HALO
The Helium and Lead Observatory

INT Workshop

FLAVOR OBSERVATIONS WITH SUPERNOVA NEUTRINOS

LaurentianUniversity UniversitéLaurentienne

SNOLAB

Clarence J. Virtue

Outline

- Intro
- Generalities
- Lead as a SN neutrino target
- Comparative ν-nuclear cross sections
- Flavour sensitivities
- Event rates
- Sensitivity to ν energy
- Neutron detection in HALO
- Backgrounds
- Efficiency
- SNEWS trigger
- Redundancy
- Status today

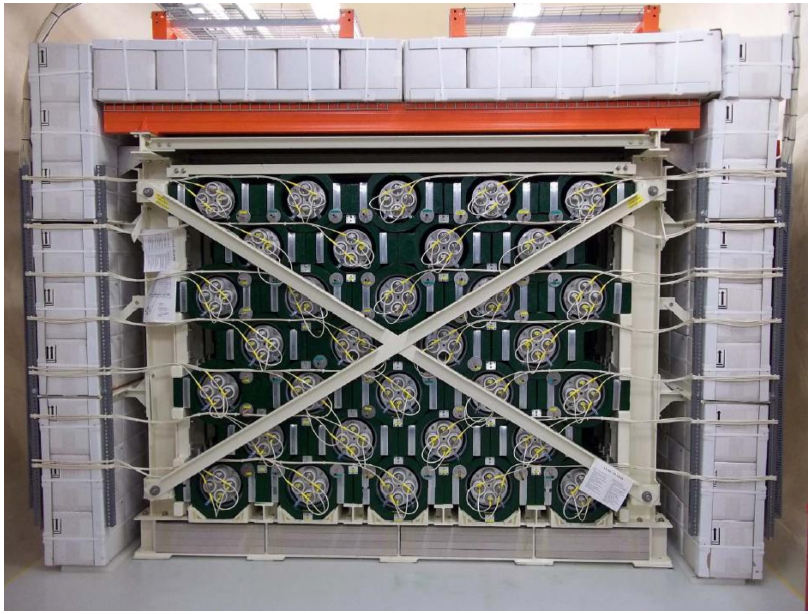
HALO - a Helium and Lead Observatory

A “SN detector of opportunity” / An evolution of
LAND – the Lead Astronomical Neutrino Detector,
C.K. Hargrove et al., Astropart. Phys. 5 183, 1996.

“Helium” – because of the availability of the ^{3}He neutron detectors from the final phase of SNO

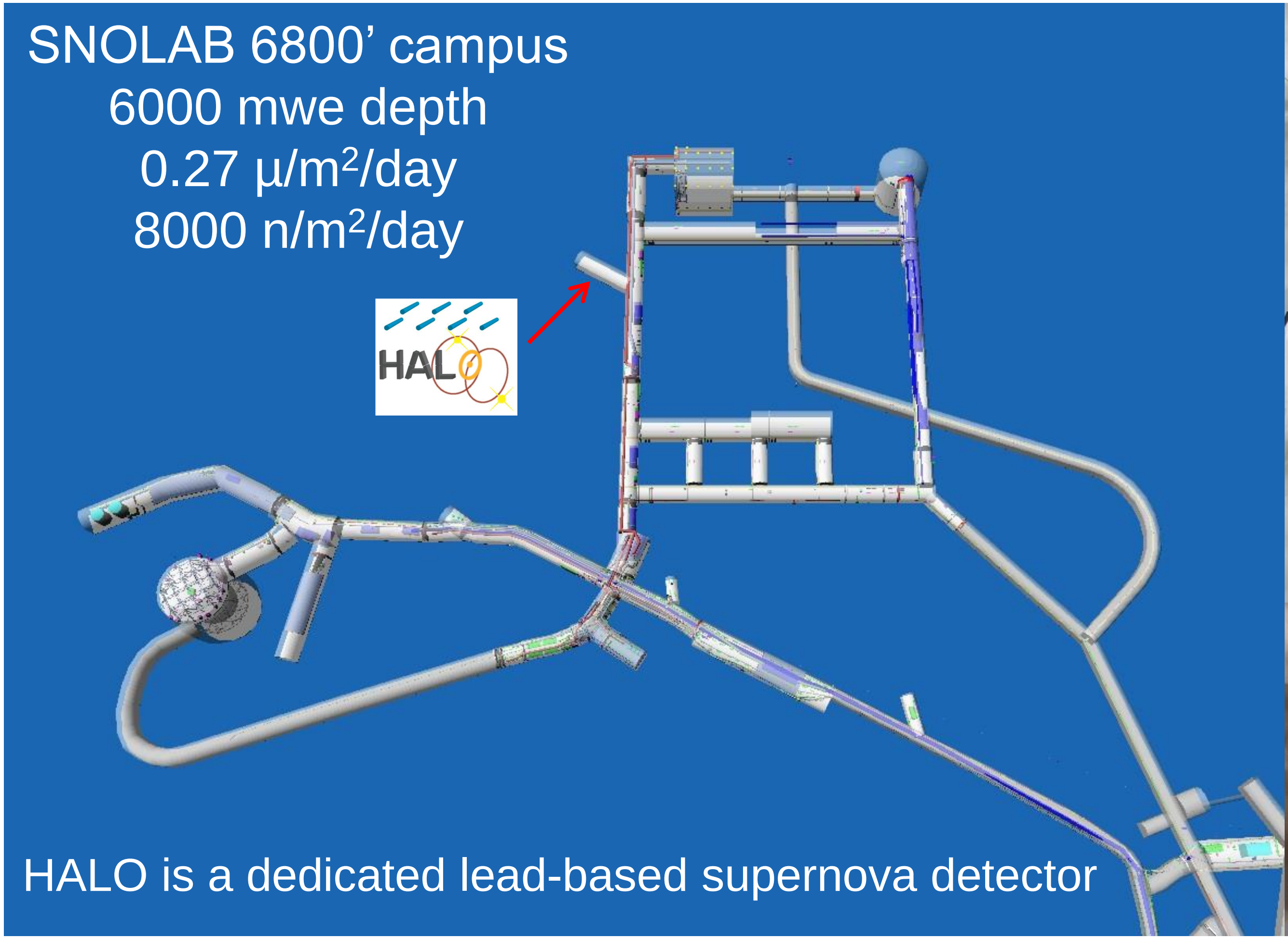
+

“Lead” – because of high ν-Pb cross sections, low n-capture cross sections, complementary sensitivity to water Cerenkov and liquid scintillator SN detectors



