RES-NOVA

Detecting Supernova neutrinos with archaeological Pb-based cryogenic detectors

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Supernovae: cosmic fireworks

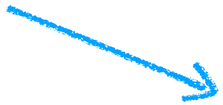
setting the stage

Supernovae (SN): high-energy **explosions of massive stars**

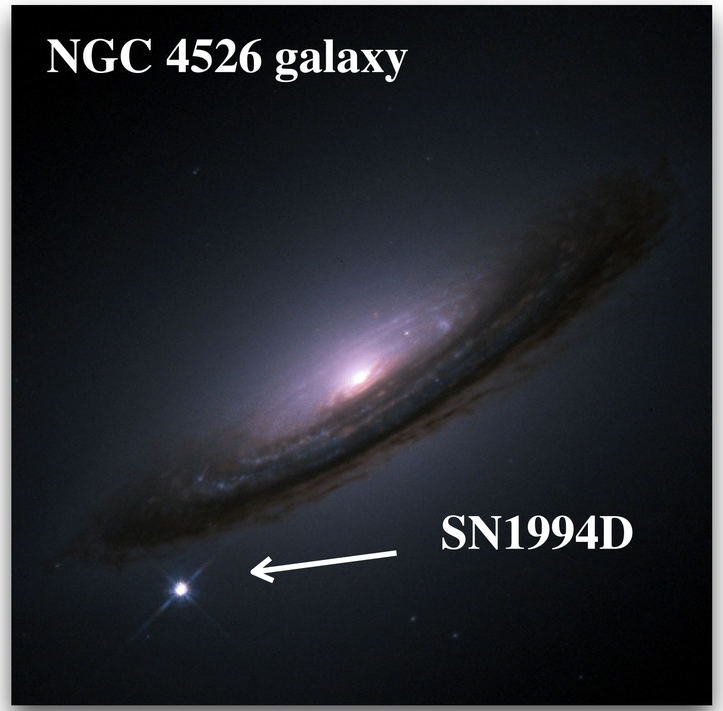
Almost total star binding energy converted into **all flavor-neutrinos**
but also **GW** and **EM** radiation

Neutrinos: direct **probes** and **messengers** of SNe hidden dynamics

Rare event (~1.6 SN/100 y): **1 observation** with underground instrumentation



1987 Birth of
Neutrino Astronomy

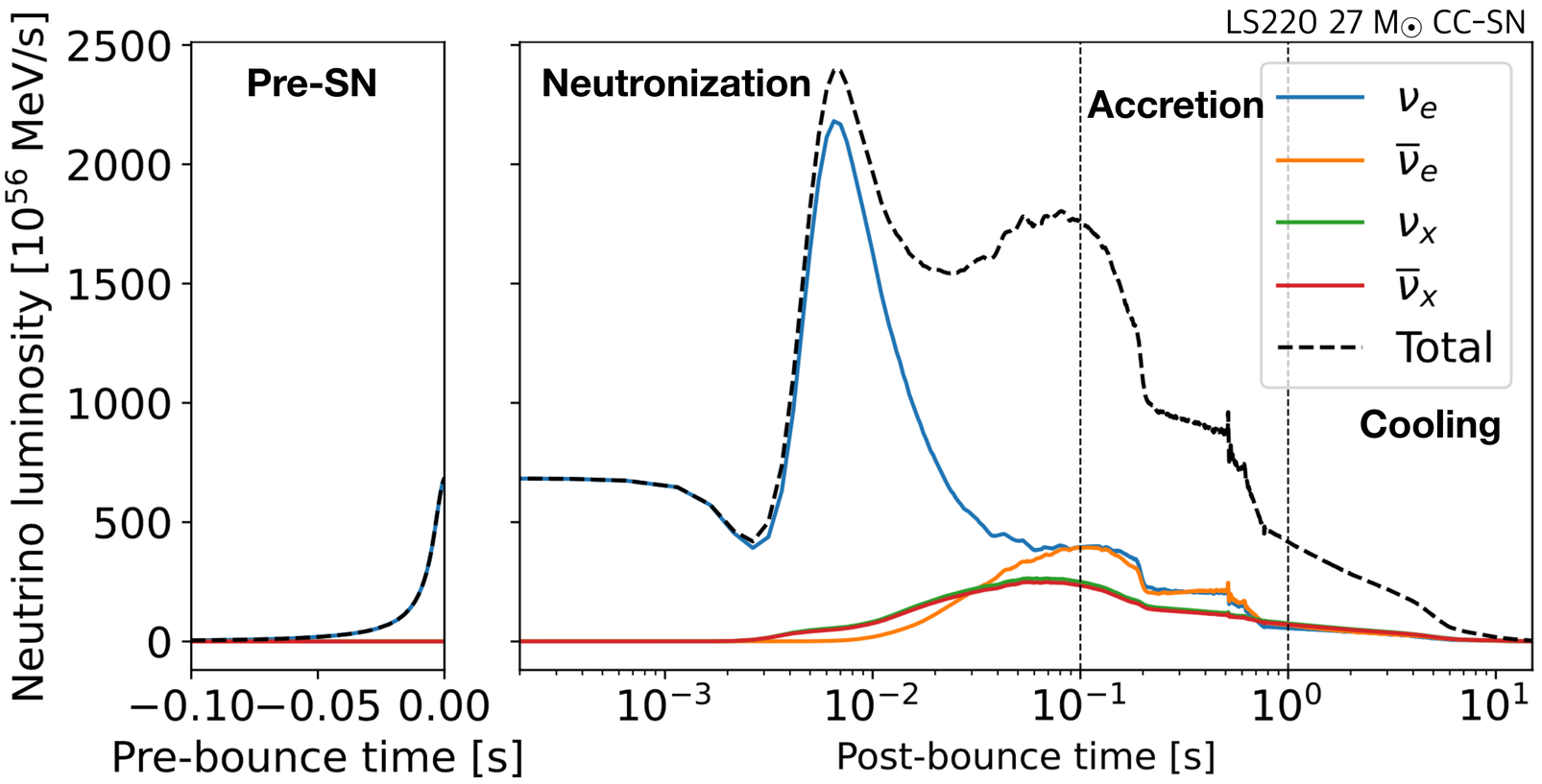


Credit: NASA/ESA, The Hubble Key Project Team and The High-Z Supernova Search Team

Neutrinos are emitted at all times

Unique neutrino signature

Neutrino transport simulation of a Core-Collapse SN



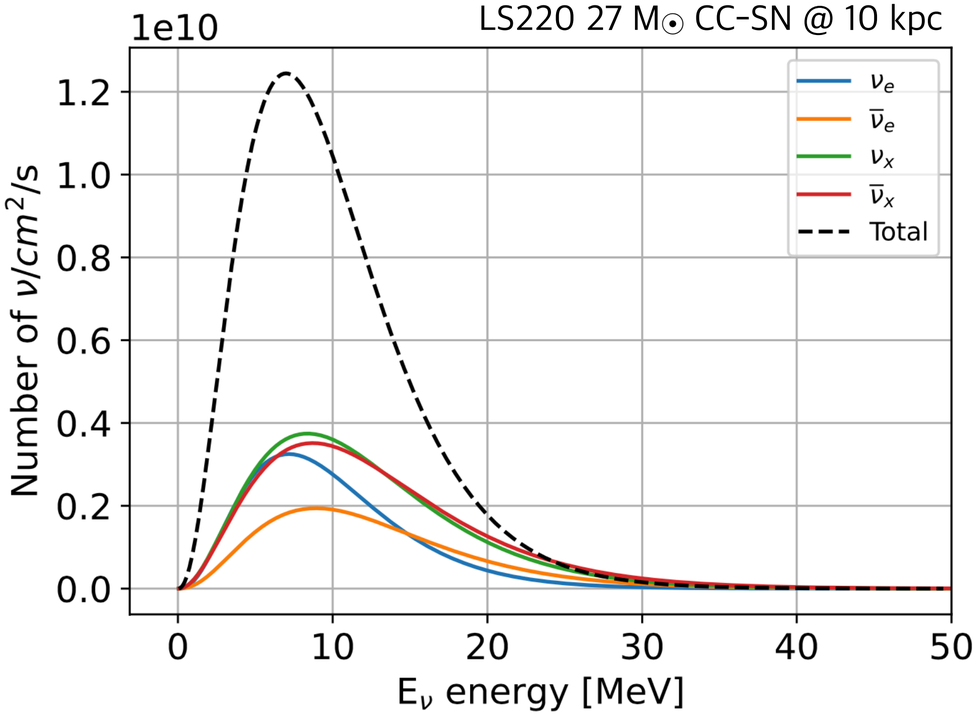
A. Mirizzi et al., Riv. Nuovo Cim.39, 1 (2016)

