Towards the DAMIC-M experiment

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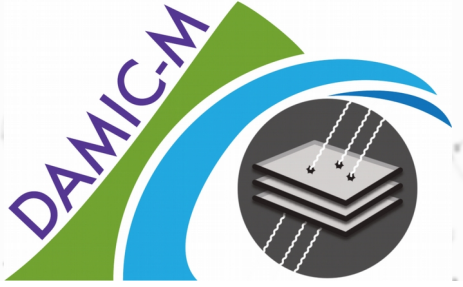
for GDR DUPhy



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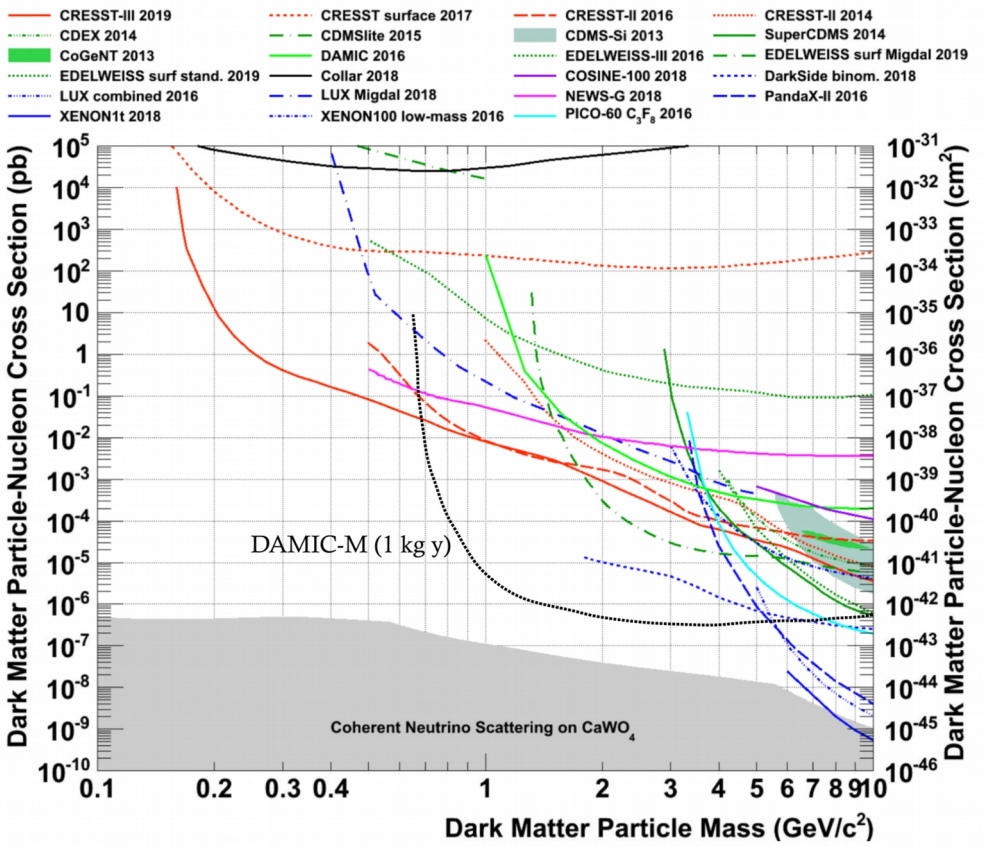
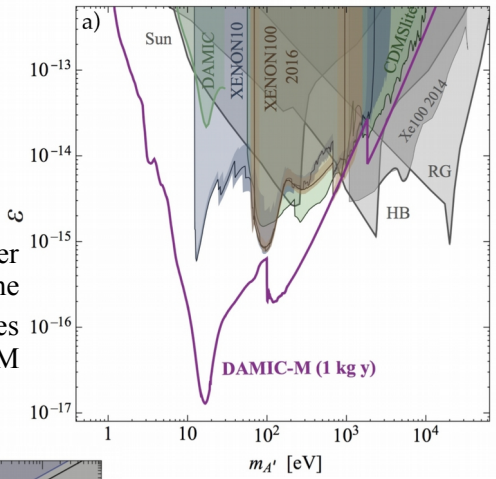
DAMIC-M expected sensitivity

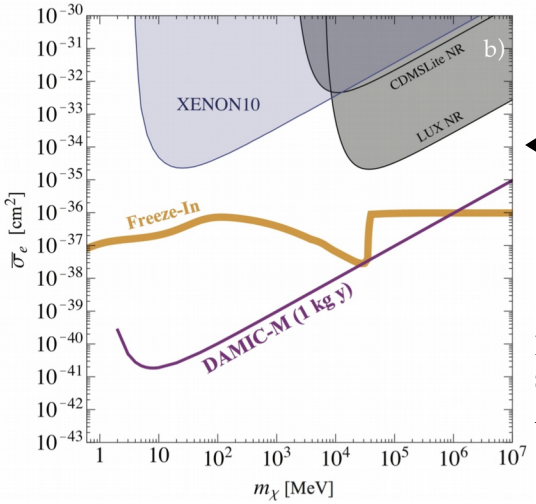


Spin-independent WIMP-nucleon scattering cross section vs DM mass

Original plot from: *First results from the CRESST-III low-mass dark matter program, 2019, arXiv:1904.00498v1*
and drawn line for DAMIC-M



Kinetic mixing parameter vs $m_{A'}$ assuming that the dark photon constitutes all of the DM



Plots from the DAMIC-M proposal in 2017.

