HALO at LNGS

IPP Town Hall – AGM

June 14, 2015

LaurentianUniversity
UniversitéLaurentienne

SNOLAB

Clarence J. Virtue

HALO at SNOLAB
- a Helium And Lead Observatory for supernova neutrinos

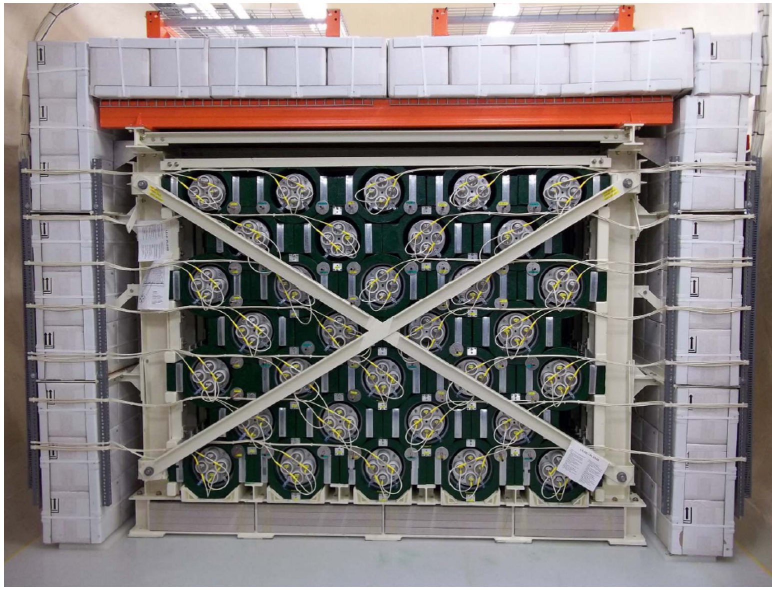
A “SN detector of opportunity” / An evolution of LAND – the Lead Astronomical Neutrino Detector, C.K. Hargrove et al., Astropart. Phys. 5 183, 1996.

“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

see talk Wednesday pm (W2-7) by C. Bruulsema



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

What is to be Learnt?

- Astrophysics
  - Explosion mechanism
  - Accretion process
  - Black hole formation (cutoff)
  - Presence of Spherical accretion shock instabilities (3D effect)
  - Proto-neutron star EOS
  - Microphysics and neutrino transport (neutrino temperatures and pinch parameters)
  - Nucleosynthesis of heavy elements
- Particle Physics
  - Normal or Inverted neutrino mass hierarchy
  - Presence of axions, exotic physics, or extra large dimensions (cooling rate)
  - Etc.

Other considerations…

- While the probability of a galactic SN in a lifetime are good (~3 per century), many current kt-scale supernova-sensitive detectors have other primary objectives necessitating down-time; extensive calibration; reconfiguration; and end of life
- For next generation 100kt-scale neutrino detectors costs go up as the energy threshold goes down and there is a risk that supernova sensitivity will be degraded or sacrificed in order to contain costs
- In the case of large-scale dedicated SN detectors, capital funding, when a timescale can't be put on the extraction of physics results, is challenging
- So.... there's a niche for low cost, low maintenance, long lifetime, dedicated supernova detectors

Supernova Neutrinos – First Order Expectations

- Approximate equipartition of neutrino fluxes
- Several characteristic timescales for the phases of the explosion (collapse, burst, accretion, cooling)
- Time-evolving ν_e, $\overline{\nu}_e$, ν_x luminosities reflecting aspects of SN dynamics
  - Presence of neutronization pulse
  - Hardening of spectra through accretion phase then cooling

