Preliminary ALPs sensitivity projections for the RES-NOVA Observatory

N. Ferreiro Iachellini
nahuel.ferreiro@mib.infn.it
Università degli Studi di Milano-Bicocca & INFN-MiB

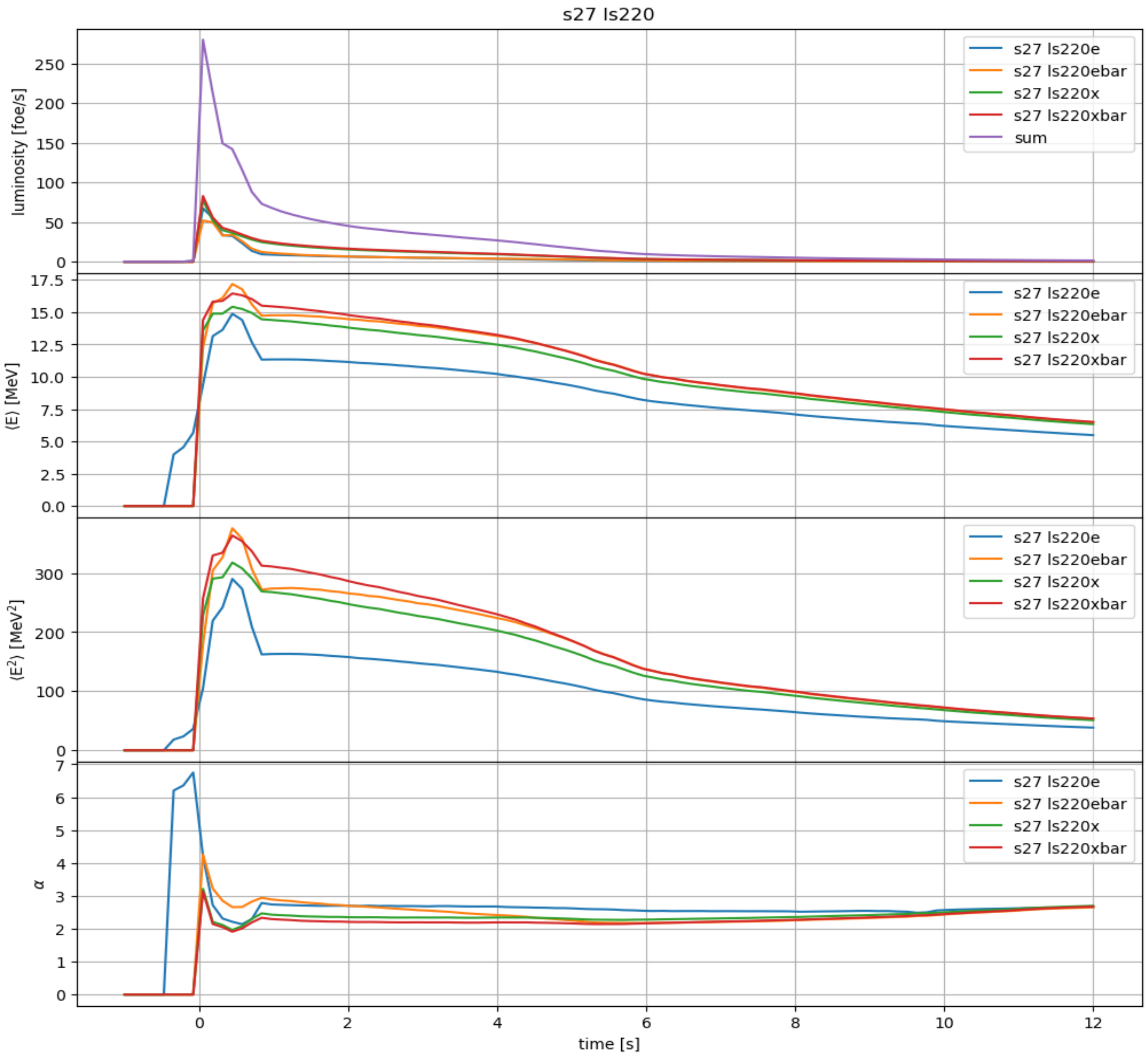
Javier De Miguel
javier.demiguel@iac.es
Istituto de Astrofisica de Canarias

RES-NOVA

From latin -> “New thing”

Latin -> more on that later

NOVA reminds to Supernovae



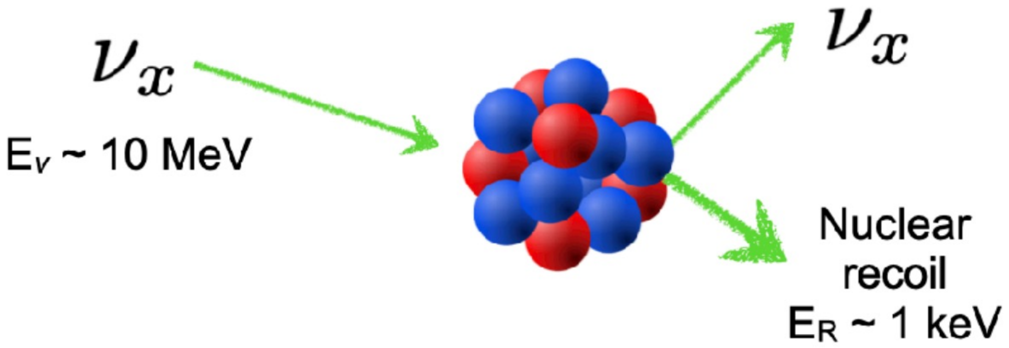
The neutrino source

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

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

Coherent Elastic ν Nucleus Scattering

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



> Equally sensitive to all ν-flavors

> High interaction cross-section

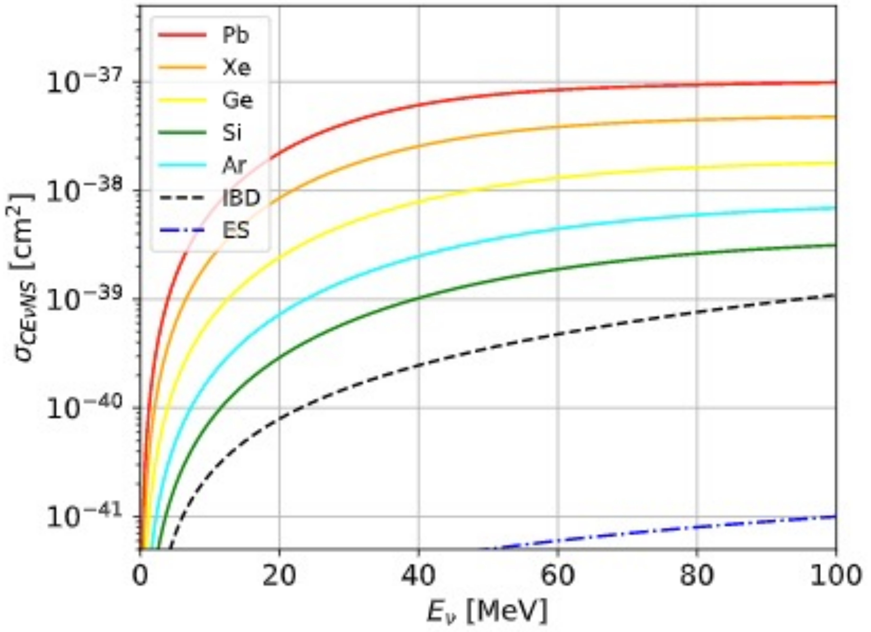


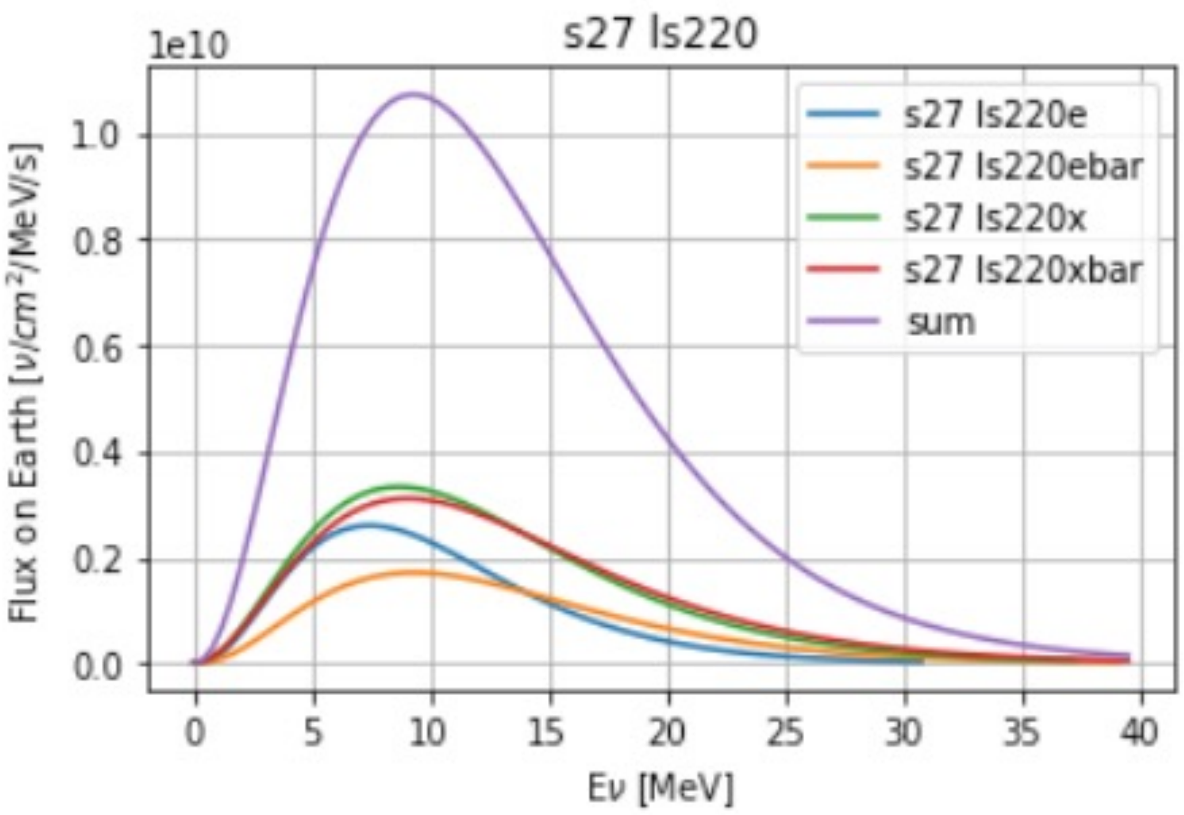
FIG. 2. Coherent elastic neutrino-nucleus scattering (CEνNS) cross sections as a function of the energy of the incoming neutrino for different target nuclei. The dashed lines show the inverse-beta decay (IBD) and neutrino elastic scattering on electrons (ES) cross-sections for comparison. Given the high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

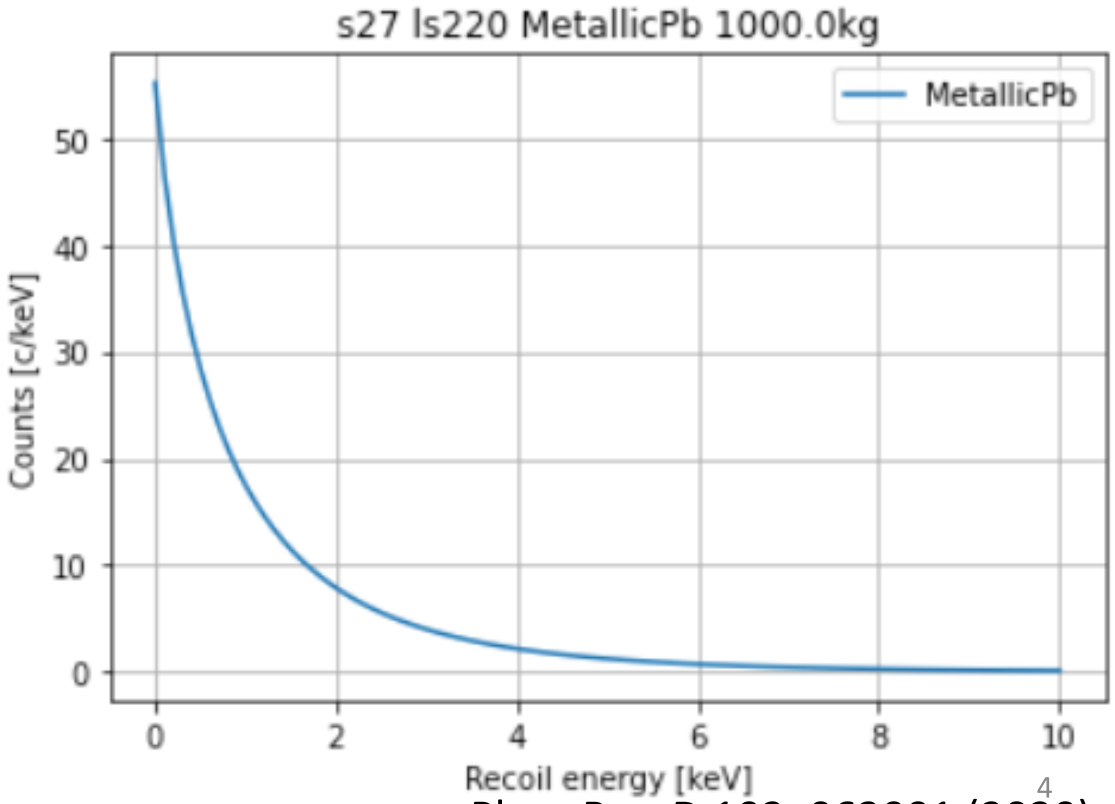
Phys. Rev. D 102, 063001 (2020)

SN CEνNS in Pb Target (on Earth)

