PIRE

GEMADARC

Ge detectors in COHERENT

Keyu Ding

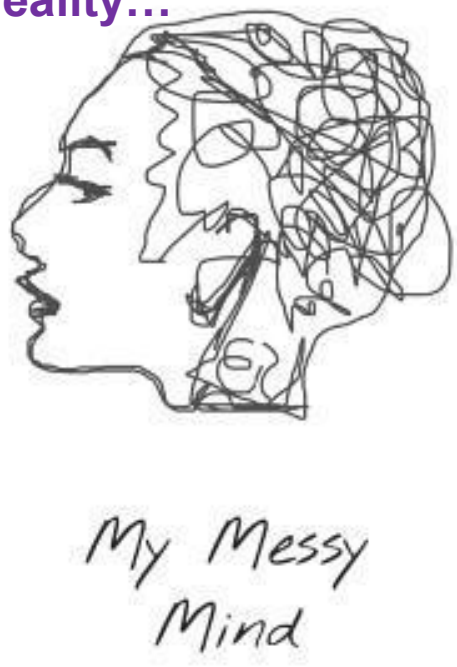
June 1, 2023

UNIVERSITY OF SOUTH DAKOTA

Neural networks try to simulate the brain by processing data through layers of artificial neurons.

Neutrinos

In reality…

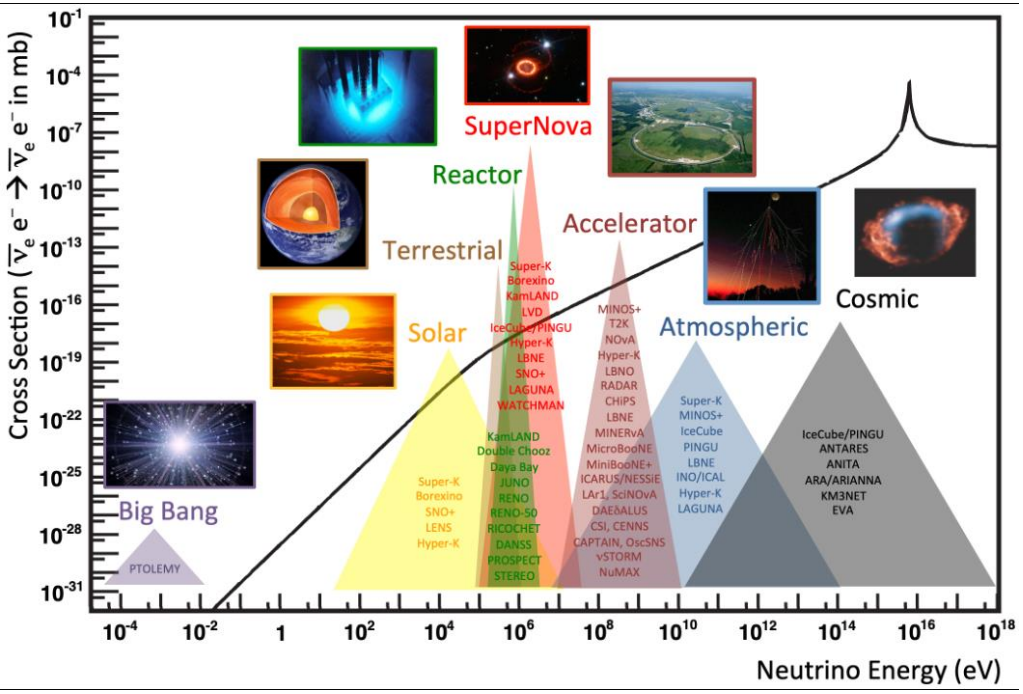


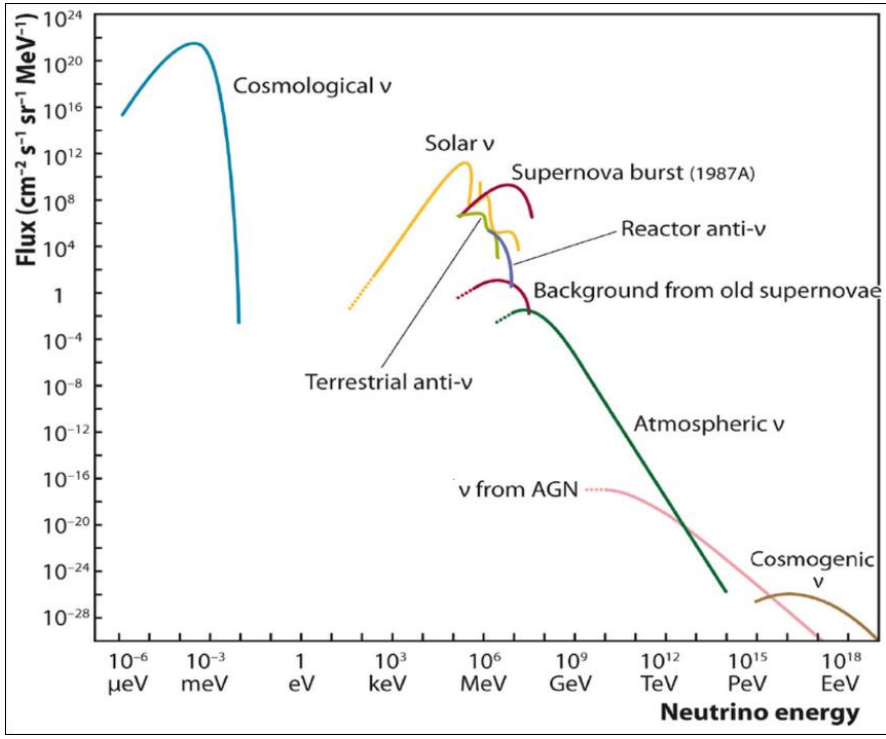
Neutrino sources

Grand Unified Neutrino Spectrum at Earth
Edoardo Vitagliano, Irene Tamborra, Georg Raffelt. Oct 25, 2019. 54 pp.
MPP-2019-205
e-Print: arXiv:1910.11878 [astro-ph.HE] | PDF

Event rate $R = \Phi \, \sigma \, N_t$

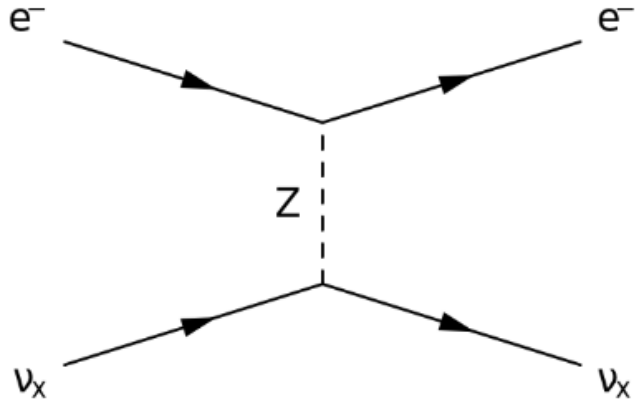
Flux · Cross section · Number of targets

