PROCEEDINGS OF SCIENCE

Latest results from DAMPE

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The DArk Matter Particle Explorer (DAMPE) satellite mission, launched in December 2015, has been in operation for more than 6 years. DAMPE is capable of measuring γ-rays and cosmic-ray electrons up to about 10 TeV and cosmic-ray ions up to about 100 TeV and more. This talk gives an overview of the mission and presents the latest results on the electron, proton and helium fluxes as well as other physical results of DAMPE. Special attention is paid to the development of machine learning methods that will allow to measure the cosmic-ray fluxes up to PeV energies.

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[*] Speaker

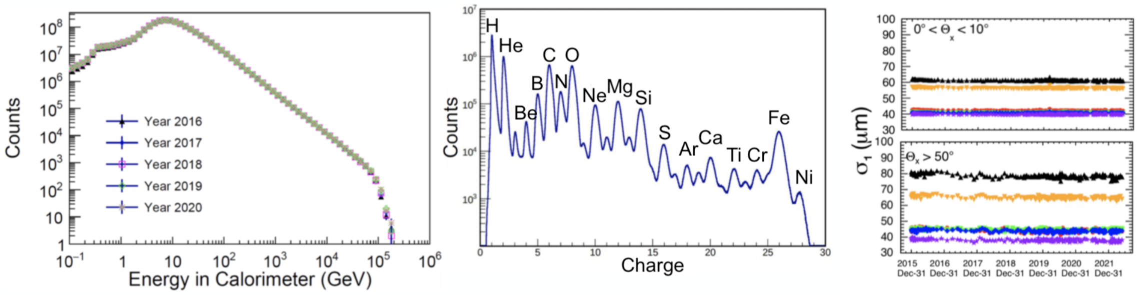

Figure 1: BGO energy response over the years (left) [6]. PSD charge identification (center) [7]. STK alignment stability (right) [3].

1. Introduction

DArk Matter Particle Explorer (DAMPE) is a space-borne instrument for the γ and cosmic-ray studies [1]. It is in operation since December 2015, observing the sky from a Sun-synchronous orbit with 500 km altitude and 97° inclination. DAMPE detector consists of four main parts:

- Plastic Scintillator Detector (PSD) for the charge measurements [2].
- Silicon-Tungsten tracKer converter (STK) for the precise track reconstruction and γ conversion [3]. STK is also used as an additional charge measuring instrument.
- Bismuth-Germanium Oxide calorimeter (BGO) with 31 X_0 thickness, that consist of 14 layers of BGO crystals, for energy measurements and hadron-electron discrimination [4]. The trigger system of DAMPE is based on the BGO signal.
- NeUtron Detector (NUD) for additional hadron-electron discrimination [5].

With stable data acquisition throughout more than 6 years (see Fig. 1) DAMPE possesses over 11 billion cosmic-ray events for analysis, including more than 250 million events above 20 GeV deposited energy and almost a million events above 1 TeV deposited energy.

2. Recently published results on cosmic-ray fluxes

2.1 Electron flux

Thanks to the relatively big geometric acceptance of about 0.35 m^2sr and deep hodoscopic calorimeter with energy resolution of about 1% at above 100 GeV deposit energy, DAMPE is especially apt for the electron flux measurements [8]. DAMPE was the first experiment to observe the break in electron spectrum at 1 TeV. The cosmic-ray electrons lose energy due to synchrotron radiation, so the electrons with energy above a few TeV are expected to originate from sources closer than 1 kpc. Thus the study of the electron flux at energies above 1 TeV is of particular interest. The main challenge is then to reduce the proton background. Electrons leave a distinct imprint in BGO calorimeter, characterised by a short shower. The distinction of electrons is a perfect application of machine learning algorithms (ML), particularly efficient for image recognition. This approach is explored in a recent paper [9]. The electron flux is the subject of current studies of the collaboration, see Fig. 2.

