The image shows the interior of the ATLAS experiment tunnel, a large, circular, industrial structure. The walls are lined with complex machinery and components. In the center, a person wearing a high-visibility vest stands on a yellow metal platform with railings. The platform has some text on it, including "CE 09-55-01-00" and "CERN". The overall scene is dimly lit, with the yellow platform providing a focal point.

Study of sMDT Chambers at the ATLAS Experiment

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December 14, 2022

Introduction

- The functioning principle of small Monitored Drift Tube (sMDT) Chambers.
- The analysis of the performance of sMDT Chambers.
- 2022 13.6 TeV collision data processing and the obtained results.
- What could be done next?

Small Monitored Drift Tube (MDT) Chambers

The monitored drift tube is the dominant tracking technology of ATLAS muon spectrometer.

ATLAS (s)MDT determines the muon momentum by reconstructing the muon trajectory in the known magnetic field and determining the curvature radius.

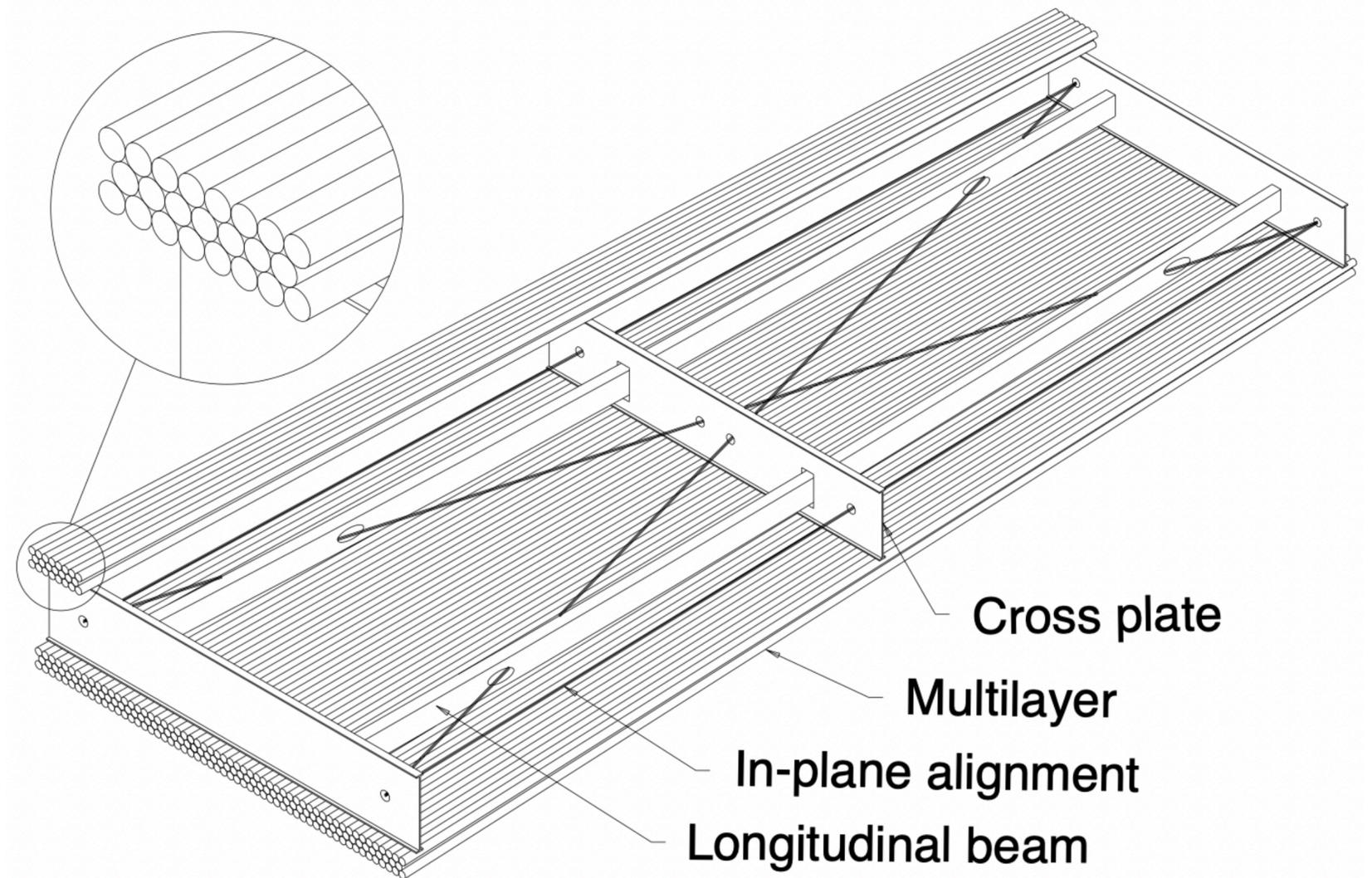


Figure 2-1

The functioning principle of Drift Tubes

The Drift Tube consists of a tube wall, a wire in the center, and a gas mixture, which fills the space between them.

The tube wall is grounded, while high voltage is applied to the wire.

When a muon transverses the drift tube, it ionises the gas atoms along its trajectory, creating free electron-positive ion pairs.

A signal is formed by the movement of the ions and electrons toward the electrodes and is then measured by readout electronics.

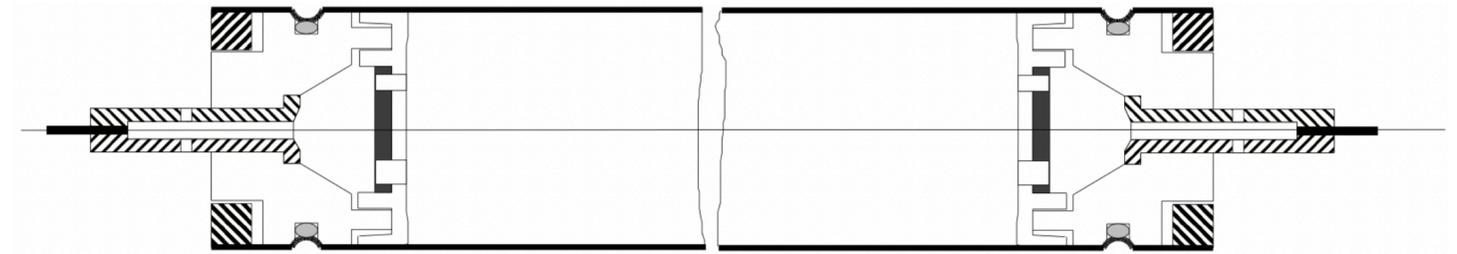


Figure 3-1: Schematic view of a monitored drift tube.

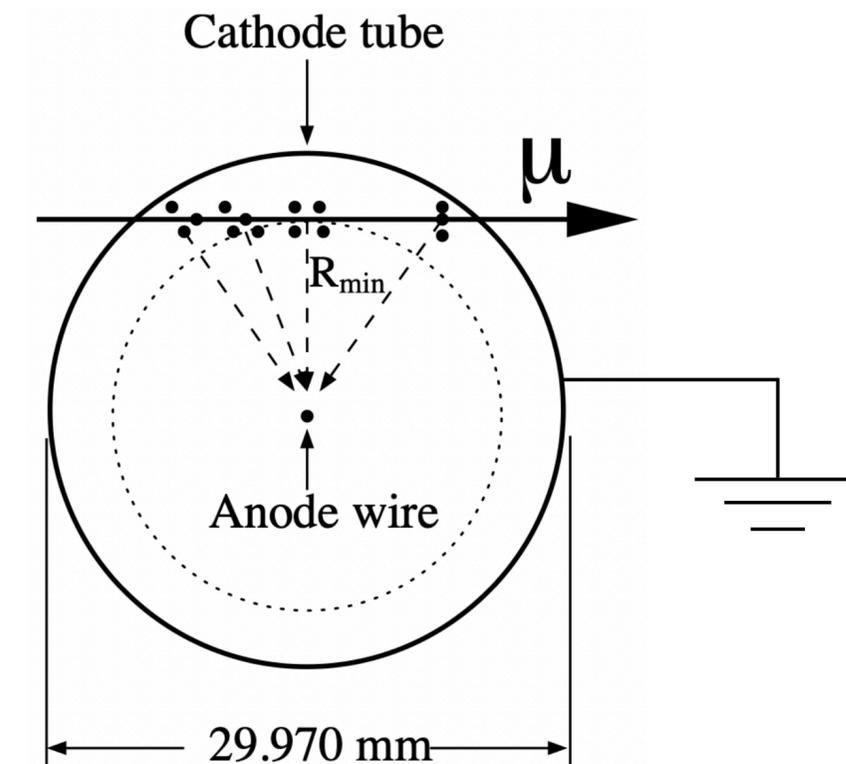


Figure 3-2: Drift tube operation in a magnetic field with a curved drift path.

