GDR Deep Underground Physics plenary meeting

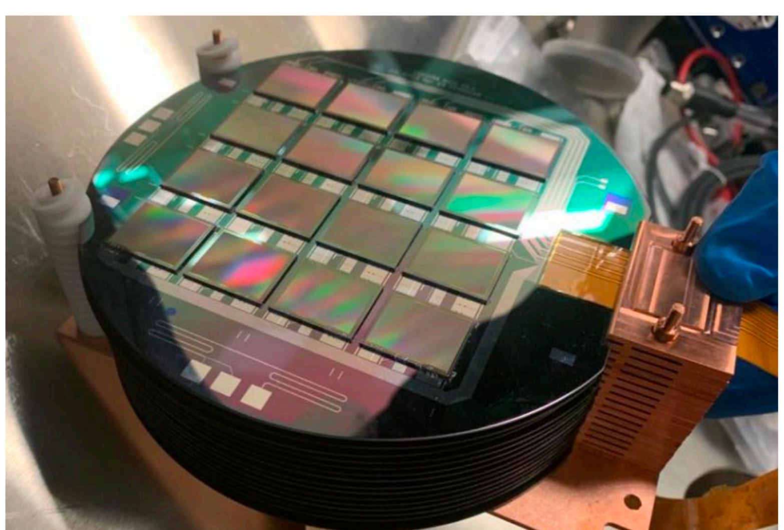
Jun 21 – 23, 2023

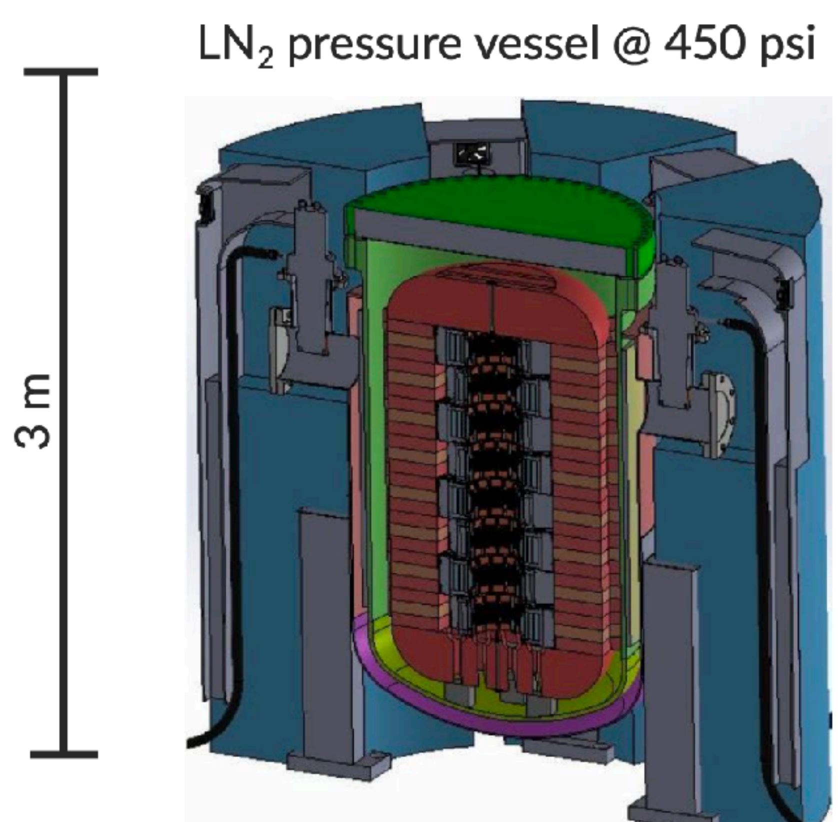
The Oscura experiment

Paolo Privitera

for the Oscura Collaboration

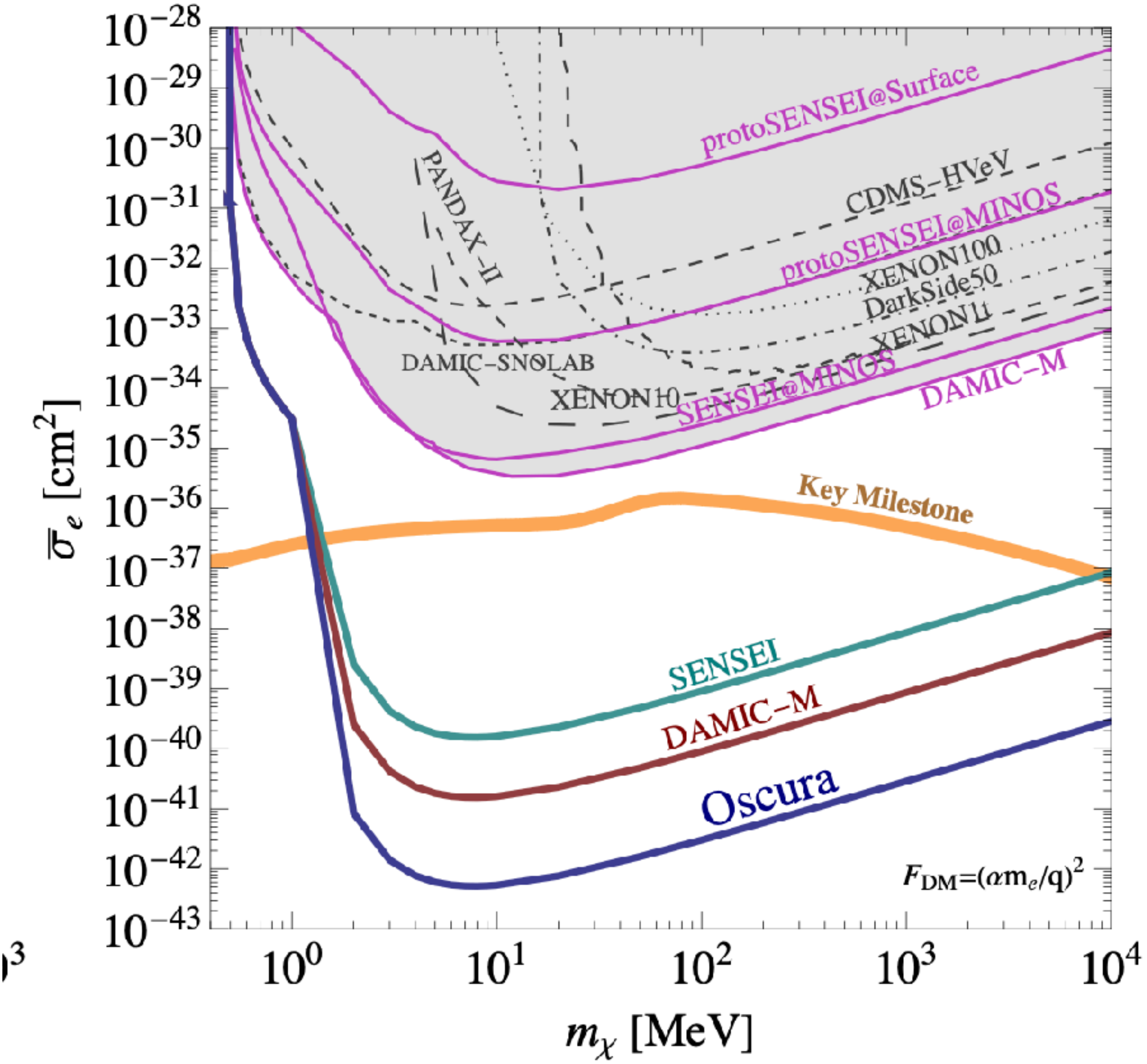
- Context
- Overall design
- Major challenges and R&D
- Timeline, DAMIC-M and Oscura





