RICOCHET

Probing Reactor Neutrinos Through Coherence

Enectalí Figueroa-Feliciano
Northwestern

RICOCHET

Science

Detectors

Location

RICOCHET

*~~**Science**~~*

Detectors

Location

RICOCHET

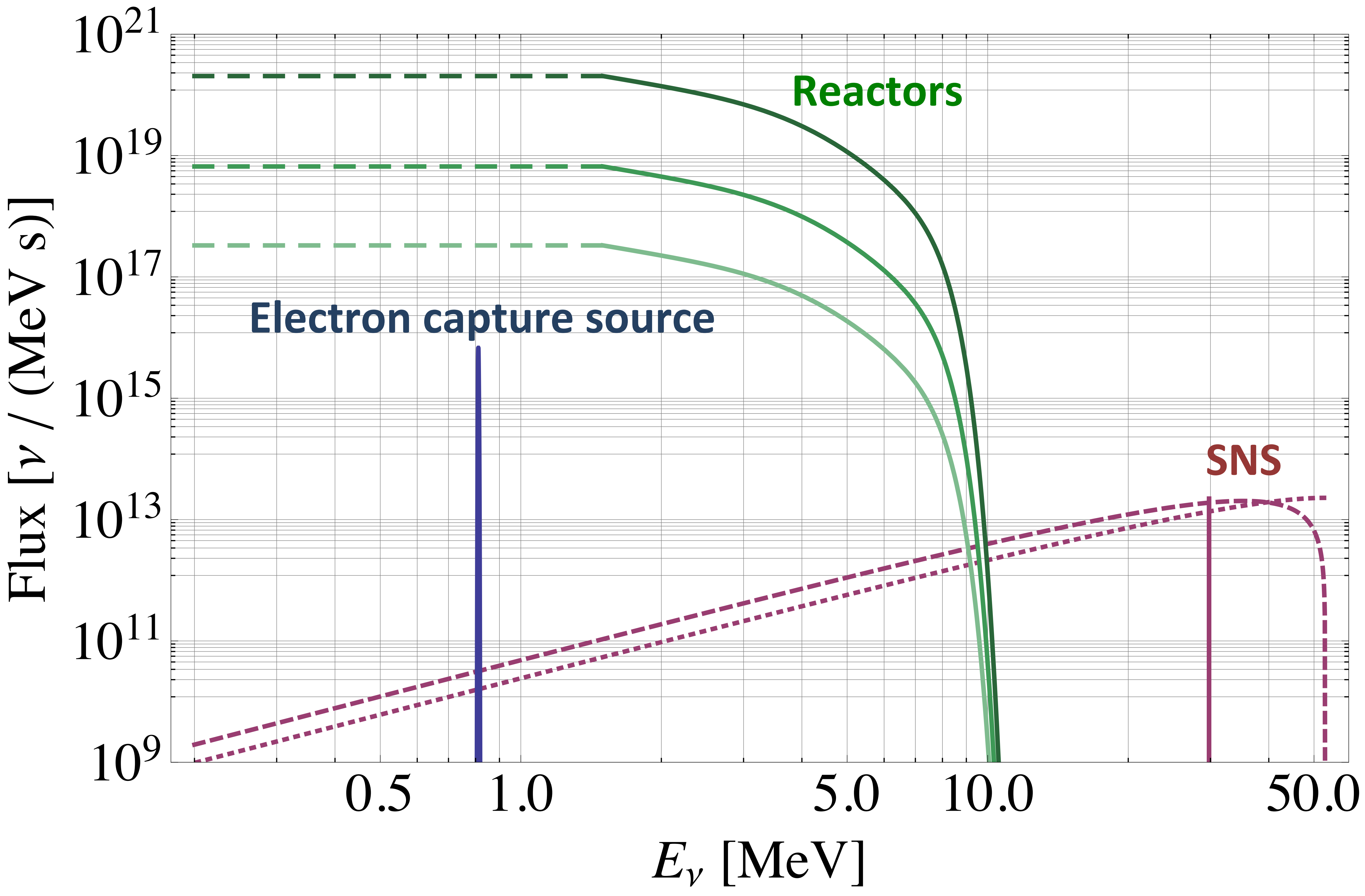
A new experiment is being assembled to demonstrate the technology.

Partnership between US and France to study neutrinos from nuclear reactors.

MIT IPNL Northwestern WISCONSIN CSNSM LPSC Grenoble

Neutrino Sources

- A variety of sources trade off flux, energy and knowledge of spectrum.



Sources	Pros	Cons
Radioactive Sources (Electron Capture)	Mono-energetic, can place detector < 1m from source, ideal for sterile neutrino search	< 1 MeV energies require very low (~10 eVnr) thresholds, limited half-life, costly
Nuclear Reactors	Free*, highest flux	Spectrum not well known below 1.8 MeV, site access can be difficult, potential neutron background
Spallation/Decay at Rest	Higher energies can use higher detector thresholds, timing can cut down backgrounds significantly	Prompt neutron flux; large shielding or distances needed

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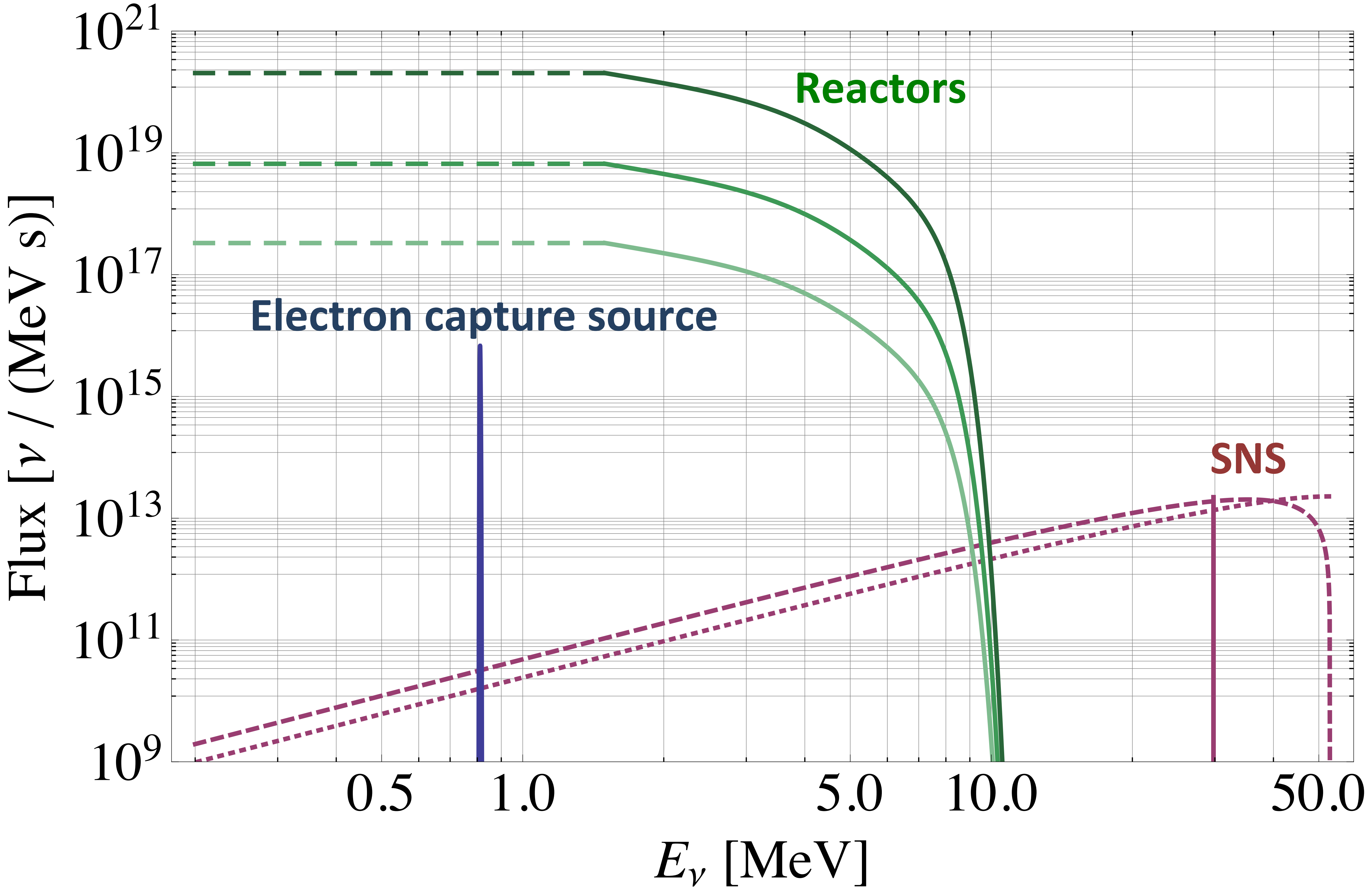

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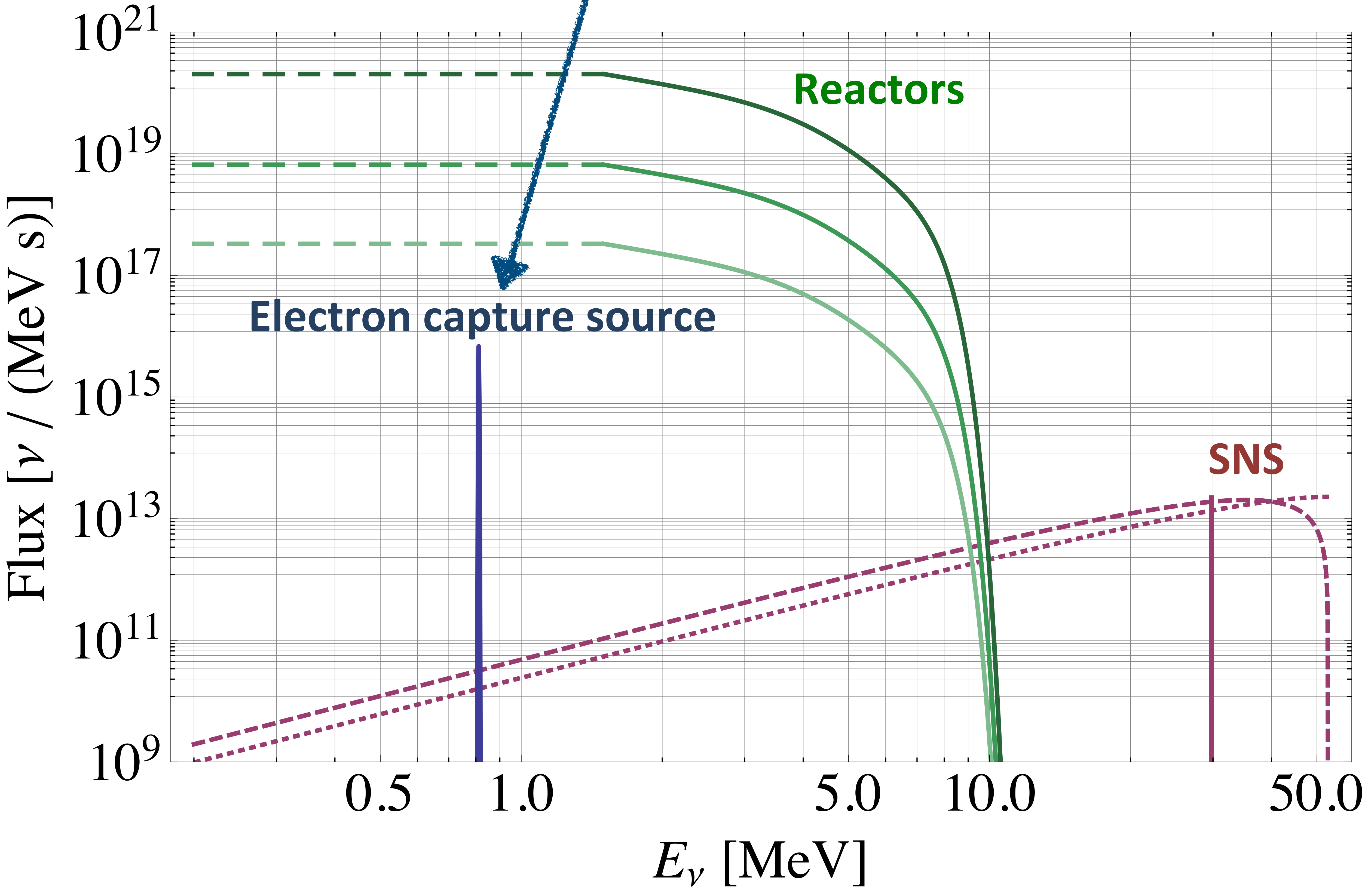
SEE NEXUS POSTER BY TOM REN



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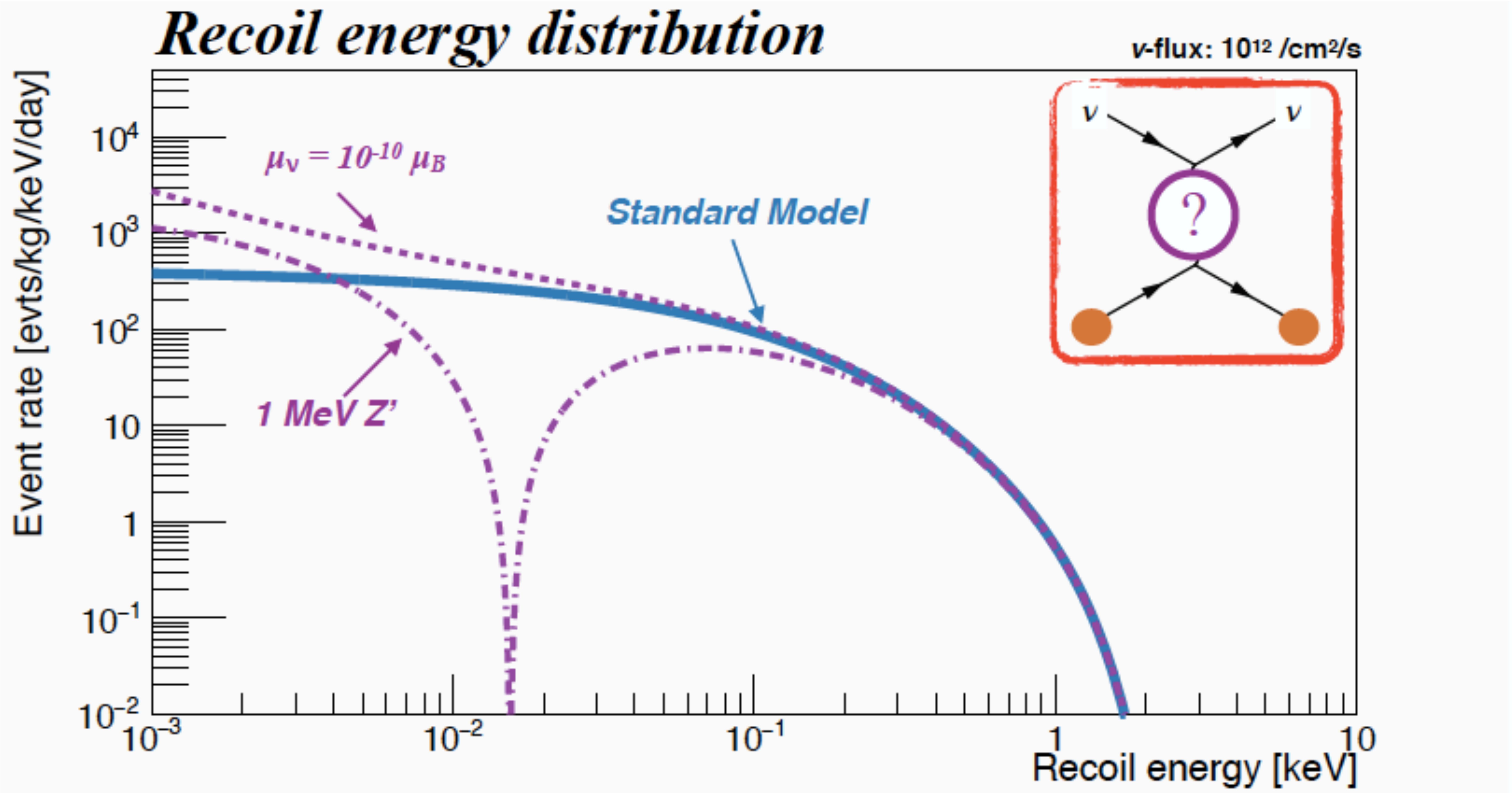
Requirement for Low Thresholds



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

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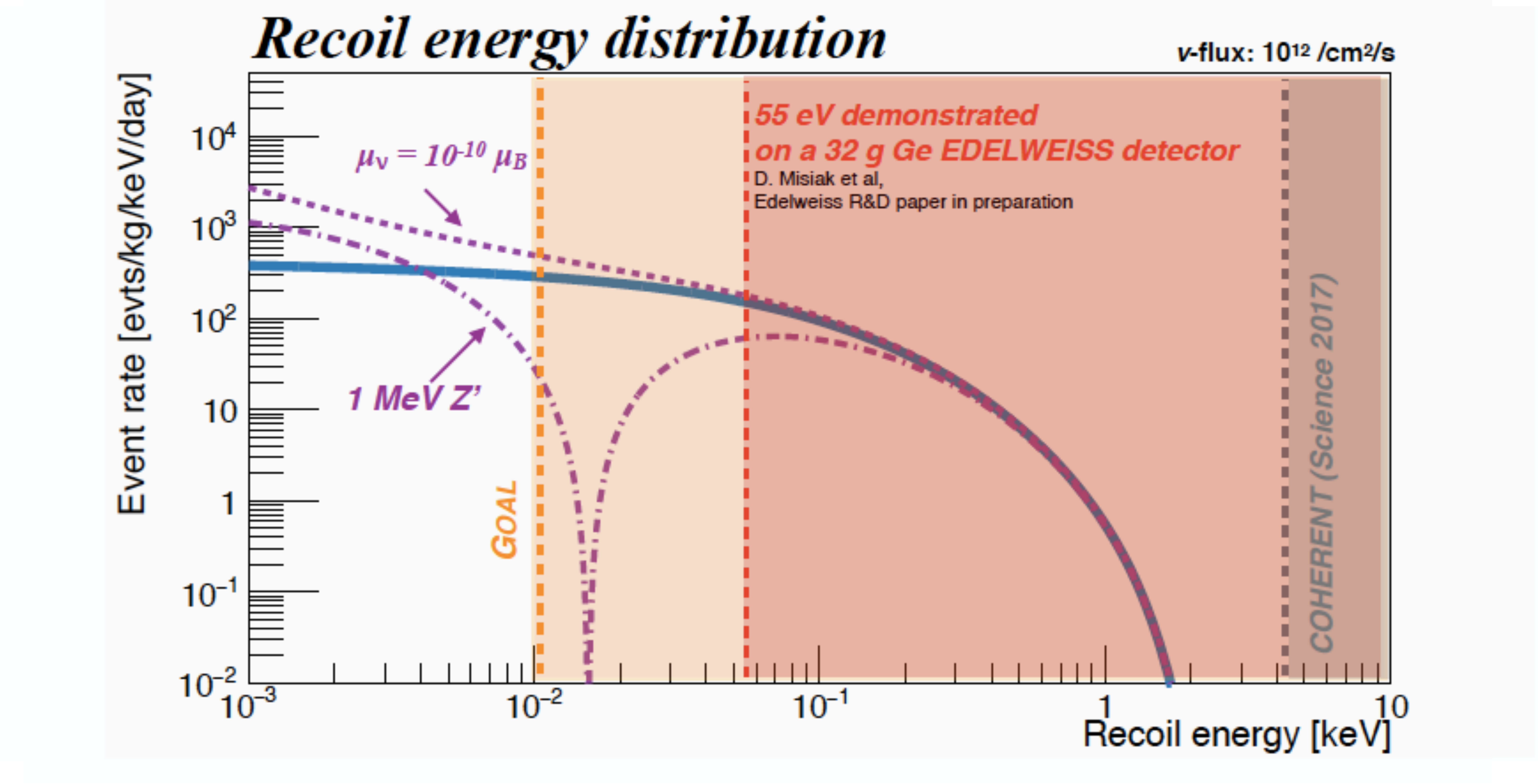

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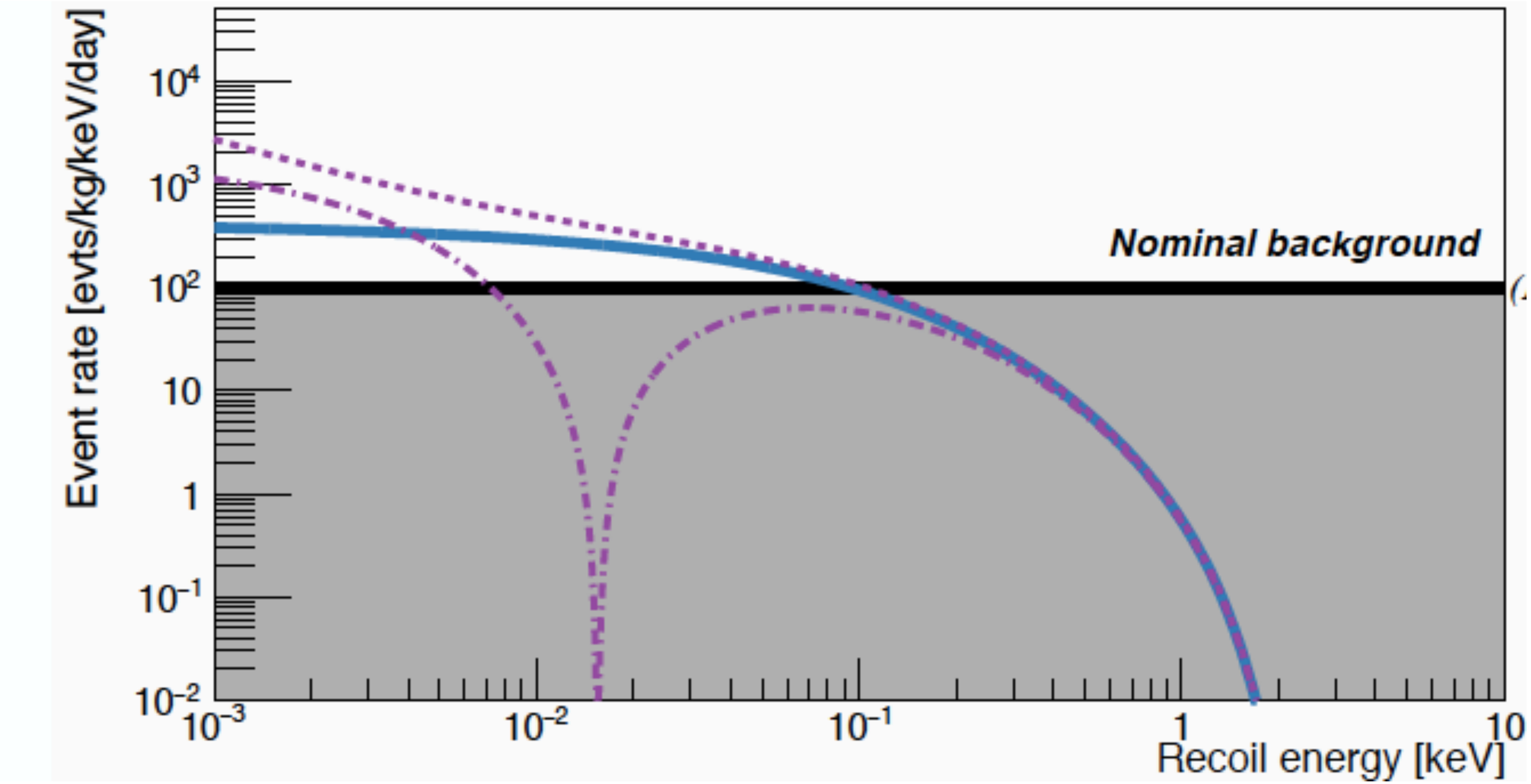
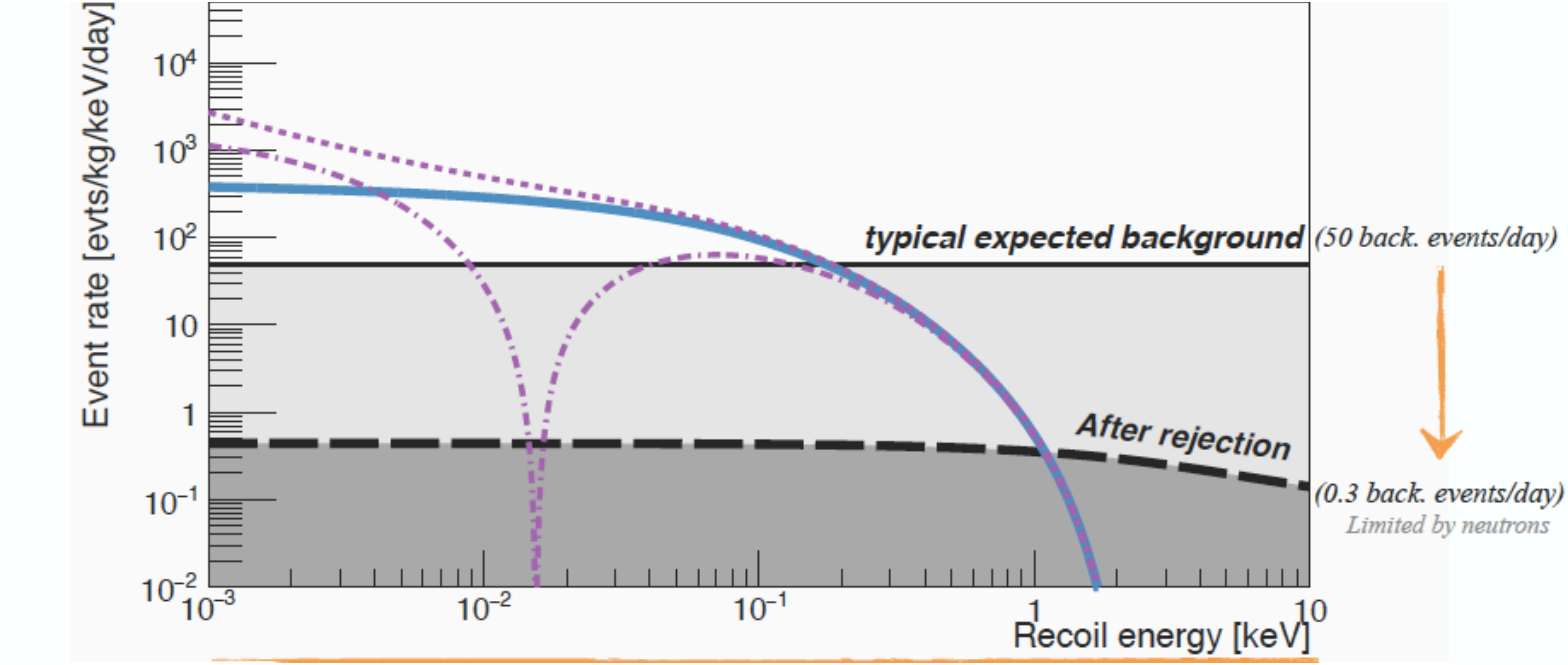
Requirement for Low Backgrounds



