Modeling of TES based Modular CEvNS detectors for the Ricochet Experiment

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Ricochet

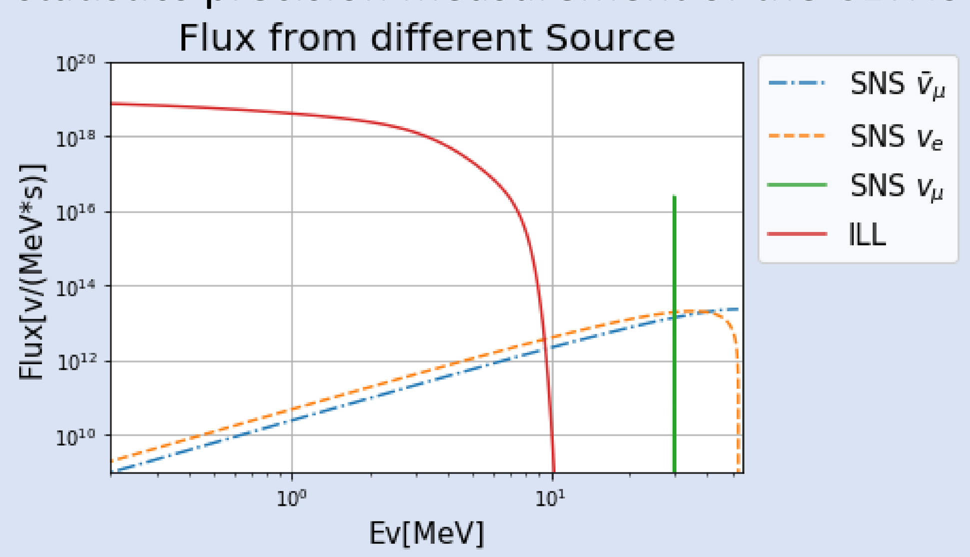
CEvNS

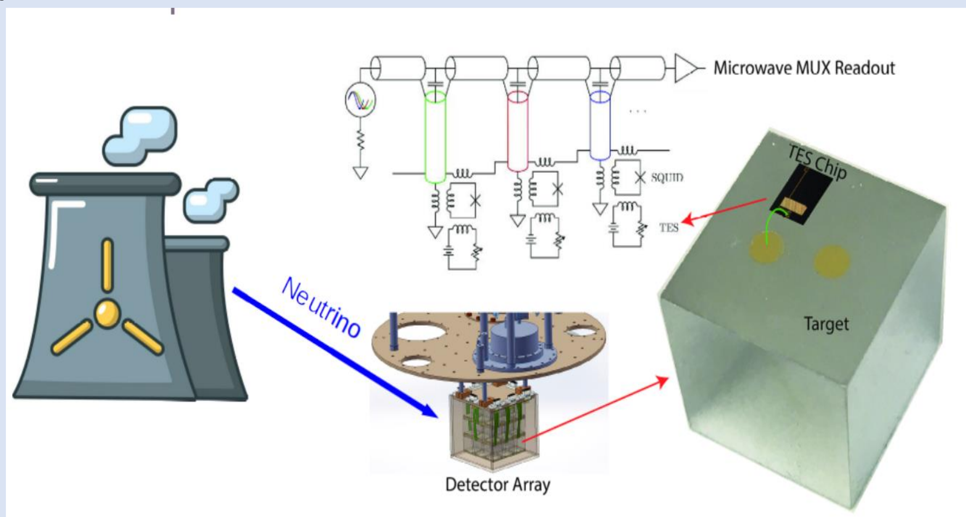
Idea originally proposed in 1974 by Daniel Freedman[1], predicting that for sufficiently small momentum transfers, the neutrino can interact coherently with a nucleus.

The process known as Coherent Elastic Neutrino(v)-Nucleus Scattering, or CEvNS is now experimentally realized by the COHERENT experiment through the Spallation Neutron Source(SNS) [2].

Experiment

The Ricochet experiment will make detailed measurements of the spectrum of CEvNS at the ILL nuclear reactor in Grenoble, France. A collaboration of European and US institutions, the Ricochet experiment will place an array of cryogenic detectors near the reactor core to perform a high-statistics precision measurement of the CEvNS spectrum.





The ILL nuclear reactor has a flux that is 1000 times higher than the SNS. However the lower neutrino energies require a much lower detector threshold (order of 50 eV) to take advantage of this increased flux.

