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# Evaluation of particle acceptance for space particle telescope*

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**Abstract:** The particle acceptance instead of the $G$-factors has been introduced for a particle telescope. The particle acceptance of a telescope module TEST is simulated by using the GEANT4 Monte-Carlo package. The results are presented and explained.

**Key words:** particle acceptance, space particle identification, telescope system, Monte-Carlo

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## 1 Introduction

In space particle exploration, the mission of the particle telescope is to determine the fluxes of various particles with different energies. In the community of space science people introduced the field of view(FOV) to describe the acceptability of an optical telescope for light (photons) and a geometry factor $G$ to measure quantitatively its acceptability. People evaluate the $G$-factor only according to the geometry of the telescope and obtain the analytic formula for some of the simple telescopes. A few explicit formulations for the geometrical factor are known in references [1–6]. Here people evaluate the $G$-factor under the assumption that a ray is covered in the FOV of the telescope, the ray will surely be accepted. The situation is very different for the particle telescope. A particle telescope must be able to identify particles and bin their energies. The general particle telescope is a system which consists of various particle detector elements and their signal's readout and processors. The detector elements perform the energy measurements while a given particle passes through or stops at the element. The telescope is able to read out the energy deposits in one or several elements, $\Delta E$ and total energy $E$ summing up all detector elements. From the $\Delta E$ and $E$ data the particle with energy $E$ can be identified and the counts of a sample of the identified particle with a measured energy will be determined in a defined time interval and space region. Even if a particle falls into the FOV of a particle telescope, it might not be recorded. So the $G$-factor would not be proper to describe an acceptability of the particle telescope. We suggest that a term of "particle acceptance", commonly used in the community of high energy physics, replaces the "$G$-factor" for the particle telescope here. The flux of the identified particle with the energies $E$ will be calculated from the following formula:

$$\begin{aligned} F_i(\mathrm{cm}^{-2}\cdot\mathrm{s}^{-1}\cdot\mathrm{sr}^{-1}) &= C_i(\mathrm{s}^{-1})/A_i(\mathrm{cm}^2\cdot\mathrm{sr}),\\ A_i(\mathrm{cm}^2\cdot\mathrm{sr}) &= G(\mathrm{cm}^2\cdot\mathrm{sr})\eta_i, \end{aligned} \tag{1}$$

where $G[\mathrm{cm}^2\cdot\mathrm{sr}]$ is the geometry factor which is defined by Eq. (2) for the detector element in the front of the telescope. $\eta_i$ is the efficiency with which the $i$-th particles are identified from the incident particles that incident into the front element of the telescope from upside. $A_i[\mathrm{cm}^2\cdot\mathrm{sr}]$ is named as particle acceptance of the telescope to $i$-th particle. $C_i(\mathrm{s}^{-1})$ is the counting rate of the $i$-th particle reconstructed from the telescope.

For an ideal front circular detector element (see Fig. 1), the geometry factor could be easily calculated

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from Eq. (2) as

$$G=\int_{\Omega}\int_{s}\mathrm{d}\omega\cdot\mathrm{d}s, \qquad (2)$$

where $\Omega$, the domain of $\omega$, is a full hemisphere (particle incident from the upside of the detector). $S$ is the area of the detector. The geometry factor is $\pi$ times the area of the detector.

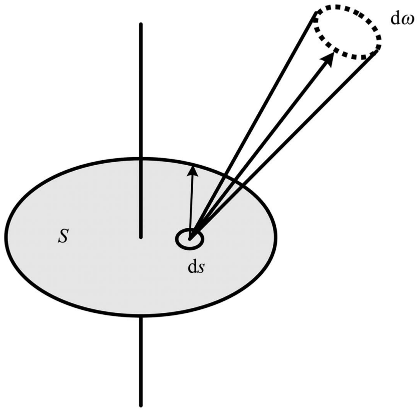


Fig. 1. A single circular detector.

From the geometry to the particle acceptance for a telescope the efficiency $\eta_i$ must be evaluated. Because $\eta_i$ not only depends on the possibility of particle's hitting the detector elements, but also depends on the capability of particle identification which is determined by the $\Delta E$ and $E$ responses of detector elements, readout electronic threshold sets and particle selection logics. There is no analytic formula to calculate the $\eta_i$. There are two ways to evaluate the $\eta_i$: The ideal but impracticable way is to calibrate the efficiencies of the telescope using the $i$-th particle beams with various energies and all the incident directions subtended by the telescope. The other way is to use the Monte-Carlo simulation which traces the $i$-th particle of a given energy hitting the front detector element from the sky and records the energy deposits in the detector elements which the particle passes through or stops on. Based on the energy deposit data and the electronic threshold sets, it's possible to do the justification that the tracing particle is recorded by the telescope or not. With this approach, the acceptance efficiency $\eta_i$ of the telescope for identified particles in a given energy range can be derived with good precision.

