Search for exotic stable charged particles and magnetic monopoles at ALICE
— An exploratory study—

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1 Motivation

With the Time-of-Flight (TOF) and the Time-Projection Chamber (TPC) ALICE owns two powerful devices to identify the particles traversing the detector. These subdetectors are not only very well suited for identifying well known particles but also offer the opportunity to search for physics beyond the standard model.

The following report will describe an exploratory study of beyond the standard model particles like exotic stable charged particles and magnetic monopoles. These particles typically posses very high masses and are reconstructable in high energy and high momentum regions. The study itself will be of an exploratory nature, since similar research has never been carried out by ALICE before. Nevertheless there are several reasons why ALICE is very well suited for the search for exotic stable charged particles like free quarks and magnetic monopoles. The main reason is that with the TOF and TPC subdetectors ALICE is the most sensitive of the four main experiments to identify unknown particles. With the lowest material budget at the central barrel, exotic particles traversing ALICE are more likely to reach the sensitive parts of the detector than in any other experiment, even with the TOF detector being situated at the outer region of the central barrel [2]. In addition to that ALICE does not only probe pp collisions but also Pb-Pb collisions which offers a much bigger variety of collision data.

First of all the procedure to obtain the mass spectra from the TOF and the TPC detector will be described as well as the analysis of an unexpected background signal. Furthermore first steps towards a mass limit of traversing particles will be described. Also the possibility to search for magnetic monopoles in the data and expected structures of free quarks will be investigated. Finally, an outlook will discuss the results and motivate further research possibilities.

2 Analysis

2.1 TOF and TPC: Energyloss and velocity distribution

To make first steps towards mass spectra from the Time-Projection Chamber(TPC) and the Time-of-Flight (TOF) detectors the energy loss and the velocity distribution from prefiltered Pb-Pb collision data with $\frac{\mathrm{dE}}{\mathrm{dx}} > 1.6\,\mathrm{MIP}$ is calculated. The prefiltered data simplifies the calculations and would have been replaced by unfiltered data if time would have allowed to do so. From the TPC data the energy loss $\frac{\mathrm{dE}}{\mathrm{dx}}$ of particles traversing the detector is obtained and from the TOF data the velocity distribution β is calculated. Both are displayed in Figure 2.1, as a function of the rigidity $\mathrm{R} = \frac{\mathrm{p}}{\mathrm{z}}$.

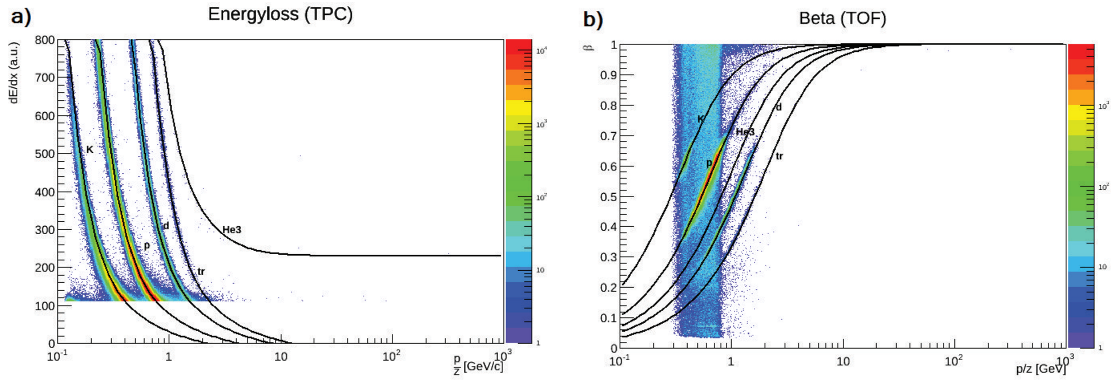

Figure 2.1: a) Energy loss from TPC and b) velocity distribution from TOF

Both plots show clear signals corresponding to kaons, protons, tritons, deuterons and ^{3}He. The energy loss of the charged particles in matter in Figure 2.1a is described by the parametrization of the Bethe Bloch formula from the ALEPH collaboration [3]. The parametrization is displayed in equation 1 where C is a calibration factor and z^2 the charge of the particle. The free parameters $P_{1...5}$ result from a fit to well known data from a 90% Neon and 10% CO_2 mixture in the TPC.

