First Test Beam Data From The ALICE Experiment at The Large Hadron Collider

Alexander Colliander Hansen
alex@nbi.dk

Bachelor Project in Physics
May 2009

Niels Bohr Institute
University of Copenhagen

Supervisor: Jens Jørgen Gaardhøje
Abstract

This report is an analysis of test beam data from the Forward Multiplicity Detector at the ALICE experiment at CERN. A method for tracking particles is developed. The Multiplicity distribution for 6 runs are examined and 2 of them are found to contain Landau distributions. The tracking method is then used on those two runs with different results. In one of the runs 80% of the particles are found to be part of particle tracks, which is acceptable. The other run only had a 10% efficiency. This low efficiency was most likely caused by part of the detector having problems during that run. The conclusion is, that the FMD is able to work as it should. And that the tracking method developed can be used to analyse the next test beam data.

Acknowledgements

I would like to thank my supervisor Jens Jørgen Gaardhøje for giving me the opportunity to write this report, and for a lot of help and guidance over the last couple of months. I would also like to thank Carsten Søgaard for helping me with particle tracking, and all those AliROOT errors I couldn’t handle by myself. A special thanks goes to Hans Hjersing Dalsgaard, who helped me with C++ programming, did his very best to help me get some more data files, and read through this report and gave some extremely useful comments. Thank you!
Contents

1 Introduction 3

2 Heavy Ion Physics 4
   2.1 The Standard Model 4
   2.2 Quark Gluon Plasma 5
      2.2.1 Quantum Chromodynamics 6
      2.2.2 Heavy Ion Collisions 6
   2.3 Multiplicity 8
   2.4 The Bethe-Bloch Equation 8
      2.4.1 Energy Loss Straggling 9

3 The LHC and the ALICE Experiment 10
   3.1 The Large Hadron Collider 10
   3.2 The ALICE experiment 11
   3.3 The Forward Multiplicity Detector 12
   3.4 ROOT 13
      3.4.1 AliROOT 14

4 Data Analysis 15
   4.1 The Test Beams 15
   4.2 Landau Distributions 15
   4.3 Geometrical Distribution 16
   4.4 Particle Tracking 16

5 Results and Discussion 17
   5.1 The Data Files 17
   5.2 Setting The Boundaries 18
   5.3 Track Directions 20

6 Conclusion 27

7 Summary in Danish 28

A Abbreviations 29
1 Introduction

On September 10 2008 a proton beam was sent all the way around the main ring of the Large Hadron Collider (LHC) at CERN for the first time. In the weeks leading up to that historical event, a number of tests were made on the LHC and the detectors placed at various points on the ring. This report will look at some of the data taken by the Forward Multiplicity Detector (FMD) at the ALICE experiment, during the test beam runs of September 7 and 8.

The beams consisted of proton bunches accelerated up to 450 GeV, which were either dumped about 100 m before ALICE, creating jets of muons going through the detectors, or sent through ALICE interacting with left over gas, creating beam-gas events.

The purpose of this report is to check that the FMD is working as intended. A signal is created from the FMD when a charged particle deposits energy in one of the FMD strips. The signal is a measure of how much energy the particle has deposited. This energy is expected to show a certain distribution around some most probable value. Since these are test beam data, not all data files will have this distribution, those data files will be rejected. The data files with the expected distribution will then be used to examine the FMD for dead spots - areas where it for some reason isn’t able to detect particles, or at least not as efficient as it should be. This report will also use the data to give an estimate of how well the geometry of the FMD is known, i.e. check that there hasn’t been introduced too large errors into the system, under the physical installation of the FMD. The method used to do this will be by tracking particles, as they are detected on each of the rings.

Even though the analysis doesn’t require much knowledge about heavy ion physics, the ALICE experiment is a heavy ion experiment, and as such part of this report will be an introduction to particle physics and heavy ion experiments. In particular it will be an overview of the Standard Model of particle physics, to an explanation of how Quantum Chromodynamics (QCD) suggests that heavy ion collisions can lead to a special state of matter known as Quark Gluon Plasma (QGP).

In this section several acronyms has been introduced, more will come during the report, as the world of particle physics is a world of abbreviations. It can be difficult to keep track of all these, and to help out the reader a list of all the abbreviations and acronyms used in the report can be found in appendix A.

If the reader is not used to experimental particle physics, he or she will now be introduced to some of the most common terms.

When the term beam is used in the report, it refers to bunches of protons being accelerated by a particle accelerator. The beam travels inside the beam pipe. When the beam is stopped it is known as a beam dump, this usually happens by leading the beam into something large and heavy. An event occurs when a detector registers particles, this usually couples to when a bunch of protons is either dumped or collided with another bunch. A run is a collection of events, in the case of the test beams, a run usually ends when one of the systems come up with an error.
2 Heavy Ion Physics

This section will provide an introduction to the physics behind Alice and the LHC. This will start with a quick overview of the Standard Model of particle physics and move into a short description of Quark Gluon Plasma and Quantum Chromodynamics. Since this report is an analysis of test beam data (no actual collisions occurred), none of the physics from those sections will be strictly relevant for the data analysis, but they do present a nice foundation for understanding the purpose of building huge expensive particle accelerators. The section will end with an explanation of particle multiplicity and the Bethe-Bloch Equation, both of which will be used in the data analysis.

2.1 The Standard Model

According to the Standard Model of particle physics all matter consists of quarks or leptons. But the Standard Model also holds a third kind of particles, the gauge bosons, also known as force carriers. They are called force carriers because they mediate the interactions between other particles, i.e. they are how we see the four forces of nature act in the Standard Model. The four forces are the electromagnetic force, the weak interaction, the strong interaction and gravity. Table 1 shows the six quarks in the Standard model, table 2 shows the six leptons and table 3 shows the four forces and their respective force carriers. Figure 1 shows how the different forces couple to the different particles.

<table>
<thead>
<tr>
<th>Quark (symbol)</th>
<th>Charge</th>
<th>Mass (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up (u)</td>
<td>$\frac{2}{3}$</td>
<td>0.35</td>
</tr>
<tr>
<td>Down (d)</td>
<td>$-\frac{1}{3}$</td>
<td>0.35</td>
</tr>
<tr>
<td>Charmed (c)</td>
<td>$\frac{2}{3}$</td>
<td>1.5</td>
</tr>
<tr>
<td>Strange (s)</td>
<td>$-\frac{1}{3}$</td>
<td>0.5</td>
</tr>
<tr>
<td>Top (t)</td>
<td>$\frac{2}{3}$</td>
<td>180</td>
</tr>
<tr>
<td>Bottom (b)</td>
<td>$-\frac{1}{3}$</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Table 1: Charges are in units of the electron charge, masses are in GeV. Values are from [5].

