

**SEARCH FOR MAGNETIC MONOPOLES USING  
PROPORTIONAL COUNTERS FILLED WITH HELIUM GAS**

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**ABSTRACT**

Slow magnetic monopoles in cosmic rays have been searched at sea level with the detector which consists of seven layers of proportional counters filled with a mixture of He + 20% CH<sub>4</sub>. The velocities and the energy losses of the incident particles are measured. The upper limit of flux for the monopoles in the velocity range of  $1 \times 10^{-3} < \beta < 4 \times 10^{-3}$  is  $2.78 \times 10^{-12} / \text{cm}^2 \text{ sr sec}$  of 90% confidence level.

**1. INTRODUCTION**

The prediction of the primordial production of super massive magnetic monopoles ( $M \sim 10^{16} \text{ GeV}$ ) by Grand Unification Theories (1), and of the subsequent acceleration of these monopoles to the velocities of  $v = \beta c$  with  $\beta \sim 1 \times 10^{-3} \sim 1 \times 10^{-2}$ , have caused interest in experimental search for slowly moving magnetic monopoles in the cosmic rays (2). Many methods to detect the monopoles have been used, but all experimental results except Cabrera (3) are negative. First, we have searched the monopoles with five layers of proportional counters filled with a mixture of 90% Ar + 10% CH<sub>4</sub>, to measure velocity by time-of-flight method and track positions for incident particles (4). The upper limits of the flux for the monopoles in the velocity range of  $1 \times 10^{-3} > \beta > 4 \times 10^{-3}$  at 90% confidence level is  $1.5 \times 10^{-12} / \text{cm}^2 \text{ sr sec}$ , which is slightly higher than the value reported in (4), because of the increase in running time. Second, mixed gas of 80% He + 20% CH<sub>4</sub> is used for the counters, since a CH<sub>4</sub> molecule is ionized through the Penning effect by a He metastable state excited by the monopole. More two layers of proportional counters are added to measure energy losses and track position along the

wire. Experimental results at second stage are described in this paper.

## 2. EXPERIMENTAL APPARATUS

The apparatus consists of seven layers of proportional counters, the aperture of  $2.24\text{m}^2\text{sr}$ , 3m height as shown in Fig. 1. Each of 2 and 6-layer has an area of  $120\text{cm} \times 500\text{cm}$ , the others  $120\text{cm} \times 450\text{cm}$ . Each layer consists of 12 counters; each of which is made of a rectangular aluminium tube with a cross section of  $5\text{cm} \times 10\text{cm}$ . Two kinds of counters are used; a T-counter which has two anode wires of  $50\mu\phi$  gold plated tungsten and a ground wire at the center of the tube, and a Z-counter which has a  $50\mu\phi$  nichrome wire at the center. 1,3,4,5 and 7-layer which consist of T-counters measure the velocities by time-of-flight method and position of incident particles, but 2 and

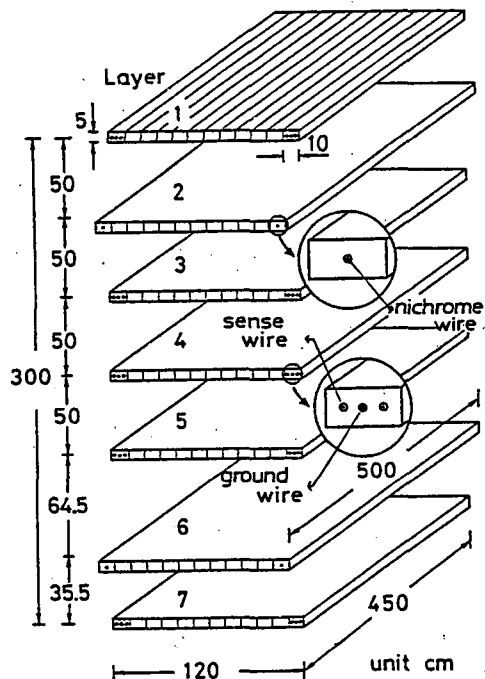


Fig. 1 The apparatus

6-layer which consist of Z-counters measure the energy losses and the position along the wire using a charge division method. A mixed gas of 80% He + 20% CH<sub>4</sub> which is chosen on the basis of the measurements of the velocity and stability for different ratio of mixture, flows through all counters at a rate of 200cc/min. The high voltage is 2.3KV, and the discriminator level for trigger signals is 7 times of minimum ionization of cosmic rays.

Each signal from 1,3,4,5 and 7-layer, 24 signals in a layer, a total of 120 goes through a amplifier/discriminator on the counter, and delayed by 10μsec. Any signals from the each layer are used to make trigger pulse using a sort of successive delayed coincidence method. The time between trigger and delayed signal from each wire is measured by 20MHz clock, 8 bit scaler and 8 bit shift register (TDC) for all 120 wires. Each of 2 and 6-layer has 12 anode wires, and the adjacent two wires are connected at one ends of the both wires. Pulse heights from both ends of the wire with length of 10m are measured with 11 bit analog to digital

converter (CAMAC ADC), the ratio and the sum of two heights gives the position along the wire with the accuracy of about 20cm and the energy losses, respectively for a incident particle. Data are taken by a on-line micro-computer and recorded on floppy diskets.

