DHCAL Data Analysis Update

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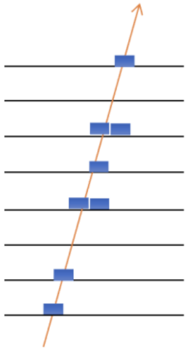
CALICE Collaboration Meeting Everywhere
March 24-26, 2021

Public Results of the Large DHCAL Prototype Tests

- CALICE-CAN-2011-001: Analysis of DHCAL Muon Data
- CALICE-CAN-2011-004: DHCAL Response to Positrons and Pions
- CALICE-CAN-2011-005: DHCAL Noise Analysis
- CALICE-CAN-2012-004: Analysis of Tungsten-DHCAL Data from the CERN Test Beam
- CALICE-CAN-2013-003: The DHCAL Results from Fermilab Beam Tests: Calibration
- B. Freund *et.al.,* "DHCAL with minimal absorber: measurements with positrons*",* *JINST* **11** P05008, 2016
- M. Chefdeville et al., "Analysis of testbeam data of the highly granular RPC-steel CALICE digital hadron calorimeter and validation of GEANT4 Monte Carlo models", Nucl. Instrum. And Meth. A 937, 41, 2019

Large gap in the completion of various analysis.
➔ Reanimate the expertise and move forward

Calibration of the DHCAL



RPC performance

Average efficiency to detect MIP: $\varepsilon_0 \sim 96\%$
Average pad multiplicity: $\mu_0 \sim 1.6$

Track Fits:

The track fits method uses dedicated muon calibration runs to assess the performance parameters of individual RPCs. This method starts with grouping the clusters that are laterally within a distance of 3 cm of each other in different layers. The group of clusters is then fit to the 3-dimensional parametric line $x=x_0+a_x t$; $y=y_0+a_y t$; $z=t$. For each layer, clusters within 2 cm of the point predicted by the fit are searched for. If a cluster is found, the layer is counted as efficient, and inefficient otherwise. If the layer is efficient, the pad multiplicity is given by the size of the found cluster.

Track Segment Fits:

The method starts with searching for four clusters that are aligned within 3 cm in four different layers. The track segment is then fit to the 3-dimensional parametric line. The measurement layer can either be within the layer span of the pick layers or outside, but only one measurement layer per track segment is allowed. In the measurement layer, clusters within 2 cm to the fit point are searched for. If a cluster is found, the layer is measured as efficient, and inefficient otherwise. If the layer is efficient, the pad multiplicity is measured as the size of the found cluster.

Calibration of the DHCAL

1. Full Calibration: $$H_{calibrated} = \sum_{i=RPC_0}^{RPC_n} \frac{\varepsilon_0 \mu_0}{\varepsilon_i \mu_i} H_i$$ H_i: Number of hits in layer i

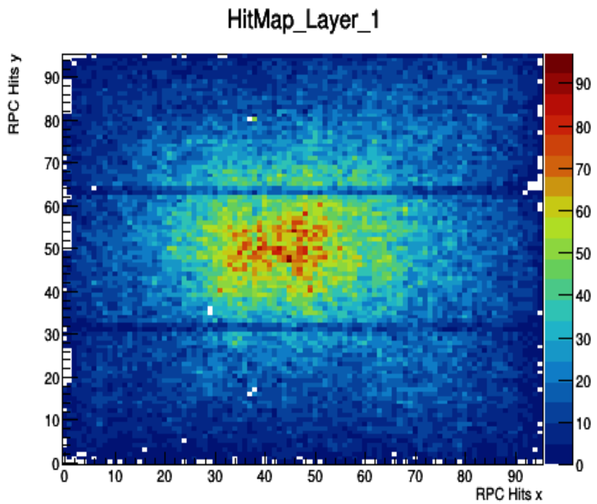
2. Density-weighted Calibration: Developed due to the fact that a pad will fire if it gets contribution from multiple traversing particles regardless of the efficiency of this RPC. Hence, the full calibration will overcorrect. Classifies hits in density bins (number of neighbors in a 3 x 3 array).

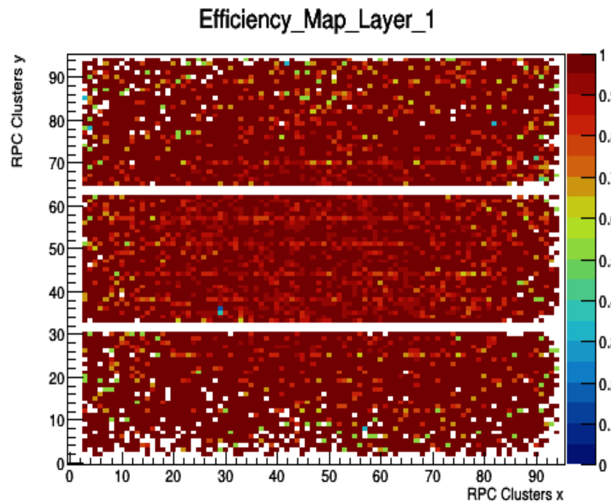
3. Hybrid Calibration: Density bins 0 and 1 receive full calibration.

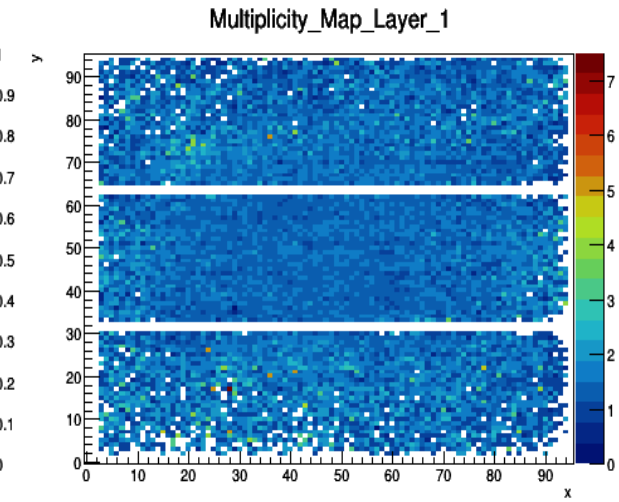
Can get quite complicated to implement. So far only full calibration with track fits was employed in the publications.

