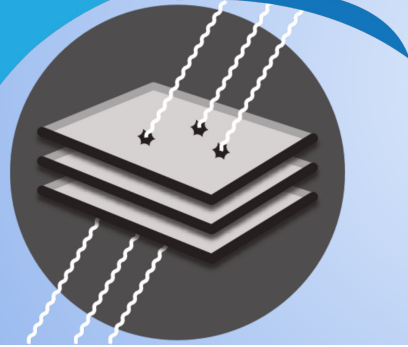


Dark Matter 2025: from the smallest to the largest scale

DAMIC-M



# Dark Matter direct detection with the DAMIC-M experiment

Carlos Centeno Lorca  
on behalf of the DAMIC-M collaboration



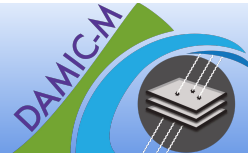
Instituto de Física de Cantabria



CSICUC

Universidad  
de Cantabria

# Overview

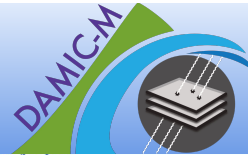


- What is **DAMIC-M**?
  - DAMIC-M CCDs
  - Detector specifications
- DAMIC-M prototype, **LBC**
  - LBC science run
  - Analysis
  - Probing benchmark models of hidden sector DM candidates!

## The DAMIC-M Collaboration



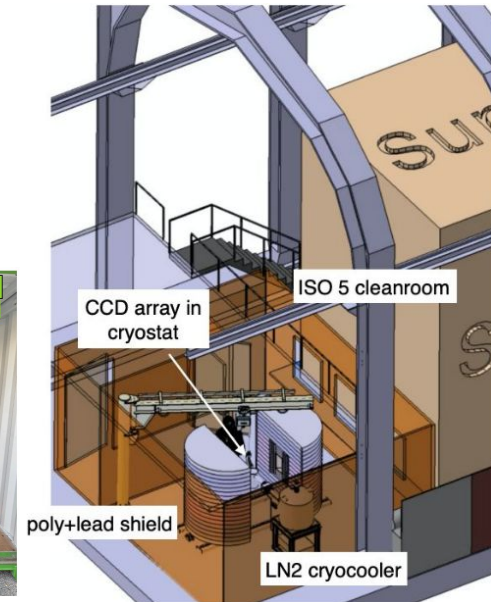
# DArk Matter In CCDs at Modane



The experiment is located at the **Laboratoire Souterrain de Modane (LSM)**.

## Physics goals:

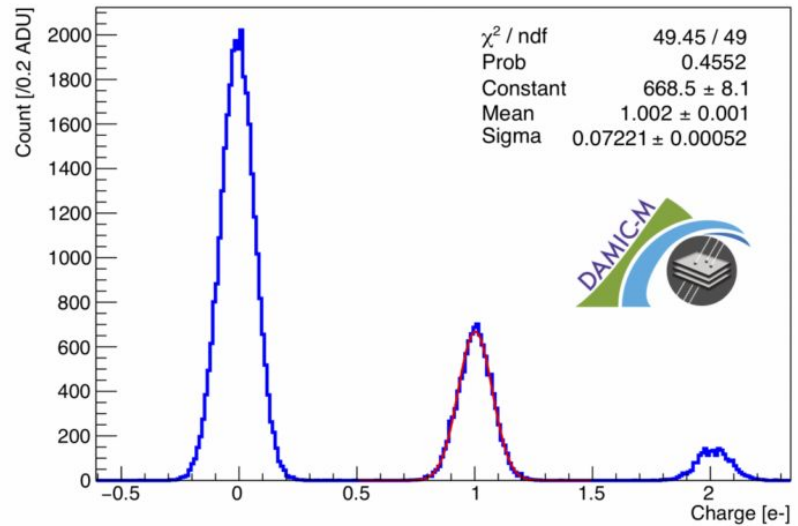
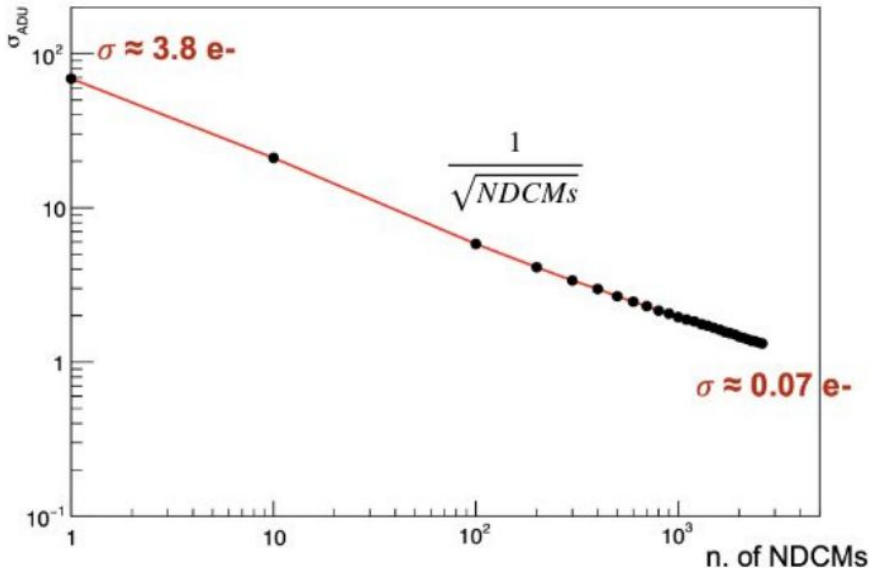
- Detect **Light DM** (WIMP, hidden sector) signals via interaction with Si nucleus or e- in the bulk of **Skipper CCDs**.
- Achieve **<1 dru** background rate (1 differential rate unit = 1 event/keV/kg/day).
- Operate ionization detector with **O(eVee) threshold**.