The emitted neutrino spectrum is (almost) Maxwell-Boltzmann

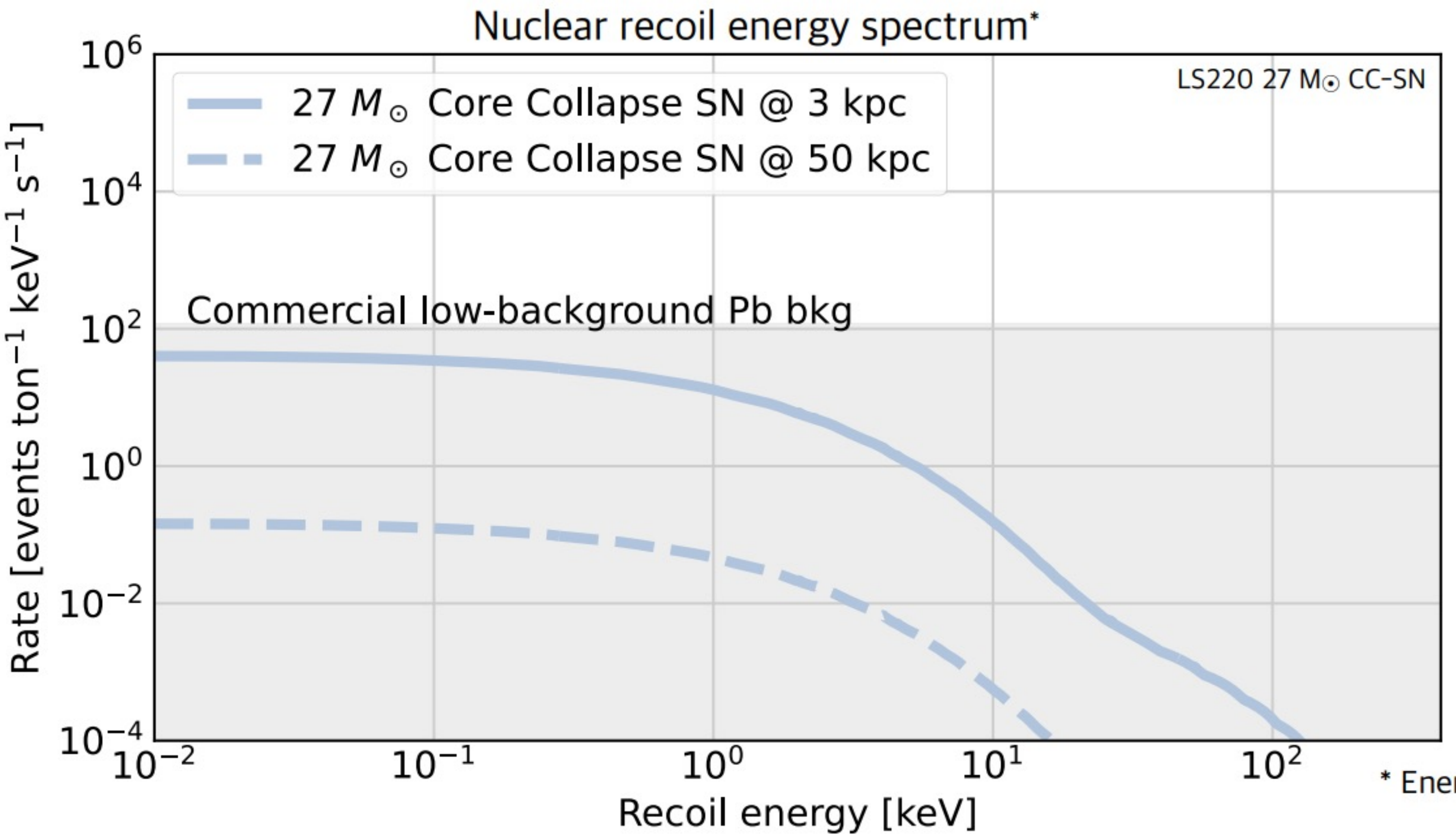
Observed nuclear recoil spectrum





Phys. Rev. D 102, 063001 (2020)

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!

* Energy resolution 0.2 keV

L. Pattavina et al., *Phys. Rev. D* 102, 063001 (2020)

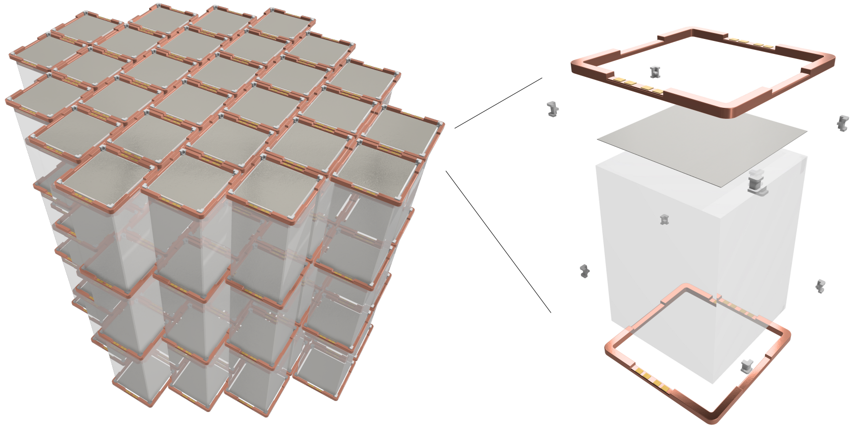
13

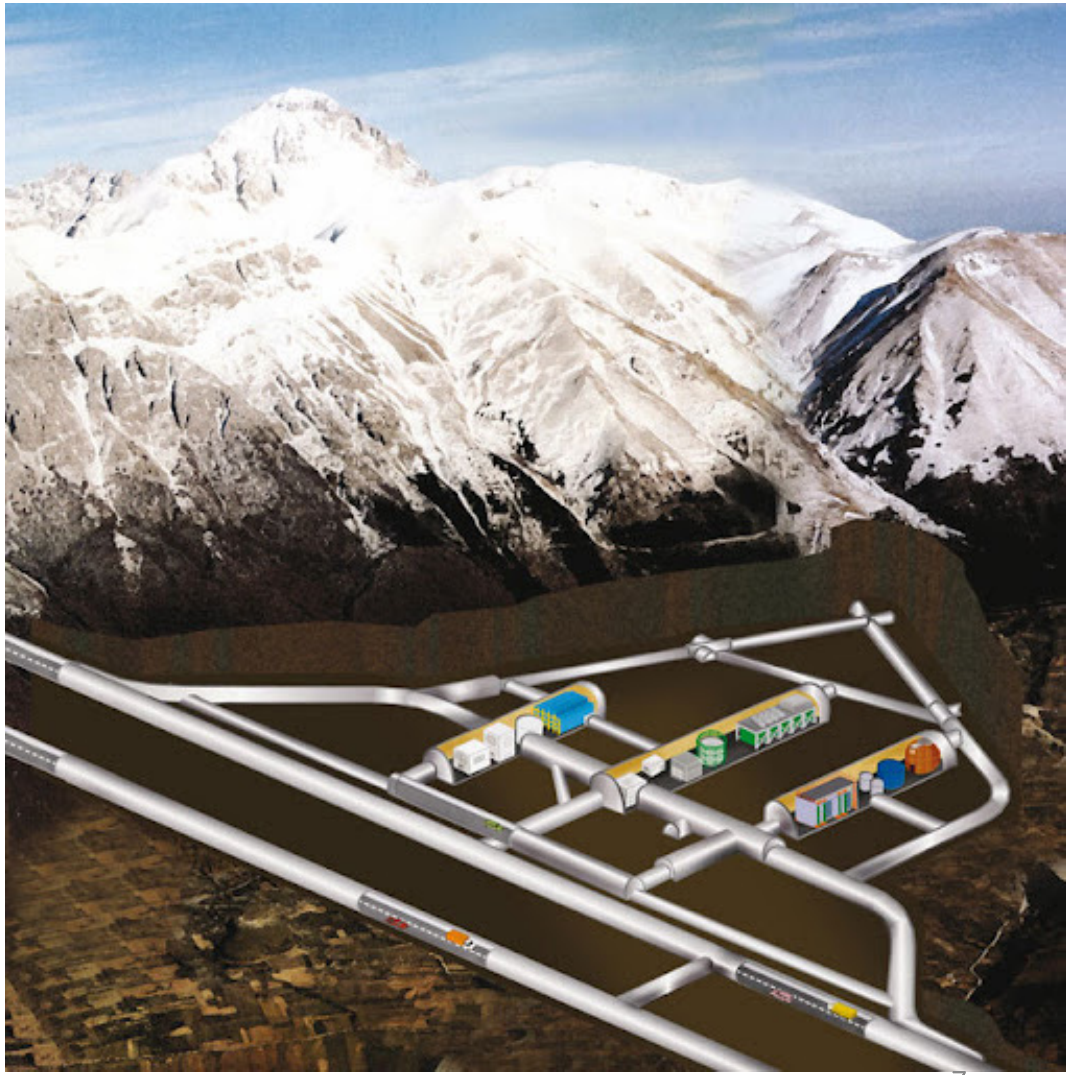
Scuba diving meets exploding stars

Nuclide	Low background Pb (Boliden®) [1]	Archaeological Pb [2, 3]
^{232}Th	<46 μBq/kg	<45 μBq/kg
^{238}U	<31 μBq/kg	<46 μBq/kg
^{210}Pb	(2.3±0.4) · 10^7 μBq/kg	<715 μBq/kg

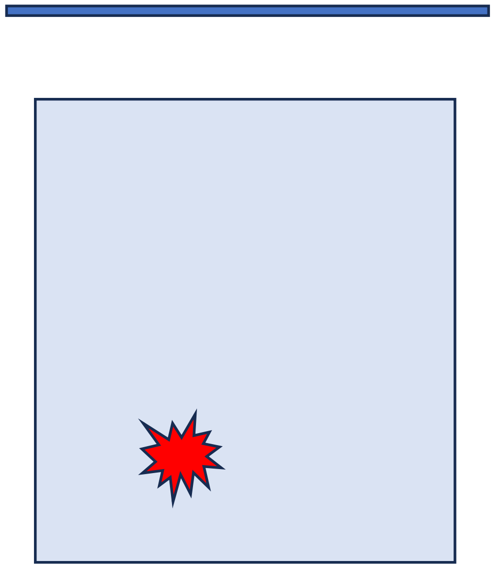
[1] G. Heusser, Ann. Rev. Nucl. Part. Sci. 45 (1995) 543-590.
[2] L. Pattavina et al., Eur. Phys. J. A (2019) 55: 127.
[3] CUORE Coll., Eur. Phys. J. C (2017) 77: 543.