Important quantities

The Drift Time - the time needed for electrons to reach the anode wire from their creation point.

The Drift Radius - the shortest distance from the electron creation point to the anode wire.

The Track - the shortest distance between the reconstructed muon track and the wire.

The Residual - the difference between the Drift Radius and the Track (**Biased** and **Unbiased Residual**).

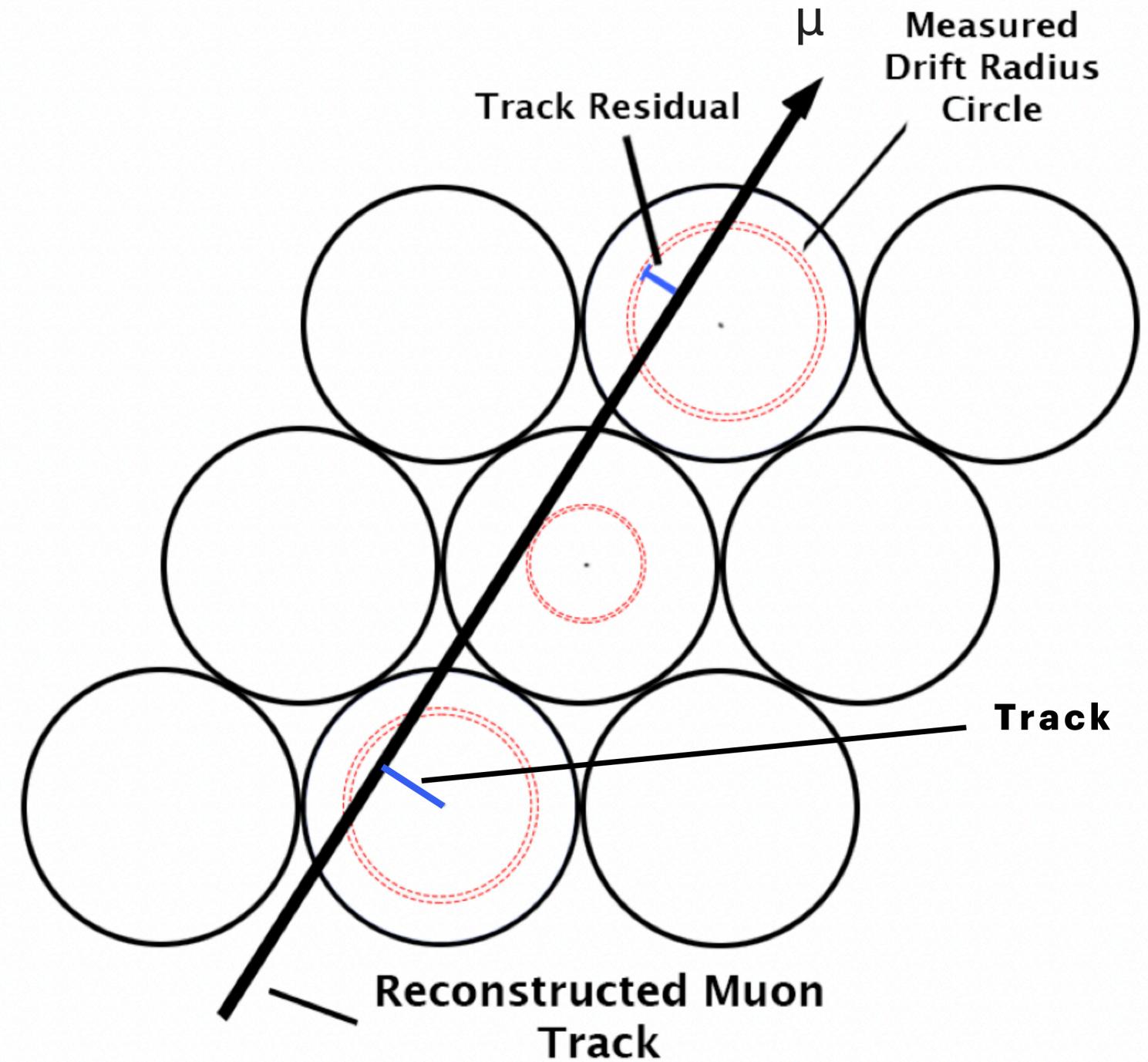


Figure 4-1: Visualization of the reconstructed muon track.

Performance analysis: the Residual Fit

The objective is to fit an equal-mean double Gaussian to the histograms of Biased and Unbiased Residuals.

```
x, bins = np.histogram(residual*1000, bins =  
np.arange(-1000, 1000, 20))
```

The weighted **mean**:

$$mean = \frac{\sum (x \cdot bins)}{\sum (x)}$$

The weighted **σ** :

