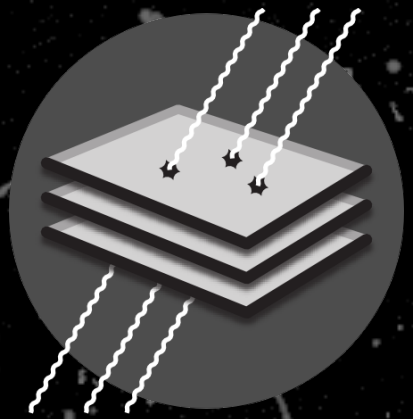

DAMIC
(Dark Matter in CCDs)

CHIPP Roadmap meeting

Jan. 18th 2023

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U. Zürich

PHYSIK INSTITUT
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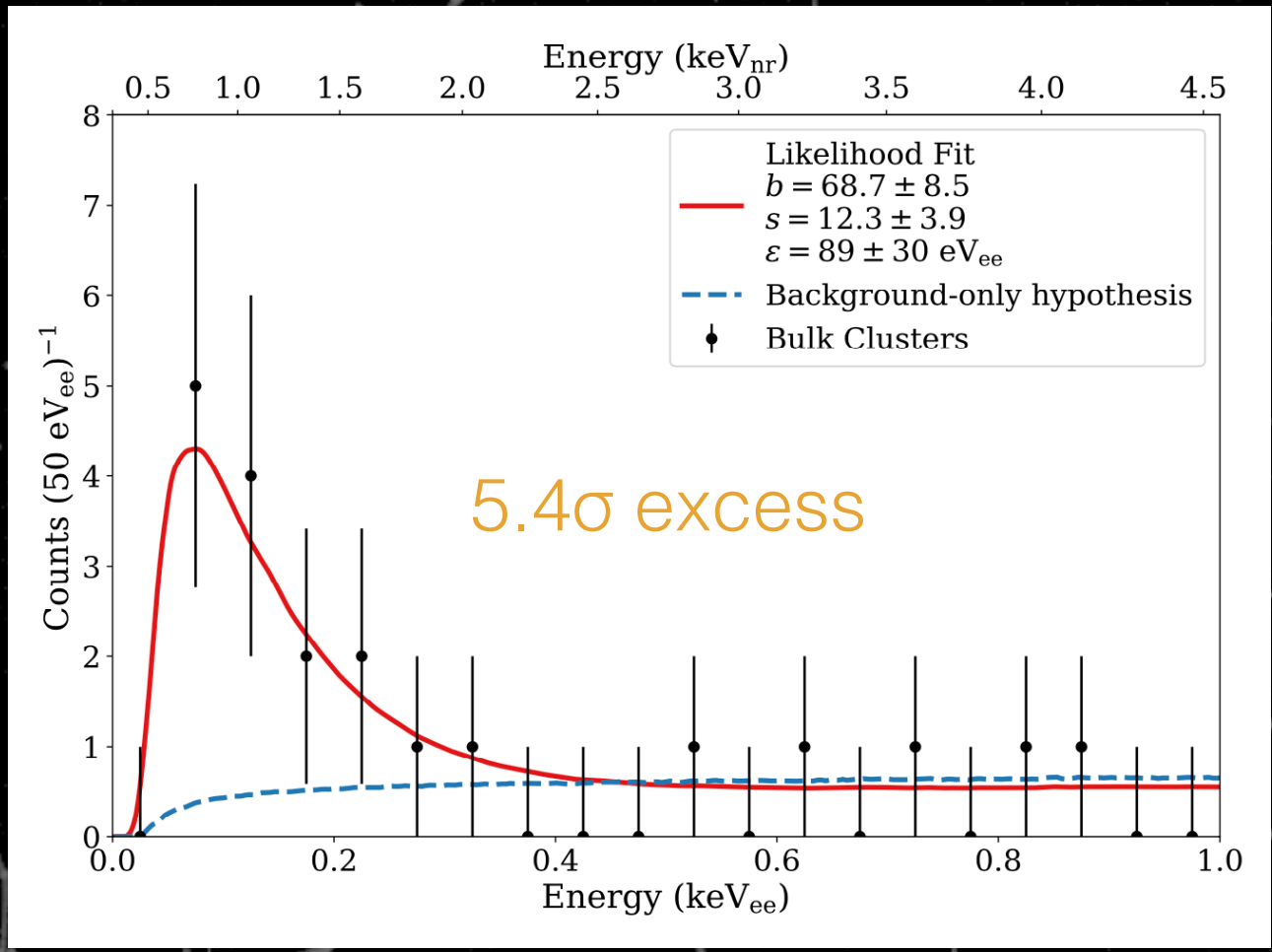
DAMIC experiment generations

- 2010-2011 : DAMIC first run at Fermilab
  - Best DM limits for WIMPs below 4 GeV
- 2015- now : DAMIC @ SNOLAB
  - Hidden photon DM search
    - 2017 : First eV-scale results
    - 2019 : Result reported today
  - WIMP search
    - 2016 : First result
    - 2020 : Low-energy excess observed (PRL 125 (2020) 241803)
    - 2023 : Low-energy excess confirmed with skipper CCD (2306.01717)
- 2023 : DAMIC-M @Modane
  - Single e-h pair resolution (achieved)
  - Test of prototype CCDs in 2021-2023 (LBC)
  - First constraints on DM interacting with electrons (PRL 130 (2023) 17, 171003)

DAMIC @ SNOLAB excess

Best fit cross-section for spin-independent WIMP scattering: M_{DM} = 2.5 GeV @ 3E-40 cm^2

