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# SEARCH FOR HIGHLY CHARGED PARTICLES IN THE COSMIC RAYS

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## ABSTRACT

The recently obtained results on $e^+e^- \rightarrow$ hadrons and multigamma production in pp collisions provide some support for a previously made argument that heavy, highly charged subnucleons may exist, and a search for such particles in the cosmic rays has been made. In 620 hours no candidates were detected, and an upper limit for the unaccompanied particle flux of $7 \cdot 10^{-10}$ cm$^{-2}$sec$^{-1}$sr$^{-1}$ at sea level under 600 g/cm$^2$ concrete is obtained with 90% confidence.

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## 1. Motivation

An experiment has been carried out to search for evidence of heavy, highly electrically charged ($\sim \pm 10$ e), stable elementary particles (not nuclei) in the cosmic radiation at sea level at a shallow depth underground.

The basic motivation for carrying out the search is the argument presented several years ago by the author that, in order to construct a finite quantum field theory consistent with Coulomb's law, stable spin 1/2 subnucleonic particles having high mass and charge may have to exist[1, 2]. In refs. [1, 2] a unified theory of hadrons and leptons was constructed which is based on this argument.

More recently some experimental data has been obtained which qualitatively and indirectly supports (see ref. [3]) the above argument, and consequently provides further motivation for the present search. We refer here specifically to (1) the preliminary observation of multigamma production with a cross section apparently not depressed by a factor $(1/137)^n$ at the CERN ISR[4], to (2) the observation of deep inelastic Compton scattering with a cross section greatly exceeding that predicted by the quark-parton model[5, 6], and to (3) the recent discovery of the large cross section for $e^-e^+ \rightarrow$ hadrons (refs. [7, 8]). This reaction provides an interesting test of the model of refs. [1, 2], because it predicts

$$\frac{\sigma(e^-e^+ \rightarrow \text{hadrons})}{\sigma(e^-e^+ \rightarrow \mu^-\mu^+)} \sim \frac{\Sigma(\text{subnucleon charges})^2}{e^2}$$

$$\sim 10^3$$

in the one photon exchange approximation and in the asymptotic limit, i.e., centre-of-mass energy >> all subnucleon masses. As the limit is approached the ratio is therefore predicted to increase greatly, which prediction may be tested in future $e^+e^-$ colliding beam experiments.

We note here that the so-called "energy crisis" described in ref. [8] would also appear to have a simple explanation in terms of the model of refs. [1, 2]. For, just as multigamma production is expected[3] and apparently occurs[4] in pp collisions, so it should also occur in $e^+e^-$ collisions. Thus one prediction of the model of refs. [1, 2] is that the energy crisis is due to $\gamma$ production. We note also that the "anomolous" effects described above that have been observed in experiments[4-8] all increase in magnitude as the centre-of-mass energy increases. In the subnucleon model of refs. [1, 2] this would be accounted for as a threshold effect in which the free subnucleon production threshold is being approached. In what follows it is argued that the lightest subnucleon of that model has a mass in the range approximately 10-100 GeV/$c^2$. In view of these high subnucleon masses it would of course be inappropriate to attempt to describe inelastic electron-nucleon scattering in the model of refs. [1, 2] in terms of an incoherent sum over electron-subnucleon interactions at SLAC energies. Only in the asymptotic regime (i.e., centre-of-mass energy >> all subnucleon masses) could the individual highly charged subnucleons be treated as incoherent scattering centres. Needless to say, the appearance of such a regime would be unmistakable.

The above experiments[4-8] provide some support for the model of refs. [1, 2]. However, just as the most direct test of the Weinberg-Salam model is the search for intermediate vector bosons[9], the subnucleon model of refs. [1, 2] is most directly tested by searching for the predicted subnucleons. This assumes, of course, that they are not permanently bound[10].