$$\sigma = \sqrt{\frac{\sum ((bins - mean)^2 \cdot x)}{\sum (x)}}$$

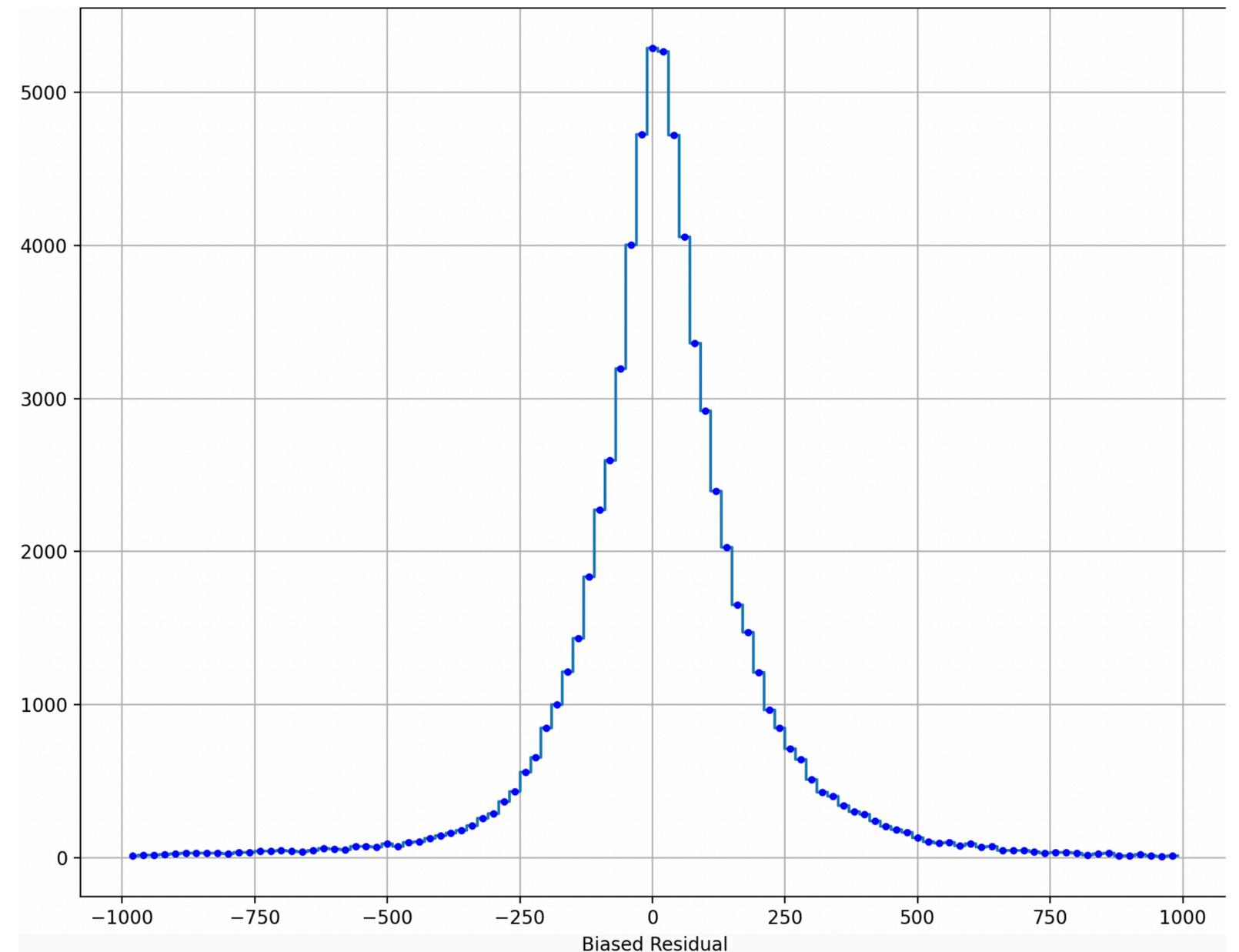


Figure 5-1: BME4C13 Biased Residual.

Performance analysis: the Residual Fit

The fitting equal-mean double Gaussian function:

$$doubleGfit = peak_n \cdot e^{-\frac{1}{2}\left(\frac{x-m}{sigma_n}\right)^2} + peak_w \cdot e^{-\frac{1}{2}\left(\frac{x-m}{sigma_w}\right)^2}$$

$peak_n$, $sigma_n$, m , $peak_w$ and $sigma_w$ are fitted to $\max(x)$, $\sigma/2$, mean, $\max(x)/10$ and $\sigma*2$

The resulting weighted value of σ :

$$\sigma = \frac{peak_n \cdot |sigma_n| + peak_w \cdot |sigma_w|}{peak_n + peak_w}$$

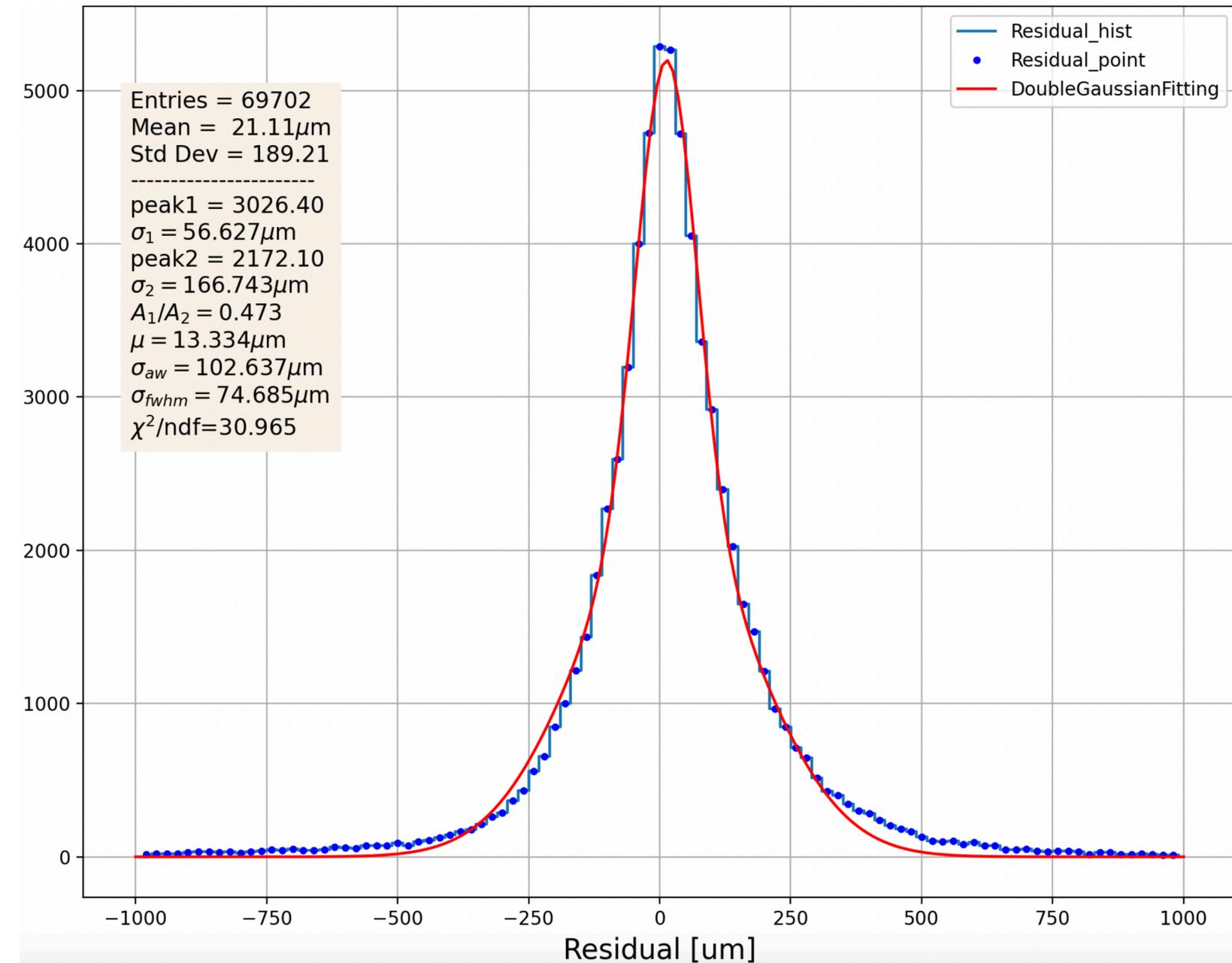


Figure 6-1: BME4C13 Fitted Biased Residual.

