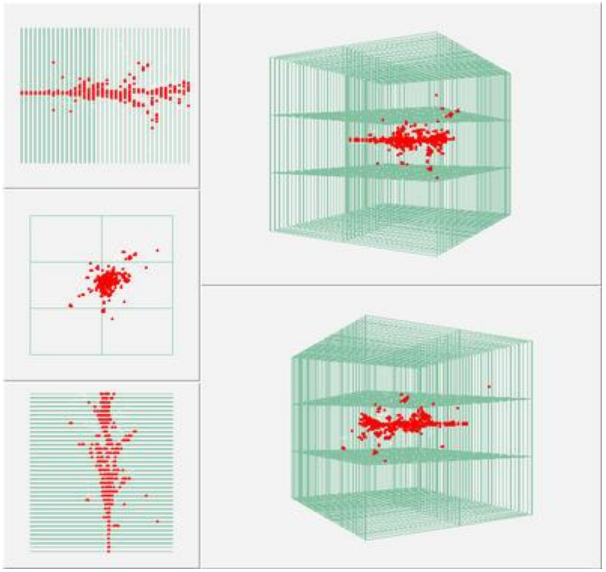
Comparison of

Muon runs analyzed with tracks
Muon runs analyzed with track segments
Pion run analyzed with track segments



Clear correlation between different methods
…but systematic differences

Pion-Positron Preliminary Analysis



First look at data

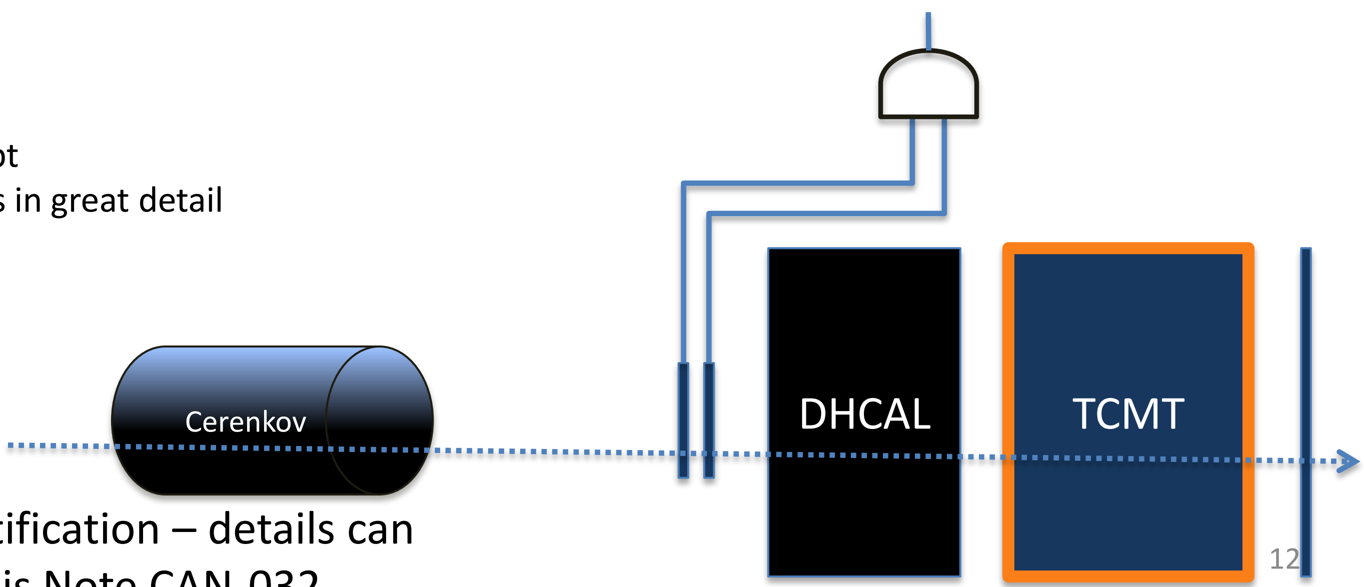
To provide possible feedback to data taking and setup
Speed is important!

