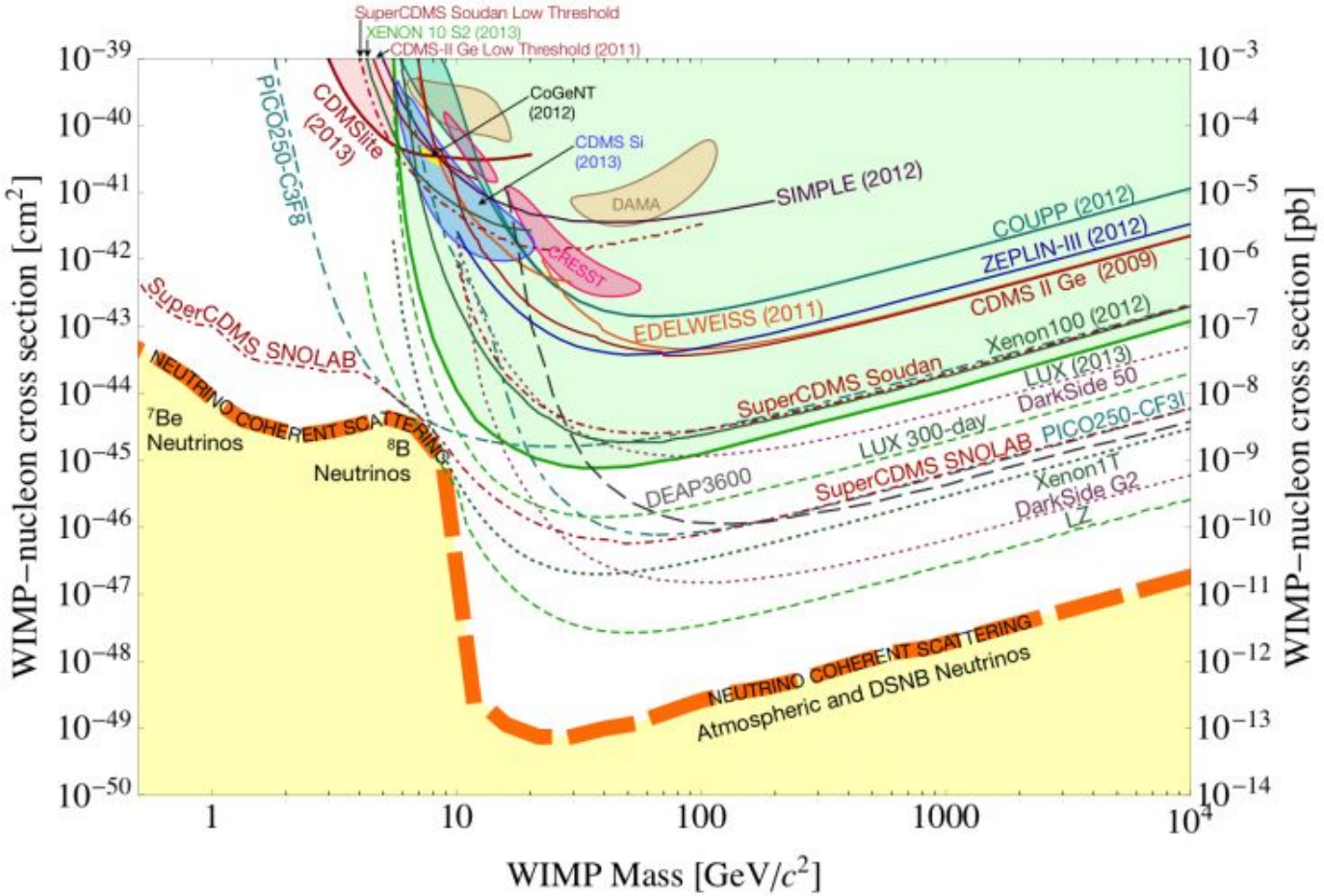
The Neutrino Floor for Direct Dark Matter Detection

Madeline Bernstein

Physics 290e Fall 2019



Snowmass CF1 Summary: WIMP Dark Matter Direct Detection (2013)

Outline

1. Coherent scattering
2. Neutrino sources
3. Creating the “neutrino floor” curve
4. Potential background discrimination techniques

