Belina von Krosigk (belina.von.krosigk@uni-hamburg.de)

LIP Seminar, 08.04. 2021

LOW MASS DARK MATTER SEARCHES AT SuperCDMS

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Emmy Noether-Programm
DFG Deutsche Forschungsgemeinschaft

Cluster of Excellence **Quantum Universe**

EVIDENCE FOR DARK MATTER


NASA/STScI; Magellan/U.Arizona/D.Clowe et al.

GALAXY CLUSTERS


Most "ordinary" matter
Most mass
Most mass
X-ray: NASA/CXC/CfA/M. Markevitch et al.
Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/D. Clowe et al.
NASA/STScI; Magellan/U.Arizona/D.Clowe et al.

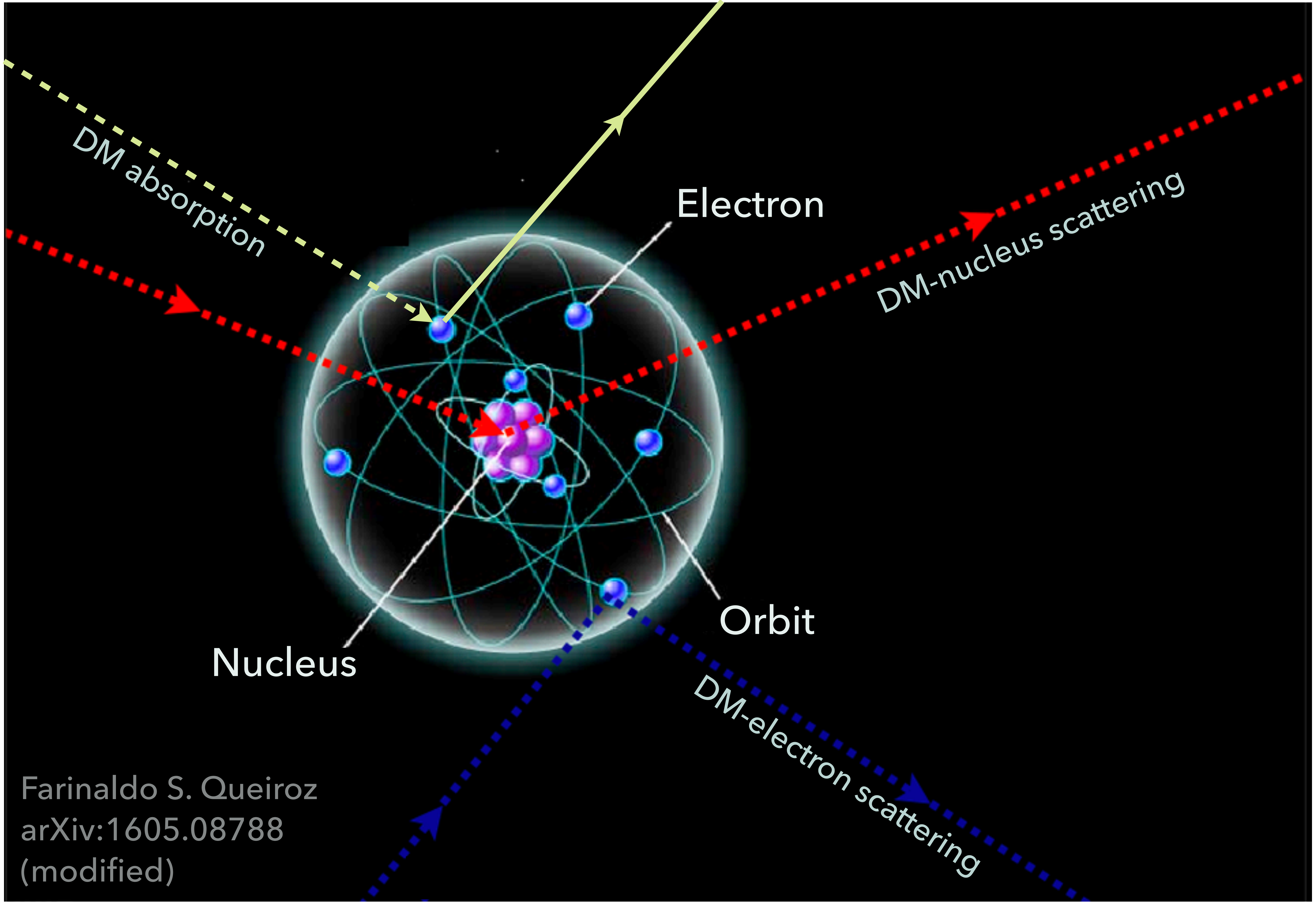
~ 85 %

OF ALL MATTER IS DARK!

Artist’s impression of a spiral galaxy embedded in a dark matter halo (Credit: ESO / L. Calçada)

Artist's impression of a spiral galaxy embedded in a dark matter halo (Credit: ESO / L. Calçada)

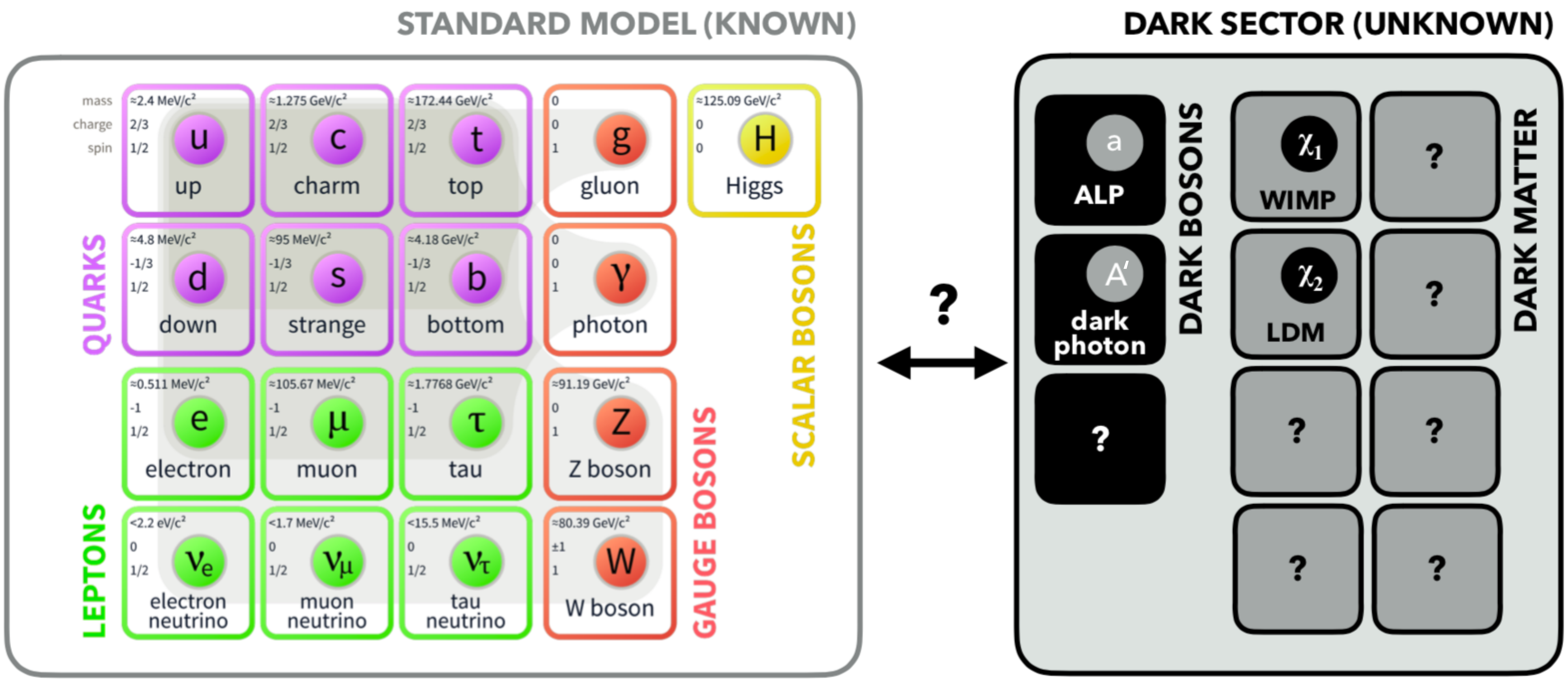
DIRECT DARK MATTER DETECTION



Any direct interaction with the atoms of the material.

THE DARK SECTOR

Image: Torben Ferber



LDM: Light Dark Matter

ALP: Axion-Like-Particle

THE SuperCDMS EXPERIMENT

THE SuperCDMS COLLABORATION

California Inst. of Tech. | C2N* | Durham University | FNAL | NISER | NIST*

Northwestern | PNNL | Queen's University | Santa Clara University | SLAC | South Dakota SM&T

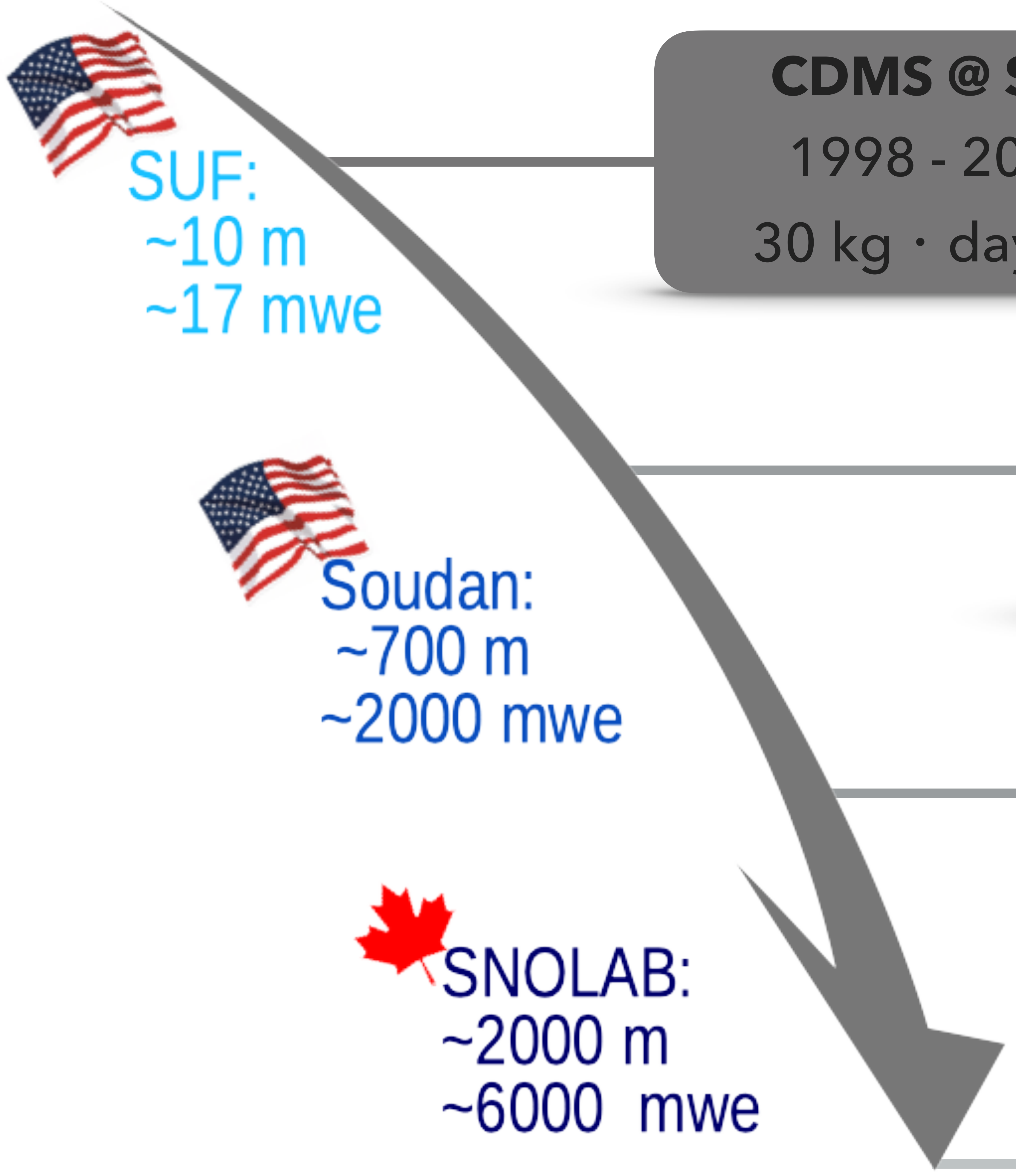
SMU | SNOLAB | Stanford University | Texas A&M University | TRIUMF | U. British Columbia

U. California, Berkeley | U. Colorado Denver | U. Florida | U. Hamburg | U. Montréal

U. Minnesota | U. South Dakota | U. Toronto

* Associate members

PAST AND FUTURE OF (Super)CDMS



CDMS @ SUF
1998 - 2002
30 kg · day Ge

SUF: Stanford Underground Facility

CDMS II @ Soudan
2003 - 2009
400 kg · day Ge

SuperCDMS @ Soudan
2009 - 2015
6.8 kg · yr Ge

SuperCDMS @ SNOLAB
2023 - 2027, 2027 - 20xx
100 kg · yr Ge, 14.4 kg · yr Si

PAST AND FUTURE OF (Super)CDMS

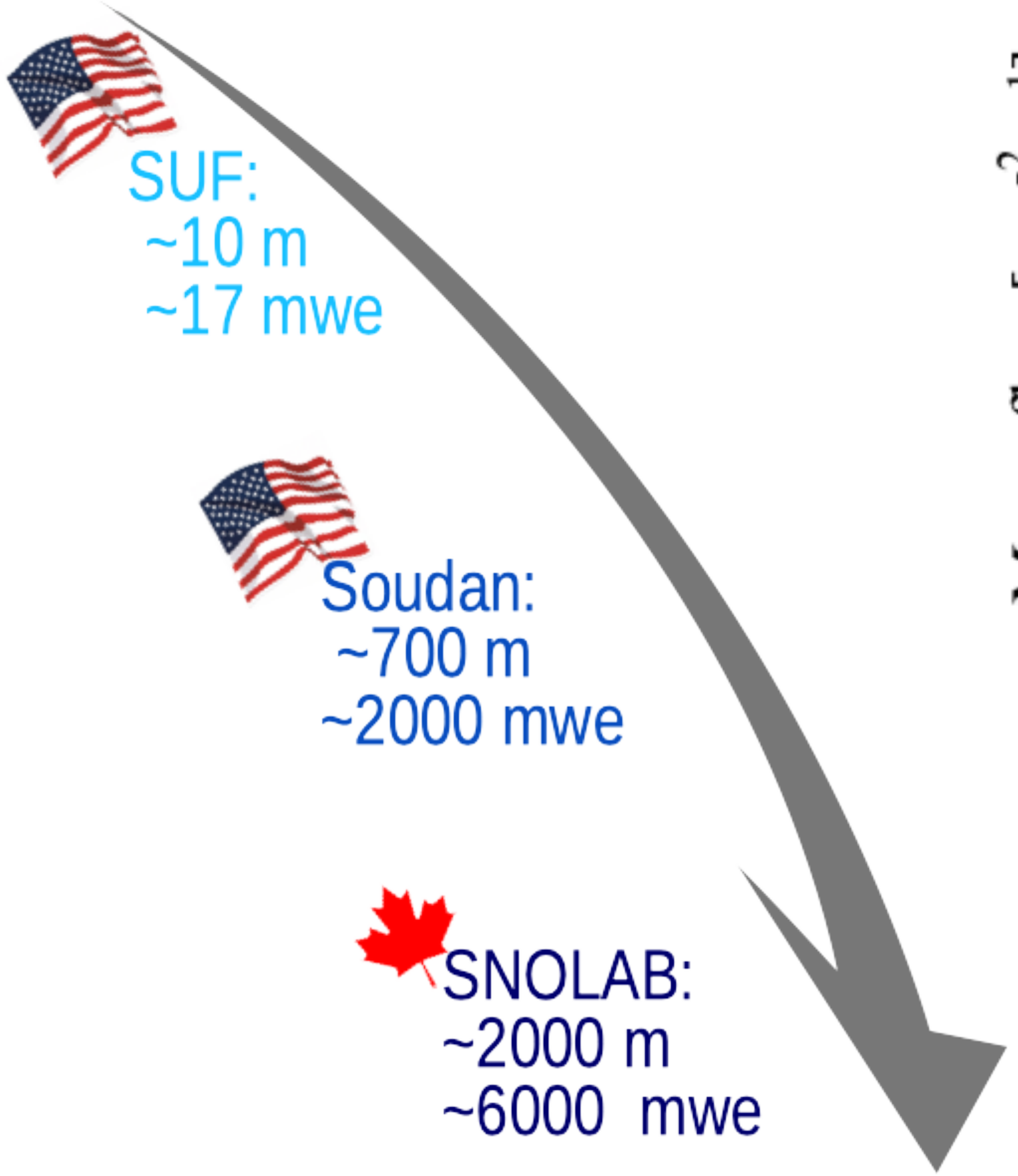
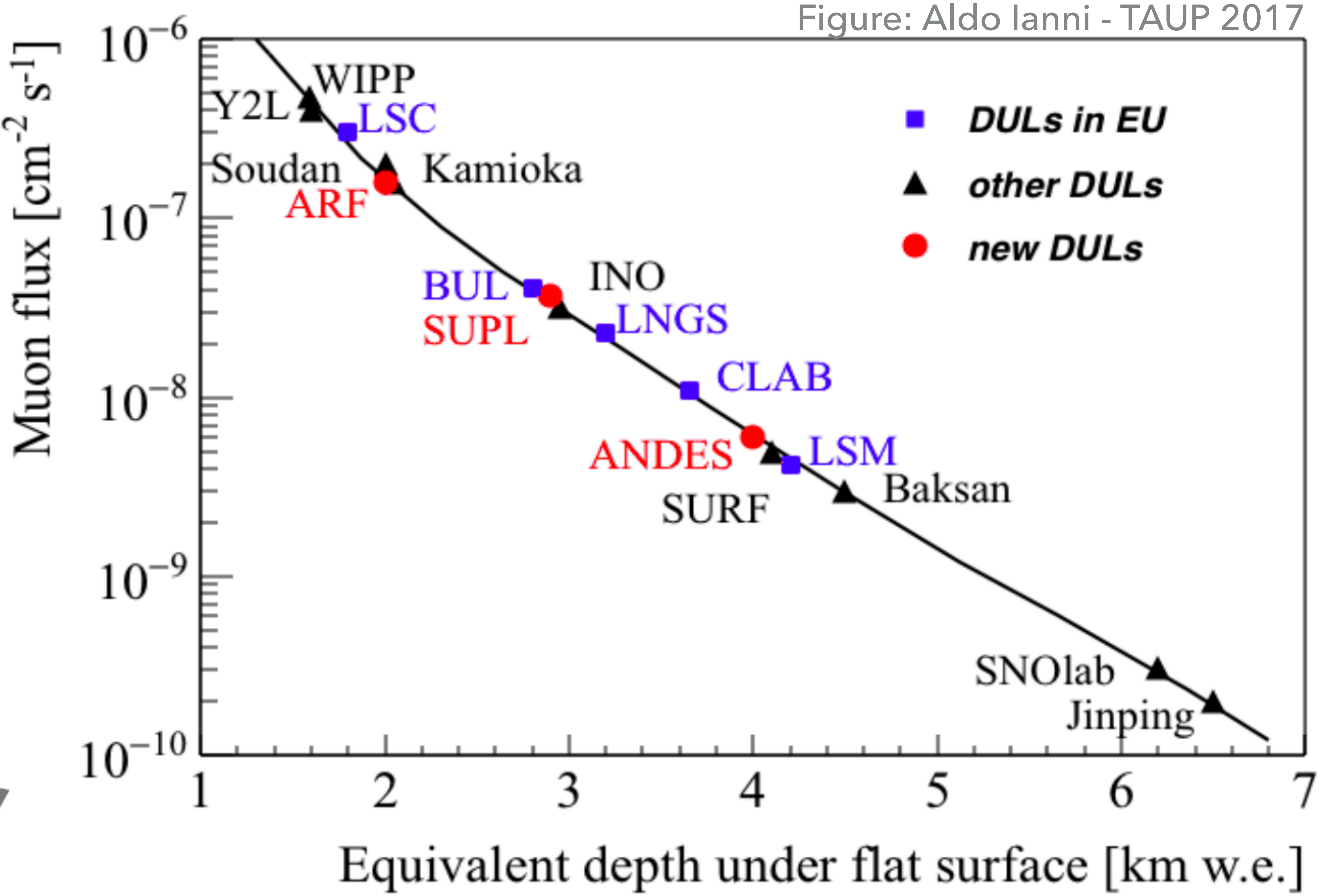
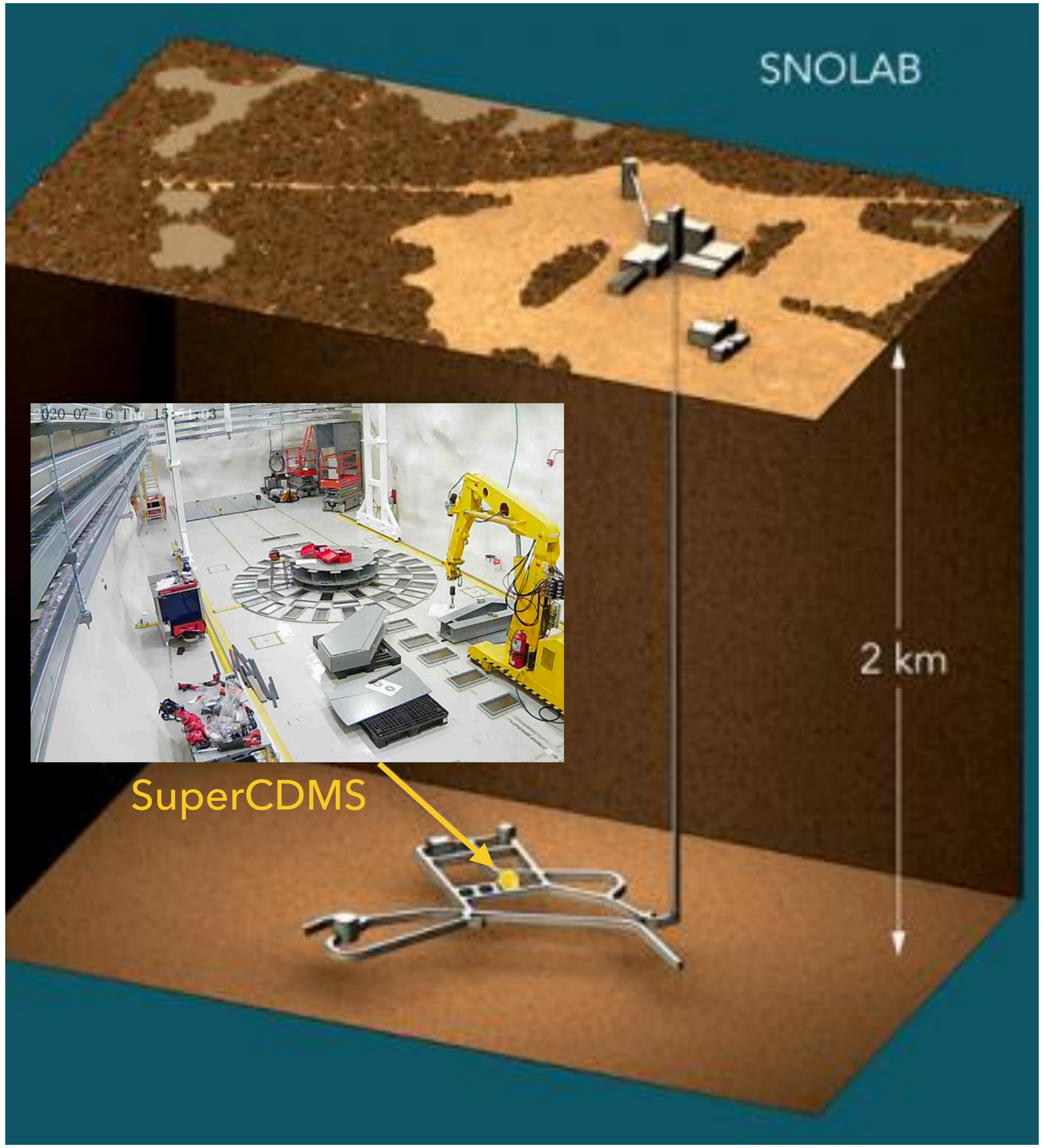