Develop analysis tools

Final analysis will require large effort
This is the beginning…

Ultimate goals

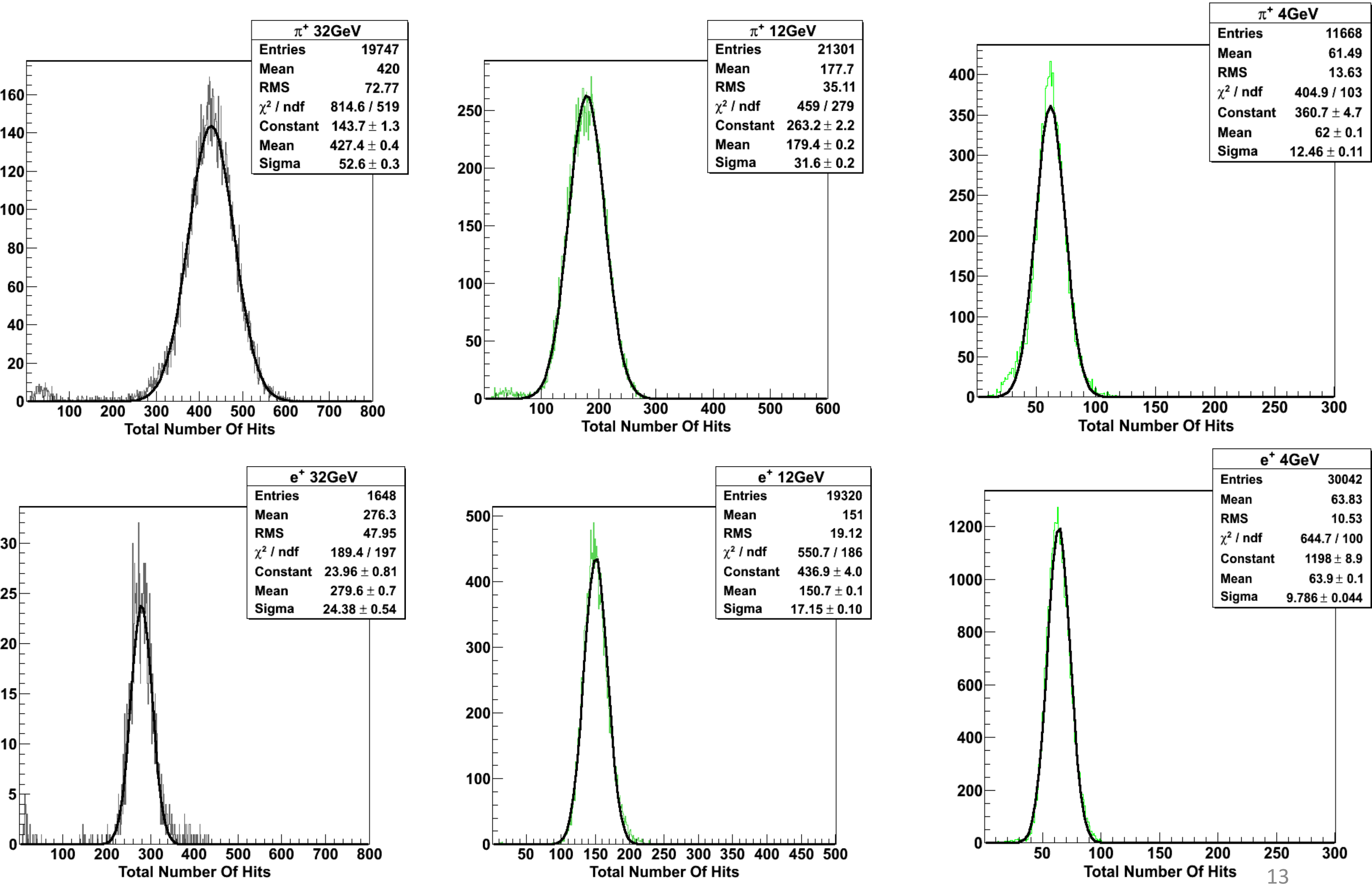
Validate the DHCAL concept
Measure hadronic showers in great detail



