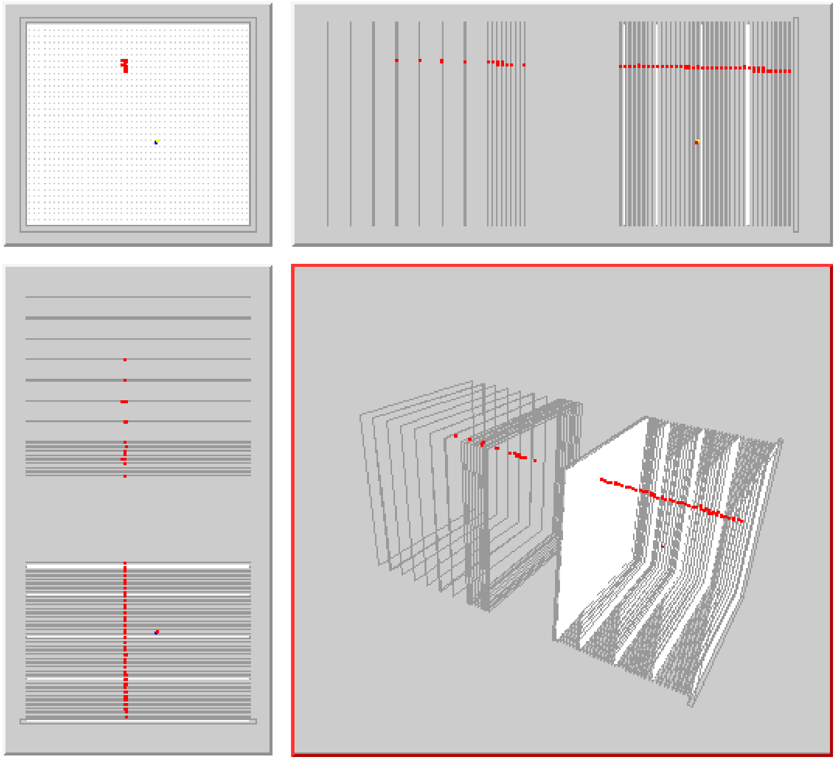
Analysis of DHCAL Muon Events



José Repond
Argonne National Laboratory

TIPP 2011 Conference, Chicago, June 9 - 14, 2011

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

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 and tuned MC
- Perform additional measurements, such as scan over pads, etc…

This talk

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…

Next talk

The DHCAL Project

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

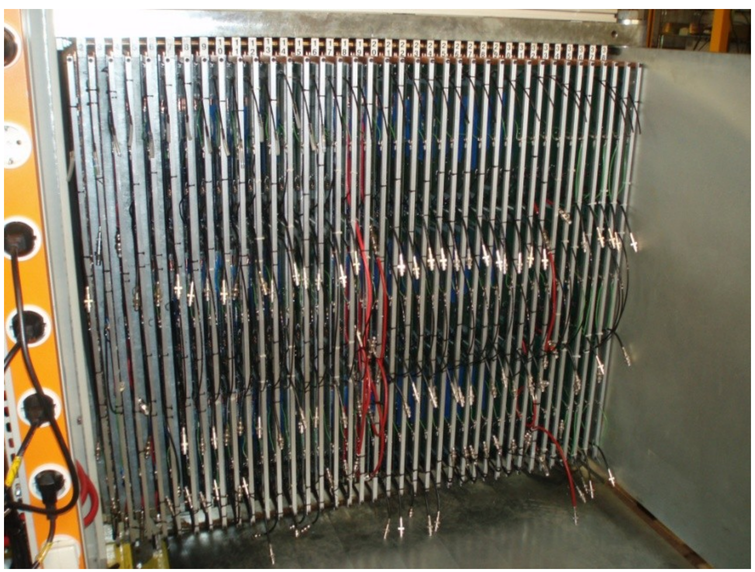
DCHAL Collaboration	Heads
Engineers/Technicians	22
Students/Postdocs	8
Physicists	9
Total	**39**

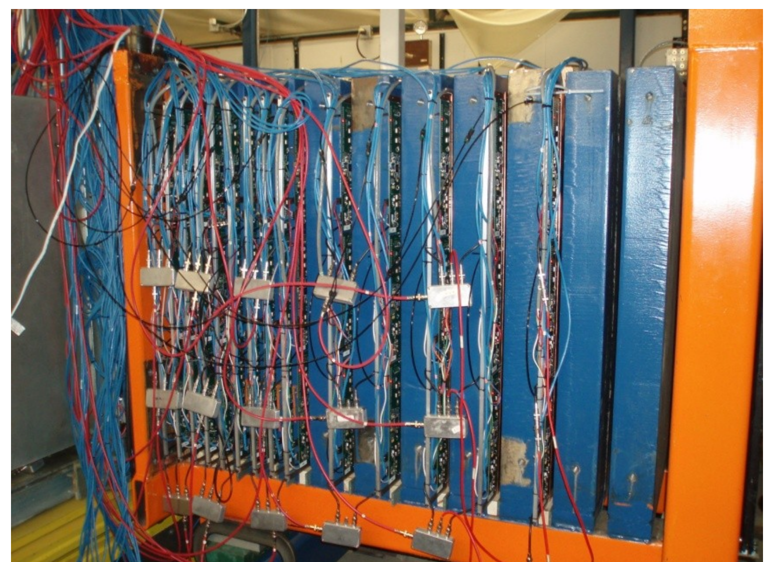
…and integral part of CALICE

Calorimeter for ILC

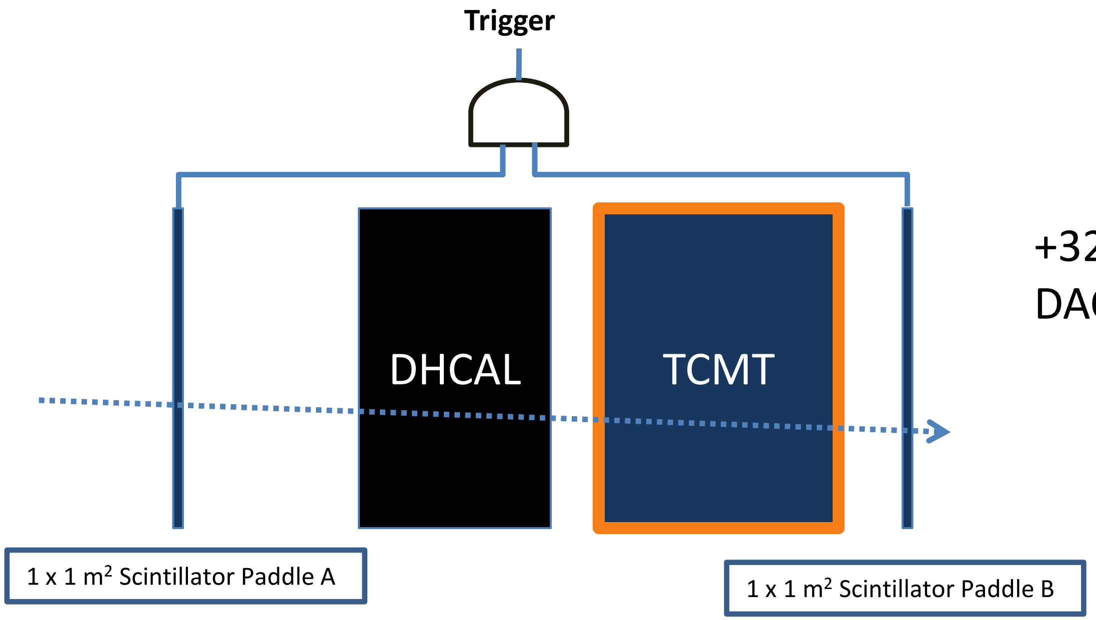
The DHCAL in the Test Beam

	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





Beam and Trigger for Muon events



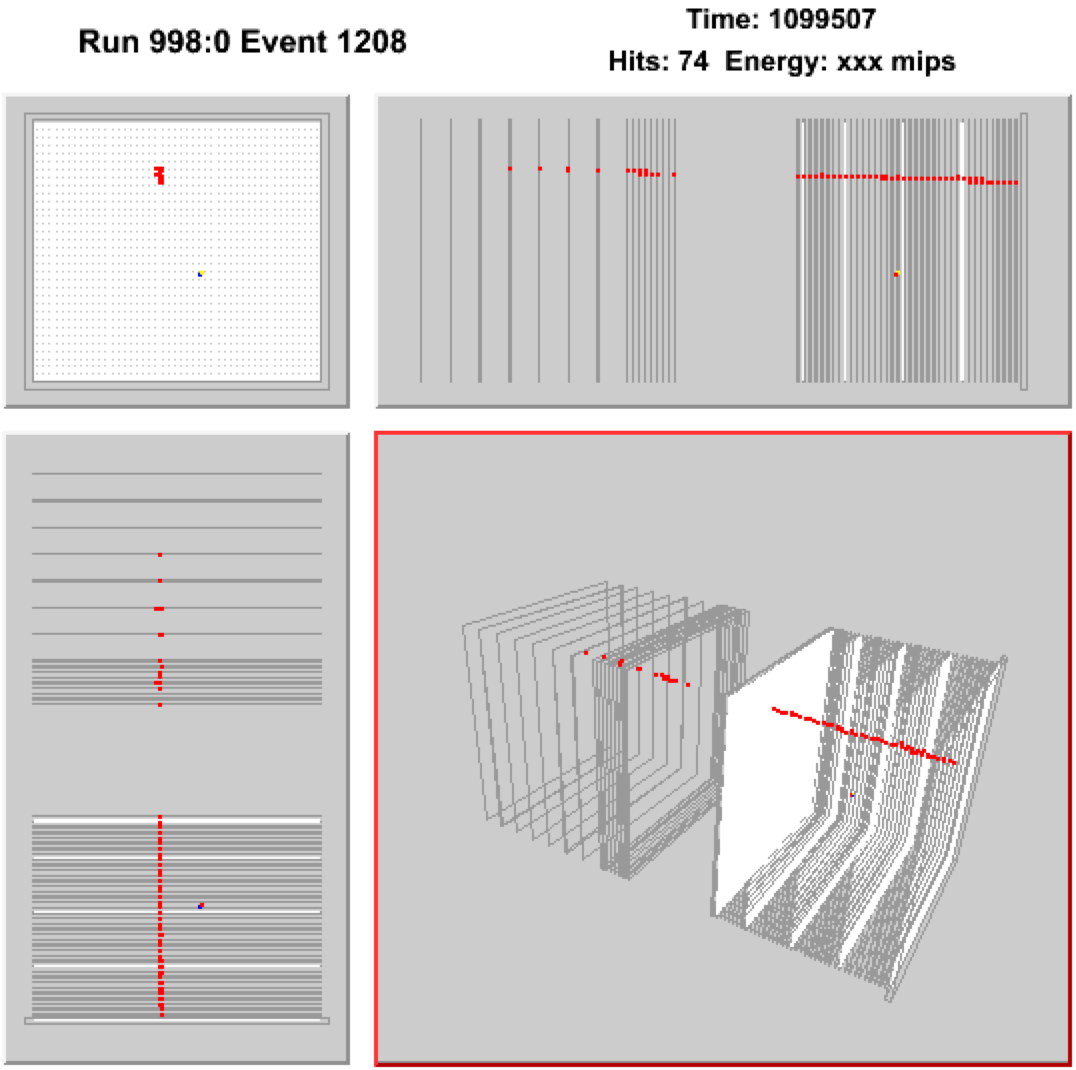
+32 GeV/c secondary beam + 3m Fe
DAQ rate typically 500 - 1000/spill

