

ECHo-LE

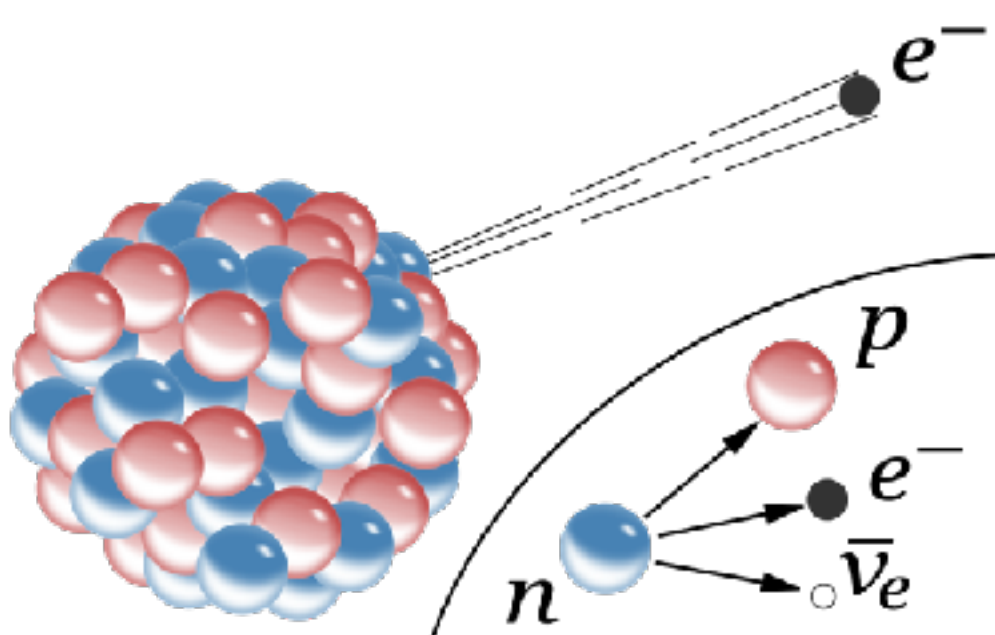
Towards sub-eV sensitivity on effective neutrino mass with Holmium-163

Raghav Pandey for the ECHo-LE Collaboration, 18 September 2026

Neutrino mass

Direct Measurement

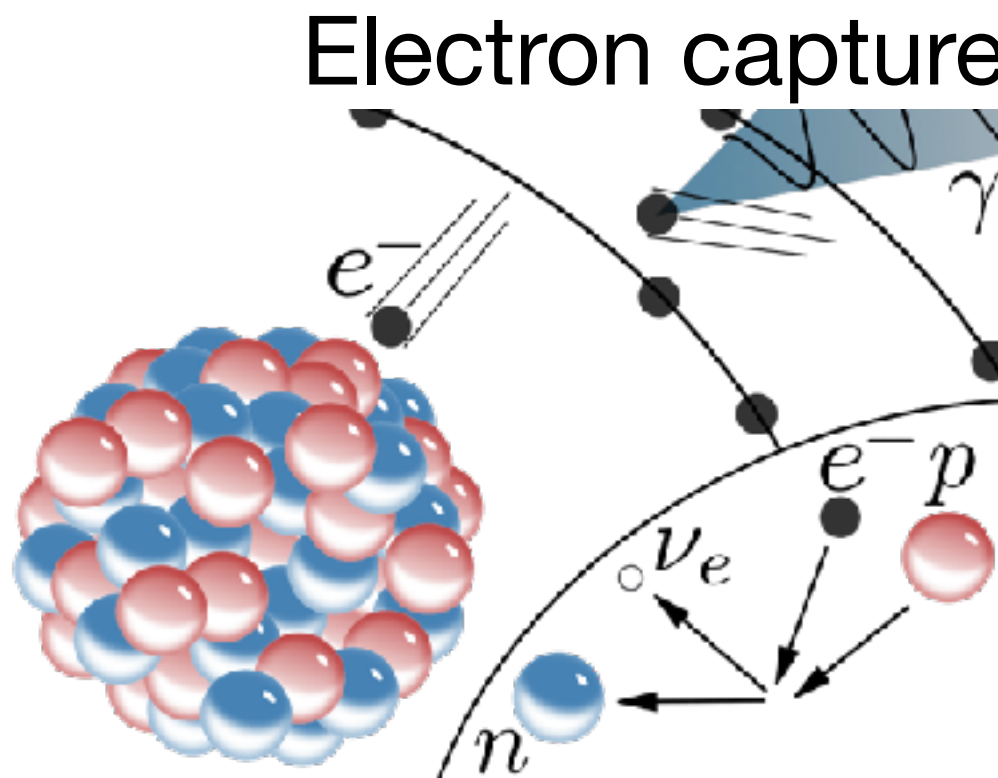
- Kinematic study of radioactive decays (beta decay, electron capture) are model independent investigations of m_{ν_e}



https://en.wikipedia.org/wiki/Beta_decay#/media/File:Beta-minus_Decay.svg

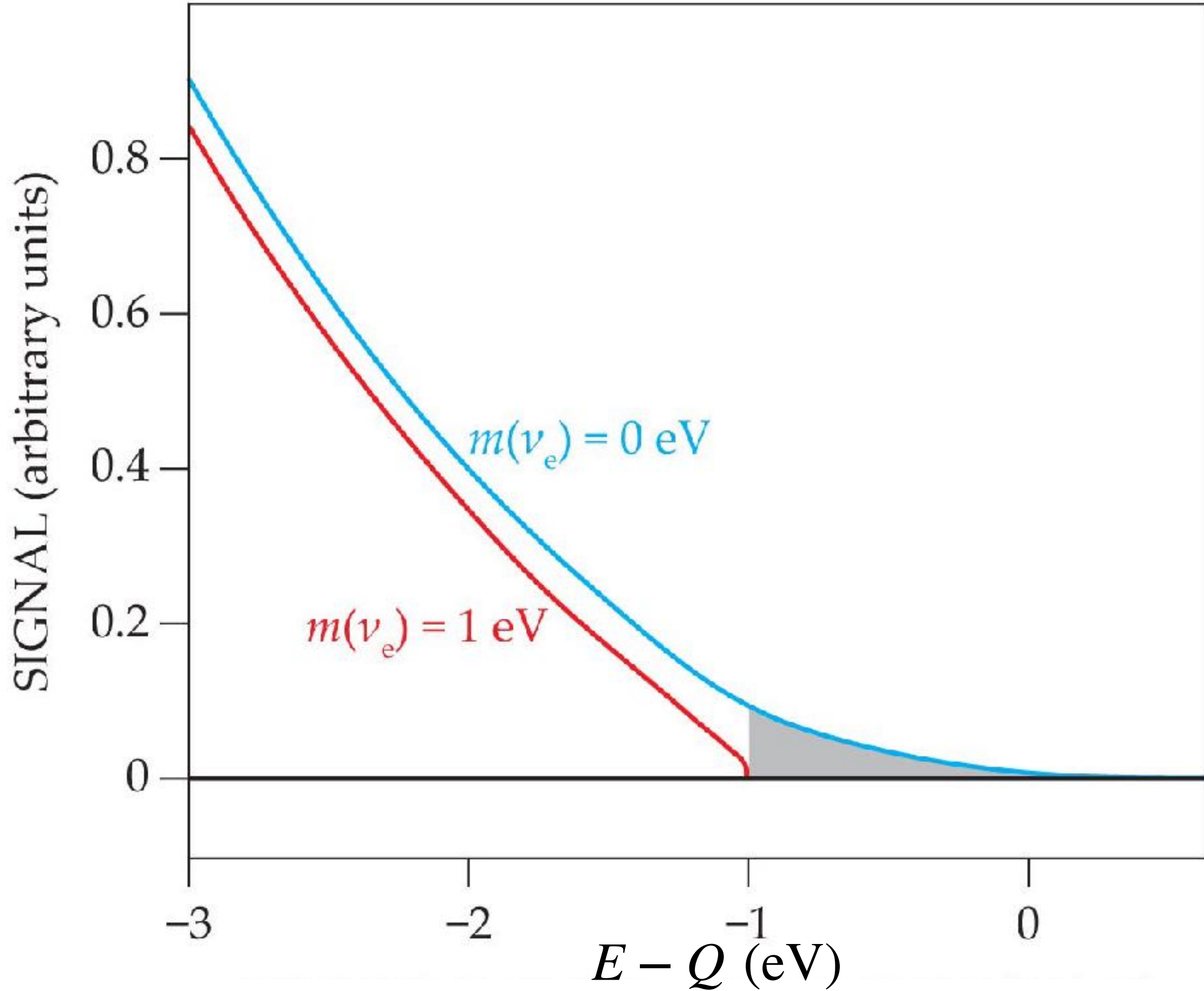
Beta decay

J. A. Formaggio, et al. Physics Reports 914 (June 2021).
arXiv:2102.00594 [hep-ph, physics:nucl-ex], pp. 1–54. doi: 10.1016/j.



https://commons.wikimedia.org/wiki/File:Electron_capture.svg

$$\frac{dW}{dE} \propto (Q - E)^2 \sqrt{1 - \frac{m_{\nu_e}^2}{(Q - E)^2}}$$

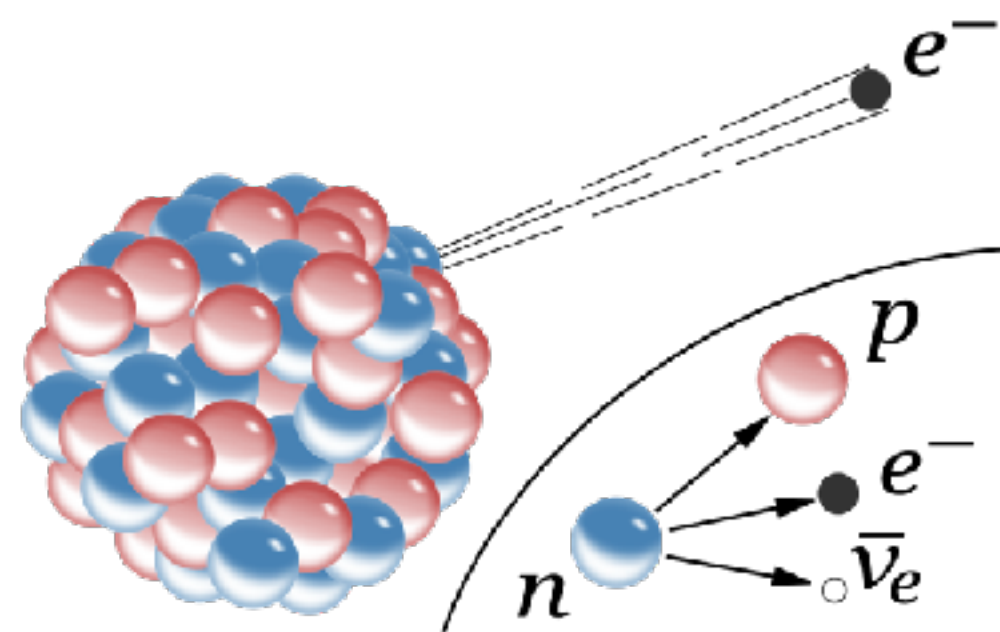


<https://medium.com/starts-with-a-bang/the-mystery-of-neutrino-mass-is-now-smaller-than-ever-a98138731900>