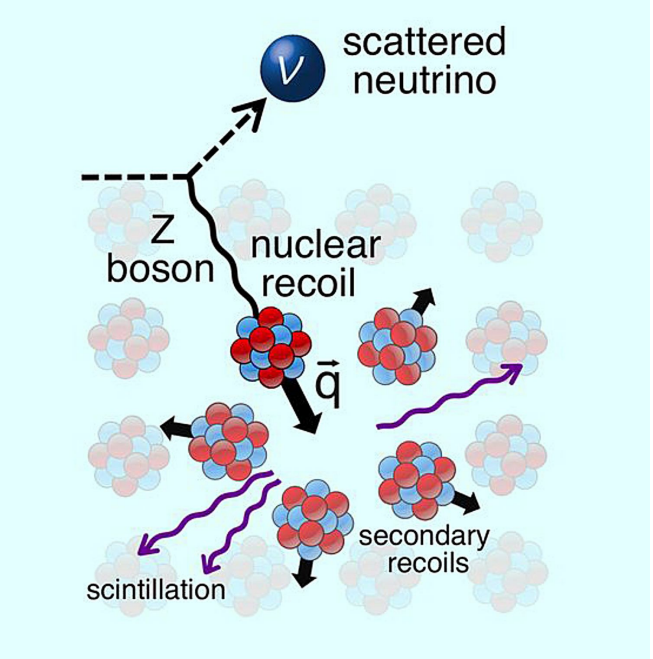
Outline

1. **Coherent scattering**
2. Neutrino sources
3. Creating the “neutrino floor” curve
4. Potential background discrimination techniques

Coherent Elastic Neutrino-Nucleus Scattering (CEvNS)

The basics:

- SM process where low energy neutrino scatters off nucleus
    - enhanced cross section with larger nuclei
- The nucleus recoils and remains in its ground state → *mimics WIMP signal*
- Theoretically predicted by Freedman (1974), and experimentally observed by the COHERENT collaboration (2017)



COHERENT Collaboration.

Coherent Elastic Neutrino-Nucleus Scattering (CEvNS)

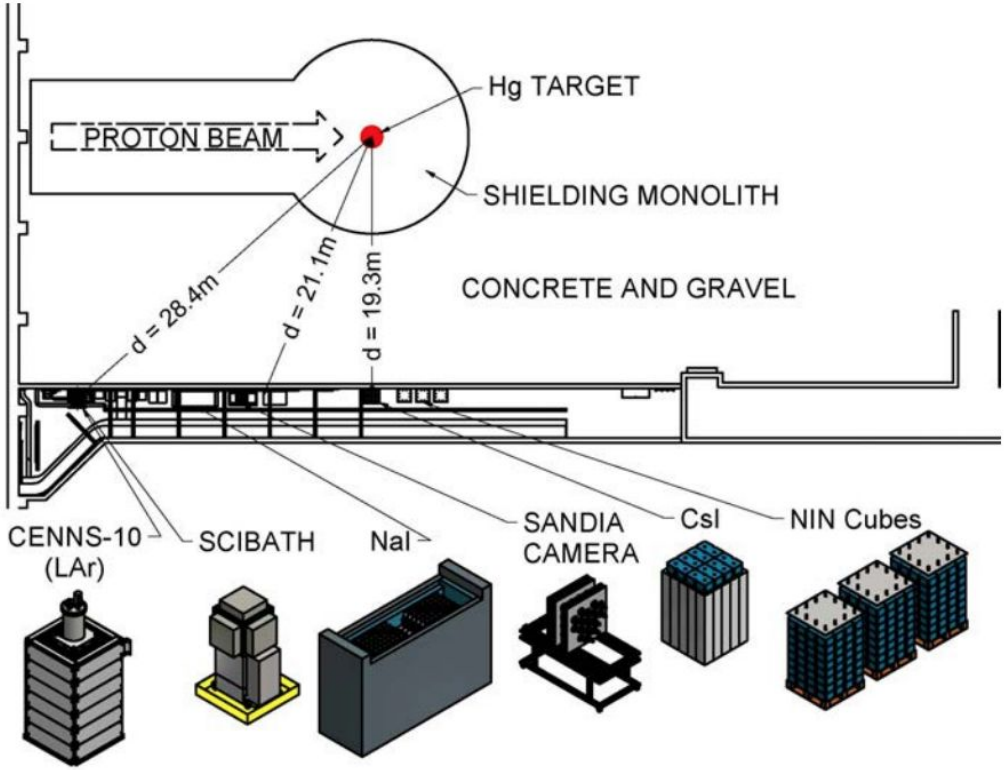
When does this process occur?

- Z boson must have wavelength longer than the size of the nucleus, so that it scatters off all nucleons equally
  - Momentum transfer similar to the size of the nucleus, $qR < 1$
  - Small recoil energies, $q \sim$ keV
- Cross section is enhanced for low energy neutrinos (< 50 MeV)
- Cross section scales with the square of the atomic number A^2

