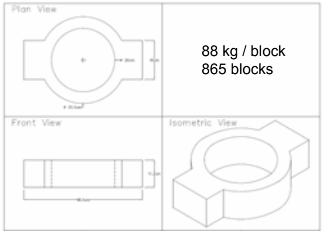
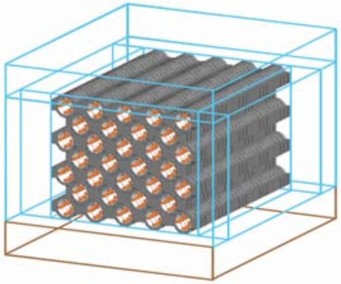
HALO: The Helium And Lead Observatory for Supernova Neutrinos



88 kg / block
865 blocks

Geometry of the lead blocks for HALO-I



The lead blocks will be arranged into 32 horizontal stacked columns 3 m long. Four 3 m long ^{3}He counters will be placed into each column of lead (shown in orange). Some neutron moderator, poly-ethylene, (shown in white) increases capture efficiency.

Not shown above is the structure required to support the lead array. Outlined in blue is a neutron reflecting material. Preliminary Monte Carlo studies suggest that carbon would be the best choice.

Philosophy and Design

The Helium and Lead Observatory (HALO) is a supernova neutrino detector under development for construction at SNOLAB. It is intended to fulfill a niche as a long term, low cost, high livetime, and low maintenance, dedicated supernova detector. It is an evolution of LAND – the Lead Astronomical Neutrino Detector; see C.K. Hargrove et al., Astropart. Phys. 5 (1996) 183.

HALO is a "detector of opportunity" in that the cost of an initial phase (HALO-I) will be kept low by using materials at hand. It will be constructed from 80 tonnes of lead, from the decommissioning of the Deep River Cosmic Ray Station, and instrumented with approximately 384 meters of ^{3}He neutron detectors from the final phase of the SNO experiment.

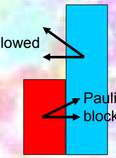
Why Lead?

Lead has several very desirable attributes as the target material for a supernova detector:

- its density leads to a relatively compact design
- its low cost makes large detectors conceivable
- its neutrino cross-sections are high due to a significant Coulomb enhancement
- both neutral and charged current interactions are accompanied by neutron emission
- lead has one of the lowest neutron absorption cross-sections of any natural element making the technology scalable to high target masses

Flavour Sensitivity

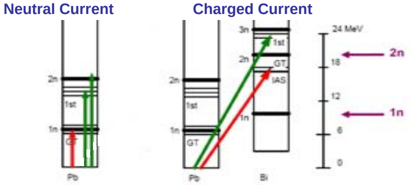
The neutron excess in the lead nucleus leads to very effective Paul blocking of p → n transitions. This in turn implies that the CC ν-Pb cross-section is dominated by electron neutrino interactions. This nicely complements existing water Cerenkov and liquid scintillator detectors that are predominantly sensitive to anti-electron neutrino interactions. The detector design does not permit the detection of the CC electrons.



NC excitations also occur and populate excited states in Pb isotopes as shown below. Calculations by Engel, J., McLaughlin, G.C., C. Volpe, Phys. Rev. D **67** 013005 (2003), assuming a Fermi-Dirac temperature of 8.0 MeV, yield about 1.1 neutron per tonne of lead for a 10 kpc supernova. Of this 23% of the expected neutrons will be from NC interactions and 77% from CC.

$$\nu_e + {}^{208}\mathrm{Pb} \rightarrow {}^{207}\mathrm{Bi} + n + e^-$$
$$\nu_e + {}^{208}\mathrm{Pb} \rightarrow {}^{206}\mathrm{Bi} + 2n + e^-$$
$$\nu_x + {}^{208}\mathrm{Pb} \rightarrow {}^{207}\mathrm{Pb} + n$$
$$\nu_x + {}^{208}\mathrm{Pb} \rightarrow {}^{206}\mathrm{Pb} + 2n$$

Excitations of Pb



Bacrania et al. nucl-ex/0202013

Physics Potential

Our ability to extract physics from the next galactic supernova depends on our ability to separate the contributions of the different flavours – ideally to measure their fluxes and energies as a function of time. No single detector will do this. HALO's detected signal will be a composite of electron neutrino CC and significant NC. Both are very much needed pieces to the puzzle.

