GDR Deep Underground Physics,
9–11 oct. 2024, Lyon, France

DAMIC-M electronics system, status and first results.

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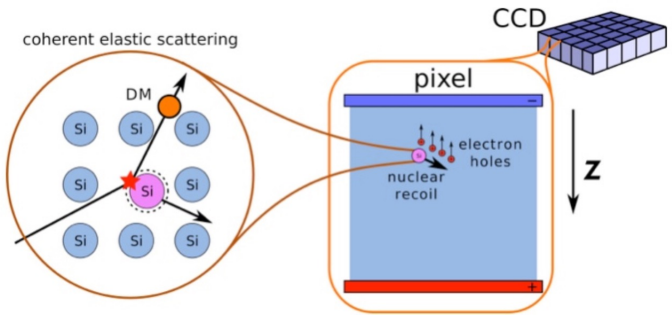
on behalf of the DAMIC-M Collaboration LPNHE (Paris), CNRS-IN2P3.

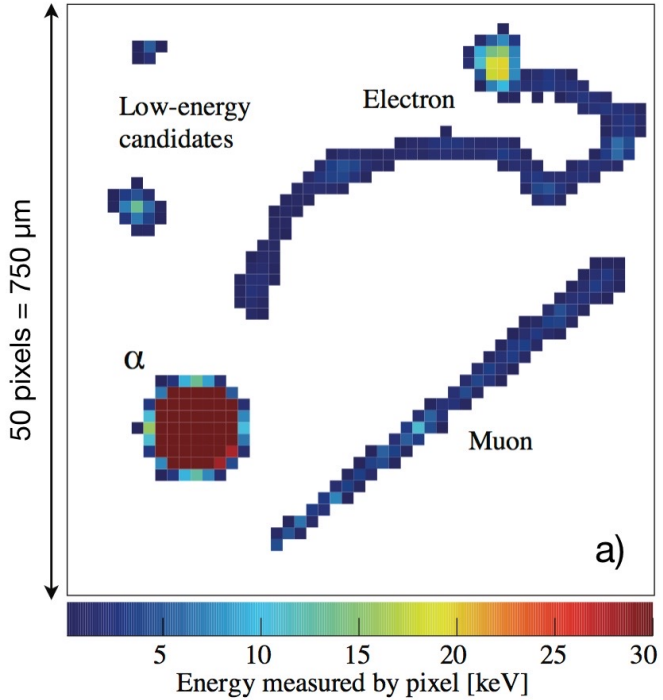
DARK MATTER IN CCDs

The experiment

What is DAMIC?

Aims to detect nuclear and electron recoils in Silicon CCDs to search for light dark matter candidates (eV to GeV).



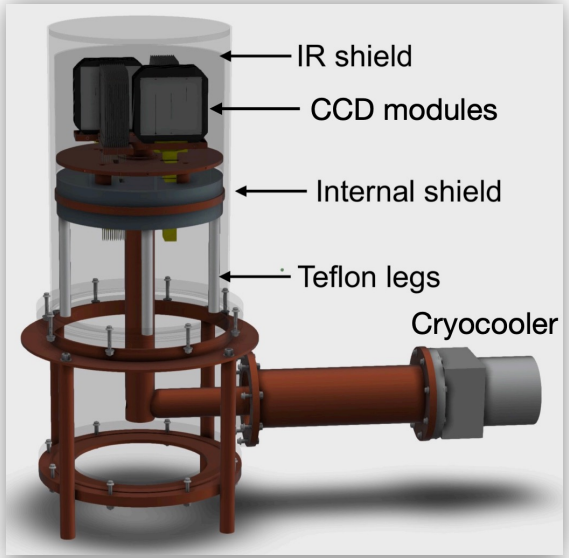


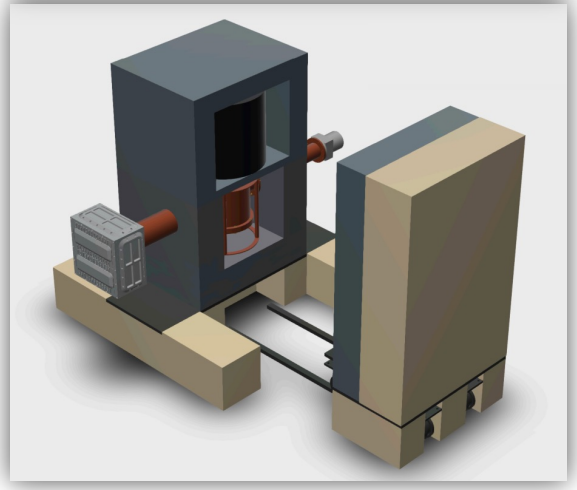
DARK MATTER IN CCDs

The experiment

Detector second generation :

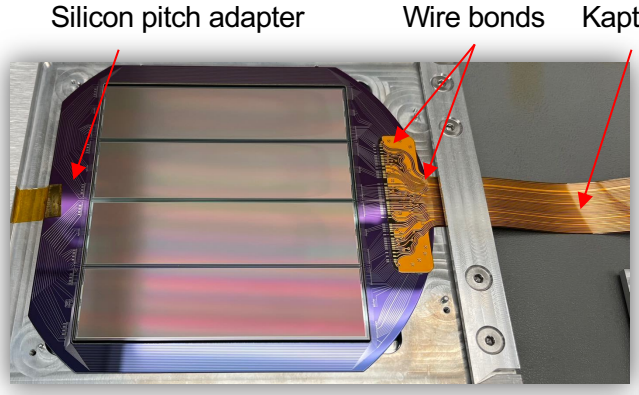
DAMIC at Modane, based in France.
52 modules of 4 CCDs 6K x 1.5K.
~1kg target mass.
Multiple non-destructive charge measurement (Skipper CCD).

