Direct Detection without Noble Gases

(title amended on Slide 7)

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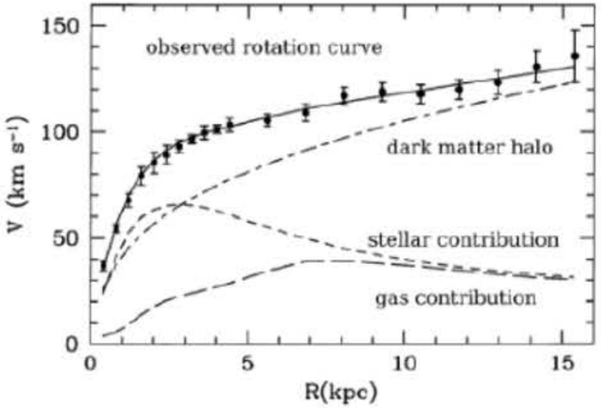
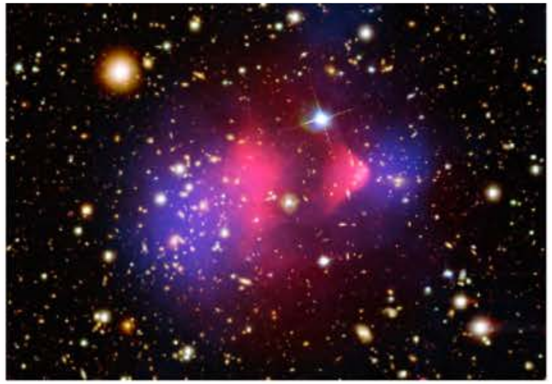
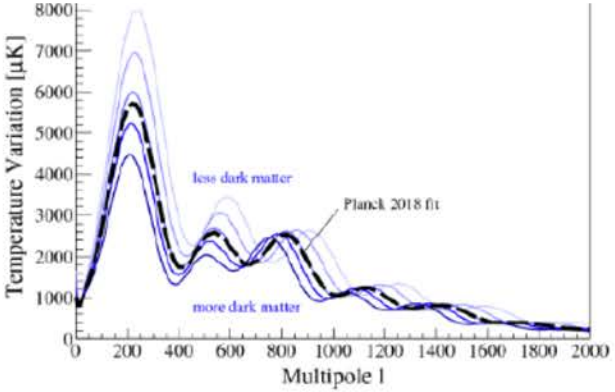
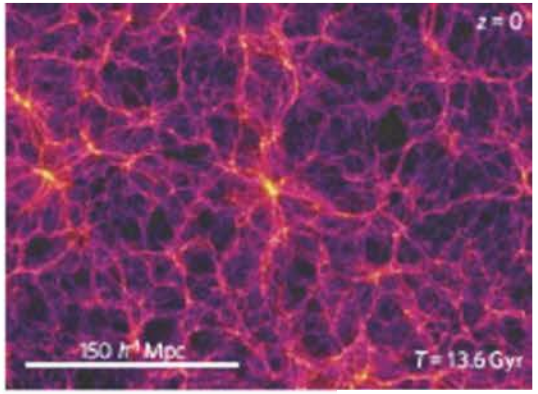
Direct Detection is like playing CLUE

We have a well-established crime scene

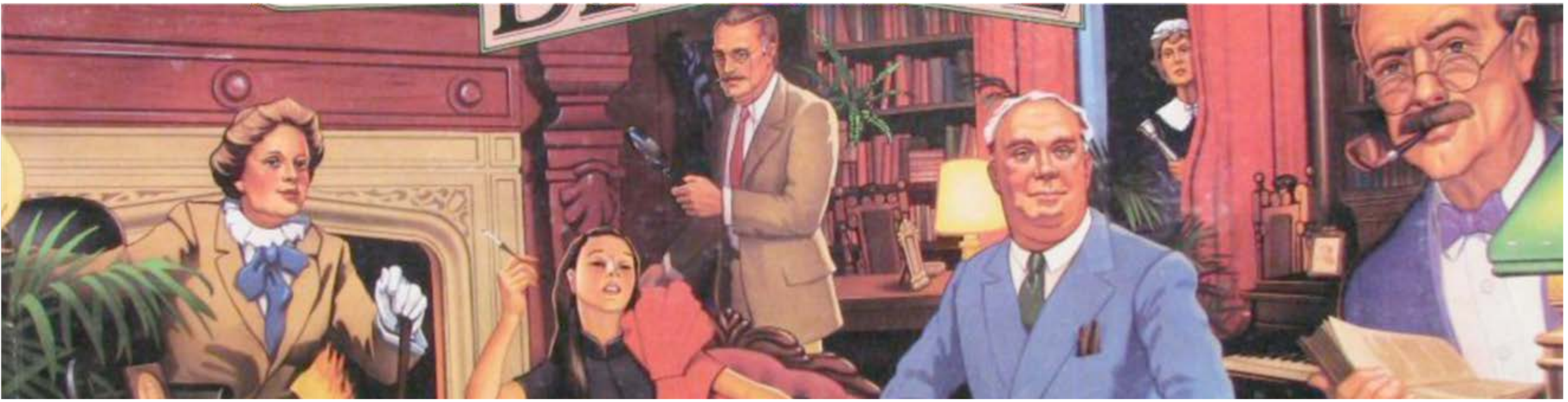








But we don't know who did it



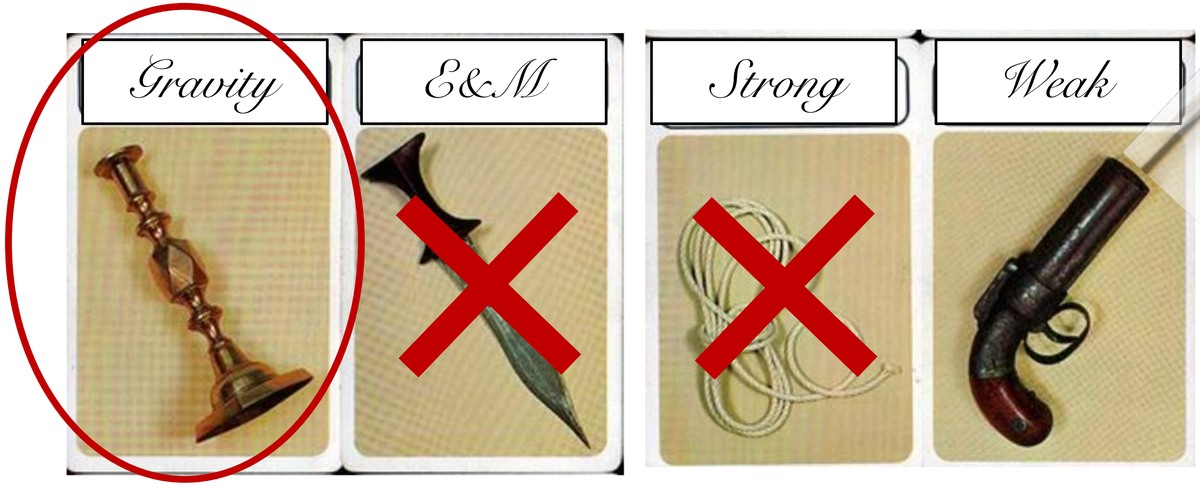
nor what weapons they have in their arsenal

Prime Suspect:

Weakly Interacting Massive Particle

The WIMP

in the Cosmos with the ...



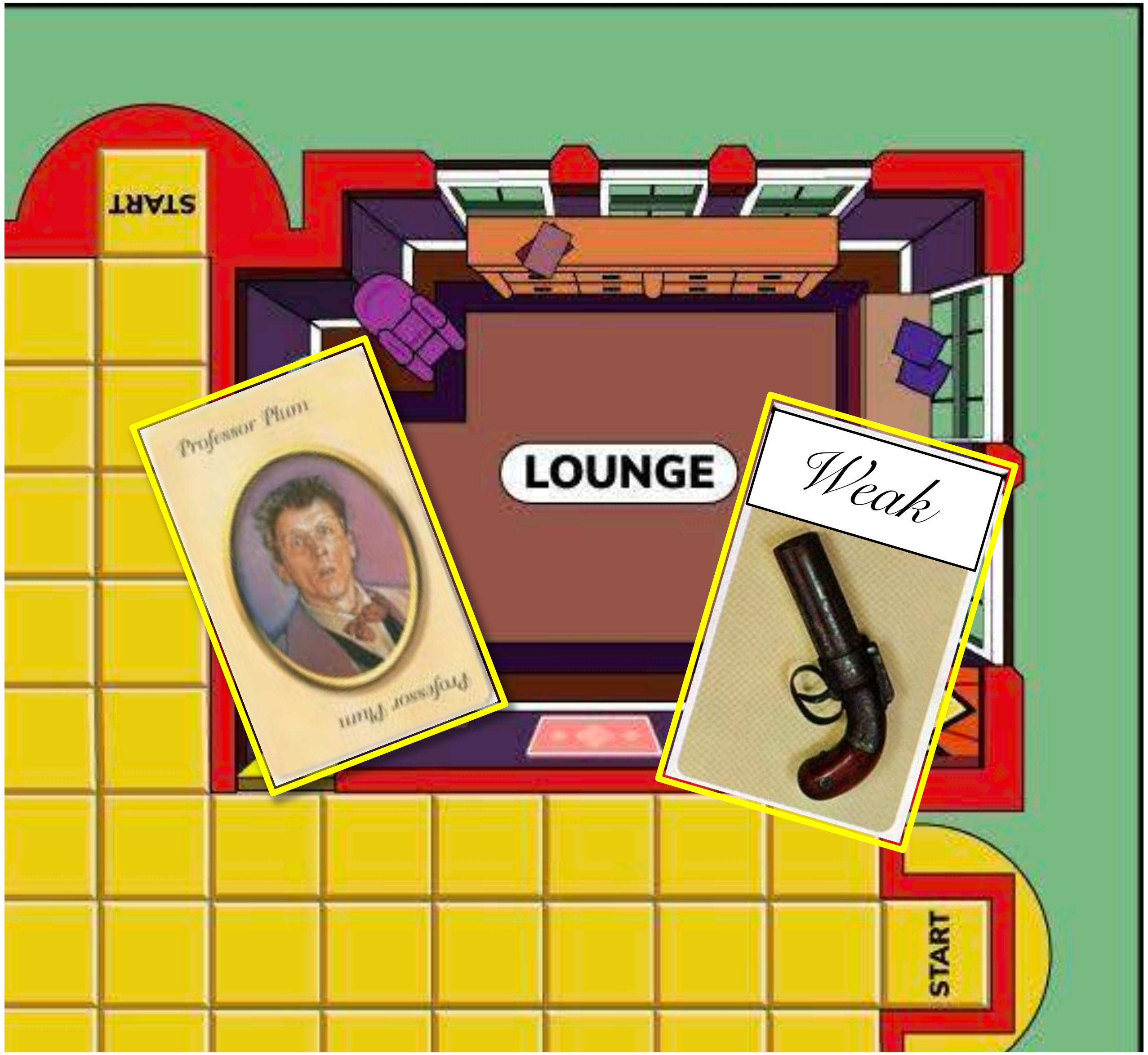
The Weak Interaction is allowed and provides the right relic density with a simple thermal equilibrium model in the early Universe. But no smoking gun yet.

The Prime Suspect is still on the loose!

But his hideout is well-known and currently staked out.

But here is where I am
having some trouble
with the title assigned by the
conference organizers:

“Direct Detection without Noble Gases”



That covers all the rest of the rooms

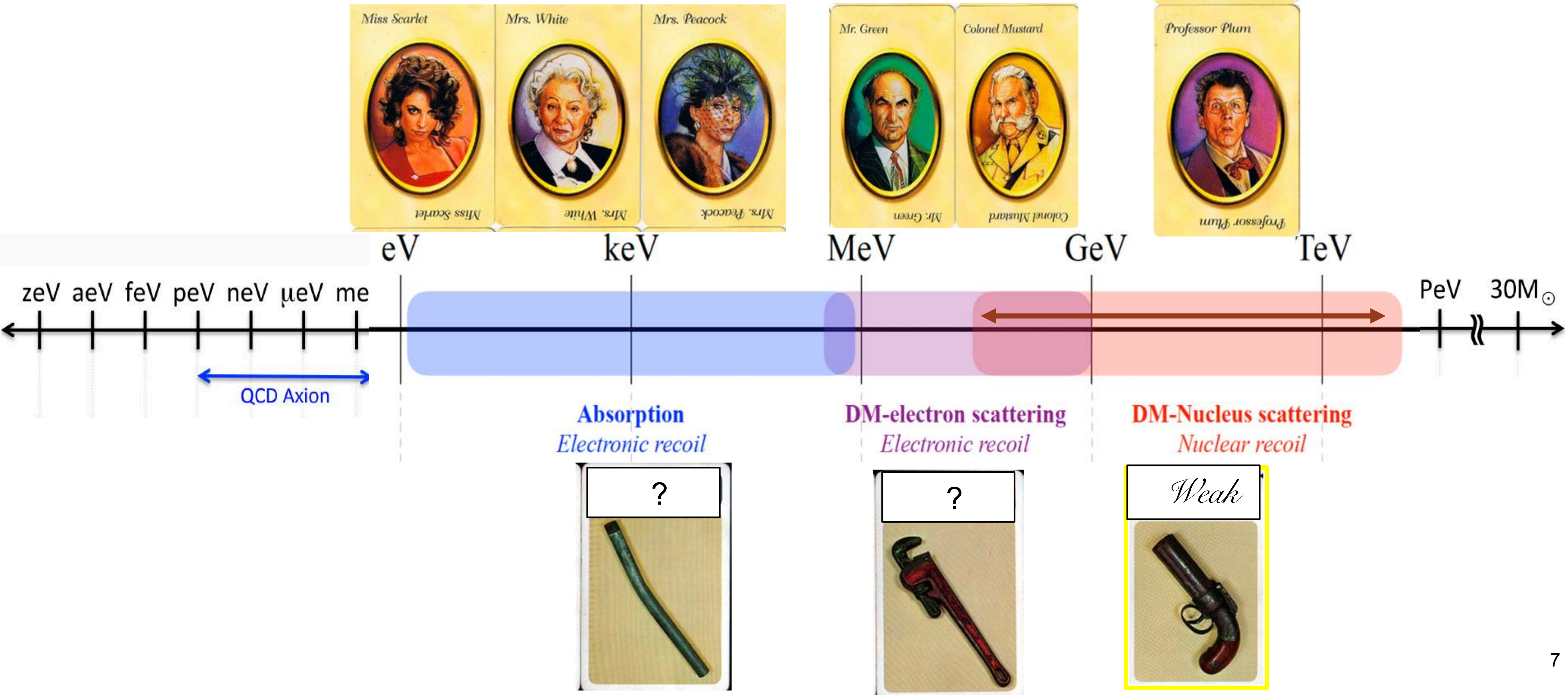
and other suspects

That covers all the
rest of the rooms

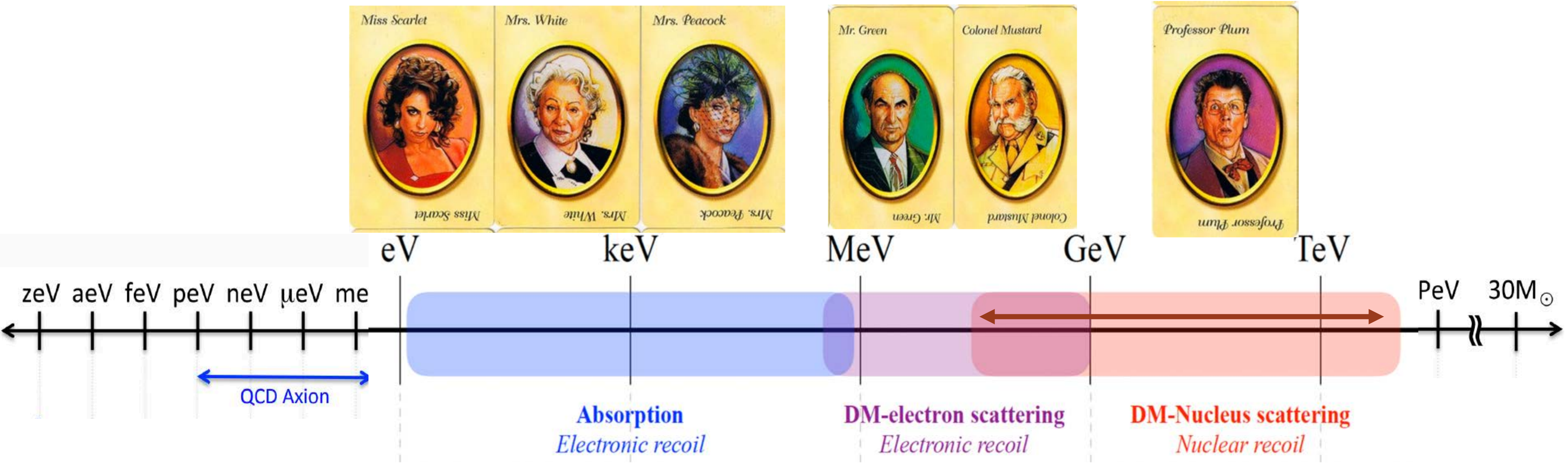
and other suspects

and plenty of new interactions

2017 Cosmic Visions mapped DM mass to generic coupling

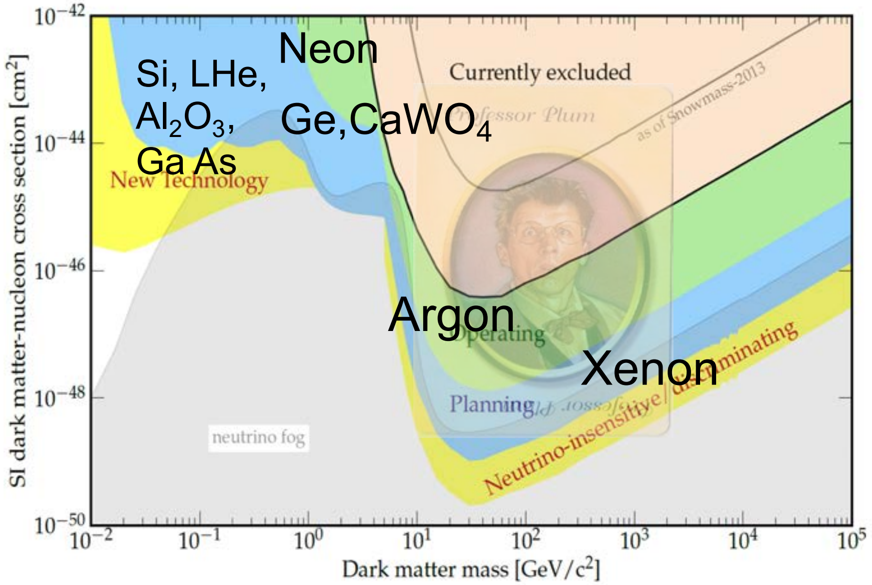


Direct Detection of Particle DM without Noble ~~Gases~~ Liquids below a TeV



And I will cede CCDs and (most) sub-GeV dark matter to Rouven who speaks next

Nuclear Recoiling Dark Matter Future – Snowmass View

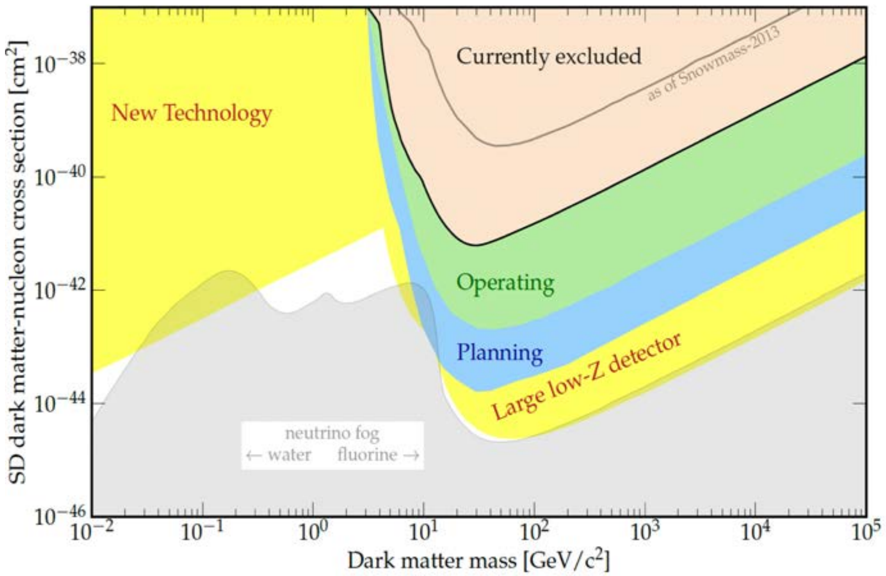


Spin-independent searches will reach the neutrino fog by mid-century

- LXe TPCs will then probe atmospheric neutrinos
- LAr (TPCs and Scintillating bubble chambers) probe solar ν

} *with large overlap*

- Solid state bolometers spawn
  - small phonon-only (TES readout of LHe, Al_2O_3, Ga As, Si)
  - and voltage-assisted phonon amplification (Ge, Si…)
- Charge-only devices (CCDs and HPGe) cut a swath
- Along with gas proportional chambers with light noble gas



Spin-dependent phase space is wide-open at lower masses
but technology to probe deep at 10 – 100 GeV/c^2 is well-developed

σ_{SD} reach can't take advantage of the coherent A^2 enhancement

One experiment proves dark matter interacts with SM particles
with force(s) other than gravity
Multiple experiments not only confirm the detection,
They are essential to probing the nature of the interaction.

Snowmass gave us a new mantra: Delve deep and Search wide
Experimental Strategy for the next 20 years

Noble Liquids continue to look for the prime suspect: Large exposure, good NR discrimination

Solid State

Phonons + SuperCDMS, EDELWEISS, CRESST. Target lower mass DM with excellent NR discrimination.
Tension: Max exposure + NR discrimination… or … Low threshold (small crystals, NTL amplification)
Phonon only: Remove charge noise and expand your choice of target (TESSERACT)
Charge only: DAMIC, SENSEI CCDs. Sub-GeV ER dark matter, single electron sensitivity
CDEX Point-contact Ge detectors.
Can you make a $0\nu\beta\beta$ detector with low enough threshold to do a light DM search?
Annual Modulation Program NaI crystal arrays with very low background and stable conditions

Bubble chambers: *Insensitive* to electron-recoil DM ➔ the best discrimination possible
PICO program: Freon (and other fluorocarbons) gives access to spin-dependent NR interactions.
Nucleation Threshold determined by T, P ➔ no energy information except by tuning conditions
SBC (Scintillating bubble chambers) Use scintillation of noble liquids to measure the energy event-by-event.
Current plan with LAr ➔ go for the ~ 1GeV NR, no spin-dependence. Target CEνNS as well as DM

Gas Detectors: Light DM mass: e.g. NEWS-G spherical proportional chamber with Ne + CH_4
Probe below the neutrino fog with directional information (e.g. CYGNUS)
Technology is advanced, but exposure is challenging.

Summary of Spin-dependent target opportunities

Couples to net nuclear spin J_N

$$\sigma_{SD} = \frac{32}{\pi} G_F^2 \frac{m_\chi^2 m_N^2}{(m_\chi + m_N)^2} \frac{J_N + 1}{J_N} \left(a_p \langle S_p \rangle + a_n \langle S_n \rangle \right)^2$$

neutron coupling

^{73}Ge (7.73%) $\langle S_n \rangle = .46$ CDMS,EDELWEISS

^{29}Si (4.68%) $\langle S_n \rangle = .13$ DAMIC/SENSEI, CDMS

^{17}O (0.037%) $\langle S_n \rangle = .5$ CRESST ($CaWO_4$)

^{129}Xe (26%) $\langle S_n \rangle = .33$

^{131}Xe (21%) $\langle S_n \rangle = -.27$

LXe TPCs

proton coupling

^{7}Li (92.4%) $\langle S_p \rangle = .5$ CRESST($LiAlO_2$, Li_2MoO_4)

^{127}I (100%) $\langle S_p \rangle = .31$

^{23}Na (100%) $\langle S_p \rangle = .25$

^{133}Cs (100%) $\langle S_p \rangle = -.37$

NaI (and CsI)
DAMA, SABRE, ANAIS,
COSINE-100, COSINUS

^{1}H (100%) $\langle S_p \rangle = .5$ Snowball (H_2O)

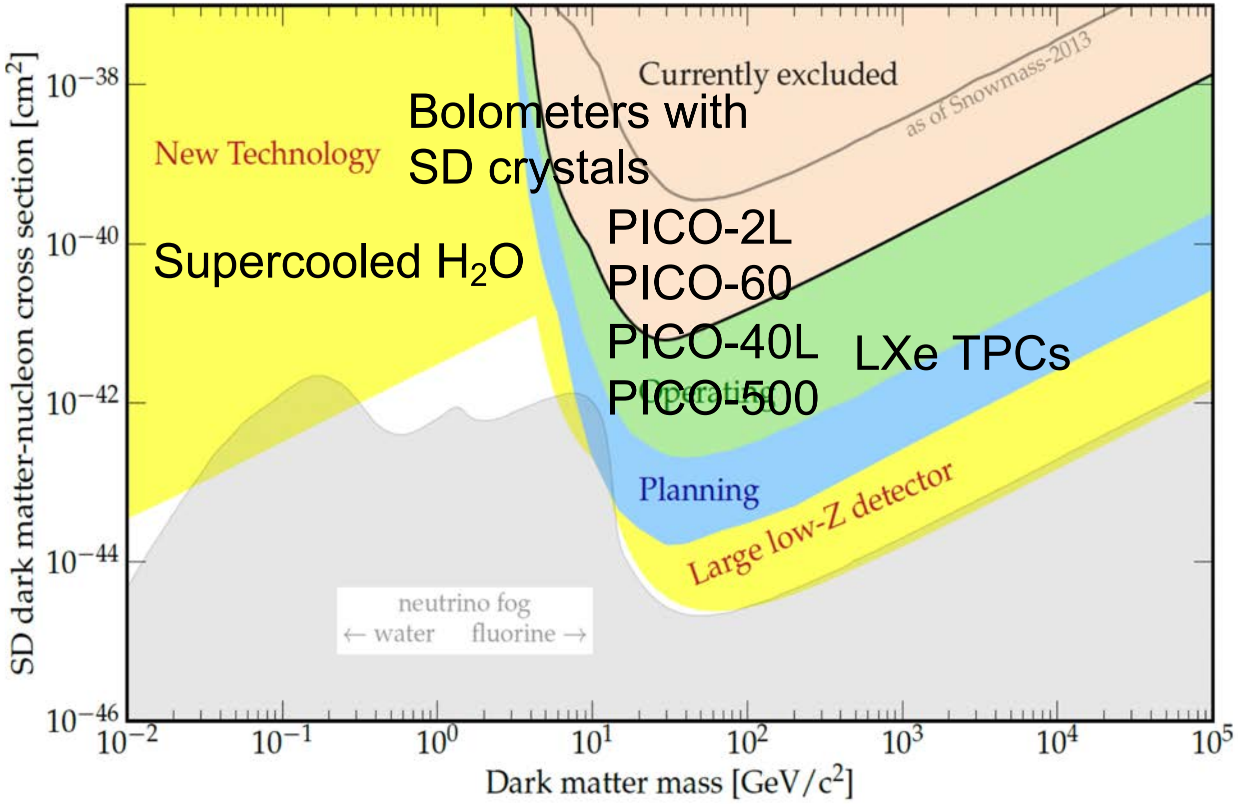
proton & neutron coupling

^{19}F (% depends on fluorocarbon) $\langle S_n \rangle = -.11$ $\langle S_p \rangle = .44$ PICO (CF_3I, C_3F_8)

^{6}Li (7.6%) $\langle S_n \rangle = .472$ $\langle S_p \rangle = .472$ CRESST ($LiAlO_2$, Li_2MoO_4)

Nuclear Recoiling Dark Matter: SD targets & technology

But you still have to make a detector out of it.
And in the end, we do not have a spin-analyzing detector,
just relative signals in multiple targets.



