Abstract: The repetitive-non-destructive readout DEPFET detectors achieve a deep sub-electron noise during. Its ability to distinguish the number of collected electrons enables experiments for direct detection of electron scattering processes of light dark matter.
We present the experimental characterization of a 64x64 RNDR-DEPFET pixel detector with a focus on the charge carrier generation rate and the achievable time resolution of several 100 microseconds to detect single electrons.

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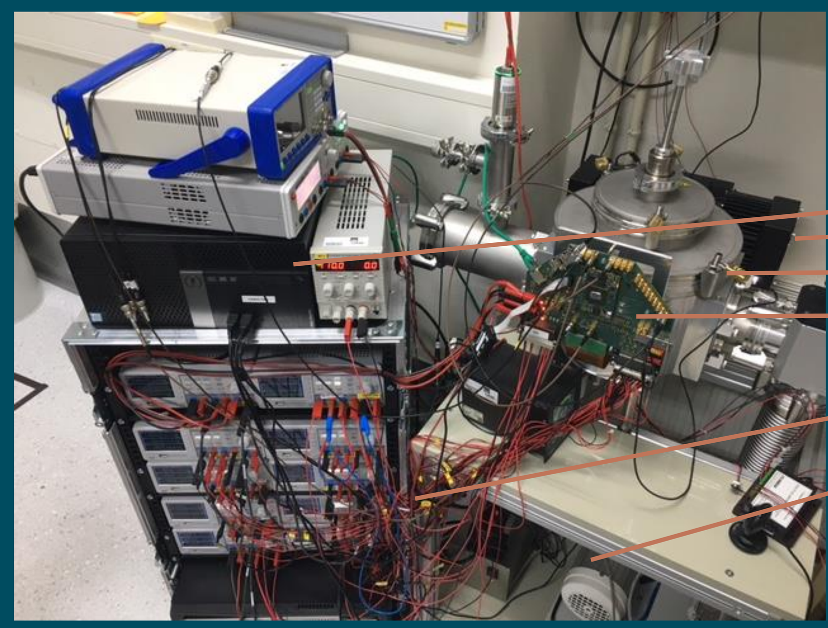
https://www.oeaw.ac.at/hephy/forschung/rare-event-searches-experimente/danae

DANAE

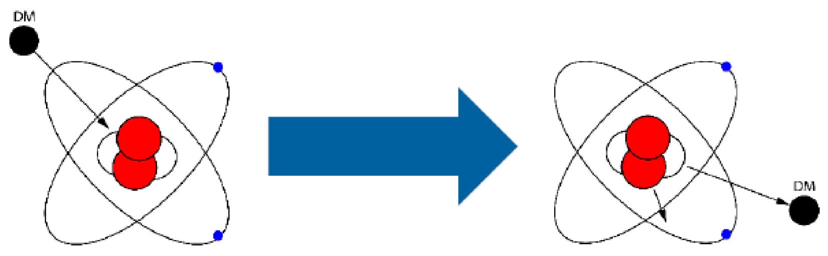
Direct detection of dark matter particles via their scattering off target electrons



Mobile DANAE prototype setup

- Data acquisition PC
- Stirling cryostat
- Vacuum chamber
- Outer PCB operation board (FPGA)
- Power tower
- Vacuum pump

Dark matter event signatures

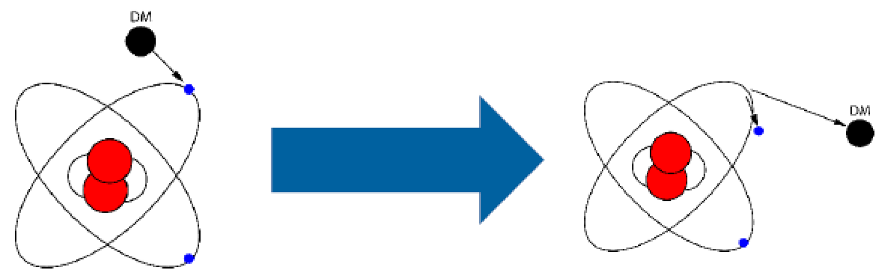


Nuclear Recoil

- WIMP Mass: 2 GeV/c² - 120 TeV/c²
- Direct search via nuclear recoil
- Threshold ~ 10 eV or 5 MeV/c²

