A MEASUREMENT OF THE PROTON SPECTRUM AT 1 AU NEAR SOLAR MINIMUM WITH THE CAPRICE EXPERIMENT

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ABSTRACT

We report on a preliminary result of the absolute proton spectrum in the energy range 0.15 to 100 GeV at the top of the atmosphere as measured by the balloon-borne experiment CAPRICE flown from Lynn Lake, Manitoba, Canada, on August 8-9, 1994. The experiment used the NMSU-WiZard/CAPRICE balloon-borne magnet spectrometer equipped with a solid radiator Ring Imaging CHerenkov (RICH) detector and a silicon-tungsten calorimeter for particle identification. More than 365 000 protons were identified in the energy range 0.15 to 100 GeV at the spectrometer. The proton spectrum is obtained with a negligible contamination below 4 GeV. Above this energy there is a small (1-2%) contamination from deuterons. The data were collected over 18 hours at a mean residual atmosphere of 3.9 g/cm^2. Observation of the proton spectrum below a few GeV without the contamination of D, e$^+$, μ^+ and π^+ has been made for the first time.

INTRODUCTION

Detailed measurements of the proton flux at 1 AU over a wide energy range is important to understand the production and acceleration mechanism of cosmic rays, as well as the solar modulation effect on these particles. Combining proton spectrum measurements from a number of different experiments, Gaisser and Schaefer (1992) find that the spectral index is in the range 2.65-2.75. However, they show that an uncertainty of ± 0.05 is significant and e.g. leads to a 20% spread in the predicted secondary antiproton flux between 5 and 15 GeV. There is also a large disagreement in the reported absolute proton flux values, the spread is of the order of $\pm 25\%$ at energies above 10 GeV and as much as a factor of 2 at lower energies after correcting for solar modulation effects. A detailed measurement with accurate determination of the detector efficiencies is therefore important.

DETECTOR SYSTEM

The NMSU-WiZard/CAPRICE spectrometer was flown by balloon from Lynn Lake, Manitoba, Canada (56.5° North Latitude, 101.0° West Longitude), on 8-9 August 1994 at an atmospheric pressure of 3.2 to 4.5 mbar (altitude of 36.0 - 38.1 km) for 23 hours. It included from top to bottom: a Ring Imaging Cherenkov (RICH) detector, (Carlson et al. 1994, Barbiellini et al. 1996a), a time-of-flight (ToF) system, a magnet spectrometer equipped with multiwire proportional chambers (MWPC) and drift chambers (DC) (Golden et al. 1978, Golden et al. 1991, Hof et al. 1994) and a silicon-tungsten imaging calorimeter (Bocciolini et al. 1996) .

PROTON SELECTION

The analysis was based on 18 hours of data collection for a total acquisition time of 60520 seconds under an average residual atmosphere of 3.9 g/cm^2. The fractional dead time during the flight was 0.7310 ± 0.0006 resulting in a total live time of 16280 ± 36 s.

Protons are the most abundant positively charged particles in the cosmic radiation, accounting for about 98% of all single charged particles . The remaining fraction is mainly deuterons and a small fraction of positrons (Reimer et al. 1995, Barbiellini et al. 1996b). As a result, the concern in determining an absolute flux of protons is not primarily to eliminate the contamination, but to estimate reliable detector efficiencies. Strict requirements on the tracking and scintillator information resulted in a clean sample of positive unit charged particles from which the protons were selected. The requirements represent a compromise between rejection power and efficiency and are partly based on experience gained previously using the same tracking and scintillator system (Golden et al. 1991, Mitchel et al. 1996, Hof et al. 1996). The average maximum detectable rigidity of the instrument was 172 GV/c.

The separation between protons and deuterons was possible between 0.4 and 5 GV/c using the calorimeter and the RICH. The calorimeter could separate protons from deuterons between 0.4 and 2 GV/c from the dE/dx measurements in the silicon strip layers. The RICH was used to measure the Cherenkov angle of the particle and thereby its velocity, and could separate protons from deuterons between 1.2 and 5 GV/c (Weber 1997).

EFFICIENCY AND CONTAMINATION

The NMSU-WiZard/CAPRICE instrument has a unique capability to reliably determine the detector efficiencies as well as to eliminate the contamination, as it allows selection of clean particle samples using independent sets of detectors. The detector efficiencies as a function of rigidity were determined using a large proton sample from the flight data.

The instrument allows the selection of protons with a negligible contamination between 0.4 and 5 GV/c. Above 5 GV/c the instrument cannot distinguish between protons and deuterons, and the small deuteron component is included in the proton sample.

PROTON SPECTRUM AT THE TOP OF THE ATMOSPHERE

All protons interacting with the payload material above the tracking system were assumed to be rejected by the selection criteria. The data were corrected for these losses with multiplicative factors, using the expression for the interaction mean free path for the different materials in the detectors given by Stephens (1997).

For the atmospheric secondary proton production, we used the data of Papini et al. (1996). The secondary produced particles were normalized with the acceptance and live time of the experiment, and subtracted from the corrected numbers using a mean residual atmosphere of 3.9 g/cm^2. Finally, the data were corrected for losses in the atmosphere above the detector due to interactions, giving the number of protons at the top of the atmosphere. The geometrical factor at different rigidities was obtained with a Monte Carlo technique (Sullivan 1971).

The resulting preliminary proton spectrum values are is shown in Table 1 and Figure 1. The errors include both statistical and systematic uncertainties. A fit of a power law spectrum between 20 and 100 GeV results in a flux of (1.01$\pm$0.13) $\times 10^4$ $\times$ E$^{-2.70\pm0.07}$.

