Observation of neutrino flux from supernovae with SuperCDMS by CEνNS.

Rodrigo Pacheco
CASST
20/08/24

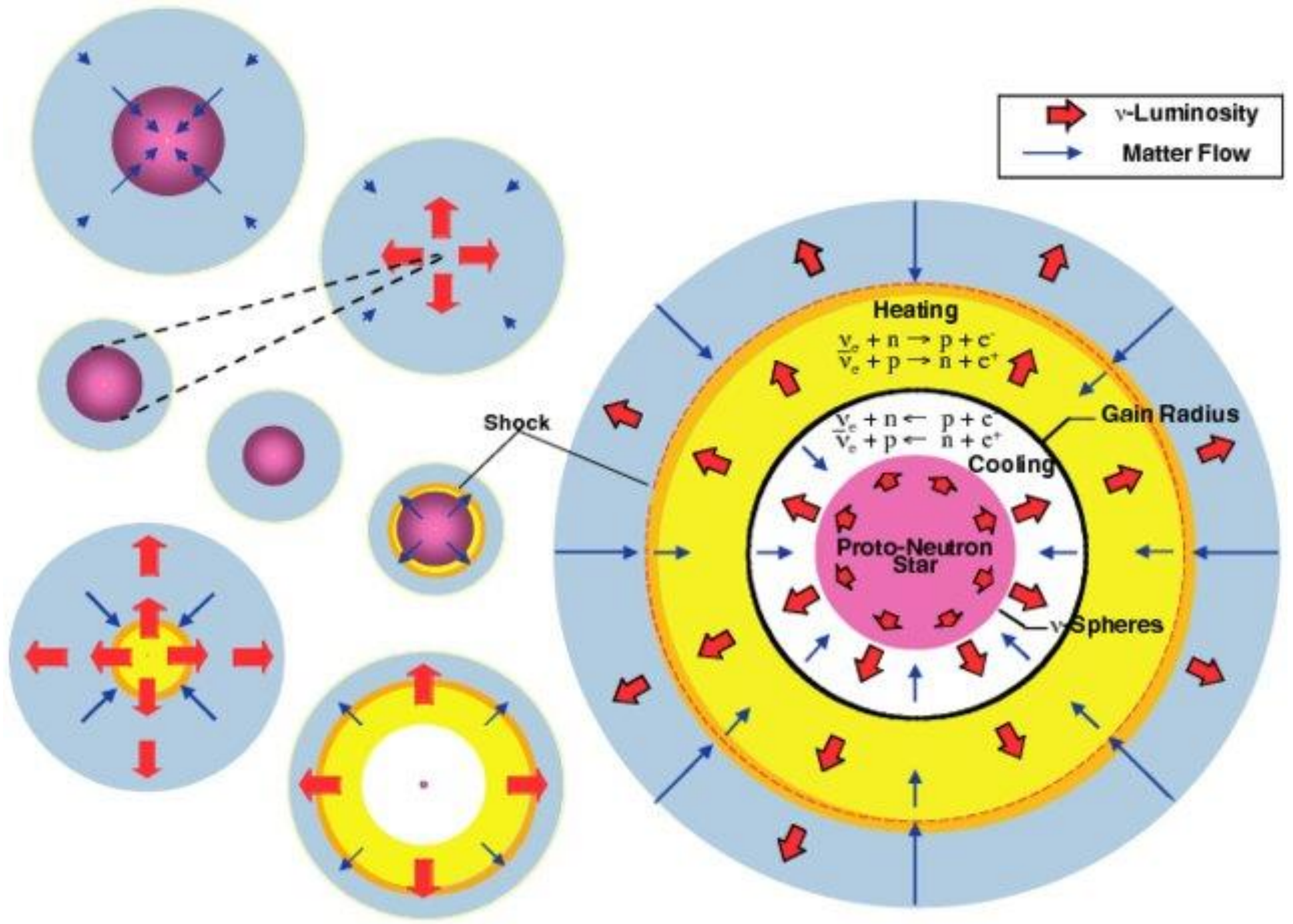
Overview

- Supernova neutrinos
- Modeling
- Cryogenic detectors
- CEνNS
- Results
- Summary

Supernova neutrinos

Supernova neutrinos

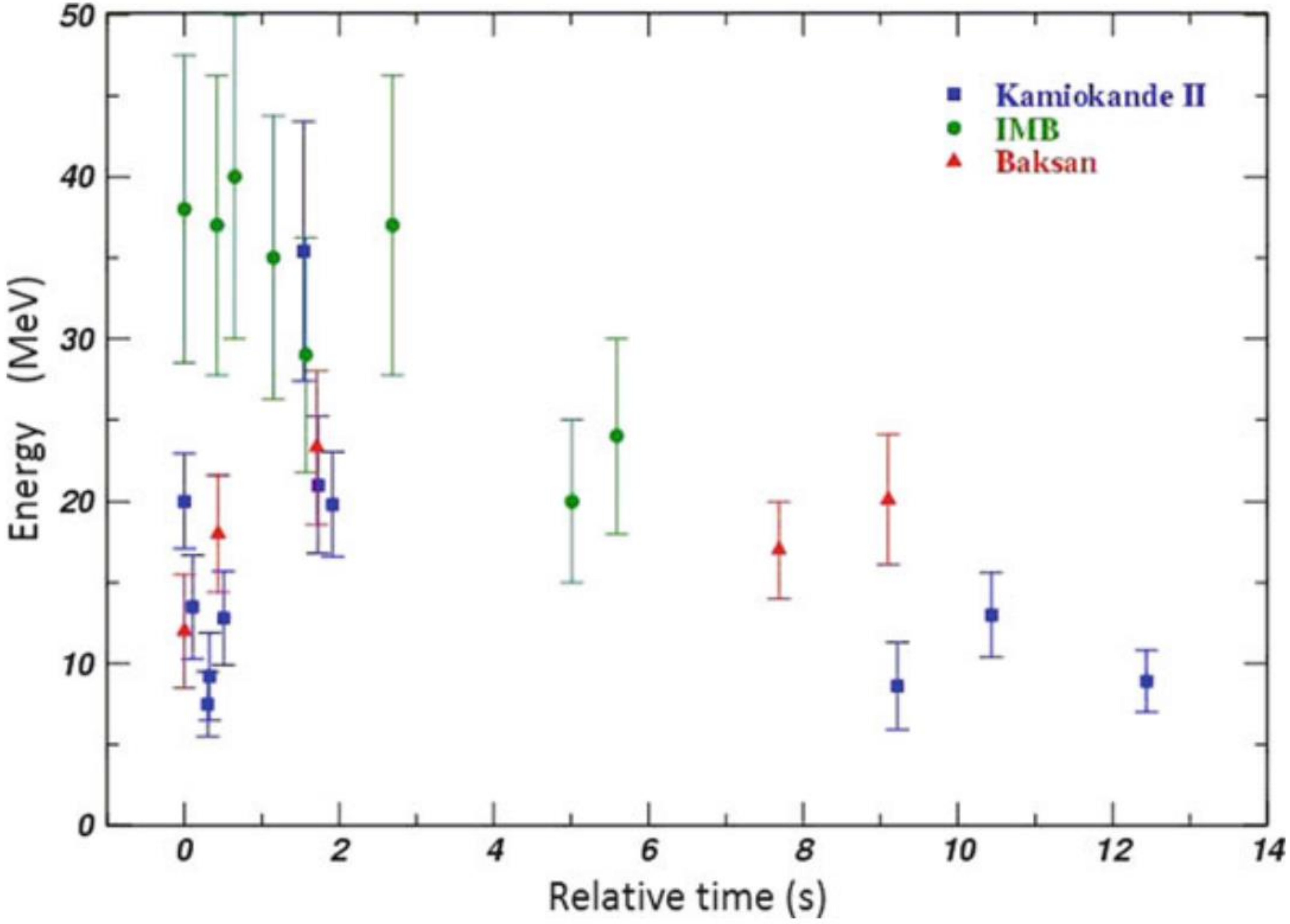
- A Supernova is the explosion of a star more massive than $8M_{\odot}$*[13]
- Most of the energy released by SN comes in the form of neutrinos of all flavors
- Neutrinos from SN 1987 A ($18M_{\odot}$ progenitor) have been observed.



