Development of Electron Neutrino Detectors Using MKID and Indium Targets

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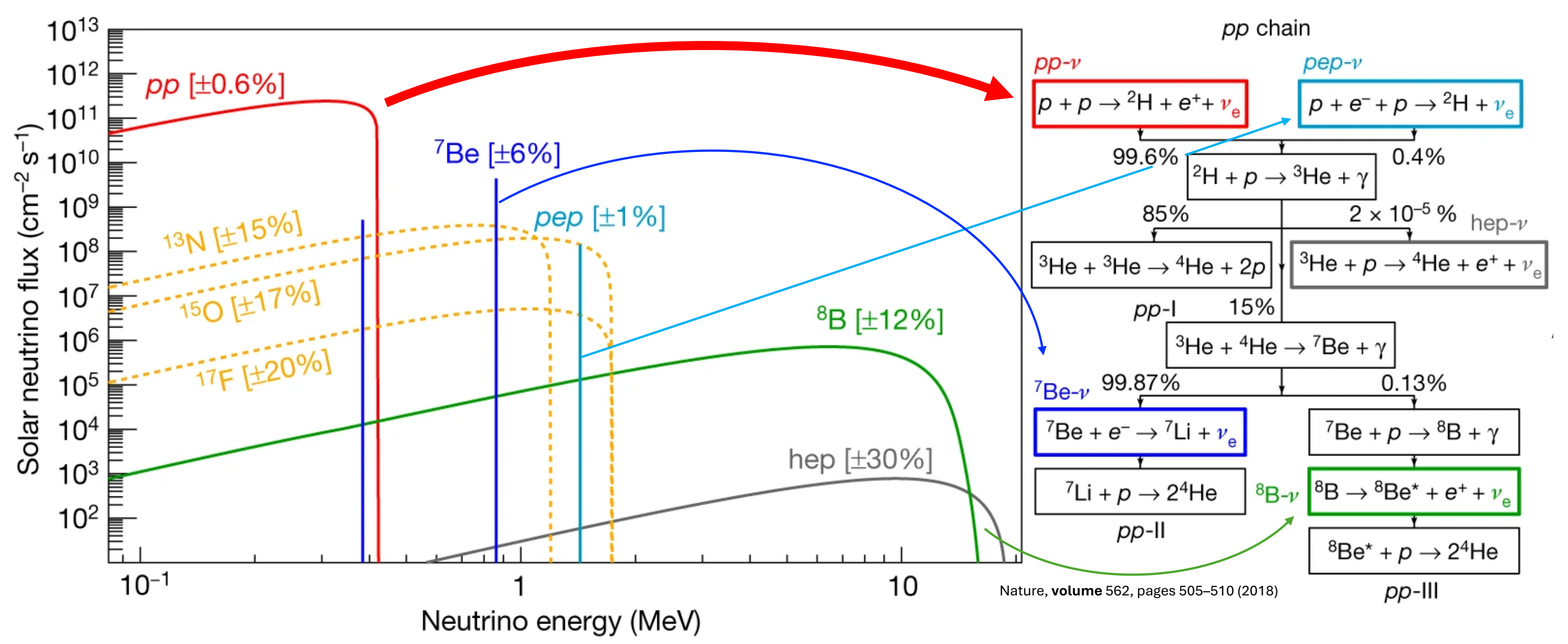
Abstract: We aim to detect the pp neutrino, produced by hydrogen nuclear fusion in the Sun, to study the neutrino oscillations and the Sun's internal structure. The energy of the pp neutrino is expected to be below 0.42 MeV. By using indium (In) as the target material, we can detect the electron neutrino with energies above 128 keV due to the reaction between In and electron neutrinos, as well as the delayed coincidence detection of two gamma rays emitted from excited ^{115}Sn. To achieve an observation rate of 100 pp neutrinos per year, we require to have approximately 1 ton of In. We plan to divide 1 ton of In into ~ 1 cm^3 blocks to optimize the detection efficiency when we couple them with detectors. We employ Microwave Kinetic Inductance Detector (MKID) as the superconducting detector because it enables us to easily achieve multiplexed readout in the frequency domain. To ensure precise coupling between the In blocks and the MKIDs, we utilize a sapphire-based mask fabricated by pulsed laser ablation. We conducted the cryogenic characterization of the prototype sample of MKID and In target coupled with a sapphire mask and showed that we successfully observed the energy from the reference radiation.