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

Requirement for Low Backgrounds



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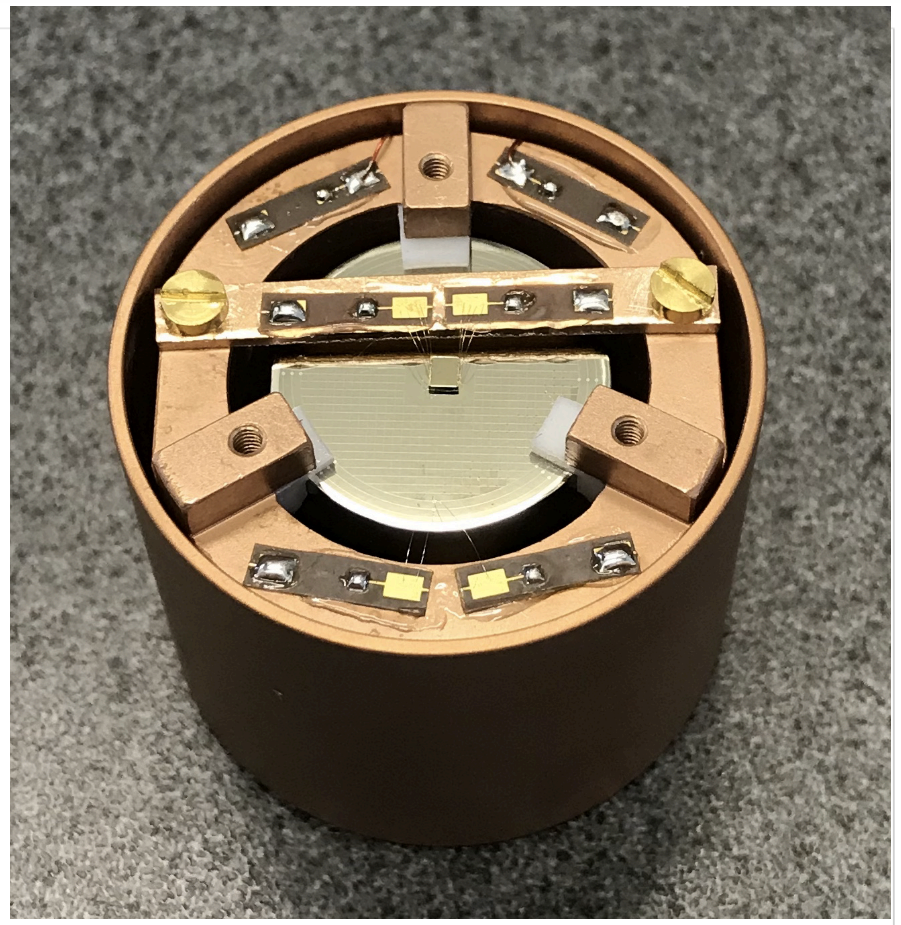
A Detector Wish List…

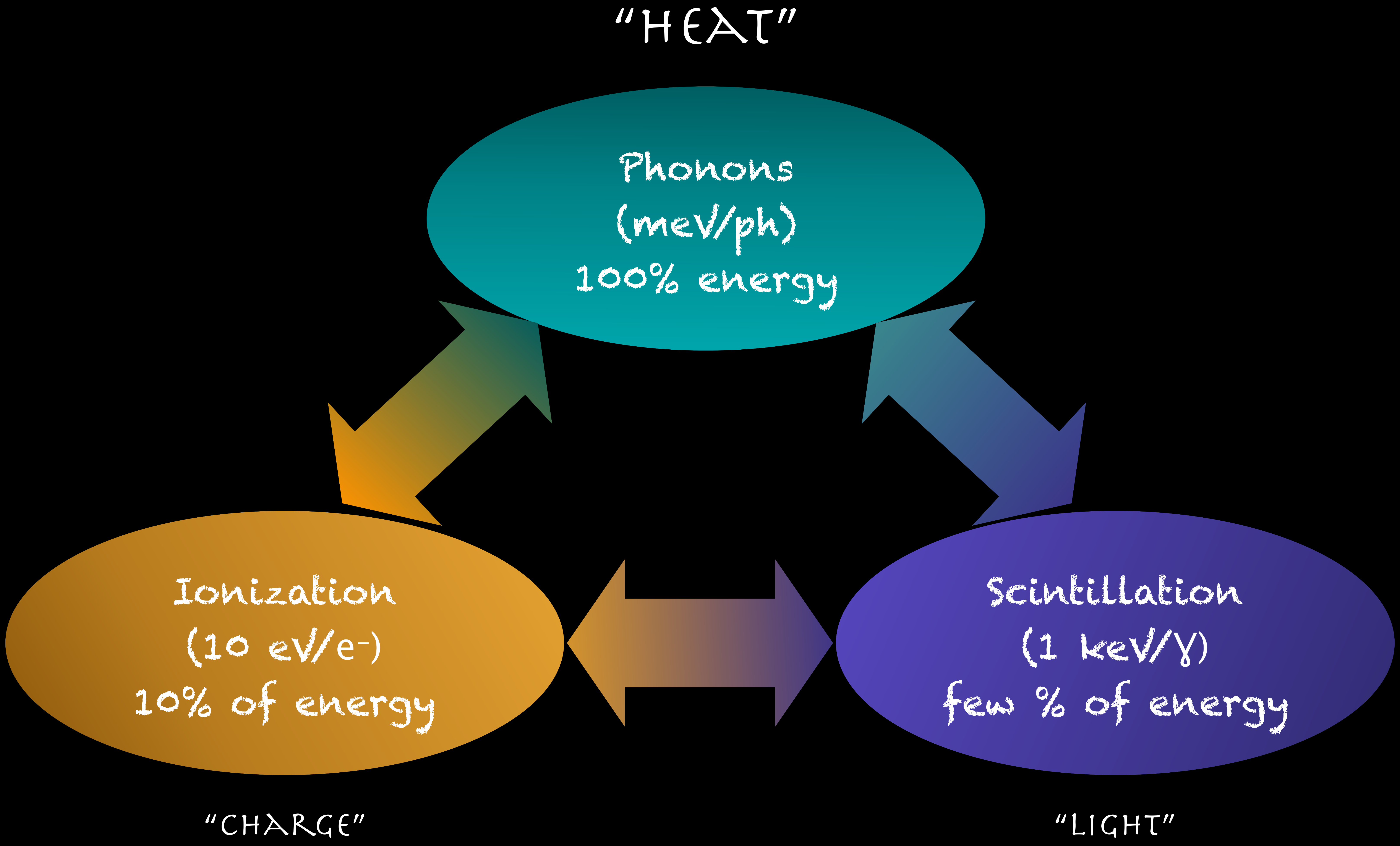


(1) VERY LOW ENERGY THRESHOLDS:	O(~10 eV)
(2) ELECTROMAGNETIC BACKGROUND REJECTION:	> 10^3
(3) SIGNIFICANT TARGET MASS:	~ 1 Kg (AND SCALABLE)
(4) TARGET COMPLEMENTARITY:	Ge (SEMI-) AND Zn (SUPER-) CONDUCTORS

…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

Different Approaches to Detection



"HEAT"

Phonons
(meV/ph)
100% energy

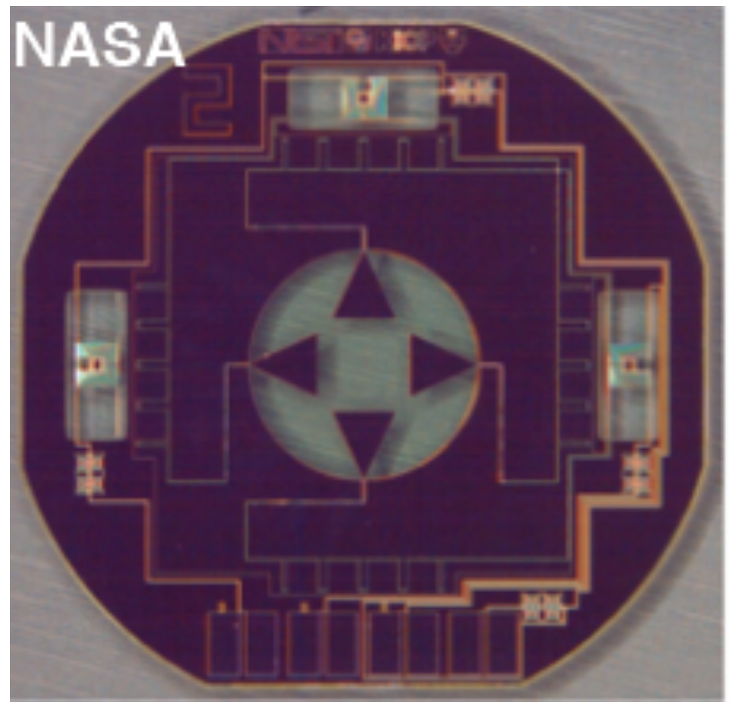
Ionization
(10 eV/e-)
10% of energy

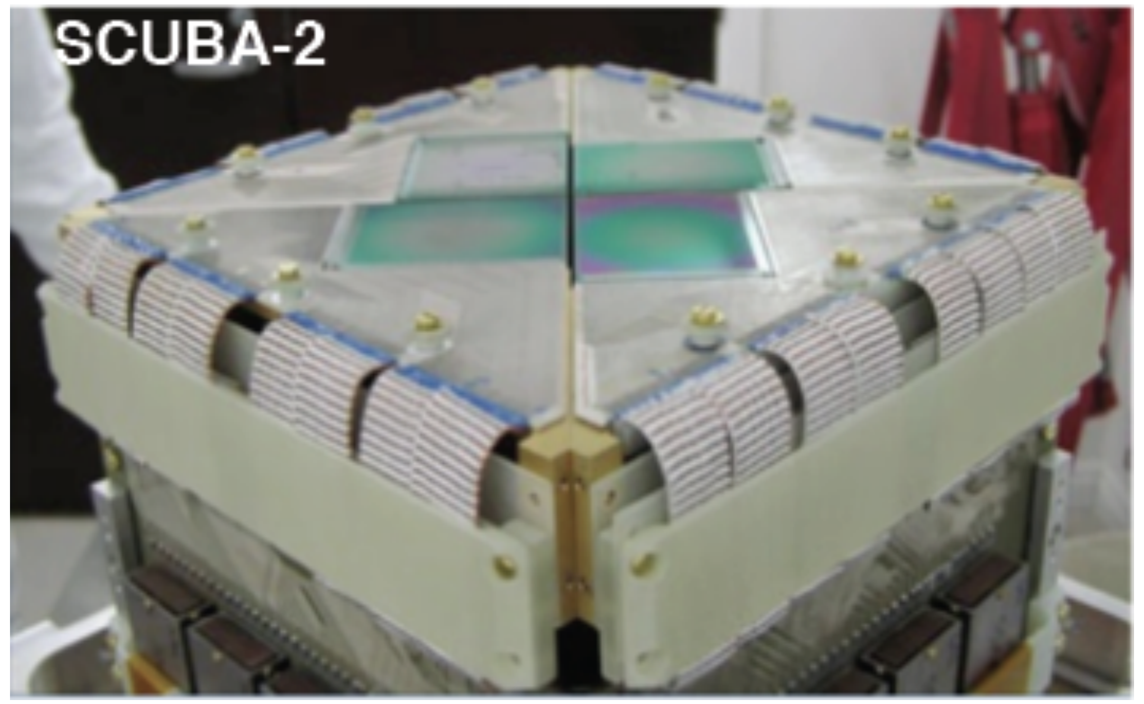
Scintillation
(1 keV/γ)
few % of energy

"CHARGE"

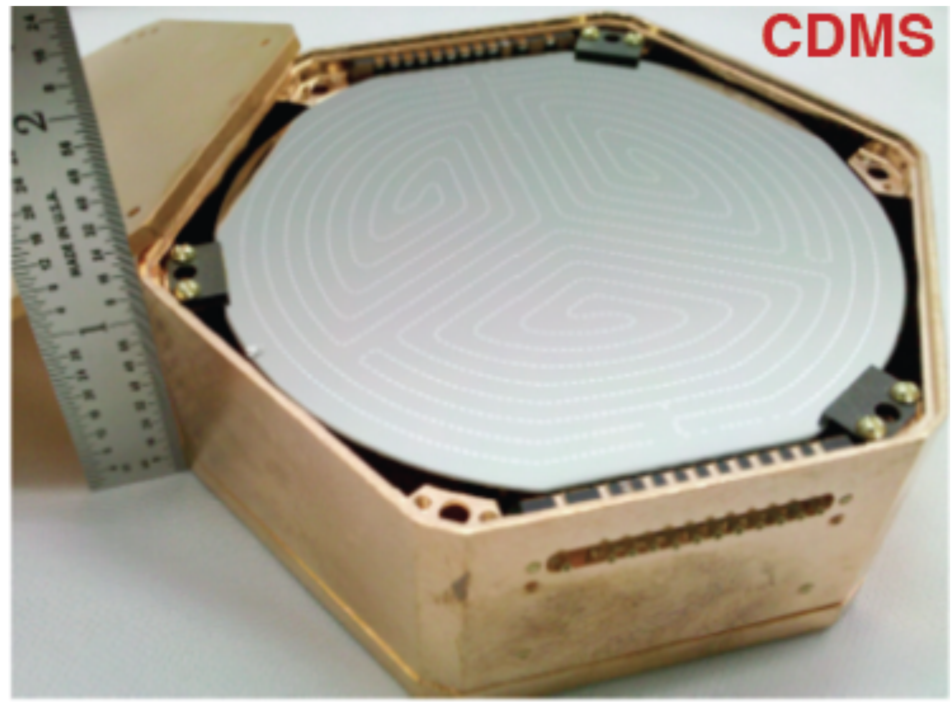
"LIGHT"

Where Phonon Technology is Used

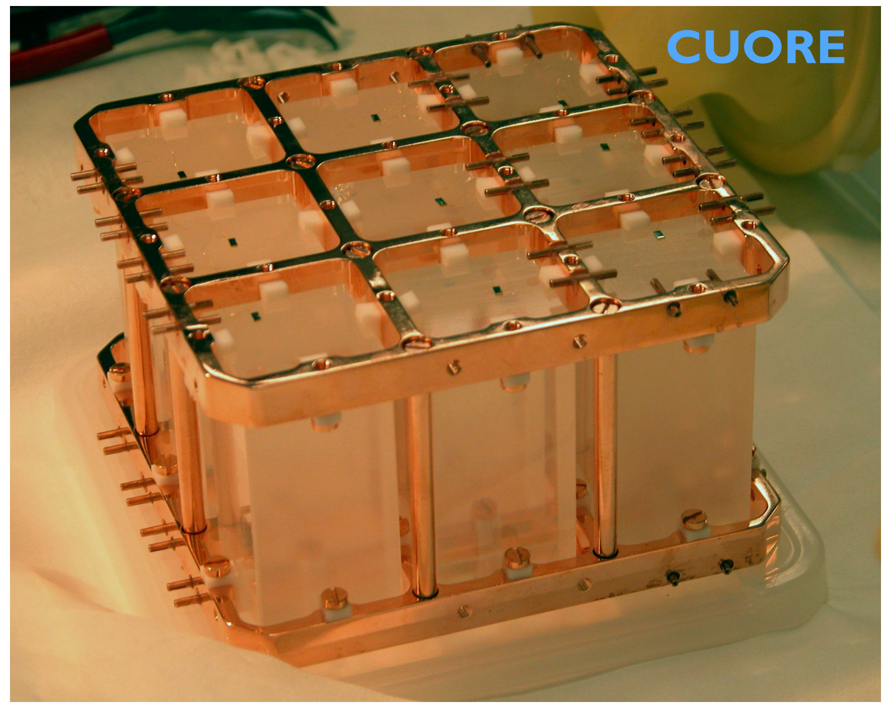




CMB, Infrared detection



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* readout to reach low threshold, with eventual goal of reaching 10 eV recoil threshold.

RICOCHET

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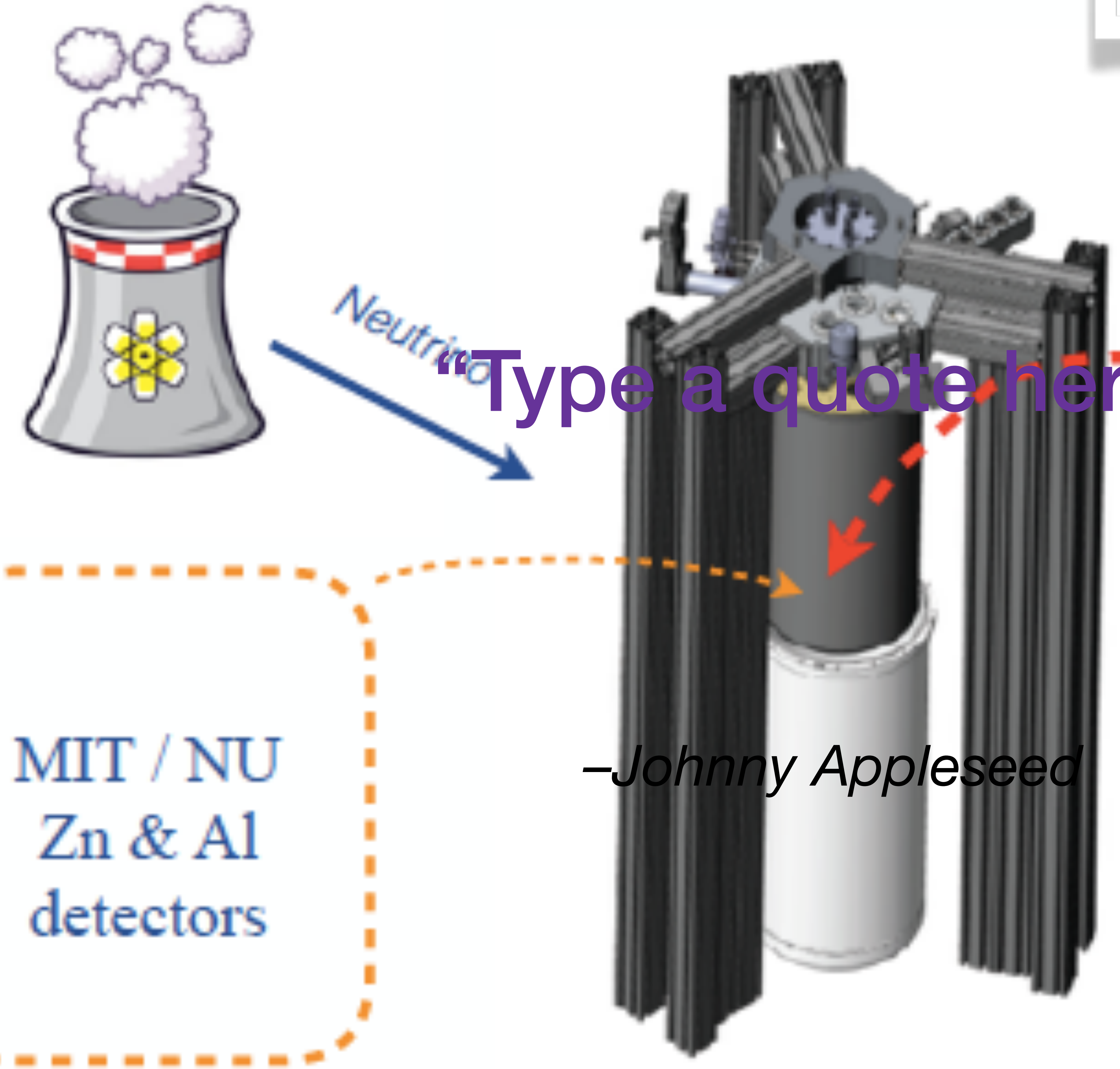


"Type a quote here."

–Johnny Appleseed

Q-Array
Zinc
Superconducting bolometers

MIT / NU
Zn & Al
detectors

CRYOCUBE
Ge & Zn (& Si?)

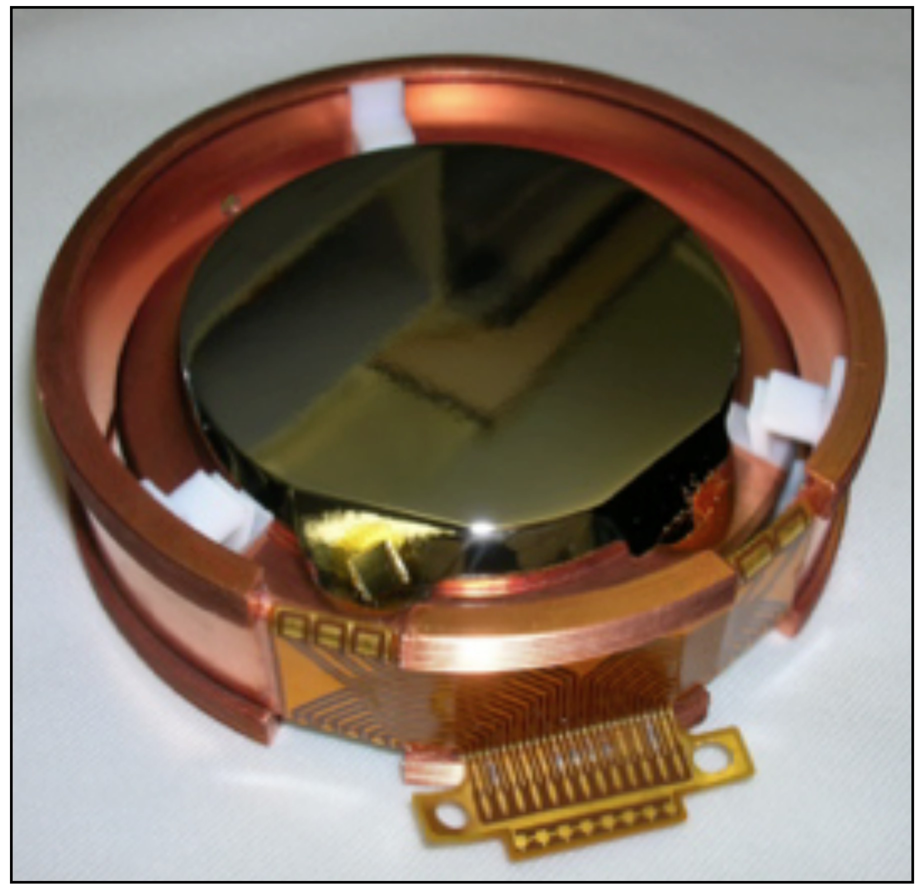
erc cnrs IN2P3

``The first low energy kg-scale CEvNS neutrino observatory combining different targets and different bolometric technologies"

What Kind of Detectors to Use?