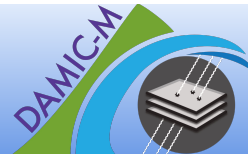


# Skipper CCDs

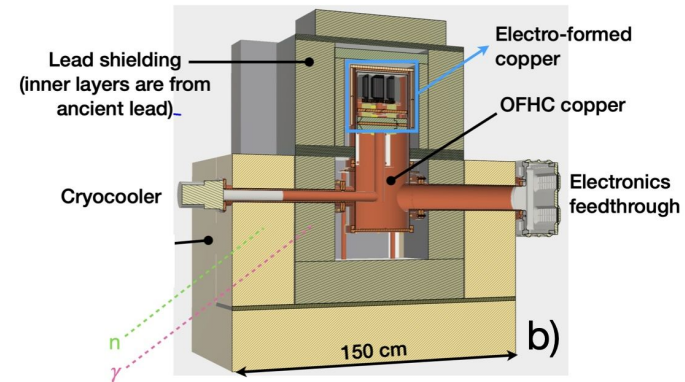
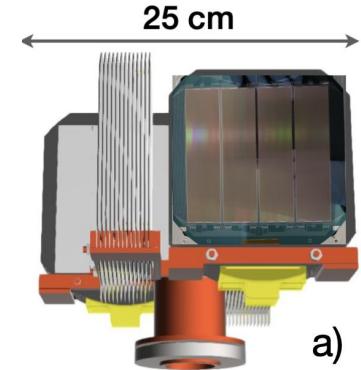
- Charges in output node read by amplifier N times allow for **single electron resolution**.
- Readout noise **decrease** by a factor  $1/\sqrt{N}$ .



# DAMIC-M detector specifications



- Array of **208 skipper CCDs** for kg-scale mass with **0.7** kilograms of sensitive mass.
- CCD specifications:
  - thickness of 675  $\mu\text{m}$ .
  - 3.3g of mass
  - 6000x1500 pixels
- Operation at  **$\sim 130\text{K}$**
- **$< 1$  dru** background rate
- **1 kg-year exposure** to probe hidden-sector benchmarks over a wide range of masses.

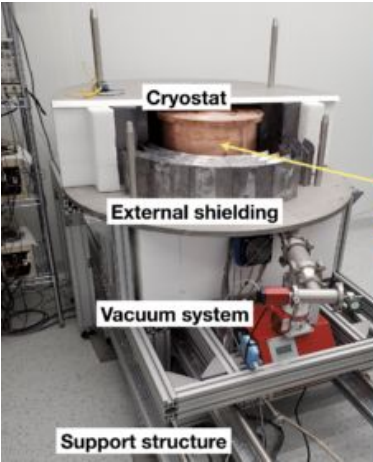
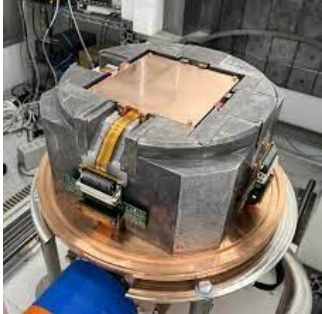


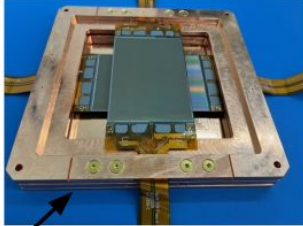
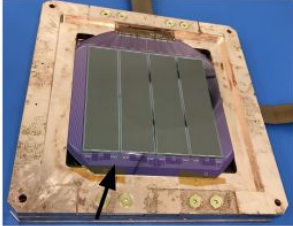
# Low Background Chamber

DAMIC-M prototype at LSM operating since February 2022.