Nota Bene: neutrino flavor oscillations not included

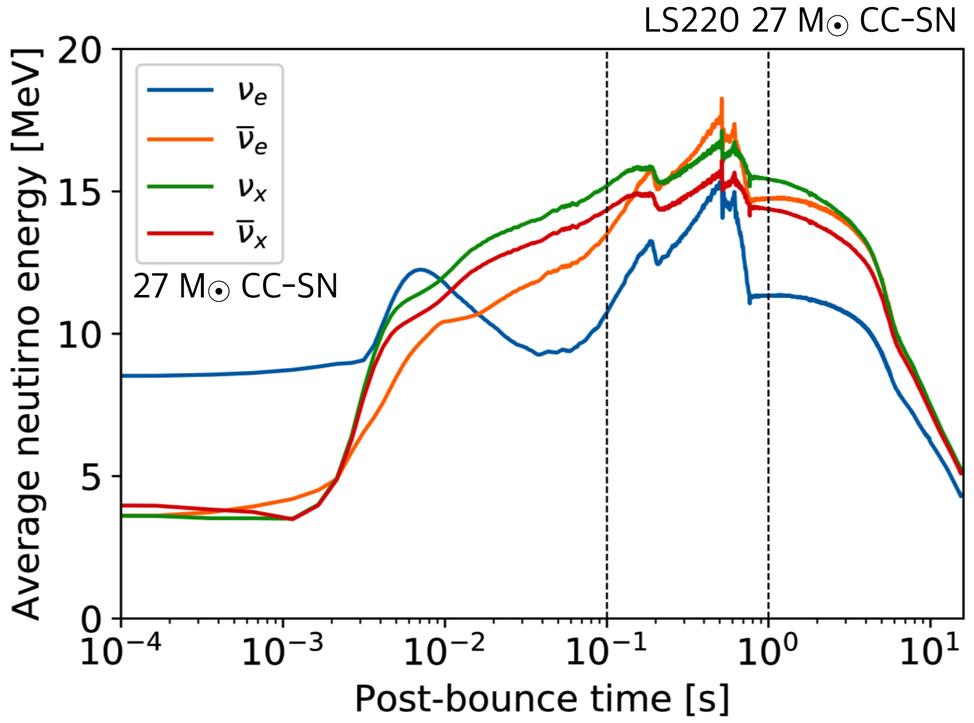
MPA Supernova Archive:
https://wwwmpa.mpa-garching.mpg.de/ccsnarchive

Supernova Neutrino signal

What is the average neutrino energy?



ν_x is the most **intense** component of the flux

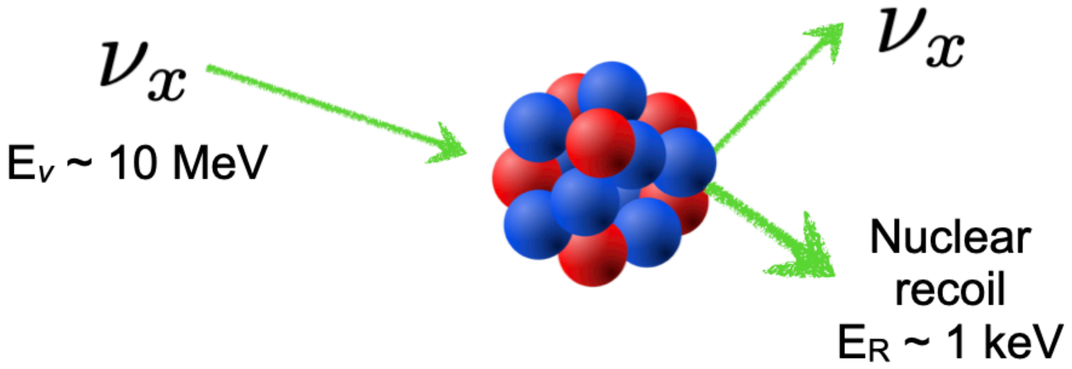


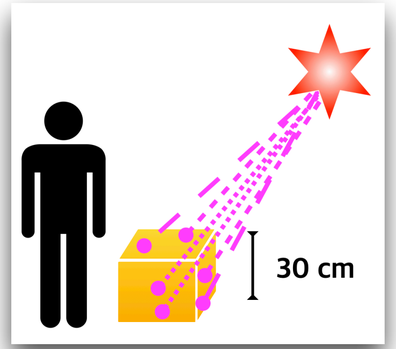
ν_x is the most **energetic** component of the flux

Current SN neutrino detectors are mostly sensitive to anti-ν_e/ν_e

All neutrino flavors are detected

Coherent neutrino-nucleus scattering





> Equally sensitive to all ν-flavors

> High interaction cross-section

$$Q_W = N - Z(1 - 4\sin^2\theta_W)$$ (~5%)

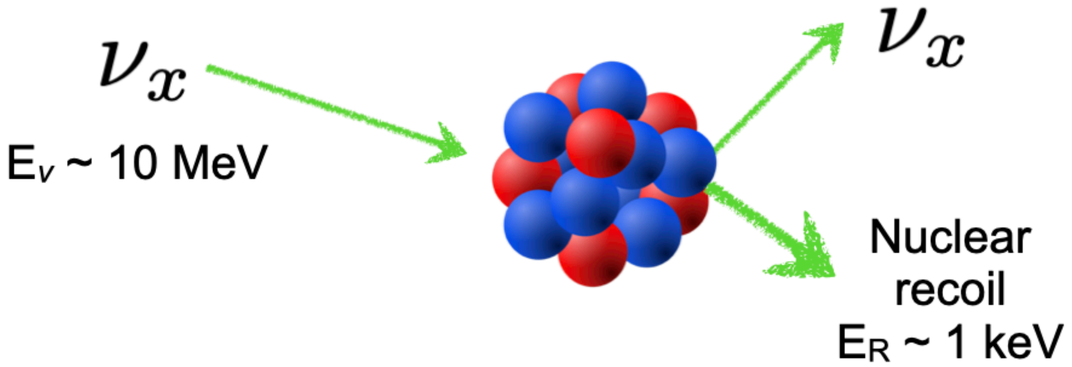
$$\sigma_{CE\nu NS}{}^{*} = \frac{G_F^2}{4\pi} F^2(q^2) E_\nu^2 Q_W^2$$

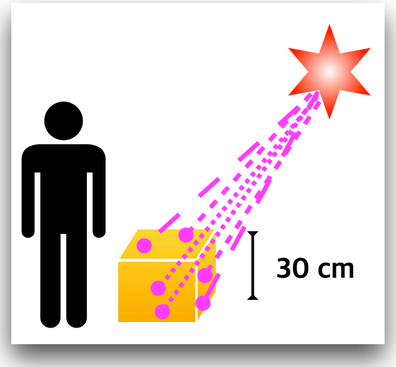
- $\sigma_{CE\nu NS}$: cross-section
- $F^2(q^2)$: Nuclear Form factor
- E_ν^2: Neutrino energy
- Q_W^2: Weak nuclear charge

