Proton rejection of the ECAL for the PEBS experiment

Master thesis

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1 Introduction

One of the most interesting discoveries in cosmic rays physics in the recent years is the anomalous abundance of positrons in cosmic rays for particles between 10 and 100 GeV. This discovery was made by the PAMELA experiment in 2008 [3] and the results are shown on figure 1. This excess was confirmed by FERMI up to 200 GeV [2]. This abundance is in contradiction with the statement that most positrons are secondary particles created in interactions between primary particles and the interstellar medium as described by GALPROP model [6] (solid line on figure 1). Such an excess can thus be explained only by a primary source of these positrons, most promising candidates being pulsars or supersymmetric dark matter models (darkSUSY). In the latter, annihilation or decay of DM particles can create positrons. In order to know which candidate is the right one, it is necessary to measure this fraction for higher energies. This is the main motivation for the PEBS (Positron Electron Balloon Spectrometer) experiment.

![Figure 1: Positron fraction as a function of the positron energy in cosmic rays.](image)

The two main needs in order to perform such a measurement are the measurement of the energy of the incident particles and proton background rejection: positrons and electrons are just a tiny amount of the cosmic rays which are essentially composed of protons (figure 2). In this report, a prototype of the PEBS calorimeter built by EPFL is presented. The calorimeter contributes to both tasks and here, the focus will be on particle identification and especially discrimination between electrons (and positrons) and protons.
2 Presentation of the PEBS experiment

A prototype of the PEBS electromagnetic calorimeter (ECAL) has been built at EPFL and tested at CERN. The goal of this report is to analyse some of the obtained data in order to find the rejection power of the calorimeter. First, PEBS experiment will be first presented in general, then the focus will be on the ECAL and finally the approach and the results on proton rejection will be shown and explained.

2.1 PEBS in general

The goal of the PEBS experiment [10] is to measure the positron and electron fraction with a very good rejection of background (mostly protons) and to measure with a good precision their energy and momentum. PEBS will be composed of a tracker and a superconducting magnet in order to measure the rigidity and charge of the particles. A good measurement of the rigidity which provides the particle momentum is essential to perform the rejection (section 4.2). Then the TRD (transition radiation detector) helps also to distinguish electrons and positrons from protons. The TOF (time of flight) rejects the particles coming upwards and gives the velocity of low energy particles. Finally, the ECAL (Electromagnetic Calorimeter) gives the total energy of the particle and contributes to the proton rejection. The final detector should be able to measure the fraction of positron up to 600 GeV (6 times higher than the PAMELA experiment) and the total (electron + positron) flux up to 1.8 TeV.

In order to measure directly the cosmic rays, the detector has to go to a high altitude, to do so it will be attached to a balloon and launched near a earth pole. The detector will then take data at an altitude of approximately 40 km for up to 40 days.

Figure 2: Cosmic rays composition.
2.2 The ECAL

In the following, we will focus on the ECAL as it is the part of the PEBS experiment which is built at EPFL.

First, an ECAL is a device designed to measure the energy of any high energetic particle which occur electromagnetic interaction (electrons, positrons and photons). To do so, the electron or positron has to radiate high energetic photons in a dense material (as lead), then these photons occur a pair production ($\gamma \rightarrow e^+e^-$). The electron and positron will also radiate and annihilate (only for positron) to create other photons and so on. Consequently an electromagnetic shower appears (figure 3). The energy of all the particles of the shower are then measured with scintillators.

The calorimeter which is built for PEBS is a sandwiched calorimeter, it is composed of consecutive layers of the interactive material and scintillators. This configuration permits a sampling of the longitudinal profile of the electromagnetic cascade, contrary to classical calorimeters which are composed only of one block of scintillating material providing only the total energy deposited inside. The longitudinal profile of the energy deposition of an electromagnetic cascade is described by [7]:

Figure 3: The PEBS detector.
\[ \frac{dE}{dt} = E_0 b (bt)^{a-1} e^{-bt} \frac{\Gamma(a)}{\Gamma(a)} \]  

(1)

where \( t = x/X_0 \), \( a \) and \( b \) are free parameters and \( E_0 \) is the total energy. The maximum of the shower occurs at \( t_{\text{max}} = (a - 1)/b \).