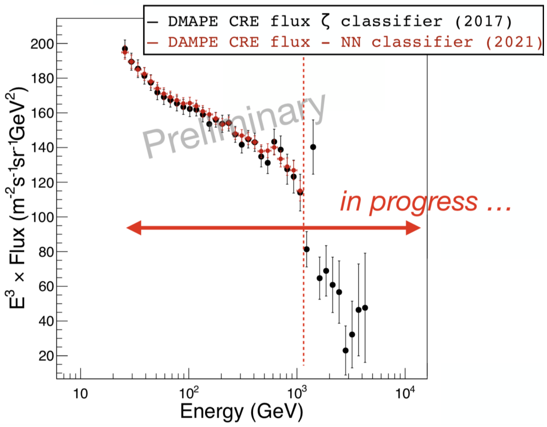

Figure 2: Electron flux. Black points from the 2017 work [8]. Red points from the ongoing study exploring the ML approach

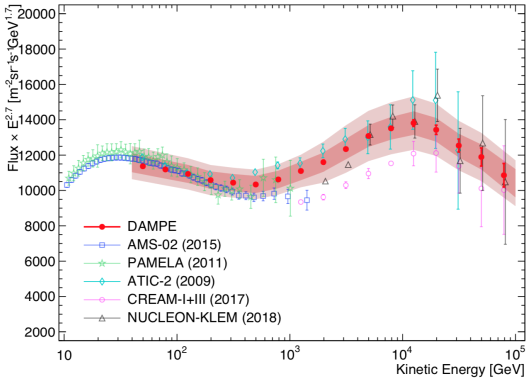

Figure 3: Proton flux with DAMPE, compared to the results of other experiments [10]. For DAMPE, the error bars show statistical uncertainties and two shadowed regions show two sources of systematics: the inner one for the analysis systematics and the outer for the hadronic model uncertainty.

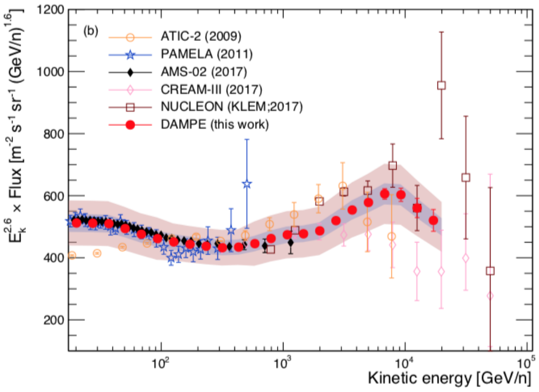

Figure 4: Helium flux with DAMPE, compared to the results of other experiments [11]. For DAMPE, the error bars show statistical uncertainties and two shadowed regions show two sources of systematics: the inner one for the analysis systematics and the outer for the hadronic model uncertainty.

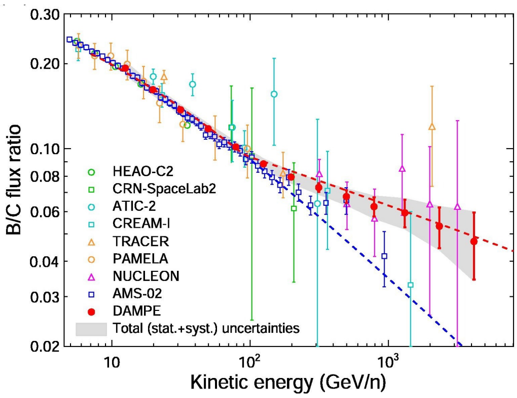

Figure 5: Boron to carbon flux measurement by DAMPE, compared to the results of other experiments [12].

2.2 Hadronic cosmic-ray fluxes

Proton [10] and helium [11] cosmic-ray fluxes were measured up to 100 TeV and 80 TeV kinetic energy respectively, see Fig. 3 and 4. Both fluxes reveal two spectral features: hardening at about 500 GeV/n and softening at about 10 TeV/n. DAMPE measurements confirm that the cosmic rays do not follow a simple power law at energies below the knee of the cosmic-ray spectrum. This may hint at new production or propagation mechanisms, or possible nearby sources of cosmic rays.