PICO superheated bubble chambers
Freon (C_3F_8), also CF_3I earlier ➔ proton coupling
Will require new vessel materials to move into the blue

XENON, LZ, PandaX ➔ DARWIN cover n-coupling,
but the xenon neutrino fog is decades higher than the
fluorine neutrino fog

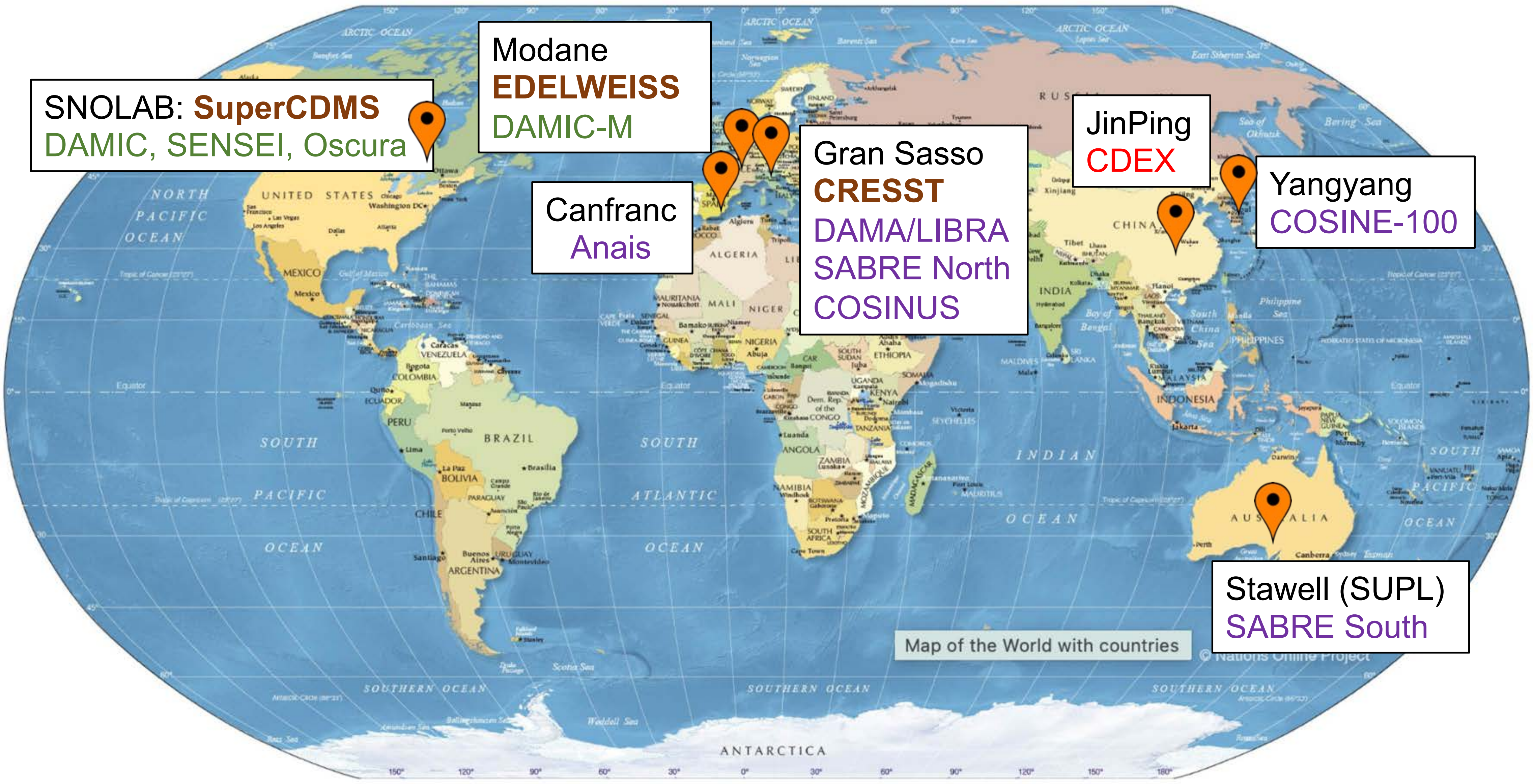
EDELWEISS, SuperCDMS n-coupling at lower masses
CRESST is exploring new SD crystals with Lithium

New technology could be a liquid/solid
phase change detector like Snowball

SI Solid State Players

Cryogenic
Bolometers

CCD-based
Point Contact HPGe,
NaI Annual Modulation



SNOLAB: **SuperCDMS**
DAMIC, SENSEI, Oscura

Modane
EDELWEISS
DAMIC-M

Canfranc
Anais

Gran Sasso
CRESST
DAMA/LIBRA
SABRE North
COSINUS

JinPing
CDEX

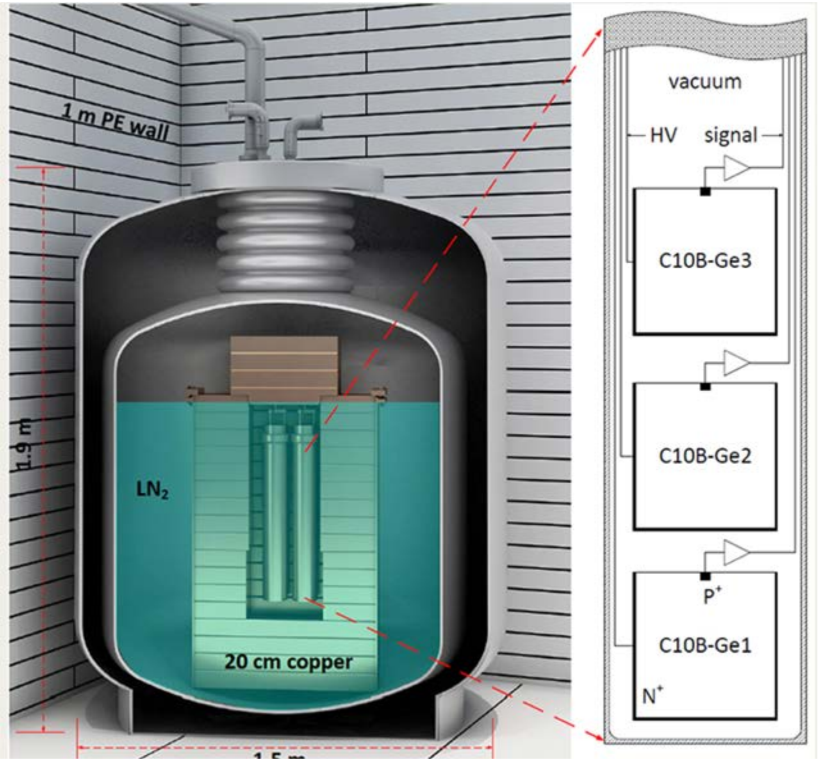
Yangyang
COSINE-100

Stawell (SUPL)
SABRE South

Map of the World with countries

© Nations Online Project

High Purity Germanium Detectors : CDEX at JinPing



- Runs at liquid nitrogen temperatures
- Excellent energy resolution
- Doubles as a neutrinoless double beta decay detector
  - Get the threshold low enough ➔ DM detector
- Use energy resolution to beat down background
- No evt by evt ER vs NR discrimination
- Some pulse shape discrimination

CDEX-10 operating now

205 kg-d exposure with 10 kg array of 9 detectors

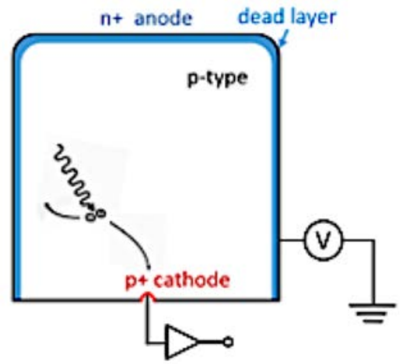


Fig. 1 The structure of 1 kg pPCGe detector.

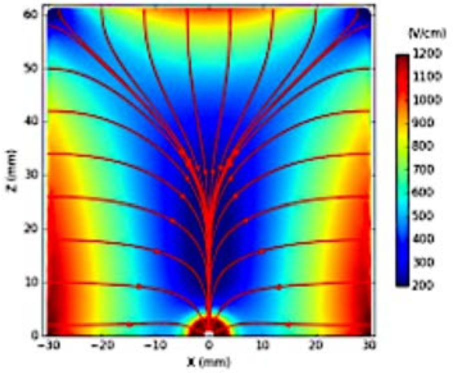
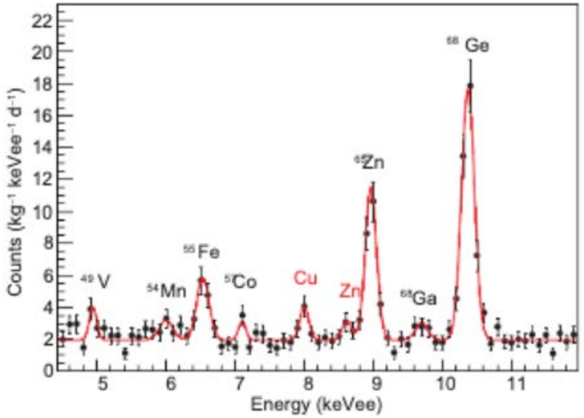
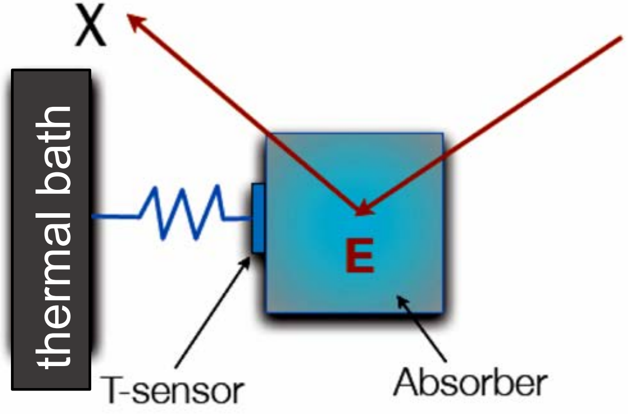


Fig. 2 Electric field simulation.



C10B-Ge1
E_{thresh} = 160 eVee,
σ_E = 219 eVee FWHM at 10.37 keV

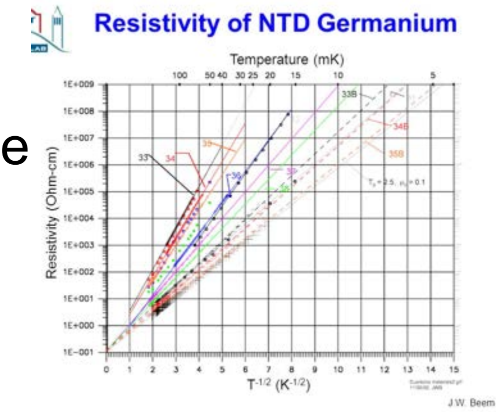
Principles of Cryogenic Solid State Phonon Detection



$$C(T) = \frac{\Delta E}{\Delta T} \propto T^3$$

Small heat capacity is key!
Large sensitivity (big ΔT) for a tiny ΔE deposition.
Tens of mK ➔ dilution fridge infrastructure.

Energy deposition (*temperature*) is measured by

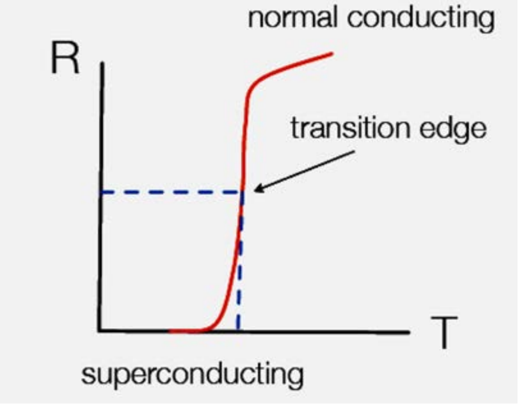


EDELWEISS

GeNTD: *Neutron-transmutation-doped sensors.* Ge wafer with T-dependent resistance induced by neutron irradiation doping. Sensitive to thermal phonons.

CRESST

TES: *Transition-edge sensors.* Tungsten film operated near Tc and read out by SQUIDs. Dominated by athermal phonons. Sensitive to ΔT ~0.1 mK



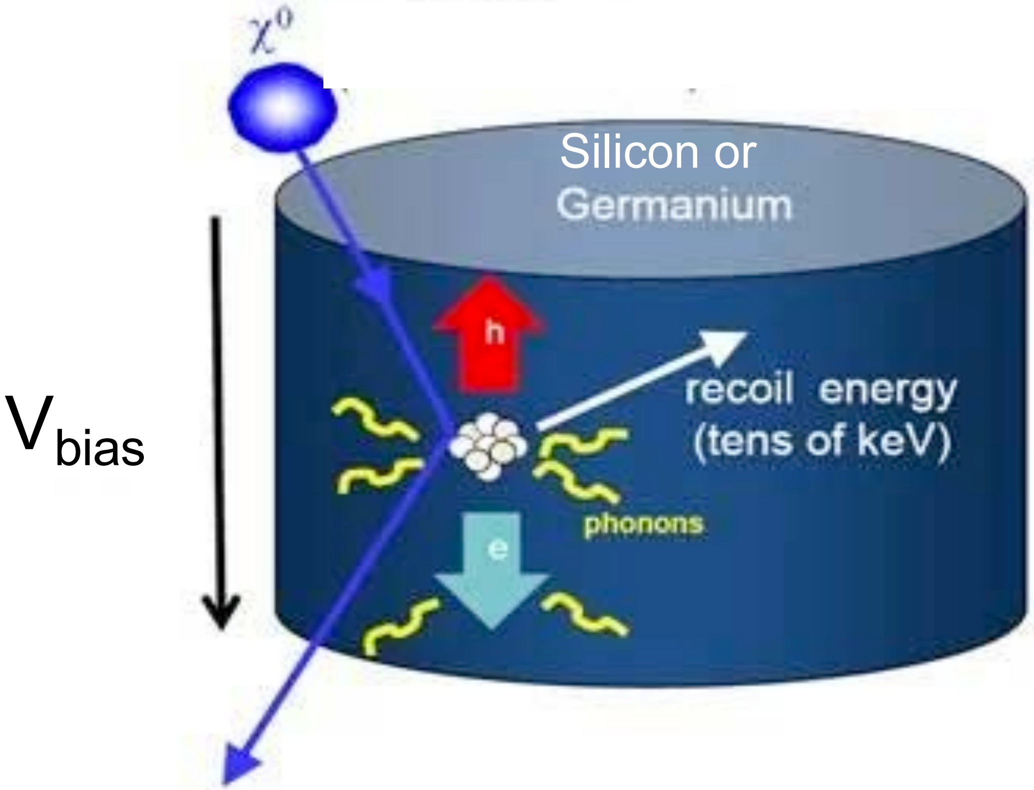
CDMS

QET: *Quasiparticle-trap-assisted Electrothermal-feedback TES*: Arrays of Al fins transmit quasiparticles to the TES. Increases collection area without increasing sensor capacitance and maintains athermal phonon properties.

Phonons supplemented by a second channel

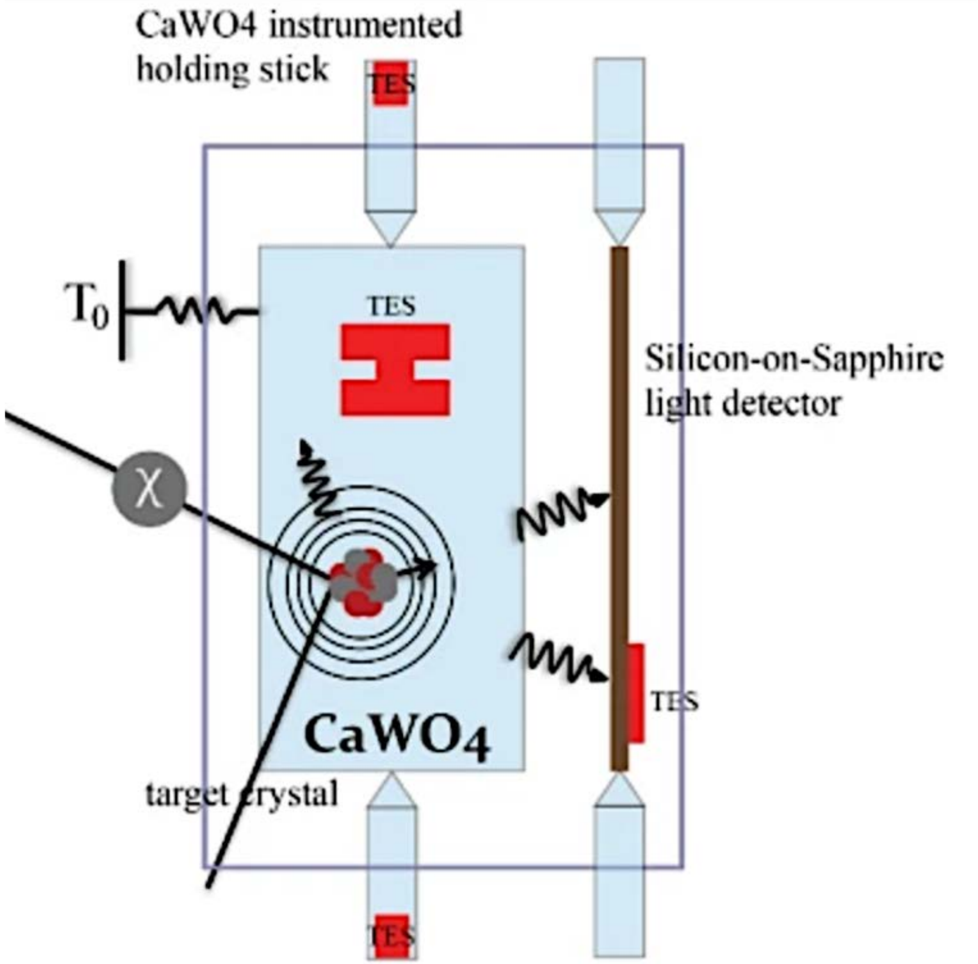
+ Ionization

CDMS and EDELWEISS



+ Scintillation

CRESST

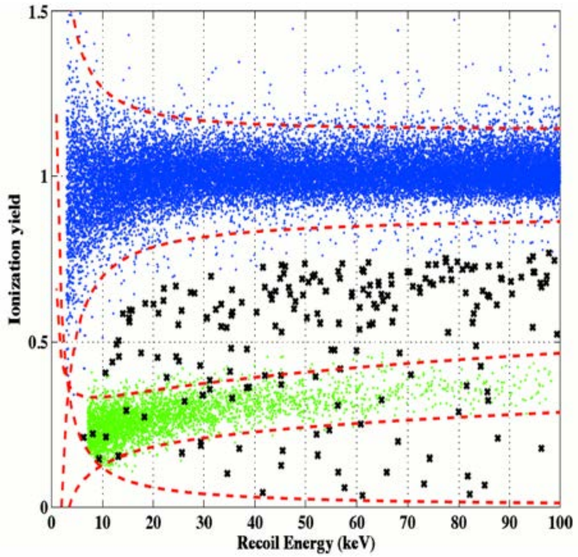


Yield-based Discrimination

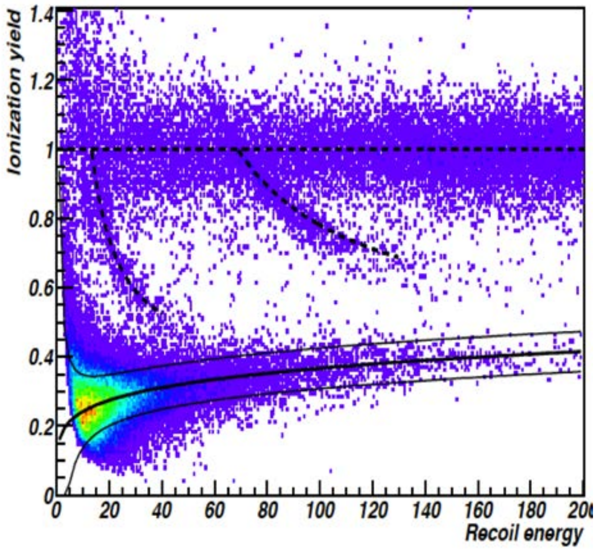
Nuclear Recoil (NR)events are “quenched” relative to Electron Recoils (ER)

Charge to Heat ratio

SuperCDMS



EDELWEISS



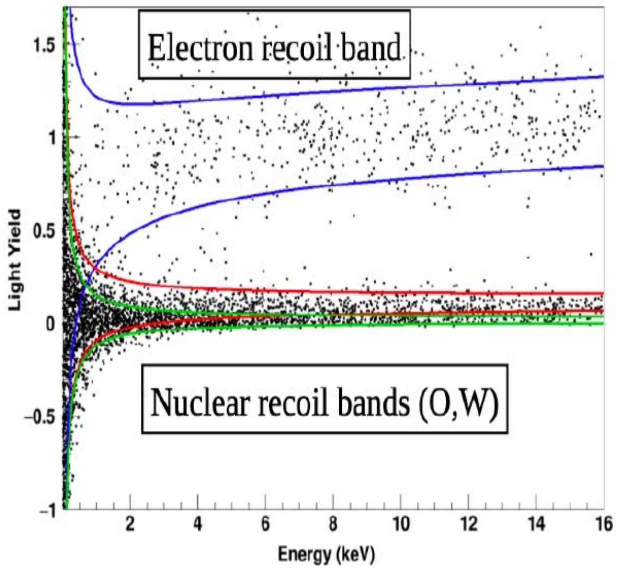
Q(Si) and Q(Ge): NR Quenched by factor ~ 3

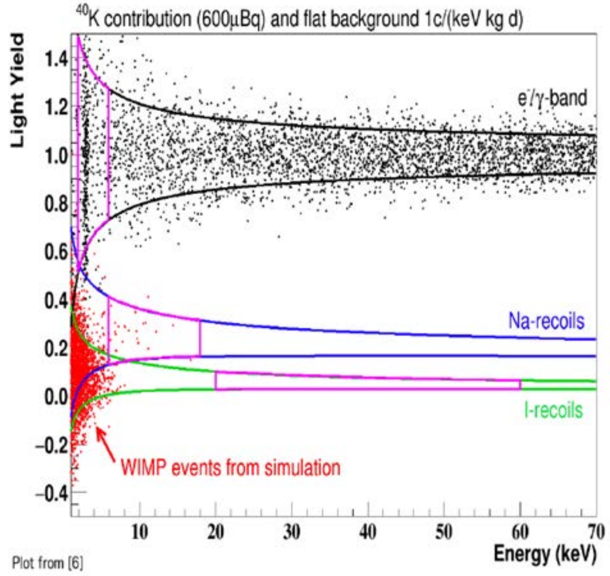
Small Q requires additional rejection of ER using E-field shaping, timing, veto channels

Light to Heat ratio

CRESST

COSINUS
(welcome to the gang!)





