New HALO-1kT

And supernova neutrino flux reconstruction

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Introduction

PRESS
START

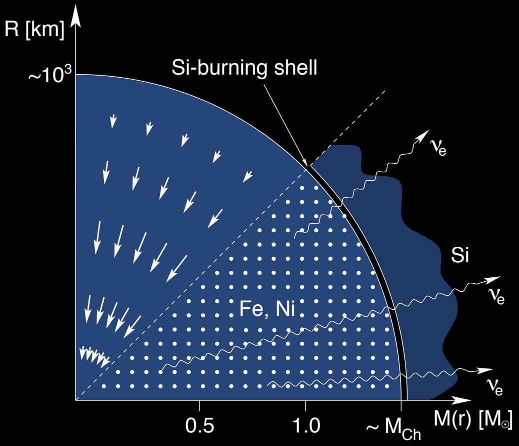
WHAT WE KNOW (FOR SURE)

- $\sim 10^{53}$ erg gravitational B.E.
- 99% in neutrinos
  $\hookrightarrow$ $\nu_\mathrm{e}\ \nu_\mu\ \nu_\tau\ \overline{\nu}_\mathrm{e}\ \overline{\nu}_\mu\ \overline{\nu}_\tau$
- $\sim 10\,$s signal

Supernova model

Phases of a SN explosion

1. Instability & collapse
2. Bounce
3. Shock propagation
4. Shock stallation
5. Accretion & cooling



[1] Images adapted from Janka *et al.* Phys.Rept. 442 (2007).

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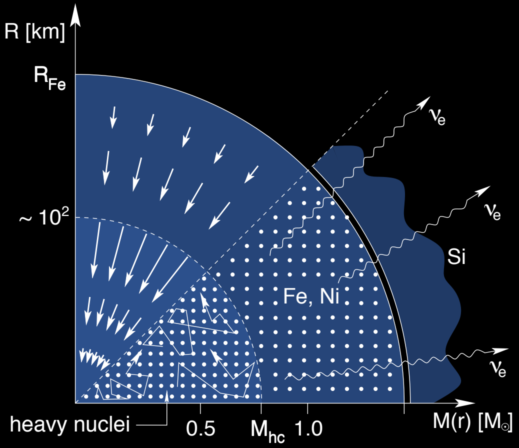

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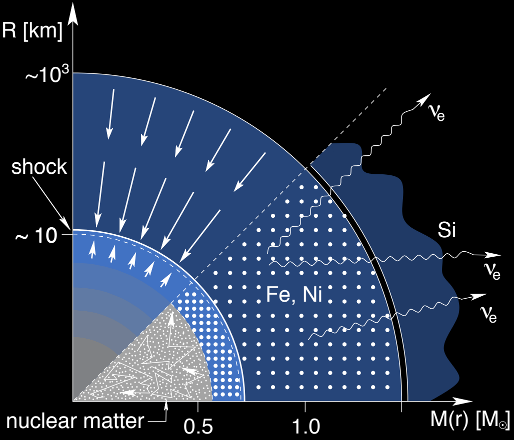

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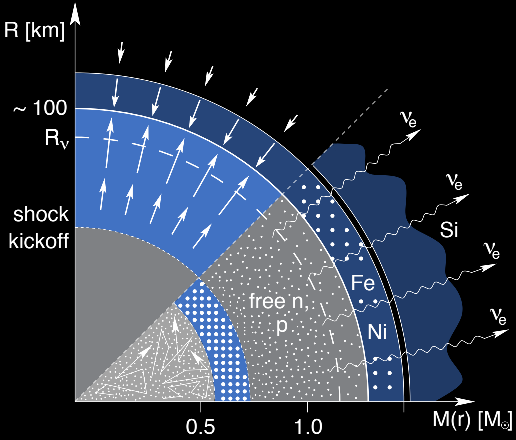

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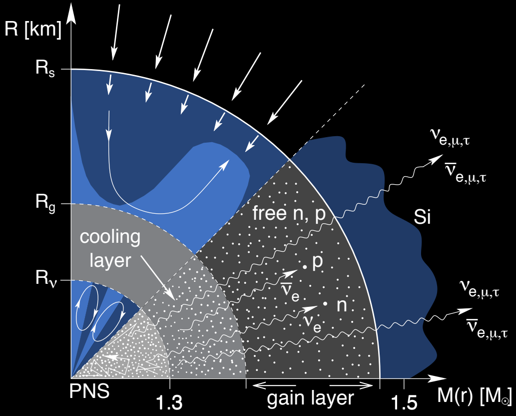