## 2 Design and simulation of TEST model

TEST, the model we designed as shown in Fig. 2, is a telescope composed of 3 silicon detectors and a YAP scintillator. The telescope detects protons (2.3–100 MeV) in five energy bins and also alpha particles (9–120 MeV) in 4 bins. The first plane D1, with 50 μm thick 28.3 mm$^2$ sensitive area, is a $\Delta E$ detector. D2 is a 500 μm thick 7 mm$^2$ active area as $\Delta E$ or $E$ detector. The YAP crystal is a calorimeter with 20 mm×20 mm×20 mm. The last plane, D4, is

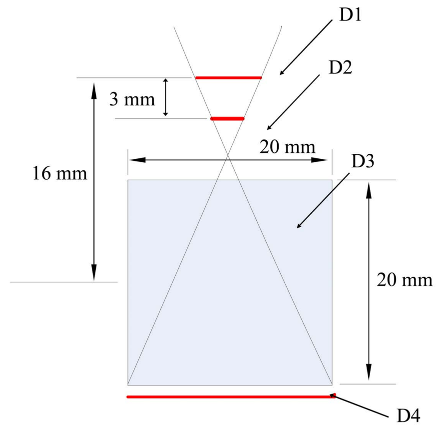


Fig. 2. The TEST model.

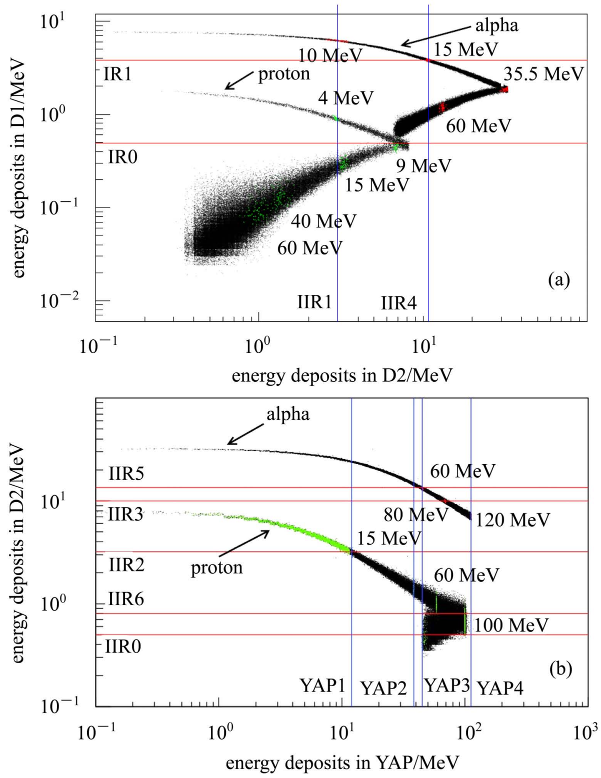


Fig. 3. Energy deposits in (a) D1(D2) and (b) D2(YAP) for various primary kinetic energies of proton and alpha, The number of MeV near by a group of scatter points indicates the primary kinetic energy of particles. The lines perpendicular to the axes of coordinate indicate the threshold values of D1(D2) and D2(YAP).

an anti-coincidence detector. Fig. 3(a) shows the simulated energy deposits in both D1 and D2, for normally-incident protons and alpha particles using the Monte-Carlo package GEANT4 [7]. As the kinetic energy (>2.3 MeV for protons and >9 MeV for alpha particles) of incident particles increases, the energy deposits in D1 decrease. but D2 is opposite, it increases with the incident particles' kinetic energy until they penetrate D2 – the "inflexion point" position for protons and alpha particles are about 8.7 MeV and 35.5 MeV respectively. Fig. 3(b) shows the incident particles, penetrating D1 and D2, deposit energy in D2 and calorimeter. Like Fig. 3(a), the inflexion point appears when incident particles penetrate calorimeter(>100 MeV for protons and >400 MeV for alpha particles).