Run	# of muon events
October 2010	1.4 Million
January 2011	1.6 Million
April 2011	2.5 Million
June 2011	2.2 Million

Some cute muon events

Note: Consecutive events (not selected)

Look for random noise hits



Estimation of contributions from noise

Data collection

Trigger-less (all hits) mode for noise, cosmics
Triggered (record hits in 7 time bins of 100 ns each) for noise, testbeam
→ Only hits in 2 time bins used for physics analysis

Noise measurement

These results from trigger-less mode

TCMT in 4/2011 run

DHCAL in 4/2011 run

DHCAL in 10/2010 run

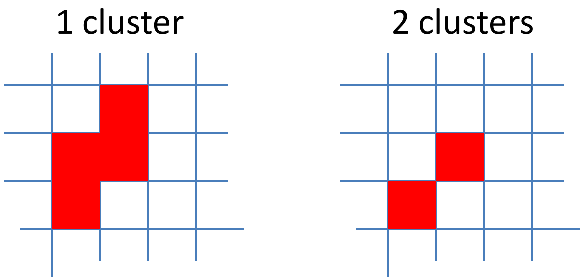
Results

Noise rate measured to be 0.1 – 1.0 Hz/cm²
Rate strongly dependent on the temperature of the stack

Noise rate [Hz/cm²]	0.1	0.5	1.0
N_{noise}/event in DHCAL + TCMT (2 time bins)	0.0094	0.047	0.094
N_{noise}/event in DHCAL + TCMT (7 time bins)	0.033	0.165	0.33

Contribution from noise negligible for most analysis

Tracking



Clustering of hits

Performed in each layer individually
Use closest neighbor clustering (one common side)
Determine unweighted average of all hits in a given cluster ($x_{cluster}$,$y_{cluster}$)

Loop over layers

<u>for layer i</u> request that all other layers have $N^j_{cluster} \leq 1$
request that number of hits in tracking clusters $N^j_{hit} \leq 4$
request at least 10/38(52) layers with tracking clusters
fit straight line to ($x_{cluster}$,z) and ($y_{cluster}$,z) of all tracking clusters j
calculate χ^2 of track

$$\chi^2 / N_{track} = \sum_{j \neq i} \frac{(x^j_{cluster} - x^j_{track})^2}{1} + \sum_{j \neq i} \frac{(y^j_{cluster} - y^j_{track})^2}{1}$$

request that $\chi^2/N_{track} < 1.0$
inter/extrapolate track to layer i
search for matching clusters in layer i within

$$R = \sqrt{(x^i_{cluster} - x^i_{track})^2 + (y^i_{cluster} - y^i_{track})^2} < 2.5cm$$

record number of hits in matching cluster

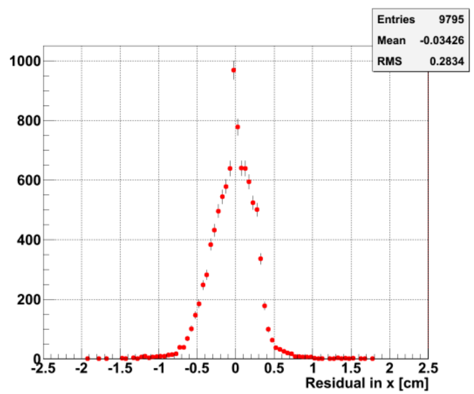
Alignment

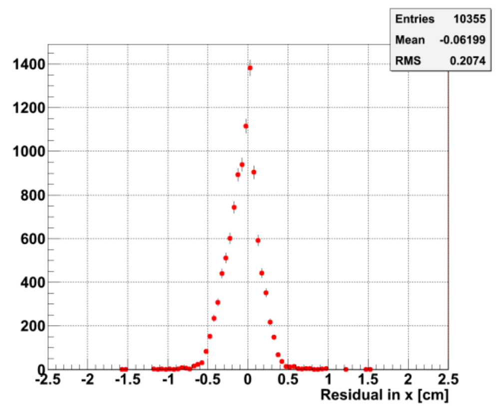
For each readout board i plot residual in x/y

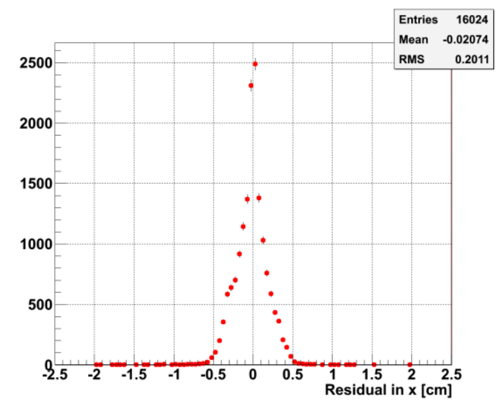
$R^i_x = x^i_{cluster} - x^i_{track}$
$R^i_y = y^i_{cluster} - y^i_{track}$

Dimensions in [cm]

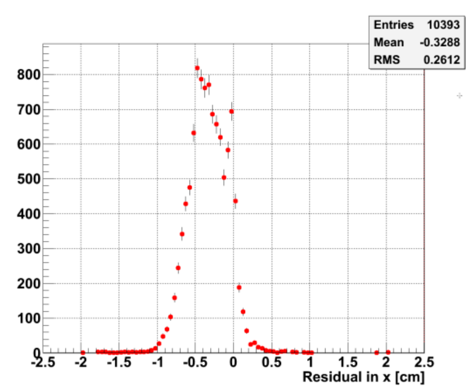
Most distributions look OK



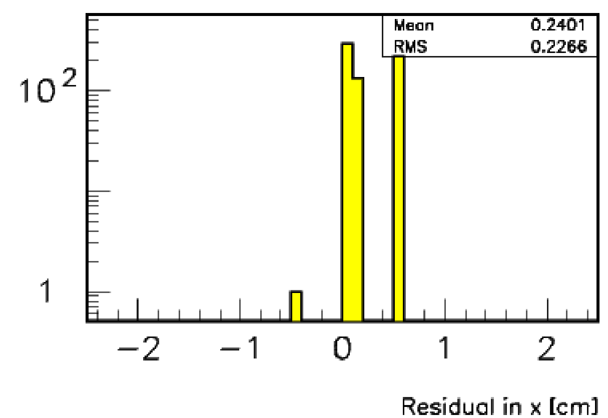




Few have double peaks

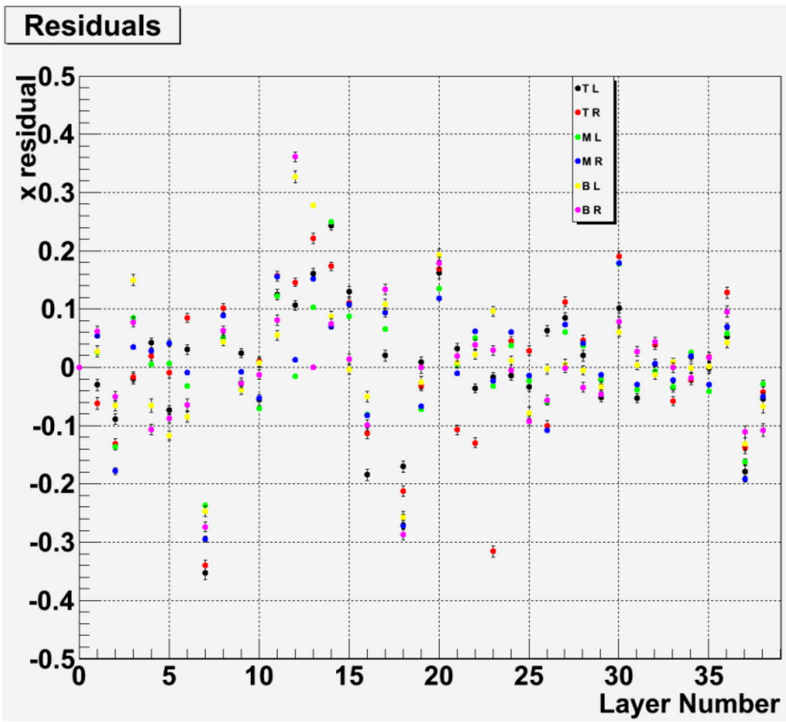


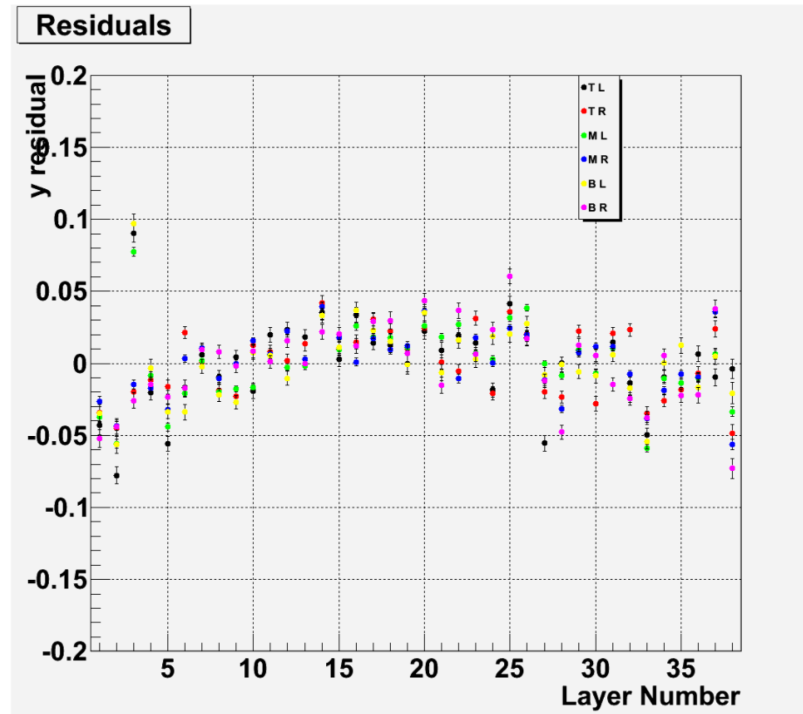
…as does simple a
Toy MC + RPCSIM



Mean residuals for each Front-end board versus layer#

Mean of residual distributions





x-residual

Variations of < 3 mm
Alignment of layers by hand
Correlation between the 6 boards within a layer

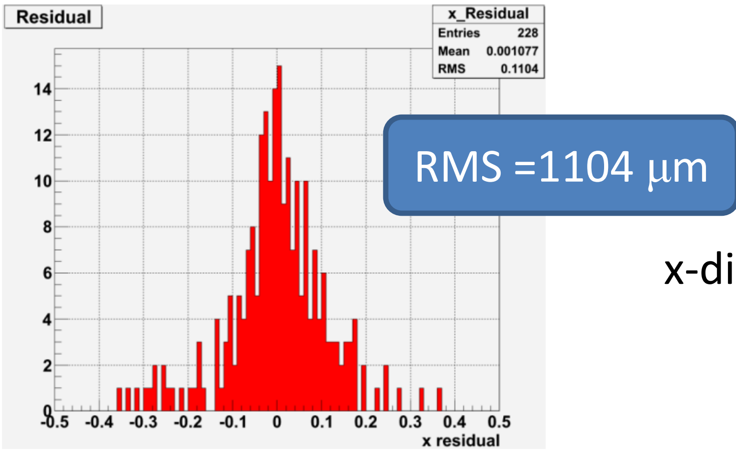
y-residual

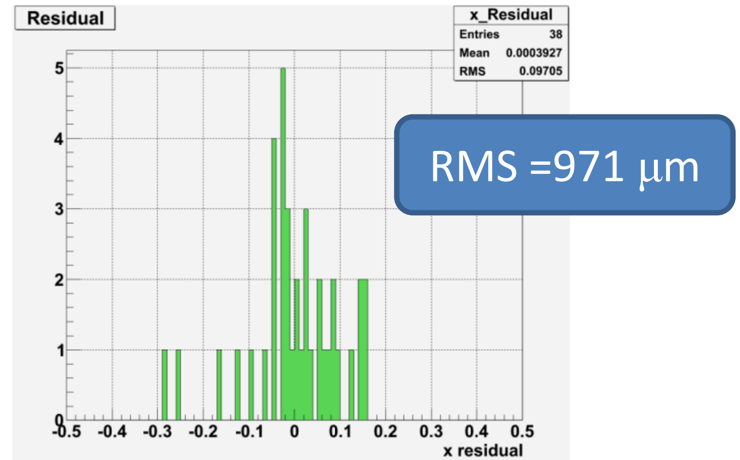
Variations <0.5 mm
Cassette resting on CALICE structure
Systematic trend compatible with cassettes being lower in center of stack by ~ 0.5 – 0.7 mm