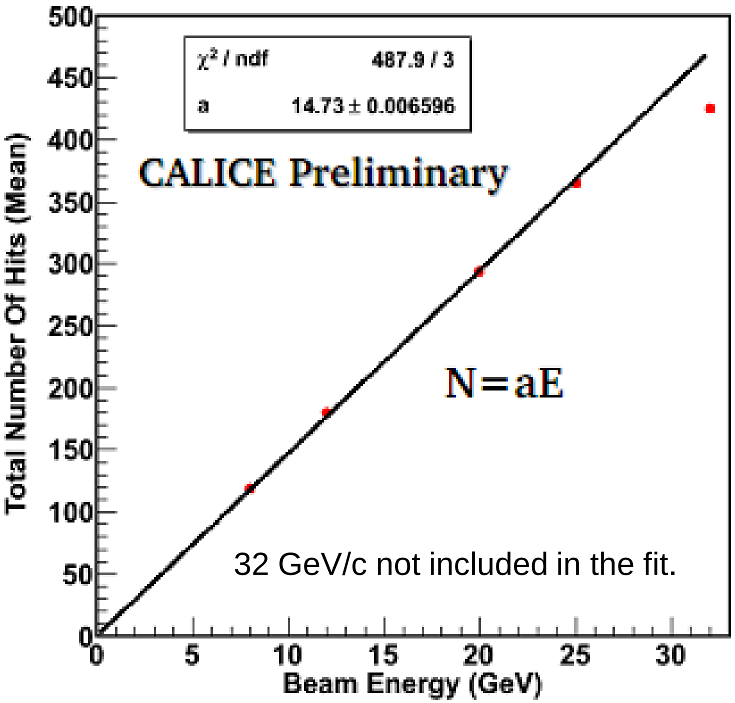
Topological particle identification – details can be found in Calice Analysis Note CAN-032

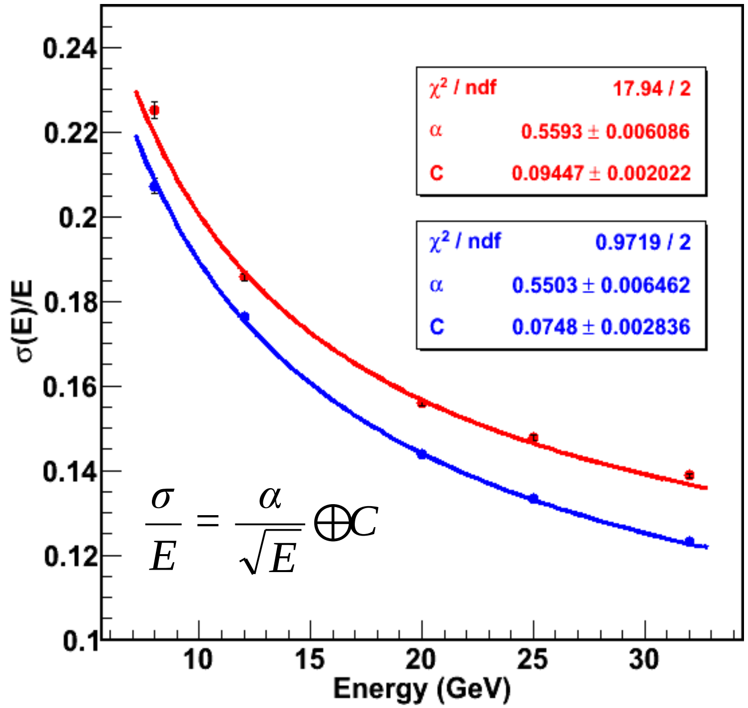
Results - October 2010 Data

CALICE Preliminary

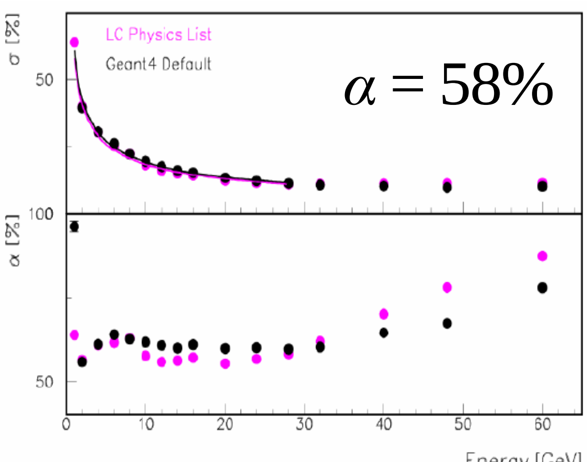


DHCAL Response to Hadrons **response not calibrated**





Standard pion selection
+ No hits in last two layers
(longitudinal containment)

