# Ricochet Proposal and Current Efforts

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# Talk Outline

- Divided into three sections:

1. Introduction and Motivation

2. Ricochet Proposal

3. Neutron Monitoring at MIT Research Reactor

# **Part I**: Introduction and Motivation

# Coherent ν Scattering

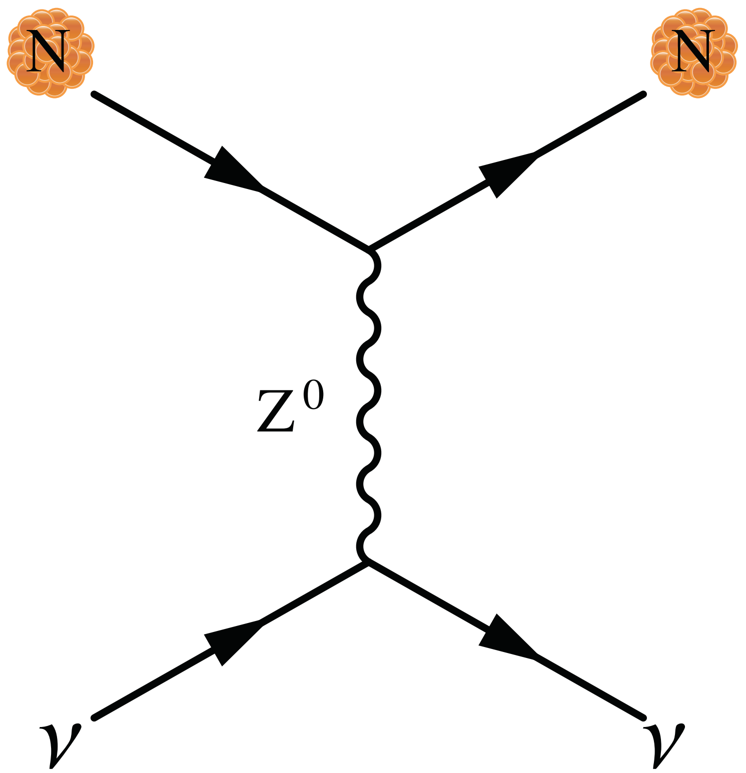
$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi} Q_W^2 M_A \left(1 - \frac{M_A T}{2E_\nu^2}\right) F(q^2)^2$$

- σ: Cross Section
- T: Recoil Energy
- $E_\nu$: Neutrino Energy
- $G_F$: Fermi Constant
- $Q_W$: Weak Charge
- $M_A$: Atomic Mass
- F: Form Factor

Unique Properties:

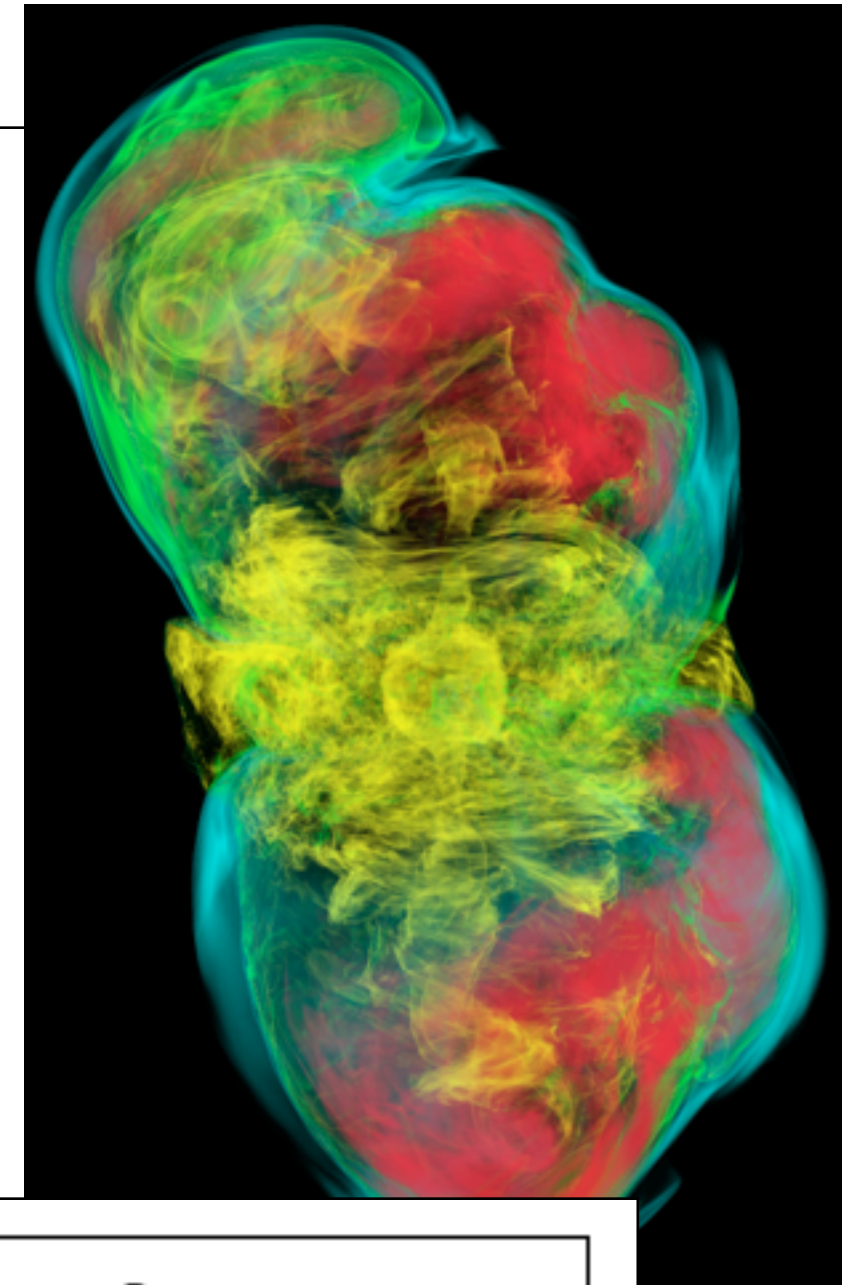
1)No flavor-specific terms - Same rate for νe, νμ, and ντ