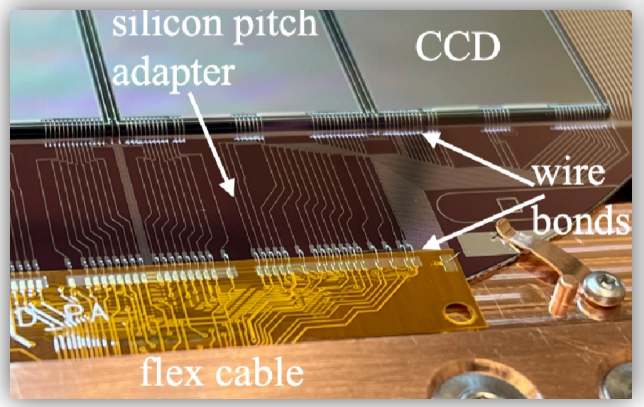


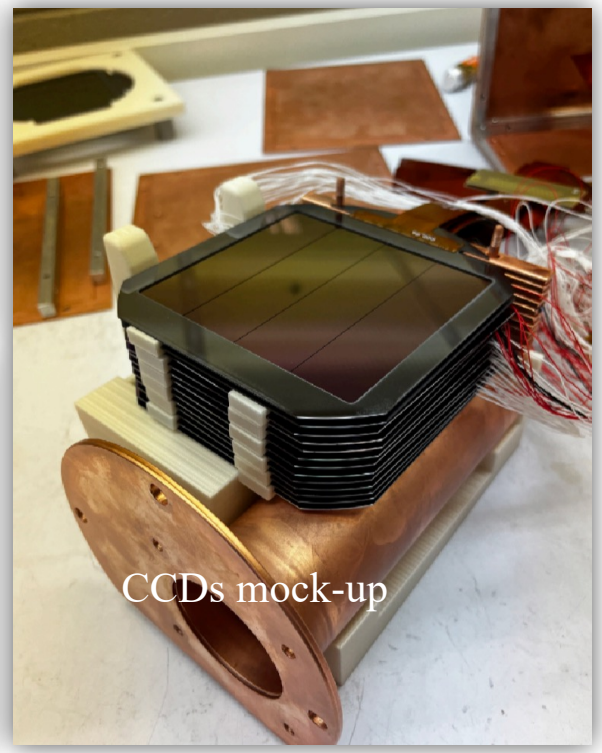


DARK MATTER IN CCDs

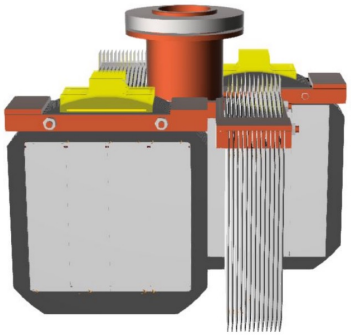
CCD module







DAMIC-M CCD stack



~200 SKIPPER CCDs

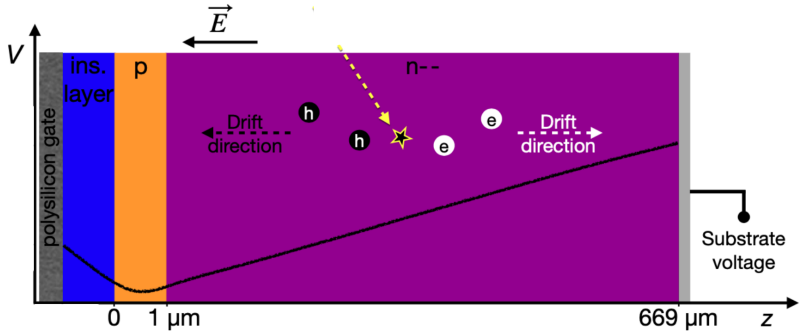
6000 pix x 1500 pix

- The 4 CCDs are glued on a silicon pitch adapter.

DARK MATTER IN CCDs

Detection principle and CCD readout

1



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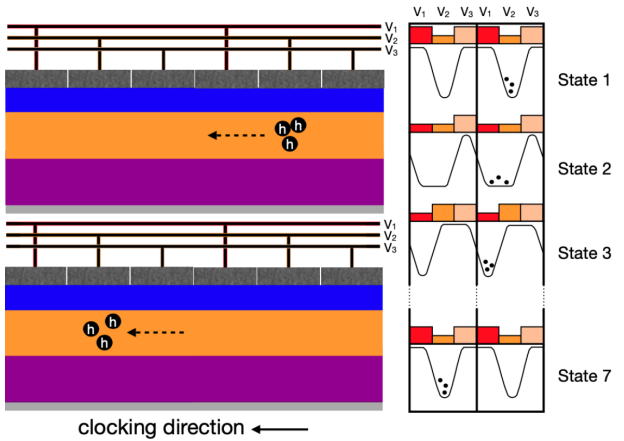

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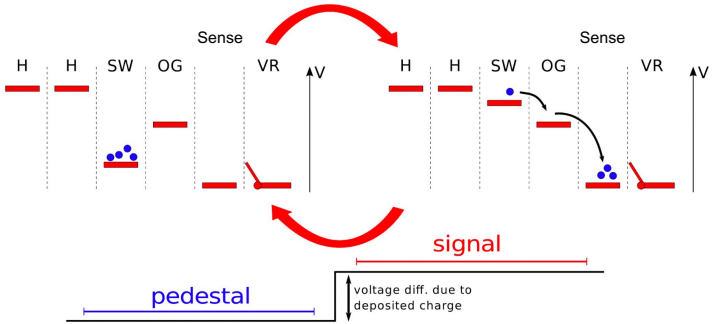

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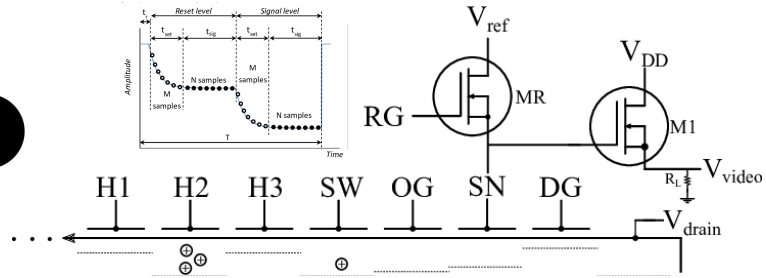
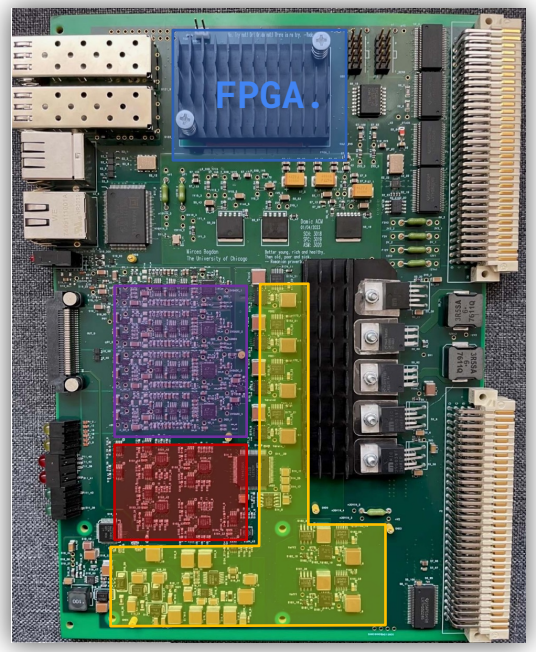


ELECTRONICS CHAIN

Frontend and backend boards

3m samtec



FE board:

- Clock RC shapping
- Bias filtering
- Signal amplification

BE board

Acquisition and Control Module (ACM)

CCD biases.

- Pre-amplifier polarisation.
- Subsrate polarisation.

Clocks generation.

- Timing and voltage control.

FPGA.

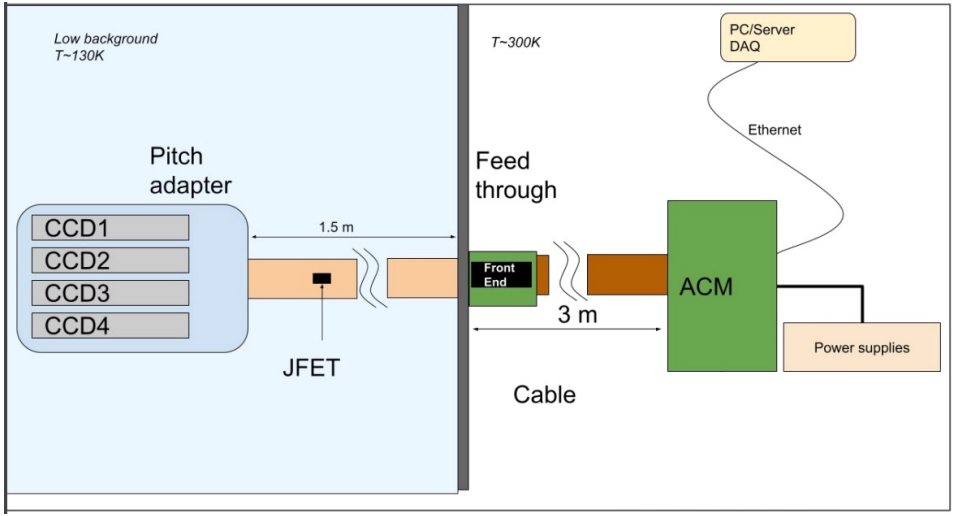
- Communication.
- Sequencer execution.
- Data preprocessing

Signal oversampling.