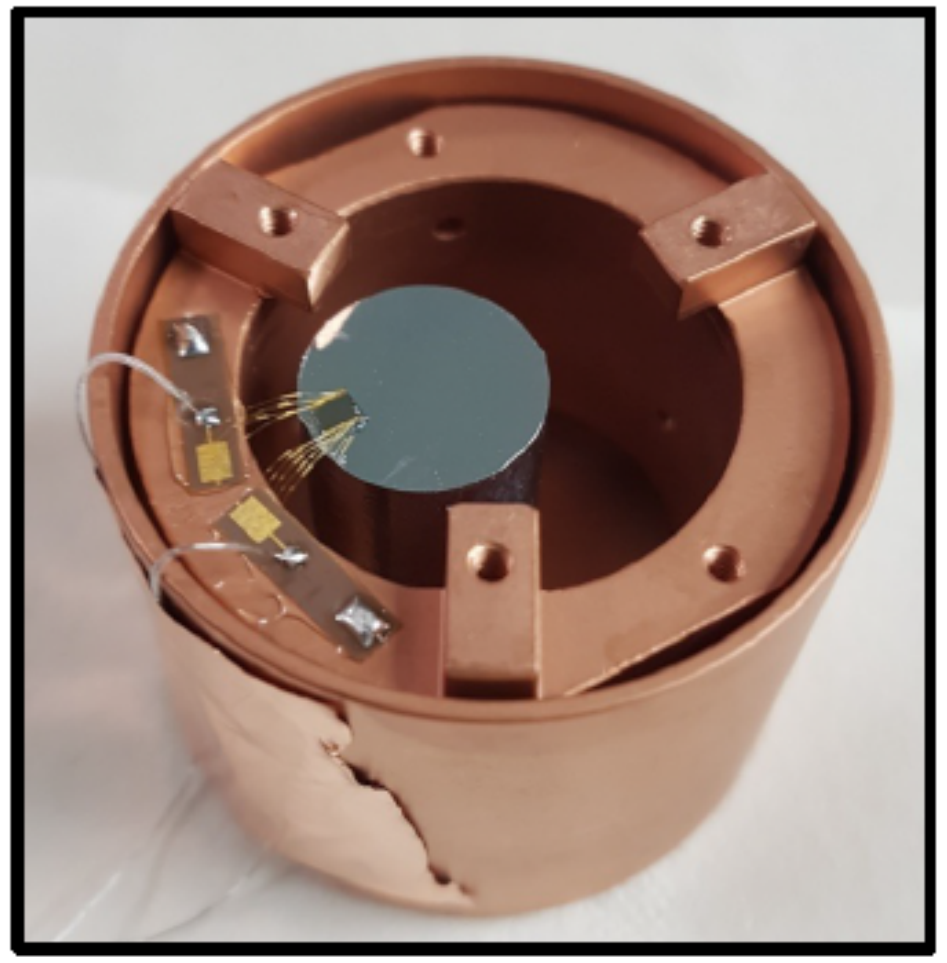
Leverage two technologies that are used by both the US and French groups.

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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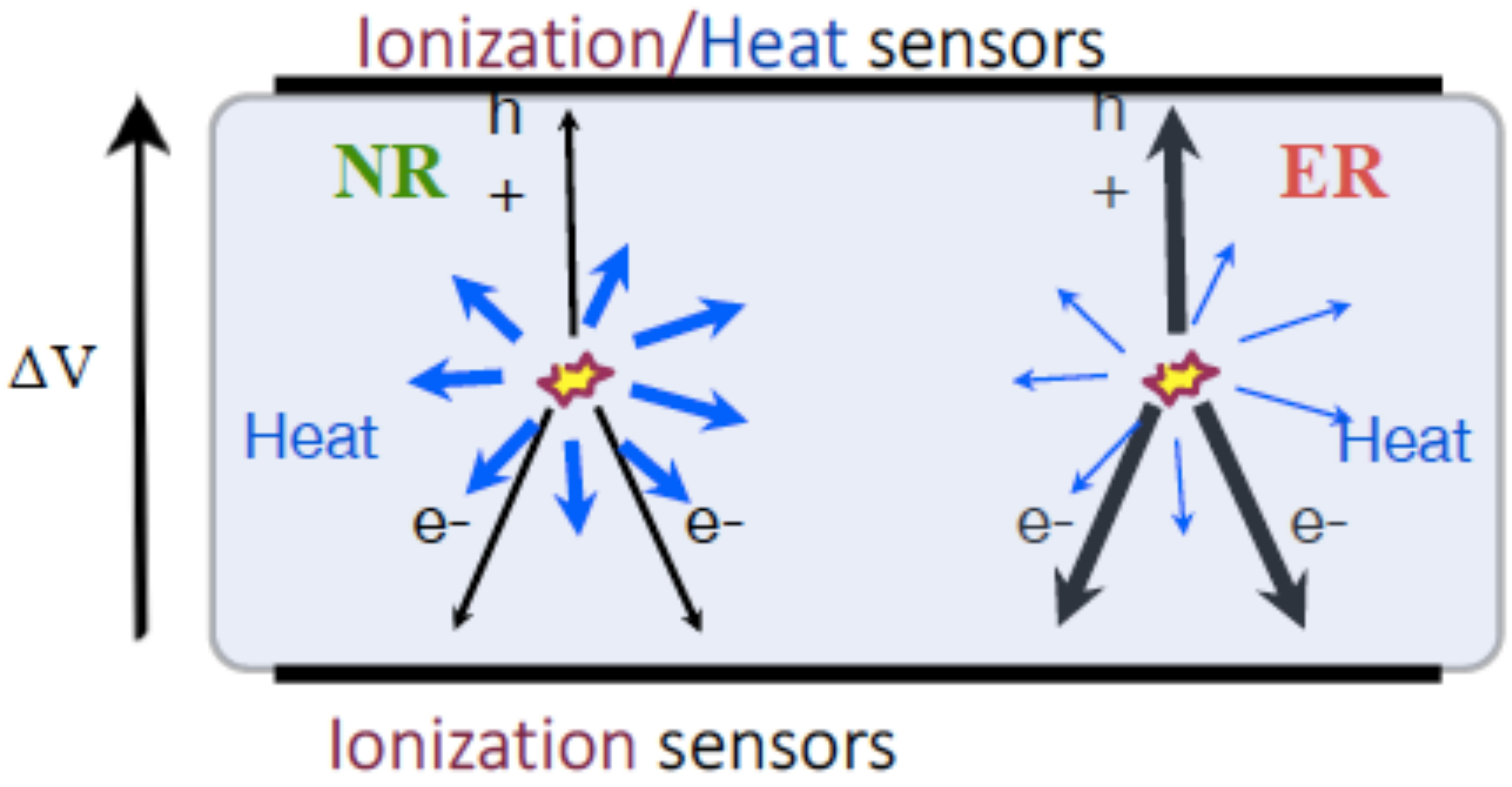

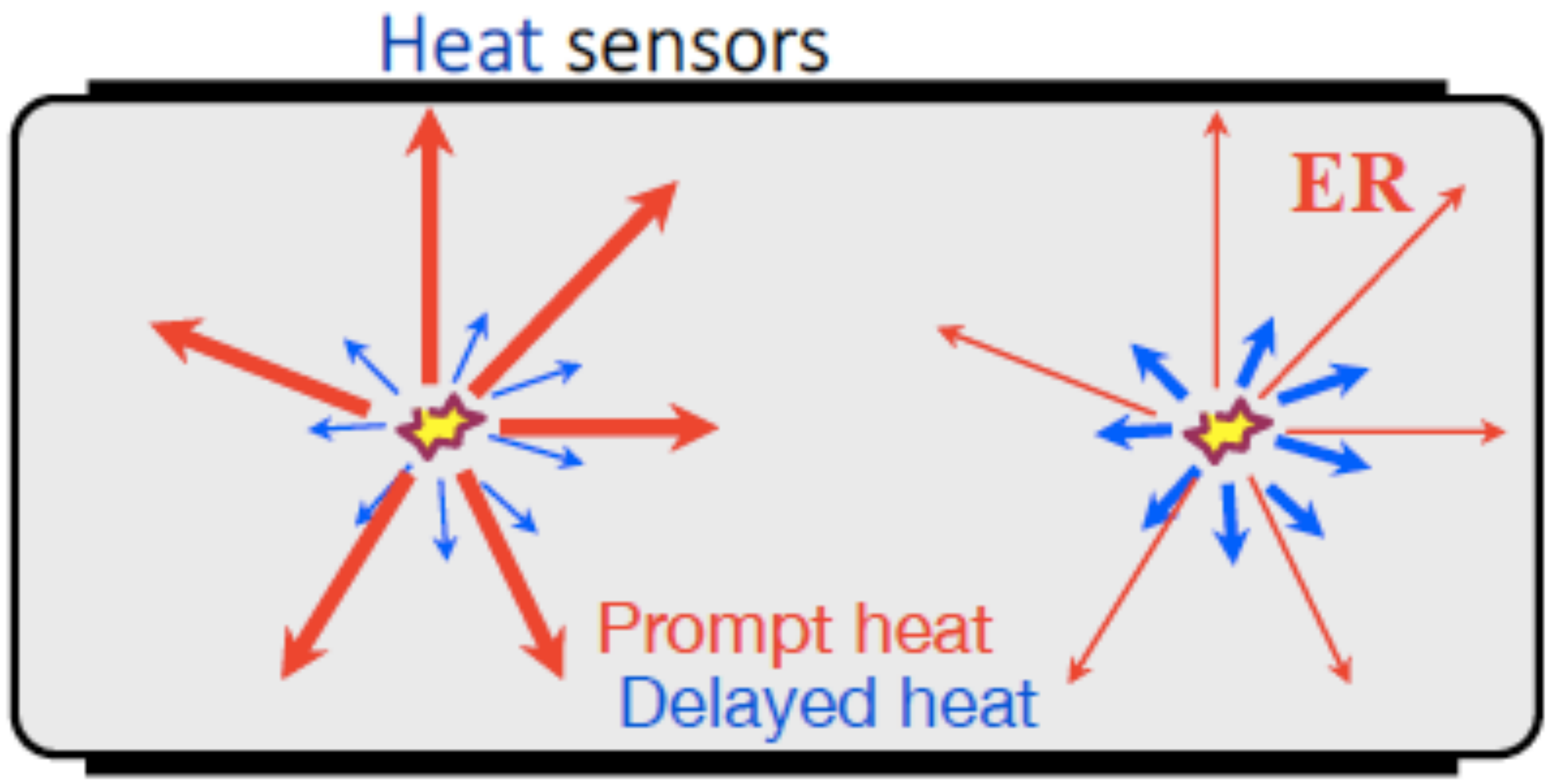

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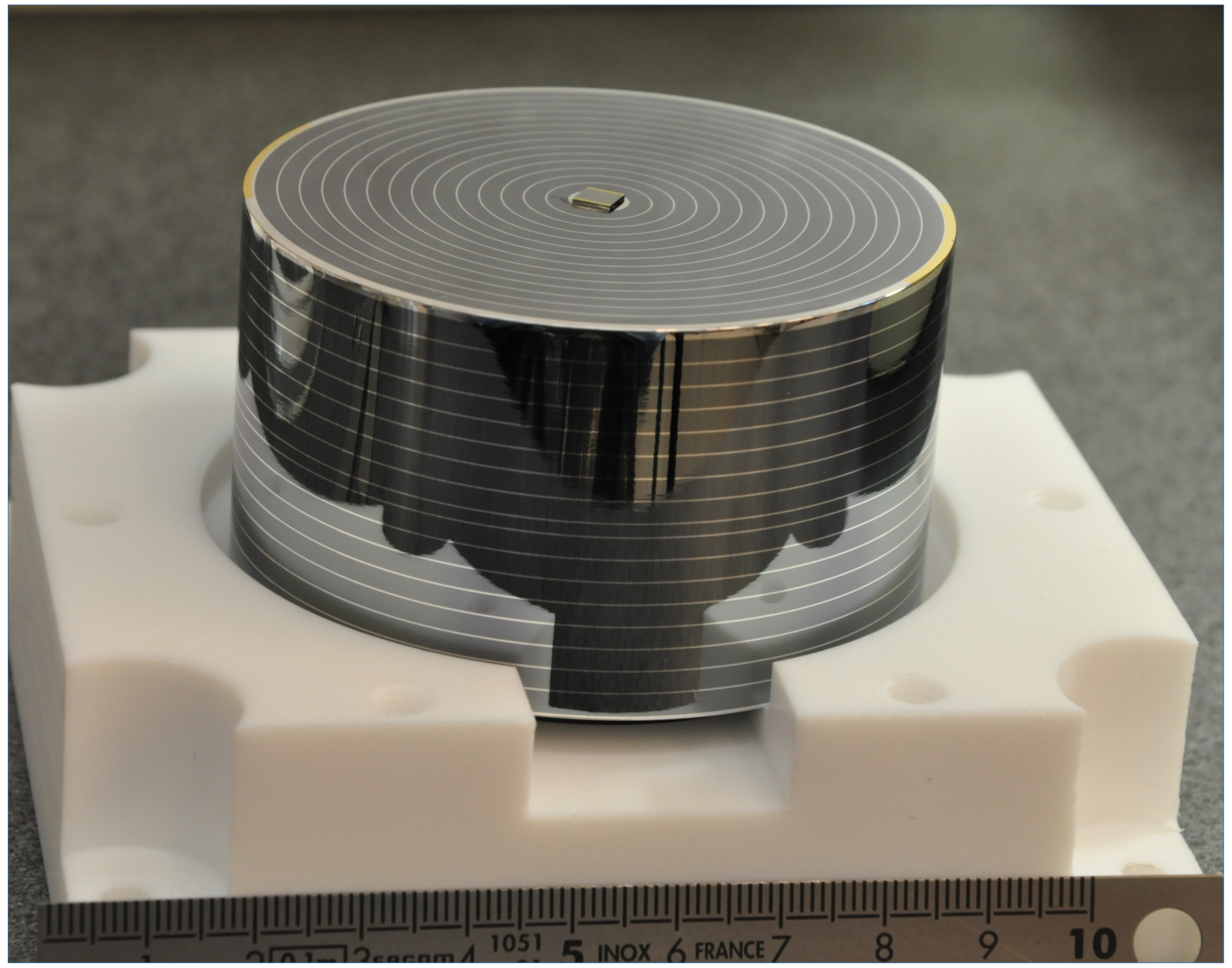
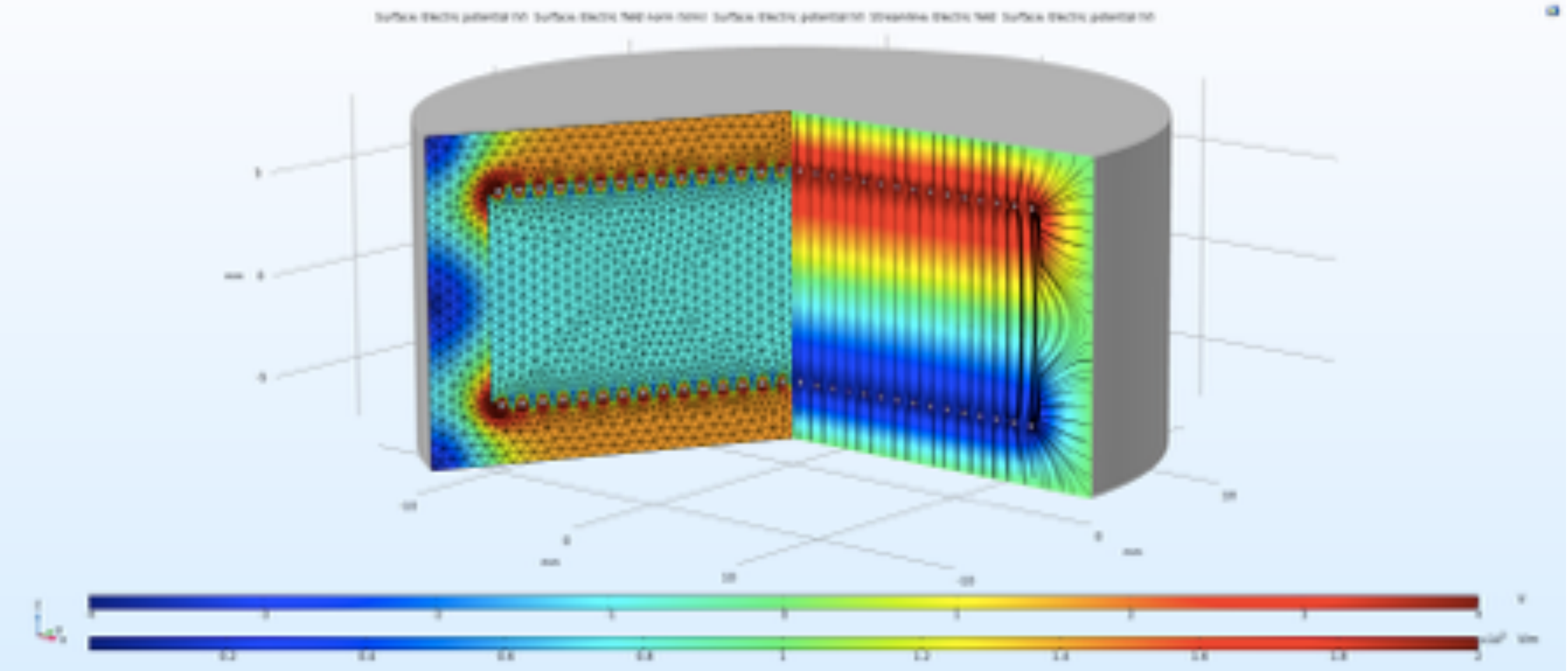
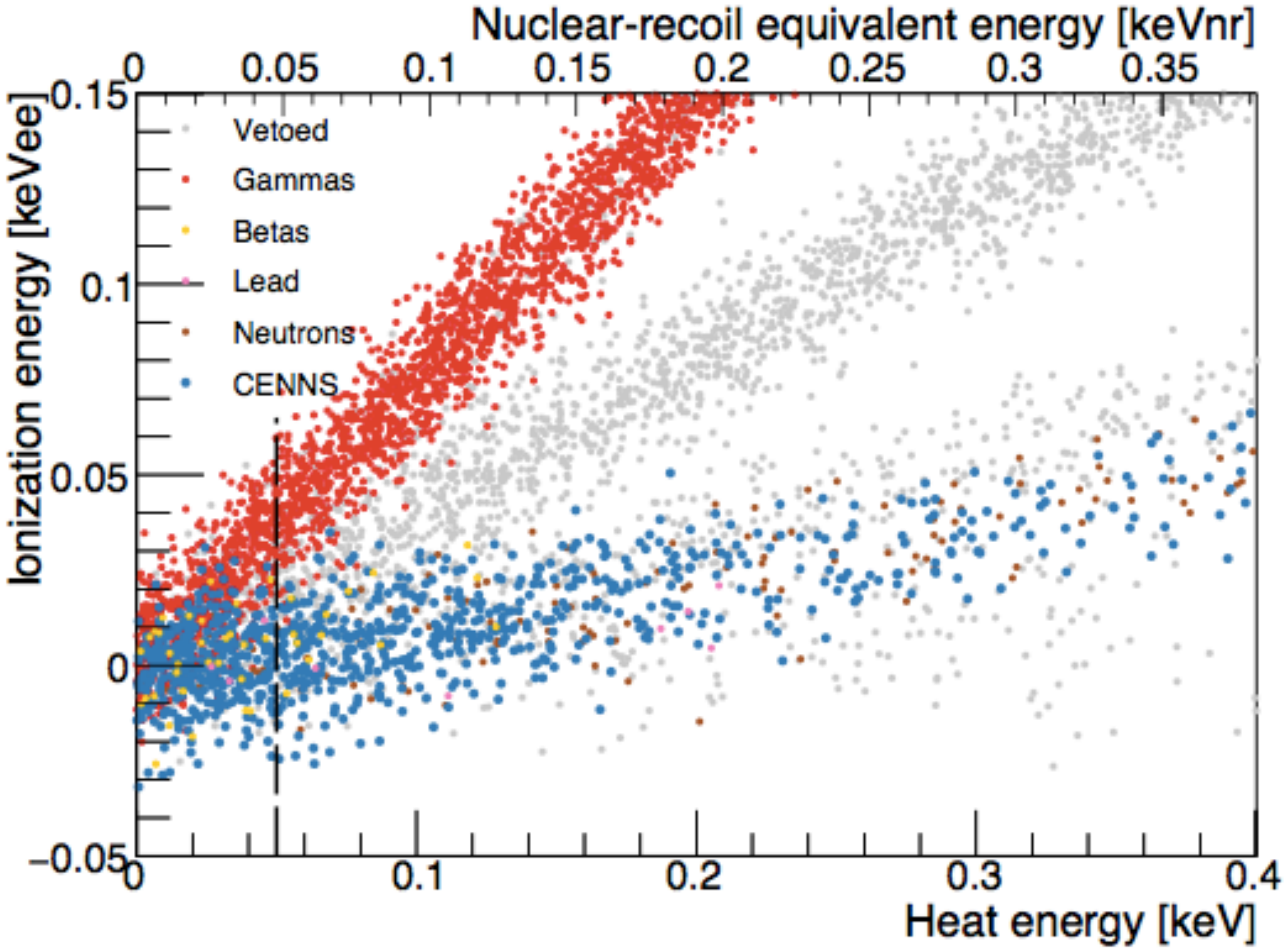


EDELWEISS-Based Ge-Detector



EM Field Model

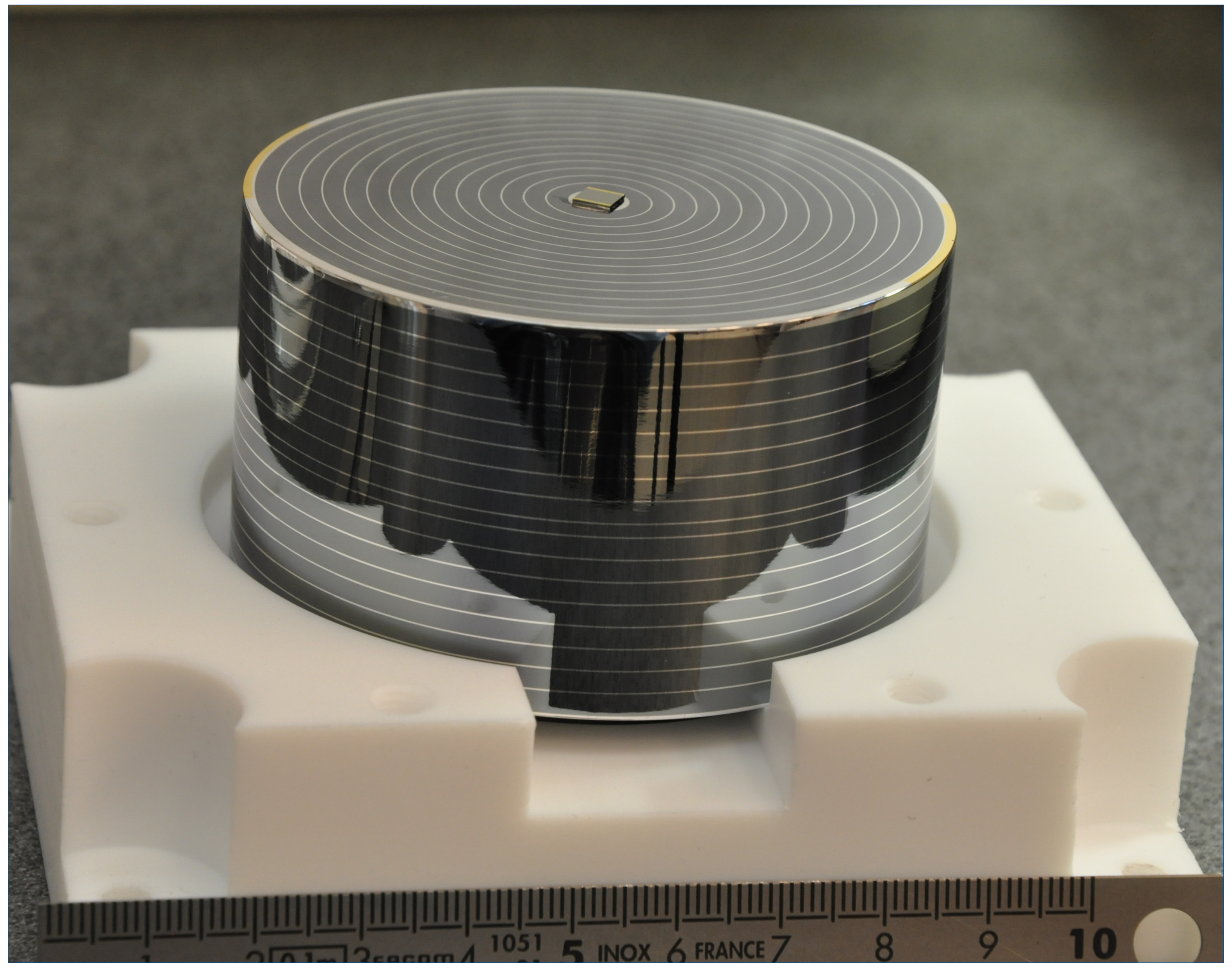


Germanium Detectors:

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

Ionization versus thermal phonon readout allows for recoil signal separation down to 50-150 eV thresholds.

