HALO-1kT: a lead-based supernova detector

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On behalf of HALO Collaboration

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Learning from supernovae

ASTROPHYSICS

- Explosion mechanism
- Black hole formation
- Neutron star EoS
- Microphysics and neutrino transport
- Nucleosynthesis

PARTICLE PHYSICS

- Neutrino flavor transformation in dense environments
- Non-standard properties (indirect)

Challenges

THEORY

- Importance of combining channels
- SNEWS is dominated by $\bar{\nu}_e$ sensitive detectors

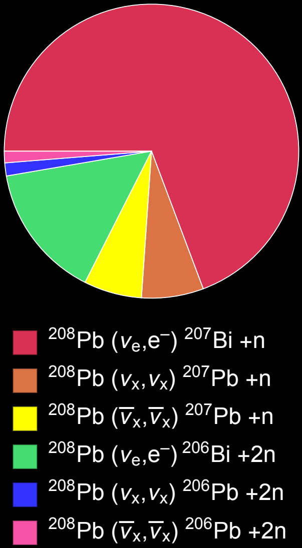
EXPERIMENT

- Down-time of current kt-scale detectors
  - $\hookrightarrow$ calibration, reconfiguration, end of life…
- Cost of big detectors (100 kton)
  - $\hookrightarrow$ some features might be sacrificed

NEED FOR LOW-COST, LOW-MAINTENANCE, LONG LIFETIME DETECTORS

Lead as supernova detector

- ν_e sensitive
  - Pauli-blocking of $\overline{\nu}_e$ CC
  - Complementary to protons (IBD)
- Neutron production
  - High Coulomb barrier $\Rightarrow$ no (α, n)
  - Low neutron absorption
- CC electrons
  - Spectral information
  - Very difficult to detect



the Helium And Lead Observatory at SNOLAB

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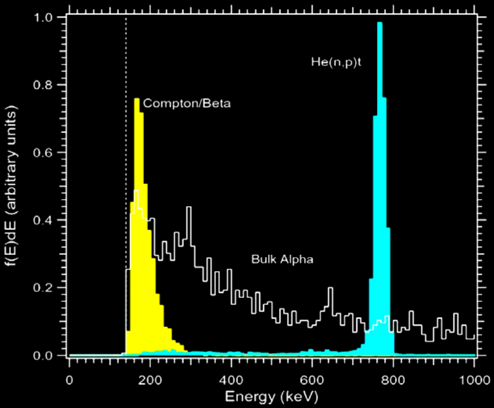
- 32 columns of lead (79 ton)
- 128 SNO's NCD counters
  - 1465 l atm of ^{3}He
  - $^3\text{He} + \mathbf{n} \rightarrow \mathbf{p} + \text{t} + 764\,\text{keV}$
- Operating since May 2012
- High livetime, low maintenance

the Helium And Lead Observatory at SNOLAB

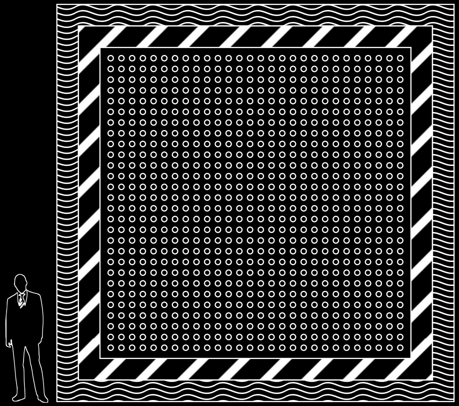


- Simulated, calibrated, understood
- Neutron capture efficiency $\sim 28\%$
- Some dozen events @ 10 kpc

NEXT GENERATION: HALO-1kT at LNGS

HALO-1kt at LNGS

- $(4.33^2 \times 5.5)\,\mathrm{m}^3$ lead core
- $28^2 \times (5.5\,\mathrm{m})$ array of ^{3}He
- 8 mm PS moderator
- 30 cm graphite reflector
- 30 cm water shielding
- Almost final configuration

