Germanium target sensed by phonon-mediated kinetic inductance detectors

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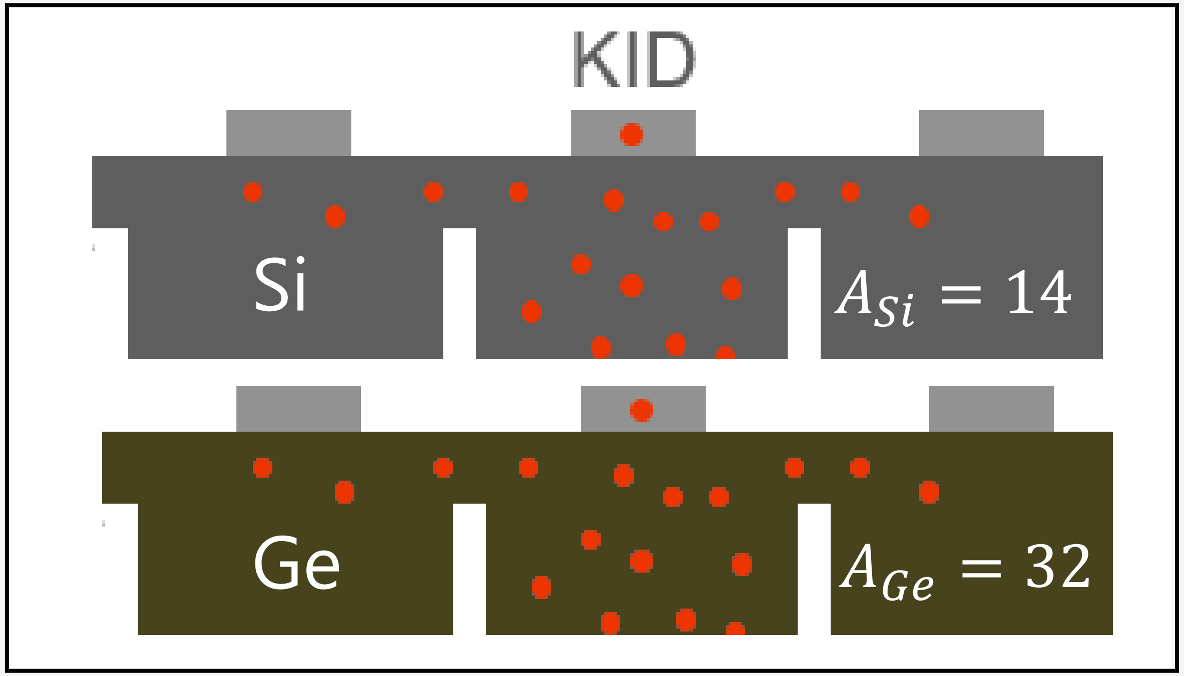
Daniele Delicato *for the BULLKID collaboration*

Istituto Nazionale di Fisica Nucleare

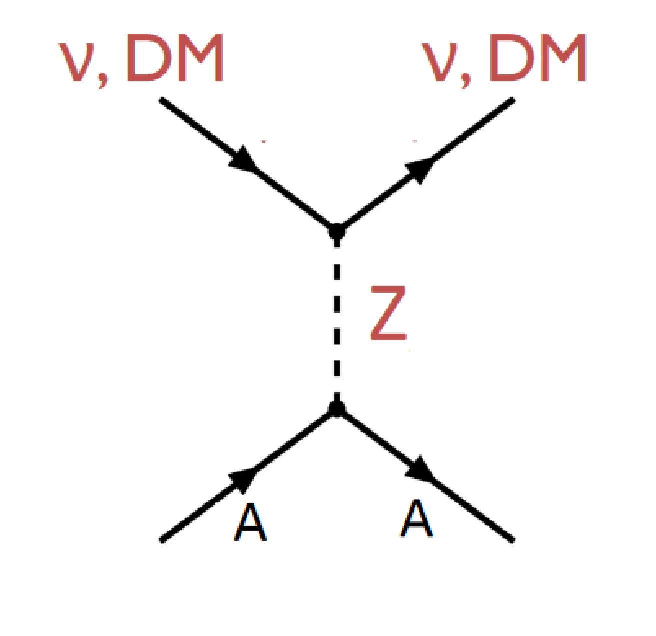
Sapienza Università di Roma

Motivation: Multi target detector for DM



$$\sigma_A = \sigma_0 \frac{\mu_A^2}{\mu_n^2} A^2$$

Stack of different substrates allows to probe the A-scaling



Motivation: Coherent elastic neutrino nucleus scattering (CEνNS)

$$\sigma_{CE\nu NS} = \frac{G_F}{4\pi} \boxed{E_\nu^2} \boxed{Q_W^2} \boxed{F(q^2)}$$

$$\sigma_{CE\nu NS} \leq 10^{-40}\mathrm{cm}^2$$

Neutrino Energy
$E_\nu \approx O(\text{few MeVs})$

Weak Force Charge
$Q_W = N - P(1 - 4\sin^2\theta_W) \approx N$

Nuclear Form Factor

$$F(q) = \frac{1}{Q_W}\int_0^{R_N} \rho_W(r)\frac{\sin(qr)}{qr}dr$$

$$\rho_W(r) = \rho_N(r) - (1 - 4\sin^2(\theta_W))\rho_P(r)$$

Fourier transform of the nucleon distribution

Coherency

Neutrino does not see the internal structure of the nucleus

$$\text{Coherent:} F(q^2) \approx 1$$

$$\downarrow$$

$$q \cdot R_N \ll 1$$

$$\downarrow$$

$$\boxed{E_\nu^{max} \approx 20\mathrm{MeV}\ [\mathrm{He}] \div 70\mathrm{MeV}\ [\mathrm{U}]}$$

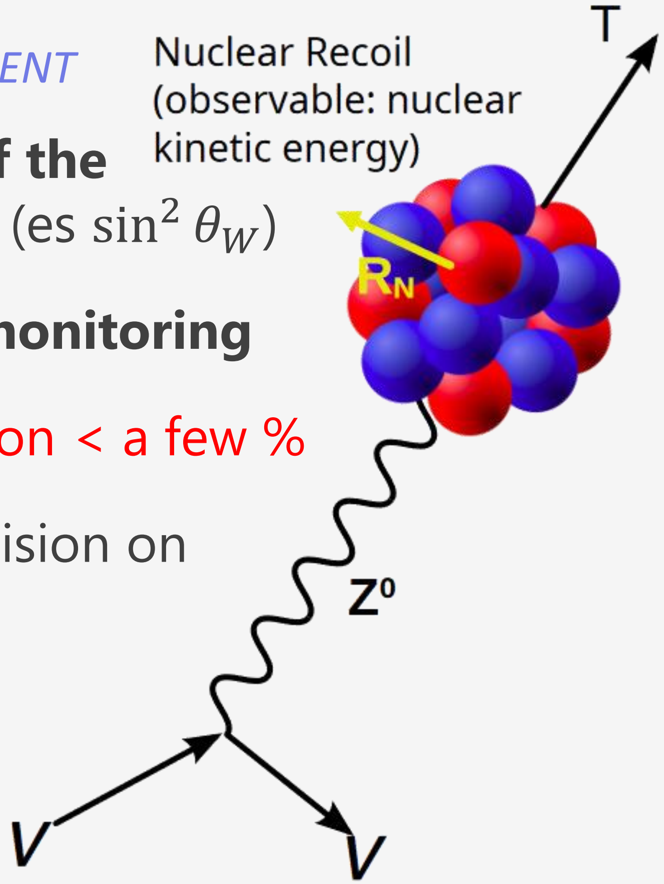
Same detection principle as WIMPs!

Observed in 2017 by COHERENT

- Precision **tests of the standard model** (es $\sin^2\theta_W$)
- **Nuclear waste monitoring**

But needs a precision < a few %

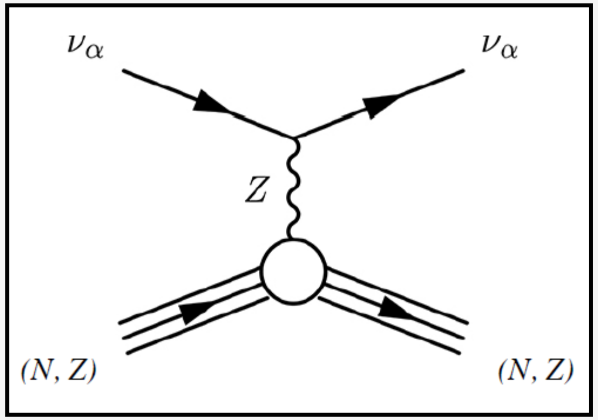
Currently 15% precision on $\sigma_{CE\nu NS}$



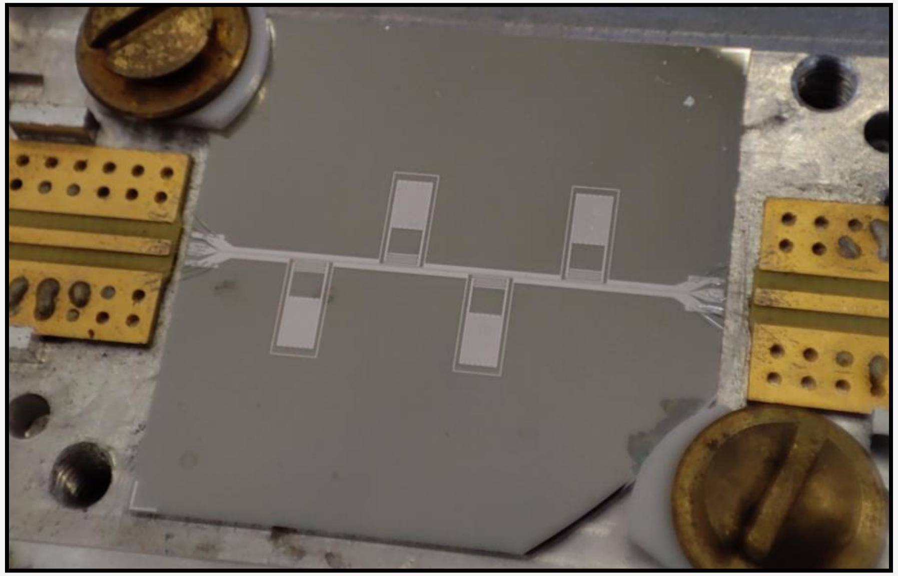
KIDs on Germanium (first prototype)

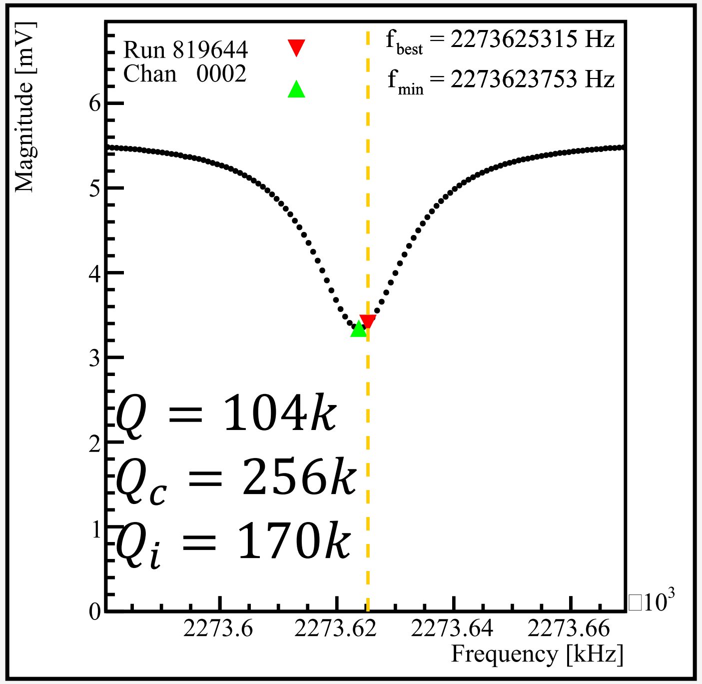
Observed in 2017 by COHERENT

Same detection principle as WIMPs!



