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RESULTS FROM THE UCSD MAGNETIC MONOPOLE SEARCH

Masek, G.E., Knapp, L.M., Miller, E.
Stronski, J.P., Vernon, W. and White, J.T.

Department of Physics, B-019
University of California, San Diego
La Jolla, CA 92093 USA

1. Introduction. The energy loss mechanism for slowly moving magnetic monopoles in helium calculated by DKMPR[1] provides a means of extending the search for such particles by ionization techniques to velocities down to $\sim 3\times10^{6}$ cm/sec ($\beta \cong 10^{-4}$). Other gases (e.g. CH_2 or CO_2) mixed with helium will be ionized with high efficiency[2] by collisions with excited helium atoms, thus allowing the use of large proportional chamber systems for the detection of the monopoles. The first reported results utilizing this mechanism was the experiment of Kajino et al.[3] using a detector with an area-solid angle product ($A\cdot\Delta\Omega$) of 24.7 m^2sr. They set a limit on the flux of monopoles of $< 7.2\times10^{-13} cm^{-2} sr^{-1} sec^{-1}$ at a 90% confidence level for $\beta > 3\times10^{-4}$. Here we report on the results of a He:CH_2 proportional tube array designed to extend the velocity limit down to $\beta \sim 10^{-4}$, and push the flux limits closer to theoretical bounds.[4] The detector which has been operating at the University of California, San Diego (UCSD) since last summer, is a prototype for a larger array currently under construction at UCSD. The data presented here is from 200 days of live time with the prototype detector.

To attain limits on the flux approaching current theoretical bounds, detectors with $A\cdot\Delta\Omega$ the order of 1000 m^2sr to 10000 m^2sr are needed. Given fiscal constraints and the desire to achieve large $A\cdot\Delta\Omega$, the basic design philosophy for the UCSD detector is to require only the simplest criteria for monopole detection. Thus the detector employs an array of proportional chamber tubes arranged to observe only a projected track and a projected velocity window. In addition, the array is operated at sea level with no earth overburden, and uses electronic rejection to eliminate the fast muon cosmic ray background. If indeed any signal were observed with this minimum criteria, this would be ample justification for construction of a more expensive, sophisticated detector.

2. Detector Description. The layout of the prototype detector shown in figure 1, consist of 225 individual aluminum proportional tubes, each approximately 2.5 cm x 2.5 cm in cross section, and each $\sim$ 7.2 m. in length. They are strung with .002" diameter gold plated tungston wire, and arranged in an array of six layers as shown in the figure. The gas mixture used was 15% CH_2 and 85% He. An ionizing particle passing through the array leaves an electronic signature of which tubes were traversed and the relative time of transit for each tube.

A simplified flow diagram of the electronics trigger and data acquisition system is shown in figure 2. Outputs from each of the 225 channels is first amplified (gain $\sim$ 300, integrating time, $\sim$ .5 μs) and then individual comparators select a minimum signal threshold. These signals are then split, half forming sums of all signals in individual

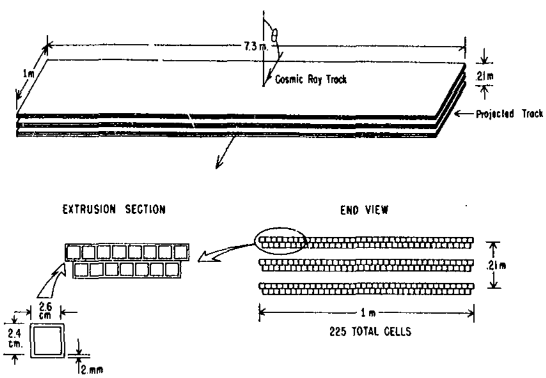

Fig. 1 - Magnetic Monopole Detector Layout.

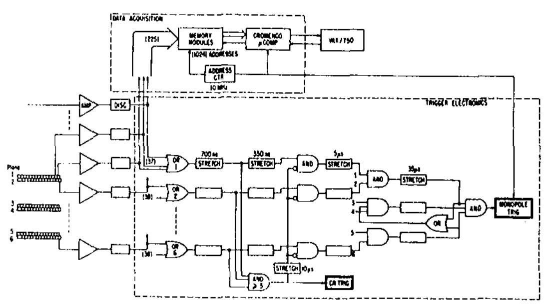

Fig. 2 - Simplified flow diagram of Electronics.

planes to be used in the trigger electronics, and the other half feeding directly to memory modules for data acquisition. In the memory modules, the separate channels are recorded on 1025 x 8 RAMS (AMD AM9128-70) whose addresses are continuously cycled at 10 Mhz. The information stored in the RAMS is read out when an appropriate signal from the trigger electronics is received.