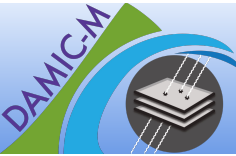
Objectives:

- Characterize DAMIC-M components in a low background environment (~5 d.r.u).
- Integration/operation of DAMIC-M electronics.
- First science results
  - DM-electron scattering search
  - Daily modulation search
  - **Probing benchmark models of hidden sector DM candidates!**



<i>Setup 1</i>	<i>Upgrade - Setup 2</i>
2 skipper CCDs 4k x 6k pix (18 g)	8 skipper CCDs 1.5k x 6k pix (26.4 g)
	
Cu box ↑ krypton cable	DAMIC-M Module= 1 pitch adapter, 4 CCDs

# LBC Data-Taking



## Setup 1: 2 skipper CCDs 4k x 6k pix (18g)

Science run 1: May-Ago 2022

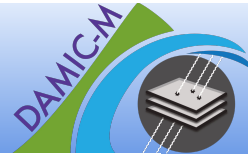
- **Read out** with 2 amplifiers per CCD
- **Binning:** 10 pix x 10 pix
- **Temperature:** ~110 K
- **Background rate:** ~12.5 d.r.u
- Commercial electronics
- **Resolution** = 0.2e- (< 1eV) at 650 skips
- **Dark Current (DC)** = 4.5E-3 e-/pixel/day
- **Exposure:** 85.2 gr-day

## Setup 2: 8 skipper CCDs 1.5k x 6k pix (26.4g)

Science run 2: Oct 2024 -Jan 2025

- **Read out** with 1 amplifier per CCD
- **Binning:** 1 pix x 100 pix (hor x vert)
- **Temperature:** ~130 K
- **Background rate:** ~7 d.r.u (EFC: Canfranc)+ open shield (~15 d.r.u)
- Custom made DAMIC-M electronics
- **Resolution** = 0.16e- (< 1eV) at 500 skips
- **Dark current (DC)**= 1.2-1.6E-4 e-/pixel/day
- **Exposure:** 1.3 kg-day

# Pattern analysis with LBC science run 2

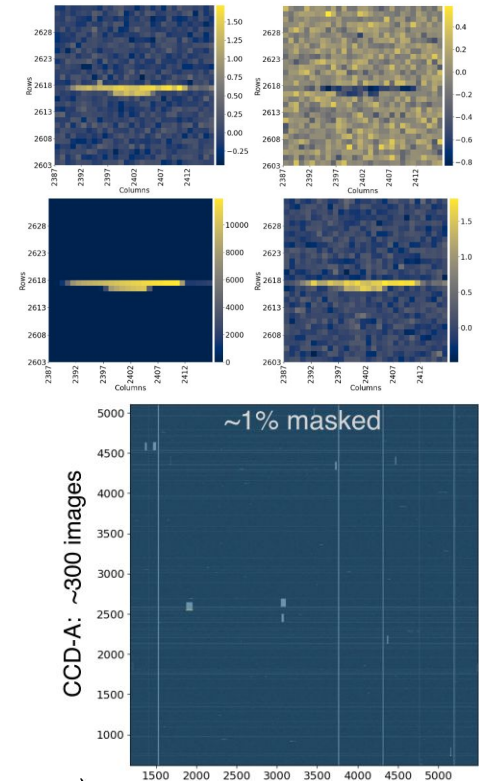


Two data sets for the analysis:

- **Unblind data (7d):** used for **masking** and to determine **data selection** procedures.
- **Blind data (77d):** for DM **search**

Cleaning procedure:

- Mask **hot regions** in CCDs (excess on the N. pixels with charge  $\geq 1e^-$ )
- Mask clusters of charged pixels ( $E_{\text{cluster}} \geq 5e^-$ ) and **cross talk** effects in CCDs of the same module.
- Mask charge-correlated pixels in CCDs of the same module & mask pixels with high variance in skipper NDCM
- **95% of data** kept for the analysis



# Pattern analysis with LBC science run 2

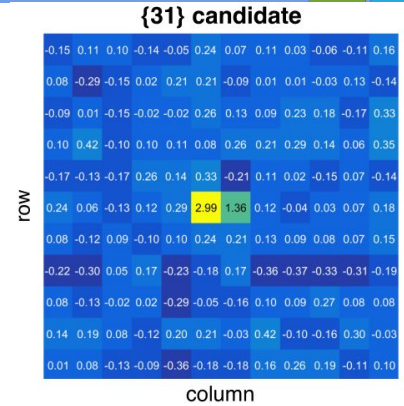
## Candidate selection:

- **Horizontal cluster** patterns that are **isolated**.
- Permutation of 2 or 3 adjacent pixels with charge **1e-,2e-,3e-**: {11},{21},{111},{31},{22},{211}

