The RES-NOVA neutrino observatory

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RES-NOVA

From latin -> "New thing"

Latin -> more on that later

NOVA -> Supernovae ☺
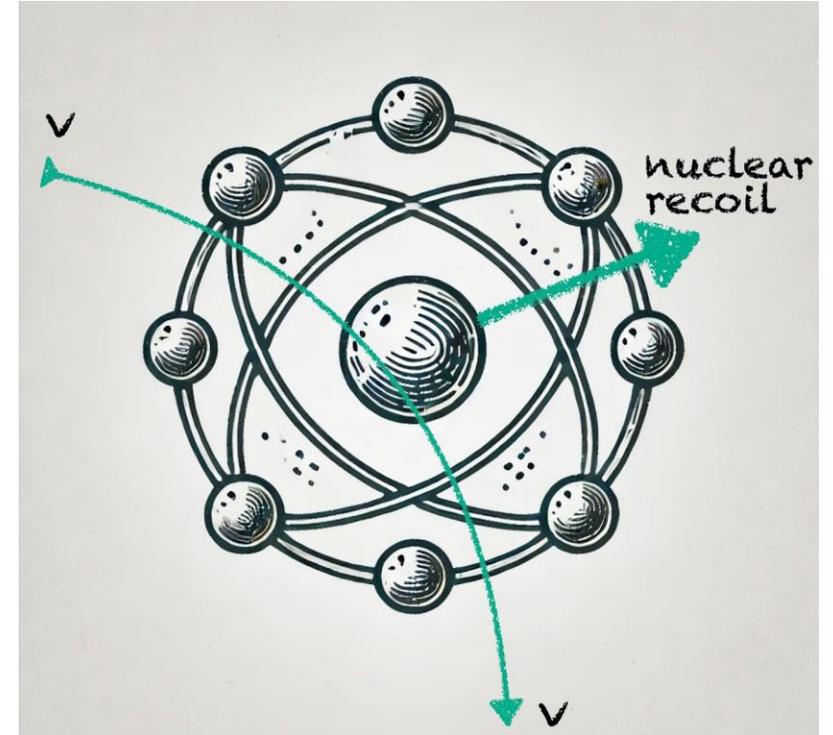
Coherent Elastic ν Nucleus Scattering

$$\frac{d\sigma}{dE_R} = \frac{G_F^2 m_N}{8\pi(\hbar c)^4} \left[(4\sin^2\theta_W - 1)Z + N\right]^2$$

$$\left(2 - \frac{E_R m_N}{E^2}\right) \cdot |F(q)|^2 \, ,$$

- Neutrinos mainly scatter off neutrons
- Coherent enhancement
- Flavor-independent
- $\mathcal{O}(10)$MeV neutrinos deposit $\mathcal{O}(1)$keV energy
- SM process
- First observation:

Science 15 Sep 2017:
Vol. 357, Issue 6356, pp. 1123-1126
DOI: 10.1126/science.aao0990

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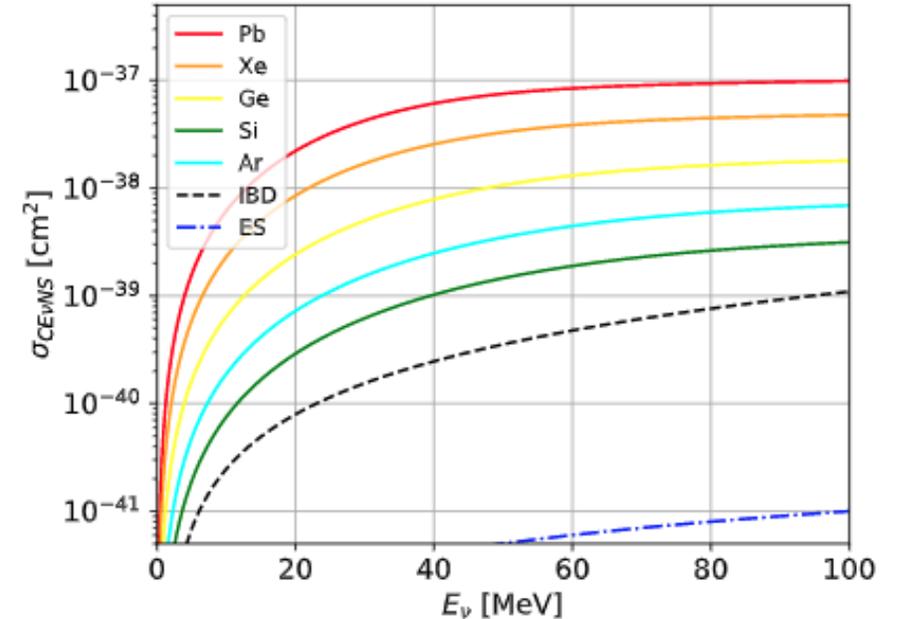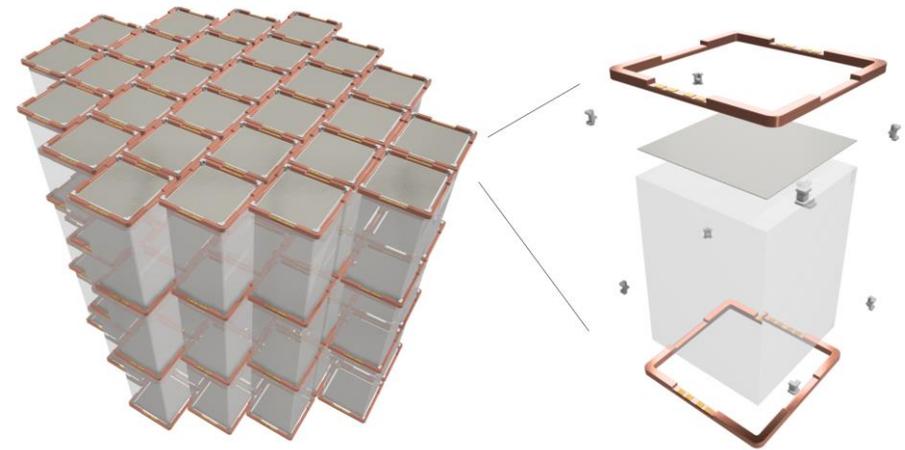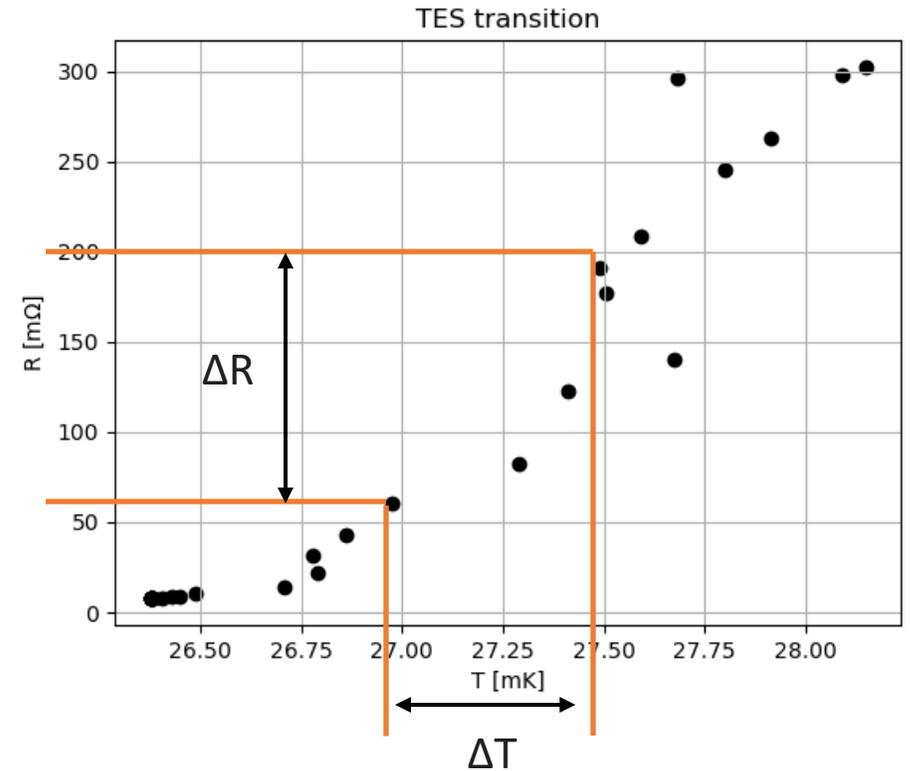DOI: 10.1126/science.aao0990

