The DAMPE experiment and its latest results

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Abstract. The DArk Matter Particle Explorer (DAMPE) is a high-performance space particle detector launched in orbit on 17 December 2015 by a collaboration of Chinese, Italian and Swiss scientific institutions, coordinated by the Chinese Academy of Sciences. It consists of a high-resolution segmented BGO electromagnetic calorimeter with a depth of 32 radiation lengths, a silicon-tungsten tracker-converter that reaches an angular resolution below 0.2°, an anti-coincidence shield and ion detector made of segmented plastic scintillators and a neutron detector made of boron-doped plastic scintillators. An overview of the experiment and a summary of the latest results coming from the observation of cosmic rays up to 100 TeV, of gamma-rays up to 10 TeV and of cosmic electrons up to 5 TeV is presented.

1. Introduction

The DArk Matter Particle Explorer (DAMPE) [1] is a particle detector launched on 17 December 2015 in a Sun-synchronous orbit at a 500 km altitude. Its main scientific goals are the study of cosmic rays, namely electrons, photons, protons and nuclei; the observation of gamma rays from astrophysical sources; the search for dark matter signatures, for electromagnetic counterparts of gravitational waves or neutrinos and for exotic particles. DAMPE has been designed to have an excellent performance: it can detect particles with energy from some GeV up to tens of TeV with a good energy resolution, an accurate angular resolution and a large field of view.

2. The DAMPE instrument

DAMPE is composed by four sub-detectors (Figure 1): a Plastic Scintillator Detector (PSD), a Silicon-Tungsten Tracker (STK), a BGO Calorimeter (CALO) and a Neutron Detector (NUD). The PSD has two tasks: to work as a veto for charged particles, and to measure the charge number $Z$ of incident high-energy particles. It is made by two layers of staggered scintillator bars in orthogonal arrangements, providing information on the $x$ and $y$ coordinates. The STK is devoted to reconstruct the particle tracks and to convert photons. It consists of 12 position-sensitive silicon detector planes (6 for the $x$-, 6 for the $y$-coordinate); 3 layers of tungsten, each 1 mm thick, are between the silicon planes 2, 3, 4 and 5 to enhance the conversion probability of gamma rays into electron-positron pairs. The BGO calorimeter is used to measure the energy deposition of incident particles and to reconstruct the electromagnetic shower profile. It is composed of 308 BGO crystal bars optically isolated from each other and arranged in 14 layers of 22 bars each; the bars of a layer are orthogonal to those of the adjacent one, to reconstruct the shower in the $xz$ and $yz$ views. The total depth of the calorimeter is 32 radiation lengths and...
1.6 nuclear interaction lengths. The last sub-detector is the NUD, made of four boron-loaded plastic scintillators. It is used to improve the overall hadron identification efficiency.

3. On-orbit performance: trigger rate, data transfer, energy calibration
The on-orbit trigger rate depends on the flux of the cosmic rays. It is lower in the equatorial regions but higher in the polar ones due to the Earth’s magnetic field bending effect. To avoid too a high rate, a pre-scale factor is applied to the trigger when DAMPE is outside the $\pm 20^\circ$ latitude band. However, the “high-energy trigger”, implemented for the main physics analysis, has a rate from $\sim 20$ Hz at the Equator to $\sim 70$ Hz at the poles and does not need to be pre-scaled.

About 15 GB of raw and control data are transmitted to ground each day and, after off-line processing, 85 GB of reconstructed data are produced. The yearly data production is 35 TB.

A method to determine the absolute energy scale of DAMPE has been developed within the Collaboration [2]. In fact, cosmic-ray electrons and positrons below a certain rigidity are bent back to space by the Earth’s magnetic field and this causes a clear cutoff in their spectrum. This cutoff was calculated using the geomagnetic field model IGRF-12 [3] and back-tracking the particle trajectories in the magnetic field, yielding a value of about 13 GeV, which was compared with the measured cutoff in the interval of McIlwain $L$ parameter between 1.0 and 1.14. A correction factor of 1.2% to be applied to DAMPE data was obtained (Figure 2).

![Diagram of the DAMPE instrument](image1.png)

**Figure 1.** The DAMPE instrument.

![Graphs showing energy calibration](image2.png)

**Figure 2.** Energy calibration: the geomagnetic cutoff (left) and its stability over time (right).
4. Measurement of the all-electron spectrum
The behavior of the spectrum of the cosmic electrons and positrons (CREs) at very high energies is related to some of the most relevant questions of physics and astrophysics [4][5], and its study is one of the main goals of DAMPE, that can extend its measurements up to about 10 TeV with an acceptance of 0.3 m$^2$sr and an energy resolution of $\sim$1% for energies above 100 GeV.

To study CREs, the particle identification (PID) and the separation from protons are crucial and can be carried out in several ways, based on the sub-detectors response and on the event topology. In our main analysis, a dedicated parameter, called $\zeta$, was computed from the lateral shower development size and the energy deposition in the last layer of the BGO. Its capability to discriminate electrons from protons was validated with beam tests at CERN: for 90% electron efficiency, the hadron background is $\sim$2% at 1 TeV and $\sim$10% at 5 TeV. Other PID strategies have been investigated within the Collaboration: for example, machine learning algorithms and neural networks showed to be very effective and are currently used in new analyses.

