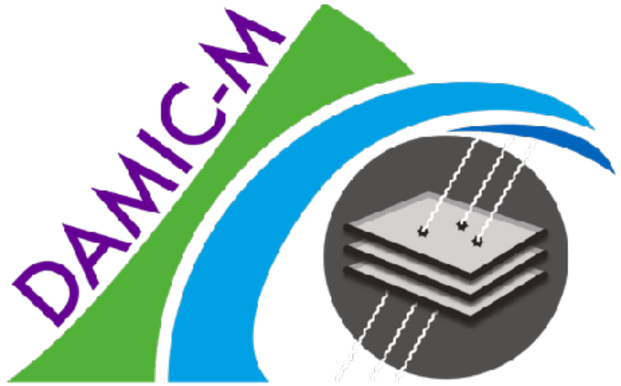
Searching for Dark Matter in the Alps with DAMIC-M

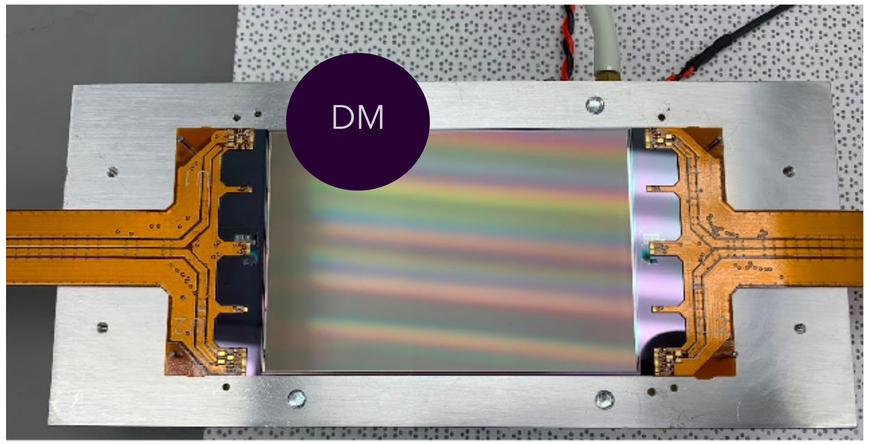
Sravan Munagavalasa
DAMIC-M Collaboration



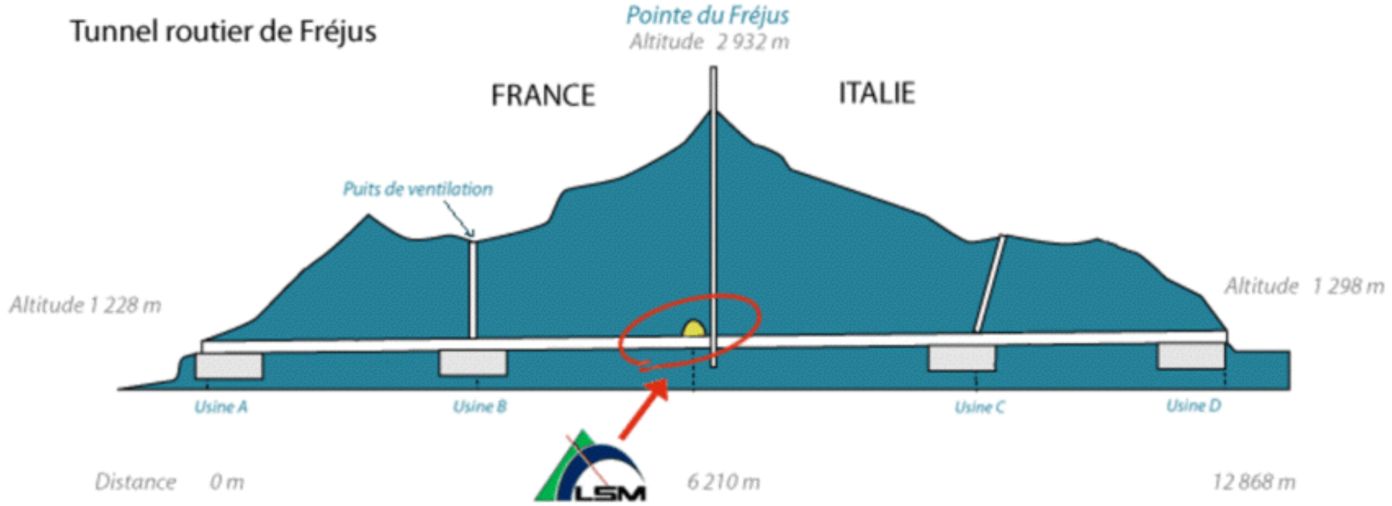
DAMIC-M

DArk MAtter In CCDs at Modane

Dark Matter
Charge-Coupled Devices
Modane, France



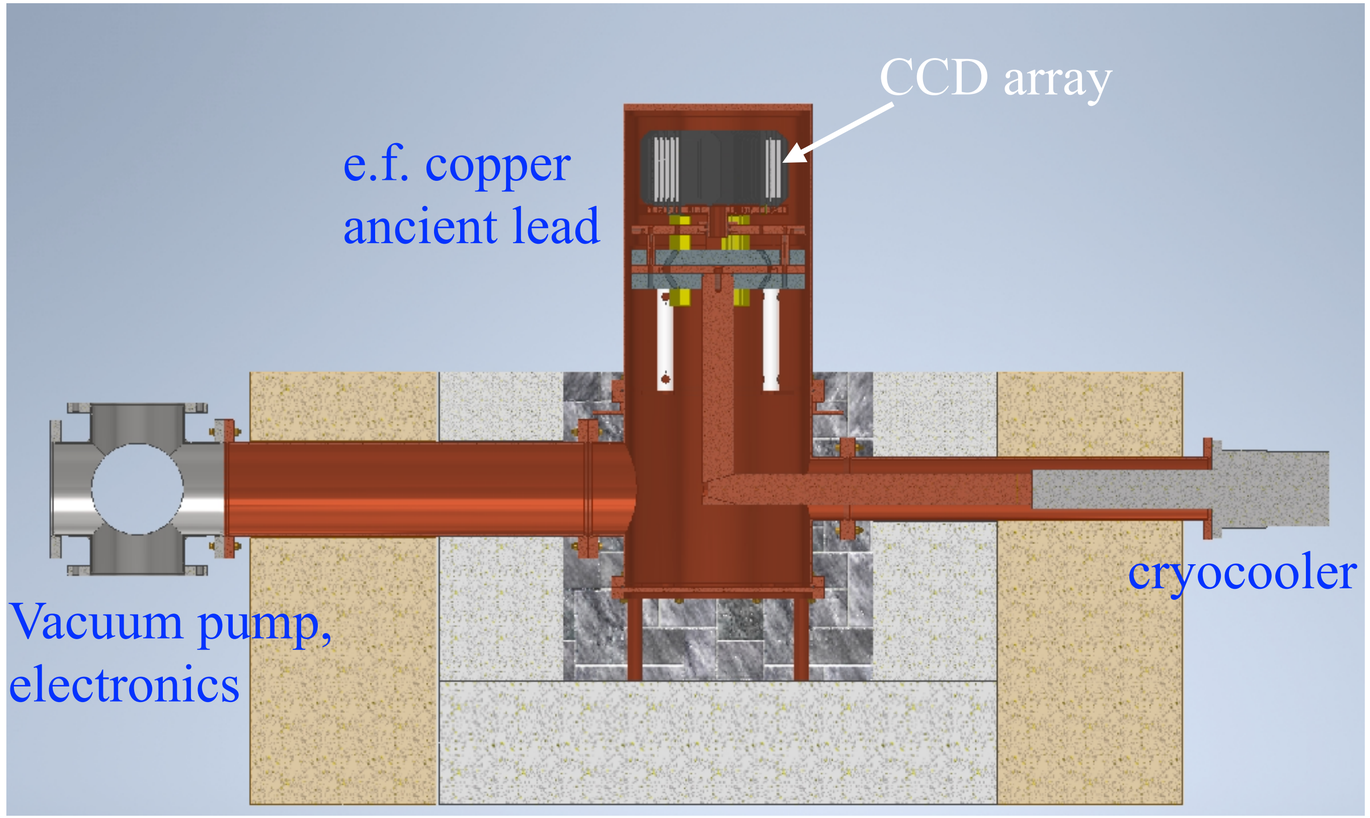
Laboratoire Souterrain
de Modane (LSM)



DAMIC-M

DAMIC-M In a Nutshell

- 1 kg-year of Target Exposure
- background rate of ~0.1 dru
- detect nuclear and electron recoils to search for light dark matter candidates
- scheduled for installation at LSM end of 2024

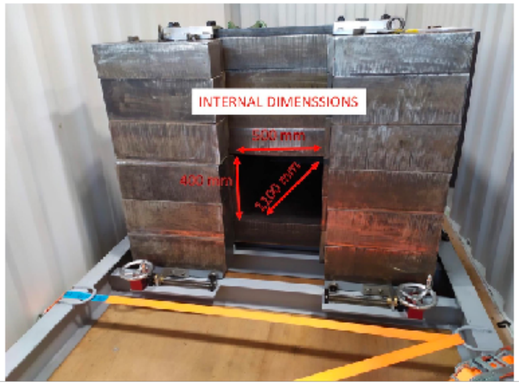


1 dru [differential rate unit] = 1 background event/keV/kg/day

DAMIC-M

Background Mitigation

18-ton shielding in shipping container to transport wafers from Europe to Canada (and back as CCDs)