* Spin 0 interaction

All neutrino flavors are detected

Coherent neutrino-nucleus scattering





> Equally sensitive to all ν-flavors

> High interaction cross-section

$$\sigma_{CE\nu NS} \propto N^2$$

cross-section

Neutron number

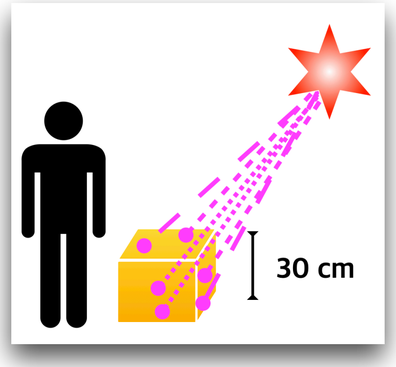
All neutrino flavors are detected

Coherent neutrino-nucleus scattering

$$\sigma_{CE\nu NS} \propto N^2$$

cross-section

Neutron number



Pb ideal target

Highest neutron number

Highest nuclear stability

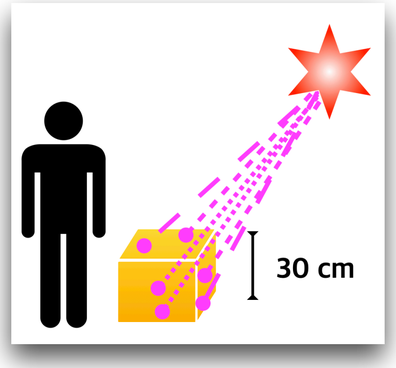
All neutrino flavors are detected

Coherent neutrino-nucleus scattering

$$\sigma_{CE\nu NS} \propto N^2$$

cross-section

Neutron number



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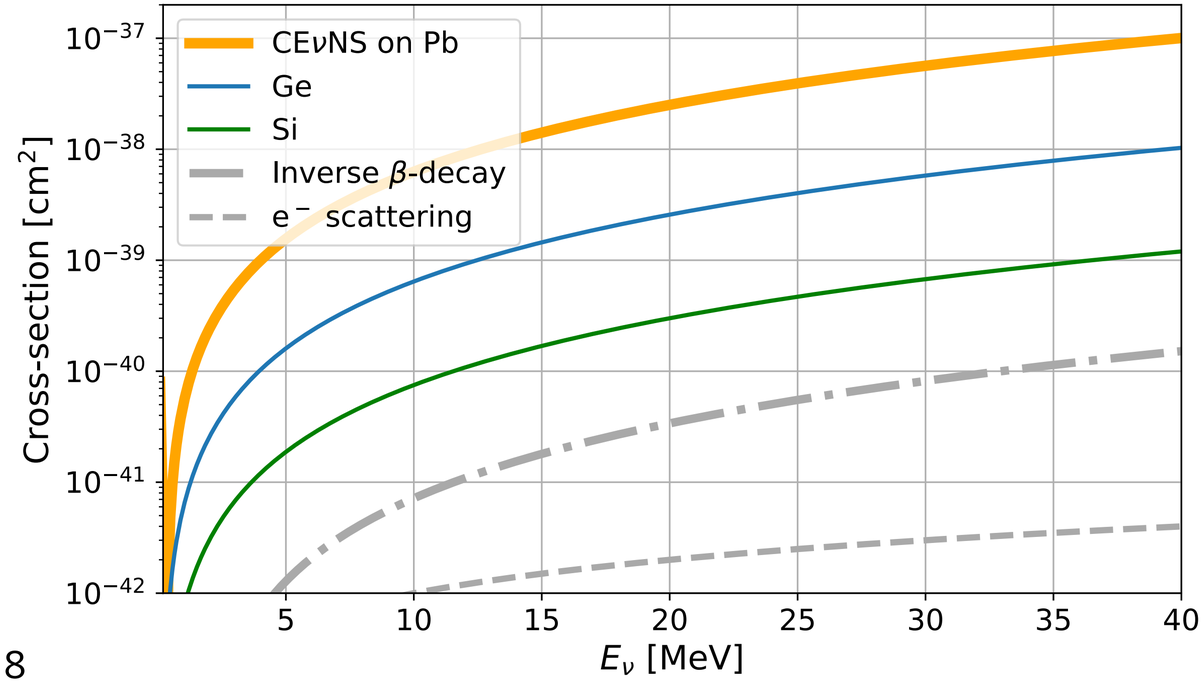

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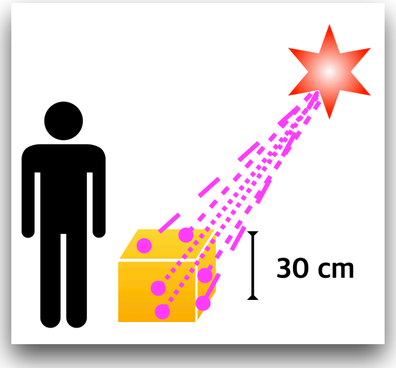
Coherent neutrino-nucleus scattering

$$\sigma_{CE\nu NS} \propto N^2$$

cross-section

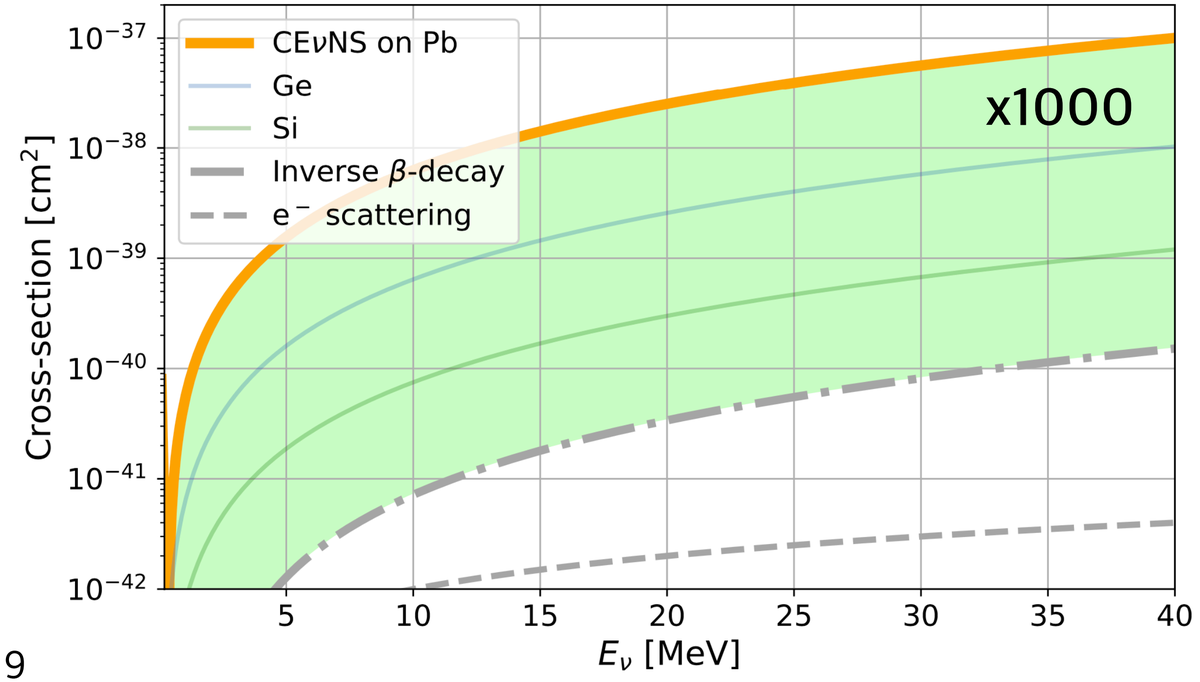
Neutron number



Pb ideal target

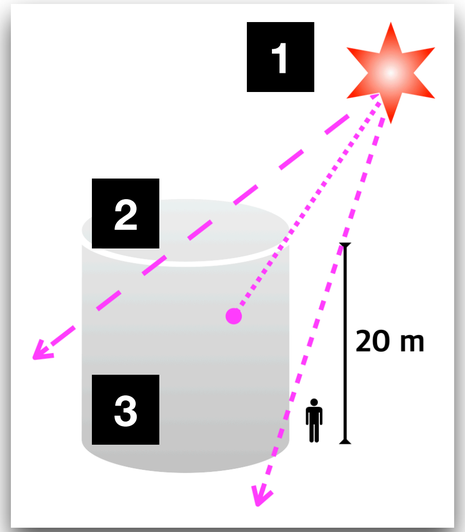
Highest neutron number

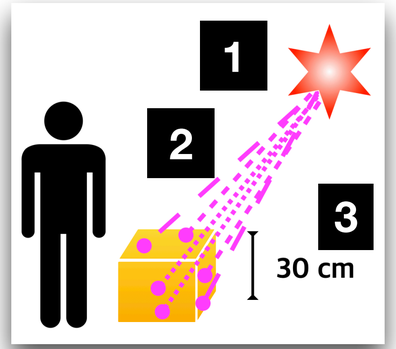
Highest nuclear stability



All neutrino flavors are detected

Coherent neutrino-nucleus scattering





Status quo:

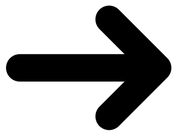
1. detection of ~1/6 SN flux
2. small cross-section
3. large volume detectors

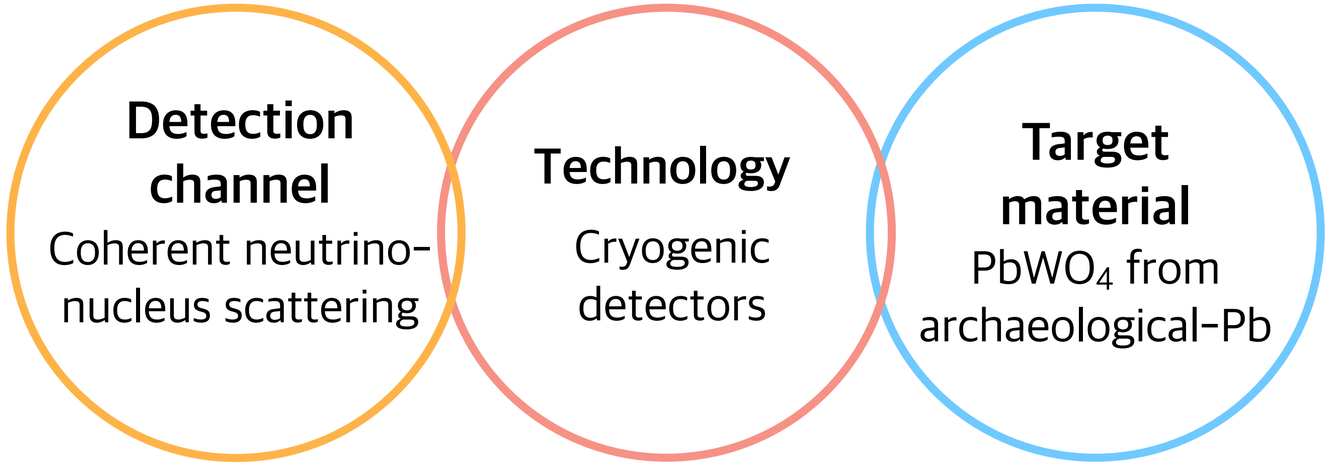
Opportunities:

1. detection of full SN ν flux
2. highest cross-section
3. cm-scale ν telescope

RES-NOVA gives unique insights into SNe

Innovative experimental approach



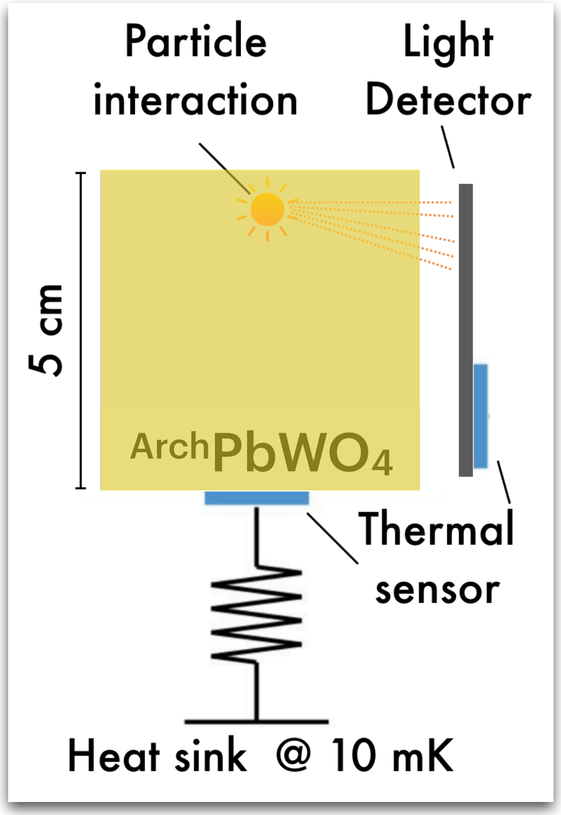


European Research Council
Established by the European Commission

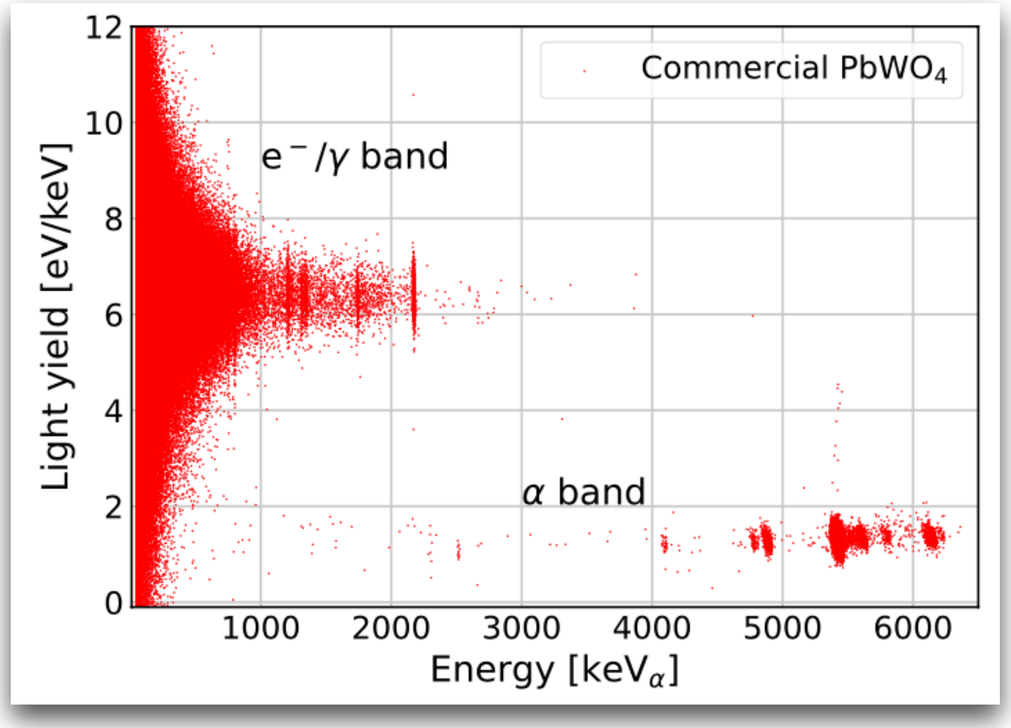
RES-NOVA detector technology

Advanced Cryogenic Detectors

Cryogenic calorimeters made from Pb



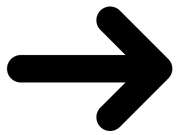
Cryogenic measurement of commercial $PbWO_4$

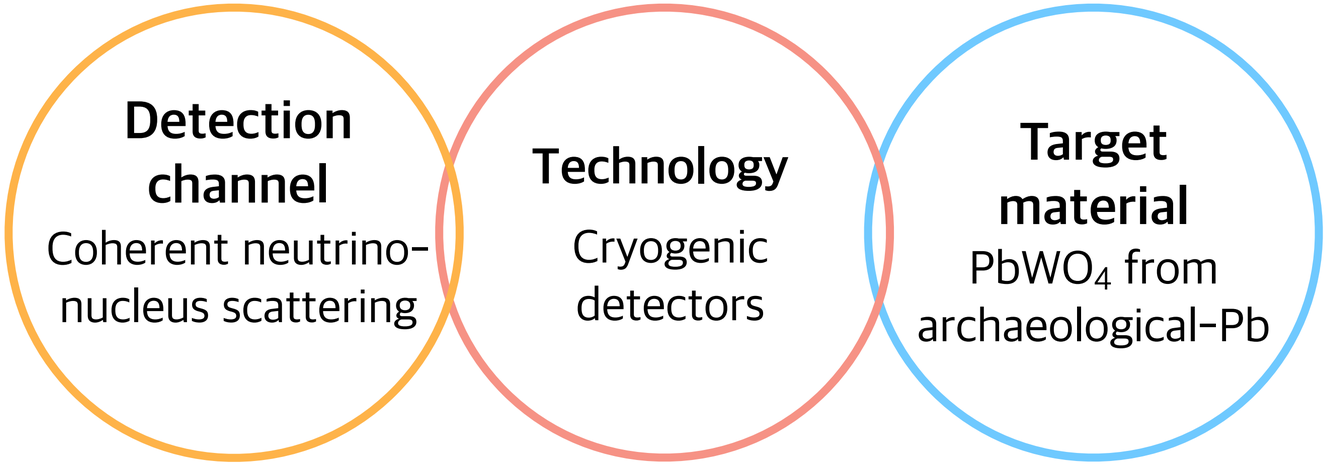


J.W. Beeman, **LP** et al., Eur. Phys. J. A 49, 50 (2013)

RES-NOVA gives unique insights into SNe

Innovative experimental approach

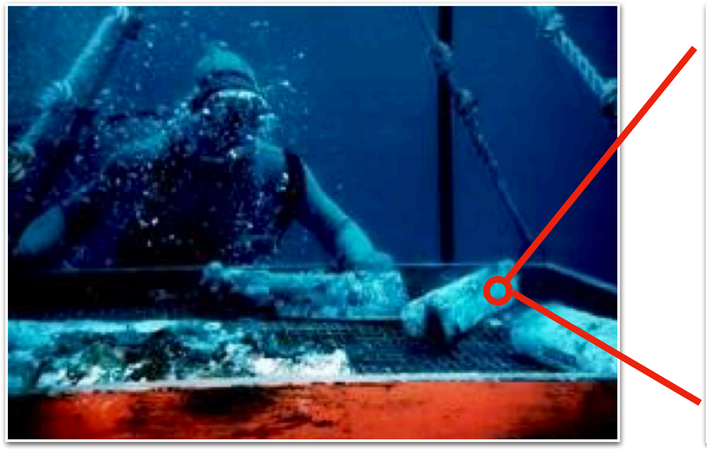


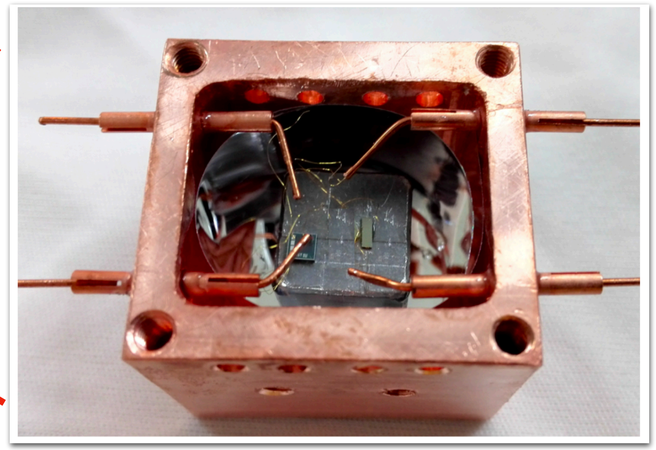


European Research Council
Established by the European Commission

Cryogenic detectors built from Archaeological Pb

taken from N. Nosengo (2010)





