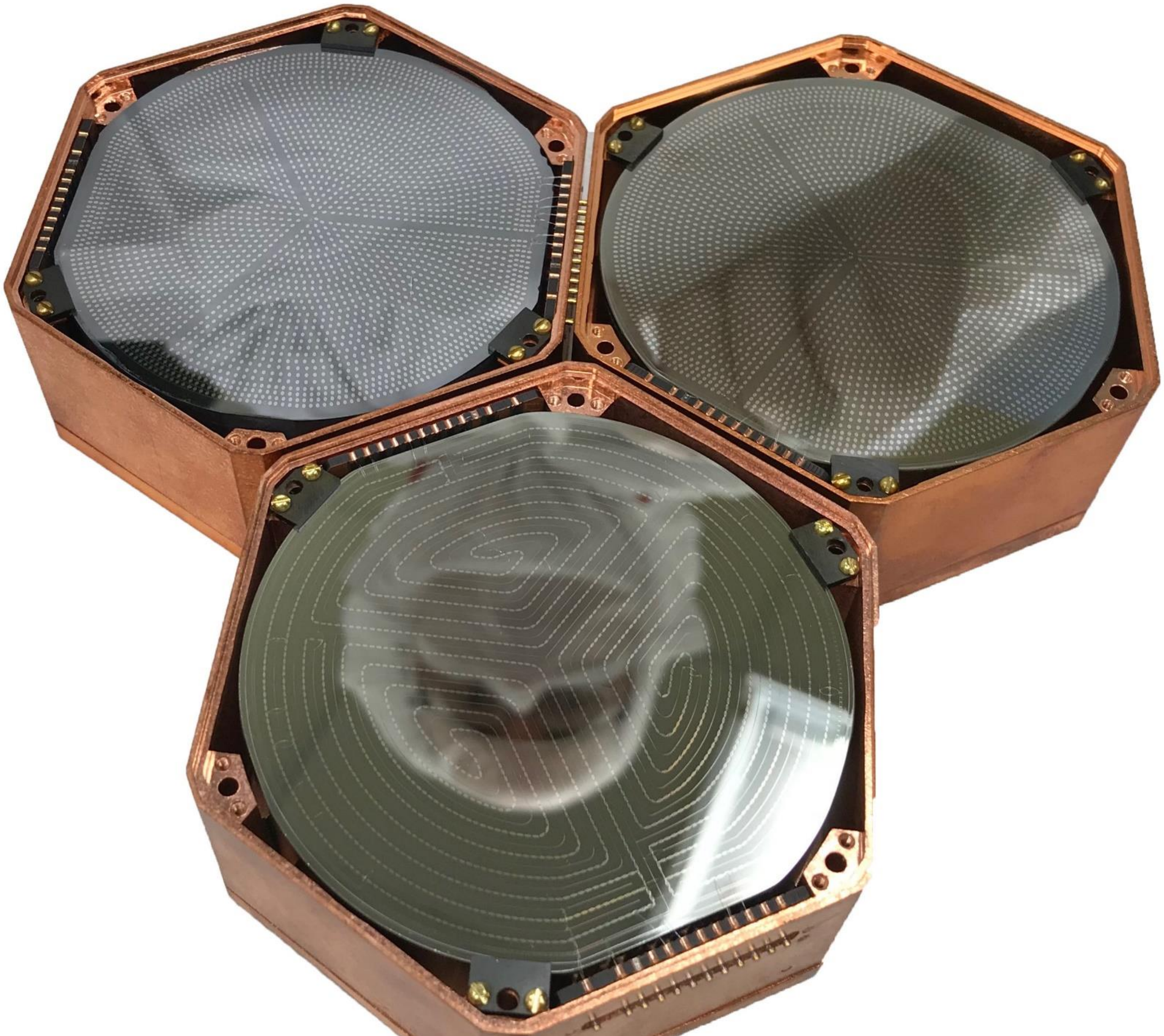
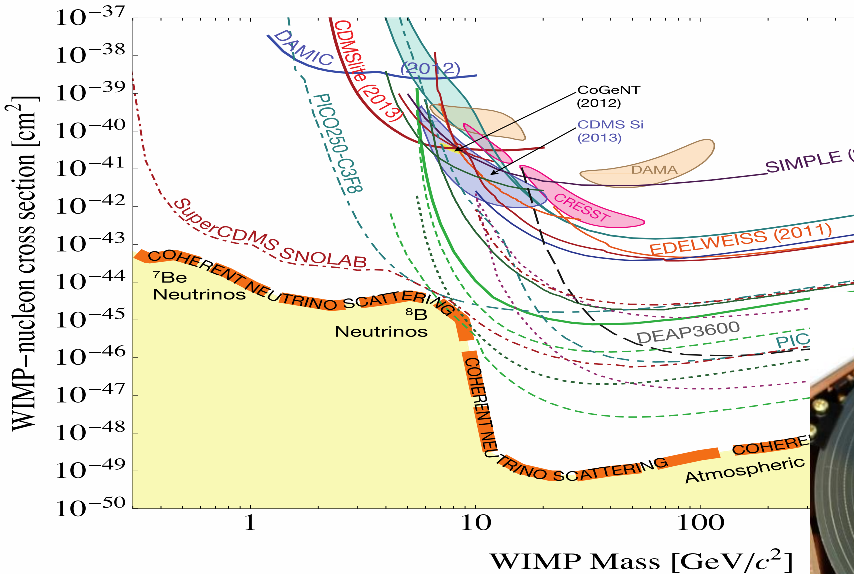
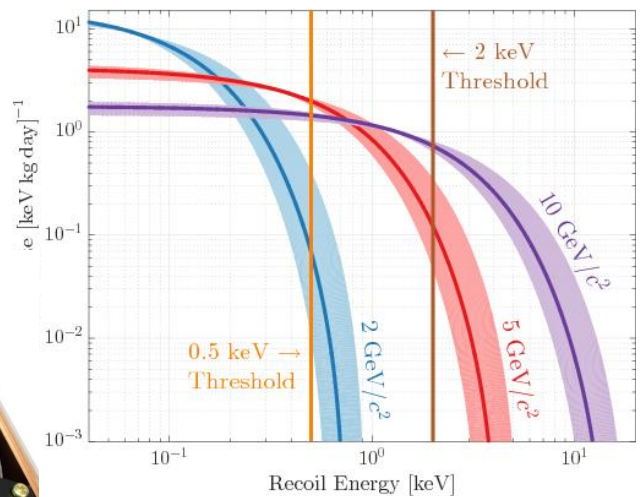
Search for Axions on the MIνER CEνNS Experiment

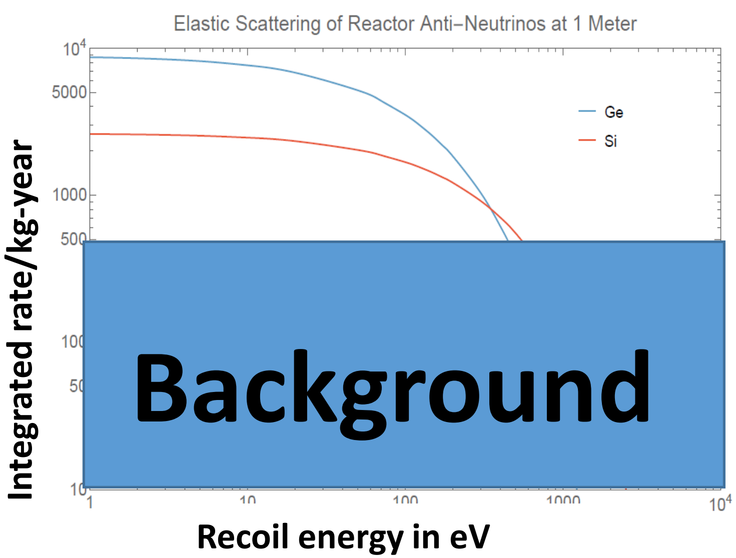


Rupak Mahapatra, Texas A&M

Coherent Neutrino Scattering: Connection to WIMPs







Requirements: Low Threshold Detectors combined with Low-background achieved through reduction and rejection

CEνNS observed at SNS (~50 MeV ν), thus accessible by many detector technologies: $E_{max} \propto E_{\nu}^{2}$

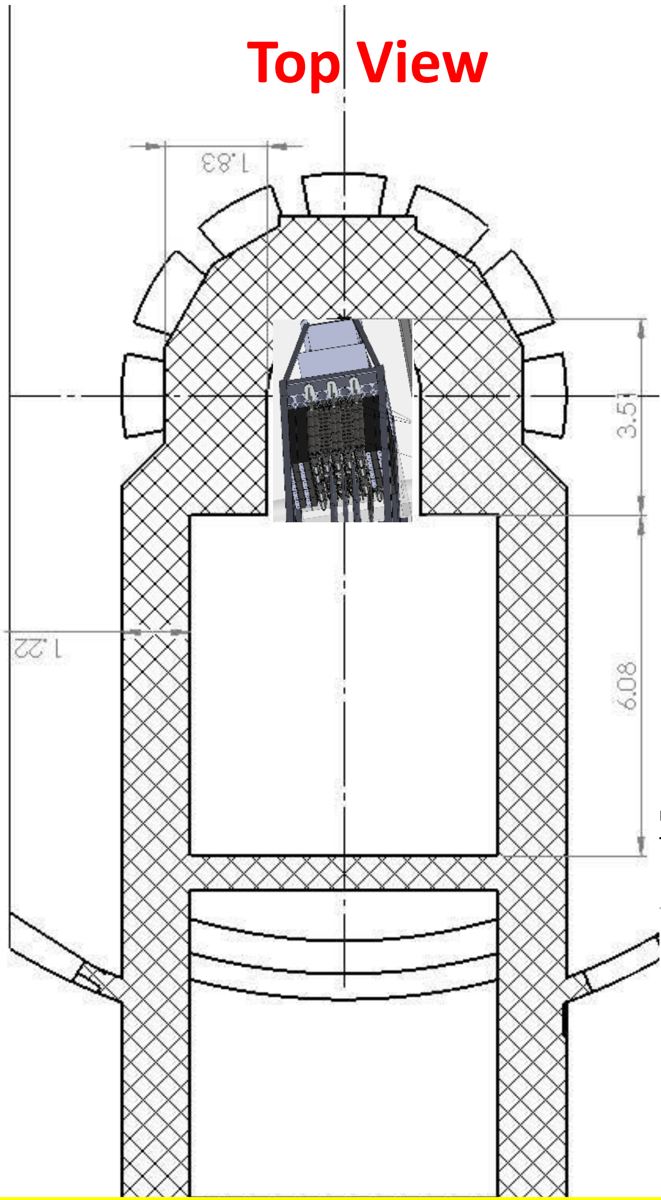
CEνNS process is yet to be discovered at a reactor!
E_{ν}~MeV hence need low threshold detectors