DM-electron cross section vs m_χ for a light A' mediator ($m_{A'}$ << keV)

DAMIC-M overview

To achieve these limits:

Massive detector

Very low threshold &
Single e^- resolution

Very low
background
(cosmic bg & radioactivity)

DAMIC-M overview

To achieve these limits:

- Massive detector
- Very low threshold & Single e^- resolution
- Very low background (cosmic bg & radioactivity)

DArk Matter In CCDs at Modane (DAMIC-M):

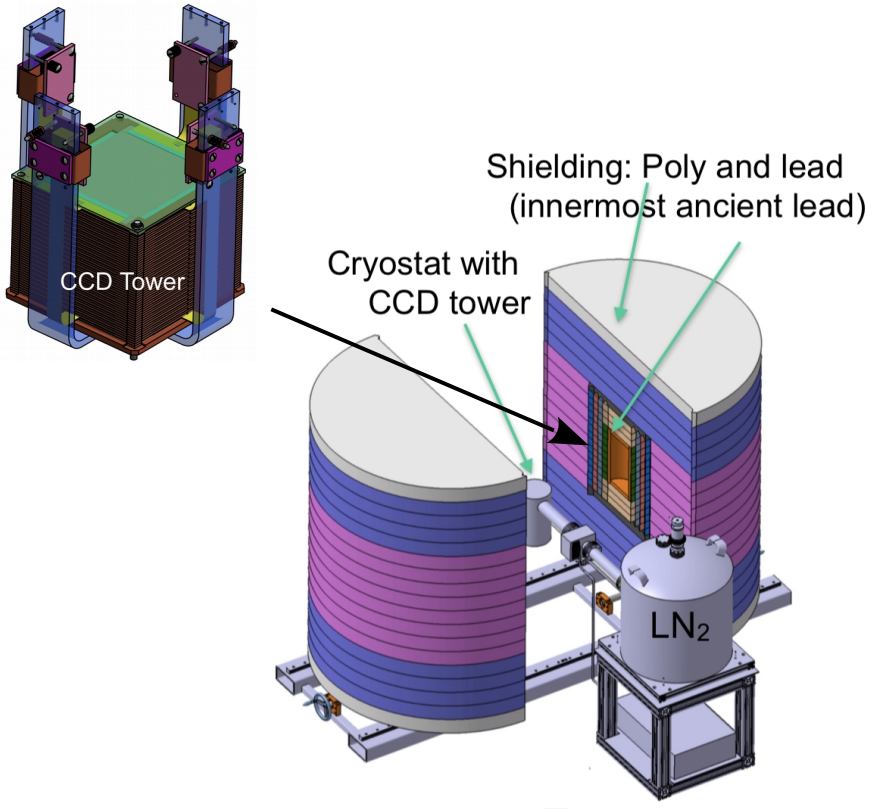
- Direct dark matter detection
- Low mass WIMPs and hidden sector DM

- Scientific grade **C**harge-**C**oupled **D**evices with a total target mass of ~1kg
- CCDs with Skipper readout implementation
- R&D of a novel acquisition system
- Radiopure materials for construction & shielding ~0.1 events/(keV kg day) = 0.1 dru
- Placed in Underground Laboratory at Modane

