JOINT INSTITUTE FOR NUCLEAR RESEARCH
Veksler and Baldin laboratory of High Energy Physics

FINAL REPORT ON THE START PROGRAMME

Testing Calorimeters with Cosmic Radiation for Mini-SPD Facility

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Abstract

This report describes the participation in data collection for the Mini-SPD setup, which is part of the NICA megaproject at JINR. The Mini-SPD installation utilizes calorimeters based on scintillators and straw trackers. Currently, the setup is undergoing reconstruction. The research focuses on testing the calorimeters with cosmic radiation to evaluate their performance. Data collection is carried out using CAEN electronics, specifically the FERS DT5202 front-end system. An algorithm was developed to filter events. Each channel corresponds to a column of the calorimeter, and our criteria exclude events where multiple columns are triggered, allowing only single vertical tracks to be recorded.

Contents

1. Introduction

The NICA (Nuclotron-based Ion Collider fAcility) project is an advanced megaproject being implemented at the Joint Institute for Nuclear Research (JINR) in Dubna, aimed at studying the physics of heavy ions and quark-gluon plasma. The primary goal of NICA is to investigate the properties of matter under extreme conditions of density and temperature, which will enable a deeper understanding of the fundamental aspects of particle interactions and their states.

The central elements of the NICA complex are two key detectors: the Multi-Purpose Detector (MPD) and the Spin Physics Detector (SPD). These detectors play a crucial role in studying ion collisions and analyzing the resulting data.

1.1 Description of the SPD and Mini-SPD Detectors

The Spin Physics Detector (SPD) is one of the primary detectors designed to study the spin properties of particles and their interactions. The SPD employs advanced detection technologies for the precise measurement of particle parameters, such as their spin, and interactions in collisions. This detector is equipped with highly sensitive components that enable detailed analysis of collisions and the study of spin effects in high-energy processes. Figure 1.1 illustrates the design of the SPD detector.