- Copper: Electroform copper machined underground MAJORANA copper at SURF
  Shipped to LSM in shielded container

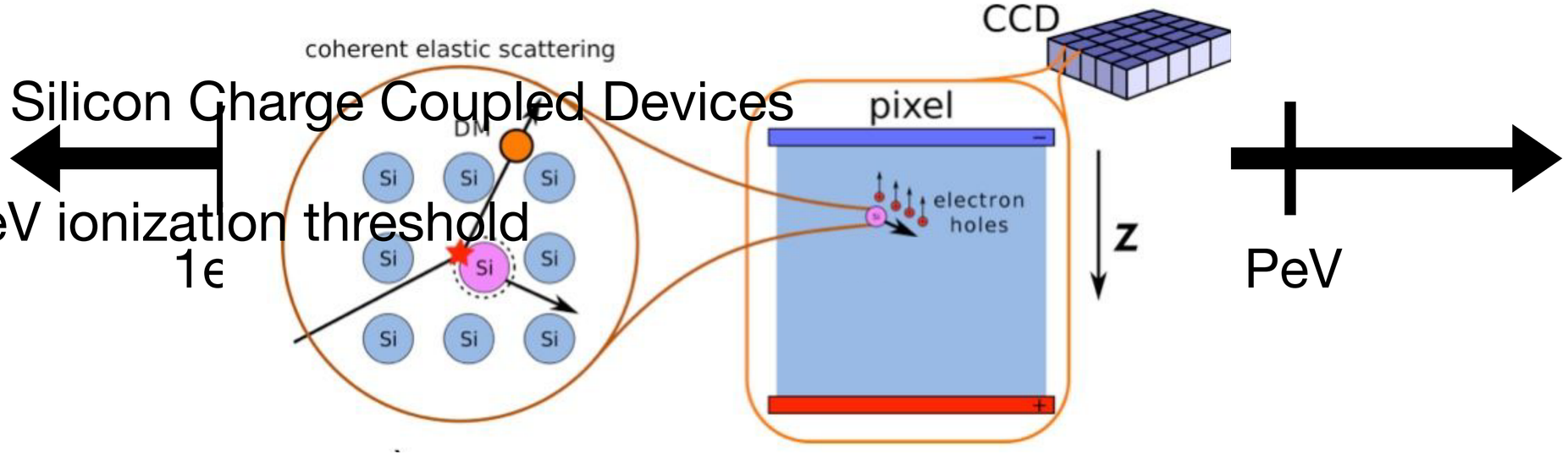
- Silicon: cosmic rays exposure < 2 months to achieve background goal. We have implemented strict shielding protocols for all transports/storage of silicon

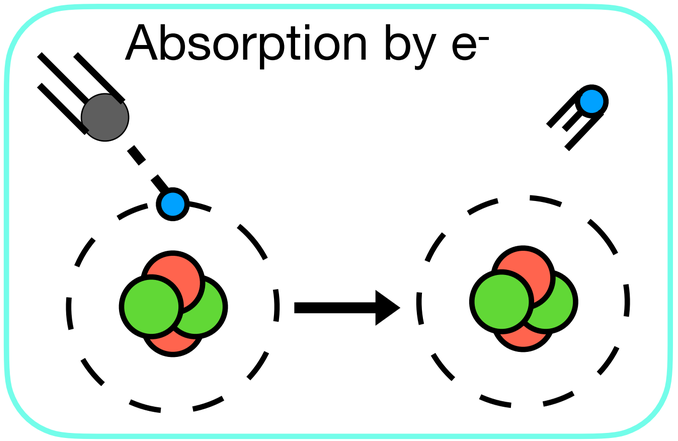
Europe -> Canada -> California -> Canada -> Washington->Modane

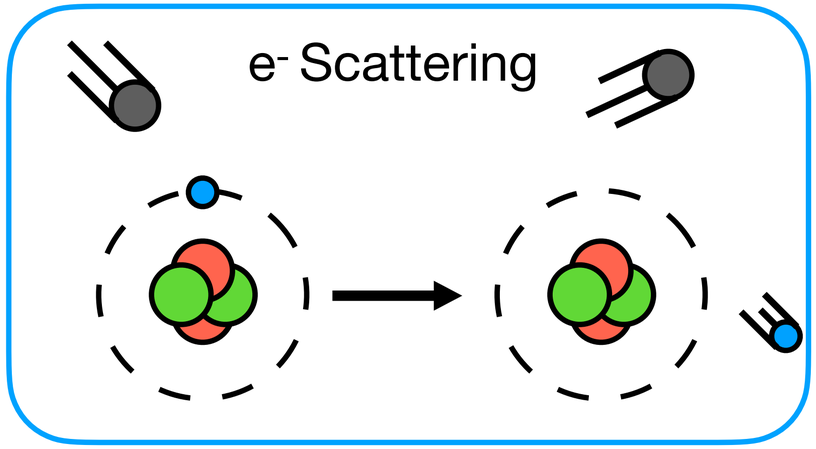
DAMIC-M

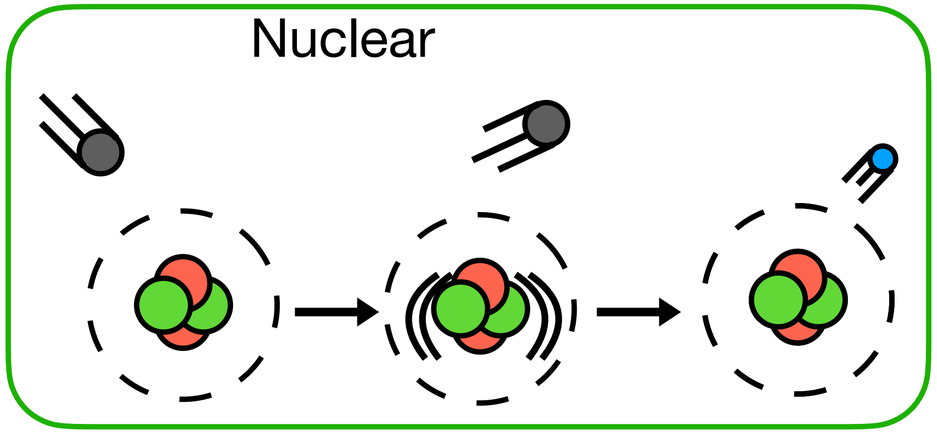
Dark Matter Candidates

- n-type Silicon Charge Coupled Devices
- $\mathcal{O}(1)$ eV ionization threshold









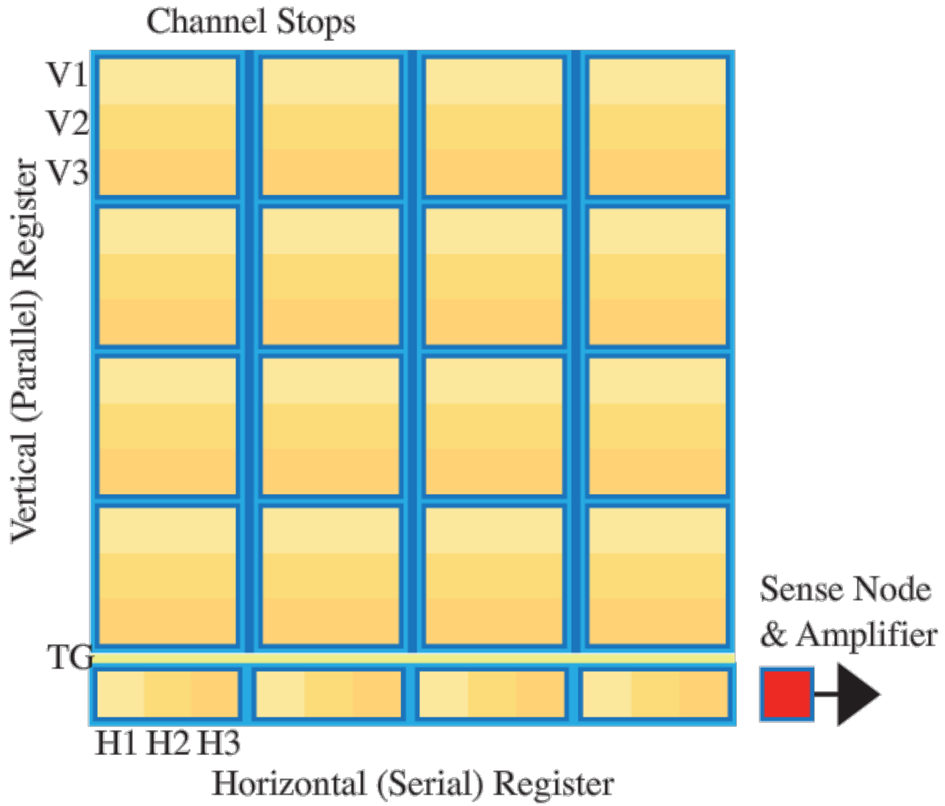
Charge-Coupled Device

Operation

- Expose
- Vertical shift down one pixel
  - Horizontal shift one pixel
    - Readout pixel