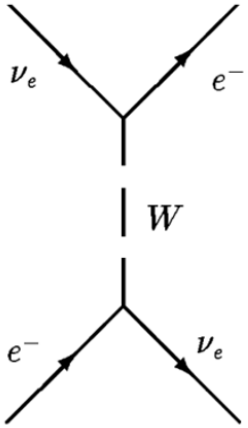


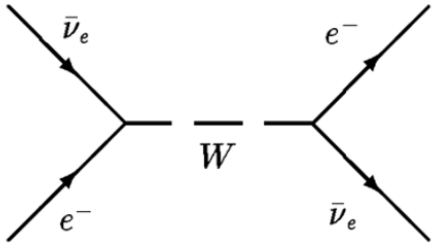


Neutrino interactions with matter

- Electron



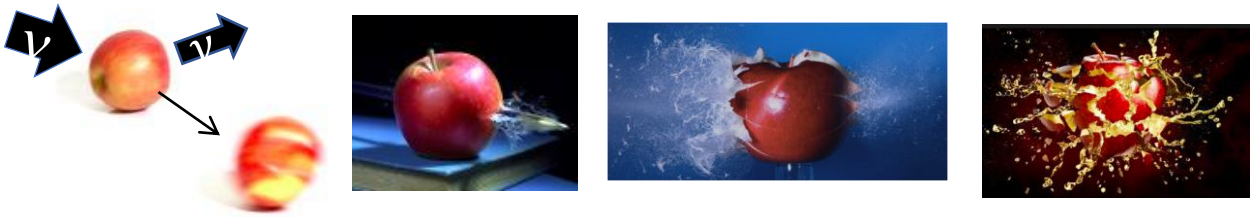




- Nucleus, however, complicated

Energies deposited

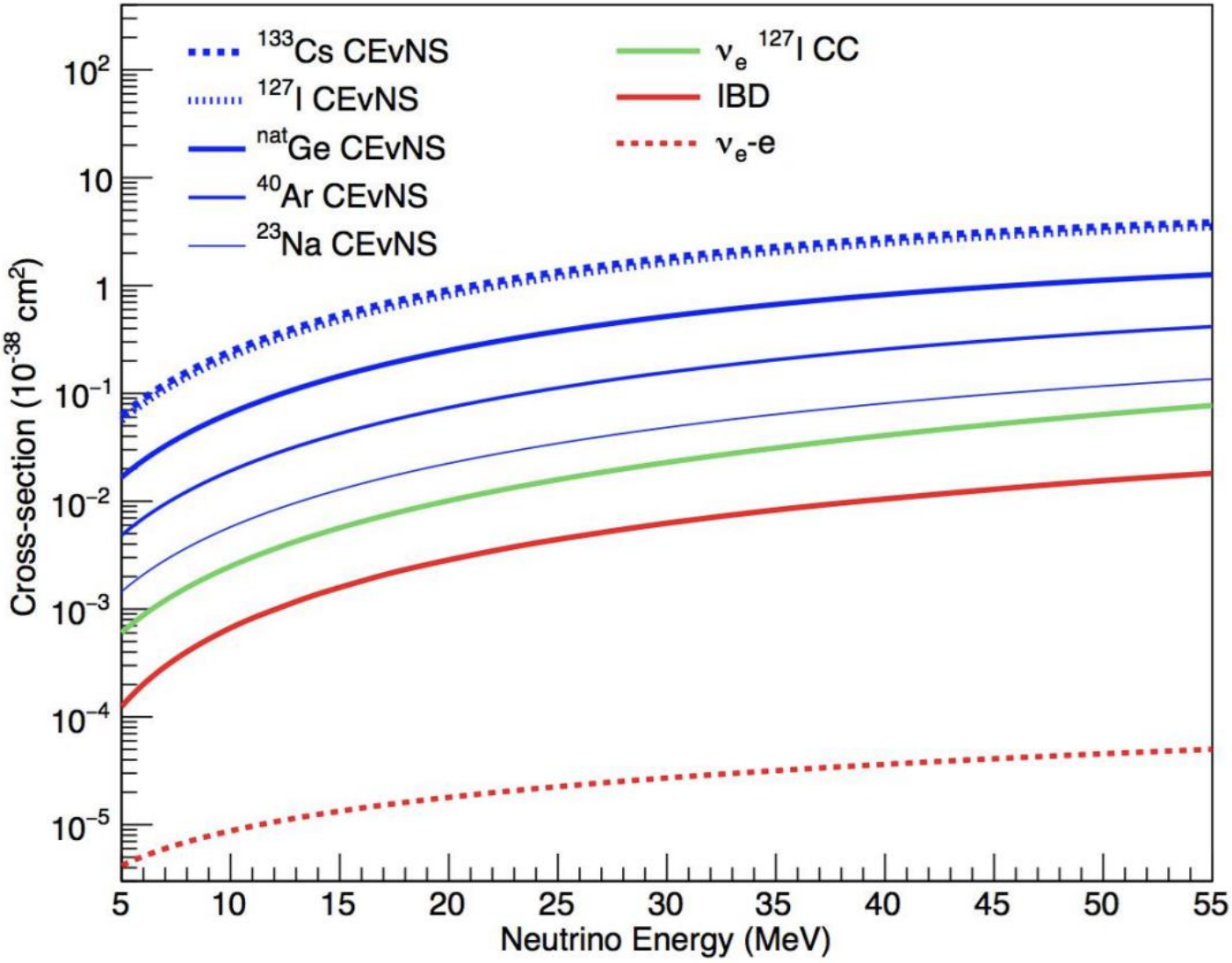
keV MeV GeV TeV PeV



Coherent elastic neutrino-nucleus scattering (CEvNS)

This is the *gentlest* interaction of a neutrino with a nucleus

Why CEvNS: high cross-section



Cross section

$$\frac{d\sigma}{dT} \simeq \frac{G_F^2 M}{2\pi} \frac{Q_W^2}{4} F^2(Q) \left(2 - \frac{MT}{E_\nu^2}\right)$$

E_ν: neutrino energy
T: nuclear recoil energy
M: nuclear mass
Q = √ (2 M T):
momentum transfer