In the trigger electronics shown in figure 2, the logic imposes the following criteria on an event to be read out:

i. All six planes must have recorded a hit within 35 μs (the maximum sensitive time for the detector corresponding to a $\beta = 10^{-4}$ particle traversing with an aximuth of $\sim 80°$).

ii. If any three planes have hits within .7 μs, the event is rejected. This is the main criteria for rejecting cosmic ray muons, and also sets the minimum transit time (1.4 μs) accepted in the trigger. (As mentioned above, final analysis cuts set a limit of 1.5 μs on accepted events, just outside the 1.4 μs trigger limit.)

iii. In addition, events are rejected unless times from the two planes in each of the three pairs (1-2,3-4,5-6) are within 5 μs, and the time of the middle pair must come after either of the outer pairs. These are broad conditions that must hold for a real track within the velocity window.

3. Detector Operation and Results. The energy loss vs β for slow monopoles in helium is calculated in reference 1. The ionization threshold for the detector determines the lower limit on the β which can be detected. In the array described here, the ionization threshold (determined by the high voltage operating point and discriminator threshold) was $I_{thres}/I_o \cong 1/3$ giving $\beta_{min} \simeq 1.1\text{x}10^{-4}$.

As described above, the data is first stored in the memory modules, and when the appropriate conditions are met in the hardware trigger electronics, the data is read out through a Cromenco microprocessor to a VAX 750 computer for off-line analysis. In addition, the microprocessor also permits a software trigger condition to be imposed. We require that in each of the three pairs of planes (1-2,3-4,5-6), there be at least one set of adjacent hits (called a cluster) in the two planes making up the pairs. The trigger conditions and subsequent rates are

TABLE 1

Rates at Various Stages in the Data Acquisition and Analysis

Stage	Rate	Rate (Normalized to CR)
Cosmic Ray Rate thru six planes	520/sec.	1
Hardware Trigger Electronics (see text)	14.4/hr	7.7×10^{-6}
Software Trigger in μ-Processor (see text)	1.35/hr	7.2×10^{-7}
Offline Analysis Cuts (see text)	0.5/dy	1.1×10^{-8}

summarized in Table 1. Thus, of the initial rate of 520 Hz of cosmic ray muons traversing the detector, only the order of one per hour are recorded by the VAX computer.

In the off-line analysis, summary files of the data are made by imposing rather broad cuts on the data to select out monopole candidates. These cuts are:

i. Track candidates are selected by requiring a projected linear fit to clusters in each of the three pairs of planes.

ii. For selected track candidates, the mean time of each of the three clusters making up a track, must be increasing or decreasing from top to bottom in the array. This selects the correct time sequence for slowly moving particles passing down through the array or up through the array.

iii. At least one of the hits associated with a track candidate has to be identified with the original hardware trigger timing sequence.

iv. The time difference between the outer planes must be greater than 1.5 μs.

v. A track is rejected if 3 planes have hit times within .7 μs.

Additionally, for the track candidate, two Chi-Squared relations are calculated. A linear fit to the mean projected position ($XMEAN_i$) of each cluster, gives a fit position ($XFIT_i$) then $XSQ = \sum_{i=1}^{3}(XMEAN_i - XFIT_i)^2$. Also a linear fit to the mean times of hits vs distance along the track on each of the six planes ($TMEAN_j$) gives a fit time ($TFIT_j$), then $TXSQ = \sum_{j=1}^{6}(TMEAN_j - TFIT_j)^2$. (The units of the two quantities are cm^2 and .1 μsec^2, respectively). The effect of the cuts described above on the rates is also given in Table 1, thus only an effective rate of 1/2 event per day survives for further consideration. The final step in the analysis consists of making an event display of each event in the summary file, and individually scanning these events. A typical event display is shown in figure 4. In the top, the projected view of the end of the array is shown, along with an indication as to which cells were hit in the event. For each hit, the time of the hit (in units of .1 μs) and the duration of the pulse (also in units of .1 μs) are given beside each cell hit. The solid line gives the fit to the track clusters and the XSQ is displayed in the upper left. In the lower left corner of the display is a plot ot time vs distance along the track. The solid