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Introduction: Electron neutrinos are generated by nuclear fusion reaction chains at the center of the sun. Among pp chain, pp neutrinos constitute the majority of solar neutrinos, but their detection is challenging due to the expected energy, < 0.42 MeV. We investigate the detection system to:

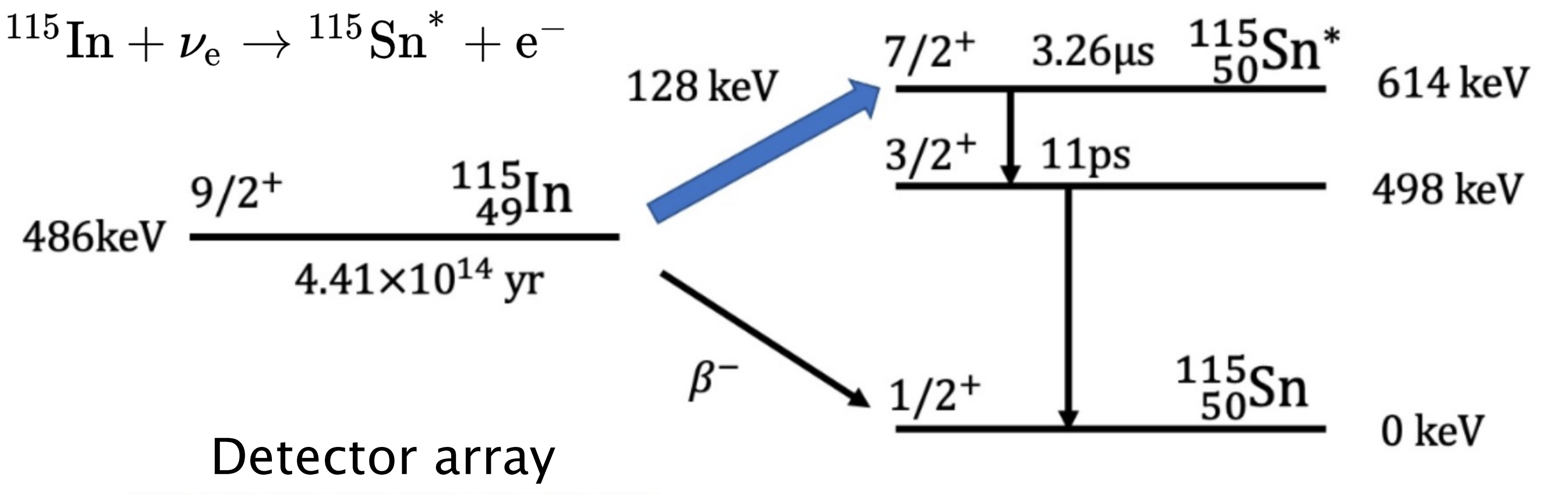
1. study constraints on neutrino mixing parameters
2. provide sensitivity to potential exotic particle emissions (like axion, dark photons, etc.)
3. study the Sun's internal structure

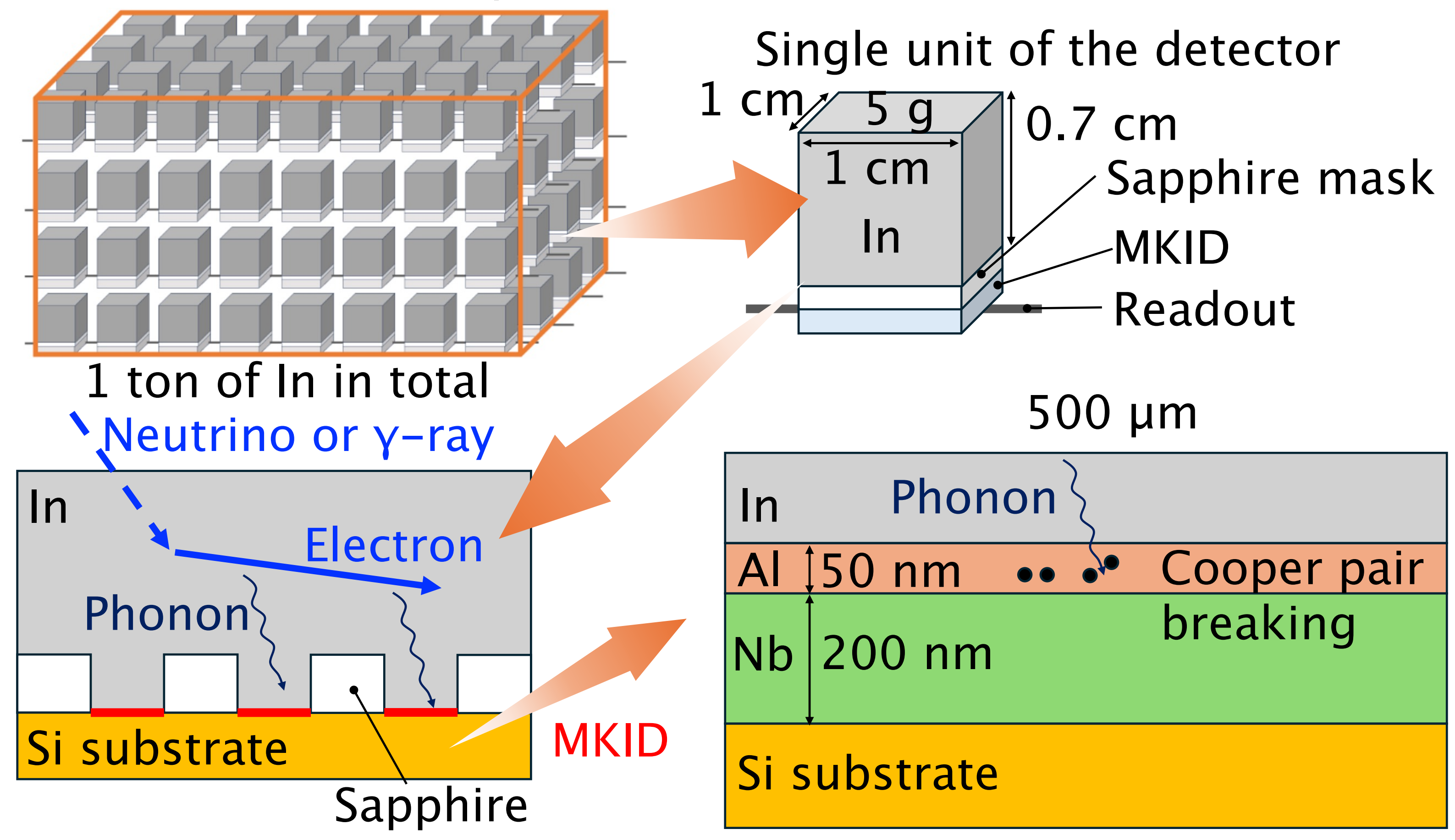
Detector design: ^{115}In reacts with neutrinos, then excites to ^{115}Sn* with generating β-ray. Subsequently, ^{115}Sn de-excites by emitting two γ-rays:

1. 116 keV γ-ray with a half-life of 3.26 μs
2. 498 keV γ-ray with a half-life of 11 ps

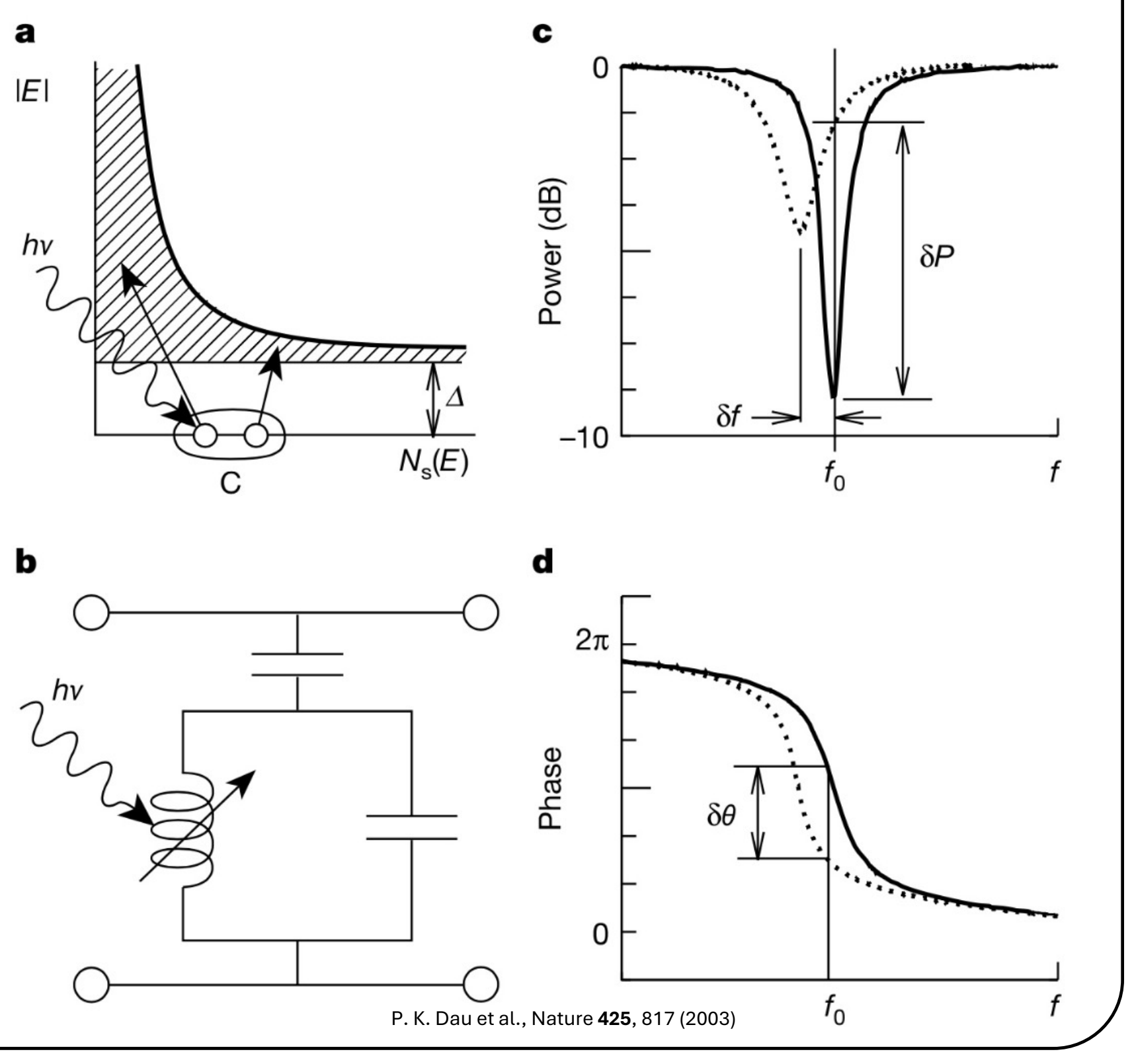
By conducting a delayed coincidence measurement of the β-ray and γ-rays, we can detect the neutrino with effectively eliminating the background events. The natural abundance of ^{115}In is 95.71%. Thus, to detect approximately 100 solar neutrino events per year, we need 1 ton of ^{115}In. We plan to divide 1 ton of In into ~ 1cm3 blocks, coupled to MKID, to optimize the detection efficiency.