Conventional Readout Limitation:

$$\sigma_{rms} \approx 3\ e^-$$

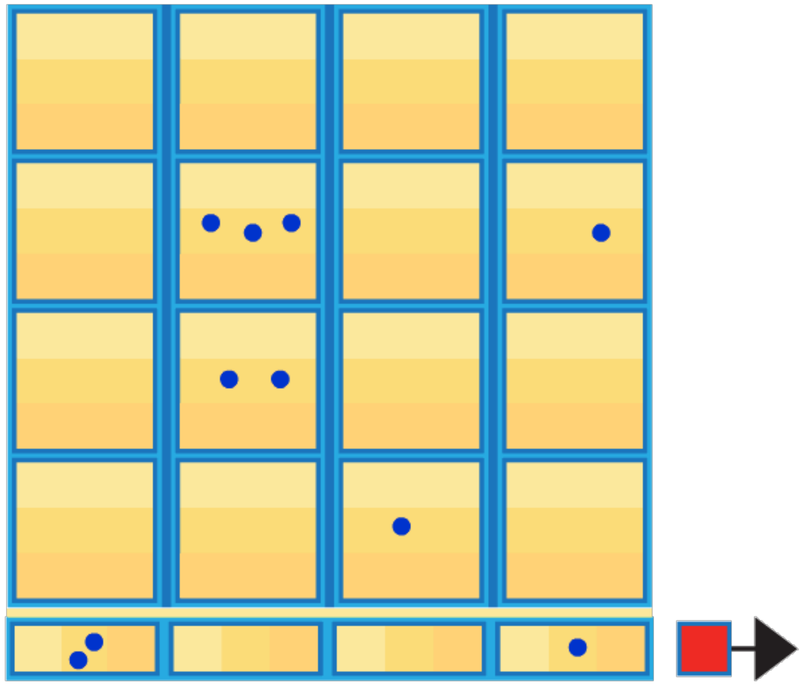


Charge-Coupled Device

Skipper Readout Stage

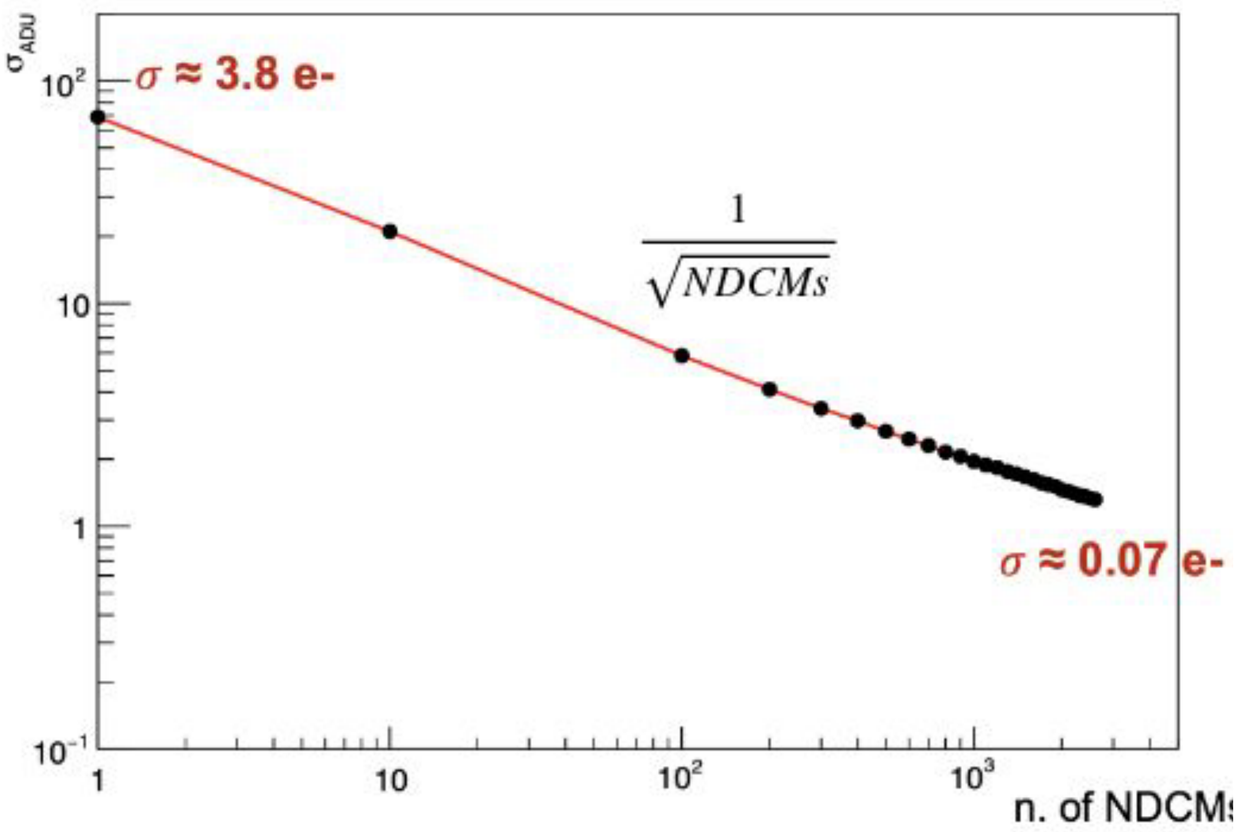
- Implement a floating readout stage
- Allows for Non-Destructive Charge Measurements (NDCM)
- Reduce Statistical Noise by

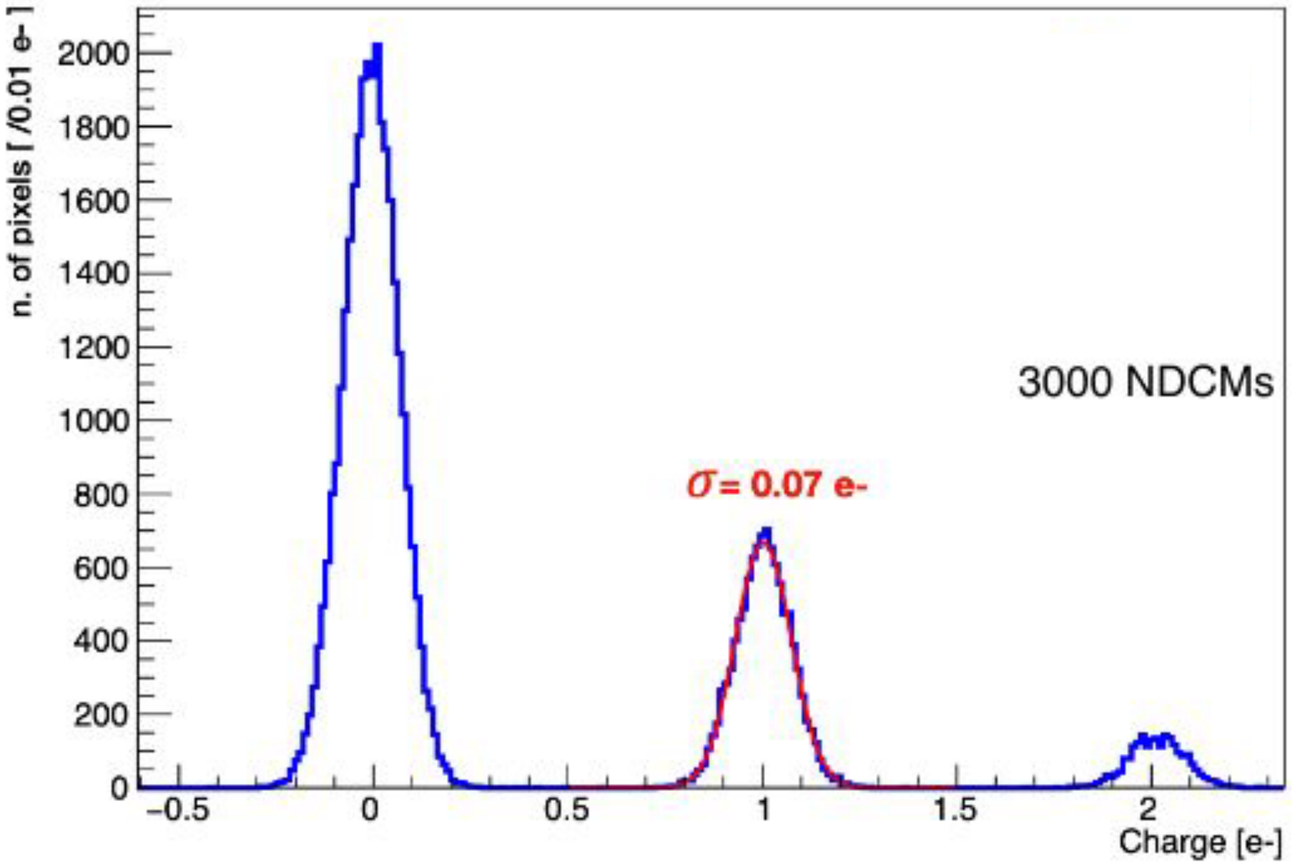
$$\sigma_{\mathrm{NDCM}} = \frac{\sigma_1}{\sqrt{\mathrm{NDCM}}}$$



