Operation of COSINUS sensors

now and in the future

Identification of Dark Matter 2026, Zaragoza, Spain

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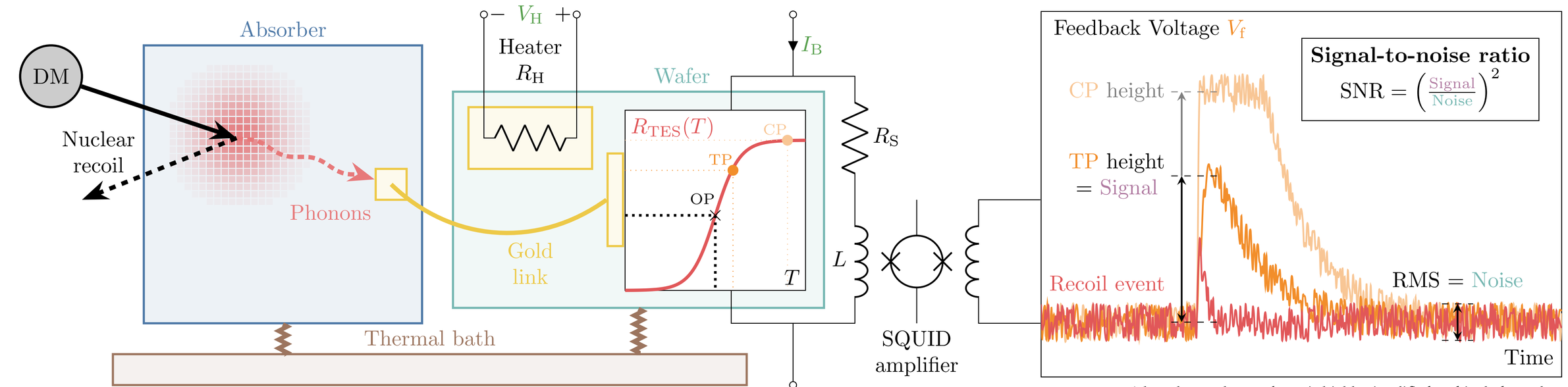
on behalf of the COSINUS collaboration



DM = dark matter, TES = transition edge sensor, OP = operating point, TP = test pulse, CP = control pulse

*the scheme shown above is highly simplified and includes only the components relevant to the measurement principle

Transition Edge Sensor

- Special thin-film resistors developed by CRESST collaboration
- **Trick**: Operate TES <u>in transition</u> in between superconducting and normal conducting state to increase temperature sensitivity

$$\Delta T \in \mathcal{O}(\mu K) \rightarrow \Delta R_{TES} \in \mathcal{O}(m\Omega)$$

- Made from tungsten (W) with low heat capacity C, maximizing change in temperature from recoil $\Delta T \propto \frac{\Delta E}{C}$
- Recoil energy ΔE in absorber produces phonons, that thermalize and rise TES temperature by ΔT, therefore also resistance ΔR_{TES}
- TES is embedded in <u>current divider circuit</u> with shunt resistor R_S and SQUID amplifier (input coil L), leading to voltage signal

Operating point determination

- OP defined as <u>position in TES transition</u> and its bias scaling, set by the mutually dependent pair of bias current (introducing self-heating) and heater voltage (external heating)

$$OP := \{I_B, V_H\}$$

Optimization methods

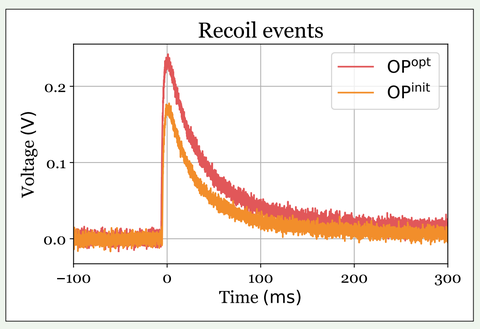
- **Goal:** Find <u>optimal</u> OP, which is defined by the best baseline resolution (BLR) for recoil events!
- **Assumption:** Best BLR when SNR is maximal!