FIG. 2. Coherent elastic neutrino-nucleus scattering (CEνNS) cross sections as a function of the energy of the incoming neutrino for different target nuclei. The dashed lines show the inverse-beta decay (IBD) and neutrino elastic scattering on electrons (ES) cross-sections for comparison. Given the high cross-section, CEνNS has the potential to provide large statistics with small detector volumes.
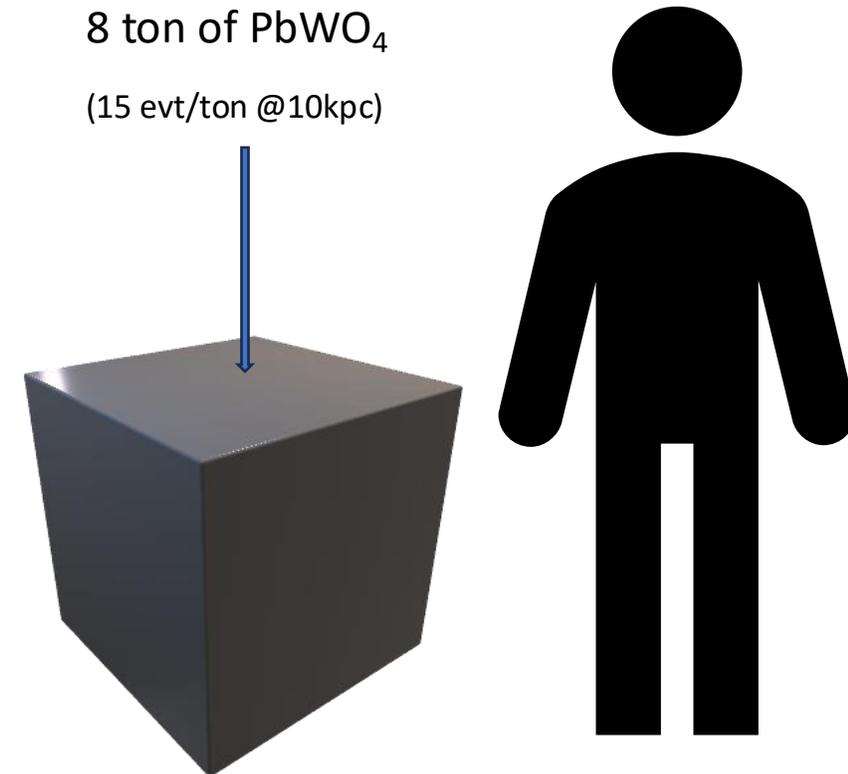
Phys. Rev. D 102, 063001 (2020)

The RES-NOVA detector

- Array of $PbWO_4$ crystals operated as (scintillating) cryogenic detectors (8.28 g·cm^{-3})

- Scintillating cryogenic detectors provide powerful background rejection thanks to the simulaneous read-out of phonon and light channels. Time coincident analysis of different detector modules allows for further background suppression

- Energy measured by means of sensitive Transition Edge Sensors

- TESs have already demonstrated the capability of sub-keV nuclear recoil energy threshold

- TES-instrumented cryogenic detectors offer excellent energy resolution

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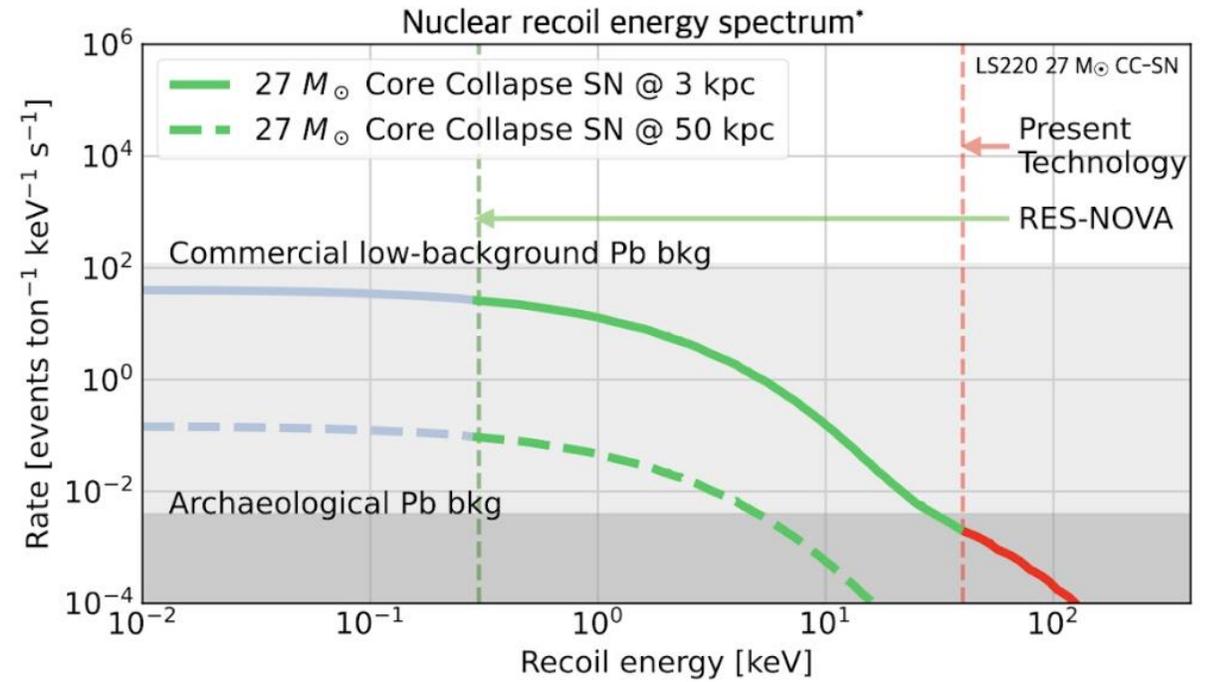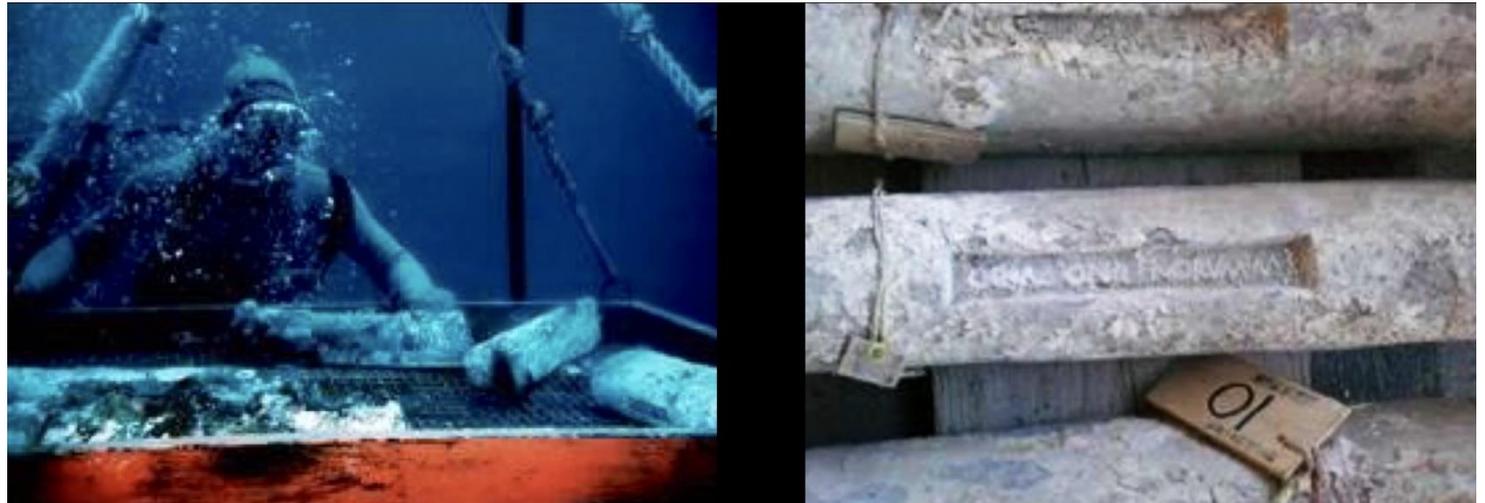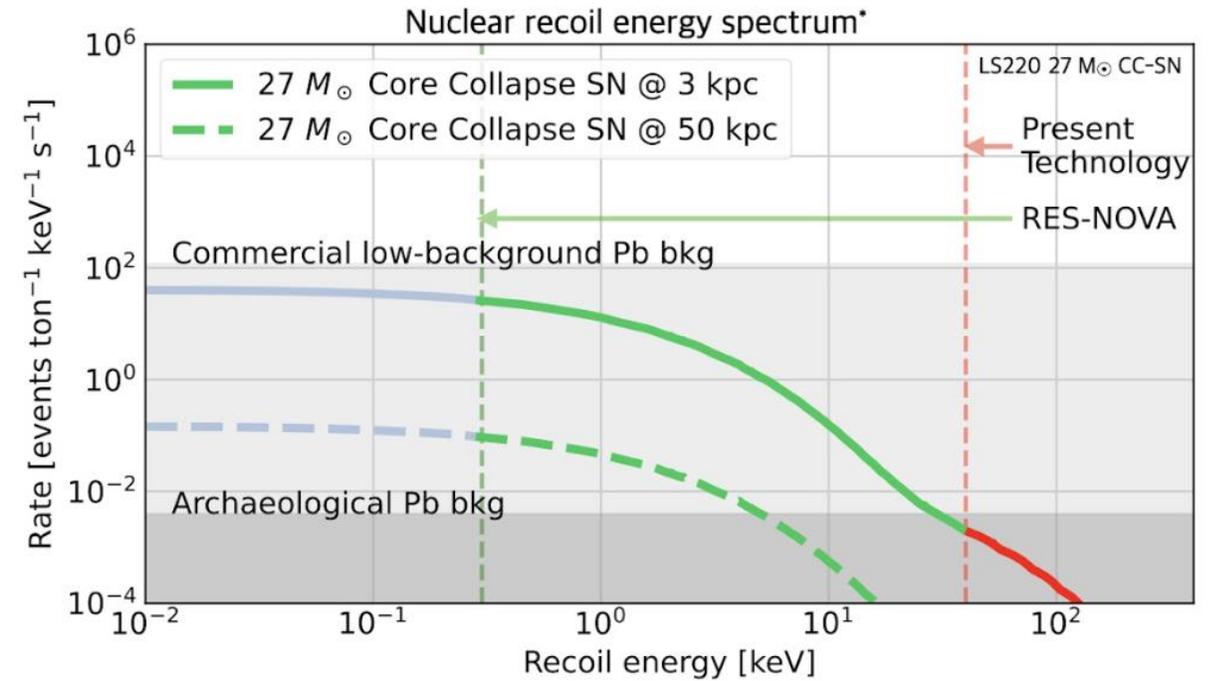- TES-instrumented cryogenic detectors offer excellent energy resolution

