Precision Measurement of the Cosmic Ray Helium Flux with AMS Experiment

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Abstract: AMS is a TeV range high energy physics experiment operating since May 2011 on board of the International Space Station on Low Earth Orbit. The precise helium spectrum as measured by AMS is presented in the rigidity range from 2 GV to 3.2 TV. Below the 10 GV the spectrum is modulated by time dependent solar activity. Above the 10 GV the spectrum can be parametrized by the single power law spectrum , modulated by solar activity with fitted solar potential value of $\phi = 0.5 \pm 0.05$ GV. No fine structures was found in the spectrum.

Keywords: Cosmic Rays Nuclei, He flux, AMS-02

1 Introduction

Numerous measurements of the He flux was done in the past by balloon and satellite experiments [1],[2],[3],[4],[5],[6],[7],[8],[9],[10],[11],[12]. The exact behaviour of the He flux with energy is important for understanding the acceleration mechanism of charged cosmic rays in our Galaxy. In the present paper we report on the measurement of the He flux, which was performed with about a half a billion He events collected by AMS-02 detector [13] during it's first two years of operation on board of the International Space Station.

2 AMS Experiment

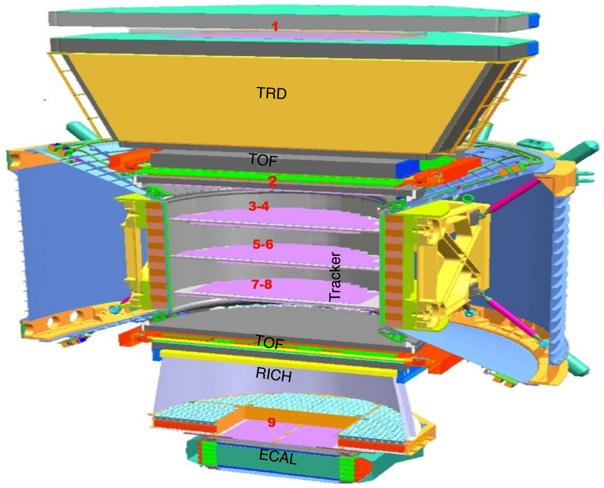

Fig. 1: A Layout of the AMS-02 detector

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The layout of the AMS-02 detector is shown in Figure 1. It consists of a permanent magnet with 0.14 T magnetic field central value, 9 planes of Silicon tracker (TK) , four layers of time of flight scintillator counters (TOF), a transition radiation detector (TRD), an array of anti-coincidence counters around the magnet (ACC), a ring imaging Cerenkov detector (RICH) and an electromagnetic calorimeter (ECAL).

Silicon tracker, which can be further subdivided into inner tracker, combining layers 2 to 8, and two external layers L1 and L9, measures the particle momentum p per unit charge Z , or rigidity, $R = p/Z$ and the sign of its charge by analysing particle trajectory behaviour in the magnetic field. The trajectory is determined by up to 9 3D coordinates measurements along the tracker layers of 300 μm thick double sided Silicon sensors. With a spatial resolution in the bending He particle direction of 6 to 7 μm, the average maximum detectable rigidity (MDR), i.e. R for which $\Delta R/R$ =1 is estimated to be 3.2±0.3 TV [14].

The charge magnitude Z can be measured independently charged particle energy loss along the particle trajectory by the Tracker L1, TRD, Inner Tracker, TOF, RICH, Tracker L9, and ECAL. As an example, the charge resolution of the inner tracker is about 0.08 charge units for He[15].

The response of the detector was simulated using GEANT4-4.9.4 package[16]. The effects of energy loss, scattering, electromagnetic and hadronic interactions, the measured detector resolution, together with precise geometry description were included. In particularly, two different models of He nuclear interactions were used, one is Geant4 Ion Light Binary Cascade model, and the other one is DPMJET-II.5[17] for rigidities above 10 GV.

3 Analysis

The incident particle rigidity together with local coordinates and directions was obtained by fitting these parameters with the 3D coordinates measured in L1, at least 4 out of 7 layers of Inner Tracker and L9. The velocity of the particle,$\beta = v/c$, was determined using the information of the time of flight hits matching the reconstructed track. The velocity resolution for the He particles was $\Delta\beta/\beta^2 \approx 0.02$[18].

