



30 November 2023

30 November 2023

christian.tanga@cern.ch



AFP Silicon Tracker Performance in 2023 data taking

Christian Nunziante Tanga

CERN, Geneva, Switzerland

Supervisors: Mario Campanelli, Sergio Javier Arbiol Val

Keywords: Silicon Tracker, AFP, Efficiency of Cluster Reconstruction, Track Efficiency

Abstract

This report provides an overview of my work concerning the performance of the Silicon Tracker detector system at ATLAS Forward Protons (AFP), designed to identify protons that remain intact after the collision. A brief description of the AFP detector is presented followed by an explanation of the methods used to estimate the efficiencies of cluster and track reconstruction. Furthermore, the results from the 2023 data are presented.

Contents

1	Introduction	3
1.1	Physics of interest	3
1.2	AFP detector	3
1.3	Silicon Tracker detector	4
2	Data overview	5
2.1	Data processing	5

3	Trigger Selection	5
4	Estimation of Cluster and Track Reconstruction Efficiencies	5
4.1	Plane cluster reconstruction efficiency: original method	5
4.2	Plane cluster reconstruction efficiency: alternative method	6
4.2.1	Justification for alternative approach	6
4.2.2	Alternative method	7
4.2.3	Cluster reconstruction efficiency: alternative method (example)	7
4.3	Track Reconstruction efficiency	8
5	Results	8
5.1	Cluster	8
5.2	Time evolution of the efficiency of cluster reconstruction	11
6	Track Reconstruction Efficiency	13
6.1	Time evolution of the efficiency of track reconstruction	14
7	Conclusions	14
8	Appendix	15
8.1	Processed Run number	15
8.2	Comparison between the two methods	16
8.3	Track Reconstruction Efficiency	16
8.4	2D distributions of cluster reconstruction efficiency	17
8.4.1	A NEAR	17
8.4.2	C NEAR	18
8.4.3	C FAR	19

1 Introduction

1.1 Physics of interest

In the context of proton-proton collisions at the Large Hadron Collider (LHC), a remarkable category of phenomena is referred to as diffractive processes, in which only vacuum quantum number are exchanged.

Diffractive interactions can be mediated by exchanging photons (QED) or Pomerons (QCD), and two features can experimentally recognize them:

- Large rapidity gaps: there is no color exchange in the diffractive interactions, therefore radiation between the interacting particles is suppressed. [3]
- Intact protons: when only vacuum quantum numbers are exchanged it is possible that the interacting hadron (proton, at the LHC) is not destroyed, but remain intact.[3]

Therefore, in diffractive processes, the protons can remain intact at the end of the collision but are scattered at small angles with respect to the beam. It's important to note that these intact protons are not detectable in the usual acceptance range of detectors, due to their small scattering angles of a few hundred microradians. To detect and study these intact protons, specialized forward devices are required: the ATLAS Forward Proton (AFP) detector. Forward detectors are required because the rapidity gap is often destroyed by the background.

1.2 AFP detector

The AFP detector comprises four stations (as shown in Fig.1): two NEAR stations are positioned 205 meters away from the interaction point on both sides (referred to as A and C), and two FAR stations are situated 217 meters away (as shown in Fig.1). Each station is equipped with a silicon tracker detector (SiT) designed to measure the deviation of scattered protons from the beam. The FAR stations are also equipped with a time-of-flight detector. The ToF detectors are designed to measure the primary vertex z-position, which is used to reduce background. When a proton remains intact due to diffractive scattering, it loses part of its energy and it experiences greater deflection from the accelerator lattice magnets compared to protons in the beam that don't collide among each other. They do interact with the magnets which cause bending effects. The optics (magnets configuration and collimators) ensure that protons that experience different energy loss on the interaction (as defined by Eq.1) focus on different points of the SiT. The reconstructed energy loss together with the information from the ATLAS central detector allows for reconstruction of the kinematics of the event.

$$\xi = 1 - \frac{E_{proton}}{E_{beam}} \quad (1)$$

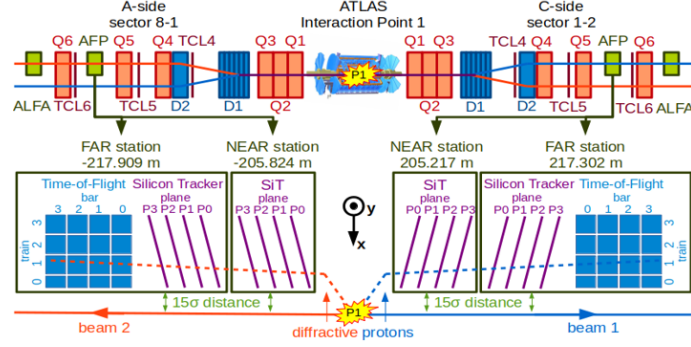


Figure 1: A schematic of the ATLAS Forward Proton detector.

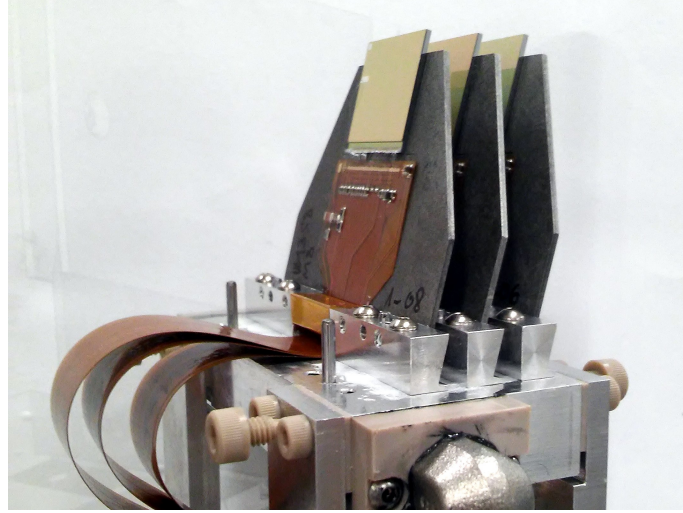


Figure 2: Four AFP Silicon Tracker detectors mounted on the heat exchanger.

1.3 Silicon Tracker detector

The Silicon Tracker (SiT) within the ATLAS Forward Proton (AFP) detector comprises four silicon planes at each station [1]. Each plane is composed of 336x80 pixels, creating a grid that spans 20 mm in the long direction and 16.8 mm in the short direction. The pixels dimensions are $50\mu\text{m}$ in the short direction and $250\mu\text{m}$ in the long direction. These planes are inclined at an angle of 14 degrees relative to the beam direction (as shown in Fig.2), which gives better resolution of $\sigma_x \approx 6 \mu\text{m}$ and $\sigma_y \approx 30 \mu\text{m}$.

When a particle passes through a plane, it fires a pixel or group of pixels which triggers a hit registration (hits can also be generated by other factors, such as thermal noise). Following this initial step, the reconstruction process proceeds with the formation of clusters. Clusters are generated by grouping neighboring hits. Subsequently, the trajectory of particles is reconstructed using a Kalman filter algorithm, with a stipulation that at least three of the four planes must register a reconstructed cluster. This reconstruction process yields tracks, which are further employed in the creation of proton objects.

Evaluating the efficiency of each stage within this sequence is essential for gaining insights into the Silicon Trackers' performance within the AFP detector.

2 Data overview

2.1 Data processing

A complete list of all processed runs with the associated average $\langle\mu\rangle$ ¹ is attached to the end of this report (section 8.1), where is also presented the list of Luminosity Blocks² (lumiblocks, LB) used for the analysis. The datasets are all taken from the Physics Main stream. Data-taking process during these runs was not smooth. One of the different issues encountered was the change in the number of active SiT planes at the beginning of June: plane 3 of C FAR and plane 2 of A FAR were disabled, but a more in-depth analysis will be expounded upon in the next sections.

3 Trigger Selection

Before starting the analysis, it is essential to identify the triggers that yield optimal statistics. It's needed to check what triggers are available and at what rates. Several different triggers gave a good enough selection. Efficiencies and prescales change the total number of events, yet numerous choices remain.

Triggers on AFP were rejected to avoid bias. Furthermore, another requirement is ensuring an acceptable number of events. Hence, the choice for trigger was the HLT_noalg_L1RD0_FILLED trigger ($HLT \rightarrow High - Level - Trigger$). HLT_noalg means that no additional algorithm was applied at the HLT [2]. Thus, triggers were chosen that trigger in the central detector and that gave a convenient rate, with enough events left to do a good analysis but not so many the files become unworkable. The HLT_noalg_L1RD0_FILLED trigger is the same as the one used in the 2022 analysis.

4 Estimation of Cluster and Track Reconstruction Efficiencies

In this section, an examination of the methods employed for assessing efficiency in cluster and track reconstruction will be conducted.

4.1 Plane cluster reconstruction efficiency: original method

To determine cluster reconstruction efficiency, the 2023 data collected at Run 3 of the LHC will be analyzed.

