IL NUOVO CIMENTO **44 C** (2021) 89
DOI 10.1393/ncc/i2021-21089-2

COMMUNICATIONS: SIF Congress 2020

Cosmic Ray helium spectrum measured by DAMPE

M. DI SANTO(*) on behalf of the DAMPE COLLABORATION

Dipartimento di Matematica e Fisica "Ennio De Giorgi", Università del Salento and INFN, Sezione di Lecce - Via per Arnesano, I-73100 Lecce, Italy

received 15 January 2021

Summary. — DAMPE (DArk Matter Particle Explorer) is a satellite-based detector designed for one of the main Space missions promoted by the Chinese Academy of Sciences (CAS) in the framework of its Strategic Pioneer Research Program in Space Science. The experiment activities are carried out by a large collaboration involving many Universities and Institutes from China, Italy and Switzerland. The satellite was launched on December 17th, 2015 from the Jiuquan Satellite Launch Center in China, and it is stably collecting data since then. The DAMPE mission is dedicated to the measurement of electron and photon spectra up to the energy of about 10 TeV, aiming to eventually find clues about the existence of Dark Matter. A further main scientific goal of the experiment is the measurement of Cosmic Ray (CR) energy spectra up to hundreds of TeV, together with the exploration of the high-energy γ-ray Sky. In this work we present the preliminary results about the energy spectrum measurement of CR helium nuclei up to $\sim 7\,\text{TeV/n}$.

1. – Introduction

Since more than a century, Cosmic Ray (CR) Physics has aroused great interest, encouraging the efforts of many scientific collaborations in the realization of experiments aiming to measure CR energy spectra in order to deepen our knowledge about these messengers from the Universe. By increasing more and more the accuracy of the measurements, it has come to the surprising observation of special features in the CR energy spectra, namely variations in the spectral index value, deviating from an expected single power-law form. In more detail, the so-called spectral *hardening* has been clearly observed at hundreds of GeV of energy by several experiments like AMS-02 [1], CREAM [2], PAMELA [3, 4], ATIC [5], NUCLEON [6] and DAMPE [7] in the proton (p) and helium (He) spectra. In the meanwhile, the TeV region reveals a further spectral

(*) E-mail: margherita.disanto@le.infn.it

feature named *softening* in the proton flux and some hints of its presence also in the helium energy spectrum [2,5-7]. These observations play a fundamental role in the study of CRs, as they can be theoretically modeled and therefore explained by different scenarios which foresee, for example, different types of sources or different diffusion mechanisms. Hence, measurements with higher resolution and at higher energies are still necessary in solving this complicated puzzle. In this work we present the analysis and the preliminary results about the CR helium flux measured by the DAMPE experiment.

2. – The DAMPE detector

DAMPE (DArk Matter Particle Explorer) [8] is a particle detector installed on-board a satellite launched on December 17th, 2015 from the Gobi Desert in China and currently orbiting around the Earth in a Sun-synchronous way at an altitude of ~ 500 km. Four sub-detectors constitute the instrument. On the top of the satellite a Plastic Scintillator Detector (PSD) is installed, consisting of two layers of plastic scintillator bars and providing a measurement of the absolute value for the incoming CR charge up to $Z = 28$, but also an anti-coincidence veto system for γ-rays. The underlying sub-detector is the Silicon Tungsten tracKer-converter (STK), composed by 6 tracker planes, used for the track reconstruction of the incoming particle, and 3 supplemental tungsten layers inserted in order to enhance the photon conversion in electron-positron pairs. A deep electromagnetic calorimeter (BGO) ($\sim 32\ X_0$, $\sim 1.6\lambda_I$), made up of 14 layers of $Bi_3Ge_4O_{12}$ crystal bars, provides the measurement of the energy deposited by the crossing CRs. The last sub-detector is a NeUtron Detector (NUD), composed by boron-doped plastic scintillator tiles, used to better discriminate between electromagnetic and hadronic showers.

3. – Selection of CR helium events

In this work we analyzed 53 months of on-orbit data recorded by the DAMPE satellite in the period from January 1st, 2016 to May 31st, 2020. The flight-data analysis has been tested and validated with Monte Carlo (MC) simulation samples of helium nuclei with incident energy ranging from 10 GeV up to 100 TeV, generated by using the GEANT4 toolkit. The main event selection criteria we applied are the following:

0) the event has been recorded by the DAMPE satellite outside the South Atlantic Anomaly region (SAA);

1) the total energy deposited inside the whole BGO calorimeter has to be greater than 20 GeV in order to avoid the geomagnetic rigidity cut-off effect;

2) the reconstructed track has to be fully contained inside the whole detector;

3) the High Energy Trigger (HET) is activated, which means that the energy deposit is greater than $\sim$13 MIP in the first 3 layers of the BGO calorimeter and greater than $\sim$2.4 MIP in the fourth one (MIP: Minimum Ionizing Particle, for the DAMPE calorimeter 1 MIP = 23 MeV). This request ensures a good reconstruction of the total primary energy from that deposited inside the BGO;

4) the energy deposited in the first two layers of the calorimeter has to be less than that released in the third and fourth layers. This condition ensures a rejection of CR events coming from the bottom of the satellite or of incoming CRs with high tilted angle with respect to the detector axis and badly reconstructed;

5) the projection of the track reconstructed in the STK has to match with the position of the PSD fired bars and with the axis of the shower developed inside the calorimeter;

6) a consistency is asked between the signals provided by the plastic scintillator layers and the first layer of the STK.

