RICOCHET

Joseph A. Formaggio

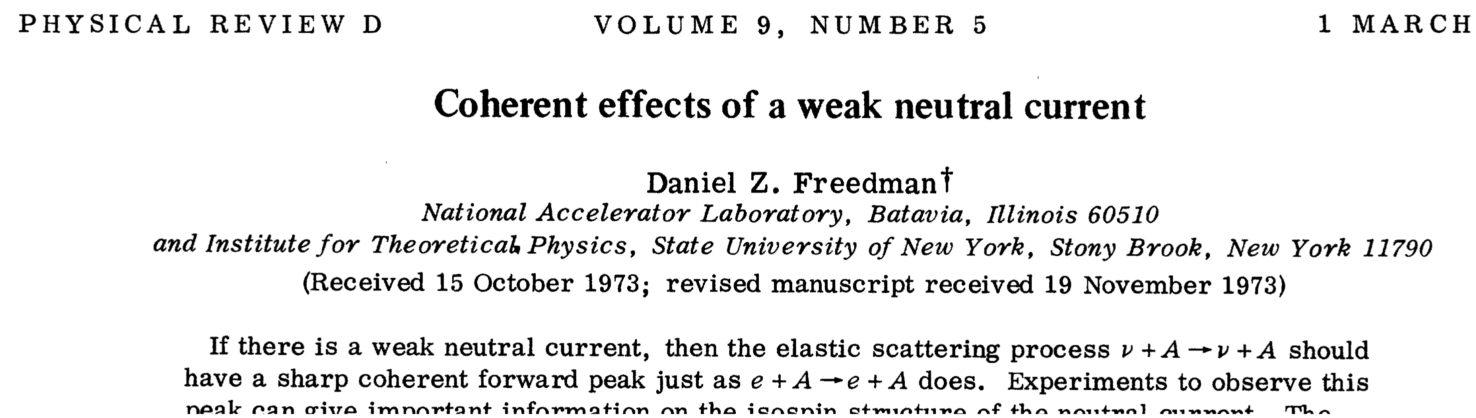
Massachusetts Institute of Technology

The CEvNS Portal

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

- Such a process would significantly enhance the cross-section, allowing it to scale with (roughly) the number of neutrons *squared*.

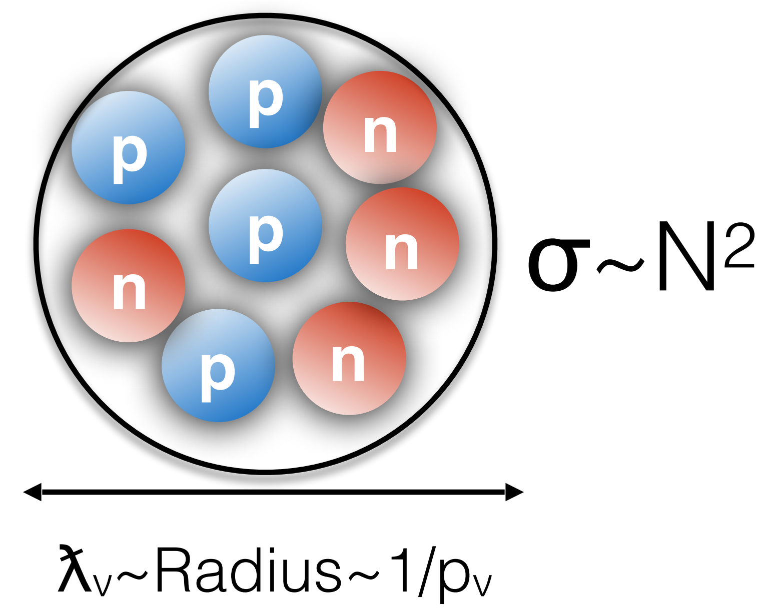
- Now an ***observed*** neutrino reaction.


PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH

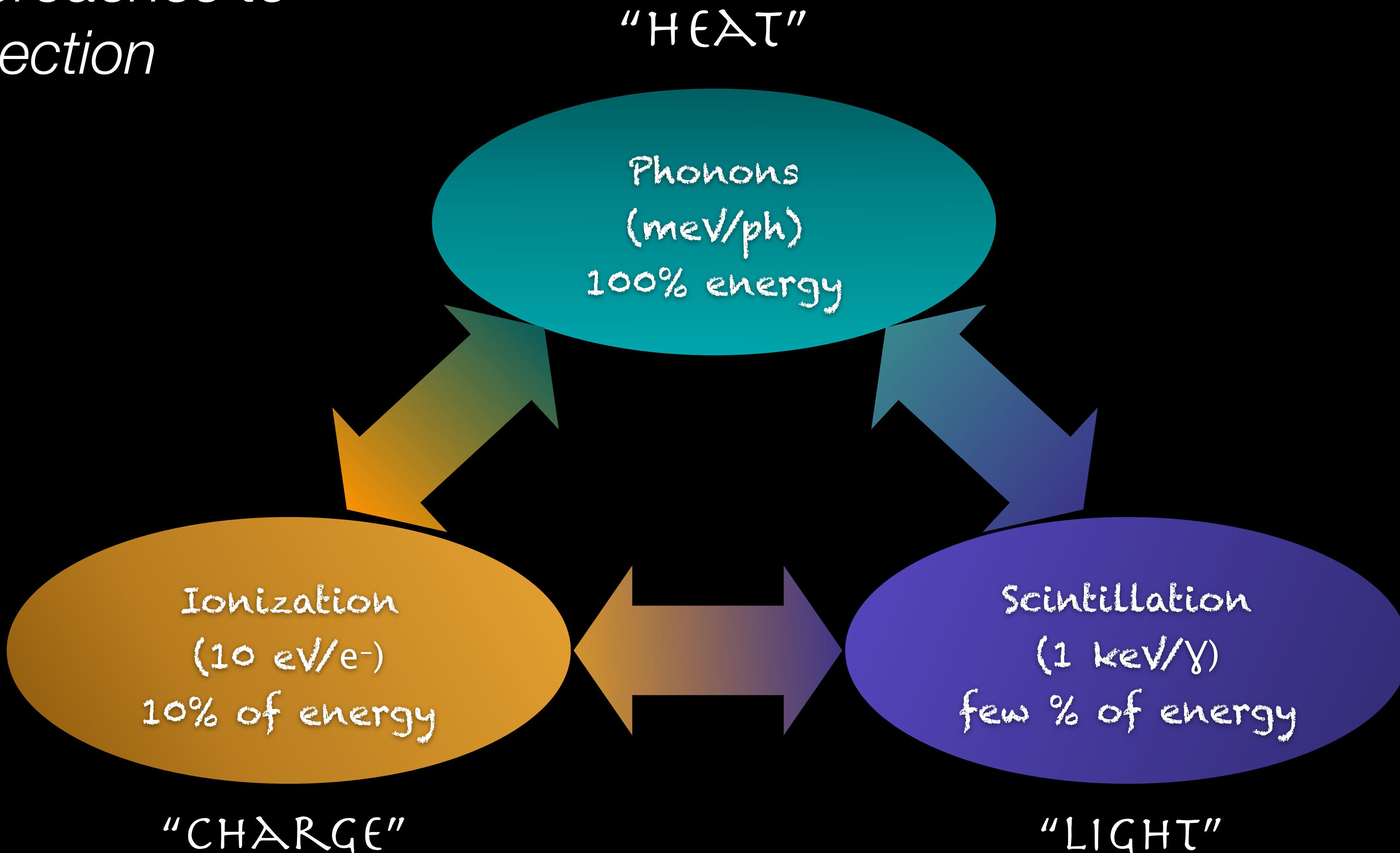
Coherent effects of a weak neutral current

Daniel Z. Freedman†
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790
(Received 15 October 1973; revised manuscript received 19 November 1973)

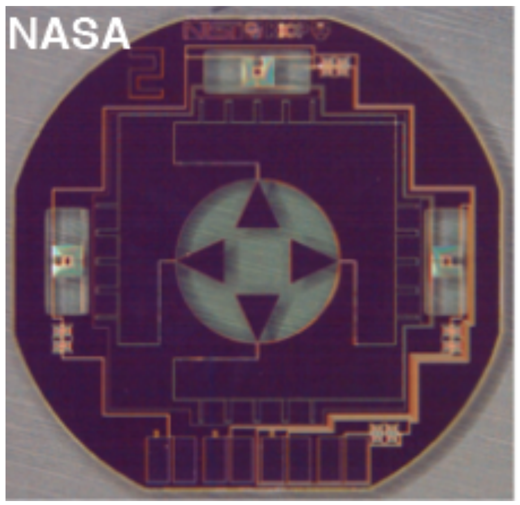
If there is a weak neutral current, then the elastic scattering process $\nu + A \to \nu + A$ should have a sharp coherent forward peak just as $e + A \to e + A$ does. Experiments to observe this

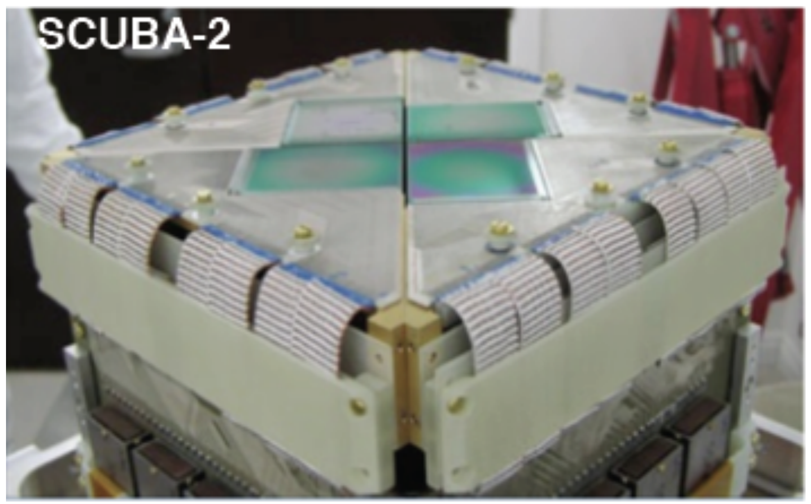


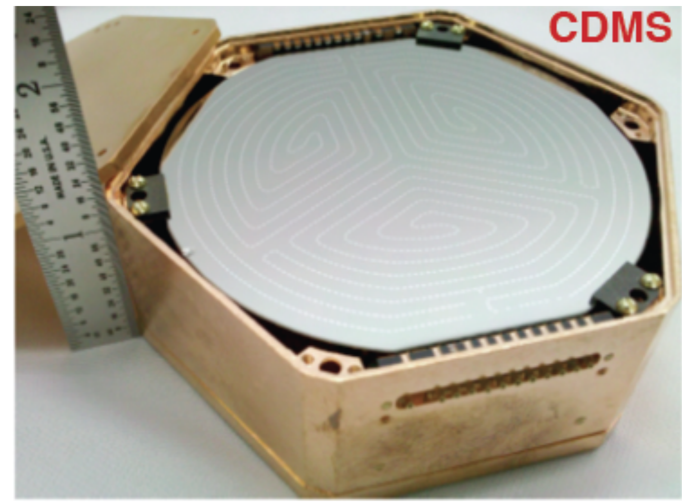
Different Approaches to Detection

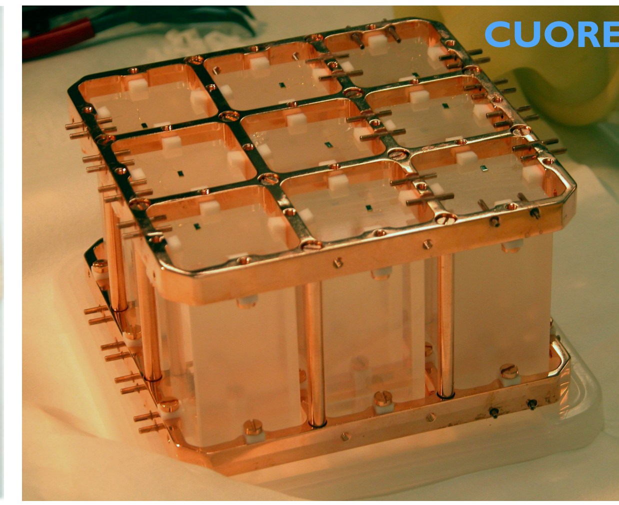


Where Phonon Technology is Used









CMB, Infrared detection

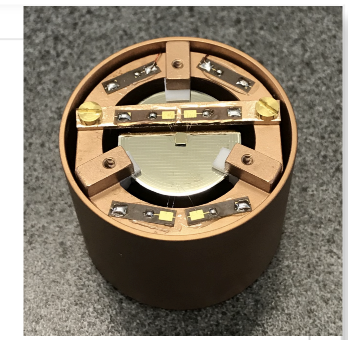
Dark matter

$0\nu\beta\beta$

To go to lower neutrino energies, lower threshold are required. Phonon readout is a promising technology already used in many other experiments.

Ricochet uses *phonons+X* readout to reach low threshold, with eventual goal of reaching **10 eV** recoil threshold.