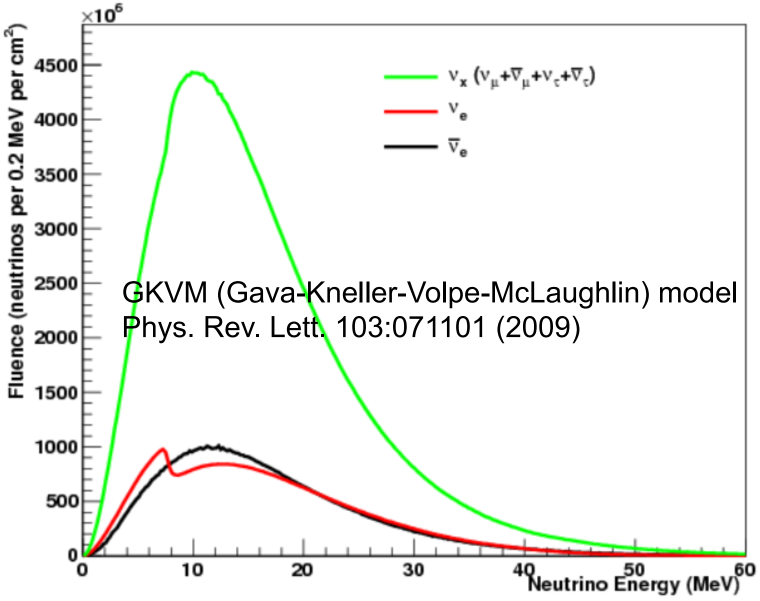
- Fermi-Dirac thermal energy distributions characterized by a temperature, T_ν, and pinching parameter, η_ν

$$\phi_{FD}(E_\nu) = \frac{1}{T_\nu^3 F_2(\eta_\nu)} \frac{E_\nu^2}{\exp\left(E_\nu/T_\nu - \eta_\nu\right)+1}$$

- Hierarchy and time-evolution of average energies at the neutrinosphere

$$T(\nu_x) > T(\overline{\nu}_e) > T(\nu_e)$$

- ν-ν scattering collective effects and MSW oscillations further imprint physics on the FD distributions



GKVM (Gava-Kneller-Volpe-McLaughlin) model
Phys. Rev. Lett. 103:071101 (2009)

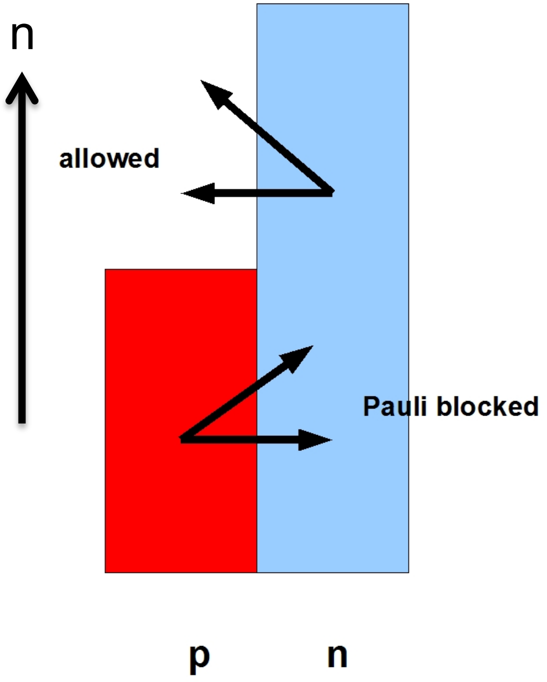
K. Scholberg, Annu. Rev. Nucl. Part. Sci. 2012. 62:81–103.

