Neutrino Experiments with Pu-241

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LLNL-PRES-
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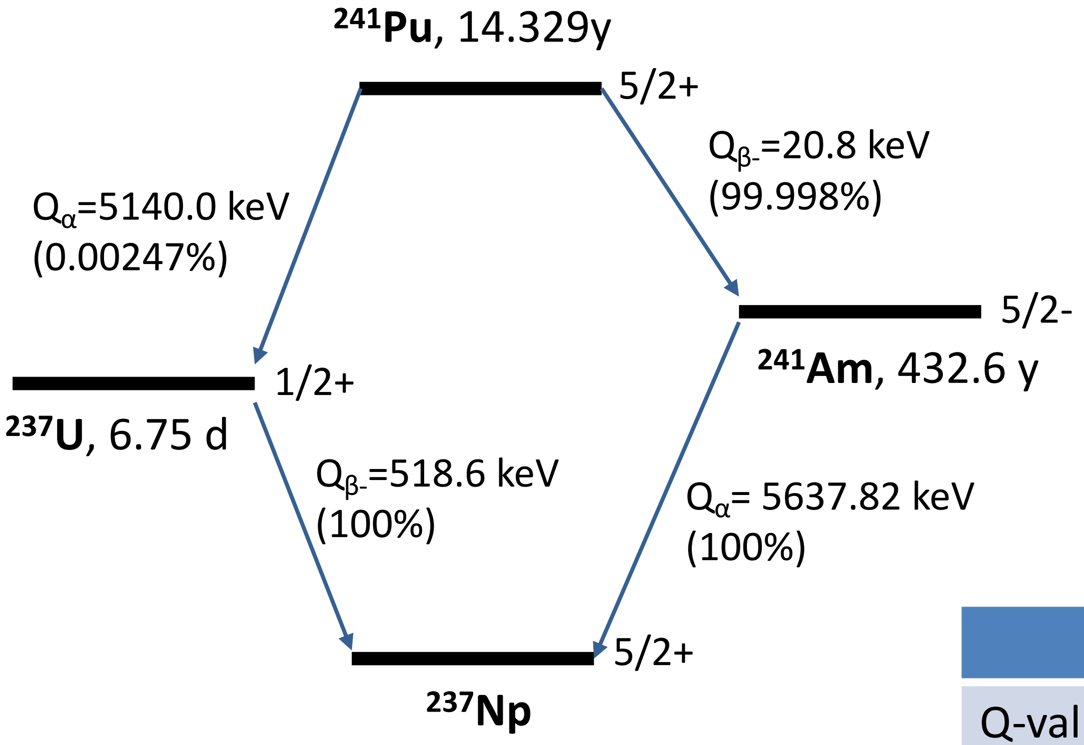
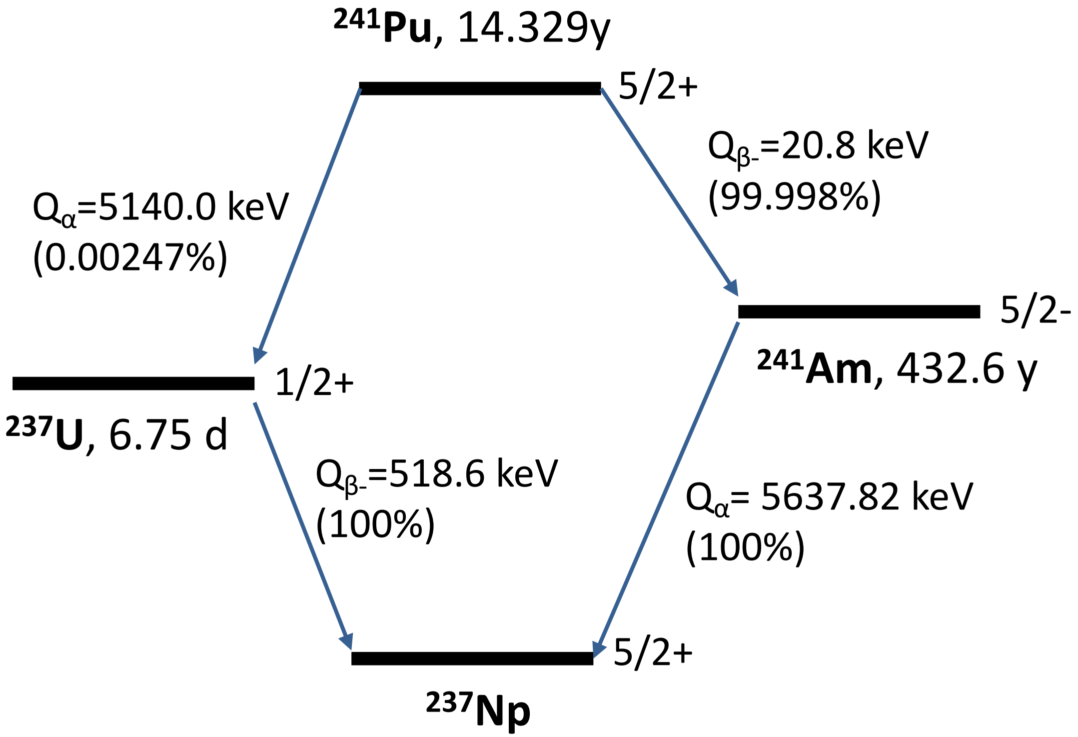
^{241}Pu Beta Decays for Neutrino Physics



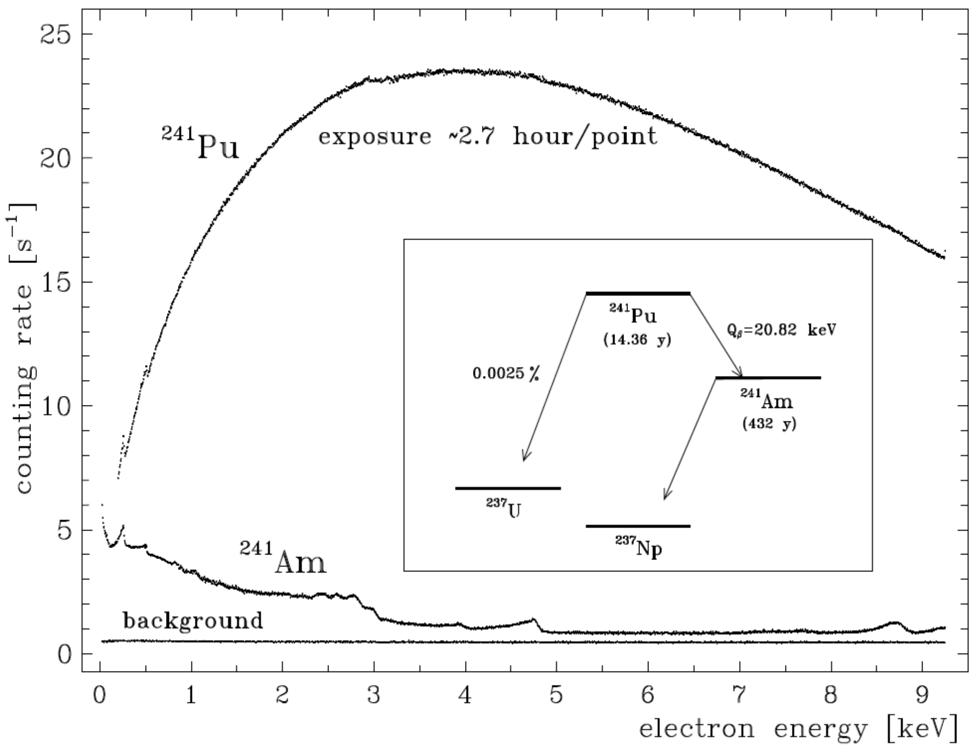
- 20.8 keV end point → ideal for keV sterile neutrino search
- Enriched source is available at LLNL
- Non-diffusive, non explosive
- **Low cost, different systematics, complementary.**
- Complementary to ^{3}H experiments

	^{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 non unique β-	Superallowed β-

