Oct 1, 2025

The HALO Supernova Neutrino Detector

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Staff Scientist, SNOLAB

HALO – The Helium And Lead Observatory

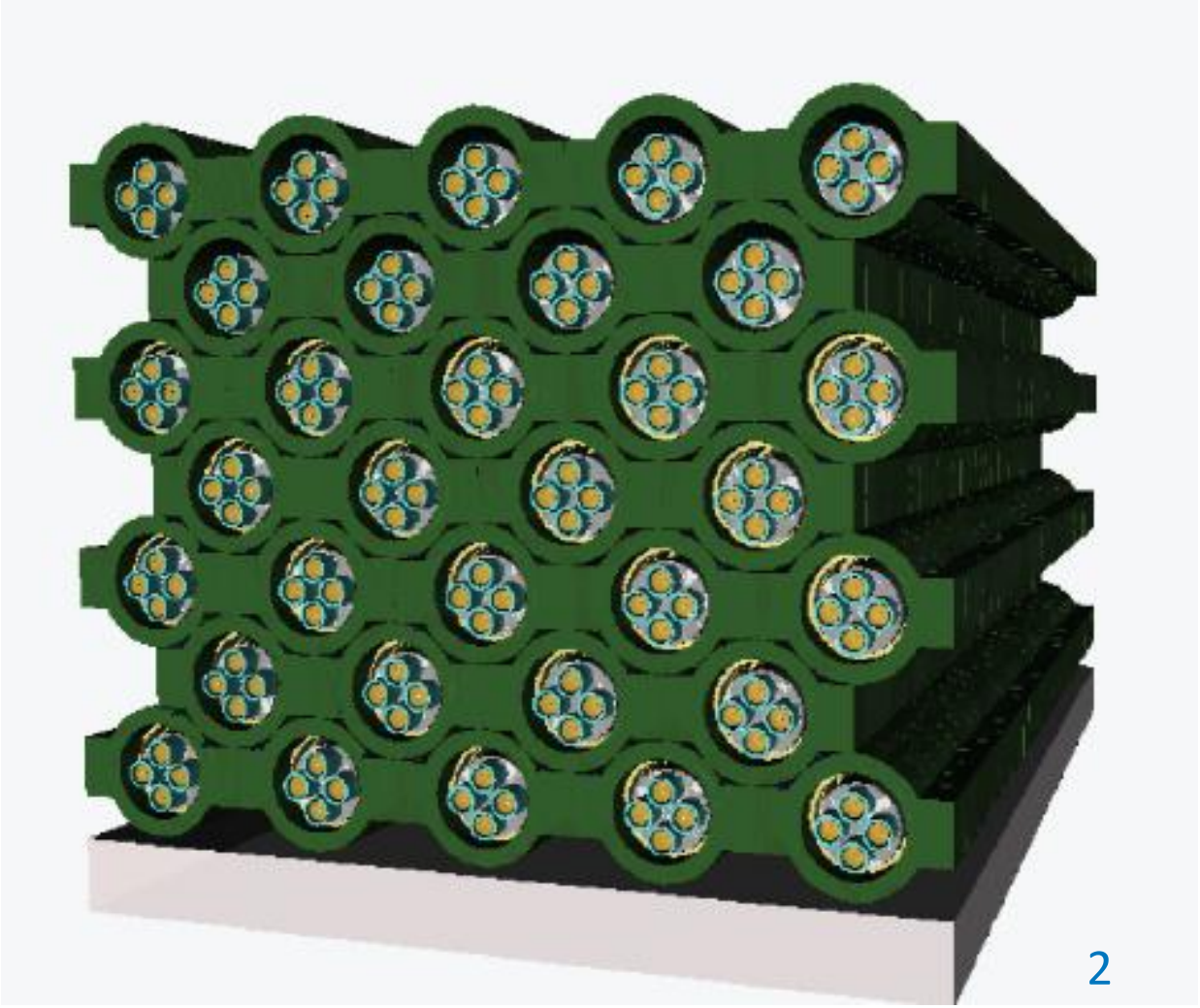
A “SN detector of opportunity” / An evolution of LAND – the Lead Astronomical Neutrino Detector,

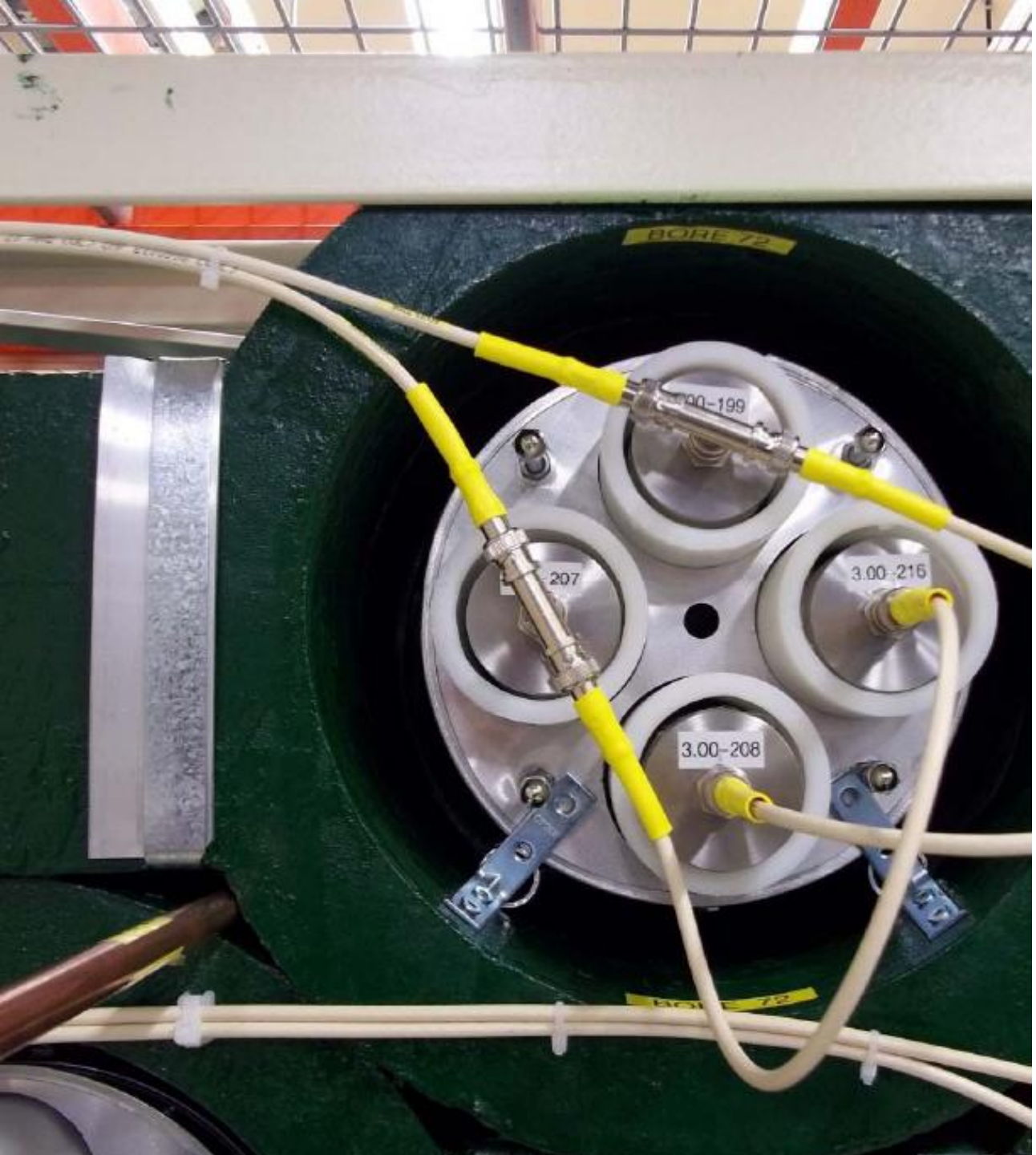
C.K. Hargrove et al., Astropart. Phys. 5 183, 1996.

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

Lead – high ν-Pb cross-sections, low n-capture cross-sections, complementary sensitivity to water Cerenkov and liquid scintillator SN detectors, available from decommissioned cosmic-ray station