Archaeological Roman Pb:

- ★ from underwater shipwreck
- ★ 2000 years old

Archaeo-Pb cryogenic detector

High radiopurity: < 1 mBq/kg

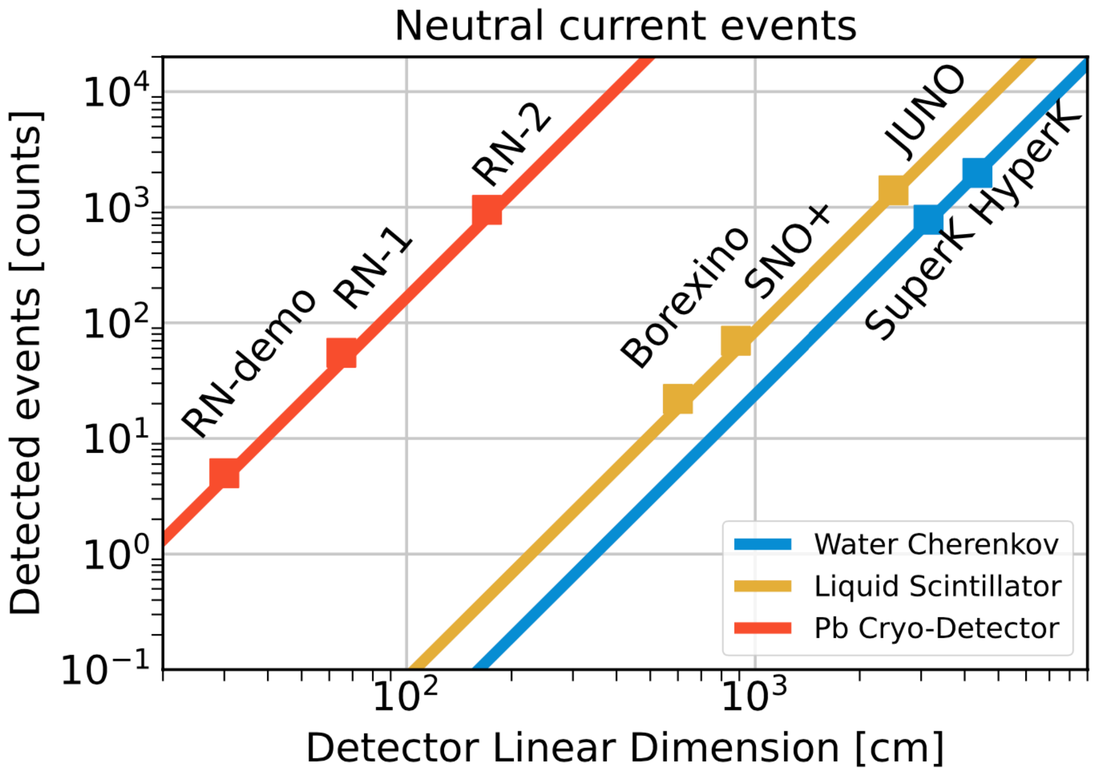
x10⁴ better than commercial low-background Pb

Several tons of ^{Arch}Pb available

L. Pattavina et al., Eur. Phys. J. A 55, 127 (2019)

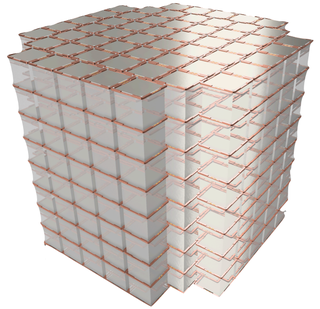
Neutrino observatory at the cm-scale

an array of $PbWO_4$ crystals

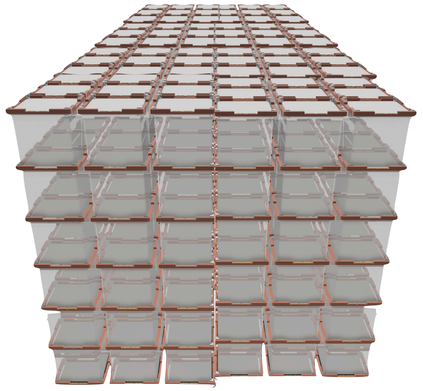


Size:	RN-demo @ LNGS $(30\ cm)^3$
Threshold:	1 keV
SN @ 10 kpc:	~10 counts

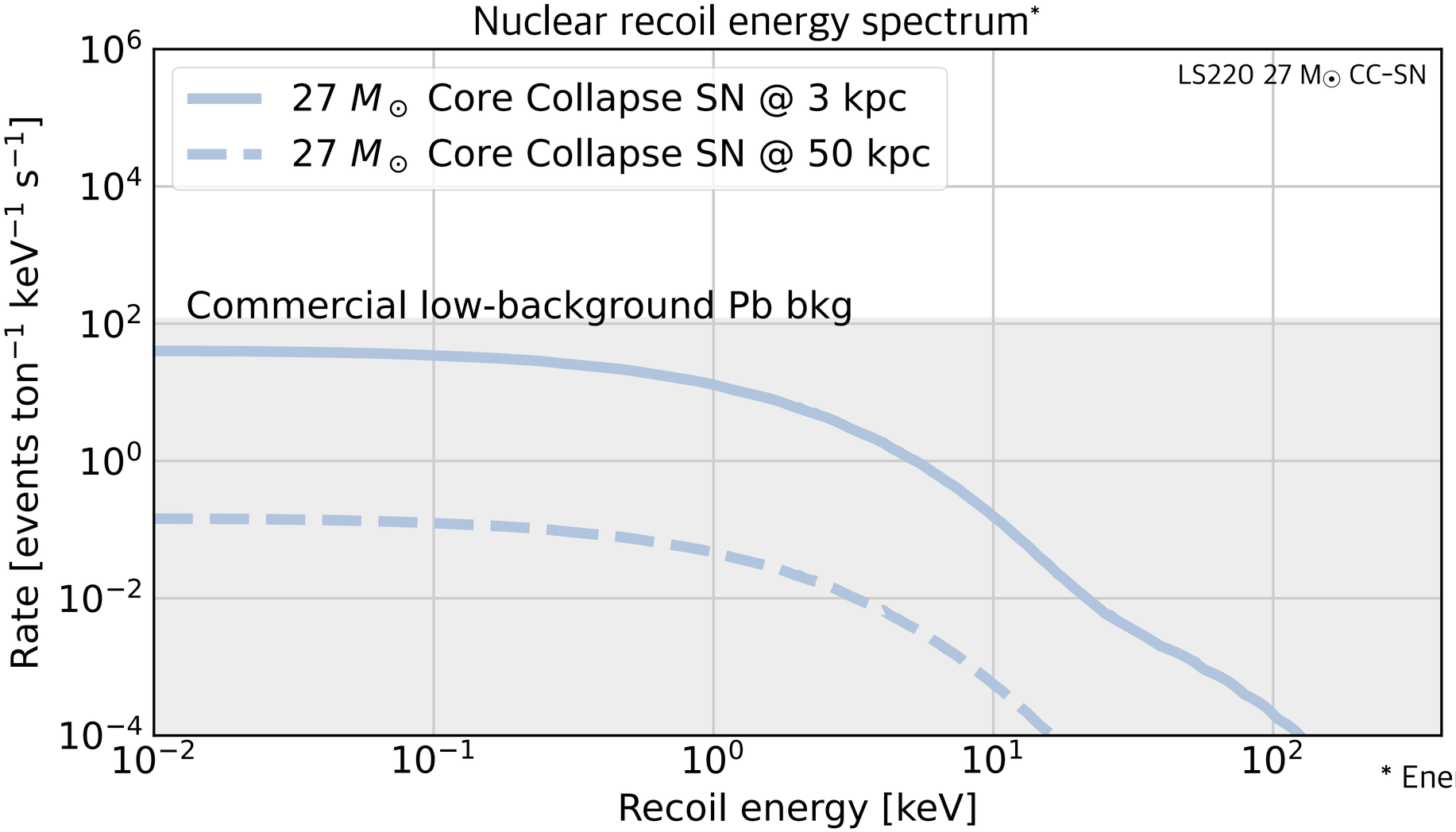
Size:	RN-1 $(60\ cm)^3$
Threshold:	1 keV
SN @ 10 kpc:	~50 counts