$$^{115}\mathrm{In} + \nu_e \rightarrow {}^{115}\mathrm{Sn}^* + e^-$$

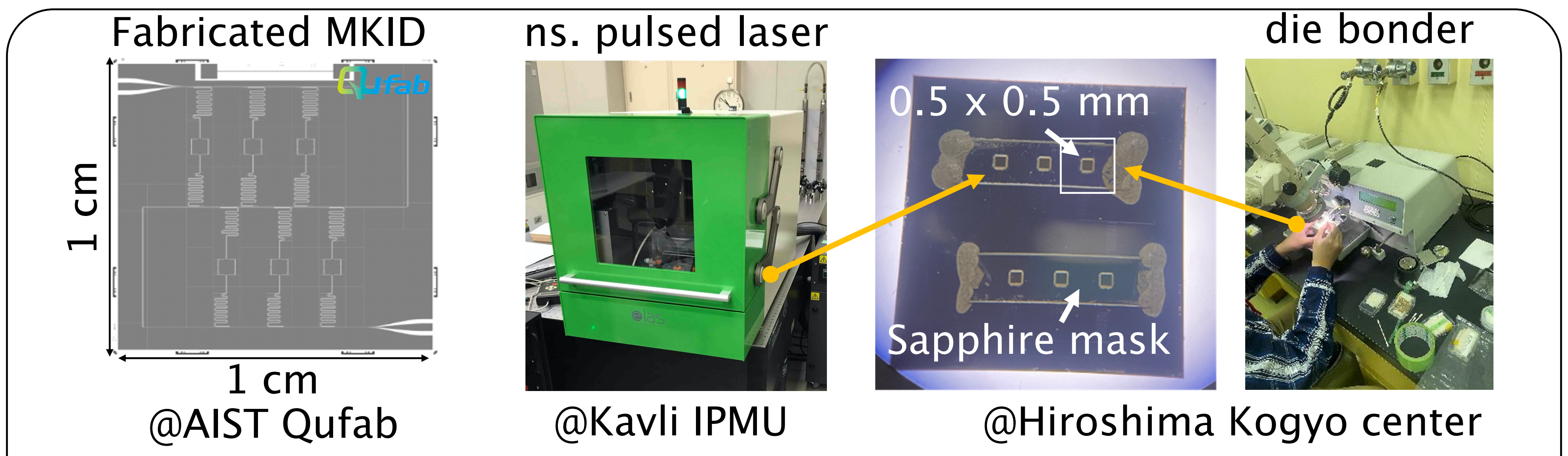




An AC voltage of 4-6 GHz is applied to the feedline and the resonator absorbs only the resonance frequency, creating a transmission peak. When energy enters the MKID, Cooper pairs break into quasiparticles, increasing kinetic inductance and reducing the resonance frequency. By detecting shifts in frequency and phase, we can measure the incident energy