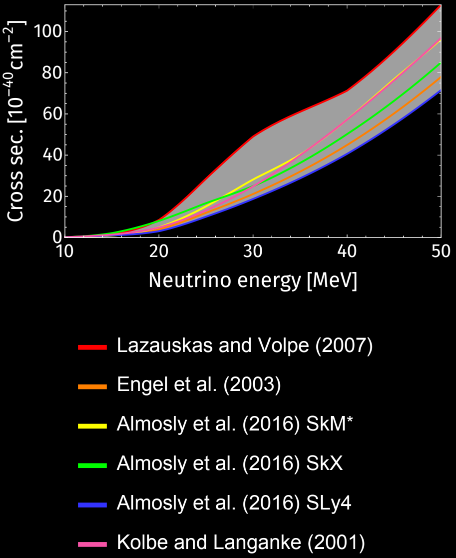


HALO-1kt at LNGS

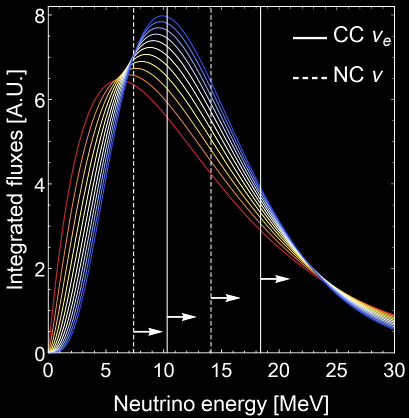
- Lead from decommissioned OPERA
  - $\times 12.7$ mass (1 kton) w.r.t. HALO
- Improved efficiency
  - from 28% to $\sim 50\%$
- $\times 20$ more statistics

Neutrino-lead cross section

- Large cross section
  $\sim (10^{-41} \div 10^{-39})\,\mathrm{cm}^2$
- Unmeasured (calculated)
- Systematic uncertainties
  - Different calculations
  - Nuclear uncertainties
- Neutrino beam @ SNS
  - Measurement planned

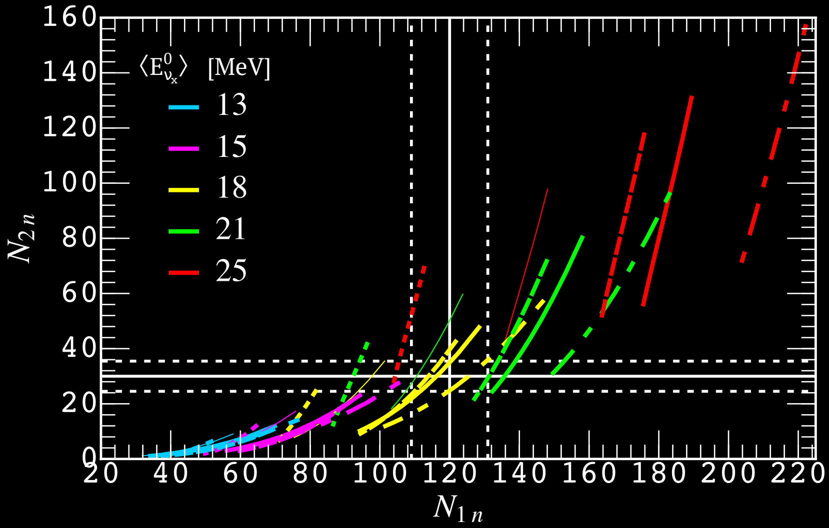


- ν_e thermometer
  - Flavor swapping
  - Collective ν–ν effects
  - Neutrino thermalization
- $\Phi(\nu_e)/\Phi(\overline{\nu}_e)$ ratios
  - Of interest for r-processes
- Pinching parameter [1]
  - Neutrinosphere radii
  - Equation of state



[1] A. Gallo Rosso et al. JCAP 1812 (2018), JCAP 1804 (2018), JCAP 1711 (2017).

Reducing the parameter space

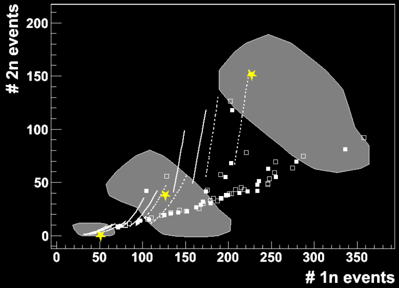


Väänänen and Volpe, JCAP 1110 (2011) 019.