## Sources of patterns:

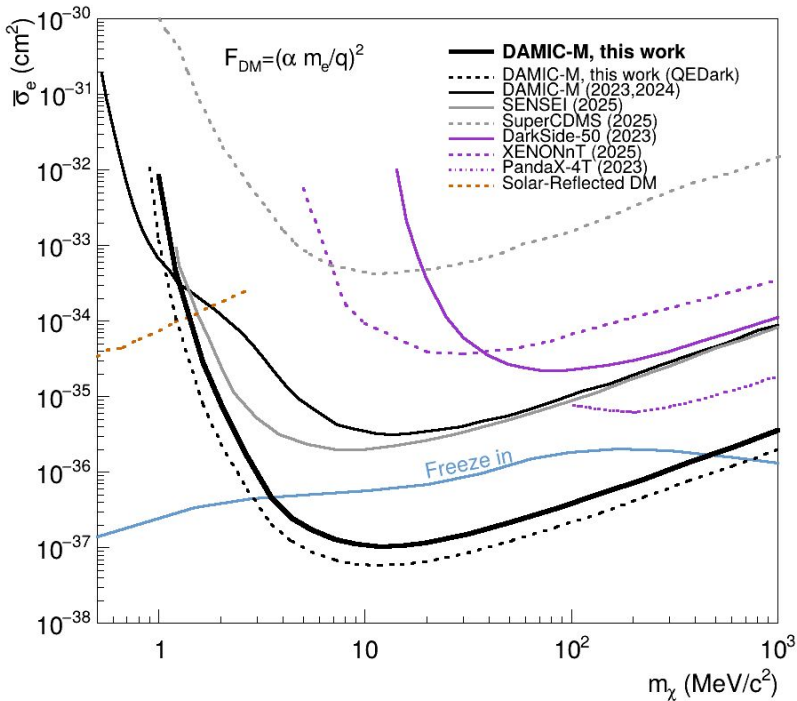
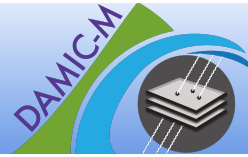
- **Radioactive BKG**: Through energy deposit and diffusion.
- **DM**: Through energy deposit and diffusion.
- **Random coincidence single e- BKG**: probability of accidental pattern  $ijk$ ,  $P_{ijk} = P_i \cdot P_j \cdot P_k$

$$L(\mu, \theta) = \prod_p \frac{(S_p(\mu) + B_p^{rc} + \theta B_p^{rad})^{D_p} e^{-(S_p(\mu) + B_p^{rc} + \theta B_p^{rad})}}{D_p!}$$



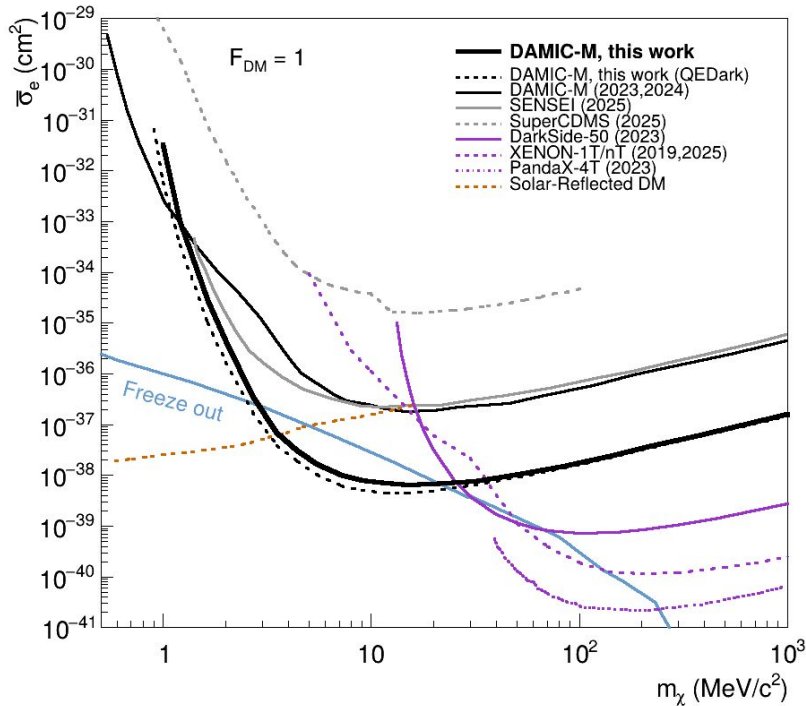
	Pattern $p$		
	{11}	{21}	{111}
$D_p$	144	0	0
$B_p^{rc}$	141.4	0.111	0.042
$B_p^{rad}$	0.039	0.039	0.016
	{31}	{22}	{211}
$D_p$	1	0	0
$B_p^{rc}$	0.019	$2.5 \cdot 10^{-5}$	$5.8 \cdot 10^{-5}$
$B_p^{rad}$	0.052	0.011	0.035