Context

Skipper CCDs have provided the world best limits on sub-GeV DM interacting with electrons.
To exploit this technology a program of experiments with increasing sensitivity is in place



	SENSEI	DAMIC-M	Oscura
n. of CCDs	50	200	20000
mass (kg)	0.1	1	10
bkg (dru)	10	0.1	0.01
Lab	SNOLAB	LSM	SNOLAB (likely)

Challenges for Oscura: increase in mass (i.e. n. CCDs and associated electronics) and substantial decrease in background

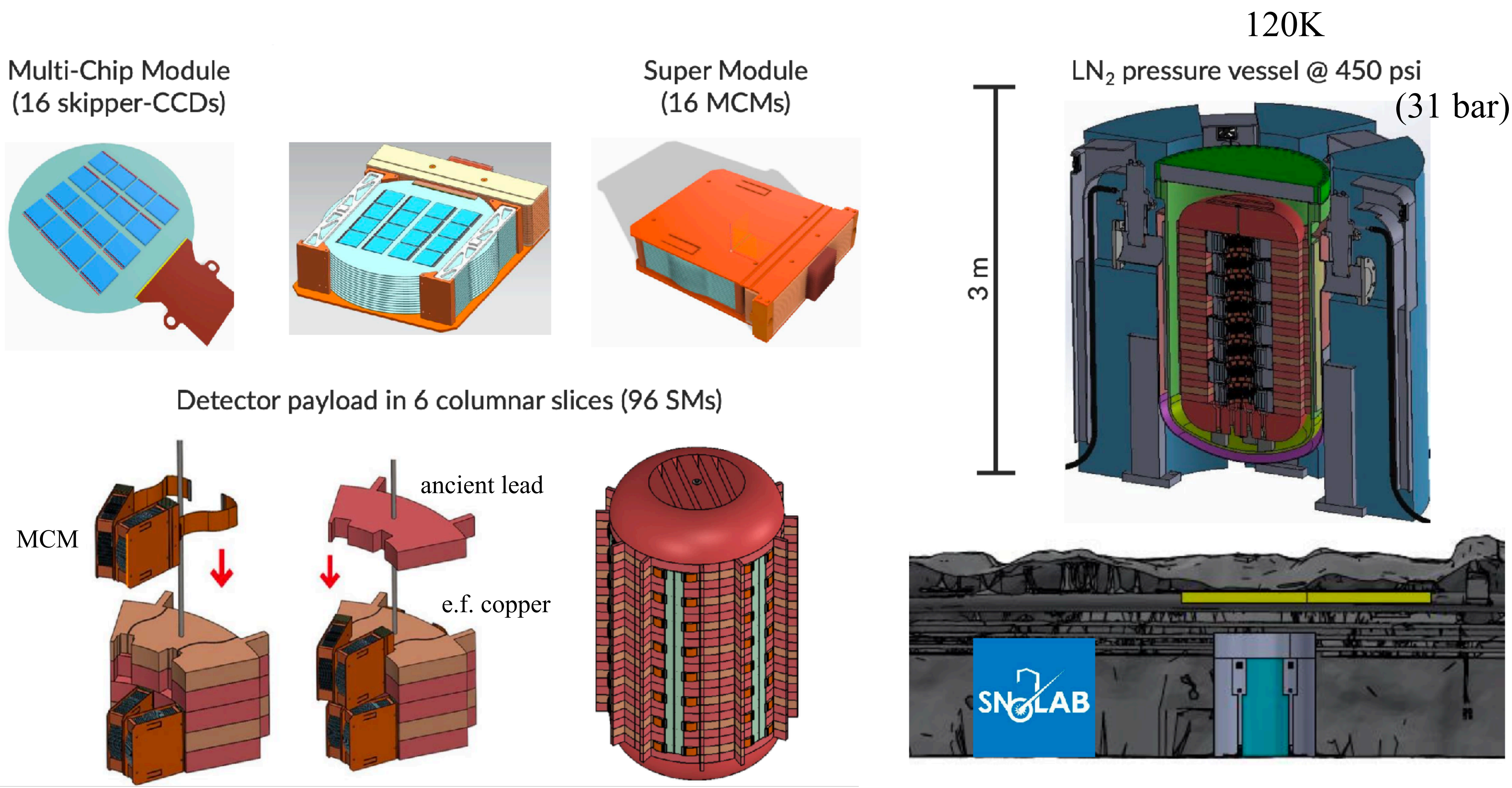
Major R&D required!

Oscura: 10-kg skipper CCD experiment

[arXiv:2202.10518]

Oscura in a nutshell:

- 10 kg detector, 20000 skipper CCDs (small format 1kx1k to reduce readout time)
- CCDs immersed in a LN_2 pressure vessel
- e.f. copper and ancient lead for internal shielding
- dedicated ASIC FE and multiplexing (in LN_2)



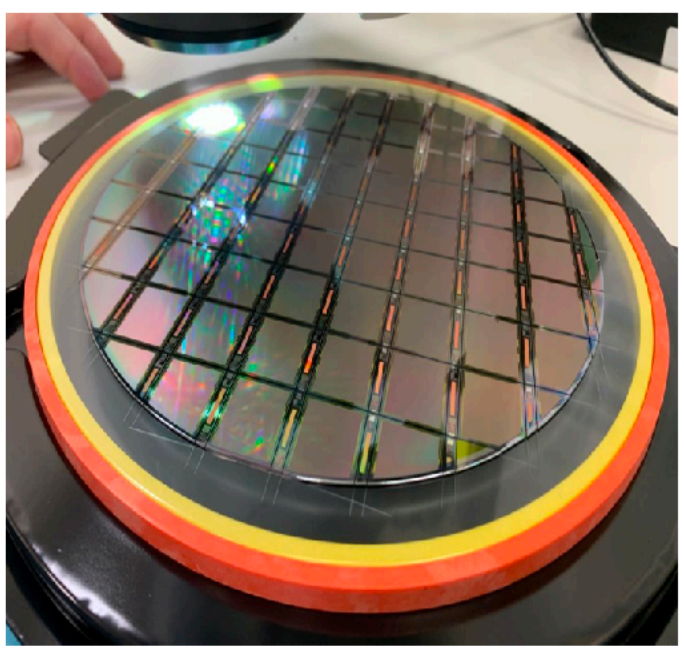
Sensors fabrication

- Teledyne/DALSA (Canada), which has developed with Steve Holland (LBNL) the high-resistivity, high-voltage process required for the extremely low dark current CCDs of the DM program (DAMIC, SENSEI, and DAMIC-M) will discontinue its 6” production line