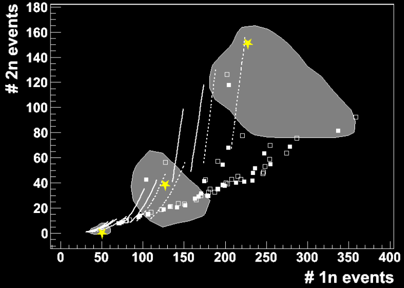
Model exclusion

— BAYESIAN UNFOLDING —

DISTANCE KNOWN



DISTANCE UNKNOWN

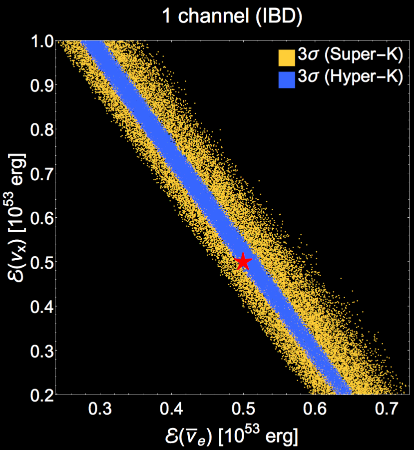


John F. Crenshaw, Duke U. (2018).

The importance of combining channels

WATER CHERENKOV

- IBD only: flux degeneracies
- Breaking through eES
- $\overline{\nu}_e$, ν_x under control
  - $\mathcal{E}_{\overline{\nu}_e} \sim 10\%$ (4%)
  - $\langle E_{\overline{\nu}_e} \rangle \sim 6\%$ (2%)
- ν_e flux almost undetermined
  (And pinching too)



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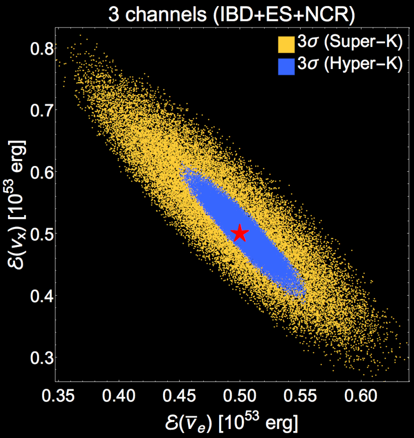

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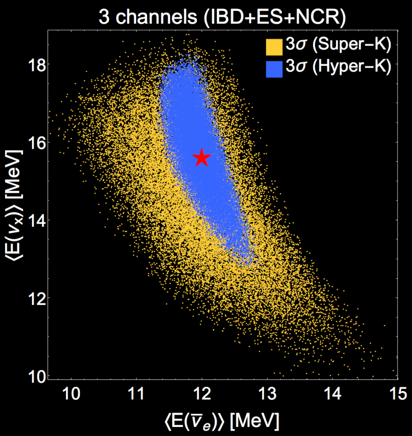

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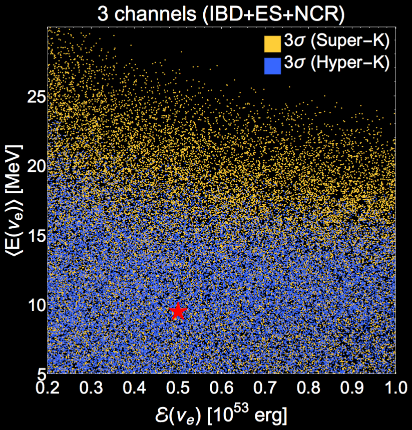

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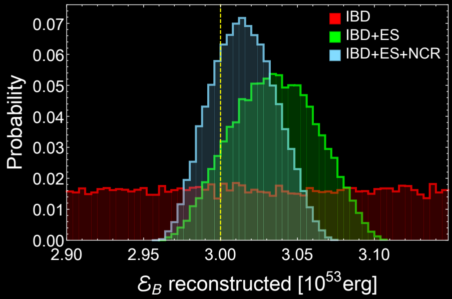
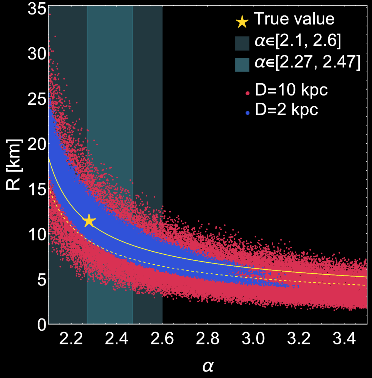
PNS properties





$\mathcal{E}_{\nu_e}$ undetermined in the prior

$$\mathcal{E}_{\nu_e} \in [0.2, 1] \times 10^{52} \text{ erg}$$

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Summary

HALO-1KT

- SN detectors need to be low maintenance, high livetime, and long lifetime
- Importance to have a ν_e sensitive detector
  - Medium/little statistics is essential
  - Especially when it brings complementary information
- HALO-1kT proposal will be submitted LNGS scientific committee