2025/06/03

Low Background Techniques

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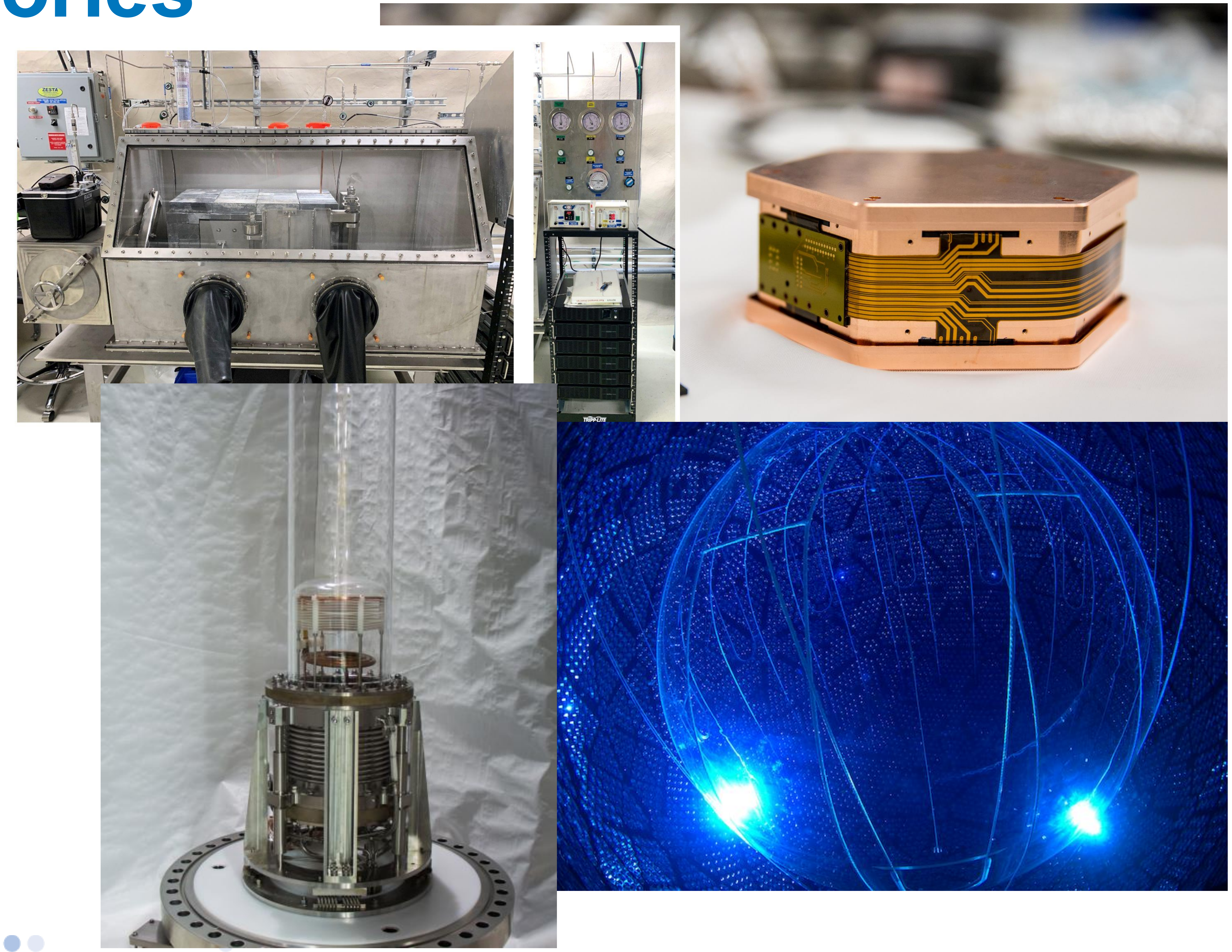
SNOLAB

Set the Stage

World Class Science is Done in Underground Laboratories

- Neutrino Physics
- Double Beta Decay
- Dark Matter
- Nuclear Astrophysics
- Quantum Technology
- Rare Processes
- Geophysics
- Gravitational Waves
- General Relativity
- Underground Biology
- Nuclear Security
- ….