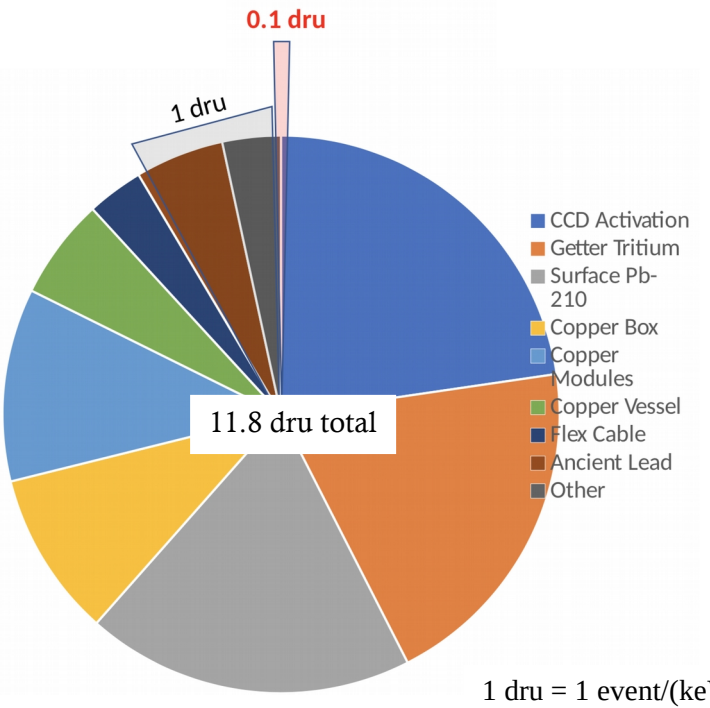
DAMIC at Modane

- ~2km of rock to stop cosmic bg
- Radon free air supply

Shielding and Background



DAMIC @ SNOLAB background = 11.8 dru
DAMIC-M background goal = fraction of 1 dru

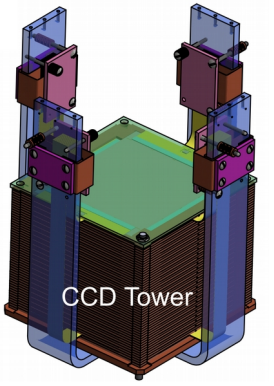


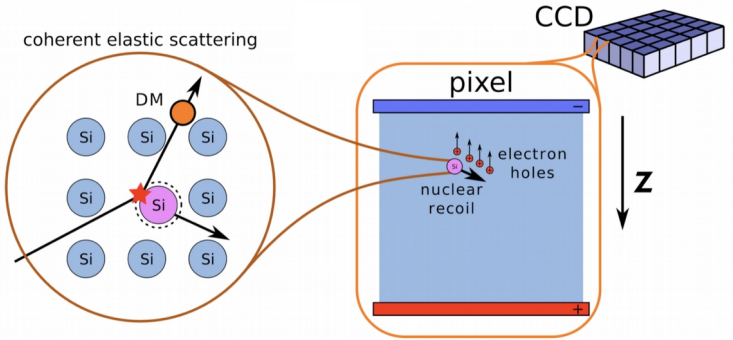
1 dru = 1 event/(keV·kg·day)

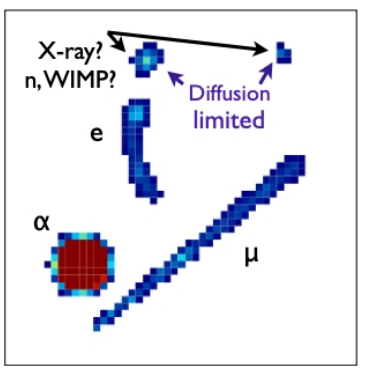
DAMIC-M CCDs

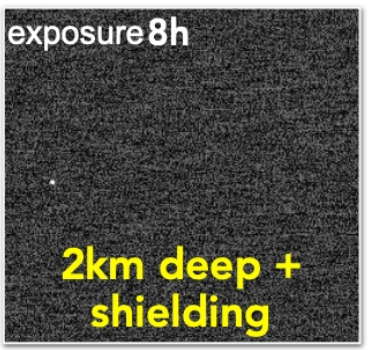
Scientific-grade Charge Coupled Devices (CCDs)

- Made of ~20g of pure n-type Si (~10cm x 10cm)
- Great spacial resolution with a pixel area of 15μm x 15μm and 675μm thick
- 3D reconstruction of the interaction point using the charge packet diffusion

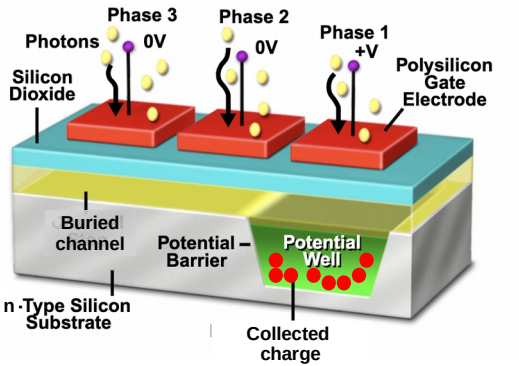






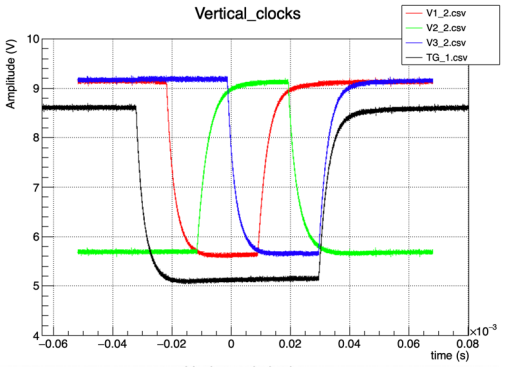


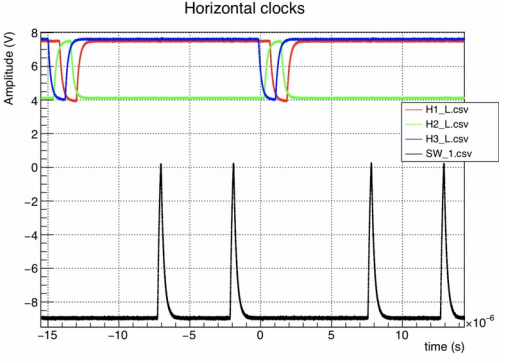
CCD Operation



CCD single pixel.

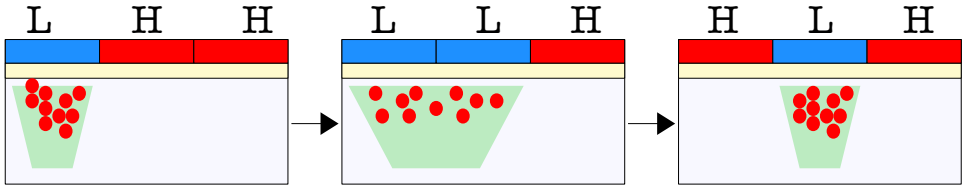
- Charge collection under active electrode
- n-type Si: collected charge → holes
- **Dark current**: thermally generated charge in the bulk of the silicon

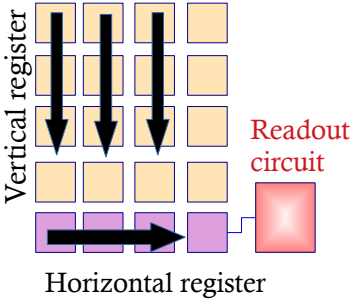




Charge Transfer

- Move the charge by alternating the voltage of the electrodes (clocks) to the Readout circuit