Charge-Coupled Device

Sub-Electron Noise Resolution

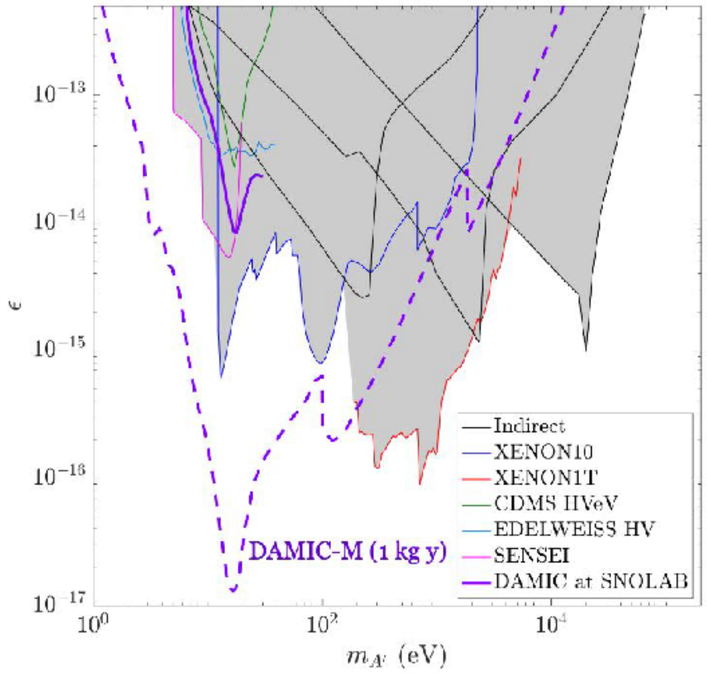


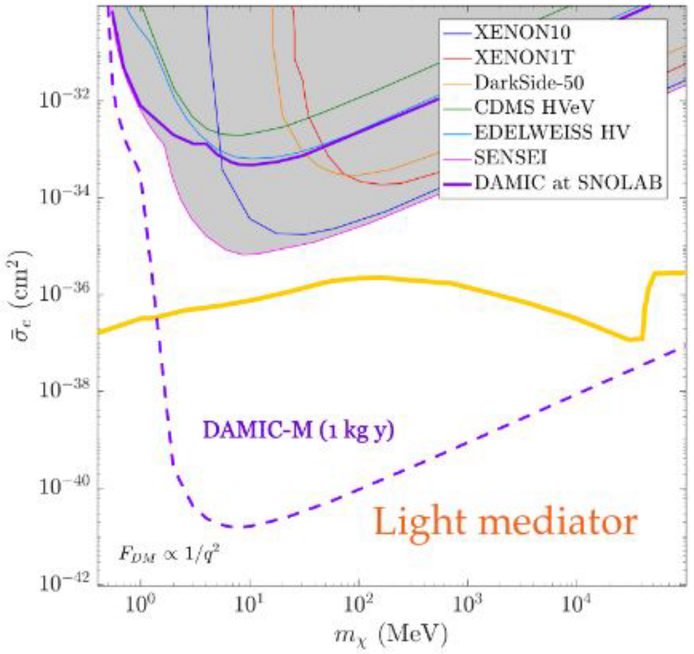


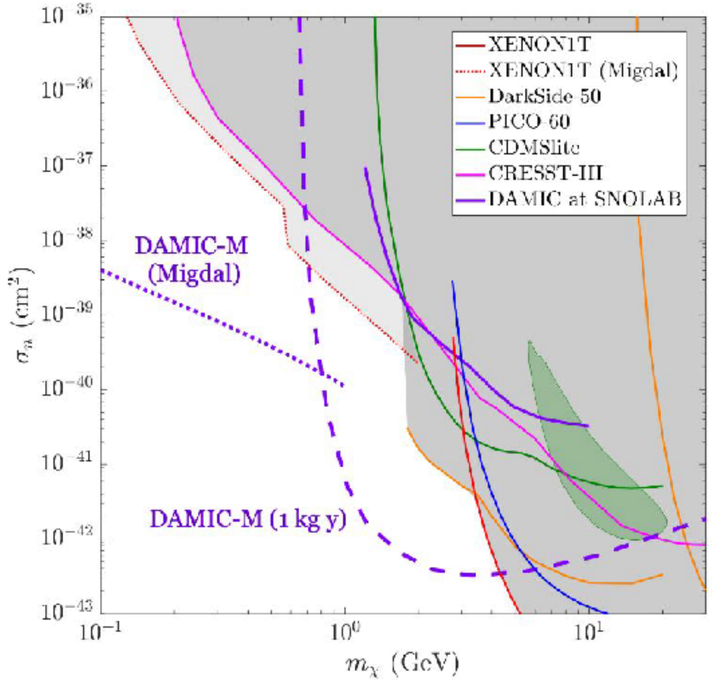
DAMIC-M

Projected Sensitivity

- Design: Low Background
- Silicon: Low Ionization Threshold
- Skipper: Low Readout Noise



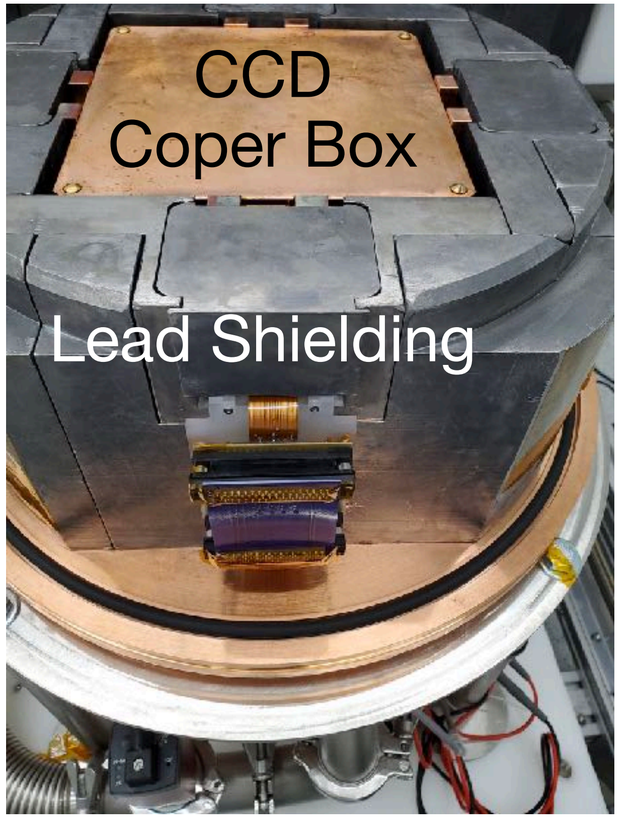


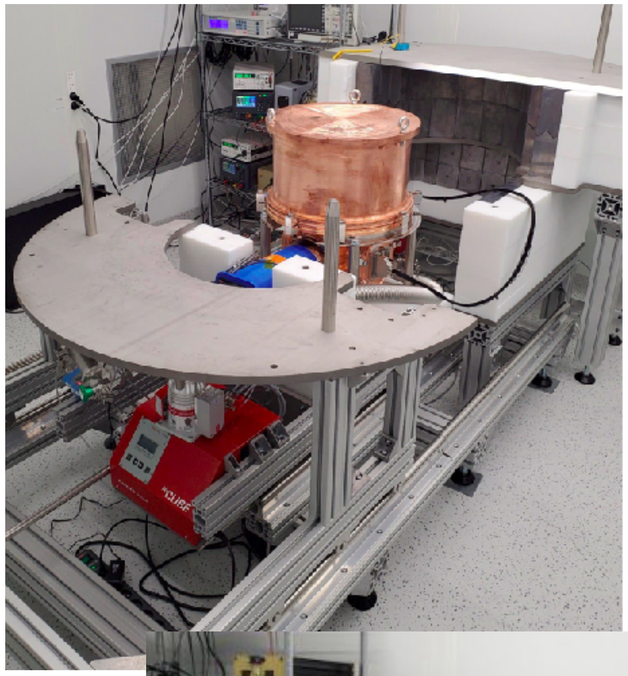


Low Background Chamber

Main Objectives

- CCD test in low background environment
- Validation of DAMIC-M readout electronics
- Test bench for data collection strategies

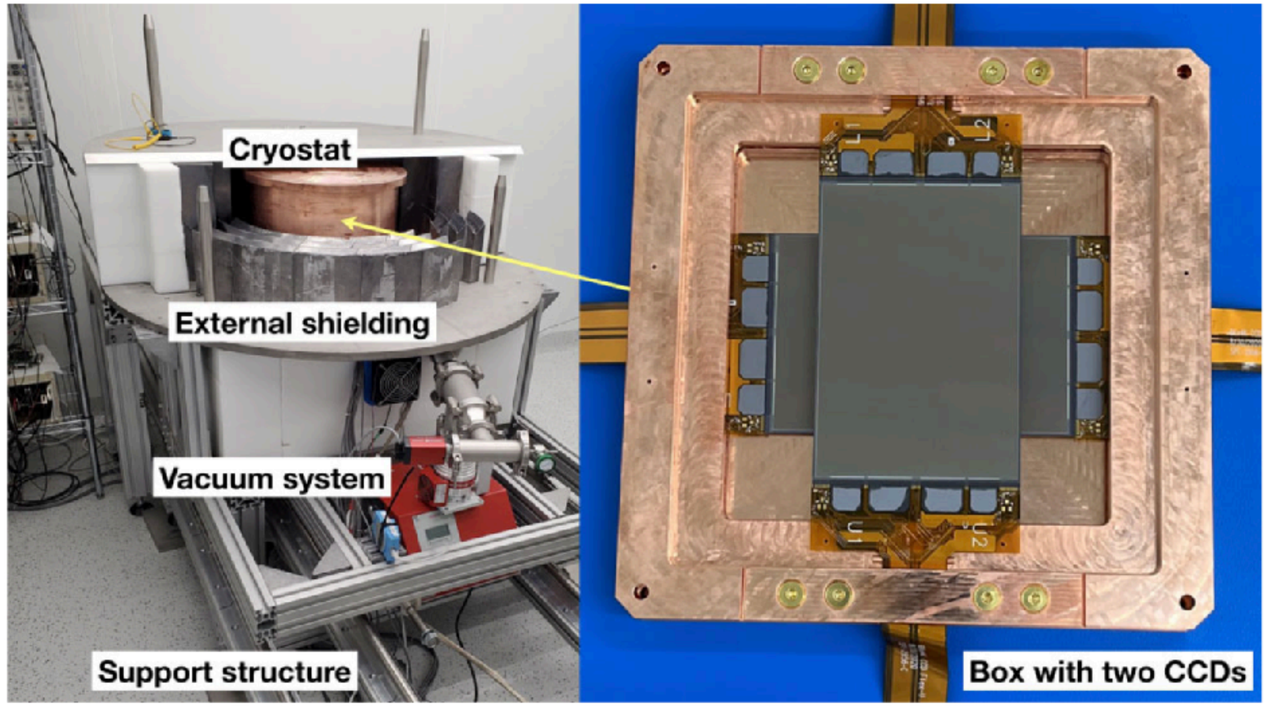




Low Background Chamber (LBC)

