GDR Deep Underground Physics plenary meeting

Oct 19 – 21, 2022
SUBATECH

Status and plans for DAMIC-M at the LSM and Oscura

- DAMIC-M
- Current and short term activities (the Low Background Chamber)
- Activities in 2023-2024
- Beyond DAMIC-M: the Oscura experiment

Paolo Privitera

for the DAMIC-M Collaboration

(first DAMIC-M science results in Jean-Philippe Zopounidis' talk yesterday)

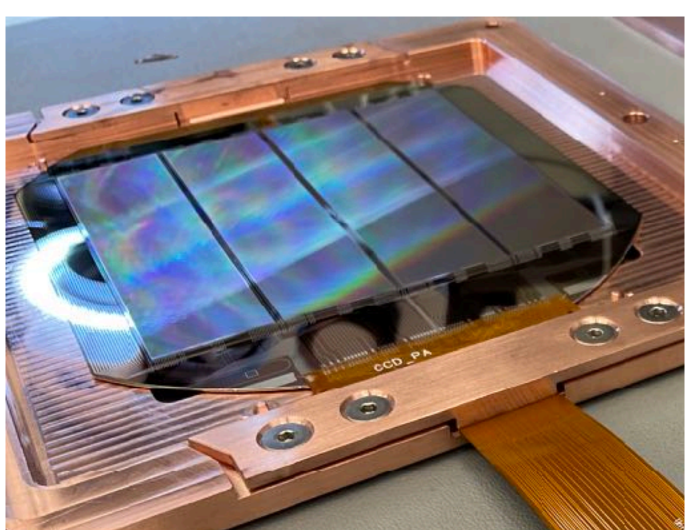
DArk Matter In CCDs at Modane

Physics goals:

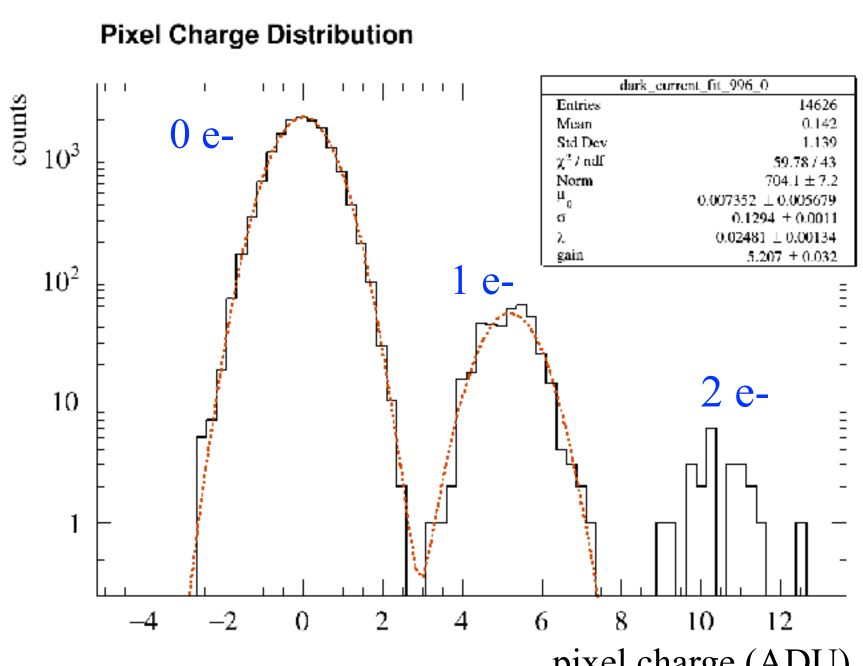
- detect nuclear and electron recoils to search for light dark matter candidates (eV to GeV)
- achieve low background rate of ~0.1 dru (1 differential rate unit = 1 event/kg/day/keV)
- operate ionization detector with 2-3 electron threshold (~eV)

CCDs for DM searches:

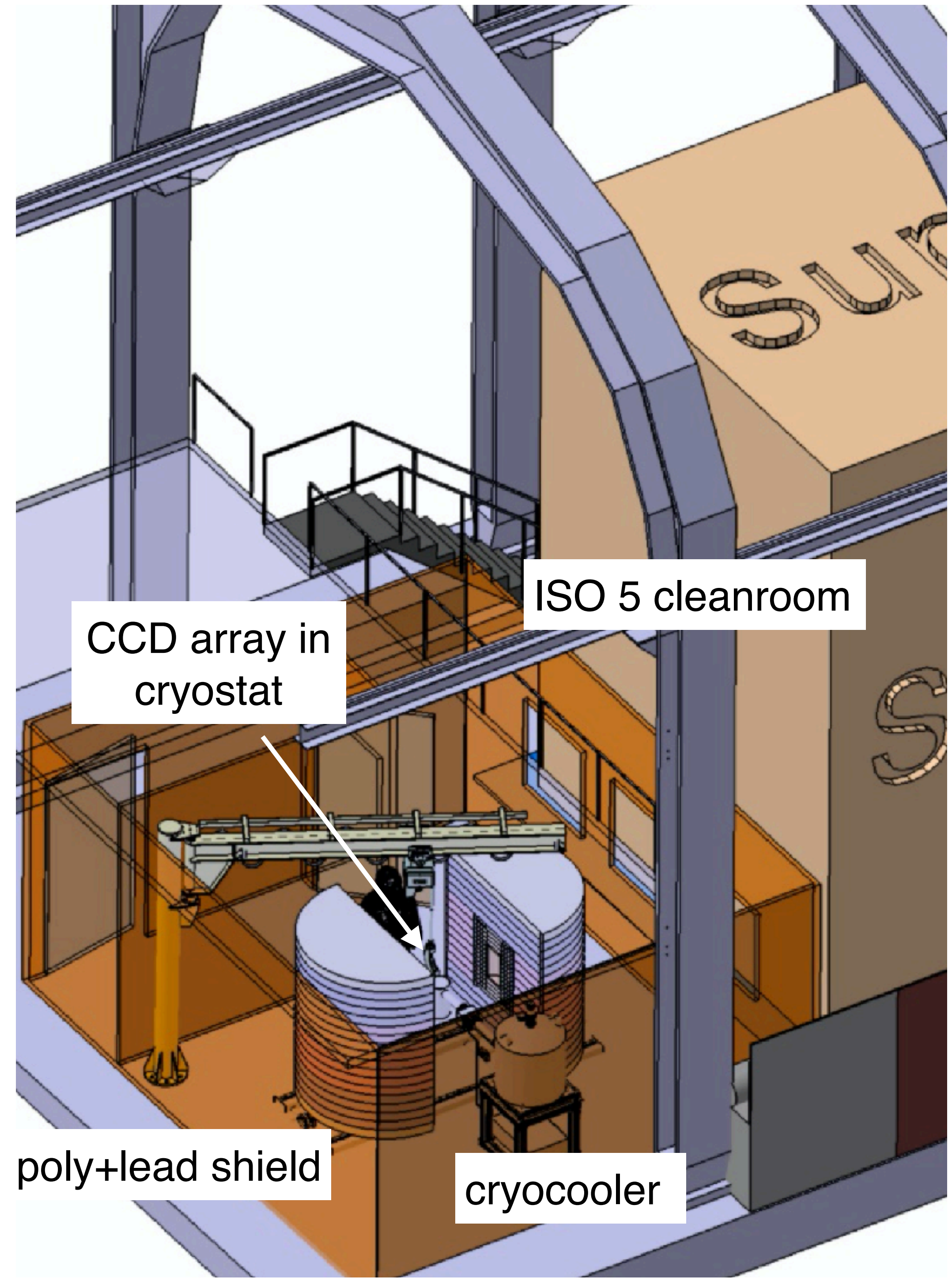
- use thick (675um), massive (~3.5g), 9Mpixel CCDs
- build array of 200 CCDs for kg-scale mass
- operate with "skipper" amplifier readout to provide single electron energy resolution (sub-eV) and self-calibration
- use pixelization for background rejection



DAMIC-M CCD module



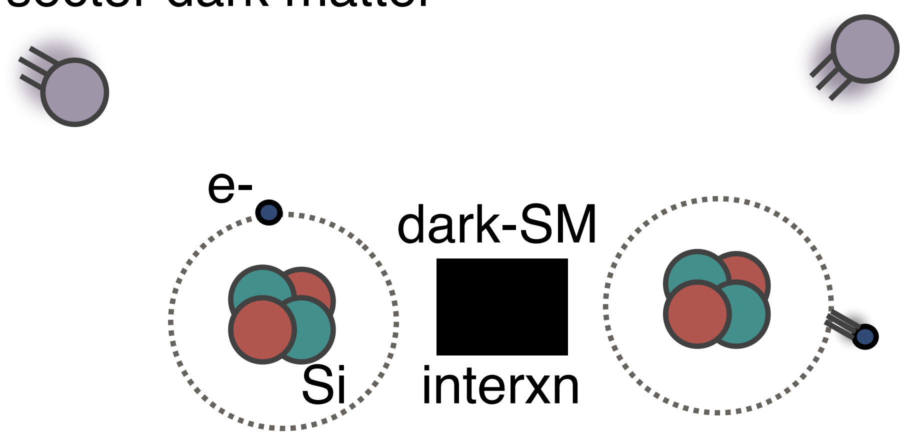
DAMIC-M @ LSM



original plan, with packaging and test of CCDs in another clean room space

Electron recoils: sensitivity to dark sector

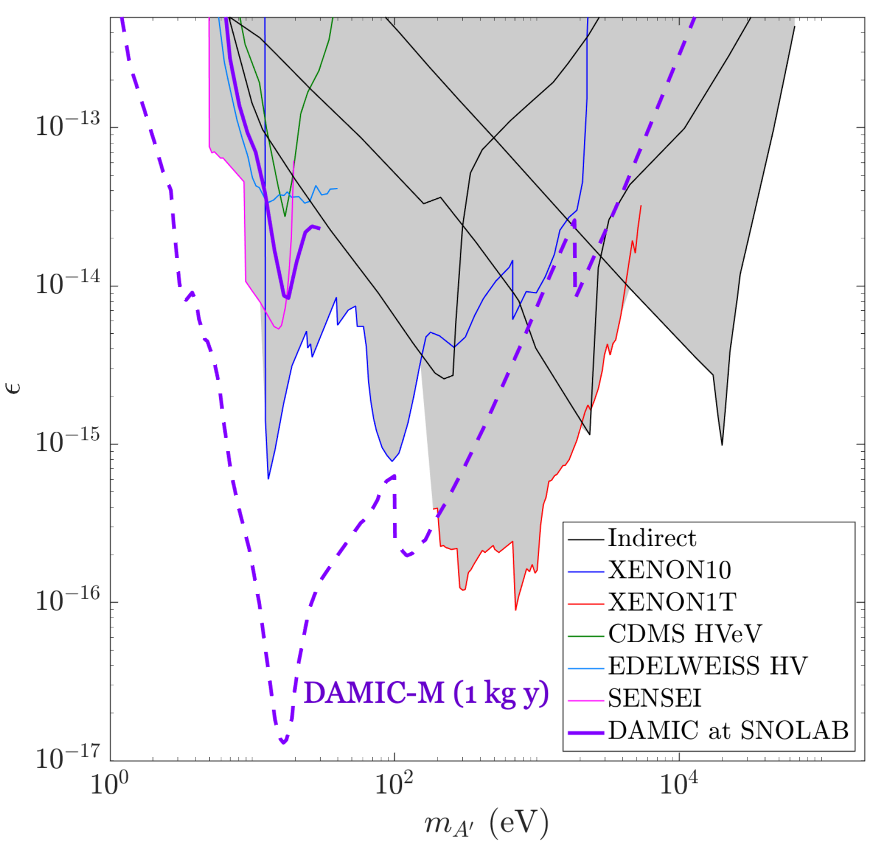
dark sector dark matter



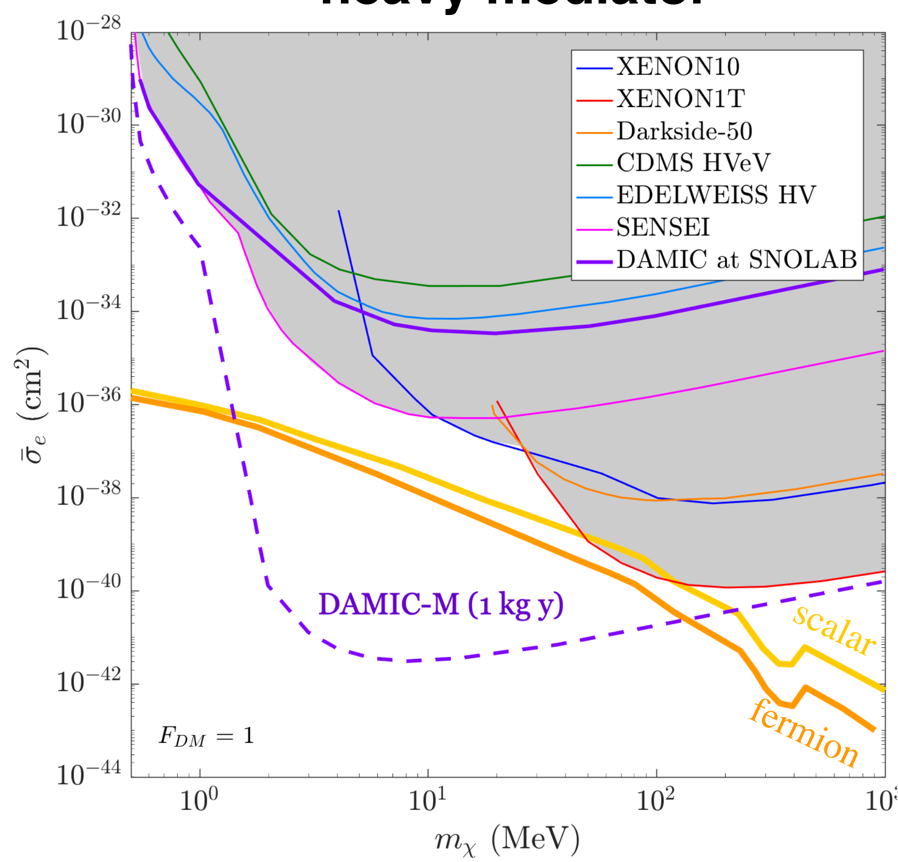
dark sector-electron elastic scattering:

- dark sector DM interacts with target Si valence electron through dark-SM interxn
- electron absorbs some energy and recoils
- creates electron-hole pairs
- CCD drifts charges and reads out

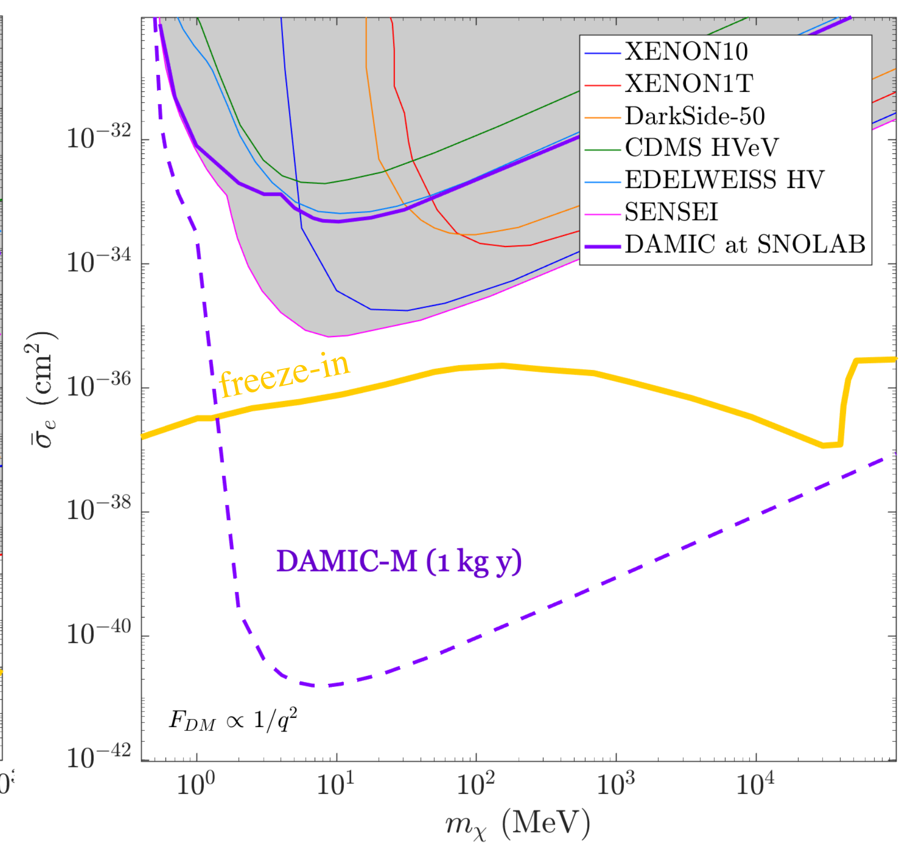
hidden photon



heavy mediator



light mediator



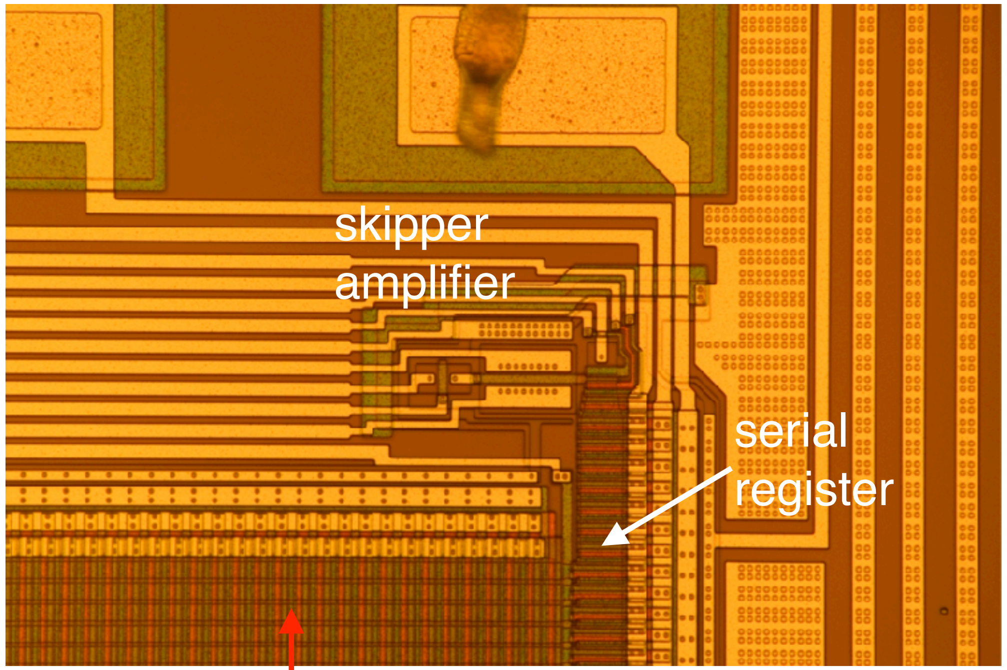
single electron sensitivity to probe unexplored sub-GeV dark matter

DAMIC-M Detector Design

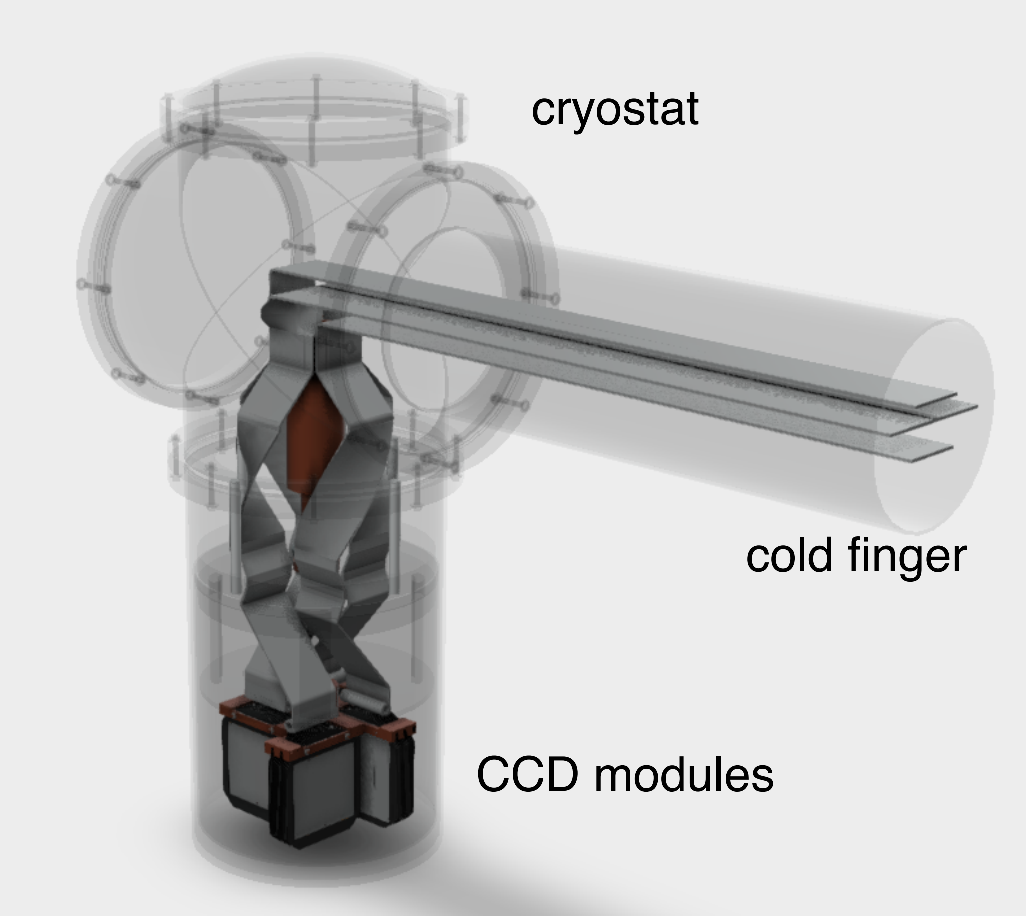
200 skipper CCDs:
- high resistivity, n-type, high purity silicon
- 6k x 1.5k pixels (15 x 15 x 675 um^3)
- fully depleted (no charge loss when drifting)
- 47/6um^2 skipper amplifiers
- low background flex cable

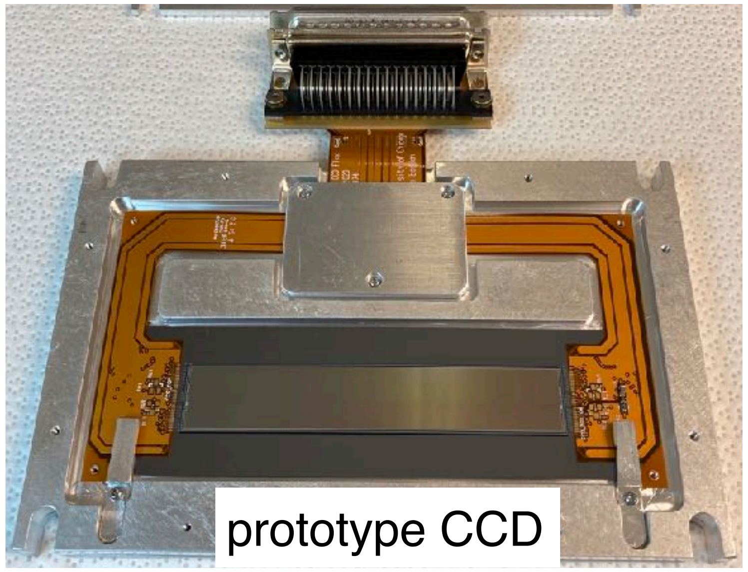
Detector:
- kg-scale, 4 CCDs per module
- electro-formed copper cryostat, IR shield
- operate at ~100K and 1e-7 mbar
- layered polyethylene + lead shielding, innermost layer of ancient lead
- custom electronics for fast readout and low noise

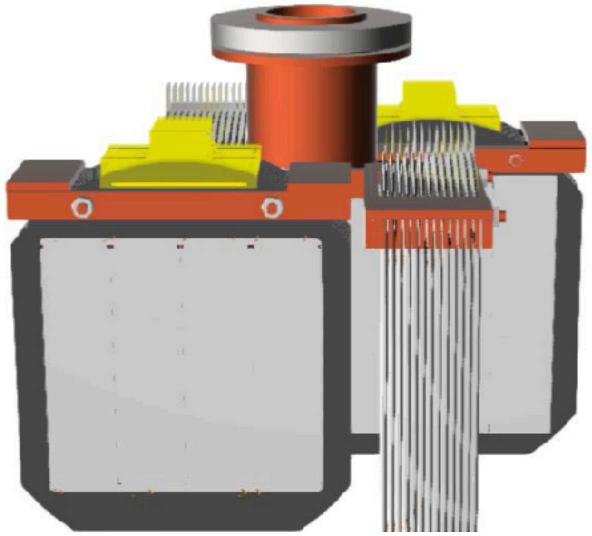
Background controls:
- cosmic activation and radon limited by time above ground/in air (fabrication, transportation, etc)



