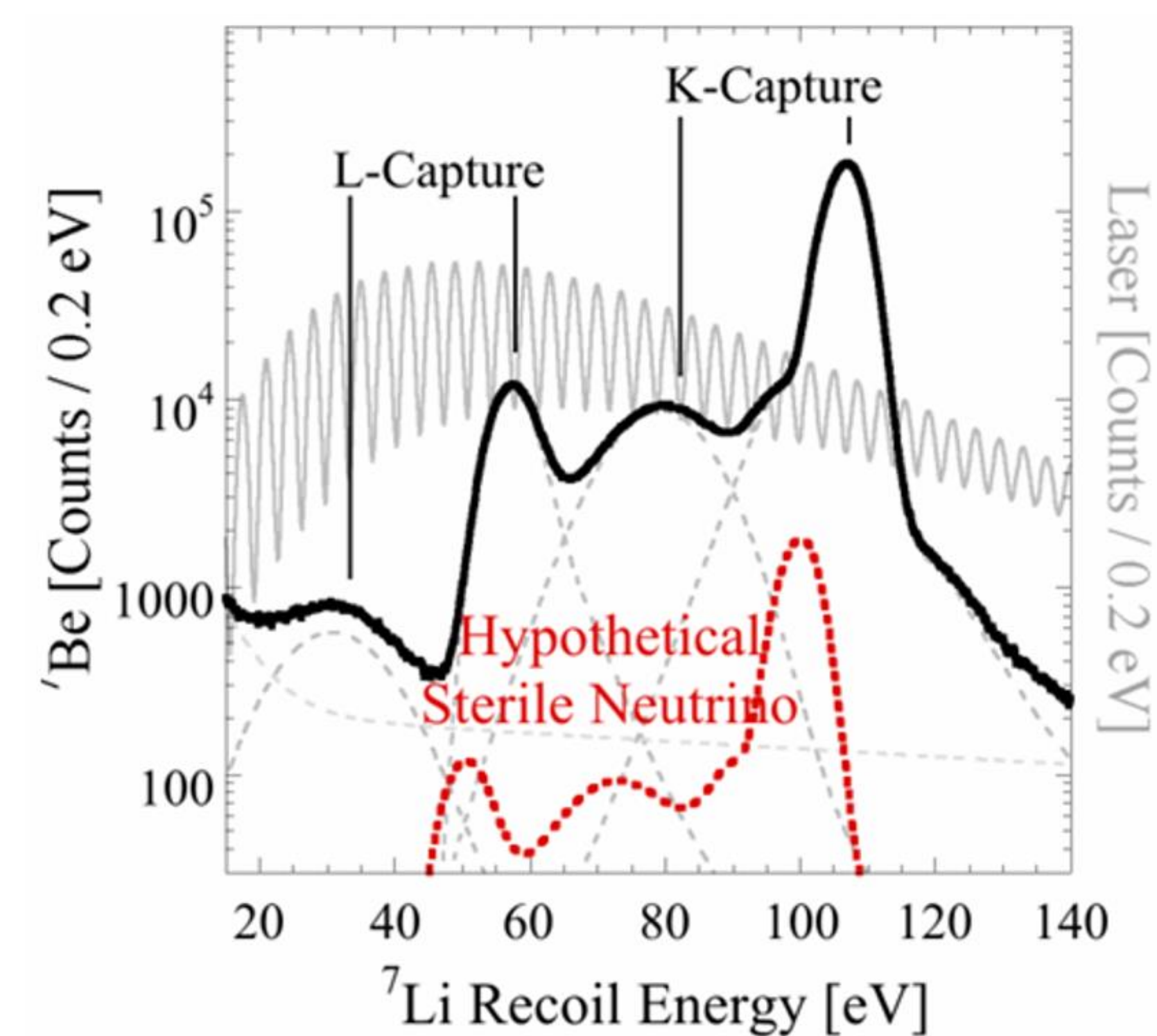


## Motivation

The measurement of atomic recoil energy must be very precise to detect any offset signals created by a heavy mass state (sterile) neutrino. Thus, it is critical that we eliminate any effects in our system that could mimic or otherwise affect our ability to correctly identify the offset sterile neutrino recoil spectrum. One such effect is the two-pixel correlated events, in which two nuclear recoil events are detected within a 5.6 μs coincidence window. This study identifies and determines the origins of such events to eliminate them in the Phase-IV detector array.

