What can photos taken inside a mountain tell us about the nature of dark matter?

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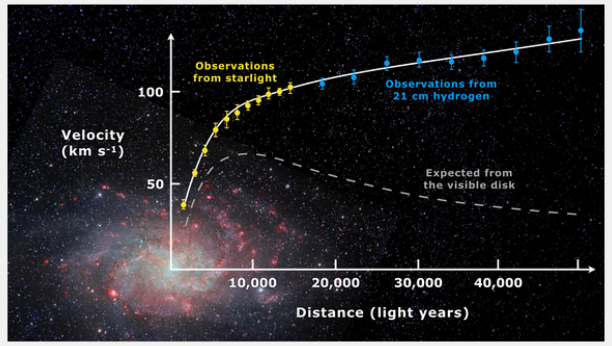
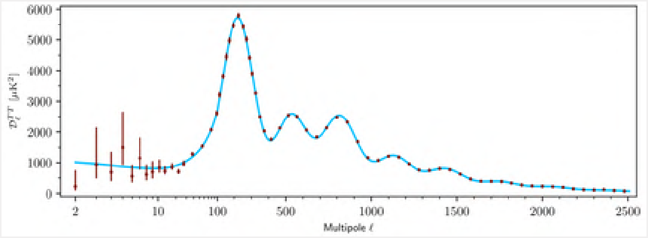
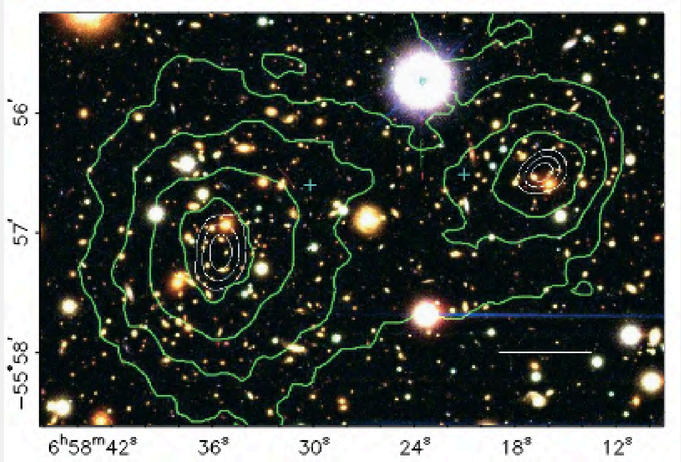
Direct detection of dark matter

We start by assuming there is some component of the Universe that is not baryonic and makes up about 85% of the matter budget.







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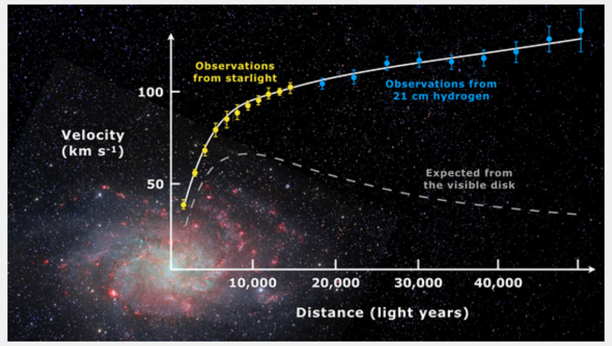

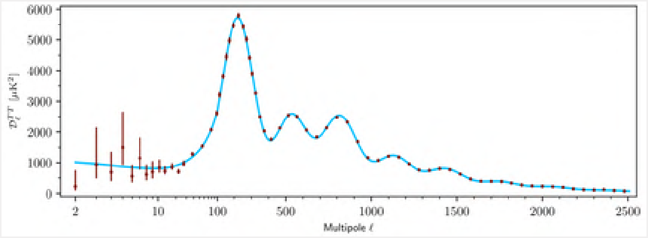

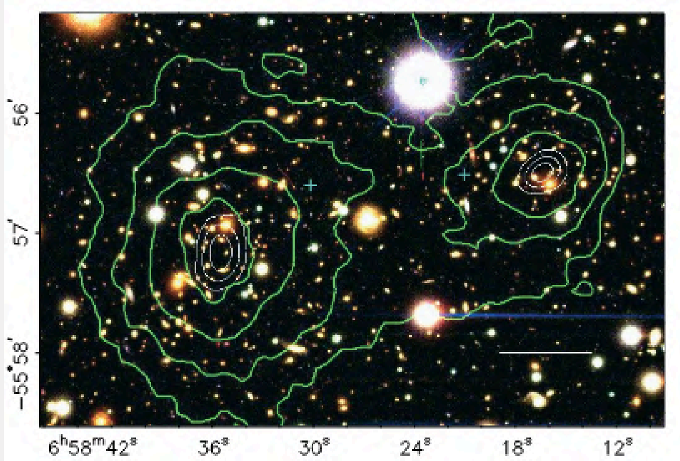

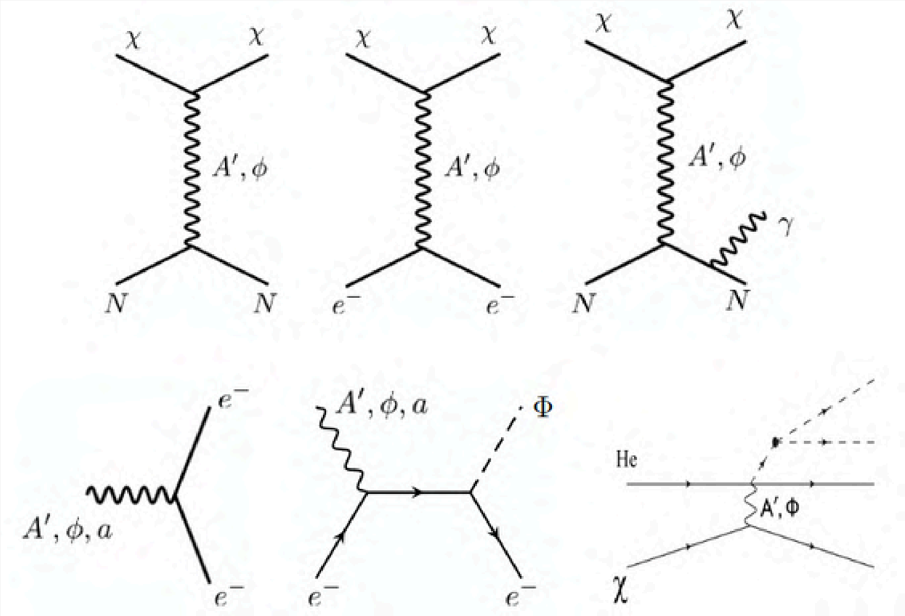

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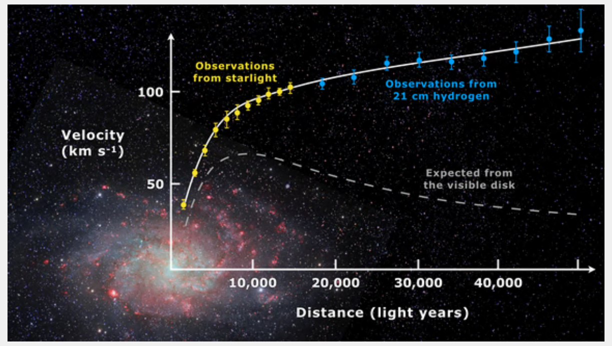
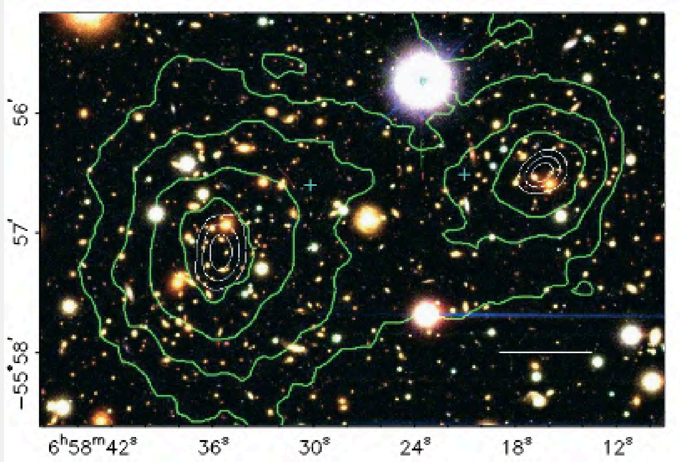
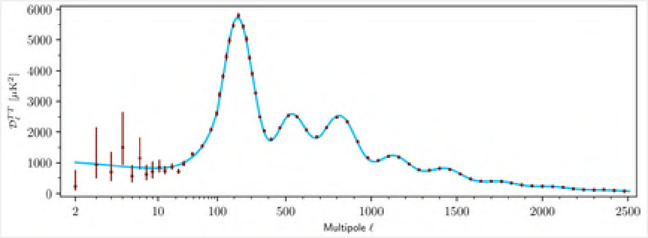
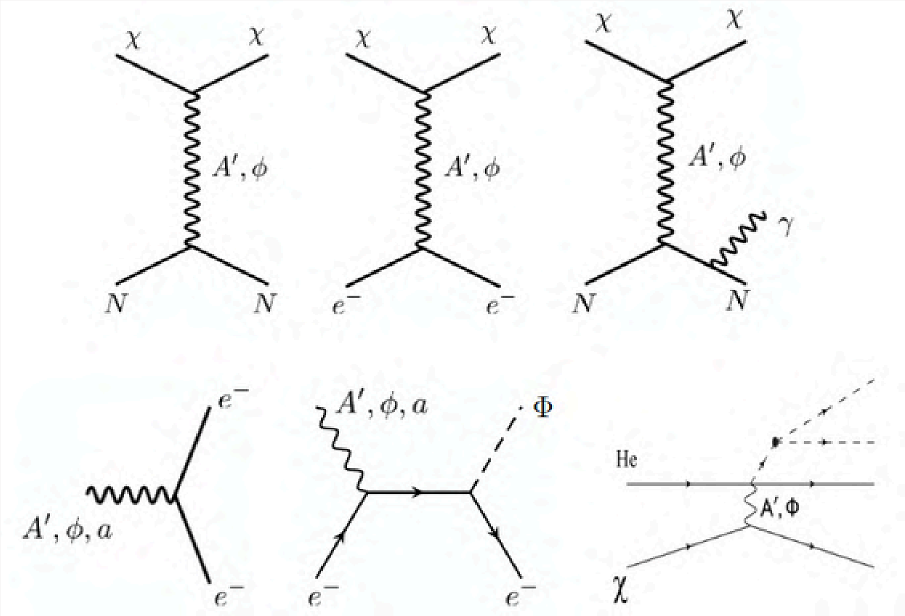


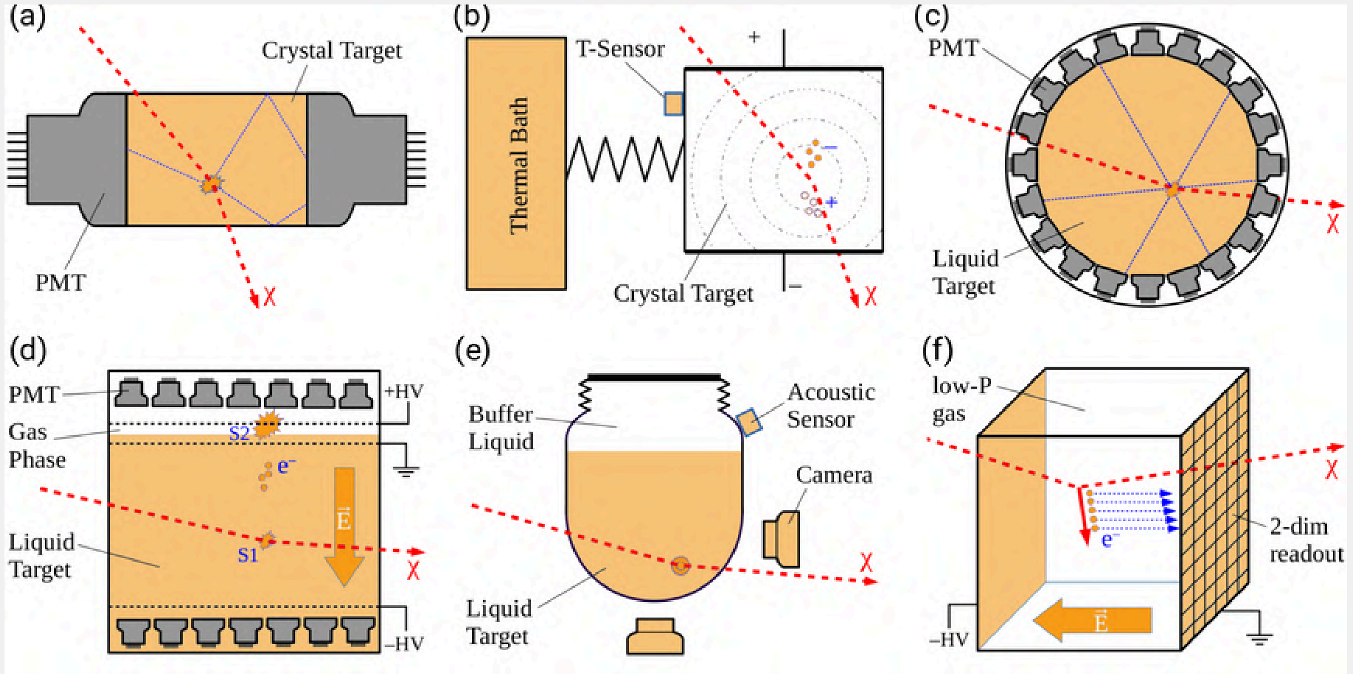






Now we make an extra assumption: dark matter can communicate with ordinary matter via some interaction other than gravity.