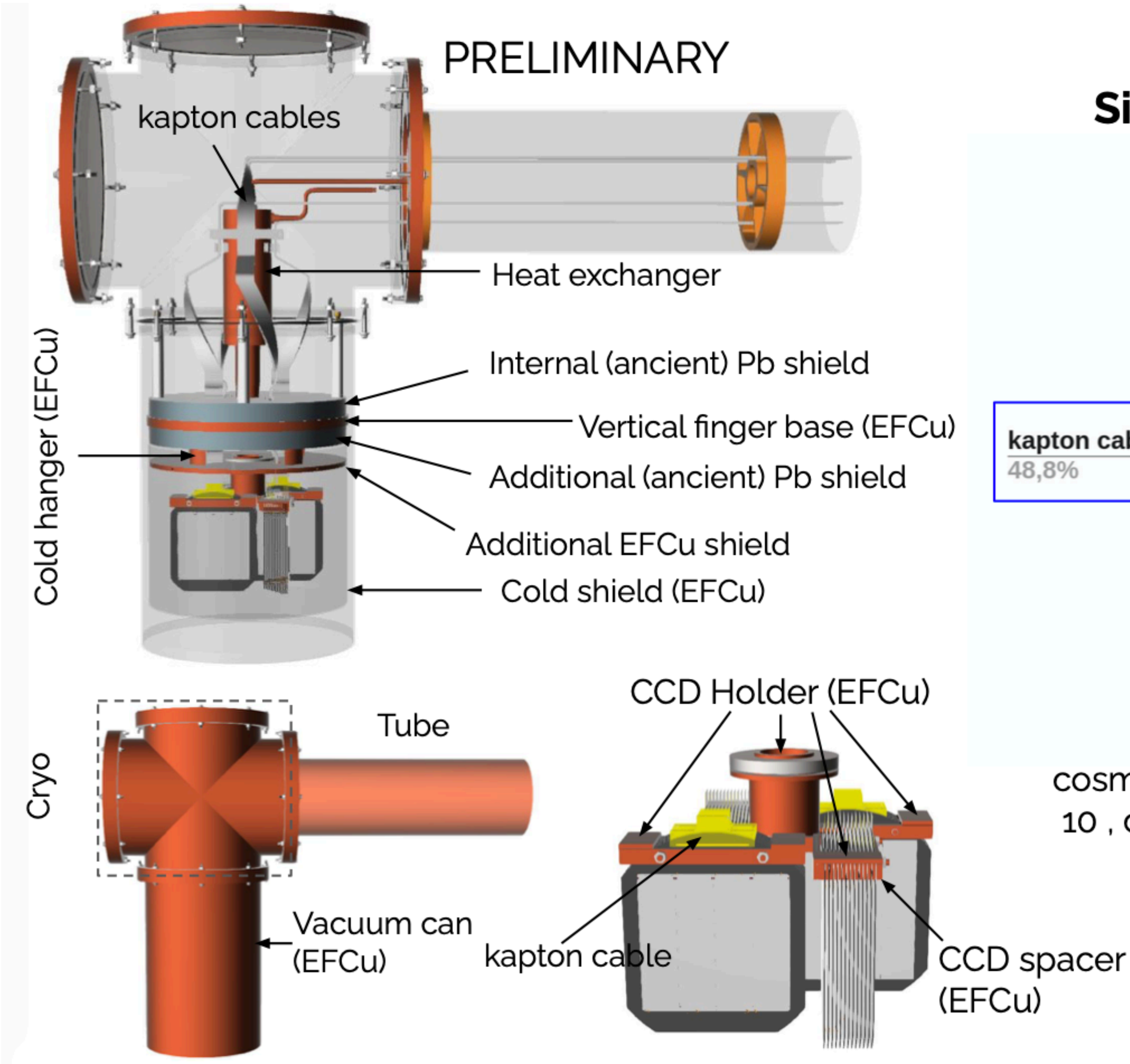
CCD pixel array



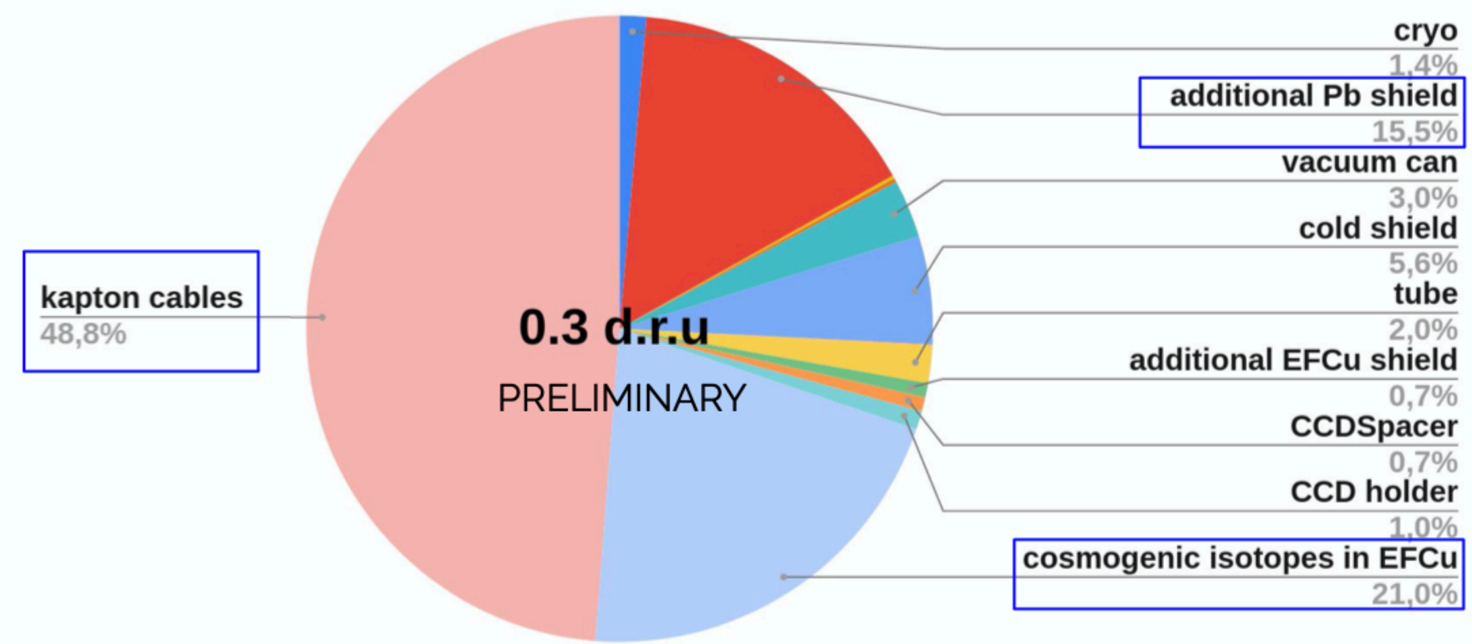



CCD modules

DAMIC-M Backgrounds



Simulations to estimate design background level:
Geant4 + custom detector response simulation

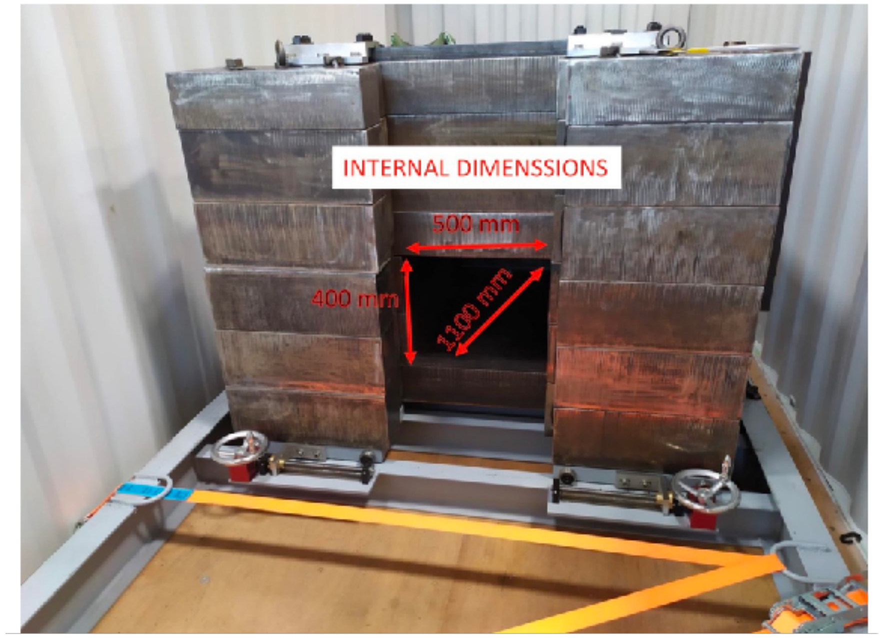


cosmogenic isotopes in Electro-Formed Cu assuming: exposure time= 10 , cooling time underground = 180 d, experiment running time = 1 yr

Background level goal within reach

- Detailed simulations informing the design
- Getting close to 0.1 dru level, improvements expected from e.f. copper production and machining underground at Canfranc and further R&D on cables

DAMIC-M Backgrounds

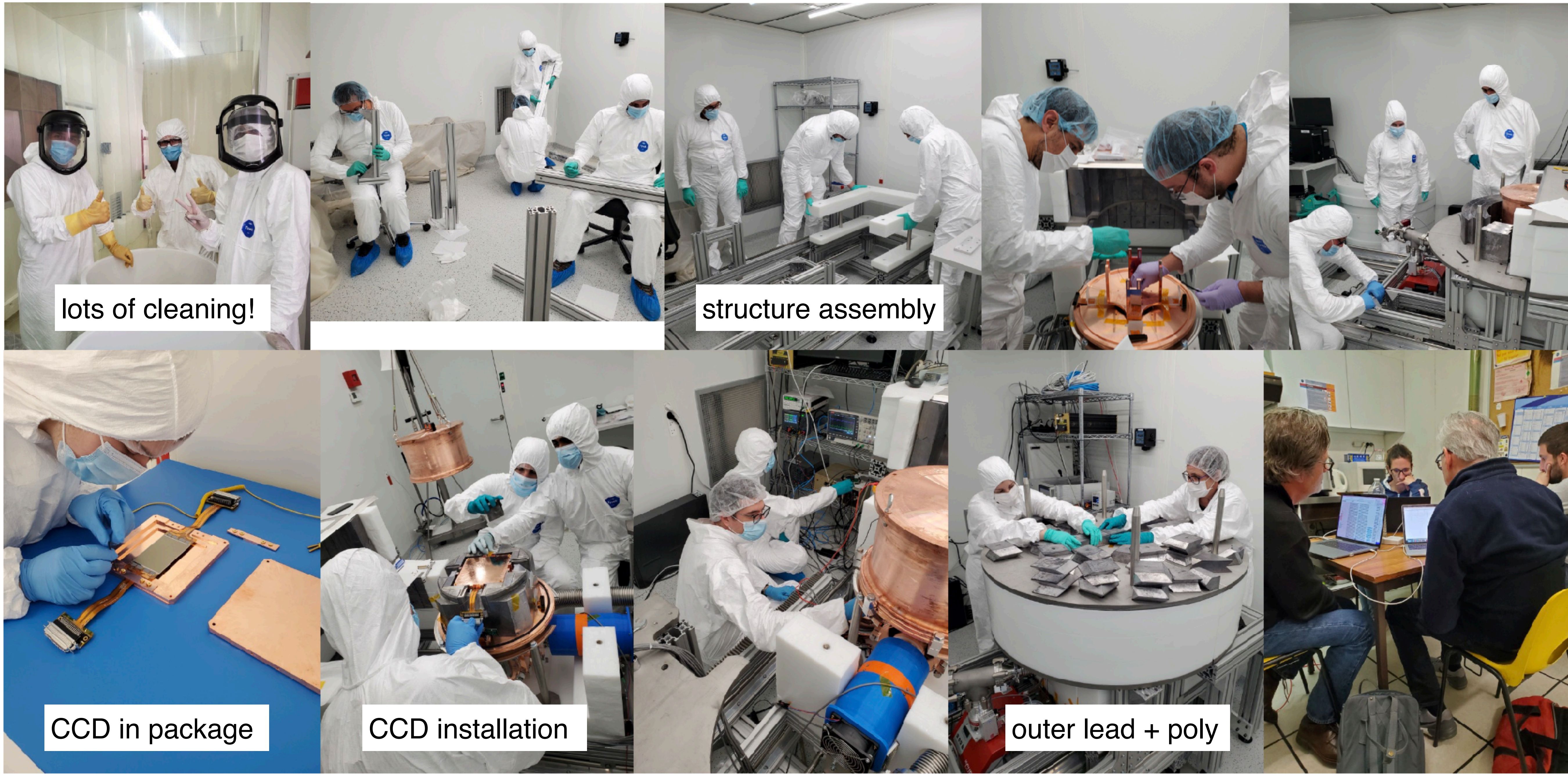


18-ton shielding in shipping container to transport wafers from Europe to Canada (and back as CCDs)

5-ton shielding at DALSA receiving dock (Bromont, Canada); now in the fab clean room

Cosmogenic activation of silicon minimized by shielding during transport and fabrication

The present: Low Background Chamber



cleaning, clean room preparation, support structure, cryostat, CCDs, external shielding, electronics, slow control, grounding, troubleshooting, ...