Main Objectives

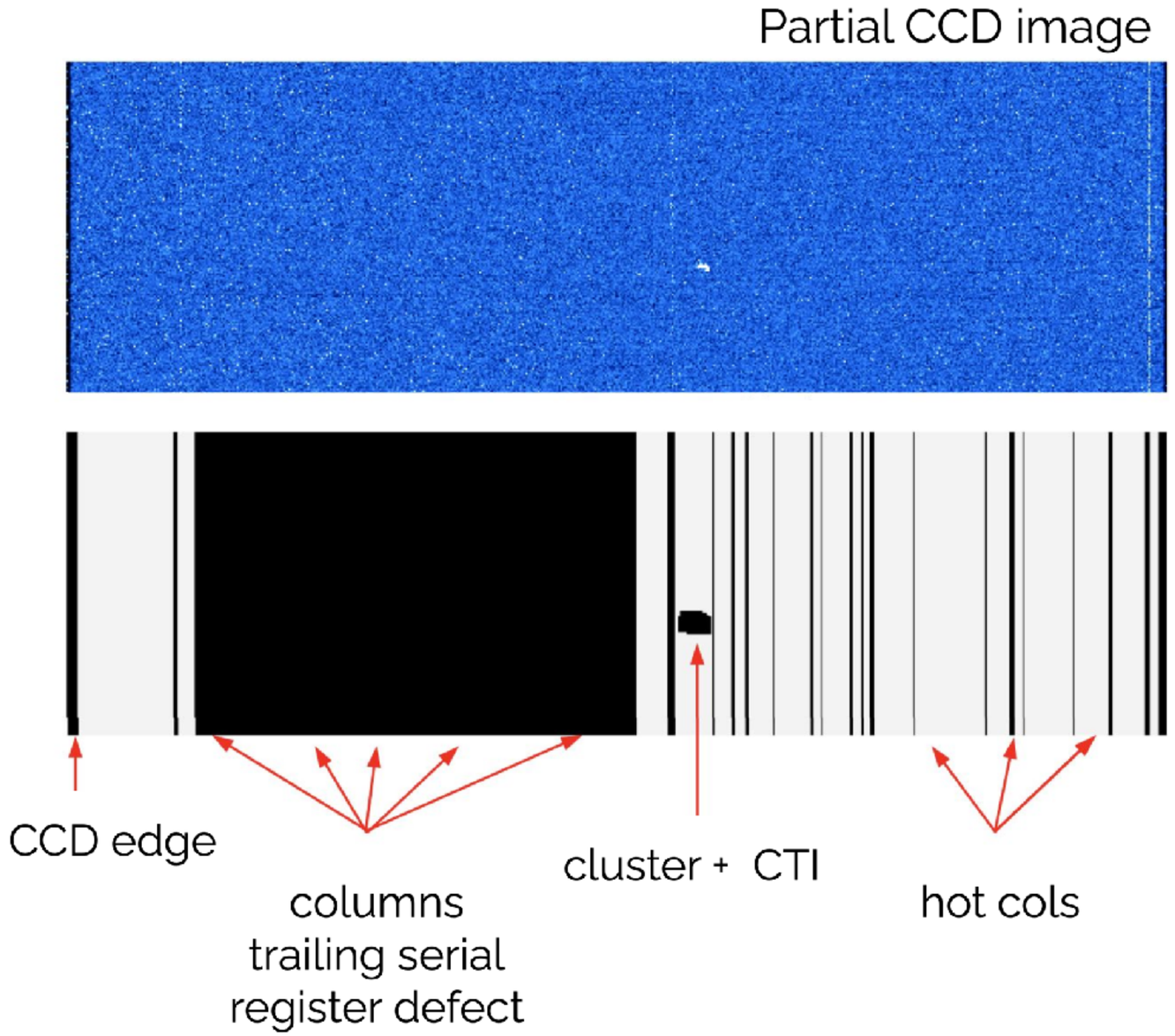
- CCD test in low background environment
- Validation of DAMIC-M readout electronics
- Test bench for data collection strategies
- Science Runs



Low Background Chamber

First Science Run

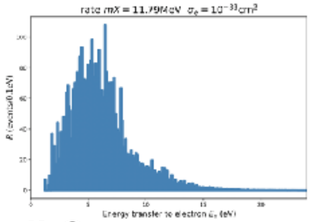
- 85.2 gram-days total (after masking)
- Background rate 12.5 dru
- Resolution 0.2e-
- Dark current 4.5E-3 e-/ pixel/day



DM-e Scattering Analysis

$$R \propto \sigma_e \int \frac{dq}{q^2}\, \eta(m_{DM}, q, E_e)\, |F_{DM}(q)|^2\, |f_{crystal}(q, E_e)|^2$$

DM halo — DM Form Factor — Transition Matrix



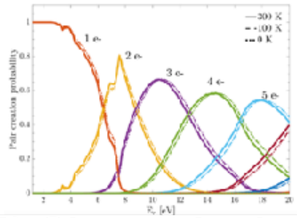
J. High Energy Phys. 05, 046 (2016)

(1) Electron Recoil Spectra

Monte Carlo

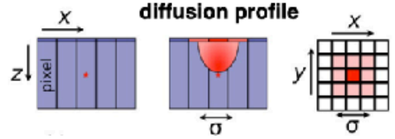
From recoil energy to ionization charge

Phys. Rev. D 102, 063026 (2020)

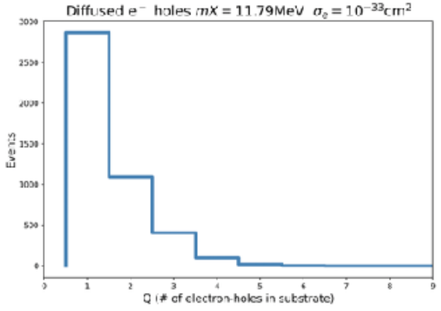


(2) Charge Ionization

Phys. Rev. D 102, 063026 (2020)