# Pattern analysis with LBC science run 2



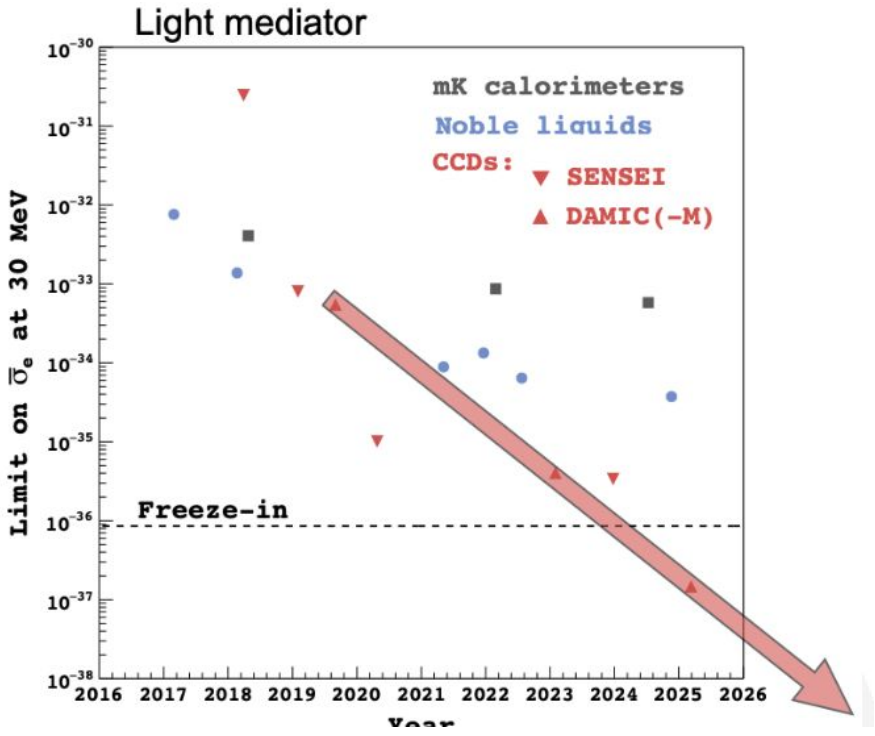
- Stringent constraints on DM particles with masses between 0.75 and 1000 MeV interacting with electrons.
- Exclusion of benchmark scenarios, for large ranges of DM masses below 1 GeV, where hidden-sector particles are produced as a major component of DM in the Universe through the freeze-in mechanism.
- Lowering the cross section opens the possibility to find candidates that won't be responsible for more dark matter than what we observe today.

# Pattern analysis with LBC science run 2



- Stringent constraints on DM particles with masses between 0.75 and 1000 MeV interacting with electrons.
- Exclusion of benchmark scenarios, for large ranges of DM masses below 1 GeV, where hidden-sector particles are produced as a major component of DM in the Universe through the freeze-out mechanism.
- Excluding the candidates above the freeze-out model means excluding all the allowed candidates. This implies that the dark matter is either in another region of the parameter space or the freeze-out model should be different.

# Conclusions



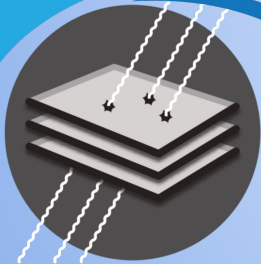
- DAMIC-M prototype detector (1.3 kg-day) excludes for the 1st time benchmark models of hidden-sector DM over wide range of sub-GeV masses. This is a significant milestone for low-threshold detector technology and the search for DM!
- DAMIC-M is currently in the construction phase at LSM so look-out for the dark matter models we can explore with 1kg-year!

