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

SENSEI

Sub-**E**lectron-**N**oise **S**kipper CCD **E**xperimental **I**nstrument

CCD-based detector with single-electron sensitivity using SkipperCCDs produced by LBL MSL

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

SENSEI

Sub-**E**lectron-**N**oise **S**kipper CCD **E**xperimental **I**nstrument

CCD-based detector with single-electron sensitivity using SkipperCCDs produced by LBL MSL

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

SENSEI

Sub-**E**lectron-**N**oise **S**kipper CCD **E**xperimental **I**nstrument

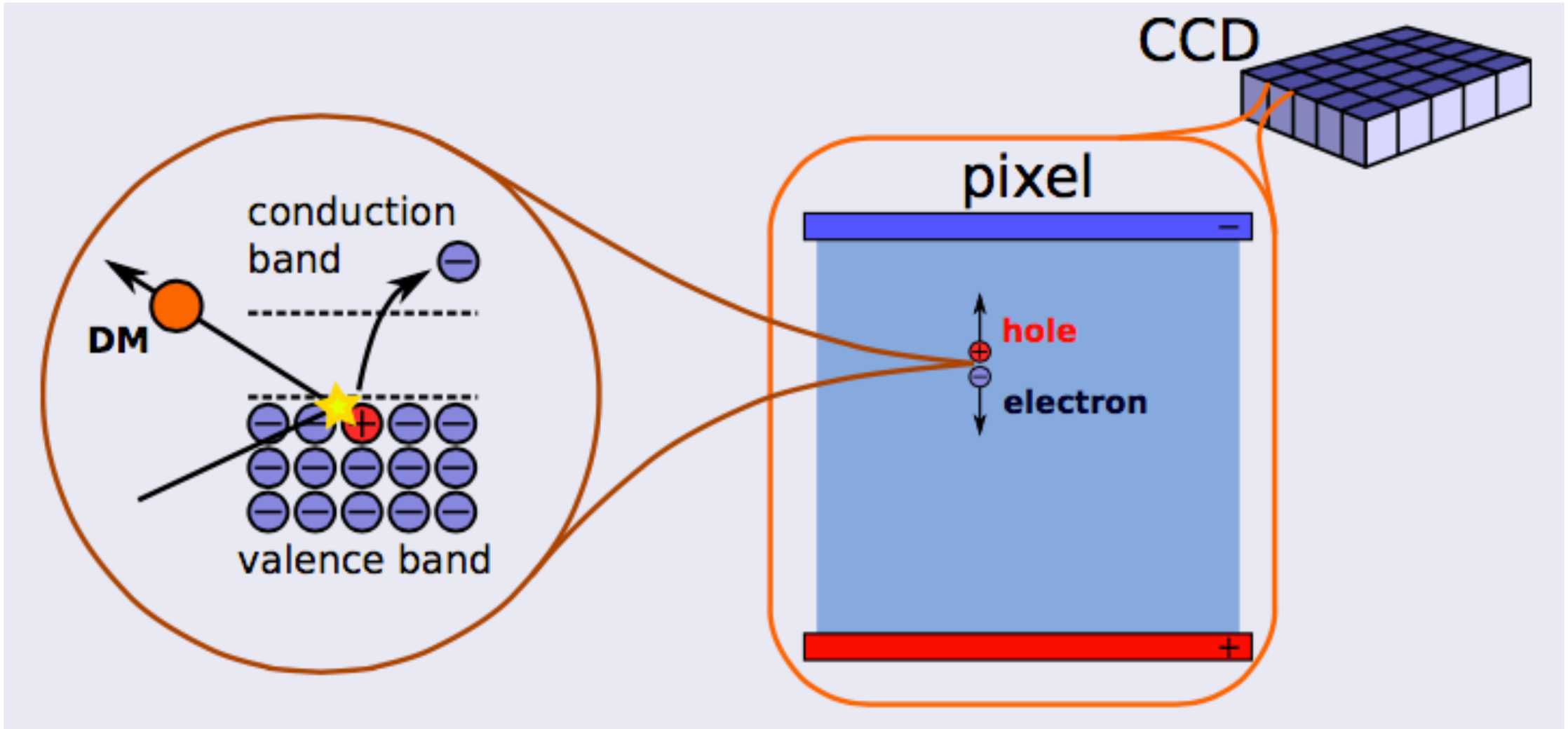
Fermilab:
- Michael Crisler
- Alex Drlica-Wagner
- Juan Estrada
- Guillermo Fernandez Moroni
- Miguel Sofo Haro
- Javier Tiffenberg

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

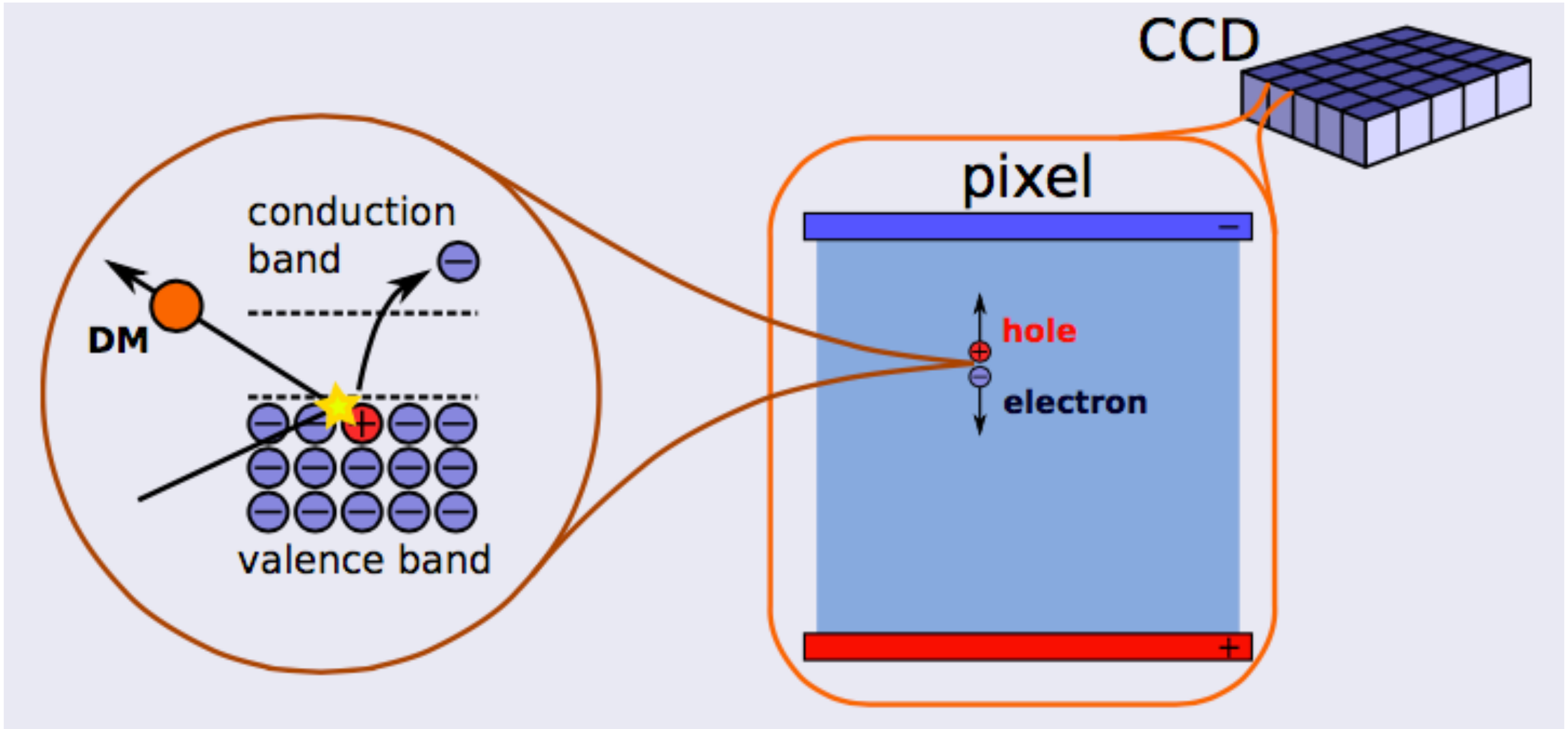
silicon CCD detector



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

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

silicon CCD detector

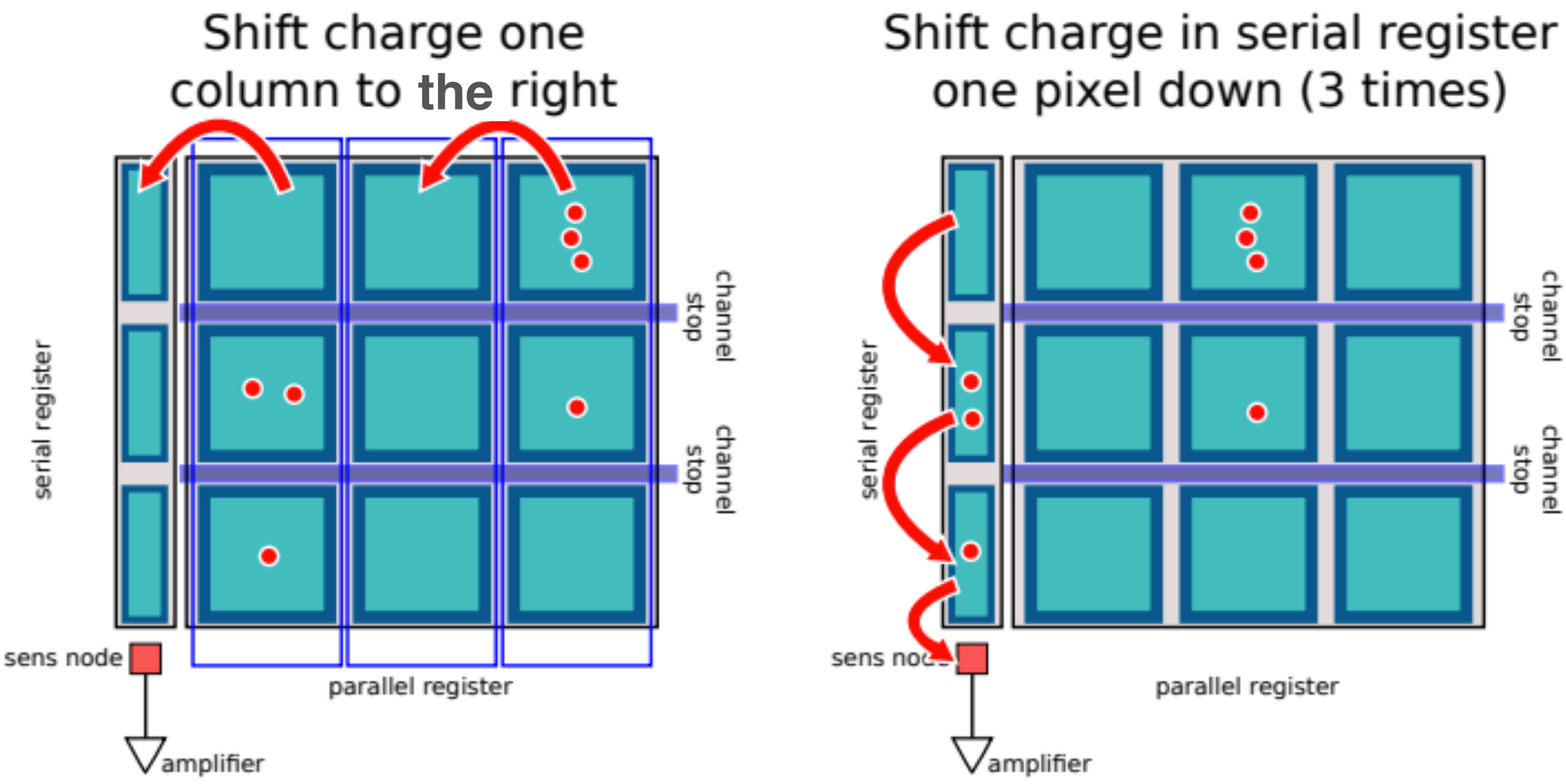


challenge: requires very low noise!

