TAUP 2019, Toyama, Japan, September 10 2019

The DAMIC-M dark matter experiment

Paolo Privitera

THE UNIVERSITY OF CHICAGO PHYSICAL SCIENCES

KICP

ENRICO FERMI INSTITUTE

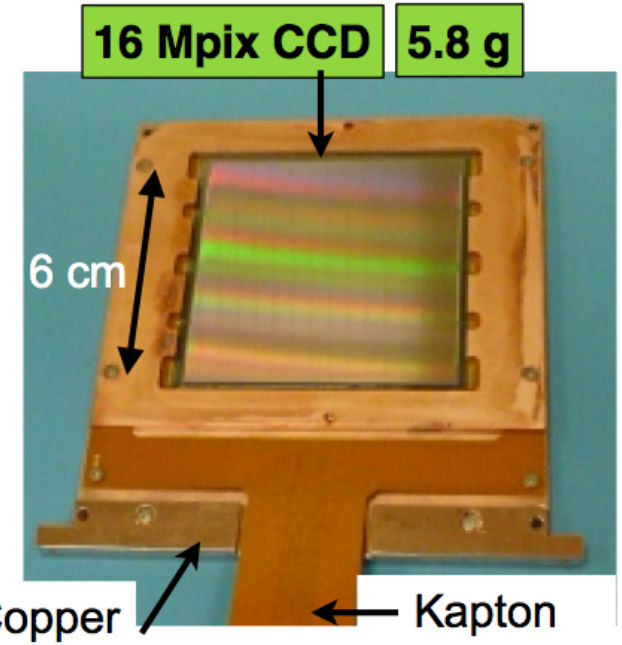
LPNHE PARIS

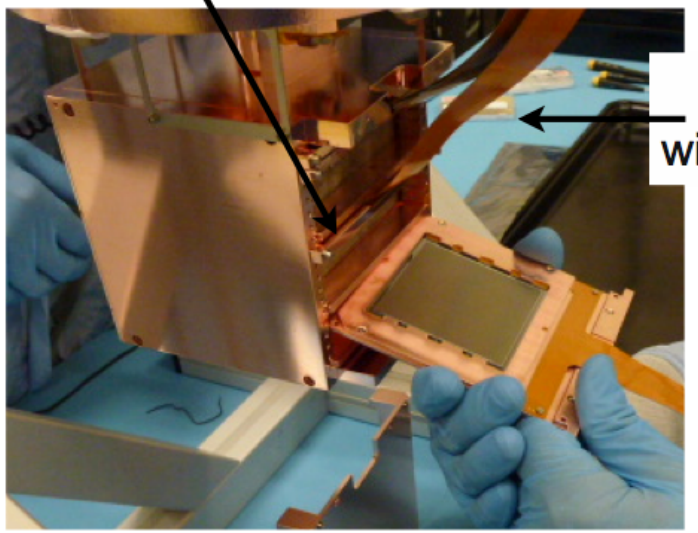
for the DAMIC-M Collaboration

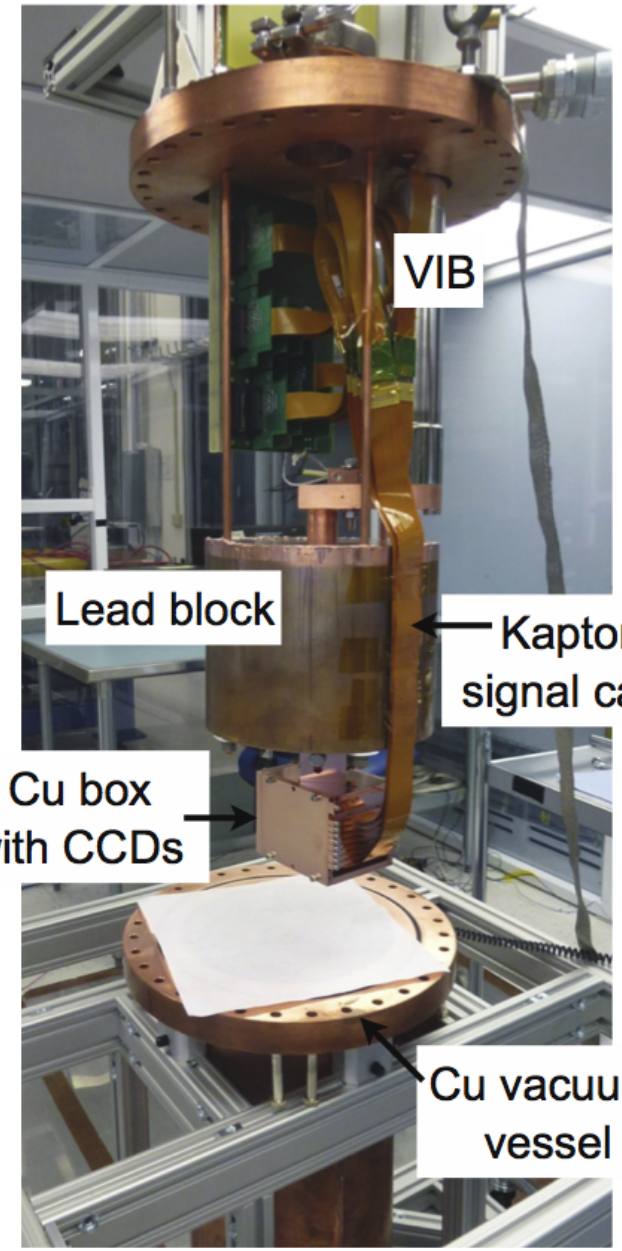
(Photo image: particle tracks in a DAMIC CCD)

DAMIC @ SNOLAB

15 μm x 15 μm pixel, 675 μm thick







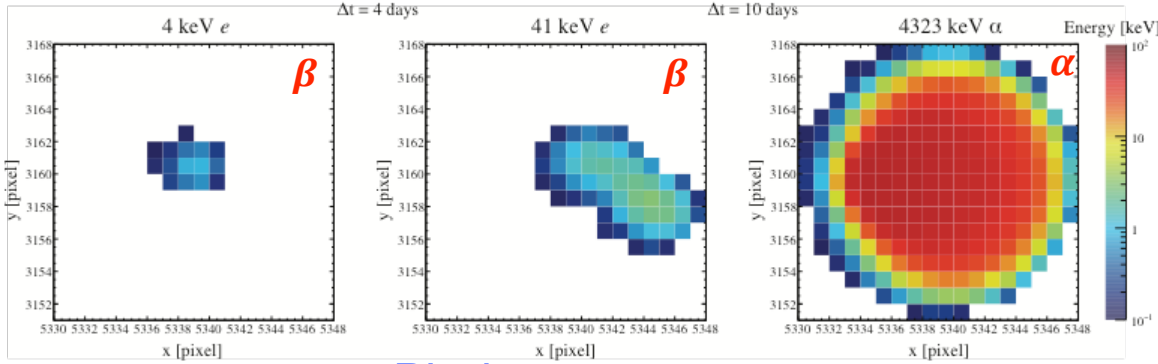
DAMIC-M builds on the experience of DAMIC at SNOLAB

A. Chavarria's talk

Dark Matter in CCDs

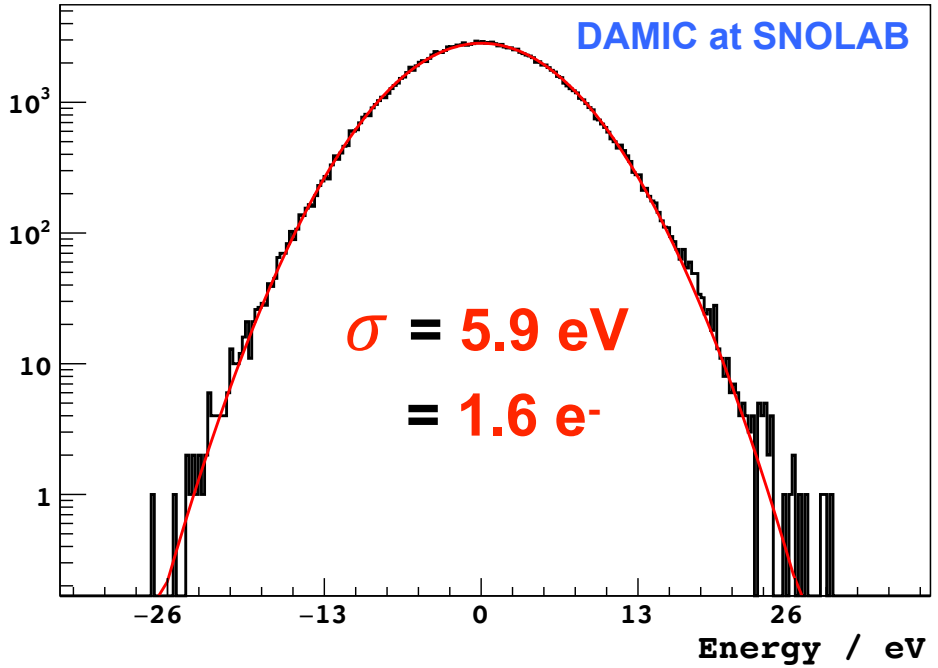
- Exquisite spatial resolution: unique background characterization and rejection

  D. Baxter's talk



^{210}Pb decay sequence

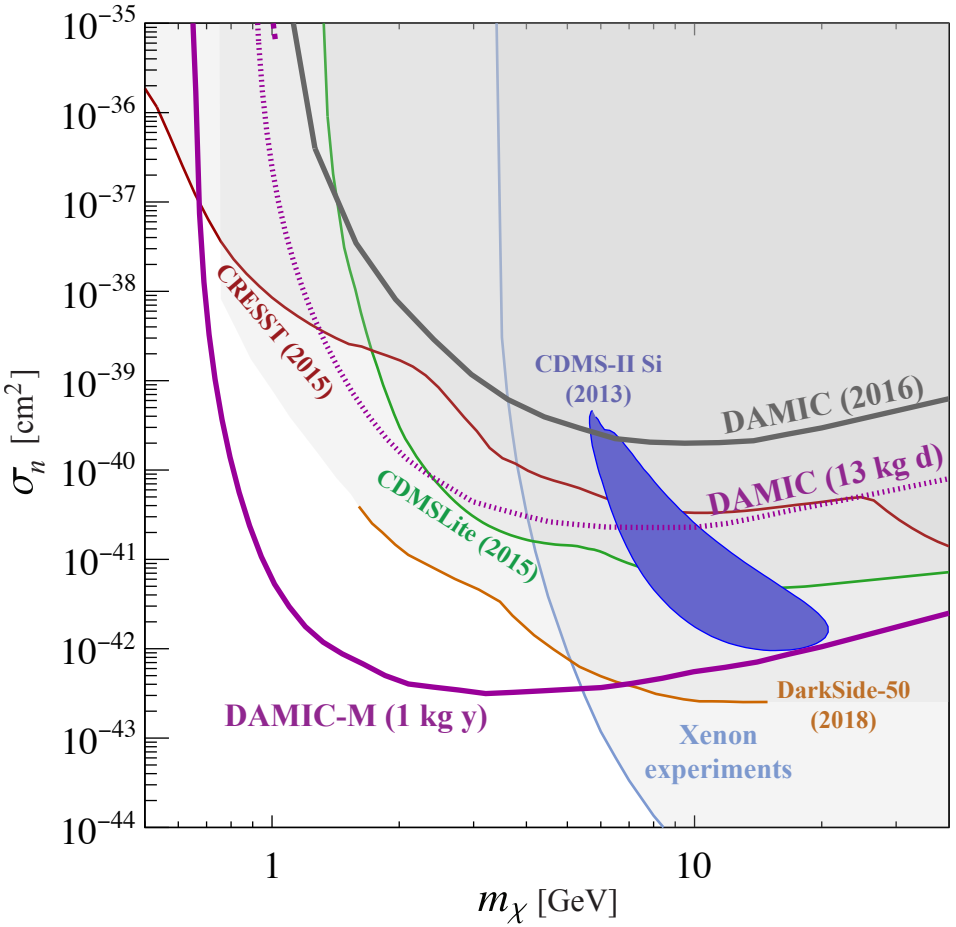
- Extremely low dark current (2×10^{-22} A cm^{-2}, < 0.001 e/pixel/day)
- Resolution of 2 e- achieved at SNOLAB



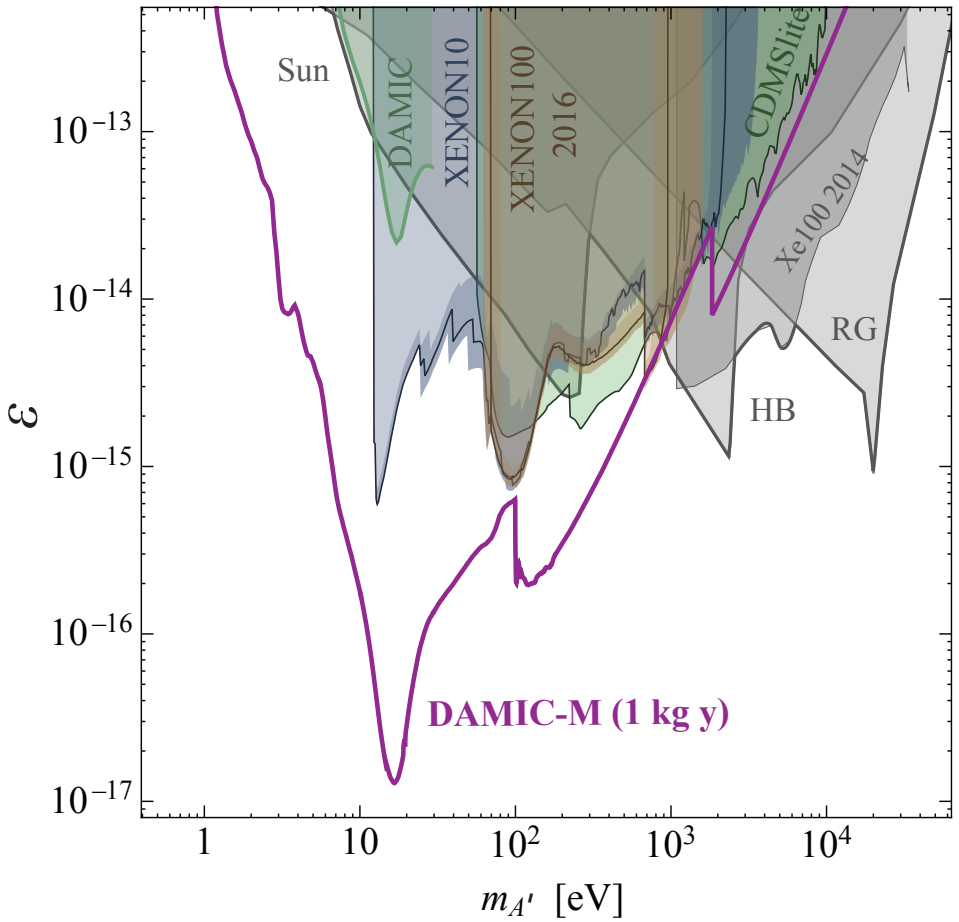
DAMIC-M will feature single electron resolution allowing for detection thresholds of 2-3 e-

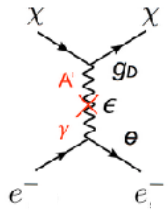
Scientific reach

WIMP nuclear recoil search



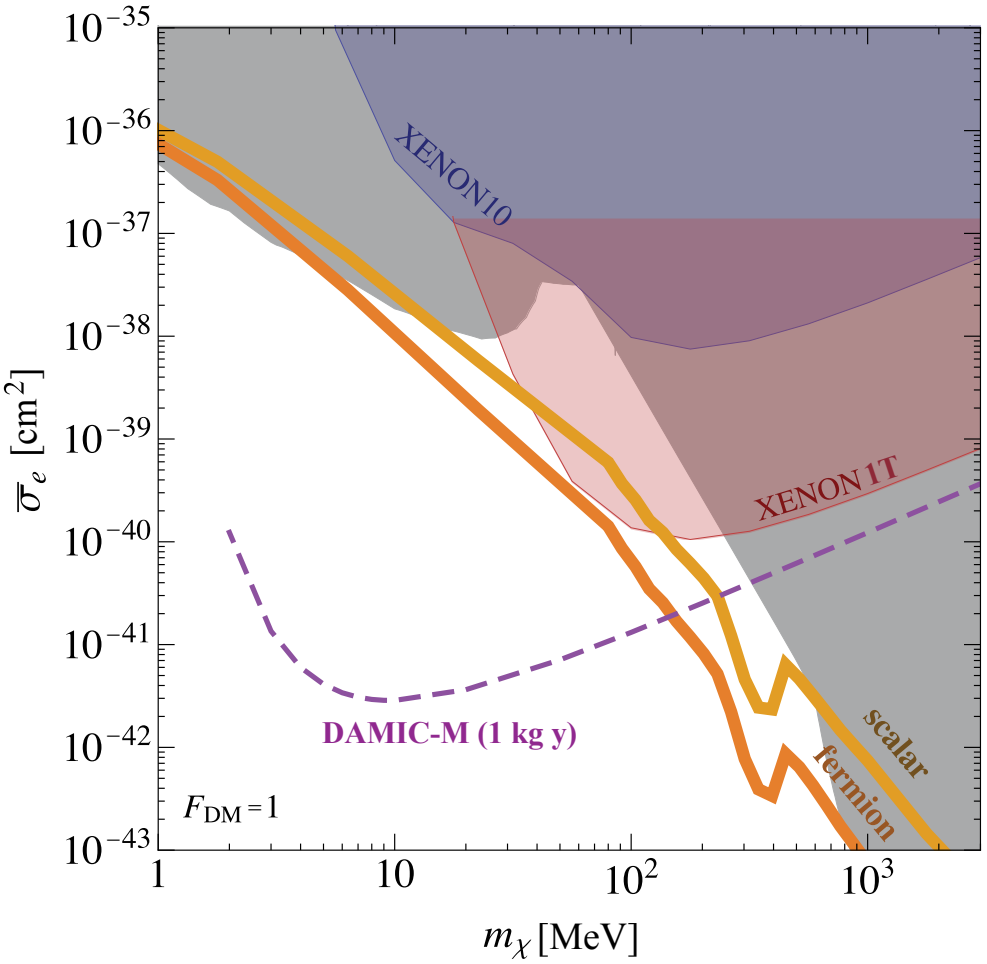
Hidden photon search

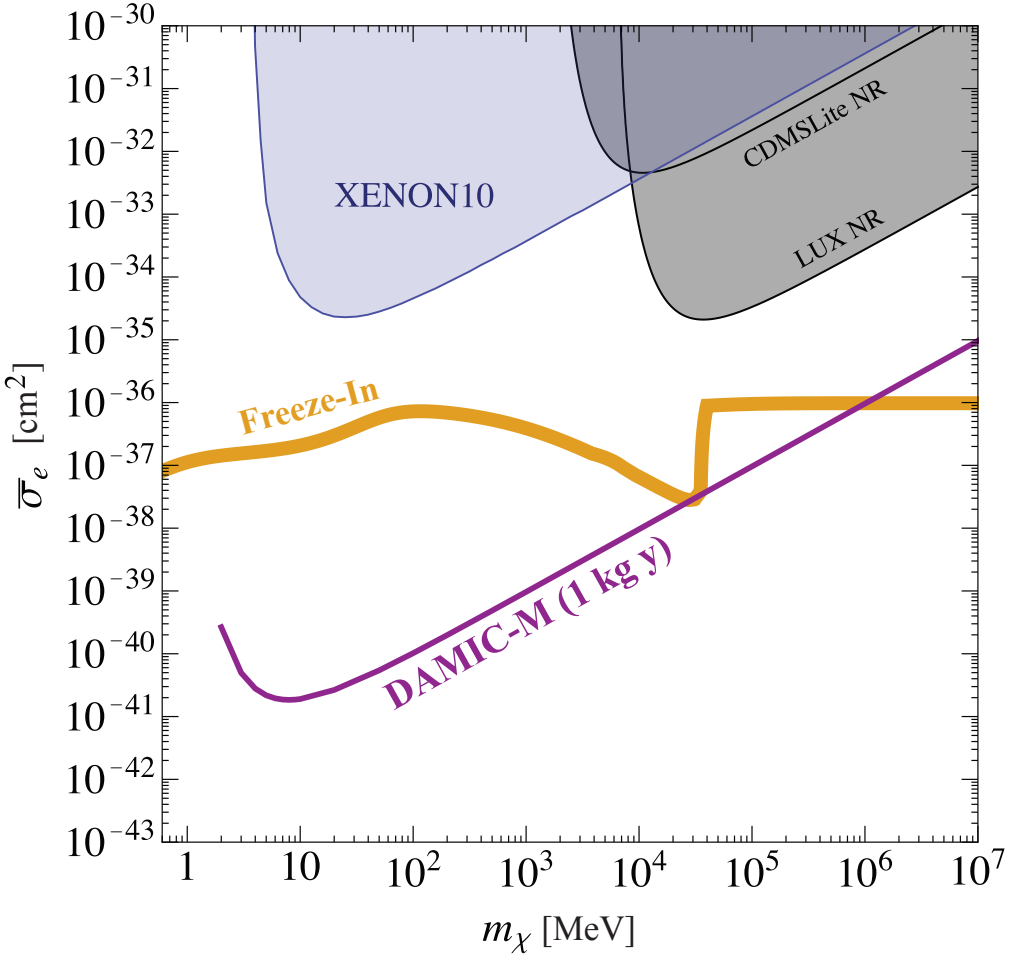




Scientific reach

Heavy mediator | **Light dark matter - electron scattering** | **Light mediator**





