Using scientific-grade CCDs for the direct detection of dark matter with the DAMIC-M experiment

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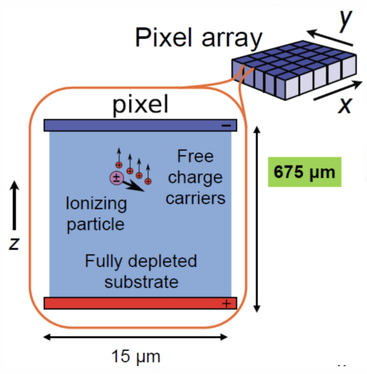
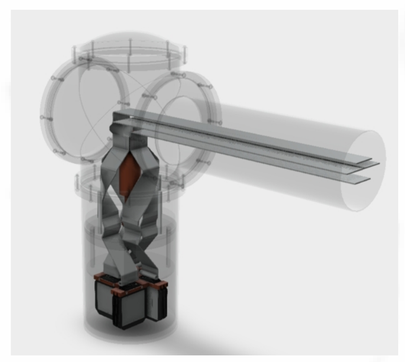
Introduction

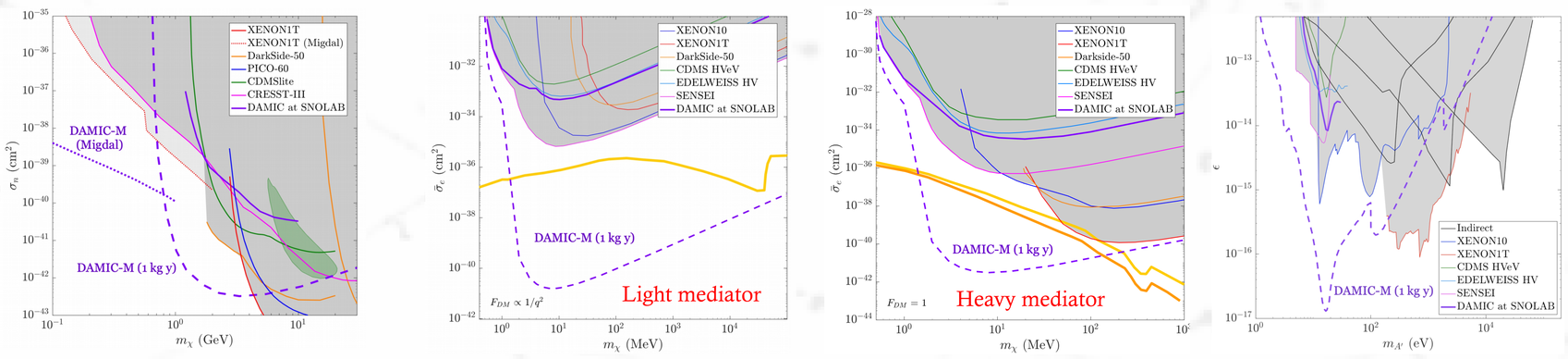
The DArk Matter In CCDs at Modane (DAMIC-M[1], 2024) experiment, successor of the DAMIC at SNOLAB[2], aims to directly detect interactions of light Dark Matter particles (<10GeV) and other hidden sector candidates with the nucleus and the electrons of the bulk of scientific grade Charge-Coupled Devices (CCD).

- DAMIC-M will use multiple n-type Si CCDs with a total active mass of ~1kg.
- Each module will be composed out of 4 individual 6k x 1.5k pixels CCDs.
- The detector will be placed in the underground laboratory of Modane (LSM) providing radon-free air supply and with 2km of rock to protect from the cosmic background.
- Total background goal is down to 0.1 dru.
- The Skipper readout implementation will allow for the best performance of the CCDs with a resolution below 1e^-.
- Great spatial resolution with pixel size 15μm x 15μm and 675μm thick and 3D reconstruction of the interaction point using the charge diffusion.
- Novel electronics are developed within the collaboration to support and optimally control the new Skipper CCDs of DAMIC-M.



