Time, Amplitude, and Position-controllable Technique for Measuring Energy Resolution and other Properties of KID-based Phonon-mediated Particle Detectors

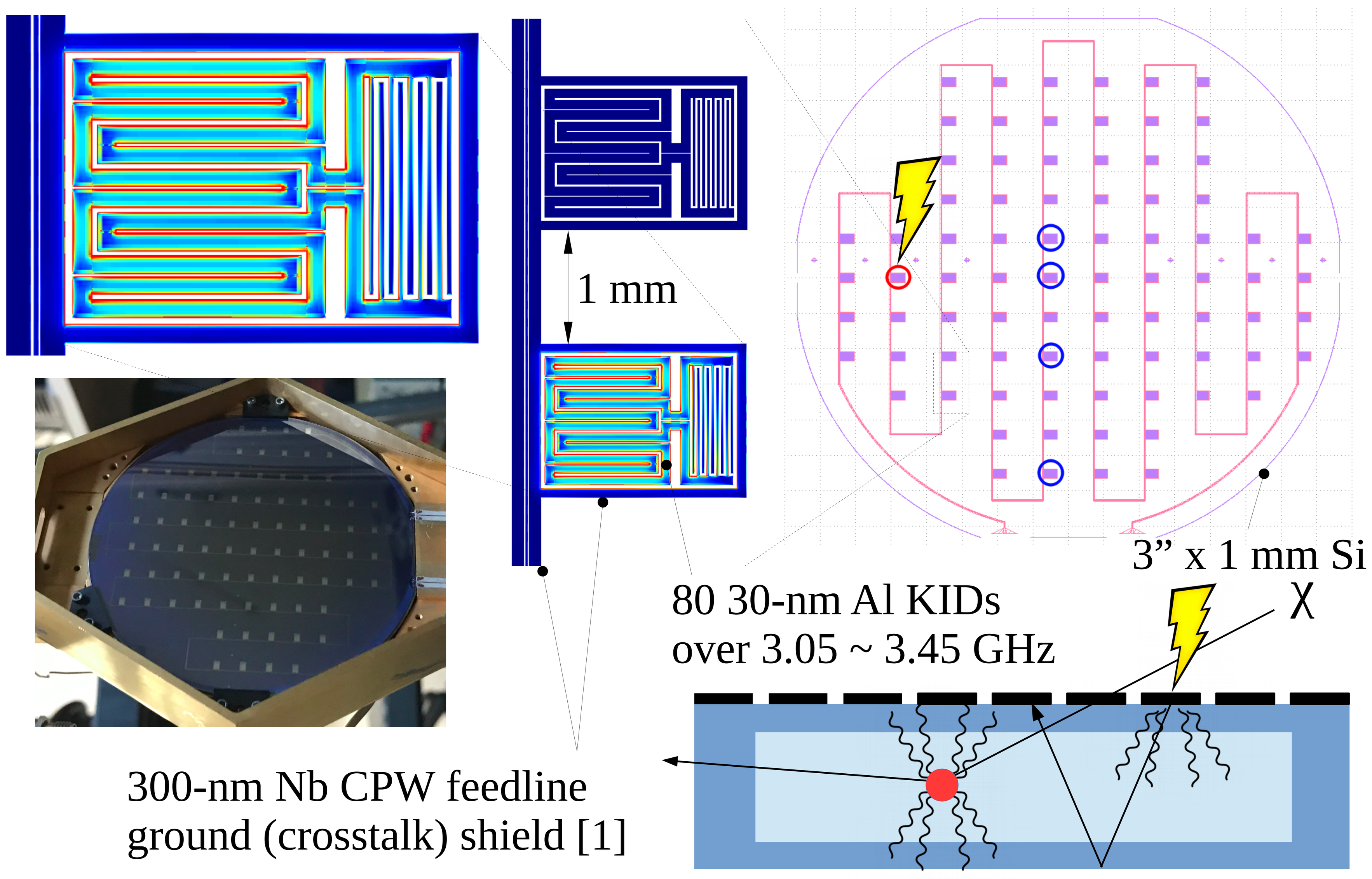
Y.-Y. Chang[1,*], T. Aralis[1], S. R. Golwala[1], B. Bumble[2], R. B. Thakur[1], O. Wen[1]

[1]Division of Physics, Mathematics, & Astronomy, California Institute of Technology, Pasadena, CA 91125, USA

