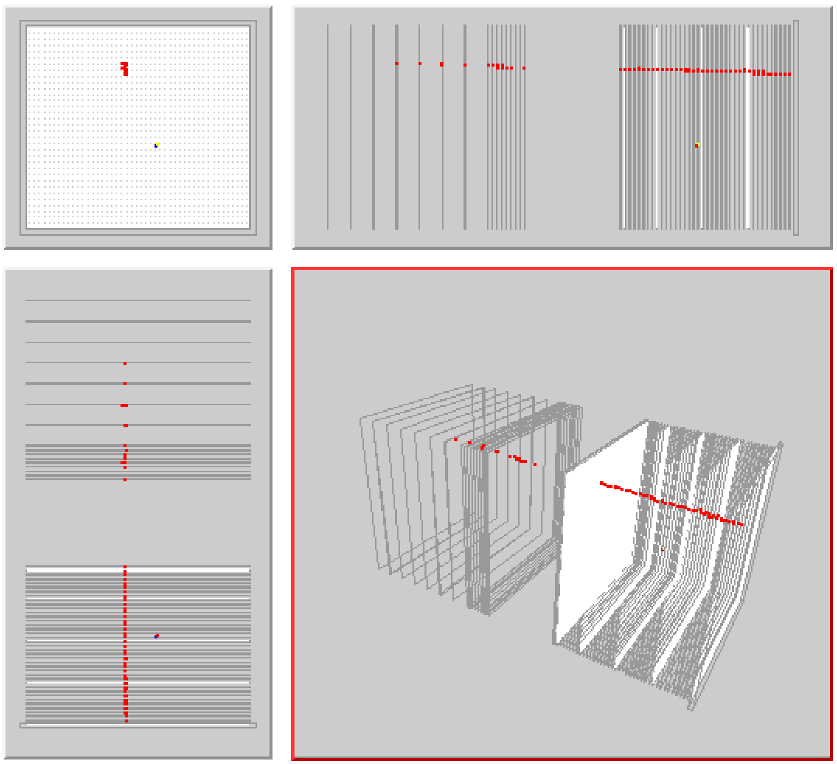
Analysis of Muon Events in the DHCAL



José Repond
Argonne National Laboratory

ALCPG 2011 Meeting, University of Oregon, Eugene, OR

DHCAL Analysis Strategy

Noise measurement

- Determine noise rate
- Identify (and possibly mask) noisy channels
- Provide random trigger events for overlay with MC events

Measurements with muons

- Align layers in x and y
- Determine efficiency and multiplicity in 'clean' areas
- Simulate response with GEANT4 + RPC_sim (requires tuning)
- Determine efficiency and multiplicity over the whole 1 x 1 m^2
- Compare to simulation and tune 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 RPC_sim
- 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…

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

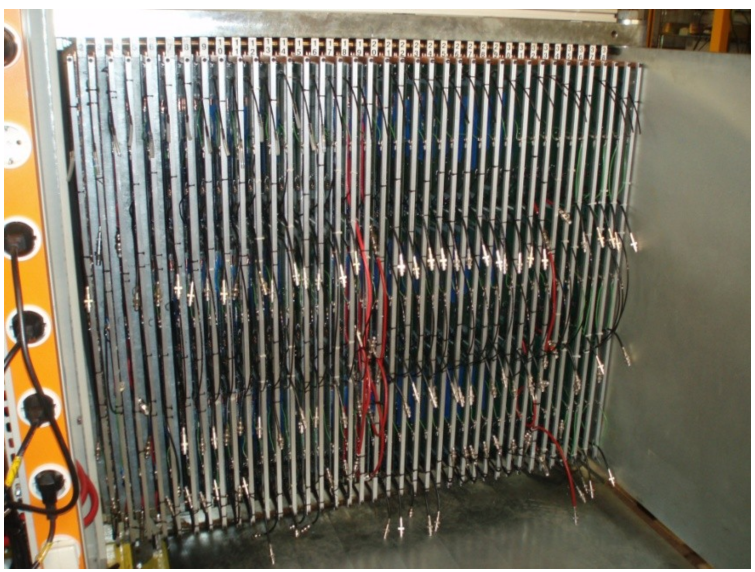
DCHAL Collaboration	Heads
Engineers/Technicians	22
Students/Postdocs	8
Physicists	9
Total	**39**

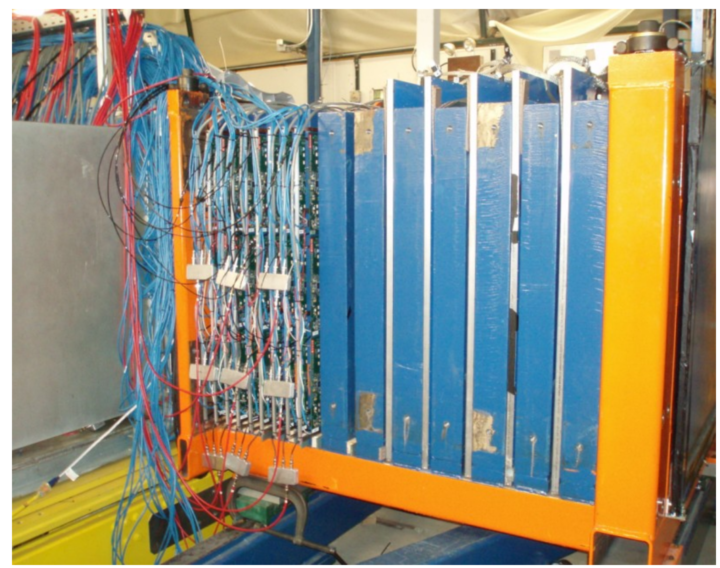
…and integral part of CALICE

Calorimeter for ILC

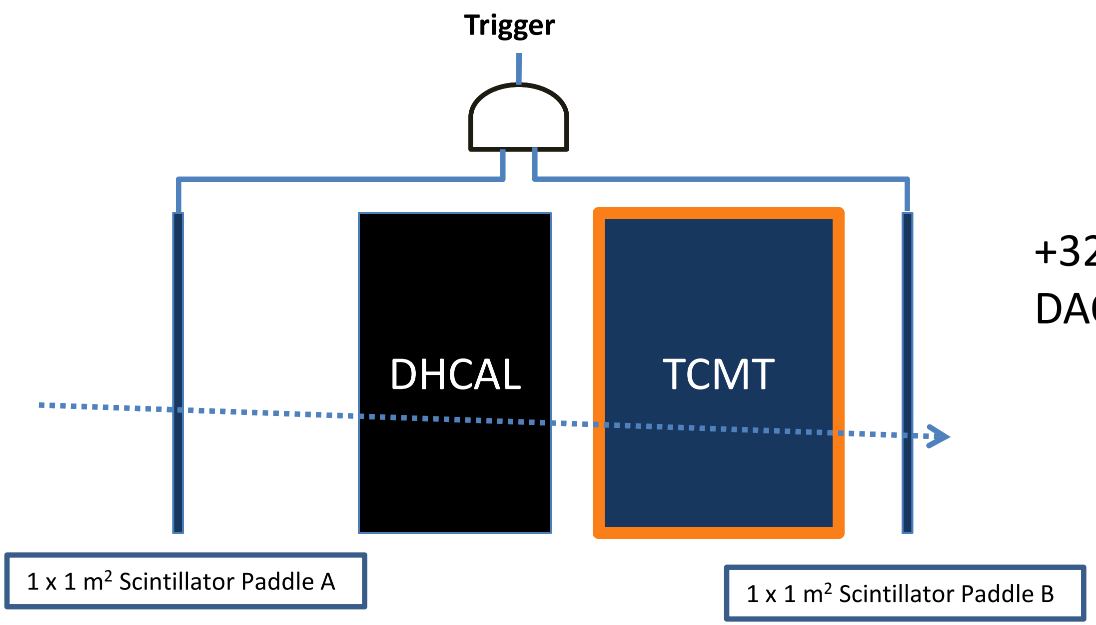
The DHCAL in the Test Beam

Run	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





Beam and Trigger for Muon events



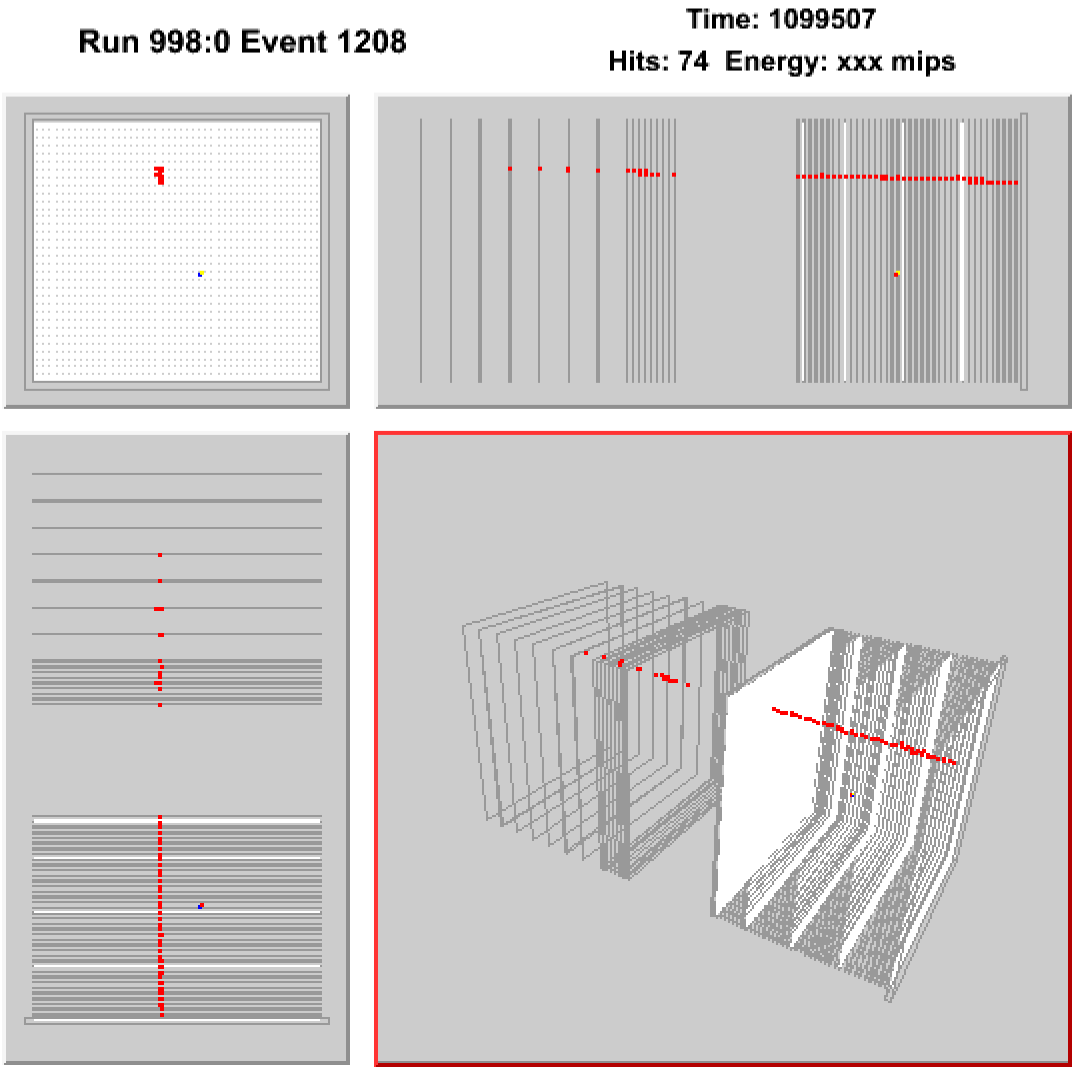
+32 GeV/c secondary beam + 3m Fe
DAQ rate typically 500/spill

