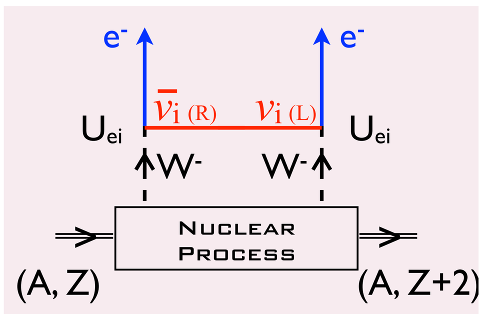
Low T_C TES for a Cuore Upgrade with Particle Identification (CUPID)

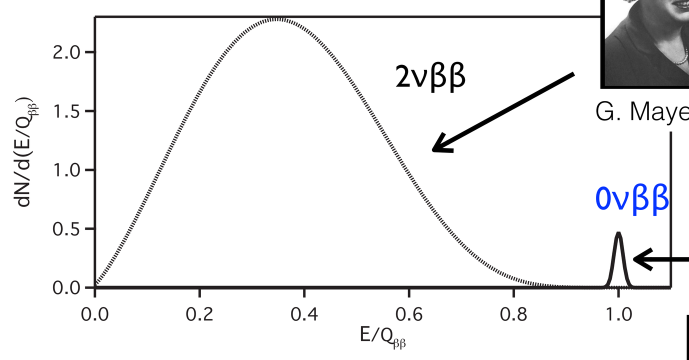
R. Hennings-Yeomans[1, 2], C.L. Chang[3, 4, 5], J. Ding[6], A. Drobizhev[1, 7], B.K. Fujikawa[1, 7], S. Han[1], G. Karapetrov[8], Y.G. Kolomensky[1, 7], V. Novosad[6], T.O'Donnell[1, 7], J.L. Ouellet[1,9], J. Pearson[6], T. Polakovic[6, 3, 10], D. Reggio[1], B. Schmidt[7], B. Sheff[1], V. Singh[1, 7], R.J. Smith[1], S. Wagaarachchi[1], G. Wang[3], B. Welliver[7], and V.G. Yefremenko[3]

1)Department of Physics, University of California, Berkeley, CA 94720 USA 2)Nuclear Science Division, Lawrence Berkeley NationalLaboratory, Berkeley, CA 94720 USA 3)High Energy Physics Division, Argonne National Laboratory, Argonne, IL 60439 USA 4)Kavli Institute for Cosmological Physics, University of Chicago, Chicago, IL 60637 USA 5)Department of Astronomy and Astrophysics, University of Chicago, Chicago, IL 60637 USA 6)Materials Science Division, Argonne National Laboratory, Argonne, IL 60439 USA 7)Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley CA 94720 USA 8)Physics Department, Drexel University, Philadelphia, PA 19104 USA 9)Massachusetts Institute of Technology, Cambridge, MA 02139 USA 10)Physics Department, Drexel University, Philadelphia, PA 19104 USA

Neutrinoless Double Beta Decay

- Hypothetical ββ decay mode allowed if neutrinos are Majorana particles, i.e $\bar{\nu}_i \equiv \nu_i$





G. Mayer in 1935

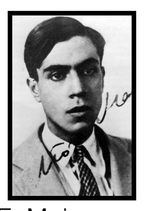
Phase space factor — Nuclear matrix element

$$\frac{1}{T^{0\nu}_{1/2}} = G^{0\nu}|M^{0\nu}|^2|\langle m_{\beta\beta}\rangle|^2$$

Decay half-life — Effective Majorana ν mass:

$$m_{\beta\beta} \equiv \left|\sum_{i=1}^{3} U^2_{ei}\, m_i\right|$$

1937



E. Majorana in 1937

- For $m_{\beta\beta}$ = 15 meV estimated half lives 10^{27} - 10^{28} years, depending on the nuclear system

- *Observation of 0νββ would mean*
  - Lepton number violation
  - Neutrinos are Majorana particles
  - Rate measures (effective) electron neutrino mass

Bolometers as a tool for discovery

- The Cryogenic Underground Observatory for Rare Events (CUORE) is a 0νββ decay search experiment of ^{130}Te utilizing TeO_2 bolometers as a detector and source. Observation of 0νββ decay implies that neutrinos are their own anti-particles, i.e. Majorana neutrinos.
- TeO_2 crystals were produced by Shanghai Institute of Ceramics, Chinese Academy of Sciences (SICCAS) in Shanghai, China. A crystal is shown on Figure 1(a) top right.
- A tower is made of 52 TeO_2 crystals. The assembly is performed inside a globe box with a nitrogen gas flow to prevent radioactive contamination from radon decays. Figure 1(a).
- The detector assembly of CUORE is made of 19 towers (988 TeO_2 crystals) and is currently taking data at the LNGS underground lab.