Biased and Unbiased Residual Fit

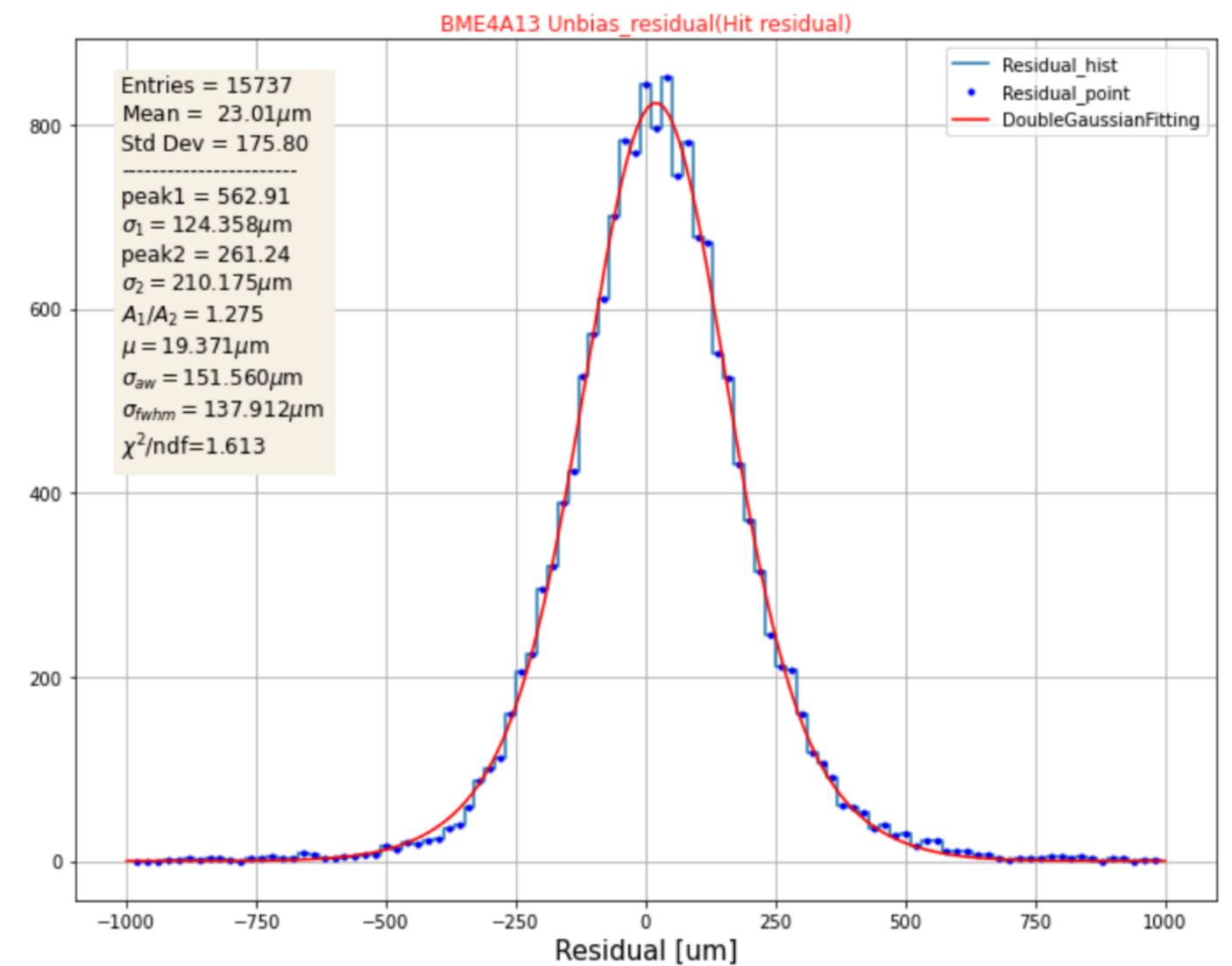
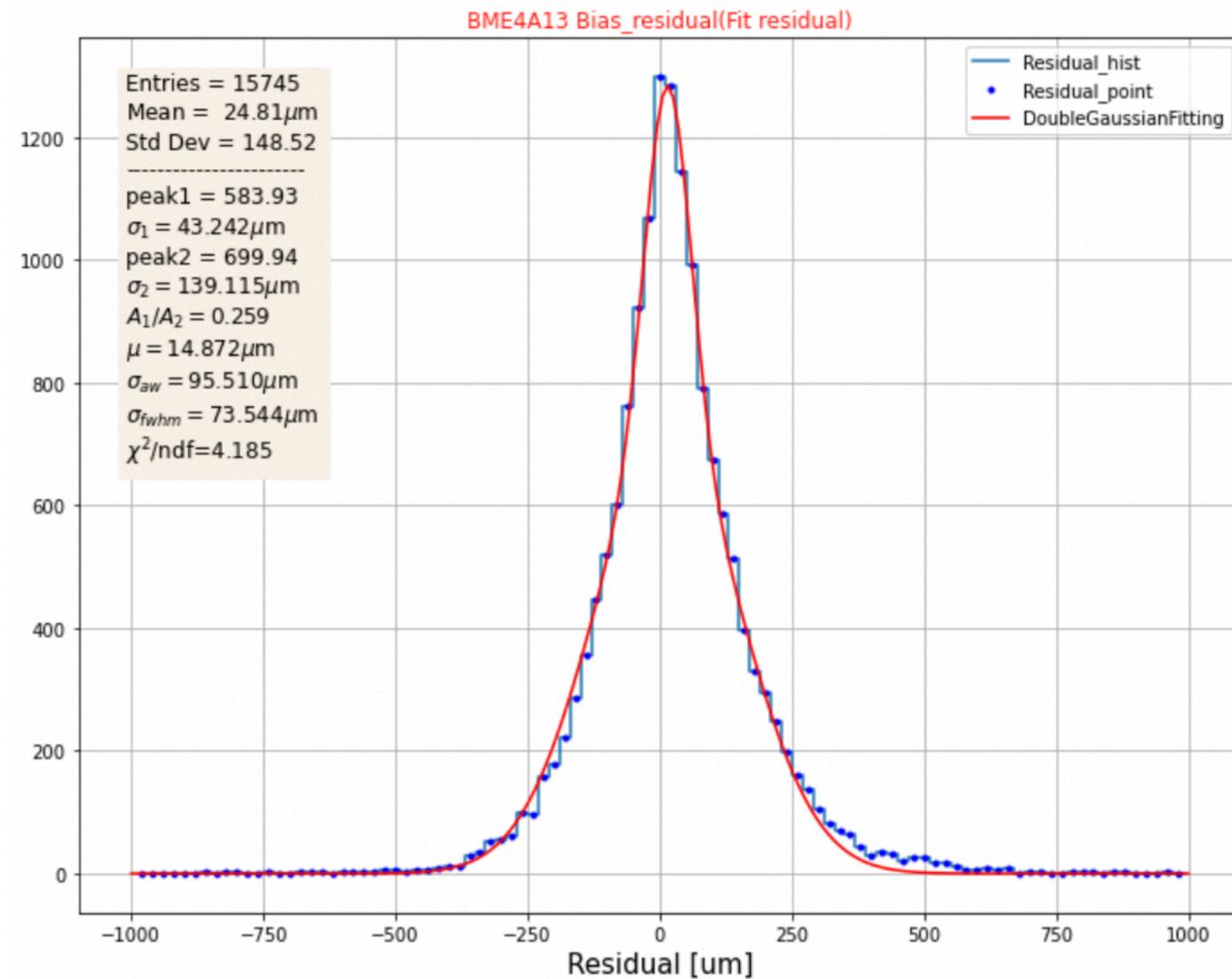


Figure 7-1: BME4A13 Fitted Biased and Unbiased Residual.

Performance analysis: Resolution

To plot the Resolution as a function of the Drift Radius, the Tube Radius is split into 7 equal intervals with a step of 1. For each interval, we compute biased and unbiased sigmas σ of residuals corresponding to a track that lay in the boundaries of a particular interval.

Having the σ_{biased} and $\sigma_{unbiased}$, the Resolution is equal to:

$$R = \sqrt{\sigma_{biased} \cdot \sigma_{unbiased}}$$

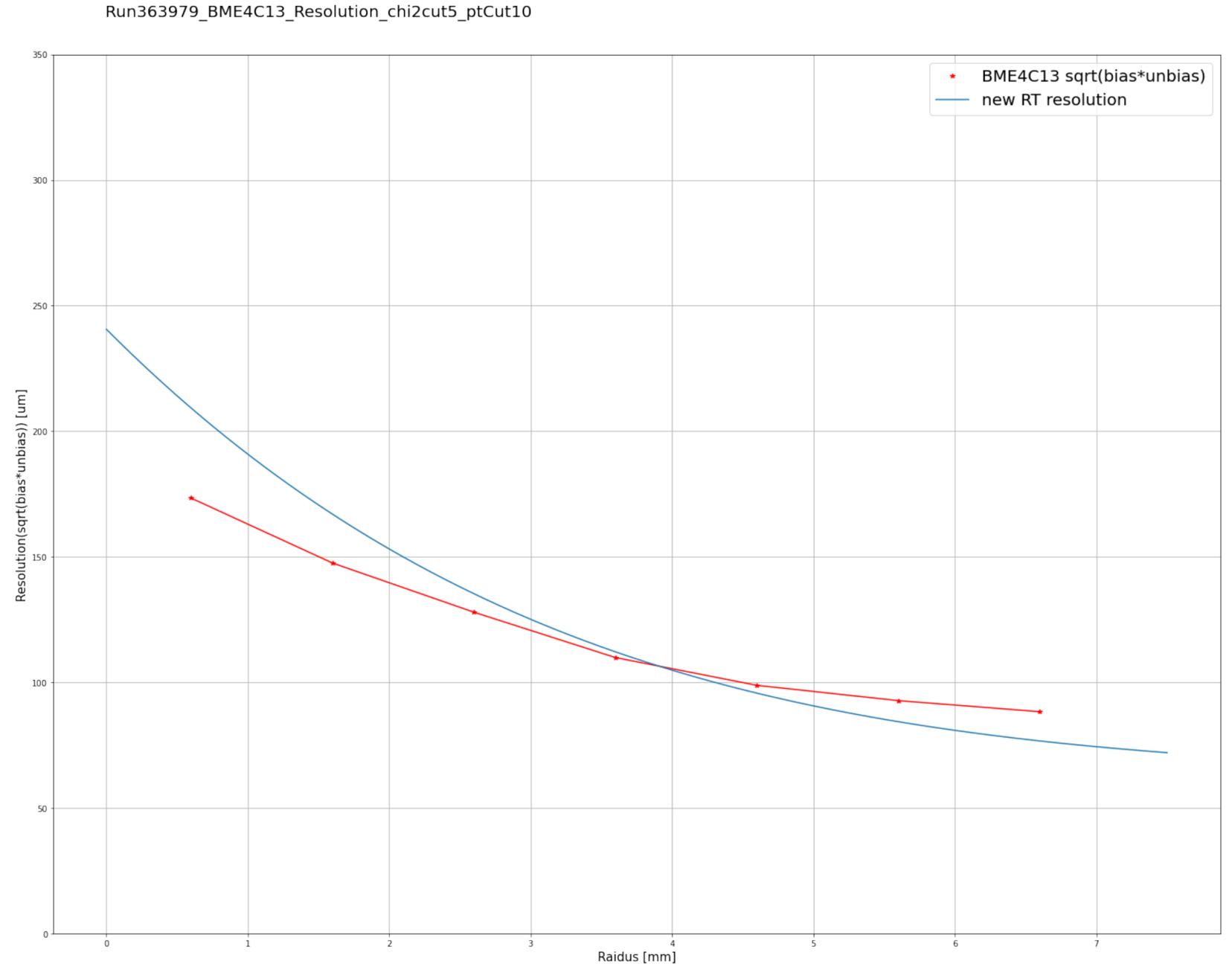


Figure 8-1: BME4C13 Resolution.

Performance analysis: Efficiency

In order to plot the Efficiency as a function of Drift Radius we follow the same method of splitting the Tube Radius into 7 intervals with a step of 1, subsequently processing Tracks that lay in boundaries of a particular interval.

For Sigma Efficiency: The hits are counted as efficient if they pass the following condition:

Unbiased residual $< 5 * \text{sigma resolution}$

For Hardware Efficiency: The hits counted as efficient are the hits with:

Unbiased Track $< \text{Maximum Radius}$

(7.1 mm for SMDT chambers)

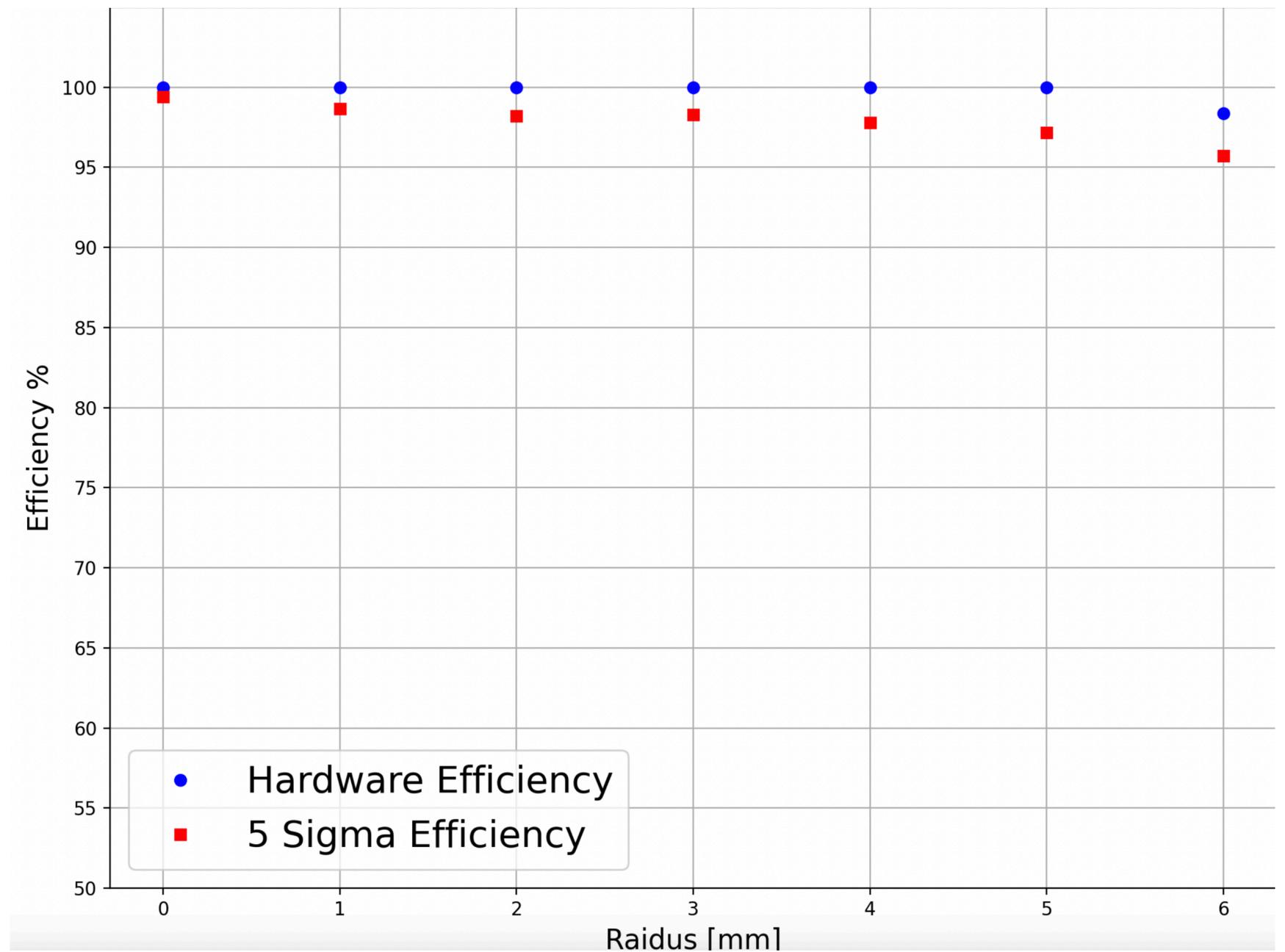


Figure 9-1: BMG2A14 Efficiency.

2022 13.6 TeV collision data: processing

The task is to process data from 14 BME and BMG sMDT chambers in regions 51, 52, 103, and 104 from run 437124.

Dataset:

data22_calib.00437124.calibration_MuonAll.daq.RAW.lumiblock-0region.ntuple.root

Cut 1: n-tuples of each event need to be separated to contain information from a single Segment.

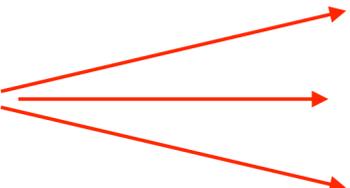
Example of a particular event with 12 MDT hits:

mdt_segIndex = [0, 0, 0, 1, 1, 1, 2, 2, 2, 2, 2, 2]

mdt_r = [1.076483, -0.509408, -2.672133, ... , -11.933061, 11.101686]

len(mdt_segIndex) = len(mdt_r) = 12

seg_nMdtHits = [3, 3, 6] seg_nSegments = 3. (number of Segments in the event)

mdt_segIndex 
mdt_segIndex = [0, 0, 0] , mdt_r = [1.076483, -0.509408, -2.672133], seg_nMdtHits = 3
mdt_segIndex = [1, 1, 1] , mdt_r = [-1.076500, 0.509400, 2.674335], seg_nMdtHits = 3
mdt_segIndex = [2, 2, 2, 2, 2, 2] , mdt_r = [-9.066158, ..., 11.101686], seg_nMdtHits = 6

2022 13.6 TeV collision data: processing

Cut 2: Introduced by selecting events where there are segments matched to tracks ($\text{trkSeg_nTrkSegs} > 0$). Simultaneously, the chamber name is attributed to each event in the dataset.