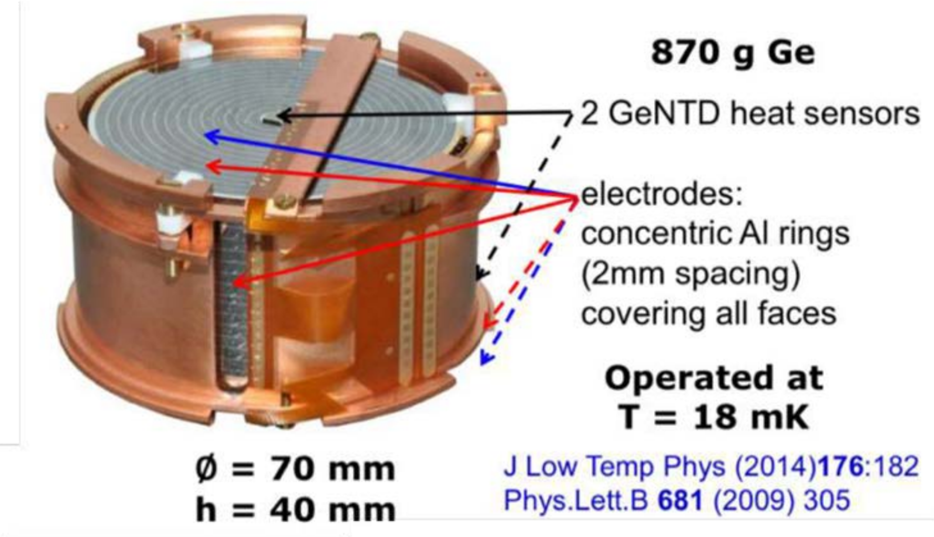
Large quenching factors
Q(O) ~ 9; Q(W) ~ 40

Q(Na) ~ 3
Q(I) ~ 20

Caution: Q is dependent on Energy. Tend to lose NR signal when moving to low mass DM ➔ Calibration required

Interdigitized / **Interleaved** electrodes provide field shaping and surface rejection

EDELWEISS F**I**D800



870 g Ge

2 GeNTD heat sensors

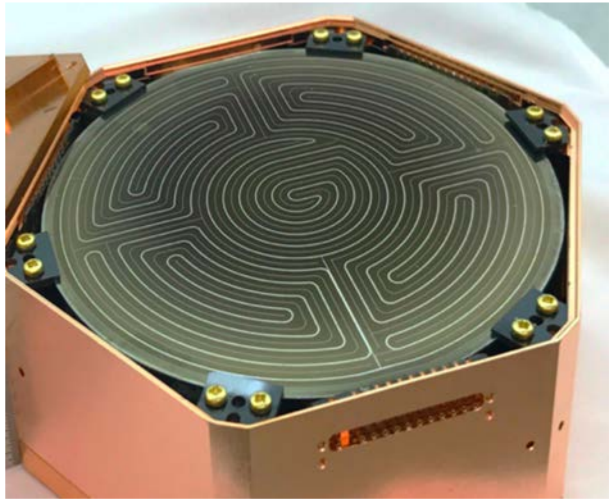
electrodes:
concentric Al rings
(2mm spacing)
covering all faces

Operated at
T = 18 mK

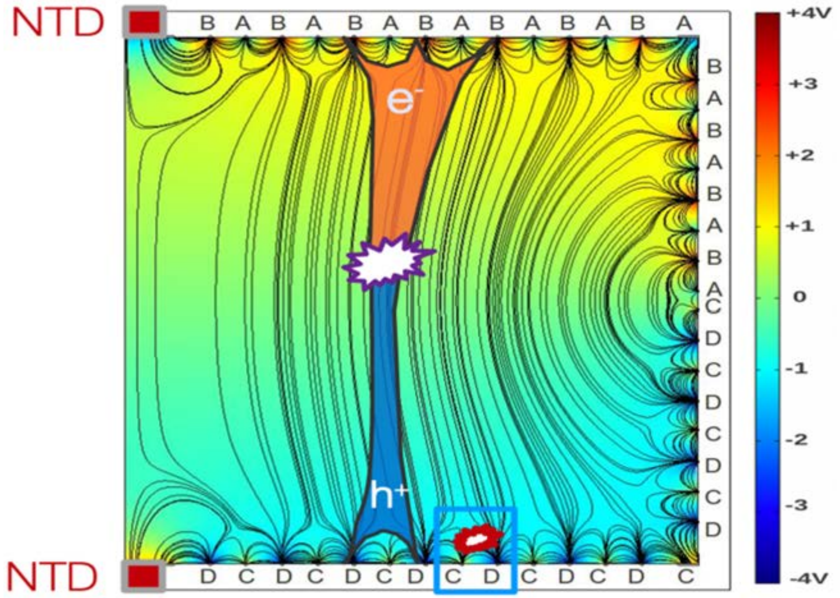
Ø = 70 mm
h = 40 mm

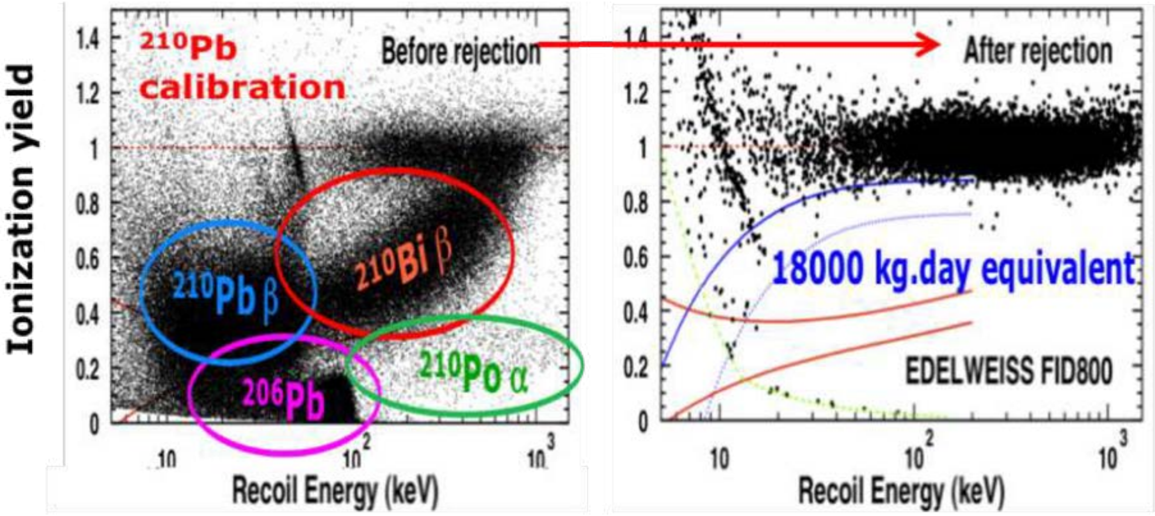
J Low Temp Phys (2014)**176**:182
Phys.Lett.B **681** (2009) 305

SuperCDMS SNOLAB 1.4 Kg Ge **i**ZIP

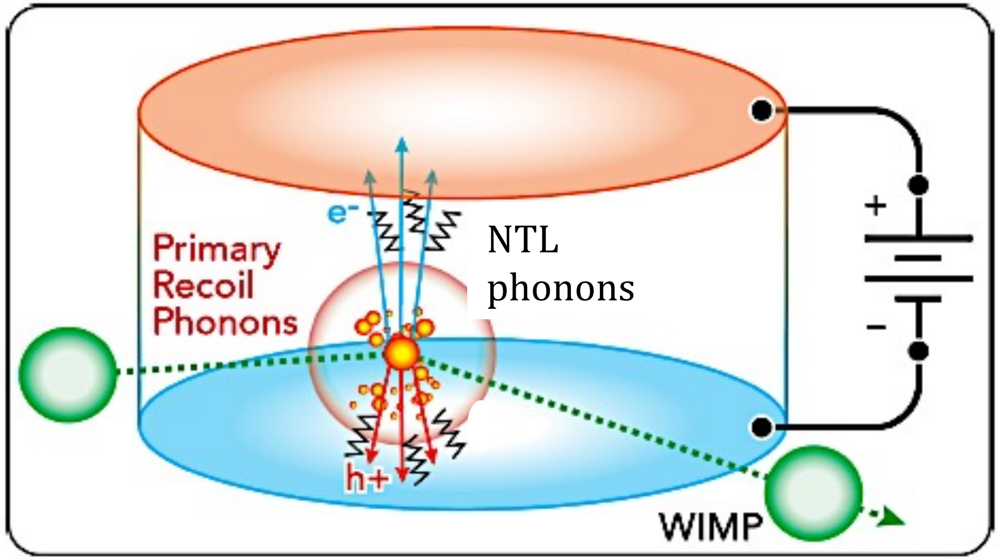


EDELWEISS - III





High Voltage Mode (SuperCDMS and EDELWEISS)



Work done by V_b in drifting electron-hole pairs releases additional NTL phonons

$$E_{tot} = E_r + N_{eh}\, e\, V_b = E_r \left(1 + \frac{Y(E_r)\, e\, V_b}{\varepsilon} \right)$$

Two different modes of operation

iZIP and FID: Low bias voltage (2-5 V) gives background-free mode ➔ NTL phonons negligible

Ratio of ionization to primary phonon signal is unambiguous

Interleaved phonon and charge sensors on both sides

Provides 10^6 ER/NR discrimination and surface rejection

HV: High bias voltage (~ 100 V) pushes to lower thresholds ➔ NTL phonons dominate.

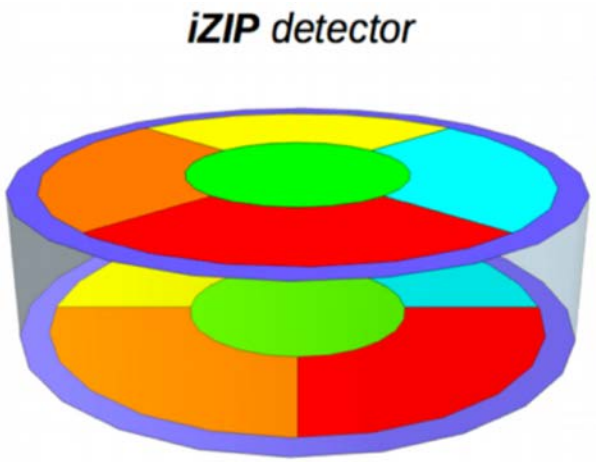
$$E_{tot} \sim E_r \, \frac{Y(E_r)\, e\, V_b}{\varepsilon}$$

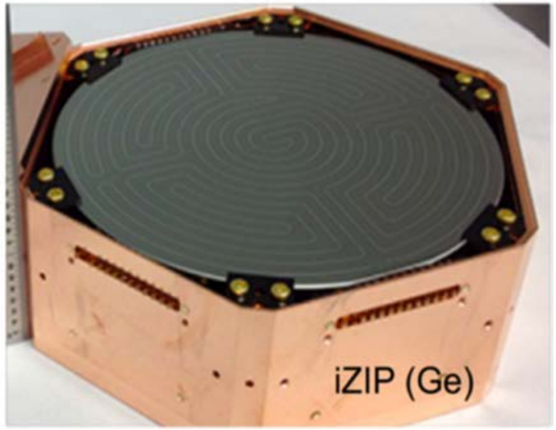
The total phonon signal is larger (amplification means lower thresholds),

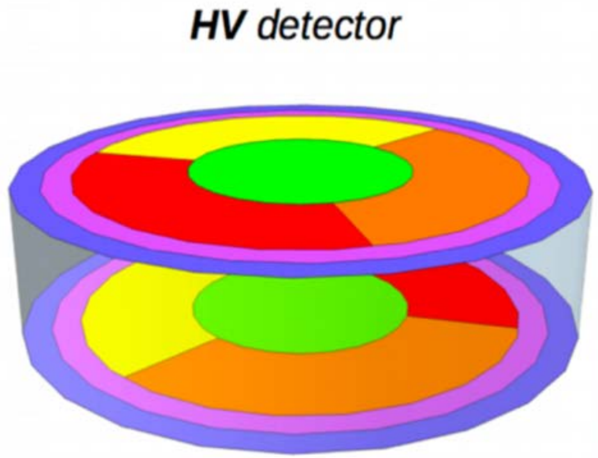
but it is essentially a measure of the charge signal read out through the phonon channel

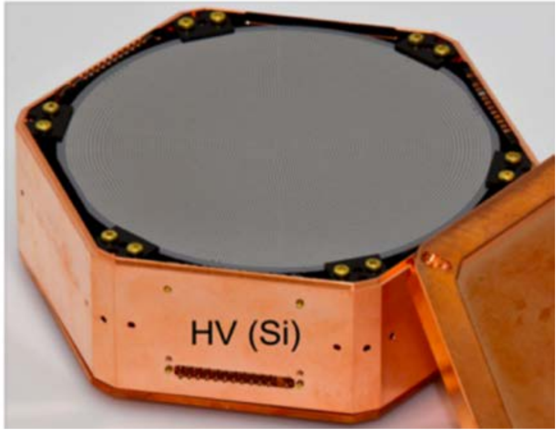
SuperCDMS SNOLAB Detectors

Two target materials Ge (1.4 kg) and Si (0.6 kg)
10 cm diameter and 3.3 cm thick



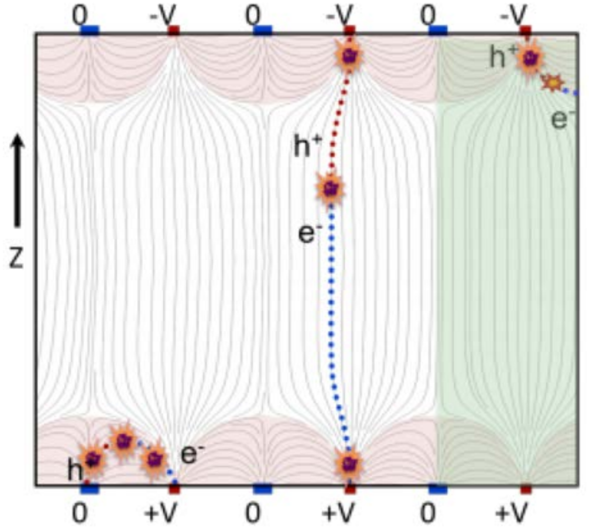






iZIP

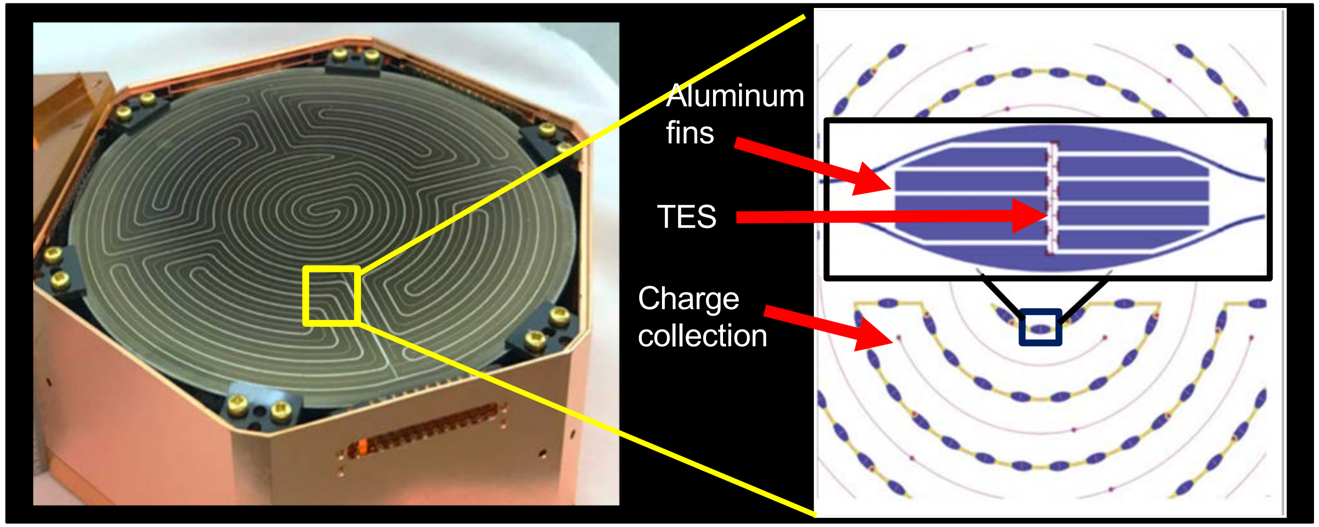
Double-sided readout with E-field-shaping provides z-dependence and surface rejection

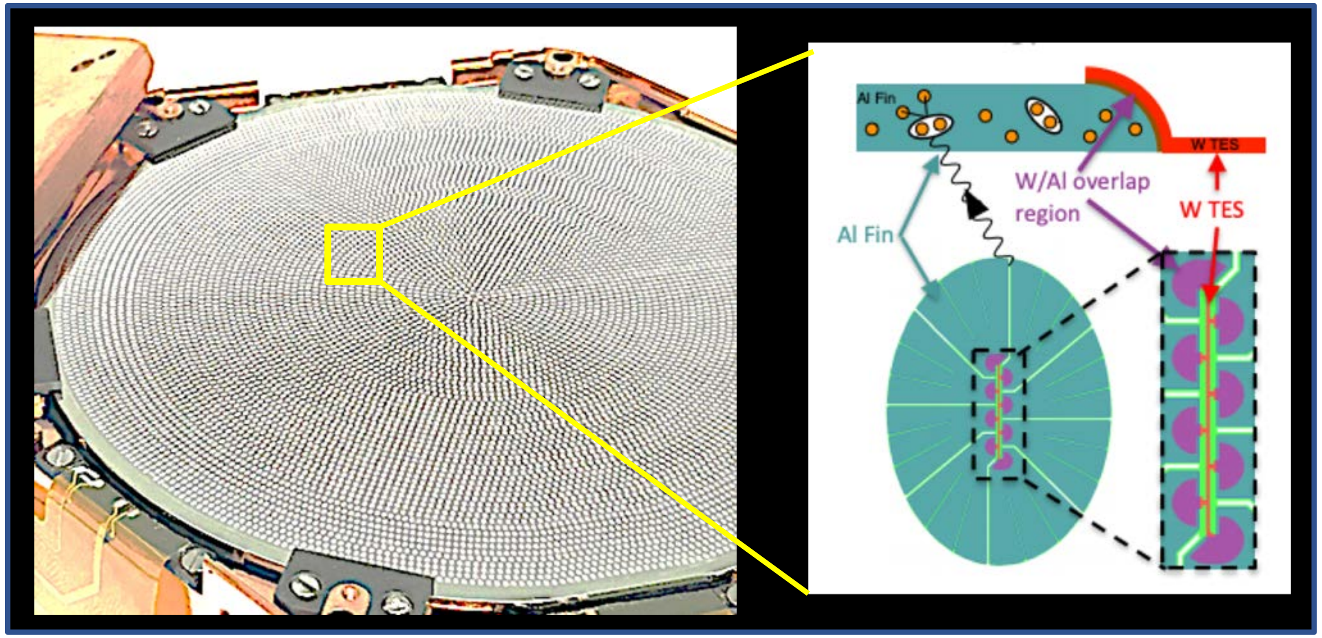


HV

No charge readout required.
Optimized for phonon energy resolution and collection efficiency (35% coverage)
Improved position resolution and double outer ring to sharpen fiducial cut.

SuperCDMS TES and collection fin design follows function





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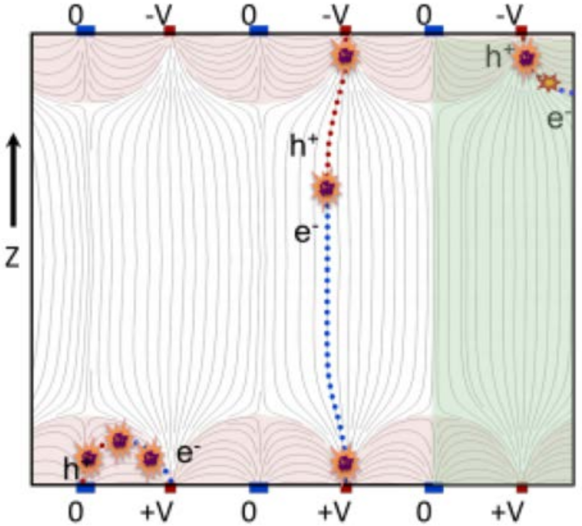
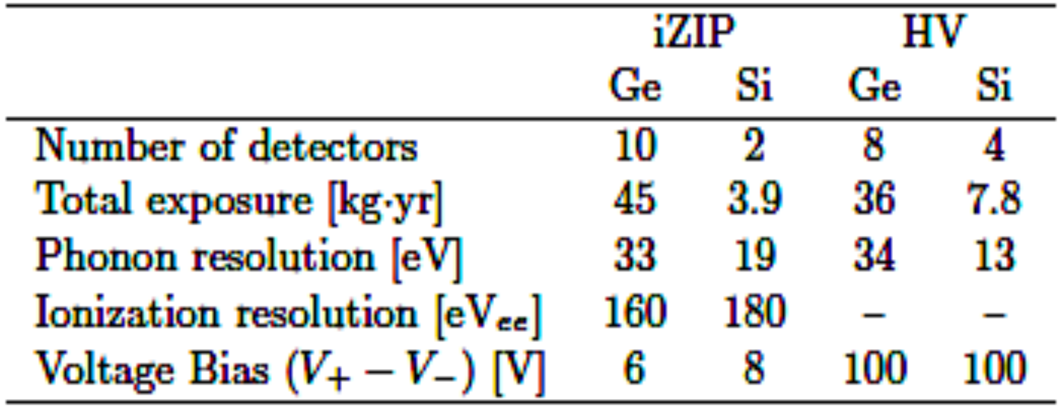


HV

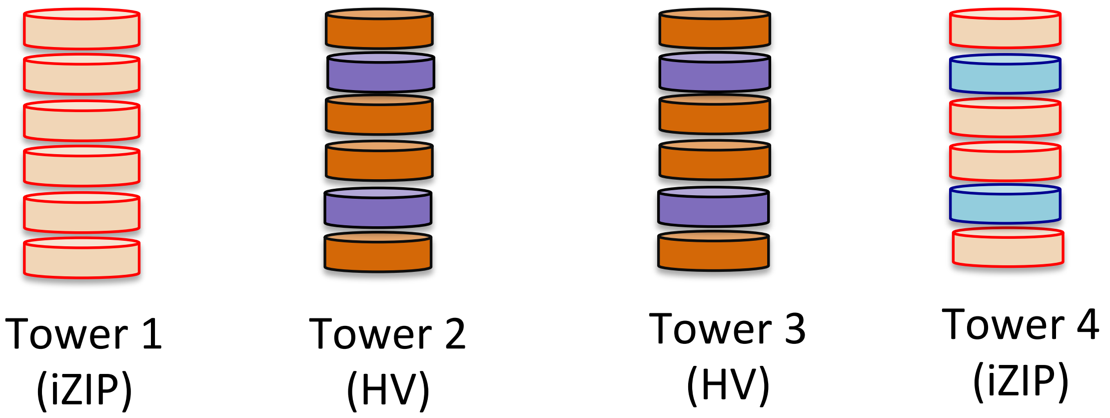
No charge readout required.
Optimized for phonon energy resolution and collection efficiency (35% coverage)
Improved position resolution and double outer ring to sharpen fiducial cut.

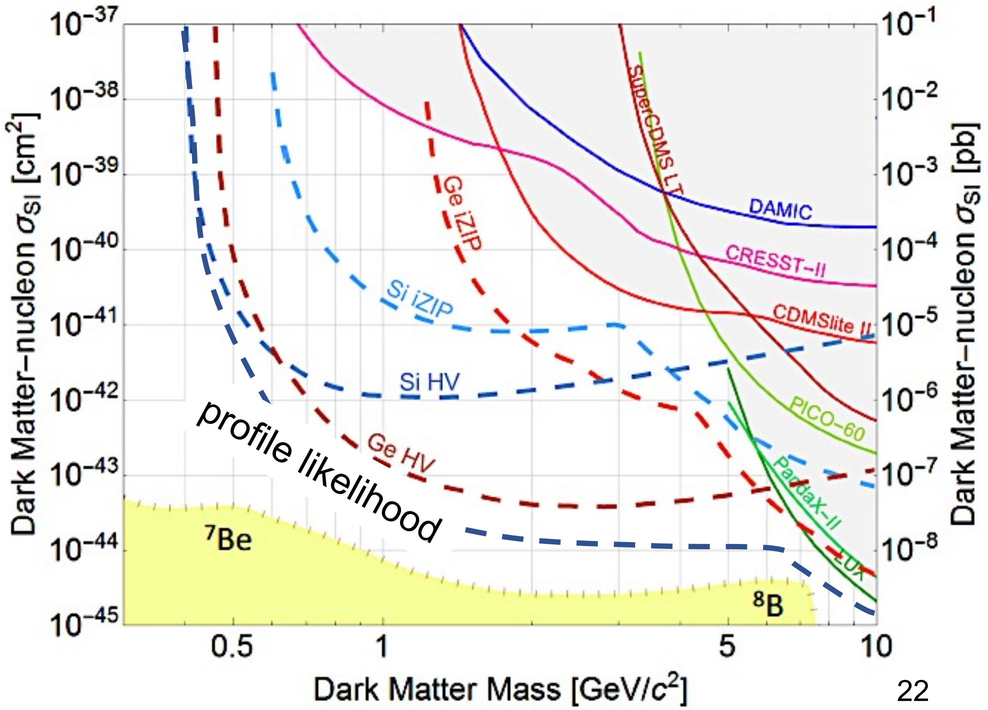
SuperCDMS Strategy
Complementary Targets and Multiple Functionality

Mode	Germanium	Silicon
HV	Lowest threshold for low mass DM Larger exposure, no ^{32}Si bkgd	Lowest threshold for low mass DM Sensitive to lowest DM masses
iZIP	Nuclear Recoil Discrimination Understand Ge Backgrounds Sensitive to ^{8}B ν-scatter	Nuclear Recoil Discrimination Understand Si Backgrounds Sensitive to ^{8}B ν-scatter



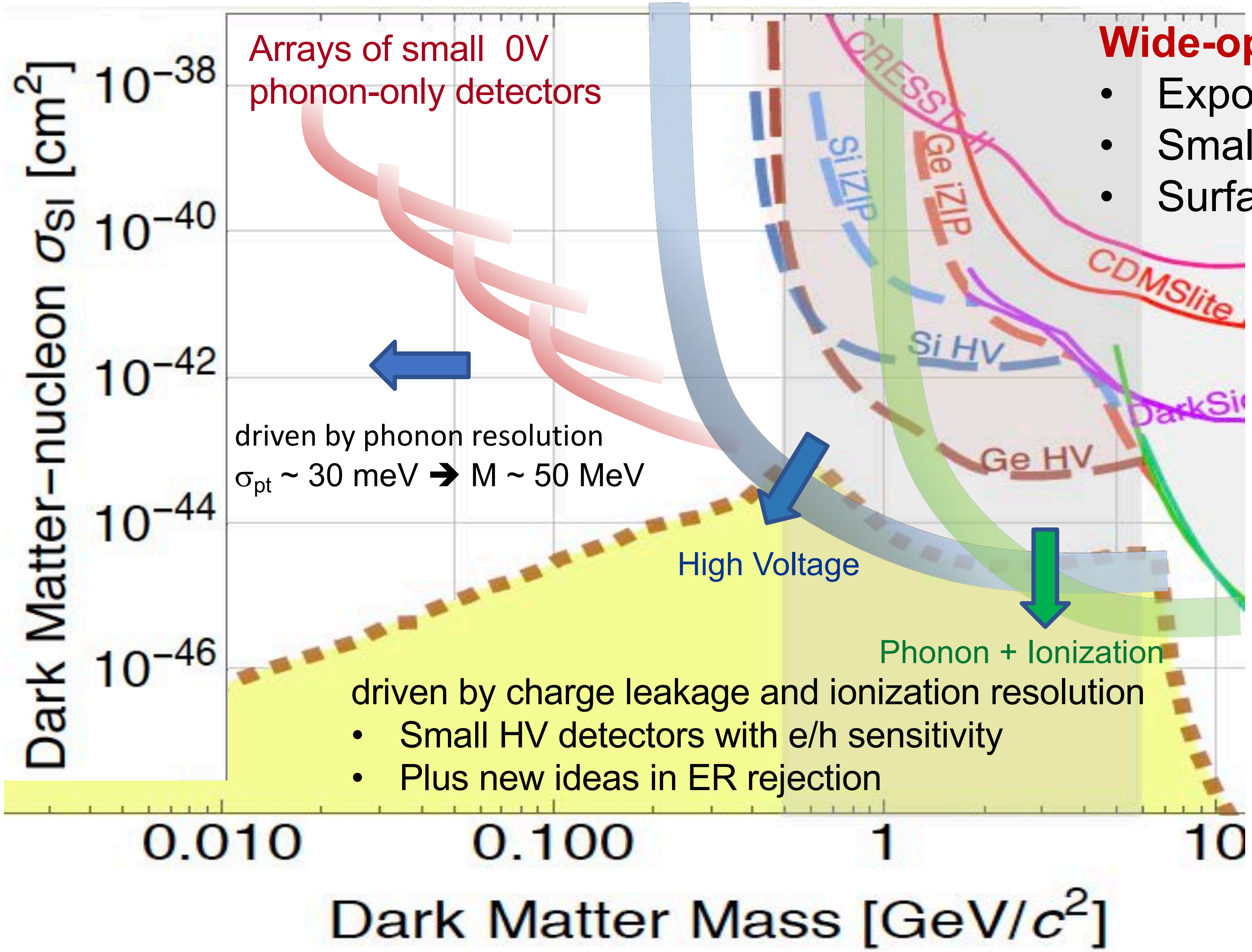
	iZIP		HV	
	Ge	Si	Ge	Si
Number of detectors	10	2	8	4
Total exposure [kg·yr]	45	3.9	36	7.8
Phonon resolution [eV]	33	19	34	13
Ionization resolution [eV_{ee}]	160	180	–	–
Voltage Bias $(V_+ - V_-)$ [V]	6	8	100	100





Project Goals assume Optimum Interval, no prior knowledge of backgrounds. To reach full potential, a profile likelihood analysis will use iZIP background data in the fit.