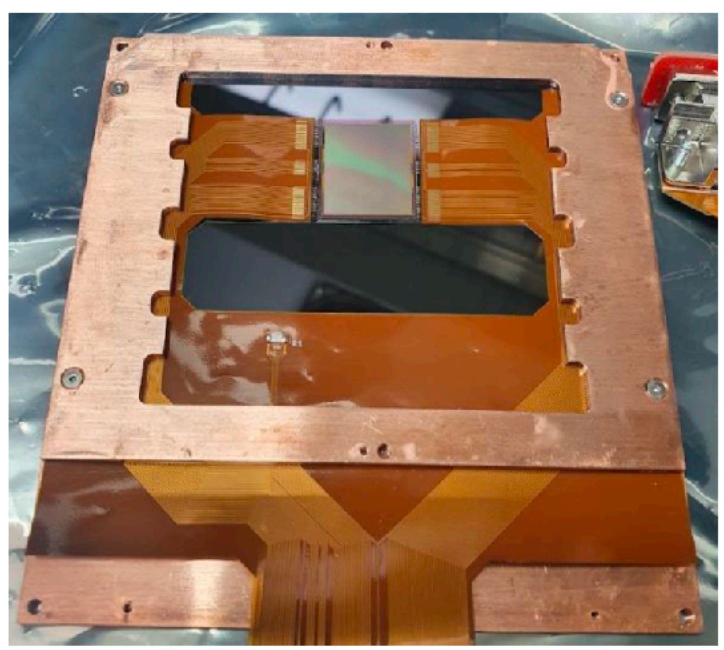
- Partnership with Microchip and Lincoln Lab (both in the USA) for the transfer of knowledge

- Oscura prototype CCDs (1kx1k pixels) successfully fabricated and tested **[NIMA 1046 (2023), 167681]**

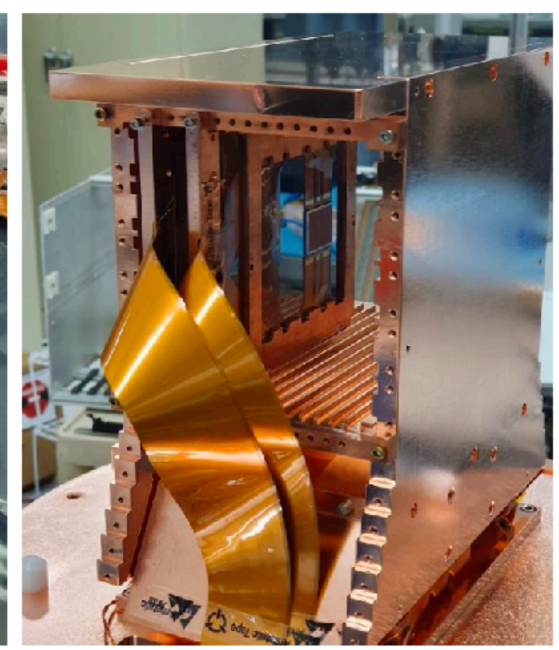
  8” = 200 mm wafer, thickness = 725 **μ**m, pixel size 15 **μ**m x 15 **μ**m