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

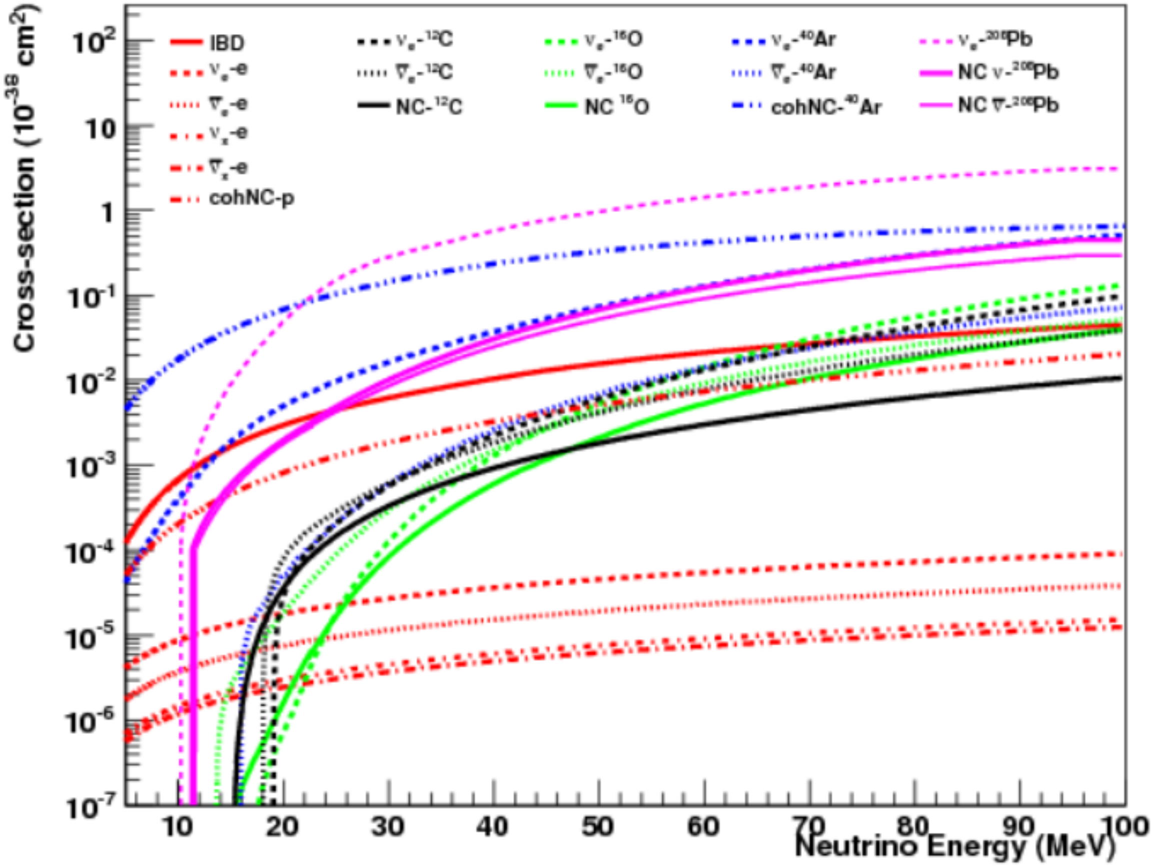


Other Advantages

- 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

Comparative ν-nuclear Cross-sections



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

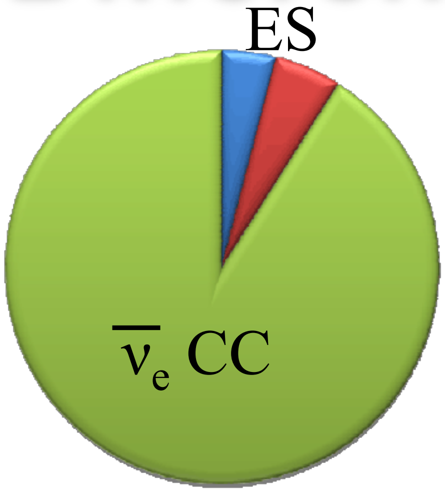
CC:
$$\nu_e + {}^{208}\text{Pb} \rightarrow {}^{207}\text{Bi} + n + e^-$$
$$\nu_e + {}^{208}\text{Pb} \rightarrow {}^{206}\text{Bi} + 2n + e^-$$

NC:
$$\nu_x + {}^{208}\text{Pb} \rightarrow {}^{207}\text{Pb} + n$$
$$\nu_x + {}^{208}\text{Pb} \rightarrow {}^{206}\text{Pb} + 2n$$

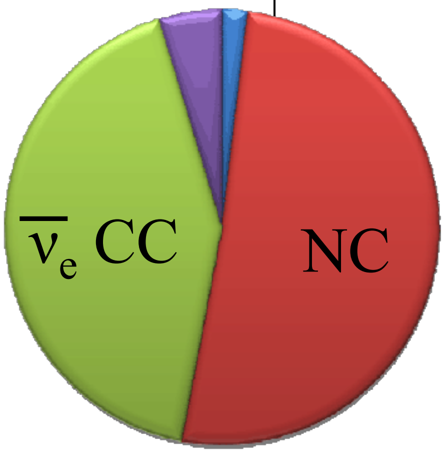
Thresholds
CC 1n 10.7 MeV
CC 2n 18.6 MeV
NC 1n 7.4 MeV
NC 2n 14.4 MeV