Review: E. Caden et al. Canadian Journal of Physics. ***103****(8): 763-774*





HALO Neutrino Detection

Neutrinos interact on lead, producing neutrons
- 1 or 2 with energy thresholds

Neutrons thermalize

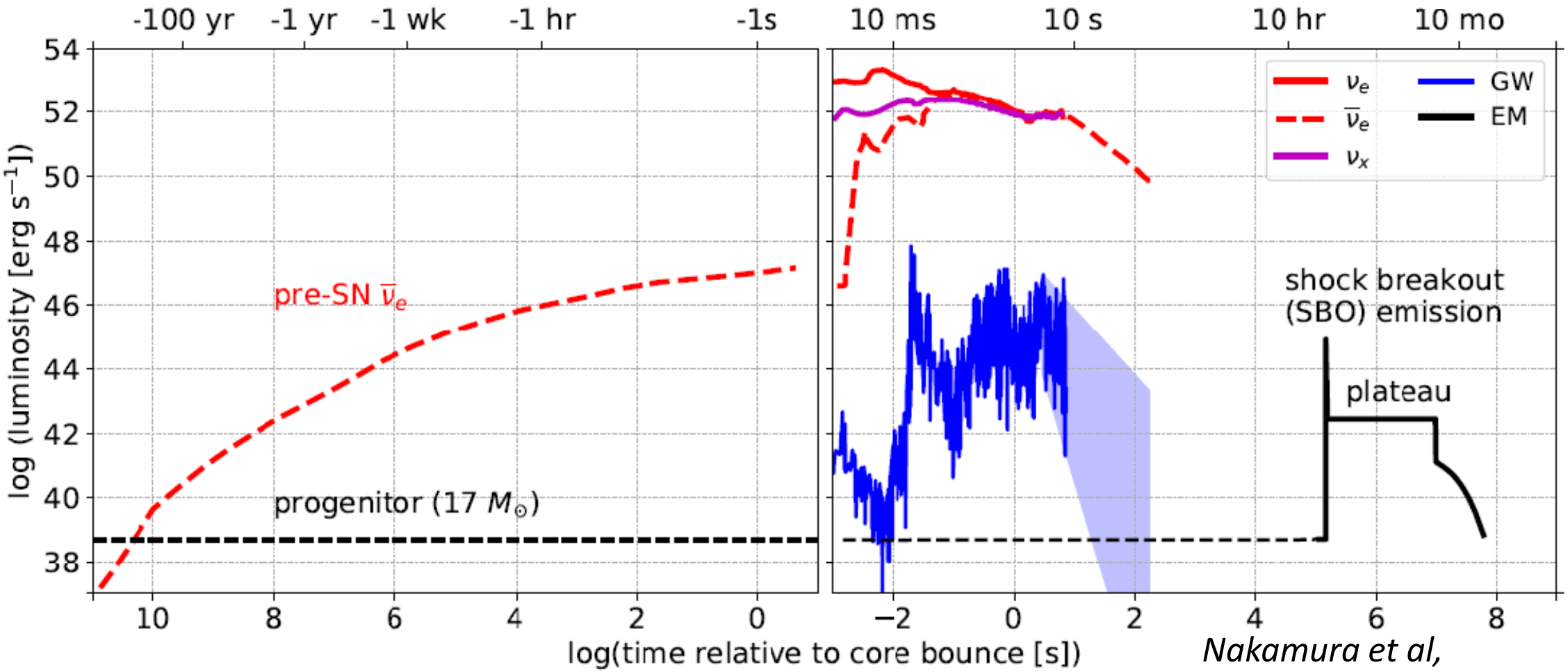
Neutrons capture on ^{3}He
- $\tau \sim 200$ us

Neutron counting only

No prompt signal

15 mHz background neutrons
- 1/minute

Multi-Messenger Astronomy with Supernovae

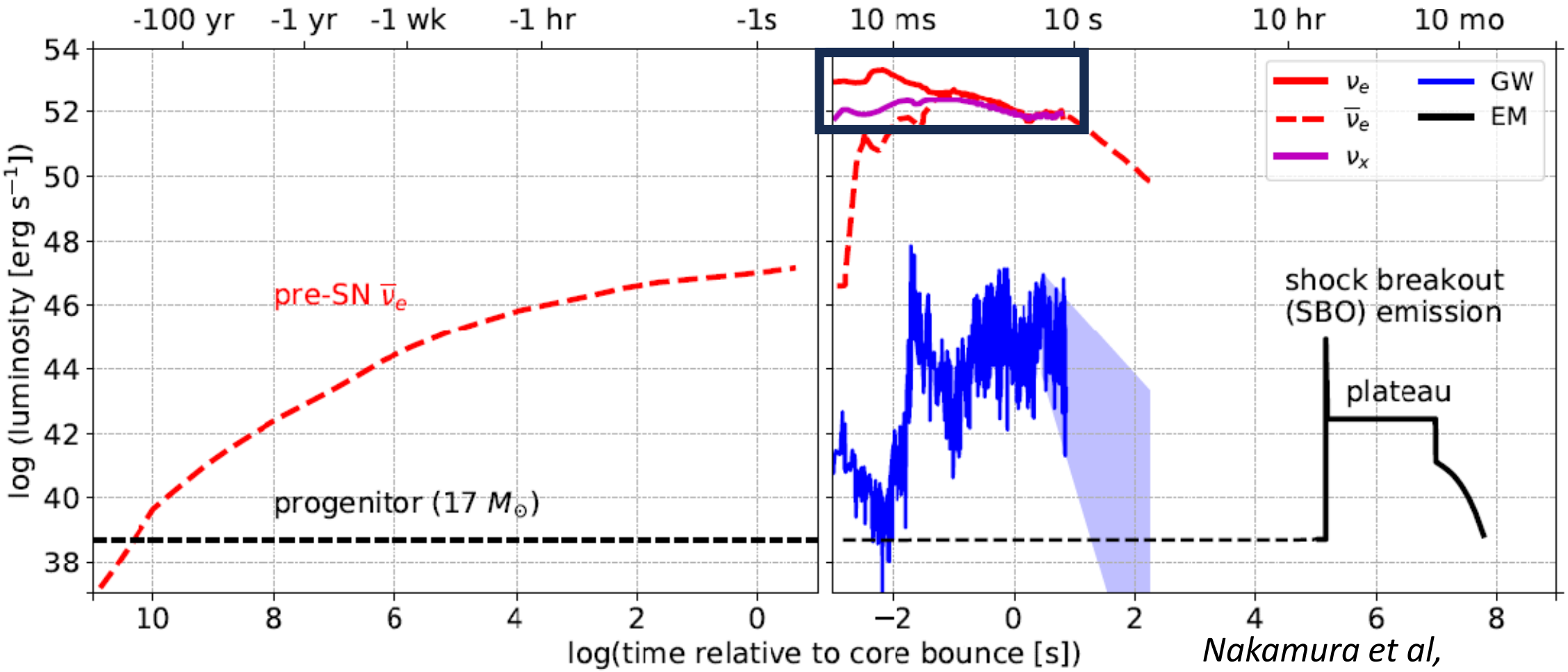


Nakamura et al, MNRAS 161, 3296 (2016)

Galactic Supernova Rate is 1.6 ± 0.5 per Century

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

Multi-Messenger Astronomy with Supernovae



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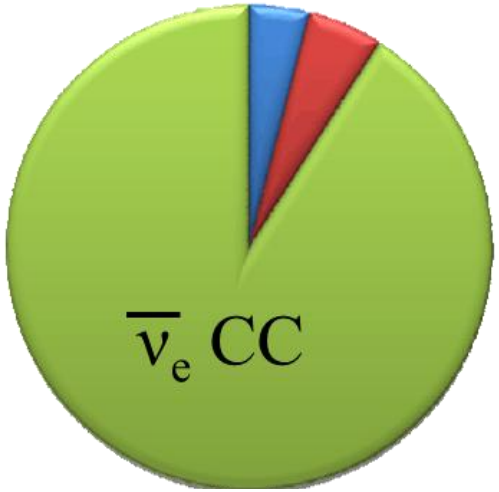
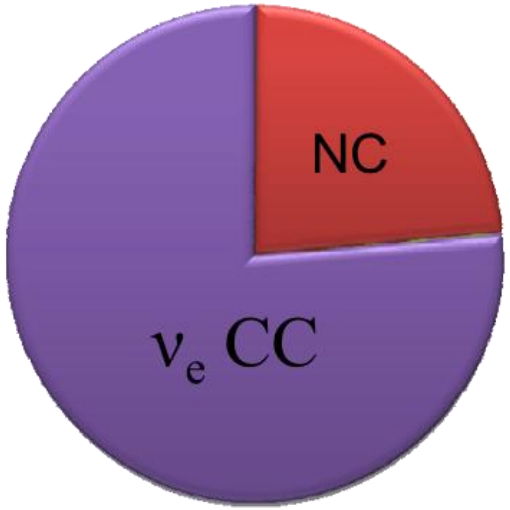
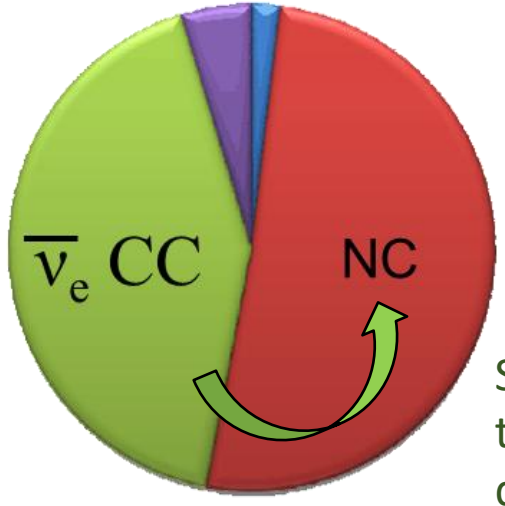
Flavour Complementarity



Water Cherenkov (w/o Gd)

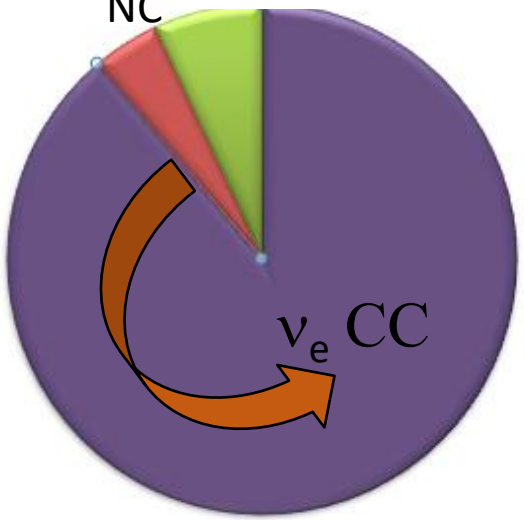


Liquid Scintillator



Strong threshold dependence

Low thresholds see NC coherent scattering



Liquid Argon

Lead

CC: $\nu_e + {}^{208}\mathrm{Pb} \rightarrow {}^{207}\mathrm{Bi} + n + e^-$

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

NC: $\nu_x + {}^{208}\mathrm{Pb} \rightarrow {}^{207}\mathrm{Pb} + n$

$\nu_x + {}^{208}\mathrm{Pb} \rightarrow {}^{206}\mathrm{Pb} + 2n$

Iron

HALO Details

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)