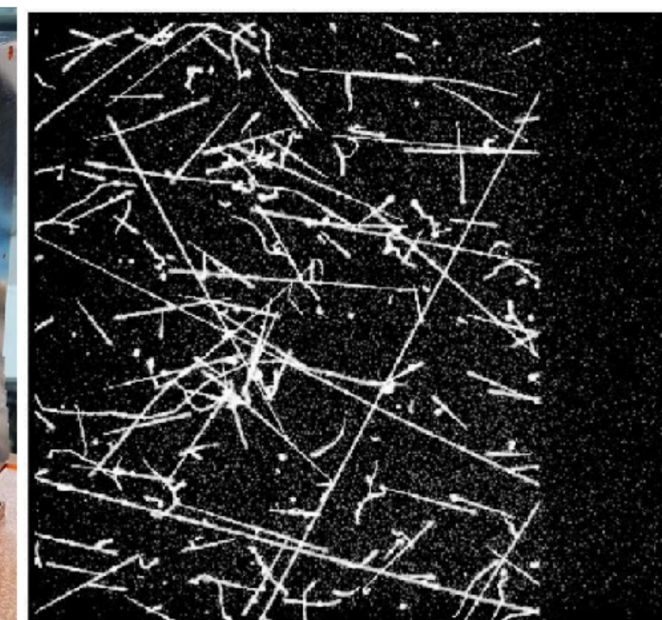
diced CCDs from 8” wafer



Oscura CCD packaged



Oscura CCD test box



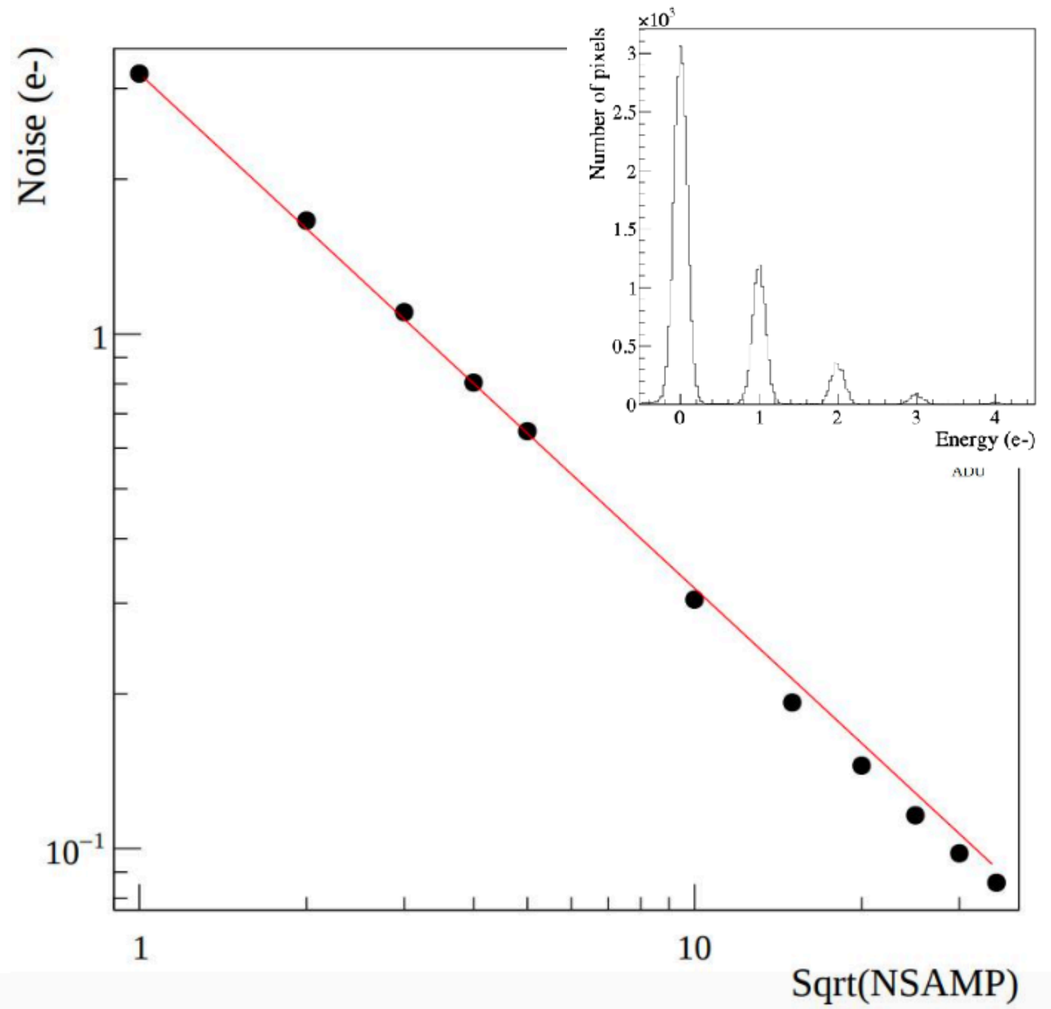
Oscura CCD tracks

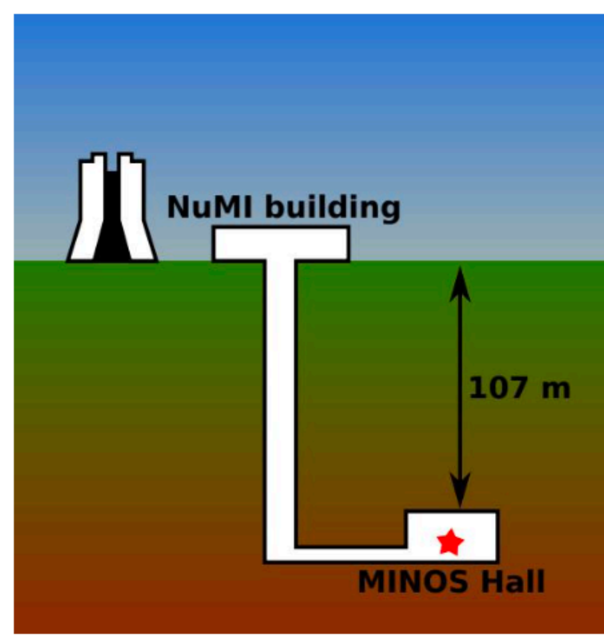
Sensors Performance

Encouraging results for this first production

Parameter	No events with >1e-	No events with 3e- or more		Prototype	Units
Dark current	1×10^{-6}	1.6×10^{-4}	✓	3×10^{-2}	e^-/pix/day
Readout time for full array	< 2	< 5	✓	3.4 (4.2)	hours
Pixel readout rate	> 188	> 76	✓	111 (89)	pix/s
Readout noise	< 0.16	< 0.20	✓	0.19 (0.20)	e^- RMS
Spurious charge	$< 10^{-10}$	$< 10^{-8}$		7.2×10^{-7}	e^-/pix/transfer
Trap density with $\tau > 5.3$ ms	< 0.12		✓	< 0.015	traps/pix
Charge transfer inefficiency	$< 10^{-5}$		✓	$< 5 \times 10^{-5}$	1/transfer
VIS/NIR light blocking	$> 90\%$		✓	95%	

- sub-electron resolution achieved
- most of the requirements are fulfilled
- dark current to be measured underground at MINOS (Fermilab)