A downgoing particle was selected as a helium candidate if the determination of its charge magnitude along the trajectory was consistent with that of He. The main potential source of background to the helium sample were protons with wrongly reconstructed charge and/or high Z ions interacting before tracker Layer1. Using the independent measurement of the charge magnitude obtained along particle trajectory, the proton and ions background was estimated to be less than 10^{-5} and 10^{-3} over all rigidity range correspondingly. As an example, Figure 2 shows the distribution of the measured particle charge in the Inner Tracker.

To reject events with large scattering the $\chi^2 < 10$ cut on the trajectory fitting quality was appled as shown on Fig. 3.

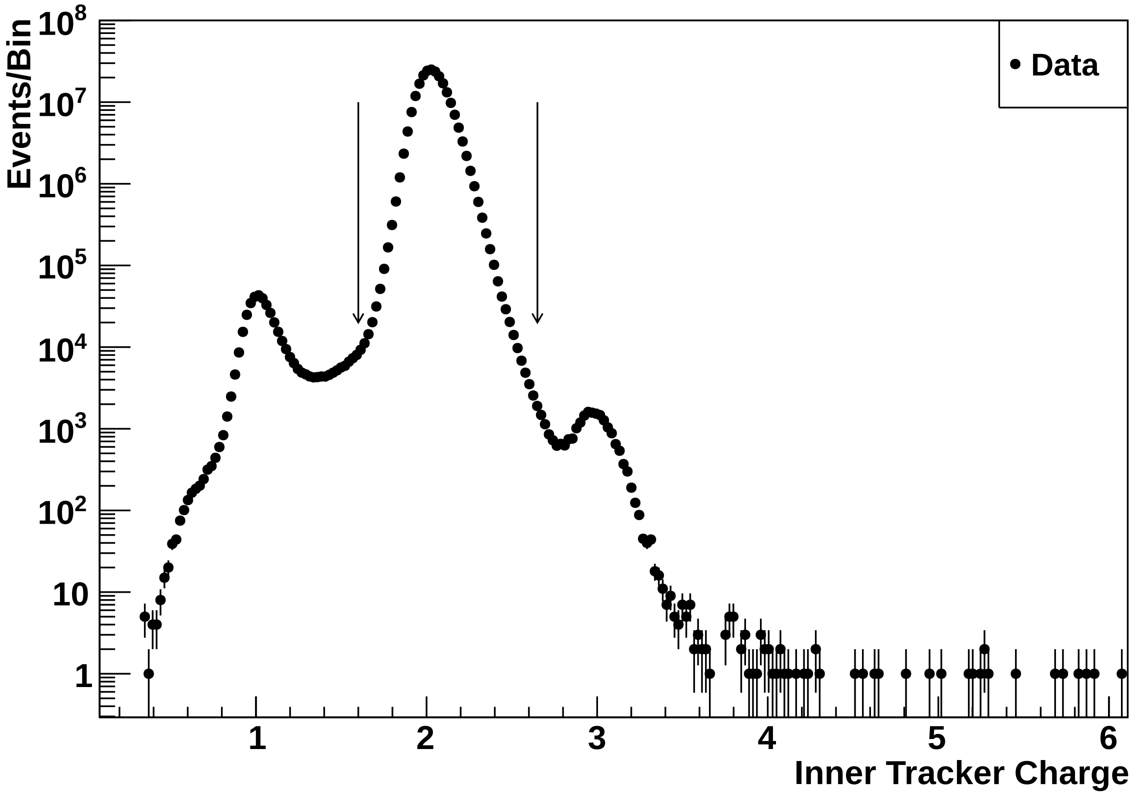

Fig. 2: A Measured by Inner Tracker charge distribution for helium candidate events selected by Tracker L1 and TOF. Arrows show the values of cut applied. The efficiency of the cut is about 99.8%.

This cut eliminated 1 to 2% of events, while significantly (factor 3 or more) reduced the number of events with wrongly measured rigidity[1].

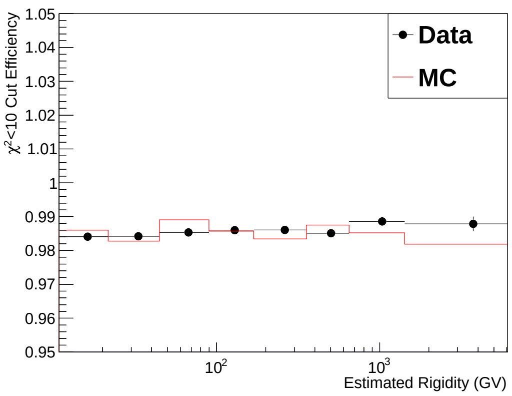

Fig. 3: A Track fit quality cut efficiency dependence from rigidity estimated by ECAL energy deposition. The efficiency is constant within 0.5%.