Germanium Approach



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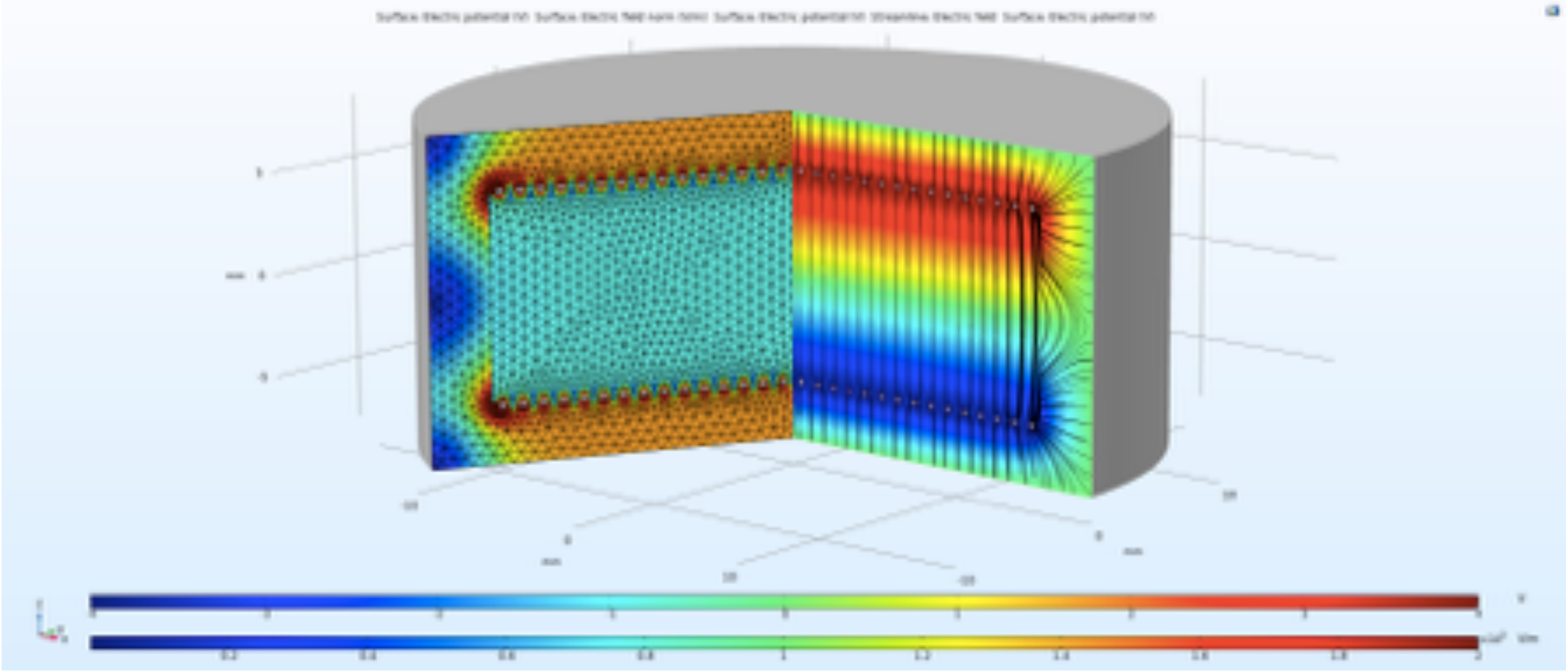

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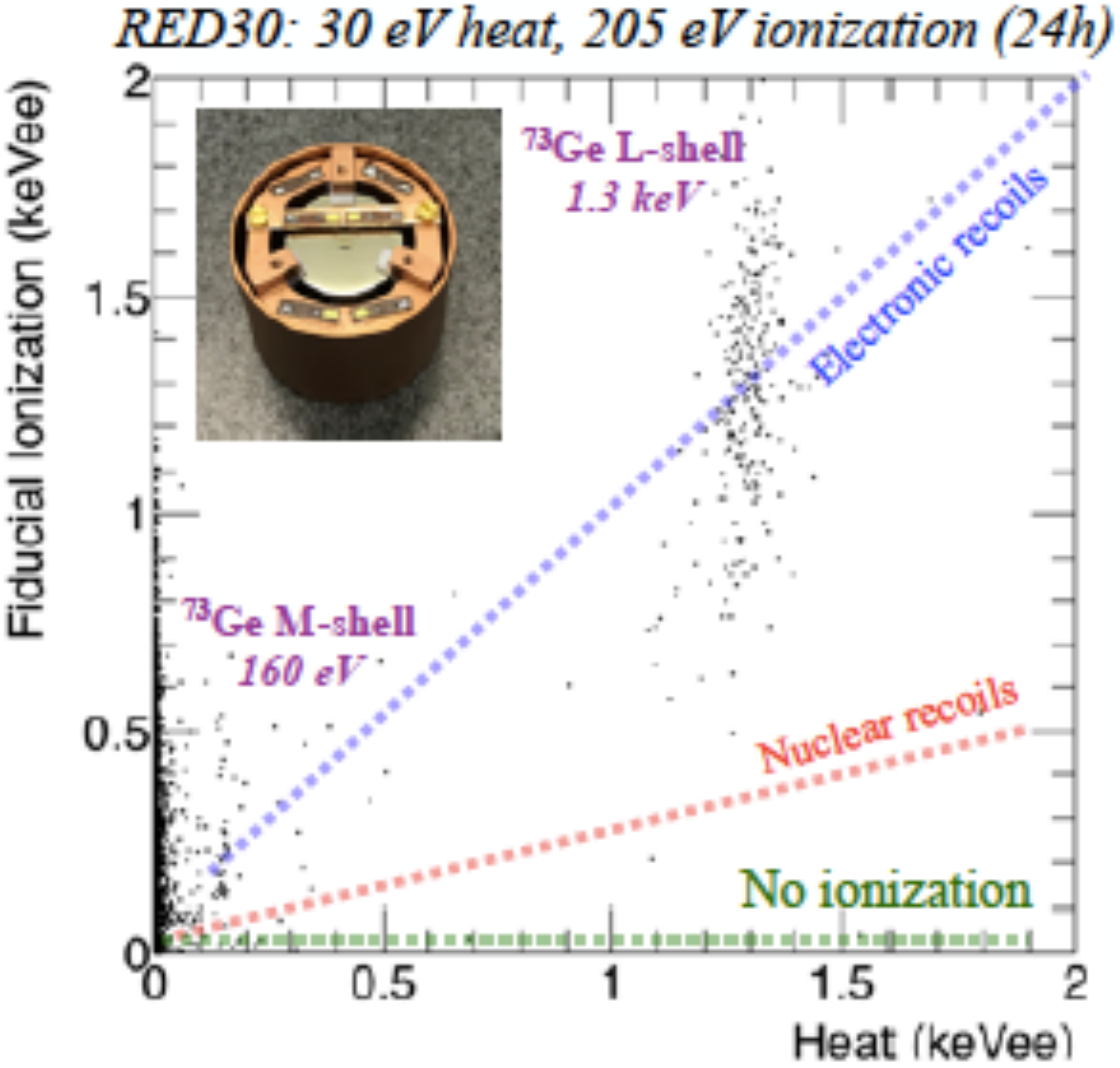

From the EDELWEISS R&D

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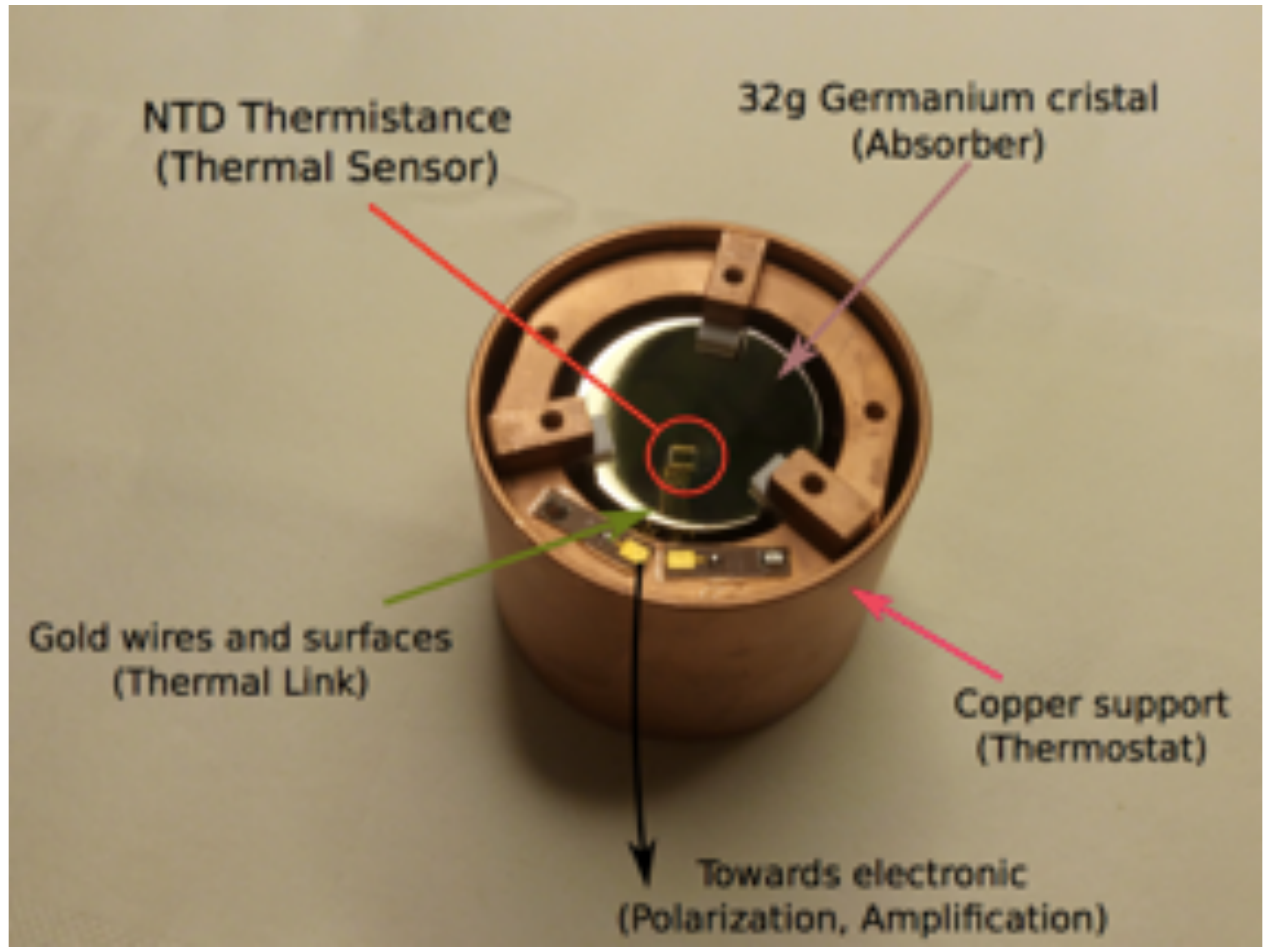
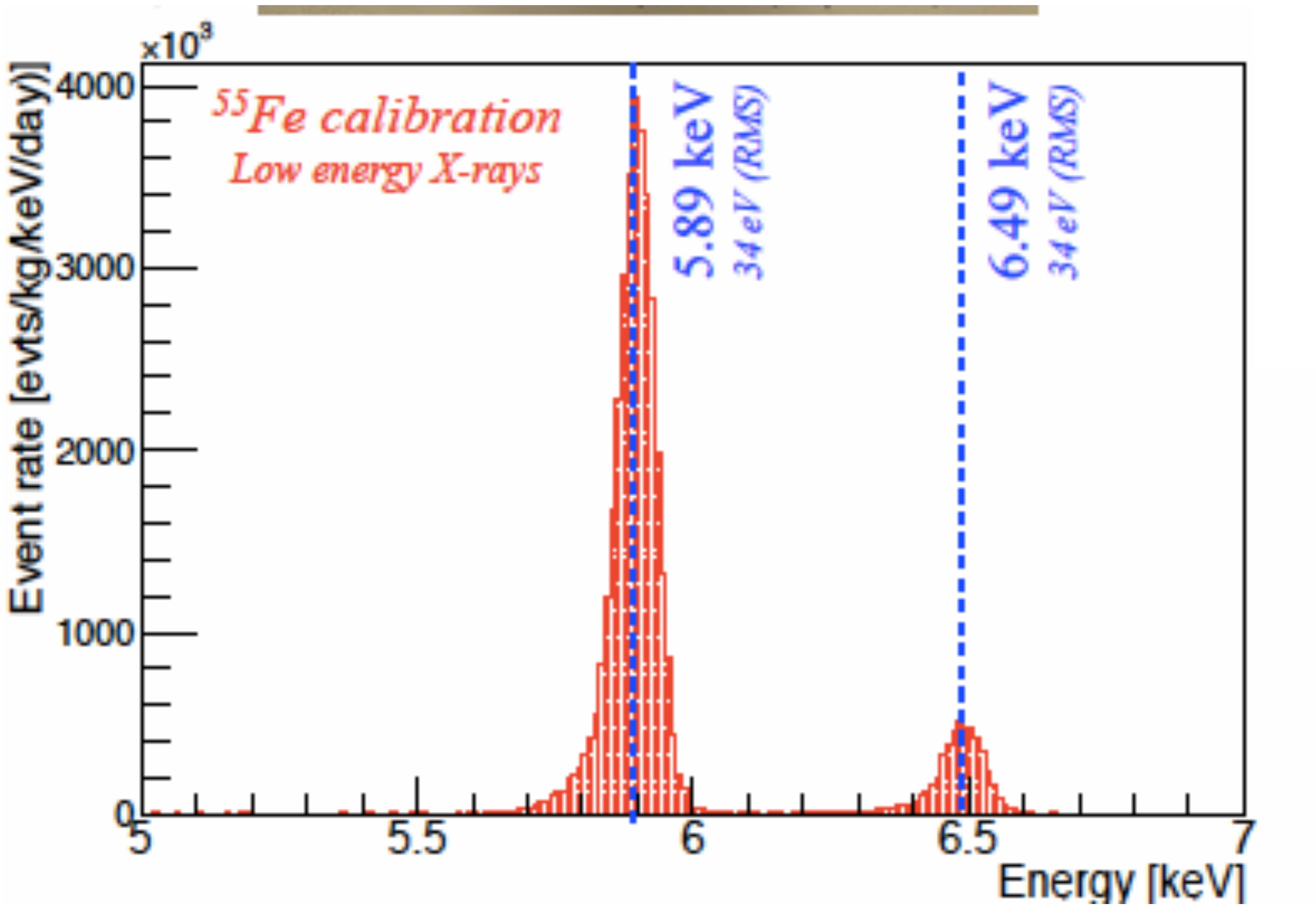
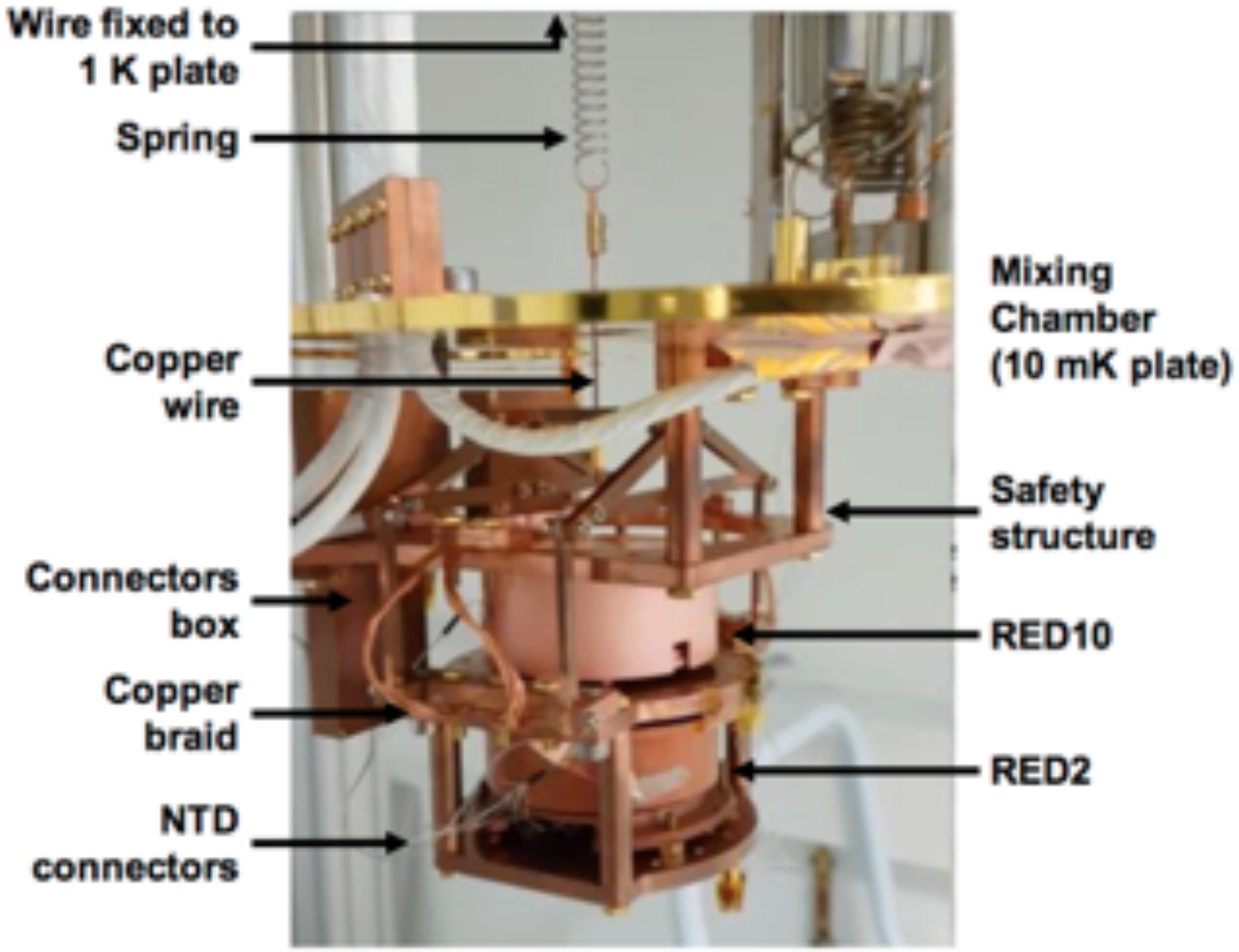
Prototype Detectors



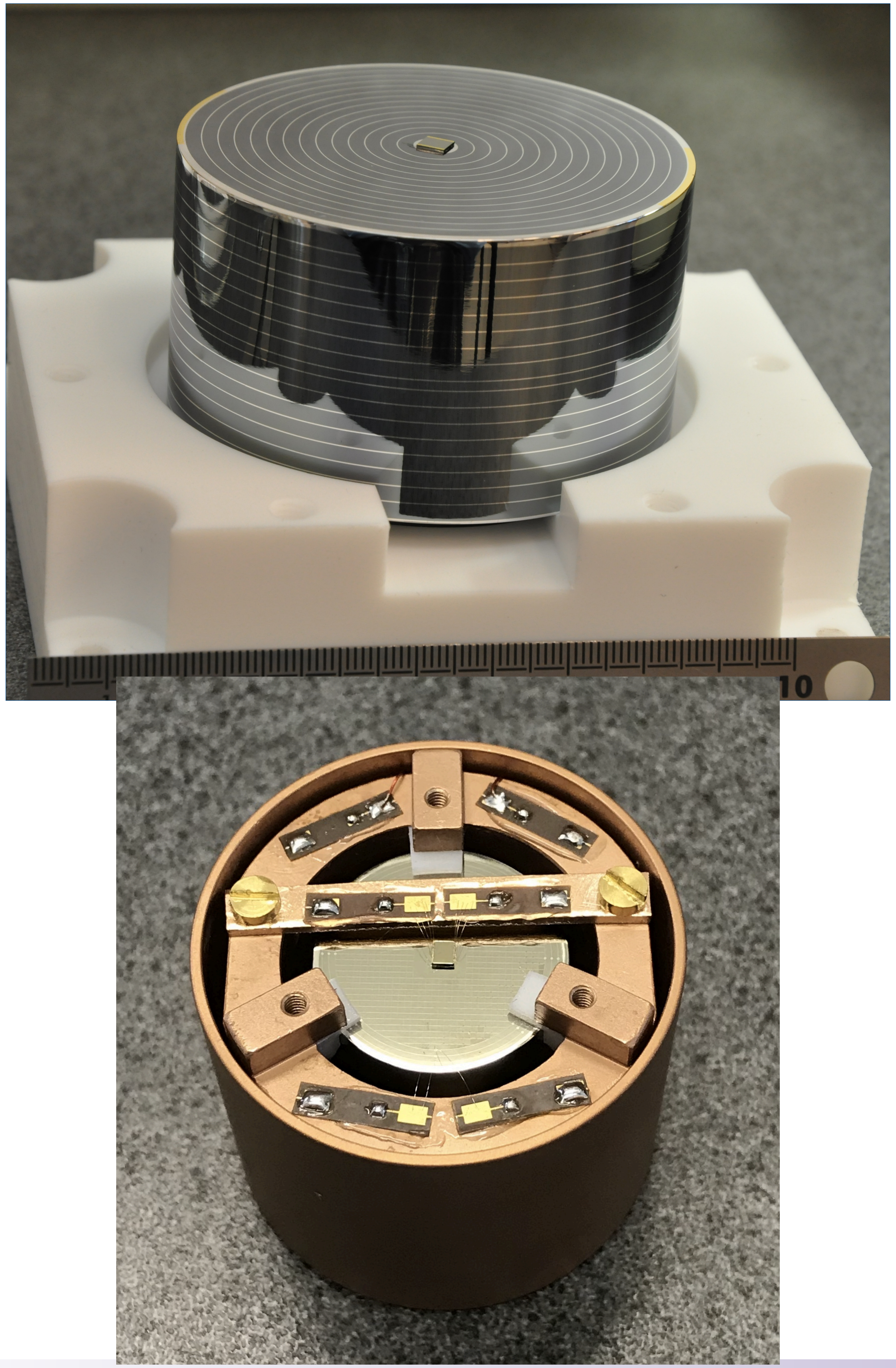


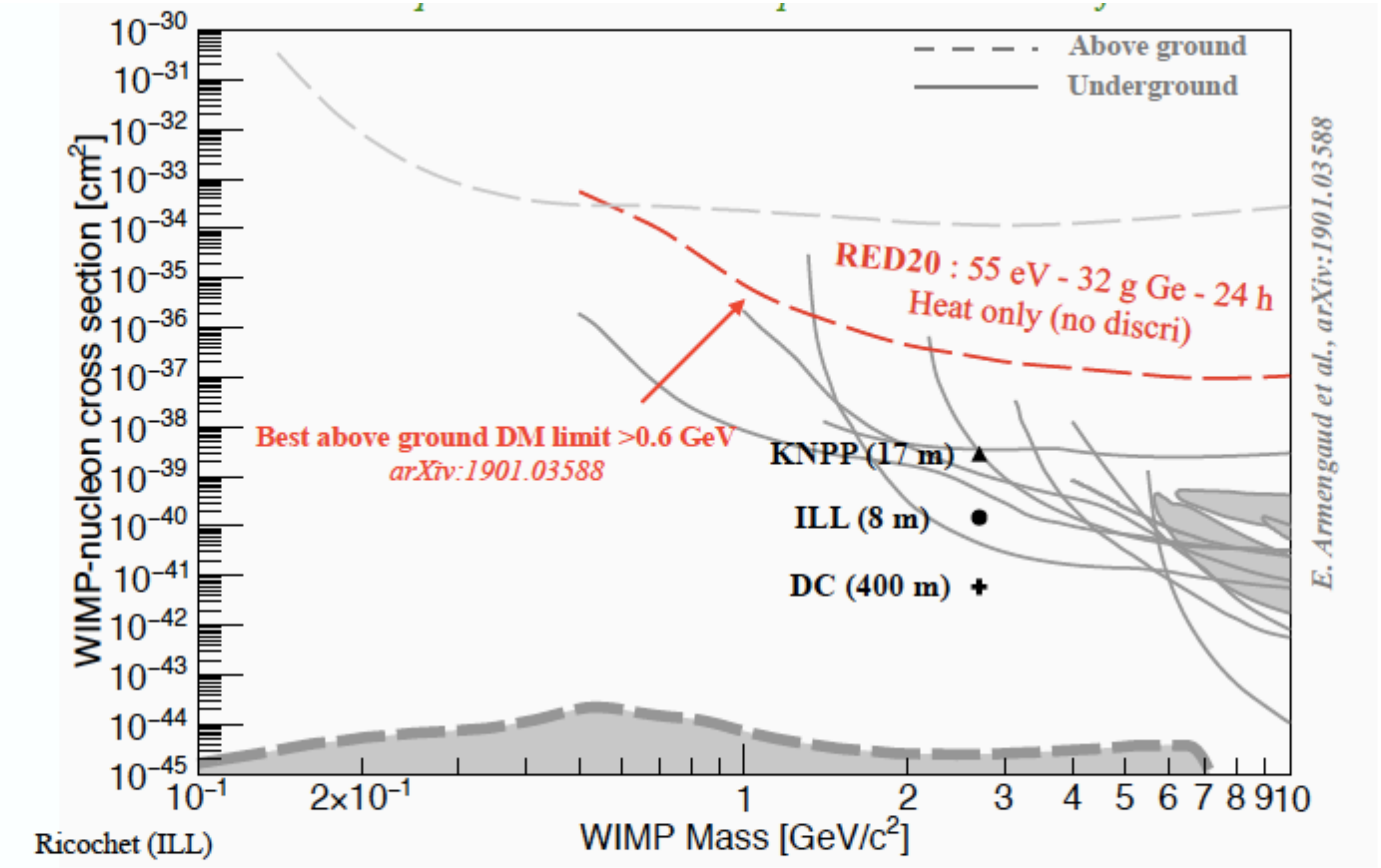
E. Armengaud et al., arXiv:1901.03588



18 eV energy resolution (RMS)
55 eV energy threshold with a 32 g detector (Ge)
stability at few ~% level