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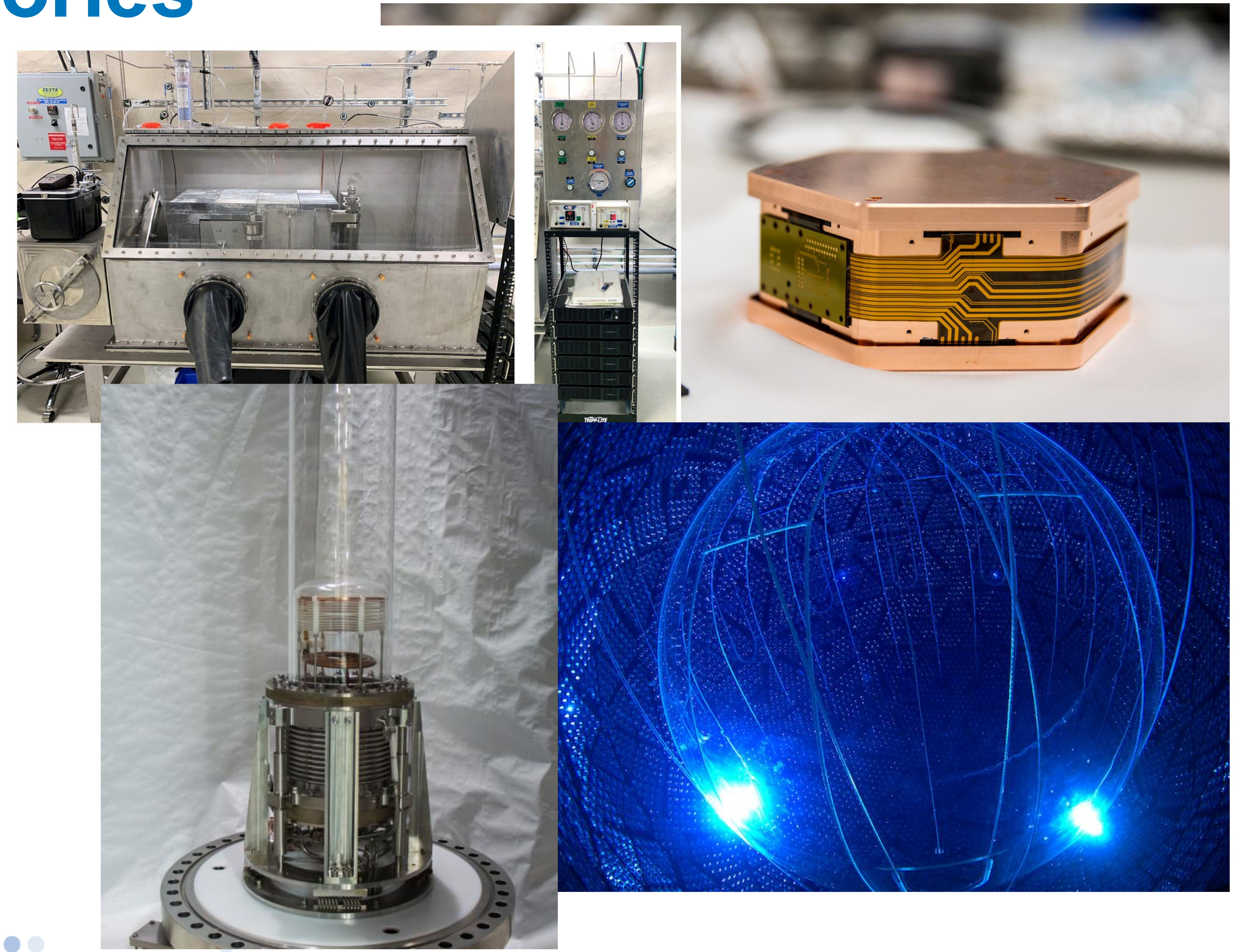
