

# Using scientific-grade CCDs for the direct detection of dark matter with the DAMIC-M experiment

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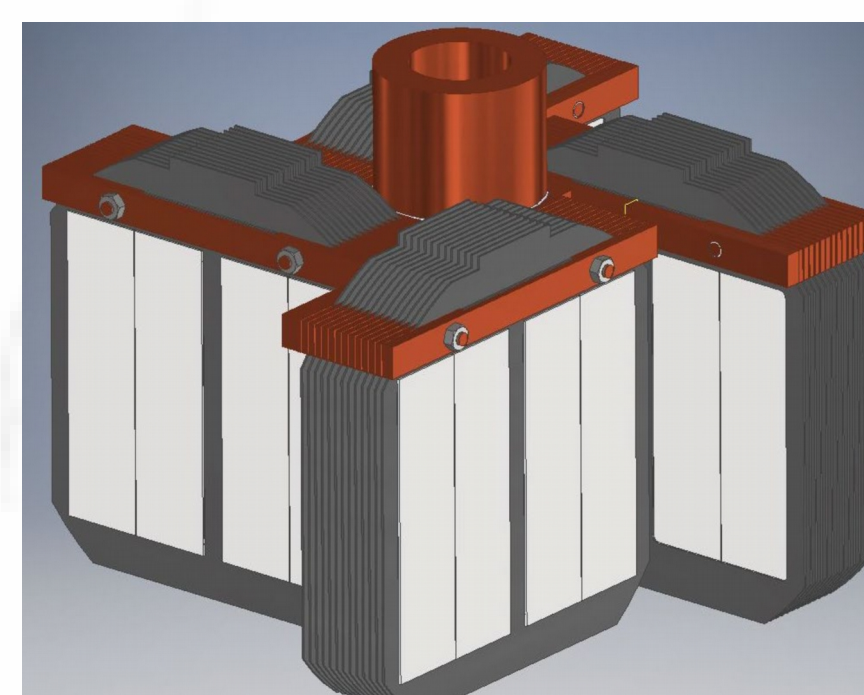