Here, it's presented an overview of the original method employed to estimate the efficiency of cluster reconstruction in a plane, which is the same method used in 2022. It involves an initial selection applied to the original sample of events:

- Single Registered Track.
- Registering clusters in each one of the three planes not under investigation.

Subsequently, every event that meets these criteria is considered a trial event.

Then, a secondary selection is applied to the trial events. A trial event is categorized as a success

¹The pile-up is quantified by the average number of pp interactions per bunch crossing.

²A luminosity block is a period of the data taking lasting about 1 minute.

event if it records a cluster in the plane under investigation, within a search range of the track. The search range is set as a circle with a radius of $2mm$, though alternative choices are possible. Fig.3, for example, shows an illustration where the focus is on the third plane (plane number 2). The first selection criteria need to be checked: in this case, there is a single registered track, and clusters are present in the other three planes not currently under investigation. The first criterion is met, resulting in labeling it as a trial event. Now, the second selection needs to be applied to this trial event. The plane under investigation contains a cluster that falls outside the specified search range. As a result, the second selection isn't satisfied, and no success events are recorded. The efficiency of cluster reconstruction is calculated as the ratio of the number of successful events to trial events. (Eq. 2).

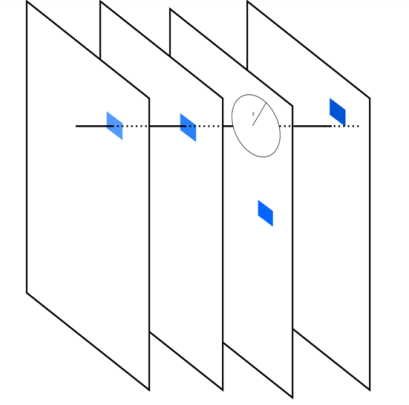


Figure 3: Evaluation of cluster reconstruction efficiency

Therefore, the efficiency and its associated error are as follows:

$$\epsilon(x, y) = \frac{N_{\text{success}}}{N_{\text{try}}} \quad (2)$$

$$\sigma_{\epsilon}(x, y) = \left(\frac{1}{N_{\text{try}}} \right) \sqrt{N_{\text{success}} \left(1 - \frac{N_{\text{success}}}{N_{\text{try}}} \right)} \quad (3)$$

where:

- N_{success} represents the number of successfully reconstructed clusters, that pass the selection for successful events.
- N_{try} indicates the total number of events that passed the selection for trial events.

The efficiency error follows from the binomial distribution.

4.2 Plane cluster reconstruction efficiency: alternative method

4.2.1 Justification for alternative approach

As mentioned in section 2.1, plane 3 of C FAR and plane 2 of A FAR were disabled at the beginning of June. In the preceding section 4.1, an overview of the plane cluster reconstruction efficiency estimation algorithm was given. For the efficiency estimation, in the first selection for trial events, it's required that one cluster be present in each plane not under evaluation. With one plane disabled,

the maximum of planes that can have a registered event is 2, unless the disabled plane is evaluated which does not register any event. Furthermore, to reconstruct a track, clusters in three planes are required, as explained in the next section (sec.4.3). All of this implies that another method needs to be implemented to address this situation.

4.2.2 Alternative method

The alternative method employed in our study involves a systematic approach to evaluating the efficiencies of SiT after the disabling of the planes. The following steps outline the implementation of this method:

- **Selecting the Target Plane:** To initiate the evaluation, a specific plane is chosen as the target for assessment (checked plane).
- **Inspecting a Non-Disabled Plane:** The next step involves the examination of a plane that has not been disabled. The objective here is to identify an event with a single registered cluster in this plane and record its position.
- **Examining the other Non-Checked Plane:** After the first cluster is recorded, we proceed to inspect another plane that has not been previously examined. This plane is scrutinized for the presence of a cluster within a specified search range, set as a circle with a radius of $2mm$. The search ranges are defined around the position of the cluster found in the first step. If such a cluster is identified, it is categorized as a "try" event.
- **Setting a Selection on the Number of Hits:** Before checking the "try" events, we establish a "threshold" for the number of hits per event. In this case, we set the number of hits to be exactly two. This criterion is based on the expected outcome for a good diffractive event and helps to reduce background events, which the efficiency is more sensitive towards now than with the original method.
- **Evaluating the Checked Plane:** Finally, we revisit the initially selected plane, referred to as the "checked plane". Here, our goal is to determine whether it contains a cluster within the defined search range, represented by a circle with a radius of 2 mm. If such a cluster is found, the event is considered a success.

4.2.3 Cluster reconstruction efficiency: alternative method (example)

Suppose we want to determine the efficiency of P3 (see Fig.4):

1. First, we verify whether there is a single cluster in the "seed plane" which could be either P0 or P1.
2. Next, we confirm if there is a single cluster in plane P1 (P0) near the cluster found in P0 (P1).
3. If both conditions mentioned above are met, we consider it a "try".
4. Finally, we check if there is a cluster near the line connecting the clusters identified in steps 1) and 2). If this condition is met, it's counted as a 'success'.

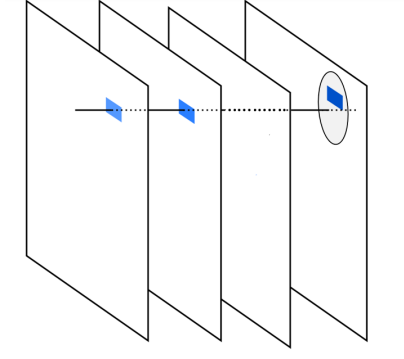


Figure 4: Cluster reconstruction efficiency evaluation with the alternative method

4.3 Track Reconstruction efficiency

The reason why the condition for the selection of trial events was not relaxed to 2 clusters, instead of 3, is because of the condition for Track Reconstruction. Considering that a track is created when clusters are present in three or more planes, the efficiency of track reconstruction can be estimated as the probability that three or more planes have recorded clusters. This estimation can be calculated using the cluster reconstruction efficiencies obtained in the section 4.1, using eq.2.

Hence, the track reconstruction efficiency and its associated uncertainty are:

$$\epsilon_{tr}(x, y) = \sum_{i,j,k \neq p} \epsilon_i \epsilon_j \epsilon_k (1 - \epsilon_p) + \epsilon_0 \epsilon_1 \epsilon_2 \epsilon_3 \quad (4)$$

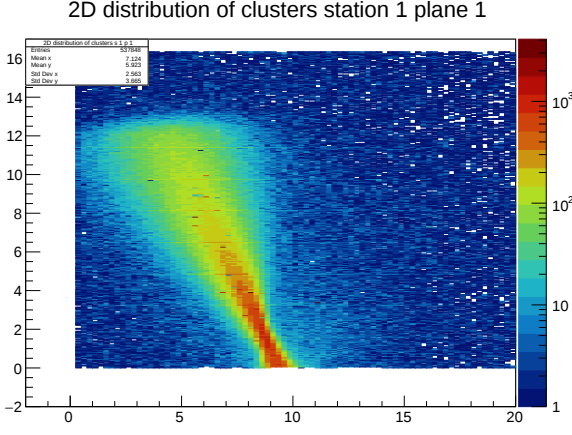
$$\sigma_{\epsilon_{tr}}(x, y) = \sqrt{\sum_{p=0}^3 \left(\sigma_p \sum_{i,j,k \neq p} \epsilon_i \epsilon_j (1 - \epsilon_k) \right)^2} \quad (5)$$

where the uncertainty comes from propagating errors on the eq.4

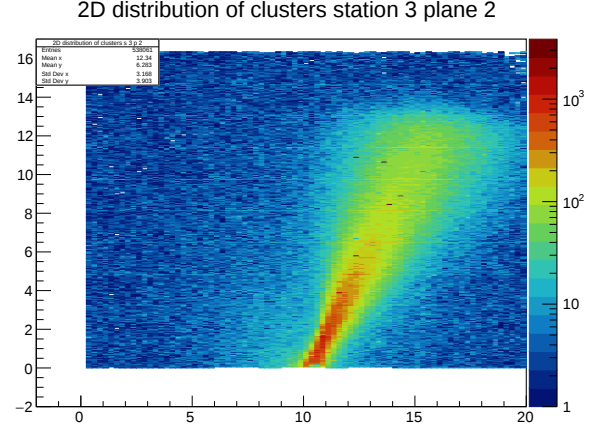
5 Results

5.1 Cluster

First, it's important to display the distribution plot of clusters on the plane. These plots enable the observation of a distinct diffractive pattern, as shown in Fig. 5a and Fig. 5b. This region encompasses the majority of events and it exhibits a higher susceptibility to radiation-induced damage.



(a) 2D distribution of clusters, station A NEAR, plane 1



(b) 2D distribution of clusters, station C FAR, plane 2

Figure 5: Distribution plots of clusters, run conducted on the 17th of May 2023 (run number: 452463)

To illustrate the evolution of cluster reconstruction efficiency over time, three runs, each separated by approximately one month from the others, are presented, before the disabling of plane 3 of C FAR and plane 2 of A FAR. In Fig.6, the efficiency of cluster reconstruction is shown (A FAR station), calculated through the original method. From these plots, it's possible to assess some issues in the A FAR station: the efficiency dropped to approximately 50% but then was recovered.