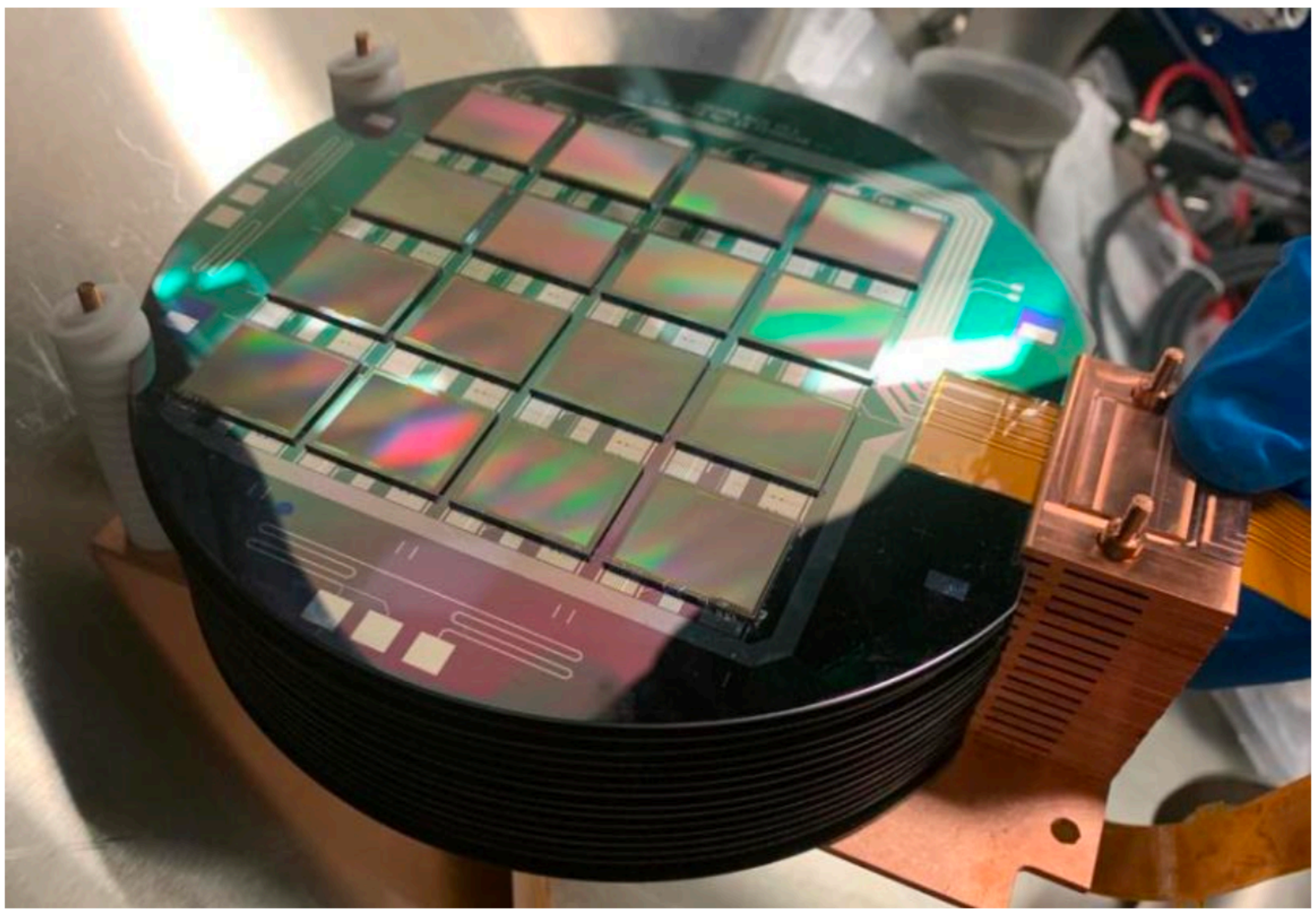




Packaging of Multi Chip Modules

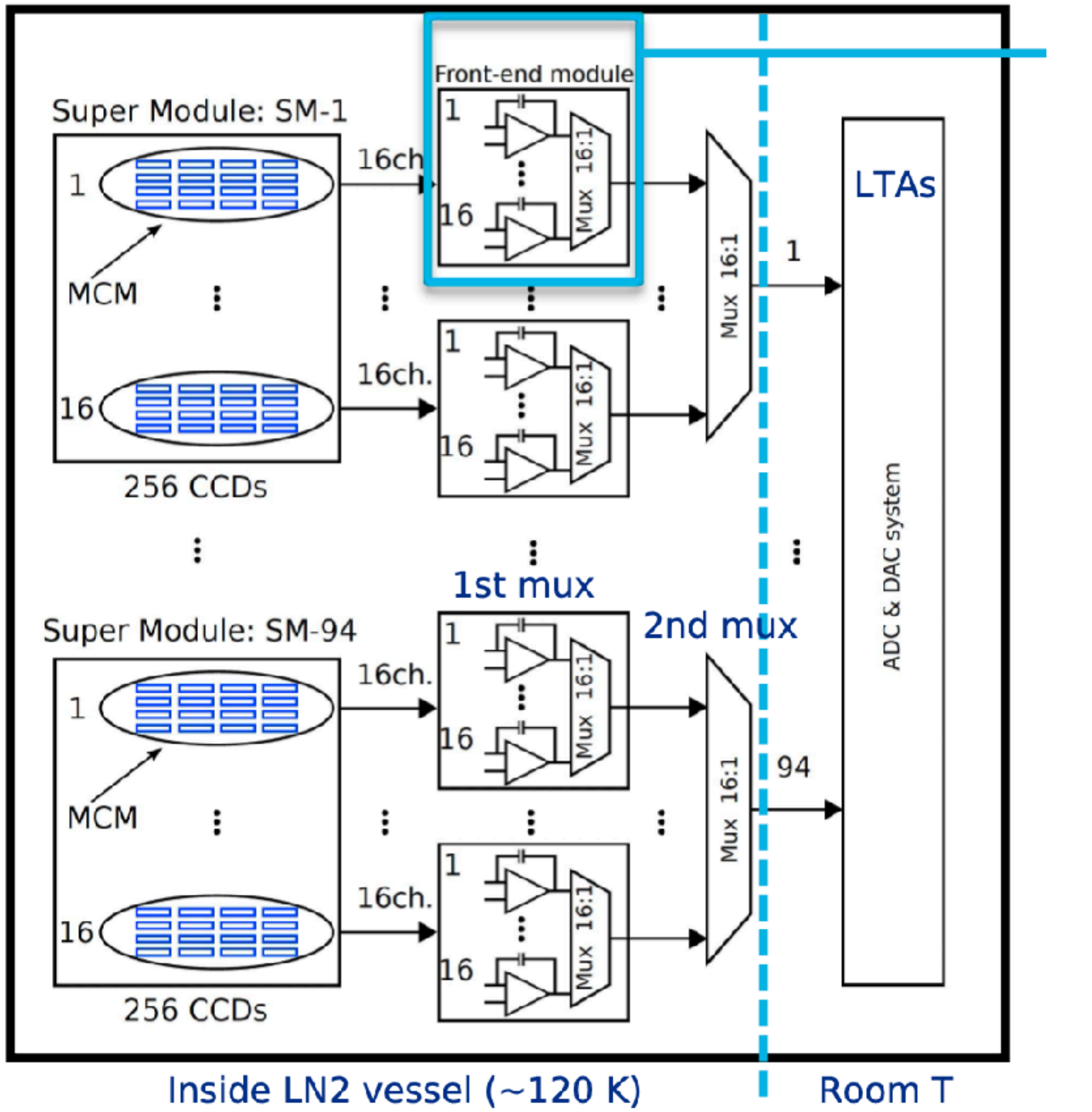
- Fabrication of prototype MCMs at the Argonne National Lab facilities (fabrication of Si pitch adapter, glueing of sensors and flex cable, wire bonding)

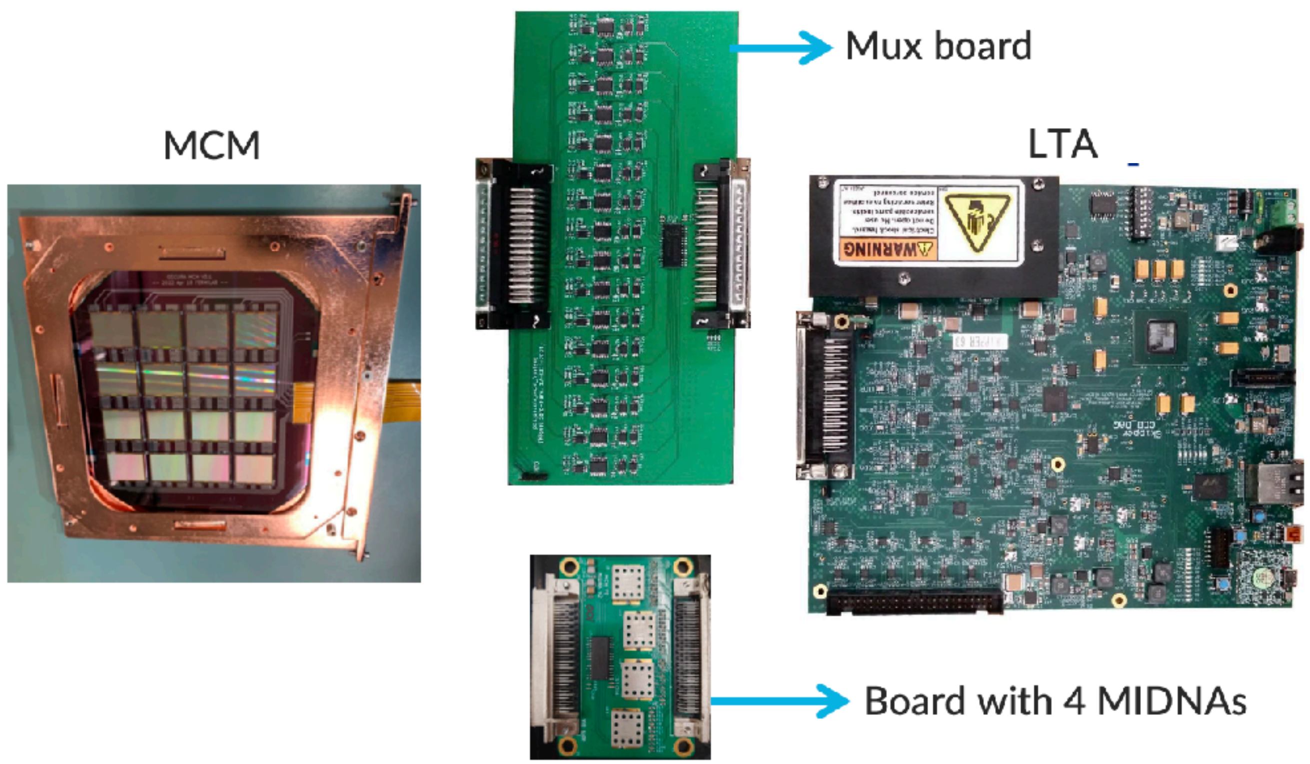
- About 1500 MCMs needed for Oscura: we plan to automatize the packaging procedures (manual for these first prototypes)



Readout electronics

- approx 24000 channels to be readout
- Cold front end electronics and multiplexing to reduce complexity (only 94 cables to feedthrough the vessel)
- 256 multiplexing (2x16 multiplex)
- One LTA CCD controller to drive 4 Super Modules (1024 CCDs); 24 LTAs for the entire experiment



