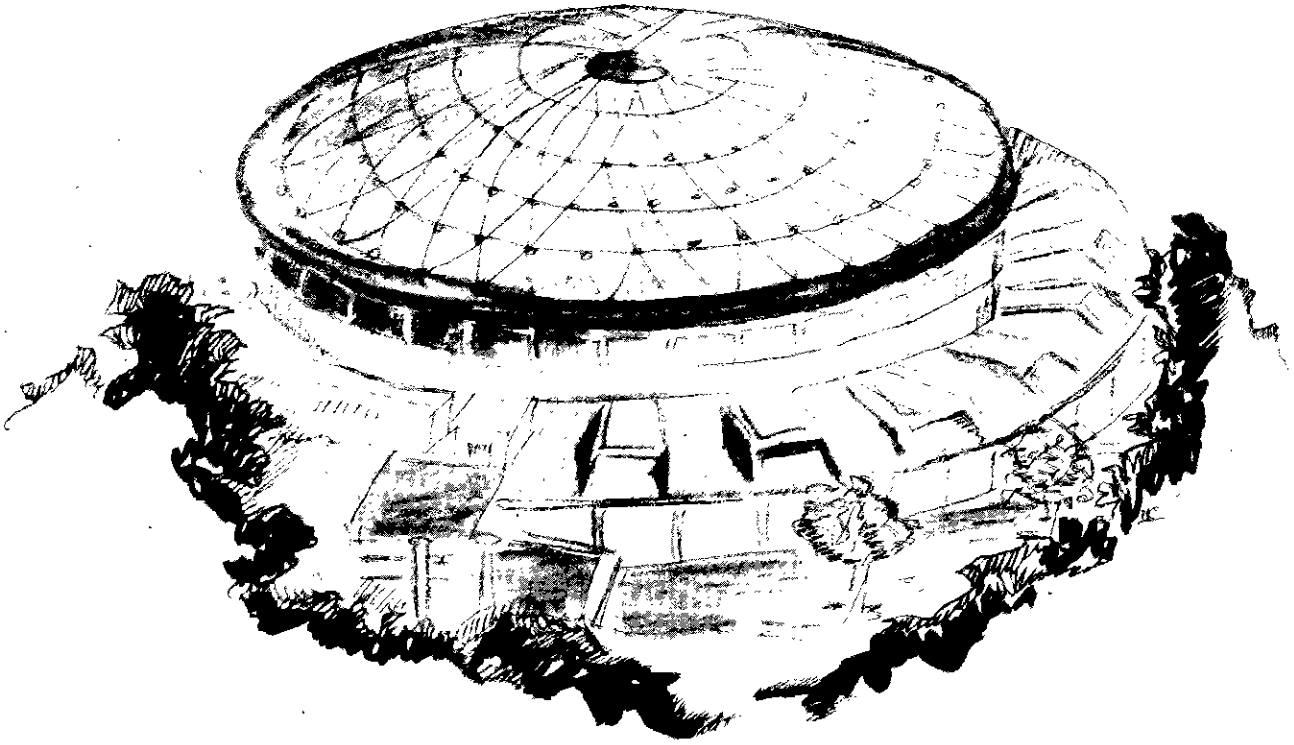
Laboratori Nazionali di Frascati

LNF-93/055 (R)
10 Settembre 1993

WIZARD - MASS Collaboration

Papers presented at the XXIII International Cosmic Rays Conference, Calgary 1993



Servizio Documentazione
dei Laboratori Nazionali di Frascati
P.O. Box, 13 - 00044 Frascati (Italy)

LNF-93-055-RB

Calgary 1993 XXIII ICRC OG 5.3.1 v.1

Observations of Proton And Helium Spectra Near Solar Maximum.

P. Papini[5],C. Grimani[6],G. Basini[1], F. Bongiorno[1], M. T. Brunetti[6], A. Codino[6], R. L. Golden[2], B. L. Kimbell[2], F. Massimo Brancaccio[1], M. Menichelli[6], M. Miozza[6], A Morselli[3], J.F.Ormes[4], M. P. De Pascale[3], P. Picozza[3], M. Ricci[1], I. Salvatori[6], P. Spillantini[5], S. A. Stephens[2,7], S. J. Stochaj[2], R. E. Streitmatter[4], W. R. Webber[2]

1. INFN-Laboratori Nationali di Frascati, Italy, 2. New Mexico State University, New Mexico, USA 3. Dipartimento di Fisica and INFN dell'Universita' di Roma "Tor Vergata", Italy 4. NASA - Goddard Space Flight Center, Maryland. USA 5. Dipartimento di Fisica and INFN dell'Universita' di Firenze, Italy 6. Dipartimento di Fisica and INFN dell' Universita' di Perugia, Italy 7. Tata Institute of Fundamental Research, Bombay, India 8. Dipartimento di Fisica and INFN dell'Universita' di Roma, Italy.

