Primary cosmic ray and muon measurements with CAPRICE

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The WiZard Collaboration has performed several investigations of the cosmic ray muon component in the atmosphere. In this paper, we review the most recent results from the balloon-borne CAPRICE experiment and discuss their relevance in the context of the atmospheric neutrino observations.

1. INTRODUCTION

The accuracy of the atmospheric shower calculations has long been debated in connection to the interpretation of atmospheric neutrino observations. It is a widespread opinion that the accuracy of atmospheric flux calculations may hardly exceed the level of 20%, due to the uncertainties on some input quantities such as the cross-sections for meson production in interactions of nucleons on atmospheric nuclei and the normalization of the primary cosmic ray flux [2].

In spite of this difficulty, atmospheric neutrino observations have provided dramatic evidence in favour of neutrino oscillations [see ref. 3 for a recent review]. This has been possible since the interpretation of several observable quantities, such as the ν_μ/ν_e ratio, the angular distribution and the zenith asymmetry of the events, is not strongly model-dependent. However, more accurate calculations of the atmospheric showers are still needed for a full description of the atmospheric neutrino phenomenology.

2. MUON MEASUREMENTS AND ATMOSPHERIC SHOWER CALCULATIONS

Muon measurements have been frequently advocated as a powerful means of cross-checking the atmospheric neutrino calculations. However, to what extent the muon flux normalization effectively constrains the neutrino flux estimates is still not accurately known, since several parameters (e.g., the k/π ratio in the meson production in particle interactions) affect differently the fluxes of the two particles. As an example, it may be pointed out here that a large part of the discrepancies recently found [4,5] in comparisons of measurements to muon calculations may presumably be ascribed to the unidimensional approximations of the calculations, which should not be among the major sources of inaccuracies for neutrino calculations.

As we have pointed out before, [6] the meaning of any such comparison between muon measurements and calculations may be substantially increased if the measurements of the primary cosmic ray flux reported from the same experiment are taken as input to the flux calculations. The advantage of this approach is twofold: firstly, we may in this way disentangle the uncertainties on the primary cosmic ray flux from those introduced by the interaction models and, secondly, the common systematic uncertainties of the measurements will be compensated. As of today, we do not have notice that the full implications of such approach have been investigated.

3. THE CAPRICE94 EXPERIMENT

The WiZard Collaboration has performed several investigations of the muon component in the atmosphere [see ref. 7 for a review]. Here we present the muon and primary cosmic ray measurements performed with the CAPRICE (Cosmic AntiProton Ring Imaging Cherenkov Experiment) balloon-borne experiment in 1994. These measurements were reported separately before [1,8].

The experiment was performed from Lynn

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Lake, Manitoba (Canada) on August 8-9, 1994 at a vertical rigidity cutoff of about 0.65 GV.

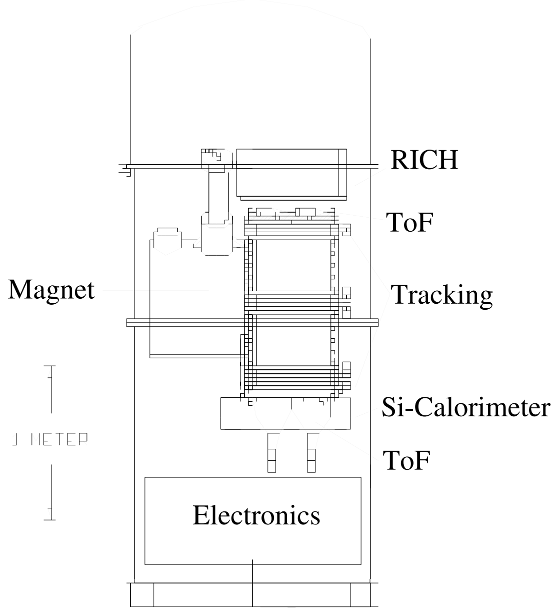

Figure 1. The CAPRICE apparatus in the 1994 configuration (CAPRICE94).

The experimental setup is shown in Fig. 1: it consisted of a superconducting magnet spectrometer, a time-of-flight (ToF) device, a Ring Imaging Cherenkov detector (RICH) and a silicon-tungsten imaging calorimeter.

The magnet spectrometer was equipped with a hybrid device made of two sets of drift chambers and 8 multiwire proportional chambers (MWPC) and reached an MDR of about 210 GV. The ToF consisted of two planes of scintillator separated by a distance of 1.1 m, located just above and below the tracking device. The time resolution of this detector was of the order of 250 ps. The RICH detector used a solid NaF ($\gamma_{th} \simeq 1.5$) radiator and a photosensitive MWPC with an active area of 50x50 cm^2. In order to get photoconversion of the Cherenkov photons, the chamber was filled with TMAE saturated ethane gas. The signals were acquired by means of a pad-readout on one cathode plane. Finally, the calorimeter consisted of 8 silicon planes, each one provided with two sensitive layers segmented along two perpendicular directions, interleaved with tungsten converters. The total depth of the calorimeter was 7 radiation lengths and 0.25 interaction lengths for protons.

4. THE CAPRICE94 RESULTS

The combined use of the information collected from different detectors enabled us to select good-quality samples of muons as well as of primary cosmic rays over large energy ranges.