A Detector Wish List…



(1) VERY LOW ENERGY THRESHOLDS: $O(\sim 10\ eV)$

(2) ELECTROMAGNETIC BACKGROUND REJECTION: $> 10^3$

(3) SIGNIFICANT TARGET MASS: ~ 1 Kg (AND SCALABLE)

(4) TARGET COMPLEMENTARITY: Ge (SEMI-) AND Zn (SUPER-) CONDUCTORS

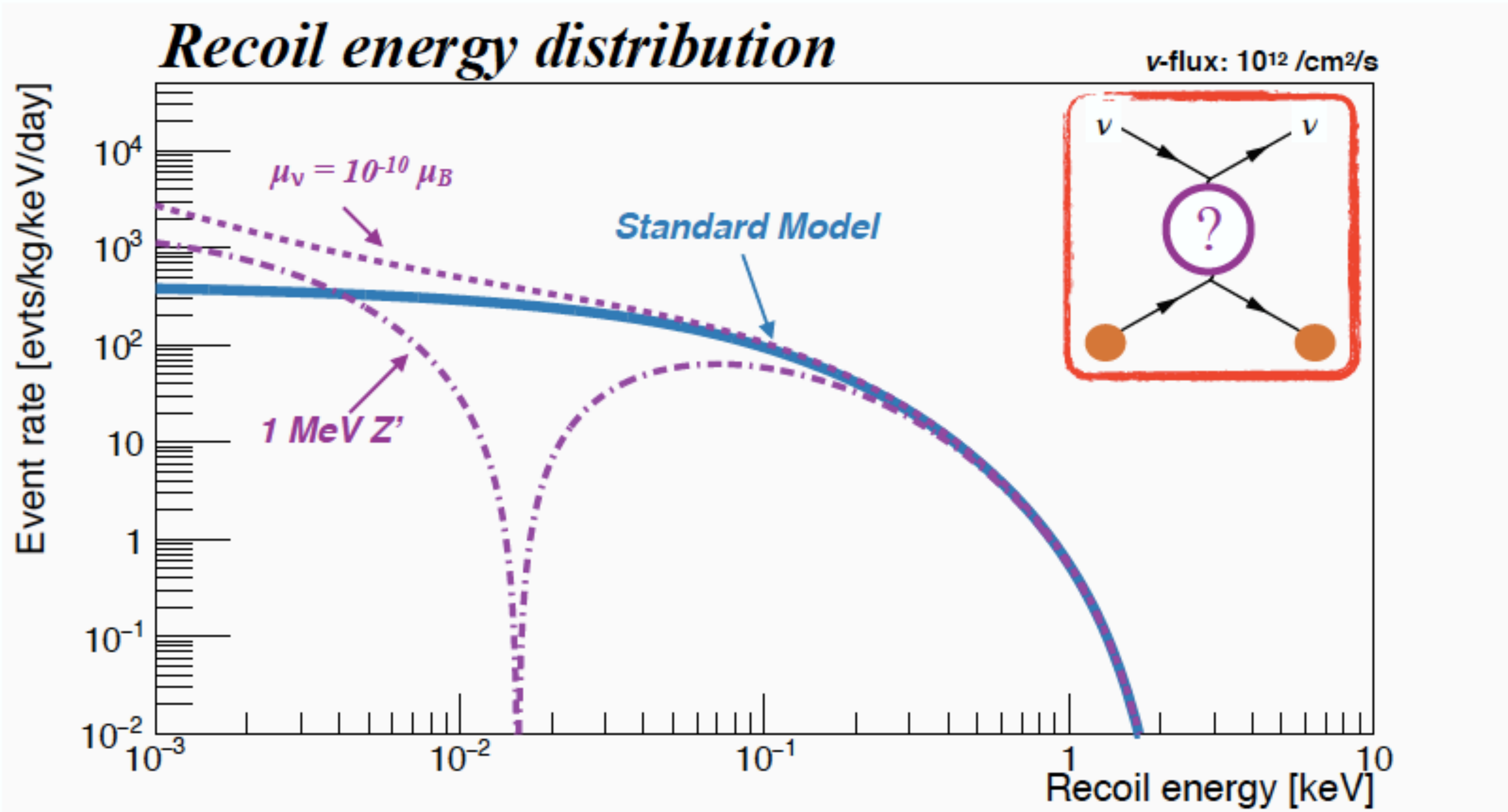
…and a Source Wish List

(1) HIGH FLUX ~ FEW GW POWER

(2) ON/OFF CYCLES ~10-30% DOWNTIME OF FLUX

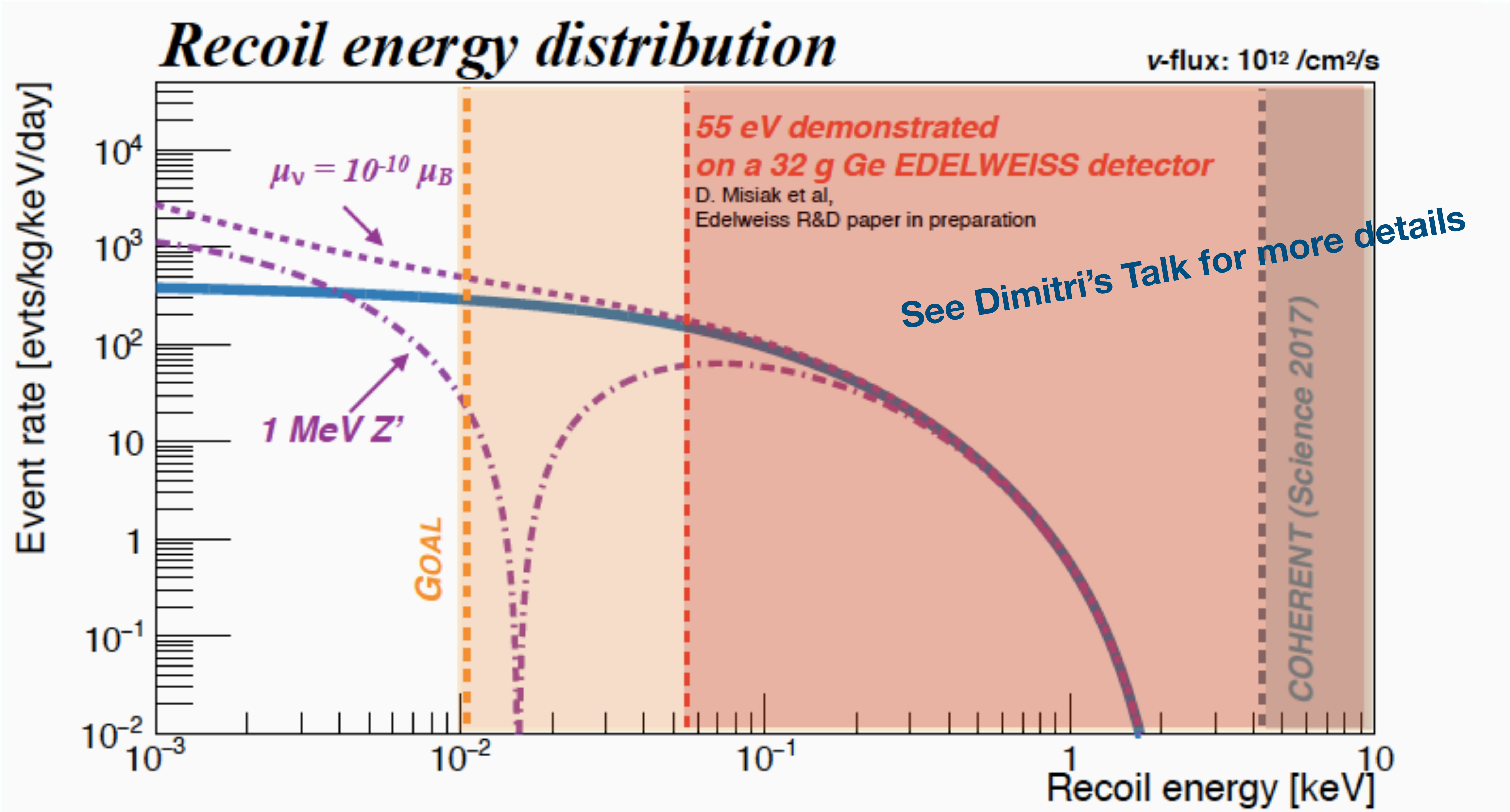
(3) OVERBURDEN UNDERGROUND (~150 MWE) OR SHIELDED

Requirement for Low Thresholds



- Signatures for new interactions is often amplified at low energies.
- ***Calls for low threshold ~O(10 eV) detectors.***

Requirement for Low Thresholds



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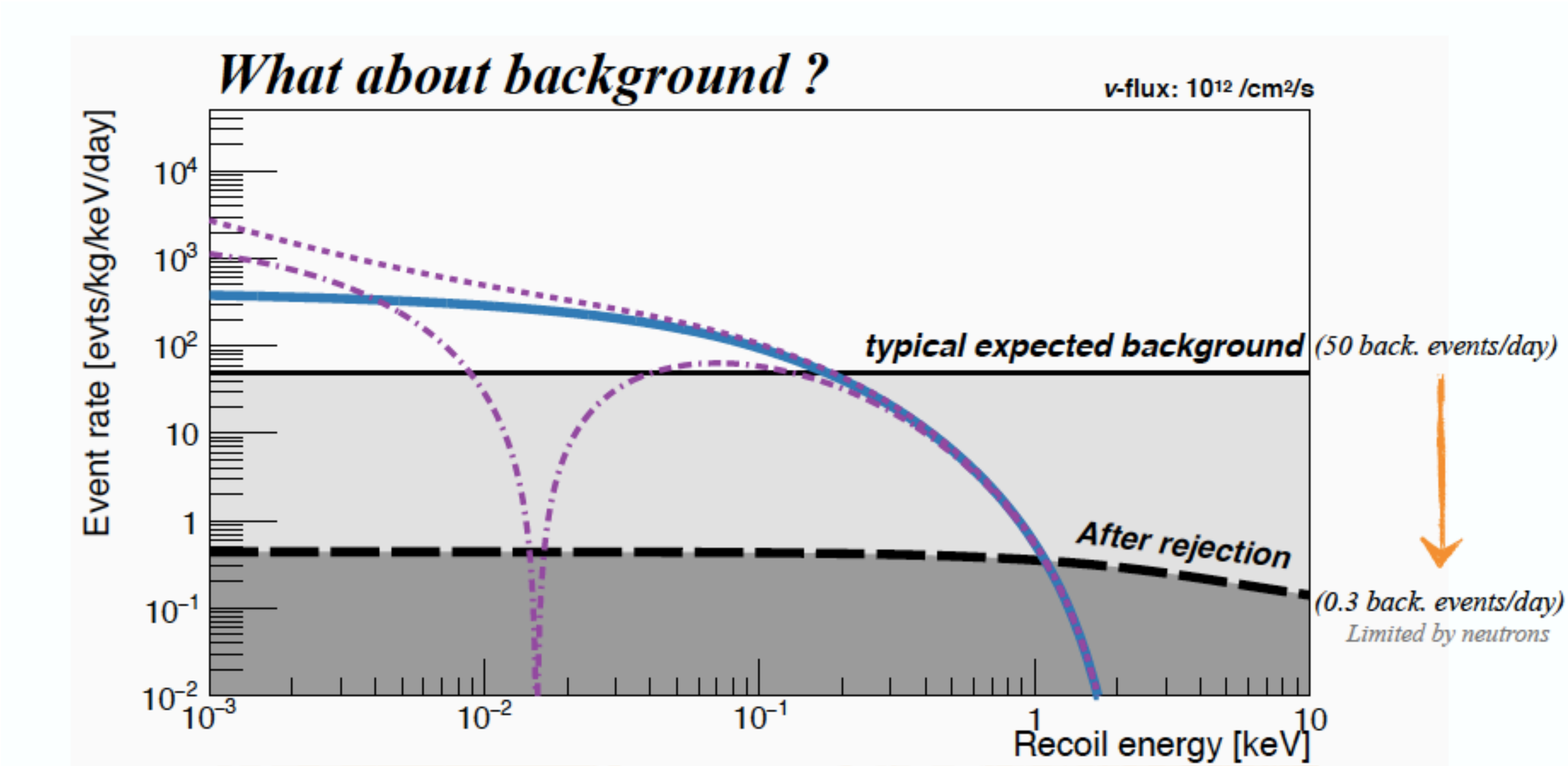
Requirement for Low Backgrounds

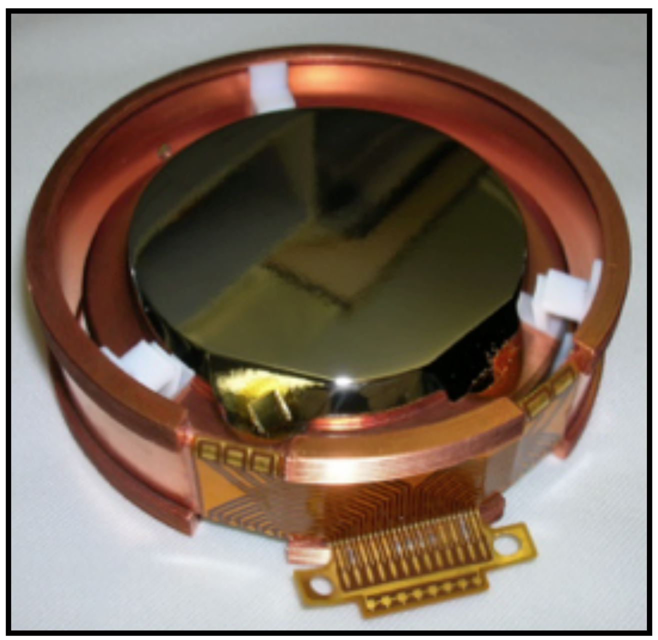


- For no background rejection, thresholds below 100 eV necessary.
- ***For factor of x1000 rejection, signal greatly enhanced for discovery potential.***

What Kind of Detectors to Use?