Efficiency and Pad Multiplicity

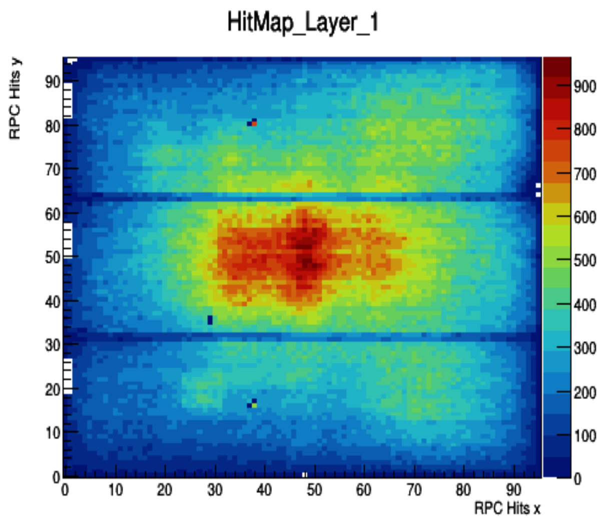
Single run

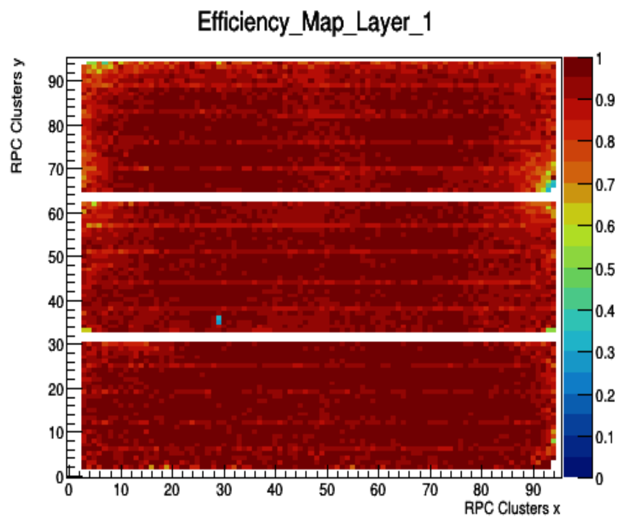


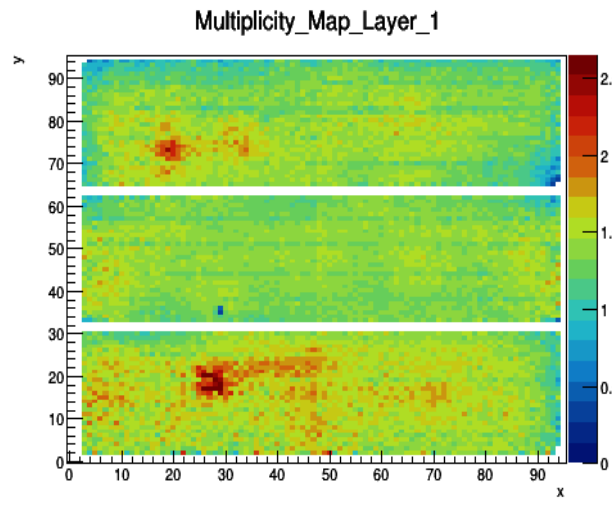




All runs in one campaign combined

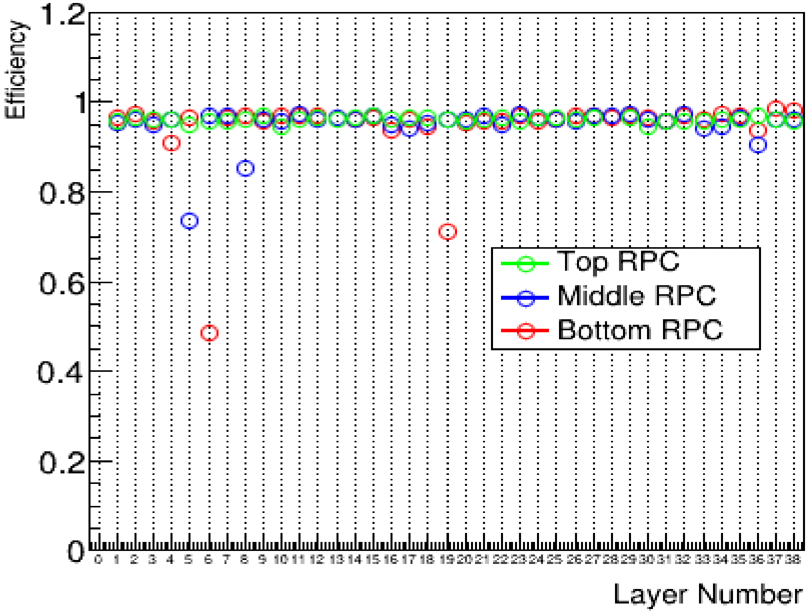


