2021/08/12

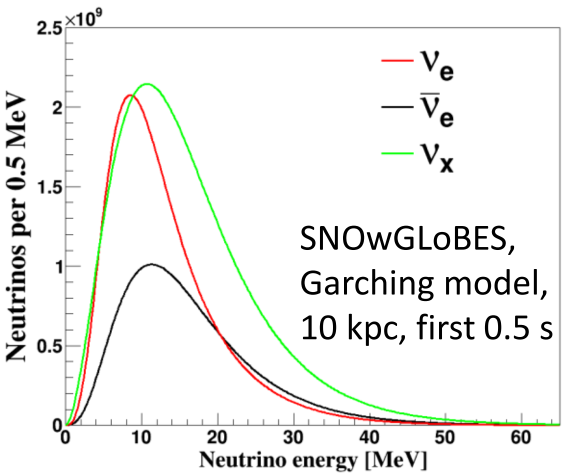
The HALO Experiment at SNOLAB

Tom Sonley

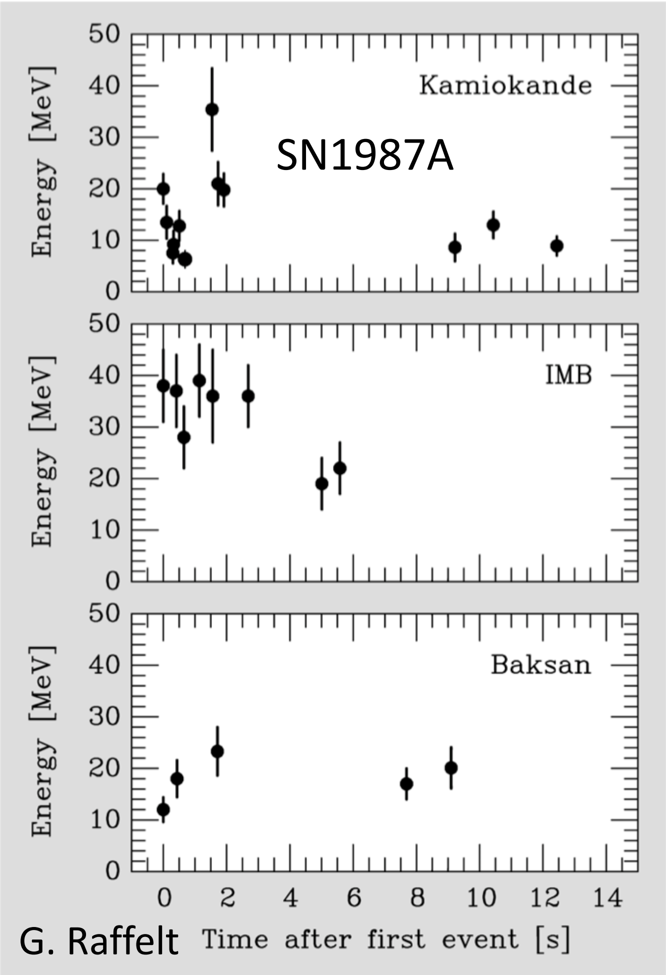
SNOLAB Staff Scientist

Supernova Neutrinos What is the interest?