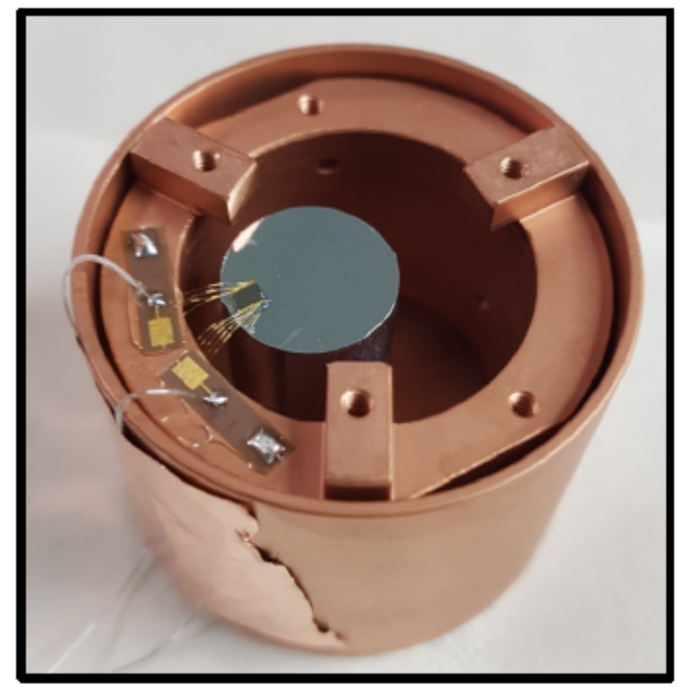
Leverage two technologies that are used by both the US and French groups.

This amplifies the science reach (complementary detectors) and reduces the science risk.



Germanium Detectors

(based on EDELWEISS technology)



Superconducting Metals (Zinc)

(new R&D effort**)

****Not really. Superconductors were also studied by Oxford, Milan and Genoa groups.**

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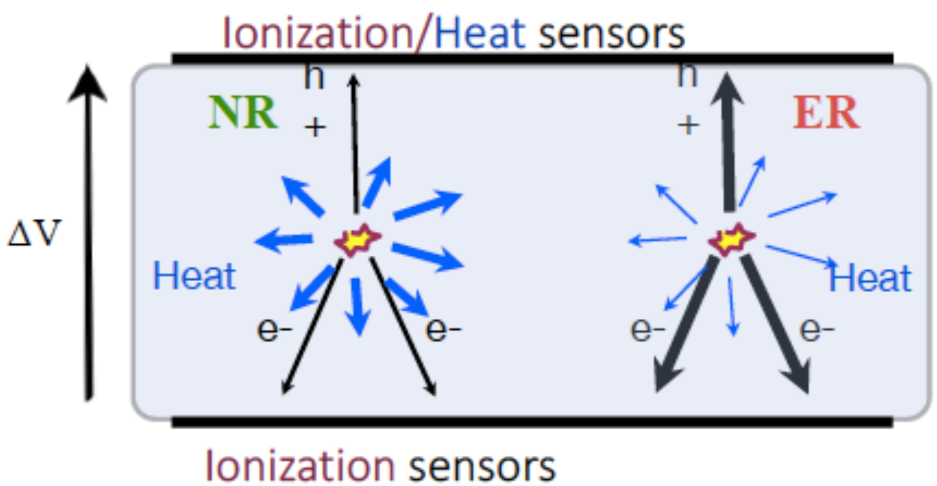
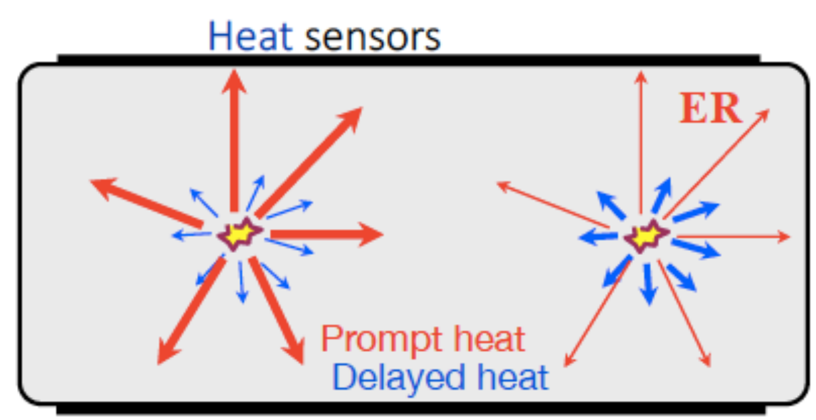


Germanium
Detectors

(based on EDELWEISS technology)
See talk on Cryocube, next talk



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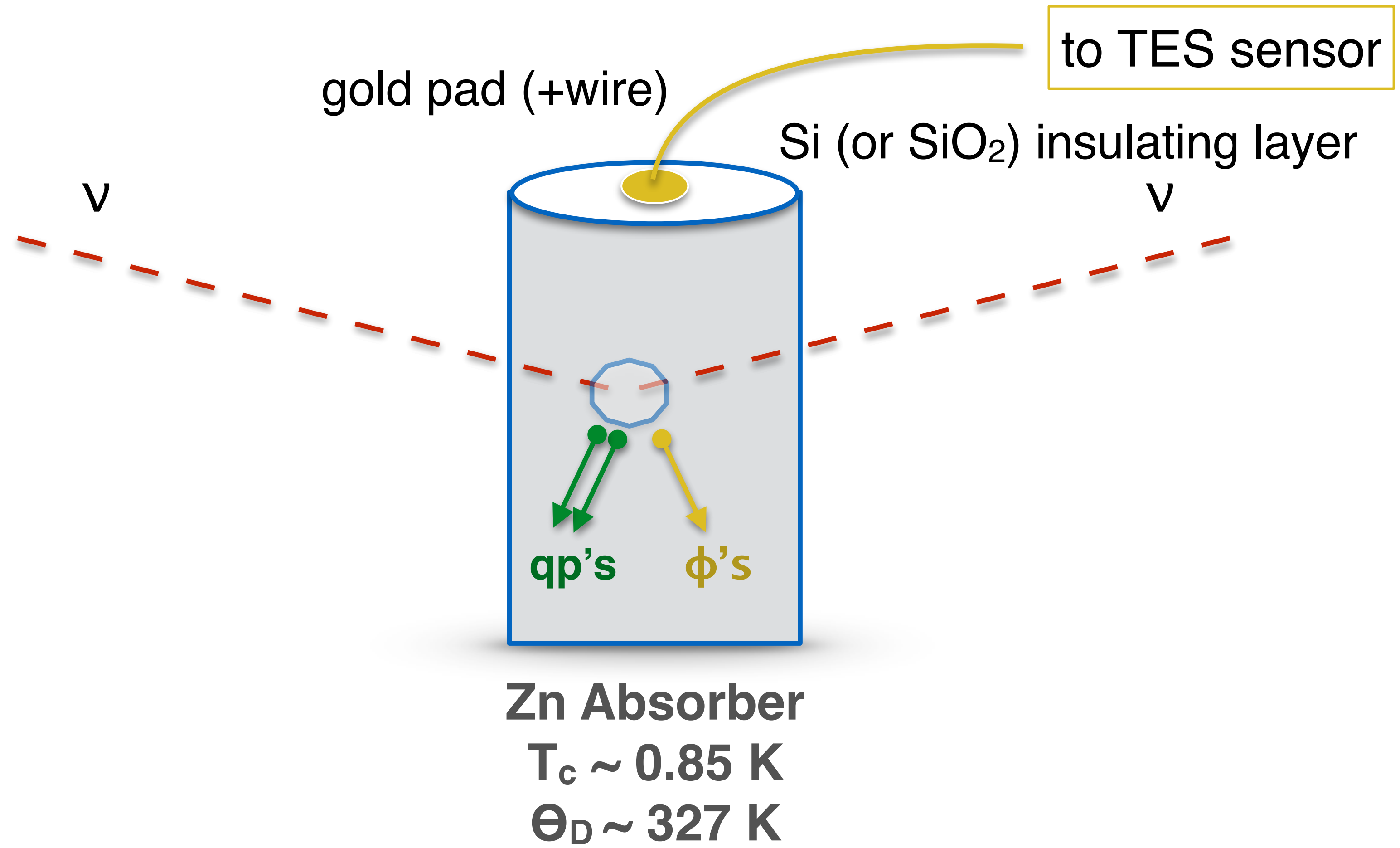
Why Superconducting Metals?



Metallic Superconductors as Detectors:

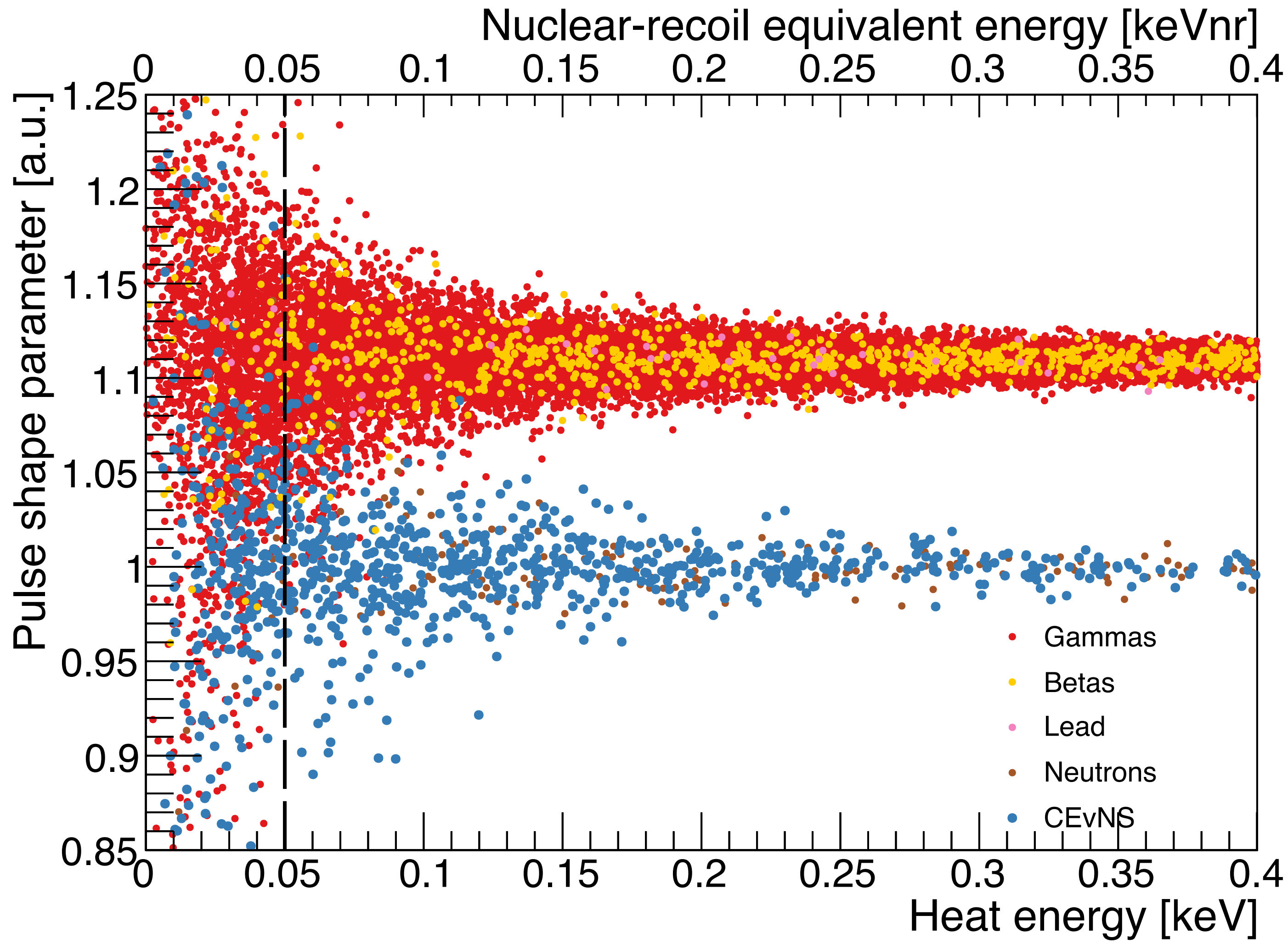
Zinc crystals become superconducting below 850 mK. If operating at 15 mK, this is well below Tc. Implies that capacitance dominated by lattice contributions (scale as T^3).

High Debye temperature implies low capacitance.

Target atomic number very similar to germanium.

Energy breaks Cooper pairs; turning into either **quasi-particles** or **phonons**.

Why Superconducting Metals?