$$\sigma_{CE\nu NS} \approx \frac{G_F^2}{4\pi} E_\nu^2 N^2$$





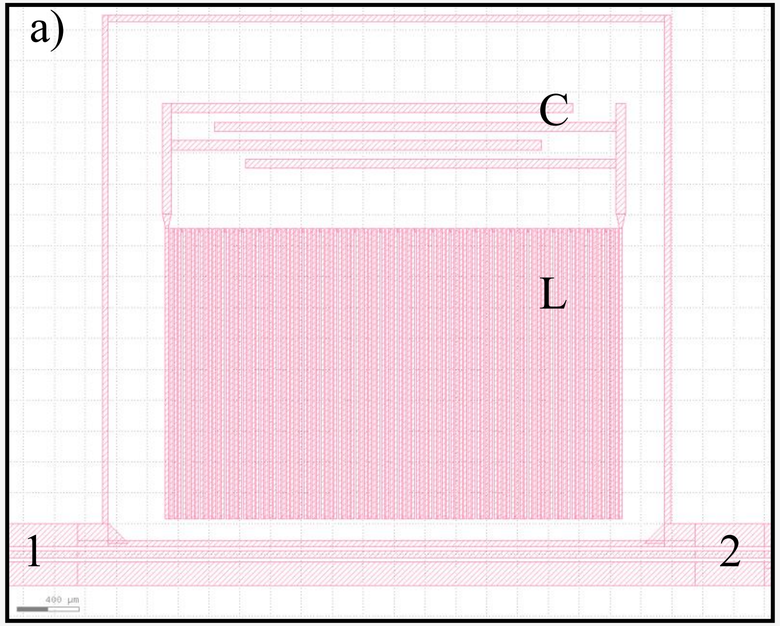
- Precision **tests of the standard model** (es $\sin^2\theta_W$)
- **Nuclear waste monitoring**

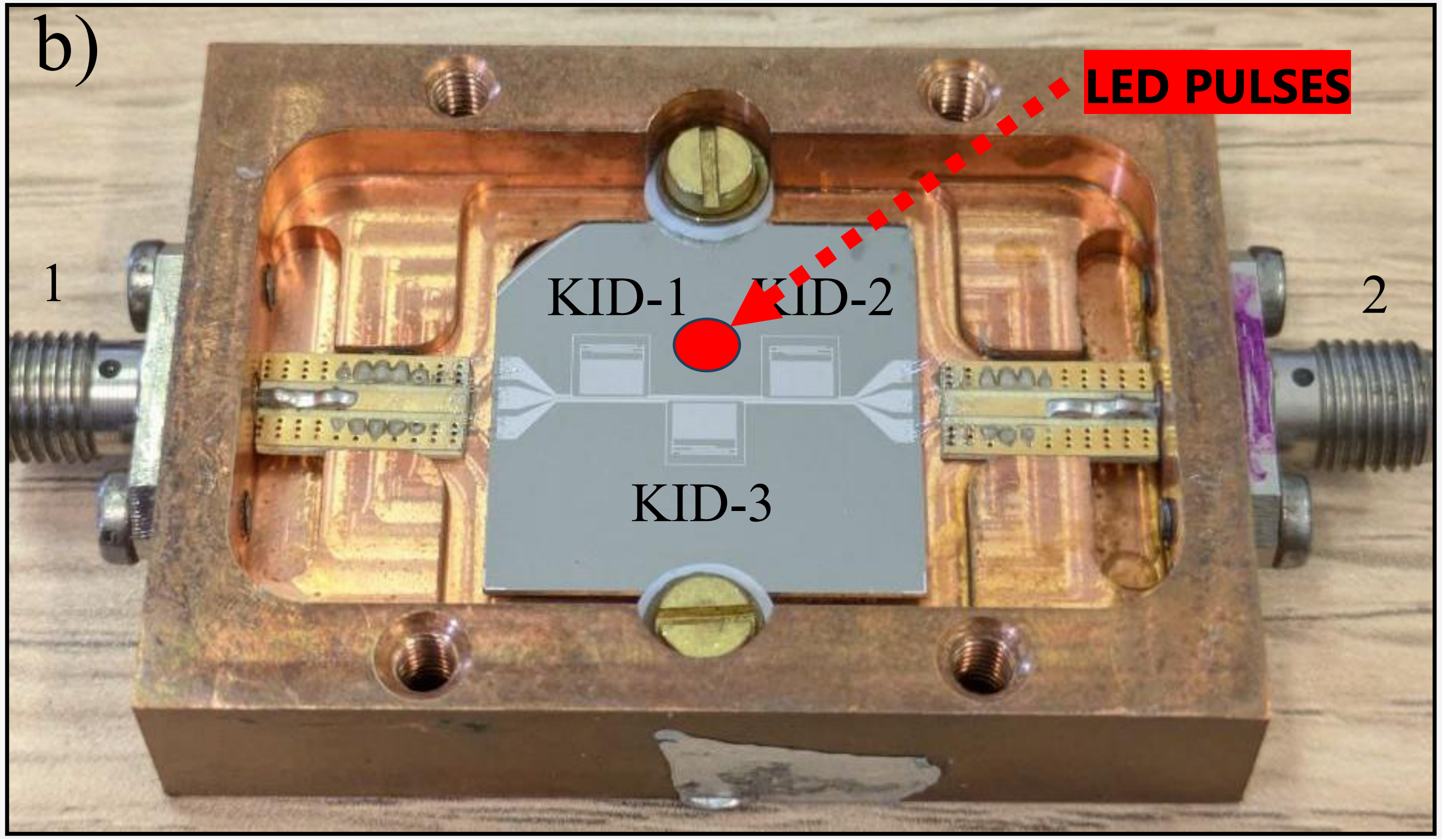
$$\sigma_{Ge} = \frac{42^2}{14^2} \cdot \sigma_{Si} = 9 \cdot \sigma_{Si}$$

However **Ge oxide is not inert**!

