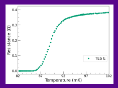
Understanding Dark Counts in Superconducting Transition-Edge Sensors

جامعة نيويورك أبوظبي
NYU ABU DHABI

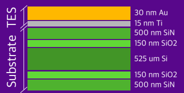
Isaac Sarnoff, Artem Knyazev, Carlo Pepe, Francesco Arneodo,
Laura Manenti, Mauro Rajteri, Tengiz Ibrayev

Transition Edge Sensors

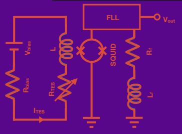


Superconducting Transition-Edge Sensors (TESs) are a relatively new type of sensor that relies on using a current to hold superconducting metal at the transition point between its superconducting and normal phases. TESs are an ideal sensor for very rare photon searches, since they have extremely low count rates, and can detect individual photons while measuring their energies.

Our TES is made of a gold-titanium layer deposited on a silicon substrate. The deposition of gold reduces the transition temperature of the titanium by the proximity effect. This is desirable as lower temperature transitions can make the TES more stable and more sensitive to lower energy depositions.



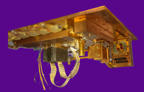
ADR and Readout



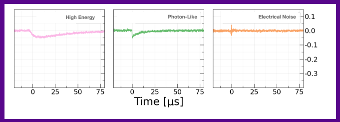
We employ a relatively standard voltage biased circuit for the TES. We use a SQUID as a trans impedance amplifier.

In order to achieve the 45mK required for the operation of our TES, we use an adiabatic demagnetization refrigerator.

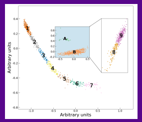
However, once the salt has depolarized, the strength of the magnetic field must be increased, and the salt repolarized before it can continue cooling. This makes our ADR a “one shot” refrigerator as opposed to the continuous operation available in dilution refrigerators.



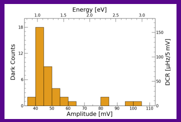
Determination Of Background Types



We observed three main types of events that can be visually distinguished which we call “High-Energy,” “Photon-Like” and “Electrical Noise” events. Photon-like events are visually identical to events from a laser. High energy events have a much slower rise and fall time and electrical noise events have large positive and negative values, cover very short timespans, and have integrated amplitudes close to zero.

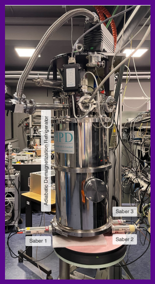


In order to efficiently sort them, we take a series of measurements of each event, including its FWHM, peak height, integrated amplitude. We then use singular value decomposition, principle component analysis and k-means clustering to seperate the points and group pulses based on their shape.



We can remove non-photon-like events. This artificially lowers our background by about 50 times to a rate of 360 uHz in the 0.8 to 3.2 eV energy range.

High-Energy Tests

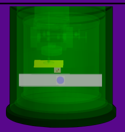


Thorium-232 and Sodium-22 were placed near the TES. Each resulted in more than an order of magnitude increases in the rate of high-energy events, but did not effect the rate of photon like events.

By placing scintillating plastic blocks coupled to photomultiplier tubes underneath of the refrigerator, we can detect cosmic rays and cosmic ray showers that go through the TES. By doing this, we can confirm directly that cosmic rays cause at least some of the high-energy events.

We also observed that one TES experienced roughly twice the number of high energy events. This TES had a substrate that was 1.9 times larger than the other TES. This leads us to the conclusion that high energy events originate from energy depositions in the substrate that propagate to the TESs rather than direct hits to the TESs themselves.

High-Energy Simulations



We also simulated our detectors, cryostat, sources, and sabers in GEANT4. We then generated cosmic rays and registered when the cosmic rays hit the detectors and the sabers as well as the energy depositions.

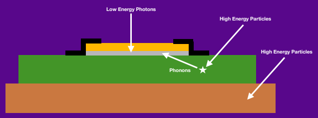
We also replicated the Thorium-232 source and the Sodium-22 source and generated decays.

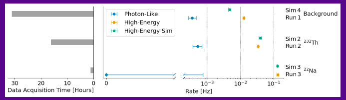
We discovered from the source simulations that using detectors associated with the size of the substrates produced event rates that corresponded to those observed. However, using the TESs size as the sensitive volume rather than the substrate resulted in significant undercounting of high-energy events.

Including the copper box that holds the substrate as part of the sensitive volume produces a drastic overcounting of events, further supporting that the substrate is the only source of high-energy events.

Conclusions

The majority of events seen by the TES come from high energy depositions in the substrate. The second largest group of events come from detector electronics rather than from the sensor. Since both of these groups can be easily discarded in photon searches, we can substantially reduce our background.





We are able to successfully attribute a large percentage of the observed high energy events to cosmic rays. However, we do not see a perfect match. ICPMS and HPGe tests suggest that the cause is in the simulation rather than the environment, but this remains to be further studied.