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DAMPE: A gamma and cosmic ray observatory in space

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Summary. — DAMPE (DArk Matter Particle Explorer) is one of the five satellite missions in the framework of the Strategic Pioneer Research Program in Space Science of the Chinese Academy of Sciences (CAS). Launched on December 17th 2015 at 08:12 Beijing time, it is taking data into a sun-synchronous orbit, at the altitude of 500 km. The main scientific objective of DAMPE is to detect electrons and photons in the range 5 GeV–10 TeV with unprecedented energy resolution, in order to identify possible Dark Matter signatures. It will also measure the flux of nuclei up to 100 TeV with excellent energy resolution. The satellite is equipped with a powerful space telescope for high energy gamma-ray, electron and cosmic rays detection. It consists of a plastic scintillator strips detector (PSD) that serves as anti-coincidence detector, a silicon-tungsten tracker (STK), a BGO imaging calorimeter of about 32 radiation lengths, and a neutron detector. With its excellent photon detection capability and its detector performances (at 100 GeV energy resolution $\sim 1\%$, angular resolution $\sim 0.1^\circ$), the DAMPE mission is well placed to make strong contributions to high-energy gamma-ray observations: it covers the gap between space and ground observation; it will allow to detect a line signature in the gamma-ray spectrum, if present, in the sub-TeV to TeV region; it will allow a high precision gamma-ray astronomy. A report on the mission goals and status will be discussed, together with in-orbit first data coming from space.

1. – Introduction

The DAMPE (DArk Matter Particle Explorer) [1] is a powerful space telescope for high-energy gamma-ray, electron and cosmic ray detection. It is one of the five scientific missions in the framework of the Strategic Pioneer Program on Space Science [2] of the Chinese Academy of Sciences (CAS) and has been realized with the contribution of Swiss and Italian institutions. Launched on December 17th 2015, at 08:12 Beijing time, it is taking data into a sun-synchronous orbit at the altitude of 500 km.

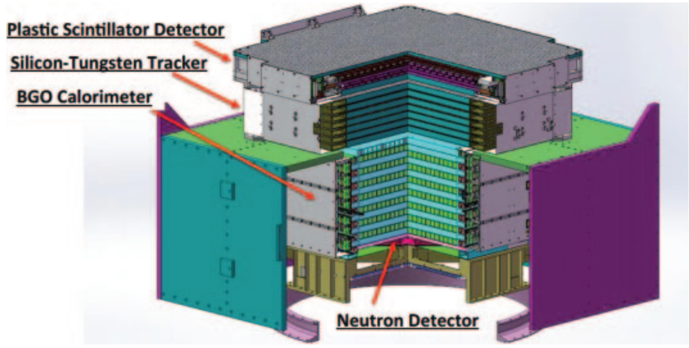

Fig. 1. – DAMPE telescope scheme: a double layer of the plastic scintillator strip detector (PSD); the silicon-tungsten tracker-converter (STK) made of 6 tracking double layers; the imaging calorimeter with about 32 radiation lengths thickness, made of 14 layers of Bismuth Germanium Oxide (BGO) bars in a hodoscopic arrangement and finally the neutron detector (NUD) placed just below the calorimeter.

DAMPE has been designed to detect electrons, positrons and photons in the range from few GeV up to 10 TeV and cosmic ray nuclei up to 100 TeV. The objectives of the DAMPE experiment are the search of Dark Matter decay or annihilation signatures, gamma-ray astronomy and cosmic rays flux and composition.

2. – On-board detectors

The satellite is equipped with four different detectors: a plastic scintillator strips detector (PSD), a silicon-tungsten tracker (STK), a BGO imaging calorimeter and a neutron detector (NUD).

In fig. 1 a scheme of the DAMPE telescope layout is shown. It consists of a Plastic Scintillator strip Detector (PSD), that serves as anti-coincidence detector and to measure particle charge, followed by a silicon-tungsten tracker-converter (STK), to reconstruct the direction of incident particles, a BGO imaging calorimeter of about 32 radiation lengths thickness, to measures the energy with high resolution and to distinguish between electrons and protons, and a neutron detector (NUD) placed just below the calorimeter, to further improve the hadronic to electronic shower rejection power.