The RES-NOVA detector

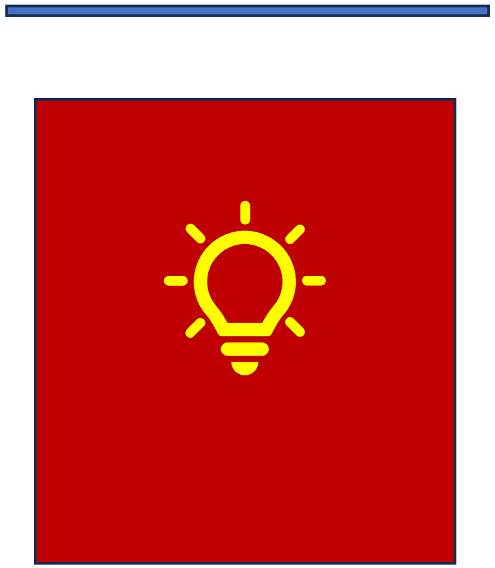




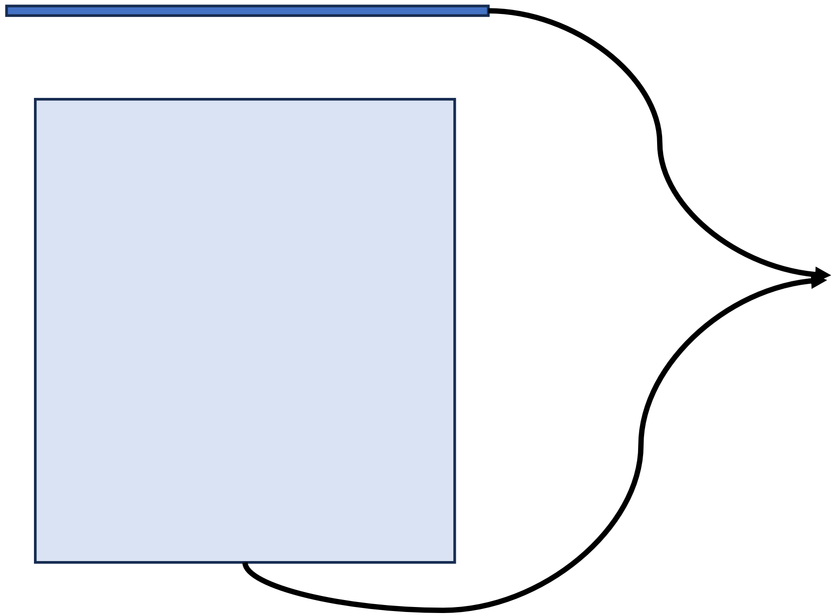
The RES-NOVA detector

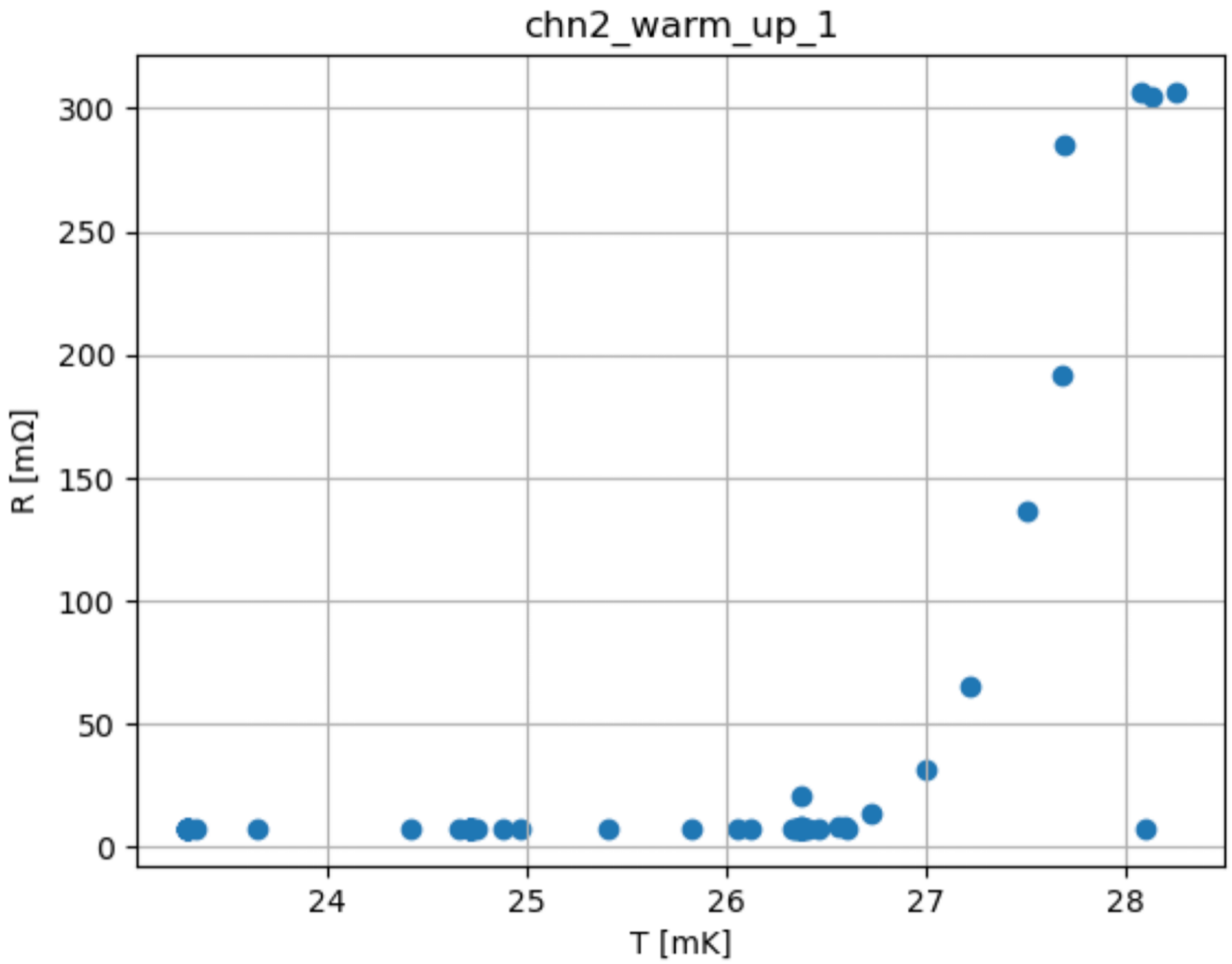


The RES-NOVA detector

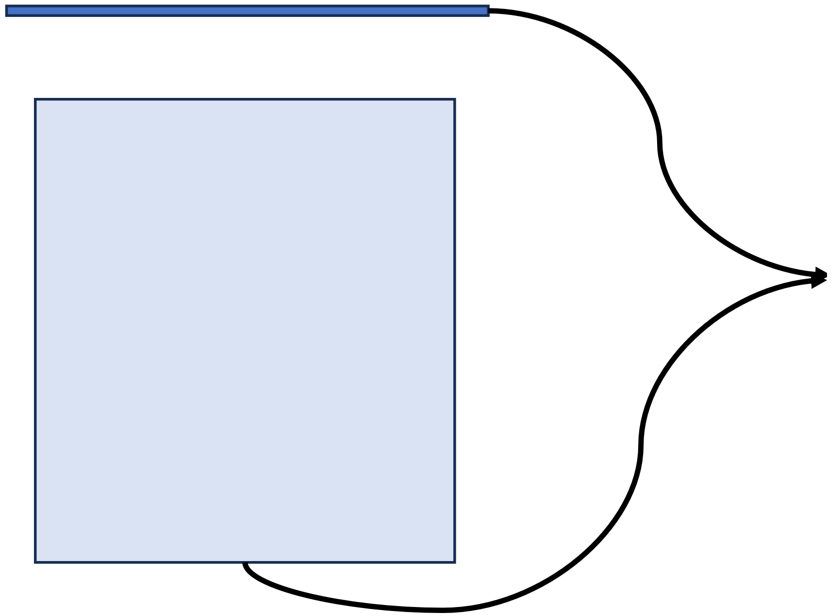


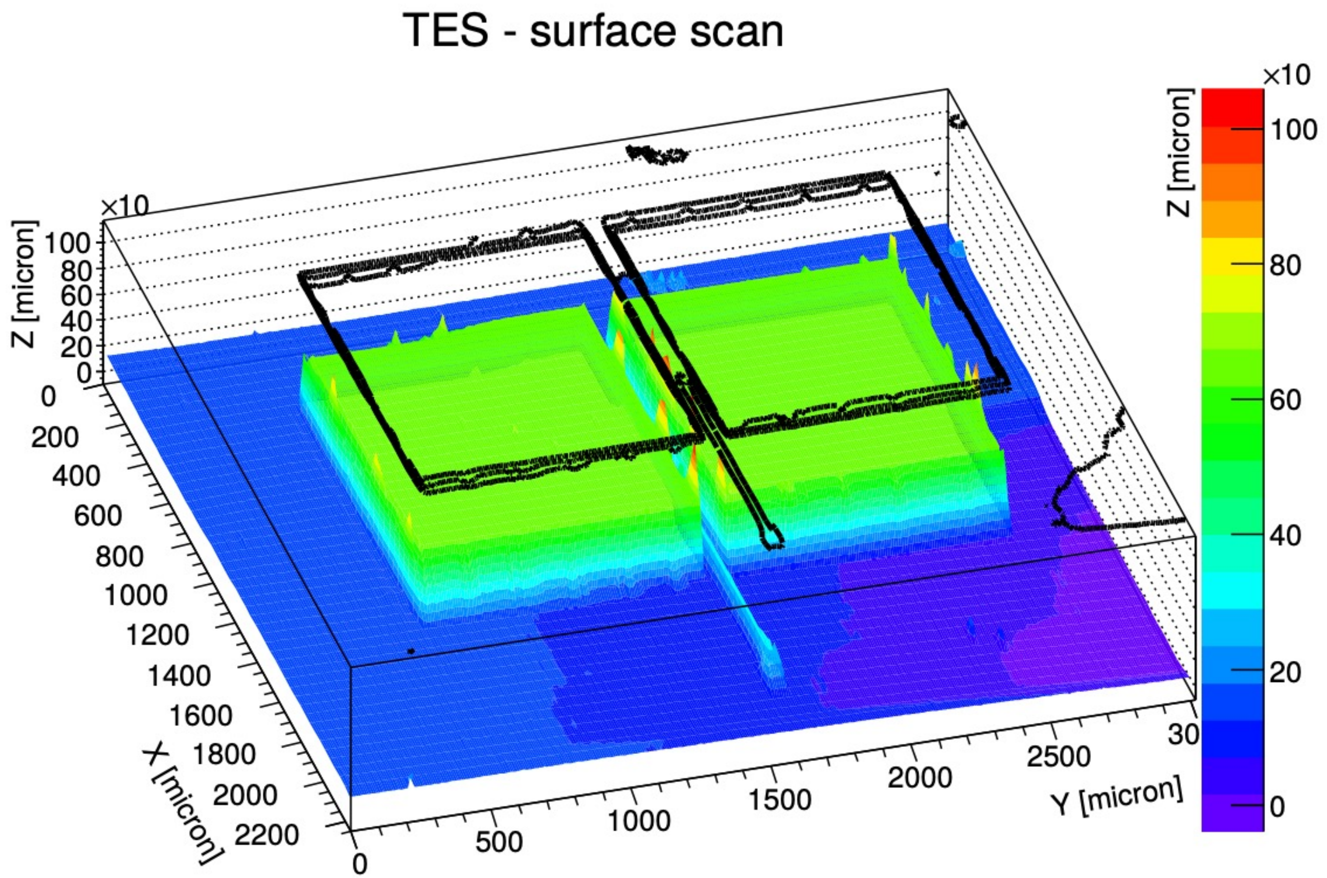
The RES-NOVA detector



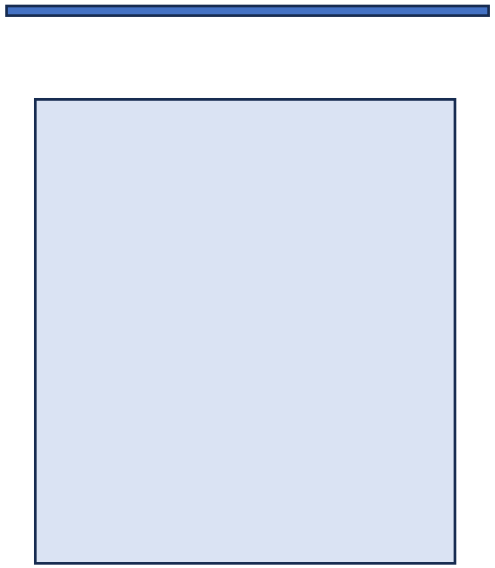


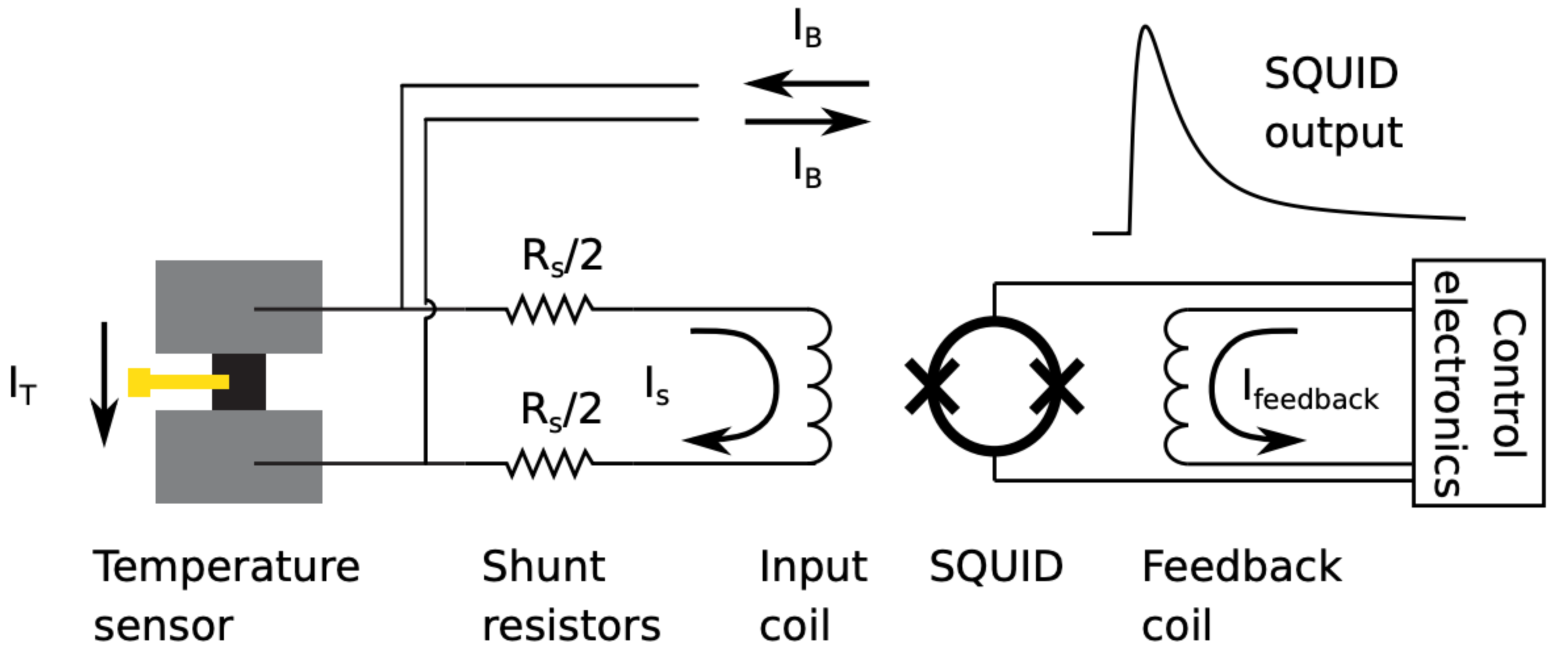
The RES-NOVA detector



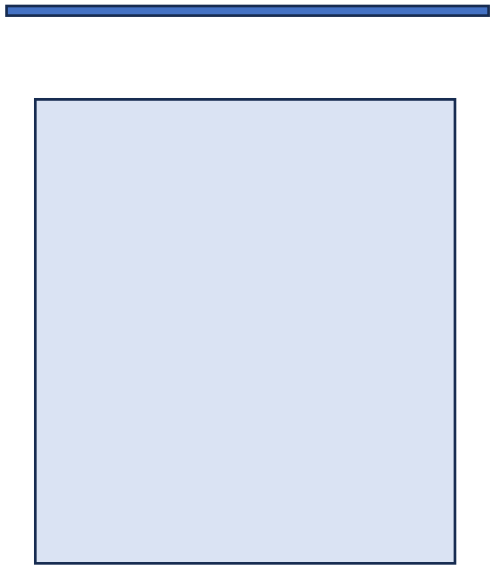


The RES-NOVA detector

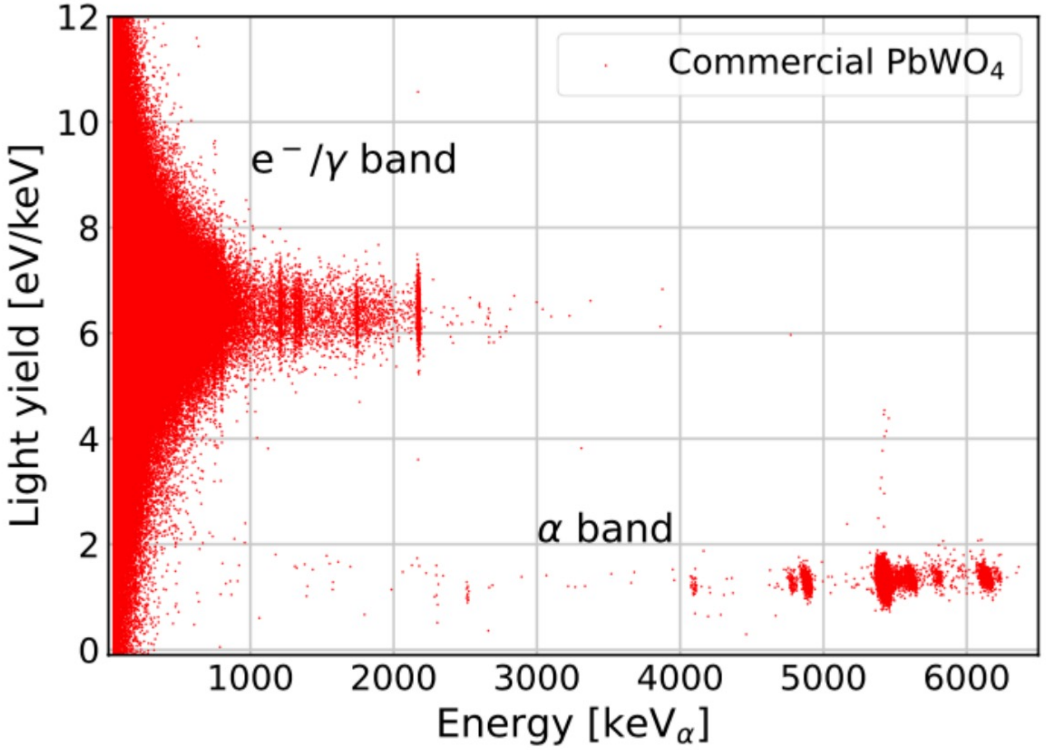