$$f(\beta\gamma) = C \cdot z^2 \frac{P_1}{\beta^{P_4}}\{P_2 - \beta^{P_4} - ln[P_3 + \frac{1}{(\beta\gamma)^{P_5}}]\}, \tag{1}$$

The velocity distribution β from the TOF data is calculated in the following way:

$$\beta\gamma = \frac{p}{m} \tag{2}$$

$$\Longleftrightarrow \beta = \frac{\frac{p}{m}}{\sqrt{1+(\frac{p}{m})^2}} \tag{3}$$

$$\Longleftrightarrow \beta = \frac{\frac{Rz}{m}}{\sqrt{1+(\frac{Rz}{m})^2}} \tag{4}$$

To make the velocity distribution depending on the rigidity $R = \frac{p}{z}$, the charge is introduced to the equation. The masses and charges for the theoretical curves are obtained from the particle data group [4].

Since the Bethe Bloch formula differs for different charges, the calibration of the $z = 1$ and the $z = 2$ particles has to be carried out separately. For the calibration of the $z = 1$ particles the proton curve is used and for $z = 2$ the ^{3}He curve is used. To calibrate the Bethe Bloch formula 25 randomly chosen $\frac{p}{z}$ bins from the proton curve in the TOF data are projected onto the y-axis. After a Gaus fit of the resulting histograms the β-distribution is fit to the mean values of these histograms. After a 3σ cut around the fitted β the Bethe Bloch formula is fit to the corresponding TPC data with the same procedure. The same is done with the ^{3}He curve, but due to the small amount of available data only four $\frac{p}{z}$ bins can be used for the calibration. From the calibrated Bethe Bloch and β curves a mass spectrum for both detectors can be calculated.

2.2 TOF and TPC: Mass spectrum

After calibration the mass spectrum from the TOF and the TPC detector is available. The mass $\frac{m}{z}$ from the TOF detector is directly obtained from the provided data, the mass $\frac{m}{z^2}$ from the TPC has to be calculated using the Bethe Bloch formula. This is done by exploiting the dependence of the Bethe Bloch formula on $\beta\gamma$ only. The prefiltered data ensures that the calibrated Bethe Bloch formula is valid in the region where it is proportional to

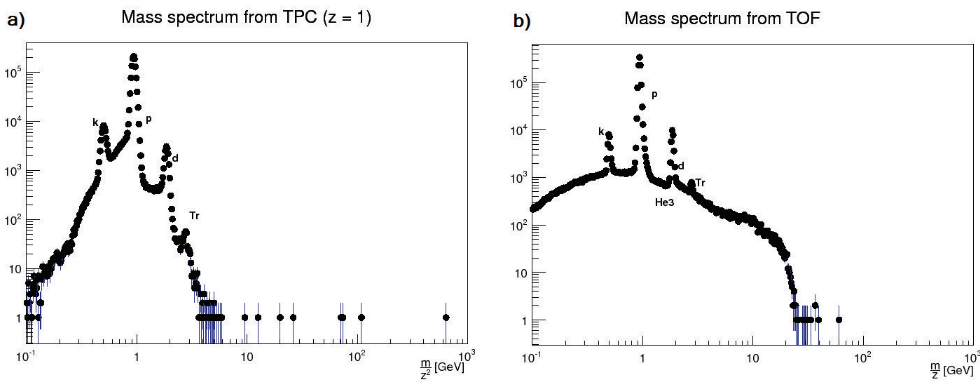

Figure 2.2: Mass spectrum from a) TPC for z = 1 and b) TOF detector

$\frac{1}{\beta^2}$. In this region the equation is bijective and can be inverted. Therefor for a specific $\frac{\mathrm{dE}}{\mathrm{dx}}$ value the inverted Bethe Bloch formula returns the corresponding $\beta\gamma$. From this the mass of the particle can be calculated with $\beta\gamma = \frac{\mathrm{p}}{\mathrm{m}}$.

To invert the Bethe Bloch formula a TGraph(n, $\frac{\mathrm{dE}}{\mathrm{dx}}$, $\beta\gamma$) is created by calculating the energy loss $\frac{\mathrm{dE}}{\mathrm{dx}}$ with equation 1 in a randomly chosen $\beta\gamma$ range. To perform the numerical inversion the x and y argument of the TGraph are exchanged. From the inverted TGraph the $\beta\gamma$ corresponding to a $\frac{\mathrm{dE}}{\mathrm{dx}}$ from the data is calculated and with that the mass is obtained via $\mathrm{m} = \frac{p}{\beta\gamma}$. The mass spectra obtained from TOF and TPC are displayed in Figure 2.2.