8 ton of $PbWO_4$

(15 evt/ton @10kpc)

The downfall of Pb

Commercial Pb has 10^4 Bq/ton of radioactive ^{210}Pb (Q-value 63 keV, $\tau_{1/2}$=22 y). That's bummer!
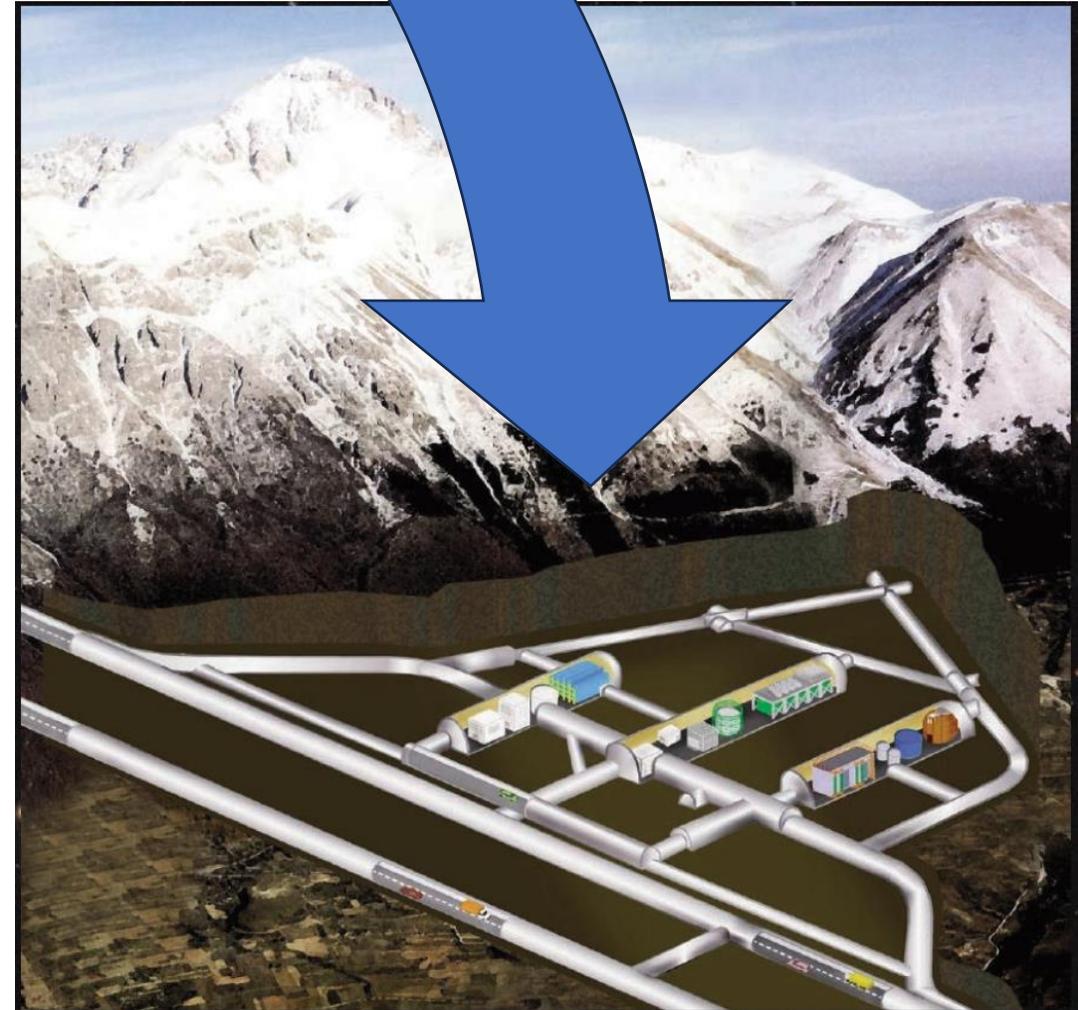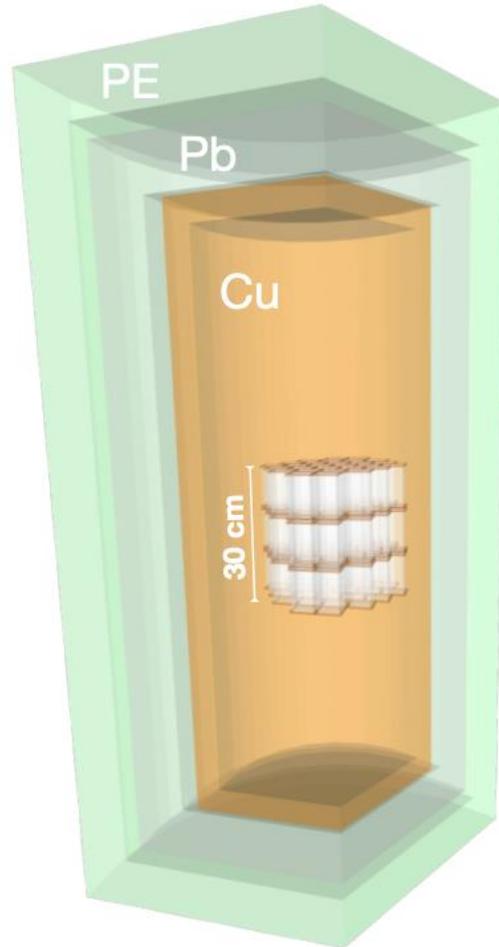
And the solution