DAMIC-M will be sensitive to light dark matter even if these candidates constitute only a small fraction of the total DM in the universe

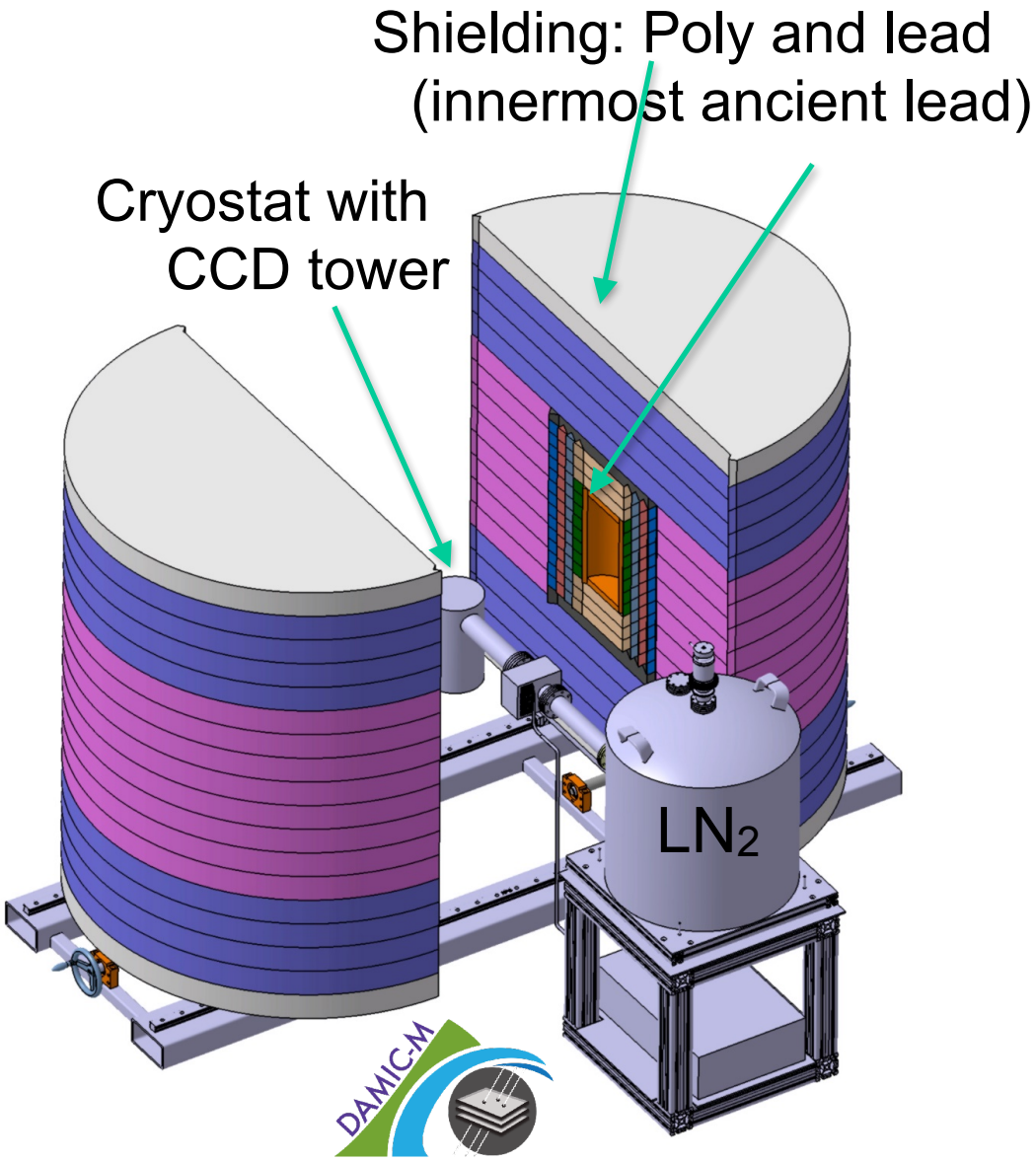
DAMIC-M

DAMIC at Laboratoire Souterrain de Modane

- 50 CCDs (kg-size target mass)
- Most massive CCDs ever built (>10 g each)
- **Single electron resolution** with "skipper" readout (demonstrated by Fermilab SENSEI group)
- A fraction of dru background

- "Classical" design (Ge detectors and DAMIC at SNOLAB)

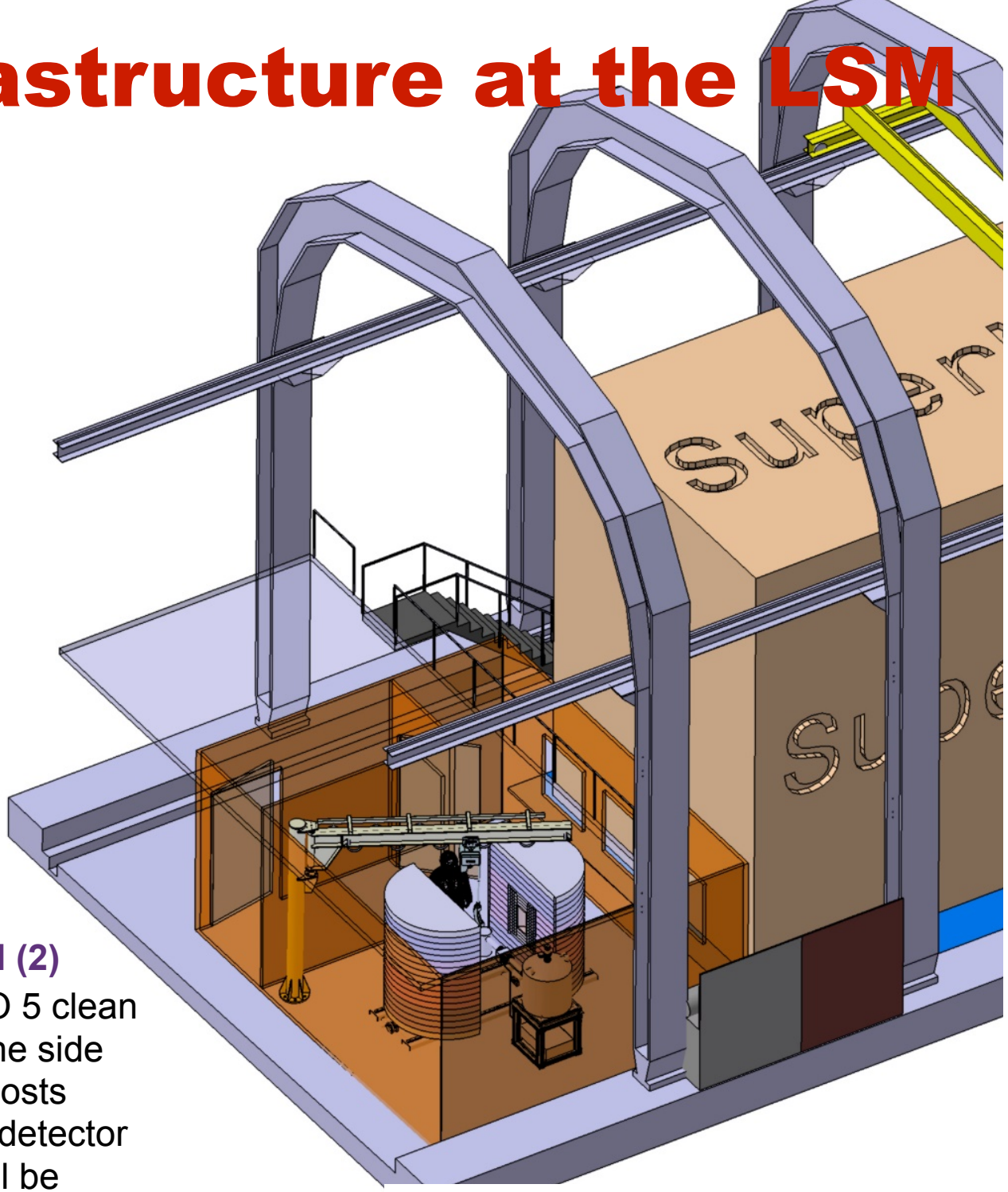
- R&D and design up to 2021
- Construction 2022
- Installation in 2023



DAMIC-M infrastructure at the LSM

DAMIC-M (1)

On the upper floor an ISO 5, radon-free clean room will host the CCD packaging and test facilities



DAMIC-M (2)

The detector will be installed in an ISO 5 clean room located on the ground floor on the side of SuperNemo. This space currently hosts NEWS-G tests before shipping of the detector to SNOLAB. DAMIC-M clean room will be installed by the end of 2019

Ali Dastgheibi Fard's talk

The journey has begun!

Silicon Ingot production by TOPSIL, Frederikssund, Denmark

	Date	Time	Time zone	Action	Place
1					
2	21.08.2019	23:00	CEST	Crystal pulling starts	TOPSIL
3	22.8.2019	11:15		Crystal pulling ends	TOPSIL
4	23.8.2019	15:00		Pick up by Borge	Copenhagen
5	24.8.2019	16:15		Rigshospitalet cellar	Copenhagen
6	28.8.2019	10:30		Ingot out of the hospital	Copenhagen
7	28.8.2019	13:00		DSV terminal	
8	30.8.2019	10:25	BST	Pick up by Emma	Immingham
9	30.8.2019	14:00		Ingot in BUGS	Boulby

transported by car to Copenhagen

Now at Boulby, waiting for wafering by Shin-Etsu Handotai Europe (Livingston, Scotland)

(DAMIC at SNOLAB wafers were produced in in China, with ingot and wafers shipped by airplane.

One air flight is equivalent to several months of cosmic ray exposure on surface)


undeground at Boulby

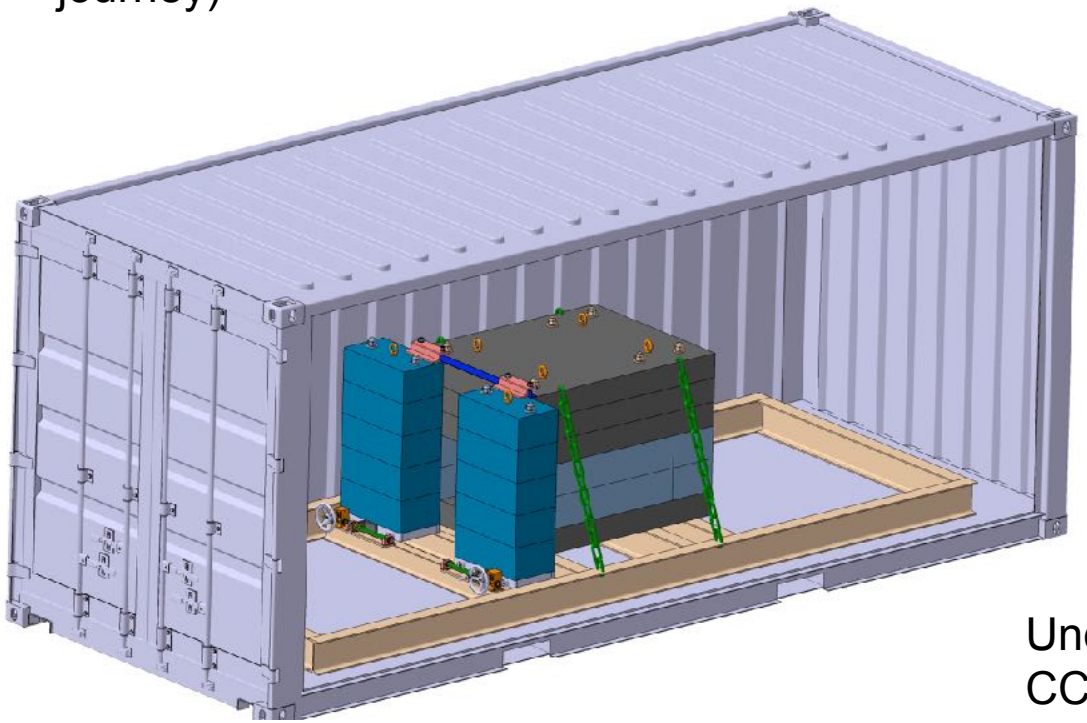
temporary storage in a shielded facility

and will continue!

DAMIC-M CCDs are fabricated by Teledyne DALSA in Canada

The wafers and CCDs will be shipped by sea in a custom-made shielded container

(8-15 days transatlantic journey)



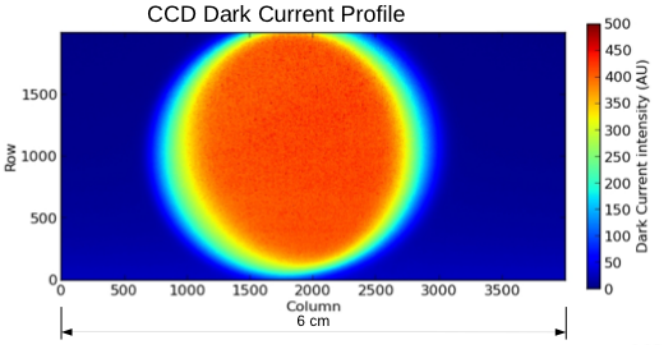
A 20' standard dry container with a ≈ 15 t iron shielding. A cavity 50 cm x 40 cm x 110 cm large enough for the CCD packages and the electroformed copper cryostat

The shielding reduces tritium cosmogenic activation by a factor ≈ 25

Underground storage at SNOLAB for wafers/ CCDs while in North America

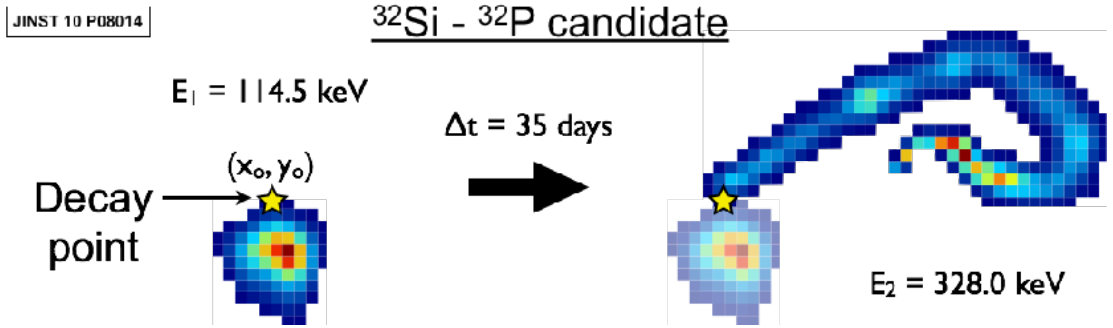
DAMIC-M Backgrounds

- Most relevant backgrounds identified by DAMIC at SNOLAB **D. Baxter's talk**
- Cosmogenic tritium: minimize exposure to cosmic rays with shielding during transport/fabrication; CCD packaging and test underground at LSM. Also, R&D ongoing to evaluate tritium removal by wafers/CCDs baking.