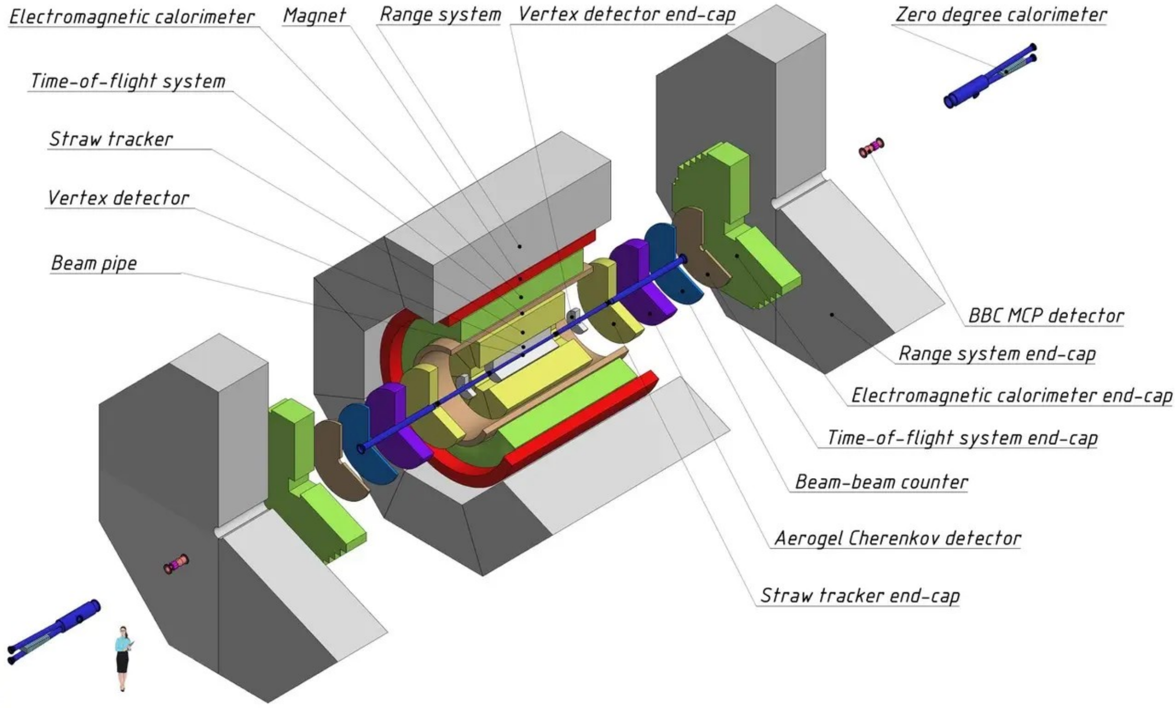

Figure 1.1 — Spin Physics Detector

The Mini-SPD is a test version of the SPD, designed for preliminary testing and calibration of the equipment before the full operation of the main detector. Currently, the Mini-SPD is undergoing reconstruction and is equipped with modern components, such as straw-based tracker chambers and scintillator-based calorimeters. The testing of the Mini-SPD includes verifying the functionality and accuracy of these components in real-world conditions, which is critically important for the successful operation of the main SPD detector. Figure 1.2 illustrates the design of the Mini-SPD.

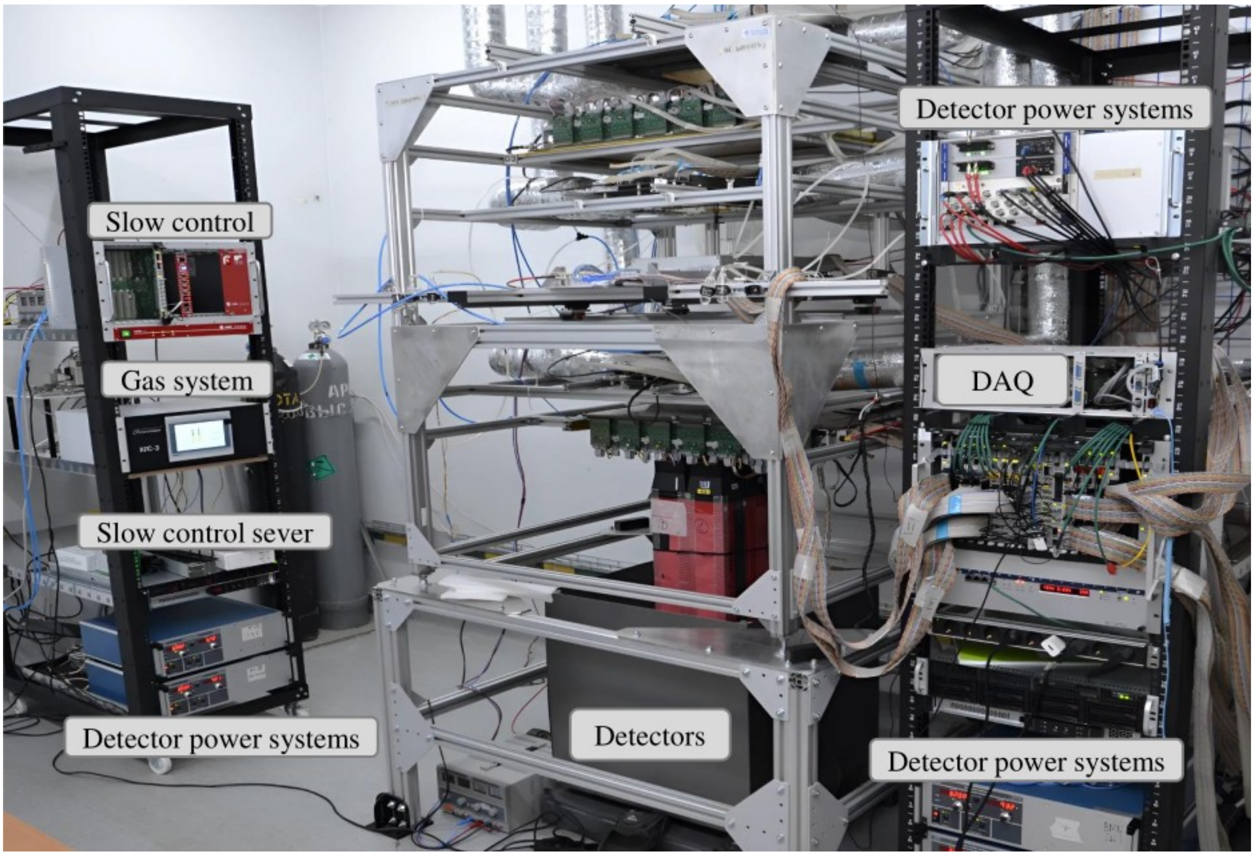

Figure 1.2 — Mini SPD setup

1.2 The Importance of Testing the Mini-SPD in the Context of the NICA Project

Testing the Mini-SPD plays a crucial role in preparing for the full-scale launch of the SPD detector within the NICA project. It allows for a comprehensive check of all systems and components of the detector, including the assessment of their performance, accuracy, and reliability. Verifying the operation of the calorimeters and trackers using cosmic radiation helps ensure the correct registration and analysis of particle data. These tests are essential for identifying and addressing potential issues before the full operation of the SPD, thereby ensuring the high quality and reliability of the data obtained during experiments at NICA.