Qi seems promising, energy calibration is the next step

KIDs on Germanium new design



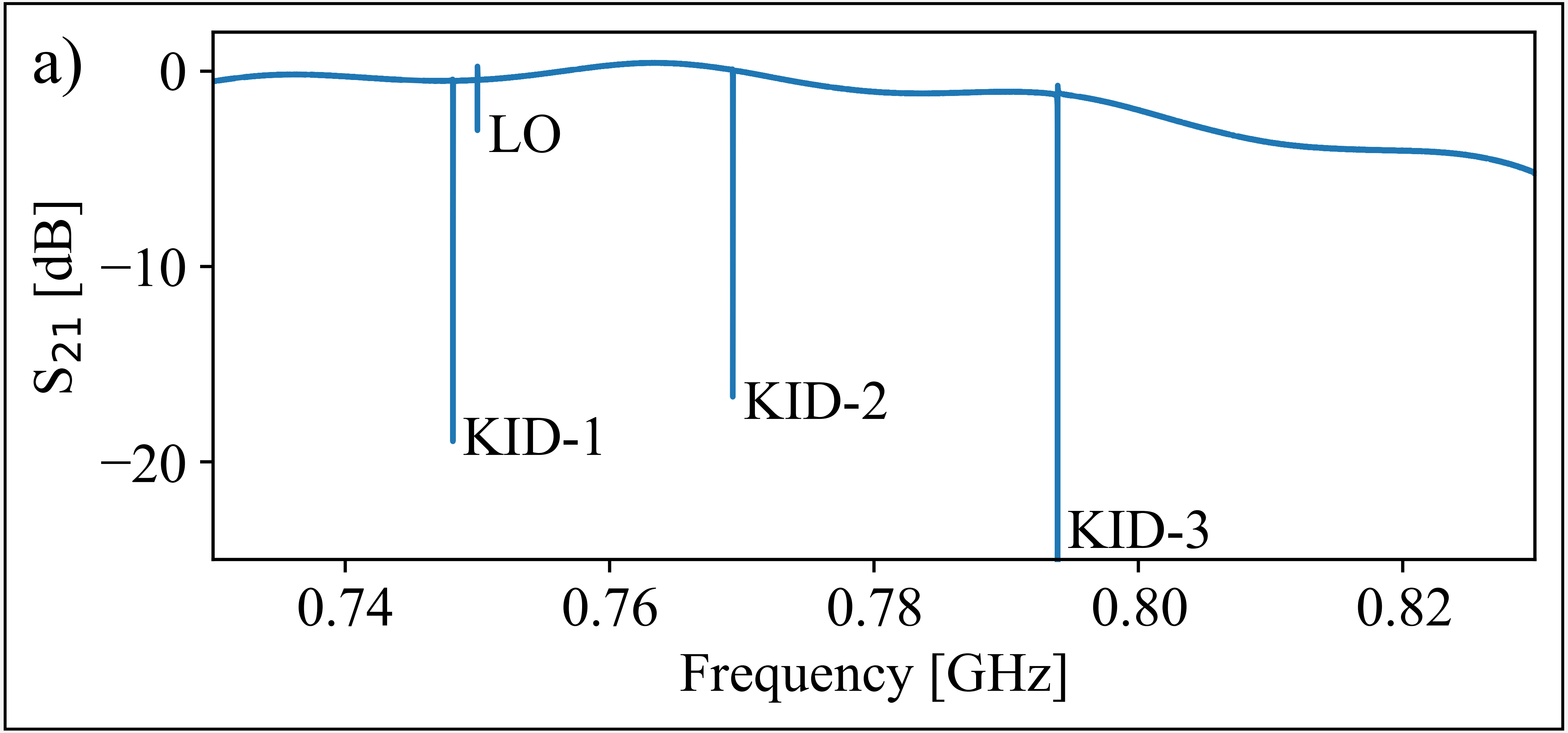


- **BULLKID-like** KID design
- **20 min** argon-etch to remove GeO_2 layer

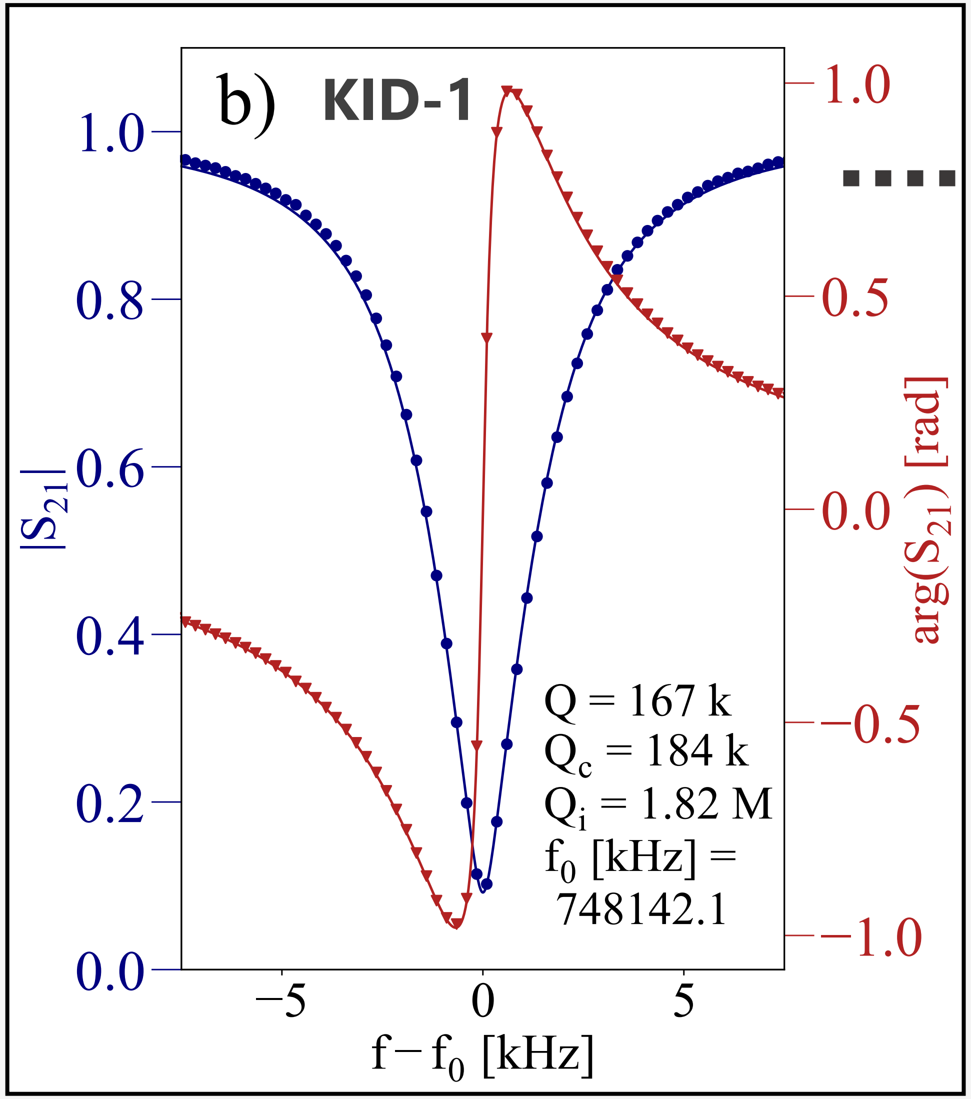
20 mm x 20 mm x 550 um tile

LED firing on the back of the tile

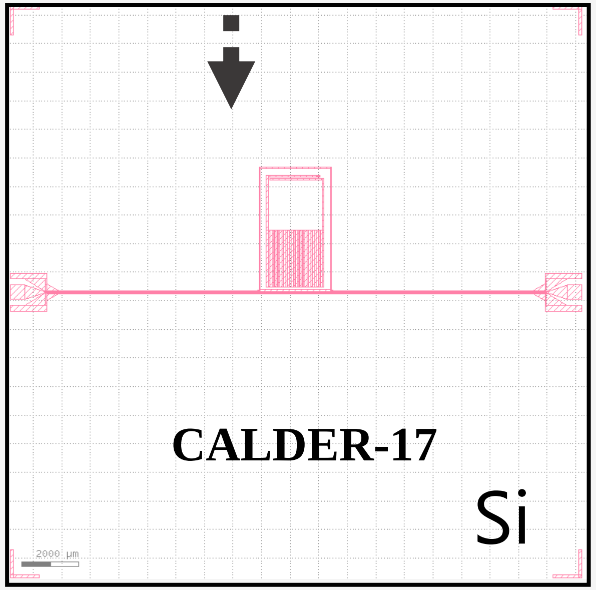
Frequency scan



Frequency scan, fit for resonance parameters



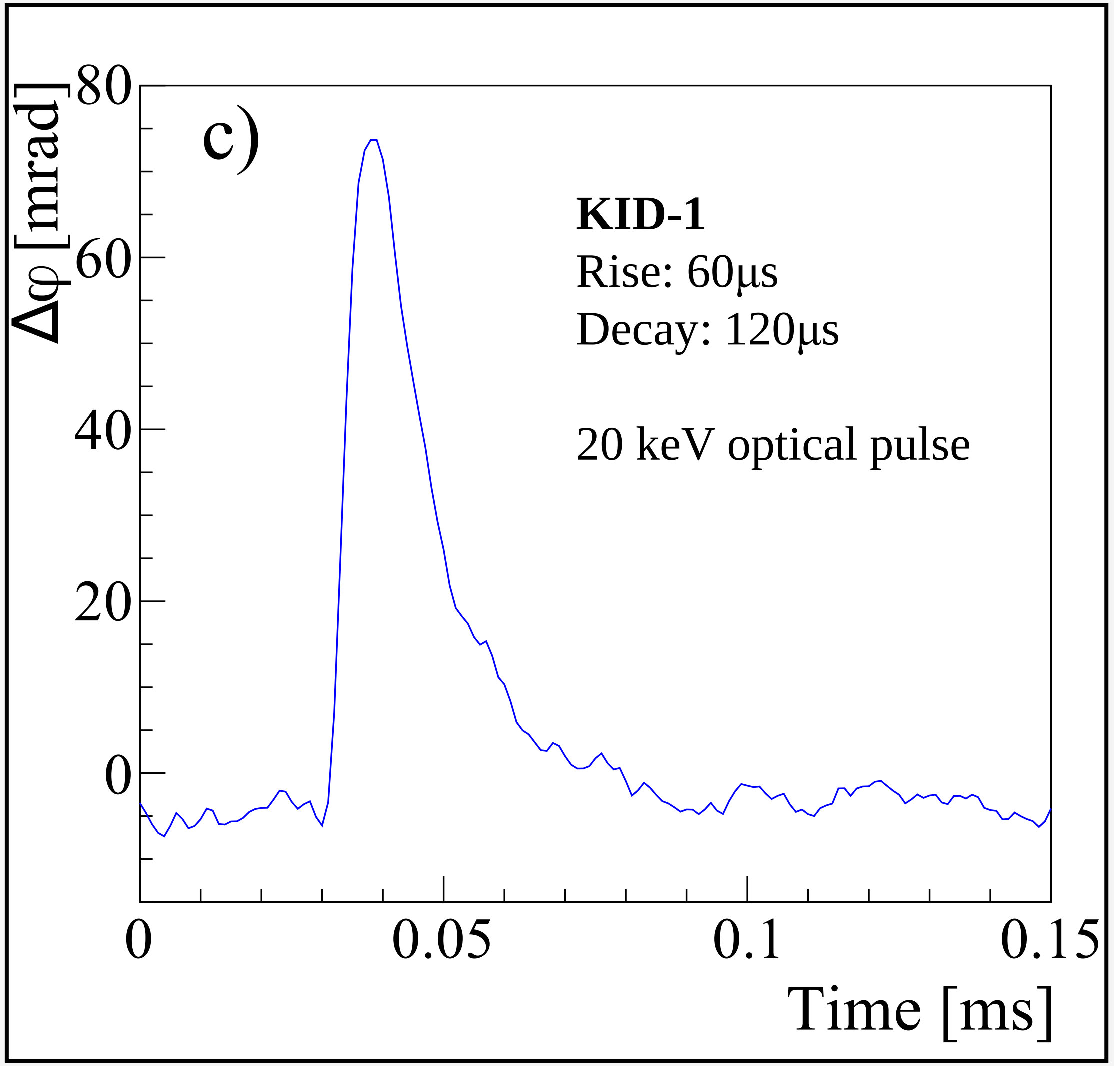
	f_0 [MHz]	Q [k]	Q_c [k]	Q_i [M]
KID-1	748.1	167	184	1.82
KID-2	769.3	114	120	2.24
KID-3	793.9	127	132	3.03
CALDER-17	2644	147	156	> 2

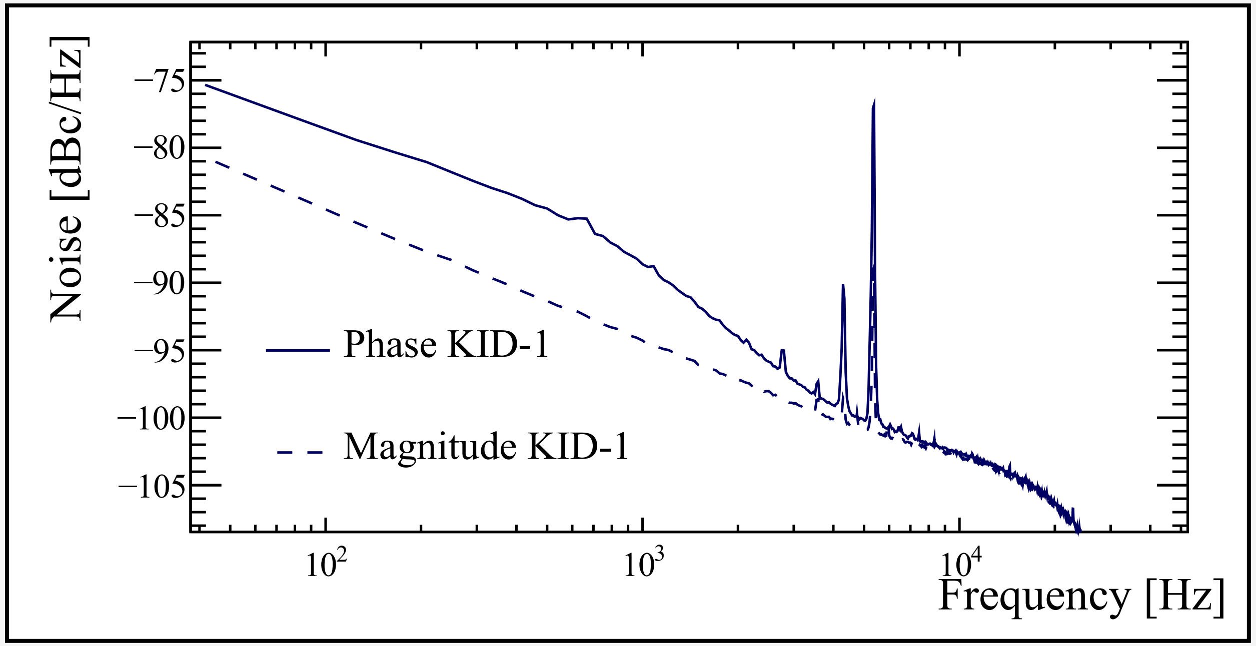


CALDER-17:

- KID phonon-mediated light detector
- Reference for KID fabrication on Si

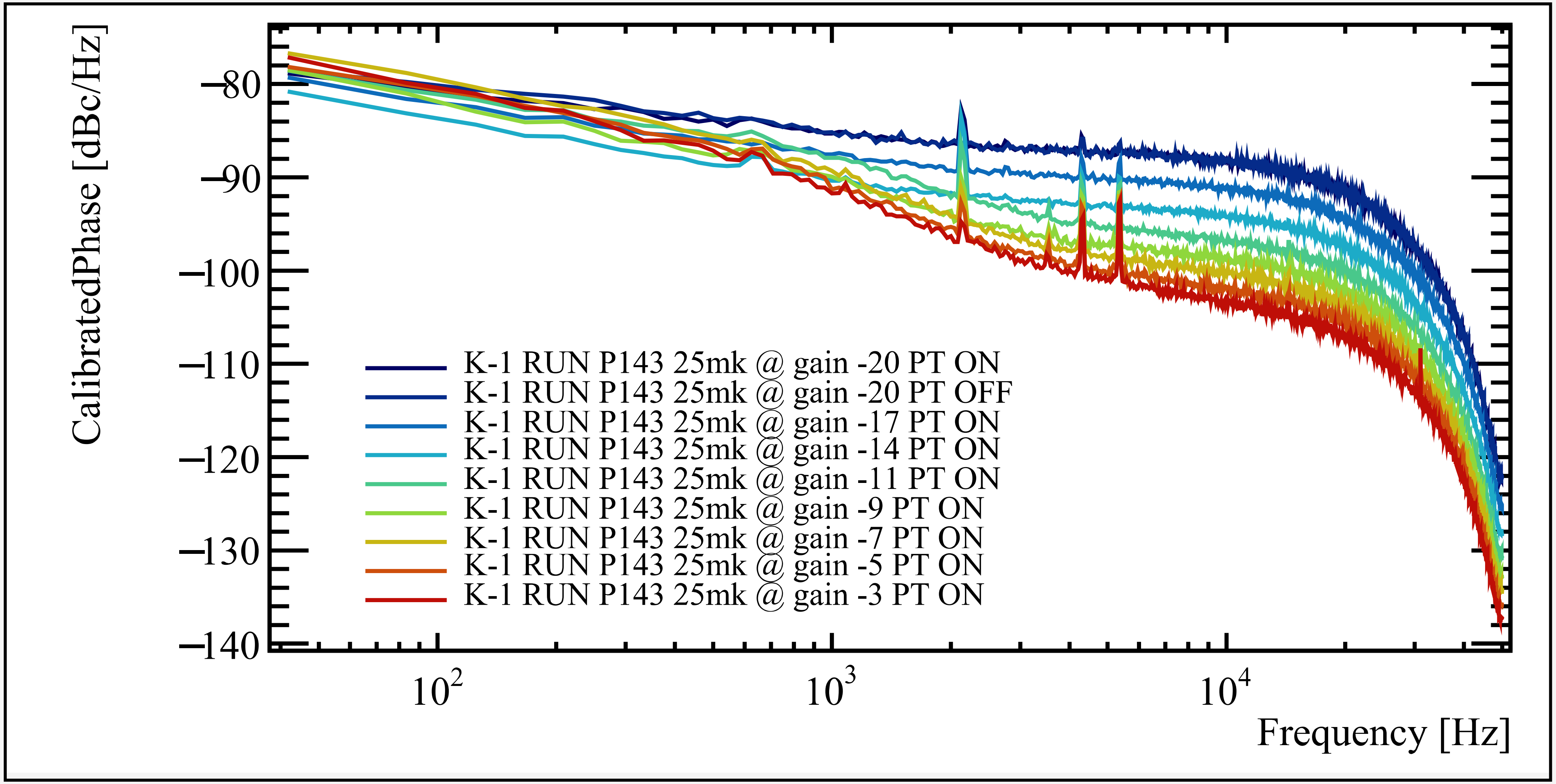
Pulse response and noise spectral shape



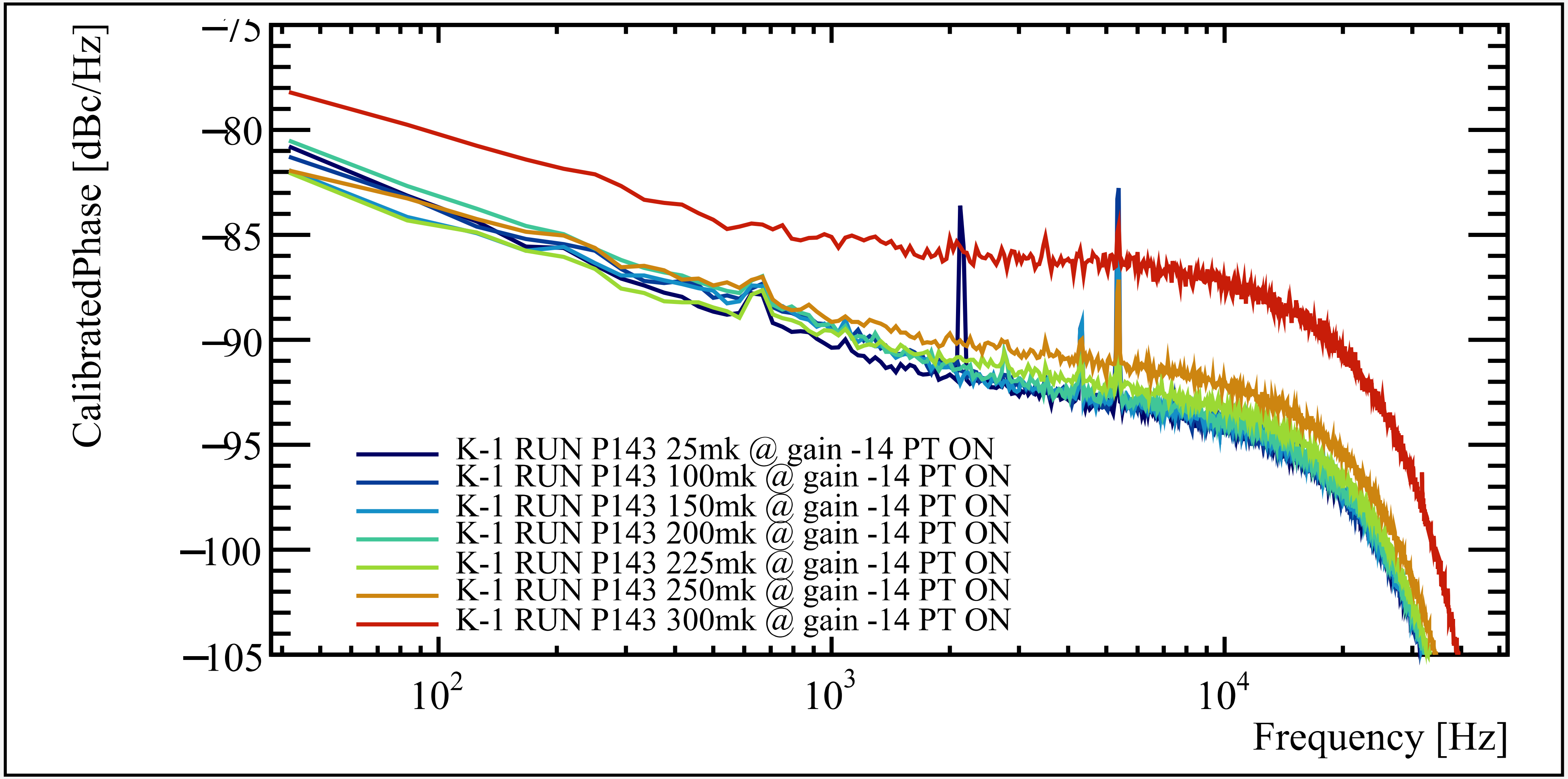


- Pulses **faster** than BULLKID and CALDER-17
- **Noise** higher than CALDER-17 but **compatible with BULLKID** figures