The RES-NOVA detector

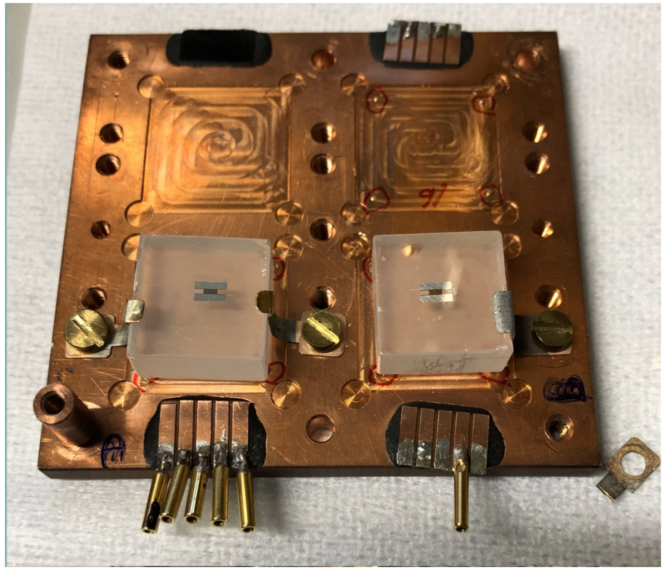


Detector energy spectrum of a cryo-$PbWO_4$

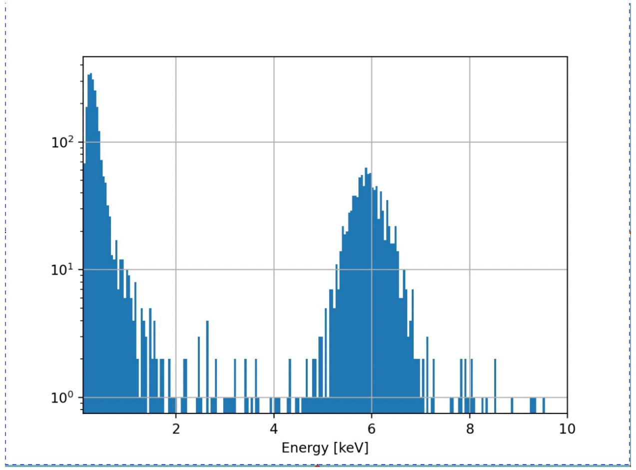


J.W. Beeman, **LP** et al., Eur. Phys. J. A 49, 50 (2013)

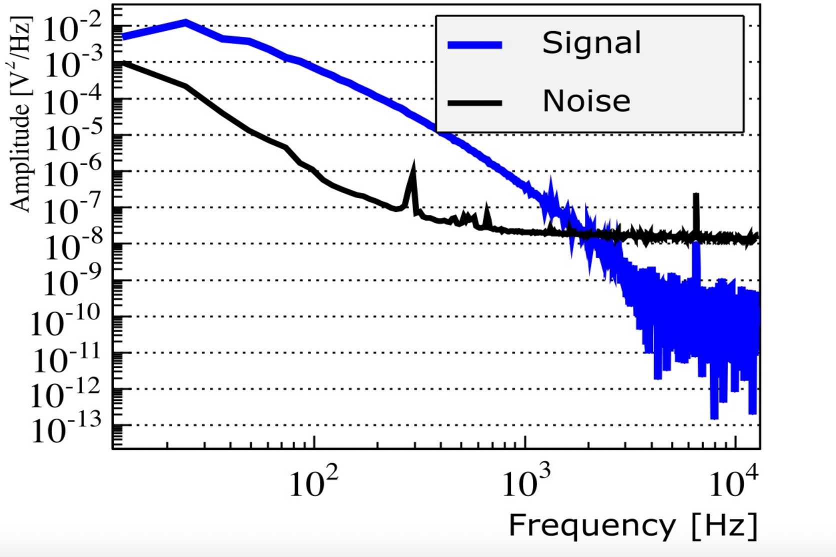
The RES-NOVA detector



- Successfully operated 16g of $^{arch}PbWO_4$
- 60eV 1sigma resolution
- 300 eV energy threshold



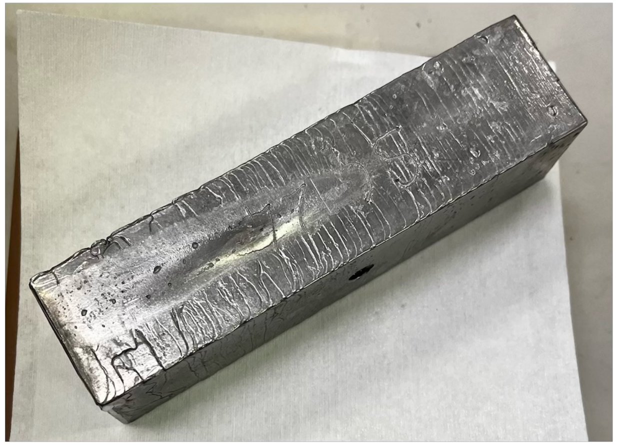
N. Ferreiro Iachellini et al., J. Low Temp. Phys. 11, 184 (2022)