ABSTRACT

Measurements of the proton and helium spectra were made on September 5th 1989 using the balloon-borne experiment MASS. The instrument was above 10 g/cm^2 for 5.5 hours near Prince Albert, Saskatchewan (Canada). The measured fluxes have been corrected to the top of the atmosphere. At the top of the atmosphere, the kinetic energy range of the observations was 0.117 - 39 GeV/n for protons and 0.171 - 19.97 GeV/n for helium. The measurements have been performed during 1989, very near the maximum of the last solar cycle. On the day of the flight the Mt. Washington Neutron Monitor rate was 1961.

1. INTRODUCTION

Protons and helium nuclei are the main cosmic ray constituents (about 98%). The intensity and energy distributions of these particles, as observed at earth, are known to be modulated by the solar wind. This knowledge was gained primarily by observations made for more than 4 decades of integral count rates above the local geomagnetic cutoff. The advent of magnetic spectrometers has possible to make much more detailed measurements of solar modulation over large energy ranges, by observing differential energy spectra. This paper represents the first step in providing a summary of observations of proton and helium differential energy spectra over the last 17 years. There are spectra from 5 previous flights of this instrument dating back to 1976 which will be reported in a future compendium of our observations. The observations reported here are of special value because this version of the instrument incorporated an imaging calorimeter, which allowed significant improvements in the accuracy to which the observing efficiencies could be determined. The flight reported here also happen to take place during the strongest solar activity experienced during our observing program. The high energy spectra from this flight provides a means of cross-calibrating and cross-checking the intensities and energy spectra observed in the earlier flights.

In this paper we describe the instrument and data analysis briefly in sections 2 and 3. Section 4 contains the results and section 5 provides a summary of the findings.

2. EXPERIMENT

The MASS apparatus consists of a superconducting magnet spectrometer, a scintillator TOF system (T1 -T2 above the spectrometer and T3 - T4 below the spectrometer), a high resolution scintillator (S1), a gas-Cherenkov detector and a streamer tube calorimeter. The magnetic spectrometer which uses multi-wire proportional chambers (MWPC) is described in Golden et al. (1991). Event read-out is initiated by a coincidence between T1, T2, T3 and T4. Events transmitted to the ground were also required to have an S1 pulse-height greater than 0.25 times that corresponding to a minimum ionizing particle.

The Cherenkov detector was filled with a 50 - 50 mixture of Freon 12 and Freon 22 that has a threshold of Lorentz factor of 23. The calorimeter each consisted of 40 layers of 64 brass streamer tubes. The material in the calorimeter is equivalent to 7.3 radiation lengths and 0.7 nuclear interaction lengths. The calorimeter permits the reconstruction of the topological structure of the particle interactions. More details on the apparatus performance and characteristics are given in De Pascale et al., 1991 and references therein.

3. DATA ANALYSIS

Data analysis has been performed selecting positive particles in the rigidity r (r=p/Zq) interval 0.310 - 40 GV/c (as measured at the magnetic spectrometer) for protons and 1 - 41.7 GV/c for helium. The selection criteria for the MWPC are those given in (Golden et al. 1991). The scintillators T1- T2 - T3 - T4 and the high resolution scintillator S1 were used to determine the charge of each particle. The amplitude of the signal (P) generated by a particle going through a scintillator is related to the particle mass (m), deflection (d) and charge (Z), from the relation:

$$P = (m\,d)^2 + Z^2$$

Therefore it is possible to separate particles with different charge, plotting the scintillator output versus the particle deflection squared. In Fig. 1 shows the separation between particles with charge 1 (protons) and 2 (helium).

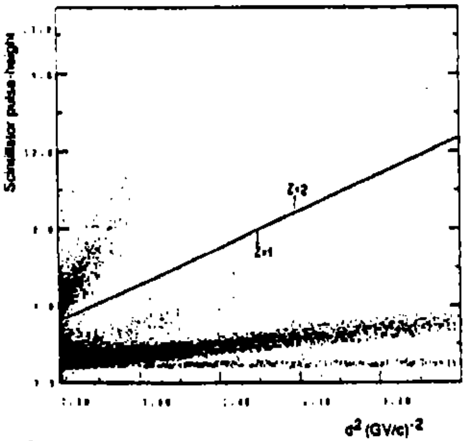


Fig. 1 Helium - proton separation using the scintillator (S1) pulse-height vs deflection squared.