In the mass spectrum from Figure 2.2a the mass peaks correspond to protons, kaons, deuterons and tritons. The mass of the ^{3}He is not included since it carries the charge z = 2. Nevertheless it is included in the TOF spectrum (Figure 2.2b), because the mass of the TOF is obtained directly from the given data. A combined plot of both mass spectra in Figure 2.3 enables a comparison of the two obtained masses.

From Figure 2.3a it can be seen that the well known kaons, protons, tritons and deuterons are concentrated in the low mass region. In the high mass region no significant events can be seen. Nevertheless a few single events lie close to the bisecting area which marks equal masses from TOF and TPC, so further analysis of these data points is recommended. Unfortunately this exceeds the scope of the Summer Student Project. Figure 2.3b displays the combined spectrum for ^{3}He. As a result from the low amount of data in this region only a few events can be seen. Also the mass spectrum on the $\frac{\mathrm{m_{TPC}}}{\mathrm{z^2}}$-axis is strongly smeared out. It can be seen that the low amount of data leads to poor statistics and prohibits an accurate calculation of the mass spectrum. Concluding it can be said that no unexpected events are found in the high mass region of the TPC and TOF detector.

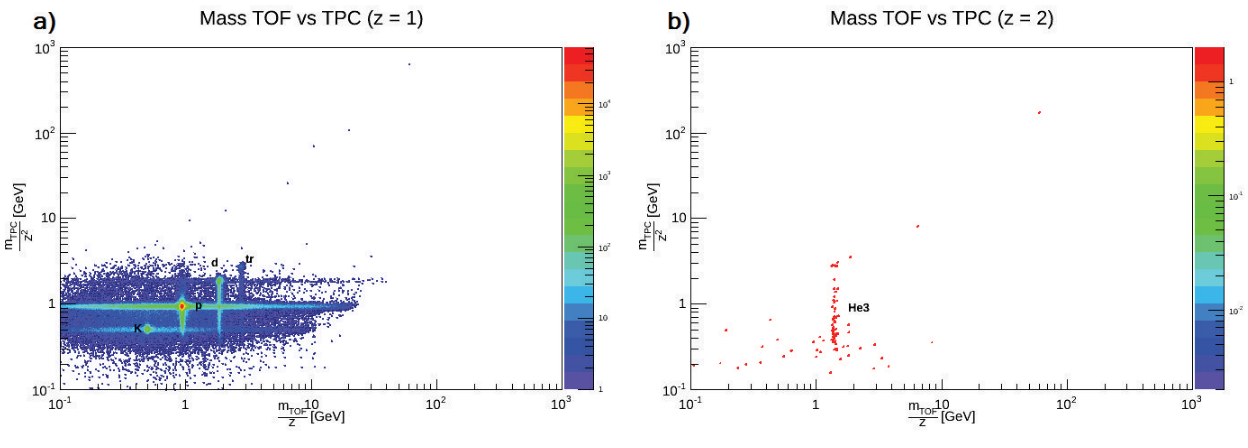

Figure 2.3: Combined mass spectrum TOF and TPC for a) z = 1 and b) ^{3}He (z = 2)

2.3 A closer look at the TOF mass spectrum

2.3.1 Unexpected background structure

During the analysis an unexpected structure in the TOF mass spectrum around $\frac{\mathrm{m}}{\mathrm{z}} = 10\,\mathrm{GeV}$ was discovered. To receive the pure signal of the structure the background left and right from the structure is fit and subtracted (Fig. 2.4a). To validate the importance of the peak its significance $\mathcal{S}$ is calculated with

$$\mathcal{S} = \frac{S}{\sqrt{S+B}} \tag{5}$$

The signal strength S is calculated by taking the sum over the bin contents of the pure signal in a 5σ range around the mean of the peak, the background signal B is obtained by taking the sum over the background values in the same region. Both the mean and the standard deviation σ are obtained from a Gaus fit of the peak. With $\mathcal{S} = 9.09146$ the resulting signal (Fig. 2.4b) is more significant and broader than expected. This evokes the assumption that the signal is fake and caused by the cut-off in the sampling time of the TOF electronics.