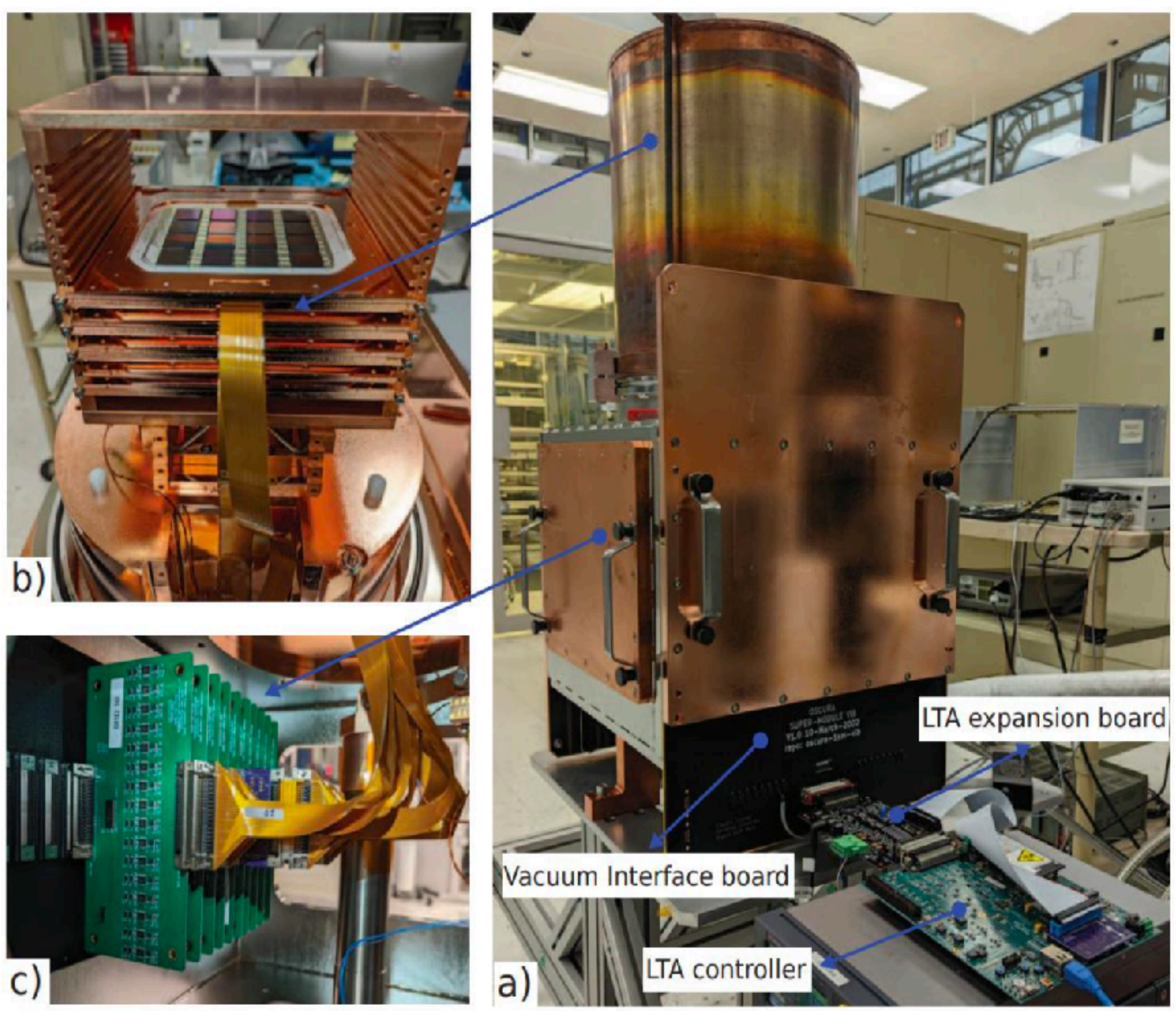


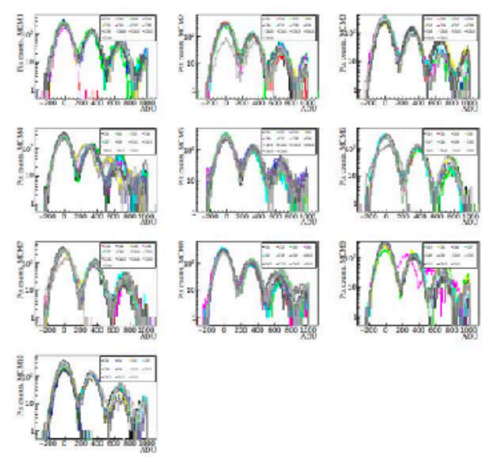
- MIDNA ASIC performs analogically the Correlated Double Sampling
- The full chain has been prototyped and successfully tested

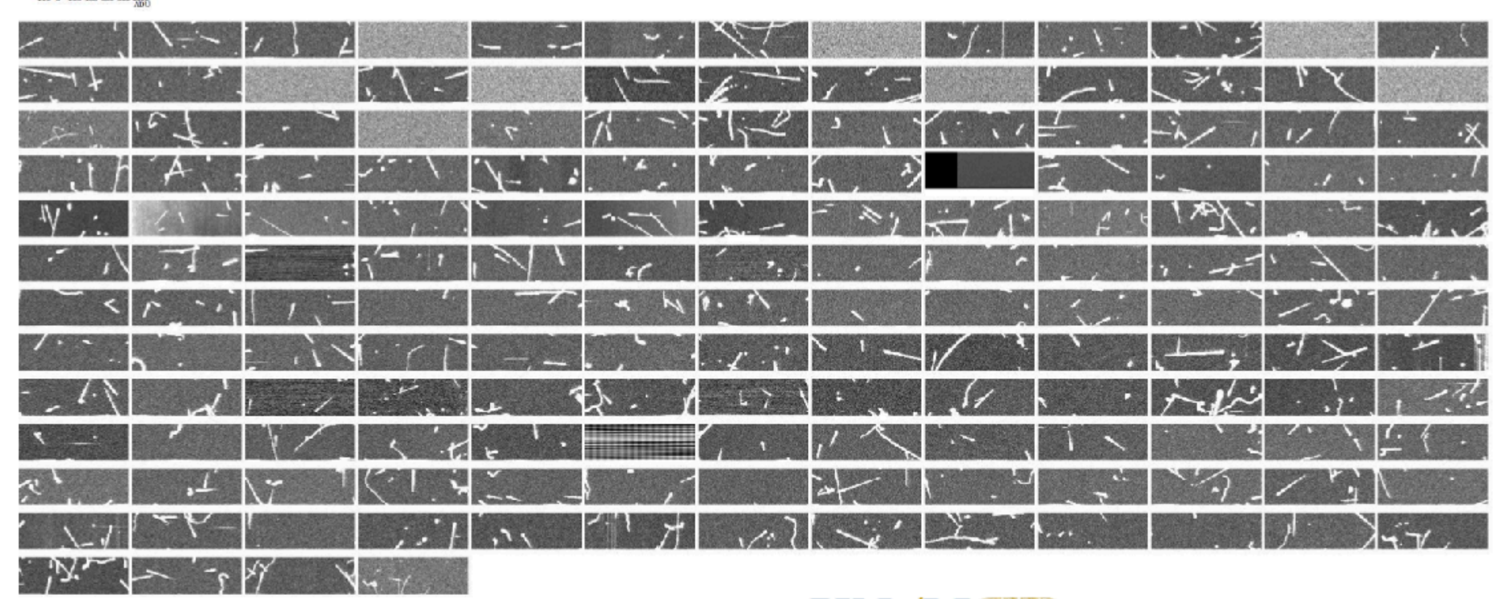
First Test with 10 MCMs (160 CCDs)

[JINST 18 P01040]

- Readout by a single LTA. Demonstrates the feasibility of the multiplexing scheme
- Large n. of CCDs (compare with LSST, 189 CCDs)
- 90% of the CCDs worked without any preselection: excellent yield!