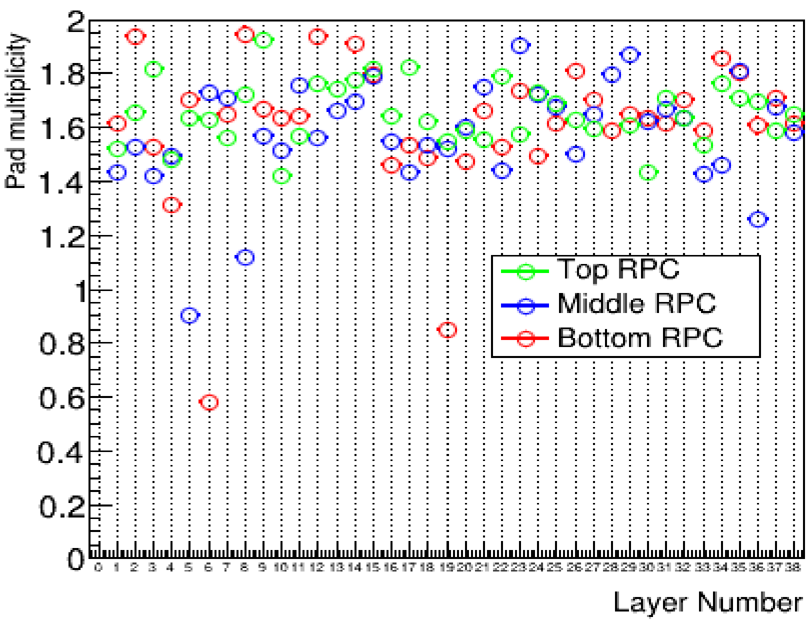


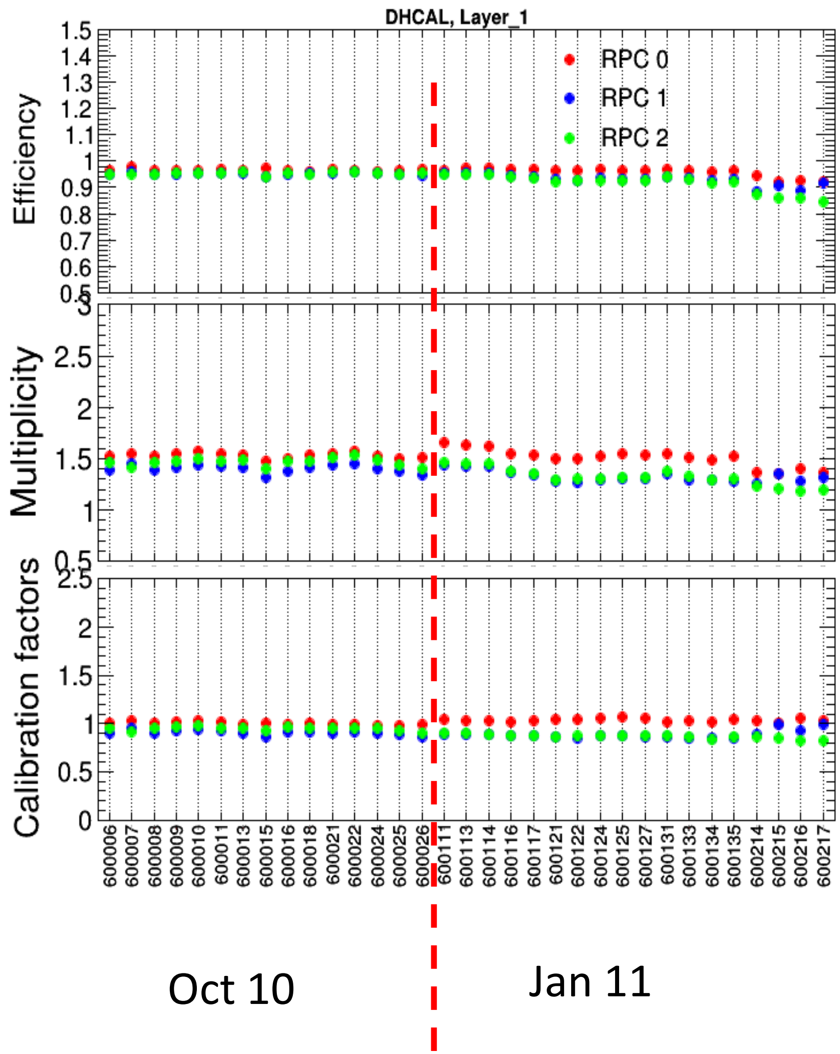


1.15 mm diameter fishing lines are visible

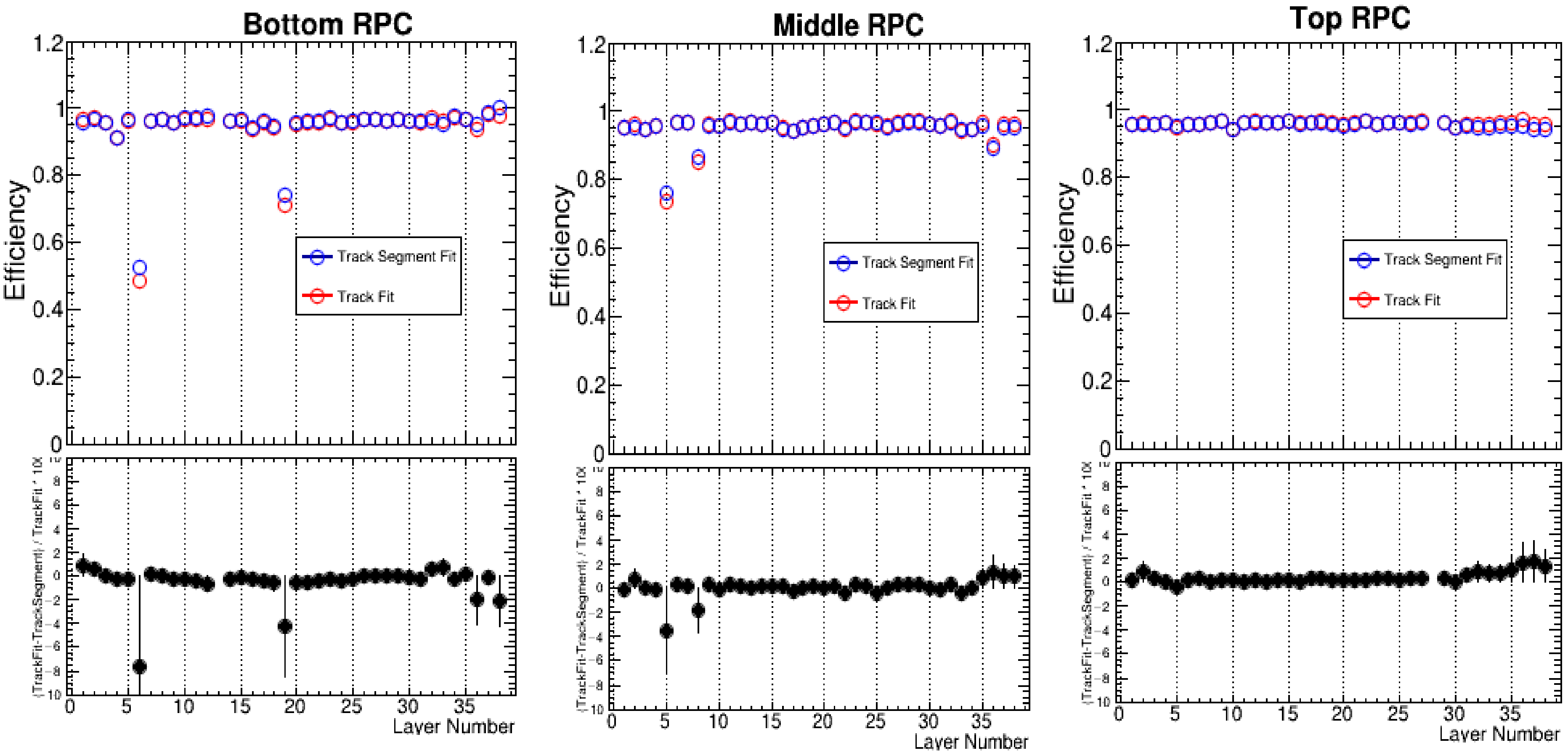
Efficiency and Pad Multiplicity Trends





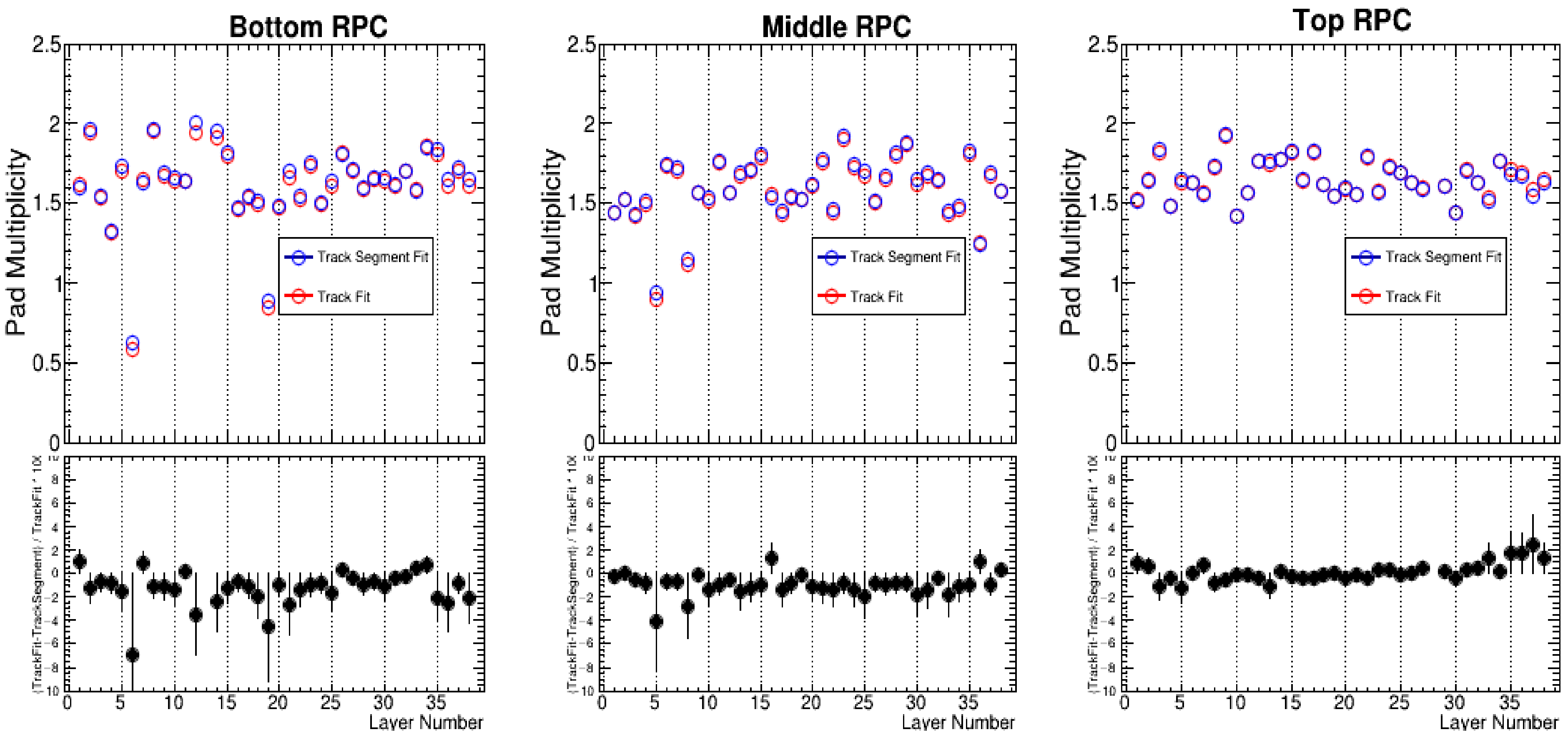


Comparison of Track Segment and Track Fit Methods



((Track Fit – Track Segment) / Track Fit)*100

Comparison of Track Segment and Track Fit Methods



((Track Fit – Track Segment) / Track Fit)*100

Geometrical Alignment of the Layers

Residuals:

$$R_x^i = x_{cluster}^i - x_{track}^i$$

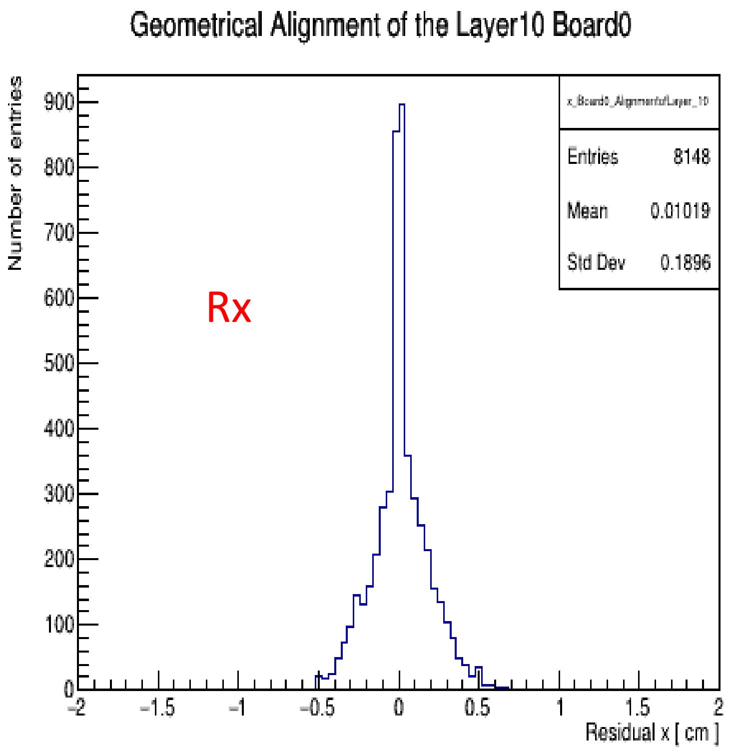
$$R_y^i = y_{cluster}^i - y_{track}^i$$

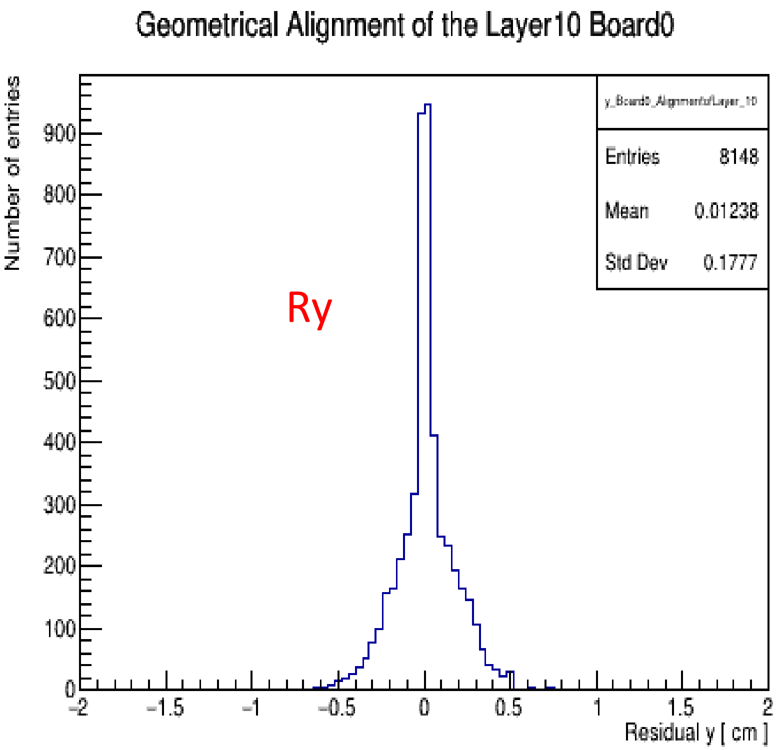
Edges in x (cut away 2 cm from the 2 edges in x) for each Board
Edges in y (cut away 2 cm from the 2 edges in y) for each Board

3D parametric line fit

$x = x_0 + a_x t$
$y = y_0 + a_y t$
$z = t$

Residual Distributions





$$R_x^i = x_{cluster}^i - x_{track}^i$$

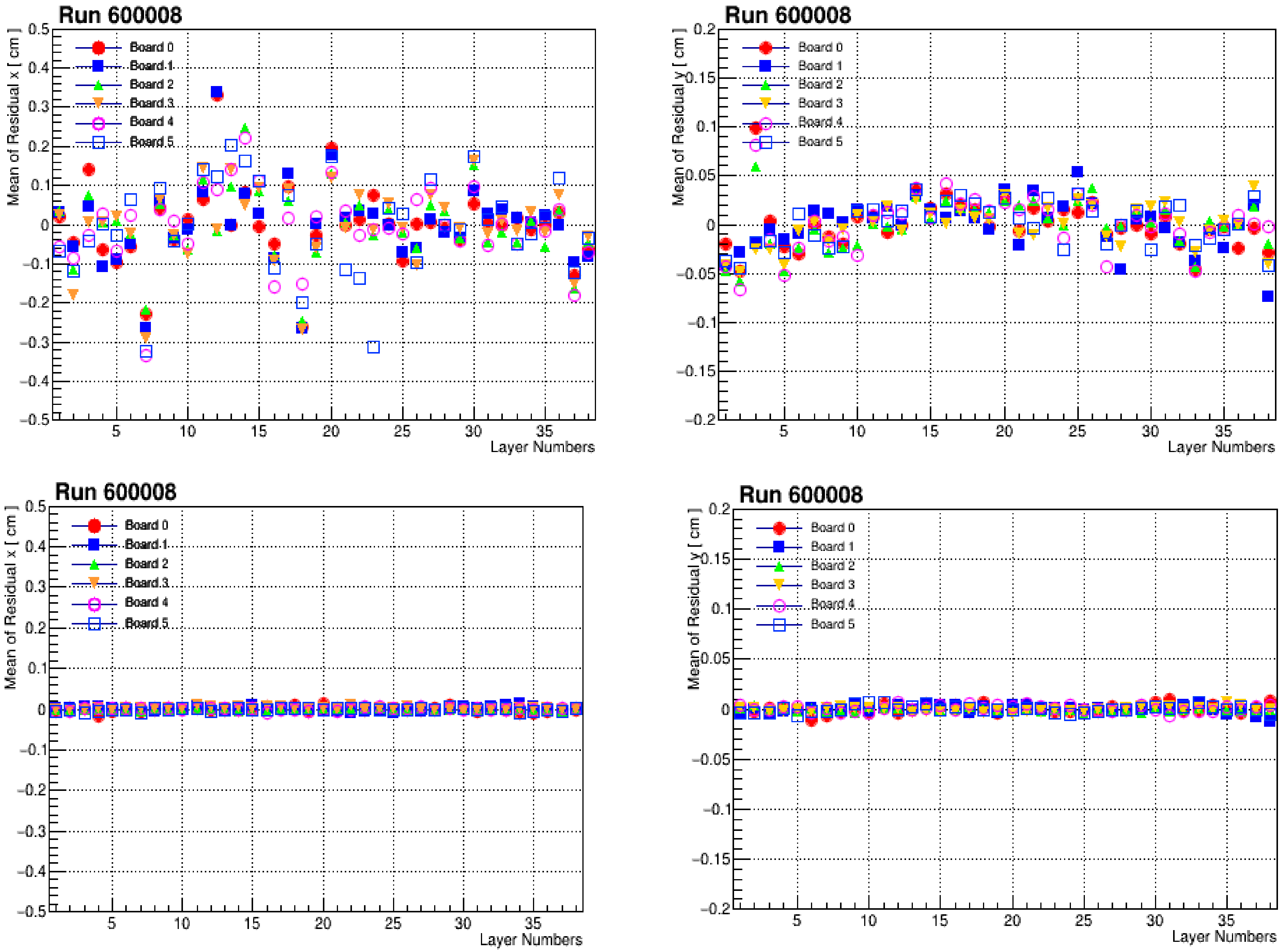
$$R_y^i = y_{cluster}^i - y_{track}^i$$

The means of the residual distributions are used to track the performance of the alignment procedure.

