CEvNS for Nuclear Security

MTV Workshop, 2020

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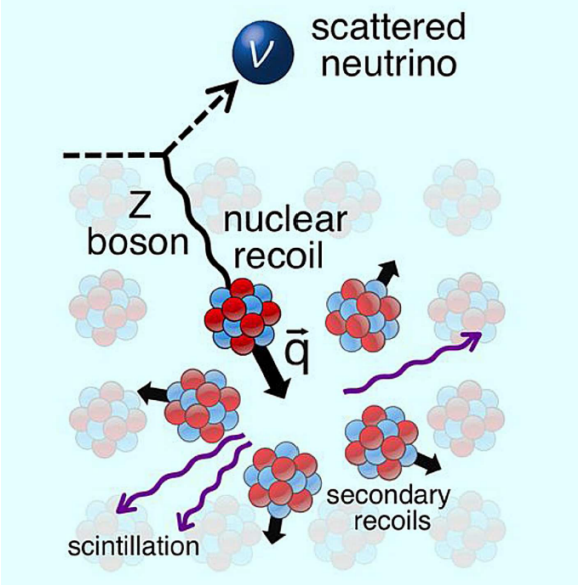
Introduction and Motivation



- Coherent Elastic Neutrino Nucleus Scattering (CEvNS) is the new kid on the block, first measured in 2017.
- Large cross section (for neutrinos), threshold-less reaction.
- Handheld neutrino detectors?

Mission Relevance

- Small (sub-ton) neutrino detectors would greatly enhance the deployment options for reactor monitoring
- Detection of neutrinos below inverse beta decay (IBD) threshold would enhance the ability to detect reprocessing waste and plutonium breeding

(Cogswell, PH, 2016)

$$^{238}\mathrm{U} + n \longrightarrow {}^{239}\mathrm{U} \xrightarrow{\beta^-} {}^{239}\mathrm{Np} \xrightarrow{\beta^-} {}^{239}\mathrm{Pu}$$