Size:	RN-2 $(140\ cm)^3$
Threshold:	1 keV
SN @ 10 kpc:	~900 counts



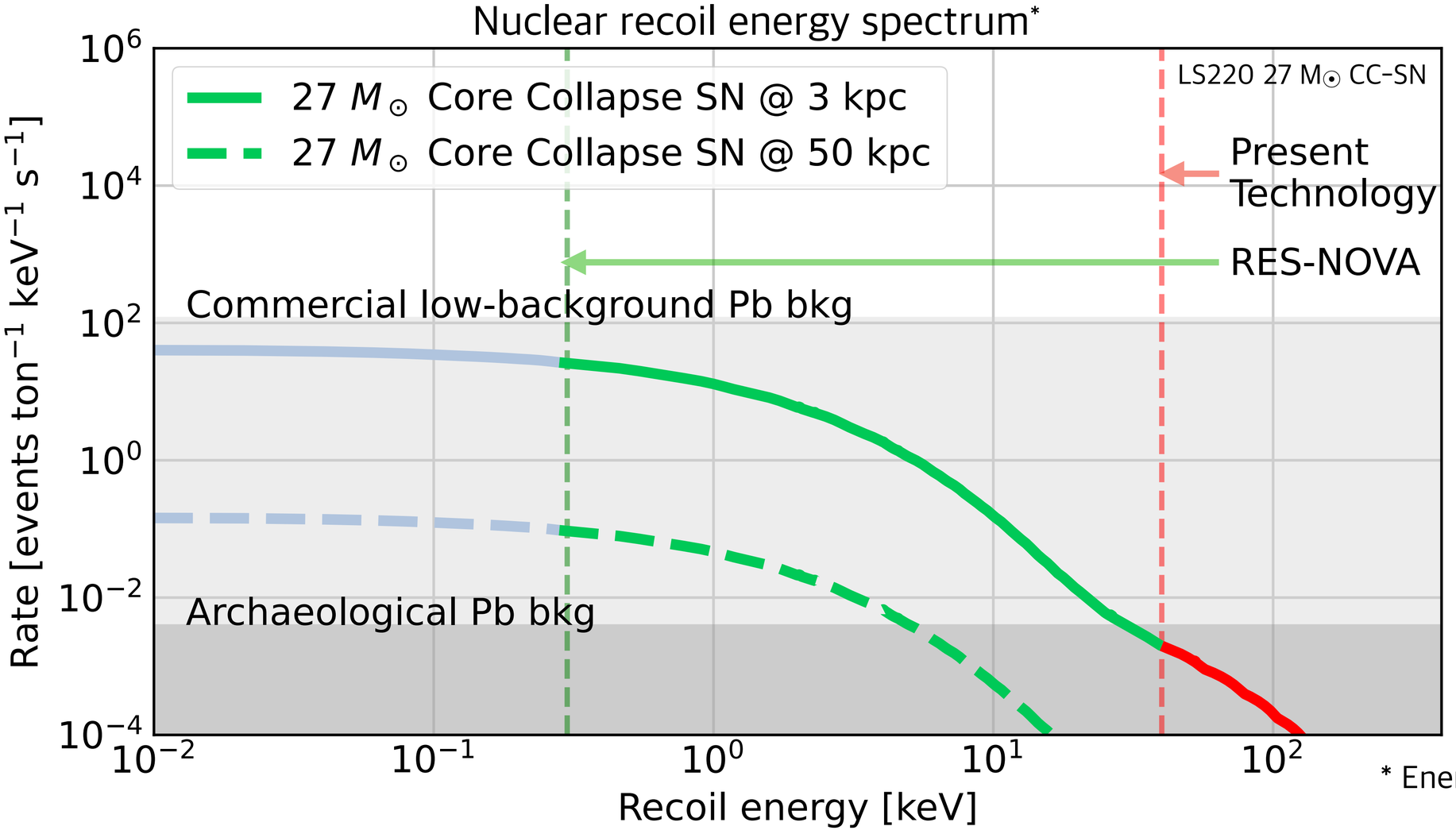
RES-NOVA detects SN neutrinos



* Energy resolution 0.2 keV

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

RES-NOVA detects SN neutrinos



* Energy resolution 0.2 keV

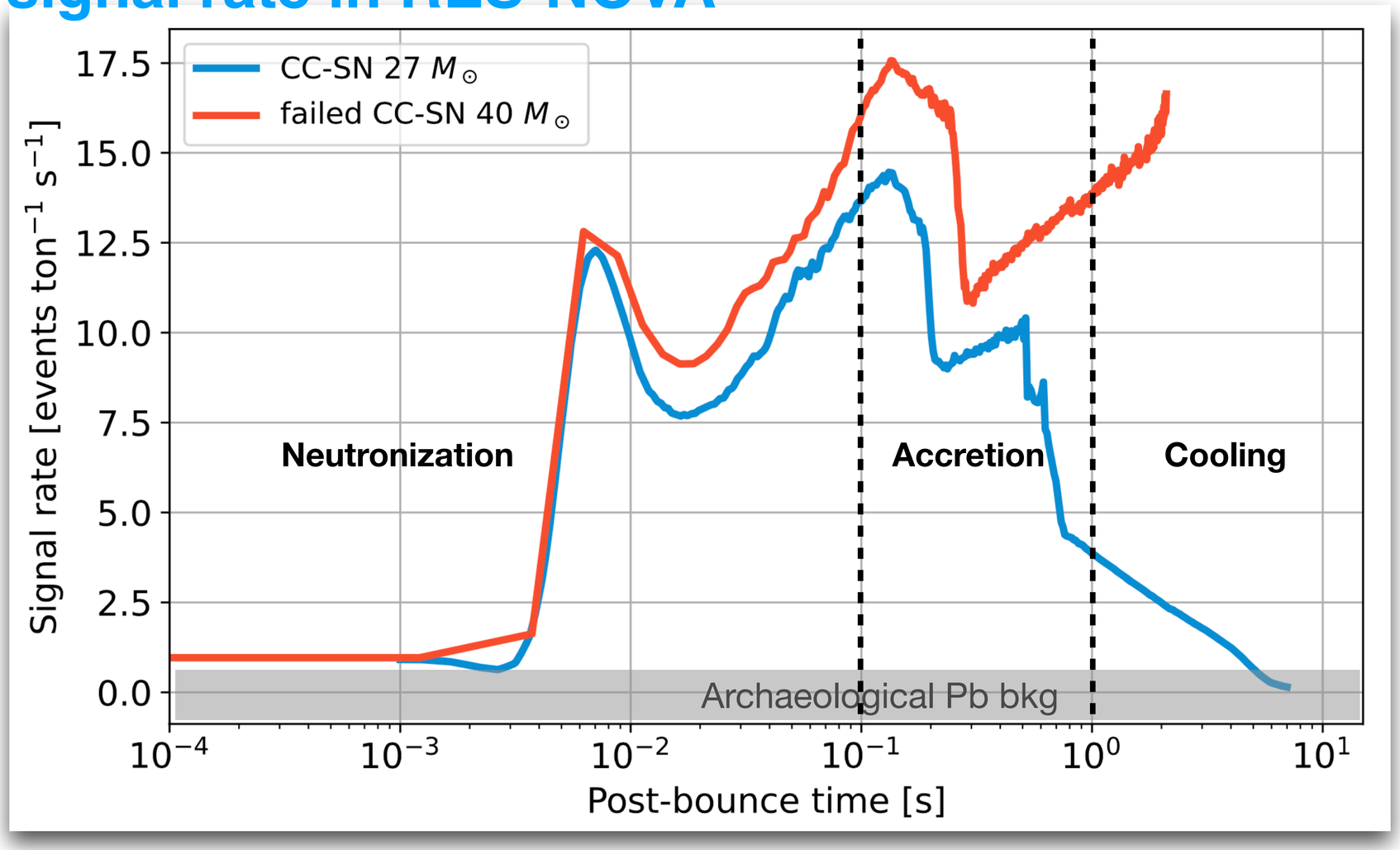
L. Pattavina et al., *Phys. Rev. D* 102, 063001 (2020)

RES-NOVA Group of Interest, *Eur. Phys. J. C* 82, 692 (2022)

