SENSEI:
First Results, Status, and Plans

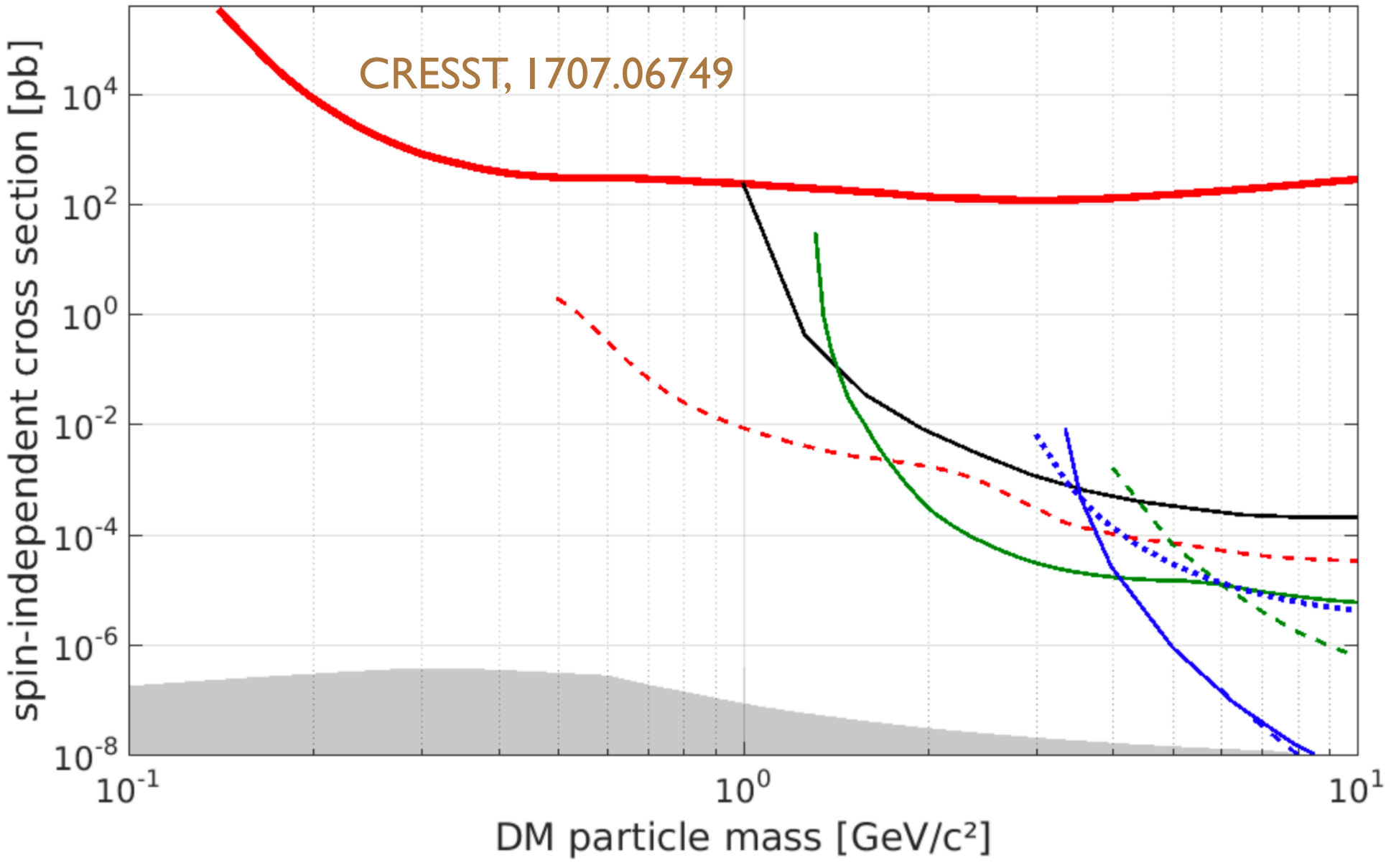
Rouven Essig
for the SENSEI collaboration

Yang Institute for Theoretical Physics

Stony Brook University

Aspen Winter Conference, March 27, 2018

Direct Detection w/ nuclear recoils: no sensitivity <<1 GeV



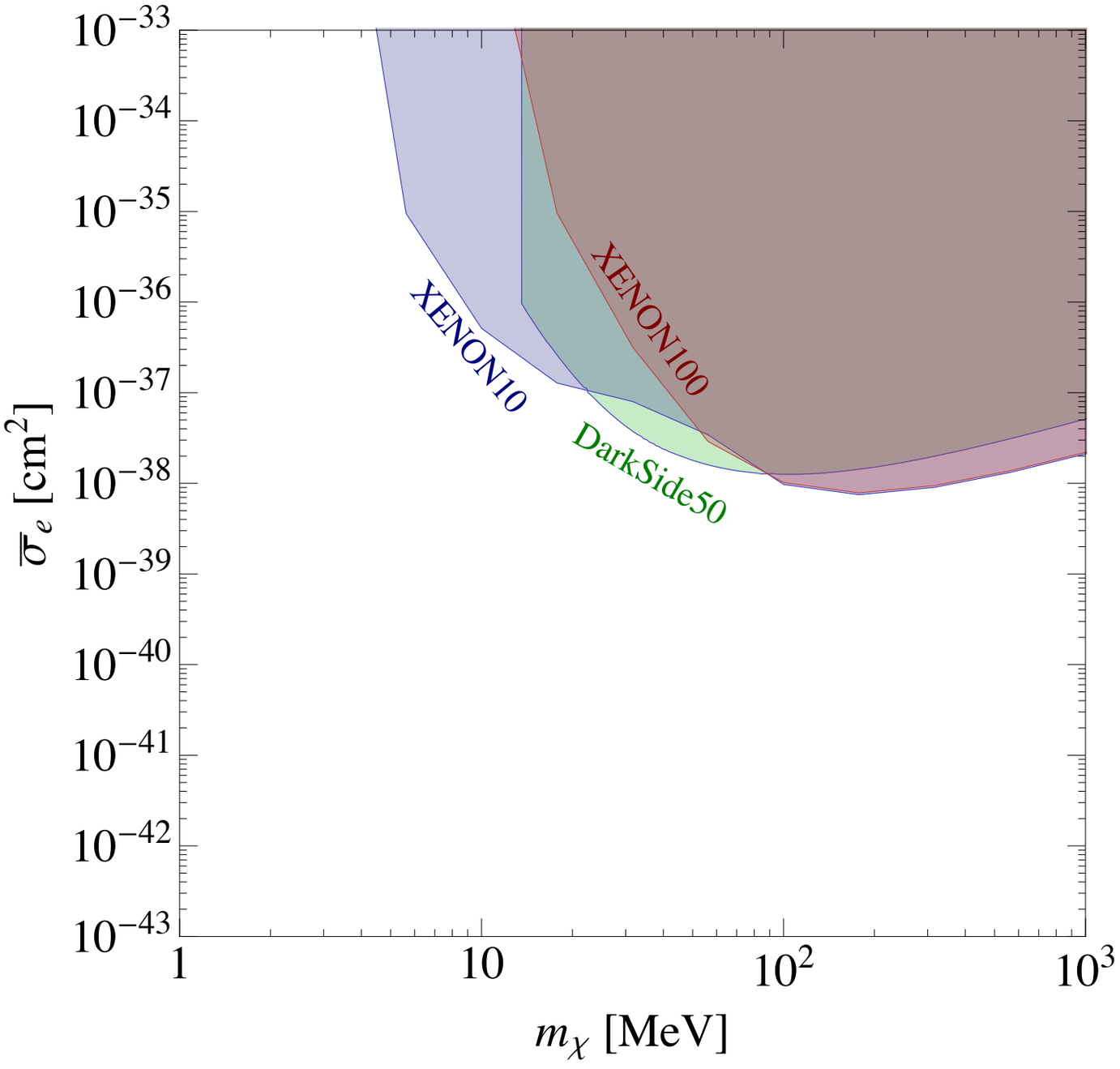
Electron recoils are much more promising

RE, Mardon, Volansky, 2011

RE, Manalaysay, Mardon, Sorensen, Volansky, 2012

RE, Volansky, Yu 2017

DarkSide-50, 2018



- Noble-liquid detectors set best constraints, down to ~5 MeV
- large detector-specific backgrounds currently limit sensitivity & discovery potential

XENON10 data: 1104.3088
XENON100 data: 1605.06262

What is SENSEI?

Sub-Electron Noise Skipper-CCD Experimental Instrument

SENSEI uses silicon CCDs with an ultra-low readout noise ("Skipper-CCDs") to search for electron recoils from DM interactions

Unprecedented sensitivity to:

- DM-electron scattering down to masses ~O(500 keV)
- Bosonic DM being absorbed by an electron down to O(eV)

The SENSEI Collaboration

Fermilab:

- Michael B Crisler, Juan Estrada, Guillermo Fernandez, Miguel Sofo-Haro, Javier Tiffenberg

Stony Brook:

- Rouven Essig

Tel-Aviv:

- Liron Barack, Erez Ezion, Tomer Volansky

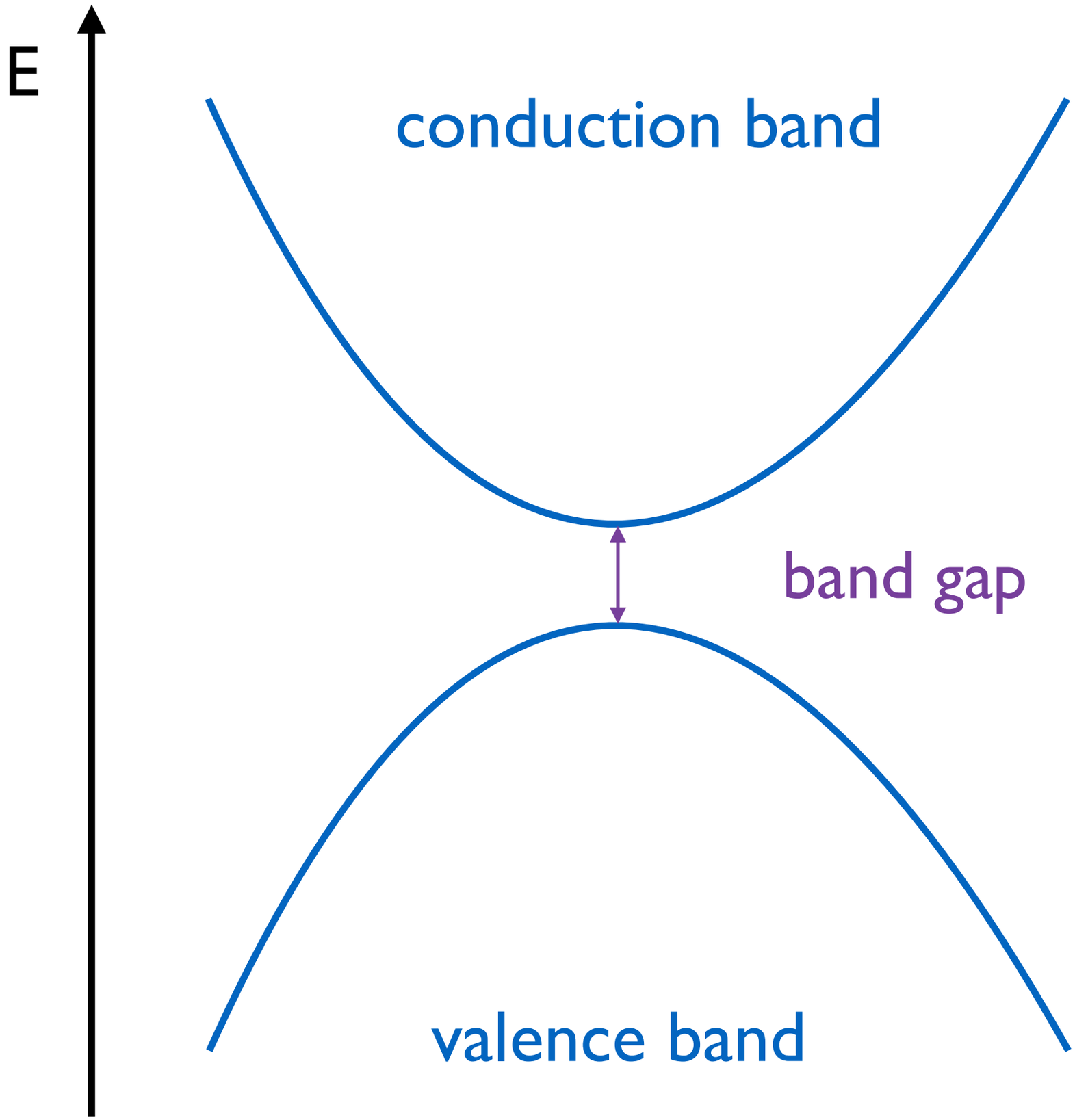
U. Oregon:

- Tien-Tien Yu

+ several additional students + more to come

Funded by Heising-Simons Foundation & Fermilab

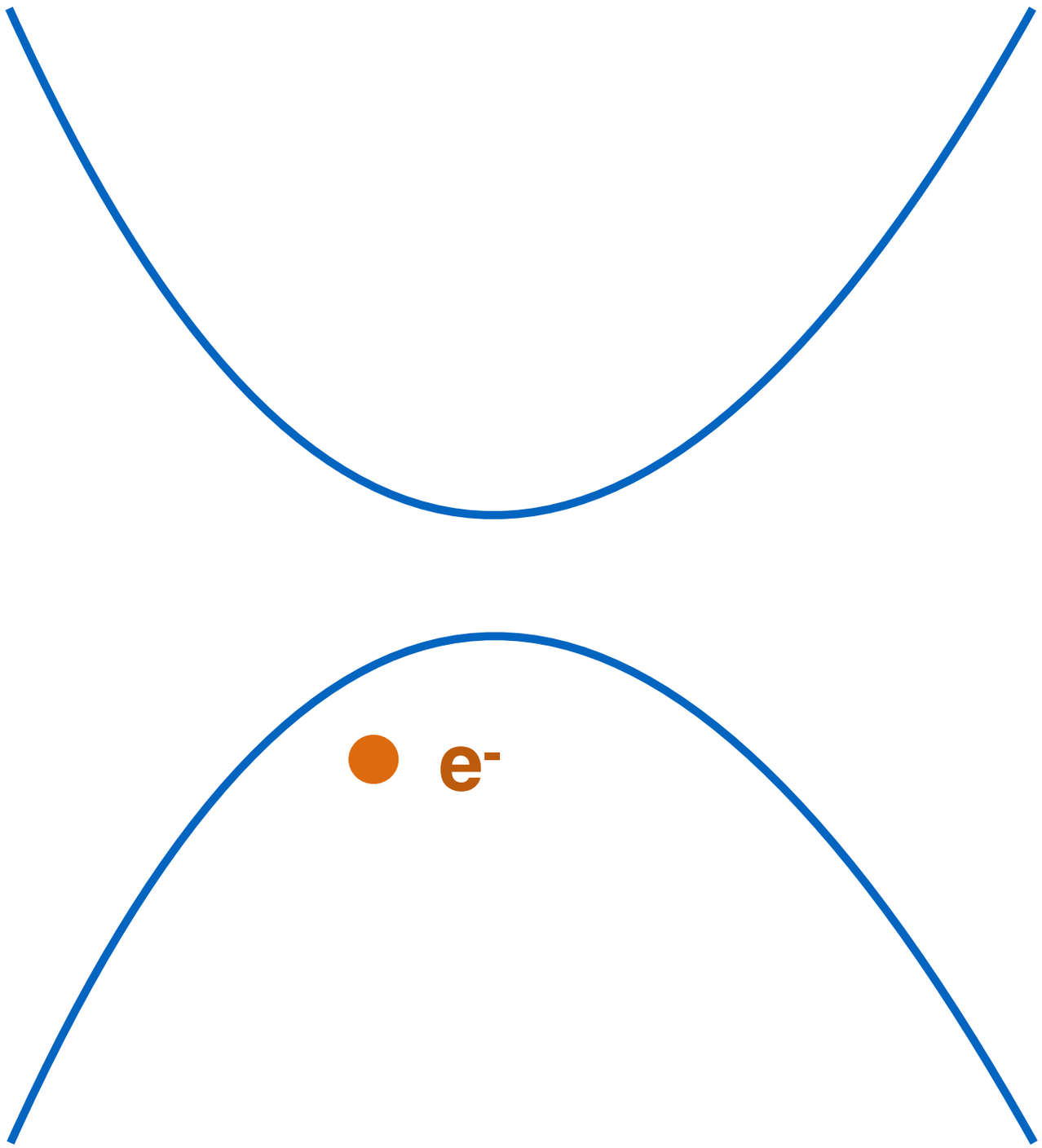
A dark matter event in silicon



band gap

Si	1.1 eV

A dark matter event in silicon



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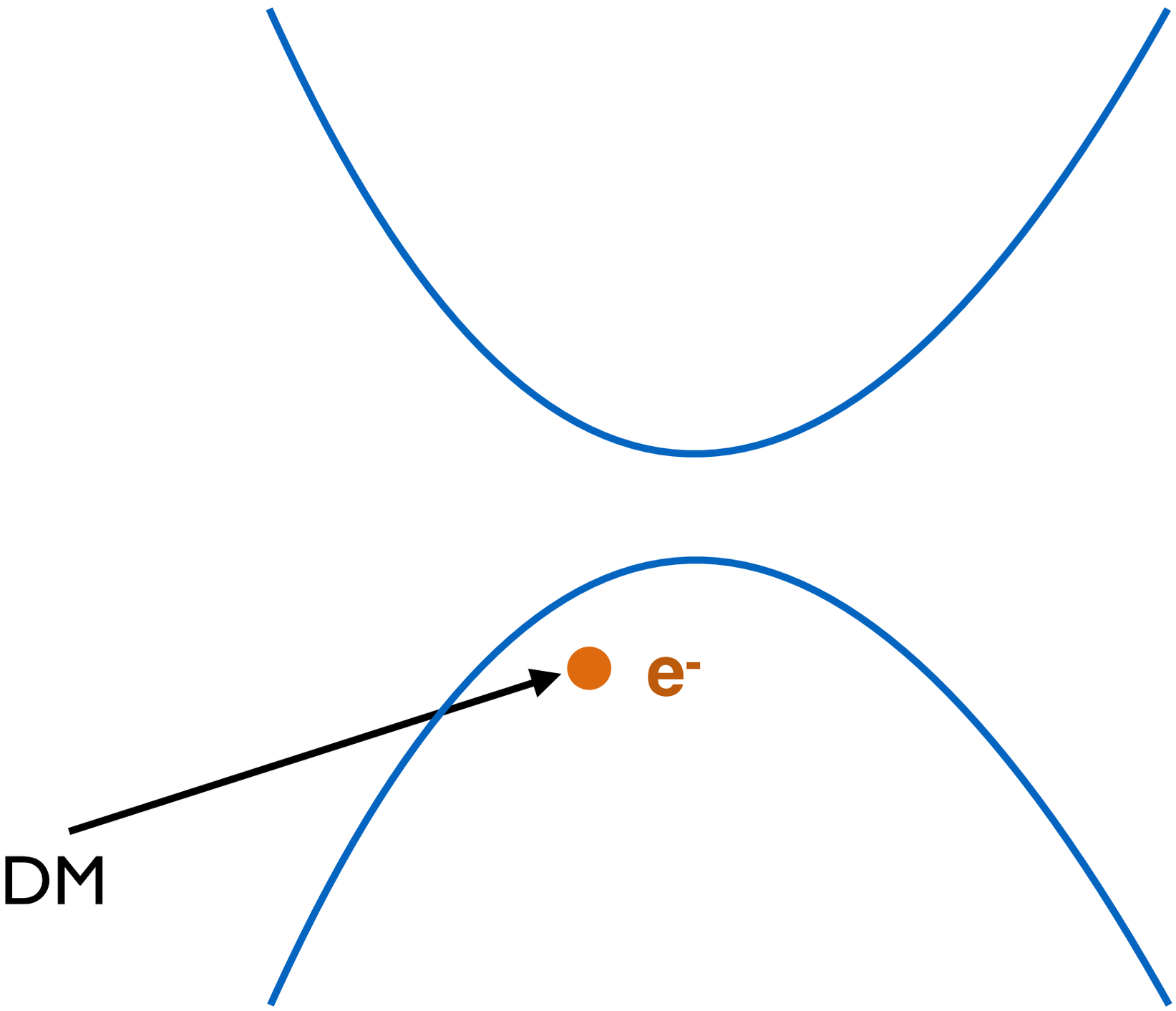