2. Mini-SPD Installation and Design

The Mini-SPD (Mini Spin Physics Detector) research installation is designed to test various types of detectors that will be used in the main SPD detector as part of the NICA project. The primary goal of the Mini-SPD is to test and calibrate detectors for subsequent use in the SPD.

2.1 Main Components of the Installation

The Mini-SPD design includes several key components:

- **Straw-trackers:** These trackers use gas-filled tubes to detect the passage of particles. Straw-trackers have high spatial resolution and can accurately determine particle trajectories.
- **Calorimeters:** The calorimeters in Mini-SPD are used to measure the energy of particles. They consist of scintillating materials that emit light when interacting with particles. This light is recorded and analyzed to determine the energy of the particles.

2.2 Current Tasks and Goals

The Mini-SPD is currently in the active testing and calibration phase. These tests involve checking the functionality of the detectors and their electronic data acquisition systems. The main tasks at this stage include:

- **Testing capabilities and modern electronics:** Electronics from CAEN are used for data collection and analysis.
- **Data collection from cosmic rays:** The setup is configured to detect muons generated by the interaction of cosmic rays with the Earth's atmosphere. Muons are detected using the calorimeters.
- **Use of SPD detector prototypes:** The testing includes the use of detector prototypes that will be installed in the main SPD detector.

This allows for early assessment of their performance and reliability.

- **Measurement of detector characteristics:** Measurements are being conducted on parameters such as spatial and temporal resolution, particle detection efficiency, drift characteristics, and gain factor.
- **Stability check of detectors and electronics:** Extended testing ensures the stable operation of the detectors and their electronic data acquisition systems over a long period.

The Mini-SPD is a critical element in preparing for the full operation of the SPD detector, ensuring high-quality and reliable future scientific research within the NICA project.

3. Testing with Cosmic Radiation

3.1 Objectives of Testing Calorimeters with Cosmic Rays

The goal of testing calorimeters with cosmic rays is to verify their functionality and reliability under conditions that closely resemble real operational environments. Cosmic radiation, particularly muons, provides a unique opportunity for calibrating and assessing the characteristics of the calorimeters, such as resolution, efficiency, and operational stability.

3.2 Characteristics of Cosmic Rays and the Significance of Muons

Cosmic rays are streams of high-energy particles that constantly bombard the Earth from space. They include protons, alpha particles, and nuclei of heavier elements. Muons are one of the most important components of cosmic rays, as they are produced by the interaction of primary cosmic rays with the Earth's atmosphere. These particles have a high penetrating ability, making them ideal for testing detectors and calorimeters. Muons play a key role in calorimeter testing for several reasons:

1. **High Penetrating Ability:** Muons can penetrate thick layers of material, allowing researchers to evaluate the performance of calorimeters at different depths and under various conditions.
2. **Stability and Predictability:** The energy spectrum of muons is well-studied, simplifying the calibration and accuracy assessment of calorimeter measurements.
3. **Natural Source:** Cosmic muons are continuously present, providing a constant stream of particles for testing without the need for artificial radiation sources.

These features make muons an ideal tool for testing and calibrating calorimeters, ensuring high reliability and accuracy of measurements within the NICA project and the Mini-SPD.

4. Data Collection and Electronics

4.1 Introduction to CAEN Electronics and the FERS DT5202 System

The FERS DT5202 system from CAEN is a distributed and easily scalable front-end data processing system used in the Mini-SPD setup. Each front-end unit of the system performs multiple functions, including a traditional analog spectroscopic chain, digital front-end processing (TDC or logical trigger board). This allows the system to adapt to various tasks and types of detectors. Figure 4.1 shows the functional diagram of the experimental setup.