Commercial Pb has 10^4 Bq/ton of radioactive ^{210}Pb (Q-value 63 keV, $\tau_{1/2}$=22 y). That's bummer!

We will deploy PbWO$_4$ grown with 2000years old archaeological lead ^{210}Pb is expected to be below 1mBq/kg
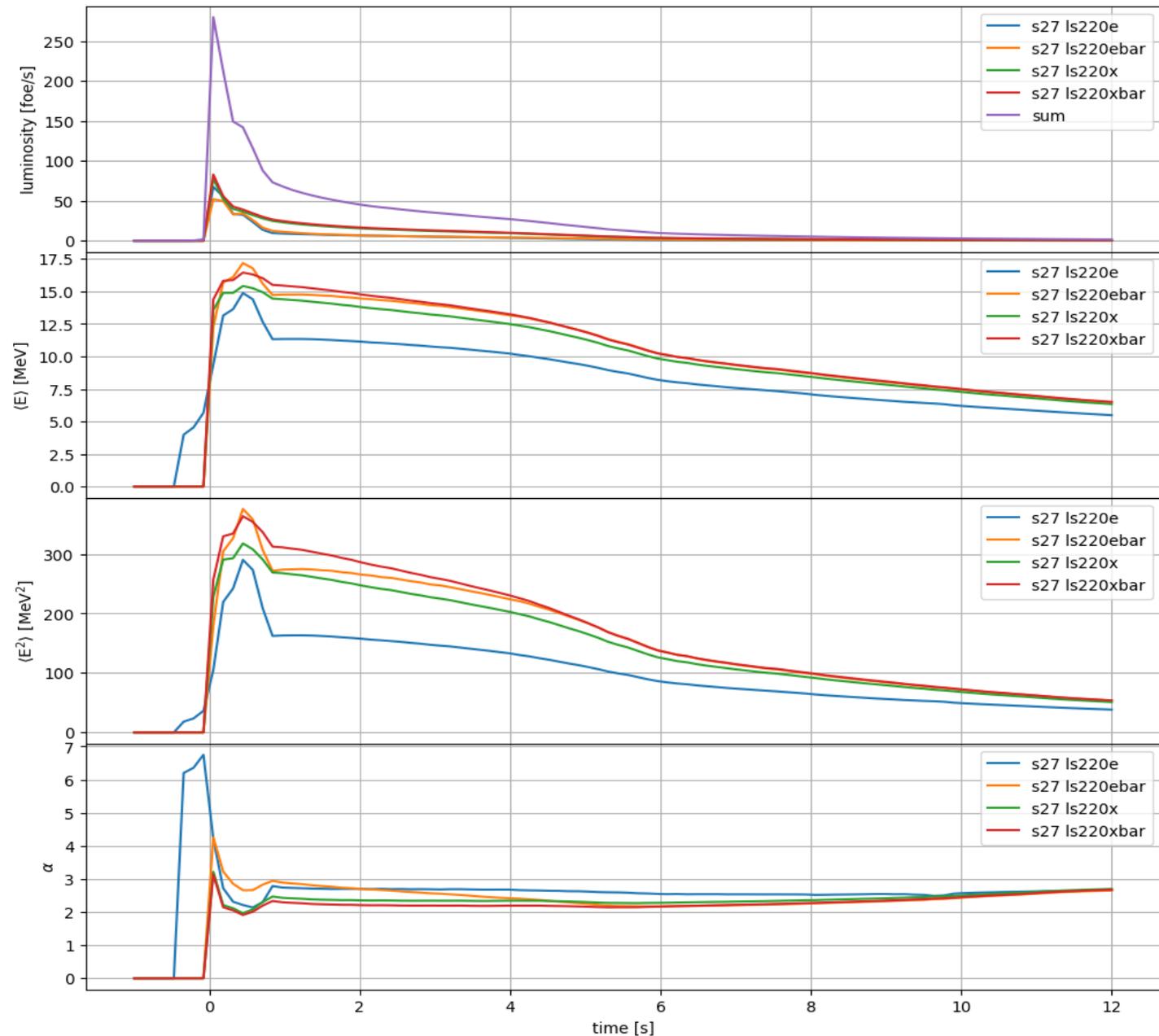
The RES-NOVA detector