Run	# of muon events
October 2010	1.4 Million
January 2011	1.6 Million

Some cute muon events

Note: Consecutive events (not selected)

Look for random noise hits



Analysis strategy

A) Establish track parameters and average response away from troubled areas

a) **Select clean muons**

- apply cleaning cuts (1 cluster in layer 0, not more than 3 hits in layer 0) ✓
- fit track to straight line (omitting layer to be measured)
- select clean tracks (cut on slope, Chi2, points on track)
- extrapolate to layer to be measured

b) **Align the boards in x and y** ✓

c) **Measure track parameters**

- measure impact point on layer 0 ✓
- measure slope in both x and y

d) **Cut out troubled areas in layer to be measured**

- dead areas
- regions between RPCs ✓
- regions around fishing lines
- edges in x
- high multiplicity layer

e) **Measure spectrum of number of pads hit**

- for all layers ✓
- for each layer separately

f) **Scan across pads** ✓

- measure average number of hits/multiplicity

B) Simulate muons

a) **Use 20 GeV/c muons** ✓

b) **Compare track parameters**

adjust impact point on layer 0 so it matches the data
adjust slope in both x and y so it matches the data ✓

c) **Cut out troubled areas in layer to be measured (apart from 'dead areas' same as data**

regions between RPCs
regions around fishing lines
edges in x ✓

d) **Measure spectrum of number of pads**

for all layers ✓

e) **Adjust RPC_sim parameters**

adjust RPC_sim parameters to reproduce the measured spectrum of number of pads ✓

C) Compare muon response everywhere

a) **Select clean muons**

apply cleaning cuts ✓
fit track to straight line (omitting layer to be measured)
select clean tracks
extrapolate to layer to be measured

b) **Measure spectrum of number of pads in regions of x and y (squares)**

for all layers only cutting out dead areas ✓

c) **Compare to simulation**

adjust simulated geometry to reproduce measurement

- thickness of fishing line
- thickness of borders
- corners?

d) **Compare each layer to average response**

determine $c_{ij} = \langle hit \rangle_{layer\ ij} / \langle hit \rangle_{total}$ i = layer number, j = 1,2,3 for top, middle and bottom RPC

→ These are the calibration constants!

D) Detailed muon studies I

a) **Select clean muons**

apply cleaning cuts ✓
fit track to straight line (omitting layer to be measured)
select clean tracks
extrapolate to layer to be measured

b) **Measure efficiency/multiplicity as function of position on pads**

Compare to simulation ✓

c) **Determine position resolution of extrapolated track positions**

Look at response as function of y

- Identify gas barriers
- Identify gaps between RPCs

E) Detailed muon studies II

a) **Select clean muons**

apply cleaning cuts
fit track to straight line (omitting layer to be measured)
select clean tracks
extrapolate to layer to be measured

b) **Measure efficiency/multiplicity**

Perform systematic studies of track selection

Tracking

Clustering of hits

Performed in each layer individually
Use close 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 $N^j_{hit} \leq 4$, otherwise don't use this cluster for tracking
request at least 10/37 layers with tracking clusters
fit straight line to ($x_{cluster}$,z) and ($y_{cluster}$,z) of all clusters j not in layer i
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

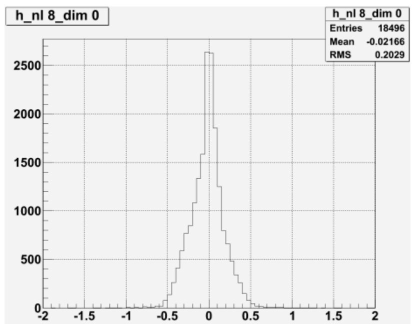
Alignment

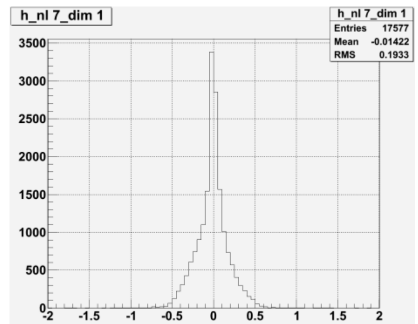
For each layer i plot residual in x/y

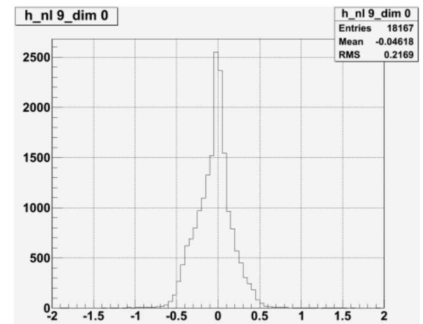
$R^i_x = x^i_{cluster} - x^i_{track}$
$R^i_y = y^i_{cluster} - y^i_{track}$

Dimensions in [cm]

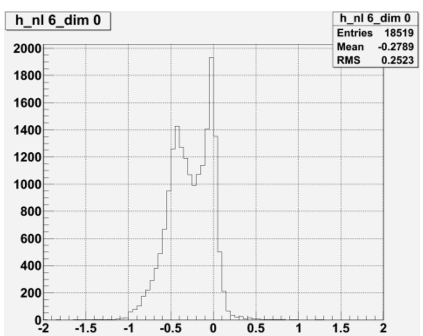
Most distributions look OK (Dimensions in [cm])