installation and commissioning during 2022

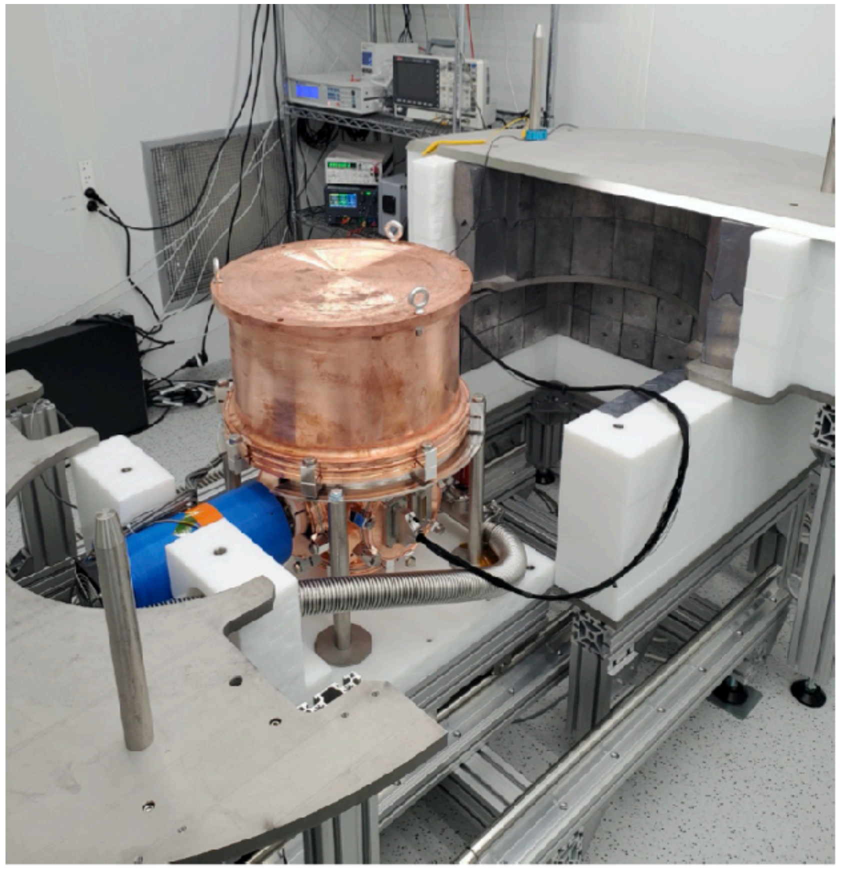
LBC objectives

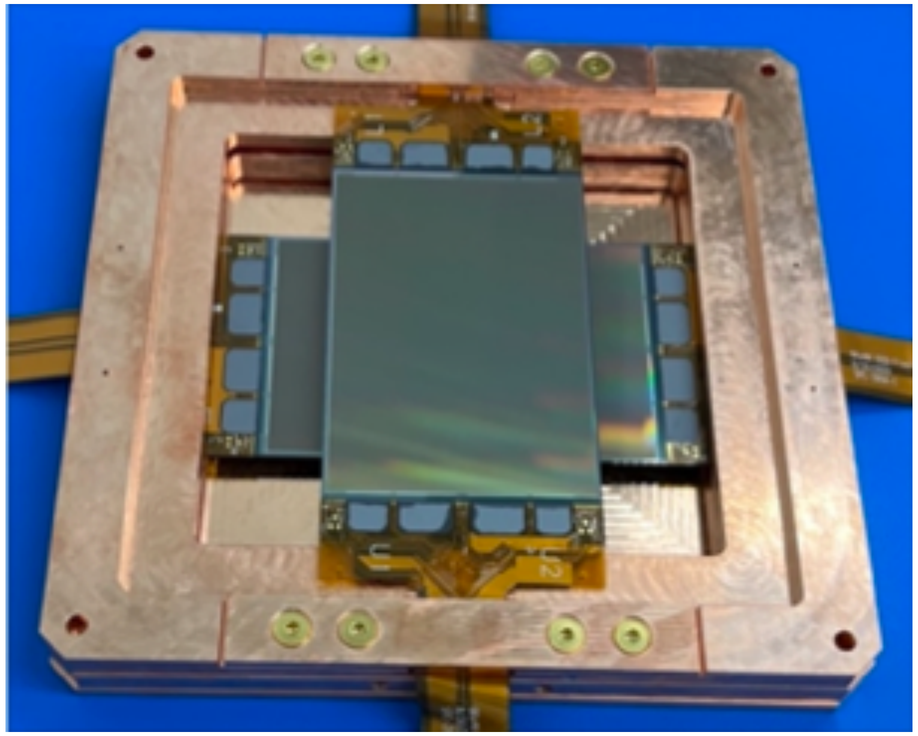
- characterize DAMIC-M components in a low background environment (goal 1 dru) in preparation for the full experiment:
  - dark current in CCDs
  - radiogenic/cosmogenic backgrounds in CCDs and packaging
  - radio assay of materials (e.g. e.f. copper parts)

- gain working experience at LSM
  - logistics/infrastructure
  - detector installation
  - detector operation

- test of other fundamental DAMIC-M components
  - CCD controller and Front End electronics
  - Slow Control
  - DAQ
  - data transfer (Lyon)
  - Data Quality Monitor

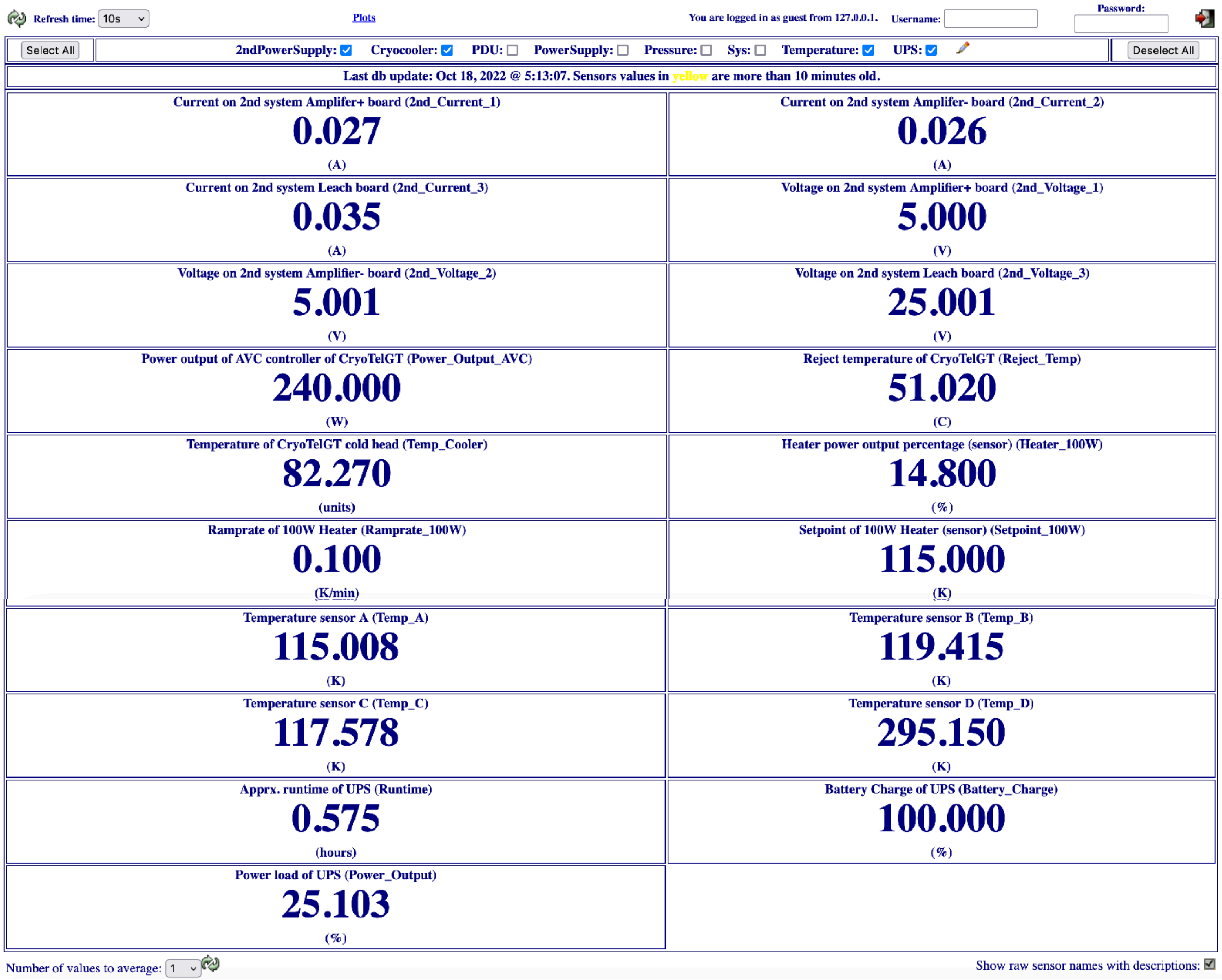
- first science results with small detector



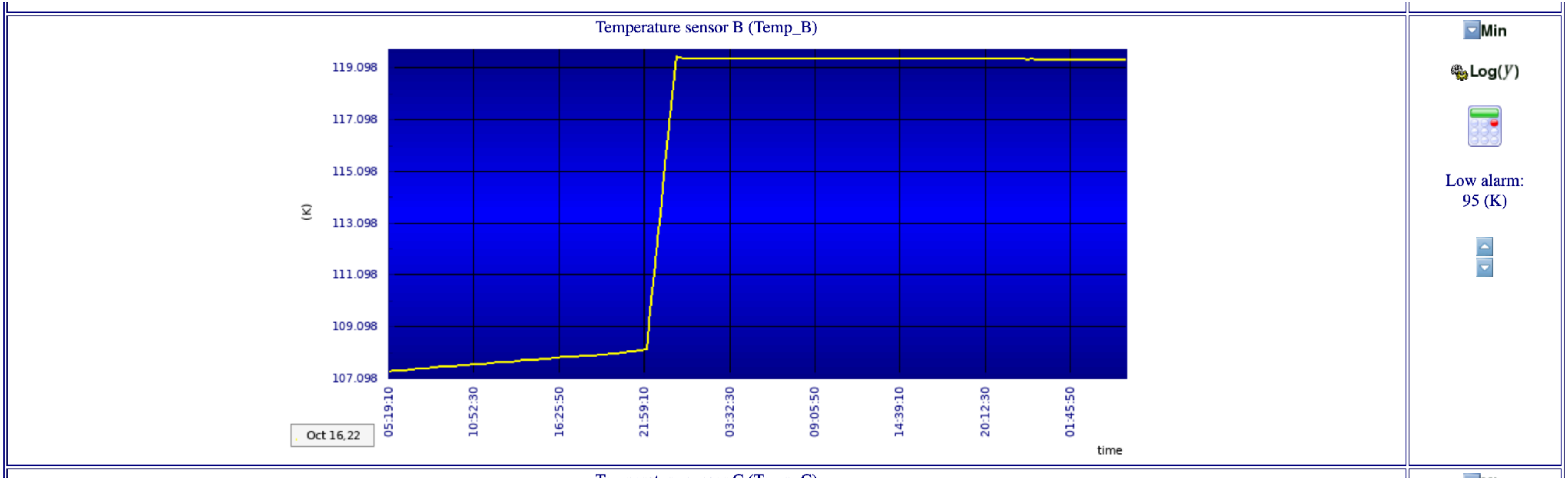


- Currently installed:
  2 CCDs, 4kx6k, ~17g target mass

LBC Slow Control



- Continuous monitoring of the status of the detector: web interface, database

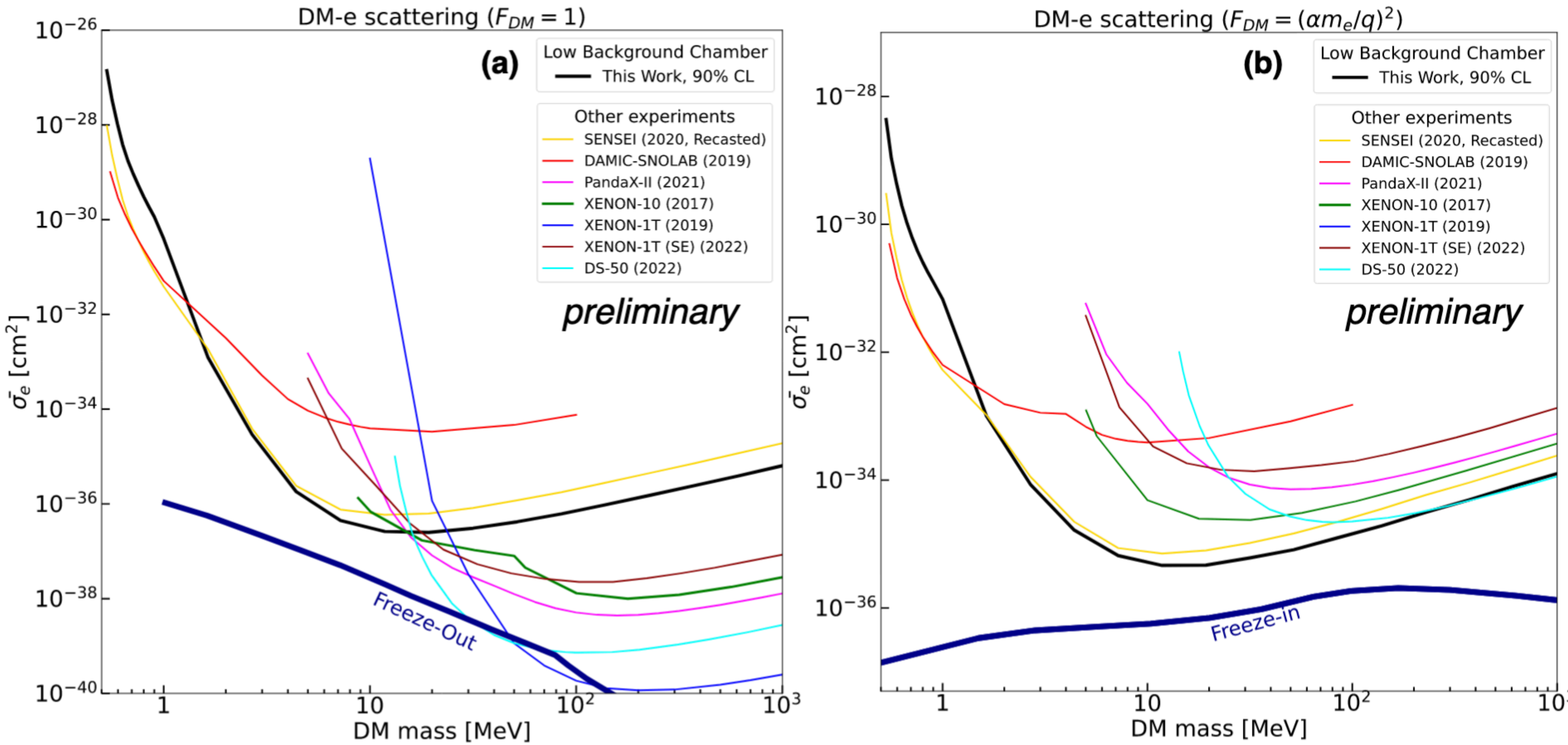


- Easy to plot monitored quantities vs time
- Remote control: we can startup from scratch/shutdown the entire system
- Alarms, with text messages/email sent to expert/shifters

- The slow control system is very robust, guaranteed smooth, continuous operation of the LBC for several months. Demonstrated that only limited time is required from LSM staff during data taking.
- It will be implemented with only minor modifications for DAMIC-M

- Similar strategy for other components, to be tested at the LBC and then ported to DAMIC-M. Other example is the DAQ, also already tested at the LBC

