The DAMPE experiment: a probe for high energy cosmic rays

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The DAMPE (DArk Matter Particle Explorer) satellite was launched on December 17, 2015 and it is taking data from more than 18 months. It is designed to probe the highest energy cosmic-ray accelerators and to study the nature of dark matter thanks to its excellent tracking and calorimetric performances in the measurements of electrons, gamma rays, protons and nuclei. A report on the mission goals and status will be given. The on-orbit detector performance will be also shown.

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1. Introduction

The DArk Matter Particle Explorer (DAMPE) was successfully launched on December 17, 2015 and DAMPE presently orbits sun-synchronously at an altitude of $500km$ [1, 2]. The main scientific goals of DAMPE are the measurement of the fluxes of charged cosmic rays (electrons, protons and heavier nuclei), the measurement of high-energy gamma rays from various astrophysical sources and the search for possible signatures of dark-matter.

2. On-board instruments

The DAMPE detector is equipped with four different sub-detectors (Fig. 1): a plastic scintillator detector array (PSD), a silicon-tungsten tracker (STK), a BGO calorimeter (BGO) and a neutron detector (NUD). The PSD is designed to work as a veto and to measure the charge (Z) of incident high-energy particles up to Z = 26. It has a double layer configuration and the directions of the scintillator bars in the two layers are perpendicular to provide information on the X and Y coordinates. Right below the PSD, the STK is used to the precise reconstruction of the particle tracks. It consists of 12 position-sensitive silicon detector planes (6 planes for the x-coordinate, 6 planes for the y-coordinate). Three layers of tungsten are inserted in between the silicon planes (2,3,4 and 5) to enhance the conversion probability of gamma rays in electron-positron pairs. The BGO calorimeter is used to measure the energy deposition of incident particles and to reconstruct the electromagnetic shower profile [3]. The calorimeter is composed of 308 BGO crystal bars optically isolated from each other and arranged horizontally in 14 layers, each one of 22 bars. The bars of a layer are orthogonal to those of the adjacent plane in order to reconstruct the shower in both views (x-z and y-z). The total vertical depth of the calorimeter is 31 radiation lengths and 1.6 nuclear interaction lengths. The last sub-detector is the NUD, which consists of four boron-loaded plastic scintillators. All DAMPE sub-detectors are involved in photon selection with different roles. The BGO calorimeter is used to distinguish electromagnetic from hadronic showers in a wide energy range and its high separation power is further enhanced by the NUD, while the PSD and STK are mainly used for the separation between charged and neutral particles.
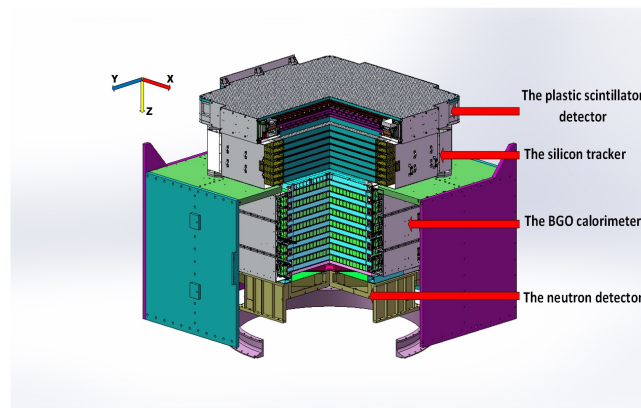

Figure 1: View of the DAMPE detector.

3. Trigger rate and data transfer

The trigger rate of DAMPE is closely related to the fluxes of the cosmic-ray particles on orbit. The effect of the high geomagnetic cutoff causes a significant reduction of the incident particles rate at low latitudes while in the pole regions where the energy cutoff value is lower the observed rate is higher.

Fig. 2 'a' shows the overall trigger rate. The sudden change of the trigger rate at $\pm 20°$ latitude is due to different pre-scale factor applied to the triggers to reduce the triggered events near the poles. The acquisition rate registers values up to 200 Hz, but the rate of the "high-energy trigger" (the one used for the main physics analyses and not prescaled) can change from about 20 Hz in the equator region up to 70 Hz at the poles (Fig. 2 'b').

Data are sent to ground 4 times per day, when the satellite passes over the Chinese ground stations. An amount of 15 GB is transmitted to ground each day, structured in about 8 GB of raw data and the remaining of slow control and orbit information data. The off-line reconstructed data in ground computing facilities results in 85 GB/day, stored in ROOT files. A total amount of about 100 GB is stored each day with an average of 35 TB of data in each year of operations.
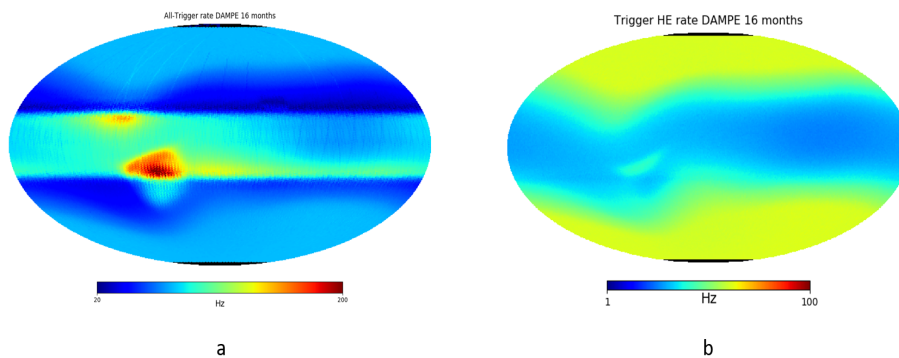
Figure 2: Trigger rate a) all the triggers b) High Energy trigger