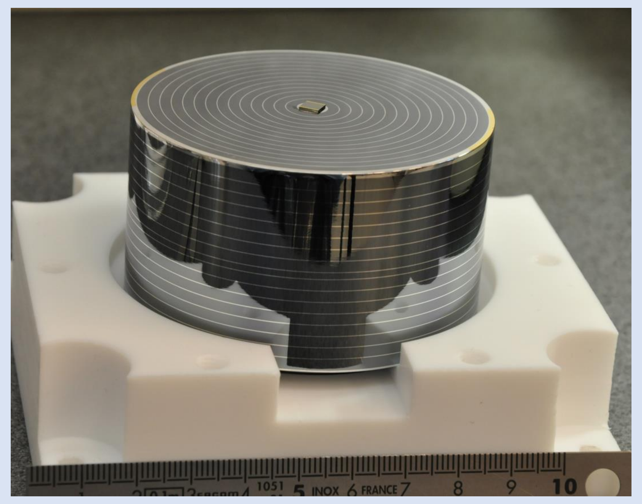
Detector

The Ricochet experiment will use 2 types of technologies. One is NTD-based Ge detector based on EDELWEISS technology.

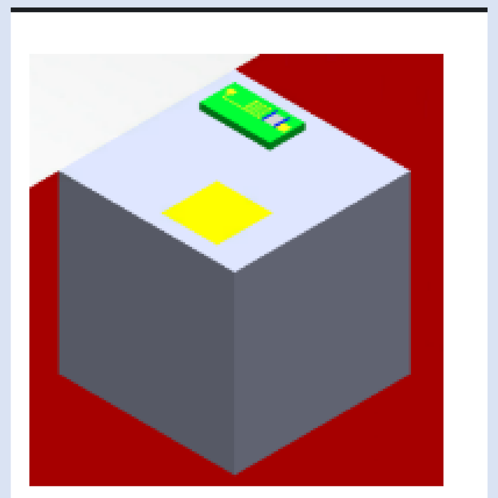
Another is TES-based Zn detector.

NTD-Ge Detector

Uses Ge targets with EDELWEISS interdigitated ionization readout + NTD thermistor heat measurement to obtain electron recoil / nuclear recoil discrimination down to 50 eV threshold. ER/NR discrimination is for the purpose of reducing the background.



NTD-based Ge detector

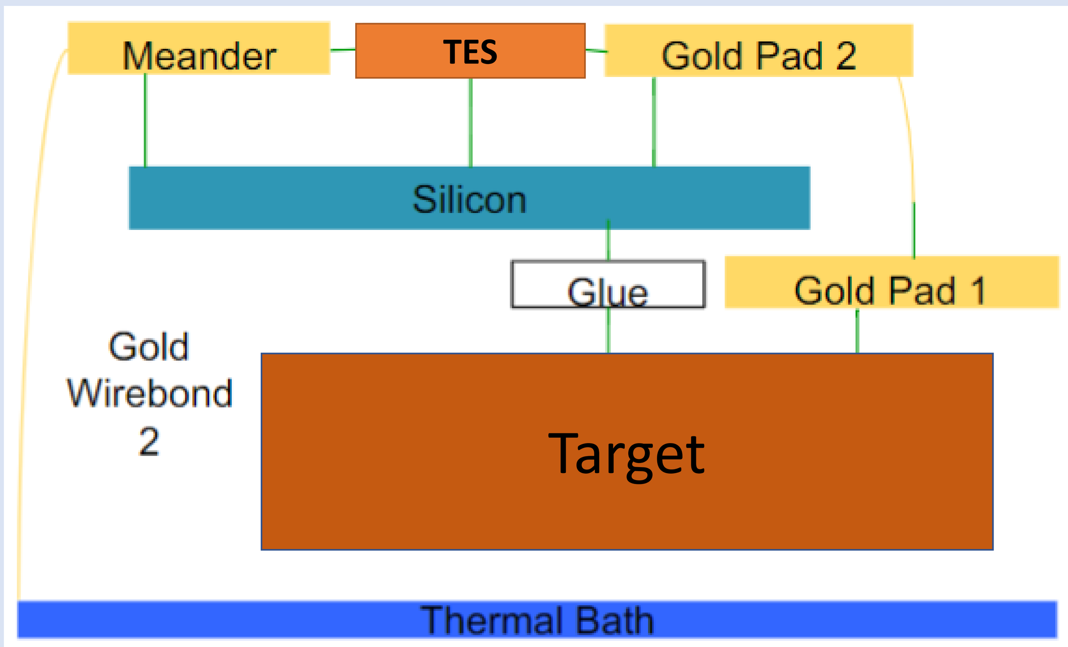


TES-based Zn detector

TES-Zn Detector

Uses Zn targets with Ir/Pt TES. Uses pulse shapes to obtain discrimination between electron recoil and nuclear recoil down to 50 eV. The thermal diagram is shown right:

Blocks represent the heat capacity of each component and green lines represent thermal connections between them.