P. K. Dau et al., Nature **425**, 817 (2003)



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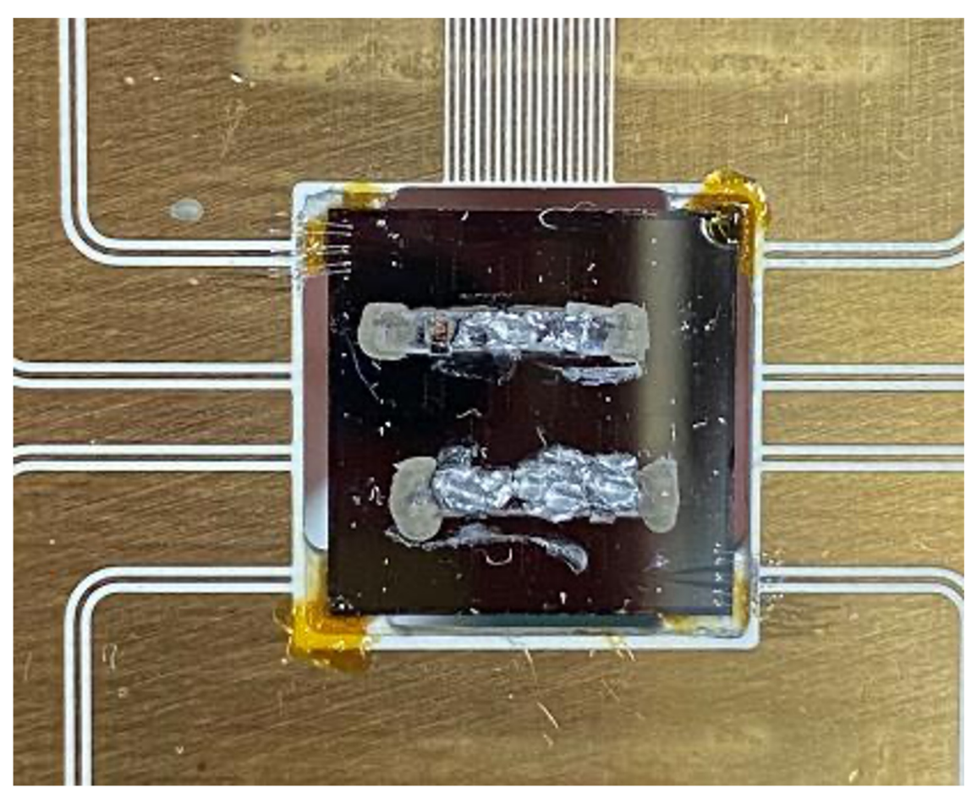
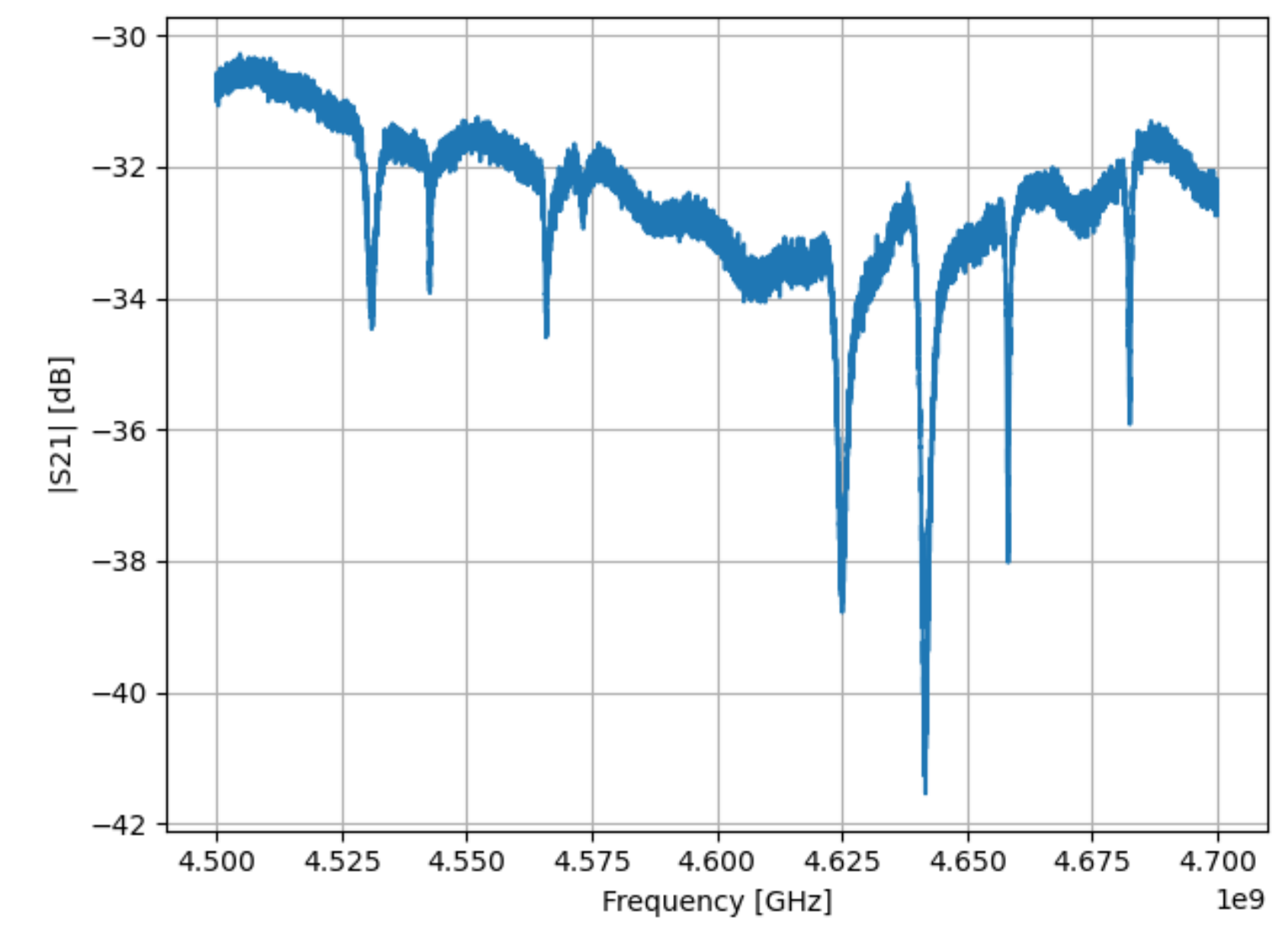
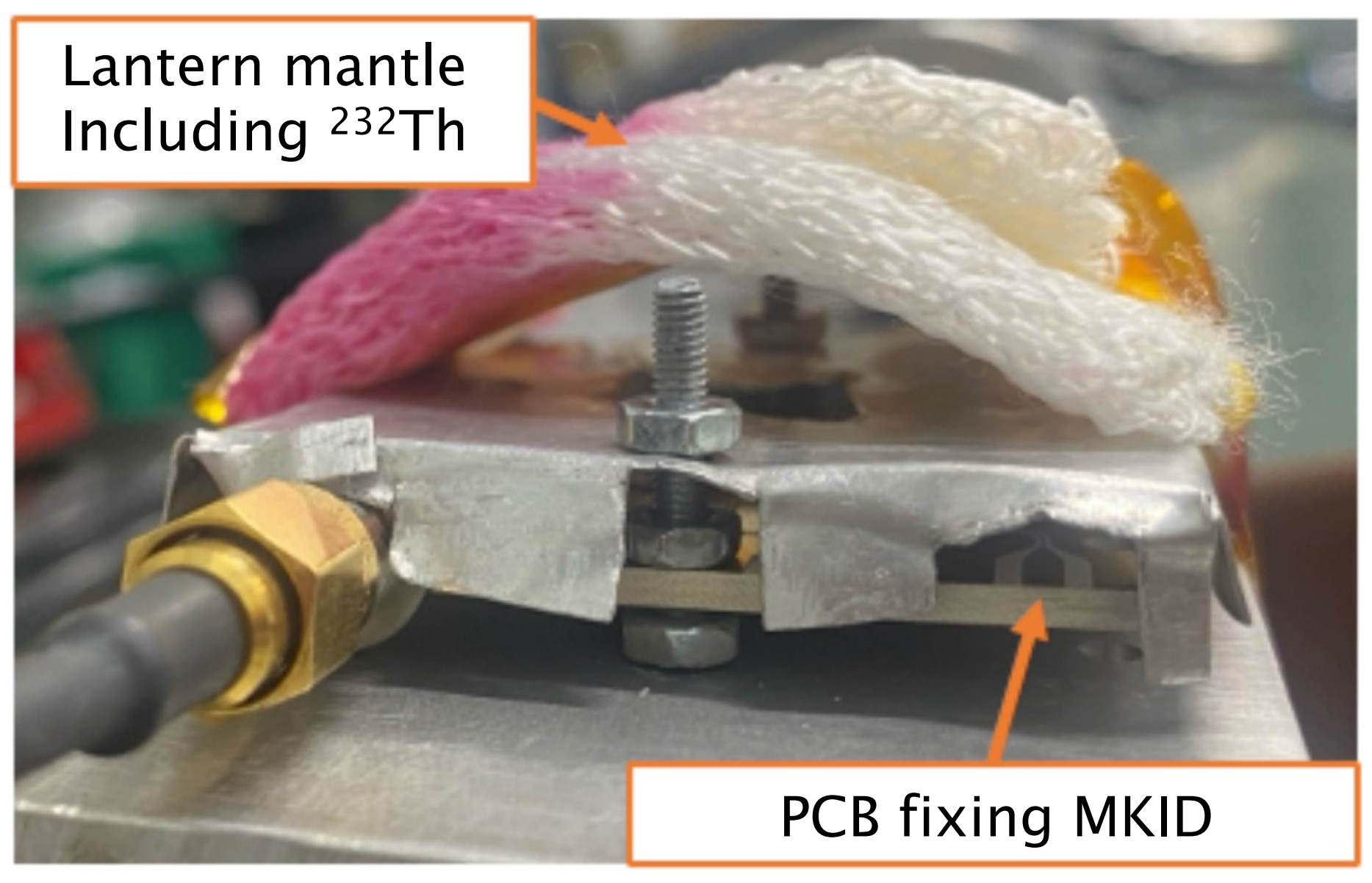