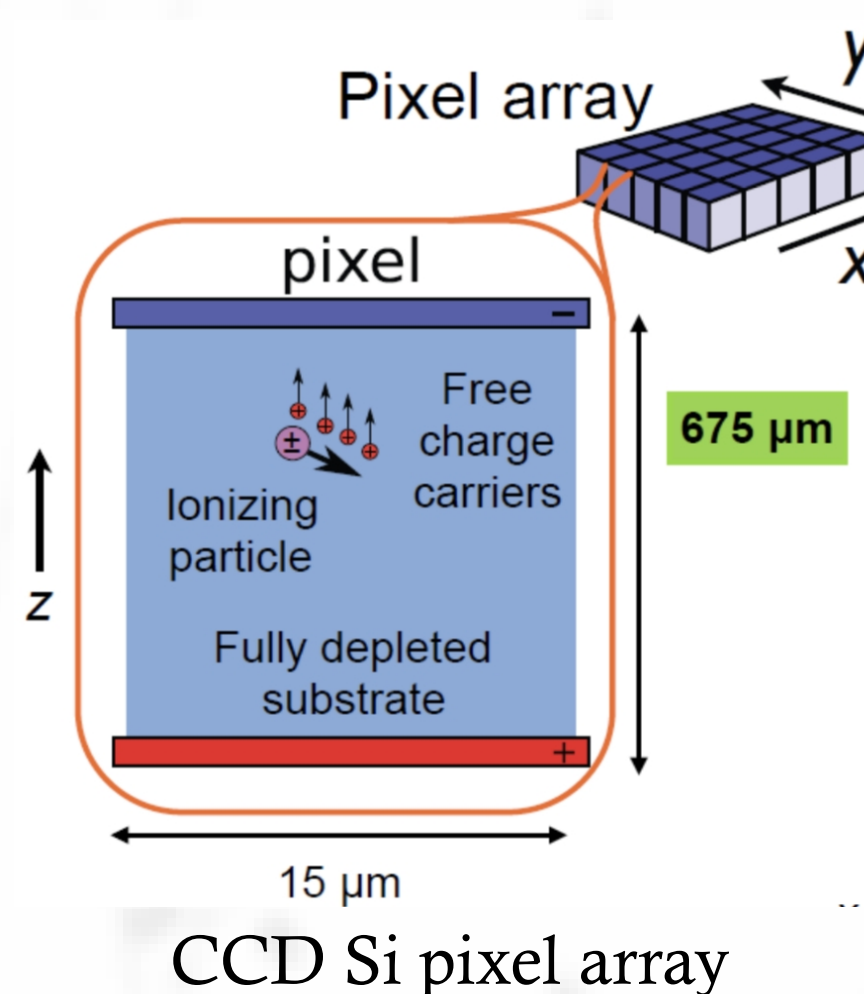
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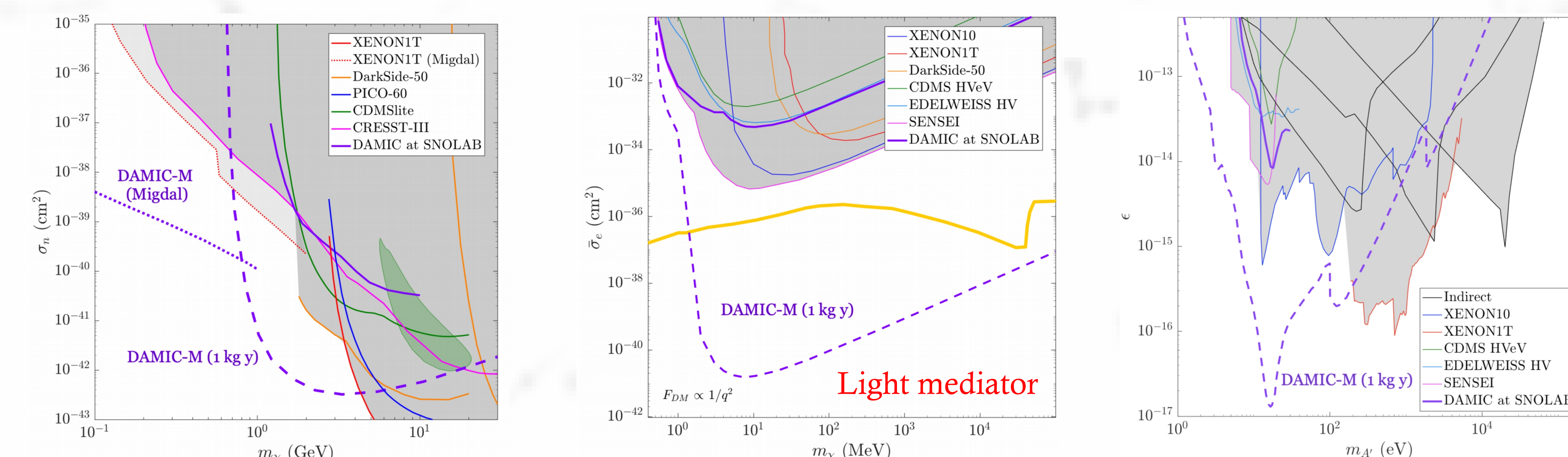
## Introduction