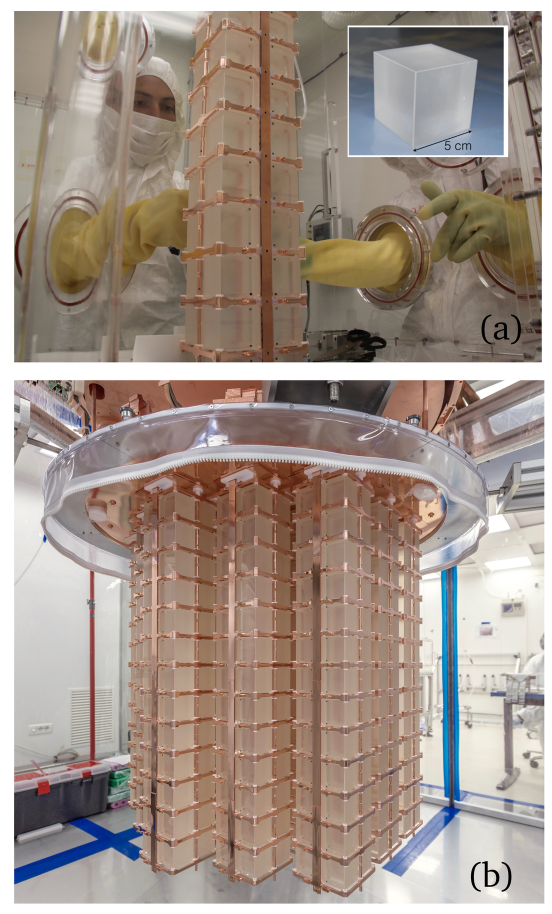
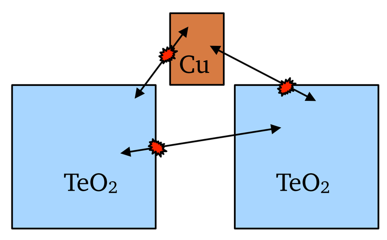
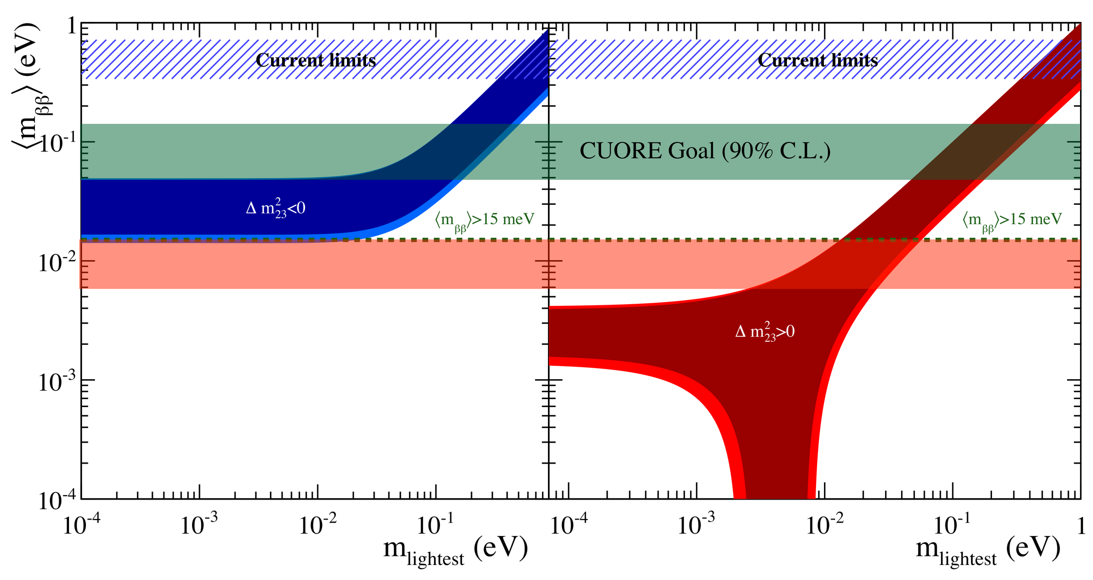


Figure 1 (a) Tower assembly. (b) 19 towers installed in CUORE.

