Characterization of sapphire detector for CEνNS search at MINER

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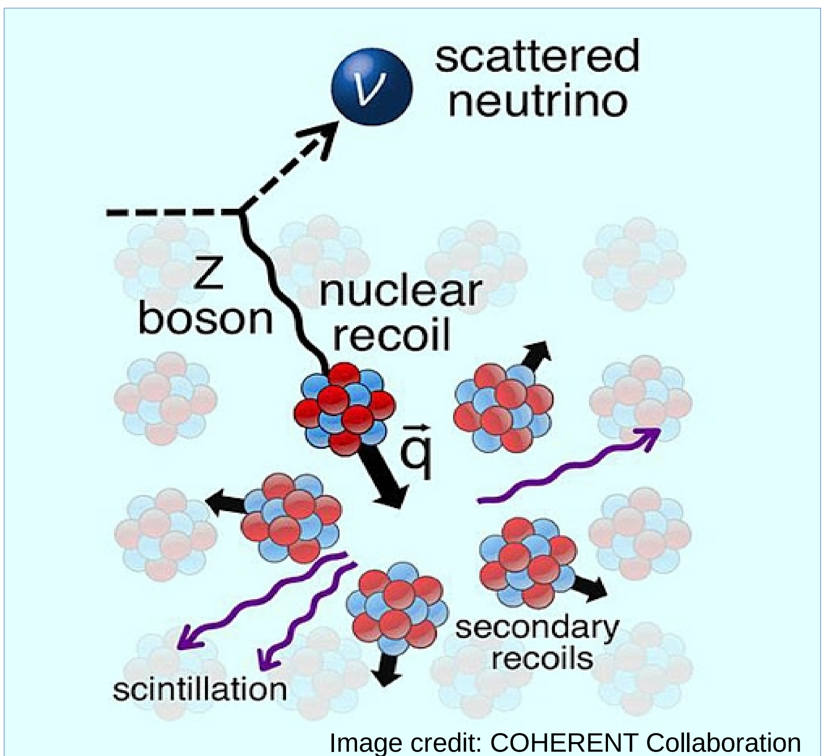
Outline:

- MINER experiment
- Reactor anti-neutrinos
- Sapphire detector
- Test facility and experimental set up
- Detector performance
- Conclusion and outlook

Introduction to MINER

Introduction

- Mitchell Institute Neutrino Experiment at Reactor (MINER) is reactor based neutrino experiment at Texas A&M University, USA.
- 1 MW reactor as the source of electron anti-neutrinos up to few MeV[1].
- MINER detectors: Ge, Si, Sapphire scintillator detector (Al_2O_3).



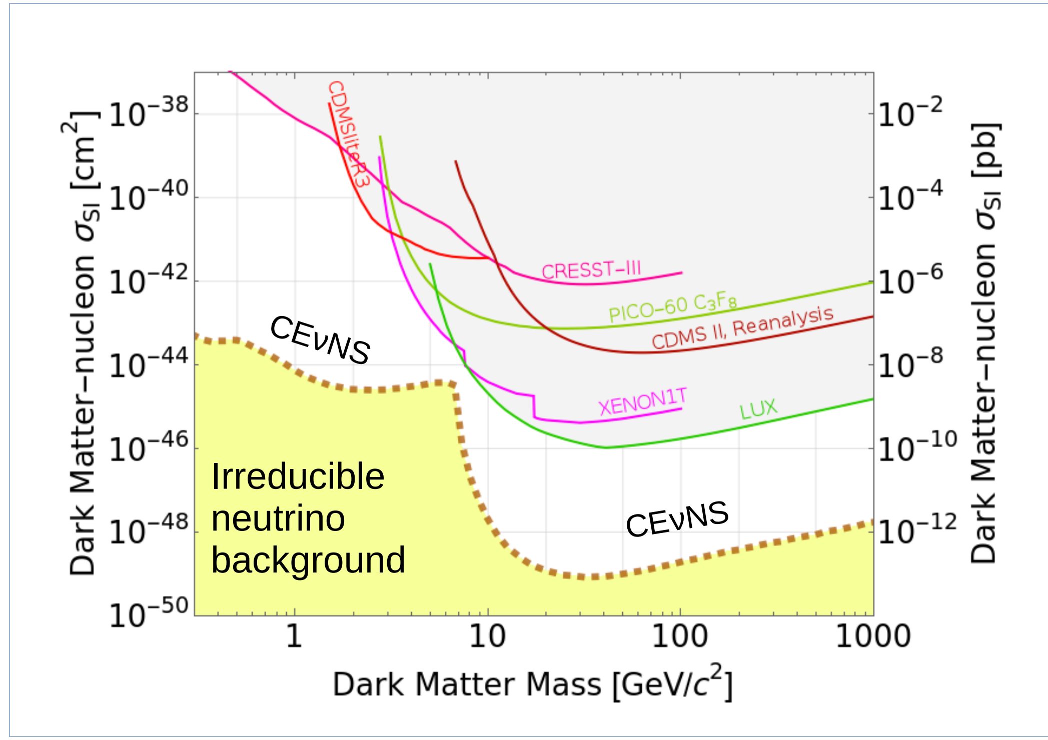


Fig1: Exclusion plot[2] for direct detection DM search experiments

Science goal

- Precise measurement of Coherent Neutrino Nucleus scattering (CEvNS) cross-section.
- Search for Axion-Like-Particles (ALP's) and sterile neutrino oscillation.

[1] V.I.Kopeikin et al, Particles and Nuclei, Letters. 2001 No. 5

[2] SuperCDMS limit plotter

Reactor anti-neutrinos (ν)

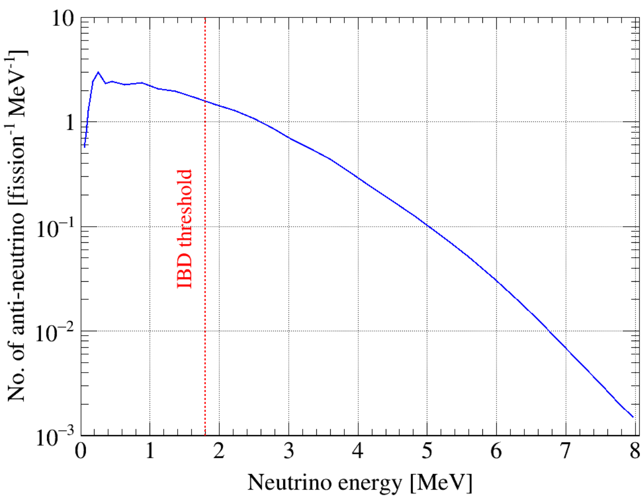
Reactor fuel	^{235}U (20%, LEU)
Reactor power	1 MW
Energy per ^{235}U fission	200 MeV
ν yield per fission	~ 6
ν energy per fission	1.5 MeV
ν flux at 1 m from core	~ 10^{12} cm^{-2} s^{-1}