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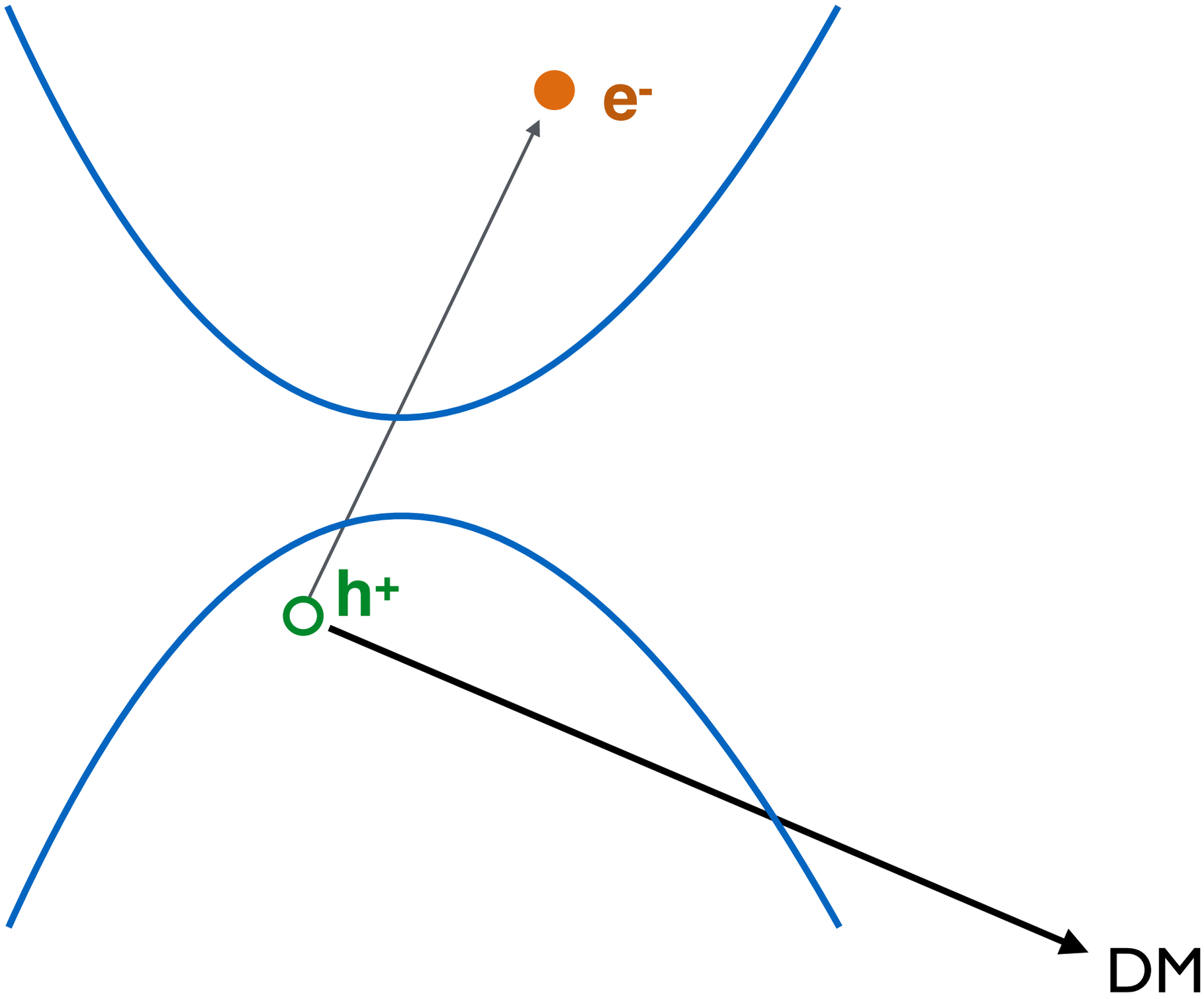

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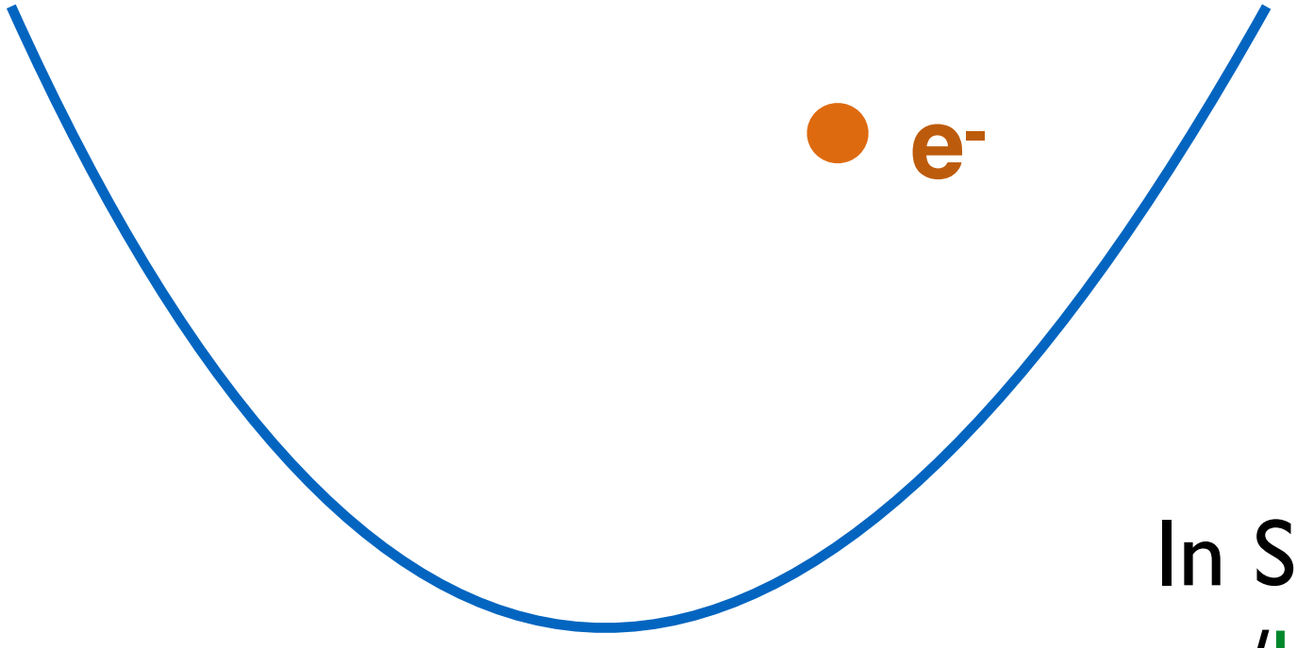
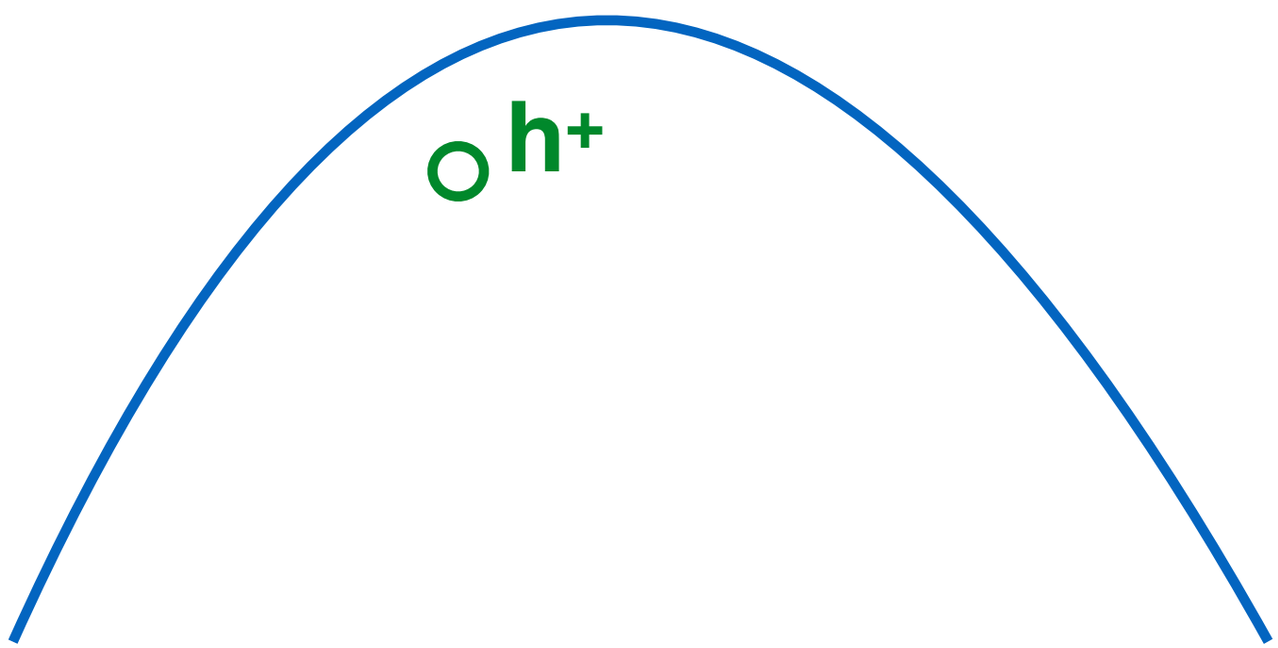
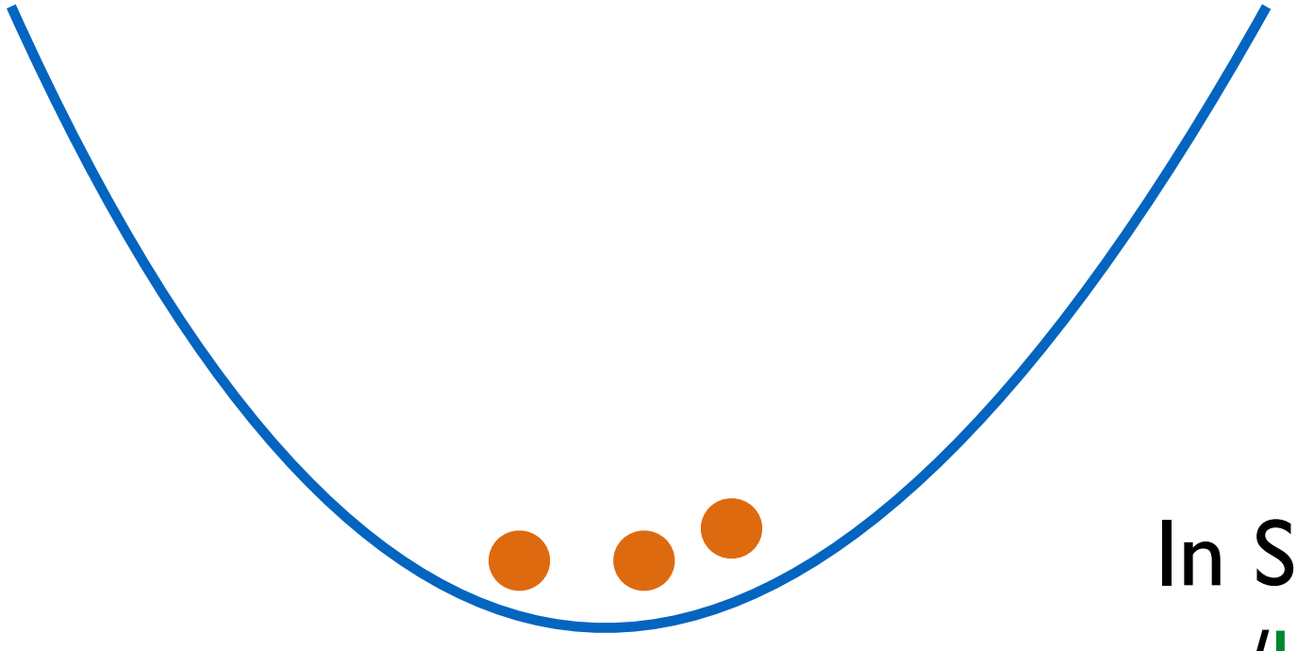




In Si, create one additional e^-/h^+ pair for each 3.6 eV of recoil energy

A dark matter event in silicon



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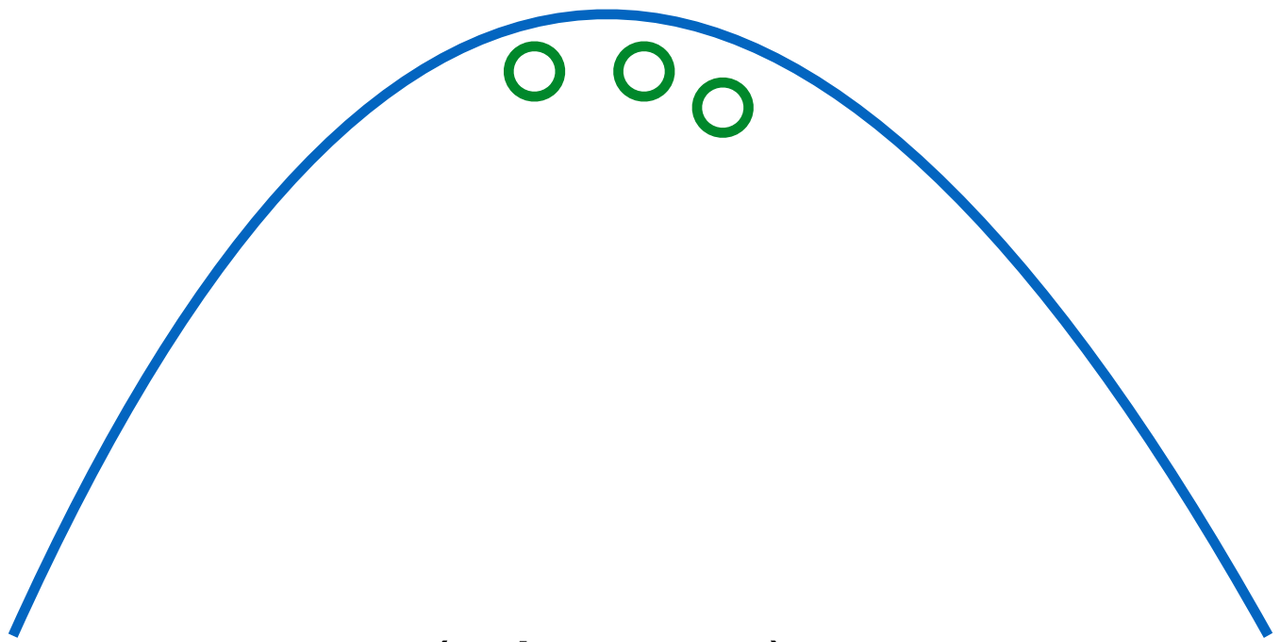
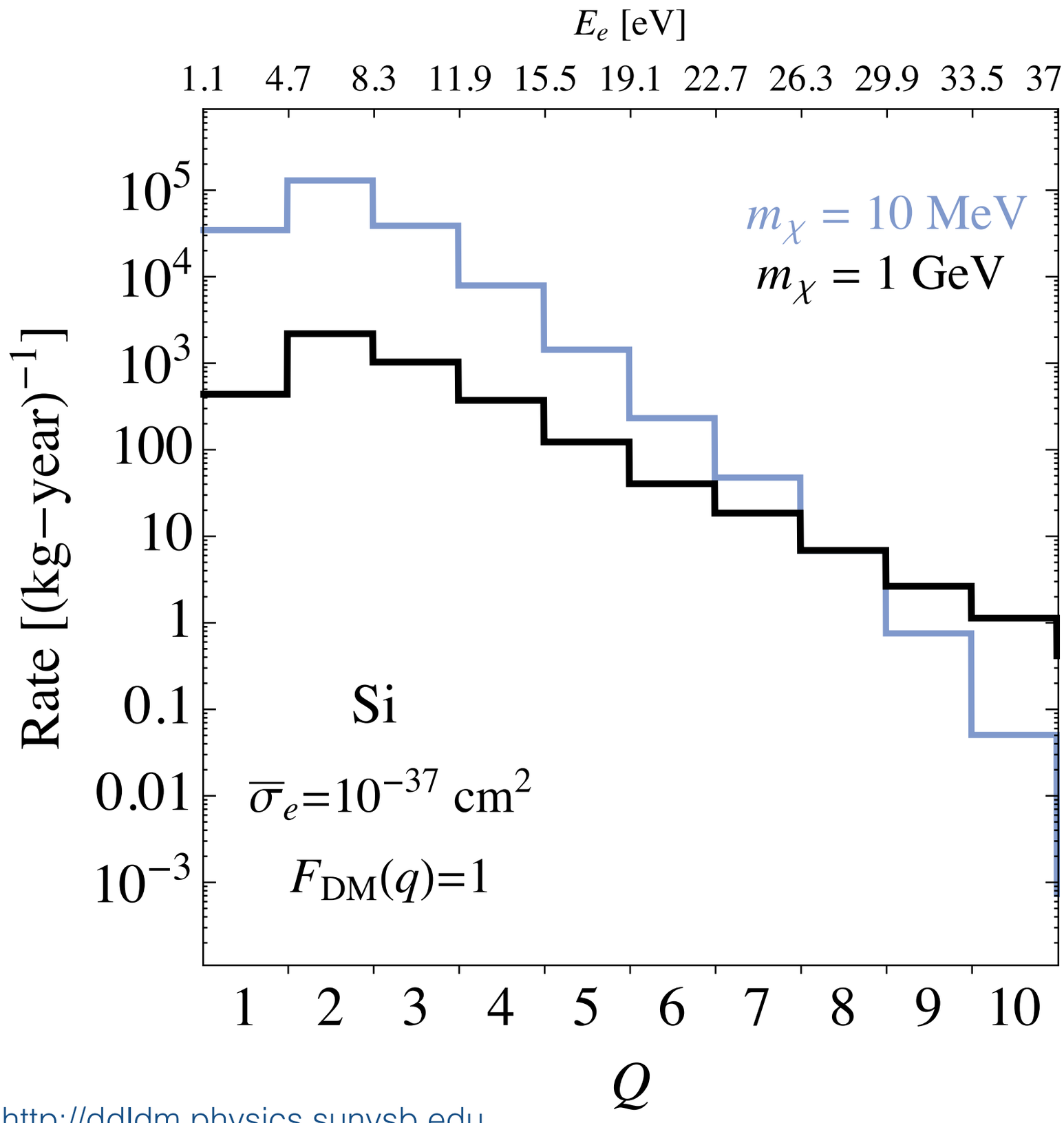


here Q = 3

(schematic)