Residuals Before and After the Alignment of the Layers

Before

After

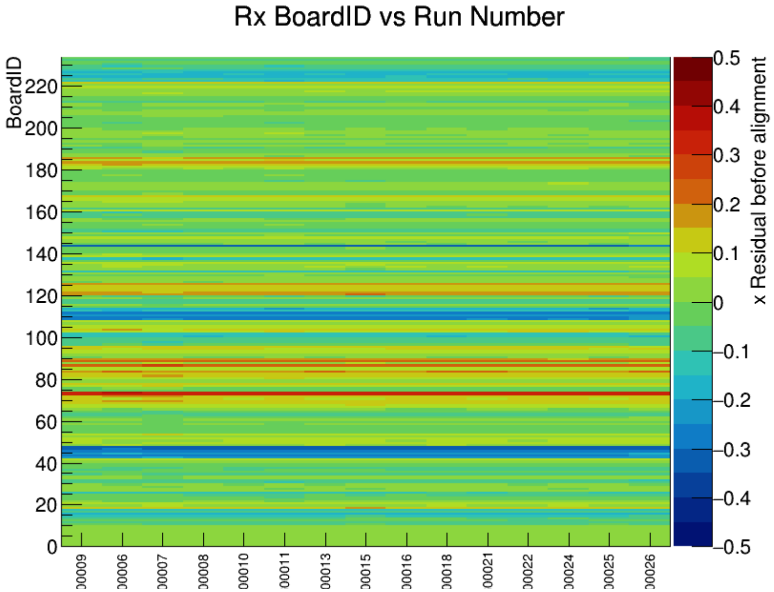


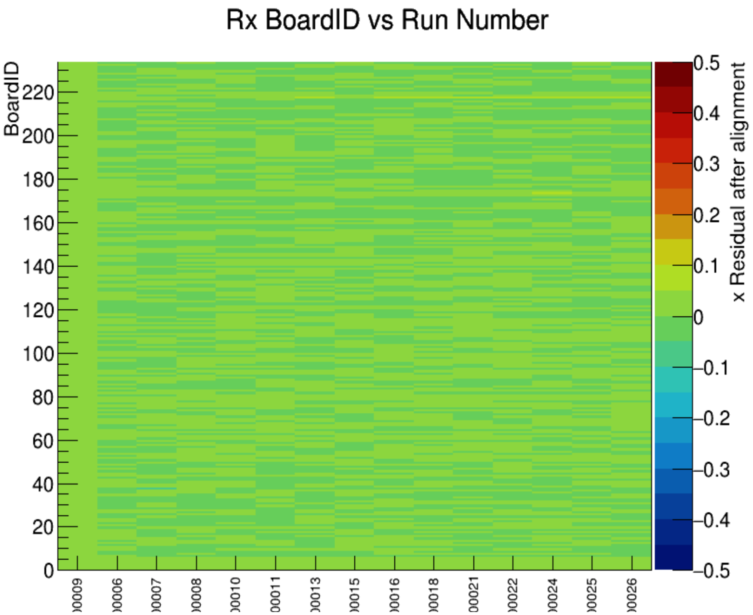
Run600009 used for Alignment

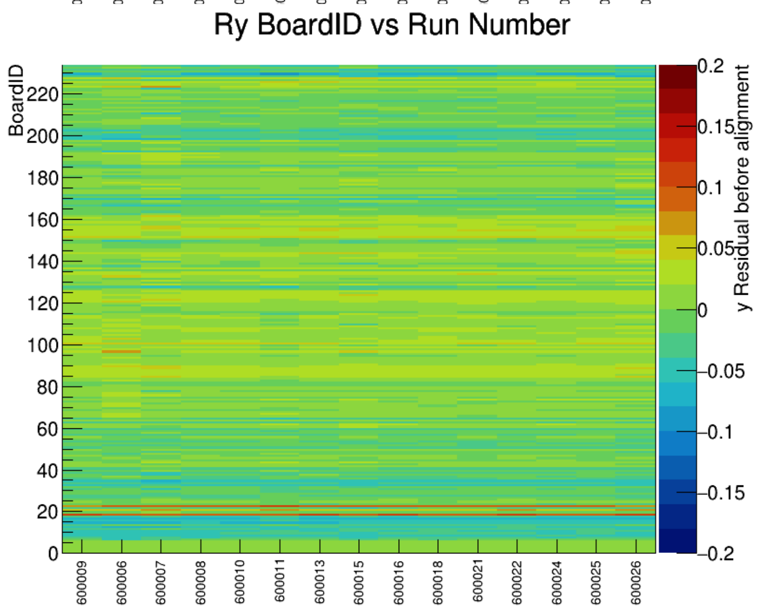
Results of Alignment for Oct 10 Campaign

