

## Magnetic Monopole search by $130 \text{ m}^2 \text{sr}$ He Gas Proportional Counter

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A search experiment for cosmic ray magnetic monopoles has been performed by means of atomic induction mechanism by using He mixture gas proportional counters of the calorimeter ( $130 \text{ m}^2 \text{sr}$ ) at the center of Akeno AS array. In 3,482 hours operation no monopole candidate is observed. The upper limit of the monopole flux is  $1.44 \times 10^{-13} \text{ cm}^{-2} \text{sec}^{-1} \text{sr}^{-1}$  (90% C.L.) for the velocity faster than  $7 \times 10^{-4} c$ .

### 1. Introduction.

The magnetic monopole has been one of the most charming objects not only in experimental but also theoretical physics. There has been so many monopole search experiments using many kinds of detectors. However, mass of monopole which grand unification theory suggests is too heavy to accelerate a monopole up to relativistic speed with the Galactic magnetic field. In this case the monopole is expected to have a velocity about  $10^{-3} c$  (where  $c$  is the light velocity) or less. For such slow monopoles, the availability of usual detectors except super conducting coil is not clear for monopole detection because the energy loss of such slow monopole is expected to be extremely small in the matter. However, Drell et al. suggested that the atomic induction mechanism in Helium or Hydrogen gas is effective for monopole detection down to  $10^{-4} c$  of monopole velocity(1). In this paper we report a result of slow monopole search experiment with He mixture gas proportional counters using the above mechanism.

### 2. Apparatus and experiment.

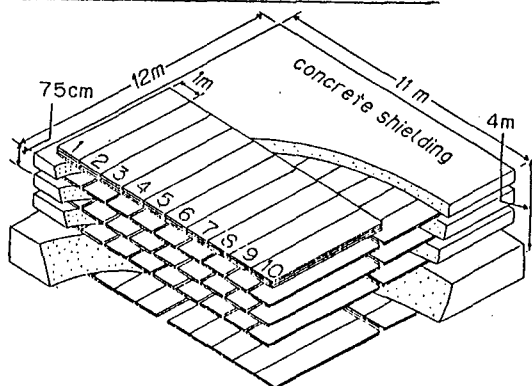


Fig.1 Apparatus for monopole detection.

For monopole search experiment, we use the proportional counters of the calorimeter at Akeno air shower array(2). The proportional counters, each unit size is  $10 \text{ cm} \times 10 \text{ cm} \times 500 \text{ cm}$ , are set in four layers among the concrete shieldings and arranged to lie in the same direction. For monopole search experiment, we changed the proportional gas to He mixture gas ( $\text{He}85\% + \text{CH}_4 15\%$ ) and provided two more layers of the same proportional counters on the top of the calorimeter. The rough sketch is shown in fig.1. Though the monopole

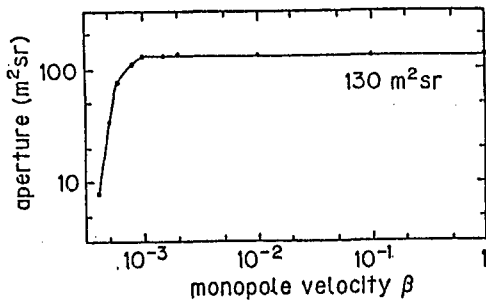


Fig.2 Aperture of the detector.

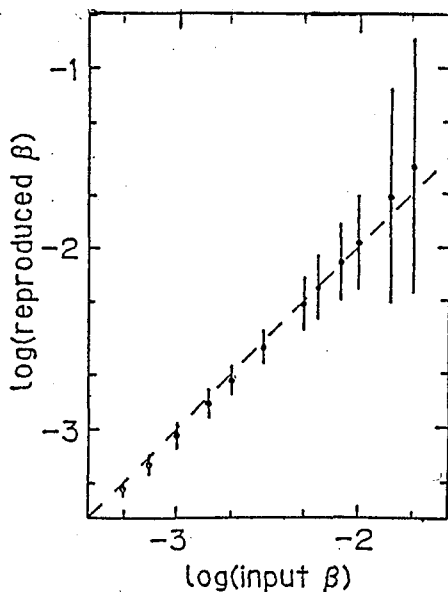


fig.3 Availability for the determination of monopole velocity.

excites only He-atoms by the atomic induction mechanism, added inner methane molecules produce free electrons in the proportional counter when they collide with the excited He-atoms through Penning effect. With the process, we can observe the signal of the monopole from the proportional counter.