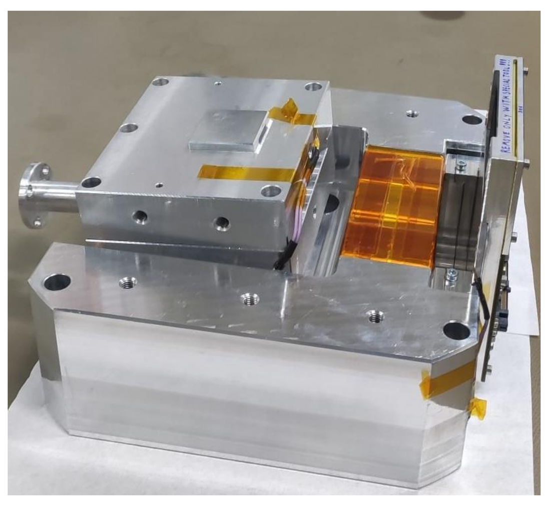
Electron Recoils

- Dark sector and light dark mat e.g. SIMP, sterile neutrinos
- Direct detection via electron scattering keV/c² - GeV/c²
- Threshold ~ 1 eV or 200 keV/c²



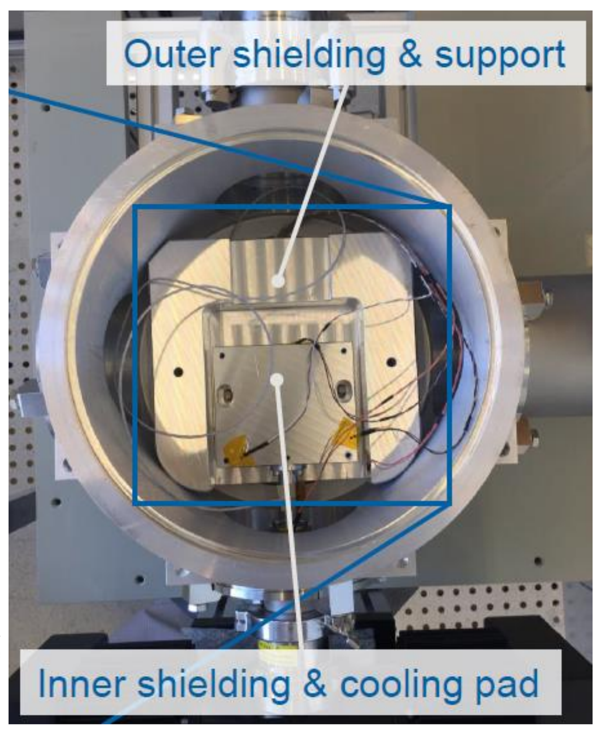
[https://doi.org/10.1016/j.nima.2019.04.109]

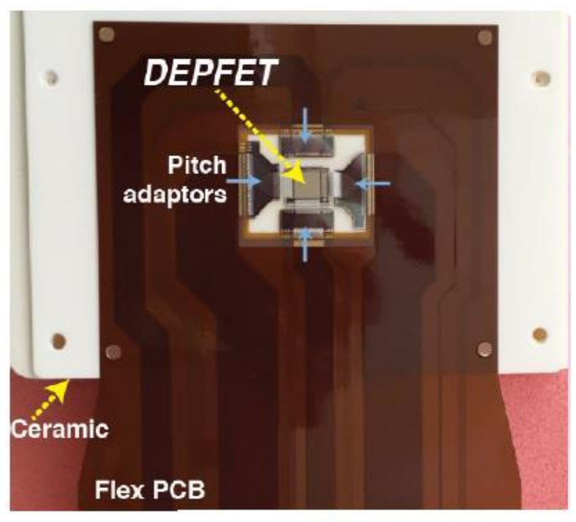
The DANAE Setup



The Danae Setup

- thermally decoupled shielding
- sensor glued on ceramic
- ceramic mounted on inner shielding
- control and readout ASICs on a PCB
- electrical connection over plug and Flex PCB