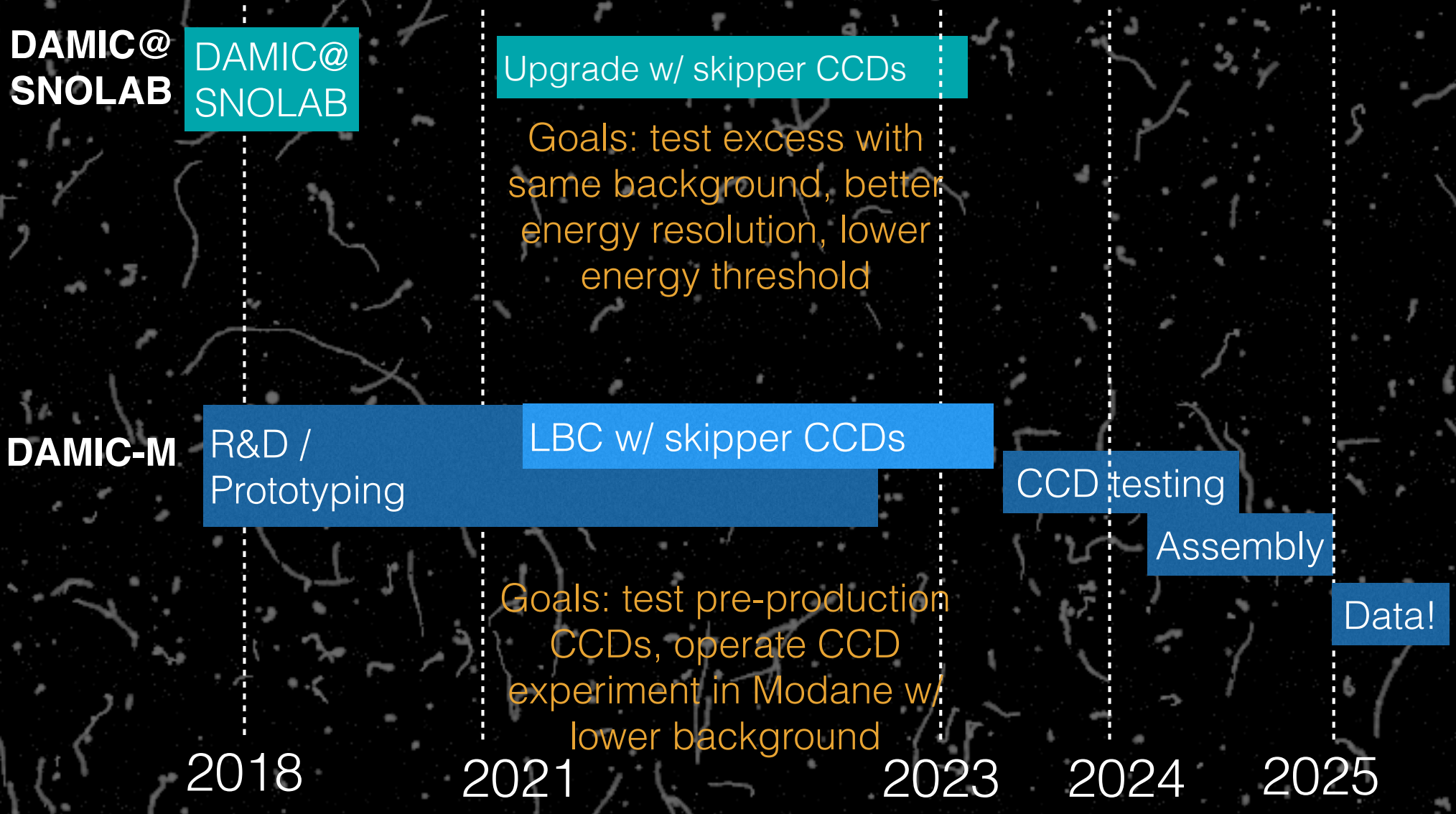
However, this signal interpretation is excluded by other experiments (Darkside-50 [1], CDMSlite [2])



Possibilities : quenching factor calibration, alternate WIMP models ?

1 arXiv:2207.11966
2 arXiv:1808.09098

Timeline


DAMIC@ SNOLAB
DAMIC@ SNOLAB
Upgrade w/ skipper CCDs
Goals: test excess with same background, better energy resolution, lower energy threshold
DAMIC-M
R&D / Prototyping
LBC w/ skipper CCDs
CCD testing
Assembly
Data!
Goals: test pre-production CCDs, operate CCD experiment in Modane w/ lower background
2018
2021
2023
2024
2025

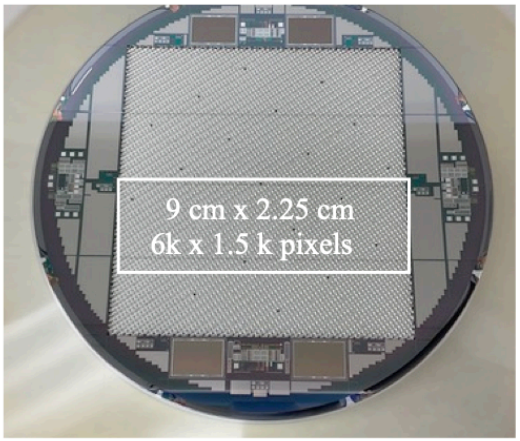
DAMIC Future

- DAMIC @ SNOLAB
  - New tests of excess planned 2024-2025
- DAMIC-M
  - Additional publications with DAMIC-M LBC
  - Detector installation & commissioning 2024-2025
  - Operation 2025
- OSCURA
  - Next generation CCD experiment
  - Funding by U.S. DOE Dark Matter New Initiatives (DMNI)
  - ~2028

DArk Matter In CCDs at Modane

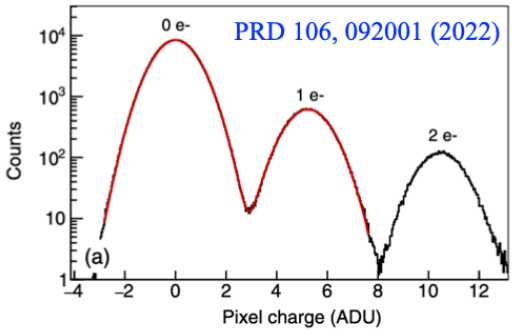
DAMIC-M in a nutshell

- detect nuclear and electron recoils to search for light dark matter candidates (eV to GeV), particularly sensitive to "hidden-sector" dark matter candidates which interact with electrons
- target exposure ~ **1 kg yr** with CCD detectors (builds on the success of DAMIC at SNOLAB, M. Traina TAUP 2023)
- **single electron resolution** to ionization signals, **2-3 electron threshold** (~eV)
- low background rate goal of **~0.1 dru**
- scheduled for installation at the Laboratoire Souterrain de Modane (LSM) end of 2024

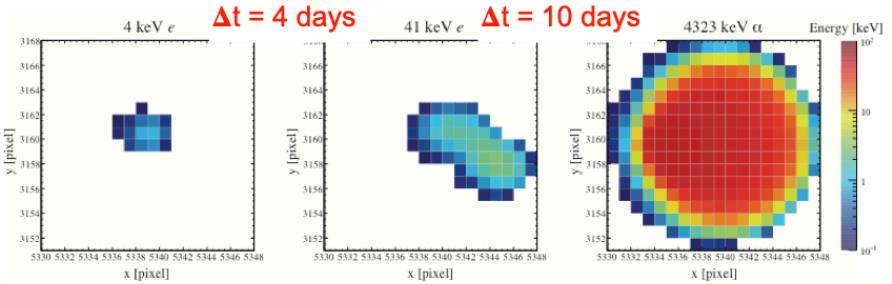


DAMIC-M CCDs

Skipper CCDs with multiple non-destructive charge measurement



measurement (and rejection) of surface and bulk backgrounds: decay chains detected as spatially correlated, time separated energy clusters