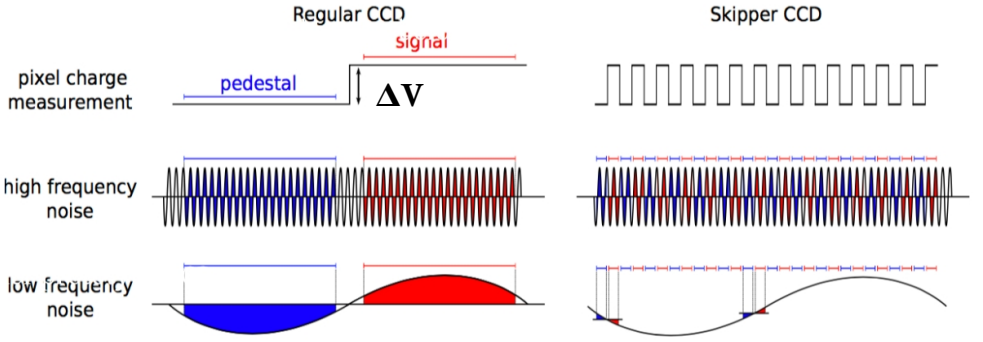


- **Clock noise**: lose or gain charge if the clocks are not well defined

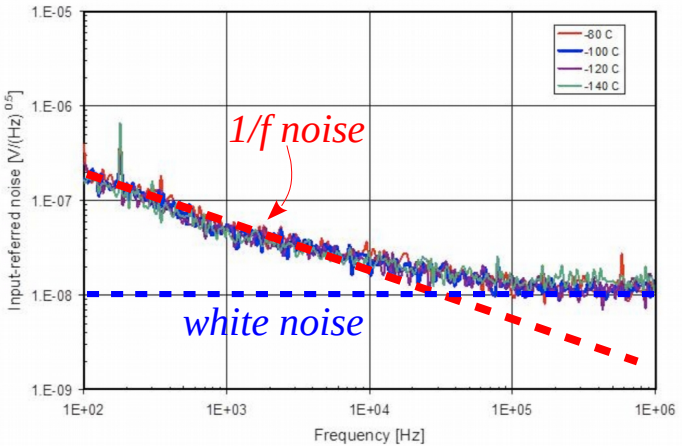
New electronics: 4CABAC board

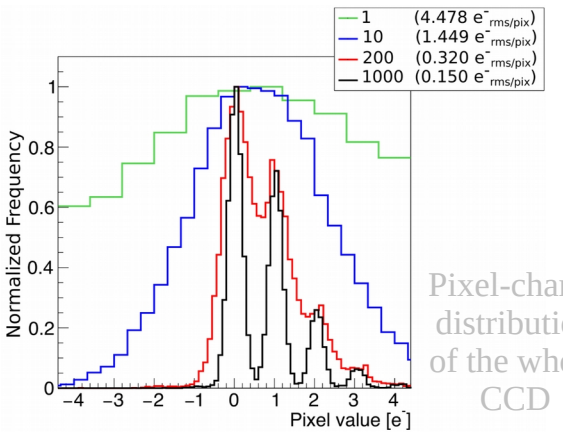
Skipper CCDs – sub-e^- resolution

- **Regular** CCD: single skip integration time *O*(**10µs**)
  - → high frequency noise is eliminated
  - → low frequency noise dominates (1/f noise)
- **Skipper** CCD: single skip integration time *O*(**1µs**)
  - → **multiple measurements of the pixel charge**
  - → low frequency noise eliminated
  - → single fast measurement of lower resolution

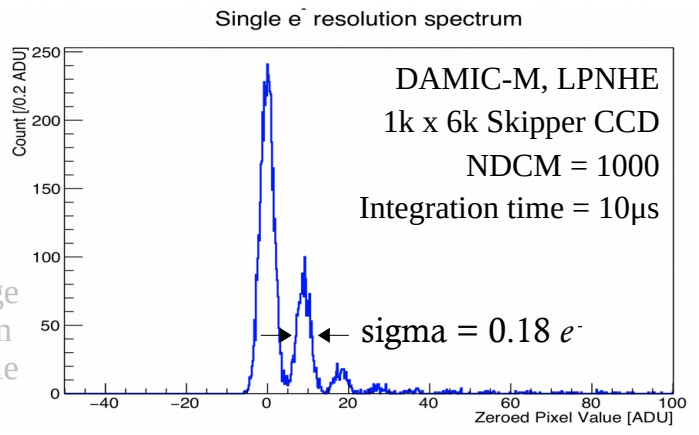


- Output noise decreases as 1/√NDCM (Non-Destructive Charge Measurements), reaching sub-e^- resolution