Protons can be also detected by the ECAL as they deposit energy via strong interaction and create hadronic showers. These showers have different properties from the electromagnetic ones (e.g. the Molière radius, position of shower maximum, etc...). When an electron starts generating a shower, it consumes directly all its energy in pair production. On the contrary, when a proton starts a shower it loses partially its energy into creating pions. Neutral pions then decay into two photons which generate the electronic cascade. However the proton still exists and can interact further providing more pions. Using these different properties, the ECAL can distinguish these two particles and contributes to the proton rejection.

![Figure 4: Simulation of an electromagnetic shower.](image)

The ECAL is made of 16 layers, each layer containing one 4\( mm \) lead plate (i.e. 0.71\( X_0 \)) and one scintillating medium plate called BC-408 (from Saint-Gobain) which is made of PVT (Polyvinyltoluene). The PVT plate is cut in 24 bars (4\( mm \) thick, 16\( mm \) large and 384\( mm \) long) which are light isolated from each other. In order to transmit the scintillating light to each side of the layer, a 1 mm diameter wavelength shifting fibre is placed in a groove cut in the center of each bar (figure 5). The orientations of the layers are alternated to provide X and Y position of the events. The most important part are the devices which are used to detect the scintillating light: they are not classical photomultiplier tubes but SiPMs (Silicon Photo-Multiplier). This choice is done because of the following advantages: unlike PMTs, they are very small, they are insensitive to magnetic fields, they have lower power consumption and as they are able to measure individual photons, they can be self calibrated. These characteristics are important for the PEBS experiment because, as it will be launched with a balloon, the detector has to be as light and small as possible and it should not consume too much energy. Moreover,
as PEBS will contain a superconducting magnet, the calorimeter will be exposed to strong magnetic fields. The main disadvantage of SiPM is that they are very sensitive to temperature fluctuations.

Figure 5: The bars of the scintillating medium with the optical fibres.

Figure 6: The silicon photo-multipliers.

2.2.1 The prototype

The calorimeter which is tested here is the third prototype of the PEBS ECAL. The layers of this ECAL contain 24, 38.4 cm long, scintillating bars. As the scintillating light is emitted on the two sides of one layer, two types of SiPM with different gains are used: MPPC (from Hamamatsu) with 3200 pixels on $2mm^2$ and MAPD (from Zekotek) with 135 000 pixels on $9mm^2$ with MAPD gain being 1 order of magnitude lower than MPPC. This configuration provides a larger scale on the energy measurement of the incident positron or electron.
2.2 The ECAL

A light injection system composed of a LED and a PIN diode is also present in the prototype. This system injects light in the detector which can then be detected by the SiPM and the PIN diode. It is useful in order to correct the error introduced by temperature changes. Contrary to the SiPM, the pin diode is not temperature dependant and it can be used as a reference for the SiPM output.

2.2.2 The test beam

The ECAL was tested in July 2012 at CERN. Beams from two accelerators were used, PS (Proton Synchrotron) and SPS (Super Proton Synchrotron). The SPS provided beams of positive particles with momenta from 20 to 180 $GeV/c$, the beam contained hadrons (protons and pions) and leptons (positrons and muons). The composition of the beam could be changed by placing different targets on the beam’s trajectory.

