SENSEI† first results, status and plans

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for the SENSEI Collaboration

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† Sub-Electron-Noise SkipperCCD Experimental Instrument
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 candidates

- **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 - $1/\sqrt{N}$
We used the parasitically-fabricated R&D sensors to learn how to optimize operations and produce early-science results
protoSENSEI: project timeline

Jan16  Jun16  Jan17
start
MINOS installation
RO electronics
integration
optimization &
characterization
Apr17
MINOS run

Clean-room

Low rad. package
commissioning
run at surface
explore high xsec
arXiv:1804.00088

Deploy at MINOS
and data taking
explore small xsec
arXiv:1901.10478
Current step: Prototype running @MINOS

Technology demonstration: installation at shallow underground site
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

Exposure: 0.019 gram-days

Exposure: 0.069 g day

Events per 0.02 e⁻ bin
### protoSENSEI @MINOS: all the information, pick your model

<table>
<thead>
<tr>
<th>Ne</th>
<th>periodic</th>
<th>continuous</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. DM in single pixel</td>
<td>1</td>
<td>0.62</td>
</tr>
<tr>
<td>2. Nearest Neighbour</td>
<td>0.92</td>
<td>0.92</td>
</tr>
<tr>
<td>3. Electronic Noise</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4. Edge</td>
<td>0.92</td>
<td>0.92</td>
</tr>
<tr>
<td>5. Bleeding</td>
<td>0.71</td>
<td>0.71</td>
</tr>
<tr>
<td>6. Halo</td>
<td>0.80</td>
<td>0.80</td>
</tr>
<tr>
<td>7. Cross-talk</td>
<td>0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>8. Bad columns</td>
<td>0.80</td>
<td>0.80</td>
</tr>
</tbody>
</table>

| 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
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

**DC (e-/pix/day)**

- **10** General purpose CCD setups. No IR cover. At sea level. Output transistor ON.
- **1** SENSEI prototype surface run (low resistivity Si) and CONNIE experiment (high resistivity Si). ~IR cover. At sea level. Output transistor ON.
- **10^{-1}**
- **10^{-2}**
- **10^{-3}** SENSEI prototype run (low resistivity Si). ~IR cover. At MINOS (100m underground).
- **10^{-4}** DAMIC experiment run (high resistivity Si). ~IR cover. At SNOLAB (2km underground). Output transistor ON.
- **10^{-5}** SENSEI expectation with high resistivity Si. IR cover. At SNOLAB (2km underground). Output transistor OFF.
- **10^{-6}**
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)

![Diagram of electron recoil in CCD with energy depositions and ionization](image-url)
SENSEI: electron recoil background requirements

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![Graph showing energy vs. number of events per 10 eV bin]

5 DRU
SENSEI: electron recoil background requirements

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![Graph showing energy deposition distribution with 5 DRU indication]
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![Graph showing energy distribution and 5 DRU](image)
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Back of the envelope estimation is conservative
Diffusion
The optimal effective pixel size can be chosen by using hw binning

\[
\mu_{\text{sigle}} = R_{\text{DC}} \times \left( \frac{T_{\text{pix}} \times n_{\text{pix}}}{T_{\text{expo}}} \right) = \mu_{\text{binning}} = \left( \frac{n_{\text{bin}} \times R_{\text{DC}}}{\text{Eff DC}} \right) \times \left( \frac{T_{\text{pix}} \times n_{\text{pix}}}{n_{\text{bin}} \times T_{\text{expo}}} \right)
\]