Experiment Plans

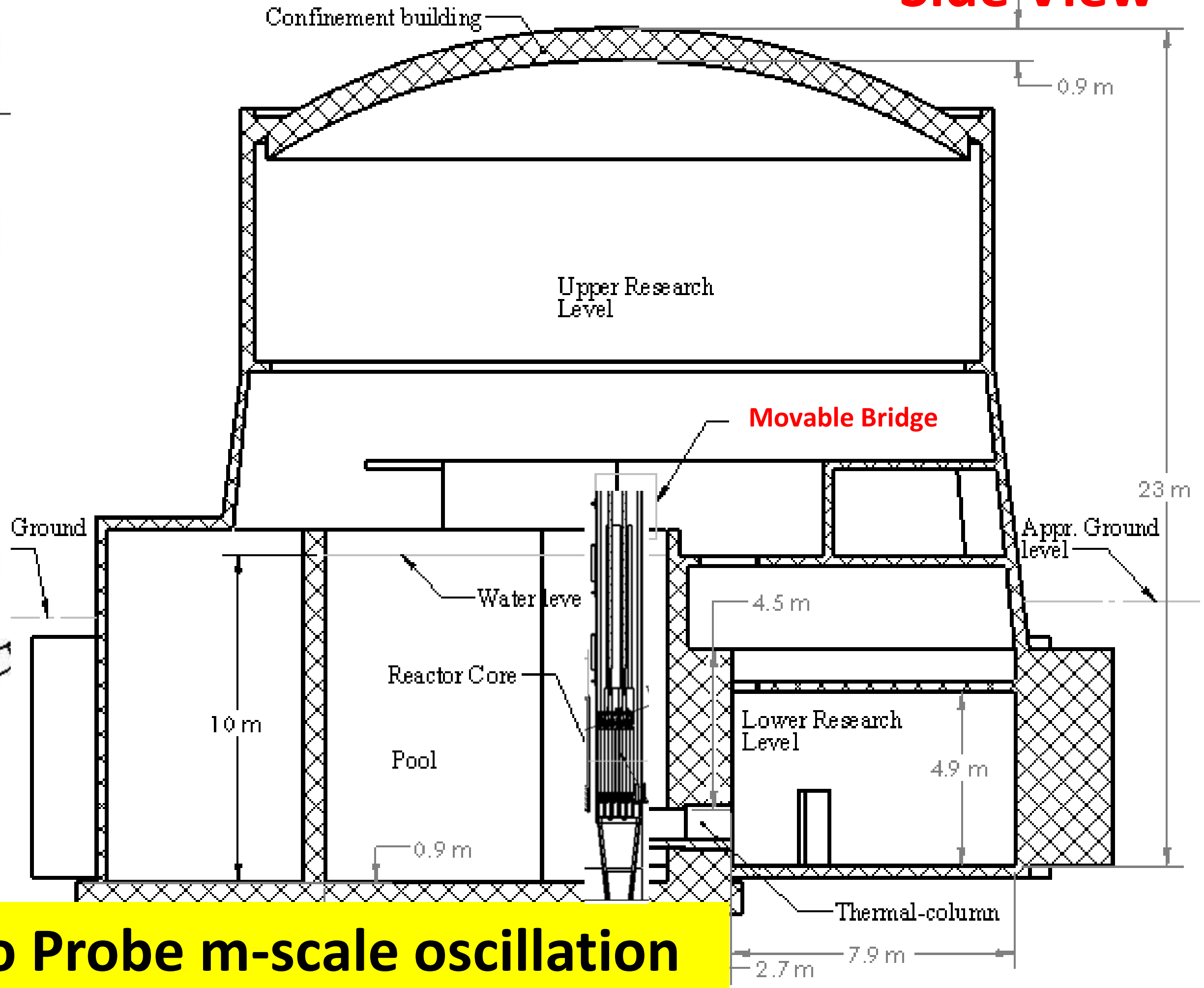
Key Features

1. Low-threshold (<100 eV) with sensitivity to CNS
2. 2-10 m proximity to core (rate enhancement)
3. Moveable Core tests short baseline oscillation
4. 4 kg (max=30) payload with CNS sens. in 4 months
5. High gamma flux is about 9.0×10^{11} cm^{-2} s^{-1} for ALP

Top View

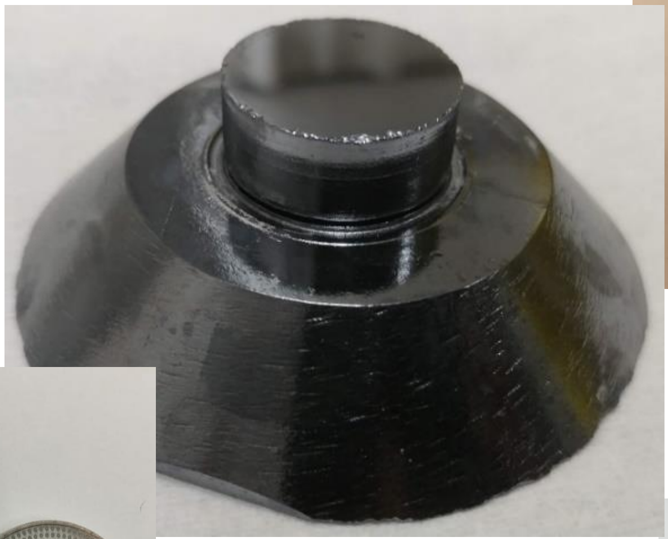


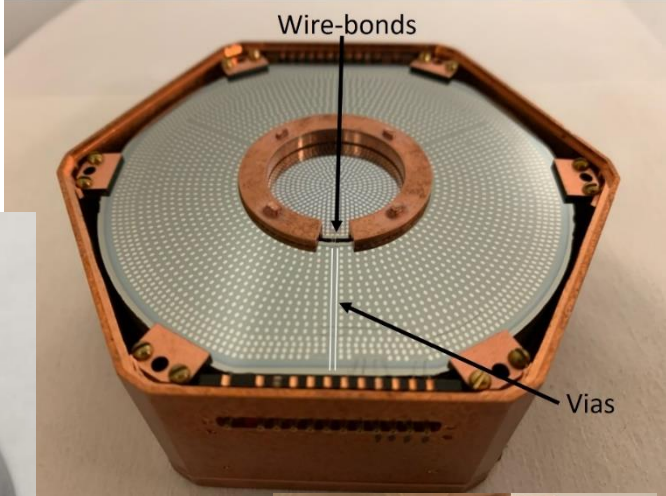
Side View

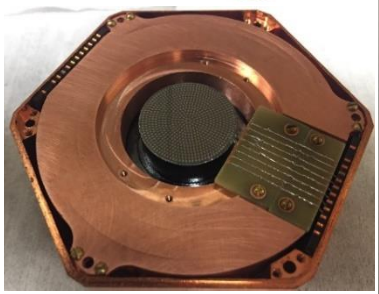


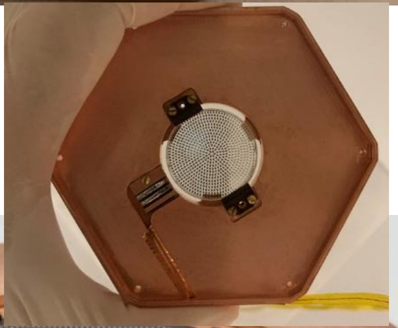
Precisely Movable Core to Probe m-scale oscillation