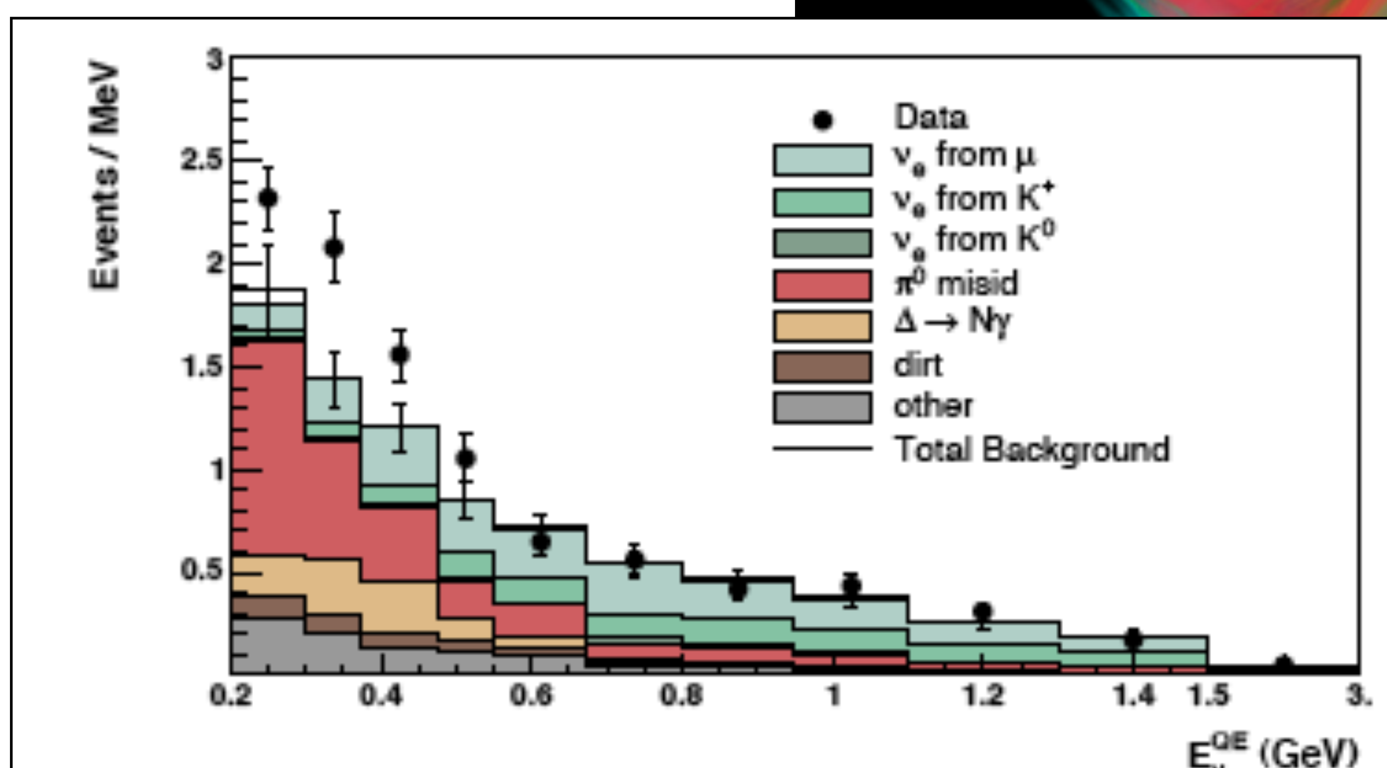
2) Potentially very high rate compared to other rare event searches



# Motivation

- Coherent Neutrino Scattering provides probes in several areas:
- Probe of supernova physics
- Sterile neutrino searches
- Ability to probe Nuclear form factors at small $Q^2$
- Applications to nuclear proliferation monitoring





# Challenges

- Difficult source/detector problem
- Very low average recoil energy - 3 options:
    - Different Target
    - Different Source
    - Higher detection Efficiency
- Large backgrounds (neutrons) that can mimic your signal

$$T_{\mathrm{max}} \leq \frac{E_\nu}{1 + \frac{M_A}{2E_\nu}}$$

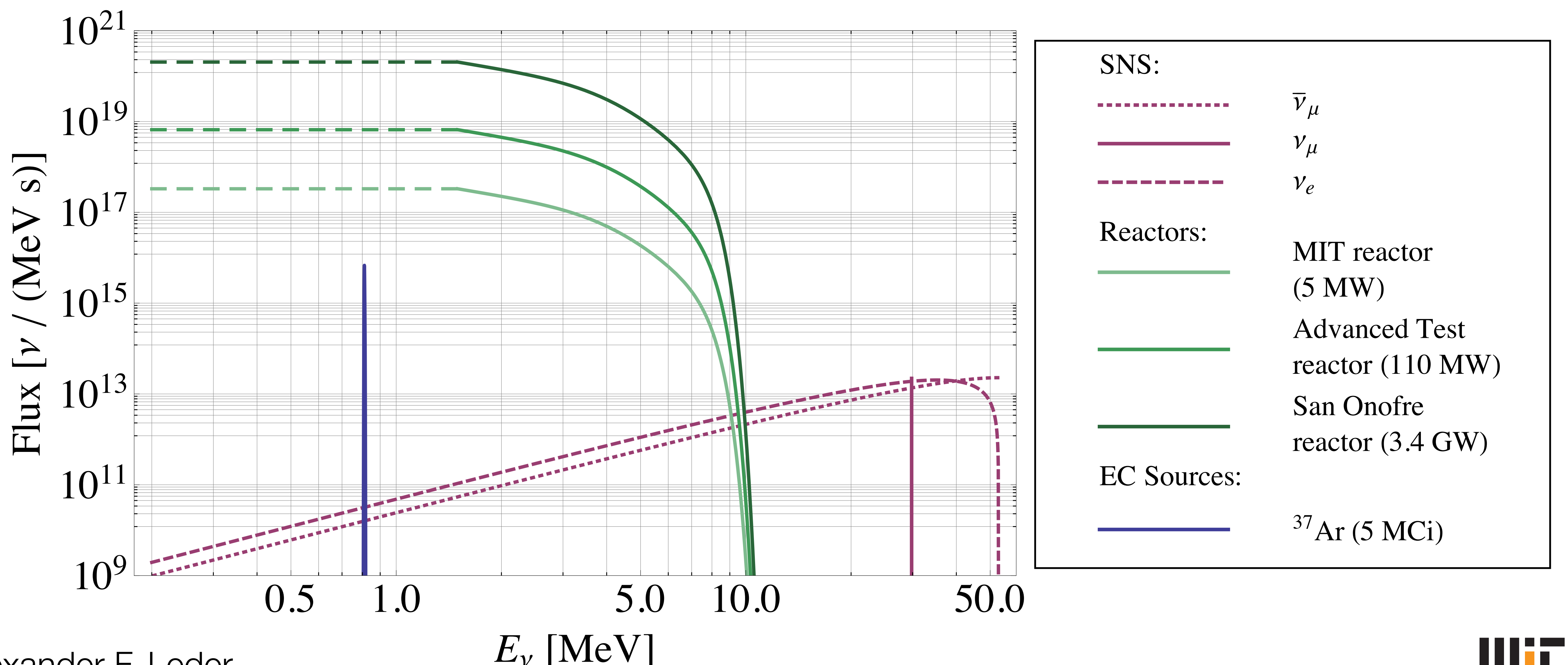
# Different Neutrino Sources

| Sources | Pros | Cons |
|---|---|---|
| Radioactive Sources (Electron Capture) | Mono-energetic, can place detector < 1m from source, ideal for sterile neutrino search | < 1 MeV energies require very low (~10 eVnr) thresholds, limited half-life, costly |
| Nuclear Reactors | Free*, highest flux | Spectrum not well known below 1.8 MeV, site access can be difficult, potential neutron background |
| Spallation/Decay at Rest | Higher energies can use higher detector thresholds, timing can cut down backgrounds significantly | Prompt neutron flux; large shielding or distances needed |

* Nothing is really free.