<table>
<thead>
<tr>
<th>Lepton (symbol)</th>
<th>Charge</th>
<th>Mass (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron ($e^-$)</td>
<td>-1</td>
<td>0.511</td>
</tr>
<tr>
<td>e-neutrino ($\nu_e$)</td>
<td>0</td>
<td>$&lt; 1.5 \cdot 10^{-5}$</td>
</tr>
<tr>
<td>Muon ($\mu$)</td>
<td>-1</td>
<td>105.7</td>
</tr>
<tr>
<td>$\mu$-neutrino ($\nu_\mu$)</td>
<td>0</td>
<td>$&lt; 1.7 \cdot 10^{-7}$</td>
</tr>
<tr>
<td>Tau ($\tau$)</td>
<td>-1</td>
<td>1777</td>
</tr>
<tr>
<td>$\tau$-neutrino ($\nu_\tau$)</td>
<td>0</td>
<td>$&lt; 2.4 \cdot 10^{-5}$</td>
</tr>
</tbody>
</table>

Table 2: Charges are in units of the electron charge, masses are in MeV. Values are from [5].

<table>
<thead>
<tr>
<th>Interaction</th>
<th>Force carriers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electromagnetic</td>
<td>Photon ($\gamma$)</td>
</tr>
<tr>
<td>Weak Interaction</td>
<td>$Z^0$, $W^\pm$</td>
</tr>
<tr>
<td>Strong Interaction</td>
<td>Gluon ($g$)</td>
</tr>
<tr>
<td>Gravity</td>
<td>Graviton</td>
</tr>
</tbody>
</table>

Table 3: The four natural forces along with their corresponding gauge bosons.

Both the quarks and the leptons have antiparticles, which have the same mass as the normal
particles, but opposite charge and colour charge\(^1\). Antiparticles are written with a bar over their symbol (so the anti-up quark is \(\bar{u}\)).

Leptons can exist freely in nature, the most common being the electron. Quarks and gluons are the only particles affected by the strong interaction. This is because quarks have a colour charge, and gluons\(^2\) couple to colour charge. Quarks can go together to form hadrons. Hadrons are “colourless” particles, and come in two types, mesons and baryons. It is believed that particles with a non-neutral colour charge cannot exist freely in the universe, and observations so far agree with this. However, Quantum Chromodynamics (QCD) predicts that quarks and gluons can exist in a phase called Quark Gluon Plasma (QGP), where they aren’t confined within hadrons. QGP will be described in more detail in section 2.2.

Baryons consist of three quarks and are made colour neutral by having one quark of each colour (or anti-color) charge\(^3\). The two most common baryons are the proton and the neutron, and are made up of the quark combinations \(uud\) and \(udd\) respectively.

A meson consists of only two quarks, and is made colour neutral by one quark having a colour charge, and the other anti-quark having the corresponding anti-colour charge. Since the quarks are all spin-\(\frac{1}{2}\) particles, baryons are fermions and mesons are bosons.

In the domain of particle physics, the description of the weak interaction and the electromagnetic interaction is combined in the framework known as Quantum Electro-Weak Dynamics. Gravity is best described by the general theory of relativity, which so far hasn’t been described with a quantum theory. Gravity and the electro-weak interaction isn’t very relevant for this report, as the ALICE experiment is designed to look at the strong interaction.

2.2 Quark Gluon Plasma

Imagine a volume containing a number of baryons. Experiments suggests that baryons have a non-zero spatial volume, even though they are made of quarks and gluons, which are considered point particles. So there will be some critical volume, at which the baryon structure can no

\(^1\)Either red, green or blue, or anti-red, -green or blue.

\(^2\)The gluon is the force carrier for the strong interaction.

\(^3\)So a baryon will have one quark with red colour charge, one with green and one with blue, or anti-red, -green, -blue.
longer be seen. There will just be a plasma of quarks and gluons interacting with each other. The quarks and gluons will then be confined within the volume, instead of being confined within the hadrons. The state inside the volume will be different from the state inside a nucleus, since the energy density will be much higher. Such a state is known as QGP [10]. Figure 2 shows how compression of a hadronic gas can lead to QGP.

![Image](image.png)

Figure 2: The phase transition to QGP from hadronic matter.

### 2.2.1 Quantum Chromodynamics

To understand why quarks and gluons cannot exist as free particles the strong interaction needs to be examined. The strong interaction is described by QCD. Doing QCD calculations isn’t straightforward, there are different approaches to doing the calculations, one of them is known as lattice QCD (lQCD). In lQCD you treat space-time as discrete points in a lattice, and solve the Quantum Electrodynamic (QED) equations of motion (Lagrangian).

Figure 3 shows the potential between two quarks caused by the strong interaction. It can be seen that the strong interaction, unlike the other three forces, grow stronger with distance. At distances of 0.5 fm\(^4\) and larger it grows linear with distance. A rough approximation of the potential is:

\[
V(r) = \frac{a}{r} + br
\]

This has several implications. One is that if two quarks in a bound state are pulled away from each other, the potential between them will grow, until some point where there is enough energy in the potential to create a new quark-antiquark pair between them, each of which will then couple to one of the two quarks from the original bound state, making two new bound states. This is known as confinement.

Another implication arise in the opposite limit, where two quarks are close together. In this limit, the closer two quarks are together the less they interact. In a sense they are free quarks in this limit, which is why it is known as asymptotic freedom. [12]

### 2.2.2 Heavy Ion Collisions

It is often said in the media that with particle accelerators, physicists are trying to recreate the Big Bang, which created the universe. More precisely, particle accelerators are used to recreate some of the conditions of the moments right after the Big Bang. Models predict that in a very brief time after the Big Bang (\(\leq 10^{-6}\)s), the universe consisted of a weakly interacting QGP (wQGP). [10]

\(^4\)1 fm = 1 fermi = 10\(^{-15}\) m
Figure 3: A plot of the quark-quark potential, calculated from lQCD [1]. In the plot $r_0 = 0.5$ fm and $V(r_0) = 0$. The $\beta$ factor in the legend is from lQCD and can be ignored. The important thing is the shape of the potential in the limit $r \to 0$ and $r \to \infty$.

Today heavy ion collisions are used to probe some of the properties of this wQGP. Collisions of heavy ions are extremely violent, and the lifetime of the created states will be extremely small ($\sim 10^{-23}$ s). Recent experiments suggest that unlike the wQGP of the early universe, the QGP from heavy ion collisions will be strongly interacting. Figure 4 is a diagram of the different phases of hadronic matter, the difference between then wQGP and the one created in modern colliders is shown.

Figure 4: Diagram showing the different phases of hadronic matter.
2.3 Multiplicity

Multiplicity or particle multiplicity is the number of particles created in a particle collision event. It can be subdivided into the multiplicity of certain types of particles, such as pion multiplicity or proton multiplicity.

