The High Energy cosmic-Radiation Detection facility: an innovative apparatus design for cosmic-ray measurement

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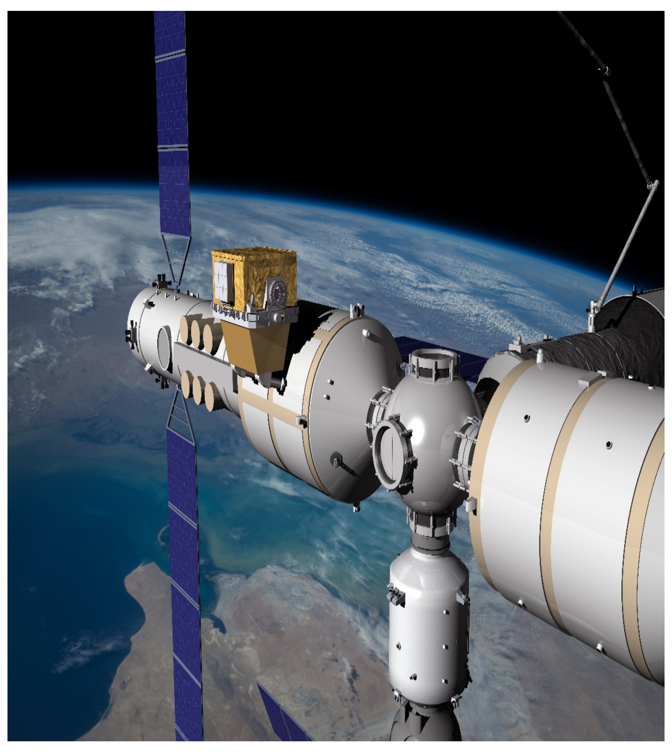
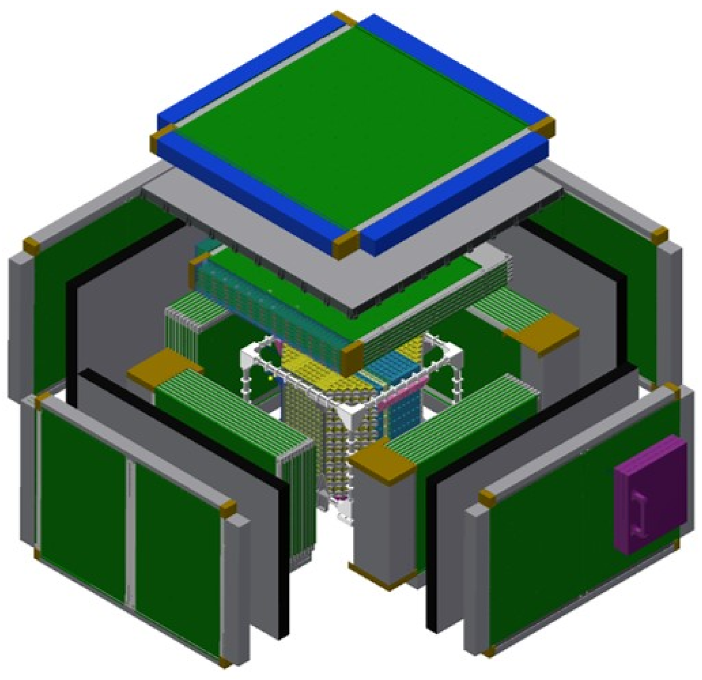


The HERD Experiment

- The High Energy cosmic-Radiation Detection (HERD) facility will be installed aboard the China's Space Station (CSS) around 2025, and it will extend the direct measurements on cosmic rays by one order of magnitude in energy. This will be possible thanks to an innovative design that was carefully optimized to overcome the limitations that affect the experiments currently operating in space. In this talk, the HERD instrument will be presented: it is based on a large, homogeneous and isotropic calorimeter made of LYSO crystals, optimized in order to have good energy resolution and large geometric factor. The calorimeter is surrounded by a subdetector system, fiber tracker, plastic scintillator and silicon microstrip from inside out with fine segmentation, to allow for good angular resolution, multiple charge measurements of incoming particles. The detector is complemented by a transition radiation detector used to calibrate the high-energy hadronic calorimeter response in a data-driven way

HERD design

HERD is composed of five scientific instruments. The primary instrument in the innermost is a deep 3-D imaging calorimeter (CALO) with an innovative design that insures better e/p separation for particles and one order of magnitude larger geometrical factor by accepting particles impinging on its top face but also on the four lateral faces. Each sensitive face of CALO is instrumented from inside out with a FIber Tracker (FIT), a Plastic Scintillation Detector (PSD) and a Silicon Charge Detector (SCD) to precisely identify charges of cosmic rays. A Transition Radiation Detector (TRD) is located on one lateral side for the energy calibration of TeV neuclei. The total mass of HERD payload is about 4 tons.