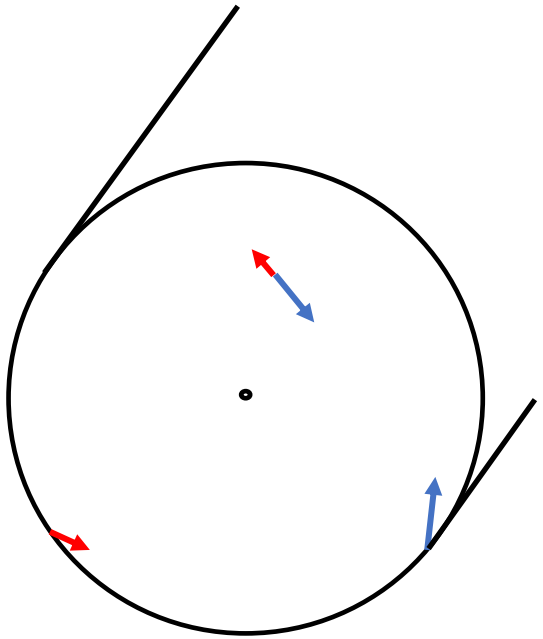
Four detectors with HDPE moderator tubes in each of 32 columns of lead rings

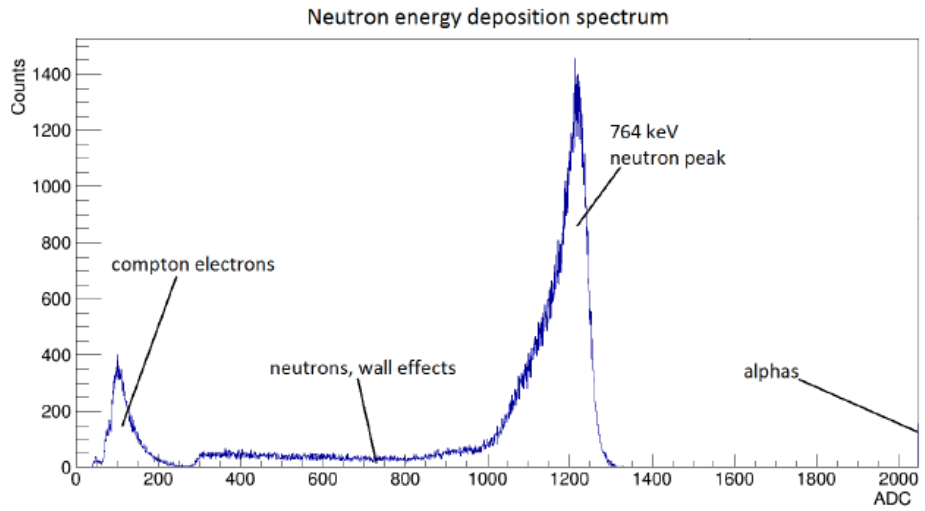
128 counters (368 m) paired for 64 channels of readout

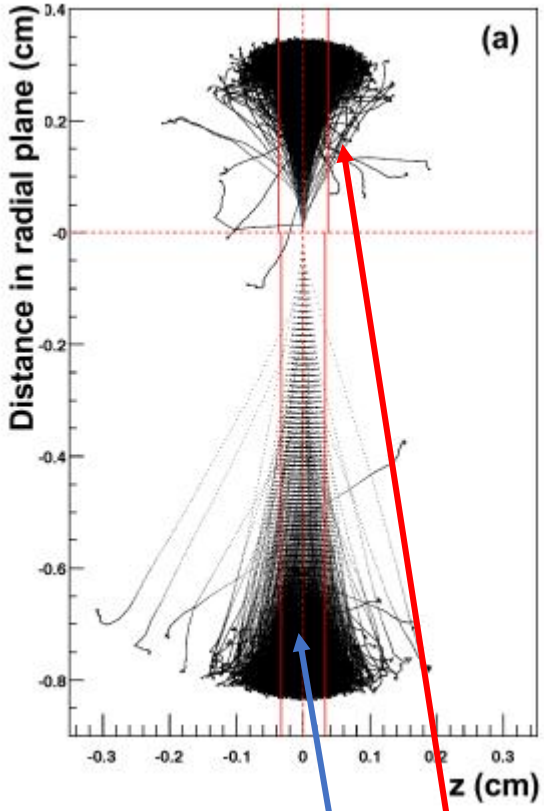
Roughly 12" of water as reflector/shielding around sides

79 tonnes of lead

^{3}He Proportional Tubes







191 keV
= 300 ADC

573 keV
= 900 ADC

$$^3\mathrm{He} + \mathrm{n} \rightarrow \mathrm{p} + {}^3\mathrm{H} + 764\ \mathrm{keV}.$$

B. Beltran et al New J. Phys. 13, 073006 (2011)

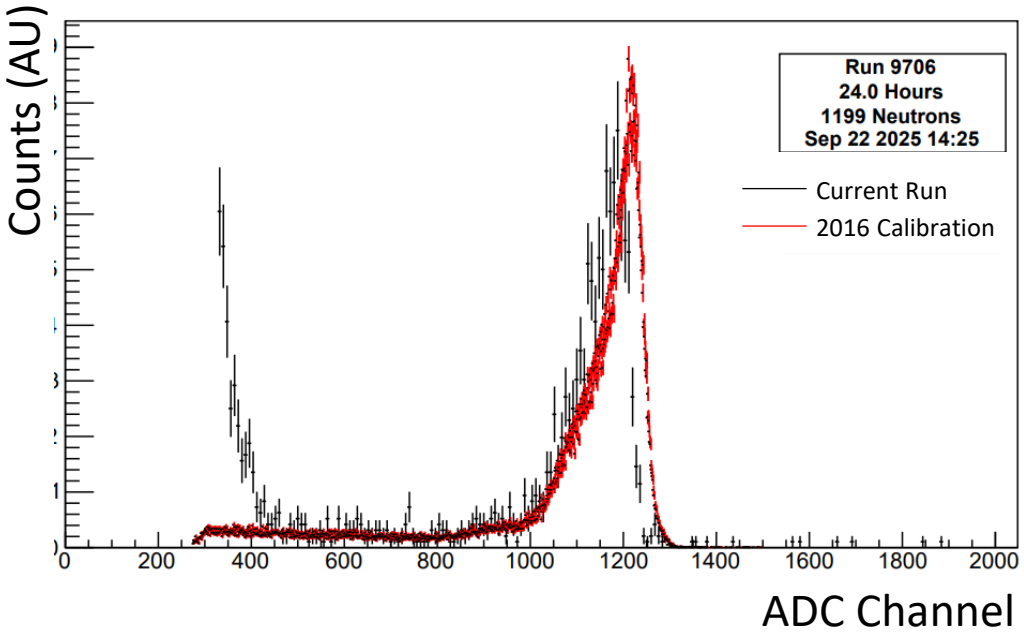
Electronics

Simple + Stable Readout:

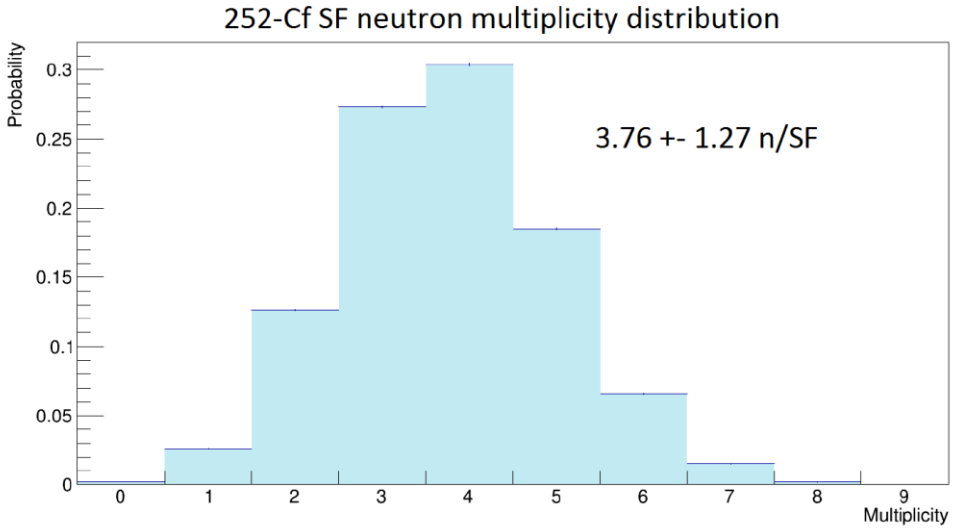
- AC Coupled pre-amplifiers on each channel
- ~2kV HV tuned to put peak at 1200 ADC counts
- Discriminators set to detect 5 Hz of beta/gamma events total
- Electronic calibration pulses injected at pre-amplifier on each channel every 4-8 hours

Highly redundant system:

- 2 DAQ machines trade off every 3 days (hot spare)
- Separate HV + ADCs for right and left halves
- Robust email alerts
- Monitoring shifts require 10 minutes/day
- 95% of issues can be resolved remotely