At the ALICE experiment, the Forward Multiplicity Detector (FMD) will, as the name implies, measure the particle multiplicity, or rather the charged particle multiplicity, as the FMD is unable to detect neutral particles. See section 3.3 for more information about the FMD.

The measurement of particle multiplicity is important, as it provides the first benchmark test for the various models of heavy ion collisions. It provides information of such important quantities as energy density and entropy. The measurement of multiplicity means that it will be possible, early on in the LHC experiment, to see if the increase in energy compared to other colliders, has changed the conditions in the reactions dramatically.

The charged particle multiplicity can be defined as \( dN_{\text{charged}}/d\eta \), where \( \eta = -\ln \tan \frac{\theta}{2} \) and is called the pseudorapidity. In the limit \( m << p \): \( \eta \rightarrow y \), where \( m \) is the mass of a particle, \( p \) is the momentum and \( y \) is the rapidity. The rapidity has the advantage that it has nice Lorentz transformation properties, whereas \( \eta \) has the advantage that is can be measured easily.

2.4 The Bethe-Bloch Equation

When the charged particle multiplicity is measured, what is really measured is the amount of energy deposited in the detector plates. In the case of the FMD this is silicon sensors. When a charged particle hits the silicon sensor, electron-hole pairs are created, which then creates a current that can be measured.

The Bethe-Bloch equation describe the mean energy loss of heavy charged particles transversing matter. Here particles heavier than the electron are referred to as heavy. The Bethe-Bloch formula with two corrections, one for what is called the density effect and one called the shell correction is [12]

\[
-\frac{dE}{dx} = 2\pi N_a r_e^2 m_e c^2 \rho Z^2 A \beta^2 \left[ \ln \left( \frac{2m_e^2c^2v^2W_{\text{max}}}{I^2} \right) - 2\beta^2 - \delta - 2C \right]
\]

The different parameters in the formula are:

- \( N_a \) Avogadro’s number: \( 6.022 \cdot 10^{23} \text{ mol}^{-1} \)
- \( r_e \) Classical electron radius: \( 2.817 \text{ fm} \)
- \( m_e \) Electron mass: \( 0.5110 \text{ MeV} \)
- \( c \) Speed of light in vacuum
- \( \rho \) Density of the absorber
- \( Z \) Atomic number of absorber
- \( A \) Atomic weight of absorber
- \( z \) Charge of incident particle in units of \( e \)
- \( \beta \) \( v/c \) of incident particle
- \( \gamma \) \( 1/\sqrt{1 - \beta^2} \)
- \( v \) Velocity of incident particle
- \( W_{\text{max}} \) Maximum energy transfer in a single collision
- \( I \) Mean excitation energy
- \( \delta \) Density correction
- \( C \) Shell correction

The Bethe-Bloch formula has been plotted in figure 5. As can be seen from the figure, the function has a minimum at a certain energy. Particles with this energy are said to be minimum
ionizing particles (MIPs). In practice, relativistic particles will have a mean energy loss close to this minimum [11].

2.4 The Bethe-Bloch Equation

Muons have a mean energy loss close to the minimum [11].

Stopping power [MeV cm$^2$/g]

Radiative

Radiative losses

Radiative

Bethe-Bloch

Anderson-Ziegler

Minimum ionization

Minimum ionization

Without δ

Figure 5: The Stopping power for positive muons in copper [11]. The area where the Bethe-Bloch approach is valid is marked by the vertical lines. Notice the minimum of the solid line, it indicates the energy loss of MIPs.

2.4.1 Energy Loss Straggling

As noted above, the Bethe-Bloch equation gives the mean energy loss. This is an indication of the statistical nature of the energy loss. Also noted above was that a relativistic particle’s mean energy loss will be around the minimum ionization energy of the detector material. Since this report deals with relativistic particles, it will be assumed that the energy deposited in the detector during the runs can be represented with some sort of distribution around this energy. This is called energy loss straggling.

It can be shown that for thick absorbers ($\frac{dE}{dx}\delta x \gg W_{\text{max}}$, where $\delta x$ is the thickness of the absorber) the distribution will be Gaussian. For thin absorbers, like the FMD, there is a larger probability for large energy losses. This has the effect of making the distribution skewed, with a tail stretching towards higher energies. The peak of the distribution will then no longer be the average energy loss, but the most probable value (MPV) of the energy loss.

Landau calculated the energy loss for very thin absorbers under the assumptions that [12]

- the maximum energy loss is infinite.
- the energy transfer in individual collisions is large enough, so that the electrons can be treated as free.
- the incident particles loss of kinetic energy is negligible.

The distribution can then be expressed as [11]

$$\Phi(\lambda) = \frac{1}{2\pi i} \int_{\sigma-\infty}^{\sigma+\infty} e^{u\ln u+\lambda u} du, \quad \sigma \leq 0$$

Figure 6 shows a Landau distribution and a Gaussian distribution.
3 The LHC and the ALICE Experiment

This section will give a description of the experimental setup. Starting with the biggest, the LHC, and then moving in towards the FMD. For the LHC and the ALICE experiment focus will be on simple facts, and their main purpose. For the FMD more technical details will be discussed, as this is relevant for the data analysis in the report. The section will end with a description of the tools used to analyse the data.

3.1 The Large Hadron Collider

The Large Hadron Collider (LHC) at CERN, with it’s 27 km circumference, is the world’s largest particle accelerator. It can accelerate protons up to 7 TeV both clockwise and counter-clockwise around the ring, making it possible to achieve collisions with a total centre-of-mass energy of 14 TeV for protons. It can also accelerate lead ions ($^{208}$Pb$^{82+}$) up to energies of 2.76 TeV/nucleon, yielding a total centre-of-mass energy of 1.15 PeV for the nucleus.[4]

The LHC takes advantage of the other particle accelerators available at CERN, so that it doesn’t have to accelerate the particles all the way, from the low energies they have when they are created in the lab.

A beam of protons is produced at LINAC 2 and boosted in BOOSTER. Then they are sent through the Ps and the Sps. From the Sps the beam is split into 2808 bunches going in either direction and injected into the LHC ring. At injection the protons will have an energy of 450 GeV.

The $^{208}$Pb$^{82+}$ are produced at LINAC 3 and sent into LEIR. Then, like the protons, they are accelerated through the Ps and Sps. The Sps divides the beam of lead ions into approximately 592 bunches going either way before they are injected into the main LHC ring.[12] The entire setup of the CERN accelerator complex can be seen in figure 7.

On four points on the ring, protons travelling in opposite directions are crossed to make collisions. Four experiments are placed at these points, the ALICE, ATLAS, CMS and LHCb...
3.2 The ALICE Experiment

The ALICE Experiment is the only dedicated heavy ion experiment at the LHC. ALICE (A Large Ion Collider Experiment) consist of several detectors, most of which are inside a magnet called the L3. The L3 is the world's largest conventional magnet and can provide a solenoidal field of 0.5 T. The main purpose of the experiment is to detect the QGP phase of matter and find its properties.

