MAGNETO-v: keV Sterile Neutrino Search in ^{241}Pu Beta Decays

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MAGNETO: DM Search with Magnetic Quantum Sensors

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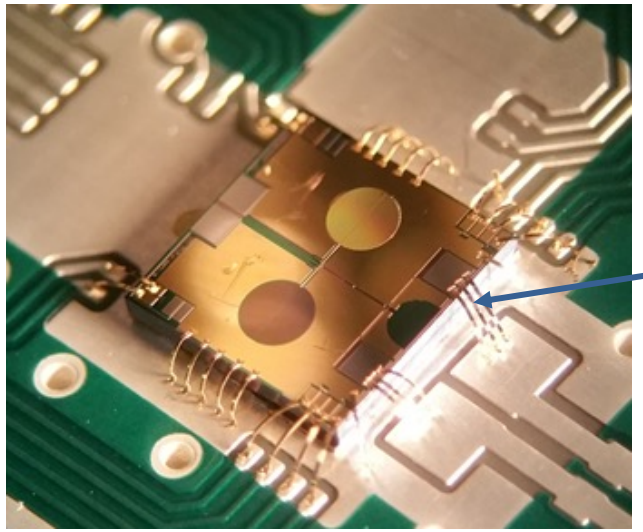
THE OHIO STATE UNIVERSITY

SLAC NATIONAL ACCELERATOR LABORATORY

Fast (<1μs) and high energy resolution (~10 eV) magnetic sensors for
MAGNETO-ν: keV-neutrino search in ^{241}Pu beta decays
MAGNETO-χ: Sub-GeV DM detection with phonon pulse shape discrimination

Magnetic Quantum Sensors (Quantum Sensor 1.0)



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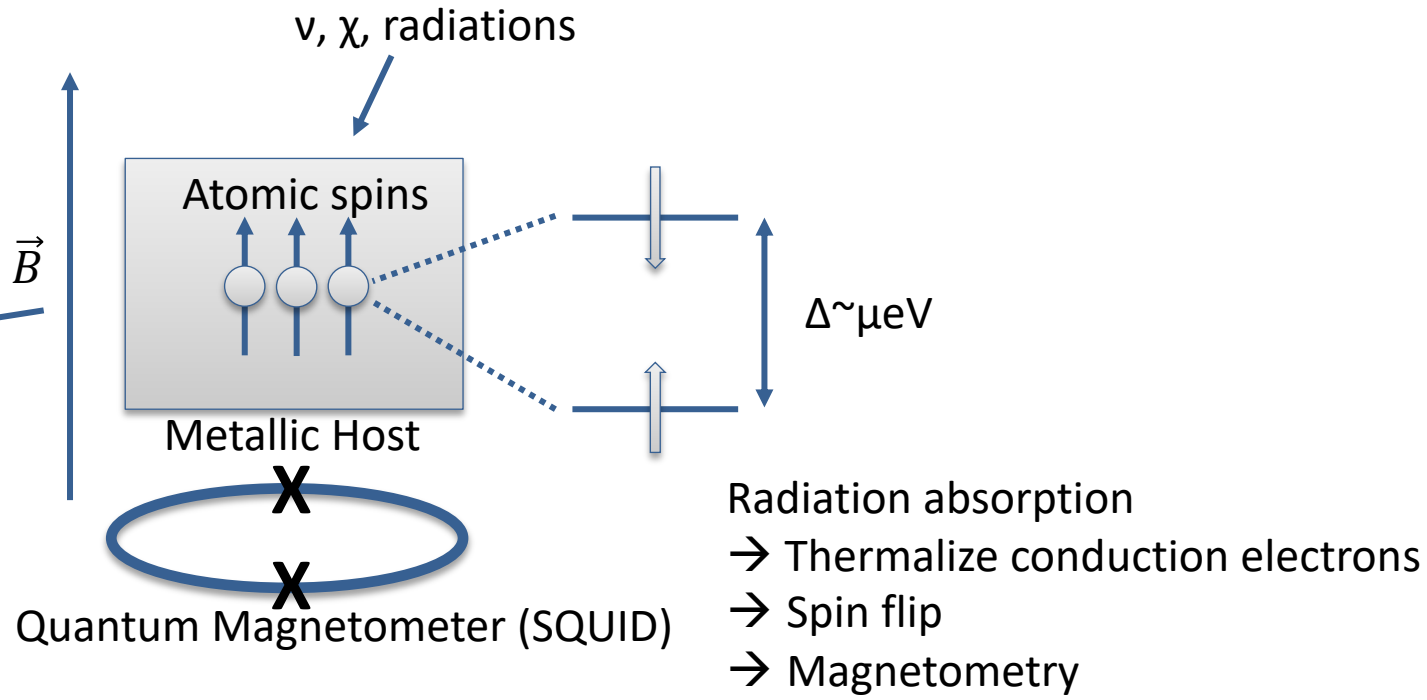
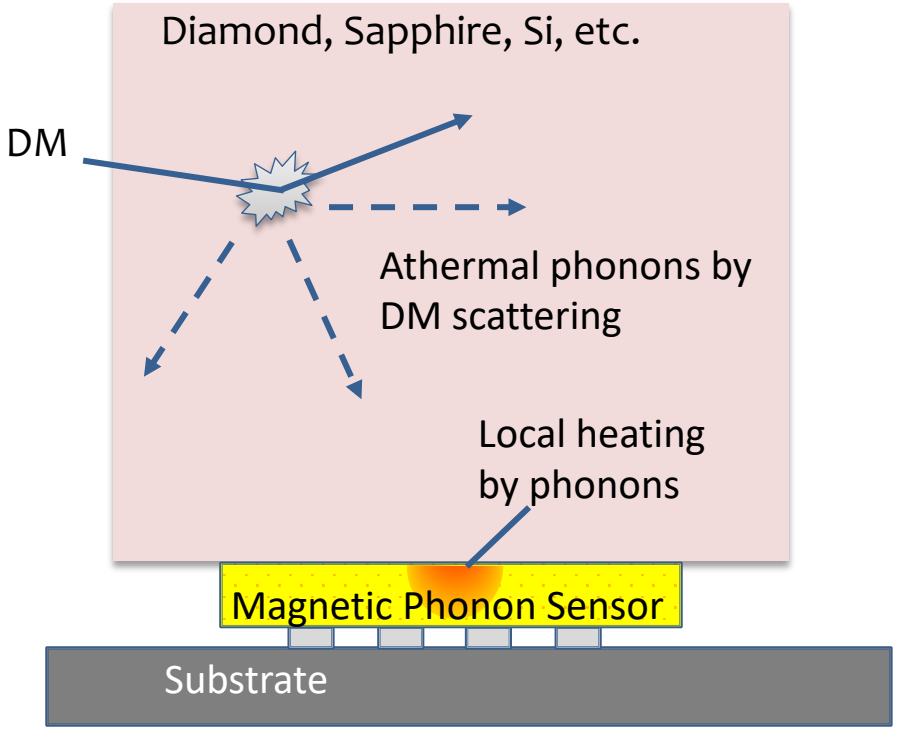