The PS delivered both negative or positive beams of lower momenta particles, from 0.5 to 10 $GeV/c$. The positive beam was mainly composed of protons but also contained some positrons, anti-muons and positive pions. The negative beam contained only electrons, muons and negative pions. The beam went through two Cherenkov detectors which can be configured and used to trigger the data acquisition.
3 Event selection

As the calorimeter should reject protons from positrons and electrons, it is important to know exactly which particles are sent to the detector during the test beam. At the SPS, there are two devices which were used to determine the mass of the particles and thus their type. The first one is a simple Cherenkov threshold detector: when a particle travels faster than the speed of light in the detector gas, it emits light in this detector. It means that its mass is above the threshold of the Cherenkov. This threshold mass is determined from the parameters of the Cherenkov (gas composition and pressure) and the particle’s momentum. The second device is the CEDAR (Cerenkov Differential Counters with Achromatic Ring Focus). It is also a Cherenkov detector but it takes into account the dimensions of the emitted light circle, it can then be set to detect a specific mass (or type). This light can be detected by 8 detectors in the CEDAR [4]. 8, 7 or 6 detectors can be set in coincidence providing three degrees of sensitivity.

At the PS, the devices used are two threshold Cherenkov detectors, the way to select the protons will be also presented here.

In this section, some properties of the events selected by the Cherenkov and the CEDAR will be analysed and compare to the others events.

3.1 Proton selection at SPS

At the SPS, two different types of beam were used, one containing mostly protons and the other positrons. The CEDAR was set according to each beam type. Here the data provided by the CEDAR during protons runs are analysed. The ratios of the number of events selected by 4 criteria over the total number of events are shown on figure 8.

With the CEDAR, at a given energy, the ratio decreases with the number of detectors in coincidence as the efficiency also decreases. The ratio with the Cherenkov is higher at low energies but lower at the highest energies (150 and 180 GeV). In this case, the velocity of the protons goes above the Cherenkov threshold for 150 and 180 GeV as shown on figure 7.
3.1 Proton selection at SPS

Figure 7: Event distribution in the Cherenkov and in the CEDAR for the 3 sensitivities at 180 and 100 GeV. Red vertical lines are the cuts between events seen and not seen by the detector. The red histogram represents the distribution in the Cherenkov of the events seen by the CEDAR with 8-fold coincidence.
3.1 Proton selection at SPS

Figure 8: Average event ratio selected by CEDAR and Cherenkov as a function of the energy. "ced1", "ced2" and "ced3" stand for light detected in respectively 8, 7 and 6-fold coincidence and "cher" stands for no light emitted in the Cherenkov.

In order to understand the variation with energy of the ratio, one has to look at the targets used at each energy. At 20 GeV, the target is only polyethylene and lots of positrons travel through the target, so the proportion of protons in the beam is already low, thus explaining the low ratio. At 40 GeV, a 8 mm thick lead target is added which stops more positrons than protons, the ratio is then higher. At 60, 80 and 100 GeV, the lead target is 18 mm thick. For these three energies, the configuration is the same and the ratio decreases with the energy, meaning that the CEDAR efficiency or the initial proton proportion also decreases. At 120 and 150 GeV, no target is used. Finally at 180 GeV, only a 18 mm thick lead target is placed on the beam trajectory.

With the 6-fold coincidence, the fraction of selected events doesn’t go below 10 % except at 20 GeV where the fraction is particularly lower.

In order to assess the quality of the proton selection, one computes two variables that depend on the nature of the incoming particle, namely the number of fired strips and the total energy deposition in the calorimeter, for different selection criteria.
A strip is defined as fired if the ADC value given by the MPPC detector attached to the strip is higher than 7 times the RMS of the pedestal added to its mean value, which means that the MPPC detects something.

At each energy, the number of fired strips is constant with the 3 sensitivities of the CEDAR as expected if they select the same type of particle. The values with the Cherenkov selection are always lower than the CEDAR selection, meaning that it selects other particles which interact less with the detector such as muons. The case at 20 GeV is particularly interesting because the beam contains lots of positrons which create electromagnetic showers in the calorimeter and so the number of fired strips should be higher, as observed.

On figure 9 the energy variation of the number of fired strips is shown. The number of fired strips in each event without selection or with the Cherenkov selection has a non-trivial variation with energy because it depends on the beam settings (targets used). But once the CEDAR selection is applied, the number of fired strips has a constant increase with the energy such as expected when the events are protons.