# Neutrino Sources

3 sources to consider:
- Electron-capture sources
- Reactors
- Decay-at-rest sources



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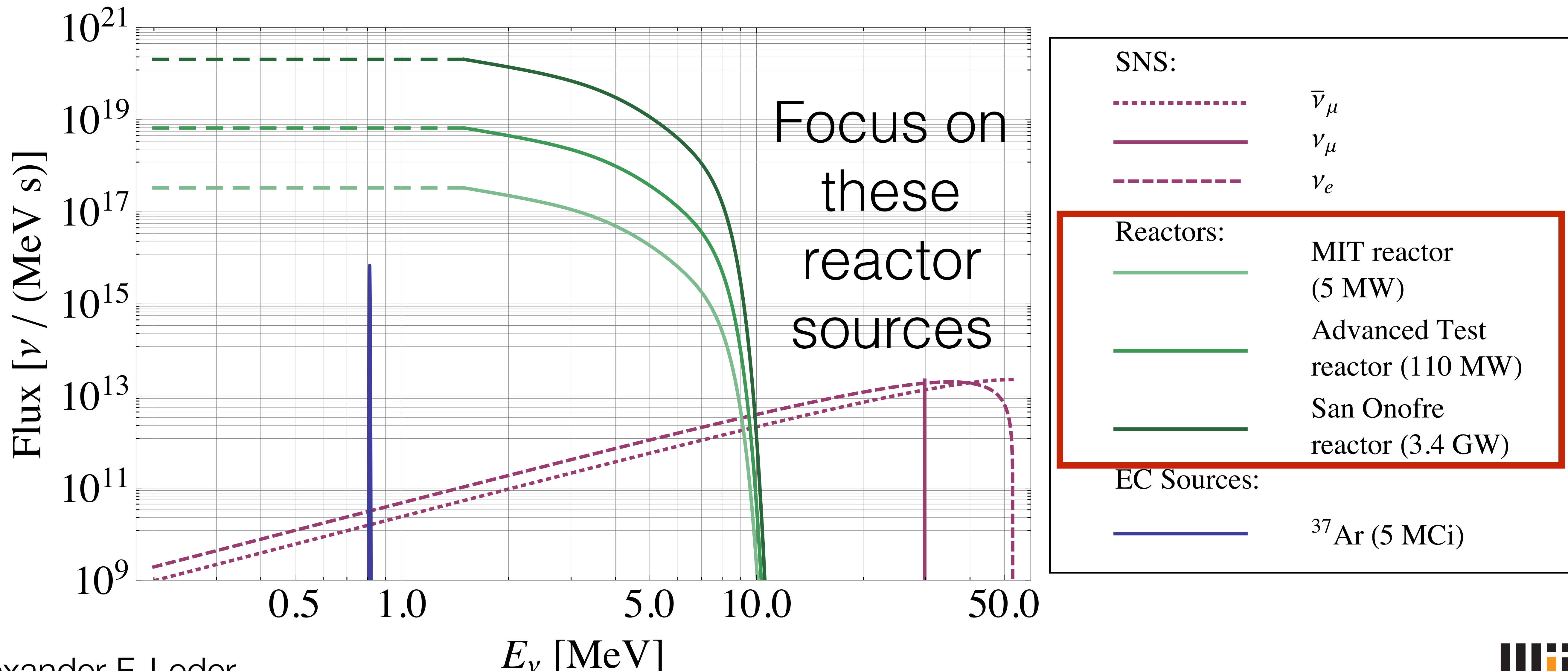

# RICOCHET

## A Coherent Neutrino Scattering Program

**Part II**: Detector Proposal

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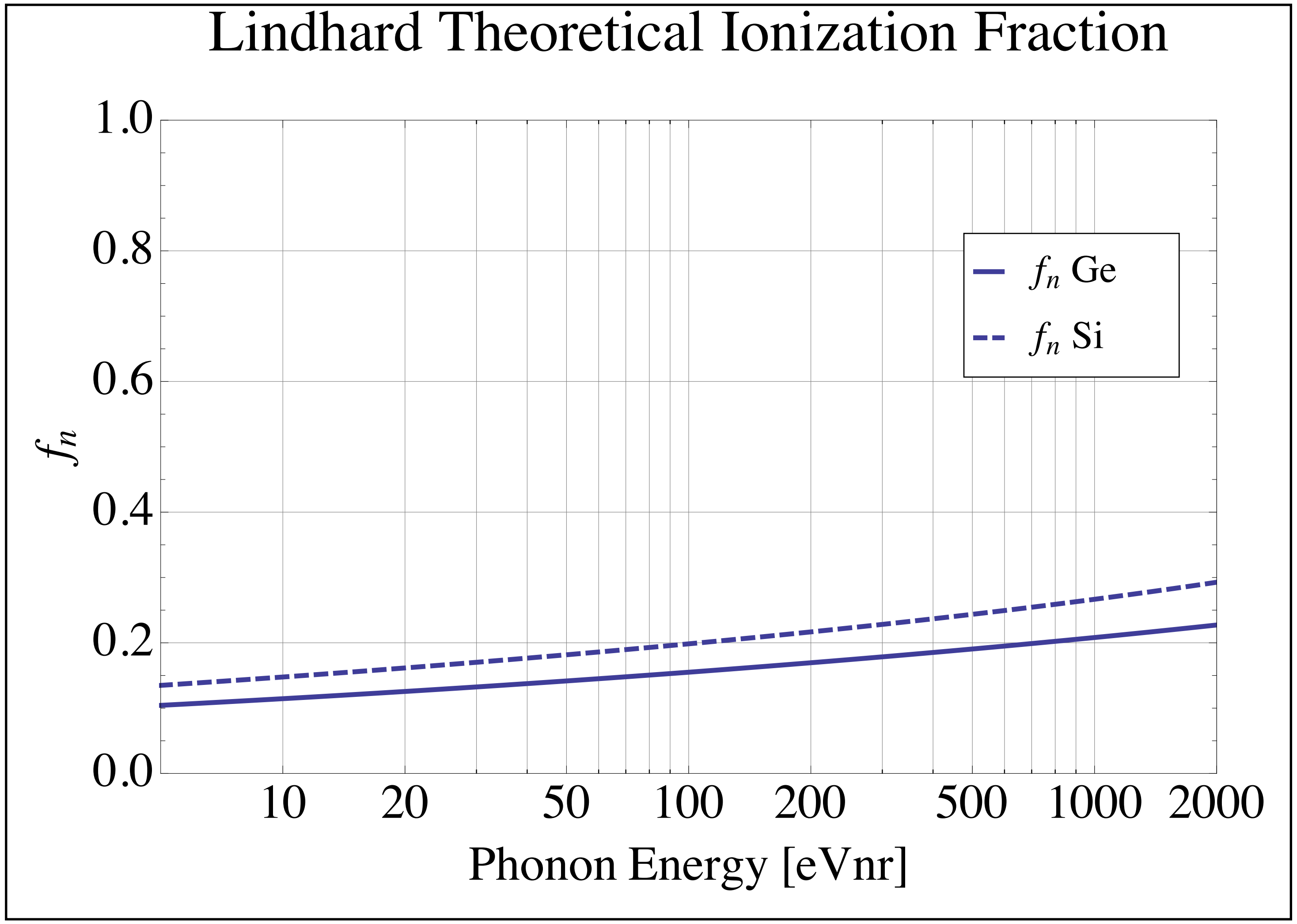
# Detector Requirements

- Threshold is the name of the game
- Important to understand intrinsic and external backgrounds
- Low signal event rate
- Sound familiar?
- Detector could be optimized in terms of material, size and/or background rejection capabilities