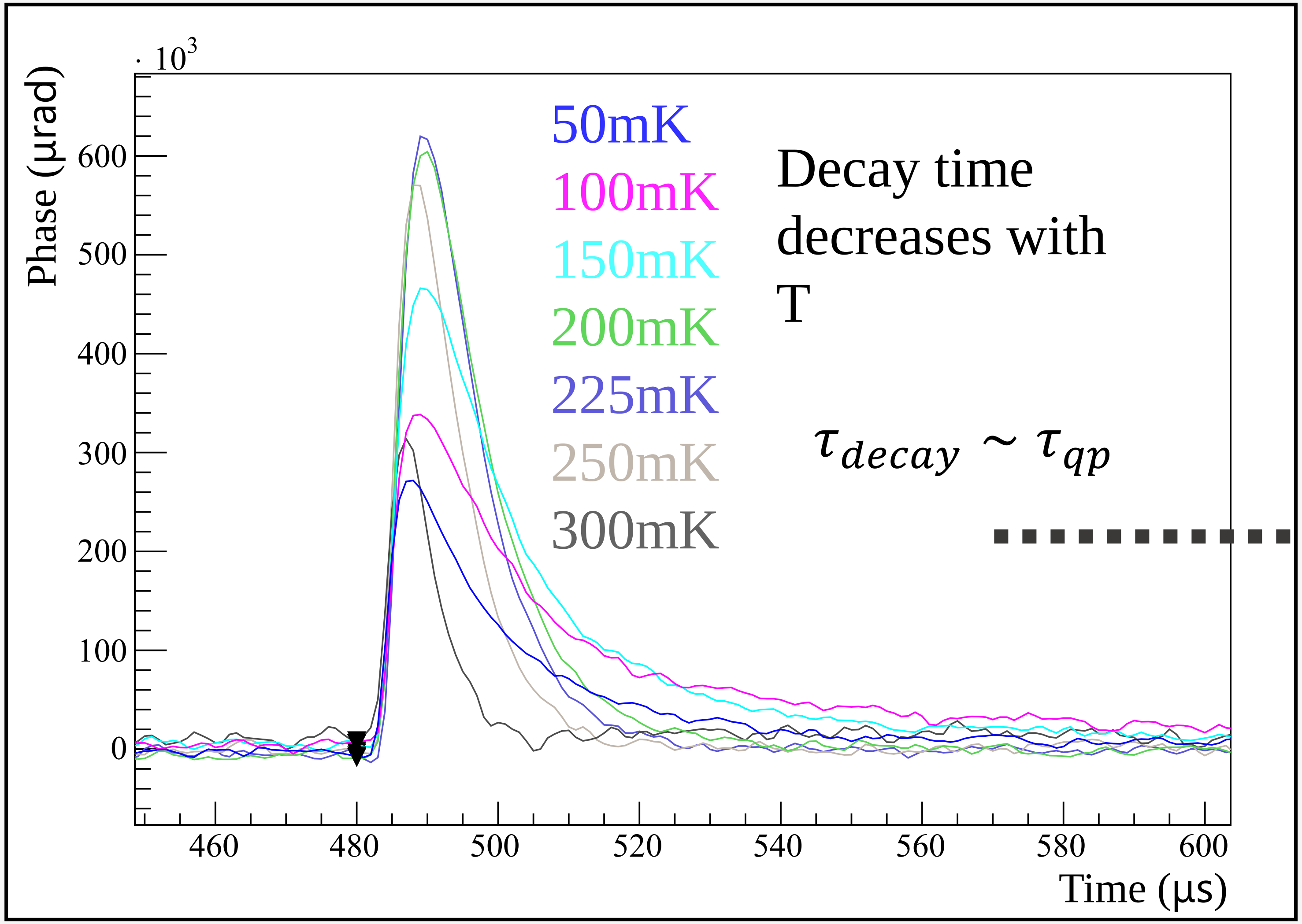
Noise as a function of power

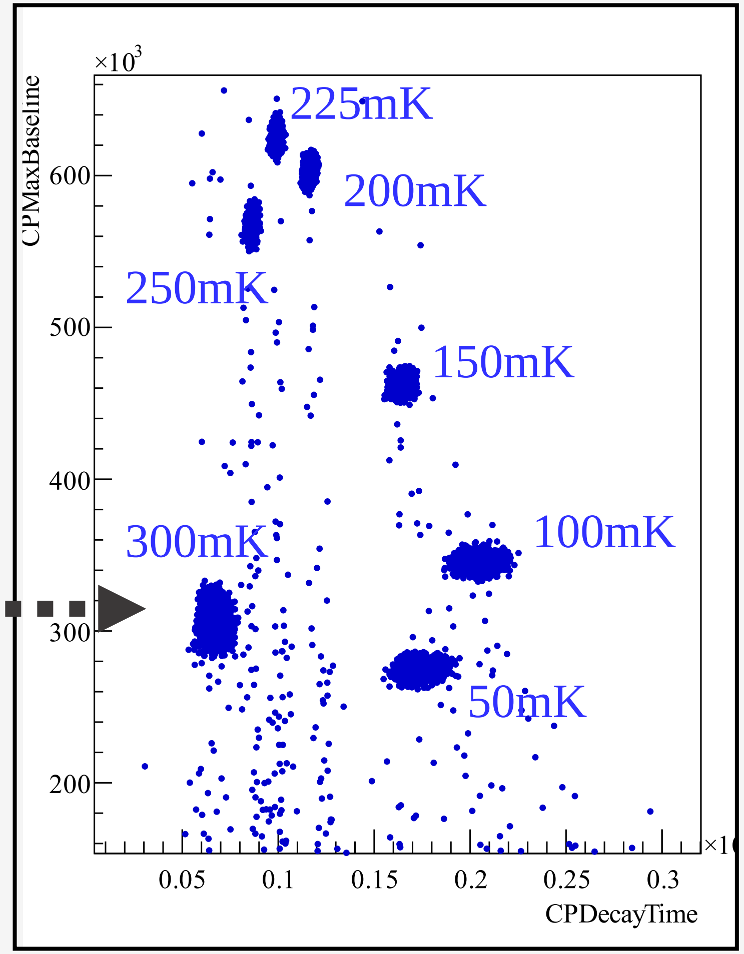


Noise as a function of temperature

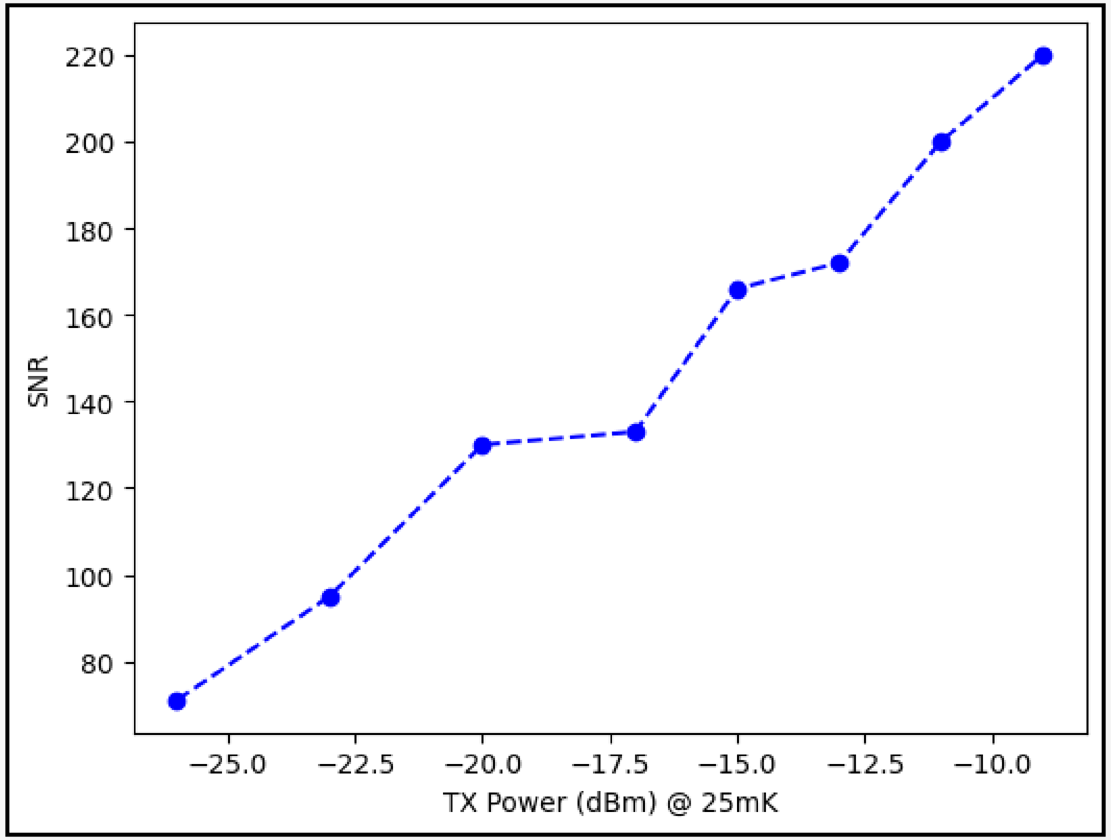


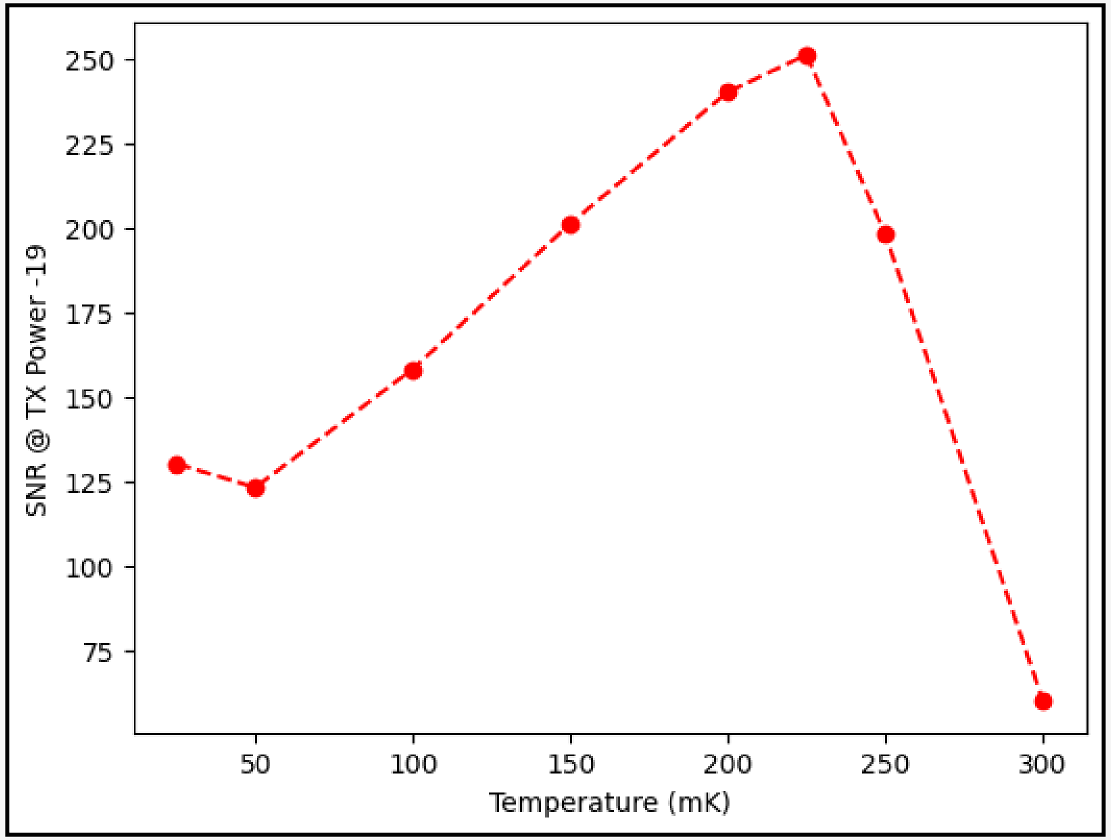
Pulse height – Temperature scan @ gain -14 / Constant LED energy





Results of Temperature and Power scans (max SNR)

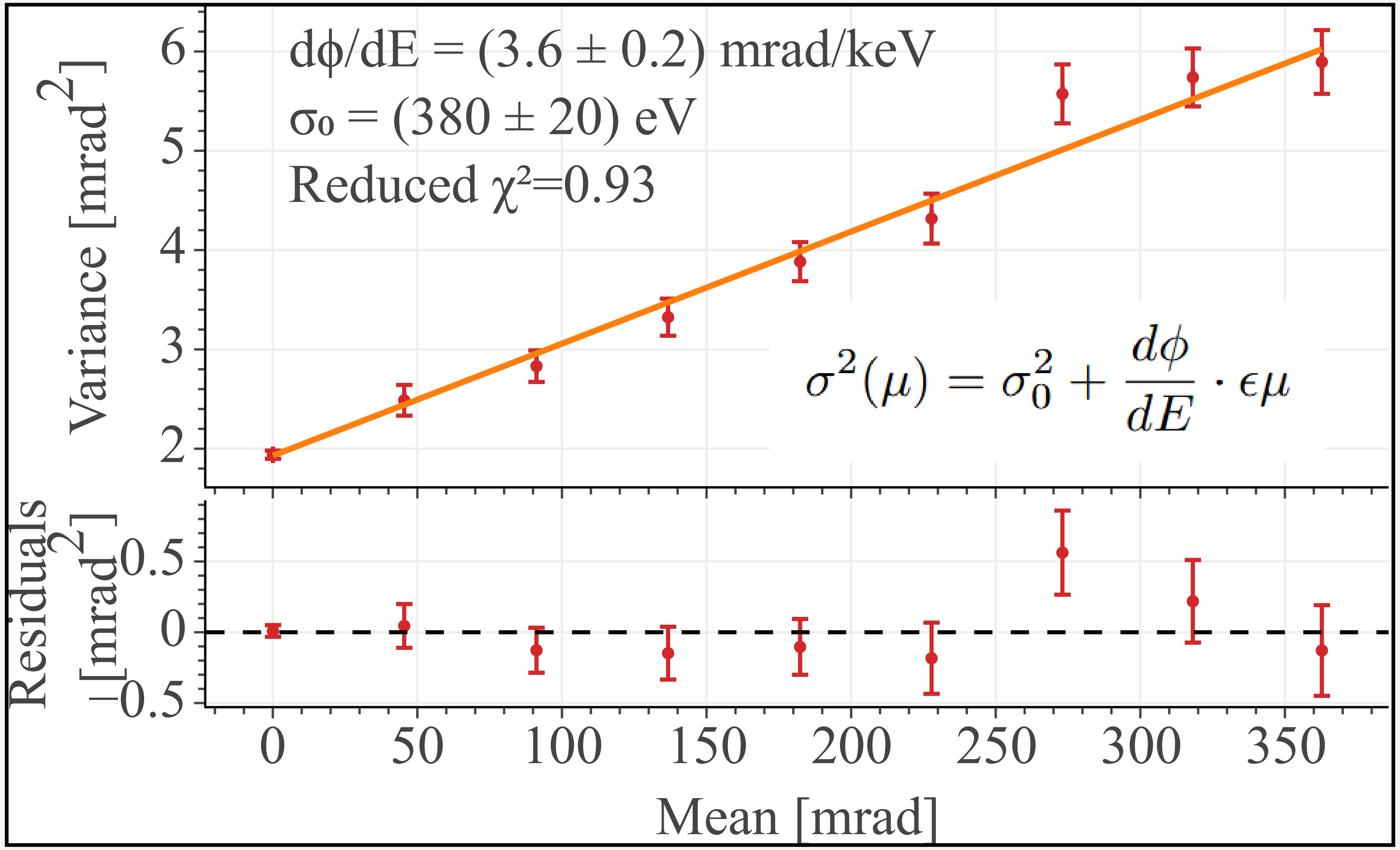




Operating conditions:
TX-Power -9
Power on chip -64 dBm

Operating conditions:
Temperature 225 mK

Energy calibration at optimum power and temperature



$\frac{L_k}{L_{tot}}$ depends on pixel geometry and material

Quality factor

$$\frac{d\phi}{dE} = \eta \frac{\alpha S_\phi(\omega, T) Q}{N_0 V \Delta_0^2}$$

Gap of Aluminum

Volume of the KID

Energy to quasi-particles efficiency

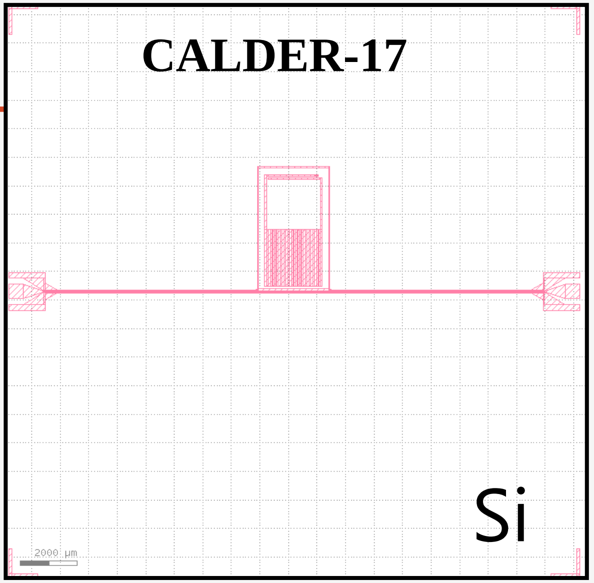
Energy calibration at optimum power and temperature

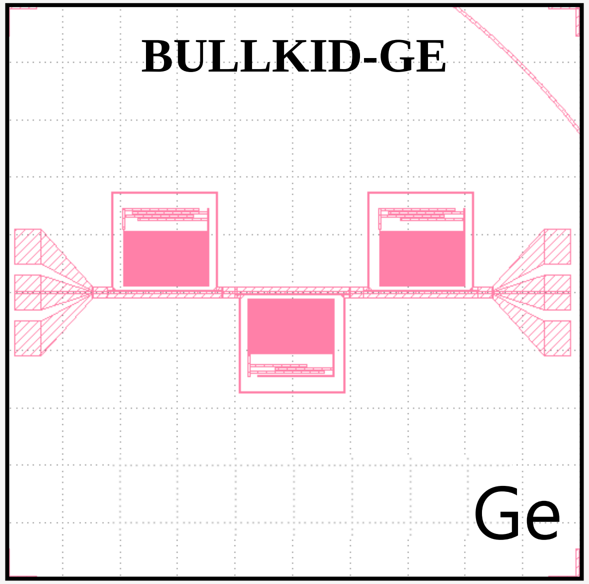
	$d\phi/dE$ [mrad/keV]	σ_0 [eV]	η [%]	$\frac{A_{\mathrm{KID}}}{A_{\mathrm{TOT}}}$
KID-1	3.6 ± 0.2	380 ± 20	2.0 ± 0.2	0.12
KID-2	2.5 ± 0.1	450 ± 22	2.0 ± 0.2	"
KID-3	2.2 ± 0.2	540 ± 31	1.6 ± 0.2	"
CALDER-17	5.8	115 ± 6	$7.4 - 9.4$	0.42

Reduced η due to

- Competition among KIDs
- Excess passive metal

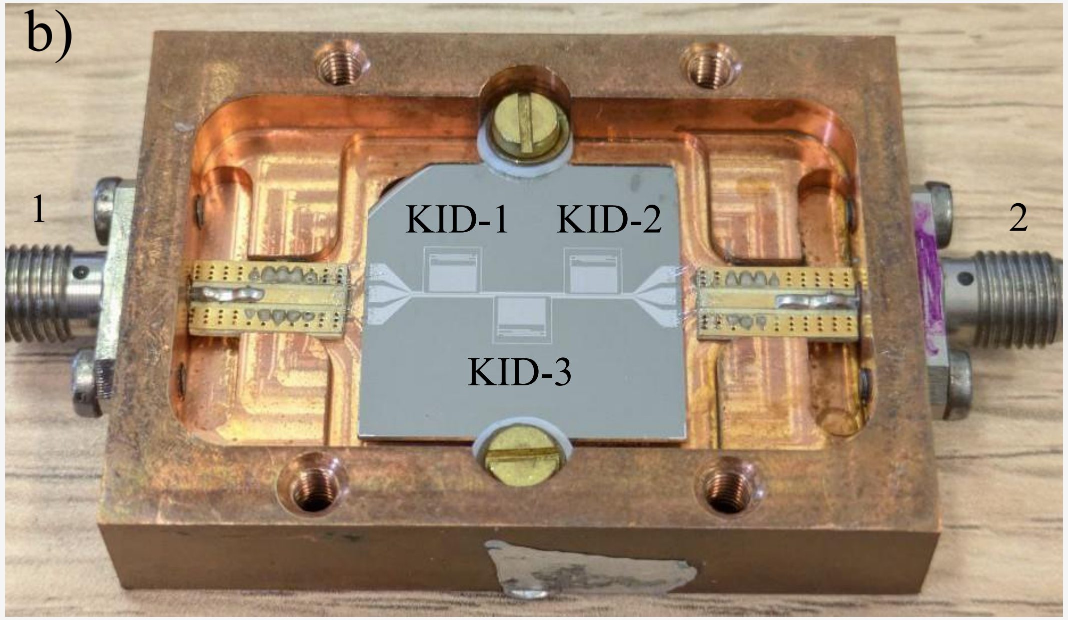
Reduced $\frac{d\phi}{dE}$ due to A_{KID}/A_{TOT}



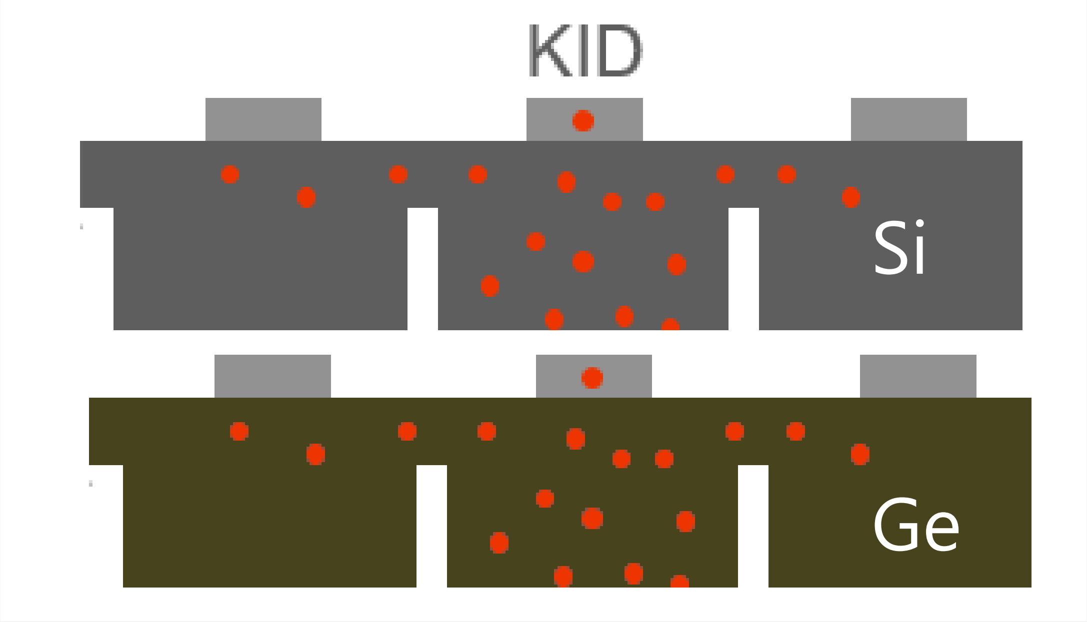


Conclusion and next steps

- Responsivity seems independent of substrate material
- Performance must be evaluated on diced sample