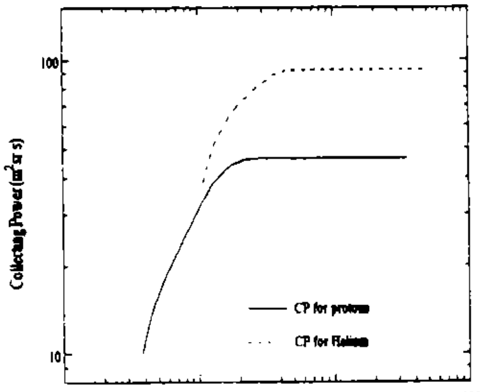


Fig. 2 . Proton and Helium Collecting Power.

4. RESULTS

The proton and helium spectra at the top of the atmosphere have been first obtained calculating the rigidity fluxes at the spectrometer, including the experiment geometrical factor, the efficiencies of the detectors and the total exposure time, then recalculating the fluxes versus kinetic energy and propagating them to the top of the atmosphere. The geometrical factor and the MWPC efficiency are energy dependent. This dependence has been described in detail in De Pascale et al., 1991.

The total elapsed time was 19812 sec., with 33% dead-time due to on-board data processing. Six percent of the data are lost due do computer dead time during transcription of the analog tapes. Since Z=1 particles require the calorimeter and Cherenkov for proper identification, we selected these particles in a restricted geometry (Basini et al. 1991). The master trigger was cross-checked with smaller trigger paddles on the ground, to make sure the overall geometric factor and sensitivity were determined. The effective efficiency of the master trigger was found to be 0.90. Helium was selected with a less restrictive geometry. The effective trigger efficiency was 0.83. The collecting power for both proton and helium are given in Fig. 2.

The proton rigidity spectrum as measured at the spectrometer (Fig. 3), were corrected to the top of the payload using a multi-step process. The first step was to correct for the ionization energy losses in the detectors located above the spectrometer. Then the secondary proton flux, mainly produced from primary proton interaction in the 5 g/cm^2 of residual atmosphere overlying the payload, was subtracted using the secondary spectra computed by Rygg and Earl, 1971. The Rygg and Earl spectrum was calculated for a Deep River Neutron Monitor rate of 6700, which corresponds to a substantially lower solar modulation than that during the observation reported here. To correct for the differences in modulation strength, the Rygg and Earl spectrum of secondaries was normalized using our observations below the geomagnetic cut-off (650 MV/c).

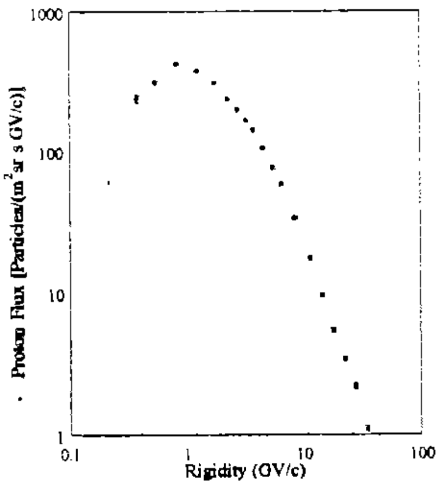


Fig. 3 : Proton flux at the magnetic spectrometer.

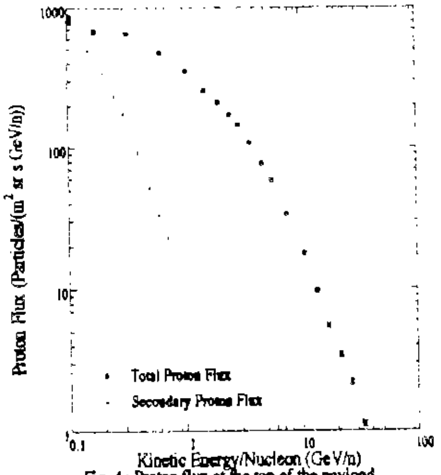


Fig. 4 : Proton flux at the top of the payload with secondary particle contribution shown.

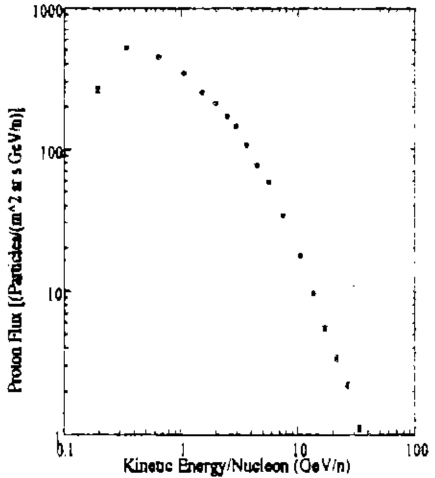


Fig. 5 : Proton flux at the top of the atmosphere.