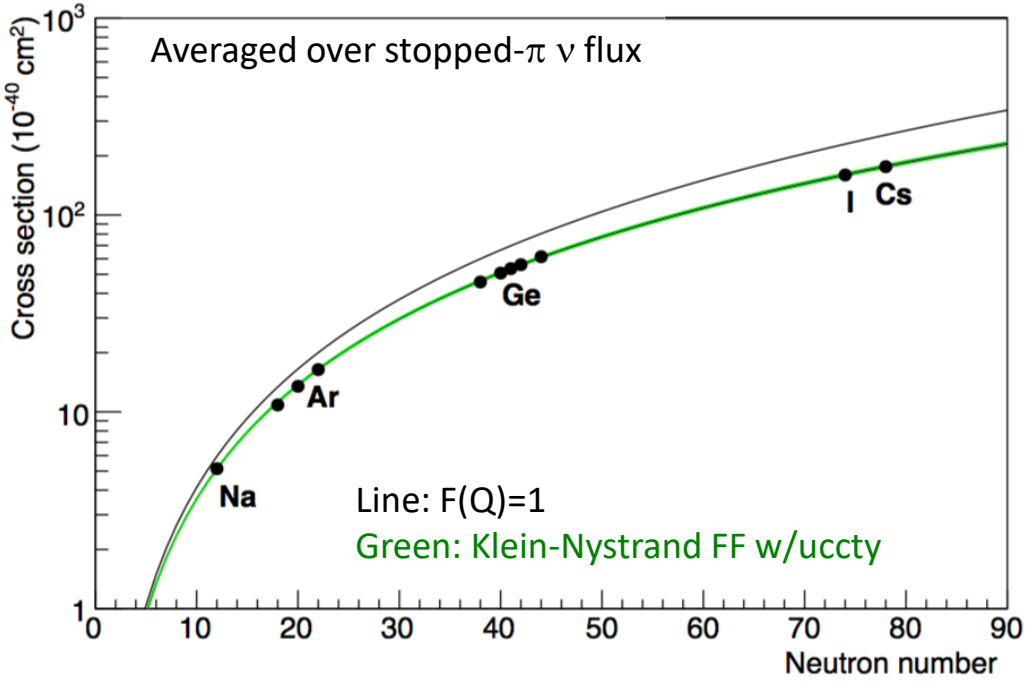
Form factor: F=1 ➔ full coherence

weak nuclear charge

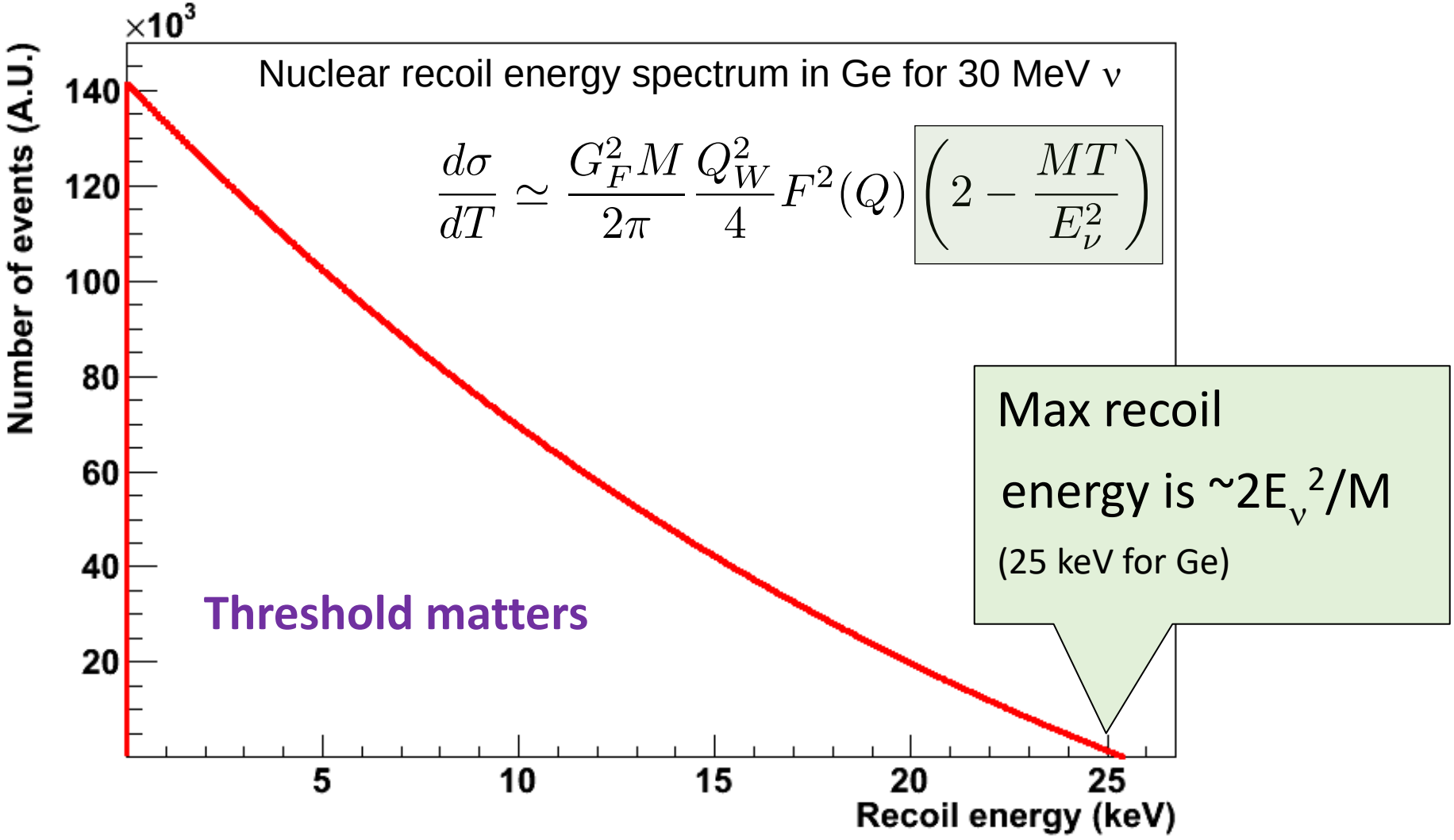
$$Q_W = N - (1 - 4\sin^2\theta_W)Z$$

$$\Rightarrow \frac{d\sigma}{dT} \propto N^2$$

Different target matters



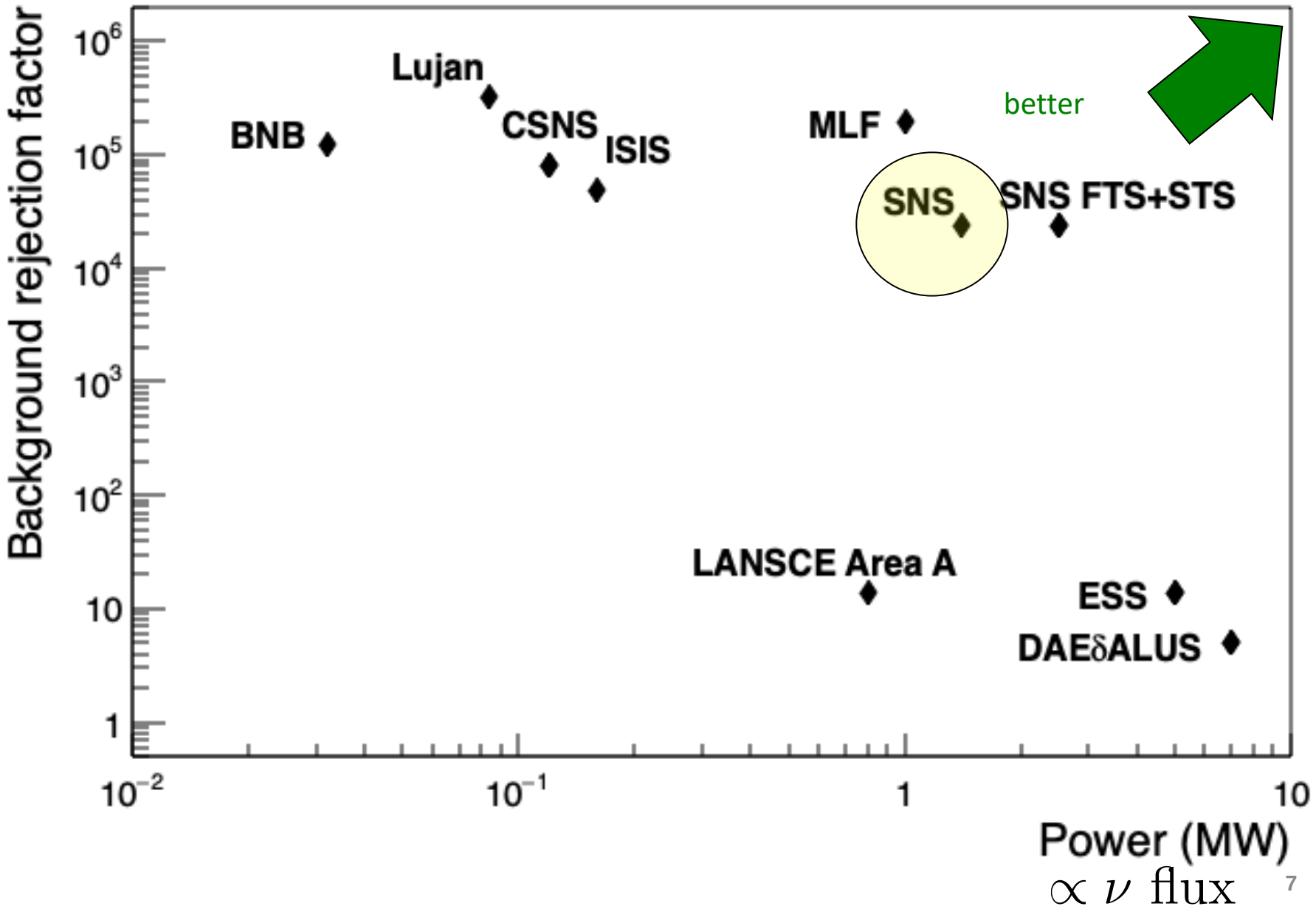
