SENSEI† first results, status and plans

Guillermo Fernandez Moroni
for the SENSEI Collaboration

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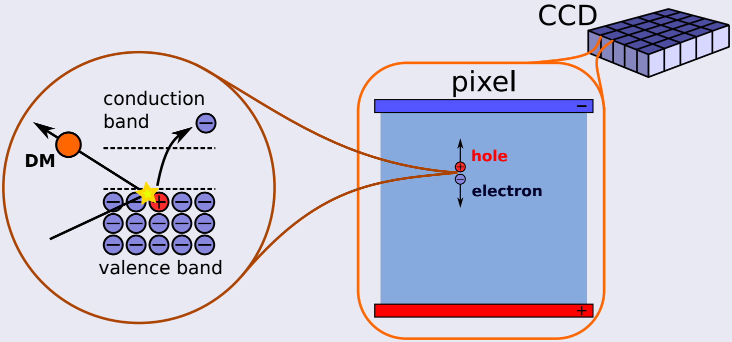
† **S**ub-**E**lectron-**N**oise **S**kipperCCD **E**xperimental **I**nstrument

Fermilab

SENSEI: lower the energy threshold to look for light DM candidates

Detect DM-e interactions by measuring the ionization produced by the electron recoils. See arXiv:1509.01598

Idea: use electrons in the bulk silicon from a CCD as target



This requires very low noise!

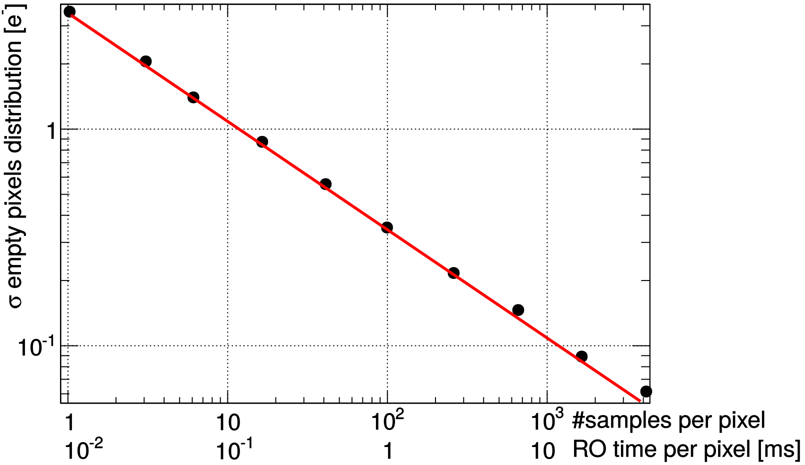
SENSEI Collaboration

Build a detector using Skipper-CCDs to search for light DM canditates

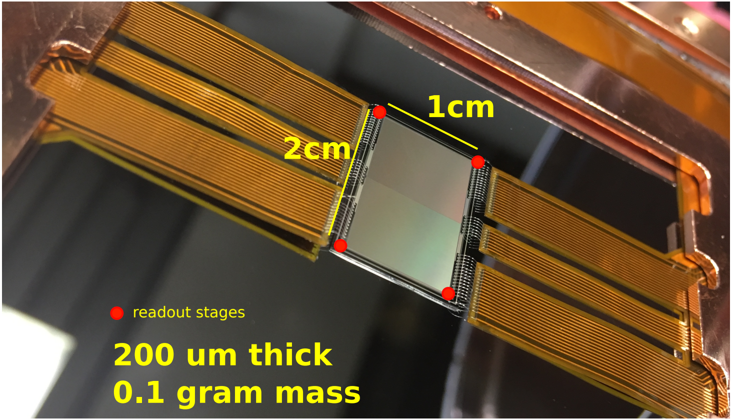
- **Fermilab:** Michael Crisler, Alex Drlica-Wagner, Juan Estrada, Guillermo Fernandez, Miguel Sofo Haro, Javier Tiffenberg
- **Oregon University:** Tien-Tien Yu
- **Stony Brook:** Rouven Essig
- **Tel Aviv University:** Liron Barack, Erez Ezion, Tomer Volansky
- **+ several additional students + more to come**