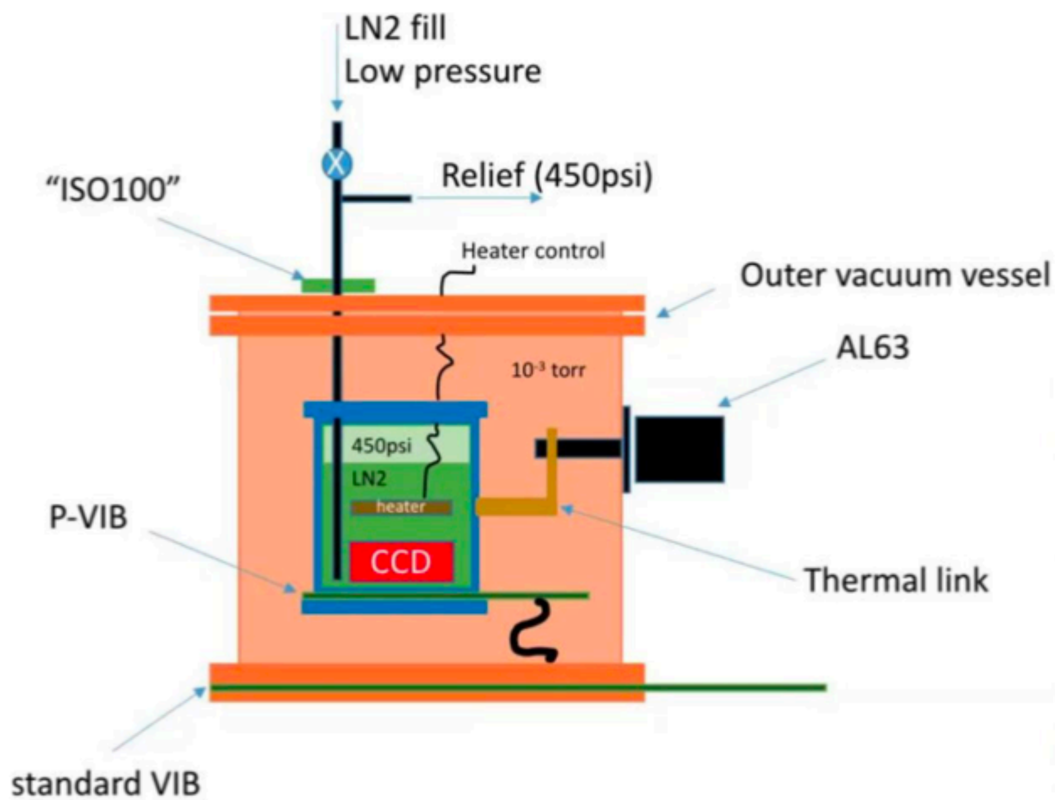






LN2 Cooling

- first tested with a single CCD (electronics outside the vessel)



- last week we successfully operated a MCM with cold electronics

- LN_2 scintillation (no measurement in the literature): preliminary measurements indicate it should not be a problem

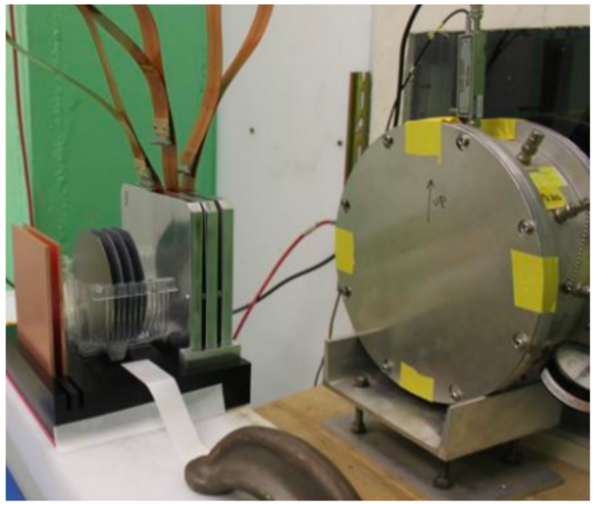
Oscura background control

Main background components

- Cosmogenic activation of Si and Cu

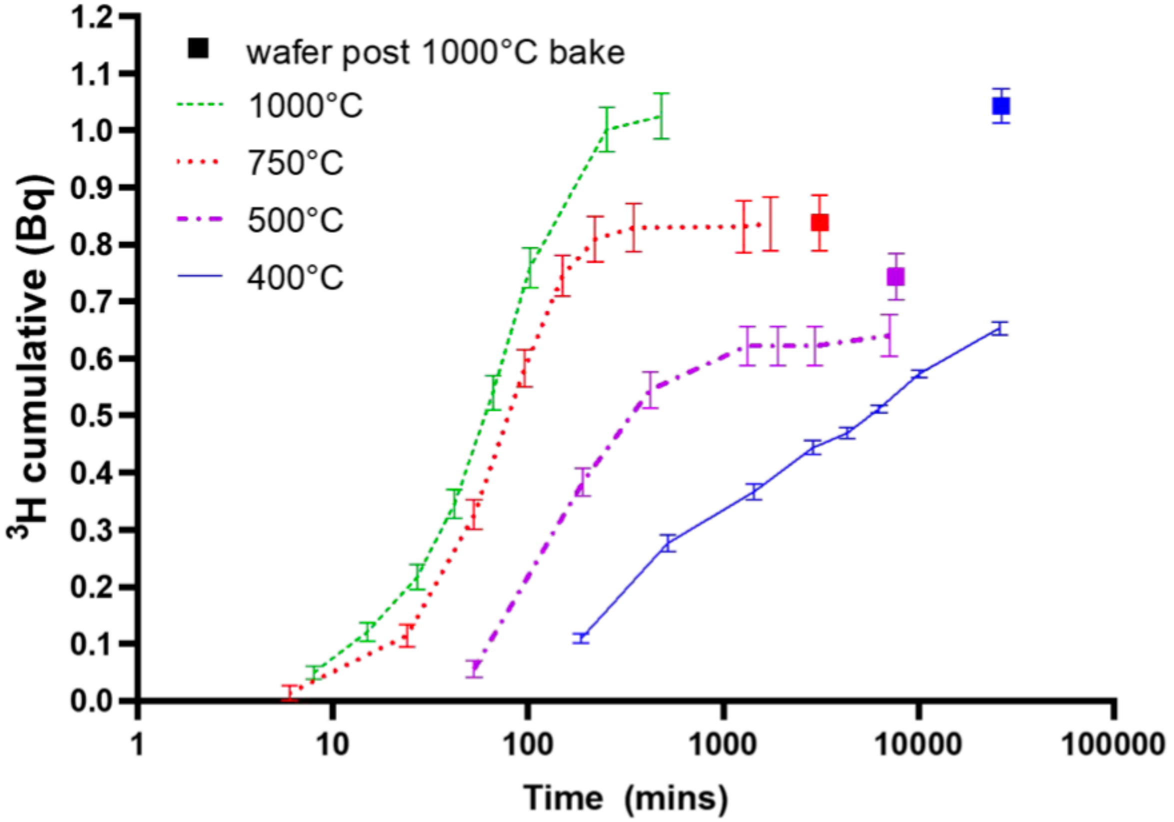
Cu: e.f. copper facility underground at SNOLAB

Si: Tritium accumulates at 2 mdru/day at sea level; 5 days max. exposure!



