

OPERATIONAL CHARACTERISTICS
OF THE UTAH ANISOTROPY DETECTOR

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Preliminary operating experience has been obtained with the Utah Anisotropy Detector. A muon detector located 486 hg cm^{-2} underground at latitude $40^{\circ} 37' \text{ N}$, it is designed to measure the sidereal anisotropy of cosmic ray primaries whose median rigidity is about 1400 GV. Counting all angular bins in a 102° sector, we obtain a counting rate of $1.4 \times 10^8/\text{yr}$ for the detector. The detector operates very much as designed. Rates appear to be quite stable, and noise rates and accidental loss rates fall below design figures.

1. Introduction. The remarkable directional isotropy of cosmic rays confined to the galaxy has long been an important constraint for containment, and propagation models. For our purposes, it is sufficient to observe that the short disk residence time implied by cosmic ray isotopic abundance's may be incompatible with the absence of a larger anisotropy (JoKippi, 1973; Wentzel, 1974; Daniel and Stephens, 1975).

Experimentally, the conclusions are considerably weaker than was thought prior to 1975. The older air shower experiments (Daudin and Daudin, 1953; Cachon, 1962) are obscured in the literature and are somewhat questionable in the absence of modern scrutiny. The air shower experiment; by Gombosi et al. (1975 a,b) is extremely interesting, but not yet definitive. The watershed underground muon measurements (Jacklyn. 1965; Cini-Castagnoli et al., 1968; Elliot et al., 1970; Speller, et al., 1972) have now been reinterpreted as having been dominated by solar modulation effects (Cini-Castagnoli et al., 1975; Marsden et al., 1976). Fenton's important new deep underground detector (Fenton and Fenton, 1975, 1976) has just begun to yield significant results. As of 1976, one could argue that an anisotropy between zero and 0.1% could not be ruled out, at least at the 3σ level.

In the meantime, the issue has been complicated even further by the discovery that cosmic ray- Be^{10} appears to be absent .(Garcia-Munoz, Mason and Simpson, 1975 a,b). Taken at face value, their results imply that a large part of the cosmic ray galactic containment time is spent outside the disc (Jokippi, 1976). The implications of their discovery for the isotropy problem are far from clear.

Even prior to the discovery of the anisotropy phase change in the northern hemisphere by Cini-Castagnoli et al. (1975), the 40 m.w.e. and 60 m.w.e. experiments had been criticized as possibly being susceptible to solar modulation effects. At the 60 m.w.e. the median primary rigidity is in the vicinity of 260 Gi, so that the cyclotron radius of the primaries is about 1 AU at the earth. We therefore elected to build a detector with an energy threshold high enough that the primary rigidity was well in excess of 1 TeV. A design counting rate in excess of 10^8 yr^{-1} was chosen in order to obtain a statistical accuracy near 0.01% in one year.