The DArk Matter In CCDs at Modane (DAMIC-M, 2025) experiment, successor of the DAMIC at SNOLAB, aims to directly detect interactions of light Dark Matter particles ( $<10\text{GeV}$ ) and other hidden sector candidates with the nucleus and the electrons of the bulk of scientific grade Charge-Coupled Devices (CCD).

- DAMIC-M will use multiple n-type Si CCDs with a total active mass of  $\sim 1\text{kg}$ .
- Each pad will be composed out of 4 individual  $6\text{k} \times 1.5\text{k}$  pixels CCDs.
- The detector will be placed in the underground laboratory of Modane (LSM) providing radon-free air supply and with  $2\text{km}$  of rock to protect from the cosmic background.
- Total background goal is down to  $0.1\text{ dru}$ .
- The Skipper readout implementation will allow for the best performance of the CCDs with a resolution below  $1e^-$ .
- Great spacial resolution with pixel size  $15\mu\text{m} \times 15\mu\text{m}$  and  $675\mu\text{m}$  thick and 3D reconstruction of the interaction point using the charge diffusion.
- Novel electronics are developed within the collaboration to support and optimally control the new Skipper CCDs of DAMIC-M.

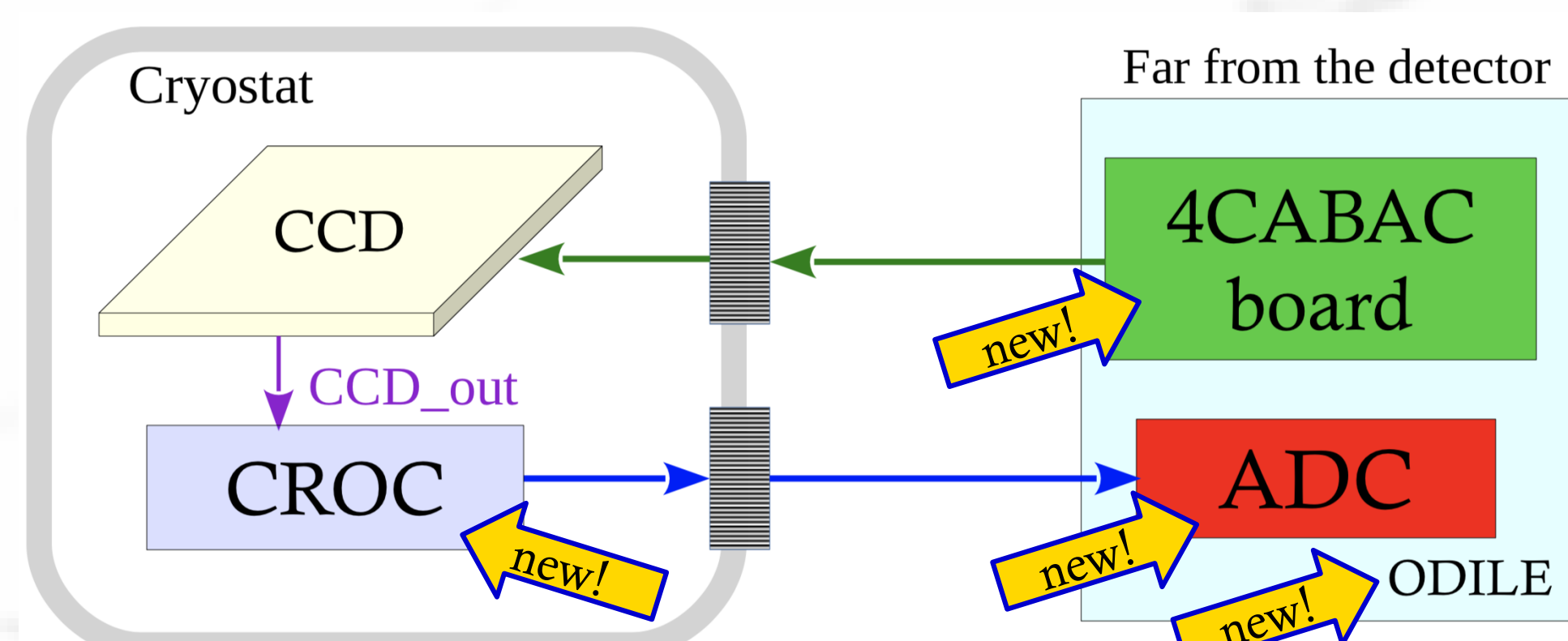


Ongoing work on DAMIC-M design of the CCD module



DAMIC-M expected limits for WIMP-nucleus cross section (left), DM-electron cross section for a light mediator (middle), and kinetic mixing parameter vs  $m_A$  (right)