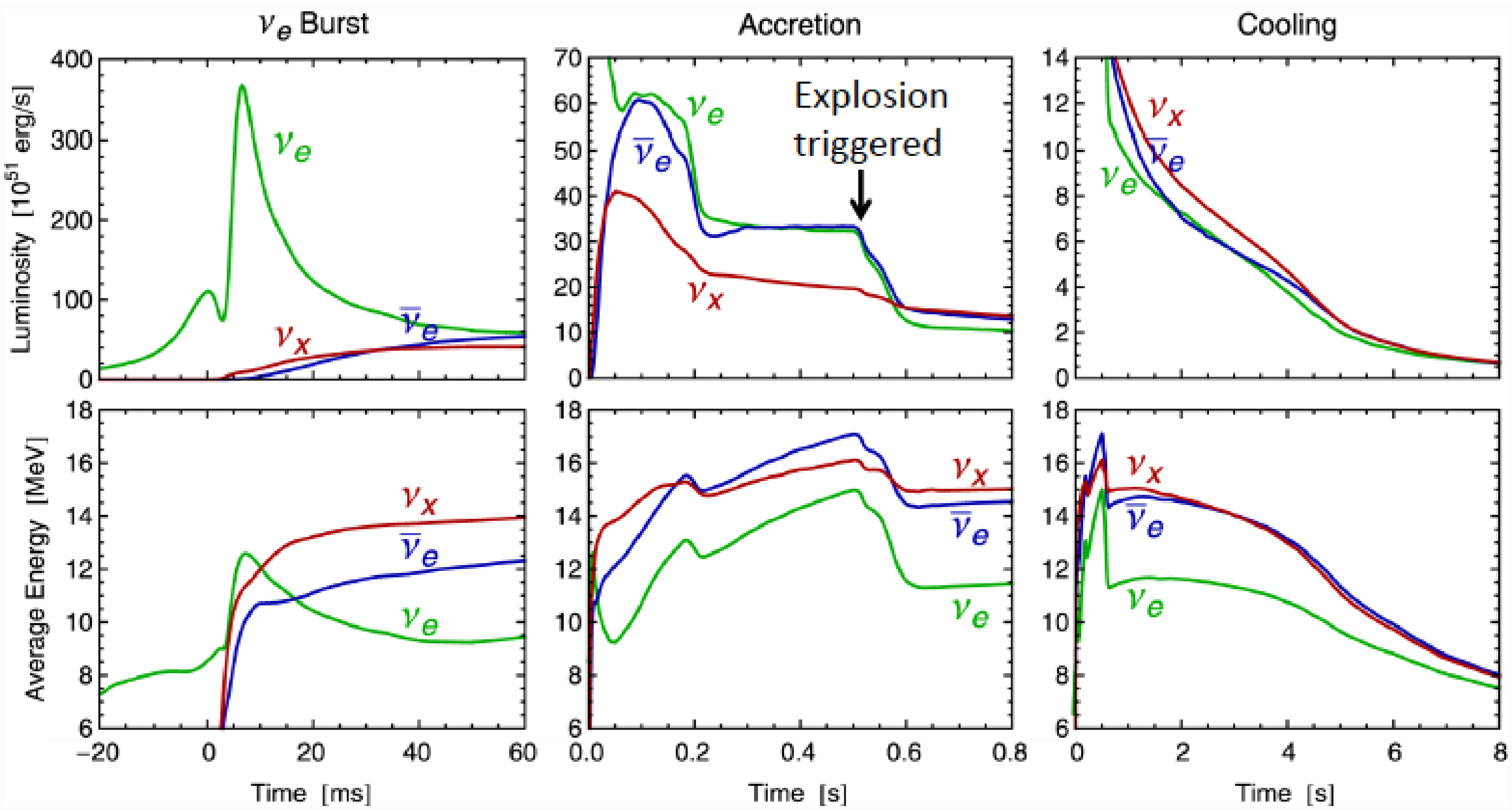
- our only window into core-collapse supernova (ccSN) dynamics
- also a ccSN is the only place where:
  - matter is opaque to neutrinos and they thermalize yielding information about the proto-neutron star environment
  - neutrino density is so large that they interact through collective phenomena resulting in spectral splits and flavour swapping
  - the low temperature, high density part of the QCD phase diagram can be explored where there are predictions of nuclear matter → quark matter phase transitions



- we start with Fermi-Dirac distributions at the neutrino-spheres with:
  $T(\nu_e) < T(\bar{\nu}_e) < T(\nu_x)$
- this signal is imprinted with:
  - collective effects
  - MSW effects
  - shockwave effects
  - large scale density oscillations



Three Phases of Neutrino Emission



- Shock breakout
- De-leptonization of outer core layers

- Shock stalls ~ 150 km
- Neutrinos powered by infalling matter

Cooling on neutrino diffusion time scale

Spherically symmetric Garching model (25 $M_\odot$) with Boltzmann neutrino transport

The Trouble with Supernovae

- Very frequent in our universe (1 per second)
- Current and next generation terrestrial supernova detectors only see supernovae within our galaxy (tiny part of the universe)
- So.... The galactic supernova rate is estimated at

  3 +/- 1 per century

- 2020 Update:

  1.63 +/- 0.46 per century

Rozwadowska, Vissani, & Cappellaro, New. Astron. 83, 101498 (2020)