gm-kg scale MINER Detectors

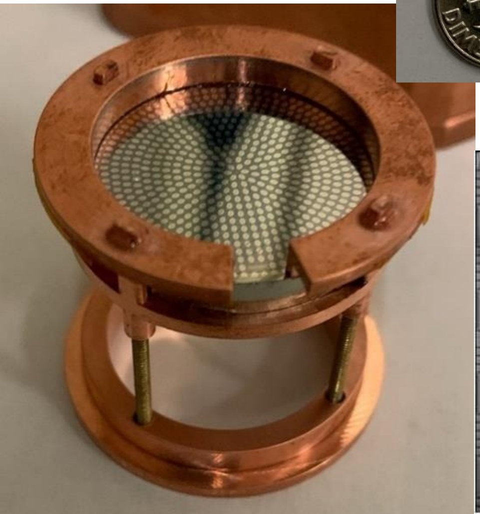


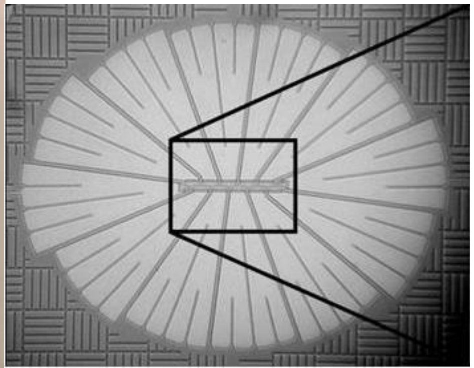


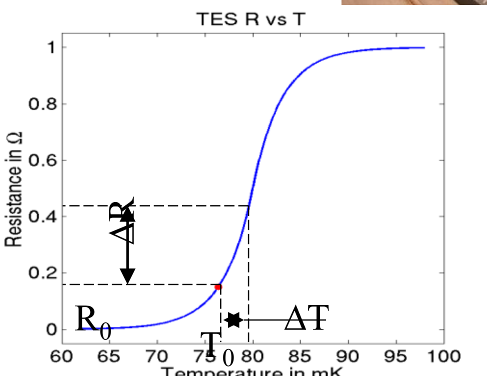


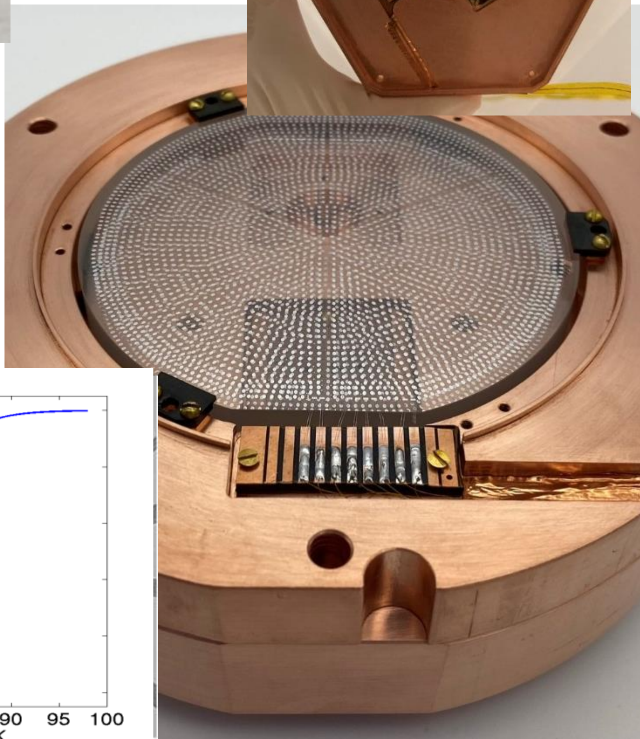


Ge, Si, Al2O3
0V, LV (few V), HV (400V)
Smallest – 10 gm Si
Largest – 1.5 kg Ge

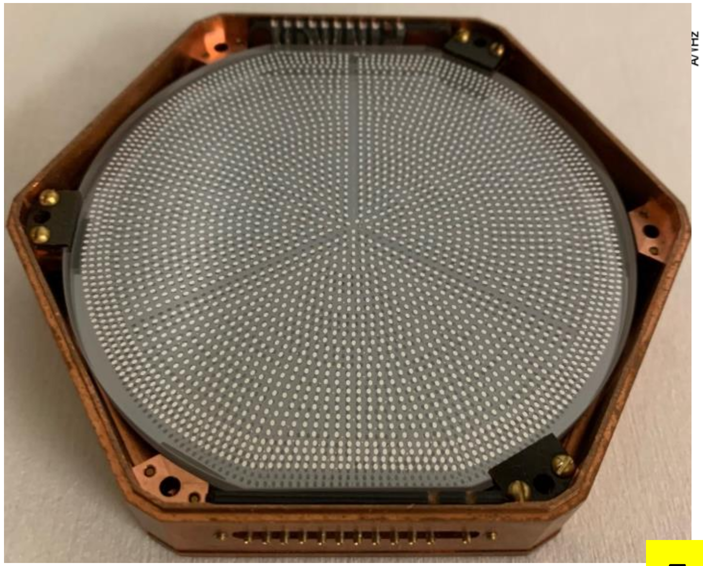


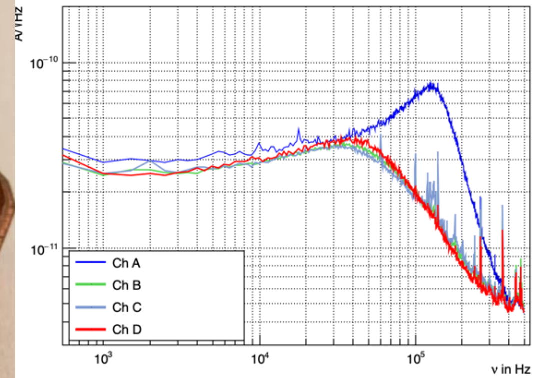


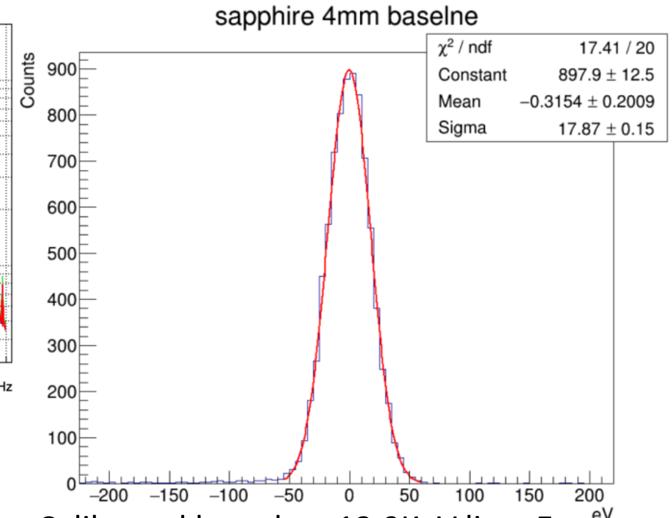




~100gm sapphire detector with ~15 eV σ baseline resolution



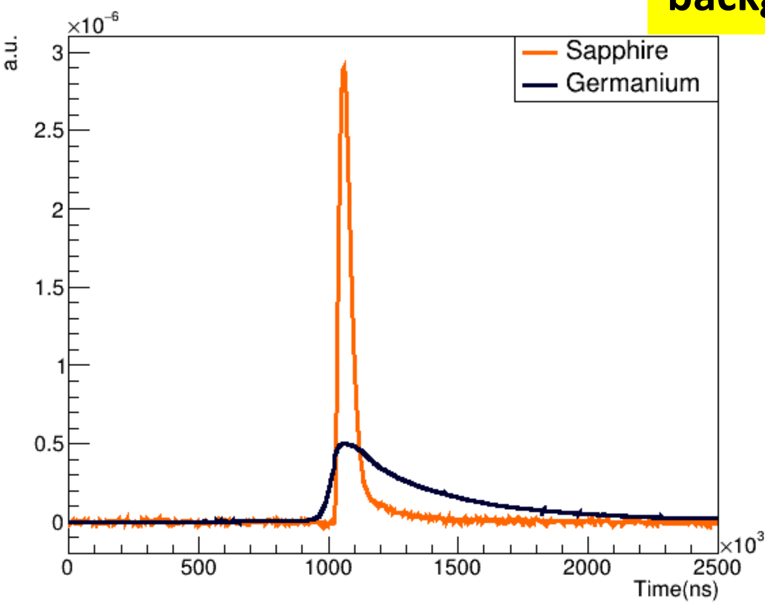


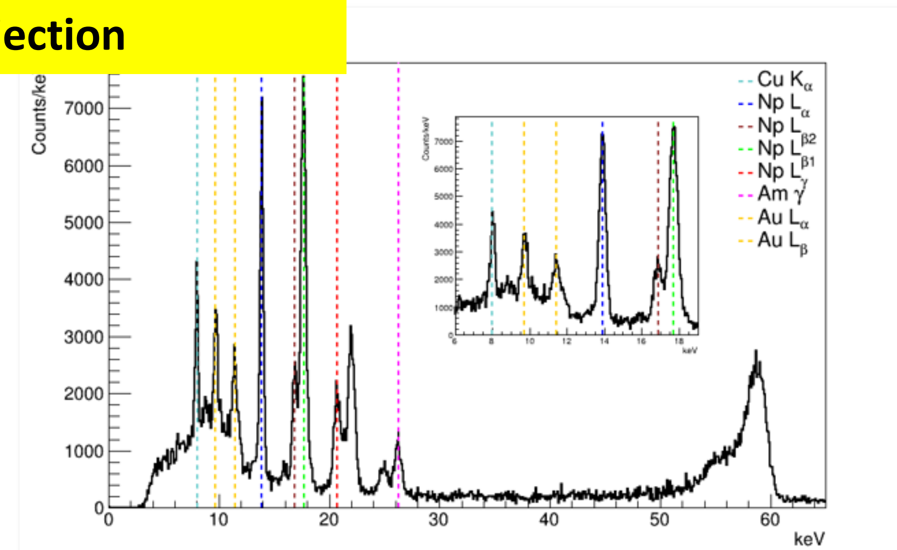


Calibrated based on 13.9KeV line. Exact
is within 15-18 eV, based on peak

~100 gm 3”x 4mm sapphire detector show
~200 gm 3”x1cm sapphire detector tested

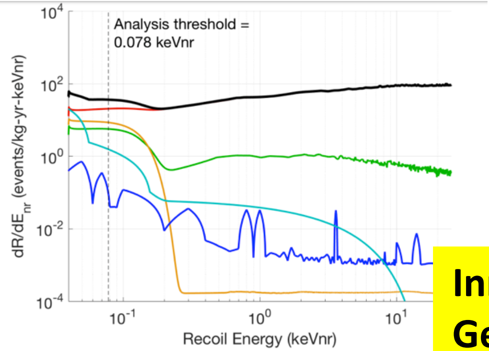
Faster phonon pulses provide better position information, background rejection



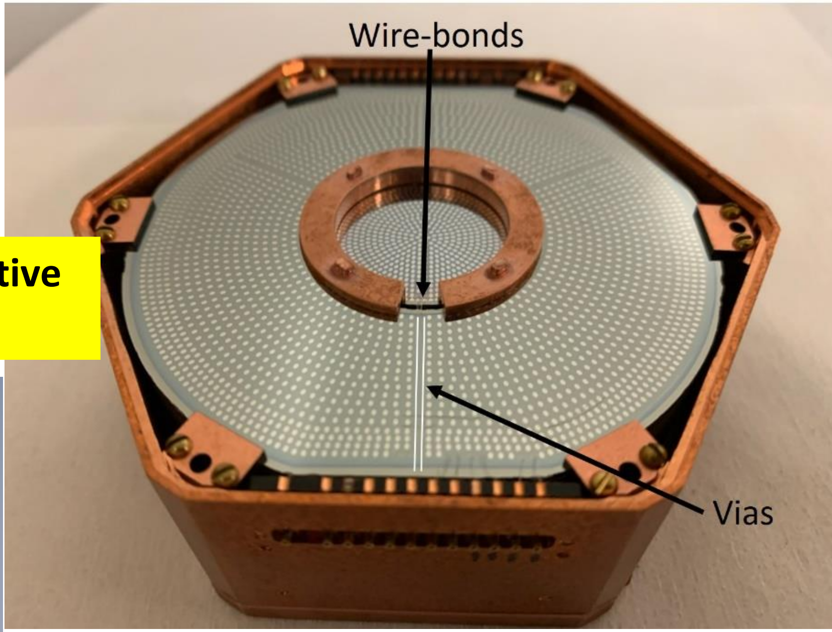


Calibration: Internal ^{55}Fe, ^{241}Am and external ^{57}Co, ^{252}Cf, AmBe.

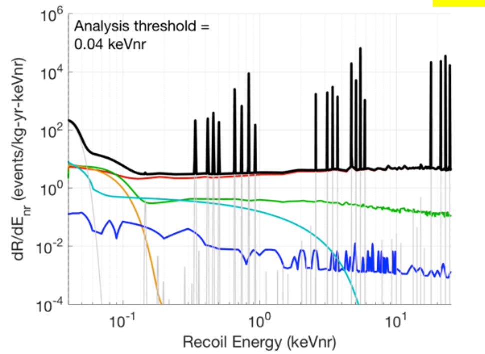
Low-Threshold Ge Detector inside Fully Hermetic Ge Shielding

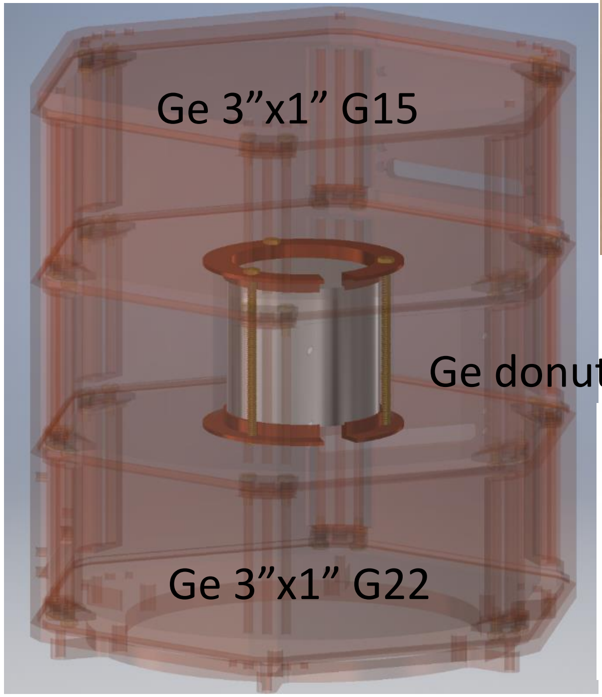


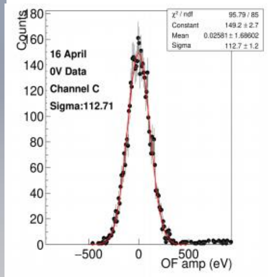
3He + 32Si (β-decay in bulk)
Ge Activation
Surface Betas
Surface 206Pb
Neutrons
CNS