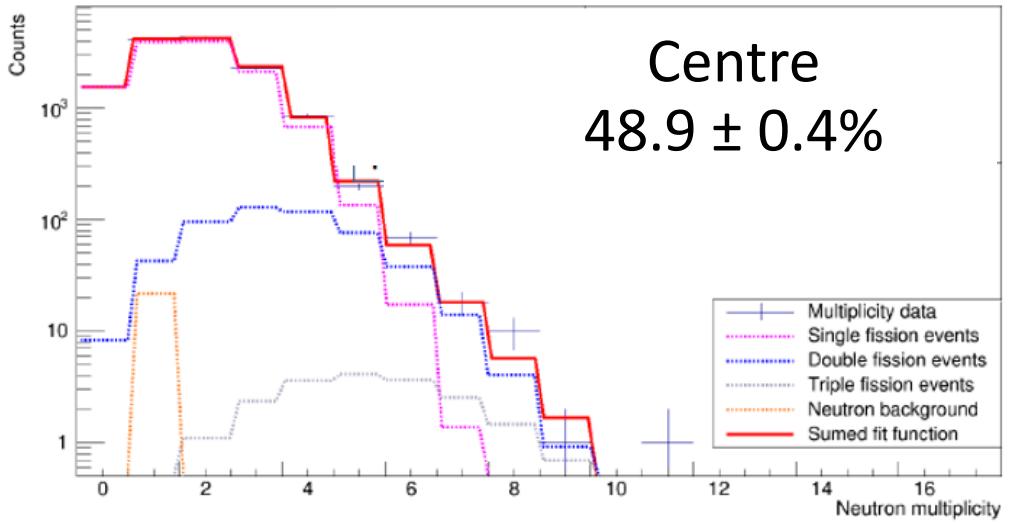


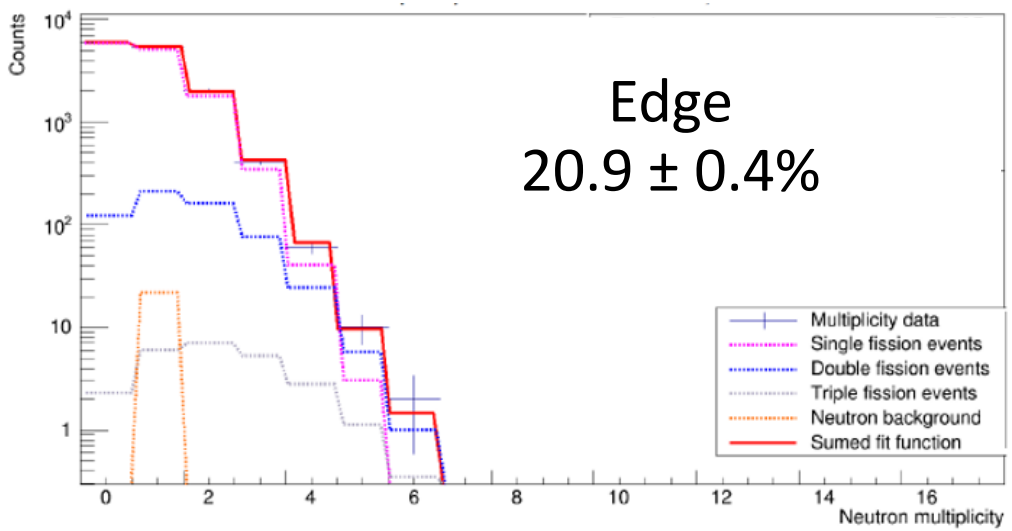
Calibration Method



Use distortion of multiplicity distribution to fit efficiency

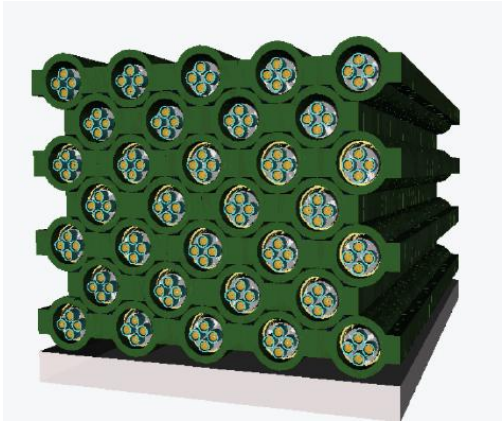
- 20 Bq ^{252}Cf / ^{250}Cf source
- ~ 4 neutrons per fission
- 192 locations
- ~ 5 days of livetime