Large cross section (by neutrino standards) but hard to observe due to tiny nuclear recoil energies:



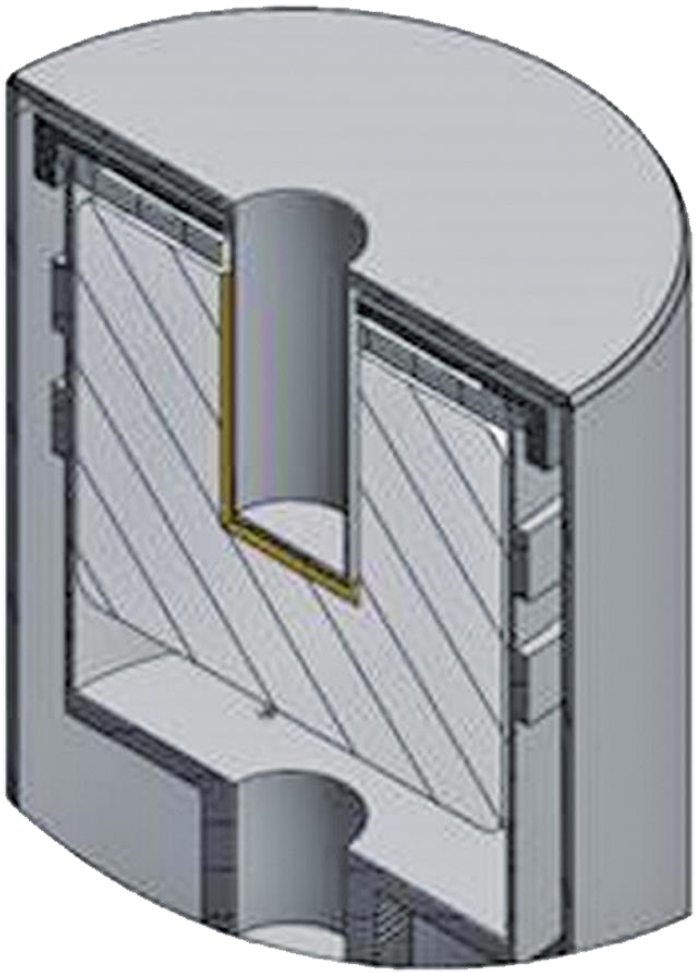
from duty cycle

Comparison of pion decay-at-rest (πDAR) ν sources

Fun fact, free neutrinos



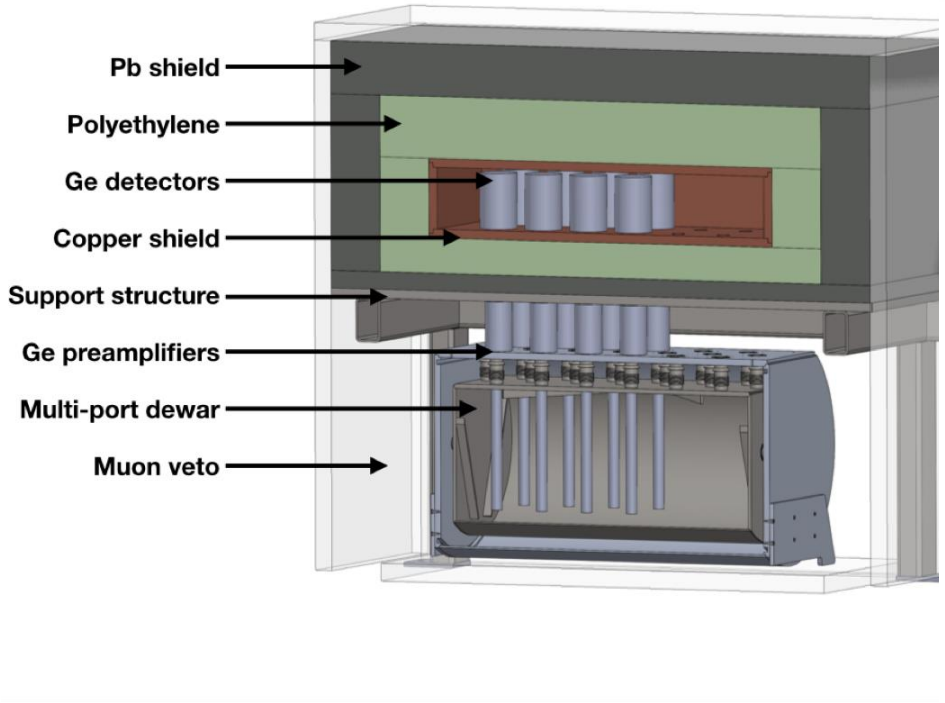
Why Ge-mini?