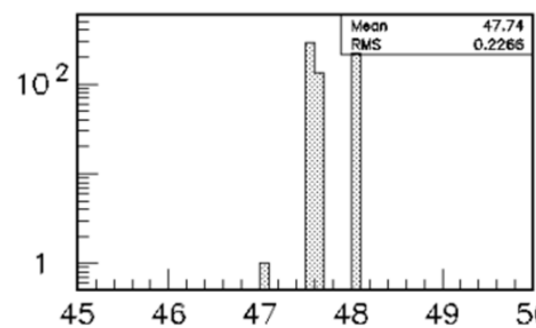




Few have double peaks

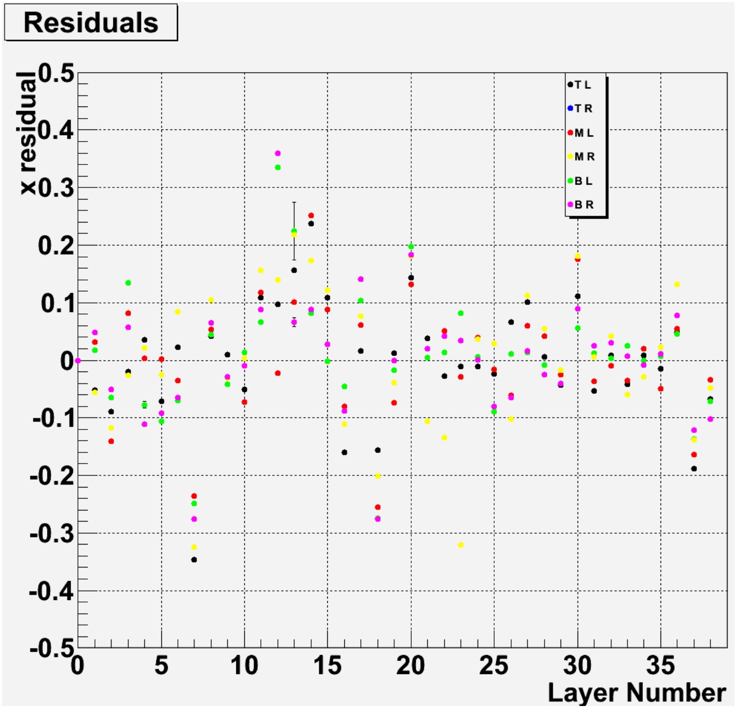


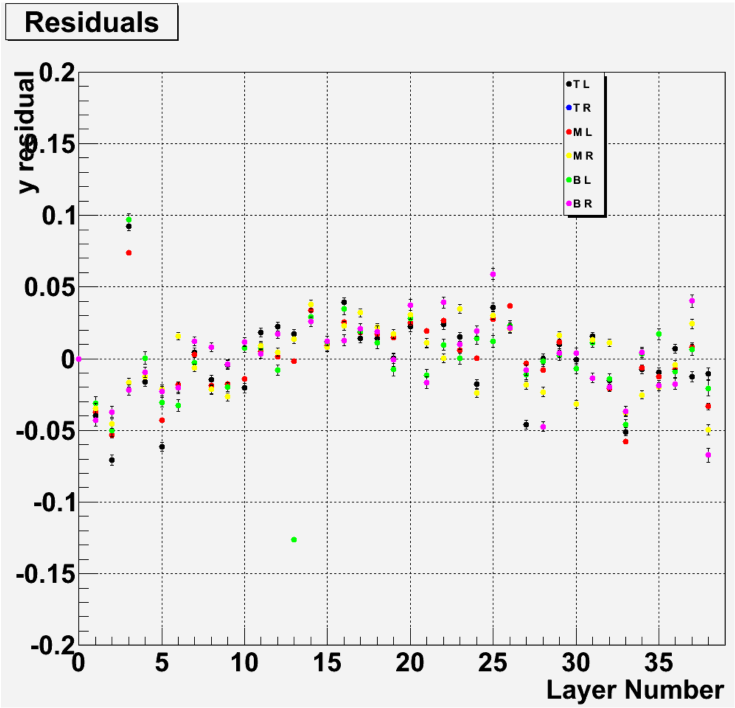
As does simple toy MC



Residuals for each Front-end board versus layer#

Mean of residual distributions





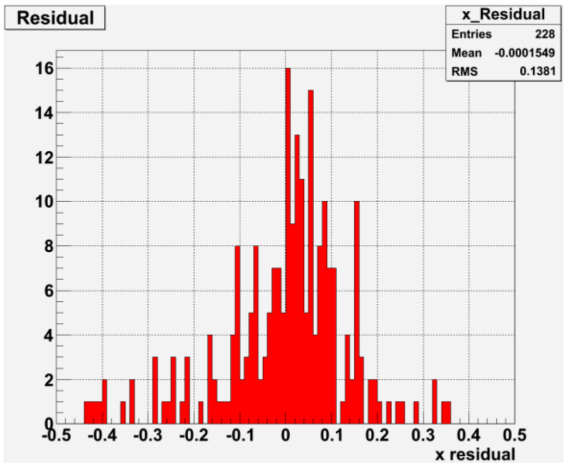
x-residual

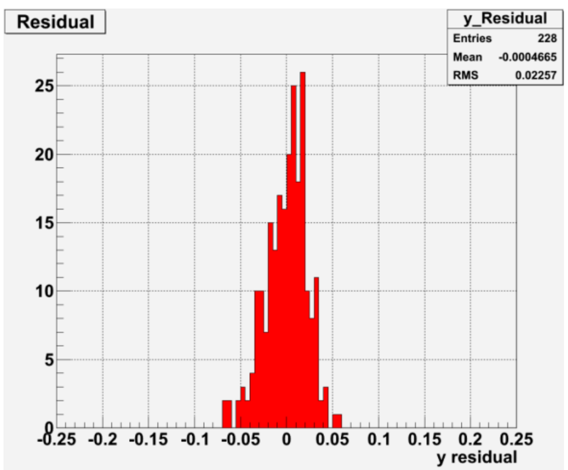
Variations of < 3 mm
Alignment of layers by hand
Correlation between boards within a layer

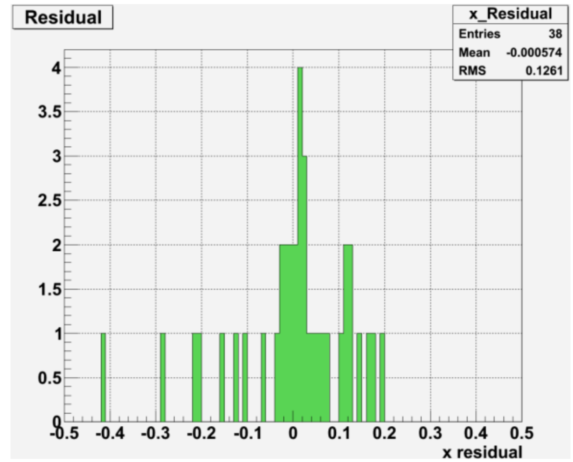
y-residual

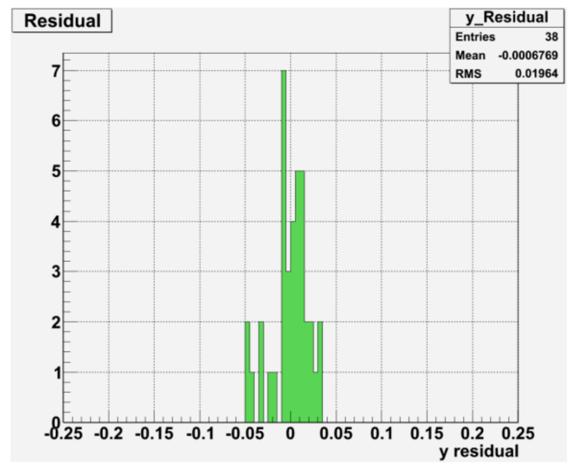
Variations of <0.5 mm
Cassette resting on CALICE structure
Systematic trend compatible with cassettes being lower in center of stack

Residuals for each Front-end board or layer



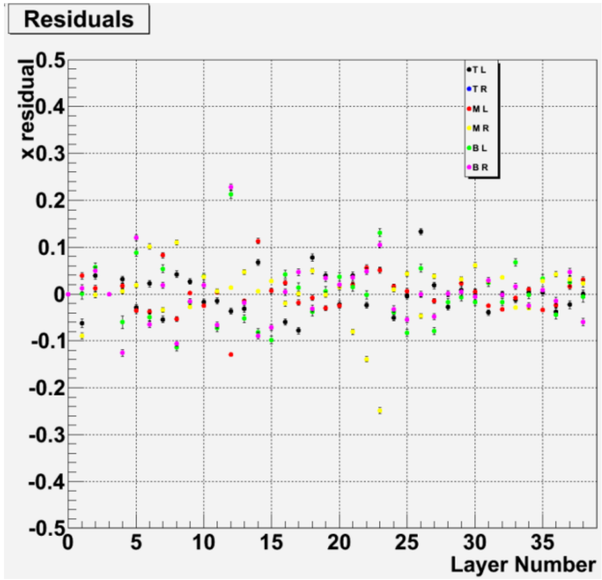


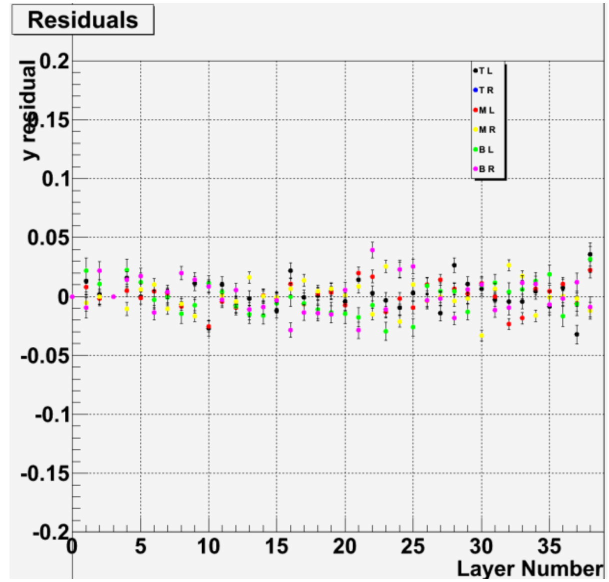




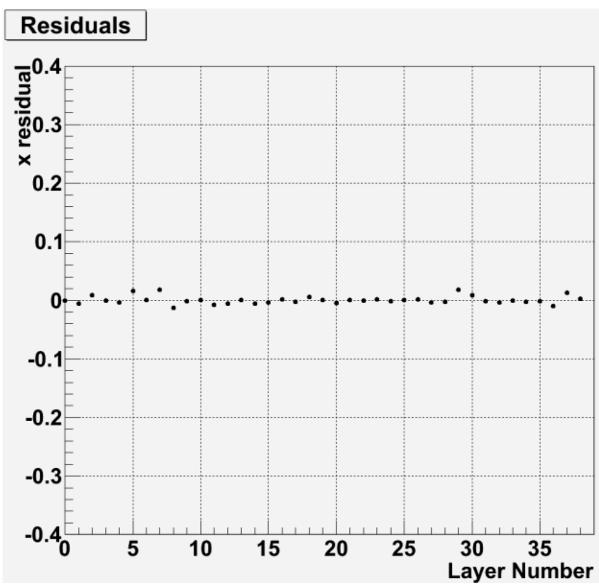
Note: mean by construction close to 0

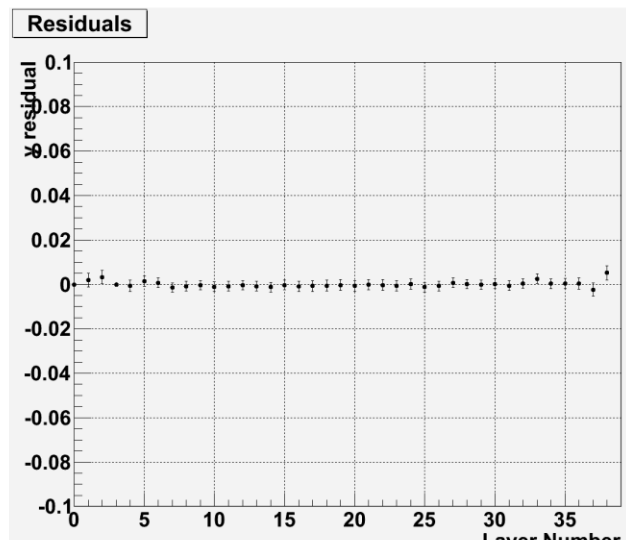
Use average residual to align layers



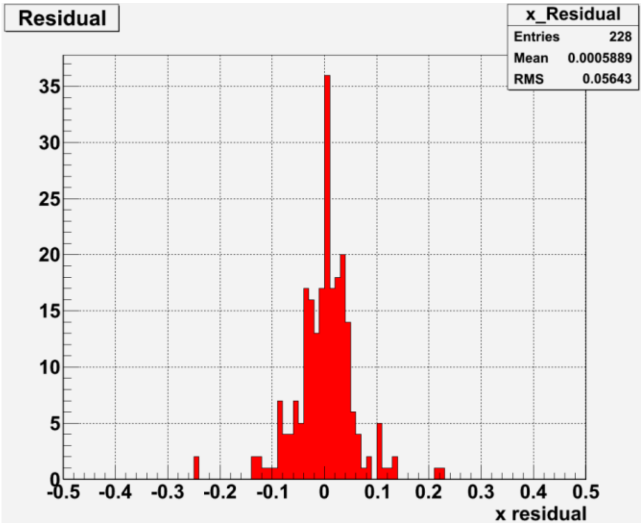


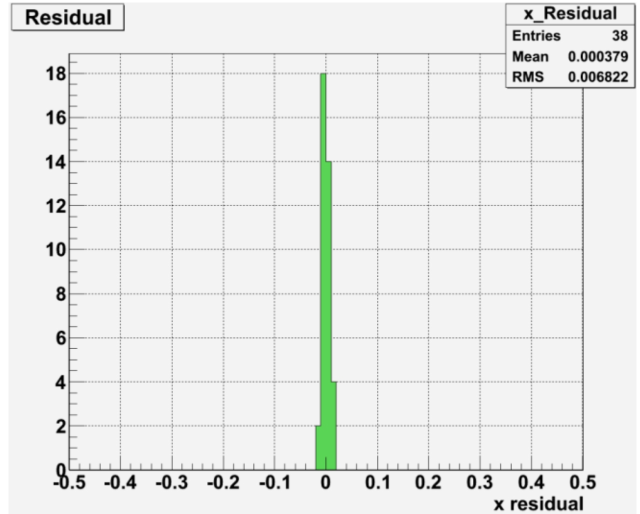
Works nicely!