^{241}Pu Beta Decays for Neutrino Physics



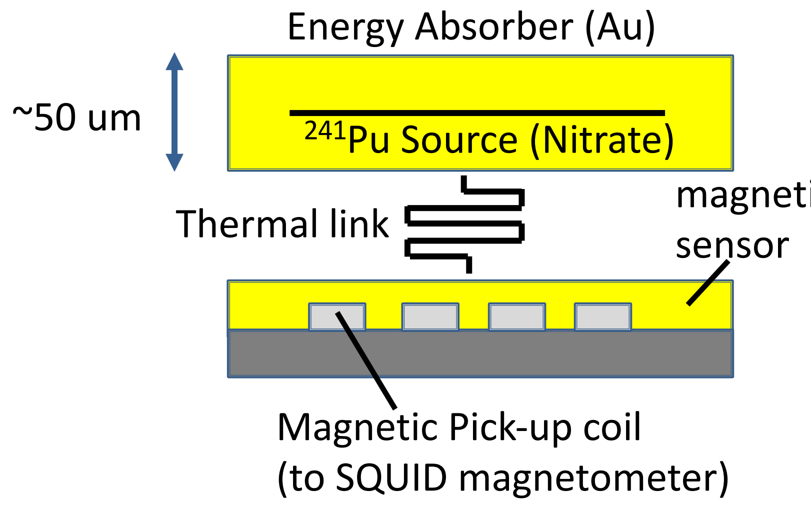
O Dragoun et al, J. Phys. G, 1999

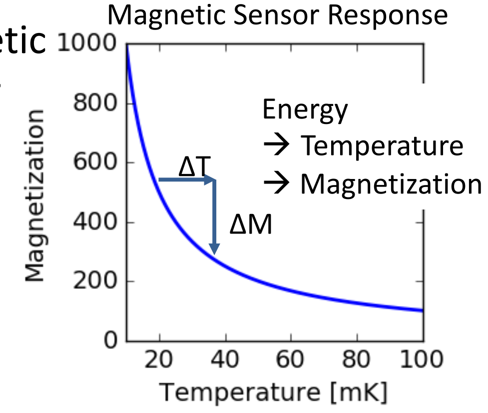


- **Usually not a great option due to γ, X-ray, electron backgrounds from ^{241}Am decays, and also isotopic impurities (^{238}Pu, ^{239}Pu, etc.)**

MAGNETO-ν: Neutrino Physics with Magnetic Calorimeters

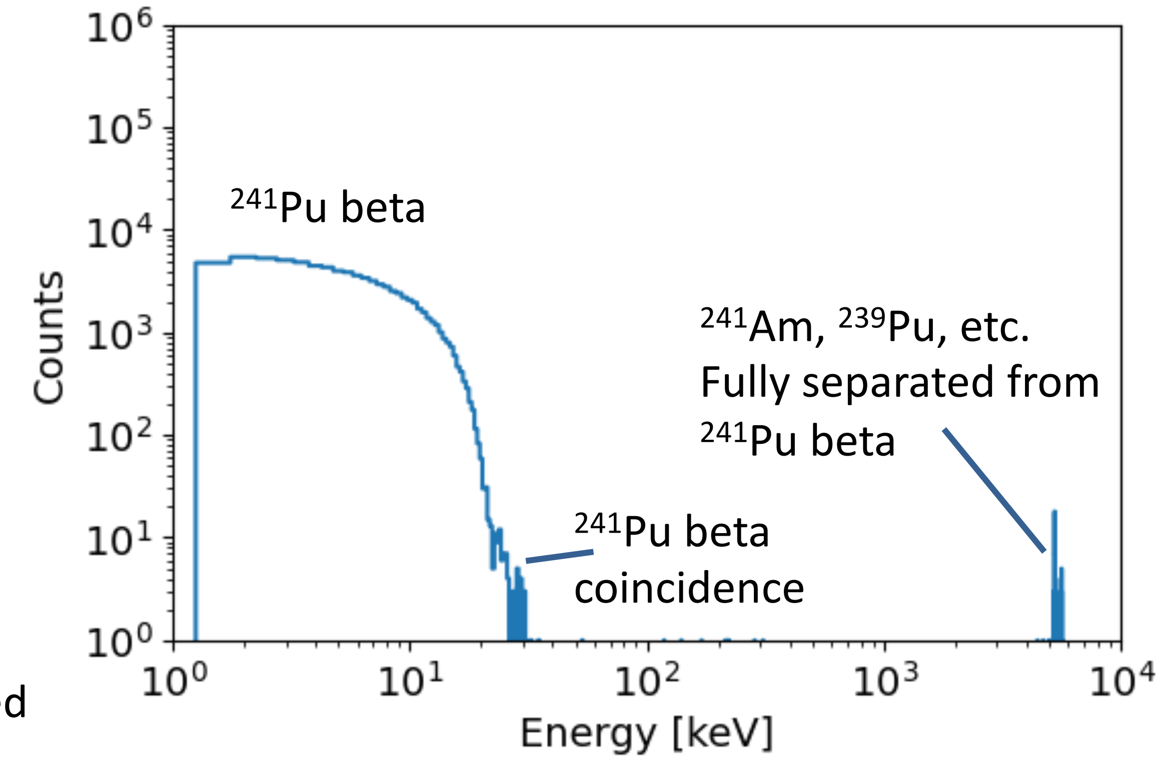
Decay Energy Spectroscopy (DES)



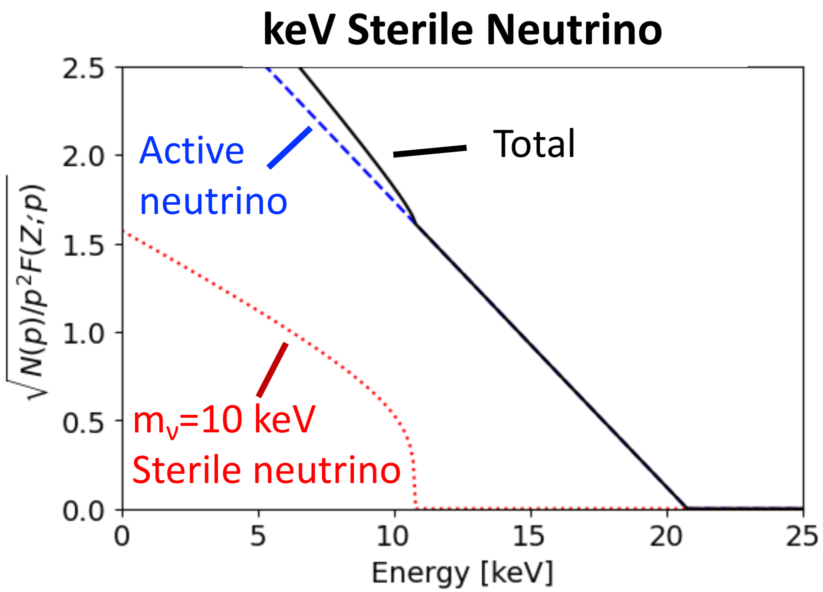


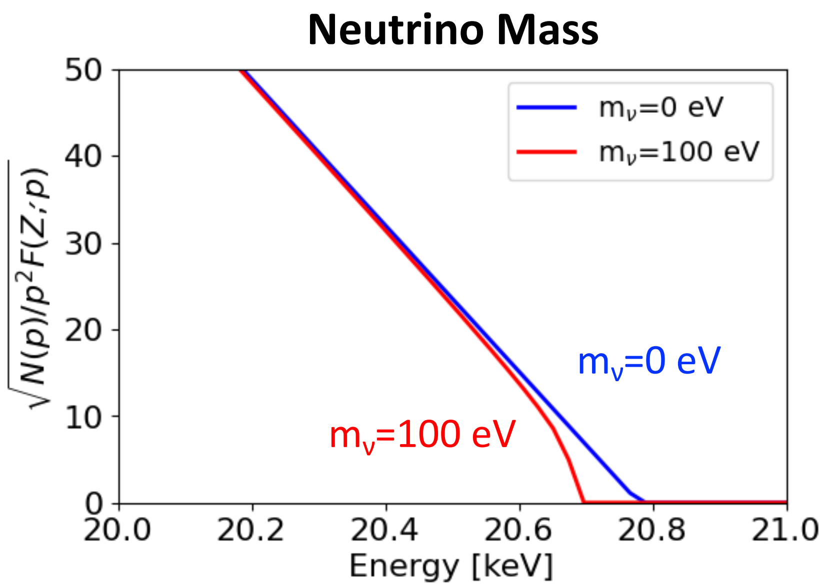
- Microcalorimetry with fully embedded source
- Magnetic Microcalorimeter (MMC) for faster counting speed
- High detection efficiency (4π)
- High energy resolution (up to a few eV)