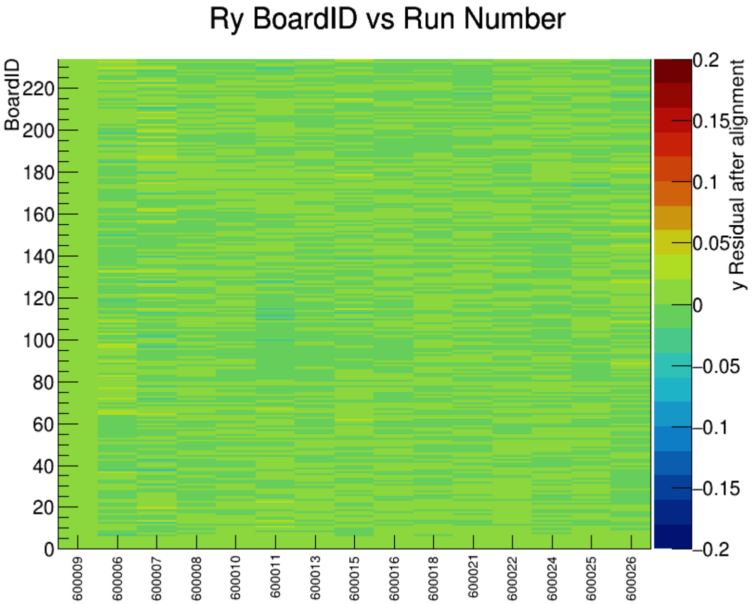
Before Alignment

After Alignment







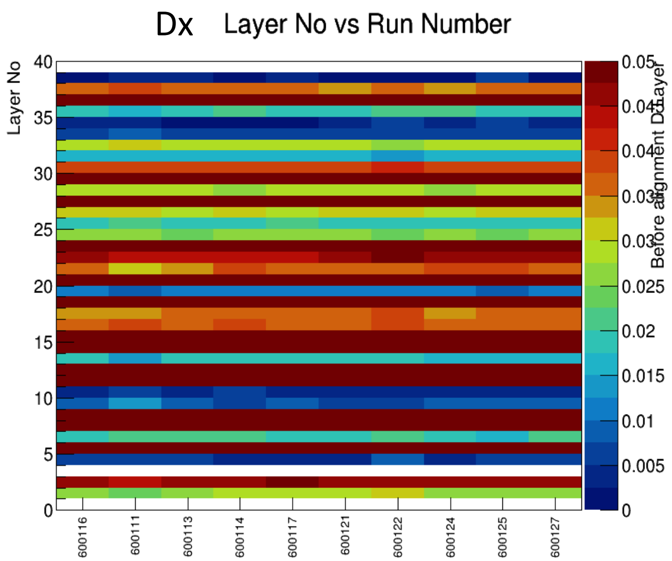


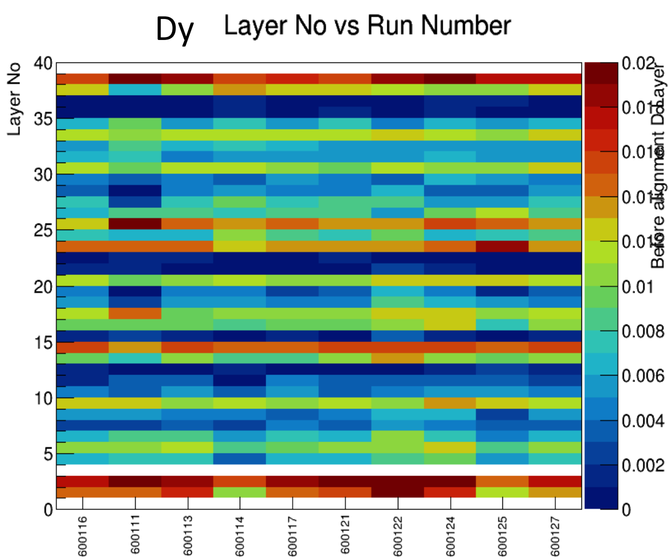
Board ID=(Layer No x 6) + Board No

Run600009 used for Alignment

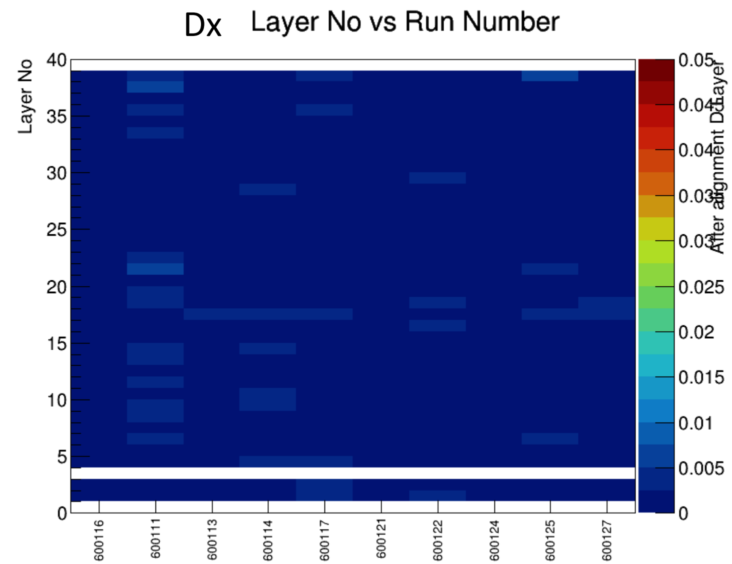
Results of Alignment for Jan 11 Campaign