NLCF 2006

$*M_{\odot} = 1.9 \times 10^{30} kg$

Supernova neutrinos



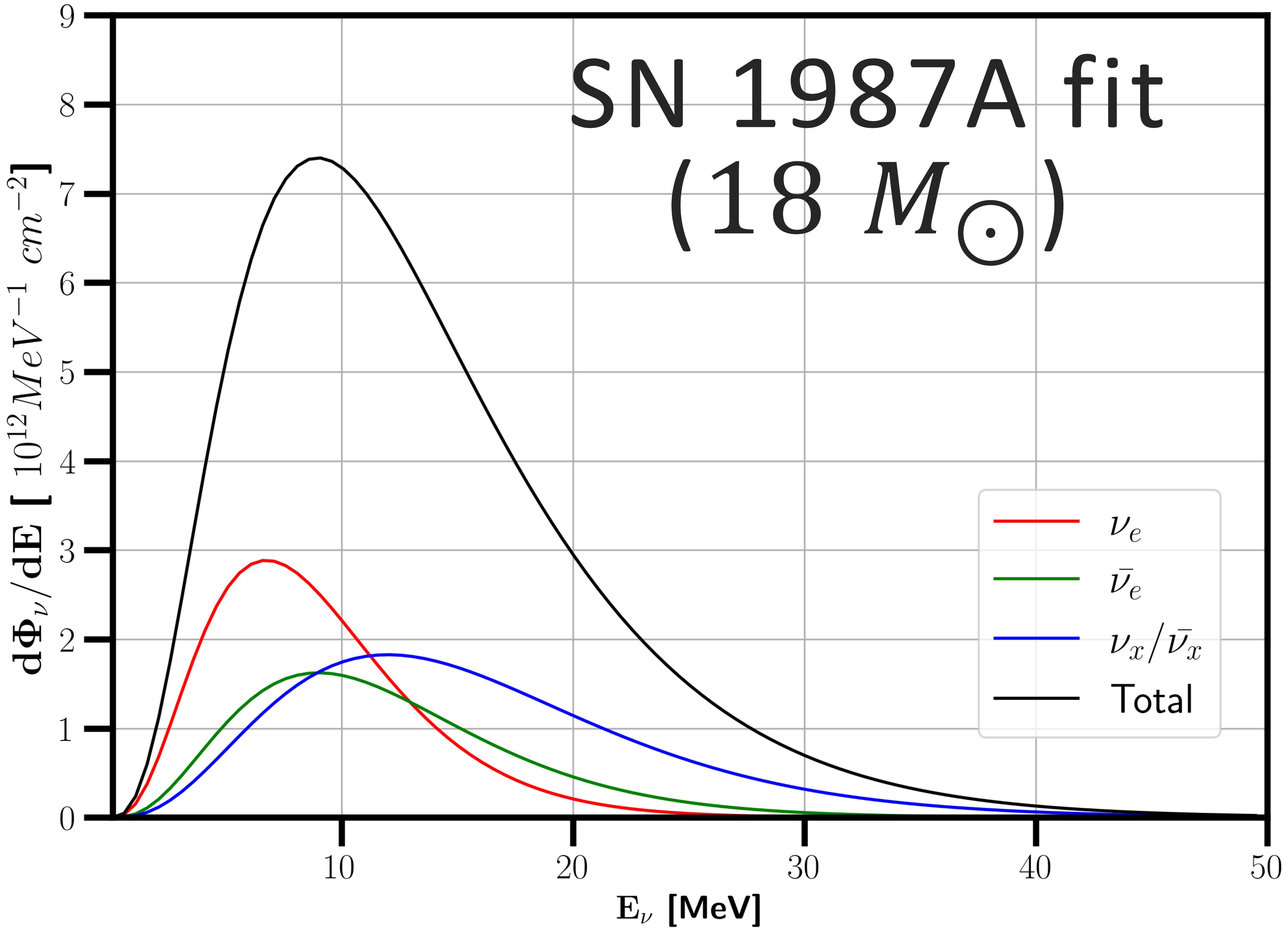
Supurio et. Al. 2018

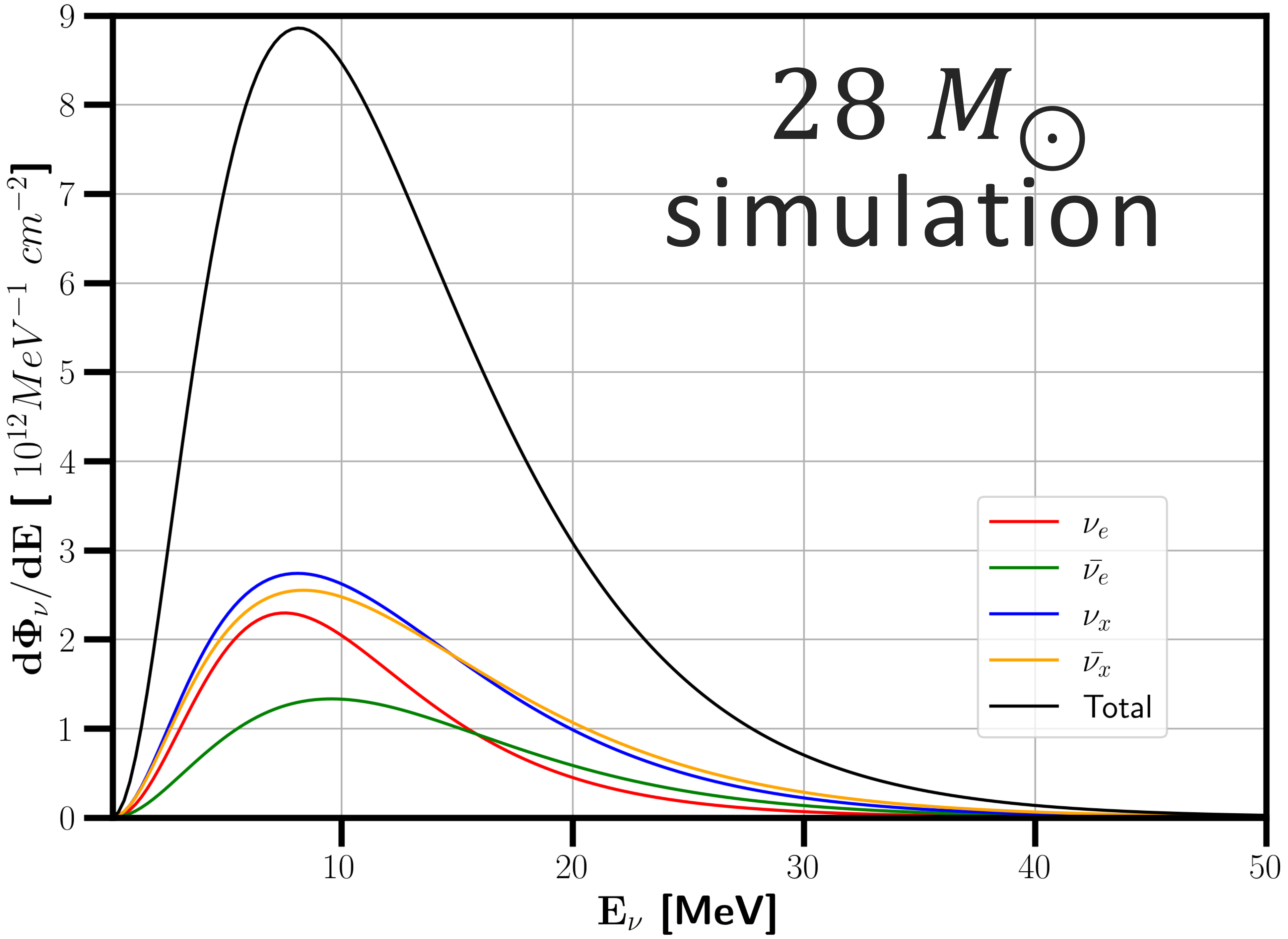
Modeling

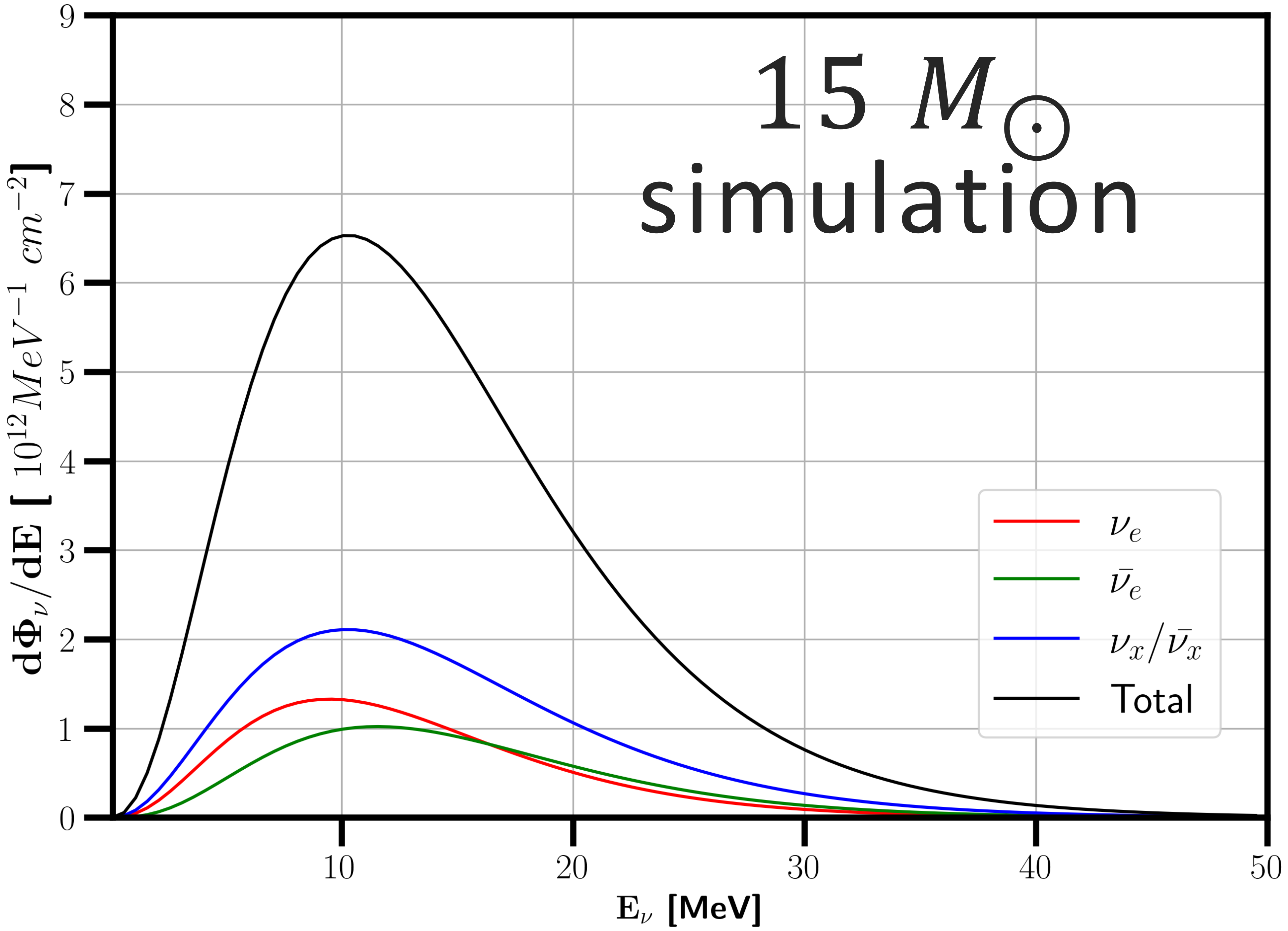
Modeling

- "Very crudely, a SN core is a black-body source of neutrinos of all flavors" [10]
- Neutrino opacity processes give place to the pinching of the curve.
- Quasi-termal emission model for neutron star SN: $8M_{\odot} < M_p^* < 20M_{\odot}$
- Simulation for Black Hole SN $M_p > 20M_{\odot}$

$^*M_p$: progenitor mass