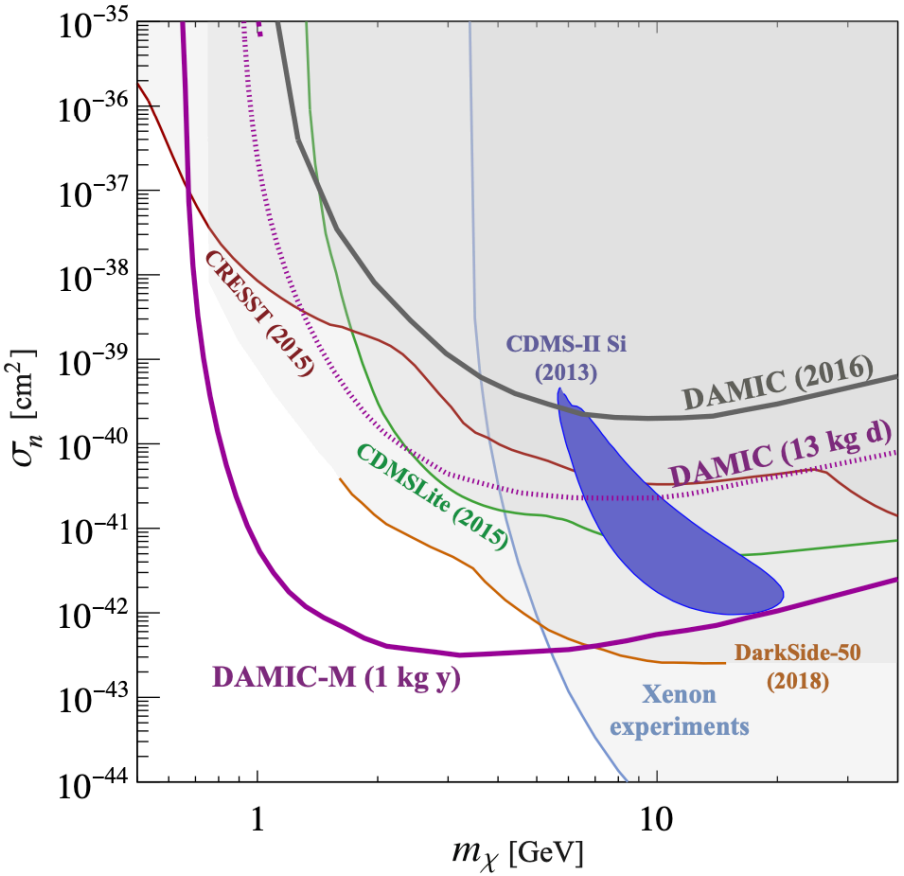


candidate ^{210}Pb decay chain

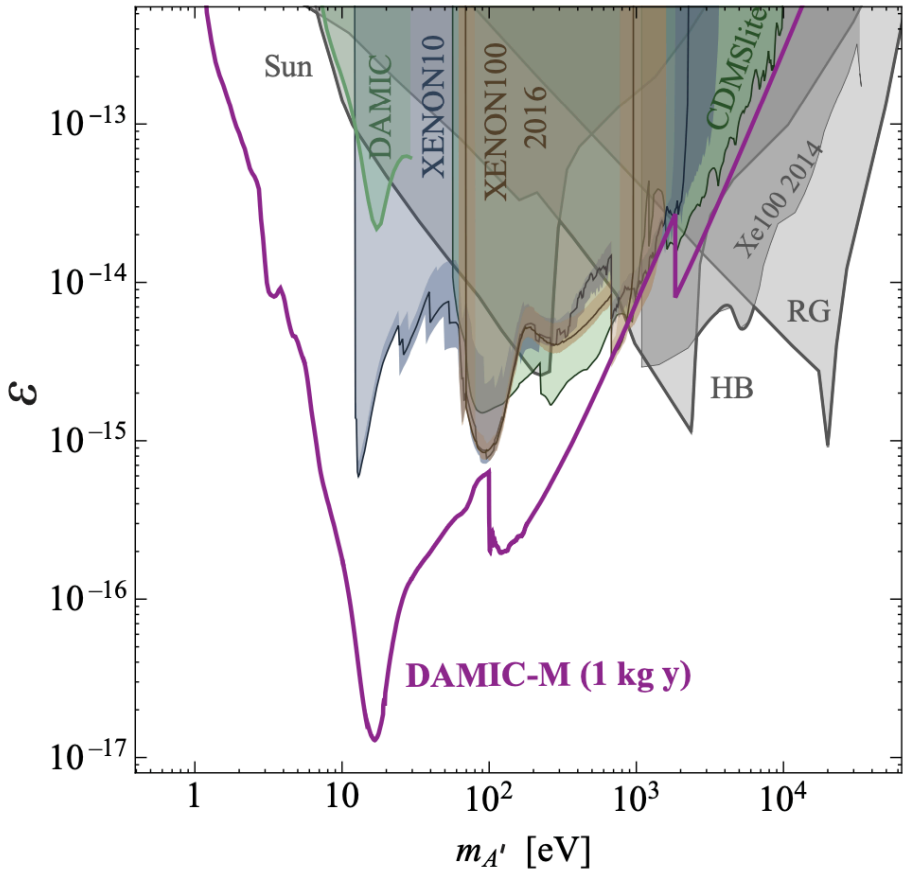
2

DAMIC-M reach

WIMP nuclear recoil search



Hidden photon search



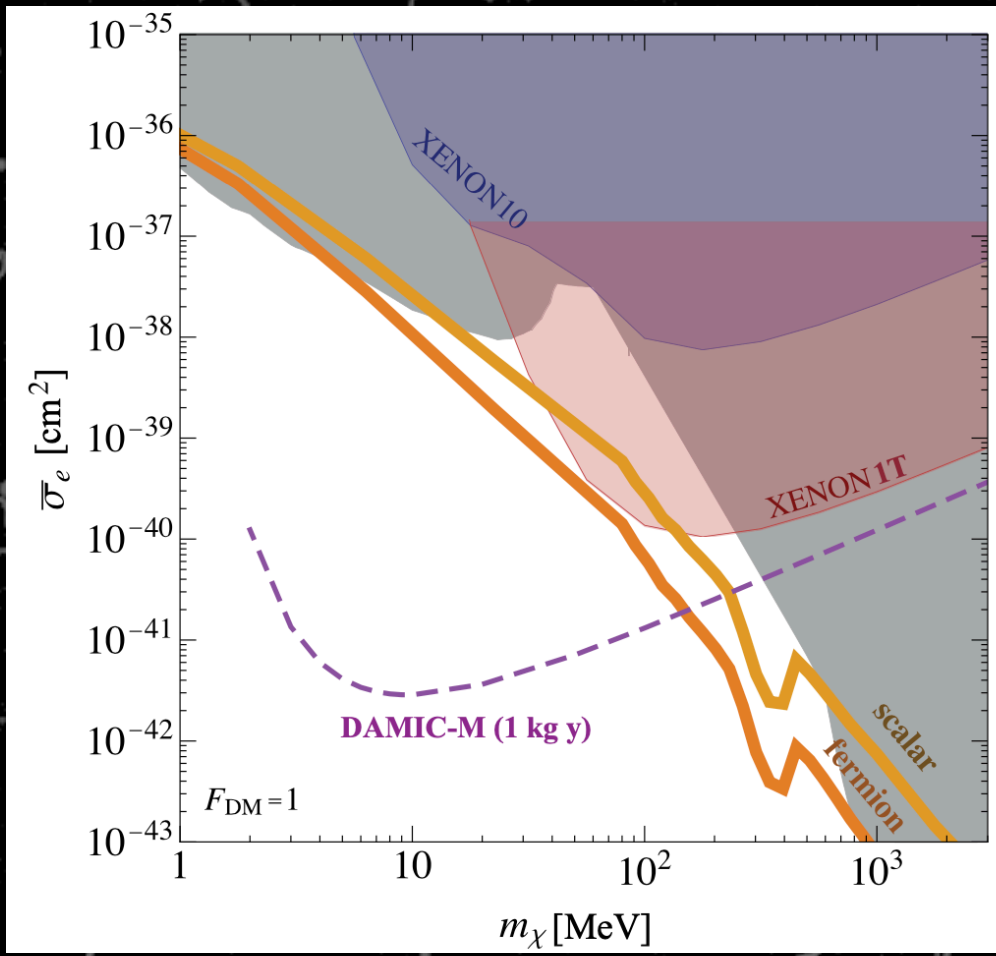
DAMIC-M reach for nuclear recoils of WIMP

As a function of kinetic mixing parameter (A' with γ) assuming A' constitutes all dark matter

