Snowmass 2021 - Letter of Interest

Astrophysical neutrino source investigation with RES-NOVA

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The RES-NOVA project 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 ultra-high radiopurity of archaeological Pb enable the operation of a high statistics experiment equally sensitive to all neutrino flavors with reduced detector dimensions in comparison to existing neutrino observatories and easy scalability to larger detector volumes. The first phase of the RES-NOVA project is planned to operate a detector with a volume of (60 cm)^3. It will be sensitive to SN bursts from the entire Milky Way Galaxy with 5σ sensitivity with already existing technology and will have excellent energy resolution with 1 keV energy threshold. Within our Galaxy, it will be possible to discriminate core-collapse SNe from black hole forming collapses with no ambiguity even with such small volume detector. 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 few %. The RES-NOVA project has the potential to lay down the foundations for a new generation of neutrino telescopes, while relying on a very simple and modular setup.

NF Topical Groups:

■ (NF4) Neutrinos from natural sources
■ (NF10) Neutrino detectors

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I. INTRODUCTION

A timely and high resolution detection of the neutrino signals produced by the next Galactic or extra-Galactic Supernova (SN) will provide the only empirical evidence of the dynamics and interaction processes intervening during a SN burst [1–4]. Thus, such a measurement will test our understanding of stellar core-collapse both on the conceptual level and for numerous quantitative aspects. Moreover, the information carried by neutrinos also allows to study possible extension of the Standard Model of Particle Physics [3, 5–11]. In fact, SNe are unique astrophysical laboratories where extreme conditions [3, 4], not reproducible on Earth (e.g. ultra-high density and high temperatures), are achieved.

The current technologies for SN neutrino detection exploit weak charge-current (CC) and neutral-current (NC) interactions with nuclei and electrons. The most significant interaction processes employed for their detection are inverse beta decay (IBD) and elastic scattering on electrons. Other channels are also used (e.g. CC with nuclei) but there is limited knowledge on the interaction cross-section. The IBD requires target material elements like organic scintillators or water, where a large number of free protons are available. This is the case of the KamLAND [12], Borexino [13] and LVD [14] experiments that are using large volume organic liquid scintillators and SuperKamiokande [15] which is using water Cherenkov detector. All these detectors have masses of $\mathcal{O}$(0.1-10 ktons).

II. THE NEED OF CEνNS FOR NEUTRINO ASTROPHYSICAL SOURCES

In this overall picture, our community is in need for a detection technique highly sensitive to all neutrino flavours [16, 17], which enables the study of neutrinos without uncertainty connected to flavour oscillations. In fact, current SN models do not take into account neutrino flavour oscillations in the stellar envelope due to the high complexity of the problem (e.g., non linear effects due to neutrino-neutrino interactions) and current numerical limitations. RES-NOVA [18] will be able to overcome these issues with its new experimental approach based on:

- Coherent elastic neutrino-nucleus scattering (CEνNS) will be adopted as detection channel [19], thanks to the high interaction cross-section: $\sim 10^3$ and $>10^4$ higher than IBD and all other conventional NC processes, respectively. Pb is the element with the highest CEνNS cross-section $\sim 10^{-38}$ cm^2, thus it is the best element to be used for this detection channel. This NC process allows for the detection of all neutrinos without uncertainties related to flavour oscillations, being equally sensitive to all flavours.

- Archaeological Pb cryogenic detectors: operation of cryogenic detectors made of archaeological Pb for an ultra-low background level in the region of interest, <1 background counts in the full-time window of the SN neutrino emission period is expected.

III. DETECTOR TECHNOLOGY

The RES-NOVA concept relies on state-of-the-art technology of solid-state cryogenic detectors, which has already proved its potential [20–23]. No specific R&D would be needed for the detector realization, other than a small scale demonstrator. The key features of the proposed new technology are:

- **Ultra-low background** - Operating an archaeological Pb-based detector is a major breakthrough in the field of astroparticle physics. Archaeological Pb features ultra-low intrinsic background levels, allowing for a highly sensitive SN neutrino detection. Archaeological Pb has an extremely low concentration of radioactive contamination, more than a factor 10^4 compared to commercial Pb [21]. RES-NOVA will run detectors made of this exclusive material.

- **Low threshold** - The SN neutrino signal is expected to be observed in the few keV region. RES-NOVA will operate an array of Pb-based cryogenic detectors with an energy threshold of 1 keV.

- **Small volume detectors** - The high interaction rate and the high density of Pb allow for a reduction of the overall experimental set-up. Running a cm-scale cryogenic detector, RES-NOVA can probe the Milky Way galaxy for SN events.

- **High detector granularity/scalability** - The high granularity enables RES-NOVA to stand possible high interaction rates induced by nearby SN events, with negligible effects on the dead-time or on the pile-up. Furthermore, the low temperature calorimetric technique offers the opportunity for an easy and fast detector scaling. The high density of Pb combined with the high interaction cross-section of CEνNS allows to reach out to the Andromeda Galaxy even with a small scale detector.

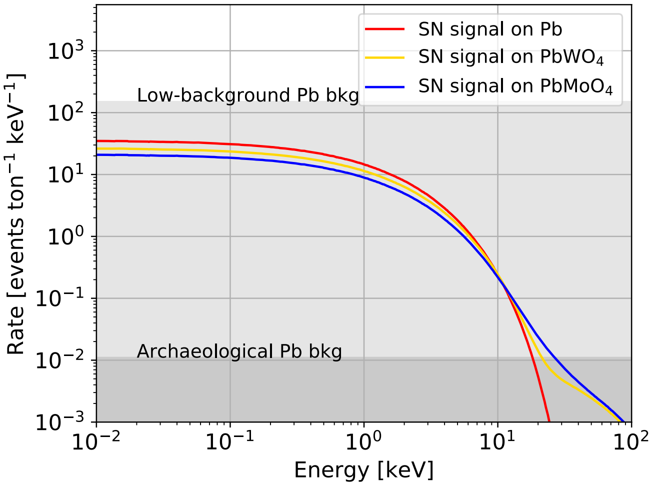

FIG. 1. Expected total number of SN neutrino events as a function of the recoil energy ($\mathrm{keV_{ee}} \simeq \mathrm{keV_{nr}}$) for a SN burst at 10 kpc in a detector made of Pb (in red), $PbWO_4$ (in yellow) and $PbMoO_4$ (in blue). The all-flavor and time-integrated neutrino signal for the 27 $M_\odot$ SN model has been adopted as input. The light and dark grey areas represent the expected background levels induced by low-background Pb [21] and by archaeological Pb [21], respectively. The background bands refer to electron and nuclear recoil interactions from ^{210}Pb, ^{238}U and ^{232}Th decay chains.

The sensitivity of an archaeological Pb-based cryogenic detector to SN neutrinos is shown in Fig. 1, where the detector energy response to a reference SN signal at 10 kpc is shown. The expected background induced by archaeological and commercial Pb are also shown.

IV. SUMMARY

In this letter we present the potential of an archaeological Pb-based cryogenic detector for the detection of neutrinos from astrophysical sources through CEνNS. The sensitivity achievable with the new proposed technology allows for the deployment of a small scale detector able to span the entire Milky Way Galaxy for high energy astrophysical events. Furthermore, the wealth of information provide by RES-NOVA will give a significant contribution to the SNEWS alert network [24].

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