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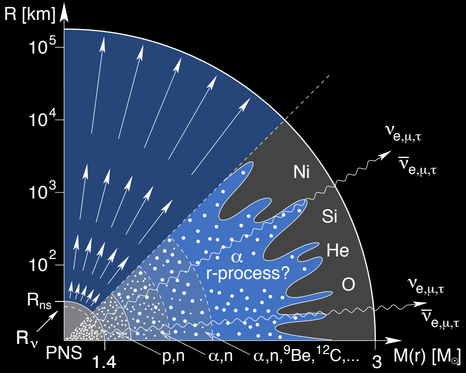

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Describing a supernova

FUNDAMENTAL PHYSICS

- General relativity
- Equation of state
- In-medium neutrino mixing effects

MULTIDIMENSIONAL EFFECTS

- Convection
- Turbulence
- Standing Accretion Shock Instability (SASI)
- Lepton-Emission Self-sustained Asymmetry (LESA)

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

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

Challenges

THEORY

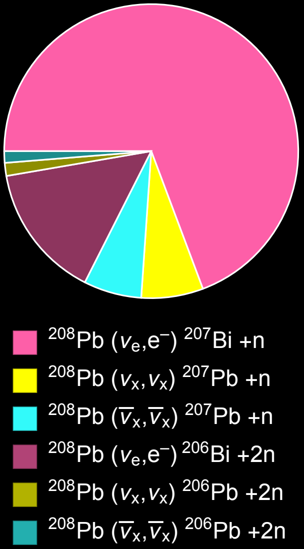
- SNEWS is dominated by $\overline{\nu}_e$ sensitive detectors
- Importance of combining channels

NEED FOR A ORTHOGONAL SOURCE OF INFORMATION

Lead as supernova detector

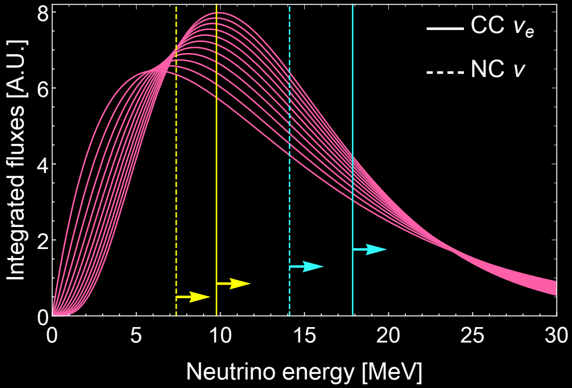
Lead as supernova detector

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



Accessible measurements

- 1n thresholds
  - NC: 7.37 MeV
  - CC: 9.77 MeV
- 2n thresholds
  - NC: 14.11 MeV
  - CC: 17.87 MeV



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

the Helium And Lead Observatory at SNOLAB

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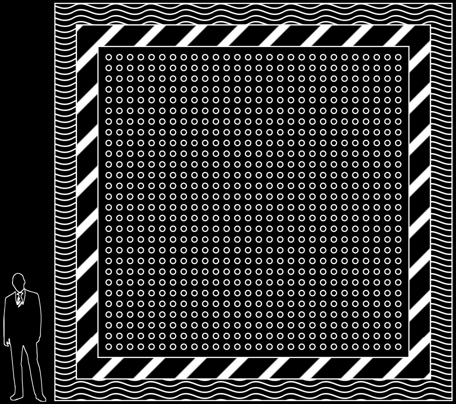
- 32 columns of lead (79 ton)
- 128 SNO's NCD counters
  - 1465 l atm of ^{3}He
  - $^{3}\mathrm{He} + \mathbf{n} \rightarrow \mathbf{p} + \mathrm{t} + 764\,\mathrm{keV}$
- Operating since May 2012
- High livetime, low maintenance