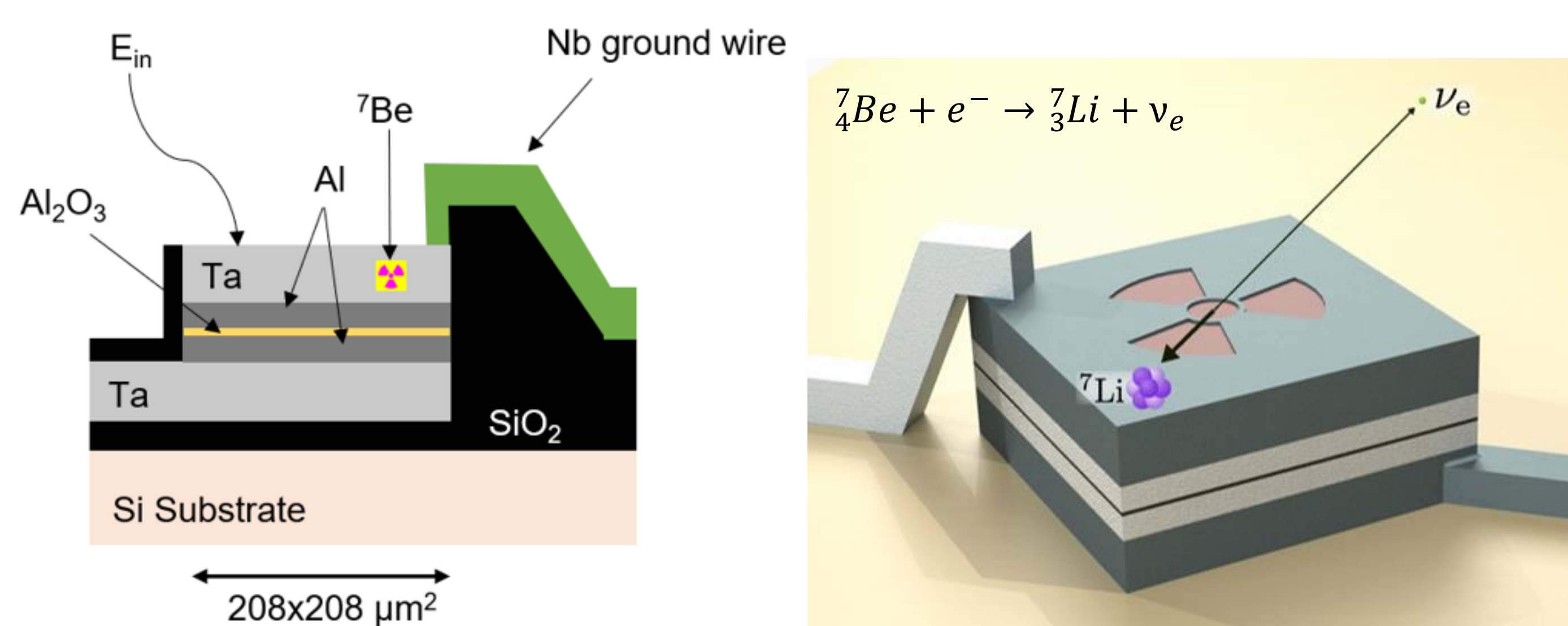
## The BeEST Experiment

- **Beryllium Electron Capture in Superconducting Tunnel Junctions**
- Search for heavy **sterile neutrinos** coupled to EC decay of <sup>7</sup>Be
- Precisely measure the **nuclear recoil** using an array of **Superconducting Tunnel Junctions (STJs)**<sup>1</sup>
- Heavy sterile neutrinos should create an **offset spectrum** with slightly lower recoil energy peaks due to their additional mass