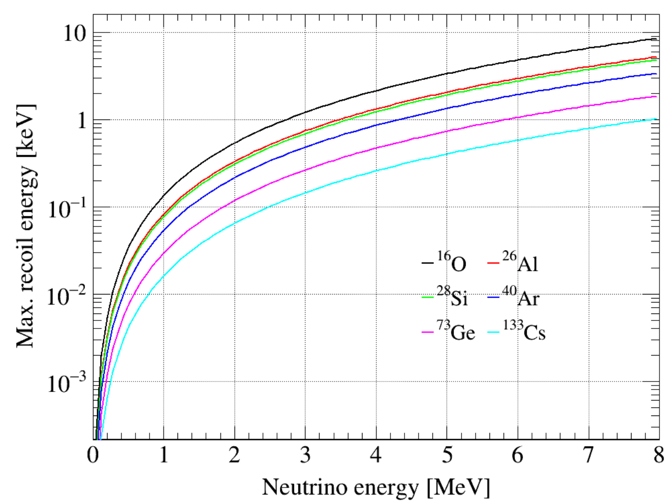
CEνNS detection at reactor

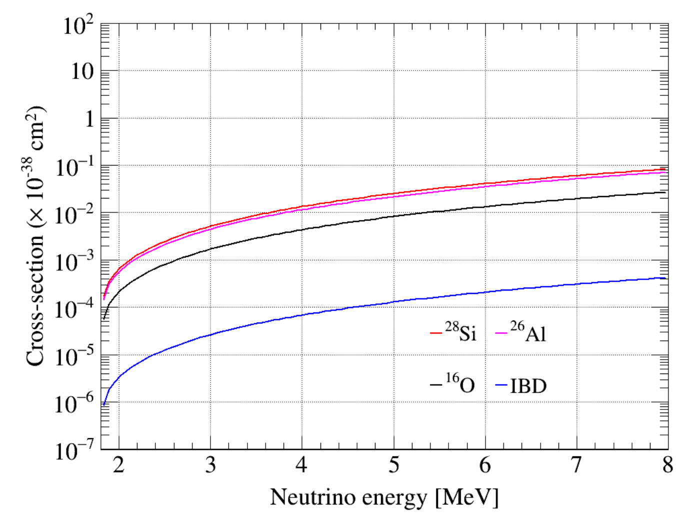
- Lower the neutrino energy, more the flux
- Lower neutrino energy implies lower recoil energy
- Lower the mass number, higher recoil energy

Challenges

- Understanding and reduction of the backgrounds
- Low energy threshold (< 100 eV) detectors.



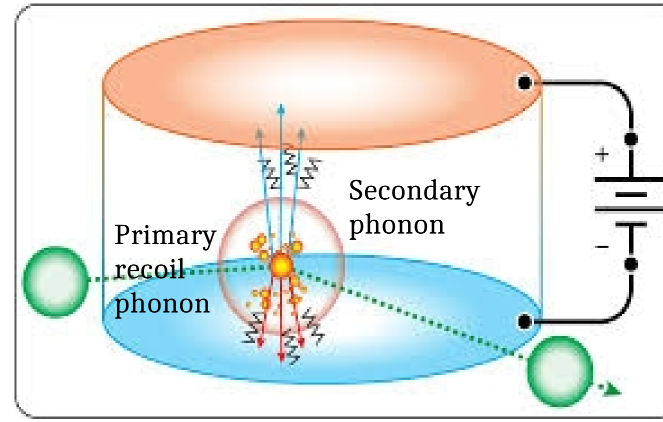


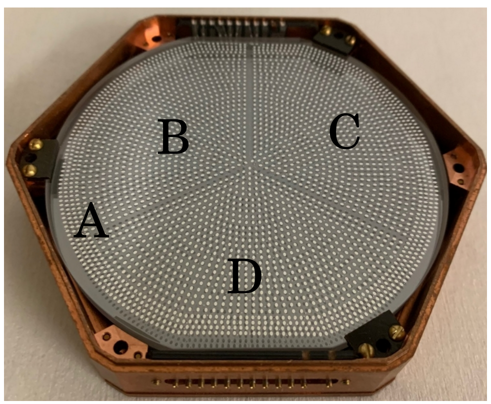


Detector and it's detection principle

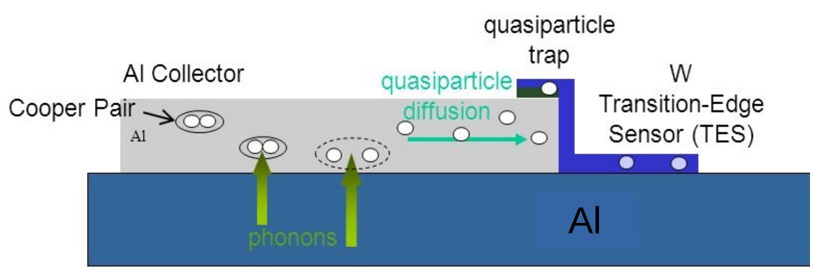
Principle:

- Interaction induces recoil phonons and photons.
- Phonons are detected by Transition-Edge-Sensors (TES) on the detector surface.
- Total photons are collected using Si HV detector placed at coincidence with sapphire .

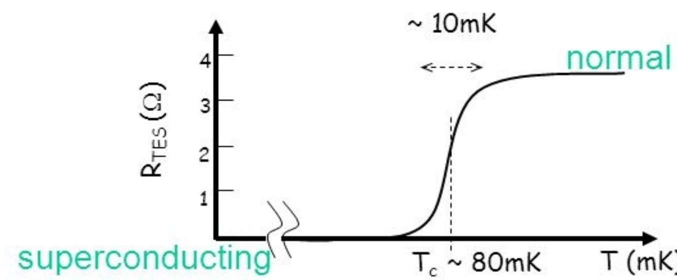




Sapphire scintillator detector



Superconducting layer on the surface operating near T_c



Read out of phonon energy as an electronic signal due to change in TES resistance

Specification:

- Detector mass: 72 g.
- Made up of Al_2O_3
- Dimension: 7.6 mm x 4 mm
- Phonon sensors: A, B, C and D.
- Voltage applied ~ 0 V

Advantages:

- Efficient in phonon collection due to better matching of phonon collector fins (Al) to Al_2O_3
- Sensitive for low recoils
- Lower baseline resolution than semiconductor detectors with TES

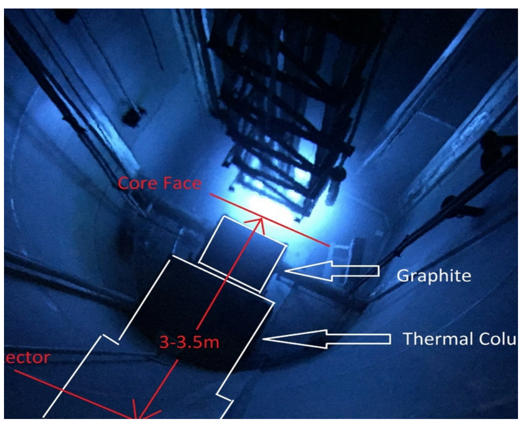
Test Facility (TF) and Experimental site at Nuclear Science Center (NSC)