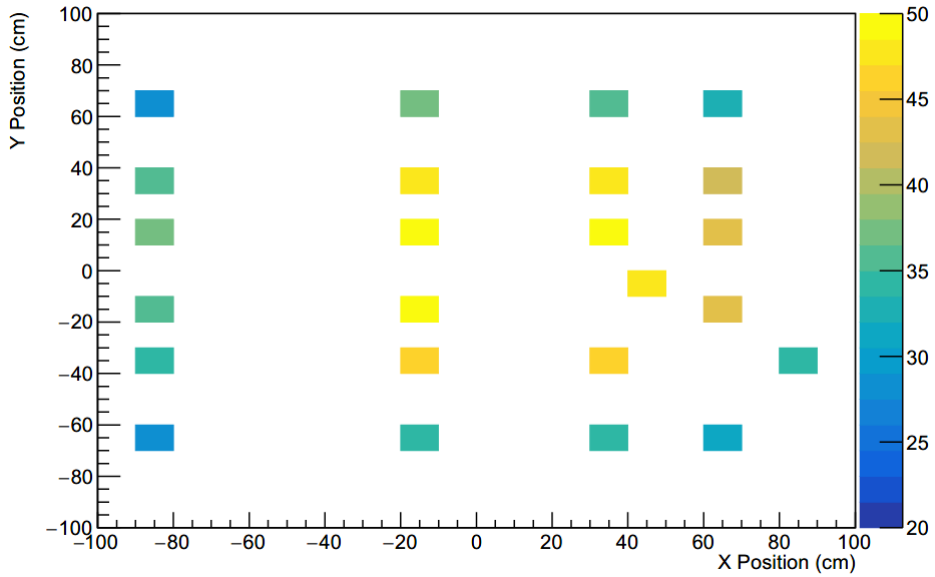


C. Bruulsema MSc Thesis, 2017

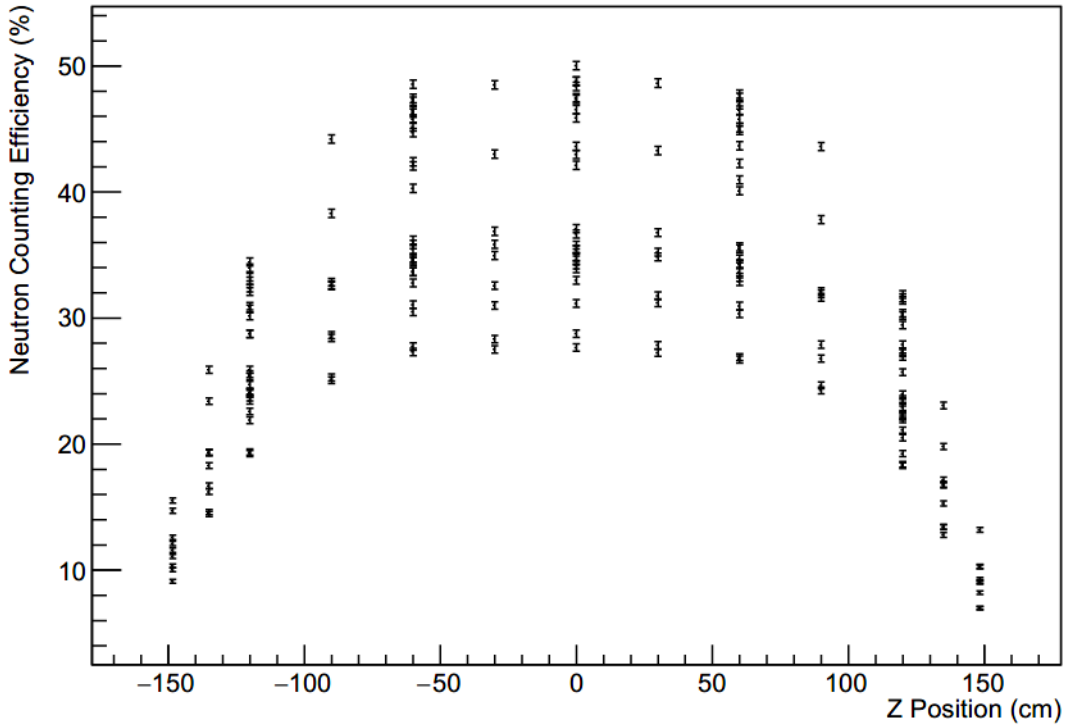
Calibration Results



Efficiency at Centre Depth

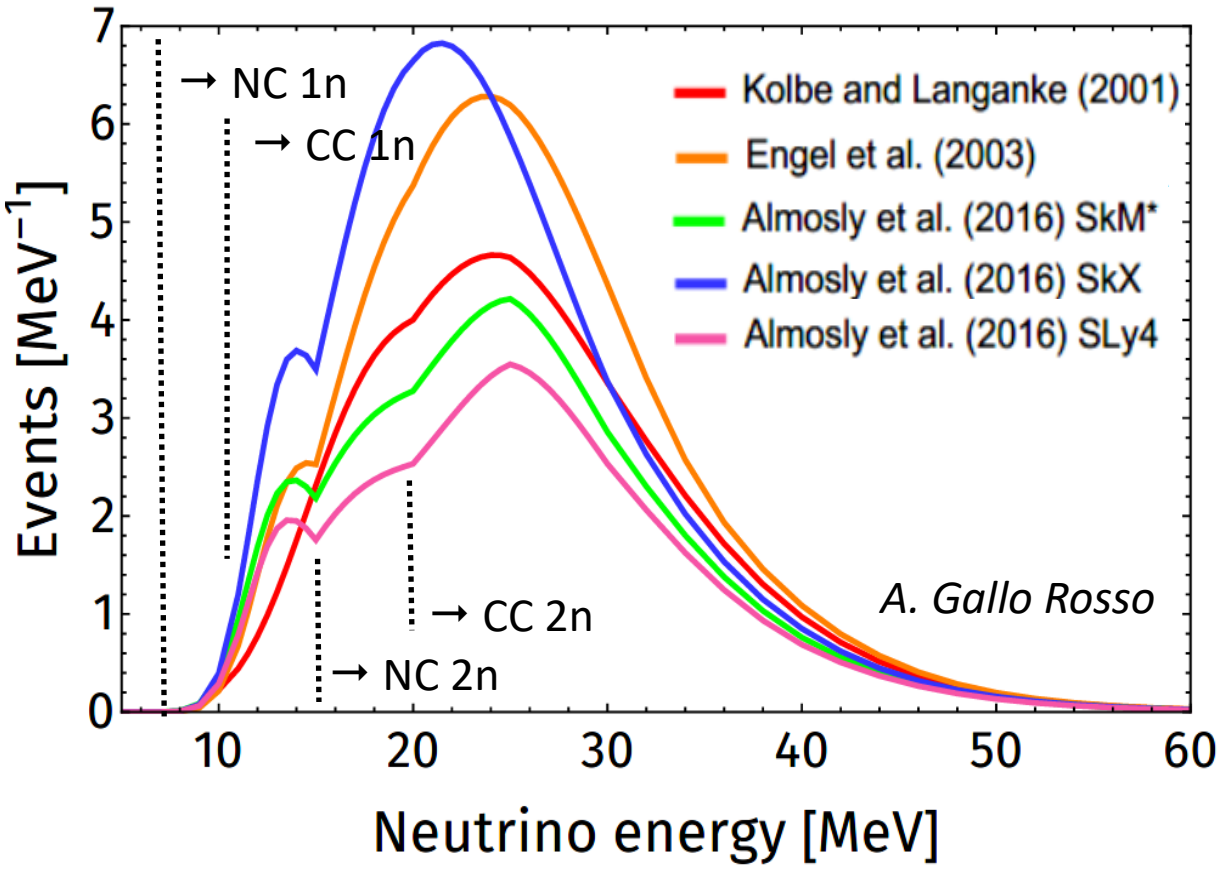


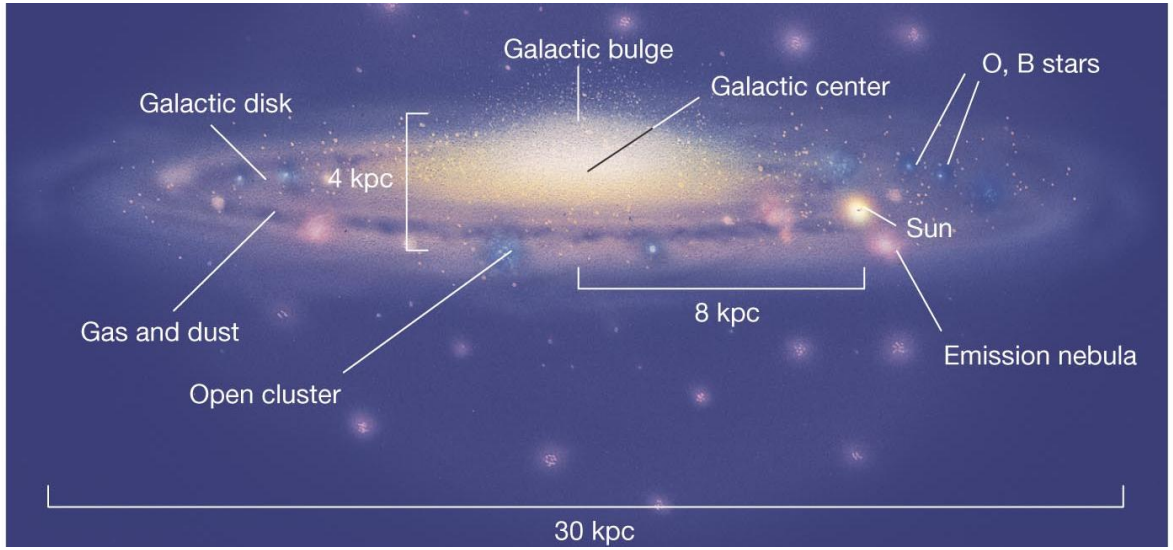
Efficiency vs Depth



Average efficiency of 28% for neutrino-induced neutrons.

Roughly 10 neutrons @ 10 kpc

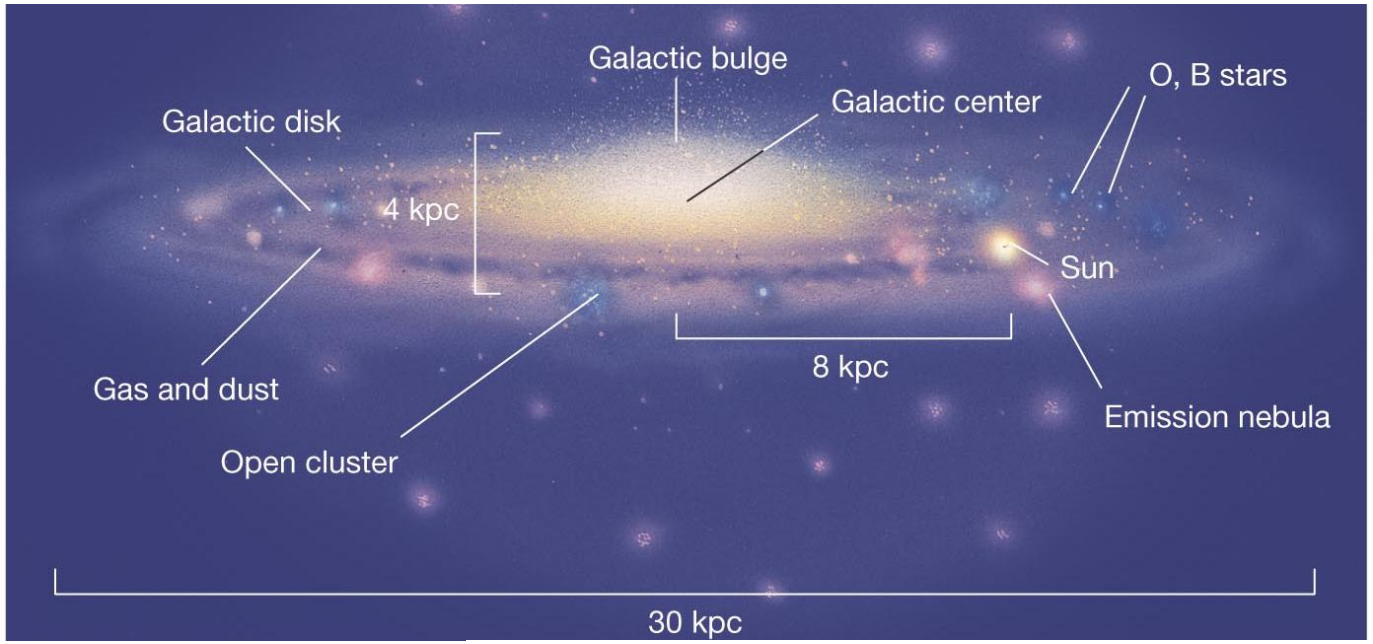




Total HALO-1kT neutrons

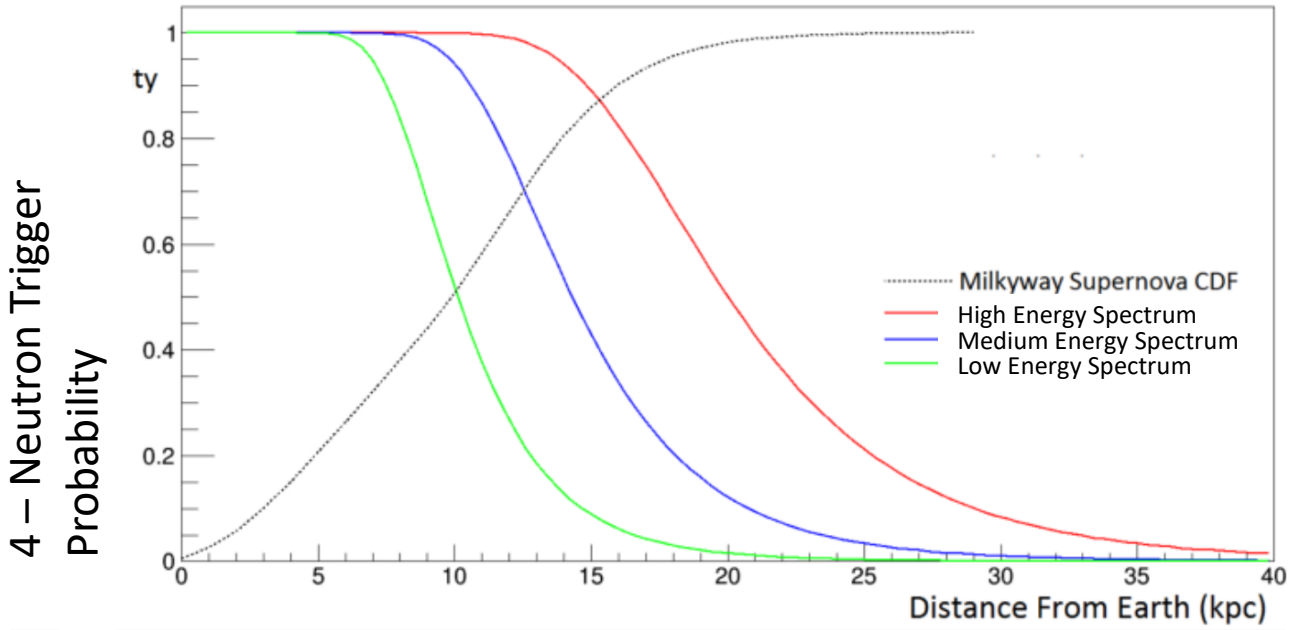
- 91
- 116
- 81
- 119
- 68

- LS220-z9.6co spectrum @ 10 kpc for HALO-1kT design
- HALO has ~10 x less target