[2]Jet Propulsion Laboratory, Pasadena, CA 91107, USA

- Kinetic Inductance Detector (KID) array self-calibration using in-array KID as calibration source
- Inject monochromatic RF pulse to excite direct quasi-particle (QP) creation and recombination phonon pulse
- Flexible choice of source location as every KID is an isolated calibration source
- Energy resolution, position dependence, QP lifetime, recombination constant

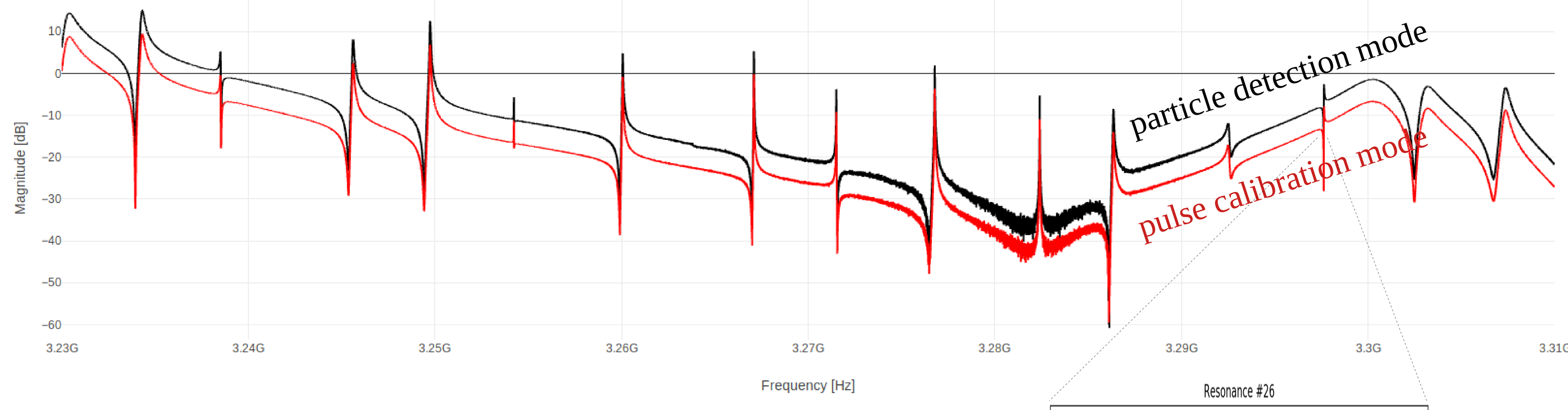
KID-based phonon-mediated particle detector [poster#409]

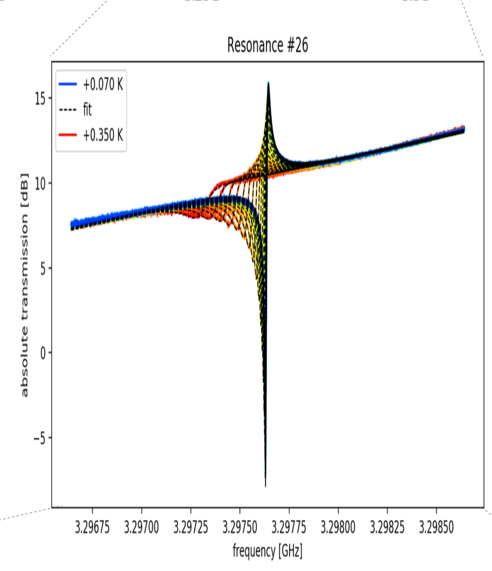


- Design/fabricated frequency shift <0.07%, allowed 180 KIDs/0.5 GHz [2]
- Expect 10–20 eV energy resolution, assuming LNA noise-dominated frequency readout, 10^2 μsec QP lifetime Al KIDs, ~30% sensitive area, c.f. [3] for other details