Dark Matter Limits on Surface





Ricochet (ILL)

- Neutrino-WIMP equivalent model independent of target material
- CEvNS signal from reactor neutrino is similar to a 2.7 GeV WIMP
- The equivalent cross section depends on the neutrino flux

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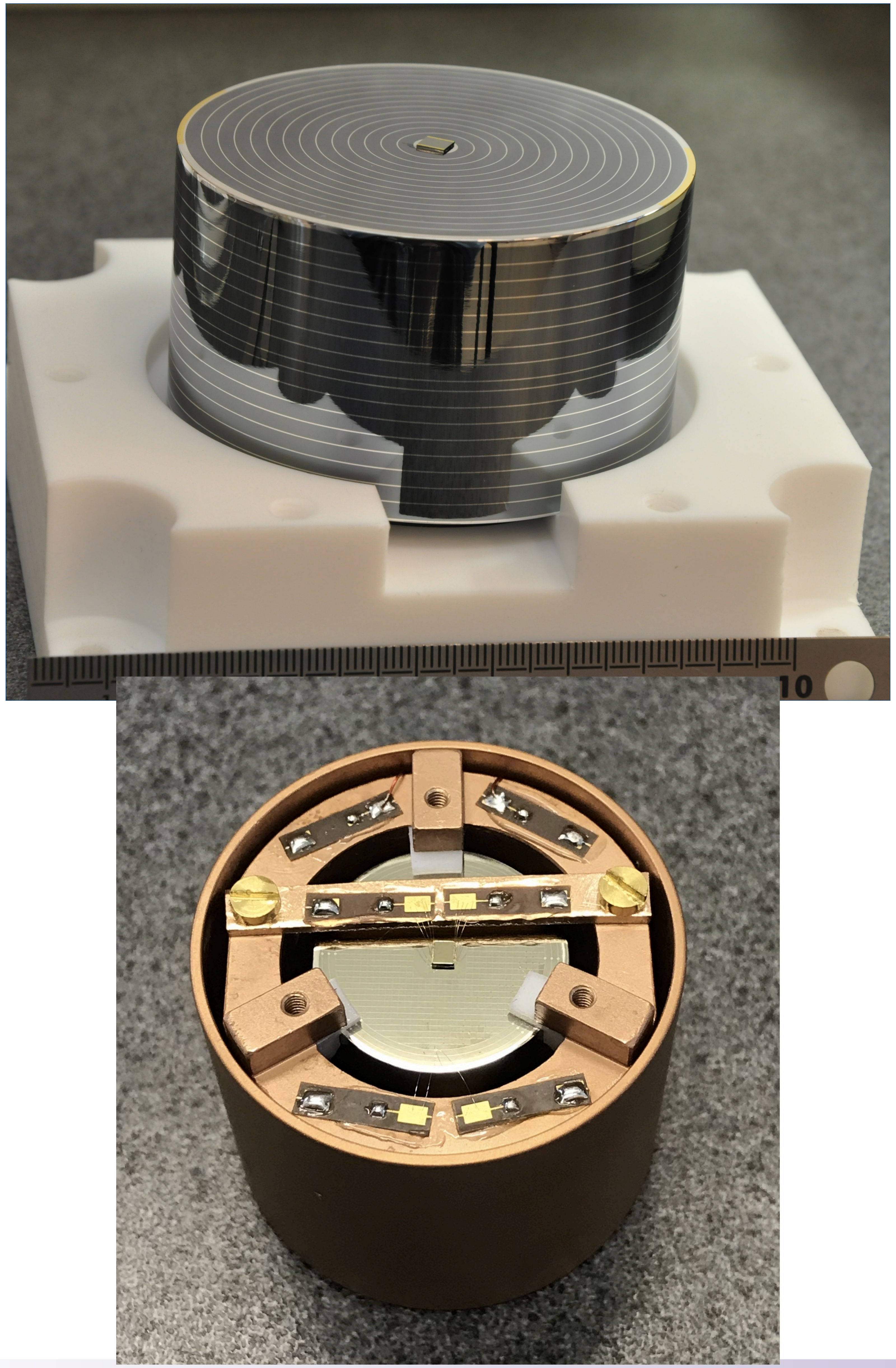

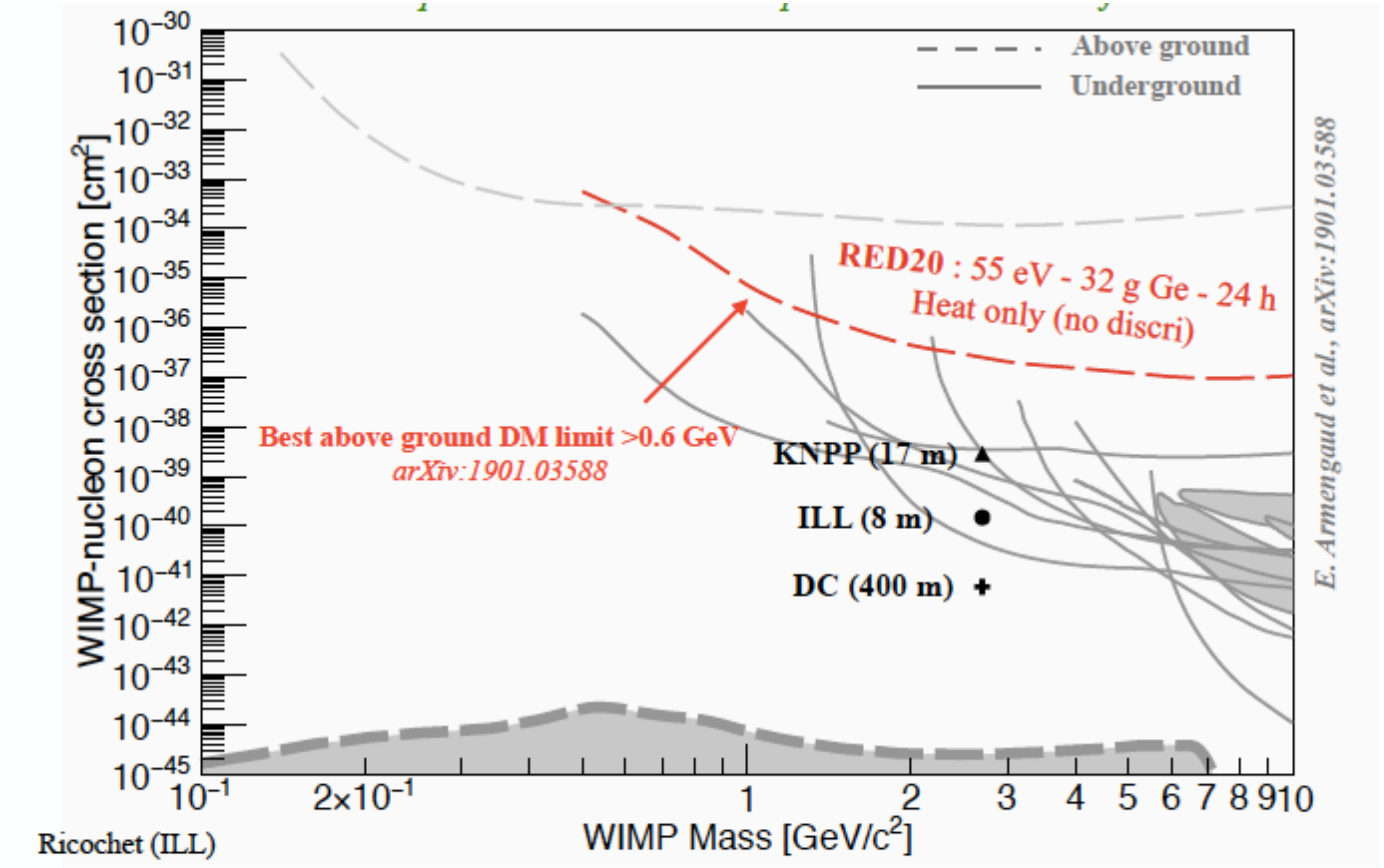

- **Neutrino-WIMP equivalent model independent of target material**
- **CEvNS signal from reactor neutrino is similar to a 2.7 GeV WIMP**
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Much of the risk reduced through demonstration!

Superconductor Approach

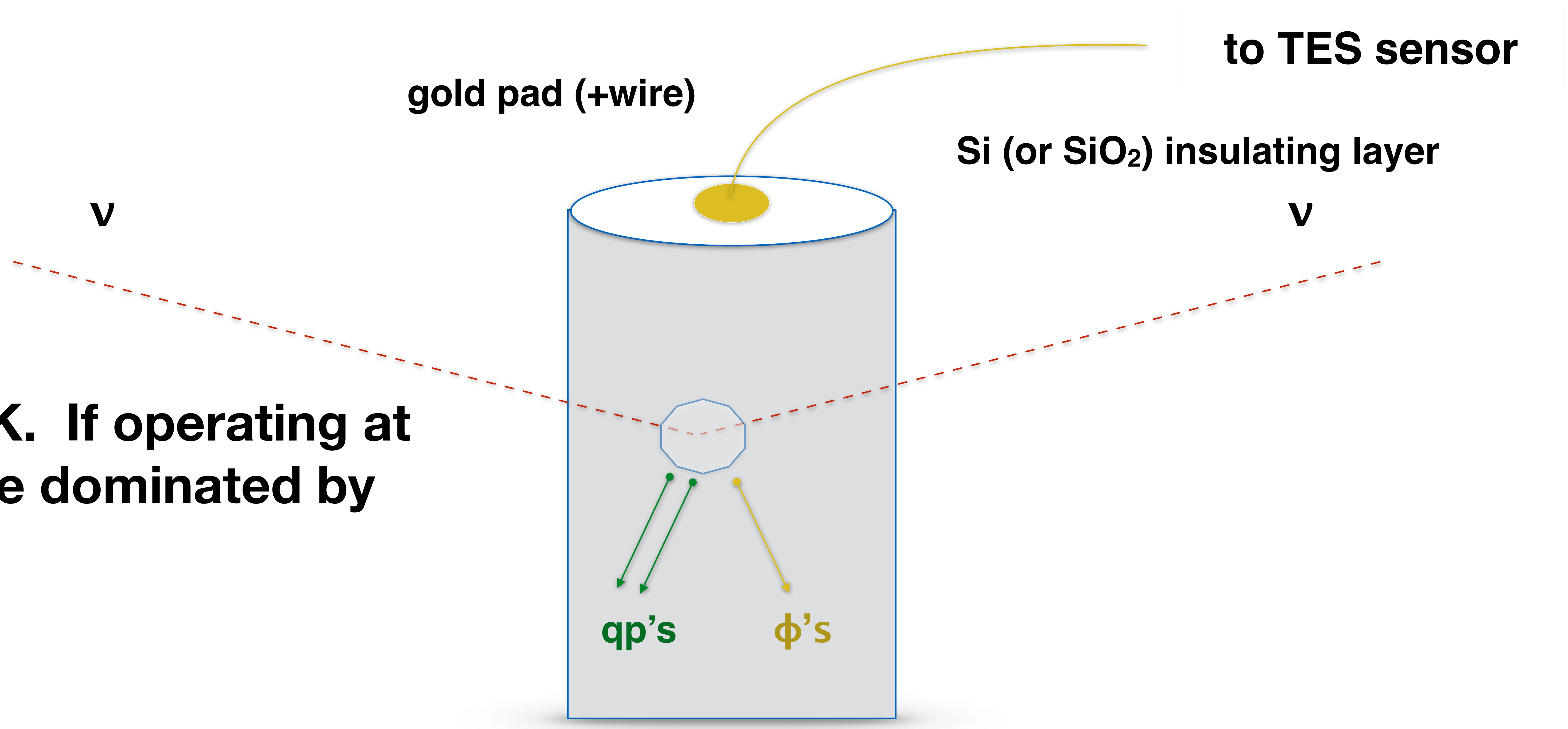
Metallic Superconductors as Detectors:

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.



Zn Absorber
$T_c \sim 0.85$ K
$\Theta_D \sim 327$ K

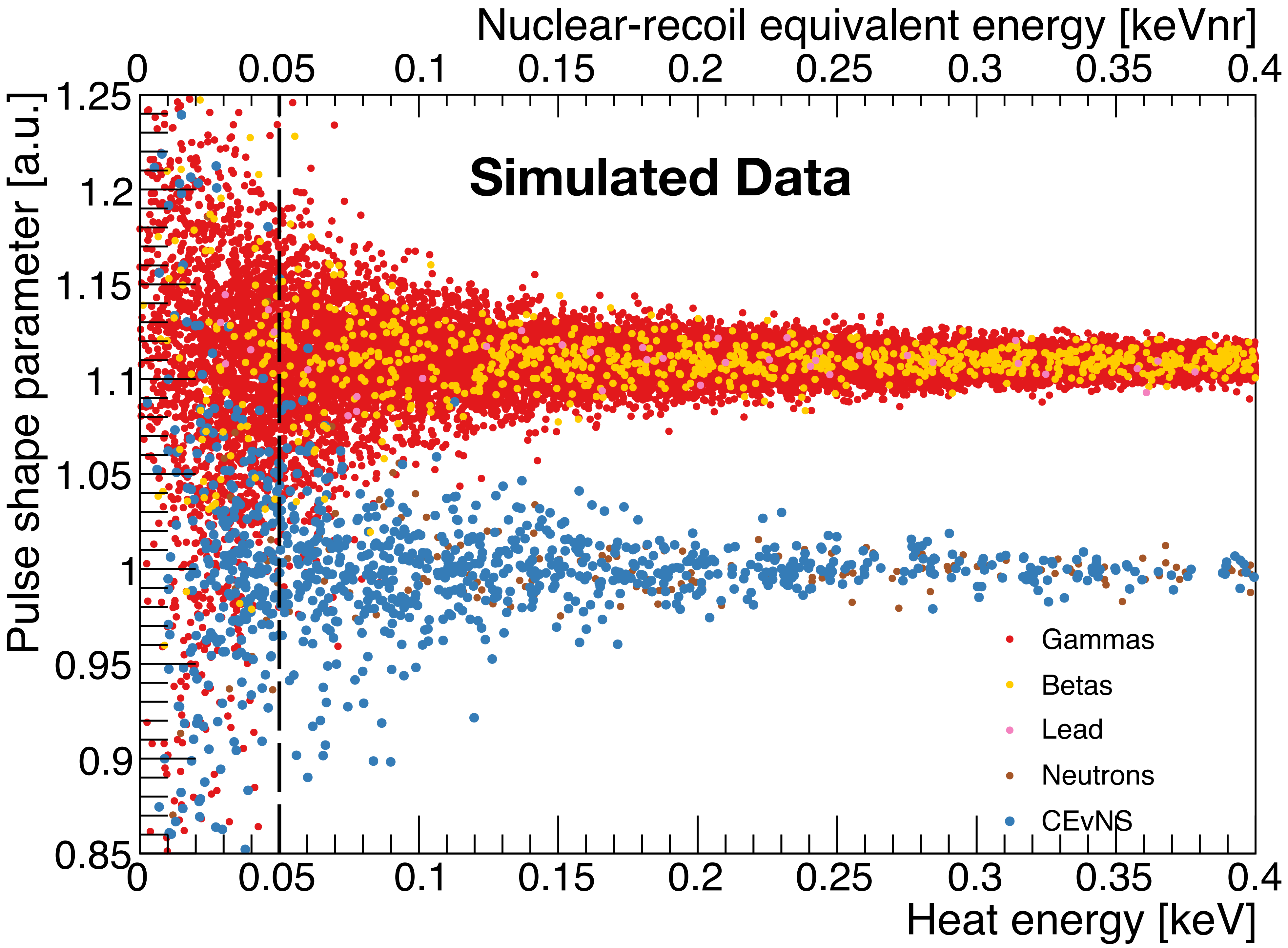
Why Superconducting Metals?

Metallic Superconductors as Detectors:

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

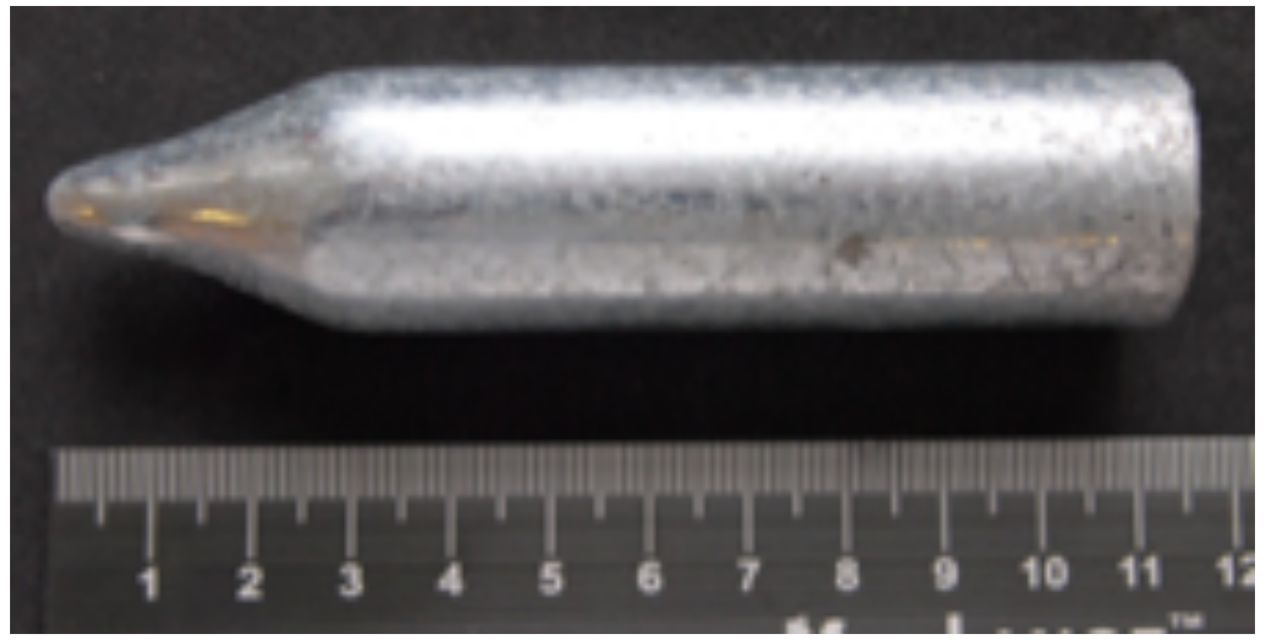
Recombination times for quasi-particles become extremely long at low temperatures (~ seconds), while (a)thermal phonons operate at much different (faster) time scales.

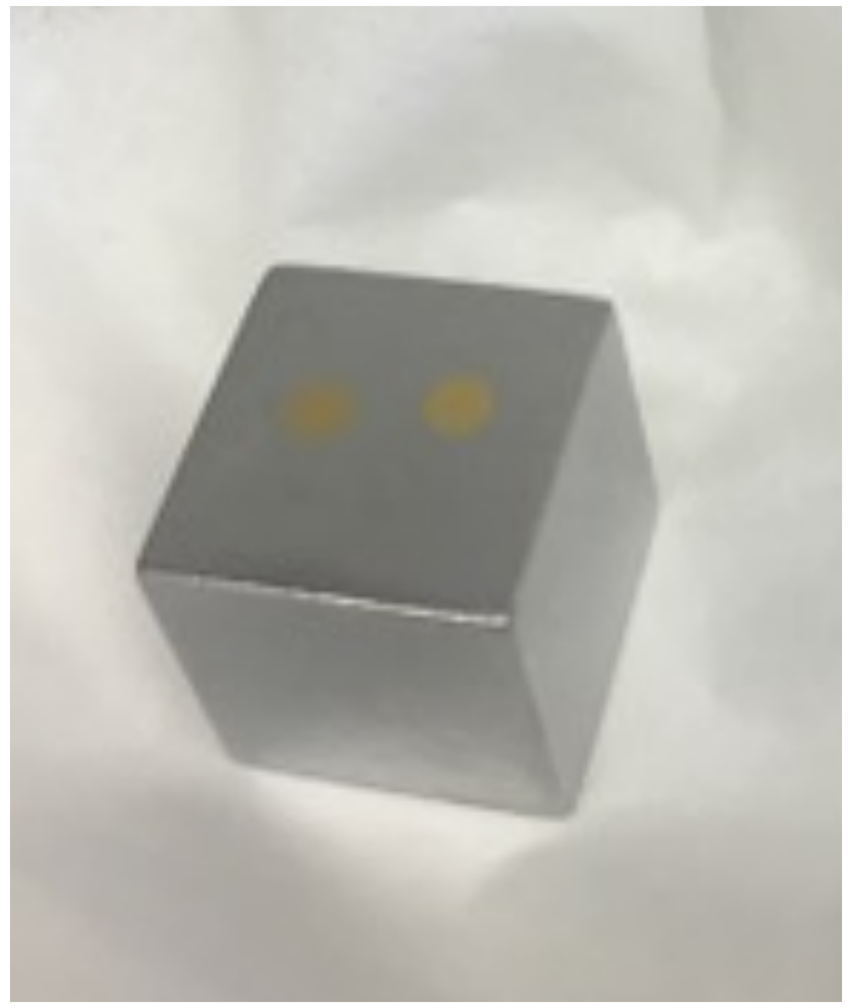
Separation of recoil from electromagnetic events using quasi-particle versus athermal phonon timing signatures should be explored.

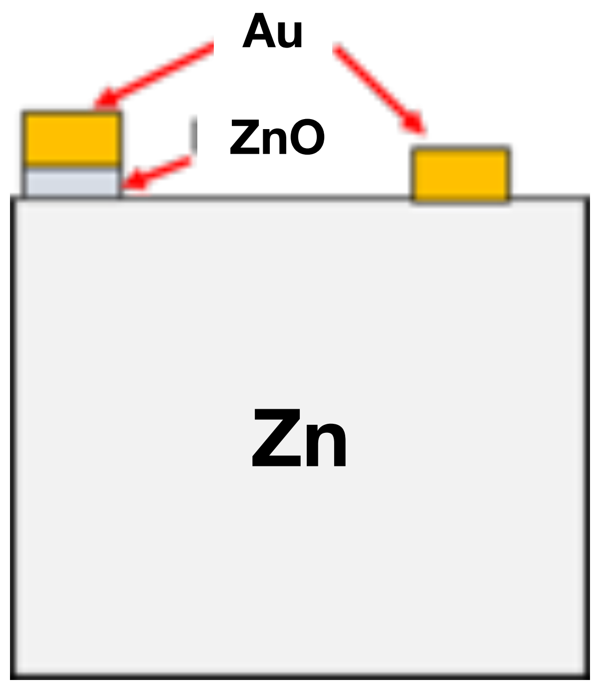


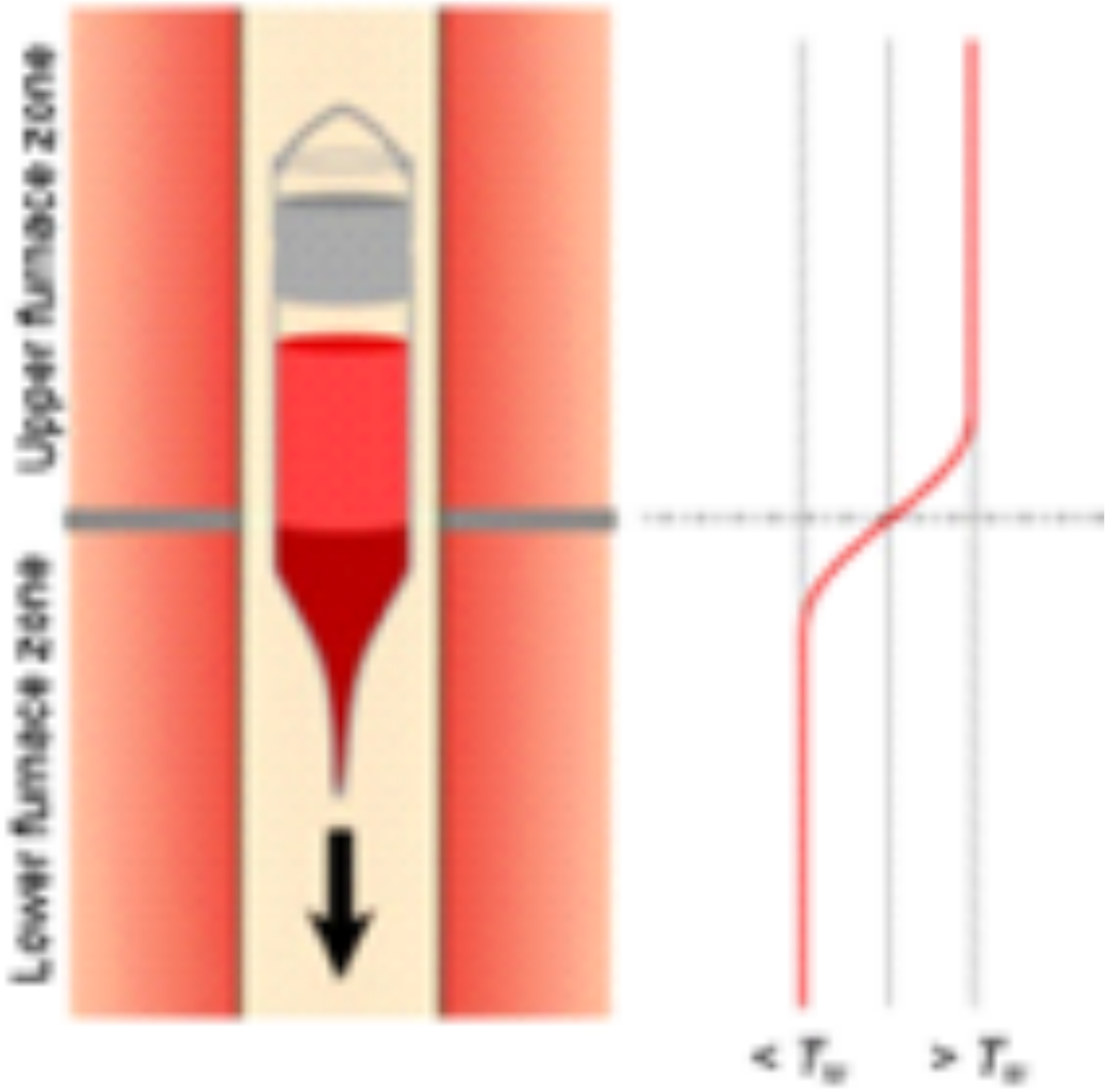
Zinc Detectors

- 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 25-40 gram zinc crystals, small Al crystals also produced.
- Switched to cubes, to allow better polishing on all surfaces.