Pushing even deeper into the nucleon-coupled DM landscape



Arrays of small 0V phonon-only detectors

driven by phonon resolution
σ_{pt} ~ 30 meV ➔ M ~ 50 MeV

High Voltage

Phonon + Ionization

driven by charge leakage and ionization resolution
- Small HV detectors with e/h sensitivity
- Plus new ideas in ER rejection

Wide-open parameter space at low mass

- Exposure is not the driving force
- Smaller detectors achieve lower thresholds
- Surface runs can provide world-leading results

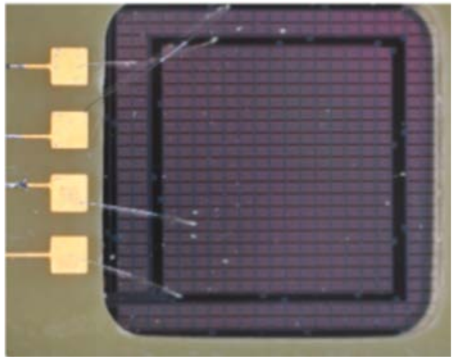
Pushing down to the neutrino floor
requires exposure and reduced bkgd

- Improve ionization resolution and reduce leakage currents or
- HV with eh sensitivity

All of this can happen in the existing SNOLAB cryostat and shielding. Improvements in detector performance can be used to circumvent backgrounds.

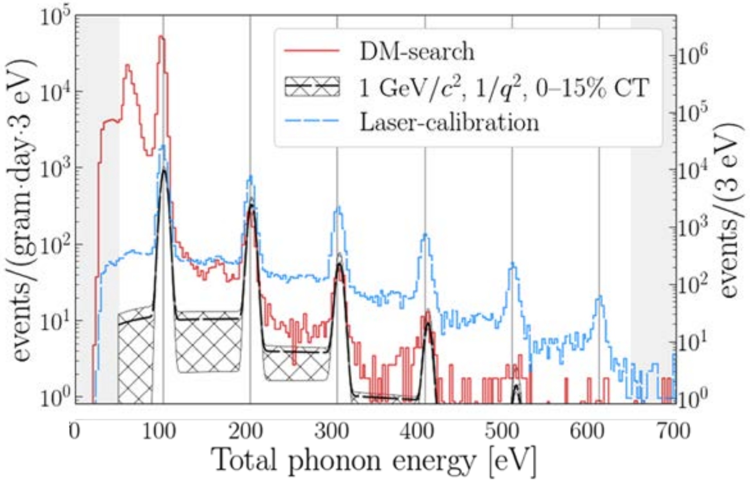
SuperCDMS is already using small 0 V and single eh-sensitive HV detectors

HVeV (Si or Ge, 1 cm^2 x 4 mm). Like a small HV detector with single e-h resolution.

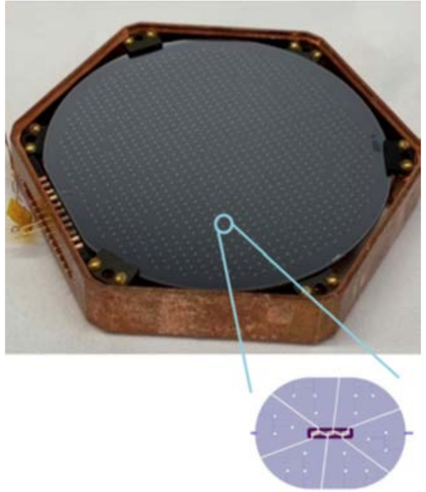


ER events are in the peaks, NR fills in gaps
A mosaic of these on 2 SuperCDMS towers
can get to the ν-fog in 0.5 – 5 GeV range

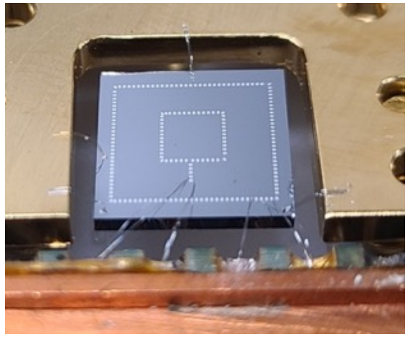
PhysRevD.102.091101



0V (aka CPD). A thin, phonon-only device with SuperCDMS TES readout



Improving *“environmental”* phonon-only backgrounds
Phonon resolution in the σ_{pt} ~ 1 eV range now.
Advances in stress-related bkgds will get to 100 meV

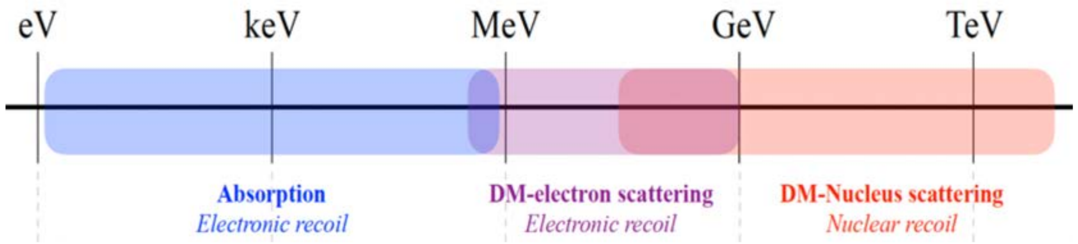


A mosaic of sub-eV σ_{pt} CPDs on 2 towers can get to masses of 50 MeV

Will also push deep into Sub-GeV Electron Recoiling regime

cryogenic phonon detectors are well-suited for these searches.

- sensitivity to 1–100 eV deposited energy
- enabled by small bandgaps ~1 eV
- and excellent energy resolution.



Light DM in the 1-100 MeV range

- DM scattering off electrons or collective excitations
- Extend cross section by 4 - 5 orders of magnitude.

Dark photon and ALPs in the 1-100 eV range.

- Absorption by electrons or collective excitations
- Improvements in leakage and resolution drives these limits.
  - 100 times better reach in kinetic-mixing parameter ϵ
  - 1000 times better reach in g_{ae}.

Same themes in the EDELWEISS program

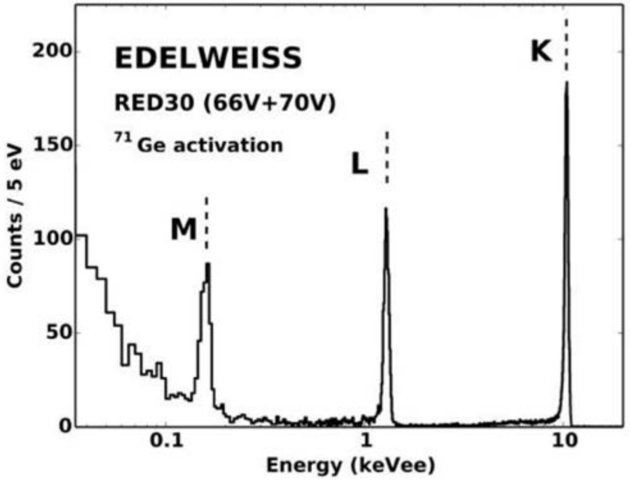
EDELWEISS - III Large exposure underground for 5 – 30 GeV WIMPs

- 870 g Ge bolometers with 200 eV_{ee} threshold
- 24 detectors in low background cryostat operated at ~ 18 mK

EDELWEISS – sub-GeV (surface and underground)

33 g Ge bolometers exploring two modes:

LV detectors: Maintain yield discrimination at low energy.
Run above ground, collaboration with RICOCHET CEνNS
RED20 18 eV (RMS) heat resolution + 55 eV energy threshold
To get to 10 eV, need to move from FETs to HEMTs

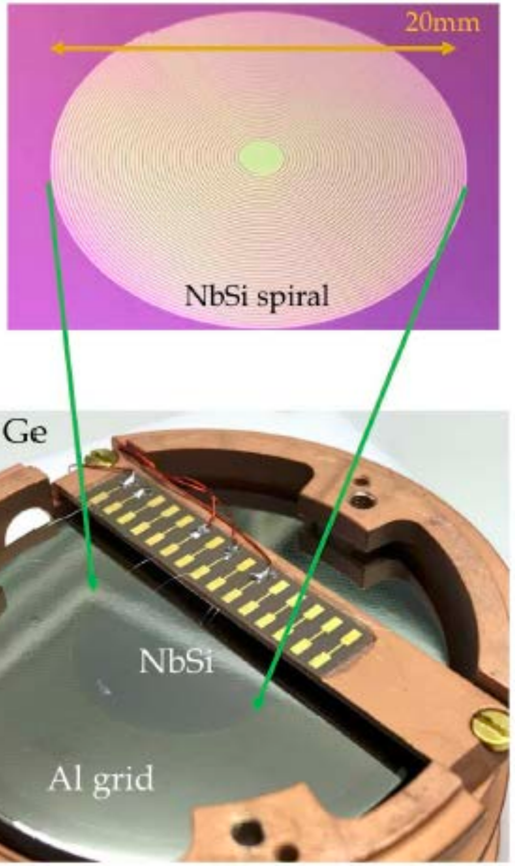


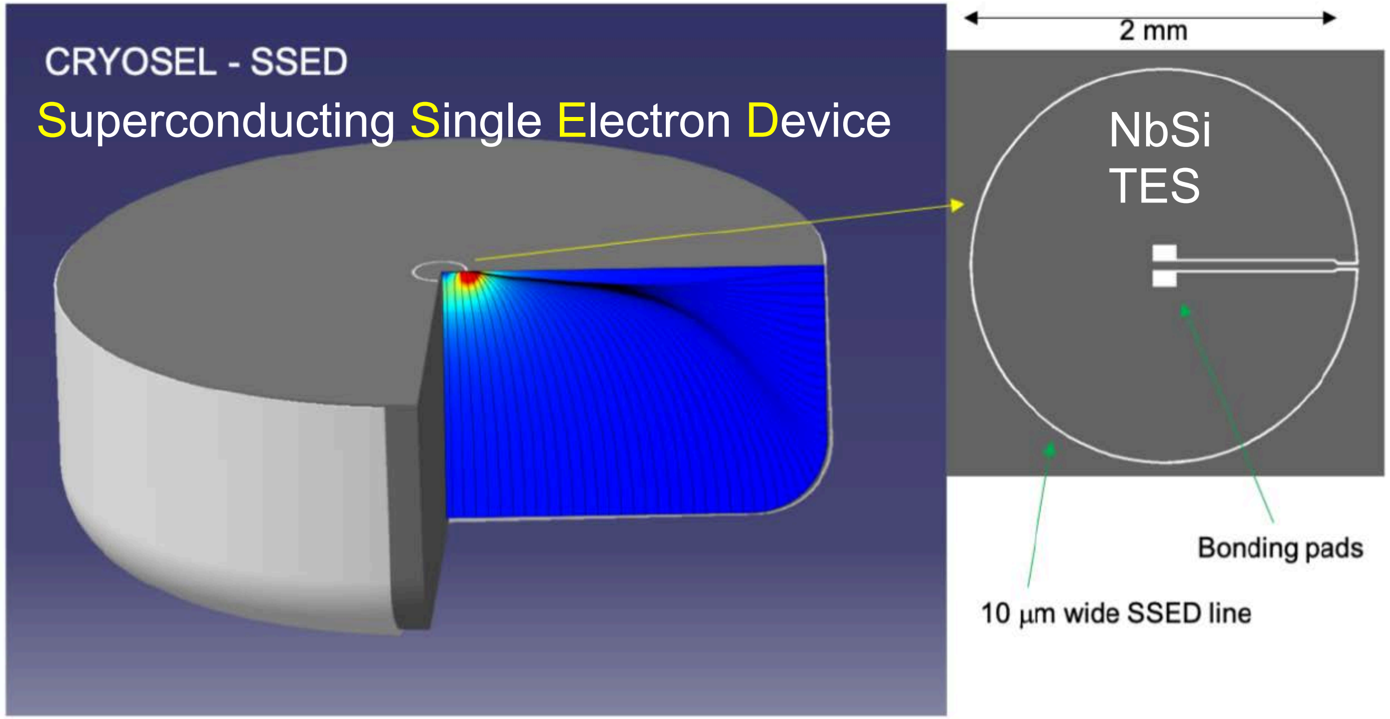
HV detectors: NTL phonon amplification
RED30 Add top and bottom electrodes and run underground
$\sigma = 1.8\ eV_{ee}$ at 70 V

EDELWEISS goes athermal

NOW: new 100 nm thick, 20 mm diameter spiral
NbSi TES sensor lithographed on a 200 g Ge crystal
Run underground in NTL mode (data next pg)

Future Edelweiss sub-GeVProgram
Cryosel = Thermal Bolometer with NTD thermistor
running at 200 V with 20 eV phonon resolution
Can identify athermal phonons from heat-only
events using the NbSi TES



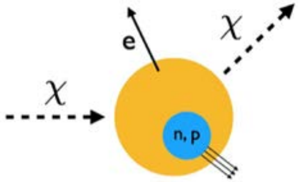


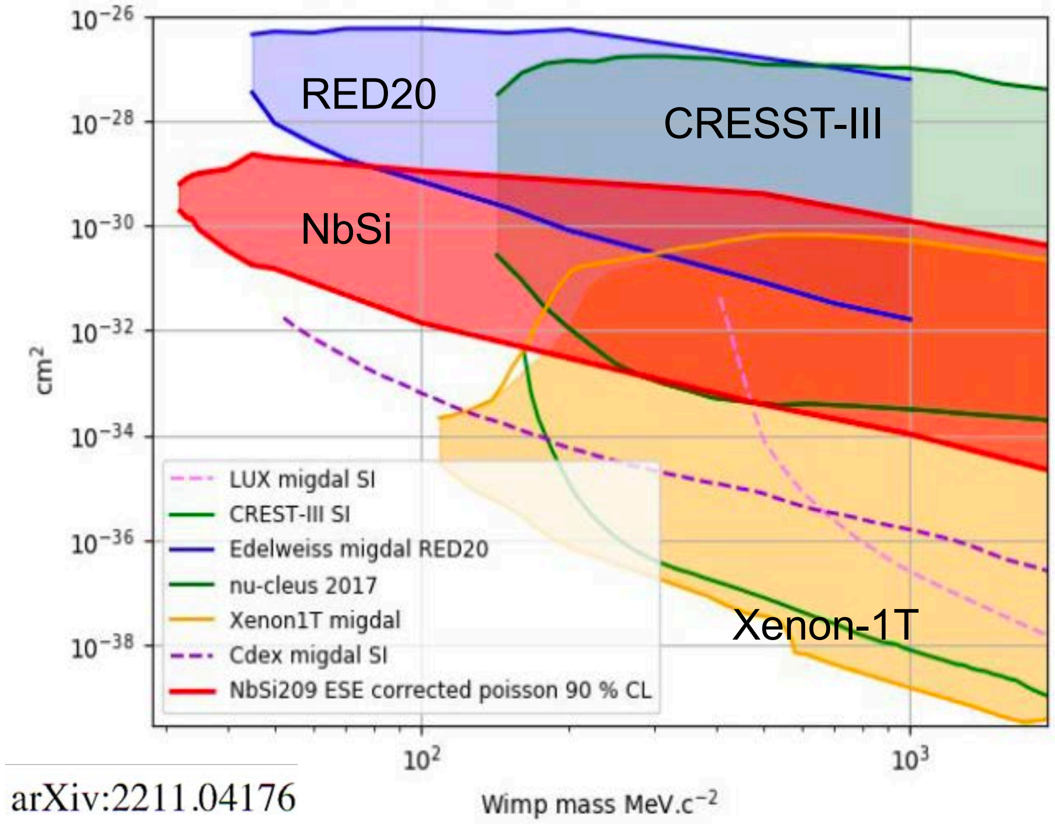
Inelastic scattering extends access to lower mass NR

An NR below threshold can be seen in the ER channel.

Migdal Effect

Readjustment of the electron cloud after NR can spit out an electron of a few hundred eV.





arXiv:2211.04176

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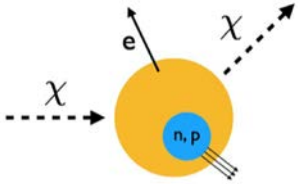

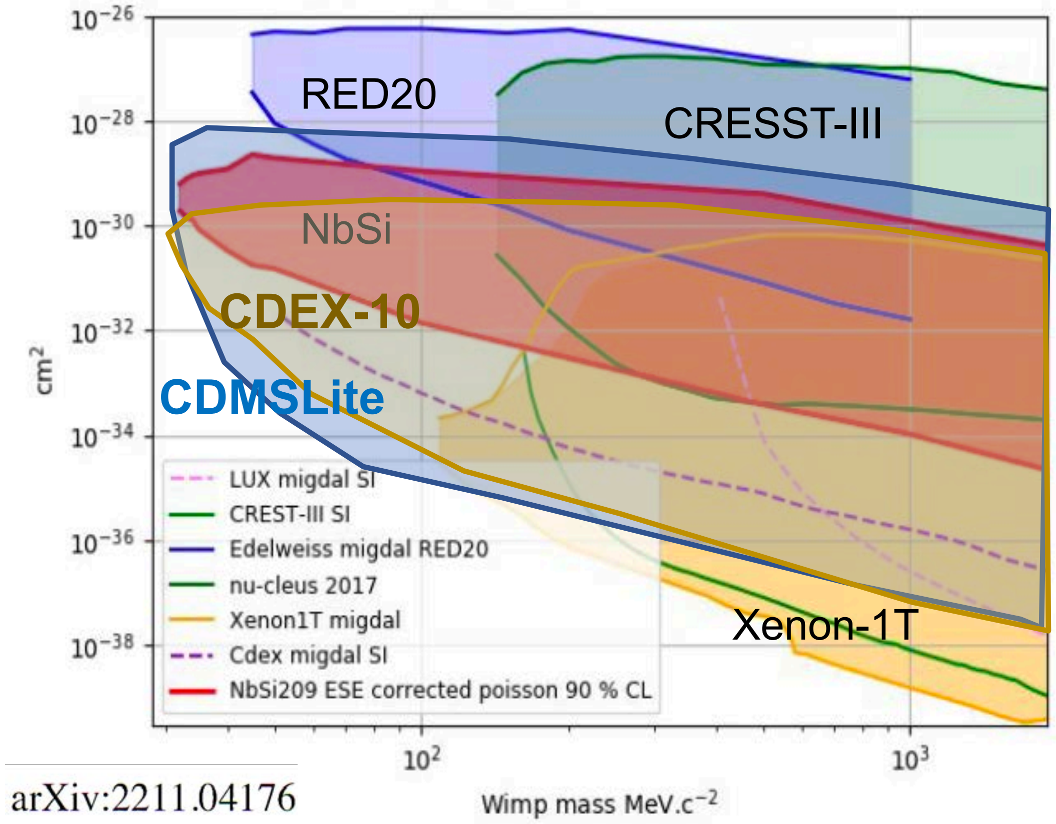

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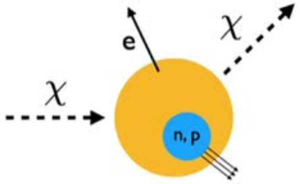
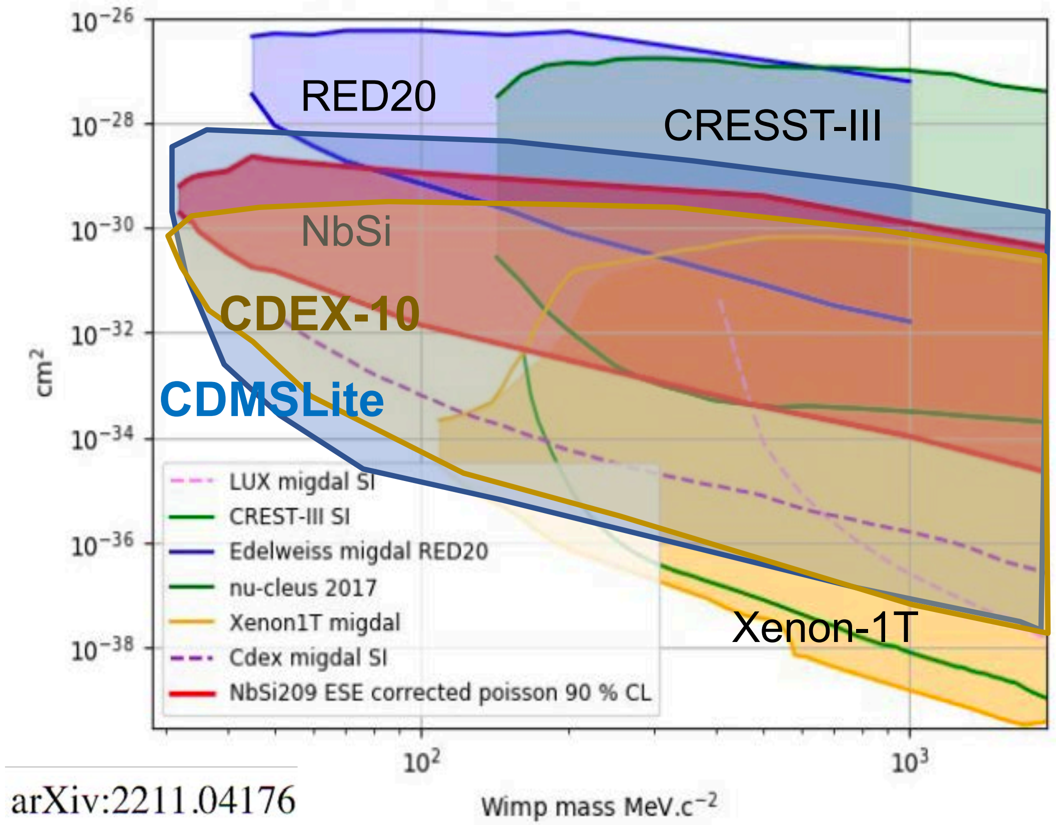
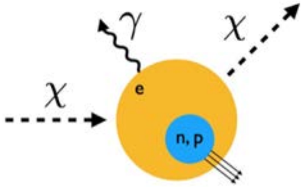




arXiv:2211.04176

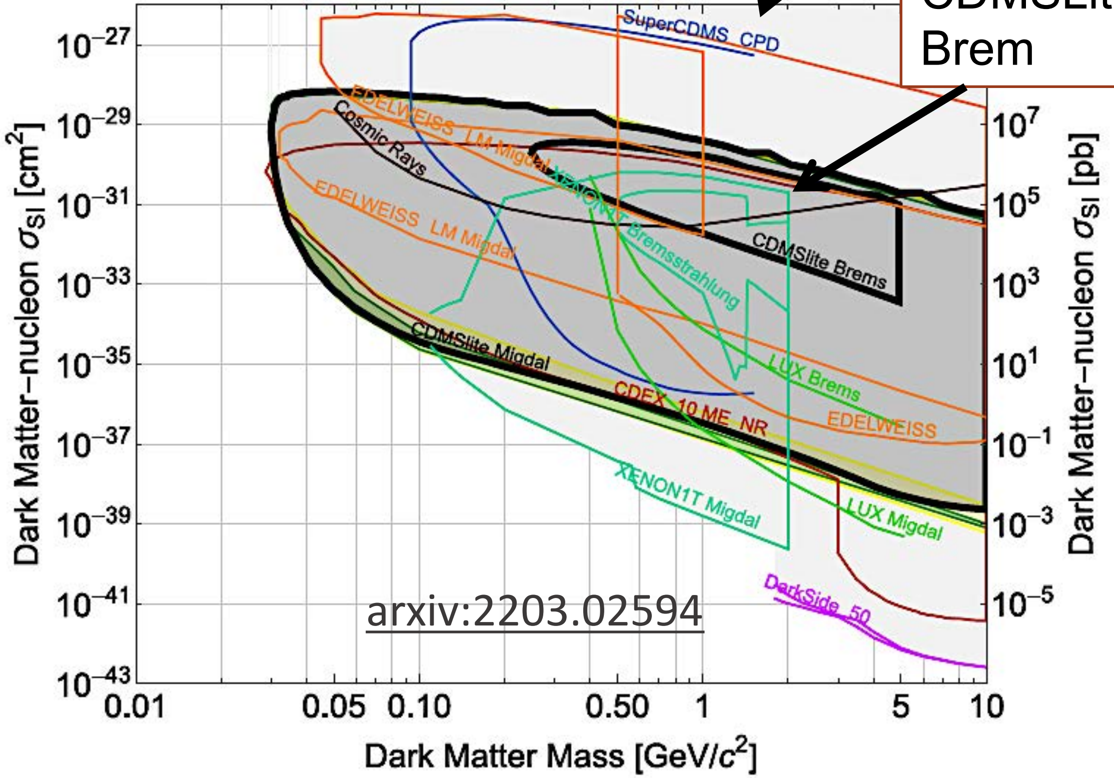
Bremsstrahlung

Probability is 3-4 orders of magnitude less



Surface runs (MIGDAL)
CPD (Si with TES readout)