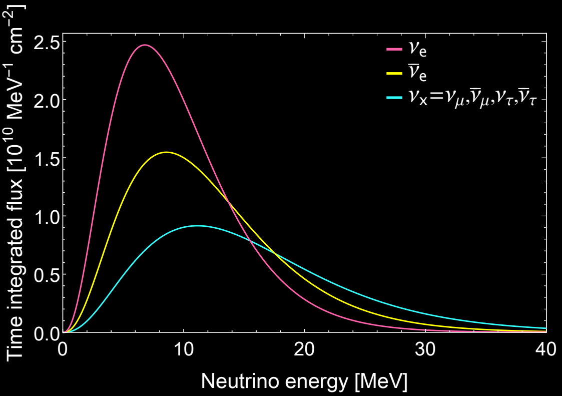
Next generation HALO-1kt at LNGS

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



Neutrino flux reconstruction

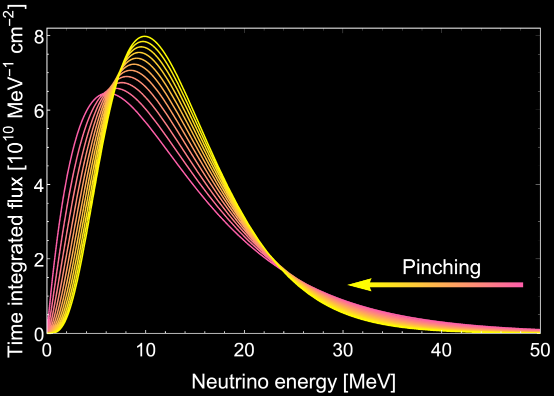
Quasi-thermal fluxes



TIME INTEGRATED FLUX (FLUENCE) — 3 PARAMETERS

Total energy $\mathcal{E}$	$\Leftrightarrow$	normalization
Mean energy $\langle E \rangle$	$\Leftrightarrow$	1^{st} moment
Pinching α	$\Leftrightarrow$	width

Quasi-thermal fluxes



TIME INTEGRATED FLUX (FLUENCE) — 3 PARAMETERS

Total energy $\mathcal{E}$ $\Leftrightarrow$ normalization

Mean energy $\langle E \rangle$ $\Leftrightarrow$ 1^{st} moment

Pinching α $\Leftrightarrow$ width

Likelihood analyses

- $\mathcal{E}_{\text{tot}} = 3 \times 10^{53}$ erg @ $D = 10$ kpc
- Oscillations: MSW effect (NH)
    - $F_{\bar{e}} = \overline{P}_{ee} F^0_{\bar{e}} + (1 - \overline{P}_{ee}) F^0_x$
- Likelihood analysis

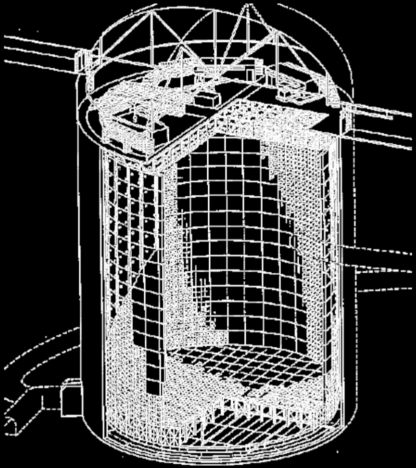
  $\hookrightarrow$ Emission parameters

Teun Hocks, *Measuring*

Likelihood analyses

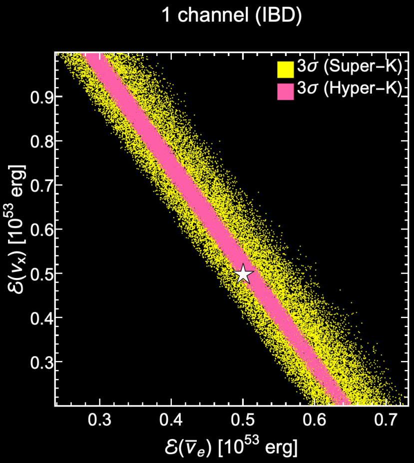
WATER CHERENKOV DETECTORS

- Super/Hyper -Kamiokande
  - 22.5 kton/0.37 Mton
- Channels
  - IBD: $\overline{\nu}_e + p \to e^+ + n$
  - eES: $\nu + e^- \to \nu + e^-$
- 100% efficiency and tagging
- 5 MeV threshold



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

The importance of combining channels



WATER CHERENKOV ALONE

- IBD only: flux degeneracies
- Breaking through eES

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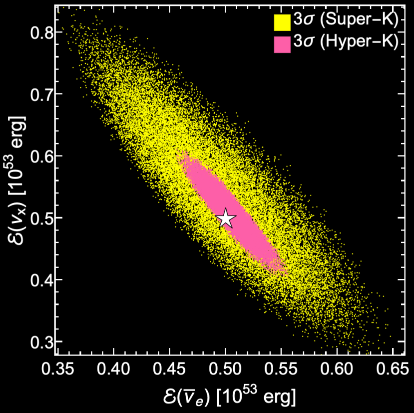
The importance of combining channels