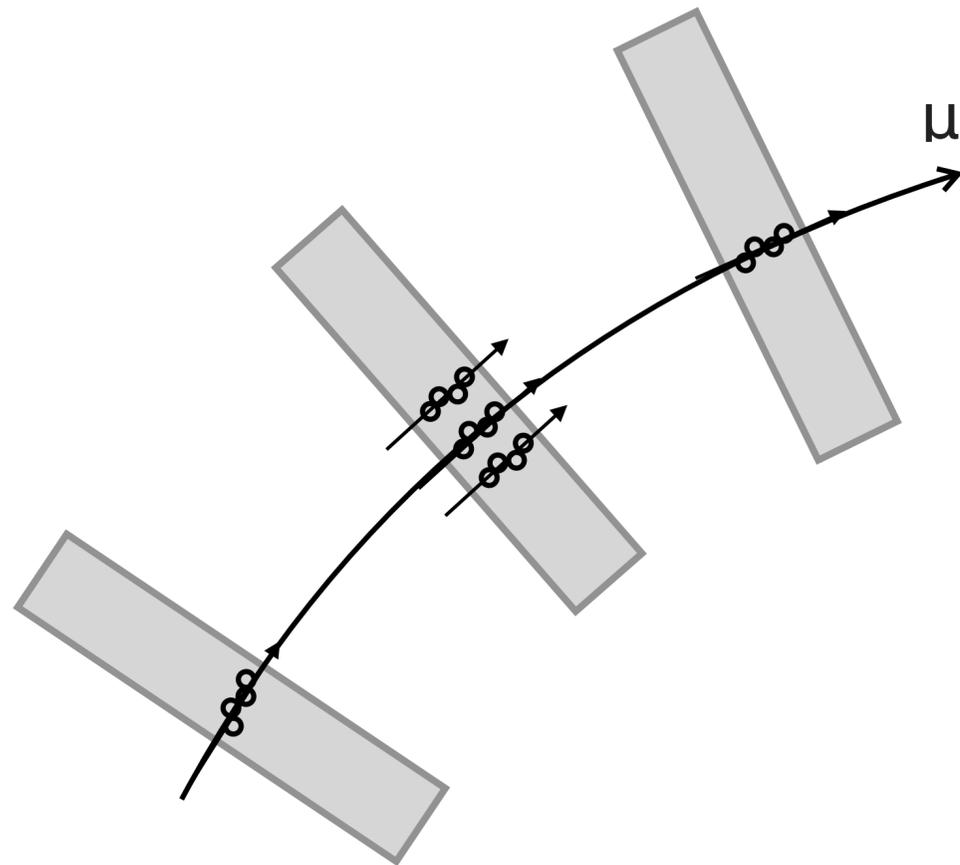


Figure 11-1: Visualisation of matching segments to a track.

Refit the Segments, obtain the new Track and the unbiased Track, and attribute the new variables to the spreadsheet.