First science results

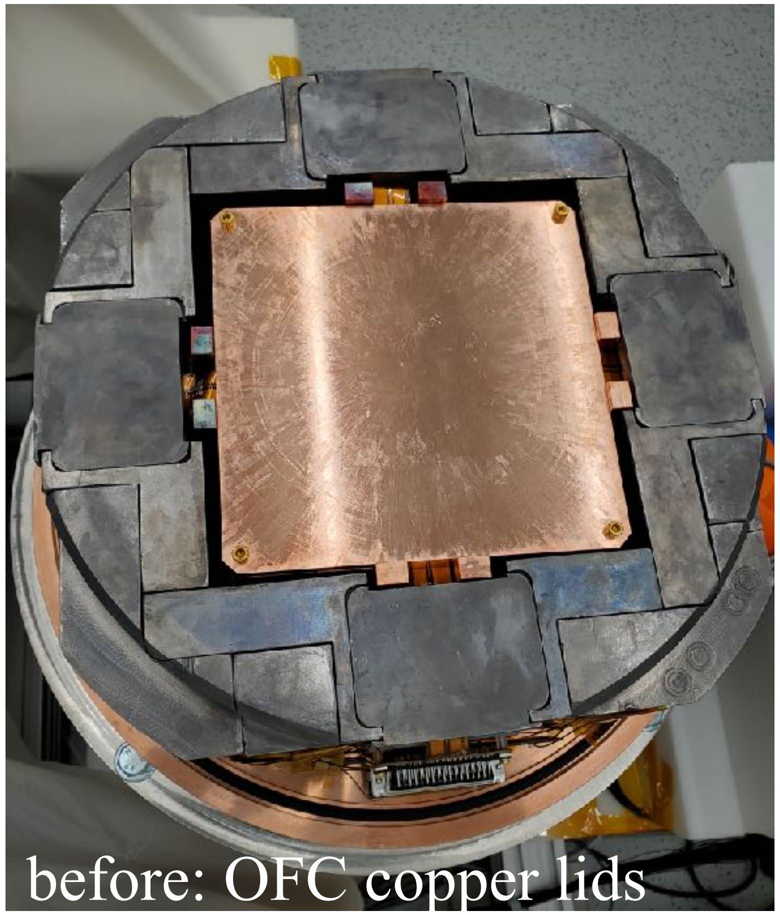


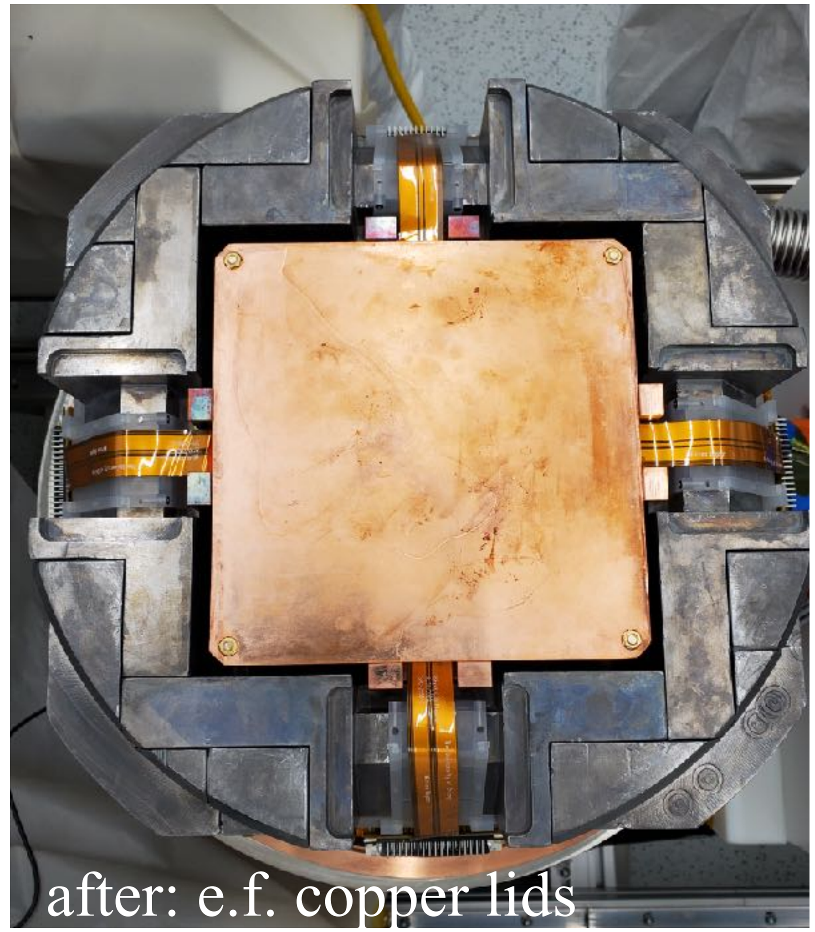
(Jean-Philippe Zopounidis' talk yesterday)

presented at Identification of Dark Matter 2022, more sensitive search to be released soon

We thank the LSM personnel for their extraordinary support during difficult times (pandemic…), essential to achieve scientific results already at this early stage

LBC short term activities


before: OFC copper lids


after: e.f. copper lids


close cryostat October 7th 2022

- Activities till end of 2022:
  - e.f. copper produced at Canfranc (installation completed)
  - dark current in CCDs (improvements in thermal contact and IR shield; installation completed)
  - installation of motorized opening/closing of shielding

- Activities in 2023
  - installation of DAMIC-M modules with pre/production CCDs
  - validation of low background flex cables
  - final electronics
  - science data run

we want to keep the LBC operating for as long as possible in 2023 (space constraints at LSM)

DAMIC-M activities in 2023

- Most of the components production is scheduled for 2023. Here I will highlight the crucial ones.

- CCD production
  - we are currently testing the pre-production CCDs (preliminary measurements indicate high yield). Expect green light for production by the end of 2022, production to be completed by Q1 2023. Shipping to LSM in shielded container.

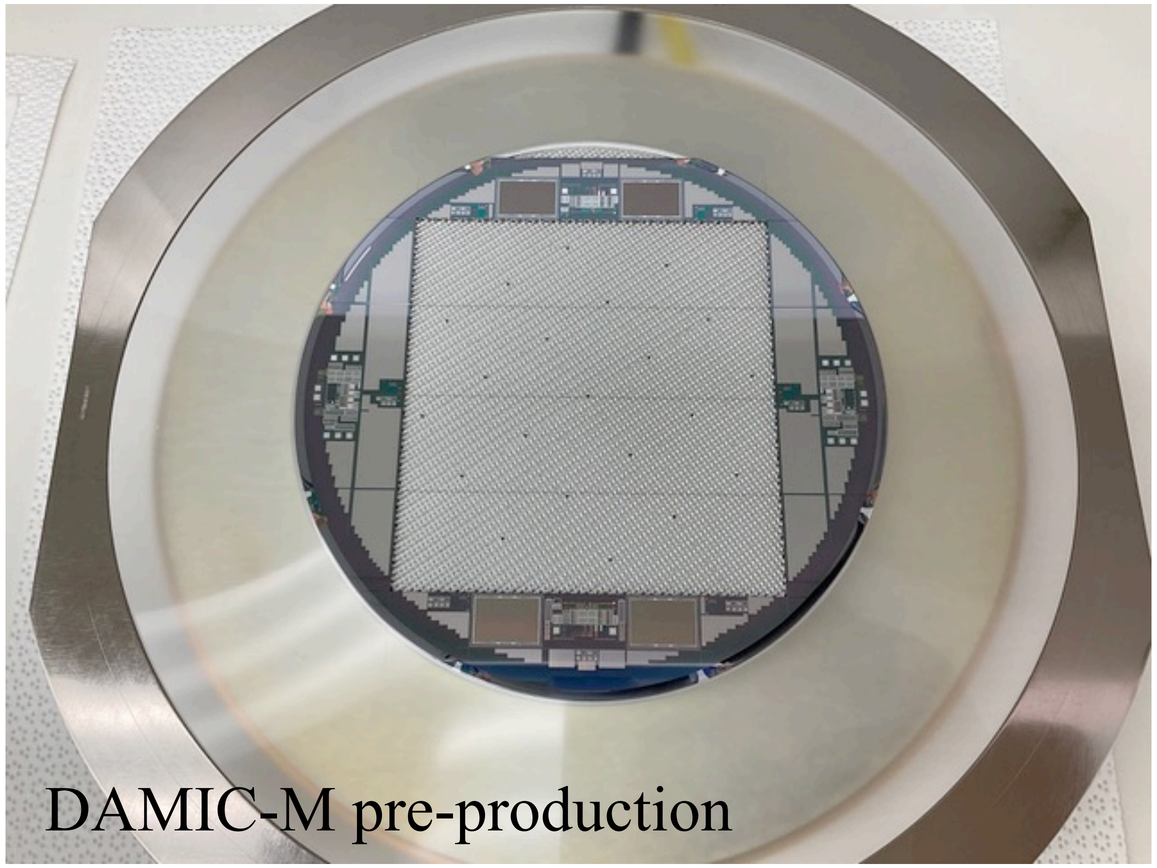
- e.f. copper
  - production to be performed at the Canfranc laboratory, Spain
  - minimize activation by growing the copper underground. Machining will also be performed underground.
  - will take full 2023 to complete the production

- electronics (worldwide procurements problems, we are almost ok)

- Most relevant for LSM
  - packaging and test of CCD modules (start Q3 2023)
    must be done underground to avoid cosmogenic activation of silicon and in radon free environment to avoid surface background

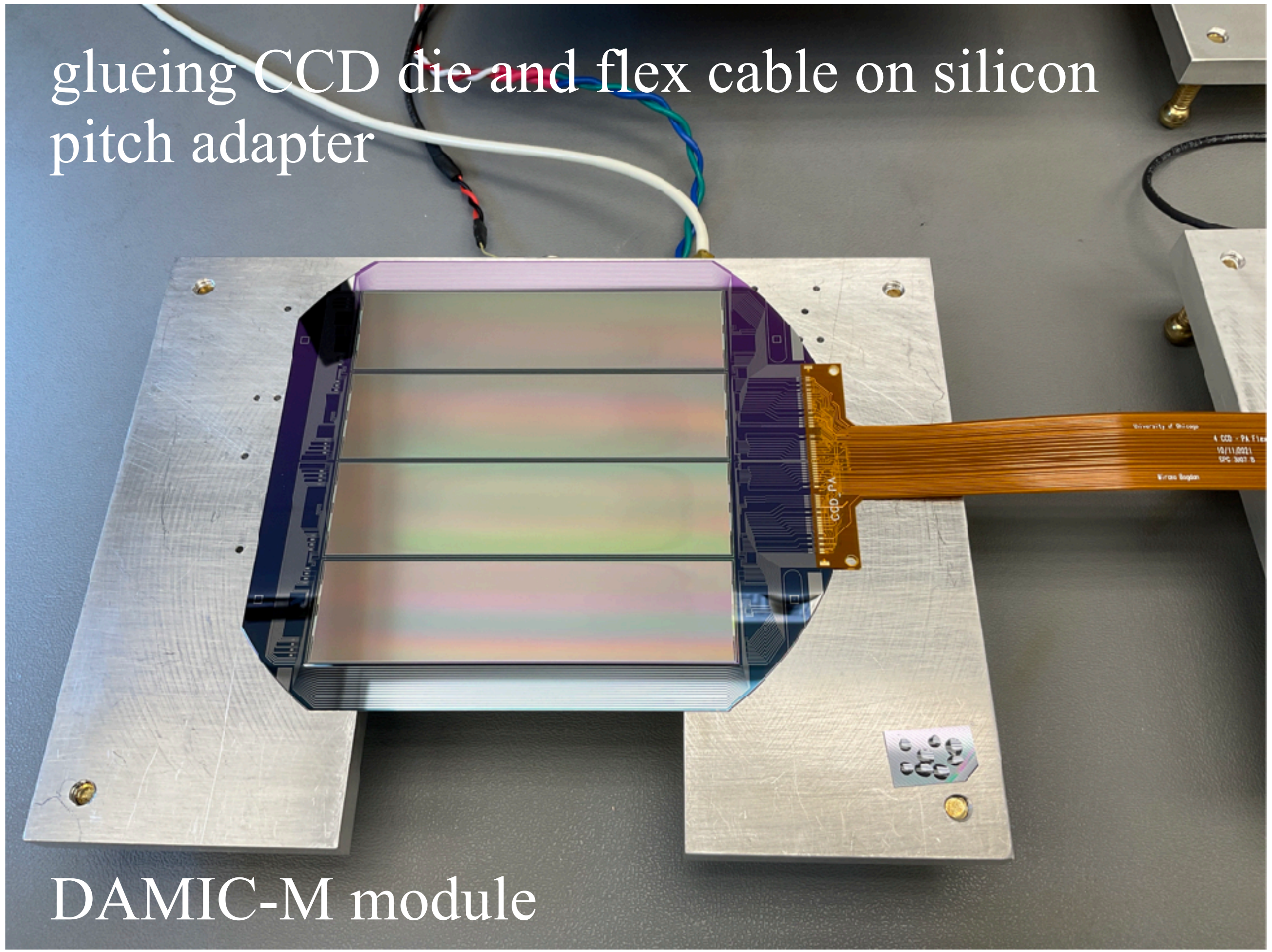
adequate clean space and radon-free air must be available at LSM for these crucial DAMIC-M activities