Activation of a DAMIC CCD at the LANSCE neutron beam. Tritium clearly detected; rate measurement being finalized. **R. Saldanha's talk**

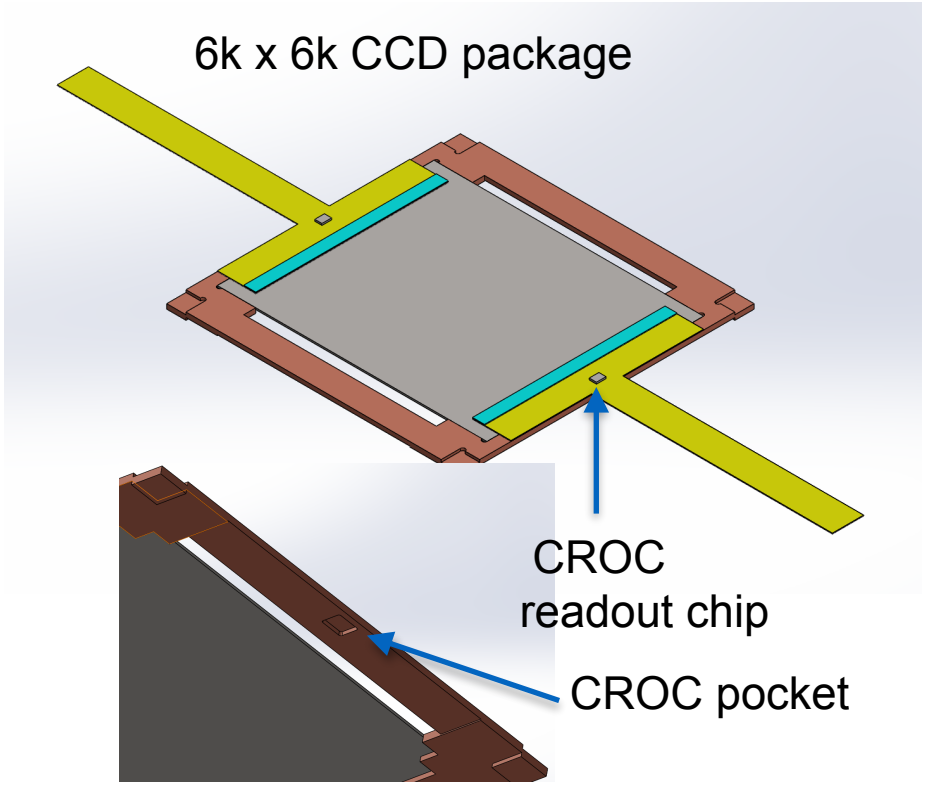
- Cosmogenic ^{32}Si: spatial correlations

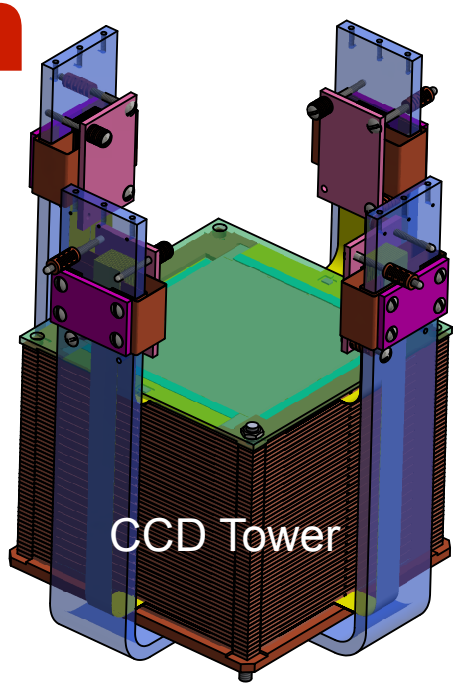


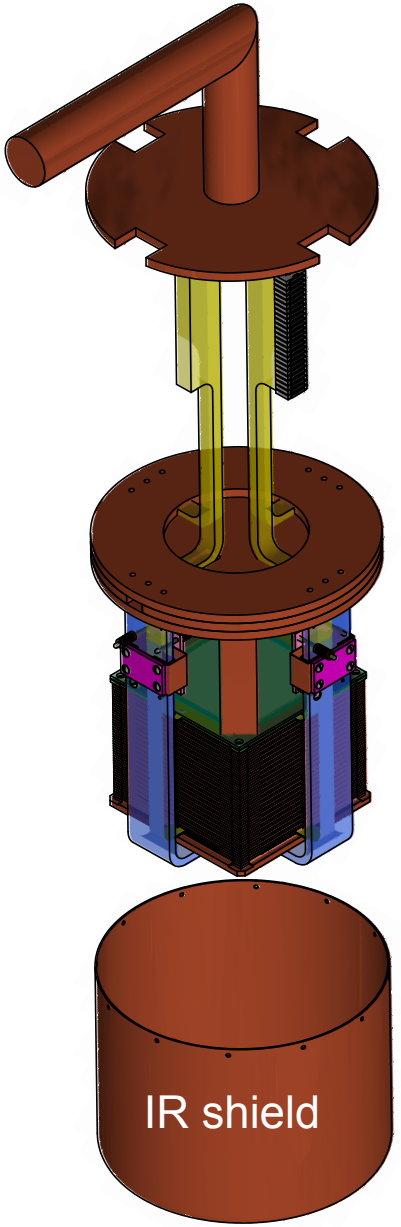
- Surface ^{210}Pb: minimize exposure to radon (radon-free clean room at LSM for CCD packaging/test; installation in radon-free tent)
- Radiogenic background: material selection and electro formed copper

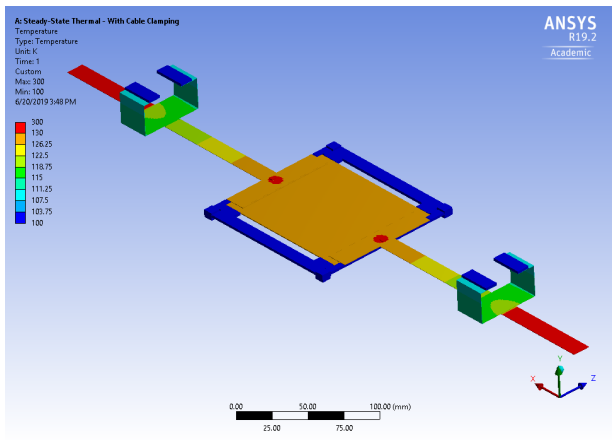
Challenging goal: 0.1 dru

Detector Design









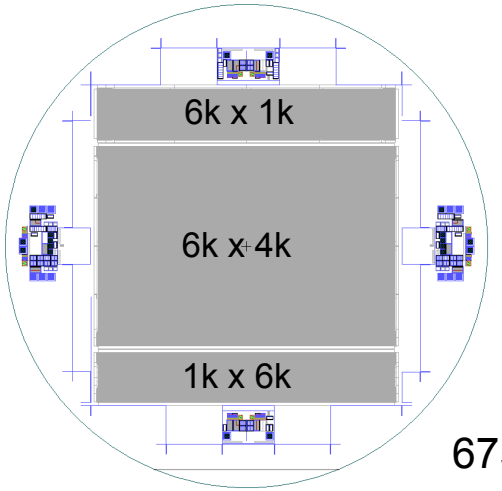
thermal modeling

electro formed copper at PNNL

Design will continue through 2021

DAMIC-M CCDs

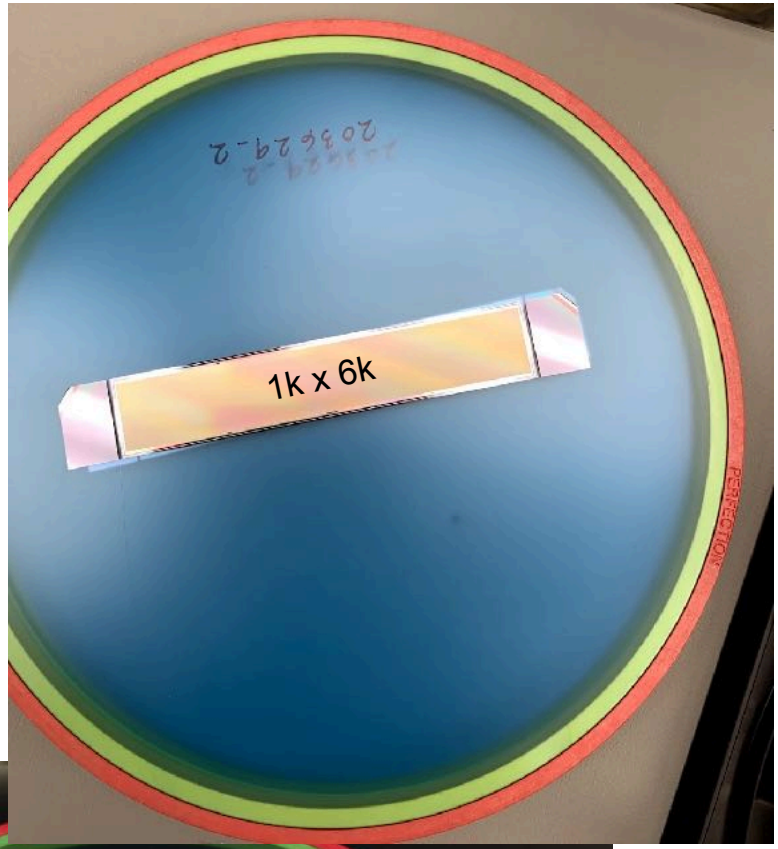
design by S. Holland (LBNL), fabricated by Teledyne/DALSA



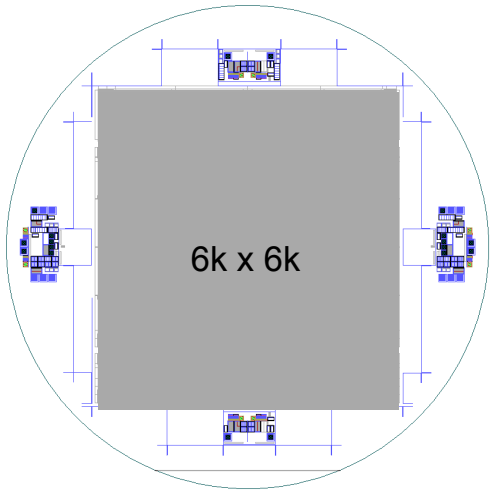
DAMIC-M prototype skipper CCDs

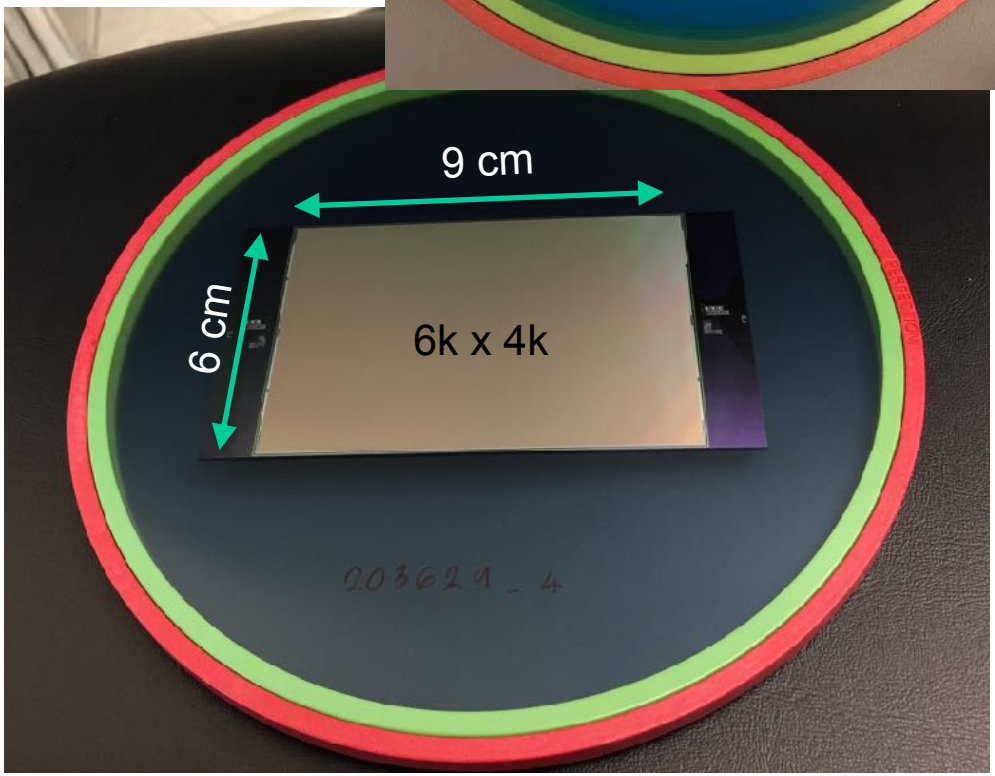
Three CCDs per 6” wafer to test different skipper readout amplifier design.

675 μm thick



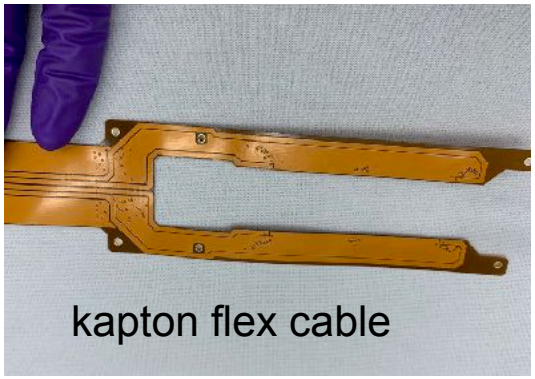
DAMIC-M production skipper CCD design
9 cm x 9 cm

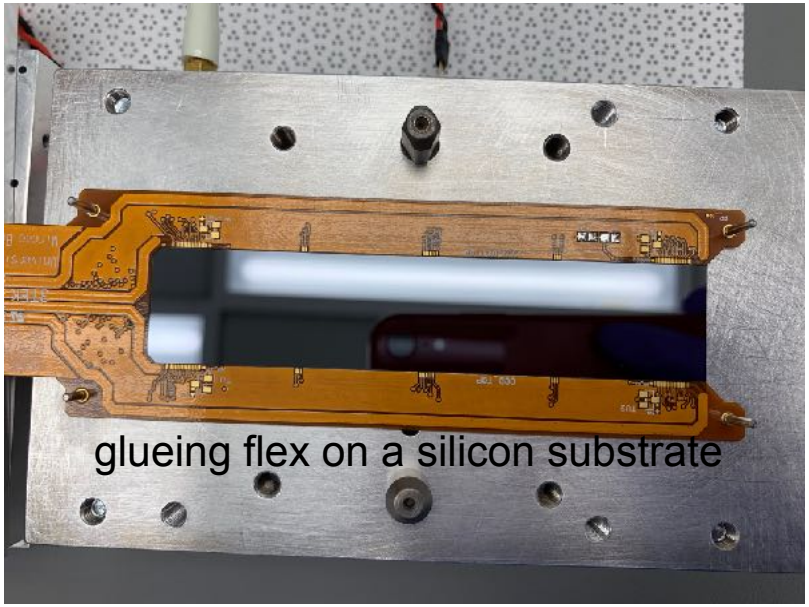


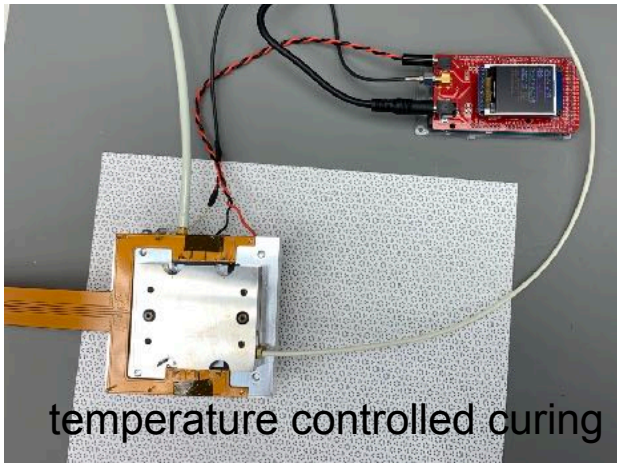


CCD Packaging

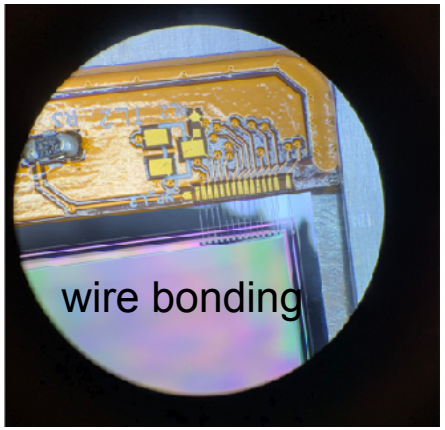
1k x 6k DAMIC-M prototype CCDs

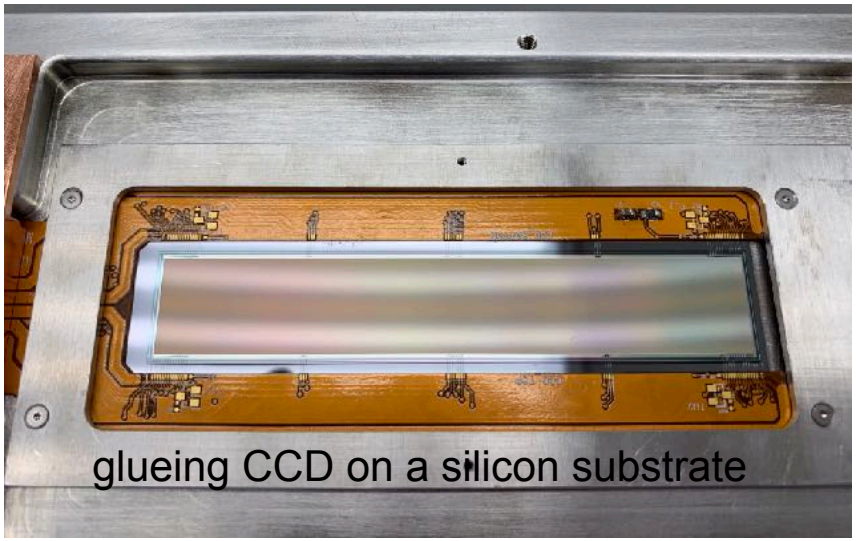

kapton flex cable


glueing flex on a silicon substrate


temperature controlled curing

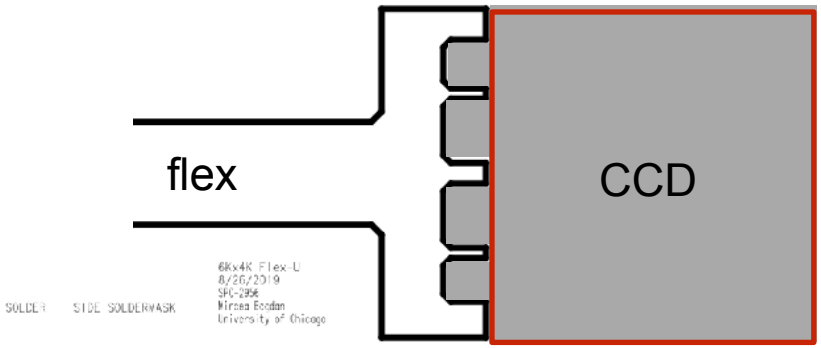
Improvement of packaging procedures originally developed for DAMIC at SNOLAB, notably by reducing the curing (and potential exposure of CCDs to radon) from a day to few hours


wire bonding


glueing CCD on a silicon substrate

Low background procedures will be implemented for the pre-production and production CCDs (the main objective of the DAMIC-M CCD prototypes is demonstrating single-electron resolution and selection of best skipper amplifiers for the production)