Perfect, we're ready to go. Grab your favorite target material, your favorite theory, go to some low-background site (the deeper, the better) and embrace the void results in your data.

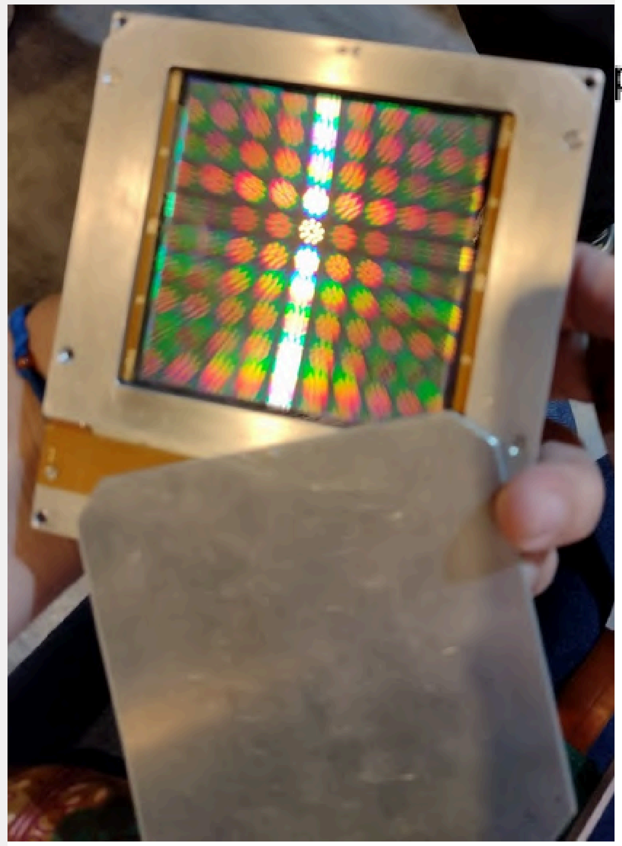


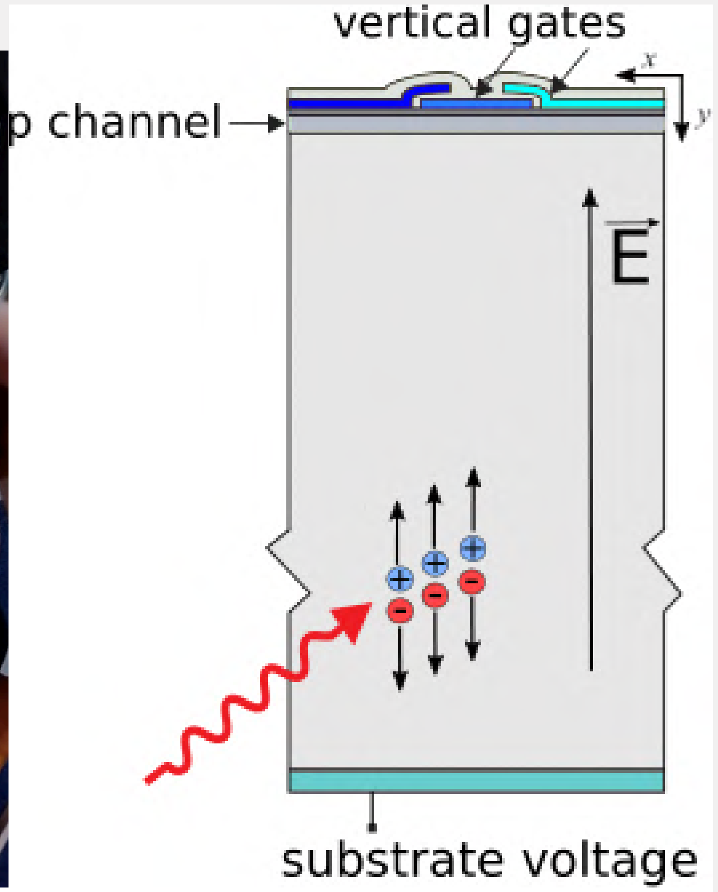
Our target of choice: silicon

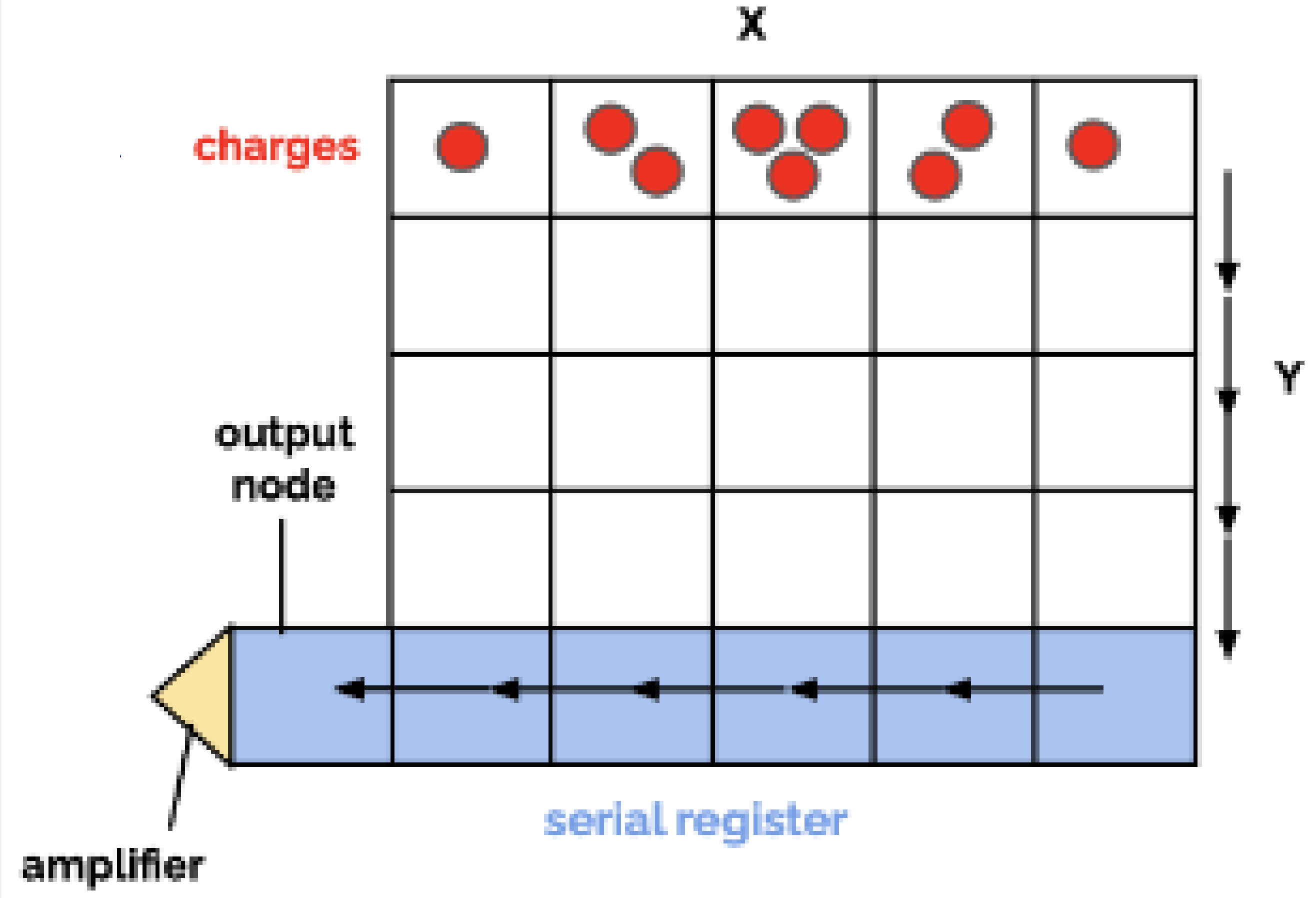
It is a semiconductor, which means that it has a very small gap between the conduction and the valence bands.

Therefore, our energy threshold can be as low as this bandgap: 1.2 eV (*)

Also, silicon detectors are already well developed; specifically, Charge-Coupled Devices (CCDs) have been used as photographic cameras since the 1970s.