CDMSLite
Brem

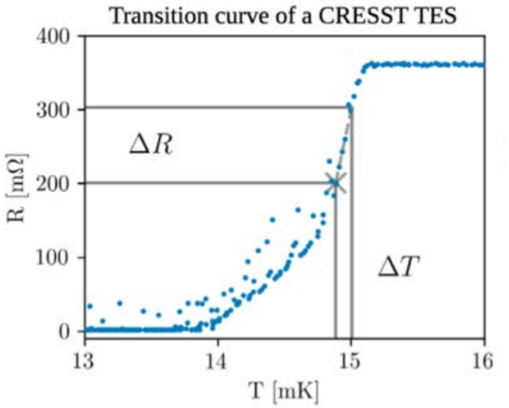


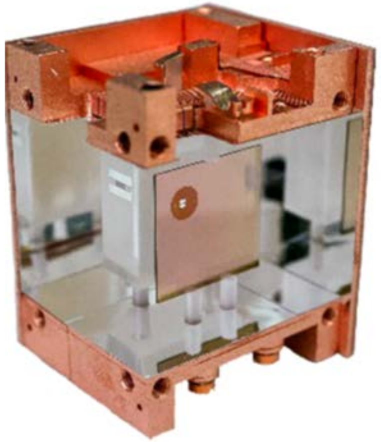
arxiv:2203.02594

CRESST – III Program

CRESST has already moved to smaller detectors for improved resolution

arXiv:1904.00498





Recent Spin Independent Limits

“Detector A”: $CaWO_4$, 23.6g
Data taking period: Oct 2016 – Jan 2018
Exposure before cuts: 5.689 kg days
Energy resolution: 4.6 eV
Nuclear recoil threshold: 30.1 eV

New Spin Dependent Limits

Two 10g LiAlOs crystals in LNGS
Lithium: *92.4%* ^{7}*Li (p)*, *7.6%* ^{6}*Li (p,n)*

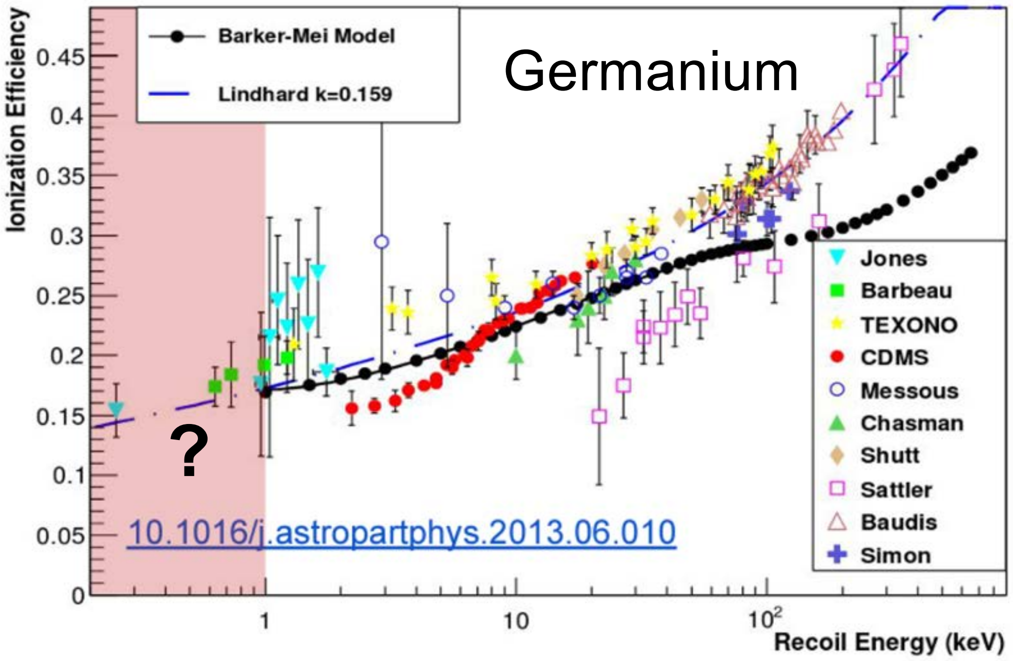
$$\langle S_n \rangle = \langle S_p \rangle = 0.472$$

Phys. Rev. C 102, 014001 (2020), 2004.05814

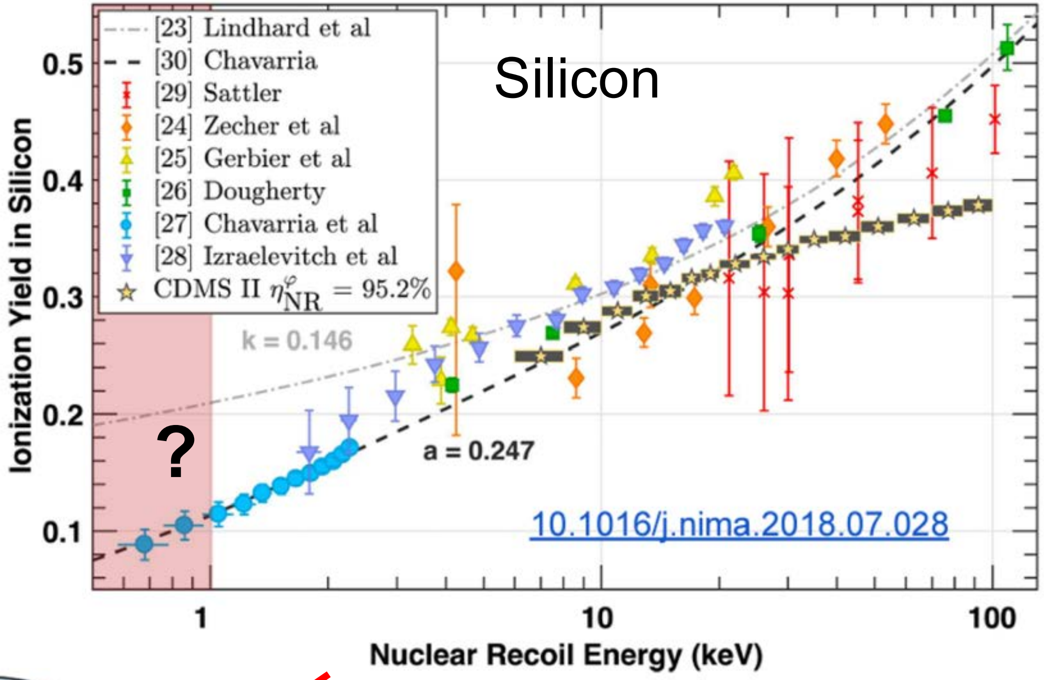
Planning for a 100 detector underground exposure

- upgrade LNGS cryogenic infrastructure
- Develop TES mass production
- Continue to improve crystal purity

A Common challenge:
Understanding the Nuclear Recoil Scale at lower energies

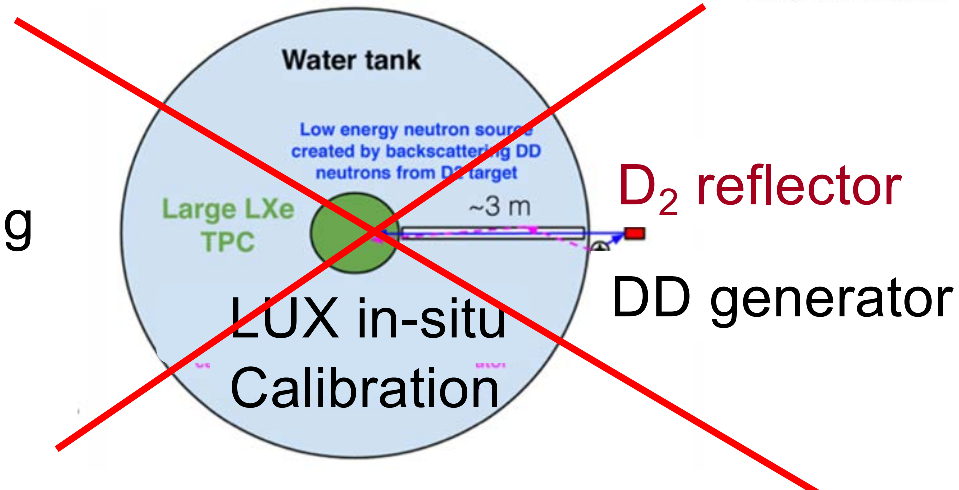


10.1016/j.astropartphys.2013.06.010

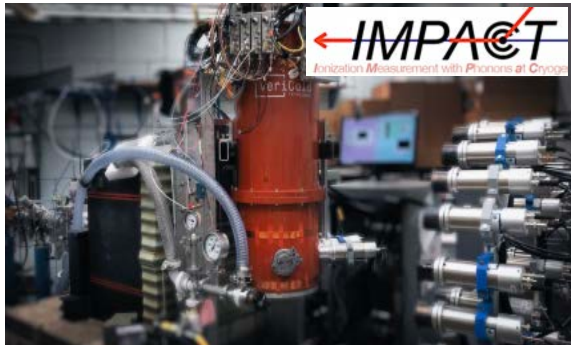


10.1016/j.nima.2018.07.028

LXe TPC style in-situ neutron scattering is not an option for cryo bolometers



SuperCDMS Nuclear Recoil Scale Measurements at low energy



Neutron beam at the TUNL facility

- Used a “portable” ADR fridge and a Silicon HVeV
- Next campaign in 2024 with a Germanium HVeV

SuperCDMS Nuclear Recoil Scale Measurements at low energy

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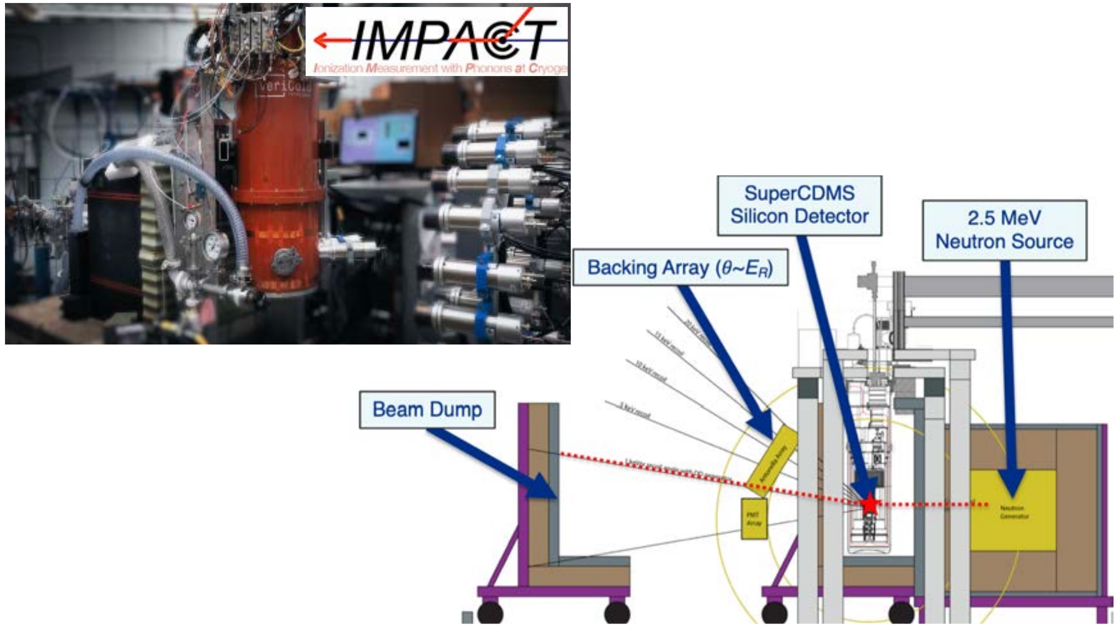
DD generator at FNAL NUMI hall (~300 mwe)

- Use the NEXUS fridge and backing array
- Run ***both*** HVeV with full-scale SuperCDMS HV



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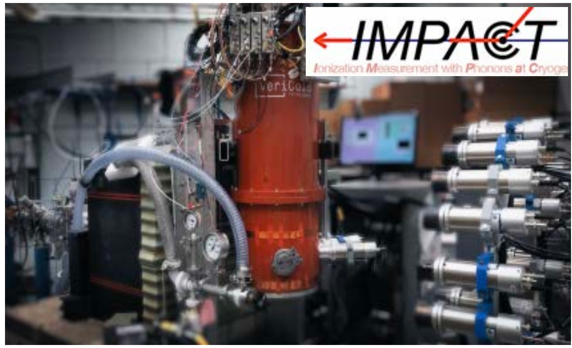

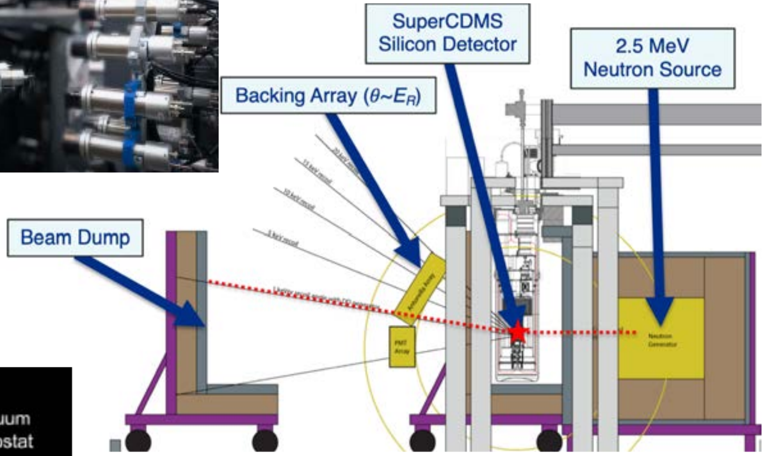

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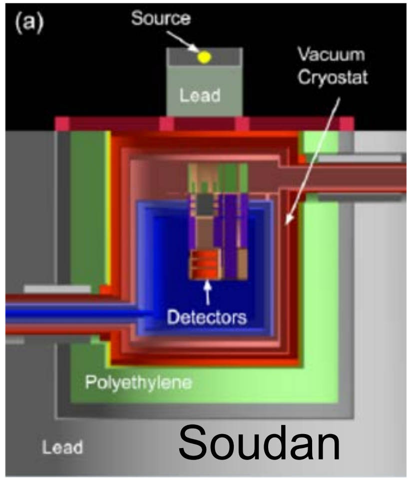
Photo-neutron Source: (^{88}Y or ^{124}Sb) gammas on ^{9}Be

- Soudan Lab, Ge iZIP run in CDMSlite mode



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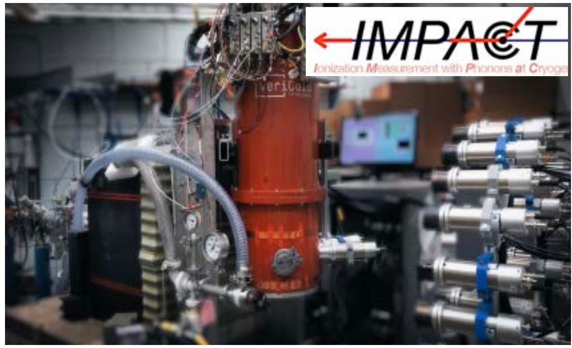

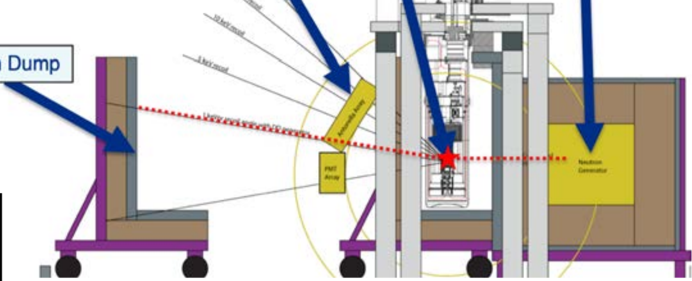

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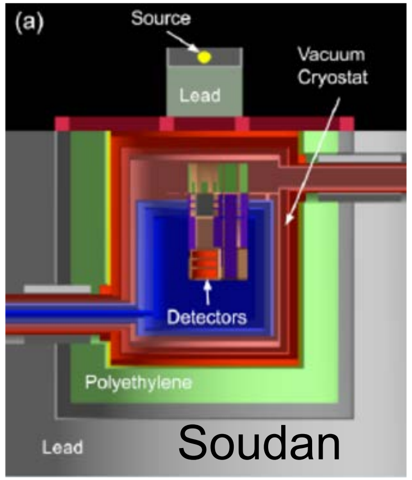

Soudan

Photo-neutron Source: (^{88}Y or ^{124}Sb) gammas on ^{9}Be

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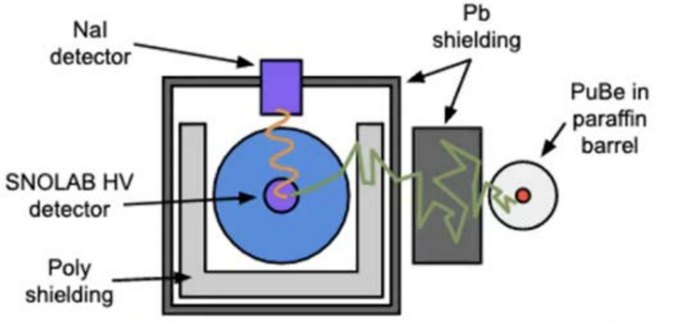
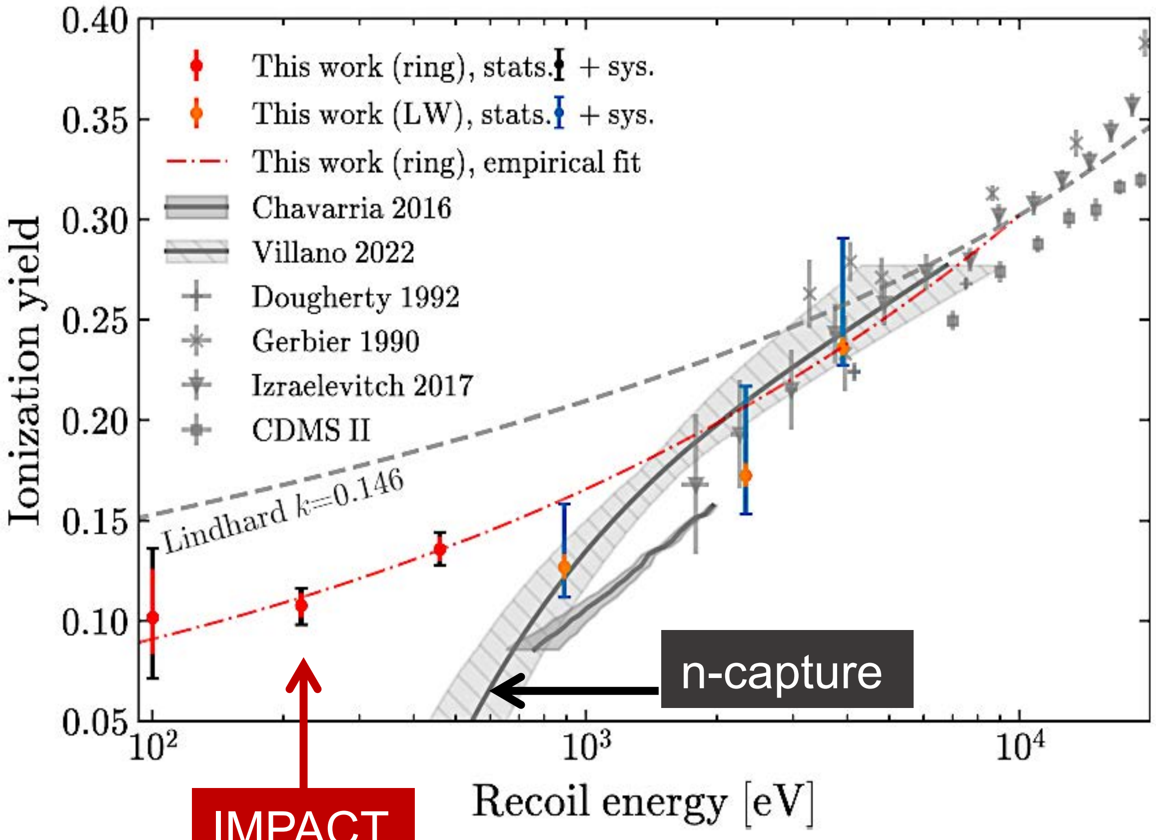


Developing new neutron capture technique

- SNOLAB Si HV in UMN cryo lab exposed to PuBe source of thermal
- Measure nuclear recoil after neutron capture, tag de-excitation γ

Good Progress, but further work is required to establish confident interpretation of low mass DM limits from Ge and Si

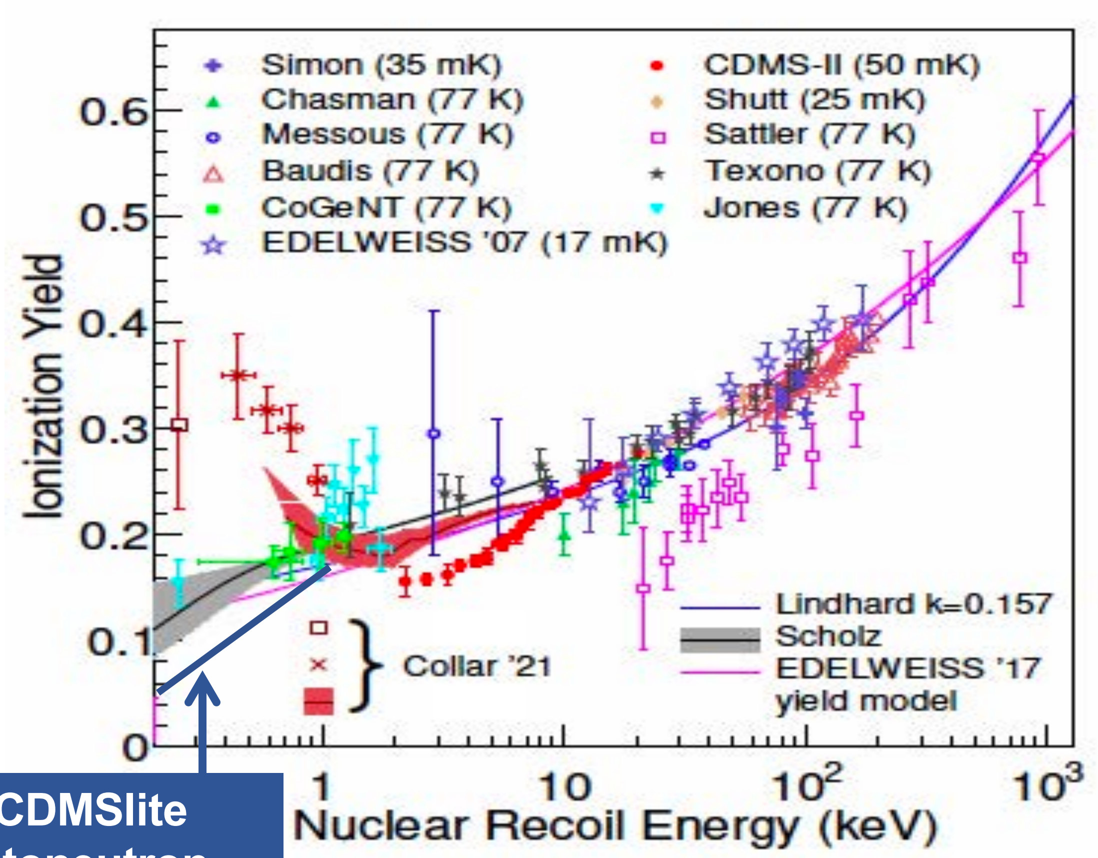
Silicon NR response
falls faster than Lindhard



n-capture

IMPACT

Quenching in Germanium may depend on temperature or internal electric field



Ge CDMSlite photoneutron

Summary

A multi-experiment Strategy for the future based on “Delve Deep and Search Wide”

- The strategy requires development of multiple targets and their readout technology in parallel
  - Not only because we don’t know where the DM is, but also
    - because understanding the ***nature*** of the interaction will require multiple targets
- We have a program that can explore down to the neutrino fog in most scenarios
- Not finding a signal (in a particular section of phase space) is as important as finding it.
- There is no guarantee that there is only one type of dark matter
  - This decade has produced a wealth of candidates with arguments as compelling as the WIMP