![Protons](image)

**Figure 9:** *Energy dependence of the average number of fired strips for different selection factors. The label "not_ced3" corresponds to the events not detected by the CEDAR with 6-fold coincidence and "without" means without any selection, corresponding to all events.*

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Finally, figure 10 represents the distribution of the total energy deposited in the calorimeter and the variation of the ratio as a function of the energy deposited. At 20 GeV, with no selection on the events, the peak corresponding to the energy deposited by positrons is clearly visible. It is well suppressed by the Cherenkov and the CEDAR. At 100 GeV, one can observe that the ratio with the CEDAR is roughly constant except for very low energy deposition where the ratio is smaller. This is coherent with the assumption that the beam also contains minimum ionizing particles which are rejected by the CEDAR but not entirely by the Cherenkov.

In order to obtain a clear proton sample, it seems that the CEDAR is the best device to use because when set so as to detect only protons, it works at all energies, even if the efficiency is smaller at low energy. Moreover with only 6 detectors in coincidence, the selection is still good and with a better efficiency.
Figure 10: Sum over all the MAPD of the fired strips for the different selection factor. Red dots are the ratios of the selected events over the total number of events in the corresponding bin.
3.2 Positron selection at SPS

The same analysis as for protons can be done for positrons. Yet, above 80 GeV, the selection using the CEDAR seems to be not efficient enough any more. In fact, on figure 11 the ratio of events selected by the CEDAR goes to very low values over 80 GeV and it doesn’t provide enough particles to perform a correct analysis.

Moreover, the number of fired strips starts decreasing already at 80 GeV (figure 12) where it should increase constantly since the electromagnetic cascade becomes wider with the energy. This phenomenon can be understood by looking at the energy distribution of the selected events on figure 13. At 20 GeV the events selected by the CEDAR are well situated in the peak but at 80 GeV, other events which are not in the electron peak are selected.

The Cherenkov is also not a good option since it wasn’t set to select only electrons and also detects protons at 150 and 180 GeV (section 3.1).

Figure 11: Average ratio of events selected by CEDAR and Cherenkov as a function of the energy. The abbreviation “cher” means the events detected by the Cherenkov.
A better way to select positrons is then to take only events which are situated in the electron peak within a width of $3\sigma$. In this range, the electron fraction is high but some protons can be selected too, their proportion is lower than 1% for energies below 120 GeV (figure 14). However, the fraction of protons at 120 and 180 GeV is in the order of some percent. This protons contamination should be taken into account during rejection analysis.

Figure 12: *Energy dependence of the average number of fired strips for the different selection factors.*
Figure 13: Sum over all MAPDs of the fired strips for different selection factors. Red dots are the ratios of the selected events over the total number of events in the corresponding bin.
3.3 Selection at PS

3.3.1 Electrons

At PS no target is used as at SPS and the first selection is done by using the Cherenkov as a trigger. The electrons are the lightest particles contained in the beam, so for a given momentum, they are also the fastest ones so it is possible for the two Cherenkovs to trigger only on the electrons and they can be put in coincidence. In order to increase the purity, the same selection as at SPS is done (figure 14).

![Figure 14: Reconstructed energy distributions for the different initial momentum. The red histograms are the electron peaks within a width of 3σ. Momenta of 3 to 10 GeV/c correspond to PS data and 20 to 180 GeV/c are events from SPS.](image)

3.3.2 Protons

On the other hand, protons are the heaviest particles, so the Cherenkovs were set to detect all others particles (pions, muons, electrons) and then were put in anti-coincidence. The beam being initially composed mostly of protons, this selection provides a pure enough sample of protons.
4 Rejection analysis

The principle of rejection comes from the fact that electrons and protons will behave differently in the calorimeter, e.g. electrons and positrons create electromagnetic cascades when protons generate hadronic cascades. Concretely, hadronic cascades are thinner and longer than the electromagnetic ones (see section 2.2). It is then necessary to find values returned by the calorimeter which are as much as possible sensitive to this difference. Five criteria were first chosen:

- **The number of fired strips.** As the electromagnetic cascade is wider, it should hit more strips than the hadronic one.