To the right is summarized the expected signal for HALO-I for a 10 kpc supernova. These are the neutrons liberated from the lead nuclei. The detection efficiency is of order 50% according to simulation studies.

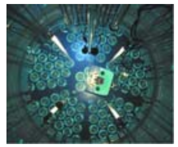
While any supernova neutrino data would provide an invaluable window into supernova dynamics, the electron neutrino CC channel has interesting sensitivity to particle physics through flavour-swapping and spectral splitting due to MSW-like collective neutrino-neutrino interactions in the core of the supernova, the only place in the universe where there is a sufficient density of neutrinos for this to occur. Such data could provide a test for $\theta_{13} \neq 0$ and an inverted neutrino mass hierarchy. In addition, the ratio of 1-neutron to 2-neutron events would be a measure of the temperature of the cooling neutron star.

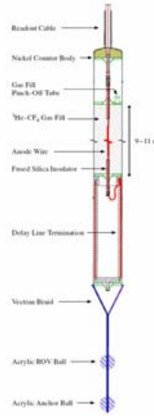
Reaction		events	neutrons per kT	neutrons for HALO-I
CC	1-n	378	378	29
	2-n	234	468	36
NC	1-n	105	105	8
	2-n	72	144	11
		Totals (10kpc)	1095	84

^{3}He Neutron Detectors

The Neutral Current Detector (NCD) Array was the primary means of measuring the neutron flux in the final stage of the Sudbury Neutrino Observatory. The NCD Array Is made with 2-inch diameter ^{3}He proportional counters, totaling more than 700 meters across over 100 strings. The unique low-background of the NCDs and their electronics allow for accurate and fast detection of thermal neutron flux.

The gas mixture within the NCDs is 85% ^{3}He and 15% CF_4 by volume, at close to 1928 Torr pressure. The ^{3}He content provides the counters with a huge neutron cross-section of 5330 b. The CF_4 provides increased stopping power for ionizing particles while improving the performance of ^{3}He as a counter gas. The outer NCD body is made through chemical vapor deposition, a process which delivers ultra-pure nickel, in a precise and uniform distribution. As a result, the ^{238}U and ^{232}Th contaminants are a few pg/g, and the walls of the NCDs are only 380 microns thick. See J.F. Amsbaugh et al., NIM A579 (2007) 1054.





The ^{3}He detectors as deployed in SNO where they were assembled in lengths up to 11 m. For HALO-I 128 3 m individual neutron detectors are foreseen to be deployed.

All images are from the NCD NIM article.

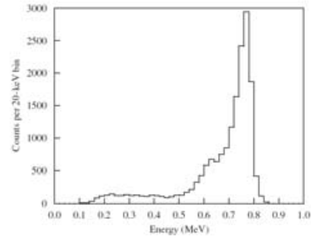


Fig. 1. NCD array neutron-capture spectrum from a uniformly distributed ^{24}Na calibration. The peak at 764 keV corresponds to deposition of the full kinetic energy of the proton and triton in the active volume of the NCD. The 573-keV shoulder, caused by total absorption of the triton's energy in the wall, is distorted by space-charge effects, discussed in Section 6.1. The 191-keV shoulder is caused by total absorption of the proton's energy in the wall.

HALO-II

The physics reach of HALO-I would clearly be extended by increasing the target mass towards a kilotonne. While 384 m of the ^{3}He detectors would be employed in HALO-I additional counters are available and a re-optimized geometry for the lead, can further increase the neutron detection efficiency. Studies indicate that the ~600 meters of detectors available for HALO-II could effectively instrument a kilotonne of lead.

Participation in SNEWS

The Supernova Early Warning System has been running "live" since March 30th 2006.

HALO is intended as high-livetime long-term participant in SNEWS.

Collaborating Institutions

Digipen Institute of Technology, Duke U., Laurentian U., Los Alamos National Lab, U. Minnesota, U. North Carolina, SNOLAB, TRIUMF, U. Washington

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