Quite generally, it is noteworthy that fractionally charged quarks, singly charged Han-Nambu "quarks", and very highly magnetically charged "quarks" (i.e., dyon-monopoles) have all been searched for previously and unsuccessfully at the CERN ISR[11-13]. Assuming that subnucleonic particles of some description do exist, it then becomes worthwhile to experimentally explore that region of the charge or ionisation spectrum which has hitherto not been explored. The present experiment is sensitive to that region (i.e., to charges $\sim\pm 10$ e).

Of course many early cosmic ray experiments using cloud chambers could have detected highly ionizing elementary particles if present. However, when regarded as searches for such particles, these experiments have large background problems due to the presence of heavy nuclei and slow tritons, etc. Likewise, previous cosmic ray searches for monopoles using plastic detectors generally[14] require a value of dE/dx greater than that of a relativistic nucleus with $Z \sim 50$, thus precluding the efficient detection of particles with charges $\sim \pm 10$ e.

Finally in this section a note is made on the expected mass and charge values of subnucleons searched for in the present experiment. Since, in any subnucleonic model, the heavier varieties of subnucleons may be unstable, a search for stable subnucleons should be designed to be sensitive to the lightest one. In ref. [3] the lightest subnucleon of the model of refs. [1,2] was estimated to have a mass $\sim 100$ GeV/$c^2$ on the basis that (1) the threshold for high $p_T$ events and multigamma production in pp collisions is $\sim 10^{13} - 10^{14}$ eV, and (2) this threshold should be similar to the free subnucleon production threshold. The above value of the threshold was deduced from cosmic ray data. Data from the CERN ISR have now become available which indicate the onset of these processes at the energies of that machine[4], and, insofar as cosmic ray experiments are generally insensitive to rare events, the somewhat lower threshold seen in the accelerator experiments is perhaps not surprising. In any case, the above quoted ISR results are assumed here to imply that, if highly charged subnucleons exist, then the lightest one has a mass in the range approximately

$10 - 100\ \mathrm{GeV}/c^2$. For the charge of the lightest subnucleon we take the estimate of ref.[3], i.e., $(\mathrm{charge})^2 \approx 1$ in units where $e^2 = 1/137$. This yields a charge of order $\pm 10$ e.

## 2. Experiment

The equipment is shown in fig. 1. It comprises, essentially, the bottom end of the cosmic ray telescope at the University of Auckland. The construction and operation of the telescope have been described in detail previously[15-17].

The telescope is directed vertically and is located at sea level in the basement of a nine-storey concrete building. The total thickness of the building above the telescope is estimated to be $\approx 600\ \mathrm{g/cm}^2$. Thus the building acts as an absorber of electrons and positrons in air showers, which showers would be expected to accompany any massive hadrons at sea level, if such particles exist. Also, it acts as a fairly diffuse absorber, thus lessening the problem of bursts produced locally in the concrete. There is a gap of 4 m between the top of the telescope shown in fig. 1 and the lowest surface of concrete above it. The above described location for the telescope is a trial one only; it may not be the optimum.

The telescope is calibrated by its response to cosmic ray muons. In the search for highly charged subnucleons coincident pulses of magnitude $\gtrsim 22$ times minimum ionizing muon pulses are required from three of the scintillators (nos. 1, 2 and 4 reading downwards) as a trigger. We estimate that this trigger is virtually 100% efficient for particles with charges $> \pm 7$ e. (The photomultipliers respond linearly up to pulse heights $\sim 50$ times minimum ionizing muon pulses.) When the telescope is triggered, the photomultiplier outputs for the four scintillators are displayed sequentially on a single sweep at 10 nsec/cm of a Hewlett Packard 183A 250 MHz oscilloscope and photographed. In this way ionisations are measured and genuine fast coincidences identified.

The lead/iron absorbers are included to rule out the possibility of triggers from nuclei (produced locally in cosmic ray stars). It is assumed that the total absorber thickness is $\lesssim$ one interaction mean free path (for bremsstrahlung, etc.) of the particles being searched for, which assumption remains to be verified of course. The spark chamber enables the identification of multiparticle events (bursts, etc.) to be made. In the highly charged subnucleon search single (bright) collinear sparks are required in each gap.