SN neutrino differential spectrum (1 kpc*)

$$\frac{d\Phi_i}{dE} \propto \frac{E_S}{4\pi d^2} \frac{E^\alpha}{\langle E_i \rangle^{\alpha+2}} e^{-\frac{(1+\alpha)E}{\langle E_i \rangle}}$$

*1 kpc = 3261.56 ly

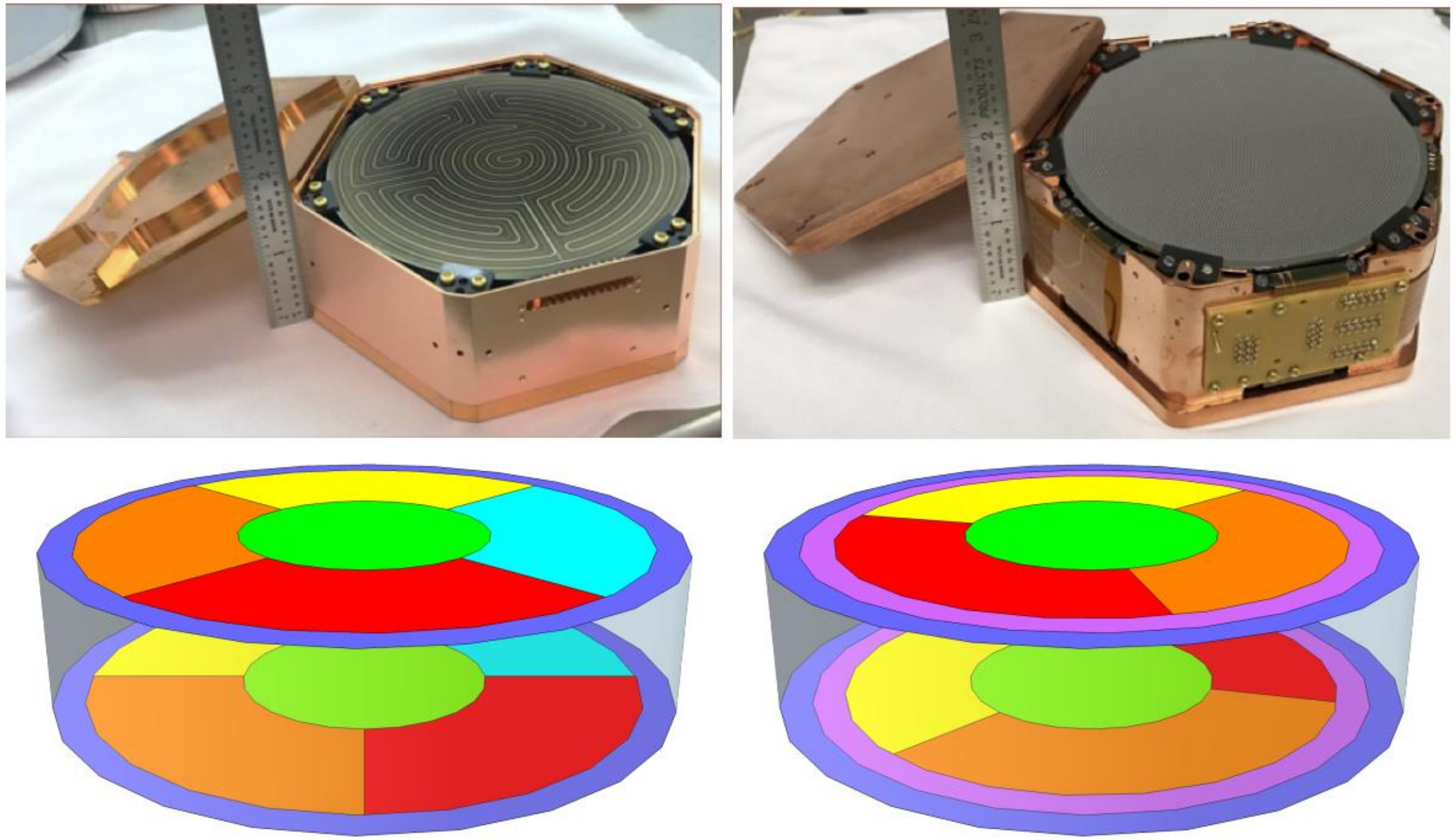
Cryogenic detectors

Cryogenic detectors

SuperCDMS: Dark Matter search at SNOLAB

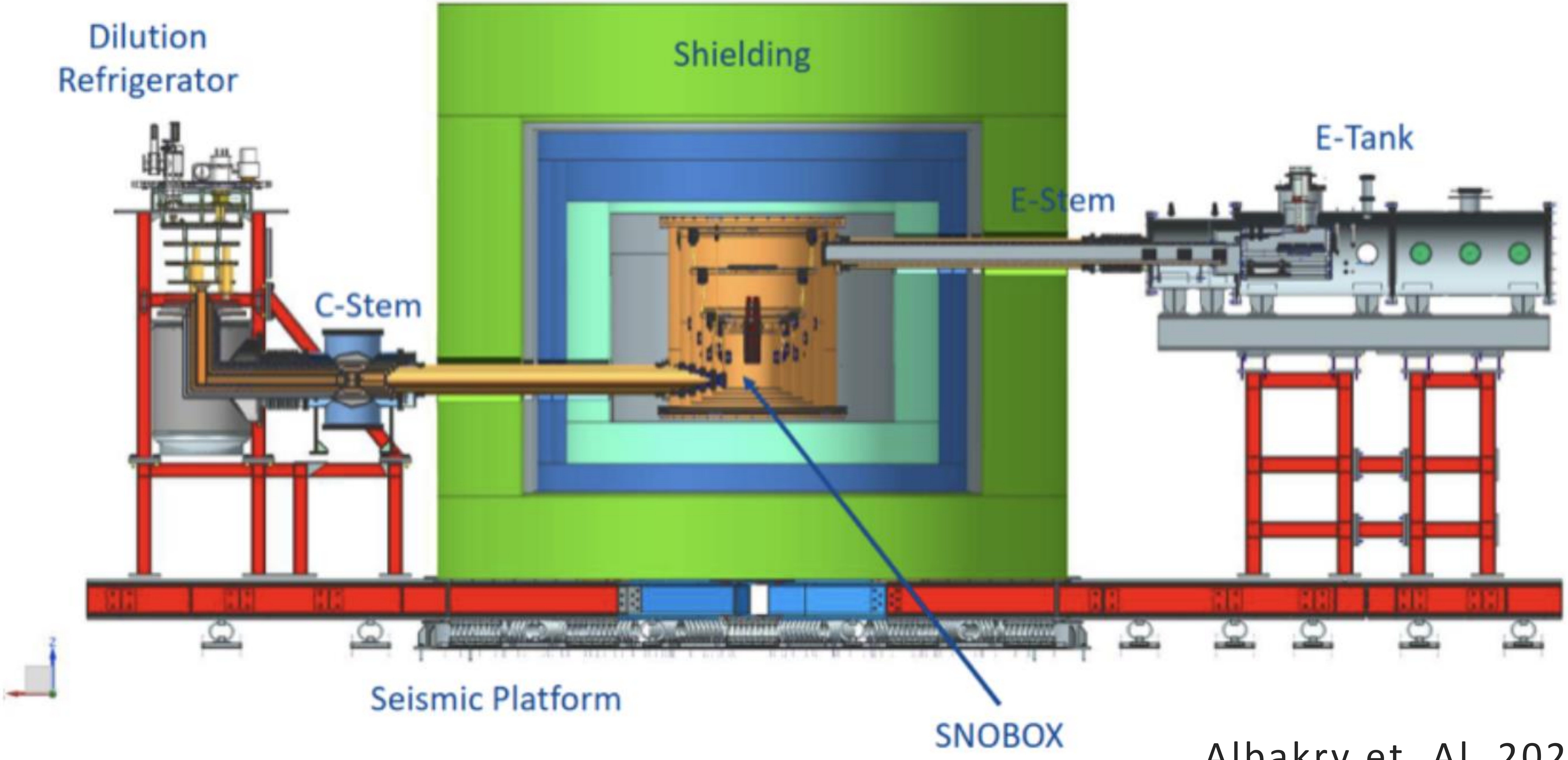
- Dilution refrigerator as cryogenic system (~10 mK)
- Silicon or Germanium detectors
- Superconducting aluminum collectors
- Transition Edge Sensors (TES)