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

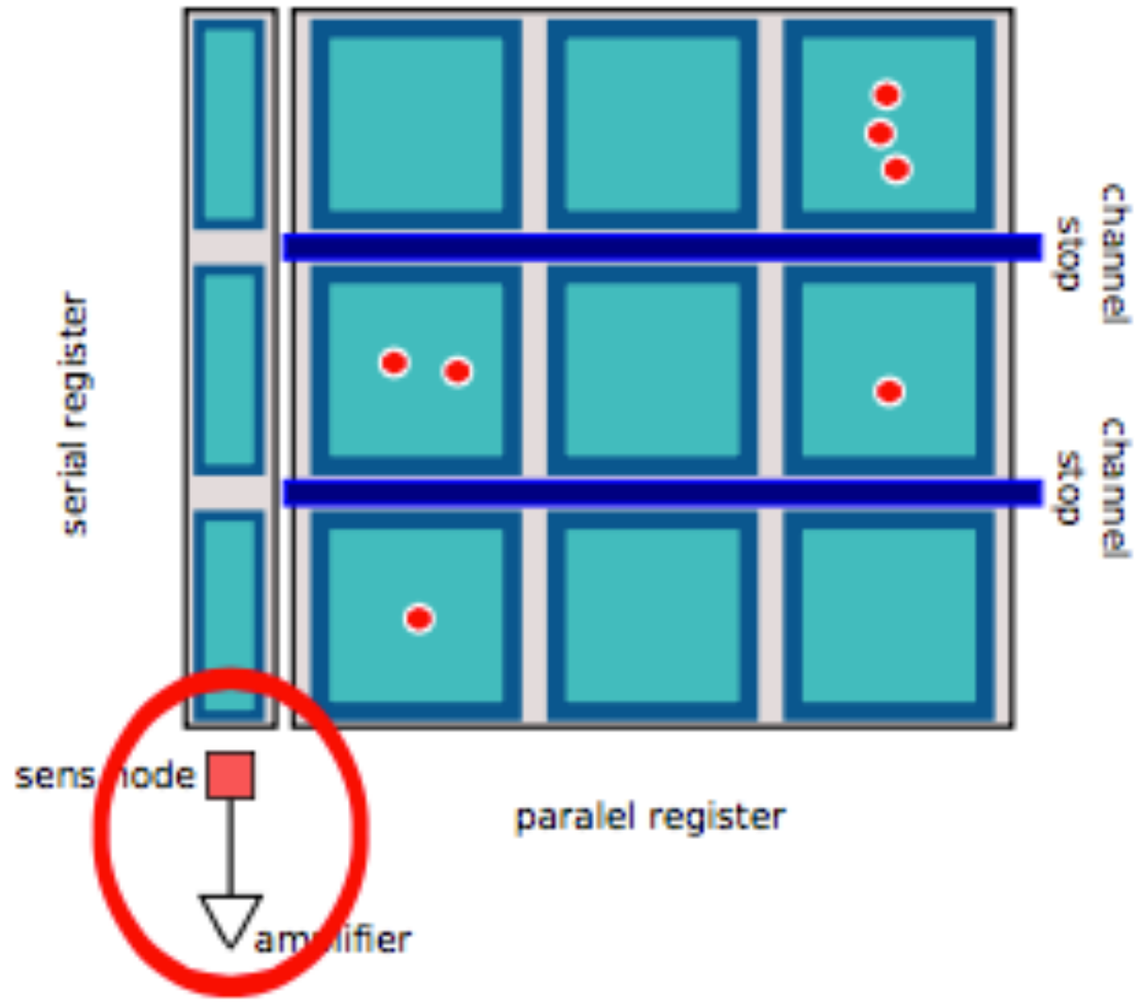
readout

3x3 pixels CCD



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

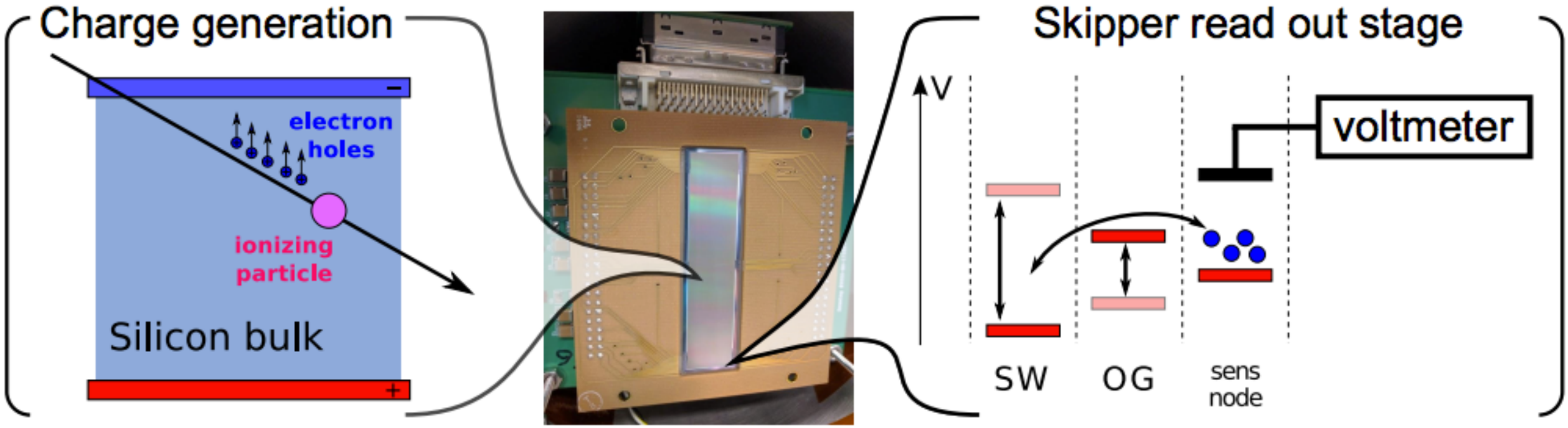
readout



Only the readout stage is modified

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

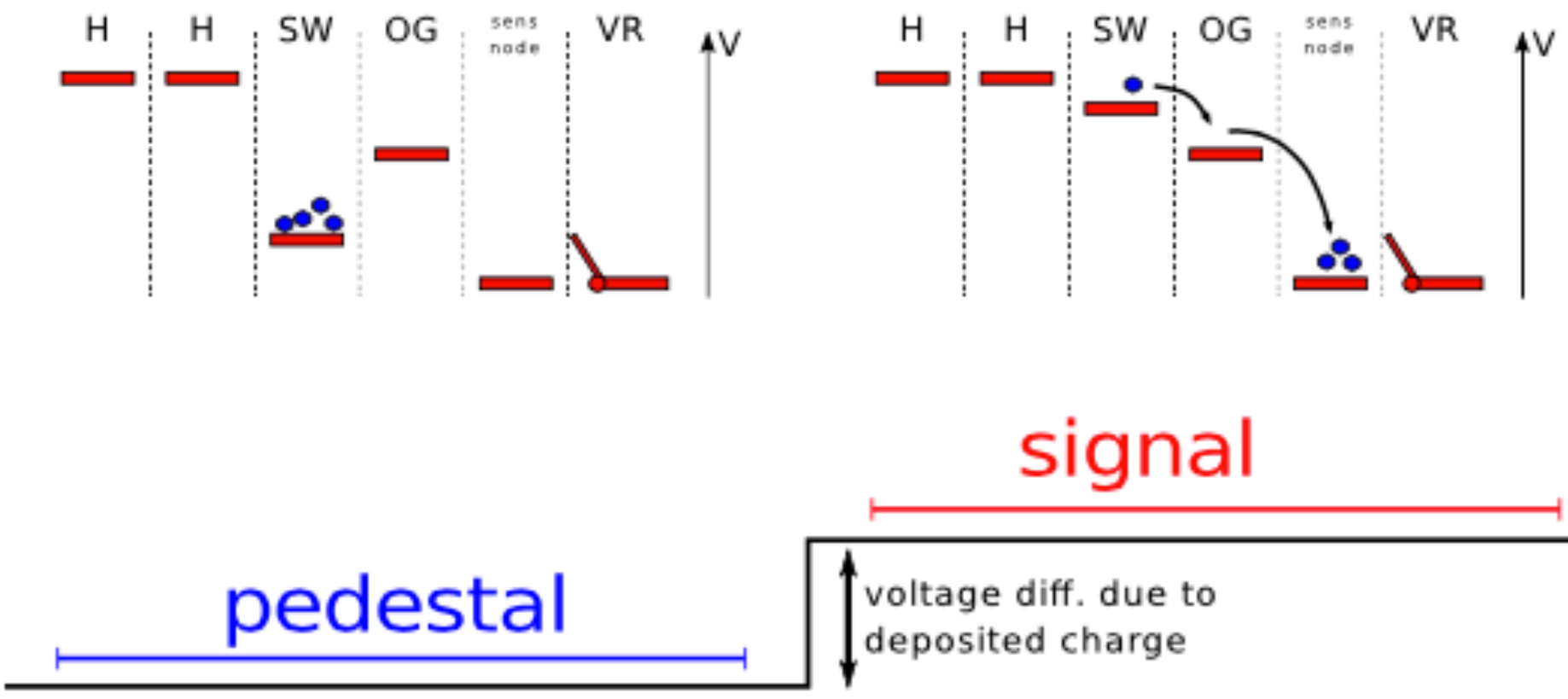
skipper readout



non-destructive readout ➡ possible to have multiple readouts

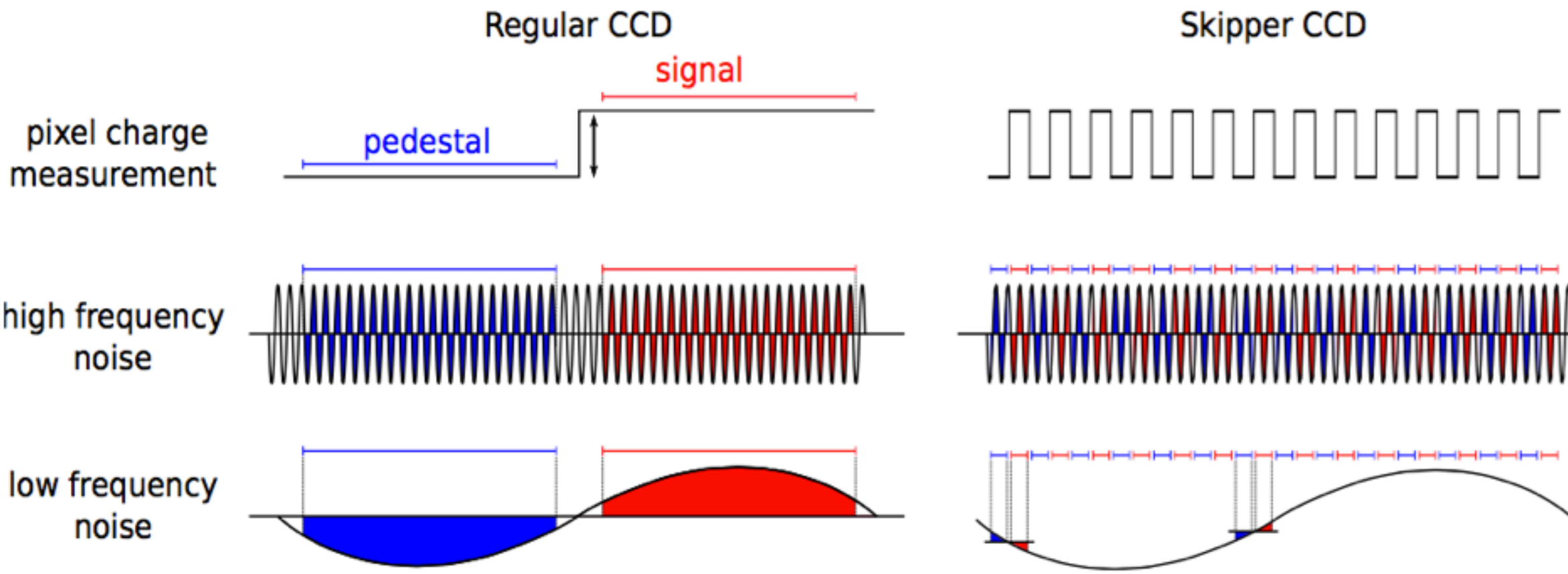
Tiffenberg, Sofo-Haro, Drlica-Wagner, Essig, Guardincerri, Holland, Volansky, TTY [1706.00028]