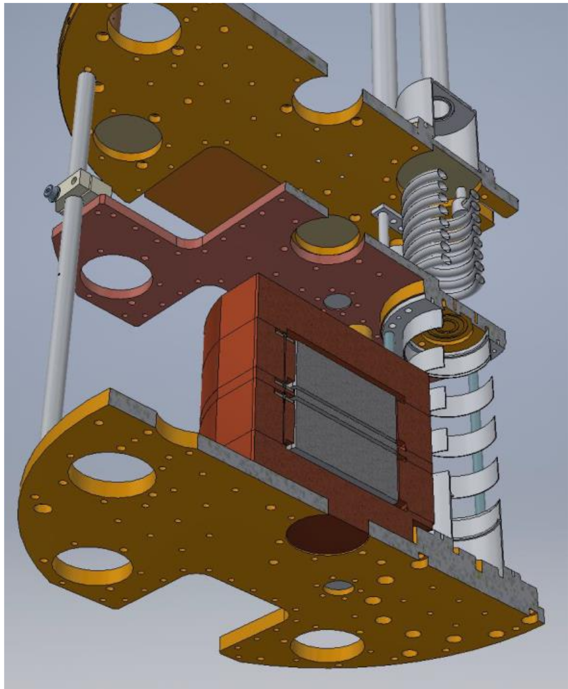


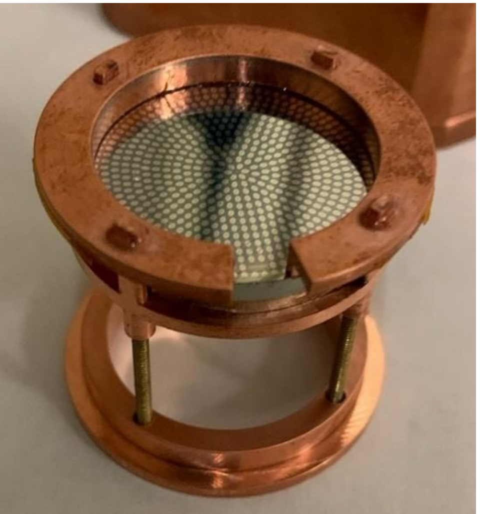
Inner Ge detector shielded by 1" active Ge veto for background rejection