Residuals for each Front-end board or layer

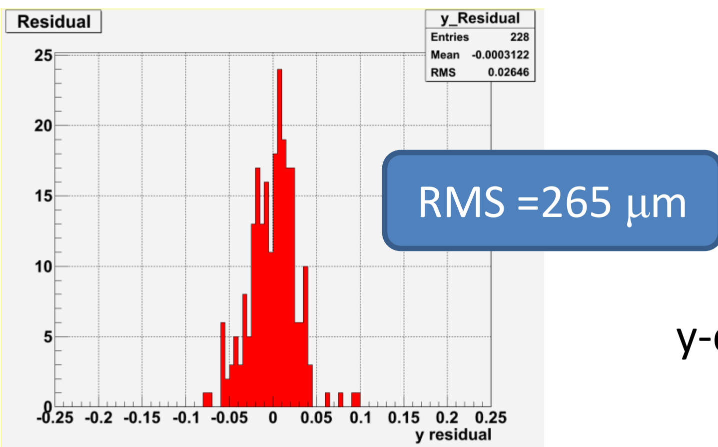
1 entry/readout board

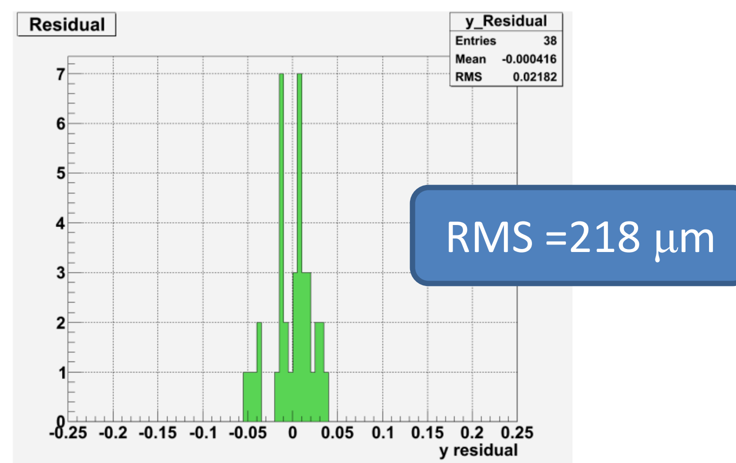
1 entry/layer





x-dimension



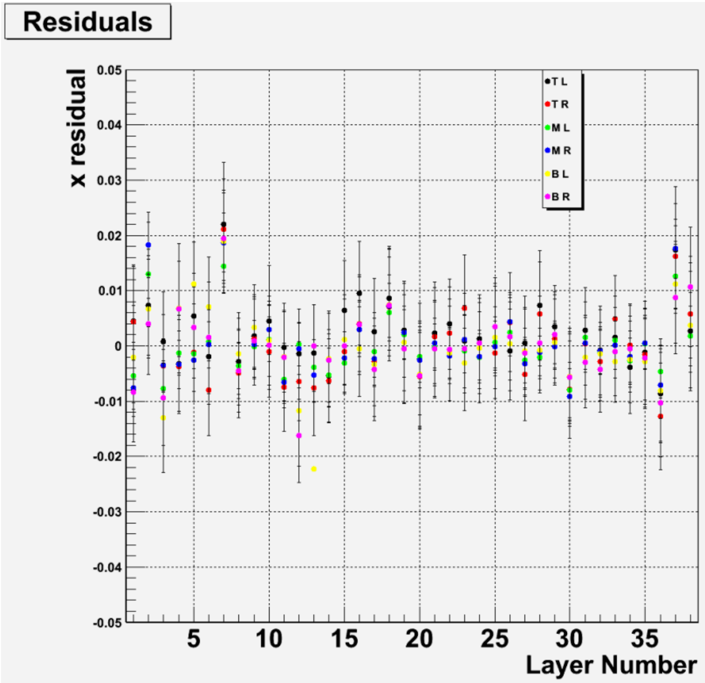


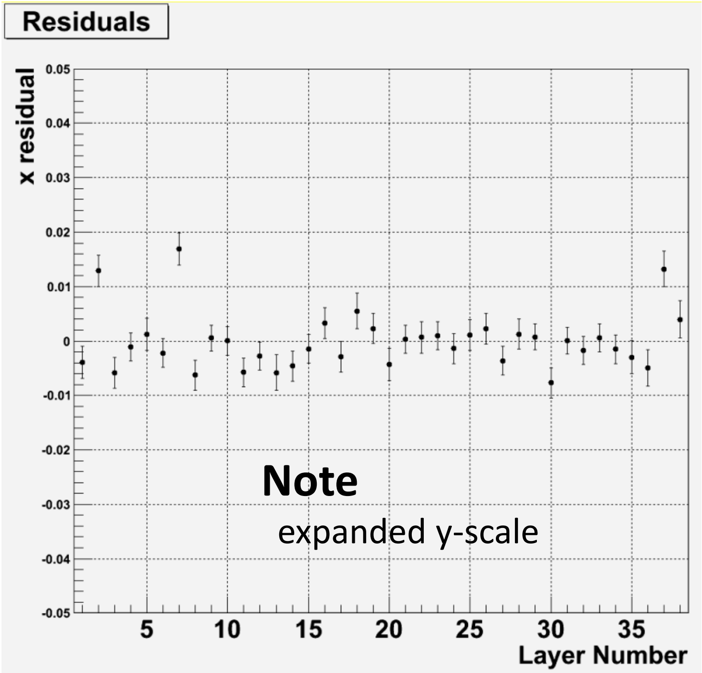
y-dimension

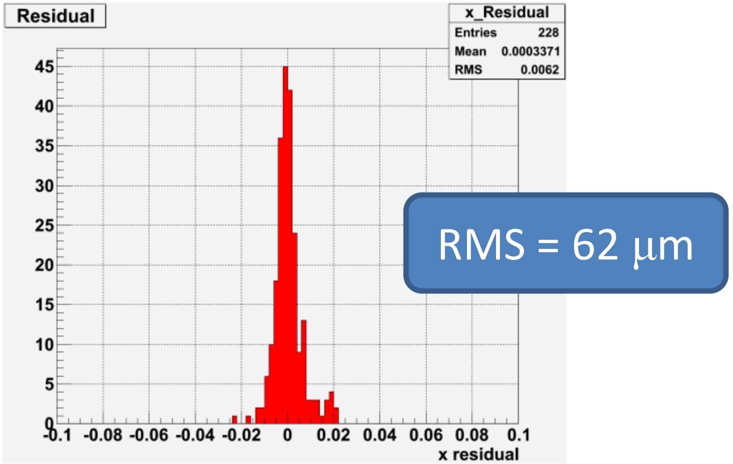
Note

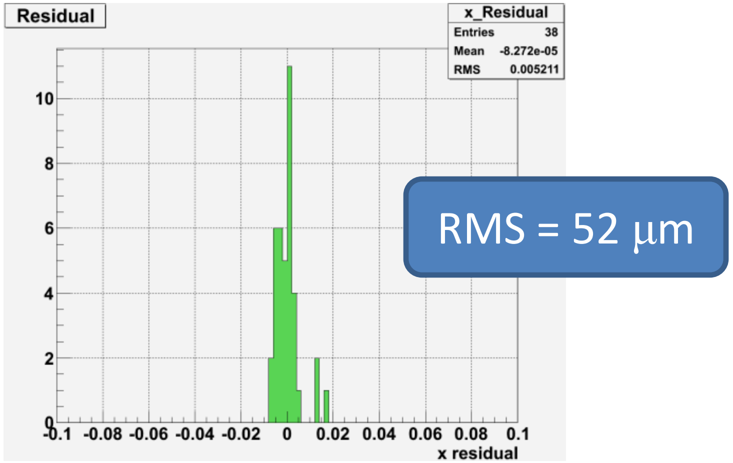
Mean by construction close to 0
External tracking not available