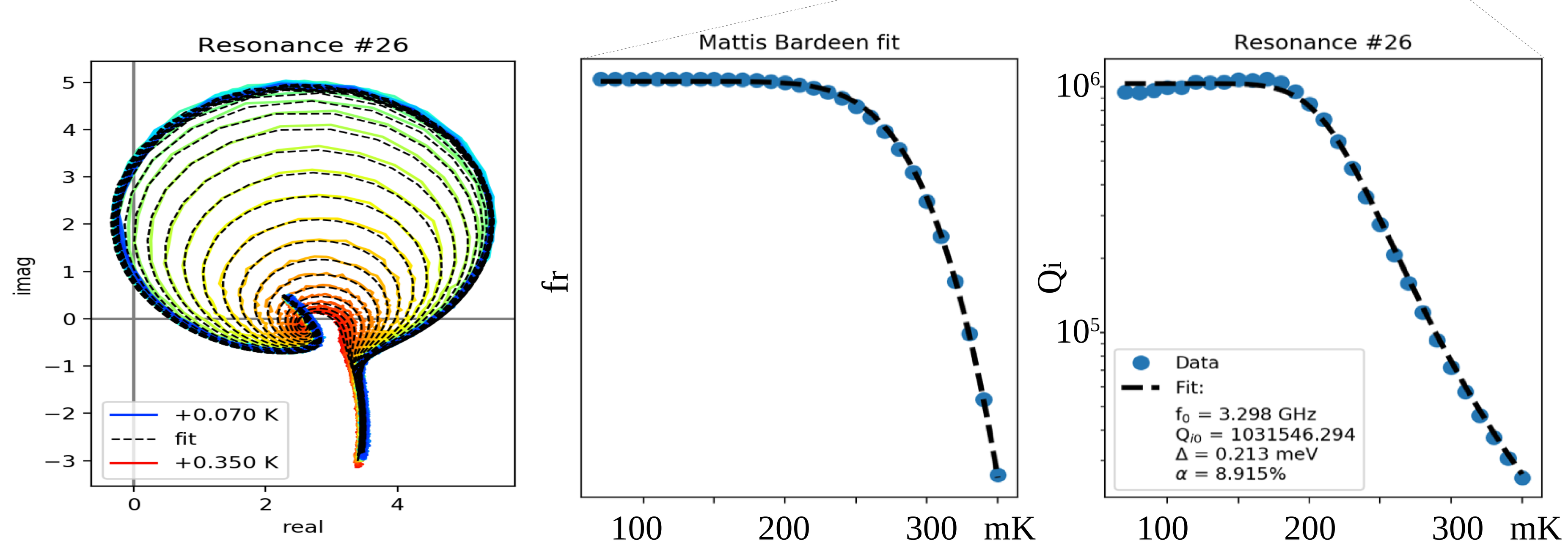
$$\sigma_E = \frac{\Delta_{Al}}{\eta_{ph}\beta(f_0,T)}\sqrt{\frac{\eta_{read}}{\alpha\, p_t}\frac{A_{sub}k_b T_N}{2\pi f_0}\frac{N_0\lambda_{pb}}{\tau_{qp}S_1(f_0,T)}} \sim 10-20\ \text{eV}$$