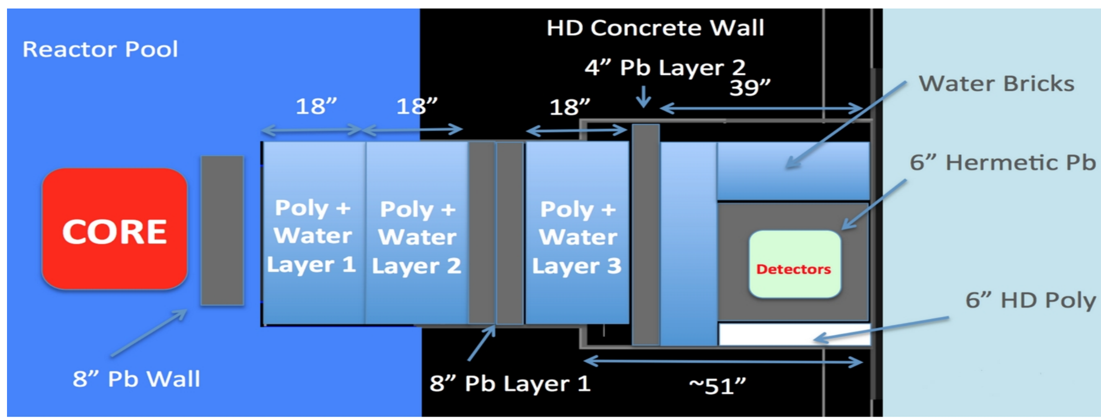
Picture of the TF

Detector testing site using NISER's Bluefors dilution refrigerator

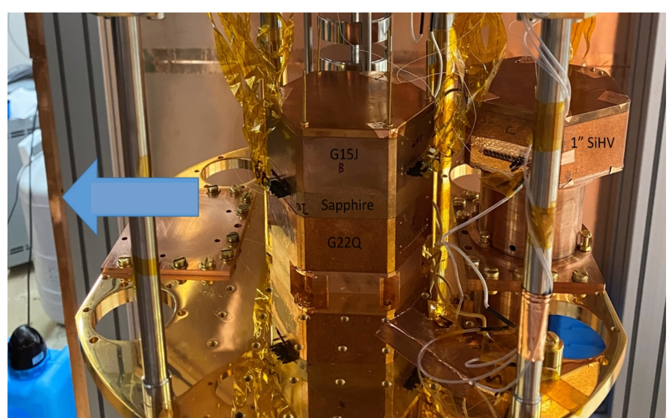
Experimental site at NSC

Top-down view of NSC



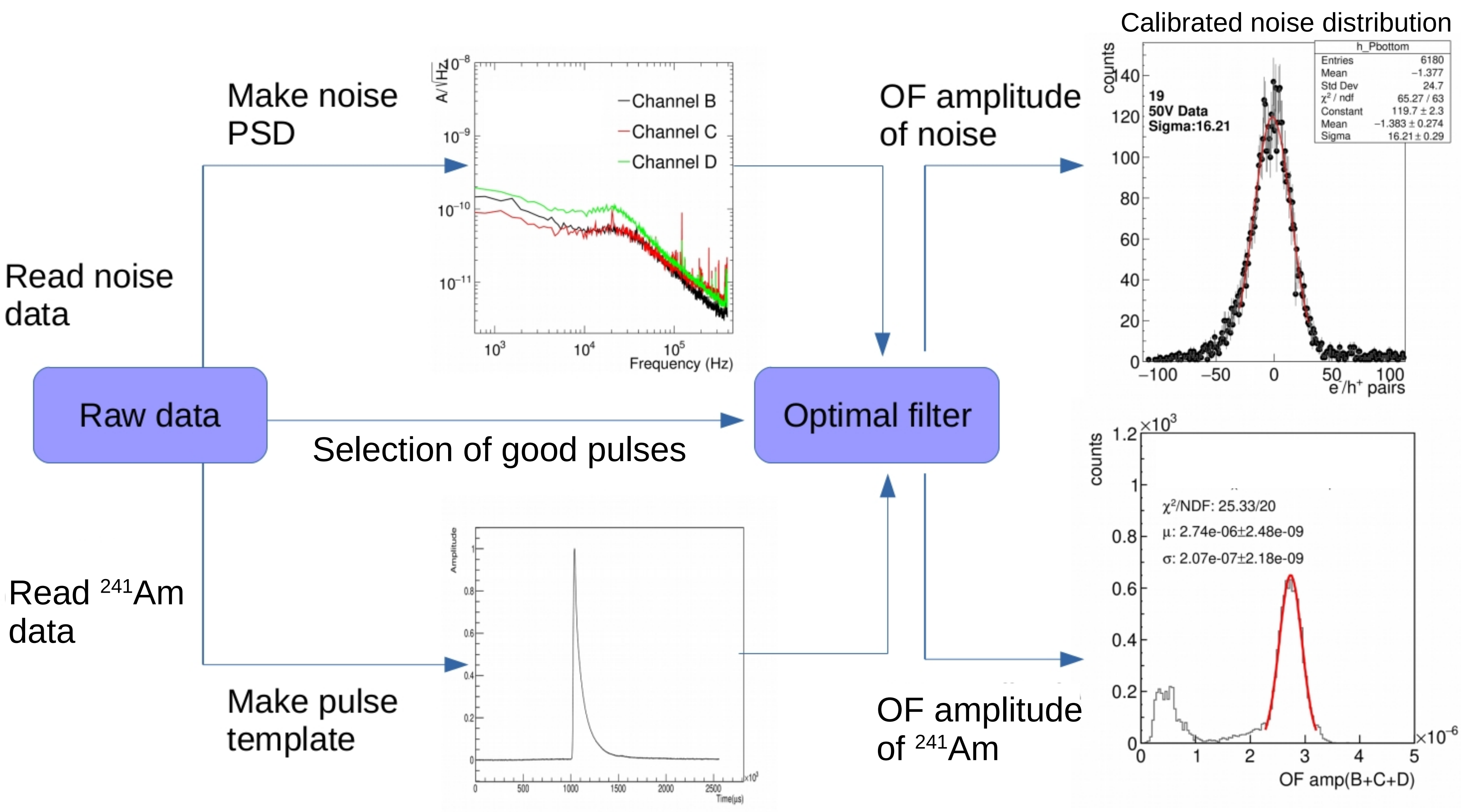


Schematic of the planned experimental setup with shielding

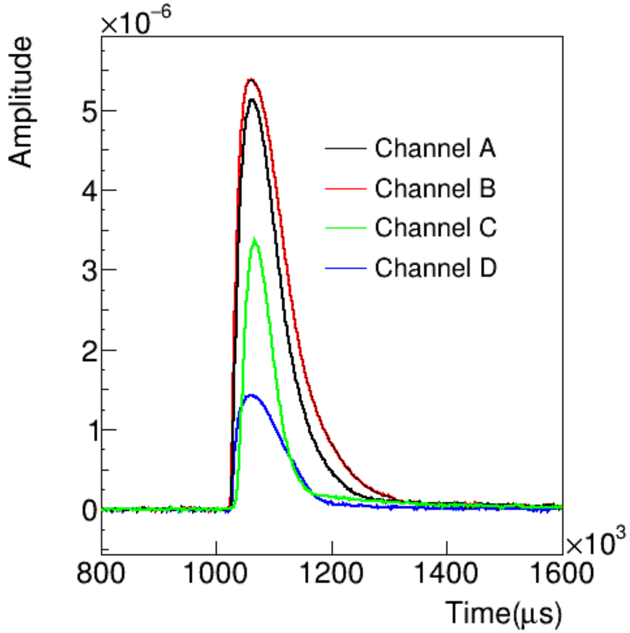


Detector's tower installation and shielding with Bluefors at NSC for MINER engineering run