CUPID: Cuore Upgrade with Particle Identification

- 988 enriched (90%) crystals, particle identification with light detection
- Sensitivity to cover IH region
  - Reduce backgrounds to 0.02 events / (ton-year)
  - 99.9% α rejection @ >90% signal efficiency
  - 5 keV FWHM resolution
  - Half-life sensitivity (2-5)x10^{27} years in 10 years (3σ)
  - $m_{\beta\beta}$ sensitivity of 6-20 meV (3σ)





CUPID Interest Group arXiv:1504.03612 & arXiv:1504.03599

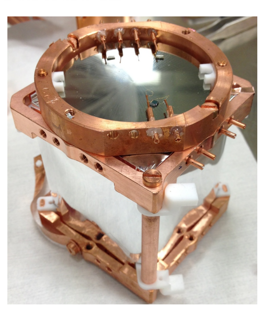
Background origin:

(a) 65% from alpha-particles from both crystal and copper surfaces due to U/Th contamination

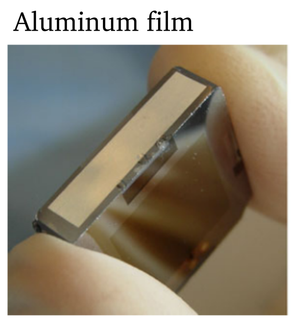
(b) 35% from external gamma rays from the ^{232}Th chain from the cryostat