Fully funded by Heising-Simons Foundation & Fermilab

Noise vs. #samples - $1/\sqrt{N}$

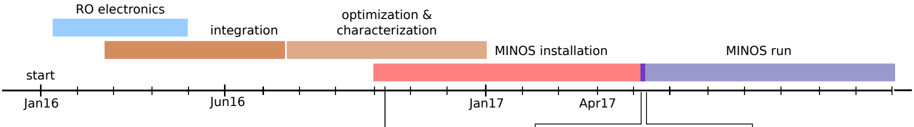


protoSENSEI: technology demonstrator



We used the parasitically-fabricated R&D sensors to learn how to optimize operations and produce early-science results

protoSENSEI: project timeline



explore high xsec

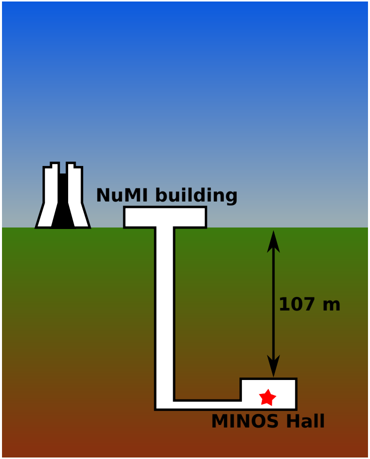
arXiv:1804.00088

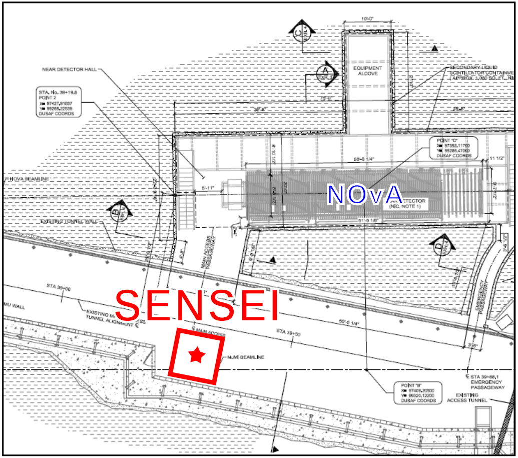
explore small xsec

arXiv:1901.10478

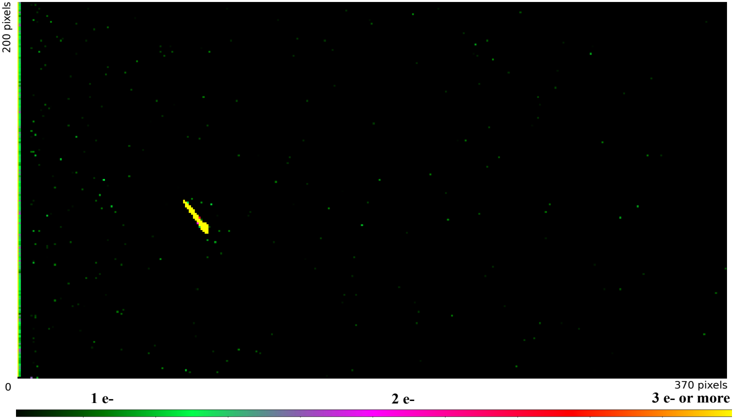
Current step: Prototype running @MINOS

Technology demonstration: installation at shallow underground site



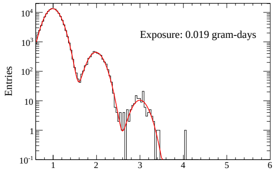


protoSENSEI @MINOS: raw image/data (70 min exposure)

