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MEASUREMENTS OF PRIMARY COSMIC-RAY HYDROGEN AND HELIUM BY THE WIZARD COLLABORATION

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ABSTRACT

We present the measurements of primary protons and helium nuclei performed by the WiZard Collaboration in different balloon-borne campaigns. A superconducting magnet spectrometer was used in these experiments together with detectors for particle recognition. These combinations of detectors made it possible to perform accurate particle measurements over a large (up to 200 GV for protons) energy interval. We focus in particular on the results from the MASS91 and CAPRICE94 experiments: We find a very good agreement between these two sets of measurements, also in comparison to other recent results. All these results seem to suggest that the normalization of primary cosmic rays may be significantly lower than previously estimated.

INTRODUCTION

Accurate measurements of the spectra of primary cosmic rays have deep astrophysical and cosmological implications, since they allow the mechanisms of galactic production and propagation of cosmic rays to be investigated. Measurements of primary particles have been performed using different techniques: magnet spectrometers have been used for energies up to 100–200 GeV/n, while calorimetric measurements can extend to higher energies. Comparisons among such measurements show sometimes significant discrepancies (up to 50%) (e.g., Gaisser, 1998).

Recently, the importance of the normalization of the primary cosmic-ray flux has been emphasized in connection to the interpretation of the atmospheric neutrino observations. A correct interpretation of these measurements depends on the accuracy of the predictions to which they are compared. The assumptions about the flux of cosmic rays which impinge on the Earth turn out to be among the main sources of inaccuracies in the simulation of atmospheric showers (e.g., Circella et al., 1997). More accurate measurements have been consequently advocated (e.g., Gaisser, 1998).

THE WIZARD COLLABORATION COSMIC-RAY MEASUREMENTS

The WiZard Collaboration is involved in a long-term investigation of primary cosmic rays with balloon-borne and satellite detectors. It has performed successful flights with the Matter Antimatter Spectrometer System (MASS) in 1989 and 1991, with the Transition RAdiation detector Measuring Positrons with Silicon calorimeter (TRAMP-Si) in 1993 and with the Cosmic AntiParticle Ring Imaging Cherenkov Experiment (CAPRICE) in 1994 and 1998.

These experiments were mainly devoted to the observation of cosmic-ray antiparticles (namely, positrons and antiprotons), as is reported separately at this conference (Boezio et al., 2000a). However the performances of these detectors were such that good particle discrimination was possible also for other species over large energy ranges. Consequently, detailed studies were also performed of the fluxes of atmospheric muons (Bellotti et al., 1996; Bellotti et al., 1999; Boezio et al., 1999a; Boezio et al., 2000b) and of primary protons and helium nuclei, as is discussed in this paper.

In addition to the balloon-borne experiments, the WiZard Collaboration has built and deployed the space telescope NINA, currently orbiting the Earth onboard the Russian satellite RESURS-IV, for the measurements of the solar, anomalous and galactic components of cosmic rays at energies of 10–100 MeV/n. The Collaboration is now building the space telescope PAMELA, which will be put into a polar orbit around the Earth on the Russian satellite RESURS-V, for measurements of antiprotons, positrons and light primary nuclei over a large energy range. The space experiment PAMELA is also presented at this conference (Vacchi et al., 2000; Bonvicini et al., 2000; Circella et al., 2000).

THE WIZARD COLLABORATION BALLOON-BORNE DETECTORS

The MASS91 Experiment

This experiment was performed from Ft. Sumner, New Mexico (USA) on September 23, 1991. The vertical rigidity cutoff for this flight was about 4.5 GV.

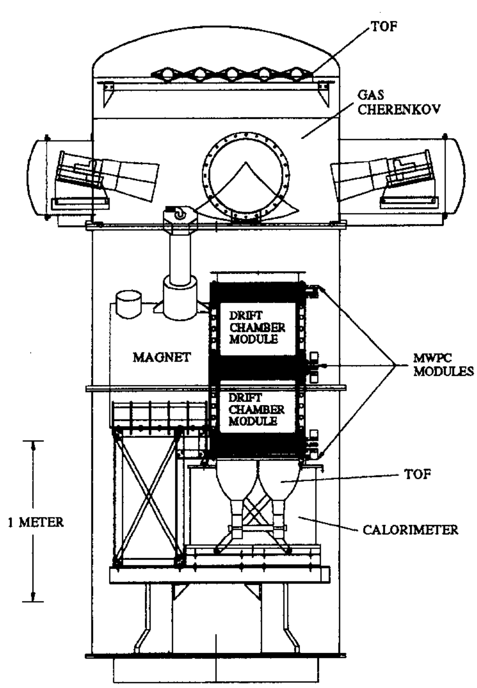

Fig. 1. The MASS apparatus in the 1991 experiment.