Figure: Aldo Ianni - TAUP 2017

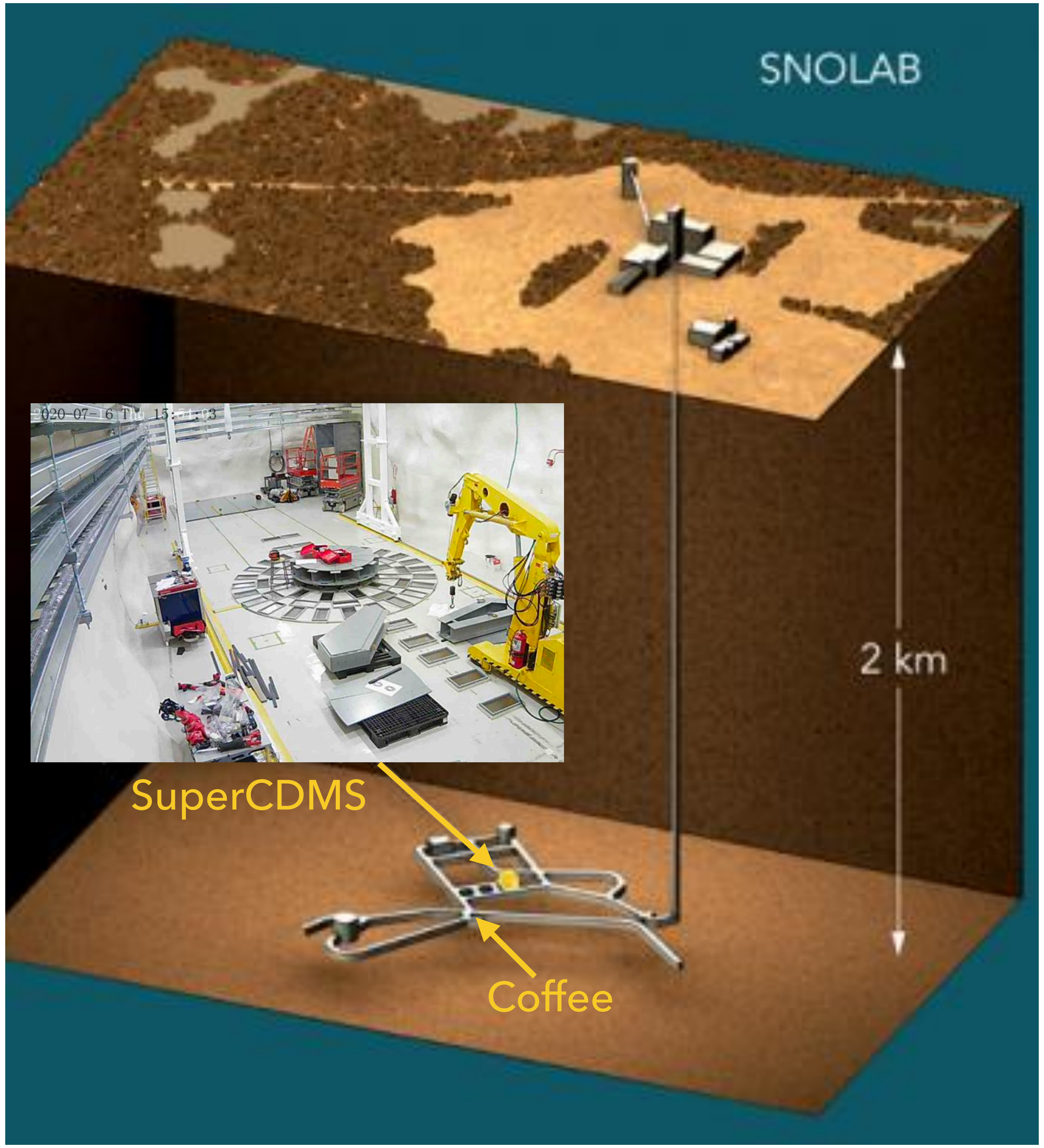


SuperCDMS AT SNOLAB



- ~ 2km deep underground in an active mine
  - 0.27 muons per m^2/day
- Cleanroom class 2000
- Home to ~ 10 low background experiments

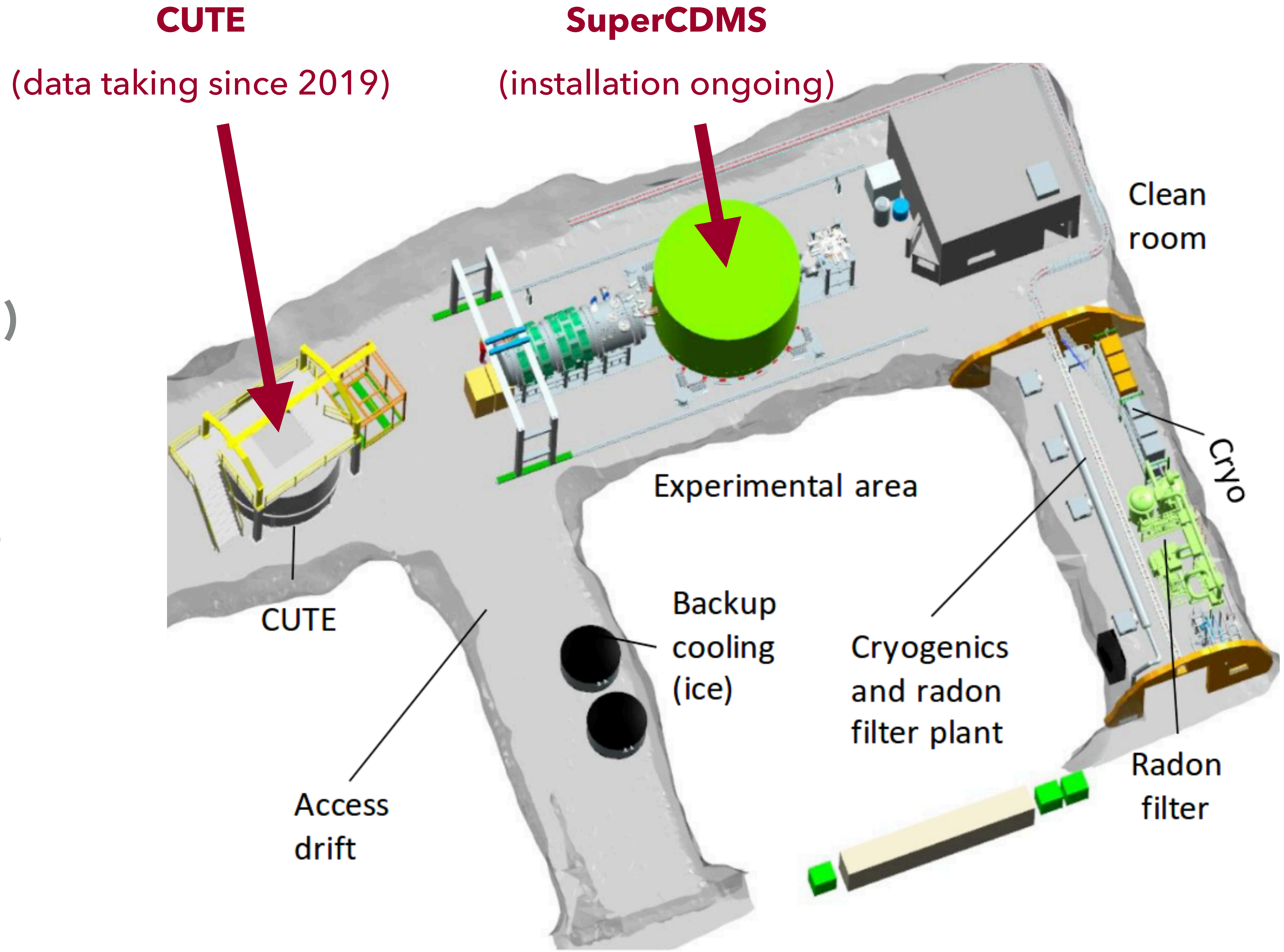
SuperCDMS AT SNOLAB



- ~ 2km deep underground in an active mine
  - 0.27 muons per m^2/day
- Cleanroom class 2000
- Home to ~ 10 low background experiments

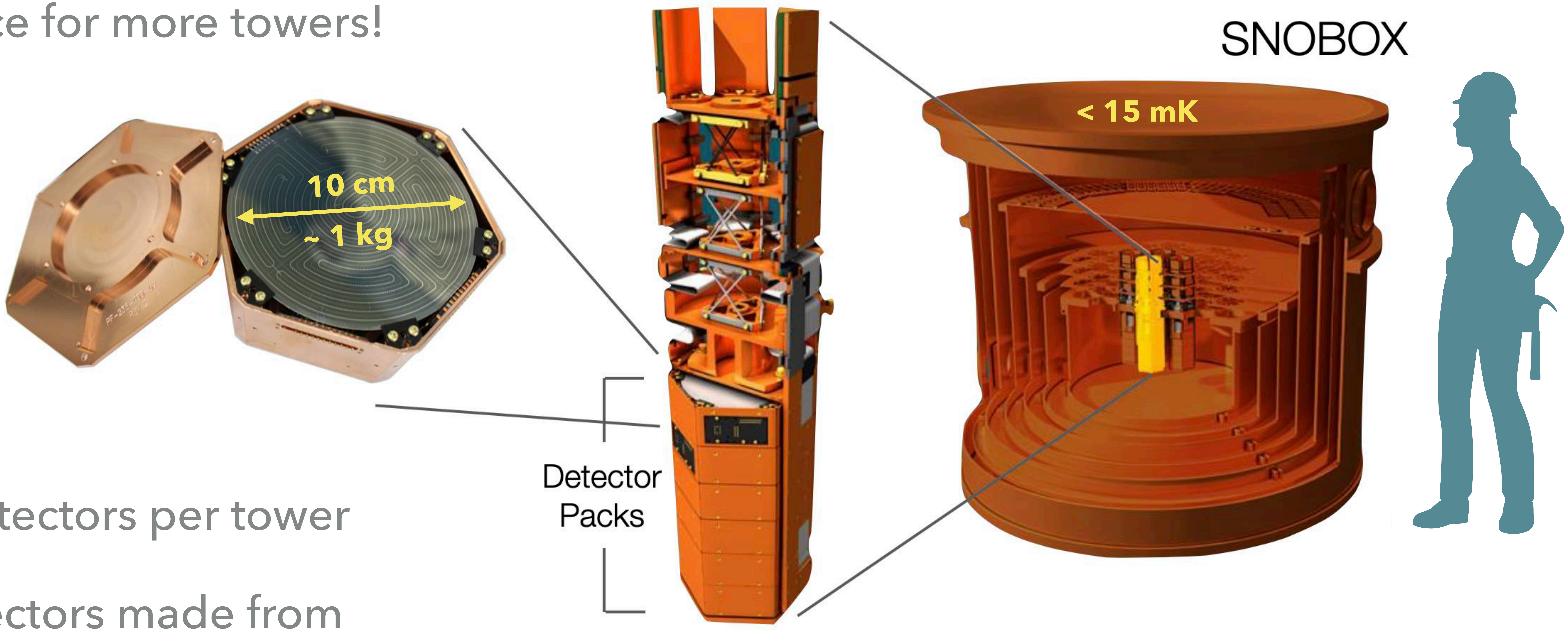
STATUS OF SuperCDMS AND CUTE

- **R&D program ongoing (HVeV, CPD)**
- Early science with CUTE in 2021
- Commissioning of SuperCDMS 2023
- **Initial payload run starting in 2023**



THE SuperCDMS SET-UP

- Starting with 4 towers
- Space for more towers!

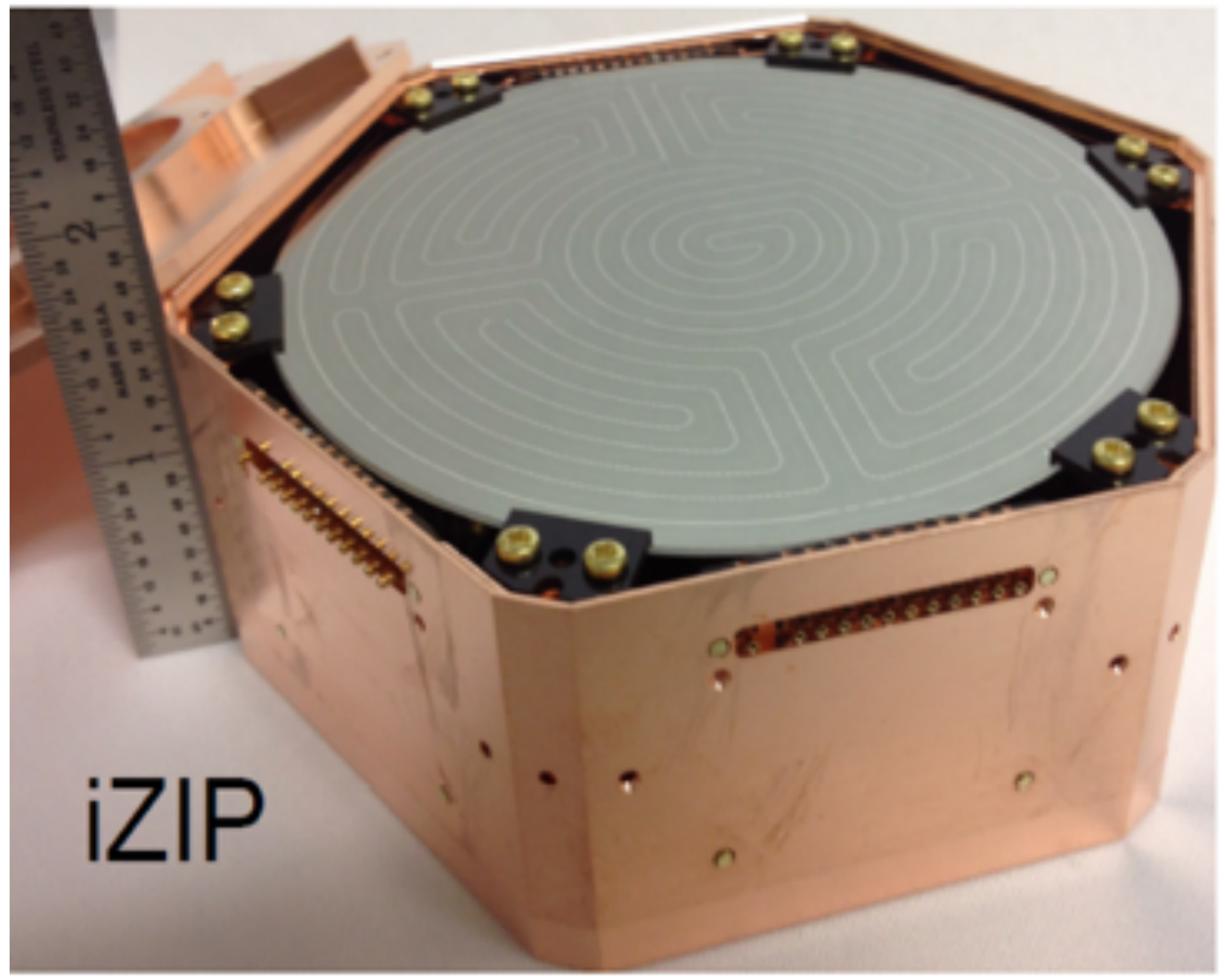


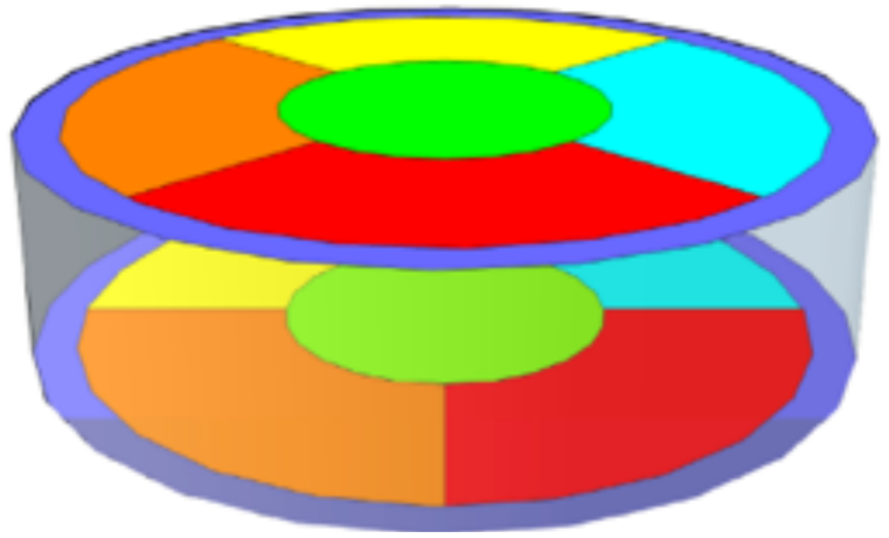
- 6 detectors per tower
- Detectors made from Si and Ge

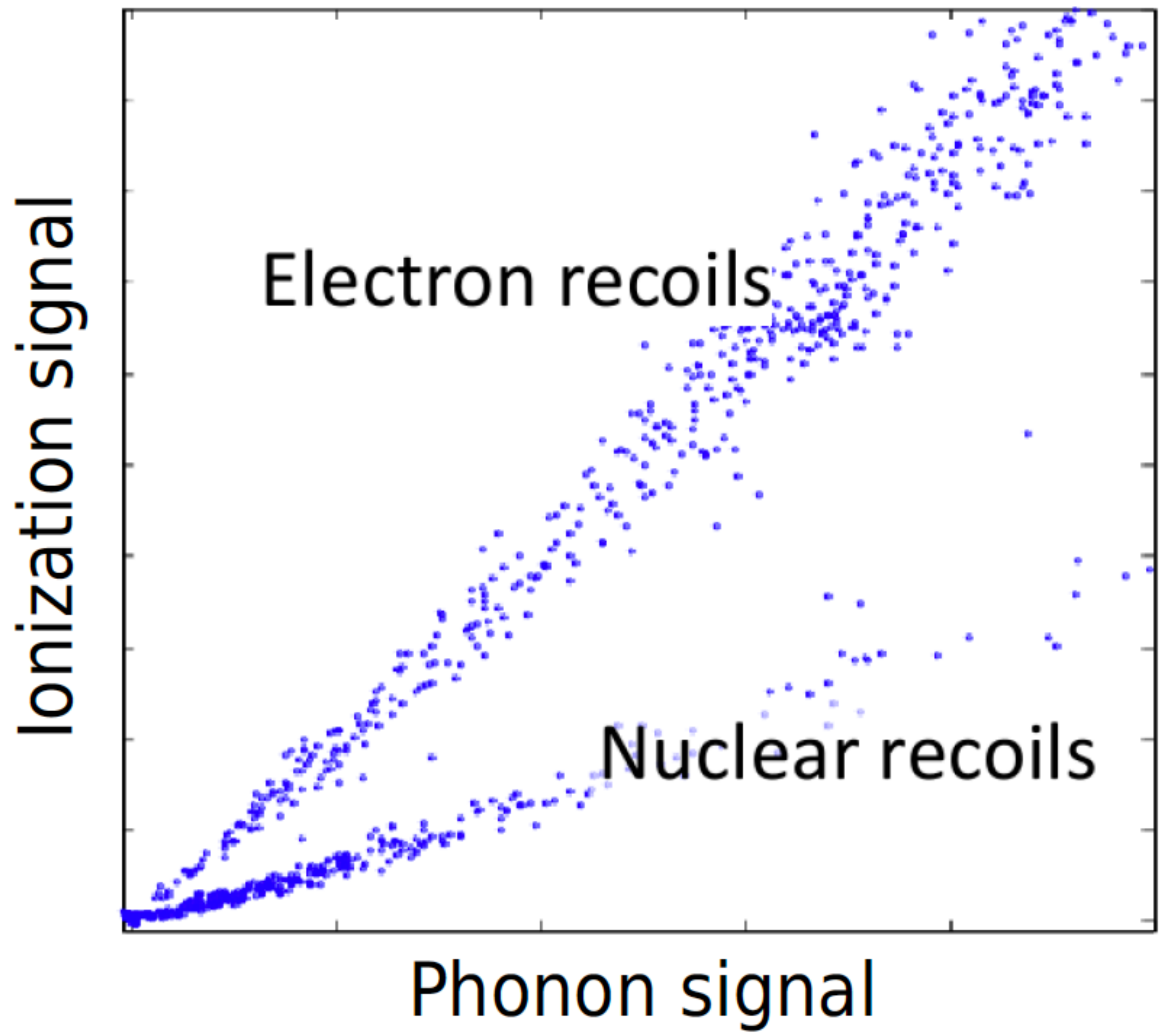
SILICON AND GERMANIUM DETECTORS

Incoming, interacting particles generate

phonons (i.e. heat / lattice vibrations) and **electron-hole pairs** (via ionization)