After alignment each readout board in x

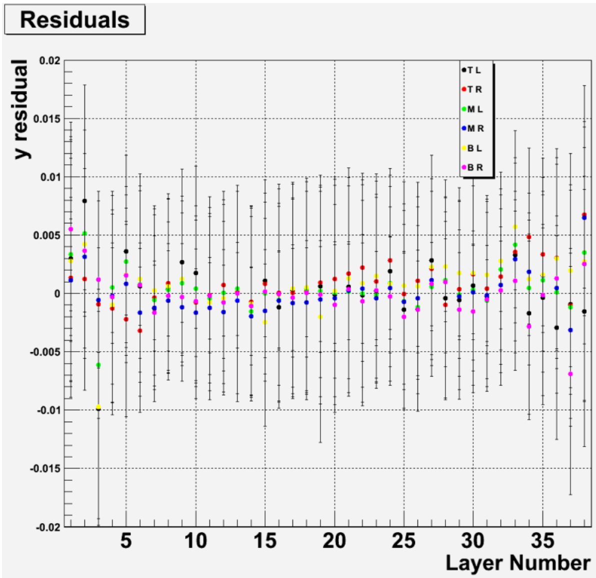


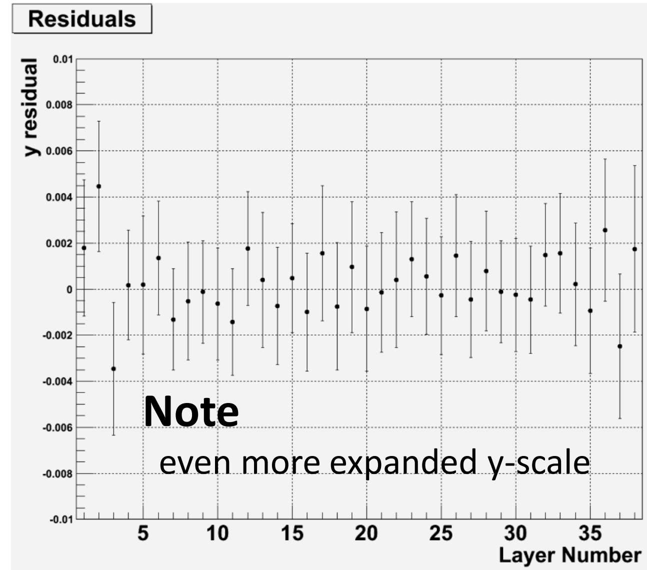


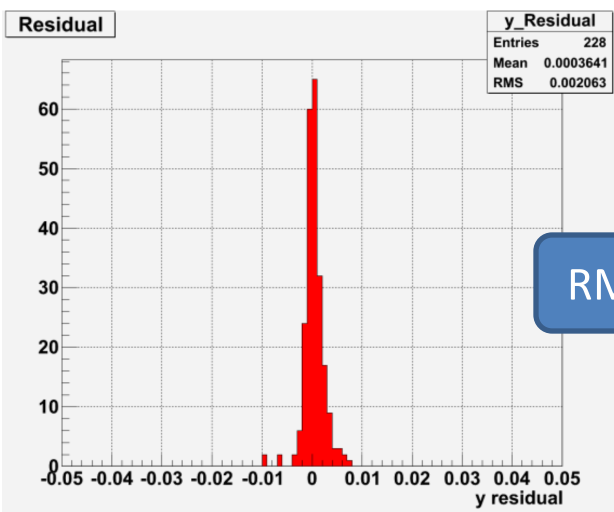




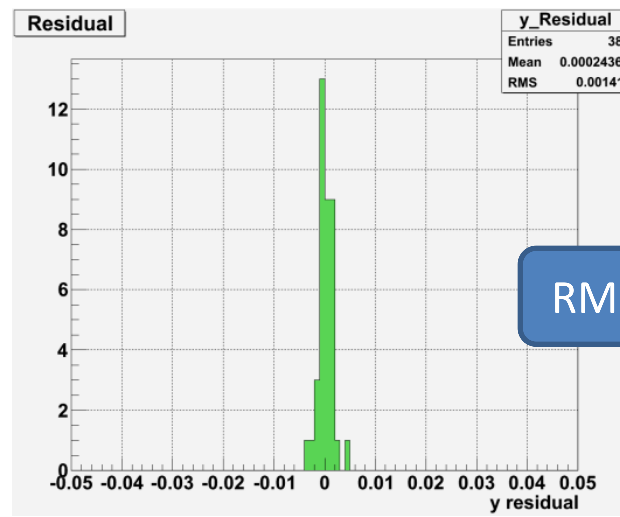
After alignment in y





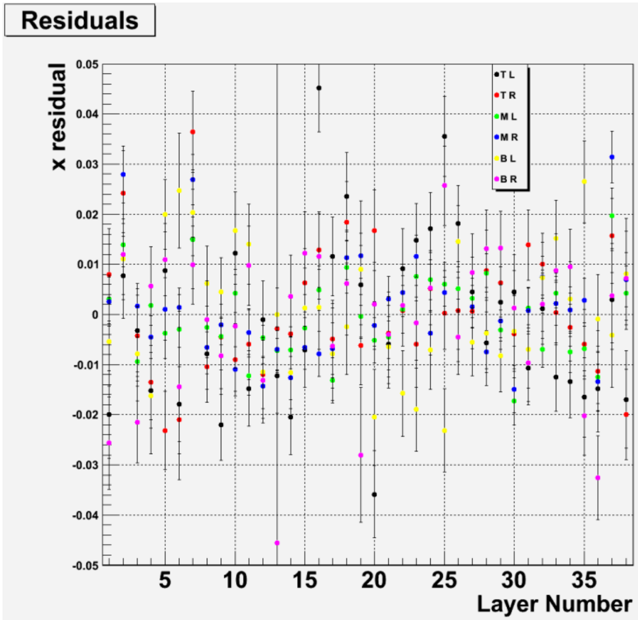


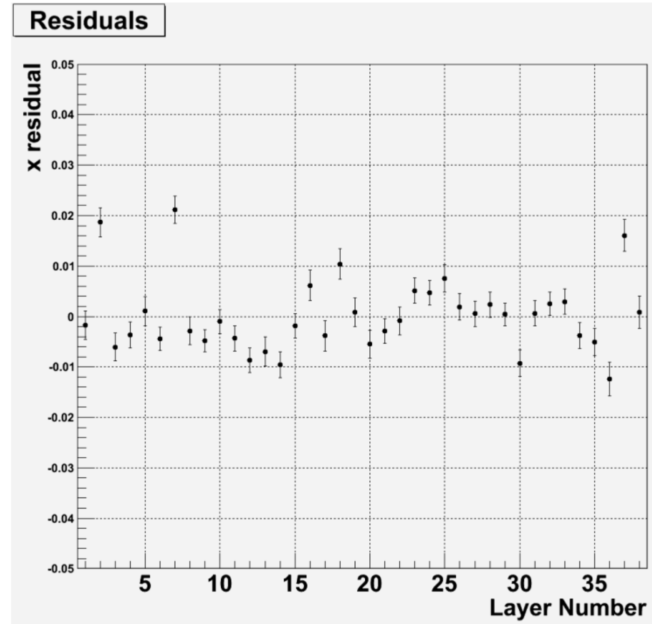
RMS = 21 μm

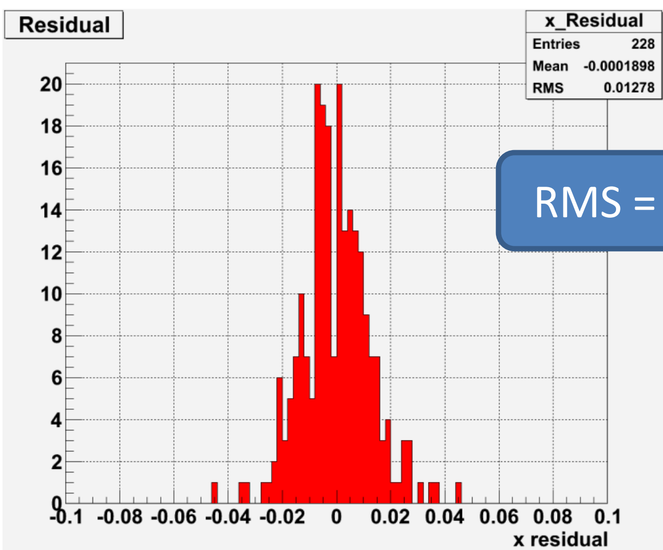


RMS = 14 μm

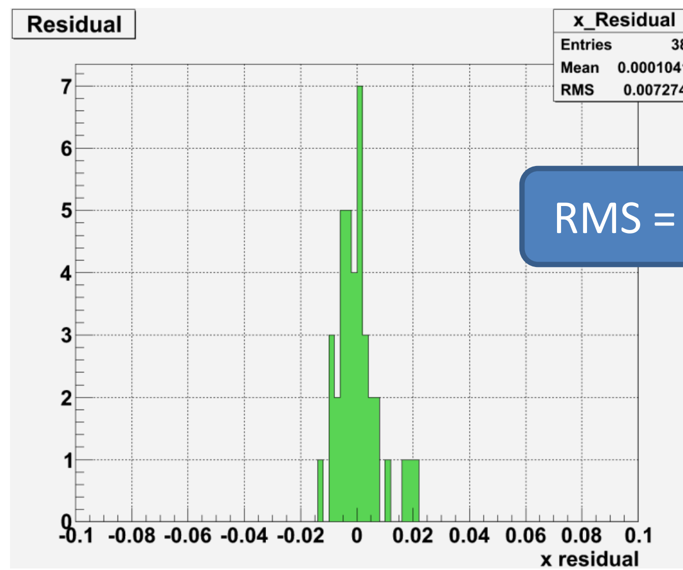
Run 610055 using alignment obtained with 610063: alignment in x







RMS = 128 μm



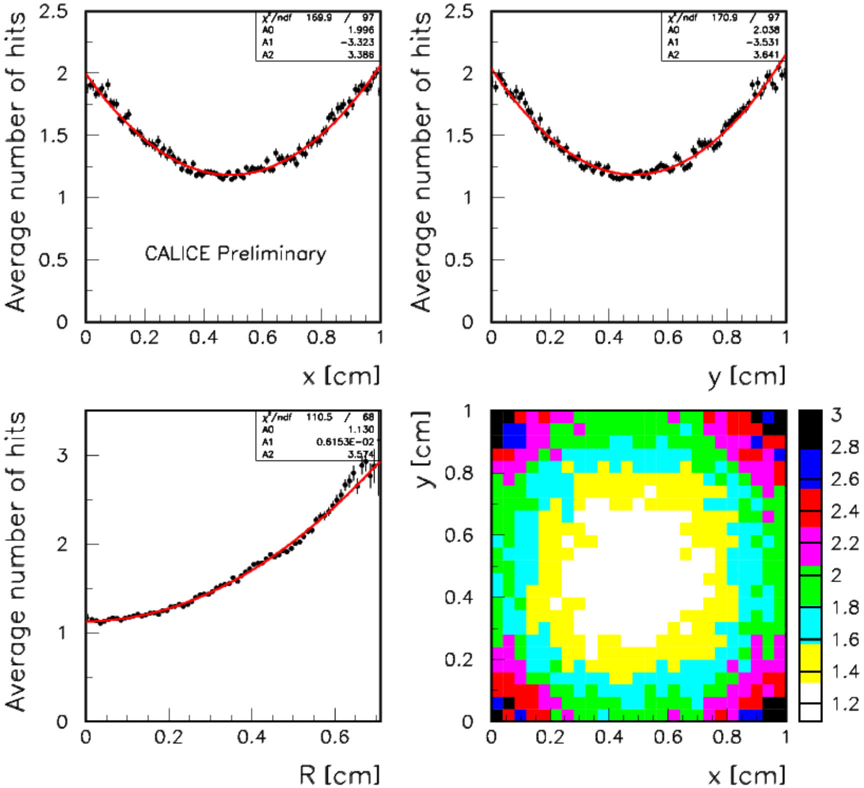
RMS = 73 μm

As expected, not quite as good, but still acceptable

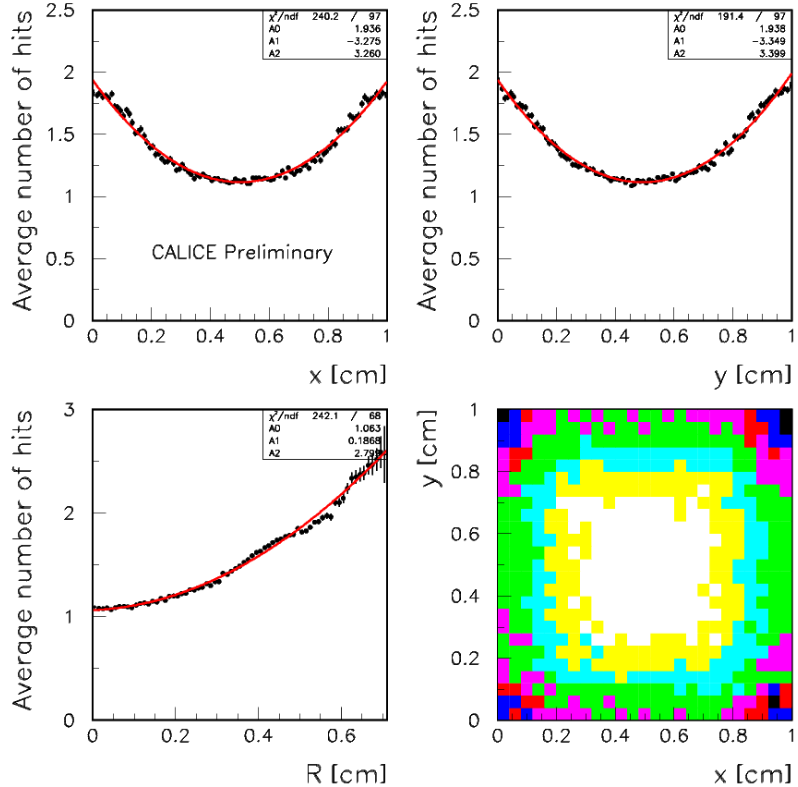
Scan across pad

$x = \mathrm{Mod}(x_{track} + 0.5, 1.)$ for $0.25 < y < 0.75$
$y = \mathrm{Mod}(y_{track} - 0.03, 1.)$ for $0.25 < x < 0.75$