HALO is using lead blocks from a decommissioned cosmic ray monitoring station

HALO at SNOLAB



SNOLAB 6800’ campus
6000 mwe depth
0.27 μ/m²/day
8000 n/m²/day

HALO is a dedicated lead-based supernova detector

Generalities / Guiding Philosophies

Self-evident truths

- complementary flavour sensitivity is good
- a dedicated SN detector is good
- SN neutrino data is the primary motivation and participation in SNEWS secondary
- if only a SN detector then accent must be on
  - high uptime / reliability
  - low maintenance / simple operation
  - low capital and operating costs
- getting our foot in the door with a small detector, ie. making the most of an opportunity, is better than not building a detector, large or small

Lead as a Supernova Neutrino Target

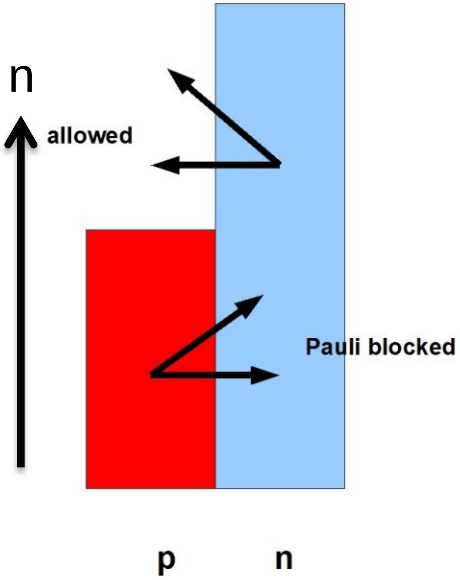
- CC and NC cross sections are the largest of any reasonable material though thresholds are high
- Neutron excess (N > Z) Pauli blocks

$$\overline{\nu}_e + \mathrm{p} \rightarrow \mathrm{e}^+ + \mathrm{n}$$

- High Z increases ν_e CC cross sections relative to $\overline{\nu}_e$ CC and NC due to Coulomb enhancement further suppressing the $\overline{\nu}_e$ CC channel
- Results in mainly ν_e sensitivity - complementary to water Cerenkov and liquid scintillator detectors
- de-excitation of nucleus following CC or NC interactions is by 1n or 2n emission

Other Advantages

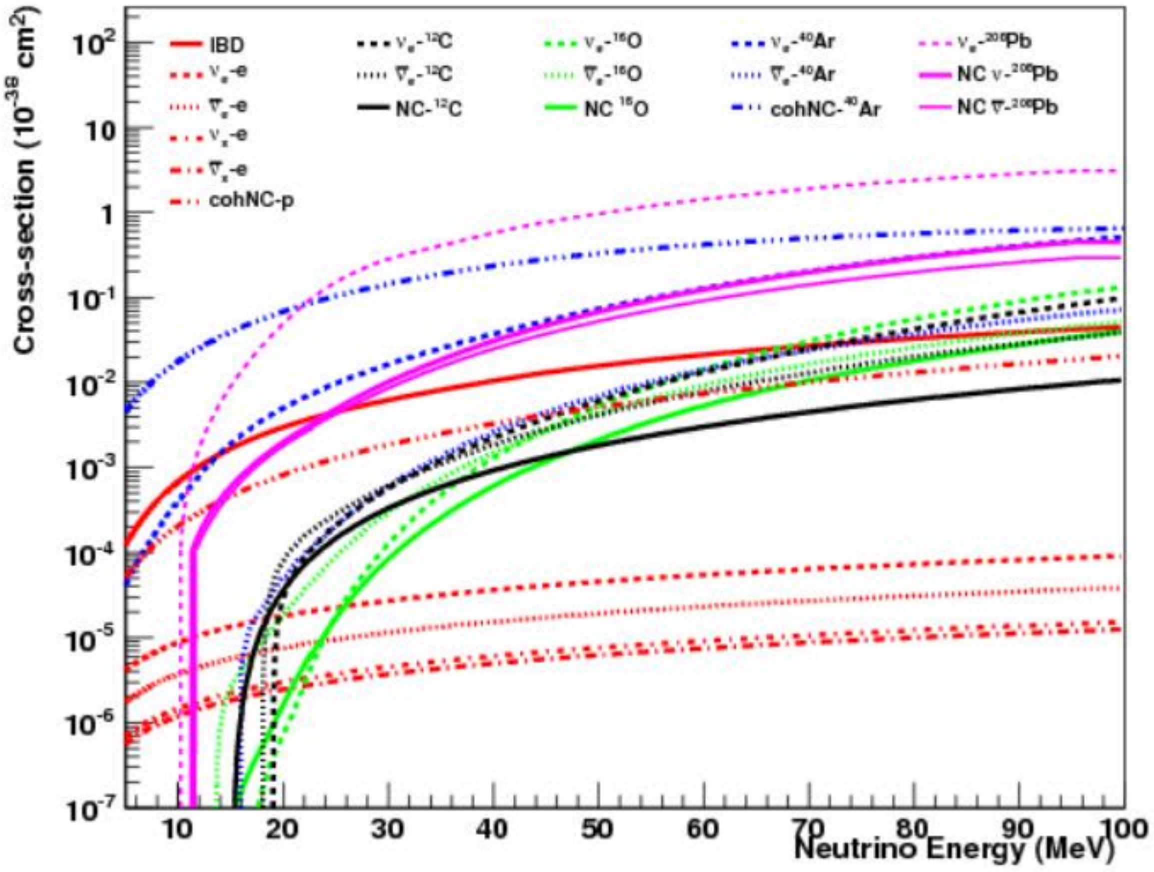
- High Coulomb barrier → no (α, n)
- Low neutron absorption cross section (one of the lowest in the table of the isotopes) → a “good” medium for moderating neutrons down to epithermal energies