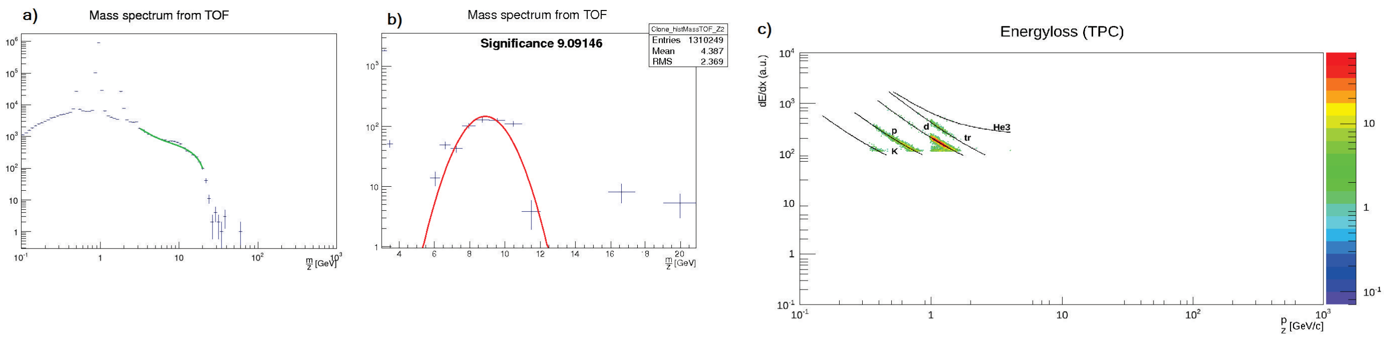

Figure 2.4: Unexpected Structure in TOF, a) the structure, b) the signal, c) corresponding $\frac{\mathrm{dE}}{\mathrm{dx}}$

From the $\frac{\mathrm{dE}}{\mathrm{dx}}$ of the signal (Fig. 2.4c) it can be seen that it originates mainly from deuterons, but also from the other well known particles. Since there is no contribution from particles at high energy and high momentum regions and due to the participation of all already identified particles to the unexpected signal it can be concluded that it originates from mis-matching in the tracking.

2.3.2 First steps towards upper limits as a function of the mass of the produced particles

To make predictions about the necessary signal strength in the high mass area to validate an event as significant signal it is assumed that a significant signal means $\mathcal{S} > 5$. From a background estimation the necessary signal strength S can then be calculated from $5 = \frac{\mathrm{S}}{\sqrt{\mathrm{S+B}}}$ as $\mathrm{S} = \frac{1}{2}(25 \pm \sqrt{625 + 100 \cdot \mathrm{B}})$. The necessary number of counts for masses bigger than $3\,\mathrm{GeV}$ is displayed in Figure 2.5.

As it can be seen from the figure, for high masses a very low number of counts is necessary to specify an event as signal. Nevertheless in the used data no significant signal at high masses were found.

2.4 Search for free quarks

To predict possible structures for free quarks their expected energy loss and velocity distribution is plotted together with unfiltered Pb-Pb data (Fig. 2.6). The energy loss is received from equation 1 by using the calibration factor from the pion signal at $3 < \beta\gamma < 4$.

It can be seen that where quarks are expected no signal is visible. A closer study of the quarks approaching the lower bands of the pion structure would be interesting but unfortunately exceeded the scope of the project.