2n cross-sections don’t appear on plot

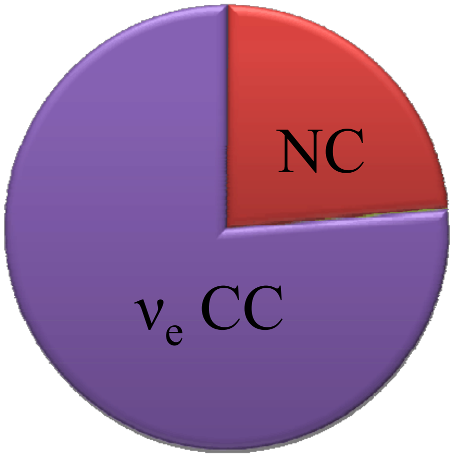
Flavour Sensitivities for Different Technologies



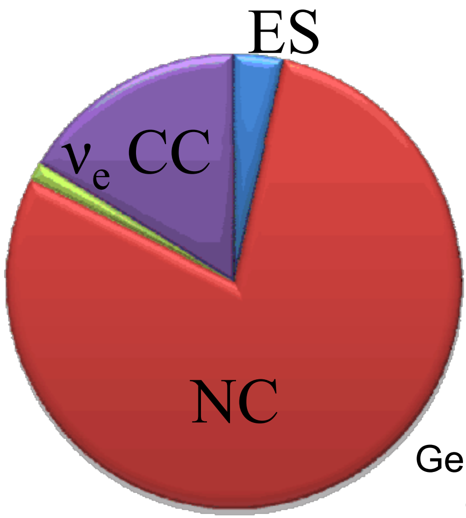
Water
Cherenkov



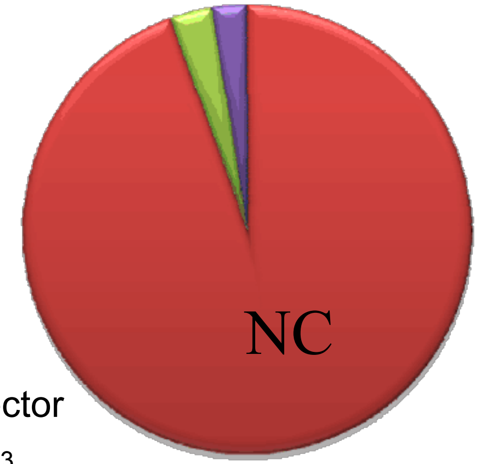
Liquid
Scintillator



Lead



Liquid
Argon



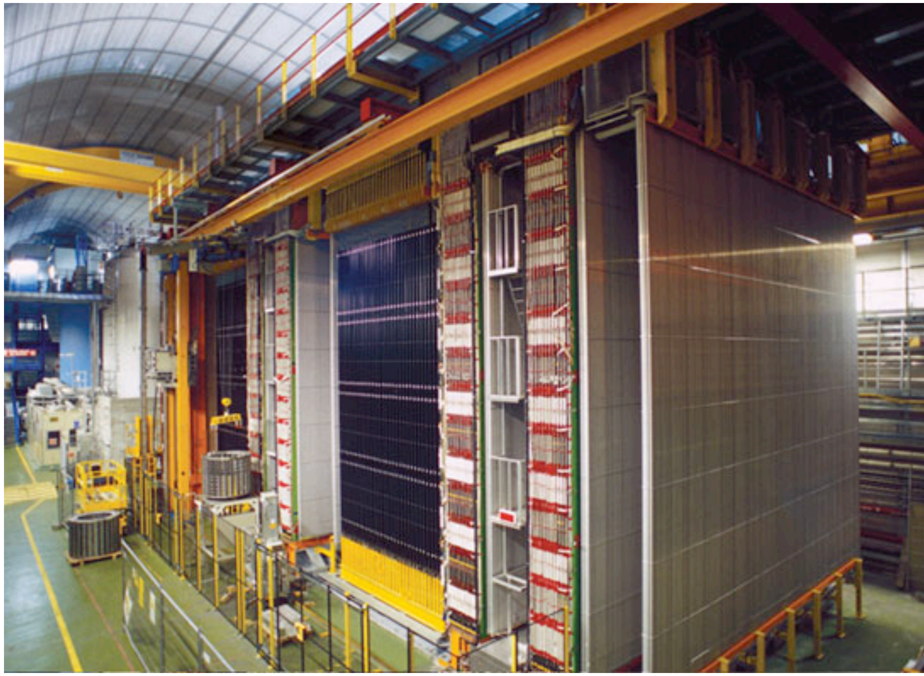
Iron

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

A New Opportunity…

The OPERA experiment at LNGS is being decommissioned this year making available ~ 1kt of lead for new experiments