iZIP HV



Albakry et. Al. 2023

Cryogenic detectors



Albakry et. Al. 2023

Cryogenic detectors

SuperCDMS: Dark Matter search at SNOLAB

- TES used to detect the phonons produced in the substrate
- Phonon resolution for Si (Ge) of 13(34) eV
- Uses a trigger system for data adquisition
- Total latency for the triggers ~ 26 ms

Cryogenic detectors

SuperCDMS

	HV		iZIP	
	Si	Ge	Si	Ge
Phonon resolution (eV)	13	34	19	33
Module mass (kg)	0.61	1.39	0.61	1.39
Number of detectors	4	8	2	10

Resolution: $\sim 5\sigma$ of the noise signal

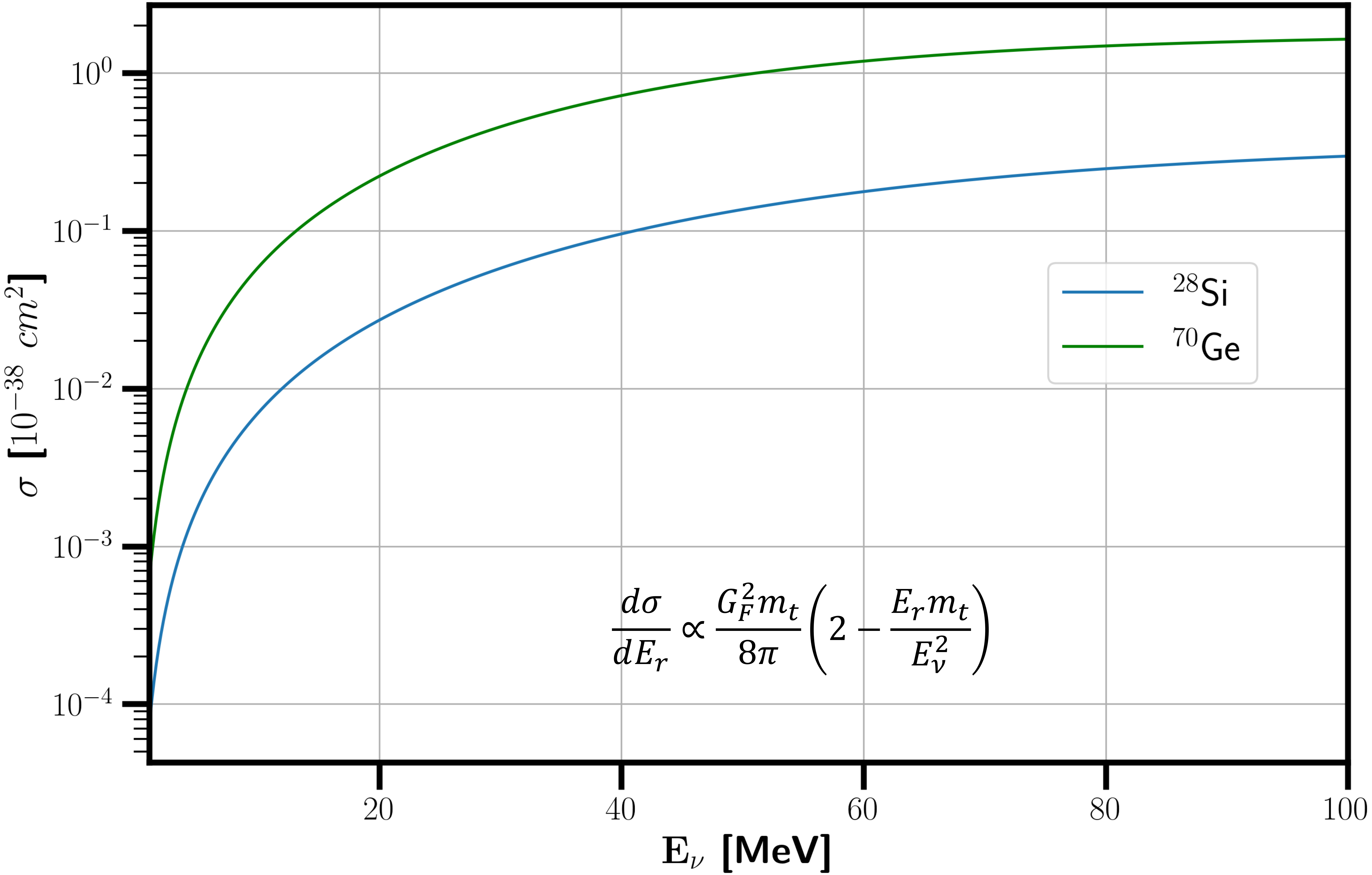
Coherent Elastic Neutrino-Nucleus Scattering (CEνNS)

CEνNS

- Neutrinos have weak interactions with nuclei
- CEνNS is a neutral current process.
- Interactions of neutrinos with nuclei produce recoil.

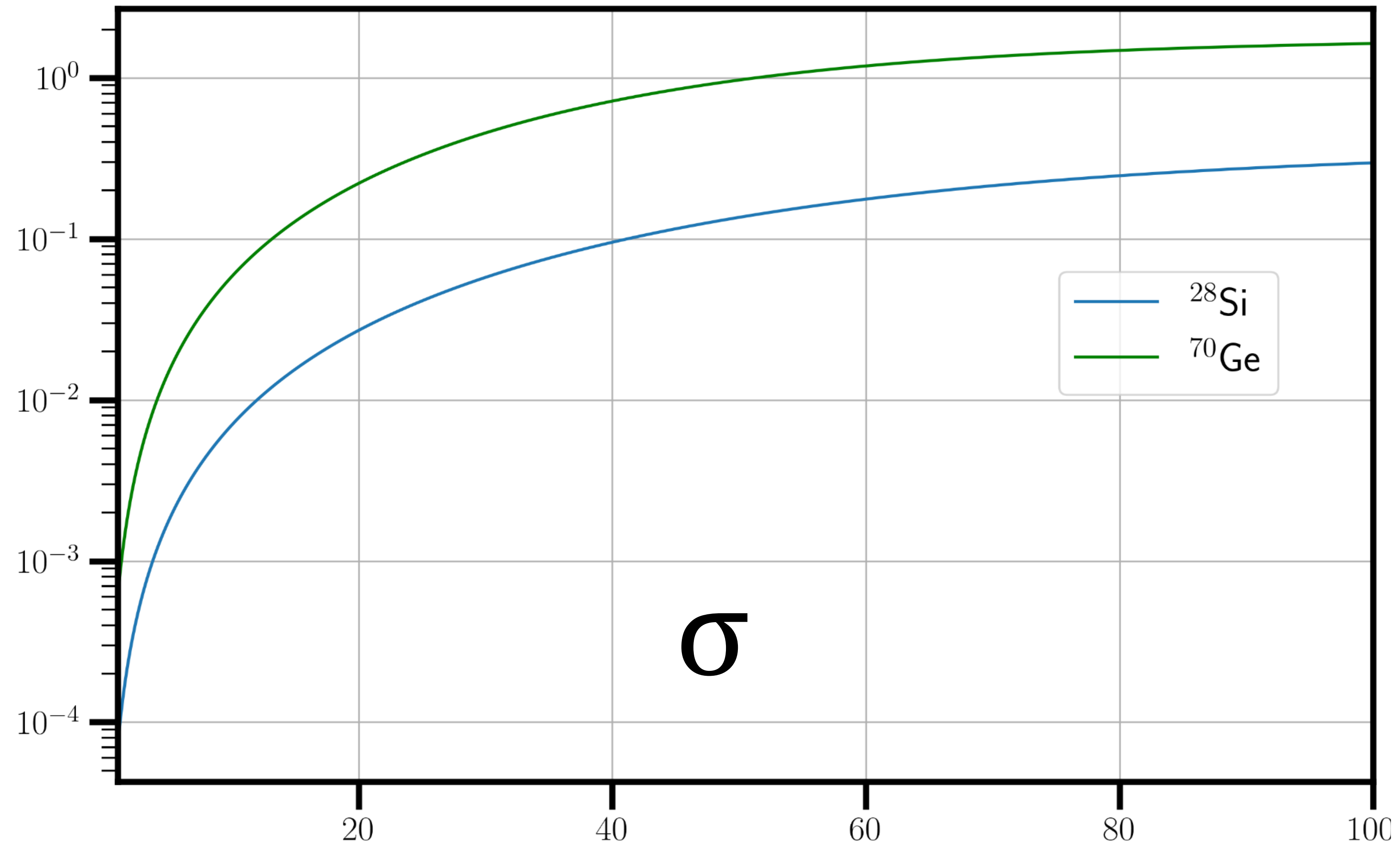
$$\frac{dR}{dE_r} = \int_{E_\nu^m} \frac{d\sigma}{dE_r} \frac{d\Phi}{dE_\nu} dE_\nu$$