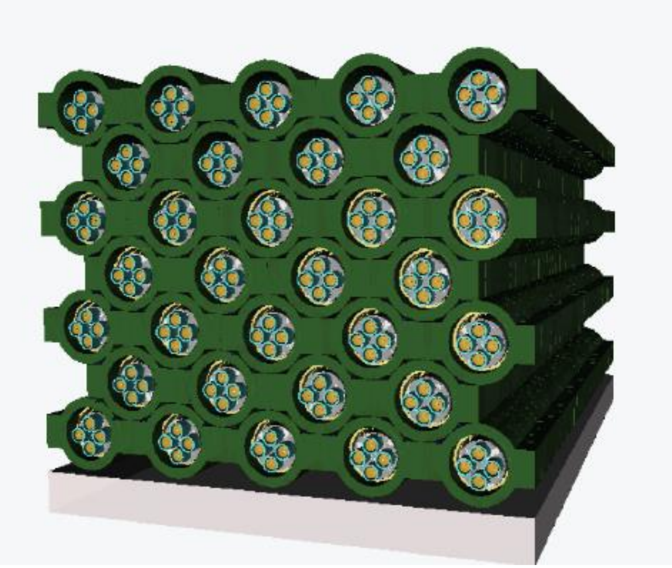
HALO - a Helium and Lead Observatory

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

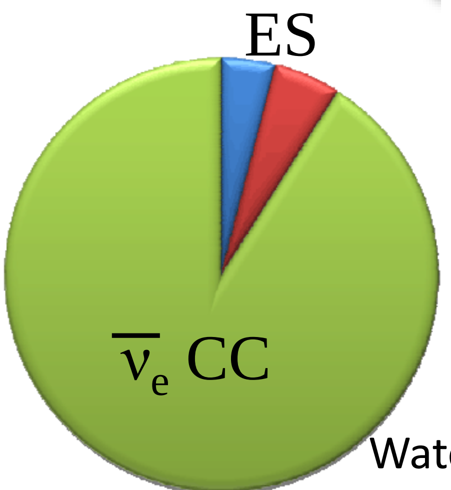


HALO is using lead blocks from a decommissioned cosmic ray monitoring station

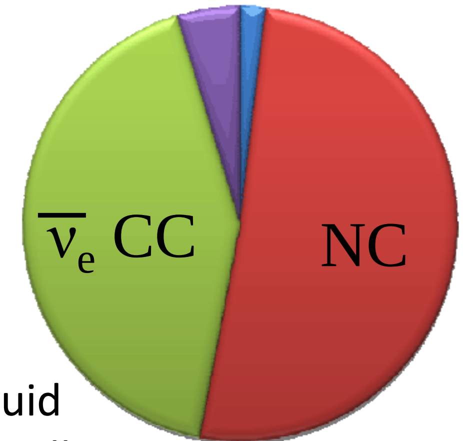
Flavour Sensitivities for Different Technologies

Lead:

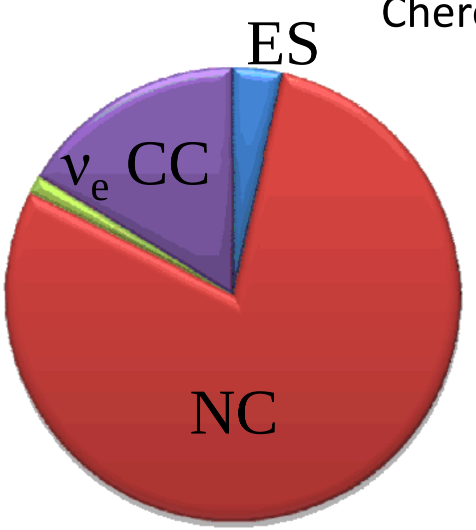
$$
\begin{aligned}
\mathrm{CC}: \quad & \nu_e + {}^{208}\mathrm{Pb} \rightarrow {}^{207}\mathrm{Bi} + n + e^- - 10.3\,\mathrm{MeV} \\
& \nu_e + {}^{208}\mathrm{Pb} \rightarrow {}^{206}\mathrm{Bi} + 2n + e^- - 18.4\,\mathrm{MeV} \\
\mathrm{NC}: \quad & \nu_x + {}^{208}\mathrm{Pb} \rightarrow {}^{207}\mathrm{Pb} + n - 7.4\,\mathrm{MeV} \\
& \nu_x + {}^{208}\mathrm{Pb} \rightarrow {}^{206}\mathrm{Pb} + 2n - 14.1\,\mathrm{MeV}
\end{aligned}
$$