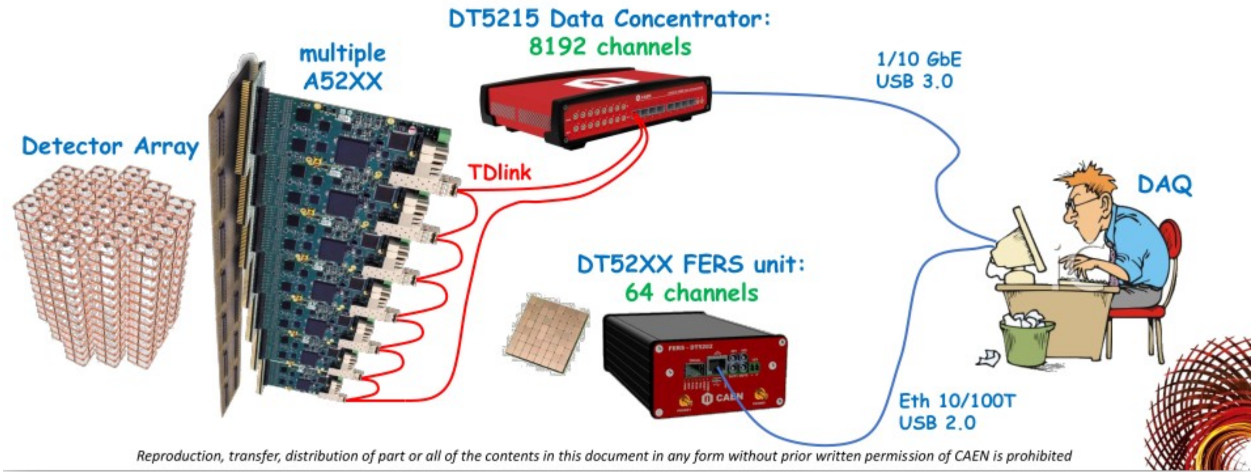

Figure 4.1 — Functional diagram of experimental setup

4.2 Description of the Front-End Electronics and Its Role in Data Collection

The front-end electronics play a crucial role in the Mini-SPD system, providing data collection and initial processing from the detectors. The FERS DT5202 system consists of a 64-channel unit based on two Citiroc 1A ASIC chips (Weeroc) for reading data from silicon photomultipliers (SiPMs). Data is collected using a Hamamatsu SiPM array and a plastic scintillator.

The front-end electronics are responsible for:

- Amplifying and converting signals received from the detectors.
- Ensuring high levels of temporal resolution and measurement accuracy.
- Filtering and selecting events based on preset triggers.
- Transmitting data to subsequent levels for processing and storage.

Figure 4.2 shows the results of the FERS system's operation, including energy spectra of the recorded events and charge distributions. These data are used to analyze the characteristics of the detectors and to fine-tune the system.