CCD packaging

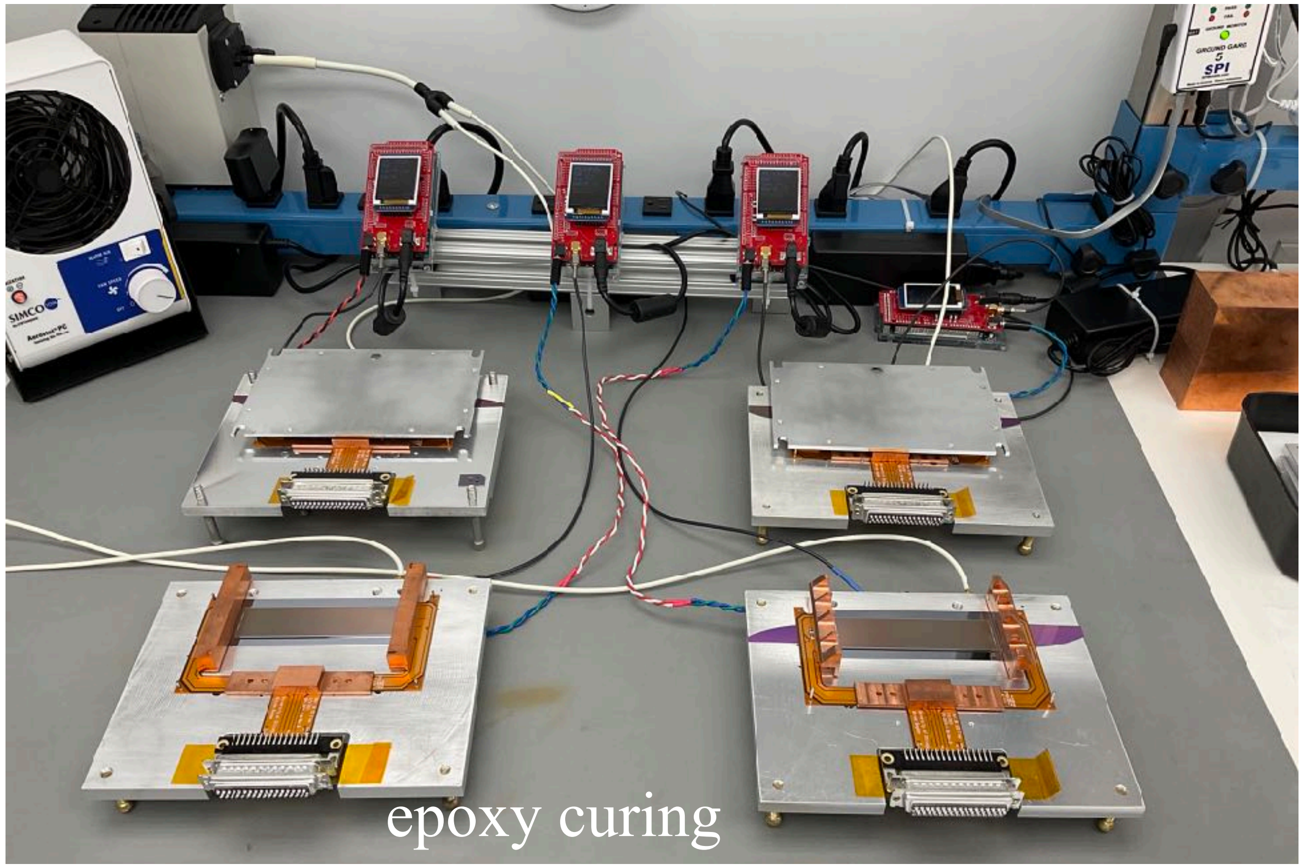

DAMIC-M pre-production

diced wafer (with CCDs and test structures)