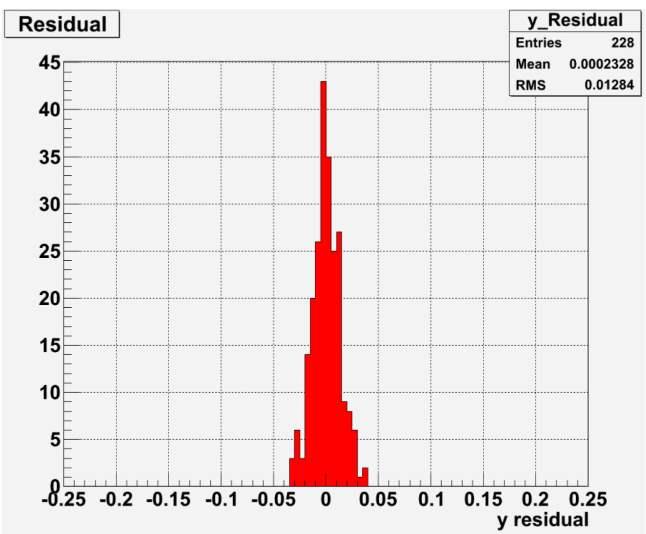


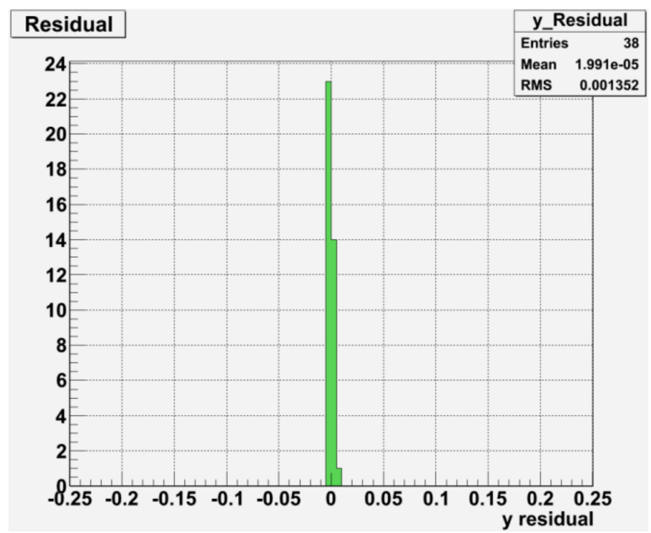


Remaining residuals after alignment









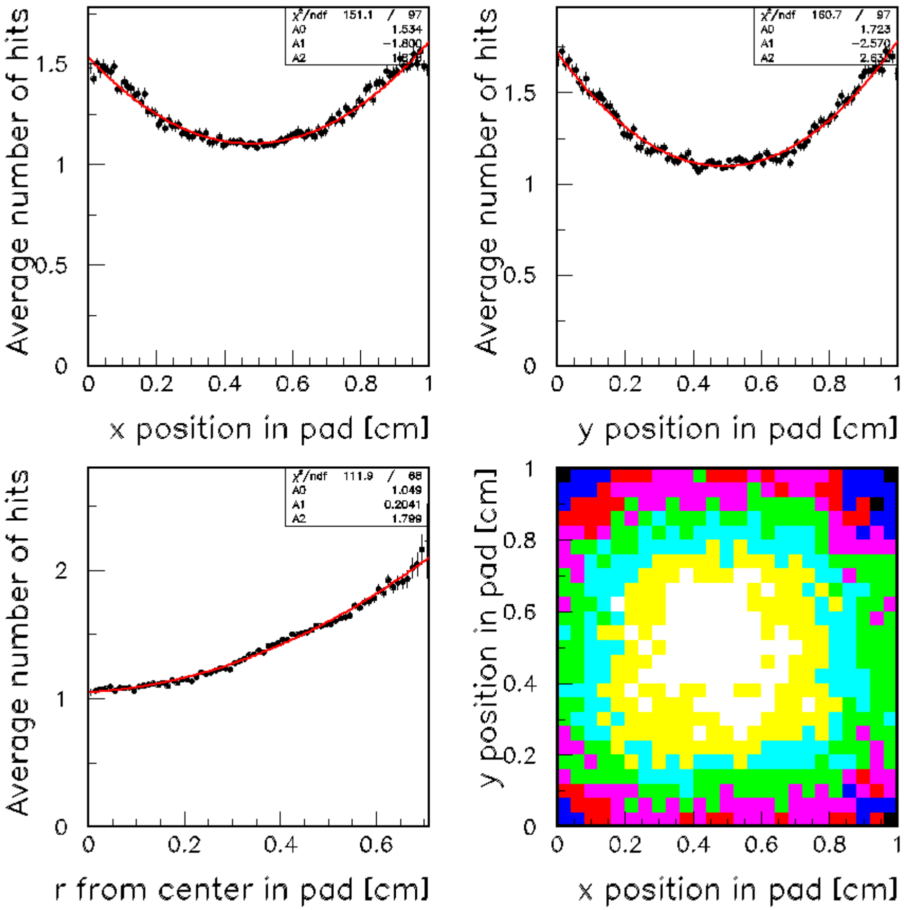
570/130 μm for FEBs

70/14 μm for layers

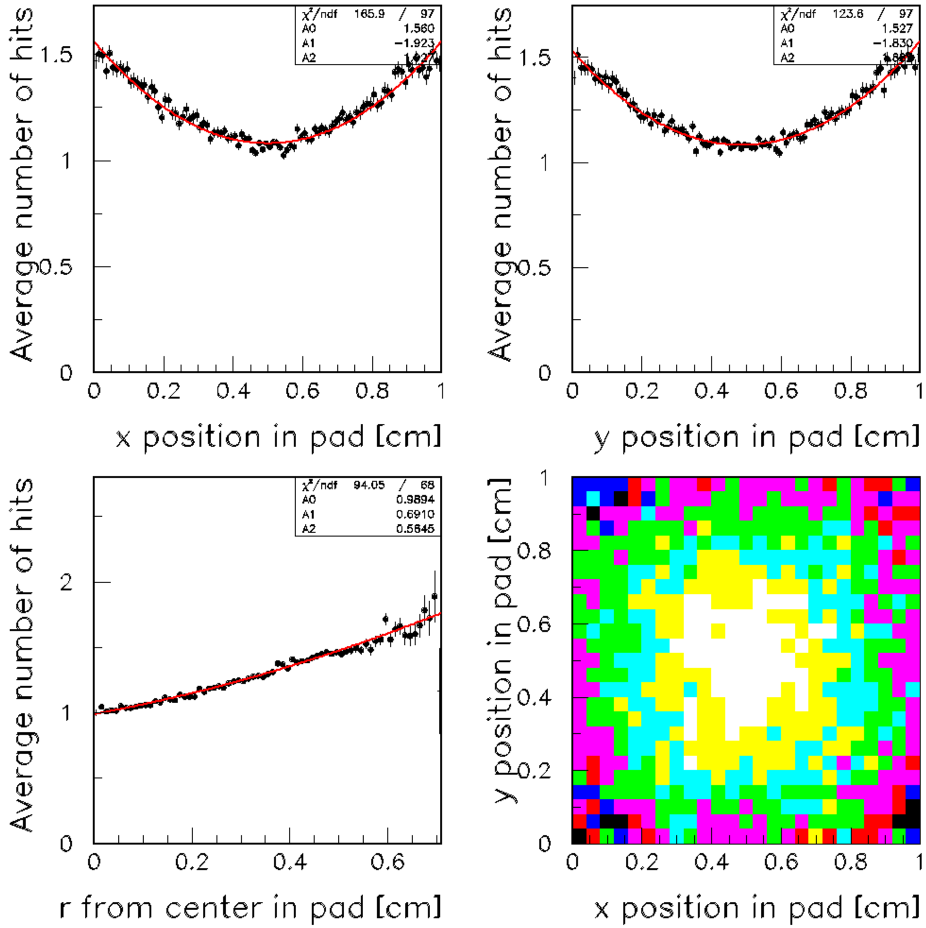
Scan across pad

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

Data



GEANT4 + (not-yet-tuned) **RPC_sim**

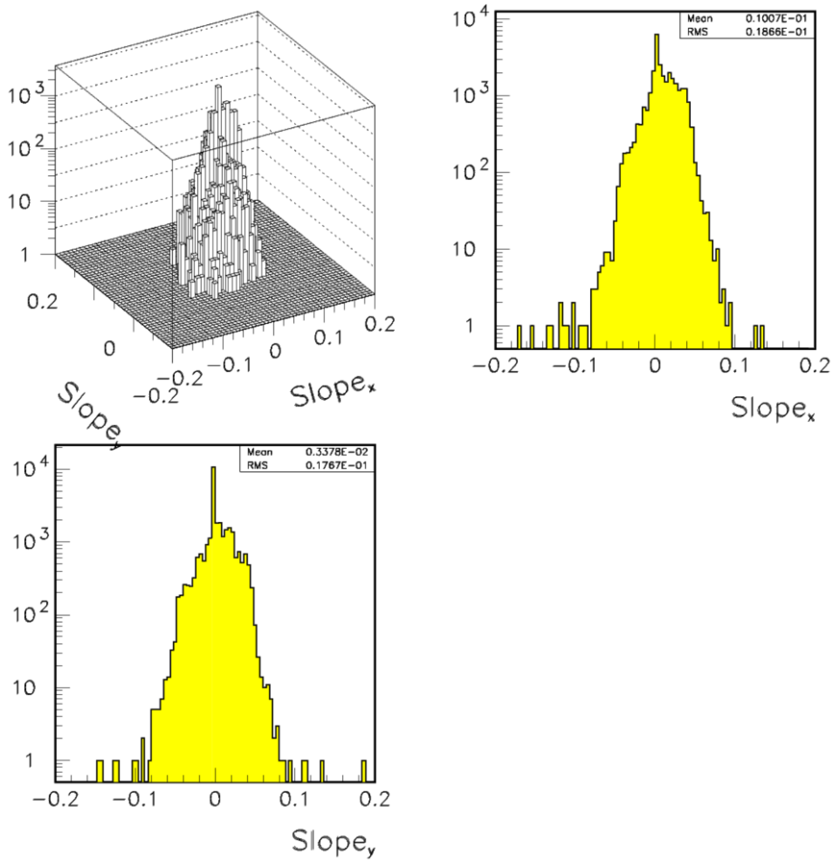


Note:

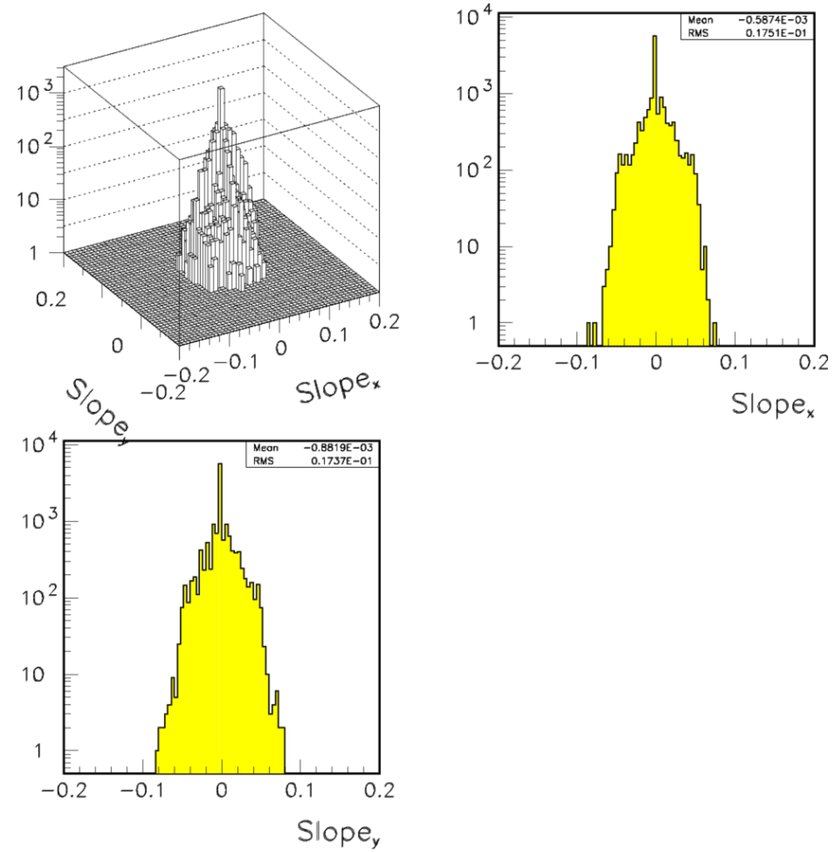
These features not implemented explicitly into simulation
Simulation distributes charge onto plane of pads…
Tracking resolution to be determined (using fishing lines e.g.)

Angles of muon tracks

Data

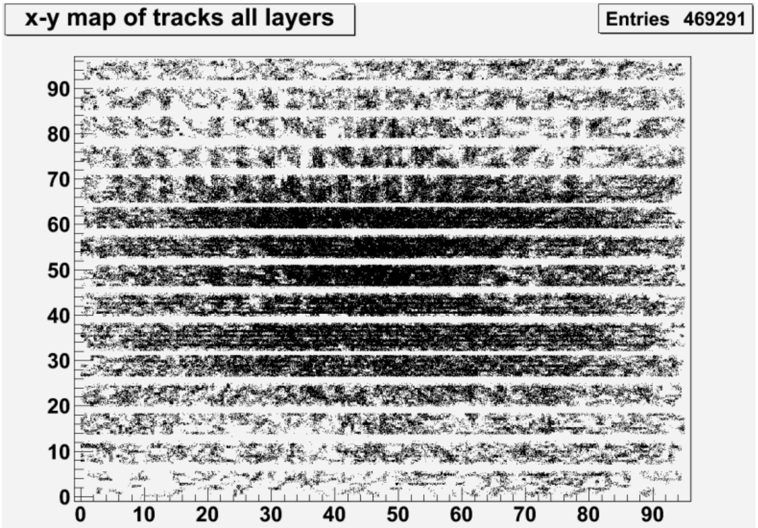


GEANT4 + (not-yet-tuned) **RPC_sim**



Good enough!

Efficiencies, multiplicities

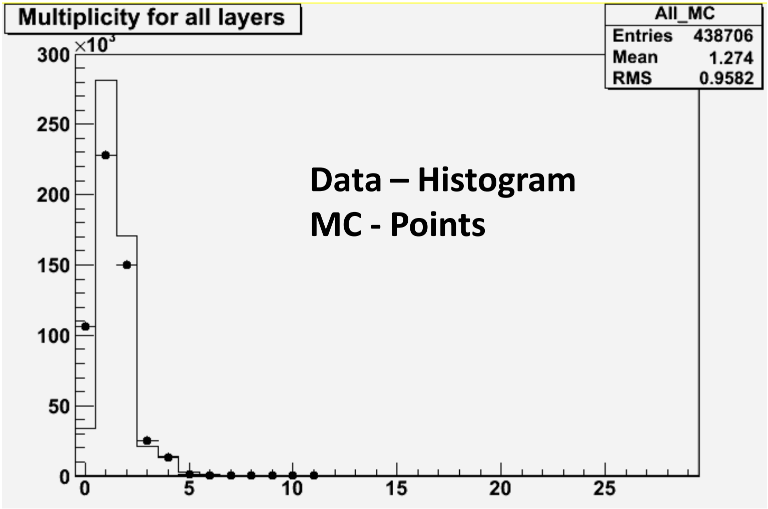


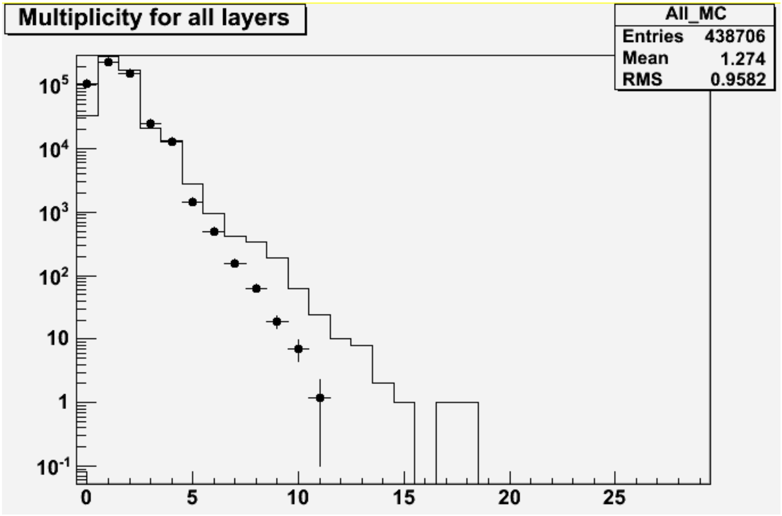
Select 'non – problematic' regions away from

- 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 mulitplicity)

Measure average response

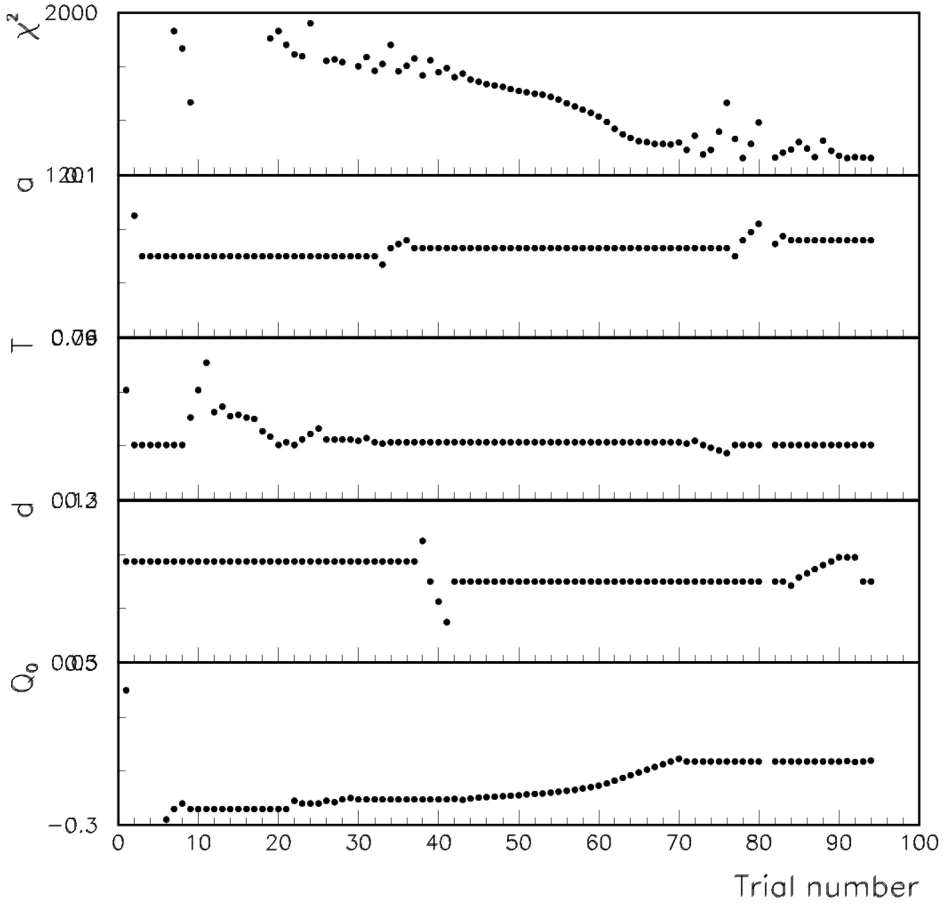
Efficiency, multiplicity



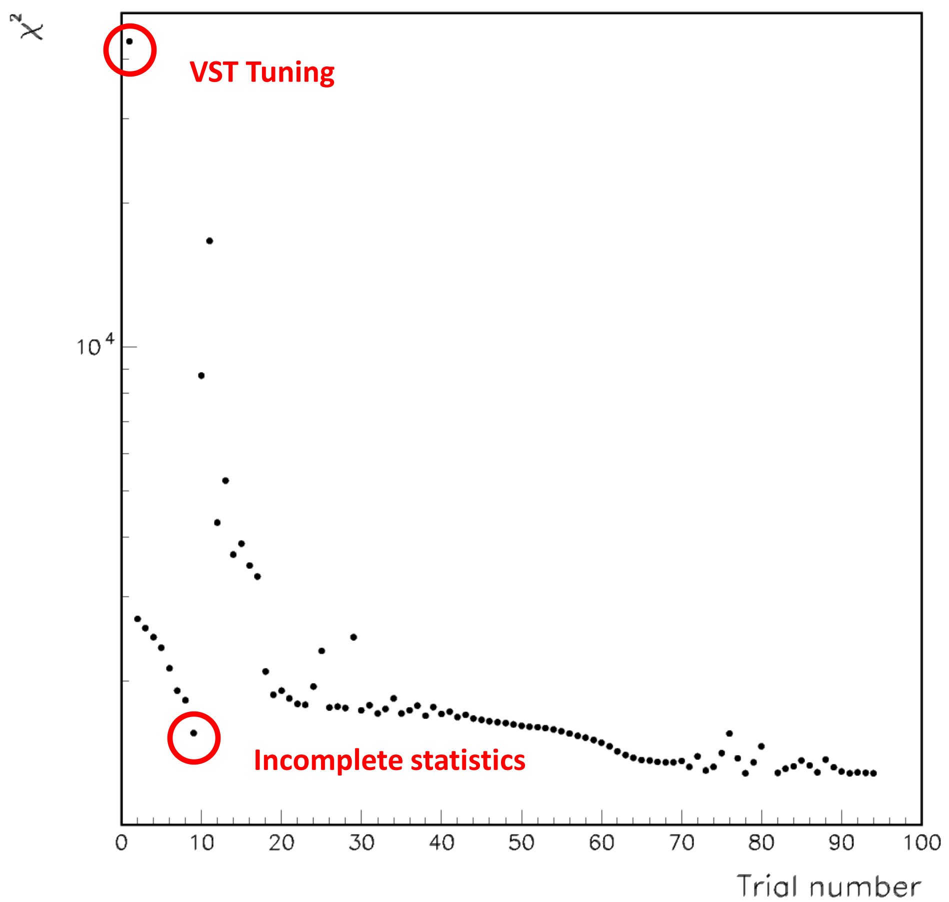


Note: Simulation of RPC tuned to Vertical Slice Test
DHCAL shows higher efficiency and lower multiplicity (thinner glass)