- **Fast response (~100 ns)**
- **High energy resolution (~10 eV)**
- **Smooth and linear response (M = 1/T)**
- **Broad and Flexible Energy range: 1eV – 1GeV**

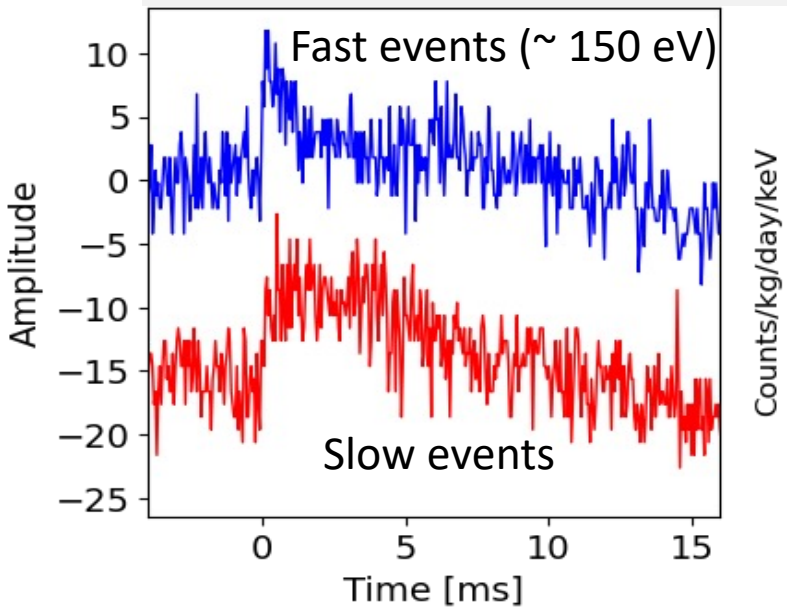
MAGNETO-χ: Sub-GeV DM Detection with phonon PSD

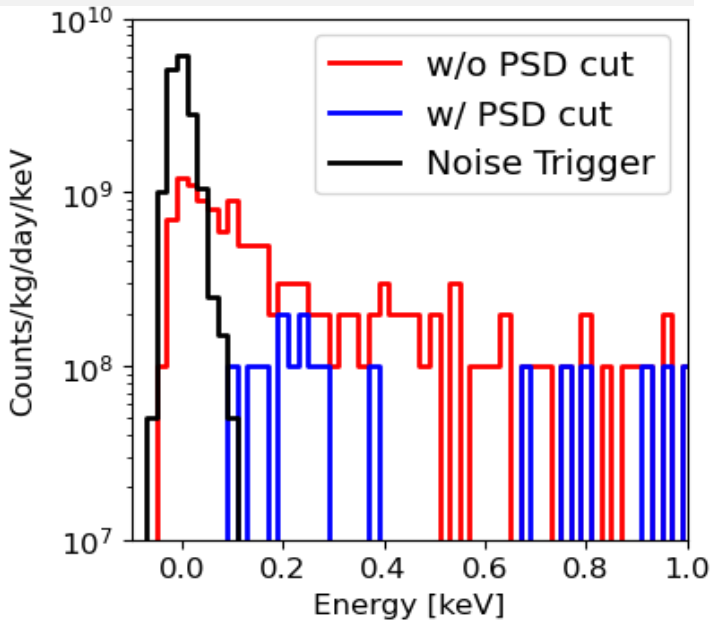
Fast phonon sensing **(< 1us risetime)**