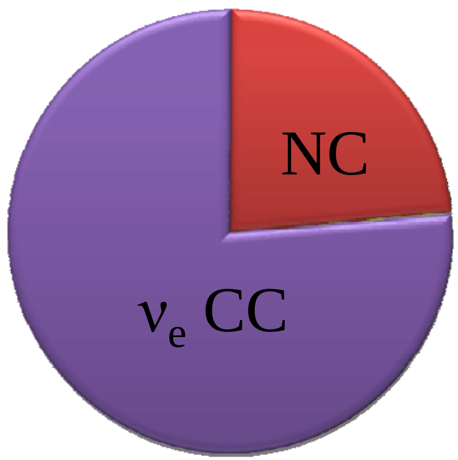
Water Cherenkov



Liquid Scintillator



Liquid Argon



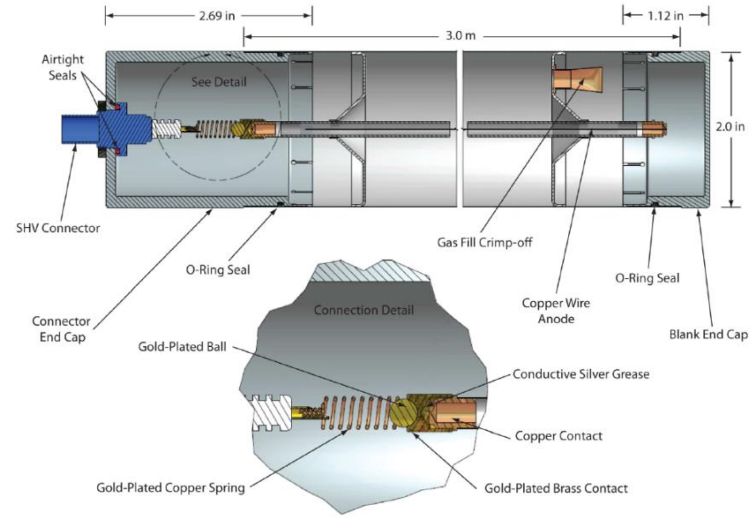
Lead

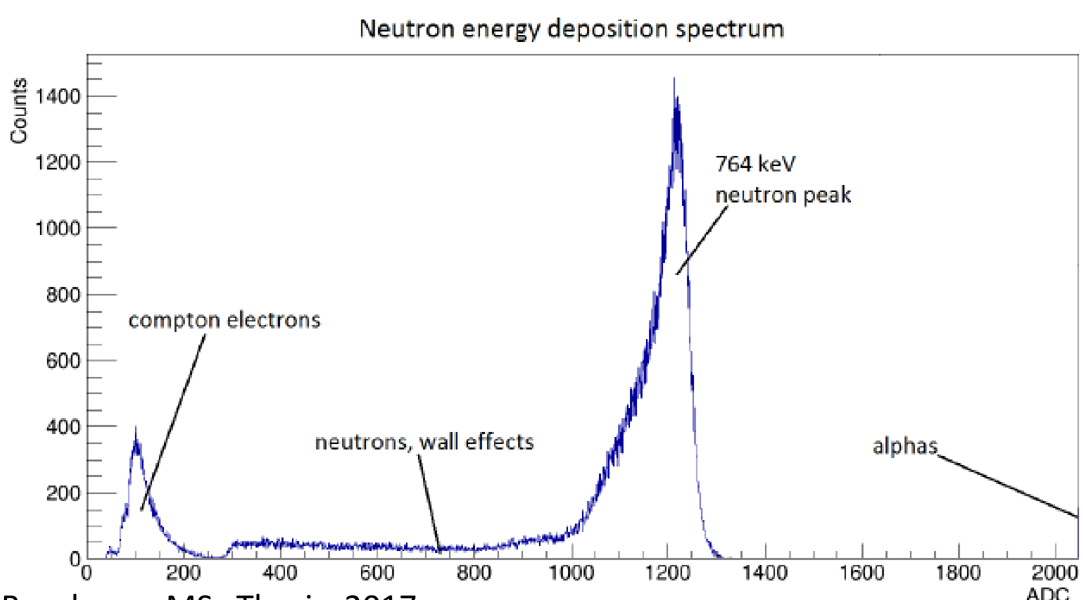
Iron

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

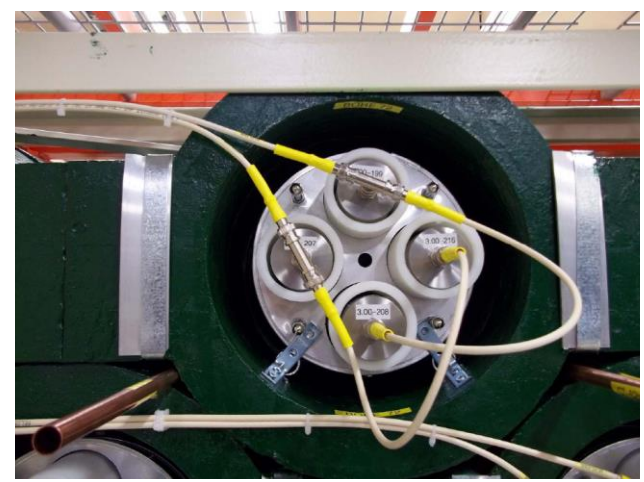
Neutron detection in HALO

- 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
- No prompt signal, 200 us neutron capture time