Figure 3. The all-electron spectrum measured by DAMPE, compared with results by HESS [7, 8], AMS-02 [9], Fermi [10] and CALET [11].

The CRE spectrum (Figure 3) has been measured by DAMPE from about 20 GeV up to about 5 TeV [6]. The main feature is a spectral break at $\sim$1 TeV, so a smoothly broken power law, with $\gamma$ varying from 3.1 to 3.9, fits DAMPE data. The next step is to improve the statistics and search for spectral structures that may be related to possible sources such as nearby pulsars, or dark matter.

5. Measurement of cosmic protons and nuclei spectra
Among DAMPE’s tasks, the measurement of the charge of the incident cosmic rays plays a relevant role. The scientific goal is to improve the direct measurement of the cosmic rays spectrum from a few GeV up to 100 TeV - a region that is poorly investigated - thanks to the very good calorimetric and geometric characteristics of the instrument. The capabilities of the PSD and the STK to measure the charge of ions nuclei have been evaluated and tuned with a beam test campaign at the CERN SPS, in which many tests have been performed with Lead and Argon beams that produced ion fragments with a wide range of charge number $Z$. Once in orbit, the PSD has measured the charge from protons to Iron ions with a resolution ranging from 0.2 to 0.4, while the STK has measured the charge from protons to Oxygen ions. Figure 4 shows the cosmic rays charge spectrum after two years of on-orbit data taking [12].

Figure 4. The cosmic rays charge spectrum measured by DAMPE after two years of data taking.
Figure 5. The preliminary fluxes of CR protons (left) and Helium (right) measured by DAMPE, compared with previous results by PAMELA [13], AMS-02 [14], ATIC-2 [15] and CREAM [16]. The error bars represent statistical errors and the grey bands show the systematic errors.

Also the fluxes of protons and Helium ions (Figure 5) as a function of the kinetic energy are being measured. The preliminary results show good agreement with the PAMELA [13] and AMS-02 [14] data for $E_k < 200$ GeV. With the accumulation of data, the region from 1 TeV up to 100 TeV is being analyzed by DAMPE with high precision and new results are expected soon.

6. Photons

DAMPE is also able to detect high-energy cosmic gamma rays. The photon selection is a challenging task, since the background of charged particles has fluxes much higher than the galactic gamma-ray emission: the minimum rejection power required at 100 GeV is $10^5$ for protons and $10^3$ for electrons. The rejection techniques are based on the event topology. Protons are mainly suppressed using the PSD response and the shower profile in the BGO calorimeter, with a contribution from the NUD, while electrons are mainly rejected using the PSD response and the first plane of the STK. Also innovative procedures, as neural networks and “random forest” classifiers [18], are under test and show excellent particle identification performance. An average number of 150 photons is identified daily by DAMPE. The major sources are resolved with a good angular resolution and their positions agree with those measured by the Fermi-LAT.

Figure 6. Phase profile of the Geminga pulsar, compared with Fermi [17].

Figure 7. Short-term variations in the gamma-ray emission of the CTA 102 blazar [19].
DAMPE can also observe the time behavior of variable sources. For instance, Figure 6 shows the phase profile of the Geminga pulsar while Figure 7 shows the short-term variability of the CTA 102 blazar.

Finally, DAMPE participates to the multi-messenger observation of high-energy cosmic phenomena: for example, it has observed the extragalactic source TXS 0506+056 that is the possible origin of the 290 TeV muon neutrino detected by IceCube in September 2017 [20].

7. Summary
DAMPE is working extremely well since December 2015. Its geometric factor is about 0.3 m$^2$sr for electrons, its Si-W tracker reaches a 40 µm spatial resolution and a 0.15° angular resolution and its 32 X$_{0}$ deep BGO calorimeter provides, at energies above 100 GeV, ∼1% energy resolution for cosmic gamma rays and ∼40% for hadrons. Absolute energy calibration is performed using the geomagnetic cutoff.

The all-electron spectrum has been precisely measured up to TeV energies and a spectral break has been directly measured at ∼1 TeV; improved precision of this spectrum may shed light on nearby sources, anisotropies, dark matter. Proton, Helium and nuclei measurements are ongoing with good preliminary results. Photon detection capability has been assessed; more statistics is being collected to profit the excellent energy resolution at high energy.

Acknowledgments
The DAMPE mission is founded by the strategic priority science and technology projects in space science of the Chinese Academy of Sciences XDA04040000 and XDA04040400. In China it is supported by the National Key R&D Program 2016YFA0400200, the National Basic Research Program 2013CB837000, the NSFC grants 11525313, 11622327, XDB23040000, 11273070, 11303096, 11303100, 11303106, 11303107, 11673075, U1531126, U1631111 and the 100 Talents Program of Chinese Academy of Sciences. In Europe the activities are supported by the Italian National Institute for Nuclear Physics (INFN), the Italian University and Research Ministry (MIUR), the Swiss National Science Foundation (SNSF) and the University of Geneva.

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