Neutrino mass

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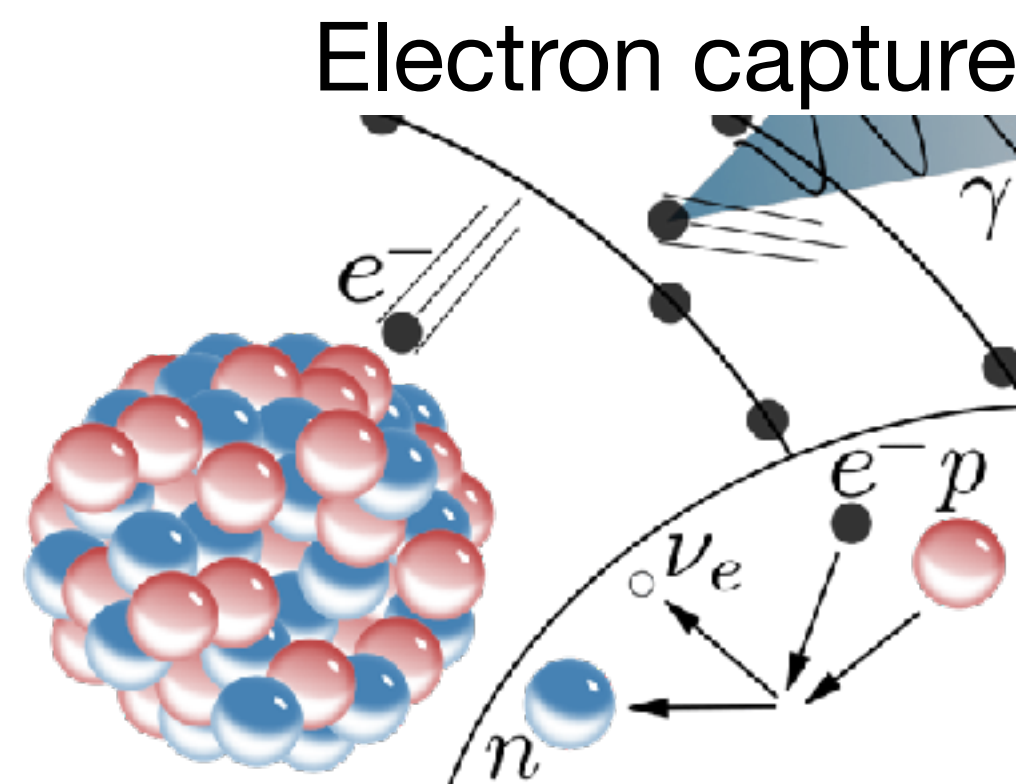
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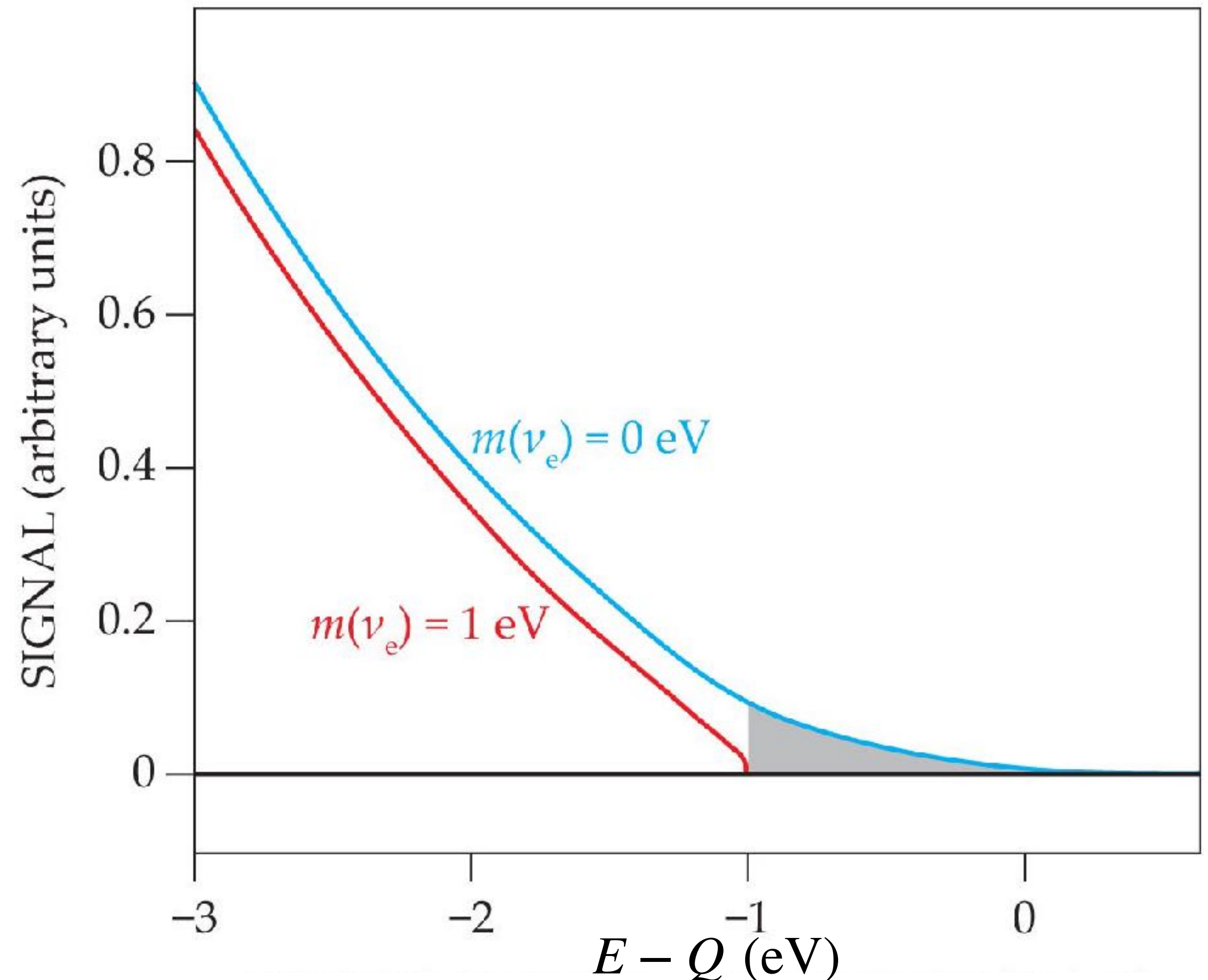
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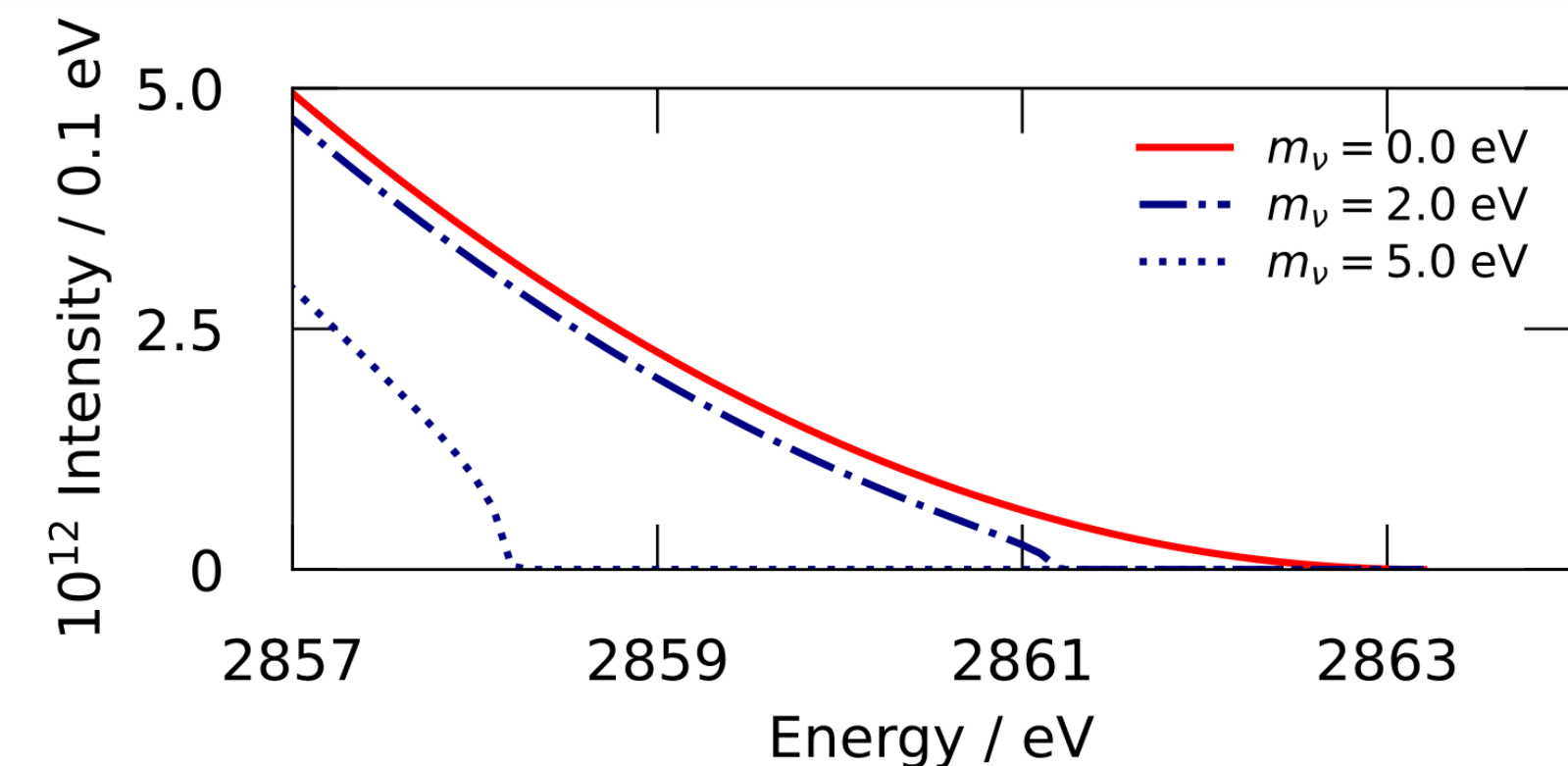
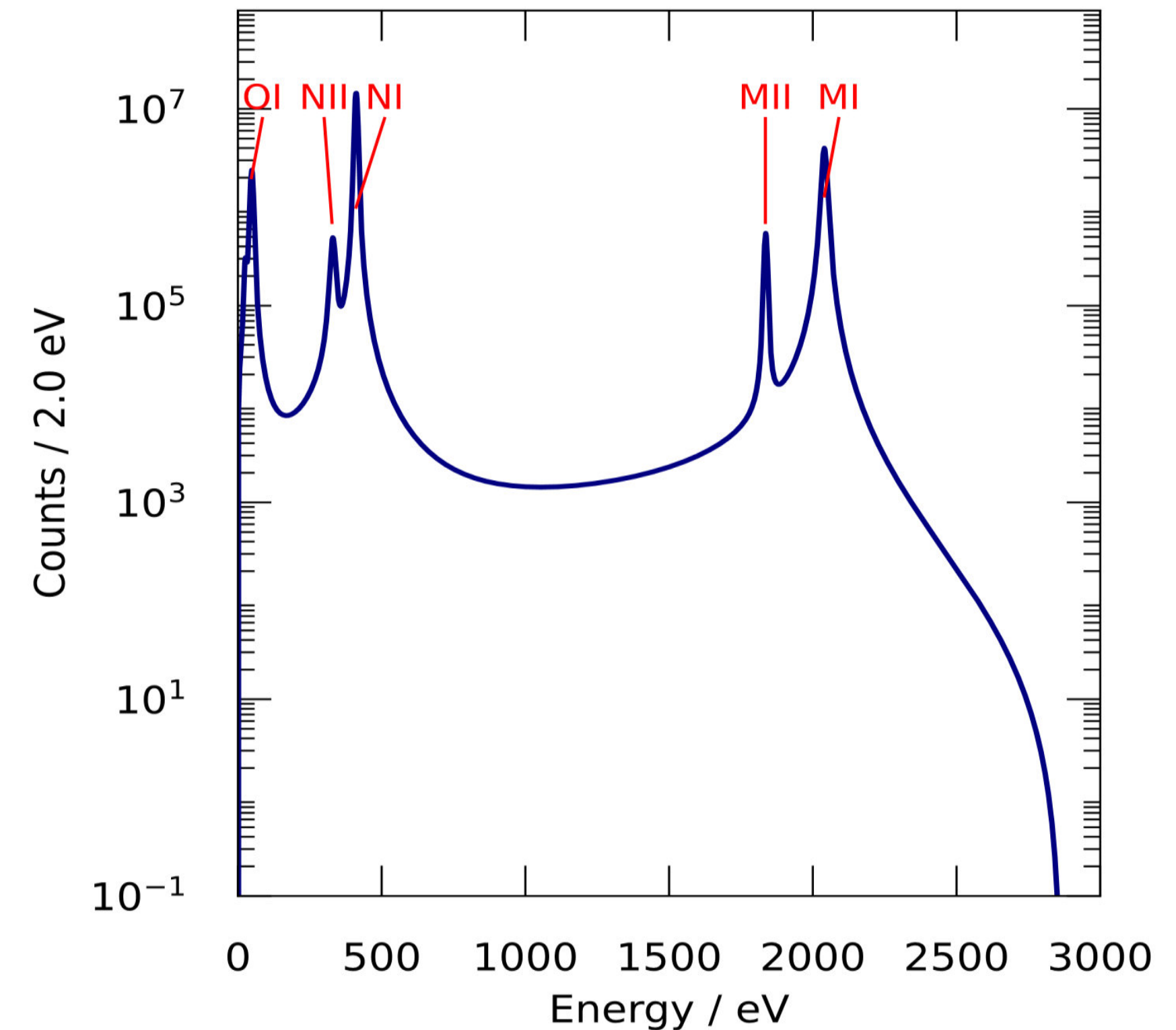
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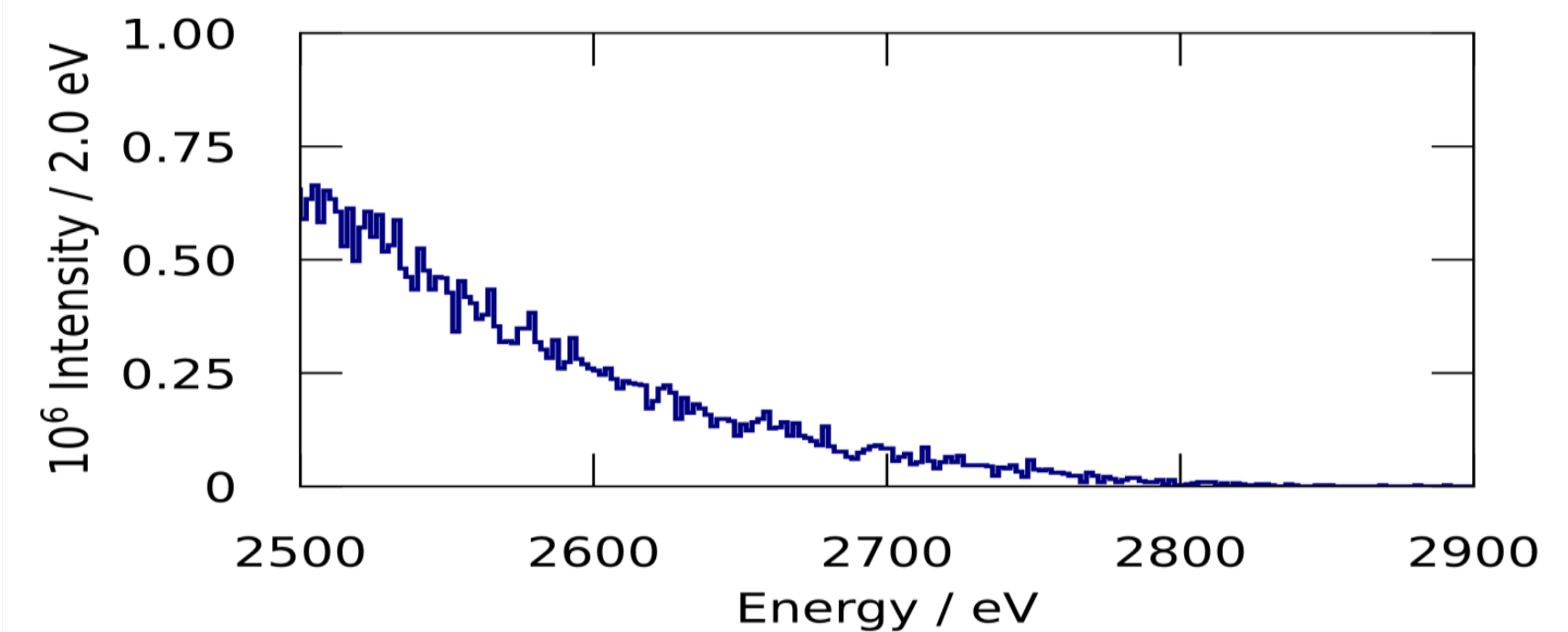
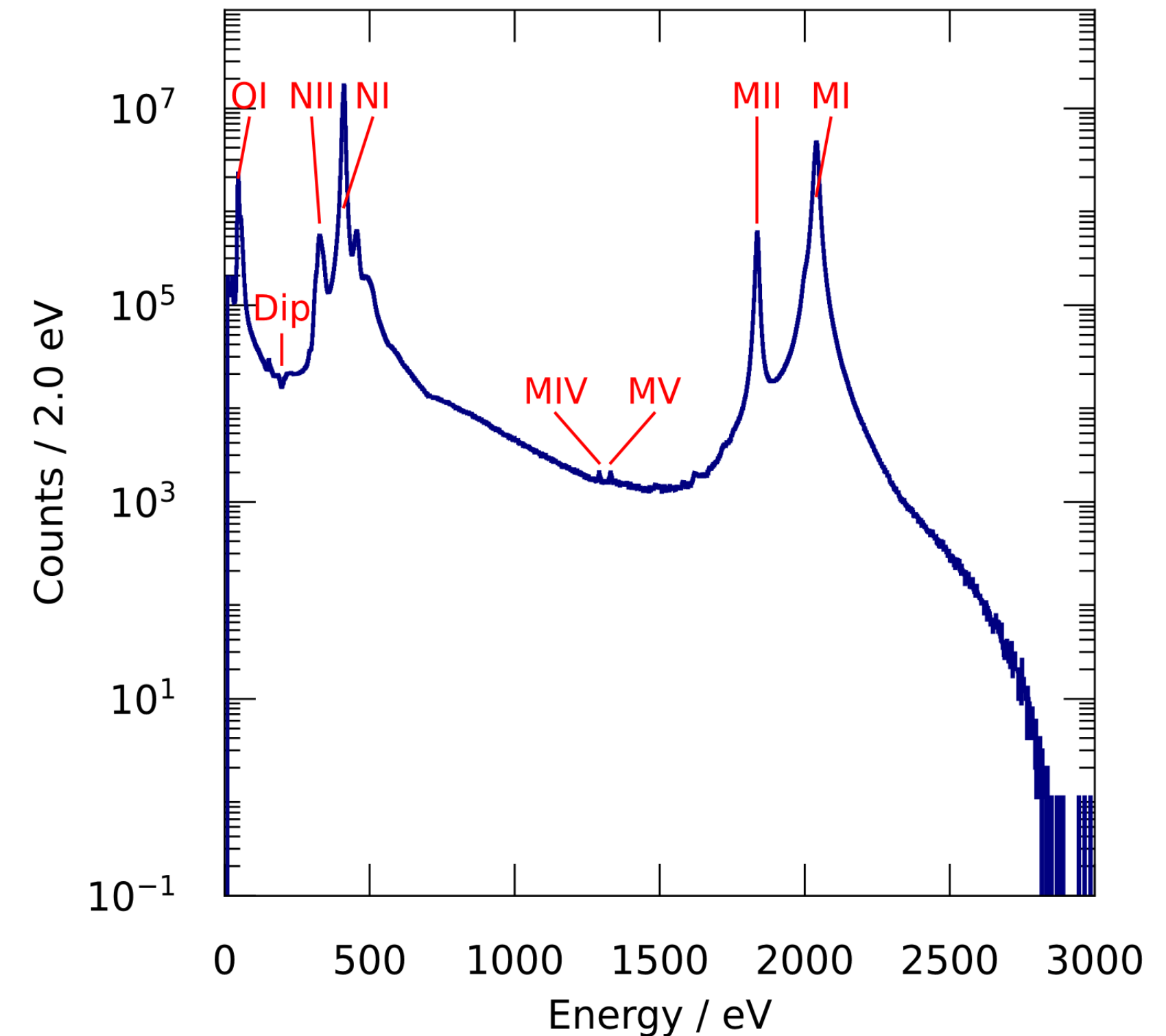
ECHo-LE: Sensitivity

- Fitting the end point region for limit on neutrino mass
- Fraction of events in region close to the endpoint extremely small