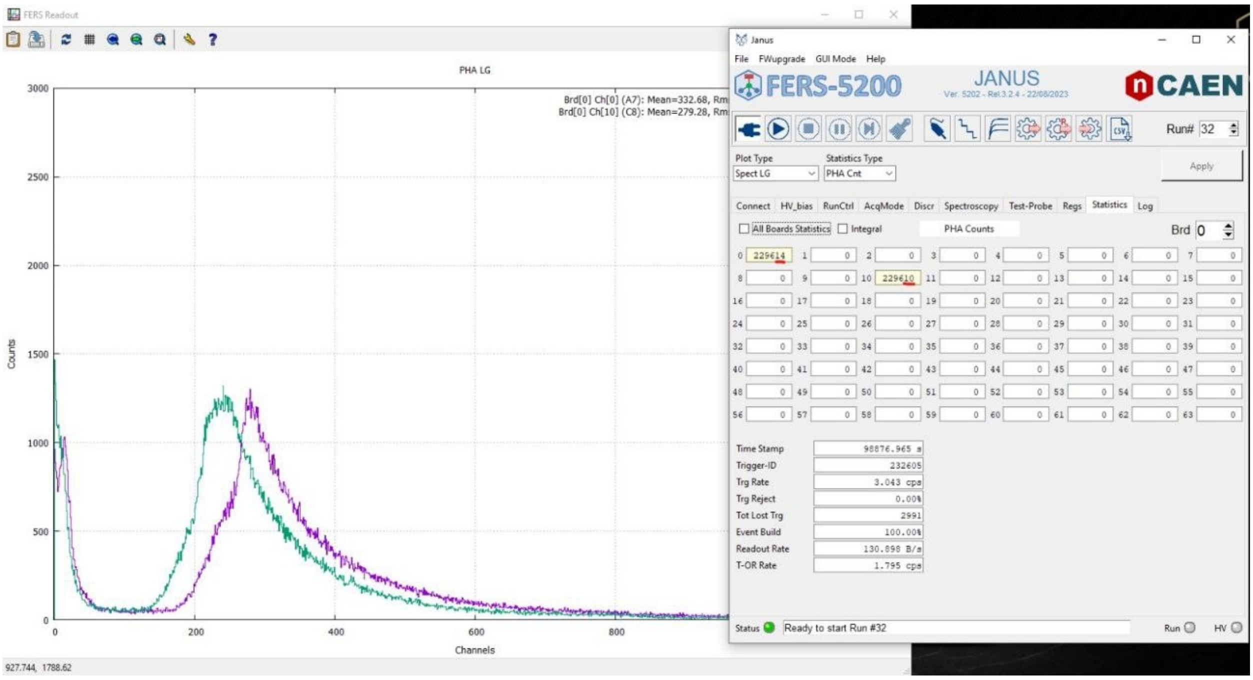

Figure 4.2 — results of the FERS operation

5. Event Selection Algorithm

5.1 Development of the Event Selection Algorithm

The event selection algorithm ensures that only relevant events, which meet specific criteria such as vertical tracks, are selected while filtering out irrelevant data. This section details the stages of the algorithm's development, the selection criteria, and the trigger system.

5.2 Criteria for Selecting Vertical Tracks and Filtering Irrelevant Events

The main goal of the algorithm is to select vertical tracks, which represent cosmic rays passing through the detector nearly perpendicular to the surface. This approach helps minimize errors and improve measurement accuracy.

1. **Criteria for Selecting Vertical Tracks:**
   - **Track Angle:** Tracks are considered vertical only if one trigger is activated per channel; otherwise, the track is deemed inclined.
   - **Minimum Energy:** Only events with energy exceeding a certain threshold are considered to exclude irrelevant and background events.
2. **Filtering Irrelevant Events:**
   - **Exclusion of Inclined Tracks:** Tracks with an angle exceeding the allowable threshold are automatically excluded.
   - **Noise Events:** Threshold values and other analysis methods are used to filter out events caused by electronic noise or other interference sources.
   - **Multiple Triggers:** Exclusion of events where the same event is registered multiple times at different levels of the detector due to miscalibration or other technical issues.

5.3 Use of ROOT Programming Language and Algorithm Flowchart

The event selection algorithm was implemented using the ROOT programming language, developed at CERN for high-energy physics data analysis. ROOT offers powerful tools for working with data, including statistical analysis, graph creation, and managing large data volumes.

The ROOT programming language was developed at CERN specifically for high-energy physics data analysis. It is based on C++ and uses an object-oriented structure, allowing for the creation of complex data structures and modular programs. ROOT provides powerful tools for statistical analysis, visualization, and managing large data volumes. A key feature is the presence of classes for working with data, such as TTree and TChain, which efficiently handle large amounts of information. Graphical visualization is facilitated through classes like TCanvas and TPad, enabling the creation of complex graphs, histograms, and functions. The interactive ROOT environment allows commands to be executed and data analyzed in real time, simplifying the research process.

The advantages of ROOT include optimization for scientific research, particularly in high-energy physics, making it an ideal tool for data analysis in this field. ROOT is characterized by high performance and efficient handling of large data volumes due to its object-oriented structure and support for parallel computing. ROOT's extensibility allows users to create custom classes and functions, enhancing the tool's functionality for specific tasks. The language is supported on various operating systems, such as Linux, macOS, and Windows, making it accessible to a wide range of researchers. An active community of users and developers ensures continuous updates and support for ROOT, contributing to its ongoing improvement and adaptation to new scientific needs. An example of ROOT's functionality is shown in Figure 5.1.