readout

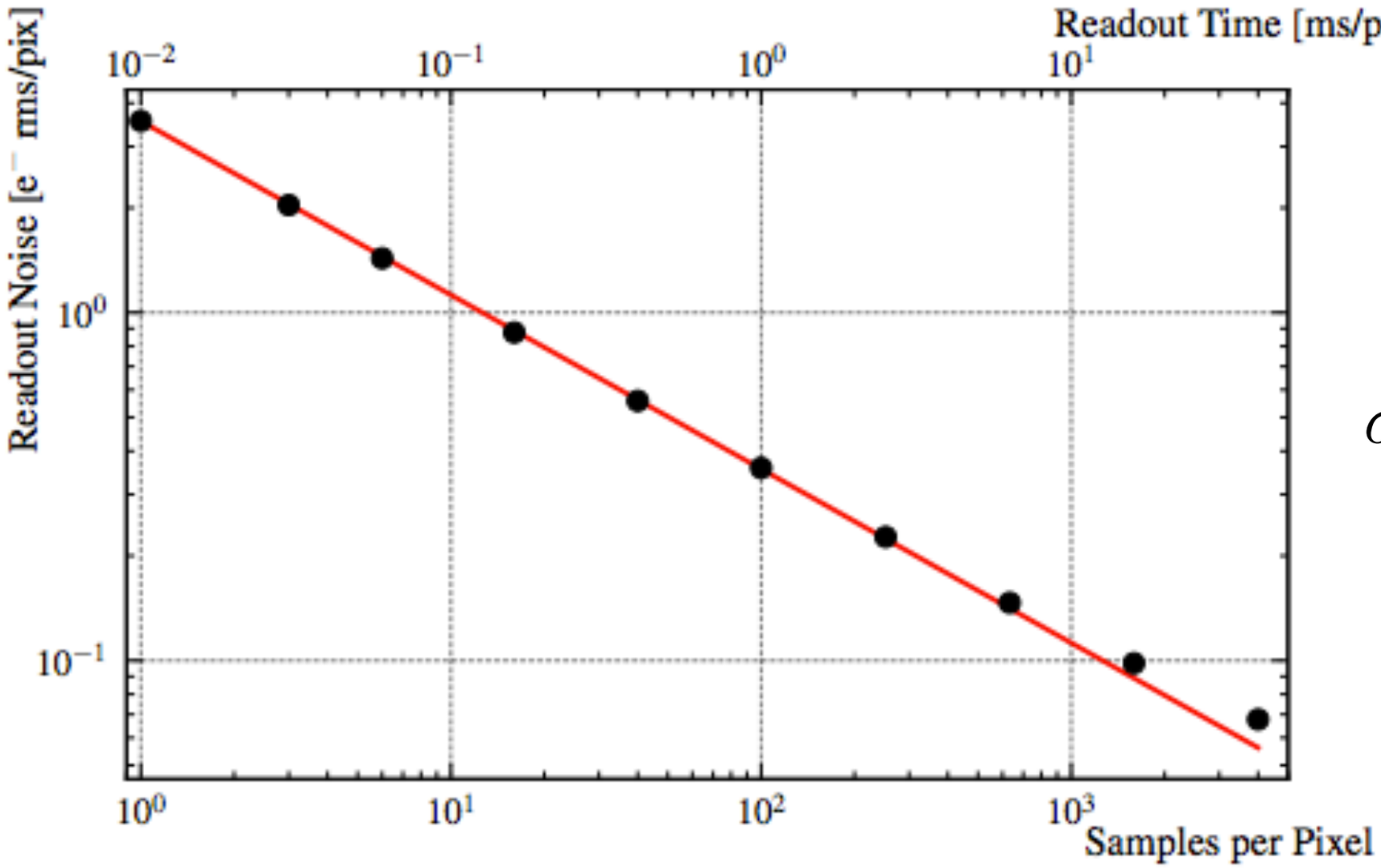


Tiffenberg, Sofo-Haro, Drlica-Wagner, Essig, Guardincerri, Holland, Volansky, TTY [1706.00028]

readout noise



readout noise



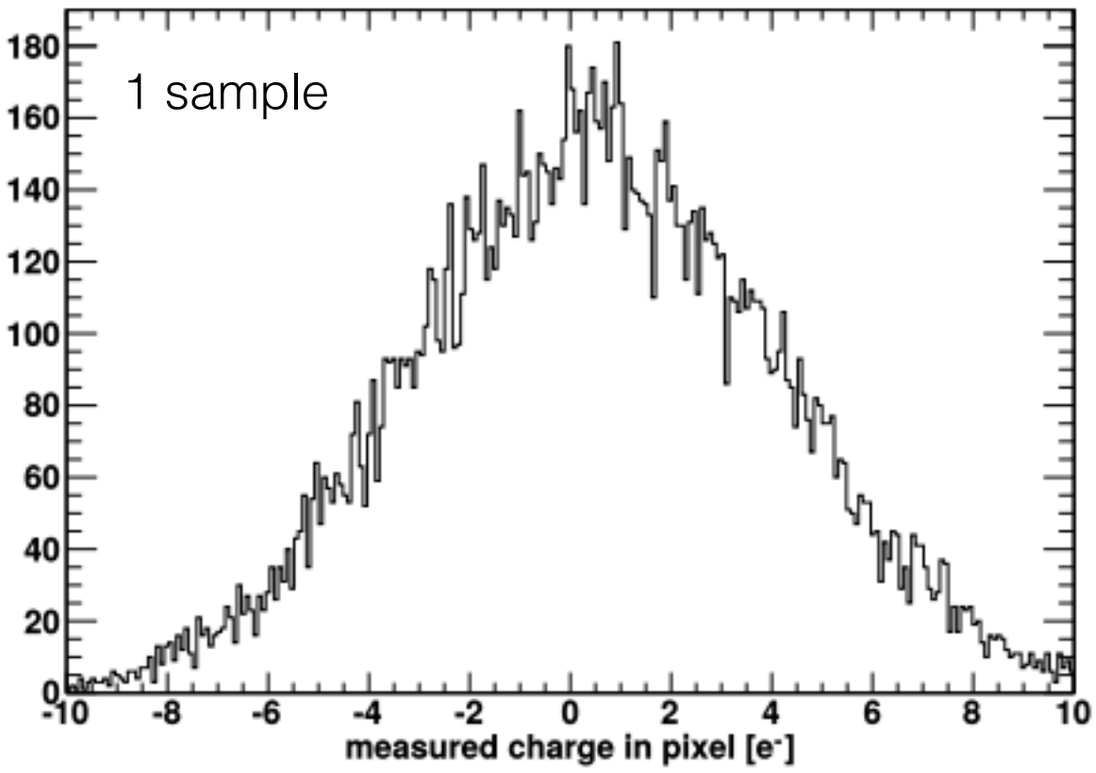
$$\sigma = \frac{\sigma_1}{\sqrt{N}}$$

reduce readout noise by increasing readout time

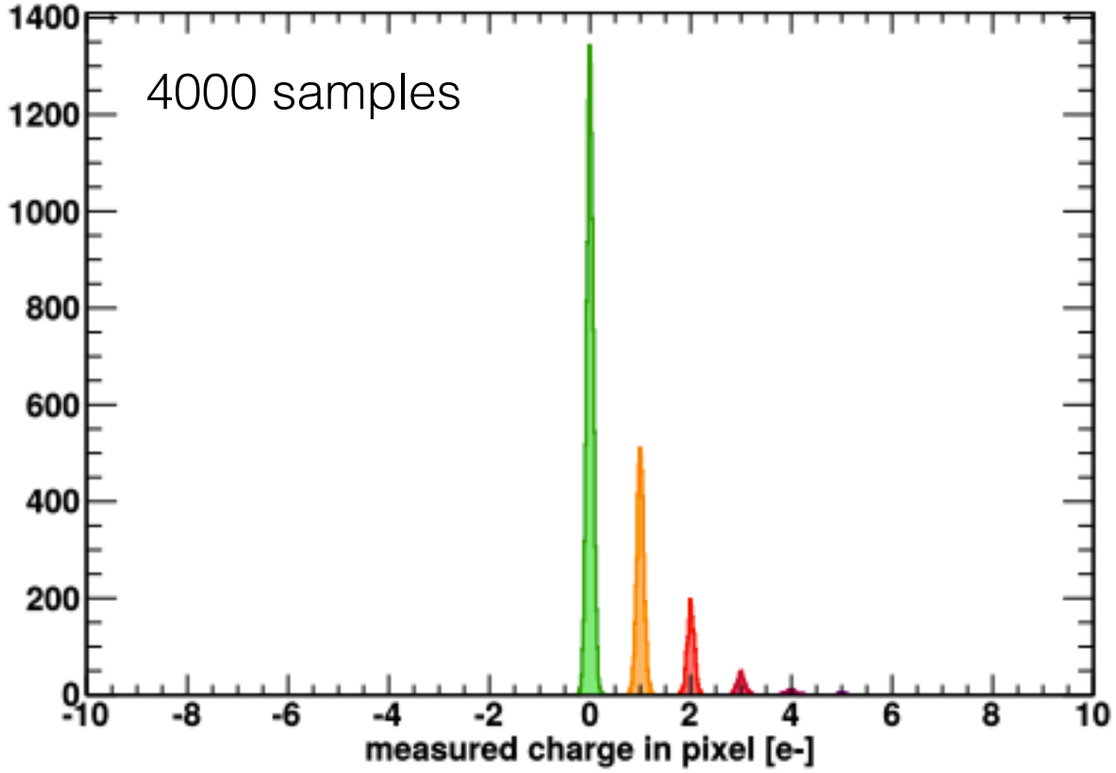
Tiffenberg, Sofo-Haro, Drlica-Wagner, Essig, Guardincerri, Holland, Volansky, TTY [1706.00028]

skipper readout

standard CCD



skipper CCD

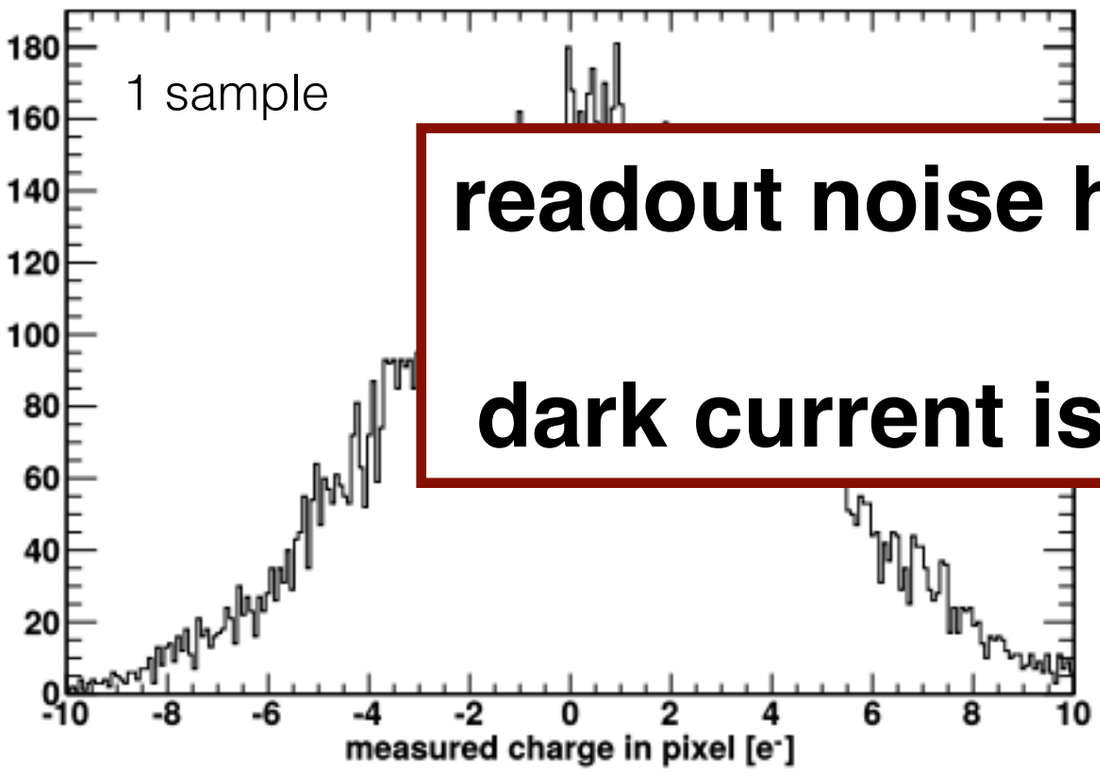


Tiffenberg, Sofo-Haro, Drlica-Wagner, Essig, Guardincerri, Holland, Volansky, TTY [1706.00028]

skipper readout

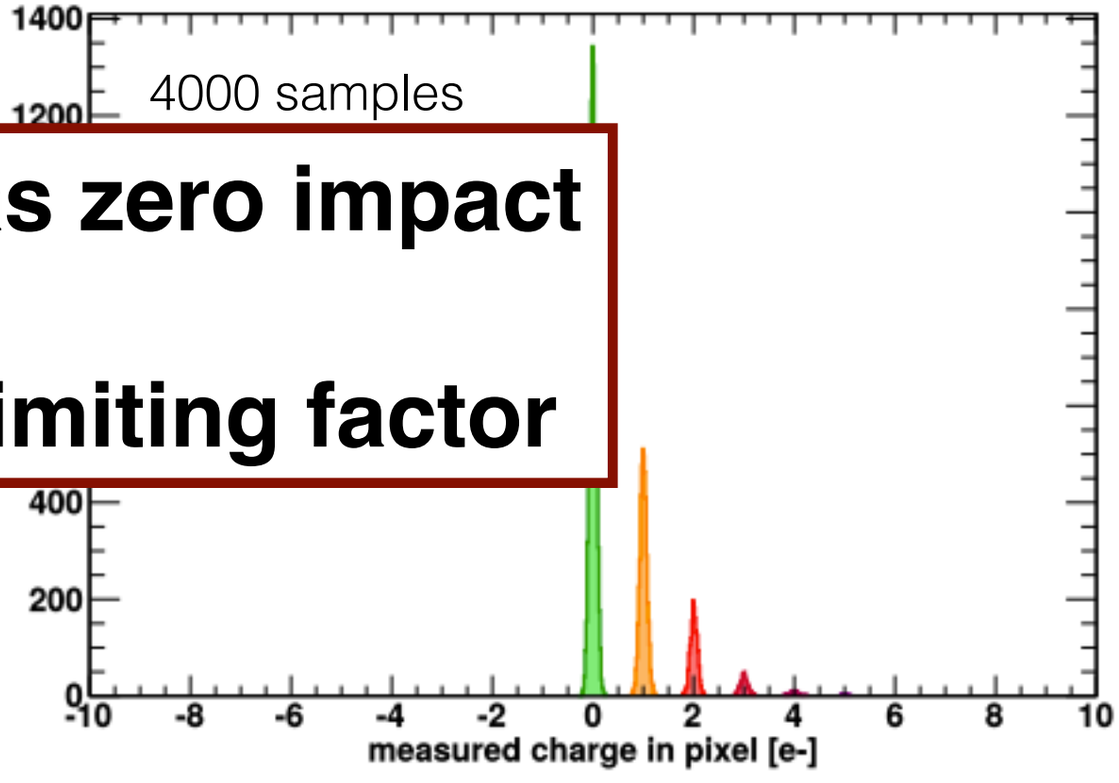
standard CCD

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

dark current [e^-/pix/day]	**$\geq 1e^-$** [pix]	**$\geq 2e^-$** [pix]	**$\geq 3e^-$** [pix]
10^{-3}	**1×10^{8}**	**3×10^{3}**	**7×10^{-2}**
10^{-5}	**1×10^{6}**	**3×10^{-1}**	**7×10^{-8}**
10^{-7}	**1×10^{4}**	**3×10^{-5}**	**7×10^{-14}**