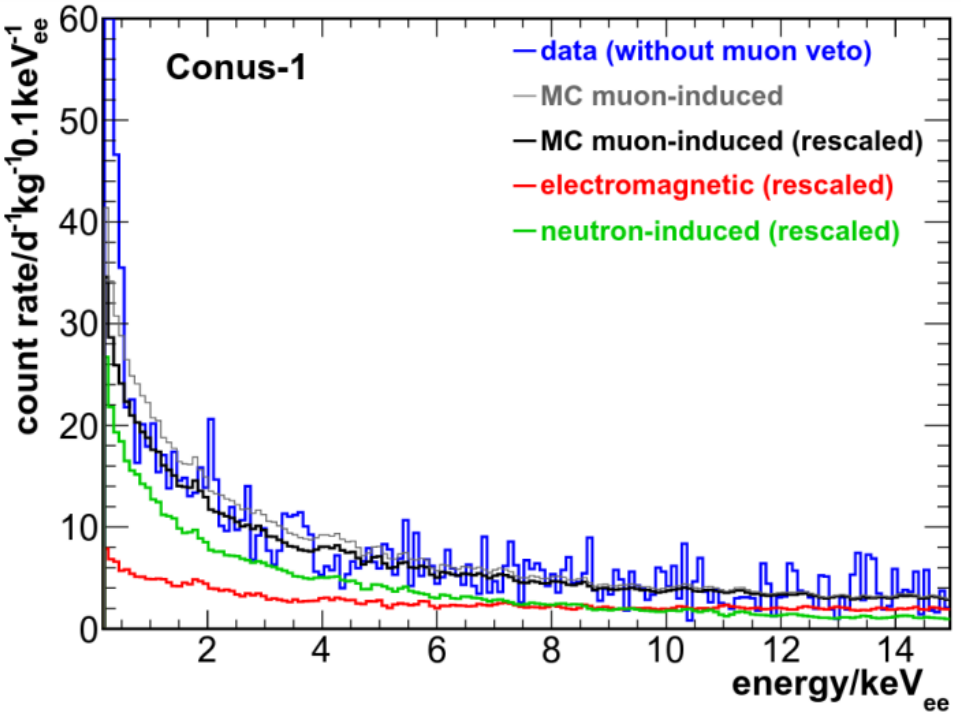


Ge-mini: inverted coaxial point-contact Ge detector

- Inverted coaxial -> large mass
- point-contact -> low threshold
- Electronic noise<150 eV FWHM
- Threshold -> 0.4 keVee, ~2-2.5 keVnr

Shielding structure

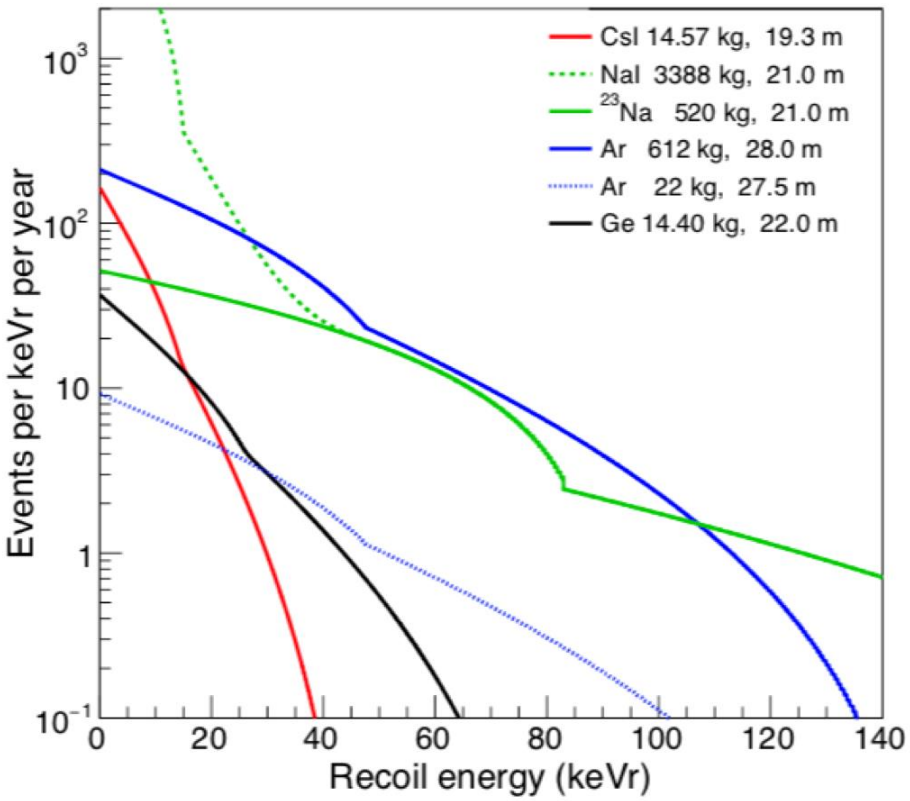




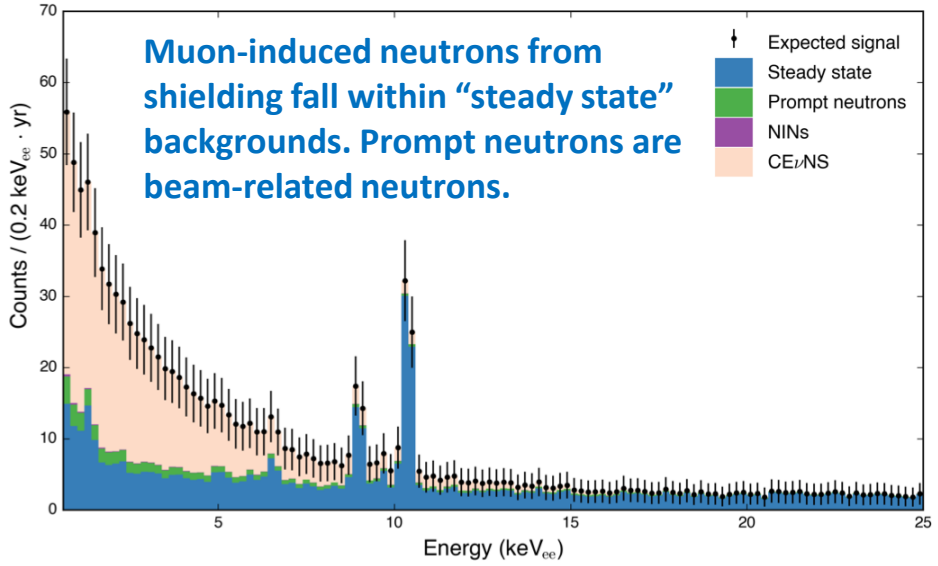
- Pb and Copper (heavy nucleus) shields from gamma-rays
- Polyethylene capture neutron
- Muon veto