# Setting the Threshold

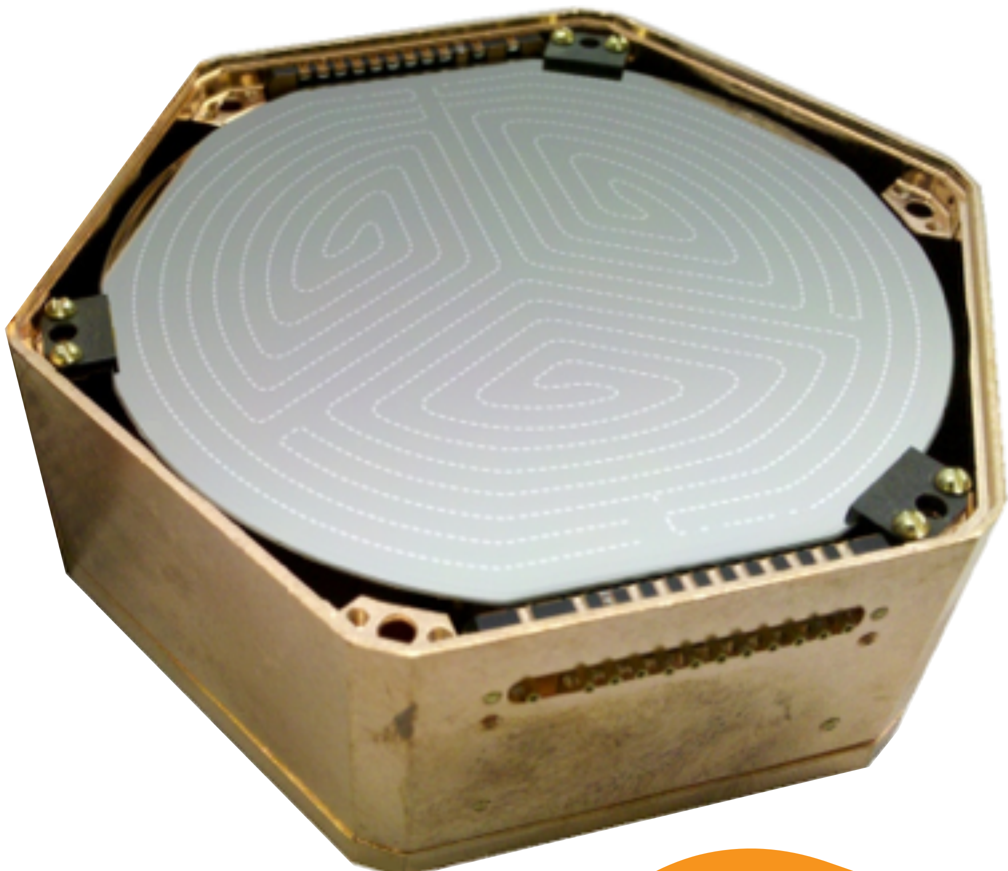
$$f_n = \frac{kg(\epsilon)}{1 + kg(\epsilon)}$$

- Small average recoil energy
- Ionization quenching factors small at these low energies
- Scintillation threshold would produce poor statistics
- Ideally you would want a large pure phonon detector, however;
    - “Sensitivity scales with volume, problems scale with surface area”