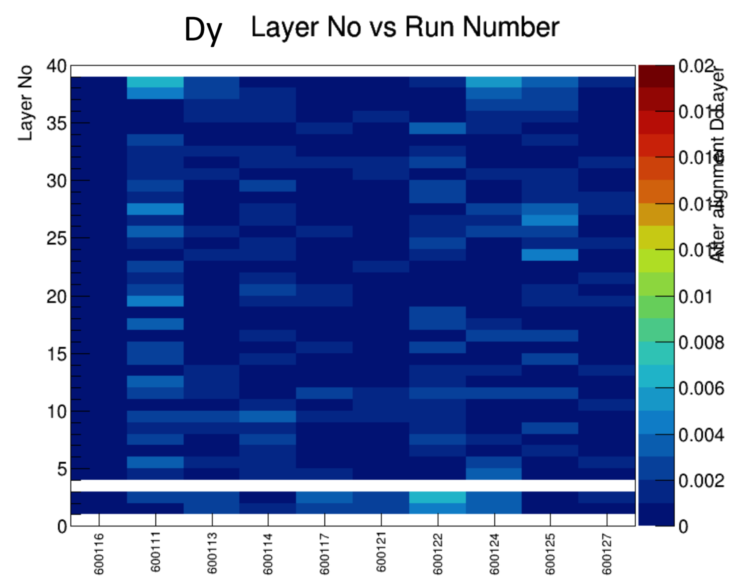
Before Alignment





After Alignment





$$D_{layer} = \sqrt{\frac{\sum_{boards} R^2}{6}}$$

Run600116 used for Alignment

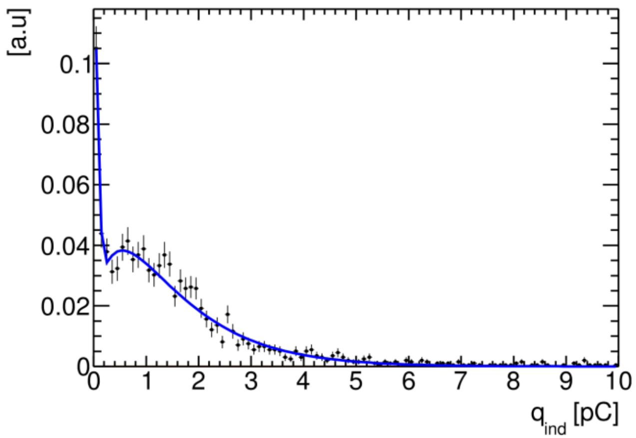
Simulation of the DHCAL Response

1. Simulate the response with Geant 4 and obtain the locations of the ionizations in the gas gap.

Min-DHCAL Positrons: Geant4.10.02; Physics Lists: FTFP_BERT, FTFP_BERT_EMY

Fe-DHCAL: Geant4. 10.01; Physics Lists: FTFP_BERT, FTFP_BERT_EMY, FTFP_BERT_EMZ, QGSP_BERT, QGSP_BERT_EMY, QGSP_BERT_EMZ

2. Sample the avalanche charge from the distribution obtained with the analog readout of the DHCAL RPC.



3. Distribute the charge over the pads.

Min-DHCAL Positrons & Fe-DHCAL: RPC_sim_5

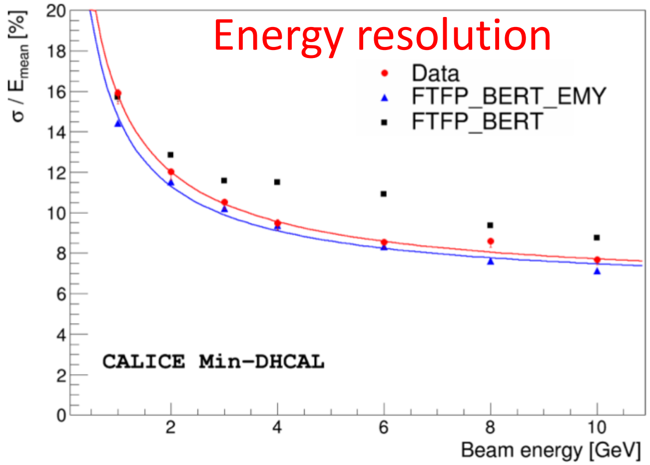
RPC_sim_	Spread functions
3	$R\, e^{-ar} + (1-R)\, e^{-br}$
4	e^{-ar}
5	$R\, e^{-(r/\sigma 1)^{\wedge}2} + (1-R)\, e^{-(r/\sigma 2)^{\wedge}2}$
6	$1/(a + r^2)^{3/2}$

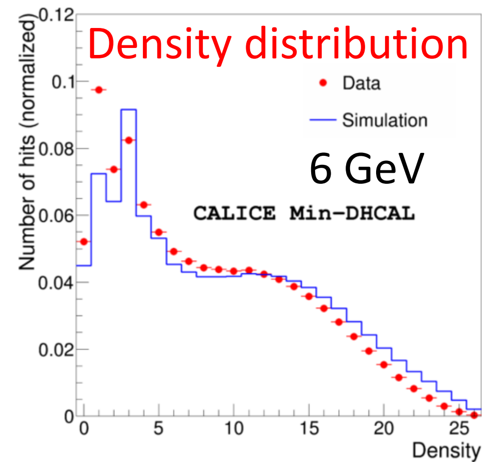
4. Apply threshold and reconstruct the hits.

Simulation of the DHCAL Response

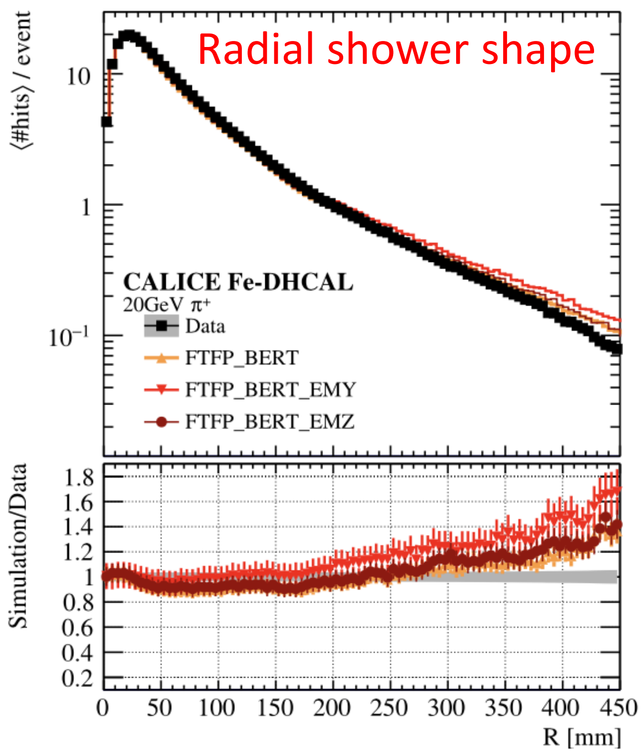
was always problematic ➔ repeat the entire study with Geant4.10.7

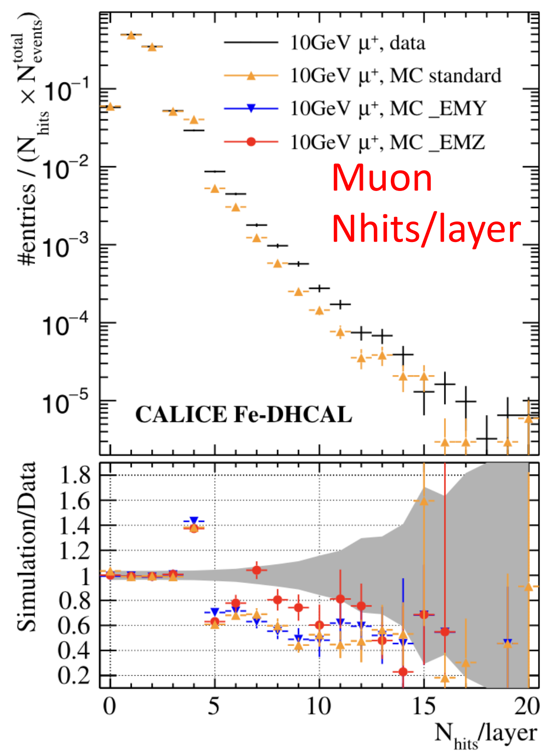
Min-DHCAL Positrons





Fe-DHCAL





Summary - Outlook

- Revisited the DHCAL calibration, validated the calibration parameters and the procedures.

- Revisited and validated the geometric alignment of the DHCAL layers.

- DHCAL MC is being migrated to Geant4.10.7 and validated.

Finalize validating the old tools, re-tune the MC and finalize:

- the muon analysis (started by Jose Repond)
- the Min-DHCAL pion analysis (started by Benjamin Freund)
- many other analysis that were advanced to some extent previously