CDMS Note 9802001 2^{nd} edition

Estimating the Neutron Background for SUF Run 18.

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1 Introduction

The upcoming CDMS run 18 in the Stanford Underground Facility (SUF) will be the first run where a sizeable number of neutrons will scatter off multiple detectors. The neutron background can be calculated by extrapolating the multiple scatters to give the single neutron scattering rate. This note describes work done with the GEANT/MICAP based Monte Carlo described in [1, 2, ?]. This second edition of this note has more accurate results that the previous edition. In the first edition, the simulation was missing the inner lead moderator. Also, the number of recoils/day "above 10 keV" should have read "between 10 and 100 keV". The numbers in table 2 have been modified accordingly. Also, a table 3 has been added for convenience.

2 Sources of Background

Angela daSilva's work on neutrons background [3] estimation provides the starting point of the calculations presented here.

The neutron background divides itself naturally into 2 categories: *internal* neutrons produced from muon interaction inside the muon veto (in the shield), and *external* neutrons produced outside the muon veto.

While the internal neutrons are far more in number, they can be rejected offline by a coincidence with the muon veto. This sample of events will help to verify (or not) the Monte Carlo estimate of these events.

The external neutrons are far fewer in number. They are interesting to calculate since they cannot be vetoed.

3 Monte Carlo

Two GEANT/MICAP programs were used in this study. The program `suf`, was used to estimate the neutron flux in the SUF cavern, based on the production spectrum in the walls (see sec 5. `suf` was derived from the program `soudan`, used to estimate the background in the Soudan mine [1]. The program `icebox` was used to simulate the neutrons produced and propagated in the shield. This is the same program used in the comparison of the Californium calibration data from run 14.

This simulation does not contain the "inner moderator" inside the cryostat. So it represents the icebox as it is for run 18. Studies in [3] indicate a reduction in the copper neutrons of about a factor of 10.

To estimate the recoils coming from the lead,copper and wax, A separate Monte Carlo simulation was run for each material. In each case, the spectrum was used to choose an initial neutron energy, and the initial position was chosen at random inside the material under consideration. So there are separate results for neutrons generated in each material.

4 Internal Neutrons

Cosmic muons produce neutrons in the lead shield, the copper cans and the polyethylene (wax) moderator. The production mechanisms are μ^- capture for slow muons ($\mu^- + p \to n + \nu_\mu$), and photonuclear reactions (γ, n) or photofission (γ, Xn) from fast muons [3].

Figure 1 shows the spectra of neutrons produced in lead and wax. Neutrons produced in copper are supposed to have the same spectrum as those in lead. Table 1 gives the absolute rate of neutron production in the 3 different materials.

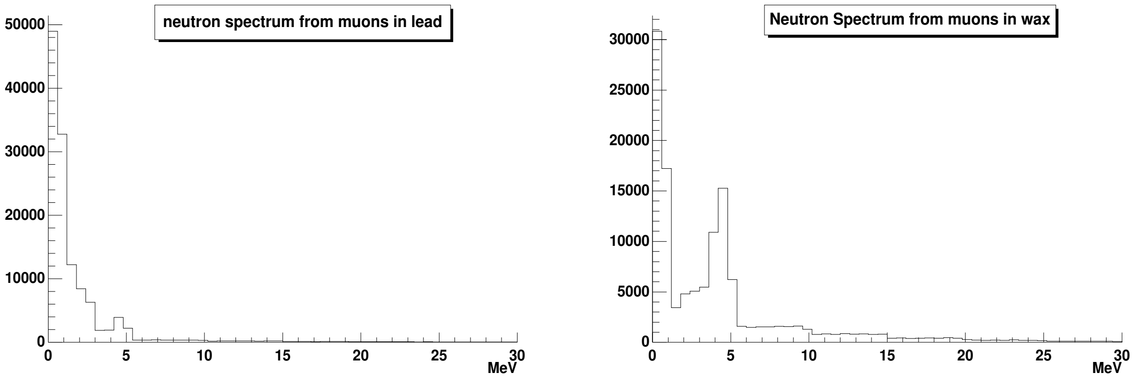

Figure 1: Left: *Spectrum of neutrons produced in lead & copper.* Right: *Spectrum of neutrons produced in wax.*

Table 1 shows estimated neutron rates from muons in the lead, copper and wax at the SUF depth [3]. Although the lead shield is the largest source of neutrons, table 2 shows that the neutrons from the copper lead to the most recoils, since the copper is inside the wax moderator.