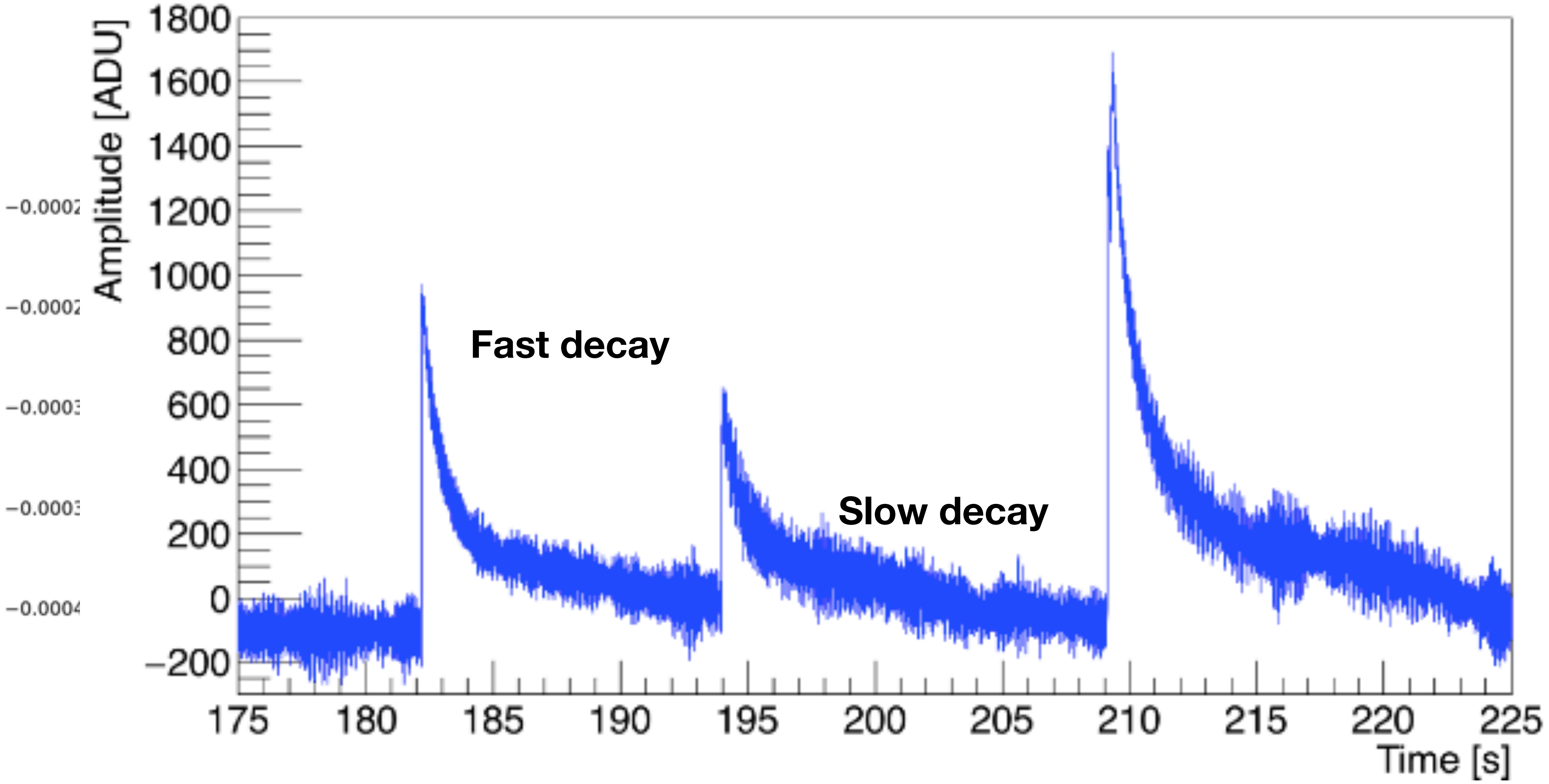


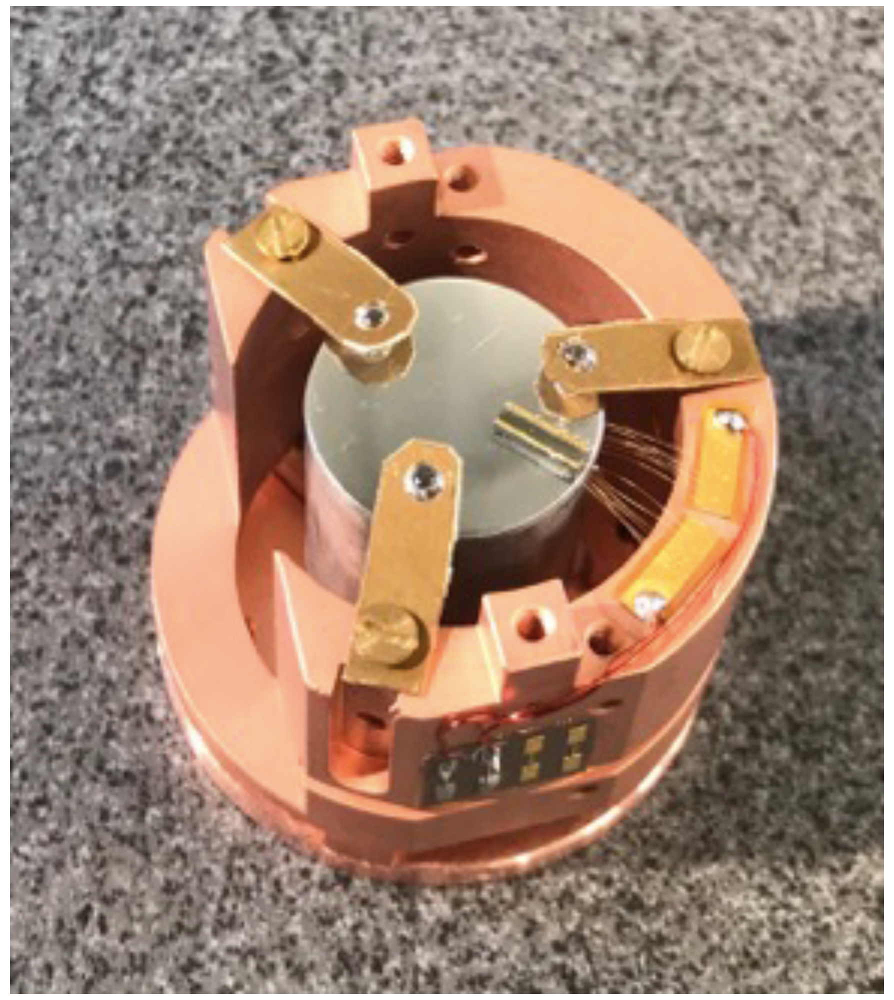




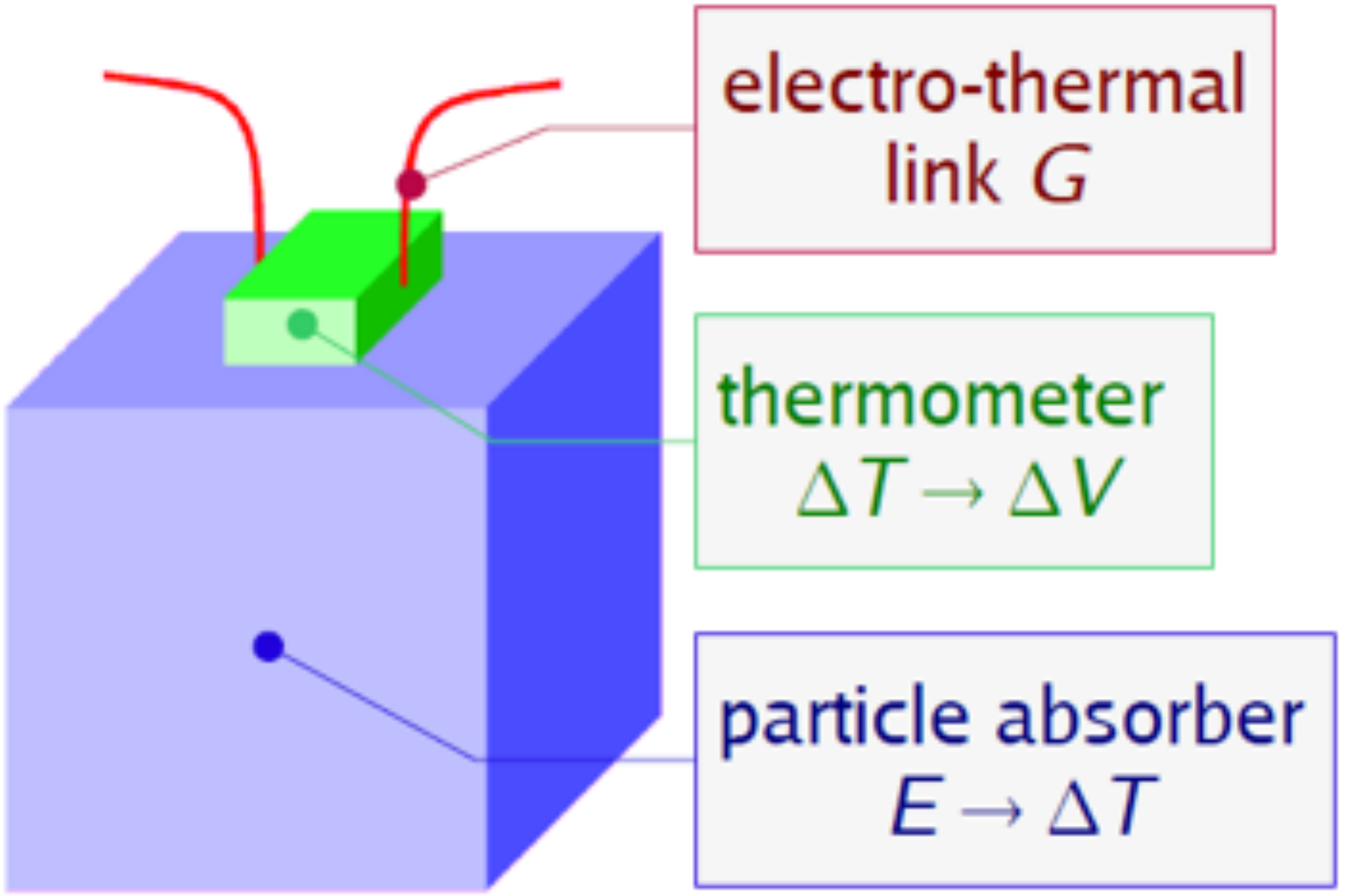
First (and Second) Pulses!

- 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.





Readout Scheme

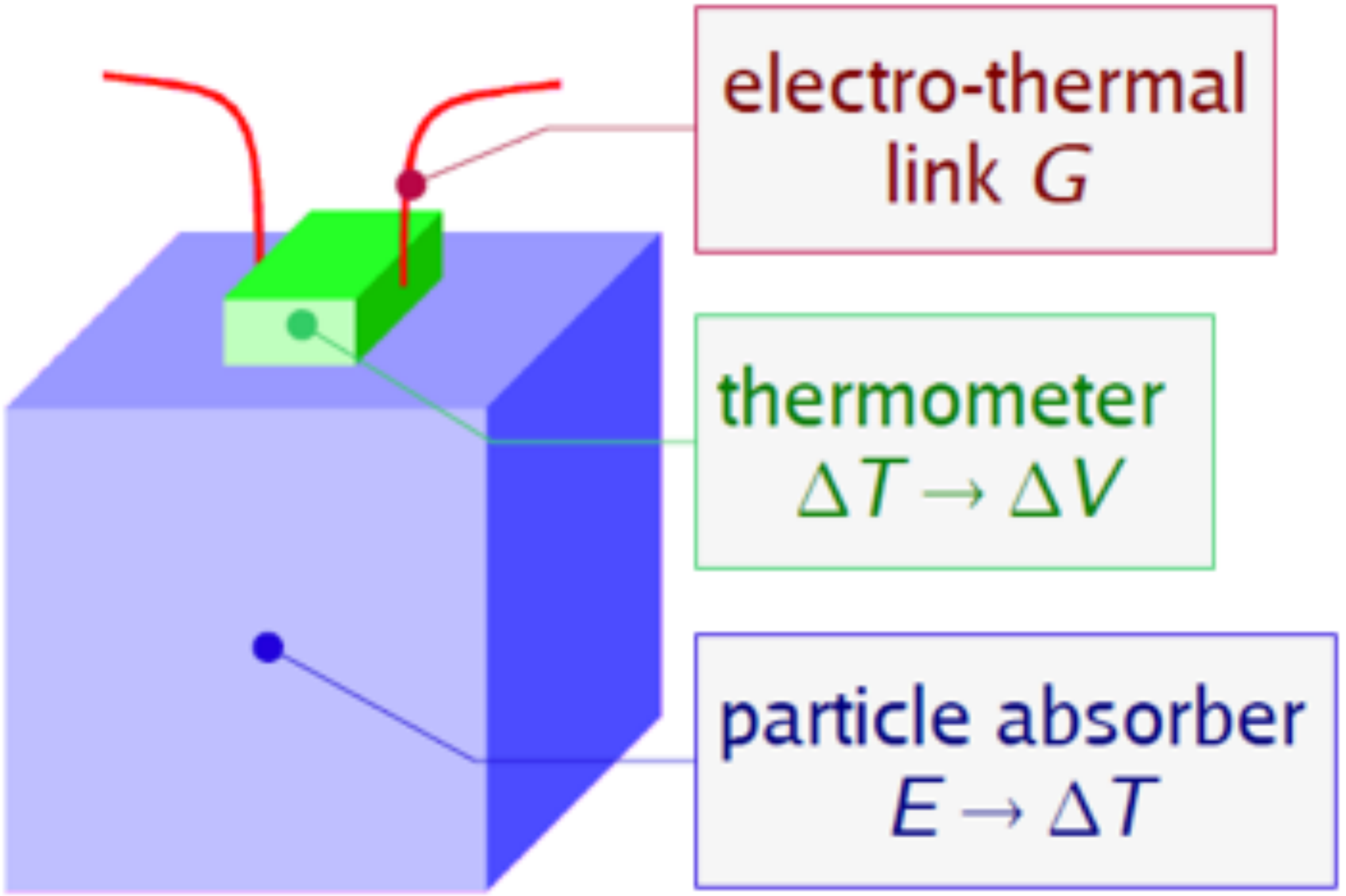


electro-thermal
link G

thermometer
$\Delta T \rightarrow \Delta V$

particle absorber
$E \rightarrow \Delta T$

Readout Scheme

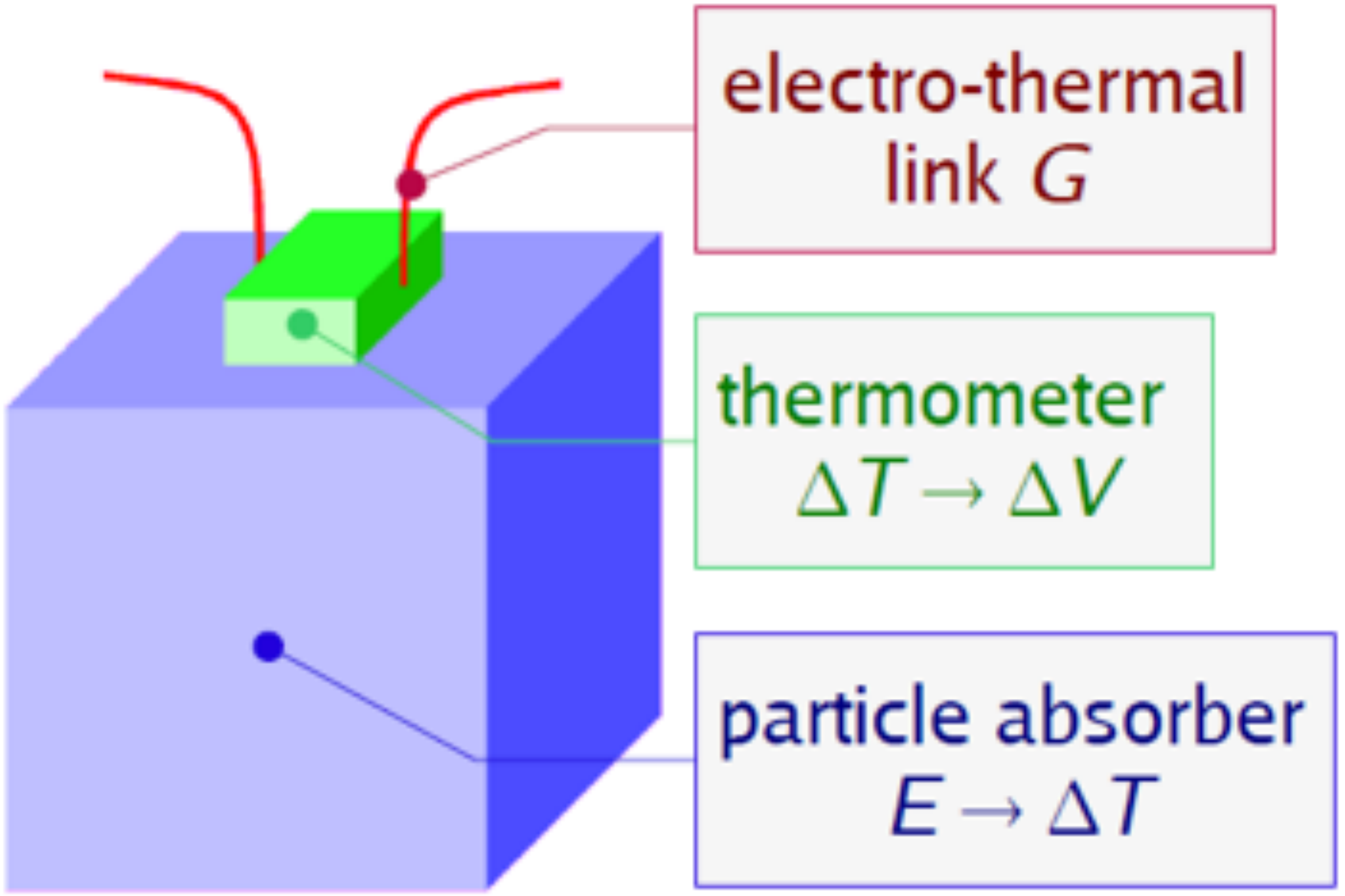


The absorber allows conversion from energy to heat (phonons)

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

Small detectors & low temperatures
=
lower thresholds

Readout Scheme



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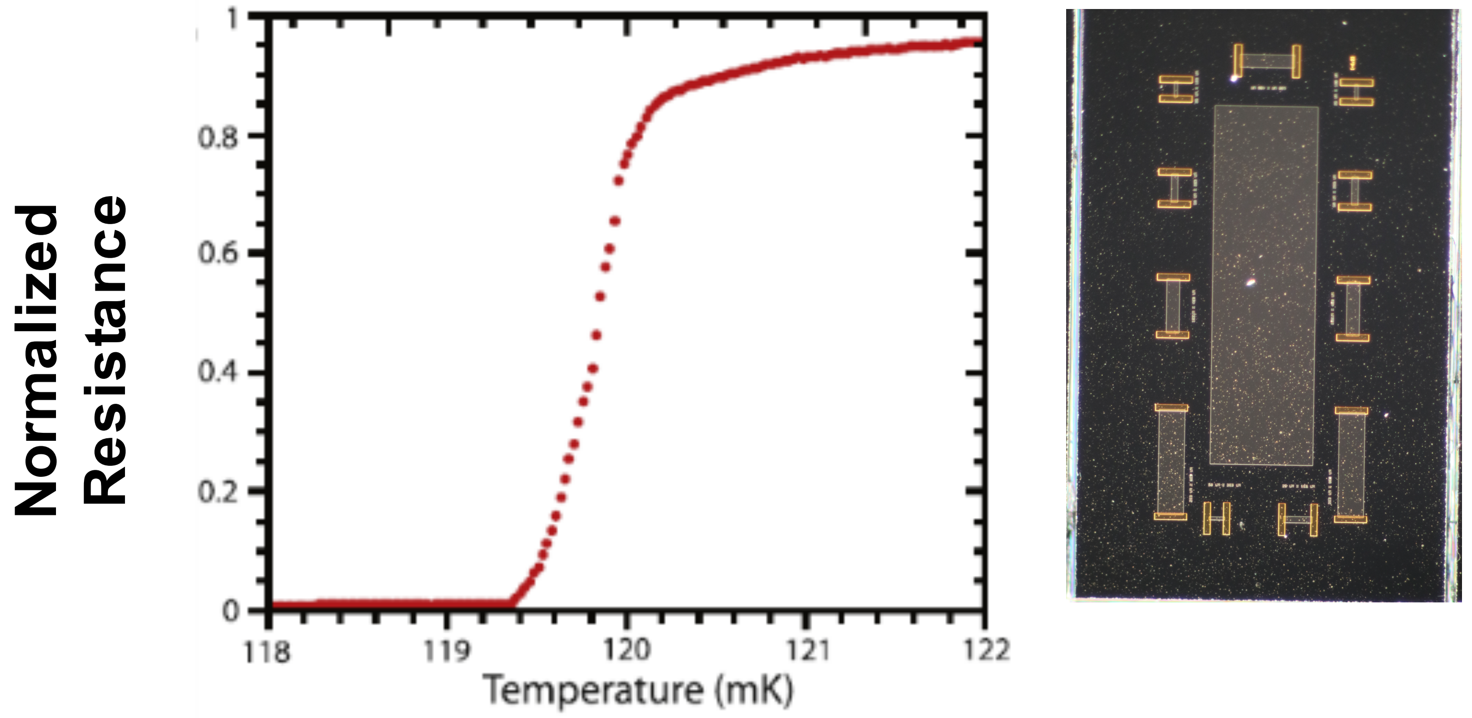
Small changes in temperature can be captured by Transition Edge Sensors (TES), which allow great sensitivity to small temperature depositions.