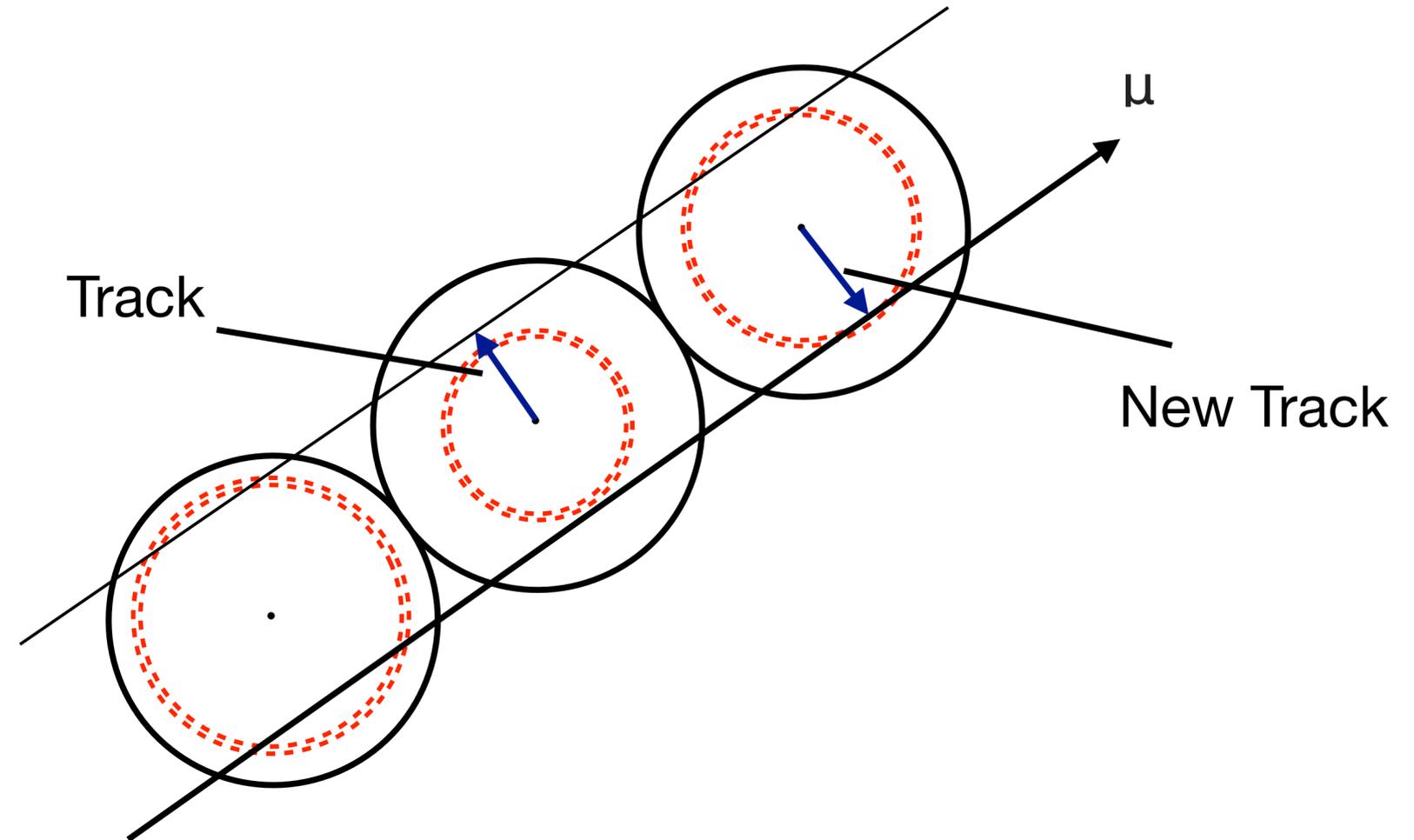


Figure 11-1: Segment refitting

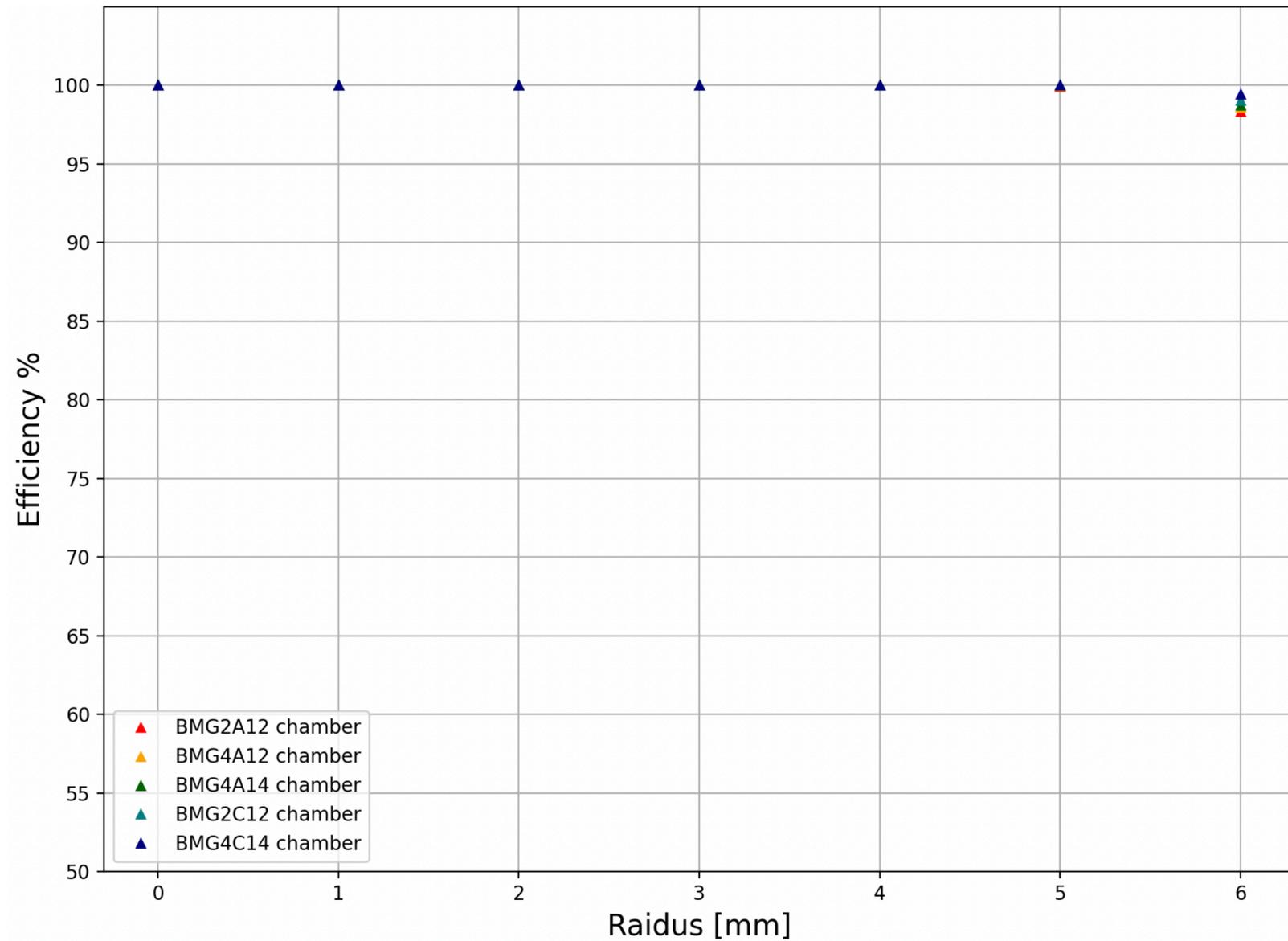
2022 13.6 TeV collision data: processing

After creating the pandas Dataframes out of selected data, writing it into .csv spreadsheets, and distributing the events according to the chamber names, 14 sMDT chamber datasets were produced.

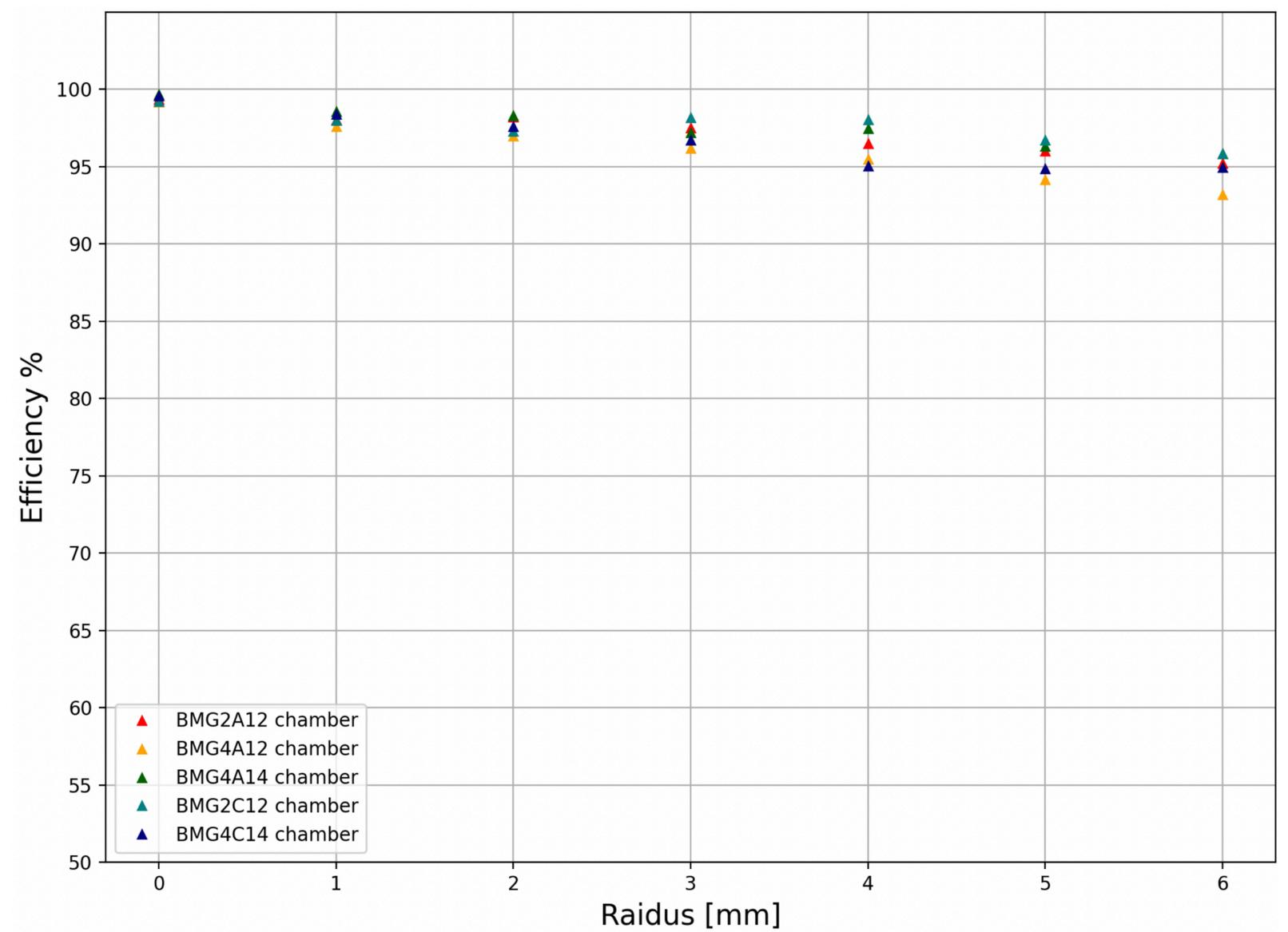
- run437124_region0051_BME4A13.csv
- run437124_region0051_BMG2A12.csv
- run437124_region0051_BMG4A12.csv
- run437124_region0051_BMG6A12.csv
- run437124_region0052_BMG2A14.csv
- run437124_region0052_BMG4A14.csv
- run437124_region0052_BMG6A14.csv
- run437124_region0052_BOE3A13.csv
- run437124_region0103_BME4C13.csv
- run437124_region0103_BMG2C12.csv
- run437124_region0103_BMG4C12.csv
- run437124_region0103_BMG6C12.csv
- run437124_region0104_BMG2C14.csv
- run437124_region0104_BMG4C14.csv
- run437124_region0104_BMG6C14.csv
- run437124_region0104_BOE3C13.csv

```
entry,mdt_nMdt,mdt_segIndex,mdt_id,mdt_tdc,mdt_adc,mdt_t,mdt_r,mdt_dr,mdt_rTrk,mdt_drTrk,mdt_resi,mdt_distR0,mdt_slewTime,mdt_lorTime,mdt_propTime,mdt_tof,mdt_bFie ✓ (...)  
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(...)
```