Energy dependent cross-section

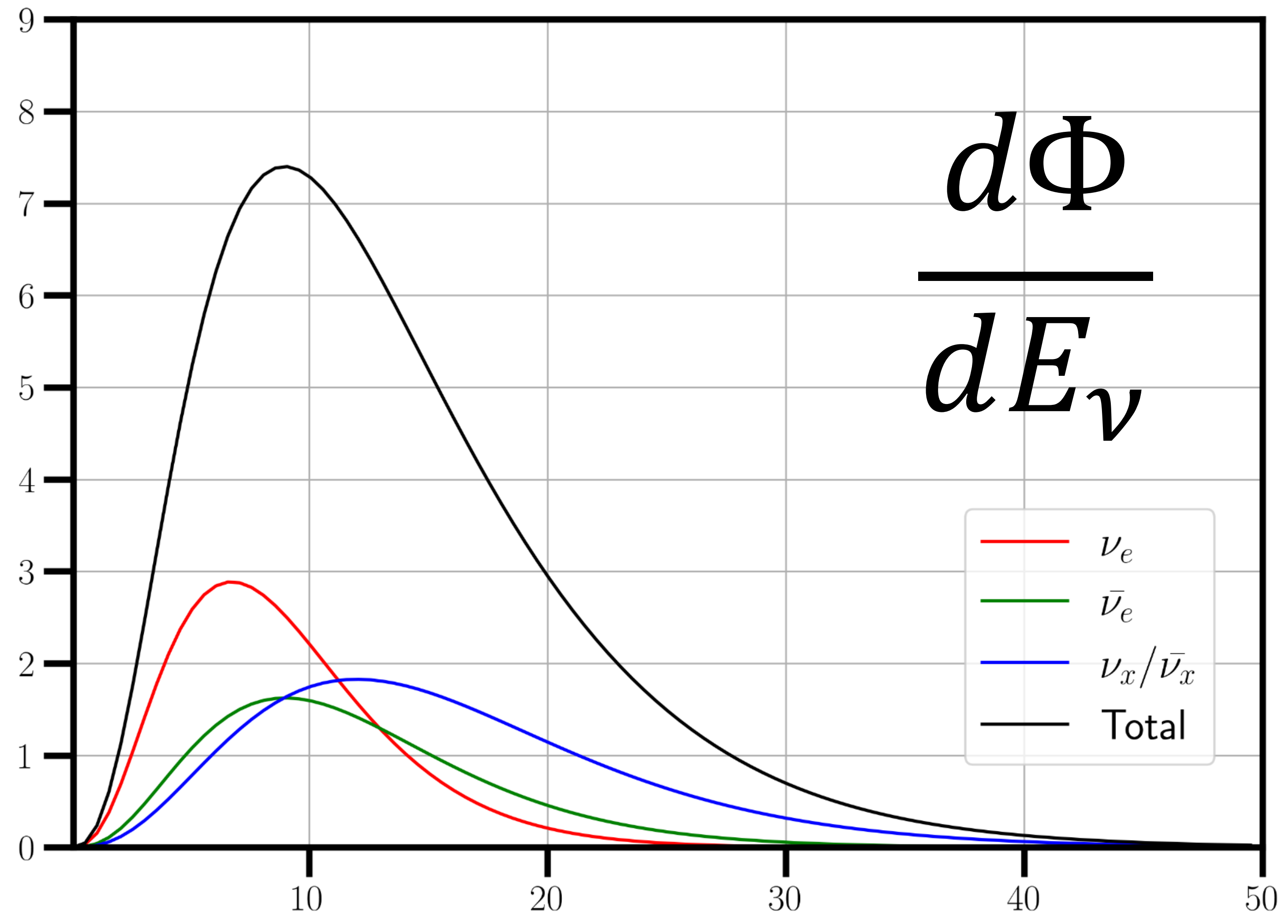


Recoil Spectrum

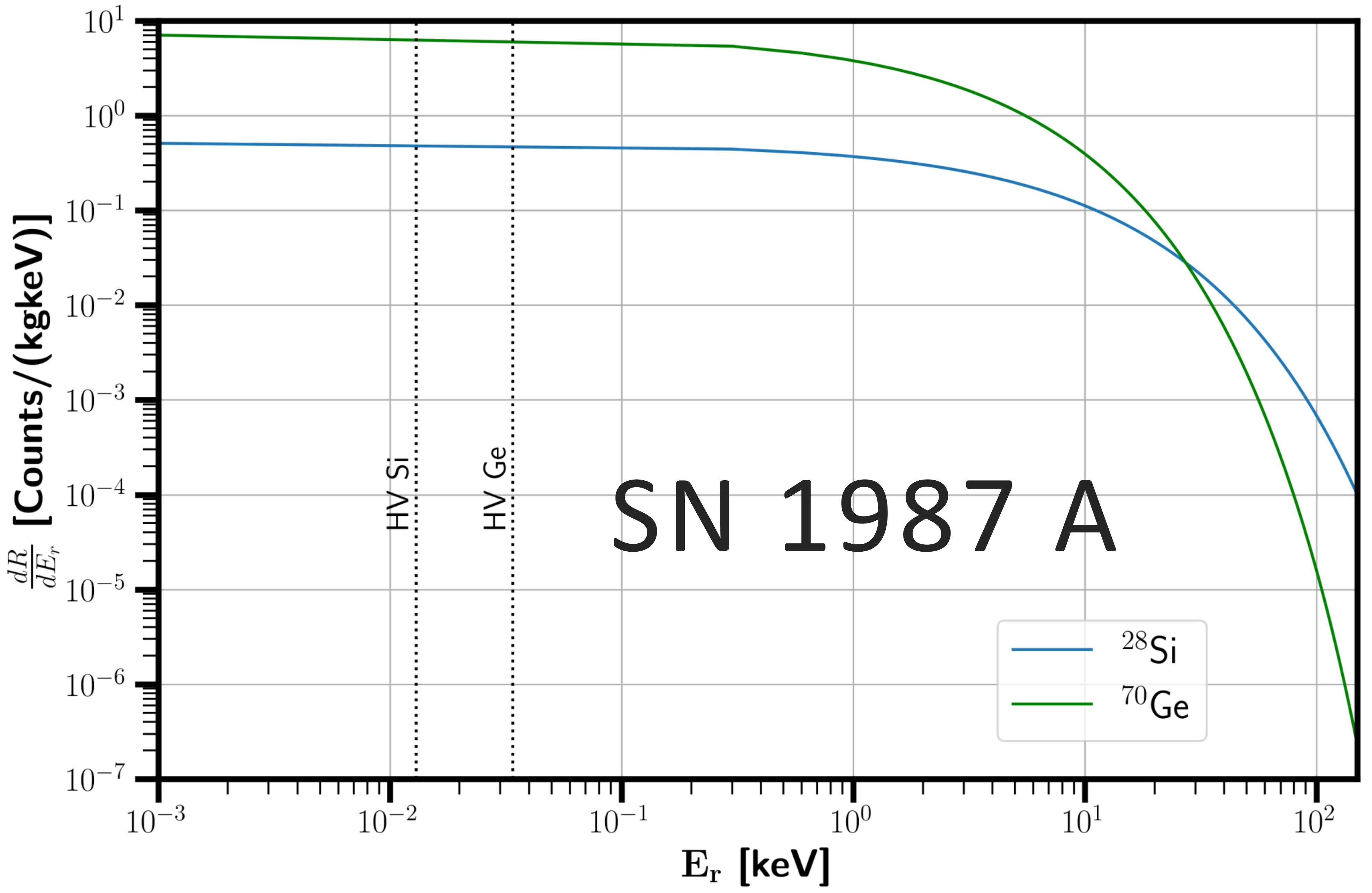
$$R = \int_{E_\nu^m} dE_\nu$$

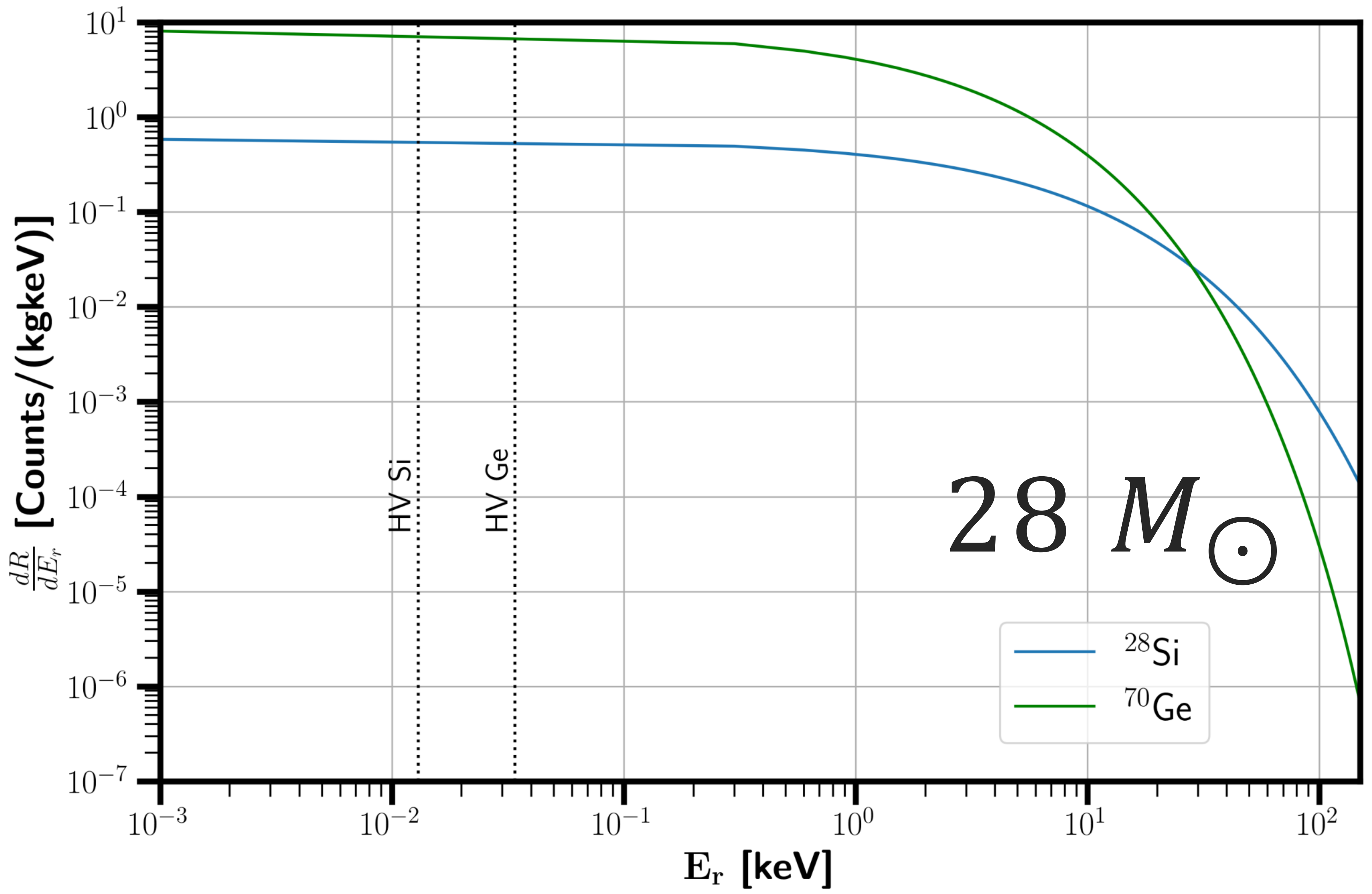