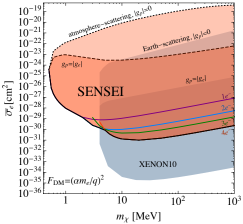


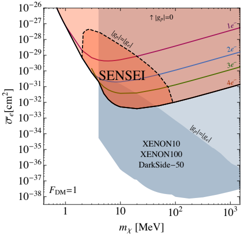
adjacent pixels with one or more electrons are grouped together

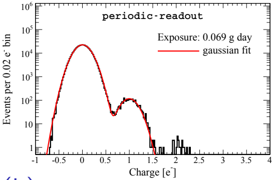
Results with Skipper CCD prototype (PRL 121, 061803; PRL 122, 161801)



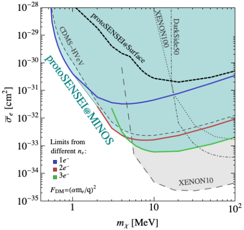
(a) First run event spectrum.



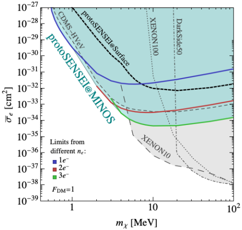




(b) Sec. run event spectrum.



(c) light mediator



(d) heavy mediator

protoSENSEI @MINOS: all the information, pick your model

N_e / Cuts	periodic			continuous		
	1	2	3	3	4	5
1. DM in single pixel	1	0.62	0.48	0.48	0.41	0.36
2. Nearest Neighbour	0.92			0.96		
3. Electronic Noise	1			$\sim$1		
4. Edge	0.92			0.88		
5. Bleeding	0.71			0.98		
6. Halo	0.80			0.99		
7. Cross-talk	0.99			$\sim$1		
8. Bad columns	0.80			0.94		
Total Efficiency	0.38	0.24	0.18	0.37	0.31	0.28
Eff. Expo. [g day]	0.069	0.043	0.033	0.085	0.073	0.064
Number of events	2353	21	0	0	0	0

What's next? General timeline

2016

LDRD funded,
fabrication of SkipperCCD prototype

2017

testing of prototype,
received funding from HSF for SENSEI experiment

2018

early science from prototypes and design and fabrication of SENSEI experiment

2019

SENSEI at MINOS (~10 gr)
commissioning at Snolab (~100 gr)

2020

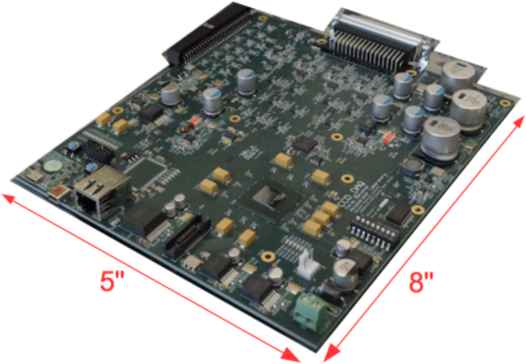
analisis of SENSEI at Minos and take data at Snolab

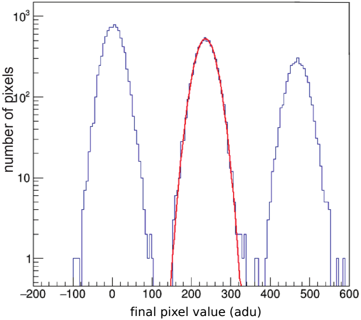
2021

analisis of Snolab data

Fermilab

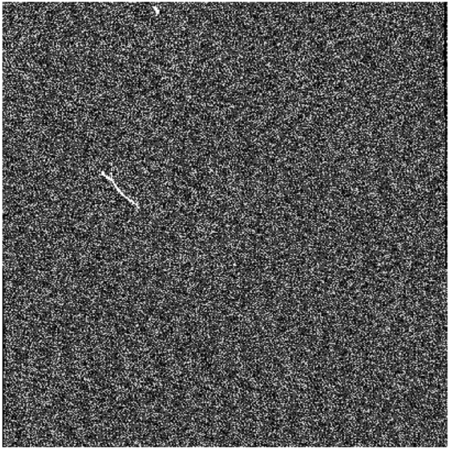
New electronics (FNAL+IIIE effort)