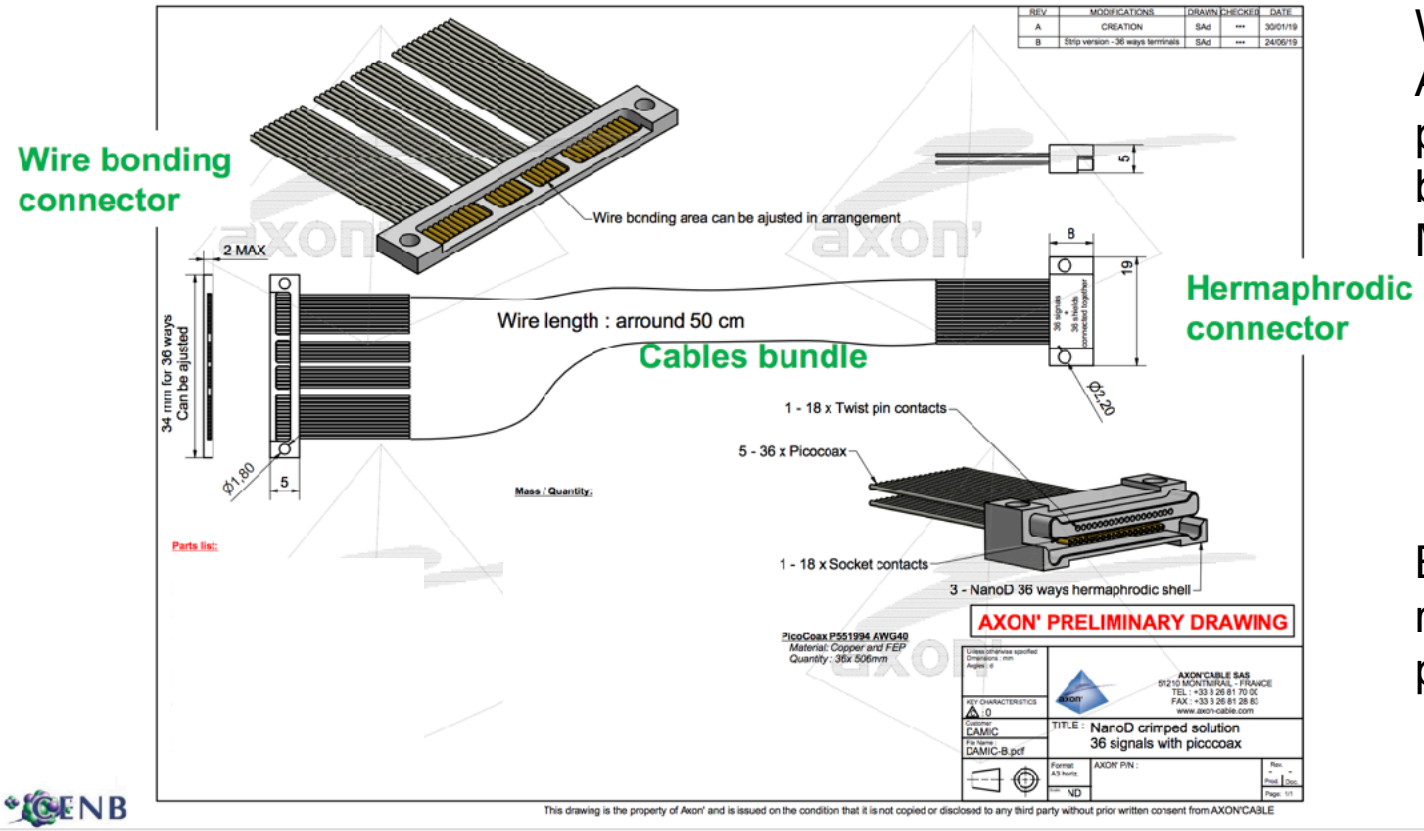
Low-background cables



Flex cable R&D:

minimize mass close to CCD;

develop clean fabrication procedures for multilayer flex (PNNL)

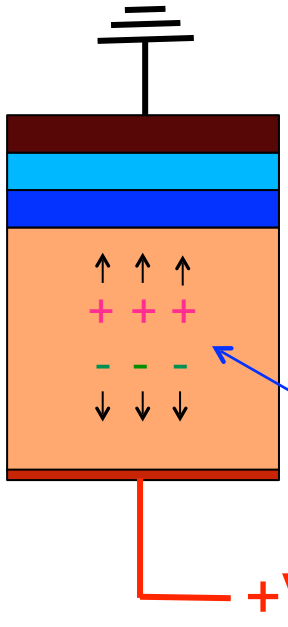


We are also pursuing with AXON a solution employing picocoaxial cables (low-background demonstrated by MAJORANA)

Both would fulfill our requirements for cables' radio purity

Charge Coupled Device

Metal-Oxide-Semiconductor capacitor

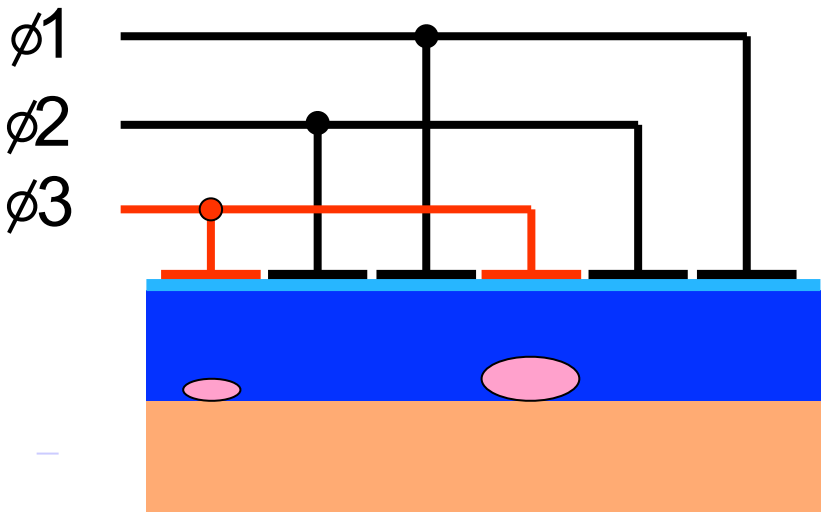


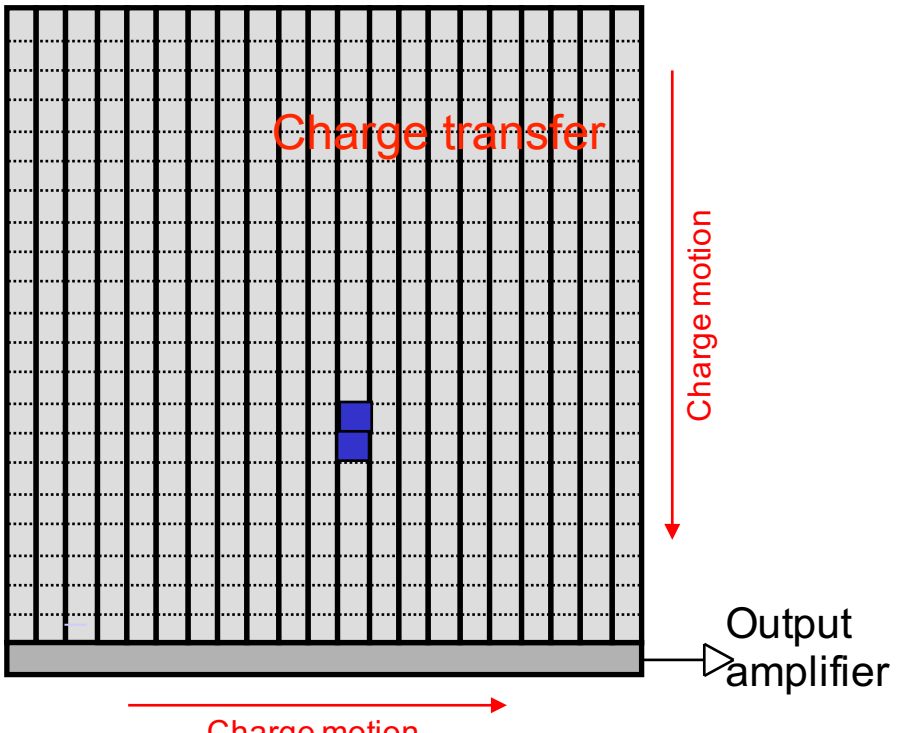
Metal gate
Si oxide (insulator)
p-type Si (buried channel)

n-type Si

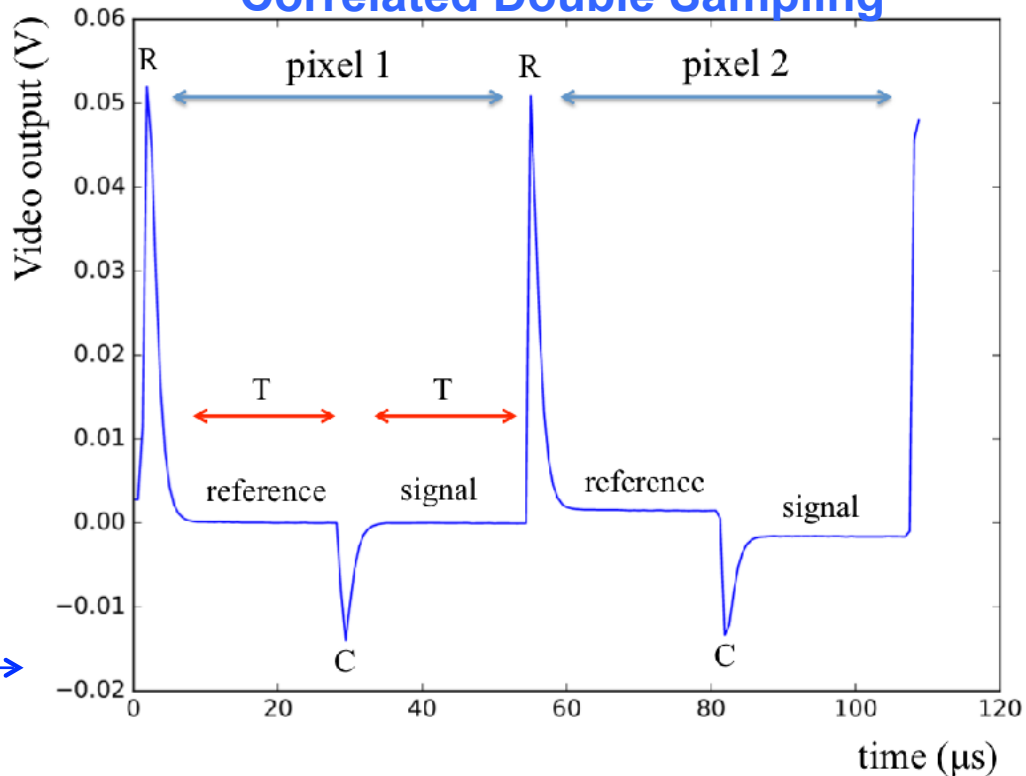
electron-hole pairs generated by a photon or ionizing particle

Charge transfer ("Clocks")



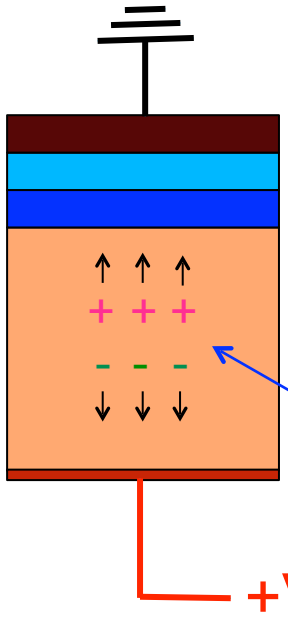


Correlated Double Sampling



Charge Coupled Device

Metal-Oxide-Semiconductor capacitor



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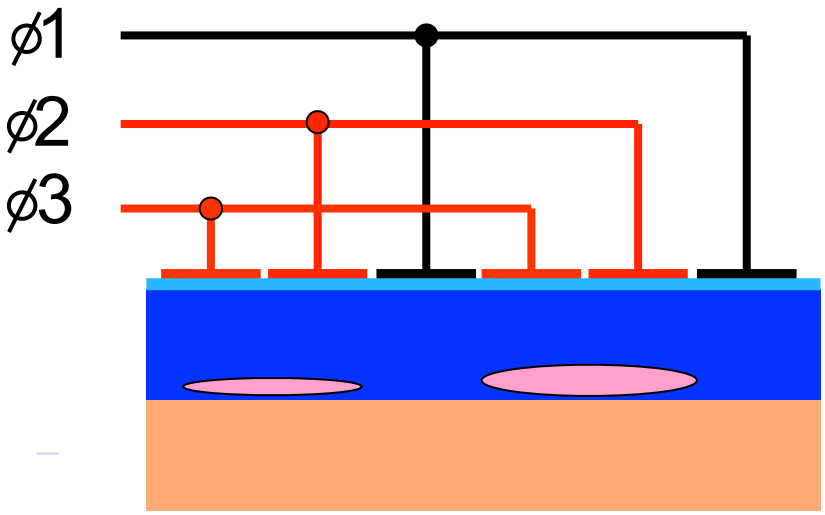
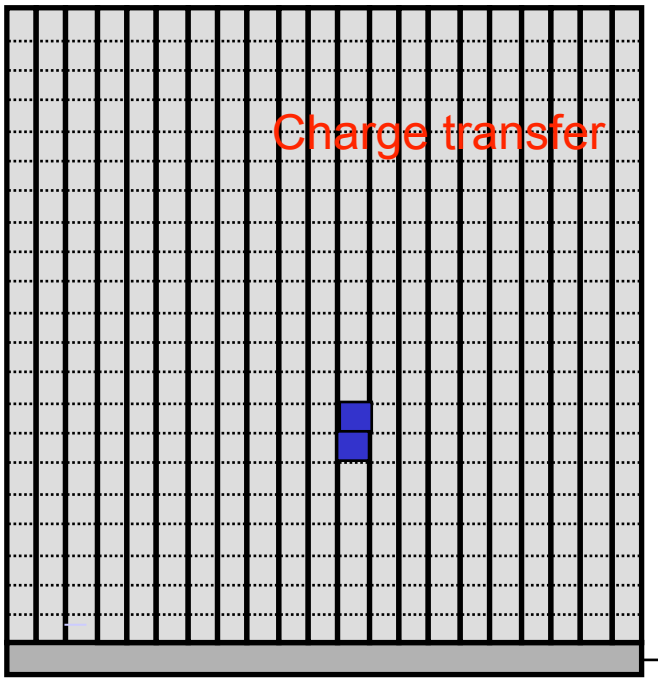
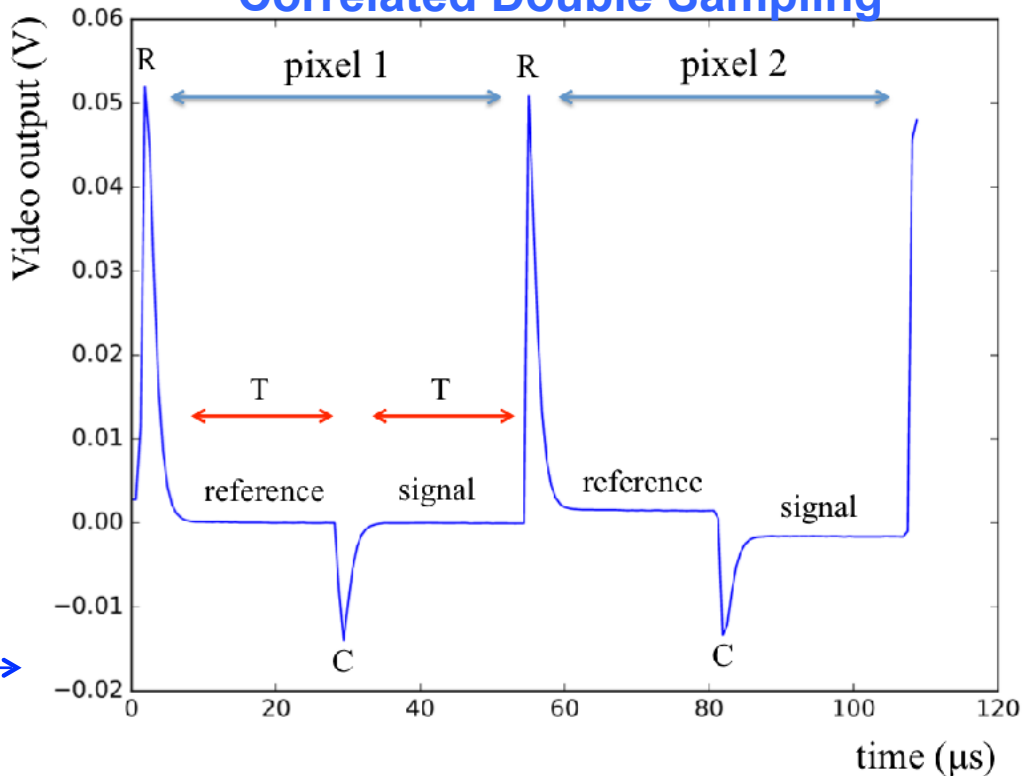




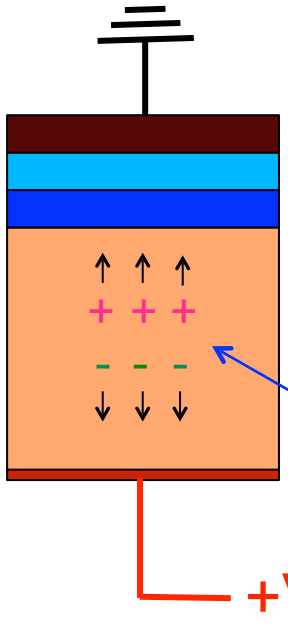
Output amplifier

Correlated Double Sampling



Charge Coupled Device

Metal-Oxide-Semiconductor capacitor



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electron-hole pairs generated by a photon or ionizing particle

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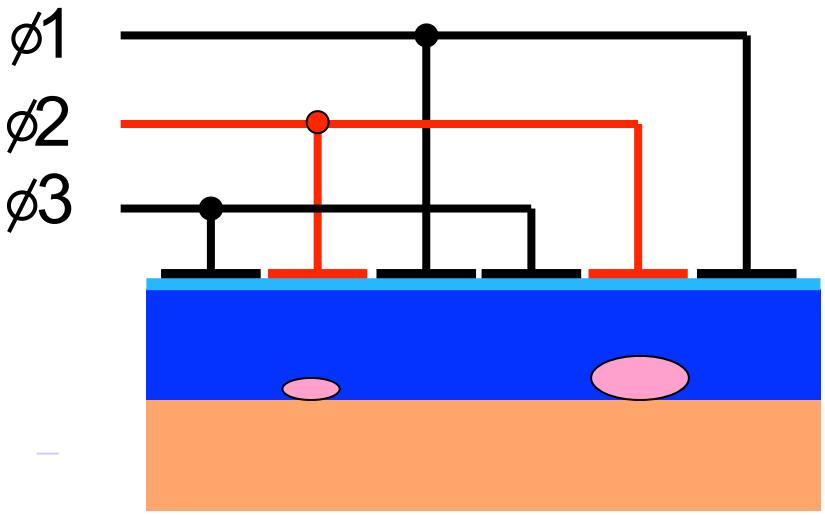