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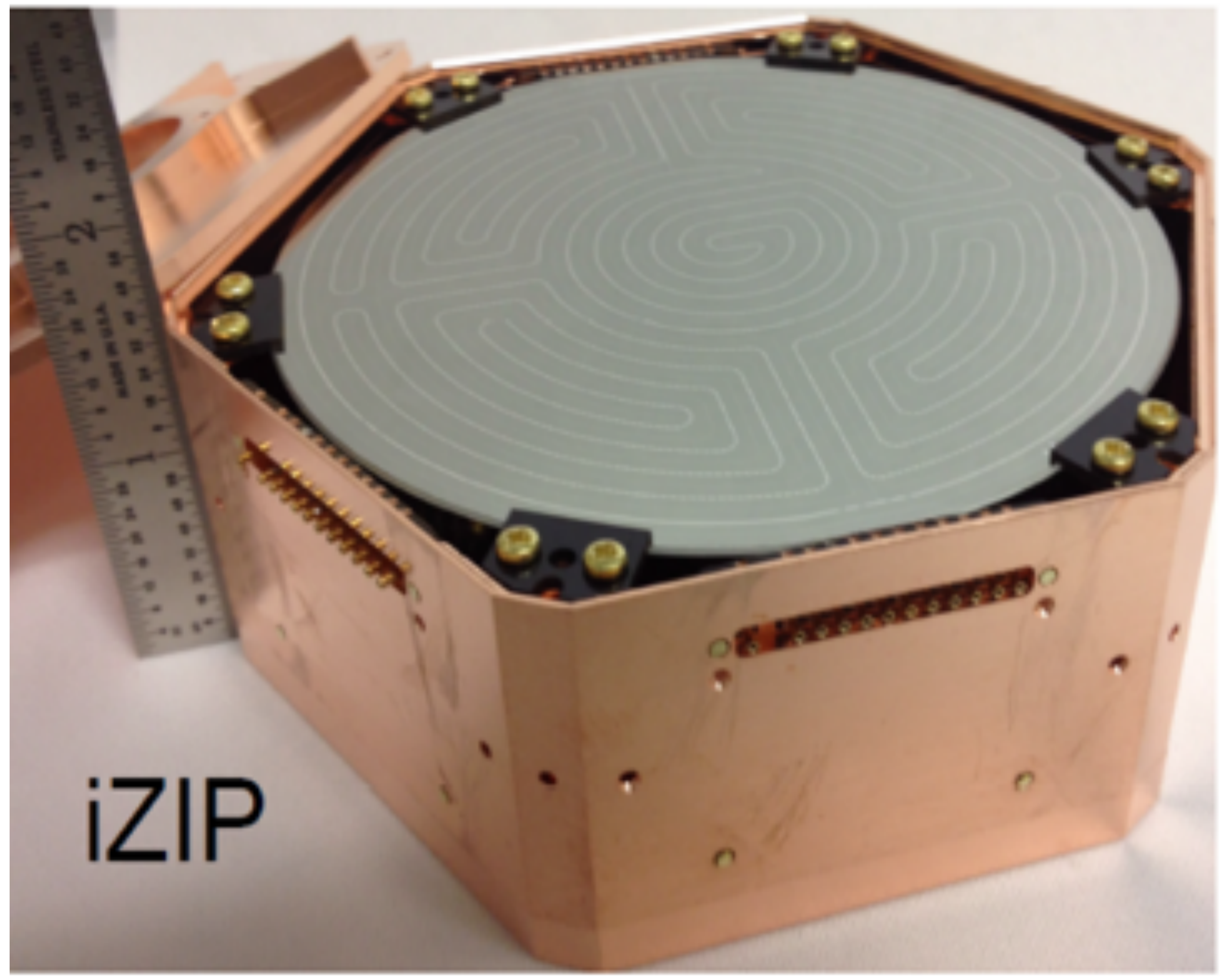
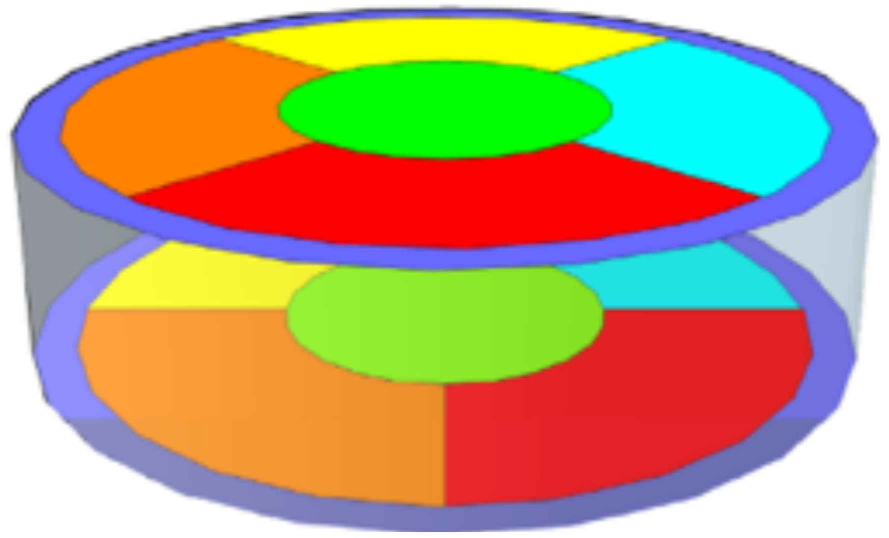
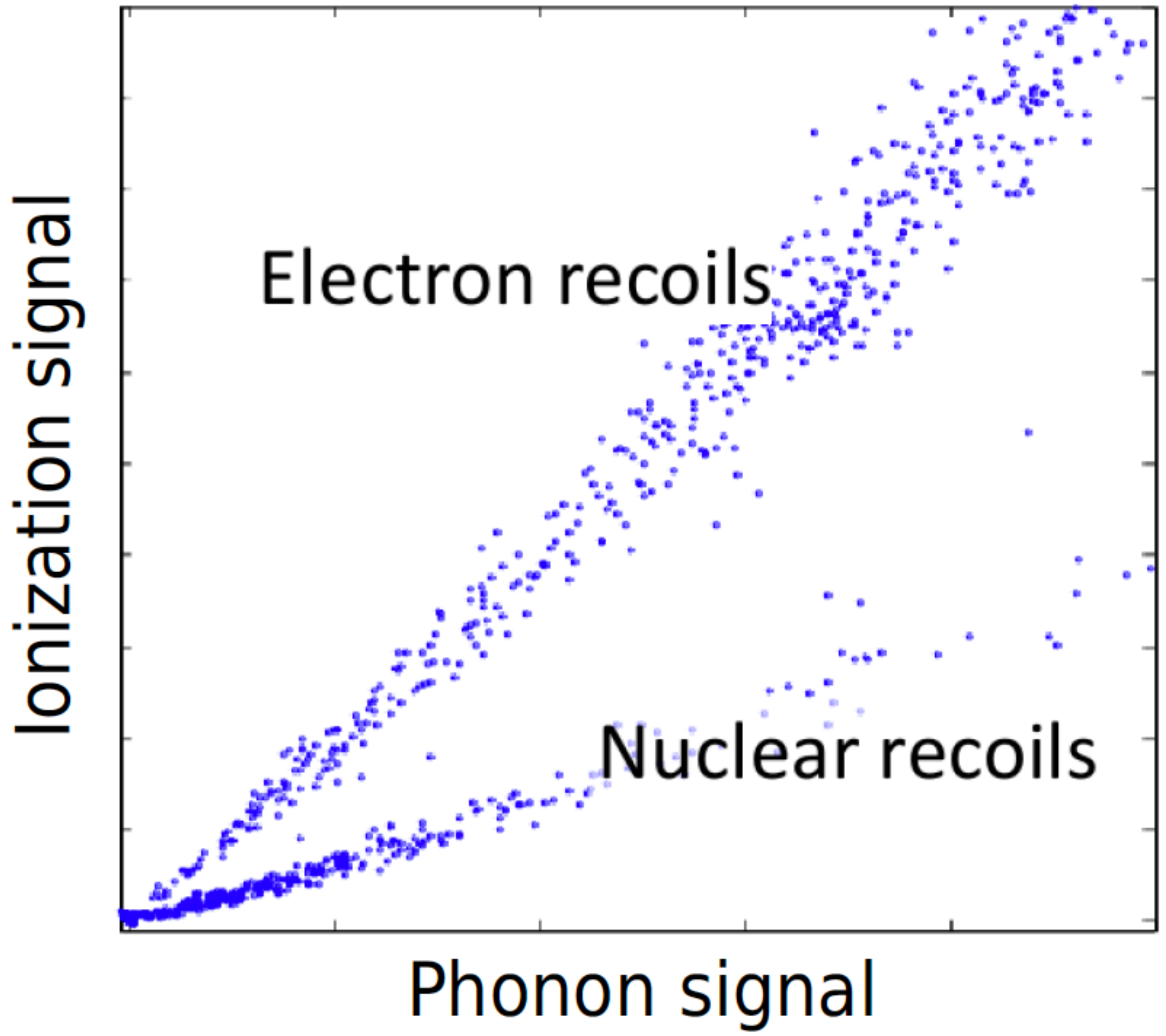


Phonon channels



interleaved with charge channels



↓

Efficient nuclear recoil (NR) to electron recoil (ER) discrimination

SILICON AND GERMANIUM DETECTORS

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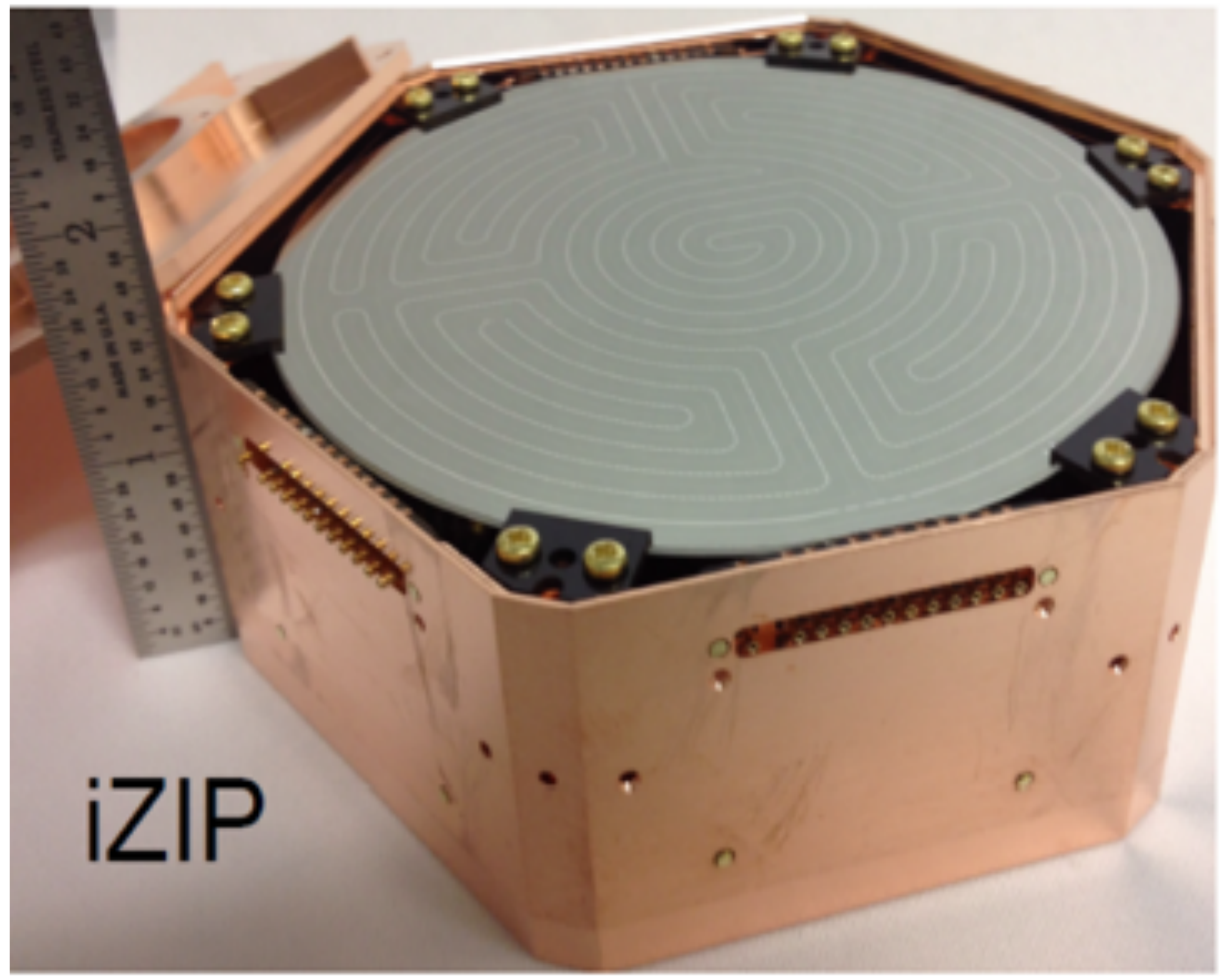
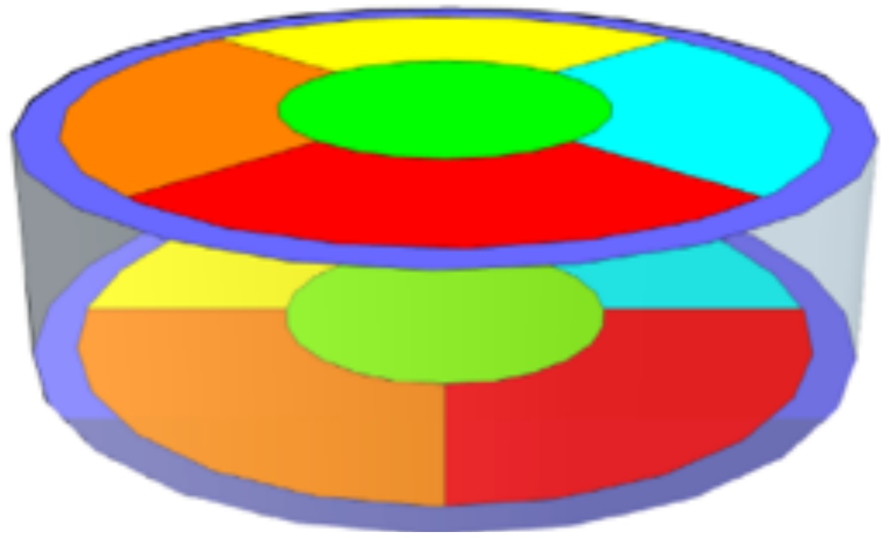


Phonon channels



interleaved with
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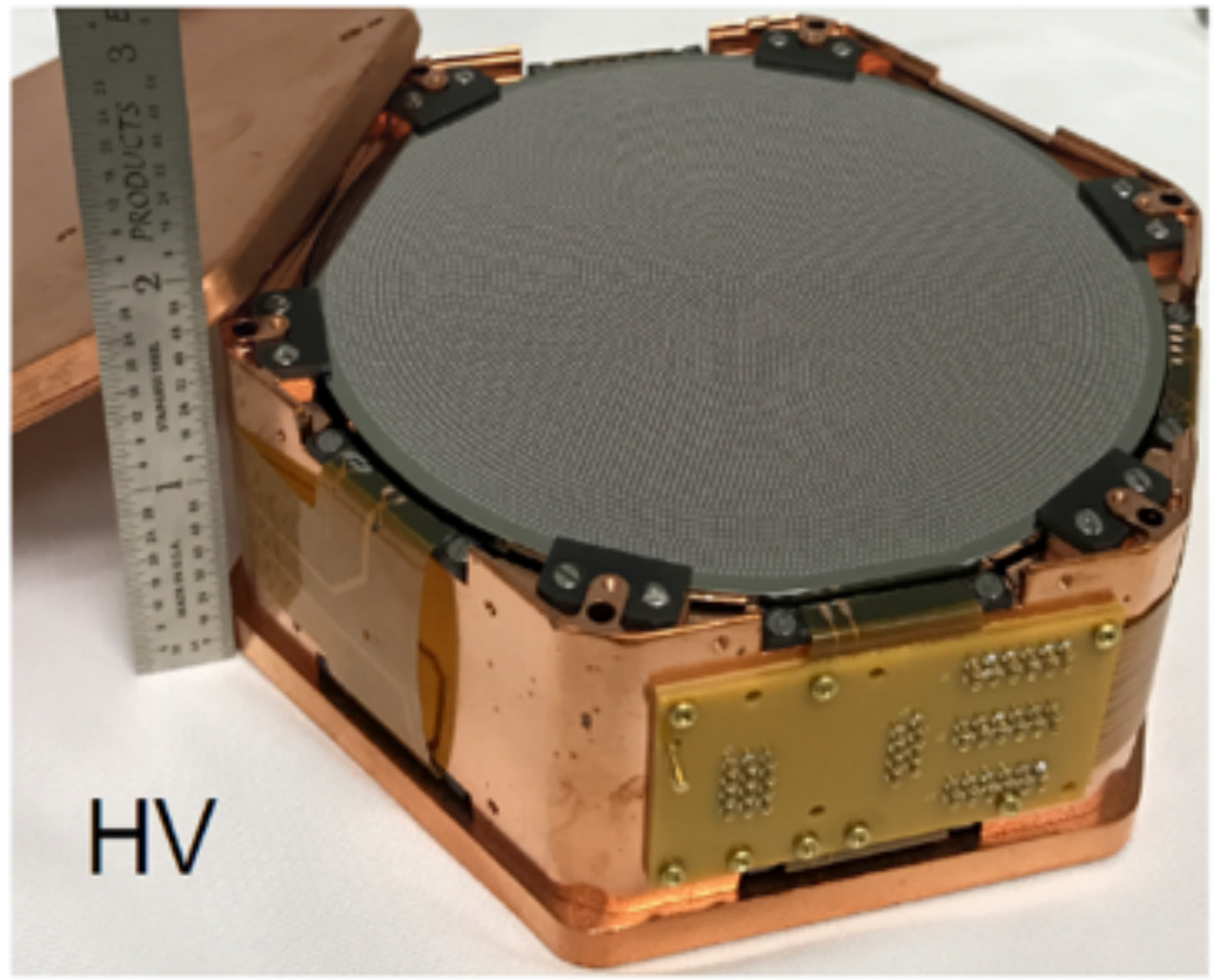
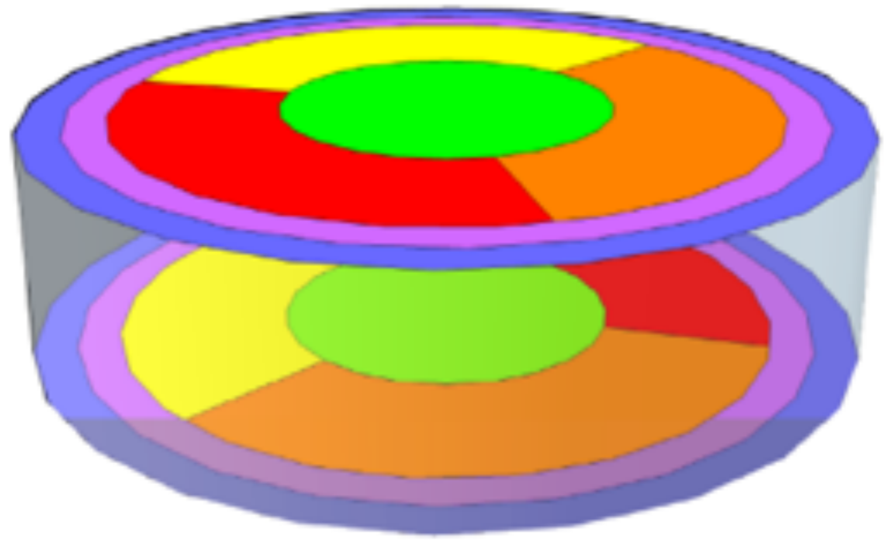


Phonon channels



Efficient nuclear recoil (NR) to
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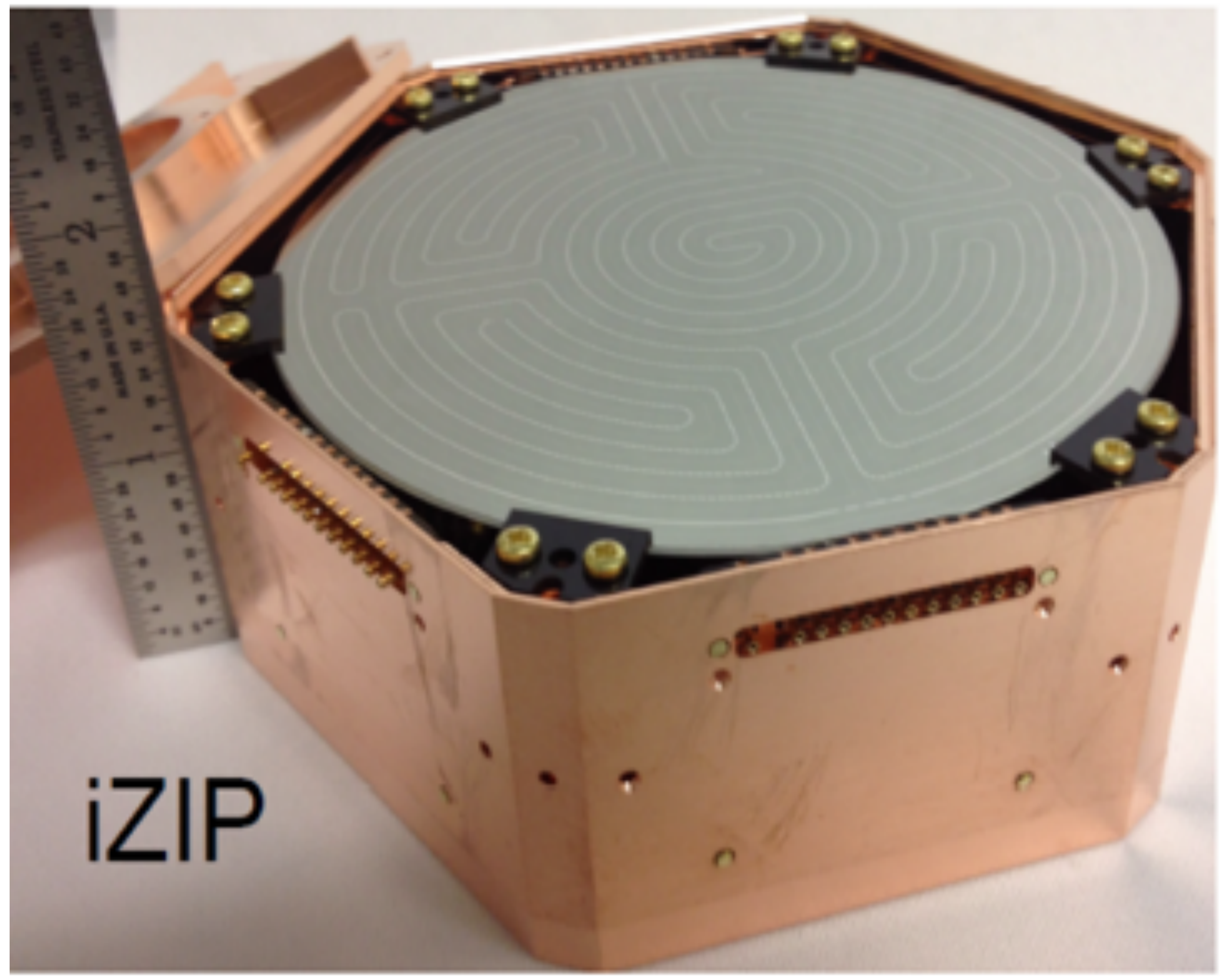
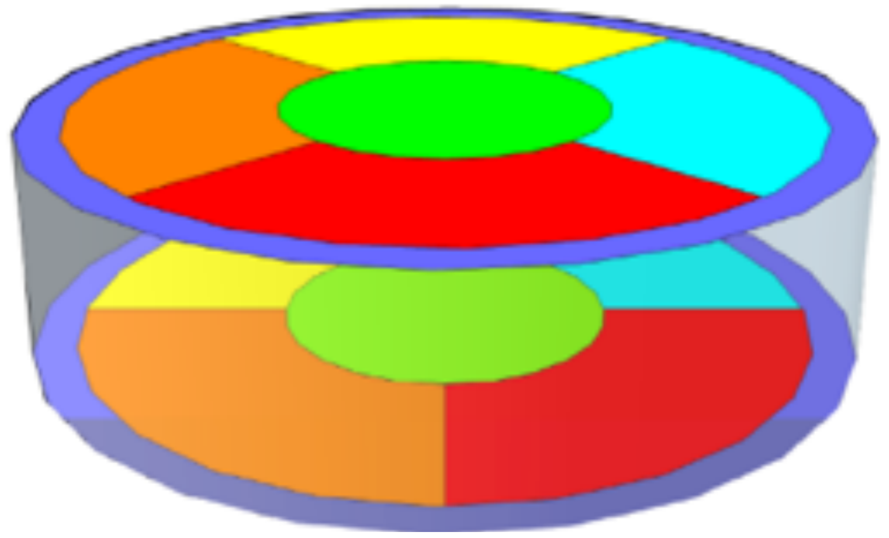