Once installed on top of CSS, HERD is expected to work continuously until the end of its lifetime. HERD is always pointed to zenith ascribed to the TEA attitude control system of CSS. The nominal and calibration operation mode are planned for HERD.

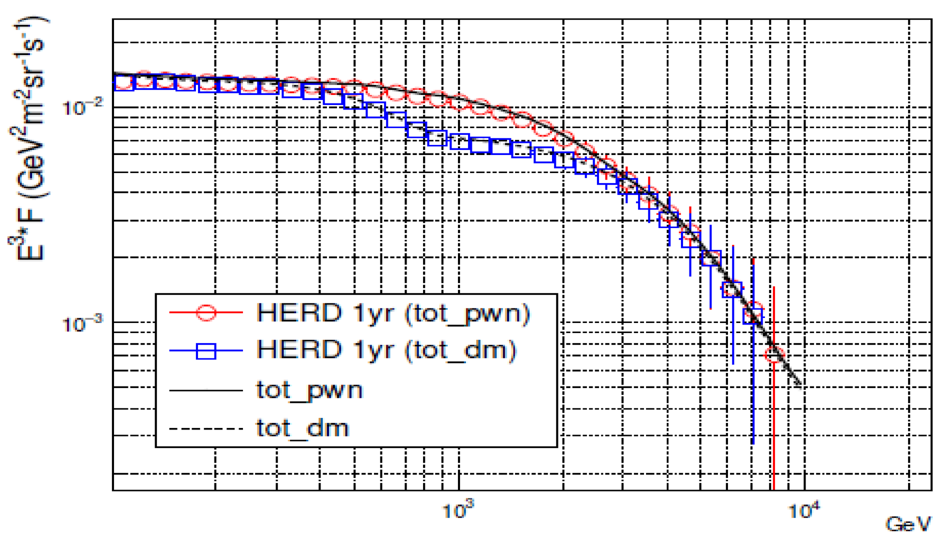
The estimated trigger rate is around 140 Hz in nominal working mode and around 350 Hz in calibration working mode.