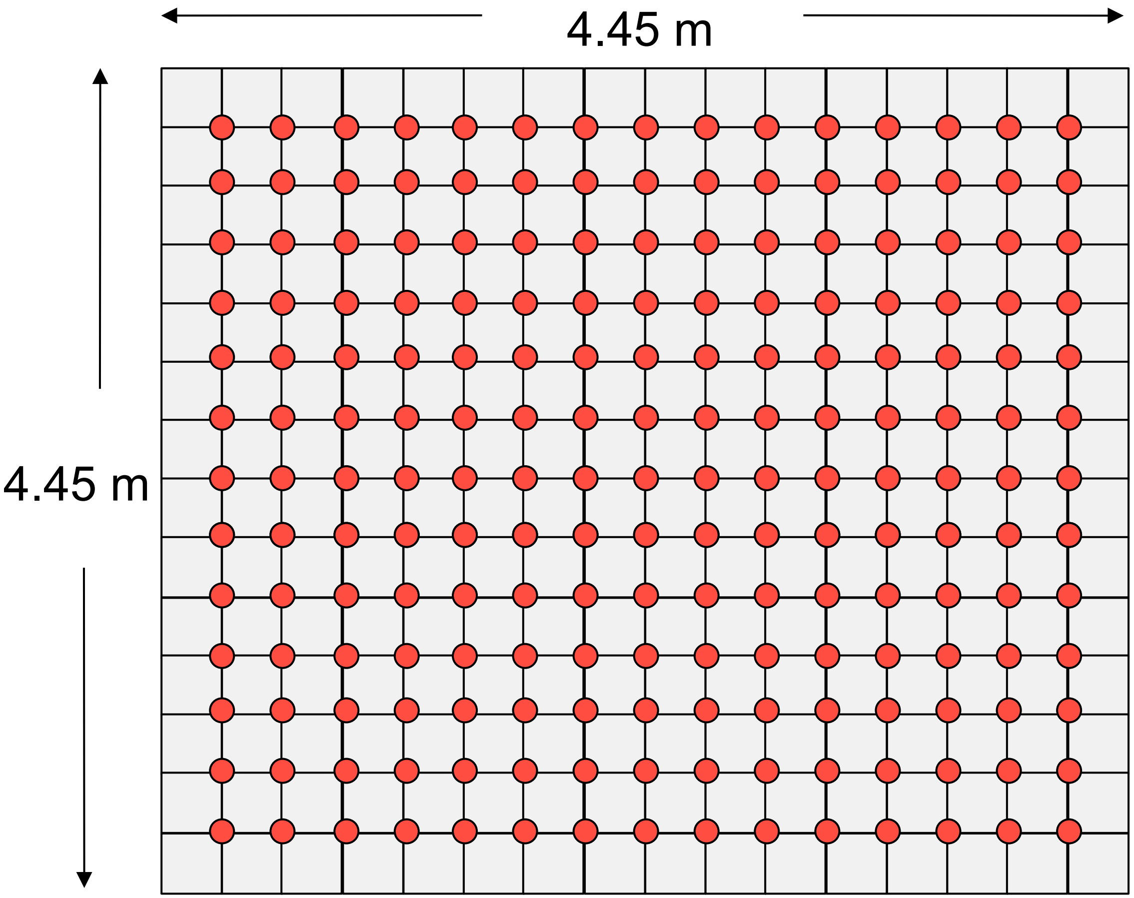
- an informal expression of interest was made at the April 2015 meeting of the Gran Sasso SAC
- Stefano Ragazzi (Director, LNGS) has committed that the lead will remain available as long as a proposal is in the pipeline and encouraged us to proceed with a formal LOI and full proposal.