ALICE is the type of detector referred to as an onion-type detector, this is because the detectors are placed in layers from the center and outward, like an onion. Starting at the Interaction Point (IP) and moving out, the first detector system is the Inner Tracking System (ITS), which will provide initial tracking. Next is the Time Projection Chamber (TPC). The

Figure 7: The LHC accelerator complex. Courtesy of CERN. The figure is not to scale.
TPC will detect if the particles has a positive or negative charge by measuring their trajectory, as it is bend by the magnetic field of the L3. Outside of this are two Particle Identification (PID) detector systems: the Time Of Flight (TOF) system and the High Momentum PID (HMPID). They will detect the transverse momenta $p_T$ of the particles, which can then be used to find the mass. By knowing this and the charge of the particle, it is possible to identify the particle.

![Image of ALICE experiment](CERN_Ac_Alice_98_CI)

**Figure 8**: The ALICE experiment. The FMD2 and 3 rings are located in the middle, where the figure indicates the ITS. The FMD1 is a bit to the left of the ITS.

ALICE has more detectors than those, among which is the Forward Multiplicity Detector (FMD). The FMD was built at the Niels Bohr Institute in Copenhagen, and it is data from the FMD that will be analyzed in this report. A more detailed description of the FMD can be found in the next section. Figure 8 is a computer generated image of ALICE.

### 3.3 The Forward Multiplicity Detector

The FMD consist of 3 sub-detectors: FMD1, FMD2 and FMD3. FMD2 and 3 have 2 rings of silicon sensors arranged in circles around the beam pipe. The 2 rings are the inner (FMD2i/3i) and the outer (FMD2o/3o). They are located on either side of the IP, about 75 cm to each side. FMD1 only has an inner ring, and is located on the same side of the IP as FMD2, but about 250 cm further away along the beam pipe. Figure 9 shows the FMD geometry.

The rings are built from wafers of silicon, approximately 300 $\mu$m thick. The FMD is able to measure charged particle multiplicity in the pseudorapidity range $-3.4 < \eta < -1.7$ and $1.7 < \eta < 5.1$ [3].

Each ring has 10240 strips. For the inner rings these are divided into 20 azimuthal sectors each with 512 strips. The outer rings have 40 azimuthal sectors with 256 strips each. Figure 10(a) shows a silicon wafer for the inner rings, and figure 10(b) shows a silicon wafer for the outer rings. Table 4 shows the amount of sectors and strips of the different FMD sub-detectors, along

\[ p_T = \sqrt{p_x^2 + p_y^2}, \] where the $z$ direction is parallel to the beam direction.
with their radial size and their $z$-coordinate.

<table>
<thead>
<tr>
<th>Ring</th>
<th># of sectors</th>
<th># of strips</th>
<th>Radial coverage (cm)</th>
<th>$z$ (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMD1i</td>
<td>20</td>
<td>512</td>
<td>4.2-17.2</td>
<td>320</td>
</tr>
<tr>
<td>FMD2i</td>
<td>20</td>
<td>512</td>
<td>4.2-17.2</td>
<td>83.4</td>
</tr>
<tr>
<td>FMD2o</td>
<td>40</td>
<td>256</td>
<td>15.4-28.4</td>
<td>75.2</td>
</tr>
<tr>
<td>FMD3i</td>
<td>20</td>
<td>512</td>
<td>4.2-17.2</td>
<td>-62.8</td>
</tr>
<tr>
<td>FMD3o</td>
<td>40</td>
<td>256</td>
<td>15.4-28.4</td>
<td>-75.2</td>
</tr>
</tbody>
</table>

Table 4: FMD segmentation and geometry [3].

The numbering of the sectors with number 0, and are then counted in the counter clockwise direction, sector 0 does not point in the same direction on all the rings. The Strip count start at the smallest radial distance on the ring with number 0, and are counted outward. The strip width is 250 $\mu$m for the inner rings, and 500 $\mu$m for the outer. The length is 13 – 50 mm and 24 – 42 mm respectively.

The FMD use pn-junctions to send out an analog signal, which is first amplified, and then sent through the Analog-to-Digital converter (ADC), ALTR0, which transforms it to a digital signal. It is then sent to the Read-Out Control Unit (RCU), which is the master of the ALTR0 read-out bus, and handles all communication out to the detector control and trigger systems, and to the Data AQuisition (DAQ) system. As the signal goes through the DAQ system it is stored for later analysis.

3.4 ROOT

In order to handle the huge amount of data generated by the detectors of the LHC, CERN has developed a program called ROOT’s Object Oriented Tools or just ROOT. ROOT can handle all aspects of the data analysis, such as data recreation, event simulation, and provides mathematical tools for data analysis. ROOT is written in the object oriented programming language C++, and can be operated either via user written C++ scripts or by typing in C++ commands in it’s command line interface. ROOT provides the user with a number of functions to make data visualization easy. [13]

---

So for an inner ring for example, the sector numbers are 0-19 and strip numbers are 0-511.
Figure 10: Silicon wafers from an inner ring (left) and an outer ring (right). Pn-junctions are used to detect charged particles. The n-type material is the entire structure, the p-type material is the black curved lines [3]. One might be tempted to think that one of the white areas on the wafer represent a strip, but in fact each strip is centered on a black line. The middle of the white areas are the borders between the strips, where the fields from the p-type material are weakest. Notice that each of the wafers above has two sectors, separated by the white line in the middle. This is essentially a dead area on the detector, but it is very small.

3.4.1 AliROOT

AliROOT is based on root and contain everything root contains. AliROOT has been developed by various physicists involved in the ALICE experiment, and contain information about the geometry of the ALICE experiment, as well as a simulation environment and some extra functions used in analysing data from the ALICE detectors. [14]
4 Data Analysis

This section will go through the data analysis process. From the criterions for selecting a data file with usable data, to the algorithm used for finding particle tracks. Each step will have it’s method and purpose described.

4.1 The Test Beams

The runs analysed in this report all come from test beams at the LHC taken in September 2008, a few days before the official opening. In the runs, beams of protons were injected into the LHC with 450 GeV. They were then dumped a few 100 meters before ALICE, creating showers of particles, mostly muons as they have the best penetration power, which got registered in the FMD. Some of the beams were sent through ALICE and interacted with left over gas in the beam pipe, creating what is called beam-gas events.

As they were test beams, a lot of settings where changed between each run, so it cannot be assumed that data from different runs should look similar.