Limitations

- no directionality
- no CC tagging
- no direct measure of neutrino energy

Comparative ν-nuclear Cross Sections



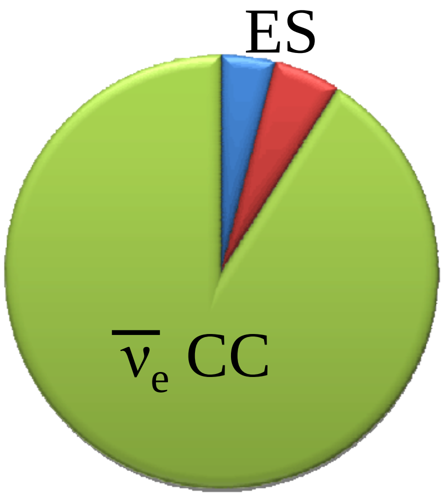
K. Scholberg, Annu. Rev. Nucl. Part. Sci. 2012. 62:81–103.

$$\begin{aligned}
\text{CC:}\quad \nu_e + {}^{208}\mathrm{Pb} &\rightarrow {}^{207}\mathrm{Bi} + n + e^- \\
\nu_e + {}^{208}\mathrm{Pb} &\rightarrow {}^{206}\mathrm{Bi} + 2n + e^- \\
\text{NC:}\quad \nu_x + {}^{208}\mathrm{Pb} &\rightarrow {}^{207}\mathrm{Pb} + n \\
\nu_x + {}^{208}\mathrm{Pb} &\rightarrow {}^{206}\mathrm{Pb} + 2n
\end{aligned}$$

Thresholds
CC 1n 10.7 MeV
CC 2n 18.6 MeV
NC 1n 7.4 MeV
NC 2n 14.4 MeV

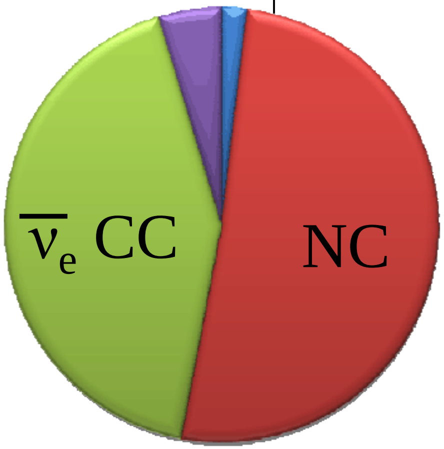
2n cross sections don’t appear on plot but provide a handle on energy distribution

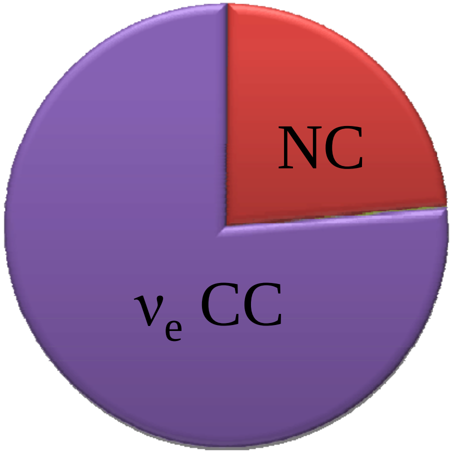
Flavour Sensitivities for Different Technologies



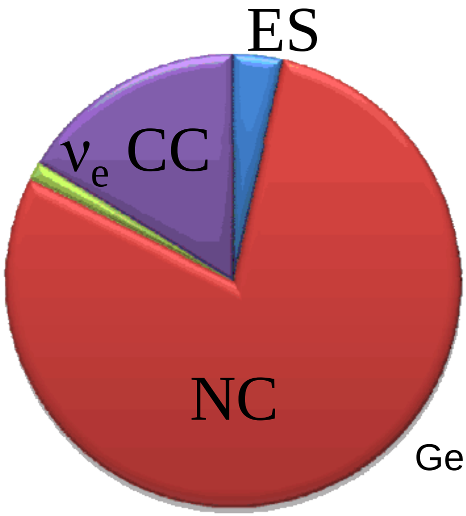
Water Cherenkov

Liquid Scintillator



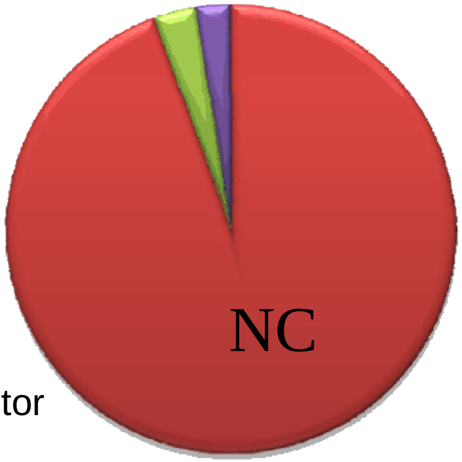


Lead



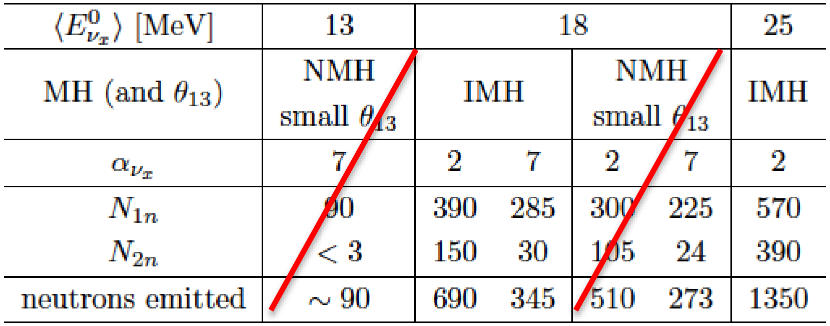
Liquid Argon

Iron



Generally functions of neutrino temperatures and detector energy thresholds, also needs updating for large θ_{13}

Event Rates / kt of Lead (100% capture efficiency)



$\langle E^0_{\nu_x}\rangle$ [MeV]	13	18				25
MH (and θ_{13})	~~NMH small θ_{13}~~	IMH		~~NMH small θ_{13}~~		IMH
α_{ν_x}	~~7~~	2	7	~~2~~	~~7~~	2
N_{1n}	~~90~~	390	285	~~300~~	~~225~~	570
N_{2n}	~~< 3~~	150	30	~~105~~	~~24~~	390
neutrons emitted	~~~ 90~~	690	345	~~510~~	~~273~~	1350

Table 6. Total numbers of events during the explosion (assuming 100 % detection efficiency, distance to the supernova 10 kpc and target mass 1 kton of ^{208}Pb). As in table 4 but assuming equal neutrino luminosities throughout the whole neutrino emission and the total time integrated luminosity 3×10^{53} erg.

from Väänänen and Volpe, JCAP **1110** (2011) 019.