The path to reach sensitivity goal

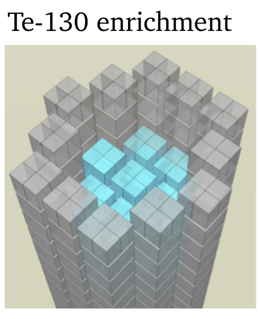
Particle ID

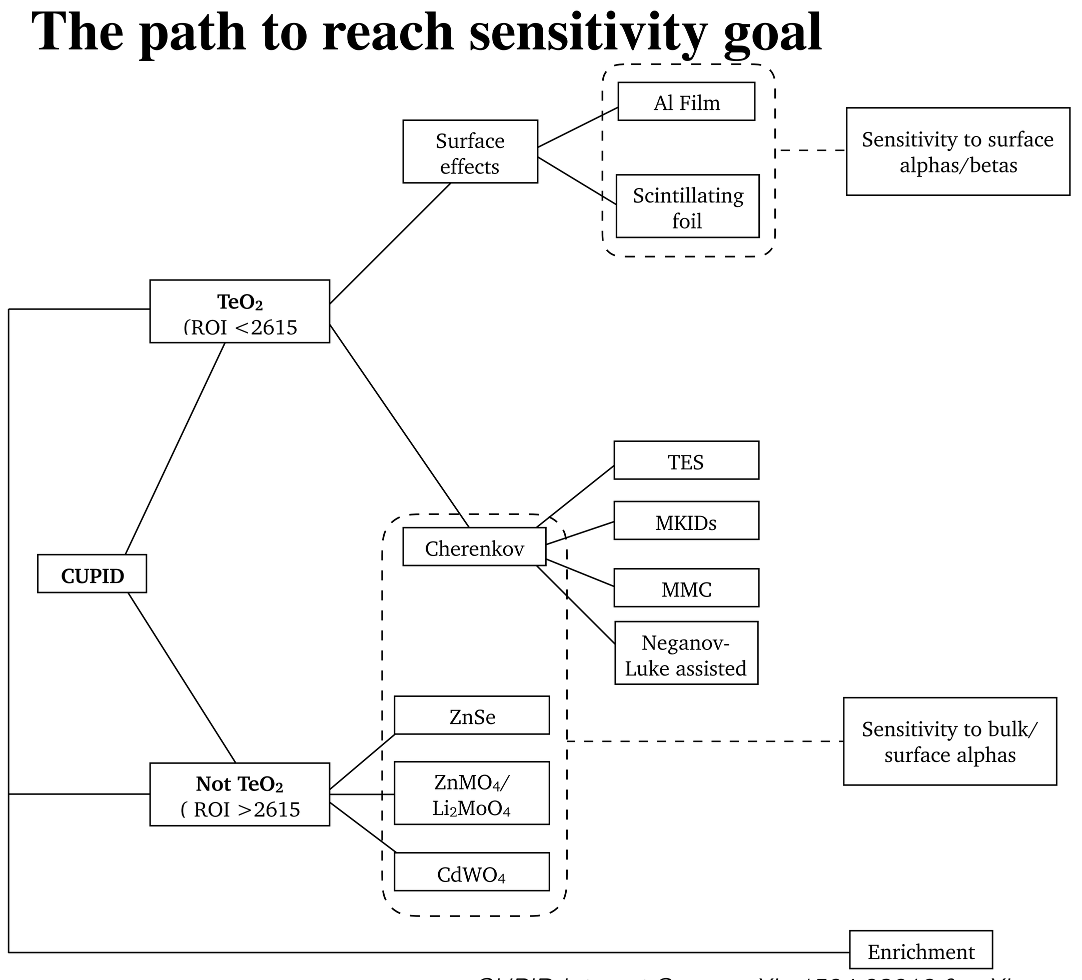


Aluminum film



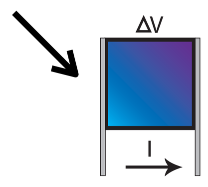
Te-130 enrichment

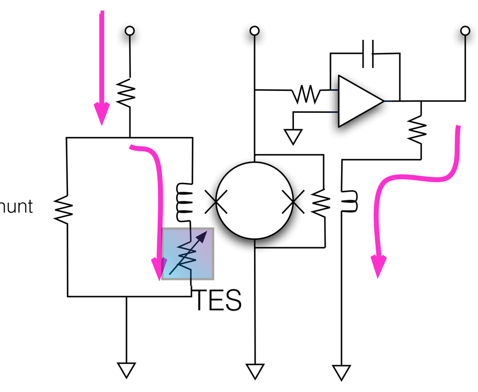


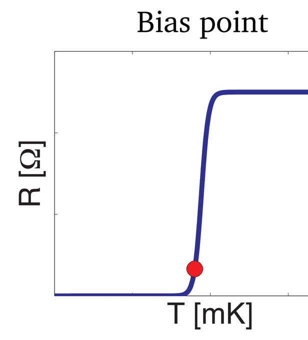


CUPID Interest Group arXiv:1504.03612 & arXiv:

Development of Transition Edge Sensors







$$\Delta E_{rms} = \sigma_E \approx \sqrt{\frac{4k_BT^2C_{tot}}{\alpha}}\sqrt{\frac{\beta+1}{2}},$$

K.D. Irwin, Appl. Phys. Lett. Vol. 66, 1998 (1995)

$C_{tot} = C_{bolo}\ (\sim T^3) + C_{TES}\ (\sim T)$ + C_{other} (e.g. caused by impurities in the crystal)

$\alpha \equiv \frac{T}{R}\frac{dR}{dT}$ β: determined by thermal conductivity between the TES and absorber/heat-bath

Low Tc TES fabrication possibilities:

- W-TES may be possible through ion implantation
- Grow W-alpha phase for Low Tc
- Utilize superconducting bilayers as TES (proximity effect)

Fabrication and Tc measurements

- We fabricated superconducting multilayers by sputtering deposition on high-resistivity silicon wafers at Argonne National Laboratory.
- Sputter depositions were made at room temperature for Au/Ir/Au trilayers and Ir/Pt bilayers.
- Deposition rates of about 2.6 A/sec for Ir, 2.9 A/sec for Au and 2.1 A/sec for Pt films were used. In the case of Au/Ir/Au trilayers, a 3 nm thick iridium layer was deposited prior to the trilayer
- After all film layers were deposited, the wafers were diced into squares of 3 mm per side. Subsequently, the chips were attached to a copper plate using GE-varnish and wire bonded in 4-wire measurement configuration for a resistance measurement.