(3) Diffusion of Charge



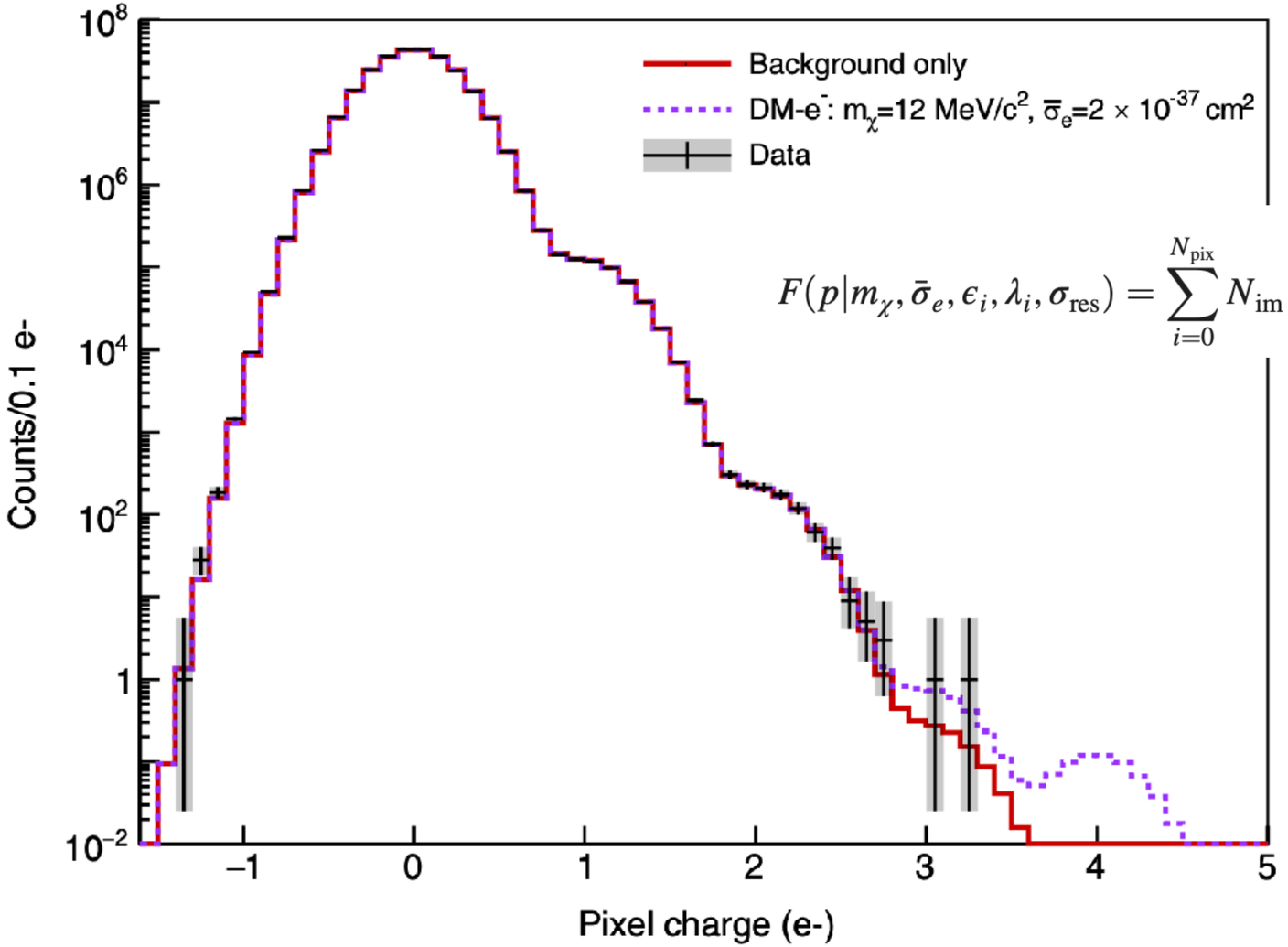
(3) Background Model

(4) Readout Noise

$$F(p|m_\chi, \bar{\sigma}_e, \epsilon_i, \lambda_i, \sigma_{\rm res}) = \sum_{i=0}^{N_{\rm pix}} N_{\rm im} \sum_{n_q=0}^{\infty} \left[\sum_{j=0}^{n_q} S(j|m_\chi, \bar{\sigma}_e, \epsilon_i) \mathrm{Pois}(n_q - j|\lambda_i - \lambda_{S,i}) \right] \mathrm{Gaus}(p|n_q, \sigma_{\rm res})$$

DM-e Scattering Analysis

Log Likelihood minimization

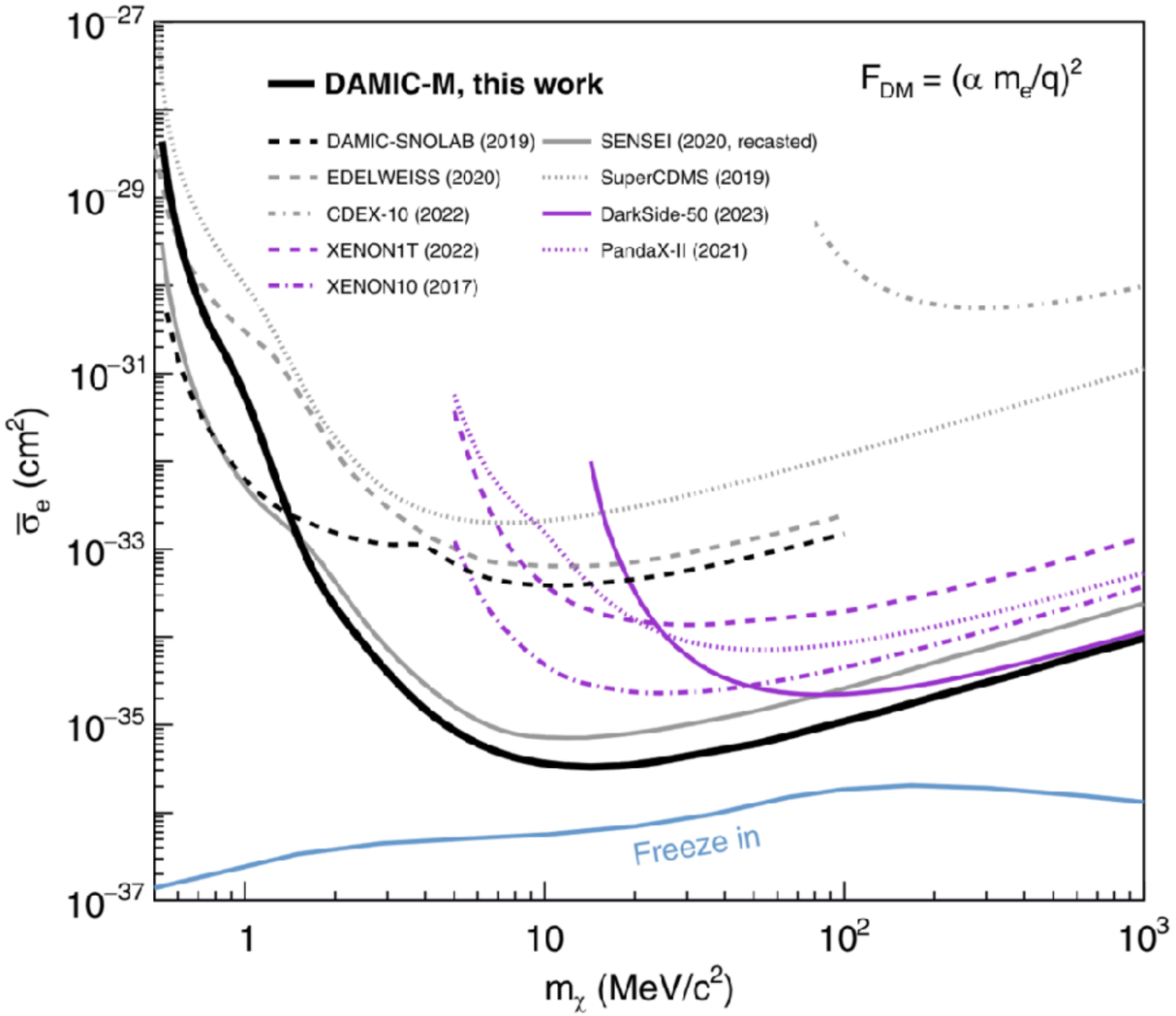


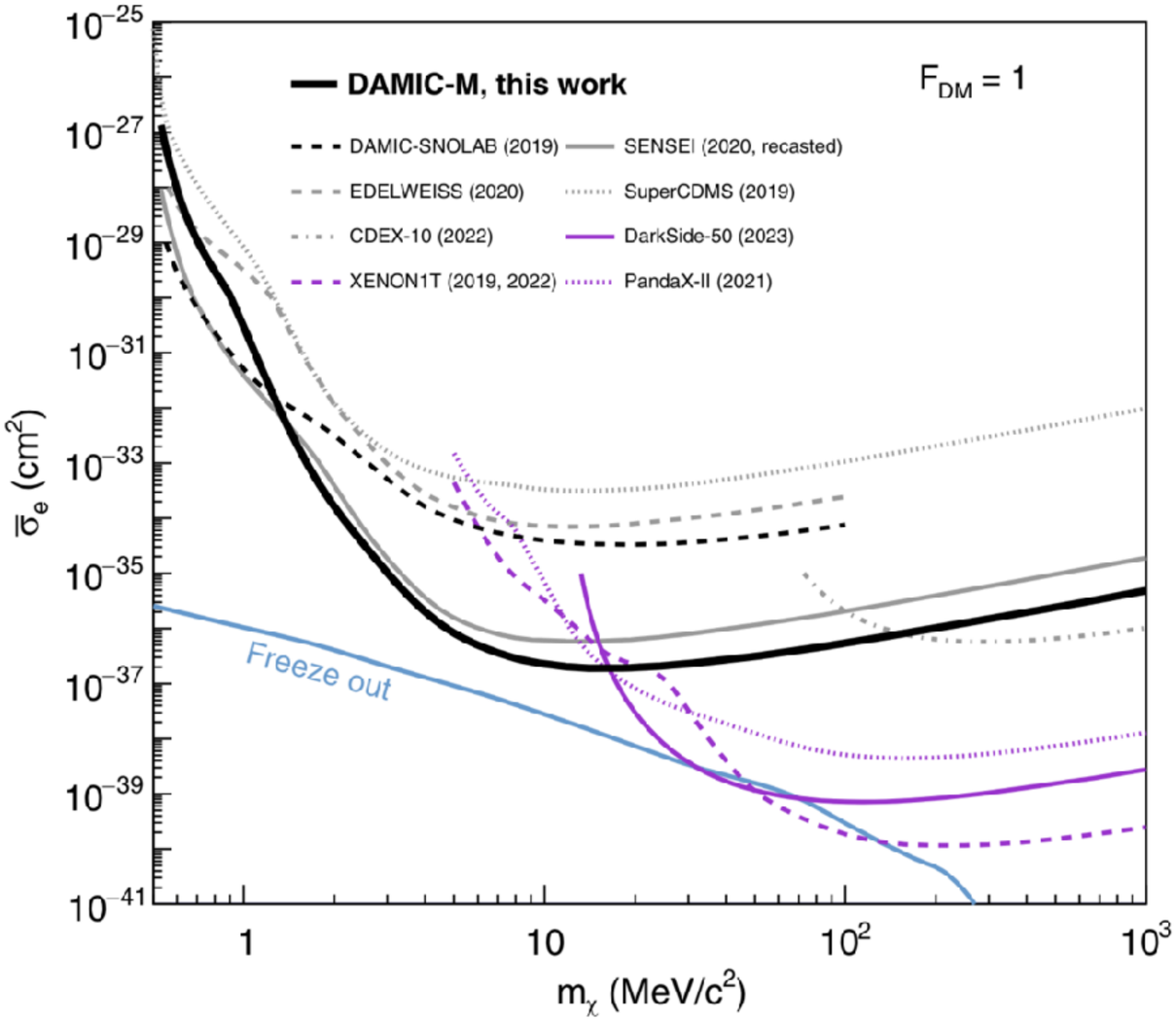
$$F(p|m_\chi, \bar{\sigma}_e, \epsilon_i, \lambda_i, \sigma_{\rm res}) = \sum_{i=0}^{N_{\rm pix}} N_{\rm im} \sum_{n_q=0}^{\infty} \left[\sum_{j=0}^{n_q} S(j|m_\chi, \bar{\sigma}_e, \epsilon_i) \mathrm{Pois}(n_q - j|\lambda_i - \lambda_{S,i}) \right] \mathrm{Gaus}(p|n_q, \sigma_{\rm res}).$$