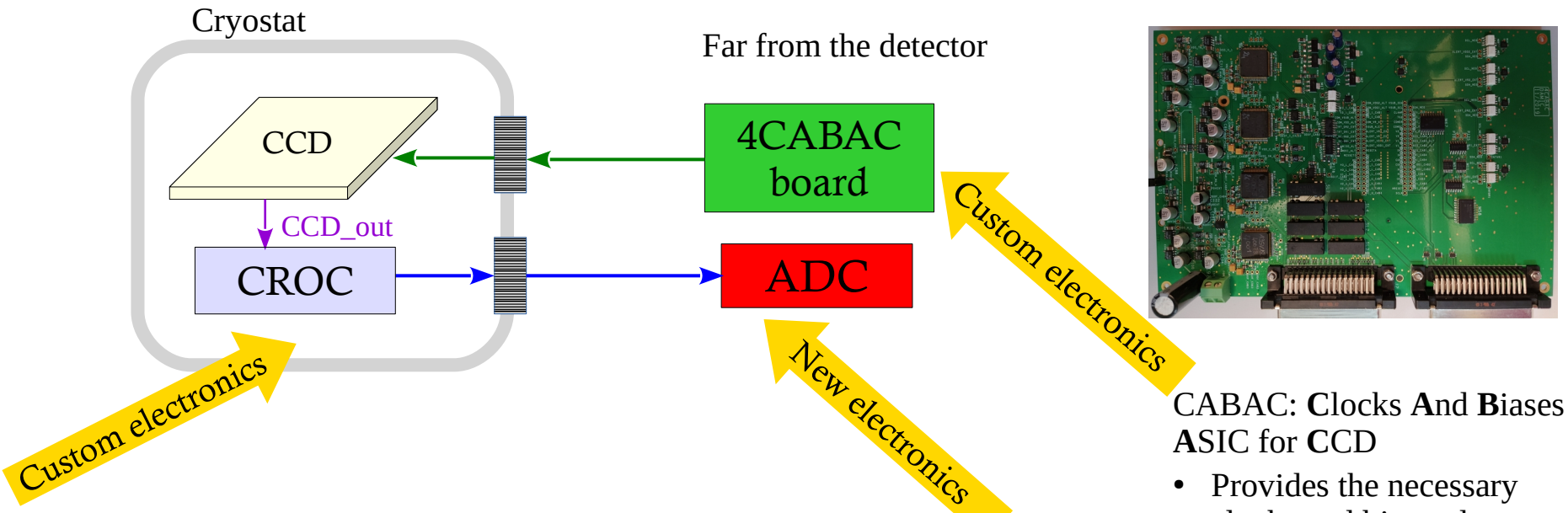




Pixel-charge distribution of the whole CCD



New acquisition system



CROC: **C**CD **R**ead**O**ut **C**hip

- Low noise
- Amplifies and pre-processes the output of the CCD to improve the SNR
- Minimizes any introduced noise until the ADC

ADC: **A**nalog to **D**igital **C**onverter

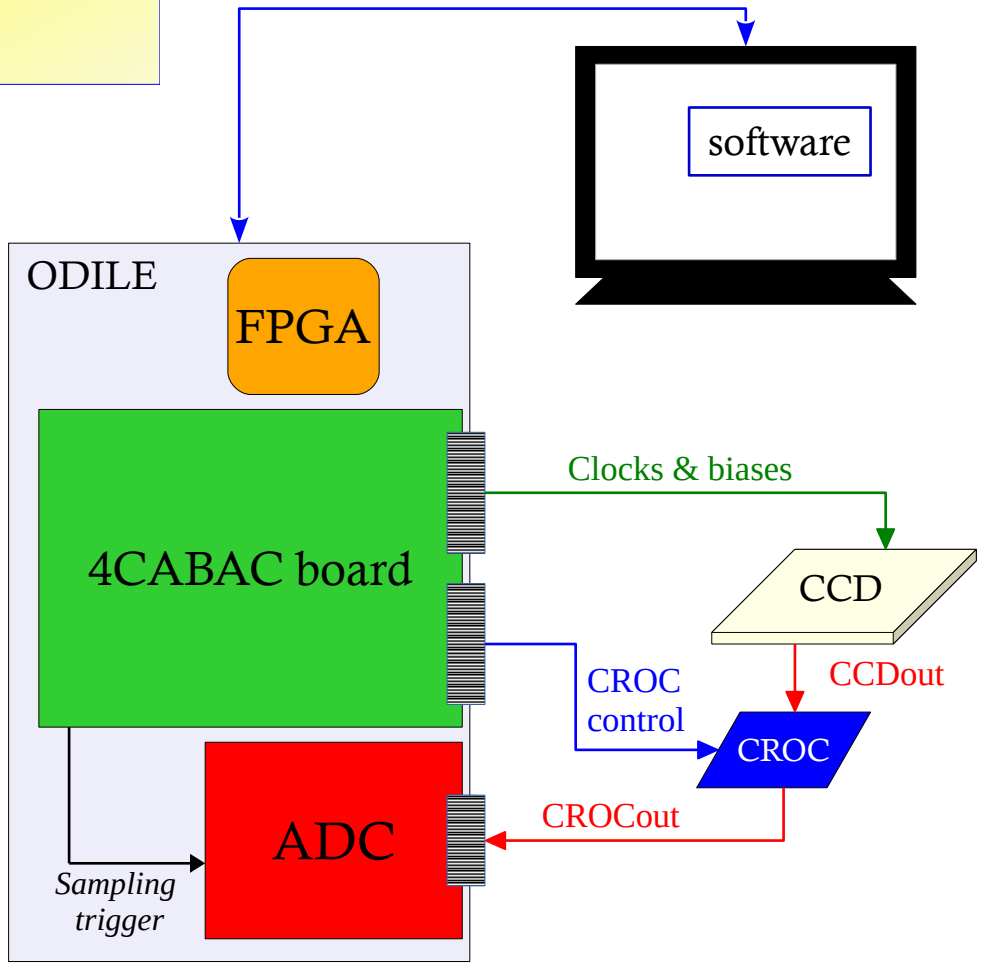
- High resolution
- Fast sampling

CABAC: **C**locks **A**nd **B**iases **A**SIC for **C**CD

- Provides the necessary clocks and bias voltages for the CCD operation
- Performs the sequencing of the clocks