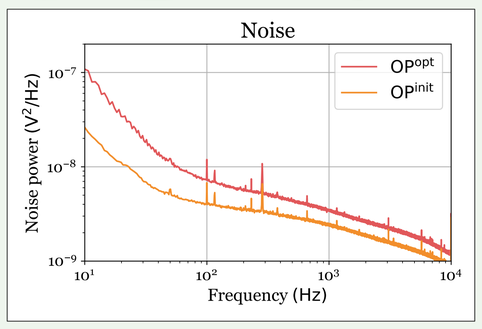
$$OP^{opt} := \{I_B^{opt}, V_H^{opt}\} = \arg\max(SNR(I_B, V_H))$$

Procedure

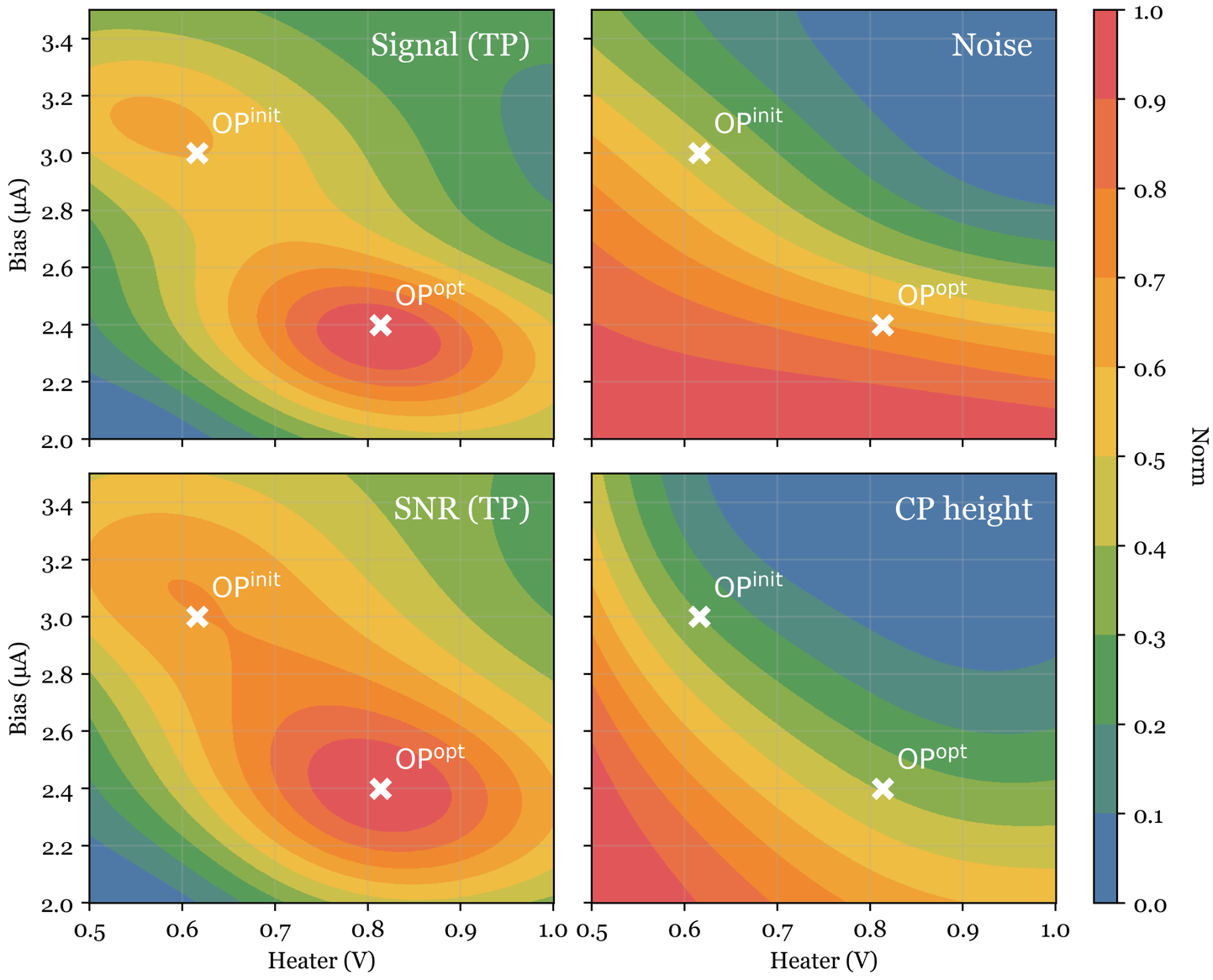
- Heater sends artificial test pulses (TP) with fixed amplitude, that imitate real particle pulses → Signal
- RMS of empty traces (in absence of pulses) → Noise
- Vary OP to find maximum of $SNR = \left(\frac{Signal}{Noise}\right)^2$
- Control pulses (CP) help to stabilize detector during operation and track actual position in transition