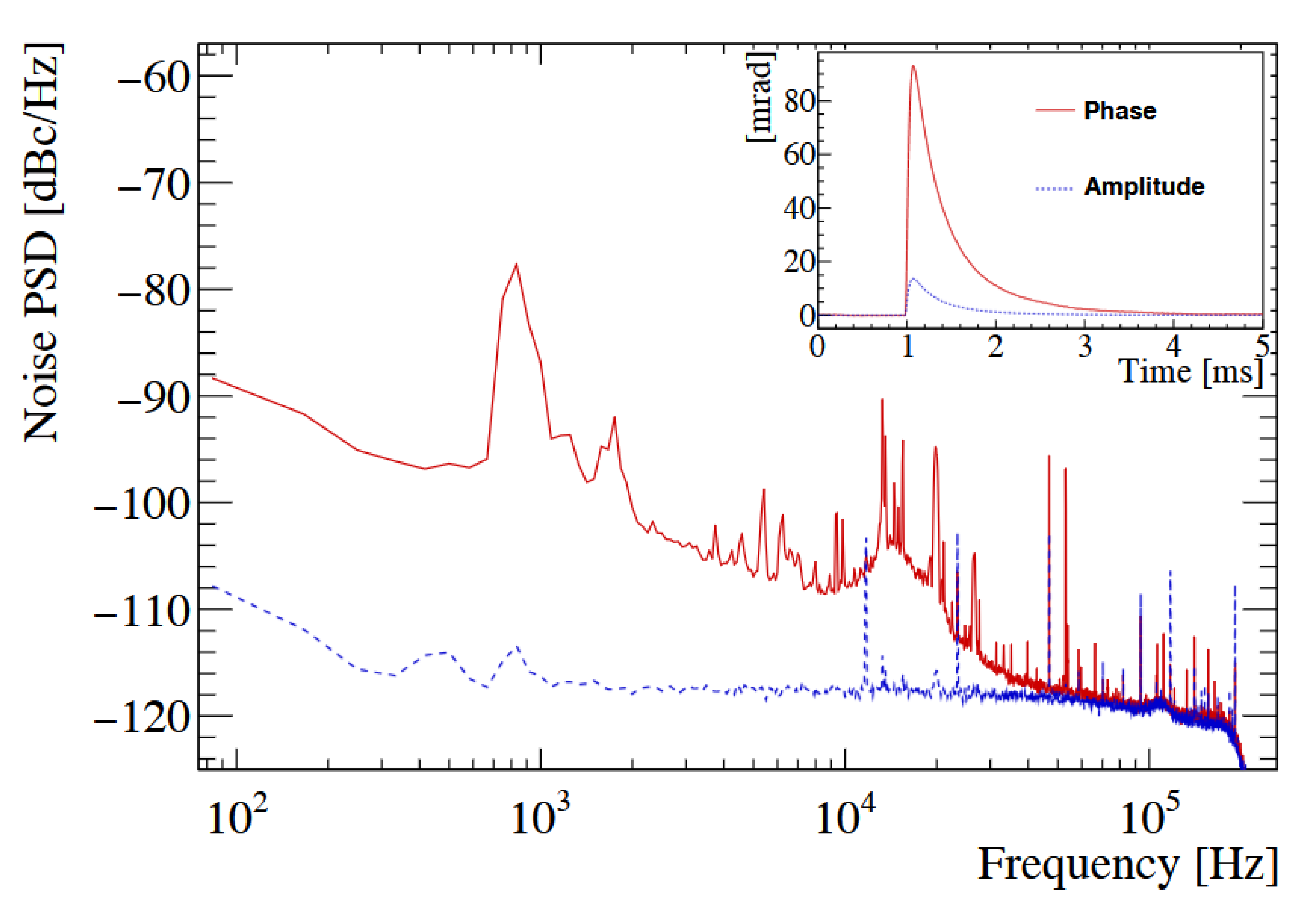


Functional tile prototype

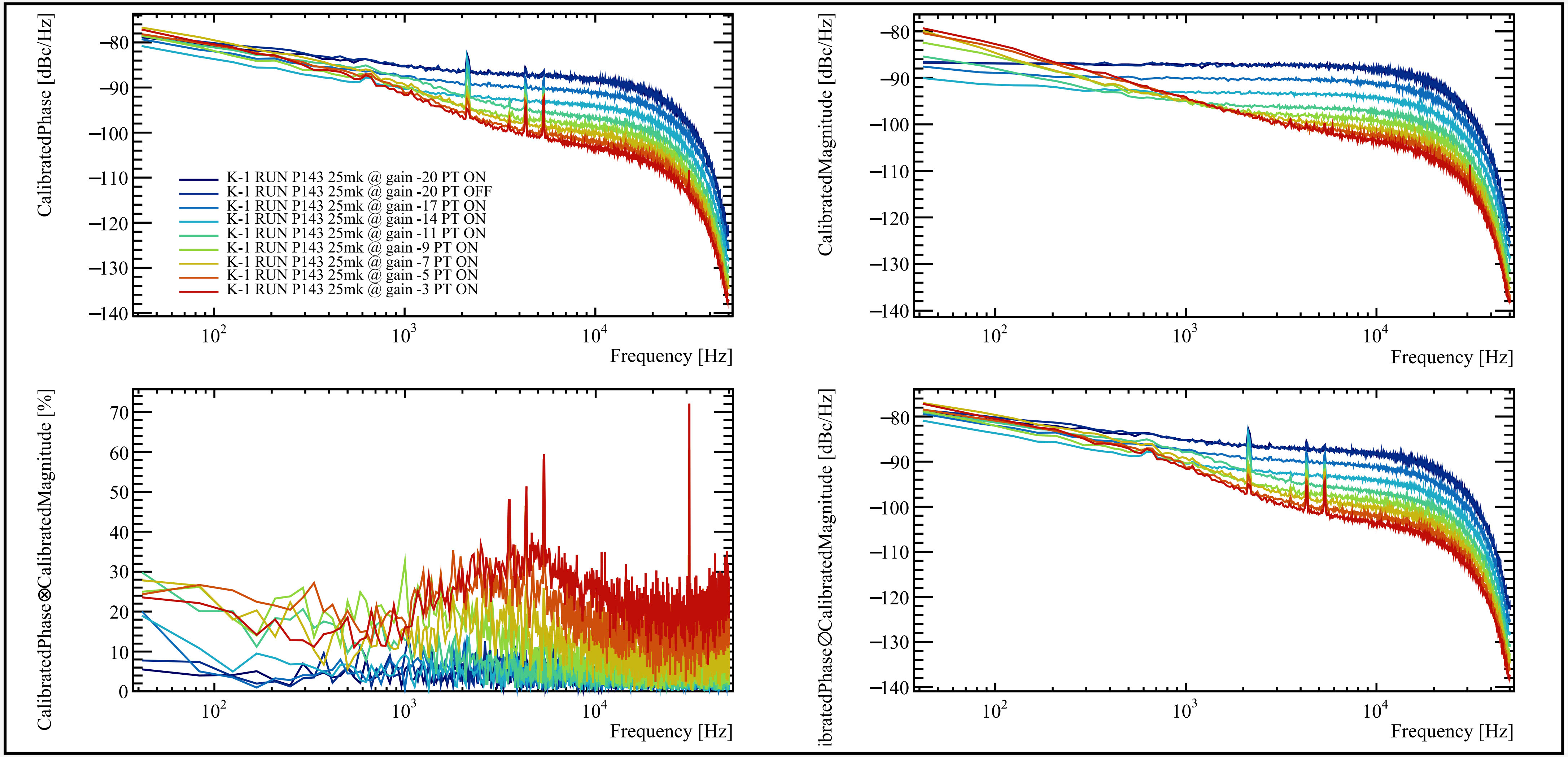


Full scale Ge BULLKID 100mm

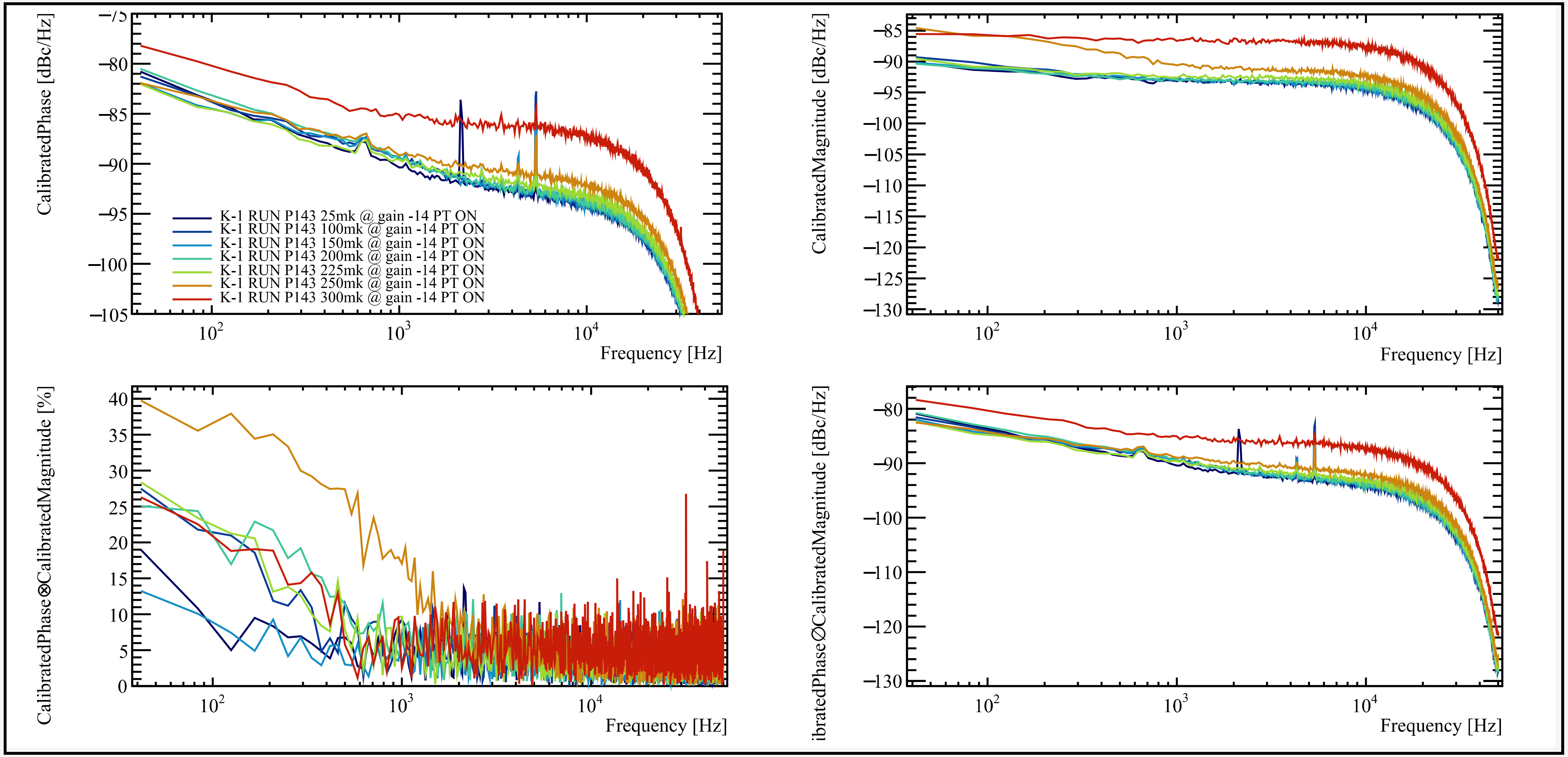
(Extra) CALDER-17 Pulse and noise power spectrum