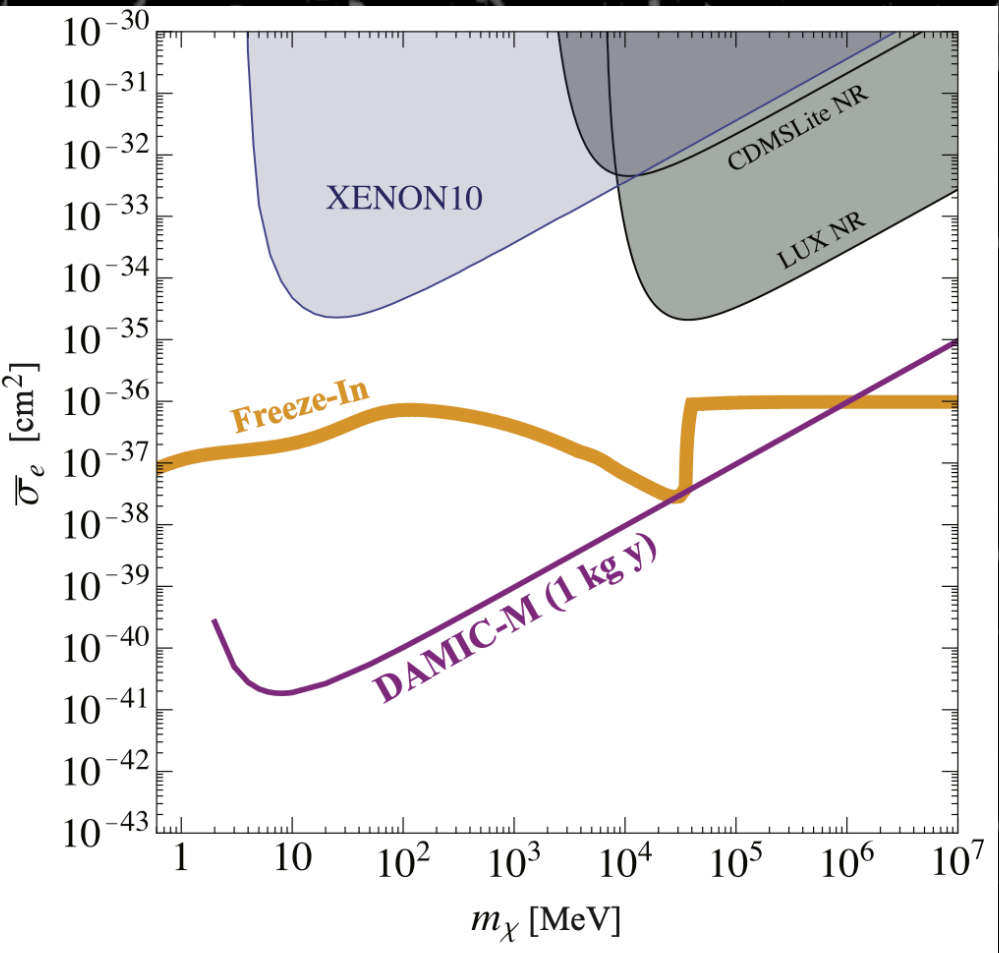
DAMIC-M reach

DM-electron cross-sections

(heavy mediator >> keV)



(light mediator << keV)



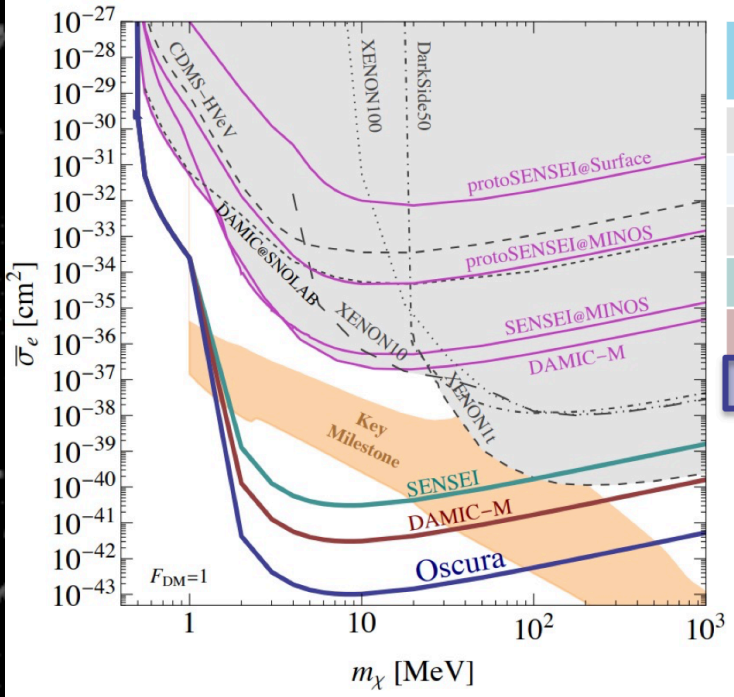
Weakly-coupled χ does not reach thermal equilibrium, and "freezes in"

Orange are theoretical predictions

OSCURA

Skipper-CCDs for direct DM search

World best limits for sub-GeV DM candidates with this technology → Ongoing program



Experiment	Mass [kg]	#CCDs	Radiation bkgd [dru]	Instrumental bkgd [e-/pix/day]	Commissioning
SENSEI @ MINOS	~0.002	1	3400	1.6×10^{-4}	late-2019
DAMIC @ SNOLAB	~0.02	2	5	$\sim 3 \times 10^{-3}$	late-2021
DAMIC-M LBC	~0.02	2	~10	3×10^{-3}	late-2021
SENSEI-100	~0.1	50	10 (goal)		mid-2022
DAMIC-M	~1	200	0.1 (goal)		~2023
OSCURA	~10	20,000	0.01 (goal)	1×10^{-6} (goal)	~2028

Oscura builds on existing efforts

The challenges are to increase mass (from 10s to 10,000s CCDs) and to reduce the backgrounds (2 orders of magnitude)

Major R&D ←

UZH in DM CCD research

- DAMIC-M contributions
  - DCS system
  - Front-end electronics (PCBs & ADCs)
  - In-situ Kr83m calibration system
  - CCD testing system
- Dark-matter nuclear recoils
  - DAMIC-M cannot distinguish electronic recoils from nuclear recoils
  - UZH group pioneered a new technique for doing so
  - Based on identifying lattice defects caused by nuclear recoils
    - PhD thesis: Steven Lee (& 2210.00469)
    - "Nuclear Recoil Identification in a Scientific Charge-Coupled Device" 2309.07869
    -

Nuclear recoils

- Nuclear recoils detected as stable defects identified electronically through local increases in dark current