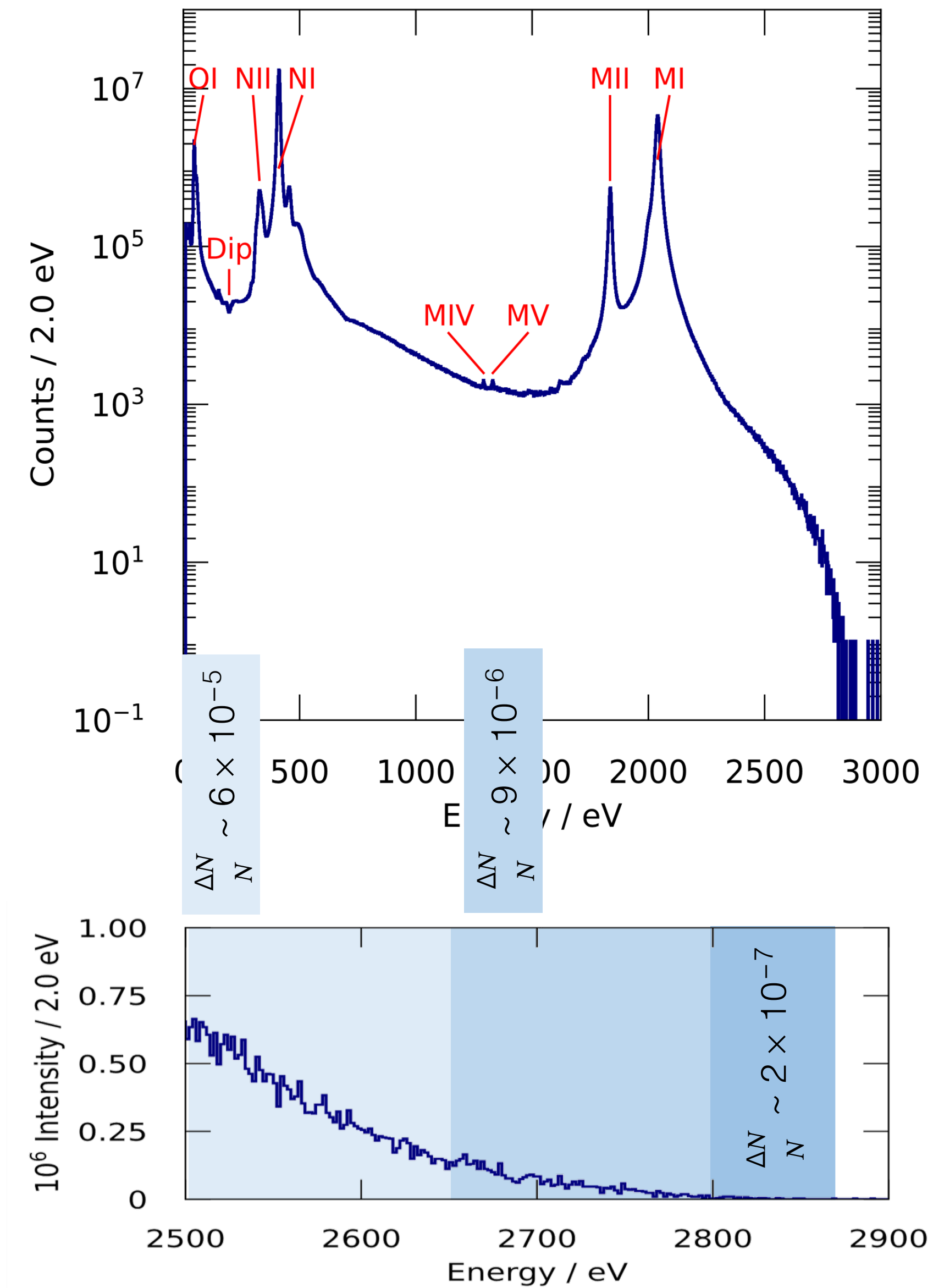
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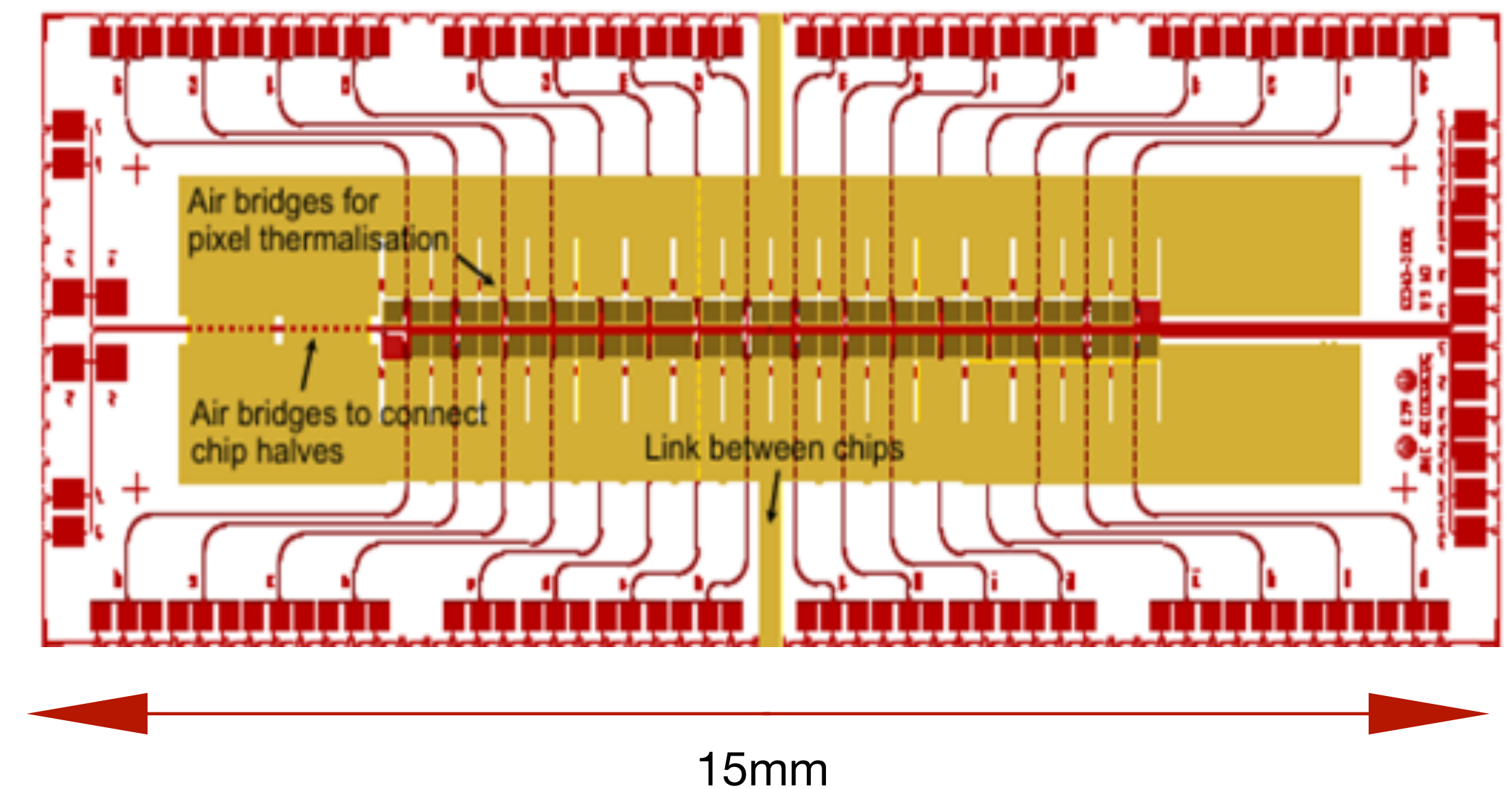
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ECHoColl., Phys. Rev. Lett. **136**, 121801

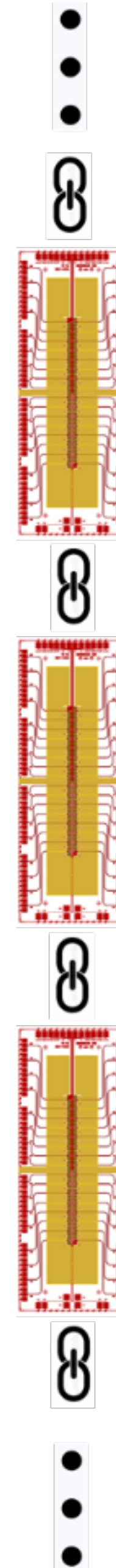
ECHo-Large Experiment

- 20,000 MMC pixel ensemble
- 10 Bq Ho-163 activity implantation
- 25 Multiplexed readout lines
- Data Analysis



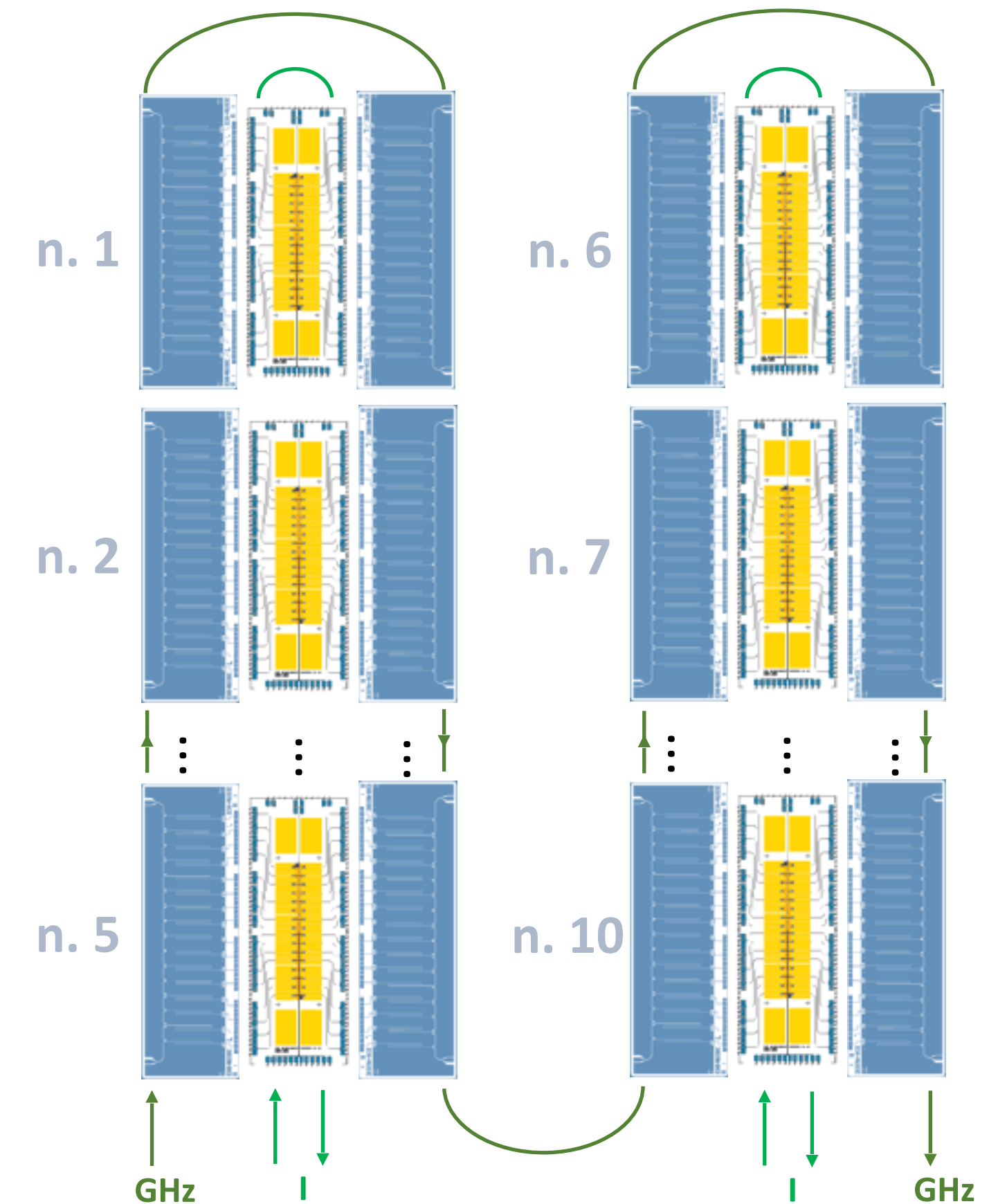
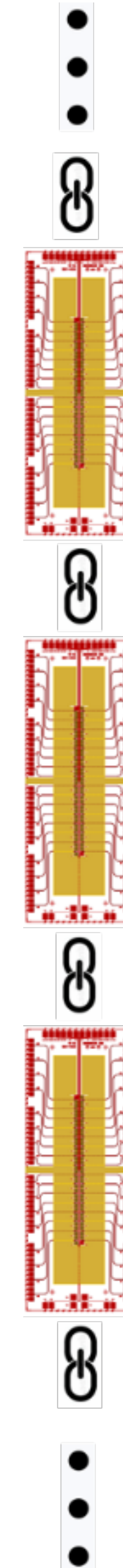
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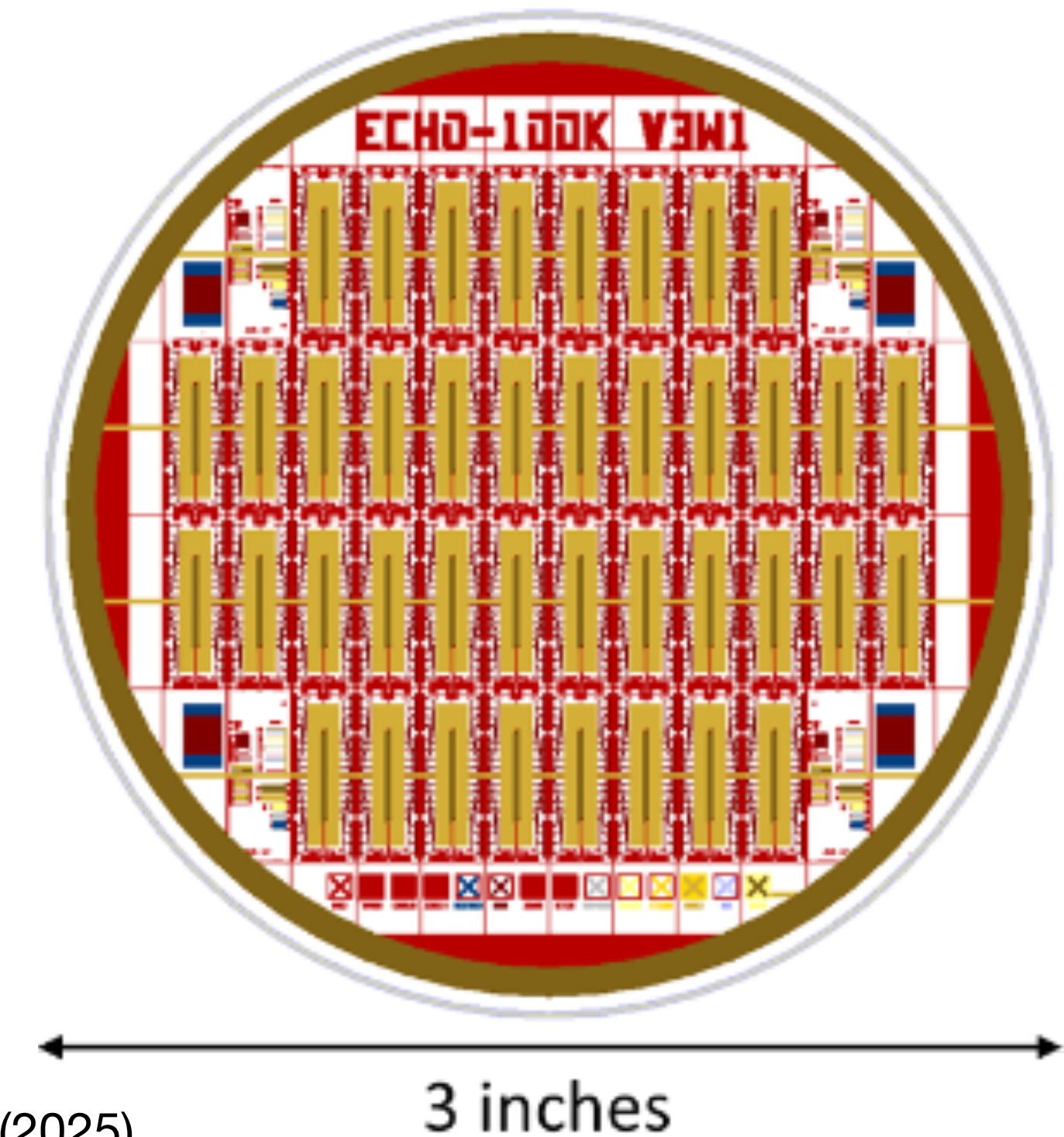
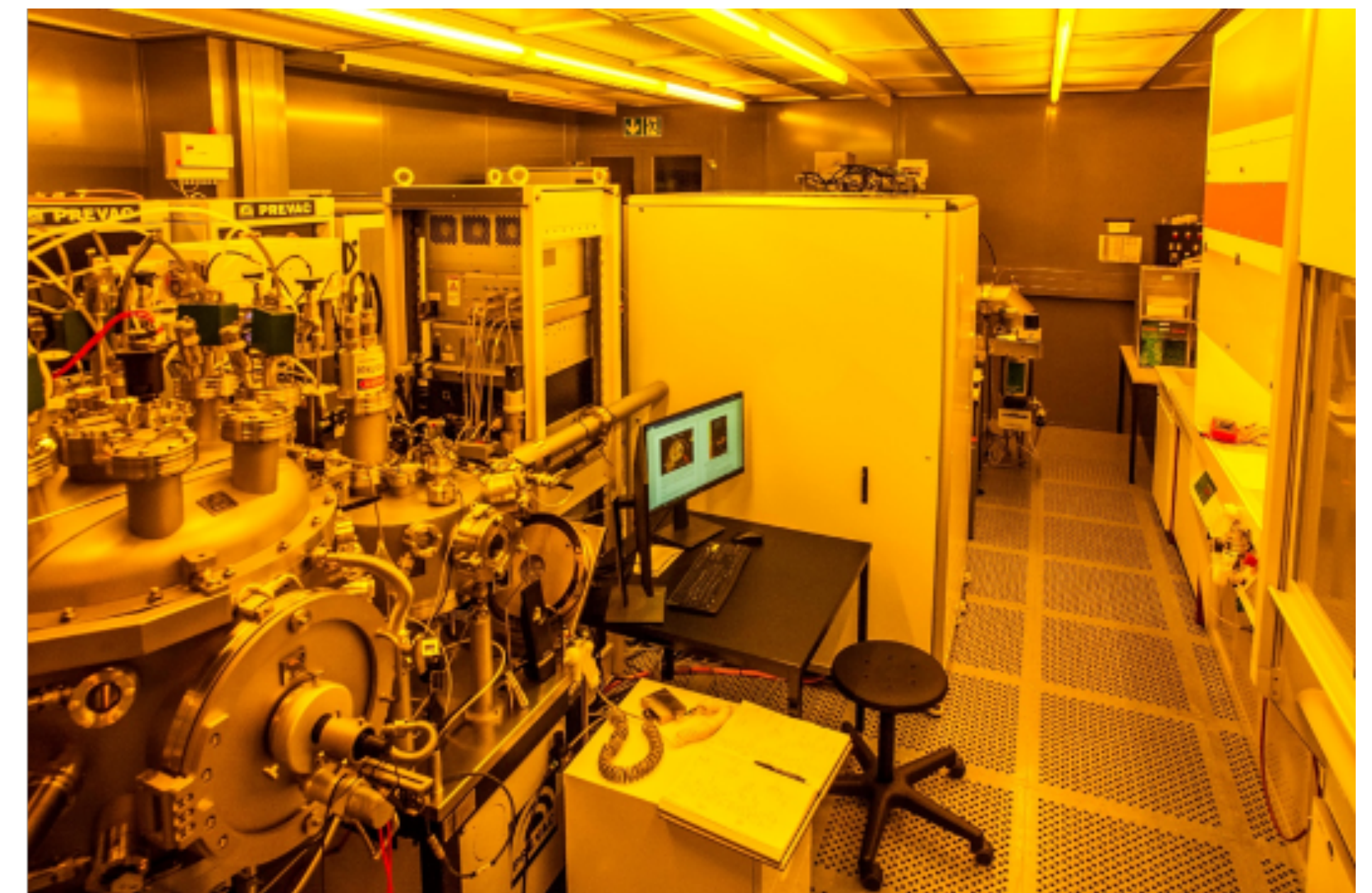
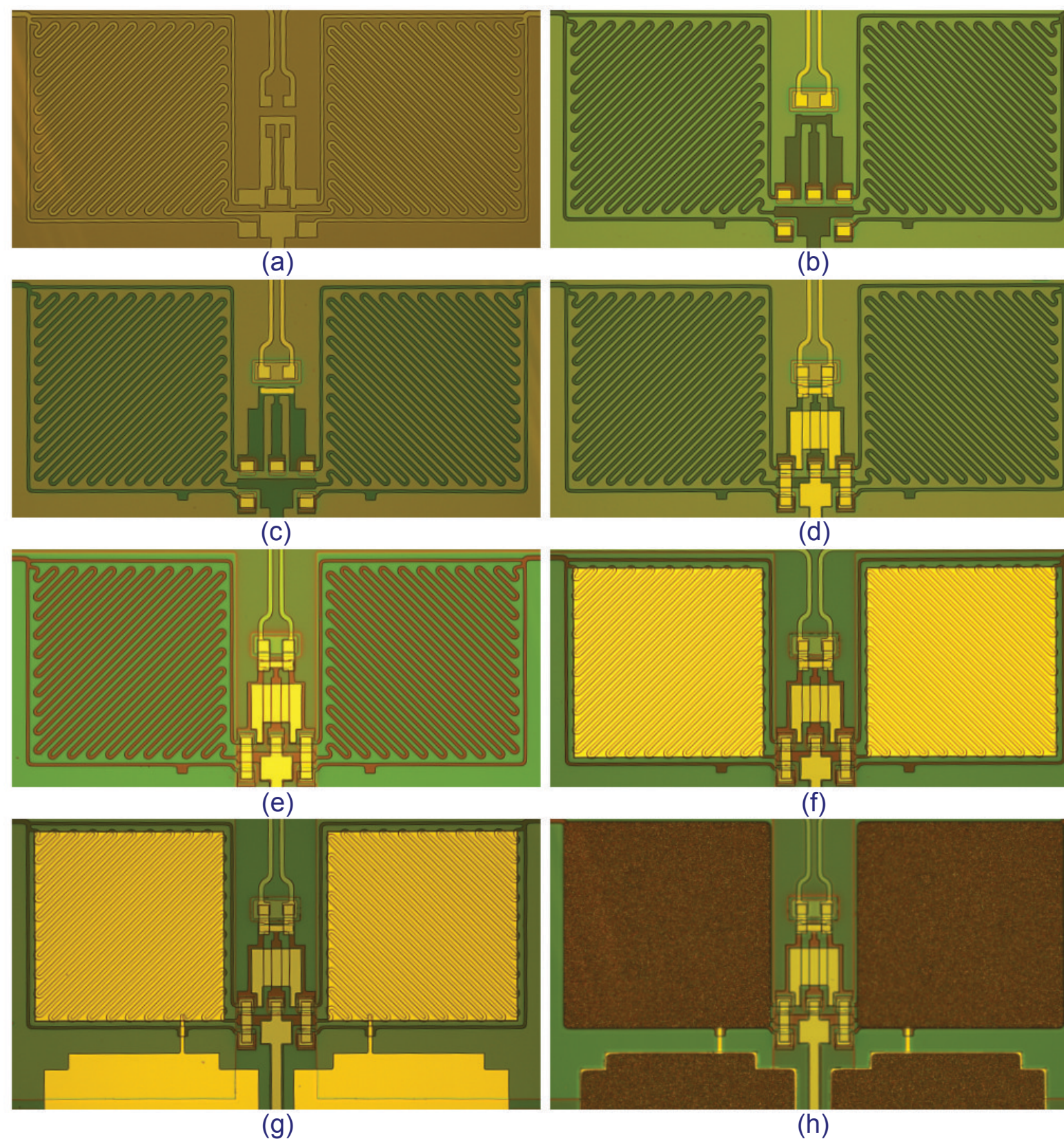