Rates increase dramatically for lower Q

RE, Fernandez-Serra, Mardon, Soto, Volansky, Yu

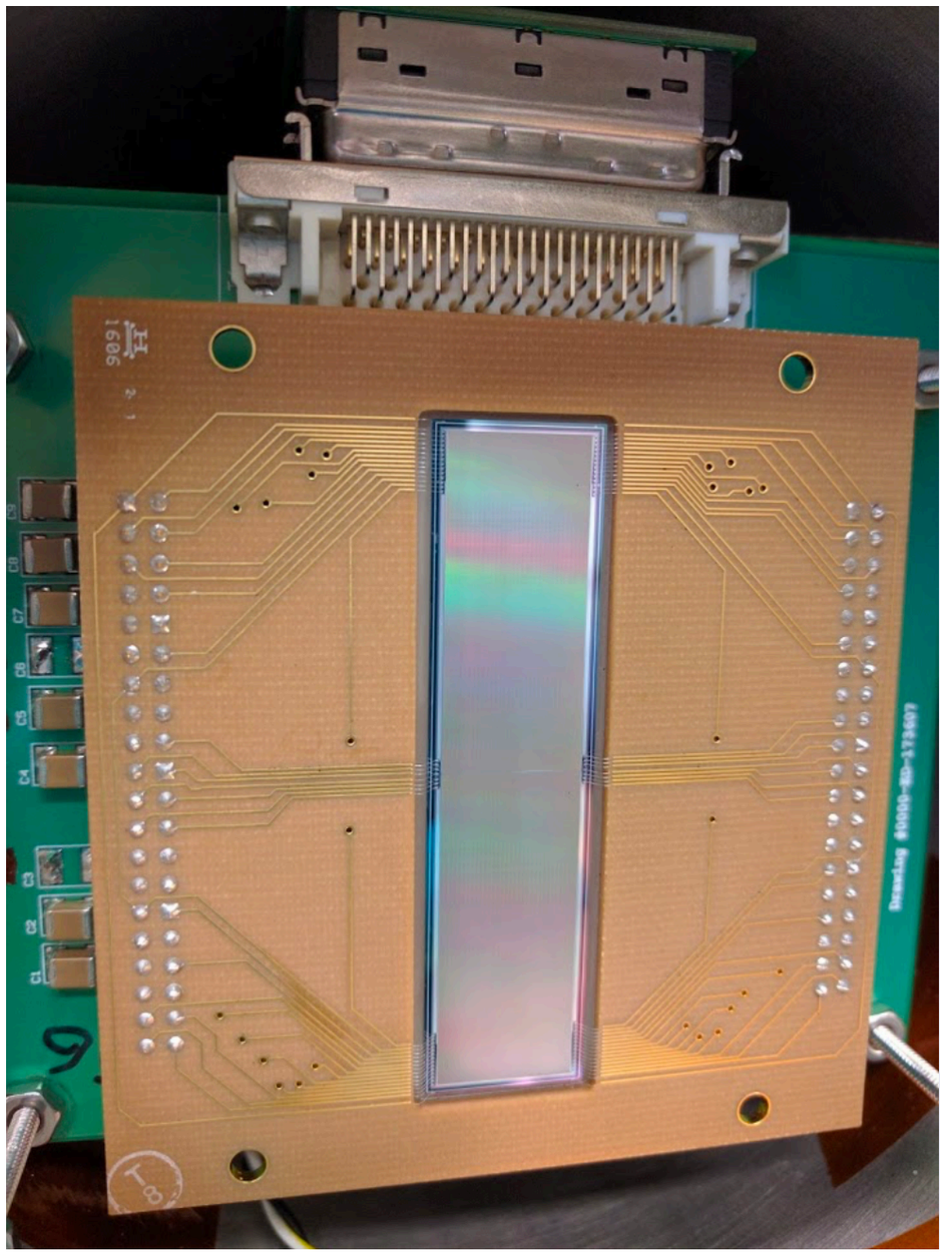


Best threshold for a Si detector before June 2017: ~ 11e$^-$ (40 eV)

A recent technological breakthrough enables much lower thresholds: SENSEI

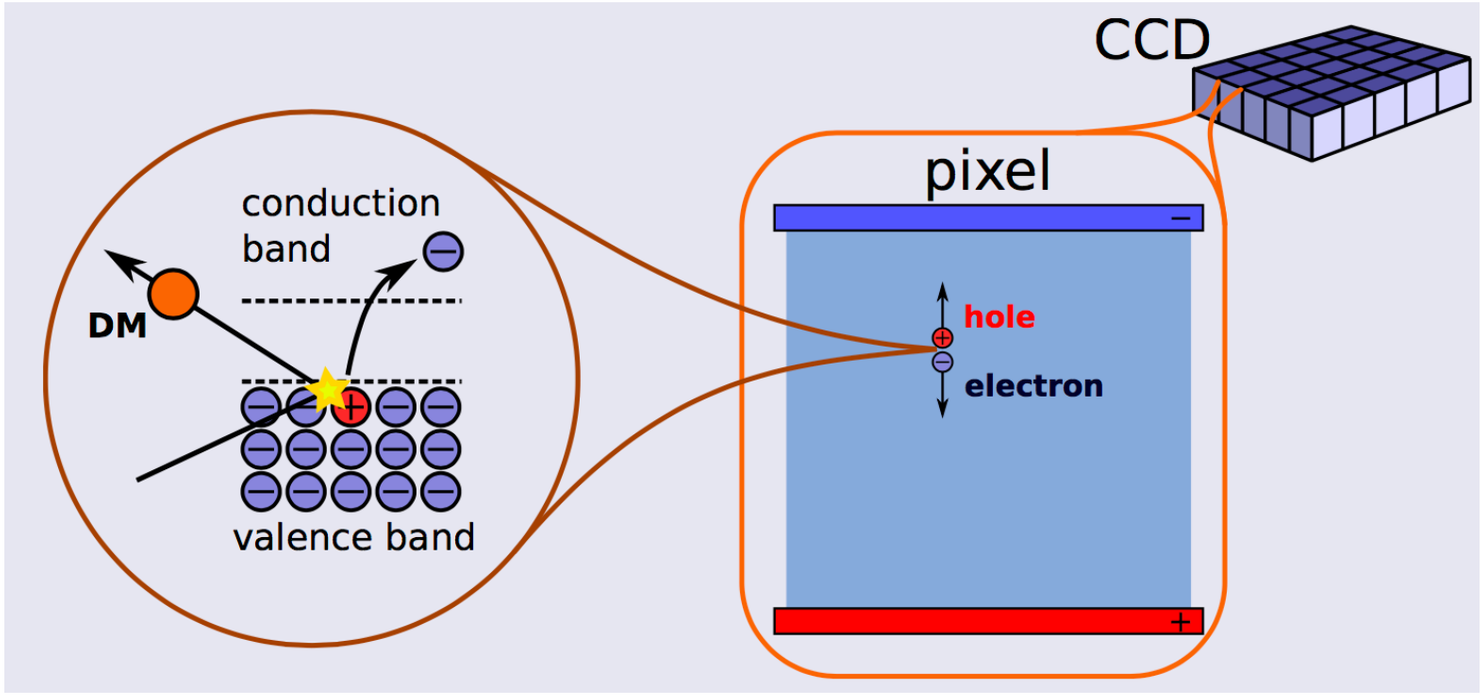
http://ddldm.physics.sunysb.edu

SENSEI's target material are special silicon CCDs

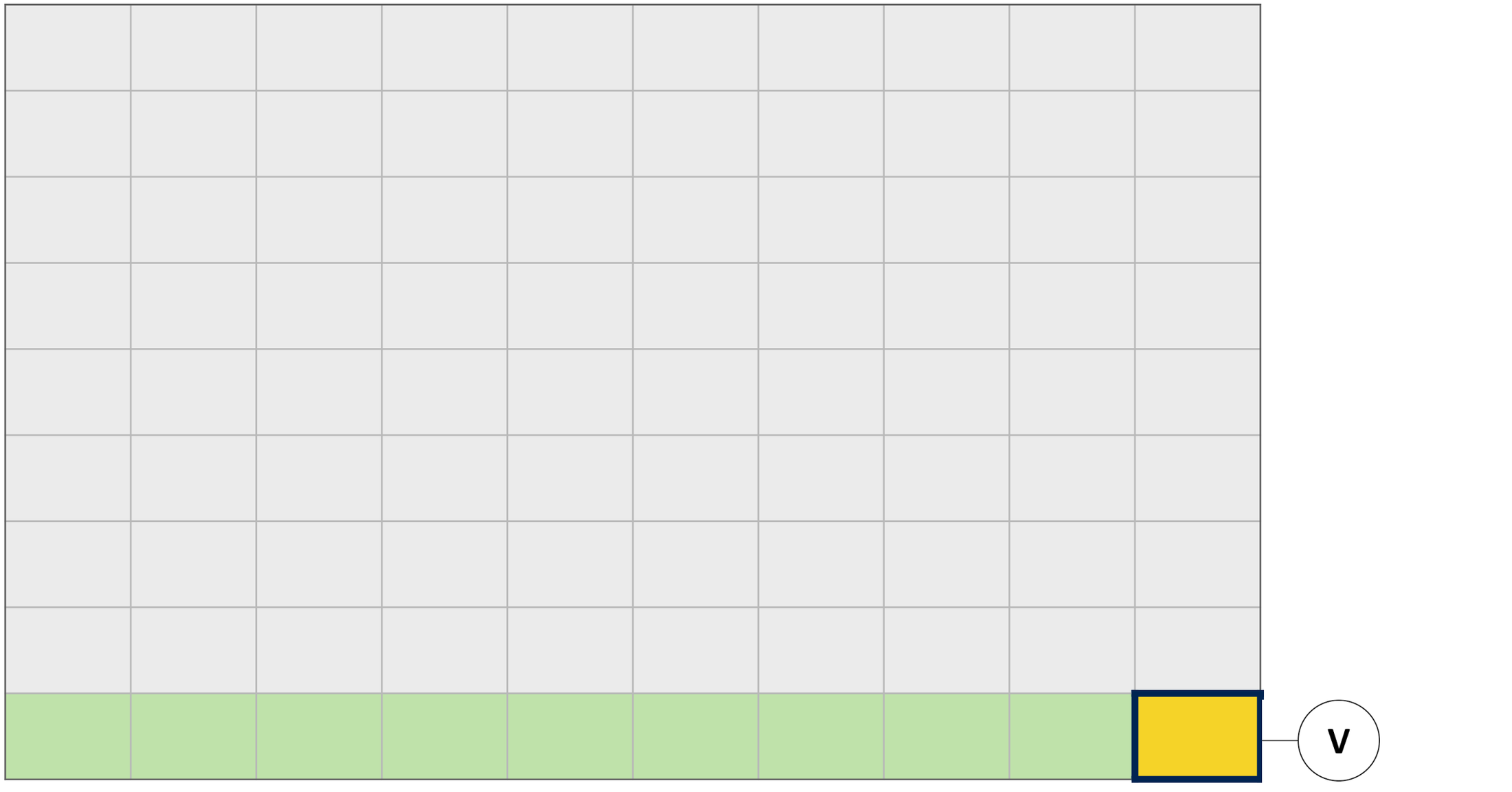


~million pixels

"Skipper CCDs"



Moving & reading the charge (schematic)



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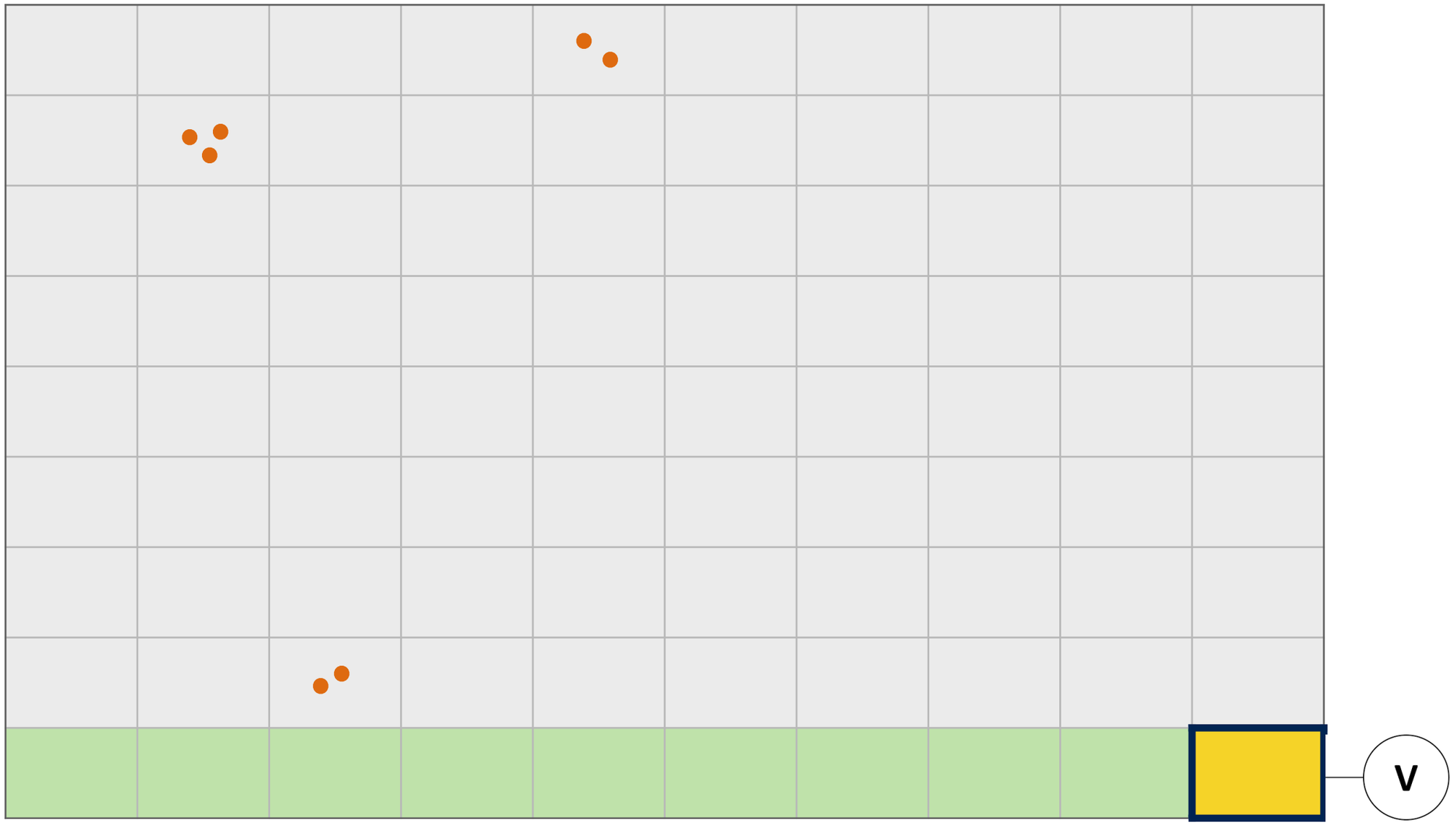
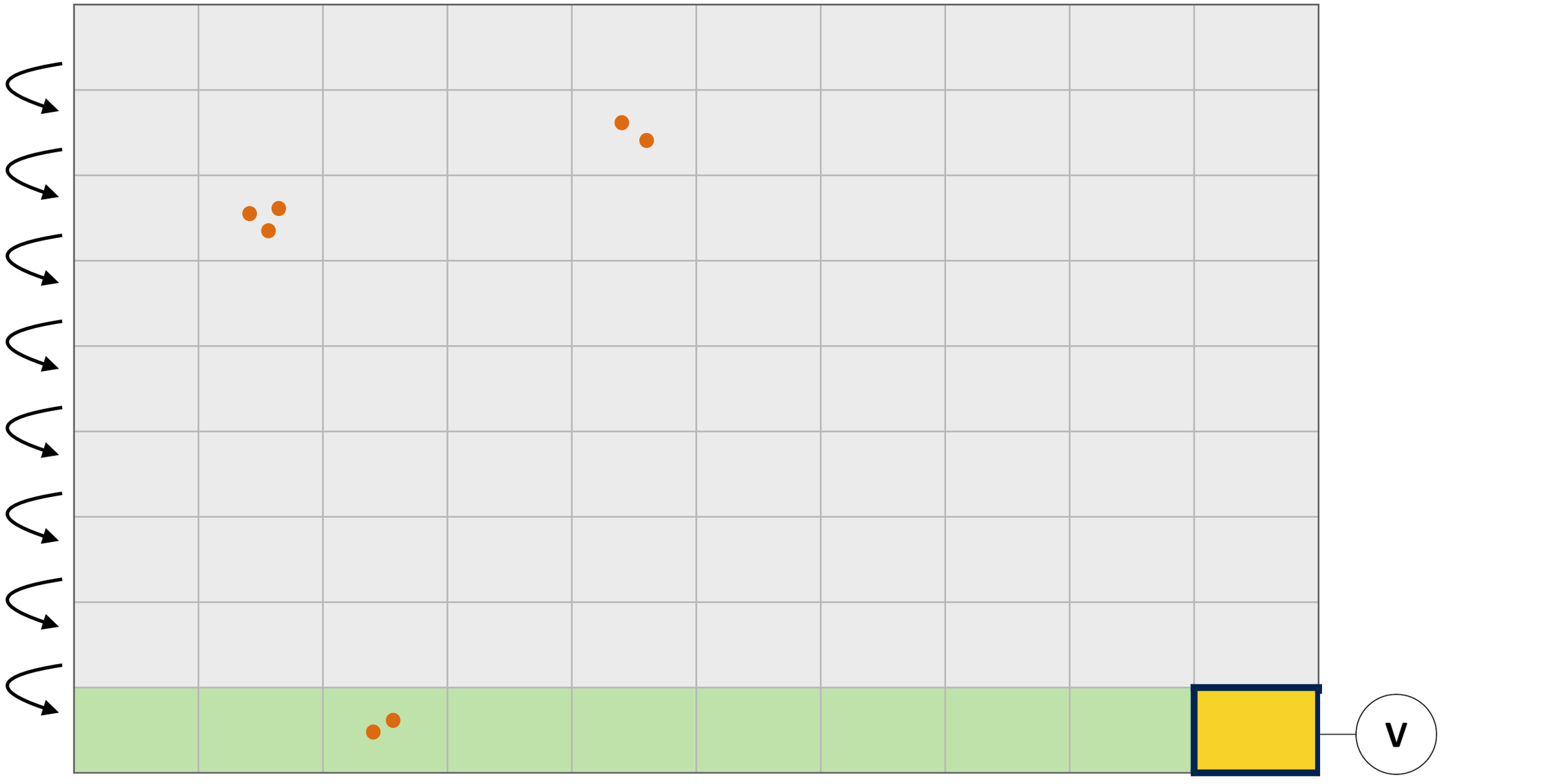