## Superconducting Tunnel Junction Detectors

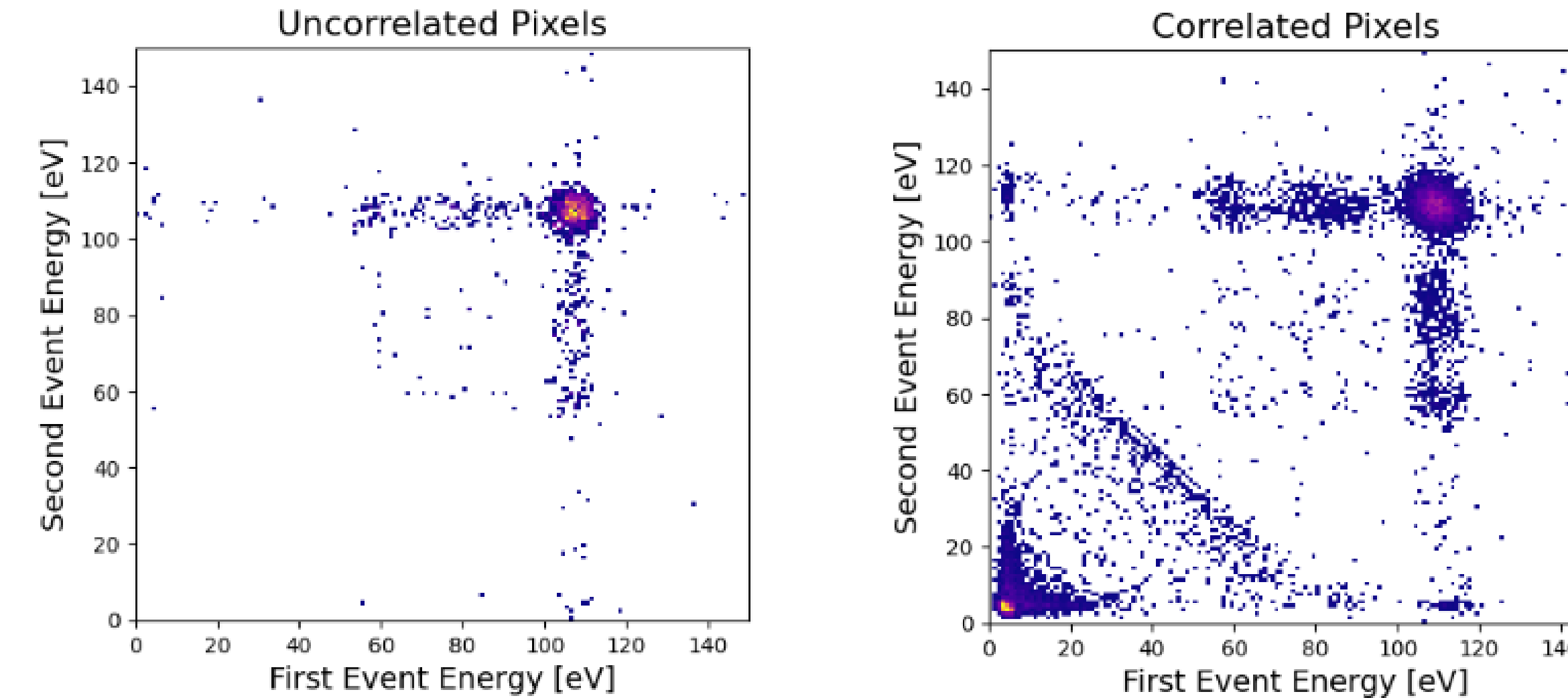
- Cryogenic sensor cooled to ~100mK, fabricated on Silicon substrate
- <sup>7</sup>Be ions **deposited** into top Ta layer<sup>2</sup> to directly detect the nuclear recoil inside Ta lattice
- Recoil energy breaks **Cooper Pairs** in the Ta, and free electrons **tunnel** through the insulating barrier to create a current that we can measure