On the other hand, in Fig. 7, there are plots illustrating the efficiency of cluster reconstruction using the alternative method. In the original method, for example, on June 11th, a slight panel pattern is evident. This pattern is also noticeable in the alternative method, but it's particularly pronounced in P3 and P0. The panel pattern is due to bad tuning of the SiT, which causes pixels to be masked with that pattern.

It is worth noting another aspect: the decrease in efficiency at the center of the diffractive pattern, resulting in a burnout area with lower efficiency. The burn-out pattern appears wider in the alternative method. It appeared also in 2022 and it was eliminated by annealing the planes and increasing the voltage to the planes. In the other station, it's even more pronounced. Plots for all stations are attached at the end of the report (see plots in the Appendix, section 8.4).

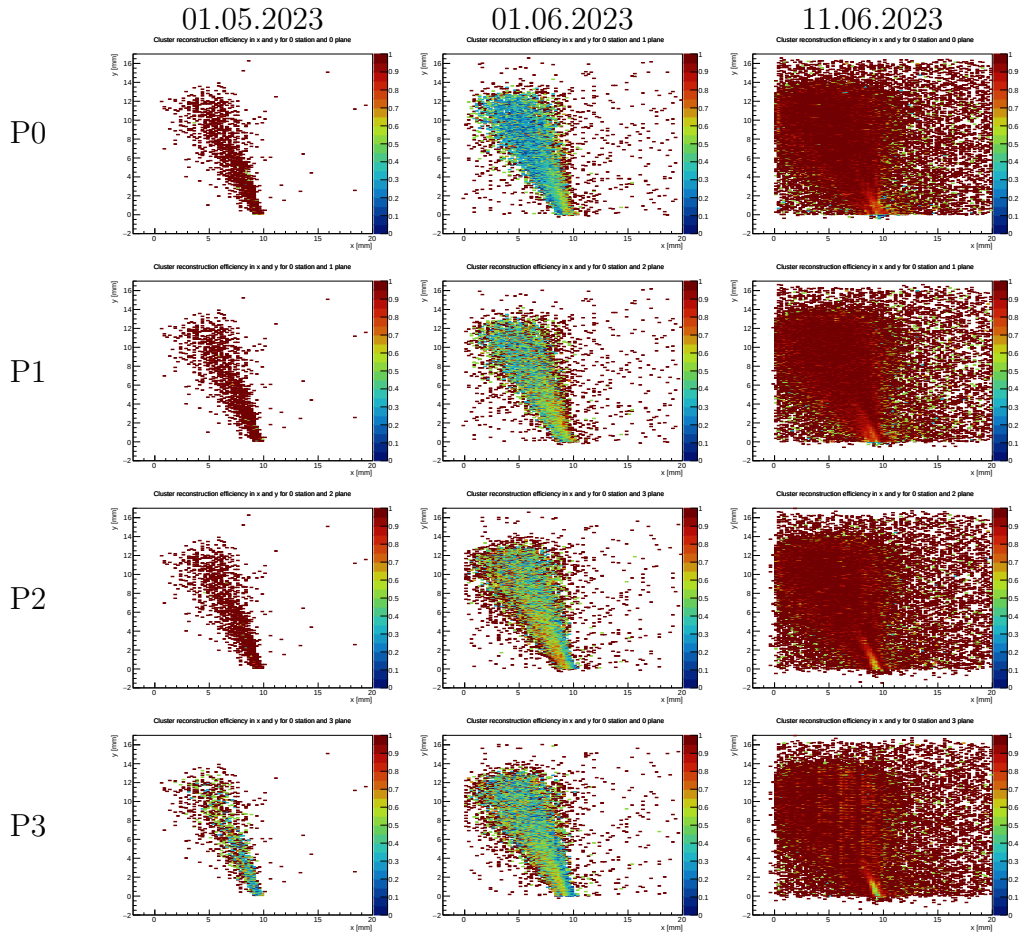


Figure 6: 2D distribution plots illustrating the efficiency of cluster reconstruction (A FAR station, original method)

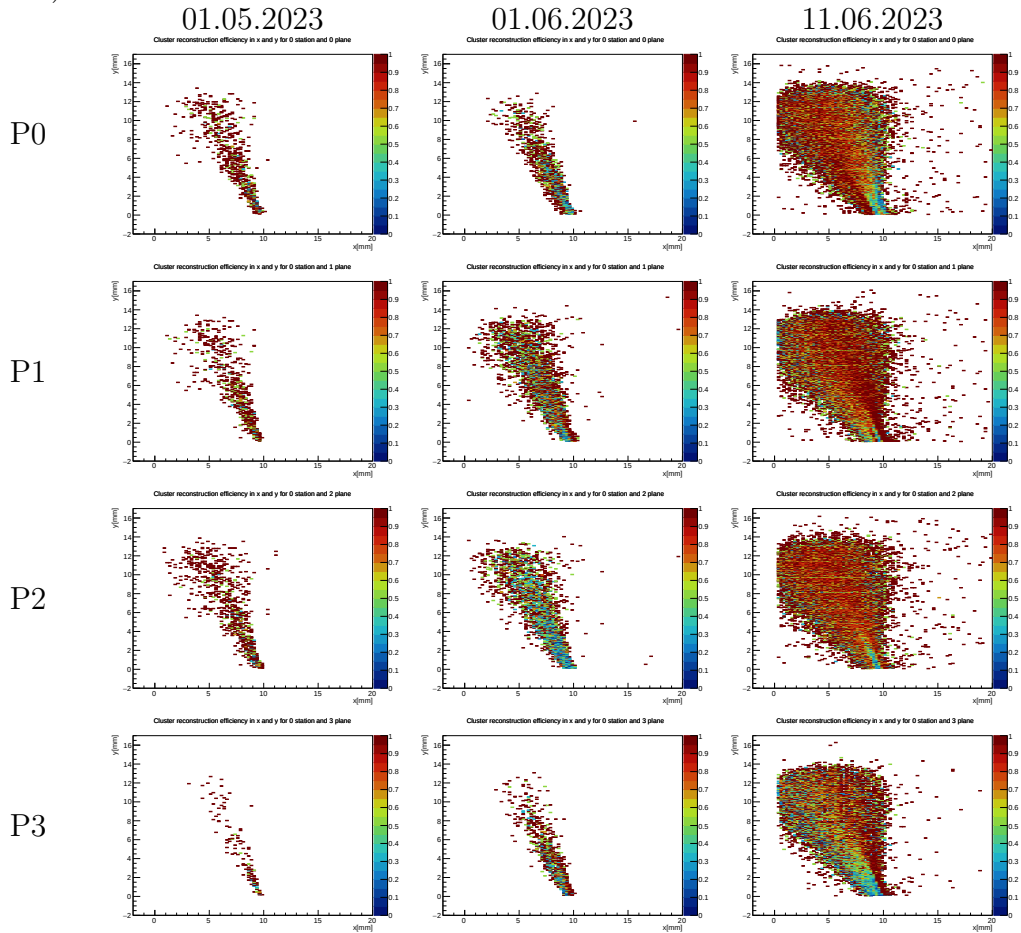


Figure 7: 2D distribution plots illustrating the efficiency of cluster reconstruction (A FAR station, alternative method)