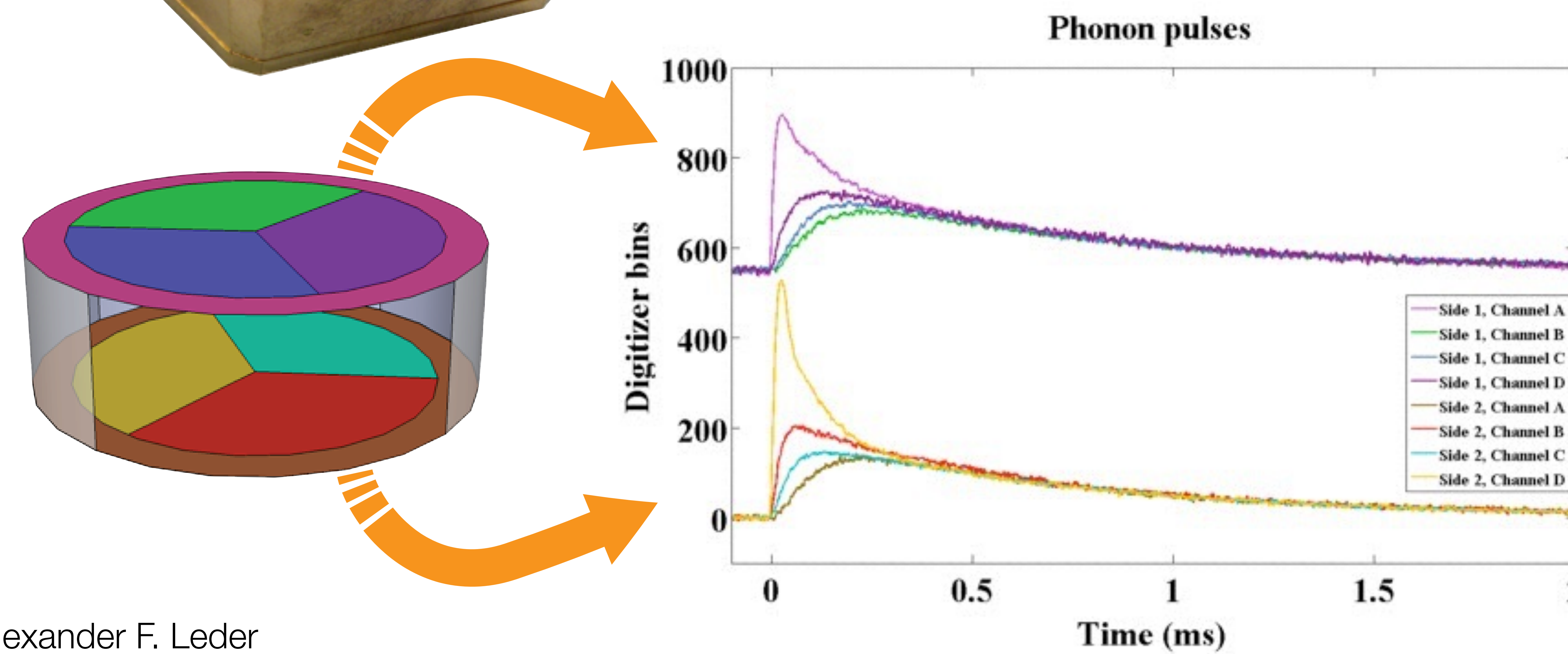



$$k_{\mathrm{Ge}} = 0.157$$
$$k_{\mathrm{Si}} = 0.146$$

# Dark Matter Detectors



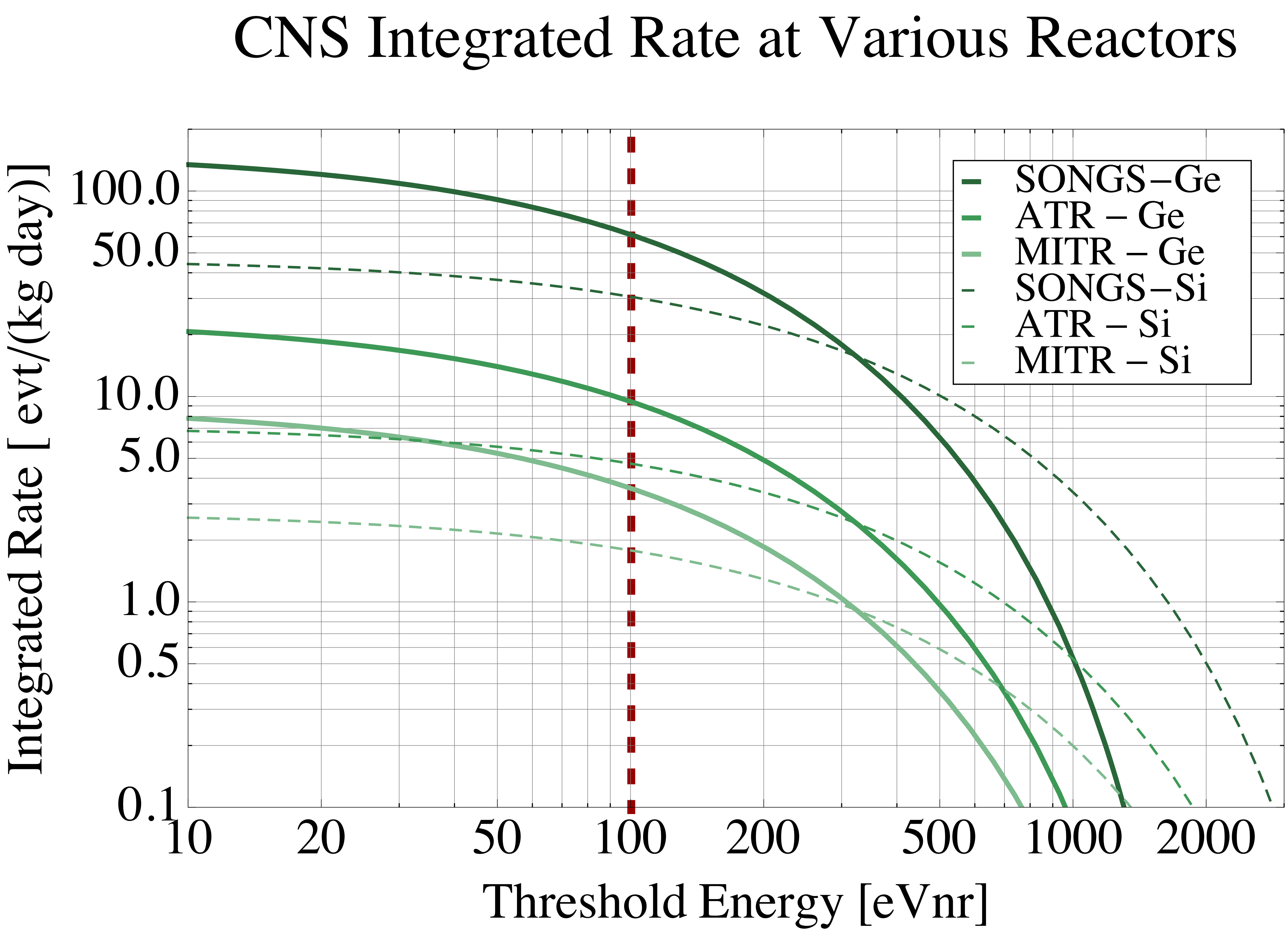
- Optimization of SuperCDMS-style detectors for low threshold (Silicon or Germanium)
- Assume 100 eV threshold for reactor experiment @ 5 kg mass
- Possibility of other materials (Osmium)



# Dark Matter Detectors

- This represents a different approach to neutrino detection
- Pure thermal detectors have in recent years shown promise in reducing their thresholds (see efforts by CDMSlite team)
- Ricochet proposal seeks to use smaller detectors to measure thermal instead of athermal phonons
- R&D ongoing at MIT

# CNS Signal



CNS Integrated Rate at Various Reactors
Integrated Rate [ evt/(kg day)]
100.0
50.0
10.0
5.0
1.0
0.5
0.1
10
20
50
100
200
500
1000
2000
Threshold Energy [eVnr]
SONGS−Ge
ATR − Ge
MITR − Ge
SONGS−Si
ATR − Si
MITR − Si

# Event Rates for 100 eVnr Threshold

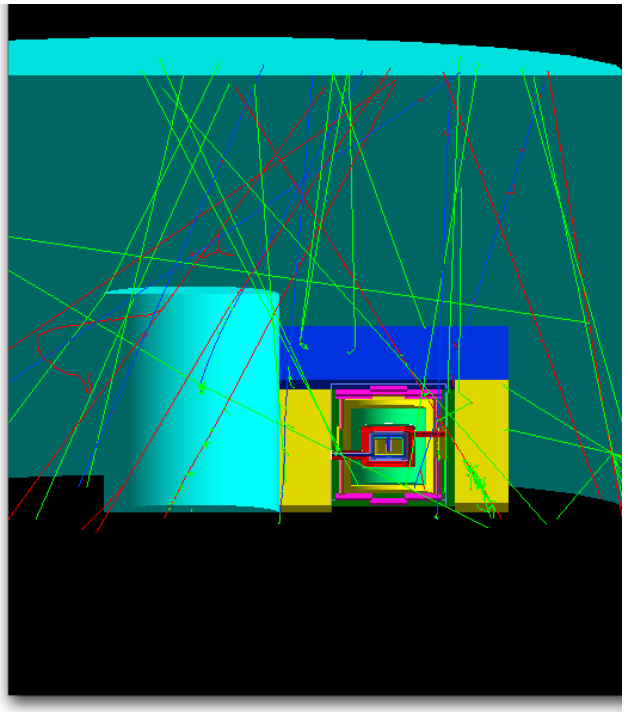
| | MITR | ATR | HFIR(?) |
|---|---|---|---|
| Baseline | 4 m | 11 m | 8 m |
| Ge evt/kg/day | 3.6 | 9.6 | 15.3 |
| Si evt/kg/day | 1.8 | 4.7 | 7.7 |

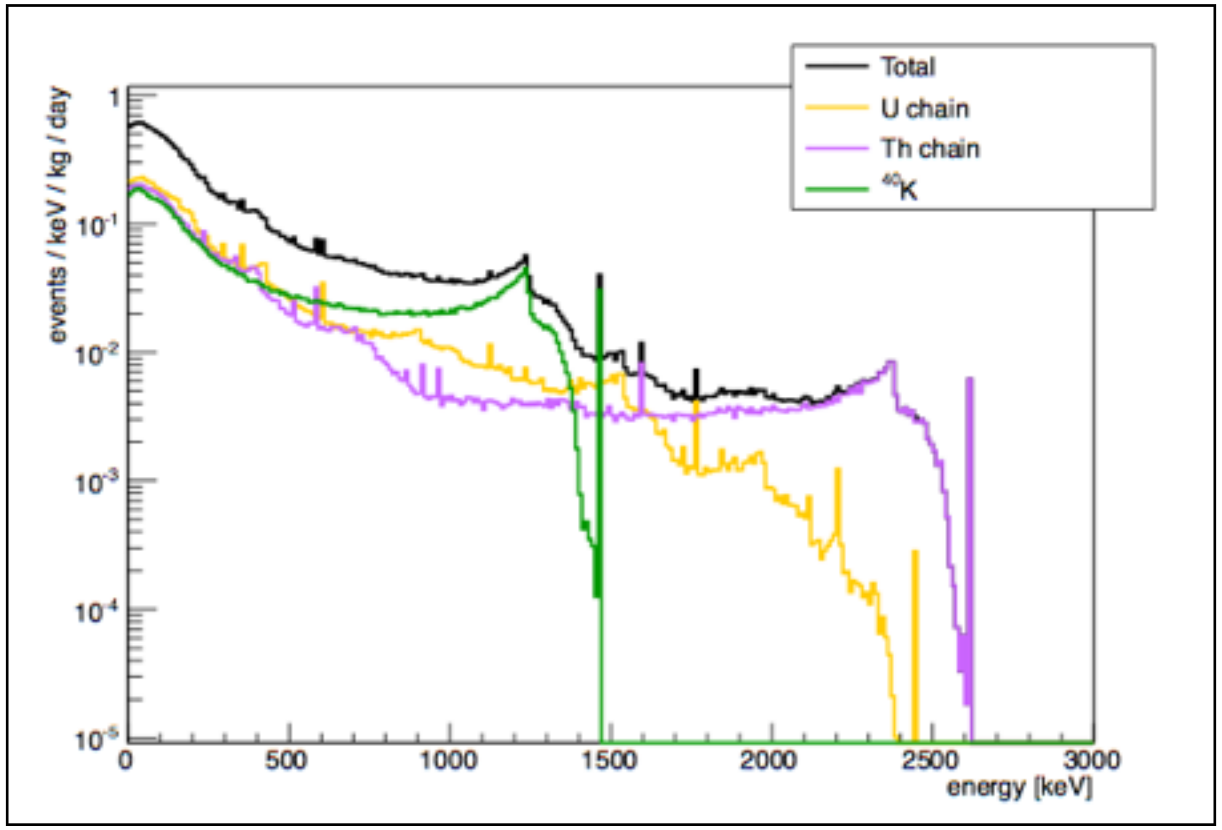
## **Part III**: Neutron Monitoring at MITR