## Identifying Two-Pixel Correlated Events

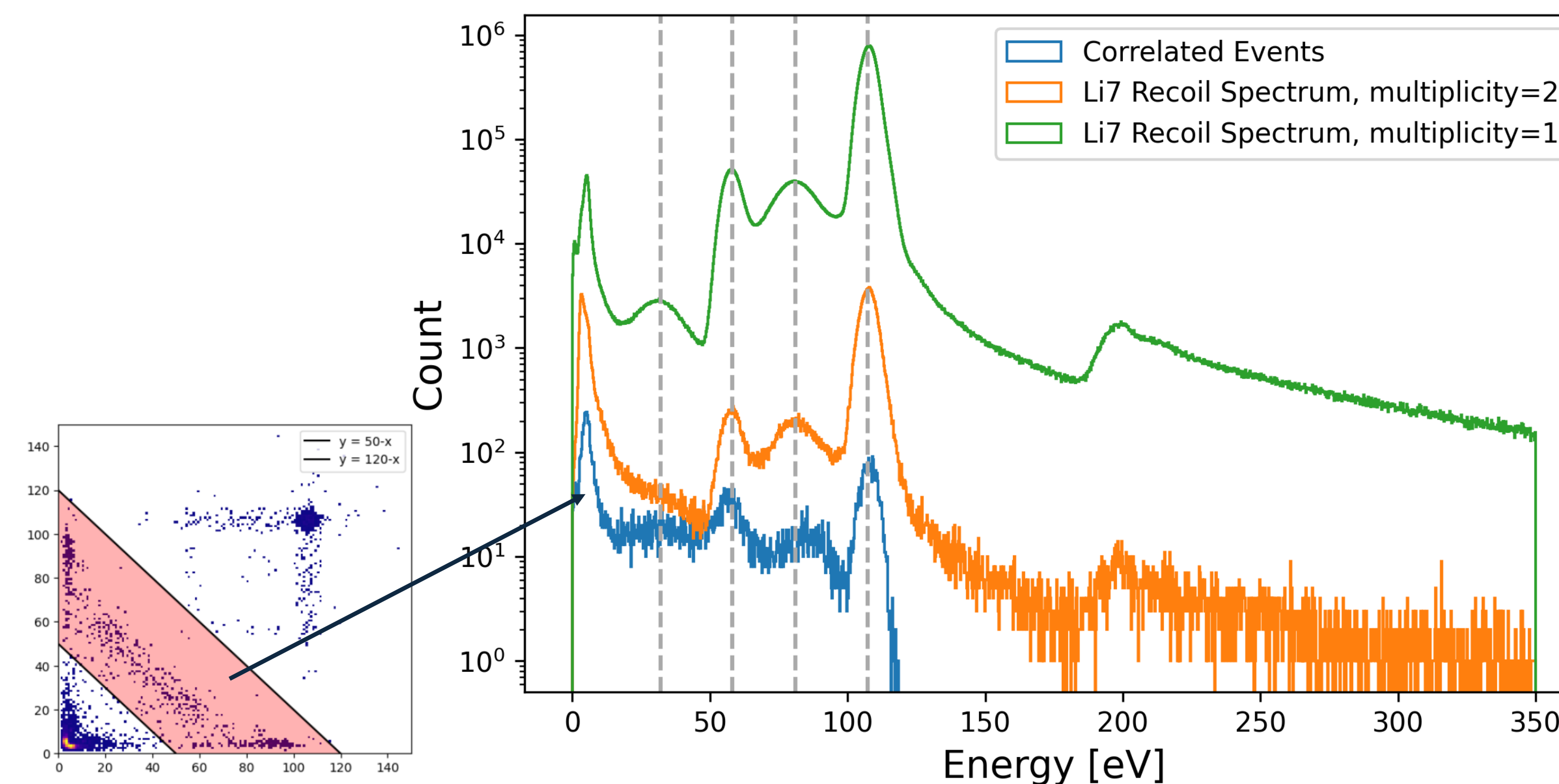
**Question:** can we see any anomalies in the multiplicity=2 data? Are these independent events or can we see some correlation in any of the channel combinations?