Phonon channels



interleaved with
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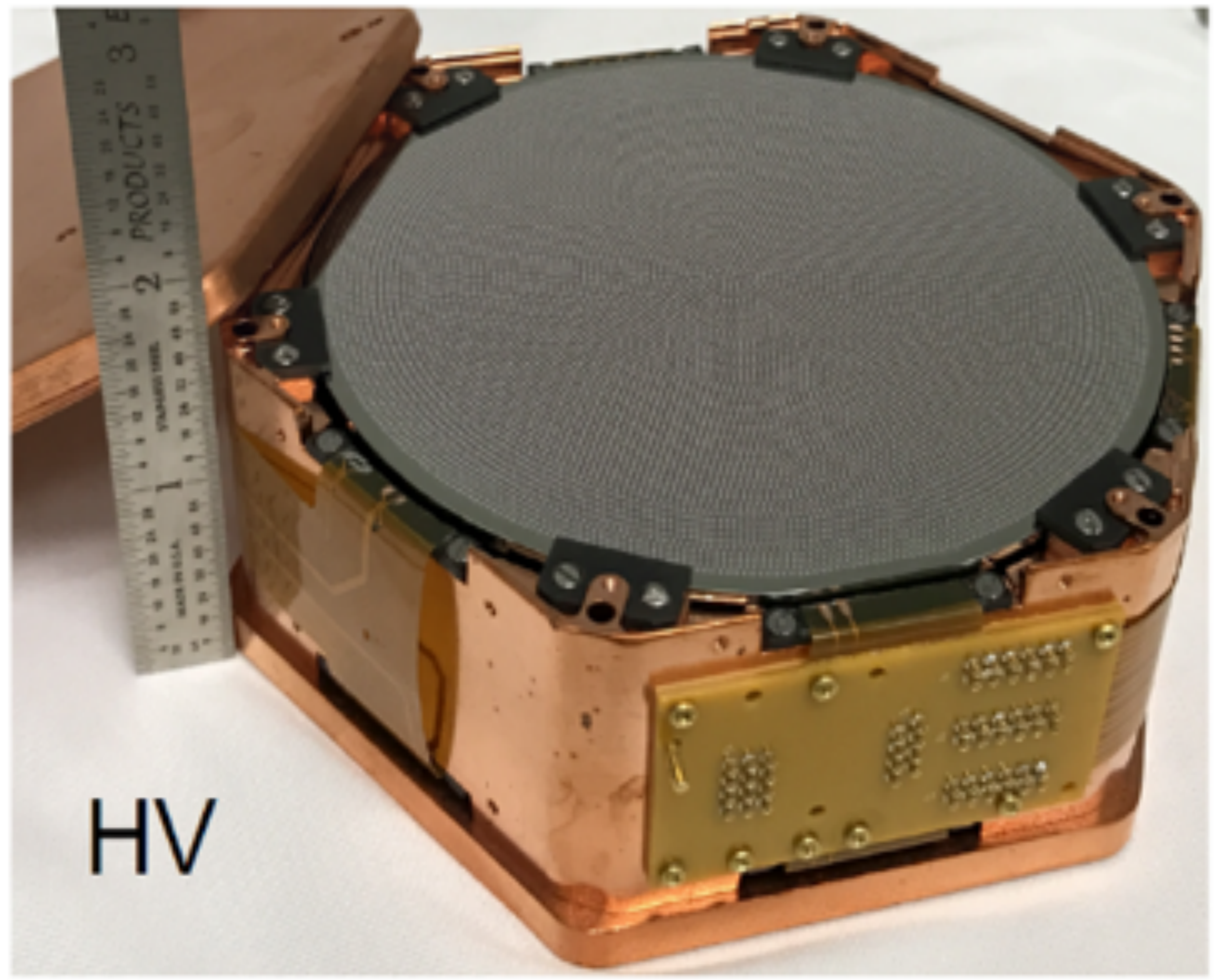
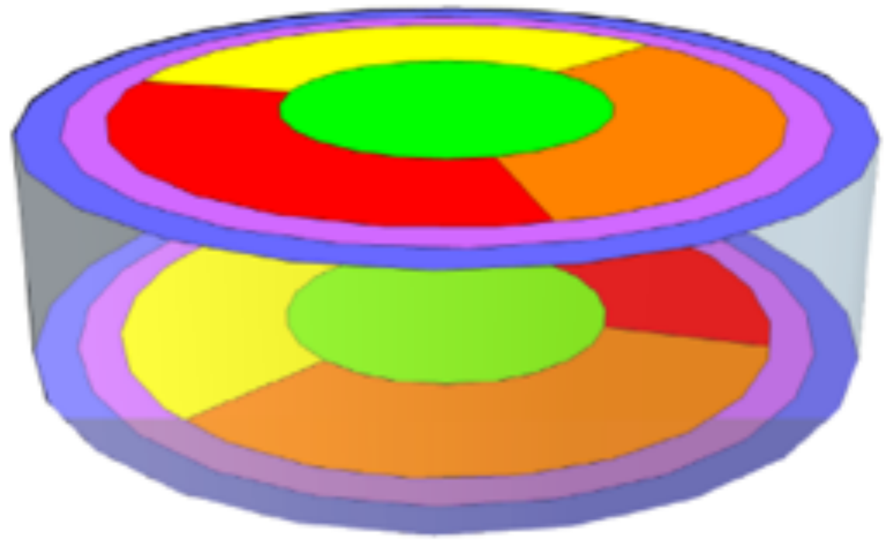
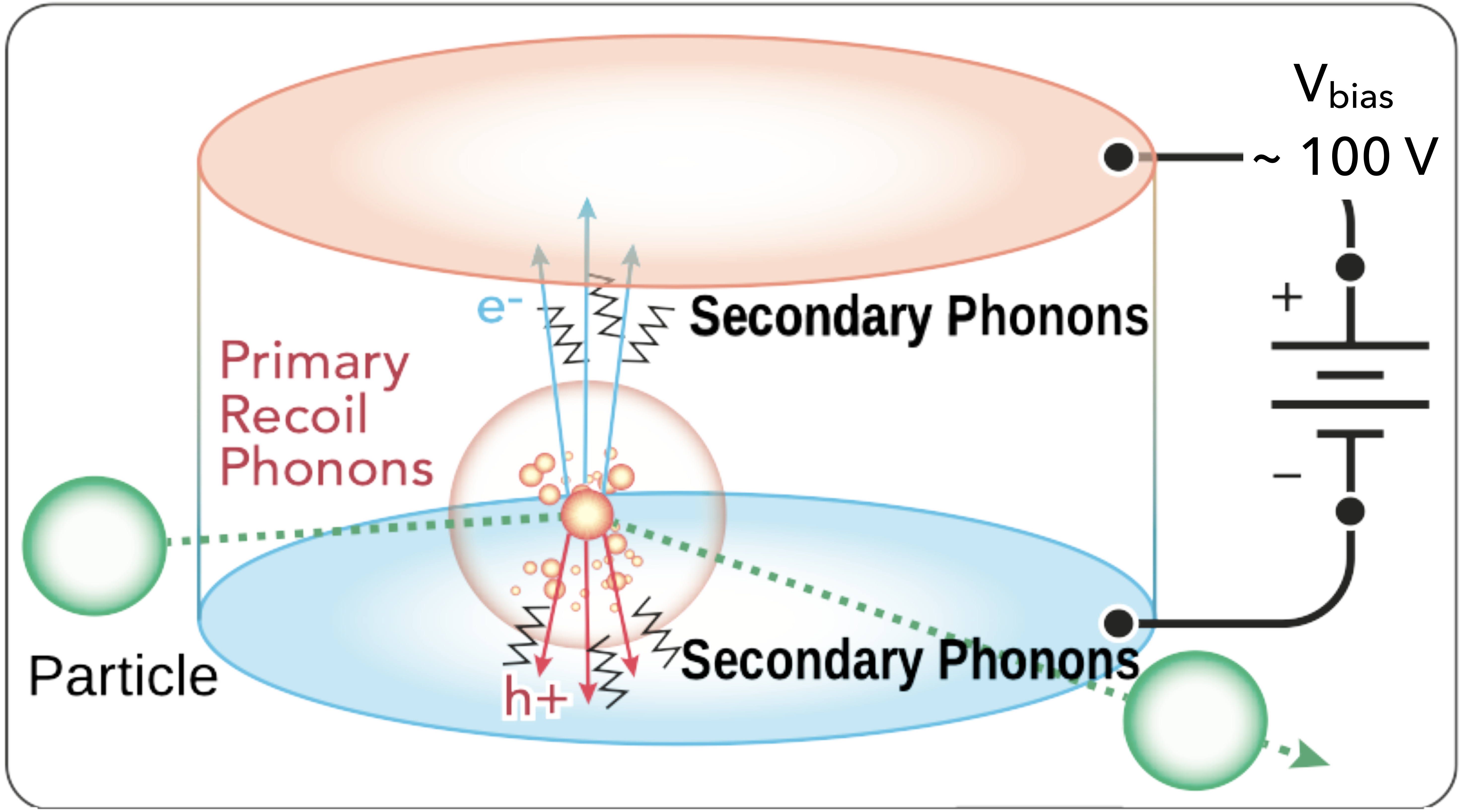


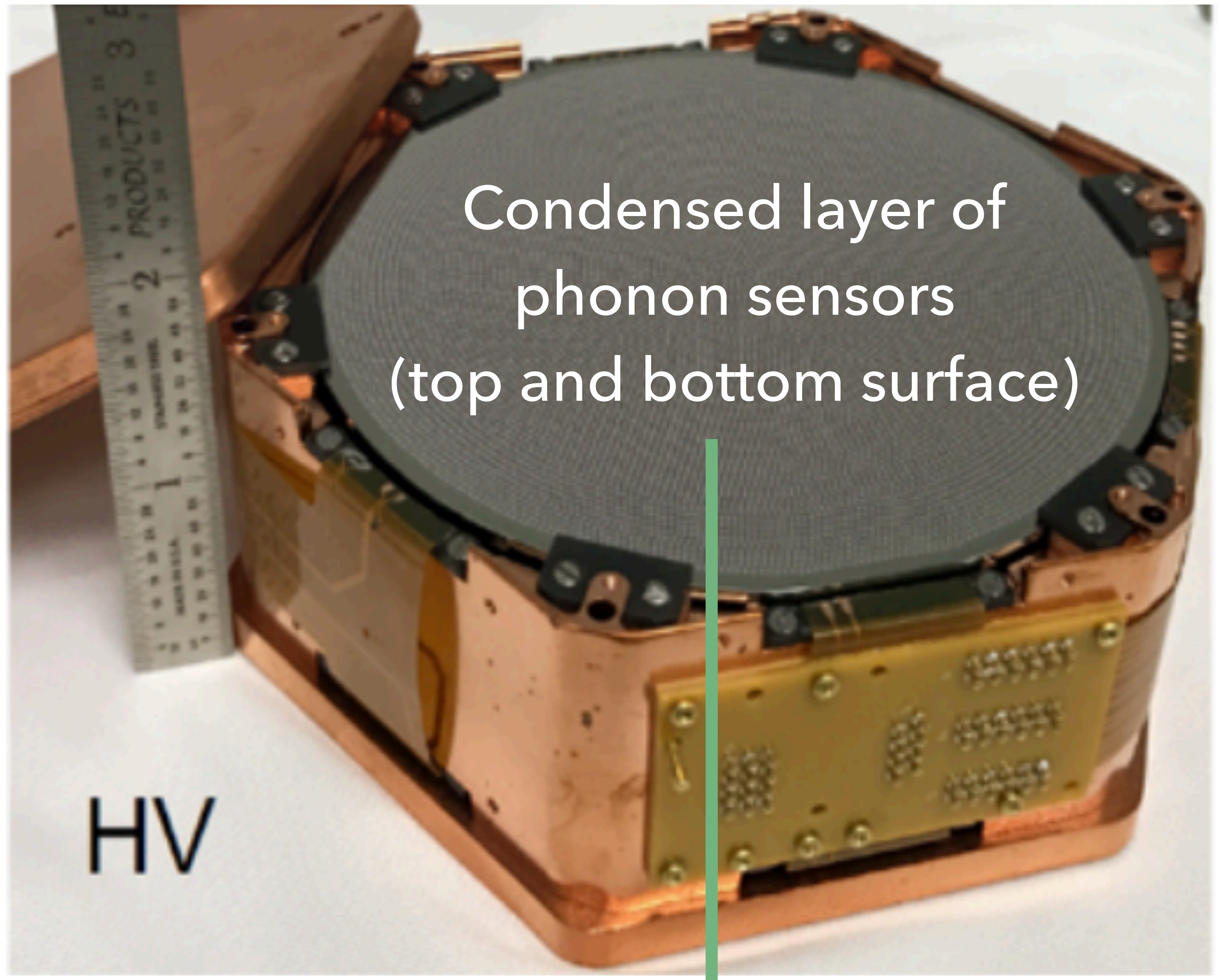
Phonon channels



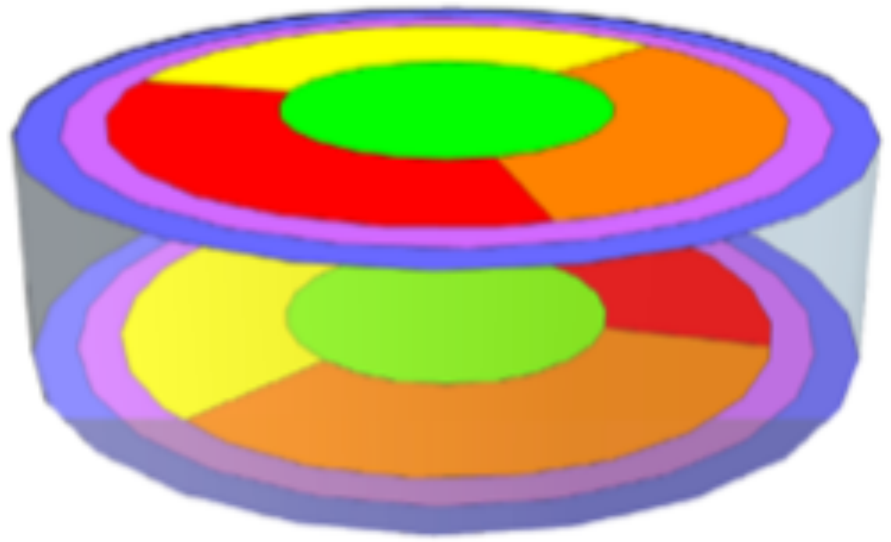
Strongly reduced energy threshold

PHONON AMPLIFICATION OF IONIZATION SIGNAL





grouped in
12 Phonon channels:



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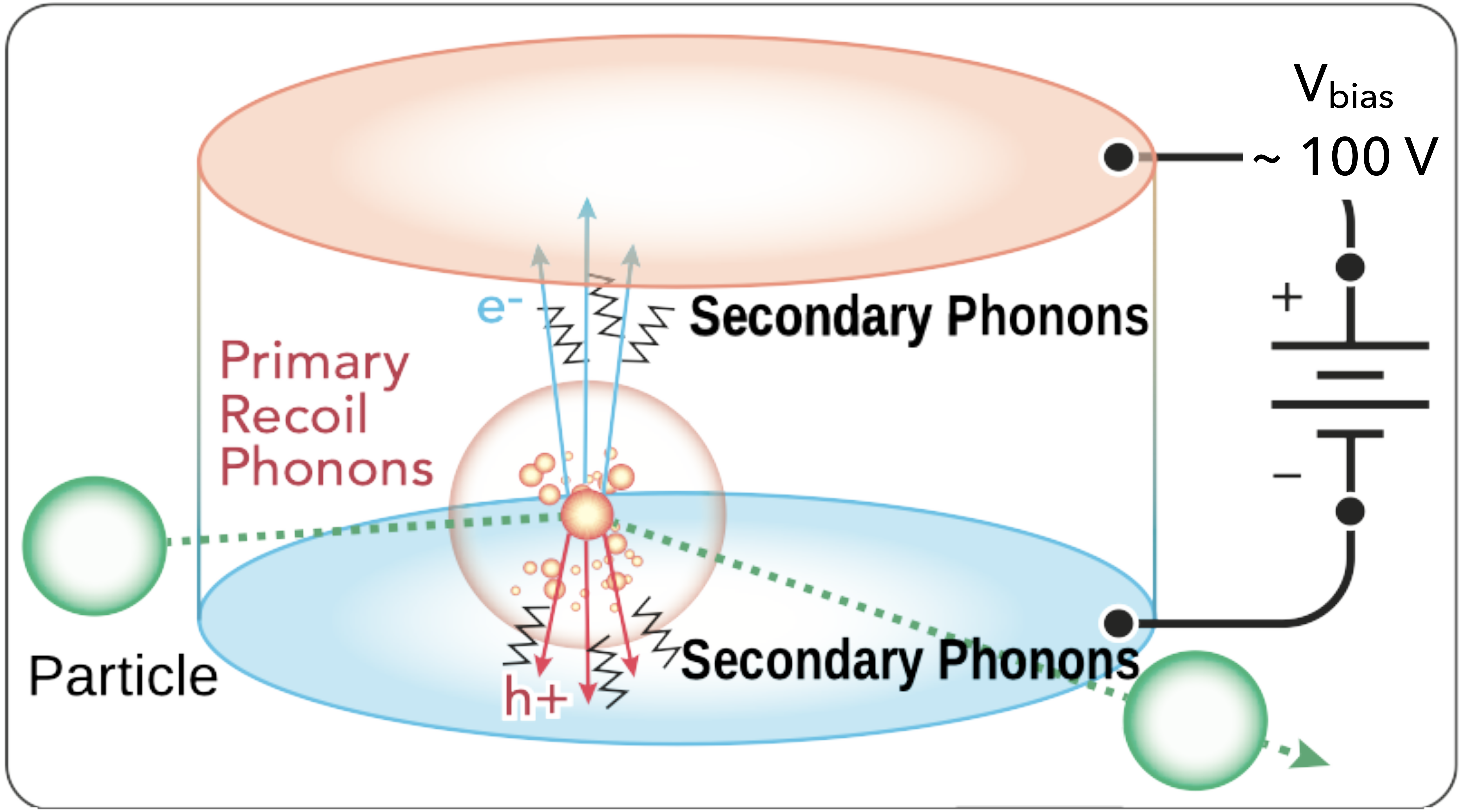

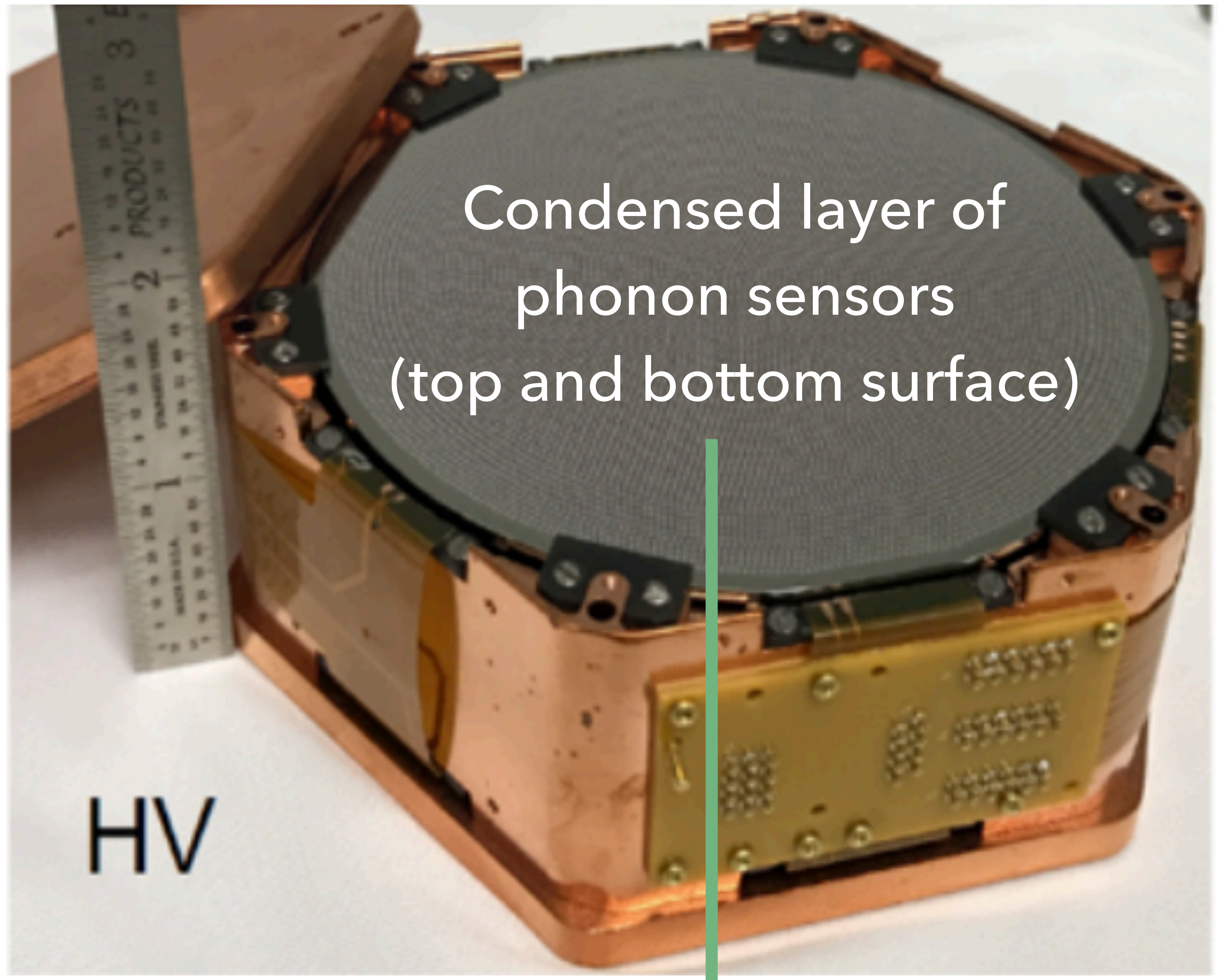

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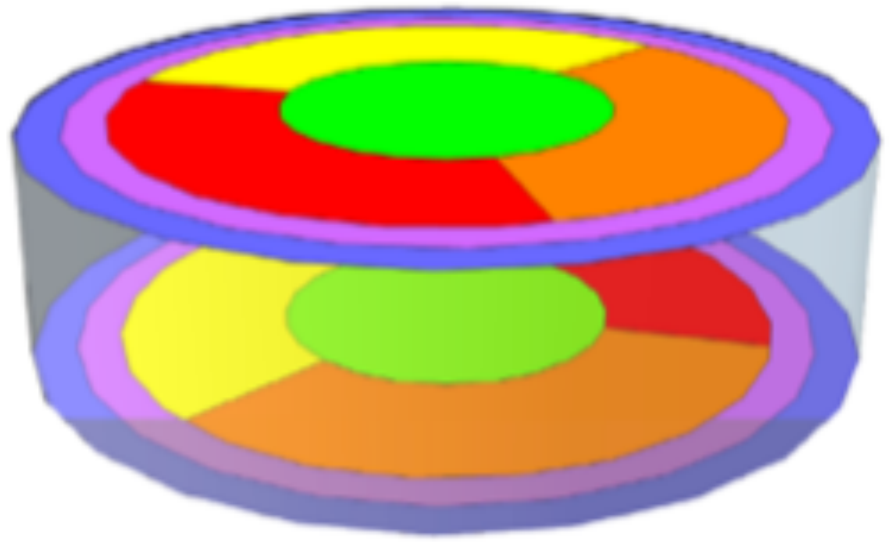
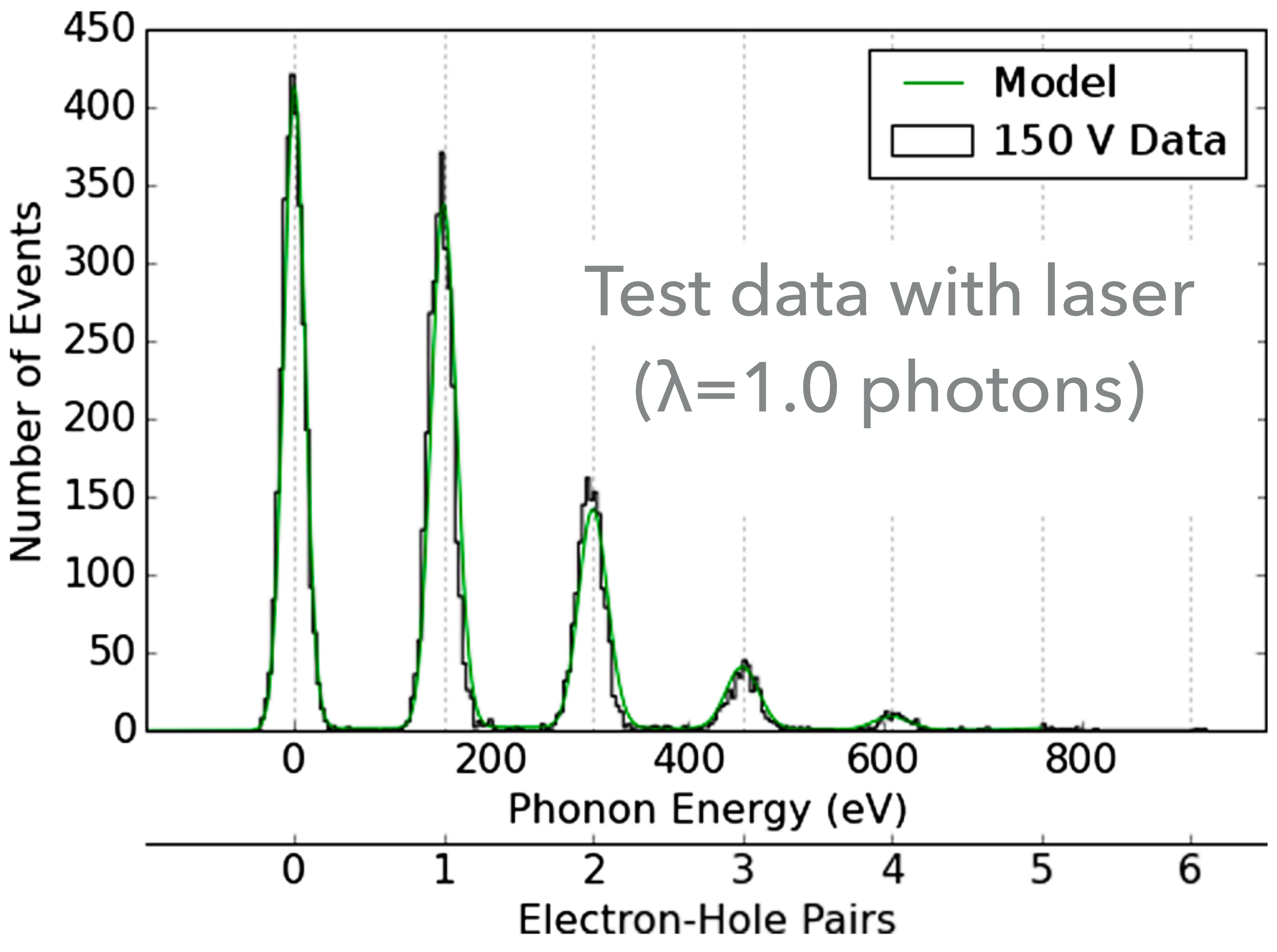


How low can we go?