COHERENT Experiment

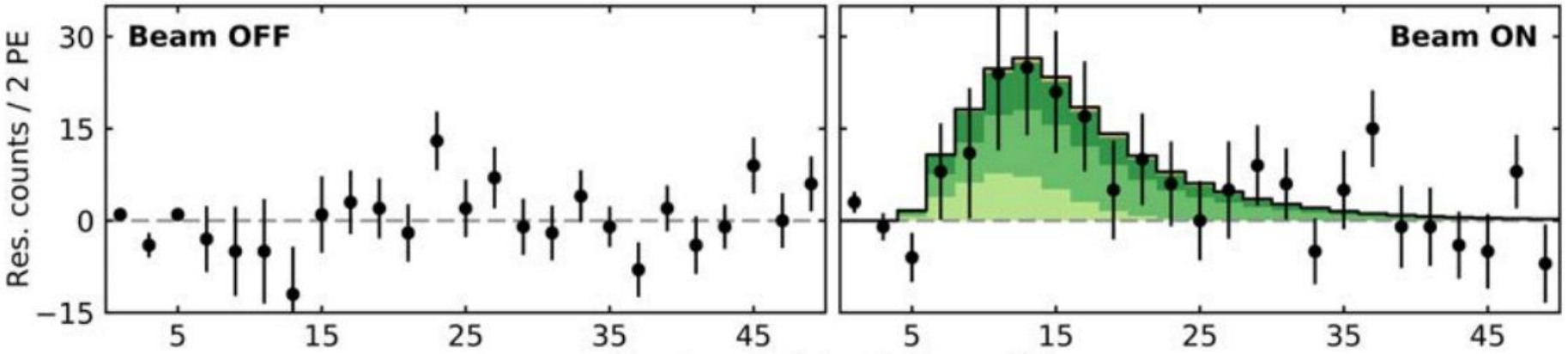
- Spallation Neutron Source (SNS) at Oak Ridge National Laboratory generates a pulsed “beam” of low energy neutrinos
- “Neutrino alley” corridor in basement, nu flux of 1.7 x 10^11 numu/cm^2
- Sodium-doped CSI
    - Large cross section (heavy nuclei)
    - Generate sufficient scintillation for keV nuclear recoils

COHERENT Experiment



COHERENT Experiment

6.7 sigma confidence (!!)
Consistent with SM predictions at 1 sigma level



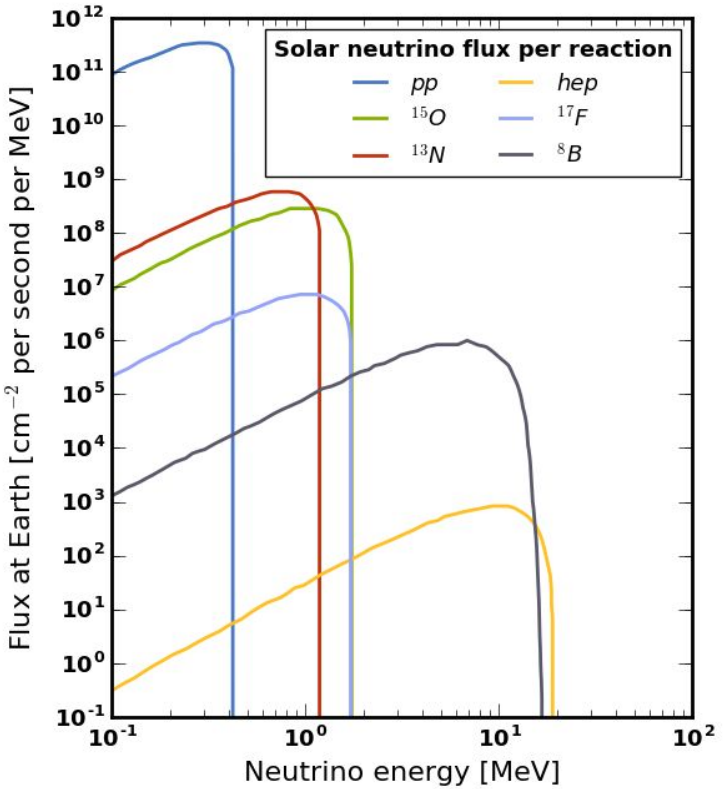
1. Coherent scattering
2. **Neutrino sources**
3. Creating the “neutrino floor” curve
4. Potential background discrimination techniques

Solar Neutrinos

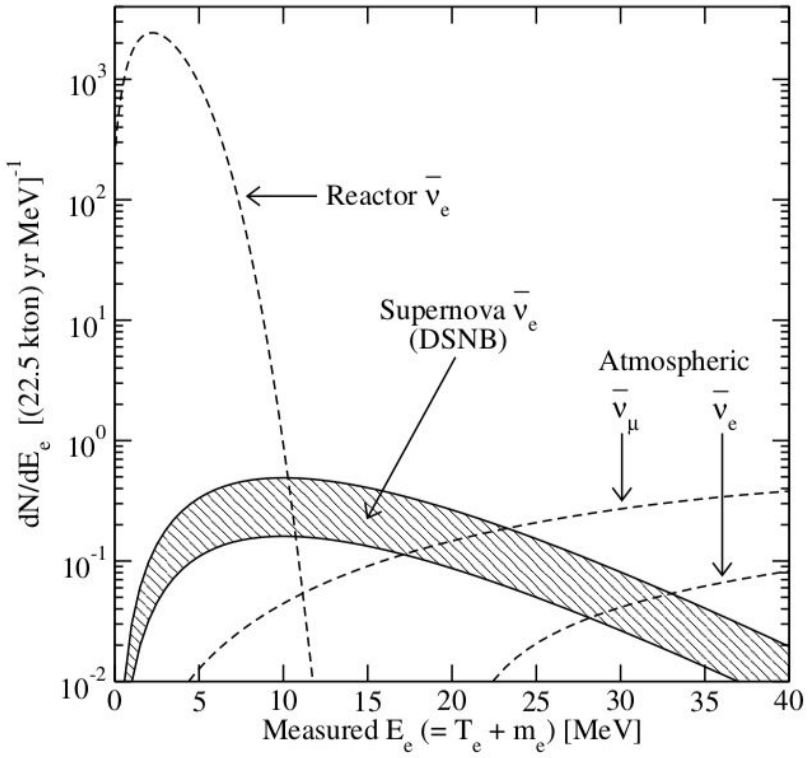
Neutrinos produced via fusion reactions in the core of the sun

