Update on the status of the SENSEI* Dark Matter Experiment

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*Sub-Electron-Noise Skipper-CCD Experimental Instrument

Collaborators

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LBNL: S. Holland

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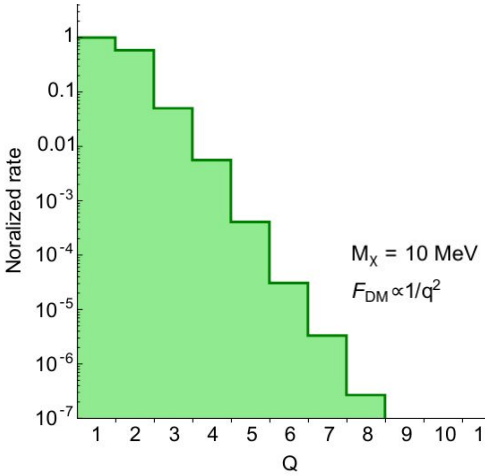
Science Objectives

Skipper **C**harge-**C**oupled **D**evices (CCDs) are low threshold, low read noise allowing us to resolve number of electrons in each pixel, down to $1e^-$ → can see event rate spectrons biased around $0e^-$

- 1-1000 MeV DM-e^- scattering (light and heavy mediators)
- 0.5-1000 MeV DM-nucleus recoils via Migdal effect
- 1-1000 eV DM absorption
- Scattering of milli-charged particles

SENSEI is a pathfinder experiment for OSCURA

Expected spectrum from benchmark models (e^- recoil)