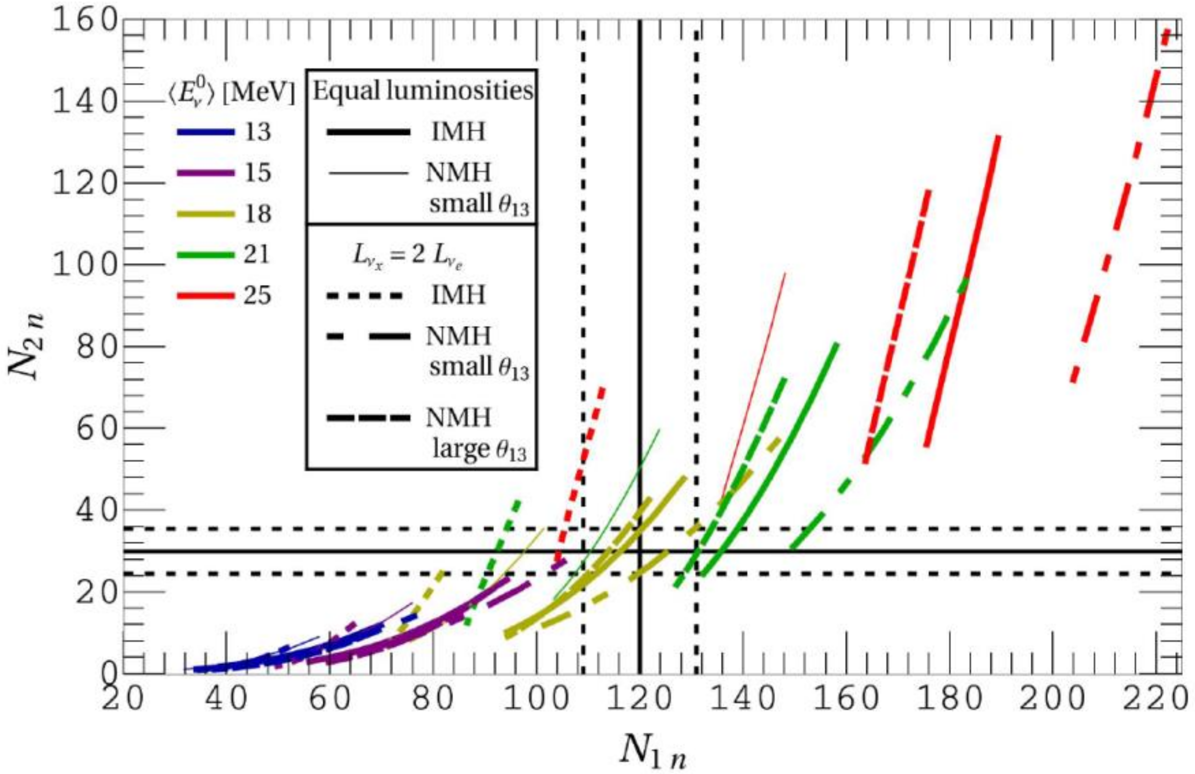
Earlier work, in 1kt of lead for a SN @ 10kpc†,

- Assuming FD distribution with T=8 MeV for ν_x.
- 860 neutrons through ν_e charged current channels
  - 380 single neutrons
  - 240 double neutrons (480 total)
- 250 neutrons through ν_x neutral current channels
  - 100 single neutrons
  - 75 double neutrons (150 total)

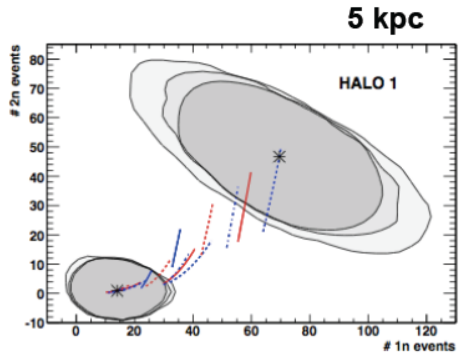
cross sections from Engel, McLaughlin, Volpe, Phys. Rev. D 67, 013005 (2003)

(more conservative neutrino temperatures reduce these event numbers by a factor of ~2)

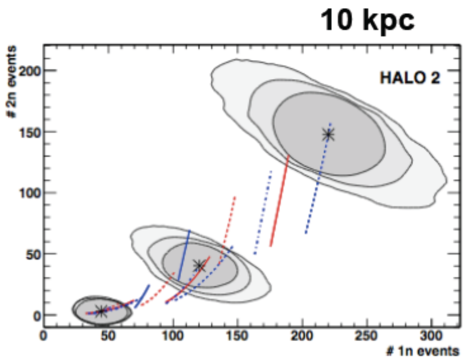
Sensitivity to neutrino energy



Distinct 1n and 2n emission thresholds in lead provide the possibility to measure neutrino temperatures and pinching parameters. N_{1n} and N_{2n} per kt from Väänänen and Volpe, JCAP **1110** (2011) 019