**Multiplicity:** number of pixels that detect an event in a 5.6 μs window



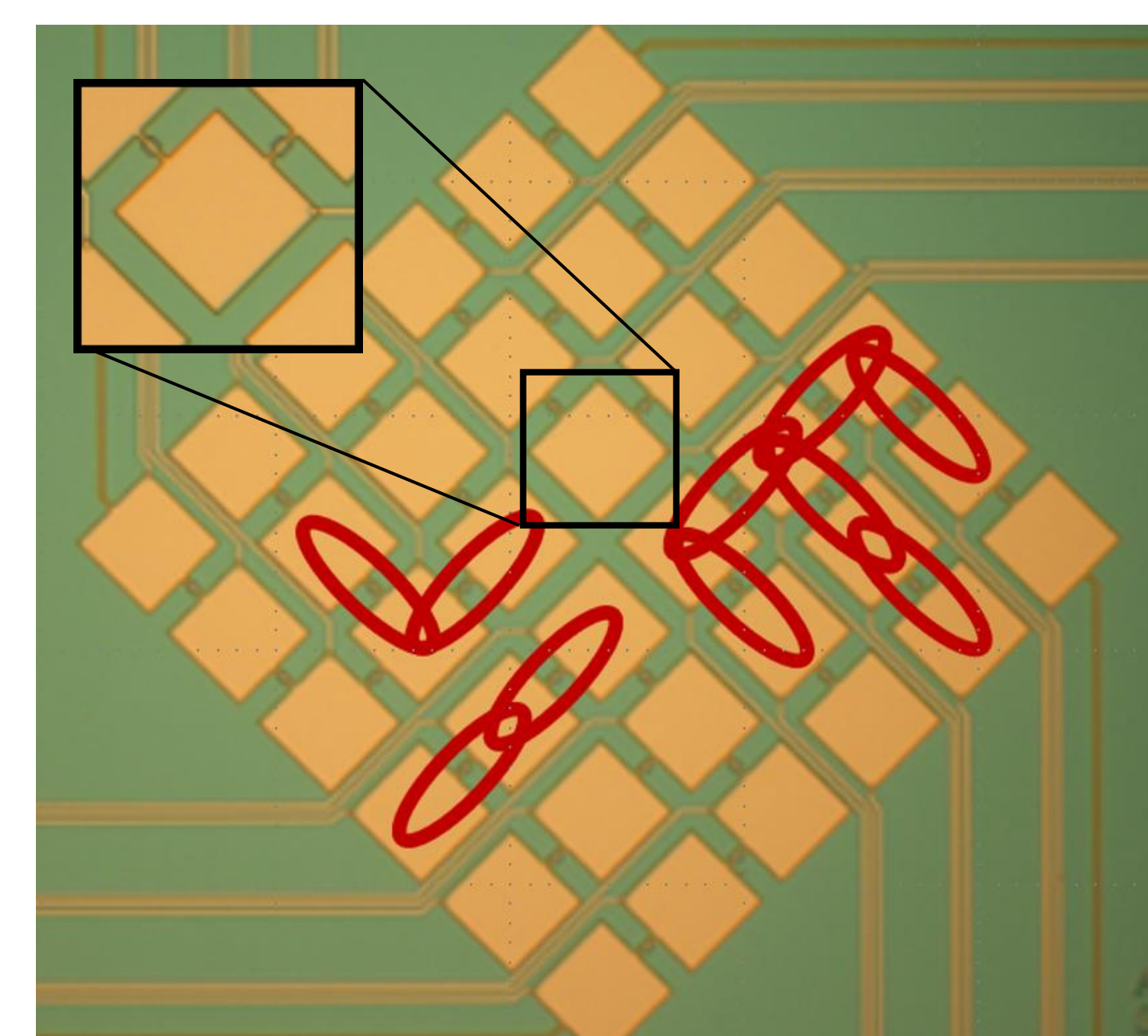
2D histograms for two channel combinations. Left: uncorrelated pair. Right: correlated pair (10 out of channel combinations showed this)

## Comparison of Energy Spectra



Correlated events (diagonal region in 2D histogram) show **recoil energy peaks** in same positions as <sup>7</sup>Li recoil energy spectrum.