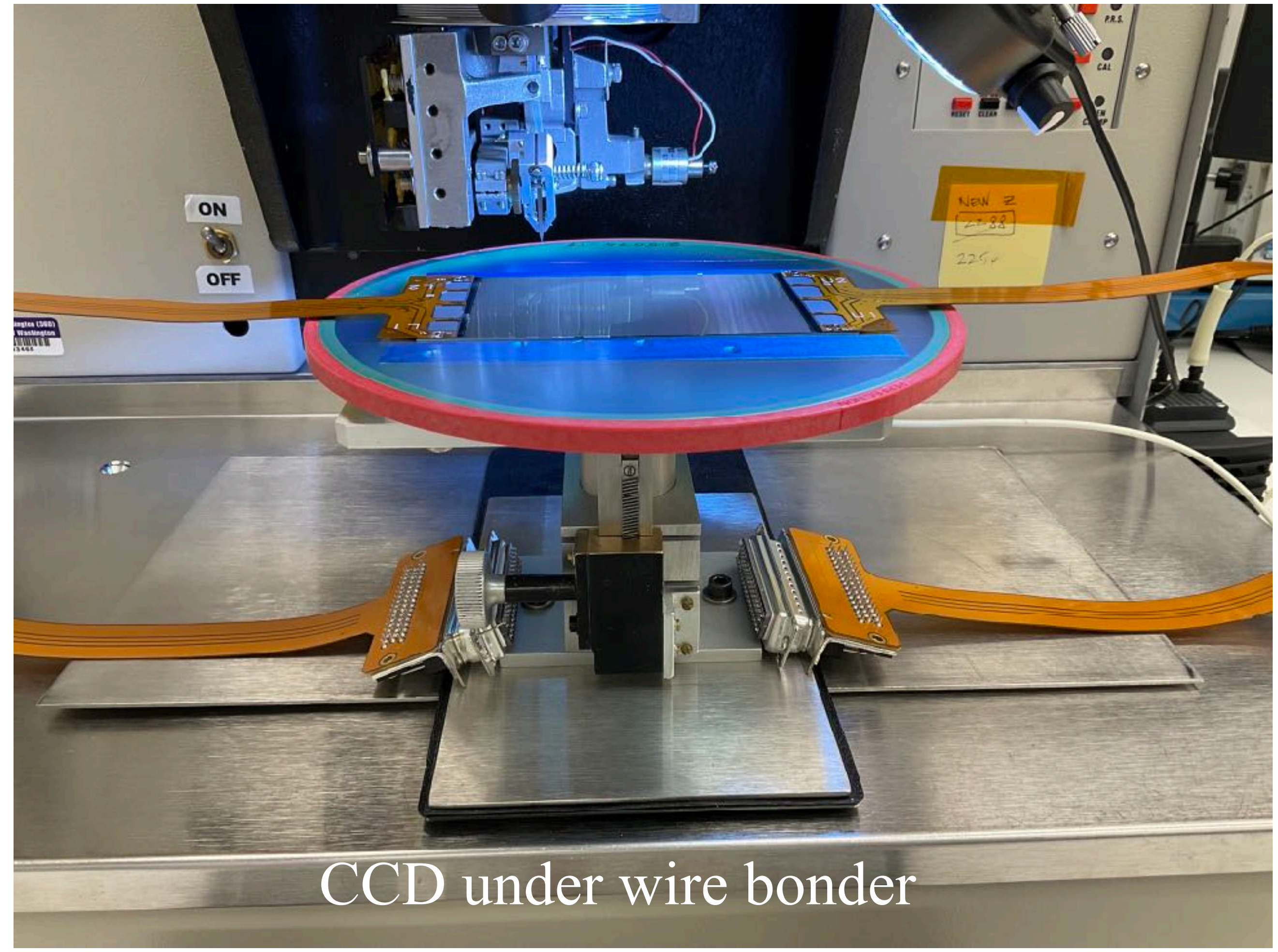

cold probe of bare CCD die

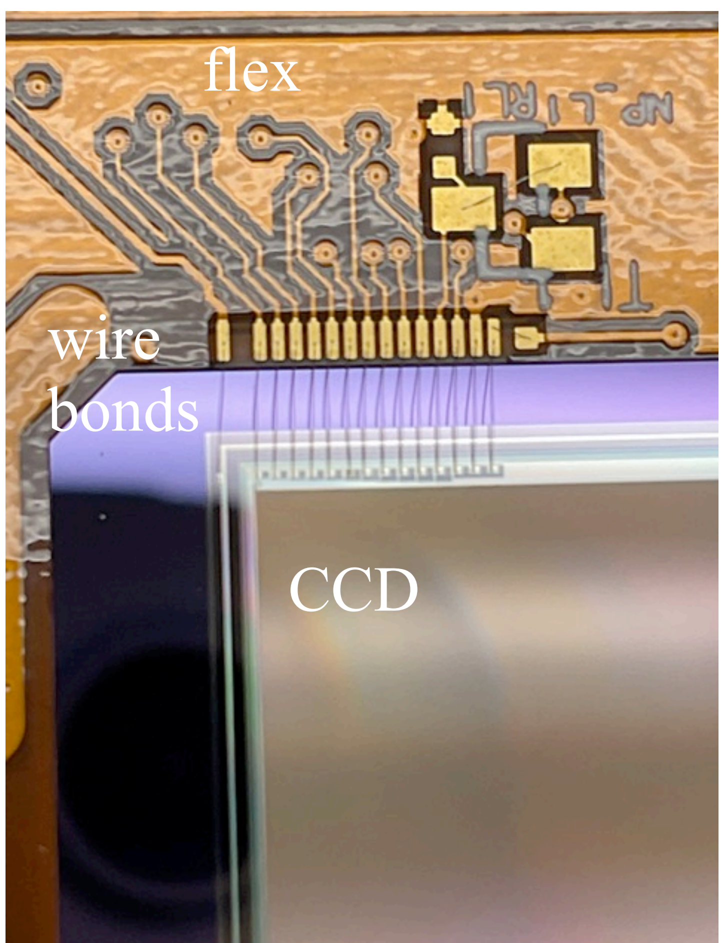

glueing CCD die and flex cable on silicon pitch adapter

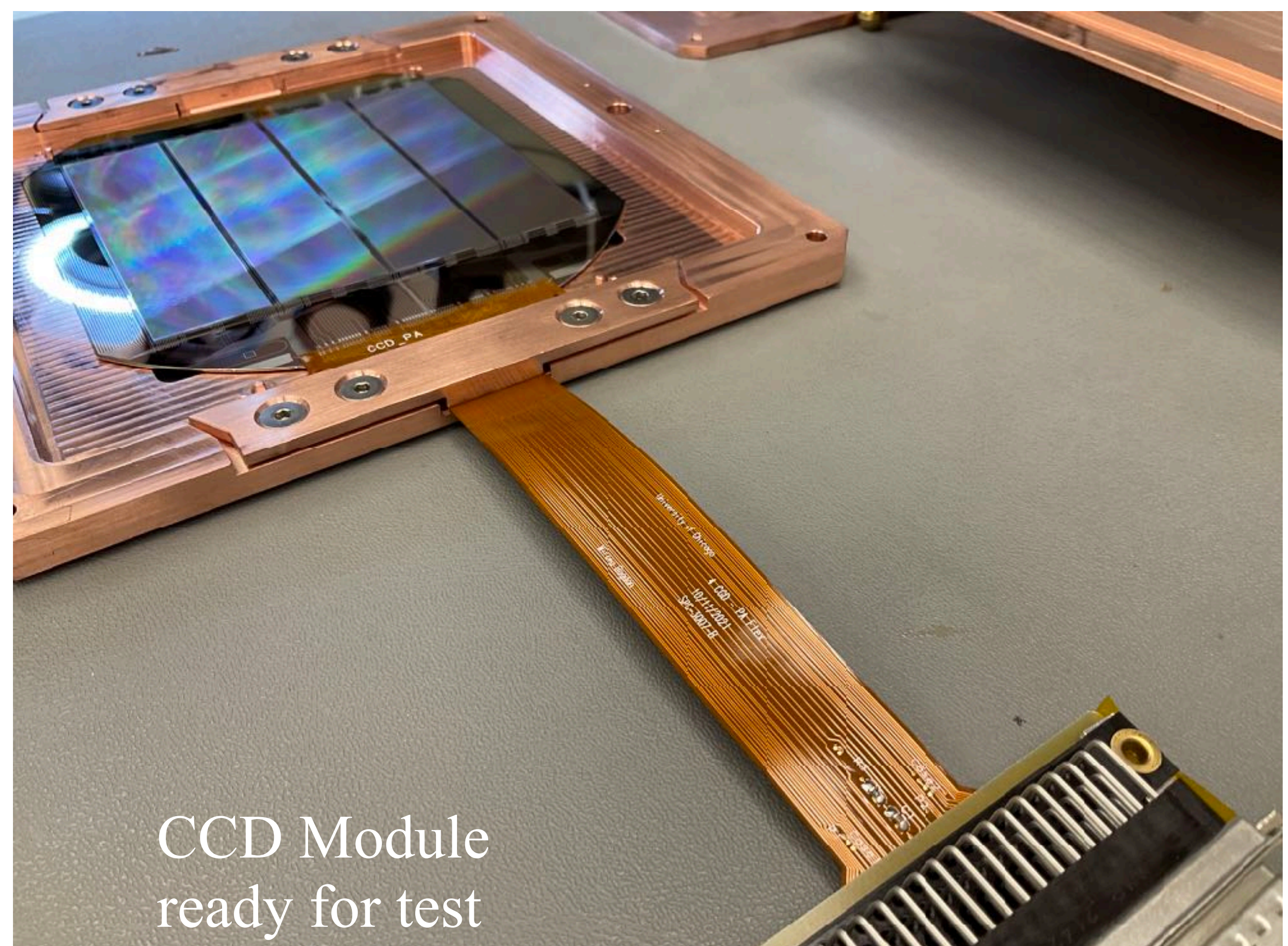
DAMIC-M module

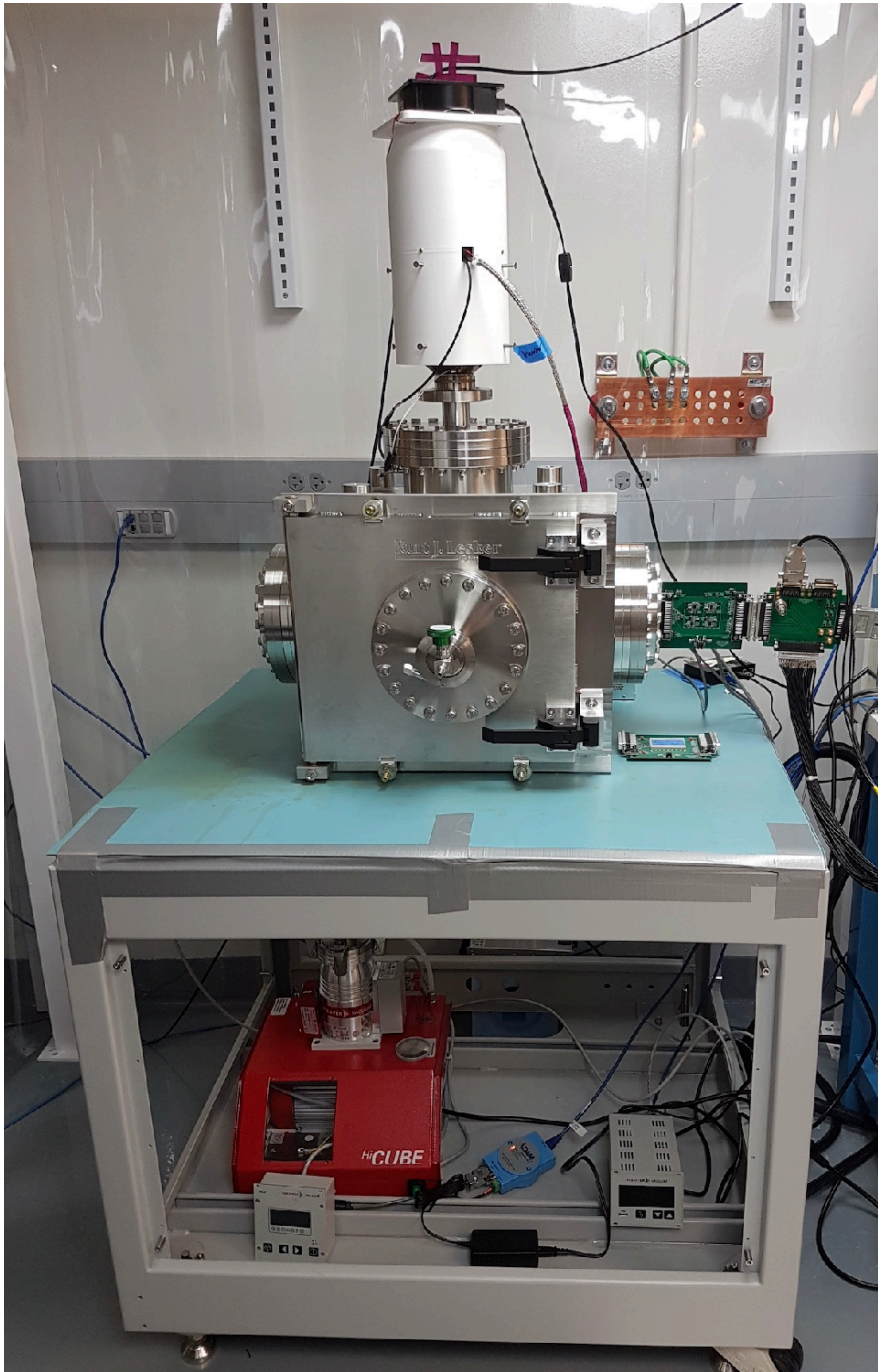

epoxy curing


wire bonder

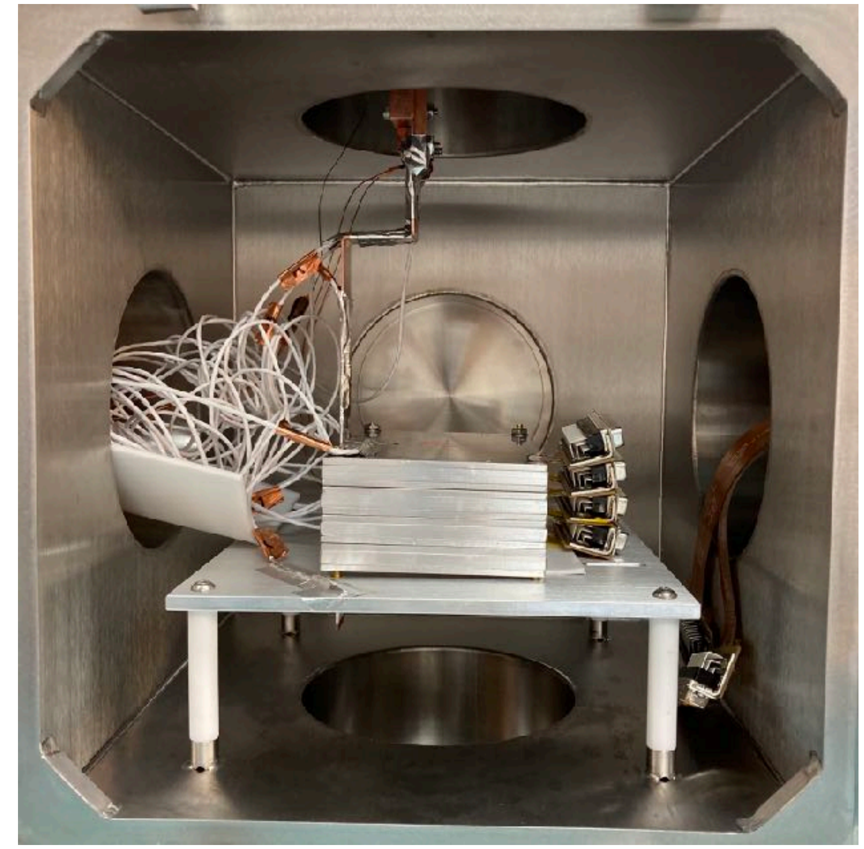

ON
OFF
CCD under wire bonder


flex
wire
bonds
CCD


CCD Module
ready for test



CCD Module test



- we foresee n. 2 test stations in clean room

  - validation of CCD Module performance at nominal working temperature: defects, amplifiers, dark current, single electron resolution

  - selection of best science-grade detectors for installation in DAMIC-M

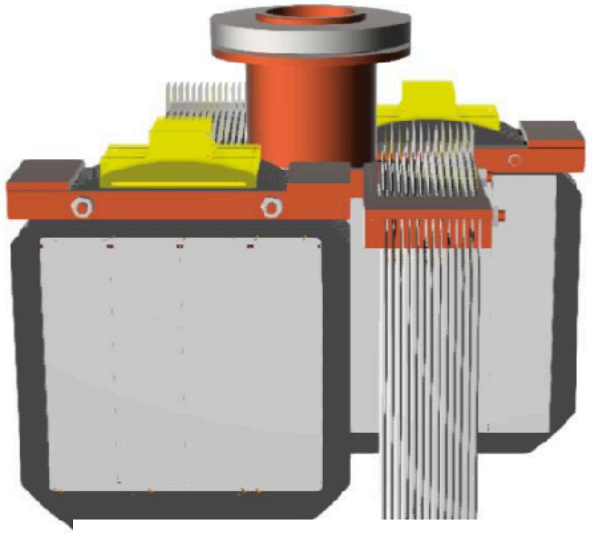
Space at LSM and activities in 2024

- Currently not enough space allocated to DAMIC-M at the LSM for CCD packaging and test

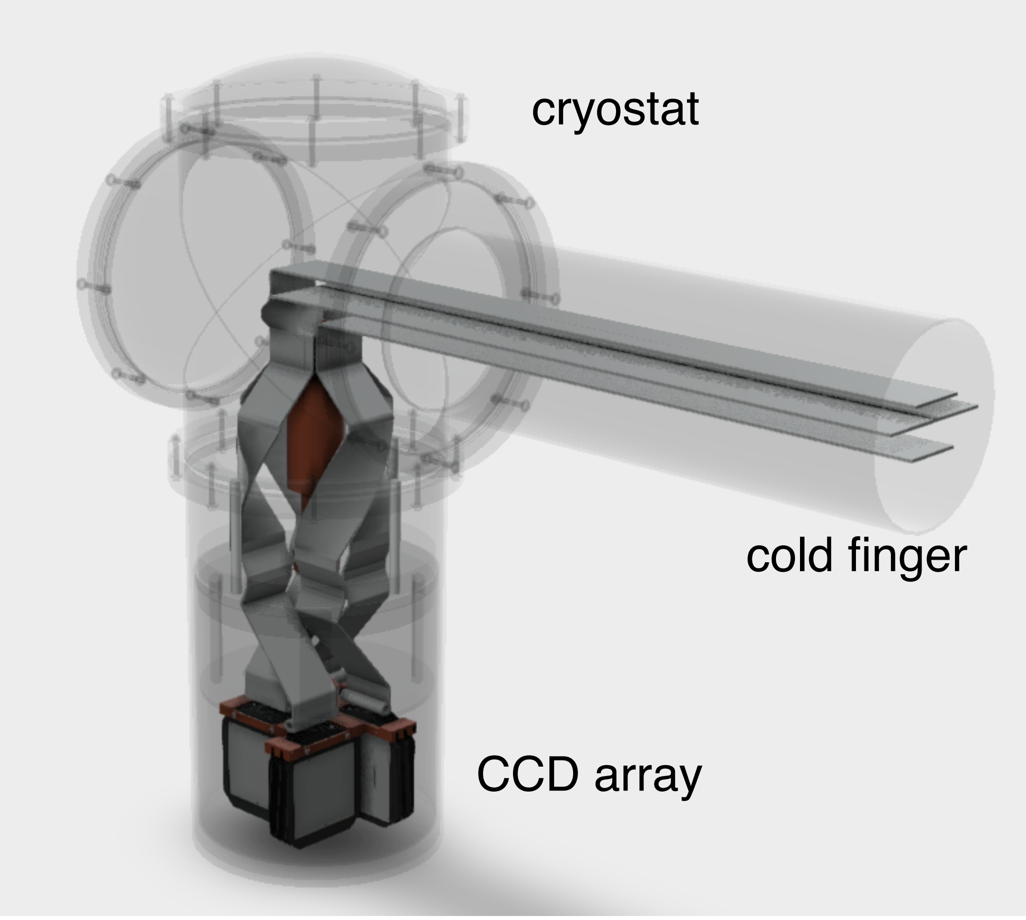
- We have made a formal request to LSM management for the use of EDELWEISS shielding and clean room to host the DAMIC-M detector. This would free the clean room currently hosting the LBC easing the pressure for space to host the packaging/testing activities

- Technical feasibility evaluated, OK
  Engineering design changes include placing the cryostat and CCD module array "upside-down" and mods to cryogenic system

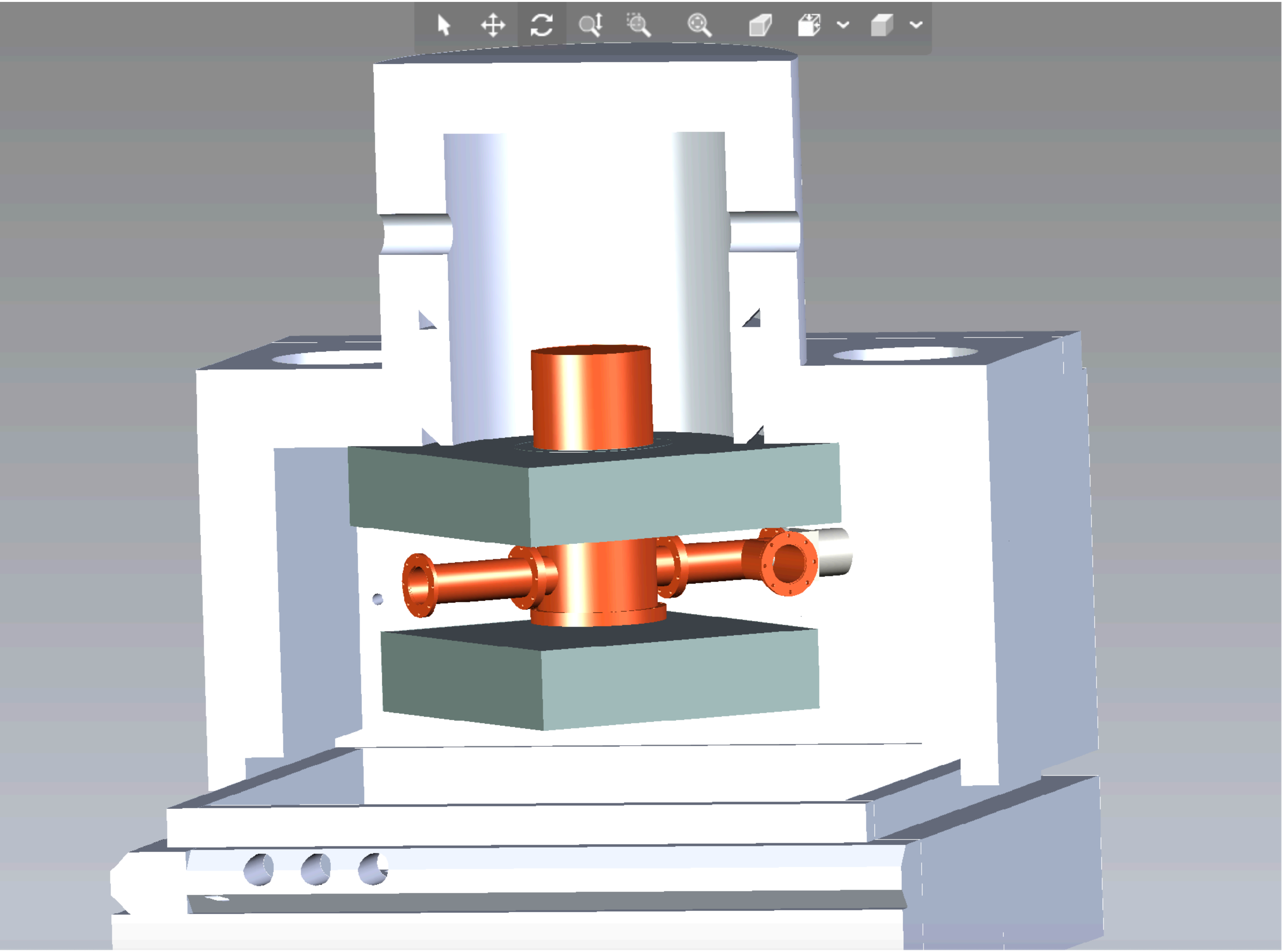
- We need from LSM a plan for making the necessary space available for DAMIC-M. The schedule presented here may be significantly affected