The previous requirements provide a sample of "well reconstructed" events where we can finally select the helium candidates, namely events with reconstructed charge $Z = 2$. The Bethe-Bloch formula guarantees that the energy released through ionization by a CR crossing the PSD is proportional to the square of the particle charge. Therefore, we analyzed the energy distributions for both the PSD layers in different ranges of energy deposited inside the BGO in order to take into account the energy dependence, and we fit them with the convoluted Landau and Gaussian distributions. The Most Probable Values (MPVs) and the sigmas (σ's) from the aforementioned fits for each BGO energy bin are then used for the final charge selection, defined as

$$MPV - 2\sigma < E_{\mathrm{PSD}} < MPV + 4\sigma. \tag{1}$$

At this stage of the analysis, the helium candidate event sample is finally defined.
It is worth to outline that in this work we applied a *saturation correction method* [9] which becomes necessary at very high energy, when the saturation of the BGO crystal low-energy gains may occur. A further issue taken into account is the *quenching effect* affecting the response of BGO crystals in the detection of ion events. To face this issue, the BGO energy response has been studied for several ions by using test beams and on-orbit data [10] and a correction function on the BGO energy deposition has been defined and used in order to obtain a more reliable measurement of the response energy.

As main contributions to the systematic error affecting the measurement of the helium flux we considered the proton contamination of the sample of events selected as induced by He nuclei entering the detector, but also the efficiencies related to the HET, the track reconstruction and the charge selection. The total systematic error is estimated as

$$\sigma_{\mathrm{sys}} = \sqrt{\sigma^2_{\mathrm{HET}} + \sigma^2_{\mathrm{Track}} + \sigma^2_{\mathrm{Charge}} + \sigma^2_{\mathrm{Contamination}}} \simeq 5.2\%. \tag{2}$$

4. – Results and discussion

The preliminary results obtained from this analysis are presented in fig. 1. The plot on the left represents the effective acceptance evaluated with MC data after all the selection cuts and computed according to the following formula:

$$A_{\mathrm{eff}} = A_{\mathrm{gen}} \times \frac{N_{\mathrm{pass},i}}{N_{\mathrm{gen},i}}, \tag{3}$$

where A_{gen} is the geometrical factor given by the MC simulation of an isotropic flux of CR helium nuclei generated above a 1.0 m radius sphere containing the DAMPE detector, $N_{\mathrm{pass},i}$ refers to the number of events selected as helium candidates in this work, and $N_{\mathrm{gen},i}$ is the total number of generated events, both in the same i-bin of primary energy. On the right side of fig. 1, the preliminary helium flux (multiplied by $\mathrm{E}^{2.7}$) as a function of the kinetic energy per nucleon up to ~ 7 TeV/n is shown. The statistical error (evaluated

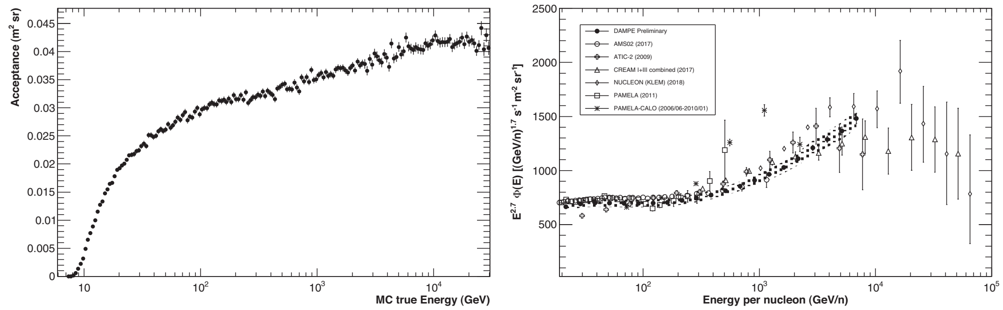

Fig. 1. – Left: effective acceptance for the helium MC event sample which satisfied each analysis selection requirements. Right Helium flux weighted with $E^{2.7}$ as a function of the primary energy per nucleon up to $\sim$ 7 TeV/n, compared with previous measurements performed by other experiments. The dashed band describes the systematic uncertainties, while the error bars represent the statistical errors.

by using the Toy MC method) is represented by the bars, while the systematics are described by the band. An *unfolding* procedure has been adopted, allowing to reconstruct the incoming CR primary energy from the deposited one. Indeed, due to the limited thickness of the DAMPE calorimeter ($\sim$ 1.6 interaction lenghts) only a part of the total particle energy is deposited inside the detector ($\sim$ 40% at 10 TeV). The result reveals a good agreement with previous measurements provided by other experiments like AMS-02 [1], CREAM [2], PAMELA [3, 4], ATIC [5] and NUCLEON [6], also confirming the presence of a *spectral hardening* observed by previous experiments at hundreds of GeV.

REFERENCES

[1] Aguilar M. *et al.*, *Phys. Rev. Lett.*, **119**, (2017) 251101.
[2] Yoon Y. S. *et al.*, *Astrophys. J.*, **839** (2017) 5.
[3] Adriani O. *et al.*, *Science*, **332** (2011) 69.
[4] Adriani O. *et al.*, *Adv. Space Res.*, **51** (2013) 219.
[5] Panov A. D. *et al.*, *Bull. Russ. Acad. Sci.: Phys.*, **73** (2009) 564.
[6] Atkin E. *et al.*, *JETP Lett.*, **108** (2018) 1.
[7] An Q. *et al.*, *Sci. Adv.*, **5** (2019) 9.
[8] DAMPE Collaboration (Chang J. *et al.*), *Astrophys. J.*, **108** (2014) 796.
[9] Yue C. *et al.*, *Nucl. Instrum. Methods Phys. Res. A*, **984** (2020) 164645.
[10] Wei Y. F. *et al.*, *IEEE Trans. Nucl. Sci.*, **67** (2020) 939.