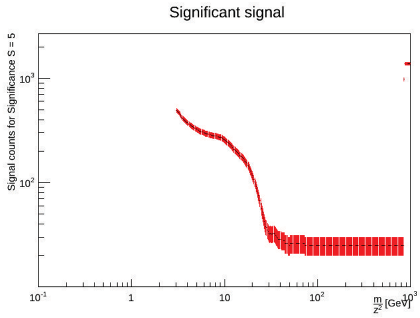

Figure 2.5: Counts necessary for significant signal

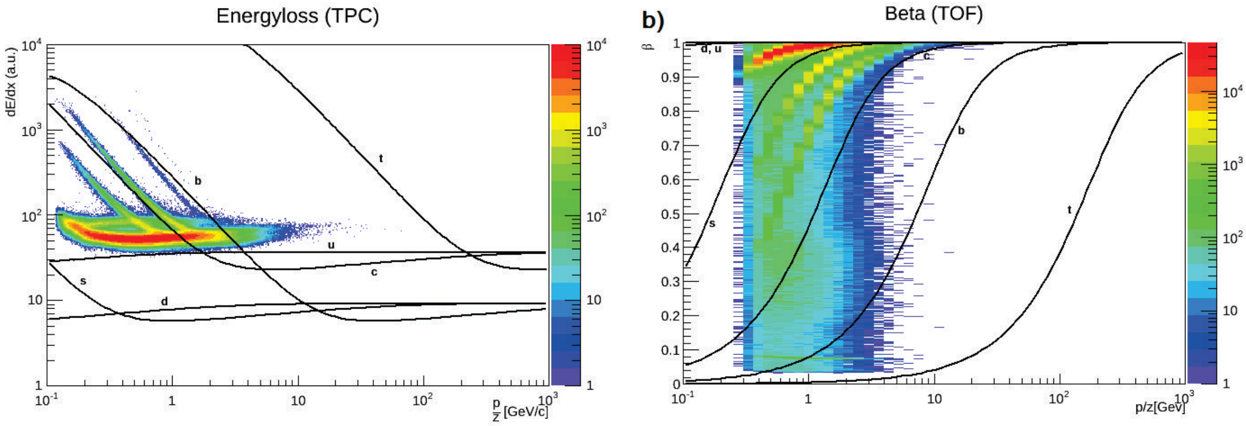

Figure 2.6: Expected $\frac{\mathrm{dE}}{\mathrm{dx}}$ and β for quarks

2.5 Magnetic monopoles

Other than electrically charged particles magnetic monopoles experience a force in z-direction in the magnetic field of ALICE. This effect is due to the magnetic charge of the monopoles and is called bending. Figure 2.7a displays the tracks of electrically charged particles in the magnetic field in the xy plane and in the z- direction. From Figure 2.7c it can be seen, that compared to other detectors monopoles in ALICE are expected to have the lowest bending in z-direction with only 5cm after traveling a distance of 1.5 meters.

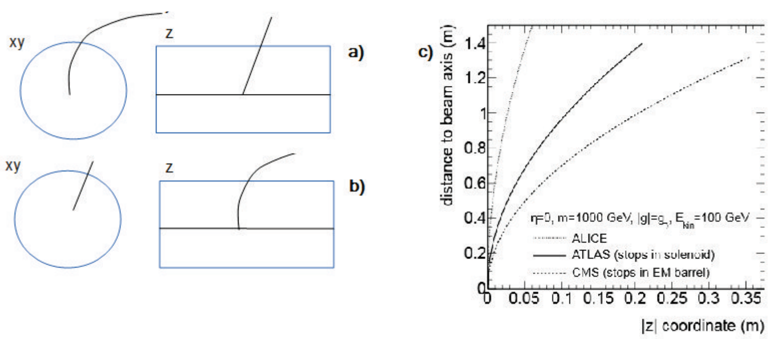

Figure 2.7: Tracks of a) electrically and b) magnetically charged particles in B-field, c) bending of monopoles in z-direction [2]

A problem of searching for monopoles in existing data is that due to the bending in z-direction it is not clear how possible monopole tracks are reconstructed by the software. Due to their high energy monopoles are expected to have straight tracks in the xy-plane (Fig. 2.7b) and therefore they might end up as high momenta tracks ($>$ 150 GeV) with large dE/dx. Checking data in this range unfortunately didn't show any unexpected signals, so for further analysis a tracking of the monopoles has to be analyzed in more detail, where also a simulation of the behavior of magnetic monopoles would be necessary.

3 Conclusion

In this exploratory study of exotic stable charged particles and magnetic monopoles at ALICE no unusual events at high masses, high energies or high momenta the TOF and TPC data are found. Nevertheless analysis of unfiltered data, a closer look at the single high mass events of the combined TOF and TPC spectrum (Fig. 2.3) and the search for particles with $z > 2$ could set stricter conclusions, but since this exceeds the scope of the Summer Student Project it is left for future analysis. However, future experiments at for example MoEDAL will keep the search for exotic stable charged particles and magnetic monopoles a current issue.

References

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