The role of cryogenic bolometer experiments in this strategy

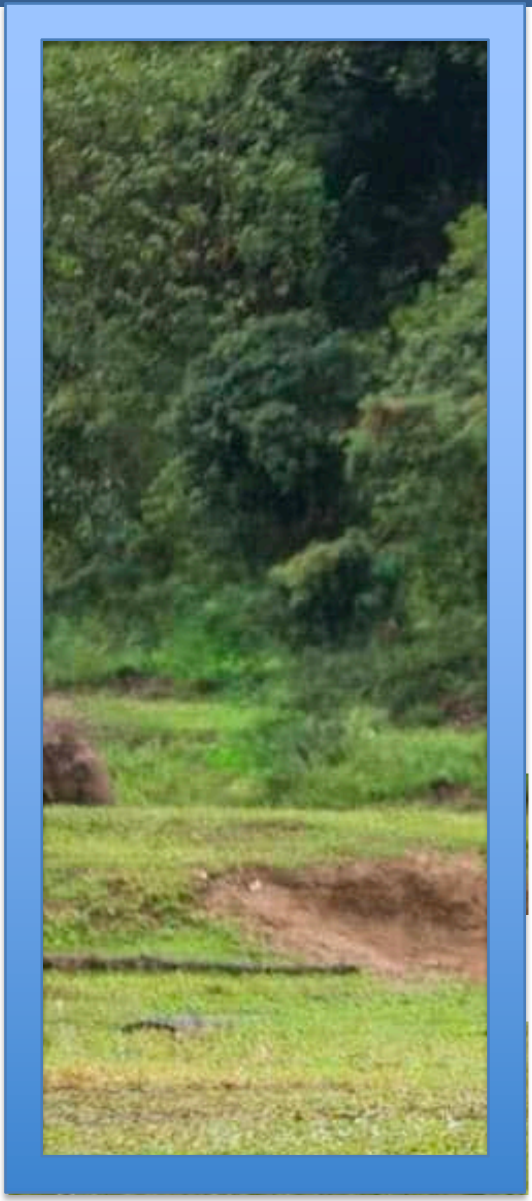
- Near term, large exposure searches which probe NR DM at lower masses
- Good sensitivity to inelastic NR (Migdal) and ER dark matter
- Active R&D on small detectors which can push deep into ER dark matter
- Improvements in the ionization yield discrimination (HEMTs, leakage current, charge resolution)
- Coordinated effort to measure NR quenching in Ge, Si
- Development of HV alternatives to access lowest energies down to single eh charge sensitivity
- Improve phonon resolution without the complication of charge

Backup Slides

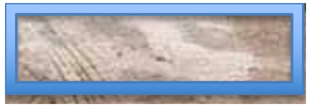
There are a lot of solutions consistent with the gravitational evidence

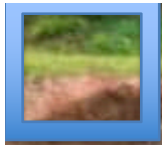
Search Wide

Not finding a vanilla WIMP is an incredible scientific accomplishment

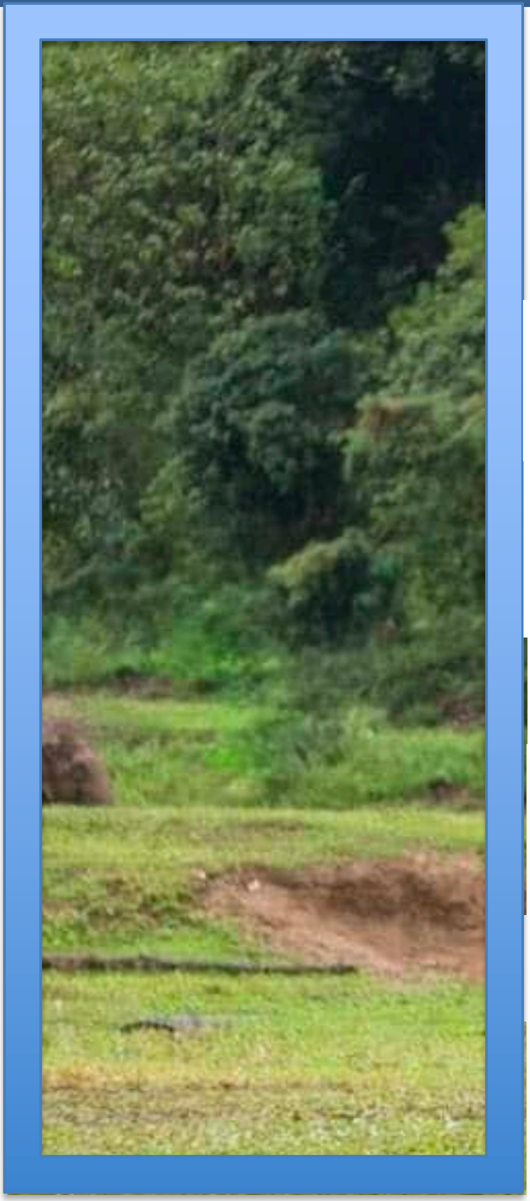


Delve Deep

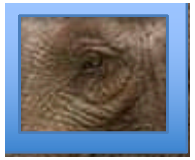


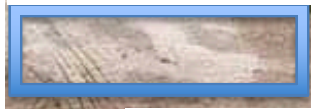


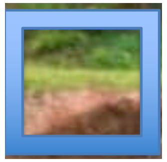
It puts any new signal in context



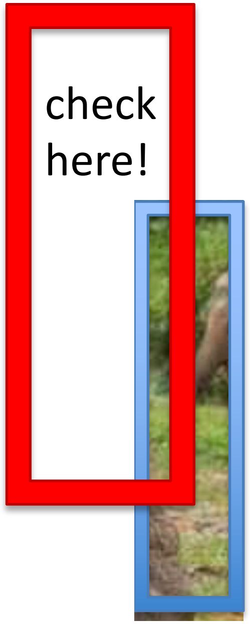
A signal! An eye fits into the theory of an animal. Use its size and what you know about animals to look for where the tail should be





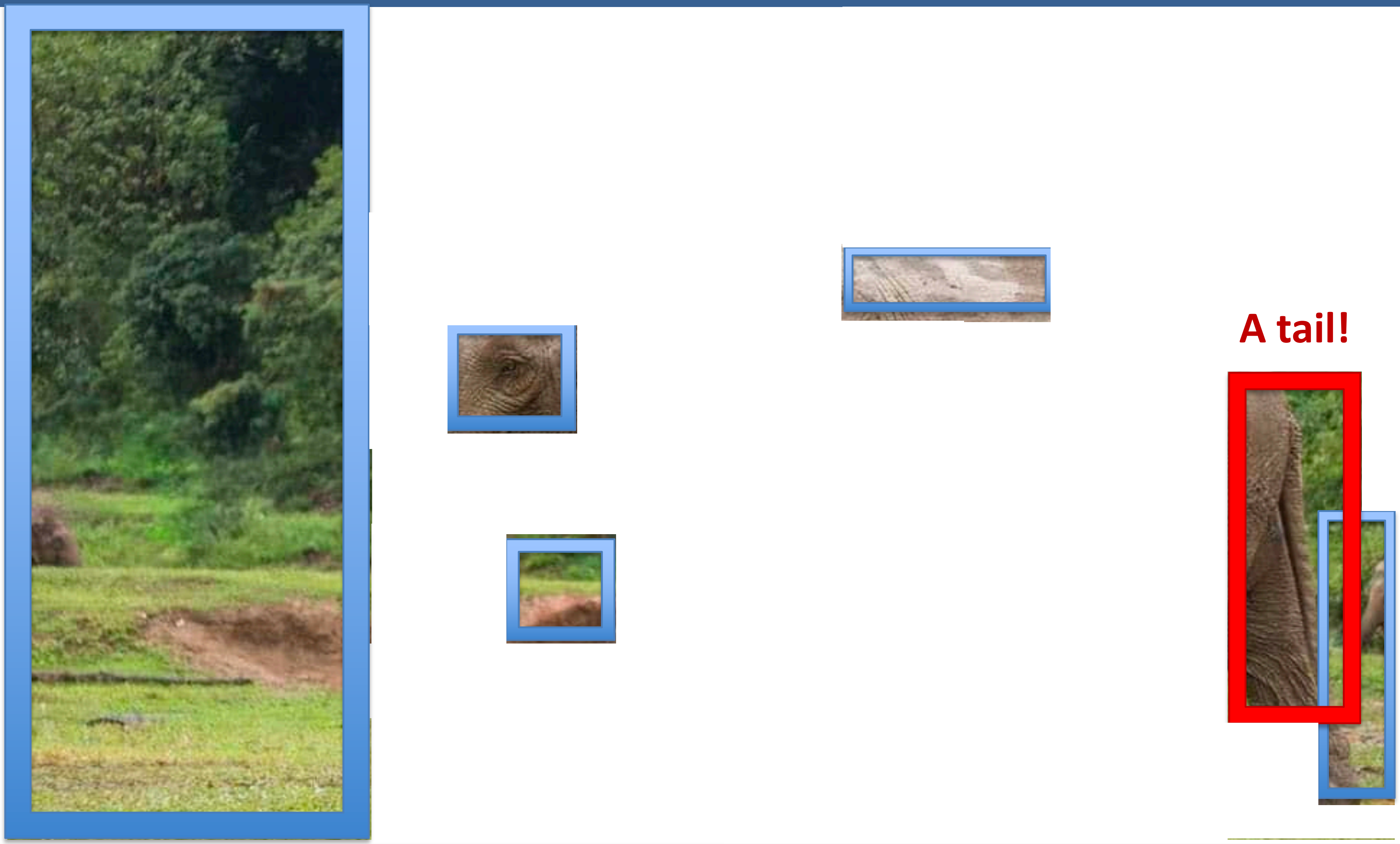


The region without an animal now tells you which direction it is facing and its environment



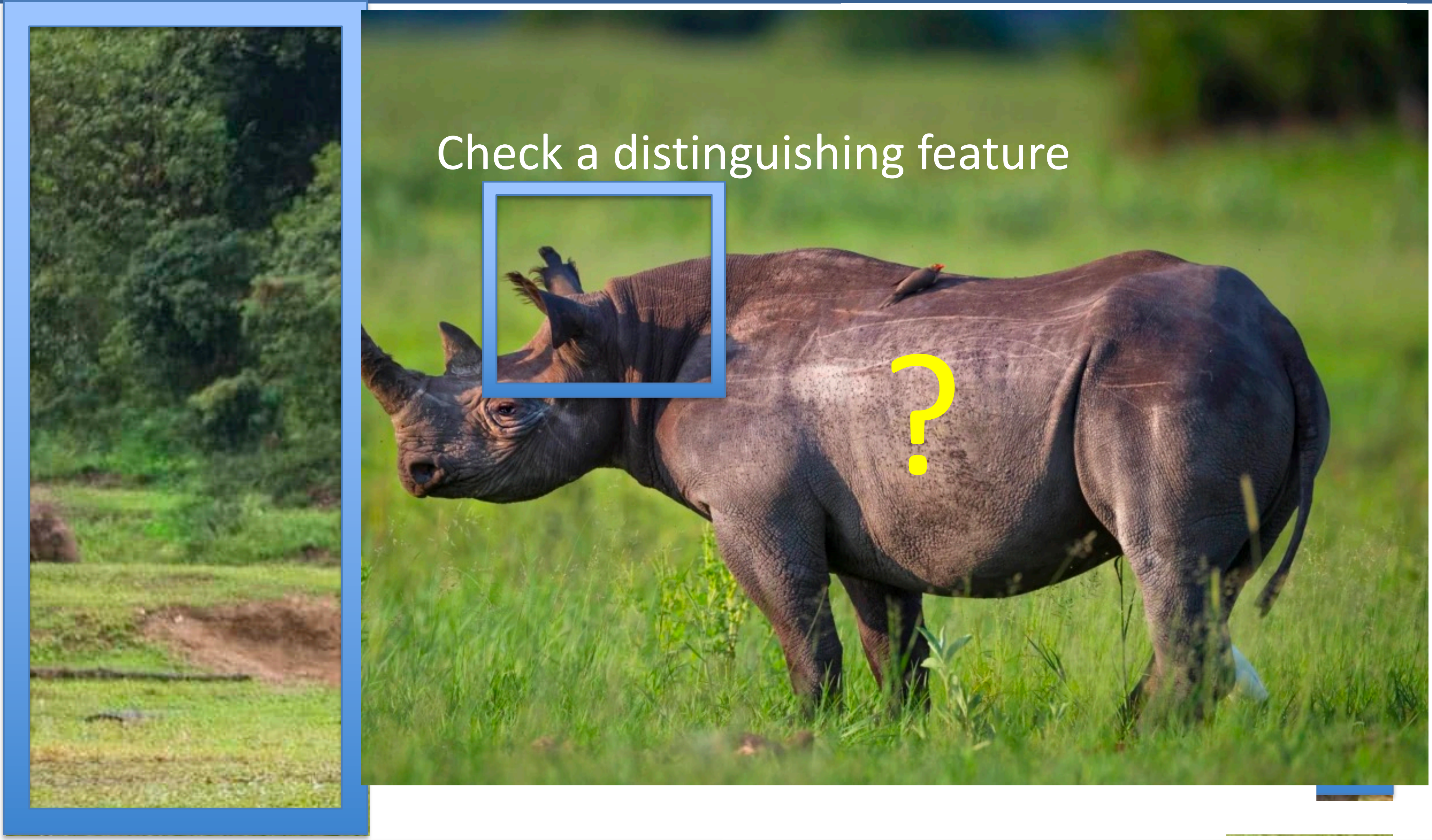
check here!

The model may require you to look with a different sort of detector

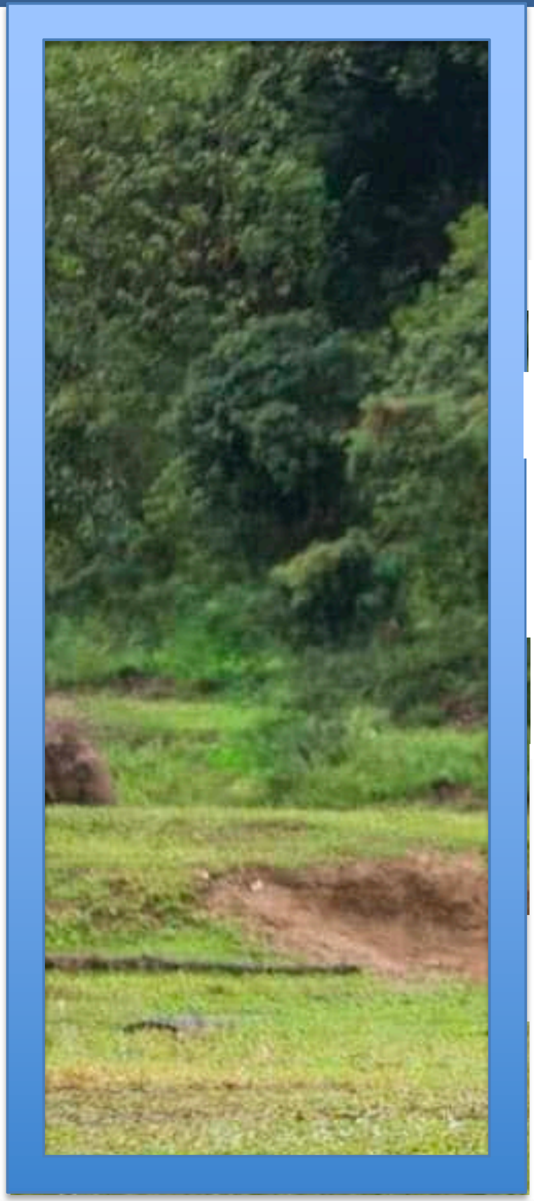


A tail!

Iterate with a new round of active model-building



And hope there is a technology available to look there



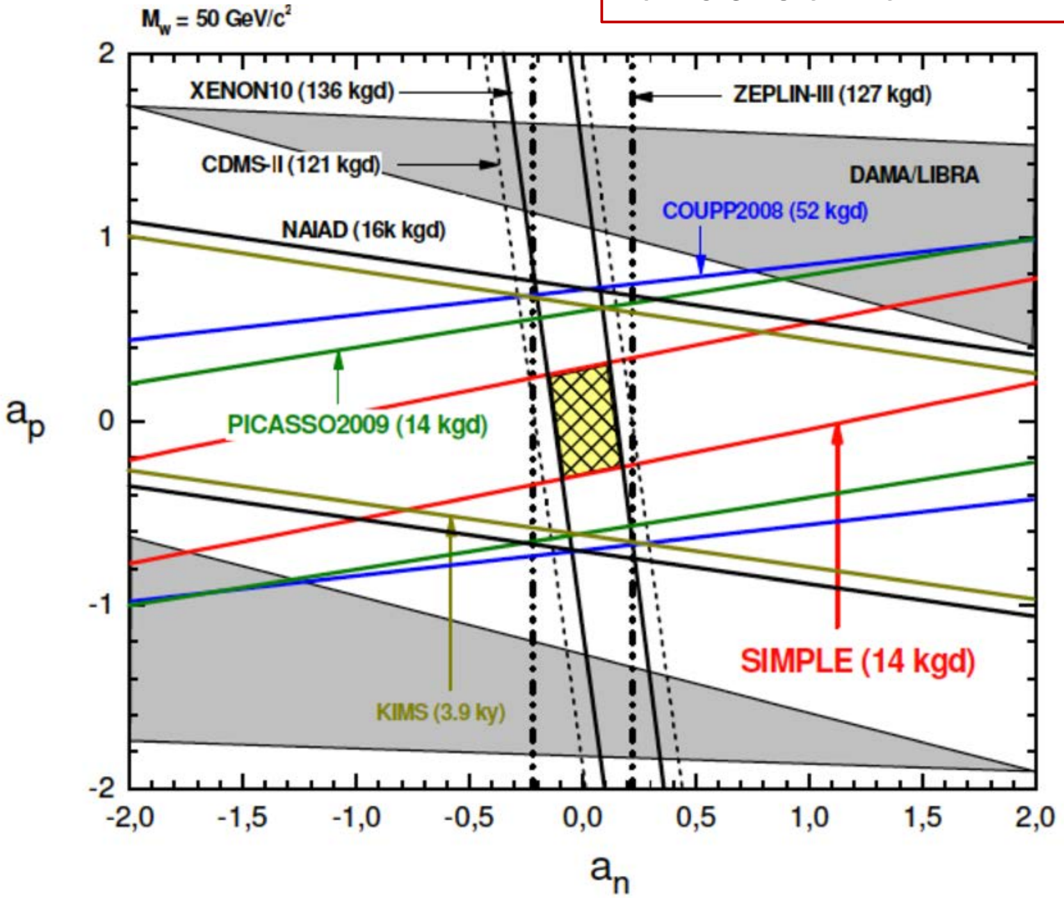
An ear fits the elephant model better than the rhino model

And this is still just one part of the jungle

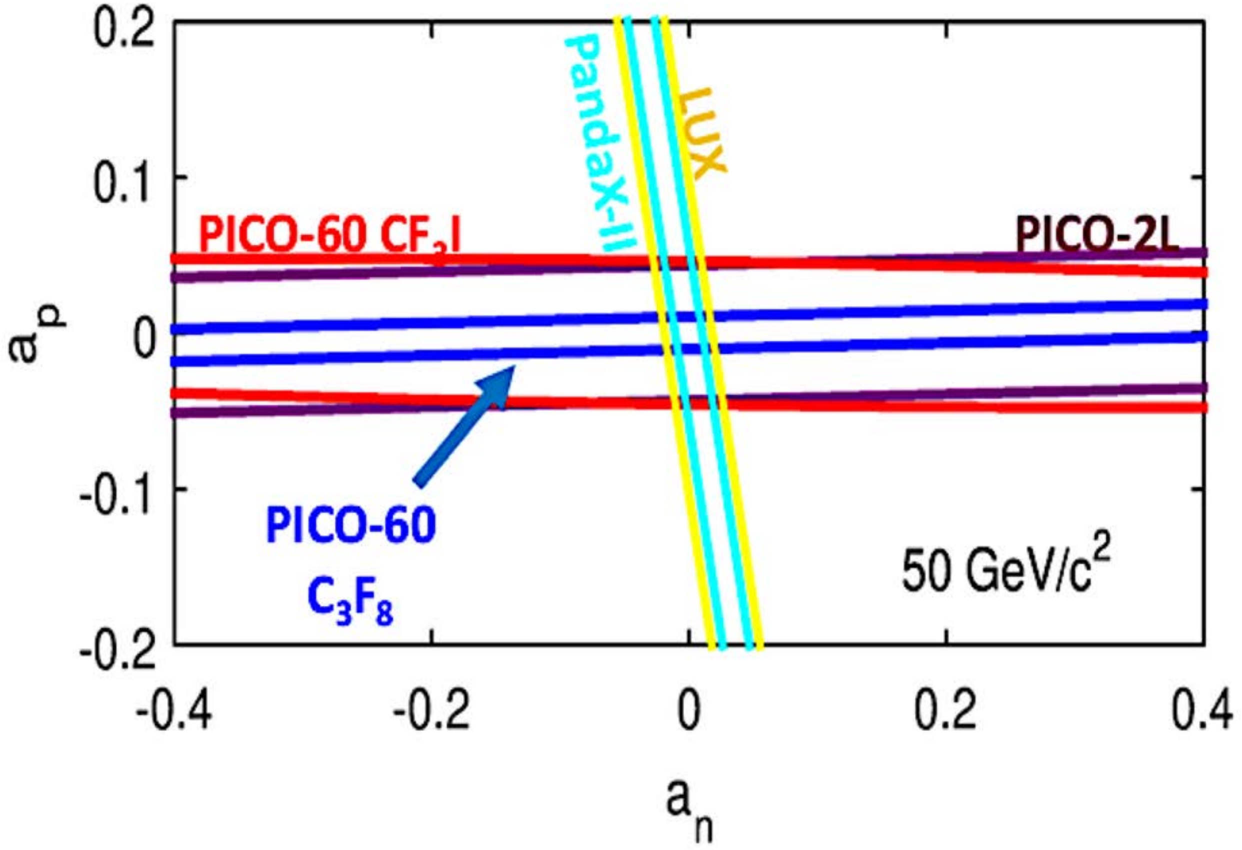
Multiple SD targets are necessary for best constraints

Example from 2010. Superheated droplet detectors
Using the n-coupled Xenon10 results improved
the SIMPLE (C_2ClF_5) p-coupled results.

$|a_p| < 0.32$, $|a_n| < 0.17$
for 50 GeV/c^2 WIMP

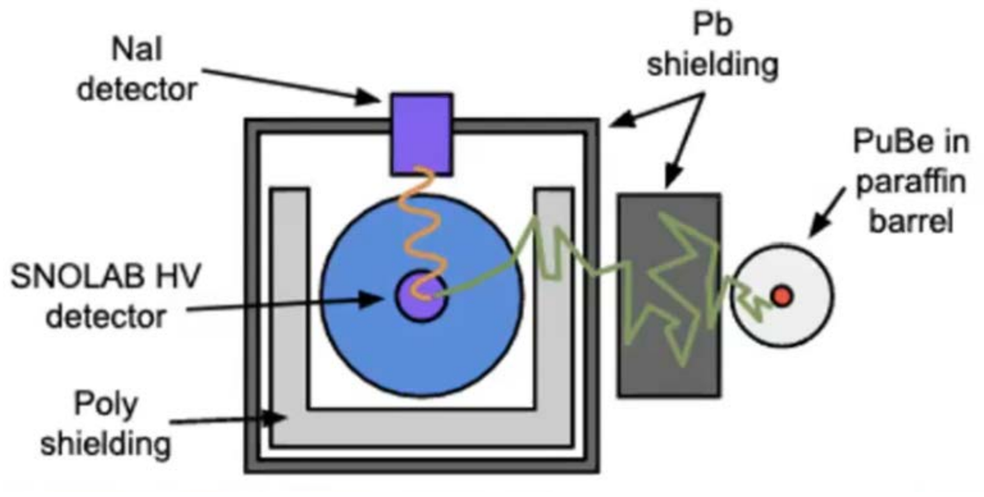


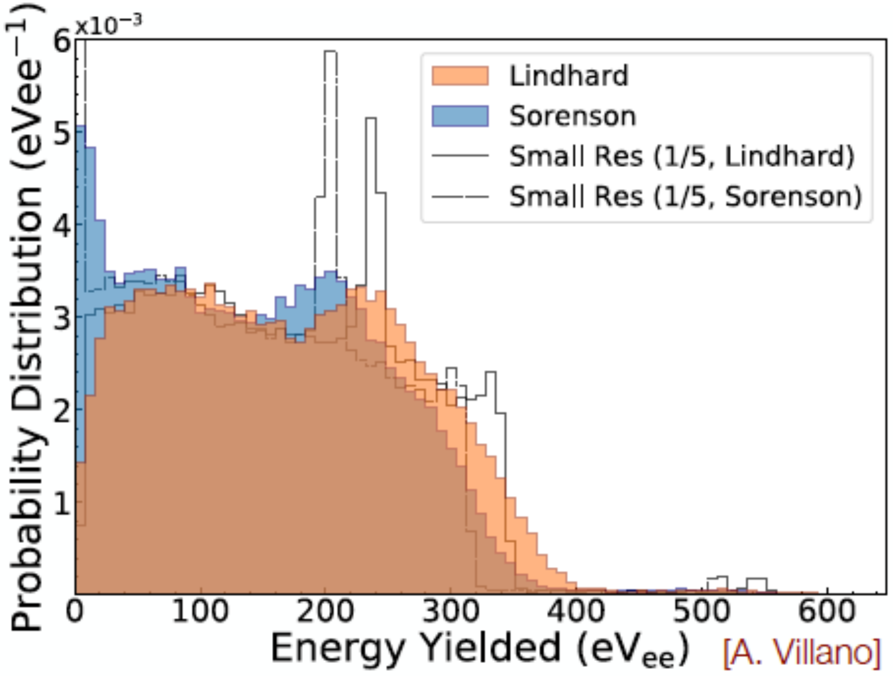
Current constraints are an order of magnitude better. Note that the players are LXe TPCs and Freon bubble chambers



Develop new in situ technique

Nuclear Recoils induced by neutron capture (n,γ) of thermal neutrons





Use NaI to tag events with escaped gammas: these represent "pure" NR.