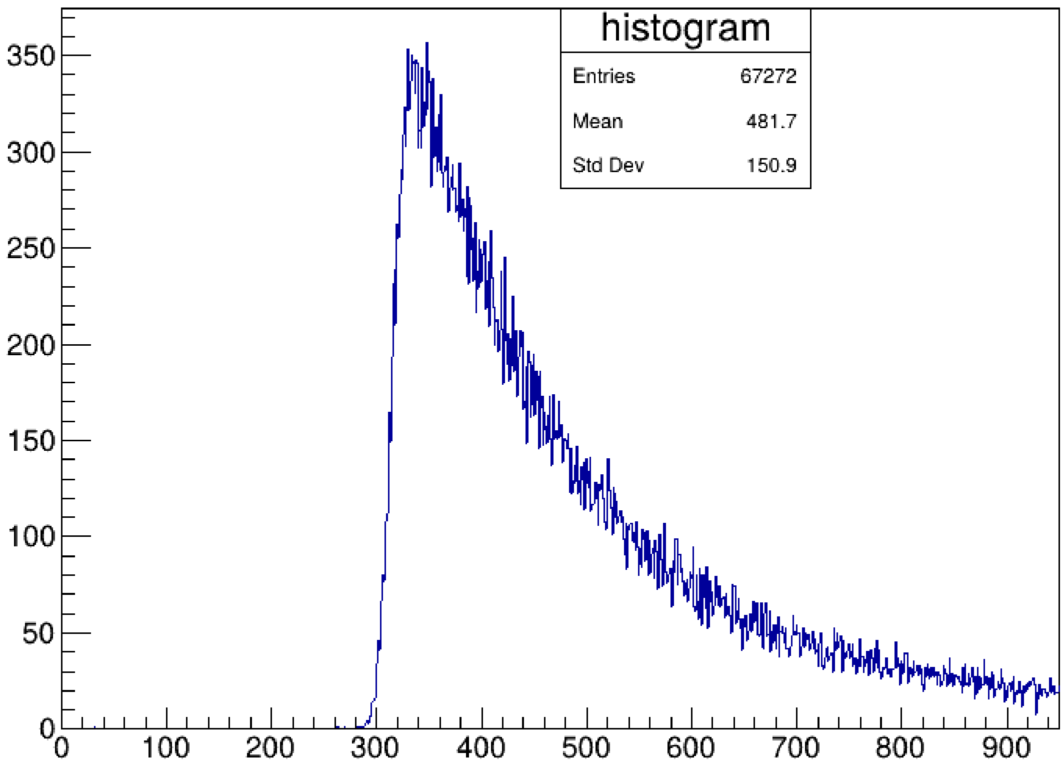

Figure 5.1 — Example of CERN ROOT Functionality

Below is the flowchart of the algorithm:

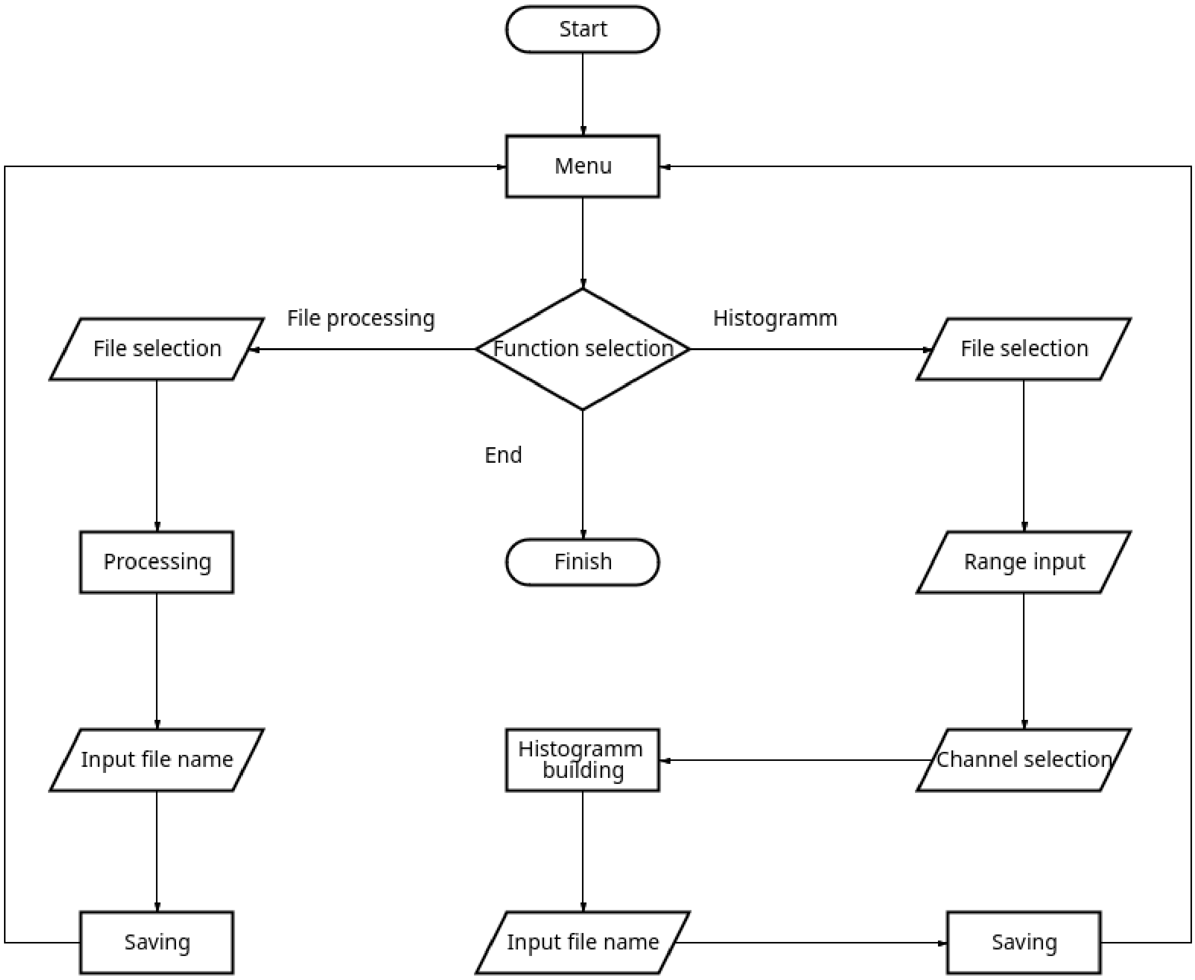

Figure 5.2 — Flowchart of the Algorithm

The following ROOT functions were used during the development process:

1. **TFile**: Used for opening data files and saving results.

```
// Opening the input file

TFile *inputFile = new TFile("input.root", "READ");

// Saving results to an output file

TFile *outputFile = new TFile("output.root",
"RECREATE");

outputFile->Write();
```

```
    outputFile->Close();
```

2. TH1F: Creating and filling a histogram.

```
// Creating the histogram
TH1F histogram("histogram", "Title;X-axis;Y-axis", 100, 0, 100);
// Filling the histogram with values
for (int i = 0; i < 1000; i++) {
    histogram.Fill(gRandom->Gaus(50, 10));
}
// Displaying the histogram
TCanvas *canvas = new TCanvas("canvas", "Canvas Title", 800, 600);
histogram.Draw();
```

3. TCanvas: Creating a canvas for displaying plots.

```
// Creating the canvas
TCanvas *canvas = new TCanvas("canvas", "Histogram Example", 800, 600);

// Displaying the histogram on the canvas
histogram.Draw();
```

4. TF1: Fitting data using the Landau function.

```
// Creating a Landau function for fitting
TF1 *landauFit = new TF1("landauFit", "landau", 0, 100);

// Fitting the data
histogram.Fit("landauFit");

// Displaying the fit on the histogram
```

```
landauFit->SetLineColor(kRed);
landauFit->Draw("same");
```

5. gStyle: Configuring the display of statistical information on histograms.

```
// Settings for displaying the statistics box
gStyle->SetOptStat("emris"); // Show all statistical parameters
gStyle->SetStatX(0.9);       // X position
gStyle->SetStatY(0.9);       // Y position
gStyle->SetStatW(0.2);       // Width of the statistics box
gStyle->SetStatH(0.2);       // Height of the statistics box
```

These functions were used at various stages of algorithm development, from opening files and creating histograms to fitting data and configuring display settings.

6. Results and Analysis

6.1 Summary of Data Collected During Testing

During the testing of Mini-SPD, a significant volume of data was collected. The event selection algorithm successfully identified relevant events that are of interest for further analysis. The main outcomes of the collected data include:

1. **Number of Processed Events:**
    - The total number of events processed by the algorithm.

- The number of events that met the selection criteria (e.g., the number of numerical values in a string).

2. **Distribution of LG Values (Channels):**
    - Histograms created for different ranges.
    - Data fitting using the Landau function to obtain more accurate distribution characteristics.