# Backgrounds

- γ, β, n, and α Backgrounds for this experiment fall into 3 categories:
  - Cosmogenic
  - Radiogenic
  - Reactor based
- Work has been performed to simulate cosmogenic and radiogenic backgrounds in GEANT4
- Current focus on neutron background both in simulation and in real life

CRY simulation





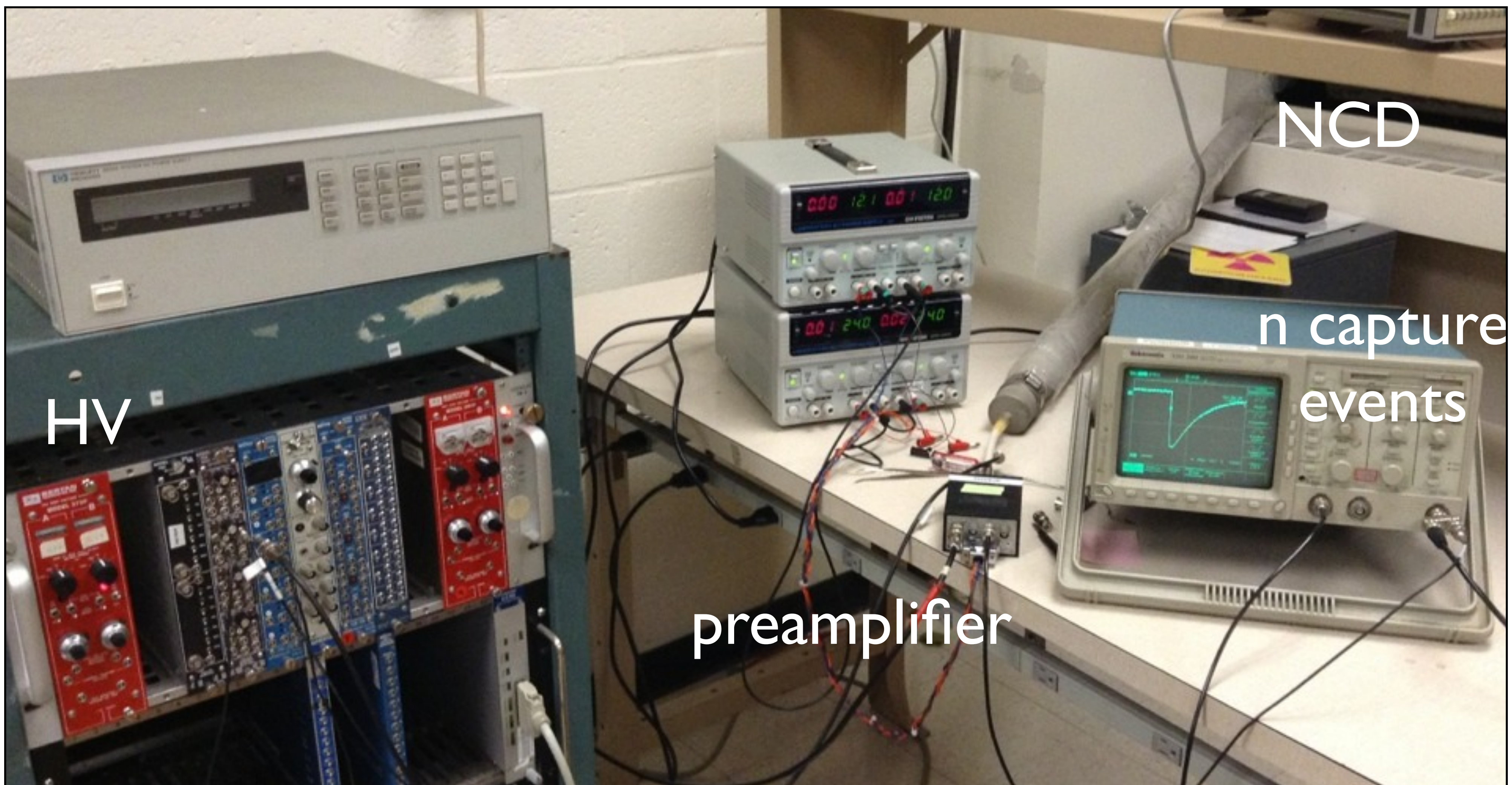

U,Th chain simulations

# Neutron monitoring - Setup

Use of He3 Neutron Capture Detector (NCD) based on the following process:

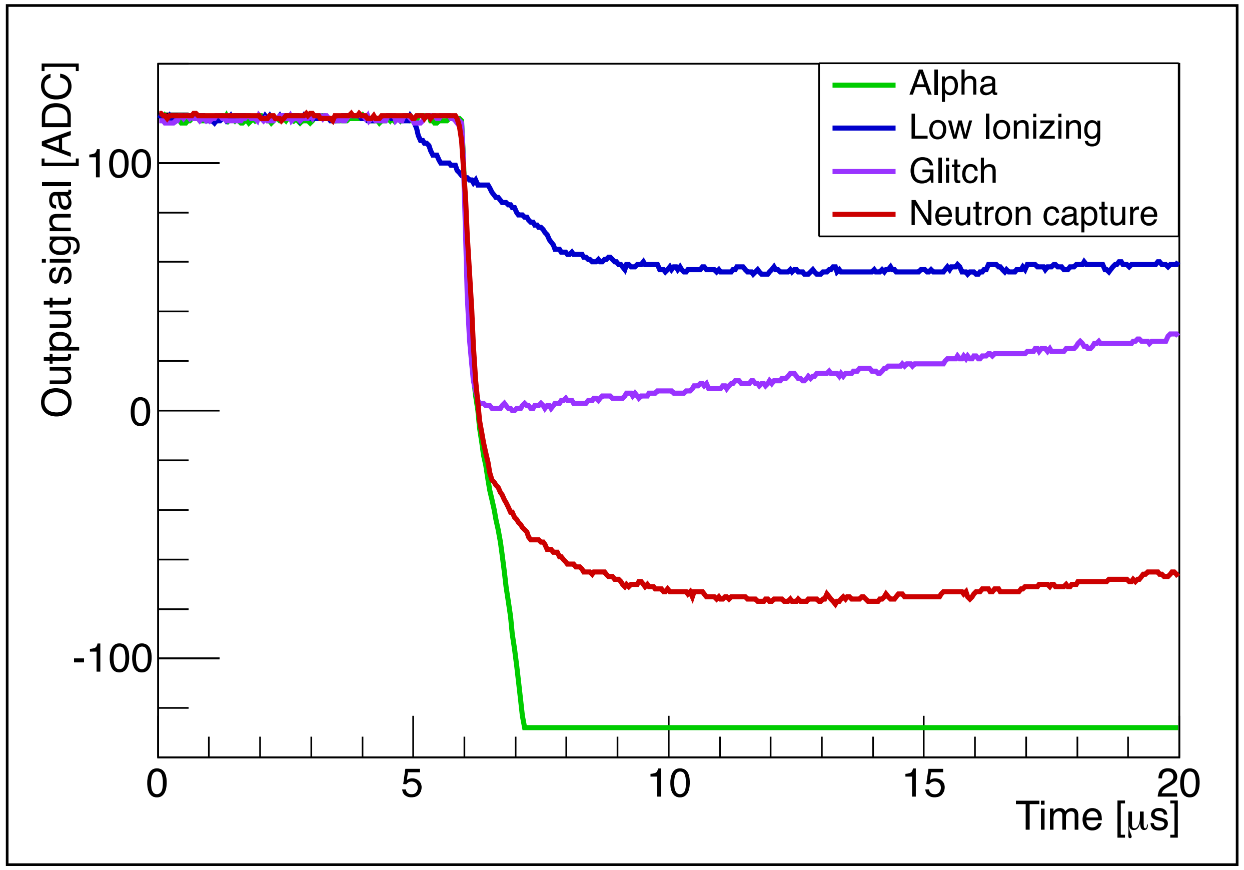
$$\mathrm{n} +^{3}\mathrm{He} \rightarrow \mathrm{p} + \mathrm{t} \quad (\mathrm{Q} = 764\ \mathrm{keV})$$

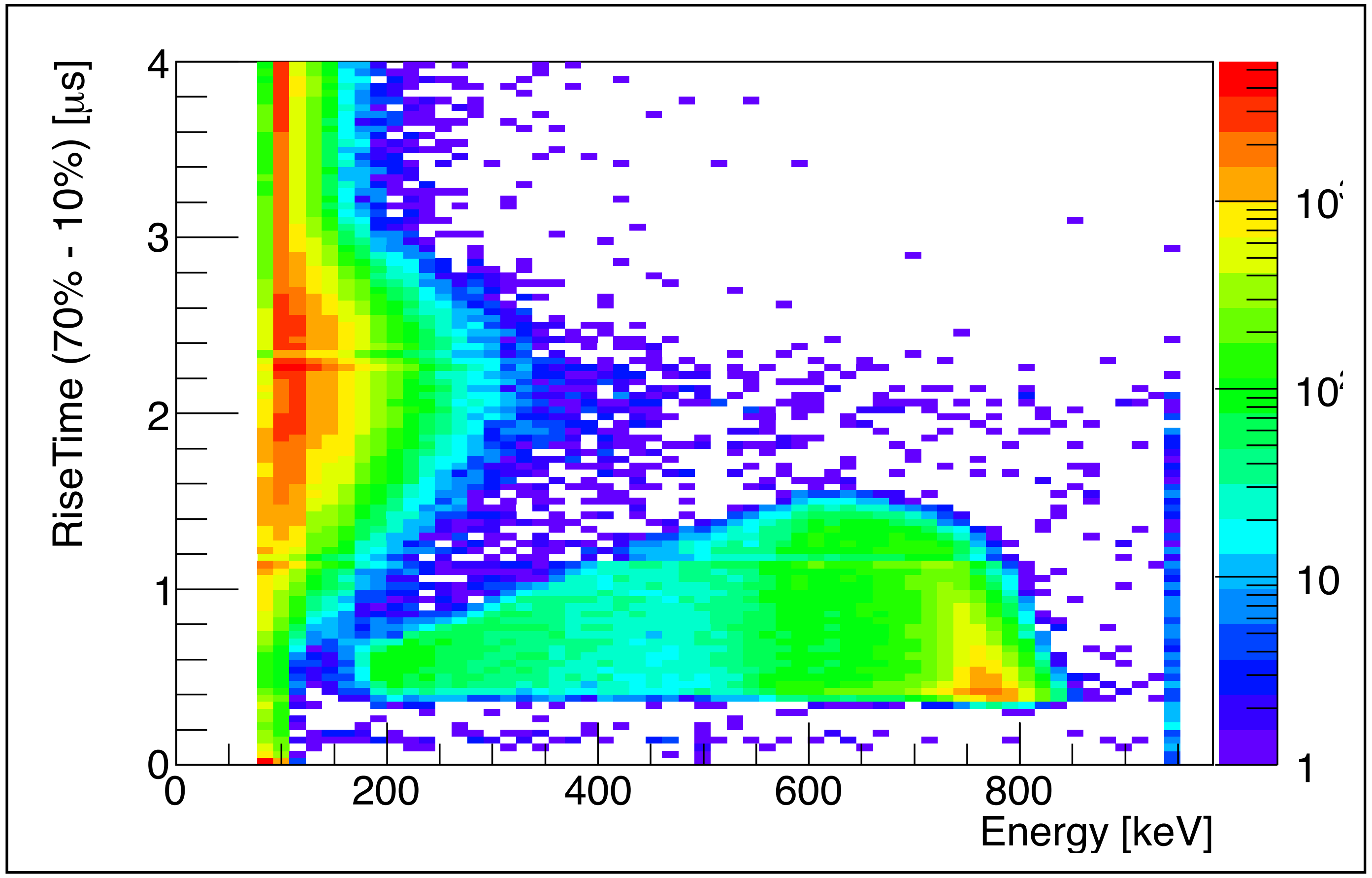
- **Cylinder shape:** 200 cm long, 5.08 cm diameter => active volume ~ 4000 cm3
- **Gaseous TPC:** 85% 3He + 15% CF4 @ 2.53 bar
- **Charge readout:** charge preamplifier Canberra 2001A
- **Optimal HV:** 1.95 kV
- **Energy resolution @ 764 keV:** 3.3%



# Neutron Monitoring - PSD

- With pulse shape discrimination on amplitude and rise time we can define a neutron signal region with 99 percent efficiency!