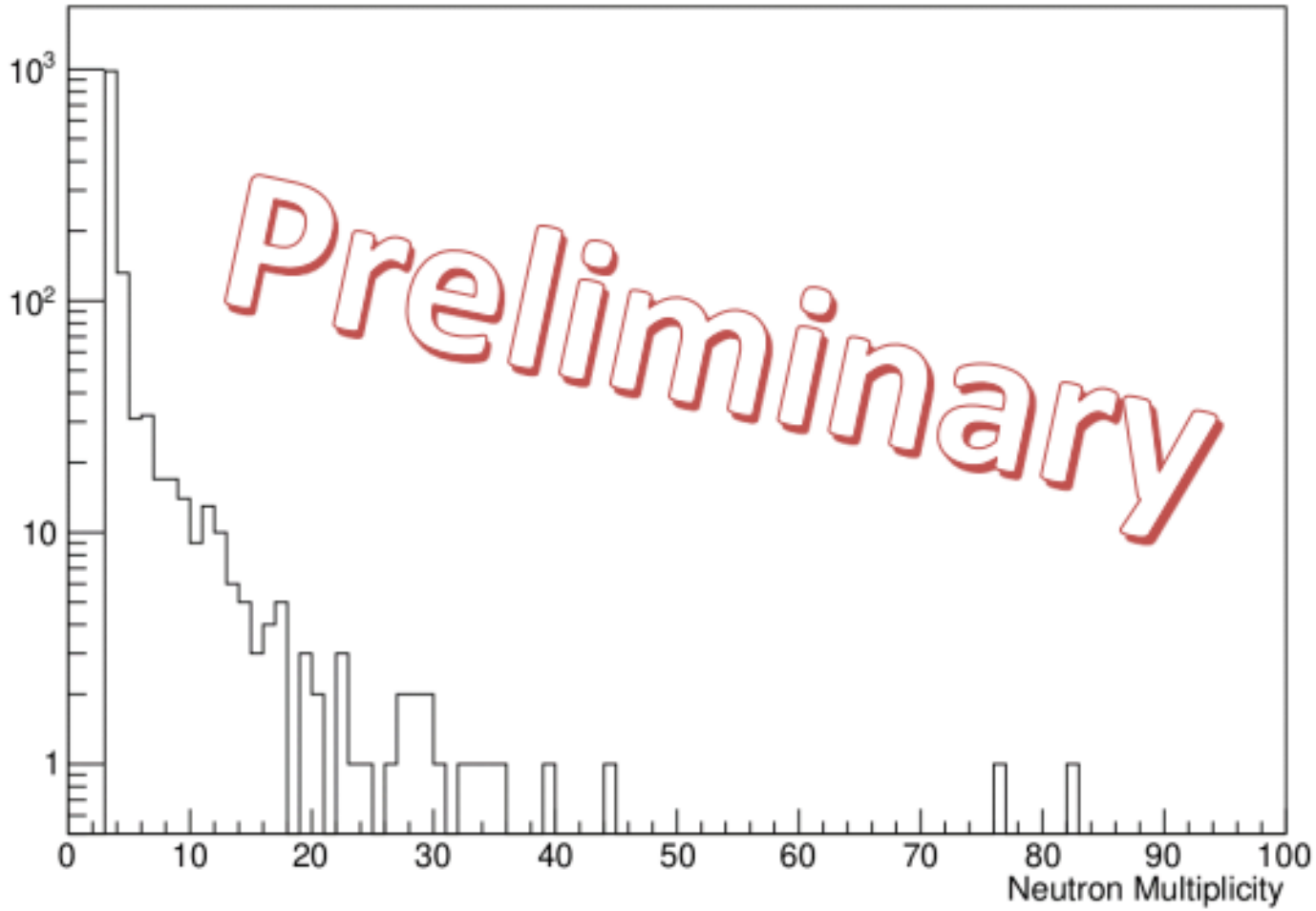
Coincidence Number	Rate
2	2 / hour
3	1 /day
4	1 / month

15 mHz background neutrons
2 second window
τ >> 200 us (non-spallation)



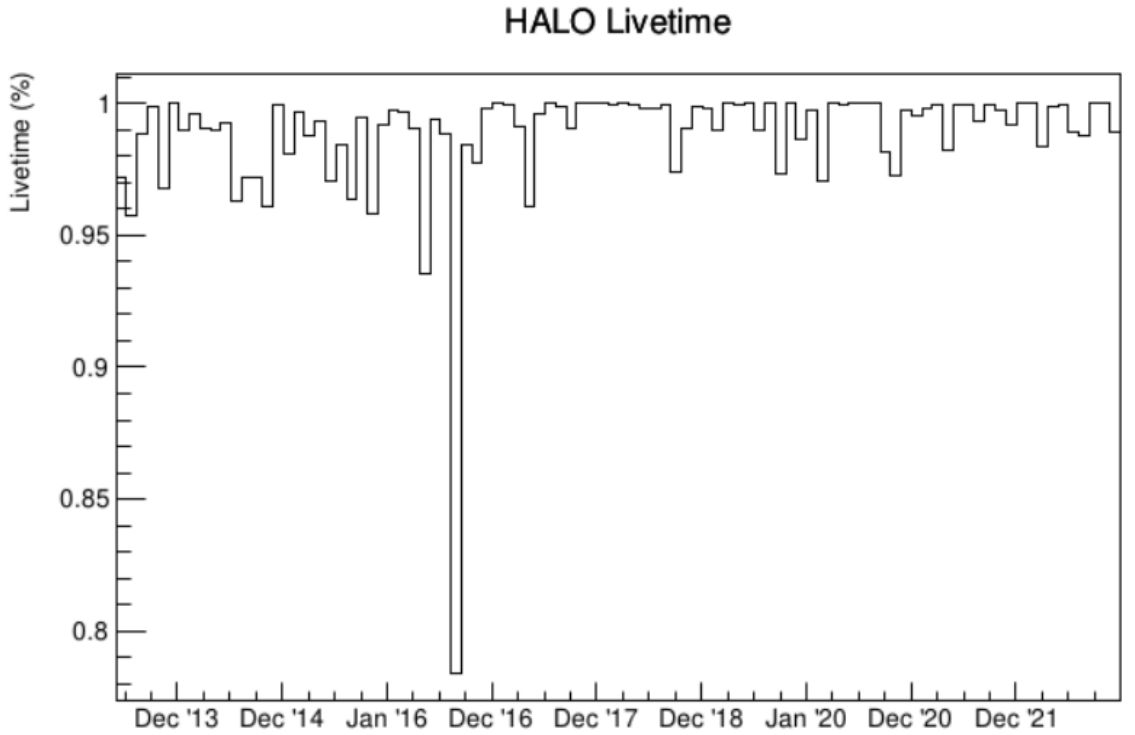
C. Bruulsema

Spallation Neutron Multiplicity



Detector 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
- DAQ overhaul in 2020
- 98.7% Livetime July 2013 – Aug 2021



Year	2013*	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Livetime (%)	98.05	98.27	98.24	96.47	99.37	99.59	99.36	99.19	99.58	99.49	99.2	99.2

* Timestamps less reliable before June 2013

SuperNova Early Warning System

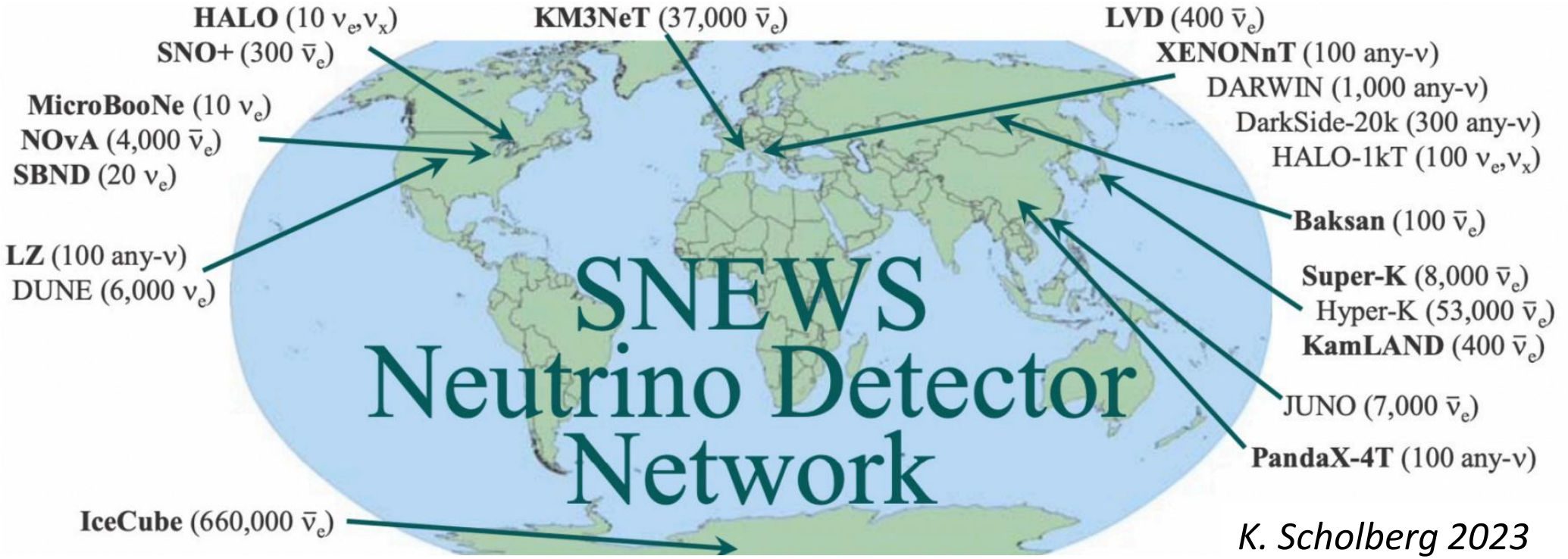
Server receives independent reports from many experiments