Data 630011



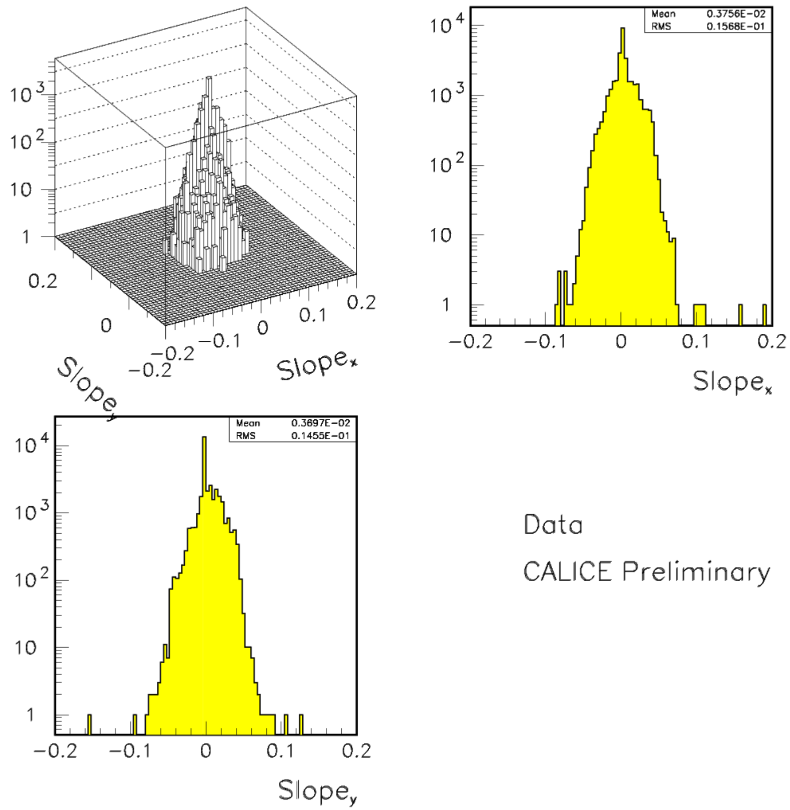
Simulation



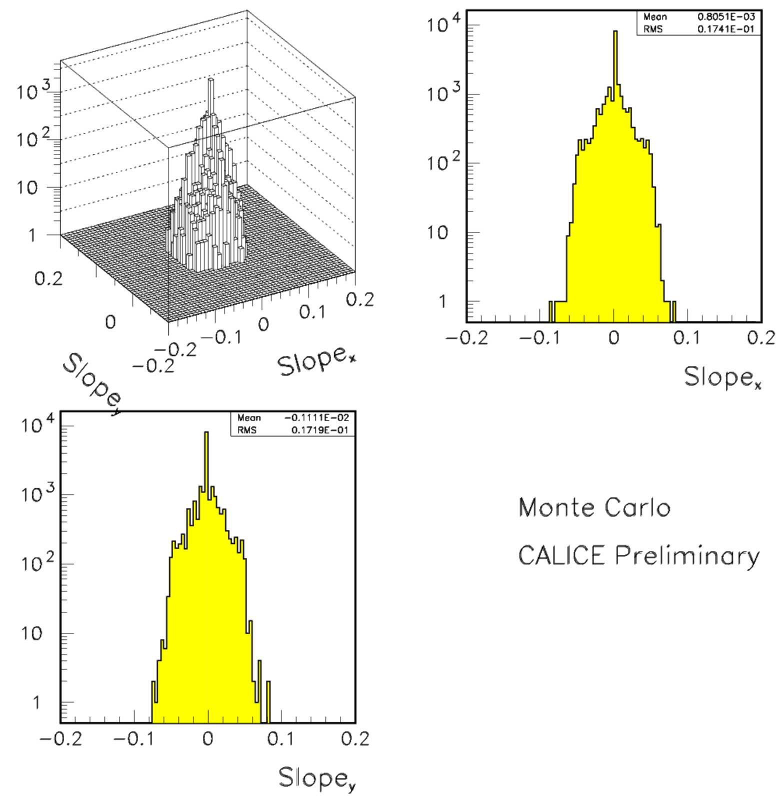
Note These features **not** implemented explicitly into simulation
Simulation distributes charge onto plane of pads…

Angles of muon tracks

Data



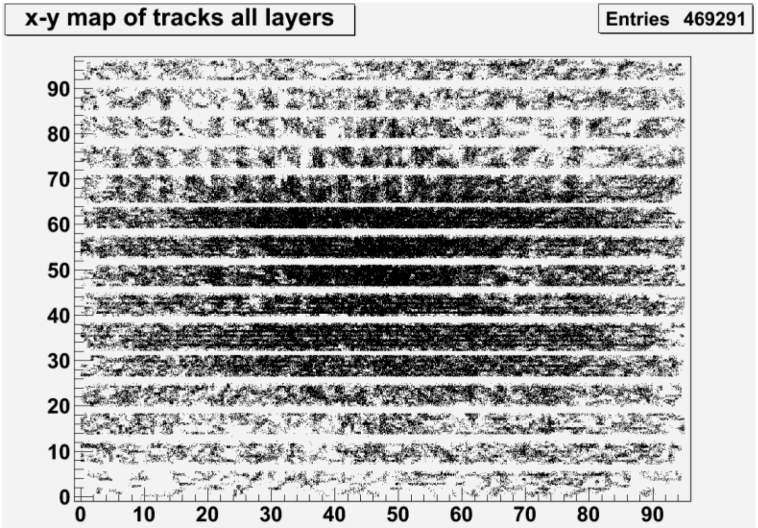
GEANT4 + RPCSIM



Note

Incident angle distribution in MC tuned to reproduce data
Simulation acceptable

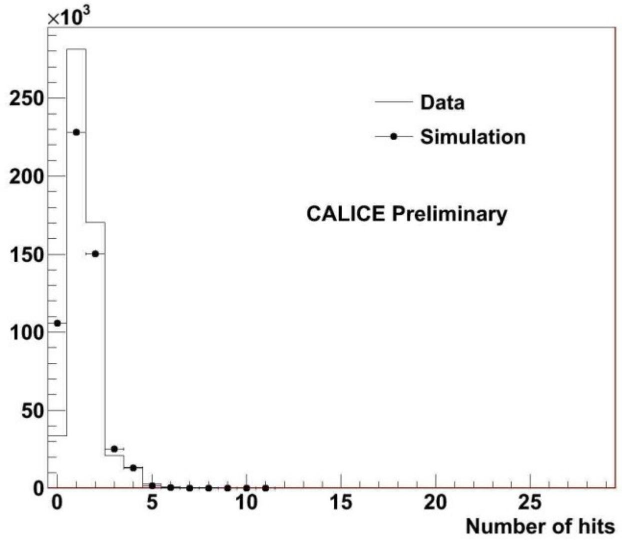
Efficiencies, multiplicities

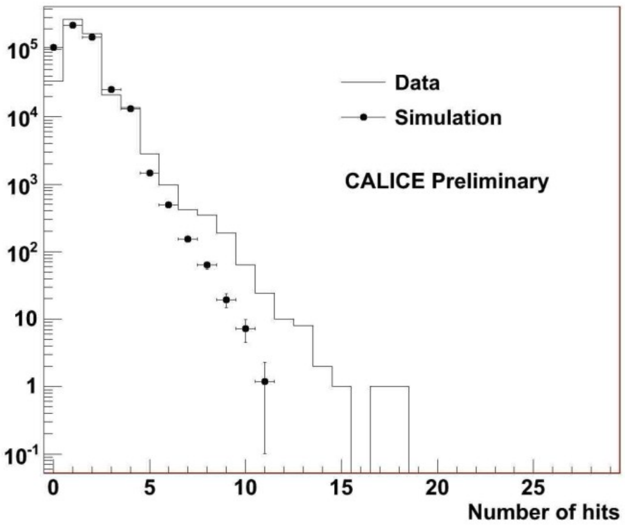


Select 'clean' regions away from

- Dead ASICs (cut out 8 x 8 cm^2 + a rim of 1 cm)
- Edges in x (2 rims of 0.5 cm)
- Edges in y (6 rims of 0.5 cm)
- Fishing lines (12 rectangles of ±1 cm)
- Layer 27 (with exceptionally high multiplicity)