Scientific goals

Dark matter and cosmic electrons spectrum

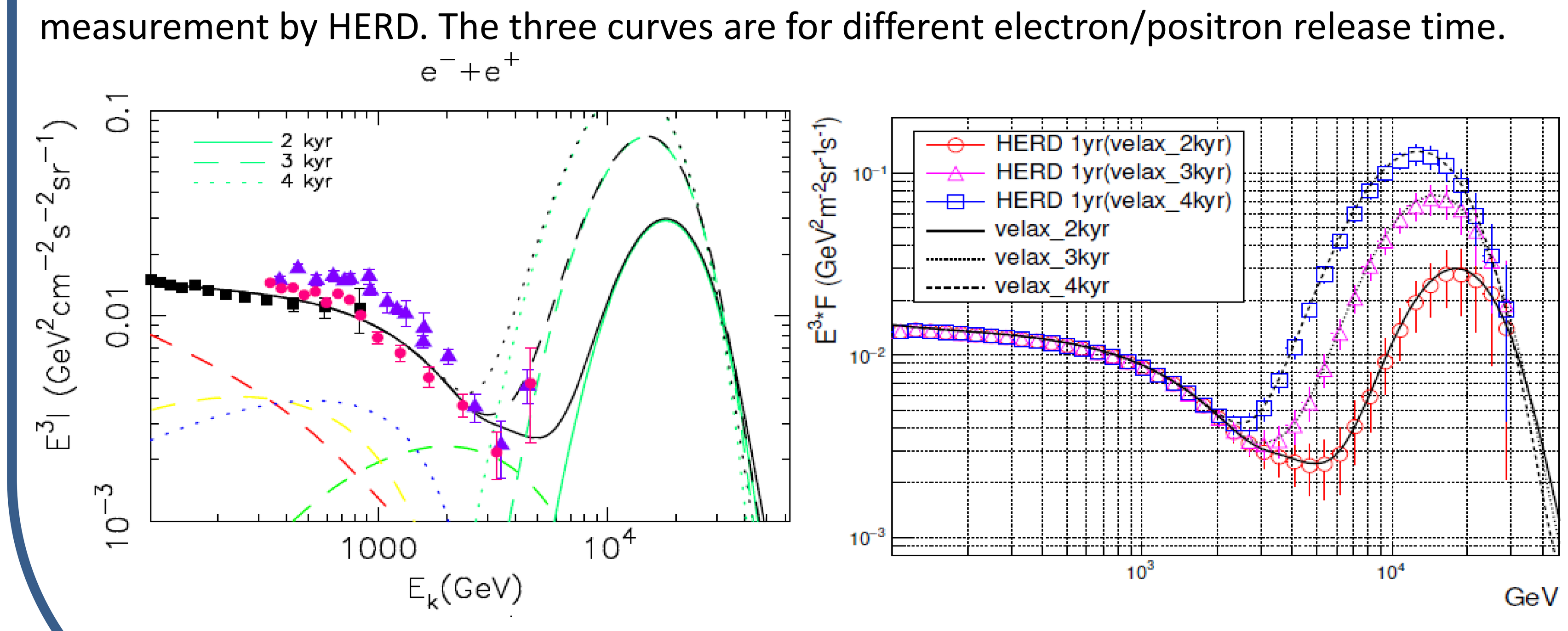
Search for signatures of the annihilation/decay products of dark matter particles (WIMP) in the energy spectra and anisotropy of high energy electrons from 10 GeV to 100 TeV and in the gamma-ray spectrum from 500 MeV to 100 TeV. The indirect detection searches for the DM annihilation or decay products in high energy cosmic-rays (CRs). The future observations of HERD will be able to detect the possible DM signals in high energy CR electrons/positrons and gamma-rays spectra.

The shape of the energy spectrum cutoff is different for the astrophysical source and DM annihilation. A possible way to distinguish the two kinds of shape at the cutoff is to measure the fine structure at the electron plus positron spectrum with a high precision instrument, like HERD.



Simulation of HERD capability to distinguish the total electron plus positron spectra in two different scenarios. With one year data accumulation HERD can clearly distinguish between a smooth spectrum (pulsar) or a spectrum with a 'kink' (DM).

The observed CR electrons above ~TeV are dominantly contributed by the sources located within ~1 kpc around the solar system, due to the small propagation distance of high energy electrons. Since the HERD experiment can measure the electron-positron spectrum up to ~10 TeV with high precision, the significant contribution from nearby astrophysical sources is expected to be detected with HERD. The nearby sources may have distinguishable feartures at the highest energy. Figures below shows possible spectrum feature at the CR electron-positron spectrum above TeV scale from the nearby source Vela X pulsar and the simulated measurement by HERD. The three curves are for different electron/positron release time.