R&D HIGH VOLTAGE DETECTOR

SuperCDMS-HVeV

Si chip (1cm² x 4mm, 0.93 g) with phonon sensors



- Single electron-hole pair resolution
- Ultra-low threshold (band-gap)

RECAP DETECTORS

iZIP

- Default detector
- ~ 1 kg Si or Ge
- Phonon and ionization readout
- **Efficient ER / NR discrimination**

HV

- Default detector
- ~ 1 kg Si or Ge
- Phonon readout only
- Phonon amplification of charge signal
- **Low threshold**

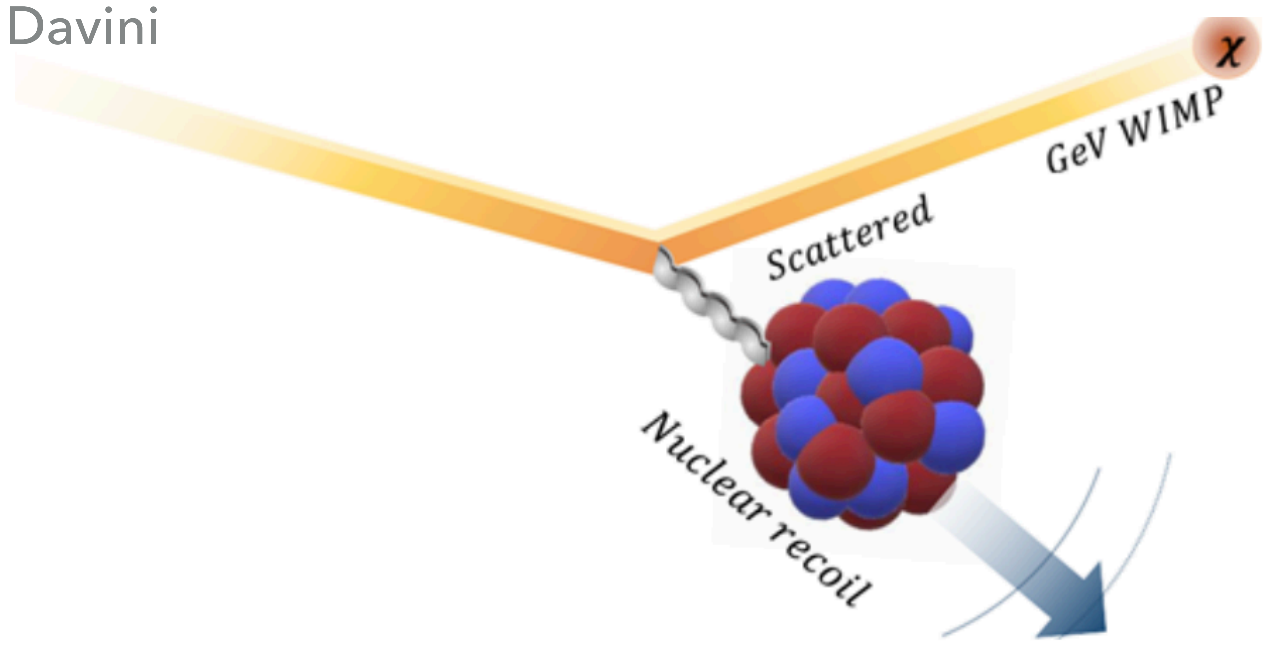
HVeV

- R&D detector
- ~ 1 g Si
- Phonon readout only
- Phonon amplification of charge signal
- **Ultra-low threshold (band-gap)**
- **Single e^-/h^+ pair sensitivity**

DARK MATTER SEARCHES

NUCLEAR vs. ELECTRON RECOIL EVENT CLASS

Image: Stefano Davini



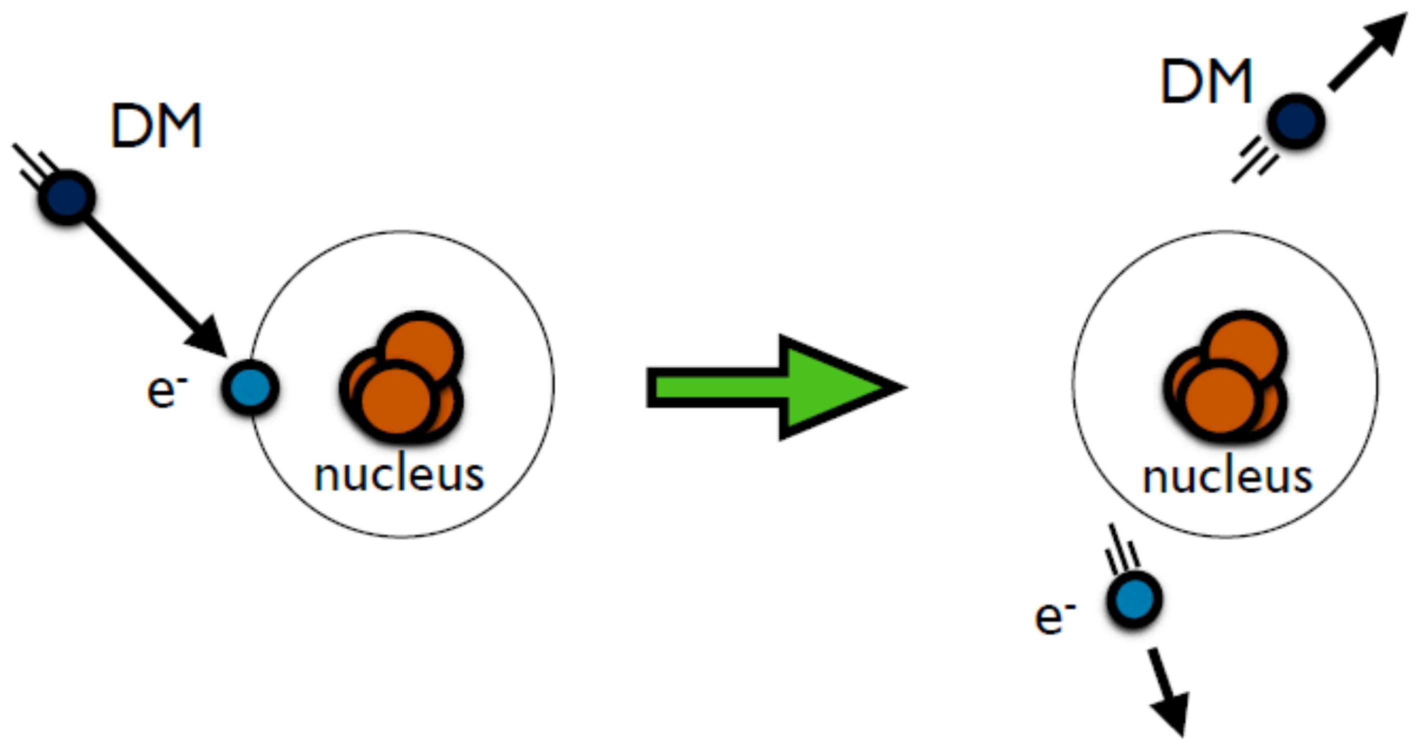
Nuclear Recoil

↓

Mostly primary phonons

- Elastic WIMP-nucleon scattering
- …

Image: Rouven Essig



Electron Recoil

↓

Mostly e^-/h^+ pairs

- Light DM-electron scattering
- Absorption of ALPs
- Absorption of Dark Photons
- …

Kurinsky, **BvK**, et al. Phys. Rev. Lett. 121 (2018) 051301

Germond, Fascione, **BvK**, et al. Phys. Rev. D 101 (2020) 052008

Wilson, Chang, **BvK**, et al. Phys. Rev. D 102 (2020) 091101(R)

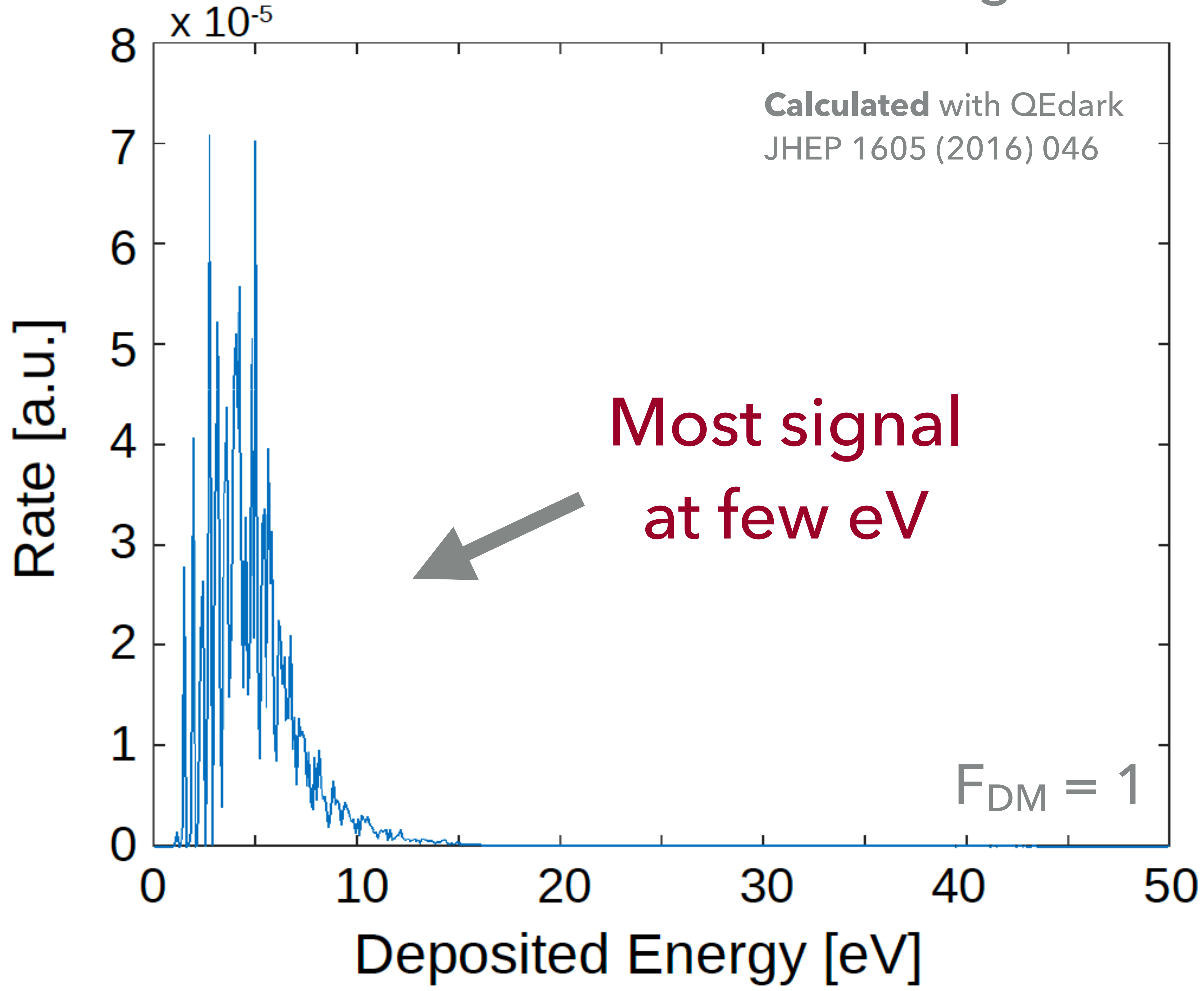
DARK MATTER SEARCHES

LDM-electron scattering

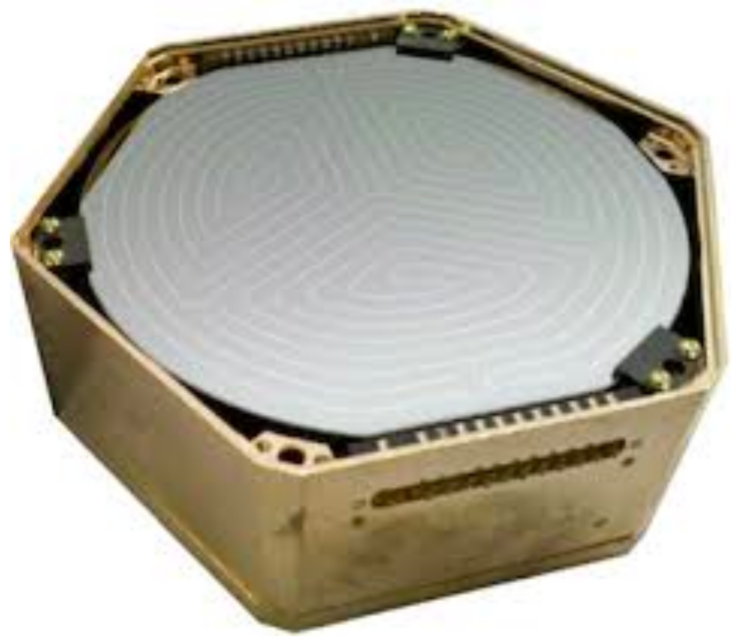
EXPECTED LDM SIGNAL SPECTRUM

(LDM: Light Dark Matter)

500 MeV/c^2 LDM on Si target



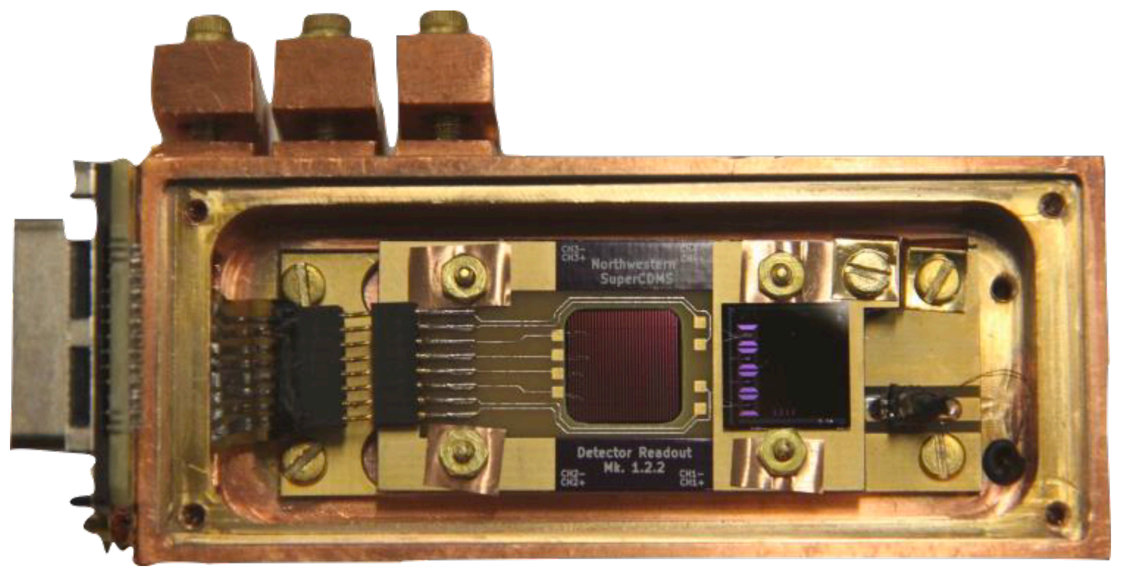
Most signal at few eV

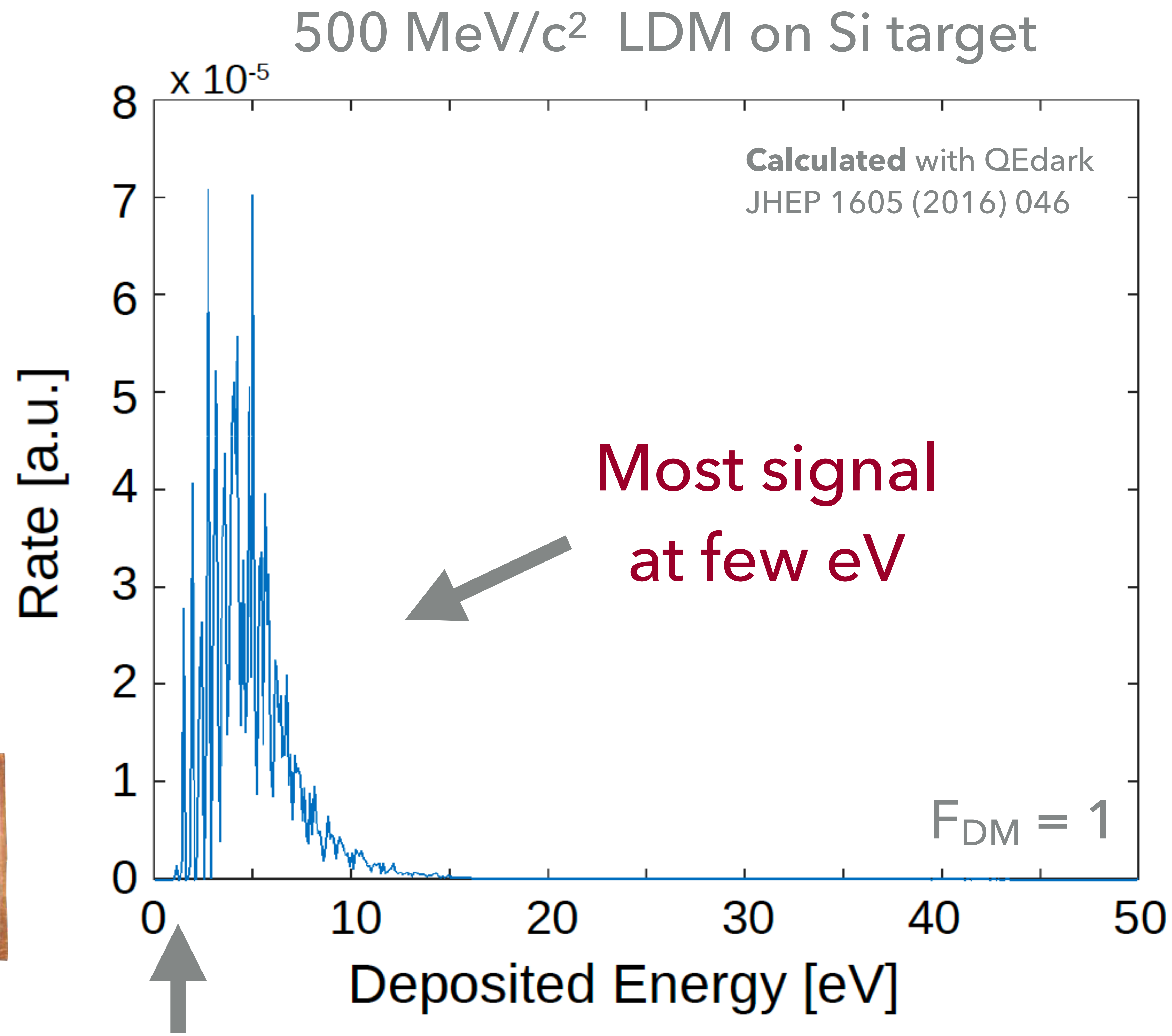


Lowest achieved SuperCDMS Soudan threshold

EXPECTED LDM SIGNAL SPECTRUM

(LDM: Light Dark Matter)





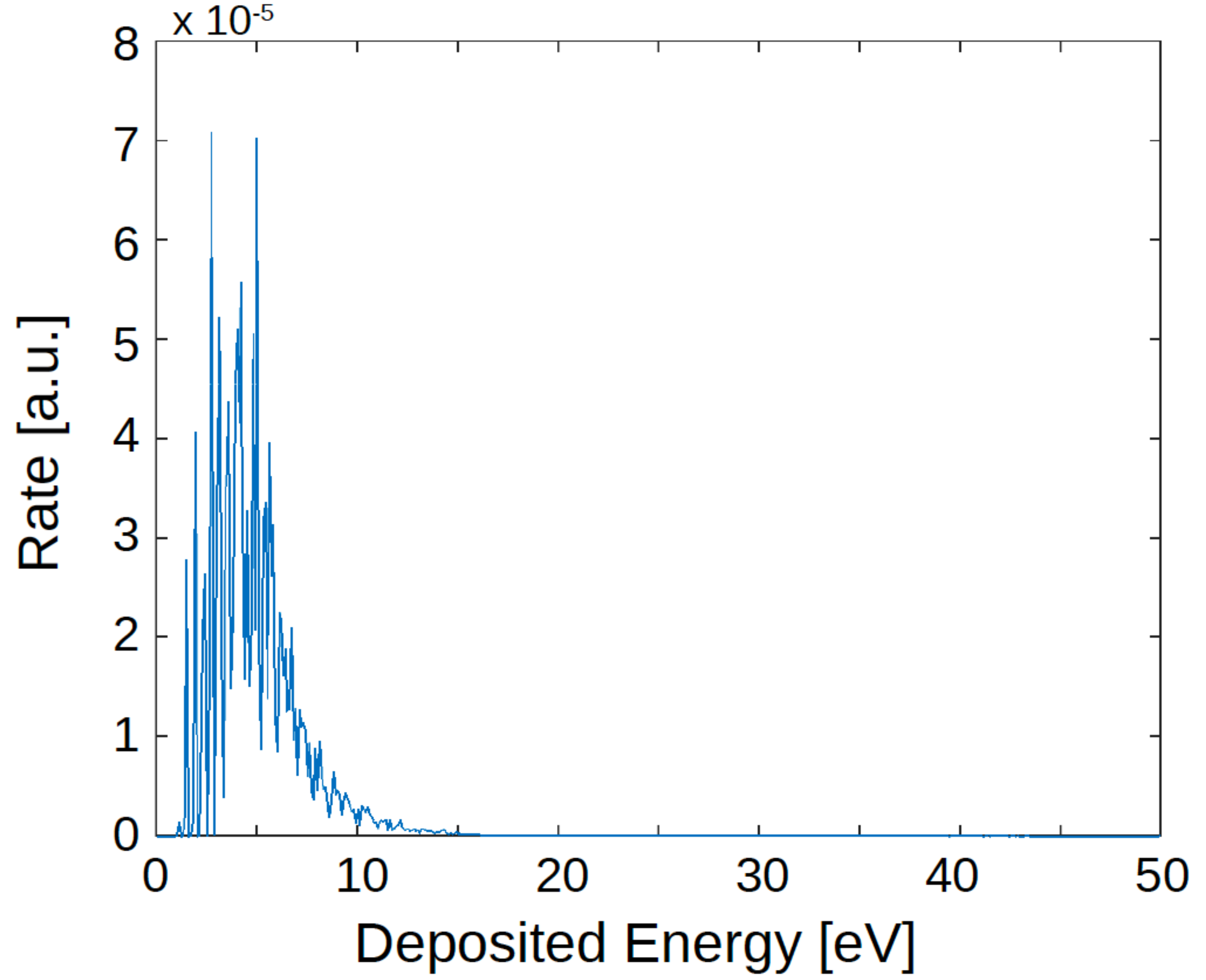
Achieved threshold with SuperCDMS-HVeV

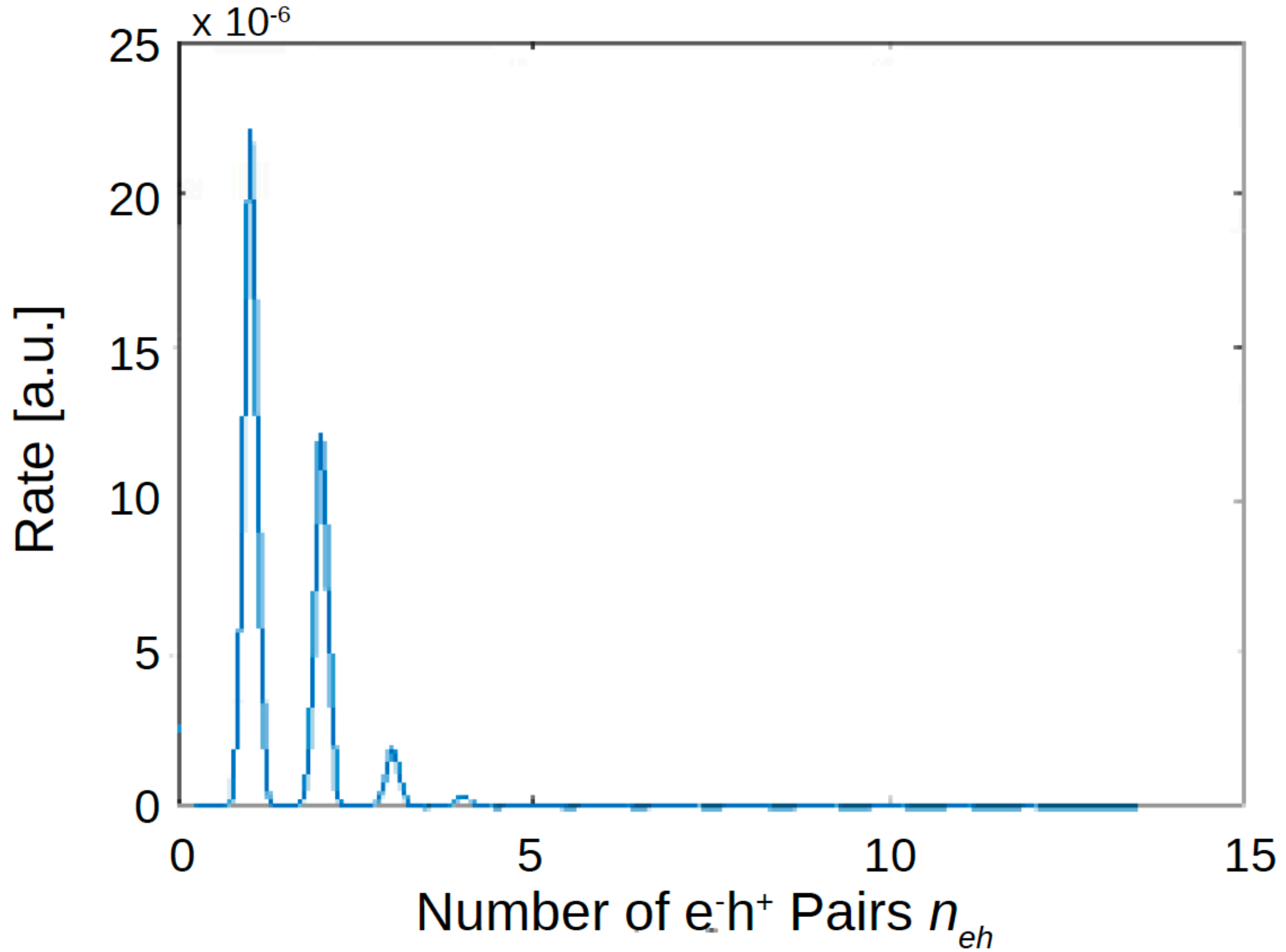
Lowest achieved SuperCDMS Soudan threshold