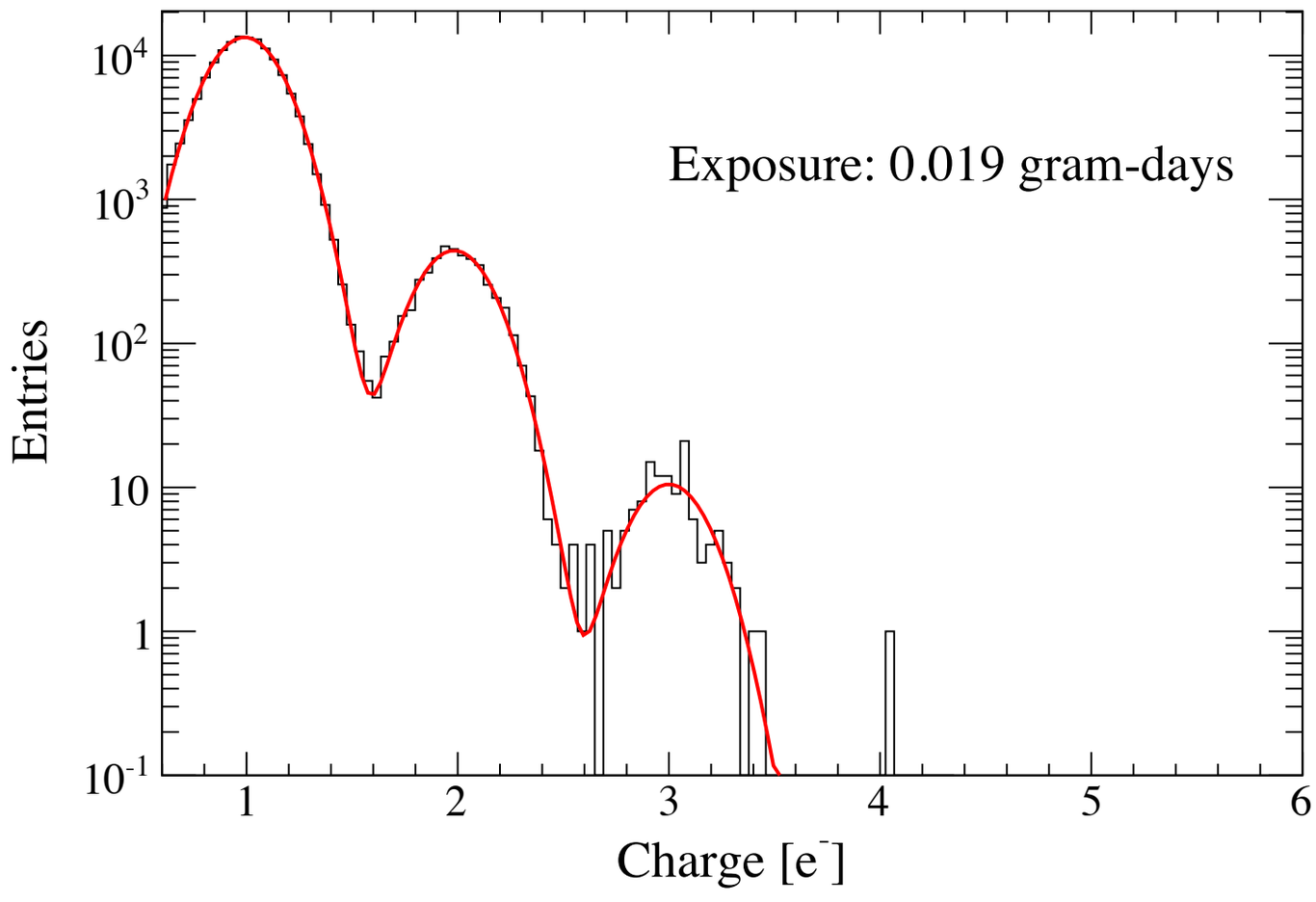
dark current

dark current [e^-/pix/day]		≥1e^- [pix]	≥2e^- [pix]	≥3e^- [pix]
measured upper bound [arXiv:1611.03066]	10^{-3}	$1x10^{8}$	$3x10^{3}$	$7x10^{-2}$
	10^{-5}	$1x10^{6}$	$3x10^{-1}$	$7x10^{-8}$
theory prediction	10^{-7}	$1x10^{4}$	$3x10^{-5}$	$7x10^{-14}$

SENSEI with a 2-electron threshold is a zero-background experiment!

first results!

0.019 g-days of commissioning data from a surface run

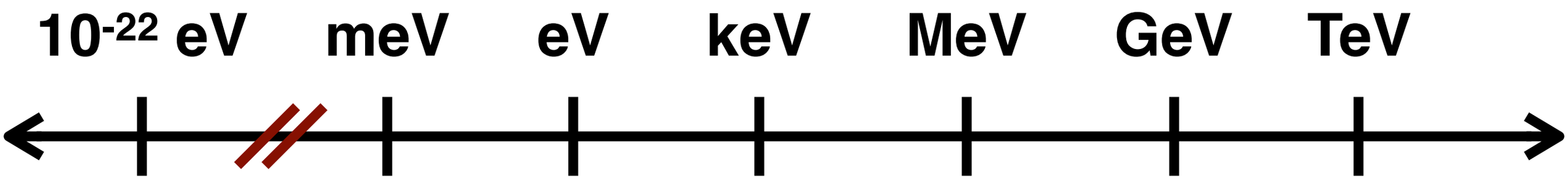


dark current: ~1.1 e⁻ /pix/day; no events with 5-100 electrons

SENSEI Collaboration [1804.00088]

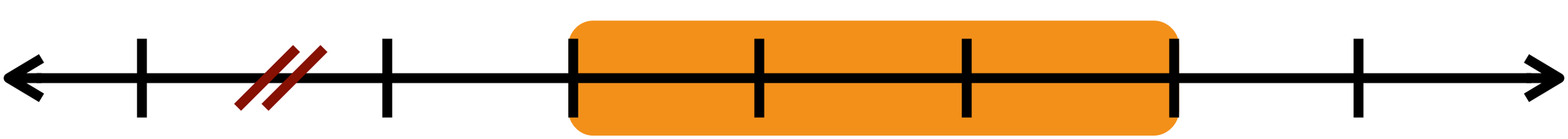
applications to dark sector physics

dark matter candidates



dark matter candidates

10^{-22} eV meV eV keV MeV GeV TeV



SENSEI territory

dark matter-electron scattering

scattering rate

solid state

astrophysics

$$\frac{\mathrm{d}\langle\sigma v\rangle}{\mathrm{d}\ln E_R} = \frac{\overline{\sigma}_e}{8\mu_{\chi e}^2} \int q\ \mathrm{d}q |f(k,q)|^2 |F_{DM}(q)|^2 \eta(v_{min})$$