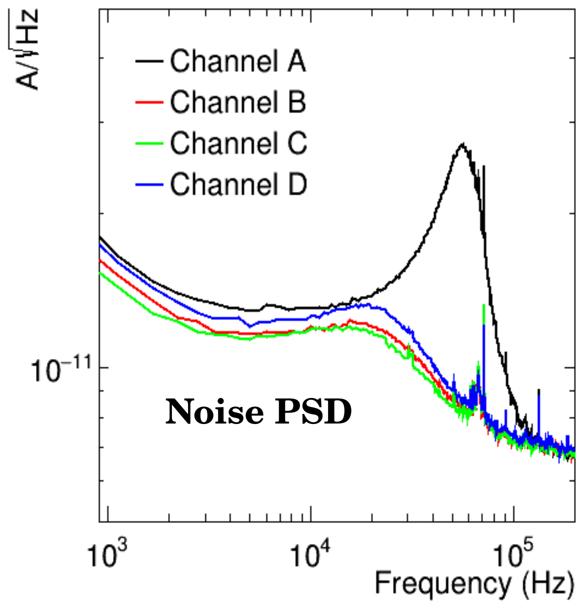
MINER data analysis flowchart

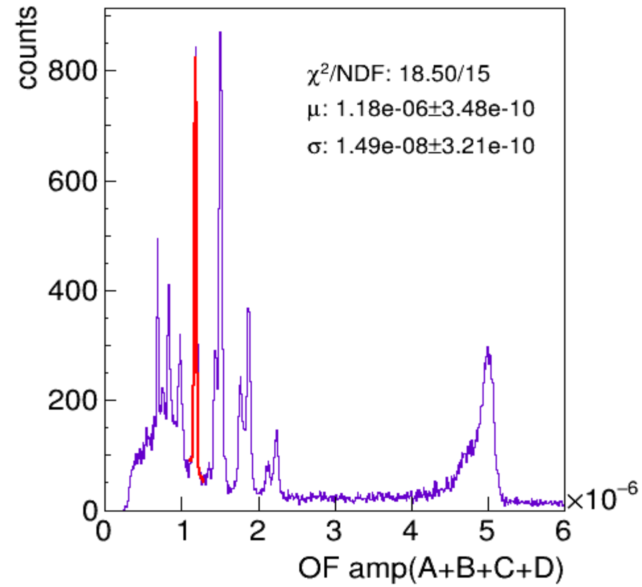


Data analysis: result from TF

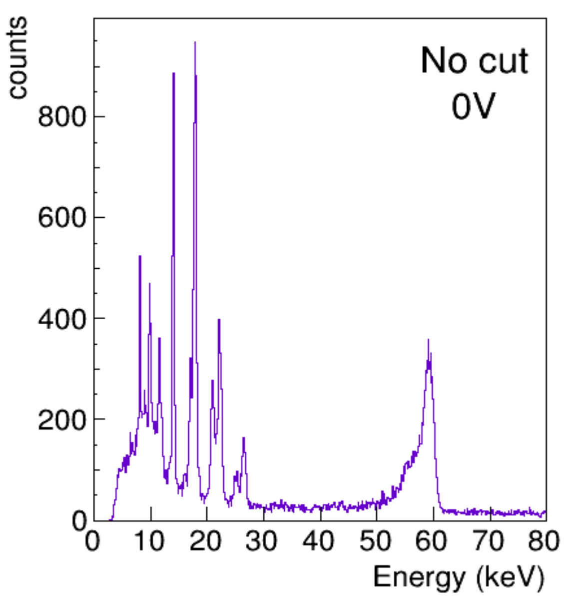


Example of pulses in 4 channels

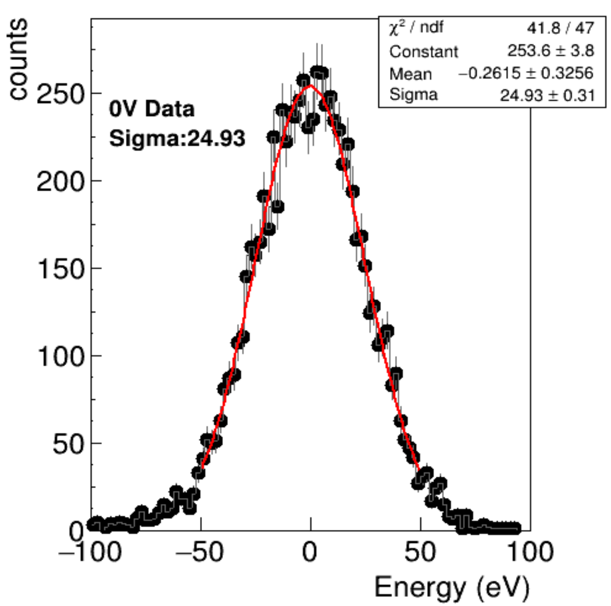




Combined phonon energy in OF unit



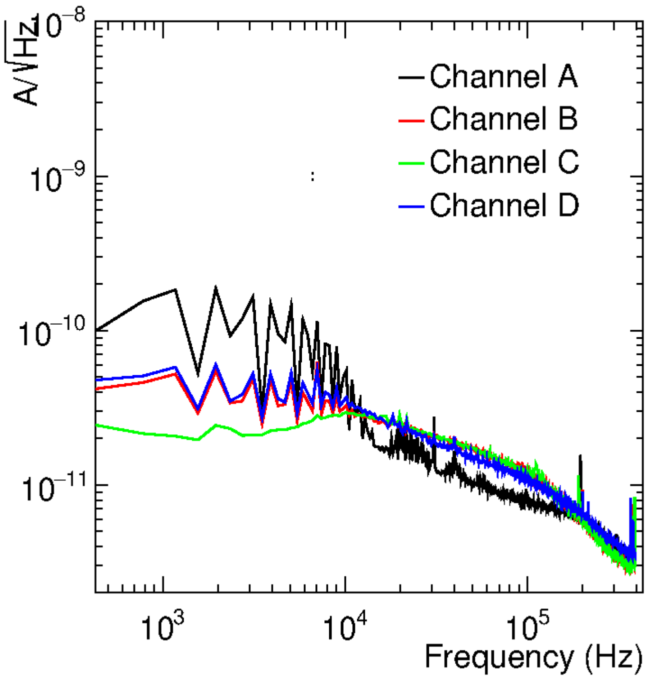
Calibrated phonon energy of sapphire