The ECHo Collaboration EPJ-ST 226 8 (2017) 1623

Detector Fabrication

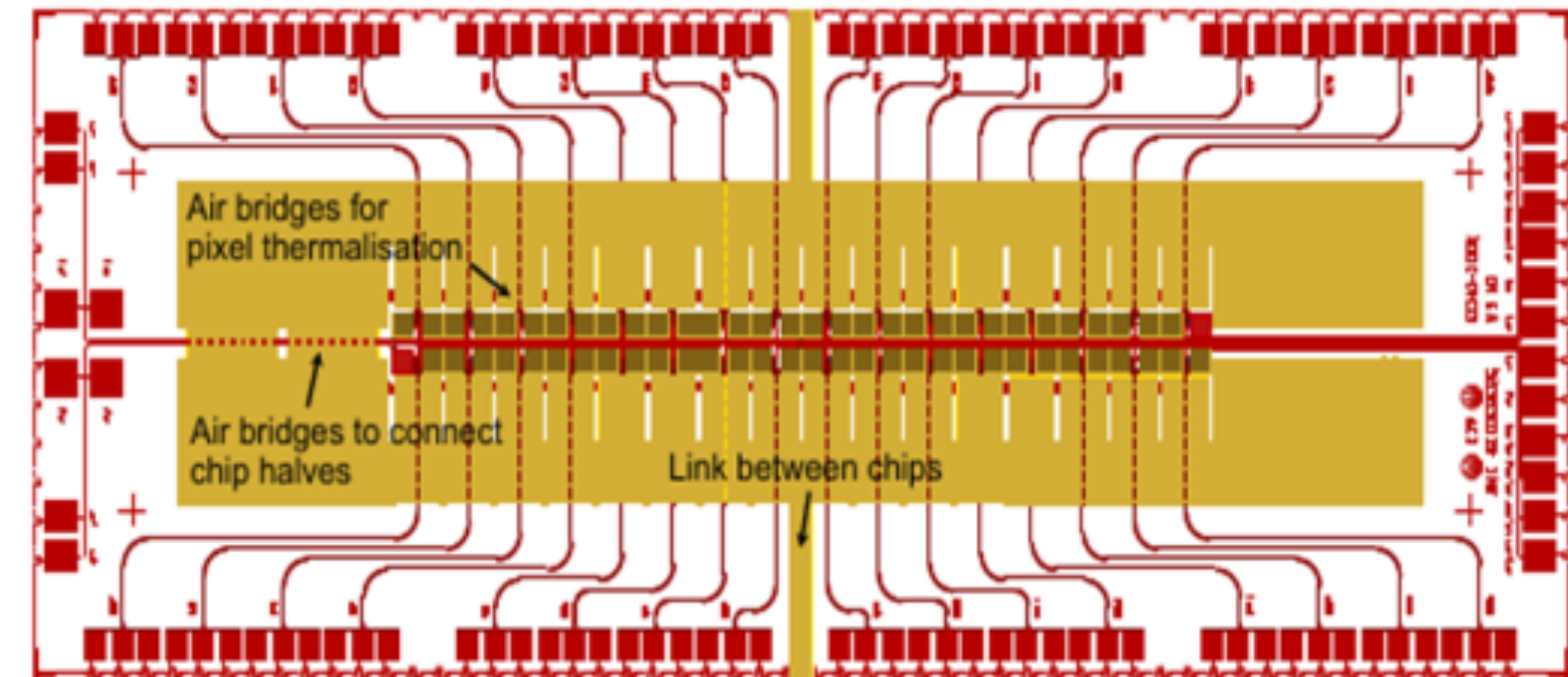
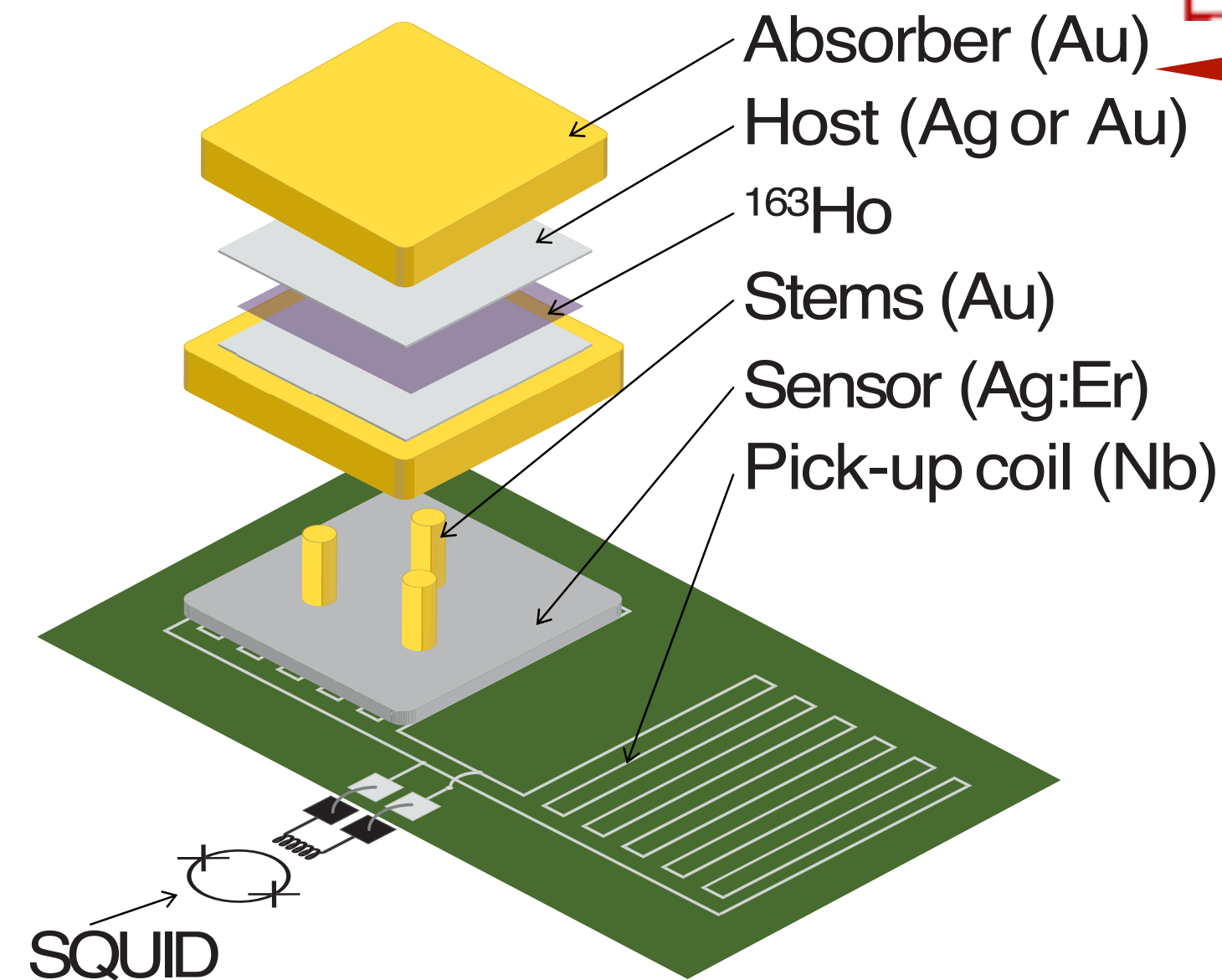
ECHo-LE Detector Fabrication

- Wafer-scale micro-fabrication
- 40 detector chips per wafer

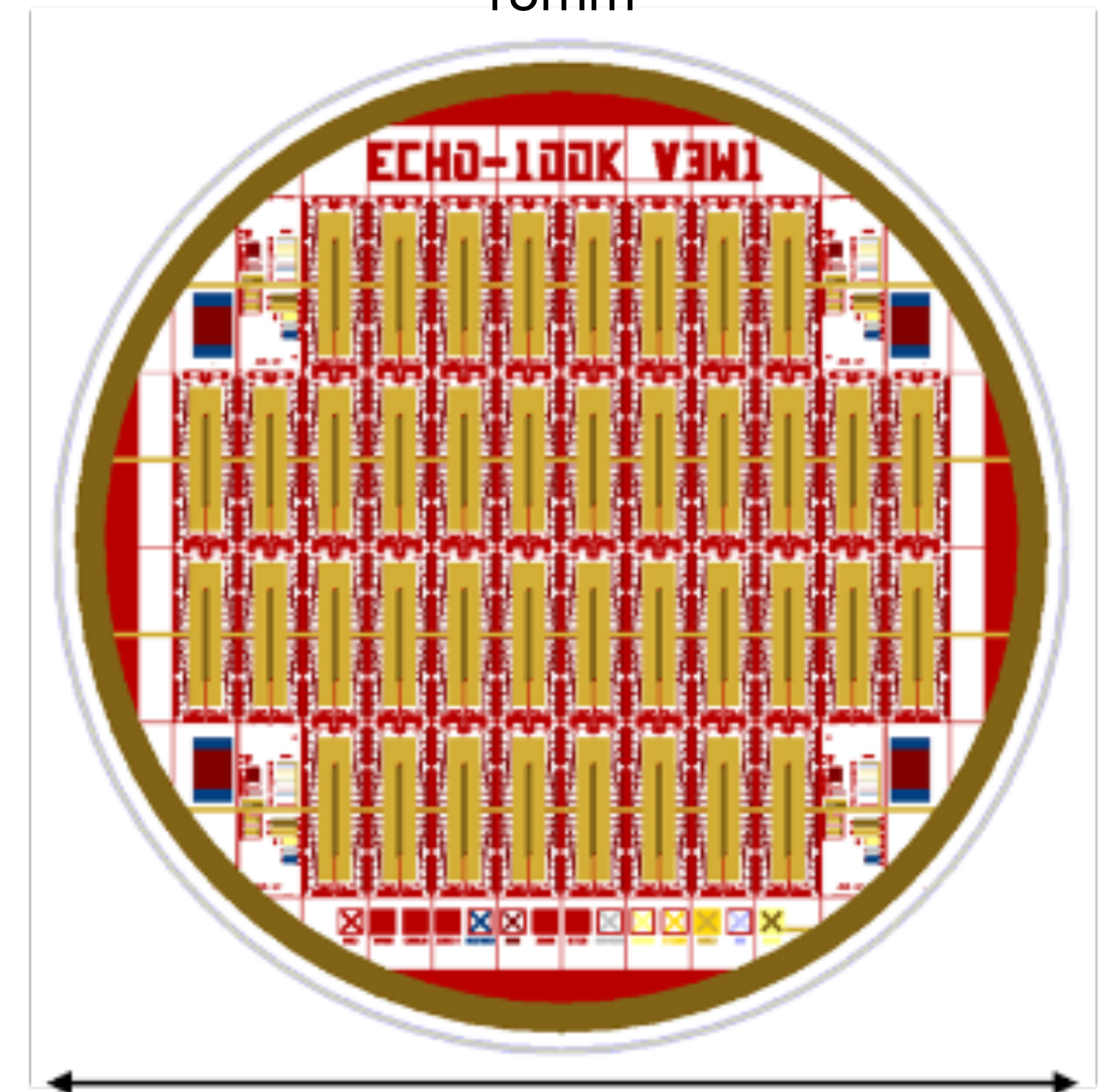


ECHo-LE Detector Fabrication

- Daisy-chainable
- Stable air-bridges for thermalisation
- Preparation friendly
 - Larger Bond Pads
 - Wafer scale electroplating of both absorber layers and thermalisation
 - Optimized niobium structures for high critical currents