- 4 fast-ADC channels **15 MSPS**.

READOUT NOISE

An important parameter



System complexity

μV signal amplitudes

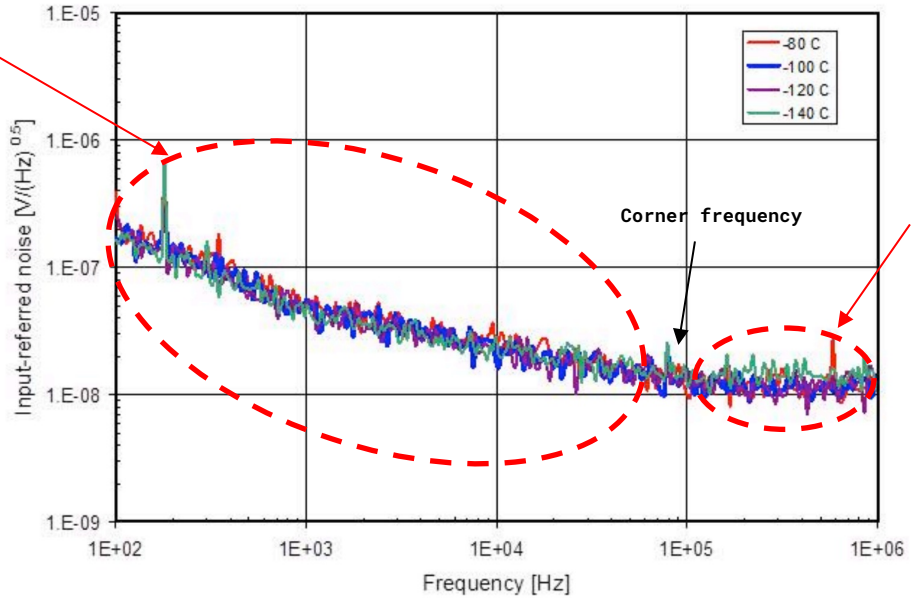
Noise must be minimized to achieve the single-electron resolution.

READOUT NOISE

Strategies to reduce electronic noise

Low frequency noise ?

Skipper readout !



High frequency noise ?

Integration !

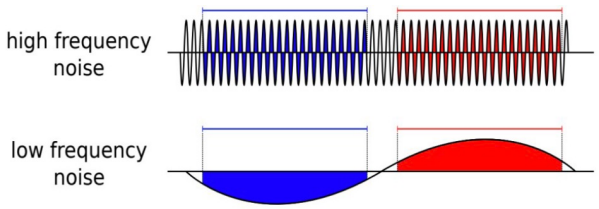
Figure description: Input-referred noise versus frequency for the output transistor measured at four different temperatures.

LBNL 4k x 4k and 4k x 2k CCDs, 250 µm thick, fully depleted p–channel devices with 15 µm pixels.

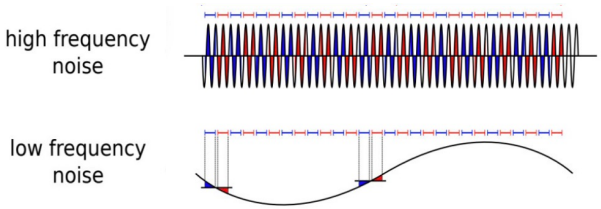
READOUT NOISE

Strategies to reduce electronic noise

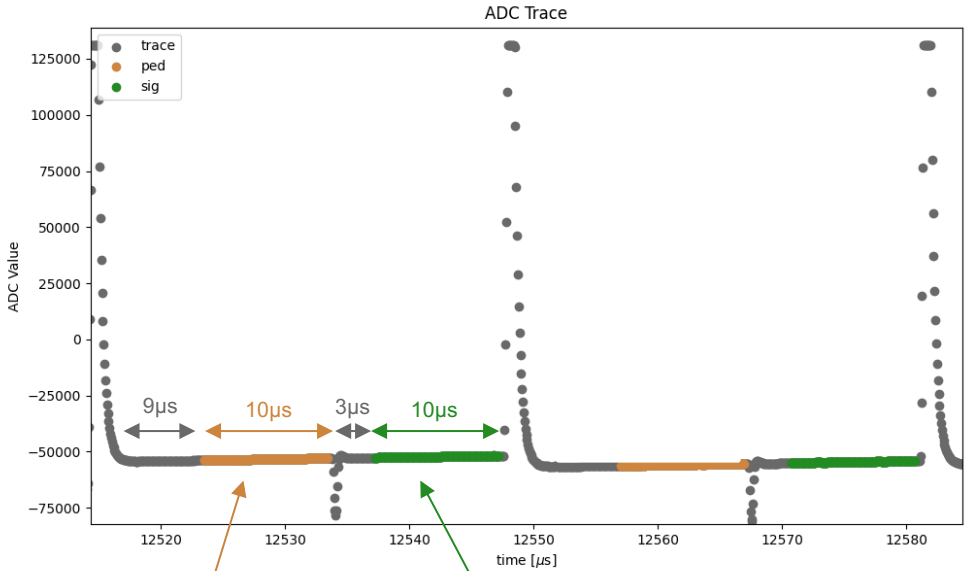
Instead of doing one long integration



We do several short ones:



Signal oversampling – 15MSPS ADCs



$$P = \sum samples \qquad S = \sum samples$$

Figures source: J. Tiffenberg. "Counting electrons with the skipper-ccd," Fermi National Laboratory.

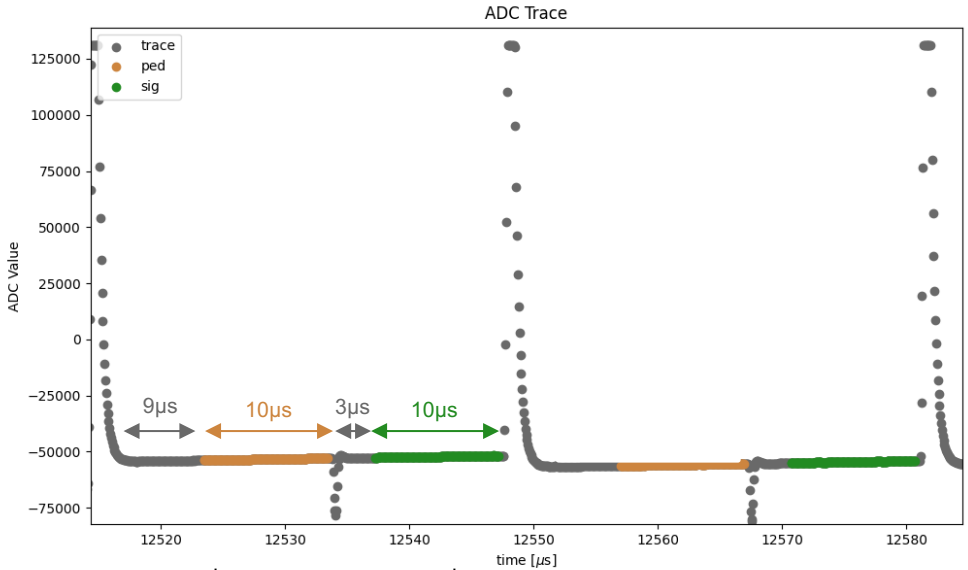
READOUT NOISE

Strategies to reduce electronic noise

Multi-skips readout:

- Noise divided by a factor of $\sqrt{NDCM}$[1]

Signal oversampling – 15MSPS ADCs



$$Pixel\ value = \frac{1}{NDCM}\sum differences$$

NDCM: number of Non-Destructive Charge Measurments

READOUT NOISE

Noise sources

What might be the other noise sources ?