Experimental DES Spectrum of ^{241}Pu Source



MAGNETO-ν: Neutrino Physics with Magnetic Calorimeters





	keV Sterile Neutrino Search	Active Neutrino Mass
Strengths	Full spectrum measurement Low background	Minimal effects from atomic physics
Challenges	Low counting speed Theoretical shape modeling	Energy resolution Background from pile-up, ^{237}U beta Self-absorption

Theoretical Modeling of ^{241}Pu Spectrum

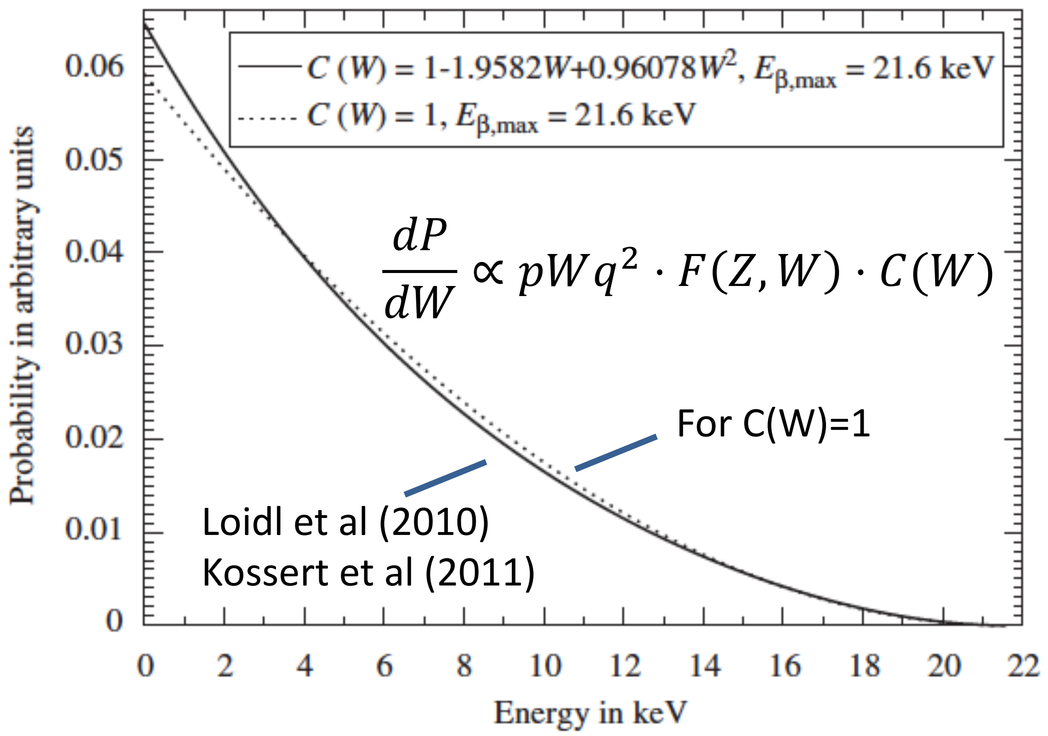
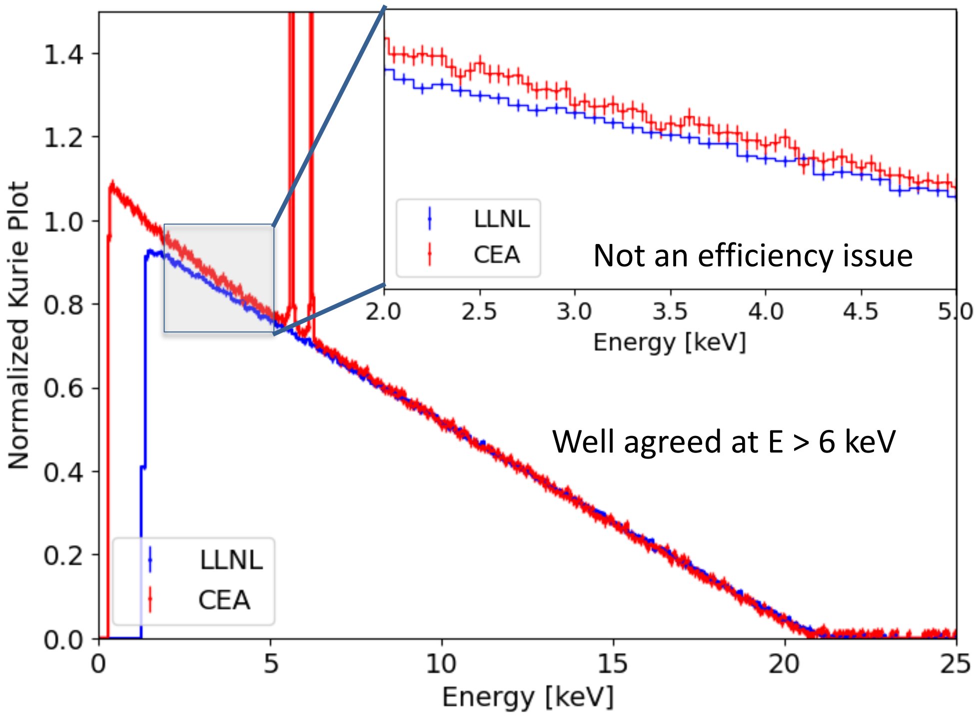


Fig. 1. Computed beta emission spectrum of ^{241}Pu with the new shape-factor function as derived in this work, using the experimental data from Loidl et al. (2010) compared to a spectrum with $C(W)=1$.

K. Kossert et al. / Applied Radiation and Isotopes 69 (2011) 1246–1250

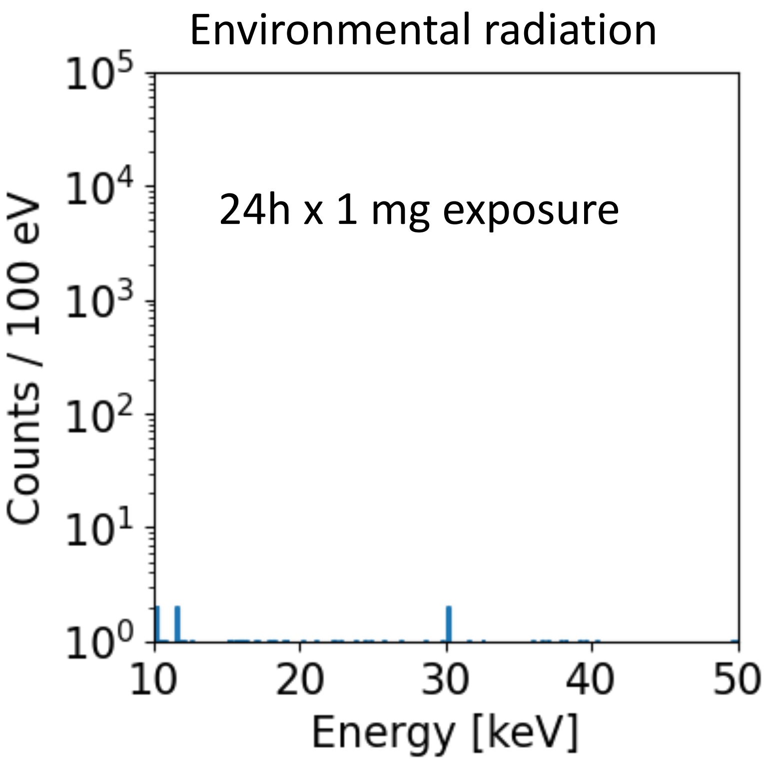
Comparing with Loidl et al. (2010)