sMDT Chambers' Hardware and Sigma Efficiency



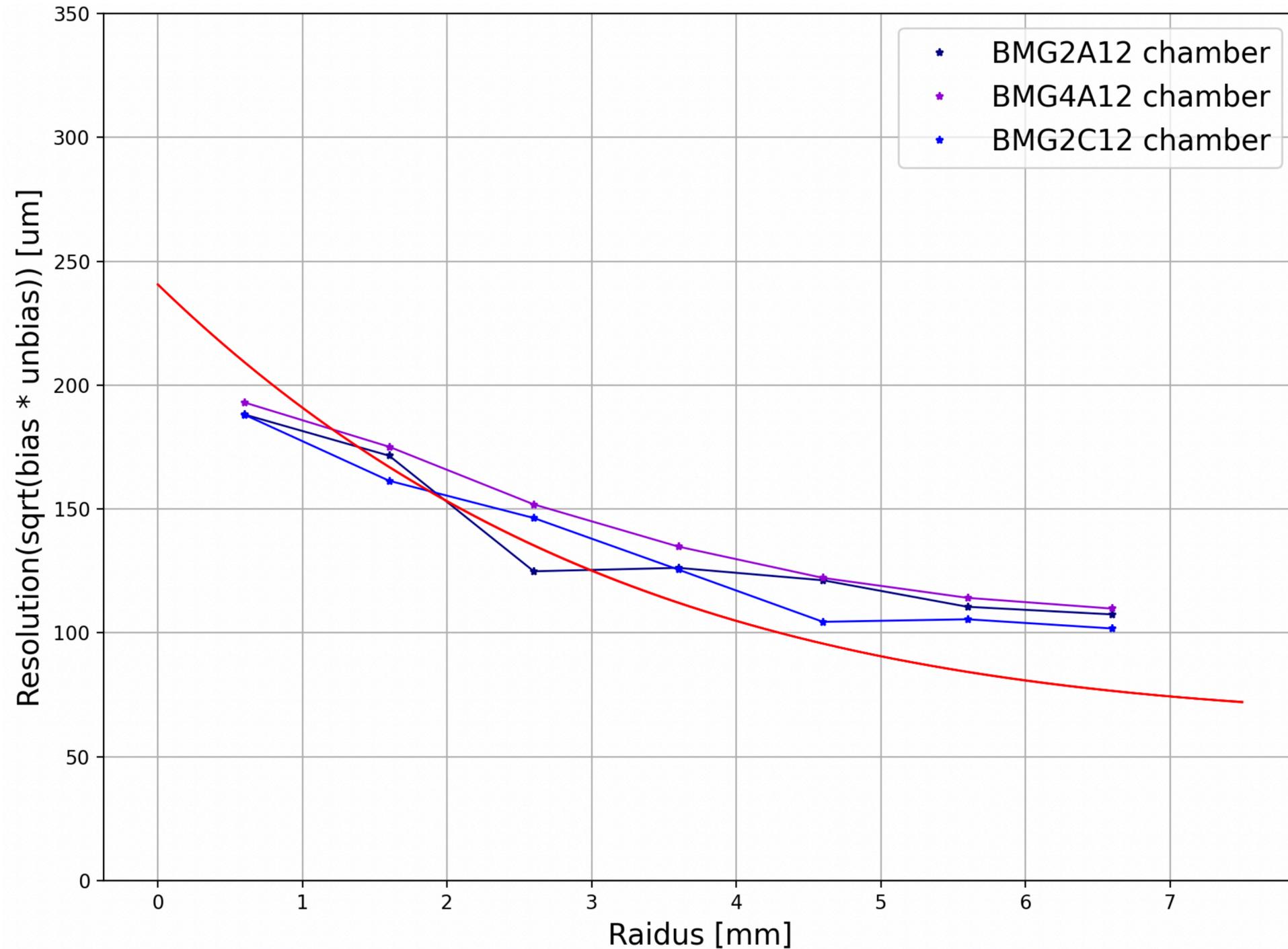
Hardware Efficiency



5-Sigma Efficiency

Cut: data.shape[0] > 500

sMDT Chambers' Resolution



Cut: data.shape[0] > 1000

What lacks and what will be done next

- Adding the error to the Resolution graph. This will indicate whether the deviation lies within the boundaries of the statistical error. Otherwise, the method of plotting the resolution needs to be revised.
- Investigating the cause of insufficient data on most chambers. On average, the shape of processed datasets is around 800. Moreover, the average Hits per Segment ratio for the dataset is around 7 Hits per Segment, which means that a great part of the data could not be taken into account.
- Producing more plots to investigate the chamber's behavior, such as 2D histograms of Residuals vs Tube radius, Track Hit Occupancy, and others.

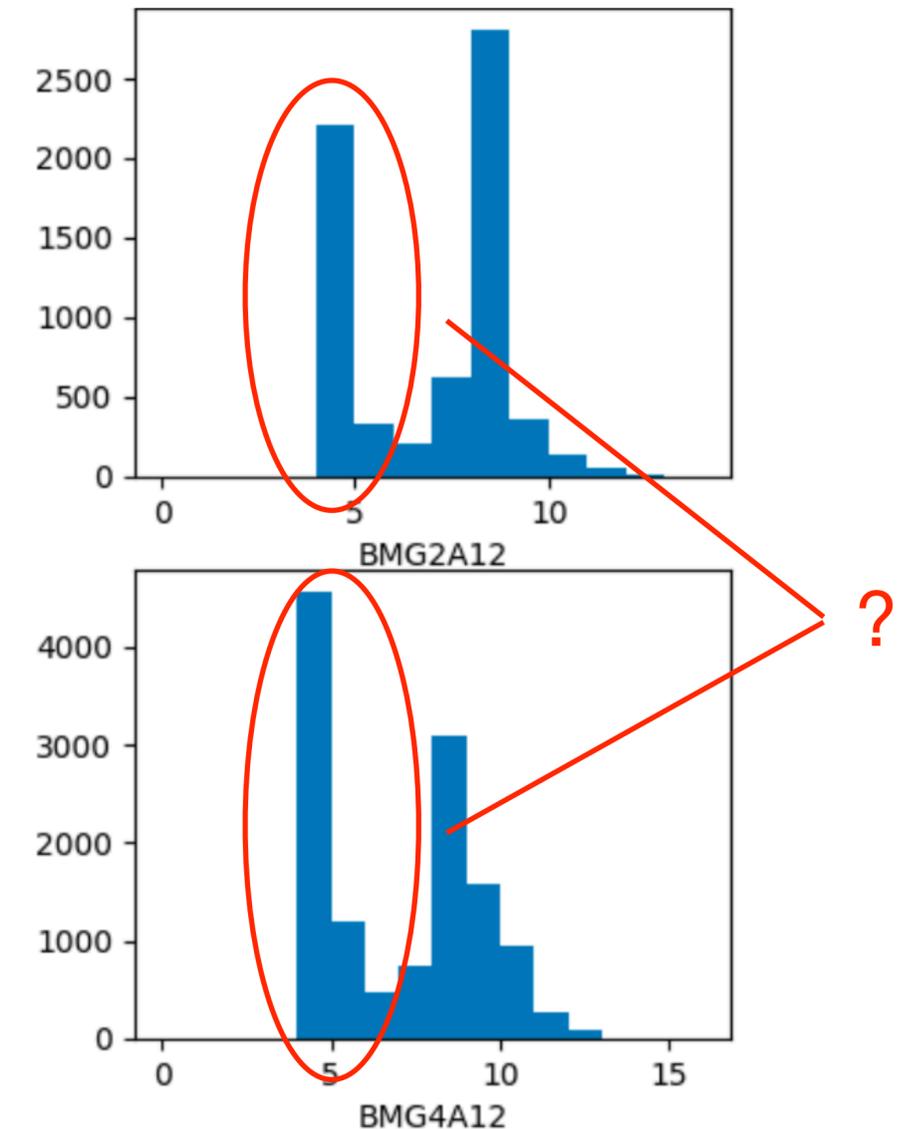


Figure 15-1: seg_nMdtHits ratio

Thank you!

sMDT Chambers' Resolution

