Progress of the HERD detector

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Abstract. The High Energy cosmic Radiation Detection facility, HERD, is proposed for the observation of high-energy electrons, gamma-rays and cosmic-rays onboard China’s Space Station. The HERD has a capability to observe the electrons (without separation between $e^+$ and $e^-$) and gamma-rays in 10 GeV-100 TeV and the cosmic-rays in 100 GeV-1000 TeV with high energy resolution. The HERD is advantageous in terms of energy resolution, geometrical factor and energy detection range.

1. Introduction
Dark matter is one of the most important mysteries of physics today. Accounting for over a quarter of the universe’s mass-energy balance, it can be observed indirectly through its interaction with the visible matter but has yet not to be detected. Cosmic ray discovered in 1912, their sources and propagation mechanisms are still subject of intense research. The all-particle energy spectrum of cosmic rays around PeV range the so-called knee is observed, but experimental data in the knee region contradict each other.

The HERD mission onboard China’s Space Station is planned for operation starting around 2020. It is designed for observing very high energy electrons [1] [2] and gamma rays [3] as well as protons and heavy nuclei. The objective of the HERD mission is to explore a new frontier at the higher energies for the origin of cosmic-rays (CR), the propagation of CR and to search for dark matters [4] [5]. We will measure electrons and gammarays from 10 GeV to 100 TeV, with an excellent energy resolution. At the same time we will measure protons and heavy nuclei from 100 GeV to 1000 TeV.

2. HERD instrument
A schematic configuration of the HERD detector is presented in Fig. 1. The HERD detector consists of two main parts: the micro silicon strip tracker, five sides covered of the instrument, for incident particle trajectory and nucleon charge measurement; the LYSO cubic homogeneous electromagnetic calorimeter, for the incident gamma and electron energy measurement;

The micro silicon strip tracker consists of a top part and 4 side parts. The top tracker as presented in Fig. 2, is constituted of silicon strips and thin tungsten foils, the latter act as converter for gamma-rays. There are seven tracking plane of x-y layers of silicon strips, each with the dimension of 100 cm x 100 cm, and five converter layers of tungsten interspersed into layer 2-6, with thickness $3 \times 1 \text{ mm} + 2 \times 2 \text{ mm} = 2 \text{ X0}$. The first layer of silicon determines if the incident particle is a gamma or a charged particle. The top tracker provides charge identification, trajectory measurement, back scatter rejection.
and some early shower development of gamma and electron. The other four sides are covered with silicon strip detector the same as the top one, only with the dimension of 100 cm × 70 cm, each side with three layers without tungsten foils interspersed, for chemical composition of the primary cosmic ray and the trajectory measurement.

![Fig.1. Schematic of HERD detector](image1)

The calorimeter is made of 9261 LYSO scintillator, the side length of cubic LYSO cell is 3cm. It is a 3D imaging calorimeter, used to measure the development of particle shower. The homogeneous calorimeter detect not only the electromagnetic shower induced by electron and gamma-rays but also the hadronic shower induced by cosmic ray nuclei.

The scintillation light of crystals is absorbed by a 300 um diameter wavelength shifting(WLS) fiber that is attached to the surface of the scintillator with a spiral structure. There are totally 20 thousand readout channels, all the fiber ends are bundled in one compact bunch, which has a size of only a couple of centimeters. The fibers at the end of the bundle can be glued together and polished making a "fiber optic plate"-like structure. The fiber bundle is coupled to the input-window of image intensifier. The shower development profile of the event in the detector is translated into the surface of the fiber optic plate (FOP). This image on the FOP can be photographed by using an externally triggered ICCD.

![Fig.2. Structure of the top tracker](image2)
3. **Simulation study on performance**

The performance of the HERD is studied by simulations with the use of GEANT4 and FLUKA. As shown in Fig. 3., the energy resolution of electromagnetic shower with the consideration of only energy deposition in crystals is about 0.1\% at 200GeV. If assume per minimum ionization particle produce 10 photoelectrons, the resolution increase to about 0.5\%. Take into account other influence, the energy resolution for electron and gamma would be better than 1\%. For cosmic ray nuclei, the energy resolution is around 20\% between hundreds of GeV to PeV. Since the electromagnetic shower development is different from the hadronic shower in energy distribution, calorimeter can be used to do particle identification of the electron and proton. Several variables are used in TMVA to do the particle identification. As shown in Fig.4., the background efficiency is about $5 \times 10^{-6}$ while maintain the electron identification around 90\%. Because the calorimeter is a homogenous detector, it can accept particle from five sides, the effective geometrical factor for electron and proton are larger than 3.7 m$^2$sr@200GeV and 2.6 m$^2$sr@100TeV, respectively. This is one of the foremost advantages of HERD compare with other missions.

![Fig.3. Energy resolution of calorimeter](image)

![Fig.4. Particle identification of calorimeter](image)

4. **Cosmic ray test of prototype**

A calorimeter prototype is constructed to verify the readout method of ICCD. Twenty four CsI(Na) crystals with the side length of 3 cm are used to constructed a $2 \times 2 \times 4$ vertex. The 24 WLS fibers are
attached to an image intensifier and then coupled to a commercial ICCD to readout the fiber signal. The ICCD is trigged by the coincidence of two plastic scintillators. The distribution of typical passing through muon event is shown in Fig.5. When a cosmic muon pass through six crystals, the output of the fiber signal will be received by ICCD. The energy resolution of cosmic muons deposited in six crystals is 14% @84MeV, this is satisfied to the requirement of HERD.

![Fig.5. Distribution of a typical passing through muon event](image)

5. Summary
The HERD mission will perform observations of very high energy electrons, gamma-rays and cosmic ray. Monte Carlo simulation results show it will be a powerful space detector in energy resolution, effective geometrical factor and particle identification. The cosmic ray test of prototype verify the feasibility of the ICCD readout.

Reference
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