In Fig. 2 we show the flux of negative and positive muons measured by CAPRICE, respectively in the 0.3–40 GeV/c and 0.3–2 GeV/c momentum ranges. The resuls in Fig. 2 are compared to expectations from a Monte Carlo calculations of atmospheric production: as yet, the reason for the apparent discrepancies is not fully understood.

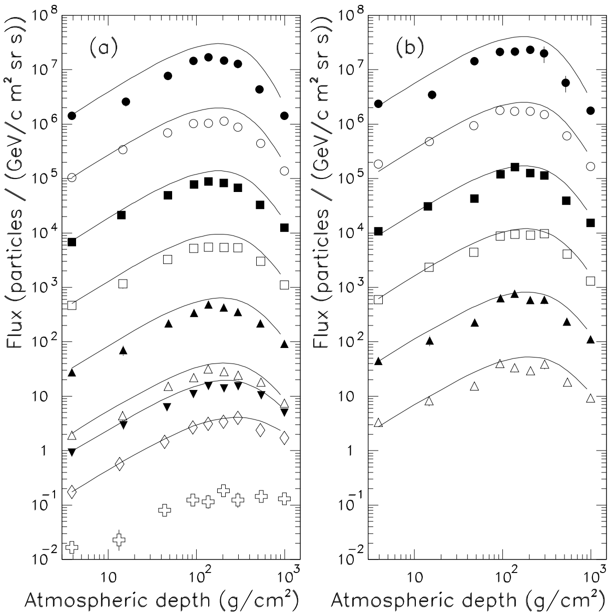

Figure 2. (a) Negative and (b) positive muon spectra measured in the CAPRICE94 experiment compared to predictions from atmospheric shower calculations [9]. From top to bottom, results are shown for the momentum ranges, in GeV/c: 0.3–0.53 (scaled by 10^5), 0.53–0.75 (10^4), 0.75–0.97 (10^3), 0.97–1.23 (10^2), 1.23–1.55 (10), 1.55–3, 2–3.2, 3.2–8, 8–40.

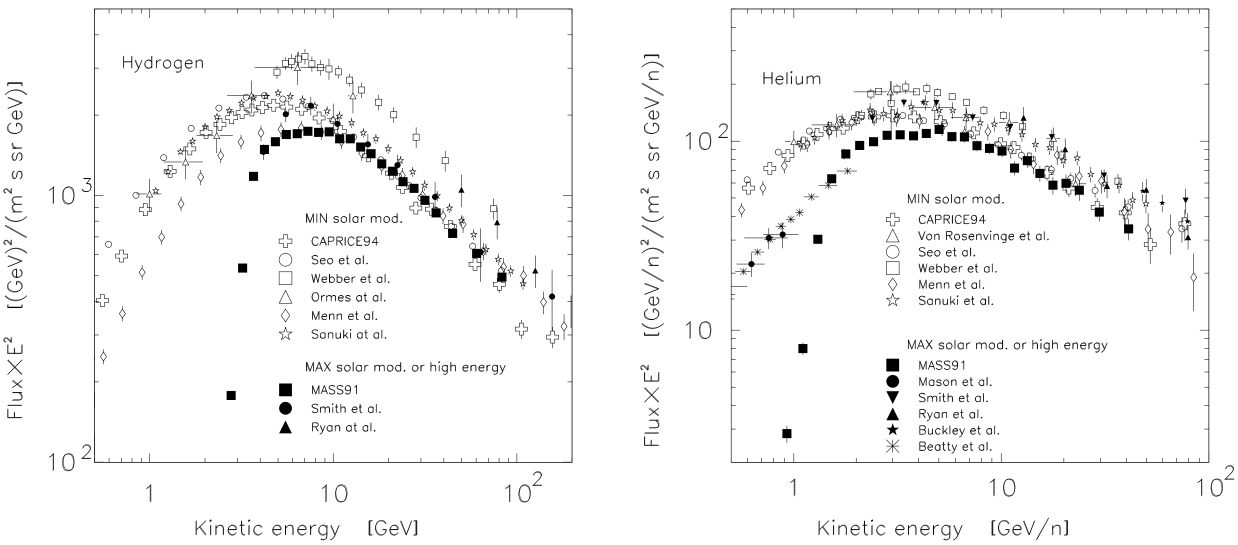

Figure 3. Energy spectra of hydrogen (left) and helium (right) measured in the CAPRICE94 experiment. Results from previous experiments are also shown [see ref. 6 for the references to the original works].

We show in Fig. 3 the hydrogen and helium fluxes measured in the same experiment, together with previous results: in particular, we note a very nice agreement between the CAPRICE94 measurements and the results from our previous experiment MASS2 [6]. In addition, we note a satisfactory agreement between our measurements and other recent results. It may be pointed out that most of the recent measurements seem to show a lower normalization than reported before. This occurrence may have profound implications for atmospheric neutrino predictions.

We refer the reader to the original references [1,8] for a full discussion of particle identification criteria and data analyses in the CAPRICE94 experiment.

5. CONCLUSION

The WiZard Collaboration has reported results on the atmospheric muon flux from a series of four balloon experiments performed in different experimental conditions. In this paper, we show muon results together with the spectra of primary hydrogen and helium measured in the CAPRICE94 experiment. Simultaneous measurements of primaries and muons can provide useful constraints to atmospheric neutrino calculations.

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