The experimental setup is shown in Figure 1: it consisted of a superconducting magnet spectrometer, a time-of-flight device, a gas threshold Cherenkov detector and a streamer tube imaging calorimeter.

The magnet spectrometer consisted of a single coil superconducting magnet, which was used also in the following flights, and a hybrid tracking device which included 8 multiwire proportional chambers and two sets of drift chambers for a total of 20 measurements along the direction of maximum bending and 12 measurements along the perpendicular view. The total height of the spectrometer was about 110 cm. The magnet was operated at a current of 120 A, giving rise to a field of intensity 0.1–2 T in the region of the tracking device. The Maximum Detectable Rigidity (MDR) for this configuration of the spectrometer was estimated to be above 200 GV for singly charged particles (Hof et al., 1996).

The time of flight consisted of two planes of scintillator separated by a distance of 2.36 m, one located at the top of the apparatus and the other one located below the tracker and above the calorimeter.

The upper plane consisted of two layers of scintillator, segmented into 5 paddles of 20 cm width and variable length inserted in the round section of the payload's shell. The lower plane consisted of a single scintillator layer segmented into two paddles. The signals from each paddle of scintillator were independently digitized for time-of-flight measurements as well as for pulse height analyses.

The Cherenkov detector consisted of a 1 m tall cylinder of Freon 22 at the pressure of 1 atm. Four segments of spherical mirror focussed the light onto four photomultipliers. The threshold Lorentz factor for Cherenkov emission was $\gamma_{th} \simeq 25$.

The calorimeter consisted of 40 layers of 64 brass streamer tubes each. The tubes from adjacent layers were arranged along perpendicular directions. The total depth of the calorimeter was 40 cm, equivalent to 7.3 radiation lengths and 0.7 interaction lengths for protons.

The CAPRICE94 Experiment

This experiment was performed with launch from Lynn Lake, Manitoba (Canada) on August 8-9, 1994. The vertical rigidity cutoff for this flight was around 0.65 GV.

The experimental setup is shown in Figure 2: it consisted of a superconducting magnet spectrometer, a time-of-flight device, a Ring Imaging Cherenkov detector (RICH) and a silicon-tungsten imaging calorimeter. The magnet spectrometer was the same as in the 1991 experiment.

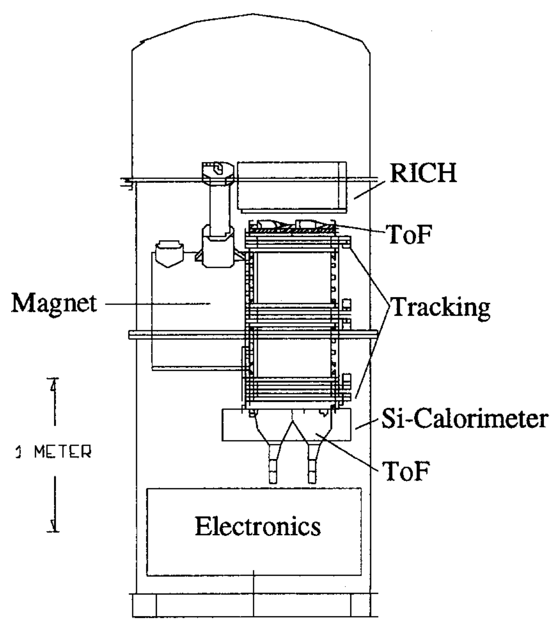

Fig. 2. The CAPRICE apparatus in the 1994 experiment.

The time-of-flight consisted of two planes of scintillator separated by a distance of 1.1 m, located just above and below the tracking device. Each plane was segmented into two paddles viewed at opposite ends by photomultipliers. The signals from each paddle of scintillator were independently digitized for time-of-flight measurements as well as for pulse height analyses.

The RICH detector used a solid NaF ($\gamma_{th} \simeq 1.5$) radiator and a photosensitive MWPC. The active area of this detector was 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.

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.

The CAPRICE98 Experiment

A renewed configuration of the CAPRICE apparatus was used in a balloon-borne experiment performed from Ft. Sumner, New Mexico (USA) on May 28, 1998 at a vertical rigidity cutoff of about 4.3 GV.

The experimental setup consisted of a superconducting magnet spectrometer, a time-of-flight device, a gas RICH detector and a silicon-tungsten imaging calorimeter.

With respect the the 1994 experiment, improvements were made to the magnet spectrometer, equipped with three sets of drift chambers, reaching an MDR larger than 300 GV and to the electronics of the time-of-flight device, which could reach a time resolution of the order of 200 ps. In addition, the RICH detector used a 1 m tall gas (C_4F_{10}, $\gamma_{th} \simeq 18$) radiator, thus shifting the range where a velocity measurement could be performed by this detector to higher energies.