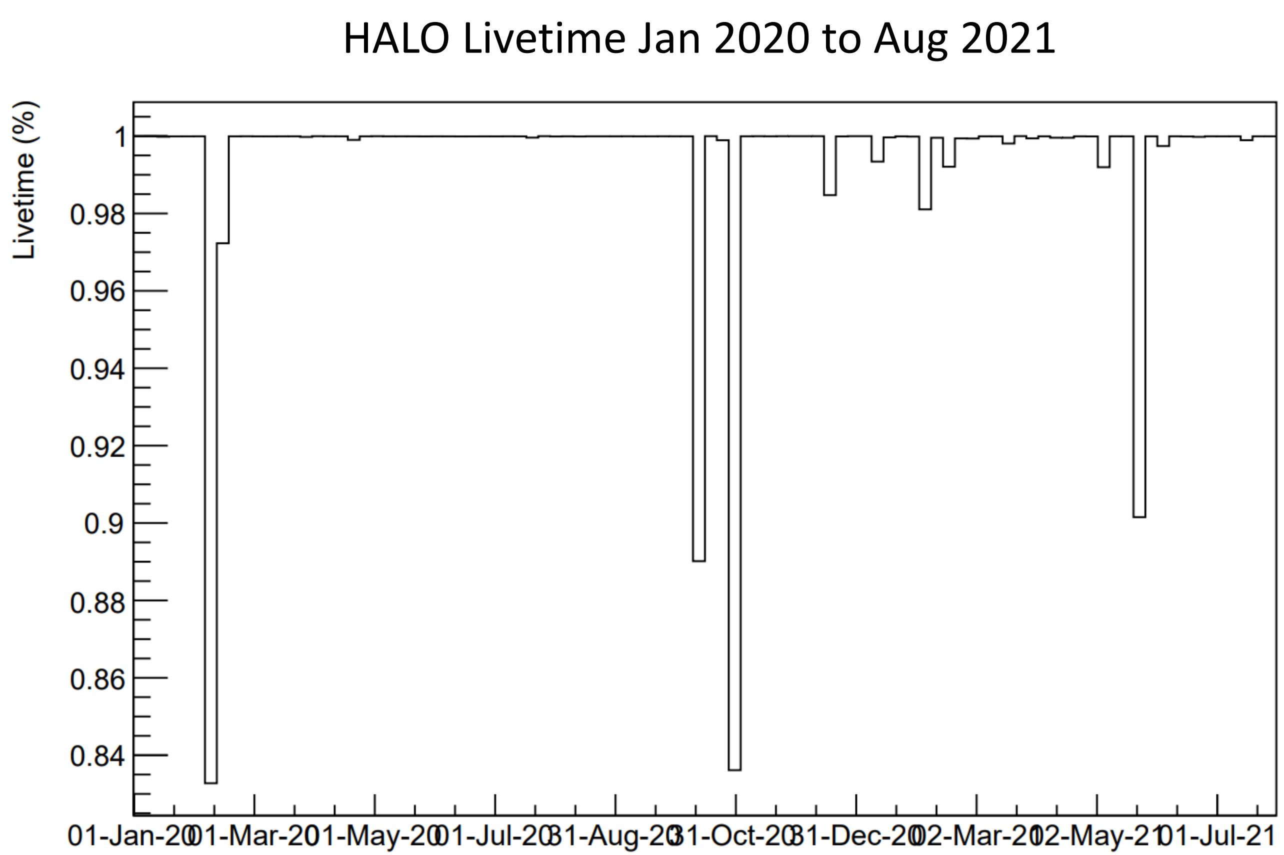


C. Bruulsema MSc Thesis, 2017

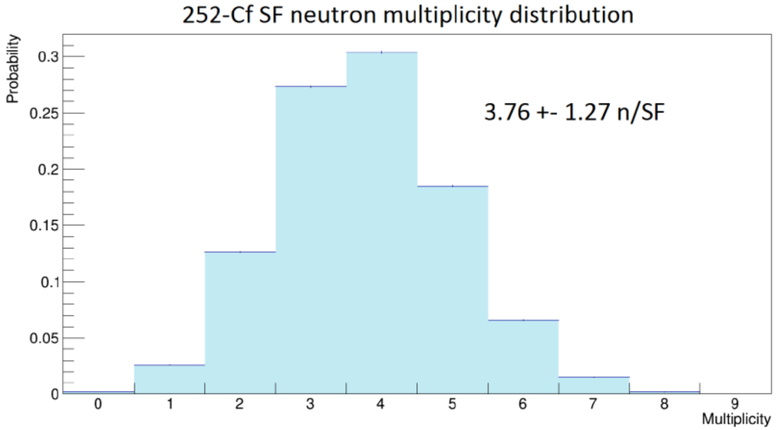


Status

- 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
- Maintenance campaign in 2020
  - Replace UPS
  - Replace DAQ Computers
  - Replace Slow Control Server
- 98.7% Livetime July 2013 – Aug 2021
- 99.3% Livetime 2020-2021