ε = 40%,50%,60%

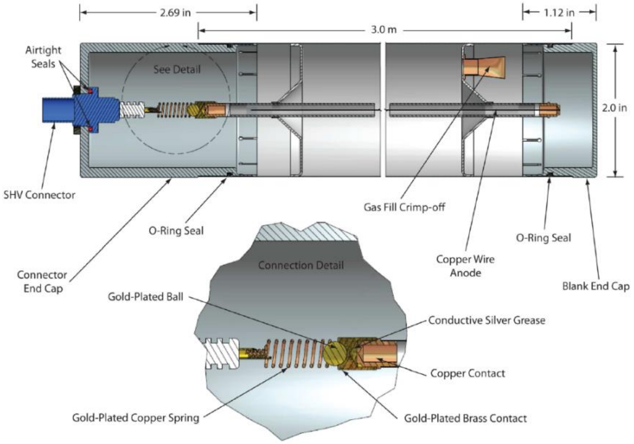


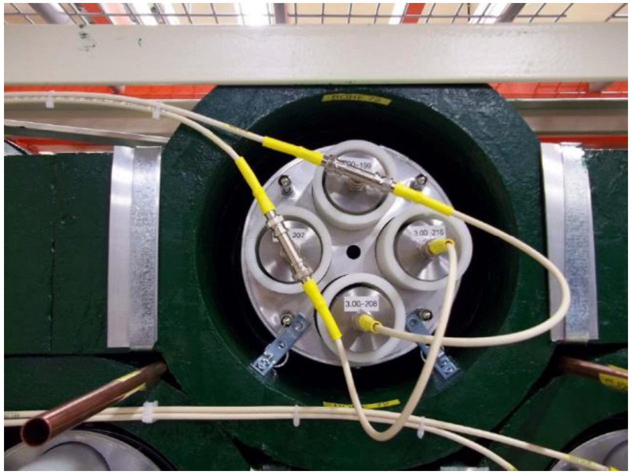
ε = 40%,60%,80%

March 2012 APS, K. Scholberg.

Neutron detection in HALO

- Re-using SNO's "NCD" ^{3}He proportional counters
- 5 cm diameter x 3m and 2.5m in length, ultra-pure CVD Ni tube (600 micron wall thickness)
- 2.5 atm (85% ^{3}He, 15% CF_4, by pressure)
- Four detectors with HDPE moderator tubes in each of 32 columns of lead rings
- 128 counters (~370 m) paired for 64 channels of readout
- an additional ~200m of ^{3}He proportional counters are also available

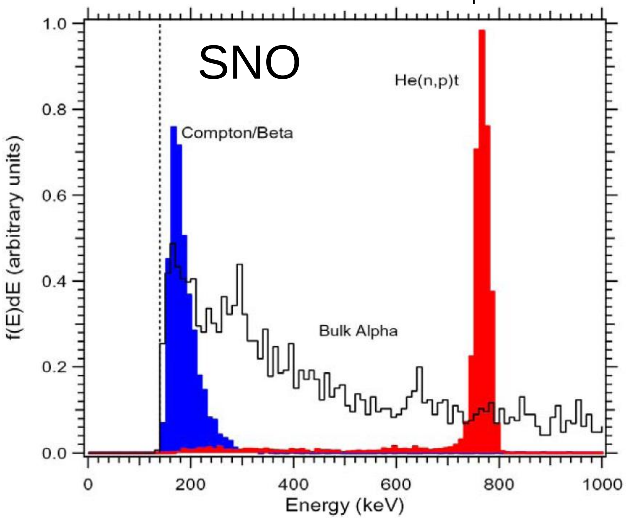


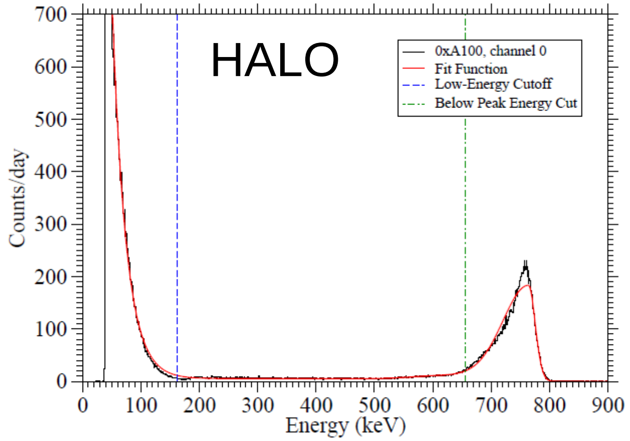


Neutron detection in HALO

- Neutron detection via

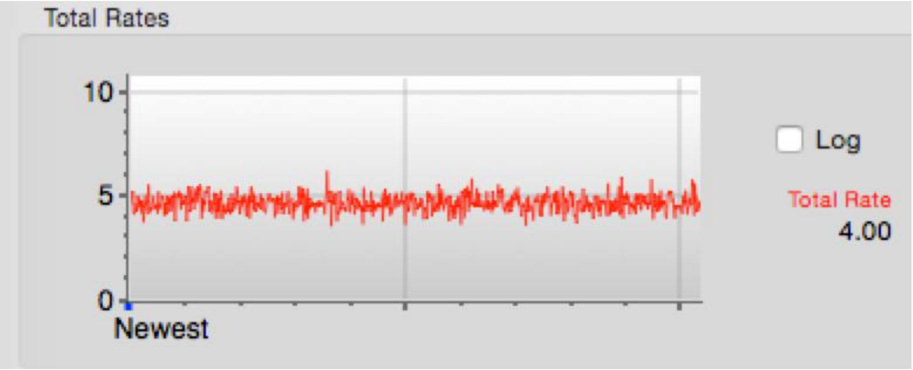
  ^{3}He + n → p + t + 764 keV
- 764 keV FE peak plus LE tail due to wall effects
- Compton and beta events at low energies
  - ionization tracks are longer than for the back to back p-t tracks
- HALO chose shorter integration times in or front end cards
  - gave poorer energy resolution for p-t events
  - larger effect on charge collection on Compton/beta events
  - resulting in cleaner separation of neutrons from Compton/betas





Backgrounds

- Background n in room at level of 4000 fast plus 4000 thermal per m^2 per day.
- Cosmic muons < 2 per day (not seen) but spallation events ~2/mo for > 5 neutrons
- Intrinsic tritium rate (18.6 keV endpoint) above 12 keV threshold ~10 Hz / detector but running at threshold of ~50 keV for total rate of 5 Hz of Compton / beta
- Current “neutron” rate in HALO is 0.015 Hz (1294 +/- 8 / day) of which
  - 23 +/- 5 from ^{238}U spontaneous fission
  - 80 +/- 43 from nearby stored ^{252}Cf calibration source
  - ~20 from internal α contamination
  - rest from leakage through shielding