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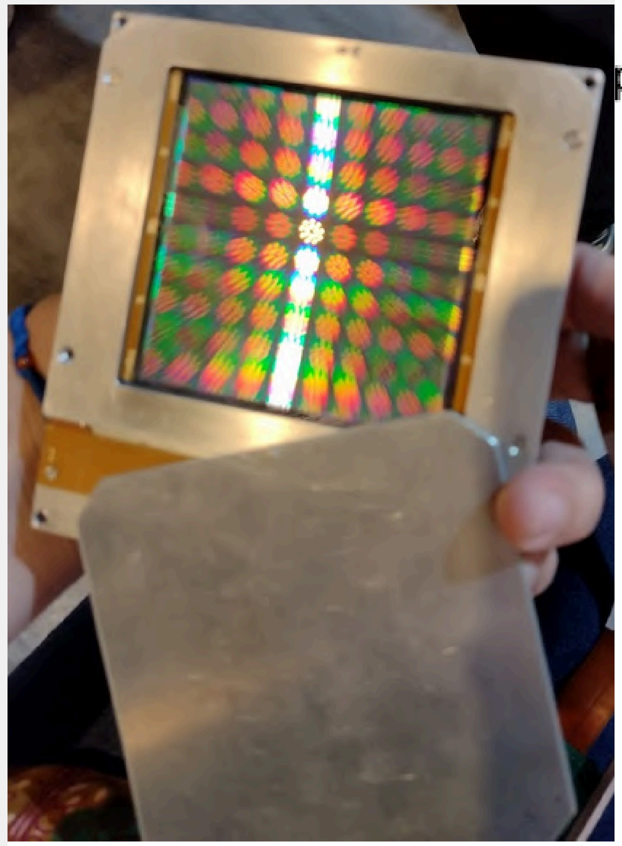
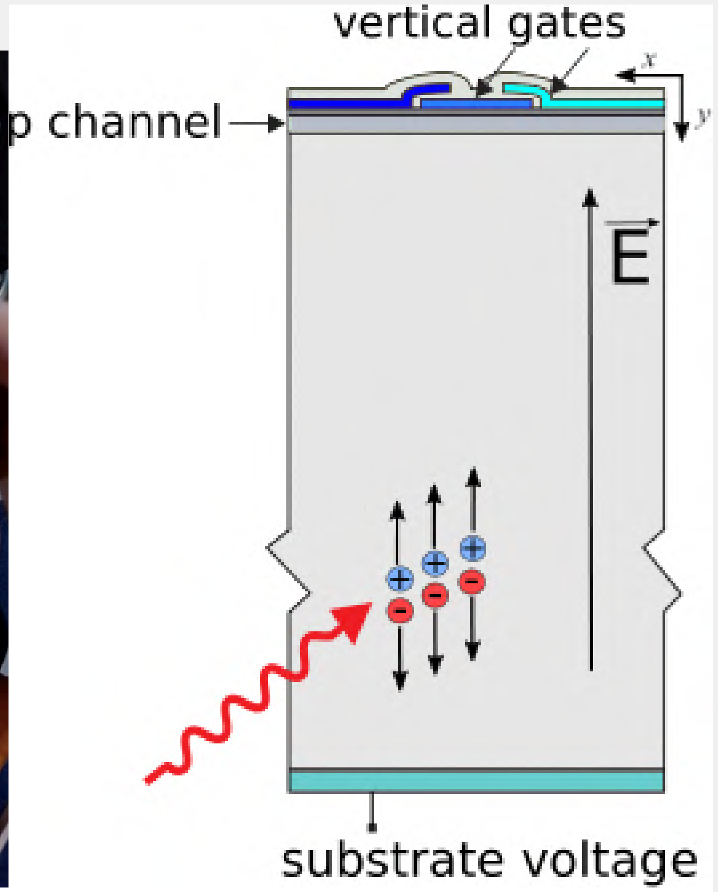
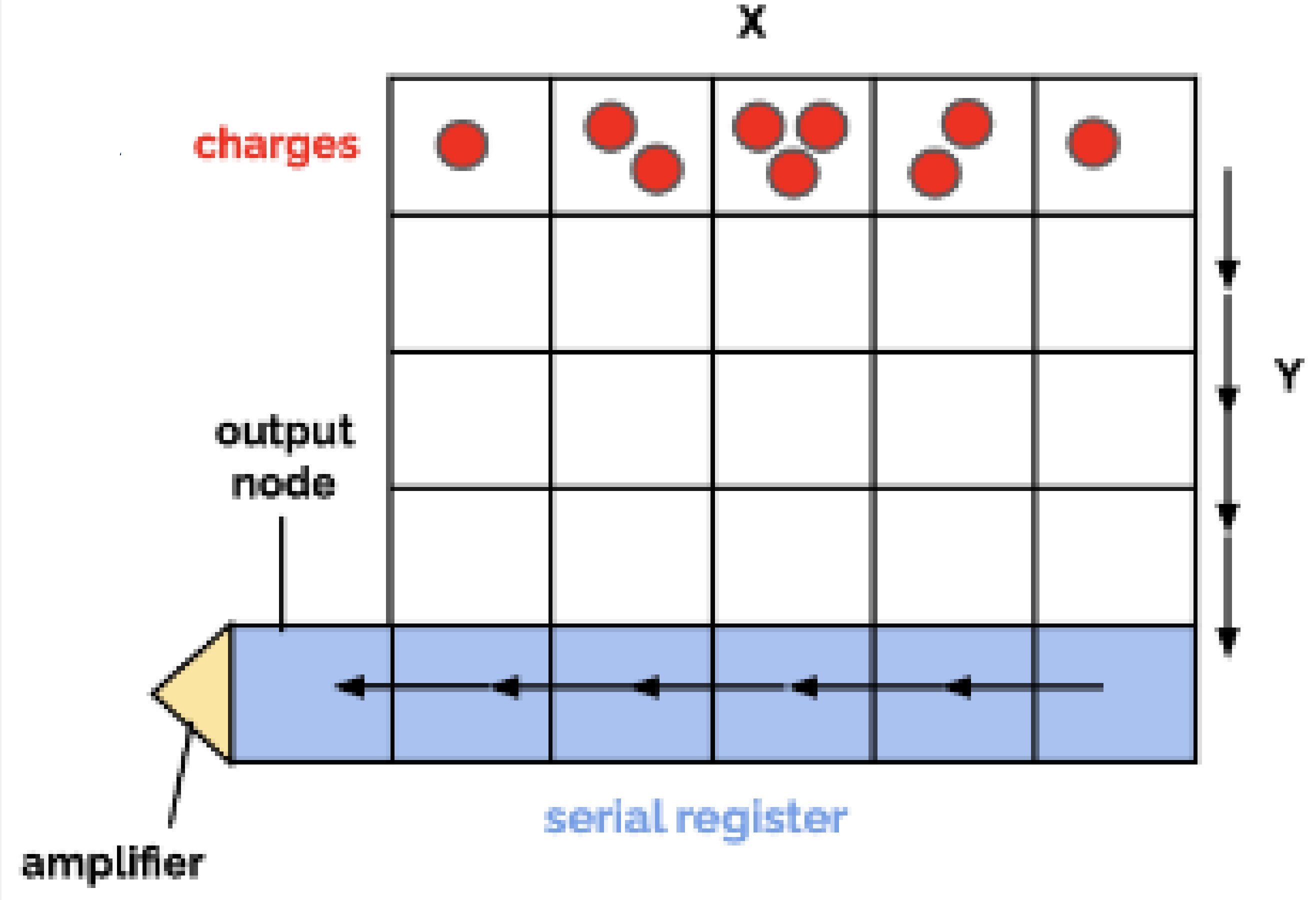




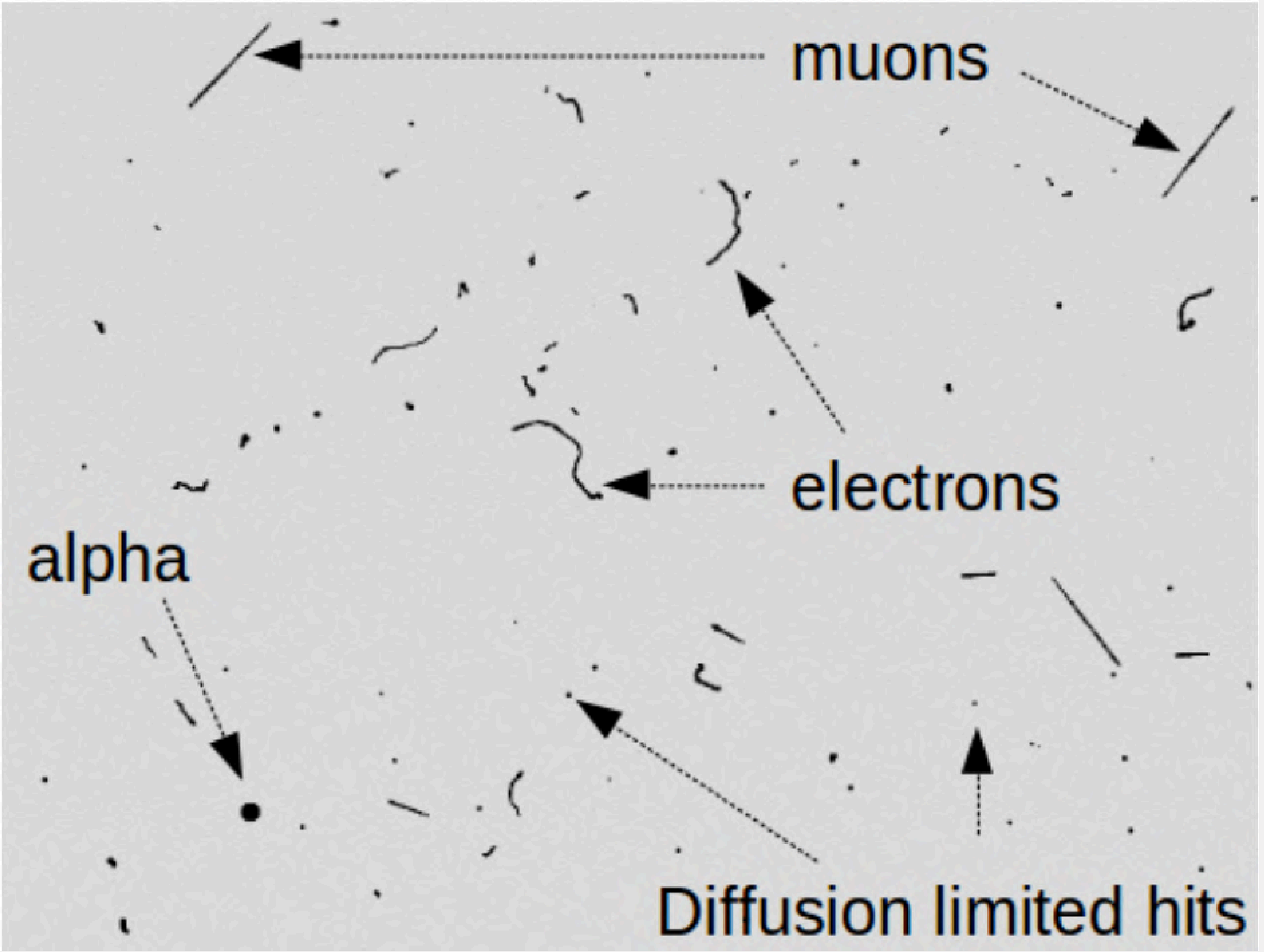


From a photographic camera to a particle detector

Photons in the visible range interact quickly with silicon: we only need a depth of some μm in the detector.

Infrared (IR) photons need a thicker detector, so some CCDs used for astronomy started having some hundreds of μm in depth.

But if we cover the sensitive area, we stop seeing photons and we can focus on the rest of the particles that arrive - hopefully, dark matter particles!



Reduction of the readout noise: the birth of the Skipper CCD

Regular CCDs measure the charge in each pixel exactly once, as the charge is destroyed during the measurement.

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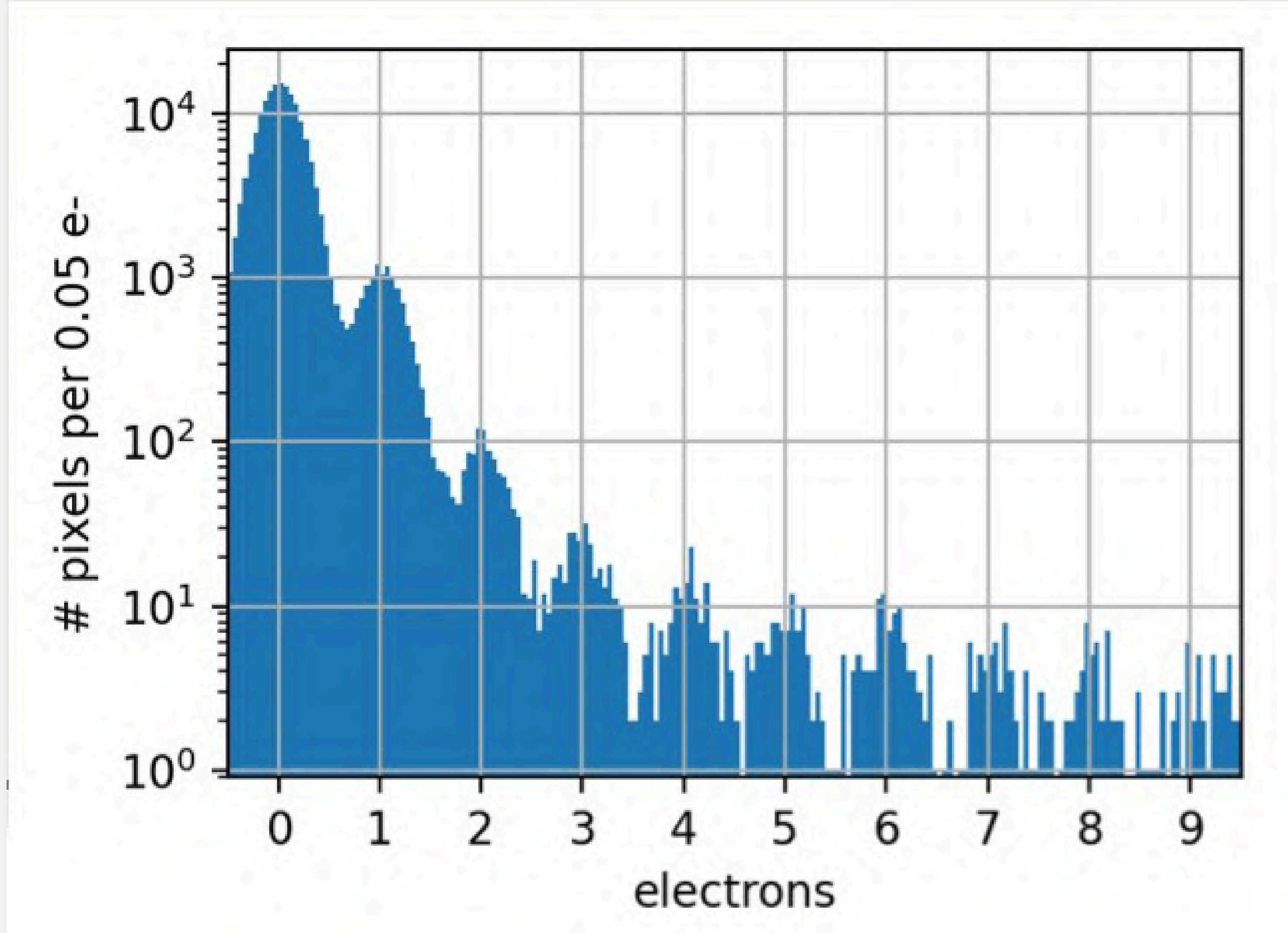
Let's check out the low-energy spectrum of the charge in the pixels: we see it is split into several populations, which means we can resolve single electron-hole pairs!