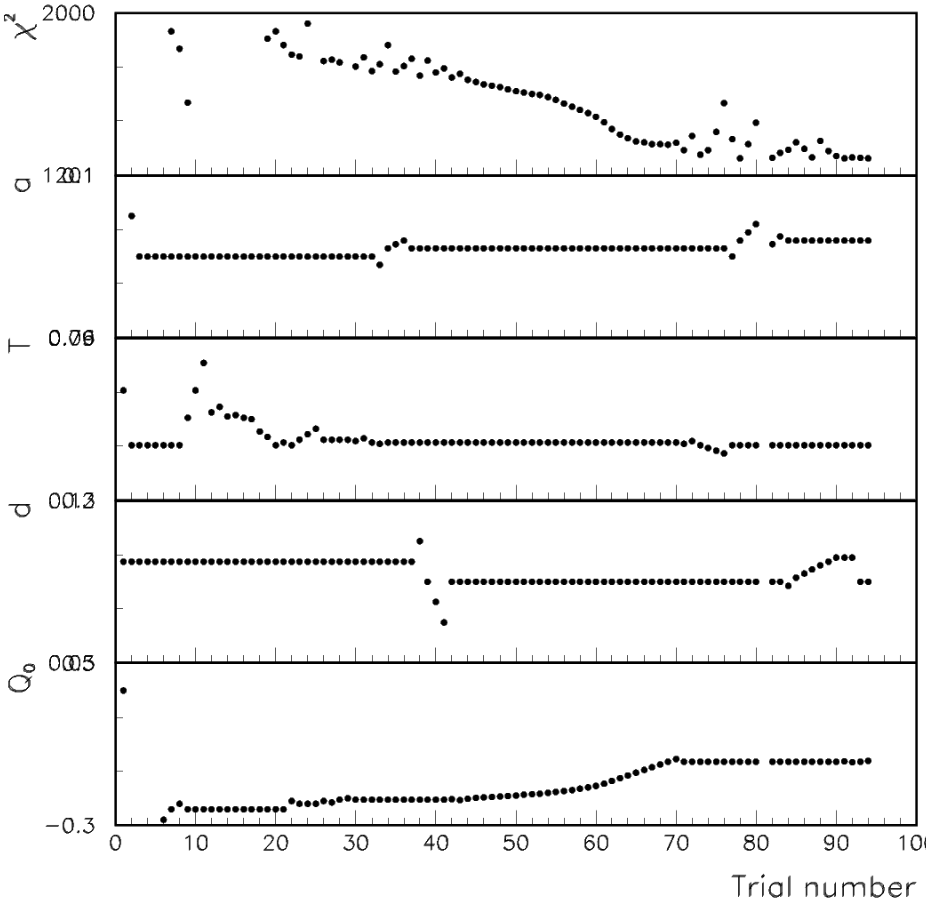
Measure average response



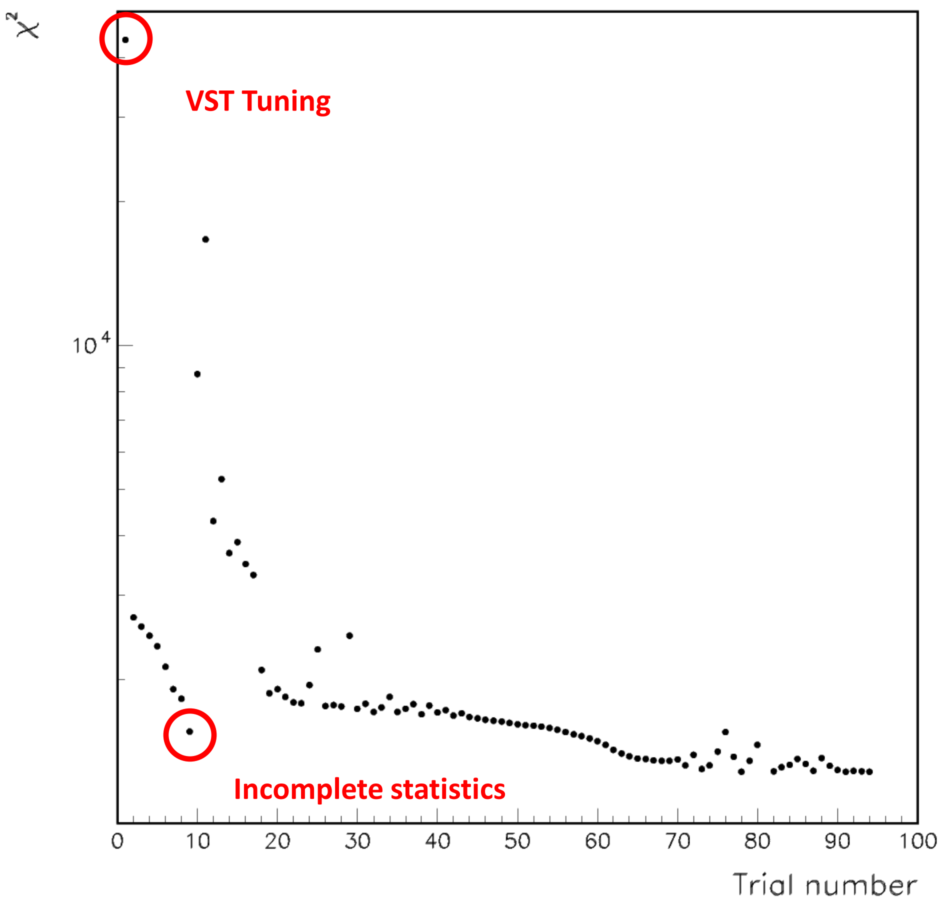


Note: Simulation of RPC response tuned to **Vertical Slice Test**
DHCAL shows **higher efficiency** and **lower multiplicity** (thinner glass)

Tuning, tuning, tuning…



χ^2 comparison of normalized histograms of multiplicity



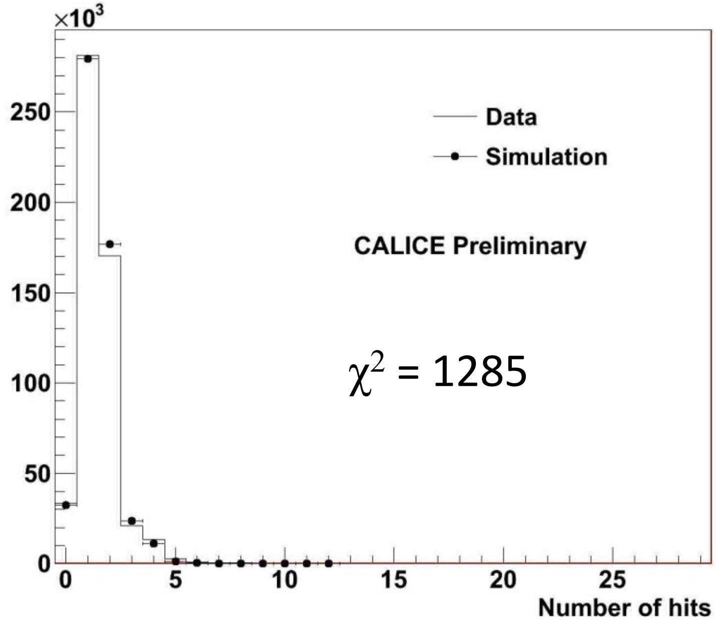
Note:

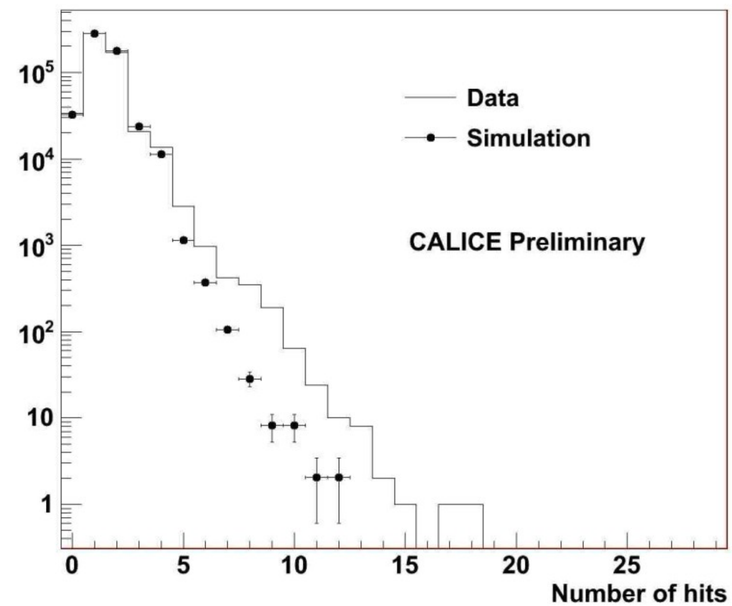
Tuning done **'by hand'**

Very large statistics of both data and simulation → large χ^2

No significant improvements after trial #70

Best fit





Note: High statistics (error bars « dots)
Efficiency well reproduced
Low multiplicity well reproduced
Tail problematic (excess of 0.6% in the data)

Further improvements

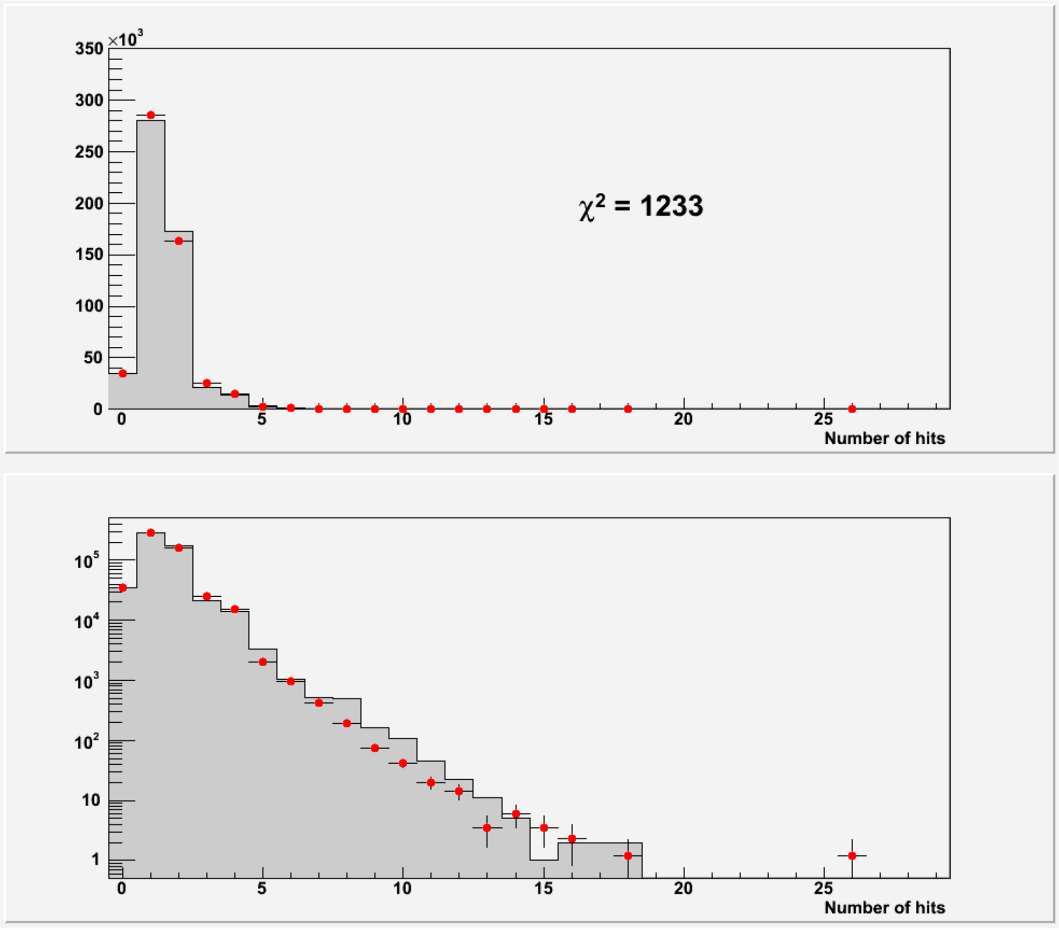
Systematic studies of track selection, functional form …

Efficiency = 93.6% in data
93.8% in MC

Multiplicity = 1.563 in data
1.538 in MC

Mean = 1.461 in data
1.443 in MC

Include 2nd exponential in charge distribution



Tail

Able to reproduce (qualitatively)

MC

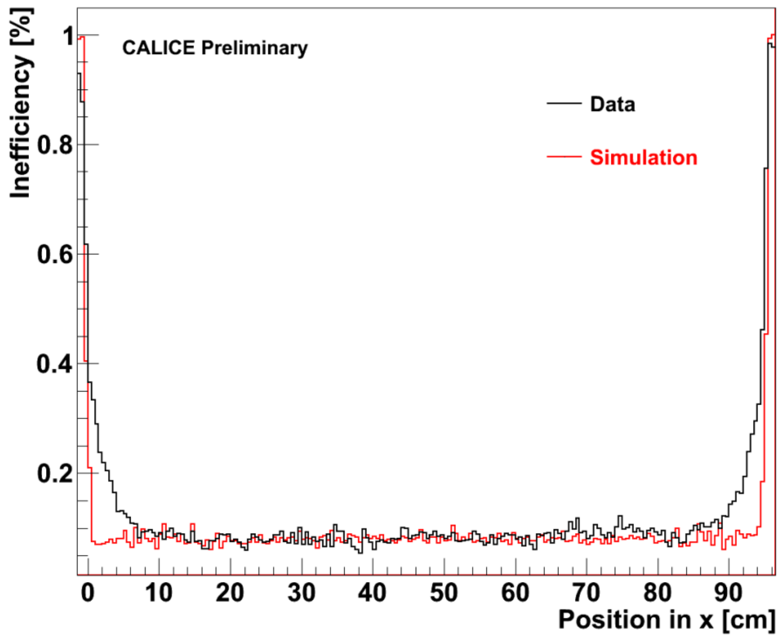
Higher statistics
→ Larger χ^2
(Absolute value meaningless)

Tuning

Still in progress (literally)
(Done by hand)

Response over the entire plane

Implemented dead areas of data in MC (= corresponding hits deleted)