particle physics

local DM density

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

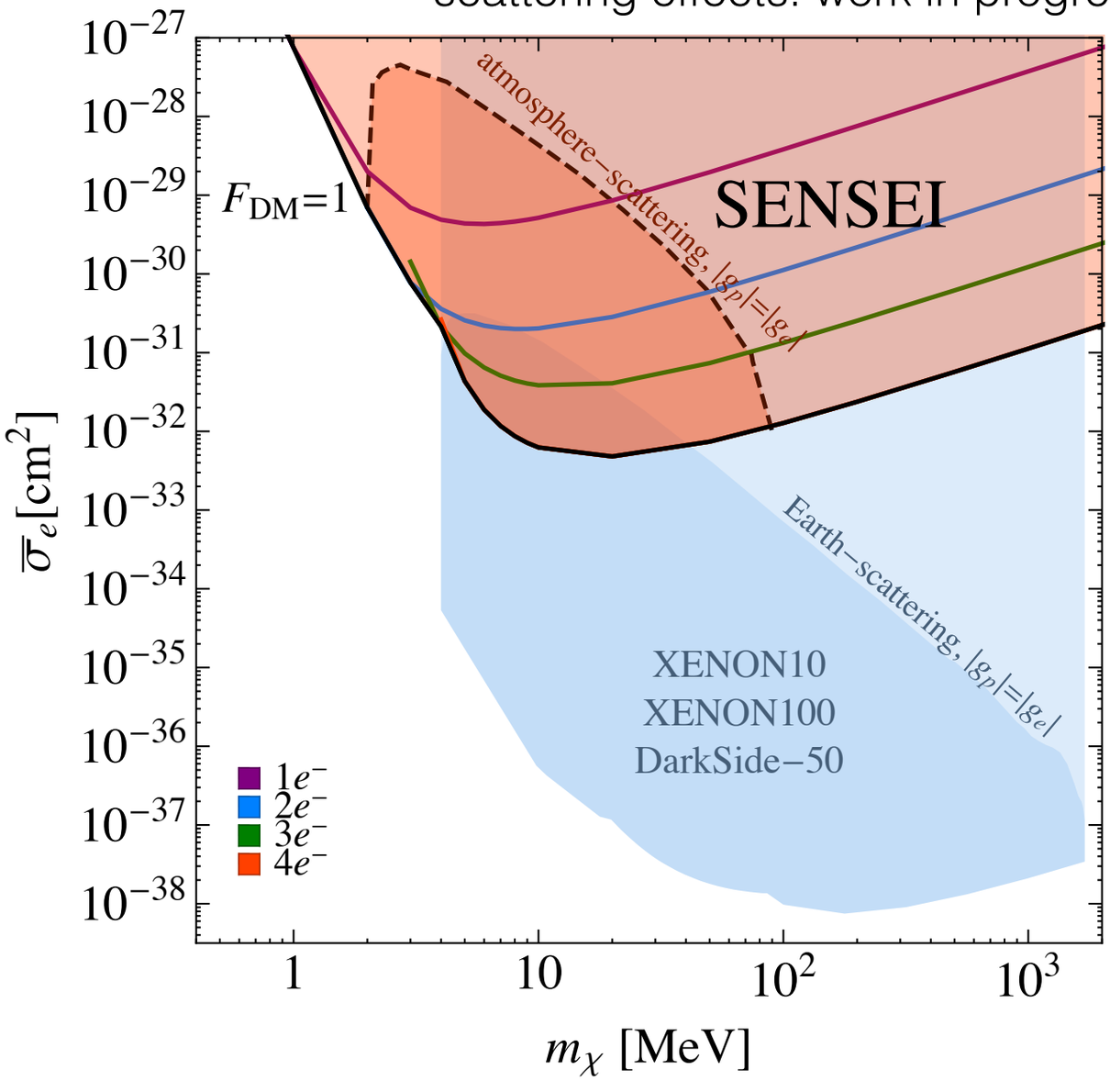
number of target nuclei per unit mass

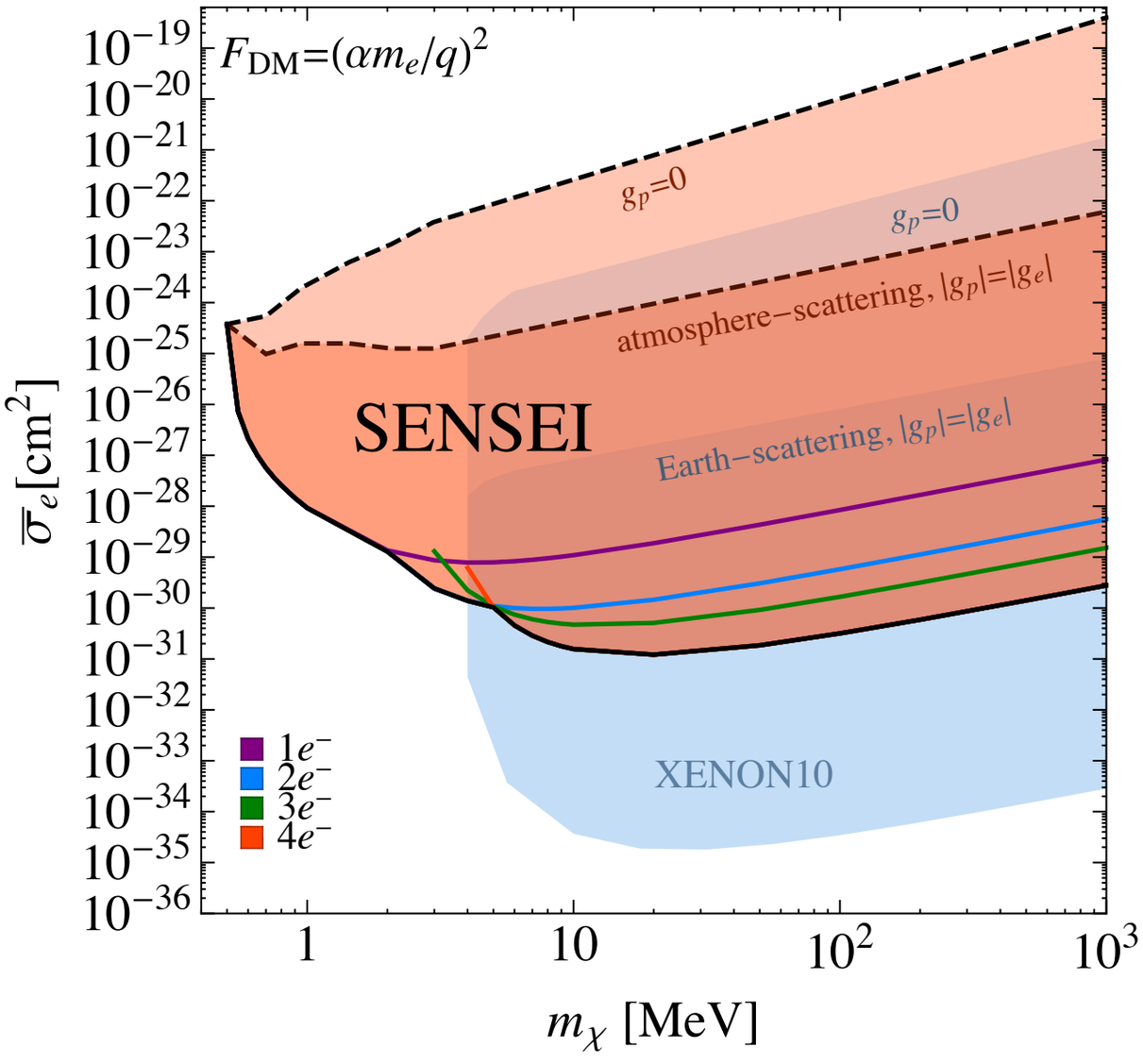
energy threshold

first results!

exposure of ~0.02 g-days

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



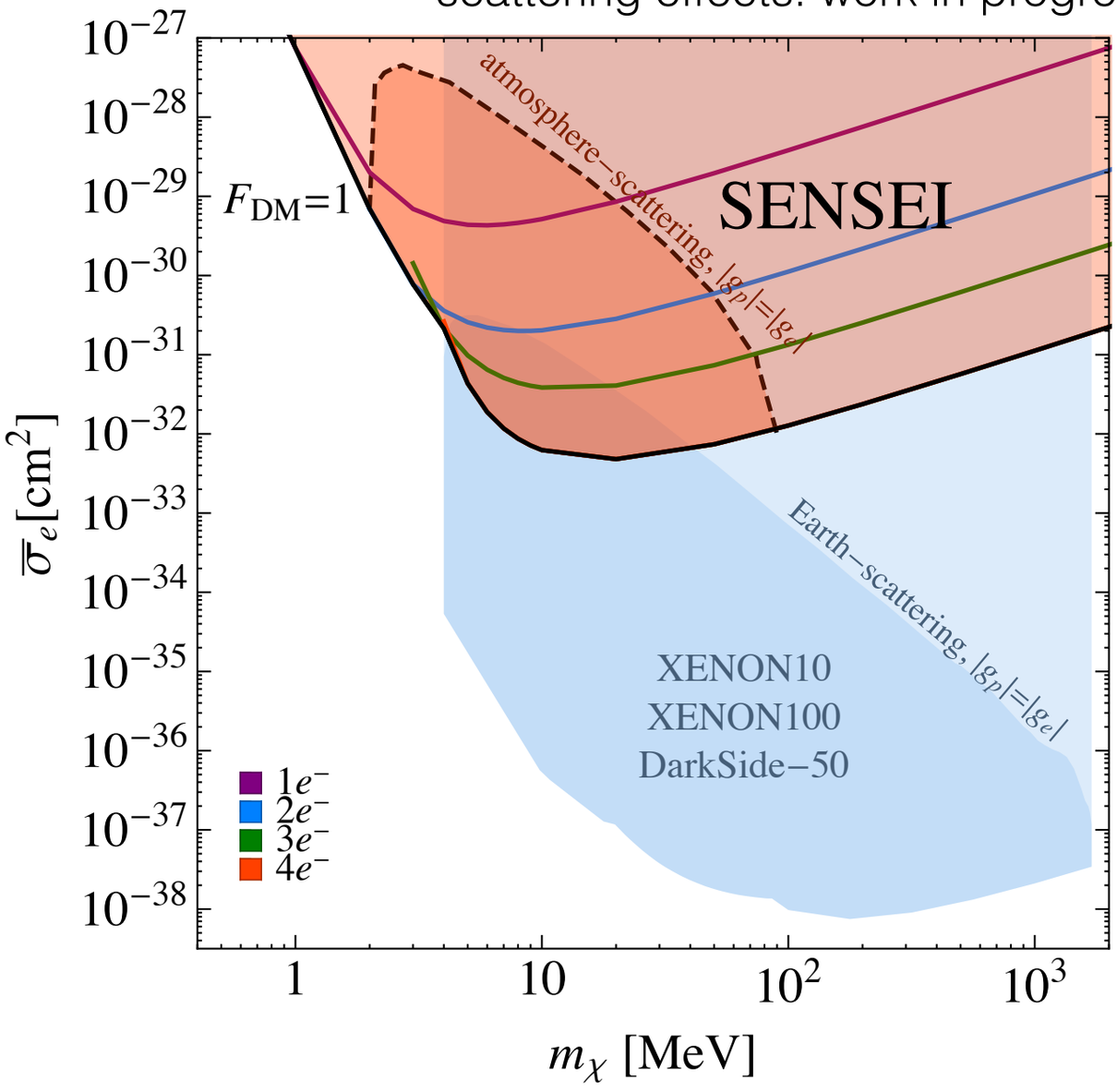


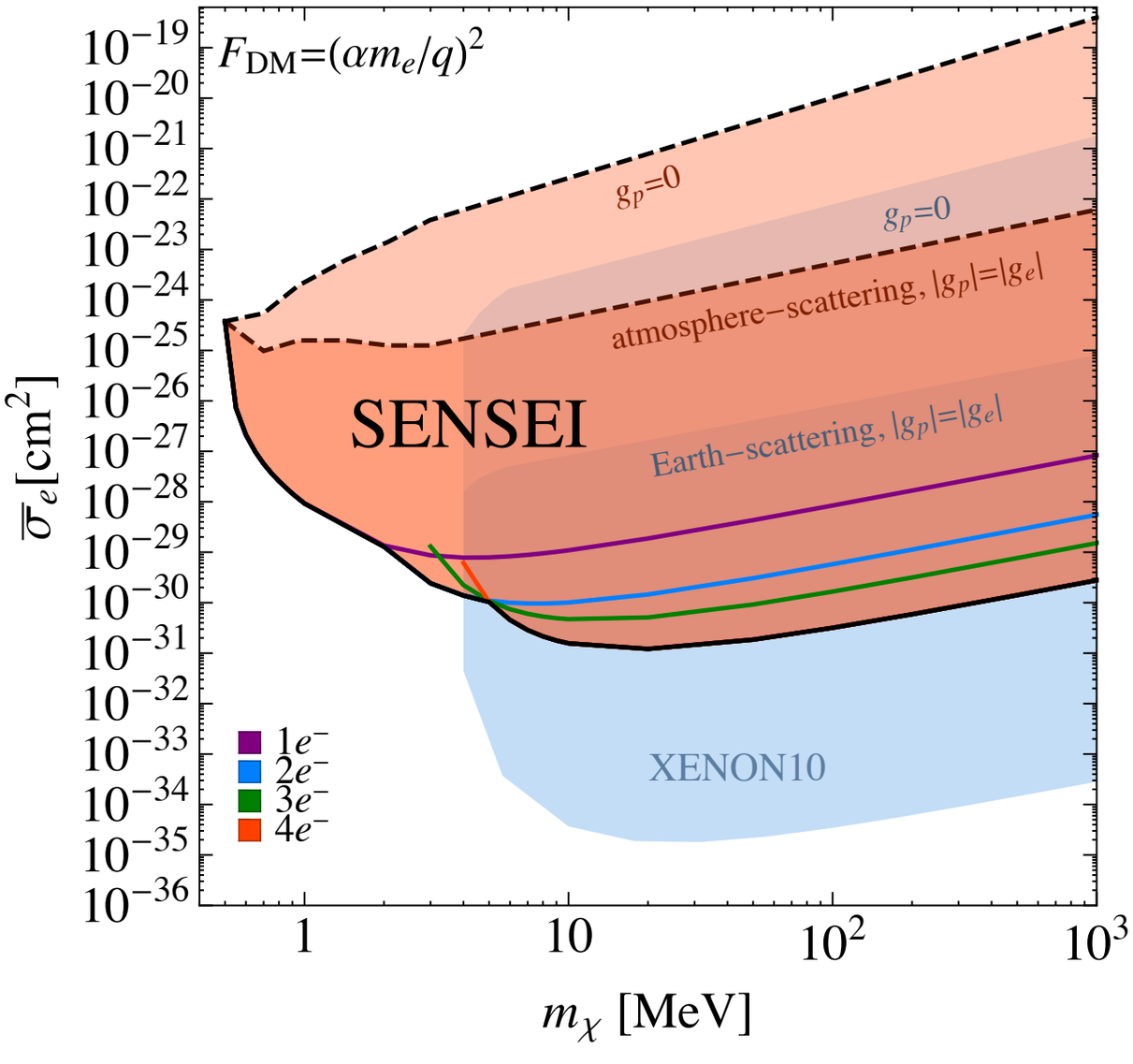
SENSEI Collaboration [1804.00088]

first results!

first direct detection constraints for ~500 keV to 4 MeV!

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

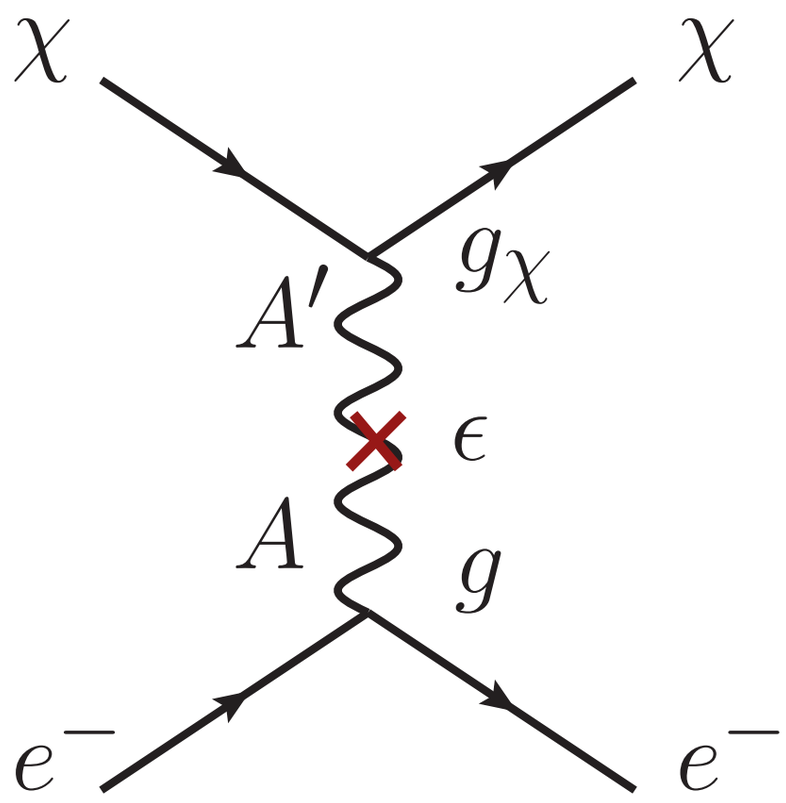




SENSEI Collaboration [1804.00088]