See "Low energy excess in MAGNETO R&D Data"
EXCESS workshop, 2022

Phonon Pulse Shape Discrimination

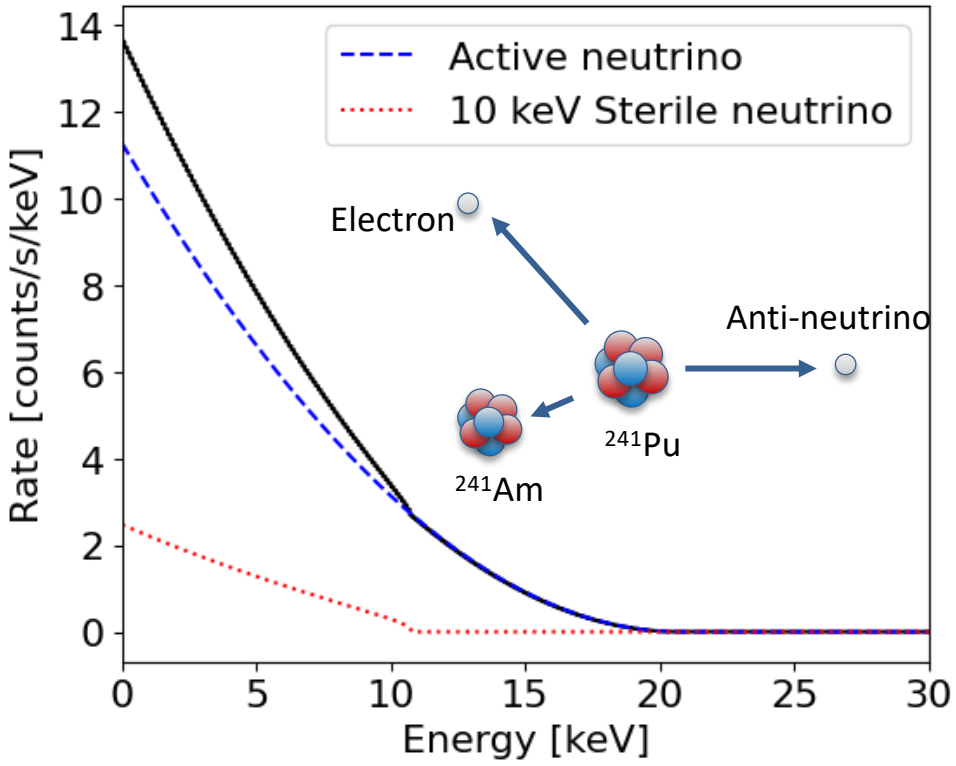




- Phonon shape analysis for **"EXCESS" events** with 100 ns risetime
- Background reduction (NR/ER, thermal/athermal)
- **Almost any type of crystals can be used**

  Crystal qualification program is ongoing for Diamonds (pCVD and scCVD), Sapphire, Si, Ge, etc.

MAGNETO-ν: keV Neutrino Search with ^{241}Pu β-decays



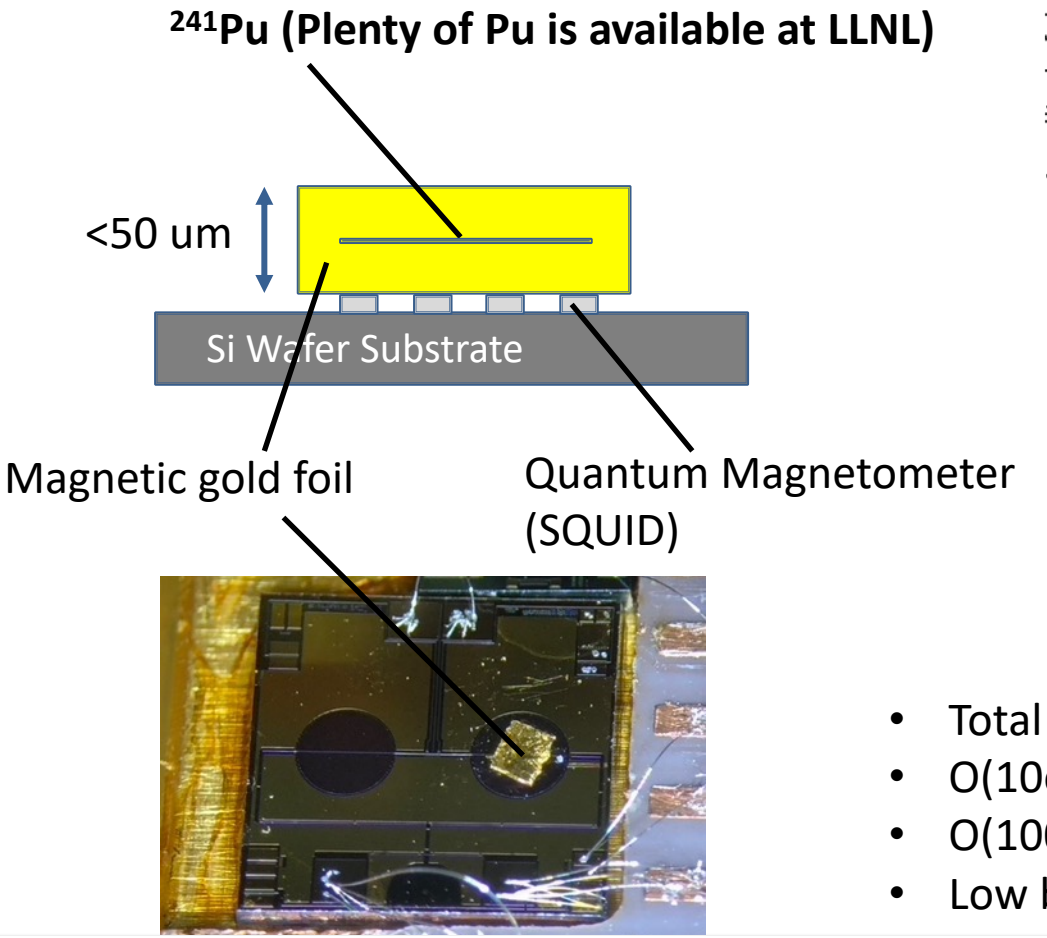
High precision beta shape analysis via "Micro-calorimetry"