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

RES-NOVA: the potential

neutrino signal rate in RES-NOVA



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

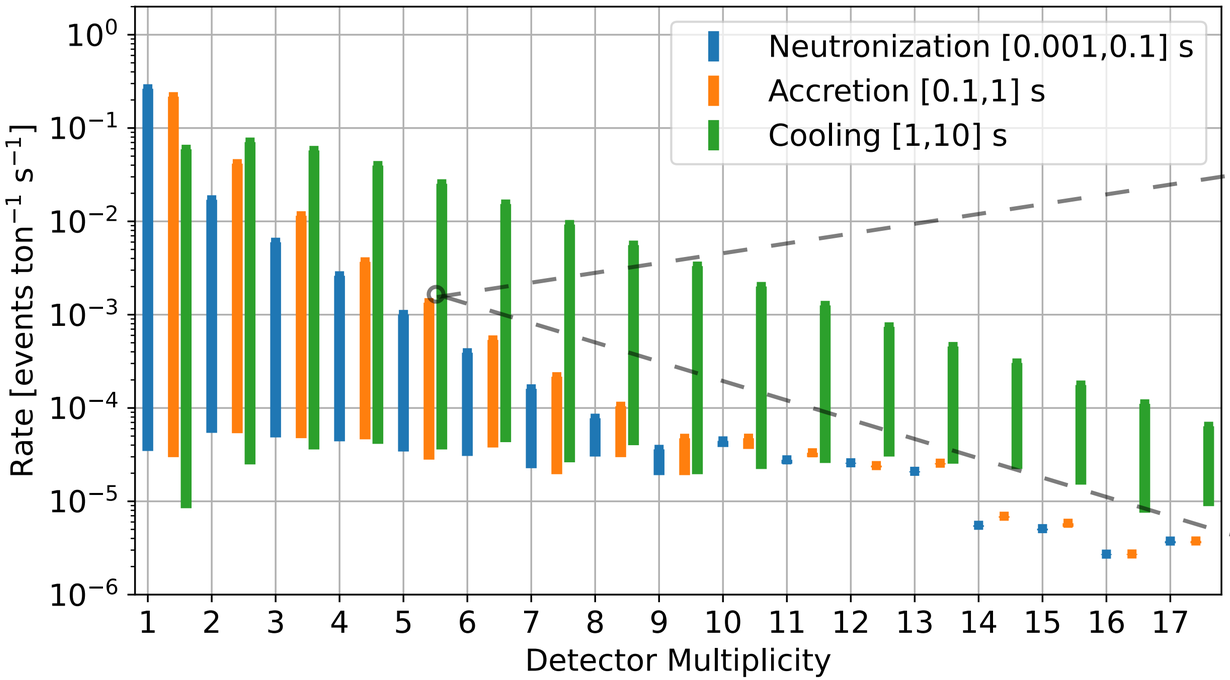
RES-NOVA background model

High multiplicity SN signal → High multiplicity bkg → Low-background

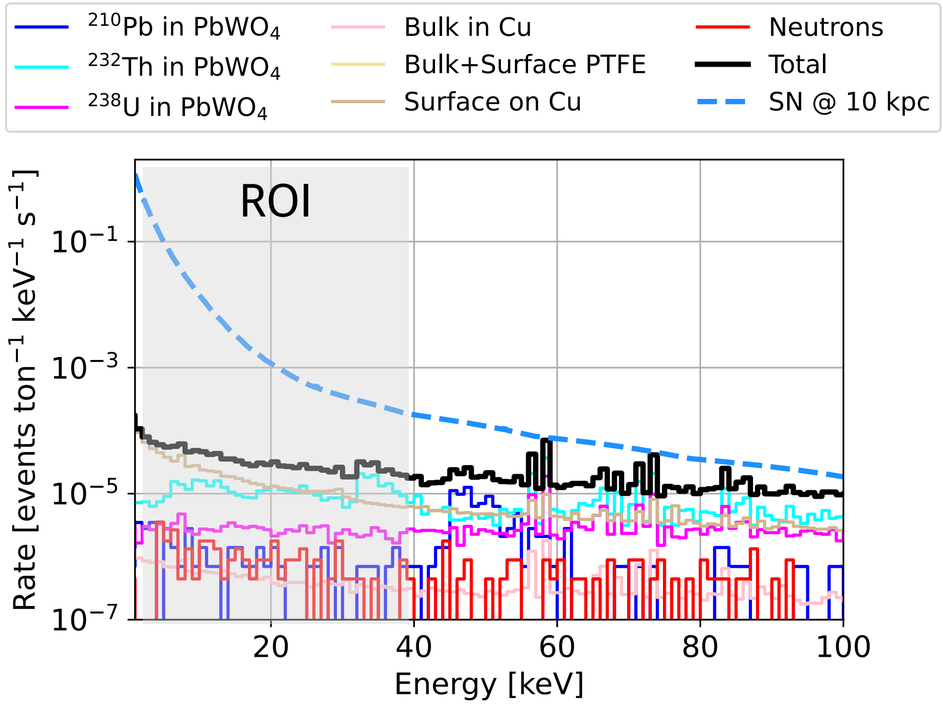
Bkg goal: <10^{-3} ev/ton/keV/s in coincidence mode (no particle ID)

<0.086 c/keV/kg/d

Background rate in the ROI



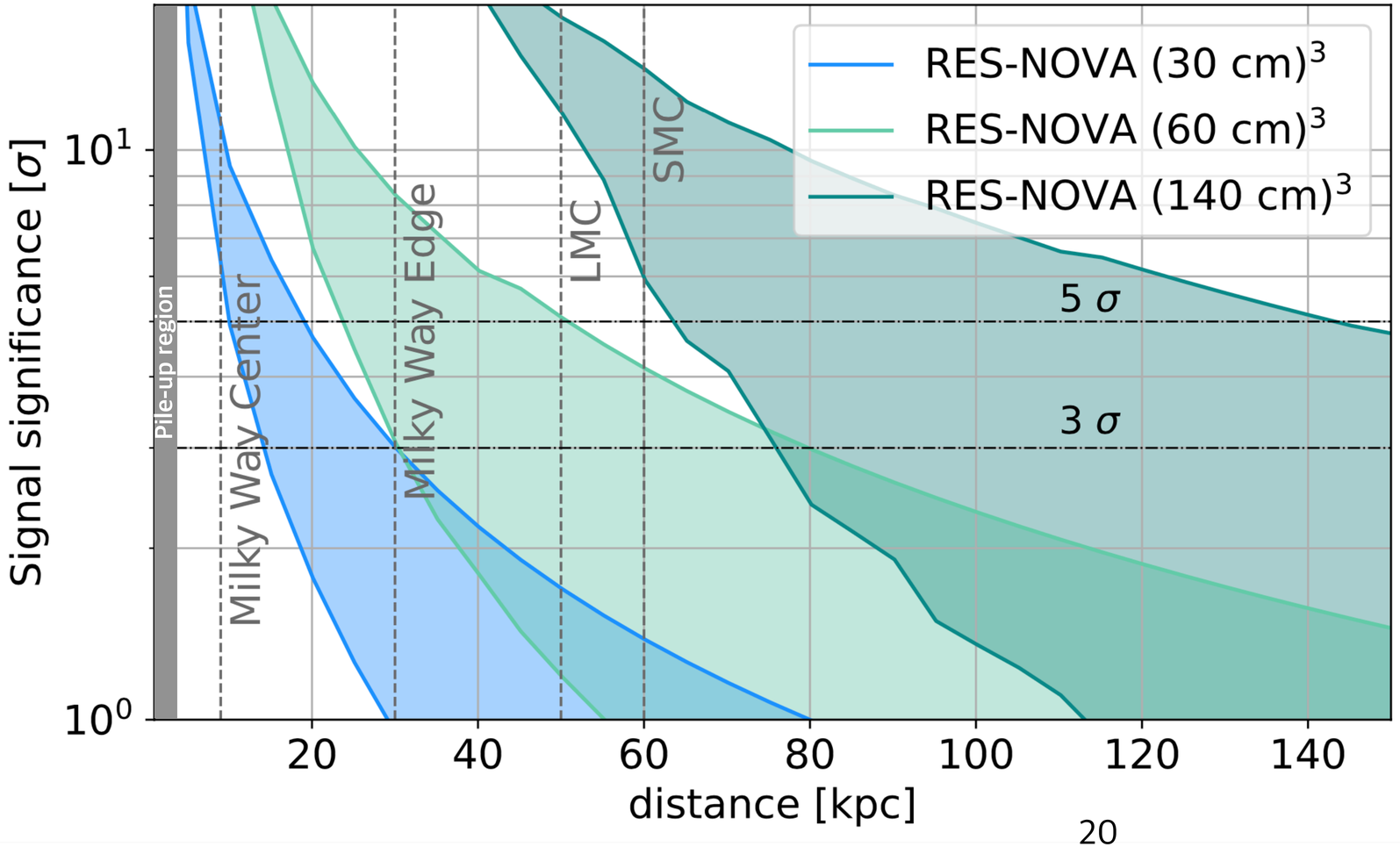
Detector energy spectrum for a SN @ 10 kpc



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

RES-NOVA sensitivity

small detector great potential



Target: **archaeo-$PbWO_4$**

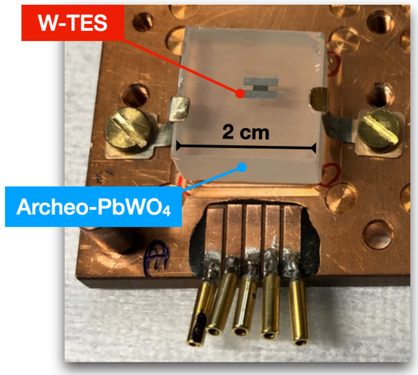
Energy threshold: **1 keV**

Bkg @ ROI: **10^{-3} c/keV/ton/s/**

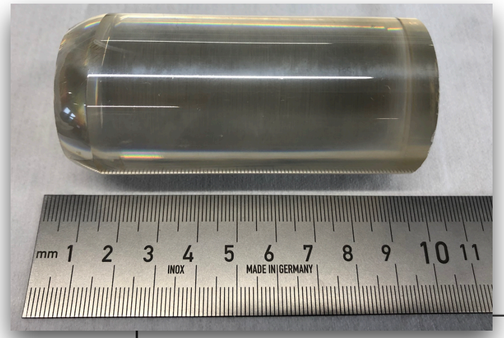
L. Pattavina et al., *JCAP* 10 (2021) 064

