Measurement of the Deuterium Flux in the Kinetic Energy Range 12-22 GeV/n with the CAPRICE98 Experiment

Vannuccini E.,[1] on behalf of the CAPRICE98 collaboration
(1) Università degli studi di Firenze and INFN, Florence, Italy

Abstract

The balloon-borne CAPRICE98 instrument was flown on 28-29 May 1998 from Fort Sumner, New Mexico, USA. The detector configuration included the NMSU-WiZard/CAPRICE magnetic spectrometer equipped with a gas ring imaging
Cherenkov detector (RICH), a silicon-tungsten calorimeter and a time-of-flight system. Deuterons were identified by using the RICH as a threshold device. This allowed for the first measurement of the deuterium flux at kinetic energies above 2 GeV/n. We report the results on the energy spectrum of the primary cosmic-ray deuterons and on the deuteron to helium ratio between 12 GeV/n and 22 GeV/n.

1. Introduction

The CAPRICE98 balloon-borne experiment (Cosmic AntiParticle Ring Imaging Cherenkov Experiment, 1998) is the latest detector built and flown by the WiZard collaboration. The instrument configuration allowed several science objectives to be achieved, among which is the measurement of the ^{2}H abundance.

Since deuterium is significantly rare in astrophysical environments, cosmic-ray deuterium is generally believed to be of secondary origin, produced during the nuclear interactions of cosmic rays with the interstellar medium. Compared with heavier secondary components, the specific feature of light secondaries, such as ^{2}H and ^{3}He, is that their interaction mean free path is considerably larger than the escape mean free path of cosmic rays from the Galaxy. Thus their abundances provide information about the propagation mechanism in the whole confinement volume. In spite of its scientific relevance no measurements exist above few GeV/n, due to the intrinsic difficulty of isotopic separation at high energies.

2. The instrument

The CAPRICE98 apparatus was designed to study antiproton and positron cosmic-ray components in the energy range from few GeV up to tens GeV. The instrument included a drift chamber tracking system placed inside the magnetic field

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generated by a superconducting magnet. The spectrometer was complemented by three additional detectors; a Si-W electromagnetic imaging calorimeter, a time-of-flight system and a gas RICH detector. The information provided by these detectors, combined with the measured rigidity, enabled particle identification. A more detailed description of the apparatus, can be found in [1,3,4].

3. Data analysis

Deuterons were selected out of singly charged positive particles by requiring no Cherenkov signal in the RICH detector. This condition allows in principle to distinguish deuterons from lighter particles between the proton and the deuteron Cherenkov threshold rigidities ($\sim$ 18 GV and $\sim$ 35 GV respectively).

The selected sample of events contained, beside deuterium, a significant contamination of protons that was estimated and subtracted. The presence of protons without a Cherenkov signal with measured rigidity above the threshold is an effect related to both the statistical fluctuations in the number of photoelectrons detected by RICH and to the spectrometer response. In order to estimate the proton background distribution, as well as the deuterium selection efficiency, a Monte Carlo approach was used, based on characteristic quantities derived from experimental data. The RICH response was parameterized using ground muons. In fact, since their Cherenkov threshold rigidity is $\sim$ 10 times smaller than protons, the spectrometer effect is strongly reduced. Two methods were used to characterize the spectrometer response. In one method the spectrometer resolution function was derived using high energy flight protons, by estimating the deflection from the measured Cherenkov angle. In the other method the spectrometer response was characterized using ground muons collected with magnet off, by fitting the straight tracks as if they were high energy particles in a non zero magnetic field. The analysis procedure is described in [12,13] and further details will be presented at the conference.

Data were corrected for the total detection efficiency, for the geometrical acceptance and for attenuation and secondary particles production due to interactions in the material above the tracking system, including the residual atmosphere (5.5 g/cm^2). The latter correction is based on the calculation described in [13].

4. Results

Figure 1. shows the deuterium flux measured by CAPRICE98 compared with results from other experiments[2,5,6,7,10,14,15]. One can notice that the CAPRICE98 measurement represents the first result on the deuterium flux obtained at energies above 2 GeV/n.