Three main branches:

1. ^{8}B : $^{8}B \rightarrow {}^{7}Be^{*} + e^{+} + nue$
2. hep : $^{3}He + p \rightarrow {}^{4}He + e^{+} + nue$
3. ^{7}Be : $^{7}Be + e^{-} \rightarrow {}^{7}Li + nue$



Astrophys. J. **621**: L85–L88. doi:10.1086/428929



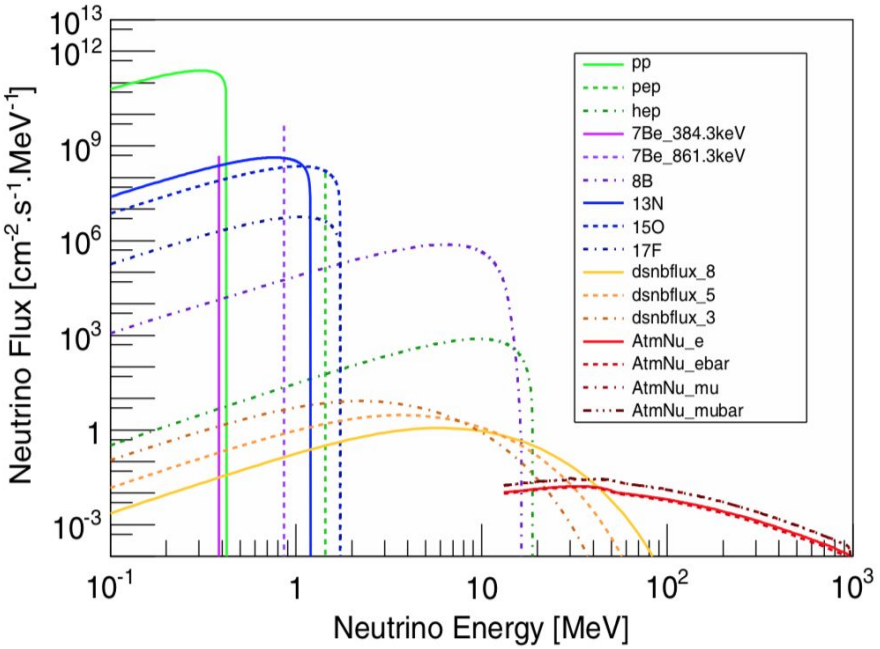
Atmospheric neutrinos

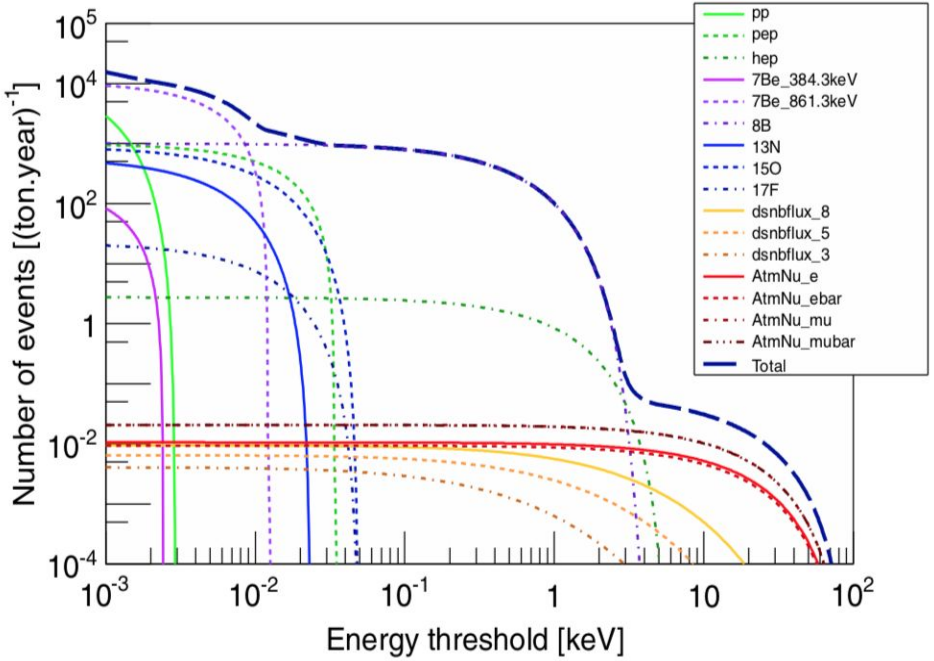
Neutrinos produced through cosmic ray collisions in the earth's atmosphere. The collisions create pions, which decay to neutrinos.