CCD Si pixel array

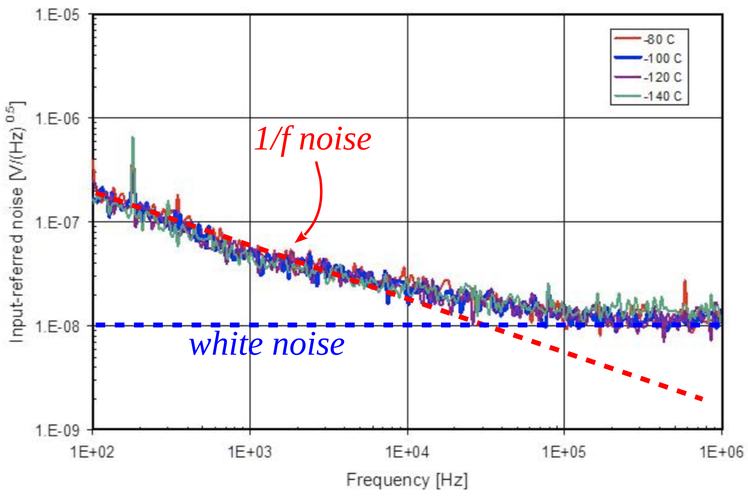

CCD module design for DAMIC-M

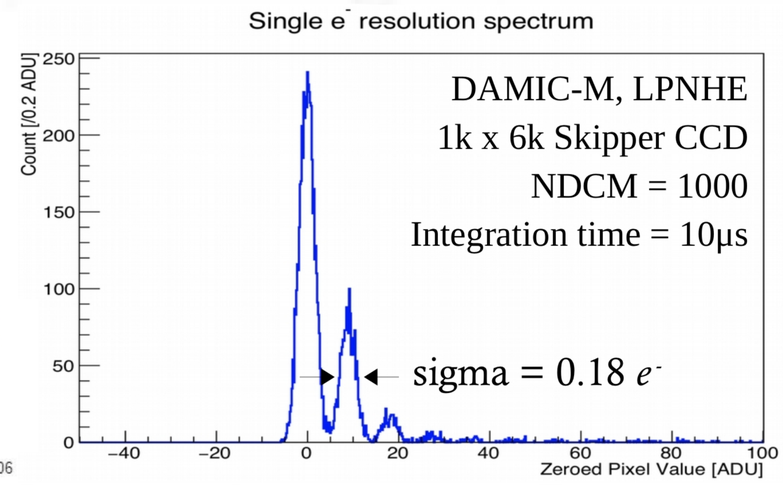


DAMIC-M expected limits for WIMP-nucleus cross section (left), DM-electron cross section for a light and heavy mediation (middle left and right), and kinetic mixing parameter vs $m_{A'}$ (right)

Skipper readout

- Regular CCD[3]: single charge measurement with an integration time *O*(10μs).
  - Thermal noise is eliminated
  - Dominated by 1/f noise
- Skipper CCD[4]: multiple non-destructive charge measurement (NDCM) with integration time *O*(1μs).
  - Short integration time → lower resolution
  - Multiple measurements → thermal noise goes down with the sqrt of the number of measurements, reaching a sub-e^- resolution
  - Fast sampling → quick readout → minimize dark current