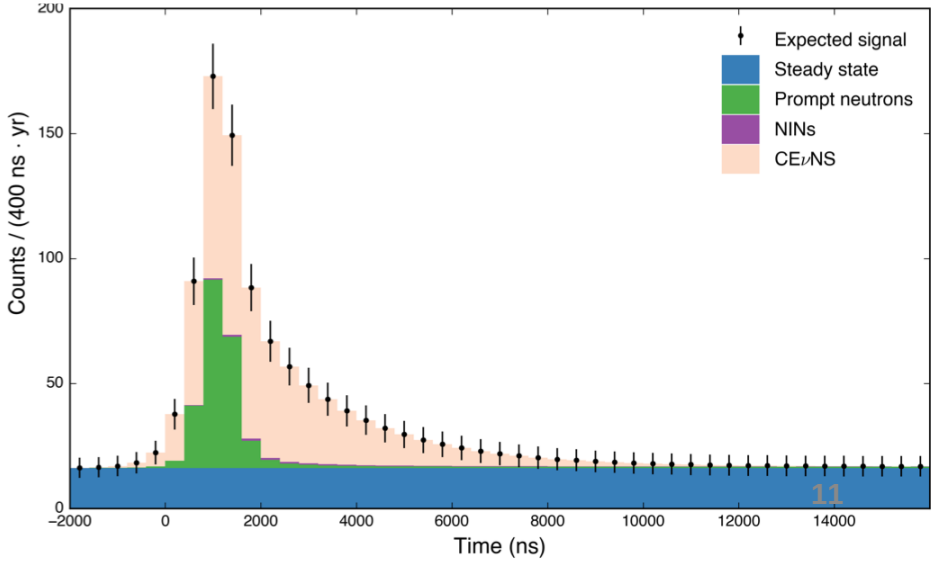
Data from similar shallow-depth Ge CEvNS experiments (such as CONUS) help guide Ge-mini background considerations

Ge-mini expected CEvNS events



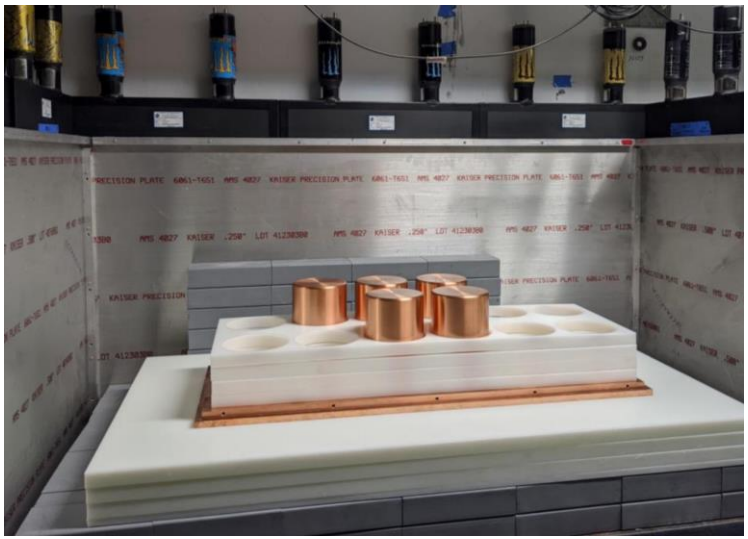
Muon-induced neutrons from shielding fall within "steady state" backgrounds. Prompt neutrons are beam-related neutrons.



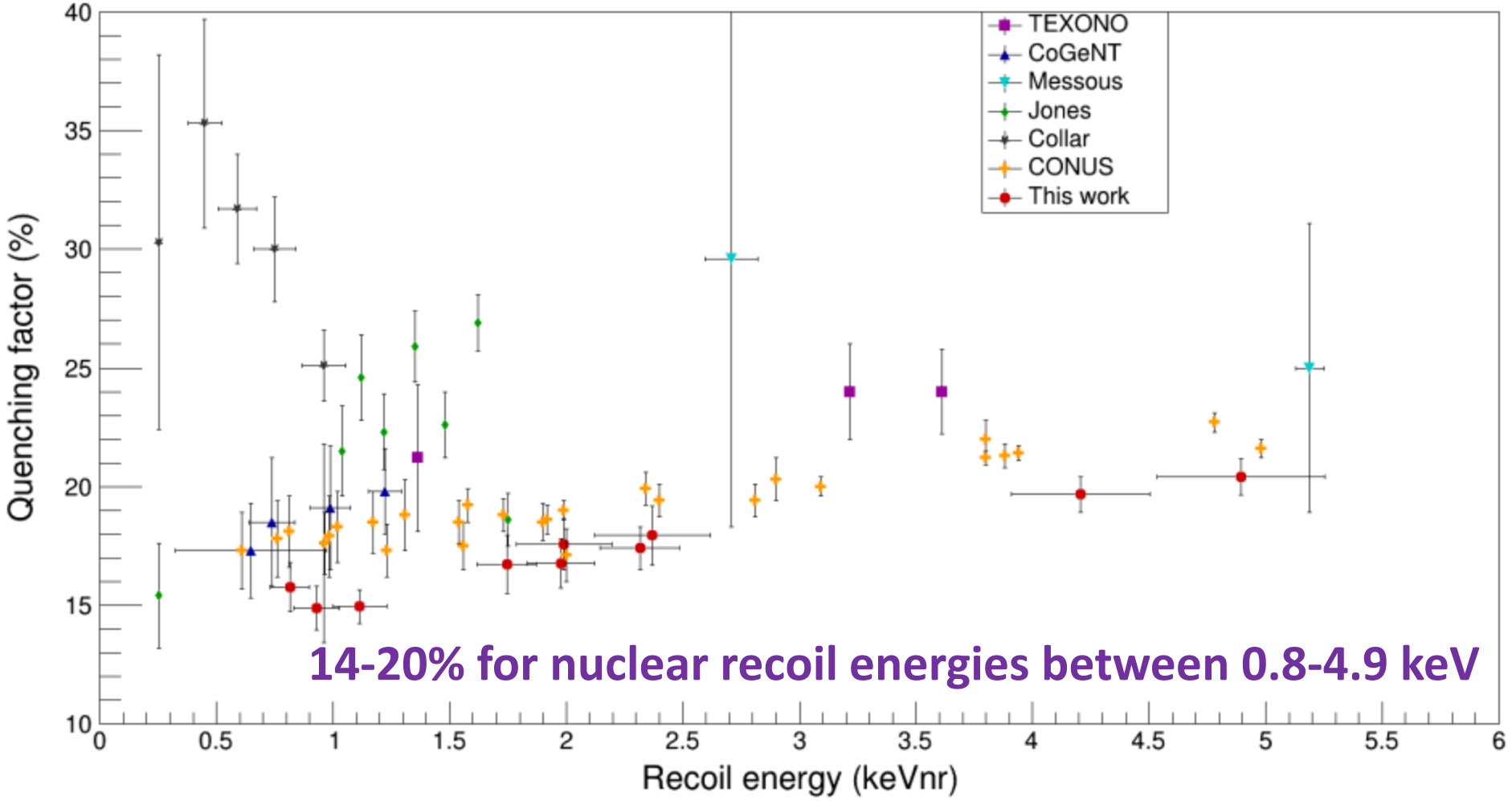


Current status: Ge-mini

- **10 kg worth has been deployed**
- **The rest 8 kg will be deployed this summer**