Issues Alerts if multiple experiments are in coincidence

SNEWS 1.0 in operation since July 1, 2005

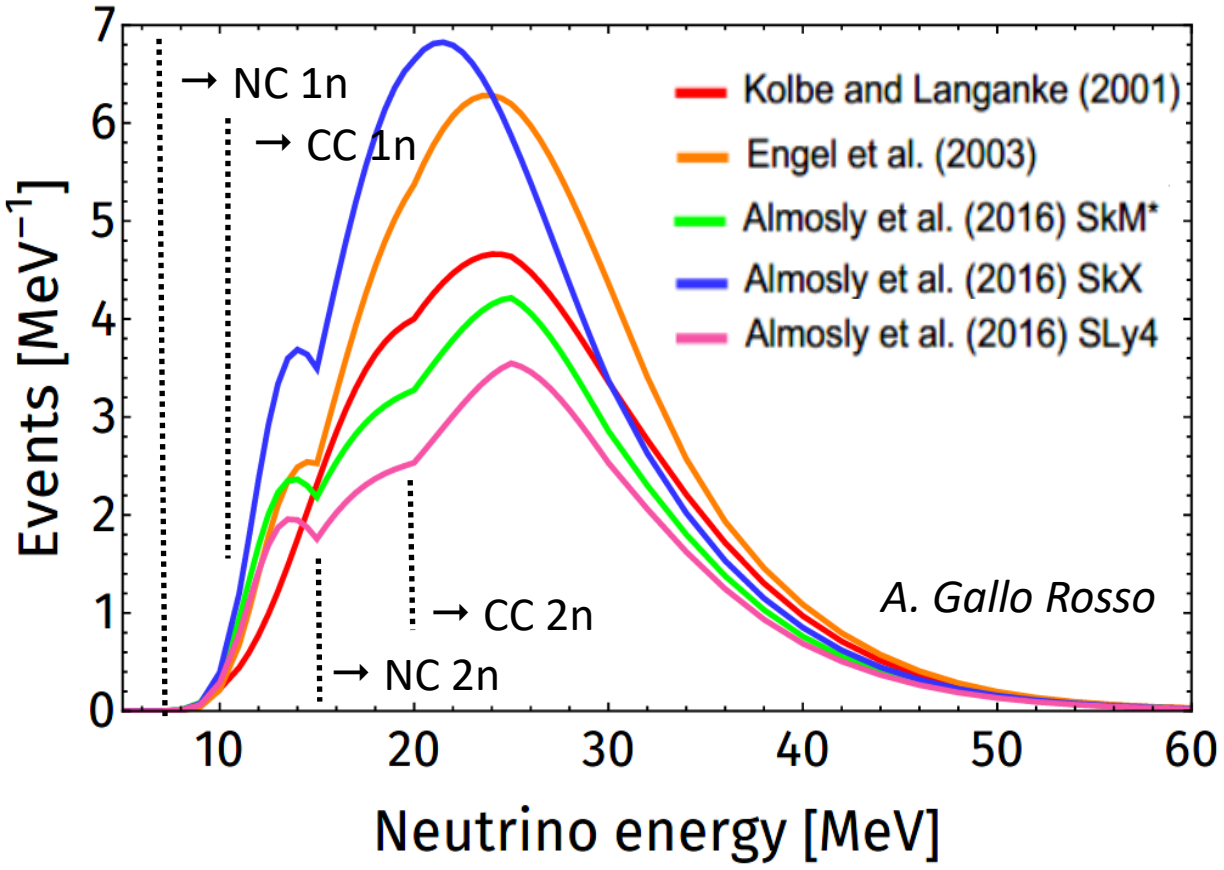
SNEWS 2.0 in testing.

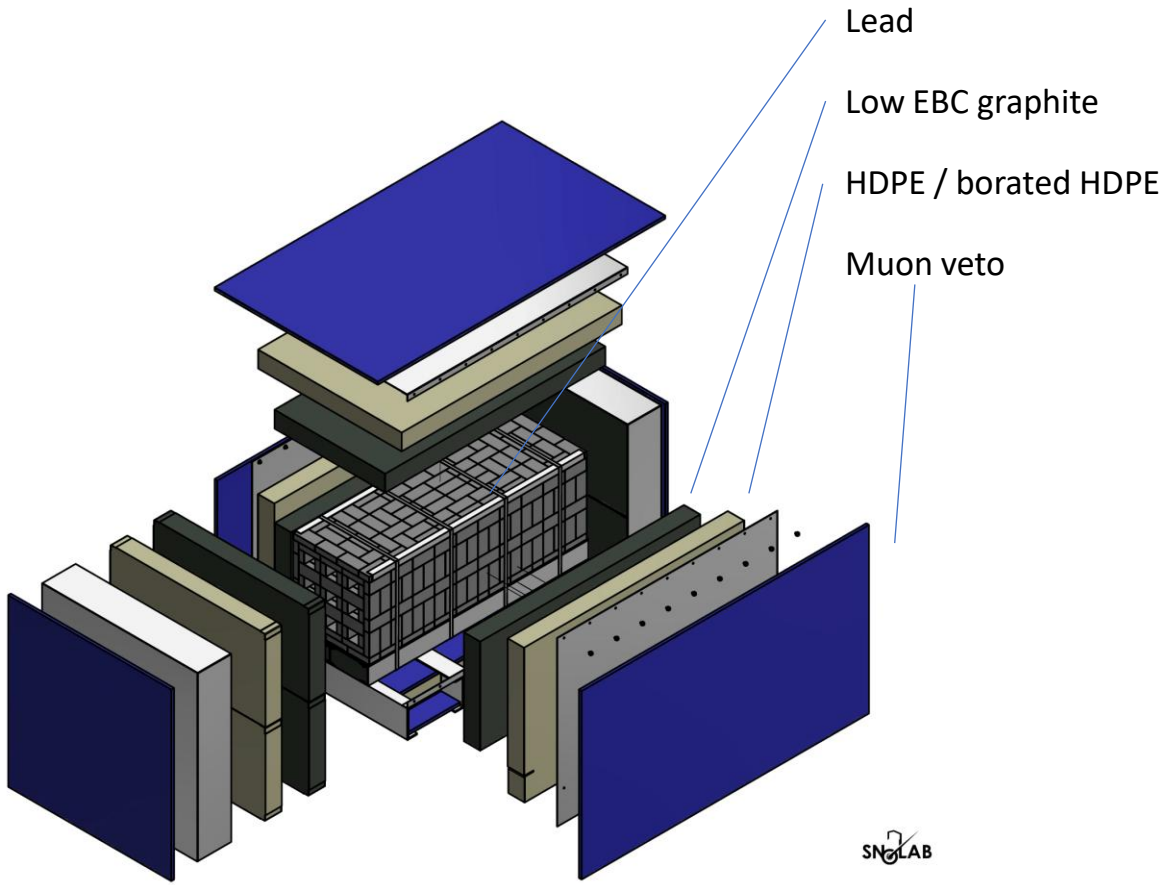
Whitepaper: https://arxiv.org/abs/2011.00035