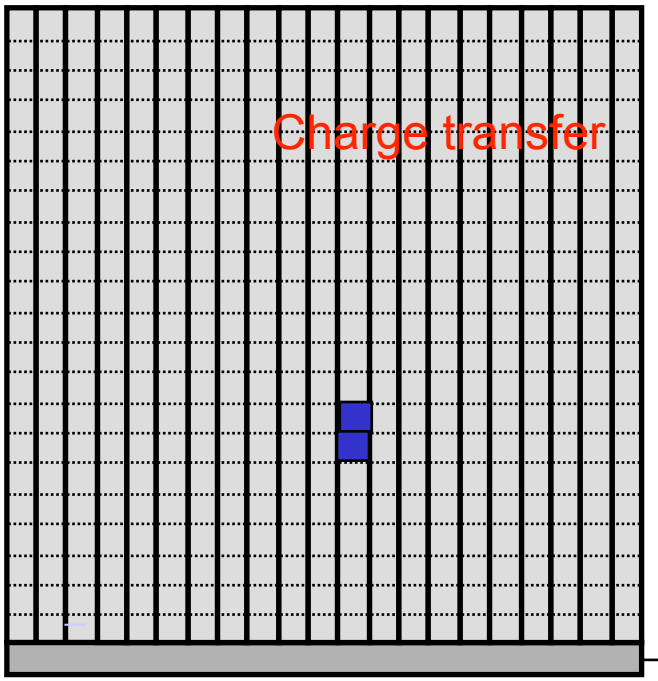

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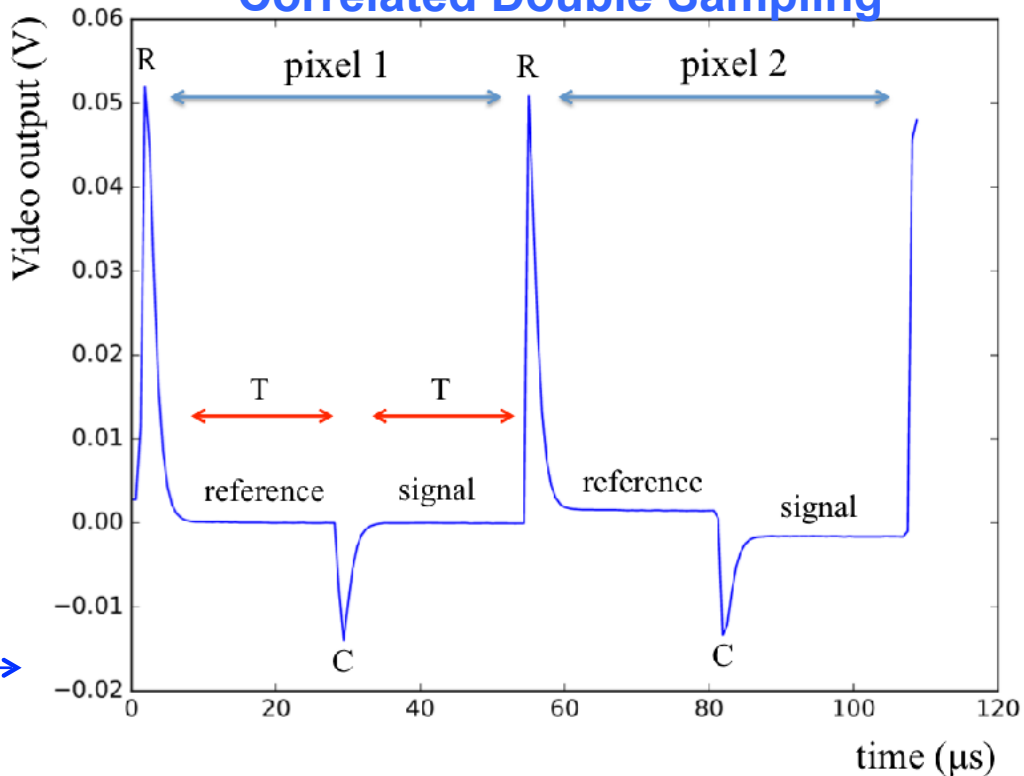

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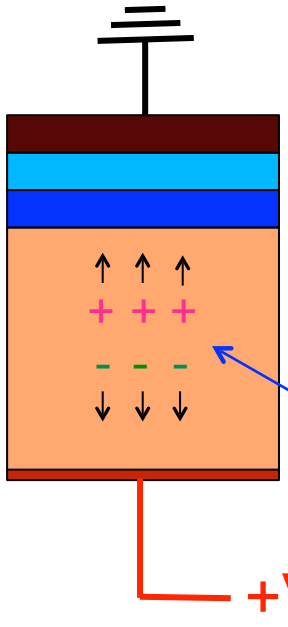

Metal gate
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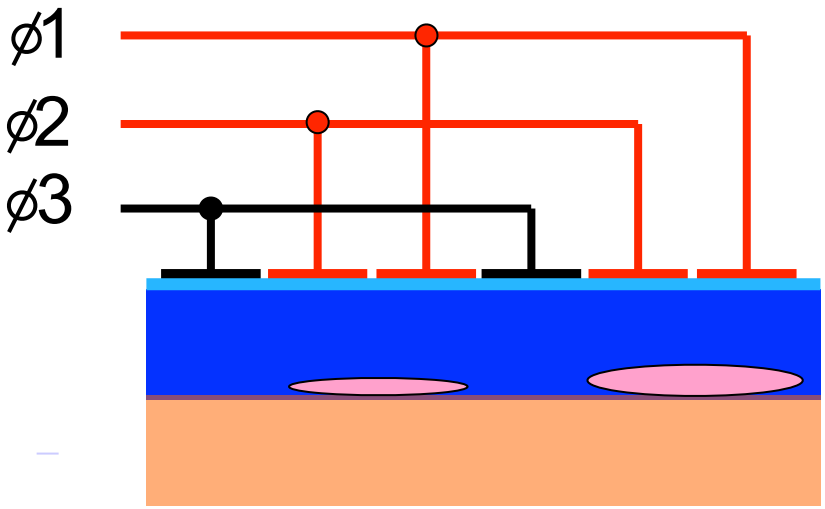
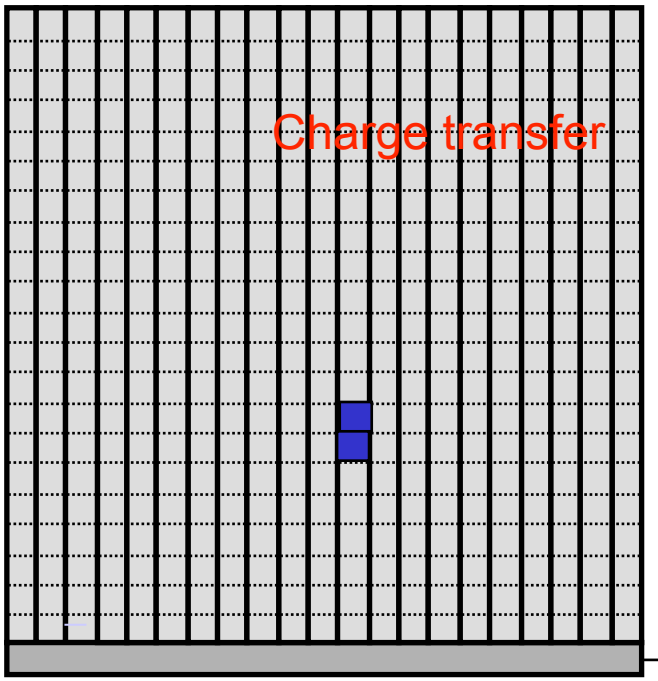
n-type Si

electron-hole pairs generated by a photon or ionizing particle

+V

Charge transfer ("Clocks")





Output amplifier

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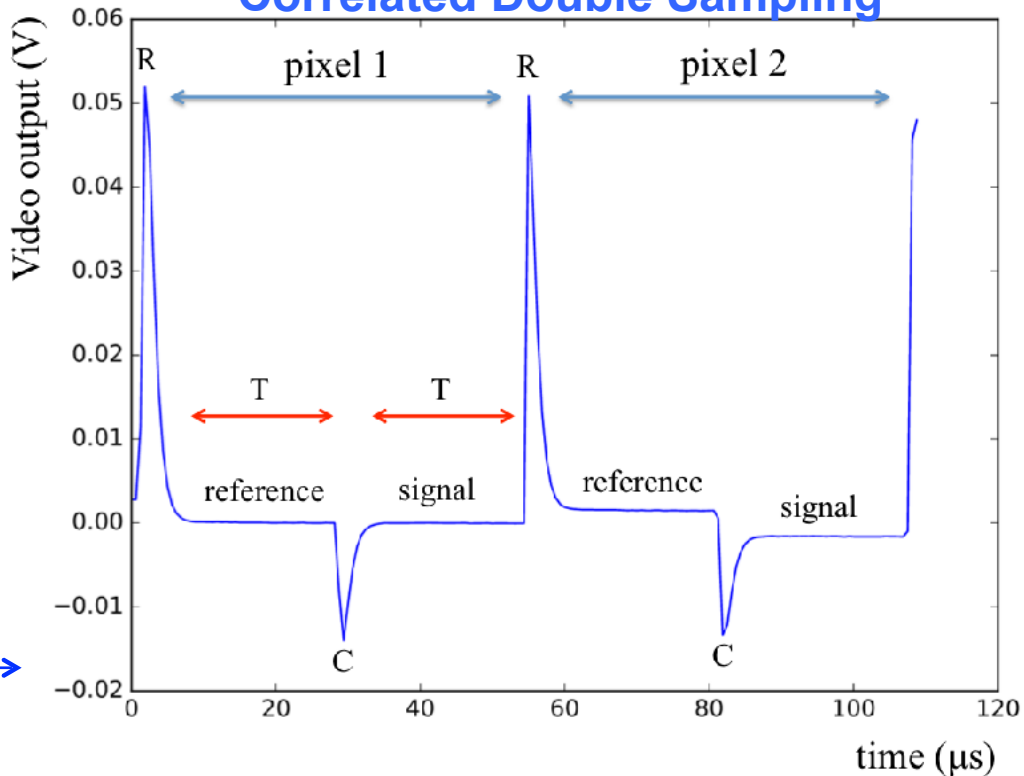

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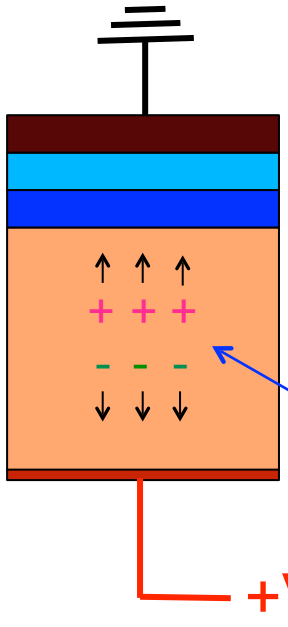

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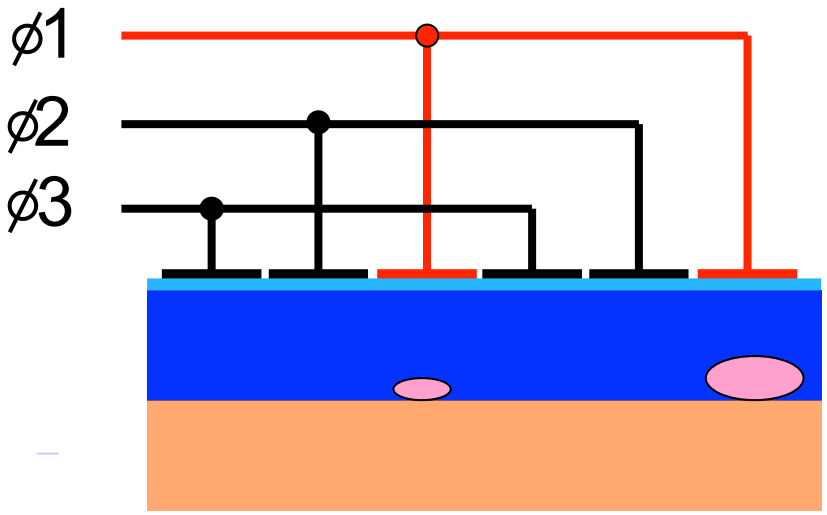
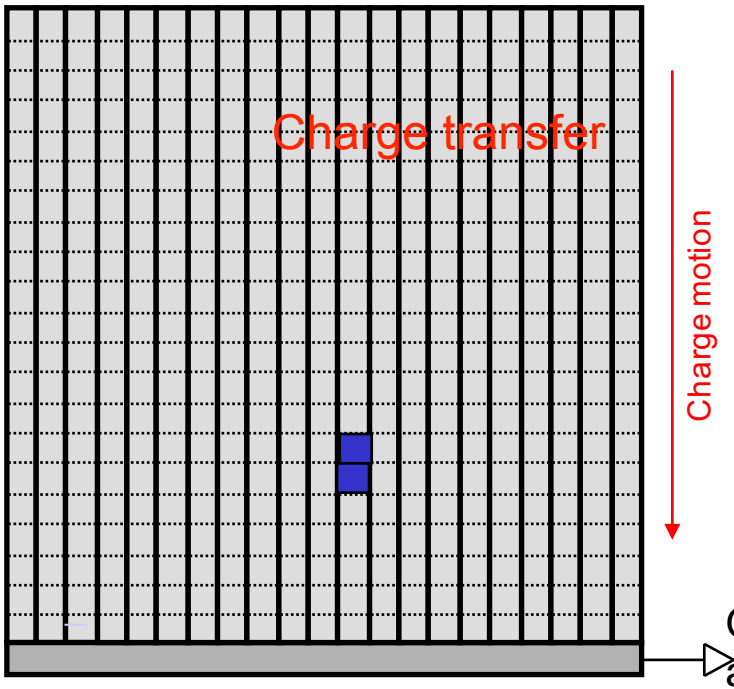
Charge transfer ("Clocks")



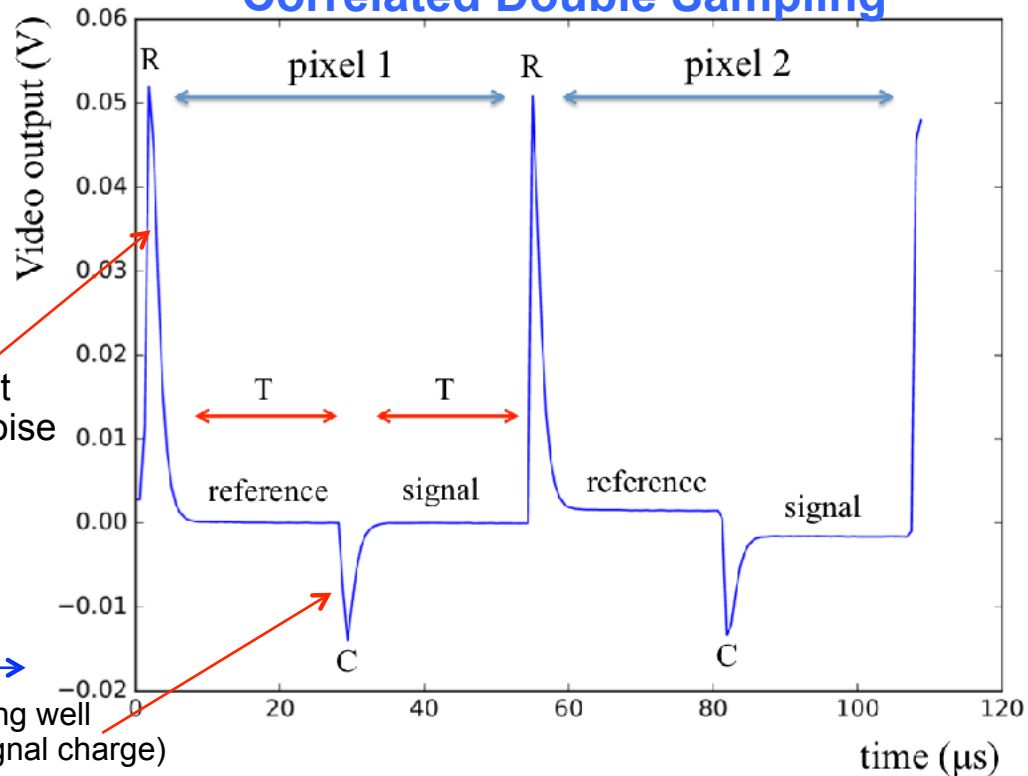


Amplifier reset (introduces noise charge)

Output amplifier

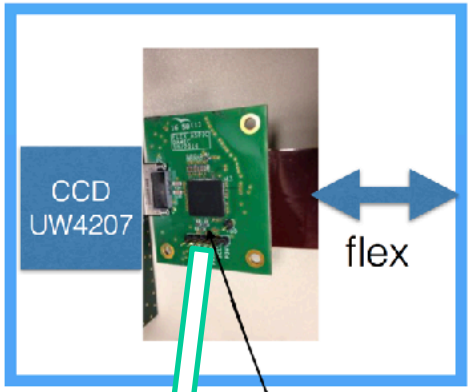
Summing well (add signal charge)

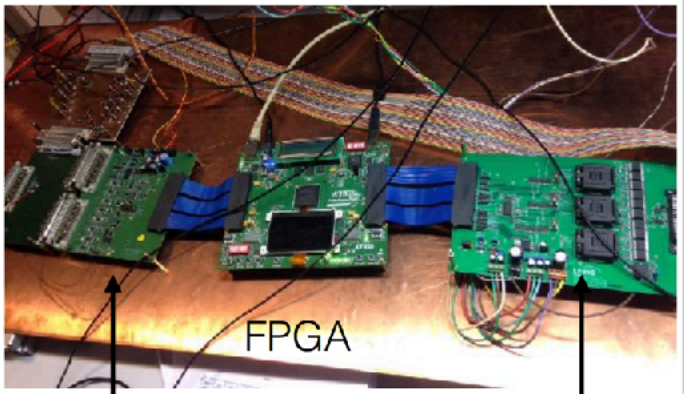
Correlated Double Sampling



Electronics

Dewar





ASPIC (LSST)

BEB3
(ADC)