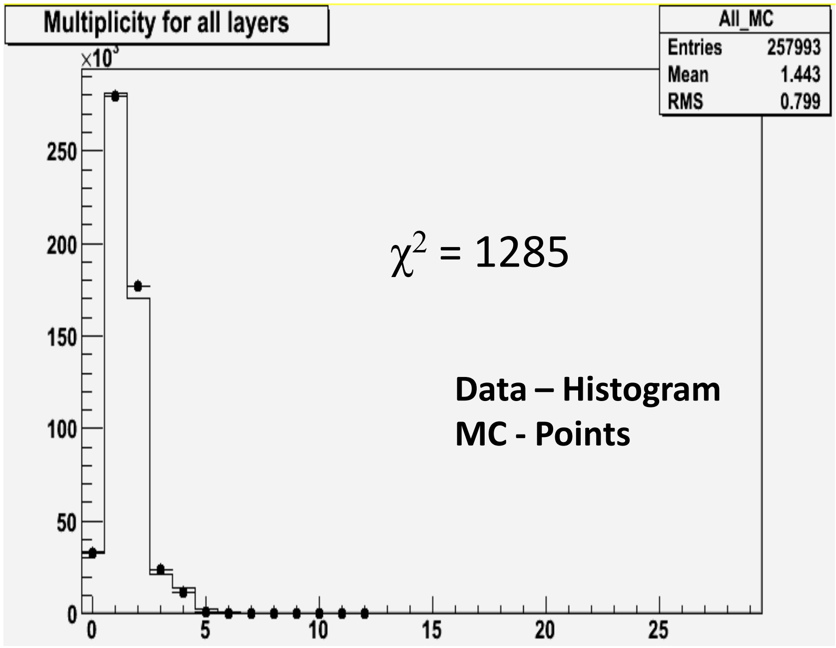
Tuning, tuning, tuning…

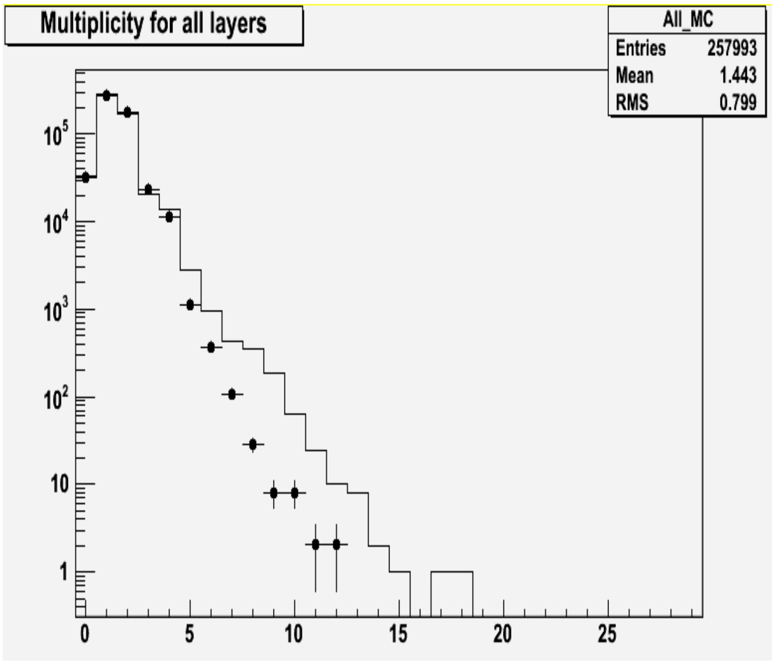


χ^2 comparison of normalized histograms of multiplicity



Current best fit





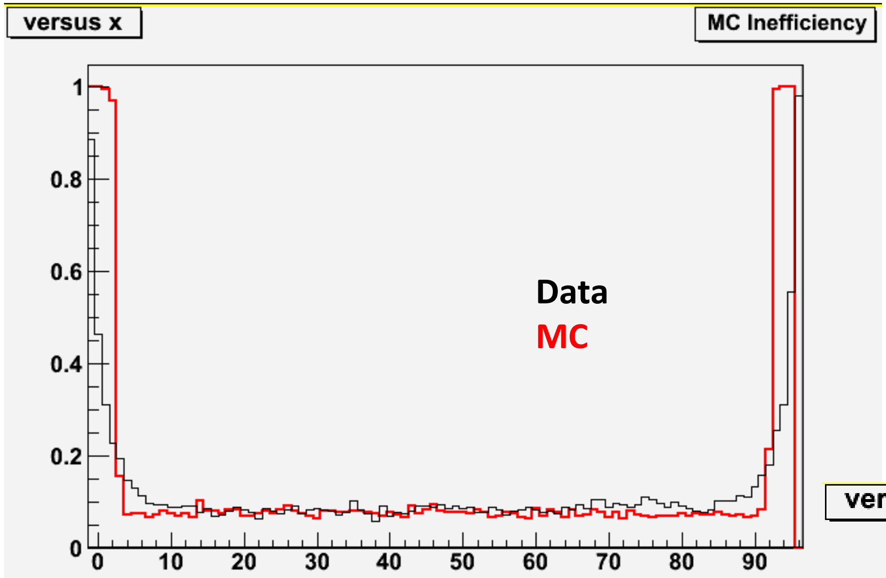
Note: High statistics (error bars « dots)
Efficiency well reproduced
Low multiplicity well reproduced
Tail problematic (excess of 0.6% in the data)

Efficiency =	93.6% in data
	93.8% in MC
Multiplicity =	1.563 in data
	1.538 in MC
Mean =	1.4614in data
	1.443 in MC

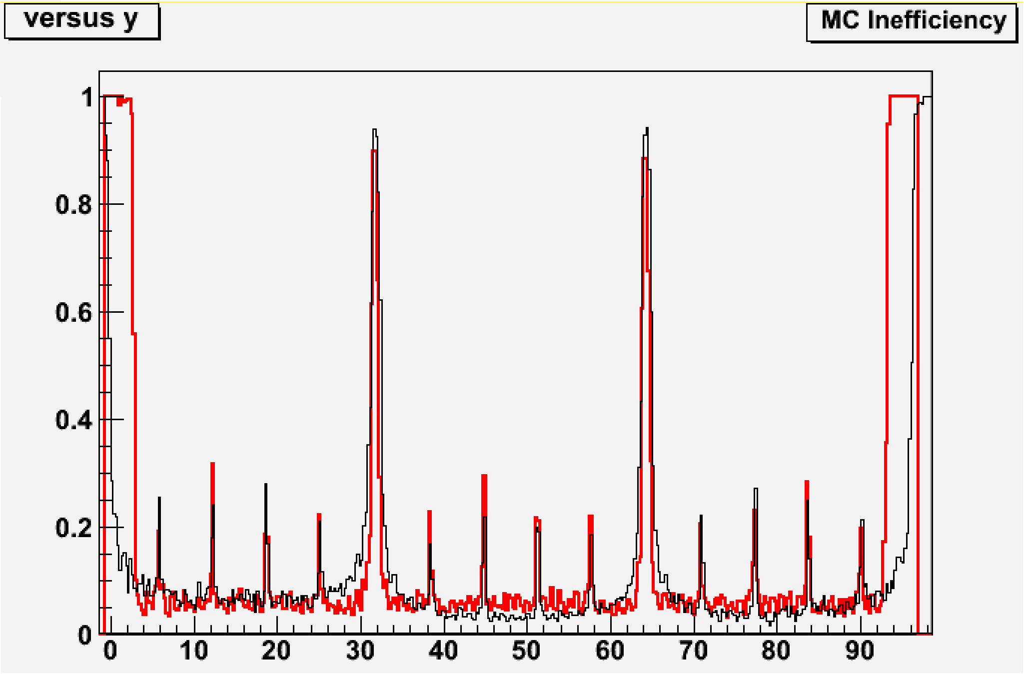
To further improve need different function to distribute charge in plane of readout pads

Response over the entire plane I

Implemented dead areas of data in MC (delete corresponding hits)