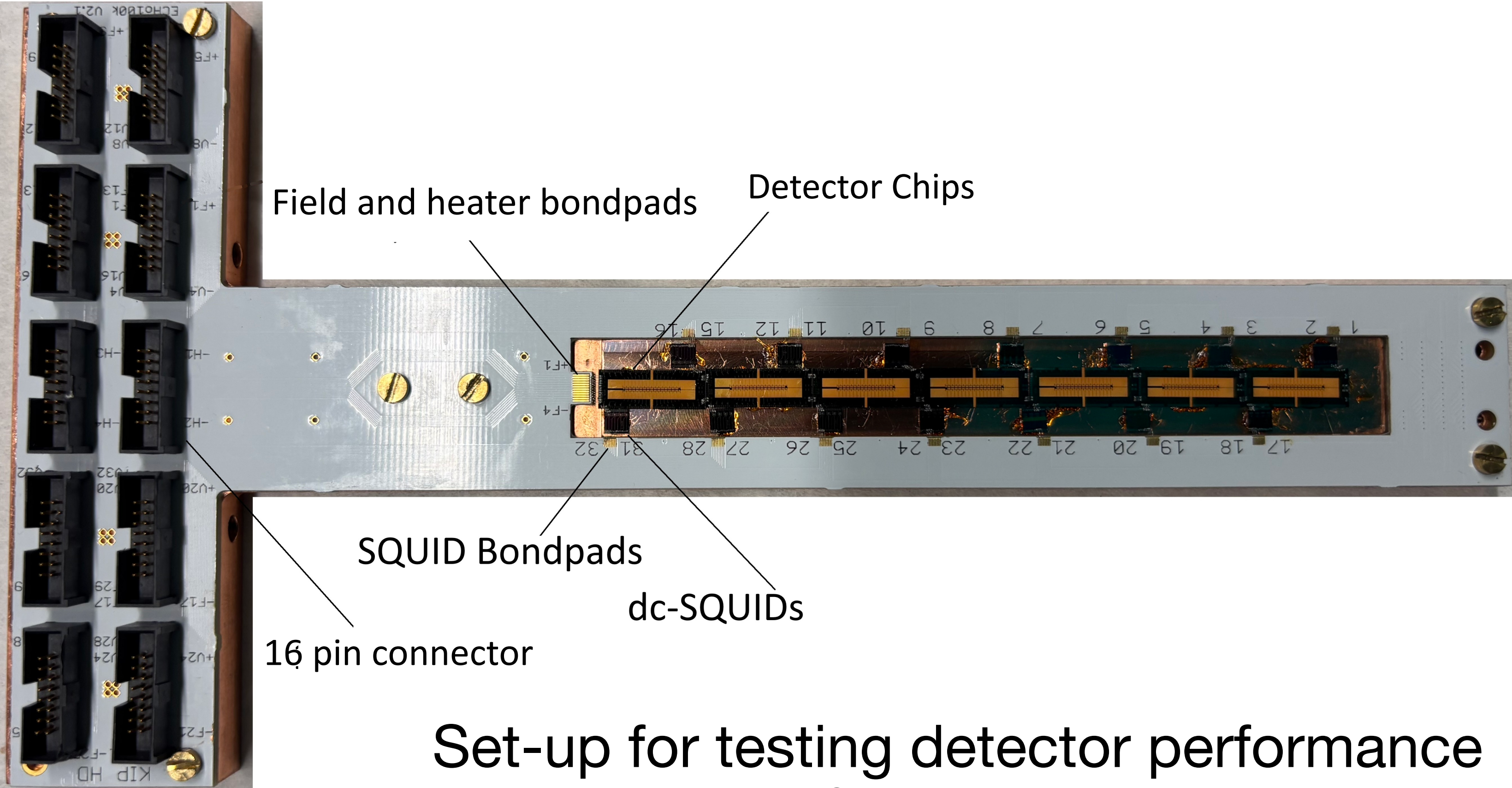
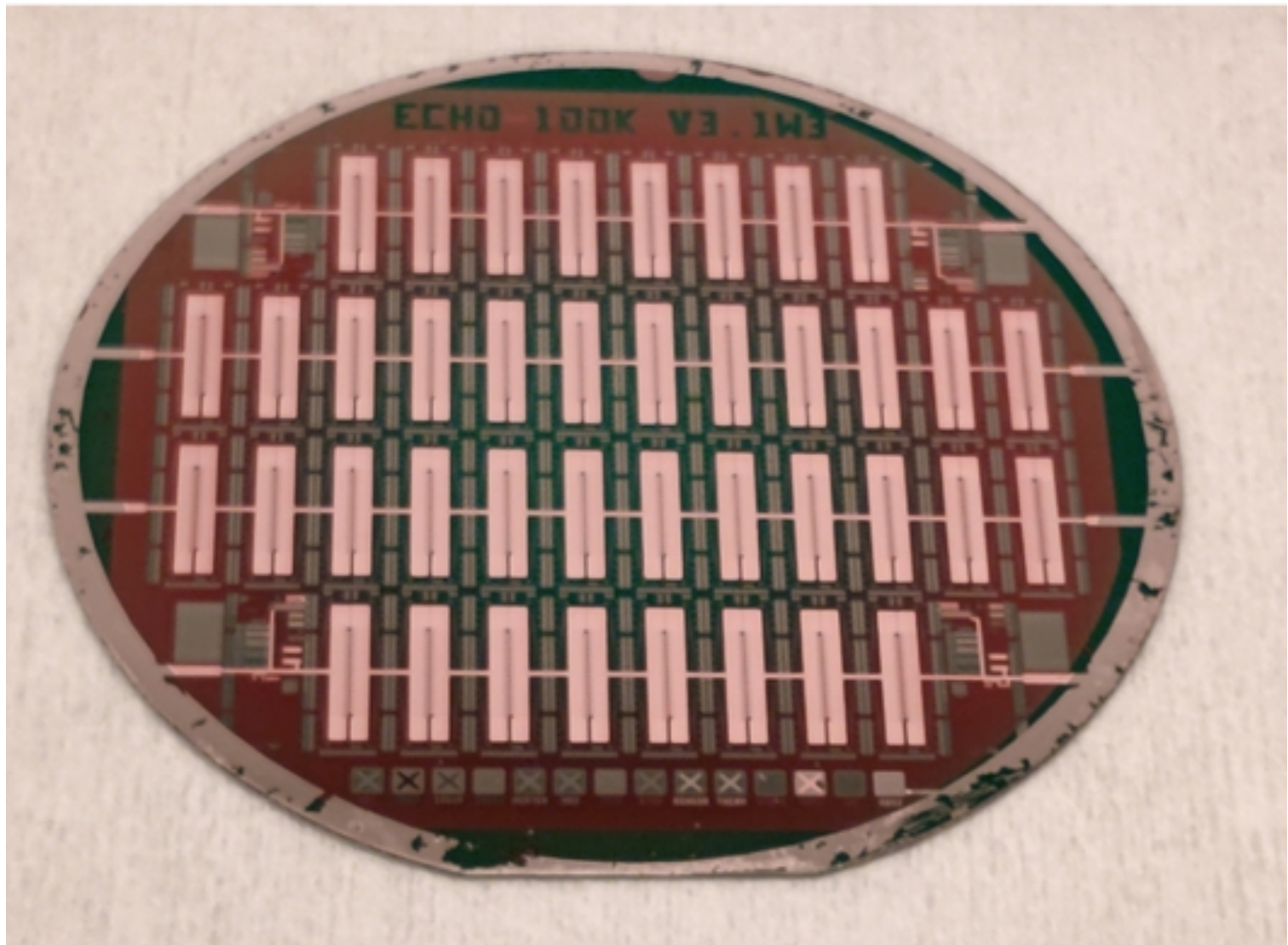
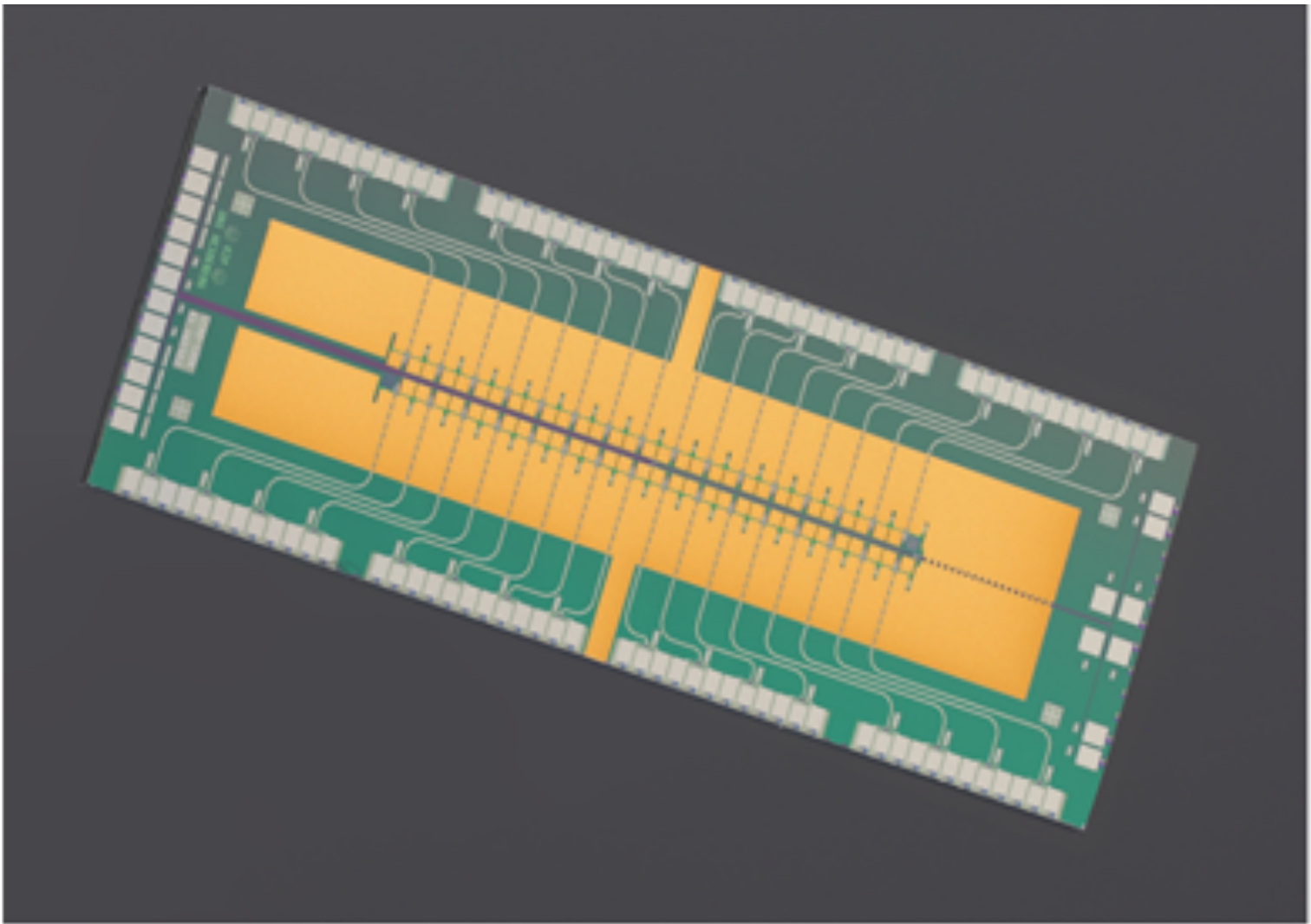


15mm



3 inches

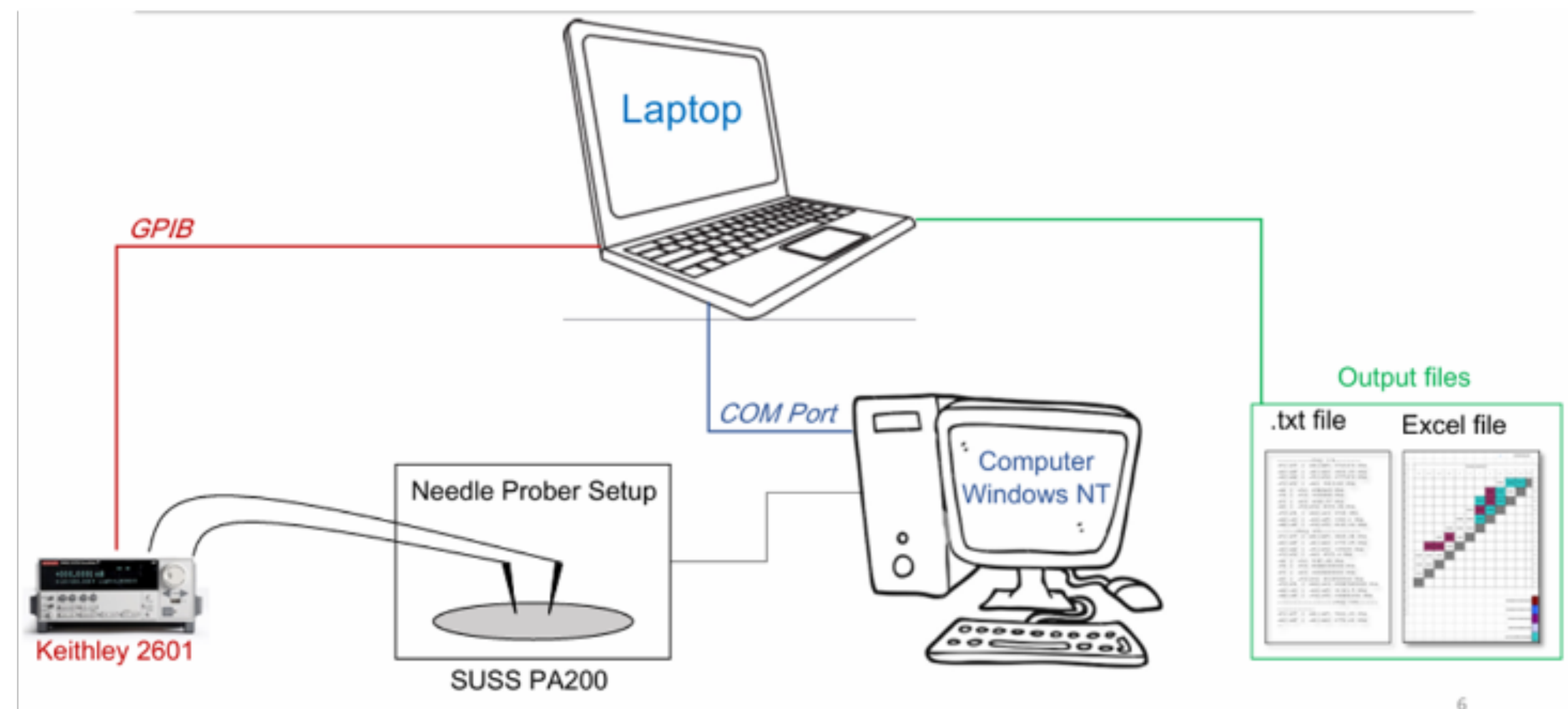
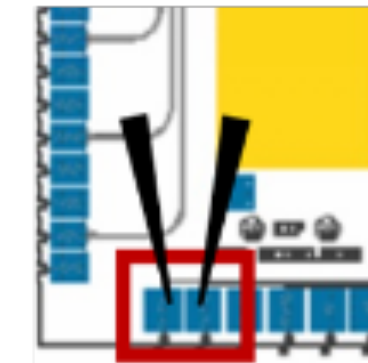
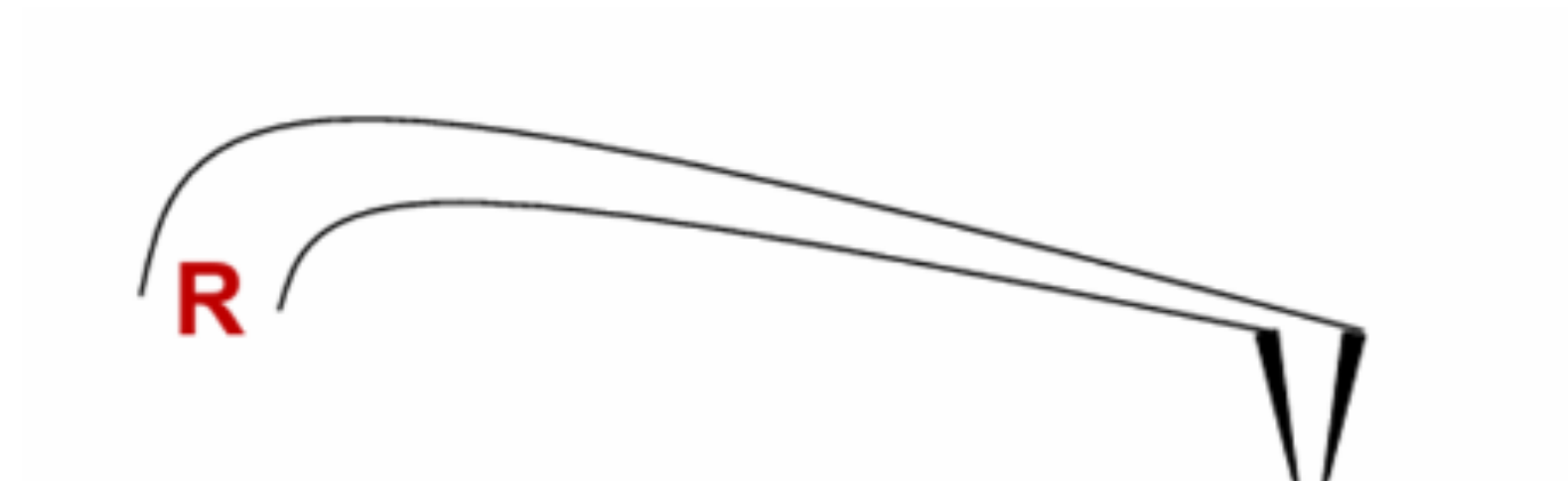
ECHo-LE Detector Fabrication



Set-up for testing detector performance
homogeneity after simultaneous
preparation of persistent current in 7
MMC-array chips