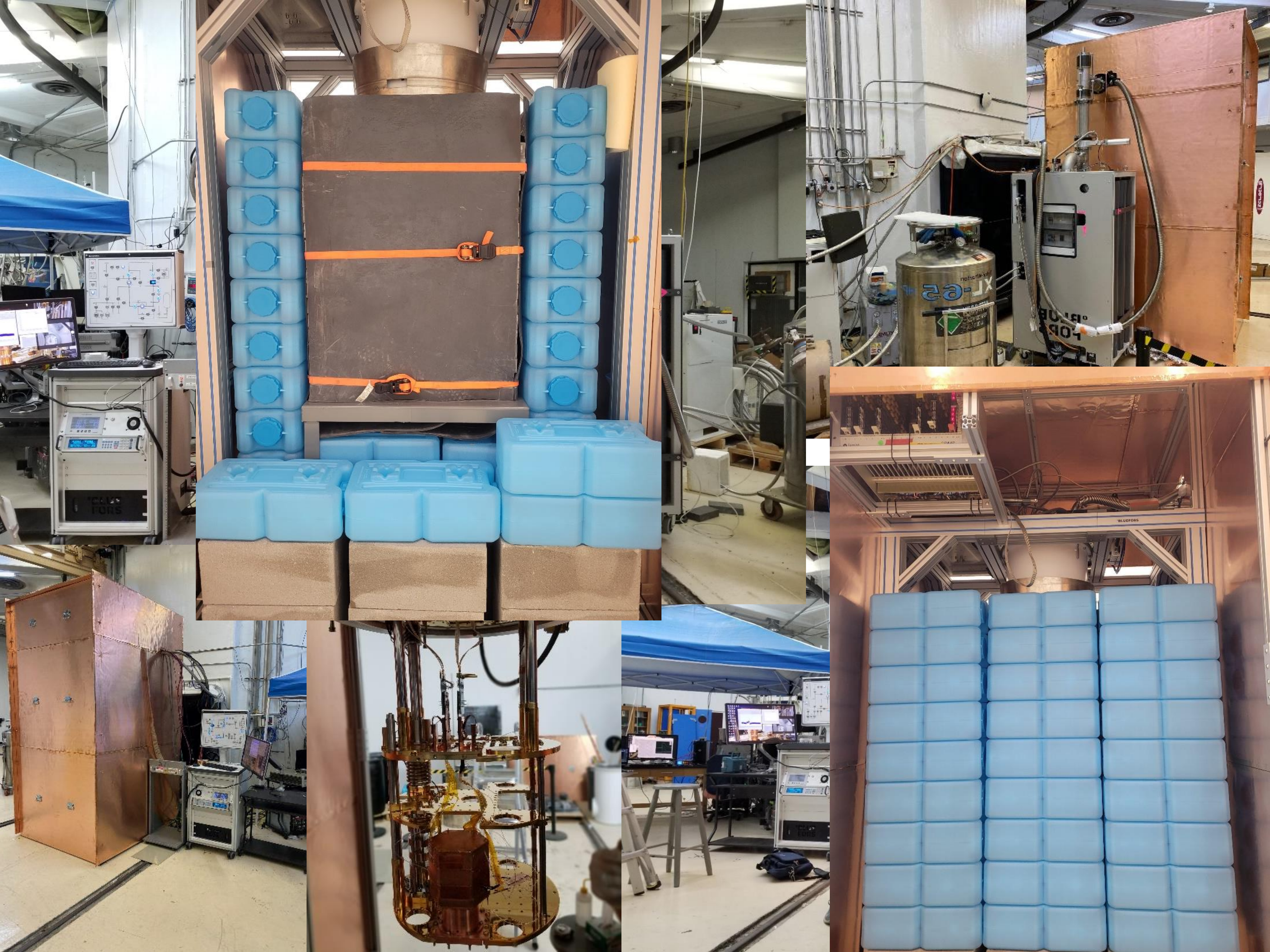




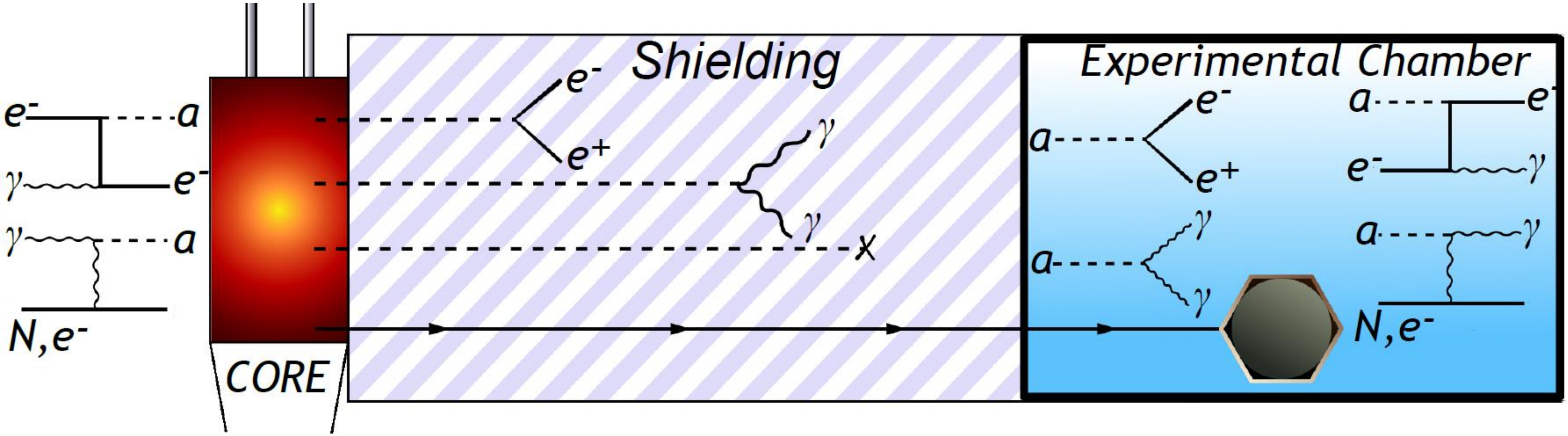


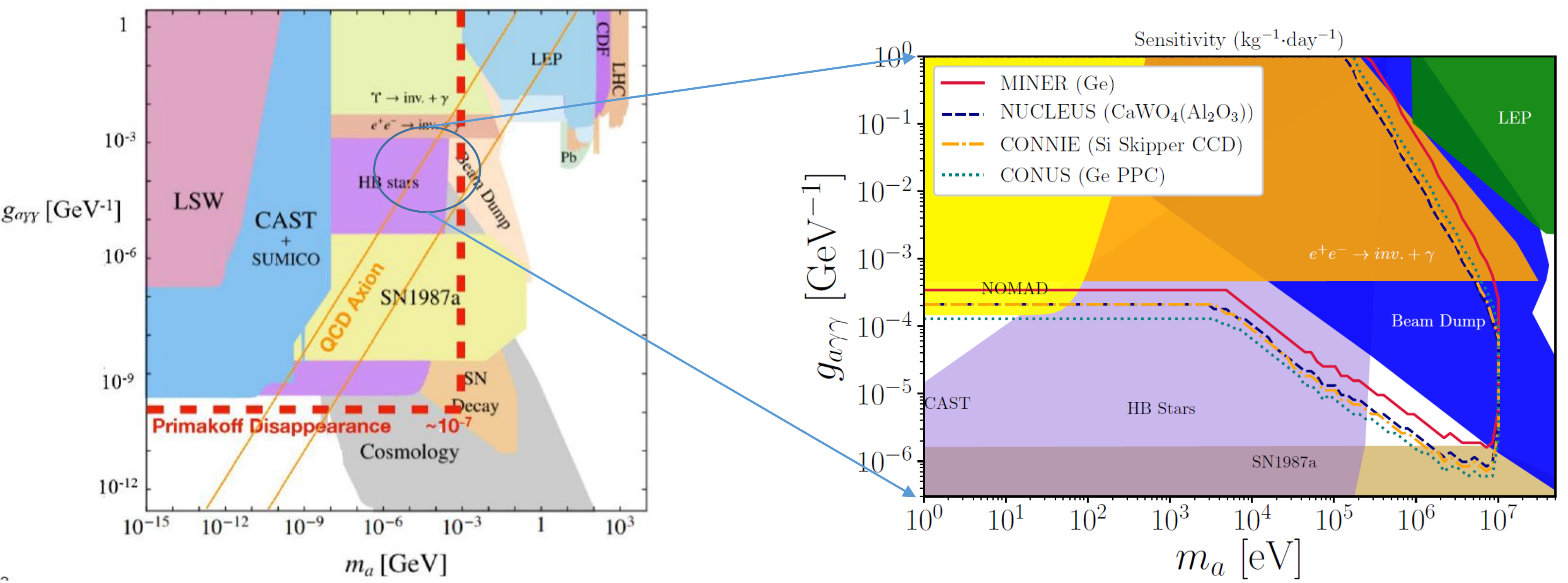


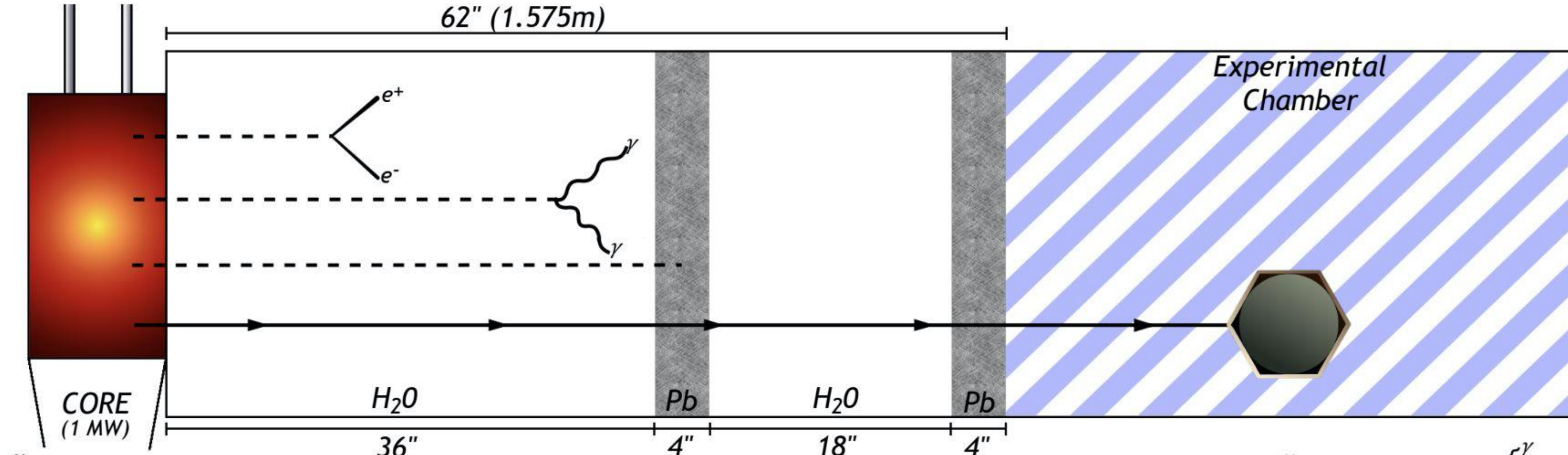
Inner copper shielding to for additional hermetic shielding being designed. Capable of hosting gm-kg scale detector

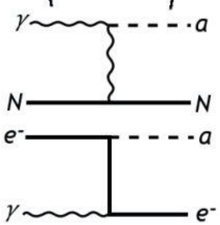


Axion Search on MINER from Reactor γ

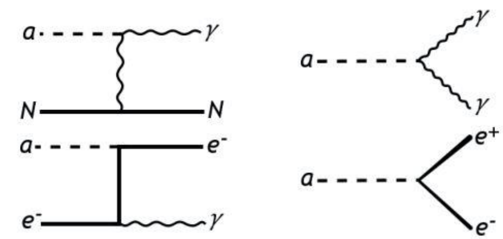








$$P_{surv} = \exp(-\frac{\ell_d m_a}{p_a \tau})$$



core-detector proximity

Survival probability

Detector length

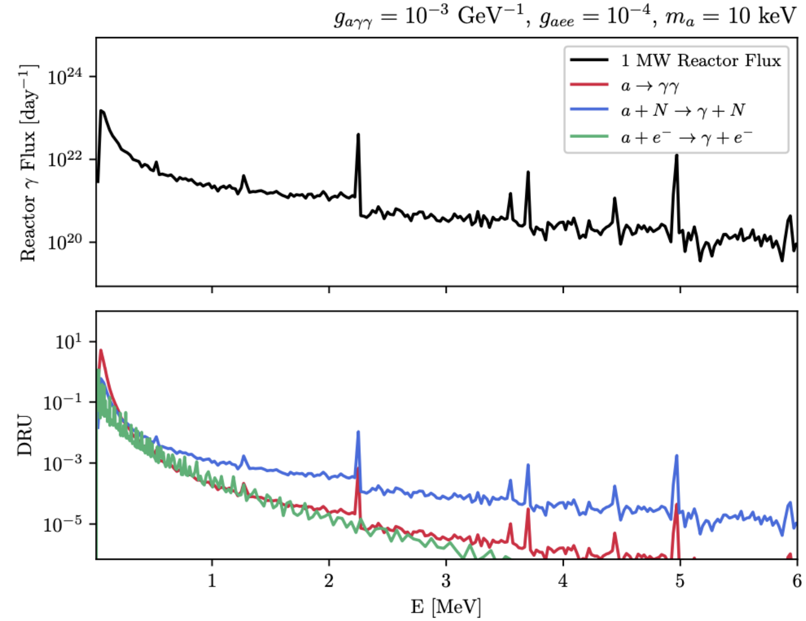
Shielding length

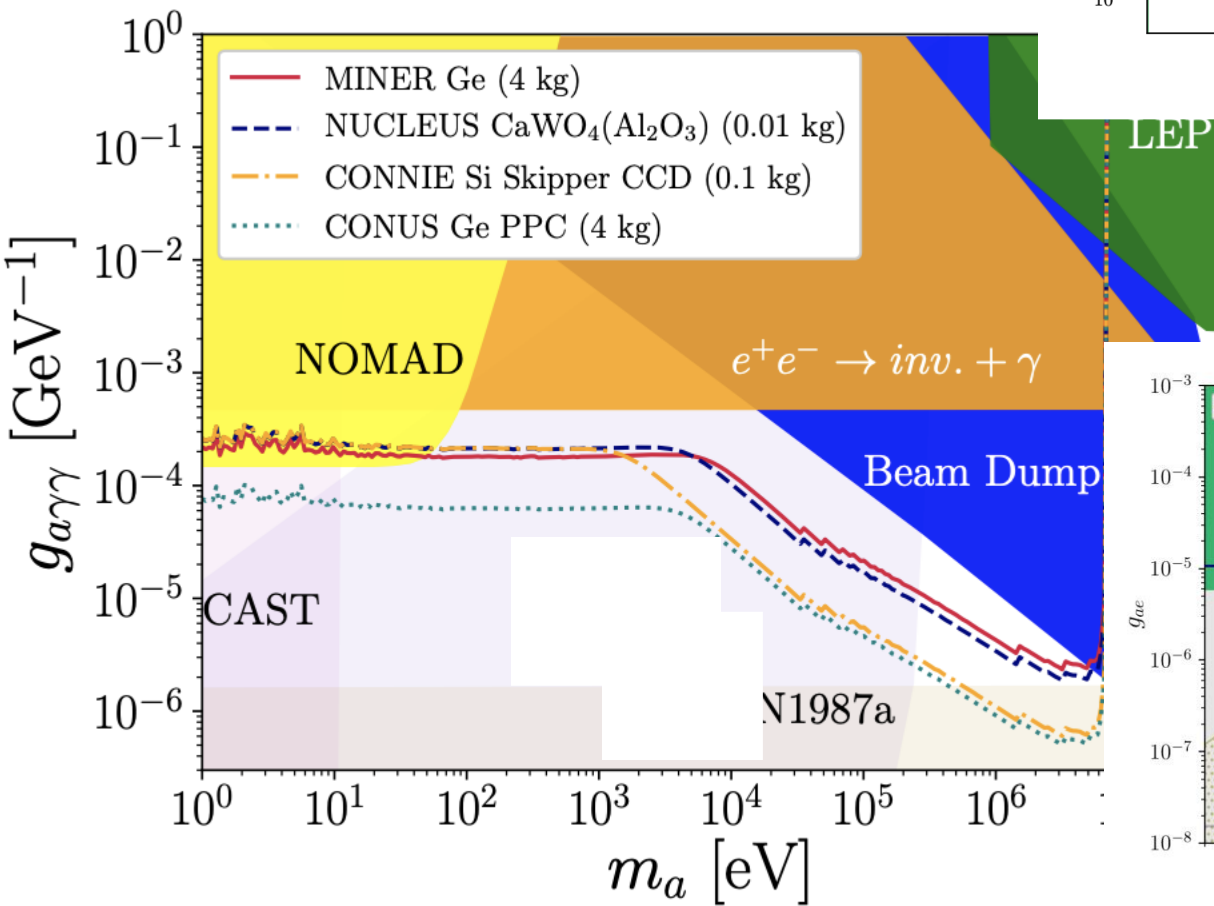
$$\Gamma(a \to \gamma\gamma) = \frac{g_{a\gamma\gamma}^2 m_a^3}{64\pi}$$

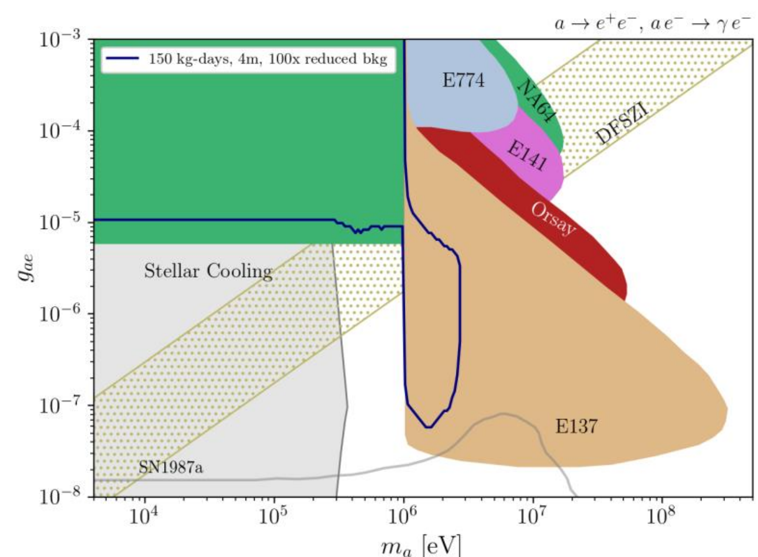
$$P_{decay} = e^{\frac{-\ell_s m_a}{p_a \tau}}(1 - e^{\frac{-\Delta\ell m_a}{p_a \tau}})$$