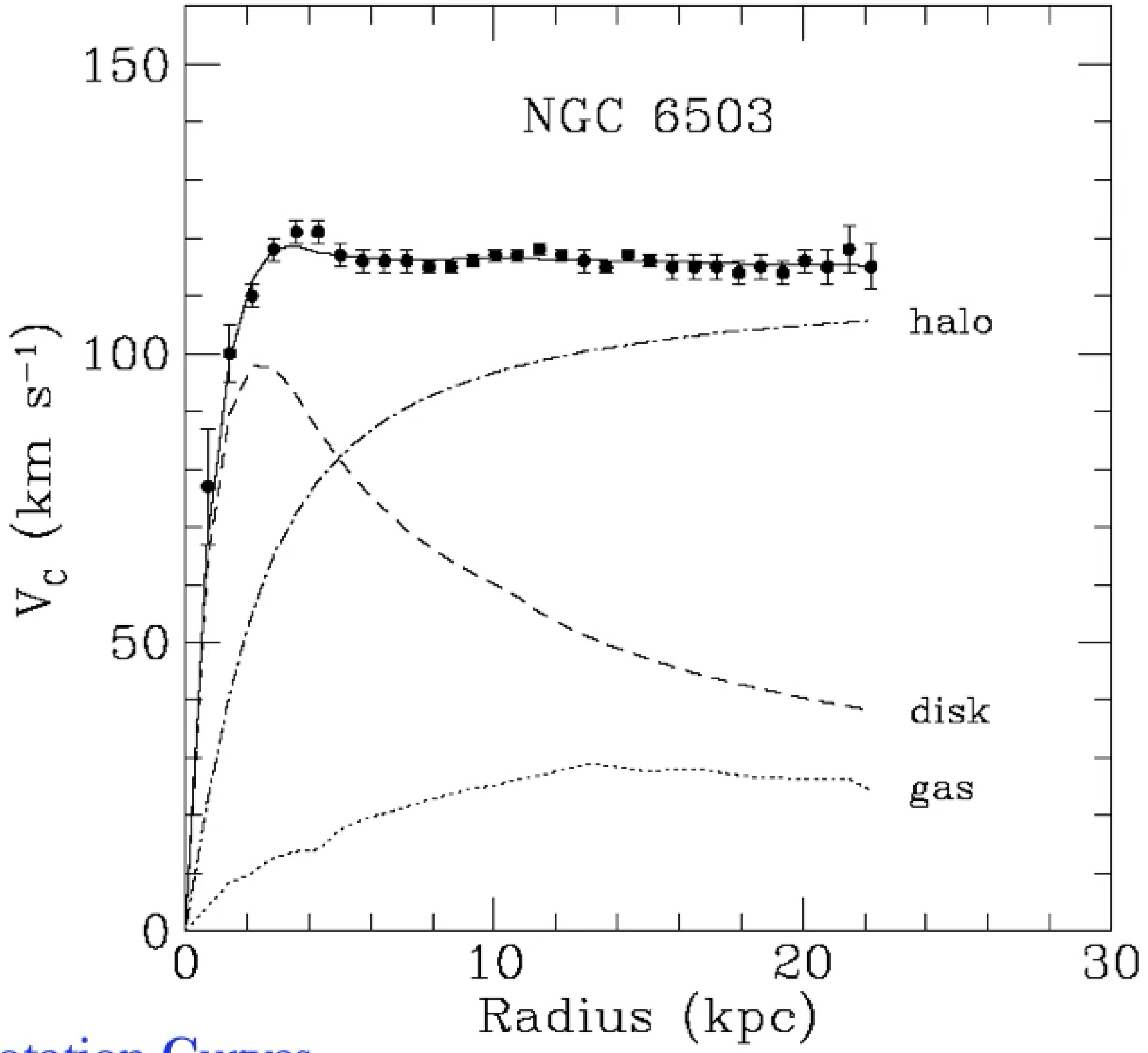
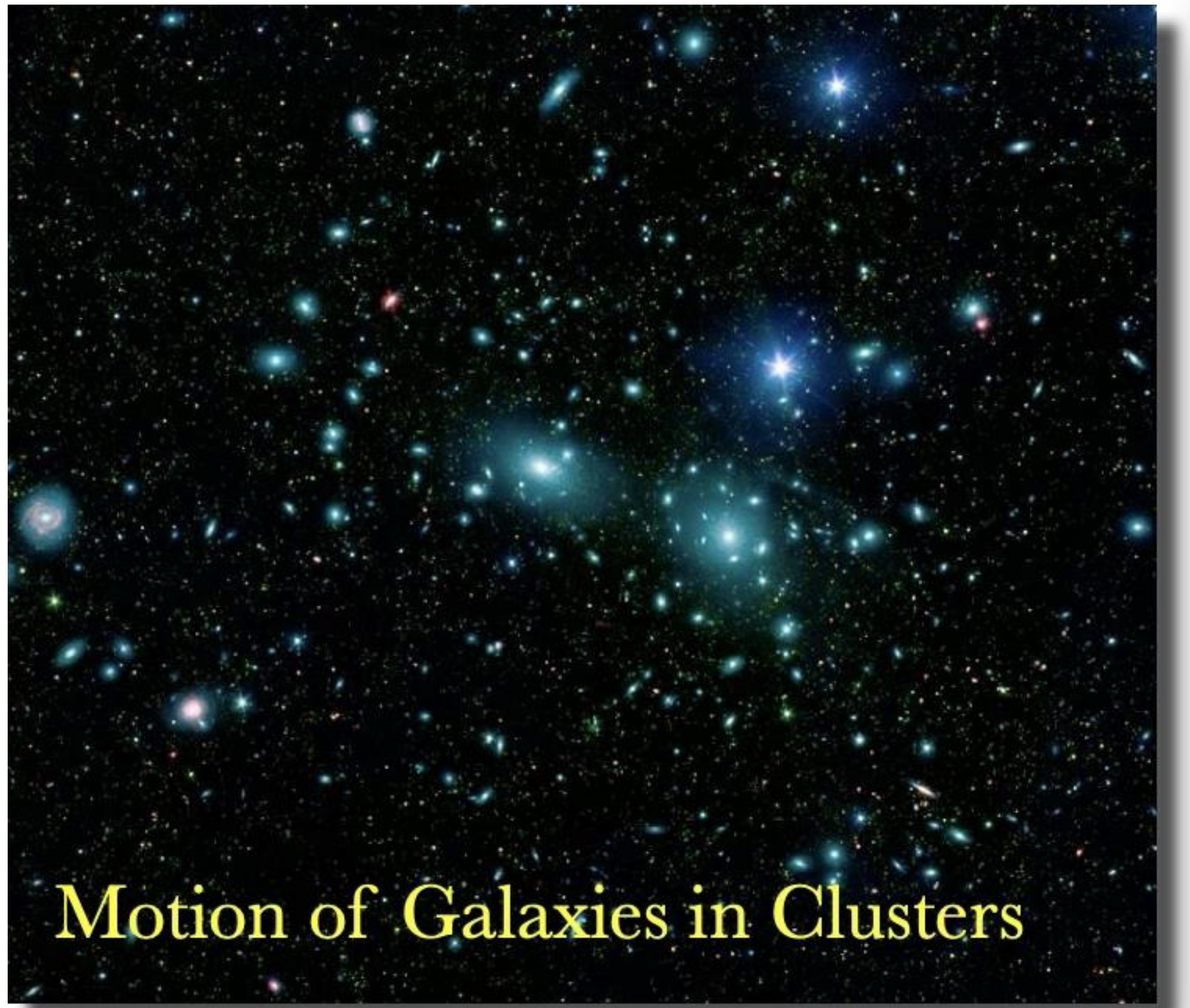