Emits neutrinos of 1.2 MeV – invisible to IBD detectors

Technical Approach

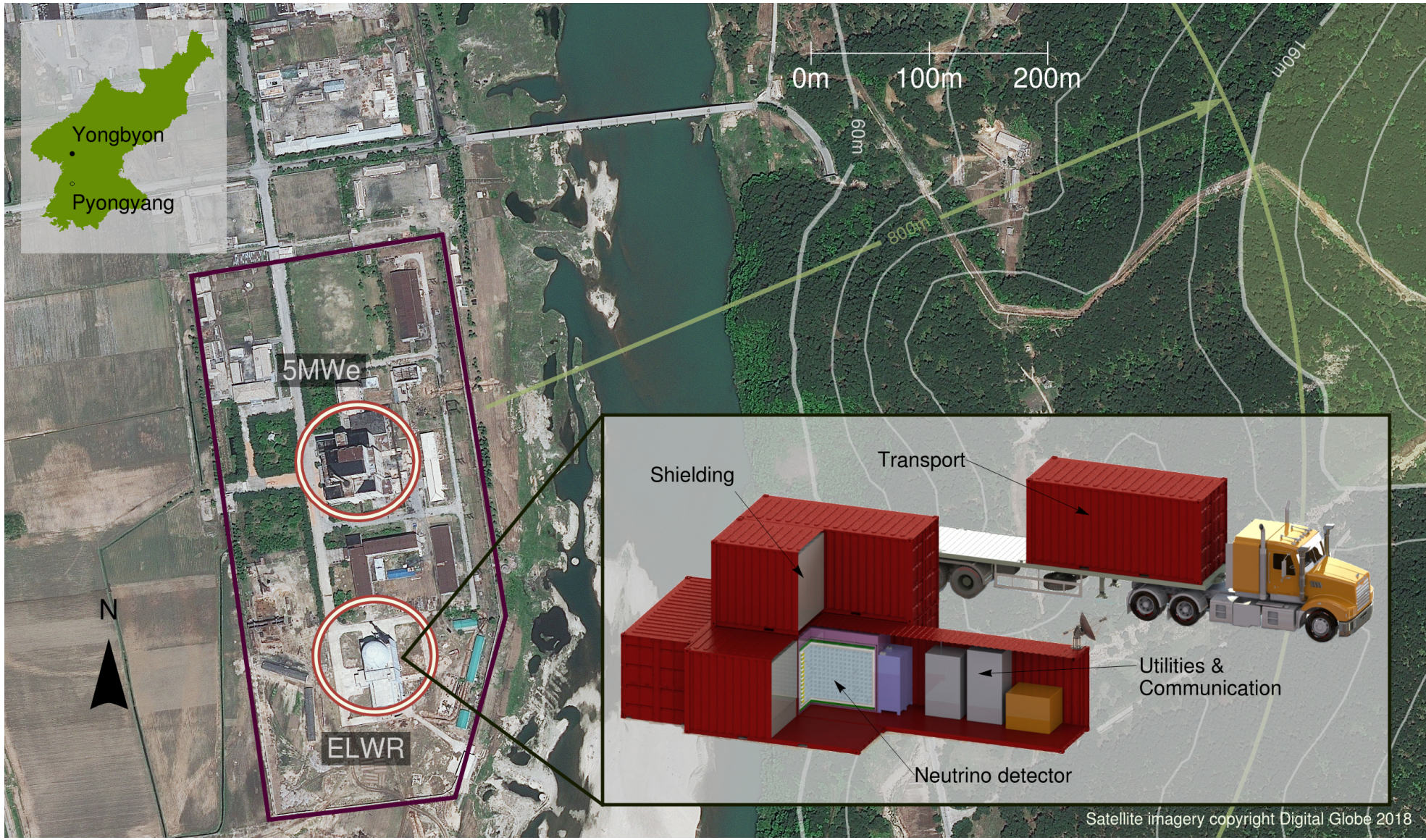
- Comparison with demonstrated capabilities of IBD detectors
- Use PROSPECT as benchmark
- LLNL is heavily involved in PROSPECT (co-spokesperson)
- ORNL is host to PROSPECT and COHERENT
- Major contributions by VT NSF REU student

  Maitland Bowen (U. Michigan)

DPRK 2018

20+ international neutrino detection experts came together to assess how current IBD technology could be used in a future nuclear agreement.

(Carr et al., 2018)



Reactor status

- Is the reactor running?
- Use PROSPECT performance as benchmark
- Includes measured backgrounds

5MWe	IR40	ELWR
1.2d	8 h	1.5 h

Time to detection at 95% C.L.

Reactor fissile inventory

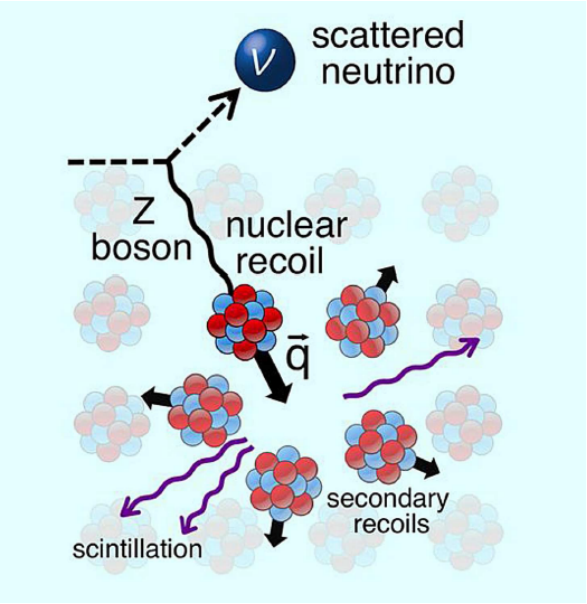
- Has a high-Pu content core been swapped against a fresh one?

BG level	ELWR	IR40	5MWe
1	134	109	1154
0.5	83	59	830
0.2	56	30	637
0	45	16	527

Days to detection at 95% C.L.