1. Electronic components intrinsic noise (Biases, Clocks generation)
2. Clock Transfert Inefficiency (CTI), Clock Induced Charge (CIC)
3. Dark current
4. Crosstalk noise

READOUT NOISE

Electronic components intrinsic noise - Biases

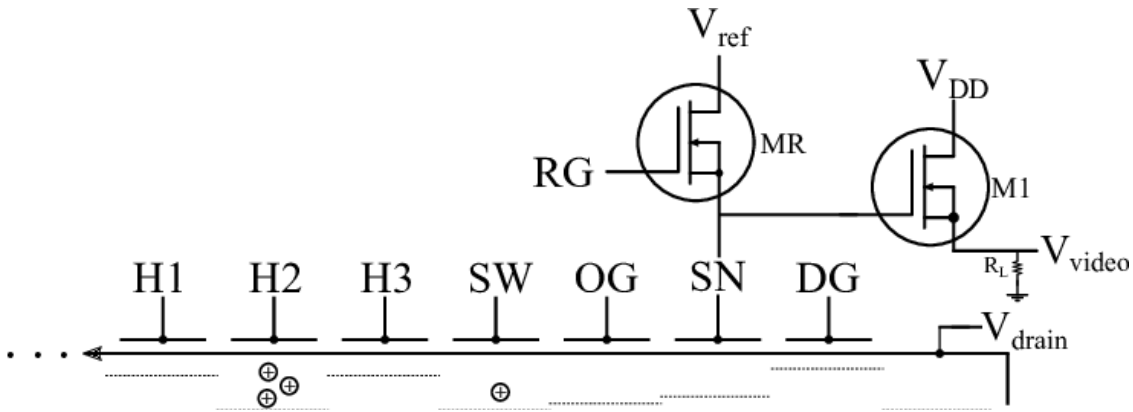


Figure description: Schematic illustration of a Skipper-CCD readout stage.

Figure source: SENSEI: Characterization of Single-Electron Events Using a Skipper-CCD. 10.48550/arXiv.2106.08347. .

READOUT NOISE

Electronic components intrinsic noise - Biases

We need low noise biases !

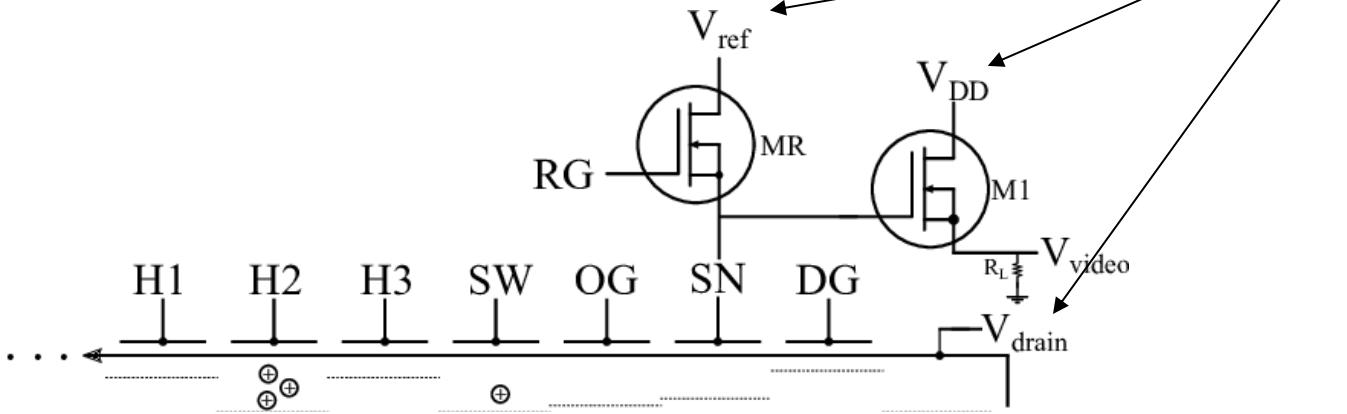


Figure description: Schematic illustration of a Skipper-CCD readout stage.

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READOUT NOISE

Electronic components intrinsic noise - Biases

TPS7A33 –36-V, 1-A, Ultralow-Noise Negative Voltage Regulator, 16µVRMS (10 Hz to 100 kHz)

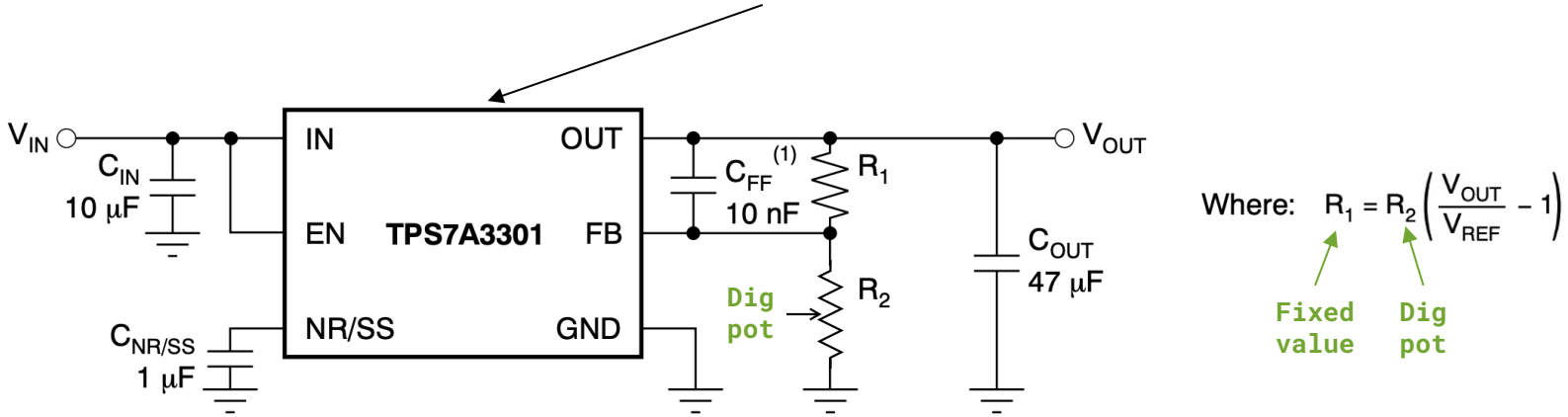

Figure description: Typical Application Schematic of a bias generator.

Figure source: TPS7A33 datasheet.

READOUT NOISE

Electronic components intrinsic noise - Clocks

We need low noise clocks !

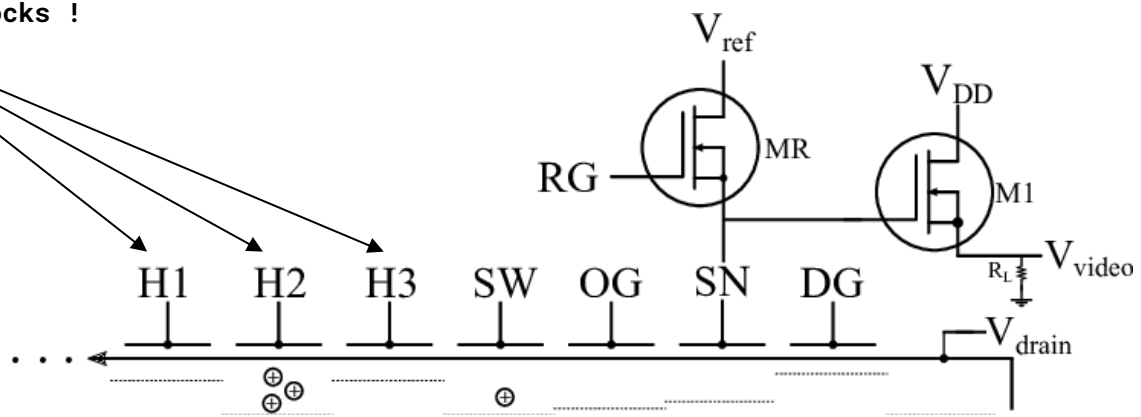

Figure description: Schematic illustration of a Skipper-CCD readout stage.