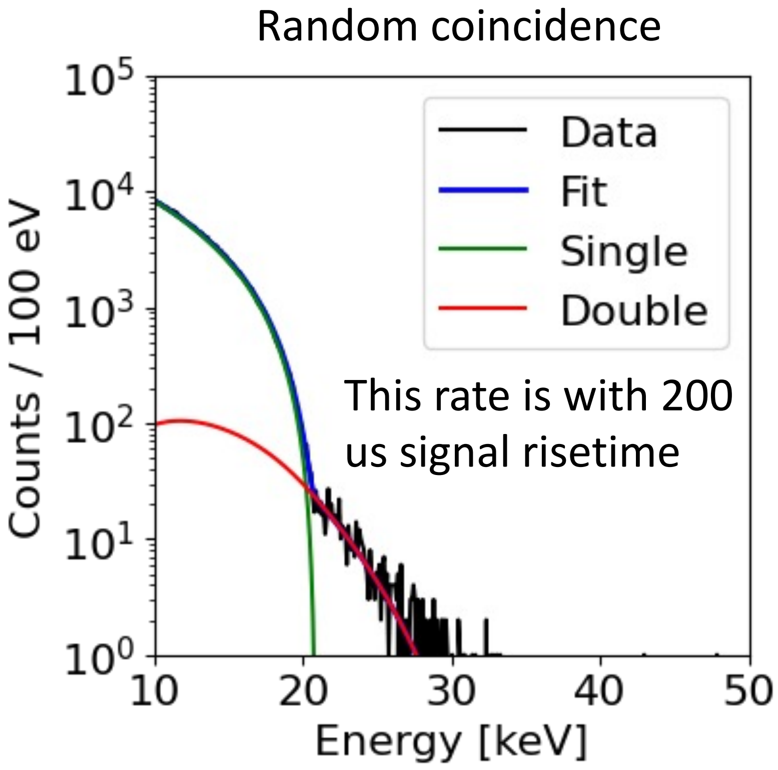
Current approaches

- Comparing with independent experimental results
- Improving theoretical models (X. Mougeot et al at CEA)

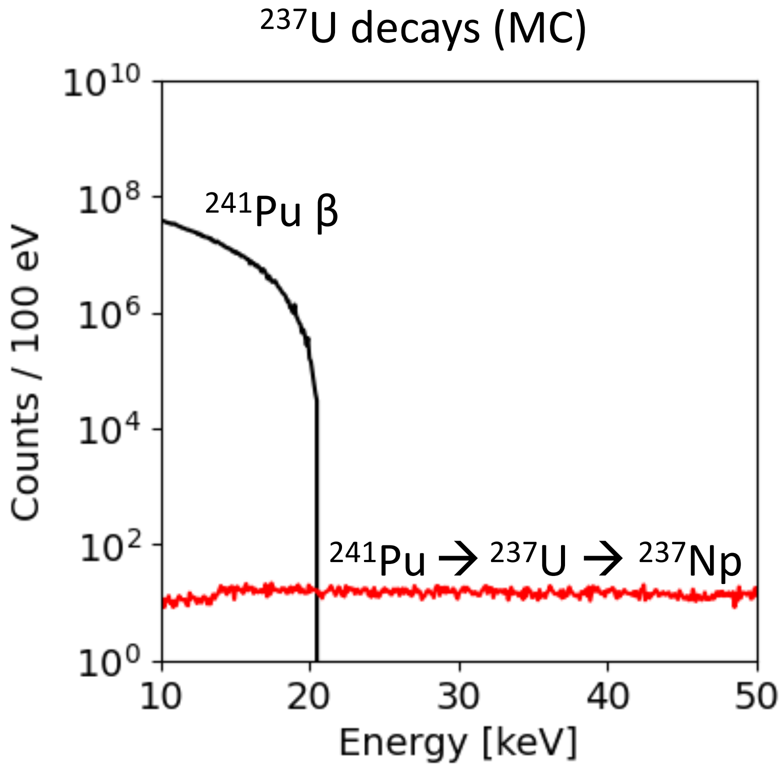
Background



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

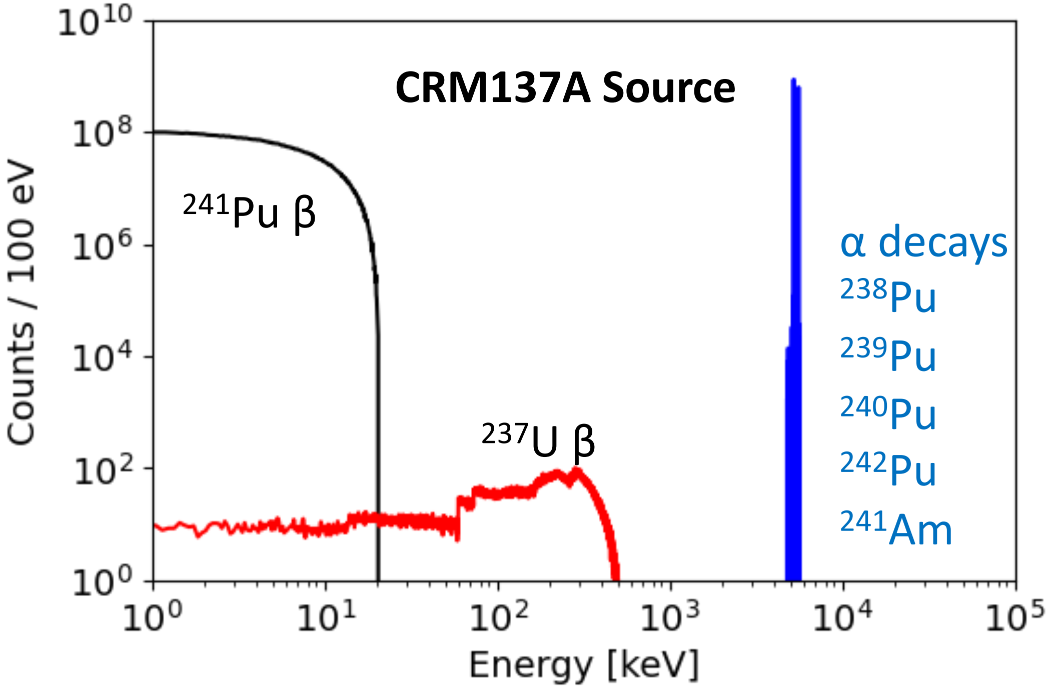


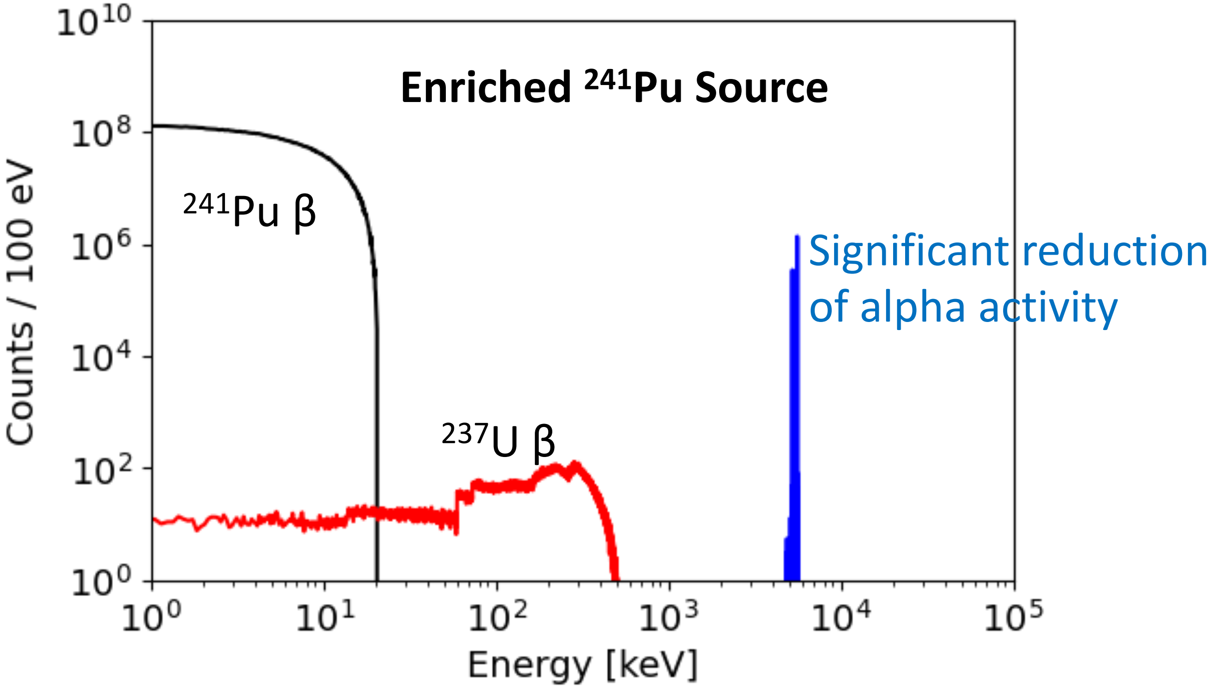
- Can be reduced by improving timing resolution
- Timing resolution has been improved to 5 us.