The experiment has been continued since the beginning of Nov. in 1984.

The apparatus is triggered when any counter in any trigger block unit, which is composed of adjacent 10 proportional counters in the same layer, produces a signal larger than 10 times of minimum ionization of single cosmic ray muons in each layer of the counters. In order to decrease shower events, the trigger pulse is killed whenever more than 2 trigger block units in any layers satisfy the trigger condition('shower veto'). With the threshold of 10 times of the minimum ionization, monopoles with the velocity faster than  $4.1 \times 10^{-4} c$  are expected to be detected by our He mixture proportional counters from the comparison of electron pairs produced by relativistic cosmic ray muons with that by monopoles which is estimated by the revised calculation of Drell et al.(3) assuming 83% of Penning effect(4).

The aperture of the apparatus for both upward and downward monopoles, which varies with monopole's velocity, is calculated by Monte Carlo simulation assuming the arrangement of the apparatus, the trigger condition and the

trigger gate time( $46 \mu s$ ), and found to be  $130 m^2 sr$  for monopoles of the velocity larger than  $7 \times 10^{-4} c$ . The detectable minimum velocity of the monopole is  $5 \times 10^{-4} c$  as shown in fig.2.

We record the pulse height of each proportional counter and the time difference(resolution time is  $0.5 \mu s$ ) between the signal from each trigger block and the main trigger signal, with which we can estimate the velocity of the monopole, in magnetic tapes by using the registration system of Akeno air shower array. The time response of our proportional counter is slow because of the drift velocity of electron in He gas(about  $1 \mu s/cm$ ). We measured the time response of our counter in the same condition as that of the experiment by using pion beam(2 GeV) from the KEK PS accelerator as a function of the impact parameter to the anode wire. Using the data, a Monte Carlo simulation was made on the availability of our apparatus for the determination of monopole velocity.

In our apparatus we can determine monopole velocity only projected to the vertical plane perpendicular to the long axis of proportional

counters. Therefore, the velocity thus determined is always less than the true velocity. The simulation results are shown in fig.3 which indicates that we can determine the velocity within the error of 50% for the monopole passing through with the velocity less than  $2 \times 10^{-2} c$ , but for faster monopole, the systematic error is too big to determine the velocity. Undeterminable region of the velocity for the apparatus was also checked experimentally by using the data triggered by relativistic cosmic ray muons. Both data are consistent with each other.

### 3. Analysis and results.

Almost all the triggered events are accidental ones caused by radio isotopes contained in the concrete or the wall of our counters or small air shower events escaped from 'shower veto'.

First of all, we reduce these events by off line computer analysis by checking that the 'on' counters make a straight line within the allowance of 20cm displacement and the number of 'on' counters in any layer does not exceed more than three.

Secondly the events survived the computer reduction are checked with more severe criterion for making a straight line (10cm allowance) by visual scan on graphic display and then are carefully studied for both the energy loss along the line and the timing data. If the monopole passes through the apparatus, the energy loss in each counter, which depend on the velocity of the monopole, is almost same to the others because the fluctuation of the energy loss by atomic induction mechanism is considered to be small. On the other hand if the apparatus is triggered by small showers or surrounding backgrounds, the signal from each counter is expected to be different in the magnitude from the others.