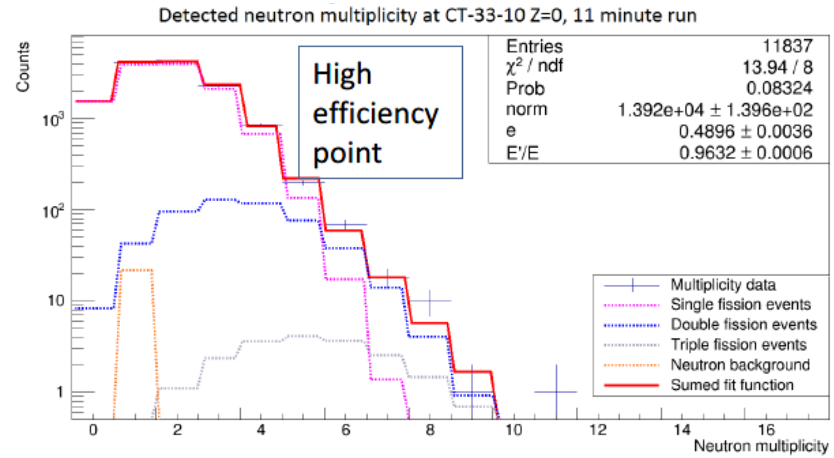


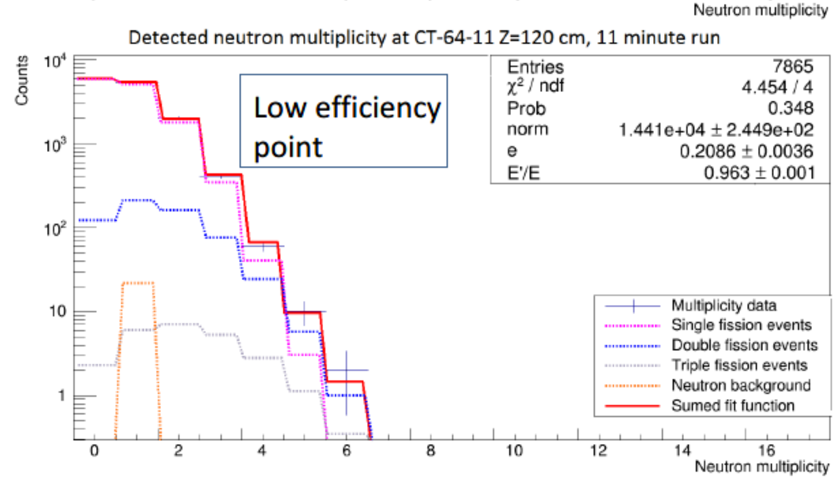
2016 Calibration Campaign

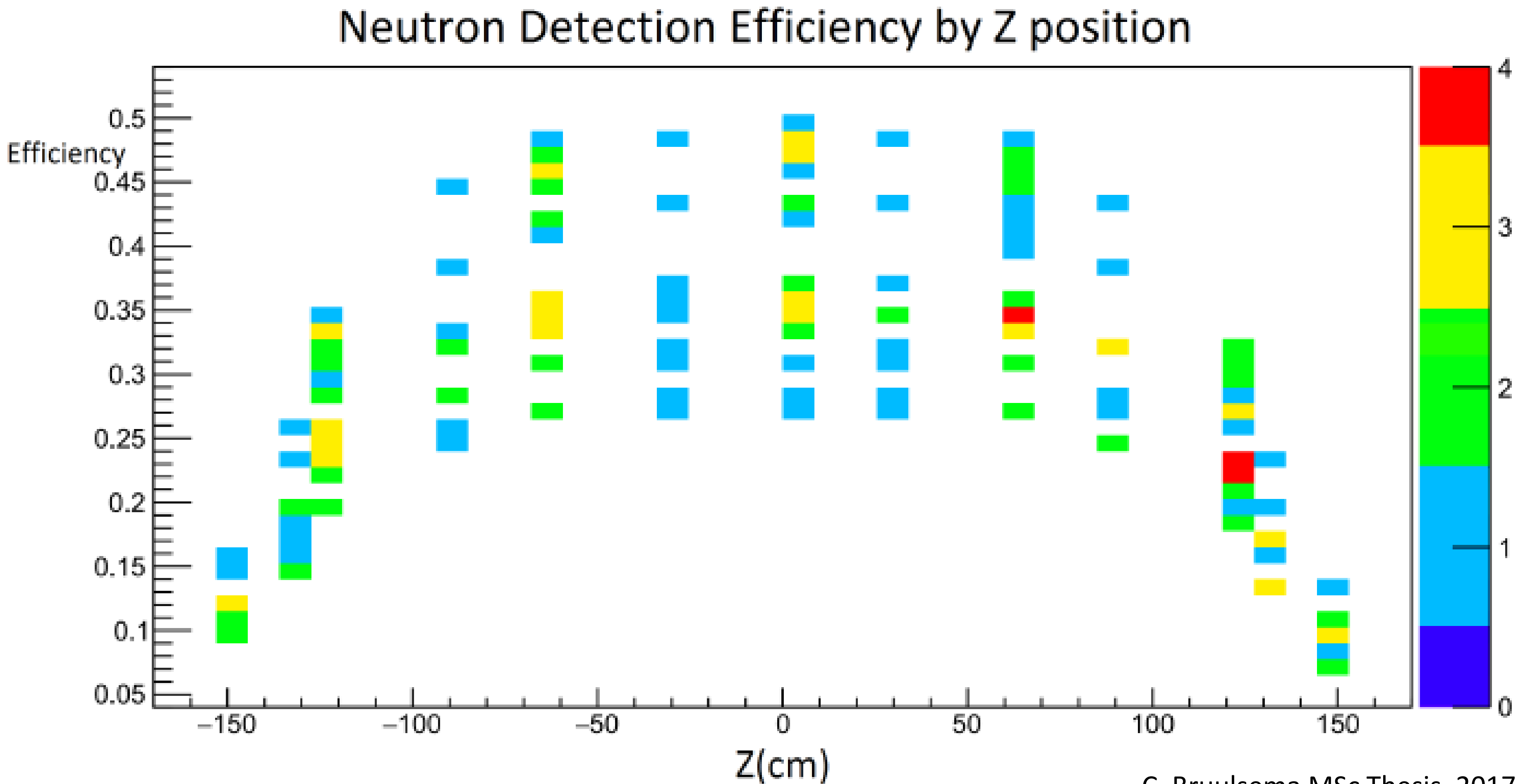


- 20 Bq ^{252}Cf source
- 192 locations
- ~ 5 days of livetime

C. Bruulsema MSc Thesis, 2017

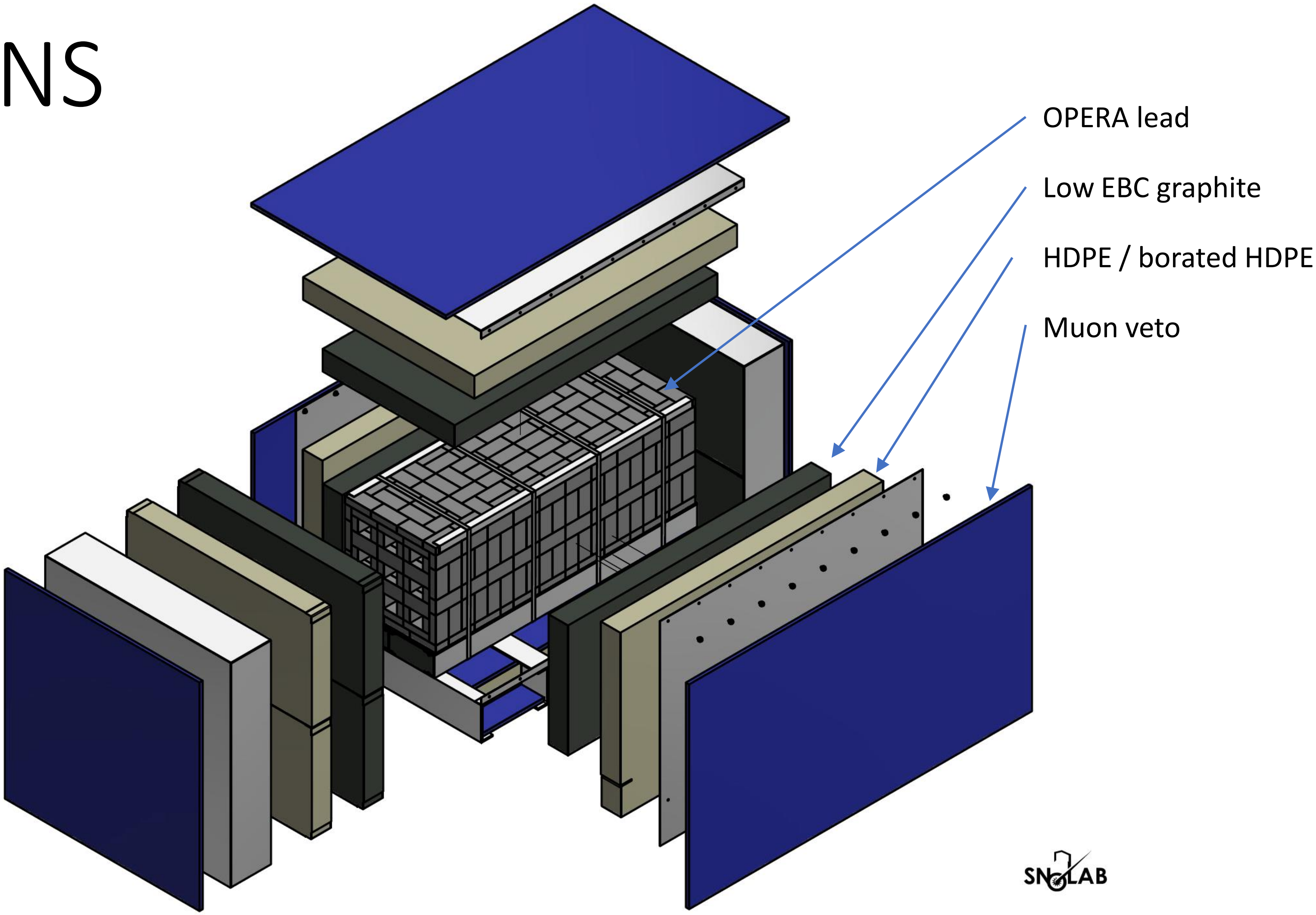






C. Bruulsema MSc Thesis, 2017

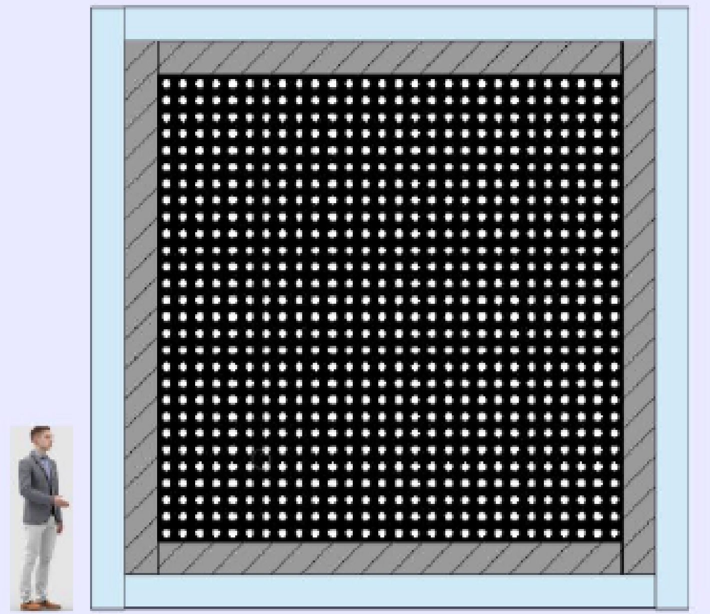
Mini-HALO at SNS



HALO-1kT proposal at LNGS

1000 tonnes of Pb (black); 30 cm of graphite on 6 sides (grey); 30 cm of water on 6 sides (blue); plus 28 x 28 array of 5.5 m long 5cm diameter He-3 counters surrounded by 8mm wall thickness polystyrene (C_nH_n) tubes. Nominal lead volume 4.5 x 4.5 x 5.5 m^3.

Note: Graphite and water shielding is not optimized in this geometry. For HALO with ~ twice the environmental neutron flux and comparatively poorer neutron shielding the rate of background neutrons detected in HALO is a very acceptable 15 mHz. Thinner layers of reflector and shielding should be adequate for HALO-1kT. The target value for HALO-1kT is expected to be ~100 mHz.



Neutron detection efficiency ~ 53%

Status Overview

- Commissioned in May 2012
- Connected to SNEWS in October 2015
- 99.3% live fraction in last 2 years
- No supernova neutrino bursts detected
- Calibration Run Spring and Summer 2016
- Maintenance Campaign Completed 2021
- Cross section measurements planned with Mini-HALO at SNS
- HALO-1kT at LNGS proposed

Funded by: NSERC CRSNG NSF