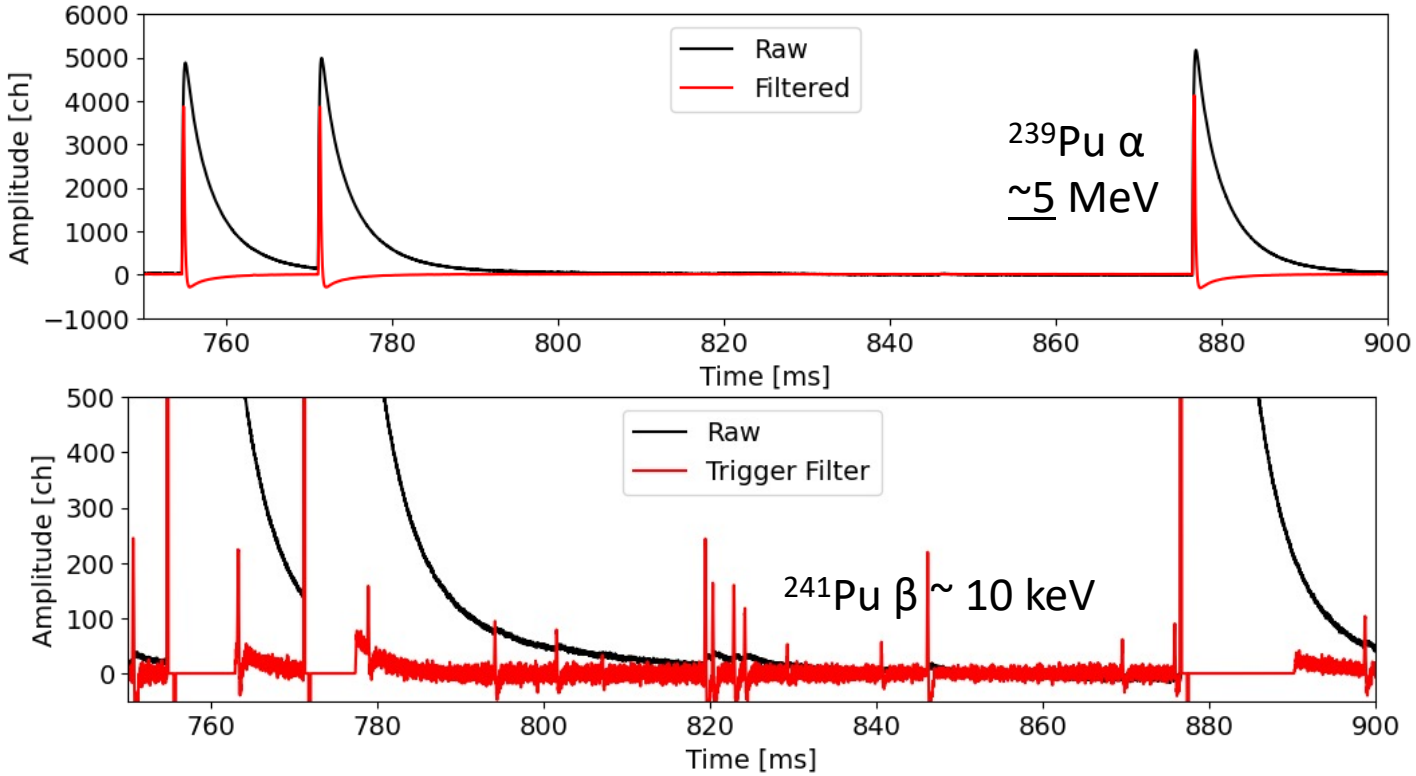
Experimental Motivation

- Ideal for 1 – 20 keV neutrino (DM) search
- Complementary to ^{3}H experiments
- **"On-shelf" available and "Easy" handling source**
- Cost-effective experiment

	^{241}Pu	^{3}H
Q-value	**20.8(2) keV**	**18.5752(5) keV**
Half-life	**14.329(29) y**	**12.32(2) y**
Decay mode	First forbidden β (99.99756(2)%) α (0.00247%)	Superallowed β (100%)