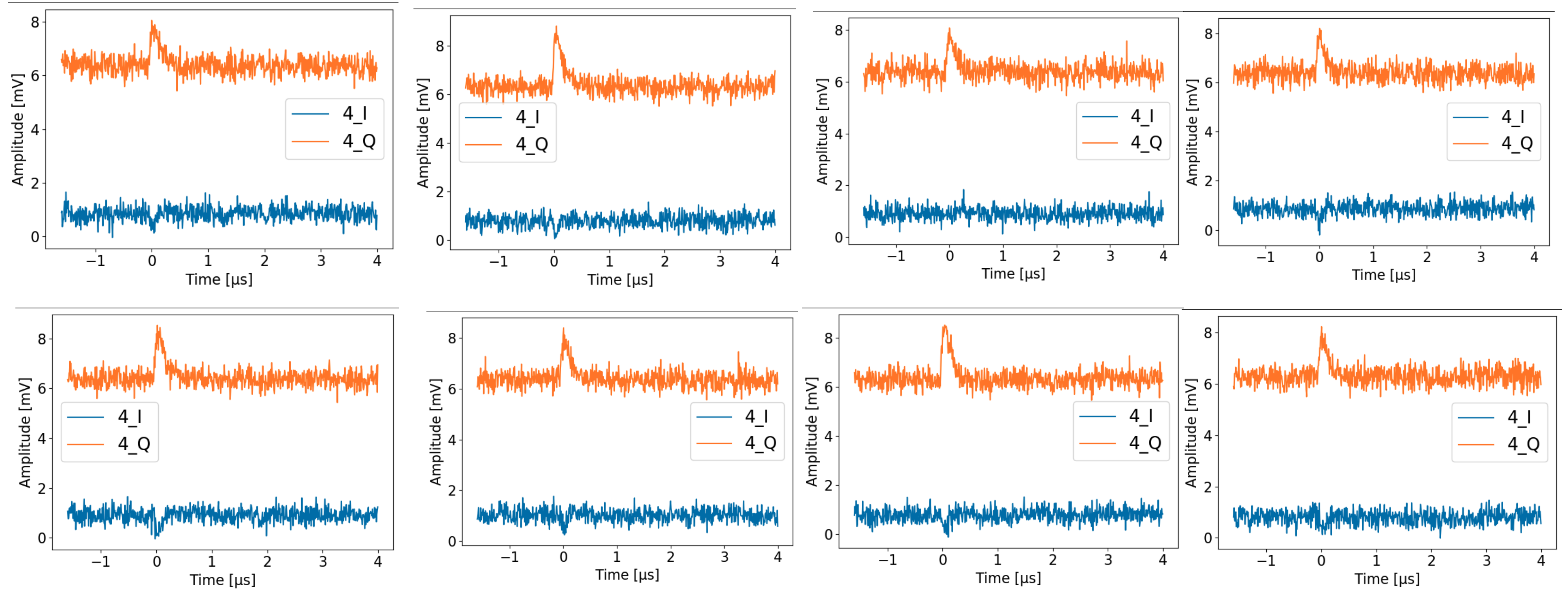
Fabrication: We fabricated MKIDs using an etching method at AIST. To prevent indium from contaminating areas outside the sensor, we created sapphire masks with holes precisely aligned to the sensor using pulsed laser ablation. We attached the masks with silver paste using a die bonder, achieving a precision of a few μm. We manually injected indium into the holes while heating with a hotplate to connect it to the MKID.