4.2 Landau Distributions

The first analysis run on the FMD data files, is to see if the multiplicity follow a Landau distribution, like the one in figure 6. Some files may only contain noise or show unusual high multiplicity of particles, indicating saturation in the detectors. Figure 11 shows a large structure in the low multiplicity region, this structure is known as the pedestal. Most of it is cut away during reconstruction, but some of it is left, to avoid the risk of cutting away particles. The pedestal correspond to noise signals that are digitalized, coming from the electronic circuits that amplify the signals from the detectors, i.e it isn’t caused by particles.

![Figure 11](image)

Figure 11: The figure shows the data from all detectors during all events in a run. The x-axis shows energy in arbitrary units. With the calibration used the MPV for a MIP is 0.6. The y-axis is logarithmic and shows the number of particles. The figure shows what is left of the pedestal after reconstruction. In the high multiplicity region of the figure the beginning of the Landau distribution can be seen.

It isn’t enough to check if all the strips, sectors, rings, detectors and events taken together give a Landau distribution. Each detector, ring, sector and strip individually should also give a Landau distribution. Unfortunately, given the amount of data points needed to see a Landau distribution, for most runs it will be impossible to see for a single strip. Instead, after seeing the entire run gives a Landau random events are looked at one at a time. For some of these events each detector is checked for a Landau, for FMD2 and FMD3 inner and outer rings are then checked separately. Then random sectors are picked out and looked at. Sometimes a single
sector will not show a landau for a single event, because only a few particles was detected, in
those cases the sector is looked at over all events in the data file, to make sure that everything
is working correctly. And finally an area covering a few sectors and strips are looked at over the
entire run. Figure 12 shows examples of these distributions.

![Example Distributions](image)

Figure 12: On all figures the x-axis represents energy in arbitrary units, where 0.6 is the MPV
for MIPs. The y-axis shows the number of particles. As can be seen all figures shows a Landau
distribution. Figures like these are used to see if a data file is eligible for further analysis.

4.3 Geometrical Distribution

Following the selection of data sets with Landau distributions, these are looked at more closely.
A lower boundary for the energy will have to be set, for reasons described in the previous section.
For this part of the analysis it just has to be somewhere between 0.3, where the fall of the pedestal
is evened out by the Landau distribution, and 0.5 where the Landau fitted completely match
the data set, as can be seen in figure 12(a). It is assumed that high energy counts are valid
particle counts, so no high energy boundary will be set.

A script is run to look at the geometrical distribution of the particles, i.e to study if one side
of the FMD detected more particles than the other. This serves two purposes. One is to check if
all parts of the detector were capable of detecting particles. The other is to see if the geometrical
distribution is uniform. Rather than just plotting sectors on one axis and strips on another, one
of AliROOT’s geometrical features\(^7\) are used to translate the sector,strip coordinates to \((x,y,z)\)
coordinates. This is needed, as the sectors on the individual FMD rings is not aligned. Both
entire runs and some individual events in each run are examined.

4.4 Particle Tracking

After the data files with Landau distributions have been found, and the geometrical particle
distributions have been studied, the data files are ready for particle tracking. The tracking is
done by the following algorithm:

\(^7\)The class AliFMDGeometry::Detector2XYZ(...) to be precise.
The coordinates of each particle with energy $E > E_{\text{low}}$ detected is put into one of three lists, one list for each FMD detector.

A line is drawn between each point in the FMD2 and FMD3 lists. Giving all possible lines through the two detectors.

If a line has a slope larger than $\alpha_{\text{max}} = 0.117$ (defined below) or smaller than $-\alpha_{\text{max}}$ in the $x$- or $y$-direction it cannot hit FMD1 and is rejected.

Each of the remaining lines are extrapolated out to the FMD1 detector and a new list is created containing the coordinates where the particles are likely to have hit the FMD1.

The FMD1 list is the searched for particles in a small area around the likely coordinates.

If there is a match in the FMD1 list, the horizontal and vertical slopes between the FMD3 coordinates and FMD1 coordinates are calculated.

If there is more than one candidate in the FMD1 list, the one with slopes closest to the average is selected, the others are discarded.

$\alpha_{\text{max}}$ is only a rough cutaway, it is calculated from FMD3 having a radius of 28.4 cm, FMD1 having a radius of 17.2 cm, and them being 395 cm apart [3]:

$$\alpha_{\text{max}} = \frac{28.4 + 17.2}{395} \approx 0.117$$

This still leaves a lot of lines that cannot hit the FMD1, but it does remove about 2/3 of the total. This saves the computer a lot of calculations, and thereby the analysis runs much faster, which is exactly why this cut off was implemented in the algorithm.

The need to look at a small area around the coordinates, found by extrapolation, arise from the fact that the FMD has limited spatial resolution, and when AliROOT changes to $x, y, z$-coordinates it simply substitutes the strip with a single point in the middle of the strip, which means an area with dimensions of at least 1 strip needs to be searched, this area is:

$$\Delta r = 1 \text{ strip} = 250\mu m \quad \Delta \phi = \frac{360^\circ}{N_{\text{sections}}} = \frac{360^\circ}{20} = 9^\circ$$

5 Results and Discussion

In this section the methods from section 4 will be put to use on the data files. Unfortunately there were some technical difficulties in getting the data from the server at CERN, which means only 6 data files were available for analysis. Of these six only two have any data above pedestal level, as will be seen in section 5.1. This inevitably leads to very inconclusive results for this report. But with a huge experiment as the LHC, such problems must be expected in the start-up phase.

5.1 The Data Files

Data files from the following six runs have been available for analysis: 57200, 57222, 57226, 57239, 57243 and 57383. Of these 57226 and 57383 contain pedestal signal and some noise. 57222 and 57239 were empty in the low multiplicity region, but had an unusual high multiplicity of particles, indicating that the detectors were saturated. This was most likely caused by improper LHC beam handling. Only run 57200 and 57243 showed landau distributions. The one

---

8The detectors are said to be saturated when the ADC receives a signal from the FMD higher than it’s threshold value.
for run 57200 can be seen in figure 12(a). Only run 57200 and 57243 will be used in this analysis.

First the geometrical distributions of all the particles found in the two runs are examined. They are depicted in figure 13. The first observation is that the lower half of FMD3o did not work during either runs, this is also noted in the ALICE online logbook [15] as an error. For run 57200 the particle distribution seem quite uniform. Run 57243 shows very few particles on FMD2 compared to FMD1 and FMD3, this is confirmed by looking at the average particles per ring in table 5. There also seem to be more particles right side of the detector than in the left. Neither of these things seem to be explainable. A further investigation is beyond the scope of this report.

<table>
<thead>
<tr>
<th>run #</th>
<th>FMD1</th>
<th>FMD2i</th>
<th>FMD2o</th>
<th>FMD3i</th>
<th>FMD3o</th>
<th>Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>57200</td>
<td>363</td>
<td>390</td>
<td>808</td>
<td>394</td>
<td>420</td>
<td>474</td>
</tr>
<tr>
<td>57243</td>
<td>229</td>
<td>89</td>
<td>79</td>
<td>180</td>
<td>63</td>
<td>126</td>
</tr>
</tbody>
</table>

Table 5: Average number of particles in the individual rings in the two runs. The last column is the average of the 5 rings. Each ring has 10240 strips, one hit is defined as one strip giving a signal, indicating a particle has hit it.