More details on the instrumental setup and particle discrimination capabilities of this experiment can be found in Ambriola et al. (1999).

PRIMARY COSMIC-RAY MEASUREMENTS FROM MASS91 AND CAPRICE94

Hydrogen Measurements

Protons constitute the most abundant component in primary cosmic rays. Therefore, the background from other particles is not expected to be significant, although this includes atmospheric secondaries created in interactions in the residual atmosphere above the detector (depths of 3–5 g/cm^2, typically).

Protons may be reliably identified by the magnet spectrometers used in the 1991 and 1994 experiments: namely, reconstruction of the track in the spectrometer allowed single events to be selected. From the curvature of the particle in the magnetic field its rigidity, hence its momentum, was inferred. The time-of-flight information was used in order to select downward moving particles. The pulse height information was used to select singly charged particles. The calorimeter provided topological information used to select non interacting particles or to discriminate between hadronic and elecromagnetic showers. In addition to this capability, the energy measurements performed by the silicon calorimeter of 1994 allowed the charge of the particles to be measured.

The mass of a particle may be inferred by means of a simultaneous determination of its momentum (or energy) and velocity. This was possible, in different energy ranges, for both these experimental setups. For instance, in the case of CAPRICE94 the isotope discrimination based on the combined use of the RICH and the magnetic spectrometer was such that deuterons could be distinguished from protons up to 5 GV, and that a ^{3}He-^{4}He discrimination was possible up to 4 GV.

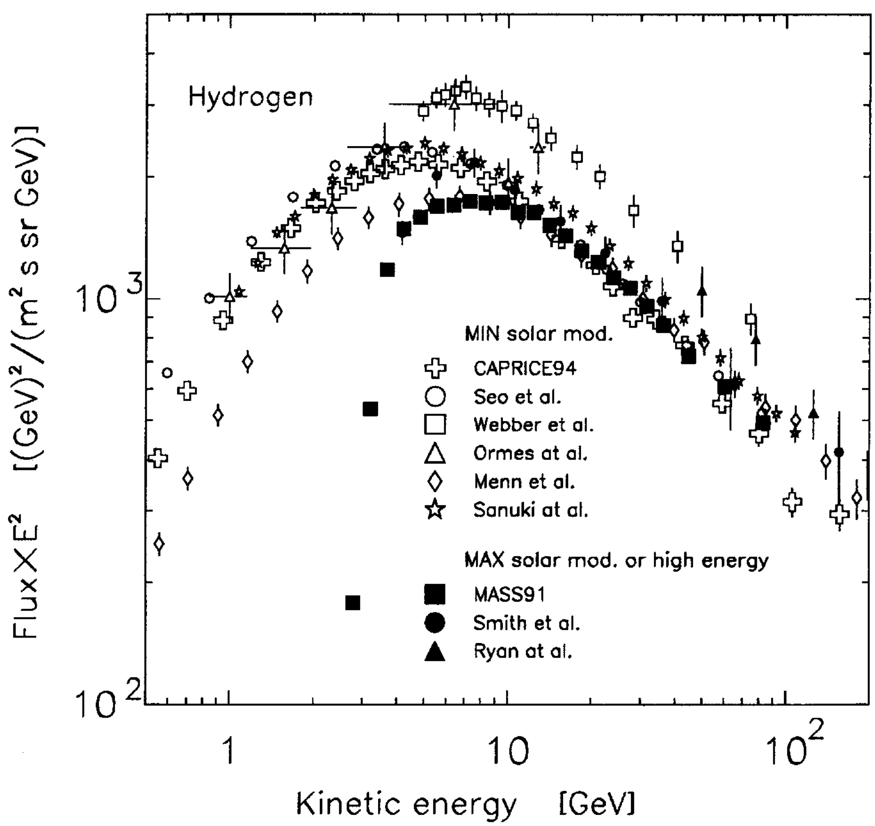

Fig. 3. The hydrogen spectra at the top of atmosphere detected by MASS91 and CAPRICE94. Results from other experiments are also shown (see Bellotti et al. (1999) for the references).

More details on particle identification and data analysis can be found in Bellotti et al. (1999) and Boezio et al. (1999b).

We show the spectra of primary hydrogen detected in the two experiments in Figure 3, where they are also compared to results from other experiments. The measurements reported by the detectors have been corrected for the interaction losses and energy degradation in the apparatus, and then propagated to the top of the atmosphere by compensating for the attenuation of the particles due to interactions in the overlying atmosphere and the production of secondary particles which contribute to the flux measured at the detector level.

We note from this figure that the two sets of results are in a very close agreement: The data agree within the estimated level of accuracy, which in both cases is of the order of 10% for energies larger than a few GeV (see Bellotti et al., 1999 and Boezio et al., 1999b for a full discussion).