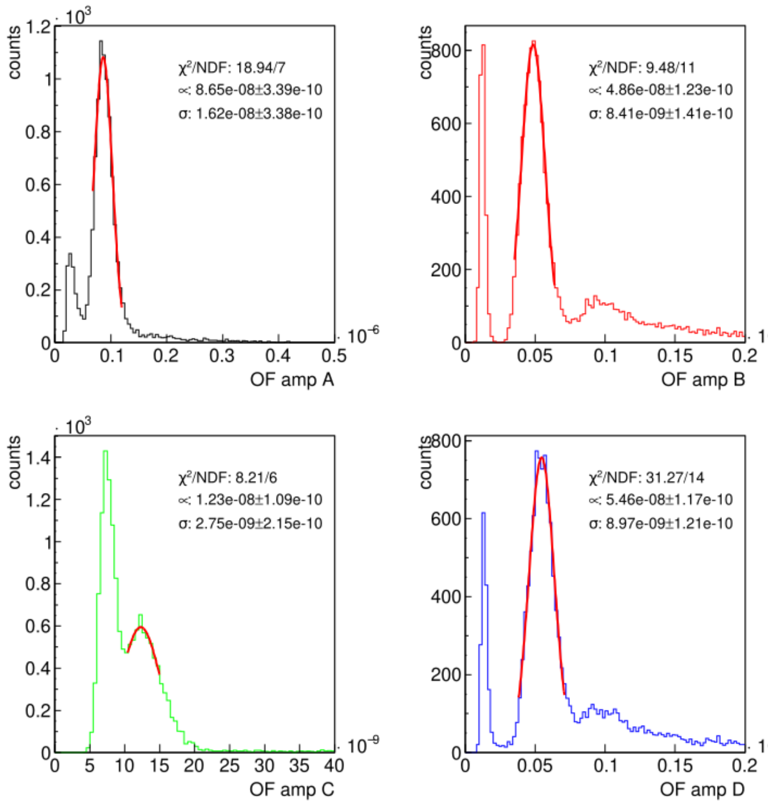
Baseline resolution

- Voltage: 0 V
- Observable: phonon energy
- Calibration source: ^{241}Am (14 keV gamma)
- Readout channels: A, B, C, D
- We observed a baseline resolution of ~ 25 eV which equates to a conservative (3σ) threshold of ~ 75 eV.

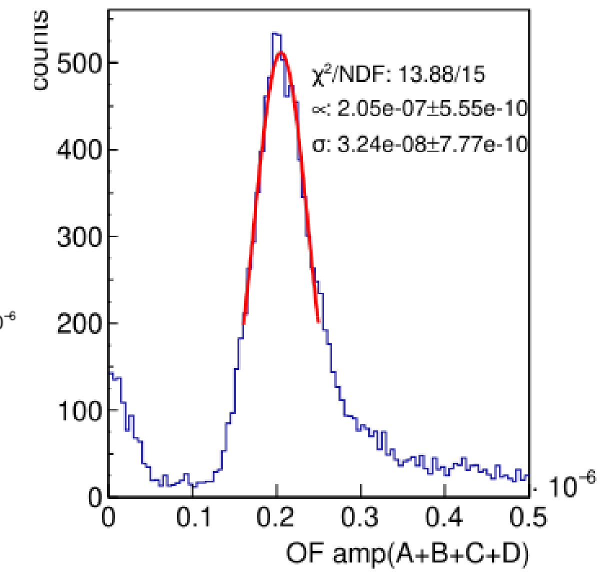
Data analysis: result from NSC (reactor off)