The boron-to-carbon and boron-to-oxygen flux ratios measured by DAMPE were recently published [12]. Both ratios reveal with high statistical significance a spectral hardening at about

100 GeV/n, see Fig. 5 for the boron-to-carbon ratio. These results deviate from the predictions of conventional turbulence theories of the interstellar medium (ISM), which point toward a change of turbulence properties of the ISM at different scales or novel propagation effects of cosmic rays.

The analysis of the ion fluxes up to iron is ongoing, see example of the charge measurements by PSD for the carbon analysis on Fig. 6.

3. Towards PeV fluxes

Moving towards the highest energies accessible by DAMPE is challenging due to multiple effects appearing when an energetic particle hits the detector. First of all, the secondary particles, produced in the shower in the calorimeter and at the tungsten layers of the tracker, propagate in all directions and at energy above several TeV can completely pollute the STK tracker and PSD detectors. This makes the choice of the right track especially difficult, and as a consequence, the PSD charge measurement loses its resolution. A neural network method [13] comes in help, providing a precise direction measurement even up to PeV energies. The method is in two steps: first a rough estimation of the incoming particle direction is made with the BGO calorimeter with the help of a neural network regressor. Next, the reconstructed BGO direction seeds the search for the more precise direction search with STK, where another neural network is applied. This method increases the tracking efficiency by a factor of more than 2 at energies above 500 TeV, compared to the conventional STK tracking method [3].

Fig. 6 shows an example of PSD charge measurements at about 4 TeV energy deposited in the BGO calorimeter. This particular picture is made with help of the machine learning tracking algorithm [13], which allows an excellent charge resolution and avoids the contamination of the carbon signal region by the secondary particles.

Another challenge arises from the limited dynamic range of BGO readout electronics. When energy deposited in a single bar of the calorimeter exceeds about 5 TeV the readout electronics of the bar would saturate, leaving this bar with zero energy registered. Two competitive saturation correction methods were published, one using an analytical approach [14] and another, more precise one, using convolutional neural networks [15]. Both methods allow to recover the energy lost due to saturation, which can reach hundreds of TeV in extreme cases.

These methods are being applied in the ongoing analyses of DAMPE collaboration, among which are the measurements of cosmic-ray ions from Li through C, N and O all the way up to Fe. The proton plus helium spectrum is currently in preparation for publication. The motivation to measure the proton plus helium combined spectrum is first to have a direct comparison with the ground-based experiments that don't have the excellent charge resolution of space-borne instruments, and second to increase the acceptance and enhance the statistics. Ground-based experiments (e.g. ARGO) suggest a knee structure at energies accessible by DAMPE. The extension of proton and helium individual and combined fluxes up to PeV energy is currently one of the main priorities of the DAMPE collaboration.

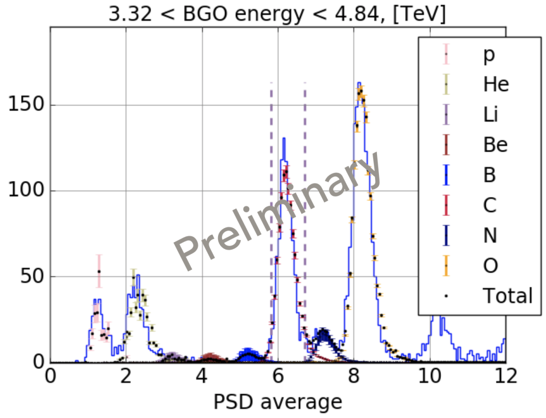

Figure 6: Example of fit of Monte-Carlo templates to the PSD charge measurement for the carbon flux studies (preliminary). Blue line shows the flight data measurements, the colored points are for the Monte-Carlo contributions of different elements.