In order to differentiate protons from alpha particles, some threshold levels of D1, D2, D3 and YAP in Table 1 could be configured for telescope FEE. According to the lines dividing the plots in Fig. 3, Table 2 shows the selection logics associated with each of the energy bins and the channel designations. For example, if a charged particle deposit energy is over IR0 and under IR1 threshold in D1, while it deposits the energy amount in D2 under IIR1 (logic P1 fulfills), then it could be determined as a proton, and its kinetic energy belongs to 2.3–4.0 MeV energy bin.

Table 1. The telescope threshold and corresponding deposit energy.

| detectors | items of threshold | values of threshold/MeV |
|---|---|---|
| D1 | IR0 | 0.49 |
| D1 | IR1 | 3.8 |
| D2 | IIR0 | 0.5 |
| D2 | IIR1 | 3.0 |
| D2 | IIR2 | 3.2 |
| D2 | IIR3 | 10.0 |
| D2 | IIR4 | 10.8 |
| D2 | IIR5 | 13.5 |
| D2 | IIR6 | 0.8 |
| YAP | YAP0 | 0.3 |
| YAP | YAP1 | 12.0 |
| YAP | YAP2 | 38.5 |
| YAP | YAP3 | 45.0 |
| YAP | YAP4 | 112.0 |
| D3 | IIF0 | 0.03 |

Table 2. The telescope energy bin logic.

| channel | particle | energy/MeV | logic |
|---|---|---|---|
| P1 | proton | 2.3–4.0 | $\mathrm{IR0}\cdot\overline{\mathrm{IR1}}\cdot\overline{\mathrm{IIR1}}$ |
| P2 | proton | 4.0–9.0 | $\mathrm{IR0}\cdot\overline{\mathrm{IR1}}\cdot\mathrm{IIR1}\cdot\overline{\mathrm{IIR4}}\cdot\overline{\mathrm{YAP0}}$ |
| P3 | proton | 9.0–15.0 | $\overline{\mathrm{IR0}}\cdot\mathrm{IIR2}\cdot\overline{\mathrm{IIR3}}\cdot\overline{\mathrm{YAP1}}$ |
| P4 | proton | 15.0–40.0 | $\overline{\mathrm{IR0}}\cdot\mathrm{IIR0}\cdot\overline{\mathrm{IIR2}}\cdot\mathrm{YAP1}\cdot\overline{\mathrm{YAP2}}$ |
| P5 | proton | 40.0-100.0 | $\overline{\mathrm{IR0}}\cdot\mathrm{IIR0}\cdot\overline{\mathrm{IIR2}}\cdot\mathrm{YAP2}\cdot\overline{\mathrm{YAP4}}\cdot\overline{\mathrm{IIF0}}$ |
| A1 | alpha | 9.0–15.0 | $\mathrm{IR0}\cdot\mathrm{IR1}\cdot\overline{\mathrm{IIR1}}$ |
| A2 | alpha | 15–35.5 | $\mathrm{IR0}\cdot\overline{\mathrm{IR1}}\cdot\mathrm{IIR4}\cdot\overline{\mathrm{YAP0}}$ |
| A3 | alpha | 35.5–60.0 | $\mathrm{IR0}\cdot\overline{\mathrm{IR1}}\cdot\mathrm{IIR5}\cdot\mathrm{YAP0}\cdot\overline{\mathrm{YAP3}}$ |
| A4 | alpha | 60.0–120.0 | $\mathrm{IR0}\cdot\overline{\mathrm{IR1}}\cdot\mathrm{IIR2}\cdot\overline{\mathrm{IIR5}}\cdot\mathrm{YAP3}\cdot\overline{\mathrm{YAP4}}\cdot\overline{\mathrm{IIF0}}$ |

## 3 Result

Here we use the GEANT4 package [7] to evaluate the particle acceptances of the TEST telescope for protons and alpha particles in the energy bins indicated.

1) Define a circular proton or alpha particle source which clings to the upper side of D1 and generates random direction events through the TEST telescope. The events of $n_{\mathrm{g}}(j)$ for protons (alpha particles) with $E_j$ are generated.

2) Follow each event's track, read out the energy deposits in detector elements D's and check the logics P's (A's) if it is fulfilling, then add one count to the $n_i(j)$ register for proton (alpha particles) of $E_j$. The total numbers $n_i(j)$ are accumulated according to the statistical precision requirements.

3) The particle acceptance for the telescope is:

$$\begin{aligned} A_i &= \eta_i G, \\ \eta_i(E_j) &= \frac{n_i(E_j)}{n_{\mathrm{g}}(E_j)} \quad i=\text{proton, alpha}, \\ G &= \pi S_{\mathrm{D_1}}, \end{aligned} \tag{3}$$

where $S_{\mathrm{D_1}}$ is the area of particle source, here we set it the same as the sensitive area of D1.