- Requires 6 times the detector mass of PROSPECT (12t)

CEvNS



CevNS is threshold-less

$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi} N^2 M_N \left(1 - \frac{M_N T}{2E_\nu^2}\right)$$

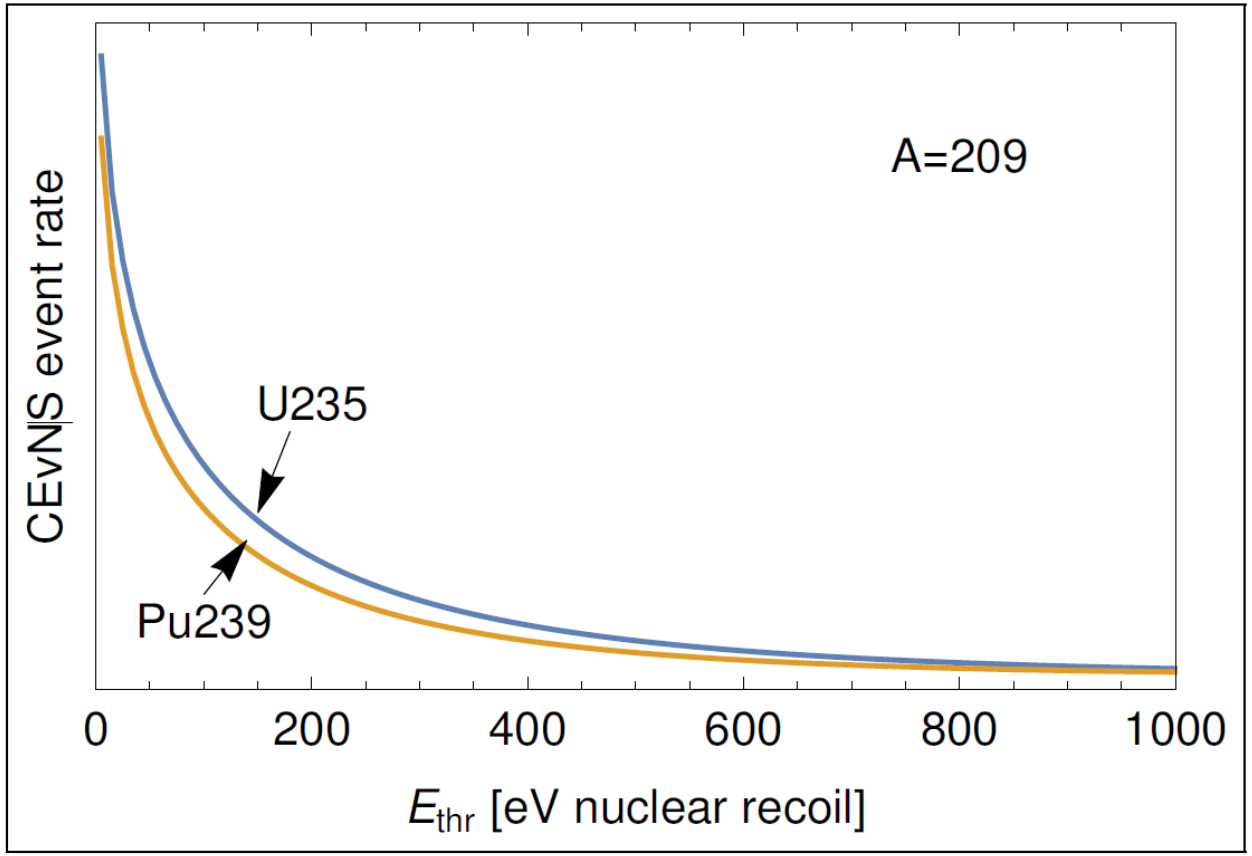
T recoil energy, N neutron number

Threshold in eV for parity in event rate per unit mass with IBD

^{12}C	^{20}Ne	^{28}Si	^{40}Ar	^{74}Ge	^{127}I	^{132}Xe	^{133}Cs
790	770	702	672	491	353	347	343