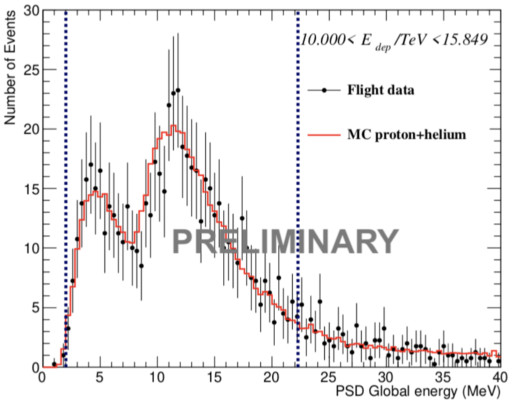

Figure 7: Example of proton plus helium MC template fit to the flight data PSD charge distribution at one of the highest energy bins. Vertical lines show the limits of the signal region.

4. Other studies with DAMPE

DAMPE physics is not limited by the cosmic-ray fluxes. A recent publication of the search for the fractional charge particles [16] demonstrates the excellent rejection power of DAMPE in this search at low energies starting at 1 GeV. An upper limit of 6.2×10^{-10} cm^{-2}sr^{-1}s^{-1} is obtained for the flux.

As of today, the DAMPE search for the cosmic-ray anisotropies has not revealed any deviation from the isotropic flux.

γ-ray studies include the search for the γ-ray sources in the sky, studies of the Fermi bubbles (their preliminary spectrum is consistent with the measurements of Fermi LAT) and line searches [17]. The latter study, thanks to the excellent energy resolution of DAMPE, shows a sensitivity comparable with that of Fermi LAT, even in spite of lower acceptance, see Fig. 8. DAMPE provides the most stringent limit on decay lifetime of dark matter particles with mass below 100 GeV.

In heliophysics, DAMPE has recently measured the so-called Forbush decrease – the cosmic ray follow-up of energetic solar flares [18]. The DAMPE large geometrical acceptance of 0.35 m^{s}sr in conjunction with the fact that its orbit visits polar regions where the geomagnetic cutoff is reduced allows DAMPE to provide high-precision measurements of the Forbush decreases.

5. Conclusions

DAMPE mission, in stable operation since 2015, provides important insights to the cosmic-ray physics and more. Stay tuned for the upcoming ion flux results by DAMPE.

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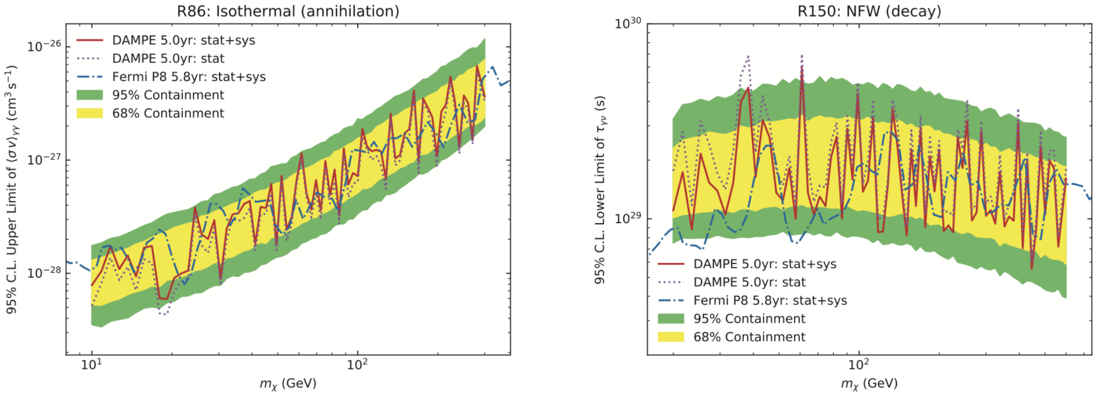

Figure 8: 95% confidence level upper limits for the γ-ray line search in annihilation (left) and decay (right) channels of dark matter [17].

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