Station	Plane	01.05.2023		01.06.2023		11.06.2023	
		Eff. I method	Eff. II method	Eff. I method	Eff. II method	Eff. I method	Eff. II method
A FAR	0	0.9640 $\pm$ 0.0046	0.930 $\pm$ 0.006	0.4398 $\pm$ 0.0024	0.6018 $\pm$ 0.0073	0.9417 $\pm$ 0.0004	0.8309 $\pm$ 0.0010
A FAR	1	0.9826 $\pm$ 0.0033	0.962 $\pm$ 0.005	0.3479 $\pm$ 0.0023	0.6906 $\pm$ 0.0049	0.9406 $\pm$ 0.0004	0.9104 $\pm$ 0.0007
A FAR	2	0.9796 $\pm$ 0.0035	0.928 $\pm$ 0.006	0.4721 $\pm$ 0.0028	0.3881 $\pm$ 0.0048	0.9363 $\pm$ 0.0004	0.8327 $\pm$ 0.0010
A FAR	3	0.3337 $\pm$ 0.0069	0.934 $\pm$ 0.009	0.5132 $\pm$ 0.0026	0.5644 $\pm$ 0.0080	0.9142 $\pm$ 0.0004	0.6748 $\pm$ 0.0013
A NEAR	0	0.9402 $\pm$ 0.0011	0.918 $\pm$ 0.002	0.9670 $\pm$ 0.0004	0.9237 $\pm$ 0.0009	0.9493 $\pm$ 0.0003	0.8546 $\pm$ 0.0009
A NEAR	1	0.9510 $\pm$ 0.0010	0.891 $\pm$ 0.003	0.9548 $\pm$ 0.0004	0.7735 $\pm$ 0.0015	0.9352 $\pm$ 0.0004	0.7674 $\pm$ 0.0011
A NEAR	2	0.9841 $\pm$ 0.0006	0.956 $\pm$ 0.002	0.9698 $\pm$ 0.0003	0.9253 $\pm$ 0.0009	0.9292 $\pm$ 0.0004	0.8896 $\pm$ 0.0008
A NEAR	3	0.9416 $\pm$ 0.0011	0.907 $\pm$ 0.002	0.9762 $\pm$ 0.0003	0.8549 $\pm$ 0.0012	0.9645 $\pm$ 0.0003	0.8140 $\pm$ 0.0010
A NEAR	0	0.9867 $\pm$ 0.0005	0.935 $\pm$ 0.002	0.9815 $\pm$ 0.0003	0.8816 $\pm$ 0.0010	0.9644 $\pm$ 0.0003	0.8308 $\pm$ 0.0009
C NEAR	1	0.9688 $\pm$ 0.0008	0.934 $\pm$ 0.002	0.9608 $\pm$ 0.0004	0.9180 $\pm$ 0.0009	0.9325 $\pm$ 0.0003	0.8251 $\pm$ 0.0009
C NEAR	2	0.9876 $\pm$ 0.0005	0.949 $\pm$ 0.002	0.9826 $\pm$ 0.0003	0.9138 $\pm$ 0.0009	0.9565 $\pm$ 0.0003	0.8398 $\pm$ 0.0009
C NEAR	3	0.9786 $\pm$ 0.0007	0.946 $\pm$ 0.001	0.9778 $\pm$ 0.0003	0.9058 $\pm$ 0.0009	0.9554 $\pm$ 0.0003	0.8329 $\pm$ 0.0009
C FAR	0	0.9878 $\pm$ 0.0025	0.967 $\pm$ 0.005	0.9370 $\pm$ 0.0005	0.9440 $\pm$ 0.0008	0.9087 $\pm$ 0.0004	0.9193 $\pm$ 0.0007
C FAR	1	0.9878 $\pm$ 0.0025	0.966 $\pm$ 0.005	0.9769 $\pm$ 0.0003	0.9243 $\pm$ 0.0009	0.9587 $\pm$ 0.0003	0.8959 $\pm$ 0.0008
C FAR	2	0.9699 $\pm$ 0.0039	0.941 $\pm$ 0.007	0.9641 $\pm$ 0.0004	0.8321 $\pm$ 0.0013	0.9406 $\pm$ 0.0004	0.7856 $\pm$ 0.0011
C FAR	3	0.6467 $\pm$ 0.0089	0.830 $\pm$ 0.014	0.9333 $\pm$ 0.0005	0.6347 $\pm$ 0.0019	0.9044 $\pm$ 0.0005	0.6028 $\pm$ 0.0014

Table 1: Comparison between the two methods

From table 1, it can be observed that the efficiency of Plane 3 at Station A FAR on May 1st (obtained using the original method) is approximately one-third of the efficiency obtained with the alternative method for the same plane.

Table 2 shows that efficiencies for FAR stations are zero with the original method, and after the disabling of the planes, due to the condition of the track reconstruction, as explained in Section 4.3. With the alternative method, lower efficiencies are observed, and A FAR P1 and C FAR P2 are less efficient than the rest of the stations.

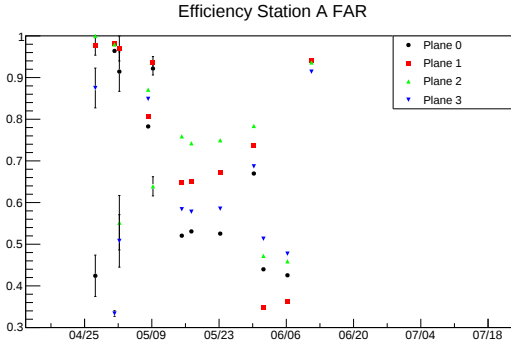
Station	Plane	02.07.2023		08.07.2023		14.07.2023	
		Eff. I method	Eff. II method	Eff. I method	Eff. II method	Eff. I method	Eff. II method
A FAR	0	0 $\pm$ 0	0.8749 $\pm$ 0.0007	0 $\pm$ 0	0.8908 $\pm$ 0.0028	0 $\pm$ 0	0.802 $\pm$ 0.018
A FAR	1	0 $\pm$ 0	0.9239 $\pm$ 0.0006	0 $\pm$ 0	0.4086 $\pm$ 0.0021	0 $\pm$ 0	0.455 $\pm$ 0.011
A FAR	2	0 $\pm$ 0	0 $\pm$ 0	0 $\pm$ 0	0 $\pm$ 0	0 $\pm$ 0	0 $\pm$ 0
A FAR	3	0 $\pm$ 0	0.7092 $\pm$ 0.0010	0 $\pm$ 0	0.8624 $\pm$ 0.0033	0 $\pm$ 0	0.715 $\pm$ 0.022
A NEAR	0	0.9753 $\pm$ 0.0002	0.9006 $\pm$ 0.0005	0.9571 $\pm$ 0.0003	0.8657 $\pm$ 0.0008	0.964 $\pm$ 0.001	0.884 $\pm$ 0.003
A NEAR	1	0.9811 $\pm$ 0.0001	0.8163 $\pm$ 0.0007	0.9477 $\pm$ 0.0003	0.7901 $\pm$ 0.0010	0.956 $\pm$ 0.001	0.802 $\pm$ 0.004
A NEAR	2	0.9822 $\pm$ 0.0001	0.9405 $\pm$ 0.0004	0.9560 $\pm$ 0.0003	0.9178 $\pm$ 0.0006	0.961 $\pm$ 0.001	0.928 $\pm$ 0.003
A NEAR	3	0.9843 $\pm$ 0.0001	0.8590 $\pm$ 0.0006	0.9606 $\pm$ 0.0003	0.7889 $\pm$ 0.0010	0.962 $\pm$ 0.001	0.822 $\pm$ 0.004
A NEAR	0	0.9714 $\pm$ 0.0002	0.9107 $\pm$ 0.0005	0.9631 $\pm$ 0.0003	0.8739 $\pm$ 0.0008	0.969 $\pm$ 0.001	0.906 $\pm$ 0.003
C NEAR	1	0.9672 $\pm$ 0.0002	0.9276 $\pm$ 0.0004	0.9503 $\pm$ 0.0003	0.8686 $\pm$ 0.0008	0.959 $\pm$ 0.001	0.915 $\pm$ 0.003
C NEAR	2	0.9688 $\pm$ 0.0002	0.9137 $\pm$ 0.0005	0.9551 $\pm$ 0.0003	0.8613 $\pm$ 0.0008	0.961 $\pm$ 0.001	0.900 $\pm$ 0.003
C NEAR	3	0.9618 $\pm$ 0.0002	0.8970 $\pm$ 0.0005	0.9512 $\pm$ 0.0003	0.8731 $\pm$ 0.0008	0.953 $\pm$ 0.001	0.892 $\pm$ 0.003
C FAR	0	0 $\pm$ 0	0.8721 $\pm$ 0.0007	0 $\pm$ 0	0.8909 $\pm$ 0.0008	0 $\pm$ 0	0.920 $\pm$ 0.003
C FAR	1	0 $\pm$ 0	0.9214 $\pm$ 0.0006	0 $\pm$ 0	0.9144 $\pm$ 0.0007	0 $\pm$ 0	0.918 $\pm$ 0.003
C FAR	2	0 $\pm$ 0	0.7633 $\pm$ 0.0010	0 $\pm$ 0	0.7470 $\pm$ 0.0012	0 $\pm$ 0	0.747 $\pm$ 0.005
C FAR	3	0 $\pm$ 0	0 $\pm$ 0	0 $\pm$ 0	0 $\pm$ 0	0 $\pm$ 0	0 $\pm$ 0

Table 2: Comparison between the two methods for run numbers: 455838, 456126, 456665 (respectively 02-08-14.07.2023)

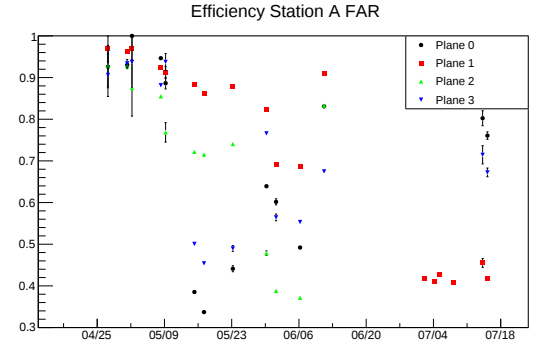
5.2 Time evolution of the efficiency of cluster reconstruction

Fig.8, Fig.9, Fig.10 and Fig.11 display plots of the plane efficiencies for cluster reconstruction as a function of time using two different methods. The FAR stations exhibit more significant losses compared to the NEAR stations, which is consistent with expectations given their closer proximity to the beam (in particular $1.7 < d < 2.3$ mm for NEAR stations and $1.5 < d < 2.3$ mm for FAR stations.). For the NEAR stations, similar behavior can be observed. Lower values of efficiencies are observed when using the alternative method. A similar temporal evolution is observed for efficiencies

with both methods. Note that the different y-axes (in the plots below) have been adapted to the data in order to clearly visualize temporal evolution.