“HALO” at LNGS

- concepts are preliminary
  - have ~550 m of ^{3}He counters (very quiet… ~40 cnts / day)
  - plus 120 m of $^{10}BF_3$ counters
  - likely more is desirable and/or an alternative technology (could be less quiet if not used in trigger)
  - cosmic muon rate ~x100 higher in LNGS
    - veto desirable, not absolutely necessary
  - modest (water) shielding should reduce ambient neutrons to negligible level, isolate and define the target volume

“HALO” at LNGS



We have ~200 ^{3}He counters available 2 – 3 m long. These could be arranged in a 14 x 14 array in the lead matrix (on a ~28 cm grid)

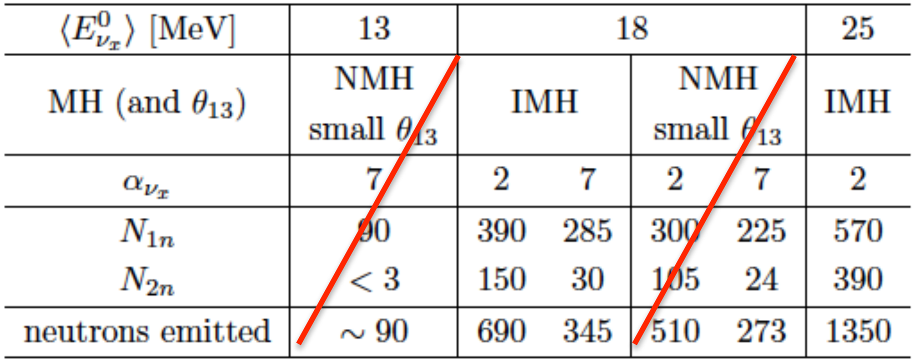
28 cm

^{3}He locations ●

"HALO" at LNGS

- increasing density of neutron detection will increase capture efficiency / scientific reach of detector AND costs
- needs full exploration with detailed simulations
- backgrounds in ^{3}He counters are lower than required for setting a low threshold SN trigger → central volume of detector instrumented with these and surrounding volume with alternative technology… to be explored

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

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

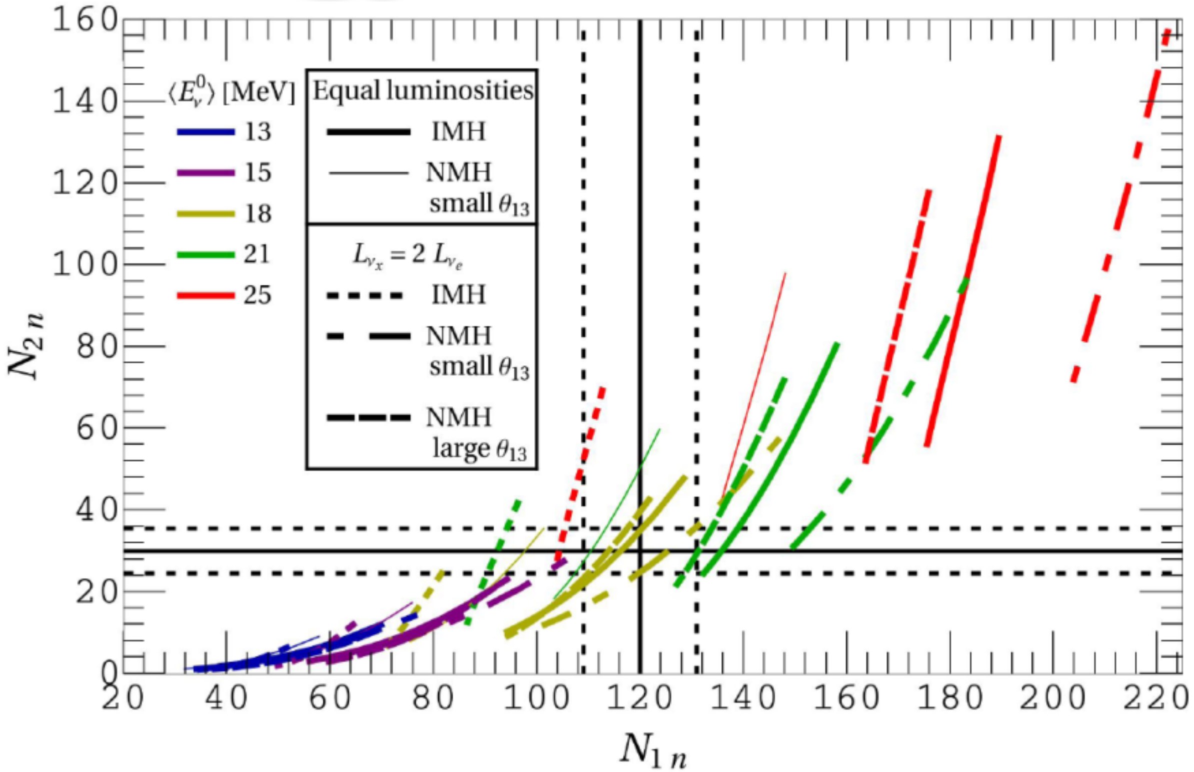
Table 6. Total numbers of events during the explosion (assuming 100 % detection efficiency, distance to the supernova 10 kpc and target mass 1 kton of ^{208}Pb). As in table 4 but assuming equal neutrino luminosities throughout the whole neutrino emission and the total time integrated luminosity 3×10^{53}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