Material	Rate (n/kg/s)	Mass (kg)	Rate (n/s)
Copper	1.2×10^{-3}	872	1
Lead	2.8×10^{-3}	19,570	55
Wax	1.3×10^{-4}	1,105	0.14

Table 1: *The rate of neutron production in the materials in the CDMS shield and cryostat. The rate (n/kg/s) numbers are from Angela's thesis [3]. The masses are estimated from the volume of the material.*

Figure 2 shows the detector multiplicity of the events from neutrons generated in the copper. The distributions from the other materials are similar. In this note, *multiple hits* and *multiplicity* refer to the number of different detectors hit, not multiple hits in the same detector.

The right-hand side of figure 2 shows the positions of multiple hits in the detectors. This plot is interesting as it shows the sizes and relative placement of the 3 detectors. We also see that BLIP2, the central detector, sees the most multiple recoils as you might expect.

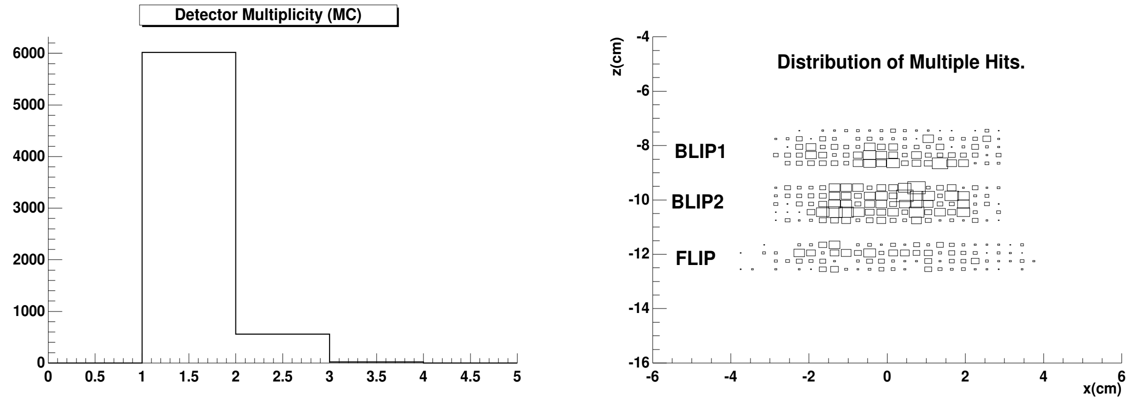

Figure 2: Left: *The multiplicity of detectors.* Right: *The position of the hits for events with multiple hits.*

Table 2 shows the integrated number of recoils above 10 keV in each detector from each source. In addition it shows the rate of multiple detectors hit for each detector and source. Neutrons induced in the copper make up the bulk of the overall rate. The table shows that about 20% of scatters in BLIP2 are multiple scatters compared to about 13% of the outer detectors. We also see that FLIP sees a higher recoil rate (mainly because it has more above the 10 keV threshold).

Detector	Recoils/day $\geq$ 10 keV				Multiple Recoils/day $\geq$ 10 keV			
	Copper	Lead	Wax	External	Copper	Lead	Wax	External
BLIP1	16.3	6.4	0.25	6.4×10^{-2}	2.3	1.1	3.3×10^{-2}	8.9×10^{-3}
BLIP2	15.7	6.9	0.26	5.9×10^{-2}	3.4	1.6	5.4×10^{-2}	1.2×10^{-2}
FLIP	22.0	10.7	0.29	7.1×10^{-2}	2.9	1.2	3.8×10^{-2}	9.8×10^{-3}