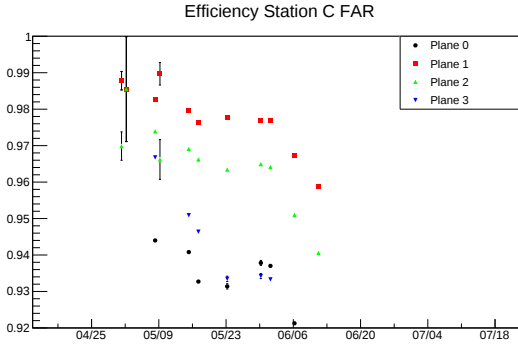


(a)

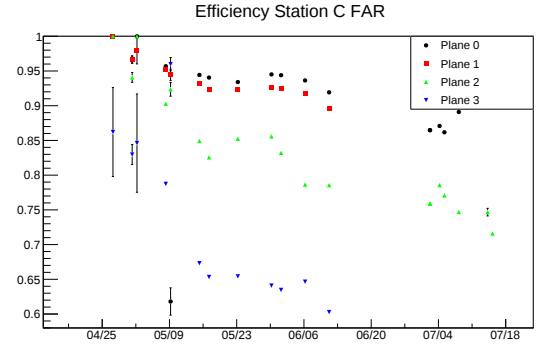


(b)

Figure 8: Time evolution A FAR, original method (a) and alternative method (b)

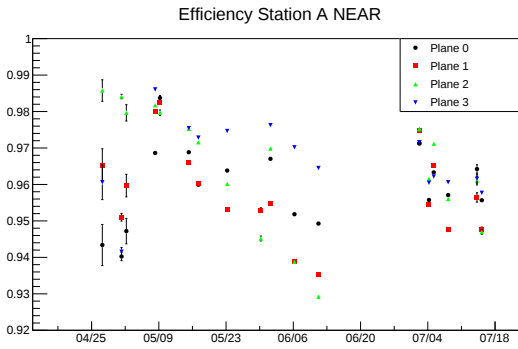


(a)

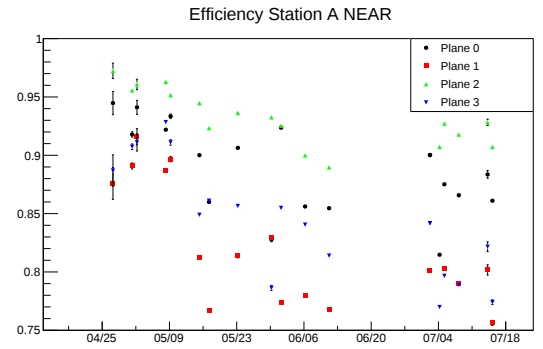


(b)

Figure 9: Time evolution C FAR, original method (a) and alternative method (b)

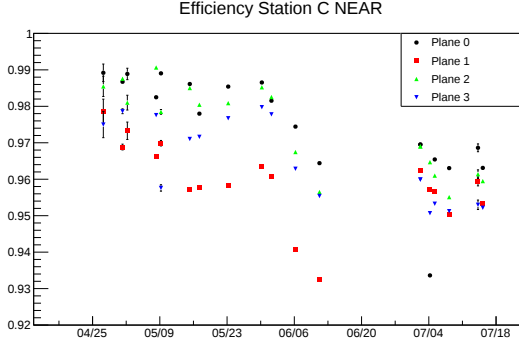


(a)

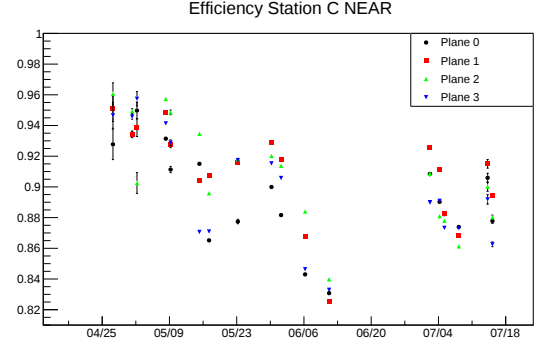


(b)

Figure 10: Time evolution A NEAR, original method (a) and alternative method (b)



(a)

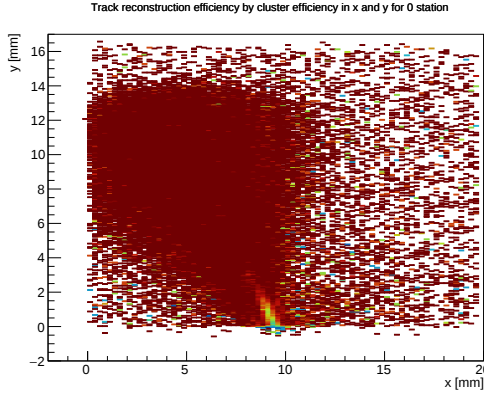


(b)

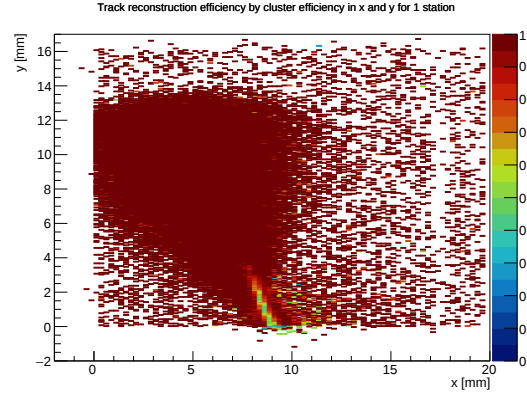
Figure 11: Time evolution C NEAR, original method (a) and alternative method (b)

6 Track Reconstruction Efficiency

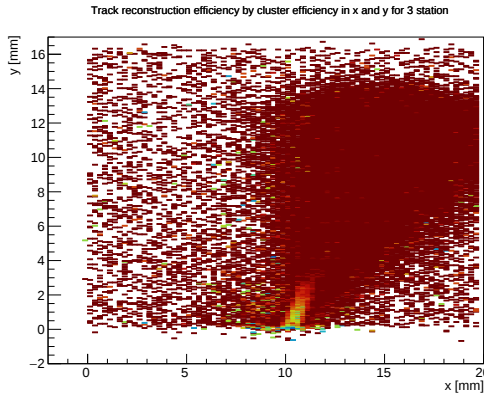
As mentioned in section 4.3, the efficiency of track reconstruction can be estimated as the probability that three or more planes have recorded clusters. In Fig.12, 2D distributions of reconstruction efficiency of all four stations for run number 454222 (taken on the 11th of June 2023) are presented. Track reconstruction efficiency does not drop below 97% for this run (see Table 3).



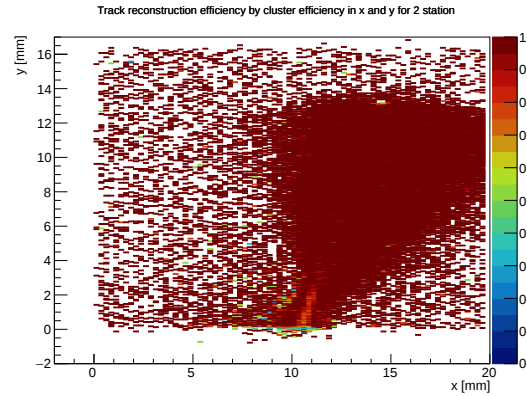
(a)



(b)



(c)



(d)

Figure 12: Track Efficiency Plots: A FAR (a), A NEAR (b), C FAR (c), C NEAR (d)

Station	Plane	Efficiency
A FAR	0	0.975748 ± 0.000132502
A NEAR	1	$0.983181 \pm 9.77135e-05$
C NEAR	2	$0.987388 \pm 7.62434e-05$
C FAR	3	0.972609 ± 0.000144858

Table 3: The efficiencies of track reconstruction for run number 454222

6.1 Time evolution of the efficiency of track reconstruction

In this section plots of the efficiencies for track reconstruction as a function of time are presented. The efficiency of track reconstruction is not as significantly impacted by the damage, as is the case with clusters, for station C NEAR, C FAR, and A NEAR. But, from the graphs below, it's possible to notice some issues with Station A FAR. It's much more affected by the damage (see Table 6 in the Appendix 8.3). Note that the different y-axes (in the plots below) have been adapted to the data in order to clearly visualize temporal evolution.