The final results are given in Fig. 4(a) and Fig. 5. The particle acceptance is not a constant for the TEST telescope. Particle acceptances of P1 and A1 are a little larger than other logic bins. Because the particles in this kinetic energy bin could not penetrate D2, so D1 and D2 are a complete $\Delta E$-$E$ telescope.

The acceptance is evaluated by D1 and D2 only. For each energy bin the acceptance shows a “mountain shape” distribution that is due to the energy deposits in a detector element which have a distribution like the Gassian or Landau shape (Fig. 4(b)). We set the IIR1 threshold 3 MeV for D2, for example, most 4 MeV protons energy losses in D2 are under IIR1. That means 4 MeV protons have more possibility accepted by the P1 channel than the P2 channel and in P2 the situation is reversed. The acceptance of P1 at 4 MeV does drop less than that of P2 drops. Also some of the protons with energies more than 4 MeV will fulfill the P1 logic and mix into P1 channel and some of the protons with energies lower than 4 MeV will mix into the P2 channel. Adjust the IIR1's value properly and the distribution curves of acceptance at 4 MeV could be optimized. The same argument for the bound at 9 MeV: the threshold IR0 is the key set affecting the event loss and mix up between P2 and P3. Protons with energies more than 9 MeV will pass through the D2 detector, the YAP detector signal must be involved in P3, P4 and P5 logics.

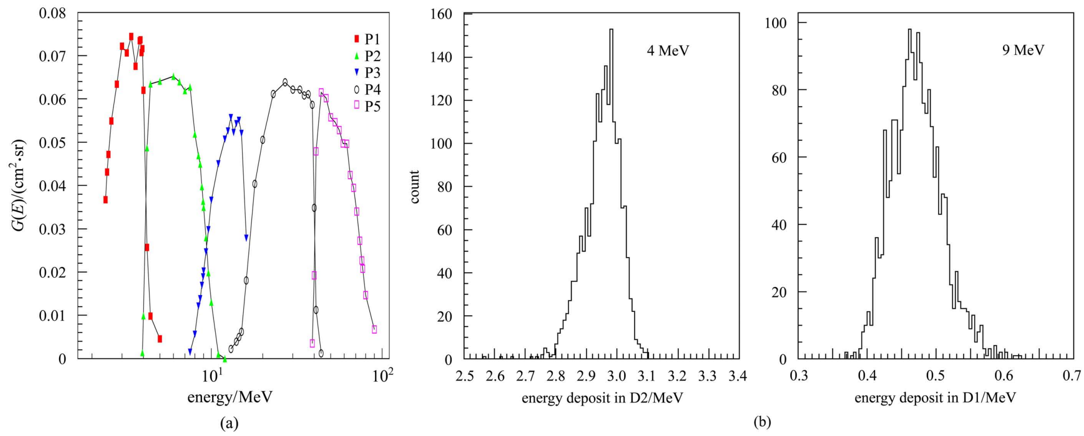


Fig. 4. The particle acceptance of proton for TEST (a) and energy distribution in element of TEST (b).

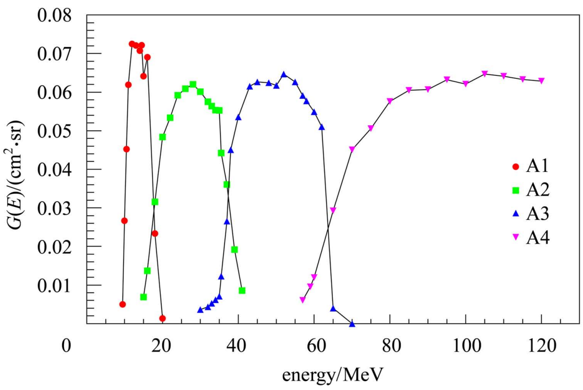


Fig. 5. The particle acceptance of alpha for TEST telescope.

## 4 Conclusion

The particle acceptance is a key parameter of the space particle telescope. There is no analytic formula to evaluate it properly. The TEST telescope presented here shows that the Monte Carlo simulation is a powerful tool for evaluating the particle acceptance of the particle telescope. According to the data output from the simulation the thresholds calibrated of FEE can be properly adjusted and particle selection logics can be well optimized. The full simulation, in which the instrumentation effects are taken into account and the results are selectively tested using a sample of particle beams, is able to reliably evaluate the particle acceptance of particle telescopes.

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