Diffuse supernova neutrinos (DSNB)

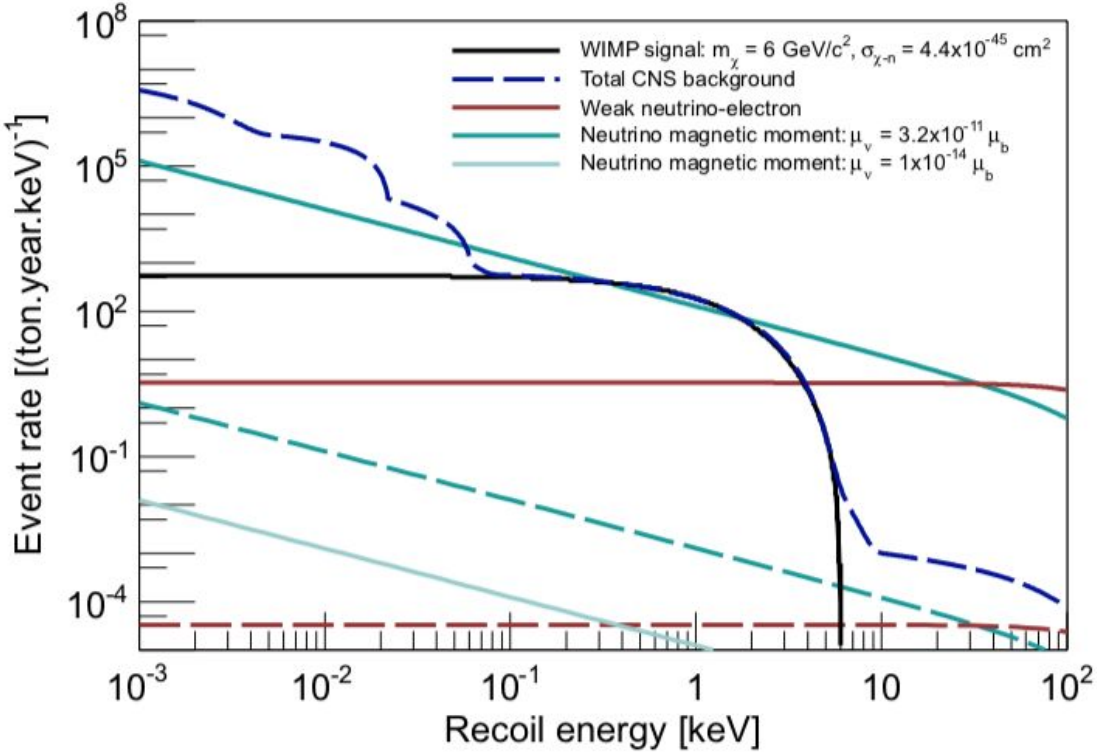
Accumulated neutrino flux from all supernova explosions in the history of the universe

Total Neutrino Background





Which looks extremely similar to the WIMP signal…



1. Coherent scattering
2. Neutrino sources
3. **Creating the “neutrino floor” curve**
4. Potential background discrimination techniques

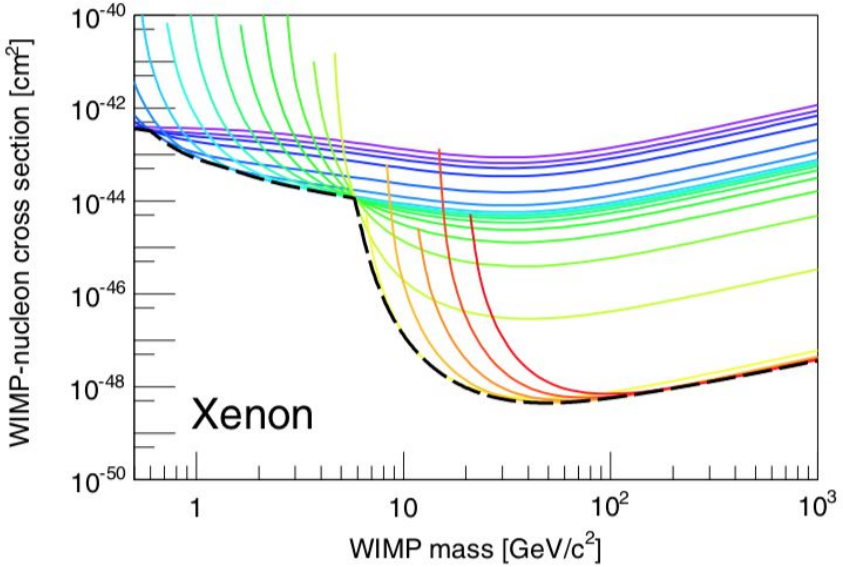
Background free exclusion sensitivity limit