5.2 Setting The Boundaries

Before studying the slopes of the particle tracks found, a lower cut $E_{low}$ has to be set, as discussed in section 4.2. Figure 14 shows the method efficiency of the particle tracking at different values of $E_{low}$. The method efficiency is calculated as

$$Efficiency = \frac{\text{Particles tracks found}}{\text{Particles detected by FMD1}}$$

for each event in the run. It is important not to confuse the method efficiency with the detector efficiency, the method efficiency does in no way represent how well the FMD works. It should only be used to compare different data files.

Unfortunately, because of the huge discrepancy in the efficiency between the two runs, nothing definite can be said from the figure. But the low efficiency in run 57243 can be due to FMD2 not working very well during the run. Another problem is that in both runs only the first 20 sectors of FMD3o worked. The Green dots shows a possible extrapolation to include all of FMD3o in one of the runs.

The extrapolation was done by first doing tracking on the inner rings of all detectors, then all of FMD2o and the working half of FMD3o was included. The increase in efficiency was calculated, it was the assumed that the increase would have been twice as big, had the whole of FMD3o worked, which gives the efficiency shown with green dots in figure 14. The fact that all of FMD2o is included does give a small risk of certain boundary tracks from FMD1$\rightarrow$FMD2o$\rightarrow$FMD3i, making the estimated efficiency in the extrapolation slightly too high, but this is assumed to be negligible compared to the uncertainty.

The most reasonable values of the method efficiency is obtained at $E_{low} = 0.35 \pm 0.05$ or $0.6E_{MIP} \pm 0.1E_{MIP}$. This is confirmed when looking at the multiplicity distributions. Since the data has not been corrected for energy sharing\(^9\), the low threshold might be preferable.

\(^9\)One particle depositing energy in two strips next to each other, creating two low energy signals.
There is also the question of how large an area needs to be searched for the FMD1 coordinates. No change in efficiency was found by going from $\Delta\phi = 9^\circ$ to $\Delta\phi = 18^\circ$$^{10}$. Figure 15 shows the efficiency at different $\Delta r$. The data from run 57200 shows that for $\delta r = 375 \mu m$ (corresponds to searching in an area of 3 strips along the radial), the efficiency is higher than 1, which suggests...

---

$^{10}$The notation used here is that $\Delta$ is the entire area covered, the $\delta$ used in the figures should be understood as $r \pm \delta r$ and $\phi \pm \delta \phi$, so $2\delta x = \Delta x$. 

Figure 13: The first five figures show geometrical distribution of particles on the individual rings. The last figure shows all of the previous five superimposed on each other, this is included in order to enhance common, but low statistics effects, which aren’t large enough to show up on the individual detectors. Both runs had $E_{low} = 0.30$ and $\delta r = 250$. 

---

(a) run 57200. Units are in cm.

(b) run 57243. Units are in cm.
5.3 Track Directions

In this section the slopes of the particle tracks found are analysed, in the hope that they might be able to show some common features in the two runs. Figure 16 shows 2-dimensional histograms of the slopes of the tracks. The figure seems to show that the tracks are parallel to the beam pipe. However, as noted in the caption of the figure it only gives a precision of 0.001875, which may appear to be very accurate, but corresponds to an uncertainty of

$$0.001875 \cdot 400 \text{cm} = 0.75 \text{cm} = 750 \mu\text{m}$$

or 30 strips, when taken all the way from FMD1 to FMD3. And this is of course not nearly enough to conclude anything about them being parallel with the beam pipe. Making the resolution higher in the 2d-histogram made made it harder to see what was going on. So to get a higher resolution 1-dimensional histograms are used for further analysis. These can be seen in figure 17.
5 RESULTS AND DISCUSSION

5.3 Track Directions

Figure 15: The method efficiency at different $\delta r$, with $\delta \phi = 4.5^\circ$ and $\delta r$ in units of microns. Note that only half of FMD3o is working. The reason for getting an efficiency above 1 is that the script doesn’t remove the FMD1 coordinates from the list, when it has been matched with a particle track. While this is not a problem when looking at a small area, it represents a problem here, where it cause efficiencies above 1.

Now it is possible to get something useful from the figures with a high precision. Figure 17(a) has 1500 bins, making one bin correspond to 640 $\mu$m or about 2.5 strip. Figure 17(b) only has 500 bins, owing to the fact that the data file for run 57243 contain a lot less data, than the one for run 57200. This gives a precision of about 7.5 strips, while this is far from ideal, but is at least better than what the 2-d histograms could produce.

Surprisingly the figures are very similar for the two runs this time. Both of them showing distributions which are sharper than a Gaussian in the middle, and centered around 0 in both the $x$- and $y$-direction. The problem with these 1-dimensional histograms is that they don’t show if the particles with $dx/dz \approx 0$ also had $dy/dz \approx 0$. The green line of $dr/dz$ has a peak value in the bin with $dr/dz = 0$ in run 57200, so some of the particles are completely parallel to the beam pipe, at least within the uncertainty. But the vast majority of the particles do not seem to be travelling completely parallel to the beam pipe. In run 57243 the green line even has peaks at 0.02.

Changing values for $E_{\text{low}}$ does not change the shape or the mean values of the distributions. Tables 6 and 7 shows the mean values of the slopes and their root mean square (RMS) for different values of $E_{\text{low}}$.

The tables show some very interesting things. In both runs the particles generally had a slope of about -0.004 in the vertical direction, corresponding to a drop of 1.6 cm over the entire FMD. In the horizontal direction in run 57200 the particles had an average slope on the order of $10^{-4}$, corresponding to 400 $\mu$m from FMD1 to FMD3. Whereas in run 57243 the particles
5.3 Track Directions

Figure 16: The figures show the slopes of the particle tracks found. Each axis is divided into 128 bins, this gives a precision of 0.001875 for each bin. They were drawn with $E_{low} = 0.35$ and $\delta r = 250 \, \mu m$.

Figure 18 shows a 3-dimensional view of the FMD, with particle hits plotted, and lines connecting the hits where tracks has been found. It is seen that only one track has slopes of less than 0.0001 in both the horizontal and vertical directions. This corresponds to 400$\mu$m, and moved an average of 1.6 cm in the horizontal direction, opposite to the one in run 57200. This could be an indication of different beam setups or dump sites in the two runs.

(a) run 57200. The x- and y-axis shows $dx/dz$ (horizontal slopes) and $dy/dz$ (vertical slopes) respectively.