Running now with large NaI array and new Si HV detector with better resolution

Capture spectrum depends on yield model and detector resolution. Here shown for two yield models and two resolutions

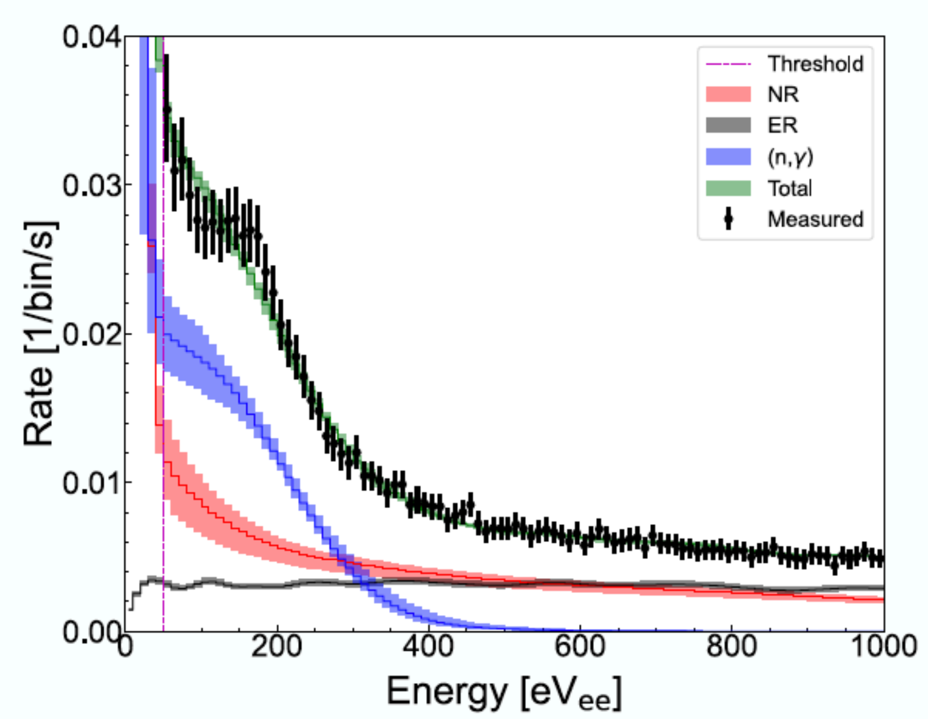
Neutron capture observed
Yield again shows low energy suppression in silicon.

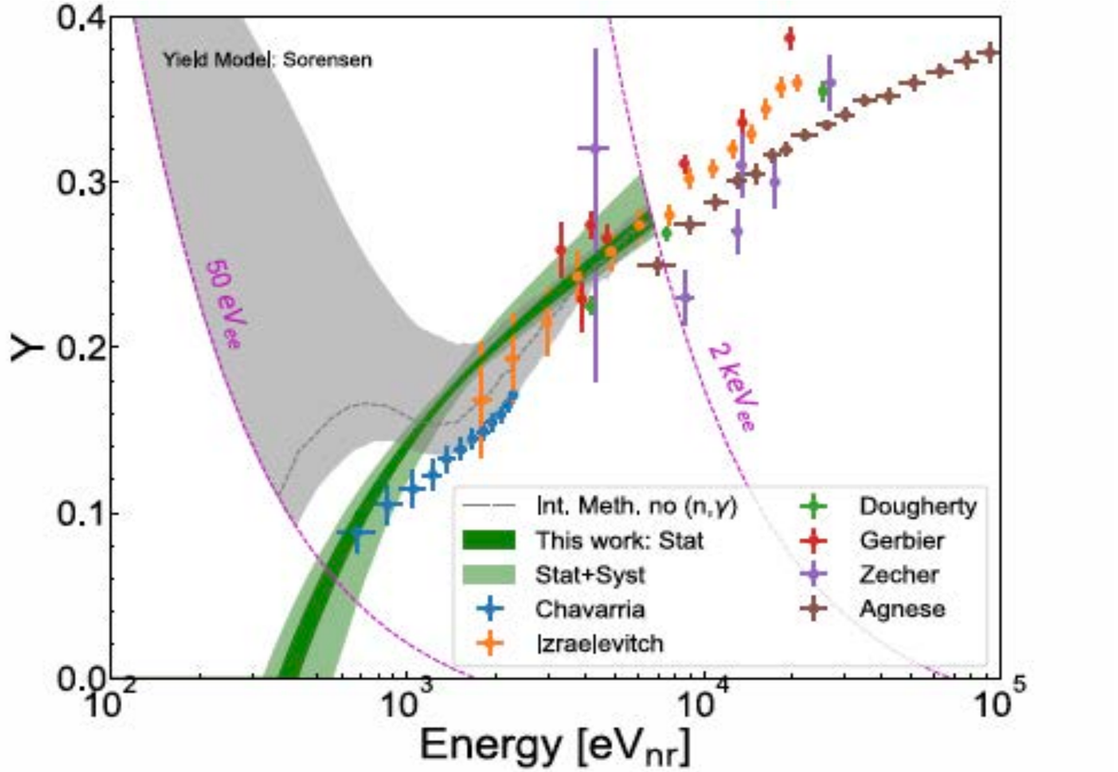
Fit data to simulated ER + NR
For NR, choose a yield model.

Data shows a clear (nγ) feature

Yield models all require a neutron capture component (by 25σ)
Best fit using the Sorenson yield model clearly indicates suppression and possible threshold.

- https://arxiv.org/abs/2110.02751
- https://arxiv.org/abs/2104.02742





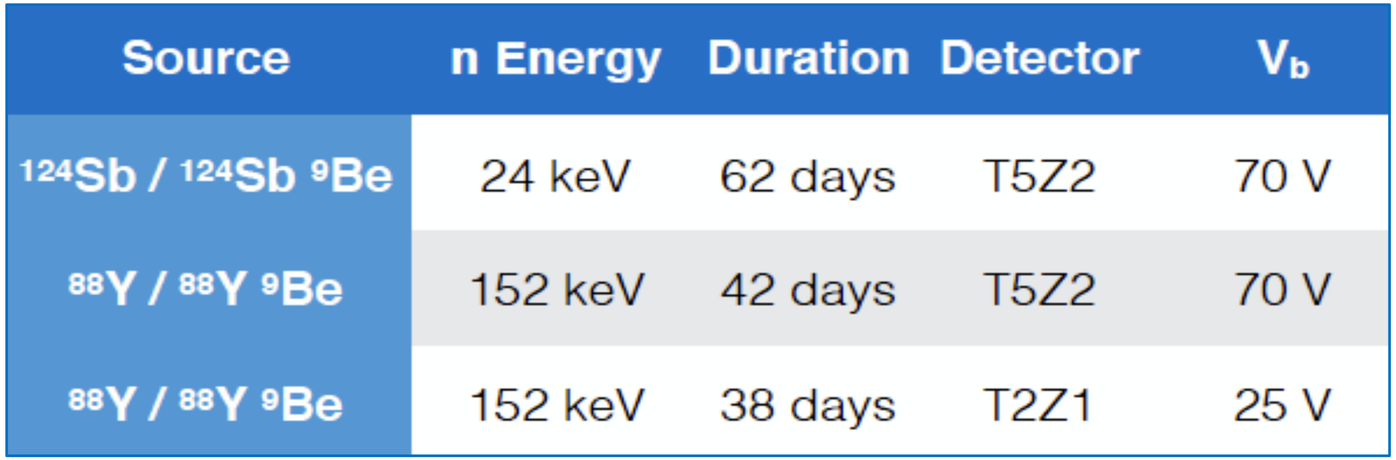
Measure $Y(E_r)$ in Germanium using a photo-neutron source

arXiv:2202.07043

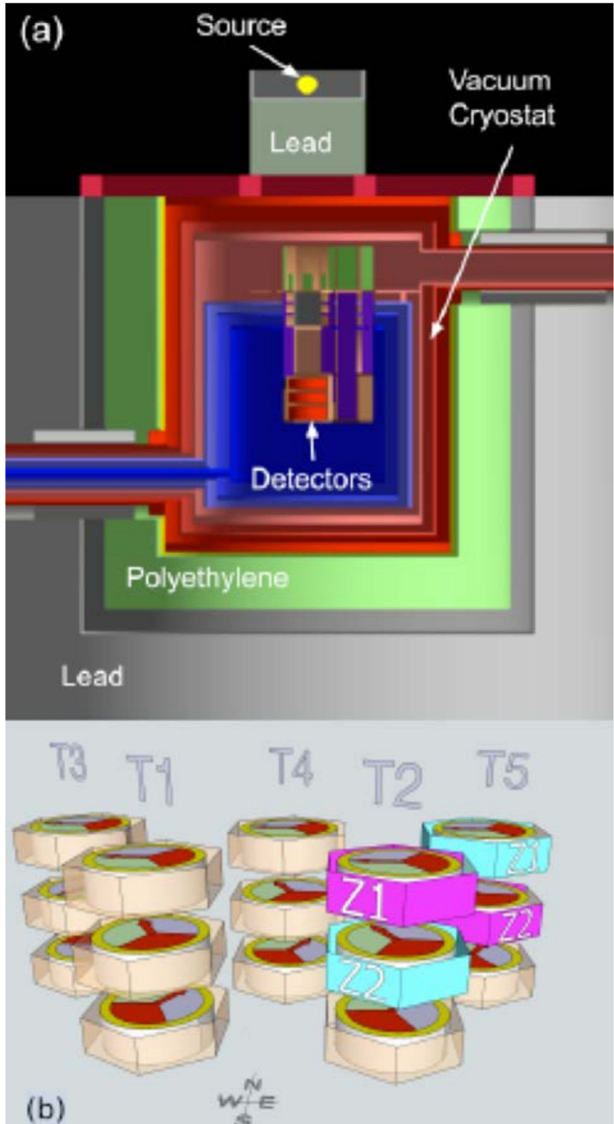
Last set of runs before disassembling Soudan Facility

Illuminated the SuperCDMS array of germanium iZIPs

For each run, one iZIP was in CDMSlite HV mode.



Source	n Energy	Duration	Detector	V_b
^{124}Sb / ^{124}Sb ^{9}Be	24 keV	62 days	T5Z2	70 V
^{88}Y / ^{88}Y ^{9}Be	152 keV	42 days	T5Z2	70 V
^{88}Y / ^{88}Y ^{9}Be	152 keV	38 days	T2Z1	25 V



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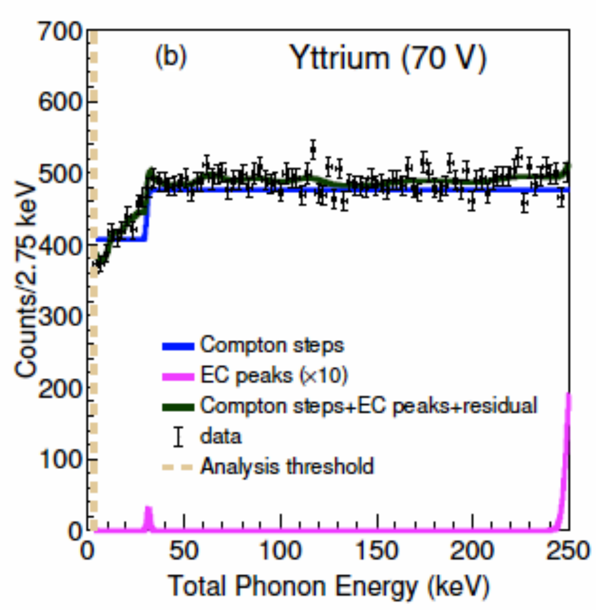
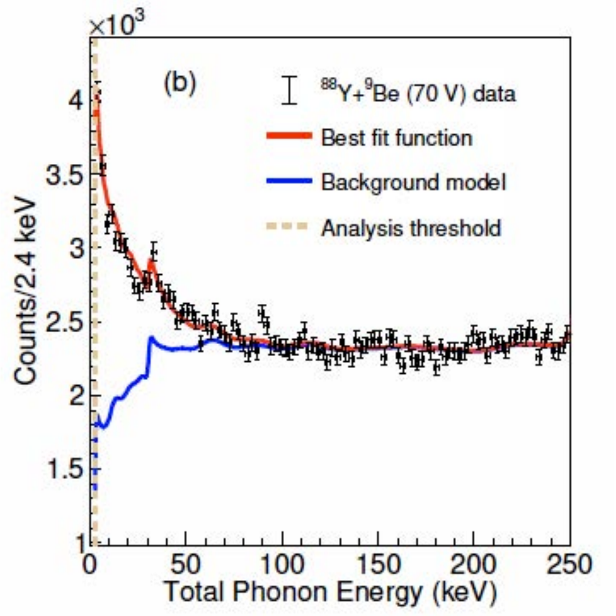
arXiv:2202.07043

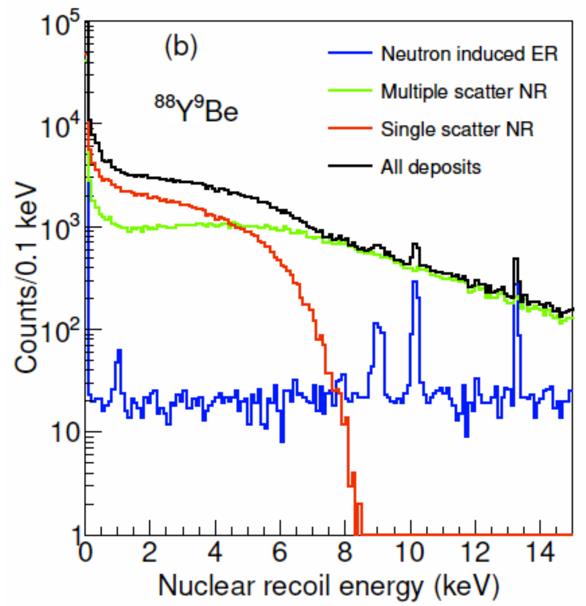
Data without Be disk

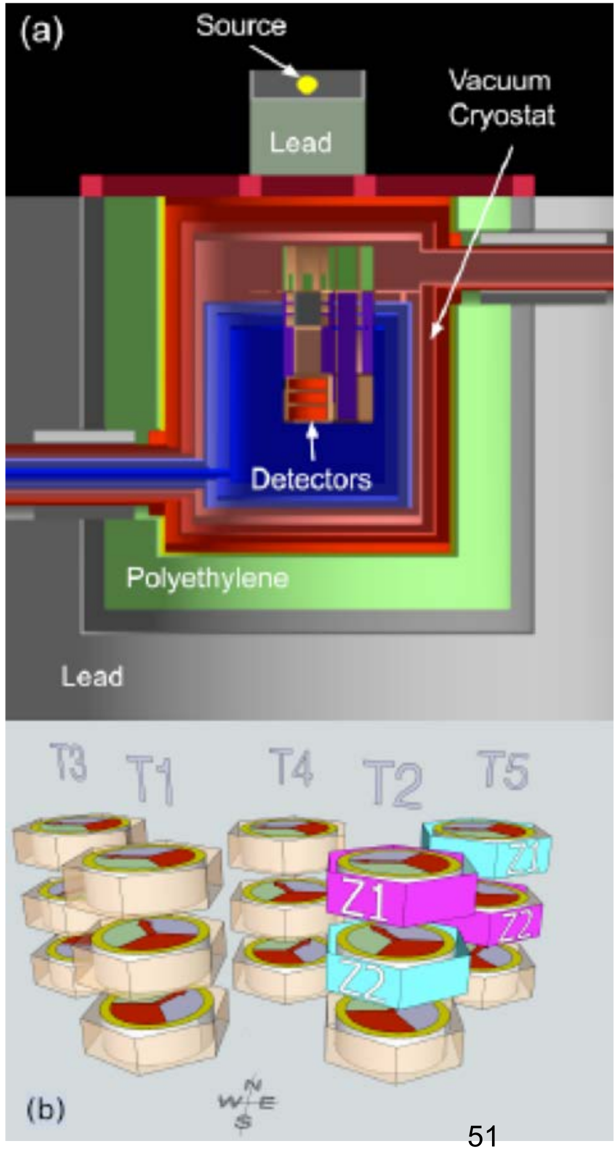


Data with Be disk



Geant4 MC





Source	n Energy	Duration	Detector	V_b
^{124}Sb / ^{124}Sb ^{9}Be	24 keV	62 days	T5Z2	70 V
^{88}Y / ^{88}Y ^{9}Be	152 keV	42 days	T5Z2	70 V
^{88}Y / ^{88}Y ^{9}Be	152 keV	38 days	T2Z1	25 V

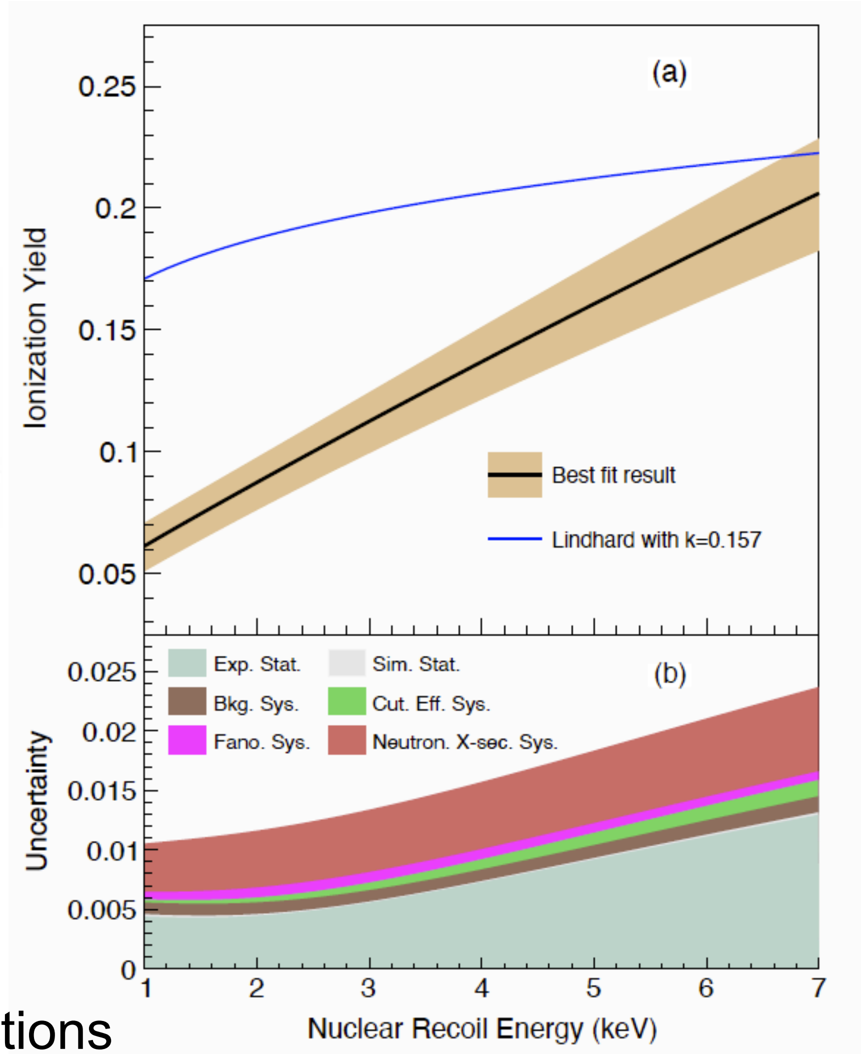
Soudan CDMSlite photo-neutron source results for germanium

https://arxiv.org/abs/2202.07043

Likelihood fit to modified Lindhard

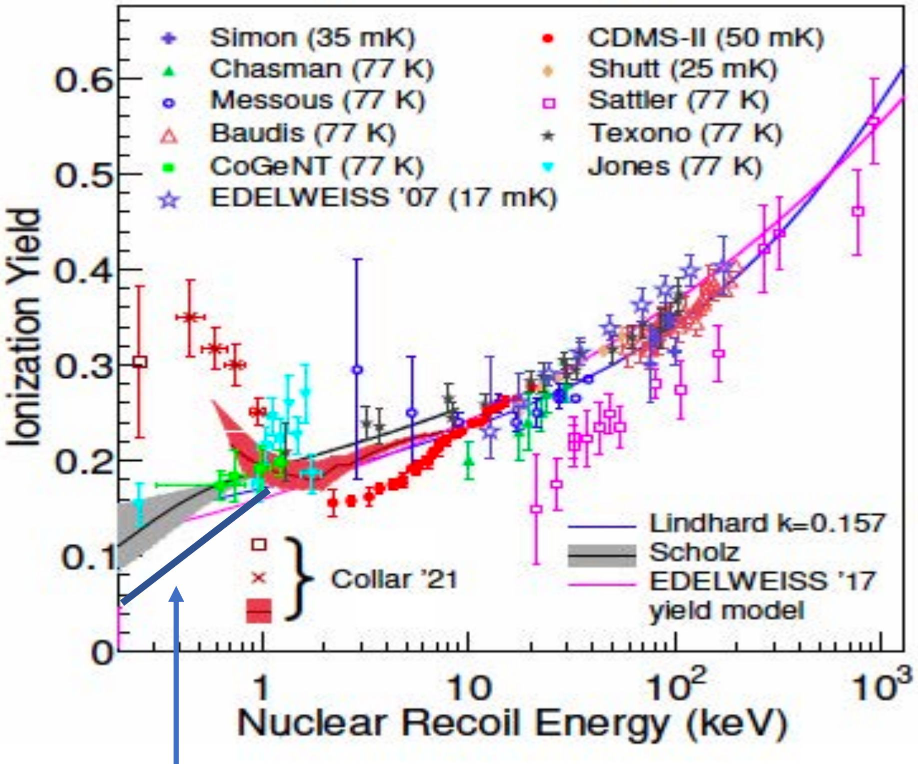
$$Y_r = \frac{kg(\epsilon)}{1+kg(\epsilon)}$$

$$k(E_r) = k_{low} + \frac{k_{high} - k_{low}}{E_{high} - E_{low}}(E_r - E_{low})$$



Uncertainty dominated by statistics and precision of neutron scattering cross sections

Inconsistent with recent Collar measurement.
Is Yield T-dependent?
Or modified by internal field?



CDMSlite result

Measure $Y(E_r)$ in Silicon

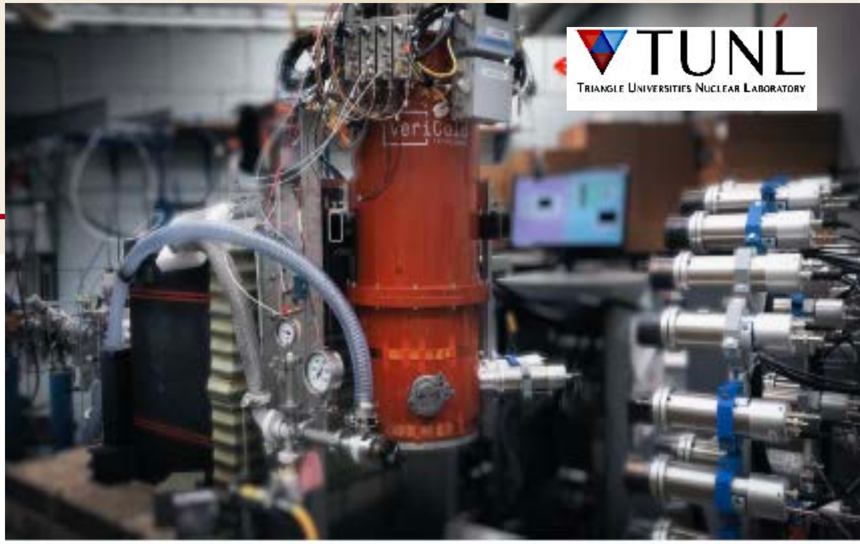


Image credit: Tom Ren

Neutron Beam Energy ➔ E_n

- 1.9 MeV pulsed (2.5 MHz) protons on LiF target
- Tune to the ^{28}Si elastic scattering resonance (56 keV)

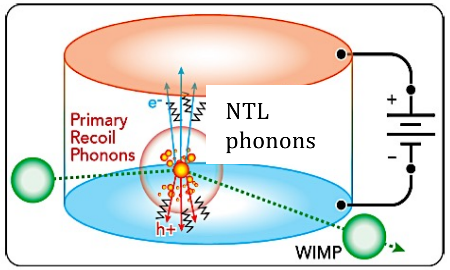
Neutron scattering angle ➔ E_r

- Backing Array (26 PMTs) at 2 distances
- 3 “lone wolf” to reference large angles
- Also measure TOF and γ backgrounds

$$E_r = 2E_n \frac{M_n^2}{(M_n + M_T)^2}\left(\frac{M_T}{M_n} + \sin^2\theta - (\cos\theta)\sqrt{\left(\frac{M_T}{M_n}\right)^2 - \sin^2\theta}\right)$$