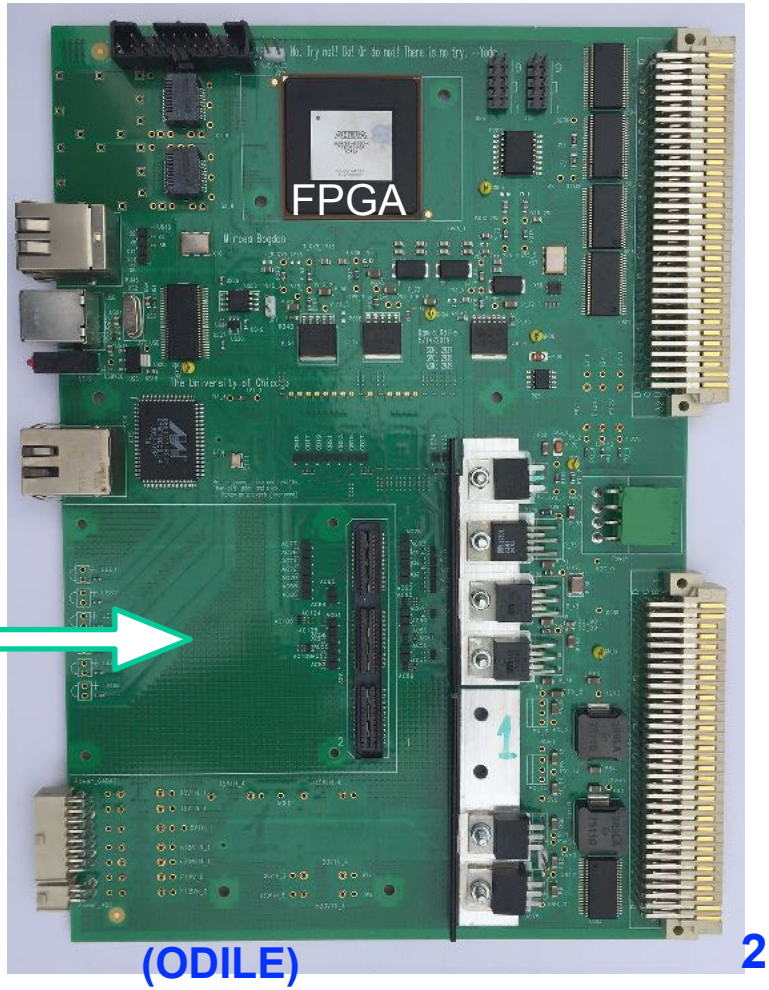
3CABAC board
(CCD Clocks)

successful test of CCD Controller components (CABAC ASIC for clocks, ADC, ASPIC chip for CDS)

delivered, under test

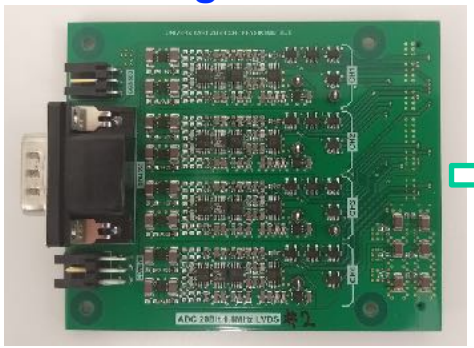
now integrated in a single controller board, one CCD per board

CCD Controller Mother Board

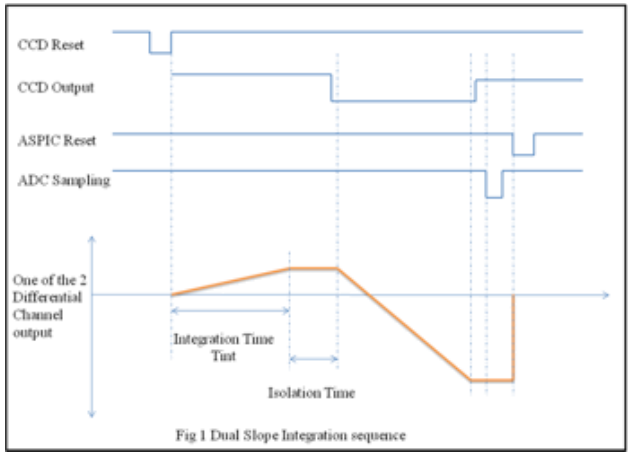


(ODILE)

ADC daughter board



Two ADC being evaluated
20 bit 1.6 MHz
18 bit 15 MHz

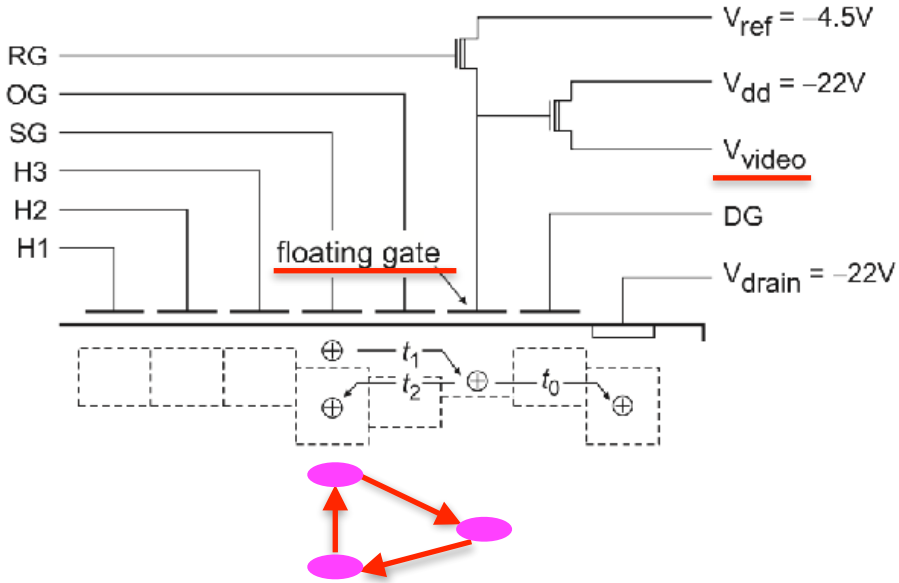


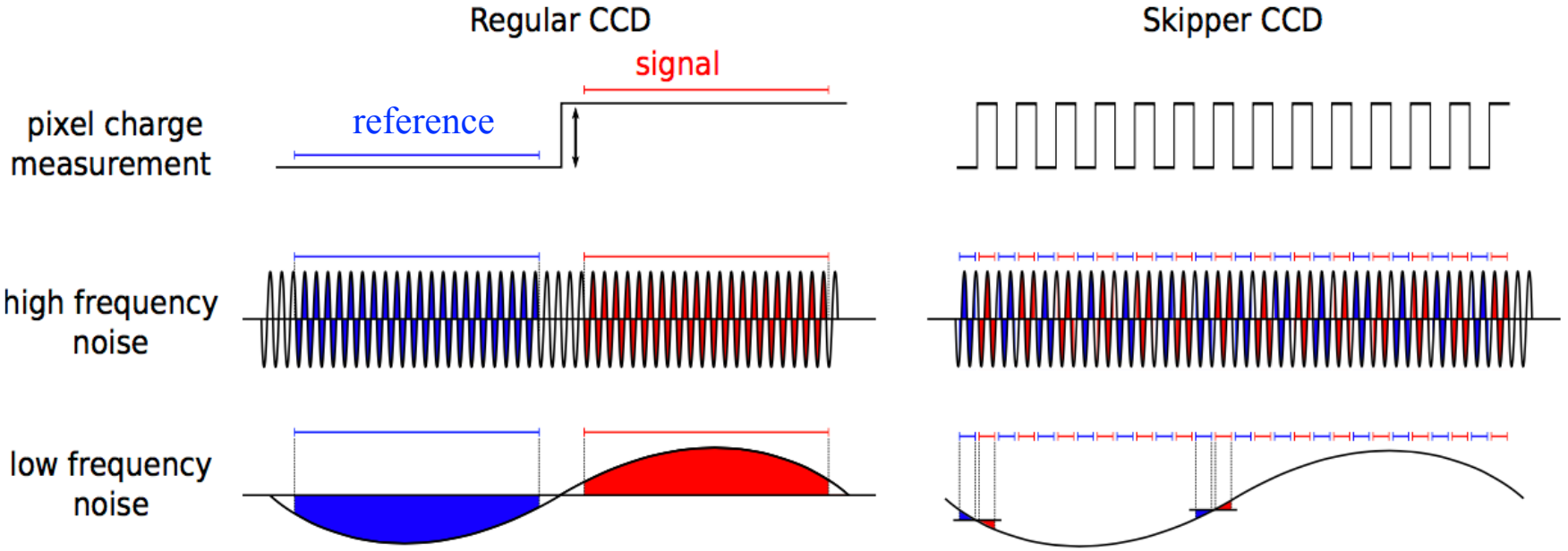
Skipper CCD readout

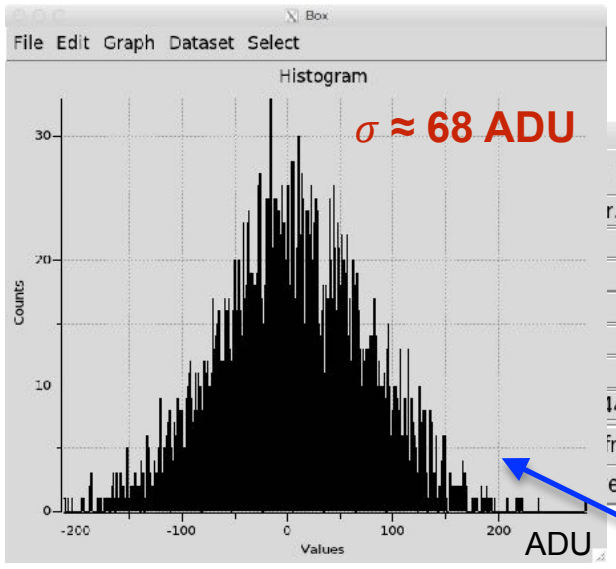
Noise dominated by the 1/f low frequency noise of the output amplifier

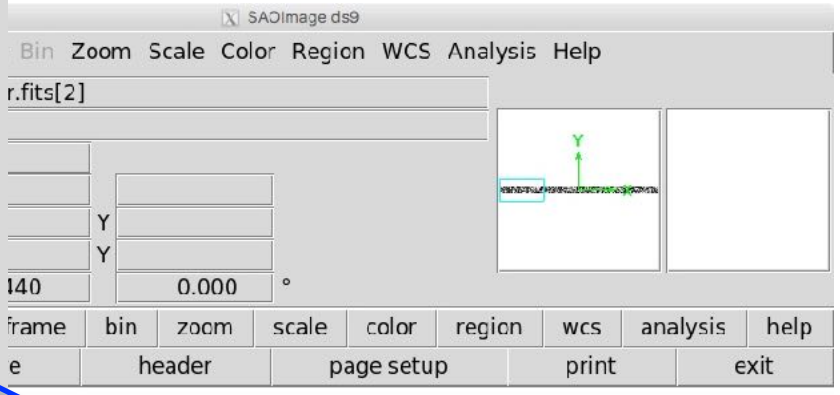
Non-destructive charge measurement! (NDCM)

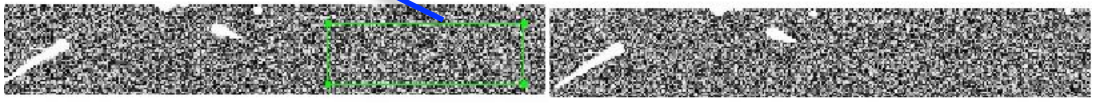
Measure the charge fast (kill 1/f noise) and N times (noise ≈ 1/√N)







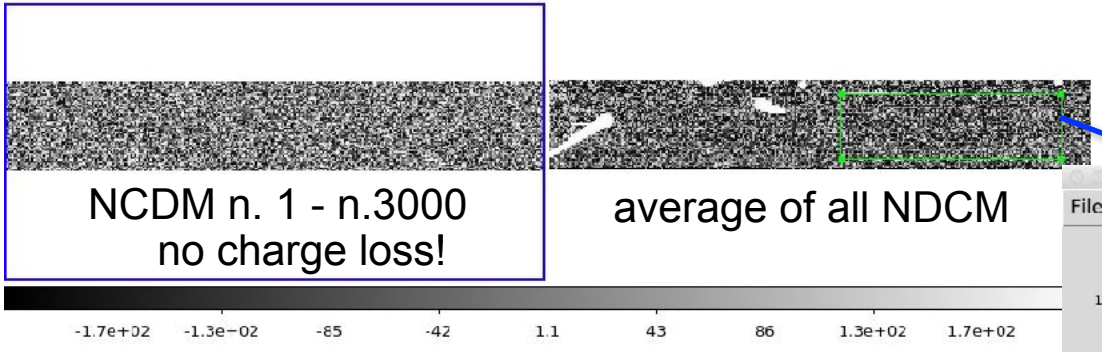




NDCM n. 1 NCDM n. 3000

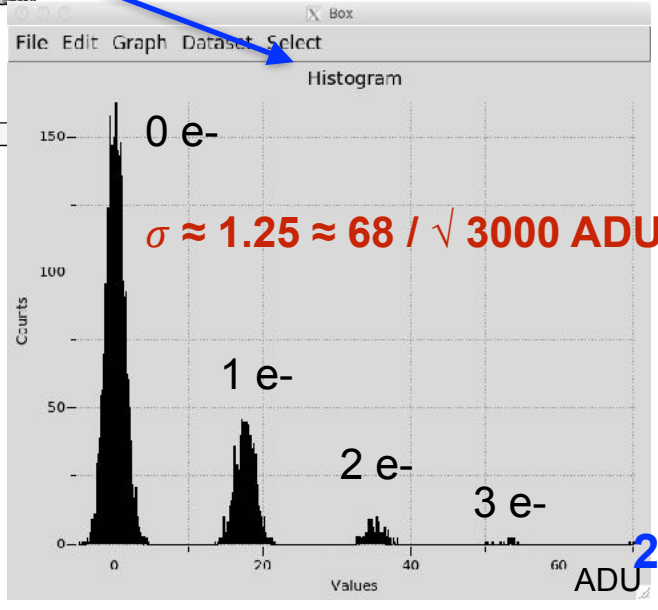
DAMIC-M prototype skipper CCDs

RAW DATA!



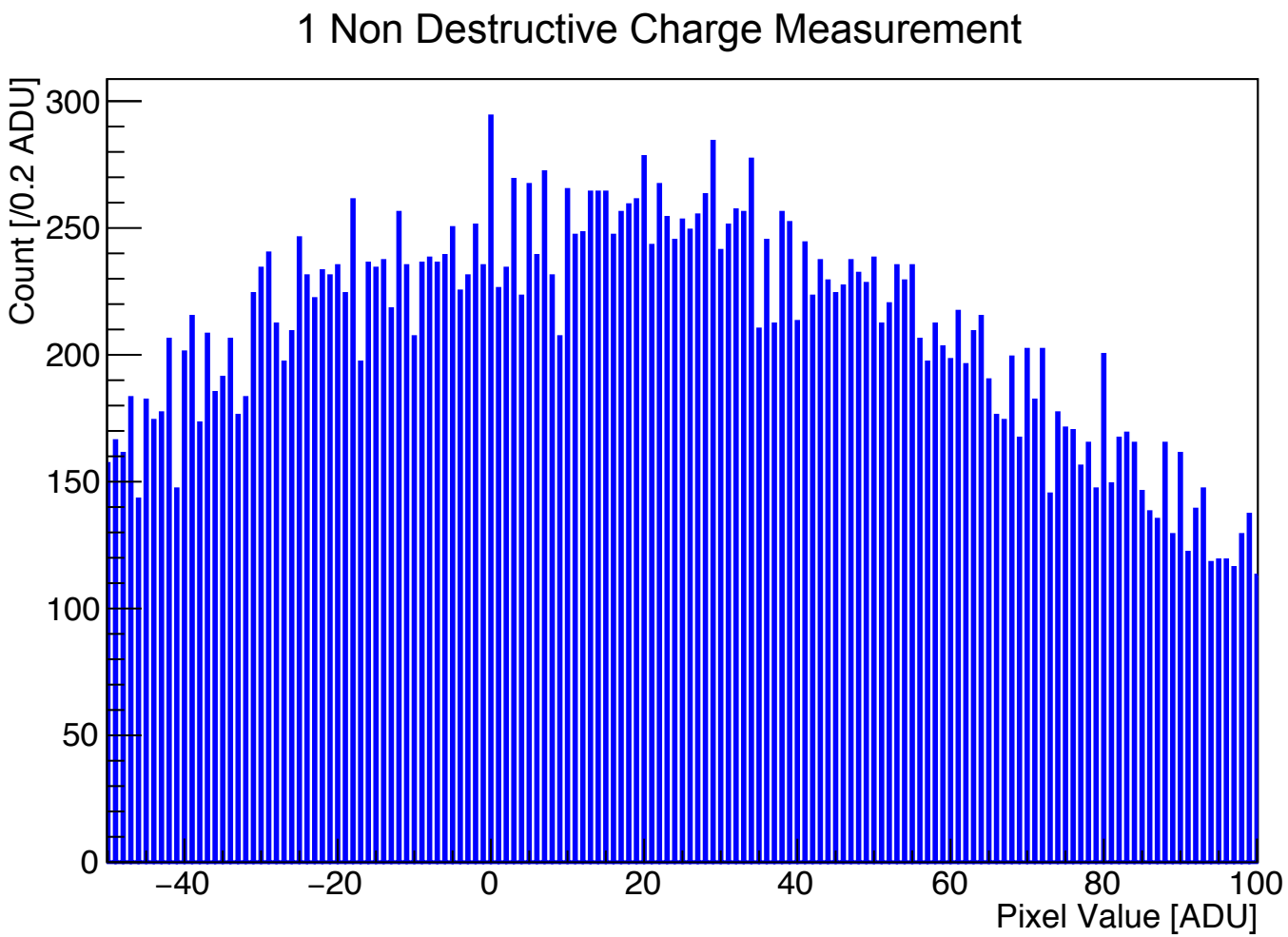
NCDM n. 1 - n.3000
no charge loss!