TES Resistance @ Tc



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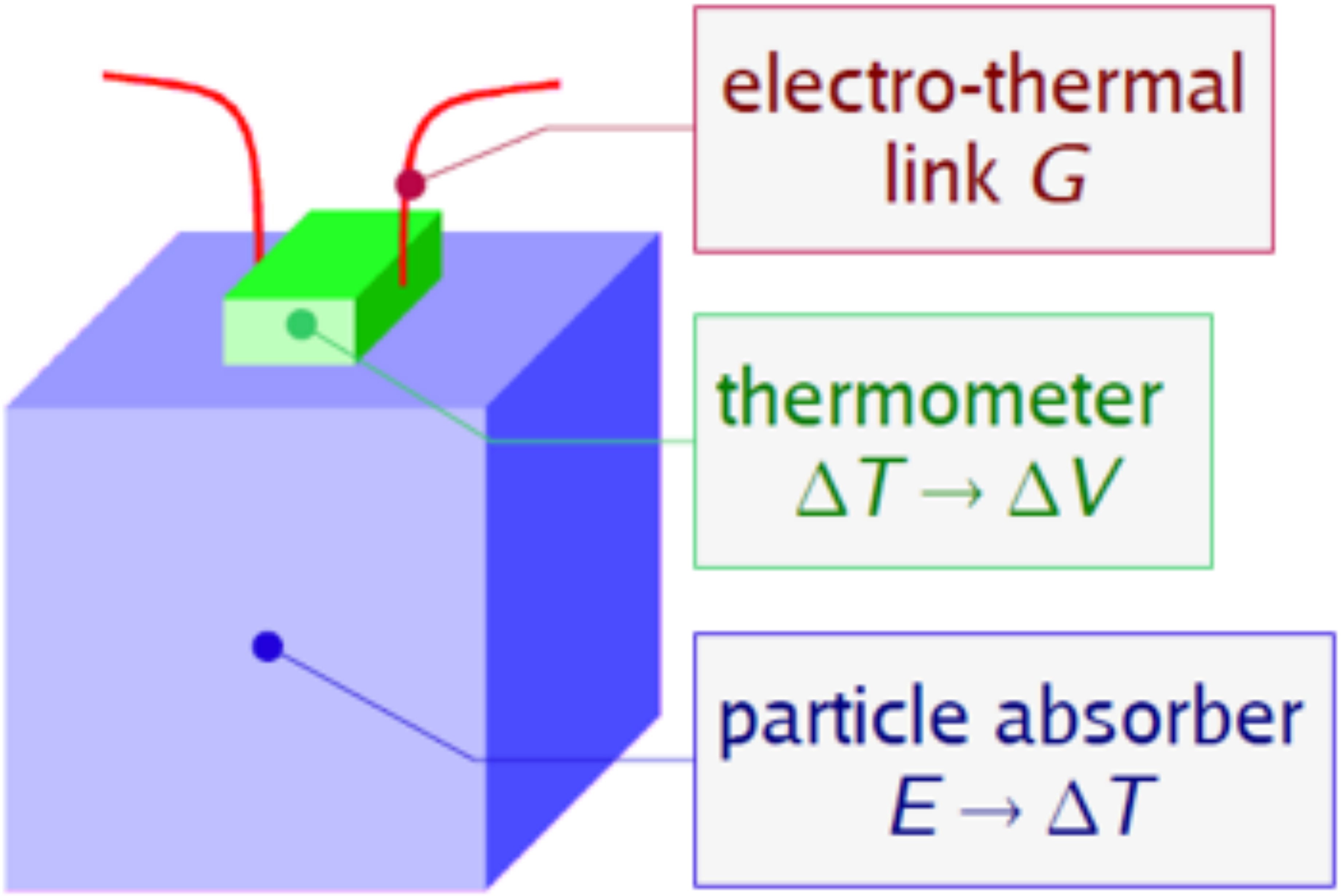

electro-thermal link G

thermometer $\Delta T \rightarrow \Delta V$

particle absorber $E \rightarrow \Delta T$

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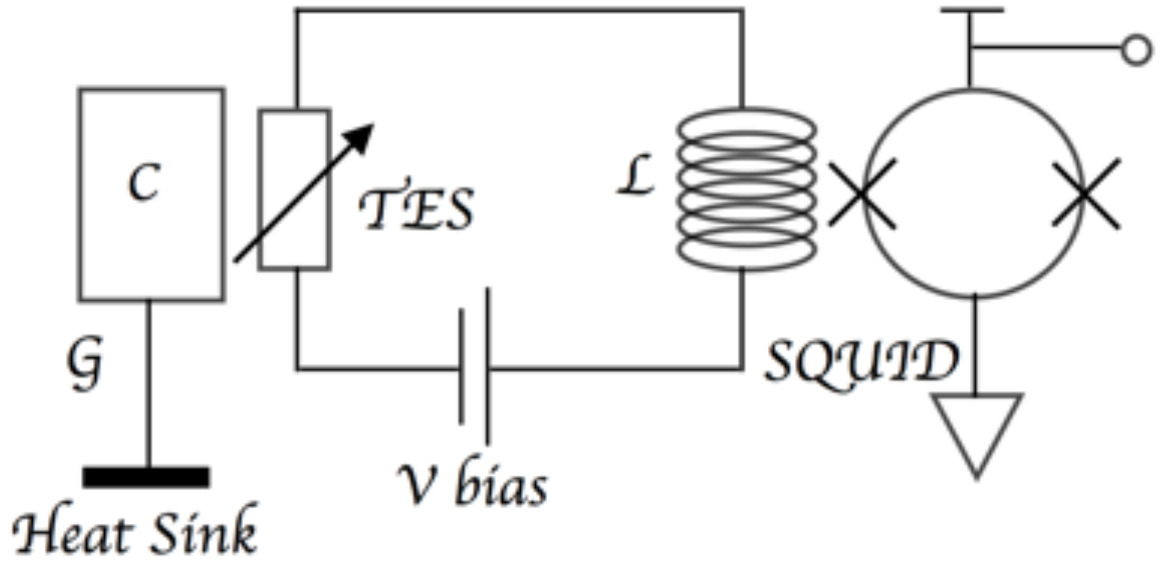

Readout of TES done using SQUID amplifiers, quantum-limited magnetometers, ideal for small currents.

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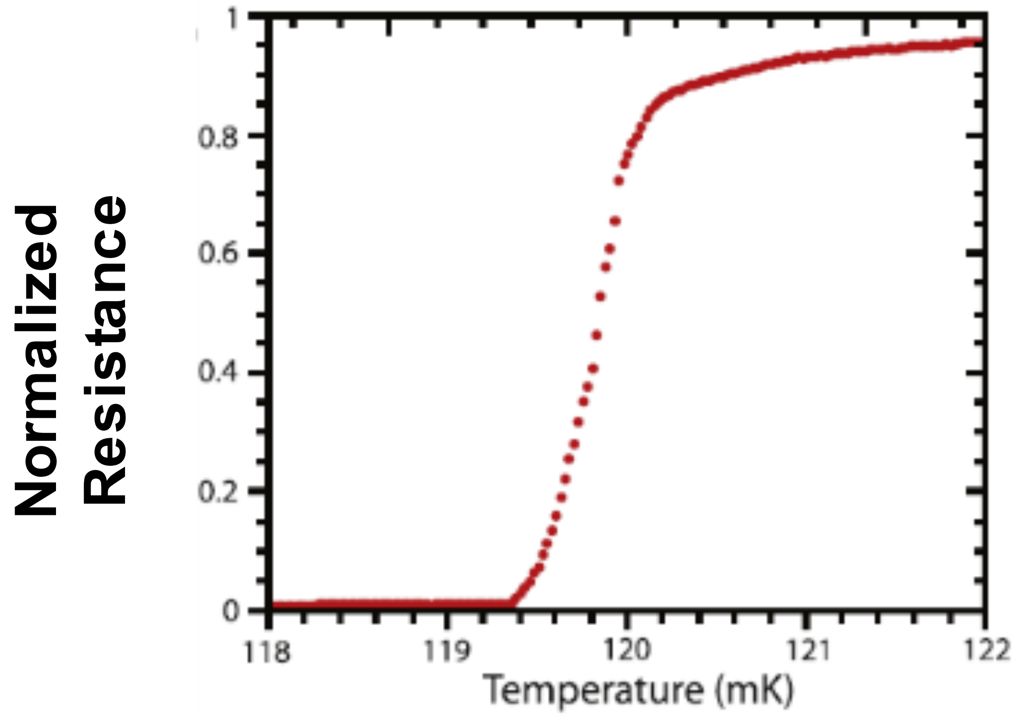
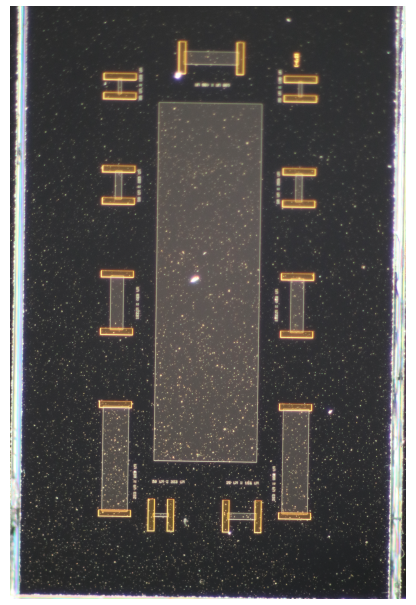
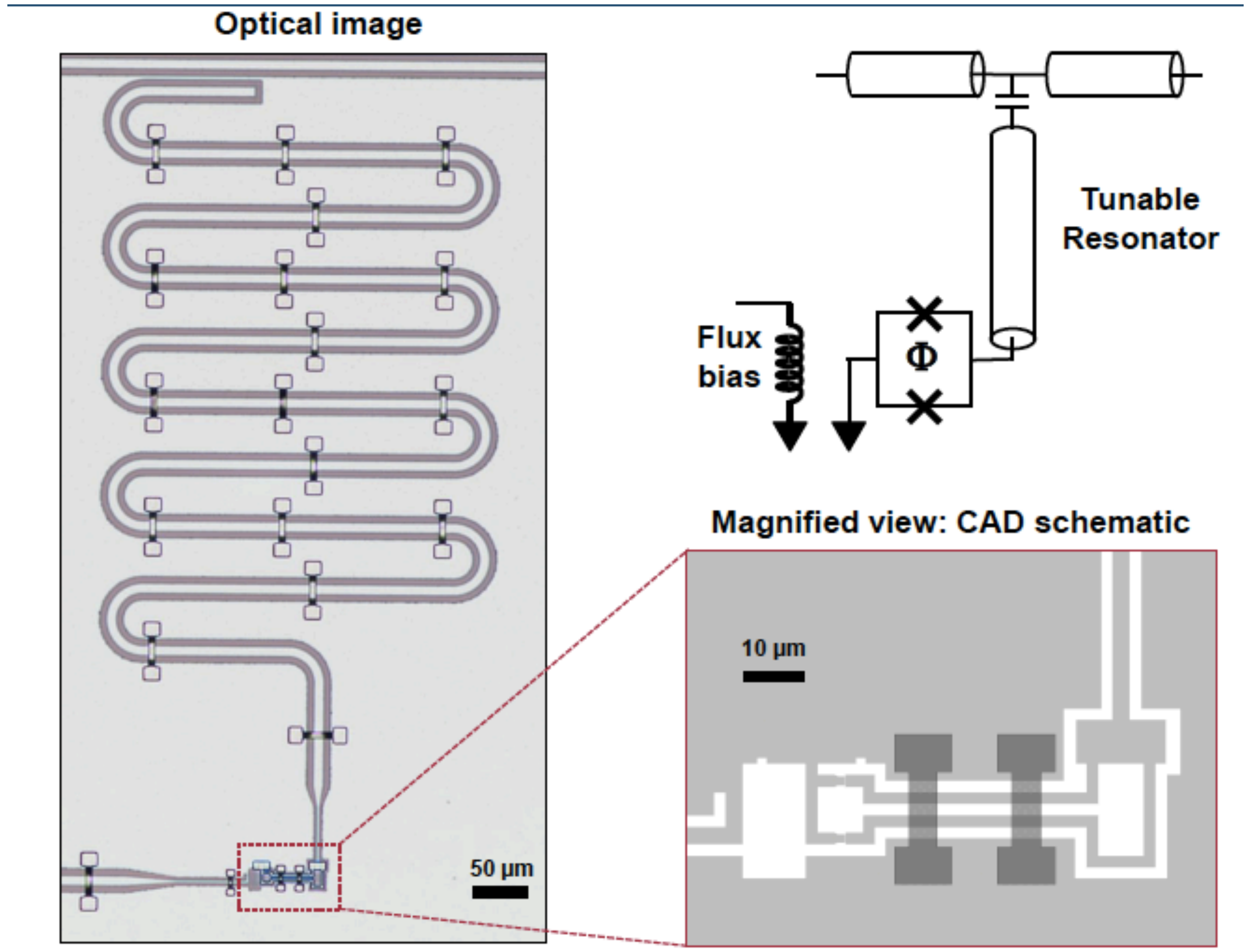




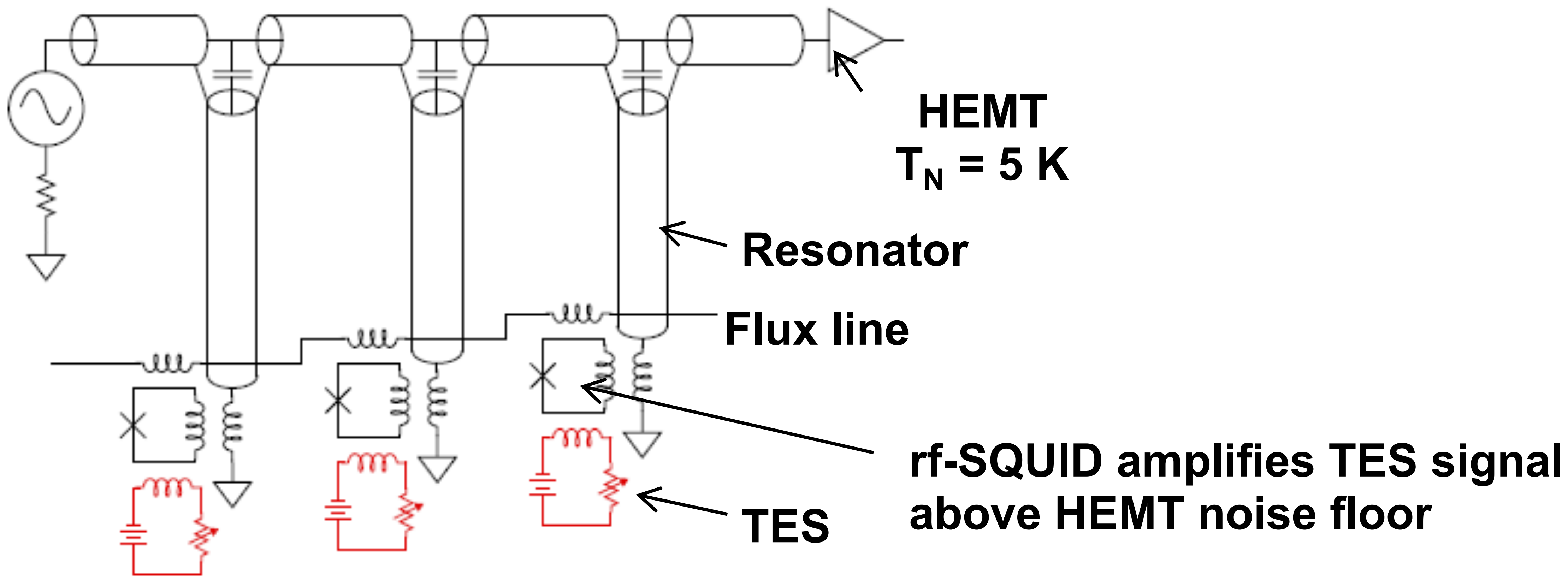
SQUID Readout

See Talks by Christopher Leitz (today) and Steven Weber on Monday!

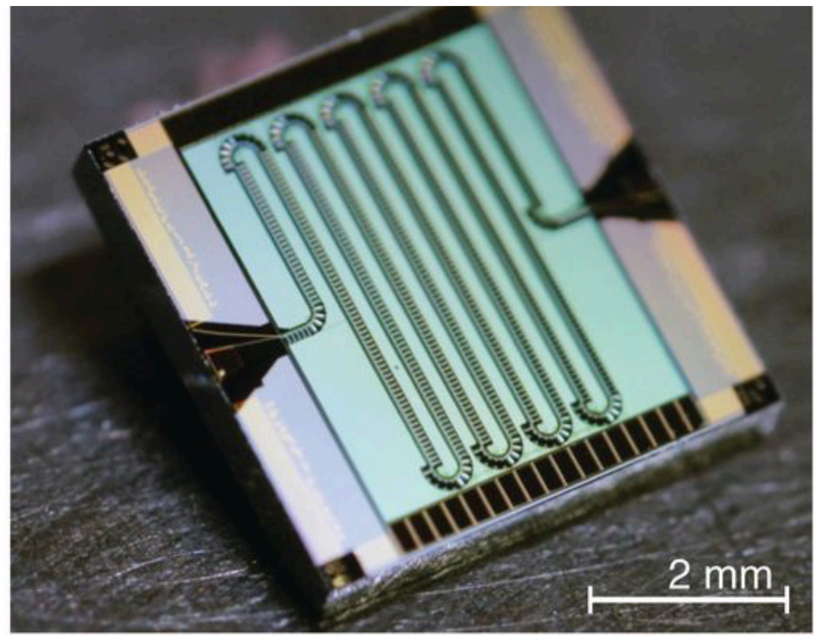
- Successfully secured ACC grant with **Lincoln Laboratories** to work on multiplexing SQUID array.
- Leverage large fabrication infrastructure for development of **quantum readout devices**.
- Developing RF-SQUIDs (micro-resonators) to read multiple channels with one system.
- Tuned resonators based on transmission line impedance. Each resonator is tuned to a specific frequency (around 7 GHz).



uMux Schematic



rf-SQUID amplifies TES signal above HEMT noise floor



Traveling Wave Parametric Amplifiers

RICOCHET

Science

Detectors

Location

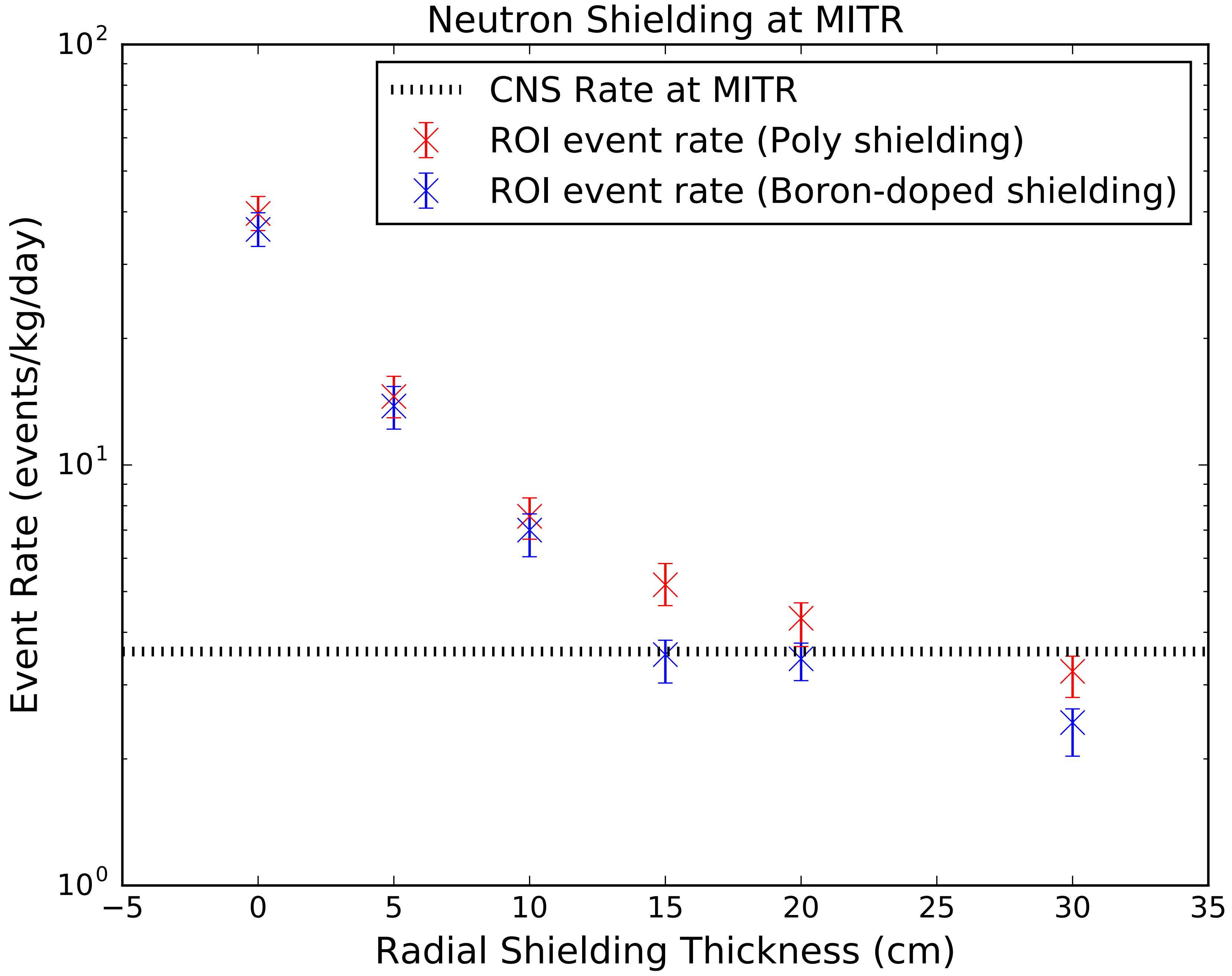
Count Rate

- The following table lists the potential detection and rate capability assuming a 1 kg target detector and a 50 eV energy threshold. This is the reach from current technology.
- Megawatt reactors can yield rates at meter-scale distances; Gigawatt reactors at hundreds of meters distances.

	Power (Megawatts)	*Distance (meters)*	*Neutrino Flux*	*Detected Events (per day)*
Double Chooz (France)	***4250***	***400***	***5×10^{10} ν/cm²/s***	***0.6***
MITR (USA)	***5.5***	***4***	***6×10^{11} ν/cm²/s***	***7.4***
ILL (France)	***58.3***	***10***	***1×10^{12} ν/cm²/s***	***12.5***
Double Chooz (France)	***4250***	***80***	***1.2×10^{12} ν/cm²/s***	***14.3***
Brokdorf (Germany)	***3900***	***17***	***2.4×10^{13} ν/cm²/s***	***290***
Kalinin (Russia)	***3000***	***10***	***5×10^{13} ν/cm²/s***	***645***

The Early Ricochet Program

- Early potential location, the MIT research reactor in Cambridge, MA
- Details:
  - 5.5 MW thermal tower
  - 4.5x10^{11} ν/cm^2/s @ 4 meters from core
  - 4 weeks on, 1 week off operating cycle
- PROs:
  - Ideal for sterile neutrino searches
- CONs:
  - practically no overburden,
  - reactogenic background is very large