EXPECTED LDM SIGNAL SPECTRUM - quantized

(LDM: Light Dark Matter)

500 MeV/c^2 LDM on Si target

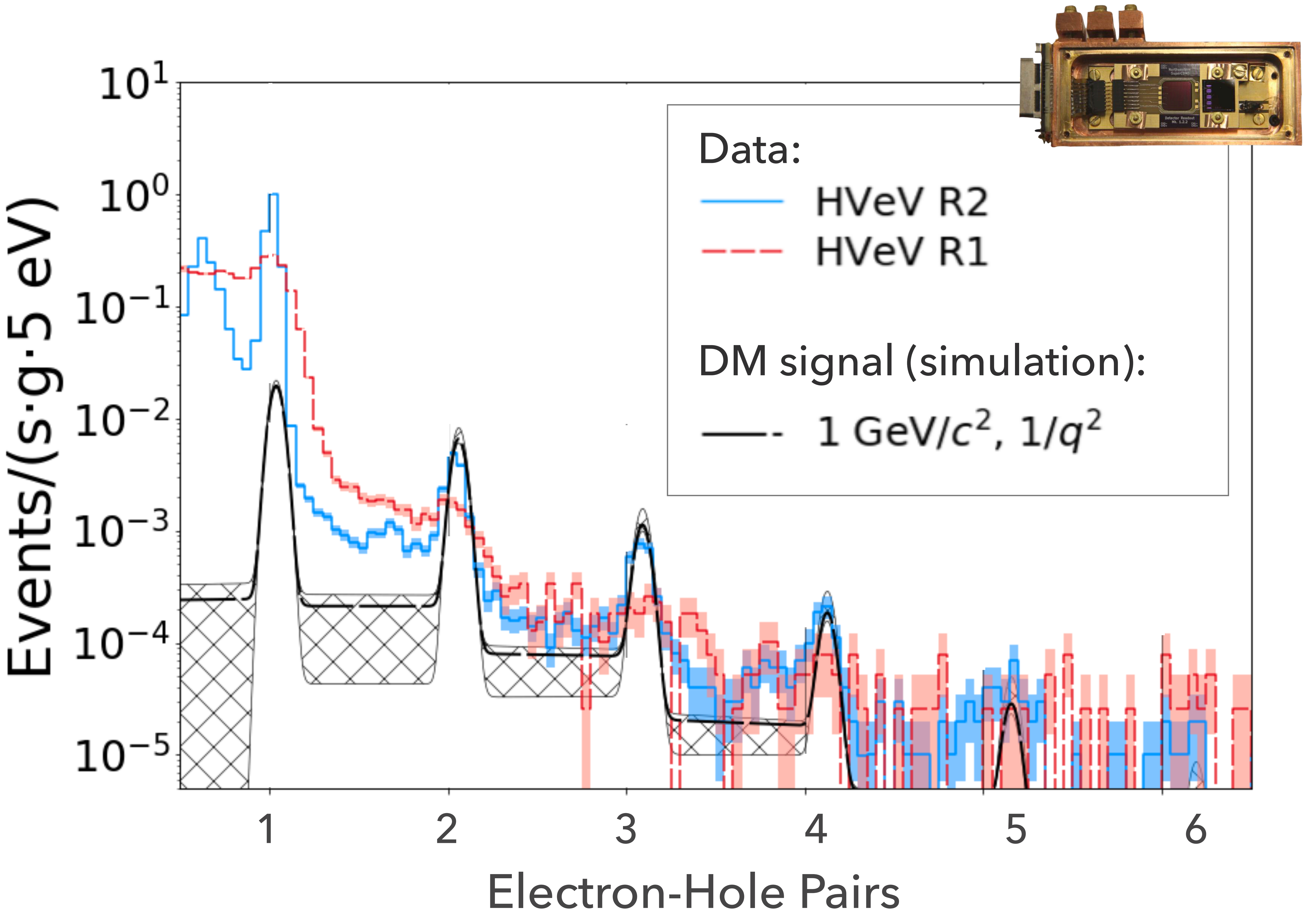




Ionization model

EXPECTED LDM SIGNAL SPECTRUM – quantized

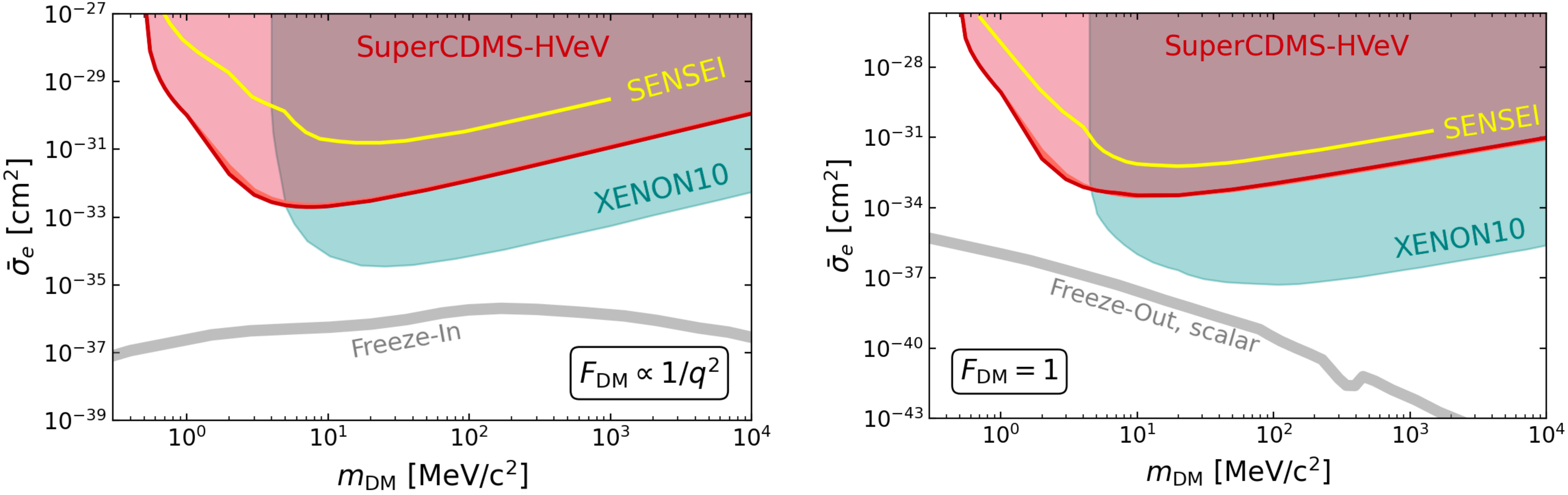
(LDM: Light Dark Matter)

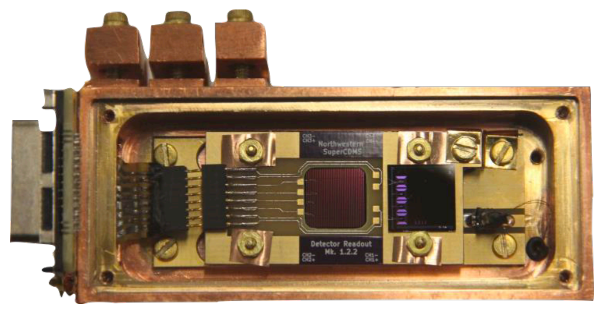


LDM-electron scattering rate:

$R(m_\chi) \sim \bar{\sigma}_e$

FIRST SuperCDMS-HVeV RESULTS





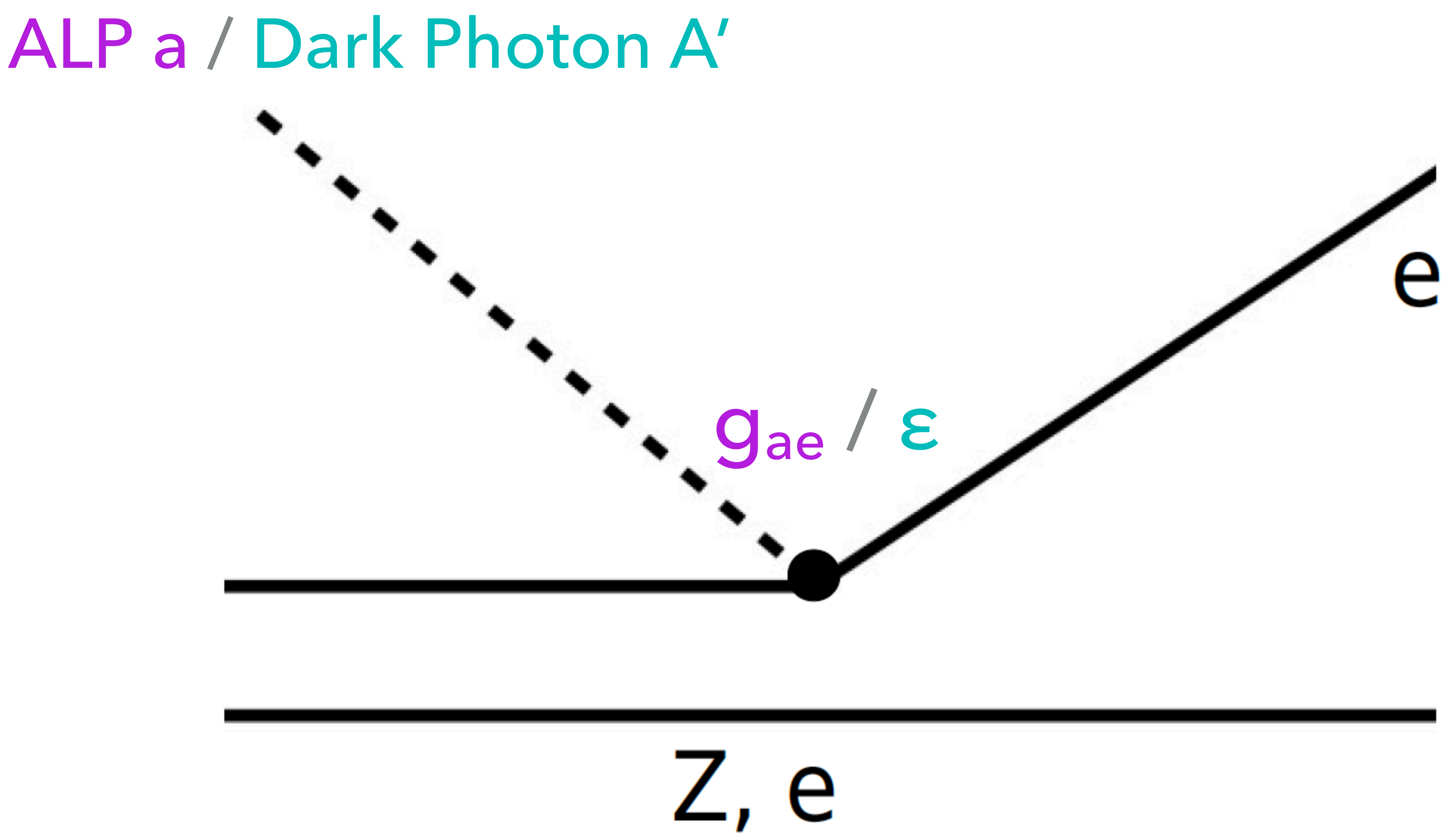
1st Science Results with ~ 0.5 g/day data

Kurinsky, **BvK**, et al. PRL 121 (2018) 051301 (Err. PRL 122 (2019) 069901)

DARK MATTER SEARCHES

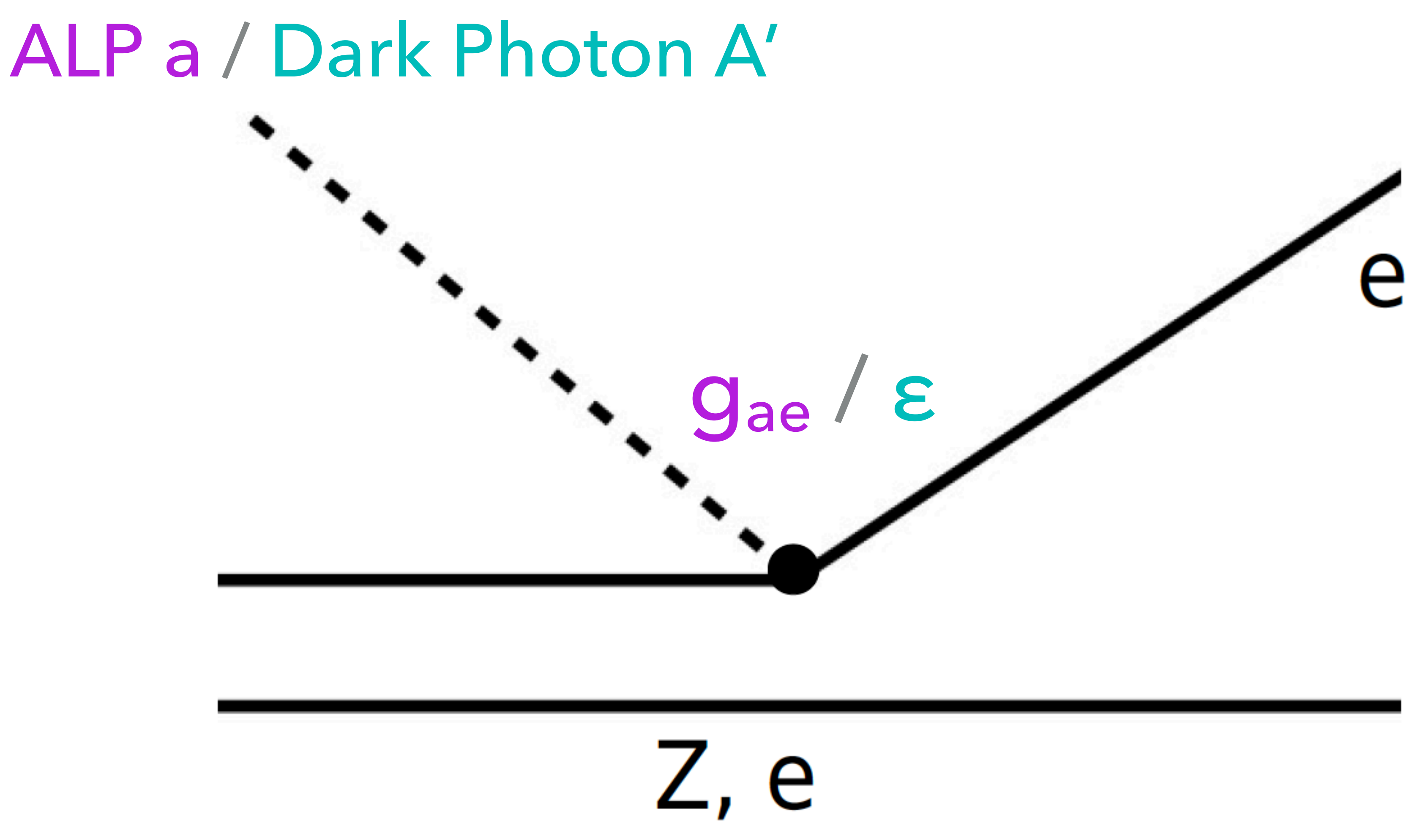
Dark boson absorption

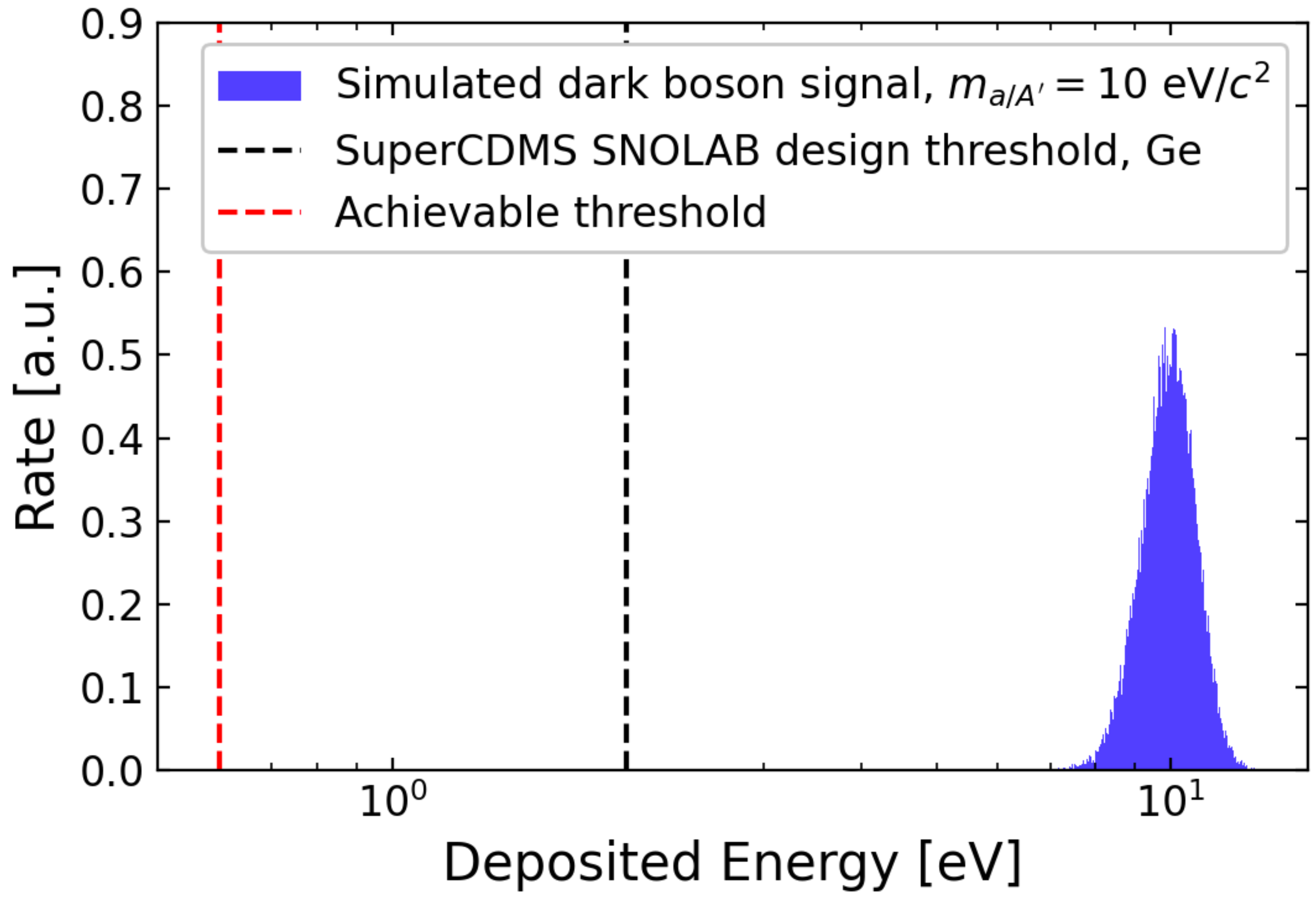
DARK BOSON ABSORPTION



- Analogous to photoelectric absorption
- Electron emitted with energy = ALP / Dark Photon mass

DARK BOSON ABSORPTION





Unlike previous interaction: **Deposited energy directly proportional to m_a or $m_{A'}$**

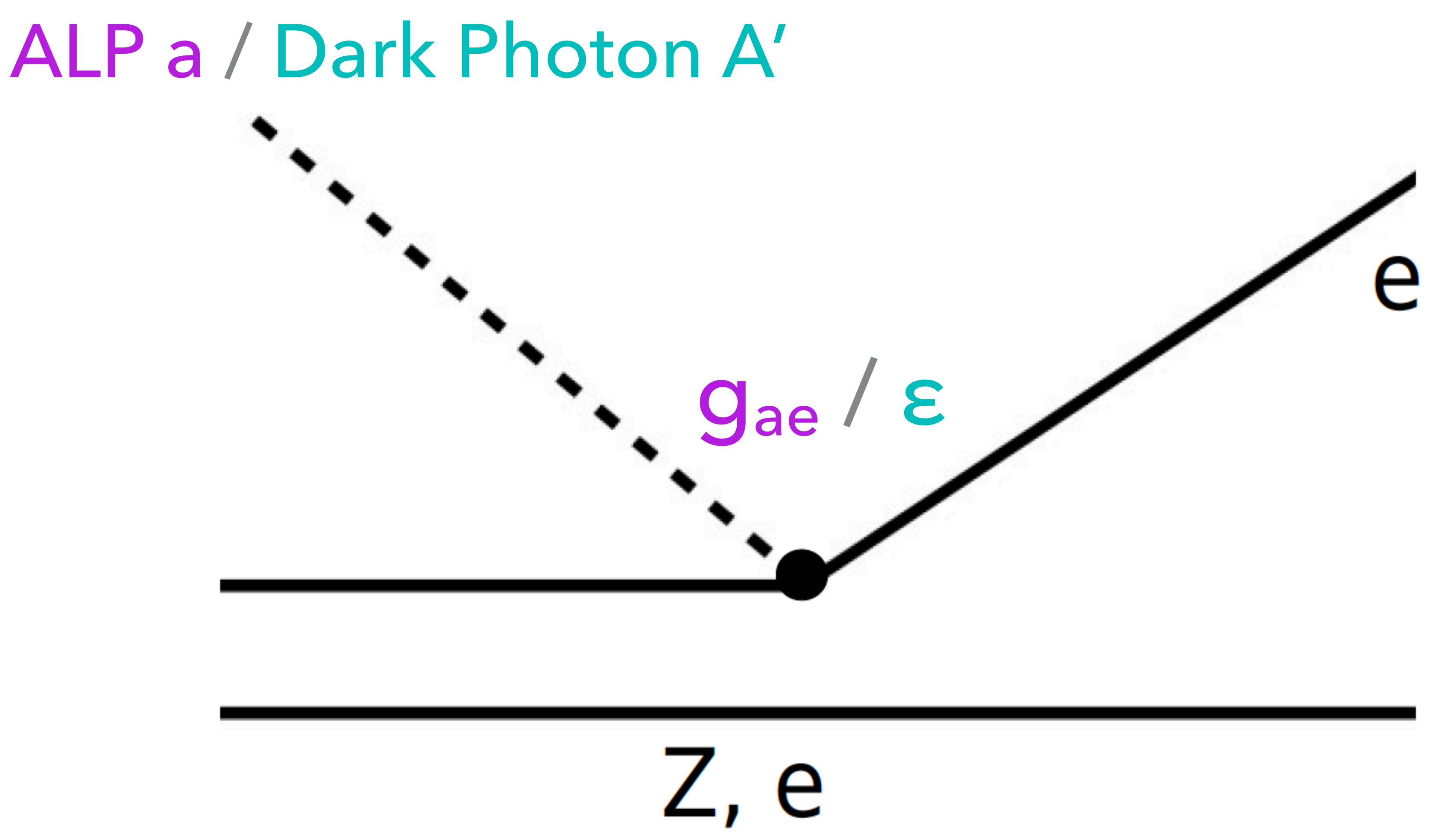
$$\text{Rate}\ (m_a) \sim \rho_{DM}\ g_{ae}^{\ 2}\ \sigma_{p.e.}\ (E=m_a c^2)$$