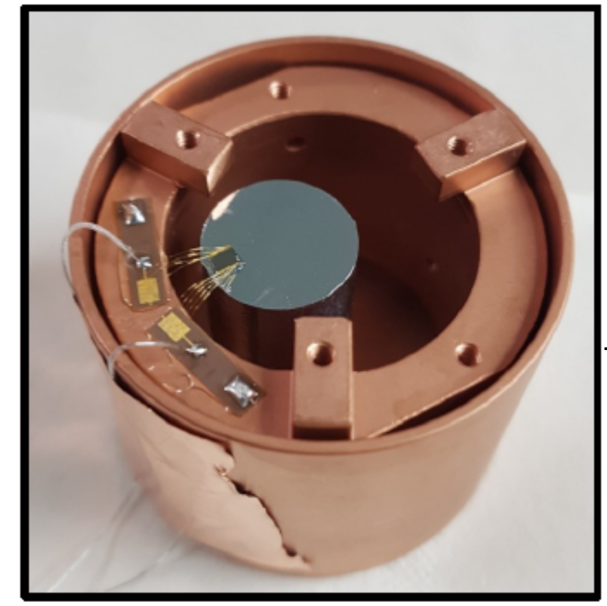
Metallic Superconductors as Detectors:

However, quasi-particles and phonons do not evolve in the same way.

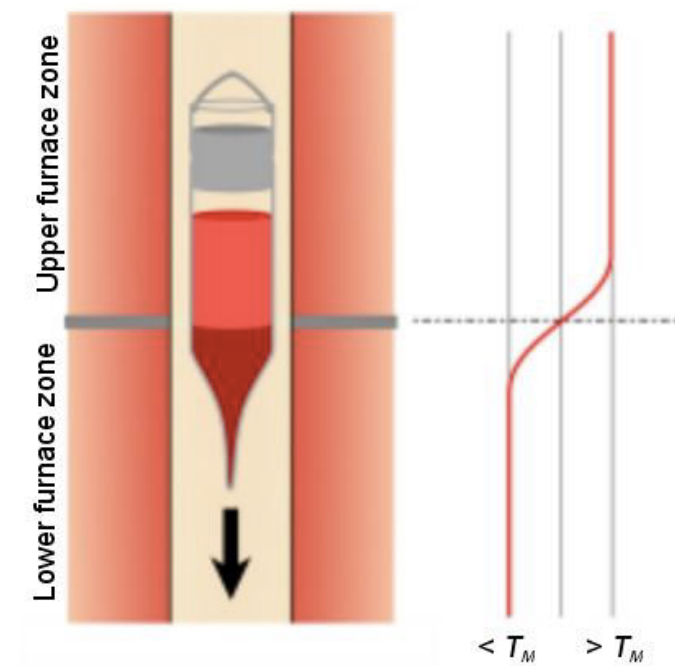
Recombination times for quasi-particles become extremely long at low temperatures (~ seconds), while (a)thermal phonons operate at much different (faster) time scales.

Separation of recoil from electromagnetic events using **quasi-particle** versus **athermal phonon** timing signatures should be explored.

Zinc Detectors



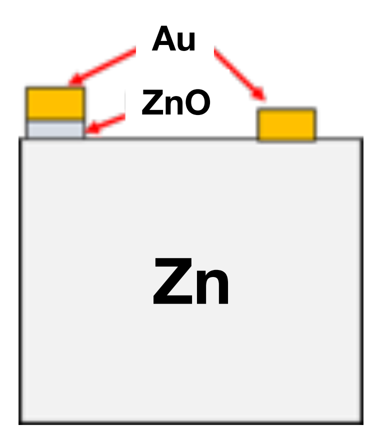
- Prototype single crystals are now being made thanks to a contract with RMD, Inc. (specializes in low background detector crystals).

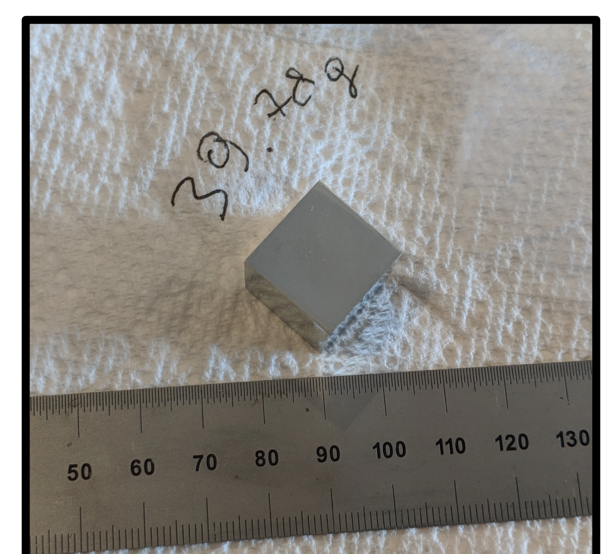


- Crystals grown from zinc and aluminum ampules now readily made, without much difficulty (Bridgman method).

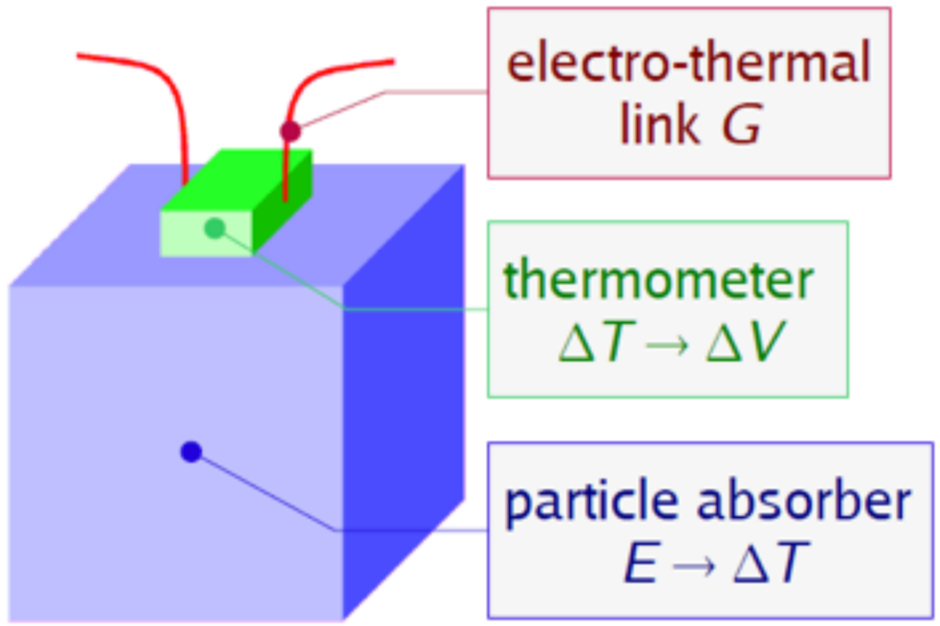
- Have in hand several 25-30 gram zinc crystals, small Al crystals also produced.

- So far Zn crystals grown as cylinders. Will be switched to cubes, to allow better polishing on all surfaces.





Readout Scheme



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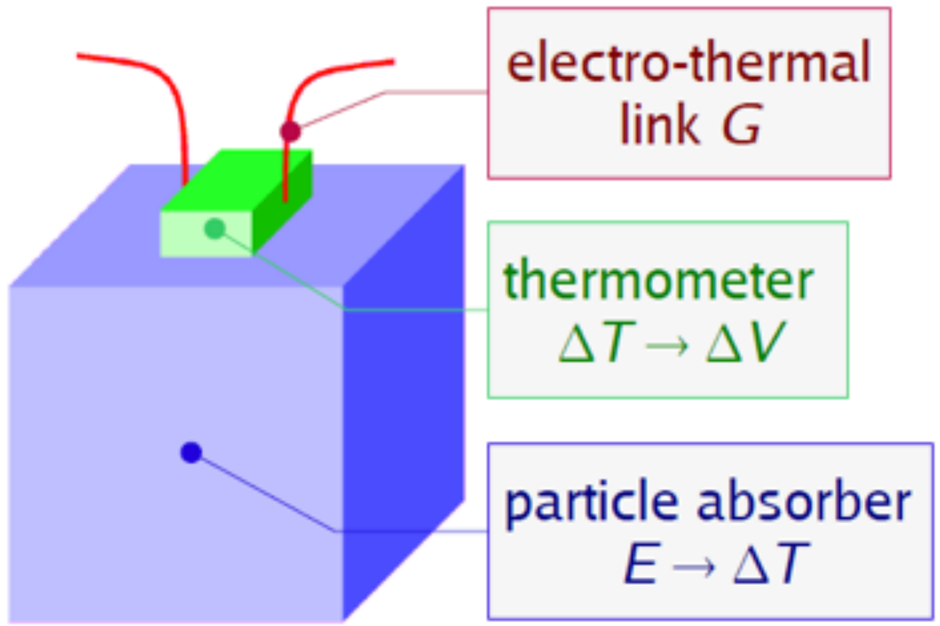
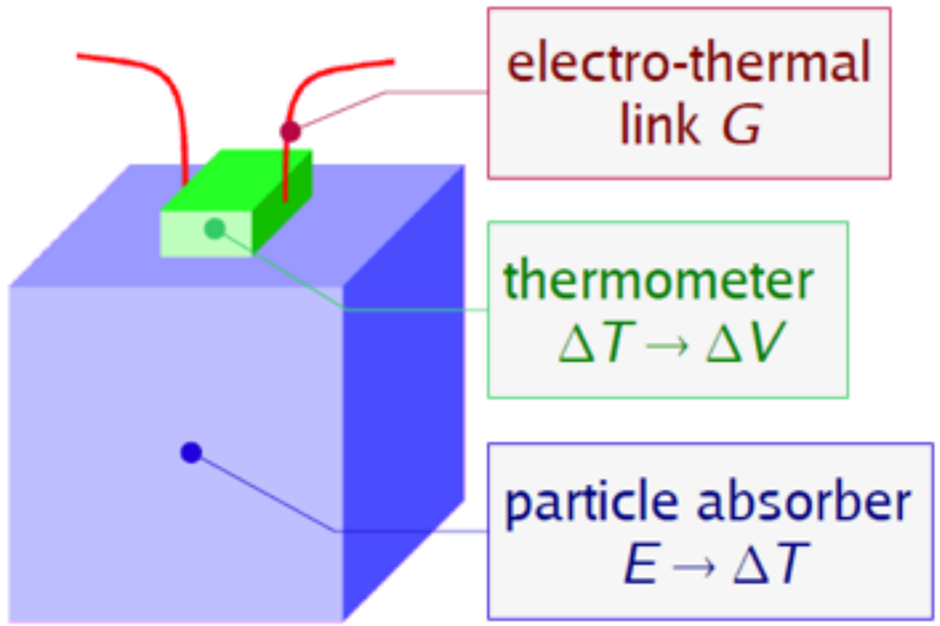


The **absorber** allows conversion from energy to heat (phonons)

For semi-conductors and superconductors, only lattice vibrations contribute to thermal capacitance ($C \sim T^3$)

Small detectors & low temperatures
=
lower thresholds

Readout Scheme



Small changes in temperature can be captured by **Transition Edge Sensors** (TES), which allow great sensitivity to small temperature depositions.

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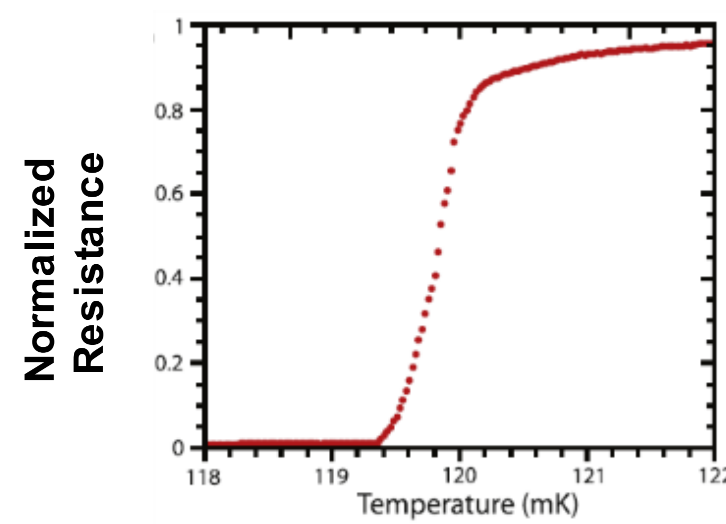
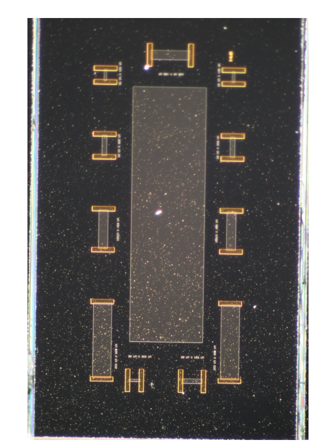
TES Resistance @ Tc





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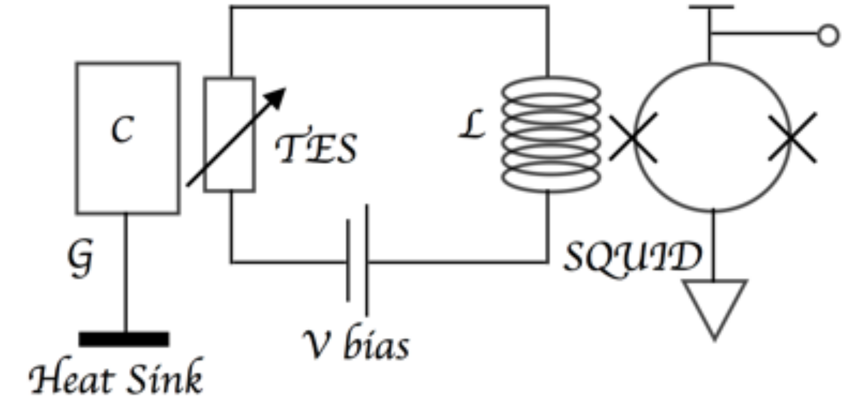

Readout of TES done using **SQUID** amplifiers, quantum-limited magnetometers, ideal for small currents.