QF, no drama in this talk…



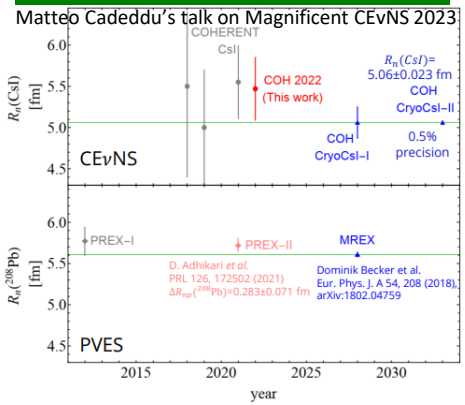
Long Li's dissertation

Broad Impact of πDAR CEvNS Studies

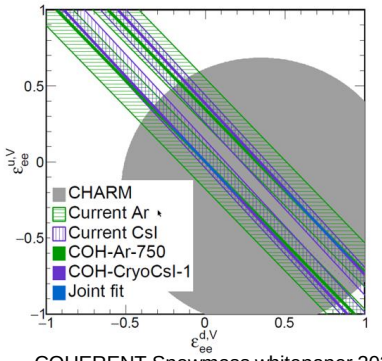
Largest σ in Supernovae dynamics

Nuclear Form Factors

Matteo Cadeddu's talk on Magnificent CEvNS 2023

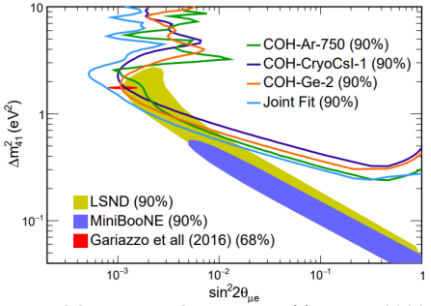


Non-Standard Interactions



COHERENT Snowmass whitepaper 2022

Sterile Searches



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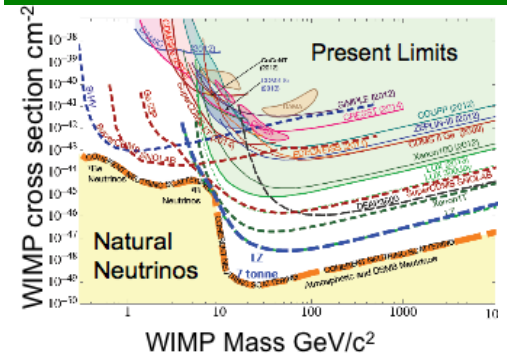
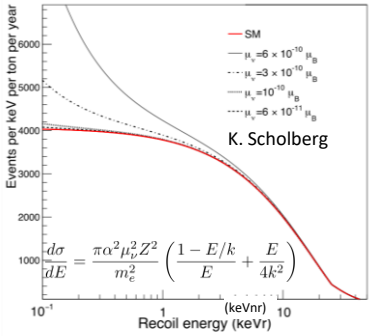
Background for Dark Matter searches

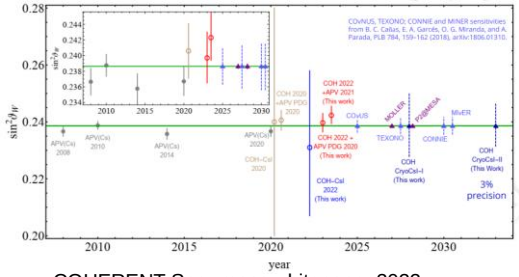


Neutrino Magnetic Moment



See also Kosmas et al., arXiv:1505.03202

Weak Mixing Angle



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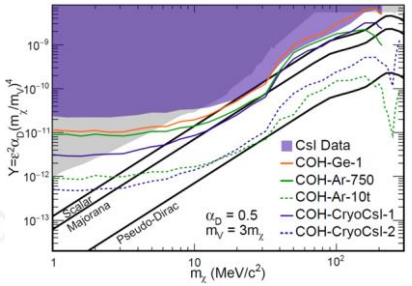
Matteo Cadeddu's talk on Magnificent CEvNS 2023

Accelerator DM searches



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BSM light mediator too…

Take away

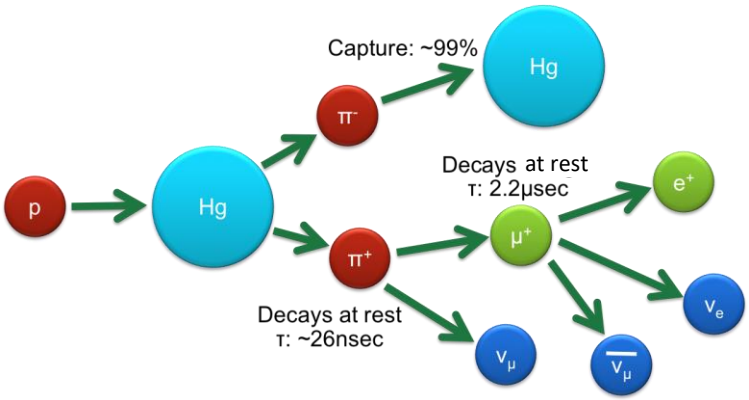
- CEvNS are something!
  - High cross-section, require low energy threshold detectors
  - Well predicted in the standard model
  - Precision measurements can be a great tool to probe physics in the standard model and beyond

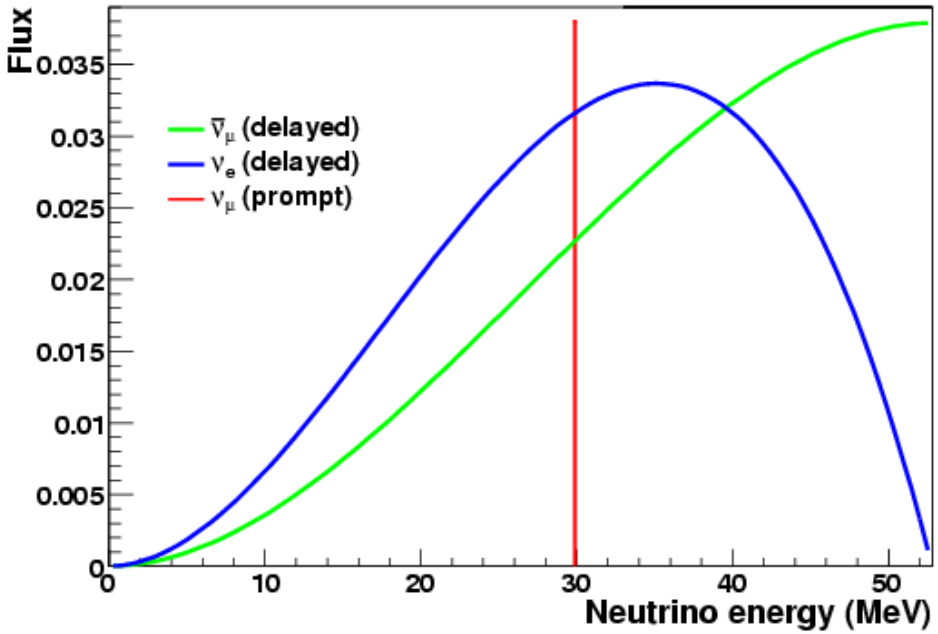
COHERENT Collaboration

- ~80 members, 21 institutions
- Formed in 2013 to observe CEvNS in multiple nuclear targets to measure N^2-scaling of cross section
- Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL) is also a perfect source of neutrinos.
- Intense flux of low-energy pulsed neutrinos also useful for studying inelastic neutrino-nucleus interactions
- Intense proton pulses also useful for dark sector searches