A Model: Hidden Photon

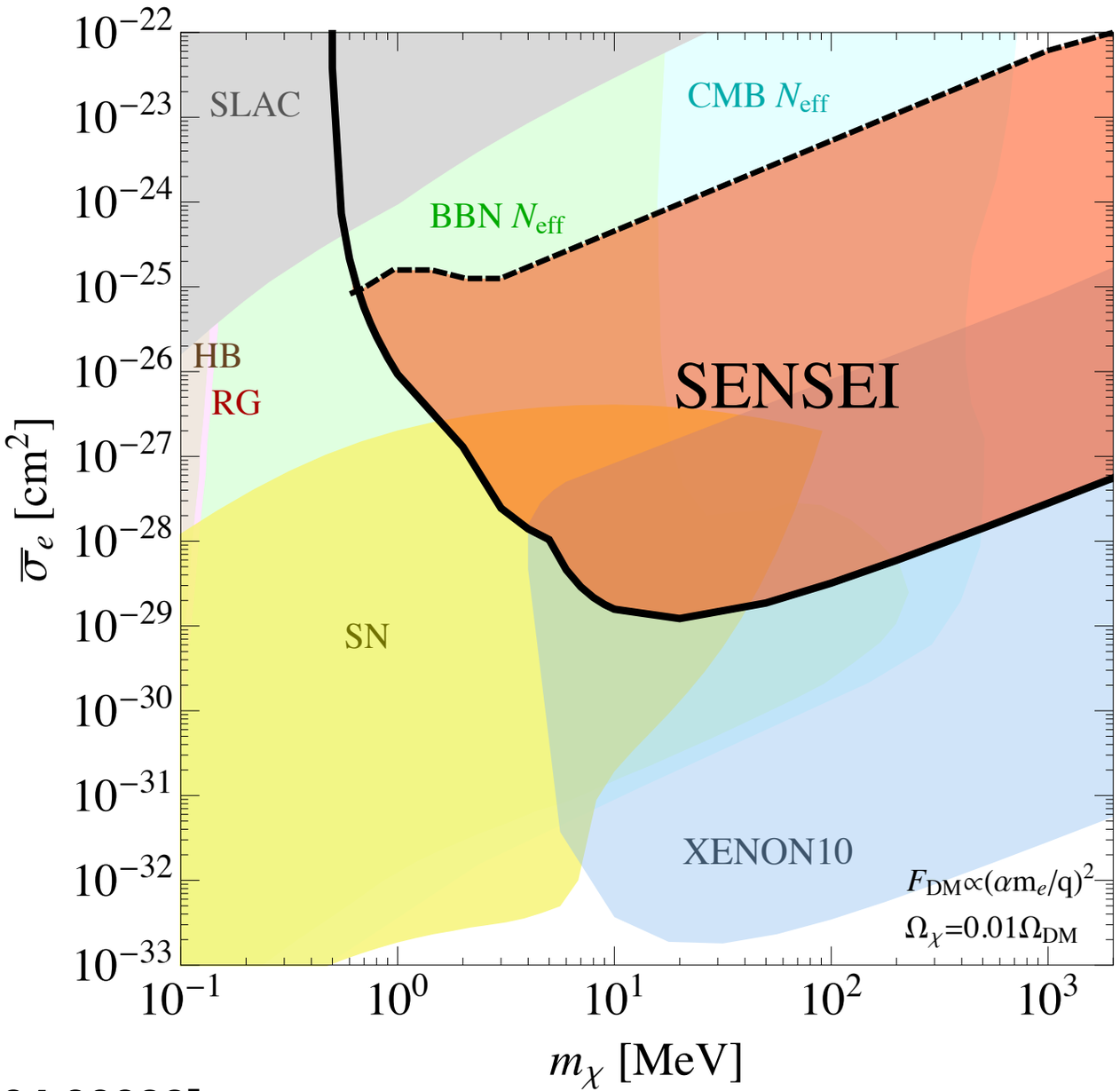
$$\mathcal{L} = F_{\mu\nu}^2 + F'^2_{\mu\nu} + m_{A'}^2 A'^2_\mu + g_\chi J^\mu_\chi A'_\mu + g J^\mu_e (A_\mu + \epsilon A'_\mu)$$



$$F_{DM}(q) = \frac{m_{A'}^2 + \alpha^2 m_e^2}{m_{A'}^2 + q^2} \simeq \begin{cases} 1\,, & m_{A'} \gg \alpha m_e \\ \frac{\alpha^2 m_e^2}{q^2}\,, & m_{A'} \ll \alpha m_e \end{cases}$$

first results!

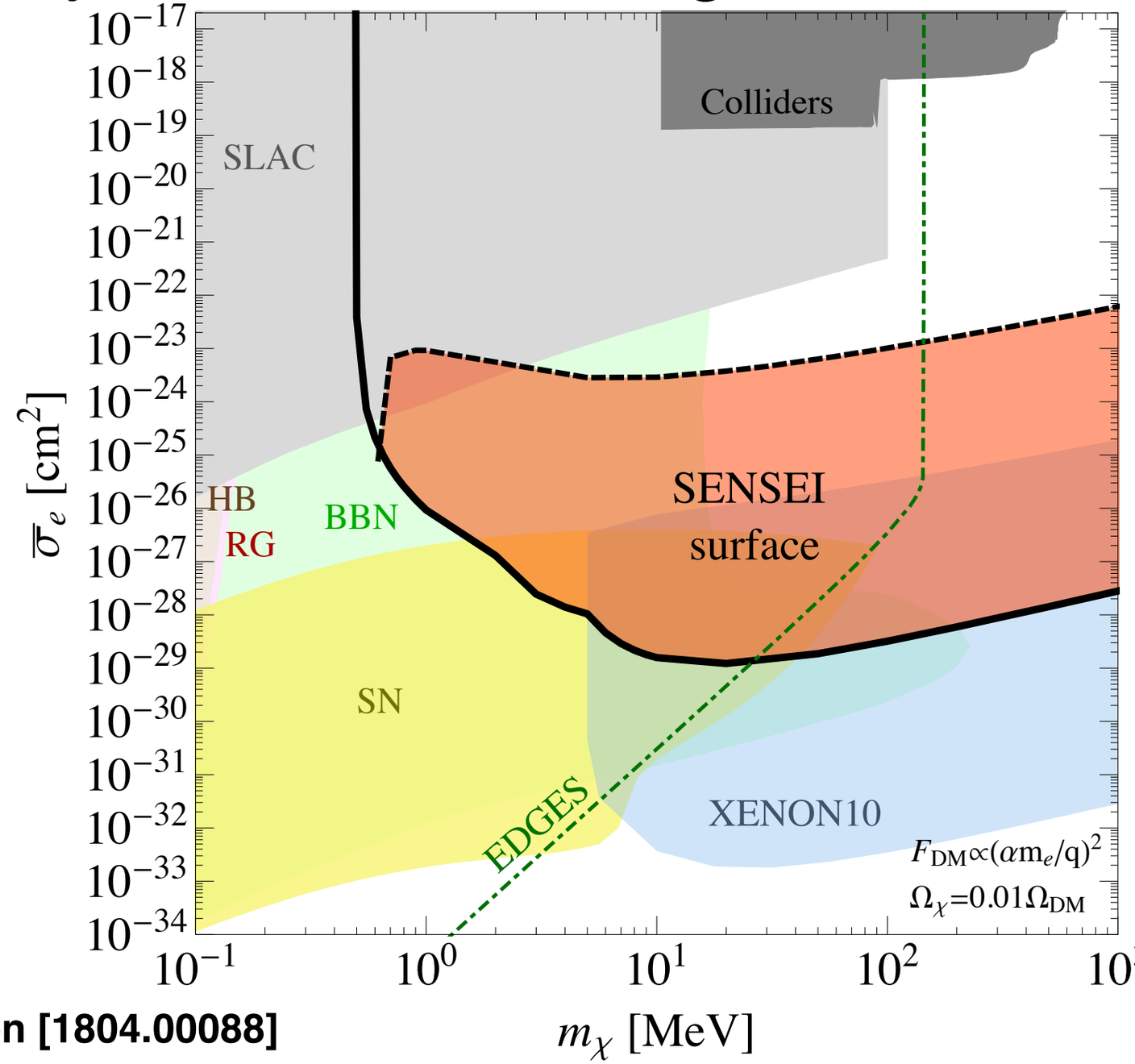
~0.02 g-days of commissioning data from a surface run



SENSEI Collaboration [1804.00088]

first results!

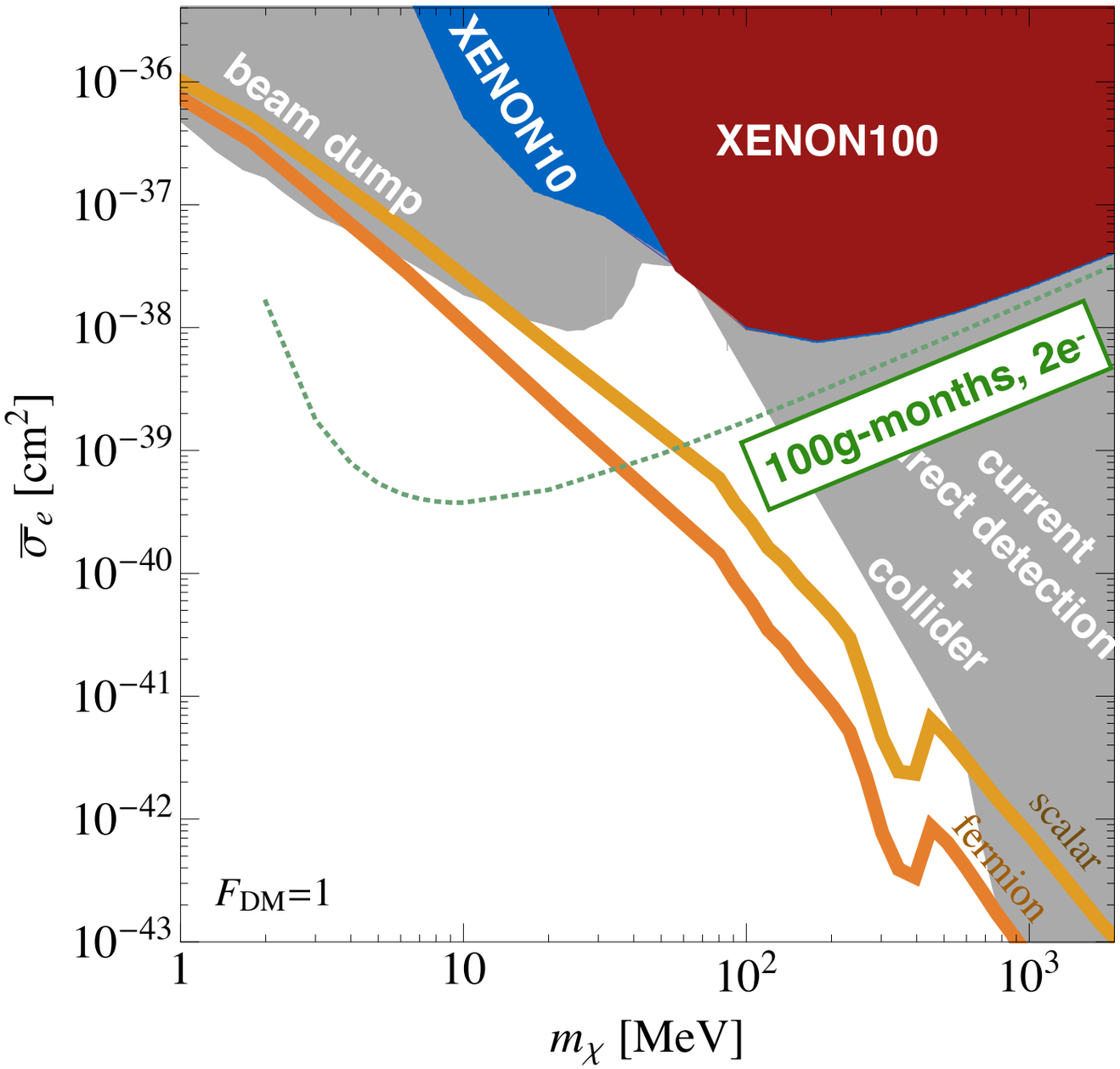
~0.02 g-days of commissioning data from a surface run