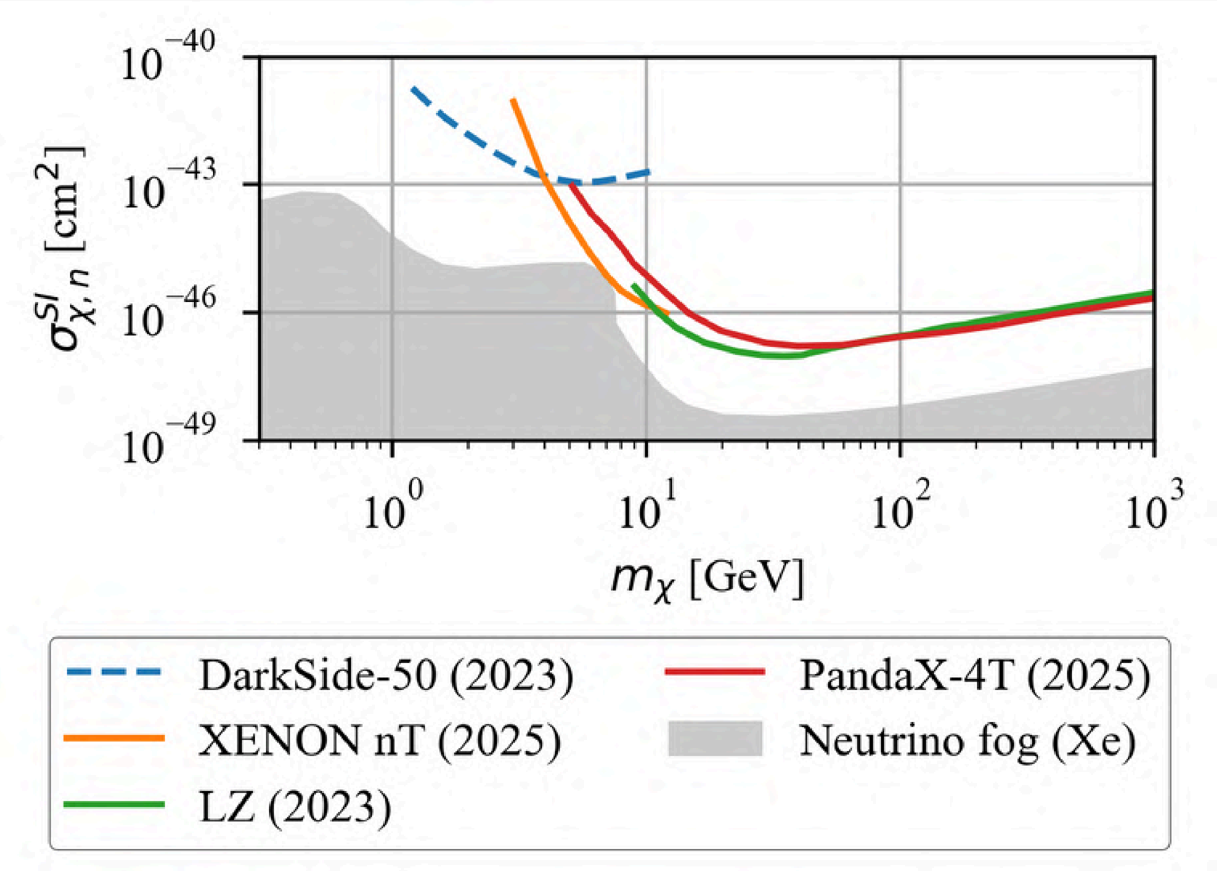


Back to dark matter: choosing our theory

WIMPs (Weakly Interacting Massive Particles) have been a compelling candidate for explaining dark matter for some time. (You can google "WIMP miracle")

In fact, many direct detection experiments have been set up to look for them: XENON, DarkSide, and SuperCDMS, for example, are just some of them. They didn't find dark matter yet.

SI WIMP-Nucleon exclusion plot



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Pursuing a WIMP search with CCDs seemed feasible at first, until the experiments hit the “low energy excess” wall.

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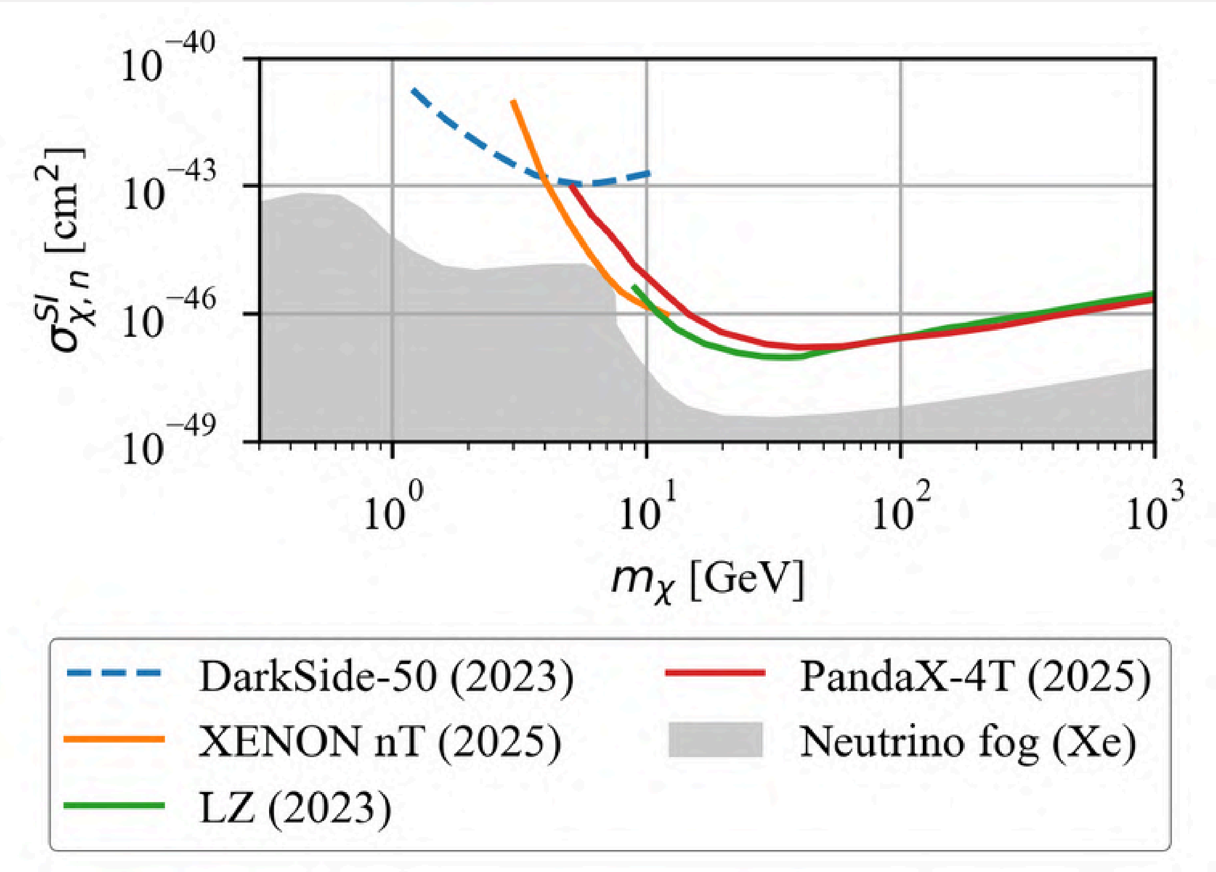

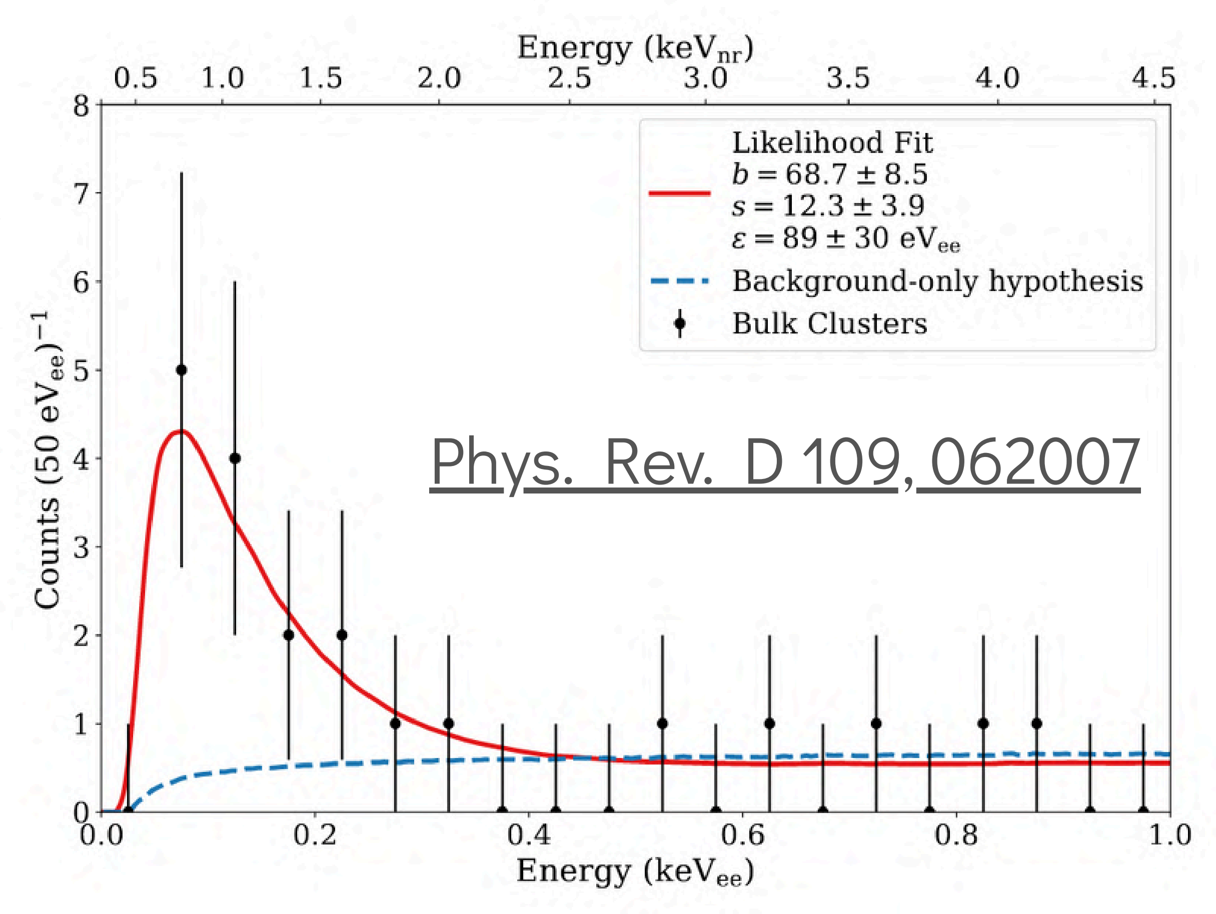

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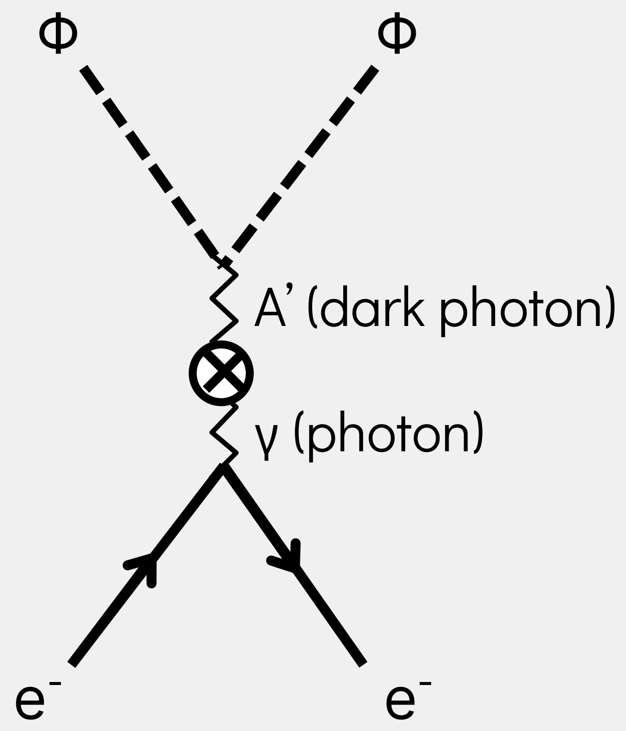

There are other well-motivated candidates for dark matter, and slowly the spotlight is moving towards them.