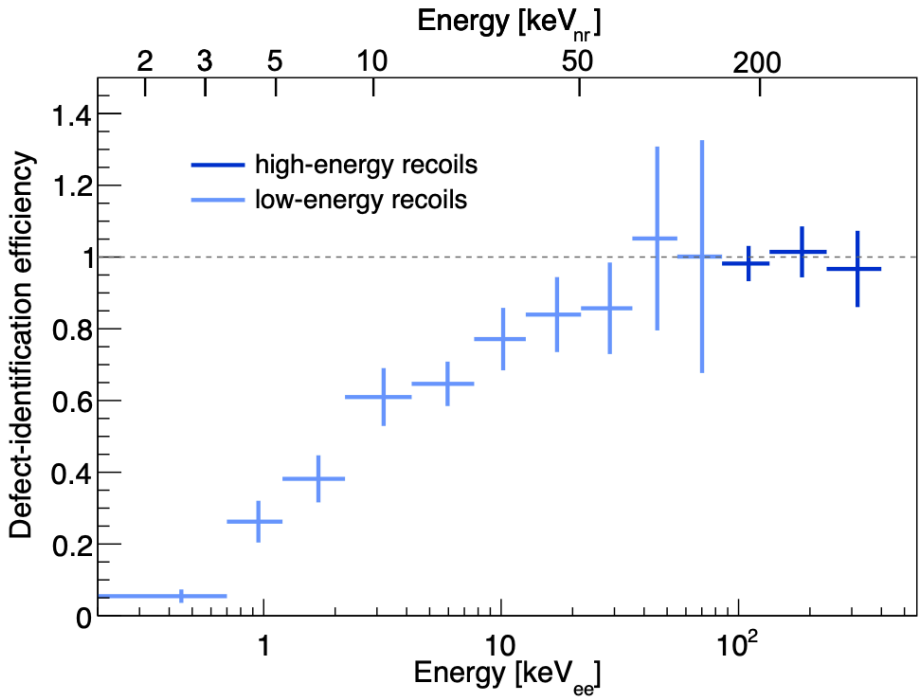


FIG. 7. Fraction of nuclear-recoil ionization events that are spatially correlated with a defect above threshold as a function of energy. The corresponding fraction for electronic recoils is $< 0.1\%$.

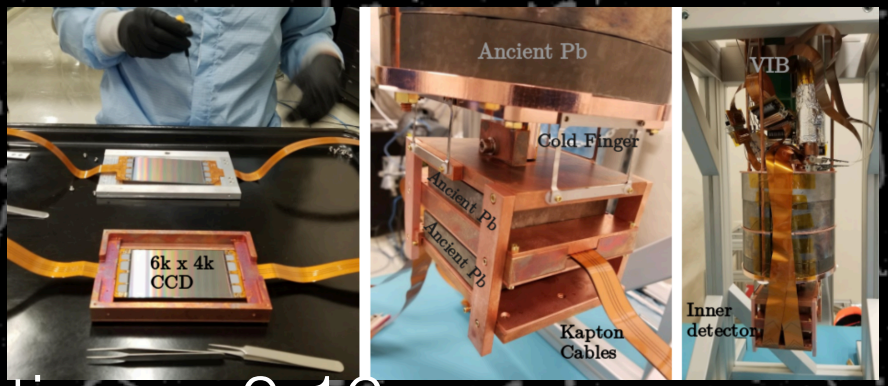
Future UZH efforts

- Focussing on nuclear recoil detection using radiation defects
- Goals
  - Establish practical techniques for stimulating and observing defects during DM experiment operation
  - Develop algorithms to improve efficiency for detection down to low energies
    - Theoretically, defects can be produced with only 20 eV recoil energy and detected with higher efficiency than through ionization
  - Possibly use laser stimulation of defects (Two Photon Absorption)
- Collaborators
  - U. Washington, CERN, IFCA
- Experiments
  - Studying effect at UZH, UW, & CERN
  - Plan to demonstrate technique in DAMIC@SNOLAB
  - Potential for use in DAMIC-M, OSCURA
  - Or dedicated experiment