Although the above described apparatus is not sufficiently sophisticated to be able to provide positive unambiguous evidence for highly charged subnucleons, it is powerful enough to provide an upper limit on their flux.

## 3. Results

In 620 hours of operation no unaccompanied highly charged particles were observed to penetrate the telescope. From this we deduce that the flux of unaccompanied subnucleons in the cosmic rays with charge $> \pm 7$ e is $< 7 \cdot 10^{-10}$ cm$^{-2}$sec$^{-1}$sr$^{-1}$ with 90% confidence at sea level under 600 g/cm$^2$ concrete. By unaccompanied is meant here no other charged cosmic ray particles within a transverse distance $\approx 30$ cm and within $\approx \pm 3$ nsec. These factors are determined by the geometry and resolving time of the telescope.

Finally we note that, under certain assumptions, the above measurement may be related to the mass of the lightest subnucleon, which was estimated in section 1 to be in the range 10 - 100 GeV/c$^2$. Suppose we assume, as a simple approximation, that (1) the free subnucleon production cross section in pp collisions above threshold $\approx$ the subnucleon Compton wavelength squared, and (2) the subnucleon mean free path $\approx$ three times the nucleon mean free path, and (3) the subnucleon inelasticity $\approx$ nucleon inelasticity. With these three assumptions we deduce that the expected subnucleon flux $\approx 3 \cdot 10^{-9} - 10^{-14}$ cm$^{-2}$sec$^{-1}$sr$^{-1}$, for subnucleon masses $\approx 10$ - 100 GeV/$c^2$, at a depth of 6 m w. e. below sea level. This follows from the known cosmic ray spectrom[18]. We also find that the upper limit observed in the present experiment for the subnucleon flux corresponds to a lower limit of $\approx 15$ GeV/$c^2$ for the mass of the lightest subnucleon. This limit on the mass is of course extremely tentative. Even if highly charged subnucleons exist, any of the three assumptions listed above may be grossly in error. We conclude by noting that the range of mass values effectively explored here could presently be extended at the CERN ISR, or even at DORIS or SPEAR.

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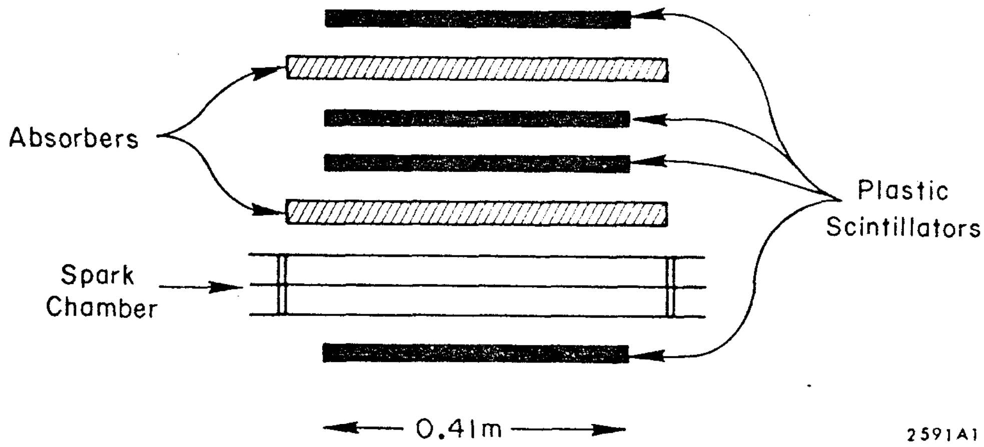


Fig. 1

Telescope used for search for highly charged particles in the cosmic rays. The scintillators are NE102A ($41 \times 41 \times 0.64$ cm$^3$). They are viewed by 56 AVP and XP1021 photomultipliers through adiabatic light guides. Each gap in the spark chamber is 5 cm wide. The top absorber is 2.5 g/cm$^2$ Fe + 31.5 g/cm$^2$ Pb. The bottom one is 5.0 g/cm$^2$ Fe.