## New electronics



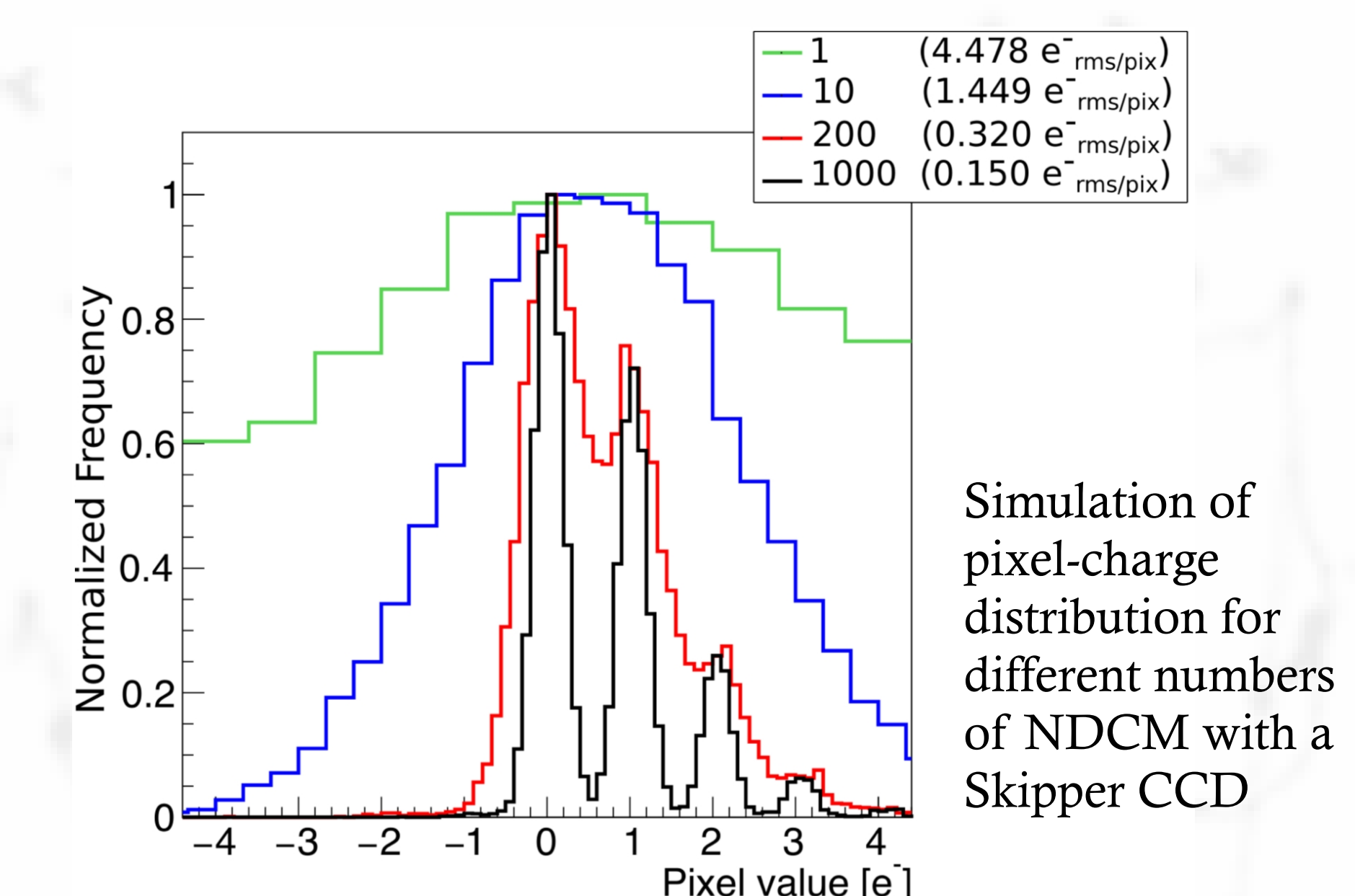