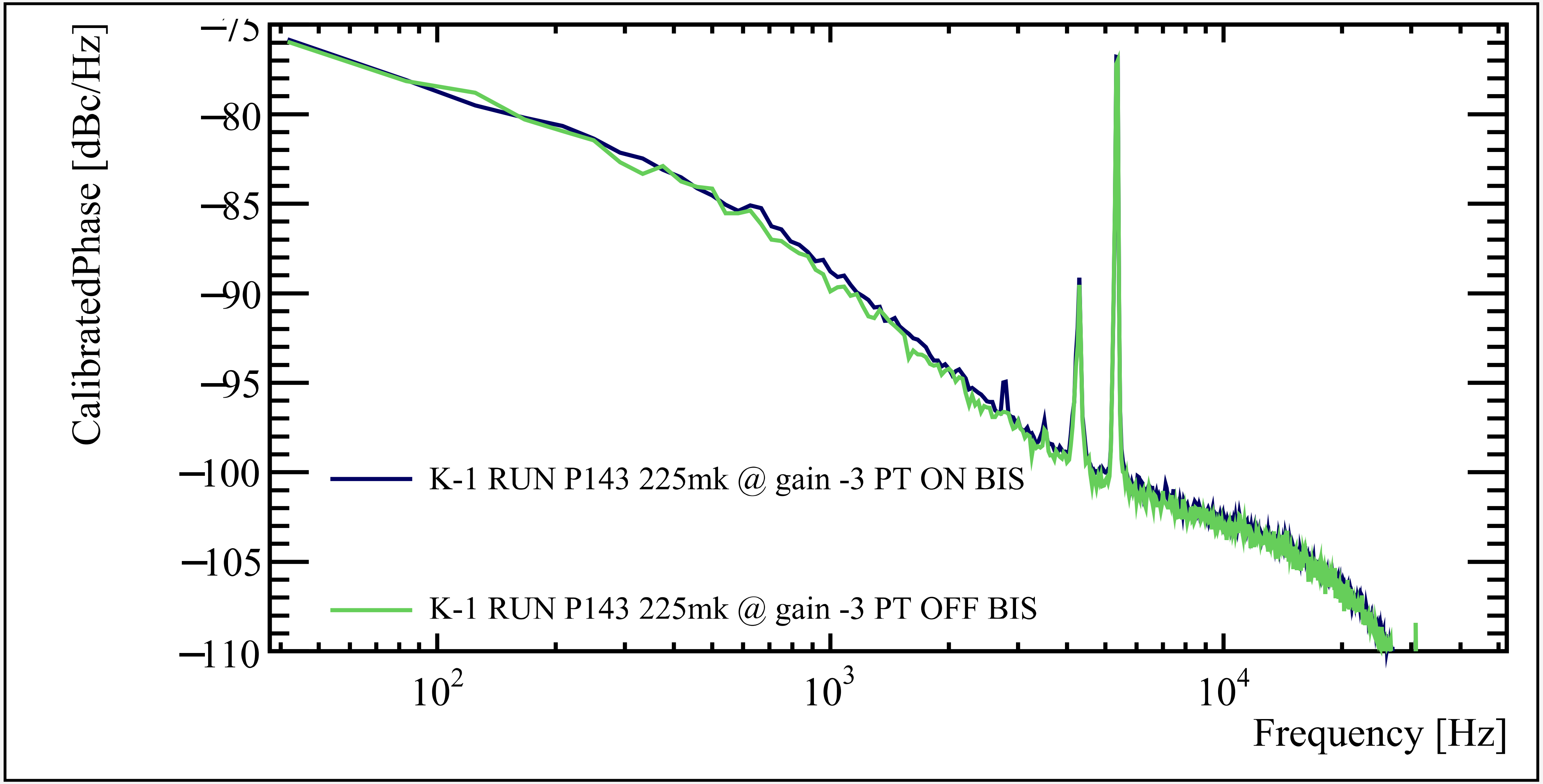
Noise PS – Power scan



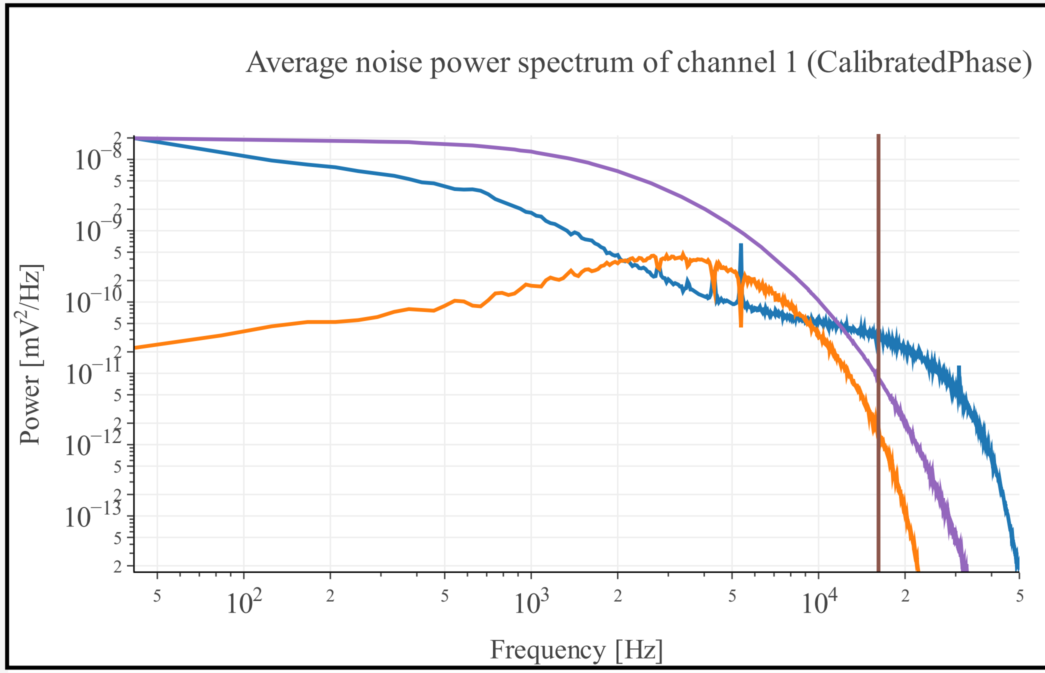
Noise PS – Temperature scan

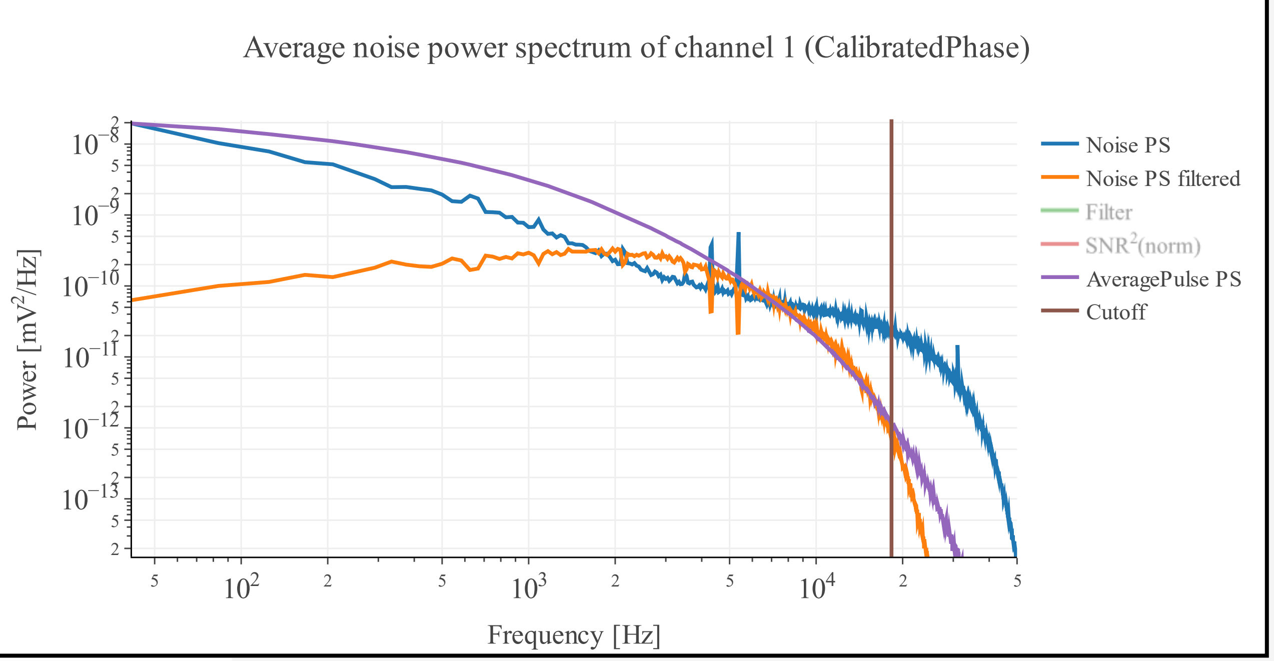


Noise PS – PT ON / PT OFF **(No difference)**



Results of Temperature and Power scans (max SNR)