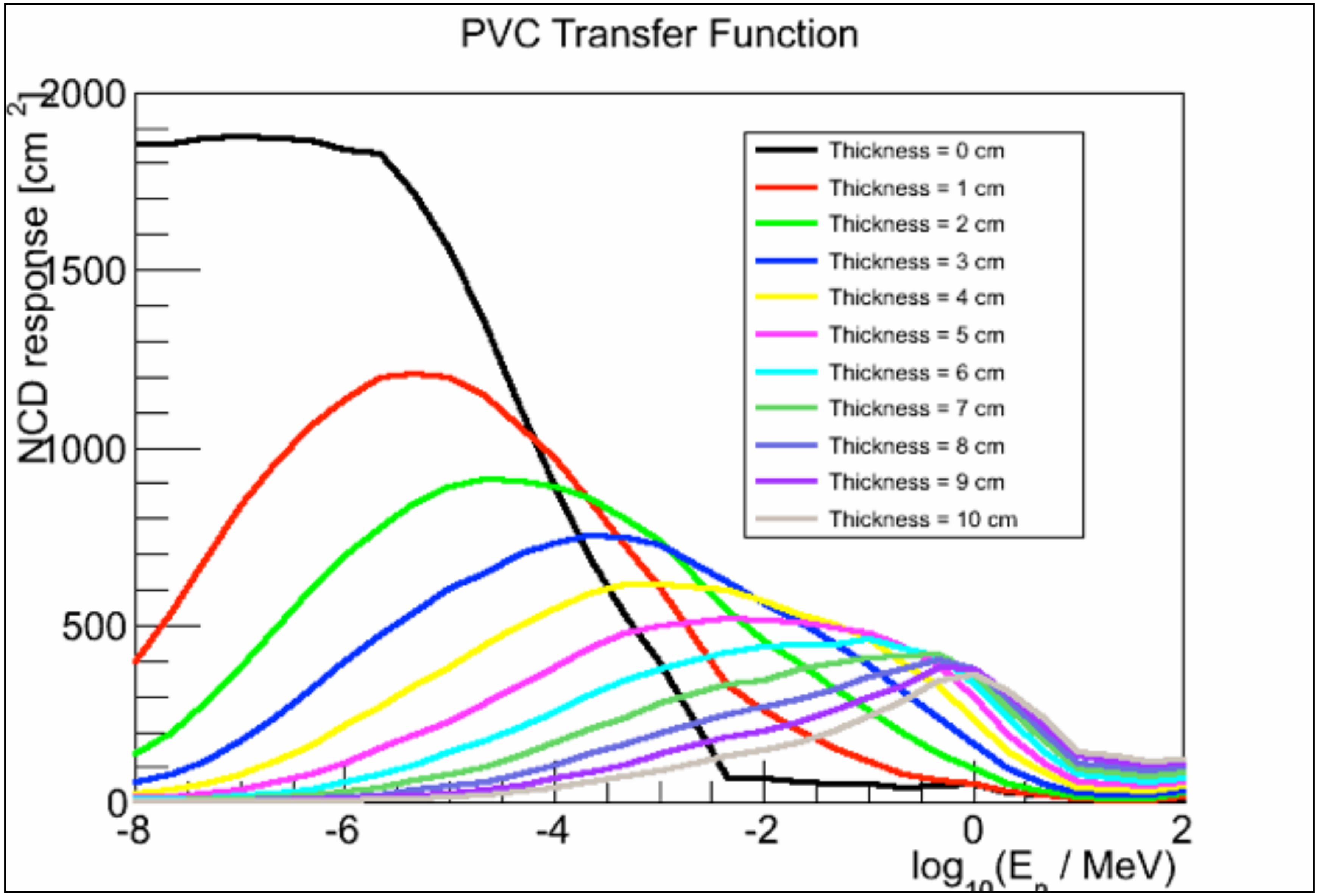
# Neutron monitoring - Transfer Functions

## A Bonner sphere approach

NCD are mostly sensitive to thermal neutrons (cross section ~ $10^4$ barns)

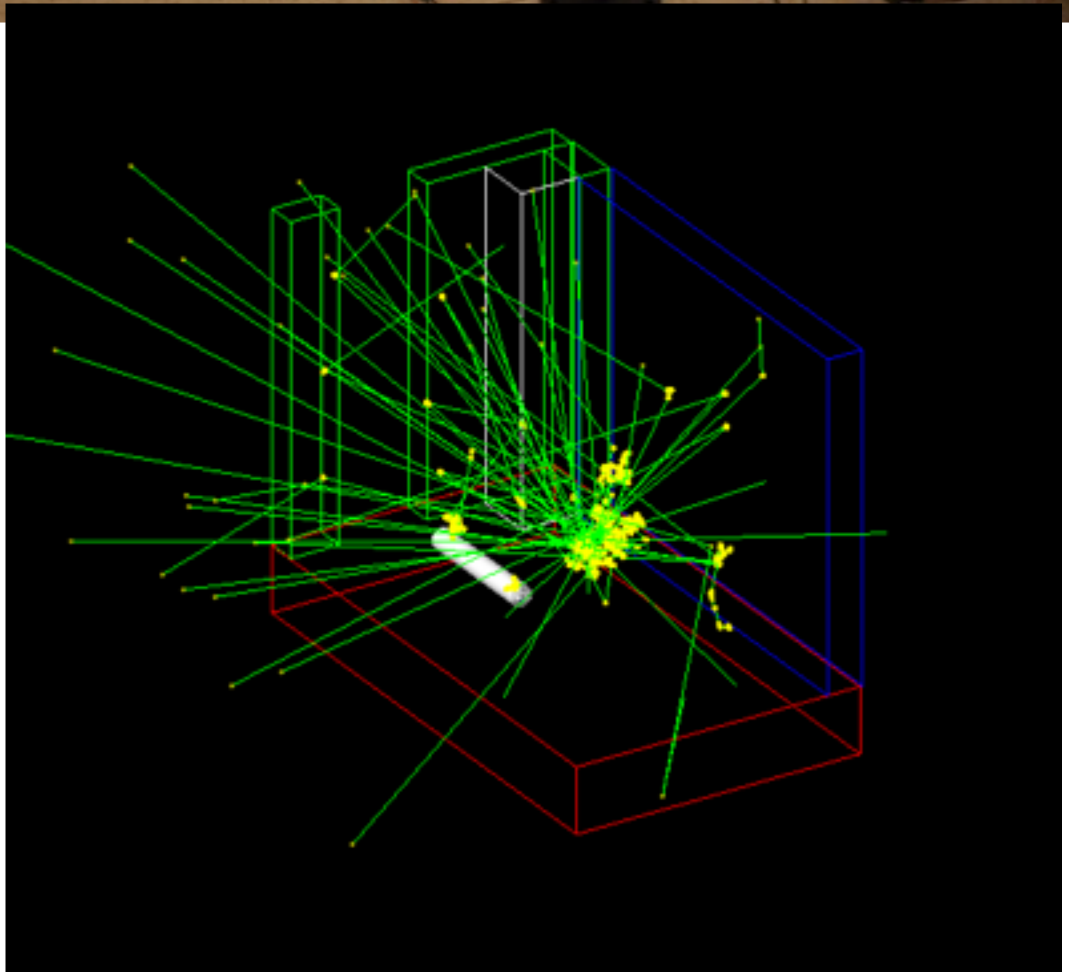
Use layers of PVC to slow down neutrons due to multiple collisions with hydrogen (mostly)

With PVC thicknesses up to 10 cm, we are sensitive to MeV neutrons!



# Neutron Monitoring - Current Efforts

- Current efforts are focused on developing a neutron MC that can reproduce the data collected at the MITR
- Confirm that our transfer functions work
- Perform an estimate of the neutron background we could expect with a CDMS style Silicon/Germanium Detector



# Conclusion

- Coherent Neutrino Scattering offers an exciting probe into new physics as well as opening the door to several applications
- Due to low per-event recoil energy, detection requires low-threshold dark matter-style detectors
- Current effects focus on neutron monitoring at MITR to outline expected background for Ricochet-style experiment
- Results expected soon

# Thank you for your attention

Questions?