Table 2: *The rate of neutron recoils in the detectors from various sources.*

E_{min}(keV)	Recoils/day		
	BLIP1	BLIP2	FLIP
5	31 (4.7)	31 (6.8)	38 (4.7)
10	23 (3.4)	23 (5.1)	33 (4.1)
20	14 (1.8)	15 (3.0)	26 (3.1)

Table 3: *The Integrated recoil (multiple recoil) rates above E_{min} in the three detectors.*

Figures 3-4 show the recoil spectra for single and multiple hits in each of the detectors from the sum of the copper, lead and wax neutrons. The sum is dominated by the copper neutrons. The spectra are shown normalized to 1, to facilitate comparison of the shape of the multiple and all recoil spectra. The FLIP spectrum (fig 4) has a different shape due to the lighter nuclear mass and different cross-section.

We see that the multiple recoils in all cases tend to be lower energy. At least half of the multiple recoils are after the neutron has lost some energy in a previous collision. The shape is otherwise very similar.

5 External Neutrons

External neutrons come from natural radioactivity from U and Th in the rock, Muon capture in the walls, and hadronic cascades. The integrated production rate in the rock is 94 neutrons/kg/day, of which 41 n/kg/day are from μ interactions in the walls, 34 n/kg/day are from natural radioactivity, and 19 n/kg/day are from hadronic cascades in the cosmic rays. See [3] for the contributions to the spectrum from each of these sources.

For this study, the overall external neutron production spectrum was taken from [3] and generated in the walls of the SUF cavern (see figure 5a). These neutrons were propagated and those entering a volume roughly the size of the shield are shown in the spectrum in figure 5b. Given the mass of rock considered and the surface area of the shield, I determined a neutron flux inside the SUF tunnel of 1.7×10^{-4} neutrons/cm^2/s. This is about 100 times more than the estimate of the neutron flux in the Soudan mine[1]. I believe the estimate of the neutron flux in the SUF tunnel is subject to a large uncertainty, say a factor of 10. But I have not taken the time to estimate the uncertainty accurately.

Figures 6a & b show the estimated spectra of the neutron recoils in BLIP1 & 2. The shaded regions show all recoils, and the bold lines the multiple recoils. The spectra are normalized to 1 to compare shapes. Table 2 shows the integrated rates above 10 keV. The spectra in both BLIPs look the same, as expected.

The bottom of figure **??** shows the spectrum of the external neutrons in the FLIP detector. Again, the shaded histogram is all recoils, and the bold is the multiple recoils. The statistics are poor, but the shapes are statistically similar.

The overall rate of external neutrons is about 0.4% of the rate from internal sources. If the veto is 99.6% efficient, then the number of recoils from external neutrons will be about the same as those from neutrons