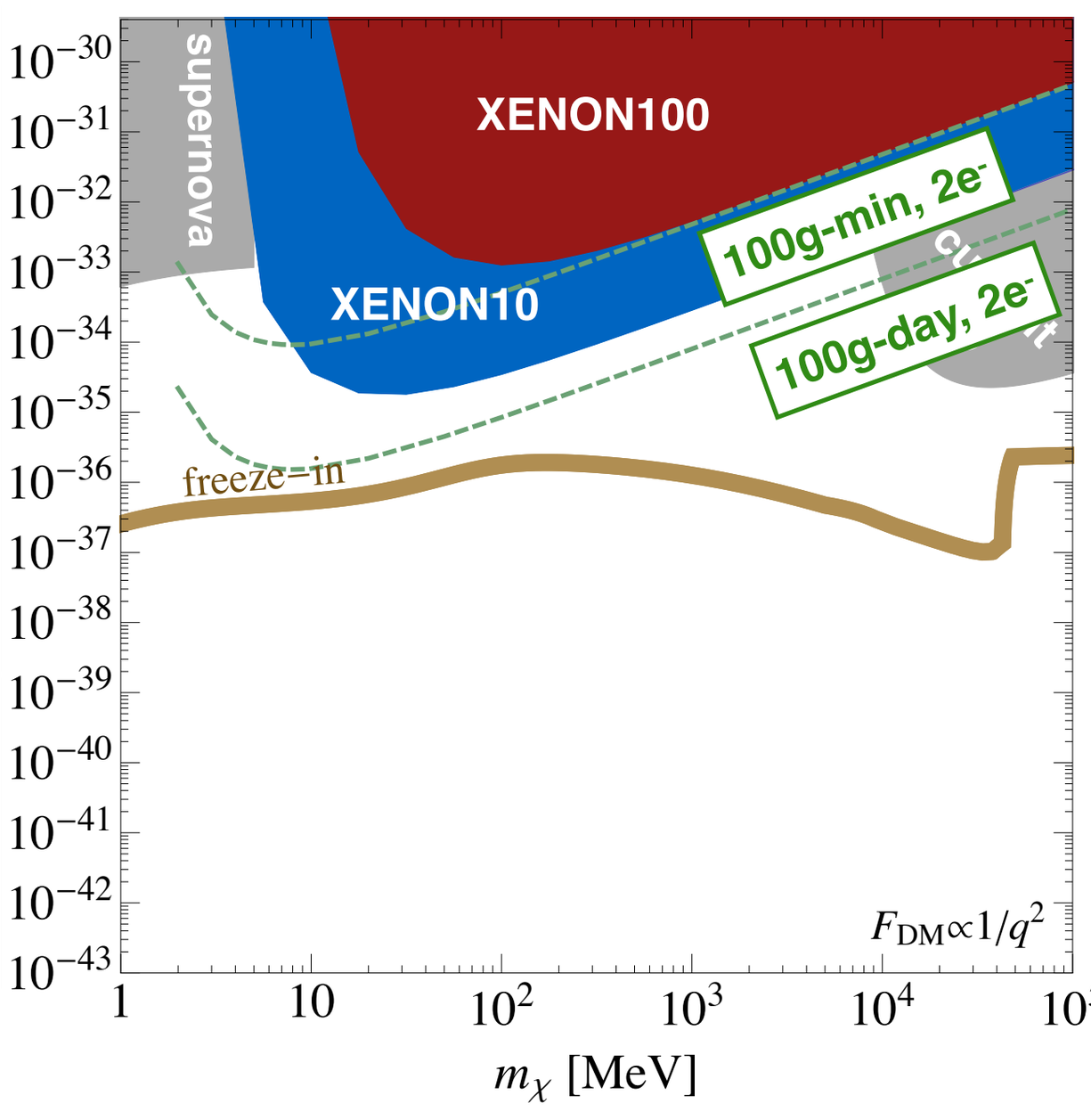


***Barkana, Outmezguine, Redigolo, Volansky [1803.03091]**

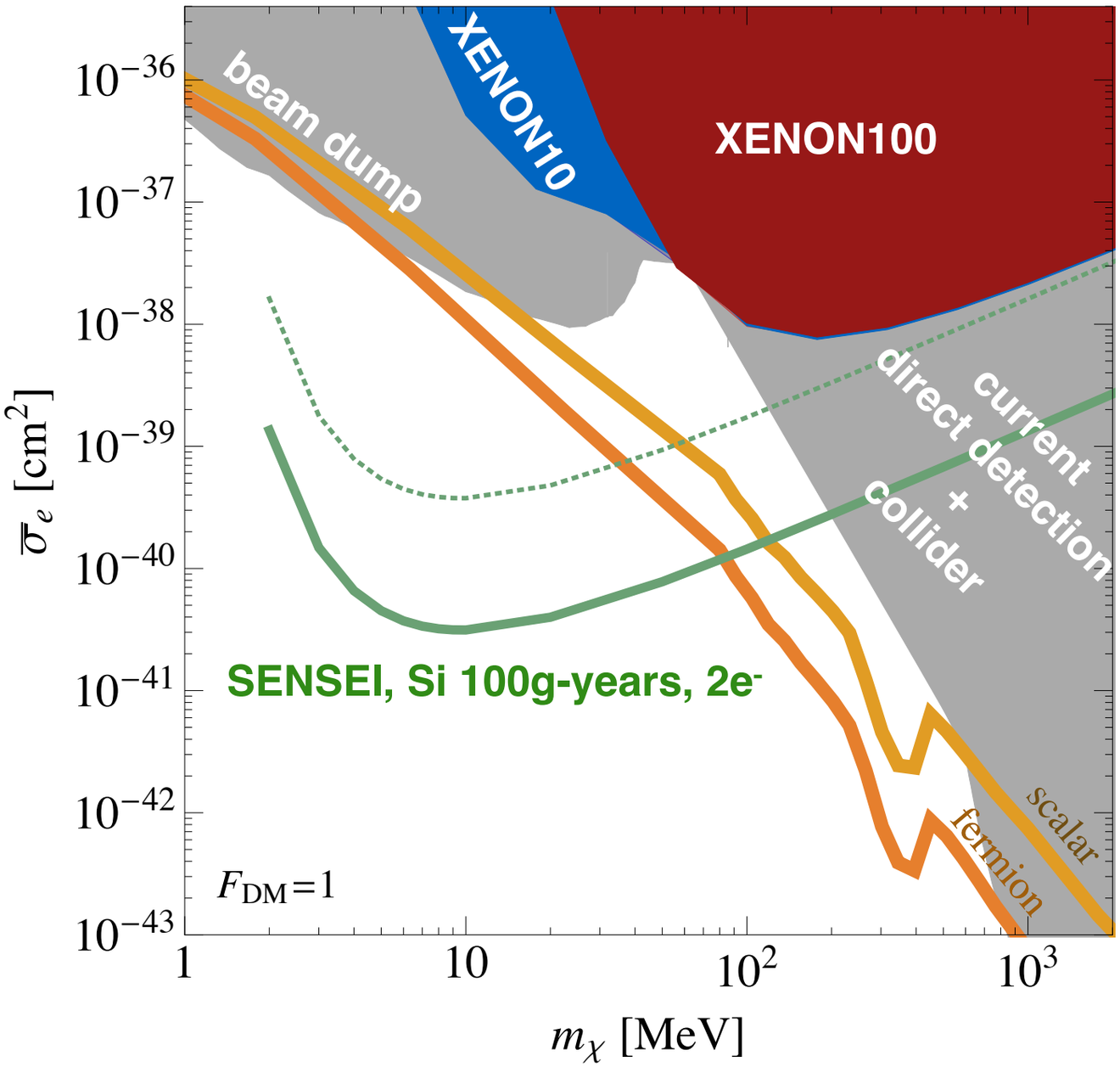
SENSEI Collaboration [1804.00088]