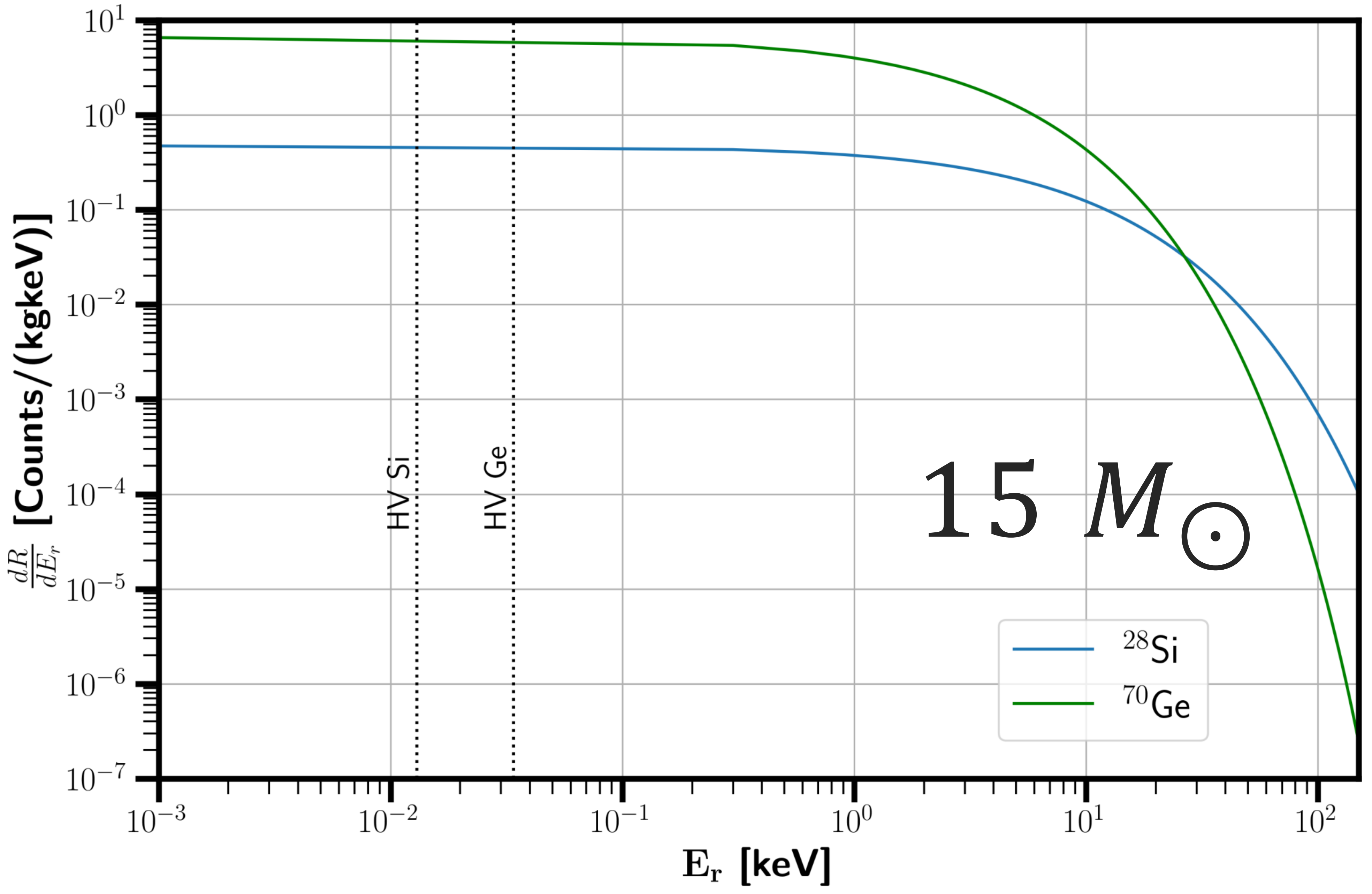
$\times$



Recoil spectrum





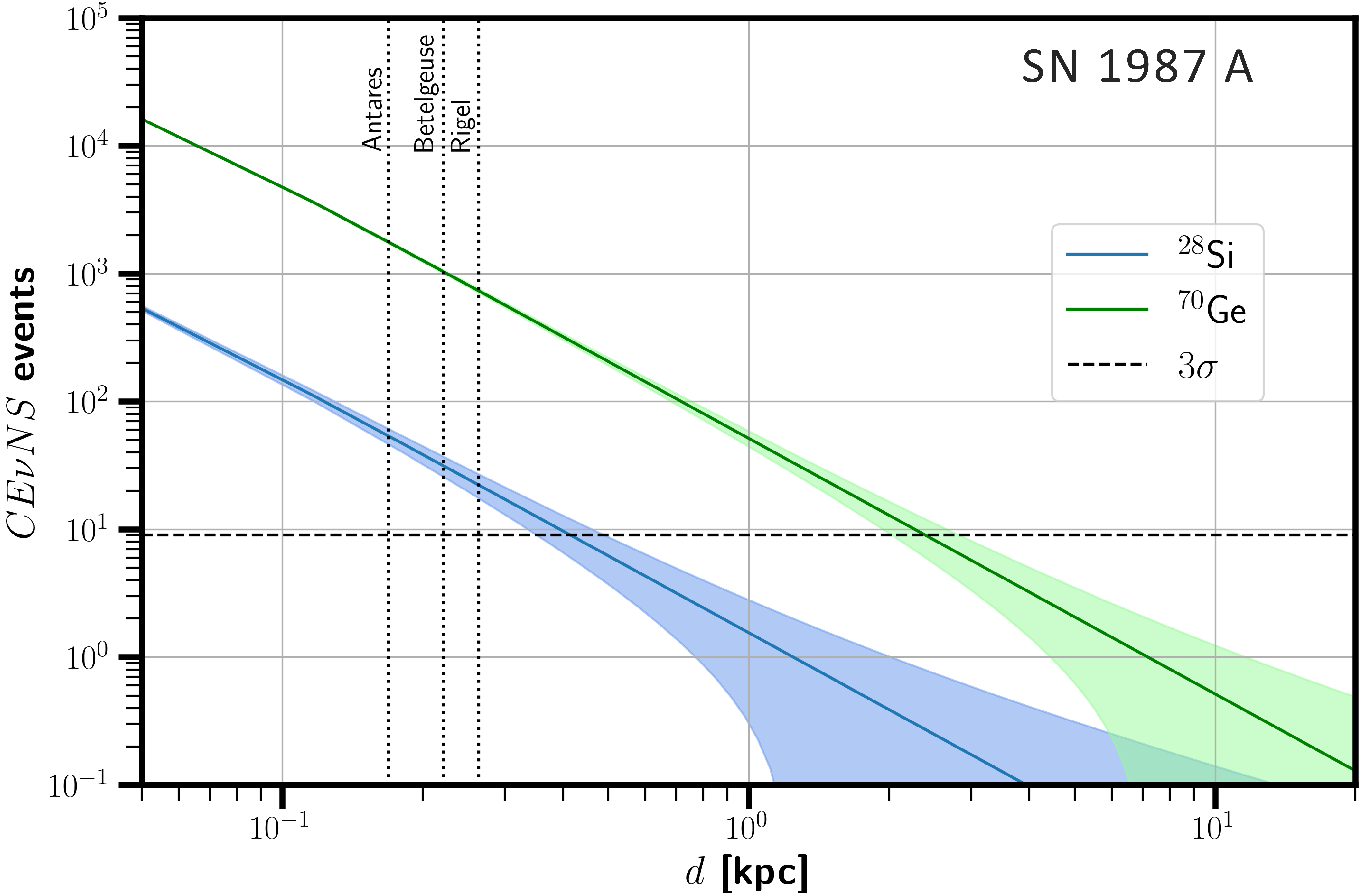


Results

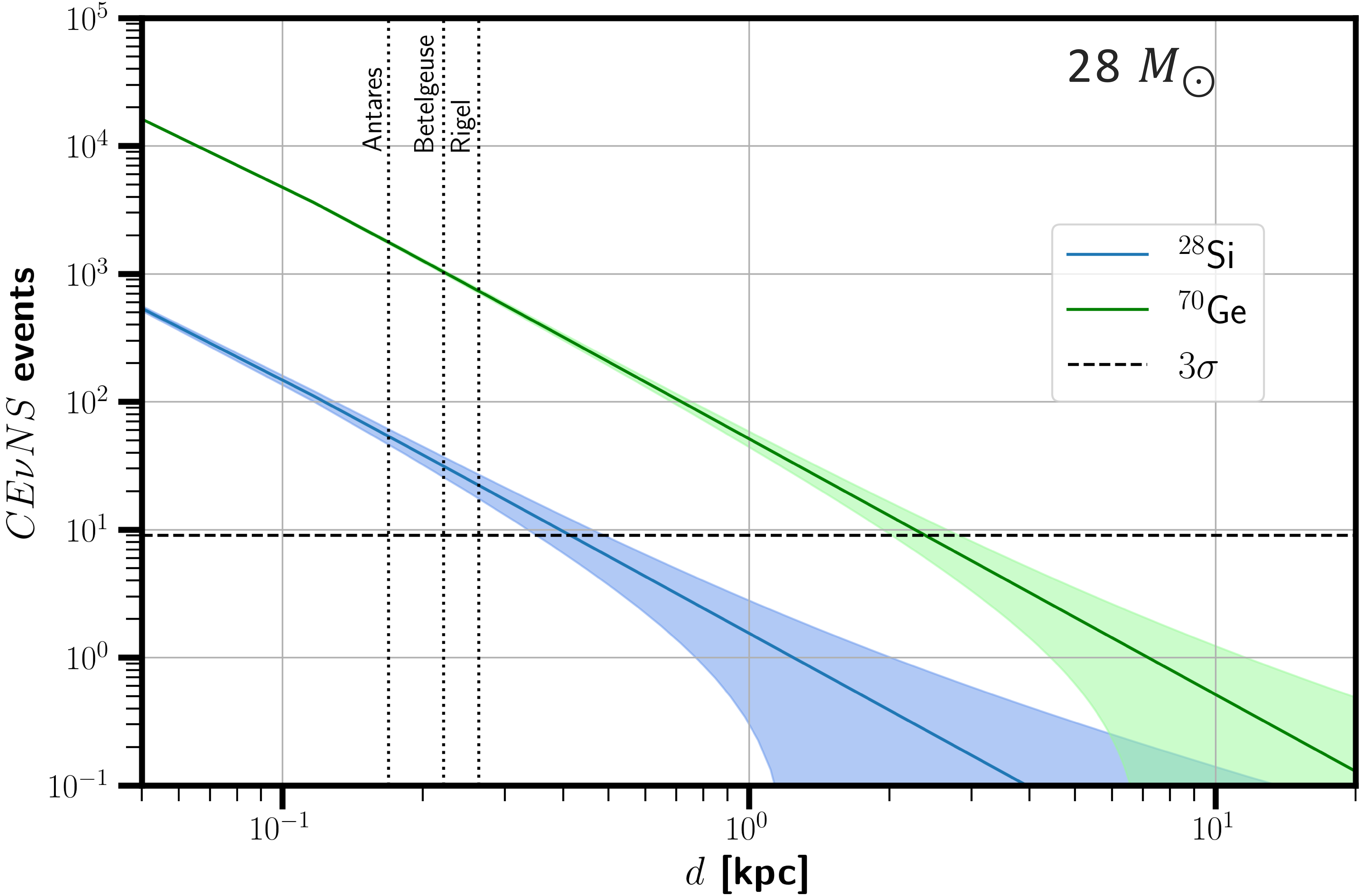
Results

Number of events

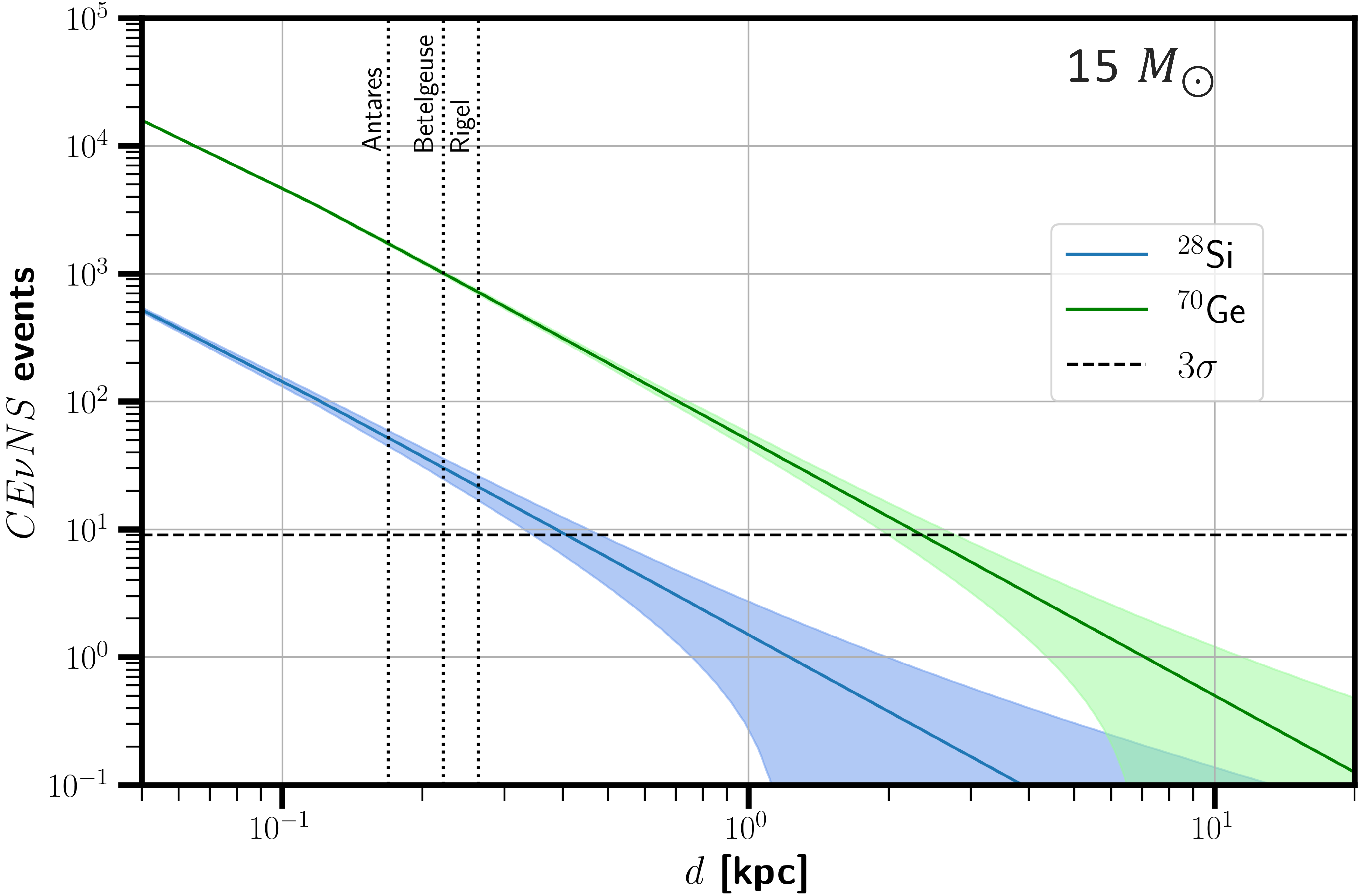
- Different energy thresholds and masses for IZIP and HV detectors and also by substrate (Si and Ge)
- Event pileup probability due to trigger latency $\sim 1 - e^{-N}$
- Discovery potential (3σ) set assuming zero background events