2˙1. *Plastic Scintillator Detector (PSD).* – To measure the flux of charged particles or to have a veto for gamma ray detection, DAMPE is equipped with a high efficiency PSD, with a large dynamic range to measure the charge of high energy nuclei up to $Z = 26$. PSD is composed by 2 layers (x, y) of strips with a thickness of 1 cm, 2.8 cm wide and 88.4 cm long. The sensitive area is 82.5 cm × 82.5 cm. Detector design has been optimized to have no dead zones [3].

2˙2. *Silicon-Tungsten Tracker (STK).* – The STK detector [4] is devoted to the precise reconstruction of charged particle trajectories, to the measurement of ion charge and to the photon conversion in e^-/e^+ pairs. It consists of 12 planes of position-sensitive silicon strips (6 for the x-coordinate and 6 for y-coordinate). The STK is composed by 768 single-sided AC-coupled Silicon Strip Detectors (SSD). The SSD has a size of $95 \times 95 \times 0.32\,\mathrm{mm}^3$ and is segmented in 768 strips, 48 μm wide, with a 121 μm pitch. 4 SSD are assembled

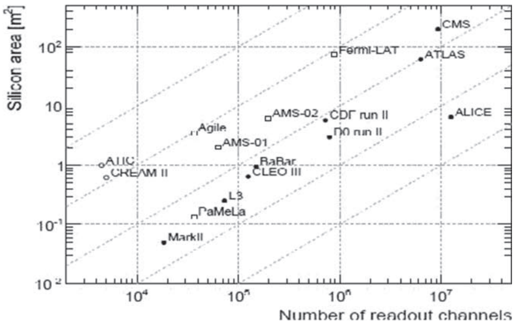

Fig. 2. – Comparison of STK features with silicon detectors used in other experiments.

Table I. – *STK specifications.*

Si layer active area	0.5776 m^2
Si thickness	320 μm
strip pitch	121 μm
Tungsten thickness	1 mm
Fraction of radiation length	0.976
Power consumption	82.7 W
Mass	154.8 kg

together to form a ladder ($76 \times 76\,\mathrm{cm}^2$) and 16 ladders are placed on each STK plane.

Three 1 mm thick tungsten plates are placed in between the silicon planes to convert gamma rays in e^-/e^+ pairs.

In fig. 2 a comparison with other experiments in terms of active area and number of readout channels is shown, while in table I the main STK parameters are summarized.

2·3. *BGO Calorimeter (BGO).* – The BGO calorimeter is used to measure the energy of incident particles and to distinguish between electromagnetic and hadronic particles [5]. The calorimeter is composed by 14 layers, each containing 22 BGO crystal bars (see fig. 3). Each bar has a size $2.5 \times 2.5 \times 60\,\mathrm{cm}^3$ and is read by 2 PMTs coupled at its ends. To extend the dynamic range of the calorimeter, signals are read from 3 dynodes (2,5,8). The total vertical depth is $\sim$ 32 radiation lengths and ~ 1.6 nuclear interaction lengths. In table II the main BGO parameters are summarized.

Table II. – *BGO specifications.*

Active area	$60 \times 60\,\mathrm{cm}^2$
Depth	~ 32 rad. lengths
Sampling	$> 90\%$
Long segmentation	14 layers
Lateral segmentation	~ 1 Moliere radius

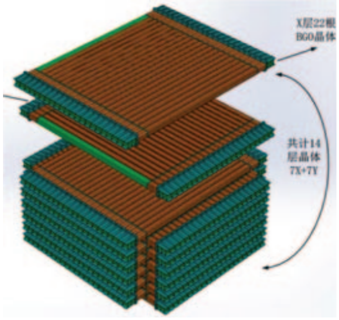

Fig. 3. – Exploded view of the BGO.

2·4. *Neutron Detector (NUD)*. – To further improve the possibility to distinguish between electronic and hadronic showers, a NeUtron Detector is placed under the BGO calorimeter. It consists of 4 large area boron-doped plastic scintillators (size $30 \times 30 \times 1\,\mathrm{cm}^3$). The NUD detects delayed neutron resulting from a shower in the BGO: typically hadronic showers produce 1 order of magnitude more neutrons than electronic ones. Neutrons are detected via the capture process $\mathrm{n} + {}^{10}\mathrm{B} \rightarrow {}^{7}\mathrm{Li} + \alpha + \gamma$ [6].