Note: x-axis in [cm] (not pad number)



x-distribution

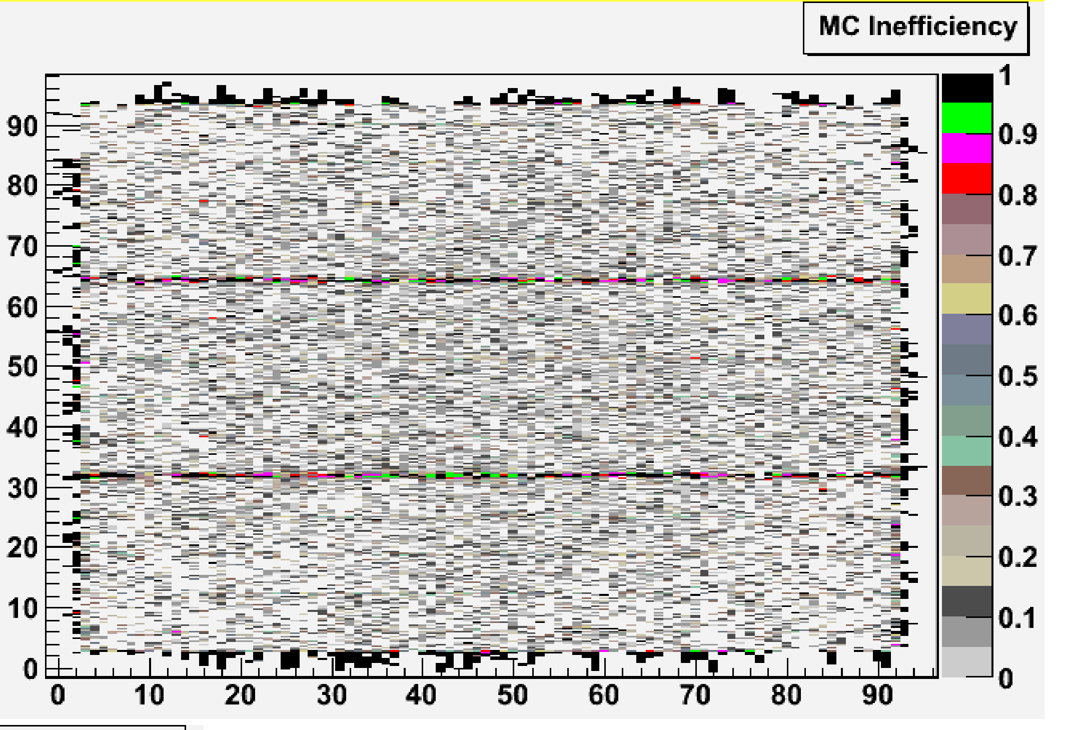
Well reproduced, apart from edges

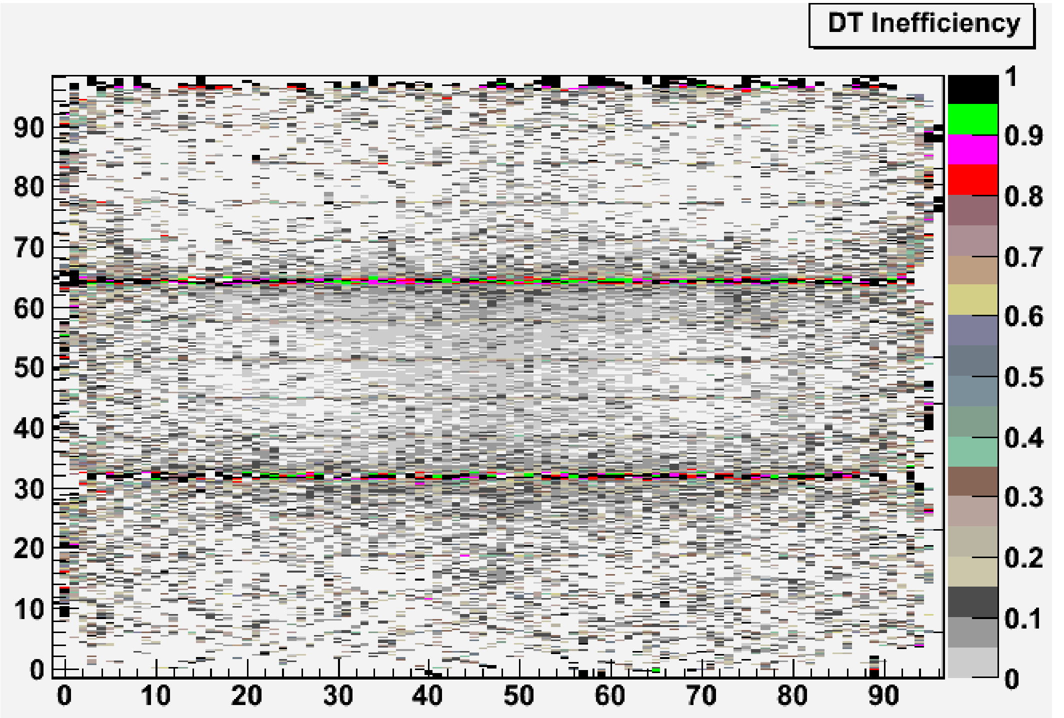
y-distribution

Inter-RPC gaps well reproduced
Fishing lines well reproduced
Edges again problematic

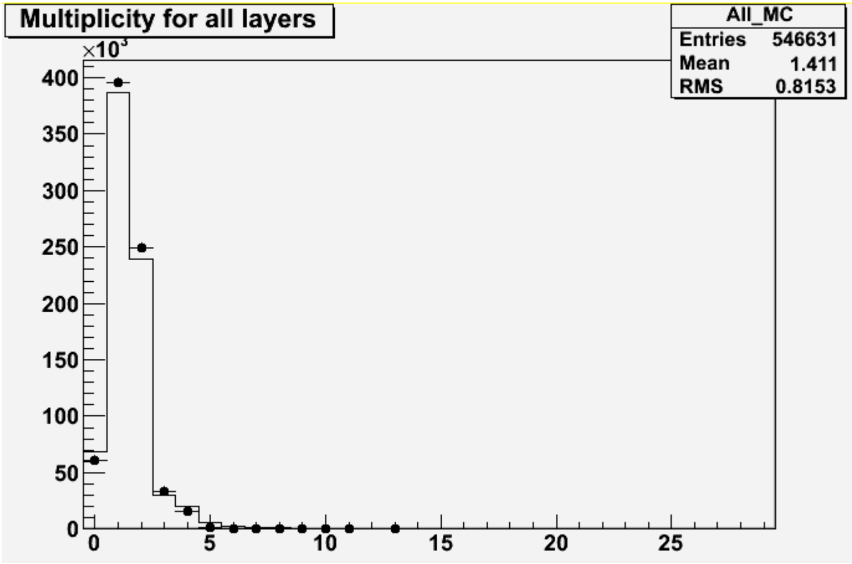
Response over the entire plane II

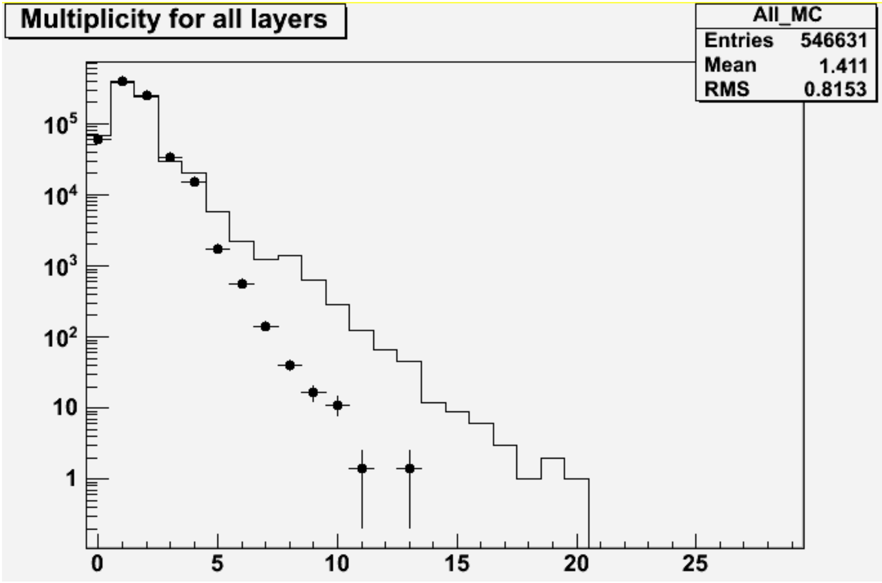
Note: distribution of tracks not the same in data and MC





Average response over the entire plane





Note: There are systematic uncertainties

→ due to track selection

→ still need to be studied

These number include the dead areas

Some tuning of the MC still needed

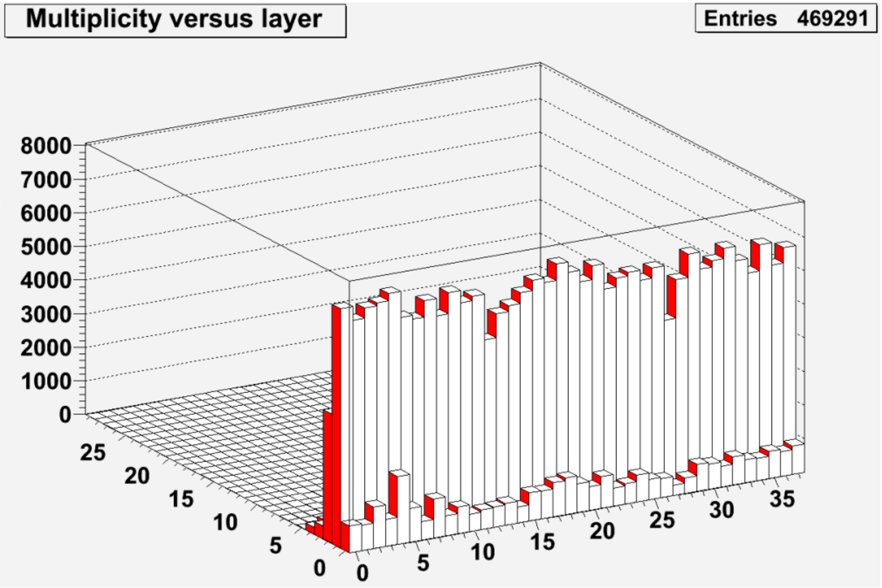
Efficiency = 90.9% in data
92.1% in MC

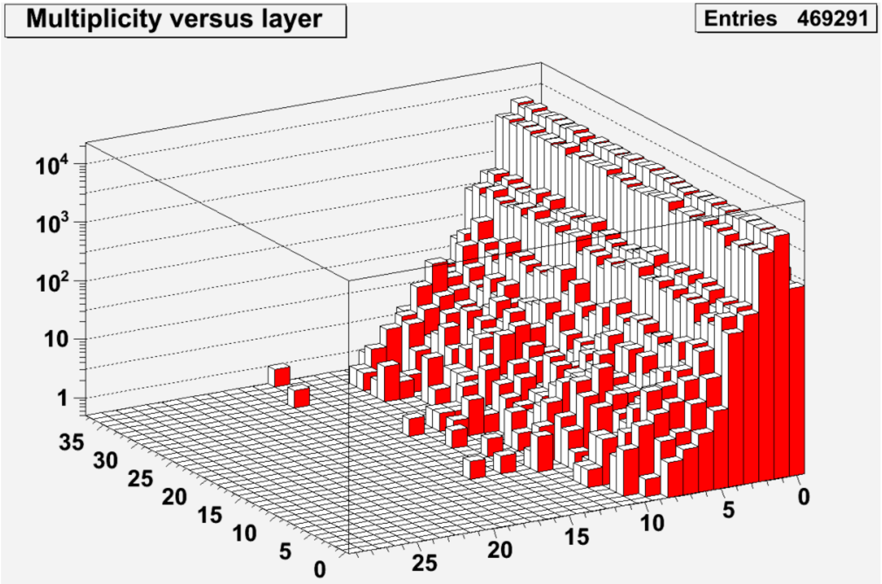
Multiplicity = 1.611 in data
1.535 in MC

