PROCEEDINGS OF SCIENCE

The HERD experiment: new frontiers in detection of high energy cosmic rays

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The HERD (High Energy cosmic-Radiation Detector) experiment is a future space based experiment for the direct detection of high energy cosmic rays. It will be installed on the Chinese space station in 2027. The detector is based on a homogeneous, isotropic, deep and 3D segmented calorimeter, surrounded by multiple sub-detectors for charge, timing and track measurement. Thanks to its innovative geometry, the detector will be capable to detect particles from all directions having a large geometric acceptance. Together with a good energy resolution, this will provide the detector an effective geometric factor about one order of magnitude larger than that of current space experiments for protons and electrons detection. Thanks to this feature, the HERD experiment will measure cosmic ray proton flux up to 1 PeV, performing the first direct measurement of the cosmic ray knee region. In addition HERD will measure electron+positron flux up to tens of TeV, and will search for possible indirect signals of dark matter and local sources of electrons and positrons. These energy limits, for protons and electrons, will be more than one order of magnitude higher than that of the current space experiments. Moreover, measuring high energy photons, HERD will search for sources of high energy cosmic rays and for indirect signals of dark matter.

XVIII International Conference on Topics in Astroparticle and Underground Physics (TAUP2023)
28.08–01.09.2023
University of Vienna

[*] Speaker

PoS(TAUP2023)142

1. Introduction

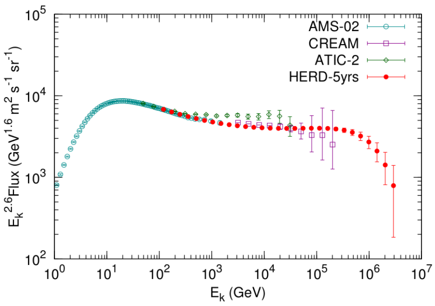
Since the cosmic ray differential flux depends from the energy as $E^{-\gamma}$, with the spectral index γ that varies between $\simeq 2.6$ and $\simeq 3.3$, direct detection of high energy cosmic rays is limited by the small mass affordable (and also geometrical dimensions) for space experiments. Examples of in orbit experiments for high energy cosmic rays direct detection are: AMS [1], CALET [2] and DAMPE [3]. The first one is a magnetic spectrometer, while the other two are calorimetric experiments. All the three experiments can accept only particles entering the detector from one single face, and their effective geometric factors (geometric acceptance multiplied for the detection efficiency) are of the order of 0.2-0.3 m^2sr for both electron and proton detection.
In this context the innovative HERD experiment [4] [5], that will be installed on the Chinese Space Station in 2027, is designed in order to extend the direct detection of high energy cosmic rays to energies more than a order of magnitude bigger compared to the current experiments. In this proceeding we will show the main scientific objectives of the HERD experiment, and we will illustrate the most important characteristic of the detector.

2. Scientific Objectives

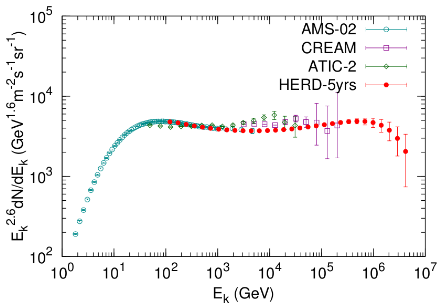
The HERD experiment will extend the protons and nuclei flux up to the PeV/nucleon energy region, the electrons+positrons flux up to tens of TeV, and will also detect gamma rays and perform gamma-ray astronomy. In the following paragraph we analyze the objectives distinguished for particle type.

2.1 Protons and nuclei

Herd will extend measurements of protons and nuclei fluxes up to PeV/nucleon energy, thus it will detect for the first time directly the proton and helium cosmic ray knee. In Figure 1 we show the prediction for HERD five year measurement of proton and Helium fluxes As we can see in the figure, HERD will be capable to detect directly the knee of this two particles, providing new information about the structure of this spectral feature.



(a)



(b)

Figure 1: (a) Projection of HERD five years measurement of proton flux. (b) Projection of HERD five years measurement of Helium flux. [5]

HERD will measure also fluxes of other nuclei up to Iron and beyond, measuring ratios between different species (like the Boron-Carbon ratio) to study the propagation mechanism of cosmic rays and confirming the presence of hardening and softening in the nuclei spectra, as these structures have already been observed in Proton and Helium spectra, and finally searching for new possible spectral features.

2.2 Electrons and positrons

For what concern electrons+positrons flux, HERD will extend its measurement up to tens of TeV, in order to look for possible local sources. Indeed we expect that if we detect electrons or positrons at tens of TeV, they should be accelerated by local sources (not more distant than few kpc from the earth), otherwise due to the continuous energy loss processes they won't reach the earth. If this kind of local sources exists we expect some structures in the electrons+positrons flux in the multi-TeV energy region, like that shown in Figure 2 if the SNR Cygnus loop can accelerate at high energies these leptons. In addition, since these source should be local, we expect a correlation of the structure in the flux with a certain degree of anisotropy, because the particles don't have time to be made isotropic by the galactic magnetic field, before being detected. In addition, HERD will

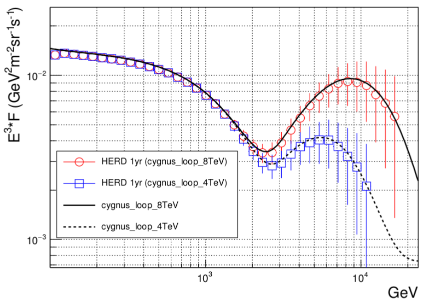


Figure 2: Projection of the HERD measurement of electrons+positron flux if the SNR Cygnus loop can accelerate high energy electrons and positrons. Two curves are presents because two different energy cut-offs in the source are considered.[5]

search for possible indirect signals of Dark Matter, indeed we expect that if DM particles decaying produce high energy electrons, this will led to some structures in the high energy electrons flux [6], in this case without any significant anisotropy [7].