RF and superconductivity characterization



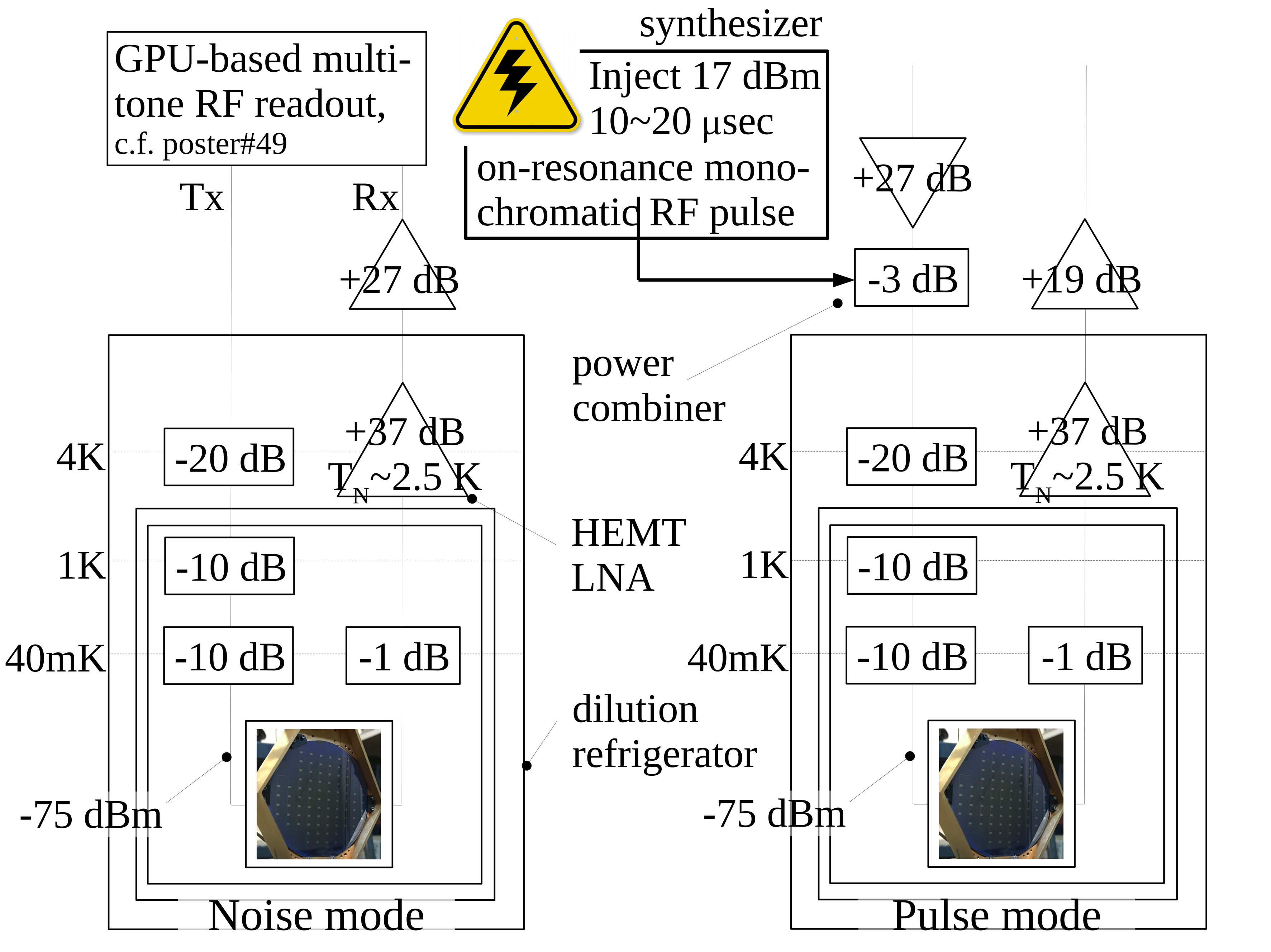


- 55 mK base temperature data taking
- 95% pixel yield
- Q_i (internal quality factor) ~ 5×10^5–2×10^6
- Mattis-Bardeen fit to temperature data
  - Δ (superconducting bandgap) ~ 0.2 meV
  - α (kinetic inductance fraction) ~ 0.05–0.10



Signal generation, readout, and data acquisition

- Readout power adjusted to -75 dBm at detector for optimal responsivity
- Two data acquisition modes:
  1. Noise mode: noise limited by HEMT LNA or device; acquire pulse-free data for noise PSDs and fit pulse template to pulse-free data
  2. Pulse mode: Reduce gain on Rx to allow reception of large monochromatic RF pulse power and artifacts produced; acquire pulse data for KID being pulsed (readout power pair breaking) and for other KIDs (phonons received through substrate from pulsed KID). Acquire high SNR pulse templates for pulsed KIDs and other KIDs through trace averaging
- Both modes calibrated so that data sets are placed in "ideal S_{21} plane," where resonances loop along real axis and asymptote to (0,0) toward resonance.

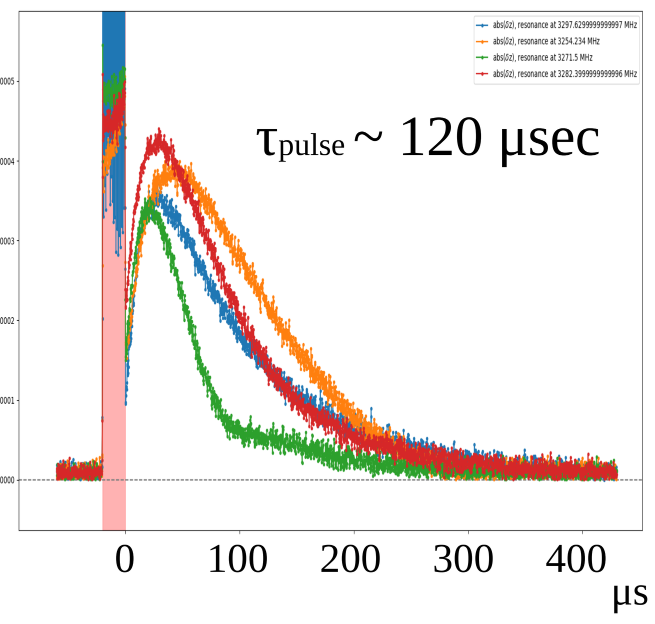


Pulse calibration

- Outer pixel chosen for pulse generation, inner 4 pixels for phonon pulse detection
  see red/blue circles in top center mask layout
- Device transmission (dS_{21}) is converted to energy absorbed (dE) by