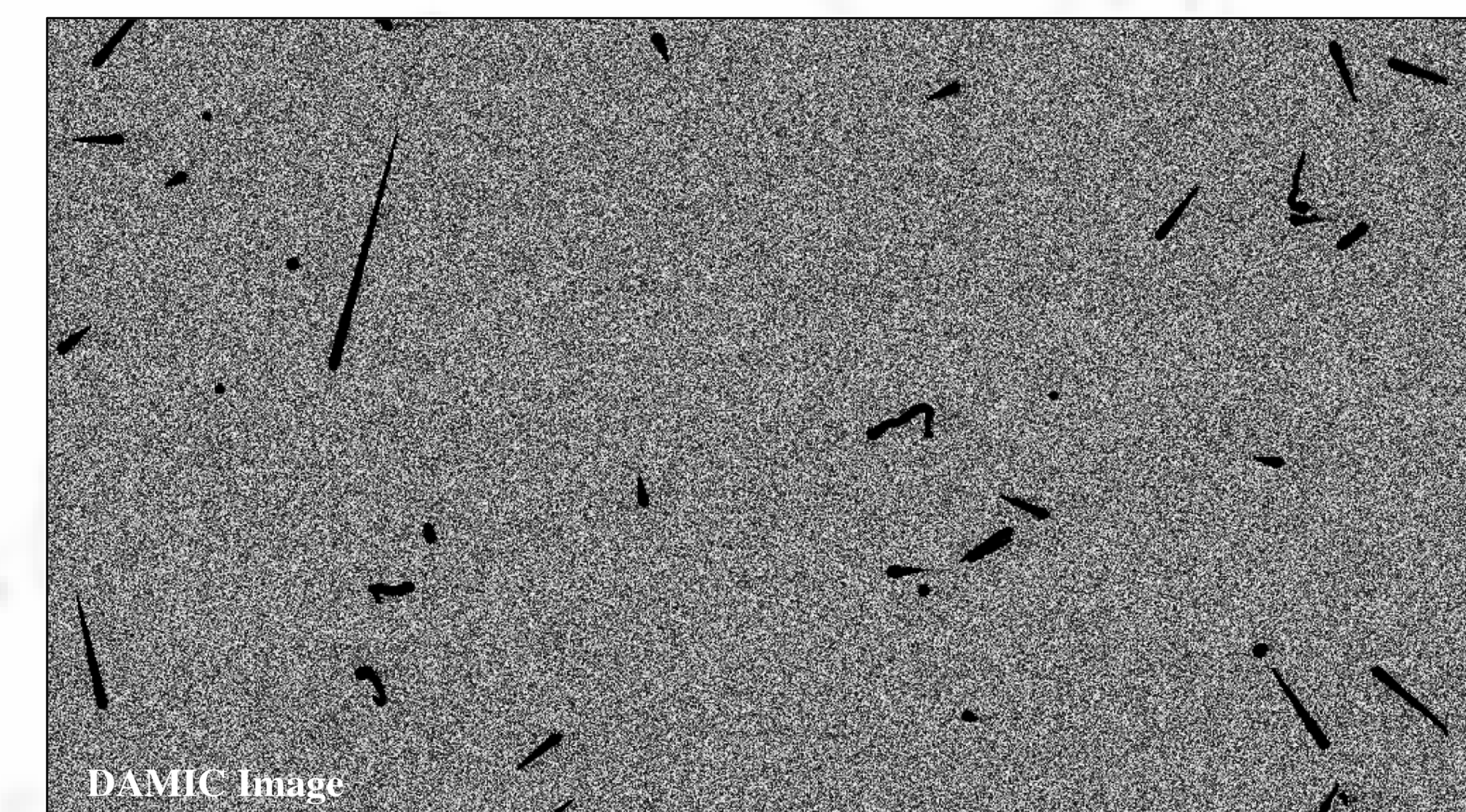
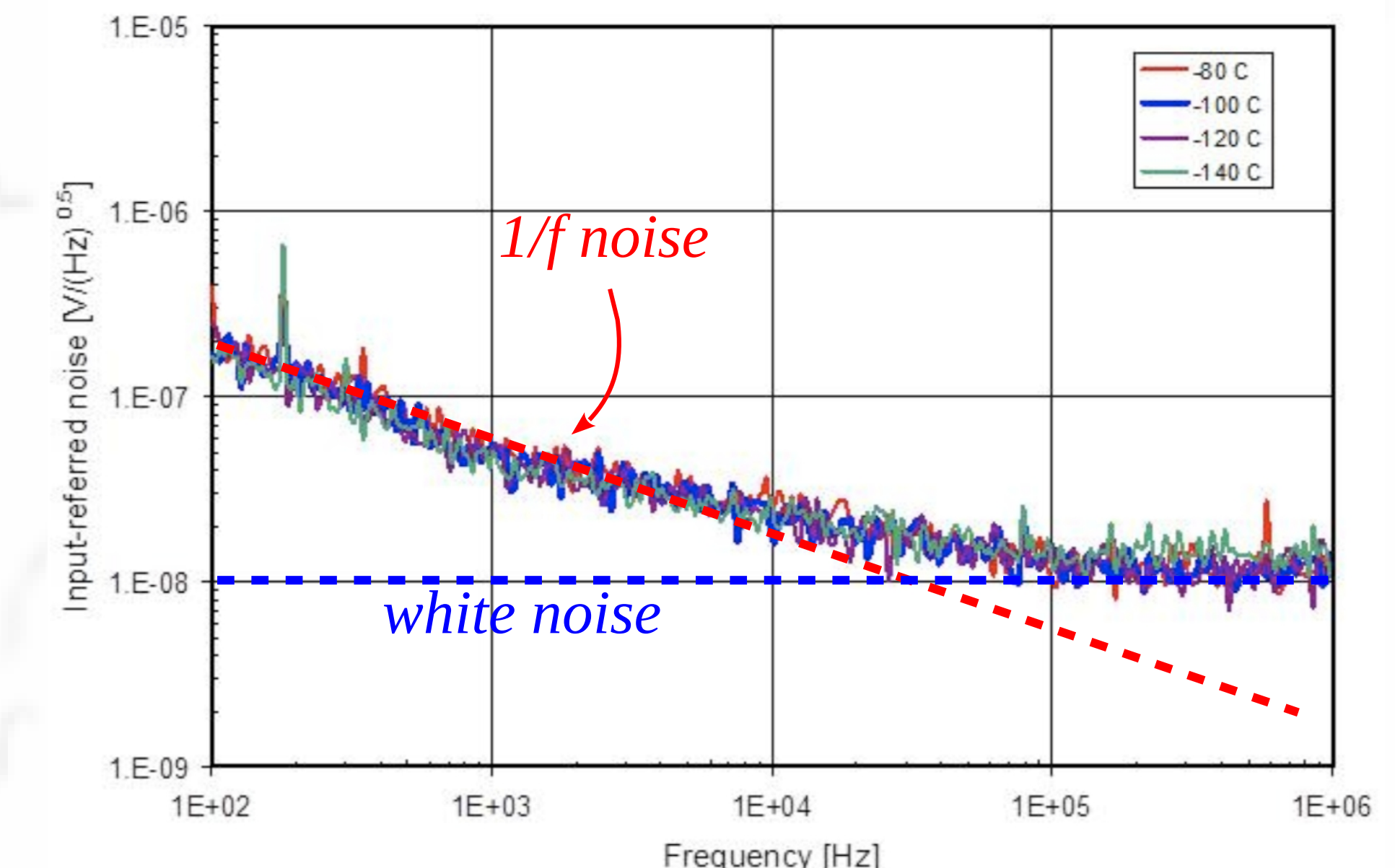
New acquisition system for CCD control of DAMIC-M