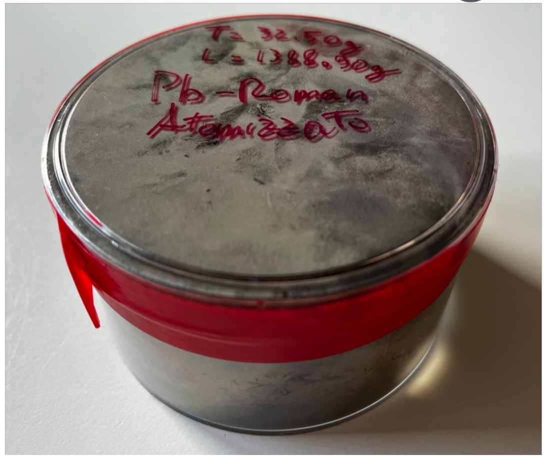
Archeo-Pb how to

Archaeo-Pb @ LNGS

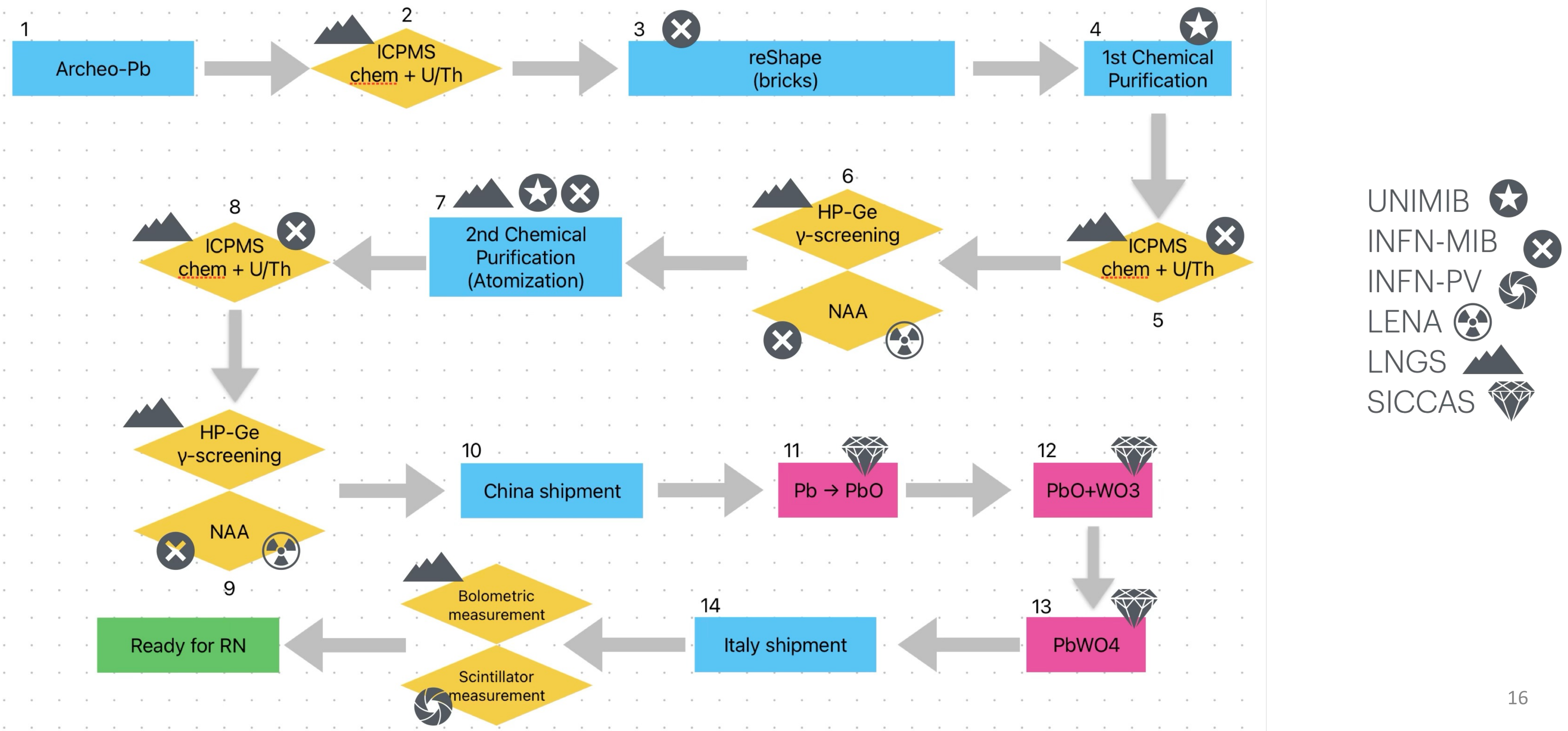
Archaeo-Pb purified @ MIB



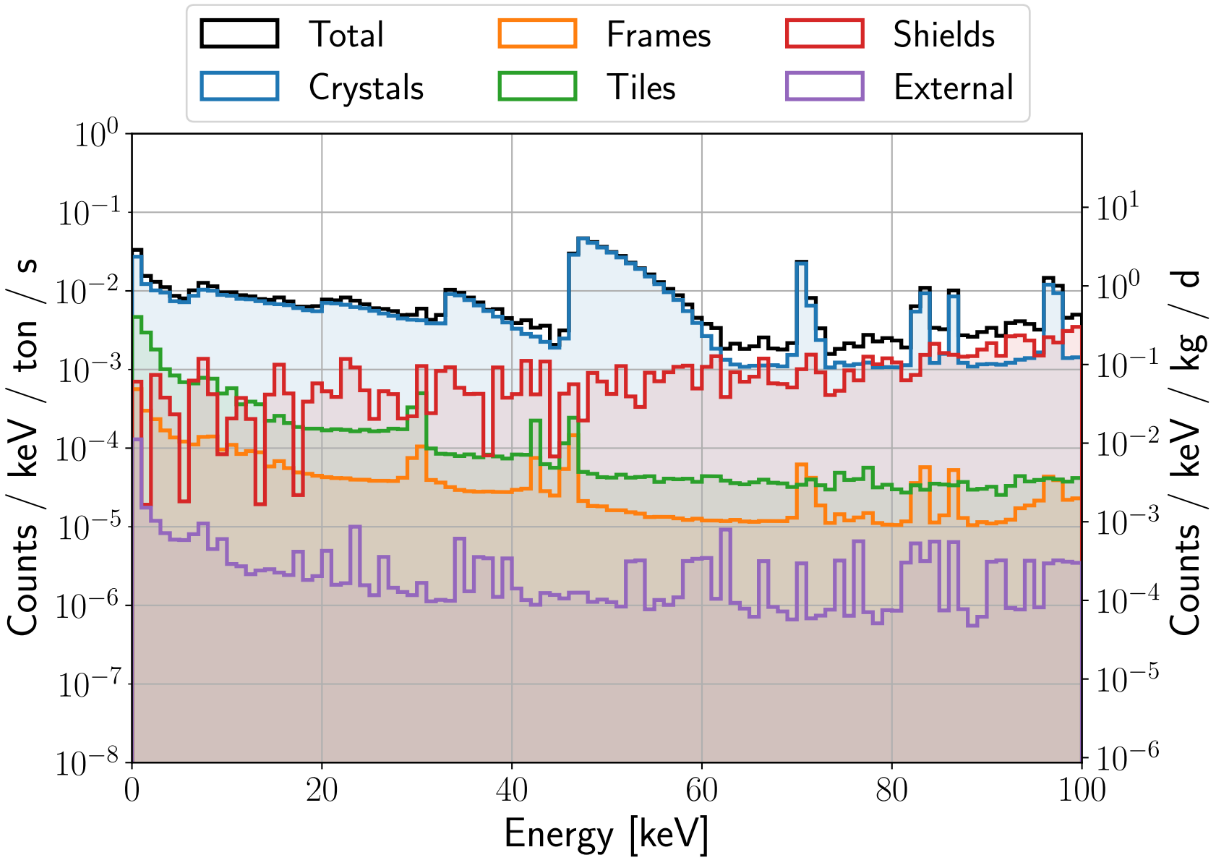
Archaeo-Pb atomized @ 3D-Lab

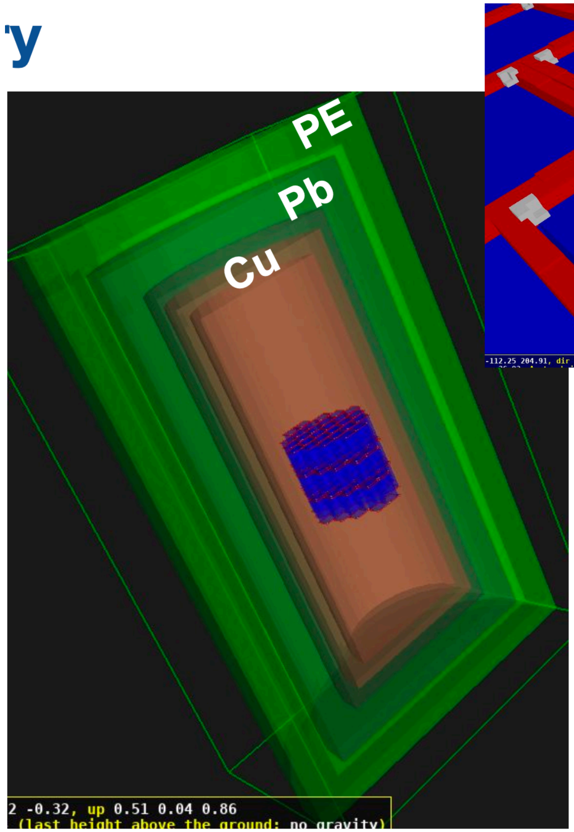


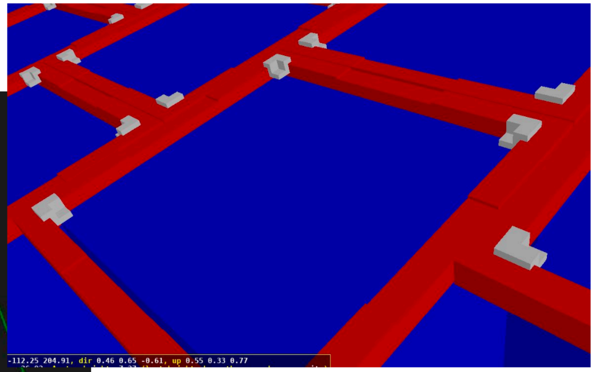
Archeo-Pb how to

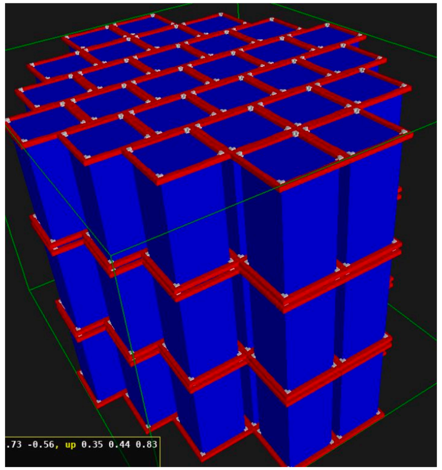


Our background model - complete

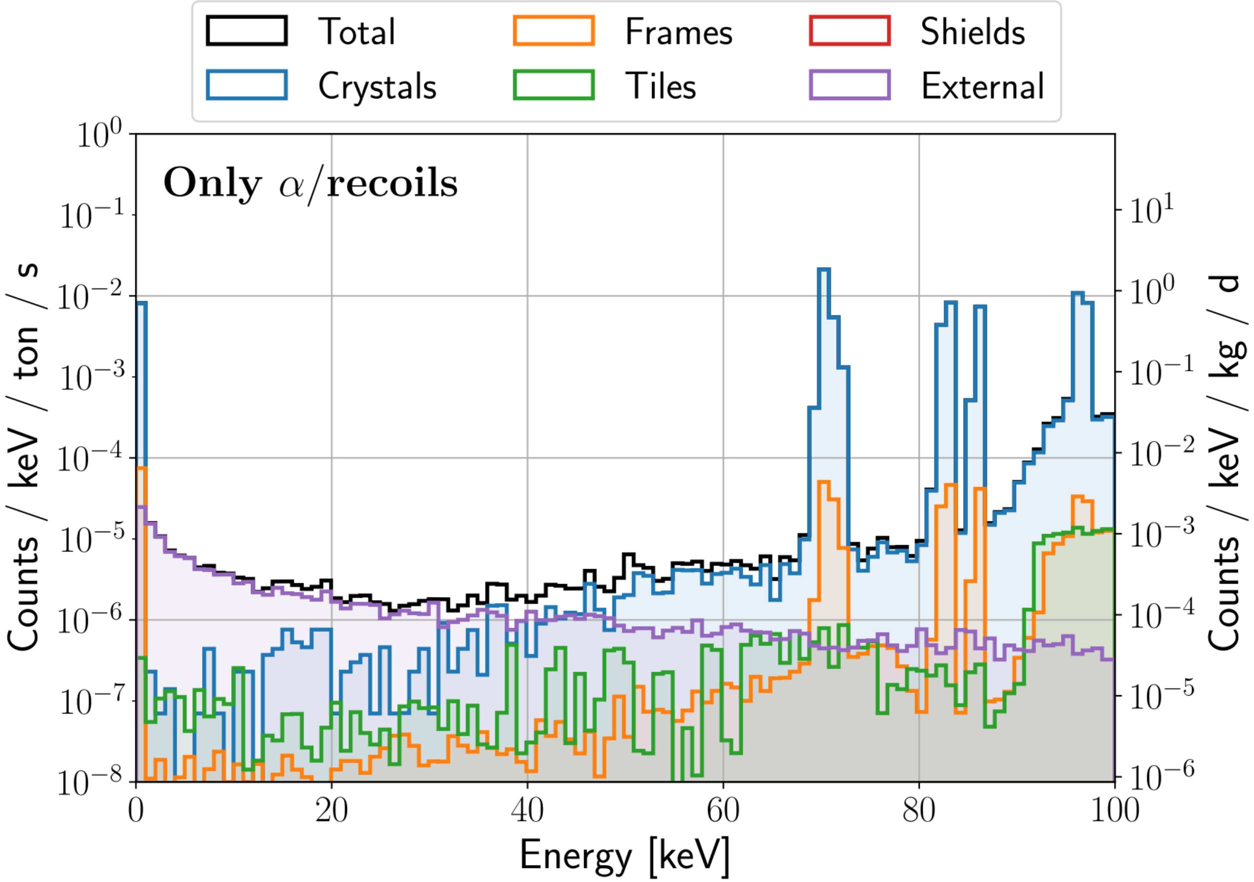


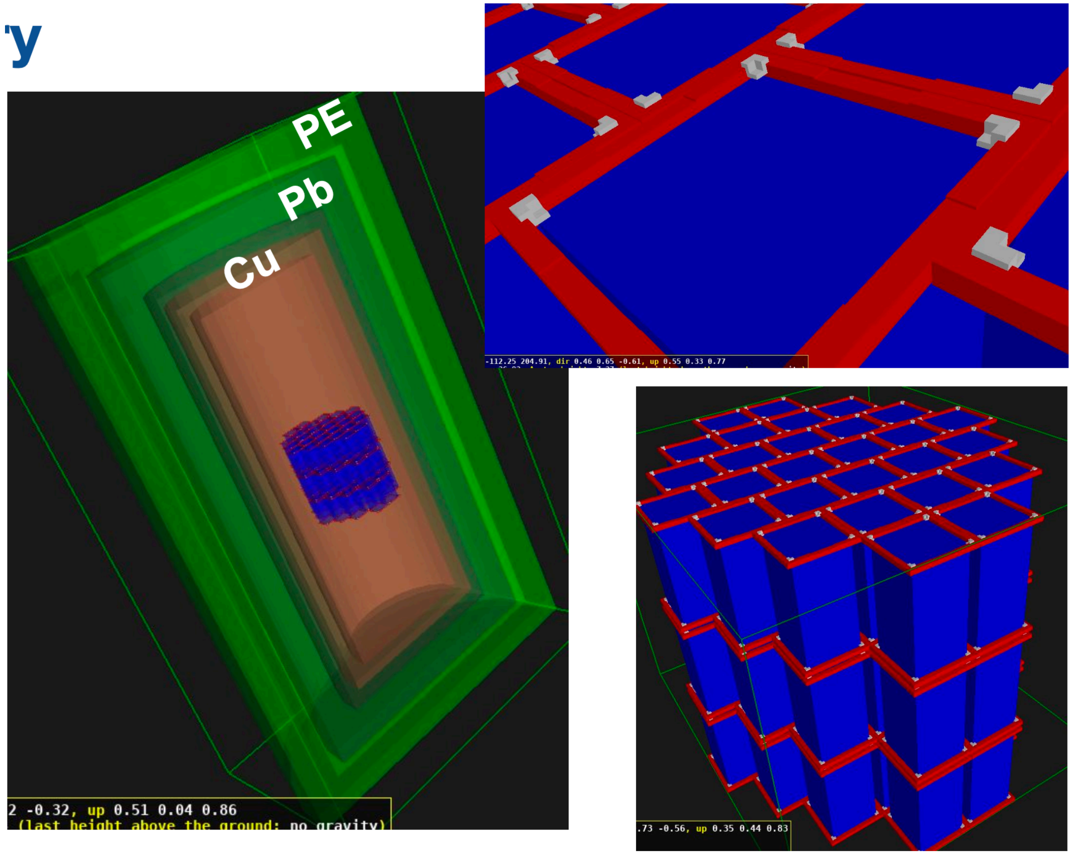






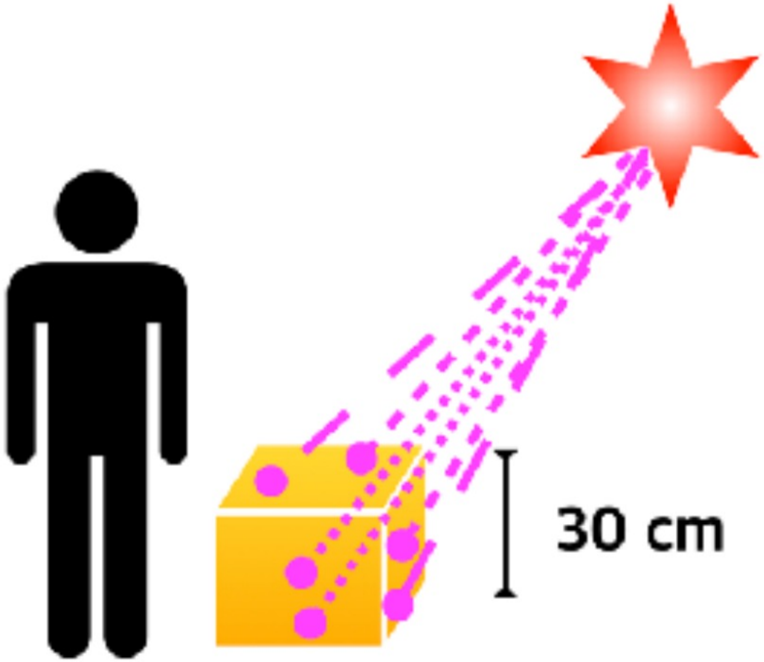
Our background model – nuclear recoils

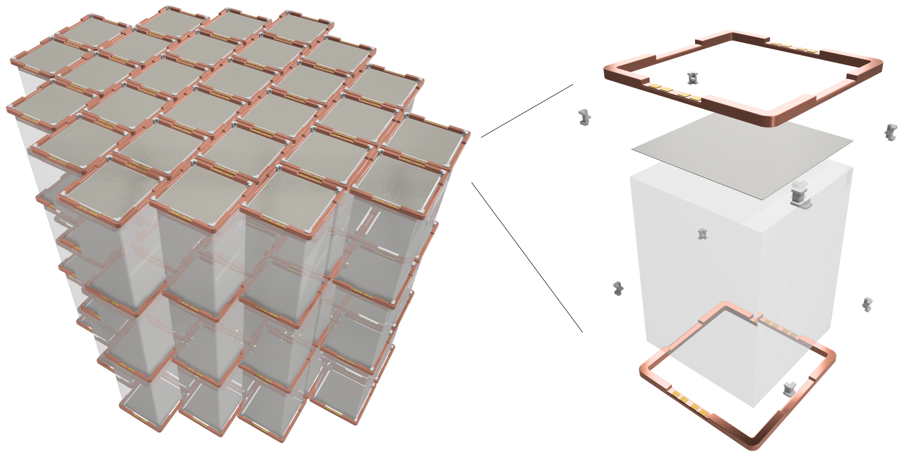




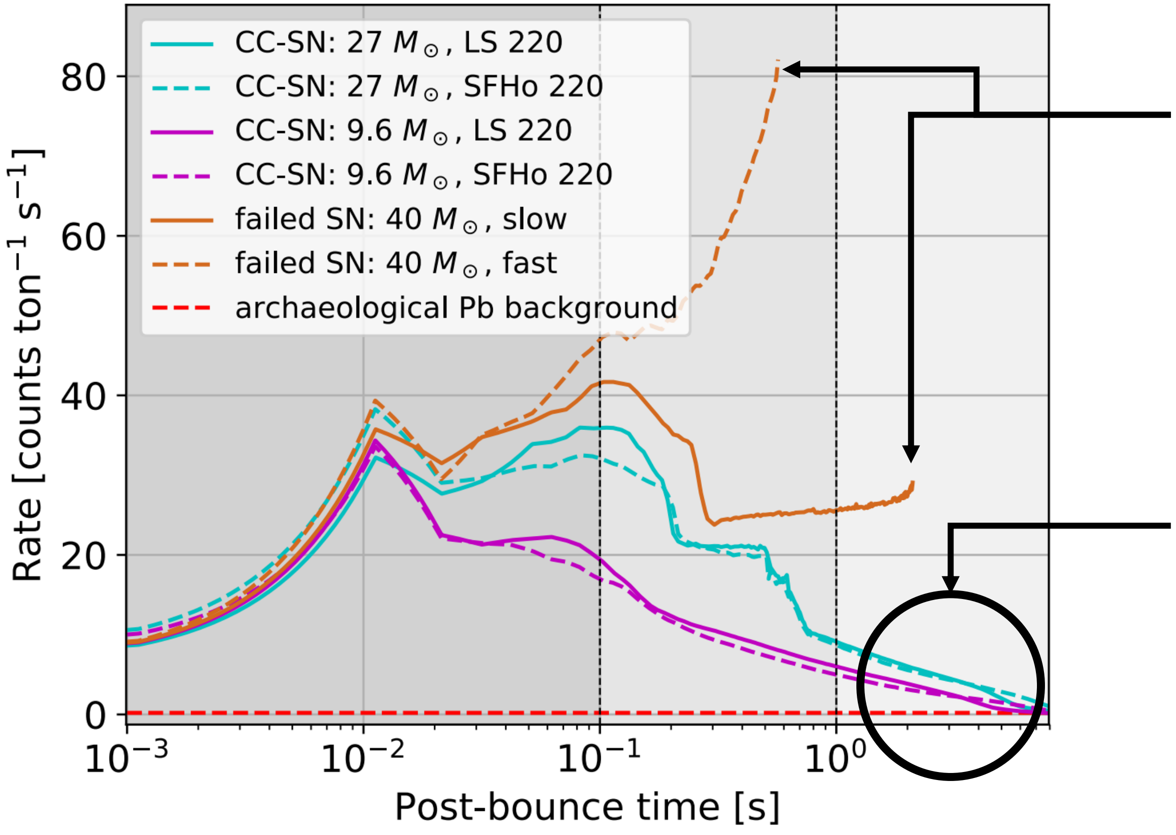
The RES-NOVA detector