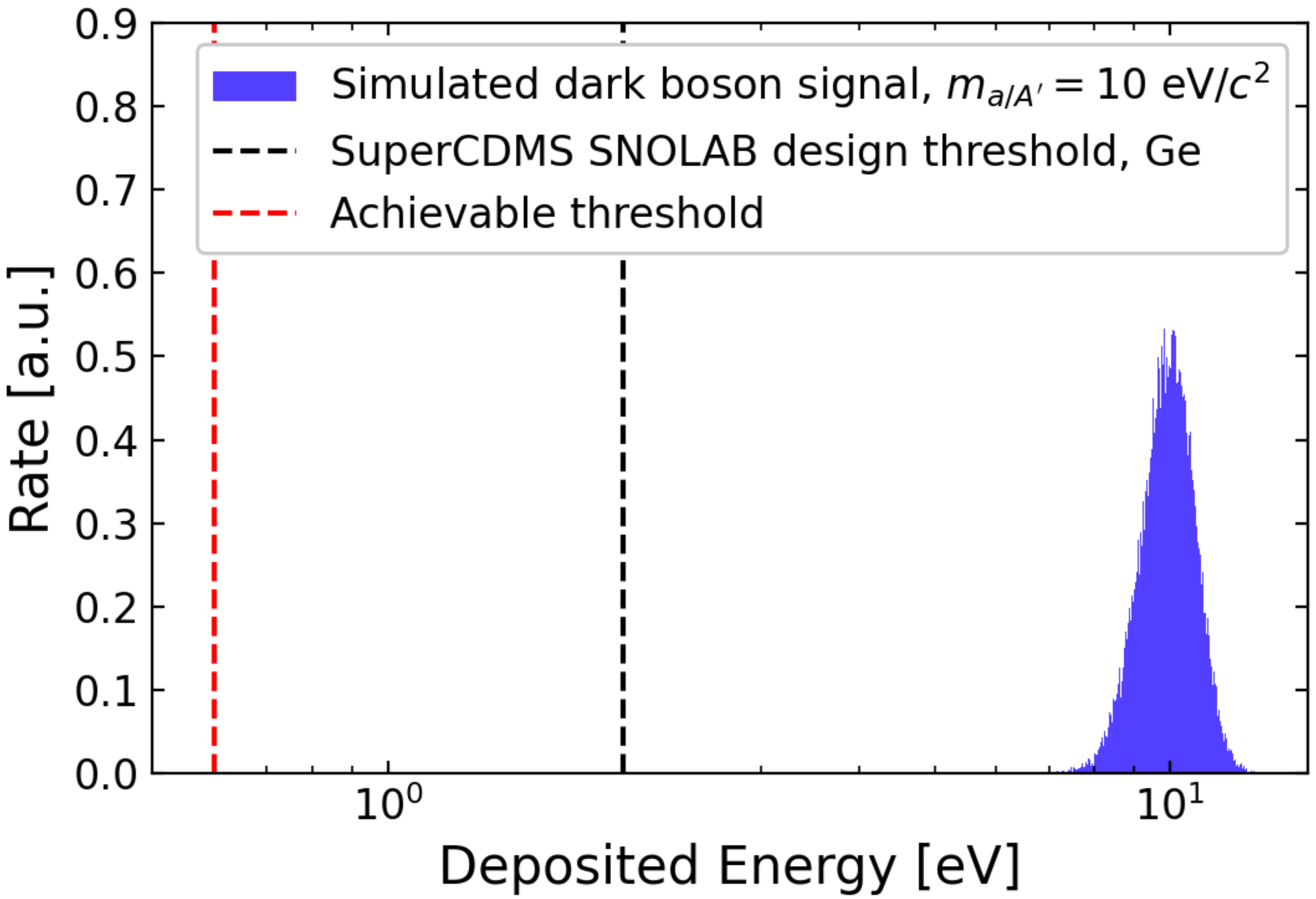
$$\text{Rate}\ (m_{A'}) \sim \rho_{DM}\ \varepsilon^{\ 2}\ \sigma_{p.e.}\ (E=m_a c^2)$$

ρ_{DM}: Local halo DM density

$\sigma_{p.e.}$: Photoelectric absorption coeff.

DARK BOSON ABSORPTION

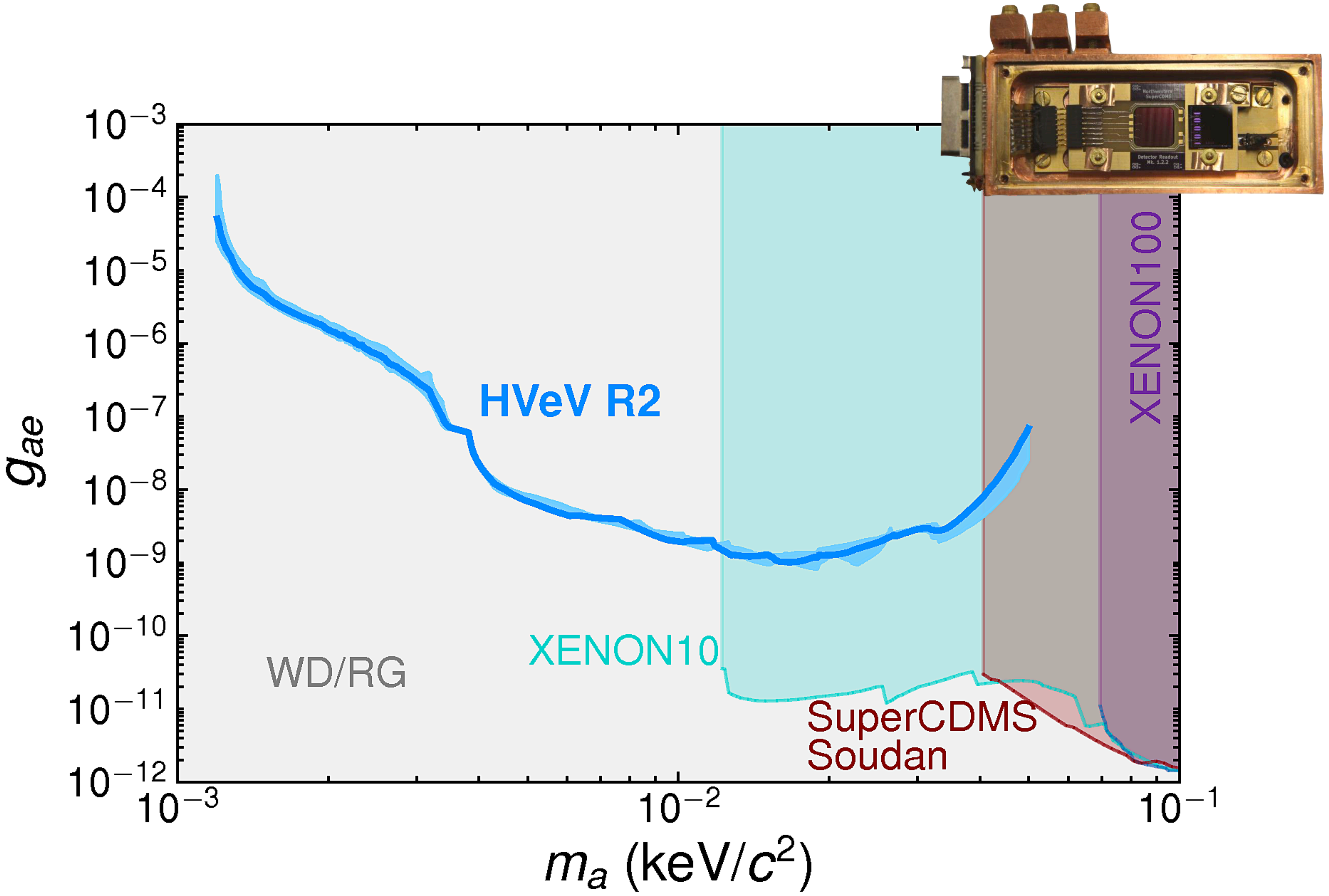




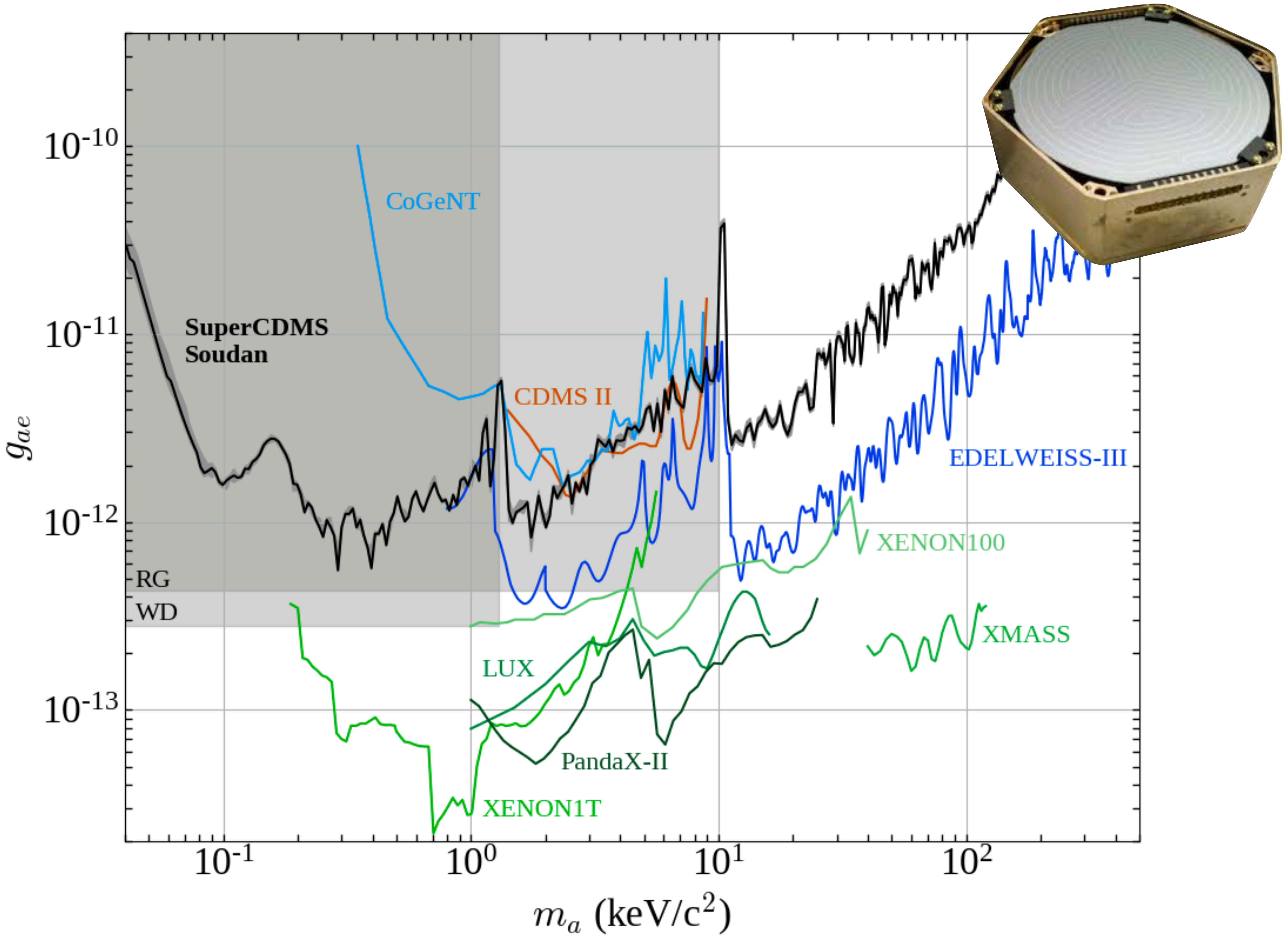
Unlike previous interaction: **Deposited energy directly proportional to m_a or $m_{A'}$**

The lower the energy threshold the greater the mass reach!

ALP ABSORPTION LIMITS



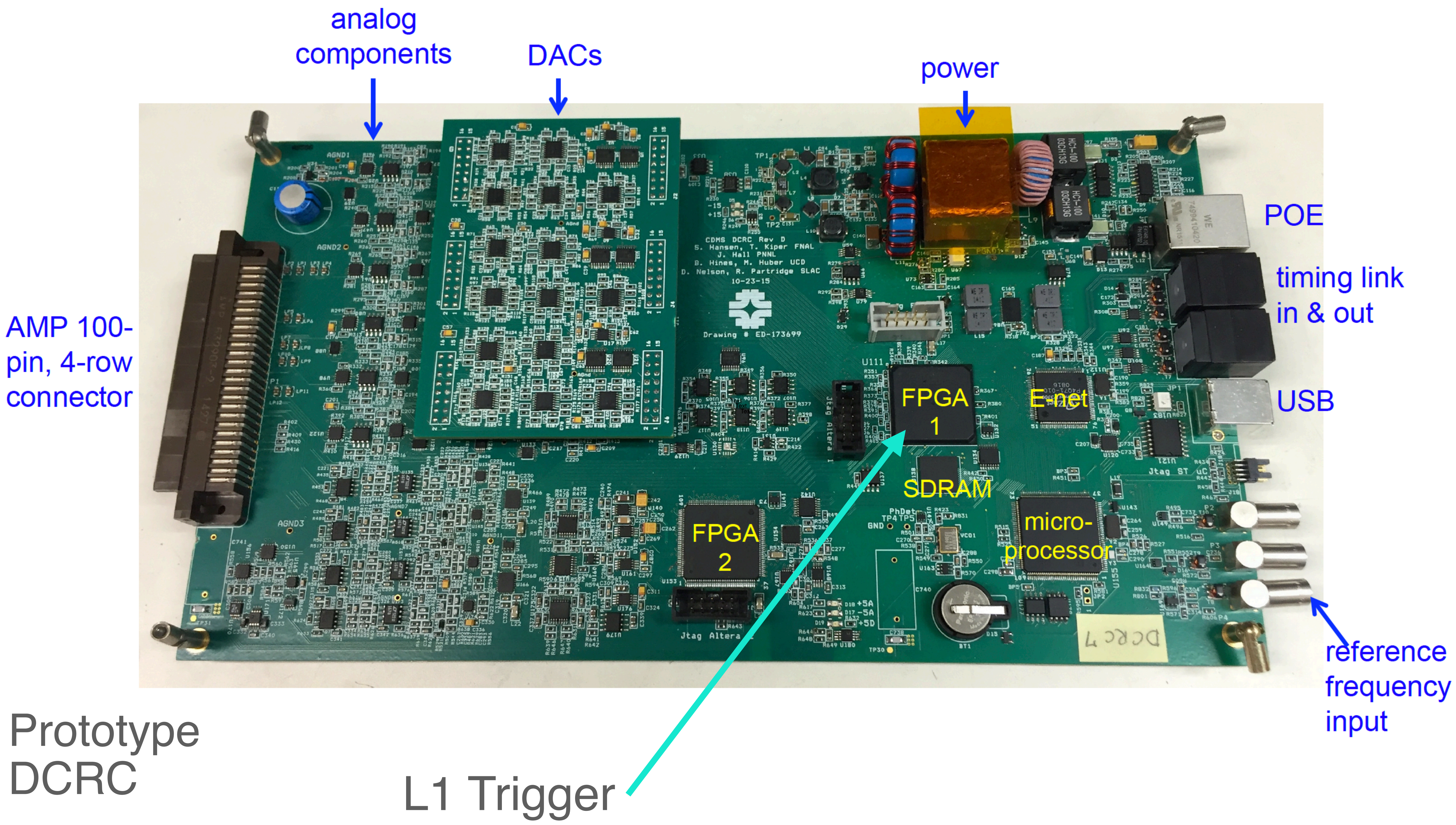
Wilson, Chang, **BvK**, et al. Phys. Rev. D 102 (2020) 091101(R)



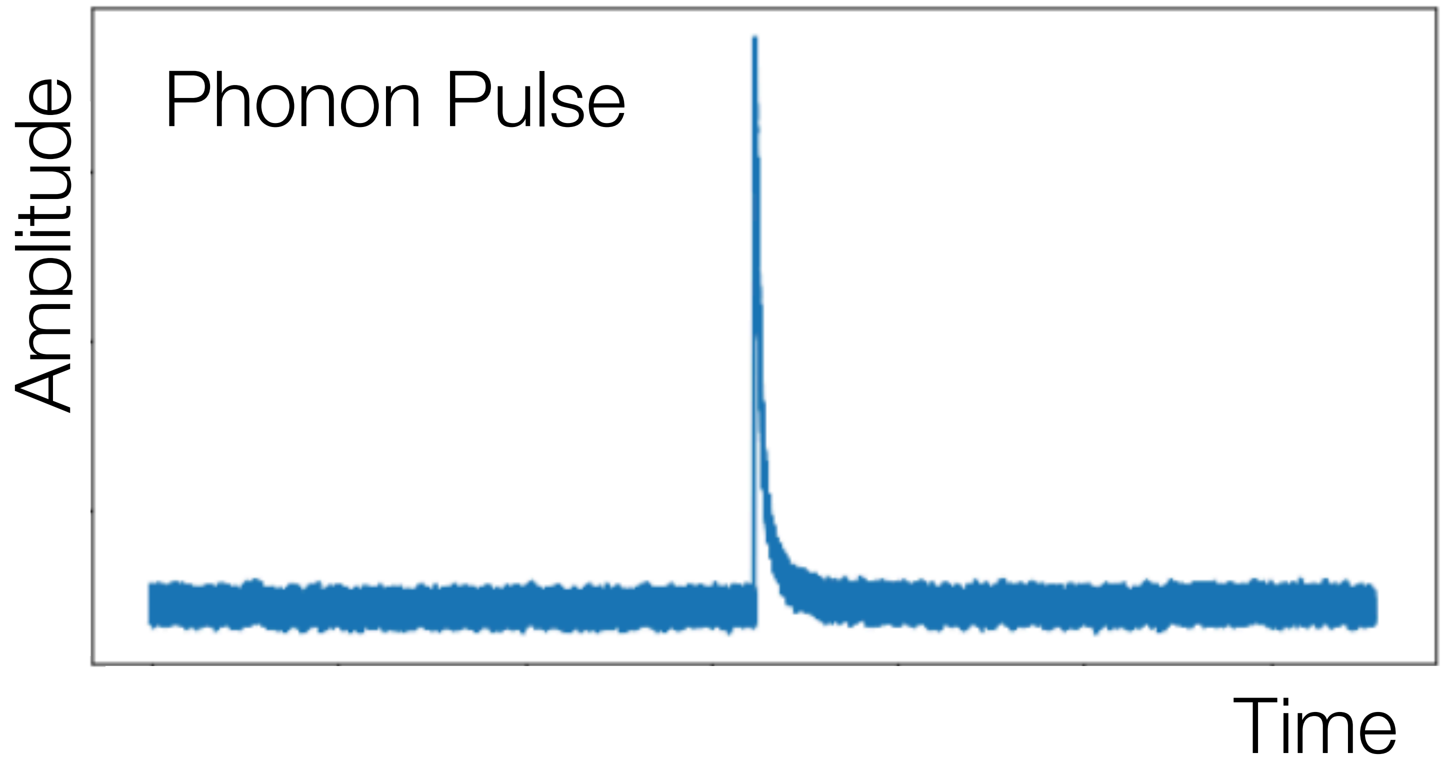
Germond, Fascione, **BvK**, et al. Phys. Rev. D 101 (2020) 052008

TRIGGER FOR LOW MASS DARK MATTER SEARCHES

CUSTOM DETECTOR CONTROL AND READOUT CARDS (DCRC)



Prototype DCRC



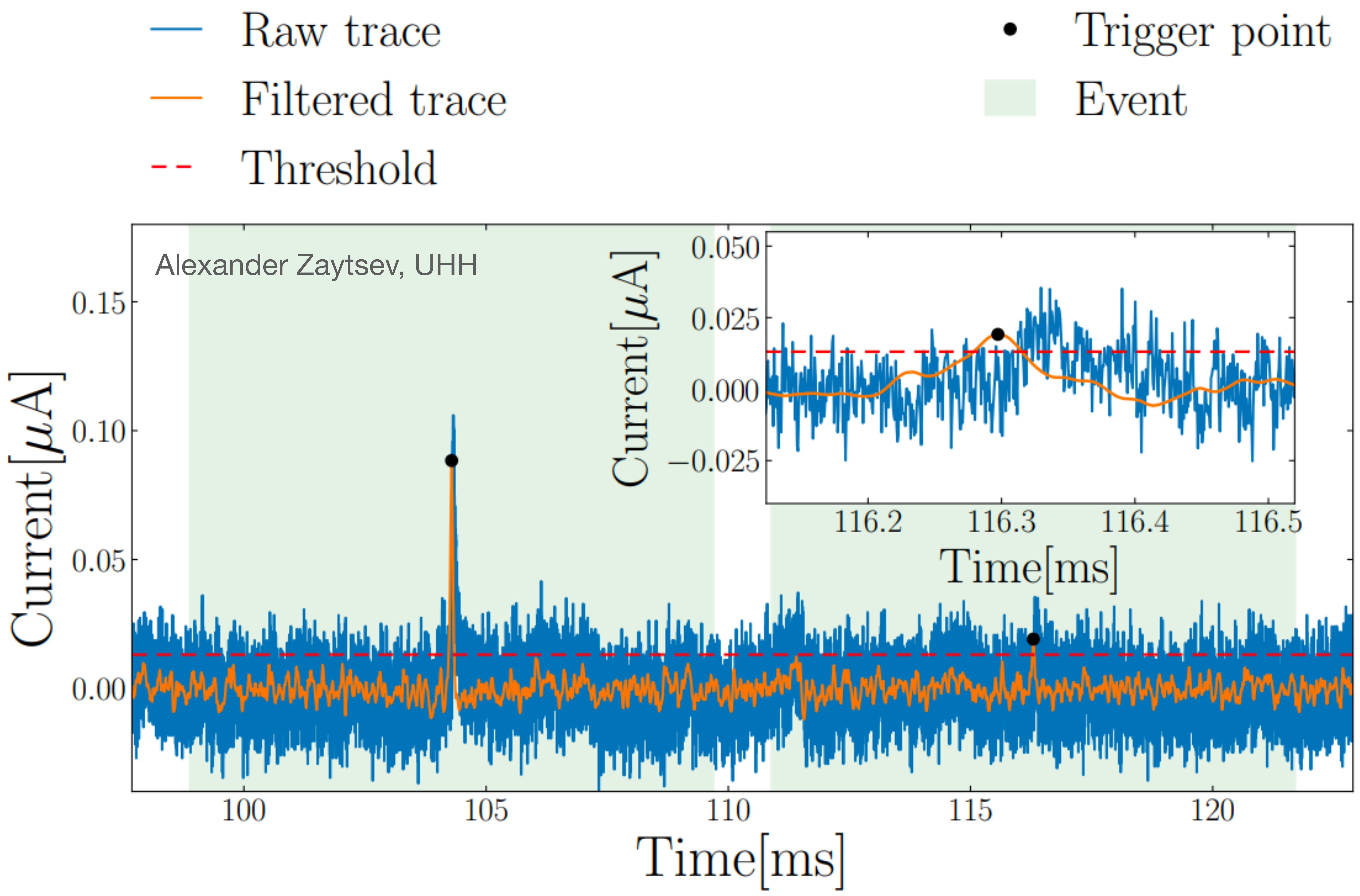
- L1 triggers on phonon signal
- Sampling:
  - 625 kHz (phonon)
  - 2.5 MHz (ionization)

PRINCIPLES OF TRIGGERING AT SuperCDMS

- Continuous trace, HVeV detector
- **Offline** Trigger:
    - Filtering with "Optimal Filter"
    - Threshold triggering

⇓

- Same principle for **Online** Trigger on FPGA (Level 1)

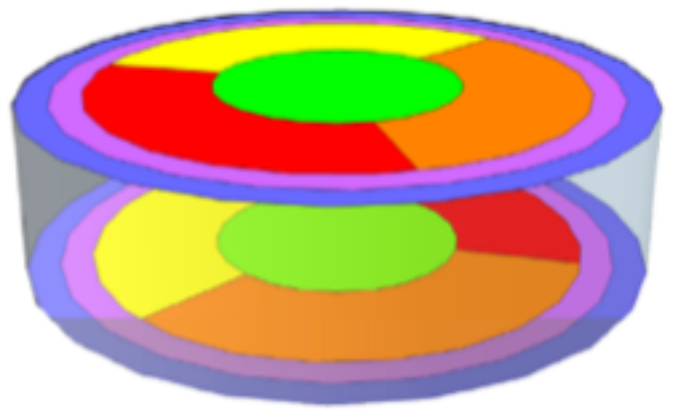


Kurinsky, **Zaytsev**, **Meyer zu Theenhausen, Wilson**, et al. arXiv:2012.12430 (submitted for publication)