CEvNS energy spectrum

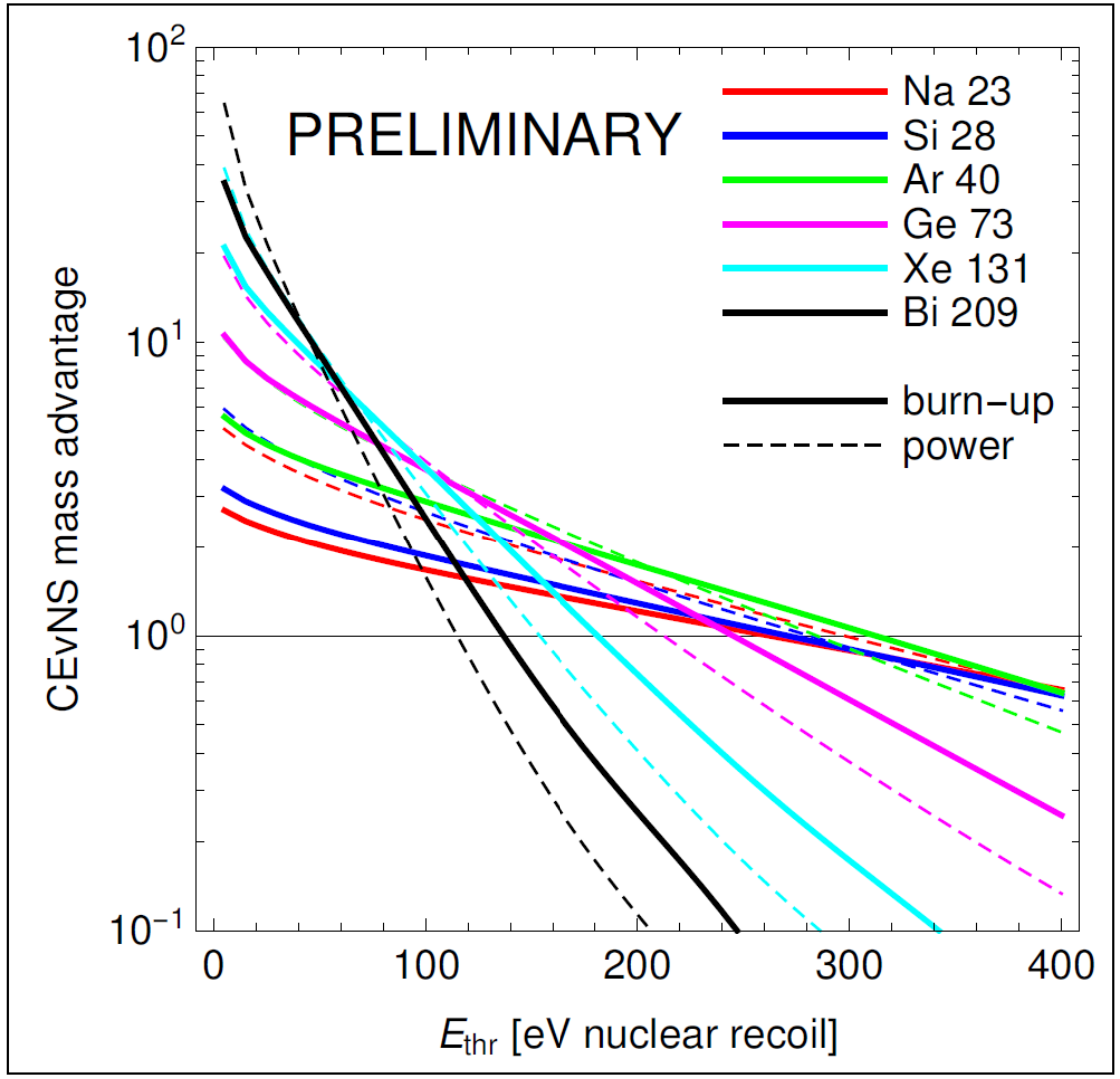
- Different fissile produces a different neutrino spectrum
- Difference persists in detection