- Array of $PbWO_4$ crystals operated as (scintillating) cryogenic detectors ($8.28\ g \cdot cm^{-3}$)
- 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 (1sigma resolution: 200 eV)
- TESs have already demonstrated the capability of sub-keV nuclear recoil energy threshold





The light curve brings information!



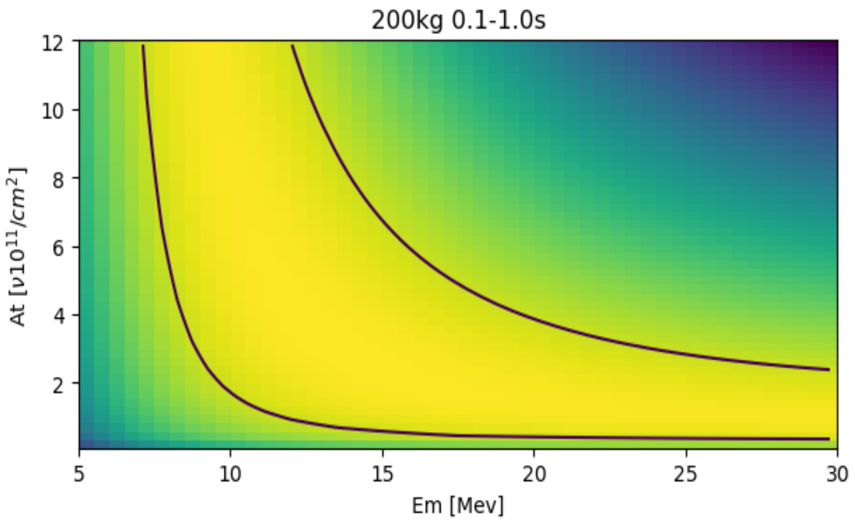
A sudden halt of the neutrino emission indicates a black hole formation

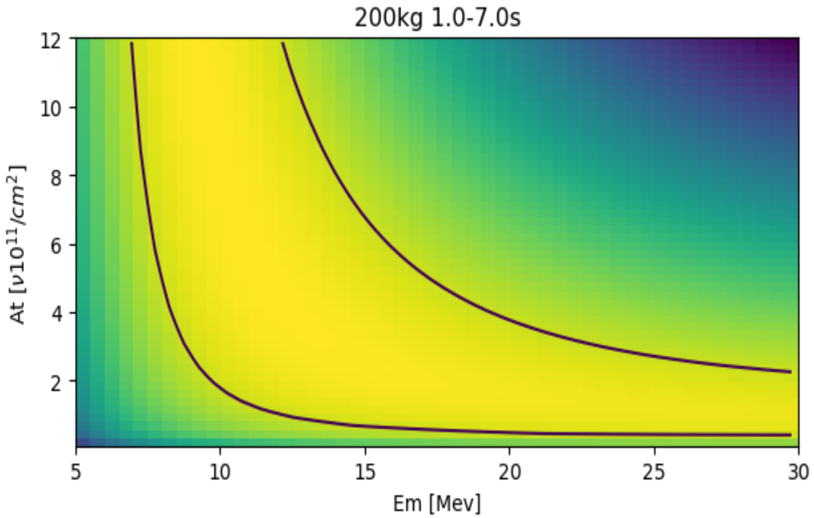
L. Pattavina et al., *JCAP* 10 (2021) 064

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

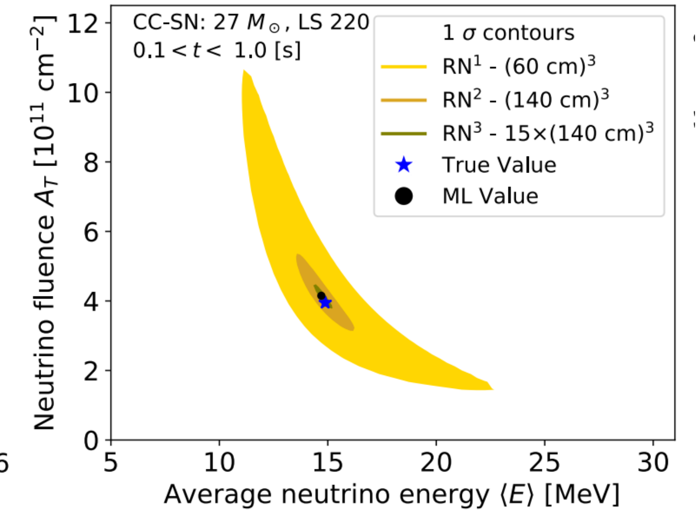
G. G. Raffelt, Phys. Rep. 198, 1 (1990)