2.3 Gamma rays

HERD will look for possible indirect signals of Dark Matter also detecting photons, indeed if particle-antiparticle couples of DM annihilate in gamma-ray couples, this could produce some structures in high energy gamma-ray flux. Moreover HERD will be a gamma-ray observatory for multi-messenger astronomy, will search for cosmic rays acceleration sources and investigate the diffuse gamma ray emission.

3. The HERD detector

In this section we show how HERD will be capable to perform the measurements introduced in the previous section. In Figure 3 we show a schematic picture of the detector. The hearth of the

payload is the calorimeter for the energy measurement and the electron-hadron discrimination. It has an innovative geometry, indeed it is composed by about 7500 LYSO cubic scintillating crystals, assembled to form a spheroidal calorimeter. In this way its response is basically the same for particle entering from every direction. This type of calorimeter was designed and studied for the first time by the CaloCube collaboration, which has demonstrated the very large geometric acceptance that can be achieved with this type of space calorimeter [8] [9]. The calorimeter is surrounded by multiple subdetectors on five faces, the only one missed is the face connected to the space station. Thanks to this new geometry the HERD detector is capable to detect particles entering from five faces, keeping the weight constant but enlarging the geometric acceptance respect to the typical geometry of currently in orbit experiments that accept particles entering only from one face. Indeed HERD will have an effective geometric factor for electrons and protons detection of about 2.4 m^2sr and 1 m^2sr respectively, respect to the 0.2-0.3 m^2sr of the currently in orbit experiments.
We will now show the most important features of every detector. The calorimeter, as already

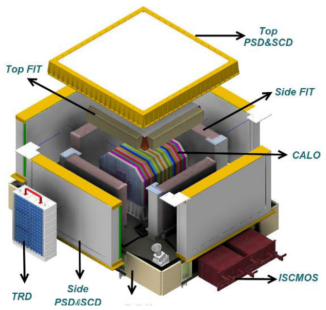


Figure 3: Schematic picture of the HERD detector [10].

said before, is composed by about 7500 cubic scintillating LYSO crystals of side 3 cm. It is homogeneous, isotropic, 3D segmented, deep (about 55 *radiation length* and 3 *hadronic interaction length*), with a very large geometric factor and a good energy resolution (about 2.5% for electrons and less than 30% for protons). The calorimeter has a double read-out, indeed the scintillation light produced by every crystal is detected by two independent systems: one based on the use of WaveLength Shifting Fibers coupled to Intensified Scientific CMOS (WLSF system) [11], and one based on the use of two photodiodes with different active areas (PD system) [12] [13] [14]. Both read-out systems should have an incredibly high dynamic range: bigger than 10^7, in order to acquire signal from the *minimum ionizing particle* for in-orbit calibration, up to 250 TeV, necessary in order to measure showers induced by PeV protons. Using two independent read-out systems will be very useful in order to have a strong control of energy scale (one of the main issues in space calorimeters), independent triggers and redundancy.
The nearest subdetector to the calorimeter is the Fiber Tracker (FIT) [15] for particle tracking and low energy gamma-ray detection. The FIT will be composed by plastic scintillating fibers read-out by SiPMs. Going to the outer layers we find the Plastic Scintillator Detector (PSD) [16] [17], for anticoincidence system and charge measurement (up to Iron and beyond). It is constituted by plastic scintillator bars read-out by SiPMs. Finally, the outermost detector is the Silicon Charge Detector (SCD) [18] for charge measurement up to Iron and beyond, and tracking. SCD is constituted by silicon strip detectors and it is placed as the outermost detector in order to perform the best

measurement of the charge minimizing the fragmentation of the incident nuclei.
In addition also a small Transition Radiation Detector (TRD) [19] [20]will be installed on a lateral face of the HERD detector. The TRD is based on a Thick-Gas Electron Multiplier, and will be used to tag protons around the 1 TeV energy, measuring their γ Lorentz factor, with which we can check the calorimeter calibration. This is an innovative idea that will let us to calibrate the calorimeter with such high energy protons that are not available in beam test facilities. Together with the double read-out system, this will give us a better control on energy scale, a very important feature since energy calibration is a very sensitive issue for space calorimeters.

4. Conclusions

In this proceeding we have shown the HERD detector with its innovative geometry, the use of new type of calorimeter 3D segmented, with spherical shape and with a double read-out system, and the use of a Transition Radiation Detector for in-orbit calibration with 1 TeV protons. Thanks to all these features HERD will increase of more than a order of magnitude the upper energy limit for cosmic rays direct detection, opening the opportunity to detect for the first time the cosmic rays knee for proton and helium with a space experiment, search for possible indirect signals of dark matter through the electron-positron flux measurements and the gamma-ray flux measurements, to search for possible local sources of high energy electrons and/or positrons, perform gamma ray astronomy. These are only the main opportunities that will be opened by HERD.
Currently we are in the finalization status of the detector development, we look forward to flight in 2027.

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