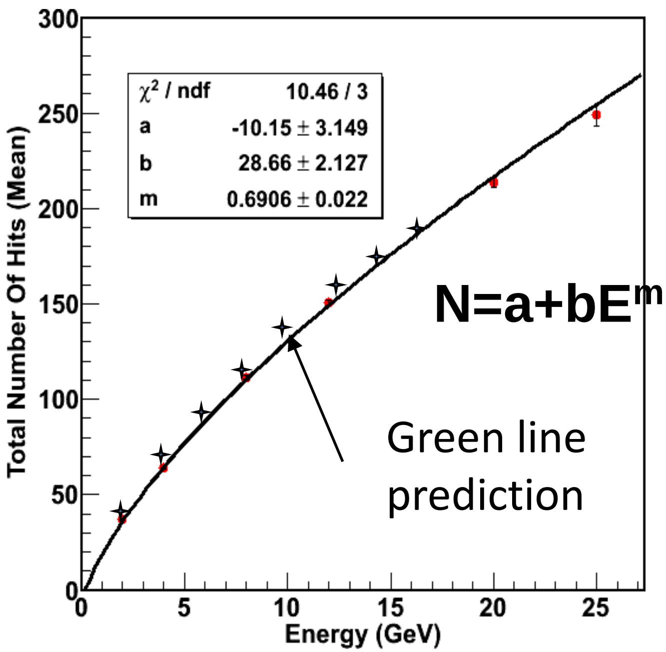


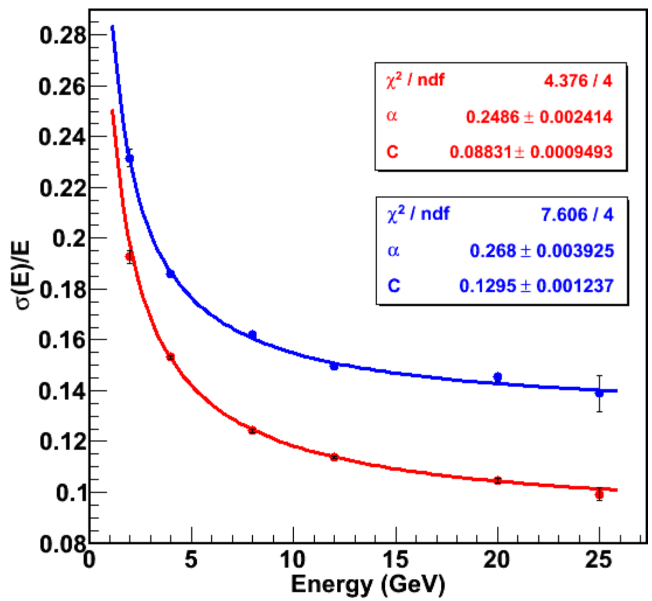
B. Bilki et.al. JINST4 P10008, 2009.

MC predictions for a large-size DHCAL
based on the Vertical Slice Test.

DHCAL Response to Positrons

response not calibrated





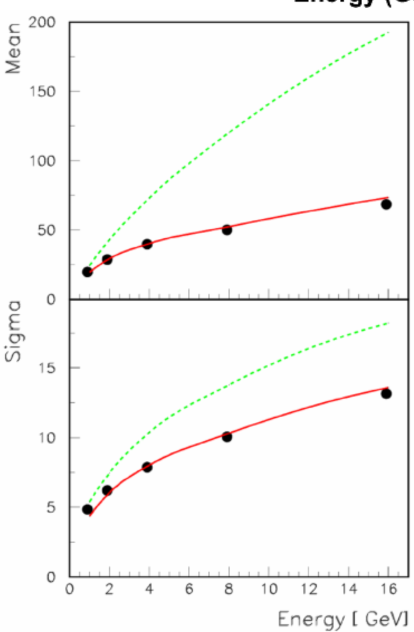
$$\frac{\sigma}{E} = \frac{\alpha}{\sqrt{E}} \oplus C$$

Uncorrected for non-linearity

Corrected for non-linearity

Correction for non-linearity

Needed to establish resolution
Correction on an event-by-event basis



B. Bilki et.al. JINST4 P04006, 2009.

Data (points) and MC (red line) for the Vertical Slice Test and the MC predictions for a large-size DHCAL (green, dashed line).

Conclusion

Hadron showers were observed with unprecedented spatial resolution.

DHCAL-specific algorithms are being generated.

Calorimetric properties are within expectations with a first-look analysis.

Next steps in the analysis:

- Calibrate the DHCAL
- Fine-tune the simulations
- Final calorimetric measurements
- Physics measurements (shower shapes, software compensation, detailed modeling of hadronic interaction, etc.)

The DHCAL concept is being validated.