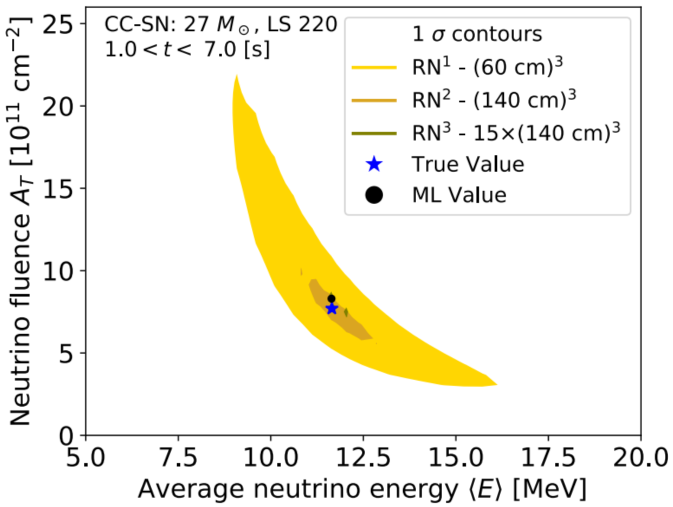
Constraining SN parameters





~200kg coming in the next 2-4 years



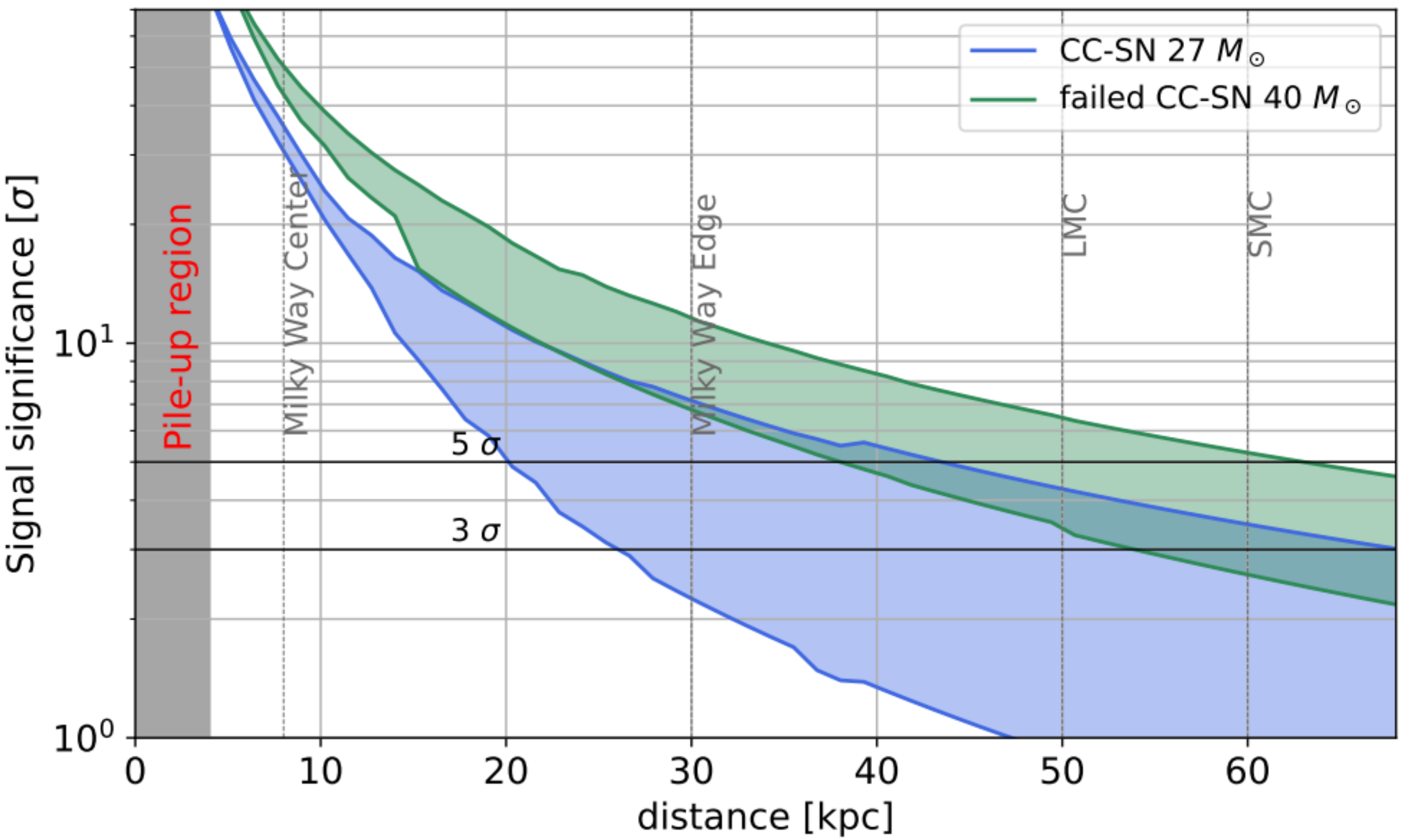


RN^1 2.4t

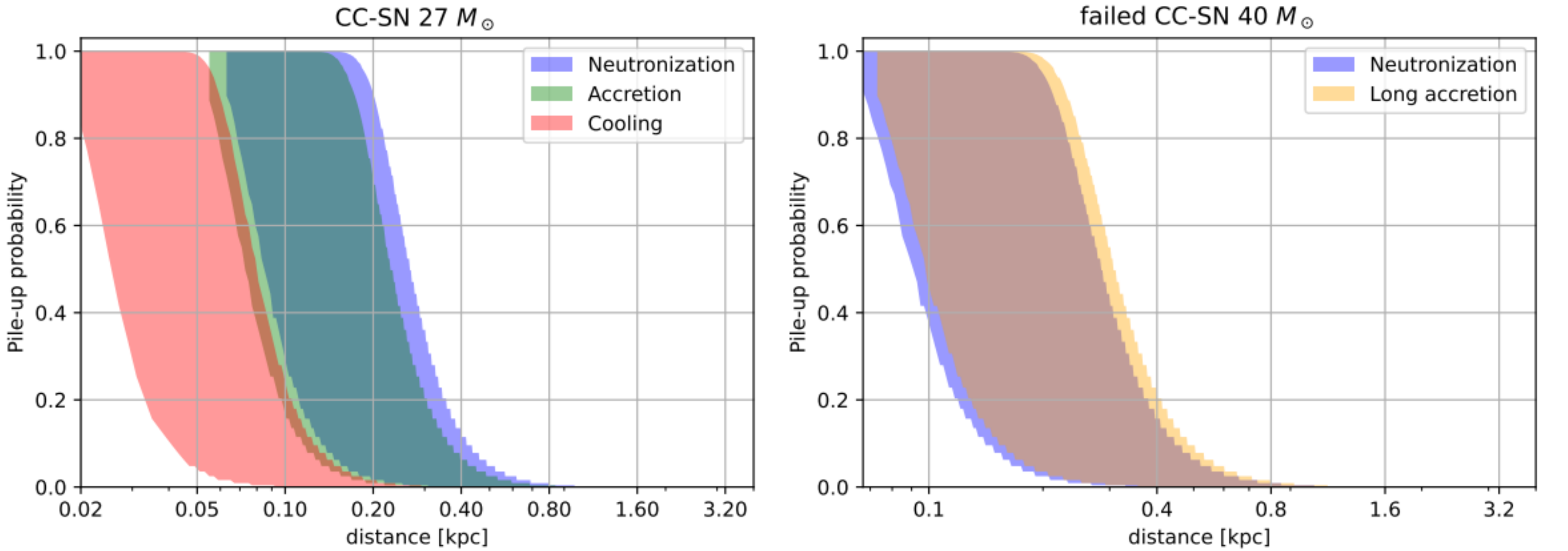
RN^2 31t

RN^3 465t

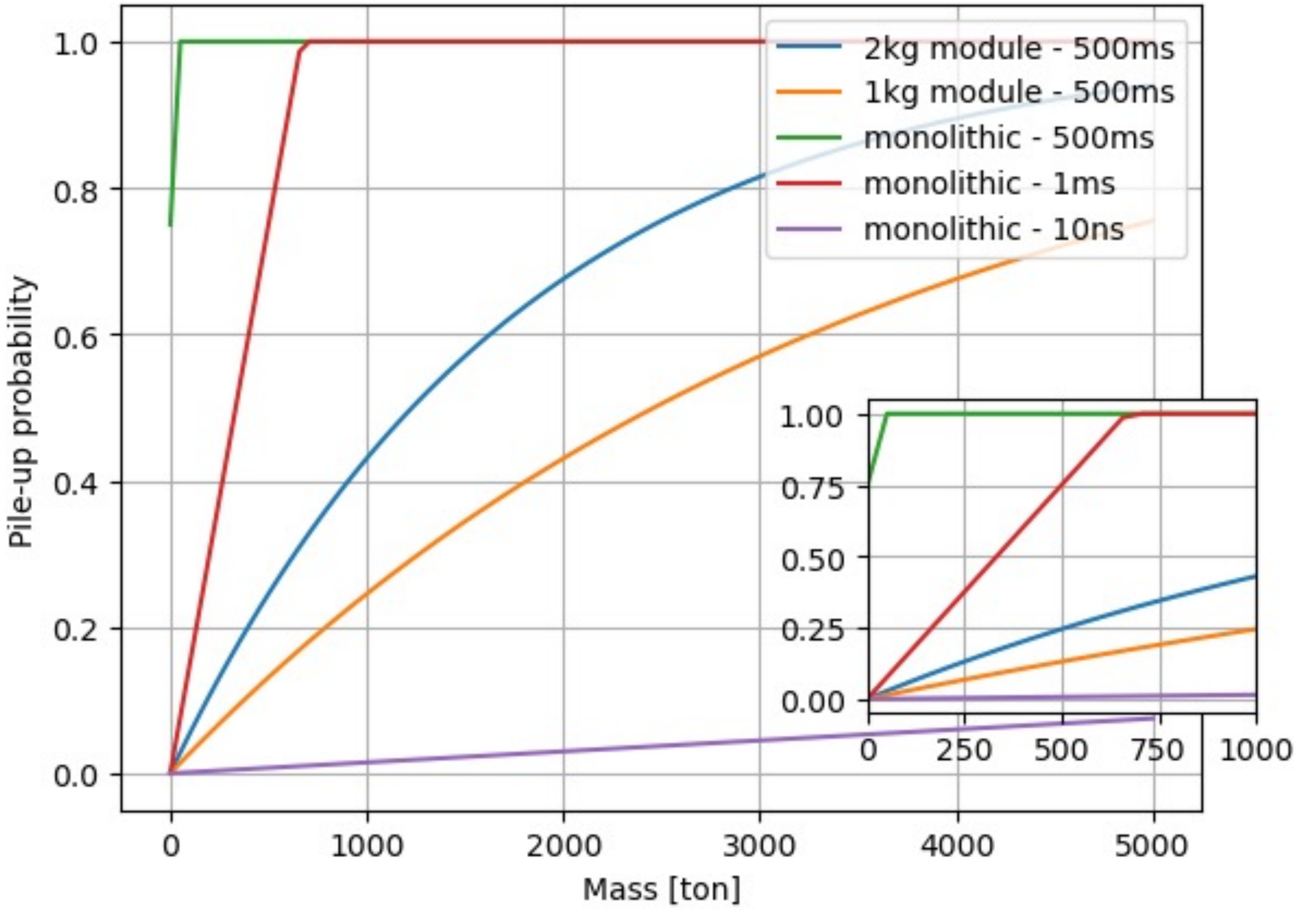
Exploring beyond the Milky way with 1.7 ton



Withstanding high rates



Withstanding high rates



Am I cheating?

A close look at an SN event

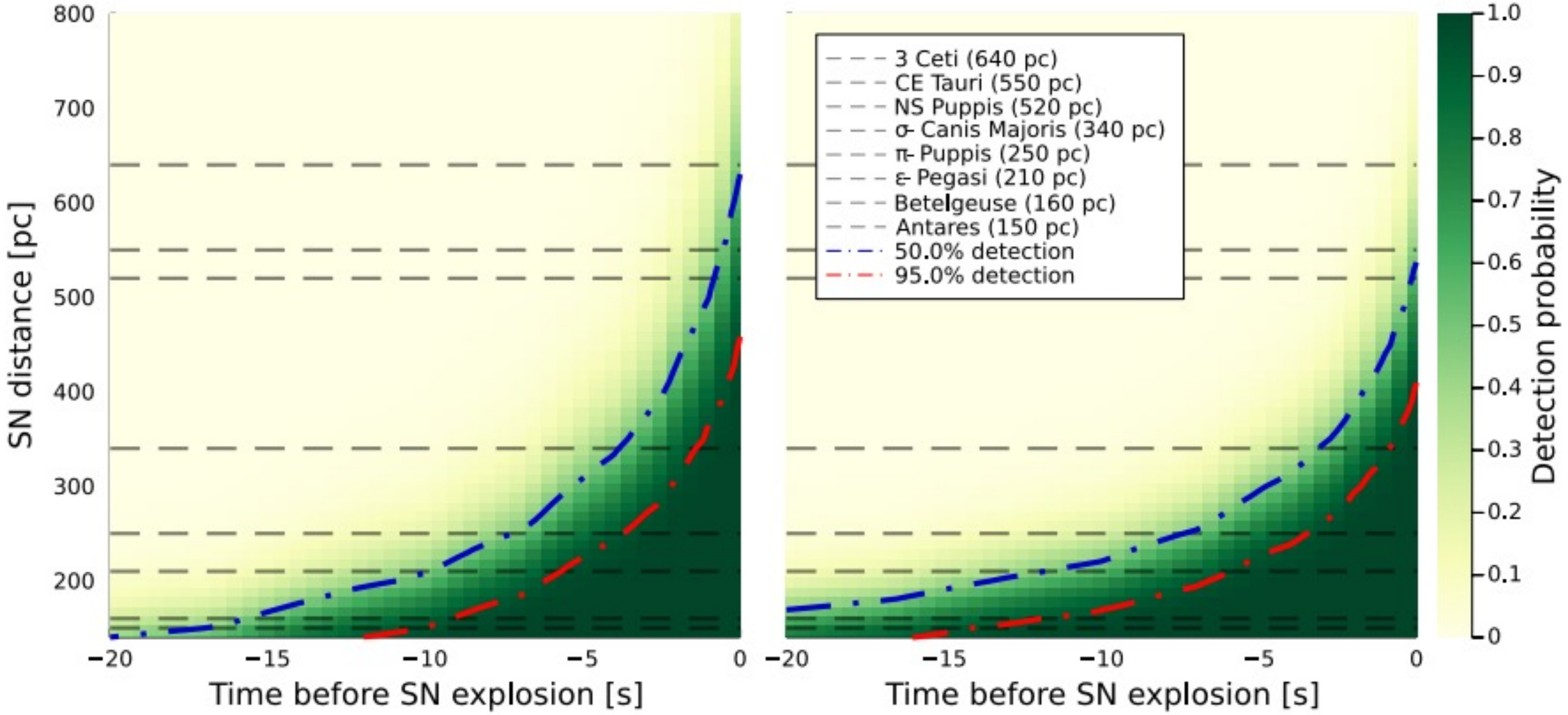


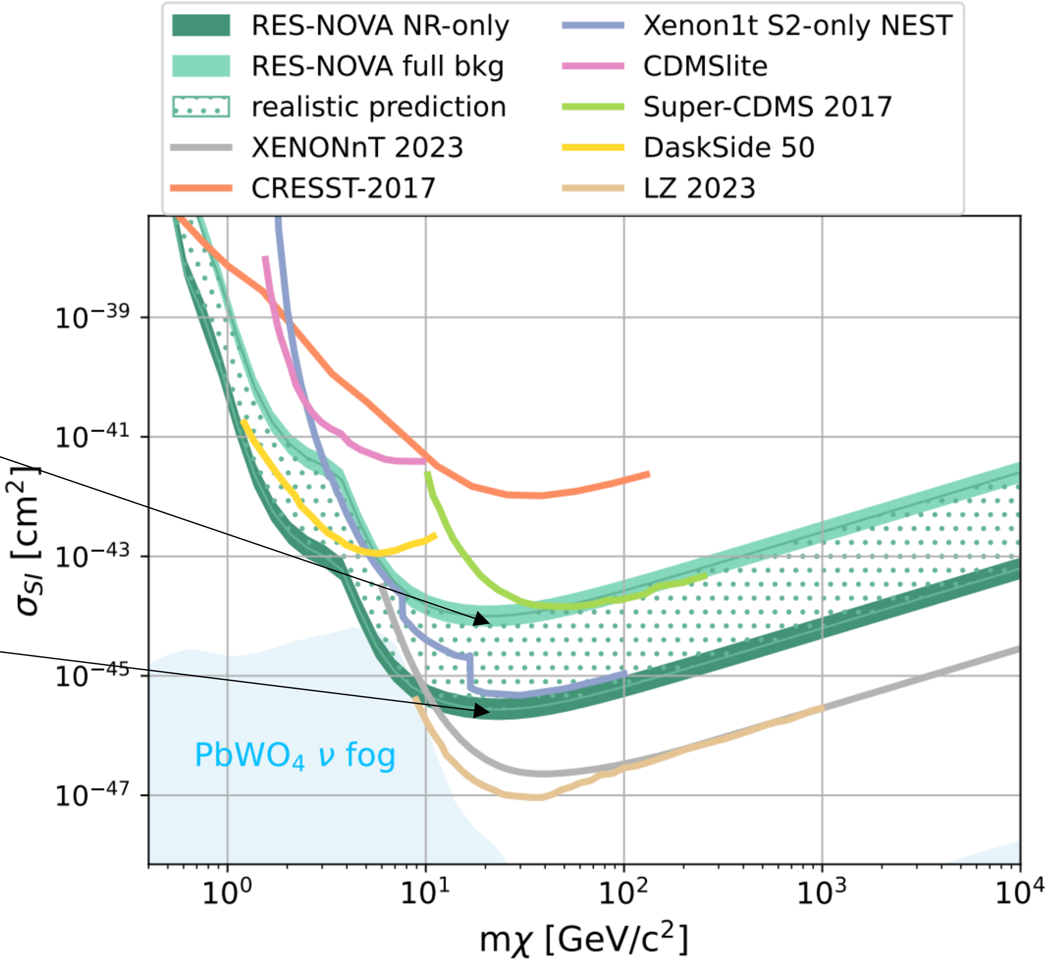
Figure 10. Success rate of neutrinos detection prior to a SN explosion for three different window sizes: 15 s (left); 70 s (right).

https://doi.org/10.1088/1475-7516/2022/10/024

Sensitivity WIMPS – spin independent

No bck rejection

Full e/gamma
bck rejection



RES-NOVA Coll., Phys. Rev. D 111, 103050 (2025)

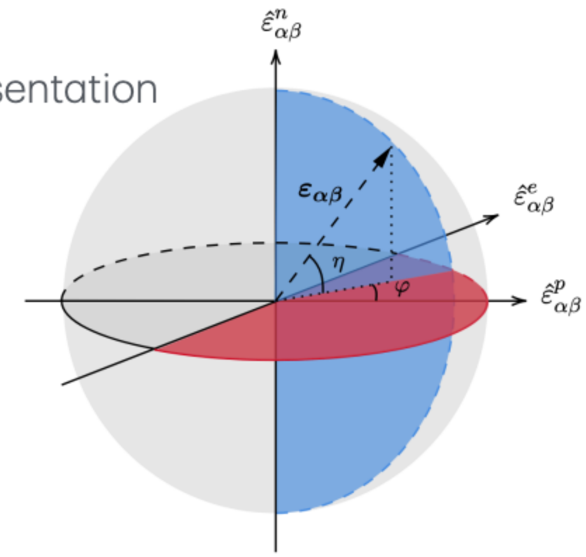
Sensitivity to Non Standard Neutrino Interactions

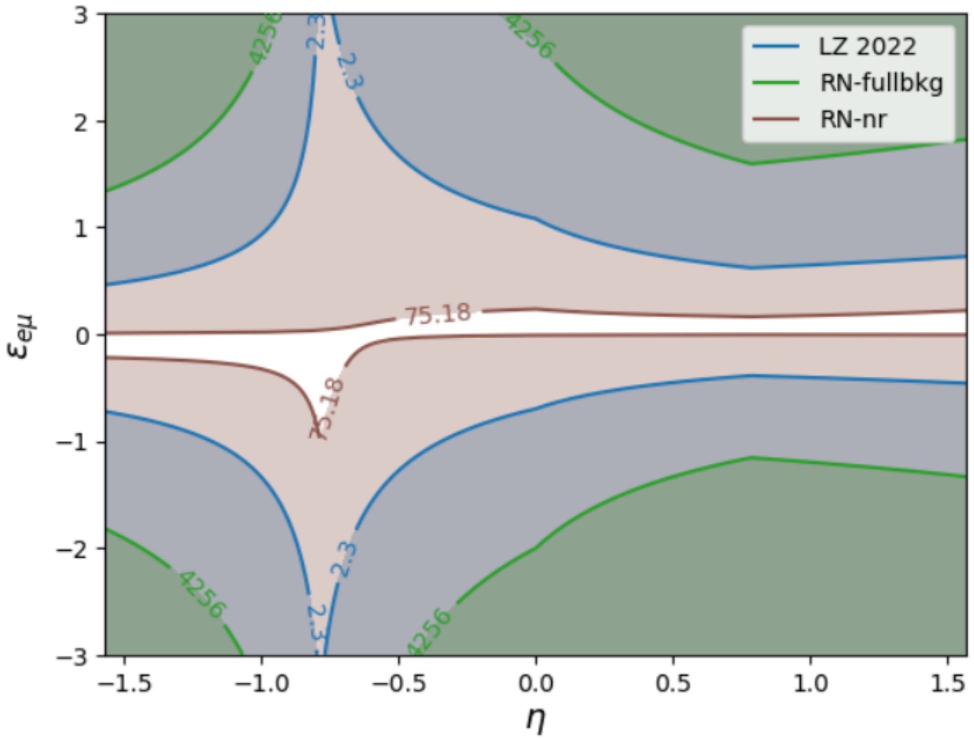
Sensitive to $\varepsilon_{\alpha\beta}$ (flavor=α,β)