Scalable up to 1 kg of CCDs

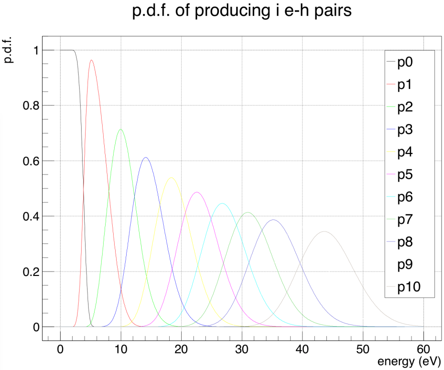
Science detectors arrived last week to Fermilab



Already packaged and showing very good performance!

New science is coming in the next weeks!!!

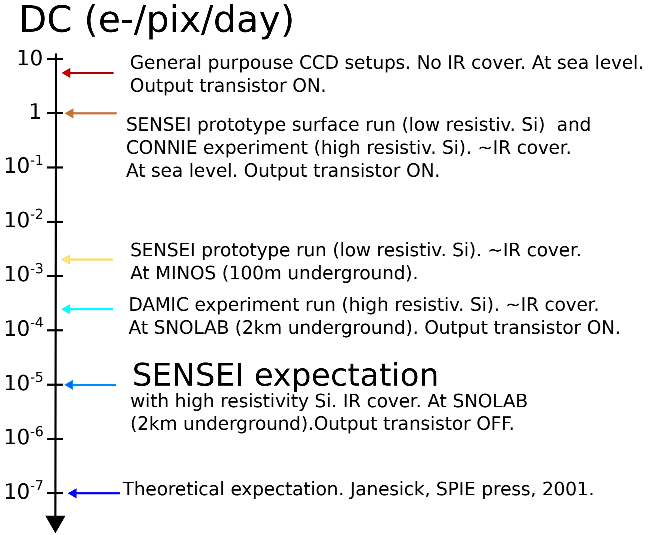
Focus on measuring the ionization efficiency



Alig model is incomplete and we are already measuring with skipper CCD using photons.

BACK UP SLIDES

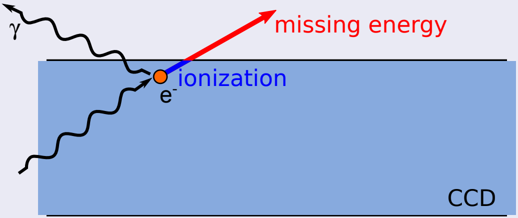
Dark current measurements and expectation



SENSEI: electron recoil background requirements

A more detailed analysis: MC simulation, G4 3D Monash model

- at lower energies atomic binding energies are relevant
- **partial energy depositions populate low E region (thin det)**



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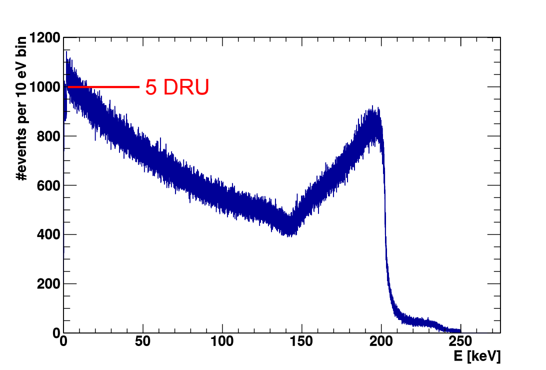

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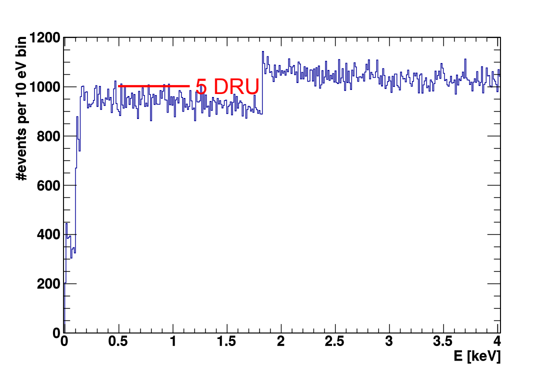