- **The reconstructed energy.** The reconstructed energy is based on a fit (equation 1) of the longitudinal profile which supposed an electromagnetic behaviour. So the energy calculated for protons should be different from the electron reconstructed energy. This parameter will be called $E_{\text{tot}}$.

- **The chi-squared test of the longitudinal fit.**

- **The $R$ parameter.** This parameter corresponds to the energy deposited in a layer times the layer number and then summed over all the layers up to the maximum of the longitudinal profile.

- **The "transverse standard deviation".** The MAPD’s ADC value of the fired strip which are in the same "column" are summed. Altogether, this gives up to 48 values: 
  \[ \sum_{X_{\text{layers}}} (ADC)_i \text{ and } \sum_{Y_{\text{layers}}} (ADC)_j \] 
  where $i$ and $j$ go through all fired strips (up to 24) in each layer. Then the standard deviation from these values is calculated separately for the strips oriented in the Y and in the X direction. Finally, the mean of these two standard deviations is taken. This parameter will be called $RM$. This criterion takes into account the fact that the electromagnetic shower is wider whereas the hadronic shower is thinner.

The shape of the cascades also depends a lot on the momentum of the incident particle. These parameters then also depend on the momentum so it is necessary to know it as precisely as possible in order to perform the rejection. The momentum was well-known during the test beam but it will be provided by the tracker during the PEBS experiment and will have an error which will influence the rejection of the calorimeter (section 4.2).

In order to compare the different criteria, a first look at the rejection provided by each of them is presented on figure 15.

The best parameter for the rejection is by far the transverse standard deviation (rejection from $10^3$ to $10^4$). Its combination with $E_{\text{tot}}$ shows also a non-negligible improvement. All other ones show little improvement; only these two rejection criteria will
therefore be used for the rest of the analysis. It is now important to determine a procedure to obtain the rejection.

4.1 Rejection using the exact momentum

In this section, it is supposed that the momentum of the particles during test beam is exactly known (nominal values provided by the accelerator staff). Figure 16 shows the momentum dependence of both $E_{\text{tot}}$ and $RM$ for electrons. The reconstructed energy varies linearly with the momentum, but the spread of $E_{\text{tot}}$’s distribution also increases a lot. Consequently, an error on the fit becomes more important for low momentum than for high momentum. The transverse standard deviation is well fitted by a second order polynomial (except for the quantile of 5% probability), the spread also changes with momentum but the effect is less important. The quantile of 5% probability is particularly low at 120 and 180 GeV, this effect comes from the fact that at these two energies, the electrons sample contains a non negligible fraction of protons (see section 3.2).

In order to suppress the momentum dependence, the fit of the median (quantile with probability of 50%) is subtracted. The distribution of the criteria for protons and electrons can be then compared (figure 17).

Figure 15: *First estimation of the proton rejection provided by each criterion with the SPS events. The momentum is given by the test beam nominal value.*

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4.1 Rejection using the exact momentum

Figure 16: Momentum dependence of the reconstructed energy and the transverse standard deviation with electrons. Quantiles of $E_{\text{tot}}$ are fitted with a linear model and quantiles of $RM$ are fitted with a second order polynomial.
4.1 Rejection using the exact momentum

Figure 17: Density distribution of a) reconstructed energy and b) transverse standard deviation for the different momenta. Red histograms for electrons and blue histograms for protons.
One can observe that the distribution of proton $RM$ and $E_{tot}$ values are well separated from the electron ones and that protons provide lower values than electrons. The overlap between these two distributions is small which is the important fact that provides a good rejection power.

The next step is to determine a cut value which separates the events considered as protons from those considered as electrons. Different cuts provide different rejections but also different electron efficiencies. Figure 18 shows the protons fraction as a function of the efficiency for the two parameters. If the number of electrons and protons are initially normalized to the same amount, protons fraction corresponds the proportion of protons which are still present in the selected events. It can be calculated by taking the inverse of the proton rejection times the electron efficiency. This parameter has the advantage to show if cuts are starting to reject more electrons than protons.