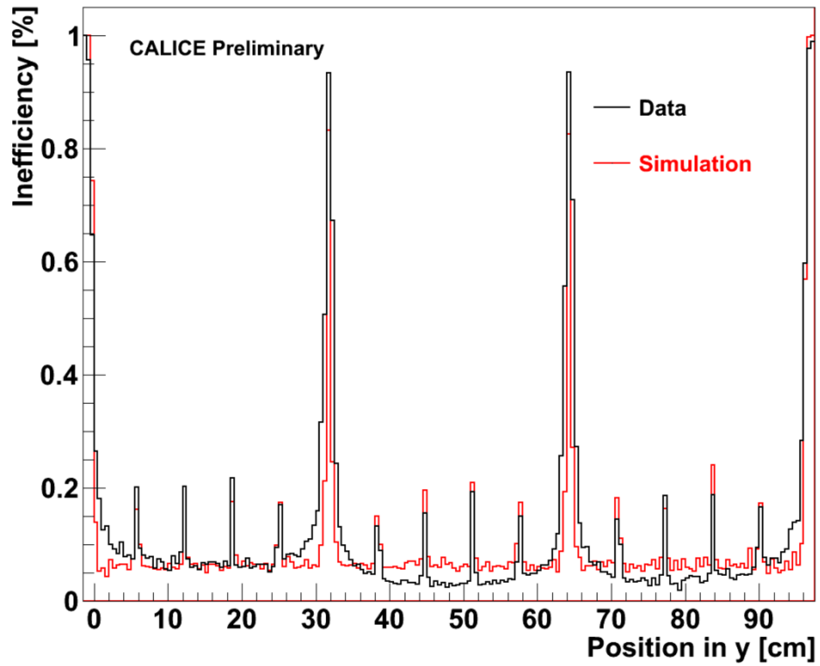


Note

x-axis in [cm] not [pad number]
Simulation using single exponential

x-distribution

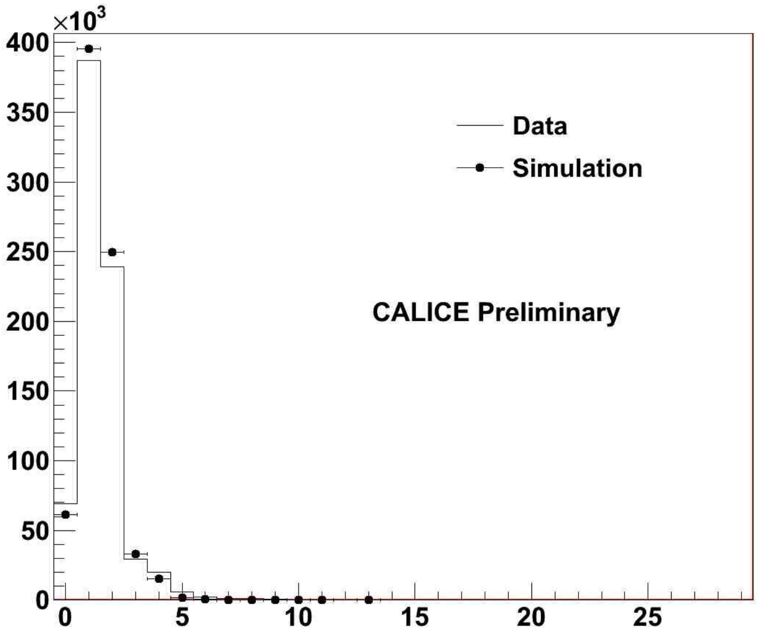
Well reproduced, apart from edges (needs special treatment)

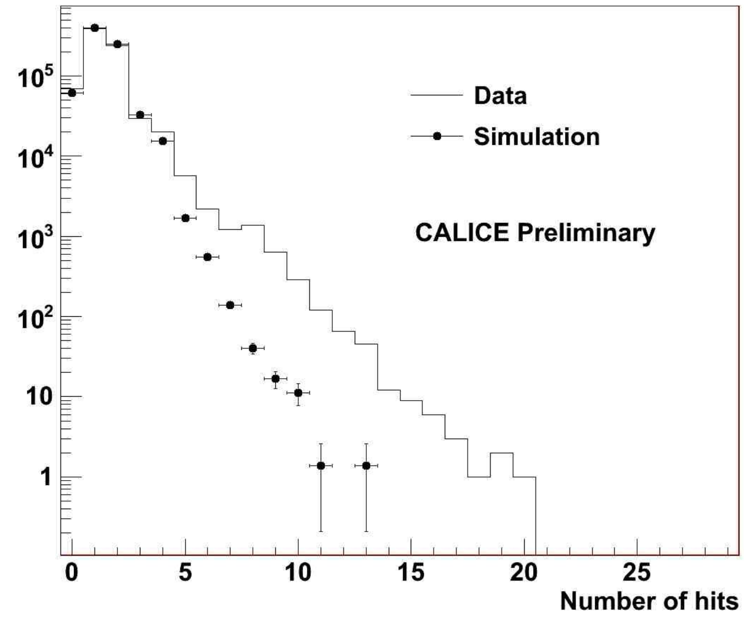


y-distribution

Inter-RPC gaps well reproduced
Fishing lines well reproduced
Edges again problematic (needs special treatment)

Average response over the entire plane (using 1 exponential only)





Note: There are systematic uncertainties
→ due to track selection
→ still need to be studied

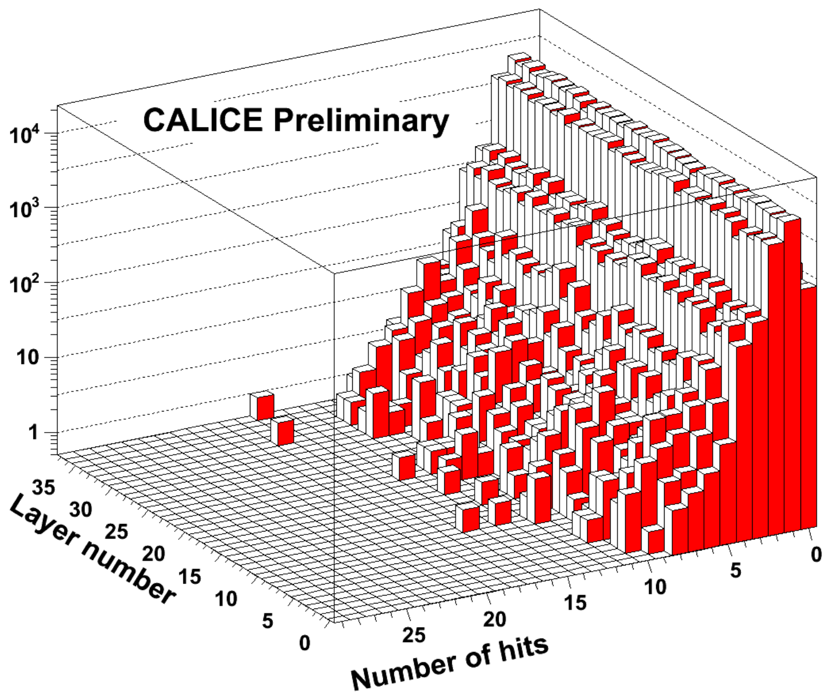
These numbers exclude the dead areas

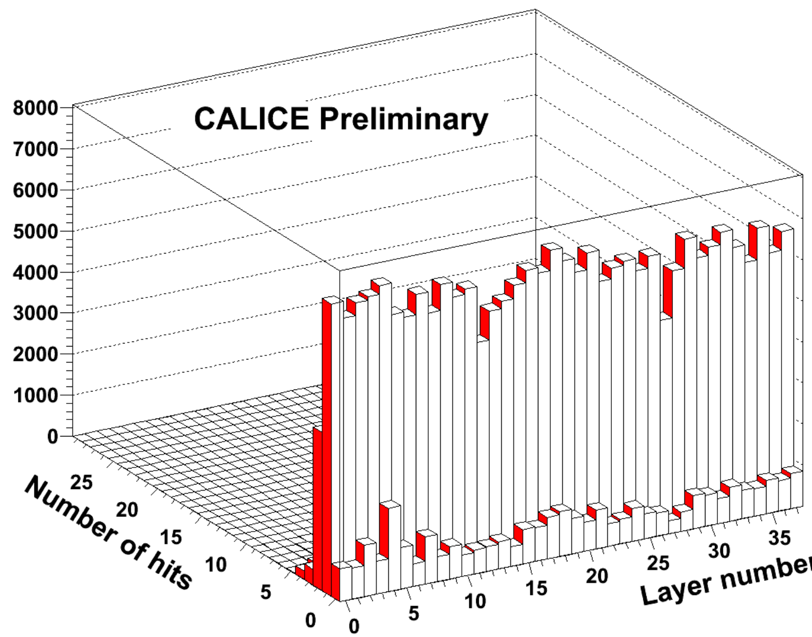
Some **tuning of the MC** still needed

Efficiency =	90.9% in data
	92.1% in MC
Multiplicity =	1.611 in data
	1.535 in MC
Mean =	1.464 in data
	1.411 in MC