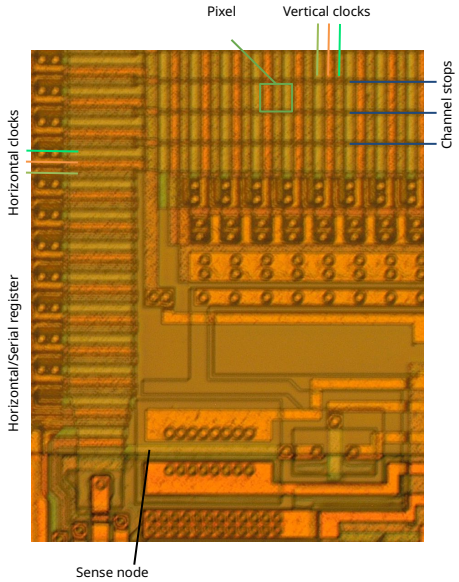


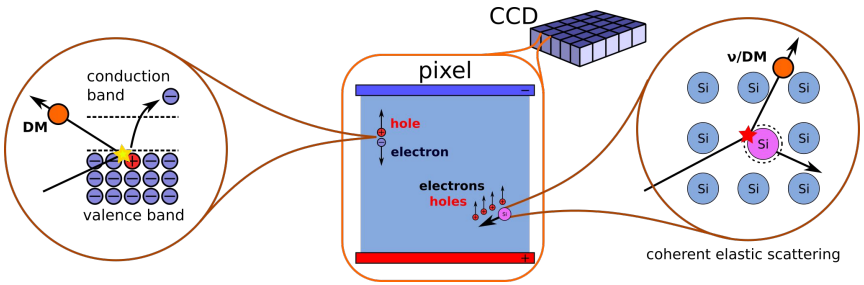
R. Essig et al, JHEP 05 (2016), 046

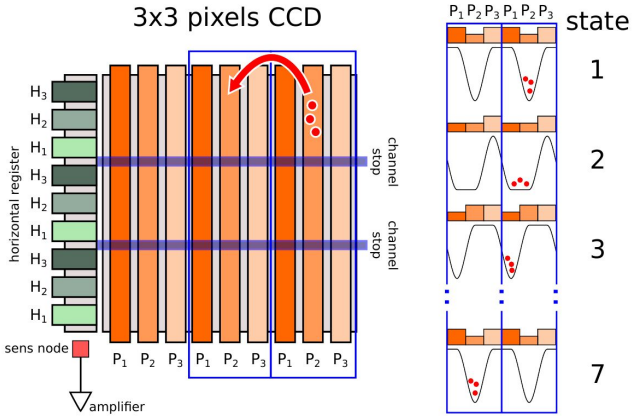
Detector Specifications

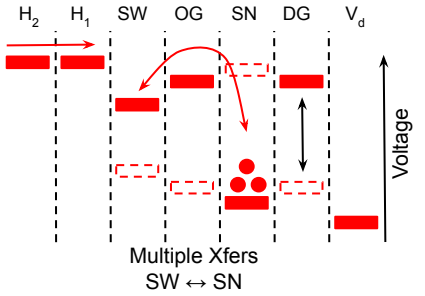
- Design by **LBNL** MicroSystems Lab
- Fabrication by **Teledyne DALSA** Semiconductor
- **Science Grade** Skipper CCD
  - Two flavors: “Skinny” Module (SENSEI@MINOS), “C-Module” (SENSEI@SNOLAB, right photo)
- Sub-electron readout noise, **~0.1 e^-**
- Energy threshold as low as the Silicon bandgap, **~1.1 eV**
- Lowest dark current (**~10^{-4} e^-/pix/day**) silicon detectors

Skipper CCD Principle of Operation





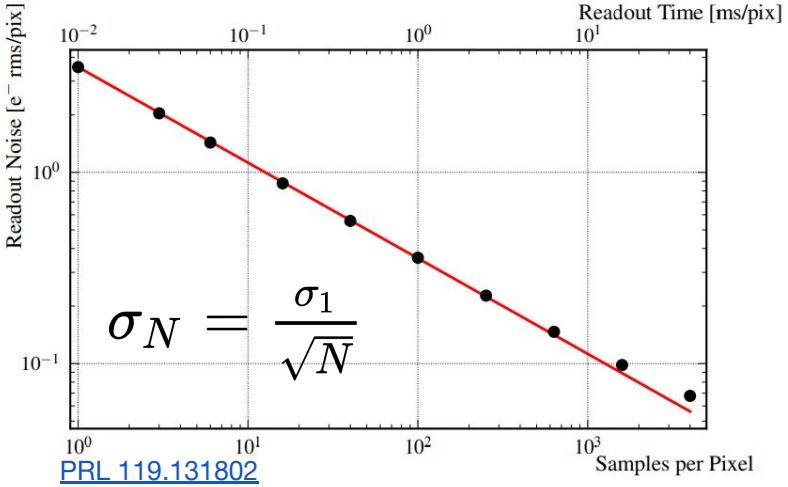




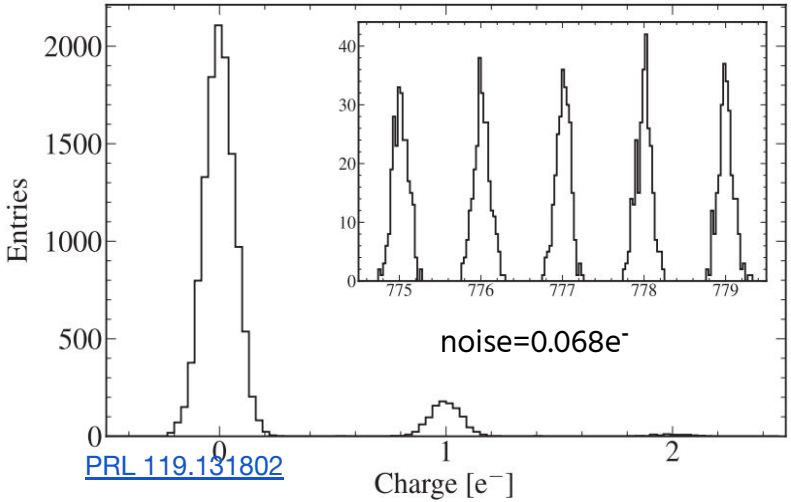
$$V_{SN} = \frac{n \cdot e^-}{C}$$

Skipper CCDs perform multiple non-destructive measurements of the charge in each pixel!