Silicon wafers exposed to Los Alamos neutron beam

- use of underground storage and shielded containers for transport (DAMIC-M)



baking successfully eliminates bulk tritium

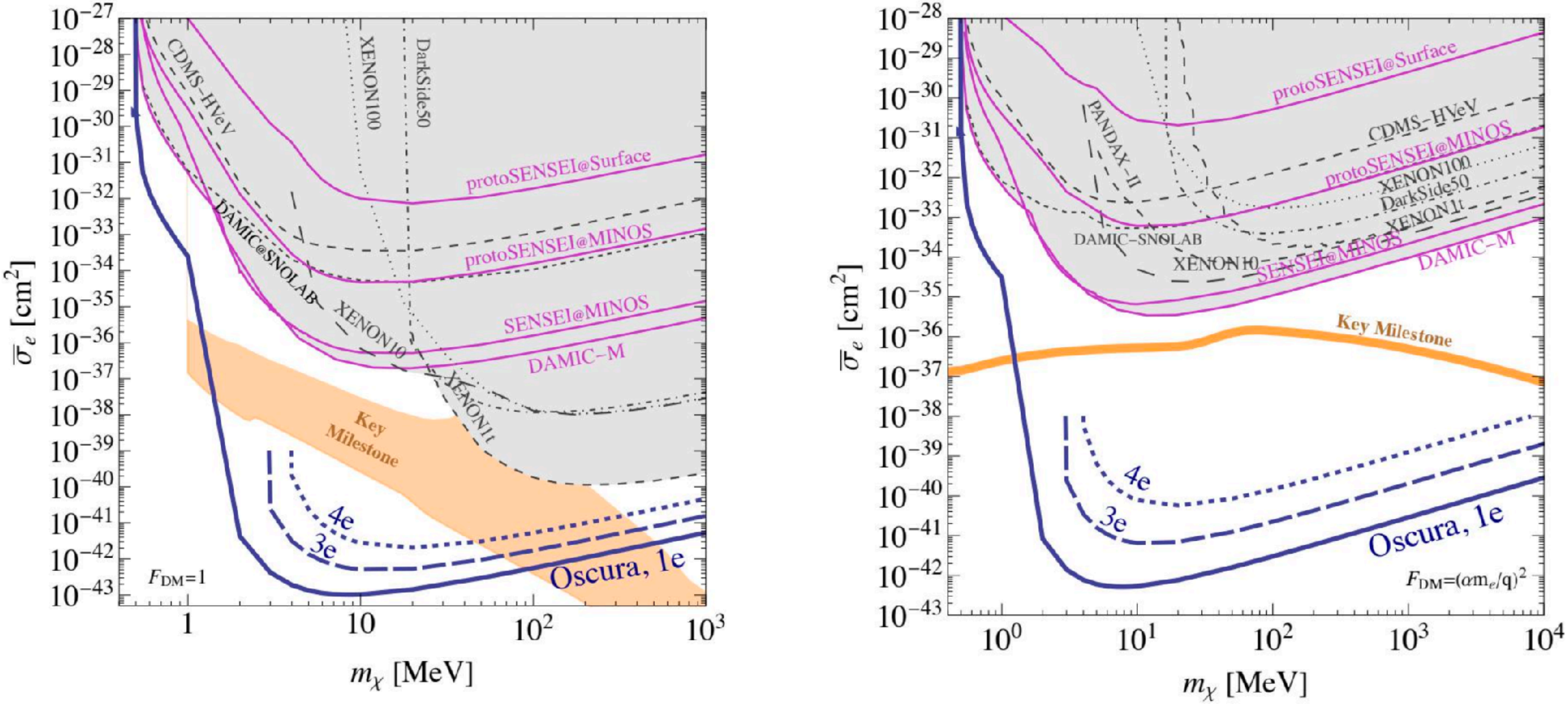
- Radiogenic backgrounds from electronics, cables and material close to the CCDs

DAMIC-M cable	^{238}U [ppt]	^{232}Th [ppt]
Commercial	2670 +/- 30	270 +/- 60
Customed	31 +/- 1	11 +/- 1

DAMIC-M essential to demonstrate feasibility of Oscura background goal (0.01 dru)

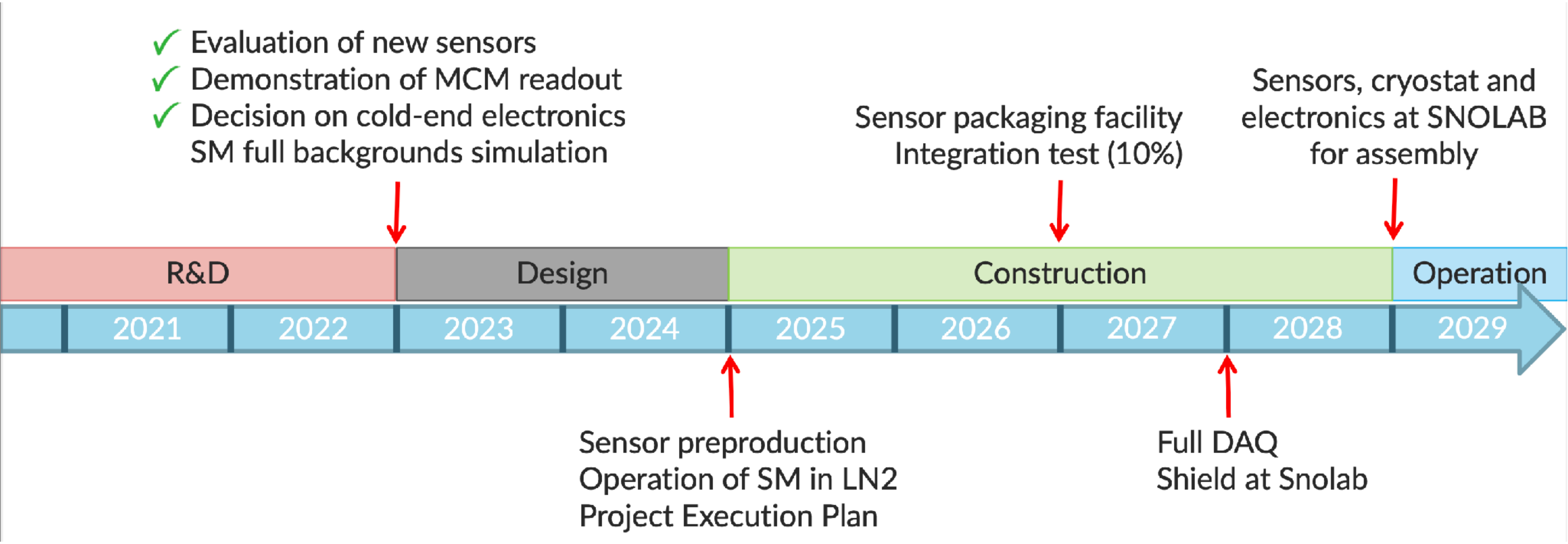
Oscura Sensitivity

30 kg yr



DM-electron scattering mediated by a heavy (left) or light (right) mediator

Oscura Timeline



Outlook, DAMIC-M and Oscura

- Oscura is an ambitious project built on the success of the CCD technology for low-mass DM searches. Now in advanced R&D stage, with most of its technical challenges resolved
- Many of DAMIC-M solutions are essential for Oscura (e.g. background control)
- DAMIC-M and Oscura schedules are nicely staggered: DAMIC-M scientific goals achieved by end of 2026, while one kg integration-test Oscura detector is assembled
- DAMIC-M will be the lowest background apparatus with infrastructure specifically for CCDs, available before Oscura. Can be very effectively used to test Oscura components (e.g. electronics chain, MCM, SM, 1-kg integration test) and perform early science
- The current infrastructure at LSM does not allow hosting the full Oscura experiment (e.f. copper facility; radon-free air) but DAMIC-M can contribute to its development as a low-background test apparatus