The drift velocity of electrons in the gas used in this experiment are about 100ns/mm which is very slow compared with that of 90% Ar + 10% CH<sub>4</sub>, 20ns/mm. So this time jitter of the pulses is at most 2.5 $\mu$ s for drift space of 25mm. A veto pulse, which prevent cosmic ray muons and reduce trigger rate, is generated by the 4 fold coincidence among 1,3,5 and 7-layers with the time resolution of 2.5 $\mu$ sec. With this data taking system, the velocity range to be observed is between 3m/2.5 $\mu$ sec;  $\beta=4 \times 10^{-3}$  and 3m/10 $\mu$ sec;  $\beta=1 \times 10^{-3}$  for the virtual incidence of the particle to the apparatus.

### 3. ANALYSIS AND RESULTS

Each event has data on positions and, times from 120 wires of T-counters and on pulse heights from 24 wires of Z-counters. The following requirements are applied to select the monopole candidate. First, the total number of hit-wire of T-counters in a event is less than 10. Second, the wires hitted have to draw a straight line, and the least square method is applied to positions of the anode wires fired to measure the straightness. The resultant root mean square deviation of the wire positions from the straight line;  $\sigma(L)$  is calculated. Third, the arrival times of the pulses from the wires have a linear relation to the virtual position of the player. The gradient of the straight line gives the the velocity for the monopole candidates, the distribution of  $D(L)$  and  $D(1/\beta)$  for cosmic ray muons are obtained and

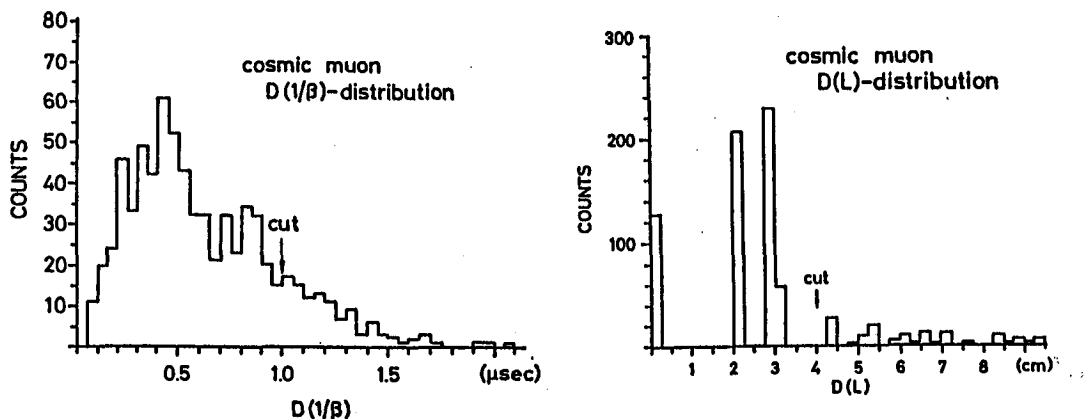


Fig. 2  $D(1/\beta)$  and  $D(L)$  distribution for cosmic ray muons.

shown in Fig. 2, where  $D^2(L)$  and  $D^2(1/\beta)$  is the sum of squares of the deviations from the straight line for position and time data respectively. From these results, selection criteria for the monopole candidates are  $D(L) < 4\text{cm}$ ;  $\sigma(L) < 2.31\text{cm}$ ; and  $D(1/\beta) < 1\mu\text{s}$ ;  $\sigma(1/\beta) < 577\text{ns}$ , which gives selection efficiency of 85%. After observation from January 1, 1984 to May 28, 1985; the running time of  $2.17 \times 10^7\text{sec}$ , 95,000 events are recorded, on which selection criteria mentioned above are applied. Until December 12, pulse heights are not measured, then monopoles are searched only by the velocity. No track has been found to have velocity range of  $1 \times 10^{-3} < \beta < 4 \times 10^{-3}$  for the running time of  $1.82 \times 10^7\text{sec}$ . Fig. 3 shows ionization losses as a function of the velocities for monopole runs after the selections are carried out. The energy loss calculated by Drell et al (5) is also shown. No track has been found to have energy loss corresponding to the velocity. Combining two results, the upper limit of the monopole flux in cosmic ray at sea level is  $2.78 \times 10^{-12}/\text{cm}^2\text{sr sec}$  at 90% confidence level in the velocity range of  $1 \times 10^{-3} < \beta < 4 \times 10^{-3}$ .

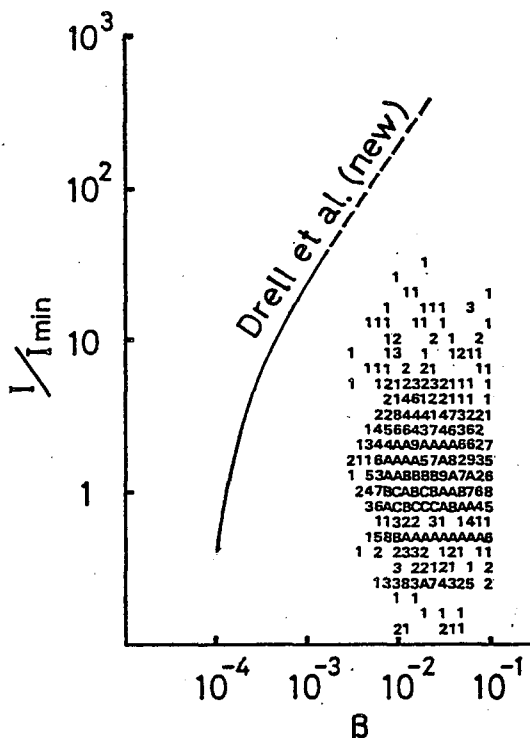


Fig. 3 The energy loss and  $\beta$  correlation for monopole candidates, where the number increases as 1, 2, ..., 9, A, B, C, ..., Z.

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