We also note a satisfactory agreement between our measurements and other recent results (Seo et al., 1991; Menn et al., 2000; Sanuki et al., 2000). However, discrepancies may be noted which can not be ascribed to the different experimental conditions, since they are apparent also at energies of tens of GeV. In particular, the recent results from Sanuki et al. (2000) are higher than both our sets of results at a level which is barely consistent with the estimated uncertainties. Menn et al. (2000) report a particle spectrum slightly flatter than ours.

In spite of these discrepancies, we may note that the level of agreement among the most recent measurements is within 10-20%, which constitutes a significant progress with respect to previous years. This occurrence is particularly important in consideration of the fact that the normalization of these recent measurements is in some cases significantly lower than older measurements.

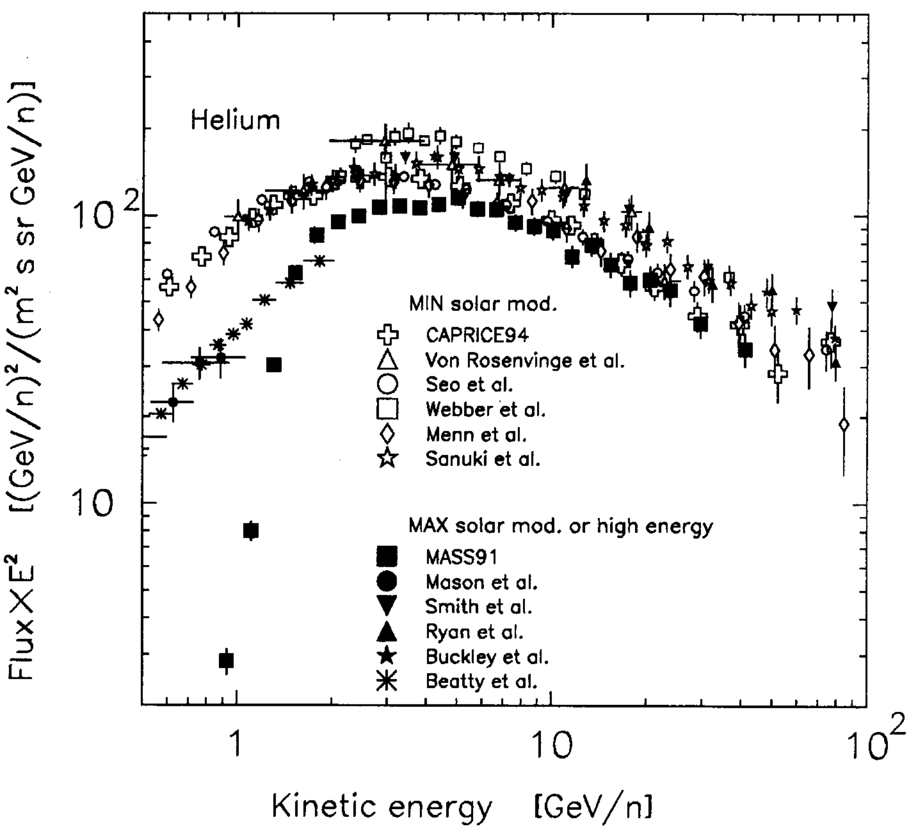

Fig. 4. The helium spectra at the top of atmosphere detected by MASS91 and CAPRICE94. Results from other experiments are also shown (see Bellotti et al. (1999) for the references).

Helium Measurements

The selection of helium events is based primarily on the identification of Z=2 particles by means of the scintillators and, in the case of CAPRICE94, of the silicon calorimeter. Due to the Landau fluctuations in the ionization loss of charged particles, protons may contaminate at a low level the helium measurements. A correction was made to the MASS91 results in order to compensate for this effect. No other source of background may significantly affect the results.

We show in Figure 4 the spectra of helium nuclei at the top of atmosphere measured by MASS91 and CAPRICE94, together with results from other experiments.

Also in this case, we note a satisfactory agreement between the two sets of results as well as between them and other recent results. However, the discrepancies found are typically larger than for hydrogen. This may result from the larger difficulties inherent in the helium measurements: namely, larger (and presumably less accurate) atmospheric corrections, smaller detection efficiencies, corrections for the possible background from singly charged particles. In fact, all of the detectors which report both helium and hydrogen measurements quote typically larger uncertainties on the helium flux.

It may be pointed out that most of the recent measurements seem to show a lower normalization than reported before.

CONCLUSIONS

We have summarized the contribution coming from the WiZard Collaboration experiments to the investigation of the primary cosmic rays at energies of 1–200 GeV/n. In particular, two different experiments give hydrogen and helium results which consistently show that the normalization of previous measurements could have been overestimated.

This scenario will soon improve thanks to the upcoming results from the latest balloon-borne detector deployed by the WiZard Collaboration in 1998.

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