- Flat background

^{241}Pu Sources



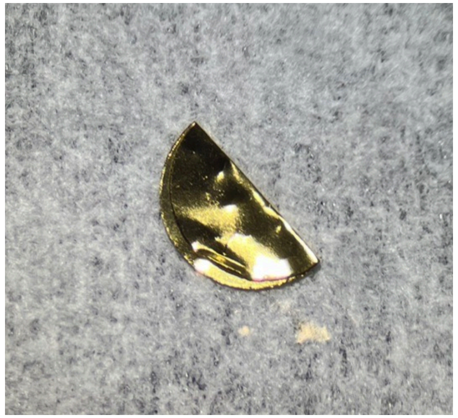


Activity Ratios of Pu Sources

	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%

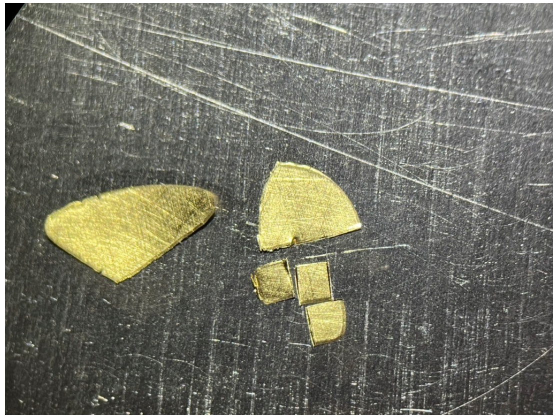
^{241}Pu Source and Detector Preparation

5mm ϕ x 25 um gold foil

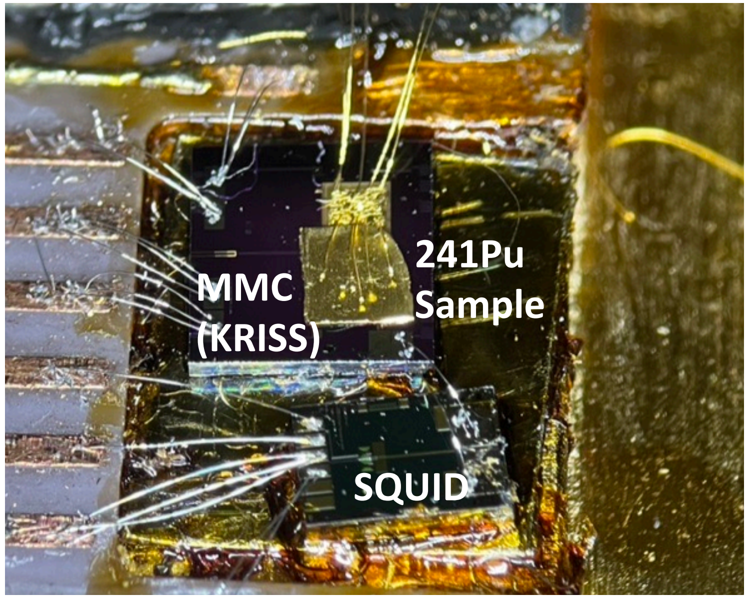


Pu-containing nitric acid solution
→ Drop and evaporation with 80C heater
→ Fold over the foil by half

Rolling with Ti shims



Press by rolling mill
→ ~40 um thick total
→ Cut to ~1.5 mm square (~1.5 mg)

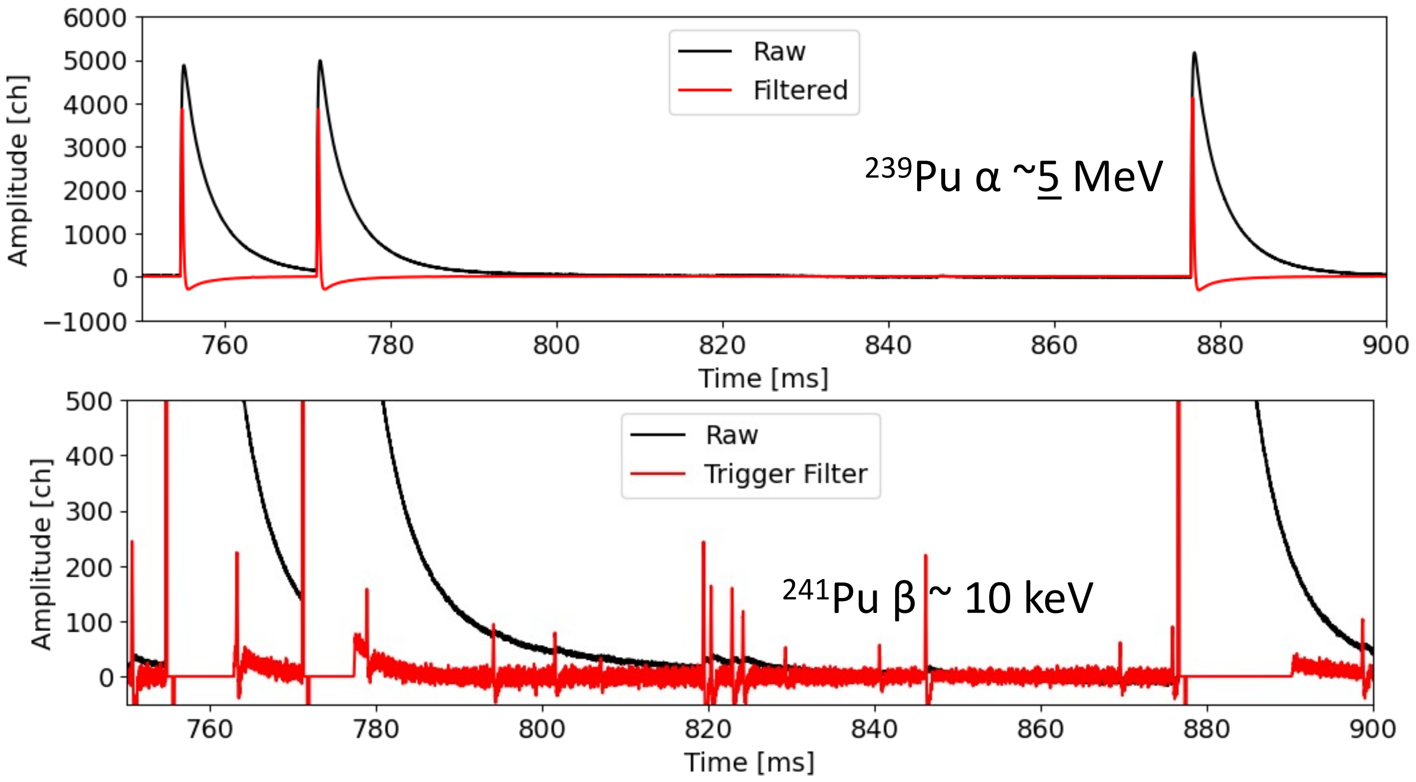


Couple to MMC for DES

- Use wirebonding (current)
- Direct embedment to magnetic sensor (future)
- MeV-scale MMC device was used