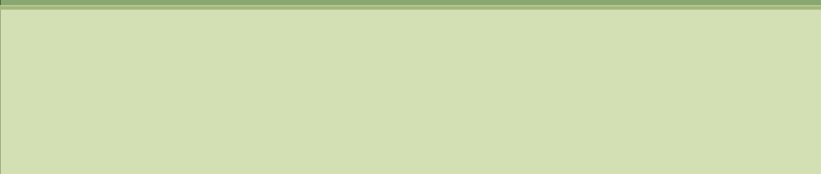
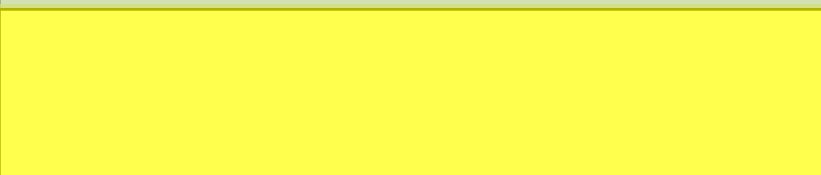
Detectors Status

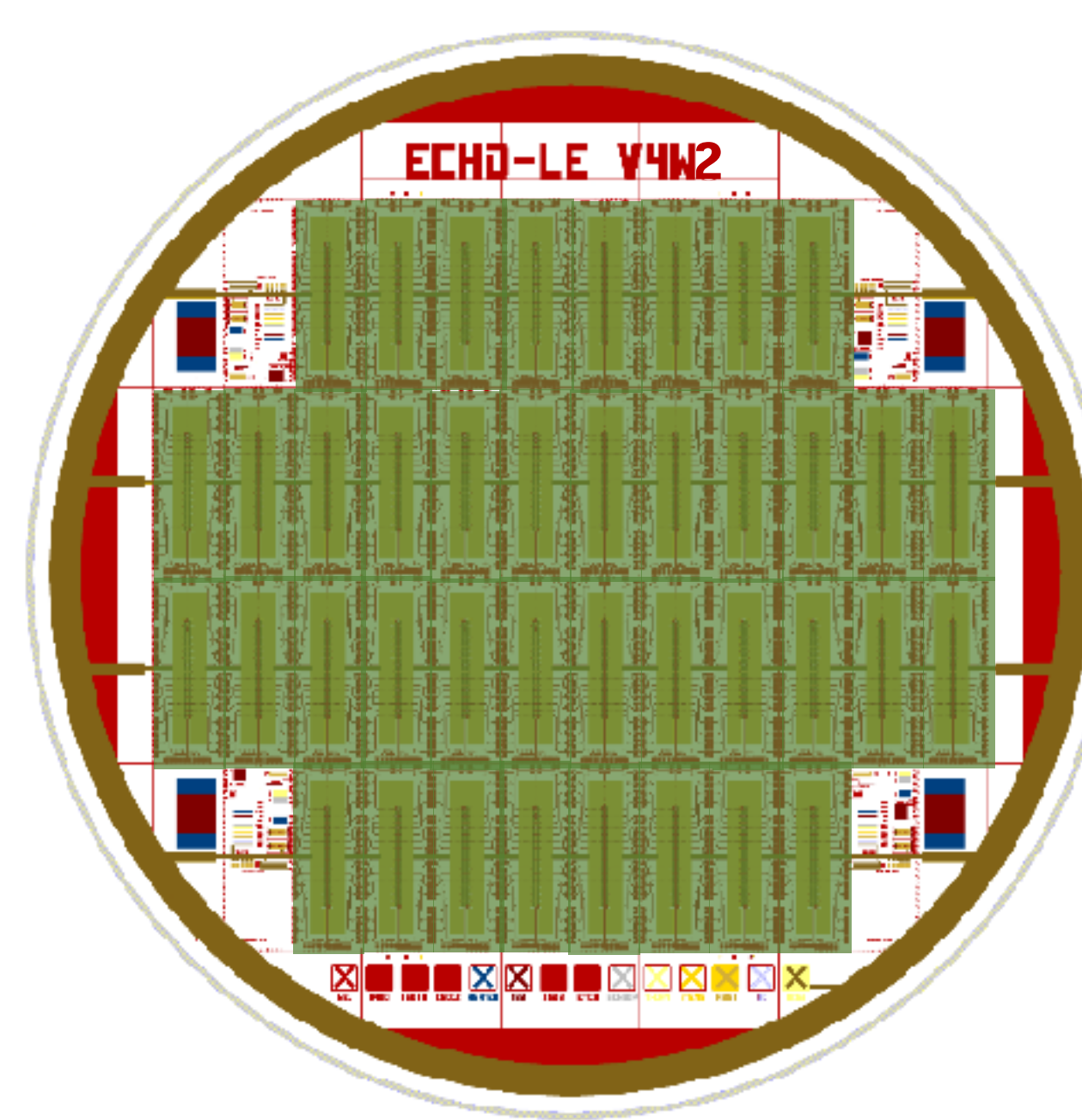
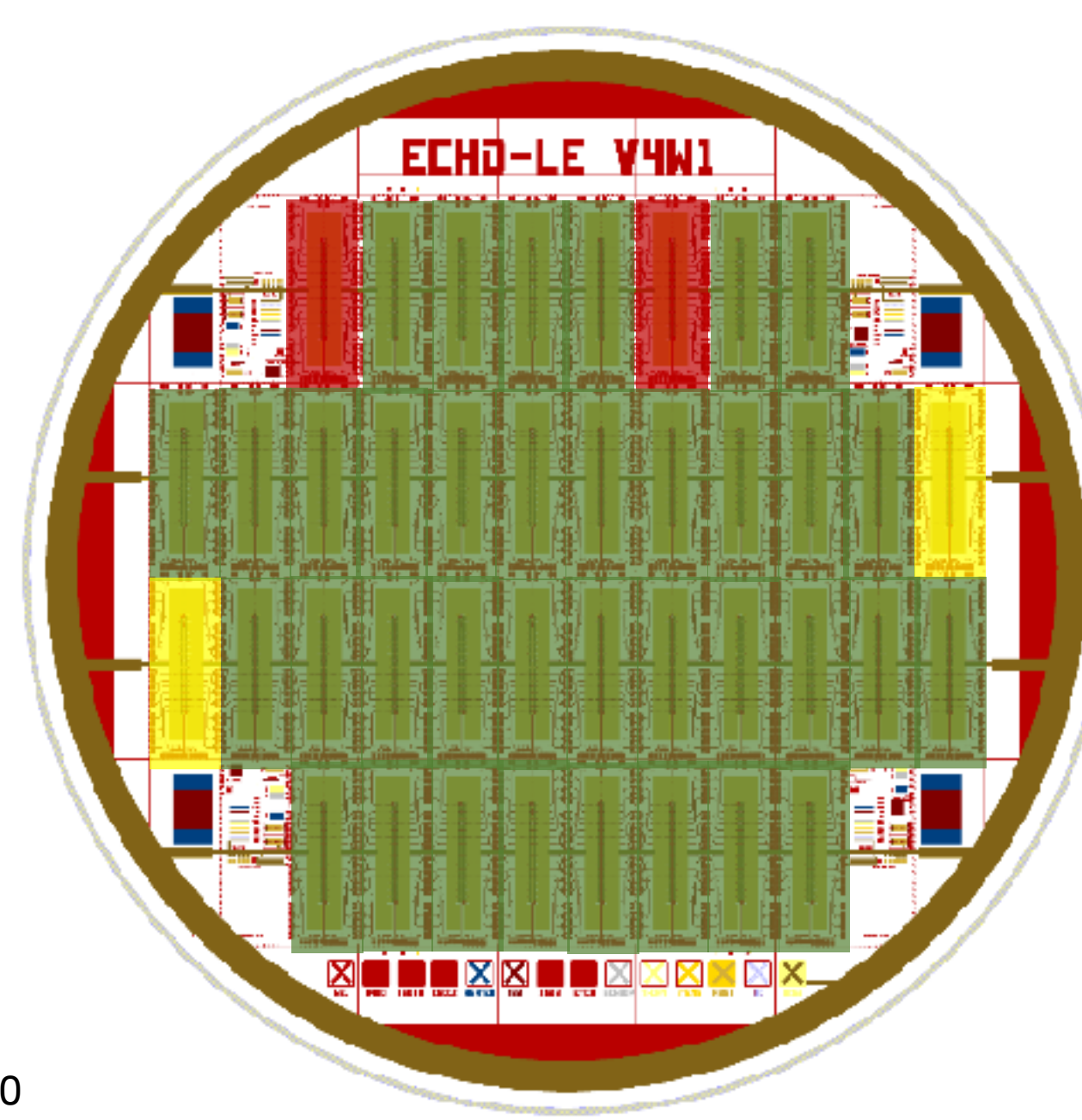
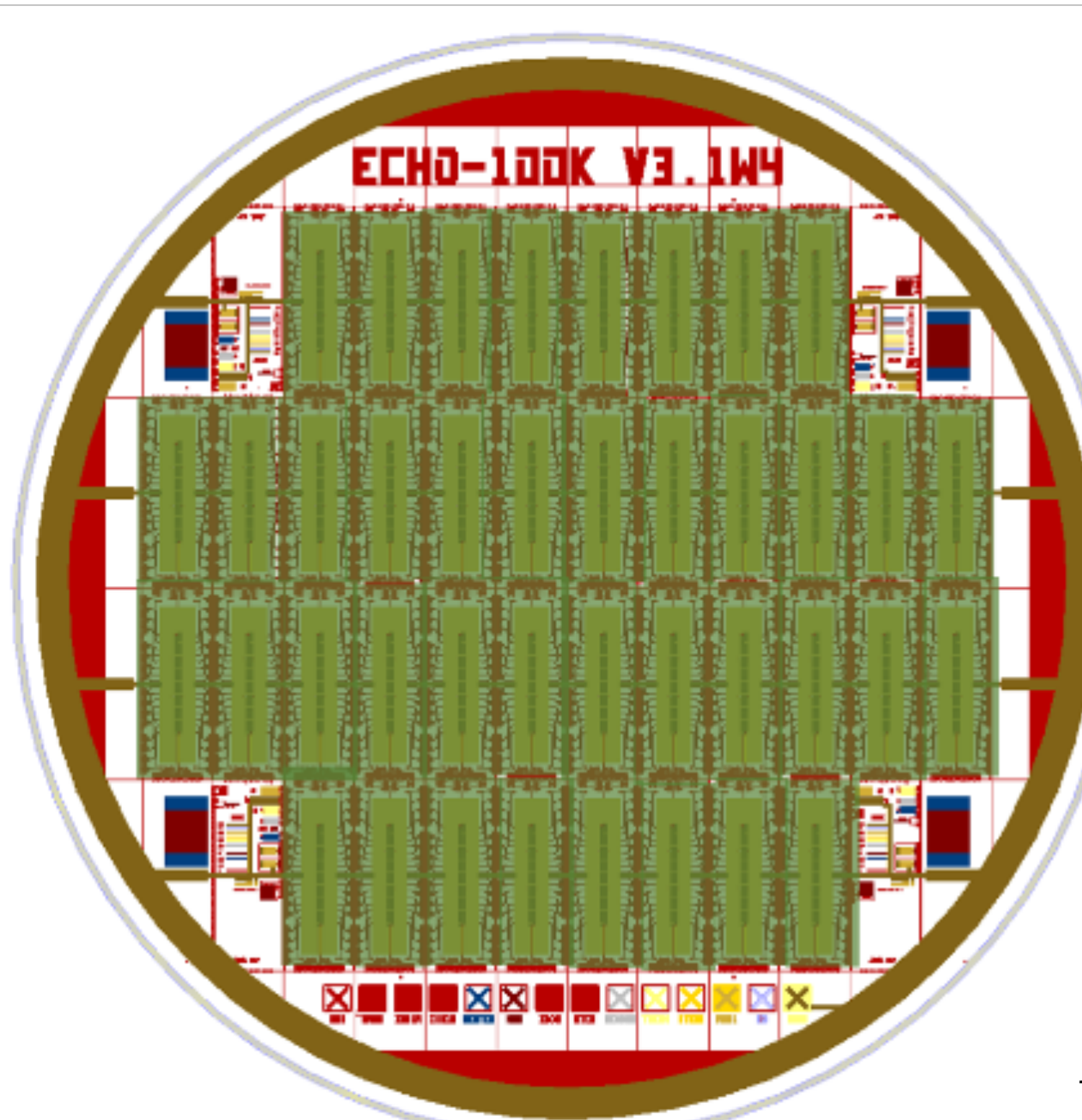
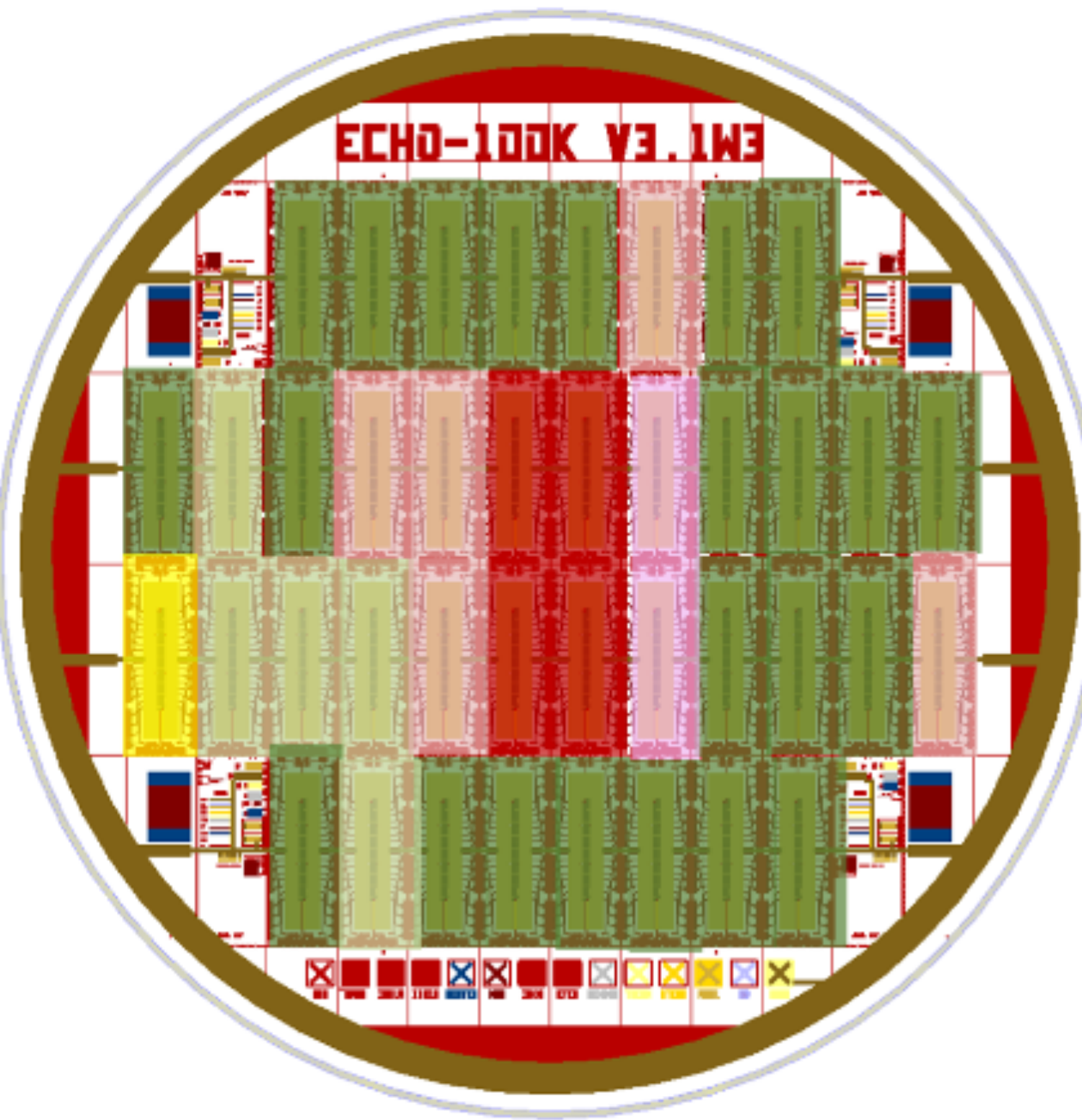
- Needle prober tests an important gauge for low temperature performance
- High yield seen from optimised process



Detectors Status

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- High yield seen from optimised process

Color	NeedleProber Result
	All good
	Some bad striplines
	Many bad striplines
	1 bad Quadrant
	2 bad Quadrants
	≥ 3 bad Quadrants