- Underground installation at Laboratori Nazionali del Gran Sasso

- 3400 m.w.e. of shielding against cosmic radiation

- Convenient highway access for commissioning and operation

The neutrino source

$$f_\beta^0(E,t) = \frac{L_\beta(t)}{4\pi d^2} \frac{\phi_\beta(E,t)}{\langle E_\beta(t)\rangle}$$
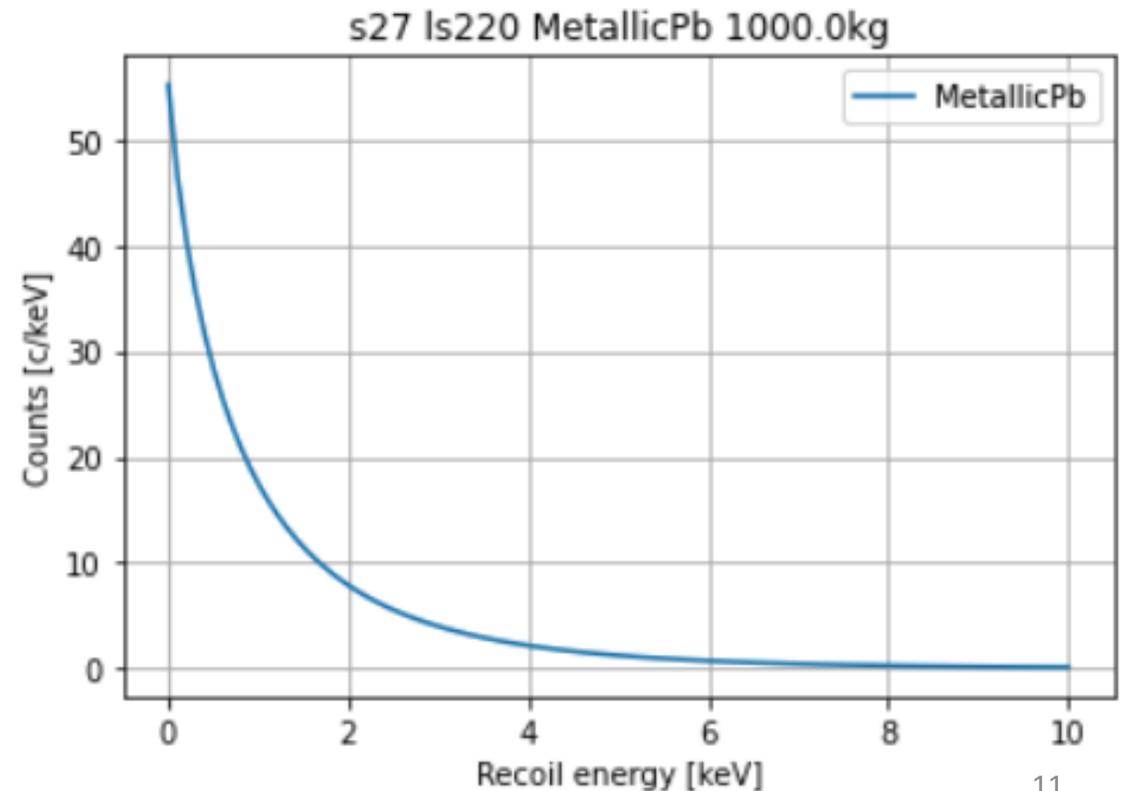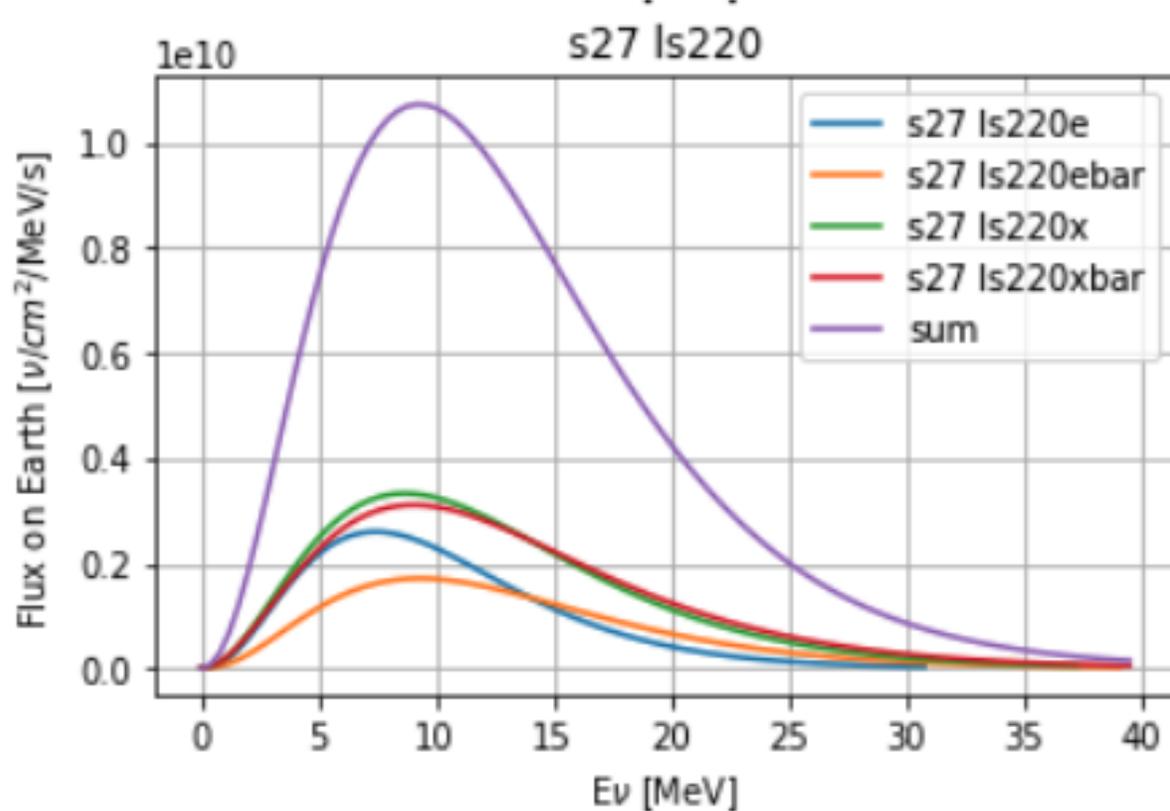
$$\phi_\beta(E,t) = \xi_\beta(t)\left(\frac{E}{\langle E_\beta(t)\rangle}\right)^{\alpha_\beta(t)}$$

$$\exp\left(-\frac{(\alpha_\beta(t)+1)E}{\langle E_\beta(t)\rangle}\right)$$

SN CE𝜈NS in Pb Target (on Earth)

The emitted neutrino spectrum is Maxwell-Boltzmann

Observed nuclear recoil spectrum

Phys. Rev. D 102, 063001 (2020)

The Proposal

- New detection channel (!)
- All-flavor sensitivity
- Ton-scale search complementary to currently running kton experiments

Neutrino observatory based on archaeological lead

Luca Pattavina[1,2,*], Nahuel Ferreiro Iachellini[3,†], and Irene Tamborra[4,‡]

[1]Physik-Department, Technische Universität München, 85747 Garching, Germany
[2]INFN, Laboratori Nazionali del Gran Sasso, 67100 Assergi, Italy
[3]Max-Planck-Institut für Physik, 80805 München, Germany
[4]Niels Bohr International Academy and DARK, Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, 2100, Copenhagen, Denmark

We propose the RES-NOVA project, which will hunt neutrinos from core-collapse supernovae (SN) via coherent elastic neutrino-nucleus scattering (CEνNS) using an array of archaeological lead (Pb) based cryogenic detectors. The high CEνNS cross section on Pb and the ultrahigh radiopurity of archaeological Pb enable the operation of a high statistics experiment equally sensitive to all neutrino flavors with reduced detector dimensions in comparison with existing neutrino observatories and easy scalability to larger detector volumes. RES-NOVA is planned to operate according to three phases with increasing detector volumes: $(60 \text{ cm})^3$, $(140 \text{ cm})^3$, and ultimately $15 \times (140 \text{ cm})^3$. It will be sensitive to SN bursts up to Andromeda with 5σ sensitivity with already existing technologies and will have excellent energy resolution with a 1 keV threshold. Within our Galaxy, it will be possible to discriminate core-collapse SN from black-hole-forming collapses with no ambiguity even in the first phase of RES-NOVA. The average neutrino energy of all flavors, the SN neutrino light curve, and the total energy emitted in neutrinos can potentially be constrained with a precision of a few percent in the final detector phase. RES-NOVA will be sensitive to flavor-blind neutrinos from the diffuse SN neutrino background with an exposure of 620 ton · y. The proposed RES-NOVA project has the potential to lay down the foundations for a new generation of neutrino telescopes while relying on a very simple technological setup.