Bounds on couplings to photons

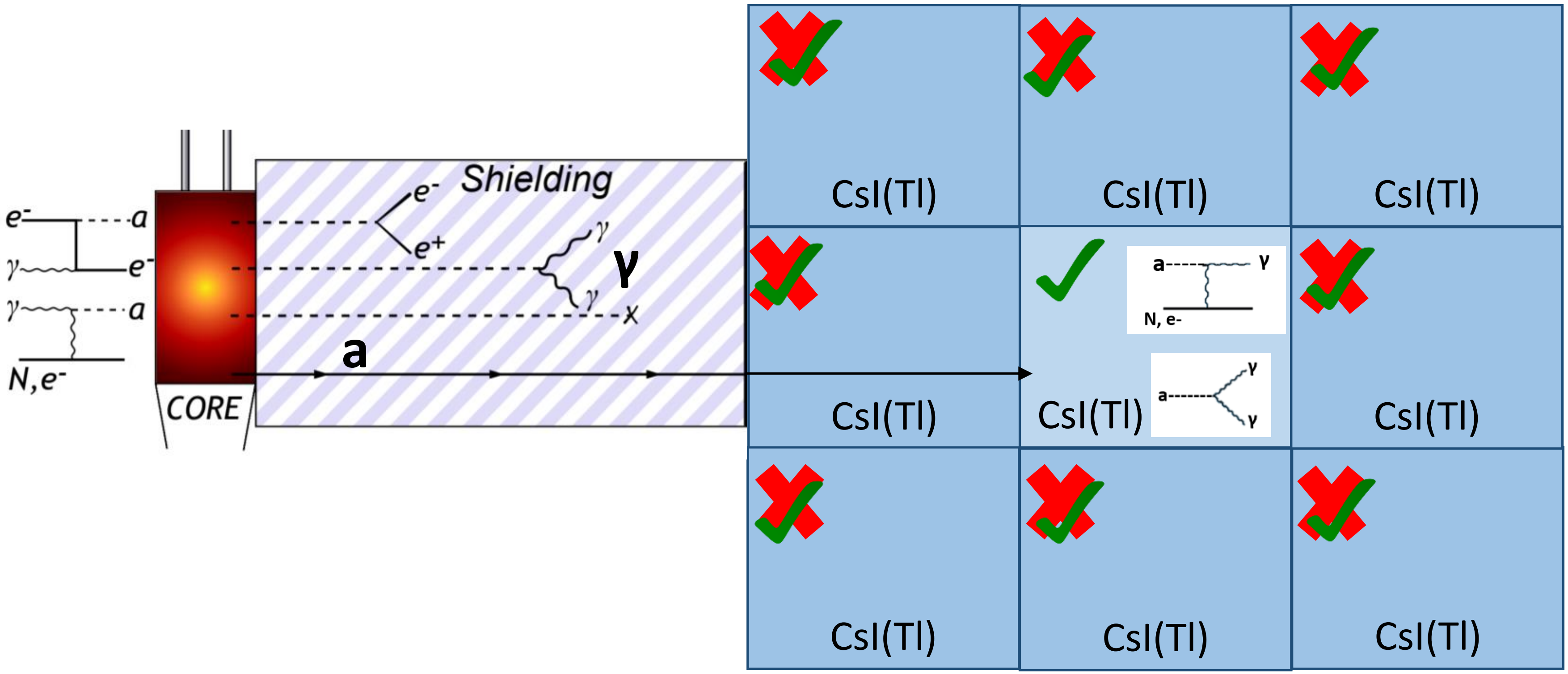
Experiment	Core Thermal Power	Core Proximity (m)	Bkg Rate in ROI (DRU)	Exposure (kg·days)
MINER (Ge)	1 MW	2.25	100	4000
ν-cleus ($CaWO_4$)	4 GW	40	100	10
CONNIE (Si CCD)	4 GW	30	700	100
CONUS (Ge PPC)	4 GW	17	100	4000



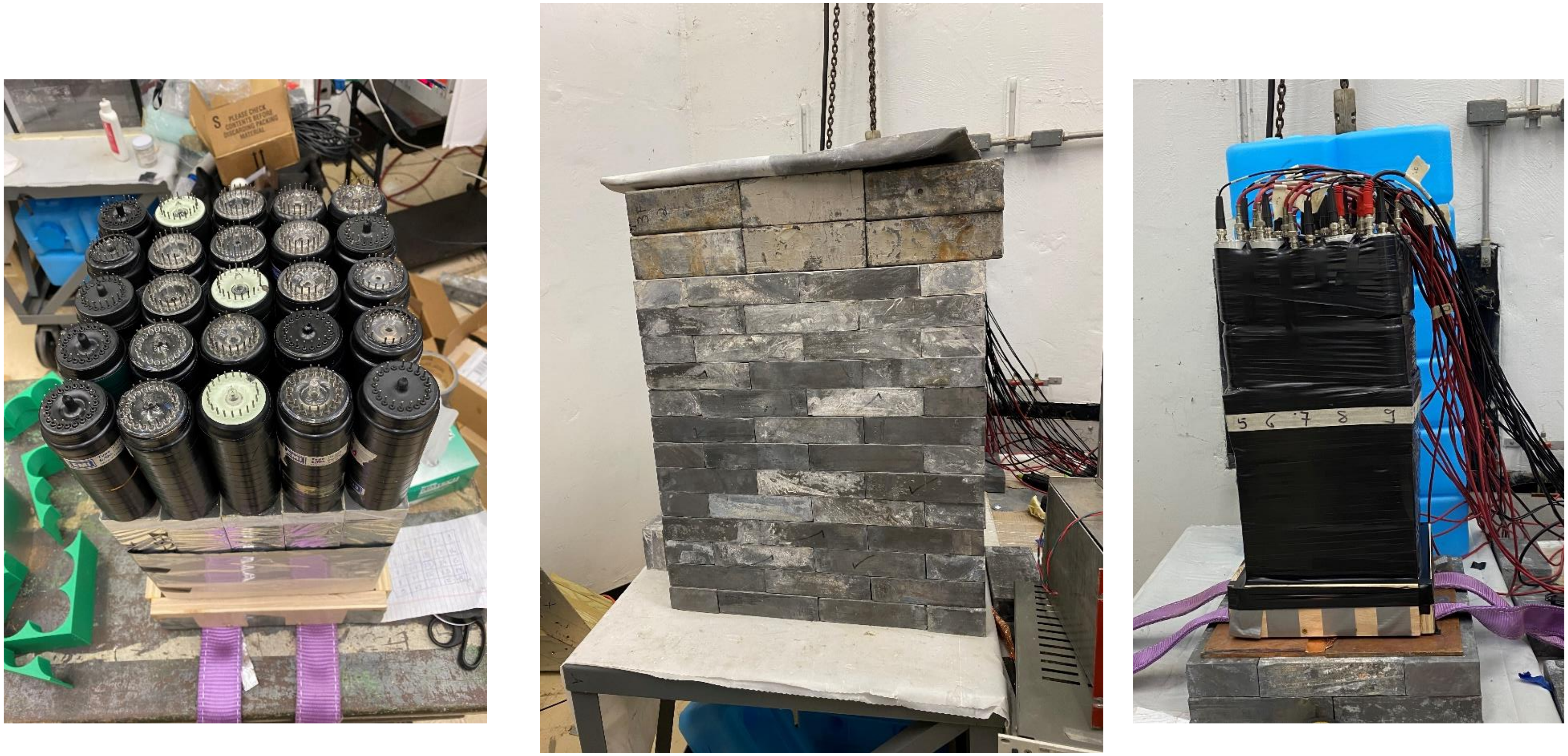




CsI(Tl) 100-kg prototype (room temp)



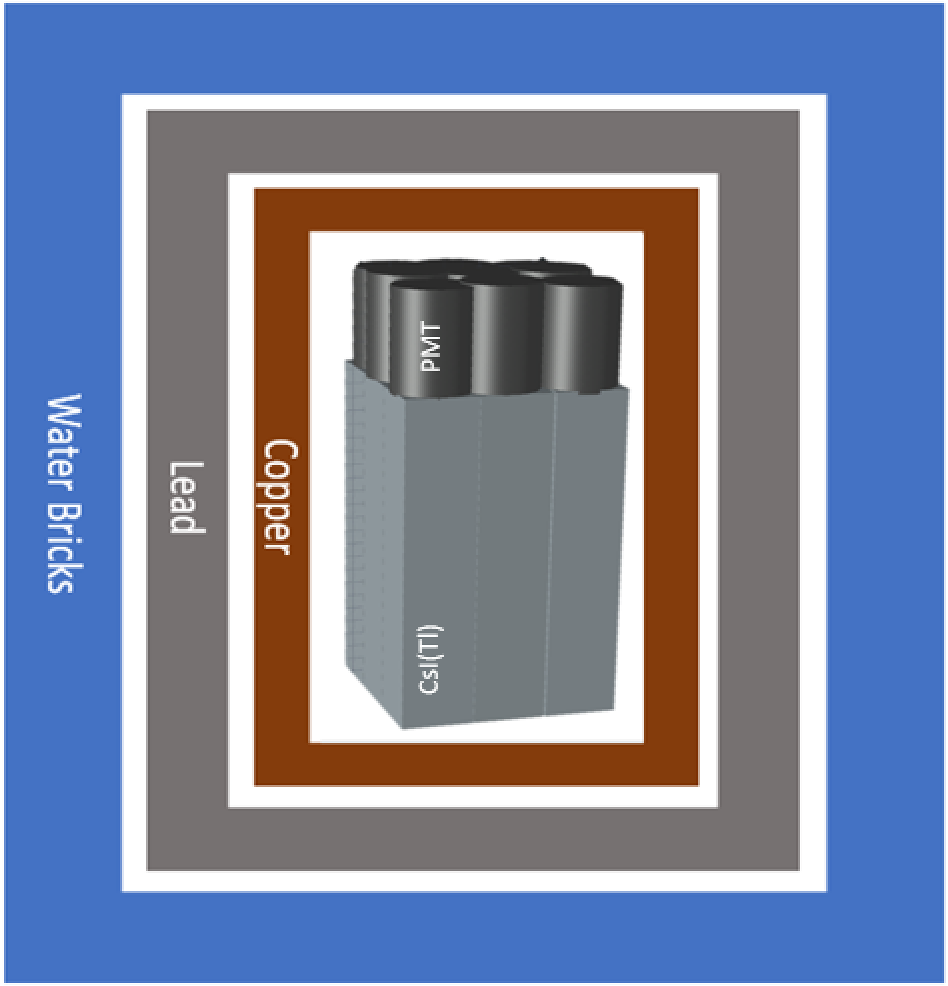
True Event: **Single Scatter event inside the inner CsI(Tl) crystal, without any of the surrounding crystals vetoing it.**



5x5 CsI(Tl) prototype setup is kept at a distance of approximately 4 meters from the reactor core at the MINER experiment.