Mean = 1.464 in data
1.411 in MC

Response versus layer number

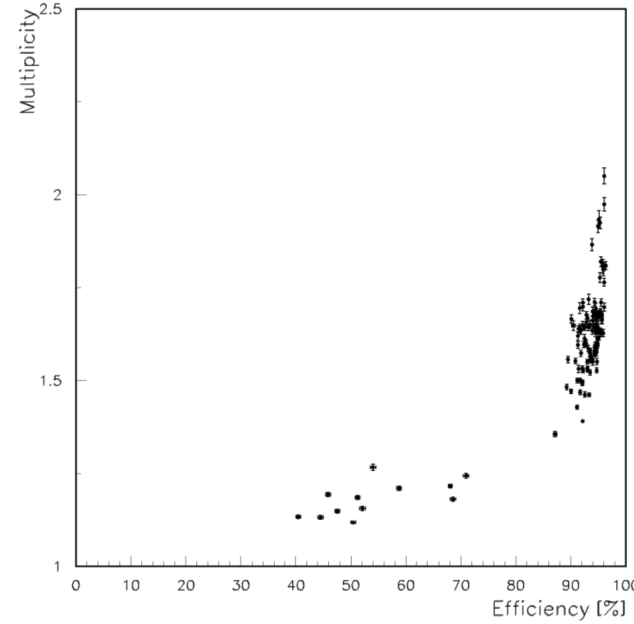
Dead areas, fishing lines, and edges are excluded



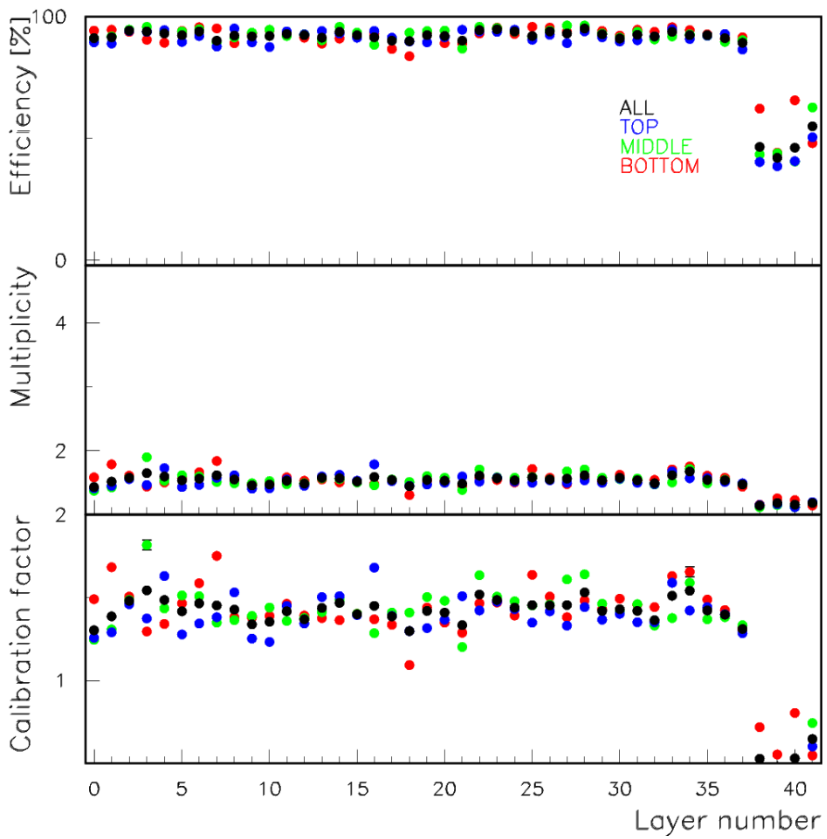


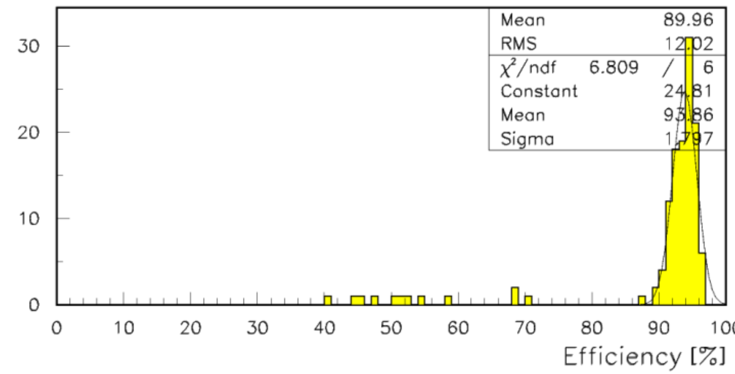
Calibration constants

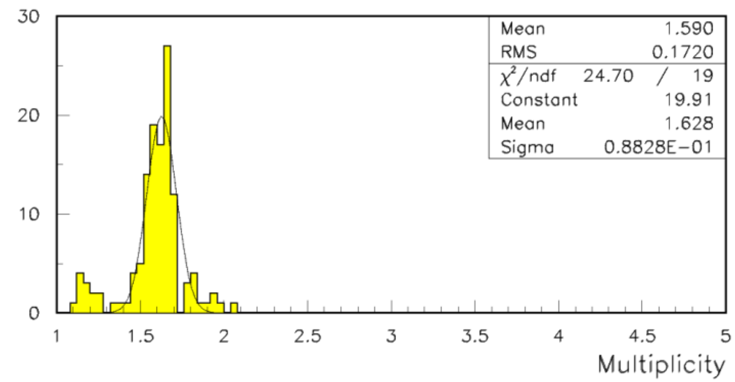
HV on TCMT not at
full value due to problems
with mainframe



DHCAL Run 610135







Calibration constants as function of time

Track segment analysis

Analysis by Burak Bilki (University of Iowa)

Track Segments Algorithm

- Use clusters in two layers (source clusters) to measure a third layer (target cluster):

  - Use Layer_2 and Layer_3 to measure Layer_1
  - Use Layer_36 and Layer_37 to measure Layer_38
  - Use Layer_(i-1) and Layer_(i+1) to measure Layer_i

- Require size of the source clusters be less then 4 hits and the distance between their centers of mass be less than 3 cm.

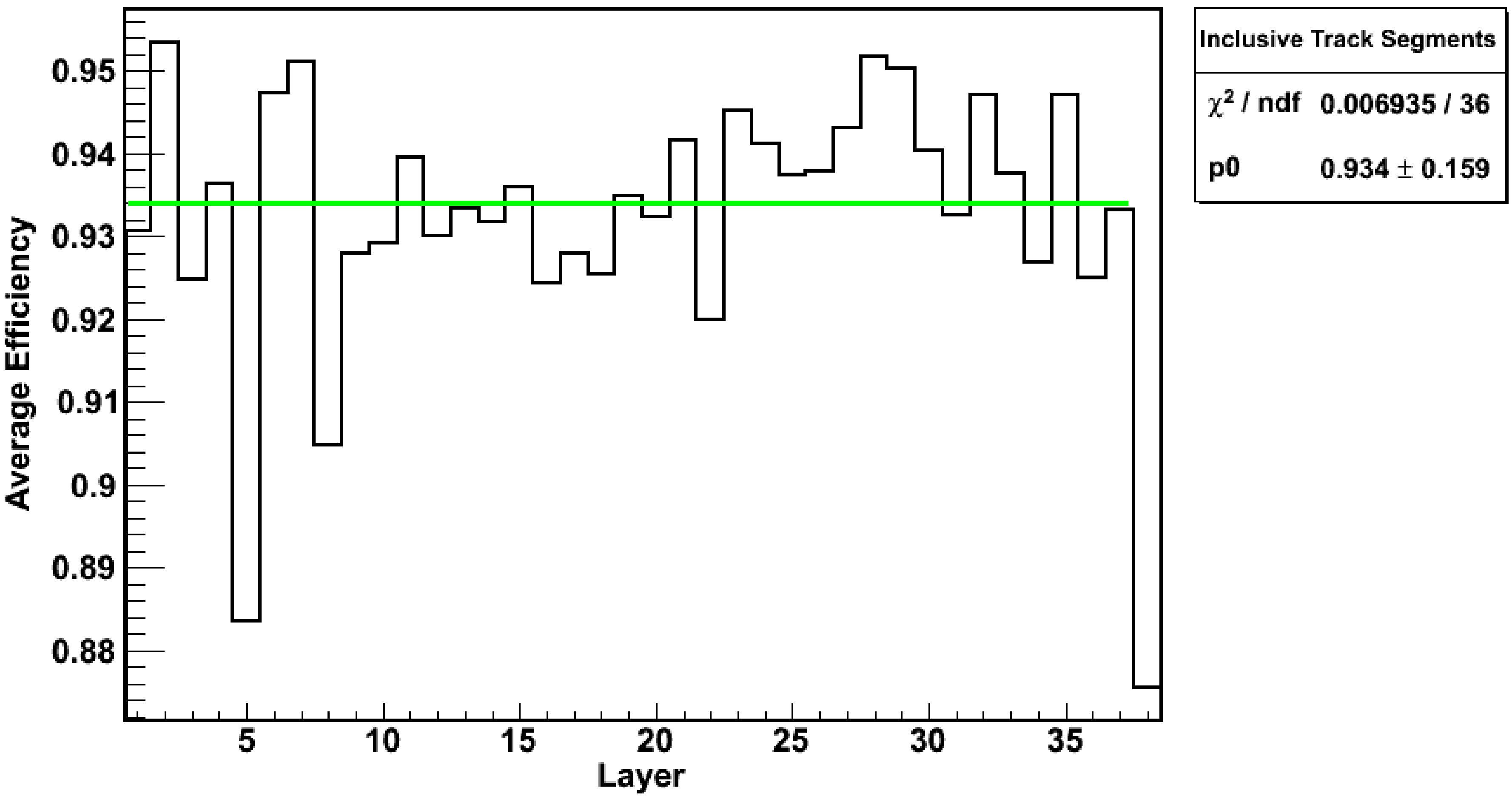
- Require the isolation of the source clusters in a 7 cm-radius circular area.

- Search for target clusters within 2 cm of the point predicted by the source clusters.

- Use Layer_(i+1) and Layer_(i-2) to measure Layer_i if the interpolated pad is in an inefficient region of Layer_(i-1).

- Similarly, use Layer_(i-1) and Layer_(i+2) to measure Layer_i if the interpolated pad is in an inefficient region of Layer_(i+1).

Track Segments Algorithm Results Efficiency



Track Segments Algorithm Results
Pad Multiplicity