Response versus layer number

Dead areas, fishing lines, and edges are excluded





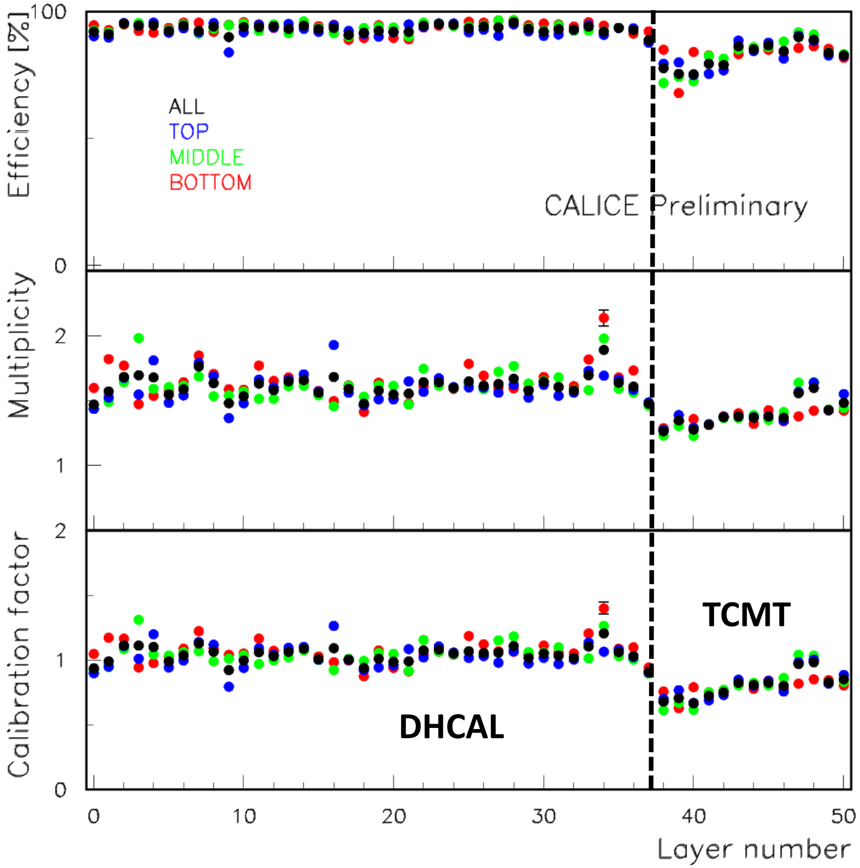
Log(z) ← same plot → **Lin(z)**

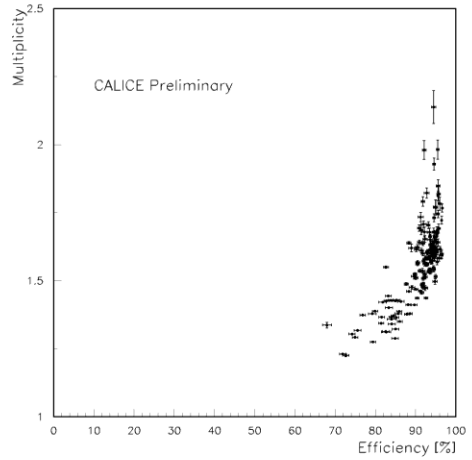
Note

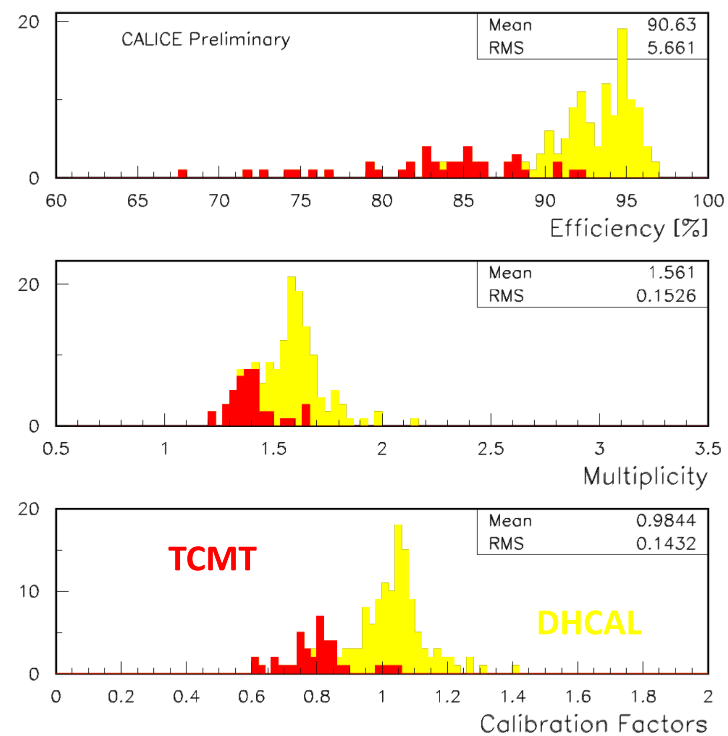
Reasonable uniformity from layer to layer

Calibration constants, etc…

Tail catcher is cooler
→ lower efficiency, multiplicity

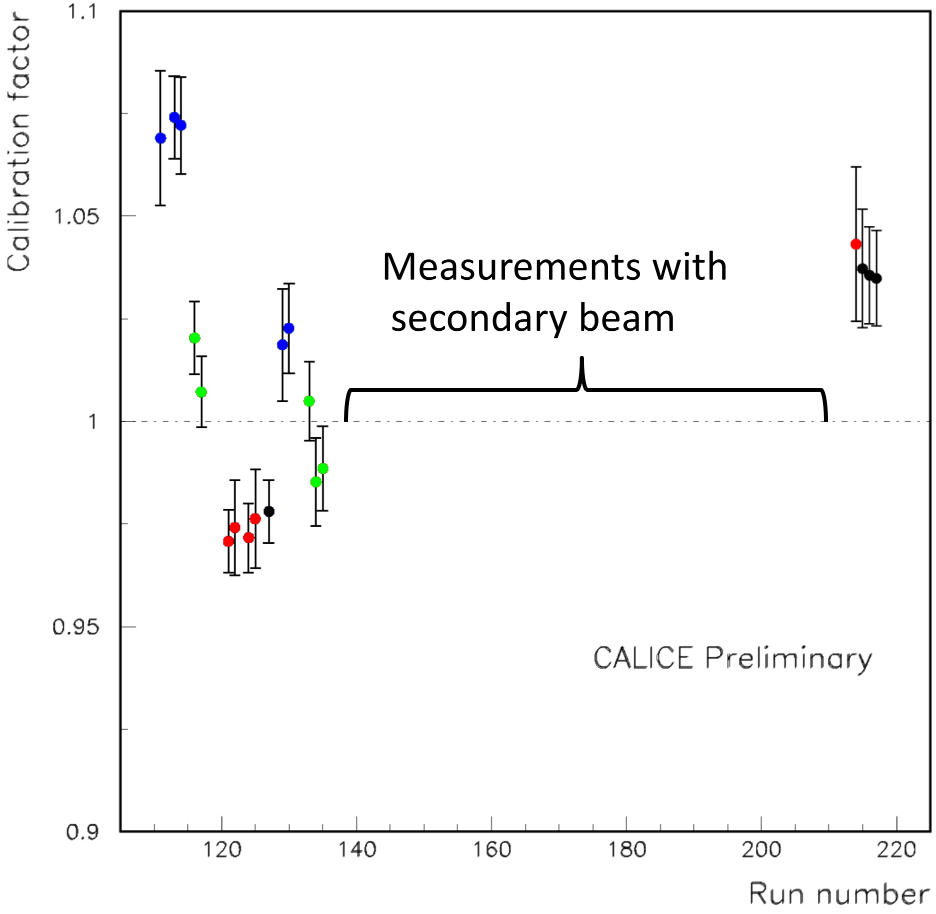






Calibration factors = mean of multiplicity distribution = ε·μ

Calibration constants as function of time



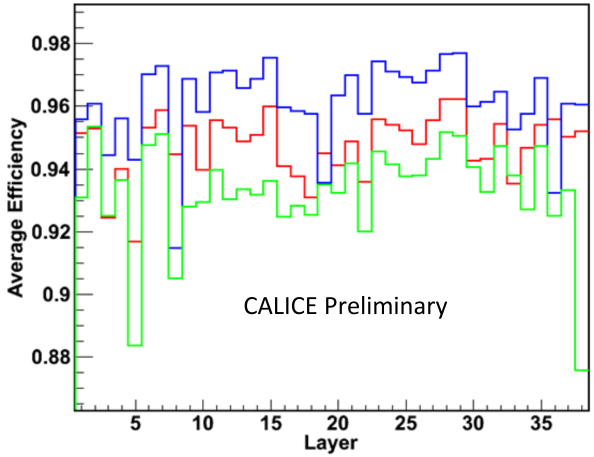
Note

Variations of +7.0 to -2.5%
Data points of equal color indicate same day measurements

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

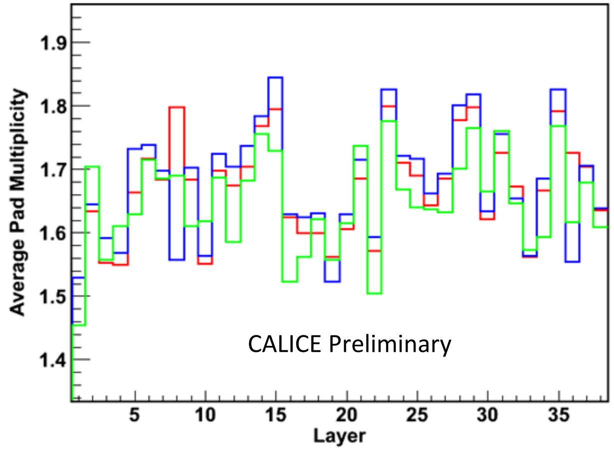


Source clusters

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

Conclusions

Analysis of muon events has begun

Preliminary results have been presented

Geometrical alignment
Response across pad
Performance parameters in 'clean' regions
Performance parameters over the entire plane
Performance as function of time
Comparison with track segment method

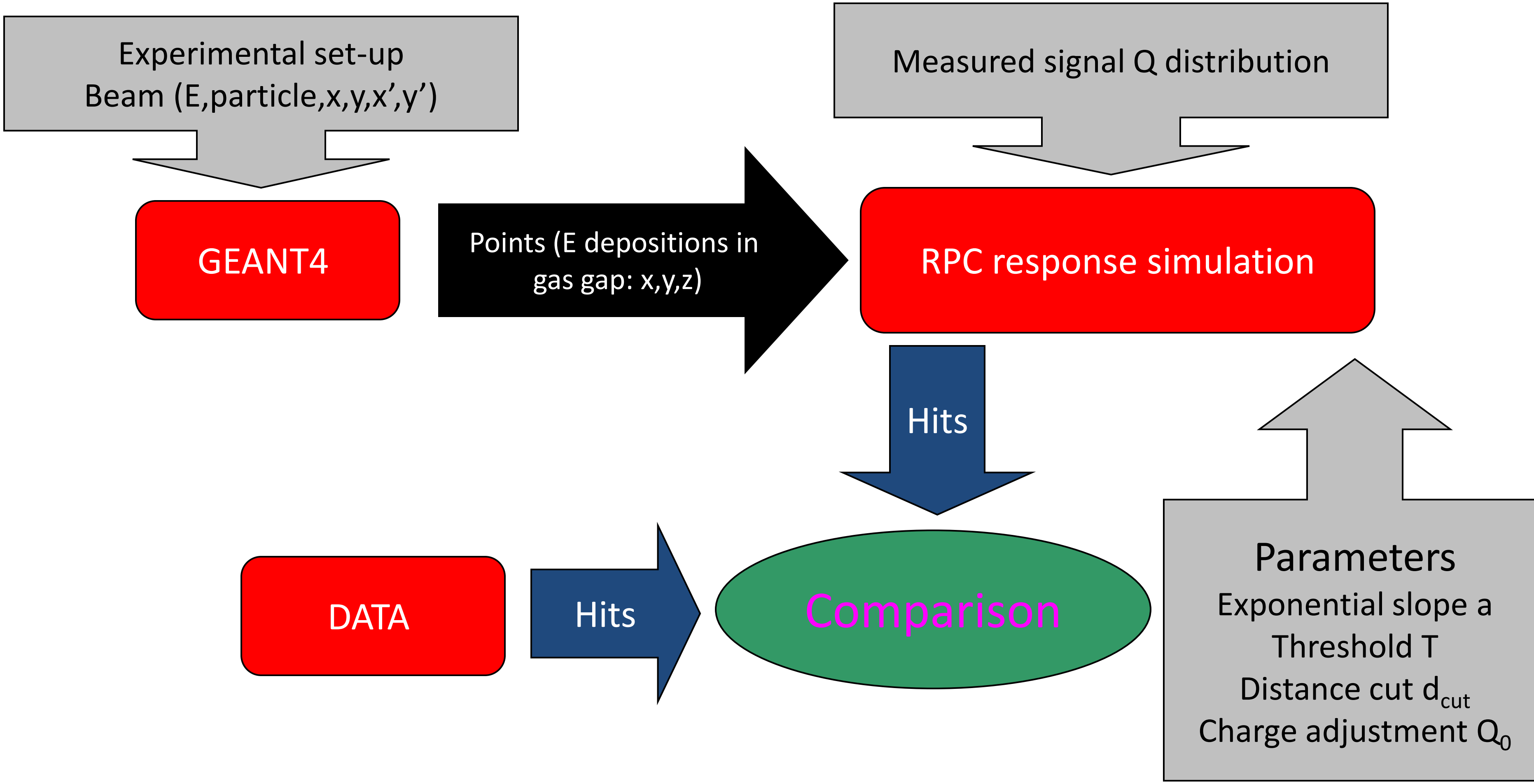
Results compared to **GEANT4 + RPCSIM simulation**

RPCSIM tuned to reproduce performance in 'clean' regions
Reasonable agreement with data observed

Data appear to be of very high quality

Backup Slides

Simulation Strategy



With muons – tune a, T, (d_{cut}), and Q_0
With positrons – tune d_{cut}
Pions – no additional tuning

RPCSIM Parameters

Distance d_{cut}

Distance under which there can be only one avalanche
(one point of a pair of points randomly discarded if closer than d_{cut})

Charge Q_0

Shift applied to charge distribution to accommodate possible differences in the operating point of RPCs

Slope a_1

Slope of exponential decrease of charge induced in the readout plane

Slope a_2

Slope of 2^{nd} exponential, needed to describe tail towards larger number of hits

Ratio R

Relative contribution of the 2 exponentials

Threshold T

Threshold applied to the charge on a given pad to register a hit