# Thank you for your attention!



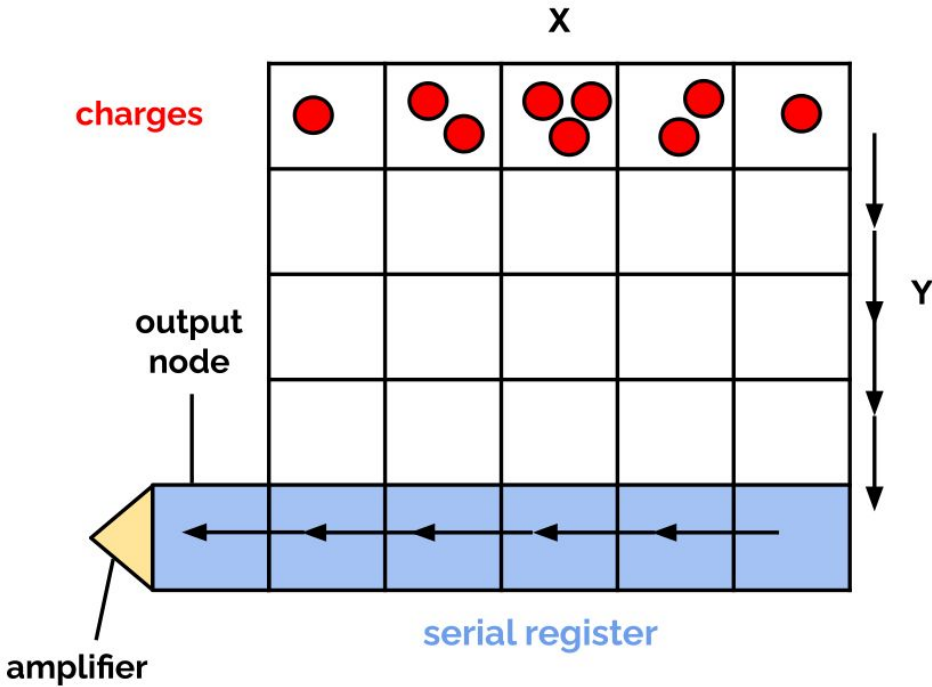
# Back up slides

DAMIC-M

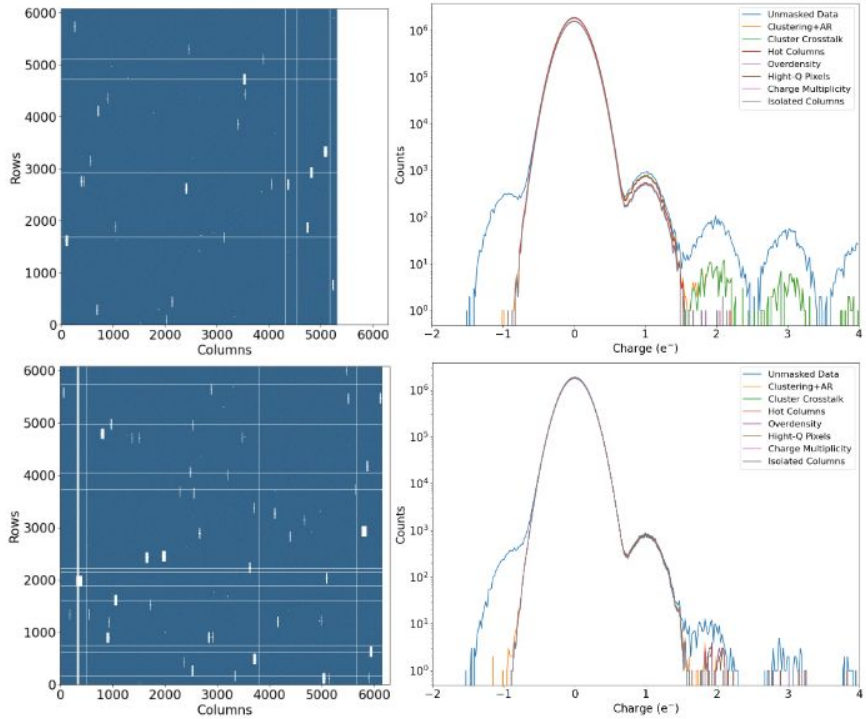


# CCD Readout

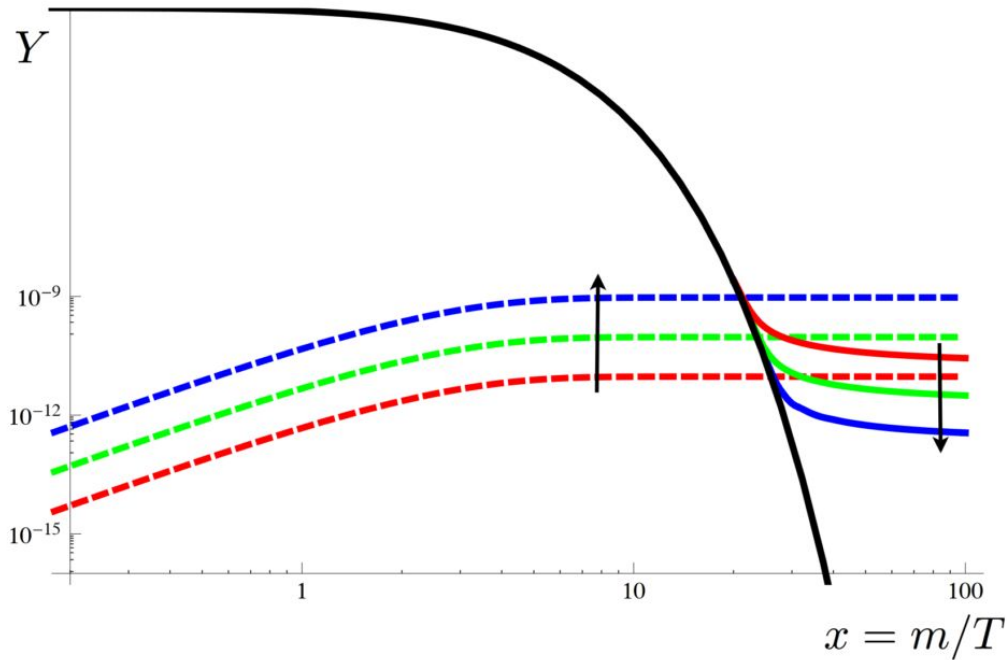
- Charges in one row are moved to the following row (Y direction).
- Charges in the serial register move pixel by pixel in the X direction.
- Charges in the output node are read by the amplifier, for DAMIC-M is a **skipper amplifier**.
  - Skips = Non Destructive Repetitive Charge Measurements (NDCMs).