average of all NDCM

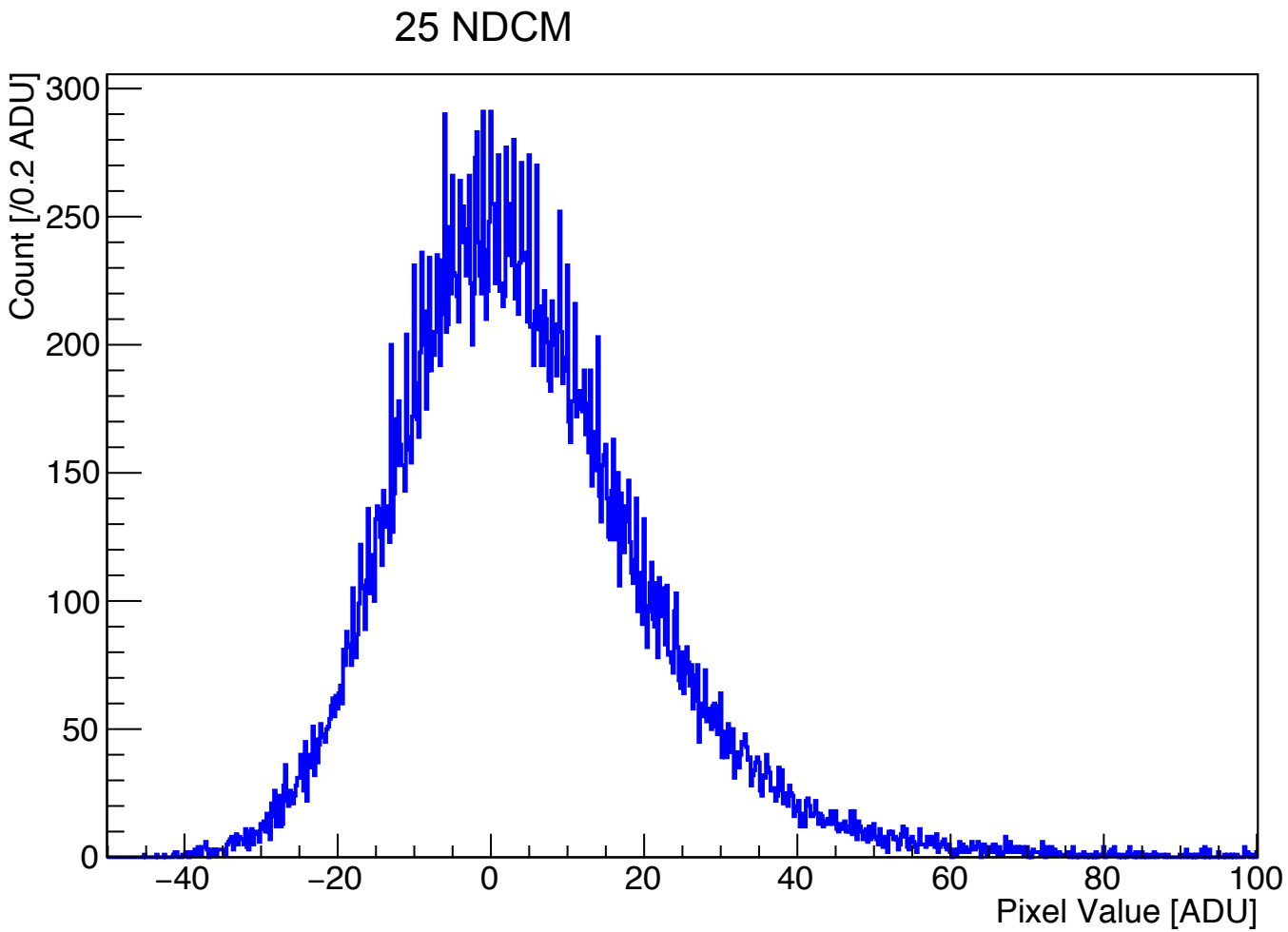


Single electron charge resolution

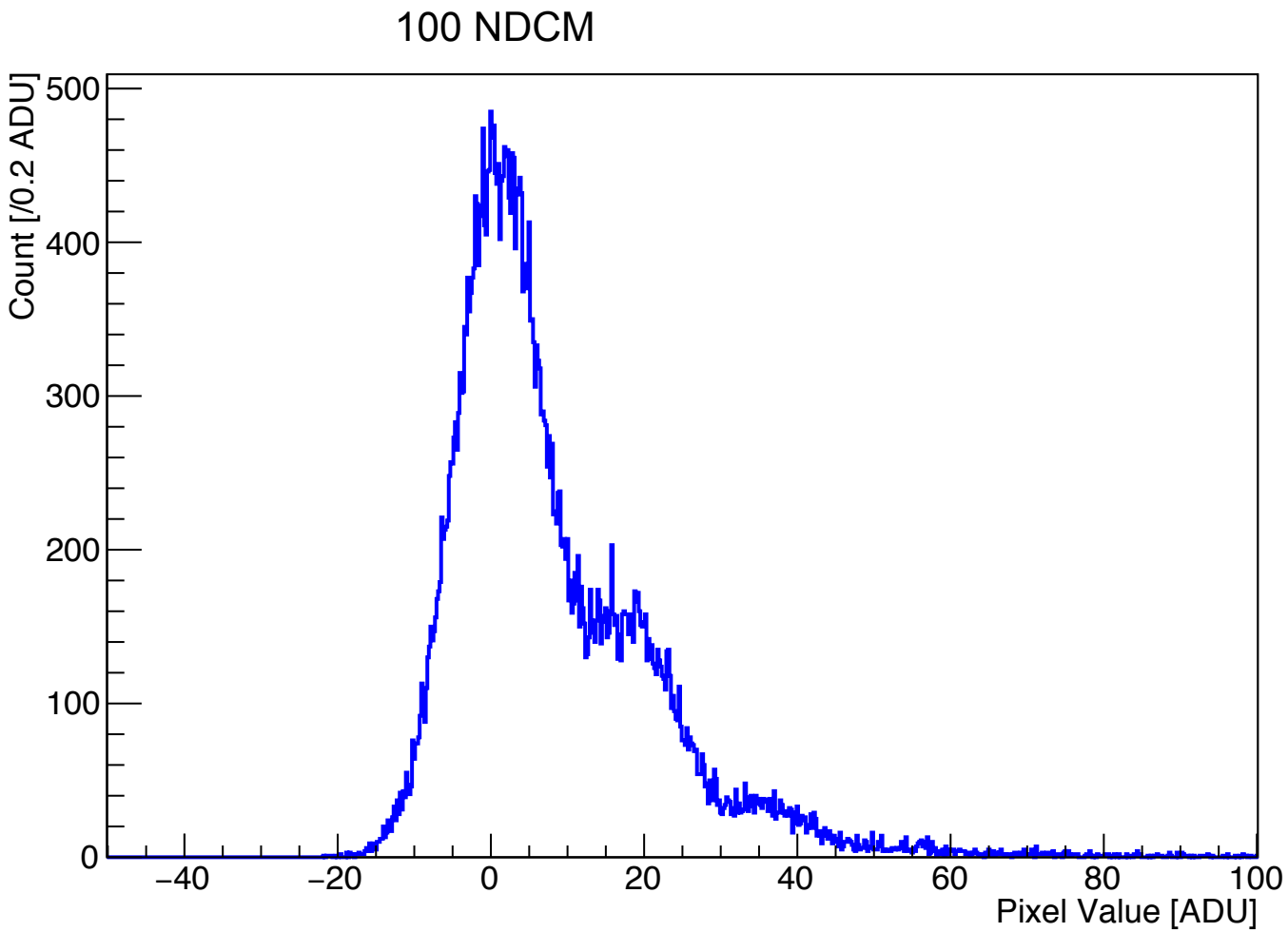
DAMIC-M Skipper charge resolution



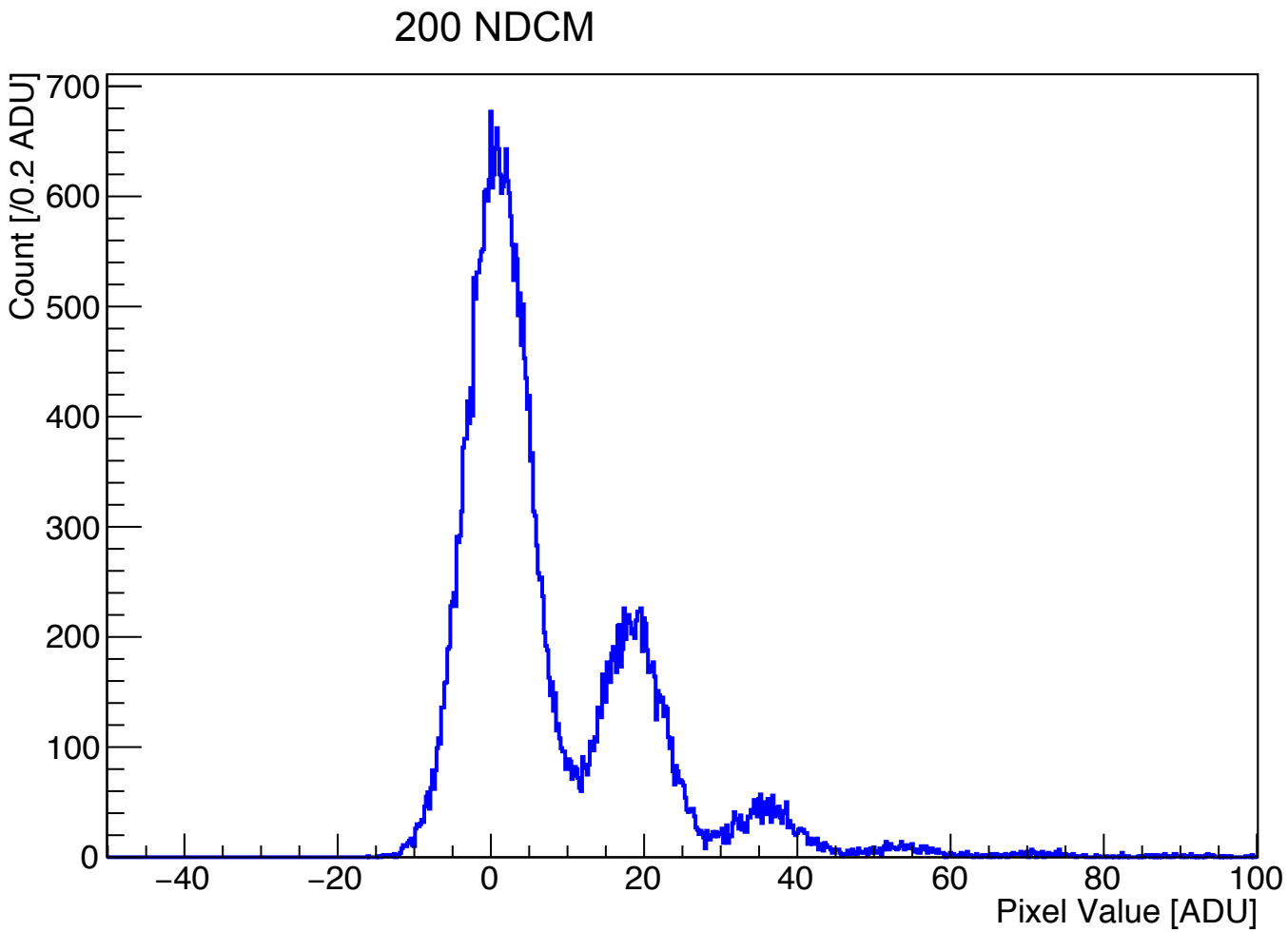
DAMIC-M Skipper charge resolution



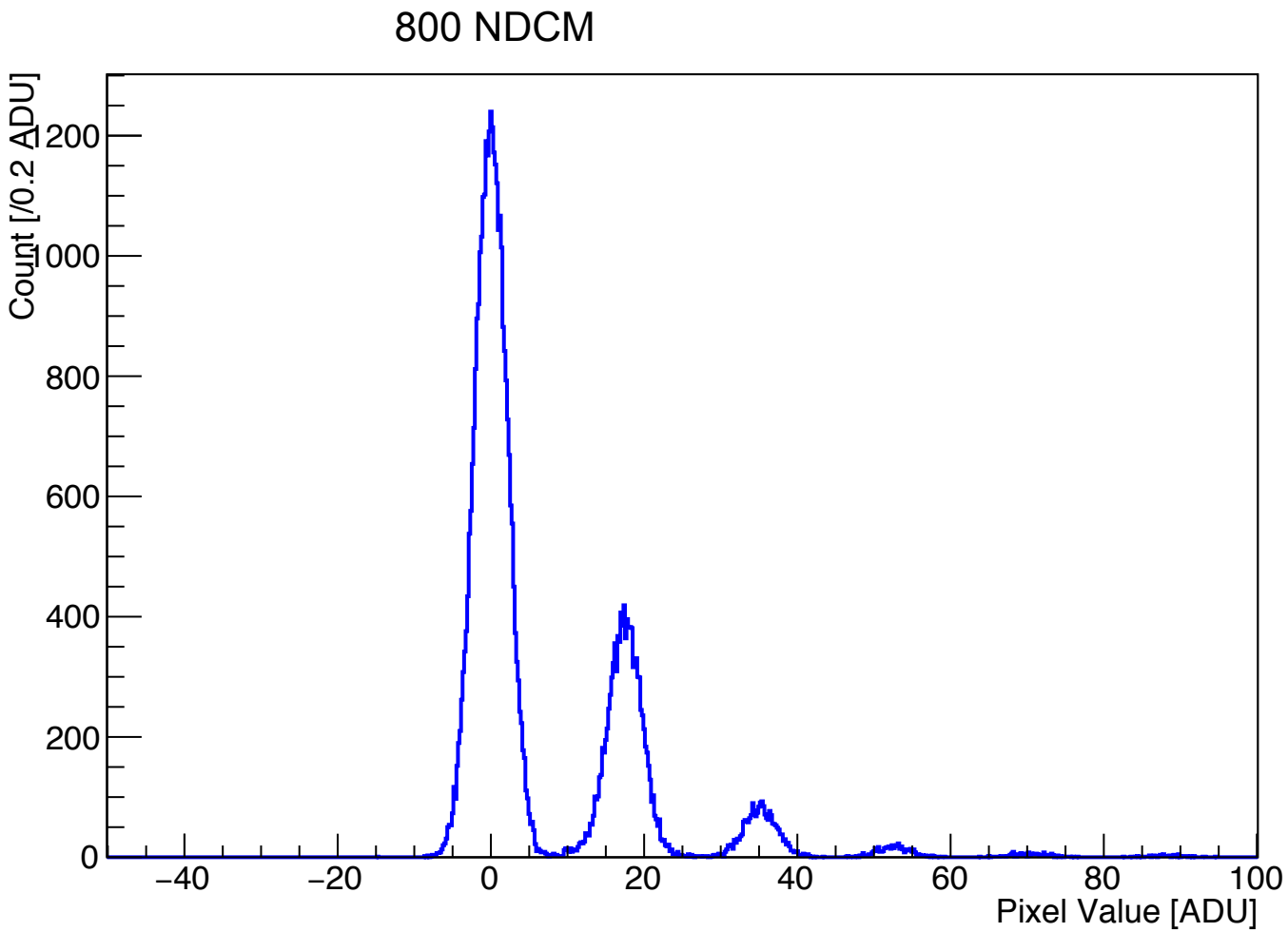
DAMIC-M Skipper charge resolution



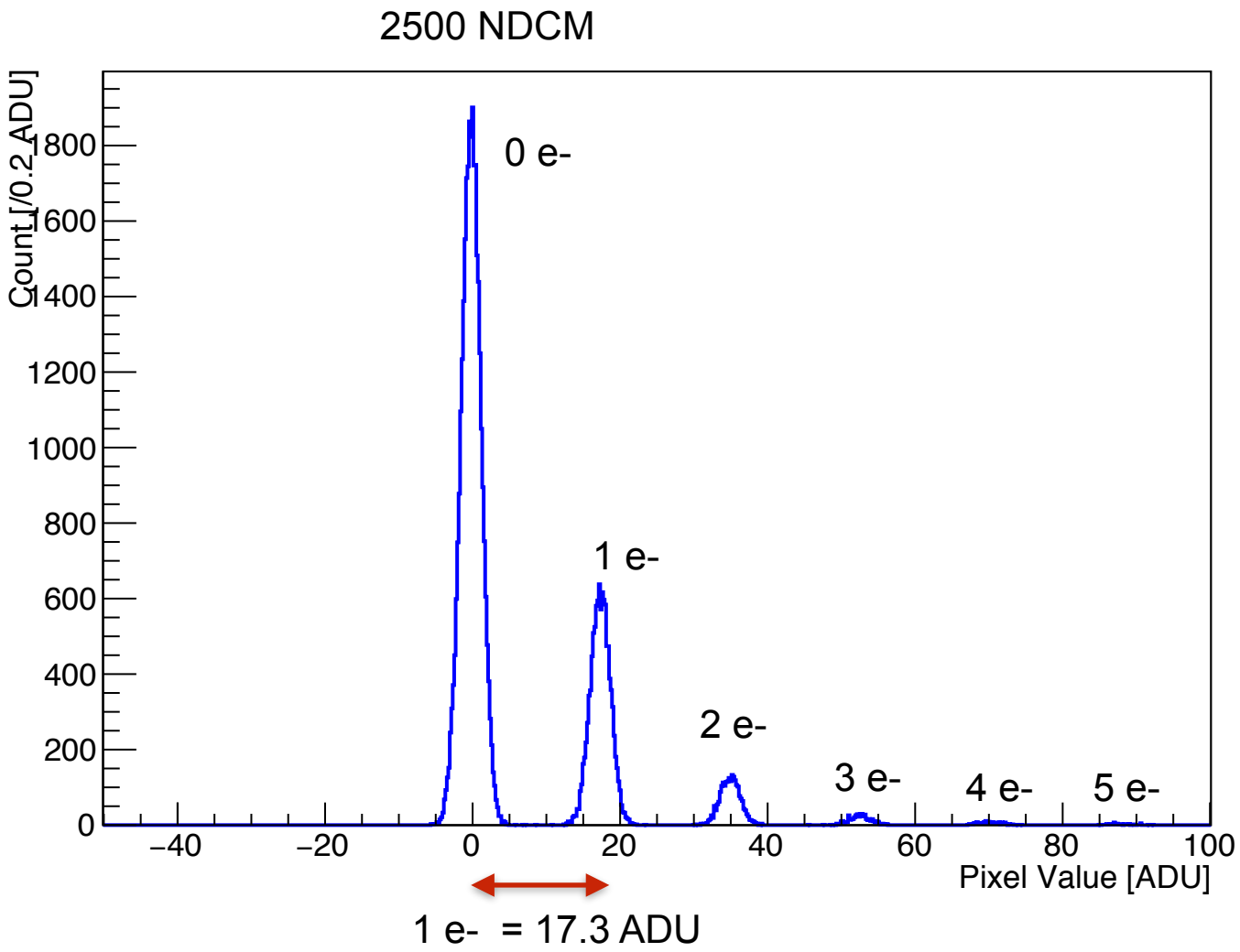
DAMIC-M Skipper charge resolution



DAMIC-M Skipper charge resolution

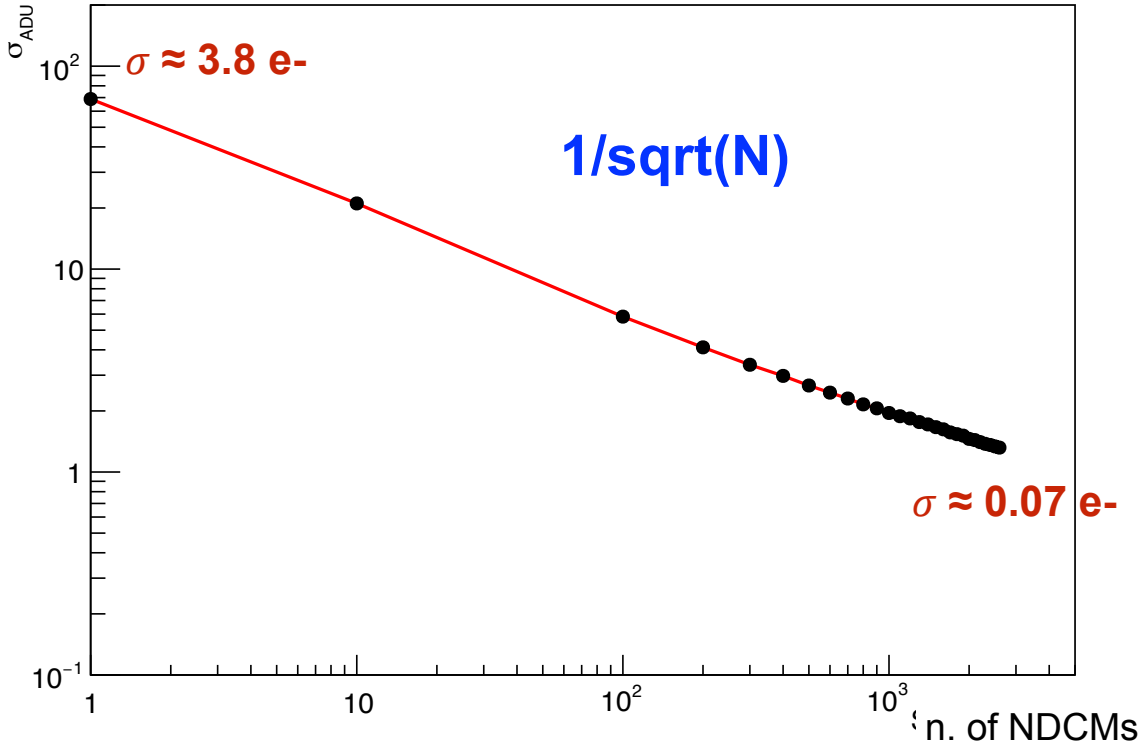


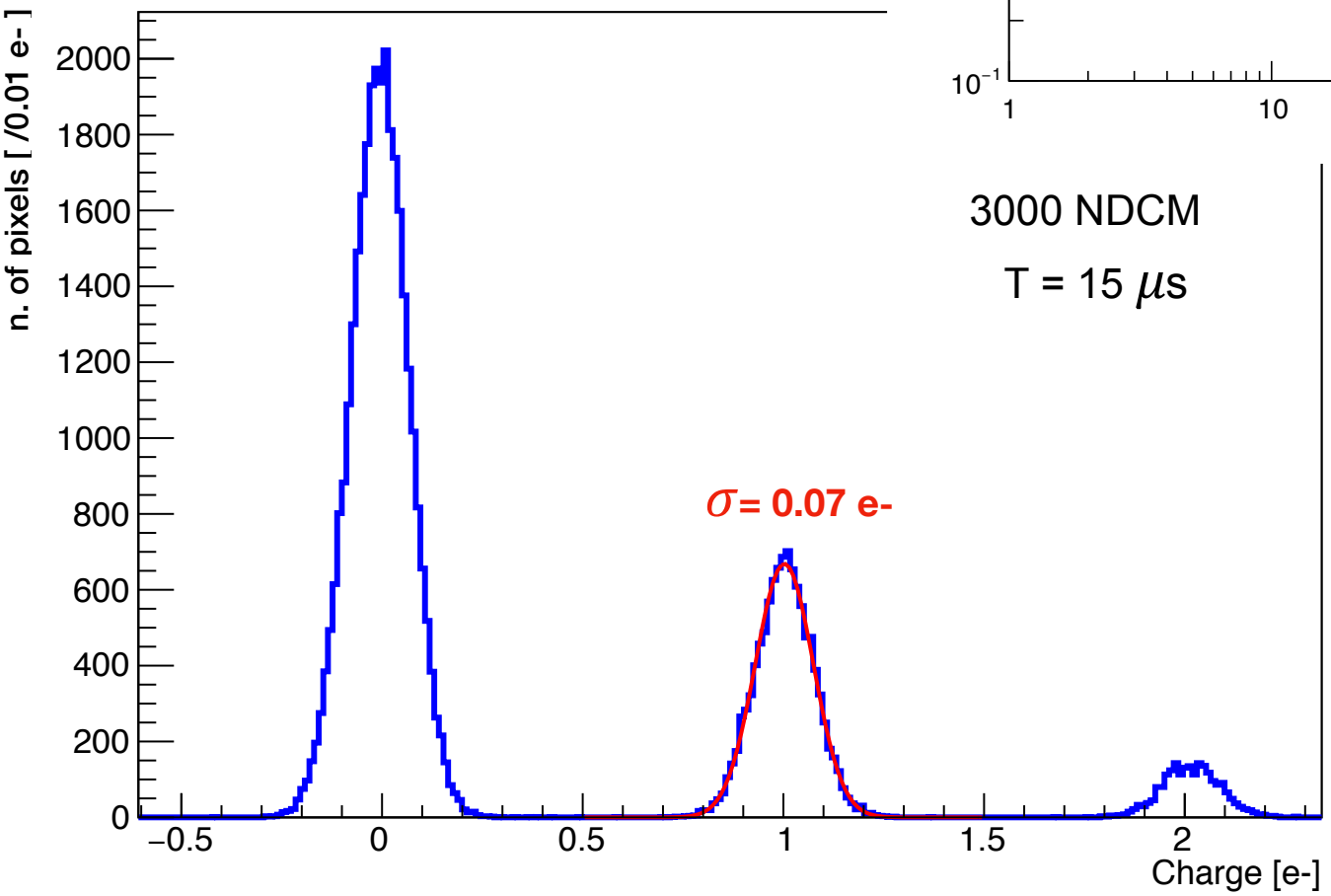
DAMIC-M Skipper charge resolution



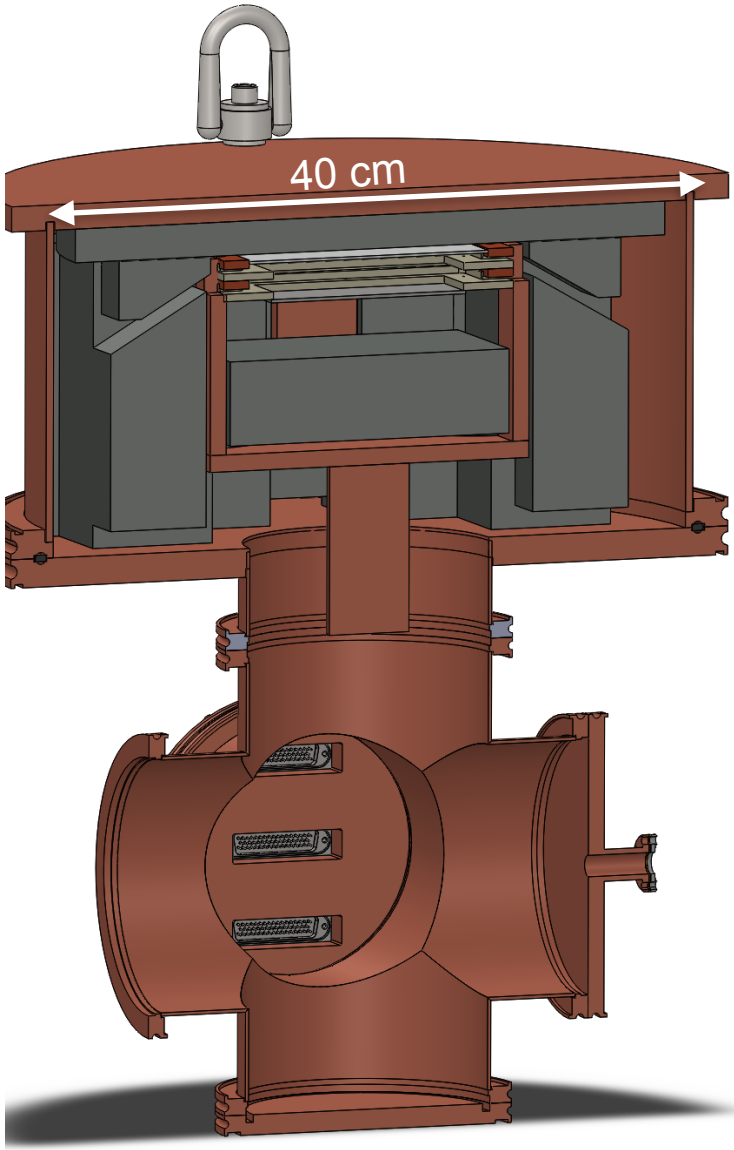
direct calibration of ADU to charge
(cross checked with ^{57}Co source)

Single electron resolution obtained for a wide range of integration times (T = 4 - 20 μs) allowing optimization with respect to electronics noise





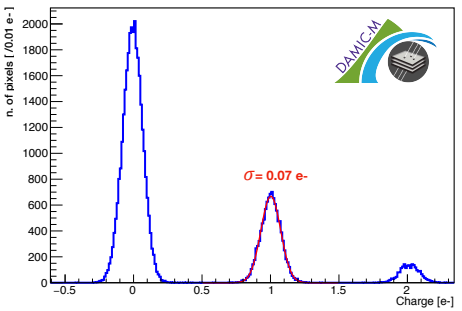
Low Background Chamber

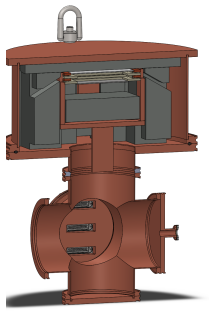


- A low-background chamber (background level ≈ dru) is in preparation
- Main objectives:
  - characterization of DAMIC-M CCDs in low-bkg environment: dark current; ^{32}Si rate; ^{210}Pb surface bkg; CCD packaging