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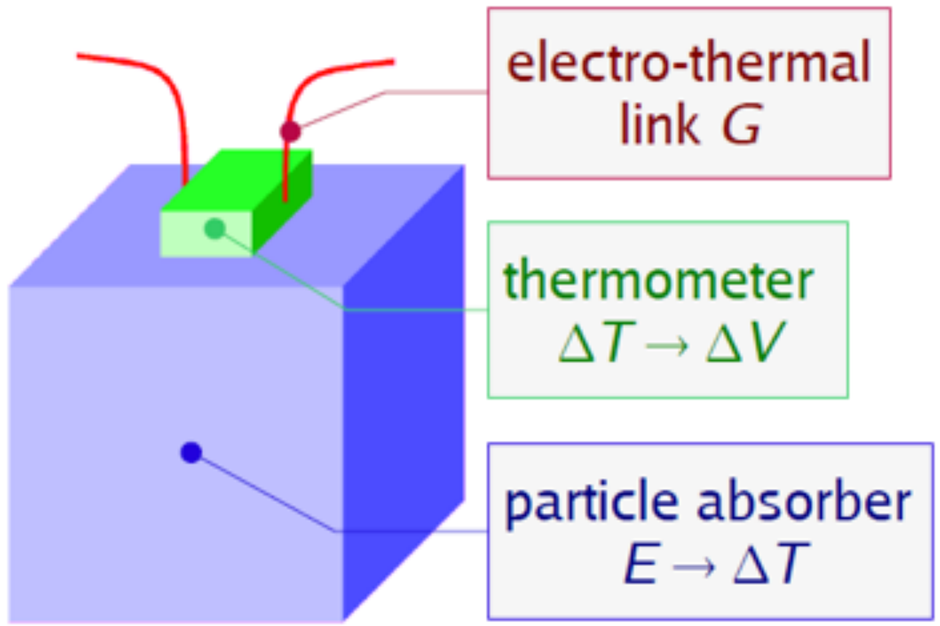

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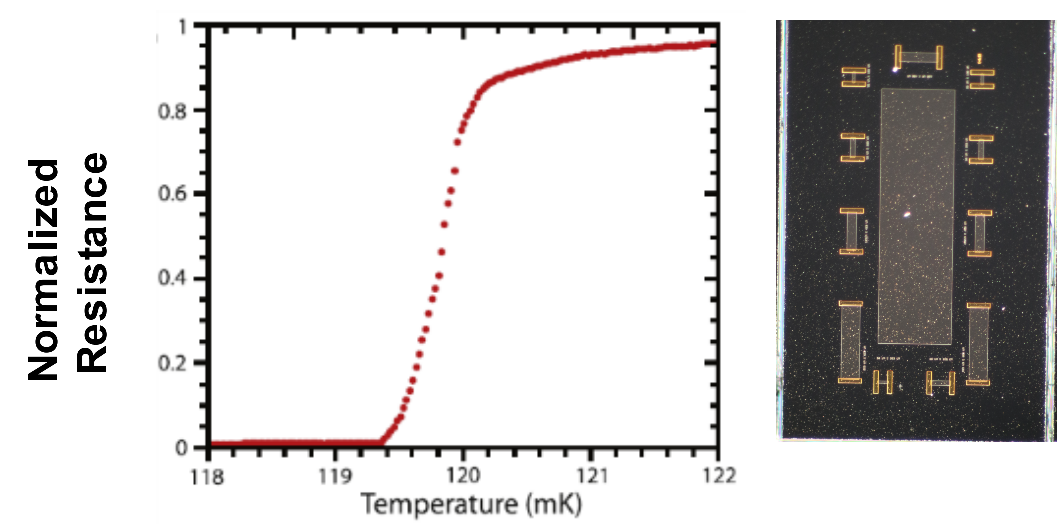
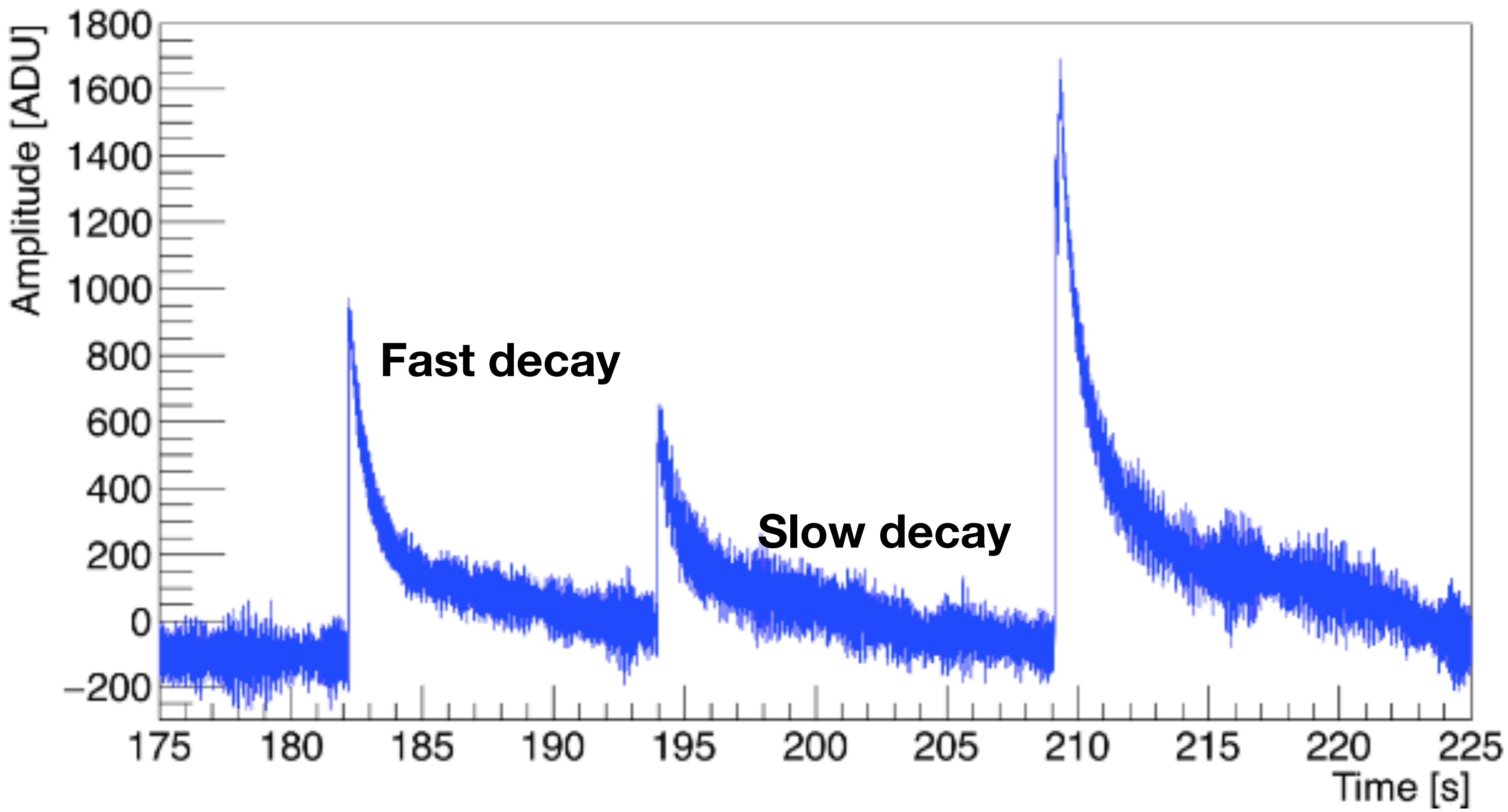


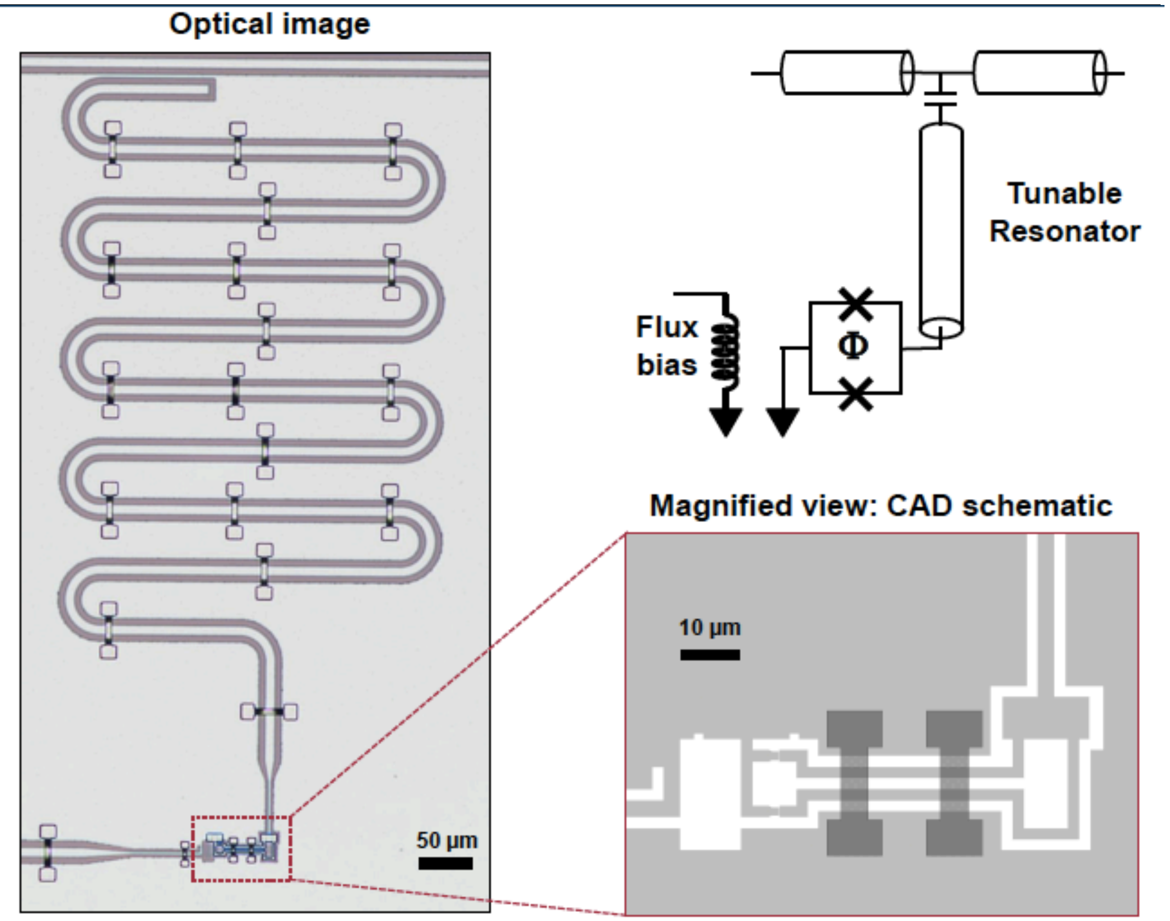
First (and Second) Pulses!



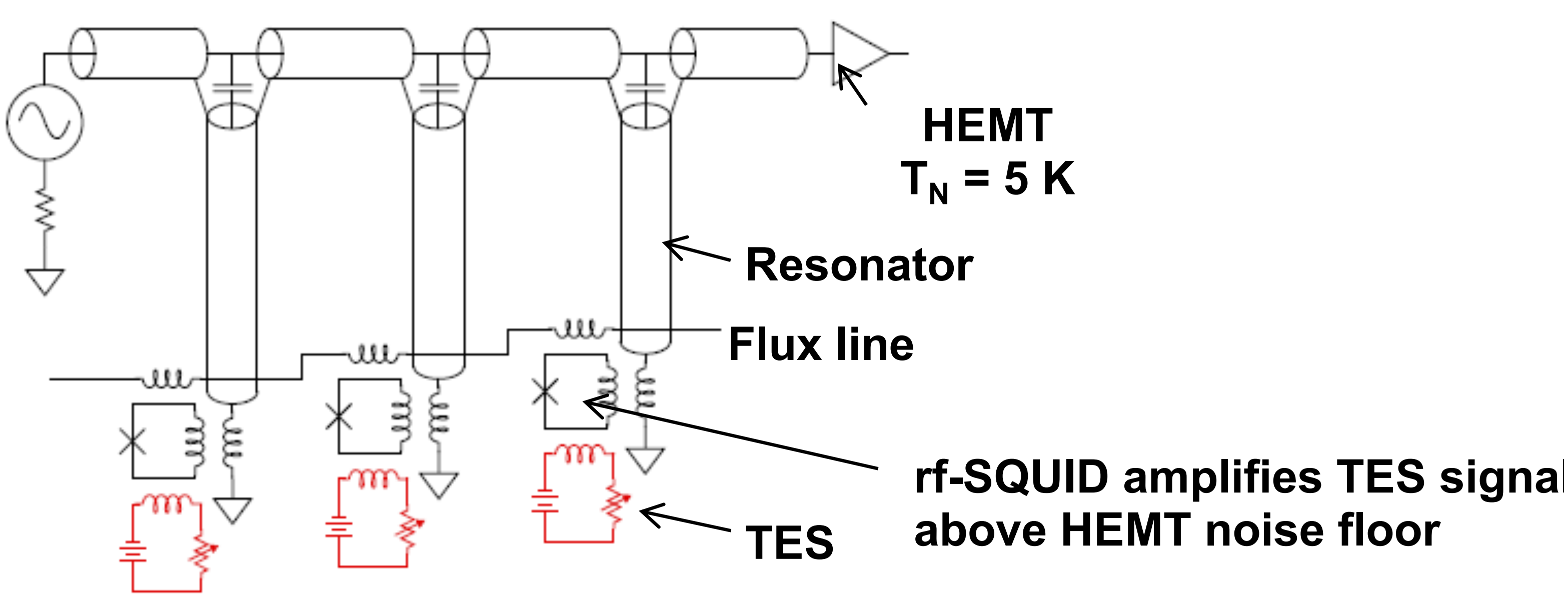
- First zinc crystals cooled to 15 mK and tested. First pulses seen!
- New zinc crystals also tested at cryogenic temperatures. Extremely long pulses with different decay times observed.
- Analysis underway to characterize pulses, energy resolution and particle identification.
- Note: This is thermal (not athermal) readout of pulses.