Figure source: SENSEI: Characterization of Single-Electron Events Using a Skipper-CCD. 10.48550/arXiv.2106.08347. .

READOUT NOISE

Electronic components intrinsic noise - Clocks

40-Channel, 14-Bit DAC, 250 nV/√Hz @ 10KHz

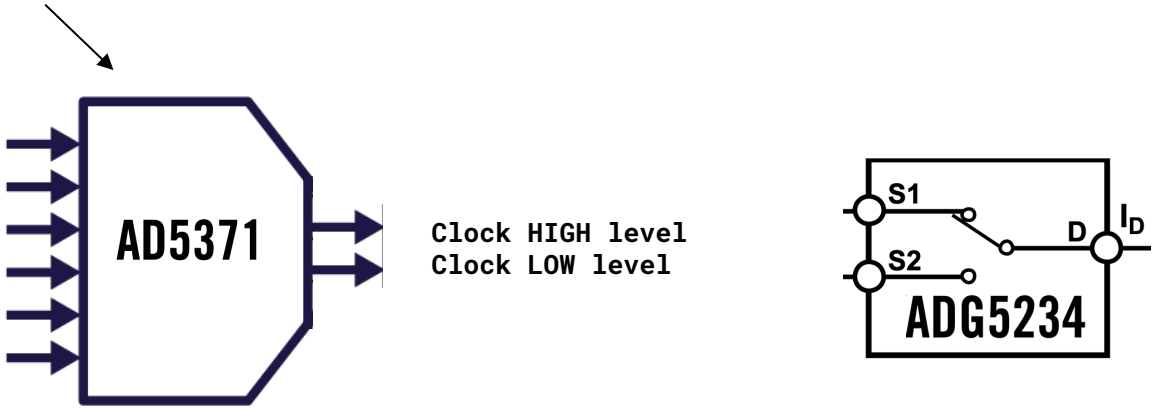

Figure description: Typical Application Schematic of a clock generator.

Figure source: AD5371 & ADG5234 datasheets.

READOUT NOISE

Clock Transfert Inefficiency (CTI) & Clock Induced Charge (CIC)

What are CTI and CIC?

CTI describses the quality of the pixel transfer.

CIC are charges that are released from trappes due to the clocks.

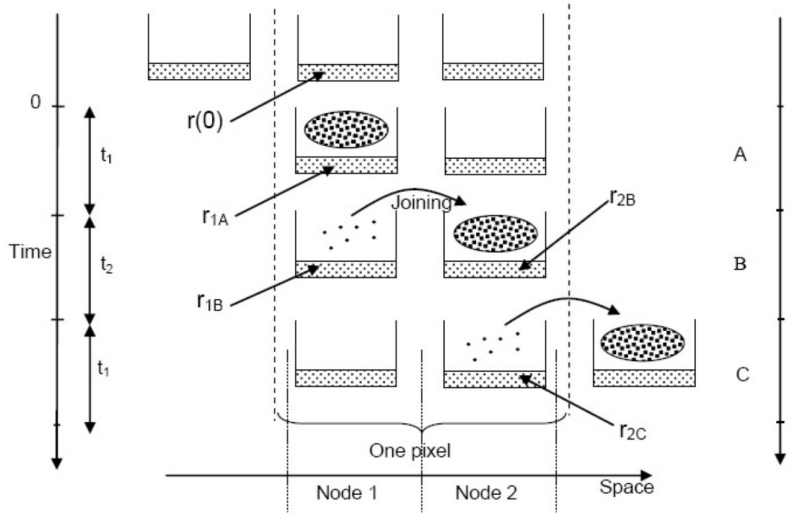

Figure description: Diagram of consecutive transfer of charge in a CCD. The diagram shows the charge transfer at different stages in time and space.

Figure source: Modeling of Charge Transfer Inefficiency in a CCD with High-Speed Column Parallel Readout. arXiv:0811.2503v1

READOUT NOISE

Clock Transfert Inefficiency (CTI) & Clock Induced Charge (CIC)

How do we reduce CTI & CIC?

- Increase the clock timings and/or the amplitudes.
- Increase the rising and falling times.

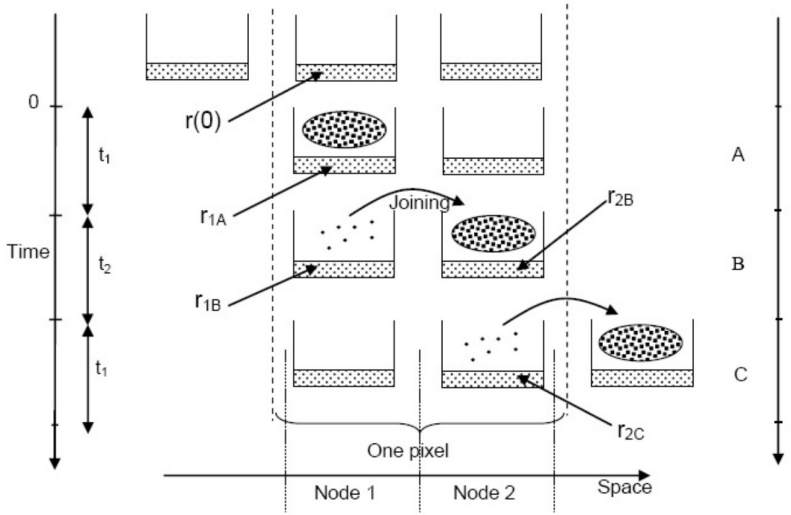

Figure description: Diagram of consecutive transfer of charge in a CCD. The diagram shows the charge transfer at different stages in time and space.

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READOUT NOISE

Dark current

What is Dark Current?

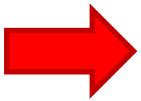
Thermally generated charge, which is not due to incident particles.
DC is **linearly** dependent on time.

How do we reduce Dark Current?

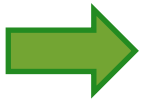
1. Lower operating temperature.

   CCDs are **cooled** to a temperature of **130Kelvin**.