For the reconstructed energy, the proton fraction presents a minimum for efficiencies higher than 80%. The cuts corresponding to this minimum are then good choices. These cuts are not the same at all energies and their dependence is shown and fitted in figure 19.

The approach to get the rejection from the reconstructed energy is then first to calculate the shift given by the fit in figure 16:

$$E_{tot}^{shift} = 0.5791 + 0.9818 \times p$$

where $E_{tot}^{shift}$ is in $GeV$ and the momentum $p$ in $GeV/c$. Then, this shift must be subtract from the initial $E_{tot}$ values and the cuts defined by the fit made in figure 19

$$cut = -0.5346 - 0.0962 \times p$$

The events with shifted $E_{tot}$ below the cut are then considered as protons and events above as electrons.

With the transverse standard deviation, the protons fraction goes to 0 at energies of 20, 40 and 120 $GeV$ because the number of events collected during the test beam with the CEDAR selection is too low to record a single event. Moreover, proton fraction doesn’t show any minimum as with reconstructed energy and the curves at 120 and 180 $GeV$ seem to be shifted on the left compared to the other ones. This shift is also a consequence of the proton contamination of the electron sample which is bigger for 120 and 180 $GeV$. The cuts are chosen differently, in order to set the efficiency at 85%, the way to do this is to subtract the fit of the quantile of 15% probability (figure 16) to the initial values. The fit gives

$$RM^{shift} = 31.93 + 14.76 \times p - 0.03012 \times p^2$$

where $RM^{shift}$ is the shift to subtract in ADC channel and $p$ is the momentum in $GeV/c$. Now, with a cut position at 0 for all momenta, the efficiency is then set at 85%. Particles
with negative $RM$ values are considered as protons and positives ones are considered as electrons.

Figure 18: Protons fraction for different cuts as a function of the efficiency.
4.1 Rejection using the exact momentum

![Graph showing cut position as a function of energy with linear fit equation: \( \text{Etot, cut} = -0.5346 + -0.0962 \times E \).]

**Figure 19:** Cut position for \( E_{\text{tot}} \) as a function of momentum with linear fit.

### 4.1.1 Obtained rejection and efficiency

The efficiency and rejection which are finally obtained are shown on figure 20.

For the energies from 20 to 180 GeV, the efficiency is higher than 75% (except at 3, 5, and 10 GeV). The error bars take into account the statistical error but also a systematic error. Statistical error assess that the number of selected events can vary of \( \sqrt{N} \) involving a variation of the efficiency. The statistical error considers the deviations of the fit which determines the cuts, these deviations imply errors on the cuts positions and so on the efficiency.

The special cases at 3, 5 and 10 GeV with 60% efficiency and bigger error bars are due to the high sensitivity of the cut position at low energies. This phenomena can be corrected by treating low energies separately (see figure 22 in appendix).
4.1 Rejection using the exact momentum

Figure 20: Electron efficiency and protons rejection as function of the energy obtained when combining the $E_{tot}$ and the RM parameter.
The aimed goal for rejection was to be above $10^3$ at 75% electron efficiency and it is reached except for 3 and maybe 20 GeV; it is even above $10^4$ between 60 and 120 GeV. The error bars are statistical and correspond to a confidence level of 90%, explaining why the errors are bigger at 20, 40 and 120 GeV.