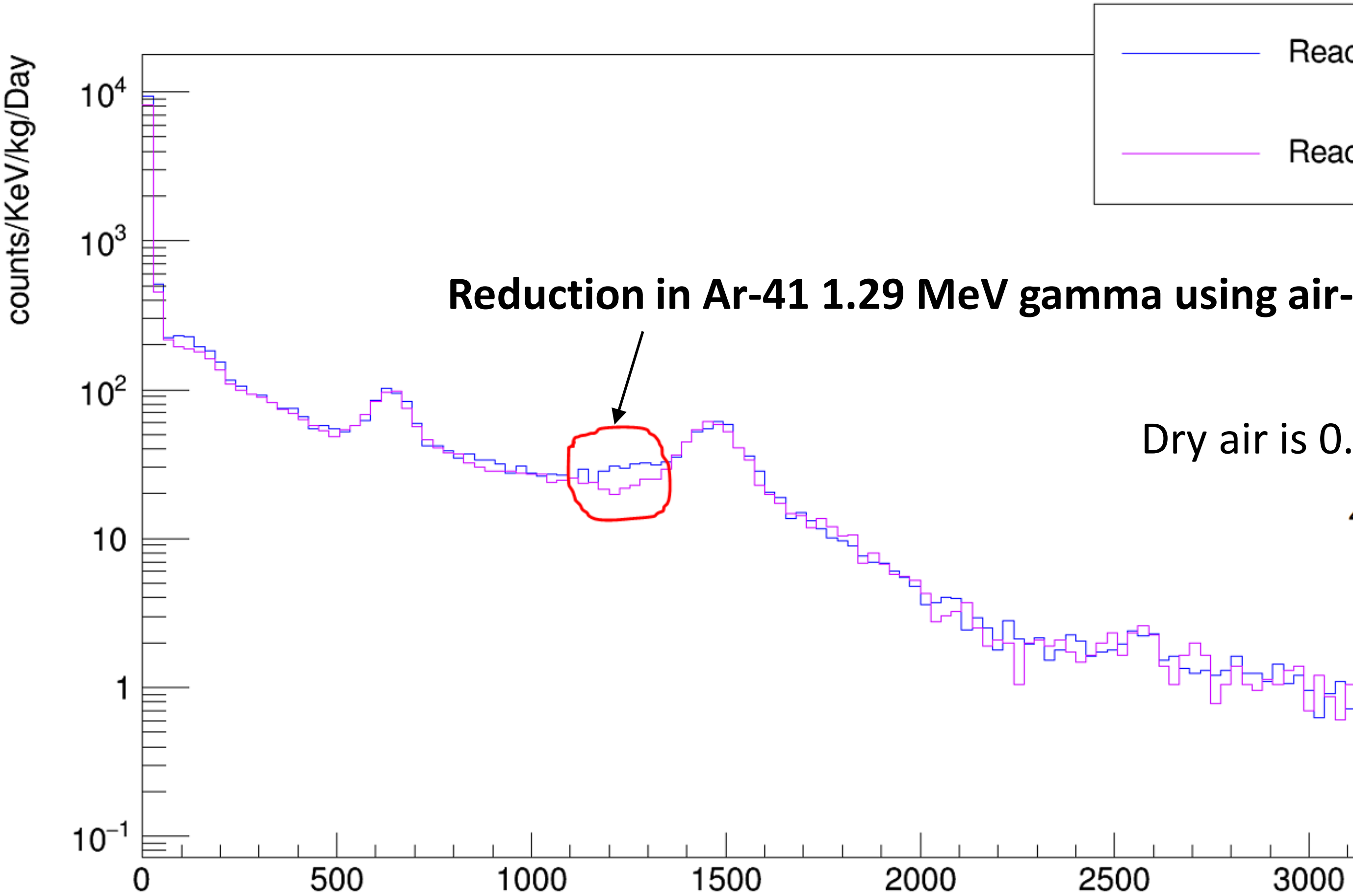
Shielding And Background Control (Passive Veto)

Shielding Across 3x3 CsI(Tl) Setup



- **4" lead is used as gamma shielding.**
- **1/4th inch copper housing to stop lower energy x-rays.**
- **Water bricks for neutron control.**

Ar-41 Reduction Using Air Purge



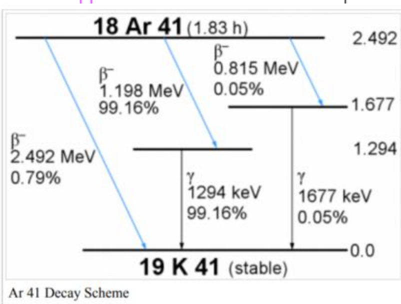
Reduction in Ar-41 1.29 MeV gamma using air-purge system

Dry air is 0.93% Ar, Ar is 99.6% Ar-40

$$^{40}Ar + n \rightarrow {}^{41}Ar + \gamma$$

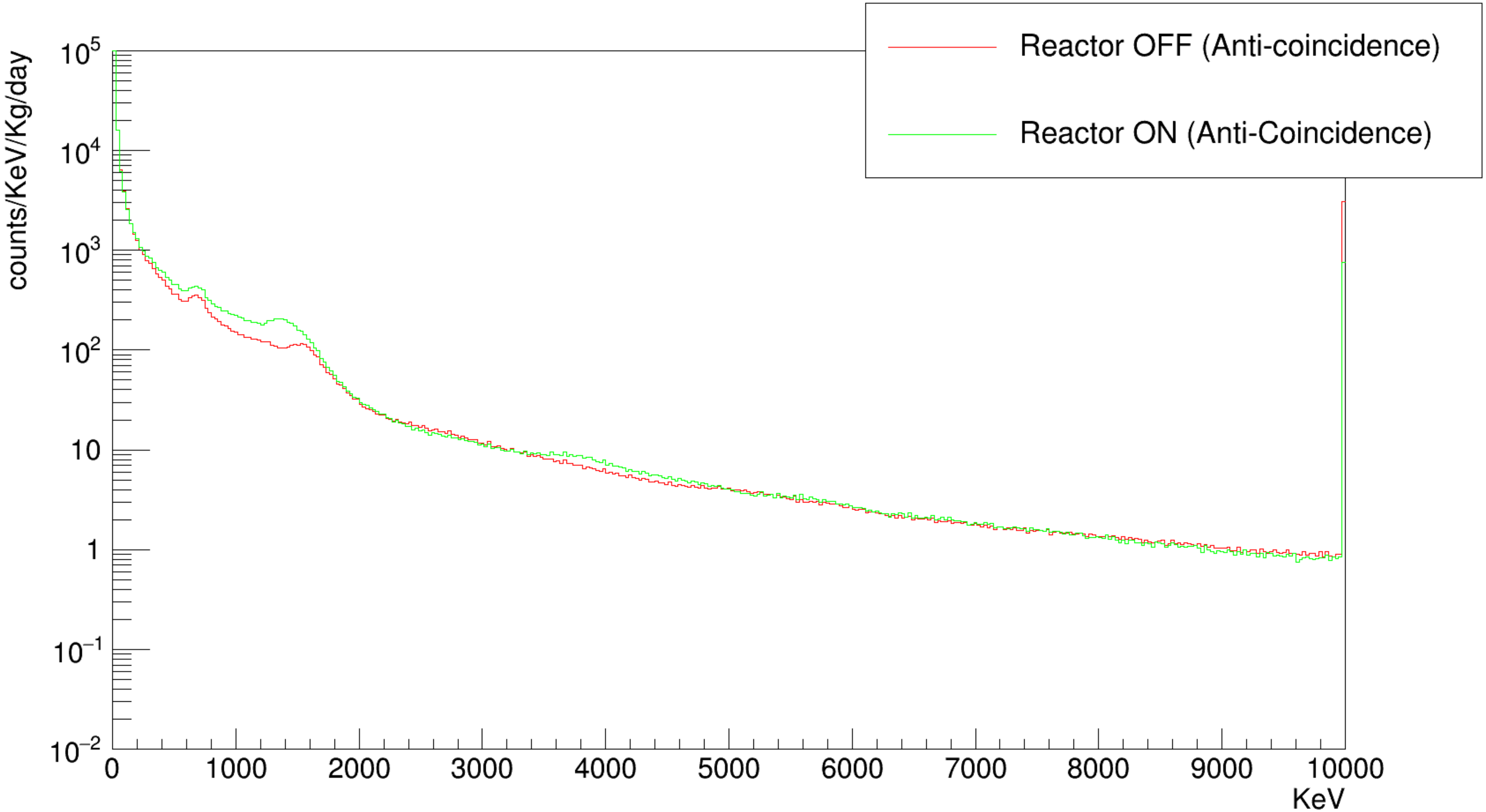
Half-life = 1.8 hours

Reactor ON with and without airpurge comparison.



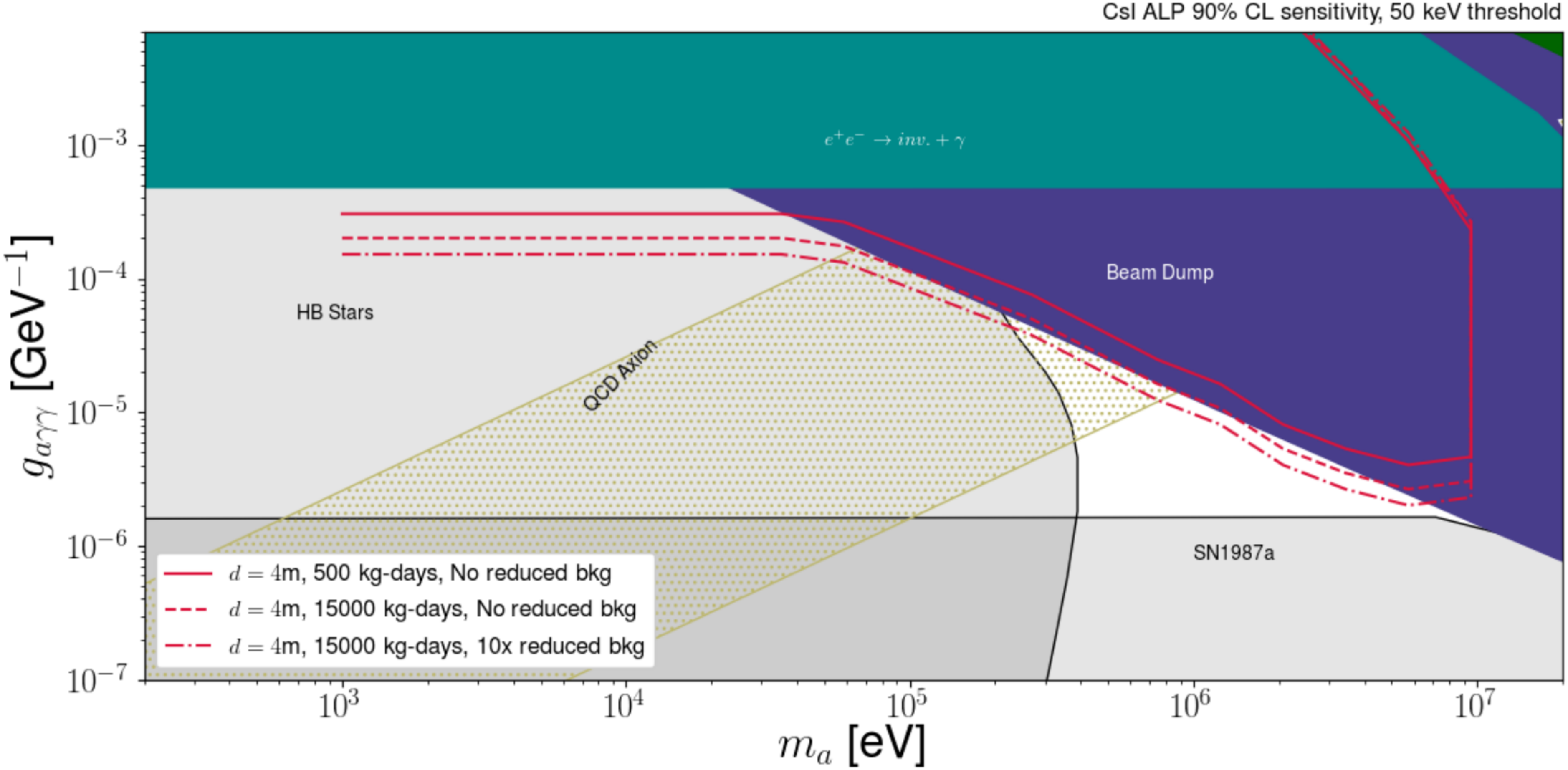
Ar-41 Decay

Background performance



Experimental Reach

Promising ALP Sensitivities (new 5x5 setup):