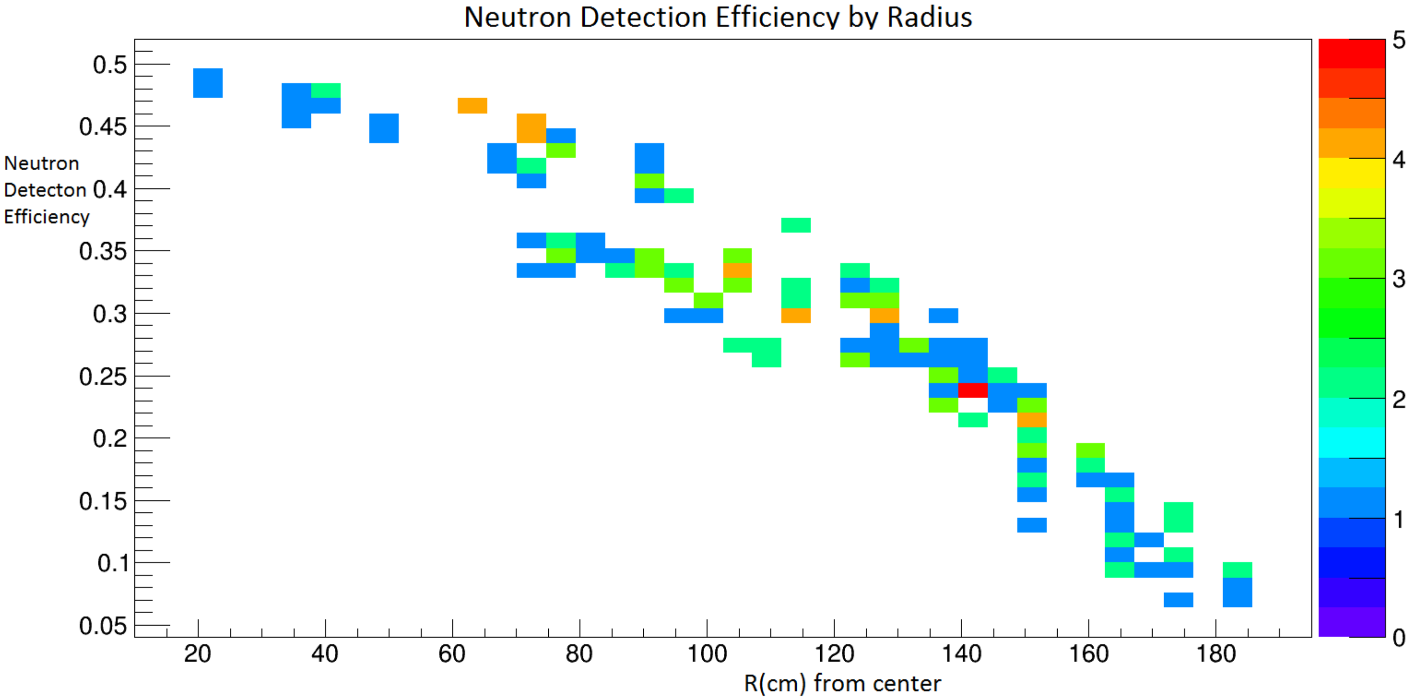


☐ Log

Total Rate
4.00

Efficiency

- measured neutron capture efficiency at 192 positions with ^{252}Cf source
- ~30% volume averaged; 47% central **new**
- requires completion of Monte Carlo studies to translate source measurements to a volume averaged efficiency at “SN” neutron energies



SNEWS trigger

- currently running with a trigger condition of 5 events in neutron window in 2 seconds
- at 15mHz neutron rate we expect random coincidences once per ~400 years
- pile-up between ^{238}U SF and randoms will greatly increase this rate, but still very acceptable
- spallation events, over in < 1 ms, are suppressed and do not generate a SNEWS trigger

→ not at all limited by background rates

- sensitivity out to ~18 kpc

→ limited by target mass

Redundancy

- the basics
  - power
    - UPS with ~2 hours runtime; automated shutdown and restart around extended power failures
    - in < 2 years SNOLAB will have 3 MW diesel generator to supply entire lab
  - network
    - two switches – stacked with multiple uplinks and spanning tree to manage multiple single points of failure
  - gps
    - two units – surface and underground
    - ovenized oscillator in underground one in case fiber to surface lost