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)

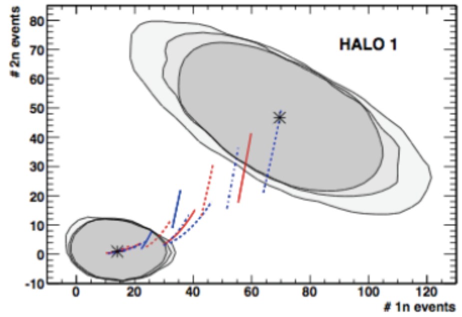
cross-sections from Engel, McLaughlin, Volpe, Phys. Rev. D 67, 013005 (2003)

Sensitivity to neutrino energy



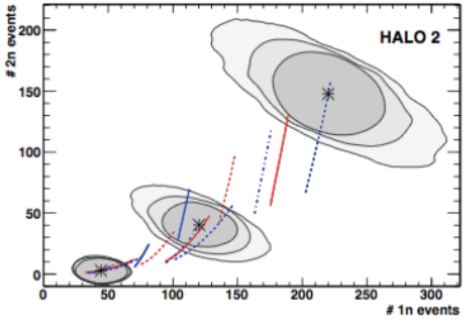
Distinct 1n and 2n emission thresholds in lead provide the possibility to measure neutrino temperatures and pinching parameters. N_{1n} and N_{2n} per kt from Väänänen and Volpe, JCAP **1110** (2011) 019

5 kpc



ε = 40%,50%,60%

10 kpc



ε = 40%,60%,80%

March 2012 APS, K. Scholberg.

Expected HQP training

- since 2010 a total of 34 students, from 11 different institutes, have been involved in HALO through:
  - UG summer employment
  - UG thesis projects
  - MSc thesis projects and internships
- most have spent time at SNOLAB
- a continuation at at least this level is expected

Equipment needs

- a portion of detector capital costs could be the object of a CFI request
- anticipate INFN, NSF contributions
- timeline
  - LNGS LOI – Fall 2015
  - LNGS Proposal 2017
  - need for capital beginning 2018

Computing requirements

- no large scale resource requirements foreseen

Expected calls on technical support

- early days…
- expected Canadian involvement to be with neutron detection
- possible calls on technical support from TRIUMF, SNOLAB or the MRS facilities for both detector development and production fabrication

Relationships with other projects

- largest, perhaps the only relationship, is between the HALO at SNOLAB project and this new HALO at LNGS effort
  - HALO at SNOLAB is an excellent testbed for neutron detection technology for HALO at LNGS
  - depending on choices to be made for n-detection technology the ^{3}He detectors *could* move to LNGS ending the experiment at SNOLAB

Relationships with international partners

- most institutions involved in HALO at SNOLAB would continue with HALO at LNGS
- there are potential new collaborators in the US; existing collaborators have been NSF funded
- there are potential new collaborators in Europe and in particular in Italy; we would anticipate INFN participation
- growth within Canada is most welcome, to maintain leadership and long-term continuity… this lead-based detector concept is “Canadian” (C.K. Hargrove)

The HALO Collaboration

The HALO Collaboration

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]

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Funded by:

halo.snolab.ca

Interested?

To help in the development of the LOI and Full Proposal please contact

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