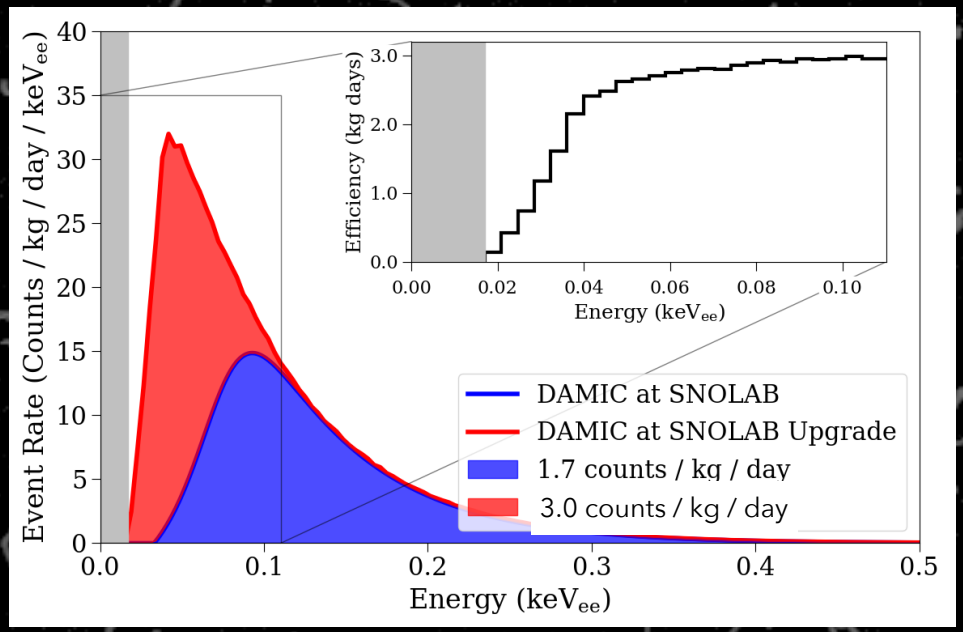
BACKUPS

Backgrounds

Upgraded DAMIC experiment

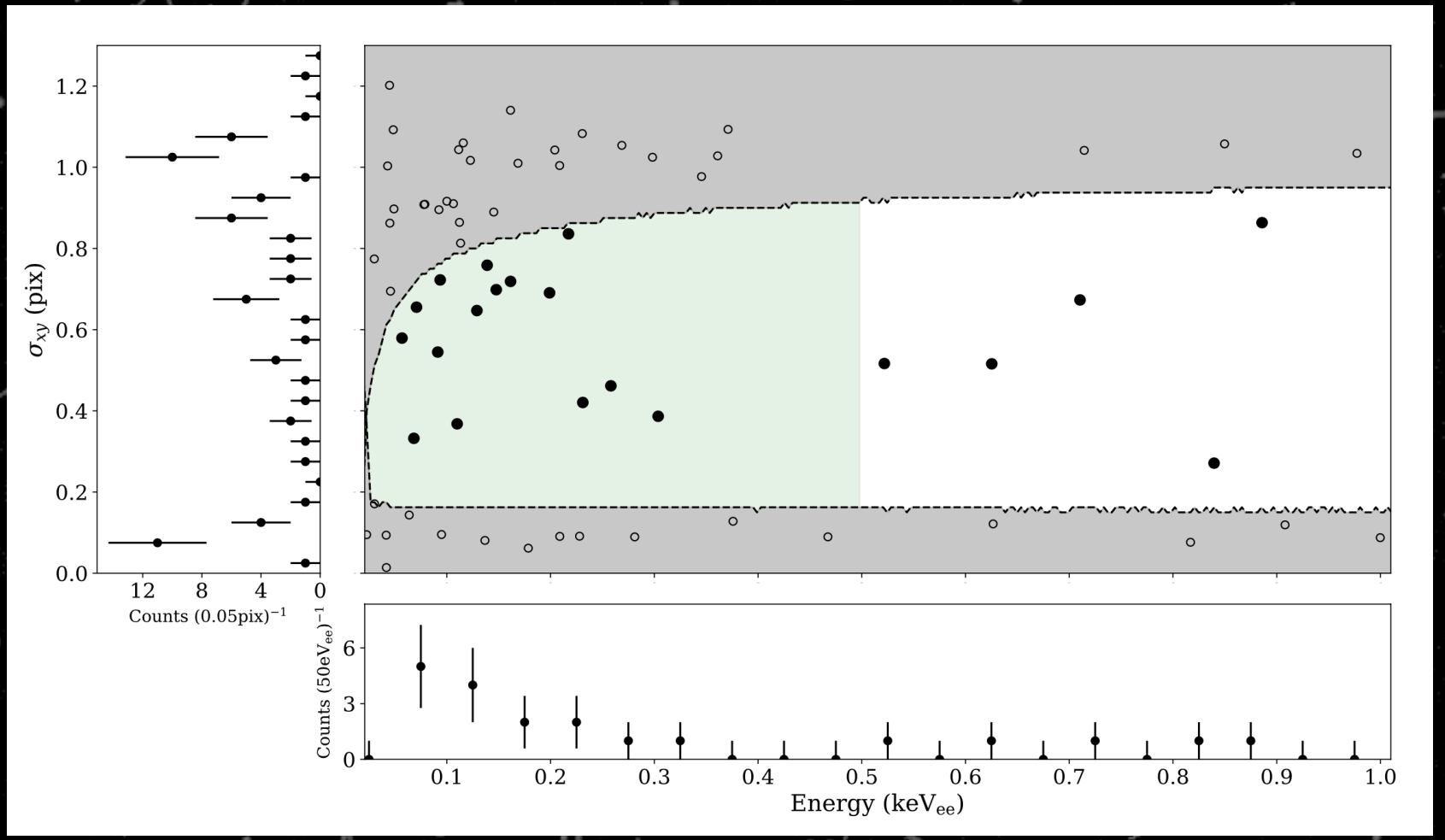


- Two 6k x 4k skipper CCDs
- Same bkg contributions
- Same bkg rate : 12 dru
- 10x lower readout noise & resolution : ~0.16 e-
- Science Run March 2022 - Jan 2023
- 4.8 kg*d exposure, 3.1 kg*d after selection
-



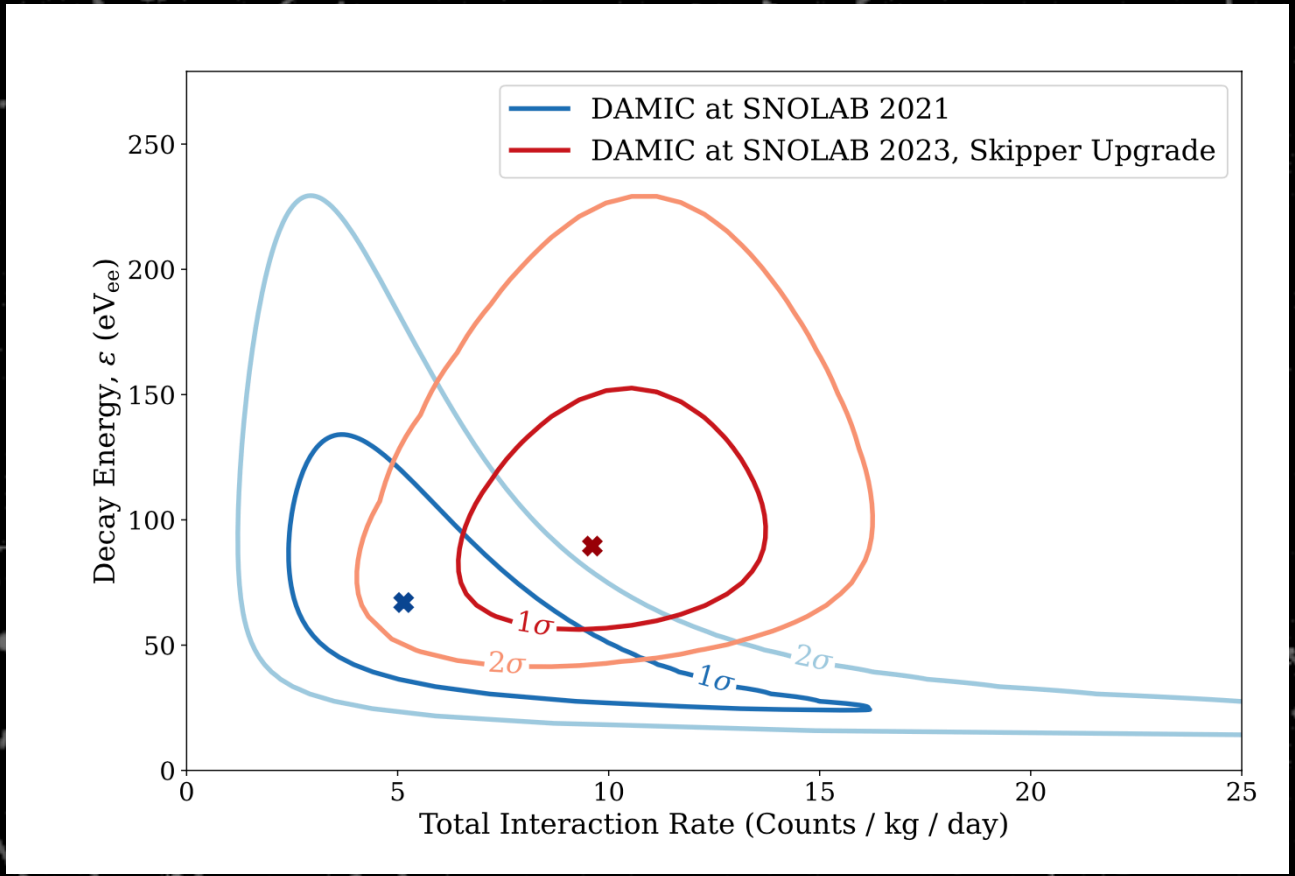
Upgrade provides twice signal efficiency due to increased acceptance at low energy