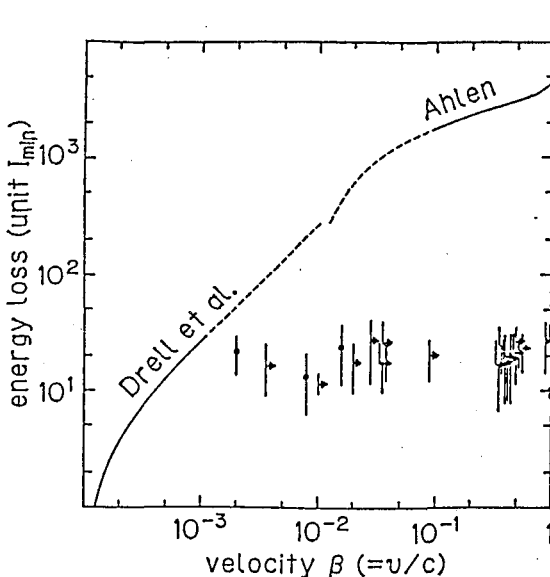


Fig.4 Events survived to the final analysis.

In fig.4 are shown the event survived the visual scan. The velocity of each event is determined by  $\chi^2$ -fitting using the timing data which are sometimes lacking in one or two counter layers because of unresponse of timing circuit and is plotted the plausible lowest value even if the  $\chi^2$ -minimum can not be found. Accordingly we cannot rule out that all these events have faster velocity up to light velocity.

The vertical bar of each event in the figure shows the one standard deviation of energy losses in 6 layers of the counters. Except two events these are considered to be produced by small cascades developed in the concrete from the signal transition in successive counters.

The exceptions in which the signals of all layers are almost the same to one another may be caused by

successive cascades by high energy muons. In any case their energy losses are still too small comparing with the calculation by Drell et al.. We can see that there is no monopole event in our data.

#### 4. Conclusion.

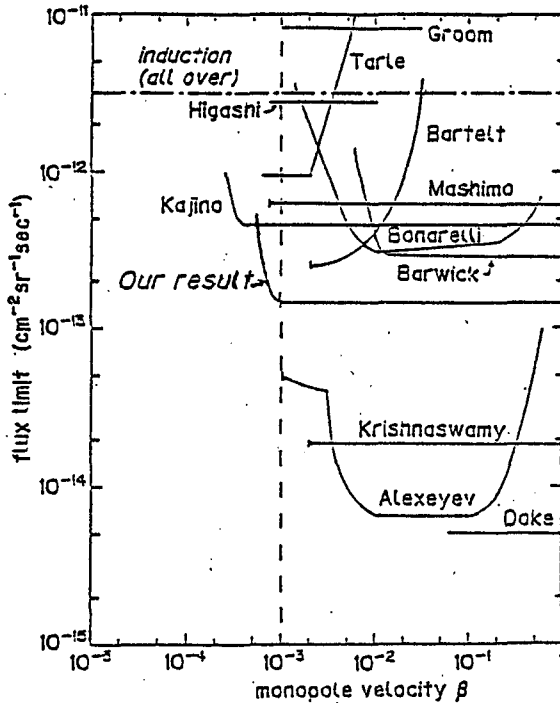


Fig.5 Upper limit of monopole flux.

upper bound shows the lowest value in the velocity region slower than  $10^{-3} c$  by counter experiment.

Up to now we have no monopole event in the observation time of 3,482 hours. Since the aperture of our monopole detector is about  $130m^2 sr$ , we have the upper limit of the flux  $1.44 \times 10^{-13} cm^{-2} sec^{-1} sr^{-1}$  for monopoles faster than  $7 \times 10^{-4} c$  in 90% confidence level. We show more detailed flux upper bound in fig. 5 as a function of monopole velocity taking into account the aperture(fig.2). In fig.5 we also show the results of other experimental groups(5) for the comparison.

Recently, Ahlen et al. investigated the availability of these detection methods for monopole detection(6). They conclude that scintillation detectors can not be applied to monopoles slower than  $6 \times 10^{-4} c$  and Argon counters to  $2 \times 10^{-3} c$ . For other experiments in fig.5, we show the results only for the applicable velocity regions in accordance with the discussion by Ahlen et al.. It is seen that our

#### 5. Acknowledgments.

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