Inject In @Okayama U.

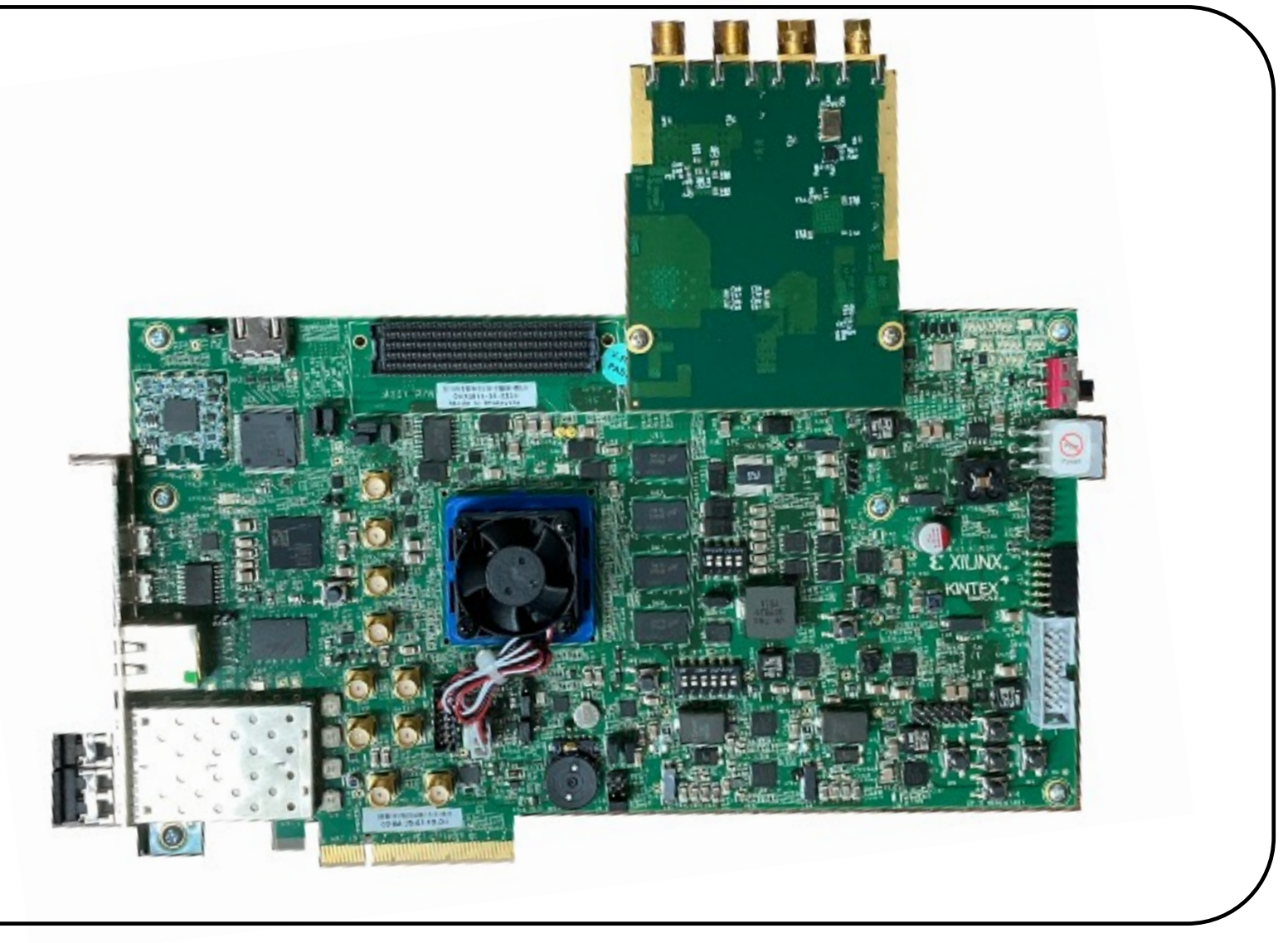






Measurement: We cooled our prototype detector to 0.1 K using the dilution refrigerator and successfully observed the resonant peaks. We also detected the energy response of β-rays emitted from thorium decay in the mantle. Using the homodyne principle, we extracted amplitude and phase of MKID as I/Q signals. We collected totally 16 events for 10 min. for a single channel, with τ~500 ns, which is the first detection of the external energy using In+MKID connected with sapphire mask.
We observed coincident events of the multiple resonances due to the athermal phonon propagation in the Si substrate.

Multiplexing: Since we need to readout signals from multiple resonators simultaneously, we develop a time-domain readout system using a Field Programmable Gate Array (FPGA), which firmware comes from one of the CMB telescopes, GroundBIRD. Currently it can be readout up to 64 channels.



Summary and Future plan: We have established a way to connect an In target to the MKID sensitive pad and confirmed the resonance peaks. We detected signals from lantern mantle by using our prototype In+MKID. However, the events observed are not yet confirmed to be ^{115}In or others including cosmic rays. Thus, Multiple channel readout of the In+MKID to identify the source of events.
We also detected athermal phonon propagation effect and need to protect the MKID from it to remove the background events.