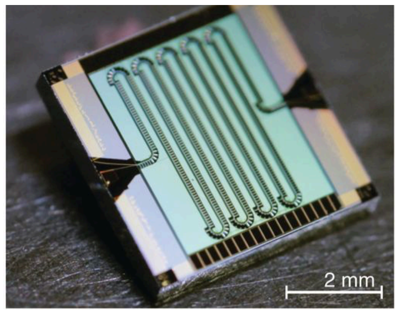
SQUID Readout

- Successfully secured ACC grant with Lincoln Laboratories to work on multiplexing SQUID array.
- Developing RF-SQUIDs (micro-resonators) to read multiple channels with one system.
- Tuned resonators based on transmission line impedance. Each resonator is tuned to a specific frequency. Input current from TES will change resonance and alter transmission parameters.



uMux Schematic





Traveling Wave Parametric Amplifiers

Ricochet @ Chooz

- Considering two possibilities

- ***The Chooz Near Site***
  - Chooz two core reactors (8.25 GW power combined).
  - About 400 meters from the cores with 150 m.w.e. overburden.
  - Almost zero neutron background from reactor. Infrastructure already exists. Existing good relation with power company.
- ***The Very Near Site***
  - Have also looked at location within nuclear complex, 80 meters from the core.
  - No overburden, but 25x more flux.
  - Other near location sites being explored.

The Chooz Reactors

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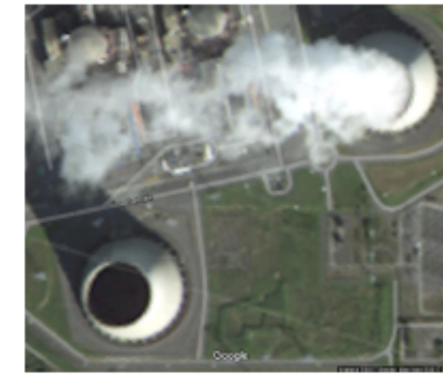
The Chooz Reactors

A decision will be made by the collaboration by fall 2019

And now… The Science

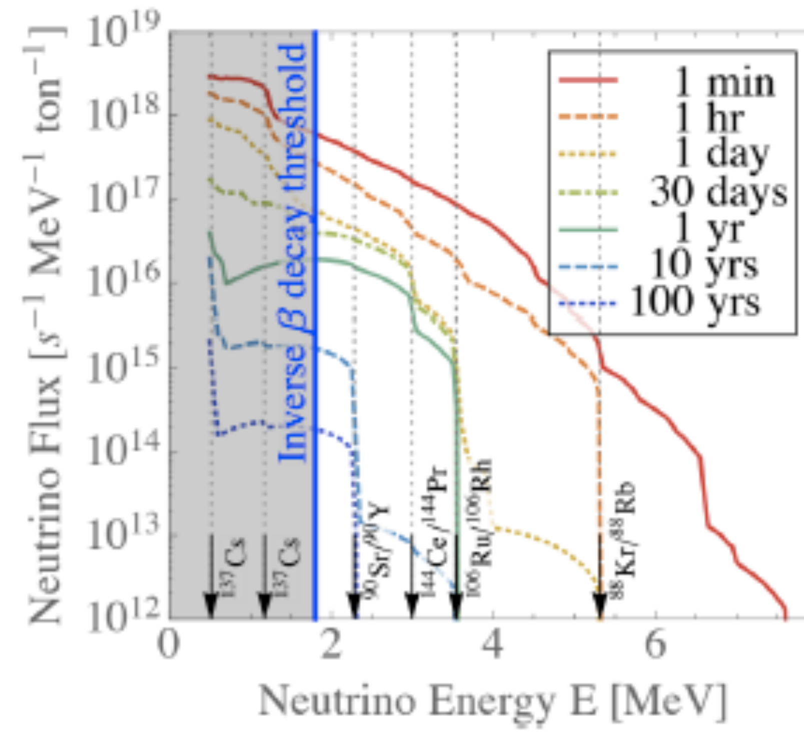


- Using reactor neutrinos for CEvNS is a vector for multiple measurements.

  - Neutrino Magnetic Moment
  - Flavor Changing and Conserving NSI
  - Massive Mediators
  - Nuclear Monitoring.

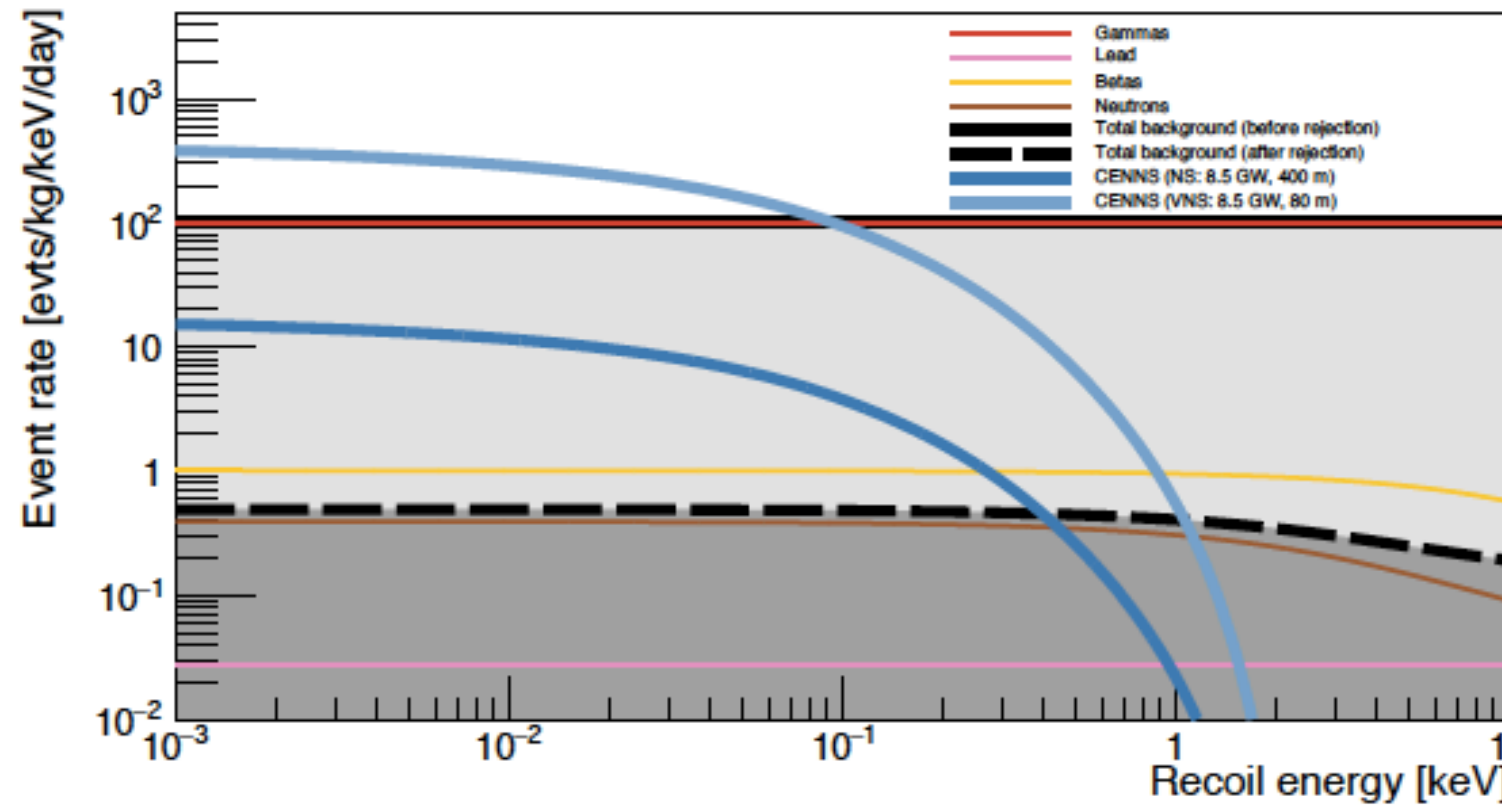
- The case is further strengthened if multiple Z/A targets are used within the same measurement.

- Furthermore, with COHERENT's recent measurement, the risk of the channel not existing has been removed.