WATER CHERENKOV ALONE

- IBD only: flux degeneracies
- Breaking through eES

2 channels (IBD + eES)



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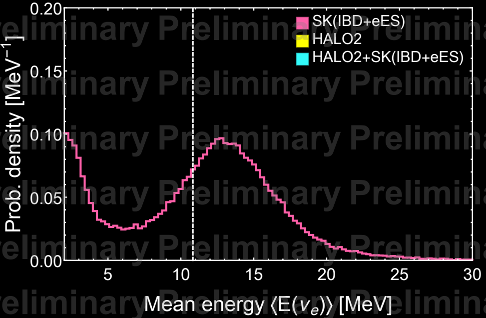
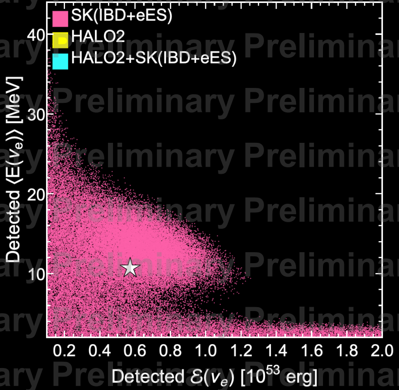
Detected fluxes

- LS220-s27.0co[2]
- HALO-1kT & Super-Kamiokande
- Likelihood analysis

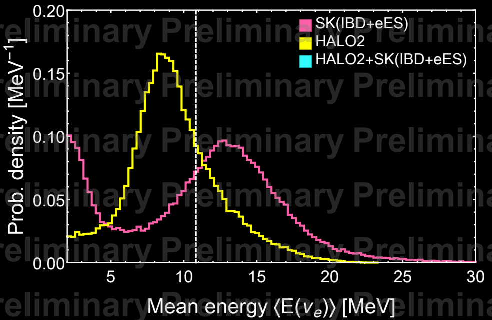
  $\hookrightarrow$ Detected parameters

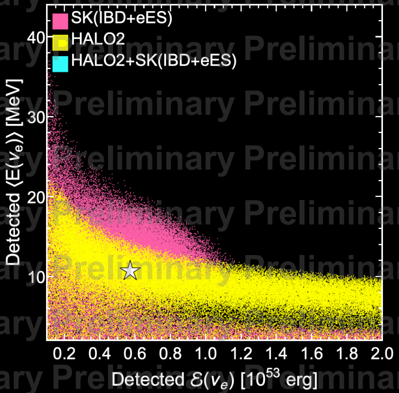
[2] A. Mirizzi *et al*, Riv. Nuovo Cim. 39 (2016).


SK(IBD+eES)
HALO2
HALO2+SK(IBD+eES)
Prob. density [MeV⁻¹]
0.20
0.15
0.10
0.05
0.00
5
10
15
20
25
30
Mean energy ⟨E(νe)⟩ [MeV]


SK(IBD+eES)
HALO2
HALO2+SK(IBD+eES)
Detected ⟨E(νe)⟩ [MeV]
40
30
20
10
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Detected ℰ(νe) [10^53 erg]

Detected fluxes





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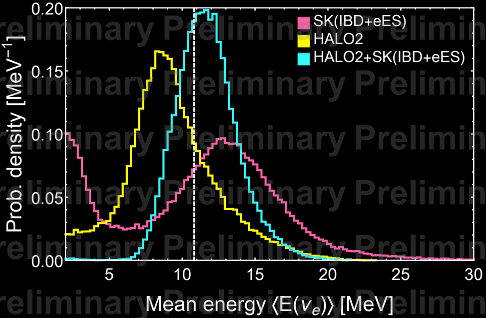

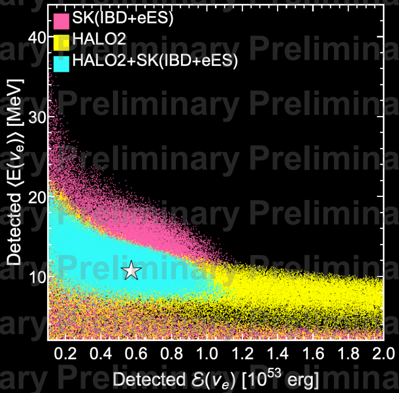

Summary

NEXT SUPERNOVA

- Once in a lifetime event: be ready!
- (Hopefully) surprises: getting the most of it is mandatory

HALO-1KT

- Stable, low maintenance, high livetime, long lifetime
- ν_e sensitive detector $\Rightarrow$ complementary information
- HALO-1kT proposal will be submitted LNGS scientific committee