Complementary to oscillation/spallation experiments

CEvNS is sensitive to vector NSI couplings to quarks

Geometrical representation of NSI couplings





Sensitivity to Non Standard Neutrino Interactions

Oscillation-Independent Probes of Neutrino Non-Standard Interactions from Supernovae

ANGELA R. BEATTY,[1,2,*] ANNA M. SULIGA,[3,†] AND VOLODYMYR TAKHISTOV[4,5,6,7,‡]

[1] *Department of Physics and Astronomy, San Francisco State University, 1600 Holloway Ave, San Francisco, 94132, California, USA*
[2] *Department of Physics, University of California Berkeley, Berkeley, California 94720, USA*
[3] *Center for Cosmology and Particle Physics, New York University, New York, NY 10003, USA*
[4] *International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles (QUP, WPI), High Energy Accelerator Research Organization (KEK), Oho 1-1, Tsukuba, Ibaraki 305-0801, Japan*
[5] *Theory Center, Institute of Particle and Nuclear Studies (IPNS), High Energy Accelerator Research Organization (KEK), Tsukuba 305-0801, Japan*
[6] *Graduate University for Advanced Studies (SOKENDAI), 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan*
[7] *Kavli Institute for the Physics and Mathematics of the Universe (WPI), UTIAS, The University of Tokyo, Kashiwa, Chiba 277-8583, Japan*

ABSTRACT

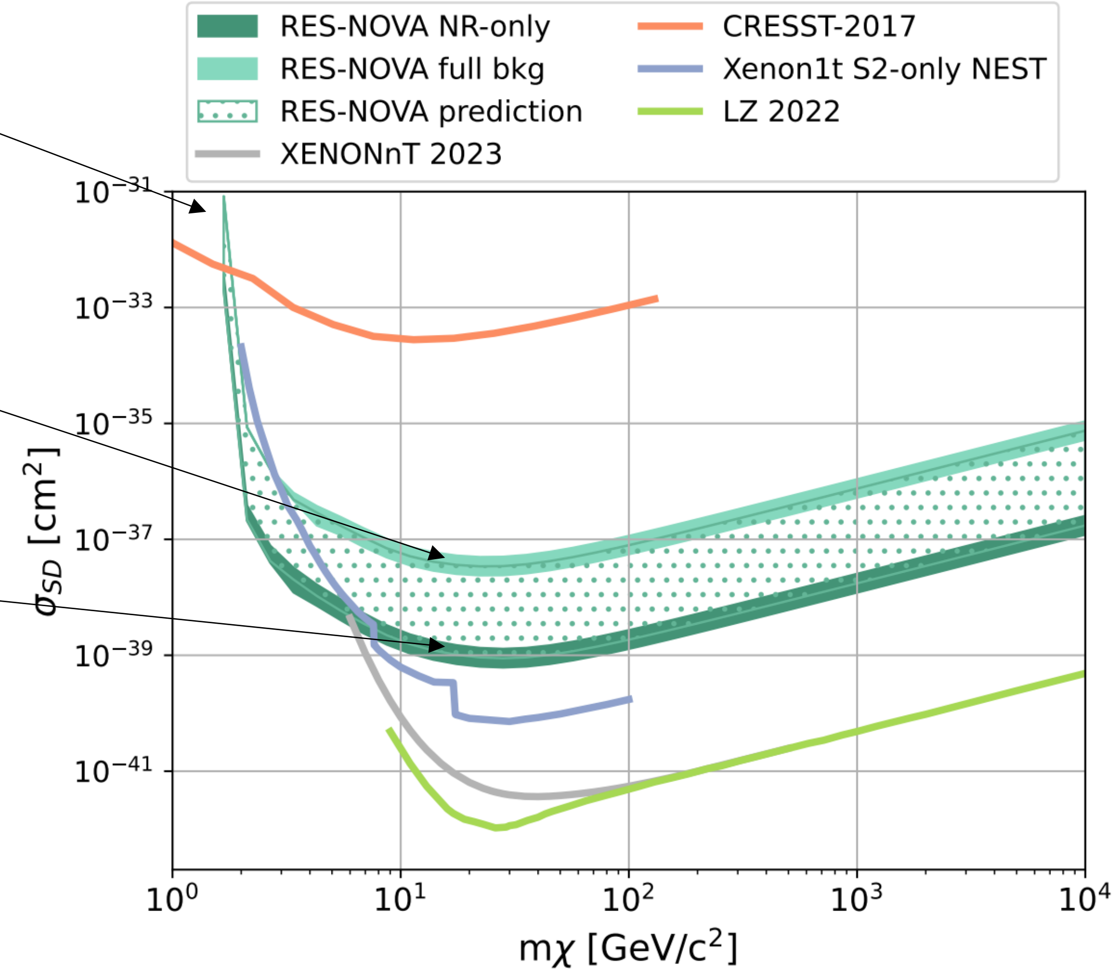
We introduce the first oscillation-independent astrophysical method to probe non-standard neutrino interactions (NSI) in core-collapse supernovae. Using a self-consistent treatment of NSI effects in both supernova neutrino emission simulations and flavor independent neutral-current scattering in detectors, we show that anti-correlated coincidence signatures between liquid scintillator experiments such as JUNO and dark matter detectors such as DARWIN/XLZD, ARGO, or RES-NOVA break degeneracy between NSI and flavor conversions effects. For a Galactic supernova within $\lesssim 1$ kpc this approach enables independent probes of neutrino-quark NSI couplings in parameter space overlapping and extending beyond existing terrestrial limits. Our results establish a novel oscillation-independent avenue to test fundamental neutrino interactions in extreme astrophysical environments.

Sensitivity WIMPS – spin dependent

^{17}O leading sensitivity

No bck rejection

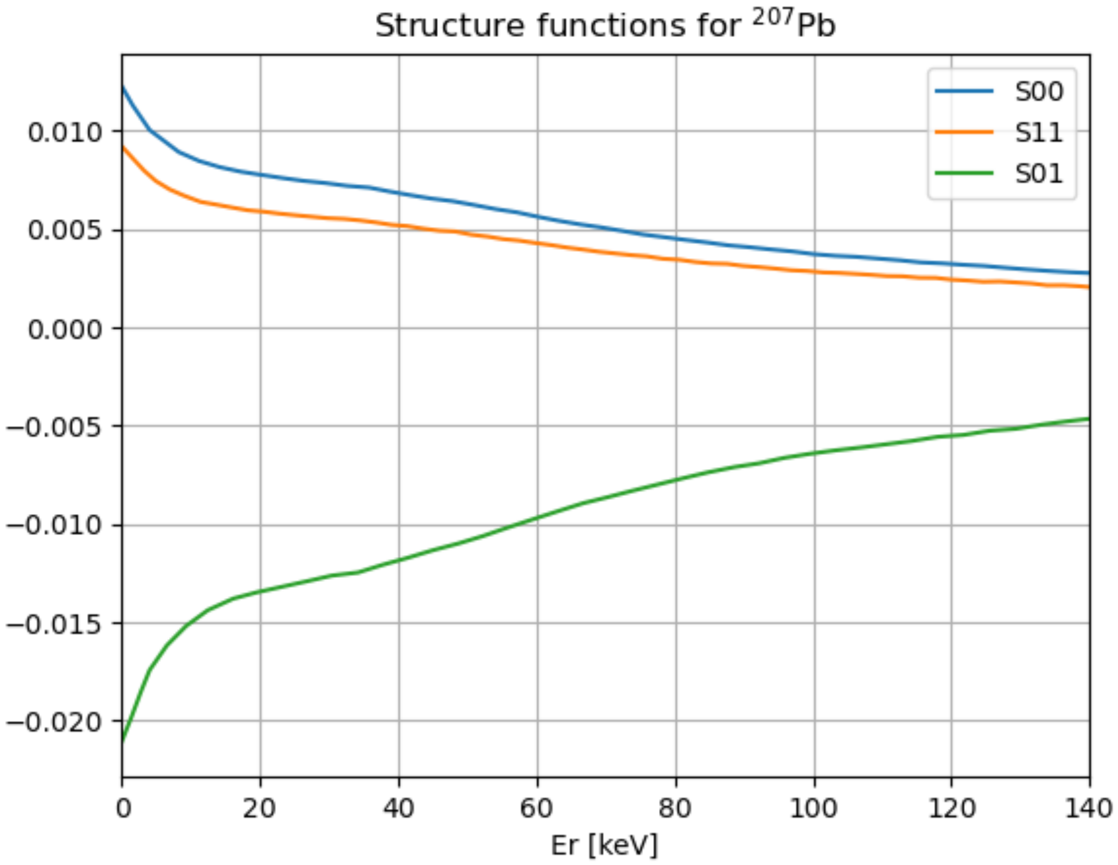
Full e/gamma
bck rejection



RES-NOVA Coll., Phys. Rev. D 111, 103050 (2025)

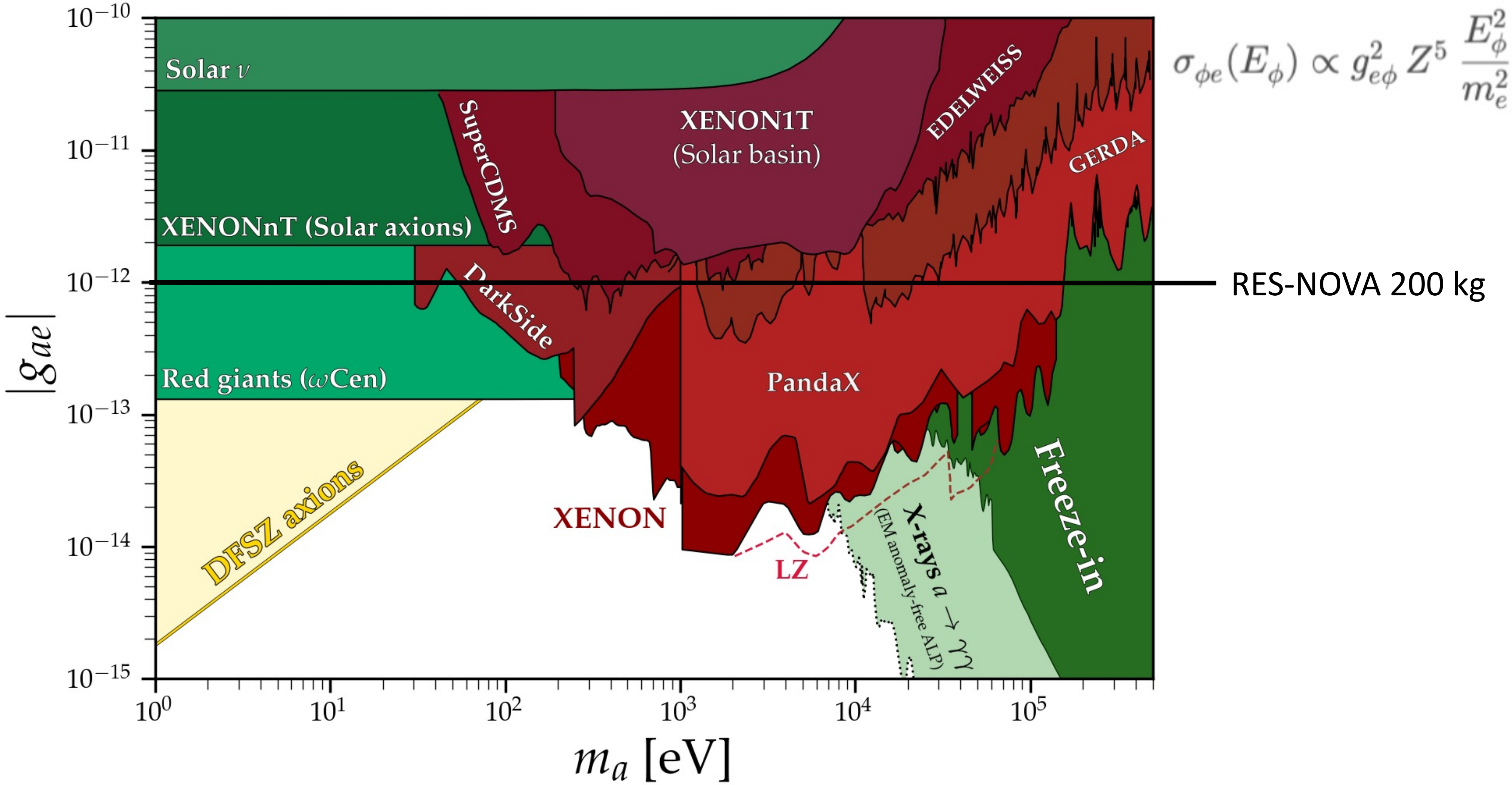
Spin-dependent sensitivity

^{207}Pb has a natural abundance of 22.1% and it's a 2p1/2 neutron hole within the doubly magic ^{208}Pb



Kosmas, T. S. and Vergados, J. D. Cold dark matter in SUSY theories, 10.1103/PhysRevD.55.1752

Solar DFSZ sensitivity projection



$$\sigma_{\phi e}(E_\phi) \propto g_{e\phi}^2\, Z^5\, \frac{E_\phi^2}{m_e^2}\, \sigma_{pe}(E_\phi)$$

Conclusions

- We don’t have the largest mass, but we got the (so far) largest Z/A
- We don’t have the largest sensitivity, but we withstand nearby SN events
- We have just begun connecting to the WISPs community
- Help us contributing with our (near future) data

Thank you!