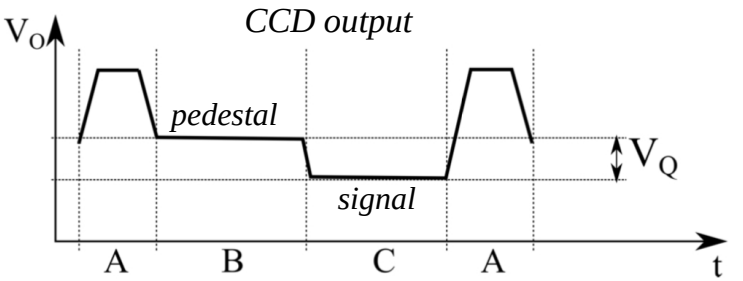
Full Setup & New Electronics

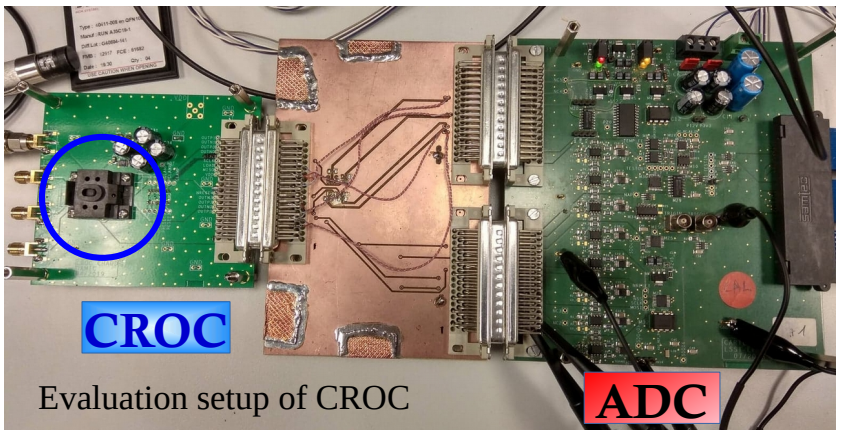
Everything is controlled by the FPGA of the **ODILE - Online Digital Interface for Low-noise Electronics** - motherboard.



CROC: CCD ReadOut Chip

- 4 channel, single-ended input to differential output (CCD output is single ended)
- Operation modes:
  - ***Transparent*** for Digital Correlated Double Sampling – DCDS:
    Operates as a simple amplifier with programmable gain. The ADC **samples both the pedestal and signal levels** and a digital subtraction provides the amplified voltage to which the charge of the pixel corresponds.
  - ***Dual Slope Integrator*** (DSI):
    Integrates in a hardware way both the pedestal and signal levels with reversed polarities for the same exact duration. The ADC samples once this voltage level that is the amplified voltage to which the charge of the pixel corresponds.