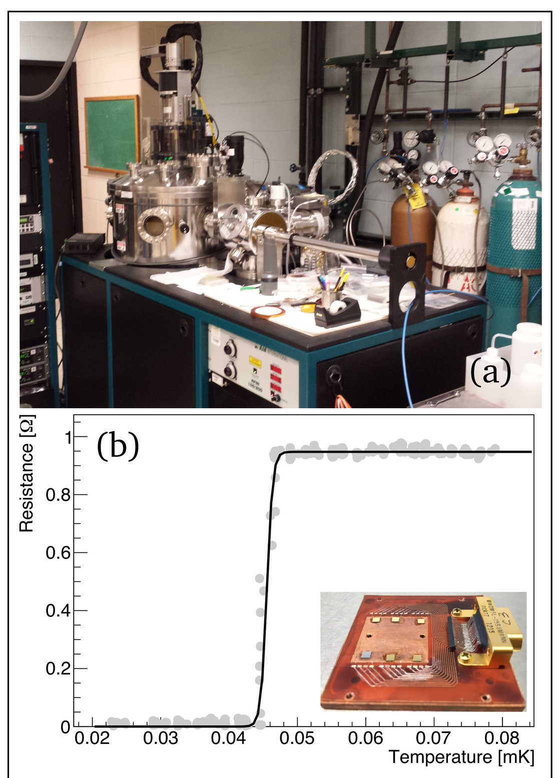


Figure 2 (a) Sputtering chamber at ANL. (b) Resistance vs temperature data and fit for an Ir/Pt bilayer (Ir=100 nm and Pt=60 nm).

Demonstration of Tc suppression between 18-100 mK

- We found two room temperature multilayer systems, fabricated by sputtering deposition, that could be utilized as materials for low-T_c superconducting TES fabrication: Ir/Pt bilayers and Au/Ir/Au trilayers.
- The superconducting thin film multilayer systems presented here could be applied in next generation Dark Matter searches and in next generation experiments searching for neutrinoless double beta decay in which both a secondary light detector of either Cherenkov or scintillation light may be required.
- The fact that these thin films can be deposited at room temperature allows for the possibility to sputter room temperature TES on the bulk of the crystals for improved timing and energy resolution.