2. Reduce readout time.



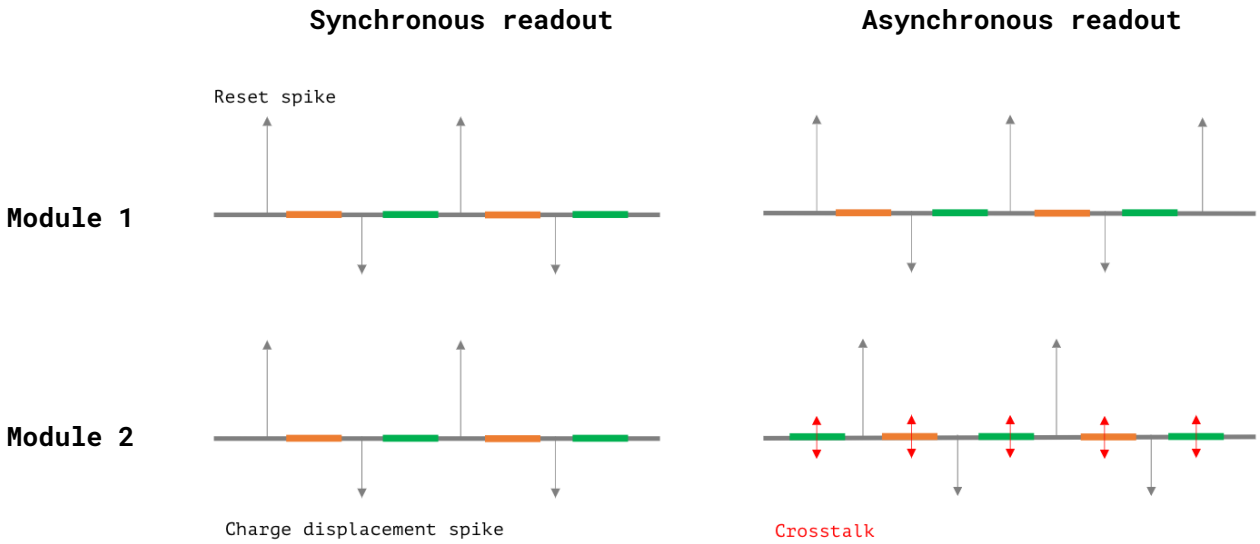
Reduce integration time and skips.



Readout-noise DC **compromise**.

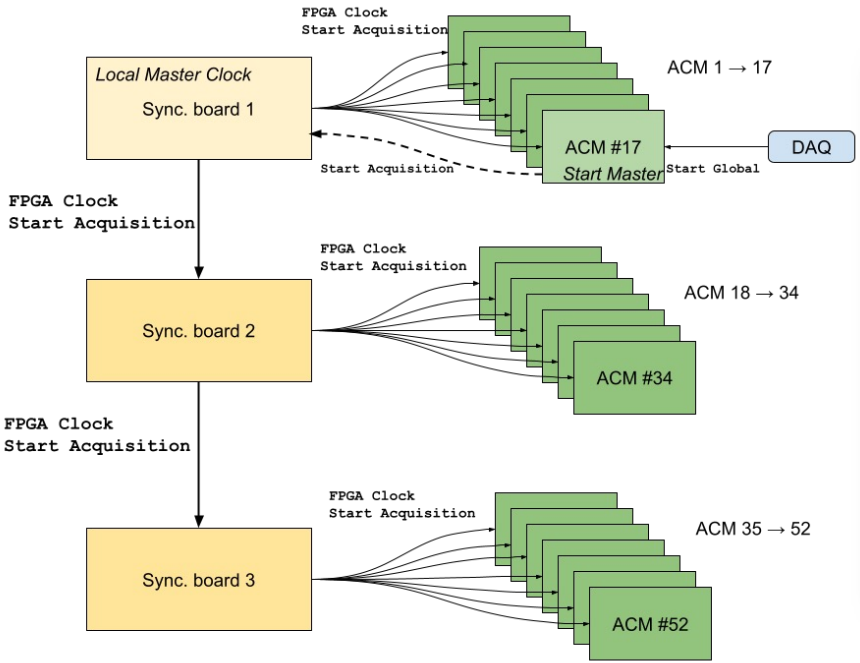
ELECTRONICS CHAIN

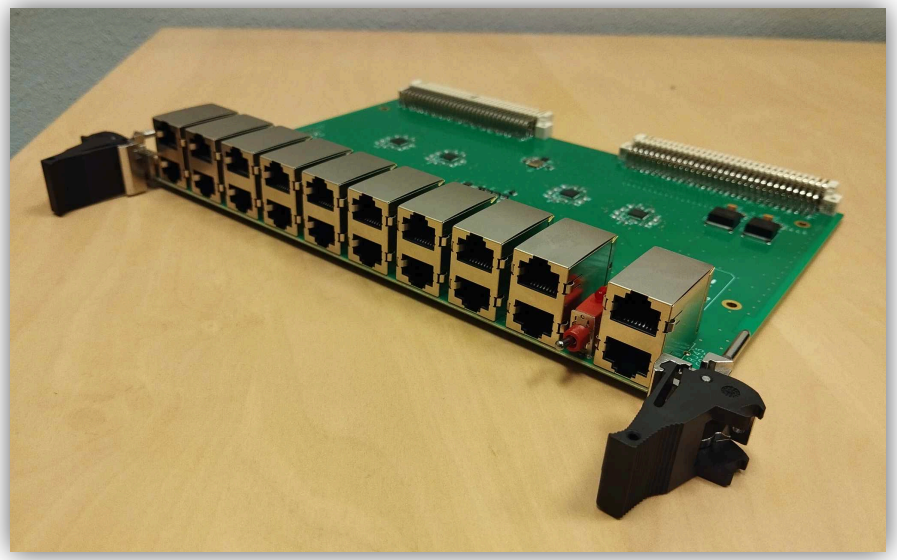
Crosstalk noise



ELECTRONICS CHAIN

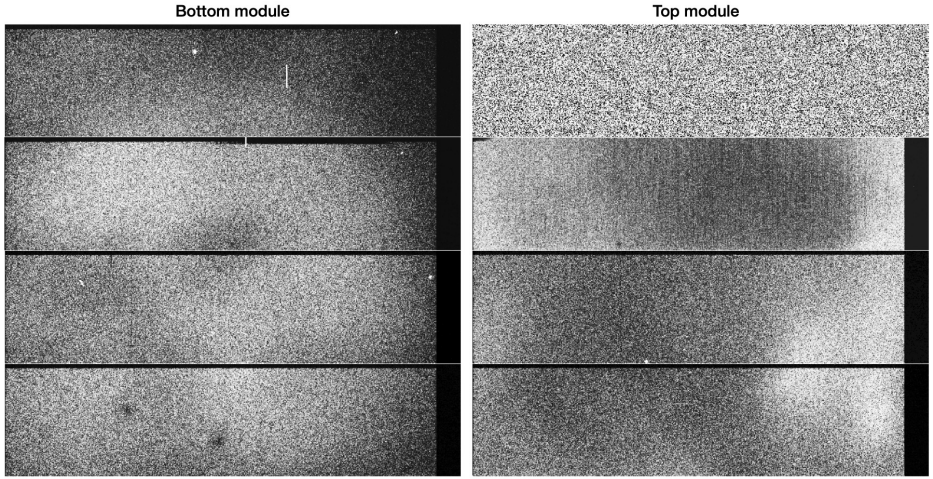
Synchronisation board

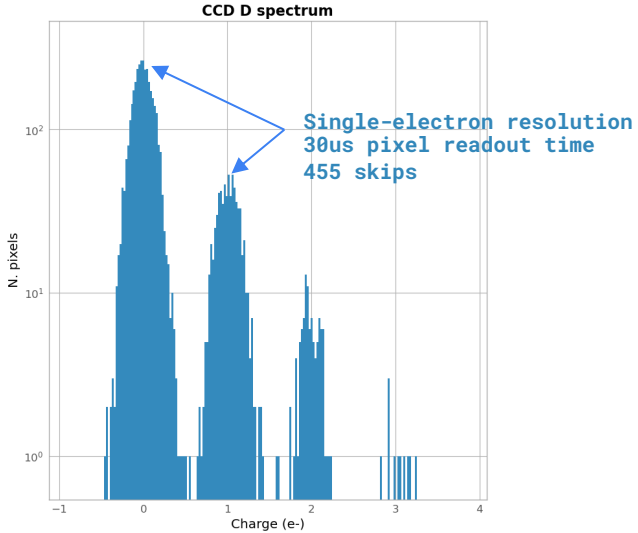


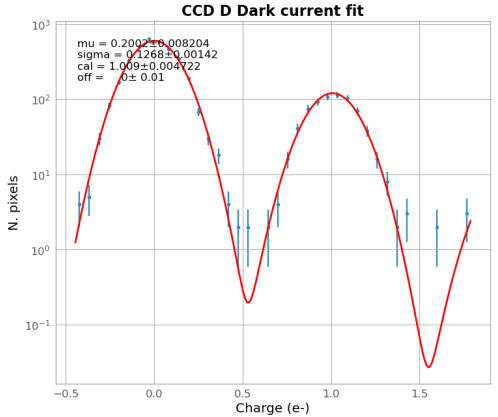


DAMIC-M PROTOTYPE

Noise readout results







Electronics noise improved:

Old electronics
(ARC Astronomical Research Cameras CCD Controller)

5 boards for 1 module
$7e^-$

New electronics

1 board for 1 module
$< 3e^-$

DAMIC at MODANE

Conclusion and perspectives

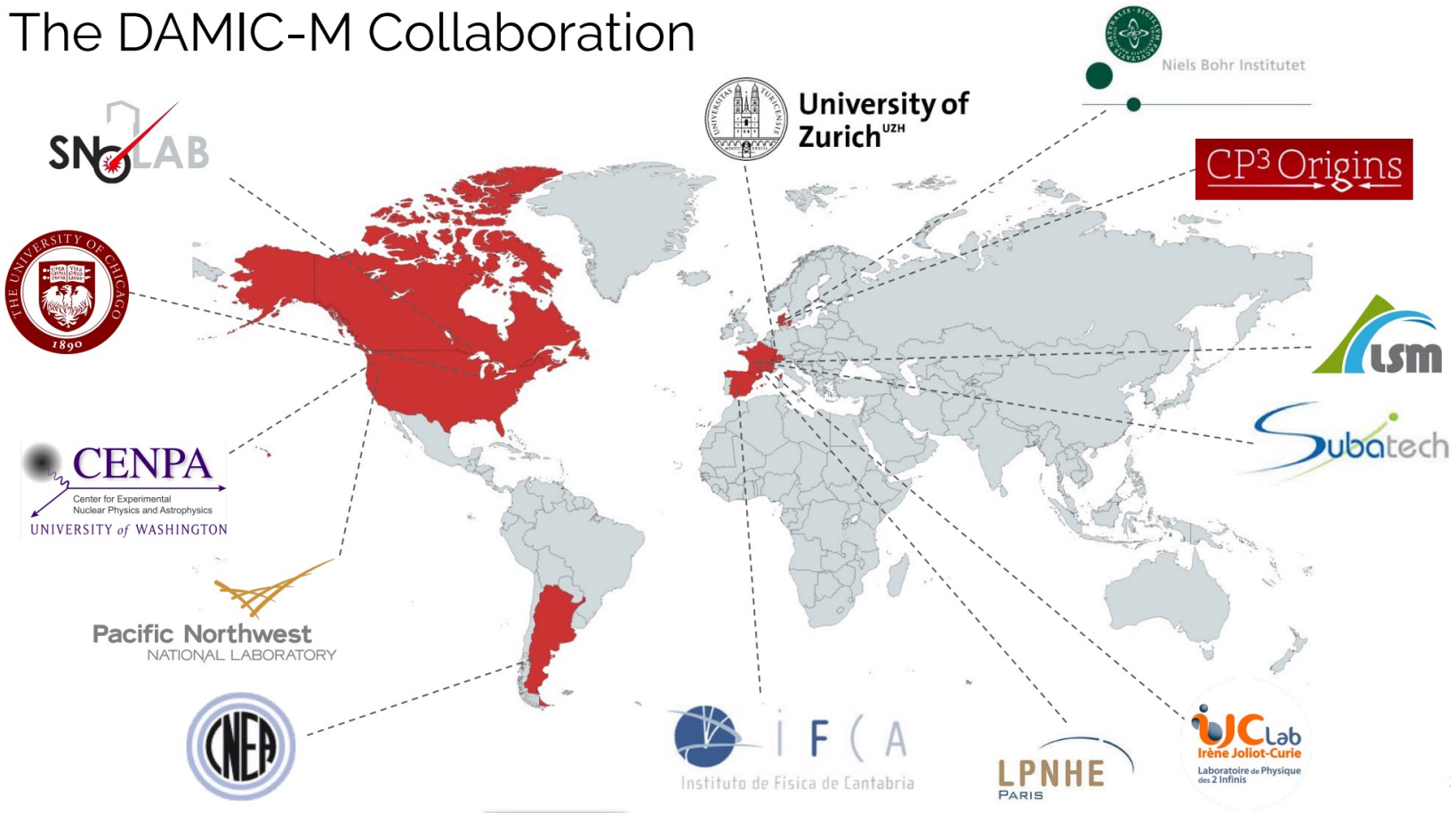
Achieved :

1. Low noise electronics
2. A functional prototype of the detector

Planned :

1. CCD modules commissiong.
2. Final cryostat and shielding commission.
3. Half-detector installation during 2025.

The DAMIC-M Collaboration



BACKUP

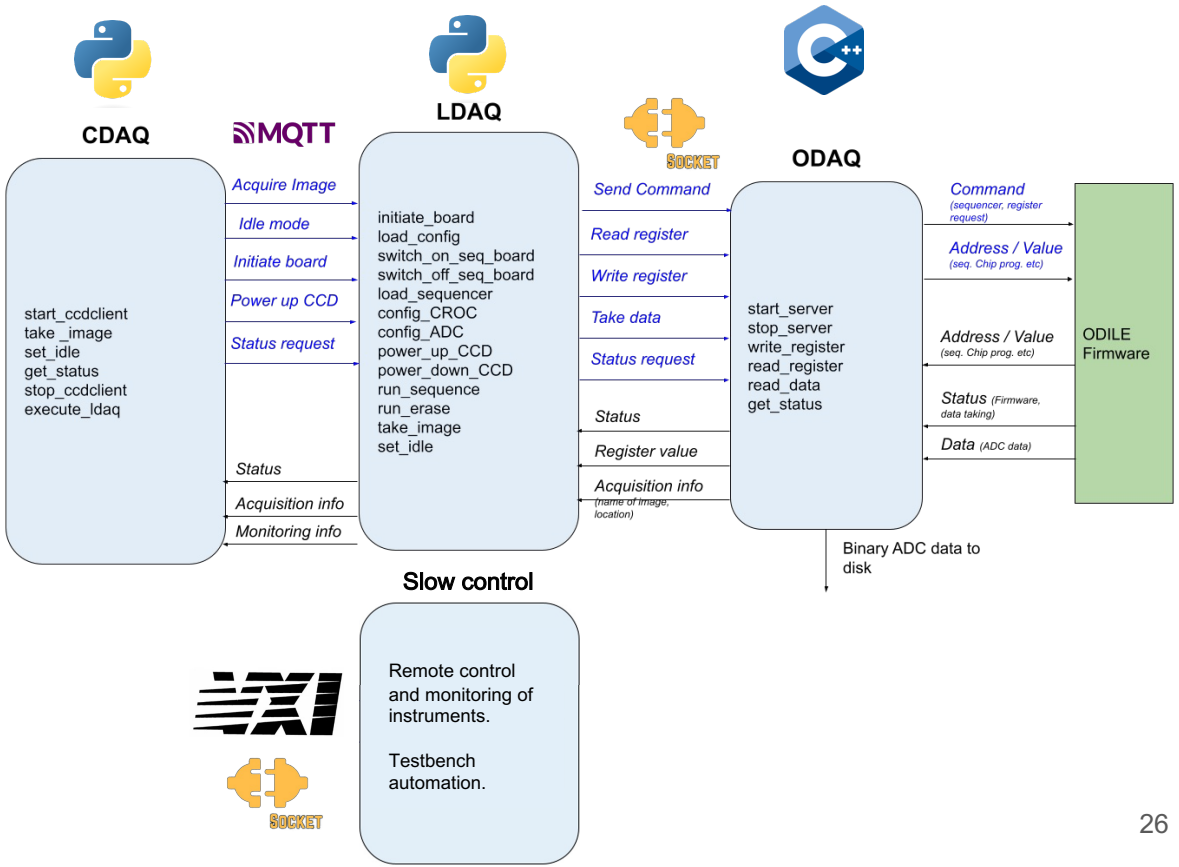
SOFTWARE

DAQ

ACMDAQ (Olivier Deligny, IJCLAB):
- C++ communication protocols.