Mass advantage

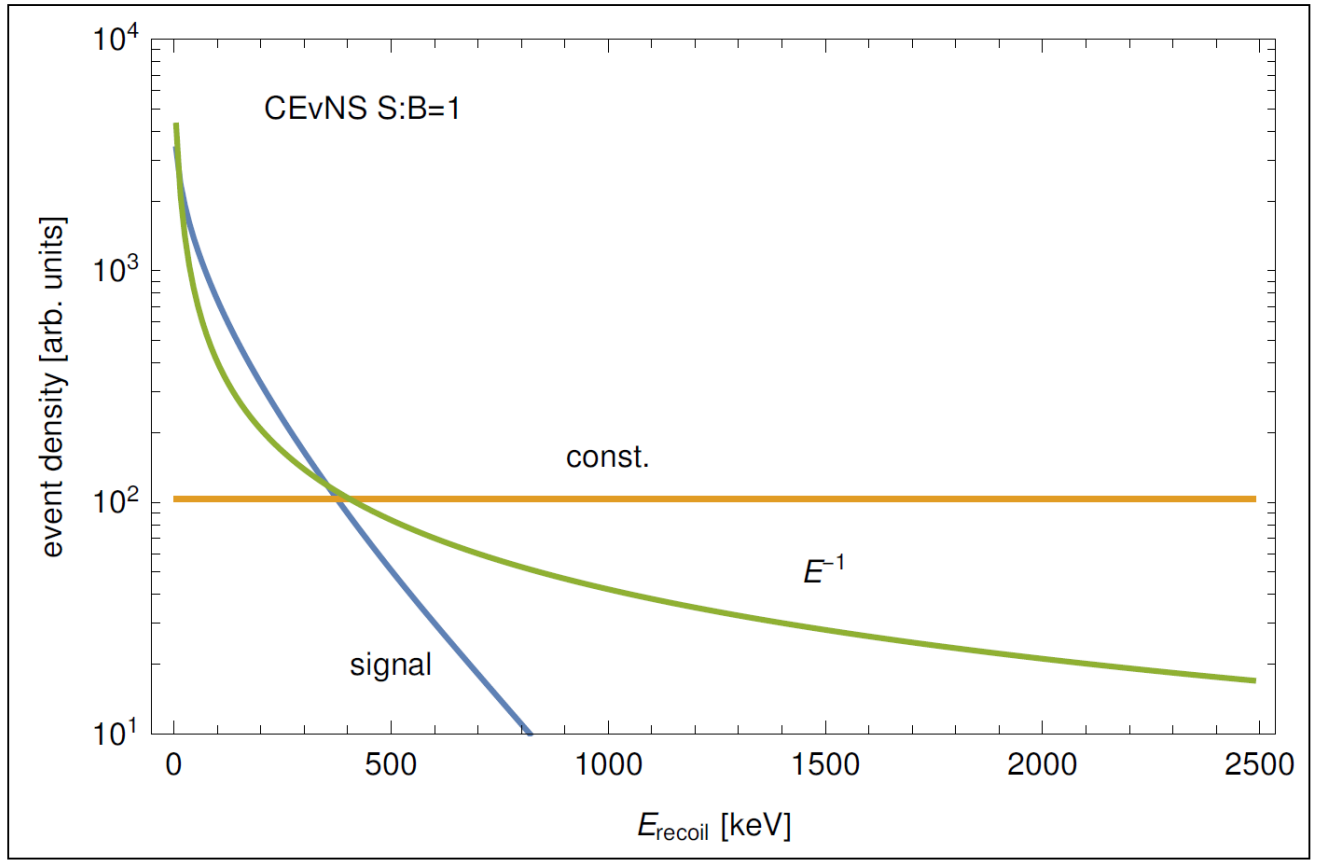
- Even at 5eV threshold:
  0.6t Xe for core swap
  50kg Xe for reactor power