Theories which include a “dark sector” that interacts with the standard model via a “portal” can provide with an explanation to dark matter abundance.

In particular, in the vector portal scenario, there is a new U(1) gauge symmetry (a “dark photon”) that mixes kinematically with the standard model hypercharge - effectively coupling the dark matter candidate particle to the standard model.

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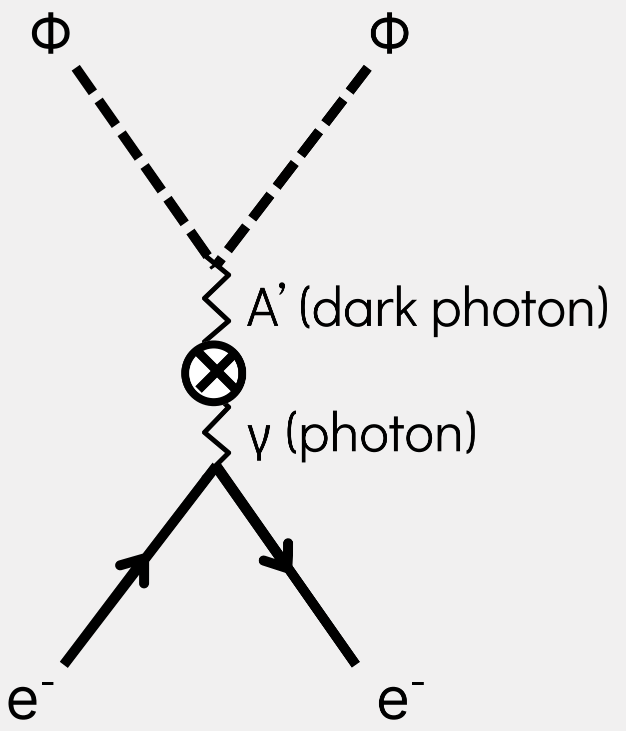

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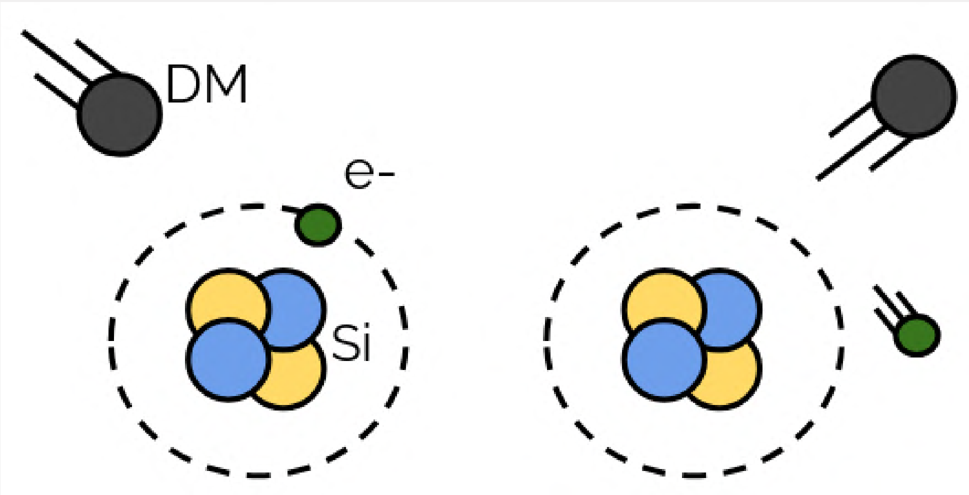
We will look for a particle in the MeV mass range that scatters off electrons in our target.



Go underground!

Of course, if we turn on our detector at surface, we will see lots of background events: We don't want cosmic radiation!

Only rock can protect us from muons. If only there was a tunnel under a mountain with a cavern big enough to host our detector...

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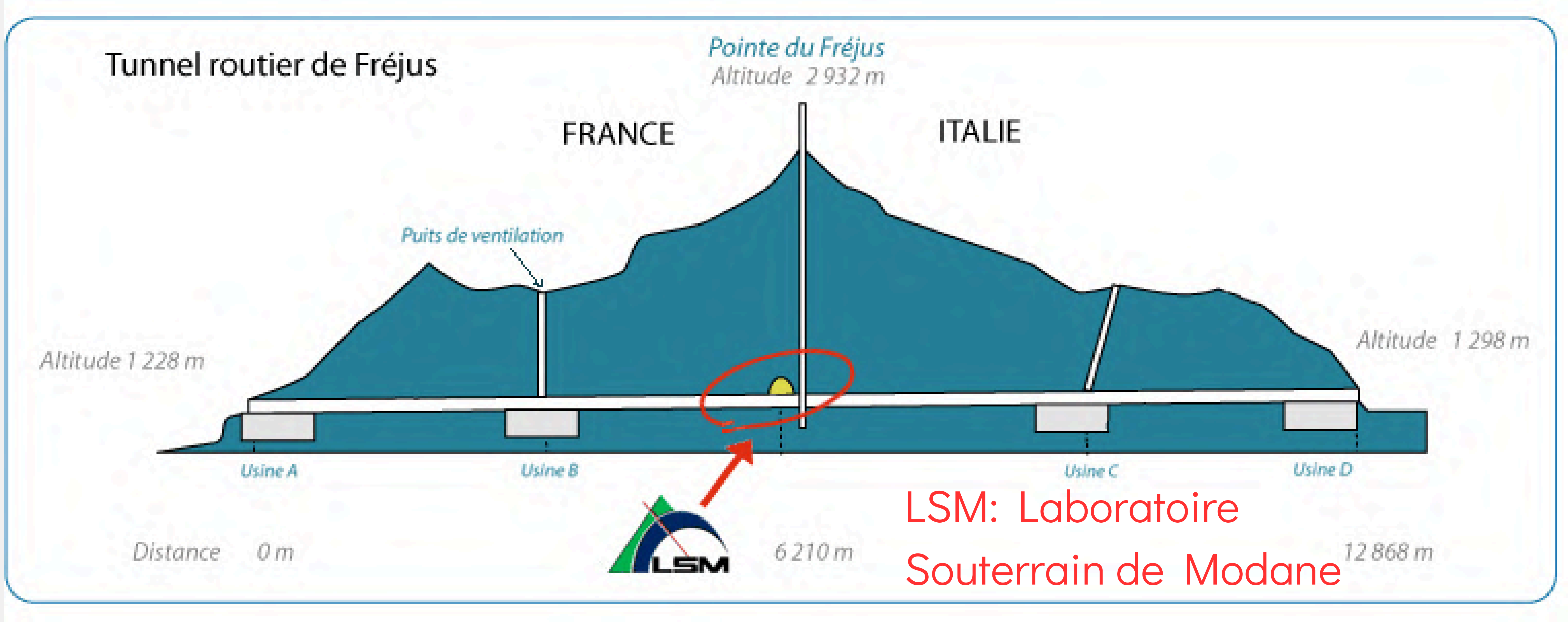

DArk Matter In CCDs at Modane: DAMIC-M

The experiment is simple:

- Grab a bunch of Skipper CCDs
- Put them inside the LSM
- Take data
- Discover dark matter.