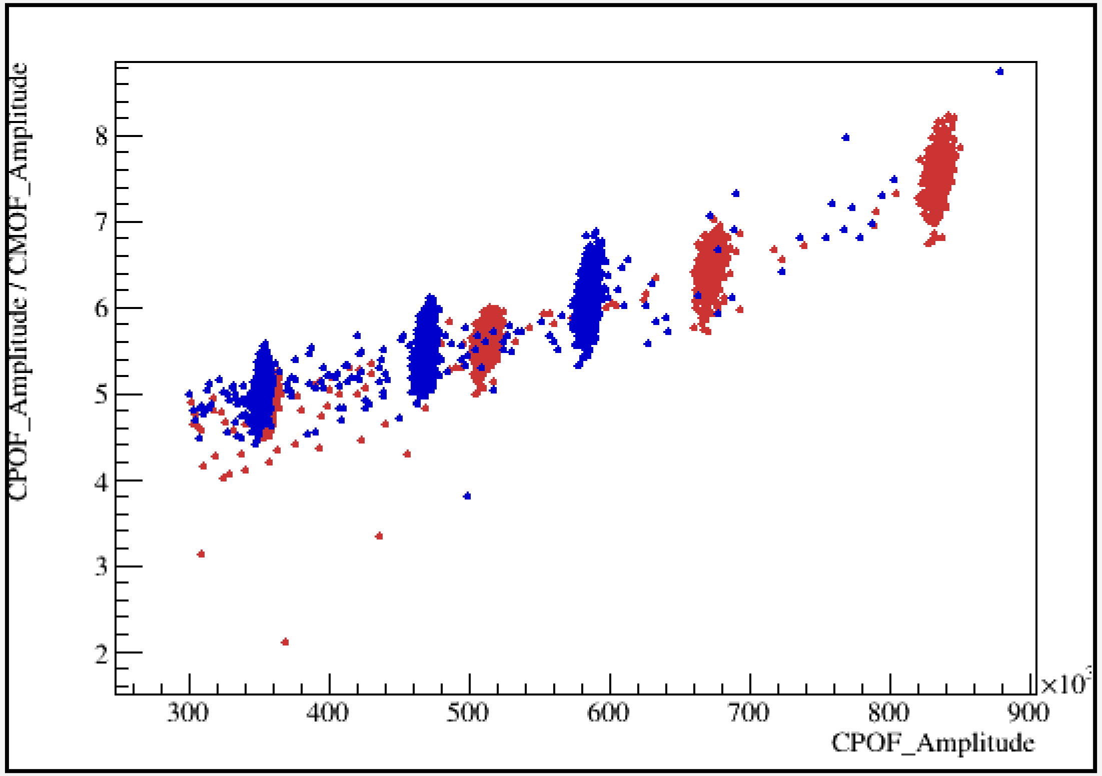


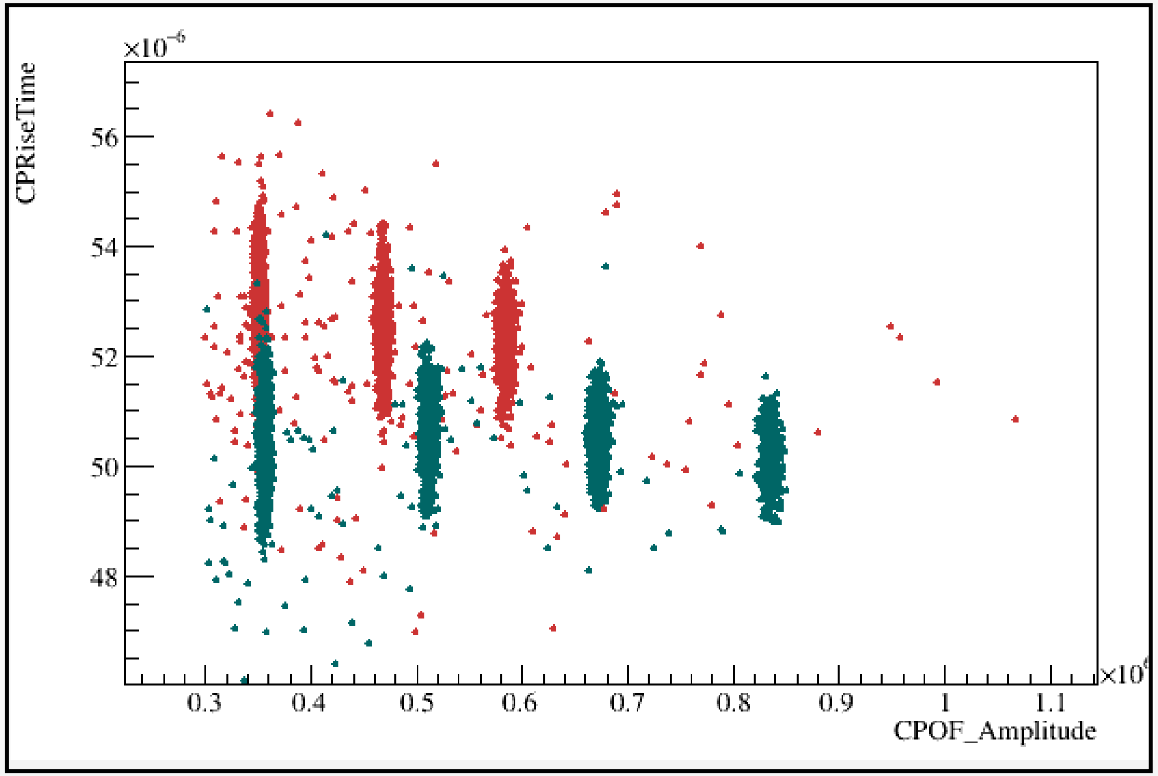


Sampling frequency = 100000.0 [Hz]
Temperature: 225 [mK]
Differentiation: ON
Tx Gain: -3
Low pass filter cutoff: 1.61667e+04 [Hz]
Filtered/Original amp: 1.00000e+00
Average pulse amplitude: 5.45507e+05 [ADC counts] (5.45507e-01 [mV])
RMS of original noise: 2.79008e+03 [ADC counts] (2.79008e-03 [mV])
RMS of filtered noise: 1.44865e+03 [ADC counts] (1.44865e-03 [mV])
SNR after the filter: 3.76561e+02 [mV/mV]

Sampling frequency = 100000.0 [Hz]
Temperature: 25 [mK]
Differentiation: ON
Tx Gain: -3
Low pass filter cutoff: 1.82917e+04 [Hz]
Filtered/Original amp: 1.00000e+00
Average pulse amplitude: 2.68719e+05 [ADC counts] (2.68719e-01 [mV])
RMS of original noise: 2.23368e+03 [ADC counts] (2.23368e-03 [mV])
RMS of filtered noise: 1.21432e+03 [ADC counts] (1.21432e-03 [mV])
SNR after the filter: 2.21292e+02 [mV/mV]

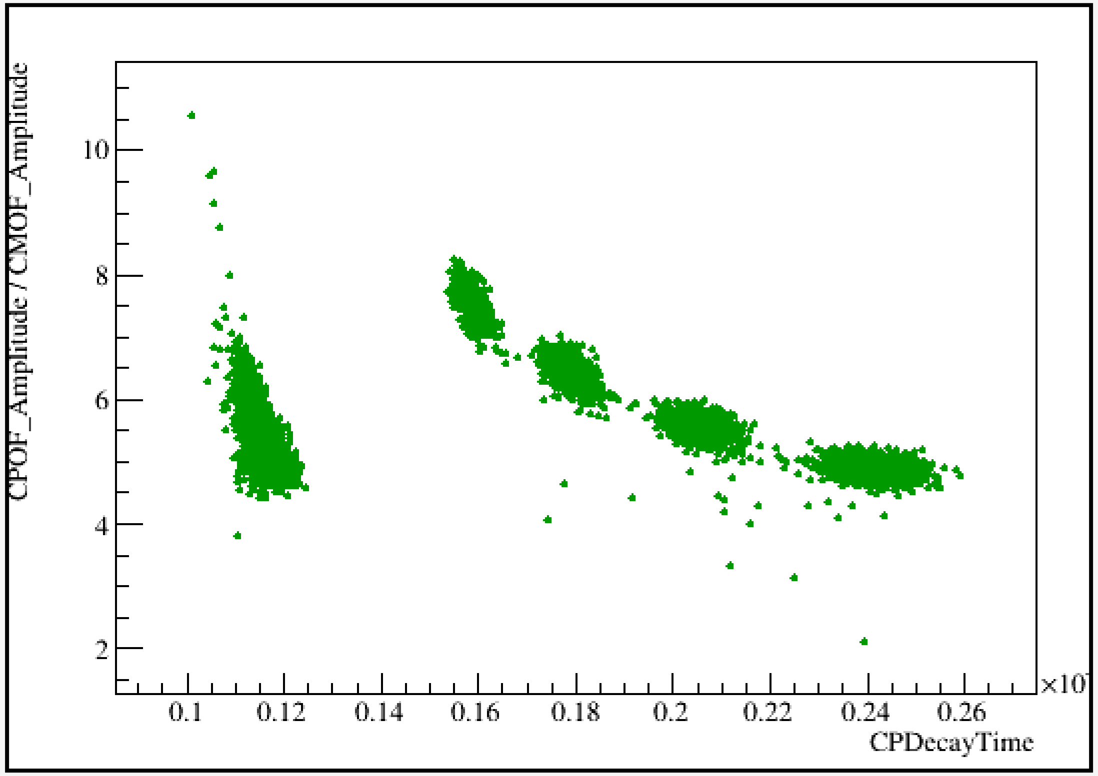
CPOF_Amplitude / CMOF_Amplitude @ 50mk and 225mK

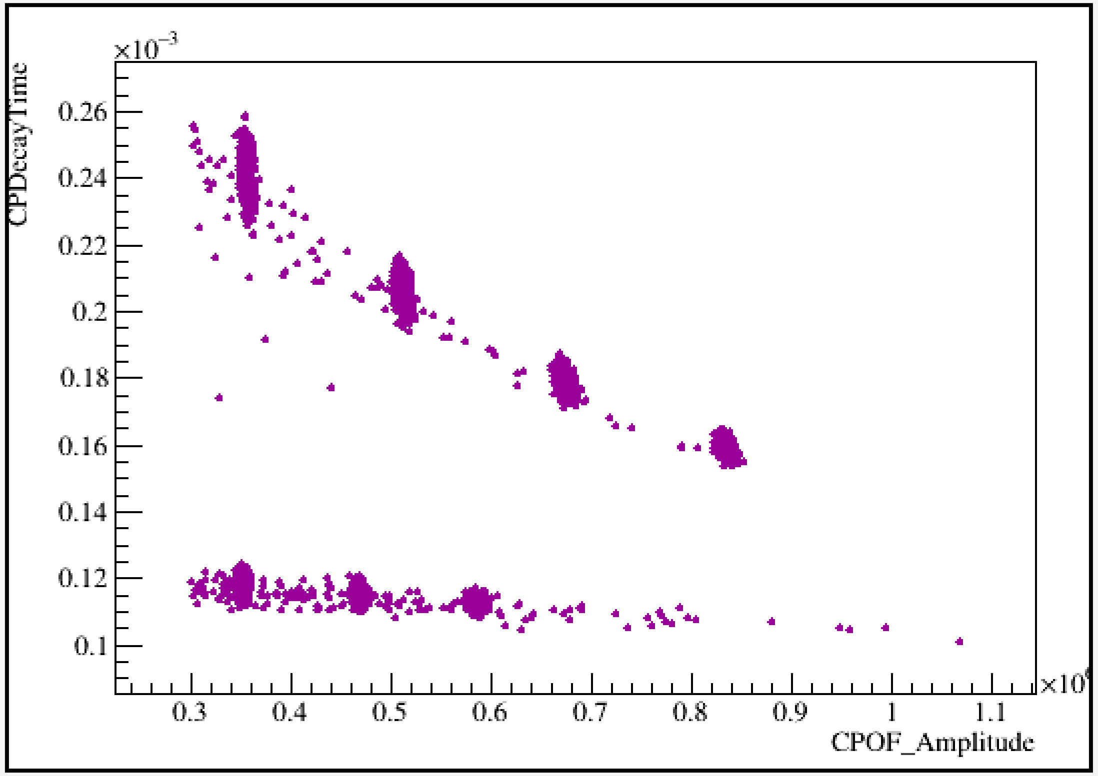




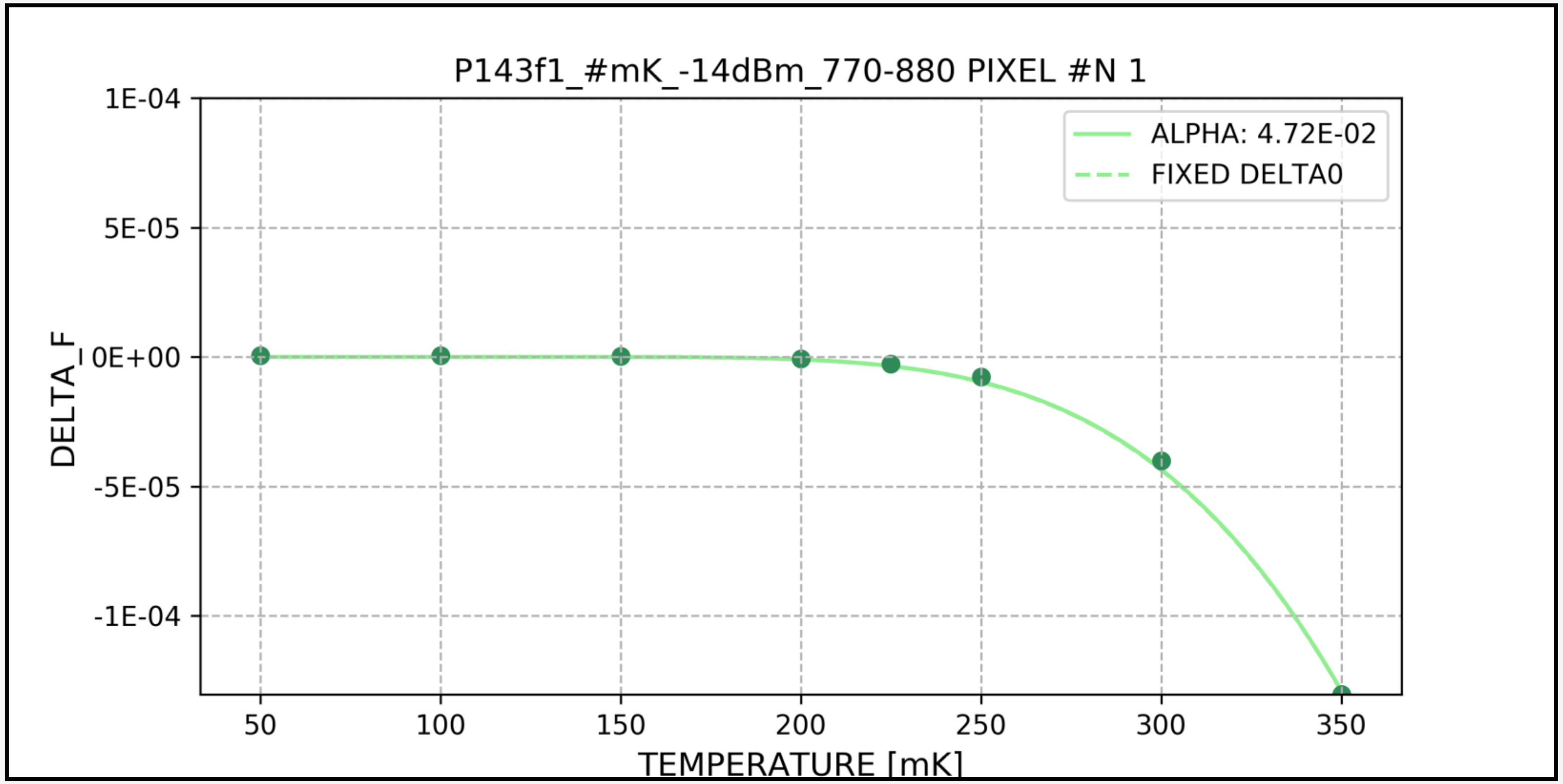
Phase / Magnitude ratio is the same at base temperature and @ 225mK

CPOF_Amplitude / CMOF_Amplitude @ 50mk and 225mK





Run P143 – Temperature vna scan



ALPHA: 4.75E-02
DELTA0: 1.8979E-04
ALPHA2: 4.59E-02
DELTA0_FIXED: 1.89E-04