## Location Map

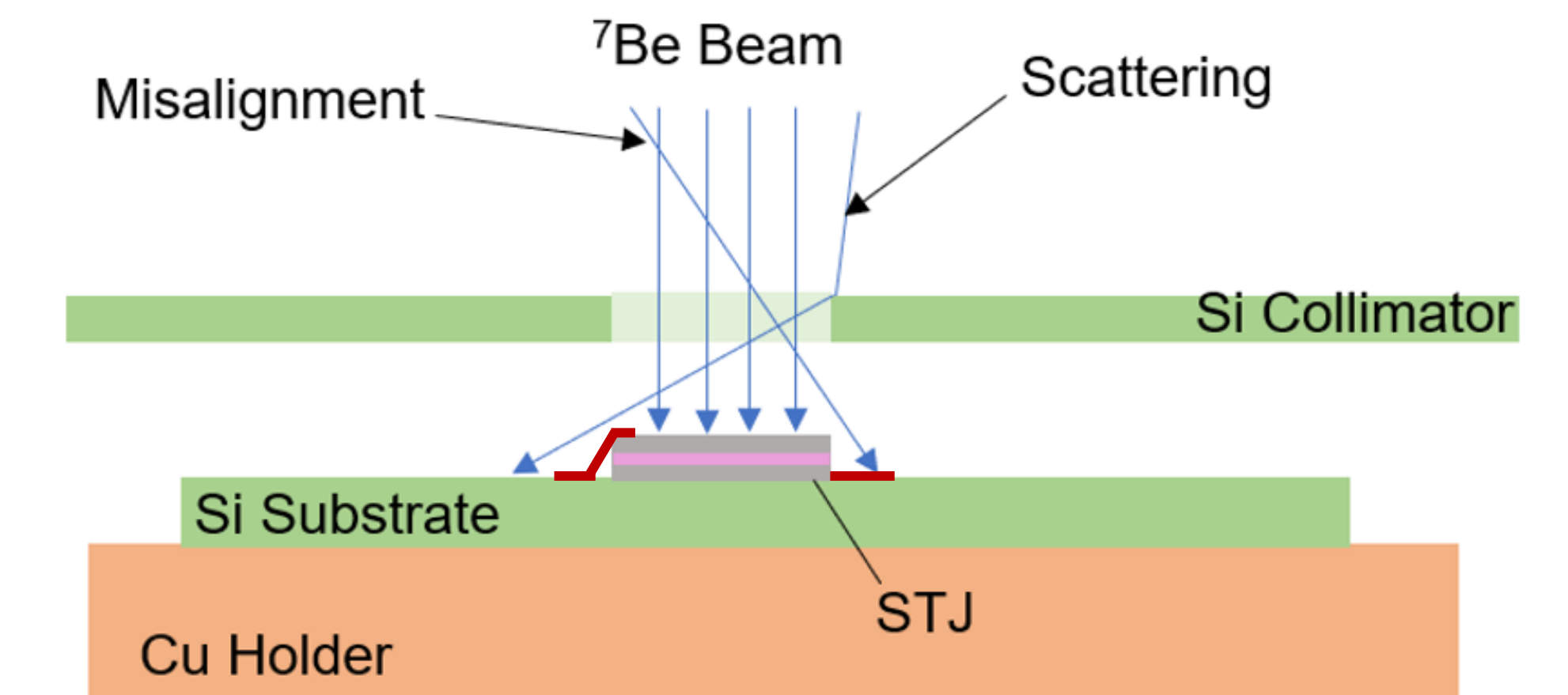


Map location of all ten correlated event pairs:

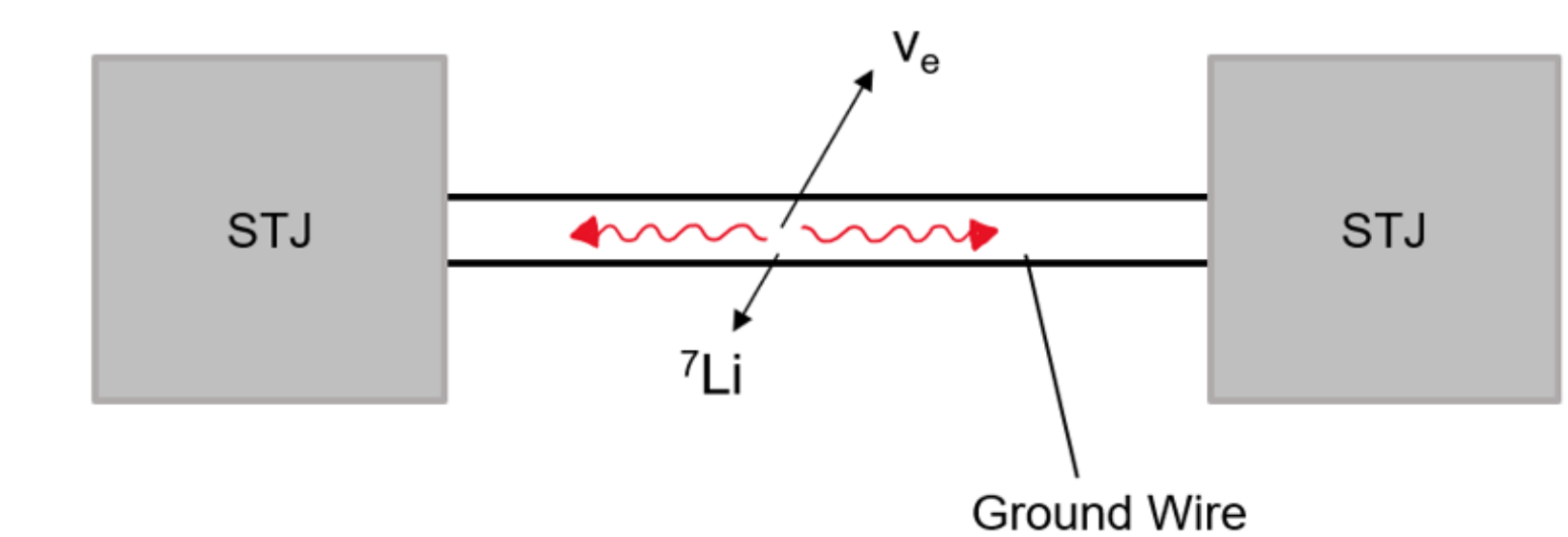
- All correlated pairs are **directly adjacent** pixels
- All pairs share a Niobium **ground wire**
- No correlated pairs exist that don't share a ground wire
- If EC decays are supposed to trigger one STJ at a time, why can we see a correlation?

Note: only 16 of the 36 pixels were operational, so if all pixels were collecting data the number of adjacent correlated pairs will likely be higher.