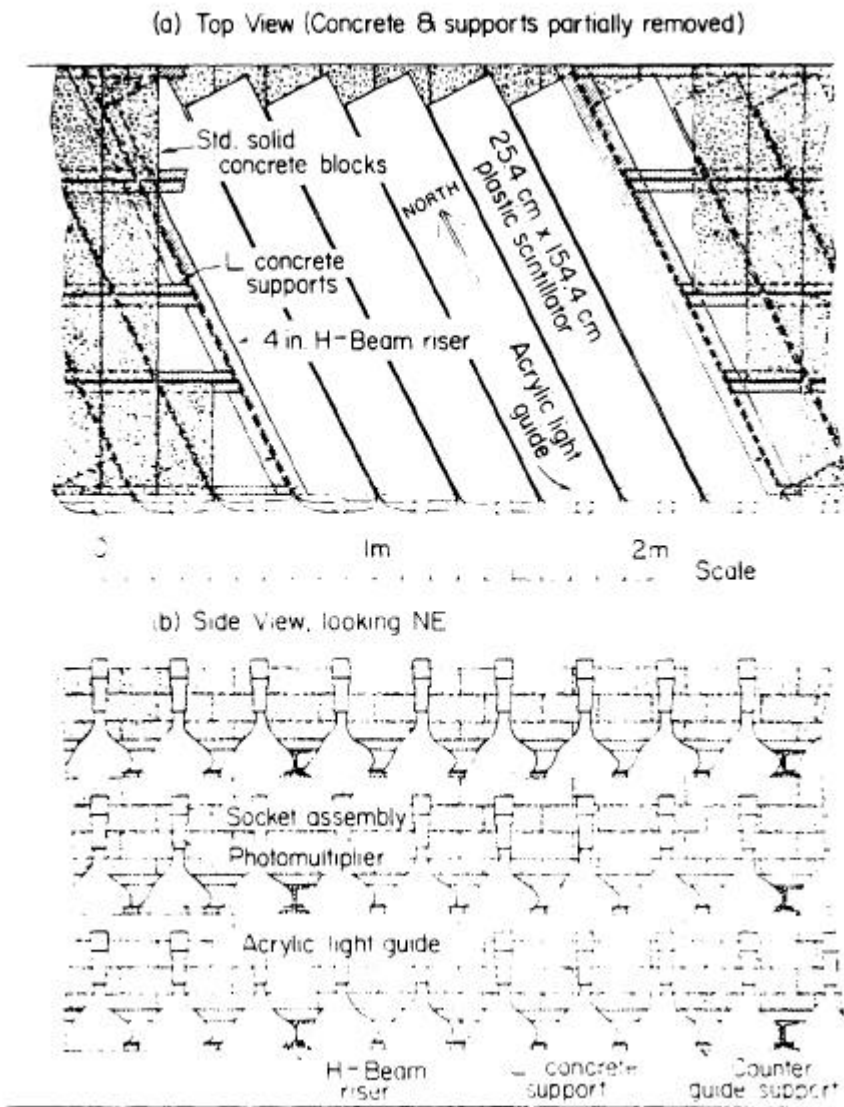


Figure 1. Plan view of the counter array.
There are 100 counters in each layer, for a total array length of 30 m.

The total area of plastic scintillator in each layer is 37.3 m^2 .

The photomultipliers are operated in a grounded cathode configuration from a single high voltage (HV) supply. Distribution is accomplished via a string of power transistors whose collector-base voltages are established by 25 V Zener diodes.

Each counter drives two discriminators, one set well up on the counting plateau and one at about the 50% level. The marginal discriminators provide a precise stability monitor for each counter. When loose coincidence requirements are met, data from all 600 discriminators are stored temporarily in one of two equivalent sets of latches. Should a second event arrive during the 1.7 ms required for event readout by the computer, it is stored in the alternate latch set. The probability of accidental event loss is 6×10^{-5} .

At the time of the Munich meeting (Bergeson *et al.*, 1975) all major components had been built or acquired but were not completely installed. Turn-on has been slower than anticipated. As of 04/77, data tapes are being produced in a routine manner, although a fair amount of tuning is still needed. These first data demonstrate that the detector meets or exceeds design goals with respect to counting rate, stability, noise rates, accidental losses and data format flexibility.

2. The Apparatus. The detector and electronics have already been described in some detail (Bergeson *et al.*, 1975, 1976), and we present only a brief summary in this paper.

The detector consists of three layers of plastic scintillation counters, arranged as illustrated in Fig. 1. Each counter consists of a 0.7 cm thick plastic scintillator sheet (Pilot F) and a heat-formed acrylic light guide bent through 90° . It is viewed by an RCA 6655A or EMI 9805KF photomultiplier.

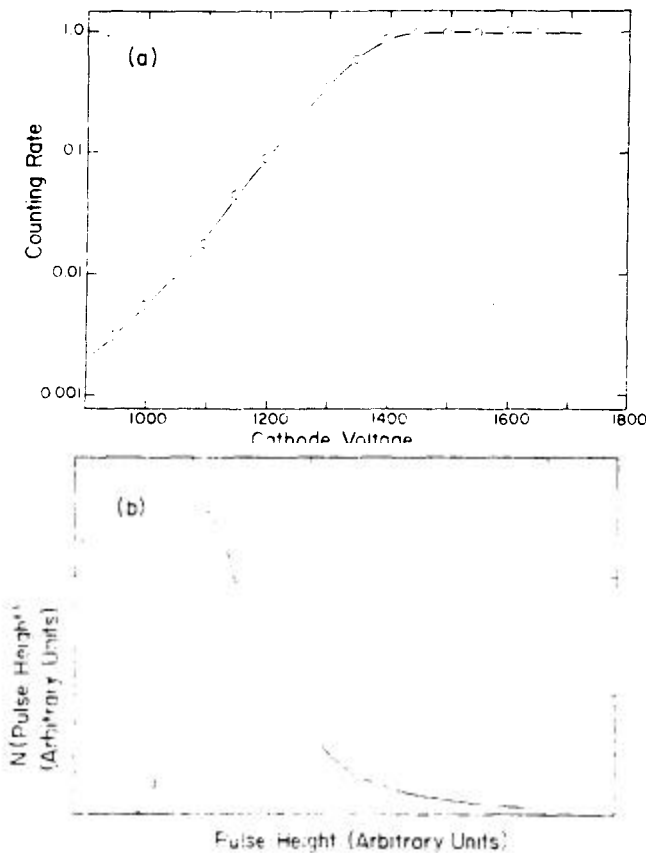


Figure 2. (a) High voltage plateau curve for a typical counter in triple coincidence. (b; Muon pulse height distribution in the counter, calculated from the data in (a).

Discriminator outputs are 110 ns wide. Since even a short overlap is sufficient, the effective coincidence time resolution is 220 ns. Discriminator pulses present when the latches close (about 30 ns after the coincidence pulse leading edge) register as having fired, so that the effective time resolution of the system is 110 ns.