(b) run 57243. The x- and y-axis shows $dx/dz$ and $dy/dz$ respectively.
5 RESULTS AND DISCUSSION

5.3 Track Directions

Figure 17: Histograms of the track slopes projected down to the $dx/dz$ and $dy/dz$ directions. $dr/dz = \sqrt{(dx/dz)^2 + (dy/dz)^2}$ is also shown. They were drawn with $E_{low} = 0.35$ and $\delta r = 250 \mu m$.

can thus be said to be parallel with the beam pipe, within the uncertainties. Then there are a few red lines, indicating particles that have moved less than 2 cm in both the horizontal and vertical directions.

As the beams originated some hundred meters before FMD1, it is tempting to extrapolate the lines out, to see if they have a common point far away from the detector. As figure 19 indicates, this is not the case. Some of the lines do seem to cross about 35 m away, but mostly they seem to be coming from all around the detector.
### Table 6: Average values. run 57200.

<table>
<thead>
<tr>
<th>$E_{\text{low}}$</th>
<th>$dx/dz$ RMS</th>
<th>$dy/dz$ RMS</th>
<th>$dr/dz$ RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.30</td>
<td>1.911 · 10^{-5}</td>
<td>0.02122</td>
<td>-0.003347</td>
</tr>
<tr>
<td>0.35</td>
<td>4.829 · 10^{-5}</td>
<td>0.02118</td>
<td>-0.003394</td>
</tr>
<tr>
<td>0.40</td>
<td>6.256 · 10^{-5}</td>
<td>0.02121</td>
<td>-0.003440</td>
</tr>
<tr>
<td>0.50</td>
<td>20.64 · 10^{-5}</td>
<td>0.02063</td>
<td>-0.003601</td>
</tr>
</tbody>
</table>

### Table 7: Average values. run 57243.

<table>
<thead>
<tr>
<th>$E_{\text{low}}$</th>
<th>$dx/dz$ RMS</th>
<th>$dy/dz$ RMS</th>
<th>$dr/dz$ RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.30</td>
<td>-0.003669</td>
<td>0.02077</td>
<td>-0.005325</td>
</tr>
<tr>
<td>0.35</td>
<td>-0.004195</td>
<td>0.02011</td>
<td>-0.004495</td>
</tr>
<tr>
<td>0.40</td>
<td>-0.004847</td>
<td>0.02087</td>
<td>-0.003815</td>
</tr>
<tr>
<td>0.50</td>
<td>-0.003828</td>
<td>0.02026</td>
<td>-0.004078</td>
</tr>
</tbody>
</table>

Figure 18: run 57200, event 30. Units are in cm. A blue line indicates a slope of less than 0.0001 in both the $x$- and $y$-direction. A red line indicates a slope of less than 0.005 in both directions. A green line indicates a slope larger than 0.005 in at least one direction.

But figure 18 also indicate two more things that need to be investigated. One is how the geometrical distributions of the particles included in tracks look compared to the geometrical distributions of all the particles. These are shown in figures 20a and 20b, which can be compared to the geometrical distributions in figures 13a and 13b. For the inner rings a correlation between the densities can be seen, as both distributions show less density near the center. The outer rings show less of a correlation, but that is expected from what is known about the track directions, as only relatively few particles has the large slopes, that most tracks hitting both the FMD1 and FMD3o would have. Once again run 57243 has a higher density on the right side.
Figure 19: run 57200, event 30. Units are in cm. Extrapolation of figure 18 out to 50 m before the tracks hit FMD1, no common origination can be seen. While the beam was dumped more than 100 m from the FMD, it only gets worse going further than 50 m back.

Figure 20: Geometrical distributions for the particles where tracks could be found. Both histograms were drawn with $E_{low} = 0.30$ and $\delta r = 250$.

The last thing that needs to be examined is the difference between the slopes from FMD1 to FMD2 ($\alpha_1$) and the slopes from FMD2 to FMD3 ($\alpha_2$). Figure 21 shows $\alpha_1 - \alpha_2$. The maximum difference can be seen to be $10^{-4}$. In the script the lines are drawn from FMD3 and towards
FMD1. The distance between FMD1 and FMD2 is roughly 250 cm. A slope of $10^{-4}$ over that distance correspond to a shift of 250 \(\mu\text{m}\) or 1 strip width. This is less than the uncertainty in the geometry, so even for the maximum values of $\alpha_1 - \alpha_2$ the difference is of no importance.

Figure 21: Units on the $x$-axis are in $d/dz$. Histograms of $\alpha_1 - \alpha_2$, where $\alpha_1$ is the slope of a track between FMD1 and FMD2, and $\alpha_2$ is the slope of a track between FMD2 and FMD3.
6 Conclusion

In this report an analysis of Lhc test beam data from the FMD has been presented. Of the six runs available for analysis, 2 were rejected because the FMD was saturated during the runs, 2 were rejected because they only contained noise. This left 2 runs where the data showed the expected Landau distribution: run 57200 and run 57243.

Run 57200 showed a nearly uniform geometrical distribution of particles, only the innermost strips showed a drop in particle density. An explanation of this drop could not be found.

Run 57243 had appeared to have a malfunction on FMD2, which detected less than half the amount of particles FMD1 and FMD3 detected. FMD1 and FMD3 showed a high density of particles on the inner strips, to one side of the beam pipe. It was found that only half of FMD3o was working in both runs.

In the last part of the analysis a tracking method was applied to the data. A method efficiency was introduced as a measure of the ability of the script to track particles. Different values for the minimum energy to be recognized as a particle and not noise were tested. A cut off value of $E_{\text{low}} = 0.6E_{MIP} \pm 0.1E_{MIP}$ was found after analysing figure 14 and 12. It was then noted that the lower cut off of $0.5E_{MIP}$ might be preferable, as the data files wasn’t corrected for energy sharing.

Different areas were searched on FMD1 to complete the tracks, it was found that a change of the angular area searched from $\Delta \phi = 9^{\circ}$ to $18^{\circ}$ did not have a significant effect. Changing $\Delta r$ showed that the radial search area should be $500 \, \mu m$, corresponding to two strips. Values less than this gave a noticeable drop in efficiency, as expected considering the FMD geometry. Values higher than $500 \, \mu m$ found more tracks than there were particles, indicating too large a search area. With the final values of these parameters a tracking efficiency of about $80\%$ was found for run 57200. Considering only half of FMD3o was working, and that the extrapolation of the tracks out before they hit FMD1, showed no common origin, but particles coming from all sides of the surroundings, this is a reasonable efficiency.

Run 57243 had an efficiency of about $10\%$, most likely caused by the malfunctioning FMD2. The directions of the tracks were very similar in the two runs. Both showing a peak, indicating the particles were travelling almost parallel with the beam pipe. Particles in both runs showed a tendency to move an average of $1.6 \, cm$ down while passing through the FMD. In run 57200 they also moved an average of $400 \, \mu m$ to one side, while they moved an average of $1.6 \, cm$ to the other side in run 57243.