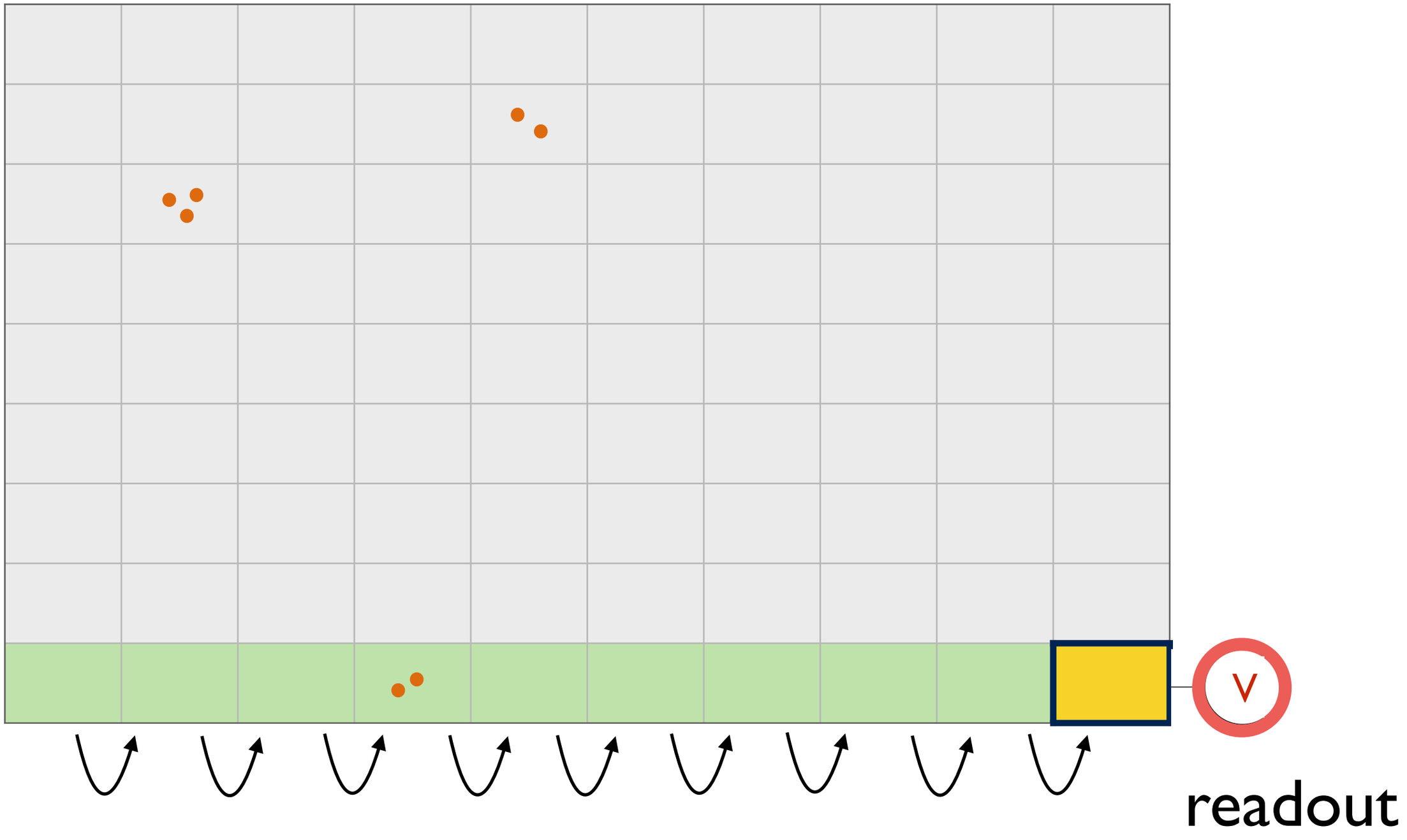
readout

Moving & reading the charge (schematic)



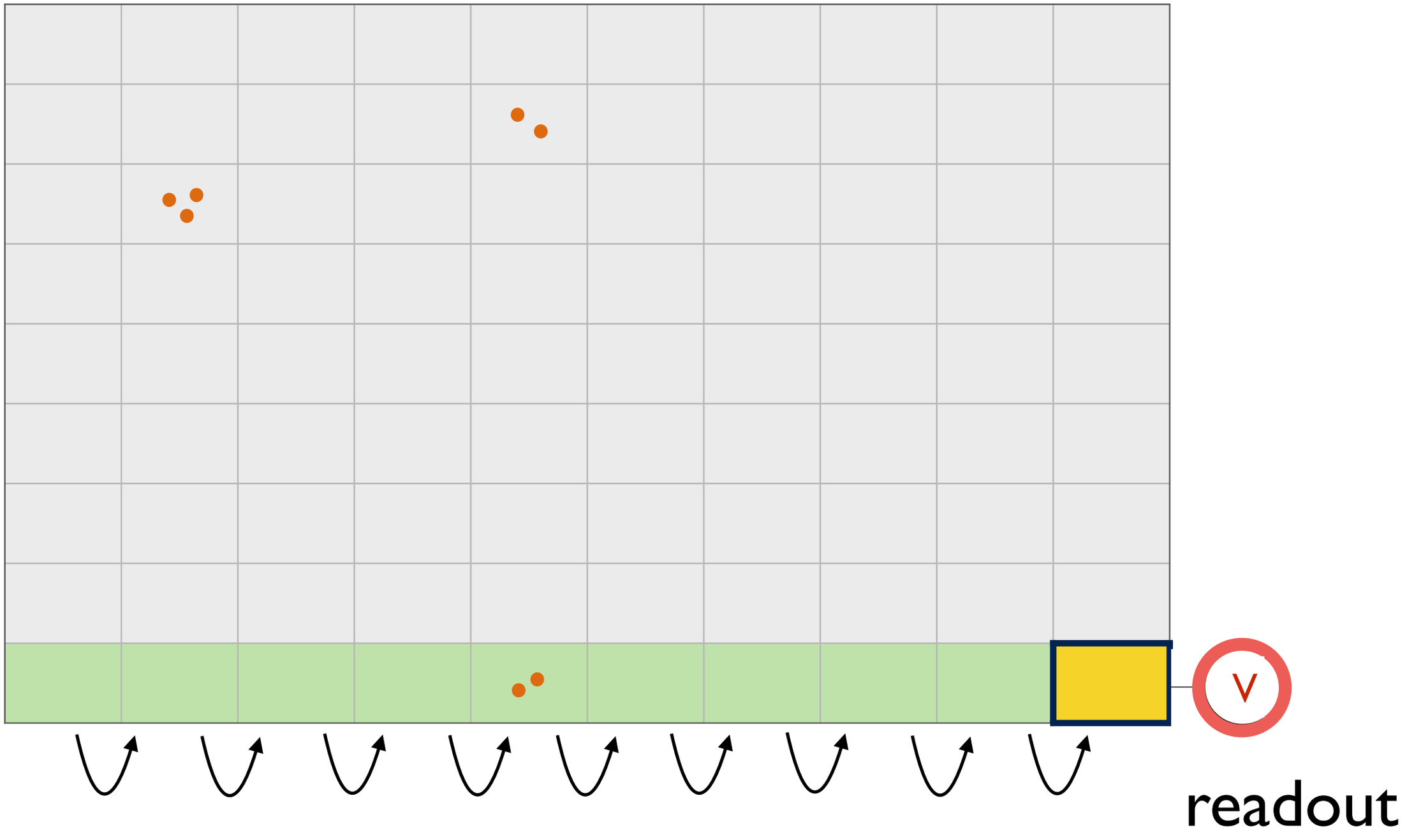
- shift each pixel charge down by one row

Moving & reading the charge (schematic)



- then shift pixel charge in bottom row to the right step-by-step and measure charge in each pixel

Moving & reading the charge (schematic)



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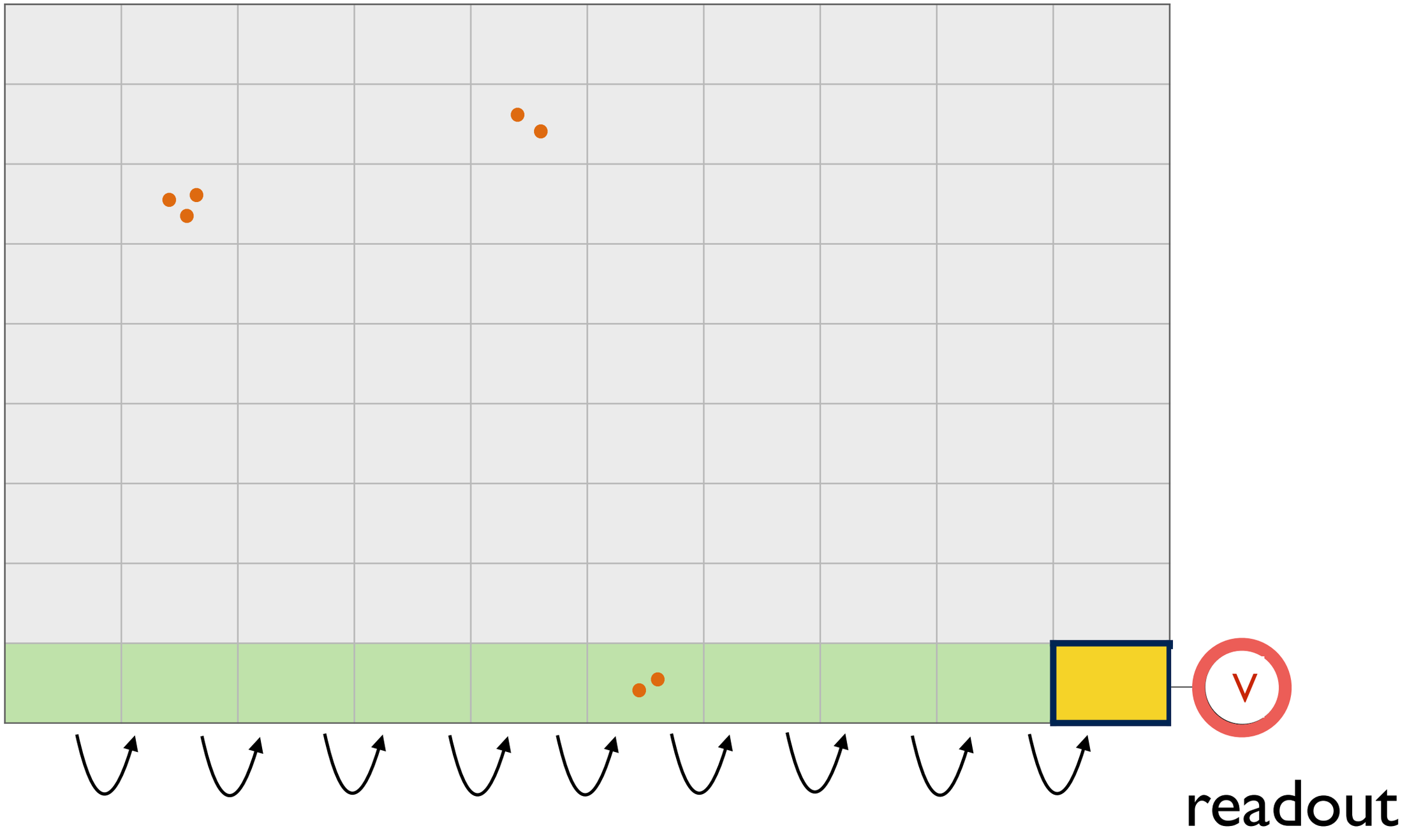

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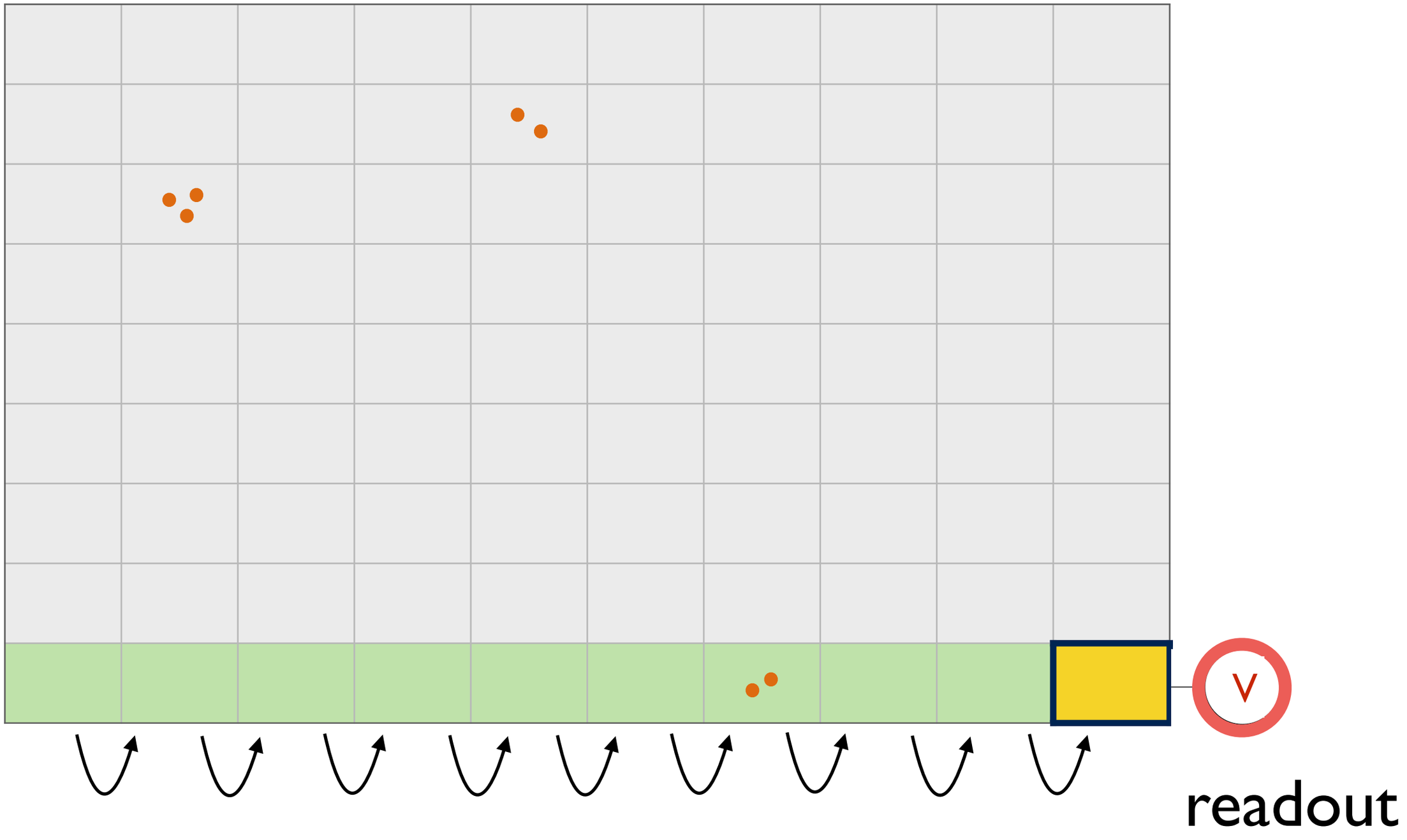

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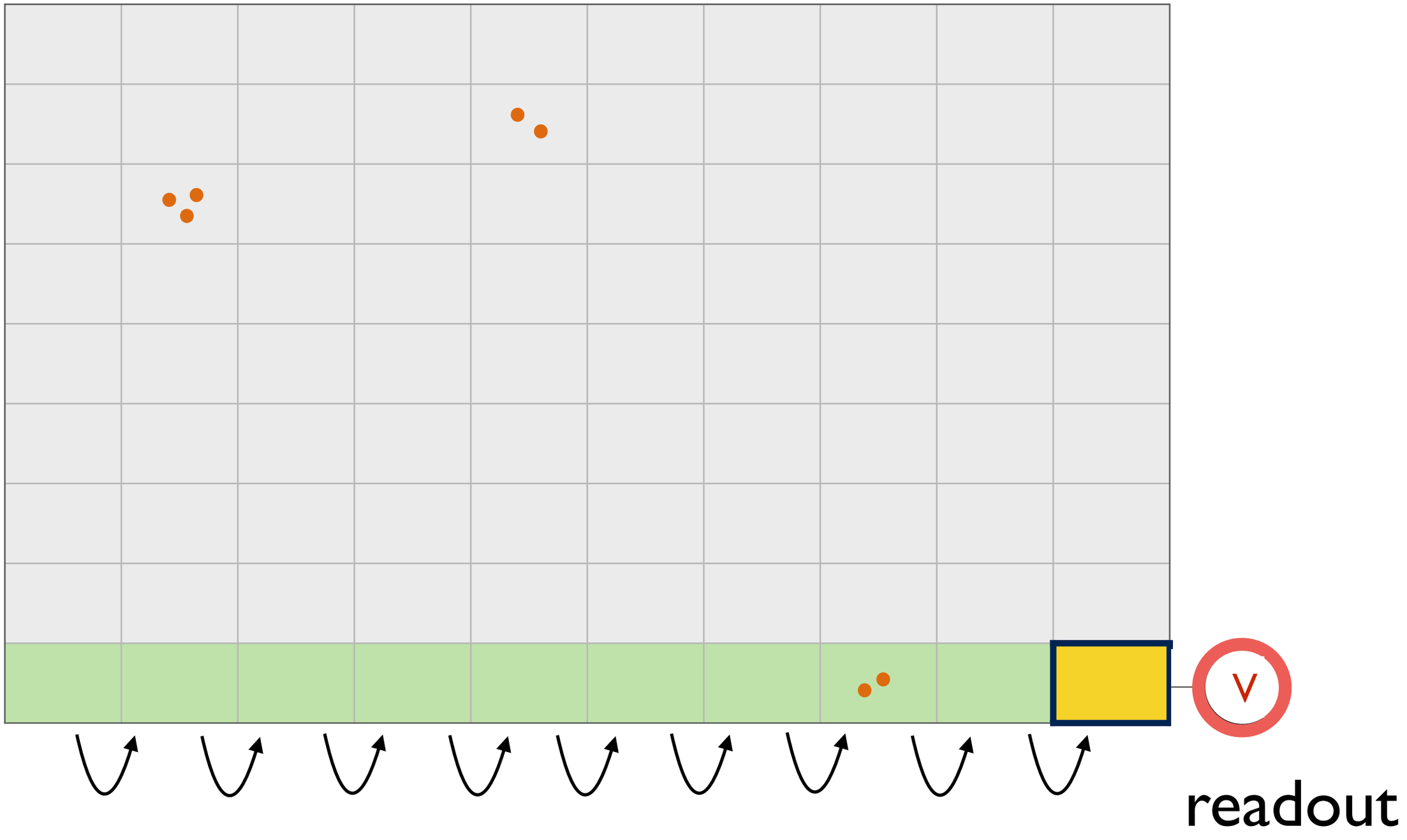