Established methods: Strategic [1] or ML-based [2]





Results for Si remoTES R&D module



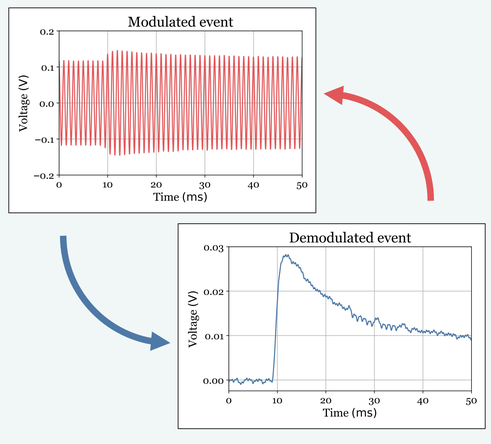
Results from recoil events

by ^{55}Fe gamma (5.9 keV) source, OP^{init} is an experience-based educated guess from an expert

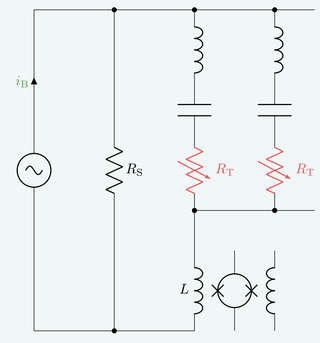
Operating point	Signal (iron event)	Noise	SNR	BLR (analysis)
OP^{init} (initial)	(0.174 ± 0.011) V	(4.366 ± 1.138) mV	1588 ± 852	(18.8 ± 0.7) eV
OP^{opt} (optimized)	(0.232 ± 0.014) V	(5.509 ± 3.233) mV	1773 ± 2093	(17.5 ± 0.5) eV
Change	+ 33.33 %	+ 26.18 %	+ 11.65 %	− 6.92 %

Future

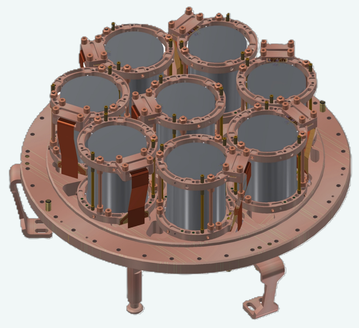
Modulation



Multiplexing

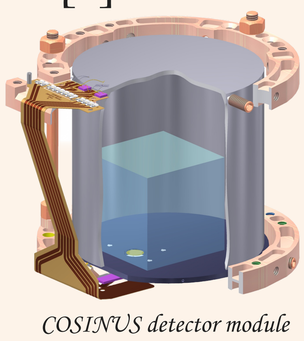


Automatization for many detectors



The COSINUS experiment [3]

- Direct detection of a potential DM signal
- Cross-check long standing DAMA claim of <u>annual modulation</u> signal [4] with same absorber material (NaI)
- Cryogenic calorimeter with <u>two-channel readout</u> (phonon and scintillation light, both instrumented with a TES) for background discrimination
- Allowing in-situ measurement of quenching factor



COSINUS detector module

[1] M. Cappelli et al., "Sensitivity enhancement techniques for cryogenic calorimeters in the NUCLEUS experiment," arXiv preprint arXiv:2603.28276, Mar. 2026. doi: 10.48550/arXiv.2603.28276.
[2] G. Angloher et al., "Optimal Operation of Cryogenic Calorimeters Through Deep Reinforcement Learning," Computing and Software for Big Science, vol. 8, no. 1, Art. no. 10, 2024, doi: 10.1007/s41781-024-00119-y.
[3] G. Angloher et al., "COSINUS—A model-independent challenge of the DAMA/LIBRA dark matter claim with cryogenic NaI detectors operated in a new low-background facility," arXiv preprint arXiv:2507.02429, Jul. 2025. doi: 10.48550/arXiv.2507.02429.
[4] R. Bernabei et al., "New results from DAMA/LIBRA," The European Physical Journal C, vol. 67, no. 1–2, pp. 39–49, 2010, doi: 10.1140/epjc/s10052-010-1303-9.

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