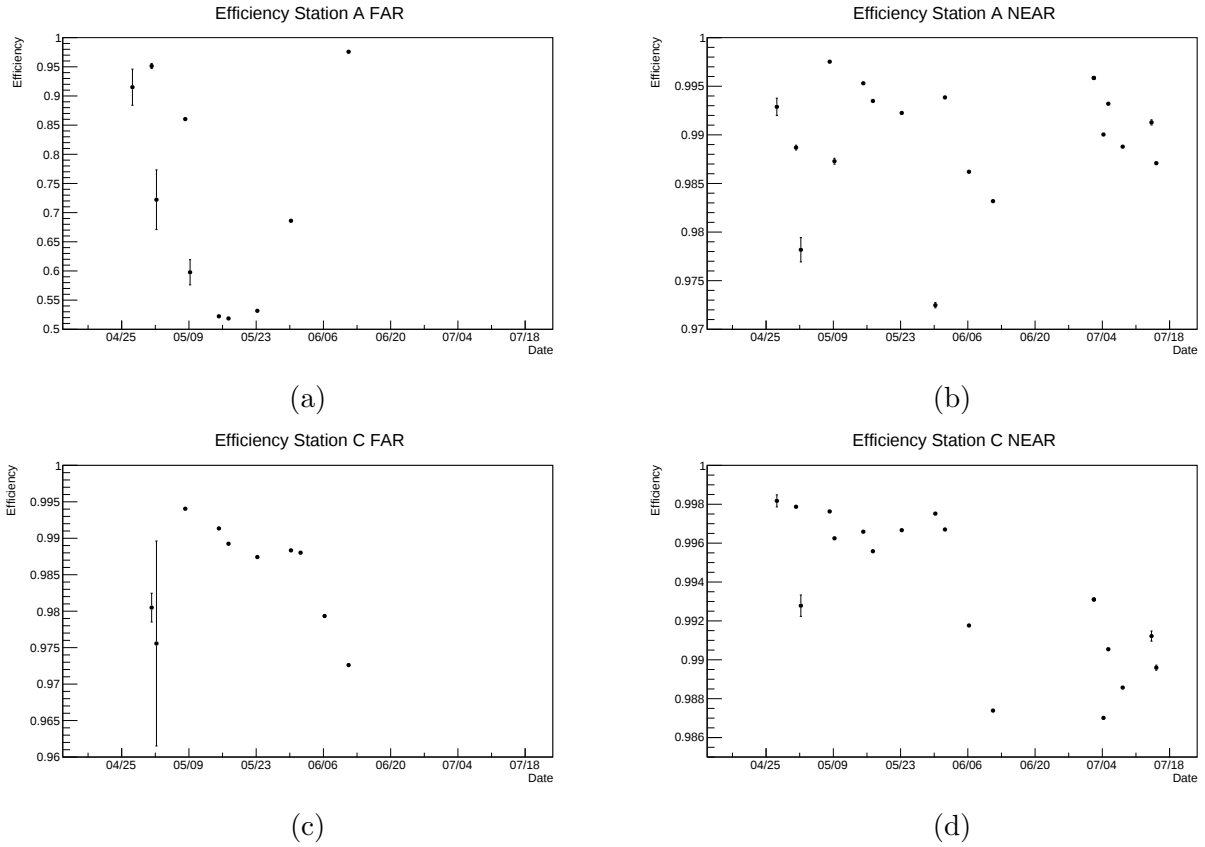


Figure 13: Time evolution of the efficiency of track reconstruction: A FAR (a), A NEAR (b), C FAR (c), C NEAR (d)

7 Conclusions

Two methods used to estimate cluster and track reconstruction efficiency in the SiT are described. The alternative method, introduced in response to the disabling of specific SiT planes, cannot yet be trusted due to spatial distribution issues: the spatial distributions are not the same. Although

the same temporal evolution in efficiencies can be observed with the alternative method compared to the original one, spatial distributions exhibit differences. Furthermore, using the alternative method (after disabling the planes), it's possible to observe that A FAR P1 and C FAR P2 are less efficient than the rest of the stations. Hence, the alternative method needs further validation. On the other hand, track reconstruction efficiency is above 97% for stations C NEAR, C FAR, and A NEAR, indicating robust performance despite variations in cluster reconstruction efficiency. Problems in the station A FAR are confirmed from the low efficiencies of track reconstruction.

Looking ahead, a deeper understanding of spatial distribution anomalies will be essential for enhancing the SiT's efficiency. These findings contribute to the ongoing efforts in SiT optimization. In conclusion, this analysis was conducted for further investigations and optimizations.

8 Appendix

8.1 Processed Run number

Run number	Date	μ_{in}	μ_{out}	LB_{min}	LB_{max}
450227	21.04.2023	24.4	36.2	79	1405
450894	27.04.2023	29.5	0	565	1117
450997	28.04.2023	26.7	38.7	1402	2053
451094	01.05.2023	28.4	40.8	207	935
451557	05.05.2023	37.3	0	288	643
451735	08.05.2023	33.4	29.6	672	1878
452028	12.05.2023	31.2	42.5	404	1098
452463	17.05.2023	32.0	38.8	242	1117
452843	23.05.2023	1.86	34.0	323	1758
453319	30.05.2023	30.6	52.9	199	622
453530	01.06.2023	28.4	42.3	598	1182
453816	06.06.2023	34.4	26.0	323	1758
454222	11.06.2023	10.8	2.0	211	1157
455534	26.06.2023	8.26	2.0	880	1068
455838	02.07.2023	N/A	N/A	2	646
455857	02.07.2023	38.4	N/A	126	646
455975	04.07.2023	10.0	30.6	377	1395
455924	05.07.2023	35.9	29.9	207	1351
456126	08.07.2023	10.9	29.0	161	1483
456665	14.07.2023	1.31	0.0012	701	827
456685	15.06.2023	44.7	59.2	232	493

Table 4: Processed number of runs

8.2 Comparison between the two methods

Station	Plane	05.05.2023		08.05.2023		12.05.2023	
		Eff. I method	Eff. II method	Eff. I method	Eff. II method	Eff. I method	Eff. II method
A FAR	0	0.9216 $\pm$ 0.0154	0.8865 $\pm$ 0.0139	0.7827 $\pm$ 0.0012	0.9466 $\pm$ 0.0011	0.5205 $\pm$ 0.0016	0.3854 $\pm$ 0.0043
A FAR	1	0.9362 $\pm$ 0.0142	0.9121 $\pm$ 0.0142	0.8063 $\pm$ 0.0012	0.9239 $\pm$ 0.0012	0.6478 $\pm$ 0.0017	0.8826 $\pm$ 0.0018
A FAR	2	0.6391 $\pm$ 0.0230	0.7685 $\pm$ 0.0234	0.8709 $\pm$ 0.0011	0.8550 $\pm$ 0.0017	0.7590 $\pm$ 0.0016	0.7218 $\pm$ 0.0026
A FAR	3	0.1170 $\pm$ 0.0066	0.9375 $\pm$ 0.0202	0.8489 $\pm$ 0.0011	0.8816 $\pm$ 0.0017	0.5840 $\pm$ 0.0016	0.5007 $\pm$ 0.0045
A NEAR	0	0.9837 $\pm$ 0.0006	0.9335 $\pm$ 0.0019	0.9686 $\pm$ 0.0003	0.9219 $\pm$ 0.0007	0.9688 $\pm$ 0.0003	0.9001 $\pm$ 0.0008
A NEAR	1	0.9826 $\pm$ 0.0007	0.8968 $\pm$ 0.0023	0.9799 $\pm$ 0.0002	0.8874 $\pm$ 0.0009	0.9661 $\pm$ 0.0003	0.8120 $\pm$ 0.0011
A NEAR	2	0.9797 $\pm$ 0.0007	0.9515 $\pm$ 0.0016	0.9817 $\pm$ 0.0002	0.9629 $\pm$ 0.0005	0.9753 $\pm$ 0.0003	0.9447 $\pm$ 0.0006
A NEAR	3	0.7741 $\pm$ 0.0019	0.9110 $\pm$ 0.0024	0.9861 $\pm$ 0.0002	0.9284 $\pm$ 0.0007	0.9755 $\pm$ 0.0003	0.8490 $\pm$ 0.0010
A NEAR	0	0.9890 $\pm$ 0.0005	0.9113 $\pm$ 0.0020	0.9825 $\pm$ 0.0002	0.9314 $\pm$ 0.0007	0.9861 $\pm$ 0.0002	0.9150 $\pm$ 0.0007
C NEAR	1	0.9699 $\pm$ 0.0008	0.9275 $\pm$ 0.0019	0.9663 $\pm$ 0.0003	0.9483 $\pm$ 0.0006	0.9573 $\pm$ 0.0003	0.9042 $\pm$ 0.0008
C NEAR	2	0.9785 $\pm$ 0.0006	0.9485 $\pm$ 0.0015	0.9906 $\pm$ 0.0002	0.9573 $\pm$ 0.0006	0.9850 $\pm$ 0.0002	0.9345 $\pm$ 0.0006
C NEAR	3	0.9576 $\pm$ 0.0009	0.9289 $\pm$ 0.0018	0.9776 $\pm$ 0.0003	0.9414 $\pm$ 0.0007	0.9710 $\pm$ 0.0003	0.8706 $\pm$ 0.0008
C FAR	0	0.7580 $\pm$ 0.0120	0.6180 $\pm$ 0.0197	0.9440 $\pm$ 0.0004	0.9569 $\pm$ 0.0006	0.9408 $\pm$ 0.0004	0.9443 $\pm$ 0.0006
C FAR	1	0.9897 $\pm$ 0.0031	0.9443 $\pm$ 0.0082	0.9826 $\pm$ 0.0003	0.9518 $\pm$ 0.0006	0.9797 $\pm$ 0.0002	0.9316 $\pm$ 0.0007
C FAR	2	0.9662 $\pm$ 0.0055	0.9236 $\pm$ 0.0099	0.9739 $\pm$ 0.0003	0.9028 $\pm$ 0.0009	0.9691 $\pm$ 0.0003	0.8492 $\pm$ 0.0010
C FAR	3	0.3480 $\pm$ 0.0086	0.9598 $\pm$ 0.0095	0.9668 $\pm$ 0.0003	0.7874 $\pm$ 0.0014	0.9509 $\pm$ 0.0004	0.6732 $\pm$ 0.0015