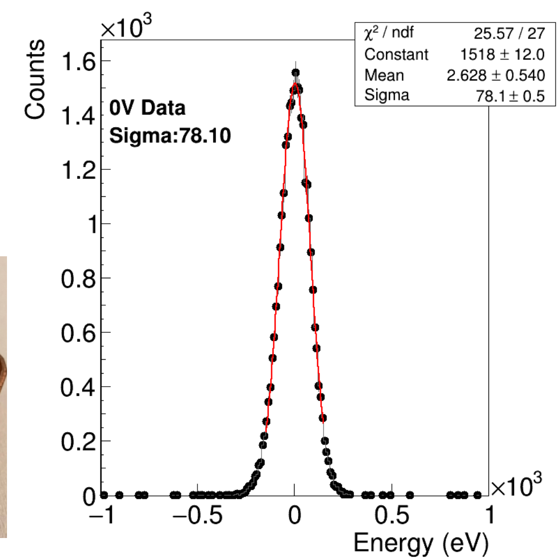


With cut

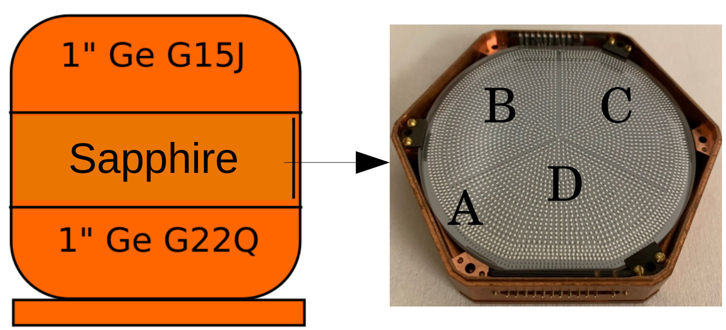


Co-added spectrum

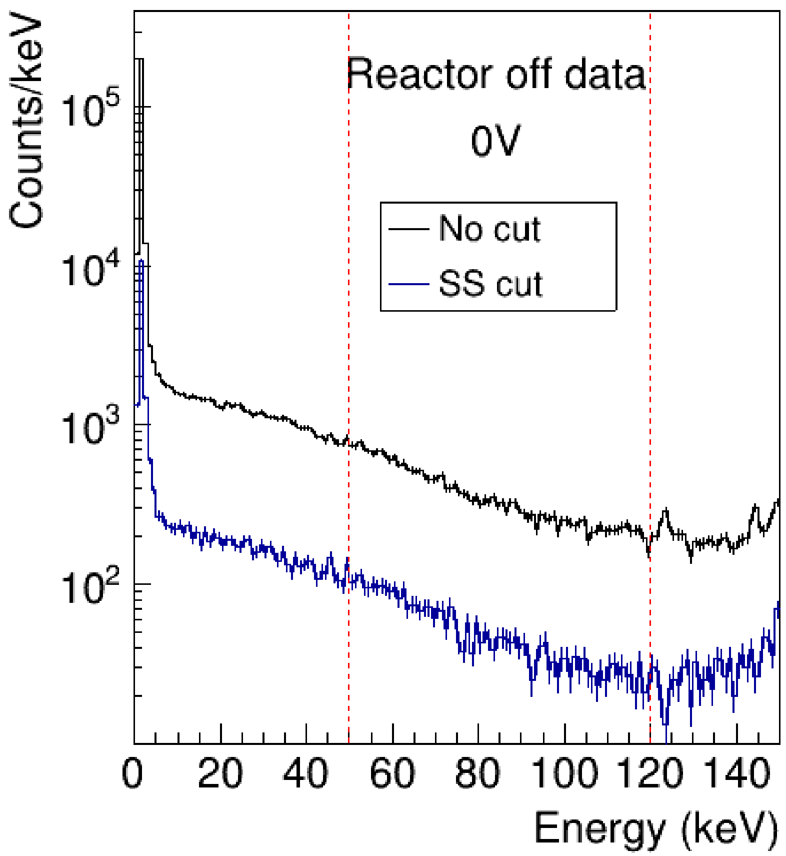




- Phonon noise performance is worser than TF.
- Data quality cuts are applied to select bulk events in search for in-situ Al fluorescence.
- 1.5 keV Al fluorescence is identified in each channels.
- Baseline resolution of ~ 80 eV is measured.



Result from NSC
SS background rate in sapphire



- Events with energy deposition above the threshold in sapphire and energy deposition consistent with noise in the other detectors are considered as single scatter events (SS).
- SS background rate is ~1200 DRU in reactor off condition.

Differential Rate Unit (DRU): counts/keV/day/kg

Data	No. of events after SS cut	Det mass	Run length (days)	Energy interval (keV)	No. of events in the range	DRU (counts/keV/days /kg)
Reactor off	54669	72 g	0.84	70 (50-120)	5377	1265

Conclusion and outlook

- Performance of sapphire detector at TF and at the reactor site has been shown from the recent data.
- The detector shows baseline resolution at TF ~ 25 eV whereas at the experimental site it shows baseline resolution of ~ 80 eV which is higher than at TF. Reasons for this are being investigated.
- From the reactor off data Al fluorescence has been identified.
- The single scatter background rate in the detector is ~ 1200 DRU in the energy range 70-120 keV.
- The detector could be a excellent candidate for CEνNS and low mass dark matter search.

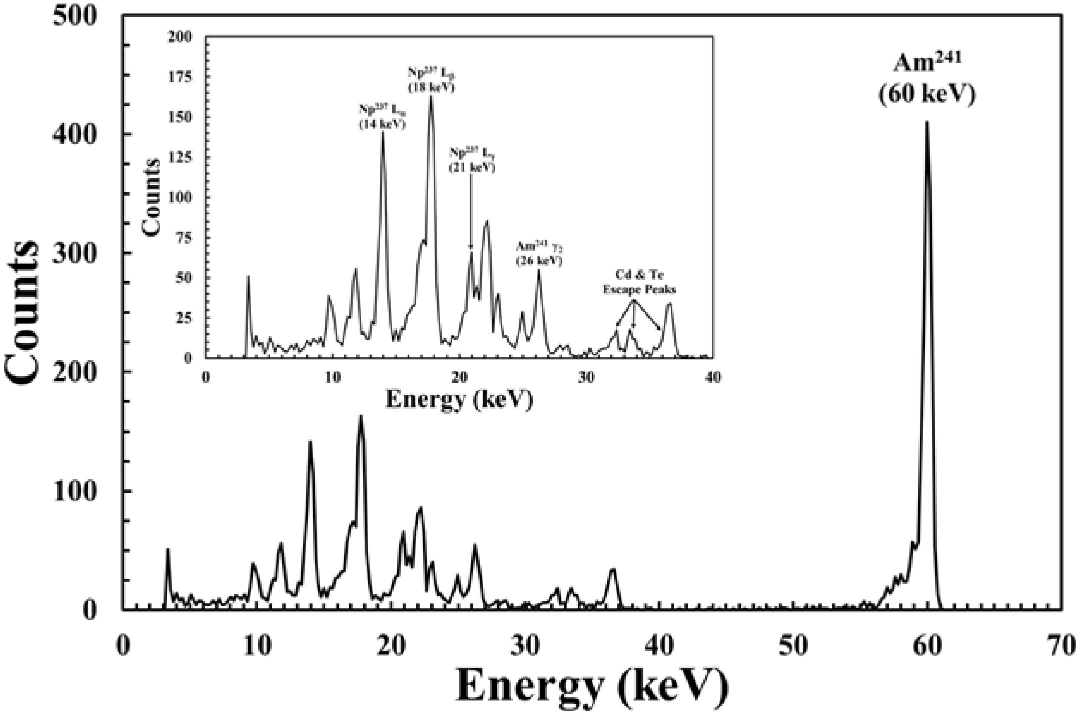
- MINER plans to take more engineering runs with different payload using sapphire with Ge and Si HV in coincidence.
- Using this detector technology MINER plans to detect CevNS and ALP's in from reactor.