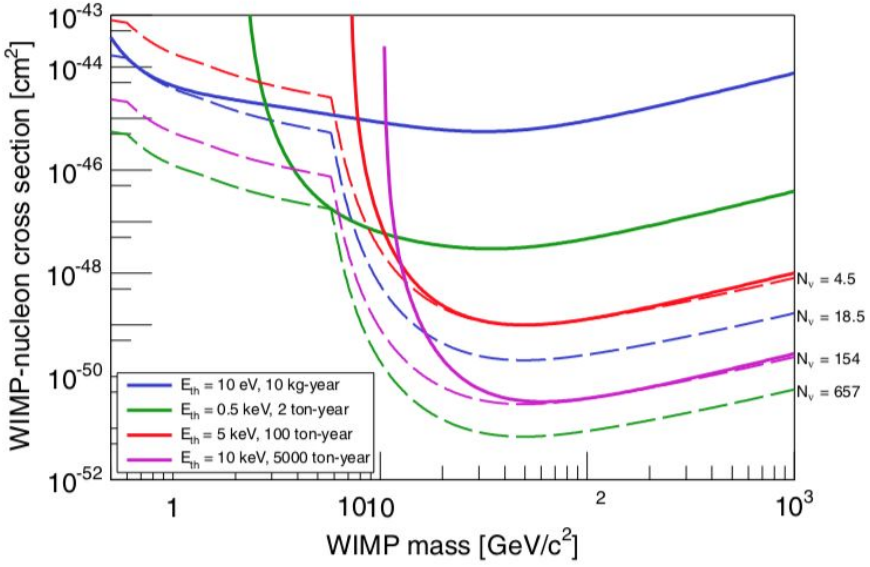
Quantifying the impact on dark matter discovery potential:

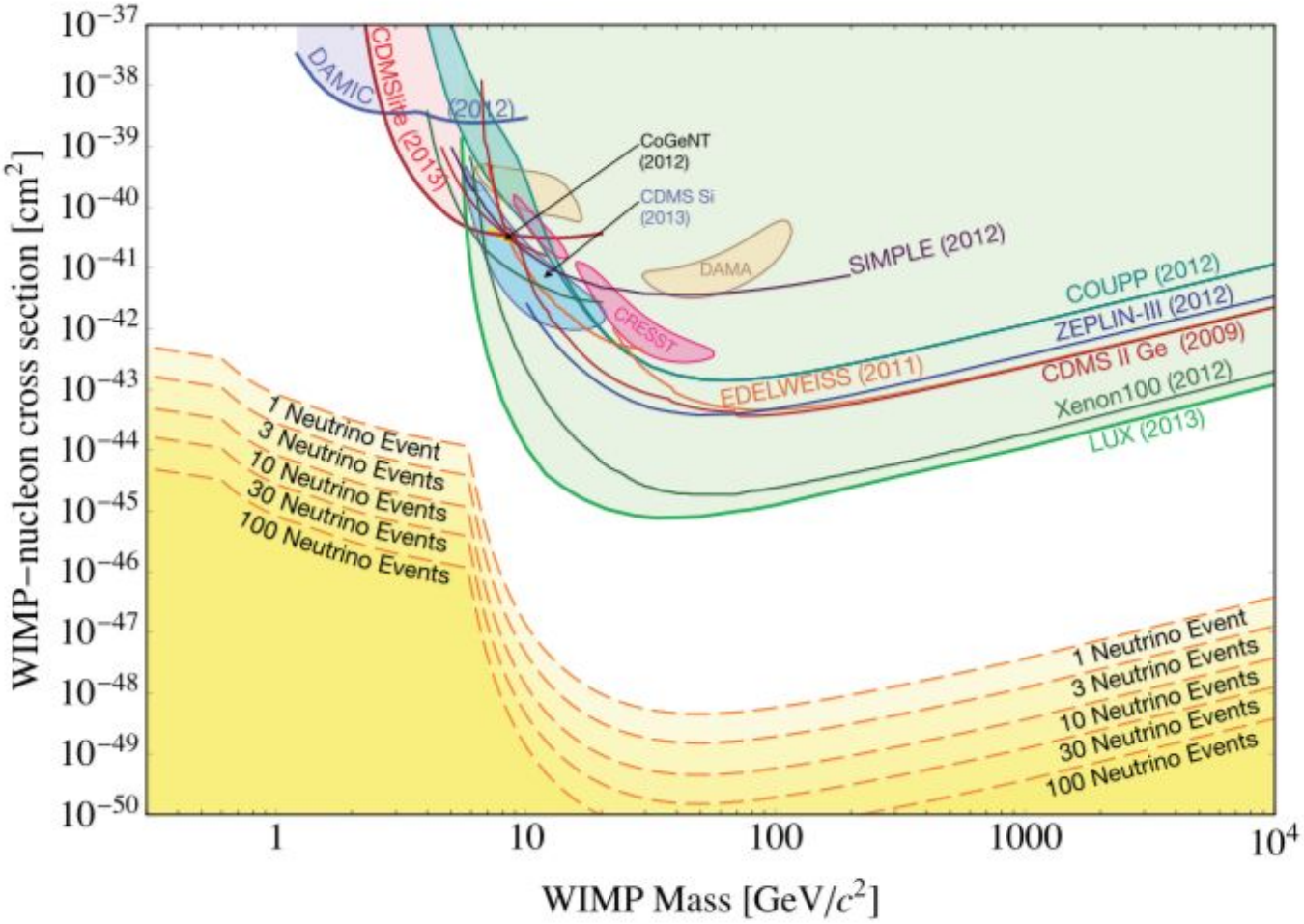
J. Billard et al. “Implication of Neutrino Backgrounds on the Reach of next Generation Dark Matter Direct Detection Experiments.” *Physical Review D*, **89** 023524