RES-NOVA proofs of principle

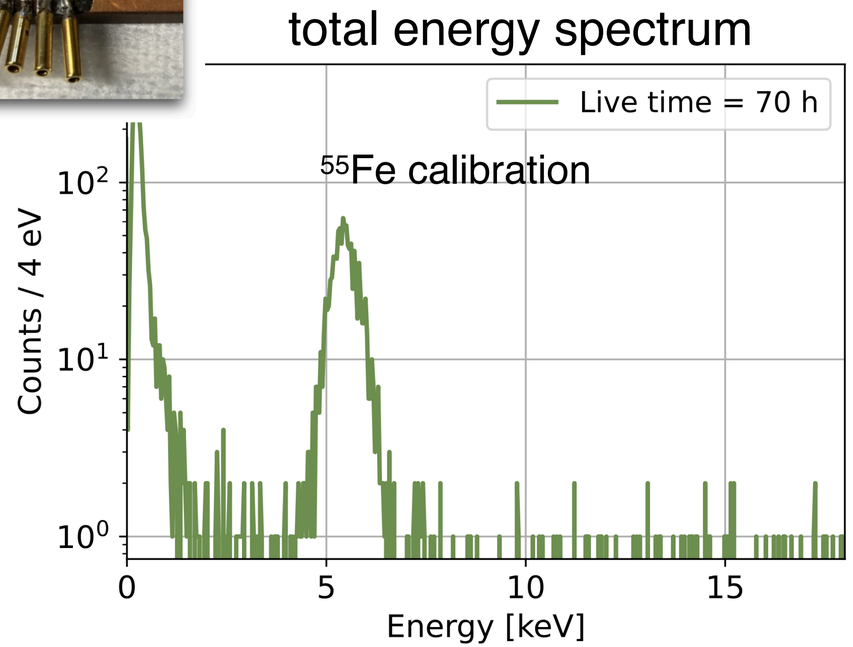
achievement of low threshold and low background

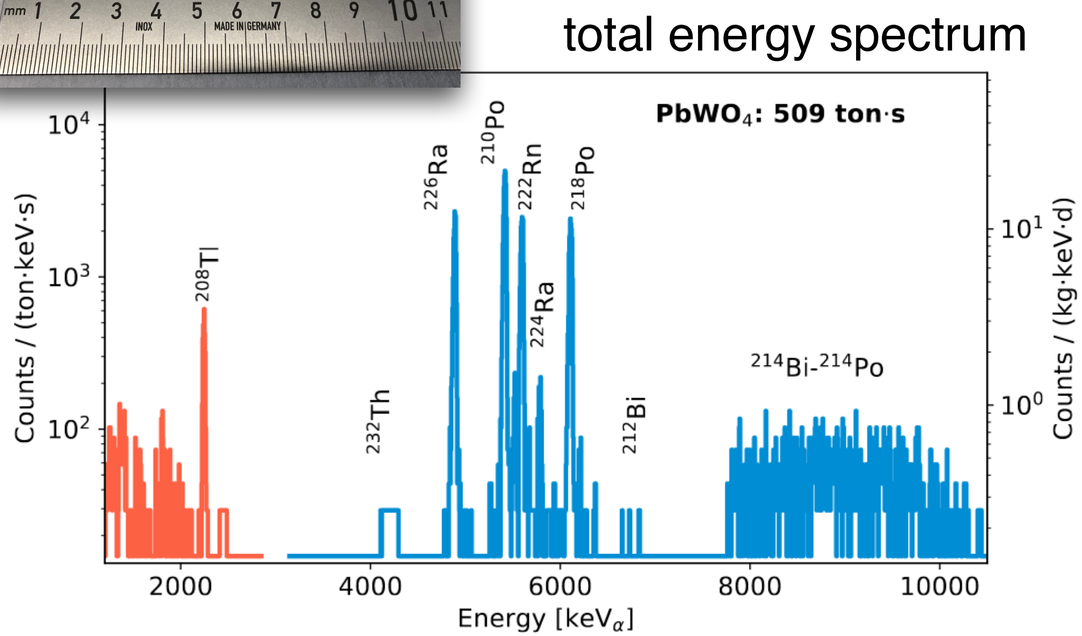


N. Ferreiro Iachellini et al.,
J. Low Temp. Phys. 11, 184 (2022)



RES-NOVA group of interest
Eur. Phys. J. C 82, 692 (2022)





Above ground @ Max Planck Munich (DE)

Nuclear recoil threshold – 300 eV ($PbWO_4$ – 20 g)

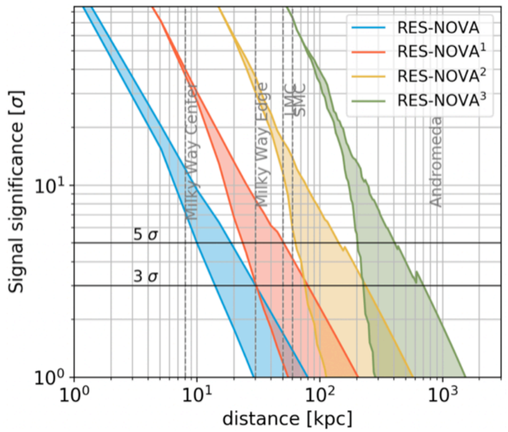
Under ground @ LNGS (IT)

Radiopurity @ μBq/kg scale ($PbWO_4$ – 0.9 kg)

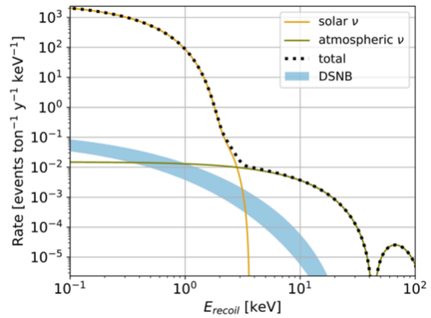
Conclusions

- RES-NOVA is a new neutrino observatory at cm-scale
  - broad physics program (DM searches, axions, …)
- RES-NOVA technology is already established
  - Archaeological Pb can be embedded in PbWO4
  - Preliminary results exceed expectations (E_{th}= 300 eV)
- RES-NOVA provides a complementary approach to the current SN neutrino observatories

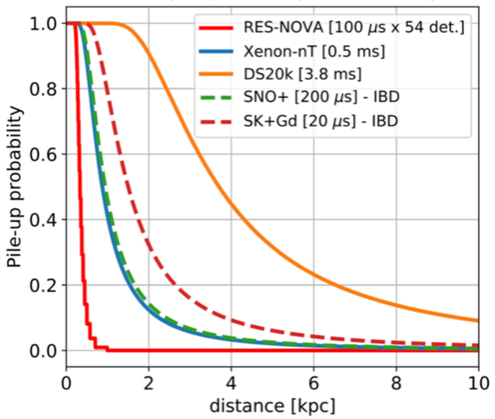
Deep space exploration



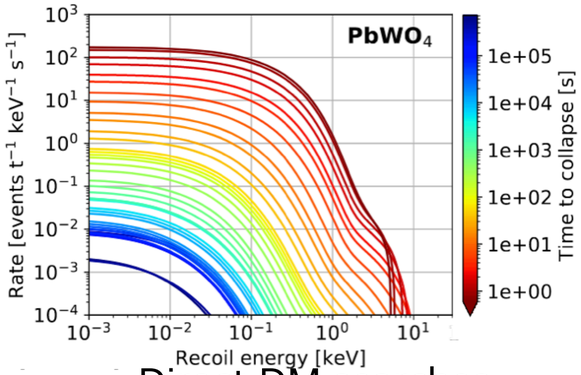
Diffuse SN neutrino Background



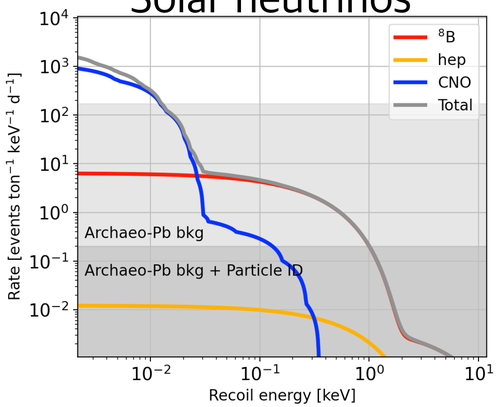
Nearby galaxy survey



Pre-SN neutrino detection



Solar neutrinos



Direct DM searches