Sensitivity studies (…so far)

RES-NOVA 170 kg $PbWO_4$
RES-NOVA[1] 2.4 t - metallic Pb
RES-NOVA[2] 31 t - metallic Pb
RES-NOVA[3] 465 t - metallic Pb

- Detection (type II error)

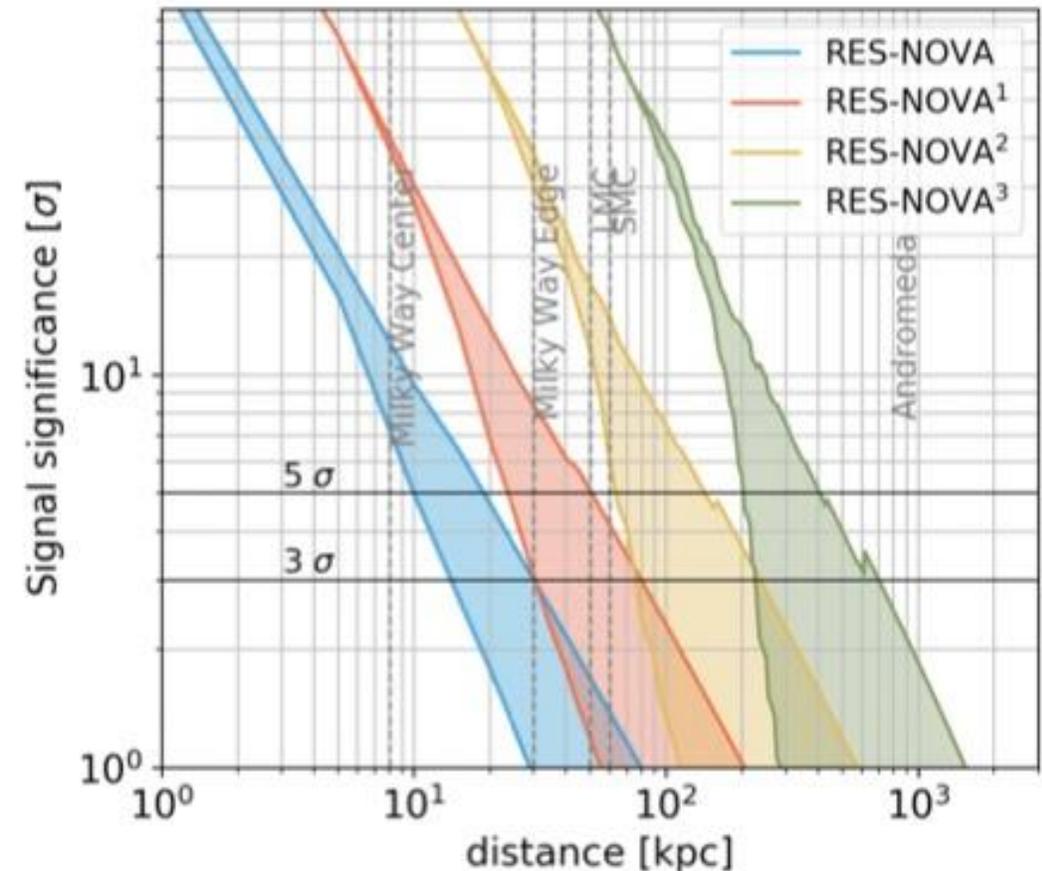- We need input from other searches (occurrence time and d)

$$f_\beta^0(E, t) = \frac{L_\beta(t)}{4\pi d^2} \frac{\phi_\beta(E,t)}{\langle E_\beta(t) \rangle}$$

- Contrain SN parameters

- Our negative log-likelihood:

$$-N_{obs}\log(N_{exp}) + N_{exp} - \sum_i^{N_{obs}} \log[pdf(E_i)]$$

Size

Technology

(essentially the cross-section folding, thanks to the energy resolution of cryogenic detectors)

13

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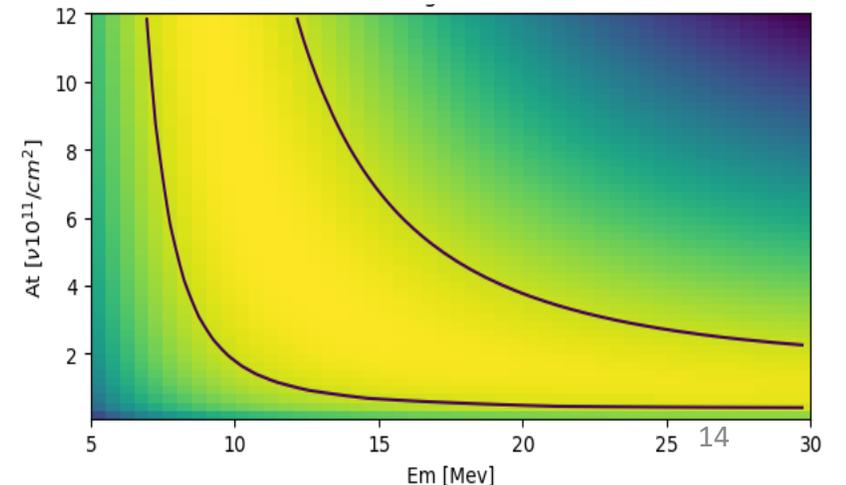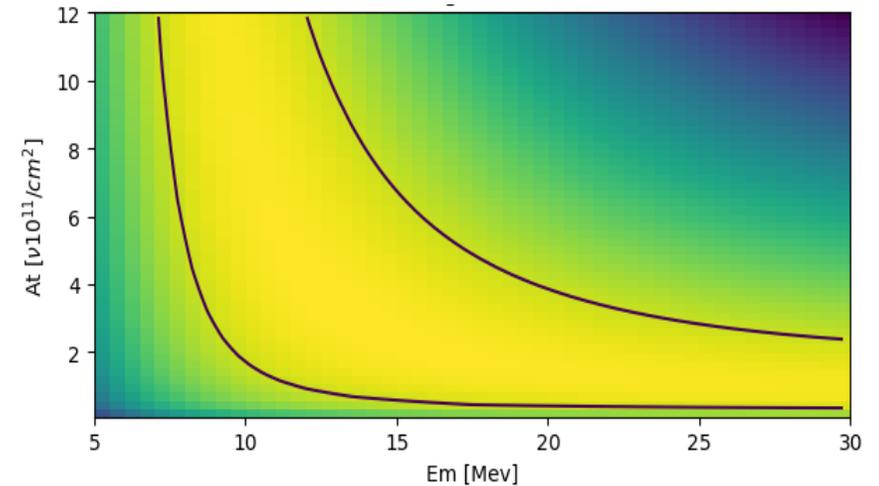RES-NOVA[3] 465 t - metallic Pb

- Detection (type II error)

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Sensitivity studies (...so far)

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RES-NOVA[2] 31 t - metallic Pb
RES-NOVA[3] 465 t - metallic

- Detection (type II error)

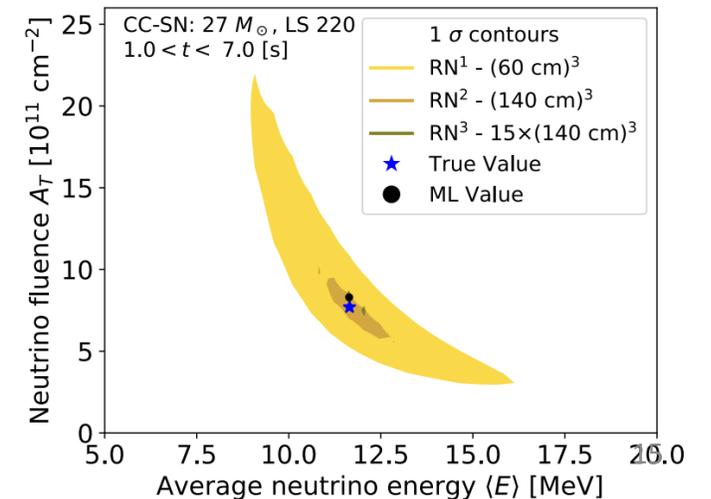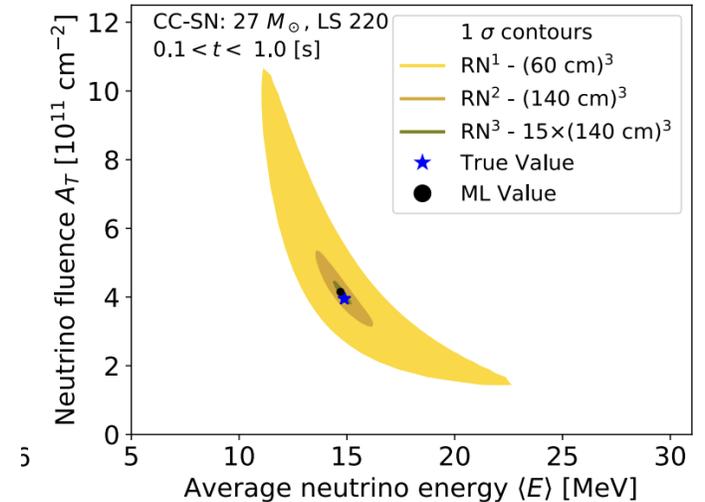- We need input from other searches (occurrence time and d)