Table 5: Comparison between the two methods for run numbers: 455838, 456126, 456665 (respectively 02-08-14.07.2023)

8.3 Track Reconstruction Efficiency

Date	C FAR	A FAR	A NEAR	C NEAR
21.04	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
27.04	0.0 $\pm$ 0.0	0.915081 $\pm$ 0.030984	0.992885 $\pm$ 0.000889	0.998175 $\pm$ 0.000311
28.04	0.975570 $\pm$ 0.014060	0.722075 $\pm$ 0.051161	0.978181 $\pm$ 0.001254	0.992783 $\pm$ 0.000550
01.05	0.980492 $\pm$ 0.001973	0.951398 $\pm$ 0.004351	0.988690 $\pm$ 0.000244	0.997871 $\pm$ 0.000069
05.05	0.816848 $\pm$ 0.008759	0.597717 $\pm$ 0.021646	0.987287 $\pm$ 0.000305	0.996249 $\pm$ 0.000100
08.05	0.994051 $\pm$ 0.000062	0.860378 $\pm$ 0.000820	0.997526 $\pm$ 0.000029	0.997630 $\pm$ 0.000031
12.05	0.991355 $\pm$ 0.000072	0.522281 $\pm$ 0.001458	0.995308 $\pm$ 0.000044	0.996589 $\pm$ 0.000034
17.05	0.989250 $\pm$ 0.000083	0.518586 $\pm$ 0.001395	0.993486 $\pm$ 0.000055	0.995583 $\pm$ 0.000040
23.05	0.987426 $\pm$ 0.000158	0.531669 $\pm$ 0.002348	0.992254 $\pm$ 0.000107	0.996667 $\pm$ 0.000056
30.05	0.988342 $\pm$ 0.000146	0.686008 $\pm$ 0.001780	0.972478 $\pm$ 0.000274	0.997519 $\pm$ 0.000043
01.06	0.988023 $\pm$ 0.000112	0.230372 $\pm$ 0.001676	0.993851 $\pm$ 0.000065	0.996703 $\pm$ 0.000040
06.06	0.979339 $\pm$ 0.000119	0.215686 $\pm$ 0.001042	0.986204 $\pm$ 0.000086	0.991765 $\pm$ 0.000057
11.06	0.972609 $\pm$ 0.000145	0.975748 $\pm$ 0.000133	0.983181 $\pm$ 0.000098	0.987388 $\pm$ 0.000076
26.06	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
02.07	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.995851 $\pm$ 0.000046	0.993102 $\pm$ 0.000066
04.07	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.990036 $\pm$ 0.000065	0.987012 $\pm$ 0.000079
05.07	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.993201 $\pm$ 0.000046	0.990544 $\pm$ 0.000058
08.07	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.988785 $\pm$ 0.000070	0.988571 $\pm$ 0.000069
14.07	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.991283 $\pm$ 0.000264	0.991220 $\pm$ 0.000260
15.07	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.987086 $\pm$ 0.000156	0.989594 $\pm$ 0.000129

Table 6: Track Reconstruction Efficiency for all processed runs

8.4 2D distributions of cluster reconstruction efficiency

8.4.1 A NEAR

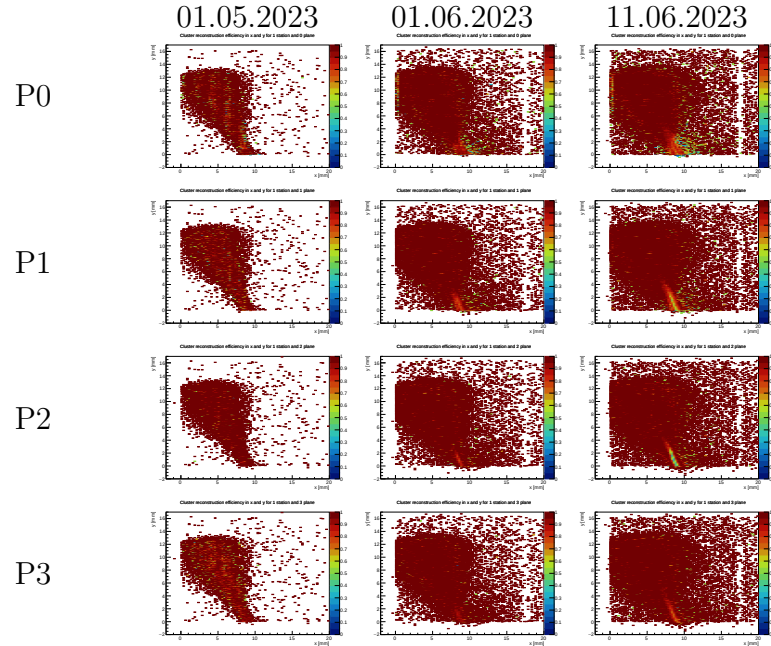


Figure 14: 2D distribution plots illustrating the efficiency of cluster reconstruction (A NEAR station, original method)

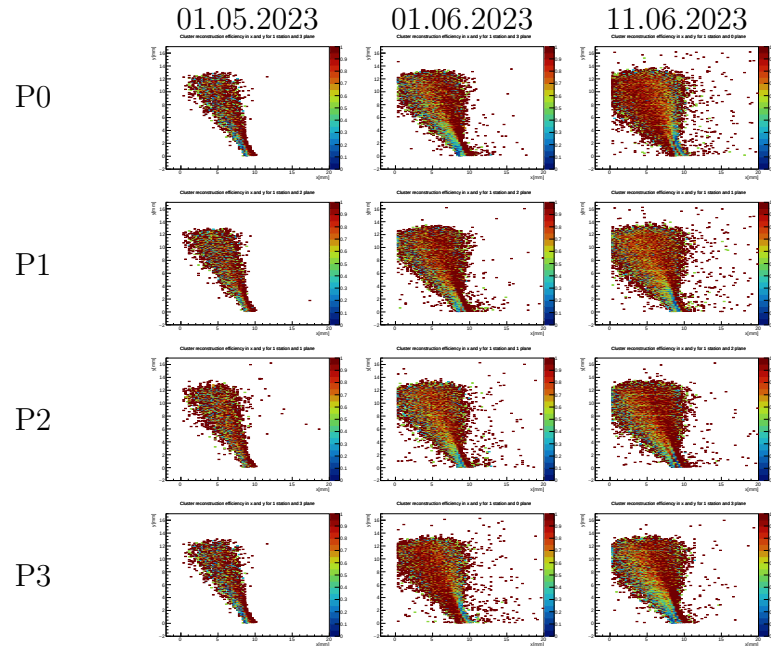


Figure 15: 2D distribution plots illustrating the efficiency of cluster reconstruction (A NEAR station, alternative method)