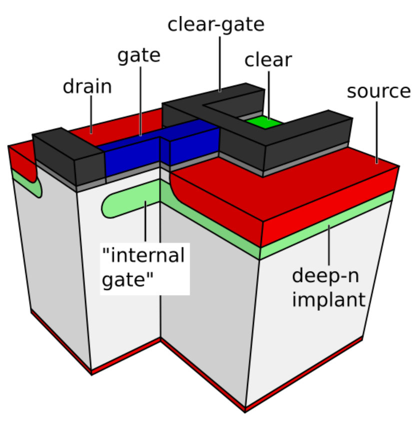




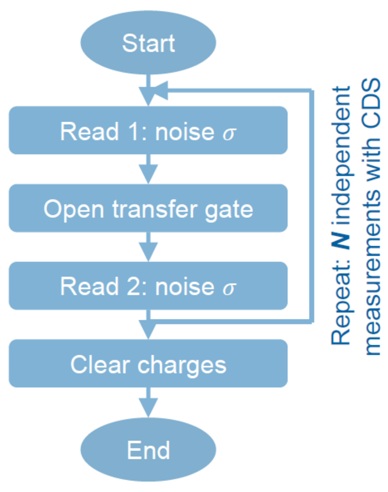
The Danae Prototype Sensor

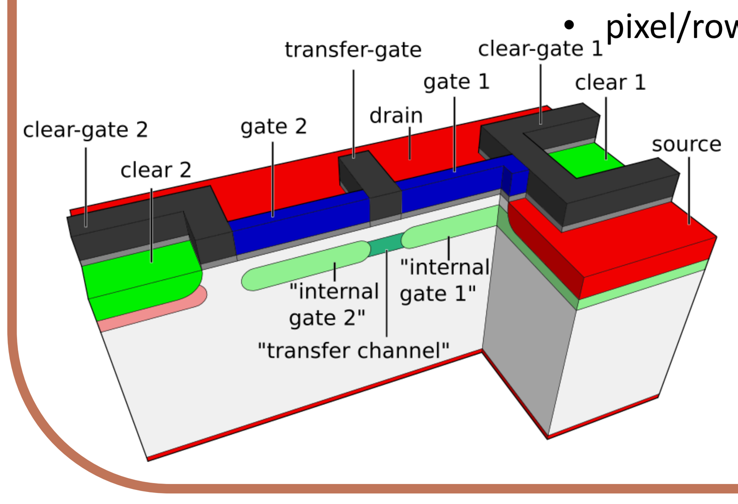
- RNDR DEPFET Matrix
- 64x64 Pixels
- 50x50 µm²
- 450 µm thick silicon

DEPFET



- pMOSFET on high resistive bulk
- combined sensor amplifier
- electrons collected in internal gate (IG)
- charge modulates transistor current
- CDS (correlated double sampling) with charge removal via clear-structure
- unit cell of larger matrix
- pixel/row addressable with gate





RNDR DEPFET

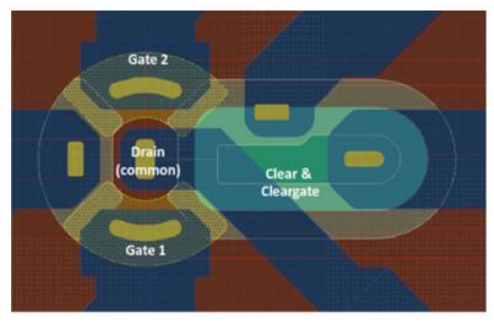
- Repetitive Non-Destructive Readout
- based on DEPFET sensor-amplifier
- two DEPFETs connected via transfer channel
- charge collected in internal gates (for CDS)
- transfer charge between IG1/IG2
- read collected charge N times

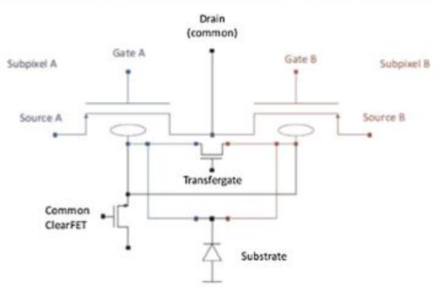
DEPFET and Skipper CCDs

- Skipper CCDs established for silicon based light dark matter searches
- E.g. DAMIC, SENSEI, OSCURA
- Tight requirements on background (about 0.01 dru, event/kg/day/keV) [arxiv: 2202.10518]
- RNDR-DEPFETs are active pixels with one r/o node in every pixel and complement properties to CCDs
  - Active pixels can be parallelized to obtain higher r/o speed
  - Active pixels are more complex and thus larger

	RNDR-DEPFET	Skipper-CCDs	Impact
Pixel size	< 50 µm²	< 15 µm²	particle identification
r/o speed	*O*(sec/frame)	*O*(hr/frame)	event veto (bkg.)
Scaling	bus-able	conventional	sensitive mass
Fabrication	HLL/MPG (Europe)	Microchip (US)	availability