L1 TRIGGER ARCHITECTURE

Filtering with "Optimal Filter"

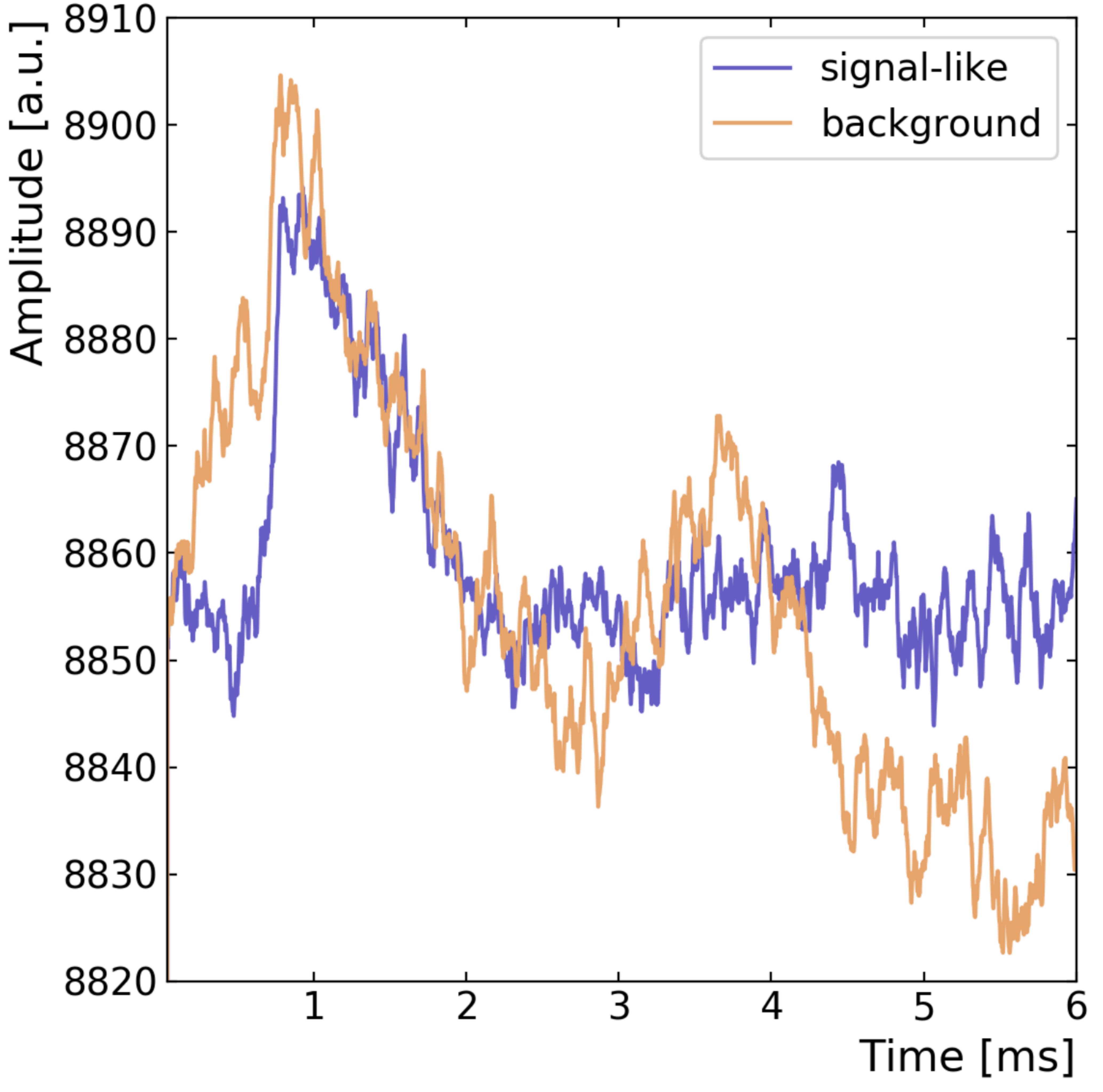
L1 TRIGGER: R&D TO FURTHER REDUCE NOISE



NxM Correlated
Optimal Filter

Filter out noise by using all phonon channels individually

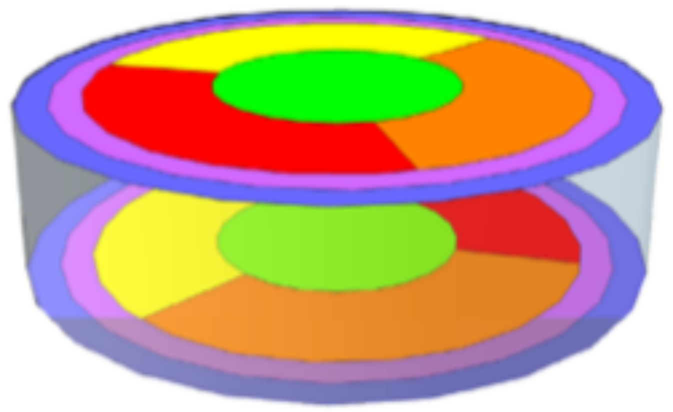
LOW ENERGY EVENTS IN SuperCDMS CRYSTALS

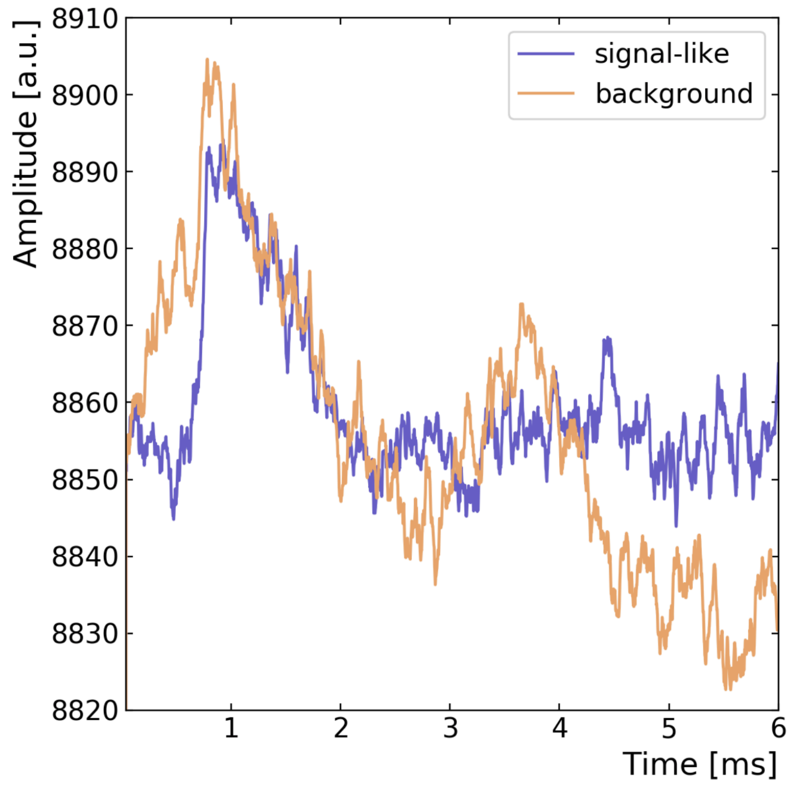


- Signal-like events:
  - particle energy depositions in crystal
  - constant, known pulse-shape
- “Background” events:
  - not particle induced
  - externally induced vibrations
  - varying, unknown pulse-shapes

Not distinguishable by existing trigger

L1 TRIGGER: R&D TO IMPROVE EVENT SELECTION





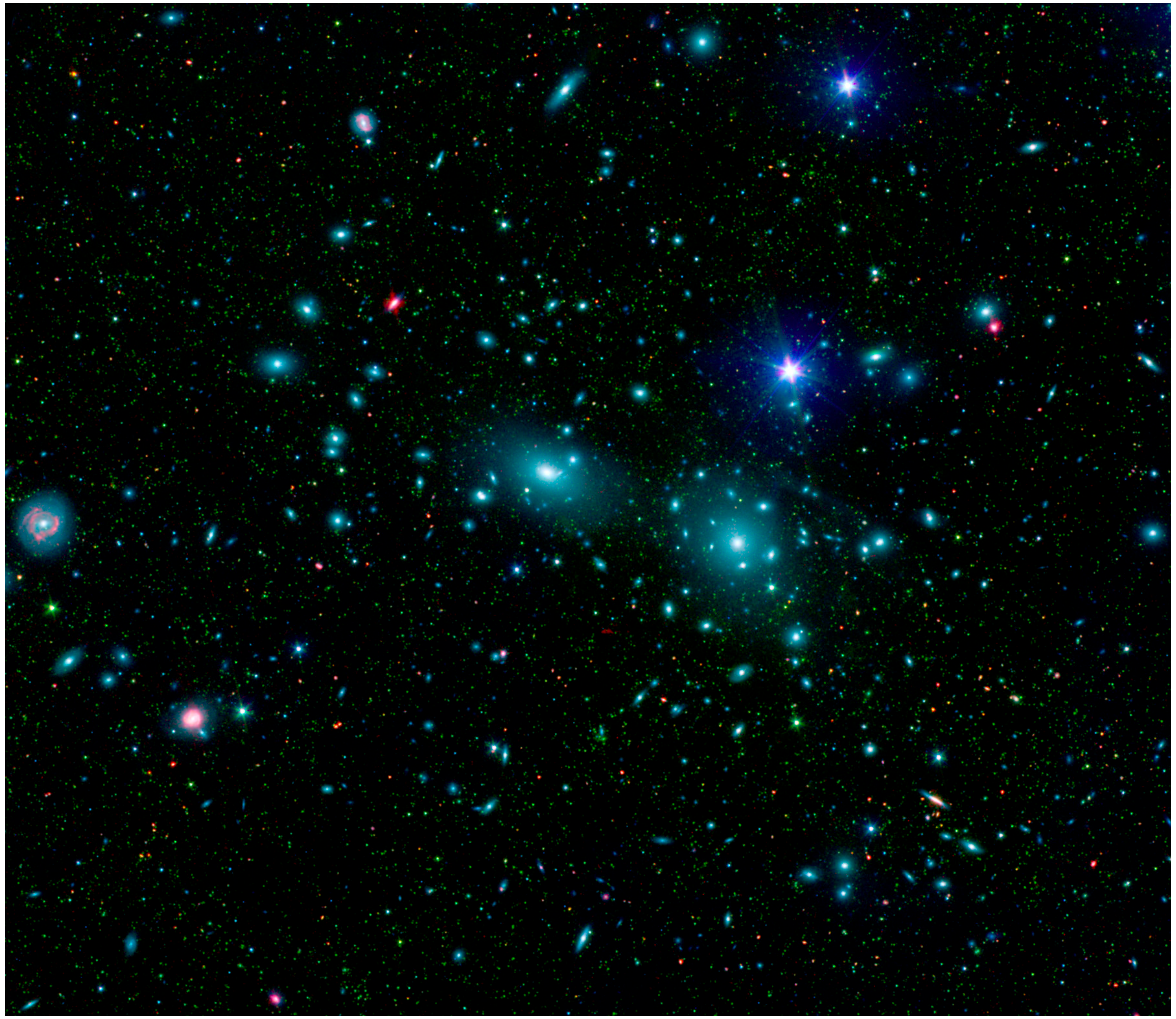
NxM Correlated Optimal Filter

Artificial Neural Network

Use Machine Learning on FPGA for event classification

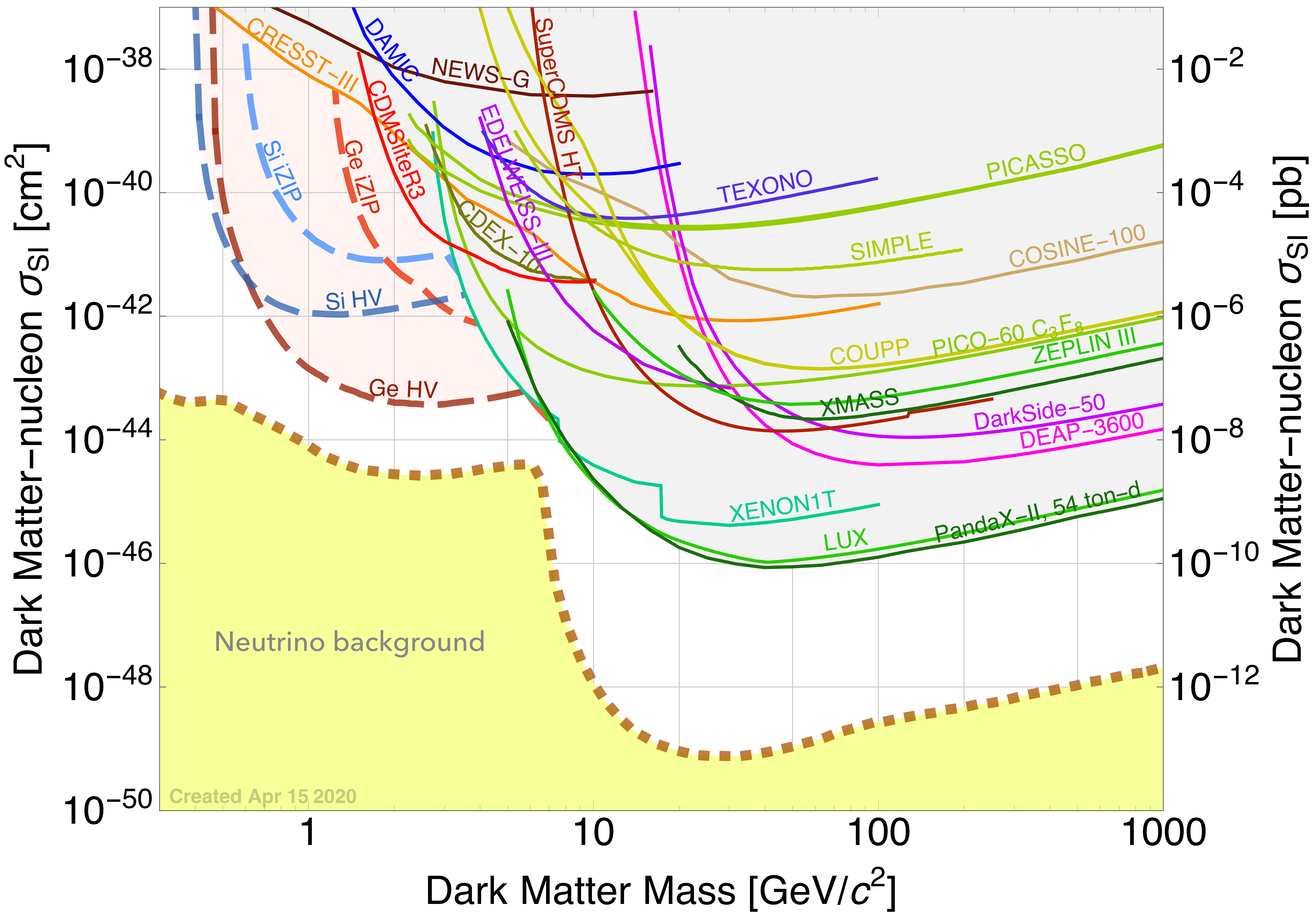
CONCLUSION

- Understanding the nature of Dark Matter is one of the biggest challenges in science today
- SuperCDMS at SNOLAB offers a unique chance to probe uncharted territory in the near future
- Never hesitate to pioneer! Reach beyond existing sensitivities can only be achieved by new ideas and concepts



ADDITIONAL MATERIAL

PROJECT GOALS FOR INITIAL PAYLOAD (2021–2026)



Ge HV: Limited by tritium (cosmogenic) betas

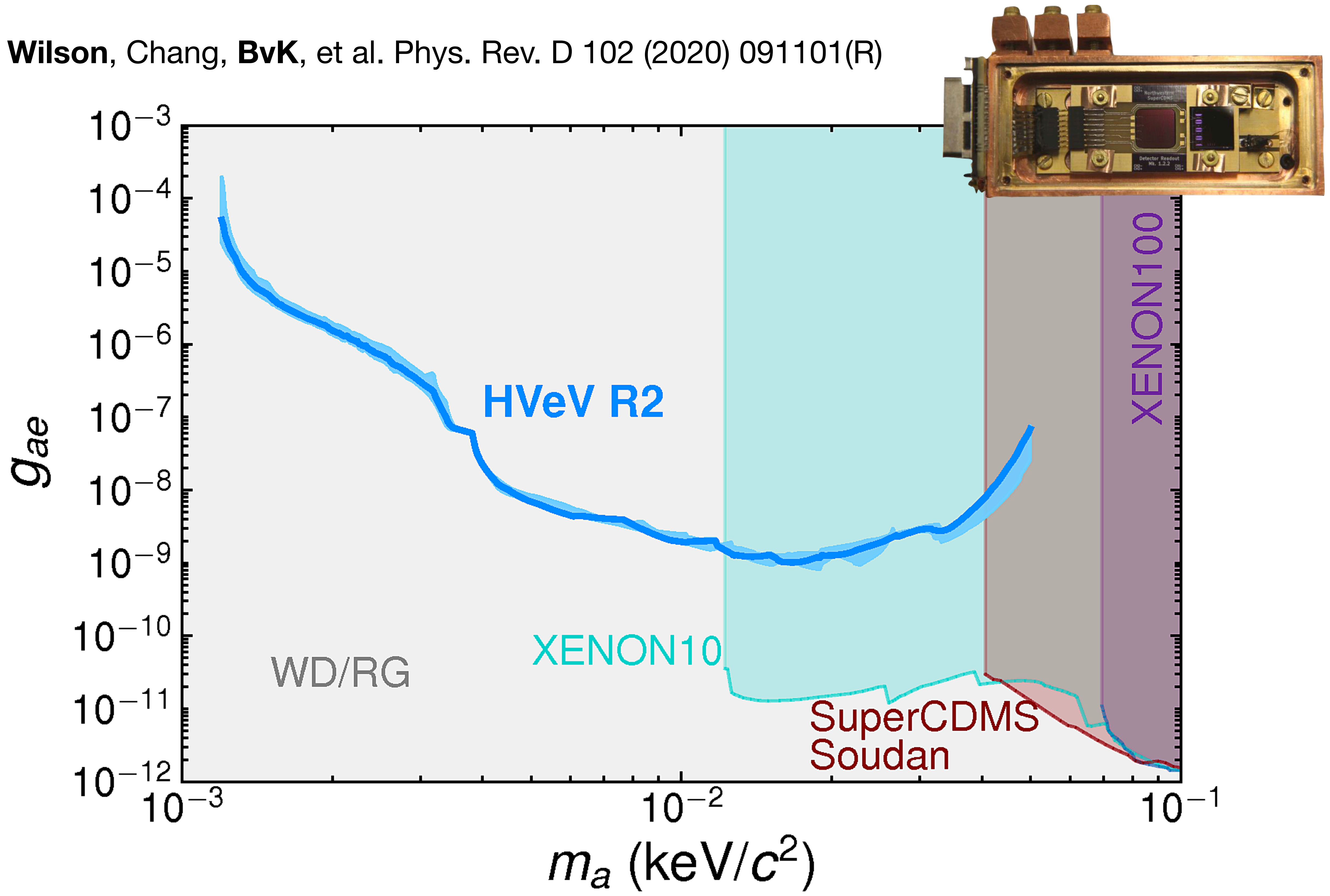
Si HV: Limited by ^{32}Si (and tritium) betas

Ge iZIP: Limited by exposure (thanks to ER discrimination)

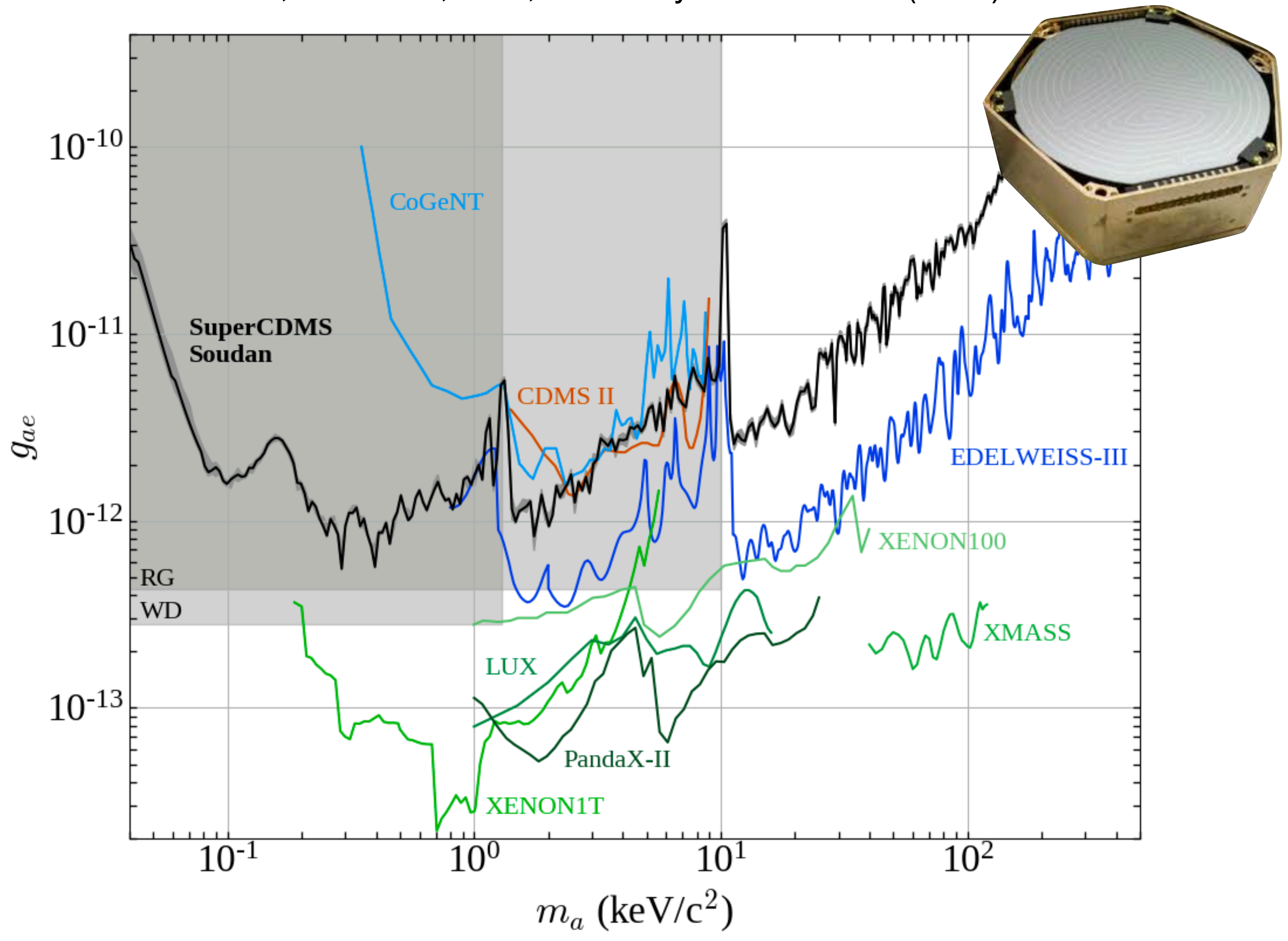
Si iZIP: Limited by exposure (thanks to ER discrimination)

ALP ABSORPTION LIMITS

Wilson, Chang, **BvK**, et al. Phys. Rev. D 102 (2020) 091101(R)



Germond, Fascione, **BvK**, et al. Phys. Rev. D 101 (2020) 052008



Dominating uncertainty at low masses: photoelectric (p.e.) cross-section

=> Precision p.e. cross-section measurements at low energies and temperatures

Stanford, **Wilson**, **BvK**, et al. AIP Advances 11 (2021) 025120

BvK, **Wilson**, et al. arXiv:2010.15874 (submitted for publication in PRD)

UNCERTAINTY OF PHOTOELECTRIC CROSS-SECTION

Stanford, **Wilson**, **BvK**, et al. AIP Advances 11 (2021) 025120

BvK, **Wilson**, et al. arXiv:2010.15874
(submitted to and recommended for publication in PRD)