- 4CABAC (Clocks And Biases ASIC for CCD): Production of precise and well controlled clocks and biases for the overall control of the CCD. to suppress the clock-induced noise during operation.
- CROC (CCD ReadOut Chip): Placed as close as possible to the CCD output to amplify and preprocess the CCD signal to improve the Signal-to-Noise ratio. Measured input noise of CROC\_v1  $\sim 3.5\mu\text{V} \sim 1e^-$ .
- ADC (Analog to Digital Converter): Fast and high resolution ADC to perform the transition from the analog to the digital domain. Few options to choose with a single-sample noise of  $O(10\mu\text{V})$ .

- ODILE (Online Digital Interface for Low-noise Electronics): The FPGA motherboard to control the whole setup.

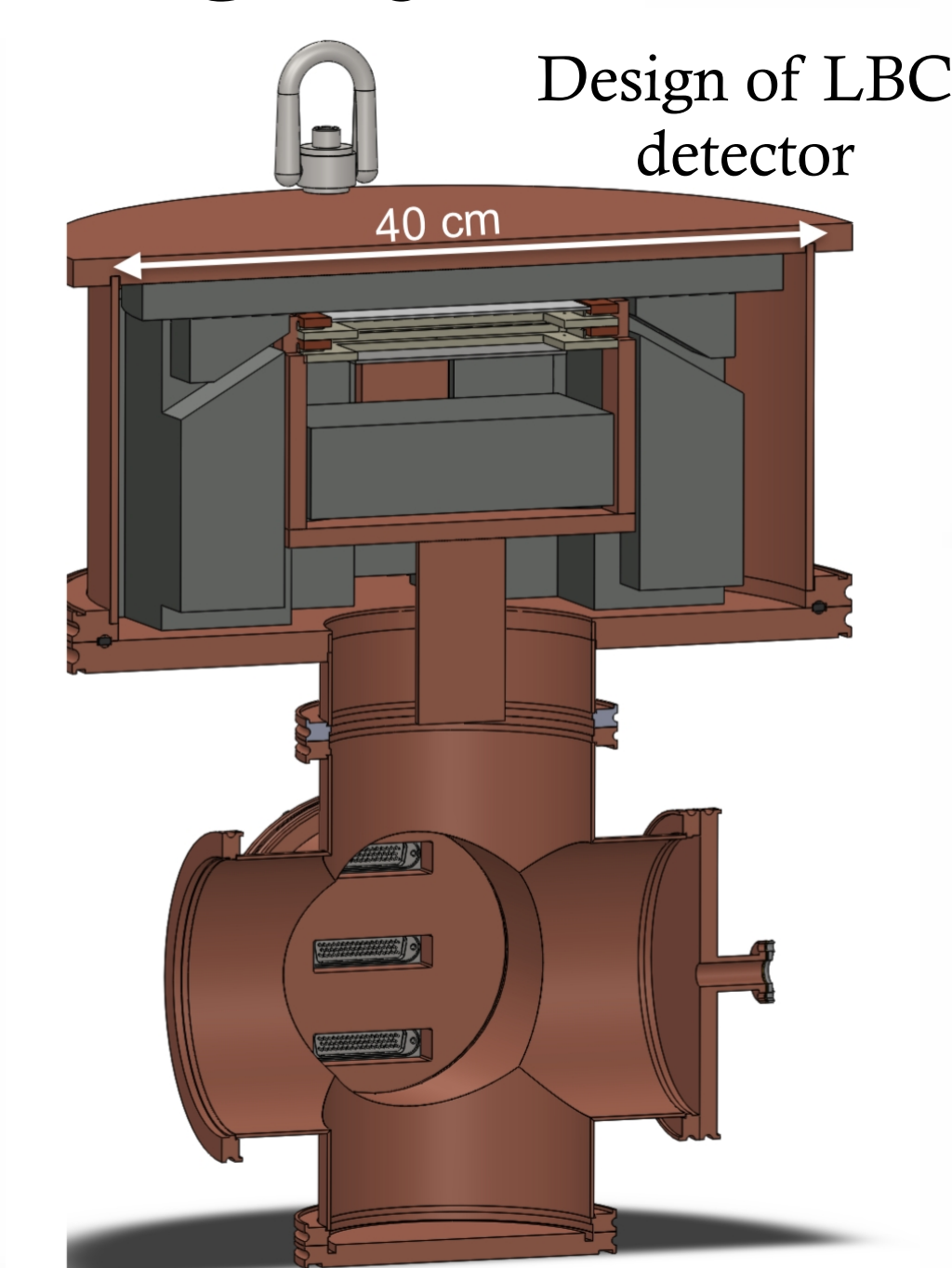
## Skipper readout

- Regular CCD: single charge measurement with an integration time  $O(10\mu\text{s})$ .
  - High frequency thermal noise is eliminated
  - Dominated by low frequency noise
- Skipper CCD: multiple non-destructive charge measurement (NDCM) with integration time  $O(1\mu\text{s})$ .
  - Short integration time  $\rightarrow$  lower resolution
  - Multiple measurements  $\rightarrow$  thermal noise goes down with the sqrt of the number of measurements, reaching a sub- $e^-$  resolution
  - Fast sampling  $\rightarrow$  low frequency noise is eliminated



Simulation of pixel-charge distribution for different numbers of NDCM with a Skipper CCD

## LBC 2021



Installation of a smaller detector prior to the final DAMIC-M (2025), called Low Background Chamber (LBC):

- 4 months of exposure with a large  $6\text{k} \times 4\text{k}$  CCD.
- Use of ancient lead and electroformed copper for the protection and support of the CCD.

Goals:

- Measure the leakage current with a Skipper CCD.
- Measure background in pre-production DAMIC-M CCDs.
- Integrate the new electronics and test the overall acquisition system.
- Measure the background of the underground laboratory at Modane.
- Produce first scientific results.

## References

- DAMIC-M Collaboration, N. Castello-Moretal., Nuclear Instruments and Methods in Physics Research Section A, Vol. 958, 162933 (2020) [arXiv:2001.01476].
- DAMIC Collaboration, A. Aguilar-Arevalo et al., Phys. Rev. Lett. 125, 241803 (2020), [arXiv:2007.15622].
- J. Tiffenberg et al. [SENSEI], Phys. Rev. Lett. 119 (2017) no.13, 131802 [arXiv:1706.00028].