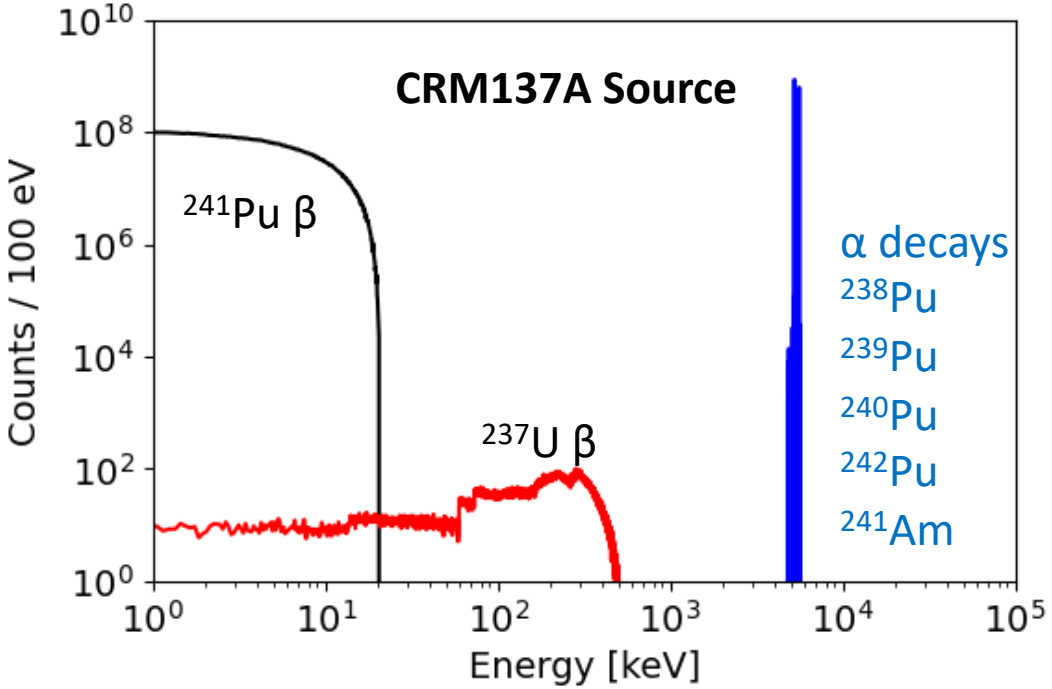
Detector: 4π Microcalorimetry

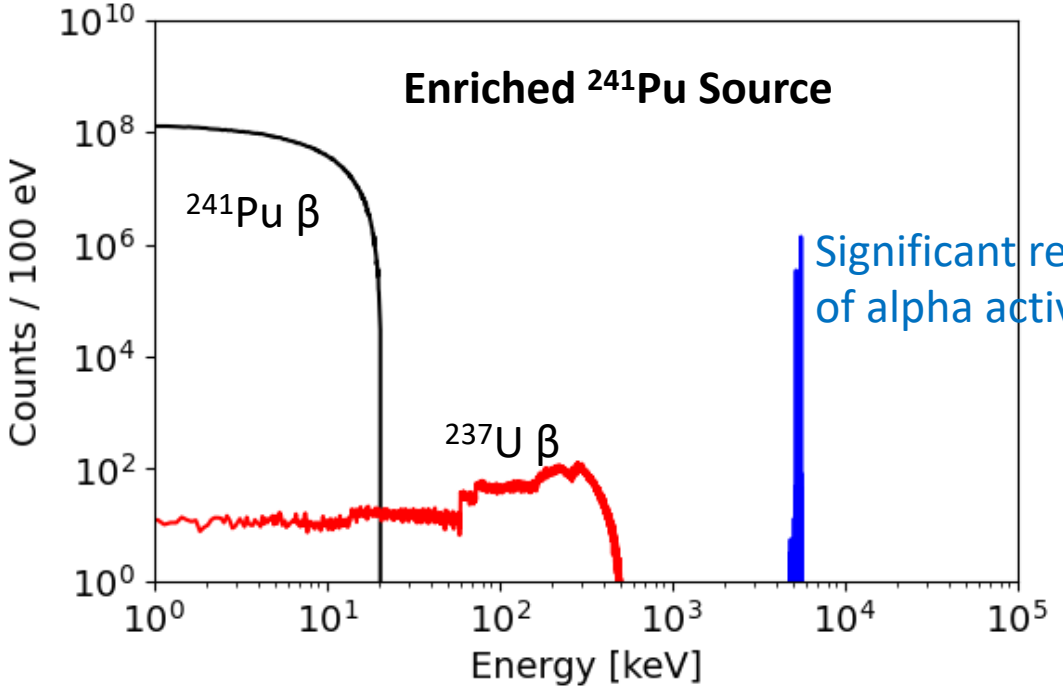




- Total Decay Energy Spectroscopy (electron + nuclear recoil)
- O(10eV) energy resolution
- O(100ns) timing resolution (>100 Bq ^{241}Pu per detector)
- Low background (~1mg detector mass)

^{241}Pu Source



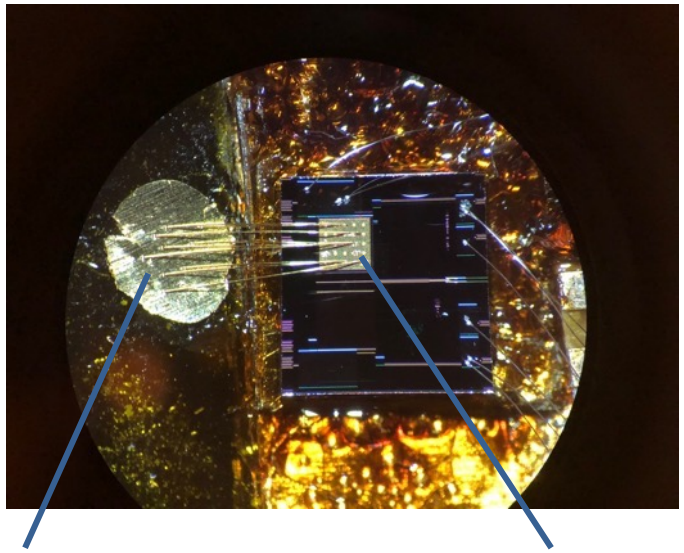


Activity Ratios of Pu Sources

	Stage	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu
CRM137A	Phase-0	6.3%	8.7%	7.7%	**77.2%**	0.009%
Enriched ^{241}Pu	Phase1,2	1.366E-2%	3.453E-3%	4.829E-2%	99.93%	5.267E-4%

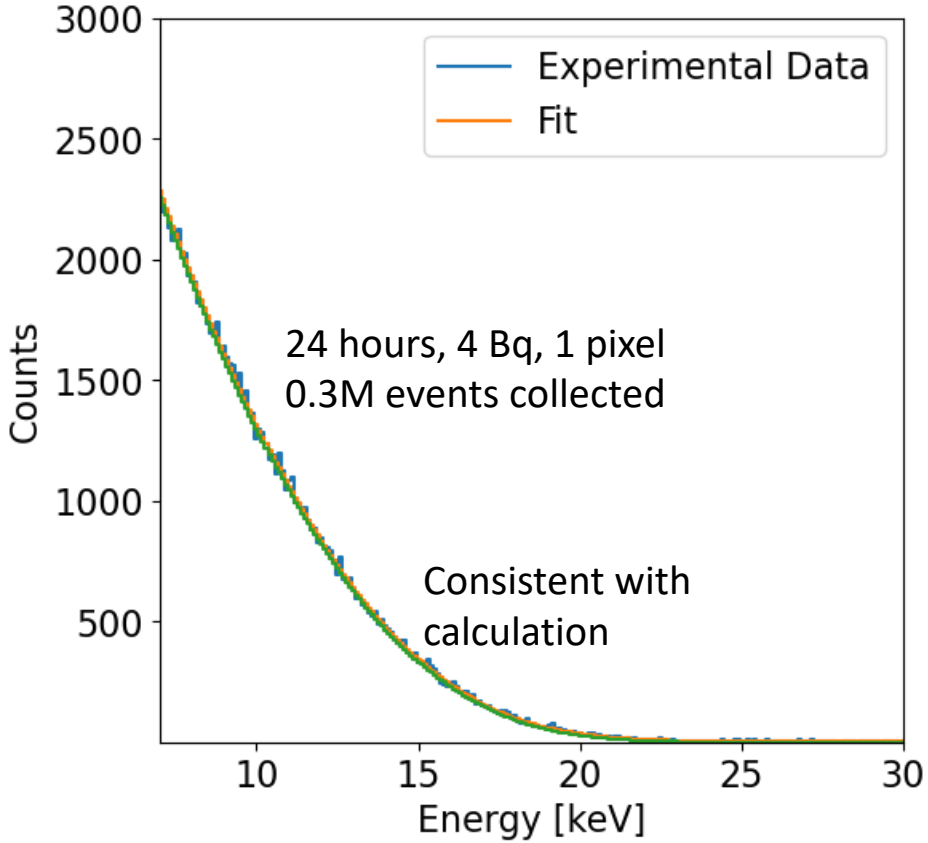
Proof-of-concept Experiment

Preliminary setup with “External” coupling of detector



Gold foil with embedded 241Pu source

Magnetic sensor device (KRISS, South Korea)