4.2 Rejection using reconstructed momentum from PEBS tracker

In the previous section, it was supposed that we know exactly the momentum of the particles. Nevertheless in the reality of the experiment, momenta are provided by tracker with uncertainties. The momentum error of the PEBS experiment tracker has been found using Monte-Carlo simulations [5]. The error for electrons or positrons is

$$\sigma \left( \frac{p}{p_{\text{rec}}} \right) = 0.18 \times p \oplus 2.7\%$$  \hspace{1cm} (5)

where $p_{\text{rec}}$ is the reconstructed momentum, $p$ is the exact momentum in GeV/c and $\oplus$ is the quadratic sum. The error for protons is

$$\sigma \left( \frac{p}{p_{\text{rec}}} \right) = 0.16 \times p \oplus 2.4\%$$  \hspace{1cm} (6)

These errors are negligible at low energies ($\sim 3.5\%$ at 10 GeV) but they become huge at the highest energies ($\sim 30\%$ at 180 GeV).

In order to implement these errors, the momenta of the particles were distributed following a Gaussian distribution centred in the real momentum and with a standard deviation given by equations 5 and 6. Efficiency and rejection can now be recalculated using these new momenta.

The first effect of these reconstructed momenta are the distribution of shifted $RM$ and $E_{\text{tot}}$, indeed the shifts depend on the momentum (figure 23) and one can observe that the overlap between the distributions increases at high energies. This implies also a change in the behaviour of the protons fraction obtained with $E_{\text{tot}}$. Actually, now there is not always a minimum (figure 24). The same rule for the selection of the cuts can’t be used, instead, when there is no minimum, cuts are taken at an efficiency of 85%. The cuts for the different momenta are shown on figure 25, they are fitted with a second order polynomial which gives

$$\text{cut} = -2.089 + 0.02053 \times p - 0.001985 \times p^2$$  \hspace{1cm} (7)

where $p$ is the momentum in GeV/c. The initial shift for $E_{\text{tot}}$ and the shift for $RM$ are kept the same. The efficiencies rejections finally obtained are shown on figure 21.
Figure 21: Electron efficiency and protons rejection as a function of the energy obtained when combining $E_{\text{tot}}$ and RM parameter.
The efficiencies are slightly shifted down compared to the ones found with the exact momenta. However, they stay above 70 % for energies going from 20 to 180 GeV. The cases of 3, 5 and 10 GeV can be solved by treating them separately exactly as for the exact momenta because the error introduced by the tracker is negligible (< 3.5 %).

The rejection is more influenced by the uncertainty of the momentum, above 60 GeV the rejection decreases down to $2.7 \cdot 10^2$ whereas it was stable when knowing the exact momentum. This effect is in accordance with the rejection predicted by the Monte-Carlo simulations [5].

5 Conclusion

The PEBS experiment needs an excellent proton rejection since it wants to measure electrons and positrons in cosmic rays up to 100 GeV, where the protons are $10^2$ more abundant than electrons and $10^3$ more abundant than positrons. Its purpose is then to reach a proton rejection of $10^6$ thanks to two devices: the TRD and the calorimeter.

Here, the rejection provided by the last prototype of the calorimeter was studied. The way to obtained protons and electrons samples from the test beam was first presented. Difficulties were experienced in order to obtain the sample of electrons. In this case, the events selected are contaminated by some protons. The fraction of protons is particularly important at energies of 120 and 180 GeV (some percent). This fraction generates a little under estimation of the final rejection or efficiency at these two energies.

Then it was shown that the rejection and the electron efficiency are dependant on the precision of the momentum measurement given by the tracker. However, when taking into account this error obtained from Monte-Carlo simulation, it was also shown that the calorimeter is able to reach by itself a rejection of around $10^3$ with an electron efficiency above 70%. These characteristics are consistent with the predicted ones from simulations and they are showing the proper behaviour of the prototype.
References


A Additional plots

Figure 22: Efficiency and rejection when treating only the events at low energy (from PS).
Figure 23: Density distribution of reconstructed energy and transverse standard deviation for the different real momenta when using reconstructed momenta from PEBS tracker. Red histograms stand for electrons and blue histograms for protons.
Figure 24: Protons fraction for different cuts as a function of the efficiency with the reconstructed energy criterion and PEBS tracker reconstructed momentum.

Figure 25: Positions of the cuts for the reconstructed energy criterion with PEBS tracker reconstructed momentum. Fit is a second order polynomial.