4. On-orbit absolute energy calibration

A method to determine the absolute energy scale of DAMPE has been developed within the collaboration [4] based on the measurement of the geomagnetic cutoff on cosmic-ray electrons and positrons. The rigidity cutoff on cosmic ray electrons and positrons was calculated using IGRF-12 [5] model and the cosmic-ray particle trajectory code of back-tracking in magnetic field. The interval of McIlwain L parameter ranges between 1.0 and 1.14 was selected to measure the electrons and positrons spectrum. A 1.25% higher energy scale has been found for DAMPE with respect to the expectation.

5. Electrons: identification and expected performance

The measurement of the electron and positron flux is one of the leading analysis within the DAMPE experiment. Measurements lead by other experiments are limited in the energy range and

DAMPE has the capability to extend up to 10 TeV these measurements trying to answer to some of the most important questions about the behavior of this spectrum at very high energies. The electron acceptance has an almost constant value of 0.3 $m^2 sr$ for energies above 100 GeV. The energy resolution is is almost 1% for E > 100 GeV [2].

The good energy resolution is due to the very thick BGO calorimeter. These characteristics allow to perform a good event selection for electrons, for which several PID strategies are being investigated within the collaboration, starting from classic cut-based analysis using *ad hoc* "shape parameters" to multivariate analysis involving machine learning algorithms and neural networks.

6. Protons and nuclei

The PSD and the STK play a major role in measuring the charge of incident high-energy particles. Good results in the measurement of ions nuclei charge have been achieved since the beam test campaign, where several tests were performed with Lead and Argon beams showing a dependency of the PSD charge resolution from Z ranging from 0.2 to 0.4. The charge measurement is done with the STK up to Oxigen while with the PSD it is possible to measure the charge from proton to iron.

7. Photon selection

The photon selection is one of the most challenging tasks of DAMPE, since the background events represented by the charged particles (electrons, protons and nuclei) have fluxes that are much higher compared to the main galactic gamma-ray emission. The minimum rejection power requested at 100 GeV is 10^5 for protons and 10^3 for electrons. Protons are mainly suppressed using the shower profile inside the BGO calorimeter, while electrons are mainly rejected using the PSD and the first layer of the STK. One of the main issues with charged particles is the back-scattering effect, that reflects on the acceptance for photons at high energies. Fig. 3 shows the acceptances for photons and electrons after a selection based on the use of Convolutional Neural Networks and a Random Forest Classifier ([6]). For energies above 500 GeV, the back-scattering affects the acceptance decreasing its value, while the decreas for energies below 5 GeV is due to the use of the high energy trigger in the events selection. Other PID algorithms are under study to further reduce the electrons contamination. An average number of about 150 photons is observed daily by DAMPE, and the count-maps after 16 months of data show a good resolution of the most bright gamma-ray sources, and a good agreement of their position with the ones observed by the Fermi-LAT.

8. Summary

The DAMPE detector is successfully operating after its launch on December 2015 with a large geometric factor of about 0.3 $m^2 sr$ for electrons, and its Si-W tracker provides for a 40μm spatial resolution and a 0.15° angular resolution. Its thick BGO calorimeter is 32 X_0 deep and its energy
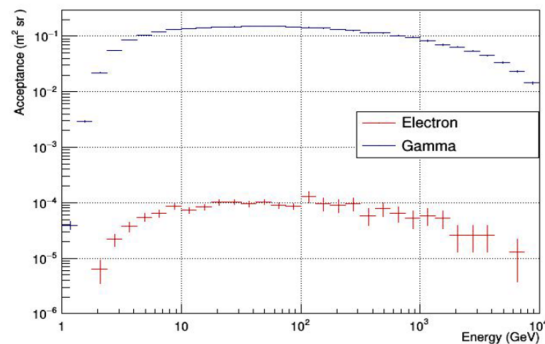
Figure 3: Acceptance for photons and electrons.

resolution is about 1% for energies above 100 GeV for the electromagnetic component of the observed cosmic rays, while for hadrons it is 40%.

The on orbit operations still continue with high efficiencies, and an absolute energy calibration has been performed using the geomagnetic cut-off. In addition, a cross-check of DAMPE's pointing performance has been done with the observed photon map.

9. Acknowledgments

References

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