Thank you

Back up

Experimental spectra of ^{241}Am

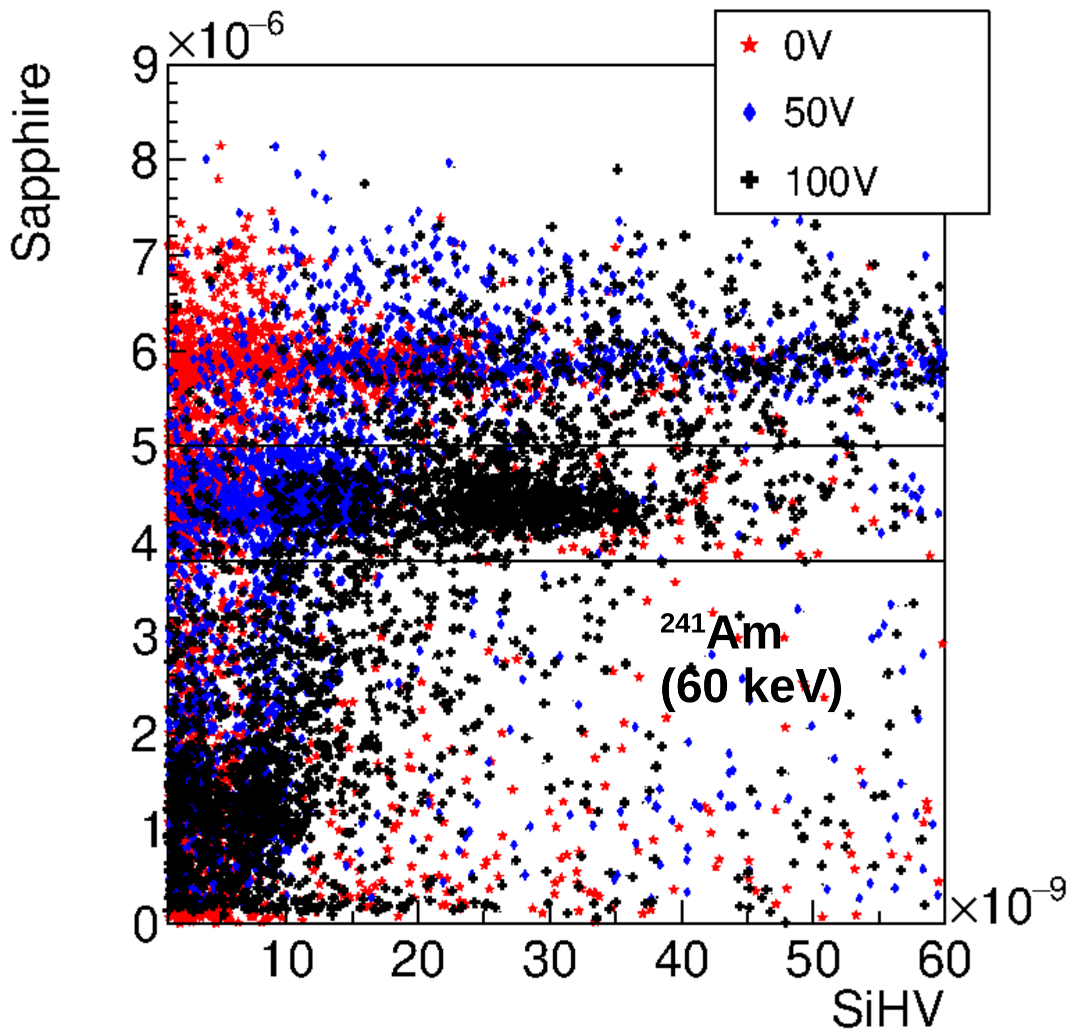
$$^{241}\mathrm{Am} \xrightarrow[\alpha\ \mathrm{decay}]{84.6\%} {}^{237}\mathrm{Np}$$

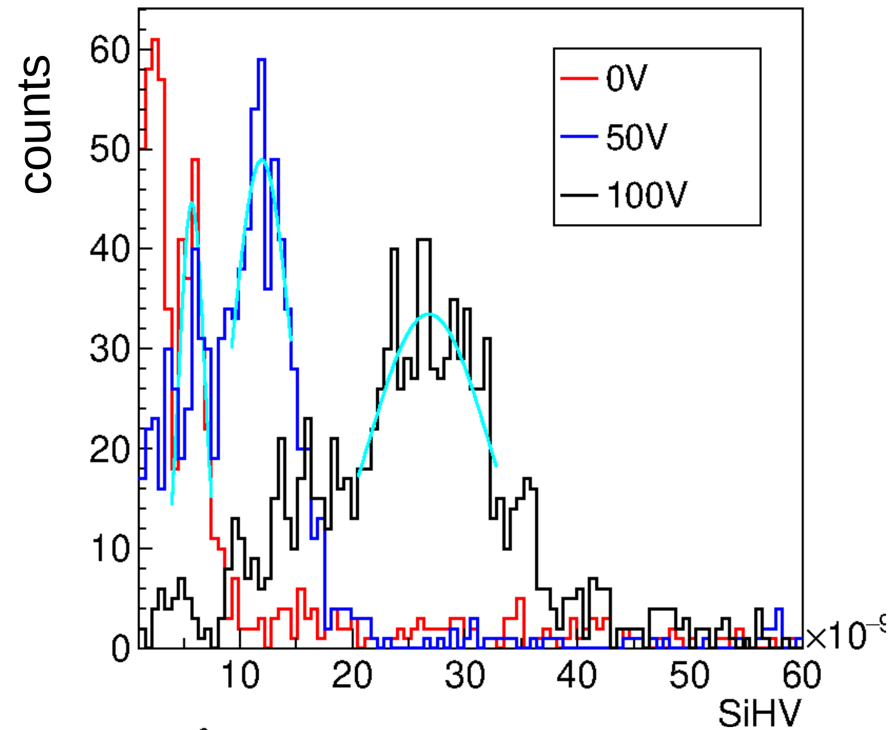


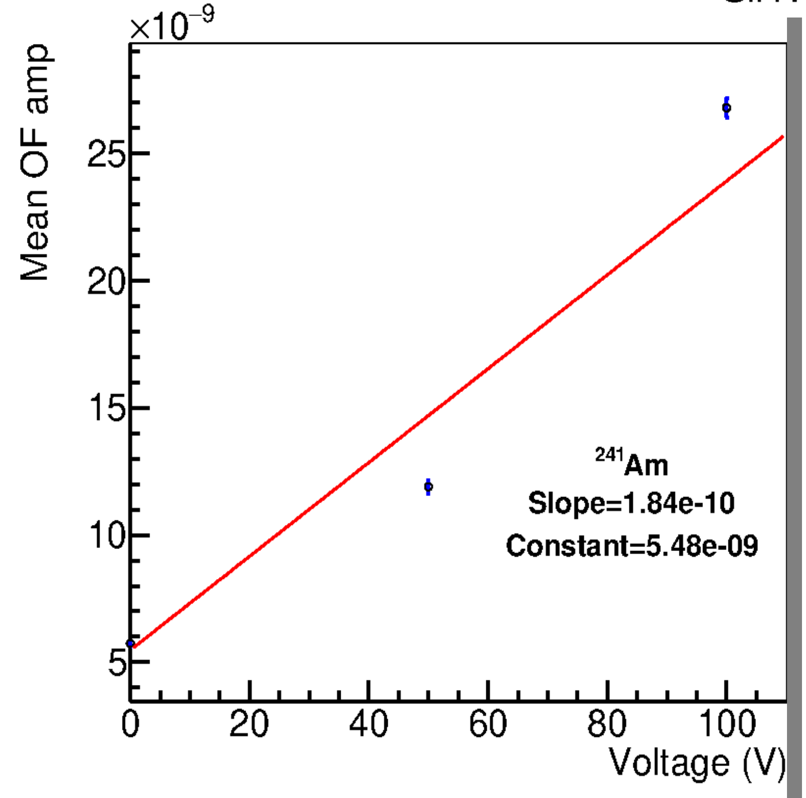
	Gamma lines (keV)	Source/ transtion lines
^{241}Am	11.8	Np L_l
	14	**Am/Np L_α**
	17.7	Np L_β
	21	Np L_γ
	26	Am
	59.5	Am

- Most of the decay of ^{241}Am populated the excited level of ^{237}Np with energy 59.5 keV.
- Several low energy gamma lines are seen for the transition of the M-shell electrons to L-shell.
- In the data, 59.5 keV line is seen only for 0V and 20V. After calibration using 59.5 keV, we obtain the calibration factor for 17.7 keV line.
- For 40V to 200V data, 17.7 keV line is used for calibration.