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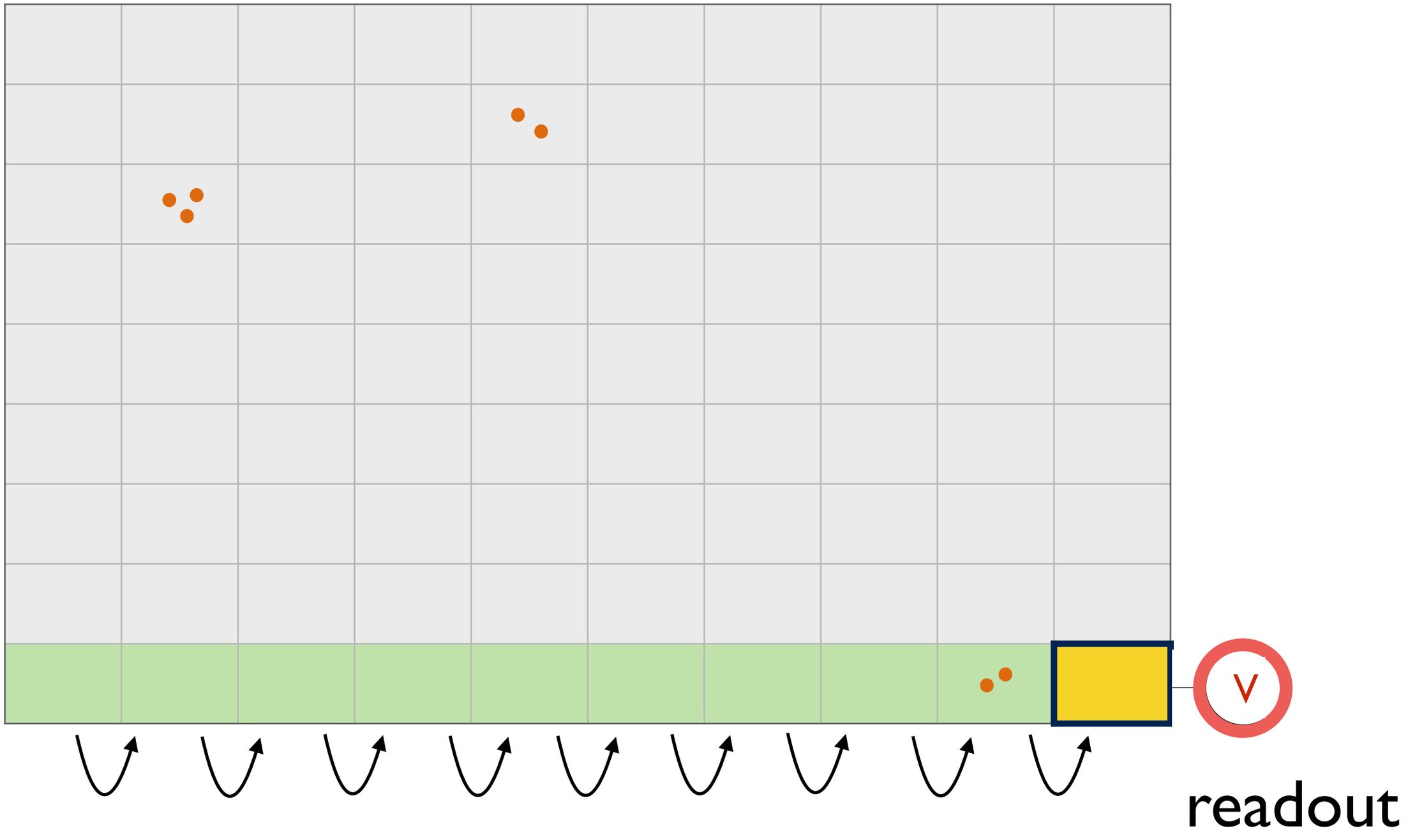

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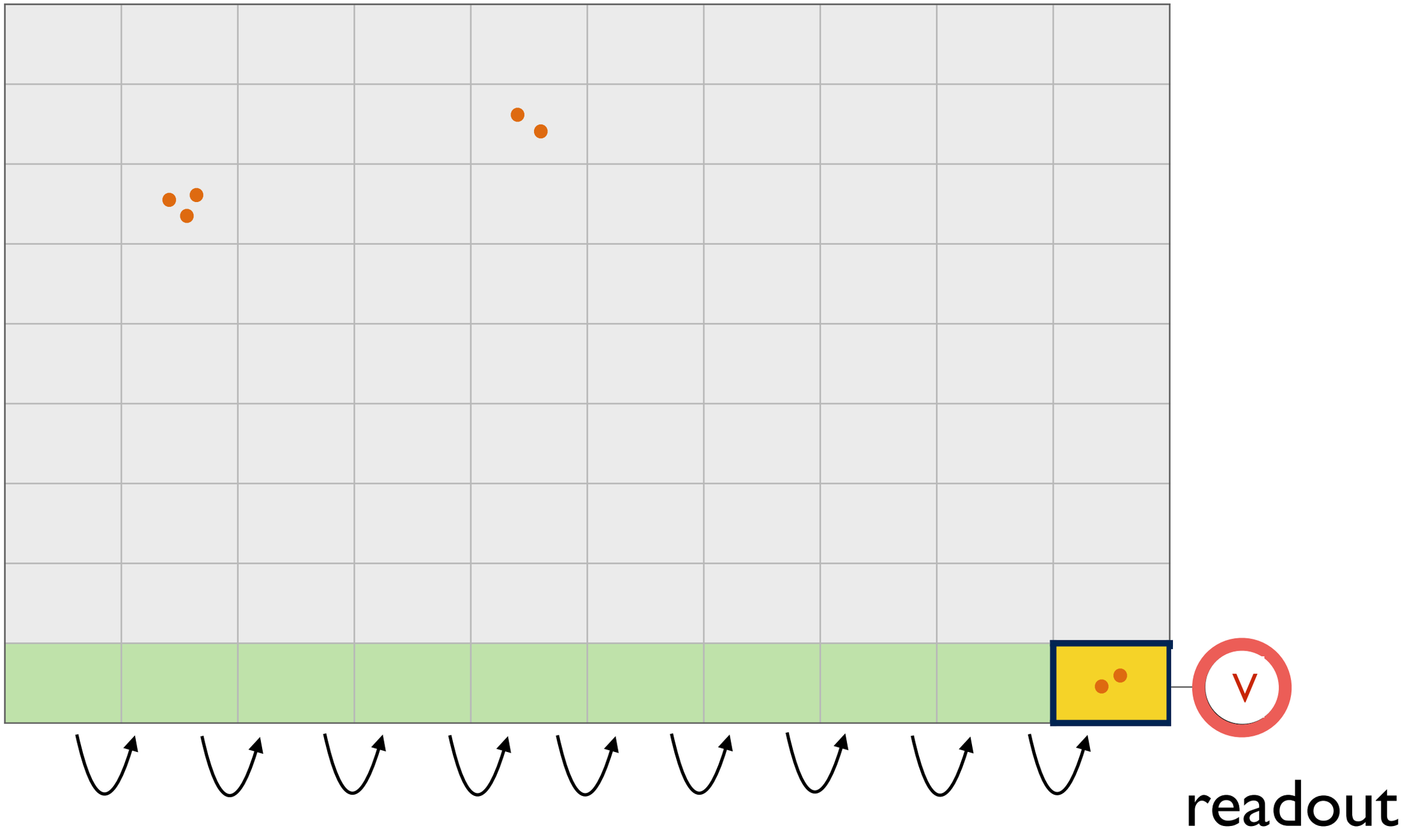

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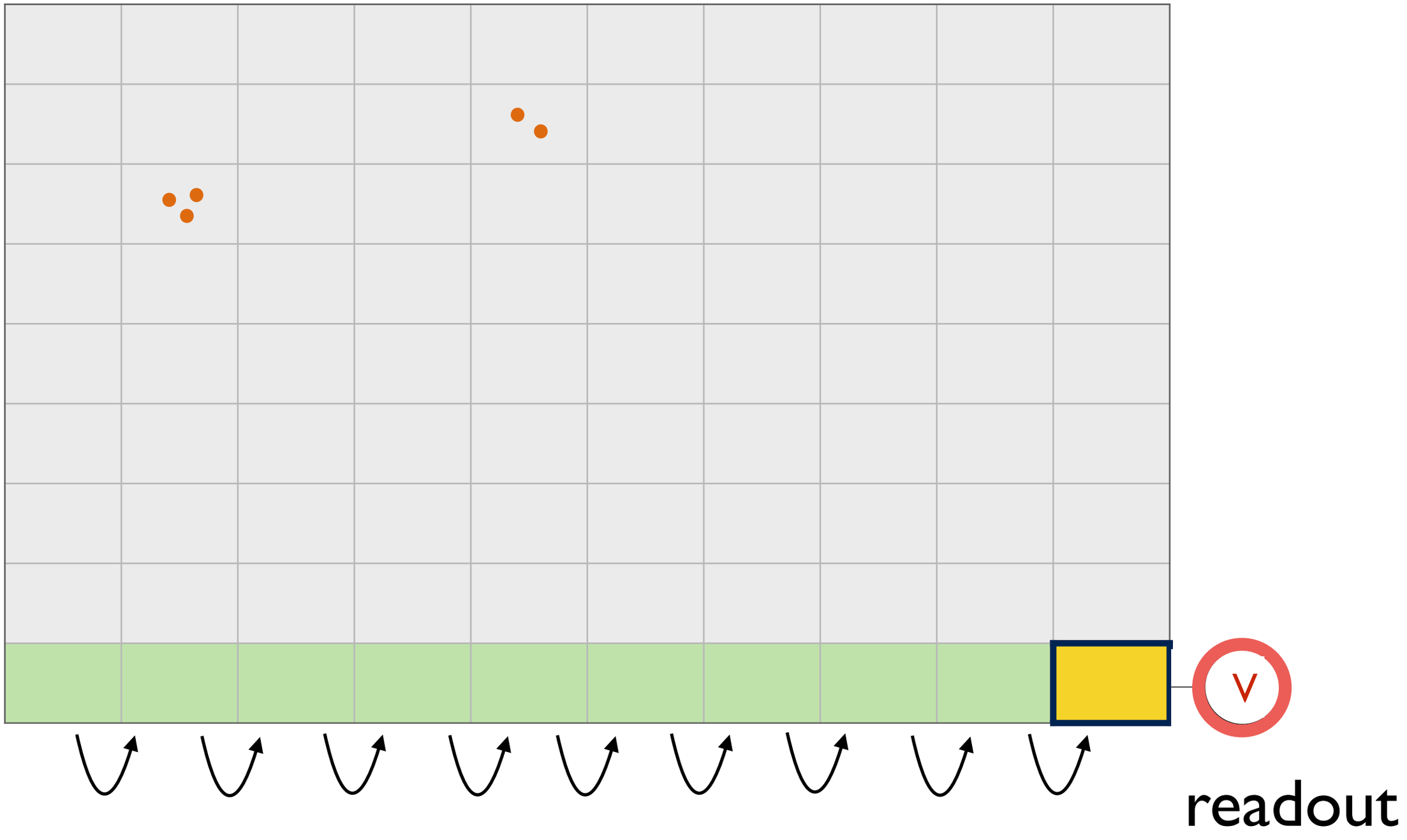

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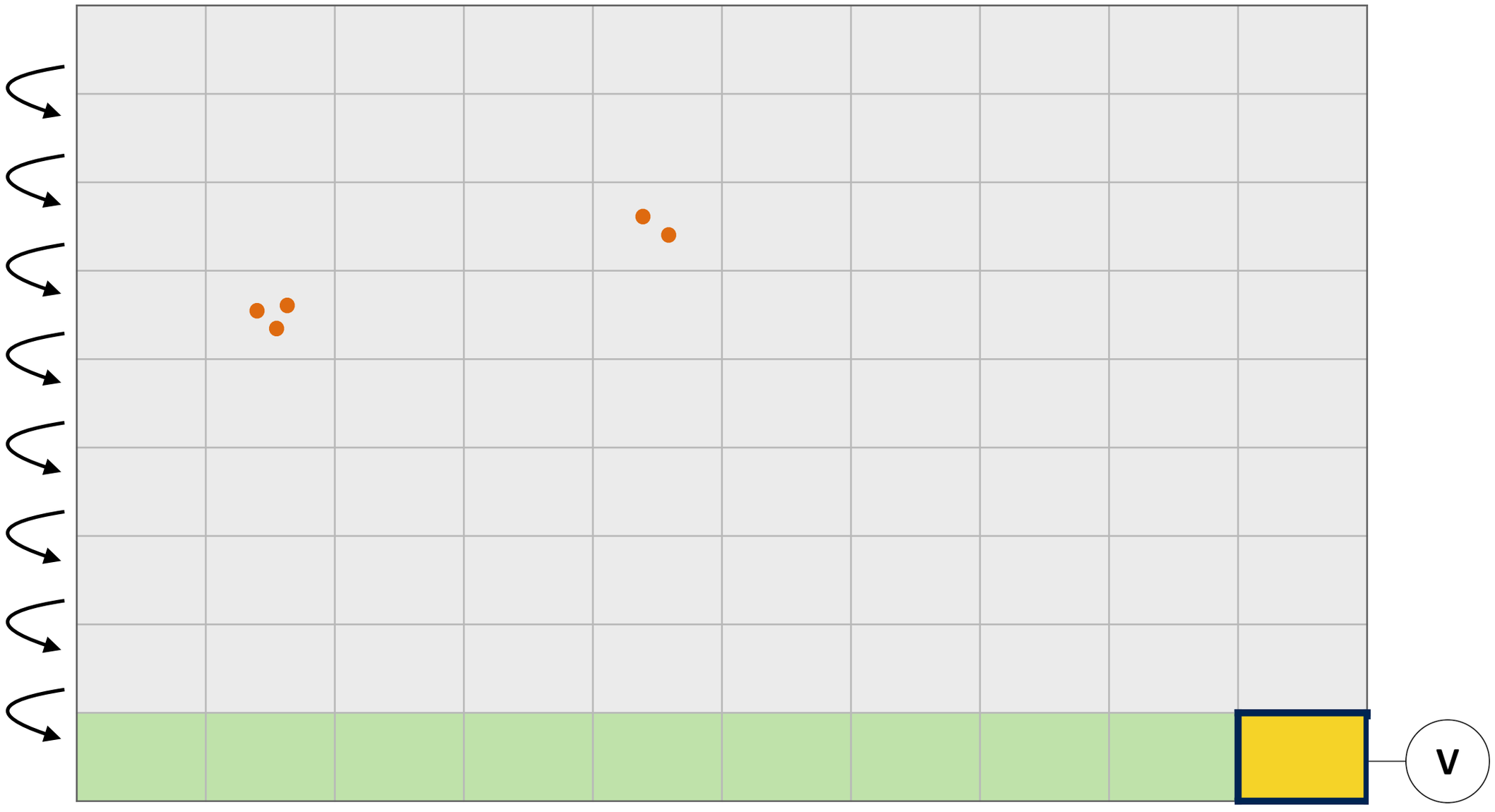
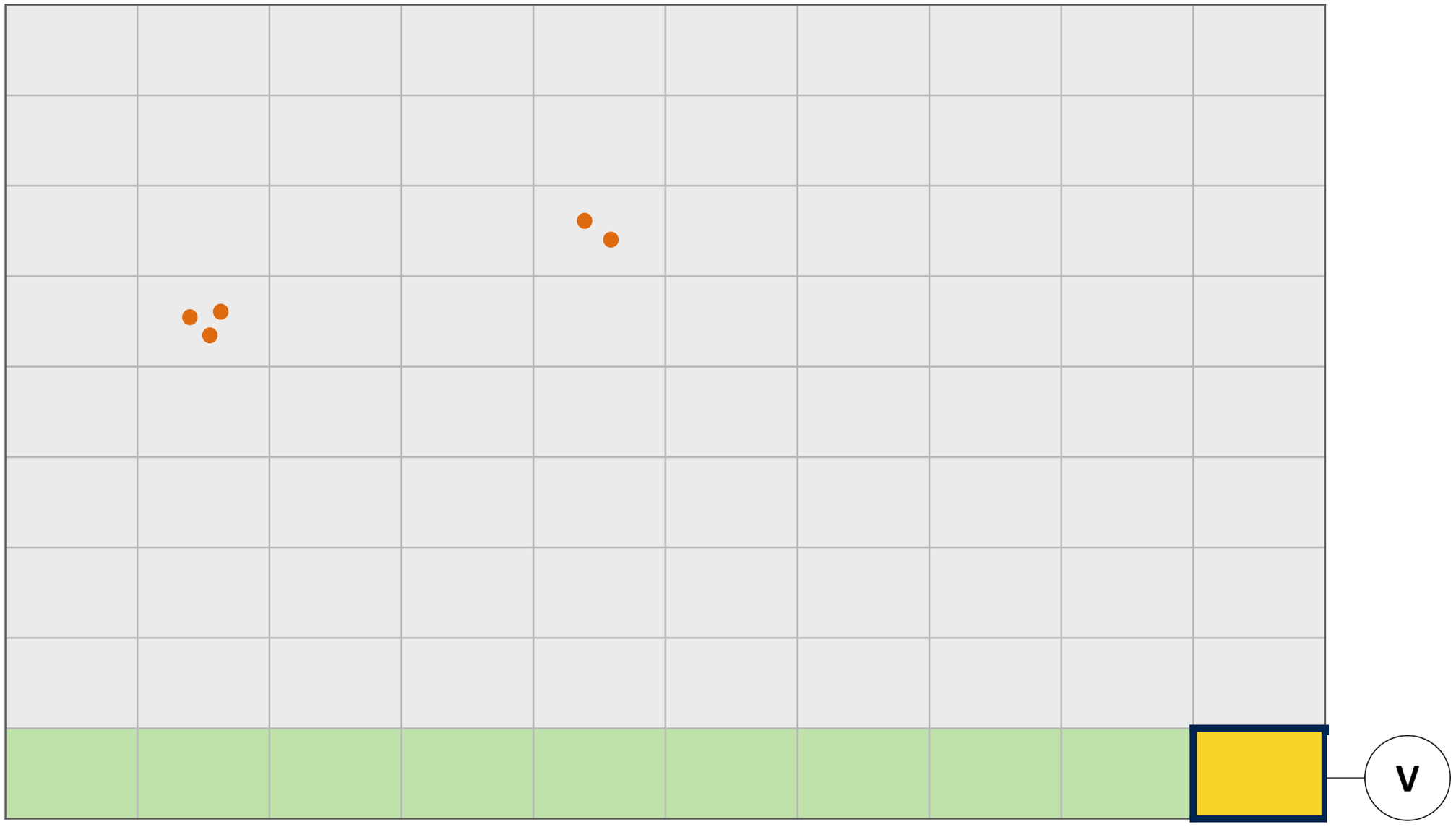


readout

- repeat

Moving & reading the charge (schematic)



readout

"ordinary"
scientific CCDs:

rms readout noise ~ $2e^-$
$\Longrightarrow$ "high" threshold ~ $10e^-$

Skipper CCD

- has a <u>modified readout stage</u> that allows multiple sampling of the same pixel without corrupting the charge packet:

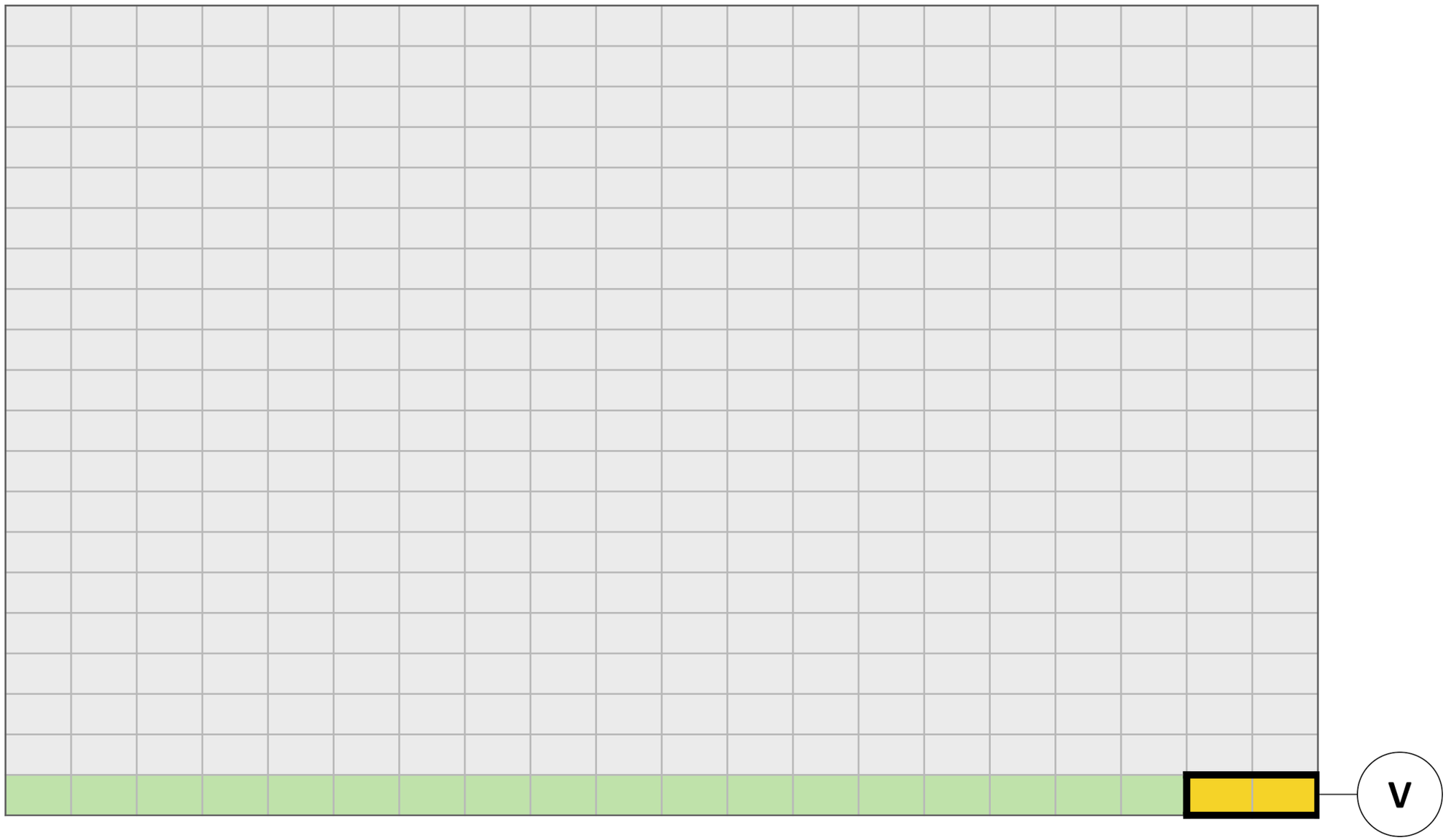
$$\text{pixel value} = \frac{1}{N}\sum_{i}^{N}(\text{pixel sample})_i$$

- developed in collaboration with LBNL MicroSystems Lab
- successfully demonstrated in a Fermilab LDRD project (2016)

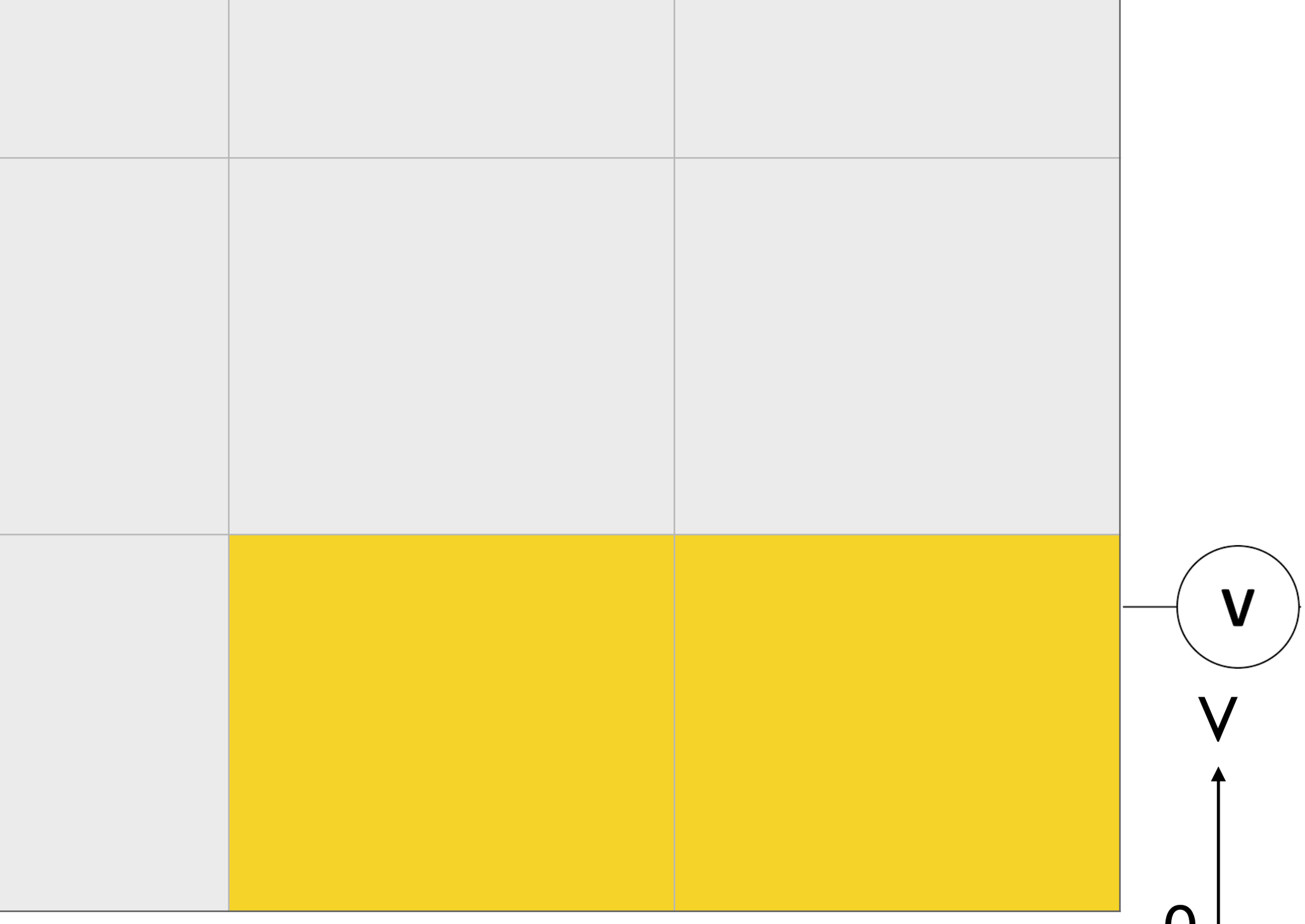
Tiffenberg, Sofo-Haro, Drlica-Wagner, RE, Guardincerri, Holland, Volansky, Yu (1706.00028, PRL)

Achieved rms noise ~ 0.06 e^- $\Longrightarrow$ Dramatic reduction in threshold!

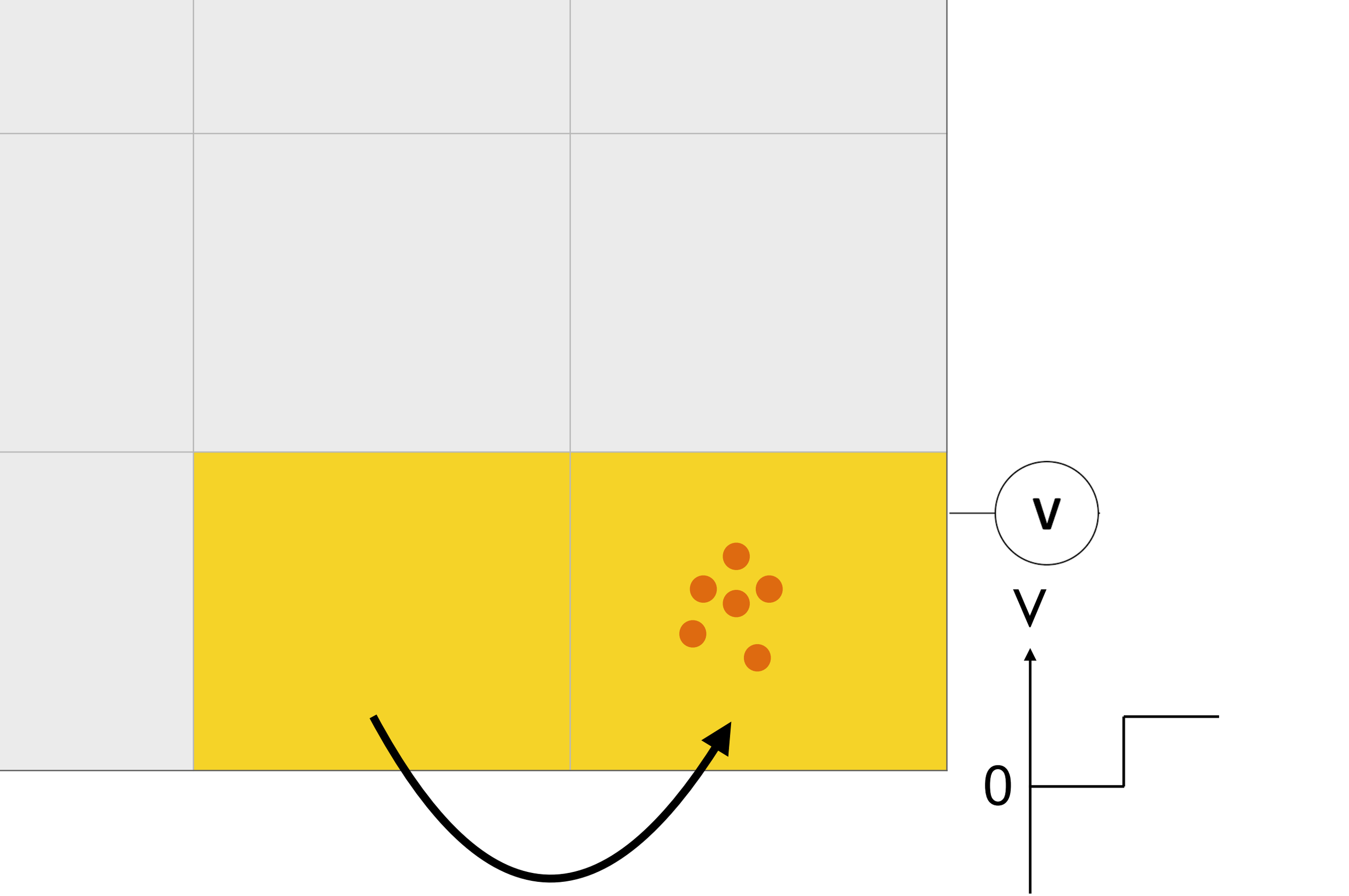
schematically

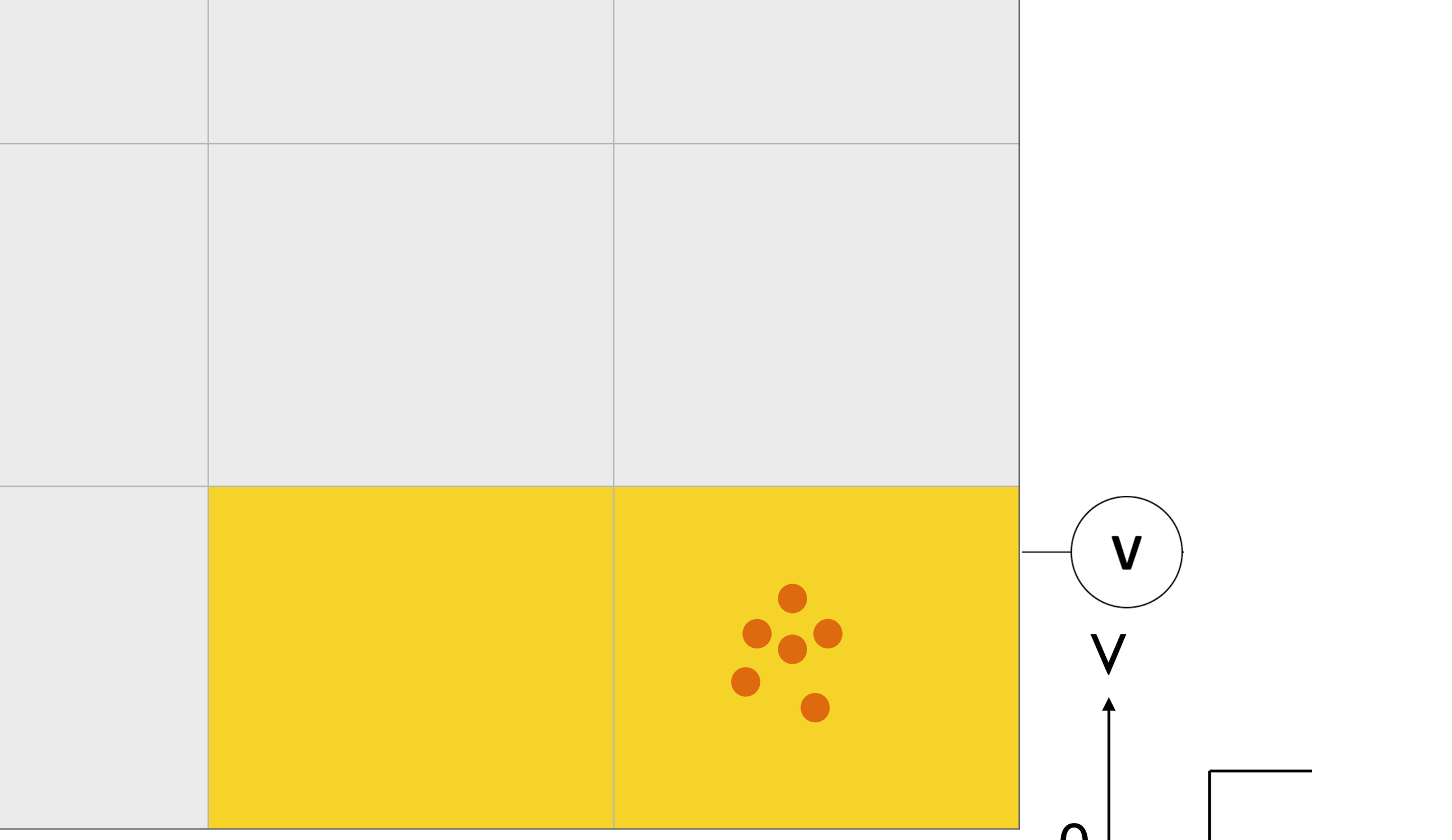


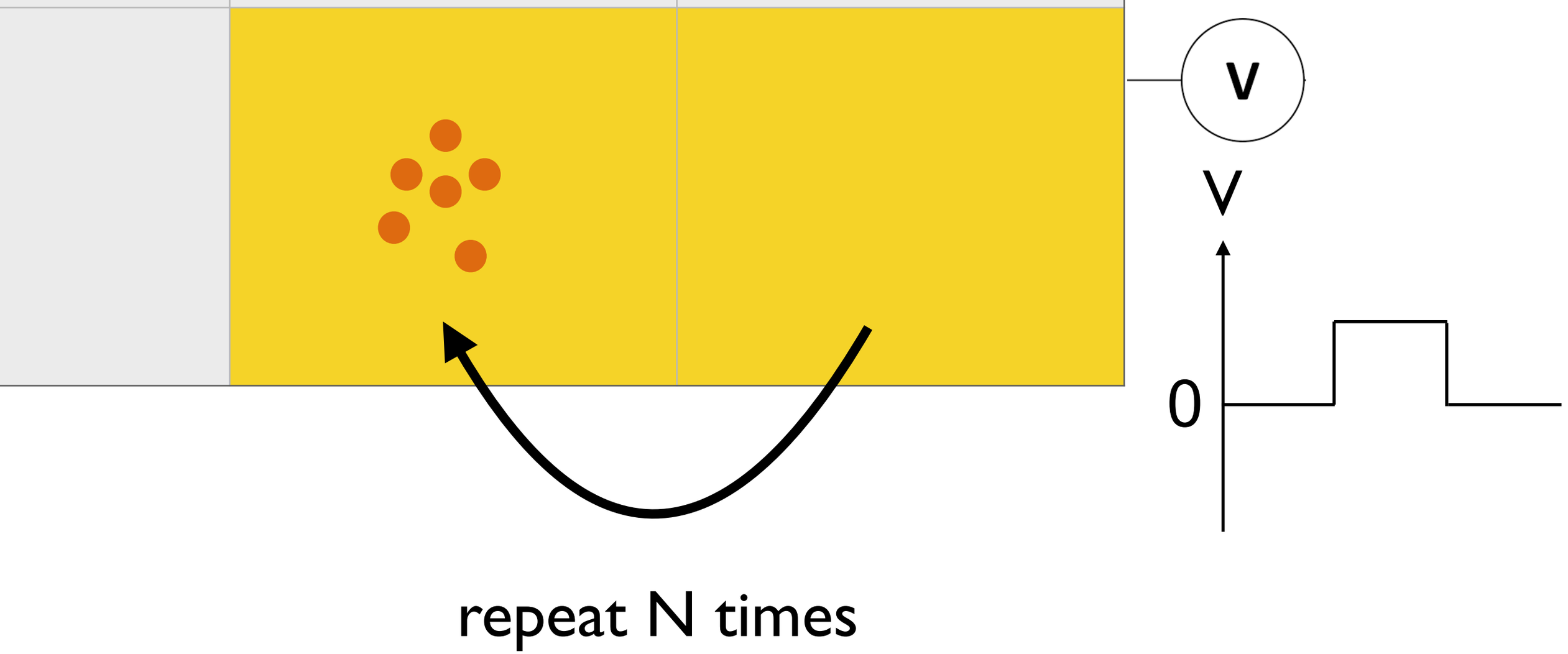
modified
readout stage


V
V
0

V
V
0

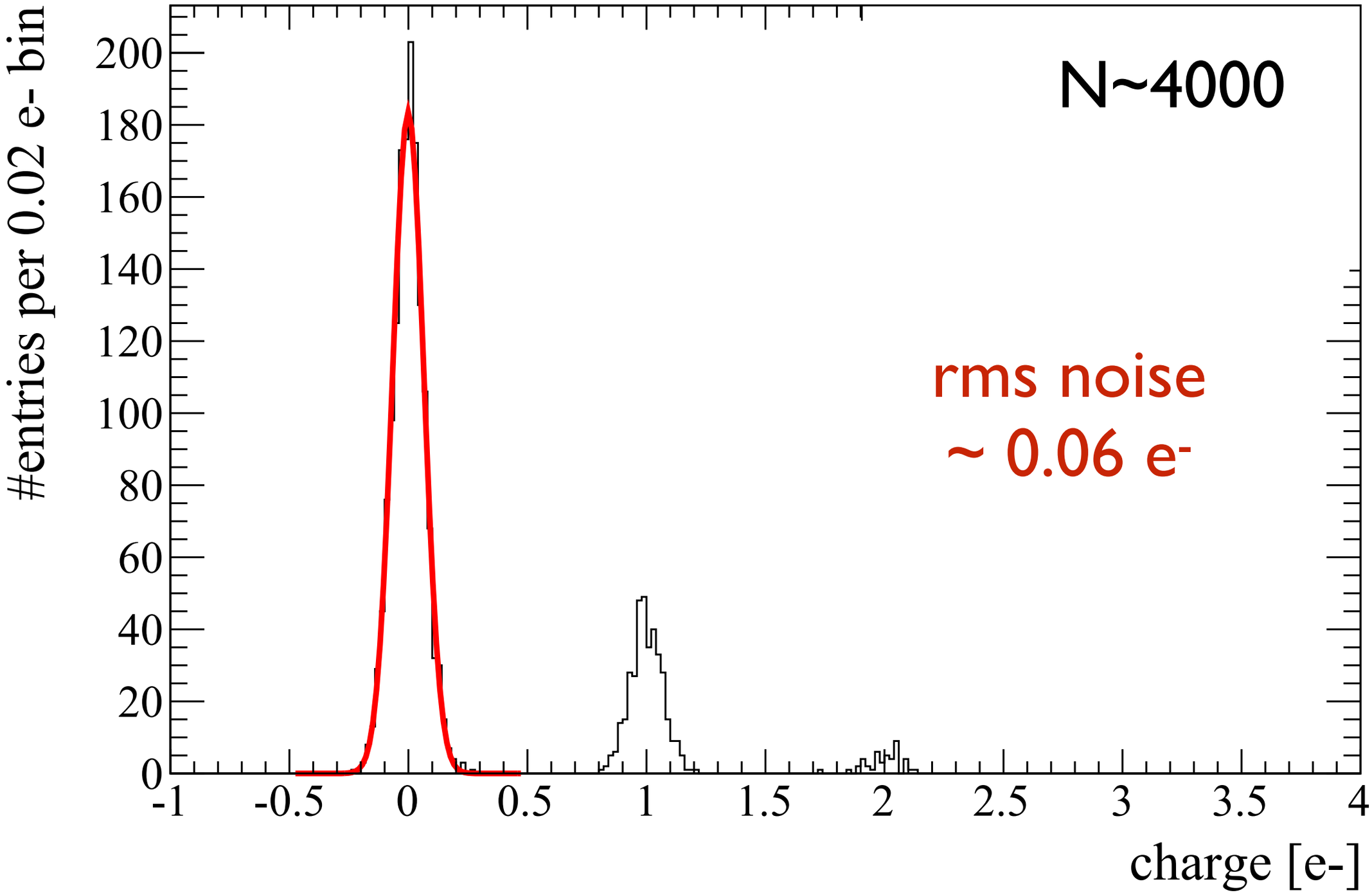

V
V
0


V
V
0



repeat N times

Counting Electrons



Tiffenberg, Sofo-Haro, Drlica-Wagner, RE, Guardincerri, Holland, Volansky, Yu (1706.00028, PRL)