Energy vs. depth

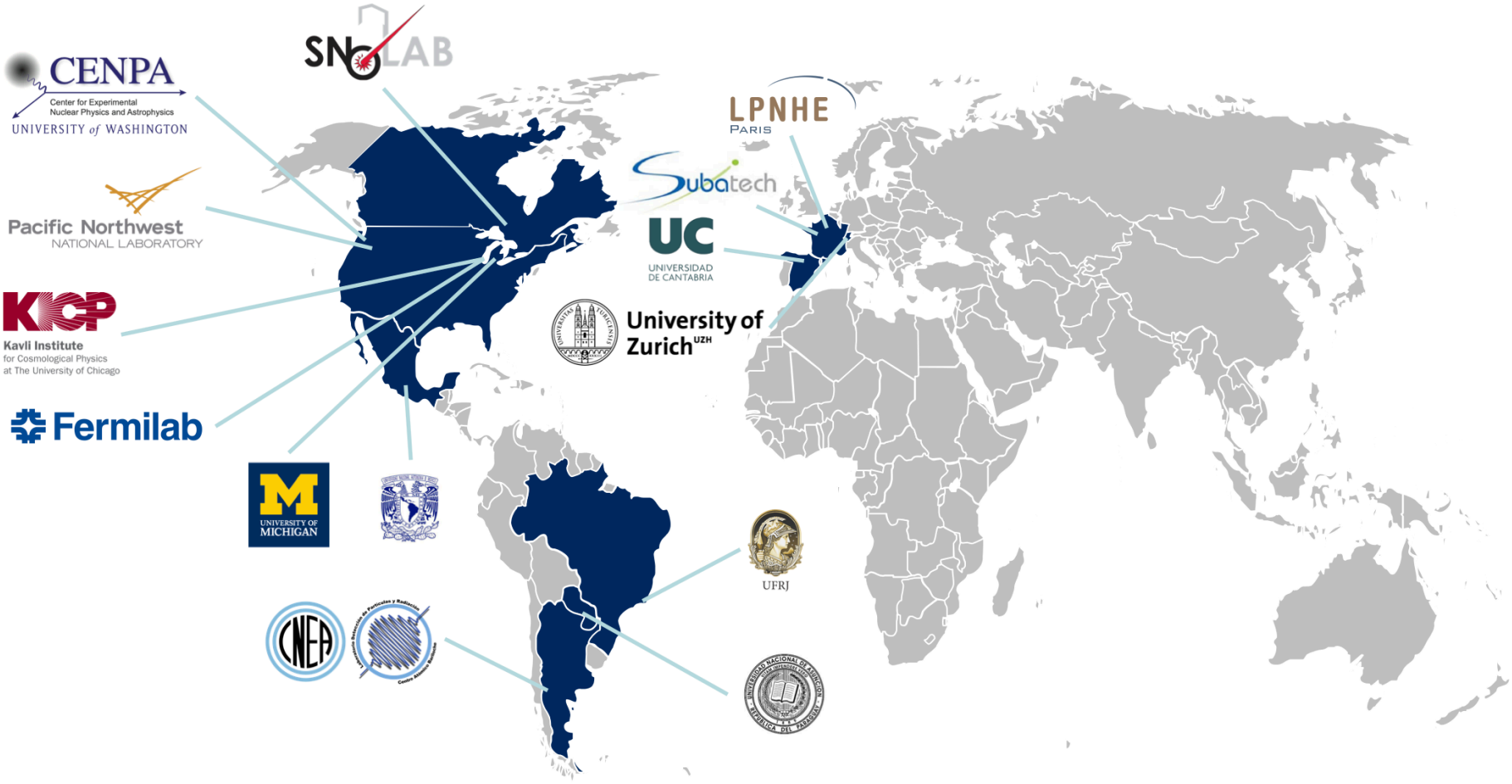


Energy threshold - 23 eV_{ee}

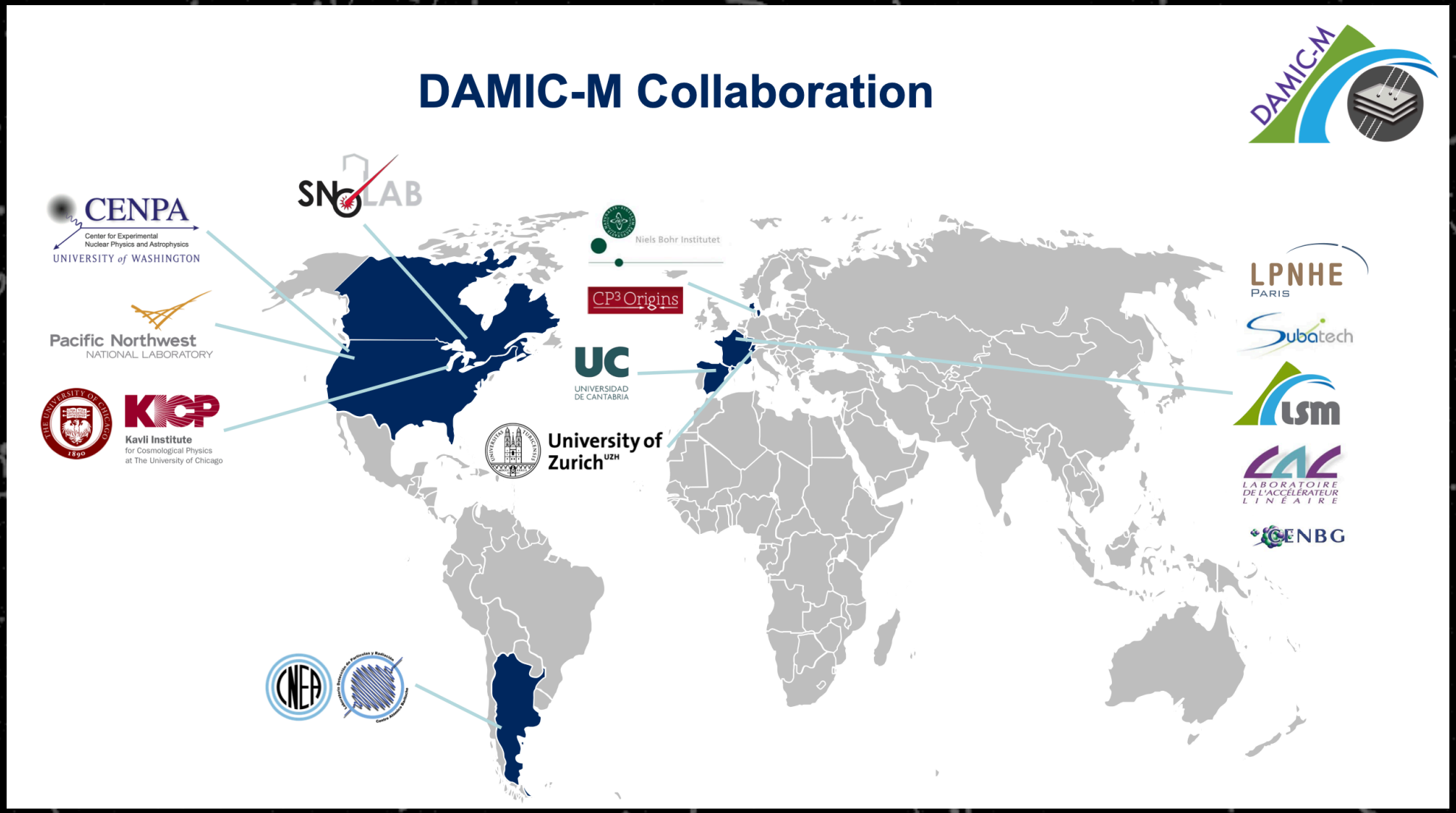
Consistency with previous result



DAMIC@SNOLAB Collaboration

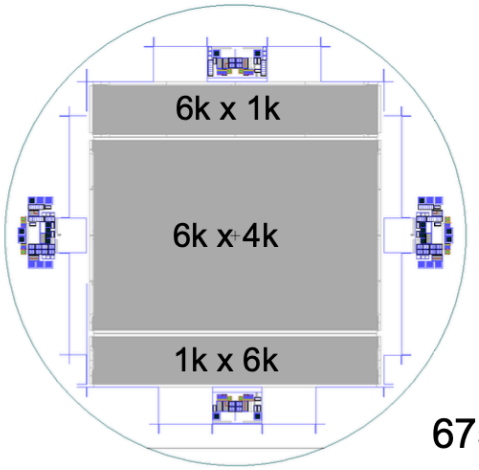


DAMIC-M Collaboration



DAMIC-M CCDs

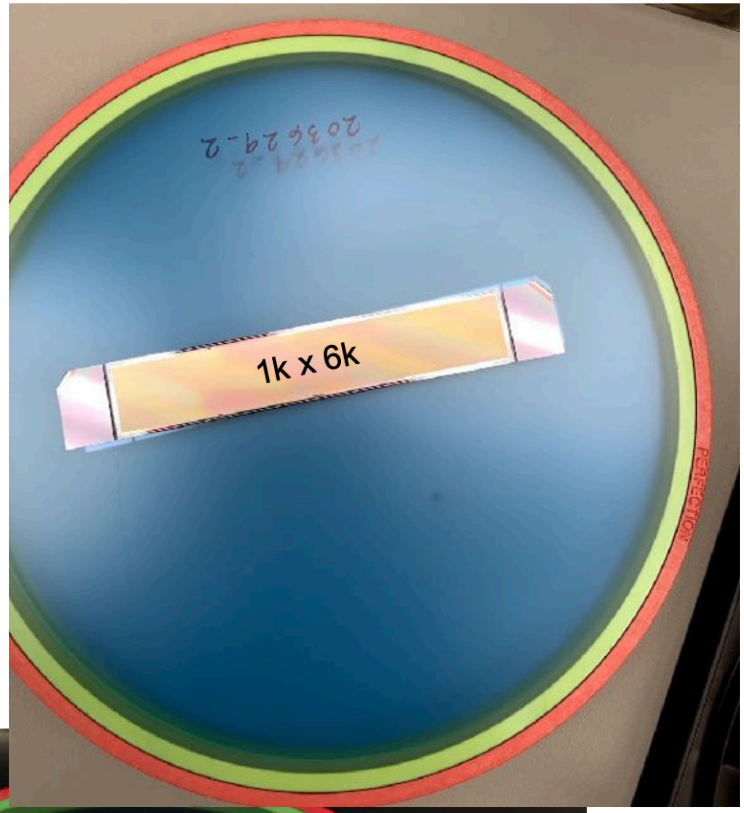
design by S. Holland (LBNL), fabricated by Teledyne/DALSA



DAMIC-M prototype skipper CCDs

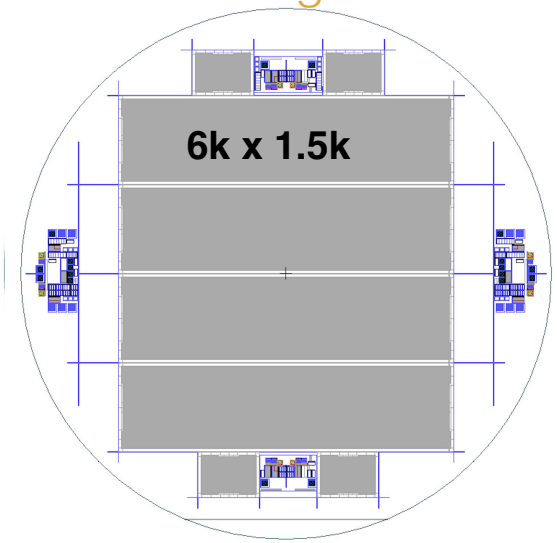
Three CCDs per wafer to test different skipper readout amplifier design.