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CC-SN: 27 $M_\odot$, LS 220
$0.1 < t < 1.0$ [s]
1 σ contours
RN[1] - (60 cm)^3
RN[2] - (140 cm)^3
RN[3] - 15×(140 cm)^3
★ True Value
● ML Value

Neutrino fluence A_T [10^{11} cm^{-2}]
Average neutrino energy $\langle E \rangle$ [MeV]

CC-SN: 27 $M_\odot$, LS 220
$1.0 < t < 7.0$ [s]
1 σ contours
RN[1] - (60 cm)^3
RN[2] - (140 cm)^3
RN[3] - 15×(140 cm)^3
★ True Value
● ML Value

Neutrino fluence A_T [10^{11} cm^{-2}]
Average neutrino energy $\langle E \rangle$ [MeV]

Sensitivity studies (...so far)

RES-NOVA 170 kg $PbWO_4$
RES-NOVA[1] 2.4 t - metallic Pb
RES-NOVA[2] 31 t - metallic Pb
RES-NOVA[3] 465 t - metallic Pb

- Detection (type II error)

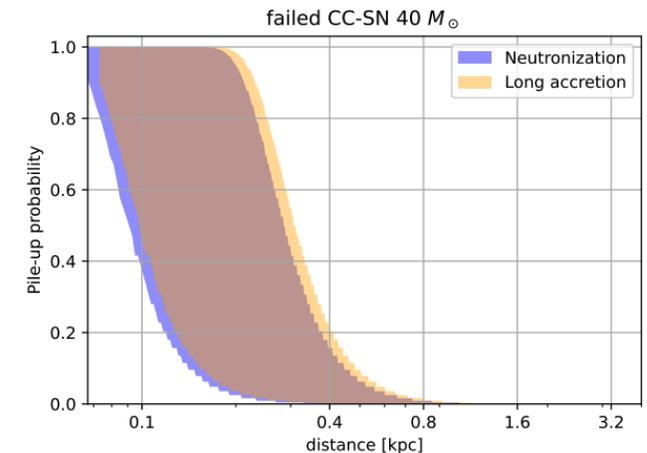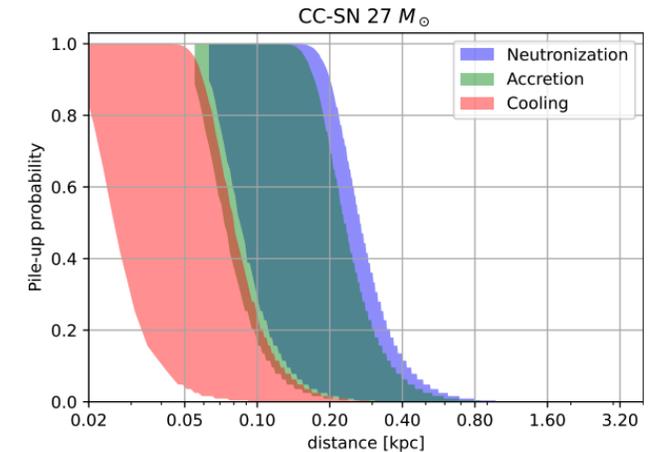- We need input from other searches (occurrence time and d)

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Technology

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CC-SN 27 $M_\odot$

failed CC-SN 40 $M_\odot$

(b)

16
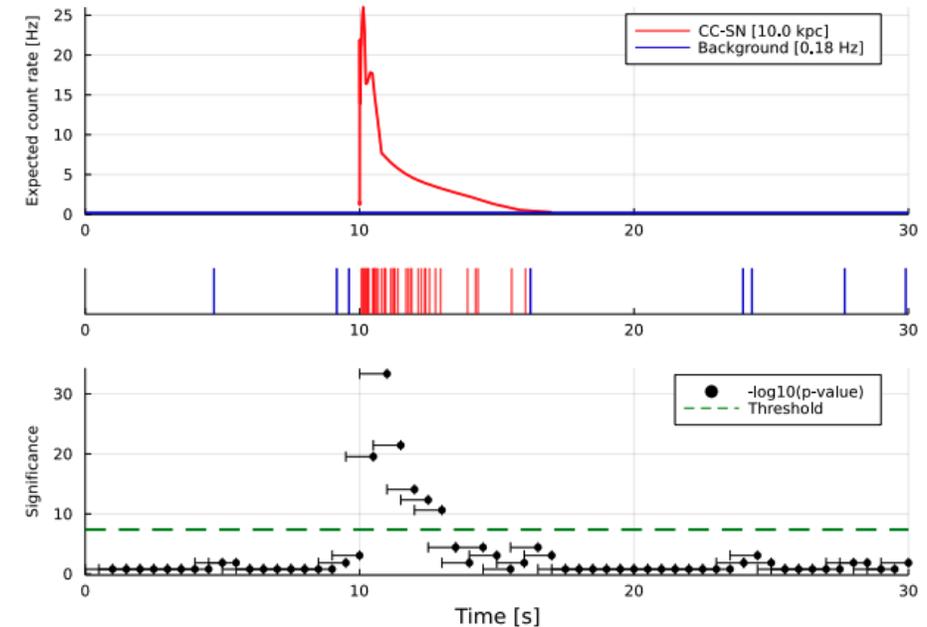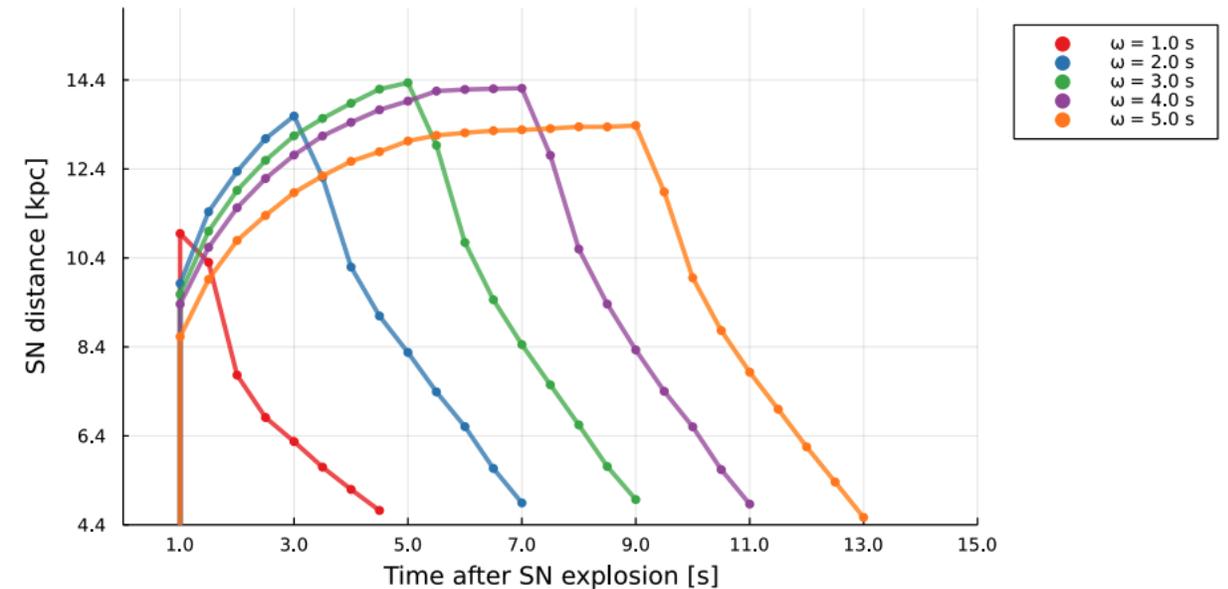
Sensitivity studies (...so far)