Implantation

Implantation updates

- High purity Ho-163 available and ready for implantation

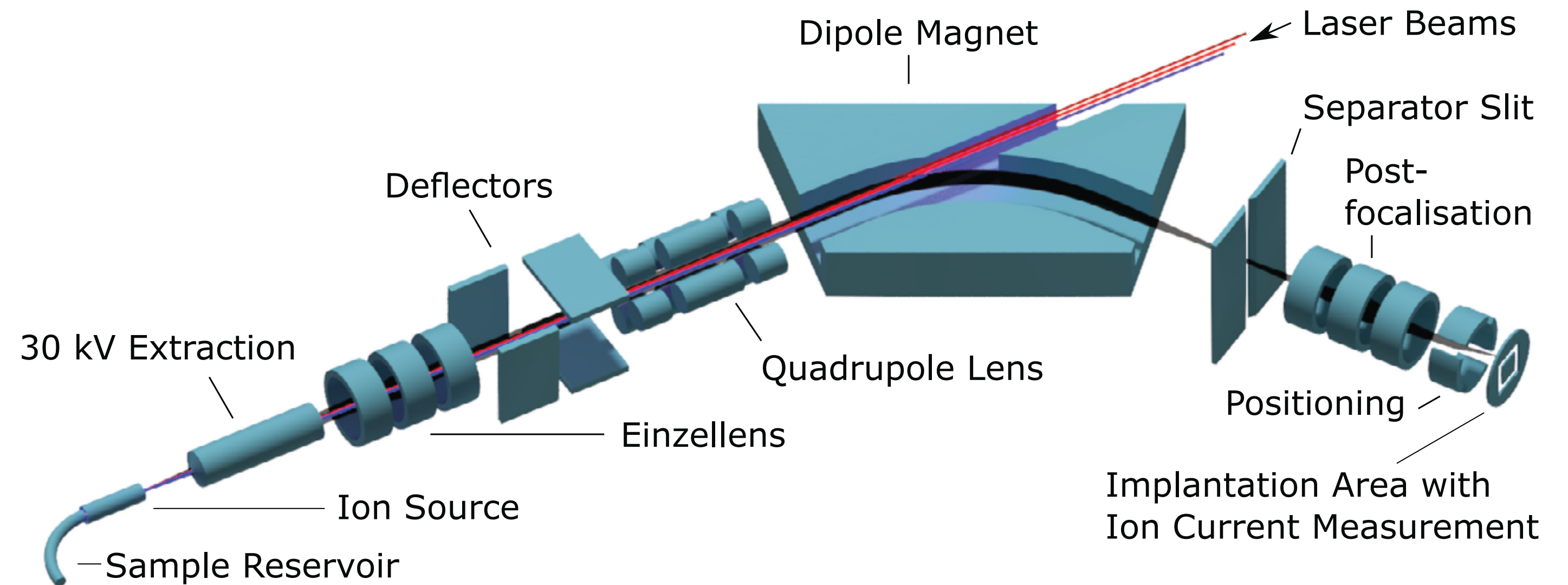


Er161 3.21 h 3/2- EC	Er162 0+ 0.14	Er163 75.0 m 5/2- EC	Er164 0+ 1.61	Er165 10.36 h 5/2- EC	Er166 0+ 33.6
Ho160 25.6 m 5+ EC	Ho161 2.48 h 7/2- EC	Ho162 15.0 m 1+ EC	Ho163 4470 y 2- EC	Ho164 29 m 1+ EC,β-	Ho165 7/2- 100

H. Dorrer et al, Radiochim. Acta 106(7) (2018) 535–48

Implantation updates

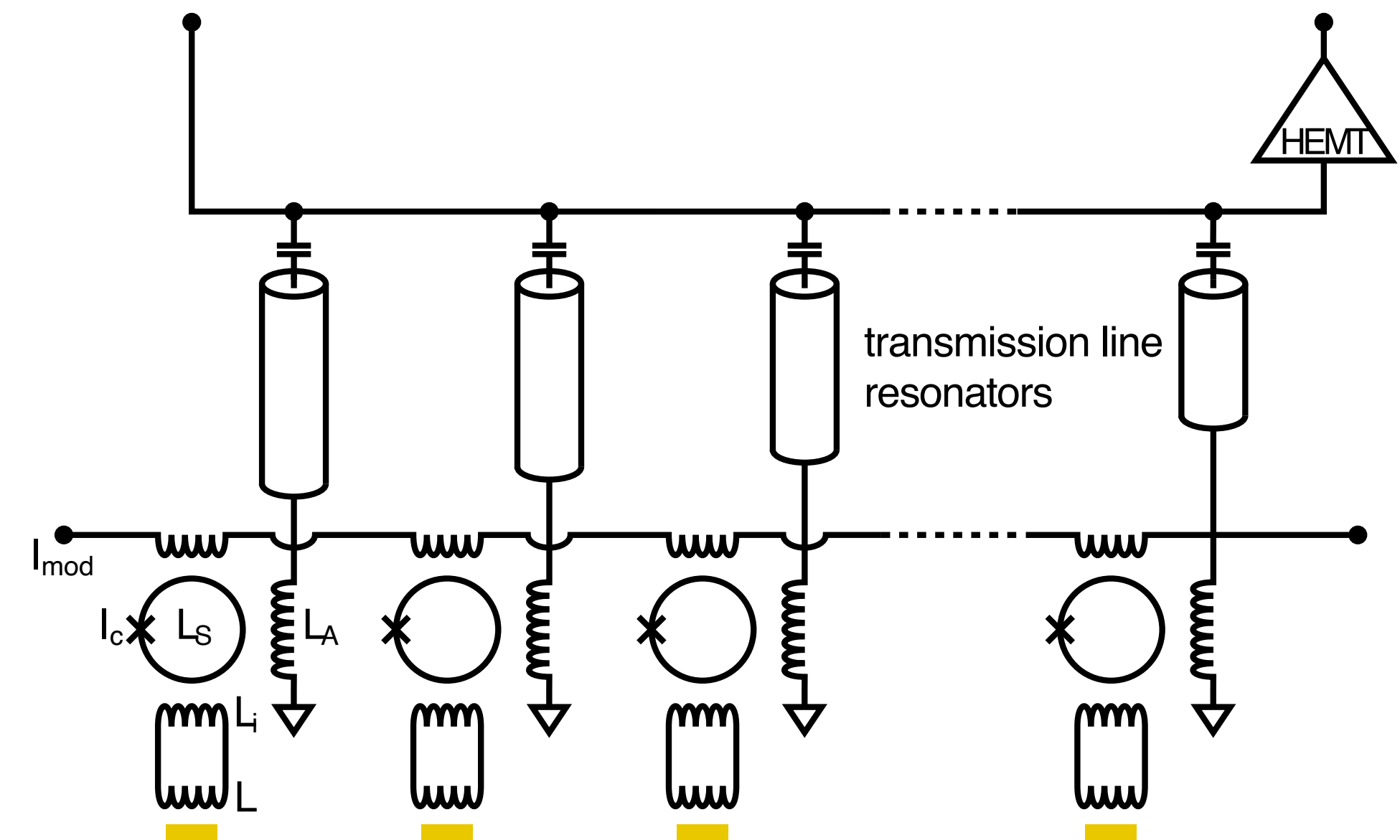
- RISIKO facility in Mainz
- Wafer scale implantation has been demonstrated, and is being optimised for 10 Bq



Multiplexing

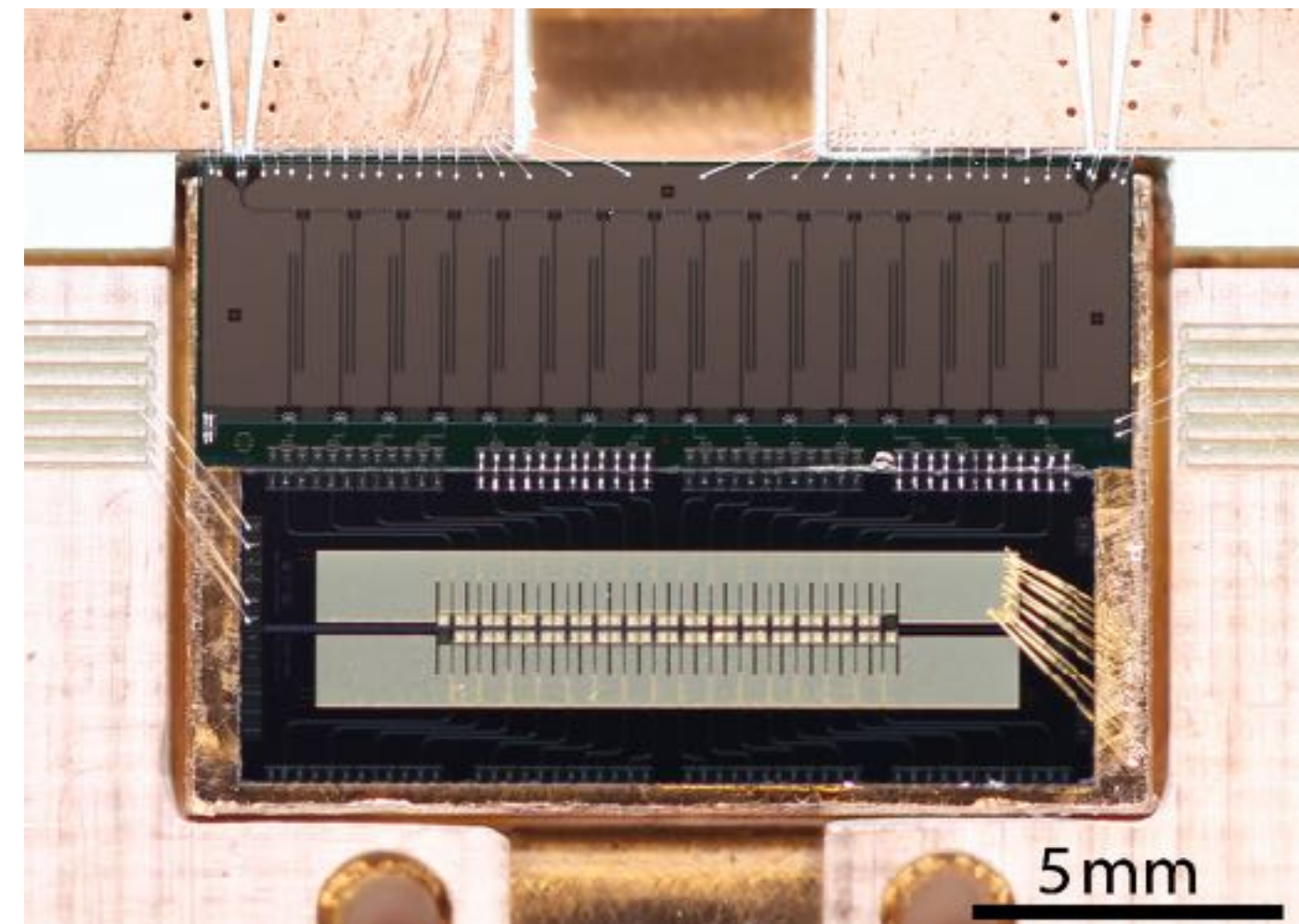
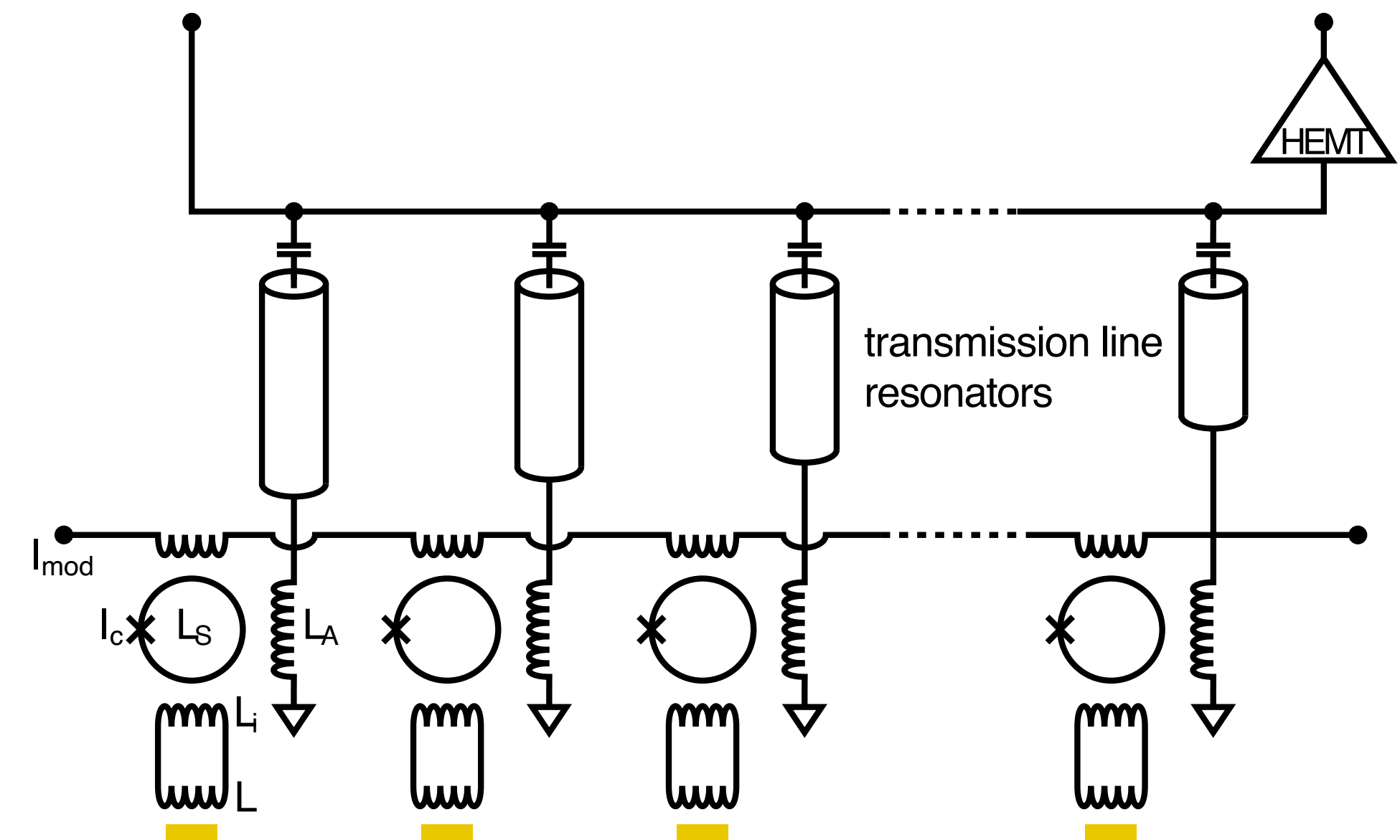
ECHo-LE Multiplexing

- Microwave-SQUID multiplexing
- rf-SQUID couple MMC pickup coil to microwave resonator
- 4 - 8 GHz
- Single readout line for 800 detectors