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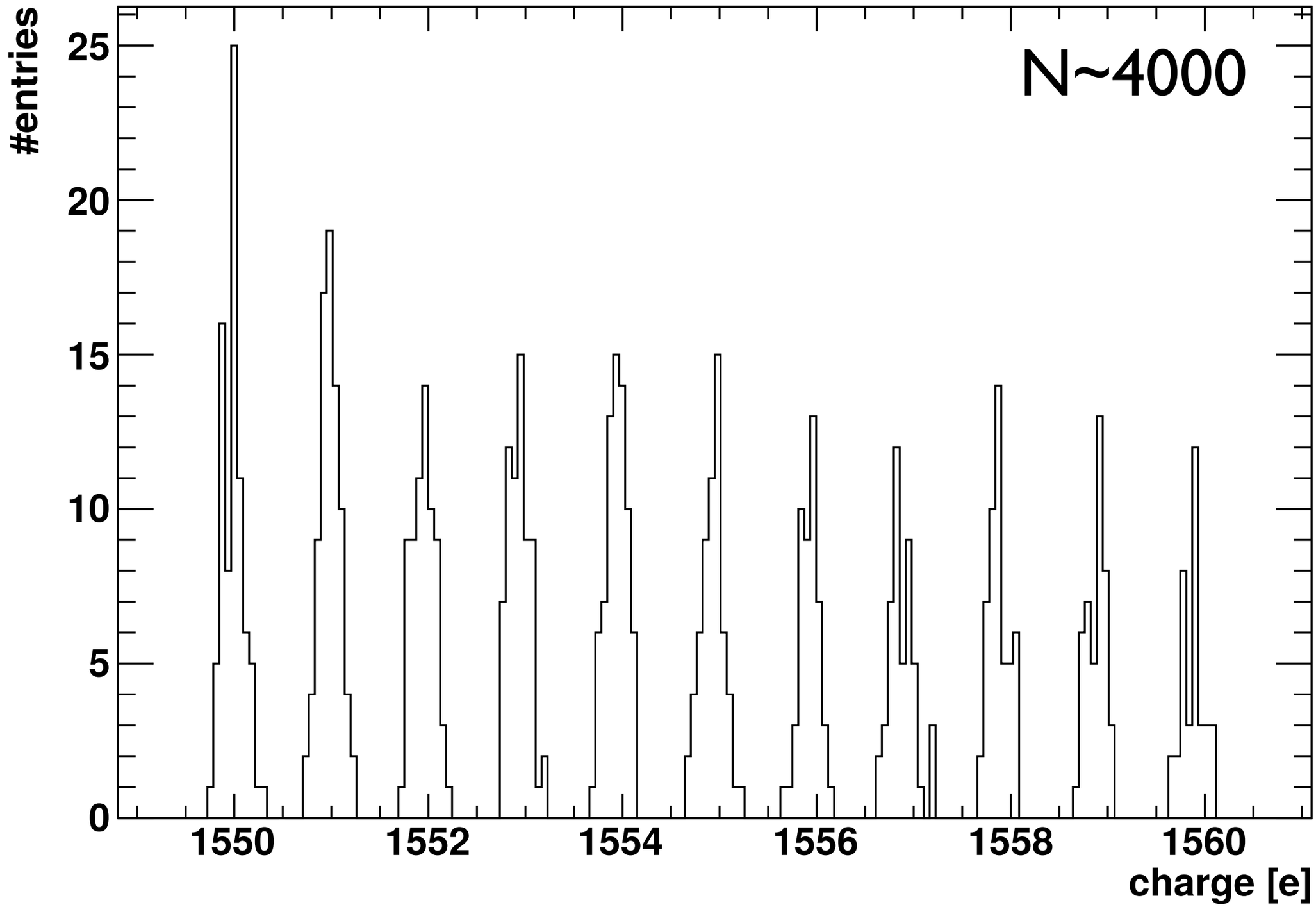


Tiffenberg, Sofo-Haro, Drlica-Wagner, RE, Guardincerri, Holland, Volansky, Yu (1706.00028, PRL)

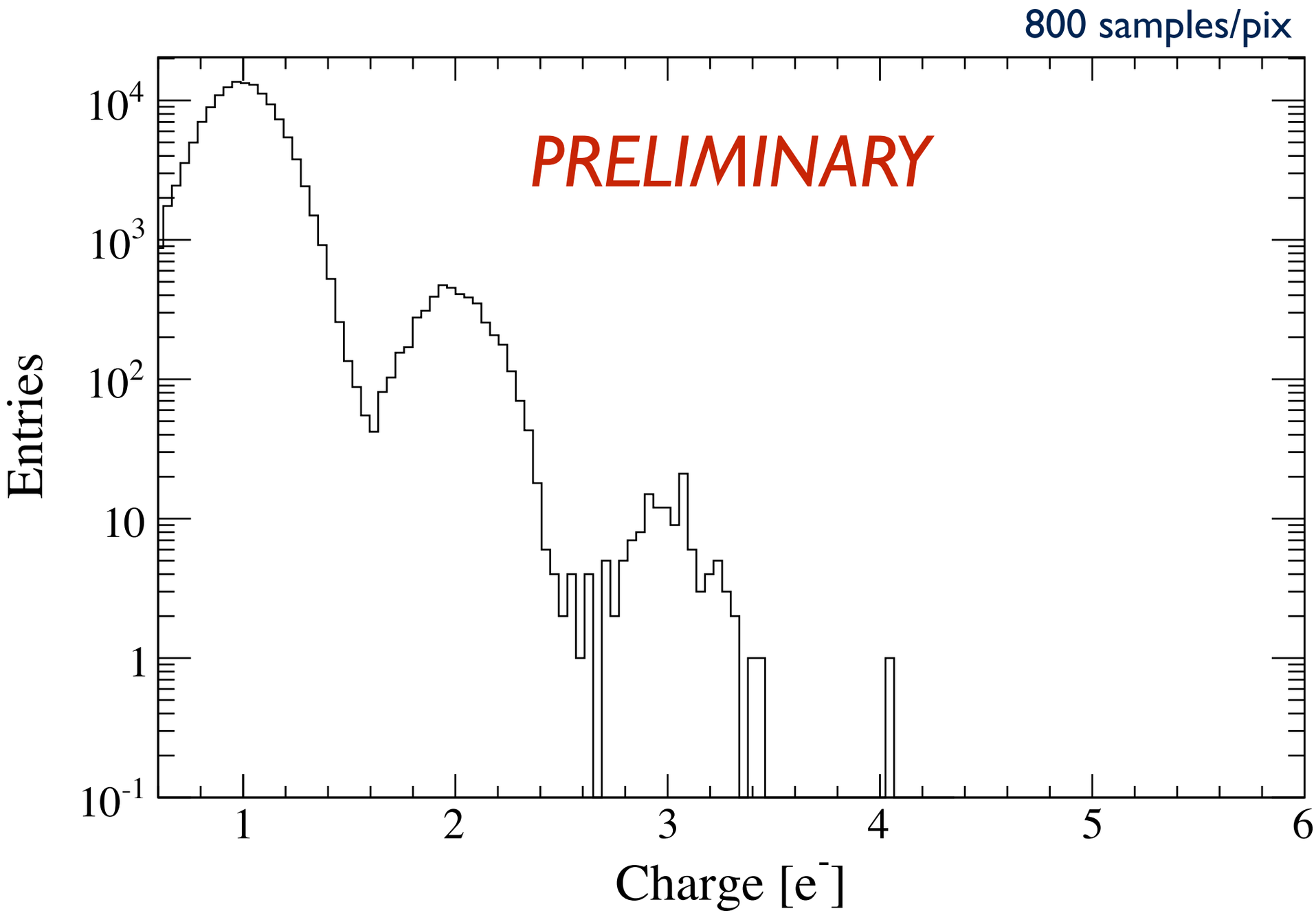
First DM Results from SENSEI prototype

- One ~0.094 gram Skipper-CCD, produced in a parasitic production run, was packaged and tested in 2017
- currently taking data ~100 m underground at MINOS FNAL
- before underground installation, we took a small amount of commissioning data on the surface
- surface exposure ~0.02 gram-days

Today: first SENSEI results (preliminary), based on surface data

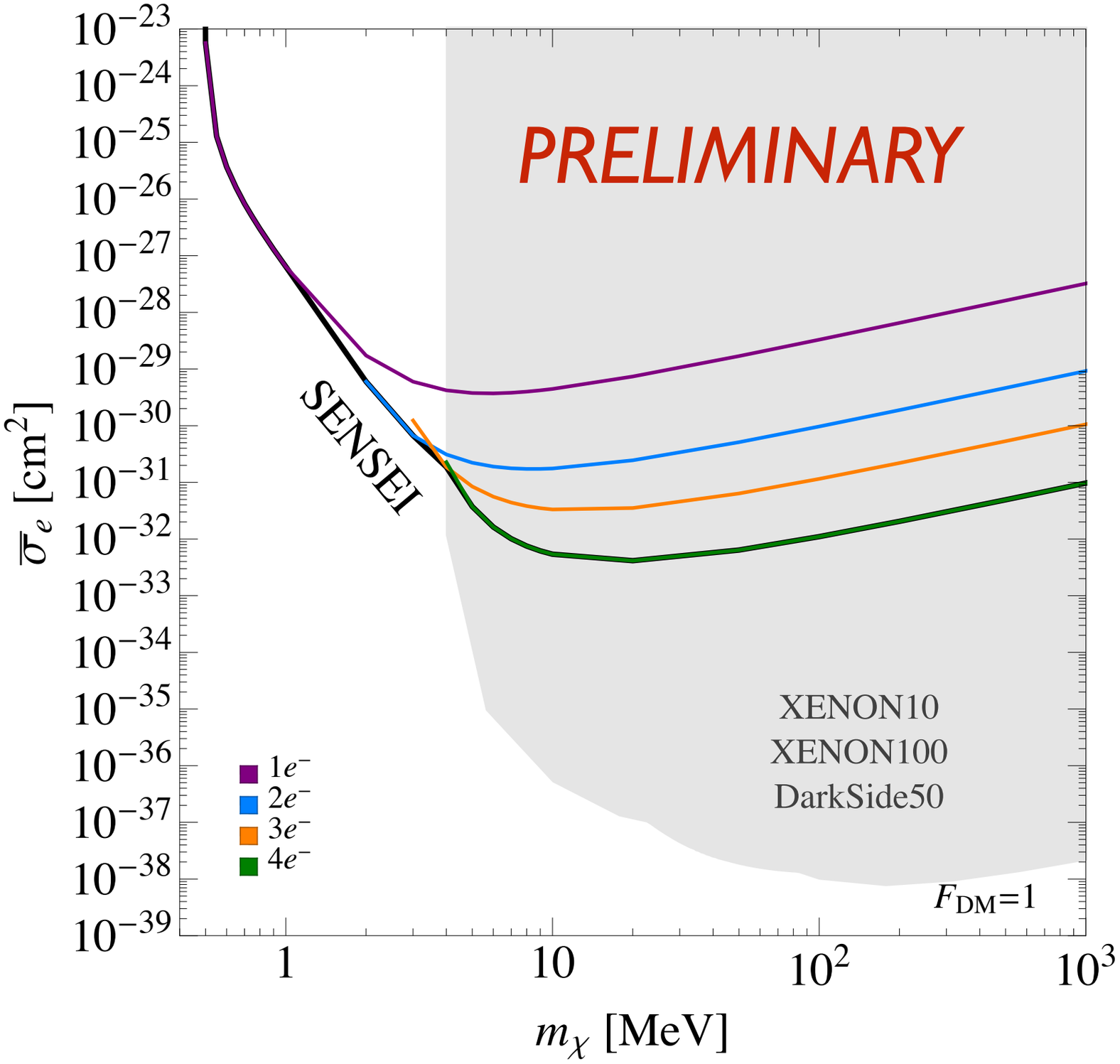
Picture of detector at MINOS

Observed Spectrum



all/mostly due to dark current (~1.1 e-/pix/day); no events with 5-100 electrons

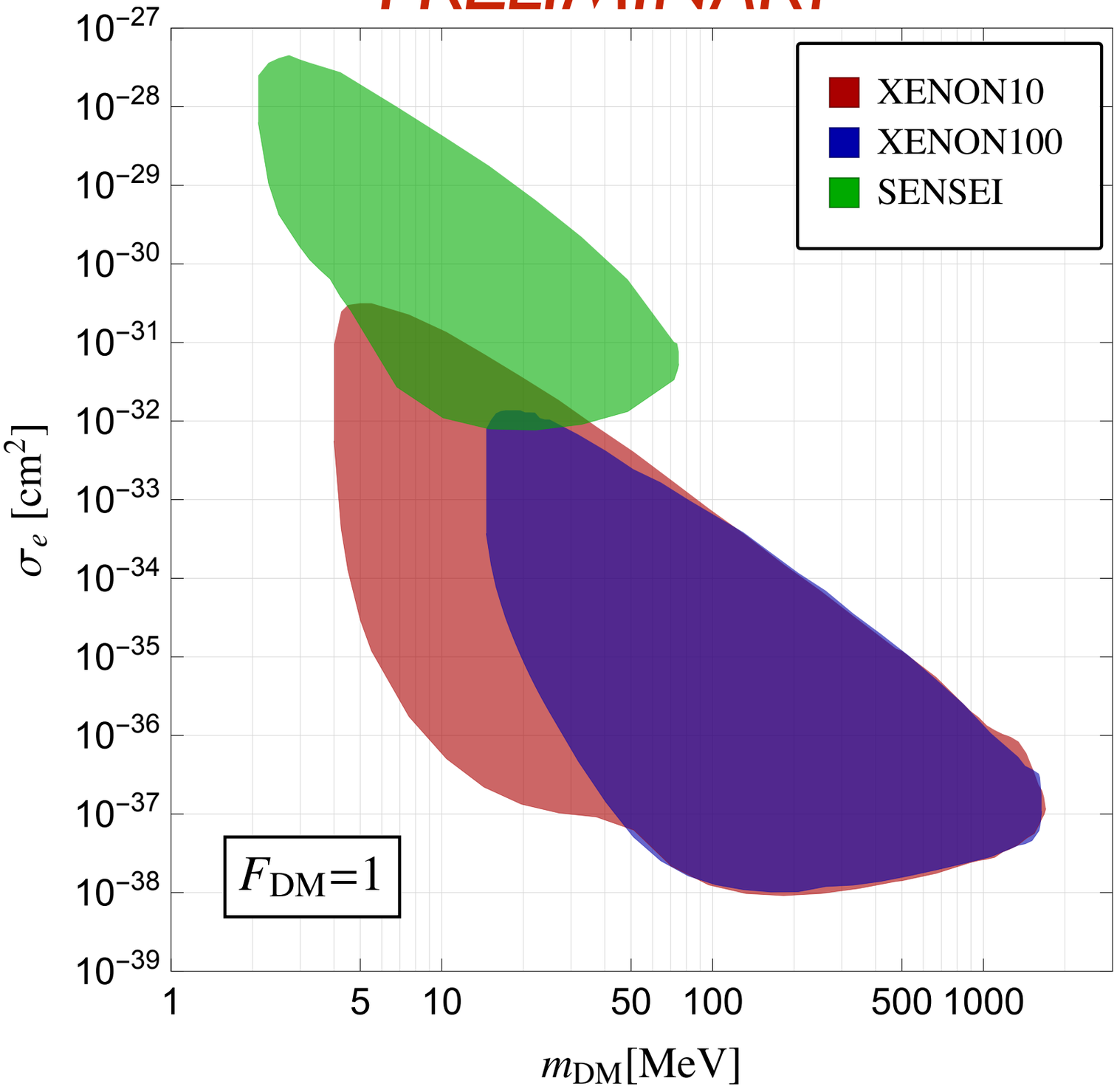
First SENSEI results (from a surface run)



- first direct-detection constraints between ~500 keV to 4 MeV!