- Generate many exclusion limits (isovalue lines of 2.3 WIMP events at 90% C.L.) for varying energy thresholds from 0.001 - 100 keV
- Adjust each curve’s exposure to obtain one neutrino background event
- Take lowest cross section as function of WIMP mass across all limits

Background free exclusion sensitivity limit



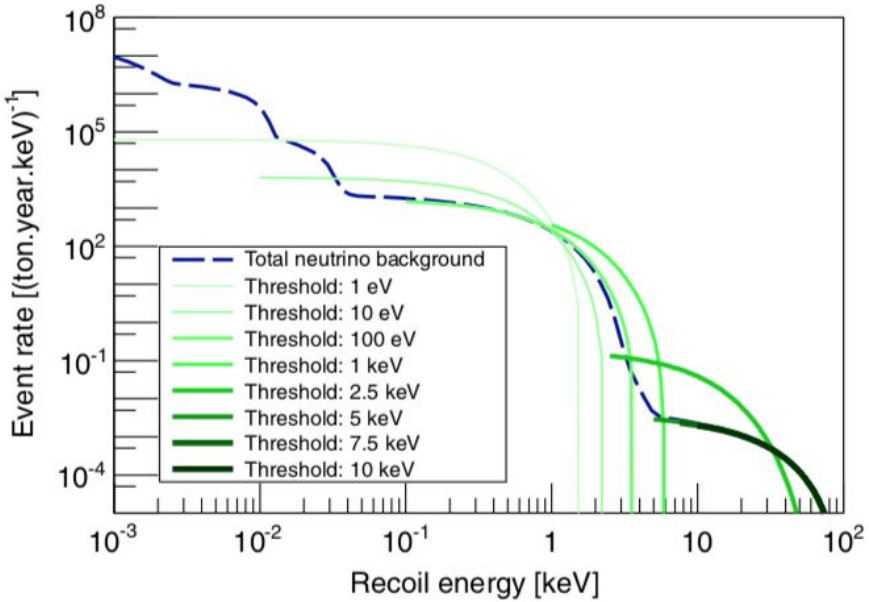



WIMP−nucleon cross section [cm^2]
10^{-37}
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
10^{-50}
1
10
100
1000
10^4
WIMP Mass [GeV/c^2]
DAMIC (2012)
CDMSlite (2013)
CoGeNT (2012)
CDMS Si (2013)
DAMA
SIMPLE (2012)
CRESST
EDELWEISS (2011)
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
Xenon100 (2012)
LUX (2013)
1 Neutrino Event
3 Neutrino Events
10 Neutrino Events
30 Neutrino Events
100 Neutrino Events
1 Neutrino Event
3 Neutrino Events
10 Neutrino Events
30 Neutrino Events
100 Neutrino Events

1. Coherent scattering
2. Neutrino sources
3. Creating the “neutrino floor” curve
4. **Potential background discrimination techniques**