Basic idea works!
Next: Increase statistics, Understand systematics and background

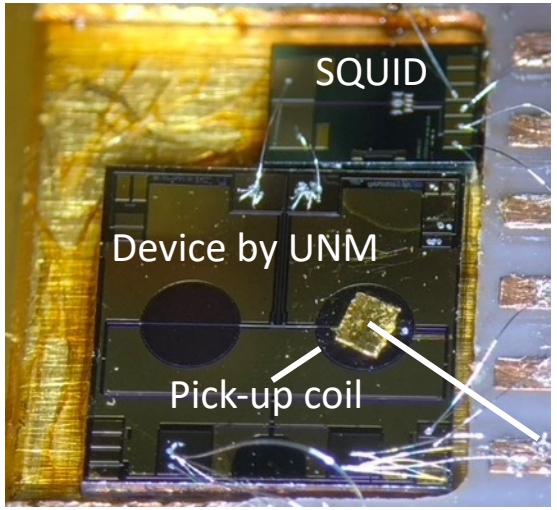
Toward Phase-1

Goal: $3x10^{10}$ total beta counts

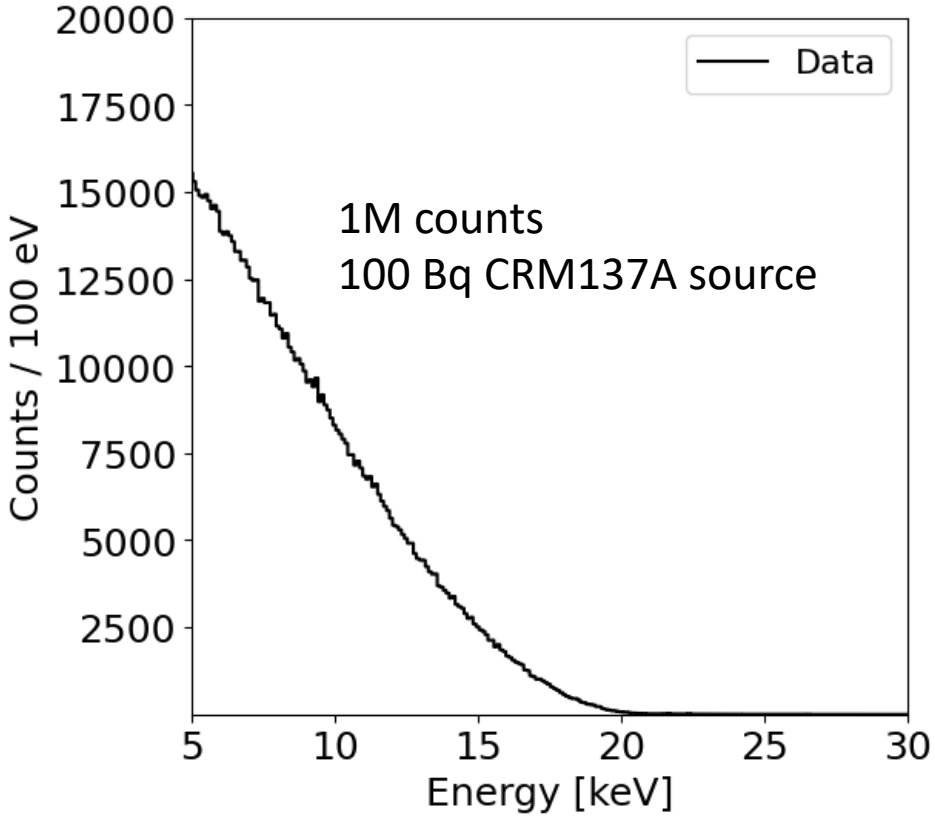
Detector R&D

- Improve timing resolution to reduce random coincidence
  (100 us → 5 us has been achieved)
- Increase counting speed to 100 cps
  (100 cps has been achieved)
- Lower energy threshold to 1 keV
  (Currently at 3 keV)