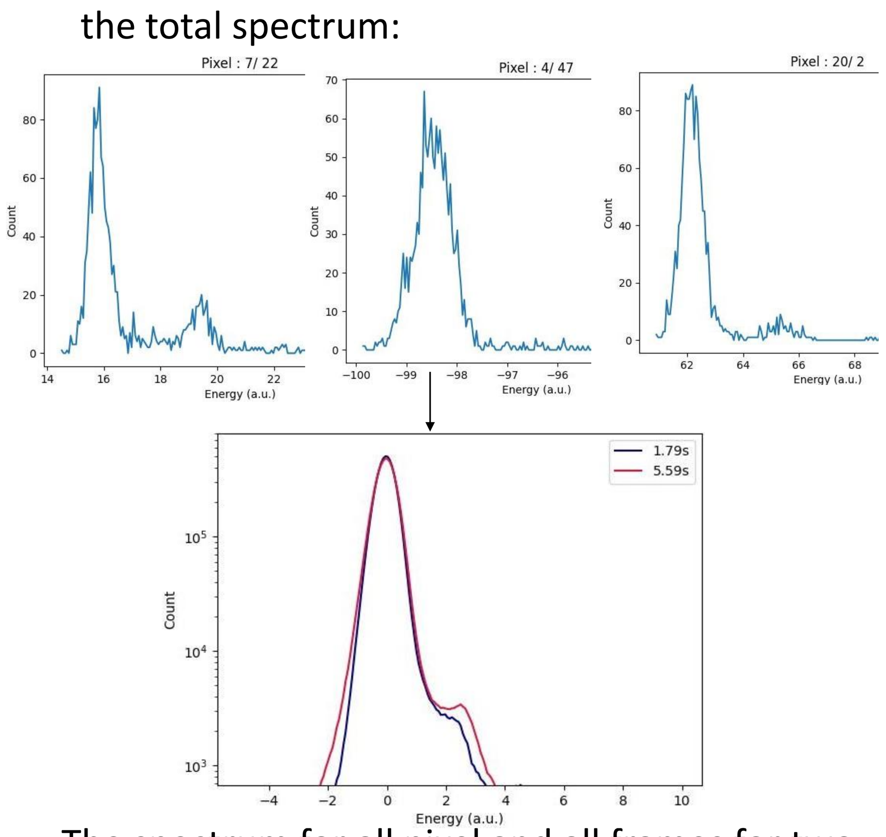
[https://arxiv.org/abs/1706.08666]





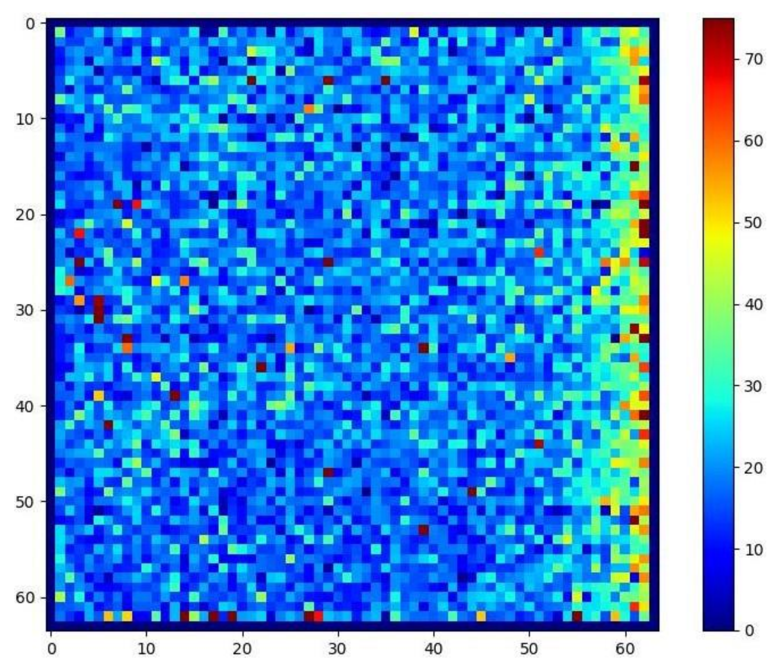
Data acquisition

The data from the individual pixels is collected for the total spectrum:



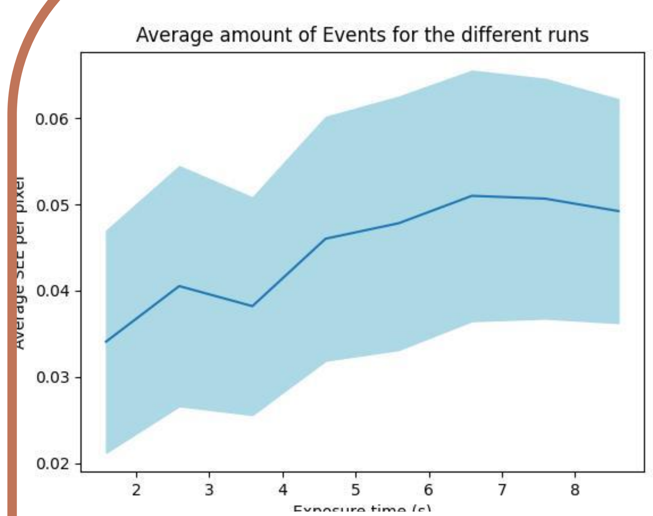
The spectrum for all pixel and all frames for two different exposure times

Event map



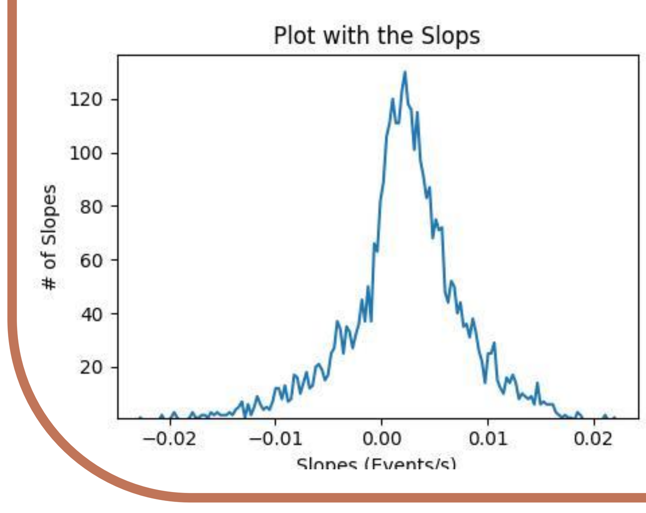
Event map for a run with 5 seconds of exposure.

- Single and multiple electron detections counted as one Event
- Events in neighbouring pixels are counted as one Event



During longer exposure times, more charges are detected.
Excluded:

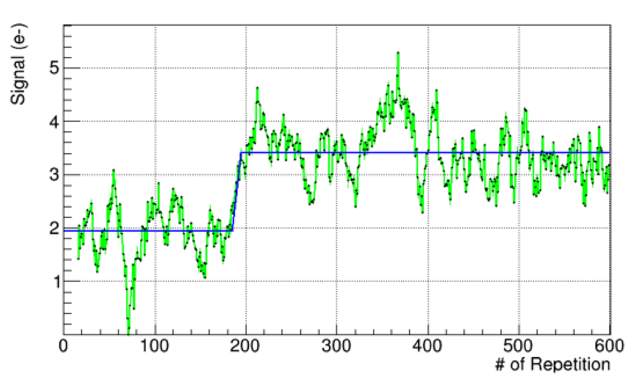
- Frames with high number of events
- Pixels that detect events to often or not often enough (hot and cold pixels)
- Pixels on edge of the sensor



The slope of the charges generated for different amounts of exposure is the generation rate.
Negative values due to too little statistics
Generation Rate: 0.0024 e^{-}/s/pix

To be Investigated

Charge loss or charge generation during the readout process



- Charges may be generated during readout
- Charges may be lost during readout

-> Change settings to reduce lost charges

Measuring charge generation during readout only possible with RNDR DEPFET

Conclusion

- Generation rate: 0.0024 e^{-}/s/pix
- Readout of whole sensor in less than 2 seconds
- Improved shielding necessary
- Further measurements for better statistics with more samples

Outlook

- More detectors to be assembled and investigated (esp. concerning charge generation
- Investigation of scale up concept to bus RNDR-DEPFET sensors on flexible PCB
- Evaluation of different applications of RNDR-DEPFET detectors like space instruments
- Test detector for different temperatures

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