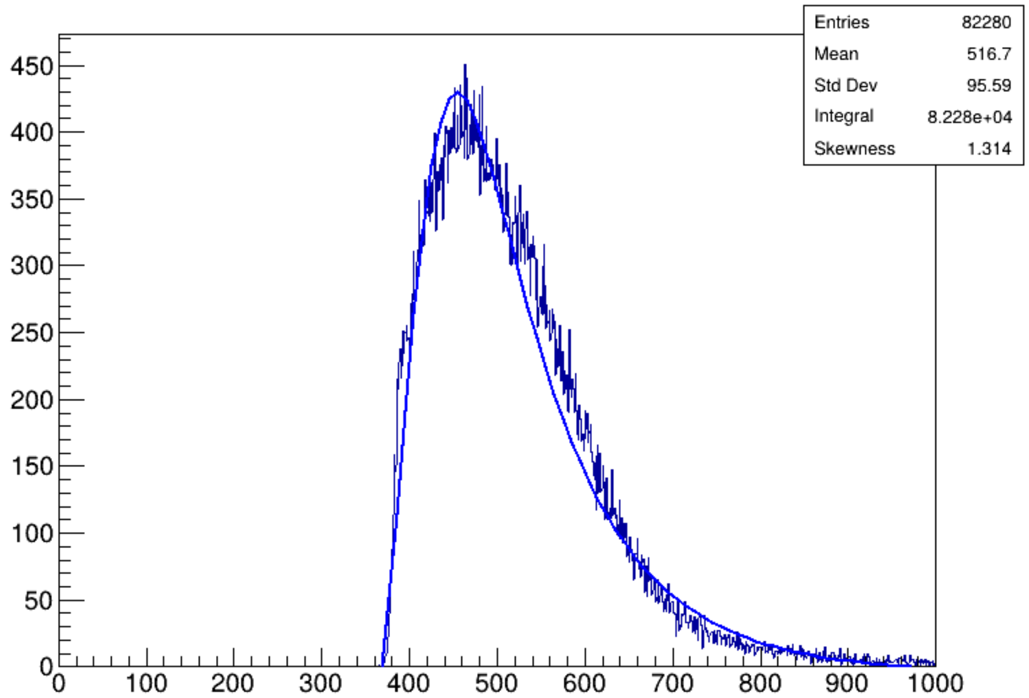

Figure 6.1 — Final Histogram with Landau Approximation

6.2 Evaluation of Calorimeter Performance and Event Selection Algorithm Efficiency

The performance of the calorimeters and the efficiency of the event selection algorithm were evaluated based on the following parameters:

1. **Calorimeter Sensitivity:**

- The ability of the calorimeters to accurately measure particle energies.
- Comparison of the measured values with theoretical models.

2. **Event Selection Algorithm Efficiency:**
   - The percentage of relevant events correctly identified by the algorithm.
   - Comparison with benchmark data to assess the algorithm's accuracy.

The results show that the Mini-SPD calorimeters demonstrate high sensitivity and measurement accuracy. The event selection algorithm successfully identifies relevant events, ensuring high efficiency and minimizing noise.

Data on cosmic rays collected during the Mini-SPD testing provided crucial insights, which impacted the understanding of the detector's operation and allowed for improvements in its performance.

7 Conclusion

In this study, comprehensive work was carried out to collect and analyze data obtained using the FERS-5200 system from CAEN. The main results include:

1. **Development and Testing of the Event Selection Algorithm:**
   - The algorithm was successfully developed and implemented to filter out irrelevant events and select vertical tracks of cosmic rays.
   - Criteria for effective event selection were identified and applied, significantly improving the quality of the collected data.
2. **Evaluation of Calorimeter Performance:**

- The calorimeters showed high efficiency in detecting and measuring cosmic rays.
- Data were obtained confirming their reliability and accuracy under testing conditions.

3. **Data Collection and Analysis:**

- The system collected a significant amount of data, which was carefully analyzed.
- The data processing algorithm demonstrated high accuracy and efficiency, allowing for the extraction of useful information from the collected data.

The results of this study are of great importance for the NICA project for the following reasons:

1. **Improvement of Detection Methods:**

- The developed methods and algorithms can be used to improve the detection and analysis of cosmic rays within the NICA project.
- The obtained data and analysis results can help optimize the performance of detectors and other system components.

2. **Enhancement of Measurement Reliability and Accuracy:**

- The implementation of new algorithms and data filtering methods can increase the reliability and accuracy of measurements, which is critically important for the successful completion of the scientific objectives of the NICA project.

The results of this study represent an important step in the development of the NICA project and can significantly contribute to achieving its scientific and technological goals.

8 Acknowledgements

First and foremost, I am sincerely thankful to Dr. Temur Yenik for providing me with the opportunity to participate in the summer internship program at the Joint Institute for Nuclear Research. His mentorship has been invaluable to my growth and learning.

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8. References

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