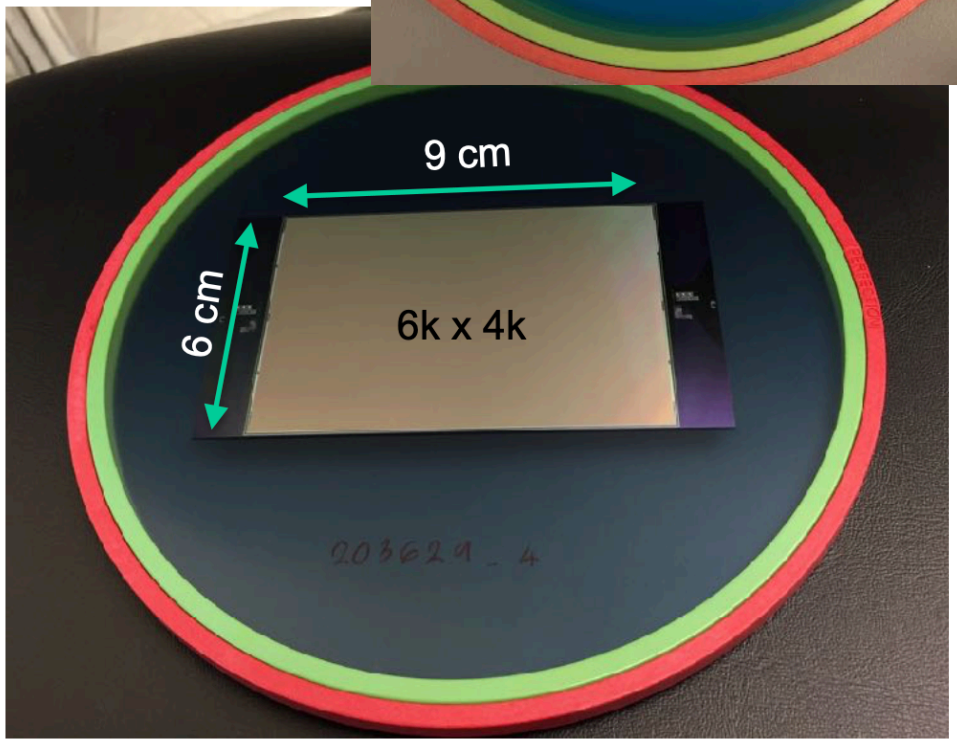
675 μm thick



DAMIC-M production skipper CCD design

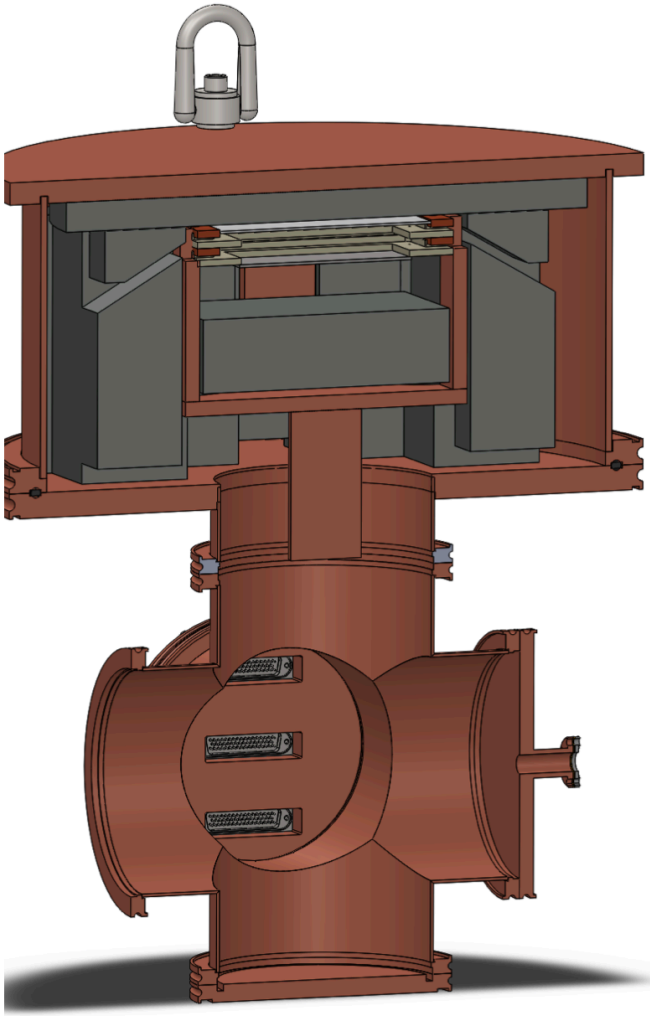
Yield better dividing CCD in 4





Now: First phase of DAMIC-M

Low Background Chamber



- A low-background chamber (background level ≈ dru) is in preparation
- Main objectives:
  - characterization of DAMIC-M CCDs in low-bkg environment: dark current; ^{32}Si rate; ^{210}Pb surface bkg; CCD packaging
  - first science results with a few CCDs
- **Installation in 2021**