Expected performance of the Chinese high energy cosmic particle detector to be in space

J. Wu¹,², J. Chang¹,²
¹Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210008, China;
²Key Laboratory of Dark Matter and Space Astronomy, Chinese Academy of Sciences(2010DP173032)
wujian@pmo.ac.cn

Abstract: This paper presents simulation results for basic operation of the first Chinese high energy cosmic particle detector aiming to detect electron/gamma at the range between 10 GeV and 10 TeV in space. The new detector is described with its characteristics of good energy and space resolution and strong separation power for electron and proton. A GEANT4 code has been used for a dynamic simulation of the detector. The detector structure is illustrated and results of simulating electron/proton/gamma incidence on the detector validate its operation.

Keywords: Cosmic electron; detector; simulation.

1 Introduction

With the recent achievements of several space experiments on cosmic electron observation such as PAMELA and ATIC [1, 2], the excess on the electron/positron spectrum beyond several tens of GeV and up to around 600 GeV is almost certain, though the source of this unexpected excess is still in pernernet discussions. One of the explanations points directly to the annihilation of dark matter particles. In the scenario of Kaluza-Klein model, the $e^+$ and $e^-$ spectrum should have a sharp drop at the dark matter particle mass due to energy conservation while other none dark matter explanation bears no such characteristics. In other words, if the corresponding spectrum can be measured up to a certain precision, it would be relatively easy to determine the source of the excess. The statistics of the current results is rather low because of the short observing time as well as the load limit to the detector themselves. On the other hand, high energy gamma signal with a $\delta$ shape is a good proof for the existence of dark matter. An appropriate space detector to observe electron and gamma for a long time will help to answer the upper questions. A simulation of such a detector definitely promotes the design and final construction of this first Chinese space project, named TANSUO, for high energy cosmic electron and gamma detection.

2 Simulation consideration and detector geometry

The main difficulty to detect cosmic electrons is the high flux of proton background which is typically several hundred times that of the electron within a rather large energy range. The key issue of the detector is to identify electron with a high suppression power on proton. The successful missions of ATIC have shown that the shower profile difference between electron (positron and gamma as well) and proton measured by its calorimeter made of BGO crystal array gives sufficient information to distinguish electrons from protons[3]. This type of detector design is also a good option for TANSUO indeed.

The preliminary design of the TANSUO detector system includes two main parts: a BGO crystal array and three scintillator hodoscopes as shown in Fig. 1. For simplicity, other components of the detector are not drawn in the figure. As a shower detector, the totally active ionization BGO calorimeter consists of 12 layers of bars, each with a dimension of 2.5 cm by 2.5 cm in cross section and 30 cm in length. Each layer has 48 BGO bars parallelly arranged in an area of 60 cm × 60 cm. The orientation of the bars in one layer is perpendicular to that of its neighboring layers. The shower axis can be reconstructed using the energy deposit in each crystal that offers three dimensional information of the shower development. The thickness of the calorimeter corresponds to more than 26 radiation length and 1.3 interaction length. This means the electron-magnetic showers induced by incident high energy electron, positron and gamma could develop well.
The three plastic scintillator hodoscopes, each having two layers perpendicular to each other, are at a distance of 9 cm sequentially.

As expected, there is a large difference in shower profile between electron/positron/gamma and proton. As we find no difference in the shower profile between gamma and electron/positron induced events as shown later, we compare proton with electron only for proton background reduction. Using the same definition of the r.m.s value as that of ATIC, we can see the difference in shower development of the upper two types of particles. Fig. 3 plots the r.m.s value versus the energy deposit fraction for the 12th BGO layer in three different energy ranges respectively. Here r.m.s is defined as:

\[
(r.m.s.)^2 = \frac{\sum_{i=1}^{n} E_i (x_i - x_c)^2}{\sum_{i=1}^{n} E_i}
\]

while the energy deposit fraction is the energy deposited in a specific BGO layer divided by the total energy deposited in all layers. \(X_c\) is the location of the center of energy for a specific layer determined by the crystal with the maximum energy deposit plus the crystal on either side of this one. \(X_i\) is the coordinate of the center of crystal \(i\) and \(E_i\) is the energy deposited in the \(i^{th}\) crystal. The sum is done
Figure 3: Energy deposited fraction versus the r.m.s. value for both electrons and protons in three energy deposit ranges: 200GeV-250GeV, 400GeV-450GeV and 600GeV-650GeV in layer 12, i.e., the bottom layer.

Table 1: Relation between rejection power and BGO thickness

<table>
<thead>
<tr>
<th>BGO Thickness (×2.5cm)</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton Rejection Power (×10^5)</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>10</td>
<td>15</td>
</tr>
</tbody>
</table>

over all of the crystals in a specific layer of the BGO array. From the plots it can be seen that electrons and protons can be separated well with a curved line cut in between the two areas.

The total rejection power is listed in Table 1 for different BGO depths under the condition that the electron detection efficiency is above 95%.

The simulation shows that the electron showers are much narrower at the top of the BGO array that those of protons. Going deeper in to the BGO crystals, the two types of distribution overlap. But the electron showers almost finish in the lower layers of the crystals and starting from layer 7, the two types of distribution separate again into two groups.

In order to separate electron and proton in a relatively simple method, we define a new parameter F-value, which is the product of energy fraction and r.m.s squared for a specific layer. Fig. 5 shows the F-value distribution for electron and proton in 4 energy bins for layer 12. A cut value of

Figure 4: Comparison of the shower profile between electrons and gamma rays. The energy deposit range is from 200GeV to 250GeV and the layer selected is 12.
10 in layer 12 will eliminate 99.9% of protons while retain 74.5% electrons.

We find in the simulation that there is almost no difference in the showers induced by electron/positron and gamma-ray respectively. Plotted in Fig. 4 is superimposed distribution of the r.m.s. value of gamma(solid line) and electron(dotted line). The energy deposit range for the plot is selected to be between 200GeV and 250GeV while the layer number is 12. The two distributions overlap almost completely. Other energy ranges and layers have similar behavior.

The separation between electron/positron and gamma ray is accomplished by the top hodoscopes. In fact, the hodoscopes are used as an anticoincidence system. Due to the fact that backscattering from the shower in the BGO calorimeter is almost isotropic, we can choose several strips around the incident trajectory for the anticoincidence. All those events with no signal in these strips are regarded as gamma ray events.

4 Conclusions and discussions

In the analysis, we always treat events with the same energy deposit range in the BGO crystals for electron/positron/gamma and proton. But averagely, an electron deposits more than 98% of the energy while a proton leave only about 41% of its incident energy. This means only those proton with higher energy would be taken into consideration in the analysis for a certain energy range for electron. The power law shape of the proton energy spectrum tells us that this will introduce much fewer background for each energy range.

Our simulation results show that the preliminary design of TANSUO detector for high energy cosmic electron/positron and gamma ray measurement has a proton background pollution better than one thousandth and is suitable for such a mission in principle.

This work was funded by the National Natural Science Foundation of China (NSFC) under Nos. 10925315, 10573039, 10920101070 and 10878006. It was also supported by CAS under contract No. KJCX-YW-T16 and Ministry of Science and Technology under No. 2010CB833002.

References