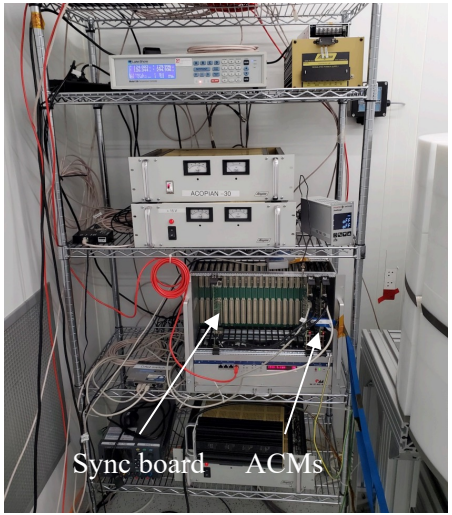
LDAQ (Romain Gaior, LPNHE):
- Python user interface.

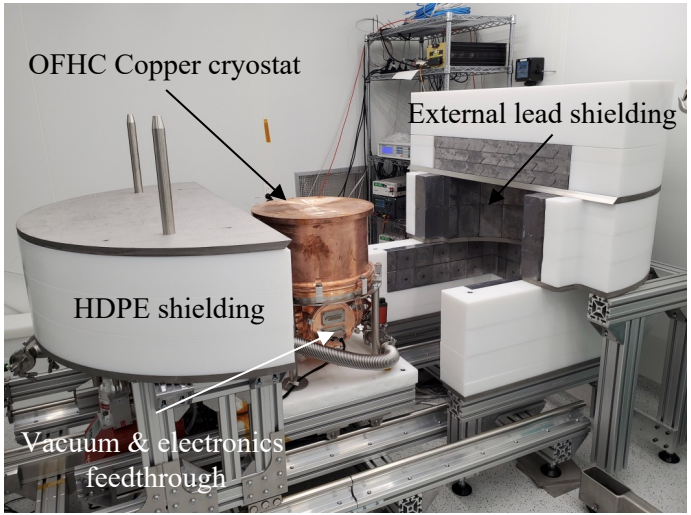
CDAQ (Xavier Bertou, LPNHE/IJCLAB):
- LDAQ/ODAQ broker.

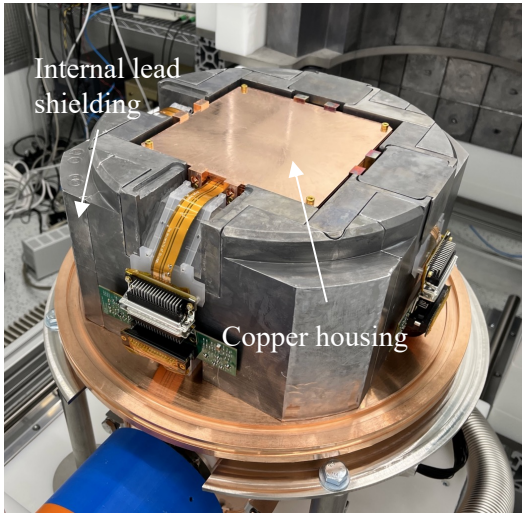


DAMIC-M PROTOTYPE

Low Background Chamber







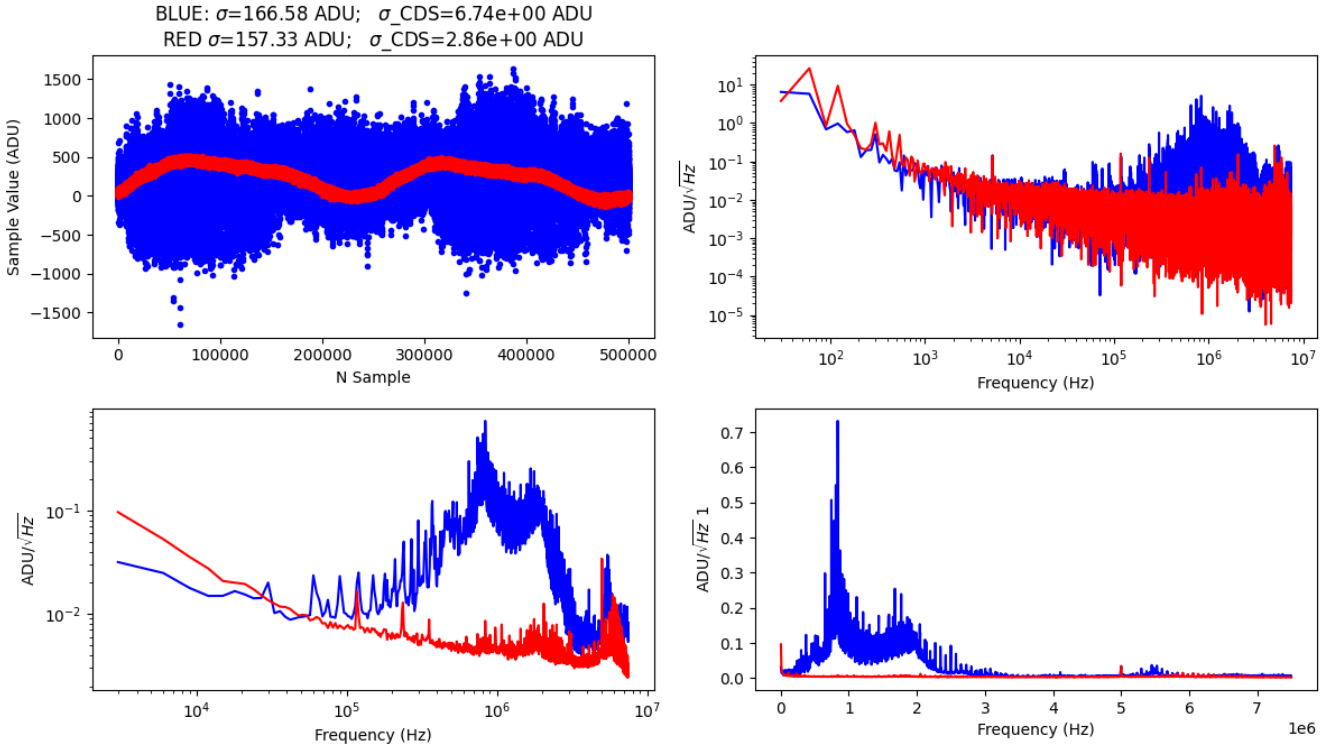
Main goals:

- **Validate** the operation of detector subsystems (Cryogenics, electronics, slow control..)
- Evaluate the performances of skipper CCDs.

DAMIC-M PROTOTYPE

Noise spectra, example of noise improvement (grounding)

BLUE: psd_ch0_103_20240904_125539_2.csv
RED: psd_ch0_103_20240904_130644_14.csv



DAMIC-M CCD MODULE

Example of CCD image