ECHo-LE Multiplexing

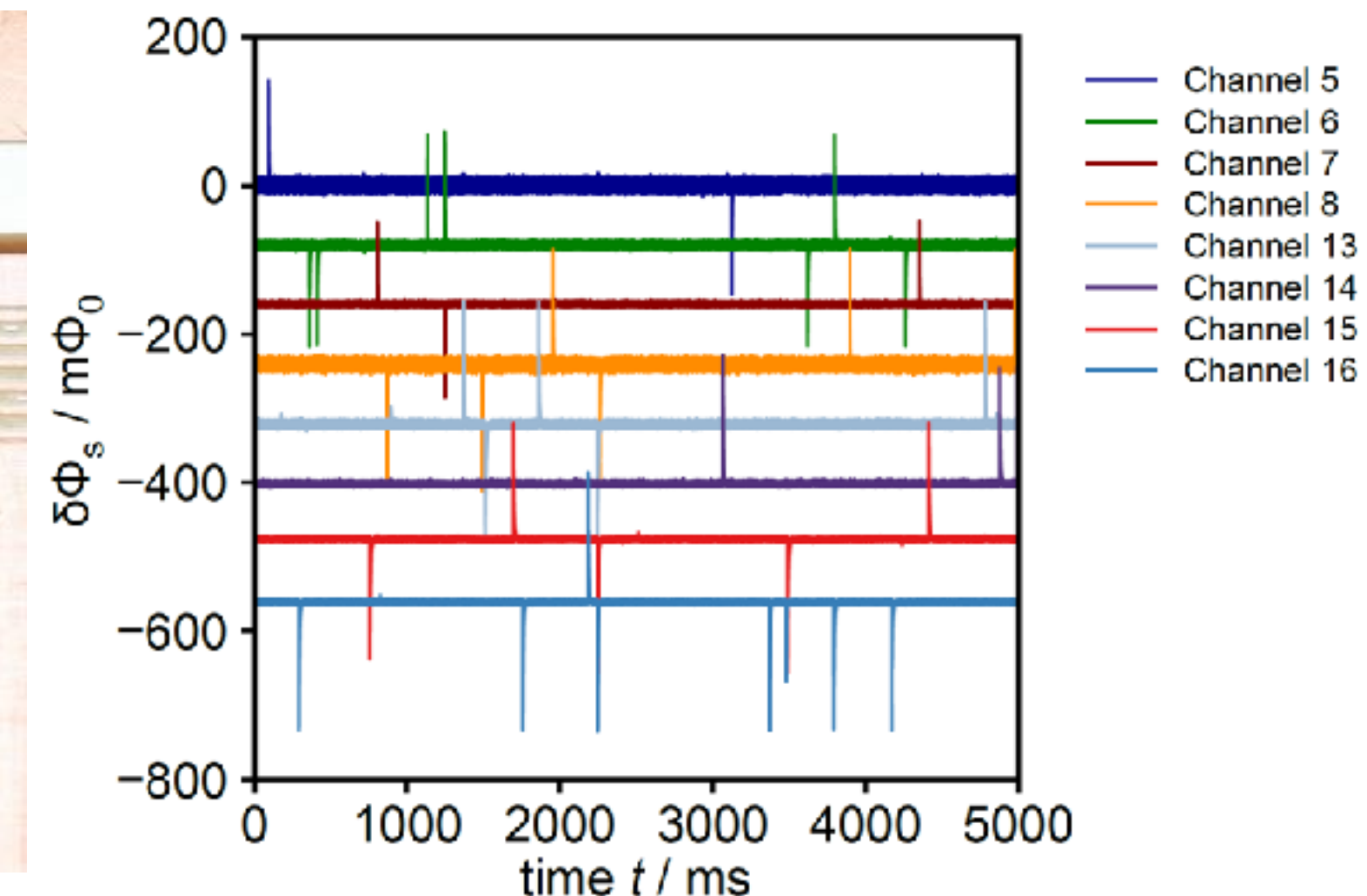
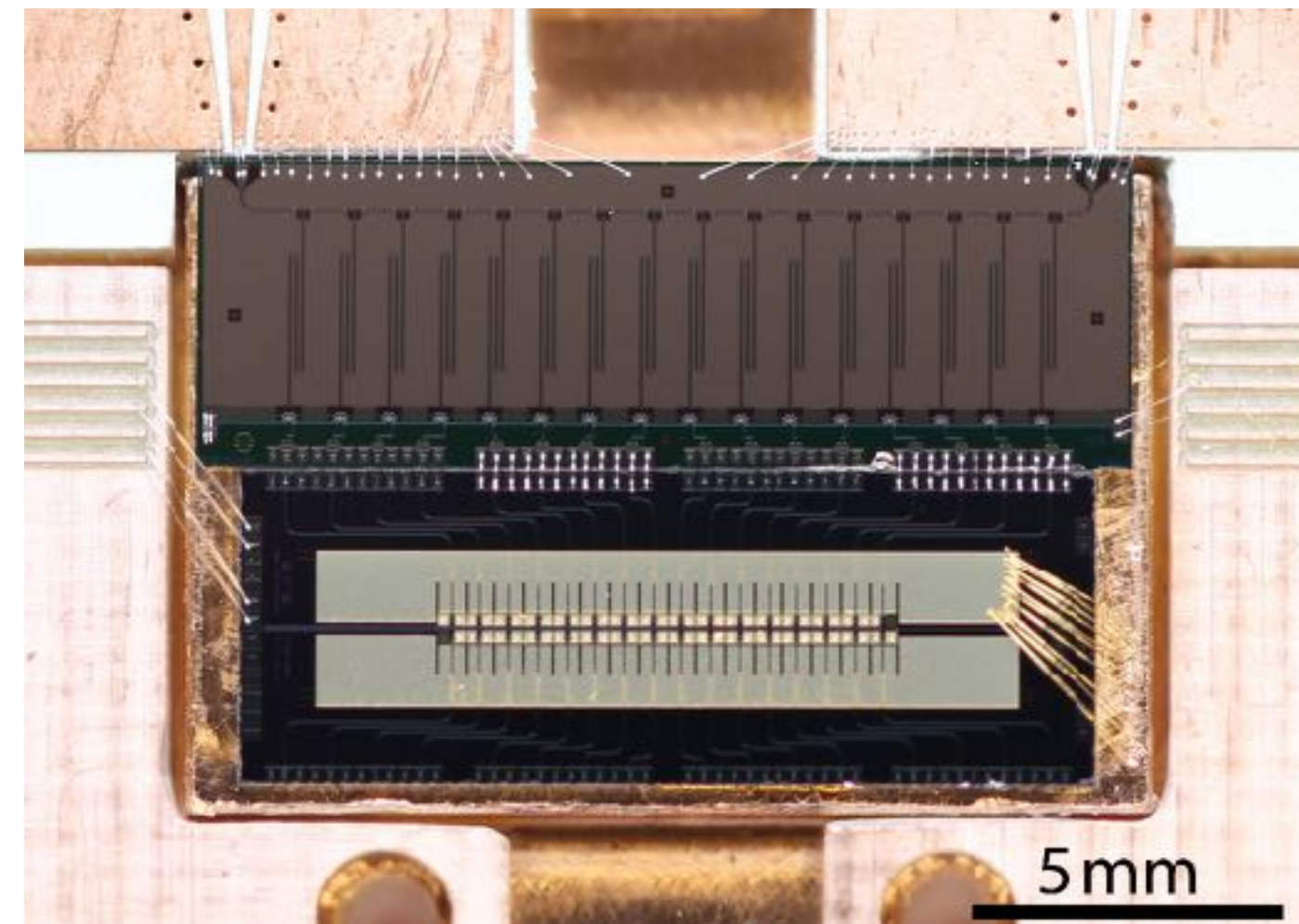
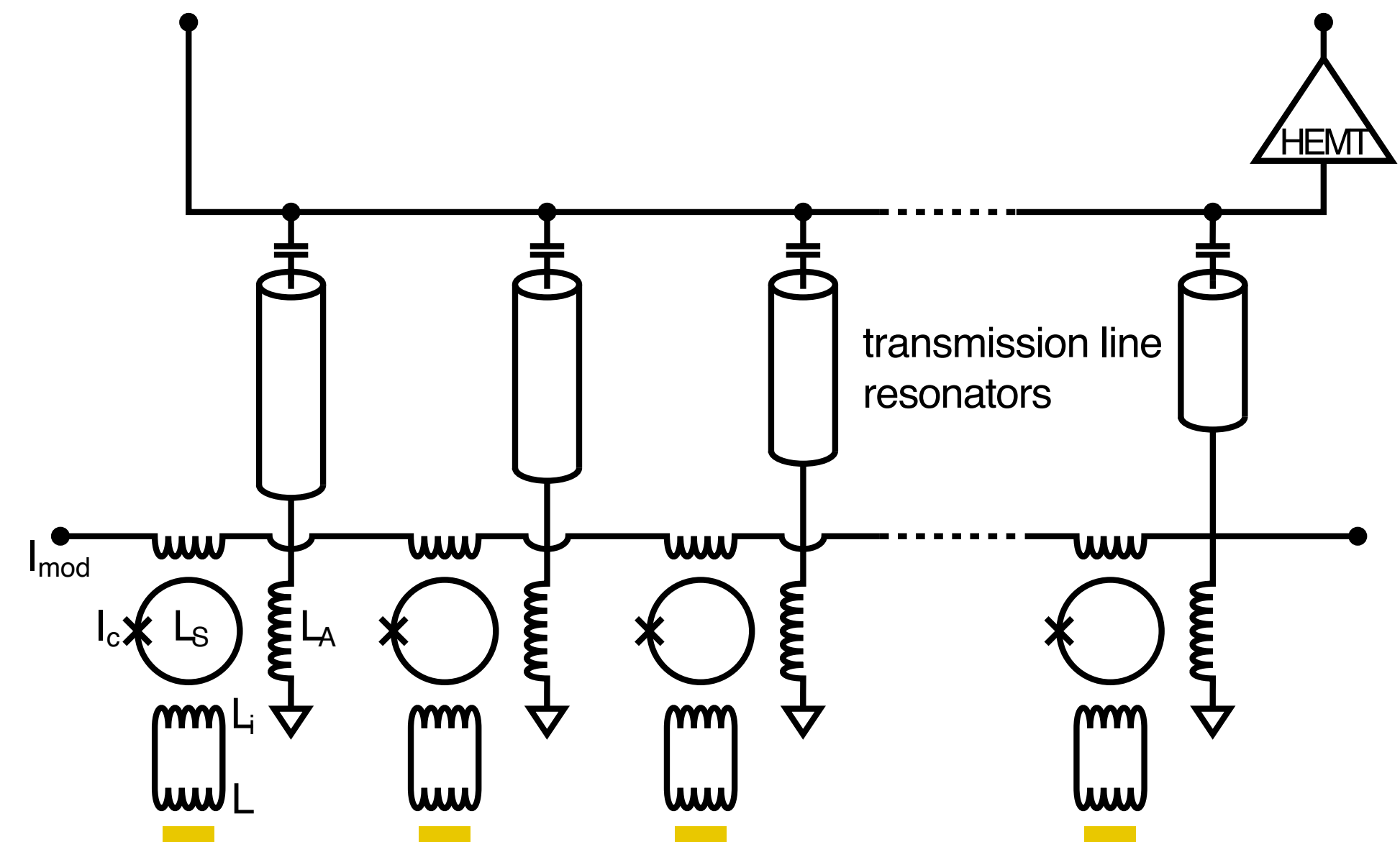
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Wegner, M., Karcher, N., Krömer, O. et al. J Low Temp Phys 193, 462–475 (2018). <https://doi.org/10.1007/s10909-018-1878-3>
M. Neidig, T. Muscheid, R. Gartmann, L.E. Ardila Perez, M. Wegner et al. (2025) e-Print: 2509.07671 [physics.ins-det]
Richter, et al., Appl. Phys. Lett. 118, 122601 (2021), <https://doi.org/10.1063/5.0044444>

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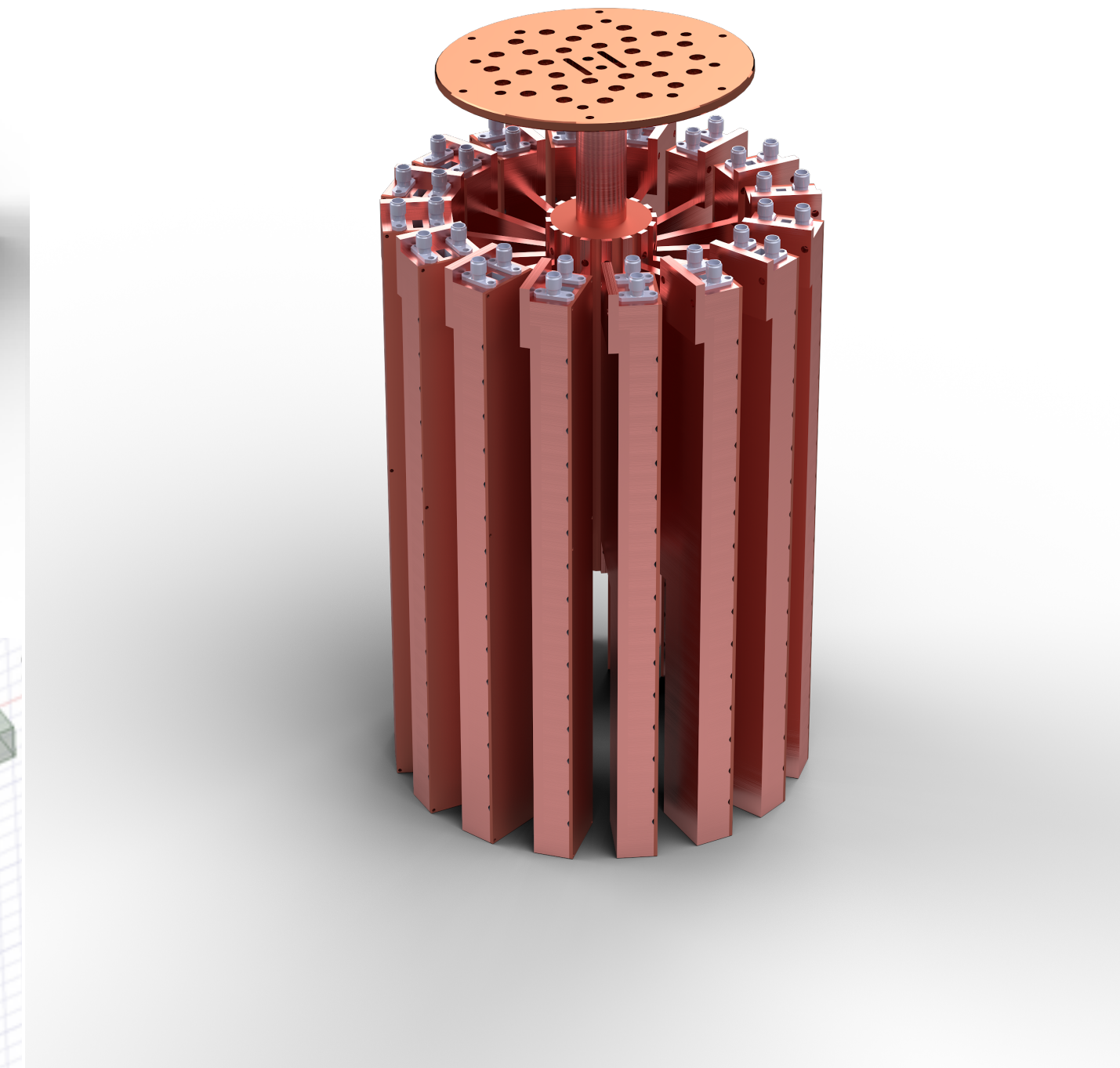
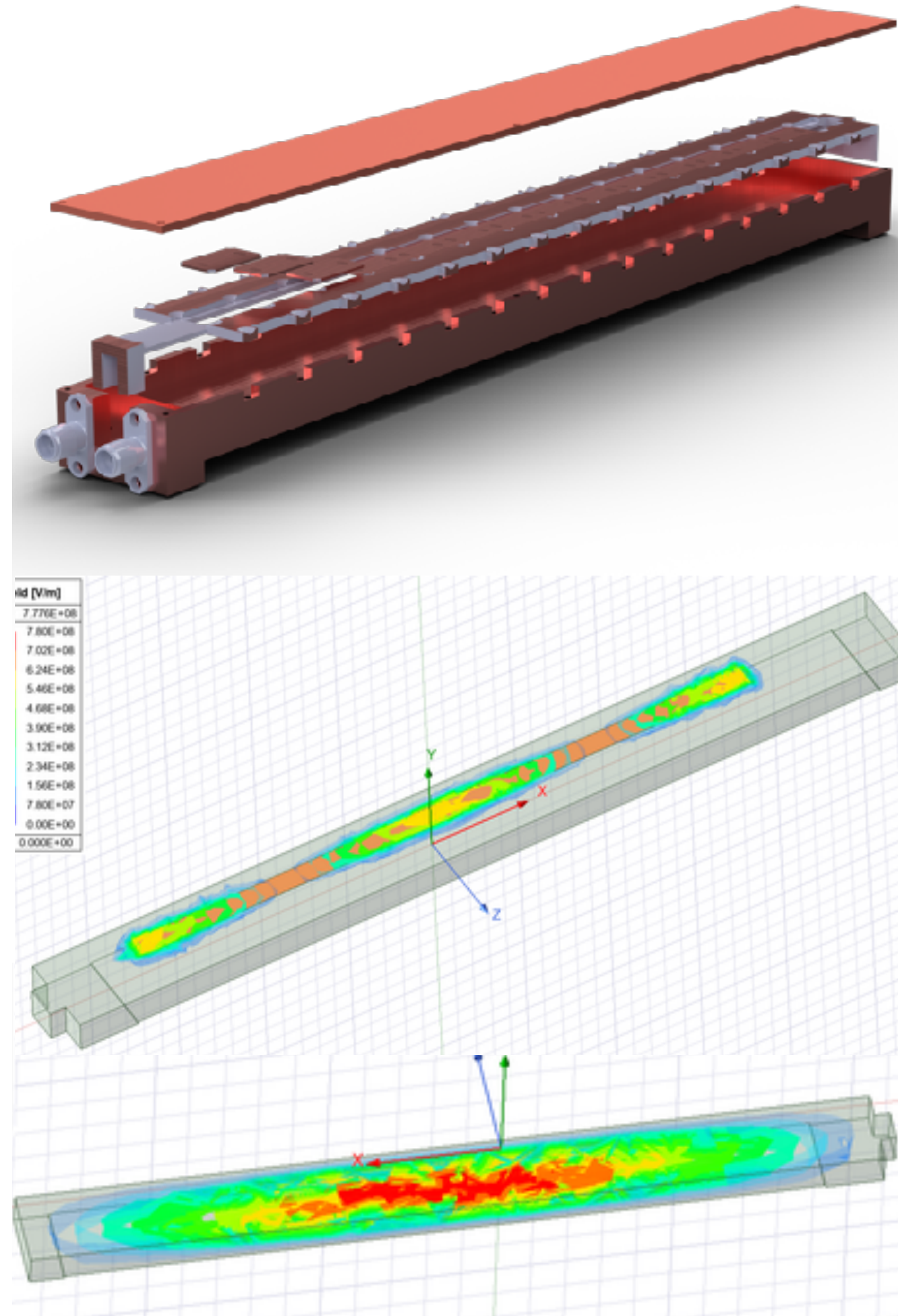
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Multiplexing Readout Line

- Resonators optimisation completed
- Renewed rf-SQUID design underway
- Detector housing, metal clamp simulations
- Full-scale readout electronics system ready for production of 15 units
- Next planned test for 10 readout lines and detector housing setup
- Real-time digital signal processing system is ready



Conclusions

- 20,000 MMC array to be operated in parallel to build a $>10^{13}$ event ^{163}Ho spectrum with goal of achieving sub-eV sensitivity on the effective neutrino mass.
- ECHo-LE detector chips:
 - Optimized for fabrication and setup preparation
 - High yield fabrication demonstrated
- Multiplexed Readout:
 - 10 cryogenic readout lines ready to test
 - Multiplexer chip optimisation to me completed