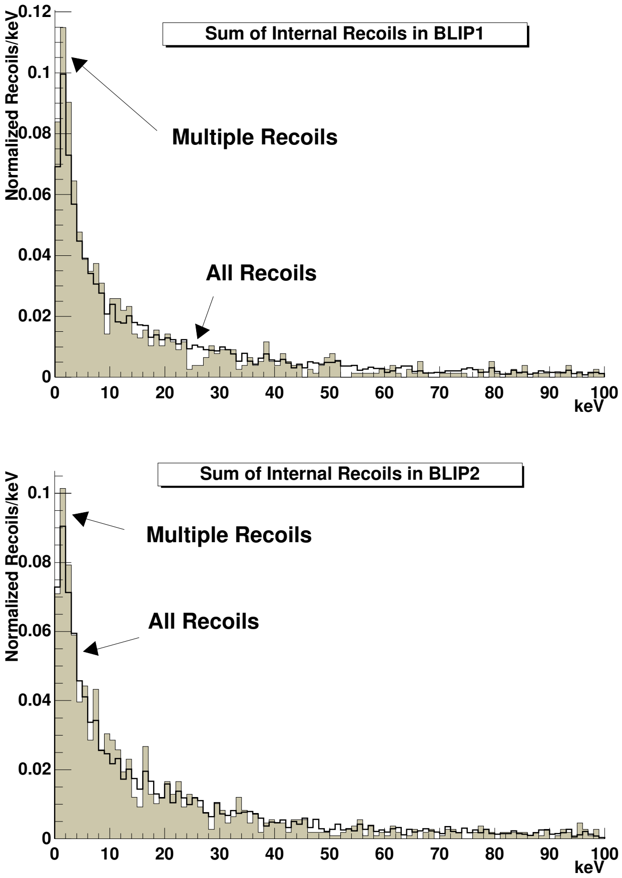

Figure 3: *Sum of recoils from neutrons produced in lead, copper and wax in BLIP1 (top) and BLIP2 (bottom). The shaded histogram shows the multiple recoils, the bold shows all recoils. Both spectra are normalized to 1.*

induced inside the veto, which slipped through the cracks of the veto. This should be vastly improved with the placement of the inner moderator.

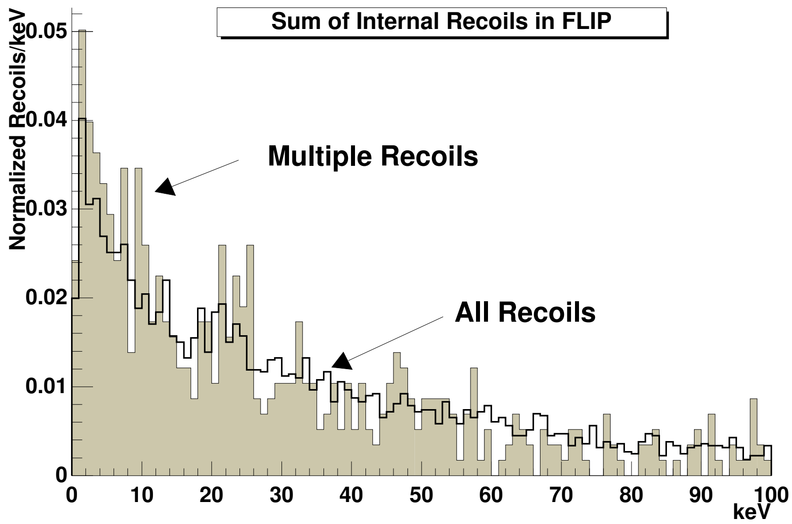

Figure 4: *Sum of recoils from neutrons produced in lead, copper and wax in FLIP. The shaded histogram shows the multiple, and the bold show all recoils. Both spectra are normalized to 1. See table 2 for relative normalization.*

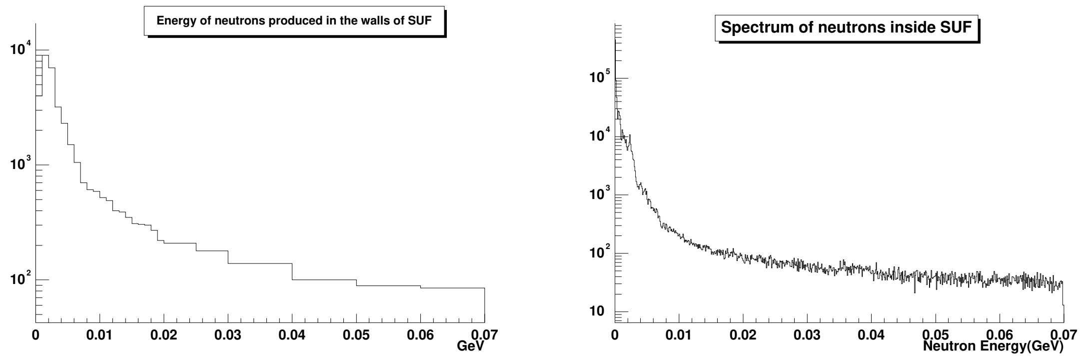

Figure 5: *Spectra of the external neutrons in SUF, outside the shield. This is the sum of contributions from natural radioactivity, cosmic muon capture, and hadronic cascades. The integrated rate of neutron production in the wall is 94 neutrons/kg/day.*