Skipper Principle of Operation



PRL 119.131802

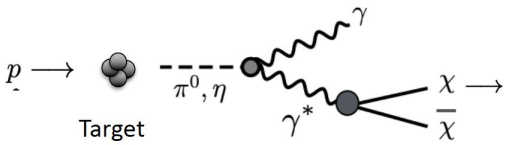


PRL 119.131802

- Sub-electron read noise ⟹ reliably resolve the number of electrons in each pixel.
- Repeated sampling also decreases 1/f noise in the measurement

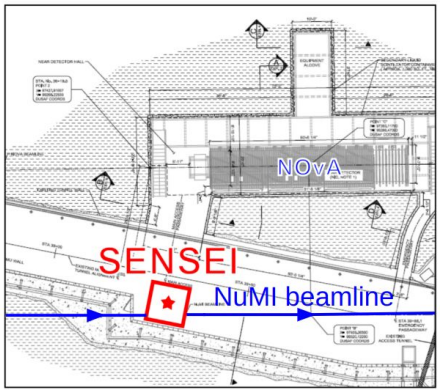
SENSEI @ MINOS | Update

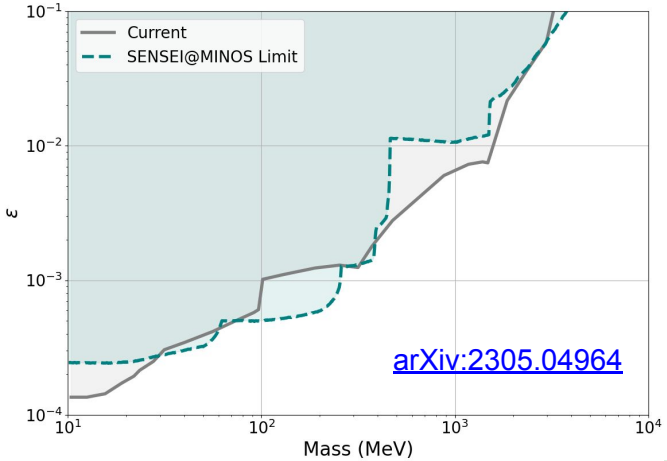
- One Science Grade 'Skinny' CCD installed in 2020. Produced DM limit: arXiv:2004.11378
- Reanalysis of 2020 data for Milli-charge particle (mCP) search published in **May 2023**:
  - mCP: Accelerator test of Standard Model extension & possible dark matter candidate
  - Protons collides with fixed target, out comes a beam of neutrinos and mCPs
  - Exploit SENSEI@MINOS location on the NuMI beamline



arXiV:1902.03246

	$1e^-$	$2e^-$	$3e^-$	$4e^-$	$5e^-$	$6e^-$
Efficiency	0.069	0.105	0.325	0.327	0.331	0.338
Exp. [g-day]	1.38	2.09	9.03	9.10	9.23	9.39
Obs. Events	1311.7	5	0	0	0	0