SN 1987 A
Antares
Betelgeuse
Rigel
^{28}Si
^{70}Ge
3σ
$CE\nu NS$ events
d [kpc]
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-1}
10^{0}
10^{1}



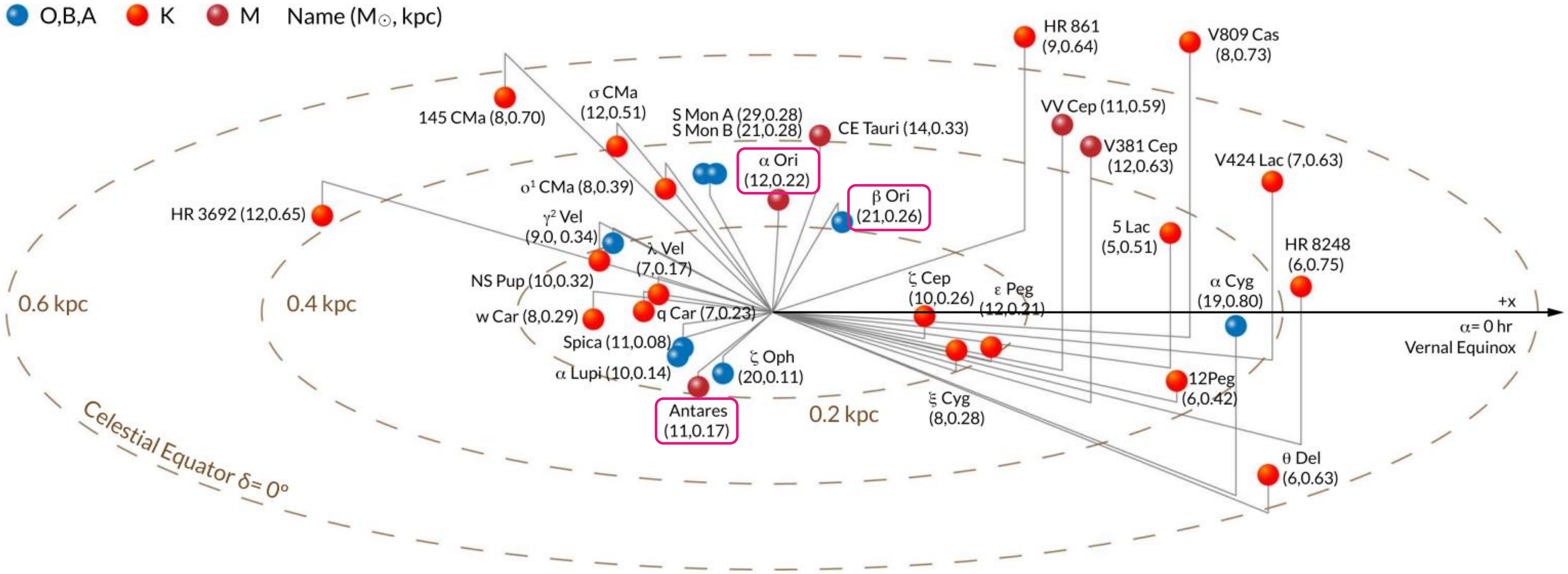
28 $M_\odot$
^{28}Si
^{70}Ge
3σ
Antares
Betelgeuse
Rigel
$CE\nu NS$ events
d [kpc]
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}


15 $M_\odot$
Antares
Betelgeuse
Rigel
^{28}Si
^{70}Ge
3σ
$CE\nu NS$ events
d [kpc]
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-1}
10^0
10^1

Results

	Substrate	Distance (kpc)
SN 1987 A	Si	$0.40^{+0.07}_{-0.06}$
	Ge	$2.37^{+0.43}_{-0.36}$
$28\ M_\odot$	Si	$0.41^{+0.07}_{-0.06}$
	Ge	$2.45^{+0.44}_{-0.37}$
$15\ M_\odot$	Si	$0.40^{+0.07}_{-0.06}$
	Ge	$2.41^{+0.43}_{-0.37}$

Pre-SN candidates closer than 1 kpc



Mukhopadhyay et. al. 2020

Summary

Summary

SNOLAB

- Supernovae is when stars more massive than $8M_{\odot}$ explode forming a neutron star or a black hole
- Neutrinos are one of the most important messengers about SN and can be detected by CEνNS
- SuperCDMS could be capable of detecting the occurrence of SN up to **2.45 kpc** with the proposed thresholds and models
- A great number of SN events closer than 1 kpc could be observed by SuperCDMS
- Even if event pileup probability is considered, only lower distances are affected
- The greatly reduced threshold of the SuperCDMS detectors and its high target mass contribute to the detection sensitivity.

Thank you!

References

[1] Abdullah M., Dent J. B., Dutta B., Kane G. L., Liao S., Strigari L. E., 2018, Phys. Rev. D, 98,
015005
[2] Abdullah M., et al., 2022, Coherent elastic neutrino-nucleus scattering: Terrestrial and
astrophysical applications (arXiv:2203.07361), https://arxiv.org/abs/2203.07361
[3] Agnese R., et al., 2017, Physical Review D, 95
[4] Angeli I., Marinova K., 2013, Atomic Data and Nuclear Data Tables, 99, 69
[5] Biassoni M., Martinez C., 2012, Astroparticle Physics, 36, 151–155
[6] Burrows A., Vartanyan D., 2021, Nature, 589, 29–39
[7] Collaboration S., et al., 2023, A Strategy for Low-Mass Dark Matter Searches with Cryogenic
Detectors in the SuperCDMS SNOLAB Facility (arXiv:2203.08463),
https://arxiv.org/abs/2203.08463

References

[8] Freedman D. Z., 1974, Phys. Rev. D, 9, 1389
[9] Halim O., Casentini C., Drago M., Fafone V., Scholberg K., Vigorito C. F., Pagliaroli G., 2021,
Journal of Cosmology and Astroparticle Physics, 2021, 021
[10] Keil M. T., Raffelt G. G., Janka H., 2003, The Astrophysical Journal, 590, 971–991
[11] K˙onig K., et al., 2023, Nuclear charge radii of silicon isotopes (arXiv:2309.02037), https://arxiv.org/abs/2309.02037
[12] Mukhopadhyay M., Lunardini C., Timmes F. X., Zuber K., 2020, The Astrophysical Journal,
899, 153
[13] Pagliaroli G., Ternes C. A., 2024, Observing neutrinos from failed Supernovae at LNGS
(arXiv:2403.06678), https://arxiv.org/abs/2403.06678
[14] Ruso L. A., et al., 2022, Theoretical tools for neutrino scattering: interplay between lattice
QCD, EFTs, nuclear physics, phenomenology, and neutrino event generators
(arXiv:2203.09030), https://arxiv.org/abs/2203.09030

References

[15] Spurio M., 2018, Probes of multimessenger astrophysics: Charged cosmic rays, neutrinos,
Y-rays and gravitational waves. Springer
[16] Tamborra I., M˙uller B., H˙udepohl L., Janka H.-T., Raffelt G., 2012, Physical Review D, 86
[17] Tamborra I., Hanke F., M˙uller B., Janka H.-T., Raffelt G., 2013, Physical Review Letters, 111
[18] Wang S., et al., 2024, Physics Letters B, 856, 138867
[19] Wilson J., et al., 2022, Journal of Instrumentation, 17, P07010