3. System Performance.

A HV plateau curve for one counter operating in the surface prototype is shown in Fig. 2(a). It represents the relative counting rate of the triple coincidence as a function of the HV on one counter, while those in the other layers are held constant. This particular tube should be set to operate at 1500 V or 1550 V, safely on the plateau. The muon pulse height distribution in the counter, as derived from this curve, is shown in Fig. 2(b). It is consistent with the result expected for a convolution of photoelectron statistics, Landau fluctuations in muon energy loss, and light attenuation in the counter. The low-level discriminator triggers at about 400 Hz with the counter operating at the plateau voltage, evidently mainly because of radioactivity in the concrete. The entire apparatus triggers at about 5 sec^{-1} . We

conclude that the background noise produces triple coincidence events at about 2×10^{-4} of the real event rate. Similarly, we should expect a spurious fired counter in 1.3% of the events.

Various coincidence combinations define hour angle sectors about 15° apart. The resolution function within a sector is triangular, with a full width at half maximum of about 15° . In Table 1 we list the observed and calculated counting rates (Bergeson *et al.*, 1975) for sectors which contribute most of the counting rate. Published underground intensities were integrated over the topography and apertures to obtain the calculated rates and mean depths. The experimental rates average 5% higher than those calculated, but it will be noted that most of the disagreement comes from the two most eastern sectors. There may be errors in the topography, or the average rock density may be smaller in that direction. The recent review by Gaisser (1976) was used to relate median primary rigidity to $\langle E_{10} \rangle$, the mean threshold muon surface energy.

More than 85% of the events are simple three-counter muon events in one of the nine sectors. Because of the middle layer geometry, these sectors correspond to 13 discrete coincidence possibilities for most counters in a given

TABLE 1

Observed and predicted annual counting rates and other parameters for the Utah Anisotropy detector. Sector angles are hour angles converted to degrees; negative angles are east of the meridian.

Sector	Exp. Rate (10^7 yr^{-1})	Calc. Rate (10^7 yr^{-1})	$\langle h \rangle$ (hg cm^{-2})	$\langle E_{i0} \rangle$ (GeV)	$\langle R_{\text{med}} \rangle$ (GV)
44°	0.23				
36°	0.43				
25°	0.92	0.92	618	158	1900
14°	1.81	1.84	533	134	1630
0°	3.15	3.06	465	115	1410
-14°	2.99	2.89	441	108	1330
-25°	2.43	2.12	440	108	1330
-36°	1.31	1.18	456	112	1380
-44°	.83				

layer, for a total of 1272 distinct possibilities when end effects are included. Events satisfying this simple geometry are recognized by the on-line computer and tallied in 1272 bins, permitting retroactive removal of any desired counter. Summaries of these data are written onto tape every half hour. All other events are individually written onto tape for more sophisticated off-line pattern recognition. A summary of the way these events distribute is given in Table 2. The data for the nine

TABLE 2

Event distribution in an average data segment. Classification is discussed in the text. IMO' corresponds to $1.53 \times 10^8 \text{ yr}^{-1}$, or 4.85 sec

"Clean" (3 counter) muon events:

Hour angle sector		
45° to 90°		
44°	1.4%	} 85.6%
36°	2.6%	
25°	5.6%	
14°	11.0%	
0°	19.1%	
-14°	18.1%	
-25°	14.8%	
-36°	7.9%	
-44°	5.1%	
-90° to -45°		3.7%
3 ctrs + 1 adjacent (δ ray)		6.4%
Multiple muons (85% doubles)		0.4%
Accidentals		0.2%
Junk		2.1%
		<u>100.0%</u>

central sectors are as given in Table 1. About 5% of the remainder are three-counter in-line events at very wide angles, and a few of the "junk" events are wide angle events with small scatterings. Six percent of the events are obvious ".S-ray" events, in which in-line counters fire, plus an adjacent neighbor in one layer. By "accidentals" we mean two nearby counters firing plus either nothing or an unrelated counter in the third layer. Our most probable accidental consists of such a real muon penetrating two layers and missing the third, plus a noise trigger in the third layer which completes the coincidence. The noise trigger is latched about half the time, depending on its timing relative to the muon. About 40% of the events listed as "junk" should probably be listed as 5-counter knock-on events, with two adjacent counters in each of two layers. The remainder of the "junk" is probably produced by local showers, since a typical event consists of a large number of nearby counters firing with no apparent pattern.

The on-line program also searches for transient or burst events, as discussed previously (Bergeson et al., 1975). So far, the number of "alarms" recorded is almost exactly the number expected from statistical fluctuations.

4. Conclusions and Expectations. Because of a faulty procedure, many of the epoxy joints between the light guides and photomultipliers broke, often with damage to the tube. It has been operating. The results reported above are based on this sample. At the present rate, the entire detector should be operating by 06/77. Except for minor fixes, there have been no design changes, and we find that most of our expectations have been conservative. Anisotropy data tapes are already being produced, and full-detector operation should be routine during the summer. Short power failures continue to plague us, but non-interruptible power may soon be available.

The U.S. Weather Bureau in Salt Lake City is currently supplying us with pressure-temperature profiles up to the 100 mb level, obtained from bi-daily balloon flights. Although we have not yet addressed the problem, the data appear quite adequate for obtaining the required atmospheric corrections.

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