PHYSICAL REVIEW LETTERS 130, 171003 (2023)

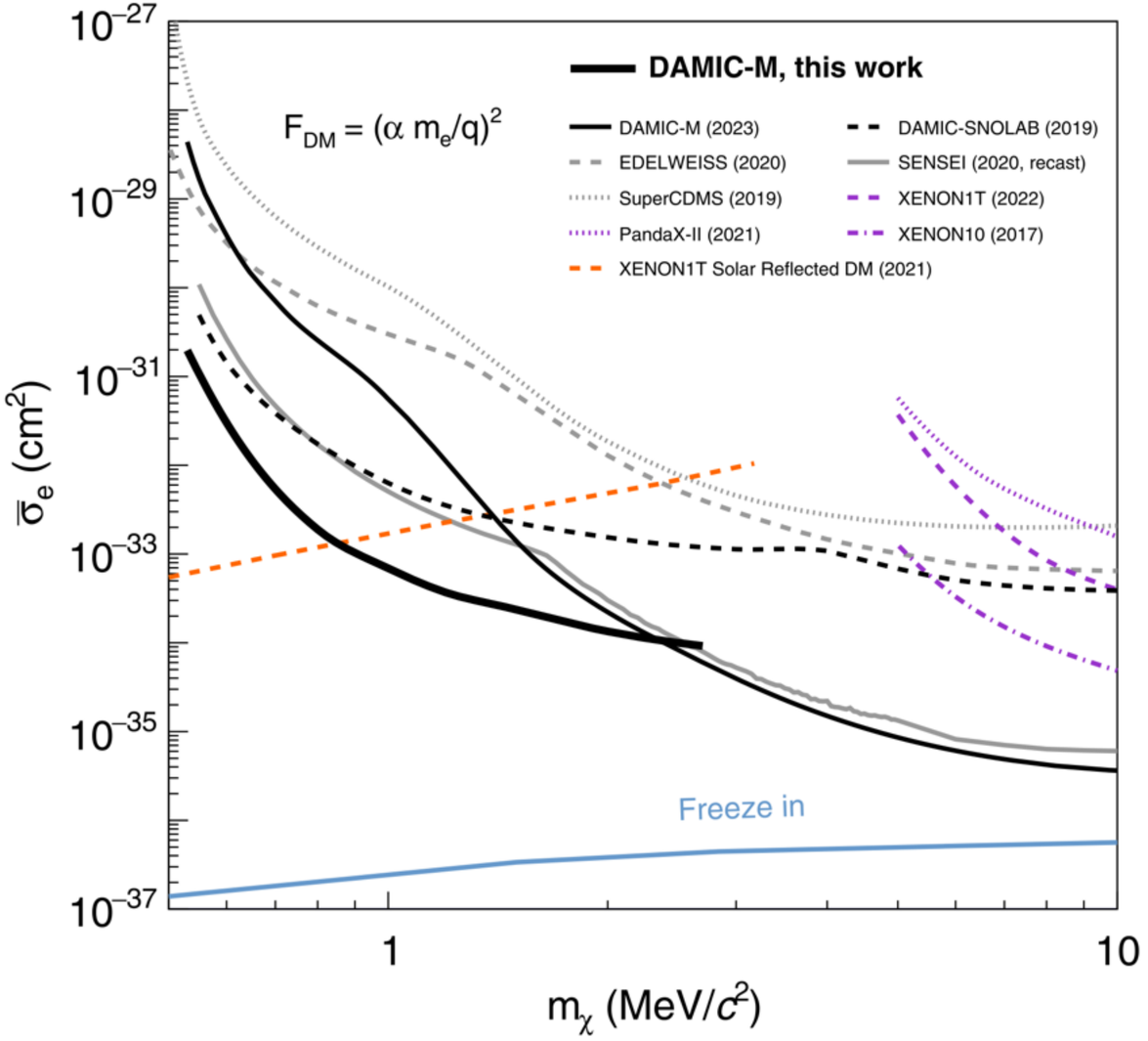
Editors' Suggestion

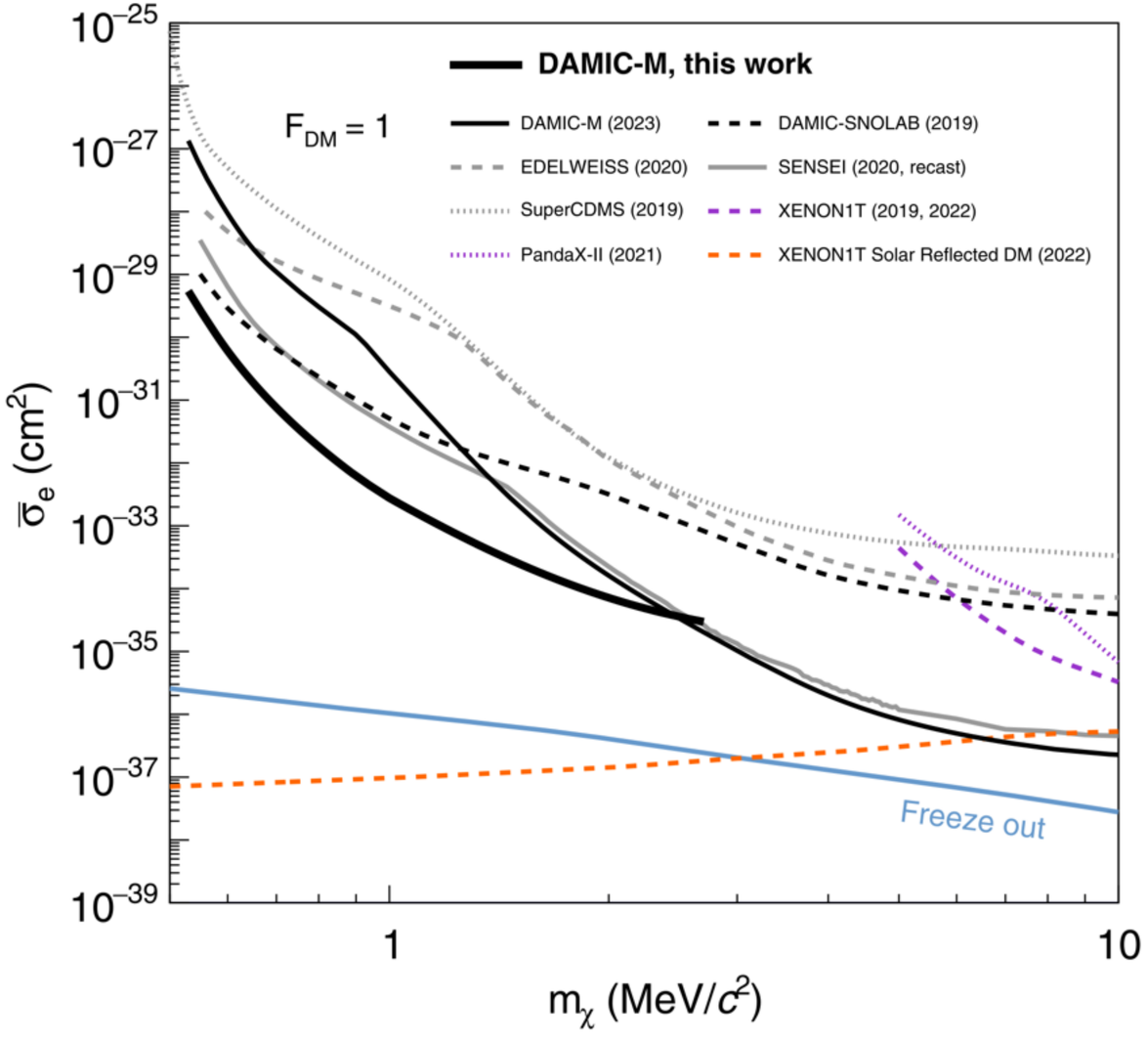
DM-e Scattering Analysis





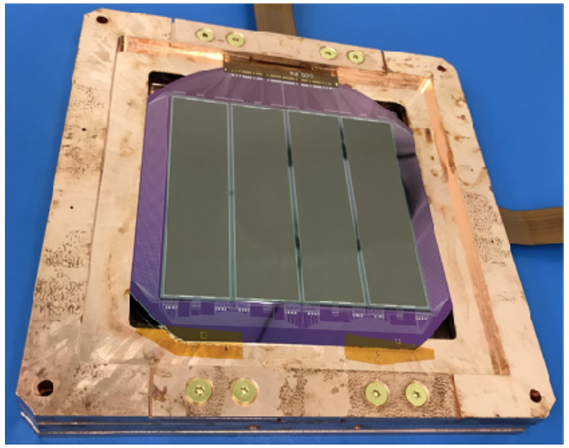
Search for Daily Modulations

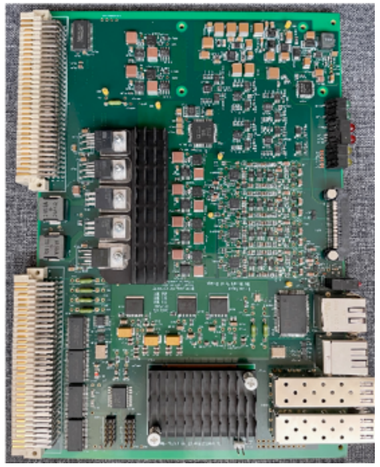


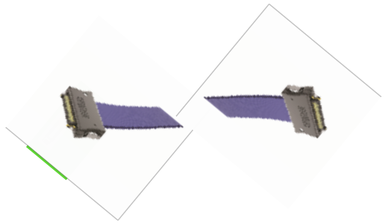


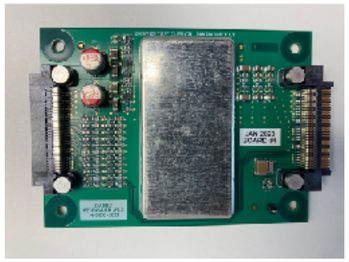
Future of LBC

- Installation of new CCD Modules
- Installation Installation of low noise DAMIC-M electronics with custom design and Firmware
- We continue to commission CCDs to reduce the readout noise and dark current
- We have achieved a background rate of 6.7 dru







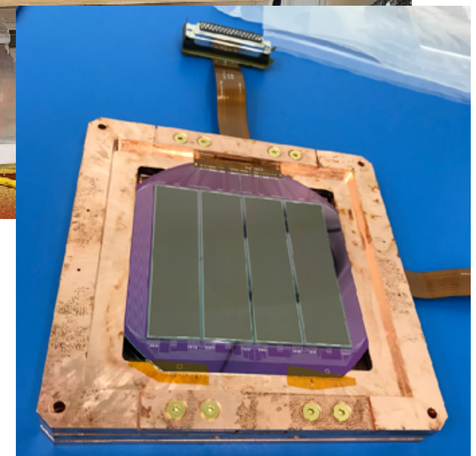


New Paper on LBC prepared for JINST