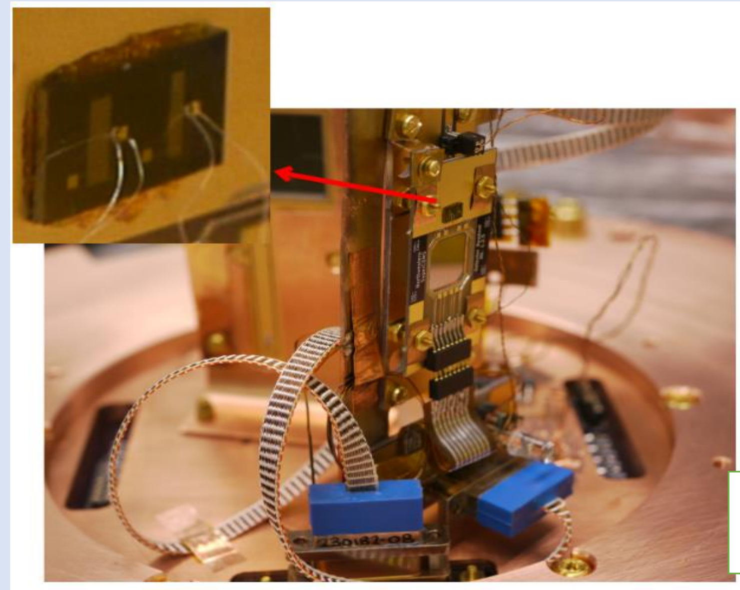


First engineering run

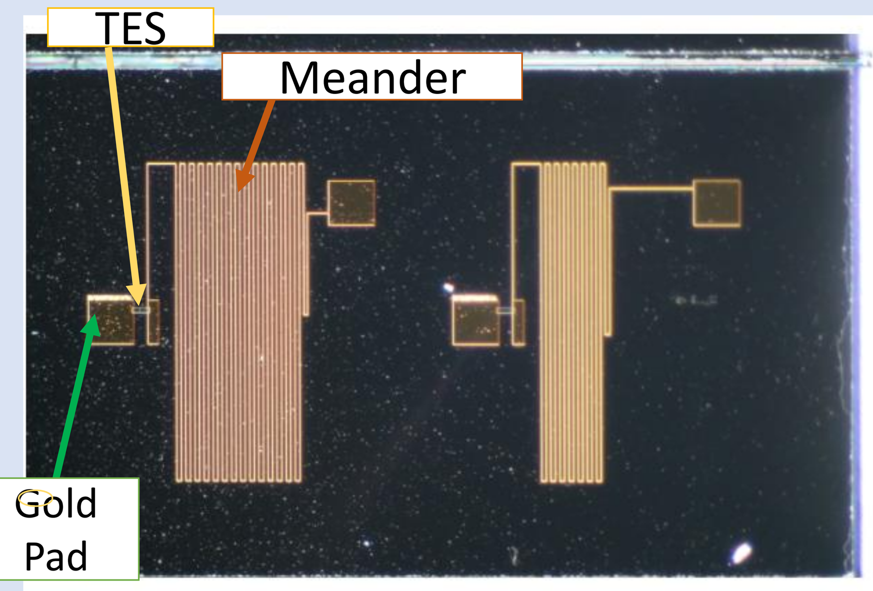
Experiment Setup

We operated an Ir/Pt TES chip fabricated by Argonne at the Northwestern Experimental Underground Site (NEXUS) at Fermilab.

The detector is run without a separate target and uses the silicon chip with TES fabricated on as a target. The goal of this experiment is to validate our model and measure the characteristics of the Ir/Pt bilayer TES.