Vedran Brdar V, Huber P, and Kopop J arXiv:1606.06309v2 [hep-ph] 20 Jun 2016

Sensitivity & Exposure

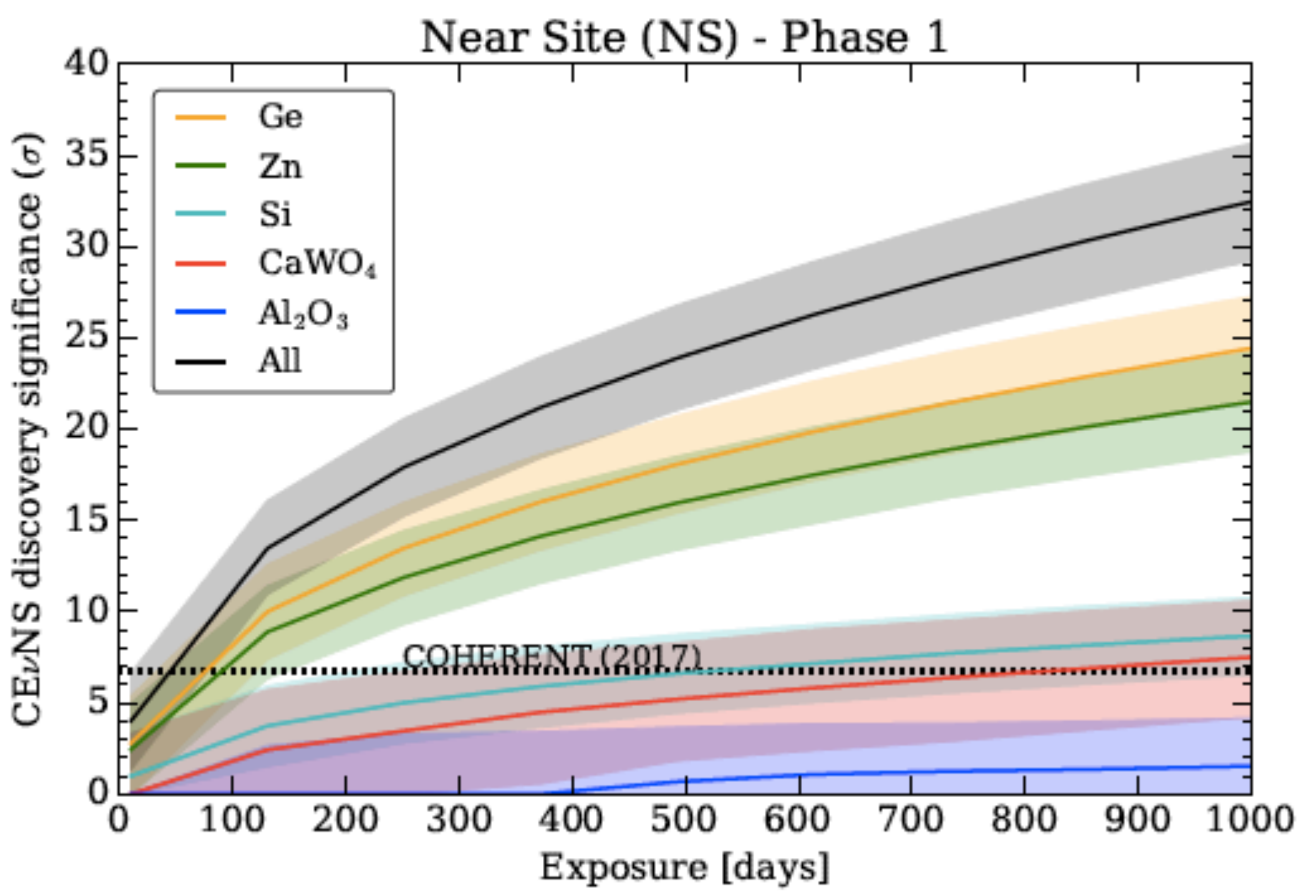


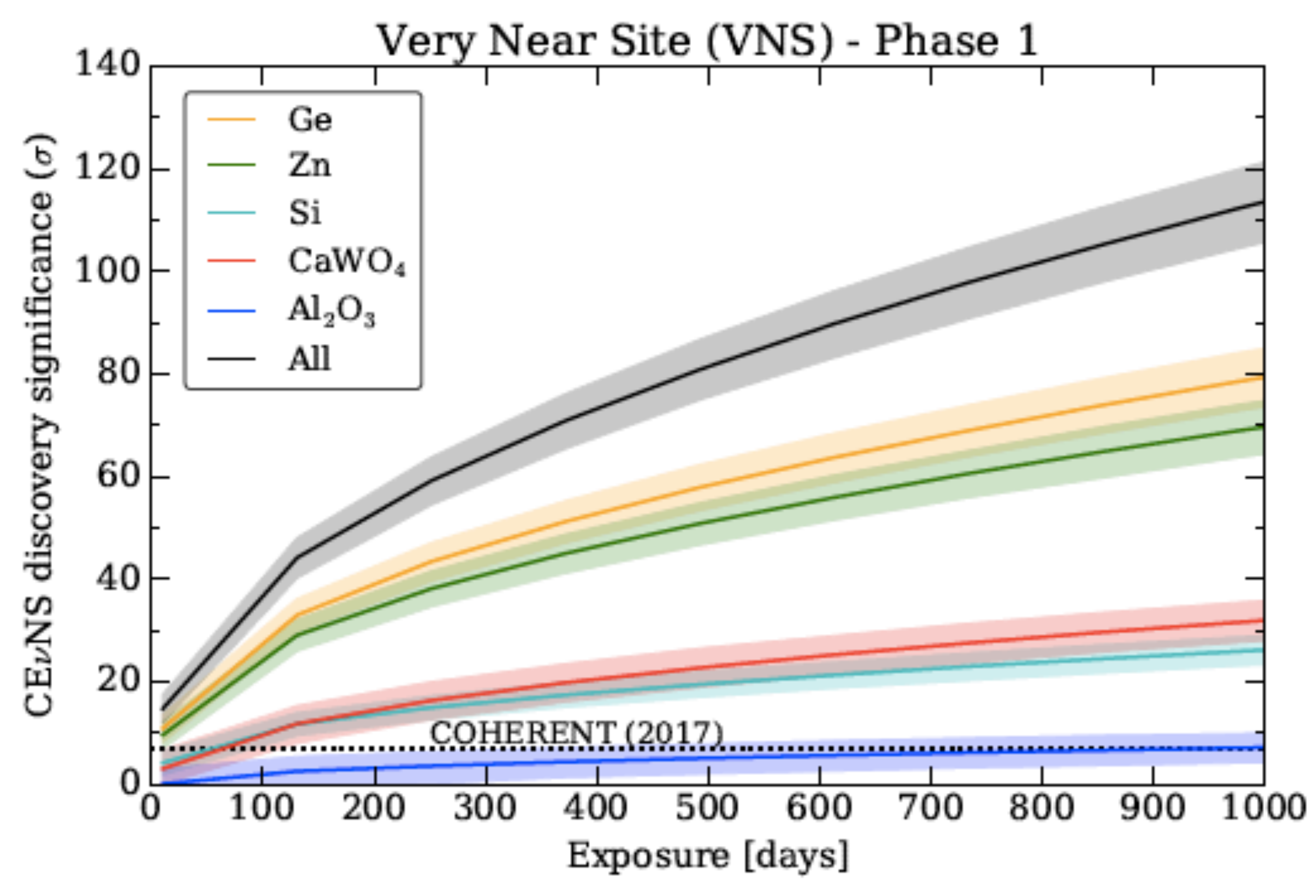
	Phase 1		Phase 2		Background reduction	
Target	E_{th} [eV]	Mass [g]	E_{th} [eV]	Mass [g]	gamma	neutron
Zn	50	500	10	5000	1000	1
Ge	50	500	10	5000	1000	1
Si	50	500	10	5000	1000	1
$CaWO_4$	20	6.84	7	68.4	1000	10
Al_2O_3	20	4.41	4	44.1	1000	10

J. Billard, J. Johnston, B. J. Kavanagh, arXiv:1805.01798

- Paper by Billard, Johnston and Kavanagh explore discovery potential for CEvNS using a reactor as a source.
- Consider a variety of targets and distances to the core.

Sensitivity & Exposure



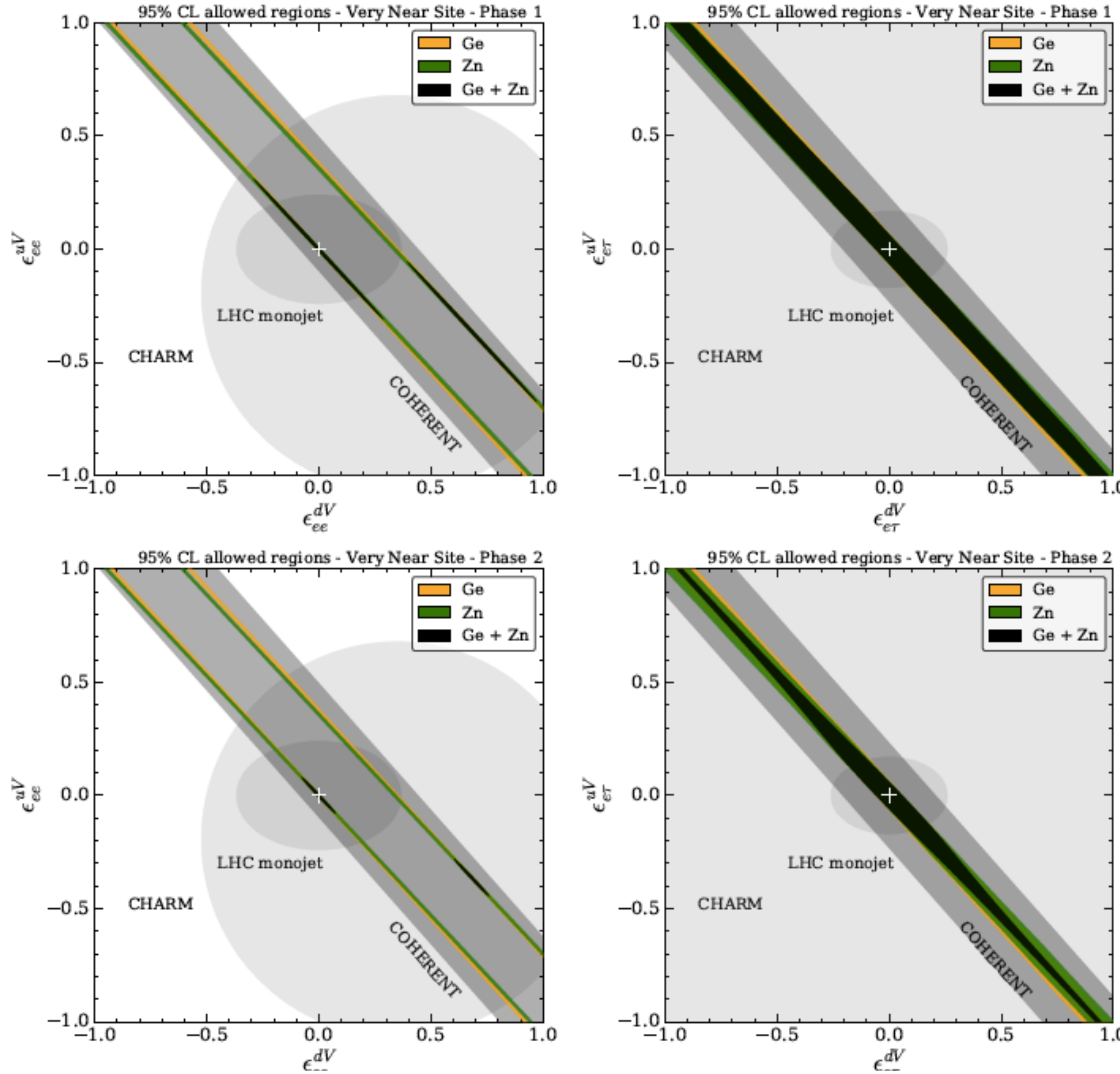


J. Billard, J. Johnston, B. J. Kavanagh, arXiv:1805.01798

- Discovery at the near site (400 m) can take place at 5 sigma with just 100 days of observation.
- At at a very near site of 80 meters, discovery with days.
- Both using reasonable assumptions on backgrounds and target loads.

NSI Reach

- The program also broadens the science reach for non-standard interactions.
- This includes anomalous couplings, as well as general deviations from Standard Model predictions.
- Can also compare directly to electron-PV scattering.



J. Billard, J. Johnston, B. J. Kavanagh, arXiv:1805.01798

$$\mathcal{A}_{(e,e)} = \frac{\left(\frac{d\sigma}{d\Omega}\right)^{h=+1} - \left(\frac{d\sigma}{d\Omega}\right)^{h=-1}}{\left(\frac{d\sigma}{d\Omega}\right)^{h=+1} + \left(\frac{d\sigma}{d\Omega}\right)^{h=-1}}$$

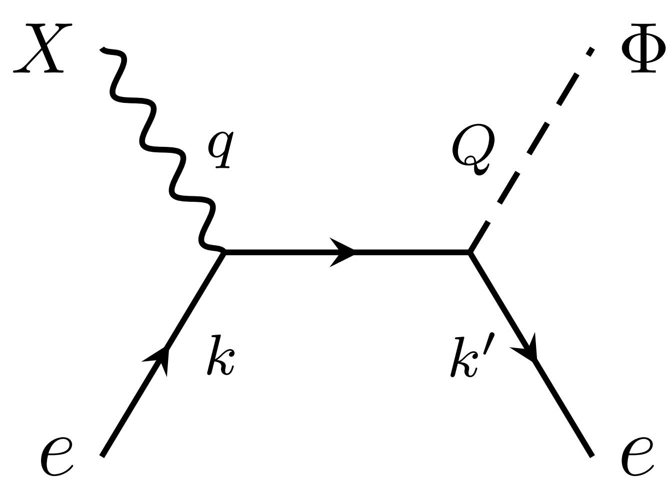
$$\left(\frac{d\sigma}{d\Omega}\right)_{(\nu,\nu)} = \mathcal{A}^2_{(e,e)} \left(\frac{d\sigma}{d\Omega}\right)_{(e,e)}$$

Parity violating asymmetry

ν-e Correspondence

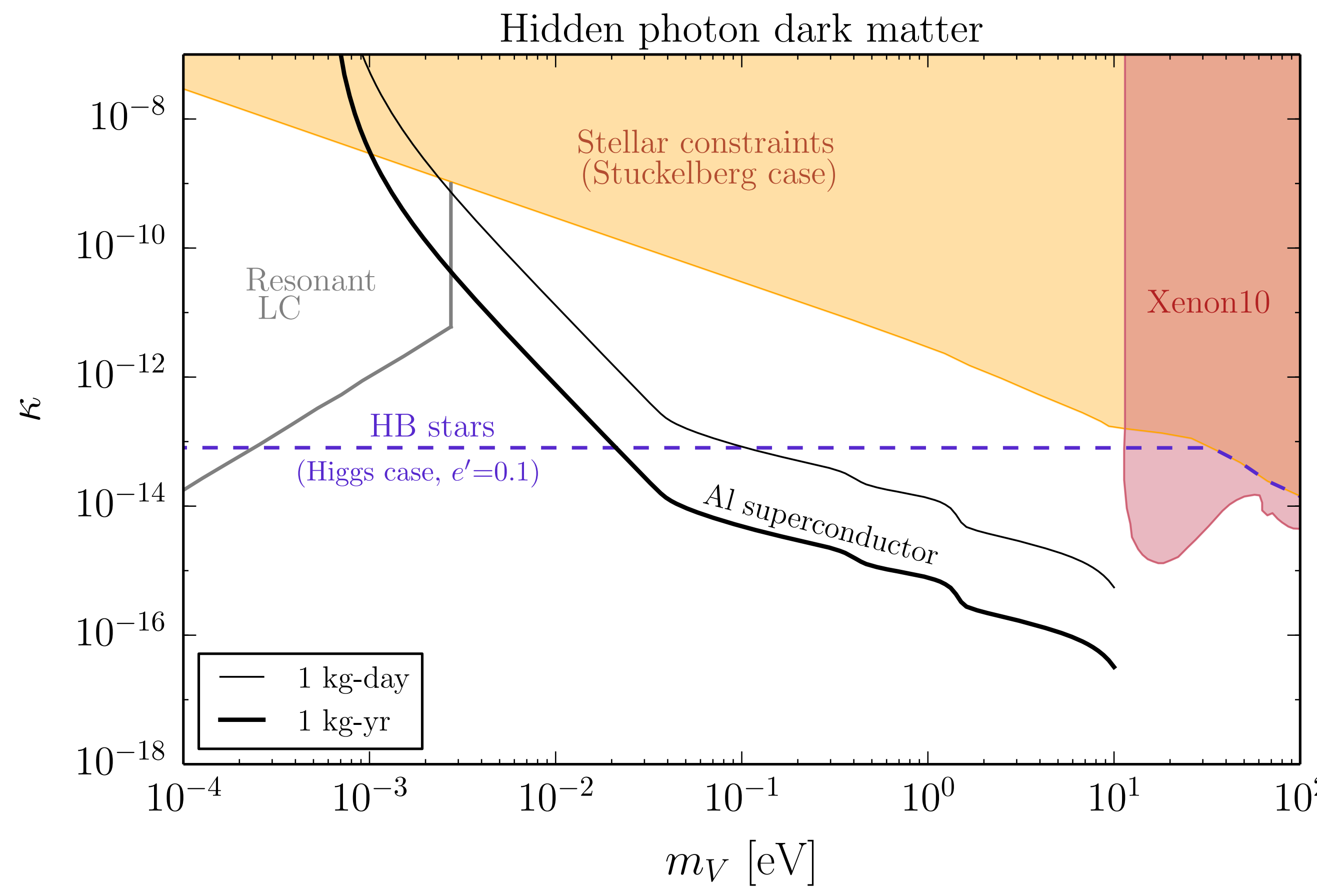
How Else Can We Use Superconductors?