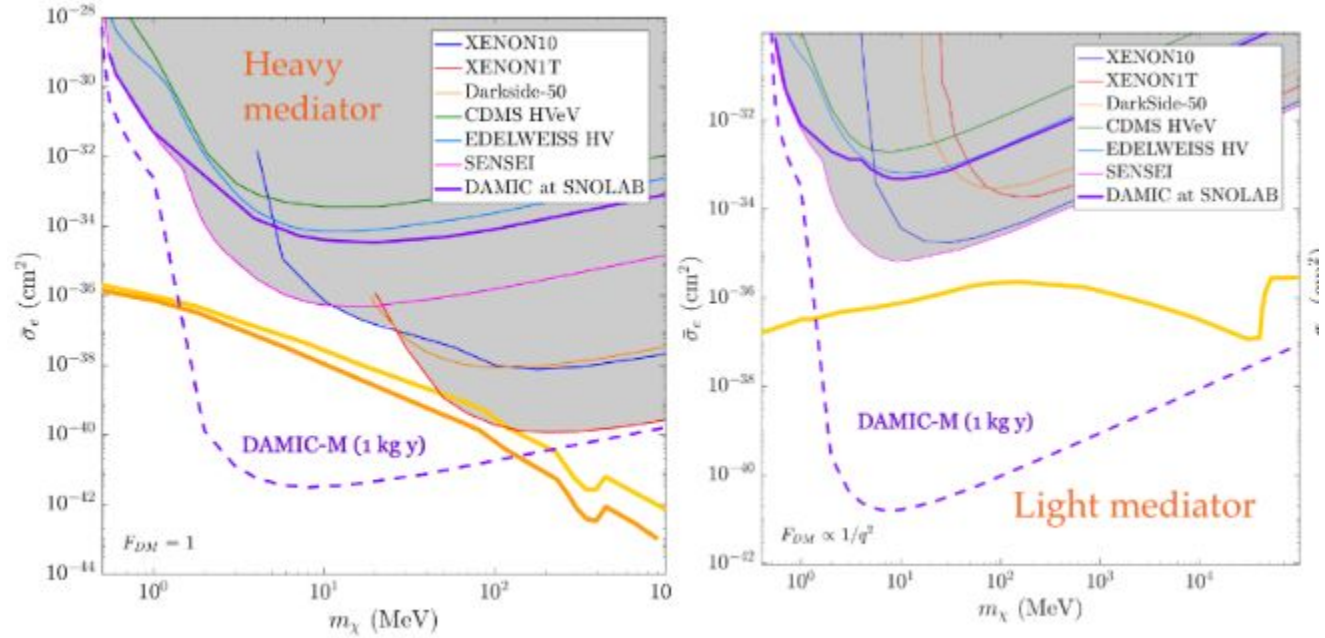
# Charge distribution



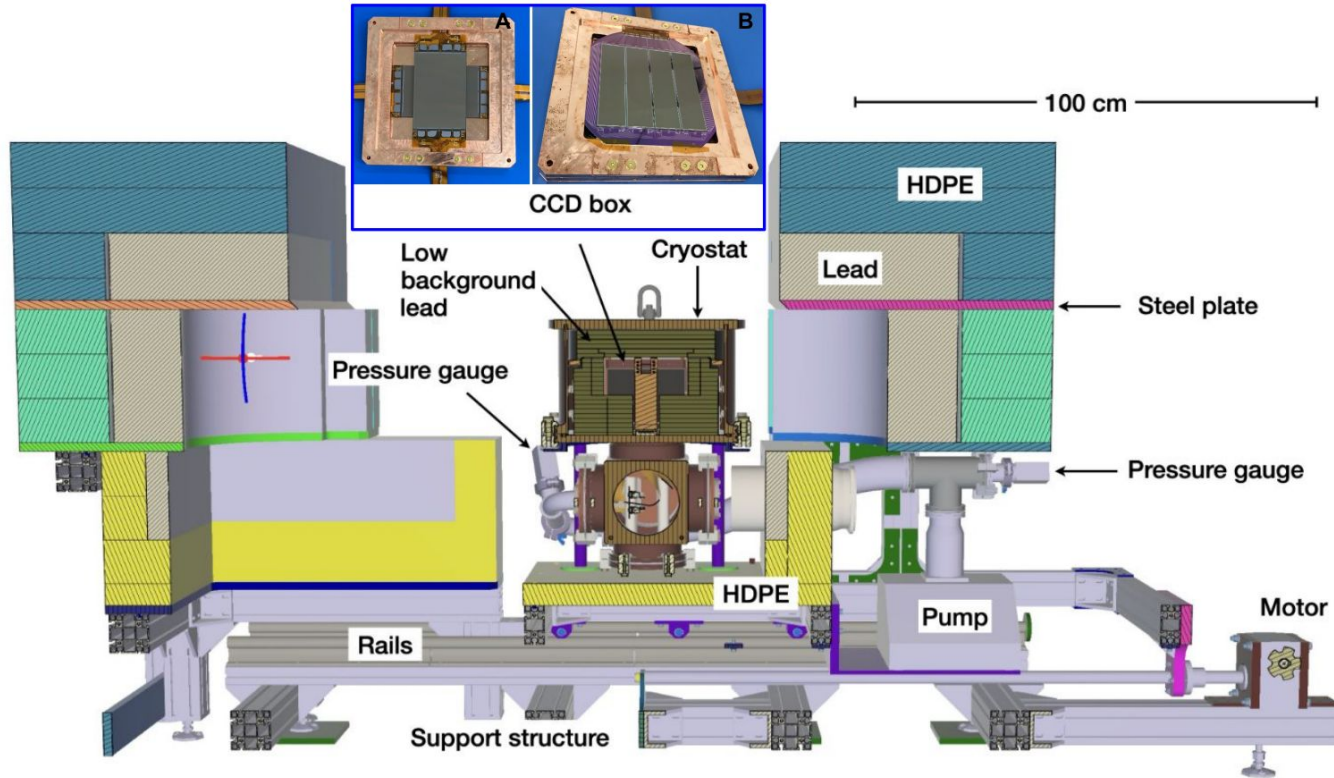
# Freeze-in and Freeze-out



# Predicted DAMIC-M limit

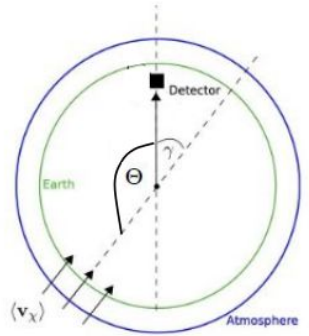
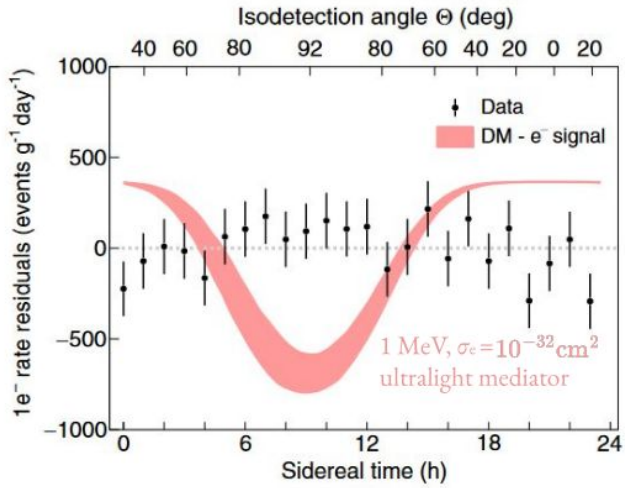