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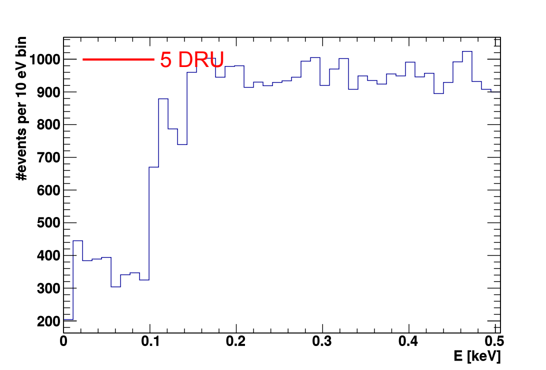

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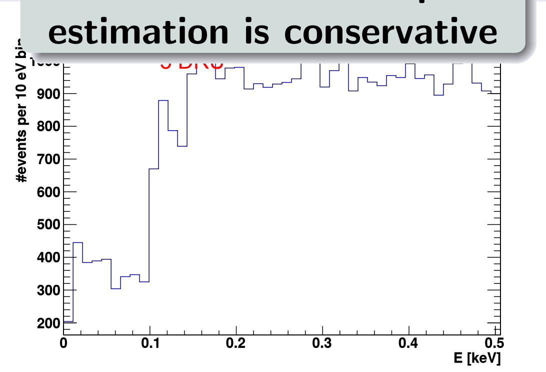
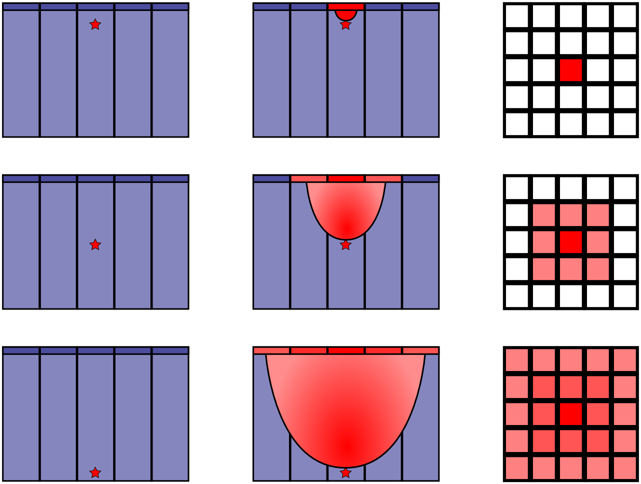
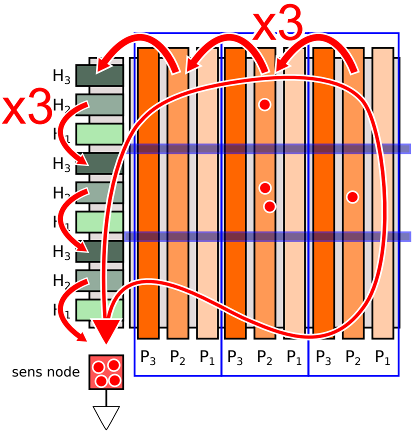
Back of the envelope estimation is conservative



Diffusion



Hardware binning



The optimal effective pixel size can be chosen by using hw binning

$$\mu_{\text{sigle}} = R_{\text{DC}} \times \underbrace{(T_{\text{pix}} \times n_{\text{pix}})}_{T_{\text{expo}}} = \mu_{\text{binning}} = \underbrace{(n_{\text{bin}} \times R_{\text{DC}})}_{\text{Eff DC}} \times \underbrace{T_{\text{pix}} \times n_{\text{pix}}/n_{\text{bin}}}_{T_{\text{expo}}}$$