K. Scholberg 2023

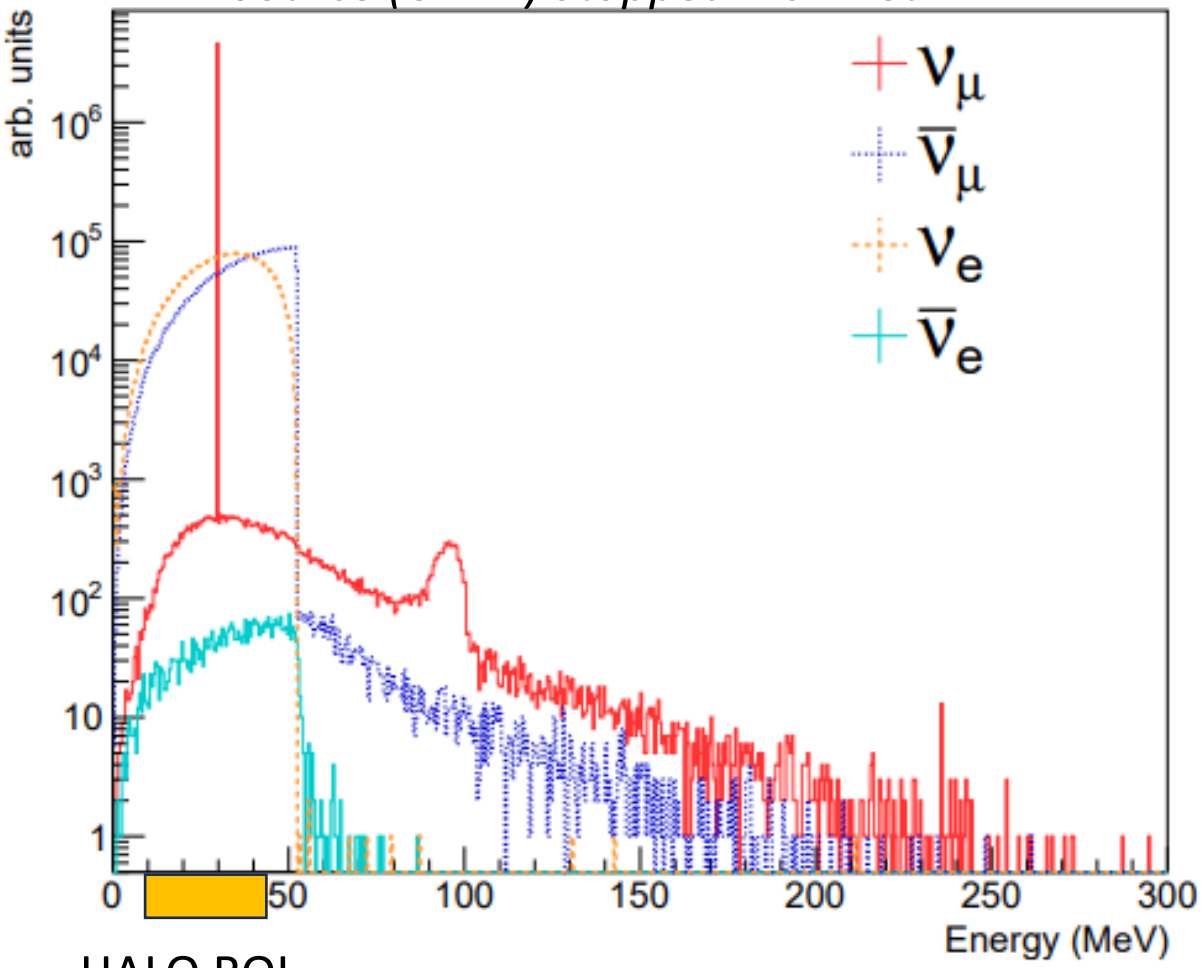
Mini-HALO Cross-Section Measurement



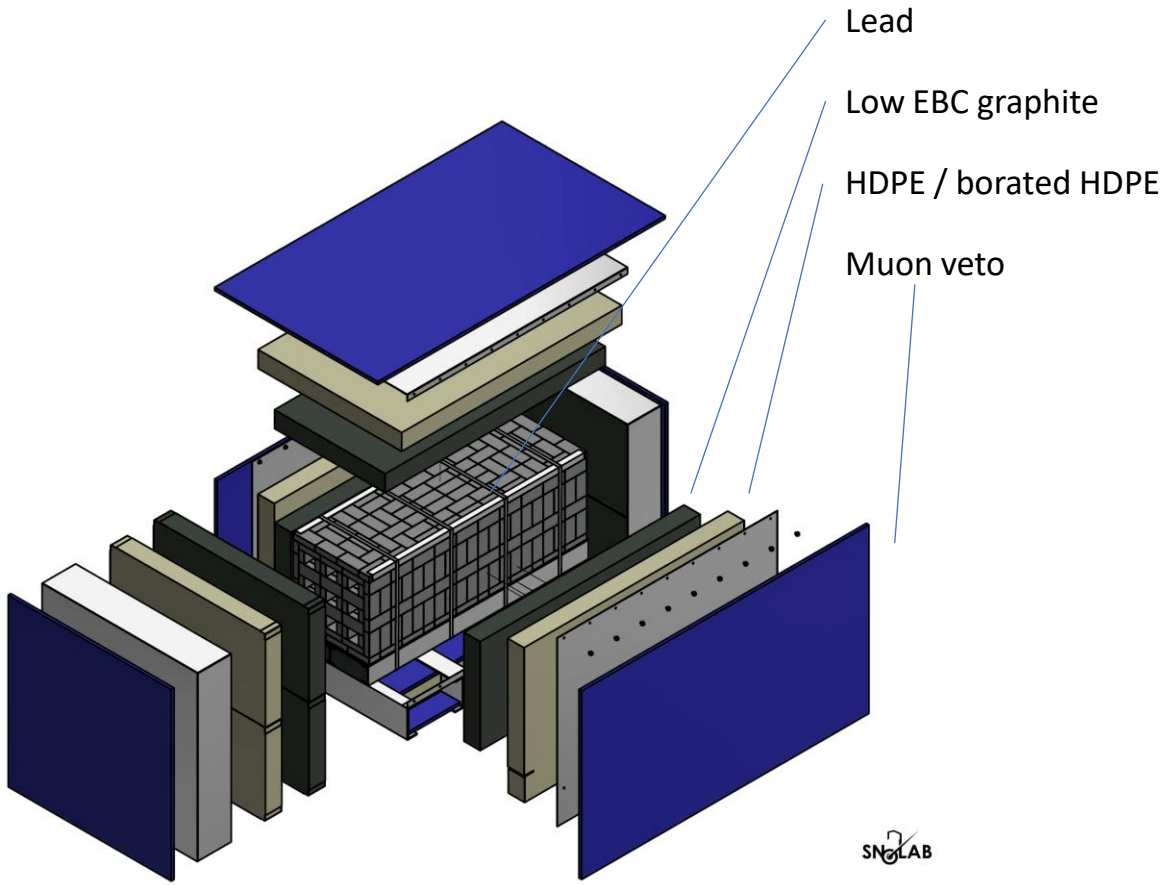


Mini-HALO Cross-Section Measurement

Neutrino Flux from the Spallation Neutron Source (ORNL) Stopped Pion Beam



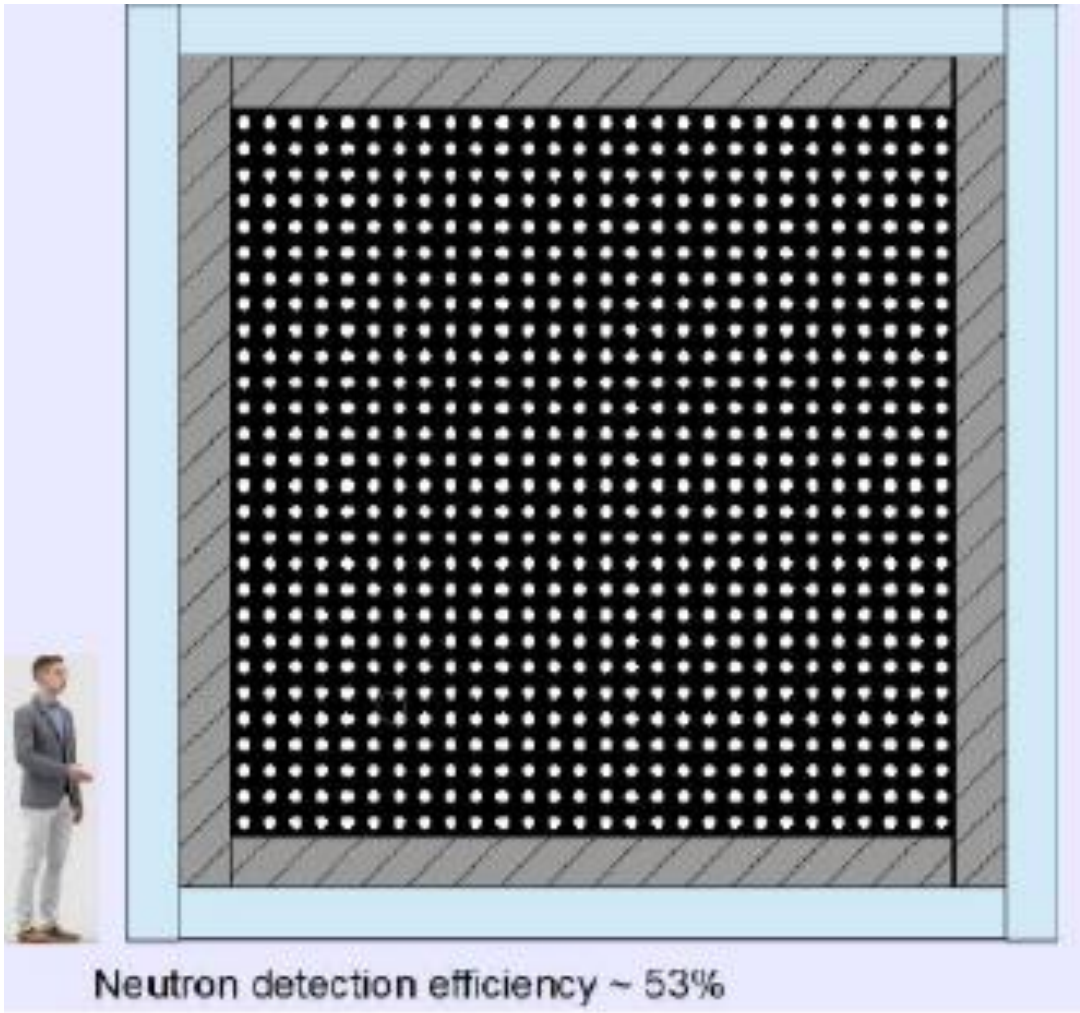
HALO ROI



COHERENT Collaboration, arXiv:2109.11049

Future Proposal: HALO-1kT

- 28 x 28 array of 5.5 m-long, 5 cm-diameter ^{3}He counters
- 8 mm-thick Polystyrene tubes around counters
- 1000 tonnes of Lead
- 30 cm graphite reflector (grey)
- 30 cm water shielding (blue)



HALO Status

- Commissioned in May 2012
- Connected to SNEWS in October 2015
- Calibration Run Spring and Summer 2016
- 1st Maintenance Campaign Completed 2021
- > 95% live fraction for 12 years
  - >99% for last 8 years
- No supernova neutrino bursts detected yet…

Funded by:

NSERC CRSNG

NSF

Duke University

UMD Duluth

TRIUMF

ICRR Institute for Cosmic Ray Research University of Tokyo

Technische Universität Dresden

University of Washington

SNOLAB Mining for knowledge Creuser pour trouver... l'excellence

Pacific Northwest National Laboratory

The University of North Carolina at Chapel Hill

DigiPen Institute of Technology

Armstrong State University

Laurentian University Université Laurentienne