arXiv:2407.17872

Progress on DAMIC-M

University of Washington, Seattle

- CCDs shipped from SNOLAB to UW for wire-bonding to CCD Pitch Adapter for DAMIC-M
- Stored Underground at UW with custom Nitrogen gas plumbing

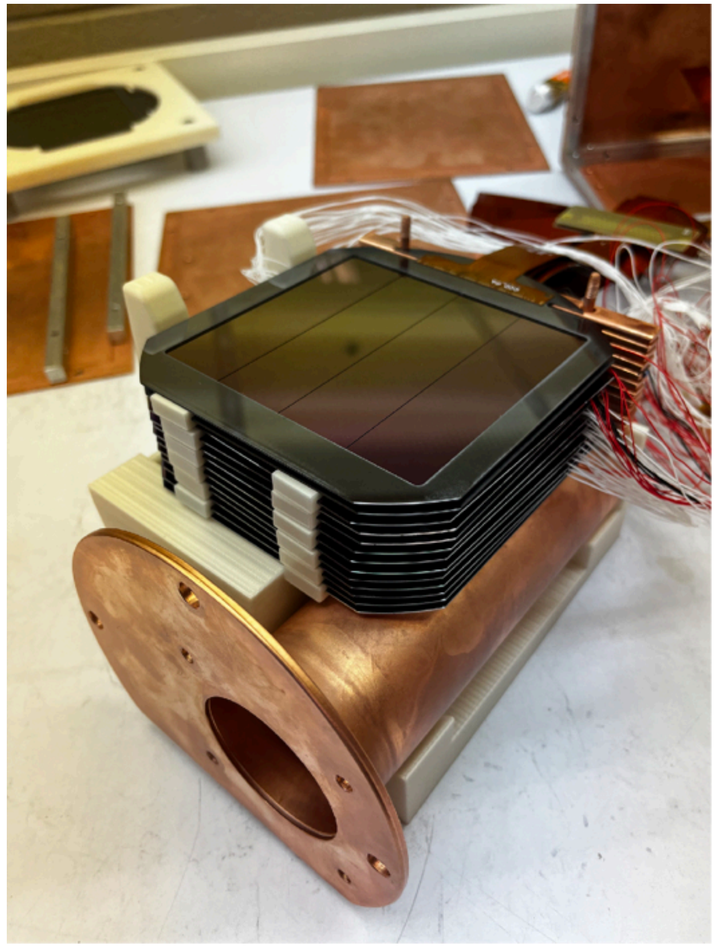


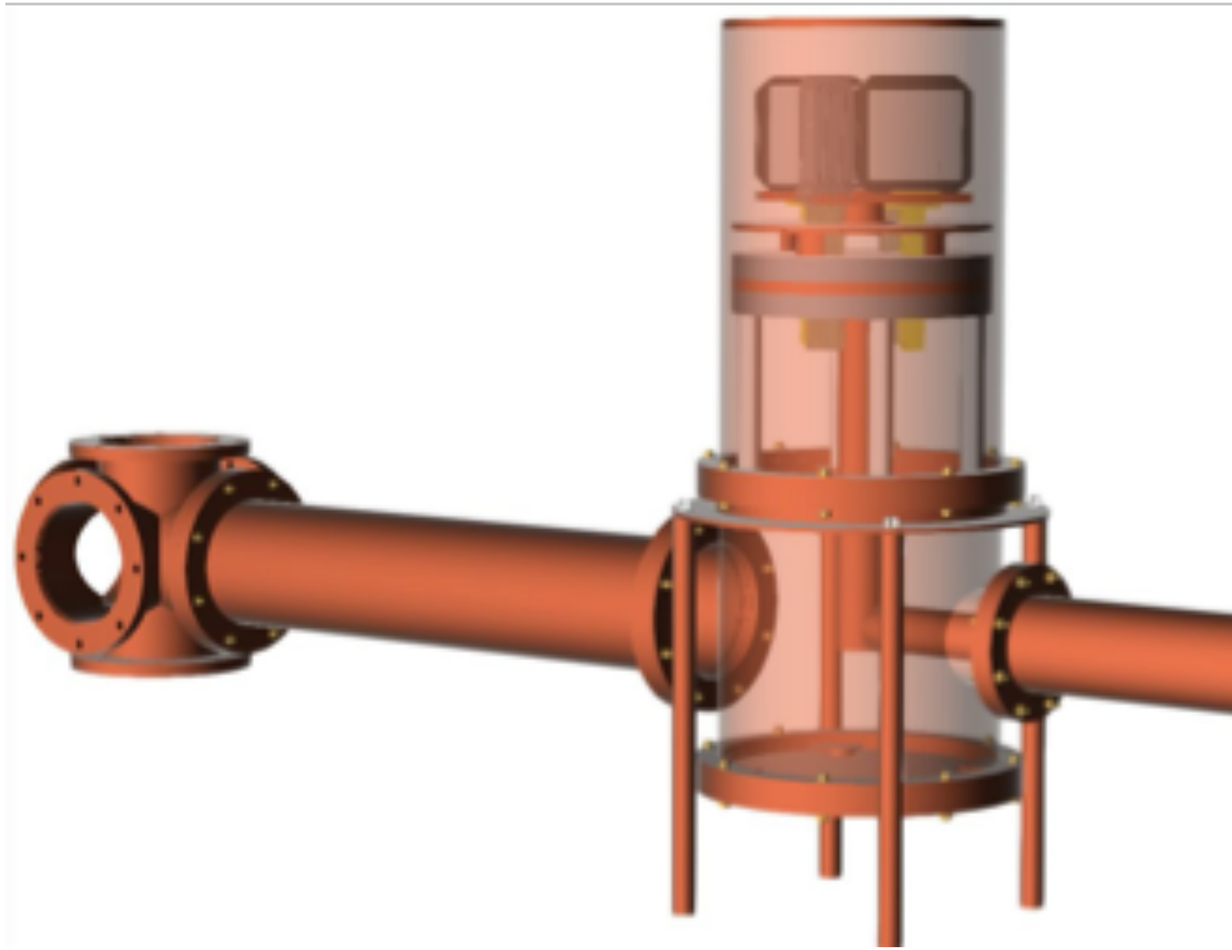
Commissioning of CCDs for DAMIC-M

University of Washington, Seattle

- 2 separate test chambers have been commissioned at UW for the testing and characterization
- Only CCDs that pass our criteria will be used in DAMIC-M

Installation of DAMIC-M by the end of the year





The DAMIC-M Collaboration

https://damic.uchicago.edu/

European Research Council
Established by the European Commission