The contribution of the secondary protons to the total flux at the top of the payload is shown in Fig. 4. The final step was to correct for the ionization energy losses in the atmosphere. In Fig. 5 we show our observed proton spectrum corrected to the top of the atmosphere. Note that the spectra were not corrected for the finite resolution of the momentum spectrometer. As reported in Golden et al. 1991, the maximum detectable rigidity was found to be 118 GV for this observation. This corresponds to nearly a factor of 3 higher rigidity than that reported in this observation.

The helium flux at the spectrometer (Fig. 6) was corrected to the top of the atmosphere by allowing for the ionization energy losses in the atmosphere and in the payload. Corrections were also made for helium interactions in the payload and atmospheric productions/interactions. The helium flux at the top of the atmosphere is presented in Fig. 7.

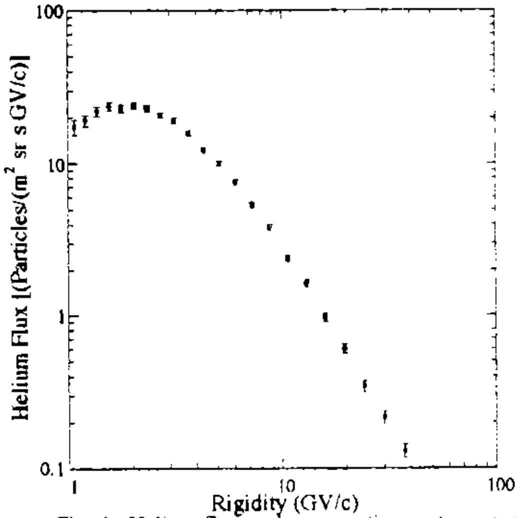


Fig. 6 : Helium flux at the magnetic spectrometer.

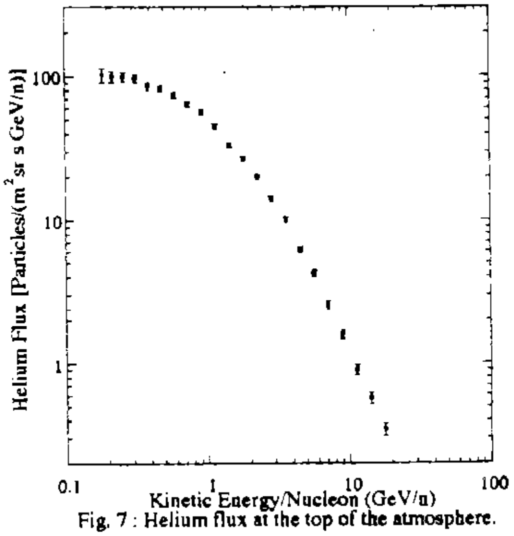


Fig. 7 : Helium flux at the top of the atmosphere.

5. DISCUSSION

Both the proton and helium intensities show extreme depression at lower energies. In comparison to data from previous flights, we find the fluxes reduced by 2-5 times at low energies (less than 10 GeV/n). The proton spectrum at the top of the atmosphere can be represented by a power law in kinetic energy/nucleon with a spectra index of (-2.33±0.03) at energies greater than 10.5 GeV/n. For helium the spectral index is found to be (-2.19±0.17) at energies greater than 8.9 GeV/n. These spectra are very flat compared to the more typical spectral indices of (2.6 - 2.7) reported by previous observations by this group and by others. As a cross-check that the momentum spectrometer was working correctly and properly calibrated, the spectrum of protons accompanied by Cherenkov light, was used to confirm that the threshold rigidity corresponded to a Lorentz factor of 23. It is believed this extraordinary change in spectral index is due to solar modulation. Data from past and future flights of our experiment, carried-out during different periods of solar modulation will give us interesting hints about solar modulation effects on both protons and helium during their propagation to the Earth.

6. ACKNOWLEDGMENT

This work was supported by NASA grant NAG-110, the Istituto Nazionale di Fisica Nucleare, Italy and the Agenzia Spaziale Italiana. A very special thank to our technical support staff from NMSU and INFN.

REFERENCES

Basini, G. et al.:1991, Proc. 22th Internat. Cosmic Ray Conf., Dublin (Ireland), **2**, 137, also submitted to Ap. J..
De Pascale, M.P., et al.,:1993, J. Geophys. Res., **98**(A3), 3501.
Der Verma, S.:1967, J. Geophys. Res., **72**(3), 915.
Golden, R.L. et al.:1991, Nucl. Instr. Meth., **A396**, 366.
Rygg, T.A. and Earl, J.A.:1971, J. Geophys. Res., **76**(31) 7445.
Teegarden, B.J.:1967, J. Geophys. Res., **72**(19), 4857.