Test setup for phase-1

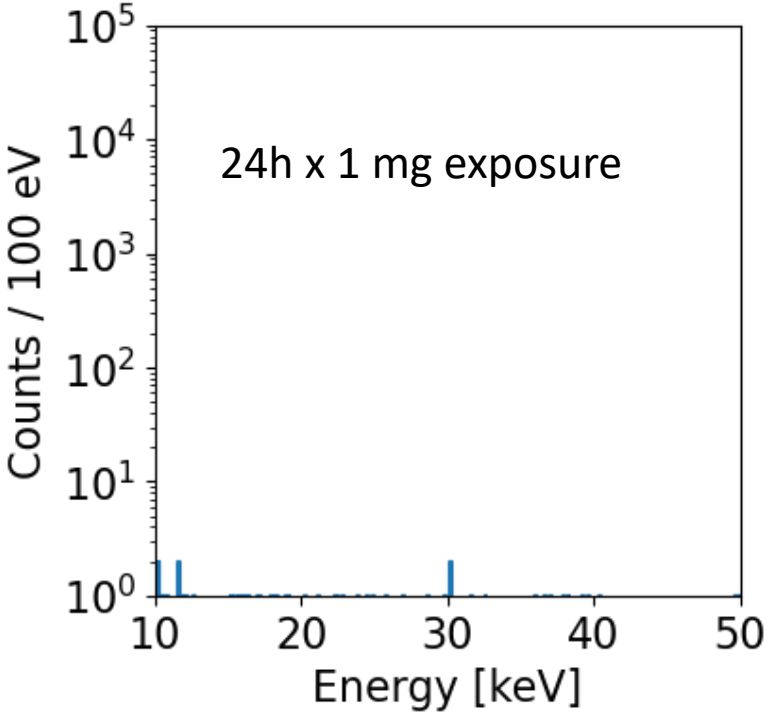


Magnetic gold foil
with source



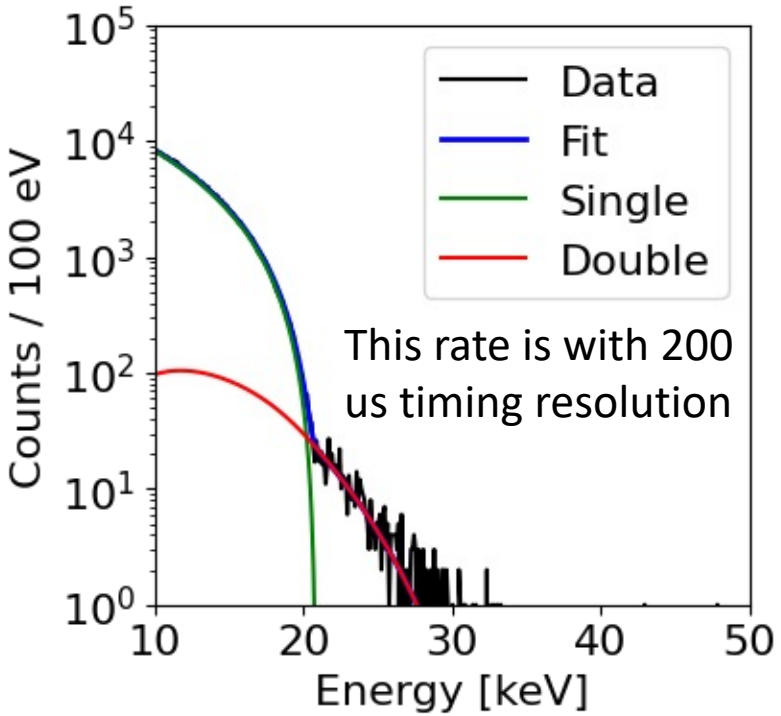
Background

Environmental radiation



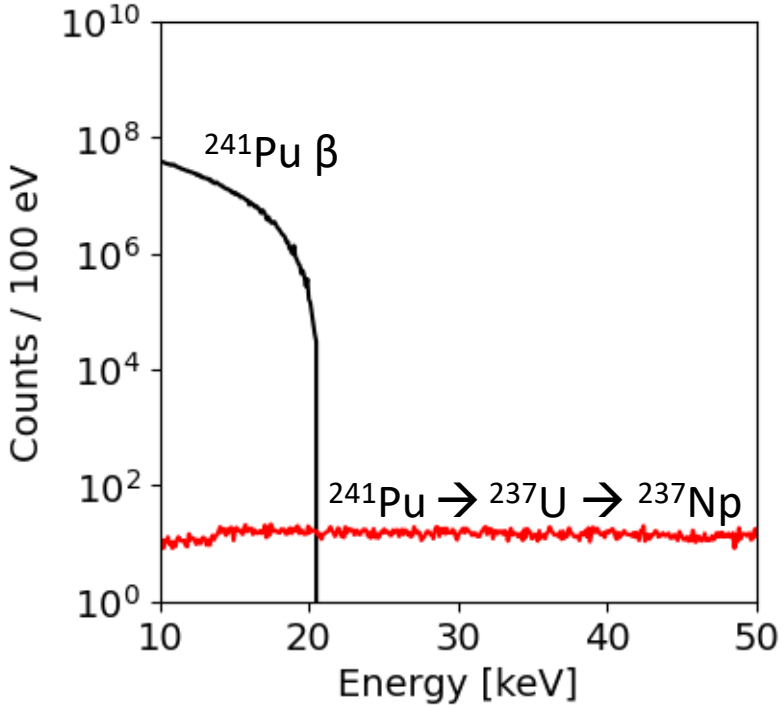
- Low rate due to small detector mass (~1 mg)

Random coincidence



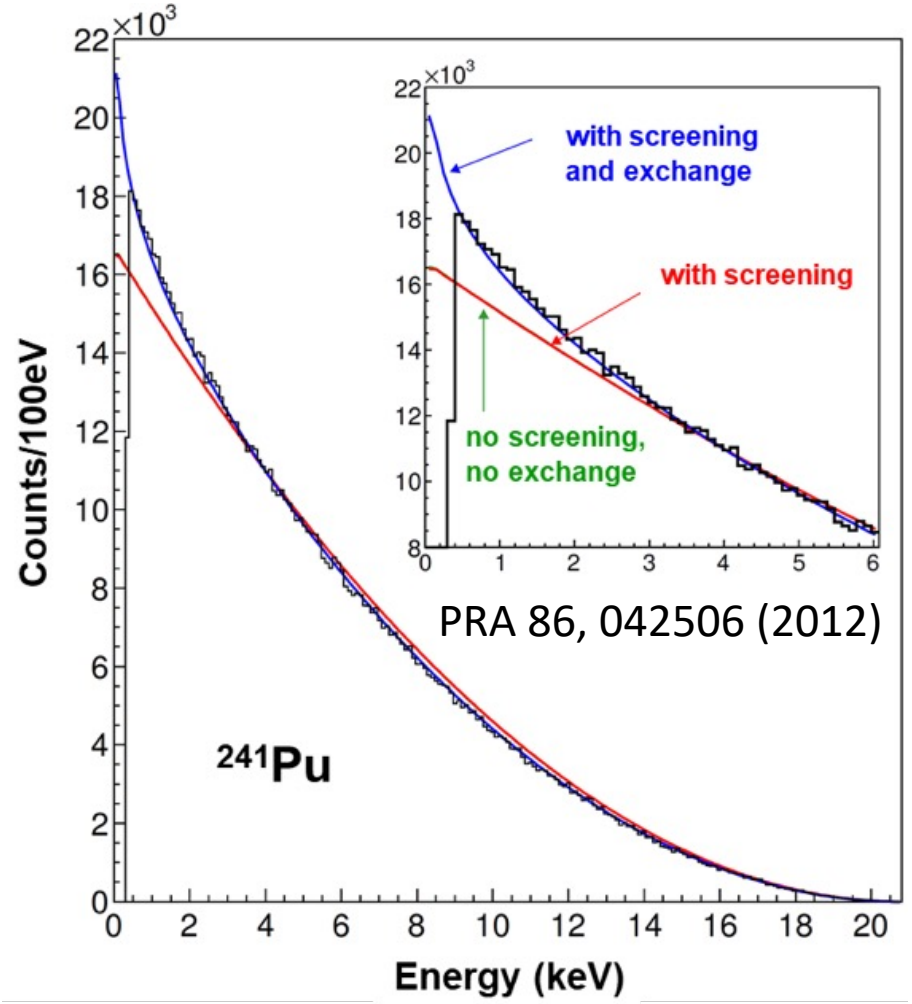
- Can be reduced by improving timing resolution
- Timing resolution has been improved to 5 us.