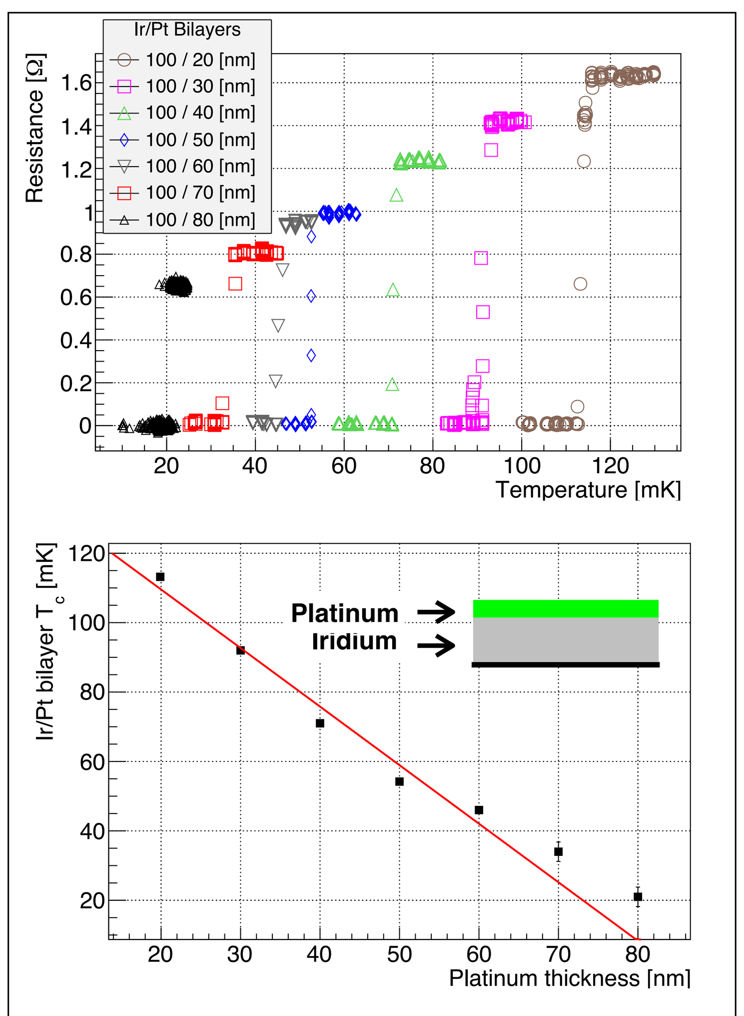


Figure 3. Top) Measurements of the T_c suppression in Ir/Pt bilayers in which both the iridium (100 nm) and platinum (20-70 nm) layers were deposited at room temperature. A bias current of 3.16 A was used and the uncertainty in the T_c measurement includes the difference between scans increasing or decreasing in temperature. Bottom) Resistance vs temperature data for Ir/Pt bilayers and from which T_c was obtained.

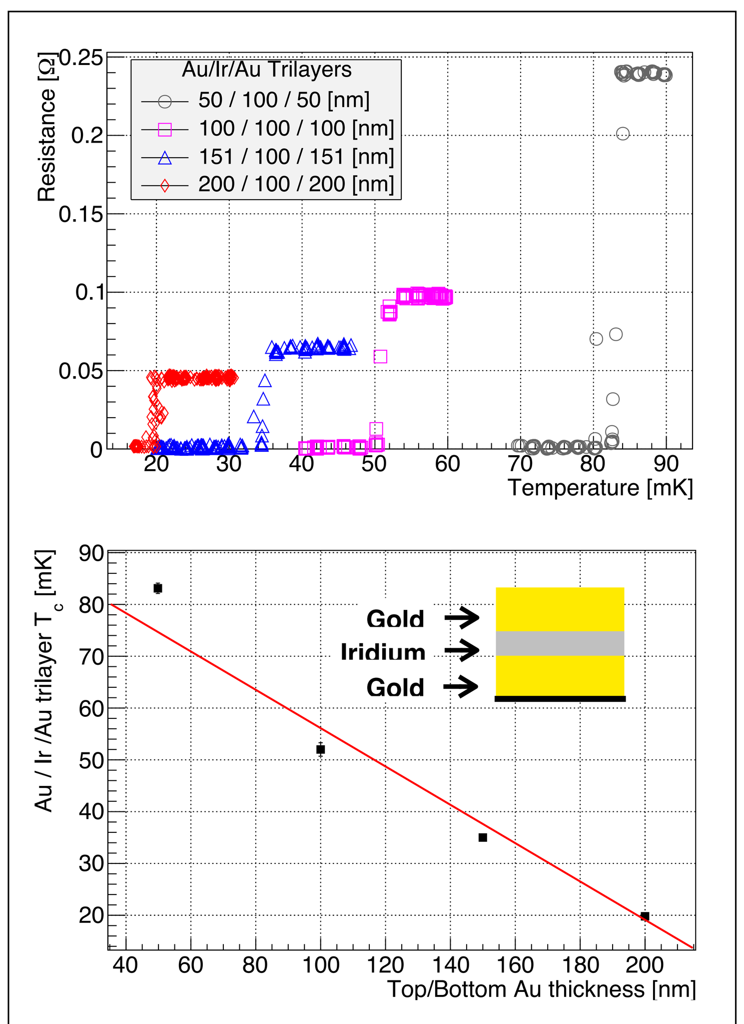


Figure 4. Top) Measured T_c vs gold thickness on top (or bottom) for Au/Ir/Au trilayers in which all three layers were deposited at room temperature. The iridium thickness is 100 nm for all samples. The same amount of gold was deposited on top and bottom of the iridium. Bottom) Resistance vs temperature data for each Au/Ir/Au trilayer. A bias current of 31.6 A was used.

Acknowledgements

We would like to thank Paul Barton and Jeff Beeman for help dicing some of the samples and J.G. Wallig for engineering support. This work was supported by the Department of Energy (DOE), Office of Sciences, Office of Nuclear Physics under Contract DEFG02-00ER41138 and by the National Science Foundation under grants PHY-0902171 and PHY-1314881. Work at Argonne National Laboratory was supported by DOE, Office of Sciences, Basic Energy Sciences, under Grant No. DE-AC02-06CH11357 and Office of Nuclear Physics, under Grant No. DE-FG02-96ER40950.