- Live detection (type I error)
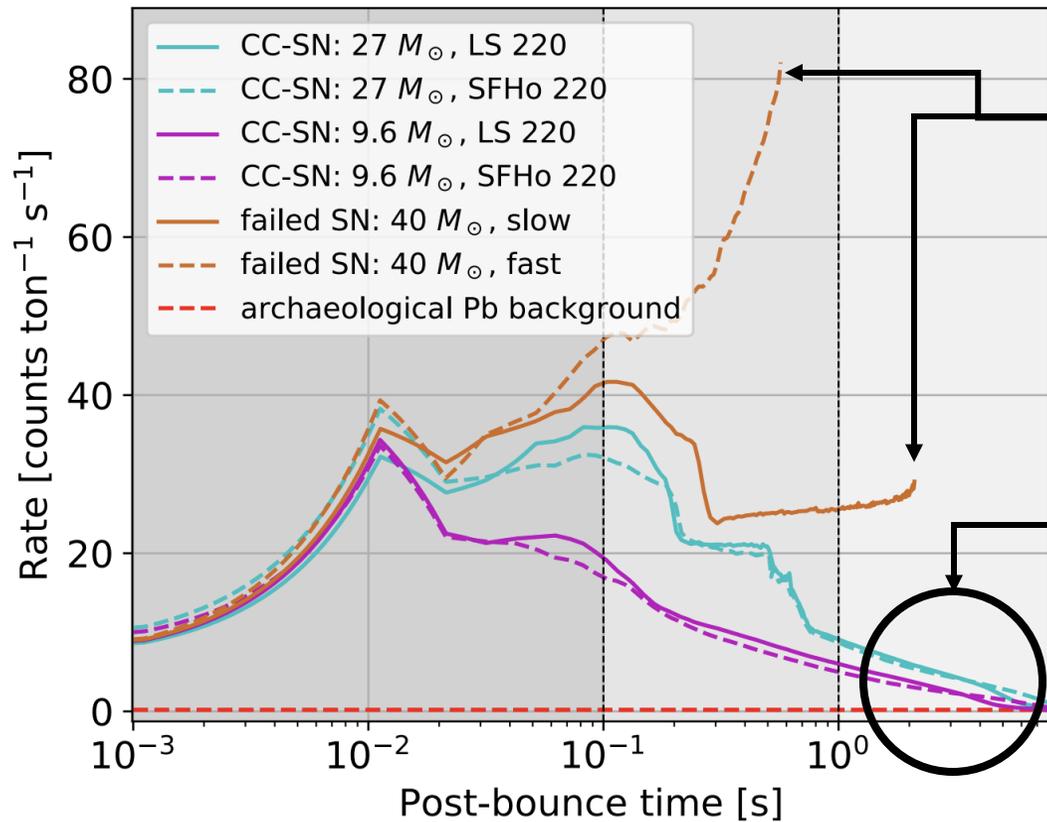
- No external inputs

- Compliant with SNEWS

(1 false/15 days)

Sensitivity studies (...so far)

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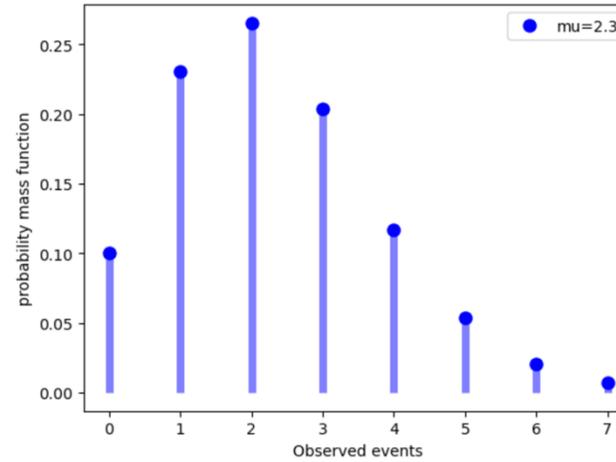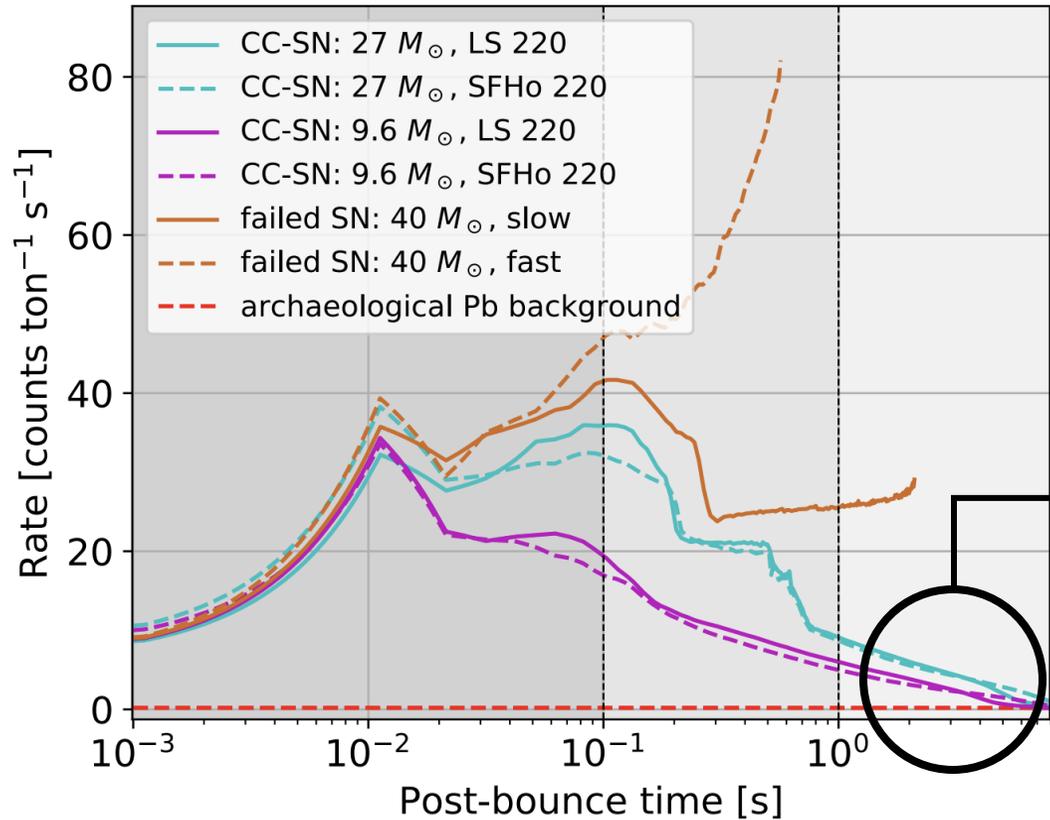
The light curve brings information!

A sudden halt of the neutrino emission indicates a black hole formation

L. Pattavina et al., *JCAP* 10 (2021) 064

The cooling of the neutron star may be a gate to BSM physics

G. G. Raffelt, Phys. Rep. 198, 1 (1990)

The light curve brings information!

We look for t such that 90% of times we see at least 1 event past t
-> we'll do better than that!

RES-NOVA[1] 2.4 t -> 3.26 s
RES-NOVA[2] 31 t -> 6.5 s
RES-NOVA[3] 465 t -> 9.19 s

Conclusions

- The high sensitivity of cryogenic detectors opens the possibility to detect SN neutrinos with "miniaturized" detectors

- Archaeo-Pb is a great candidate to detect SN neutrinos via CEνNS

- We have the skills and equipment to set-up and run the experiment

- We need your help to maximize our scientific potential!

$\Rightarrow$ https://res-nova.unimib.it (Our website, we keep it up-to-date)