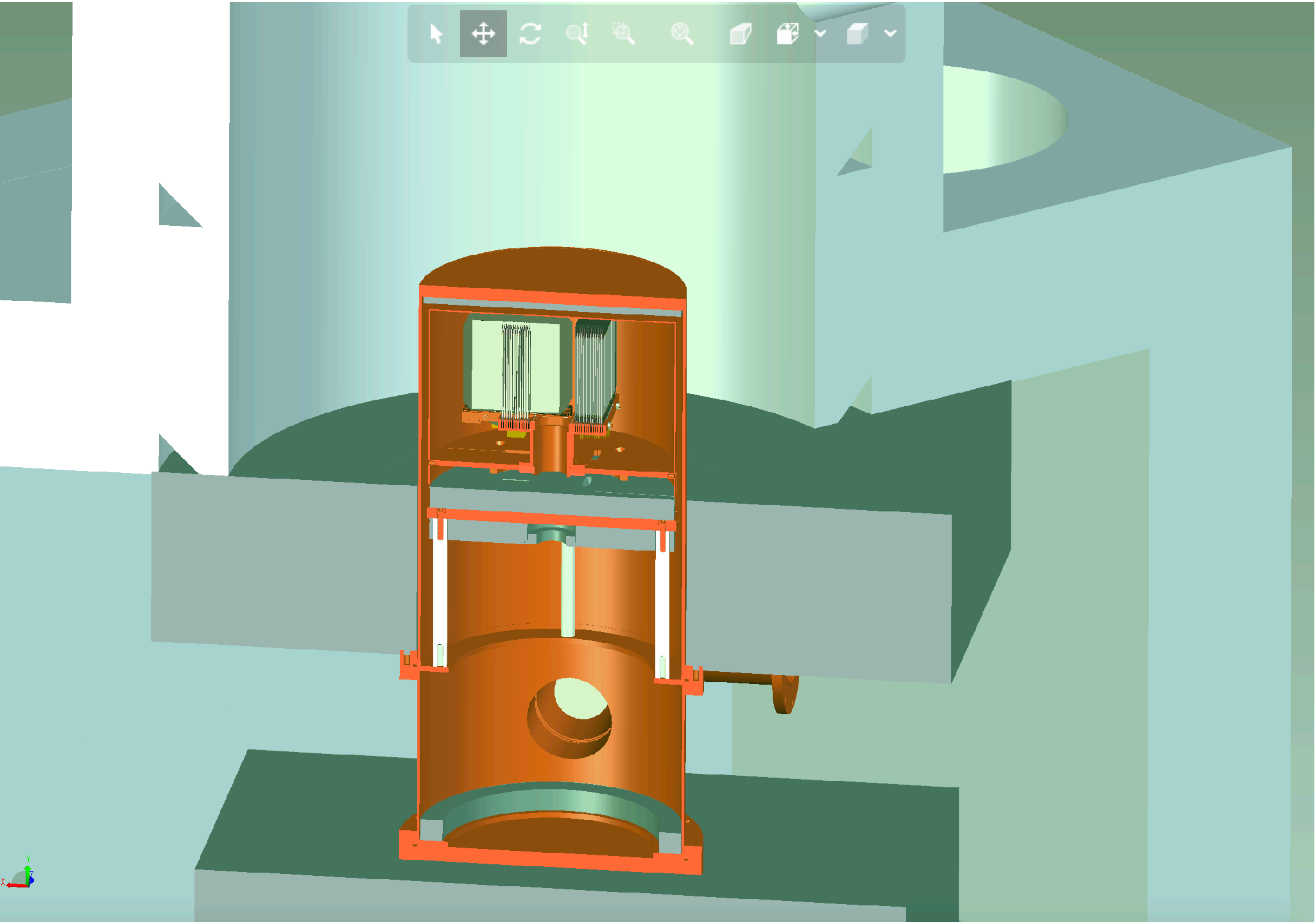


CCD module array

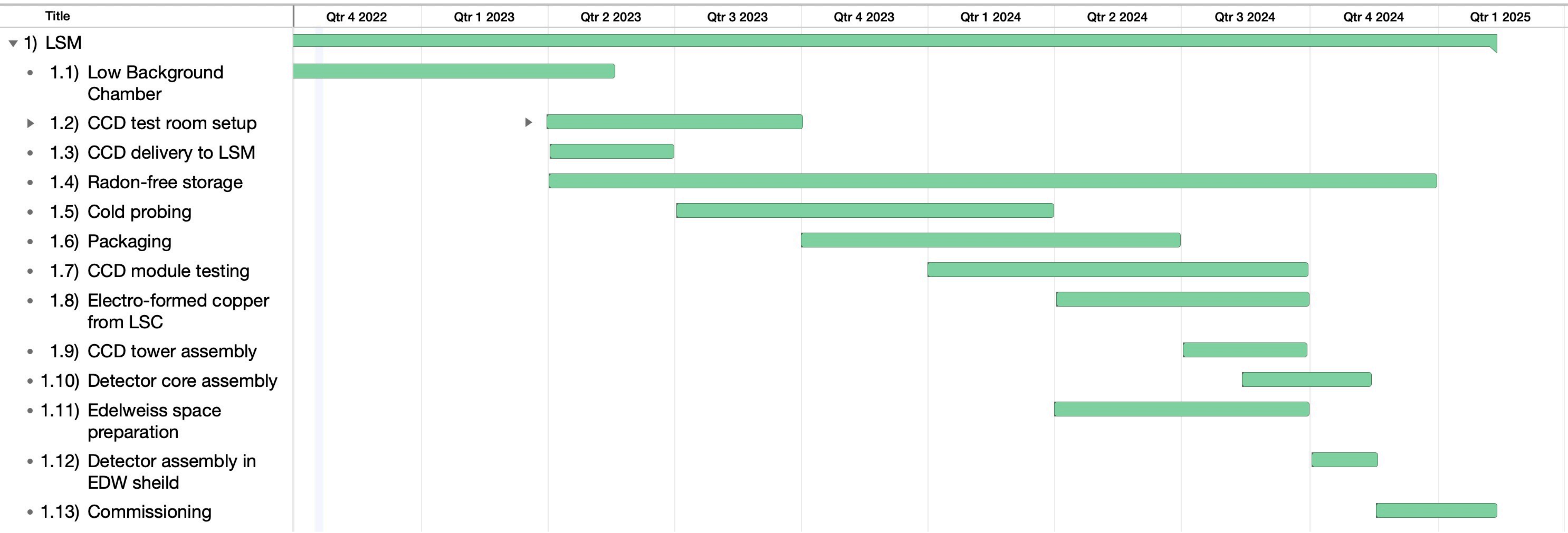


DAMIC-M original design





DAMIC-M Schedule (at LSM)



- This schedule has ample safety margins (e.g. CCD packaging/testing could be done in 4-6 months) Our goal is to complete installation in Q3 2024 and start data taking by the end of 2024. One year minimum of science data taking.

- **For a successful completion of the DAMIC-M program is essential that adequate space and infrastructure is allocated to the experiment in 2023 and 2024. The ERC Advanced Grant ends in 2024.**

Beyond DAMIC-M: Oscura

- Preparing for a 10-kg skipper CCD detector, R&D/design funded by DOE (US groups; now forming international collaboration)

- Ambitious experiment:
  - 20,000 CCDs (small size): production
  - 20 Gpixels low noise electronics
  - goal of 10 times lower background than DAMIC-M

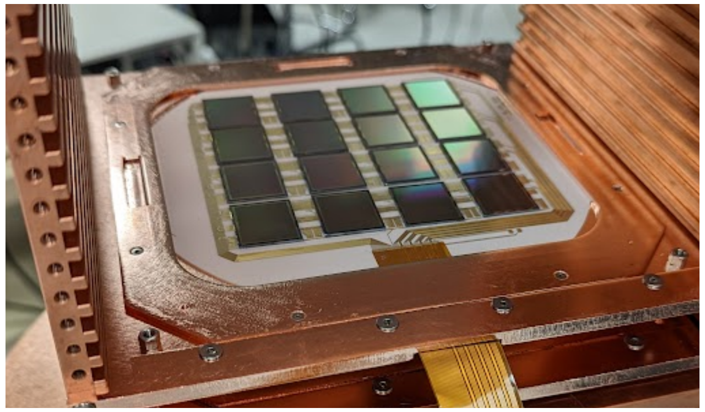
- Oscura schedule well aligned with DAMIC-M

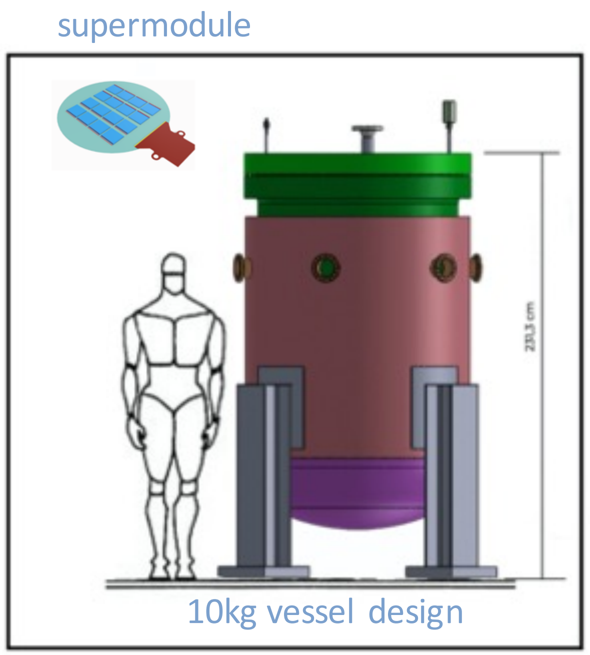
FY20-FY22:	R&D
FY23-FY24:	Design
FY25-FY28:	Construction(~$10M)
FY28-FY30:	Operations

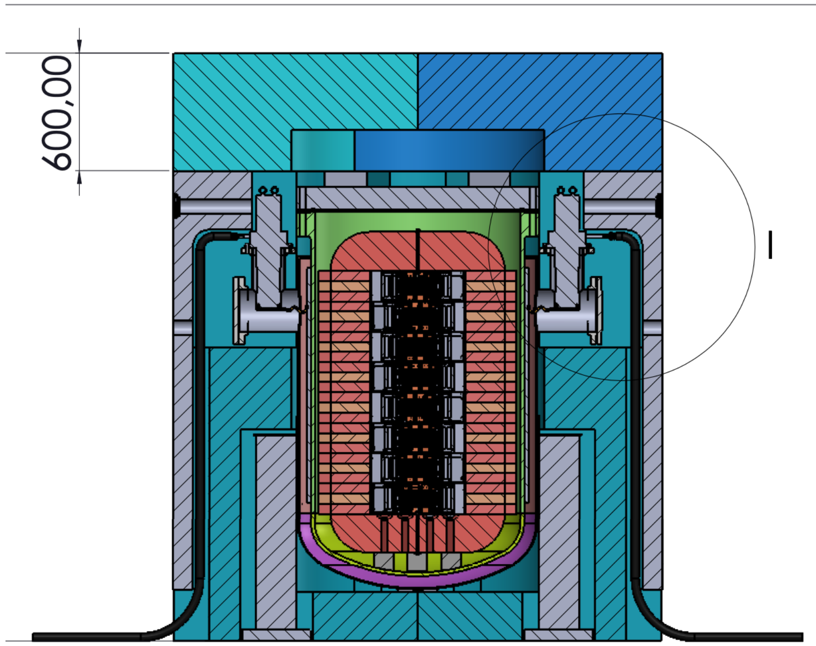
- DAMIC-M success essential for the Oscura program: kg size detector, understanding of backgrounds and dark current

- LSM potential involvement:
  - host full detector (discussions with SNOLAB already advanced)
  - use DAMIC-M as a low-background test setup to validate Oscura design; first science

Test vessel instrumented with 160 microchip skipper-CCDs.







Summary

- DAMIC-M has started its activities at LSM with the successful installation and commissioning of the Low Background Chamber. The LBC is an important milestone in the DAMIC-M program, providing first science results, background evaluation and test of DAMIC-M components. **We would like to keep the LBC operational as long as possible** (will depend on LSM space plan)

- 2023-2024 will be very busy… Production of all DAMIC-M components (CCDs, e.f. copper, cryostat, electronics, etc.); CCD packaging and testing; cryostat installation in shielding. **For a successful completion of the DAMIC-M program is essential that adequate space and infrastructure is allocated to the experiment in 2023 and 2024. We have requested the use of the EDELWEISS shielding.**

- Oscura, a next-generation, 10 kg, experiment based on the skipper CCD technology is in advanced R&D phase. Opportunity for LSM to leverage DAMIC-M investment.