Next, only events with rigidity (R) above the geomagnetic cutoff were selected, namely :

$$R > R_C \times (1.2 + 2\sigma(R_C))$$

where R_C was the maximum cutoff rigidity for the events in the AMS field of view, calculated in the dipole approximation [19] for each second time interval along the station trajectory around the Earth, and $\sigma(R_C)$ was the measurement uncertainty at that rigidity value.

4 He Flux

The differential helium flux was obtained by firstly unfolding[20] the measured rates with the parametrized[2] detector resolution function and then correcting those for the accumulated time and detector acceptance as a function of the particle rigidity and direction. The accumulated time varied with the rigidity and reached 51.2 million of seconds for the rigidities above $\approx$ 30 GV, with the average livetime of 0.81 during two years measurements. The acceptance was determined by the Monte Carlo method using simulated helium events which underwent the same reconstruction and selection procedure as for the data and was found to be nearly rigidity independent for rigidities above 10 GV. The acceptance needed to be further corrected for the trigger efficiency, the latter being studied by Monte Carlo method and *unbiased trigger*[3] events. Trigger efficiency was found

1. This was verified by comparing the number of events measured with negative rigidity before and after the cut.
2. by sum of two gaussian functions
3. This trigger required 3 out of 4 coincidence of the TOF counters in different TOF layers amplitude over threshold of $\approx 1/3$ of

to be $\approx 95\%$ for the rigidities above 20 GeV and up to 99% for the lower rigidities.

The systematic errors on the calculated flux were the following:

- Due to trigger and event reconstruction efficiency variations relating to constantly changing particle rates and thermal evnironment. Above $\approx$ 20 GV this systematic error was found to be nearly rigidity independent. Table 1 shows average contributions.
- Monte Carlo acceptance evaluation corrections. The calculated average contributions are shown in 2.
- Unfolding errors, which arised from uncertainty of knowledge of resolution functions obtained by simulation. This errors are bin to bin correlated, and were estimated to be less than 0.5% below 250 GV , while reached 10% above 2 TV;

Source	Energy Range (GV)	Error (%)
Trigger	2-20	0.3
	>20	0.5
Track &	2-20	0.5
velocity fit	>20	0.7
Total	2-20	0.6
	> 20	0.85

Table 1: Average systematics of the trigger and reconstructon.

Source	Energy Range (GV)	Error (%)
MC Statistics	> 2	0.7
He selection	2-20	0.5
	> 20	0.7
Geomagnetic cutoff	2-20	0.5
	20-30	0.2
	> 30	0
Total of the above	>2	1.0
He interactions	> 2	3.5

Table 2: Average systematics of the Monte Carlo corrections.

The estimations of the systematic errors were verified by varying selection criteria, comparing the obtained average fluxes above $\approx$20 GV at different magnetic latitudes as well as comparing the details of He interactions between data and simulation events using the charge measurements along the He trajectory as measured by AMS (see Fig.4).

The unfolding errors were estimated by changing the resolution matrix MDR by about 10%, which corresponded to our test beam data extrapolation error to that energy, and allowing up to 1/20 TV^{-1} shift in the average inverse rigidity measurement, which corresponded to our current knowledge of tracker alignment using electron and positron samples[21, 22].

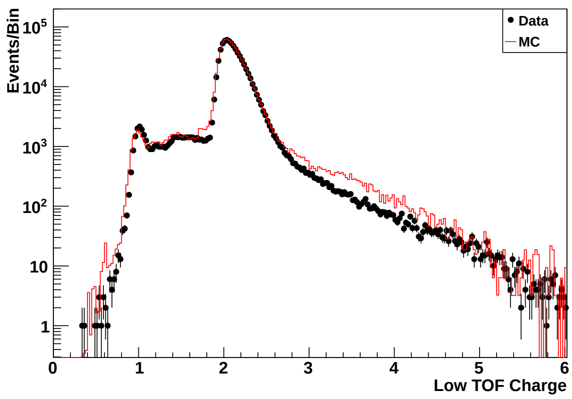

Fig. 4: The distribution of the measured charge at Low TOF for the He events with rigidity greater than 20 GV, selected by Tracker L1 tight charge cut. The difference in number of interacted events between data and MC was estimated to be about 3%.