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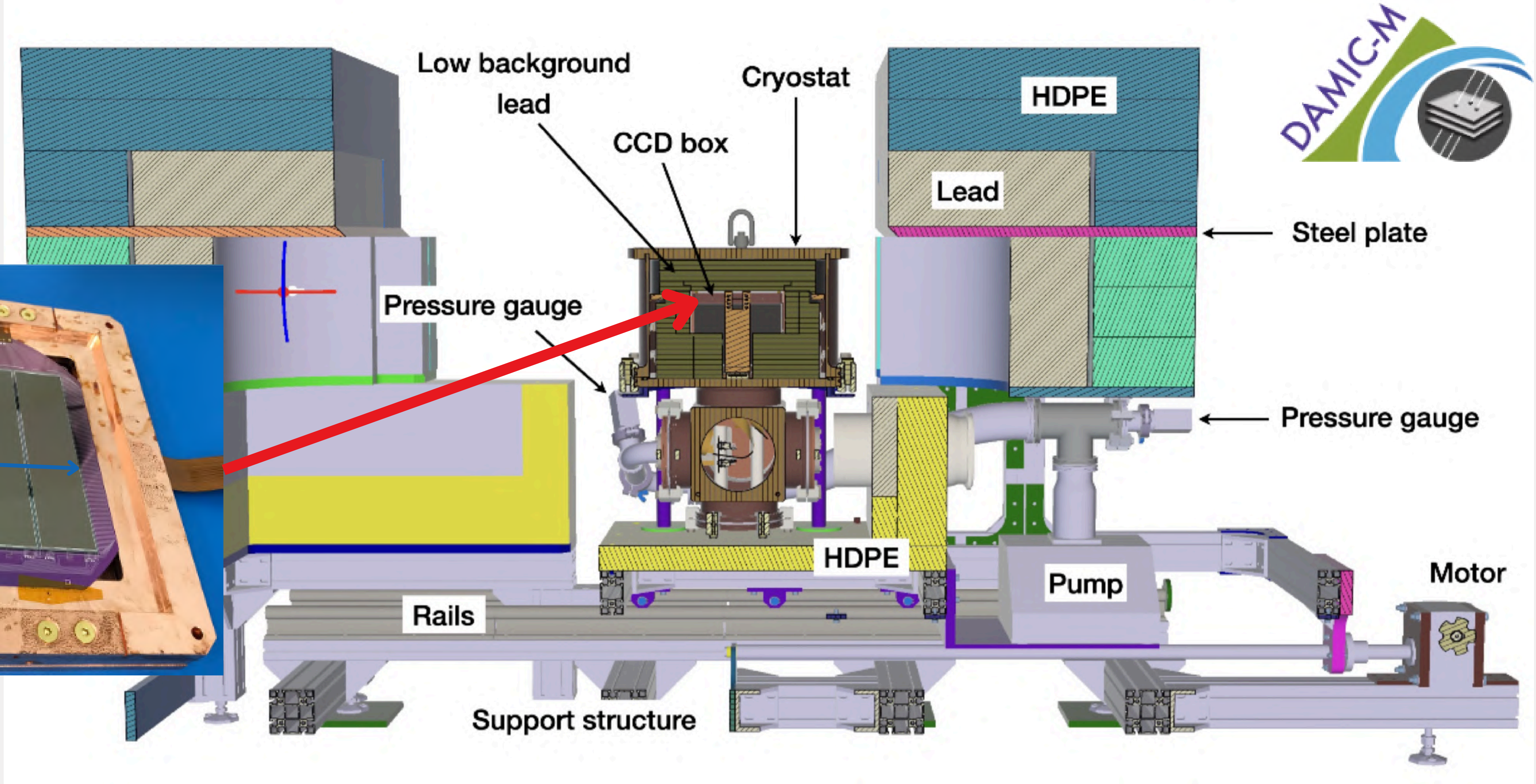
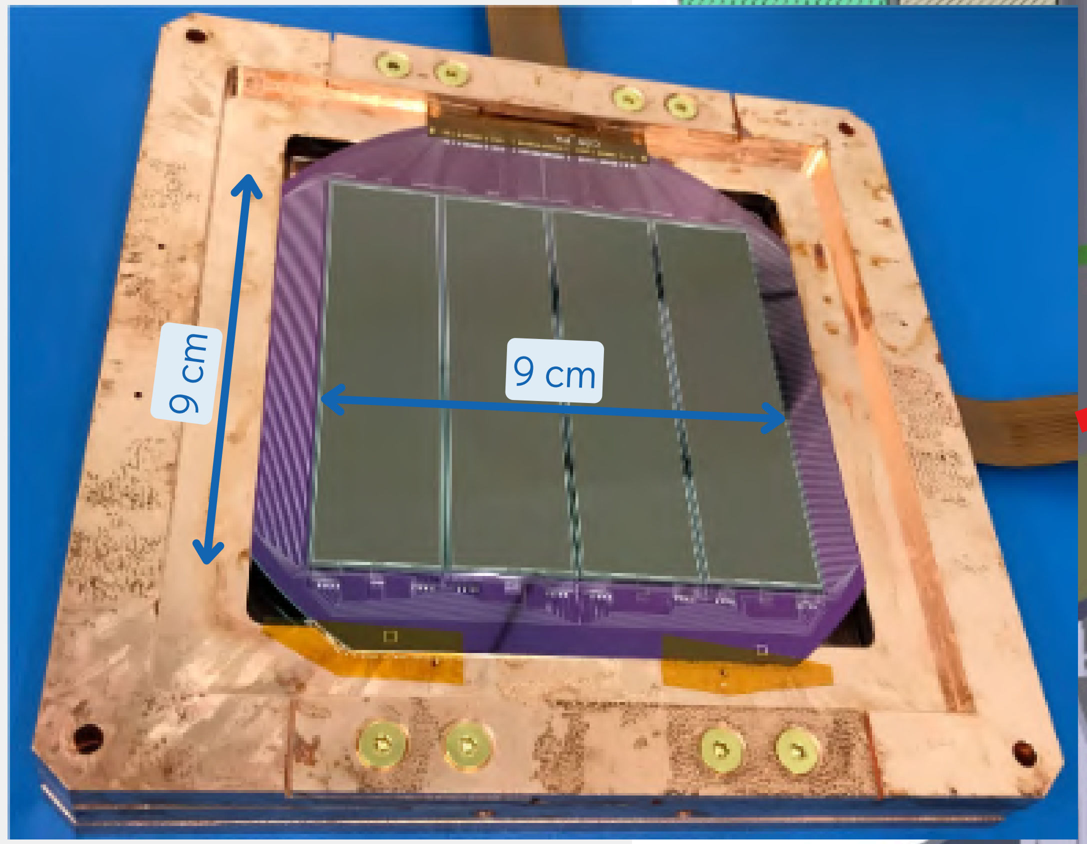
(OK, it's not so simple)

DAMIC-M protoype: the Low Background Chamber (LBC)





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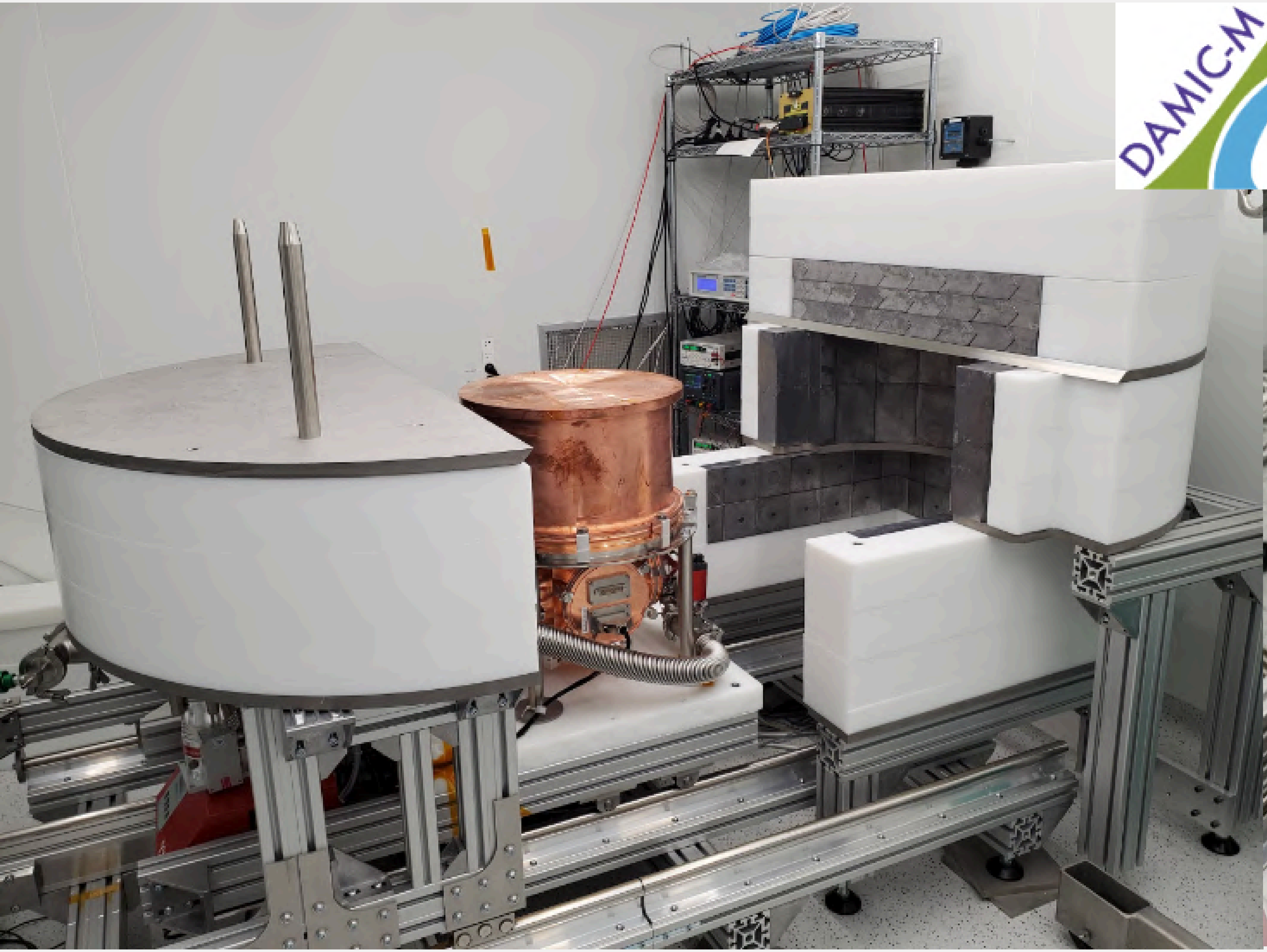
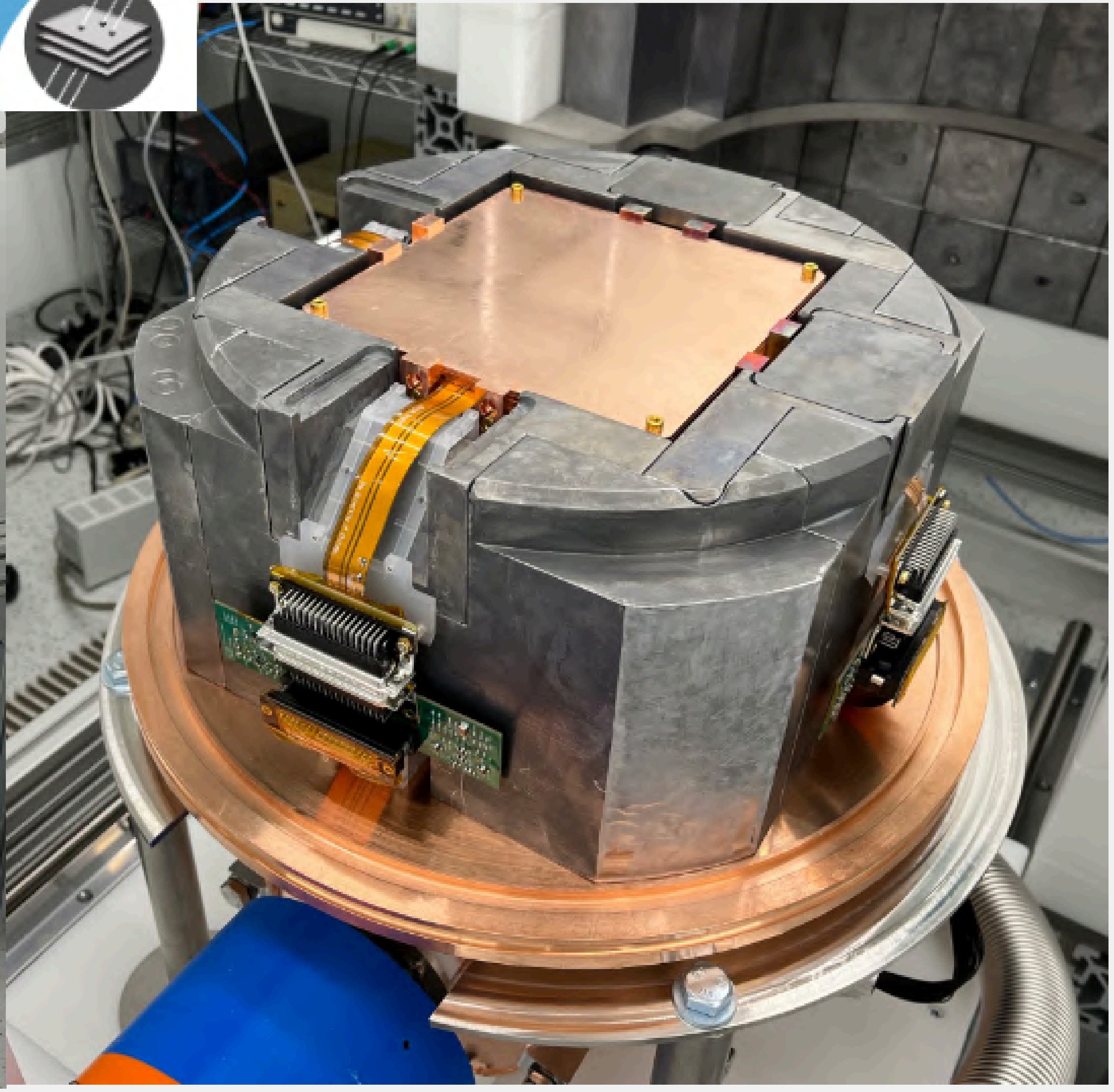
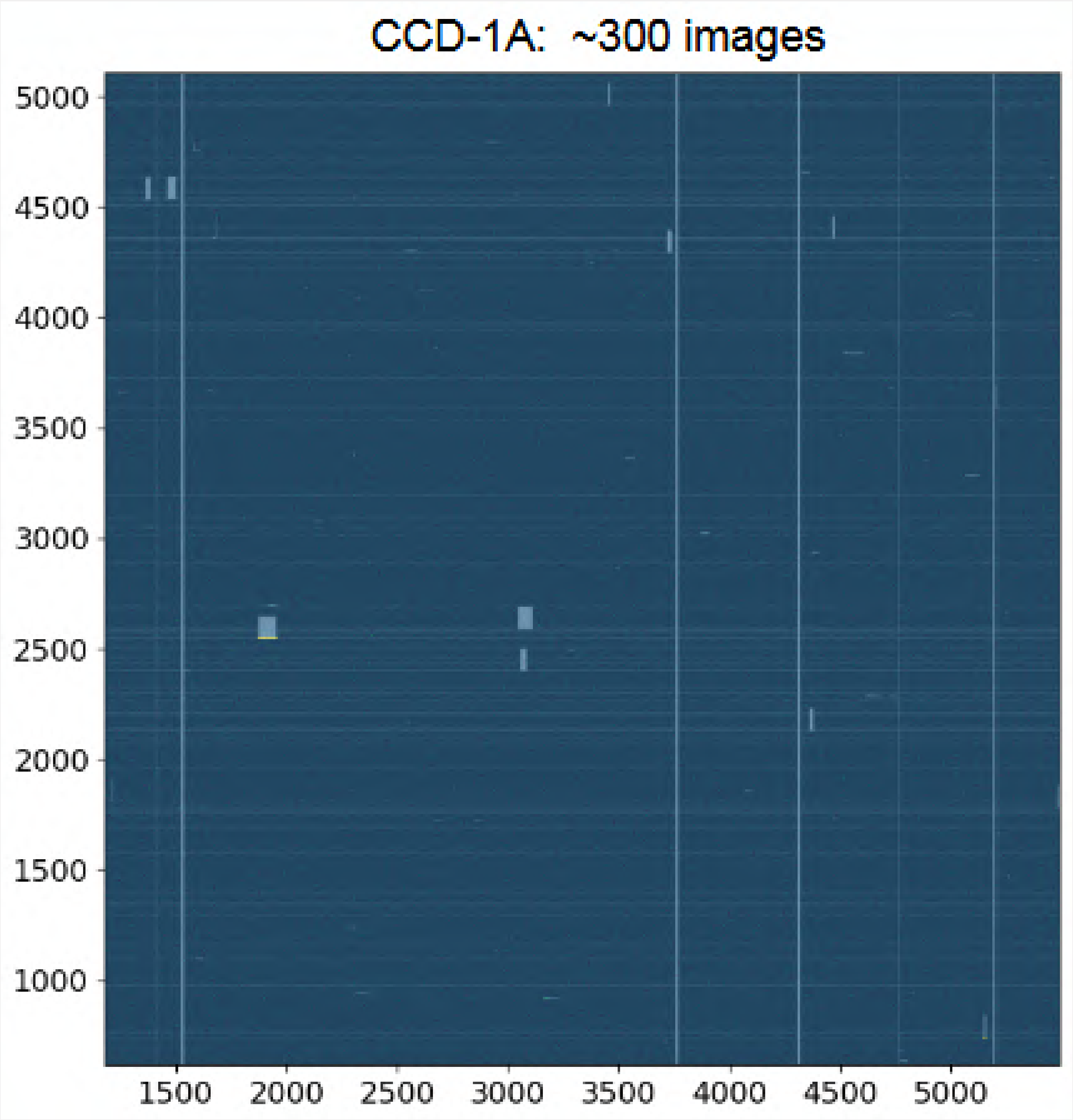