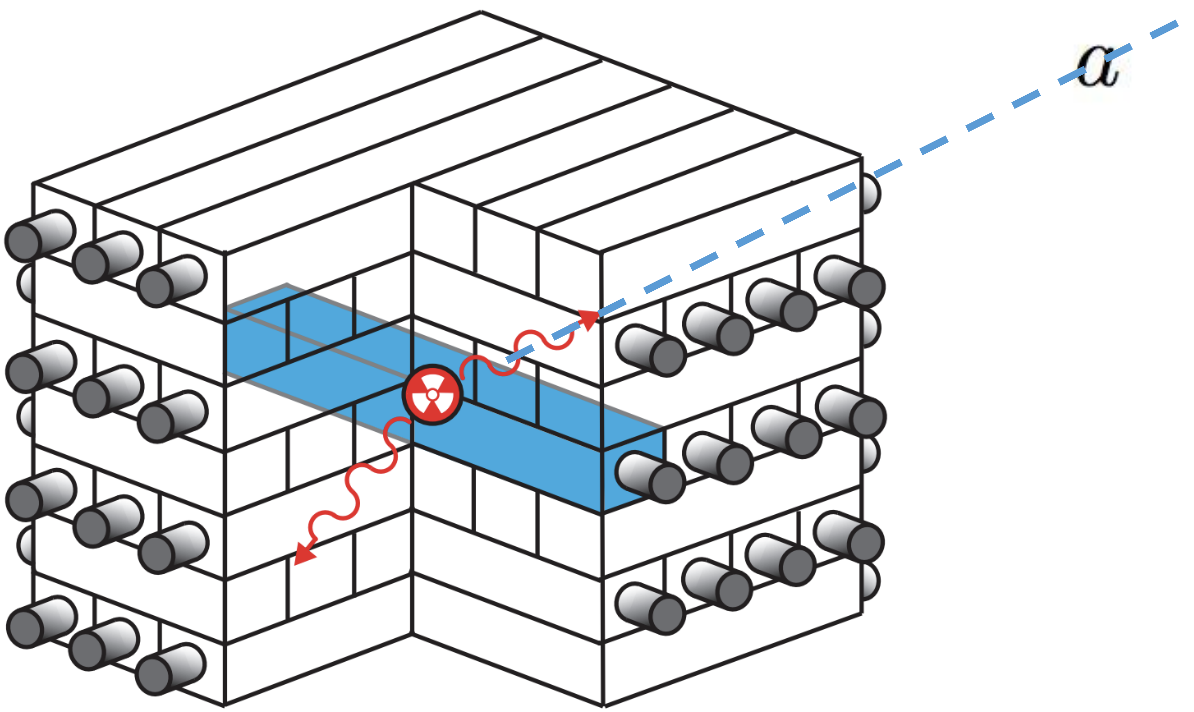


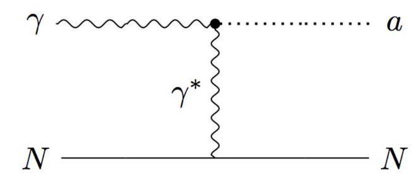
Work is in progress to scale up (have 2 tons of CsI) and reduce background by more shielding

Missing Energy Searches

JBD, B. Dutta, D. Kim, A. Kubik, R. Mahapatra, S. Rajendran, H. Ramani, A. Thompson, and S. Verma, PRD (2021)

ALP Search via Missing Gamma in Nuclear Decays





Disappearance signal from ALP processes with nucleon and photon couplings

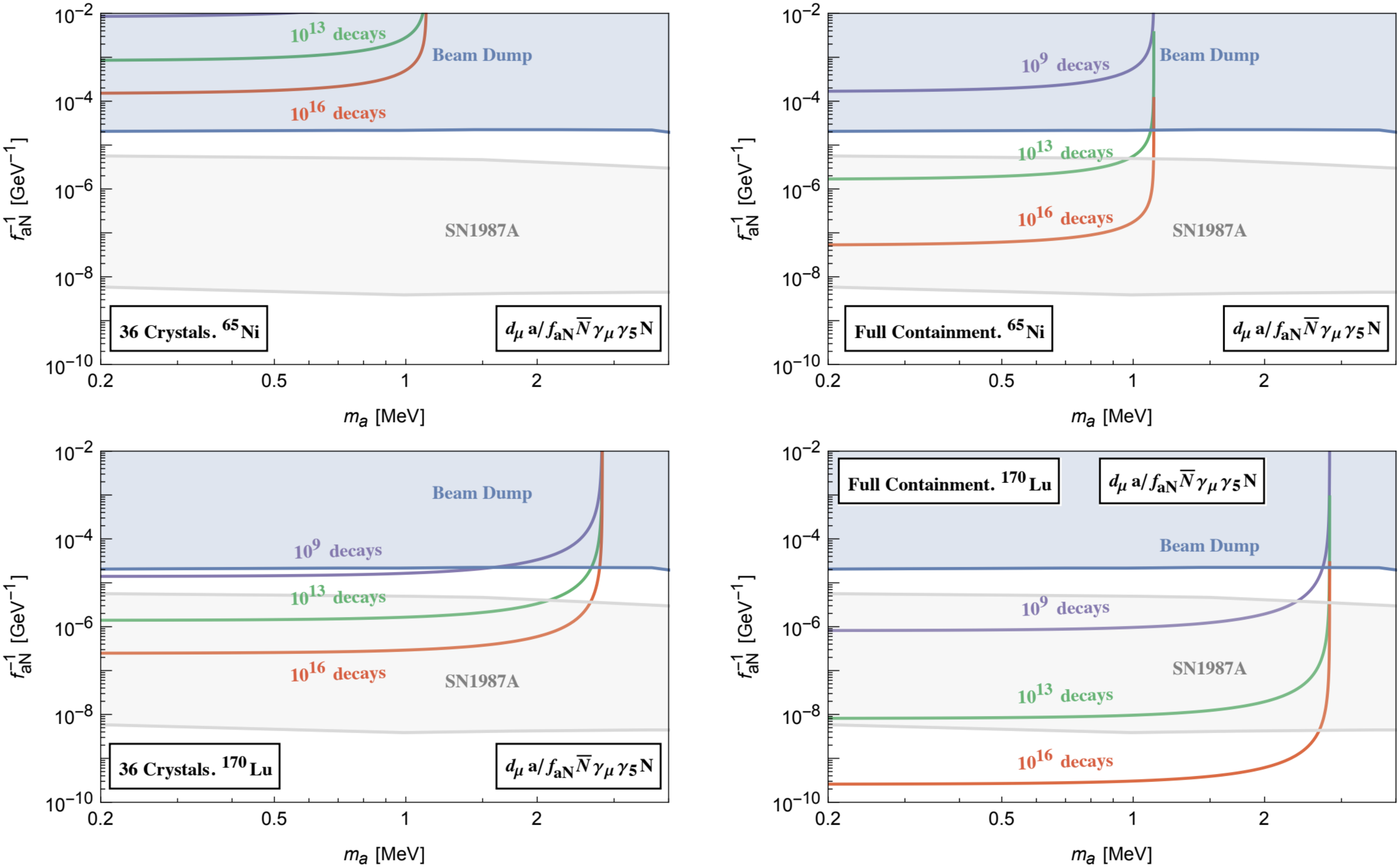
Model	$\mathcal{L}_{\text{int}}$	Transition	BR_{miss}
Scalar (nucleon coupling)	$g_p \phi \bar{N} N$	E_2	$\frac{g_p^2}{2e^2}\left(1-\frac{m_\phi^2}{\omega^2}\right)^{\frac{5}{2}}$
		E_0	$\frac{8\pi\omega^5}{\alpha\kappa(\omega,m_e)}\frac{g_p^2}{e^2}\left(1-\frac{m_\phi^2}{\omega^2}\right)^{\frac{5}{2}}$
Dark Photon	$\epsilon F^{\mu\nu} F'_{\mu\nu}$	E_2	$\epsilon^2\left(1-\frac{m_\phi^2}{\omega^2}\right)^{\frac{5}{2}}$
		E_0	$\frac{8\pi\omega^5}{\alpha\kappa(\omega,m_e)}\epsilon^2\frac{m_{A'}^2}{\omega^2}(1-\frac{m_{A'}^2}{\omega^2})^{\frac{5}{2}}$
Milli-charged Particle	$-Q\bar{\chi}\gamma^\mu A_\mu \chi$	E_2	$Q^2\frac{25\alpha}{9}\frac{\kappa(\omega,m_Q)}{\omega^5}$
		E_0	$Q^2\frac{\kappa(\omega,m_Q)}{\kappa(\omega,m_e)}$
ALP (nucleon coupling)	$f_{aN}^{-1}\partial_\mu a \bar{N}\gamma^\mu\gamma^5 N$	M_1	$0.13\left(\frac{\text{GeV}}{f_{aN}}\right)^2\left(1-\frac{m_a^2}{\omega^2}\right)^{\frac{3}{2}}$
		M_0	$\frac{50}{9\alpha}\frac{\text{GeV}}{f_{aN}}\frac{\left(\omega^2-m_a^2\right)^{\frac{5}{2}}}{\omega^5}$
ALP (photon coupling)	$\frac{1}{4f_{a\gamma}} a F_{\mu\nu}\tilde{F}^{\mu\nu}$	E_2/M_1	$\frac{\sigma_P}{\sigma_P+\sigma_{SM}}(1-e^{-\ell/\lambda})$

Candidate	$\tau_{\frac{1}{2}}$	$E_2 < E_1$?	$E_{\rm probe}$[MeV]	$E_{\rm trigger}$[MeV]
^{207}Bi	31 year	Yes	0.57	1.06
^{60}Co	30 years	No	1.33	1.17
^{46}Sc	83 day	Yes	0.89	1.12
^{48}V	16 day	Yes	0.98	1.31
^{48}Sc	43.6 hr	Yes	0.98	1.04 or 1.31
^{24}Na	15 hr	Yes	1.37	2.75

E2

Candidate	$\tau_{\frac{1}{2}}$	multipole	$E_{\rm probe}$[MeV]
^{65}Ni	2.5 hour	M_1	1.11
^{90}Nb	14.6 hour	E_0	1.80
^{170}Lu	2 day	M_0	2.82

not E2


36 Crystals. ^{65}Ni
Full Containment. ^{65}Ni
36 Crystals. ^{170}Lu
Full Containment. ^{170}Lu
$d_\mu a/f_{aN}\overline{N}\gamma_\mu\gamma_5 N$
Beam Dump
SN1987A
10^9 decays
10^{13} decays
10^{16} decays
f_{aN}^{-1} [GeV^{-1}]
m_a [MeV]

Summary

Reactor searches for ALPs carving out new parameter space due to high reactor flux

Missing gamma search – nuclear couplings competitive with astro limits, include Primakoff effect for disappearance