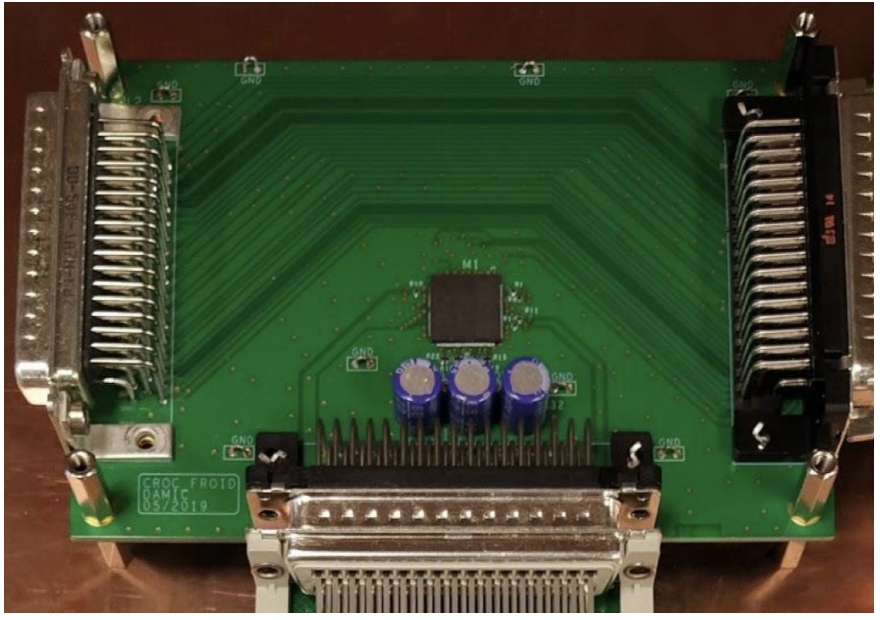




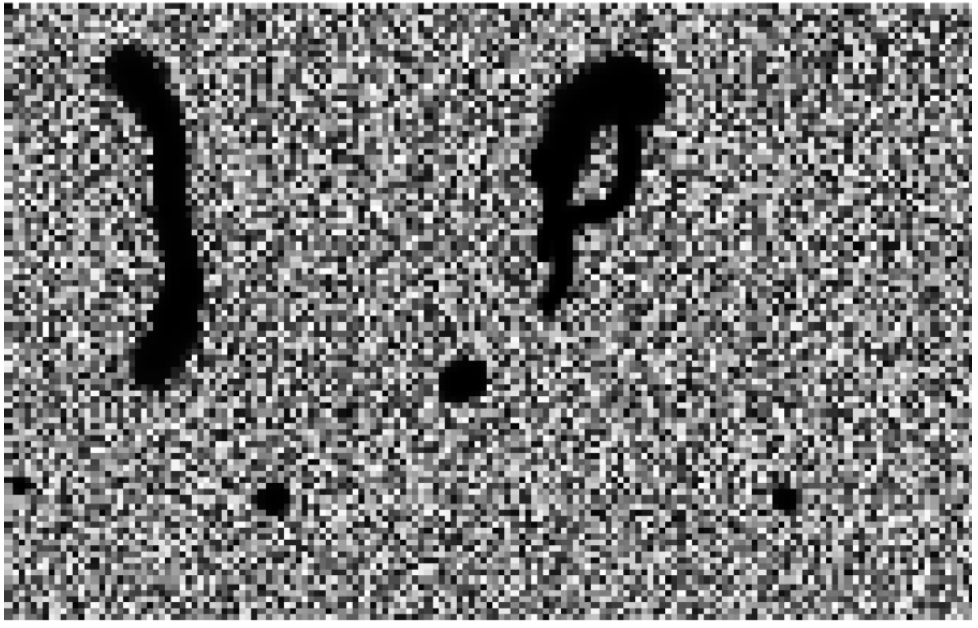
Evaluation setup of CROC

CROC froid (cold) board

A new board was designed to be used with a CCD at low temperature, using CROC.



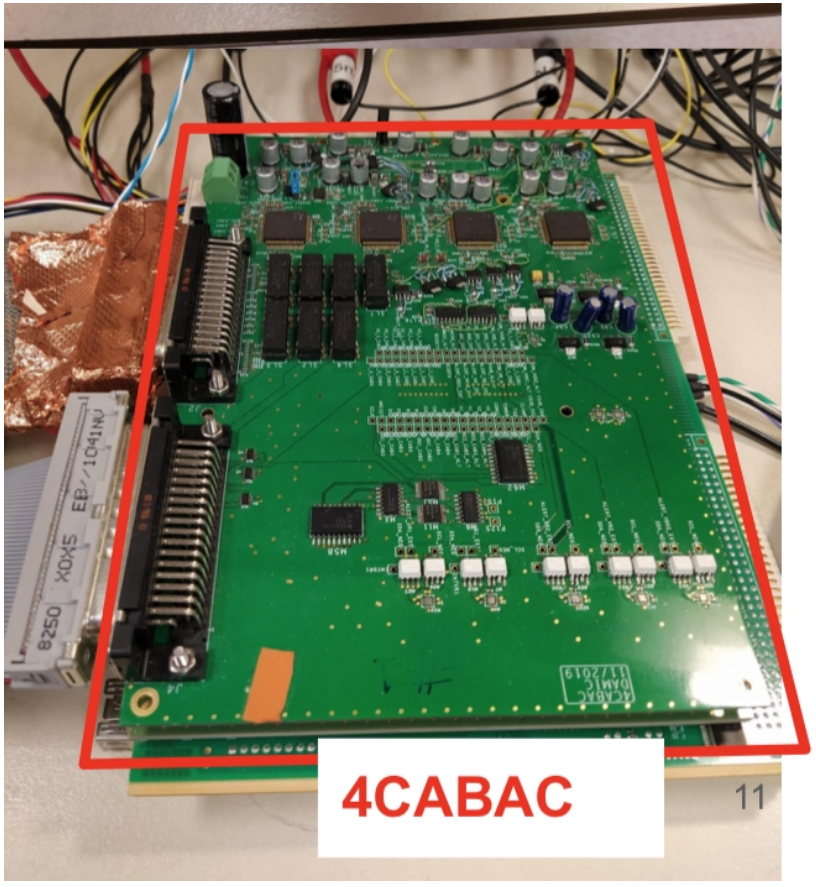
Visible tracks from a single skip image using the CROC.