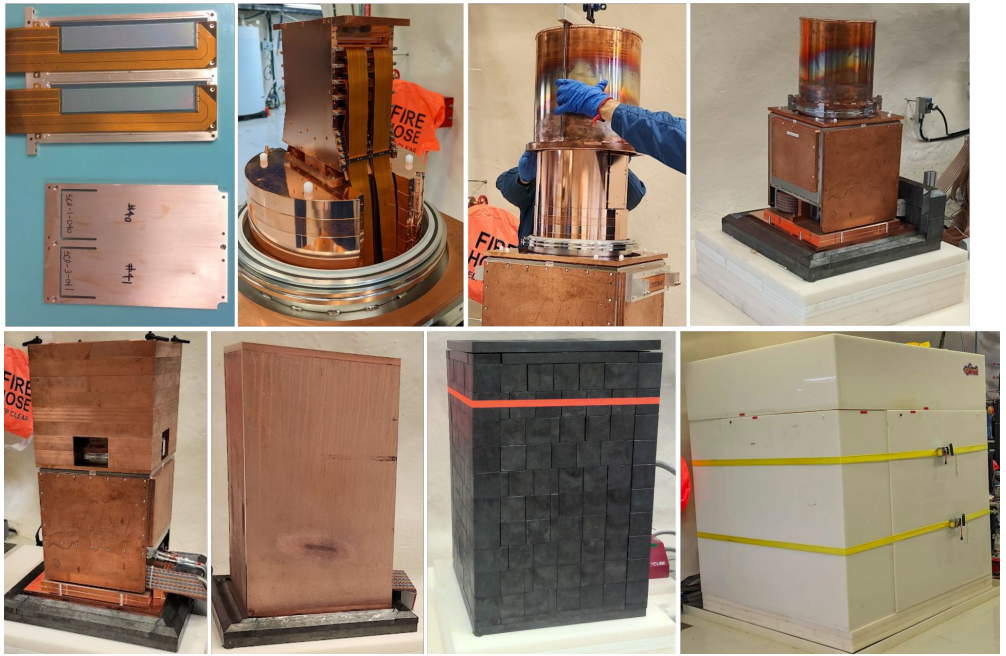




arXiv:2305.04964

SENSEI @ SNOLAB | Experimental Setup

- CCDs seated in copper trays
  - Two *x* 2.23g “C-module” per tray
- Cold copper box accommodates 12 copper trays
- Cryocooler + Heater (~140 K)
- 2 layers of OFHC copper outer shield
- 3-inch modern lead
- 42-inch polyethylene and water shield



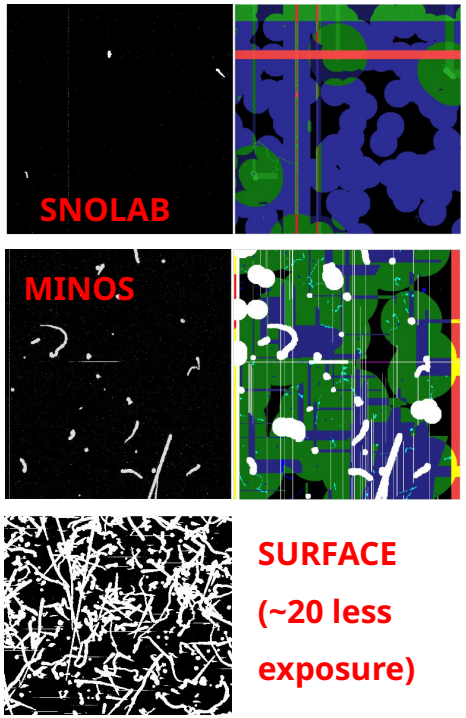
Deployment:

- Installation: Apr - Jul 2021
- Commissioning: Oct 2021 - Aug 2022
- Science: Sep 2022 - Apr 2023
- 6 CCDs (~13 g)
- 6144 × 1024 pixels,
  - Divided into 4 quadrants
- 15 μm pixel pitch
- 675 μm thick silicon absorber volume

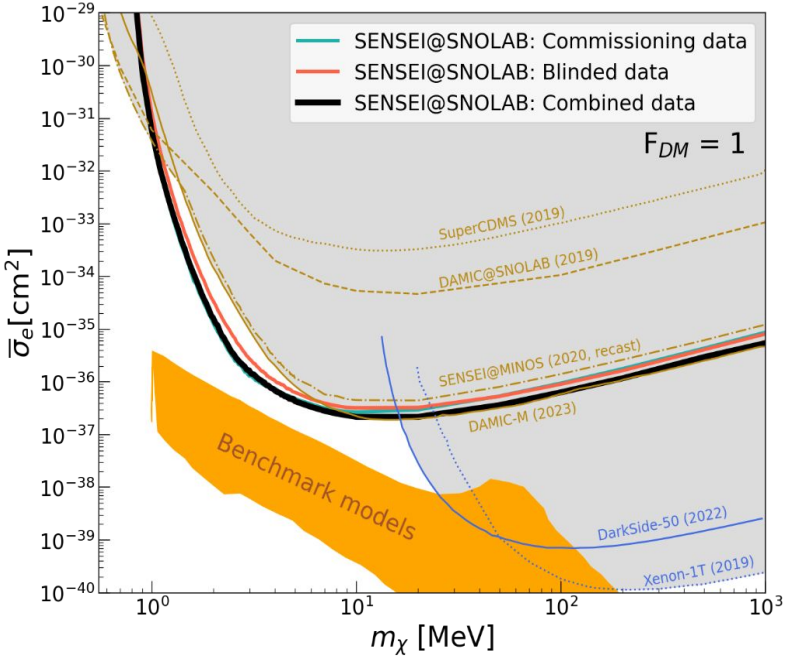
Data:

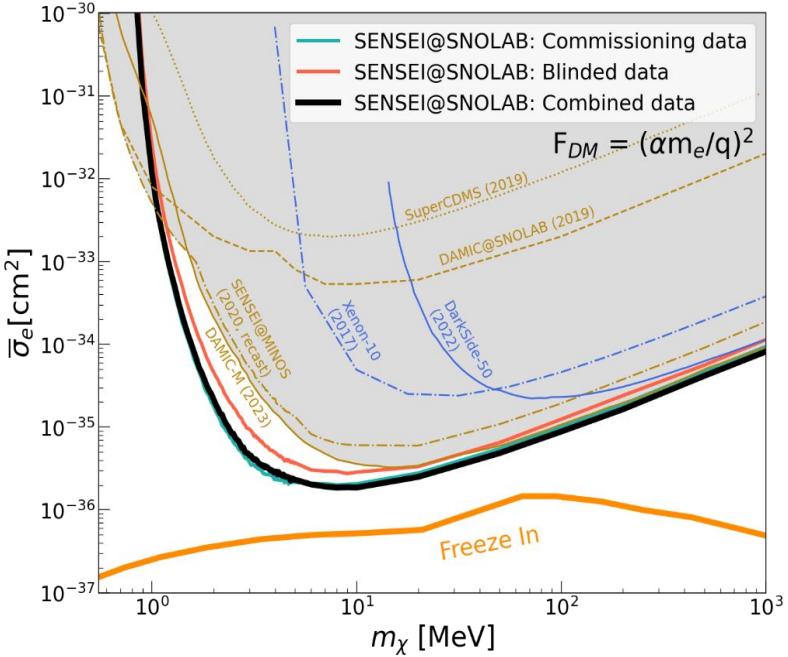
- 20 hour image exposures
- 129 images (45% blinded, 60% good)
- 7.3 hours readout per image
  - 300 samples → ~0.14 e^- noise
- 3 hour reset between each exposure
- Temperature variations of 135 K-155 K
  - Declining Cryocooler
- 1 e^- density (after cuts): ~2 x 10^{-4} e^-/pixel

- 45 good non-blinded commissioning images
- 37 good blinded images
- 2 e^- to 10 e^- channels
- Combined datasets: 50 to 70 g-days per electron channel after cuts
- Three limits:
  - blinded dataset
  - commissioning dataset
  - combined commissioning + blinded exposure



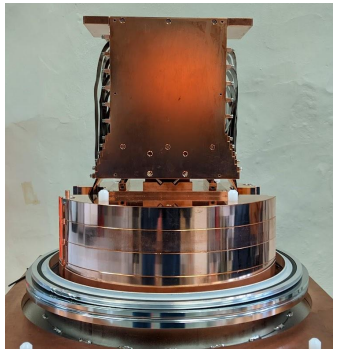
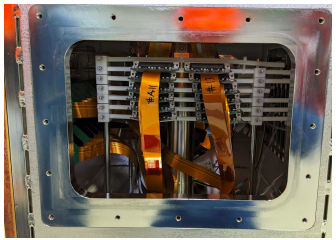
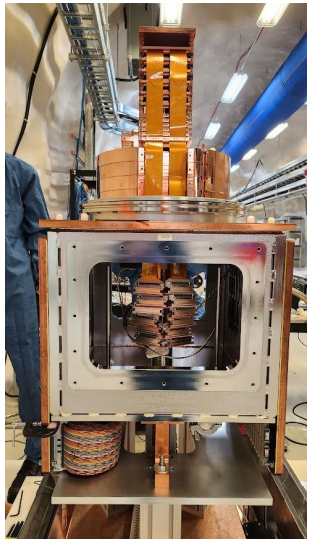
- Paper in final stages of preparation!





Upgrade Completed in **May 2023**

- Fixed cryocooler
- Installed more CCDs
  - Reading out 19 (~ 40 g) CCDs
- Currently acquiring science data


The End