DC SQUIDs (superconducting quantum interference devices) are from MAGNICON and Star Cryoelectronics

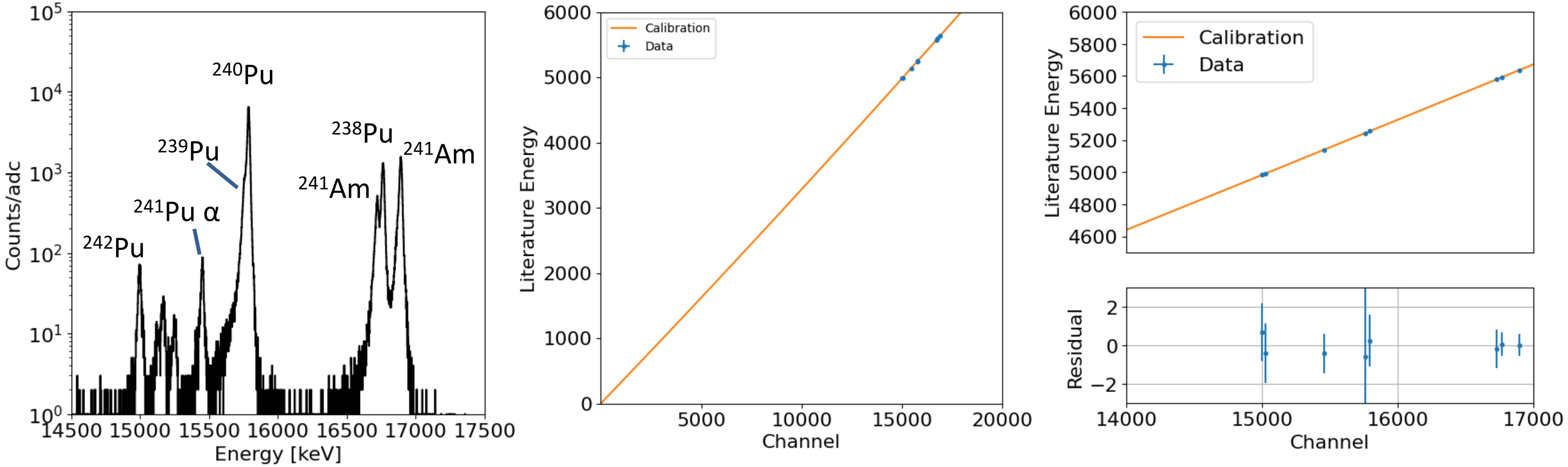
Data Acquisition and Signal Processing



- 2 weeks continuous run during year-end holiday
- 2 pixels at ~50 Bq each

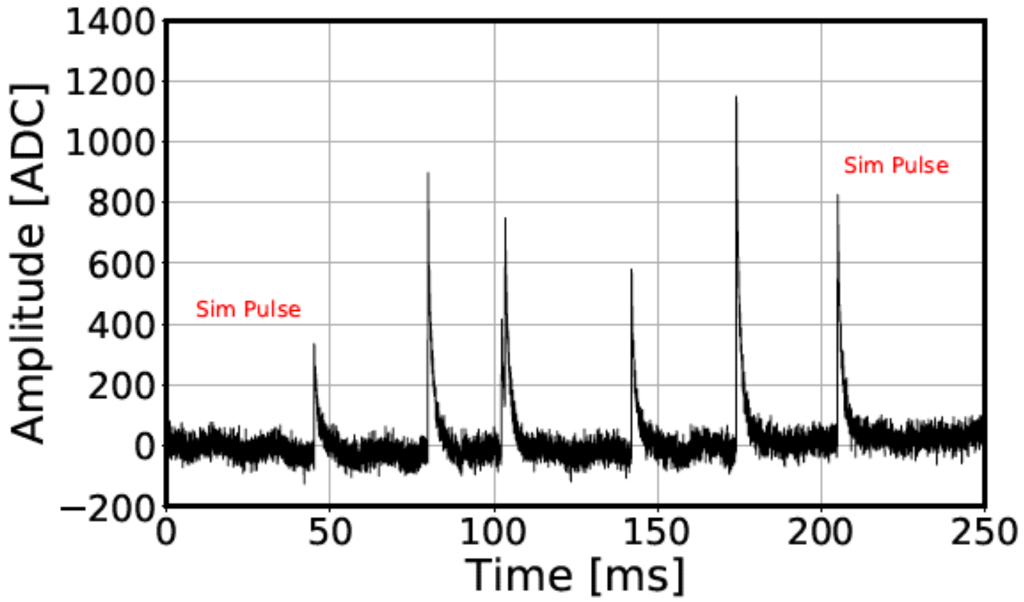
- Continuously saved waveform + offline trigger and signal processing
- Use Trapezoidal filtering for faster counting speed (trade off with energy resolution)
- Alpha (x500 larger signals) results in significant deadtime due to undershoot in the filtered waveform
  → Need high purity Pu-241 source that we already have

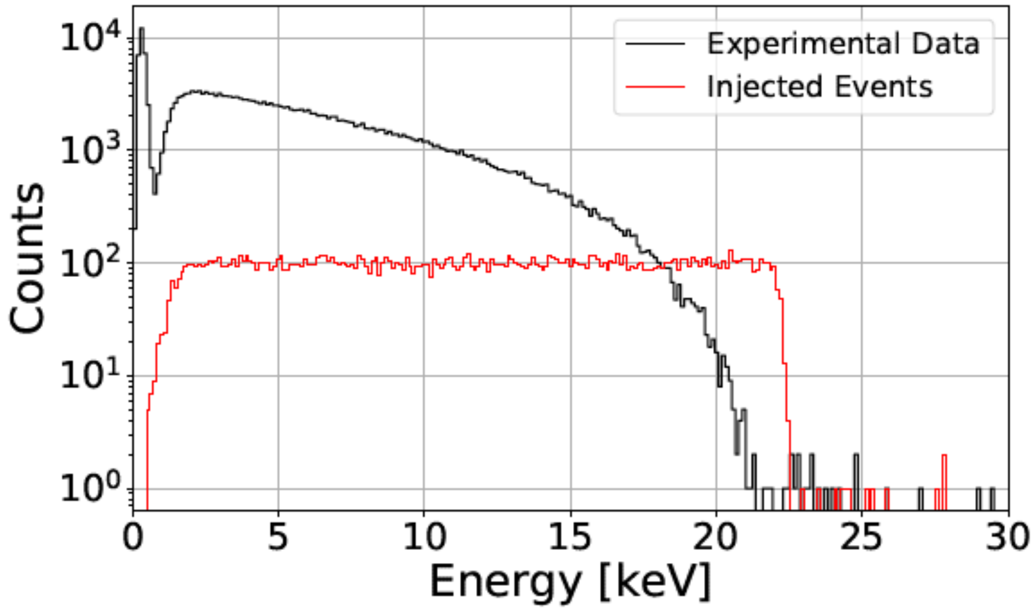
Energy Calibration – Internal Alpha Decays



MMCs have demonstrated excellent linearity, perfectly calibrated with quadratic function $y = ax^2 + bx$