Silicon Detector ➔ total phonon energy

- HVeV (0.93 g) with 2 TES channels
- Energy Resolution: $\sigma_p \sim 3$ eV
- Charge Resolution: $\sigma_{eh} \sim 0.03$ e/h



$$E_{tot} = E_r + E_{NTL}$$

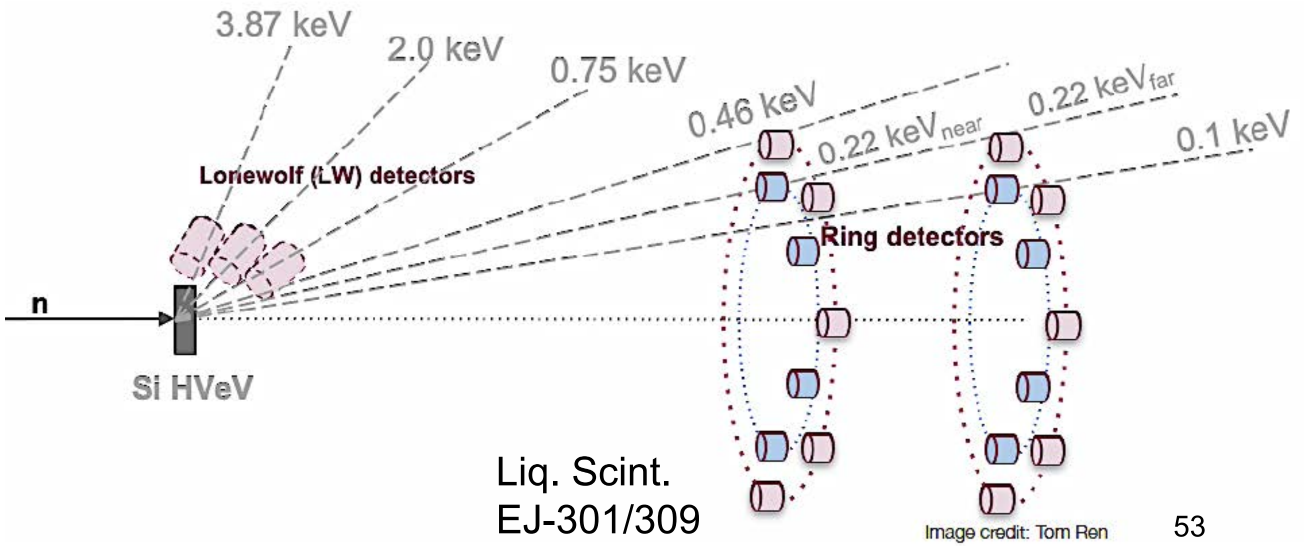
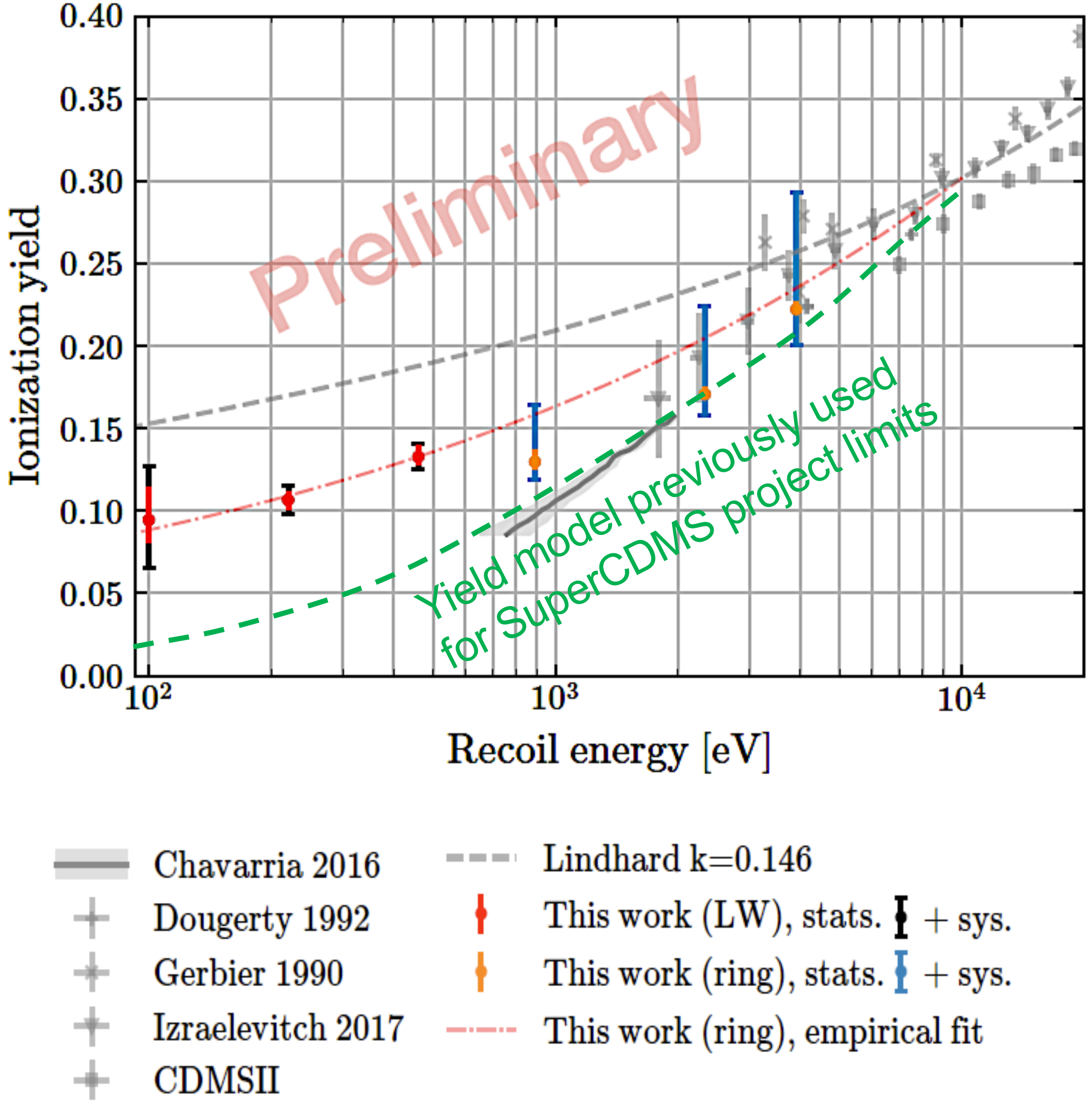
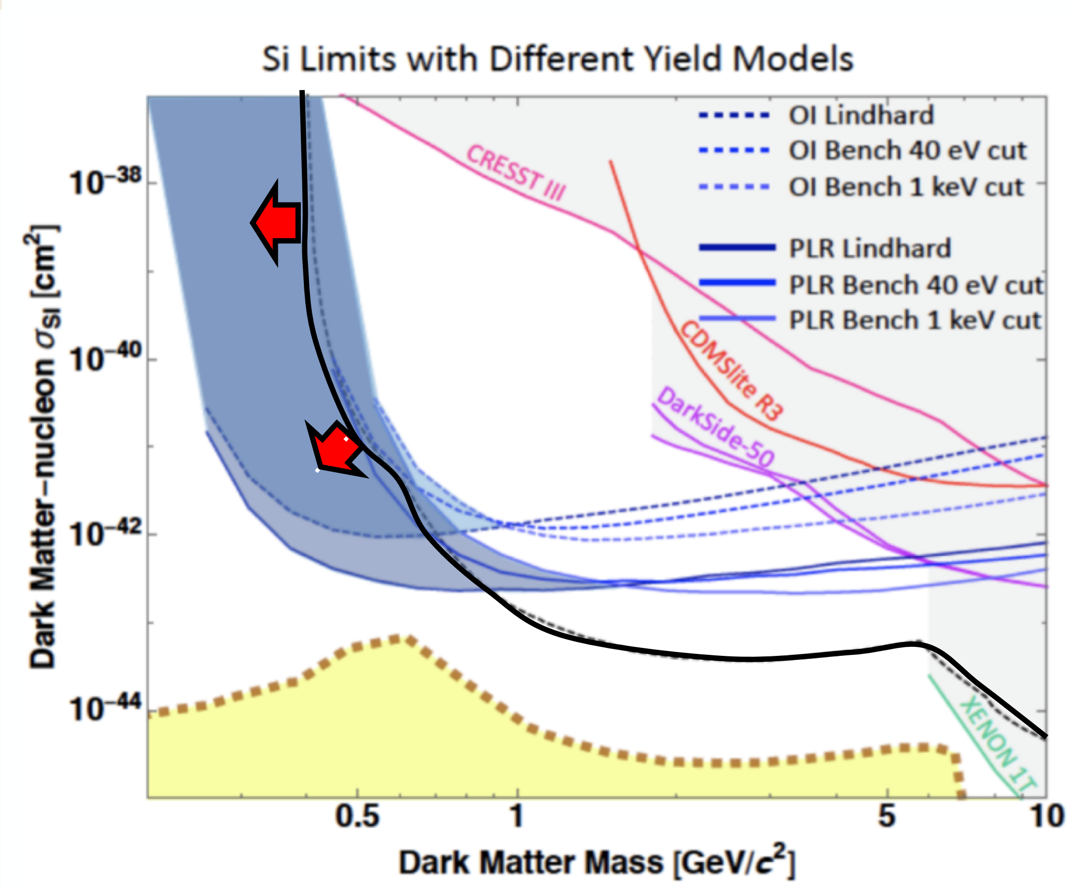


Image credit: Tom Ren

Yield has significant consequences to our low mass reach in Silicon


Preliminary

Yield model previously used for SuperCDMS project limits

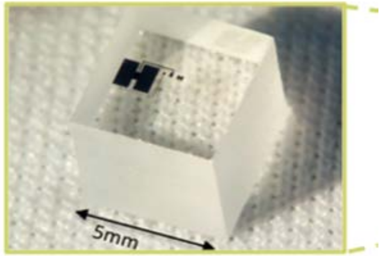

Si Limits with Different Yield Models

All our Si project limits were based on a modified Lindhard (green)that passes through Chavarria ‘16

The CEνNS Connection

CRESST→ nu-cleus

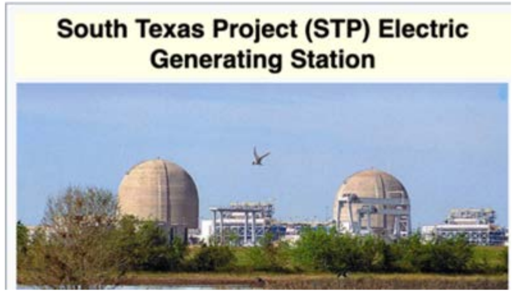
Two 3x3 arrays of
6g $CaWO_4$ + 4g Al_2O_3
read out by W TES



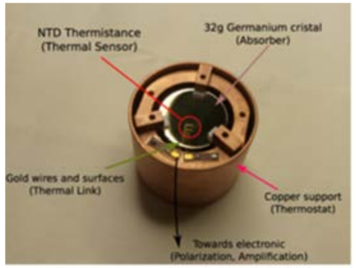
SuperCDMS→ MIνER

HV, iZIP
Al_2O_3 + QET

TRIGA research nuclear reactor at TAMU with moveable core

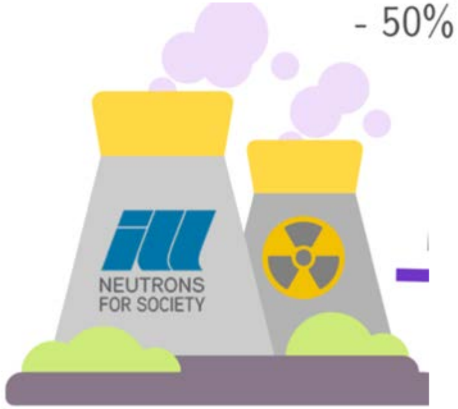

South Texas Project (STP) Electric Generating Station

EDELWEISS→ Ricochet



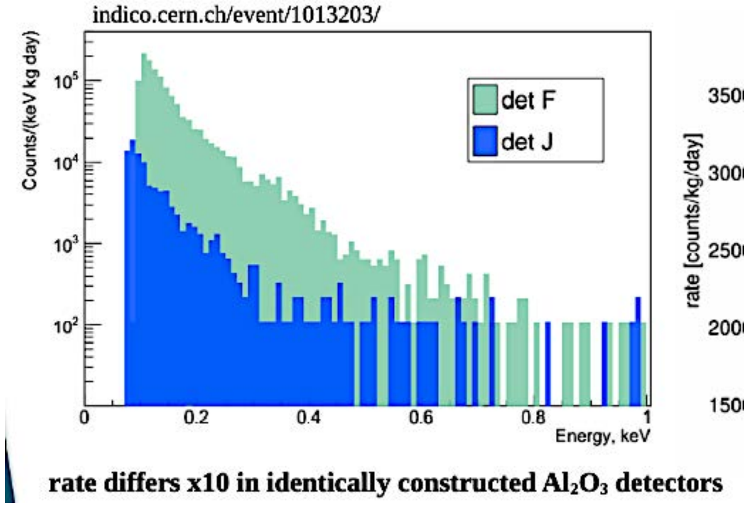
Array of 27x32g detectors:

- 8x8x8 cm^3
- 50% Ge semiconductors
- 50% Zn superconductors

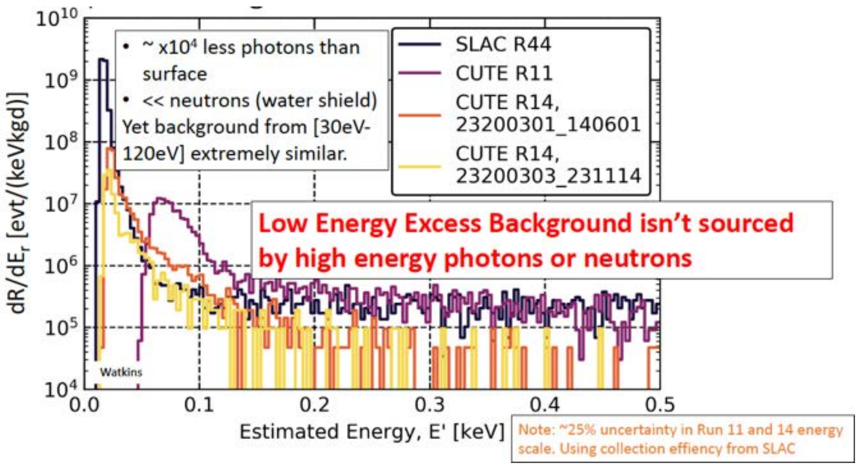


Institut Laue-Langevin
(Grenoble, France)

Recent Excess workshop identifies further clues



rate differs x10 in identically constructed Al_2O_3 detectors



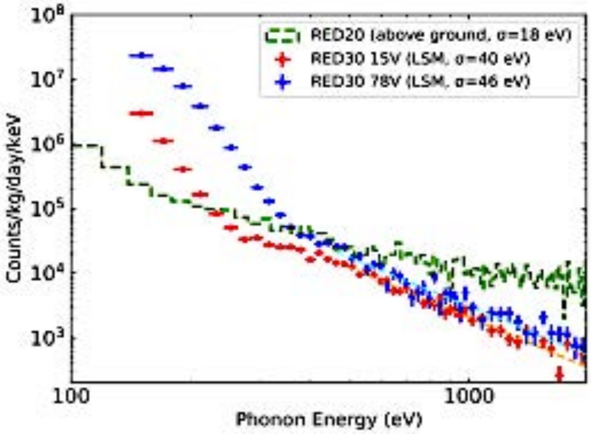
- ~ x10⁴ less photons than surface
- << neutrons (water shield)

Yet background from [30eV-120eV] extremely similar.

Low Energy Excess Background isn't sourced by high energy photons or neutrons

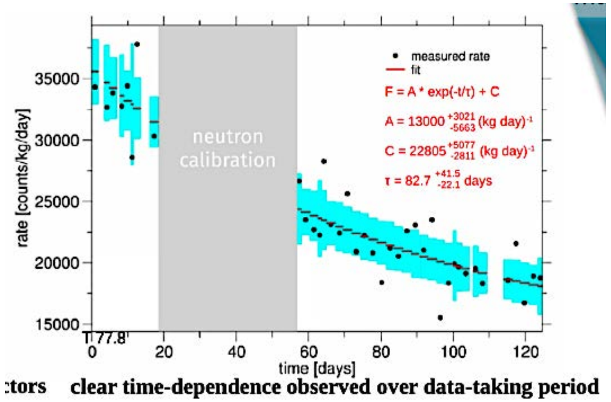
Note: ~25% uncertainty in Run 11 and 14 energy scale. Using collection effiency from SLAC

CPD (both underground and at surface)

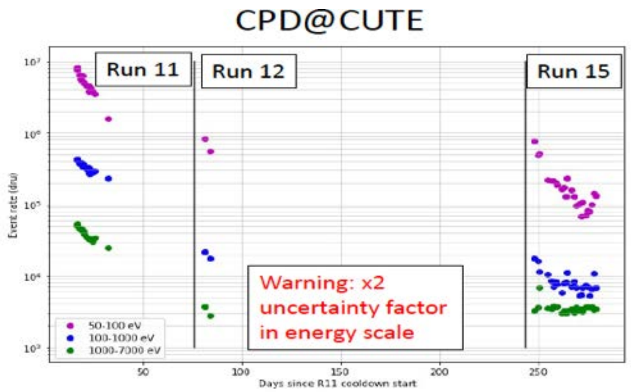


EDELWEISS “heat only” events

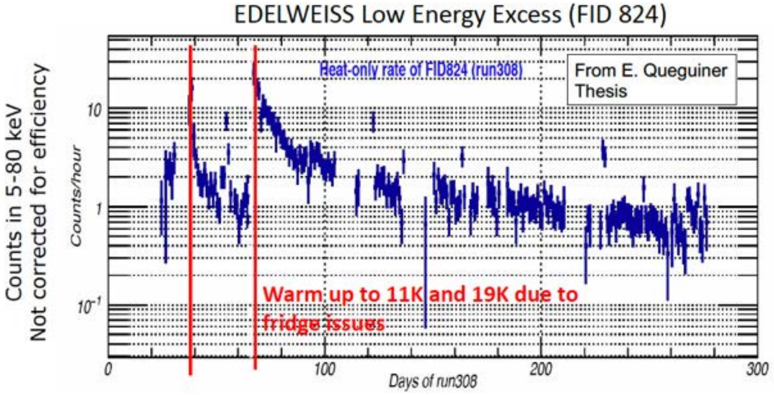
Rate differs by x 10 in ”identical” Al_2O_3 detectors



clear time-dependence observed over data-taking period



Warning: x2 uncertainty factor in energy scale



From E. Queguiner Thesis

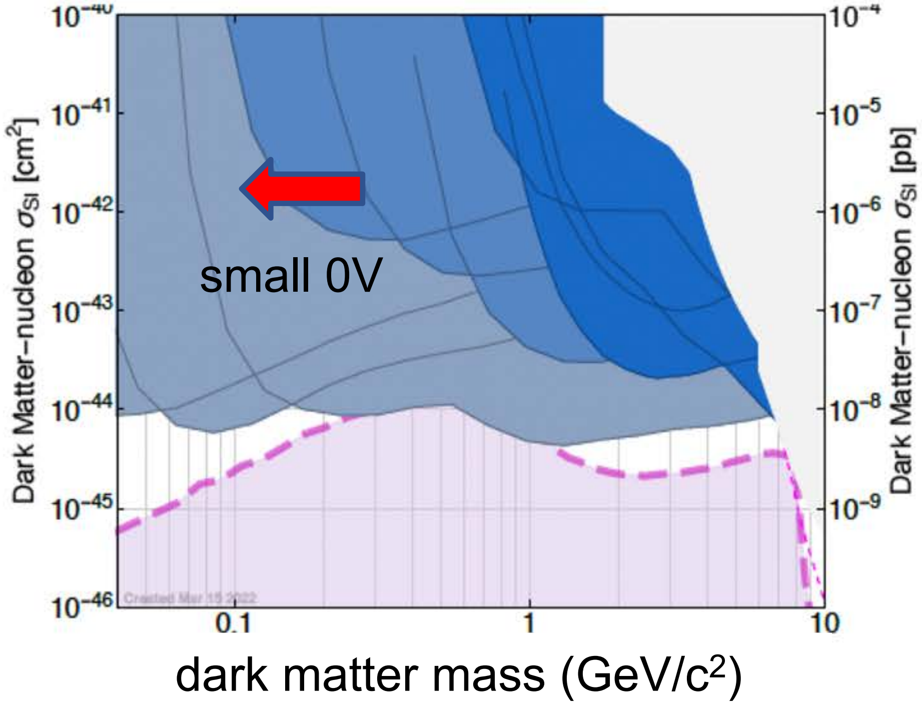
Warm up to 11K and 19K due to fridge issues

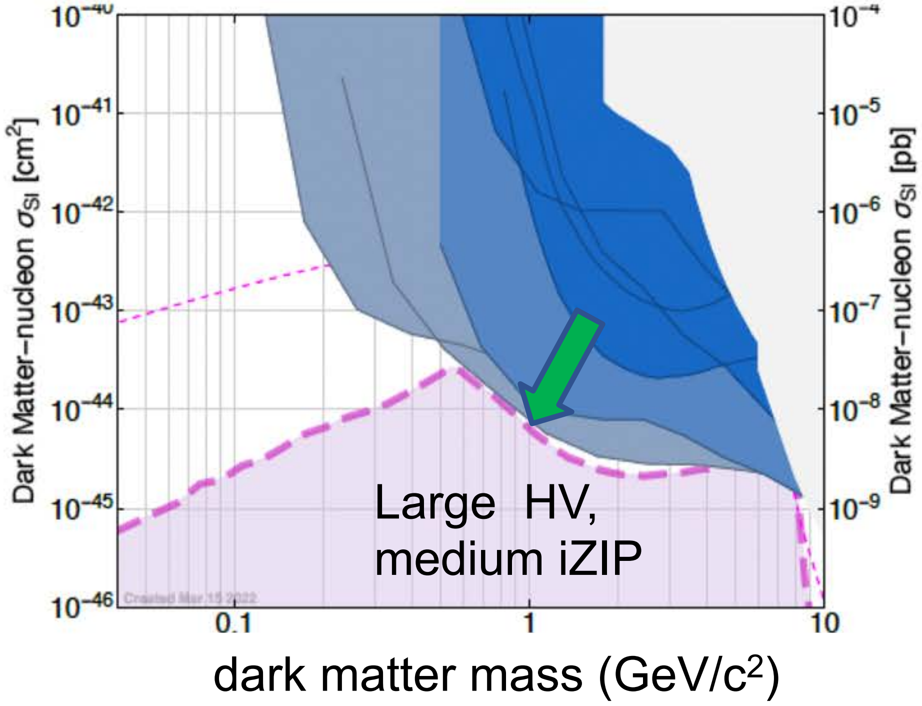
Relaxing after cooldown is a feature consistent with microfracture stresses

A Strategy for Low-Mass Dark Matter Searches with Cryogenic Detectors in the SuperCDMS SNOLAB Facility. https://arxiv.org/abs/2203.08463

Nucleon-coupled dark matter (50 MeV – 5 GeV)

Large = SNOLAB (260 cm^3)
Medium = 10 cm^3
Small = 1 cm^3



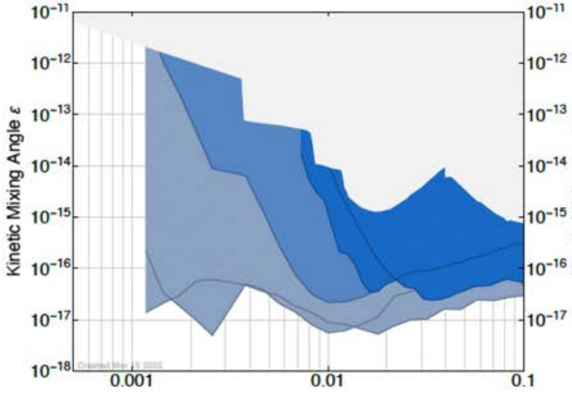


Dark blue = SNOLAB limits with 4 Towers (in our 7-tower cryostat).
Light blue = In-hand small detector mosaics filling two towers running at 80% duty cycle for 4 yrs.
Dark Grey = Mosaics of upgraded detectors (see next slide) in two towers.

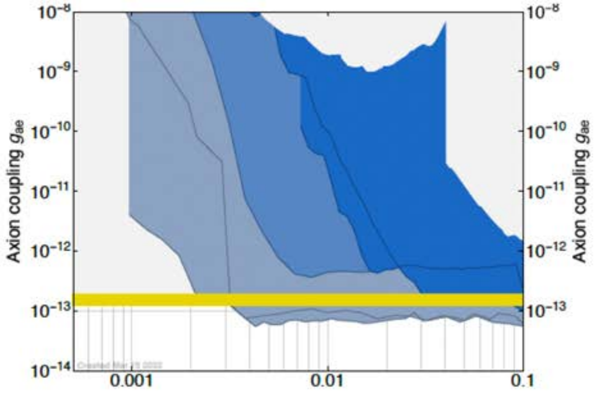
Three two-tower scenarios can fit in the the cryostat and run in parallel.

A Strategy for Low-Mass Dark Matter Searches with Cryogenic Detectors in the SuperCDMS SNOLAB Facility. https://arxiv.org/abs/2203.08463

Dark photon kinetic mixing **ALP effective coupling**

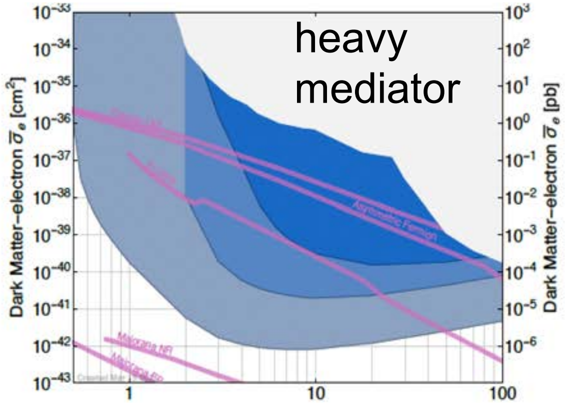


dark photon mass (keV/c^2)

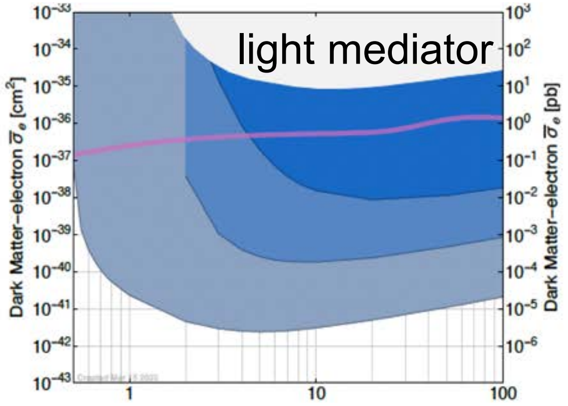


ALP mass (keV/c^2)

Light DM coupled to dark photon



dark matter mass (MeV/c^2)



dark matter mass (MeV/c^2)

Dark blue: SNOLAB limits with 4 Towers (in our 7-Tower cryostat)

Light blue: In-hand small detector mosaics filling two towers running at 80% duty cycle for 4 yrs.

Dark Grey: Mosaics of upgraded detectors in two towers.

Three two-tower scenarios can fit in the the cryostat and run in parallel.

yellow line: parameter space consistent with the hint
from white dwarf cooling. J. Cosmo. Astro. Phys. 2016, 057

pink lines are sharp targets for $M_{A'} = 3\ M_\chi$
from 2017 cosmic visions workshop