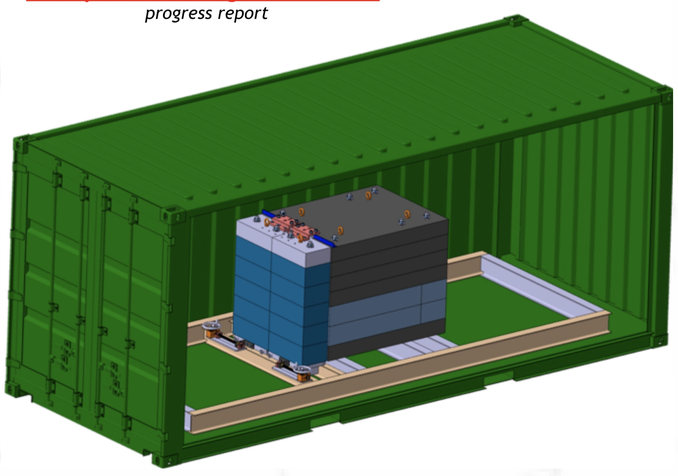


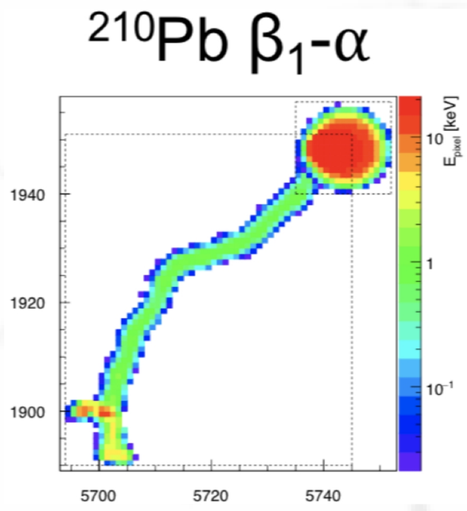


Background rejection[5]

- Background suppression by careful selection of the materials, protection during the production from radon exposition and radioactive activation and shielding during the operation with ancient lead and electroformed copper.
- CCD treatment to improve uniformity response.
- Spatially correlated sequences identification as radioactive decay chains.
- Correct by estimating accidental spatial coincidences and independent overlapping events
- Estimation of radioactive contaminants of ^{32}Si and ^{210}Pd
- Constrain ^{238}U and ^{232}Th remnants.

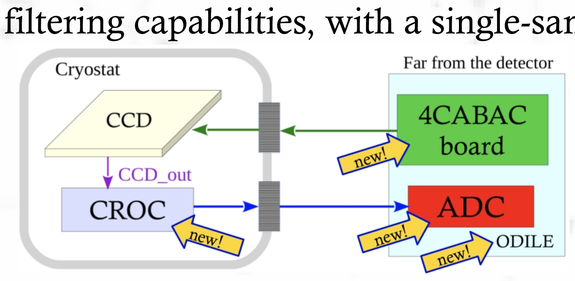
Transport Shielding for DAMIC-M
progress report





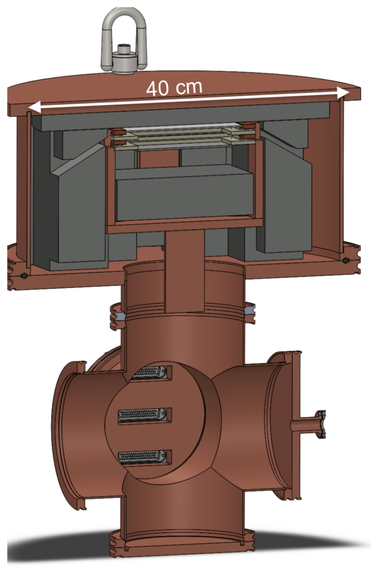
New acquisition system

- 4CABAC (Clocks And Biases ASIC for CCD): Production of precise and slope-controlled clocks and biases to operate of the CCD. Suppress the clock-induced noise during operation.
- CROC (CCD ReadOut Chip): As close as possible to the CCD output to amplify the CCD signal to improve the Signal-to-Noise ratio. Measured input noise of CROC_v1 ~3.5μV≈1e^-.
- ADC (Analog to Digital Converter): Few options with fast and high resolution ADCs of different resolution, sampling speed and filtering capabilities, with a single-sample noise of *O*(10μV).



- ODILE (Online Digital Interface for Low-noise Electronics): The FPGA motherboard to control the whole setup.

LBC 2021



Design of LBC detector

Installation of a smaller detector prior to the final DAMIC-M, called Low Background Chamber (LBC)[6]:

- 4 months of exposure with large 6k x 4k CCD
- Backgroung budget: 1 d.r.u.
- Use of Skipper CCDs

CCD studies:

- Measure the leakage current with a Skipper CCD.
- Measure background with pre-production DAMIC-M CCDs.
- Integrate the new electronics and test the overall acquisition system.
- Measure the background of the underground laboratory at Modane.
- Produce first scientific results.

References

[1] arXiv:2001.01476v1
[2] arXiv:2007.15622v2
[3] J. Janesick, "Scientific Charge-Coupled Devices", 2001
[4] arXiv:2004.11378v3
[5] arXiv:2011.12922v2
[6] P. Privitera, "The DAMIC-M dark matter experiment", at TAUP 2019

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