Coincidence between sapphire and Si HV







- ^{241}Am 60 keV peak in Sapphire shows linearity with applied voltages.

Optimal Filter (OF) method flowchart

- **OF method:** A fitting method to determine the amplitude of a noisy signal.
- OF fit maximizes S/N ratio by transforming the signal from a time domain to frequency domain where the fitting is performed by distinguishing noisy part of the signal from the underlying true signal.

Input

Signal: $S(t)$
Pulse template: $A(t)$
Noise template: $\xi(t)$
Sampling freqency

$S(t) = aA(t - t_0) + n(t)$
Where,
a = scaling factor
n = gaussian noise
t_0 = time delay

F.T.

$S(t) \rightarrow S'(\omega)$
$A(t) \rightarrow A'(\omega)$
$\xi(t) \rightarrow \xi'(\omega)$ (noise PSD)

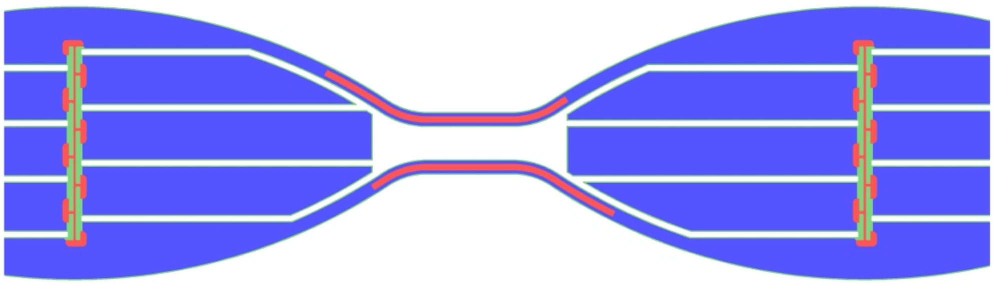
Find 'a' when χ^2 is minimum

$$\chi^2 = \int_{-\infty}^{\infty} \frac{|S'(\omega) - aA'(\omega)|^2 d\omega}{\xi'(\omega)}$$

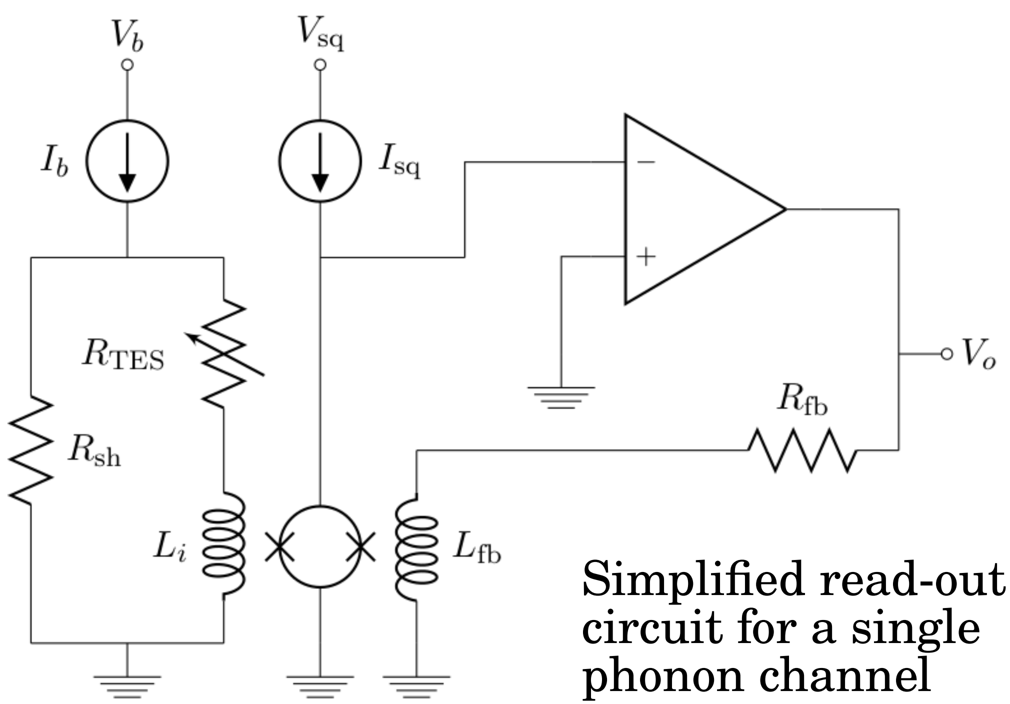
Output

OF amplitude: a
OF χ^2
t_0

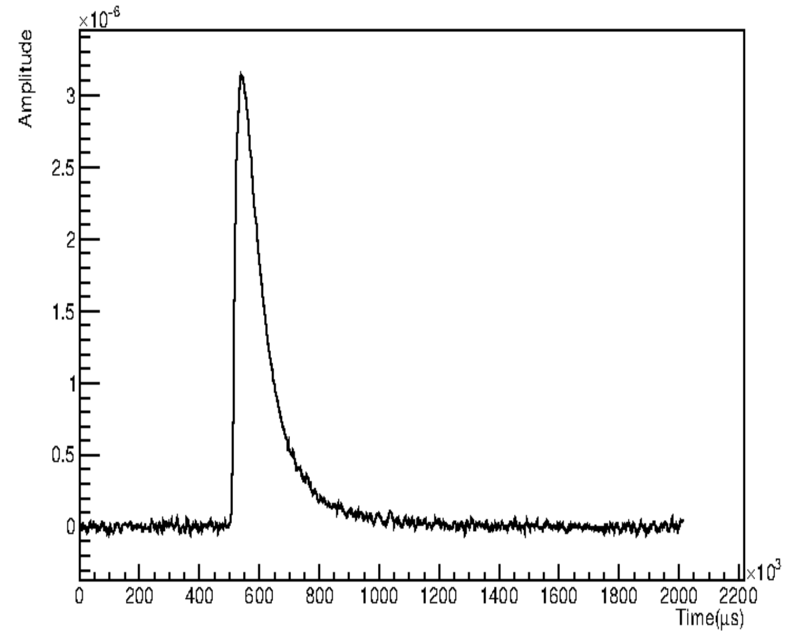
Phonon signal from sapphire



A schematic of the two TES's connected in a chain. Blue is Al, red is W.



Simplified read-out circuit for a single phonon channel



An example of pulse in sapphire