Because of the limited spatial resolution of the FMD, the particle tracks found in AliROOT might have different slopes between FMD1→FMD2 and FMD2→FMD3. This was examined by plotting the difference between the two slopes, and was found to be less than $250 \, \mu m$, which is negligible.

Overall it can be concluded that a tracking method has been found, which appear to have an efficiency of $80\%$ on a good run. It would be interesting to run the analysis on more data, to get a better understanding of what was going on. Further analysis could include a detection efficiency test of FMD2. This could be done by: 1. Connecting all particles on FMD1 and FMD3 with lines. 2. Selecting the lines having the most probable slopes, according to the tracking method. 3. Finding where the lines cross FMD2 and look for particles.

Since the incident on September 19 2008, the Lhc has been shut down. When it starts up again sometime late 2009, the FMD will be ready to take new measurements of test beams, and (hopefully) real collisions this time. The methods developed in this report will also be relevant for the new test beam data, to make sure that the FMD is still working as it should.
Den 10. september 2008 blev der for første gang sendt protoner hele vejen rundt i Large Hadron Collider (LHC) ved CERN. I ugerne op til denne historiske begivenhed blev der kort en række tests af både LHC, men også af de eksperimenter, som befinder sig langs den 27 km store ring.

Blandt disse eksperimenter er ALICE eksperimentet, som det eneste eksperiment ved LHC, er det bygget til at kigge på tung-ions kollisioner. Mere specifikt er det meningen at ALICE skal undersøge den stærke vekselvirkningsegenskaber. Samt undersøge en tilstand kaldet Kvark Gluon Plasma, som kvante kromodynamiken forudsiger vil opstå under tung-ions kollisioner.


FMD’en er bygget til at kigge på partikel multiplicitet. Multiplicitet beskriver hvor mange partikler der bliver dannet i en partikel kollision, og siger noget om vigtige fysiske størrelser som energi densitet og entropi. FMD’en består af 3 subdetektorer, FMD1, FMD2 og FMD3. FMD2 og FMD3 består af to ringe, en indre og en ydre. De er placeret på hver sin side af interaktions punktet i ALICE, med cirka 1,5 m i mellem sig. FMD1 er placeret 2,5 m væk, på samme side af interaktions punktet som FMD2 og består kun af en indre ring. Ringenes overflader er pn-juctions, som danner elektron-hul par når ladede partikler rammer dem. FMD’en er således kun i stand til at registrere ladede partikler.

Formålet med rapporten er, at undersøge om FMD’en virker som den skal, dvs. at den registrerer når partikler rammer den. Da det er data fra forskellige test opsetninger er det ikke sikkert at alle data filer kan bruges. Det vides at den mængde energi partiklerne afsætter i FMD’en bør følge en Landau distribution, og data som ikke opfylder dette kan ikke bruges til den videre analyse.


Næste del af analysen var, at prøve om det var muligt at spore partiklerne ned gennem de tre subdetektorer. For den første kørsel var det muligt at forbinde 80% af partiklerne på FMD1 med partikler fra de 4 andre ringe. Da det ikke var muligt at finde et fælles oprindelses punkt for partiklerne, og kun halvdelen af den yderste ring på FMD3 virkede, blev en effektivitet på 80% set som værende et tegn på at sporingsmetoden var god. På den anden kørsel havde sporingsmetoden en effektivitet på 10%, hvilket blev tilskrevet problemerne med FMD2.

Begge kørsler indikerede at de fleste af partiklerne havde bevæget sig næsten parallelt med beam røret. I gennemsnit havde de bevæget sig 1,6 cm ned i deres tur fra FMD1 til FMD3. På den første kørsel havde de bevæget sig ca. 400 µm i det horisontale plan. I den anden havde de bevæget sig 1,6 cm i det horisontale plan.

Konlusionen med rapporten blev, at der var blevet fundet en rimelig effektiv sporings metode, som også vil kunne bruges til næste gang der kommer test beam data. Samt at FMD’en virker som den skal.
# A Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALICE</td>
<td>A Large Ion Collider Experiment. One of the four experiments at the LHC.</td>
</tr>
<tr>
<td>ADC</td>
<td>Analog-to-Digital Converter.</td>
</tr>
<tr>
<td>ATLAS</td>
<td>A Toroidal LHC ApparatuS. One of the four experiments at the LHC.</td>
</tr>
<tr>
<td>CERN</td>
<td>Conseil Européen pour la Recherche Nucléaire or European Organization for Nuclear Research.</td>
</tr>
<tr>
<td>CMS</td>
<td>Compact Muon Solenoid. One of the four experiments at the LHC.</td>
</tr>
<tr>
<td>DST</td>
<td>Data Summary Tree.</td>
</tr>
<tr>
<td>FMD</td>
<td>Forward Multiplicity Detector. ALICE detector system. Built at the Niels Bohr Institute.</td>
</tr>
<tr>
<td>HMPID</td>
<td>High Momentum PID. ALICE detector system.</td>
</tr>
<tr>
<td>IP</td>
<td>Interaction Point. The point where the collider beams cross.</td>
</tr>
<tr>
<td>ITS</td>
<td>Inner Tracking System. ALICE detector system.</td>
</tr>
<tr>
<td>LEIR</td>
<td>The Low Energy Ion Ring at CERN.</td>
</tr>
<tr>
<td>LHC</td>
<td>The Large Hadron Collider at CERN.</td>
</tr>
<tr>
<td>LHCb</td>
<td>Large Hadron Collider beauty. One of the four experiments at the LHC.</td>
</tr>
<tr>
<td>LINAC 2 &amp; 3</td>
<td>Linear accelerators at CERN.</td>
</tr>
<tr>
<td>lQCD</td>
<td>Lattice QCD.</td>
</tr>
<tr>
<td>pp</td>
<td>Proton-proton. Referring to a beam or collision.</td>
</tr>
<tr>
<td>PID</td>
<td>Particle Identification.</td>
</tr>
<tr>
<td>Ps</td>
<td>The Proton Synchrotron at CERN.</td>
</tr>
<tr>
<td>MIP</td>
<td>Minimum Ionizing Particle.</td>
</tr>
<tr>
<td>MPV</td>
<td>Most Probable Value.</td>
</tr>
</tbody>
</table>
REFERENCES

QCD | Quantum Chromodynamics.
The quantum description of the strong interaction.

QED | Quantum Electrodynamics.

QGP | Quark Gluon Plasma.

RCU | Read-Out Control Unit.

Sps | The Super Proton Synchrotron at CERN.

TOF | Time Of Flight. ALICE detector system.

TPC | Time Projection Chamber. ALICE detector system.

wQGP | Weakly interacting QGP.

References


