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LETTER TO THE EDITOR

Cosmic ray investigation of the proton–proton cross section in the energy range 2×10^{12}–5×10^{13} eV

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Abstract. Experimental results on the intensity of surviving cosmic ray protons at an atmospheric depth of 550 g cm^{-2} by Murakarmi *et al* have been used together with measurements of the primary spectrum to show that there is no evidence to suggest a change in the magnitude of the inelastic proton–proton cross section up to 5×10^{13} eV.

The magnitude of the cross section for proton–proton collisions and its variation with proton energy is an important datum in high energy physics. Results from the accelerators, culminating in the recent studies at CERN with the intersecting storage rings (ISR) have shown its near constancy, over the range 5×10^9 to about 10^{12} eV.

Cosmic ray results afford the possibility of extending the measurements to higher energies and this is the subject of the present work. Many cosmic ray measurements have shown that the attenuation length of the nuclear active component as a whole (nucleons and pions) is constant to the limit of measurement ($\sim 10^{14}$ eV) but as this relates to both the elementary cross section, the nucleon inelasticity and the slope of the energy spectrum its interpretation is not unique (a detailed survey of the data will be given shortly by Kempa *et al*). Instead we use data from an experiment at Mt Chacaltaya by Murakami *et al* (1970) in which the flux of surviving primary protons was recorded. Provided that the device can make an accurate estimate of proton energy, and that protons which have interacted in the 550 g cm^{-2} of air above the instrument can be definitely recognized, then, if the primary spectrum is known, a good measurement of the inelastic cross section for proton–air nucleus collisions will result.

A number of estimates of the spectrum of primary protons have been made and these can be divided into two types—those derived from direct measurements, and those from indirect analyses untilizing measurements made on other components lower in the atmosphere. The most recent direct measurement is that by Ryan *et al* (1972) covering proton energies up to 2×10^{12} eV. Figure 1 shows this spectrum extrapolated to cover the range up to 5×10^{13} eV. Also shown in figure 1 is the spectrum used by de Beer *et al* (1969) in a number of studies of extensive air shower data. In the region shown it was derived largely from data on muons and implicit in the derivation was the assumption of an energy independent p–p cross section together with the adoption of a particular model for high energy collisions (see de Beer *et al* 1966 for details). If the recent results from the ISR experiment are assumed to be valid beyond their region of measurement ($1{\cdot}5 \times 10^{12}$ eV) then the indirect intensities will fall a little and be somewhat closer to the measurements of Ryan *et al* (this in itself gives a strong suggestion that there is not much variation of p–p cross section over the energy range in question).

We consider now the Chacaltaya experiment. Measurements were made of the frequency of vertical and ommidirectional events and of the two, we consider the former to be of greater value. These are plotted in figure 1. The most serious bias

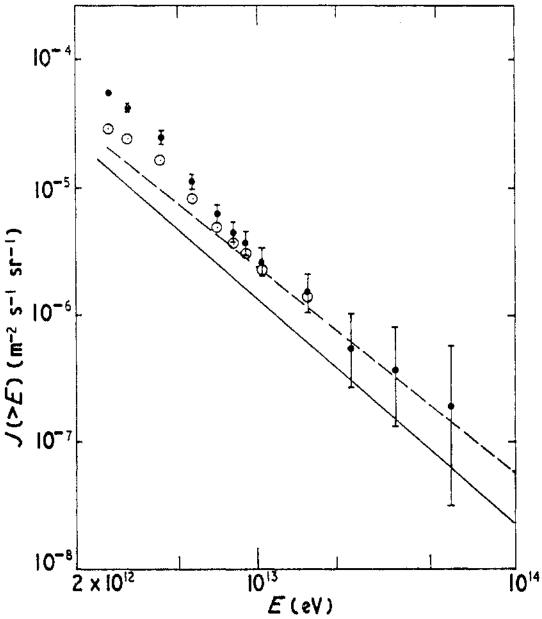

Figure 1. Integral spectrum of surviving protons in the vertical direction at a depth of 550 g cm^{-2} air. The full circles represent the measured intensities of Murakarmi *et al* (1970) and the open circles are corrected intensities using the analysis of MacKeown (1970). The full line is that predicted from an extrapolation of the directly measured primary spectrum of Ryan *et al* (1972) and the broken line comes from the spectrum given by de Beer *et al* (1969); in both cases it is assumed that the cross section for p–p interactions is unchanged from its value at accelerator energies.

effect which we know of is the presence of protons which have in fact interacted, and should therefore not be included, but are not recognized as such because of the very low density of the associated shower. MacKeown (1970) has made a detailed analysis of this point and has calculated correction factors for a variety of assumptions about the distribution of inelasticity in the proton–nucleus collisions and about geometrical factors. We have taken correction factors from this work, for what appear to be reasonable assumptions, and applied them to the points given in figure 1. The corrected intensities are indicated.

A comparison of the corrected intensities with the spectrum of Ryan *et al* shows quite good agreement as to the slope and there is thus no evidence for a change of inelastic cross section over the range 2×10^{12}–5×10^{13} eV. Such difference as there is between the points and the line can be understood in terms of a systematic error in one or other of the intensities or an error in extrapolation; we do not regard it as serious.

Our conclusion is markedly different from that of Yodh *et al* (1970, 1972) who strongly assert that the Chacaltaya results indicate an increase in cross section over the energy range in question. The reason for the difference is that Yodh *et al* used an energy spectrum of surviving protons from the Chacaltaya data which was only a lower limit and not the best estimate of the spectrum.

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