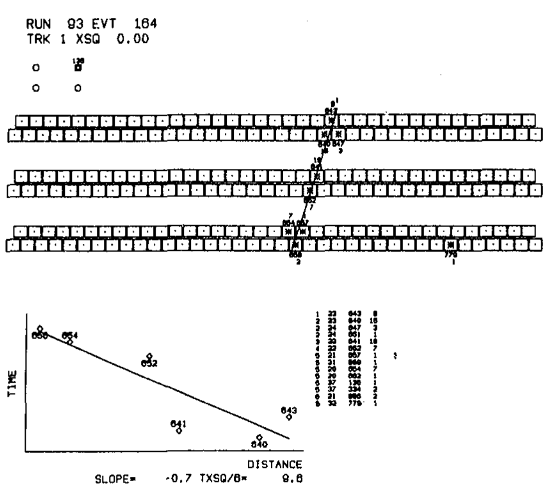

Fig. 3 - Event Display. Event shown is a μ-e event (see text).

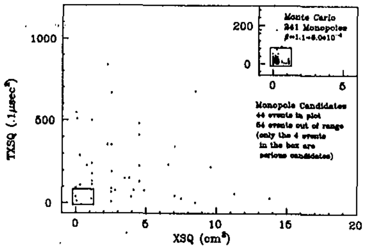

Fig. 4 - TXSQ vs XSQ for Candidate Events. The inset is the plot for Monte Carlo Monopole events.

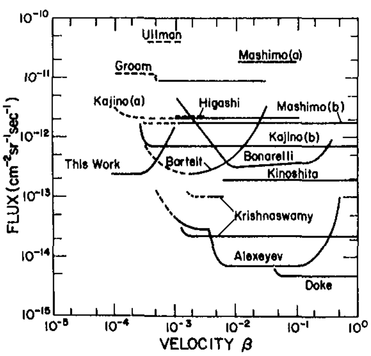

Fig. 5 - Compilation of flux limits on magnetic monopole vs β at 90% confidence level. Taken from ref. 3, but including this work.

line here gives the fit to the six mean times, and the TXSQ is displayed beneath the plots. The scanning of the 98 surviving monopole candidates on the summary files gave no events which could be interpreted as a slowly moving particle in the time window between 1.5 μs and 35 μs. The numbers scanned can be substantially reduced by employing the Chi-squared cuts. Figure 4 gives a scatter plot of XSQ vs TXSQ for all of the data in the summary files. Imposing cuts of XSQ < 1.5, and TXSQ < 84 accepts 99% of the Monte Carlo monopole events and leaves only 4 events for further consideration. Of interest is the characteristics of the summary candidates. The majority of these events can be interpreted as cosmic ray muons that stop in the walls of the detector, and subsequently decay into an electron that then passes through the remaining planes of the array (a μ-e event). A measure of the energy deposition of a particle passing through a cell is given by the width of the pulse, which is also recorded with each event. For these μ-e events the pulse width near the end of the muon range should increase. This is clearly observed with these events, and the frequence and magnitude agree with what would be expected for stopping muons. Thus these events afford a very nice check on the overall performance of the system. Moreover, the pulse width (height) information can be used as an additional requirement on the monopole candidate, although in fact it was not necessary for rejecting the candidates in this data sample.

4. Conclusion. The A·ΔΩ for this prototype apparatus is 54.6 m^2sr for particles with $\beta = 1.1\text{x}10^{-4}$ within the time window acceptance 1.5 μs to 35 μs. For a live time of 200 days, this gives an upper limit on the monopole flux (at the 90% confidence level) of $2.4\text{x}10^{-13}\text{cm}^{-2}\text{sr}^{-1}\text{sec}^{-1}$. As discussed above, the detector was optimized for the lowest detectable velocities, and the effective A·ΔΩ decreases with increasing velocity. The limits set for this experiment from $\beta = 1.1\text{x}10^{-4}$ to $\beta = 10^{-3}$ are shown in figure 5 along with recent limits from other ionization experiments.

References

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