$$dS_{21} = Q_r\,\alpha\,\kappa\, dn_{qp} = Q_r\,\alpha\,\kappa \frac{dE\ \epsilon_{super}}{V\,\Delta}$$

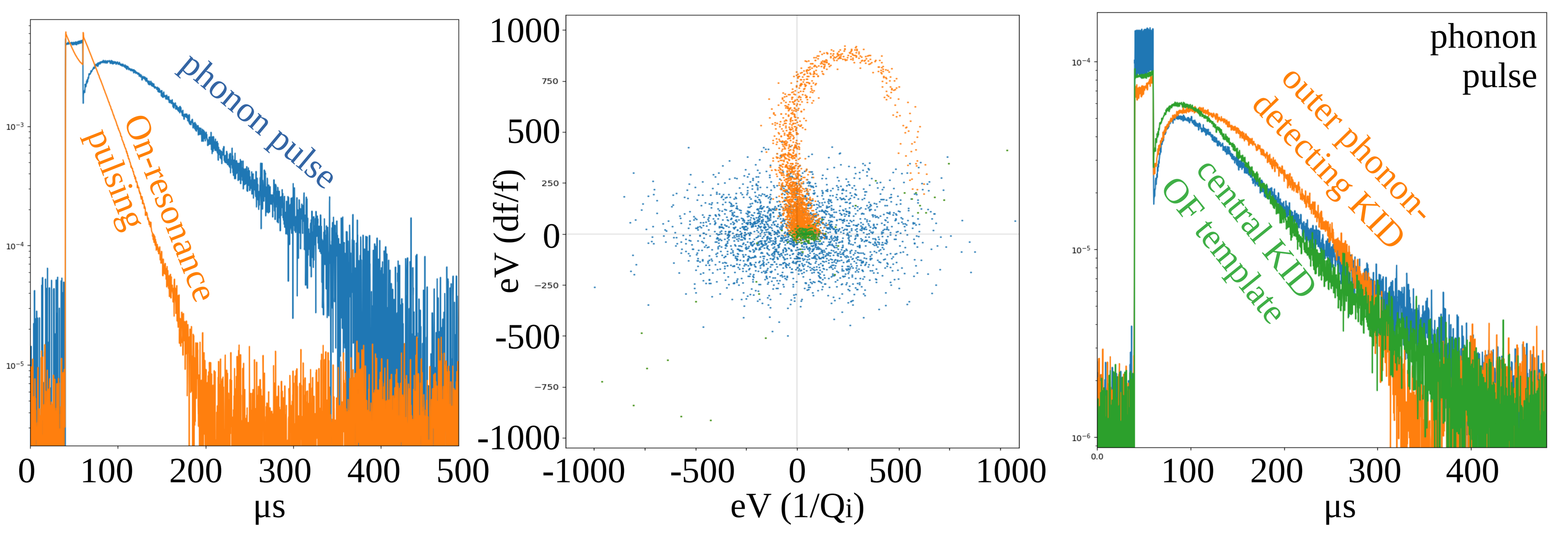
, where κ is defined in [4]



- Use "noise mode" timestream to calculate noise PSD for optimal filter (OF)
- Use "pulse mode" phonon pulse in central KID for OF pulse template
- Standard OF resolution for energy absorbed in QP system:

$$\sigma_{qp} \sim 12.6\ \text{eV}$$

- For O(10^2)-KIDs, position-resolving detector, $\sigma_{dep} = \sigma_{qp}\sqrt{n}/\eta_{ph}$, η_{ph}~0.2 observed from detector of similar coverage, e.g. SuperCDMS SNOLAB
- For threshold-optimized, single-KID detector, $\sigma_{dep} = \sigma_{qp}/\eta_{ph} \sim 63\ \text{eV}$
- From on-KID resonance pulsing, directly create QP and lifetime τ_{qp} ~ 23 μsec



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