Picture of the detector's setup

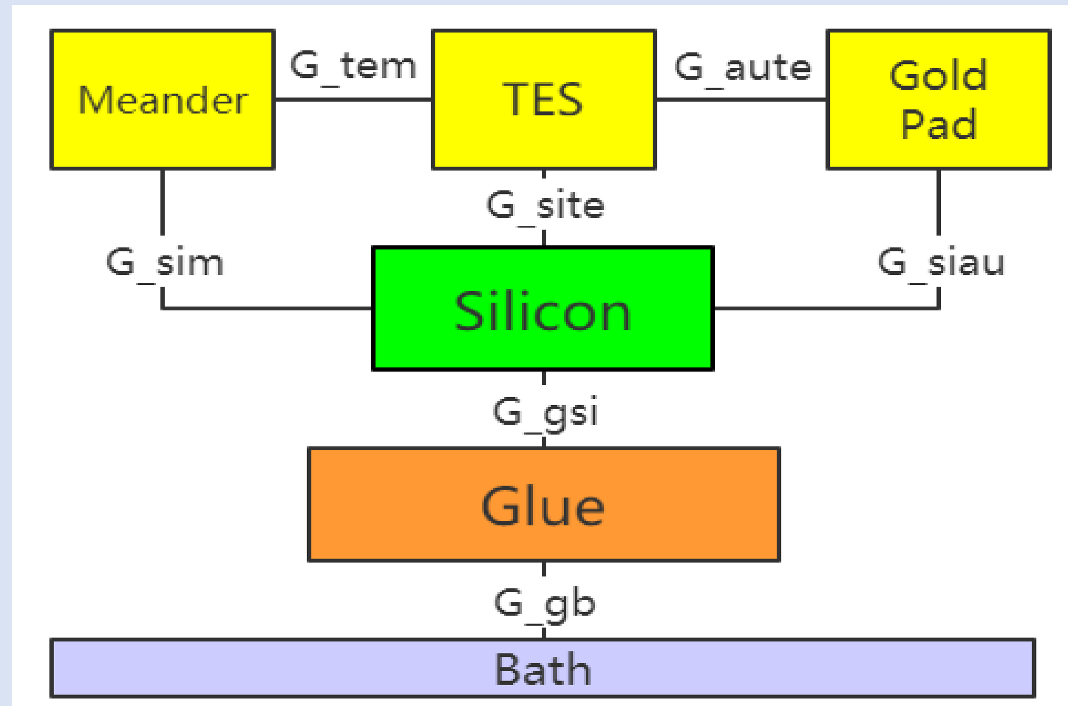


Close up of the TES Chip with 2 separate devices

Thermal Model

Thermal conducting diagram is shown right. Following is how thermal model works.

1) Define a set of differential equations to express the changes of current and voltage in the TES, and temperature of each thermally coupled element. Each is modeled with heat capacity C and heat conductivity G.
2) Build up the matrix of equations and calculate the equilibrium point of the system.
3) Use a Python non-linear solver to calculate the detector response from a certain energy input.
4) Calculate noise PSD and NEP with the equivalent linear equations.



Parameters	Values	Parameters	Values
$C_{meander} + C_{tes} + C_{goldpad}$	2e-12 J/K	T_{bath}	80 mK
C_{glue}	4e-11 J/K	T_c of TES	87 mK
G_{site}	1e-10 W/K	R_n of TES	2.3 Ω
G_{gsi}	5e-9 W/K	Bias point	30%
G_{gb}	1e-8 W/K	Input Energy	70 keV
Assume scattering events happened in Silicon			