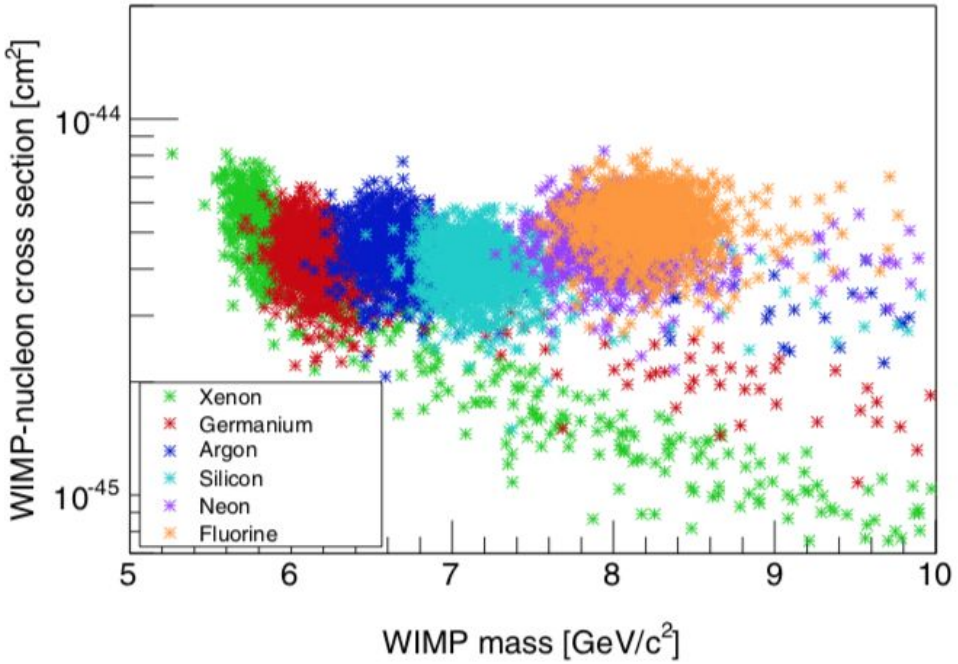
Background discrimination

- Vary energy threshold
  - Neutrino background best mimics WIMP signal when there is one very dominant contribution or a smooth superposition of different neutrino components



Background discrimination

- Validate results with different target materials
  - reconstructed WIMP parameters vary across different target materials



Background discrimination

- Vary energy threshold
  - Neutrino background best mimics WIMP signal when there is one very dominant contribution or a smooth superposition of different neutrino components
- Validate results with different target materials
  - reconstructed WIMP parameters vary across different target materials
- Measurements of annual modulation

Background discrimination

- Vary energy threshold
  - Neutrino background best mimics WIMP signal when there is one very dominant contribution or a smooth superposition of different neutrino components
- Validate results with different target materials
  - reconstructed WIMP parameters vary across different target materials
- Measurements of annual modulation
- Detectors with directional sensitivity

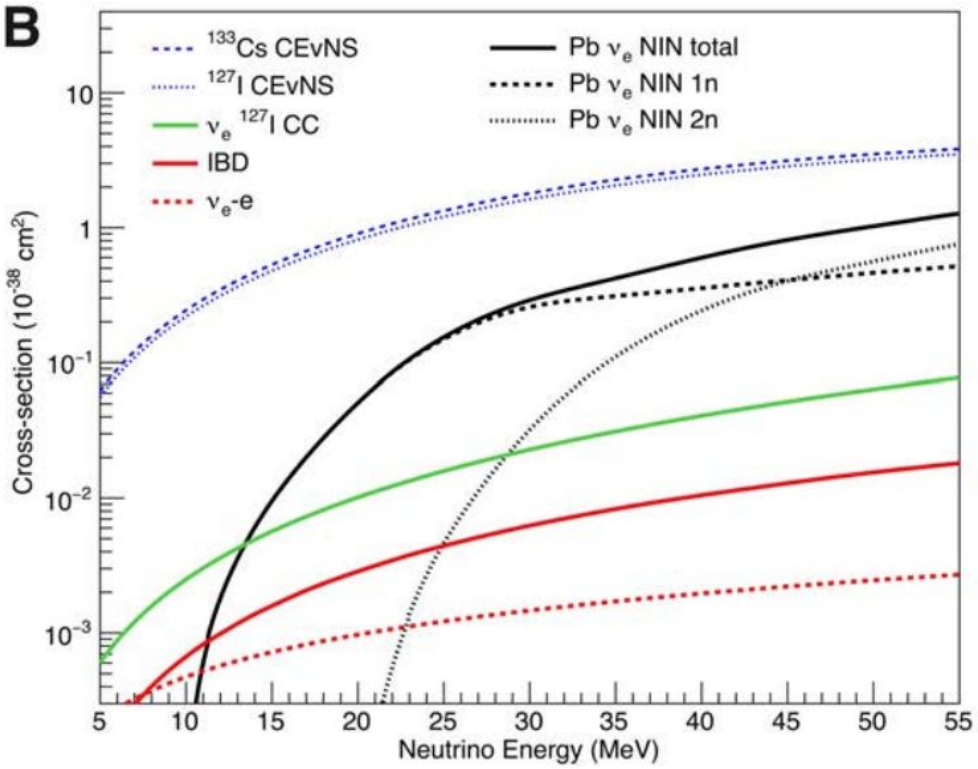
Background discrimination

- Vary energy threshold
  - Neutrino background best mimics WIMP signal when there is one very dominant contribution or a smooth superposition of different neutrino components
- Validate results with different target materials
  - reconstructed WIMP parameters vary across different target materials
- Measurements of annual modulation
- Detectors with directional sensitivity
- Precise measurements of coherent neutrino scattering rates

Conclusion

- Coherent neutrino-nucleus scattering is a prominent background as dark matter detection experiments continue to search for WIMP candidates with smaller mass and cross section
- The “neutrino floor” is an insightful way to visualize and quantify this background
- There is still hope for disentangling the neutrino background from WIMP signals.
    - Better understand the neutrino background
    - Advancements in detector technolgoy

CEvNS enhanced cross section BACKUP



COHERENT backup