- Assumes zero background



CEvNS background

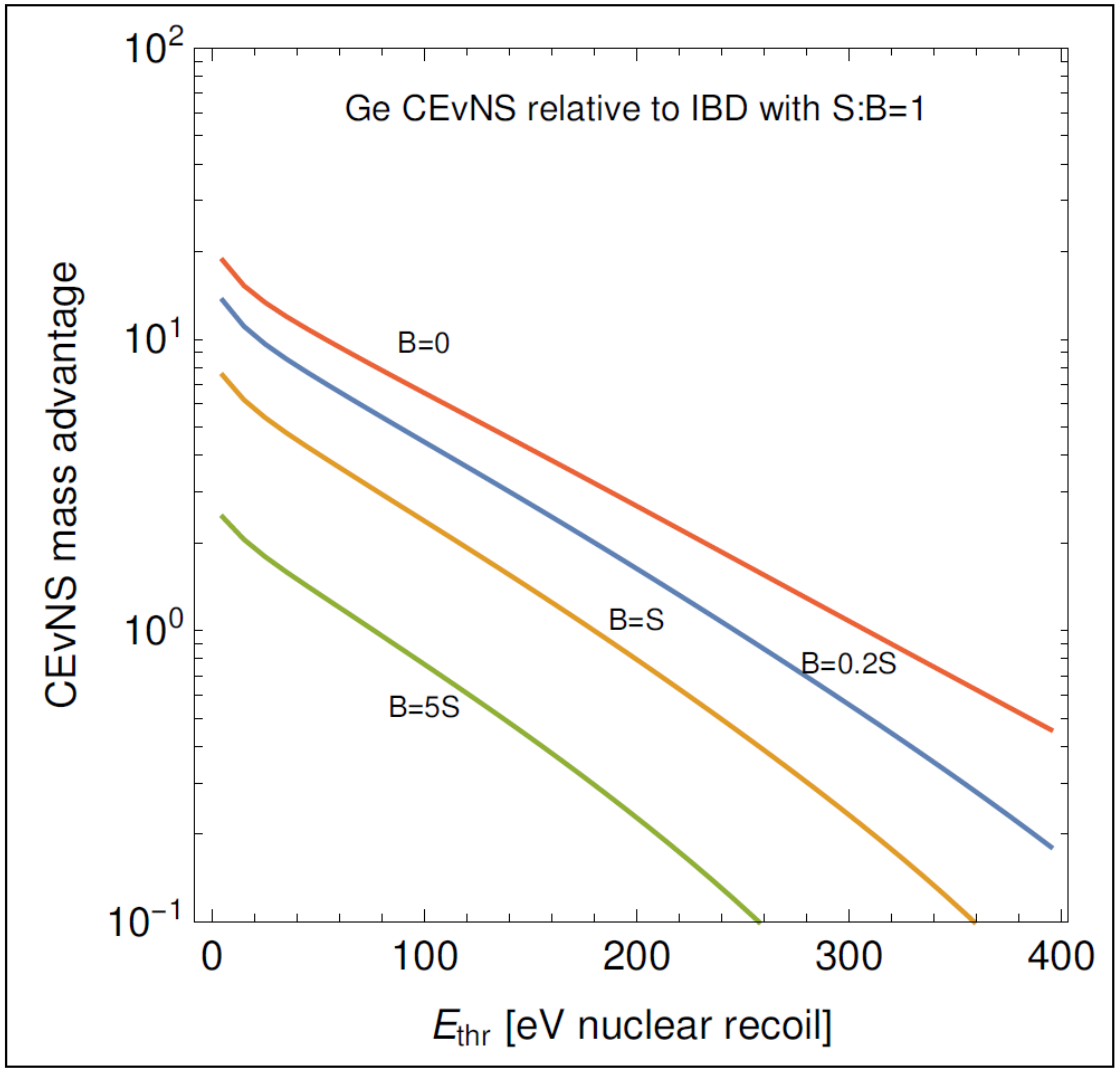
- CEvNS at reactor yet to be observed
- Educated guess as to BG shape
- Magnitude still unknown



$$S : B = 1 \Rightarrow \text{approx. } 20\,\mathrm{d}^{-1}\,\mathrm{keV}^{-1}\,\mathrm{kg}^{-1}$$

CEvNS with BG

- 1/E background worst case, but not unlikely
- Already for B=5S, no advantage relative to IBD



Conclusion & next steps

- CEvNS at reactors needs to be demonstrated
- Significant R&D needed to match IBD capabilities
- No handheld neutrino detectors soon!
- Evaluation of the current global detector R&D program vis a vis nuclear security applications:

Are we looking at the right technologies?

Acknowledgements

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