8.4.2 C NEAR

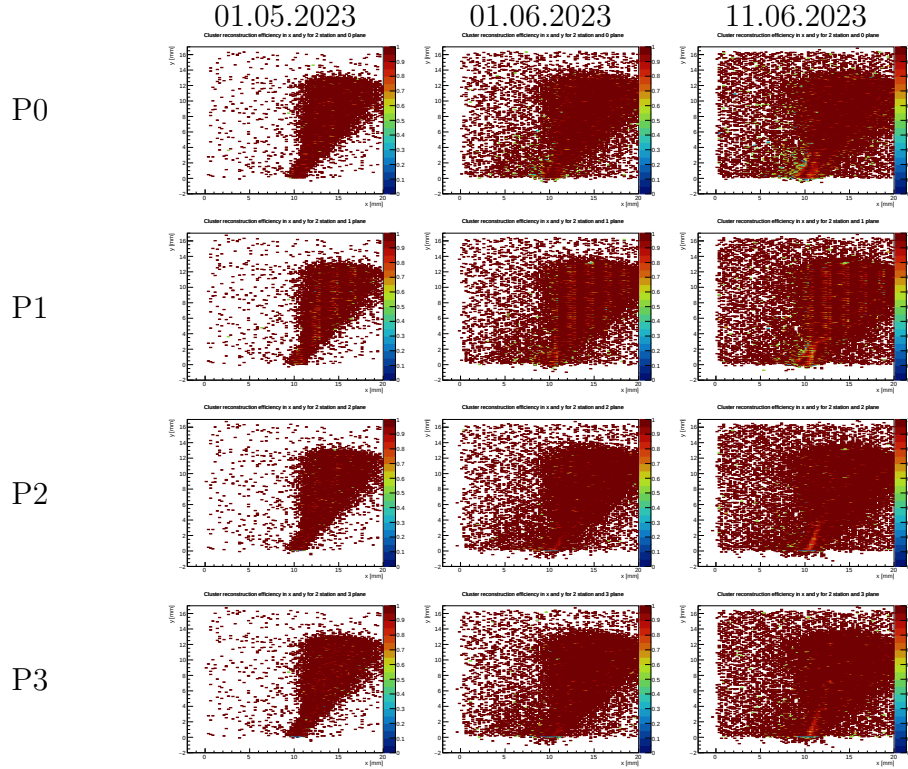


Figure 16: 2D distribution plots illustrating the efficiency of cluster reconstruction (C NEAR station, original method)

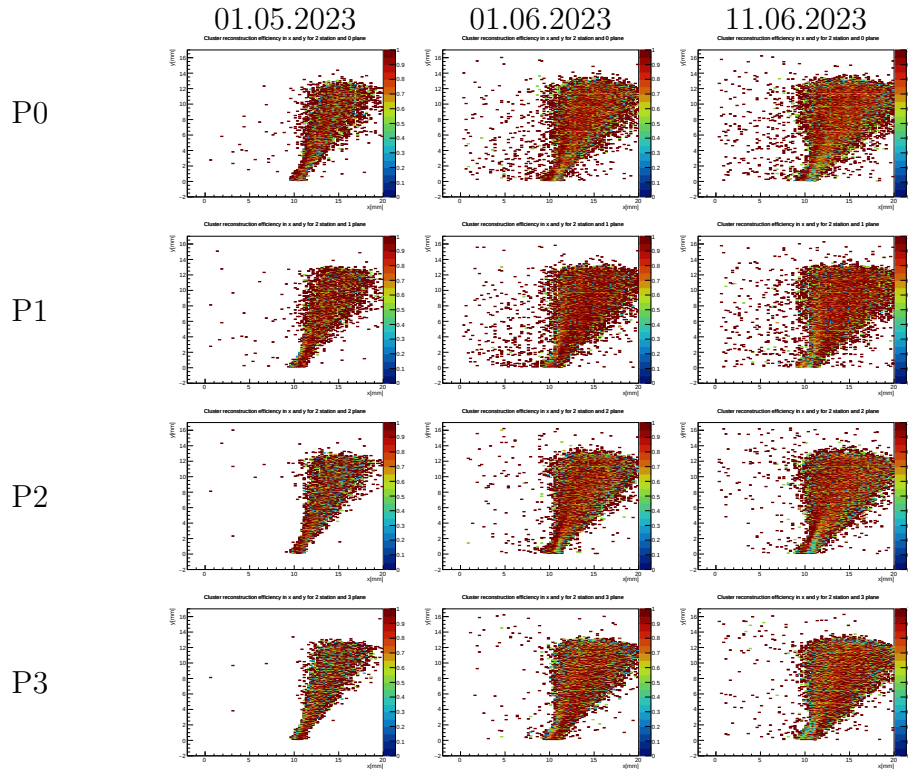


Figure 17: 2D distribution plots illustrating the efficiency of cluster reconstruction (C NEAR station, alternative method)

8.4.3 C FAR

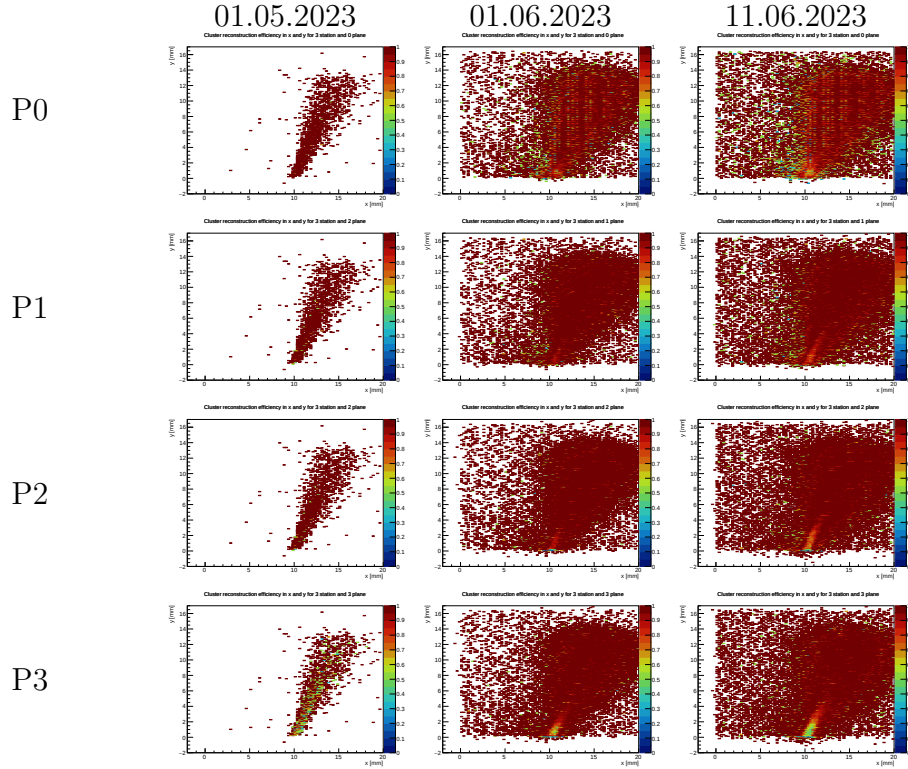


Figure 18: 2D distribution plots illustrating the efficiency of cluster reconstruction (C FAR station, original method)

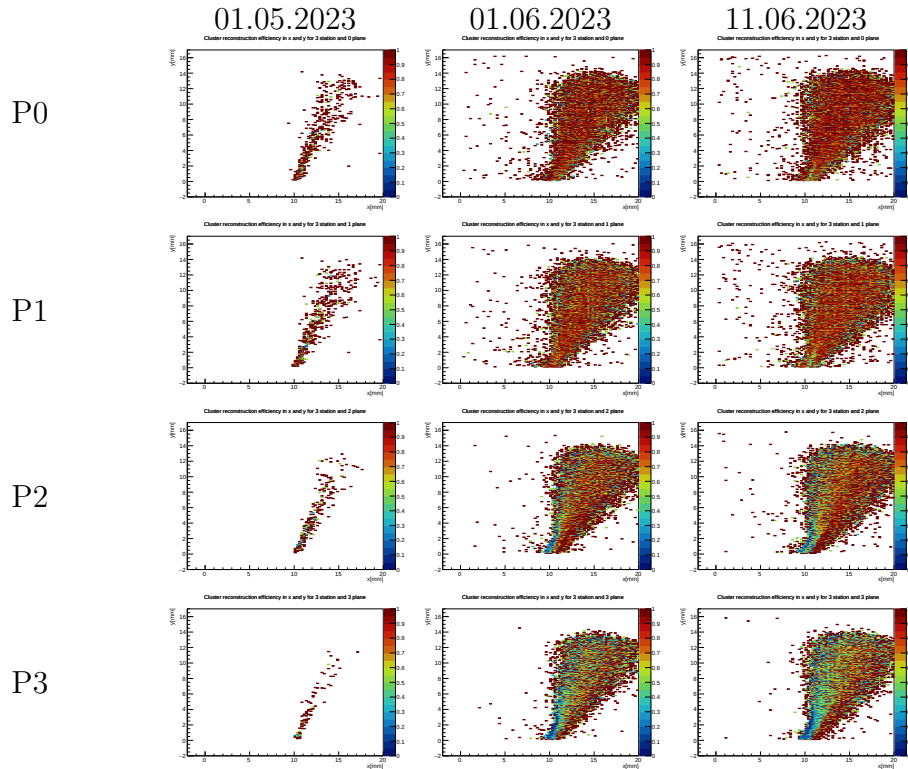


Figure 19: 2D distribution plots illustrating the efficiency of cluster reconstruction (C FAR station, alternative method)

References

- [1] *Technical Design Report for the ATLAS Forward Proton Detector*, 2015.
- [2] Paula Erland. *Evidence of the Exclusive Jet Production Using the ATLAS Detector*. PhD thesis, Institute of Nuclear Physics Polish Academy of Sciences.
- [3] Rafal Staszewski. *Study of Diffraction with the ATLAS detector at the LHC*. CERN-THESIS-2012-409.