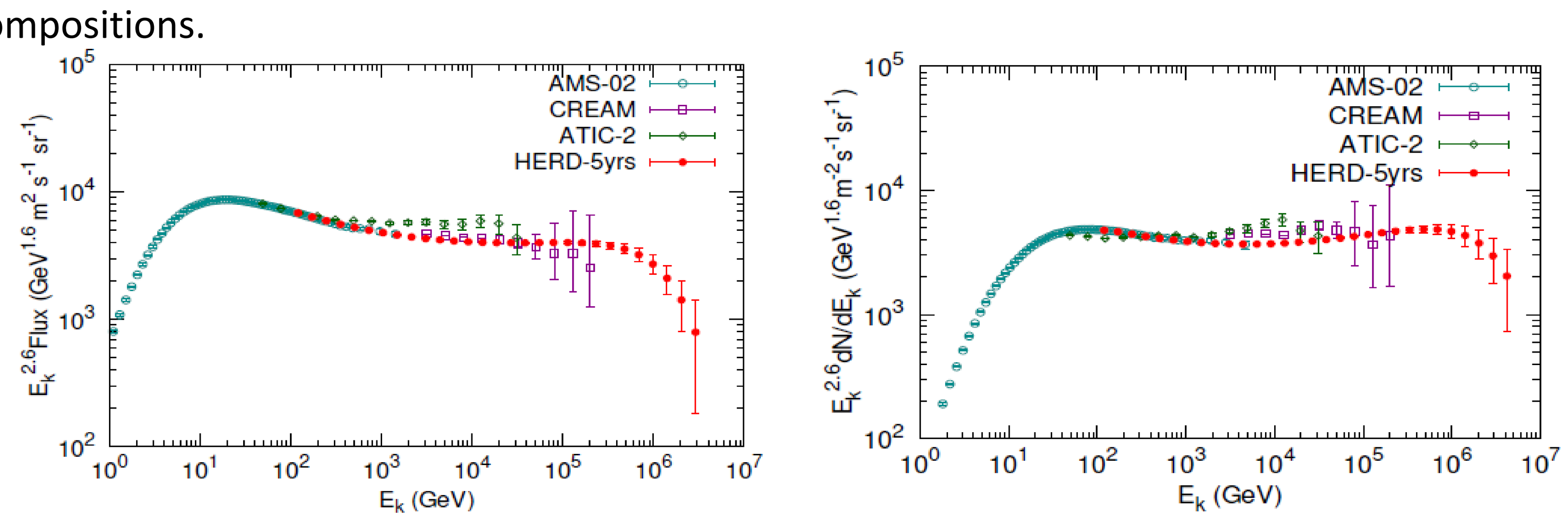
Scientific goals

Cosmic rays

It is mandatory to explore the sub-PeV region with high precision direct measurement in order to measure the various spectral indices, to detect any possible hardening and to set mass composition below the knee of the all-particle flux. If possible the detection of the steepening of each of these single species and then the explanation of the all-particle knee would be a crucial result in understanding Galactic CR physics, also serving as fundamental input to the study of the extra-galactic component.

The unique design of HERD will allow the extension of high precision measurements on proton and nuclei spectra up to very high energies, even beyond 1 PeV. Moreover a clear identification of each of the nuclear species will be possible. Energy resolution for the electromagnetic and hadronic showers will be at the 1% and 30% level, respectively.

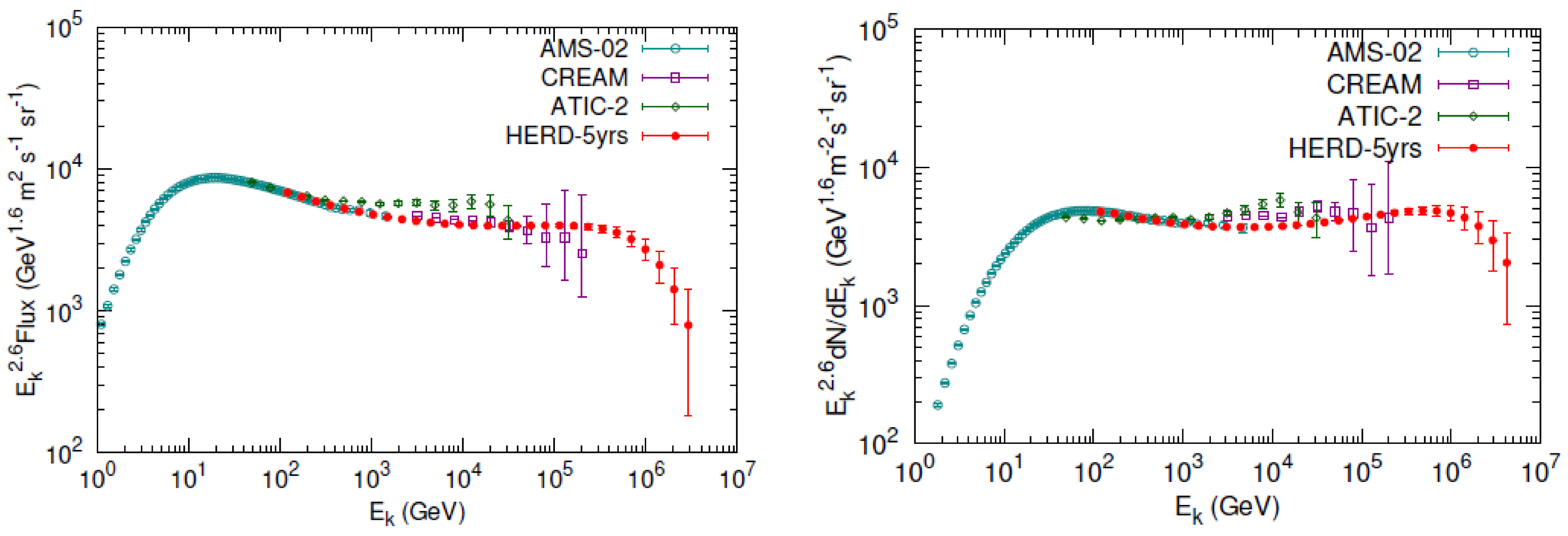
Figure below illustrates the simulated HERD measurements of the individual proton and Helium spectrum with a 5-yr exposure. The data can clearly reveal the knees of both nuclei, and can critically address the Z-dependence, A-dependence, or constant knee of different compositions.