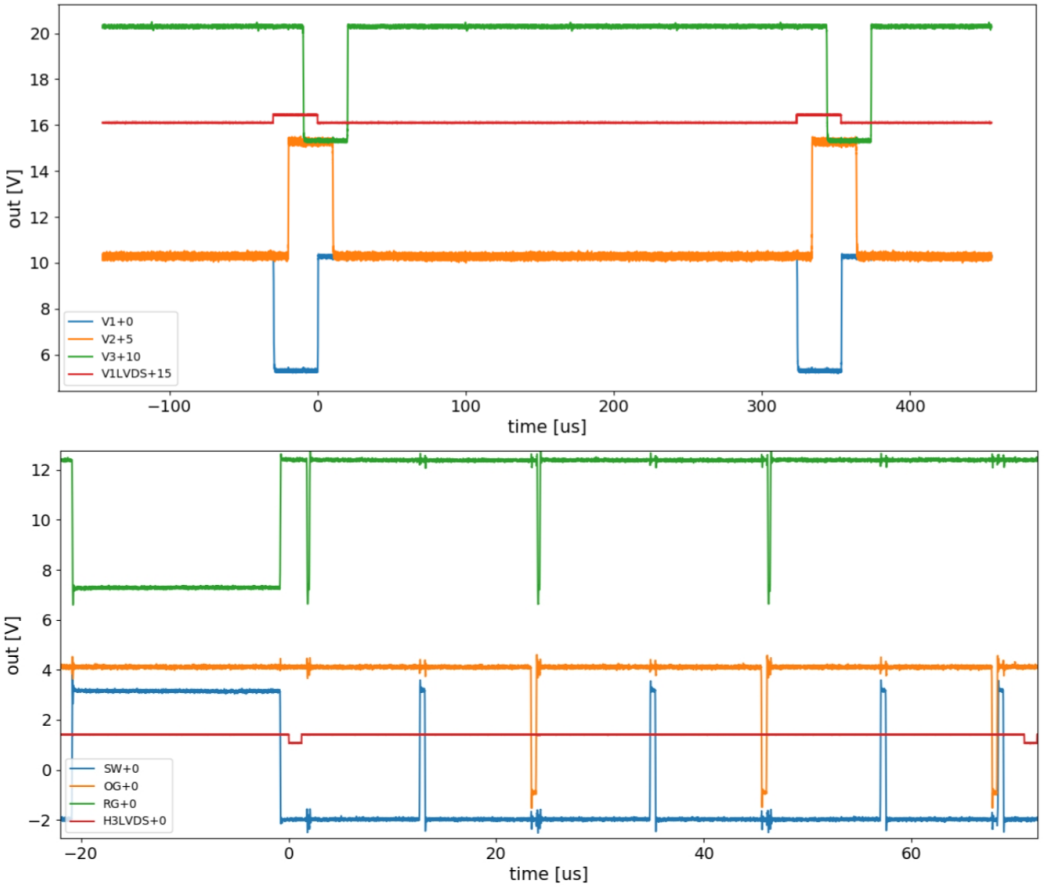


Date: 9/4/2021

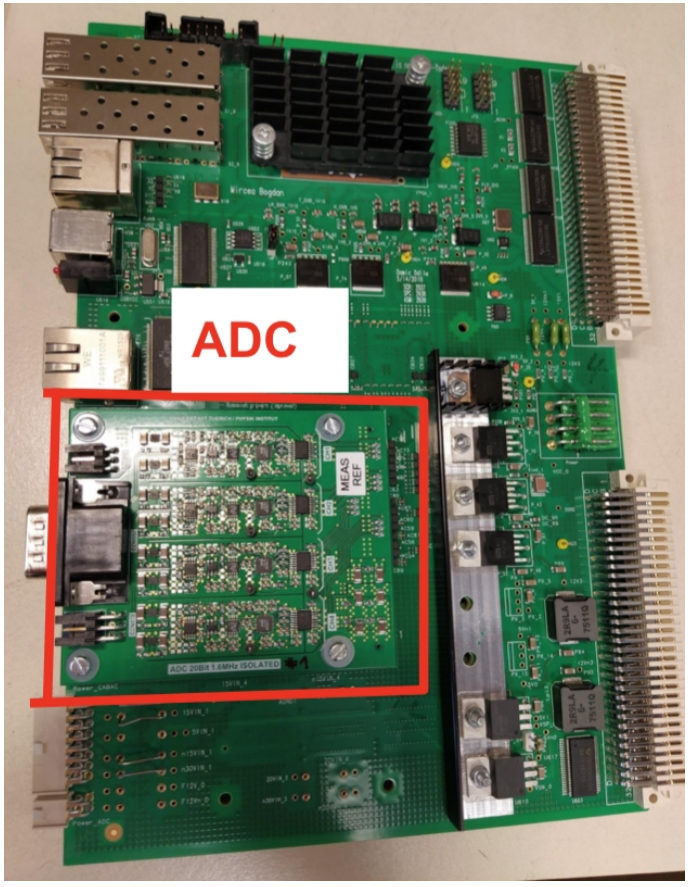
Next steps: optimize the Leach/CROC system to achieve the lowest possible noise.

4CABAC board





Analog to Digital Converter



3 ADC candidates for DAMIC-M

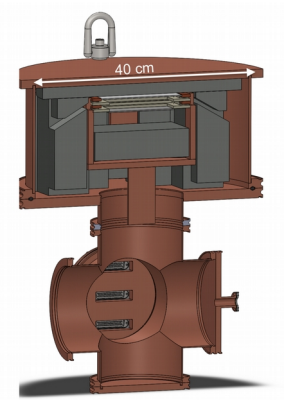
- AD4020, 20-bit 1.8 MSps 10Vpp
- MAX11905, 20-bit 1.6 MSps 6Vpp
- LTC2387-18, 18-bit 15 MSps 8.192 Vpp

All 3 are developed and remains to be evaluated with the full system for a final choice.

Timeline

Activities:

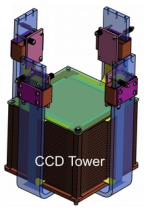
- Background studies
- Large CCD packaging
- R&D of the new electronics
- Production of the sequencer for the CCD operation
- Operate the CCD with the new acquisition system

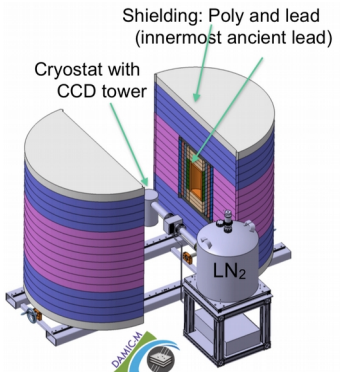


Low Background Chamber (LBC): Installation of a smaller detector with ~25g of CCD at LSM.

Objectives:

- characterization of DAMIC-M CCDs (dark current).
- Test the new electronics and the overall acquisition system.
- Measurements of background at LSM.
- First scientific results.





Installation of DAMIC-M

31 May 2021
(today)

2022

2023

… STAY TUNED

References :

[1] *DAMIC-M Experiment: Thick, Silicon CCDs to search for Light Dark Matter*, N. Castello-Mor for the DAMIC-M Collaboration, 2020