SENSEI also probes to larger cross sections than others

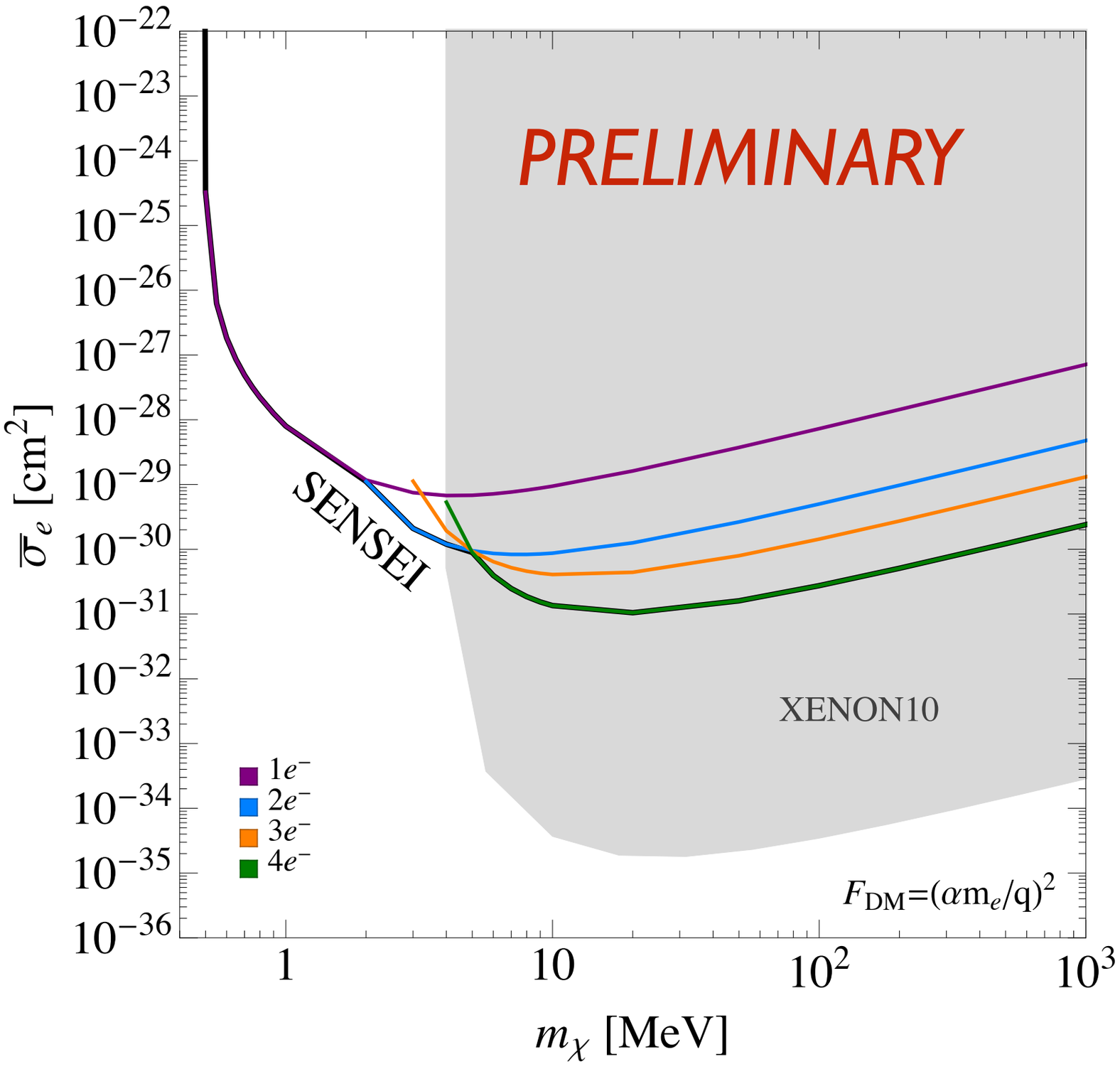
PRELIMINARY



- terrestrial effects can prevent DM from reaching detector (model-dependent)
- plot assumes dark-photon mediator

Terrestrial effects from:
Timon Emken, RE, Kouvaris, Mukul Sholapurkar (to appear)

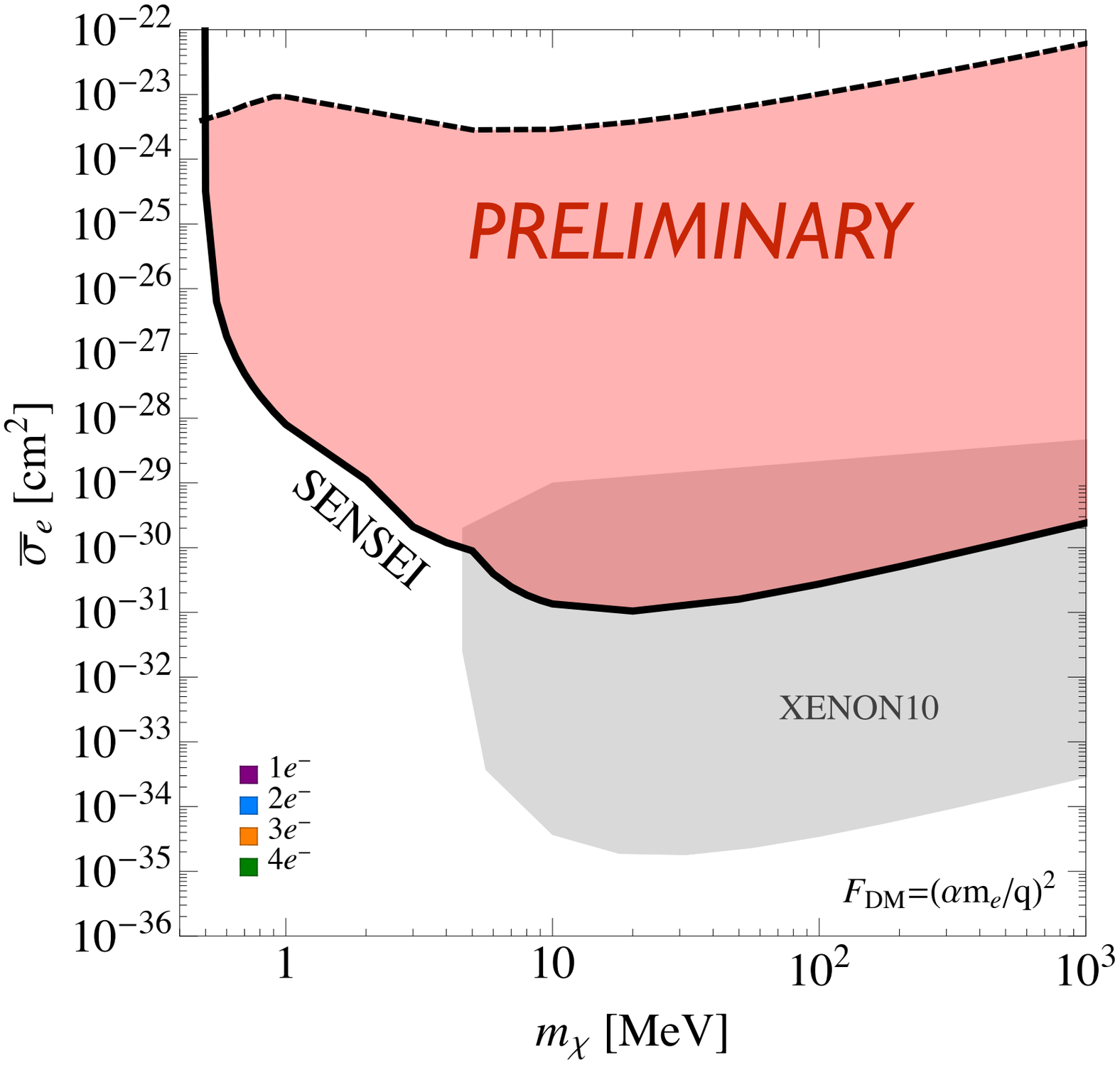
First SENSEI results: ultralight mediator



- ultralight mediator

$$\bar{\sigma}_e \propto \frac{1}{q^4}$$

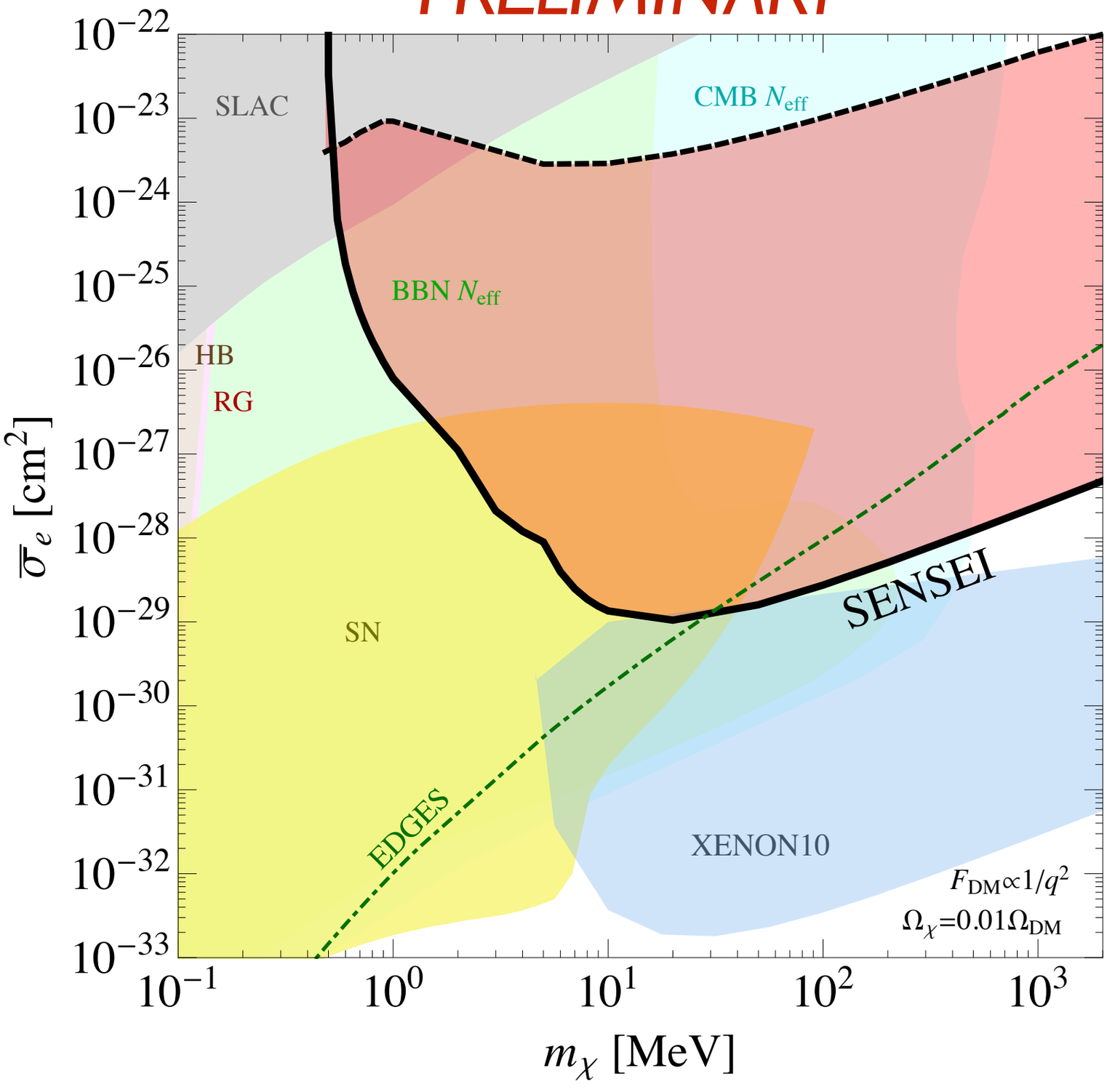
Ultralight mediator with terrestrial effects



Terrestrial effects from:
Emken, RE, Kouvaris, Sholapurkar
(to appear)

SENSEI seems to disfavor some EDGES model space

PRELIMINARY



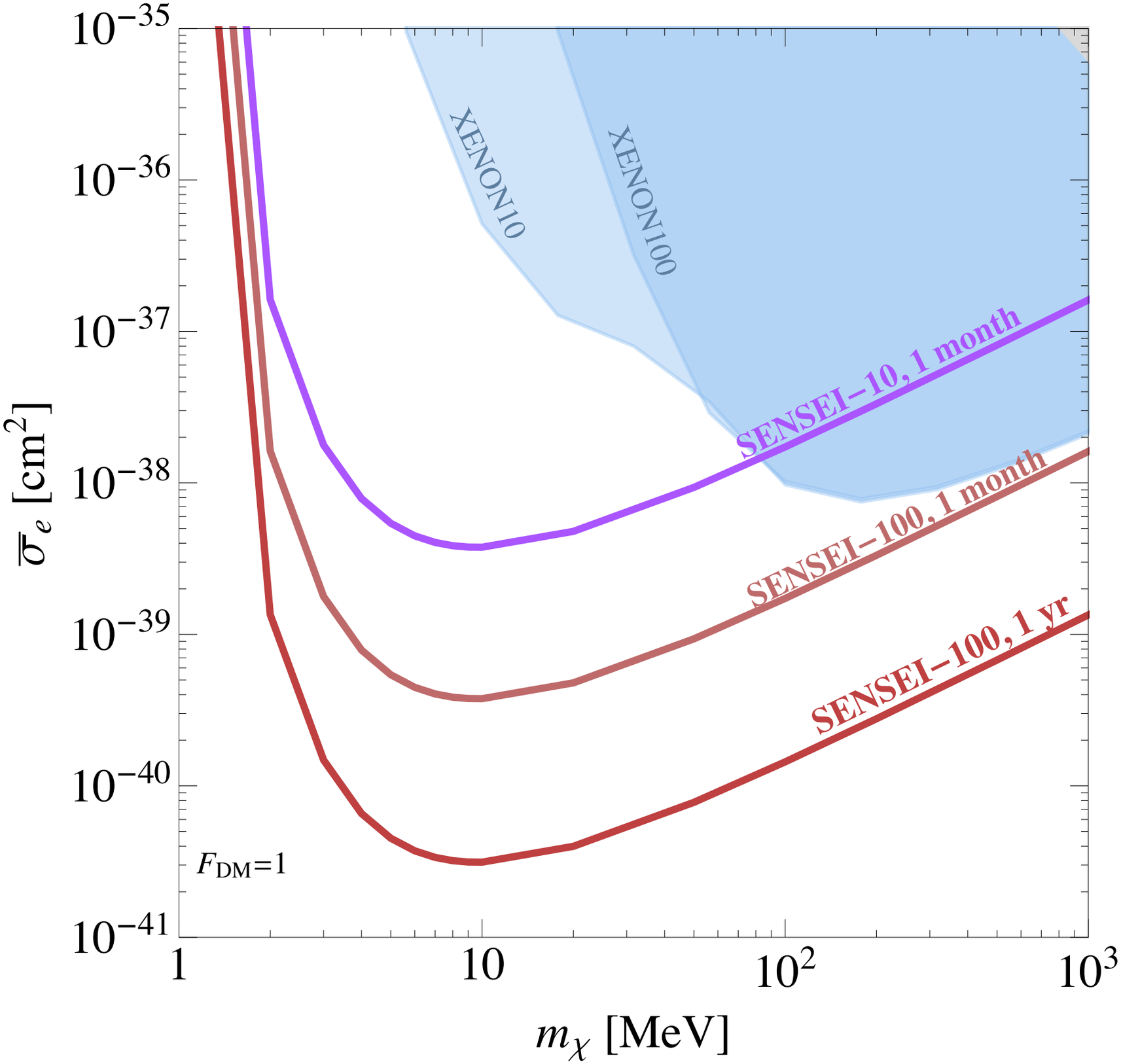
New SN constraints from:
Chang, RE, McDermott 2018

SENSEI: Goals & Current Status

deploy ~100 grams of Skipper CCDs
to search for sub-GeV DM

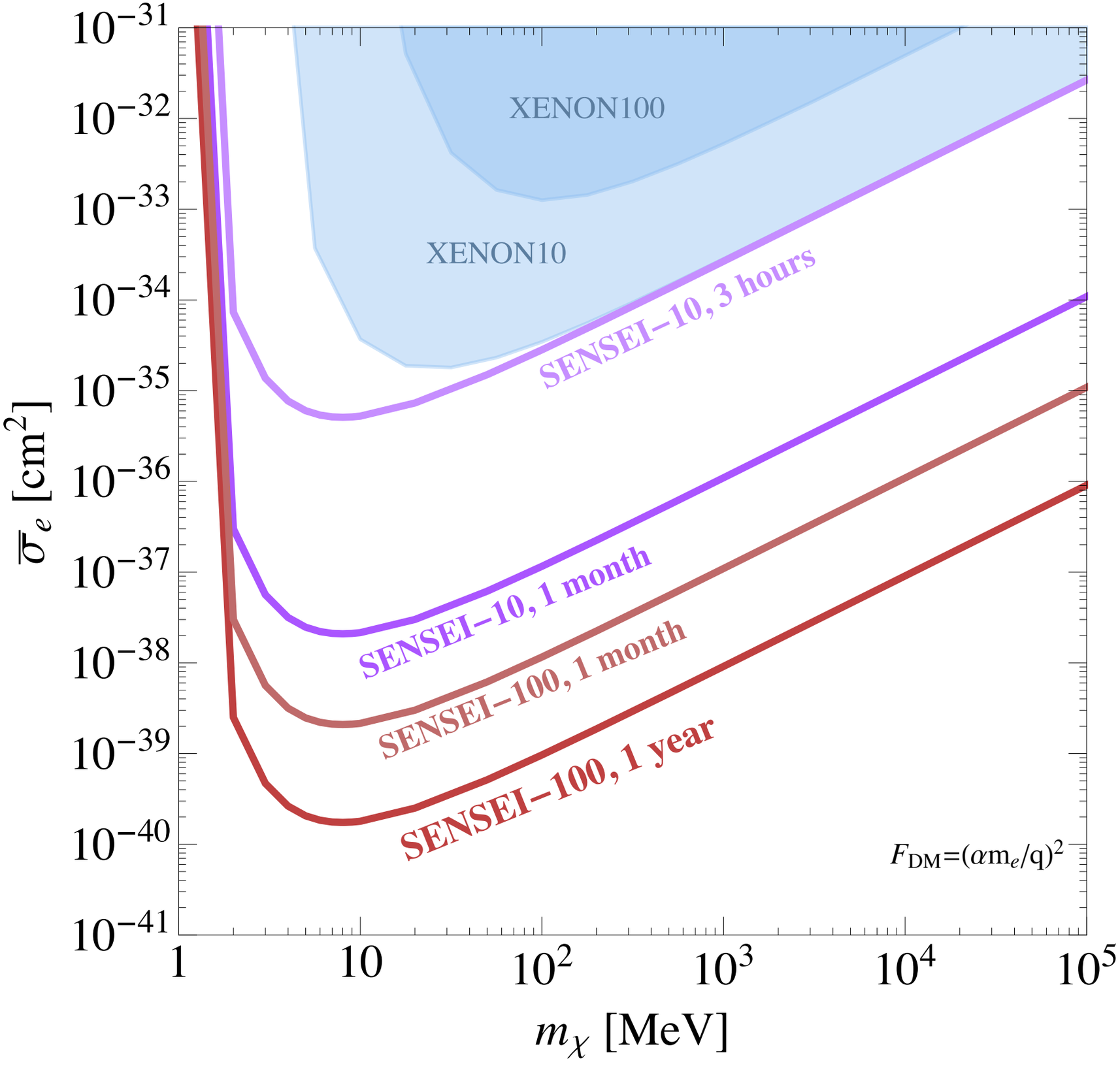
- staged approach:
  - ~10 grams at MINOS within 1 year
  - ~100 grams at a deeper site within 2 years
- improved sensors have been ordered
- designing/testing electronics, shielding, cryostat, packaging…

SENSEI projections



heavy mediator

SENSEI projections



light mediator

$$\bar{\sigma}_e \propto \frac{1}{q^4}$$

Summary

- SENSEI is the first dedicated experiment searching for electron recoils

- SENSEI's first results, using a prototype detector on the surface, probes 0.5-4 MeV masses for the first time, and larger cross sections than existing sub-GeV direct-detection constraints

- Full SENSEI experiment will use better sensors & collect almost 2 million times the exposure of this surface run in next ~3 years, probing large regions of uncharted territory populated by popular models