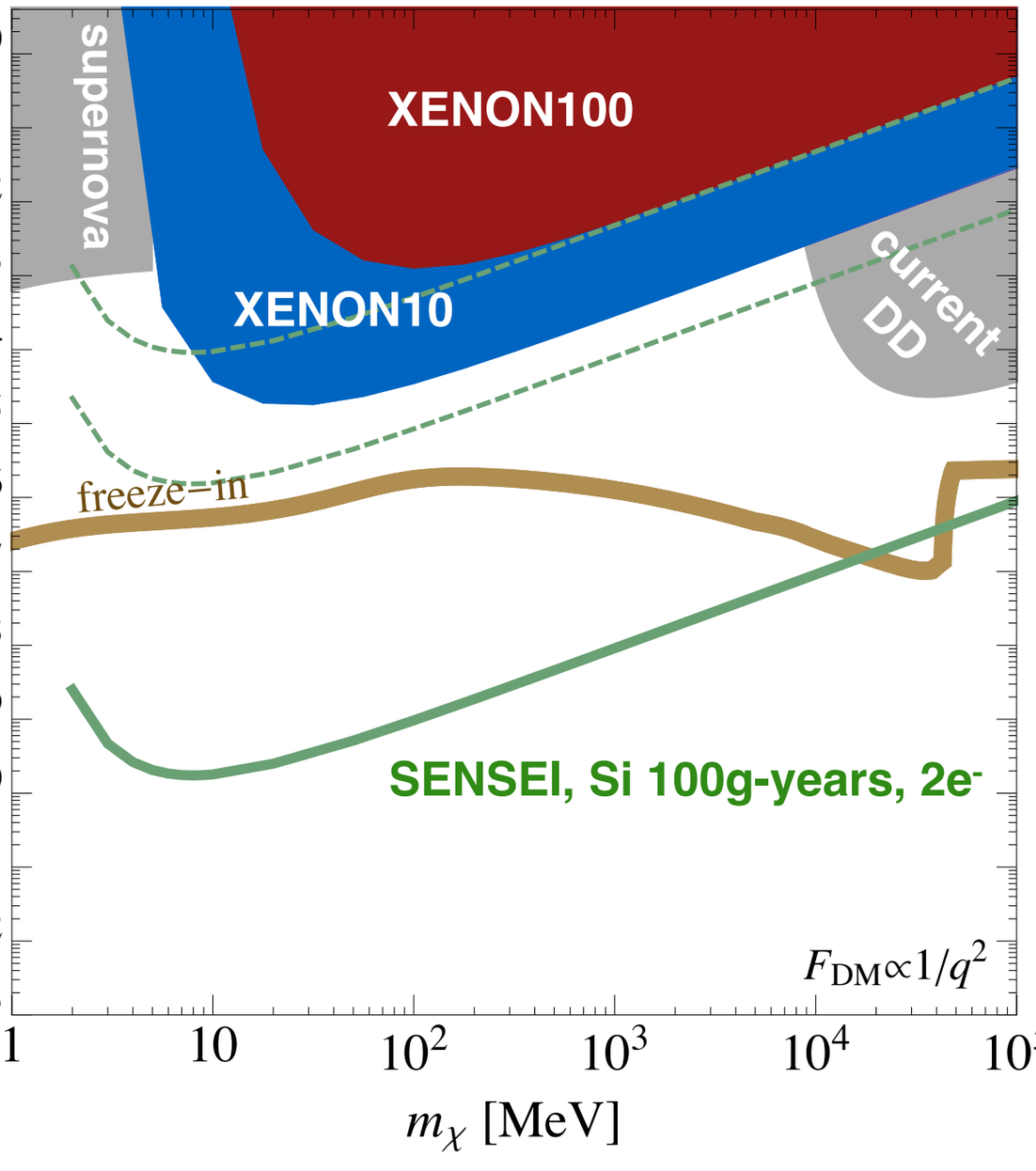
SENSEI reach





SENSEI reach



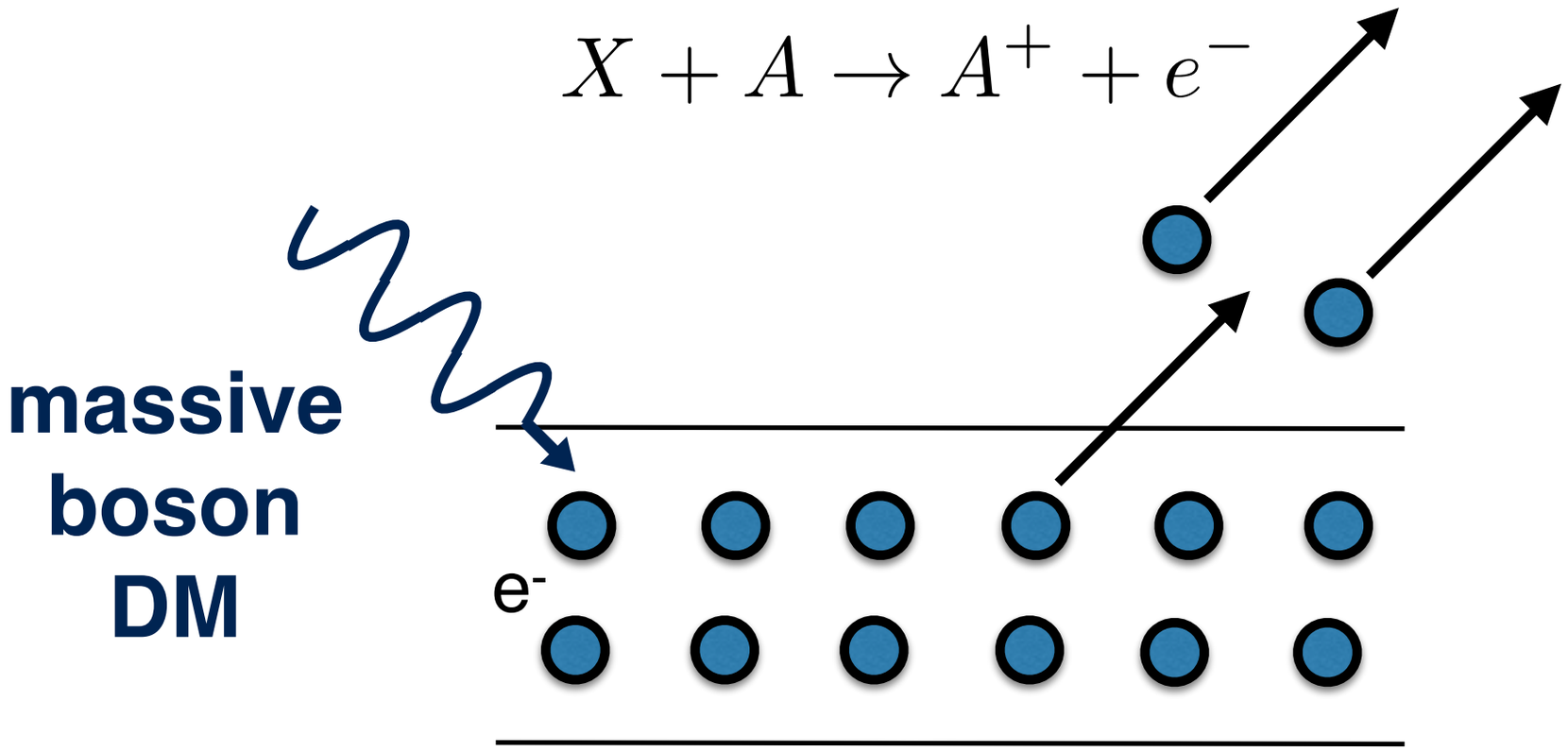


dark matter

absorption

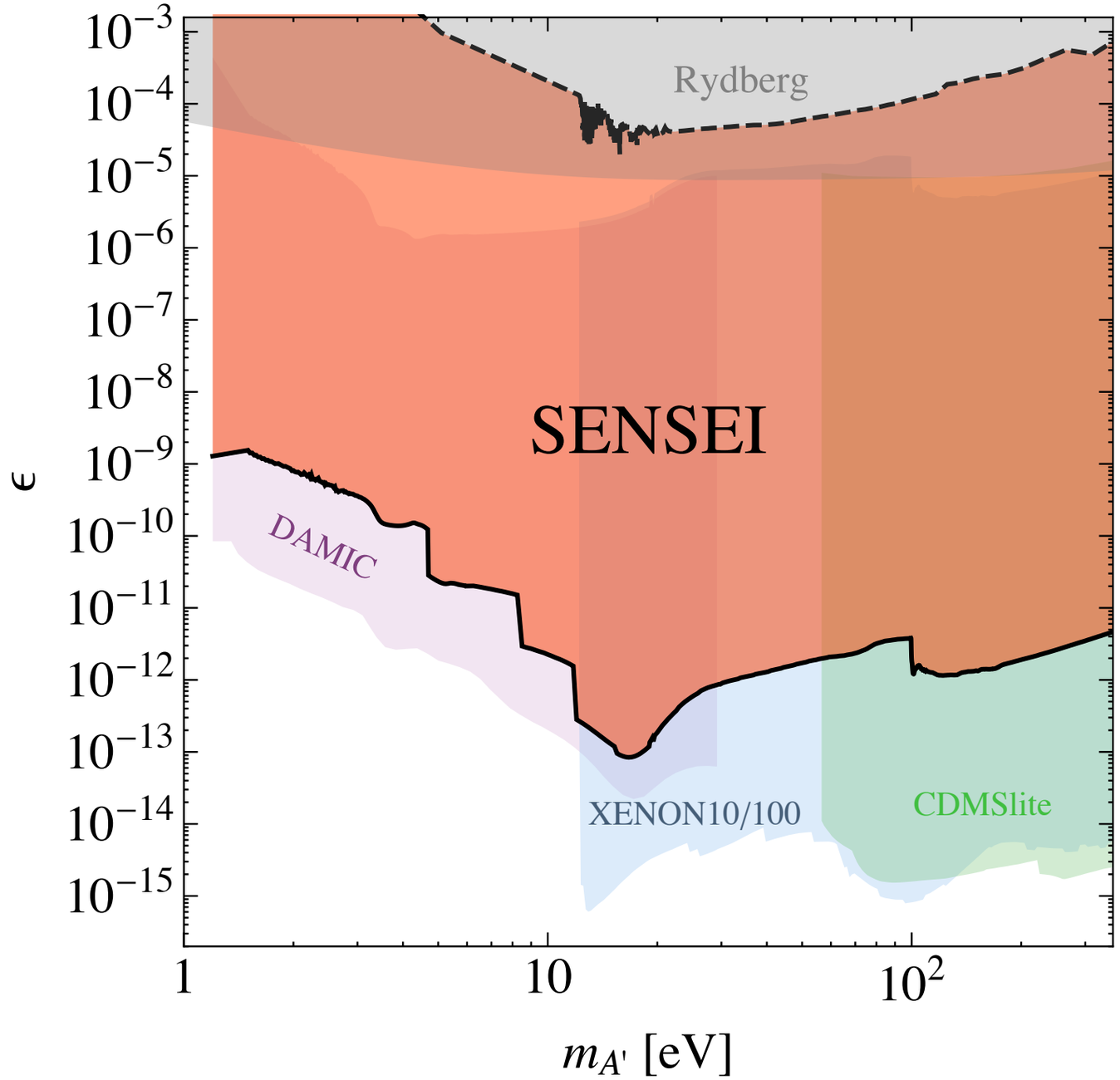
photoelectric effect

$$X + A \rightarrow A^{+} + e^{-}$$



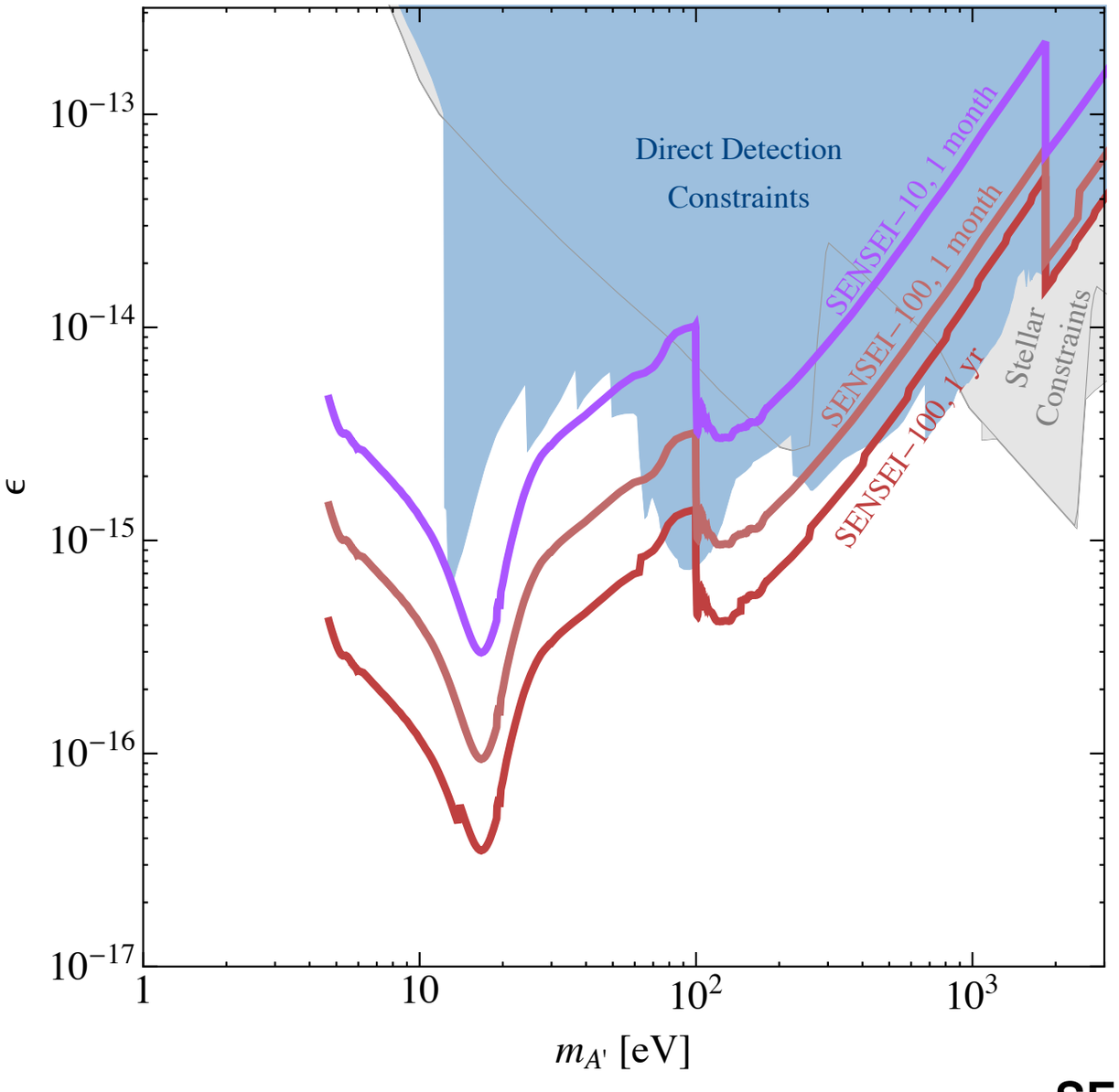
absorb all of the energy the incoming dark matter

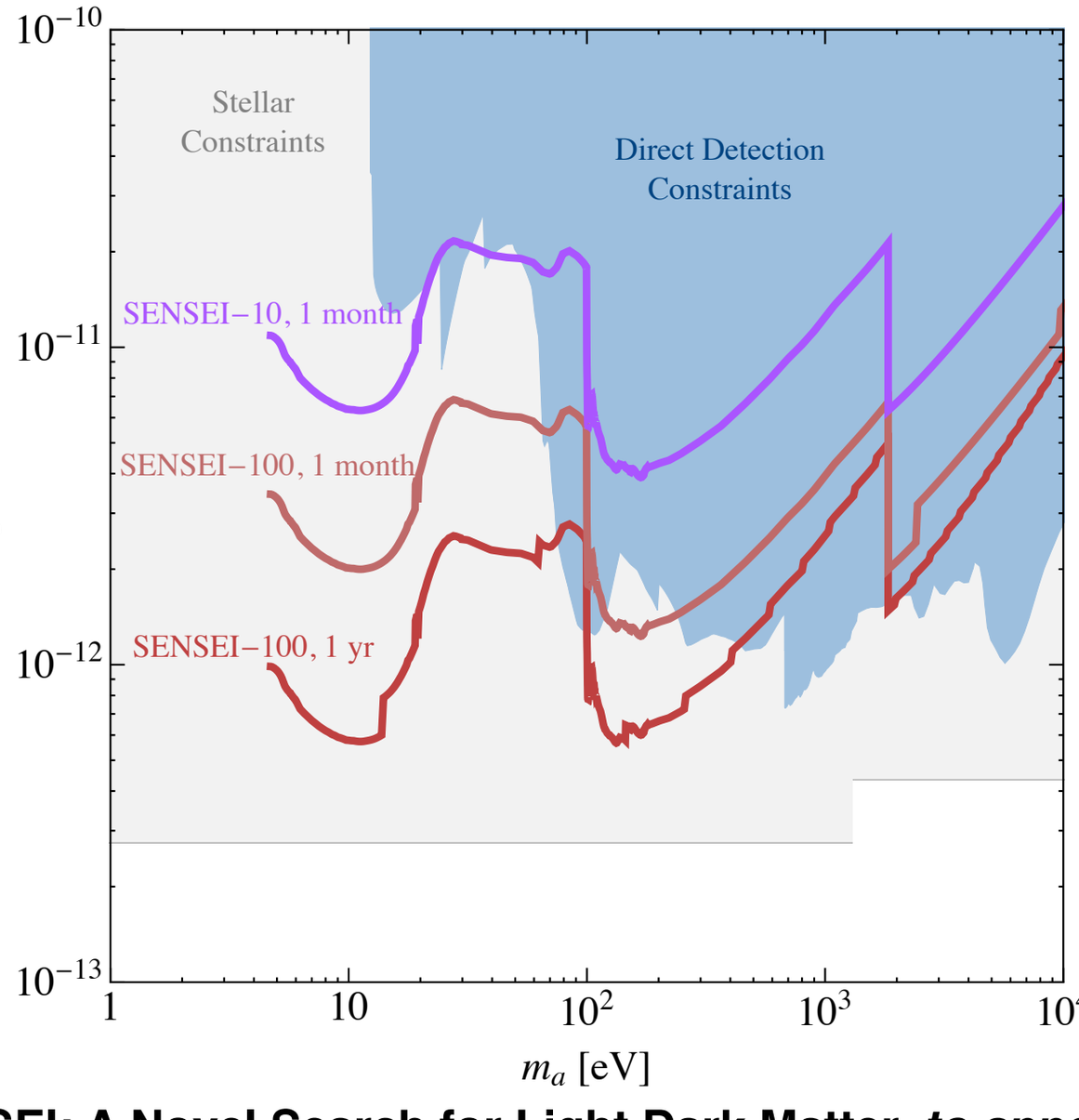
dark photon absorption



physics potential

bosonic absorption





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

based on: Bloch, Essig, Tobioka, Volansky, TTY [1608.02123]

timeline

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

analyze 100g data

timeline

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

analyze 100g data