Ronit Hochberg, Tongyan Lin, and Kathryn Zurek recently proposed also using metallic superconductors to probe bosonic dark matter at very low mass scales.



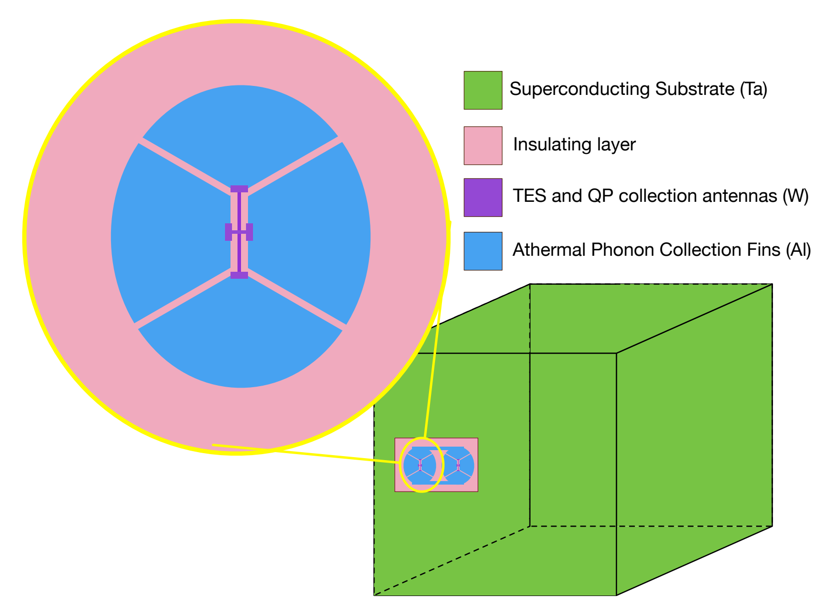
Takes advantage of long quasi-particle lifetimes and thermal phonon emissions (and very small s.c. gap energies) to see low energy interactions.

Mechanism for detection very similar to Zn crystals; our crystals can also be explored for this purpose.

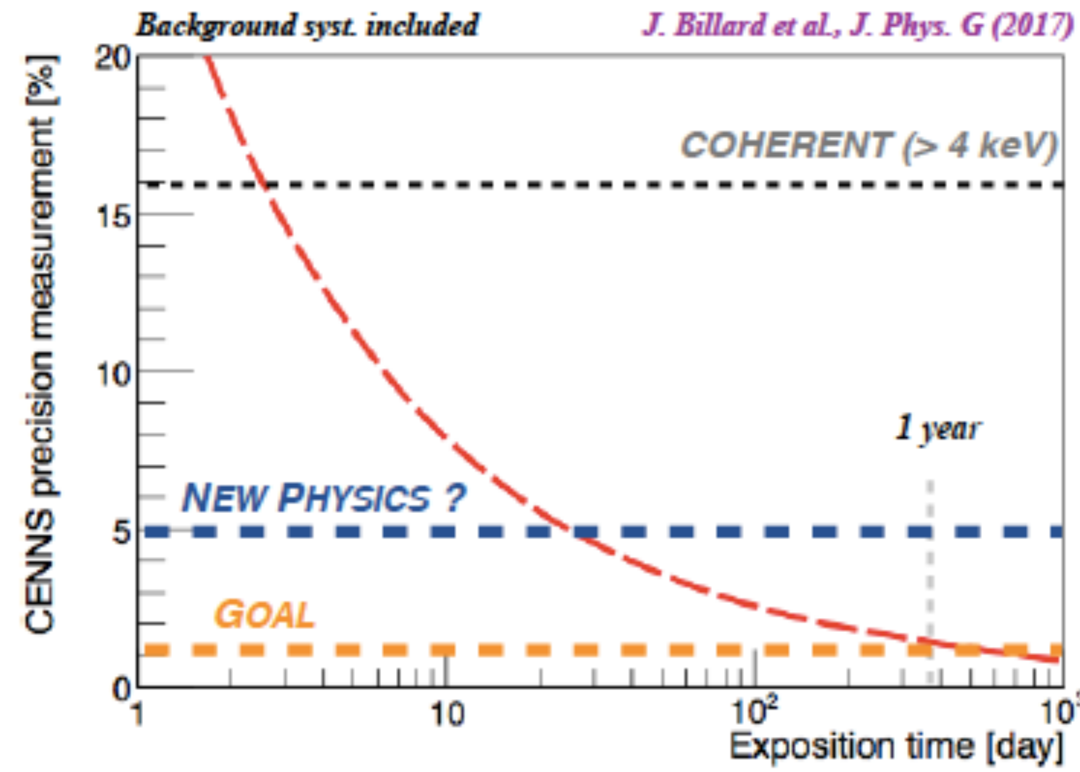


R.Hochberg, T. Lin, and K. Zurek

arXiv:1604.06800v1 [hep-ph]



Summary



After forty years, we are finally at the point where coherent neutrino scattering is detectable. This opens a myriad of doors in the ability to explore new physics and even in applications.

Ricochet is quickly building as an experiment with fast sensitivity to first CEvNS detection once installed at the Chooz near site using promising and proven bolometric technologies.

Could open the the door for a wide range of physics beyond the Standard Model.

Summary

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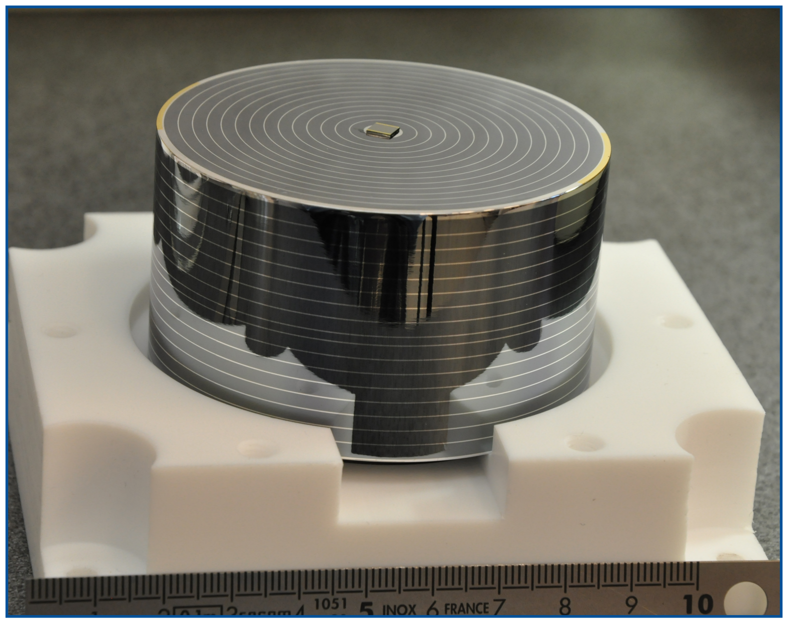
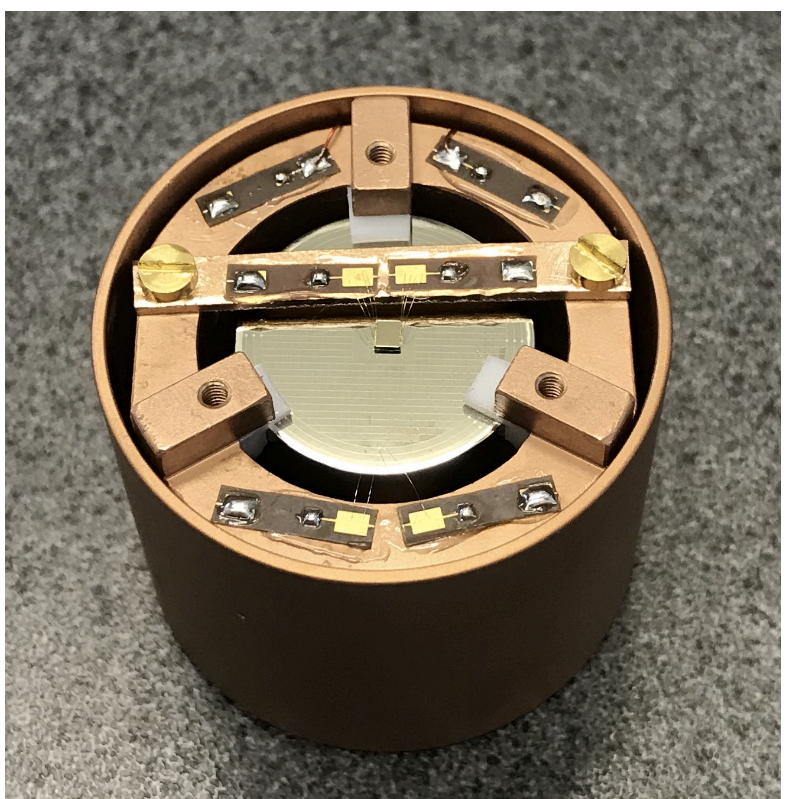
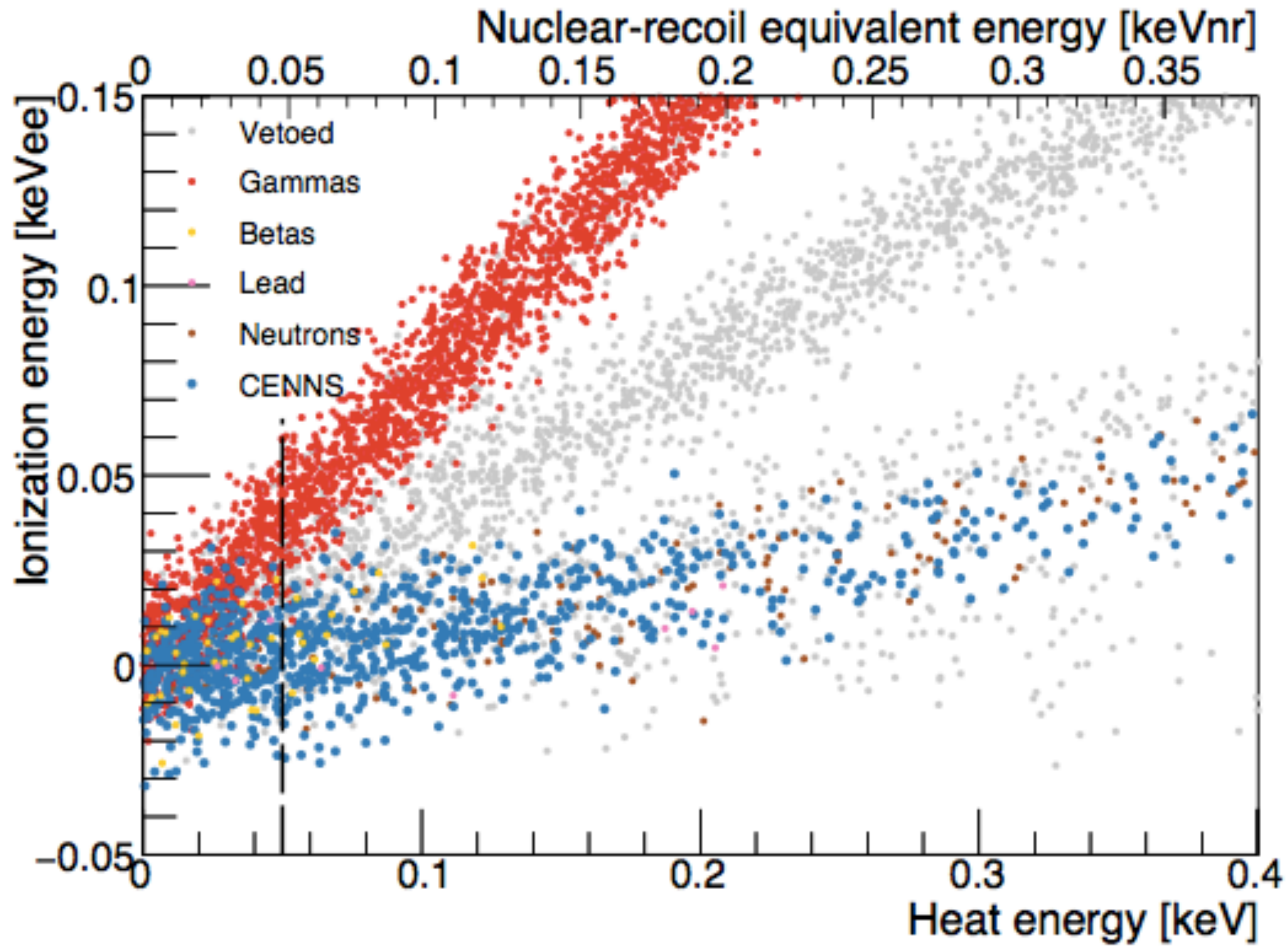
THANKS FOR YOUR ATTENTION

Repurposing DM Detectors







Germanium Detectors:

Separation of recoil from electromagnetic events using **heat** and **charge** signatures.

New 32 gram-scale detector now reach 50 eV threshold.

See talk on Cryocube talk during this workshop.