In the same figure the deuterium data are compared with predictions calculated from some theoretical estimations of the deuterium-to-helium ratio. The

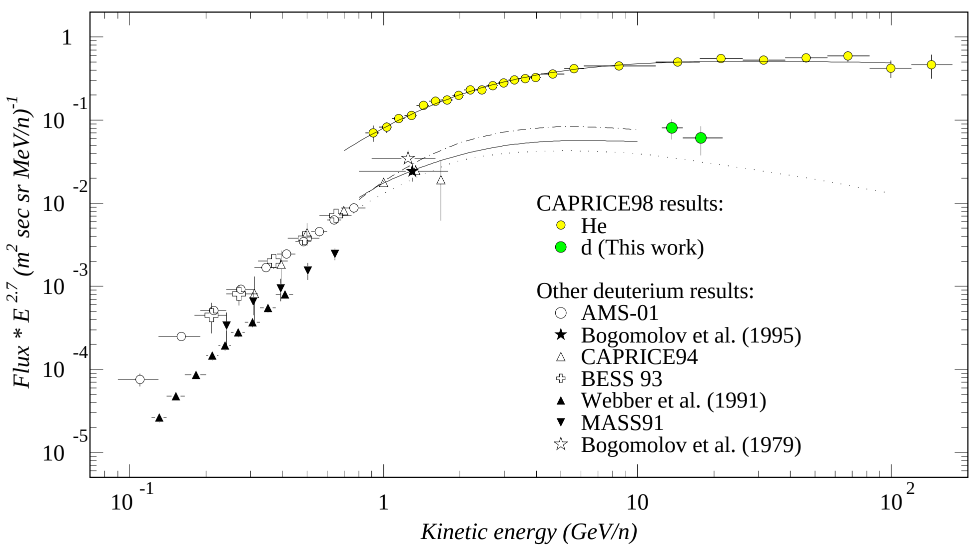

Fig. 1. Deuterium flux. Symbols: experimental results from CAPRICE98 (filled circles) and from other experiments[2,5,6,7,10,14,15]. Curves: theoretical prediction (see figure 2.).

curves in fig.1. have been obtained by multiplying the helium flux measured by CAPRICE98 (upper solid curve) with the calculated ratio.

At high energy the main production channel for deuterium is the spallation of He nuclei, even if heavier nuclei play a significant role. A meaningful quantity is thus the ratio d/He. The deuterium-to-helium ratio measured by CAPRICE98 is shown in figure 2. in comparison with other experimental data and calculations.

A standard model for interpreting data on galactic cosmic rays is the *Modified Leaky-Box Model* (MLBM). According to this model the propagation of cosmic rays is described by a unic energy-dependent parameter, the escape mean free path λ_{esc}. The general approach is to tune this parameter on heavy secondary components, and to use the resulting expression to evaluate the expected abundances of light secondaries. The main question concerning light cosmic-ray nuclei is if their propagation history is actually the same as that of heavier nuclei.

In figure 2. d/He experimental data are compared with different theoretical predictions based on the MLBM [9,11,14]. It is evident that the results, even if performed within the same propagation model, differ by large amount. This is due to different assumptions on source spectrum and composition, fragmentation cross-sections, interstellar medium composition and escape mean free path. At low energy the differences among the calculations are also related to the solar modulation model adopted and the solar activity level assumed. At high energy the solar modulation is negligible and d/He data are useful tools to constraint

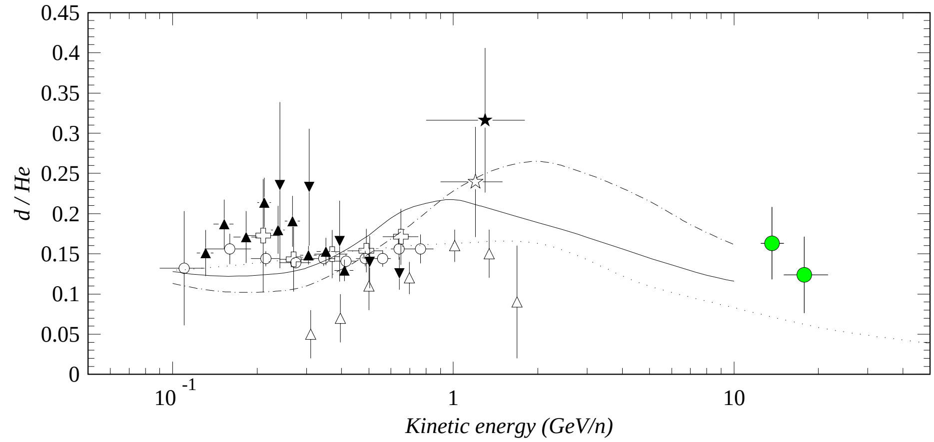

Fig. 2. d/He ratio. Symbols: experimental results from CAPRICE98 (filled circles) and from other experiments[2,5,6,7,10,14,15]. Curves: theoretical prediction from Mewaldt[9] (dot-dashed curve), Stephens[11] (dotted curve) and Wang et al.[14] (solid curve).

propagation parameter, since the prediction is free from the uncertainty on solar modulation.

5. Conclusions

CAPRICE98 provided the first measurement of deuterium abundance above 10 GeV/n. The result suggest that the light elements have a propagation history consistent with that of heavier nuclei, within the experimental errors.

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