Photos under the mountain in the LBC

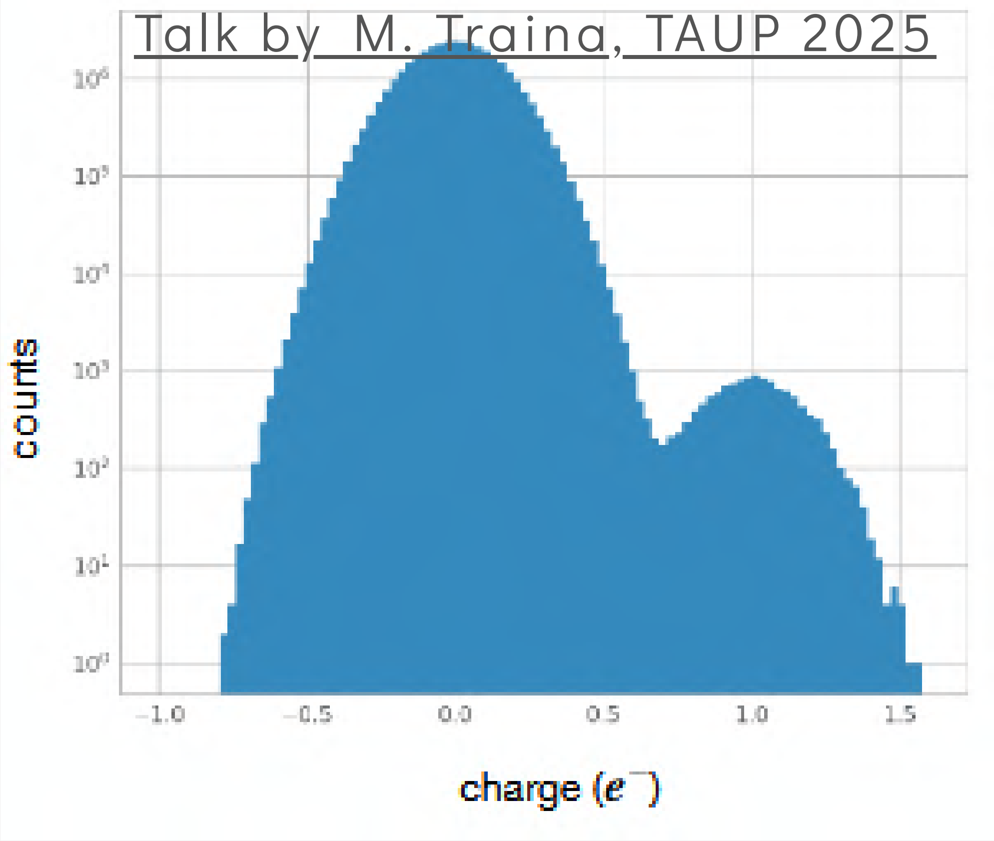
Let's look at some data:



Yes, these are 300 images taken with a Skipper CCD, squashed and stitched together in the y-axis.

The light-colored lines and spots are masked events: these are not candidates for dark matter.

The rest of the image (about a 95% of the data) has empty pixels or up to 5 electrons of charge.

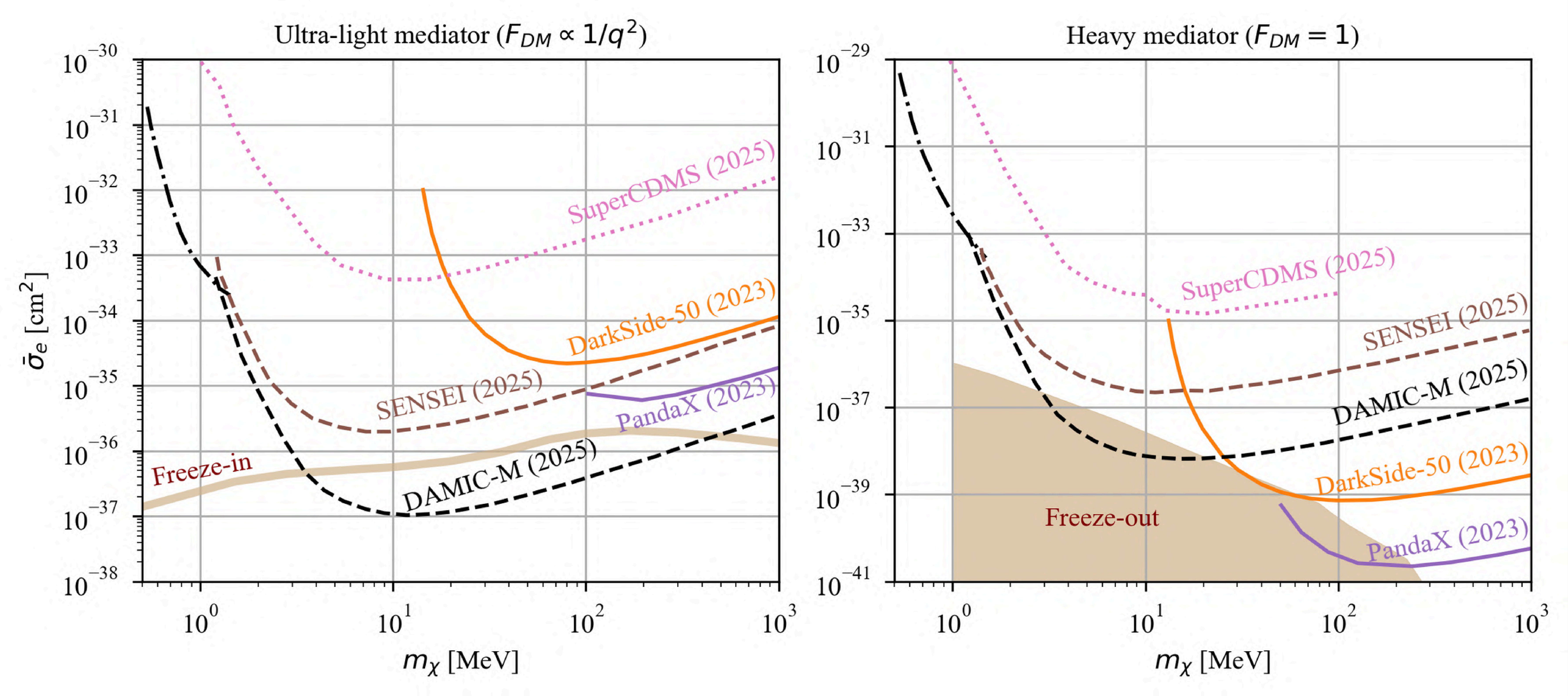


The rate of single-electron events is ~400 ev/g/day

(It is very low)

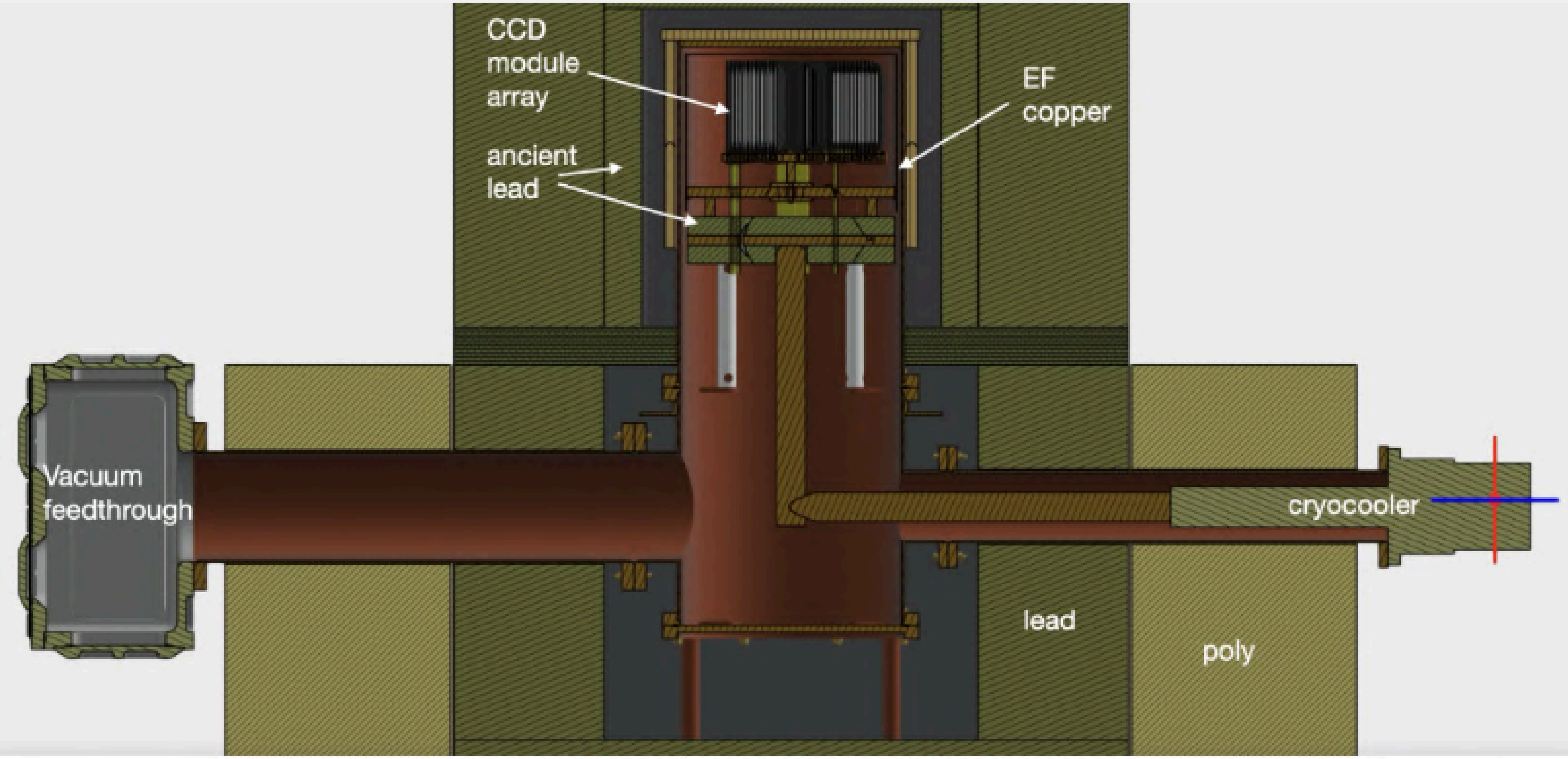
World-leading results achieved!