CONCLUSION

The proton spectrum at solar minimum has been measured without the contamination of D, e$^+$, μ^+ and π^+ between 0.15 and 100 GeV kinetic energy at the top of the atmosphere. A fit to a power law distribution between 20 and 100 GeV results in an energy spectrum of (1.01$\pm$0.13) $\times 10^4$ $\times$ E$^{-2.70\pm0.07}$ (m^2 sr s GeV)$^{-1}$. At low energies the proton spectrum bends over due to solar modulation and reaches a broad maximum around 0.5 GeV.

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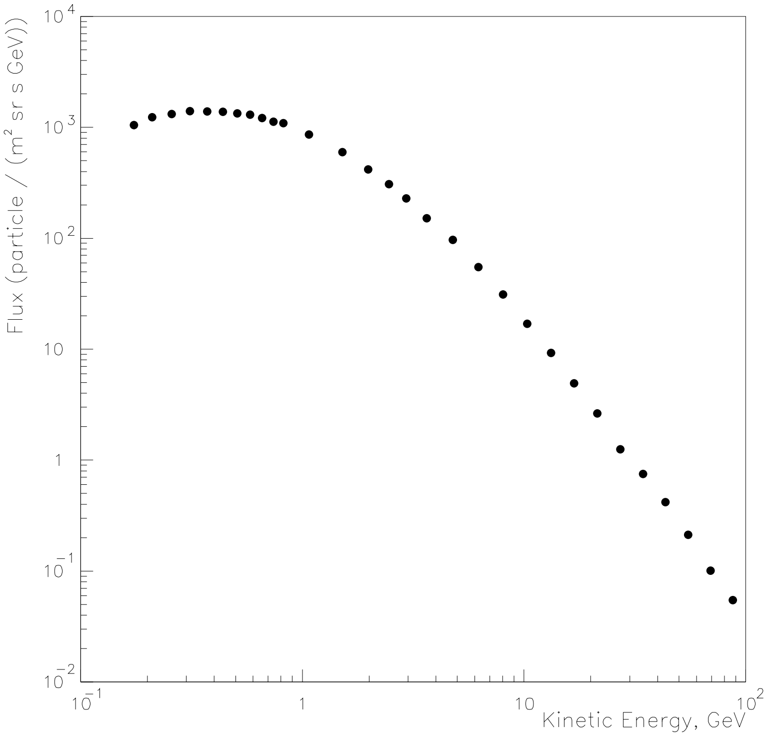

Fig. 1: The proton flux at the top of the atmosphere obtained in this work .

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Table 1: The Proton Spectrum at the Top of the Atmosphere.

Kinetic energy (GeV)		Proton Spectrum (particles/(m^{2} sr s GeV))
0.15 - 0.18	0.17	$(1.05 \pm 0.09) \cdot 10^{3}$
0.18 - 0.23	0.21	$(1.23 \pm 0.06) \cdot 10^{3}$
0.23 - 0.28	0.26	$(1.32 \pm 0.05) \cdot 10^{3}$
0.28 - 0.34	0.31	$(1.40 \pm 0.04) \cdot 10^{3}$
0.34 - 0.40	0.37	$(1.39 \pm 0.03) \cdot 10^{3}$
0.40 - 0.47	0.44	$(1.38 \pm 0.03) \cdot 10^{3}$
0.47 - 0.54	0.51	$(1.34 \pm 0.03) \cdot 10^{3}$
0.54 - 0.62	0.58	$(1.29 \pm 0.03) \cdot 10^{3}$
0.62 - 0.70	0.66	$(1.21 \pm 0.03) \cdot 10^{3}$
0.70 - 0.78	0.74	$(1.12 \pm 0.03) \cdot 10^{3}$
0.78 - 0.86	0.82	$(1.09 \pm 0.03) \cdot 10^{3}$
0.86 - 1.30	1.07	$(8.58 \pm 0.18) \cdot 10^{2}$
1.3 - 1.8	1.5	$(5.95 \pm 0.14) \cdot 10^{2}$
1.8 - 2.2	2.0	$(4.18 \pm 0.12) \cdot 10^{2}$
2.2 - 2.7	2.5	$(3.08 \pm 0.07) \cdot 10^{2}$
2.7 - 3.2	2.9	$(2.29 \pm 0.06) \cdot 10^{2}$
3.2 - 4.2	3.6	$(1.51 \pm 0.04) \cdot 10^{2}$
4.2 - 5.5	4.8	$(9.65 \pm 0.17) \cdot 10^{1}$
5.5 - 7.1	6.2	$(5.51 \pm 0.10) \cdot 10^{1}$
7.1 - 9.2	8.1	$(3.11 \pm 0.06) \cdot 10^{1}$
9.2 - 11.8	10.3	$(1.70 \pm 0.04) \cdot 10^{1}$
11.8 - 15.0	13.2	$(9.29 \pm 0.21) \cdot 10^{0}$
15.0 - 19.1	16.8	$(4.92 \pm 0.12) \cdot 10^{0}$
19.1 - 24.2	21.4	$(2.65 \pm 0.07) \cdot 10^{0}$
24.2 - 30.7	27.1	$(1.25 \pm 0.04) \cdot 10^{0}$
30.7 - 38.9	34.4	$(7.52 \pm 0.27) \cdot 10^{-1}$
38.9 - 49.1	43.5	$(4.18 \pm 0.17) \cdot 10^{-1}$
49.1 - 62.0	54.9	$(2.12 \pm 0.11) \cdot 10^{-1}$
62.0 - 78.2	69.3	$(1.00 \pm 0.06) \cdot 10^{-1}$
78.2 - 99.1	87.5	$(5.46 \pm 0.41) \cdot 10^{-2}$