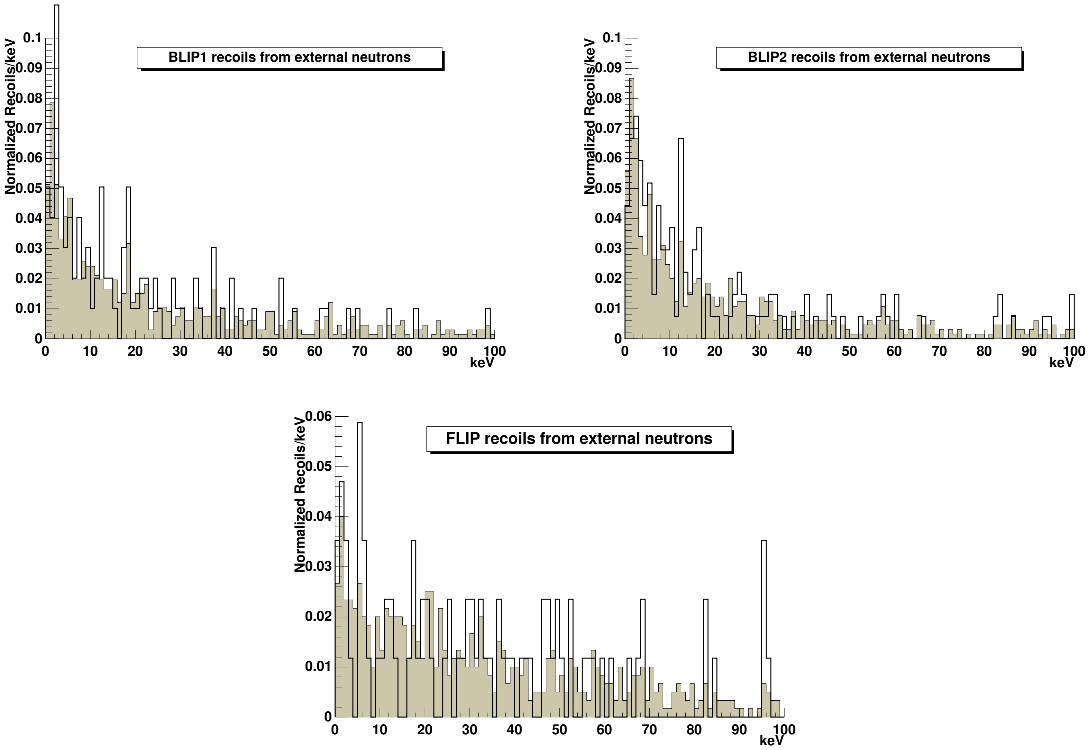

Figure 6: *Recoil spectra from external neutrons in BLIP1 (top left), BLIP2 (top right) and FLIP (bottom). The shaded histogram shows all recoils, while the bold line shows the multiple recoils. All spectra are normalized to 1 to make shape comparison directly. Table 2 gives the absolute normalizations.*

6 Conclusion

Using Angela's estimates of the neutron production and the GEANT/MICAP propagation of neutrons, along with the geometrical description of the shield, icebox and detectors, we get an estimate of the nuclear recoil spectra for run 18.

- The majority of the recoils are from neutrons induced in the copper cans.
- The FLIP detector has a higher recoil rate above 10 keV than the BLIP detectors despite it's lower mass.
- Multiple scatters occur at about 13% in the outer detectors, and at 20% in the central (BLIP2) detector.
- The recoil energy is slightly lower for the multiple scatters.
- Only about 0.4% of recoils are from neutrons from outside the veto.

These conclusion, although vague, will provide something to compare to the data. The studies presented can all be improved with analysis, and will provide a starting point for subtracting the neutron background.

References

[1] S. Eichblatt.
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`http://fnphyx-www.fnal.gov/experiments/cdms/mcarlo/soudan/neutron-bkg.ps`

[2] S. Eichblatt, A. Sonnenshein.
Simulating the Neutron Calibration Run with ICEBOX Draft, 1997.
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[3] A. Dasilva.
Development of a Low Background Environment for the Cryogenic Dark Matter Search.
Ph.D. Thesis, University of British Columbia. April, 1996.