  - first science results with a few CCDs
- Installation at LSM beginning of 2020

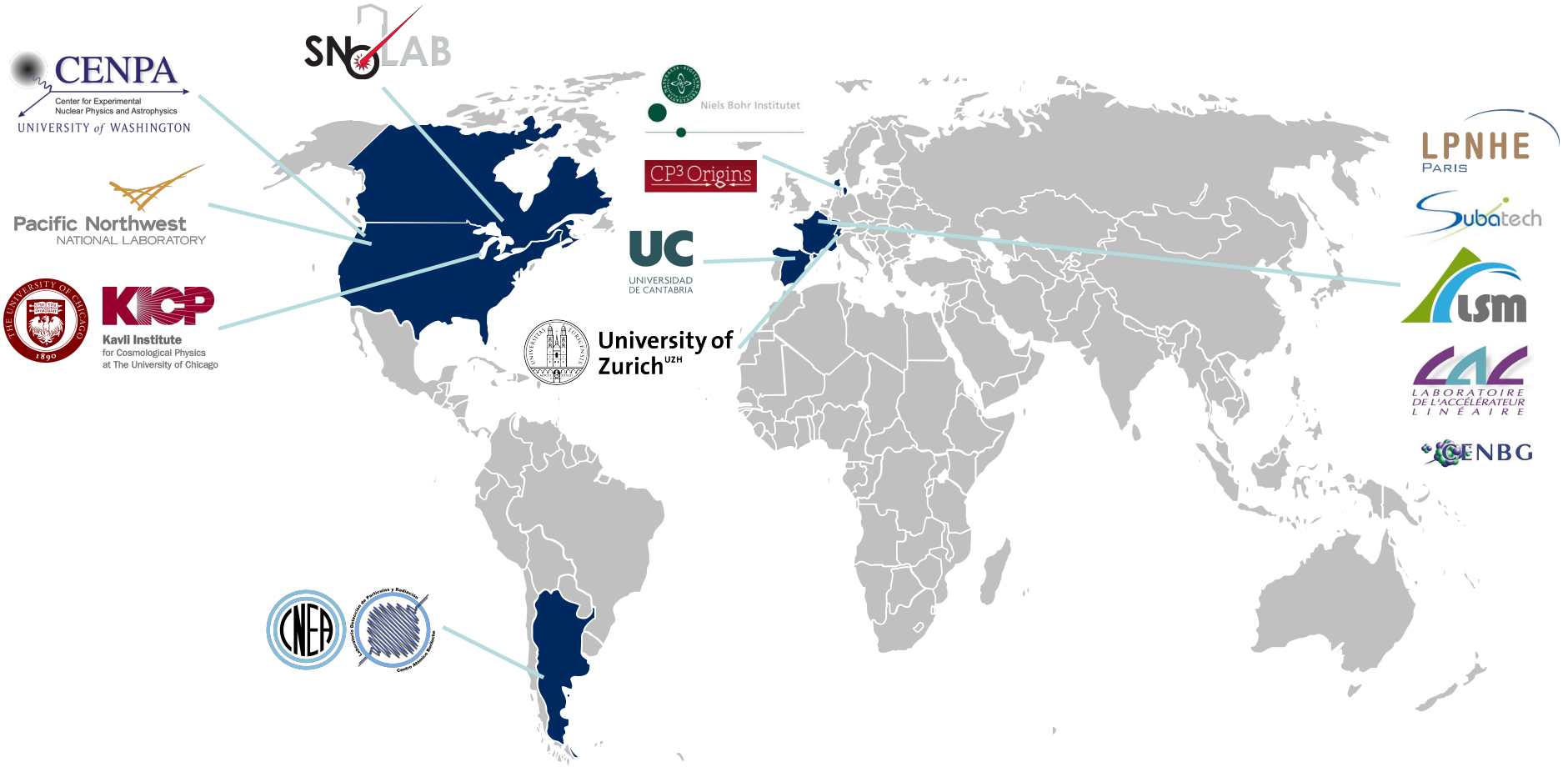
Outlook

- DAMIC-M is pushing to a kg-size detector the high-resistivity, fully-depleted CCD technology pioneered at SNOLAB
- The experiment is in its design phase. Progress on all aspects: detector design, electronics, low-background
- Major milestones accomplished: silicon ingot production; demonstration of single electron resolution with large-size, thick CCDs implementing skipper design
- We are moving fast. Before the end of this year, installation of DAMIC-M clean room at LSM and CCD pre-production. CCD production scheduled for next year.
- A low-background chamber will be installed at the LSM beginning of 2020 to characterize DAMIC-M skipper CCDs underground in a low background environment. Early science results with a few CCDs are foreseen.





DAMIC-M Collaboration



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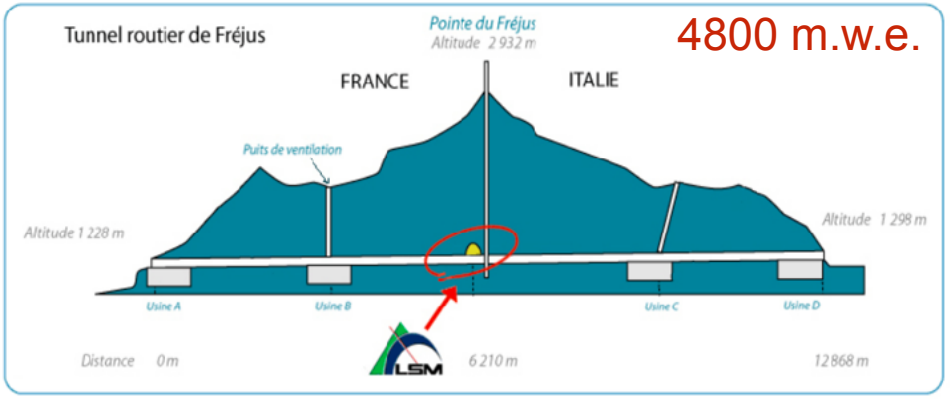

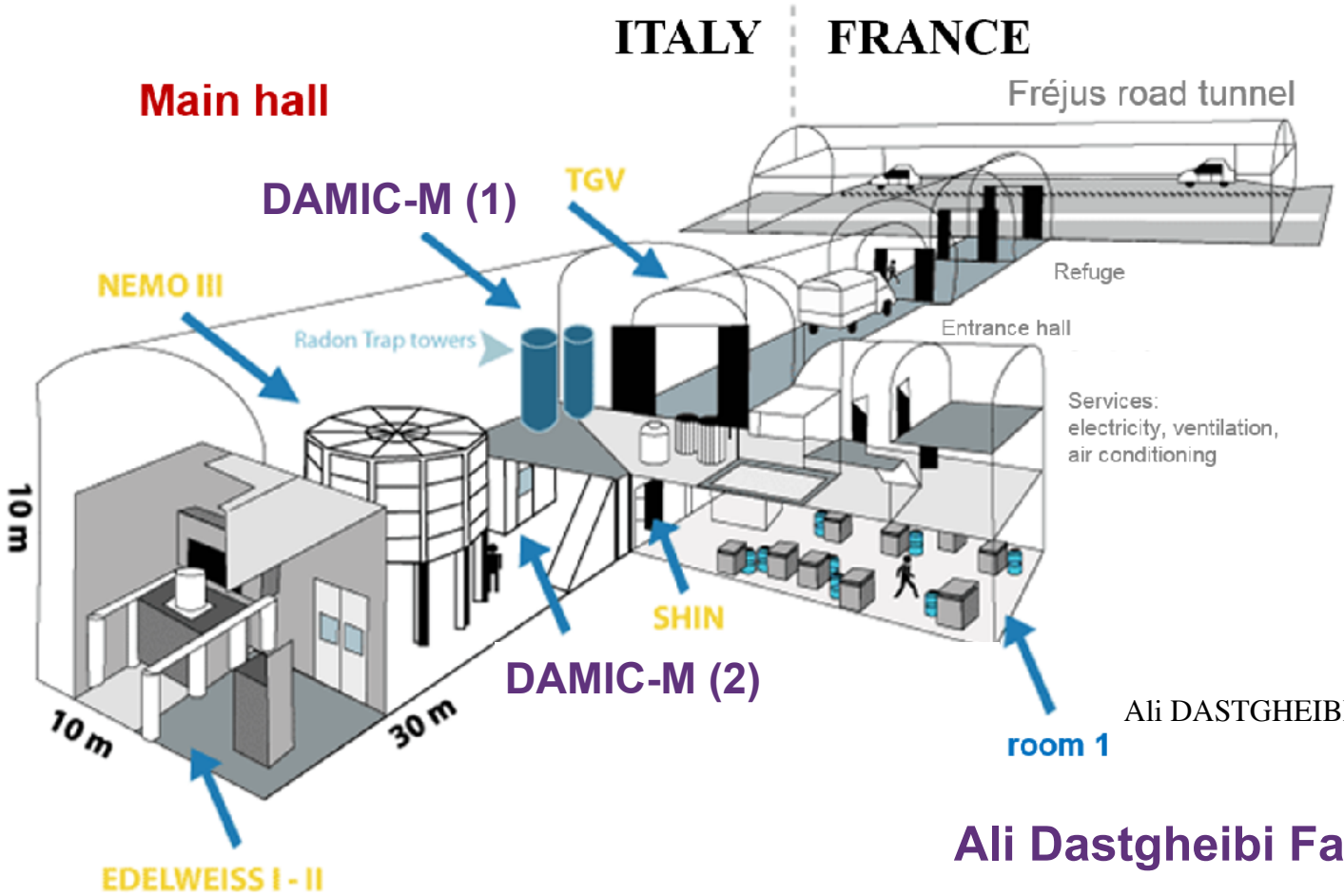

Ali DASTGHEIBI FARD

Ali Dastgheibi Fard's talk