Redundancy

128 3He neutron detectors
- paired → 64 channels

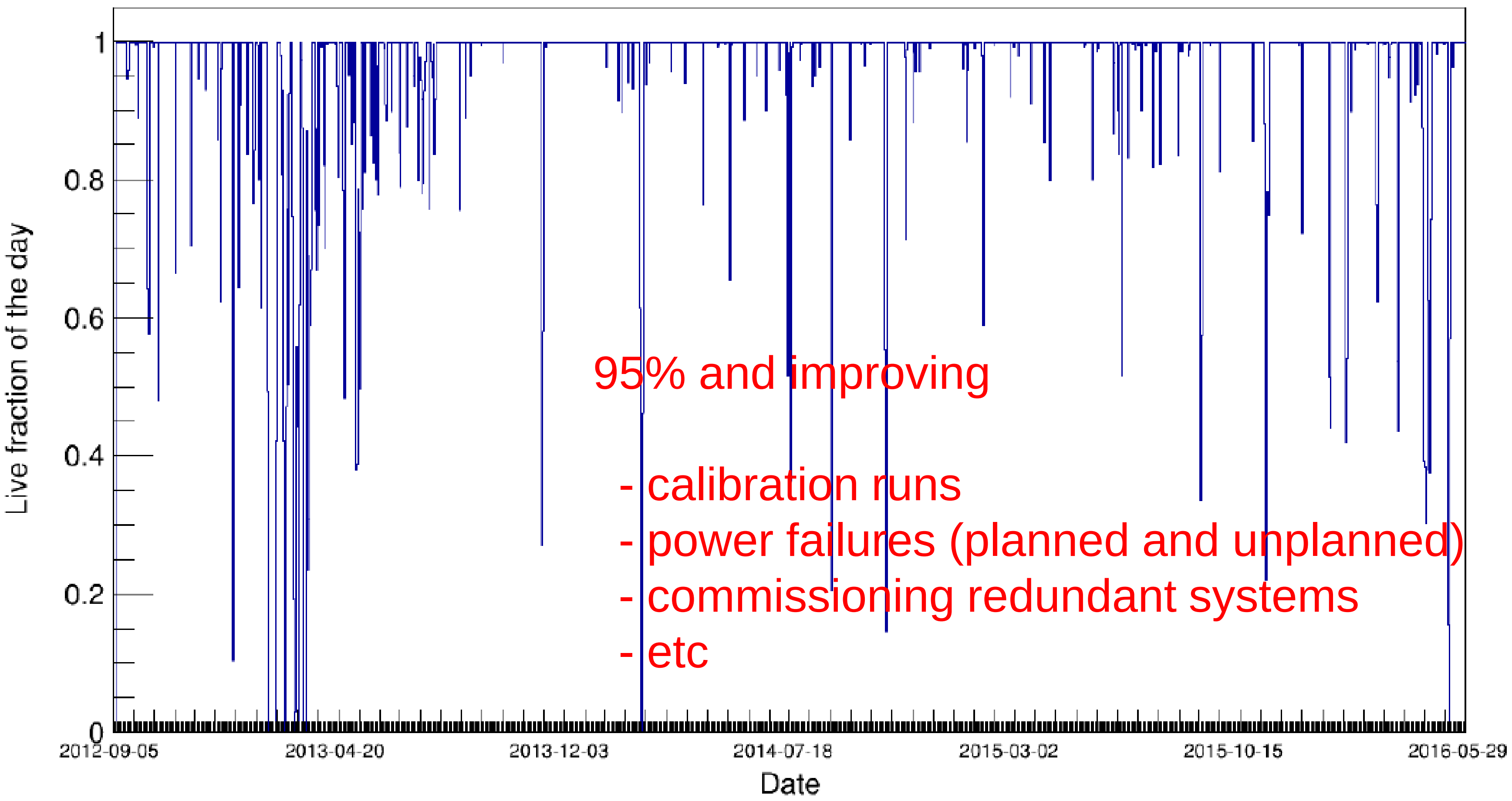
Required (one of):
- LV preamp power supply
- HV supply
- ADCs
- DAQ computer

But multiple single points of failure, so:
- divide readout left / right
- double-up on components including DAQ computer

Most single point failures leave 50% of readout functioning

Livetime

HALO Detector Live Time Between 4/9/2012 and 1/6/2016

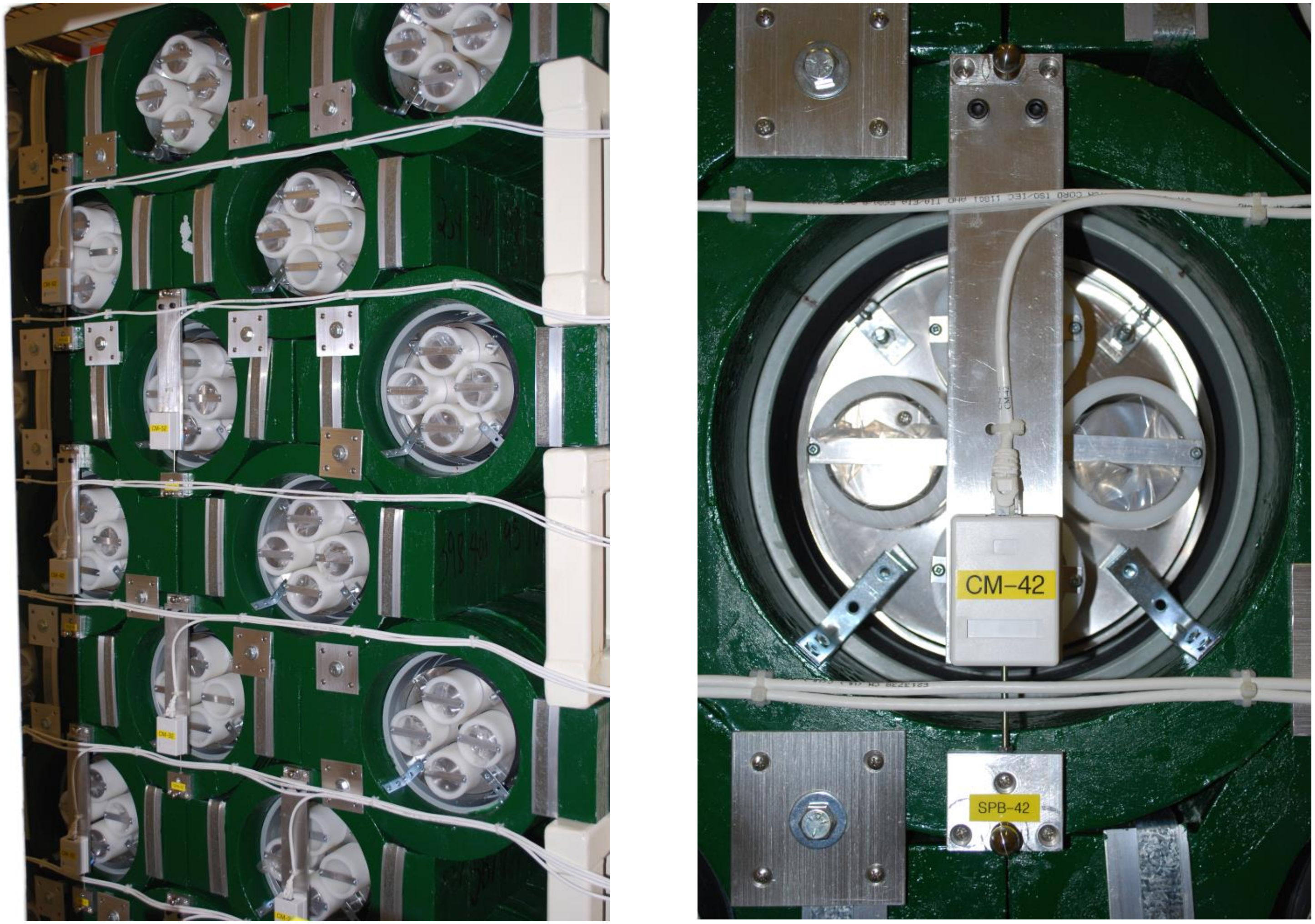


95% and improving

- calibration runs
- power failures (planned and unplanned)
- commissioning redundant systems
- etc