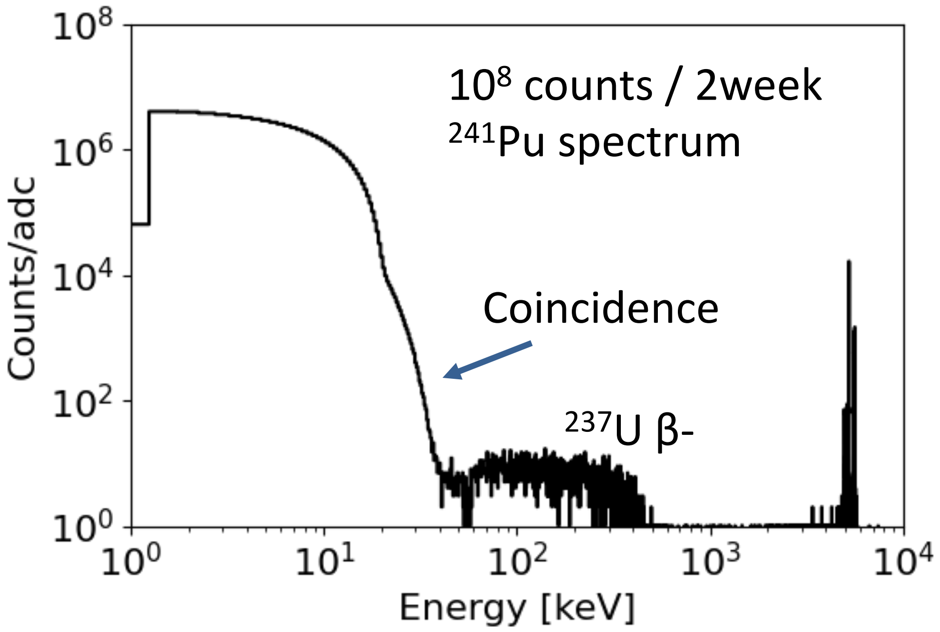
Efficiency

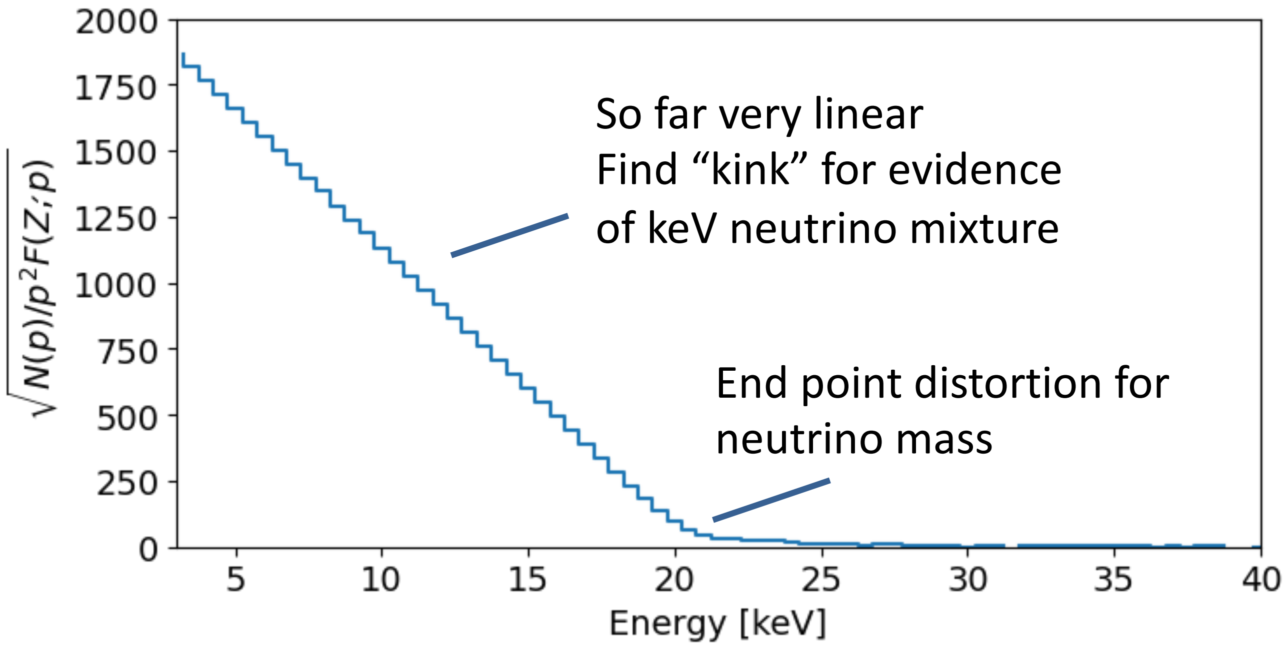




- Inject template pulses at random time stamps and obtain survival rate.
- Trigger loss, pile-up loss, analysis cut, all can be taken into account.

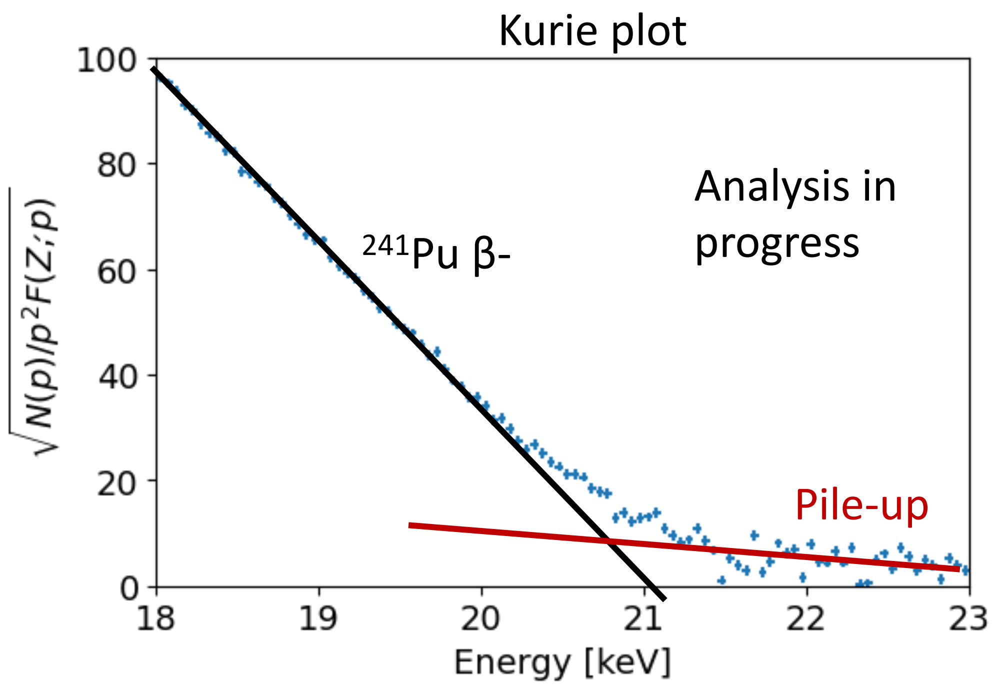
Experimental Result – 2 pixel/2 weeks, enriched Pu-241





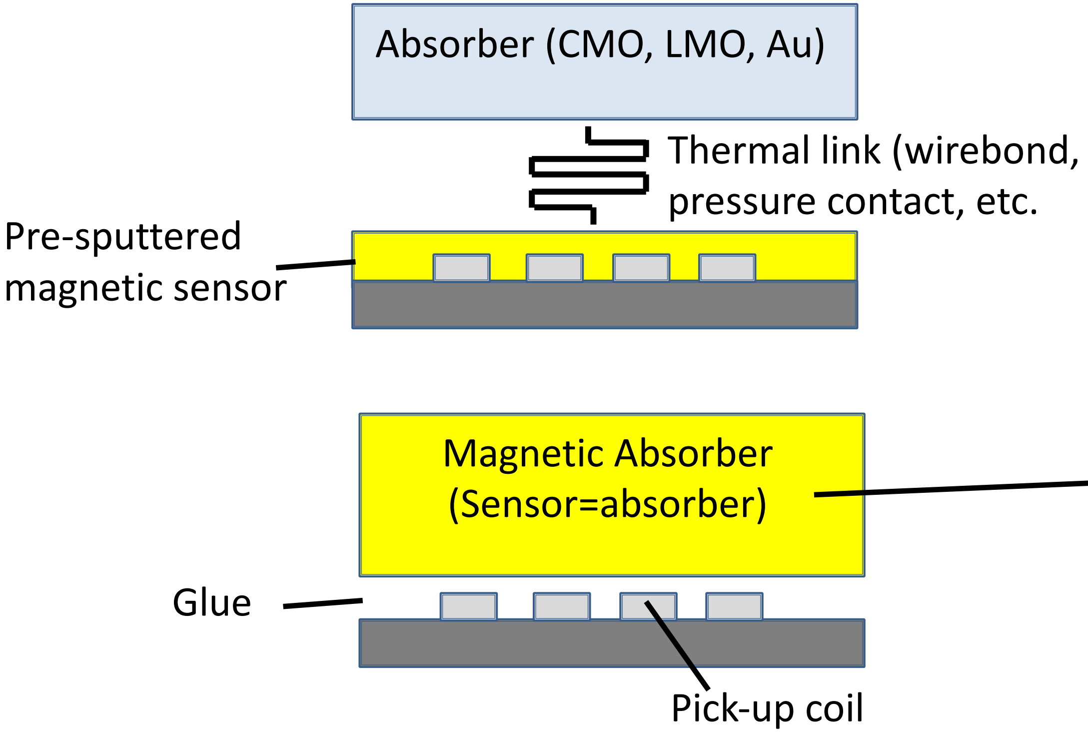
- ~100 eV neutrino mass sensitivity can be achieved in short term
- For sub-eV, improved detector resolution and speed for coincidence background reduction is required.