5 Analysis of the He Flux Spectrum

To investigate the consistency of the spectrum above the 10 GV with the power law spectrum, a fit to the measured event counts by power law spectrum Φ_0/R^γ modulated with the solar modulation parameter in the force filed approximation[23] ϕ was done by folding this spectrum with detector resolution function , estimated acceptance and measurement time in the inverse rigidity range from -0.0005 to 0.1 GV^{-1}. The $\chi^2/n.d.f$ of the fit was 81/76. The fitted solar modulation potential ϕ value amounts to $\phi = 0.5 \pm 0.05$ GV. Apart from statistical errors, only the energy dependent systematic erros ($\approx$ 1.3% above 20 GV) were included into the fit. The $\chi^2/n.d.f.$ became 51/60 for the fit being done in the inverse rigidity range from -0.0005 to 0.03 GV^{-1}, with no systematic change of the fitted fit parameters.

6 Results

Fig. 5 shows the helium spectrum as measured by AMS, multiplied by corresponding bin central value[4] in the 2.7 power together with data of previous experiments.

7 Acknowledgements

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that of minimium ionizing particle and estimated to have an efficiency exceeding 99.9% for Z=2 particles

4. which have been choosen following the recommendations in [24]

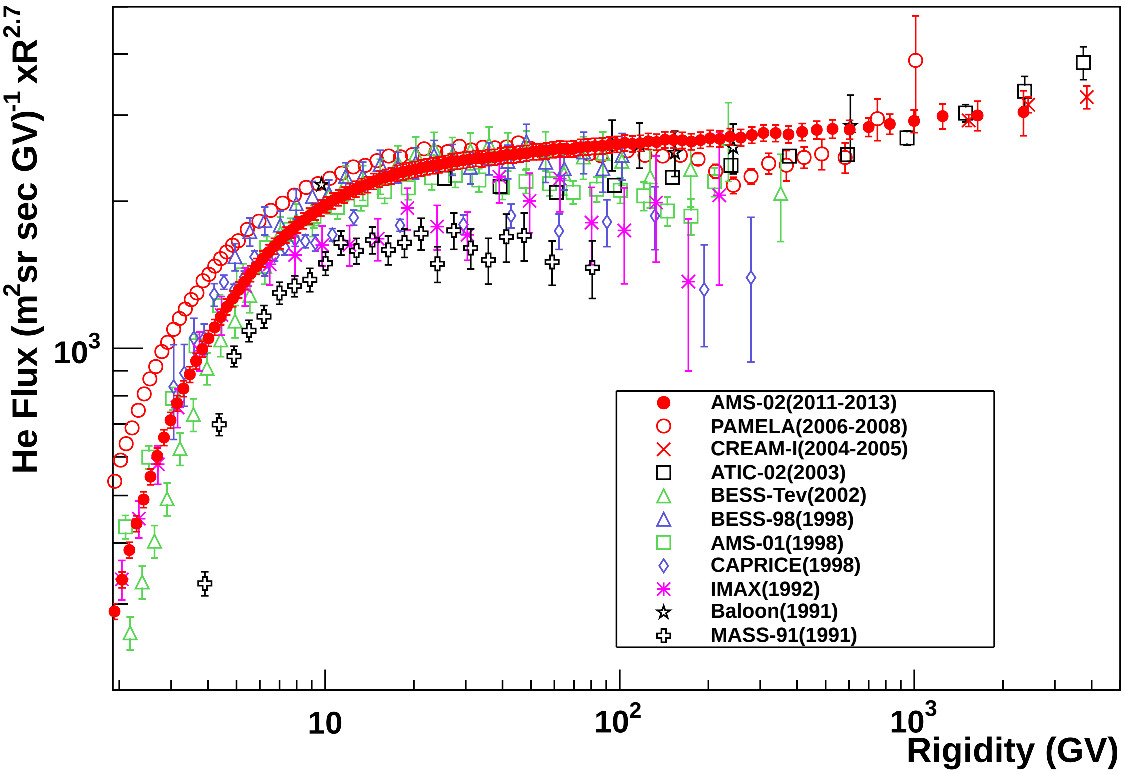

Fig. 5: The AMS Helium spectrum multiplied by the rigidity value in the 2.7 power together with the previous experimental data.

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