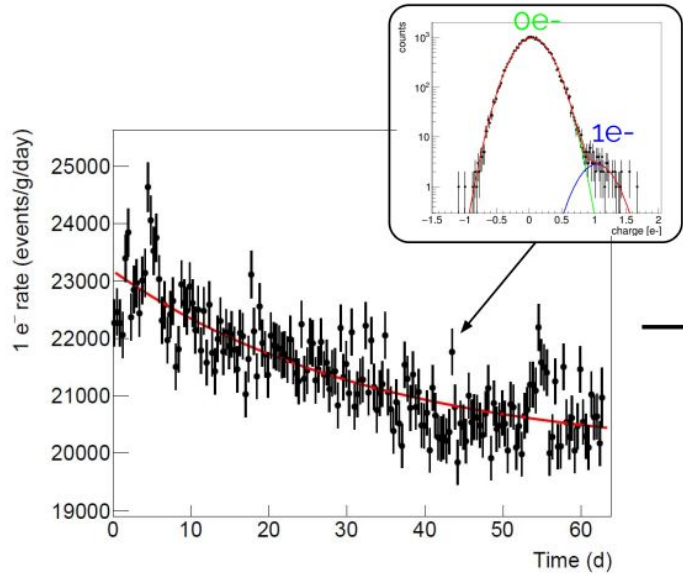


# LBC layout



# Daily modulation

Time dependent analysis to look for a daily modulated DM signal above an unmodulated background.



DM signal simulated with the VERNE code