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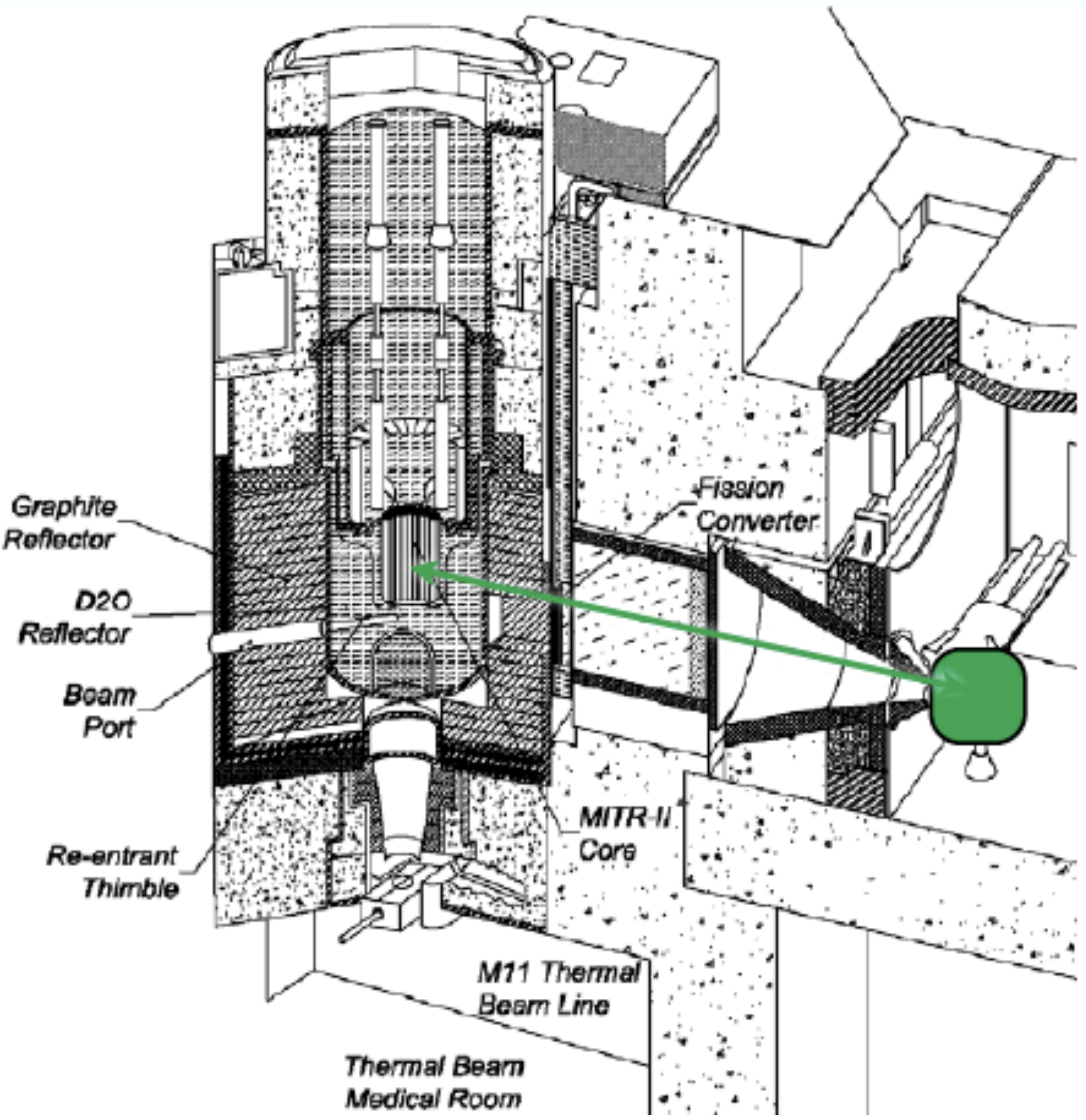
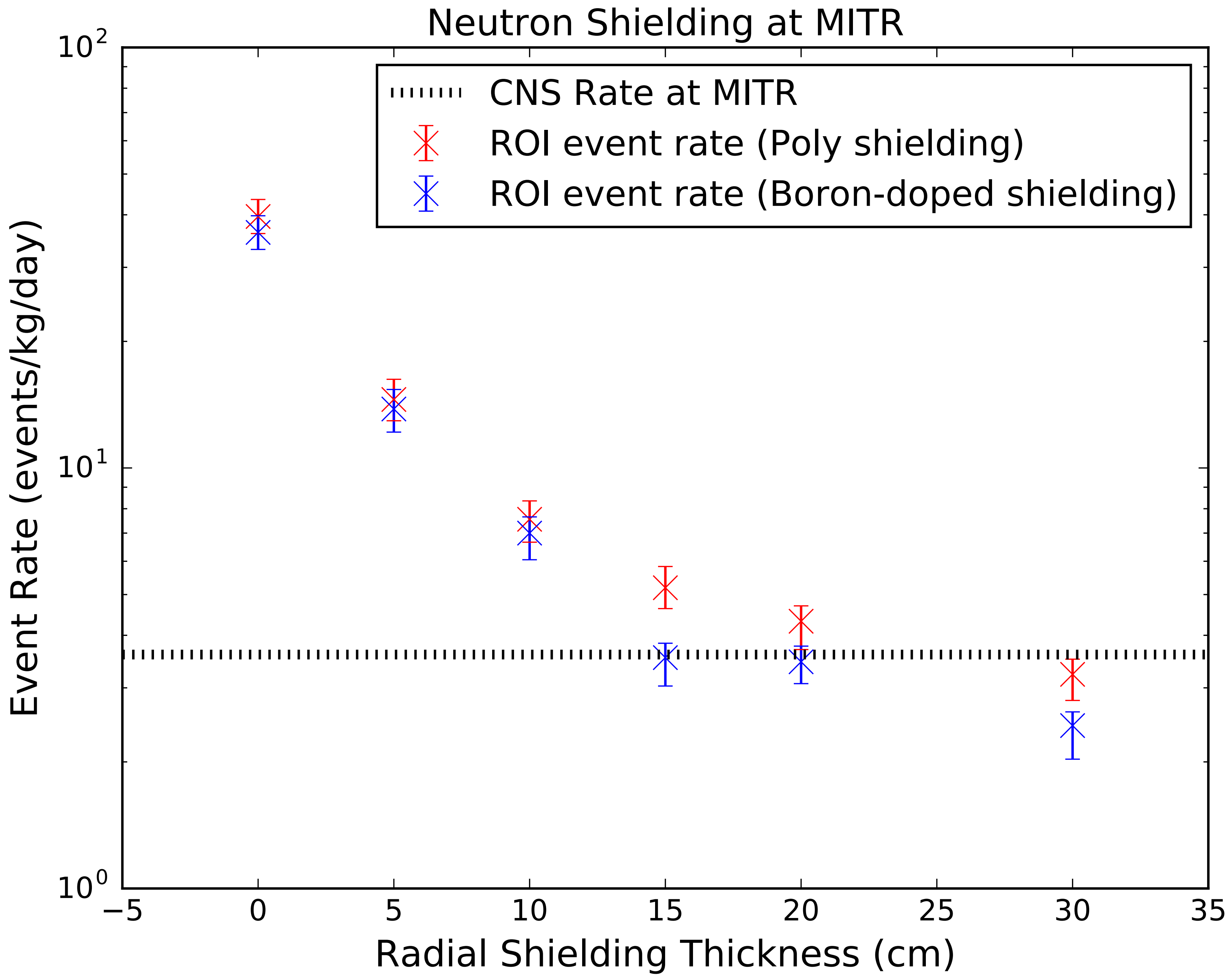




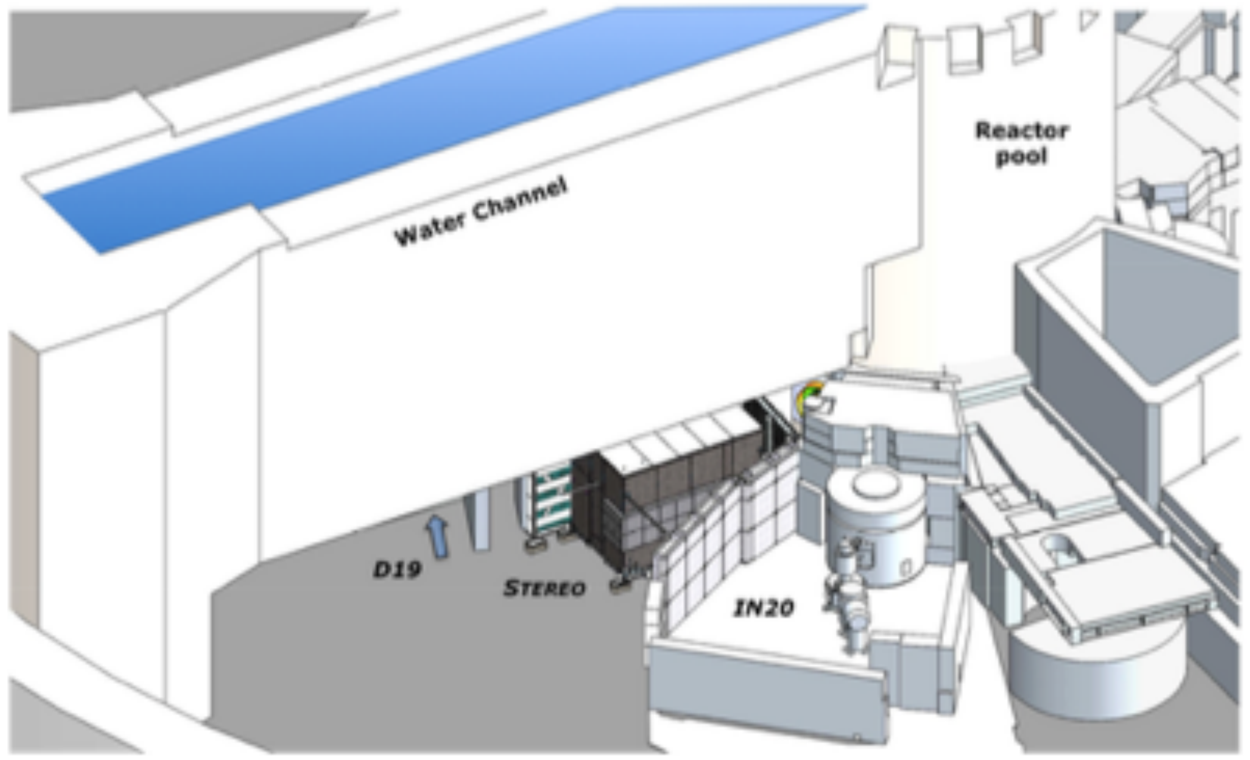
Ricochet @ Chooz

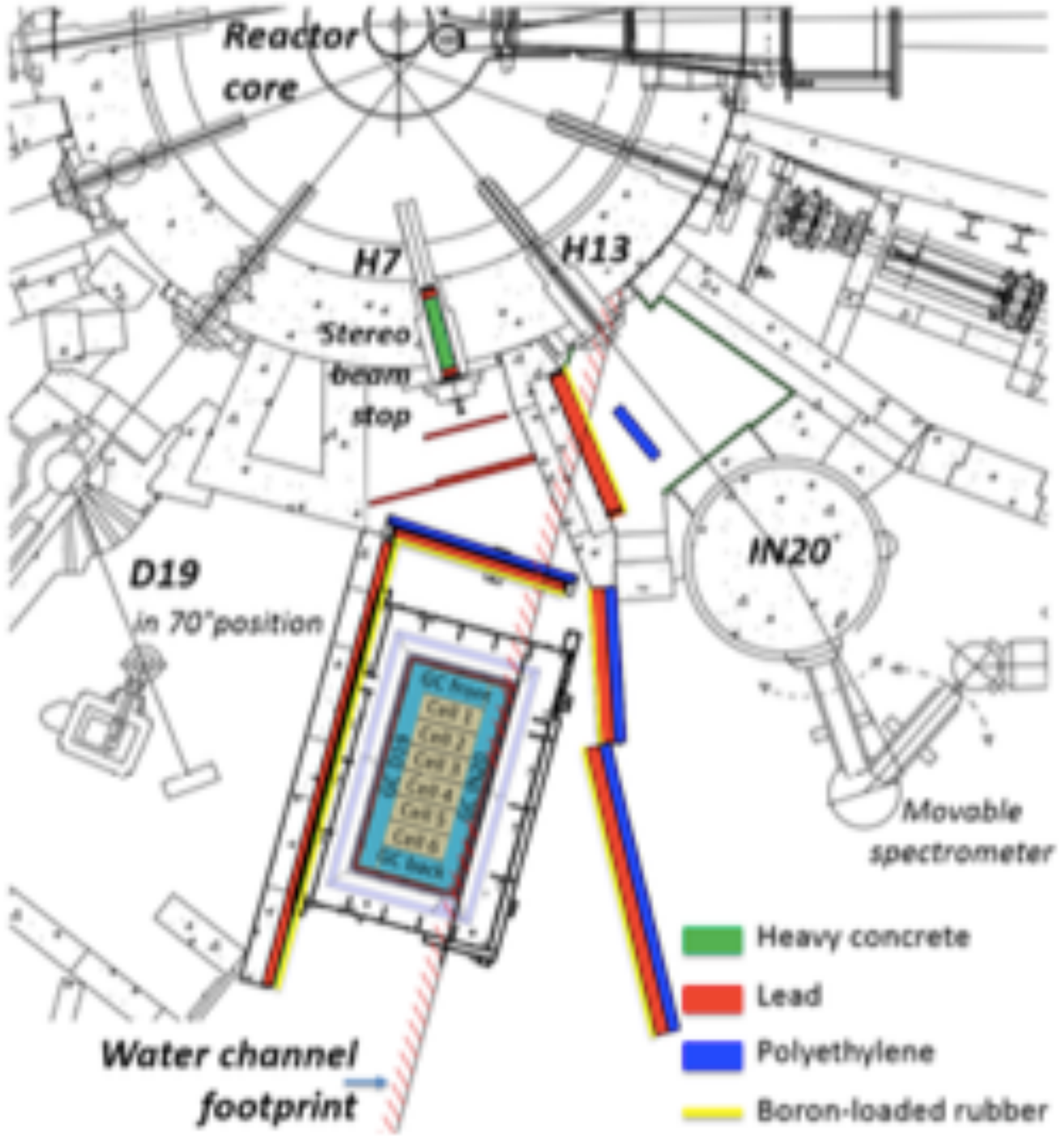
- ***The Chooz Near Site***
  - Chooz two core reactors (~8.5 GW power combined).
  - About 400 meters from the cores with 150 m.w.e. overburden.
  - Thermal power changes over the course of the year (40% with one reactor off).
- **PROs:**
  - Almost zero neutron background from reactor. Infrastructure already exists.
  - 120 m.w.e. overburden allows for significant reduction of cosmogenic background.
- **CONs:**
  - Low CEvNS rate
  - Not optimal for sterile searches

The Chooz Reactors

Ricochet @ ILL

- ***The ILL Grenoble Site***
  - 58 MW thermal power.
  - Over 20 events/day/kg at 7 m from the core.
- **PROs:**
  - 3-4 cycles per year, ideal for ON/OFF background studies
  - Significant (15 m.w.e) overburden for background reduction.
  - Benefit from STEREO experience
- **CONs:**
  - Presence of active neutron beam lines.





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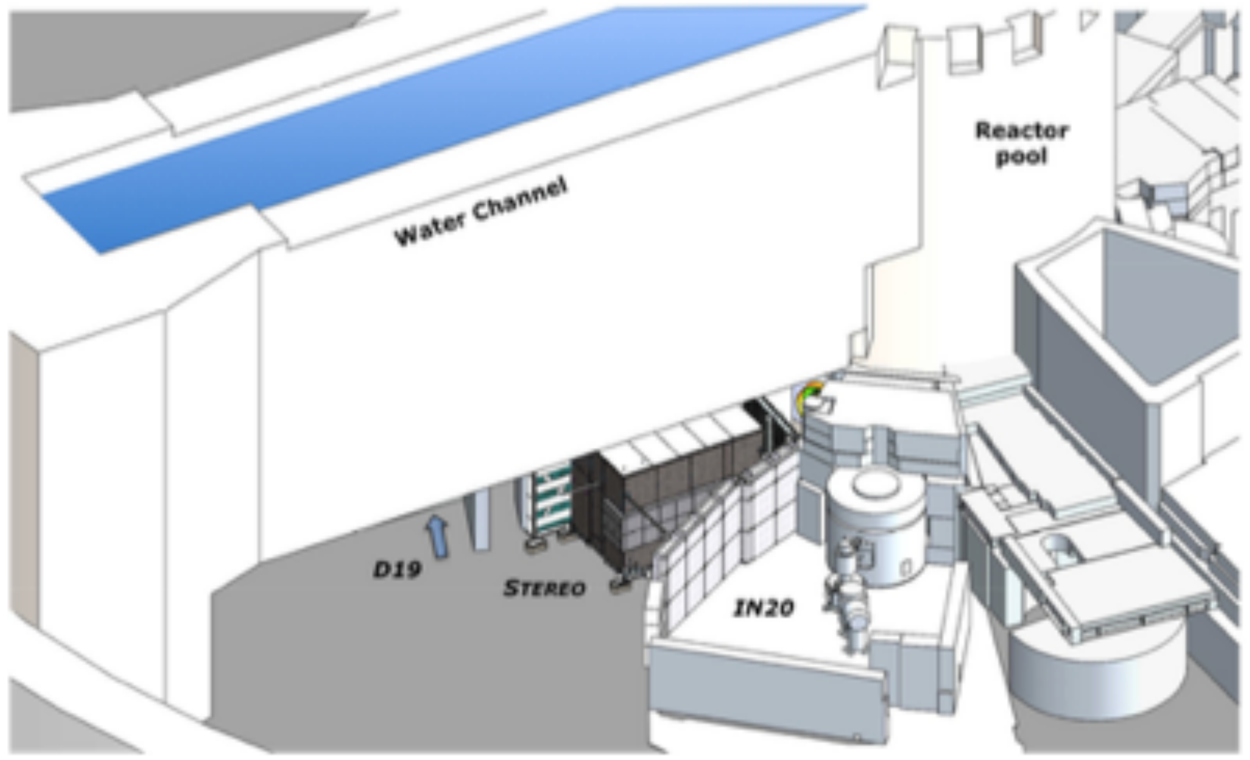
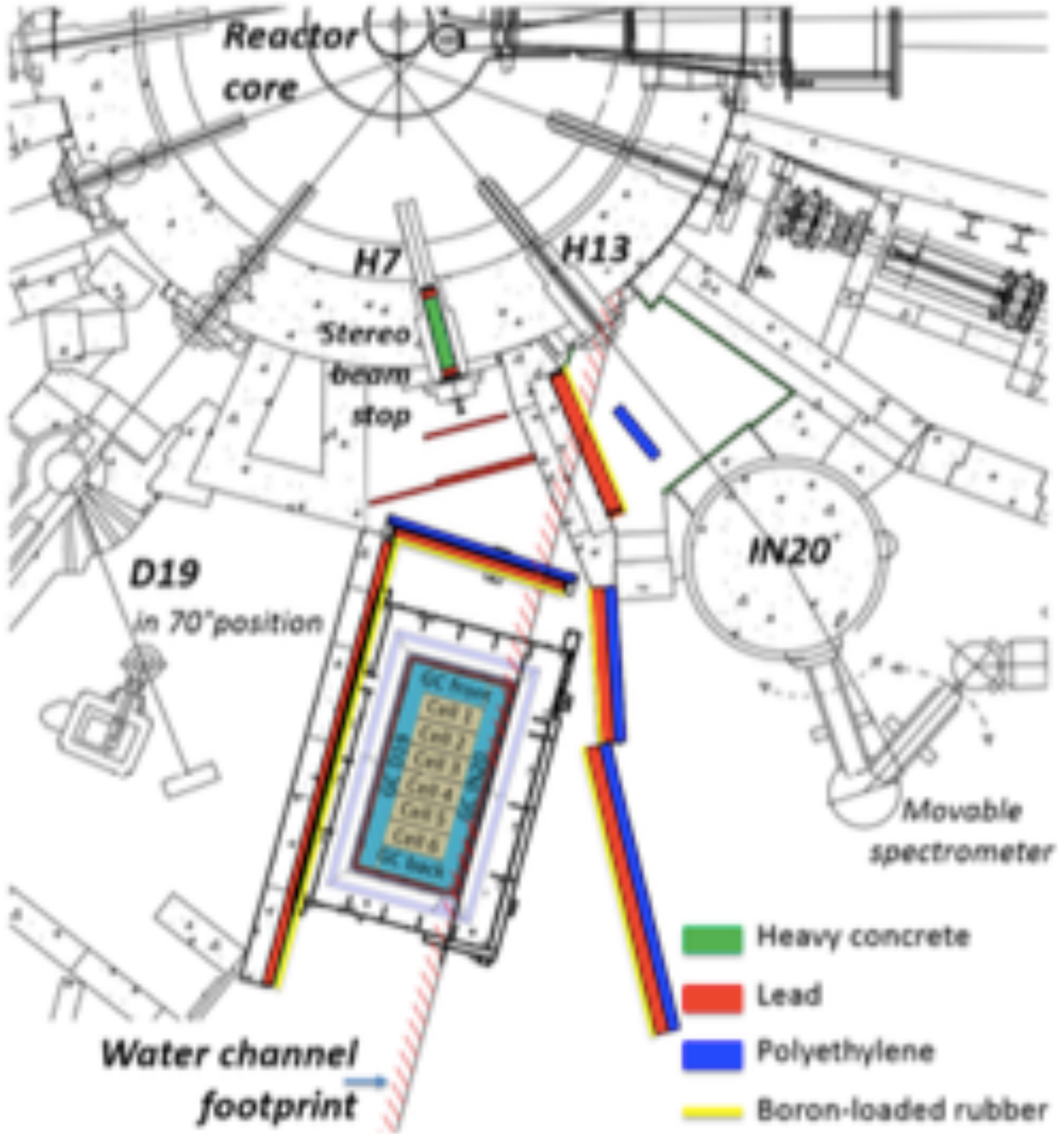




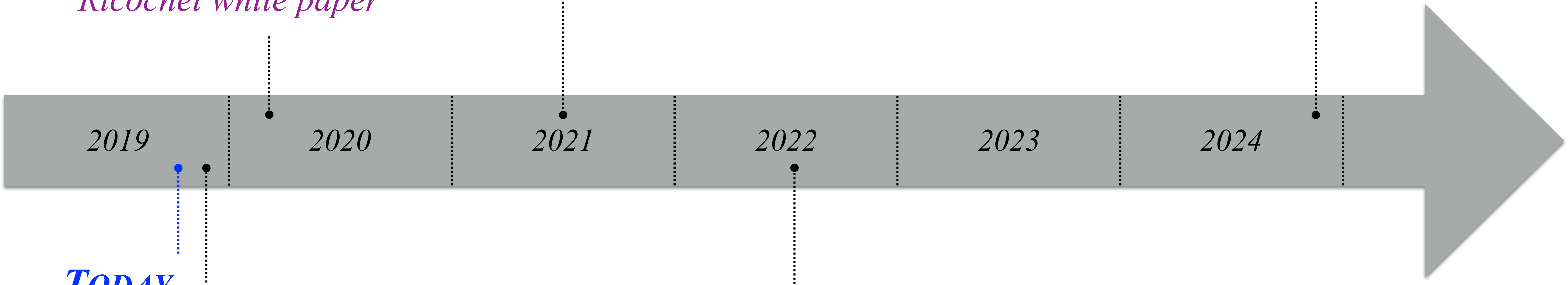
Letter of Intent submitted to ILL for consideration

Timeline

2021:
Ricochet's technical design completed
(mechanics, cryostat, cabling, and warm elec.).
Single crystal design completed (threshold & PID)

2024:
Deliver the first low-energy (sub-100 eV)
high-precision (%-level) CENNS measurement
after 1 year of data taking

2020:
Ricochet white paper



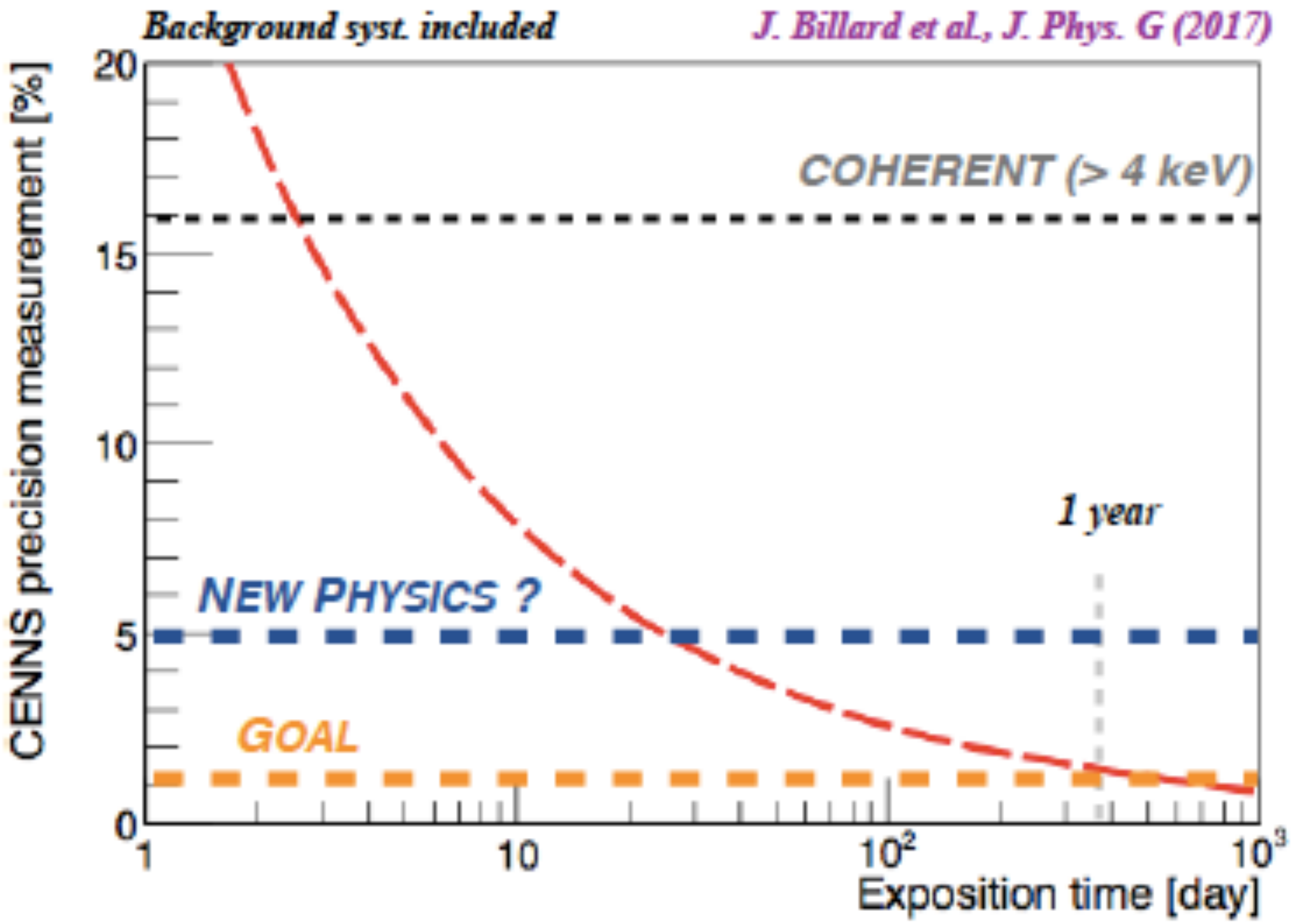
TODAY

End-2019:
Nuclear site decision and
first version of Ricochet's
experimental setup

2022:
Deployment of the Ricochet experiment
at the chosen nuclear reactor site.
CRYOCUBE & Q-Array delivery date

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 using promising and proven bolometric technologies.

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

RICOCHET

THANKS FOR YOUR ATTENTION

MIT

IPNL

Northwestern

University of Massachusetts Amherst 1863

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

CSNSM
CENTRE DE SCIENCES NUCLÉAIRES ET DE SCIENCES DE LA MATIÈRE

LPSC
Grenoble