## Origin of Correlated Events



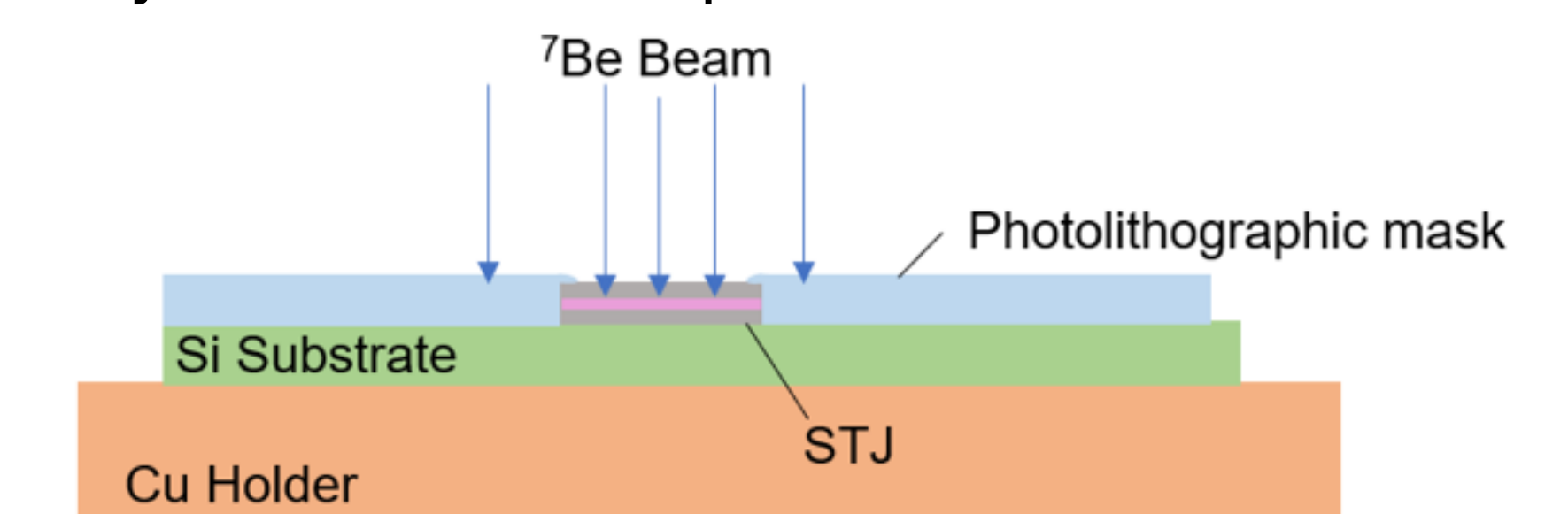
- <sup>7</sup>Be atoms are **embedded in the ground wires** during the fabrication stage and decay inside Nb ground wire
- <sup>7</sup>Li recoil is detected by STJ pixels on either side of ground wire when Cooper Pairs are broken in the Nb lattice
- Current method of using a Si collimator is not perfect: it can deposit <sup>7</sup>Be into ground wire or substrate due to **beam misalignment** or **scattering**



## Phase-IV Improvements

Proposed Phase-IV detector array improvements to eliminate two-pixel correlation effect:

- Use separate ground wires for each individual STJ pixel
- Use photolithographic mask that is deposited directly onto the substrate so only STJ surface is exposed



## References

- [1] K.G. Leach, S. Friedrich. *Journal of Low Temperature Physics*, 209, 796-803 (2022).
- [2] C.E. Bray, L. J. Hiller, K.G. Leach, S. Friedrich. *Journal of Low Temperature Physics*, 209, 857-863 (2022).

## Acknowledgements

The BeEST experiment is funded in part by the Gordon and Betty Moore Foundation (10.37807/GBMF11571), the DOE-SC Office of Nuclear Physics under Award Numbers DE-SC0021245 and DE-FG02-93ER40789, and the LLNL Laboratory Directed Research and Development program through Grants No. 19-FS-027 and No. 20-LW-006. TRIUMF receives federal funding via a contribution agreement with the National Research Council of Canada. The theoretical work was performed as part of the European Metrology Programme for Innovation and Research (EMPIR) Projects No. 17FUN02 MetroMMC and No. 20FUN09 Prima-LTD. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.

## Project Design Requirements

#	Requirements	Method	Verified	Application	Description
1	Identify multiplicity=2 events with correlation	Analysis	Y	Design of Phase-IV STJ detector array	Generated 2D histograms of energy spectra and identify trends.
2	Determine locations of correlated events	Analysis	Y	Design of Phase-IV STJ detector array	Mapped location of correlated pixel pairs on 36-pixel array.
3	Determine source of correlation and propose solution to eliminate effect	Analysis	N	Design of Phase-IV STJ detector array	Found patterns in correlation, hypothesized origins and discussed changes to Phase-IV fabrication process.