3. – On-ground detector test

DAMPE performances have been verified by more than two months of test beam activity. By means of electron and proton beams, provided by the PS ans the SPS CERN facilities, BGO performances have been studied, in particular the energy resolution (see fig. 4), the linearity and the e/p separation. A beam of argon fragments has been also used to test the apparatus with heavy ions. Details on test beam activity and preliminary results can be found in [4, 7, 8].

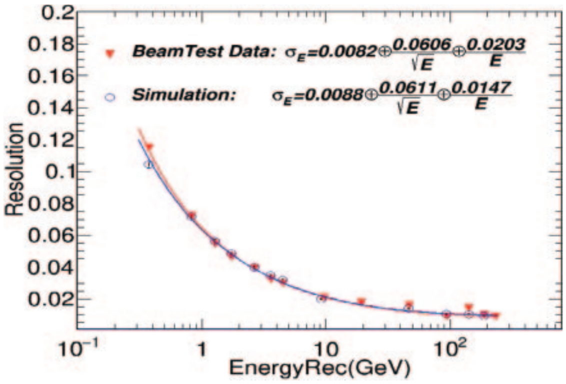

Fig. 4. – Energy resolution for electromagnetic showers measured at beam test (red triangles) compared with Monte Carlo expectation (empty blue circles).

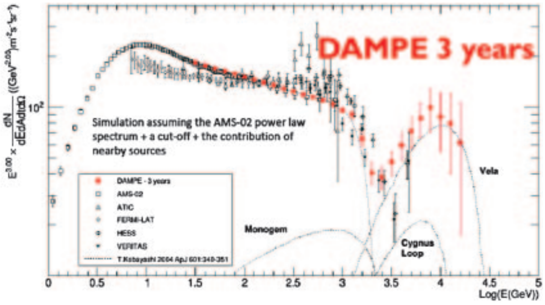

Fig. 5. – All-electron spectrum: possible DAMPE measurements (red dots) in 3 years of operations, assuming the power law suggested by the AMS-02 experiment, a cut-off at ∼ 1 TeV and nearby astrophysical sources.

4. – Orbit performances

After the launch, two weeks of detector commissioning and calibrations have been performed. During the data taking, STK pedestal calibration is performed twice per orbit and the global trigger rate is kept at 50 Hz, by means of different pre-scales for unbiased and low-energy triggers, depending of the satellite latitude. The satellite collects ∼ 4 M events/day.

Performance parameters, like temperature, noise, spatial resolution and efficiency, are very stable and close to expectations. BGO energy scale has been verified by means of the geomagnetic cut-off. A preliminary energy sky-map has been obtained already and it will be soon released.

5. – Expected measurements

DAMPE is expected to take data for more than three years. It will collect enough statistics to deeply investigate many cosmic ray open questions. The wide measured energy range for protons (up to 100 TeV) and electrons (up to 10 TeV) and the high-precision energy measurements will allow to detect possible spectrum structures, a possible electron cut-off around 1 TeV, anisotropies and other possible hints of dark matter signals in that energy range. In fig. 5, the possible DAMPE measurement of the all electron spectrum in 3 years is shown. Due to its experimental potentialities, it will be able to observe a spectrum cut-off and nearby astrophysical sources, if present.

For gamma ray astronomy, DAMPE can cover the gap between space and ground observations. Due to its energy resolution, it will allow a high-precision gamma-ray astronomy and, if present, it will detect a line signature in the gamma ray spectrum in the sub-TeV to TeV region.

6. – Conclusions

DAMPE is a powerful telescope for high-energy electrons, γ and cosmic rays, with a large geometrical aperture ($0.3\,\mathrm{m}^2$ sr), a precise STK measurements (0.1°, $40\,\mu$m) and the thickest calorimeter operating in space (∼ 32 radiation lengths).

DAMPE satellite has been successfully launched in orbit and preliminary data analyses confirm expected performances. On-orbit operations are smooth with high efficiency (4M events/day).

An intensive calibration campaign has been performed before launch and on-orbit performances confirm measurements on ground and Monte Carlo predictions, increasing the expectations of the first DAMPE physics results that will be soon released.

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