SENSEI: first results

Tien-Tien Yu (CERN & UOregon) for the collaboration

Seventh Workshop on Theory, Phenomenology and Experiments in Flavour Physics and the future of BSM physics

June 10, 2018
Main Goals:

• Build the first working detector using Skipper-CCDs.
• Validate the technology for DM and neutrino experiments.
• Build a 100g detector using a staged approach to
  • Probe DM masses down to MeV masses using electron-recoil
  • Probe ALPs and Dark Photons down to eV masses through bosonic absorption
CCD-based detector with single-electron sensitivity using SkipperCCDs produced by LBL MSL

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SENSEI

Sub-Electron-Noise Skipper CCD Experimental Instrument

Fermilab:
- Michael Crisler
- Alex Drlica-Wagner
- Juan Estrada
- Guillermo Fernandez Moroni
- Miguel Sofo Haro
- Javier Tiffenberg

Tel Aviv University:
- Liron Barack
- Erez Ezion
- Joseph Taenzer
- Tomer Volansky

Stony Brook University:
- Luke Chaplinsky
- Fnu Dawa
- Rouven Essig

University of Oregon:
- Tien-Tien Yu
silicon CCD detector

**basic idea:** use the electrons in the CCD as the target

Essig, Fernandez-Serra, Mardon, Soto, Volansky, TTY [1509.01598]
silicon CCD detector

challenge: requires very low noise!

Essig, Fernandez-Serra, Mardon, Soto, Volansky, TTY [1509.01598]
readout

3x3 pixels CCD

Shift charge one column to the right

Shift charge in serial register one pixel down (3 times)
readout

Only the readout stage is modified
skipper readout

Charge generation

Silicon bulk

electron holes
ionizing particle

non-destructive readout ➞ possible to have multiple readouts

Tiffenberg, Sofo-Haro, Drlica-Wagner, Essig, Guardincerri, Holland, Volansky, TTY [1706.00028]
readout

Tiffenberg, Sofo-Haro, Drlica-Wagner, Essig, Guardincerri, Holland, Volansky, TTY [1706.00028]
readout noise
readout noise

\[ \sigma = \frac{\sigma_1}{\sqrt{N}} \]

reduce readout noise by increasing readout time

Tiffenberg, Sofo-Haro, Drlica-Wagner, Essig, Guardincerri, Holland, Volansky, TTY [1706.00028]
skipper readout

standard CCD
Readout-noise: 3.5 e RMS

skipper CCD
Readout-noise: 0.06 e RMS

Tiffenberg, Sofo-Haro, Drlica-Wagner, Essig, Guardincerri, Holland, Volansky, TTY [1706.00028]
skipper readout

standard CCD

Readout-noise: 3.5 e RMS

skipper CCD

Readout-noise: 0.06 e RMS

readout noise has zero impact

dark current is limiting factor

Tiffenberg, Sofo-Haro, Drlica-Wagner, Essig, Guardincerri, Holland, Volansky, TTY [1706.00028]
**dark current**

<table>
<thead>
<tr>
<th>dark current [e-/pix/day]</th>
<th>$\geq 1e^{-}$ [pix]</th>
<th>$\geq 2e^{-}$ [pix]</th>
<th>$\geq 3e^{-}$ [pix]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-3}$</td>
<td>$1 \times 10^{8}$</td>
<td>$3 \times 10^{3}$</td>
<td>$7 \times 10^{-2}$</td>
</tr>
<tr>
<td>$10^{-5}$</td>
<td>$1 \times 10^{6}$</td>
<td>$3 \times 10^{-1}$</td>
<td>$7 \times 10^{-8}$</td>
</tr>
<tr>
<td>$10^{-7}$</td>
<td>$1 \times 10^{4}$</td>
<td>$3 \times 10^{-5}$</td>
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<td>measured upper bound [arXiv:1611.03066]</td>
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SENSEI with a 2-electron threshold is a zero-background experiment!
first results!

0.019 g-days of commissioning data from a surface run

Exposure: 0.019 gram-days

dark current: \( \sim 1.1 \) e\(^{-}\) /pix/day; no events with 5-100 electrons

SENSEI Collaboration [1804.00088]
applications to dark sector physics
dark matter candidates
dark matter candidates

SENSEI territory
dark matter-electron scattering
scattering rate

\[
\frac{d\langle \sigma v \rangle}{d \ln E_R} = \frac{\overline{\sigma}_e}{8 \mu^2_{\chi e}} \int q \, dq |f(k, q)|^2 |F_{DM}(q)|^2 \eta(v_{\text{min}})
\]

local DM density

\[
R = N_T \frac{\rho_{\chi}}{m_\chi} \int_{E_{R,\text{cut}}} d\ln E_R \frac{d\langle \sigma v \rangle}{d \ln E_R}
\]

number of target nuclei per unit mass

d energy threshold

solid state

astrophysics

particle physics
first results!

exposure of ~0.02 g-days

scattering effects: work in progress by Essig, Emken, Kouvaris, Sholapurkar

SENSEI Collaboration [1804.00088]
first results!

first direct detection constraints for \(\sim 500\) keV to 4 MeV!

scattering effects: work in progress by Essig, Emken, Kouvaris, Sholapurkar
A Model: Hidden Photon

\[ \mathcal{L} = F_{\mu\nu}^2 + F'_{\mu\nu}^2 + m_{A'}^2 A'_{\mu}^2 + g_{\chi} J_\chi^\mu A'_{\mu} + g J_e^\mu (A_{\mu} + \epsilon A'_{\mu}) \]

\[ \begin{align*}
F_{DM}(q) &= \frac{m_{A'}^2 + \alpha^2 m_e^2}{m_{A'}^2 + q^2} \\
&\approx \begin{cases} \\
1, & m_{A'} \gg \alpha m_e \\
\frac{\alpha^2 m_e^2}{q^2}, & m_{A'} \ll \alpha m_e
\end{cases}
\end{align*} \]
first results!

~0.02 g-days of commissioning data from a surface run
first results!

~0.02 g-days of commissioning data from a surface run

SENSEI Collaboration [1804.00088]

*Barkana, Outmezguine, Redigolo, Volansky [1803.03091]
SENSEI reach

\[ \sigma \propto \frac{1}{q^2} \]

SENSEI reach chart showing the current direct detection reach of XENON10 and XENON100 for different mass regions. The chart includes regions for beam dump, 100g-months, 2e\(^-\), current direct detection + collider, supernova, 100g-min, 2e\(^-\), 100g-day, 2e\(^-\), and freeze-in. The chart also shows the reach for scalar and fermion DM with different cross-sections and mass ranges.
dark matter absorption
absorb all of the energy the incoming dark matter
dark photon absorption

\[\epsilon \sim \sigma \delta^2 \]

\[\frac{\epsilon}{\sigma} \sim \frac{\delta^2}{\sigma} \]

\[m_{A'} \text{[eV]}\]

\[\epsilon \]

SENSEI

Rydberg

DAMIC

XENON10/100

CDMSlite
physics potential

bosonic absorption

SENSEI: A Novel Search for Light Dark Matter, *to appear*

based on: Bloch, Essig, Tobioka, Volansky, TTY [1608.02123]
2016
LDRD funded, fabrication of SkipperCCD prototype

2017
testing of prototype @MINOS, received funding from HSF and FNAL to design and build 100g detector

2018
assembly and testing of 10g detector at MINOS, take data

2019
deploy 100g detector at deeper underground site

2020
analyze 10g data, continue data taking with 100g detector

2021
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timeline

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