No, we didn't find dark matter (yet), but we ruled out some candidates from the extensive list:

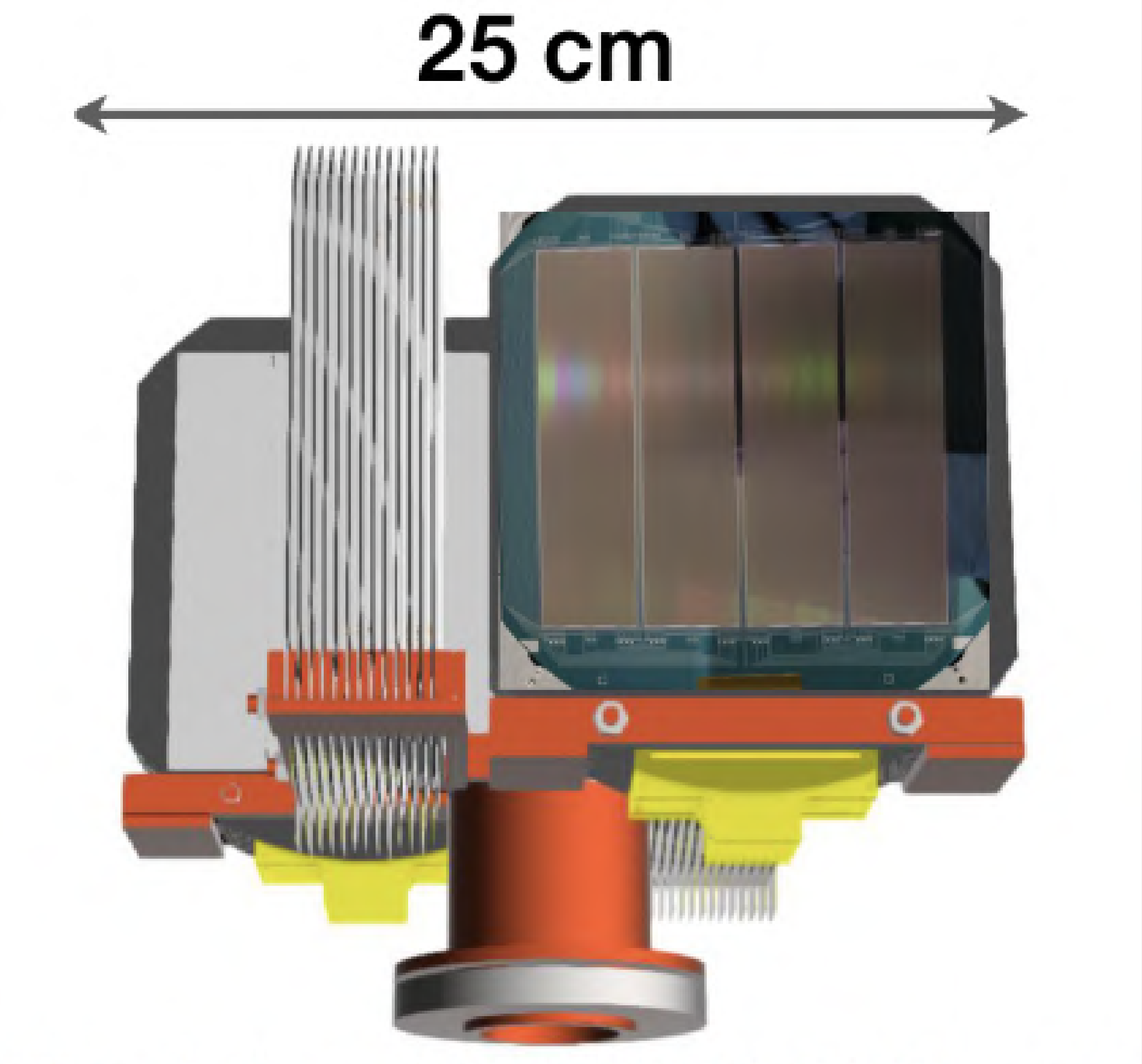


So... What's next?

Get ready for the full DAMIC-M setup! Around 350 g of Skipper-CCDs taking pictures inside the mountain.



Rendering of DAMIC-M final design



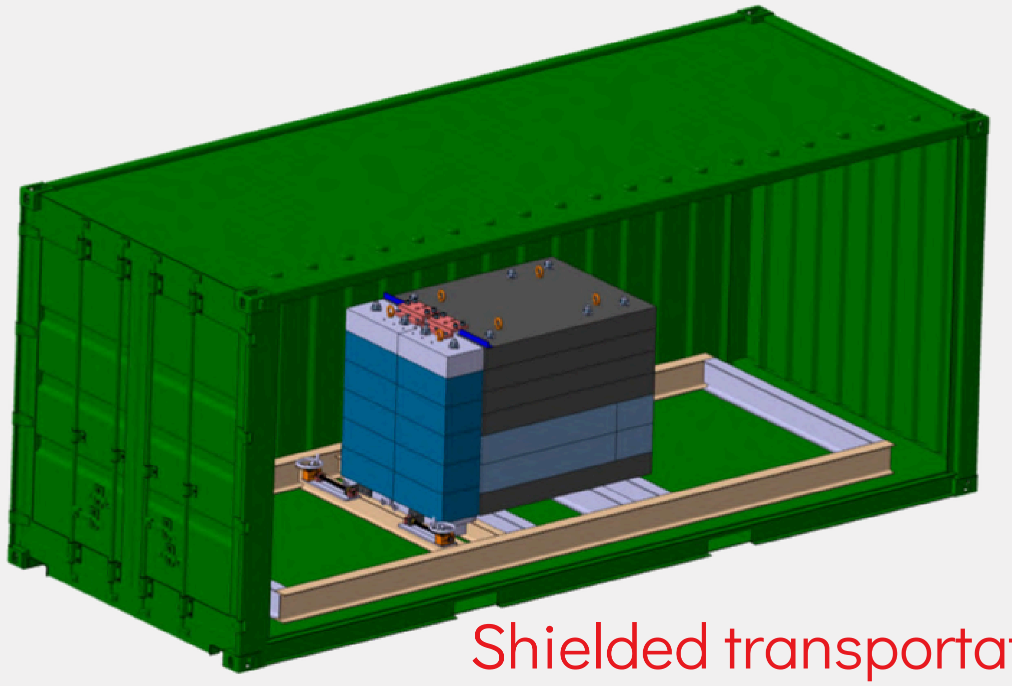
Rendering of DAMIC-M CCD array

The sensors are... sensitive. Treat them carefully!

- Limit exposure time to cosmic rays
- Limit the detector surfaces' exposure to radon
- New materials: Electro-Formed copper, low-background cables
- Chemical treatments of Cu, Pb components to remove surface Pb210

Radon-free storage

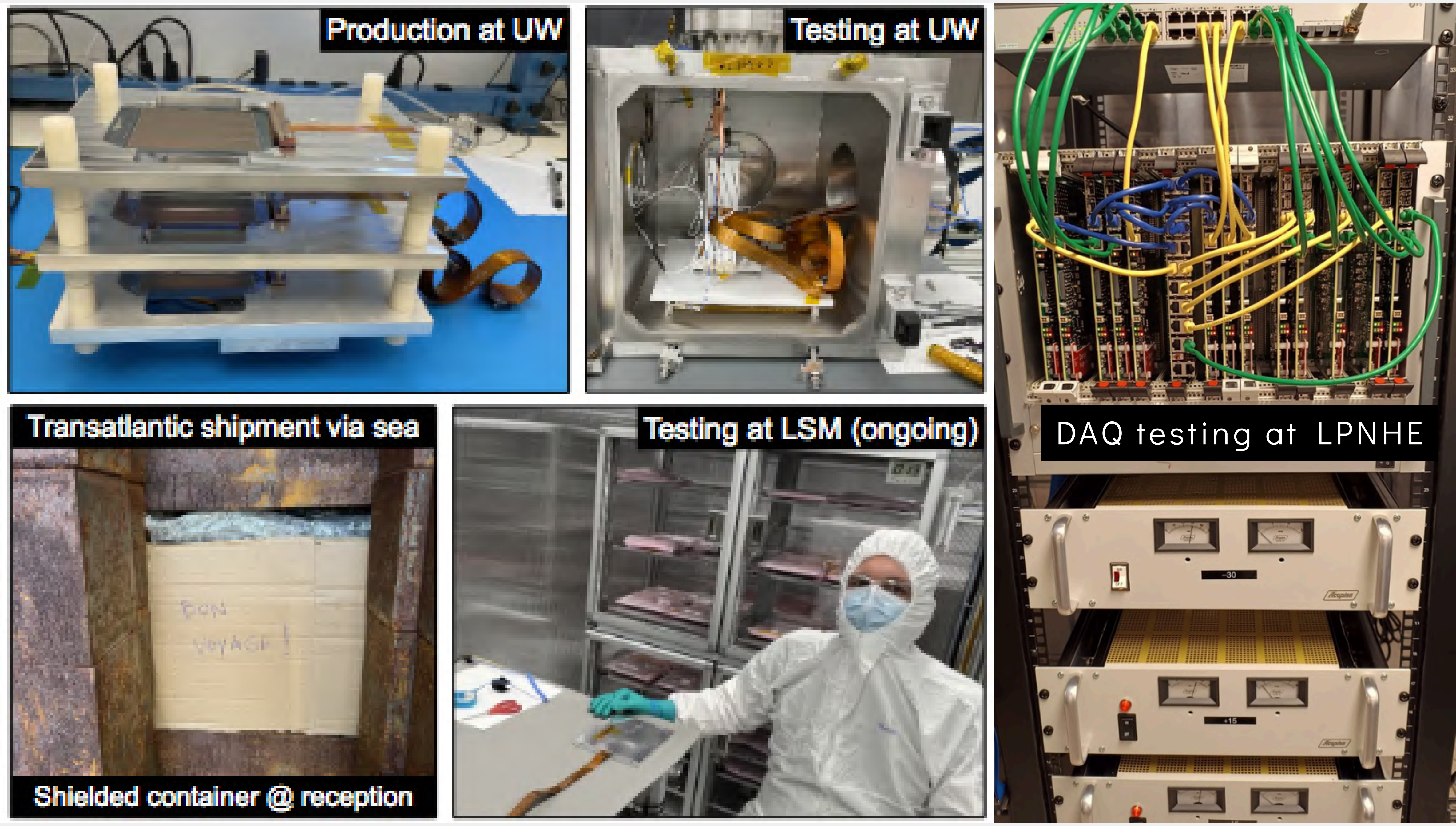
Shield during CCD production



Shielded transportation

Are we there yet?

- 28 Skipper CCD modules, with 4 CCDs each, have been manufactured
- Underground testing is almost done at a specifically-designed test chamber in LSM
- All readout boards have been manufactured, DAQ stress testing ongoing at LPNHE



To sum up...

- Skipper CCDs take photos inside a mountain and enable us to explore new Dark Matter candidates via direct detection

- DAMIC-M prototype sensor has set stringent limits to MeV-scale particles interacting with electrons

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Stay tuned, and do not hesitate in asking further questions!

Thank you.