^{237}U decays



- Flat background

Systematic Uncertainties



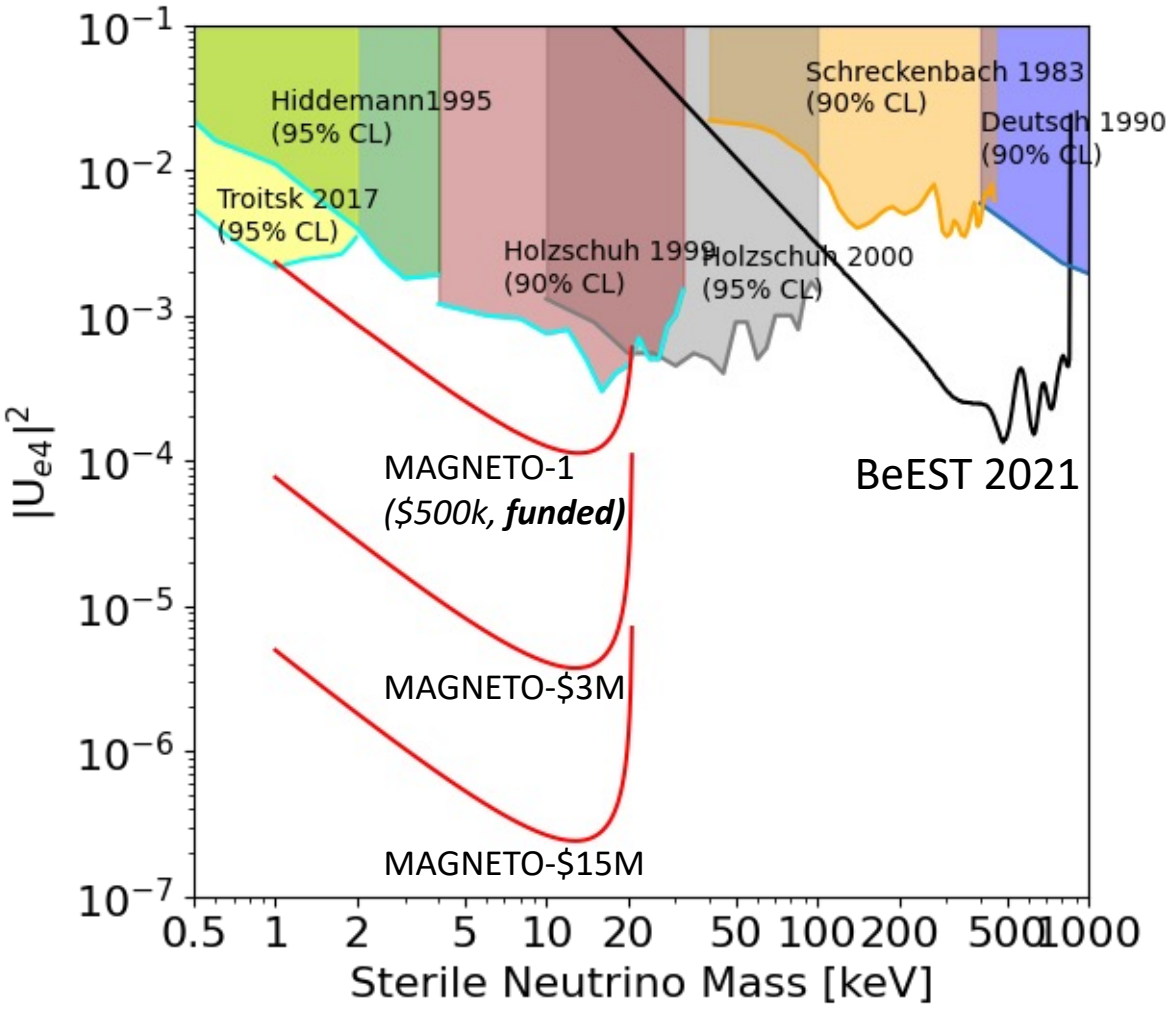
Theoretical

- Screening and exchange effects
- Radiative corrections
- Overlap correction

Experimental

- Trigger efficiency
- Event selection efficiency
- Random coincidence

MAGNETO Sensitivity



Summary

- Cost-effective experiment for keV neutrino search
- Complementary to Tritium experiments (Tristan, KATRIN)
- Phase-1 run in 2024, approaching $|U_{e4}|^2 \sim 10^{-4}$ at 1 keV < m_4 < 20 keV range.

Challenges

- Uncertainties on theoretical beta shape
- Accurate energy calibration

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