Event Fitting

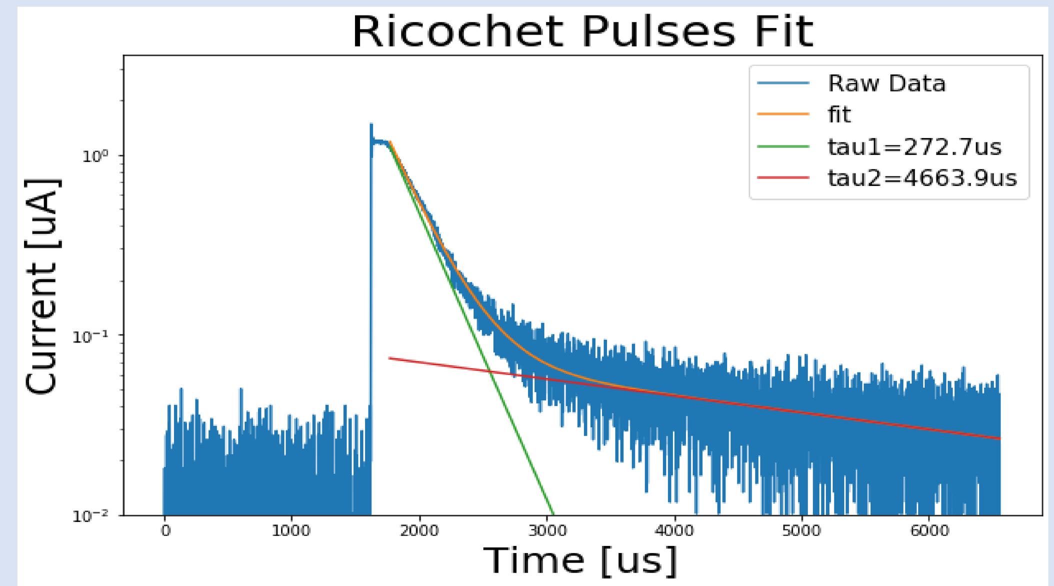
We obtained 3 events from the environmental background after running for 30 minutes. We fit the events with a double exponential function (right):

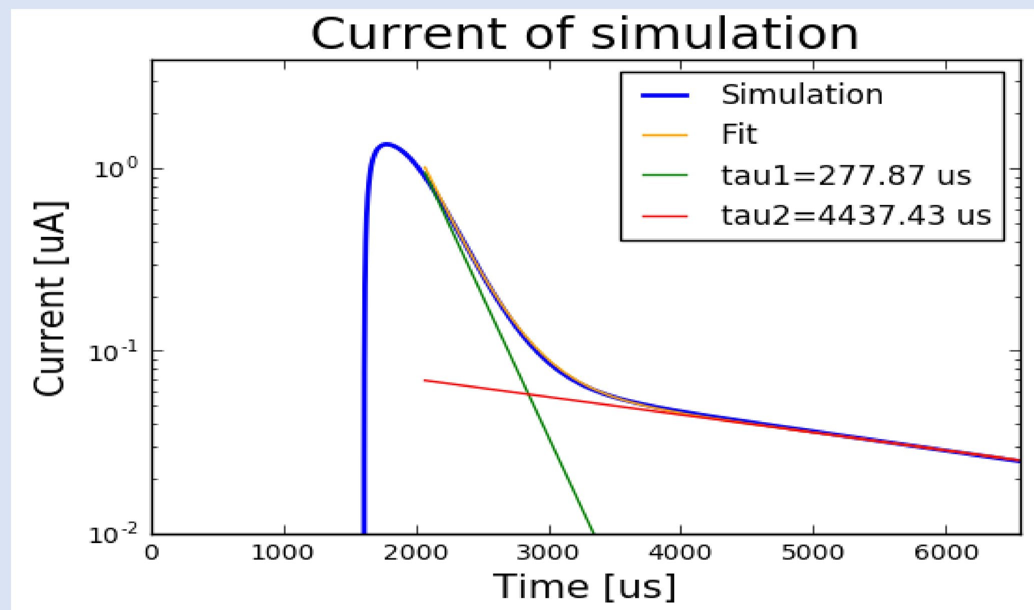
$$I = I_1 * Exp\left(-\frac{t}{\tau_1}\right) + I_2 * Exp\left(-\frac{t}{\tau_2}\right)$$

The fit shows 2 distinct time constants, one an order of magnitude slower than the other. Our hypotheses are:

1) The faster component is the gold, silicon, and TES thermalizing with the glue.
2) The slower component is the whole system thermalizing with the bath, through the glue.

Right is the simulation result with the parameters shown above. By tuning the G_{gsi} and G_{gb}, the time constants of the simulation can be similar to real pulses which aligns with our hypotheses.





Next Steps

While the progress has been slowed by the pandemic, the detector is cold again and we are taking data. We will study the thermal and complex impedance of the device, and irradiate it with gamma sources. This data will be used to design the next iteration of the TES based Ricochet detectors.

Reference

[1] Freedman, Daniel Z. "Coherent Effects of a Weak Neutral Current." *Physical Review D* 9, no. 5 (January 1974): 1389–92. https://doi.org/10.1103/physrevd.9.1389.

[2] D. Akimov et al., Science 357, 1123 (2017)