Carnegie Mellon University · Duke University · UF University of Florida · Laurentian University / Université Laurentienne · Los Alamos National Laboratory · NCCentral University · NC State University · Oak Ridge National Laboratory · Sandia National Laboratories · 서울대학교 Seoul National University · SLAC National Accelerator Laboratory · University of South Dakota · The University of Tennessee Knoxville · Tufts University · TUNL Triangle Universities Nuclear Laboratory · Virginia Tech · University of Washington · Washington & Jefferson College

Stopped-Pion (πDAR) Neutrinos





$$\pi^+ \longrightarrow \mu^+ + \nu_\mu$$

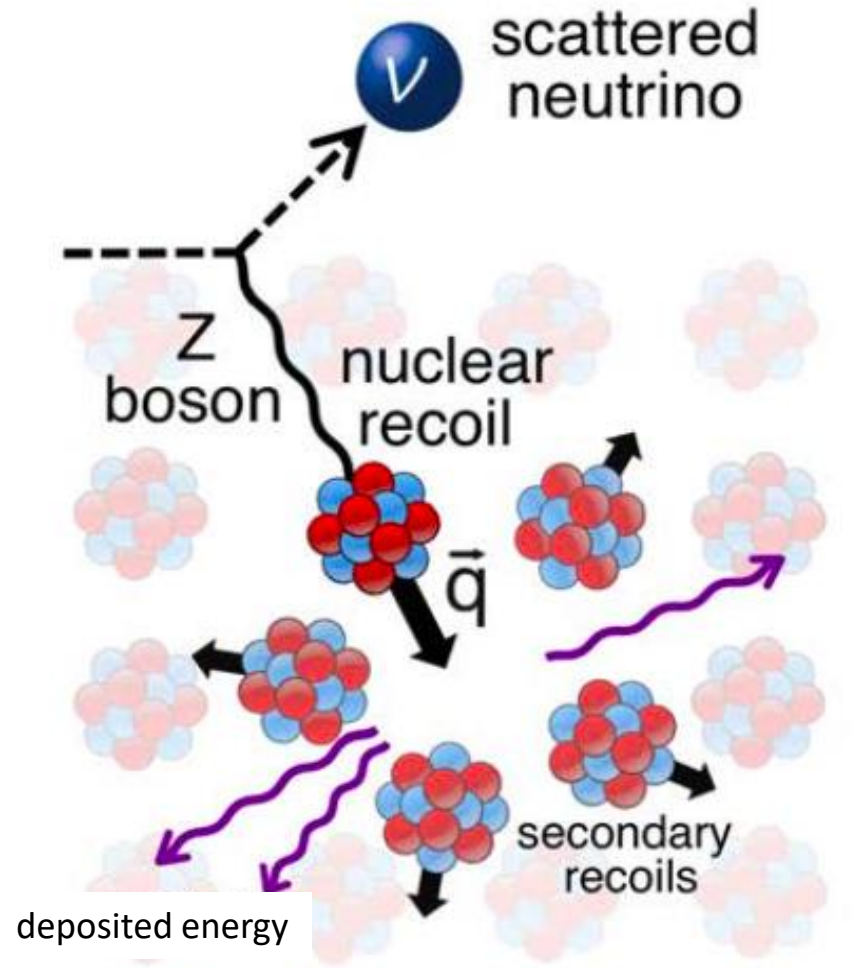
2-body decay: monochromatic 29.9 MeV ν_μ PROMPT

$$\mu^+ \longrightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

3-body decay: range of energies between 0 and $m_\mu/2$ DELAYED (2.2 μs)

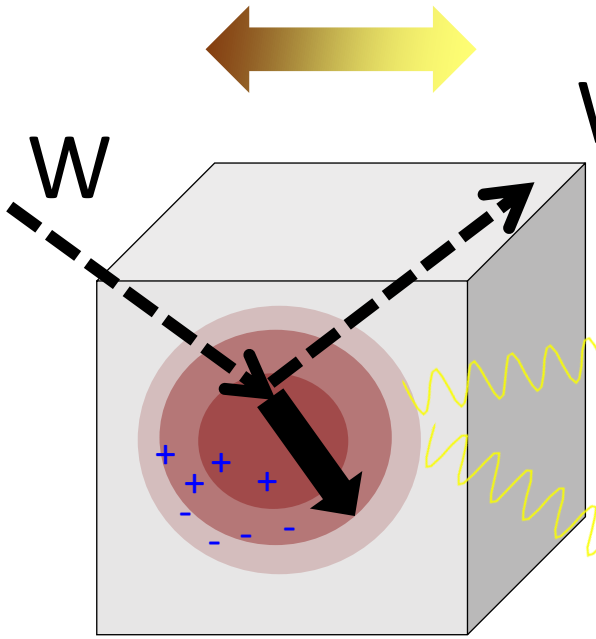
The only experimental signature:

tiny energy deposited by nuclear recoils in the target material



➔ **WIMP dark matter detectors** developed over the last ~decade are sensitive to ~ keV to 10's of keV recoils

Low-energy nuclear recoil detection strategies



phonons
(heat)

feel a warm pulse

photons

see a
flash

scintillating crystal
noble liquid

Cryogenic
Ge, Si

ionization

feel a zap

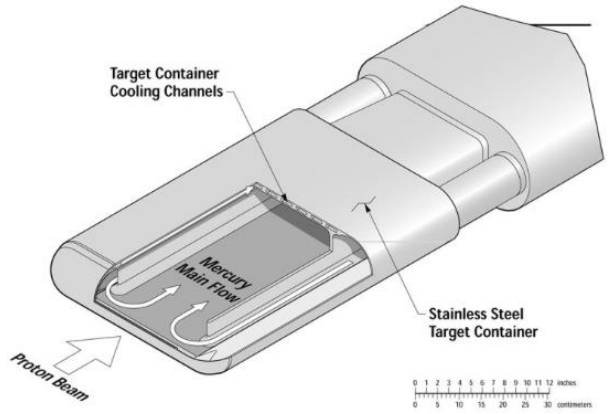
HPGe

2-phase
noble liquid

http://dmrc.snu.ac.kr/english/intro/intro1.html

Spallation Neutron Source

Oak Ridge National Laboratory, TN



Proton beam energy: 0.9-1.3 GeV
Total power: 0.9-1.4 MW
Pulse duration: 380 ns FWHM
Repetition rate: 60 Hz
Liquid mercury target

The neutrinos are free!