Construction

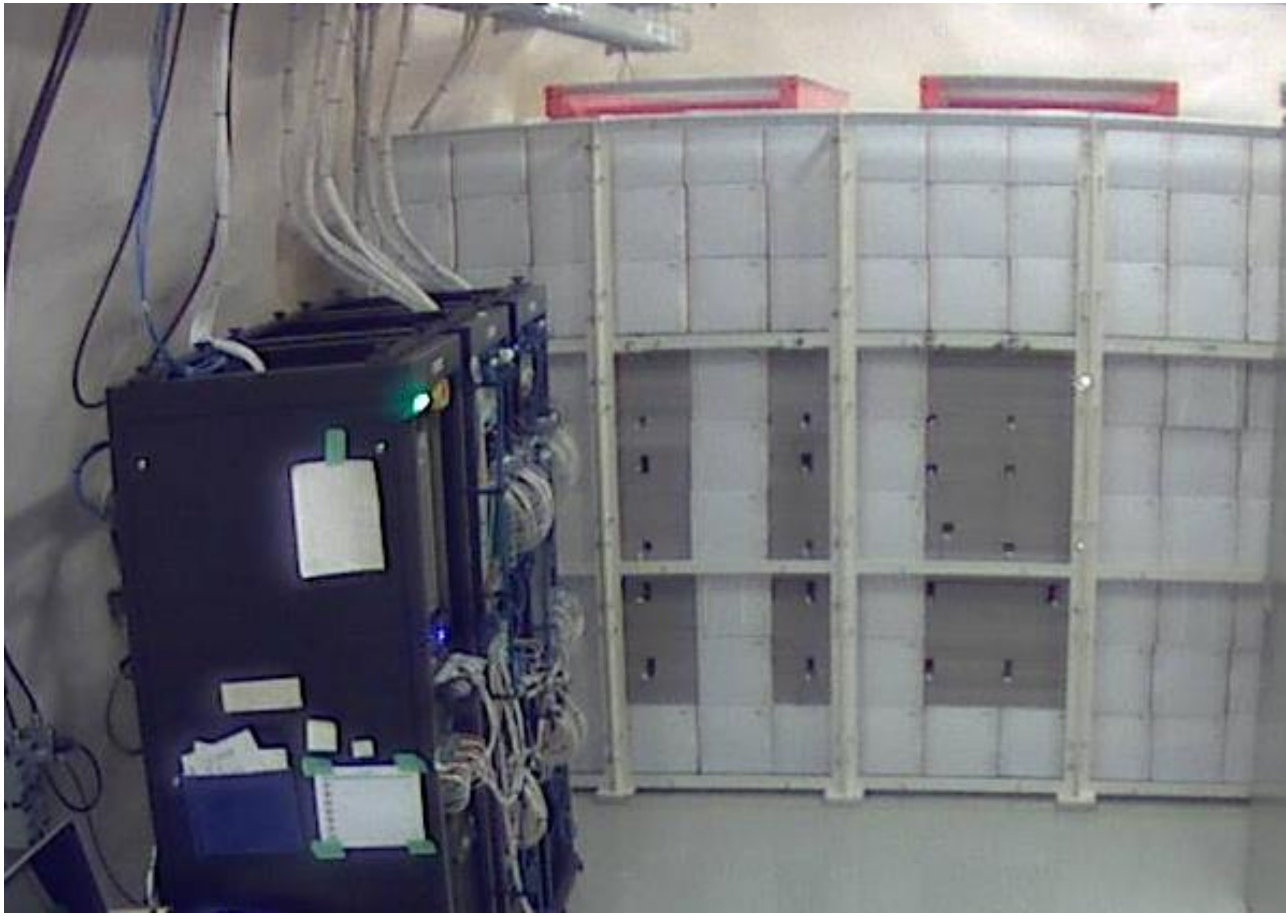
Creep Monitoring



Preamplifiers

Status today

- Full detector being read-out since May 8th 2012.
- Daily shift-taking since July 27th 2012.
- Burst trigger implemented and connected to SNEWS since October 8, 2015
- Full calibration done with and without front shielding wall April 2016
- work continues on redundant systems and monitoring tools



The HALO Collaboration

HALO

Armstrong
STATE UNIVERSITY

DigiPen
INSTITUTE OF TECHNOLOGY

TECHNISCHE
UNIVERSITÄT
DRESDEN

Duke
UNIVERSITY

LaurentianUniversity
UniversitéLaurentienne

UMD
DULUTH

THE UNIVERSITY
of NORTH CAROLINA
at CHAPEL HILL

Pacific Northwest
NATIONAL LABORATORY

SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE

ICRR
Institute for Cosmic Ray Research
University of Tokyo

TRIUMF

W UNIVERSITY of WASHINGTON

C Bruulsema[1], C A Duba[2], F Duncan[3,1], J Farine[1], A Habig[4], A Hime[5], A Kielbik[1], M Howe[6], C Kraus[1], S Luoma[1], R G H Robertson[7], K Scholberg[8], M Schumaker[1], J Secrest[9], T Shantz[1], J Vasel[4], C J Virtue[1], B von Krosigk[10], R Wendell[11], J F Wilkerson[6], S Yen[12] and K Zuber[10]

[1] Laurentian University, Sudbury, ON P3E 2C6, Canada
[2] Digipen Institute of Technology, Redmond, WA 98052, USA
[3] SNOLAB, Sudbury, ON P3Y 1M3, Canada
[4] University of Minnesota Duluth, Duluth, MN 55812 USA
[5] Pacific Northwest National Laboratory, Richland, WA 99352, USA
[6] University of North Carolina, Chapel Hill, NC 27599, USA
[7] University of Washington, Seattle, WA 98195, USA
[8] Duke University, Durham, NC 27708, USA
[9] Armstrong State University, Savannah, GA 31419, USA
[10] TU Dresden, D-01062 Dresden, Germany
[11] ICCR, University of Tokyo, Kamioka Observatory, Japan
[12] TRIUMF, Vancouver, BC V6T 2A3, Canada

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