Experimental Result: End-point Region

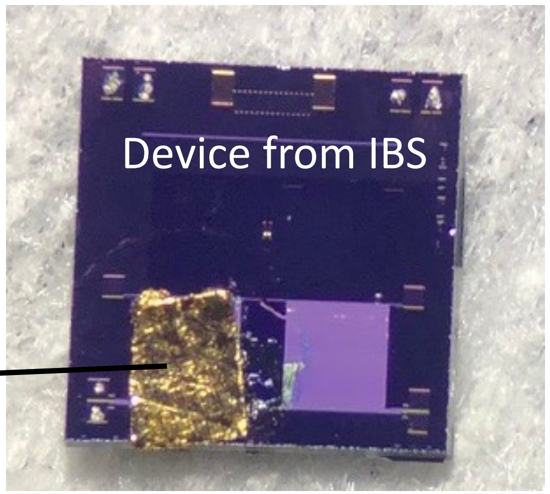


- ~100 eV neutrino mass sensitivity can be achieved in short term, but it requires different optimization of measurement conditions
- For sub-eV, improved detector resolution and speed for coincidence background reduction is necessary.

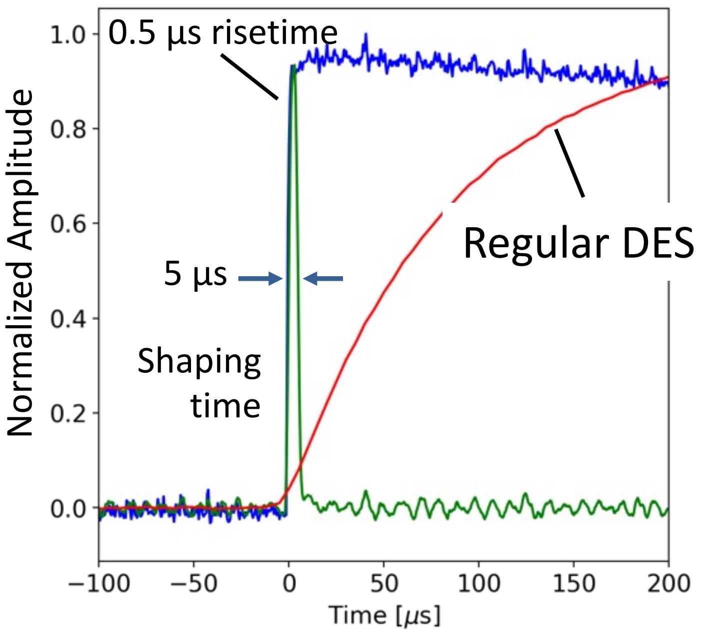
LLNL's Unique R&D: Magnetic Absorber for Fast Counting



Demonstration Setup



Experimental demonstration



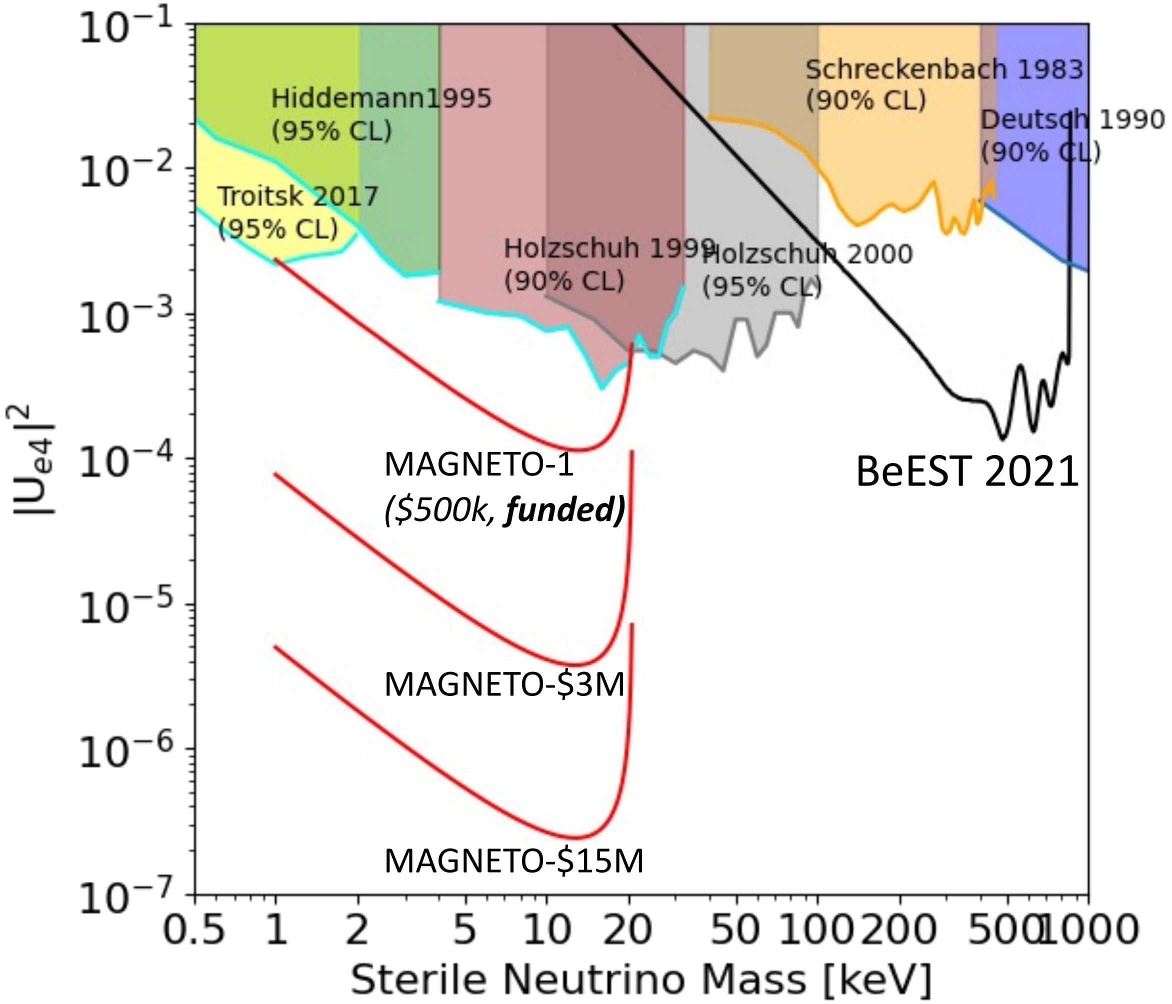
- Use magnetic material as absorber
- Full magnetic signal within 1 us

→ x100 improvement of speed

→ x100 reduction of coincidence pile-up

- **>x100 reduction of coincidence background**
- **Improved Statistics**

Summary



Summary

- Successful first step toward high precision ^{241}Pu measurement.

Challenges for neutrino mass

- Improved energy resolution
- Coincidence reduction (improved speed)
- ^{237}U background understanding
- Energy calibration
- Accurate detector response calibration
- Statistics

Challenges for keV neutrino

- Theoretical shape, Q-value
- Statistics

→ Scale-up to large array detector (multiplexing)

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