The Boron-to-Carbon ratio (B/C) is important to probe the propagation of CRs. The previous measurement of the B/C ratio to ~ 1 TeV/n found that the energy-dependence of such a ratio follows a power-law of $E^{0.333}$. However, the data above ~ 300 GeV/n are subject to relatively large uncertainties. The HERD measurements will extend the precise B/C ratio to a few TeV/nucleon, and thus can precisely determine the propagation behavior of CRs.

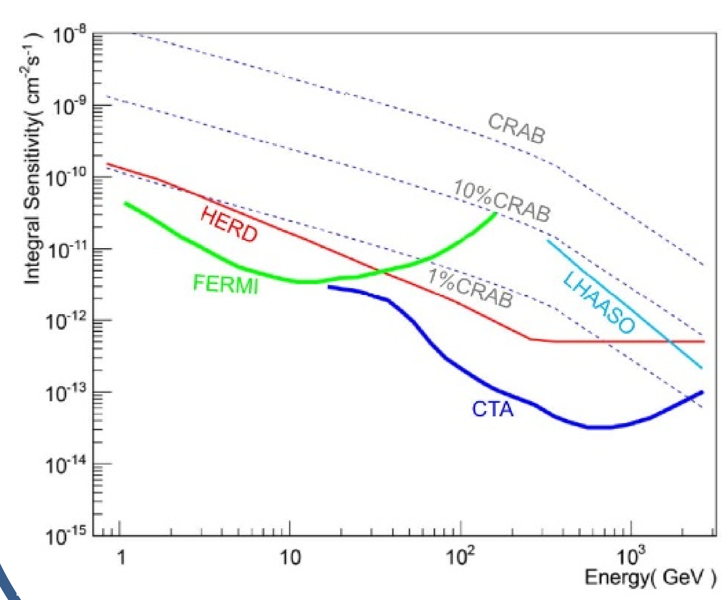
The Iron nuclei are the end products of stellar nucleosynthesis. Elements heavier than Iron typically need to be produced via the r-process of supernova explosions or neutron star mergers. The heavy nuclei in CRs are thus very good tracer of the acceleration sites of CRs. The current measurements of CR Iron nuclei are very limited, and the measurements of even heavier elements are typically lack. HERD is expected to significantly improve such measurements.

Figures present expected energy spectra of protons (left) and Helium nuclei (right) measured with 5-yr exposure of HERD, compared with that observed by AMS-02, CREAM, and ATIC-2.



Gamma rays

The observations in the energy range above 1 GeV by HERD will play a unique and complementary role in multi-wavelength studies across the electromagnetic spectrum with other space and ground telescopes. HERD with its unusually large field of view and unique energy coverage is well suited to the search of electromagnetic counterpart of gravitational wave events.



In Fig. we show the simulated HERD sensitivity for 1 year observation. In order to compare the potential for gamma ray science by HERD the sensitivities of other experiments are also shown. We can see that HERD is the most sensitive instrument for gamma rays from tens to hundreds of GeV with wide field of view. Such performance guarantees its importance for monitoring and searching for the gamma ray sources discussed above.