Dark Matter in a Nutshell



Rotation Curves

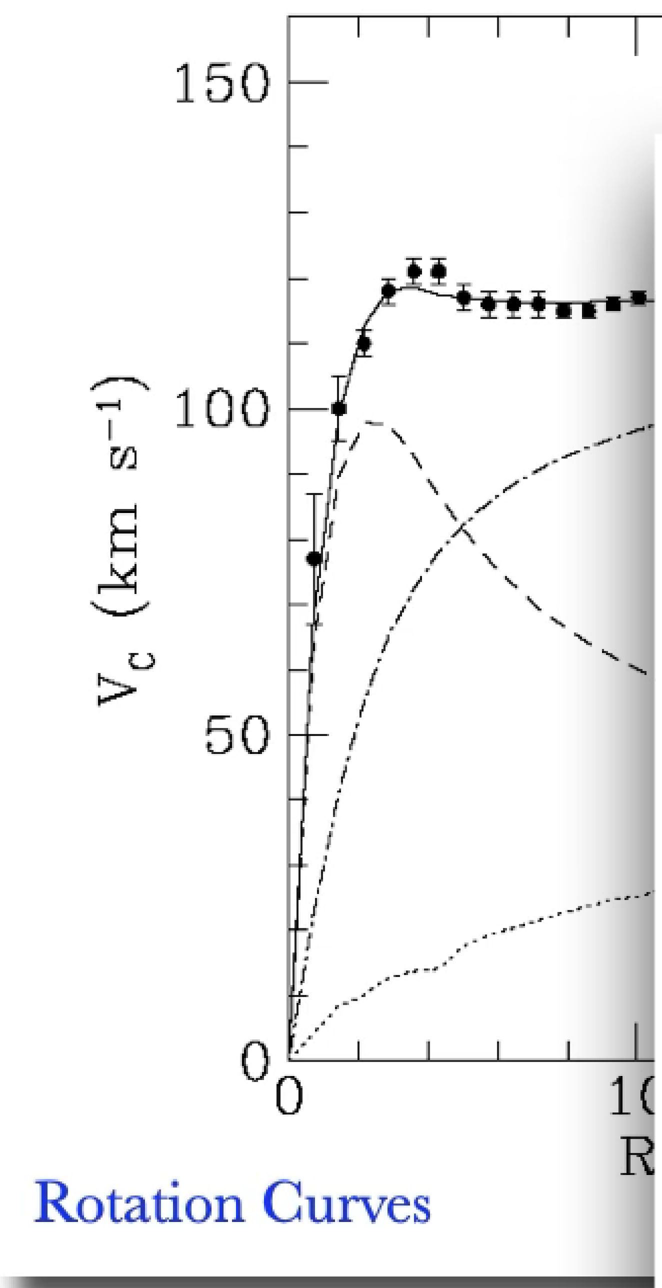


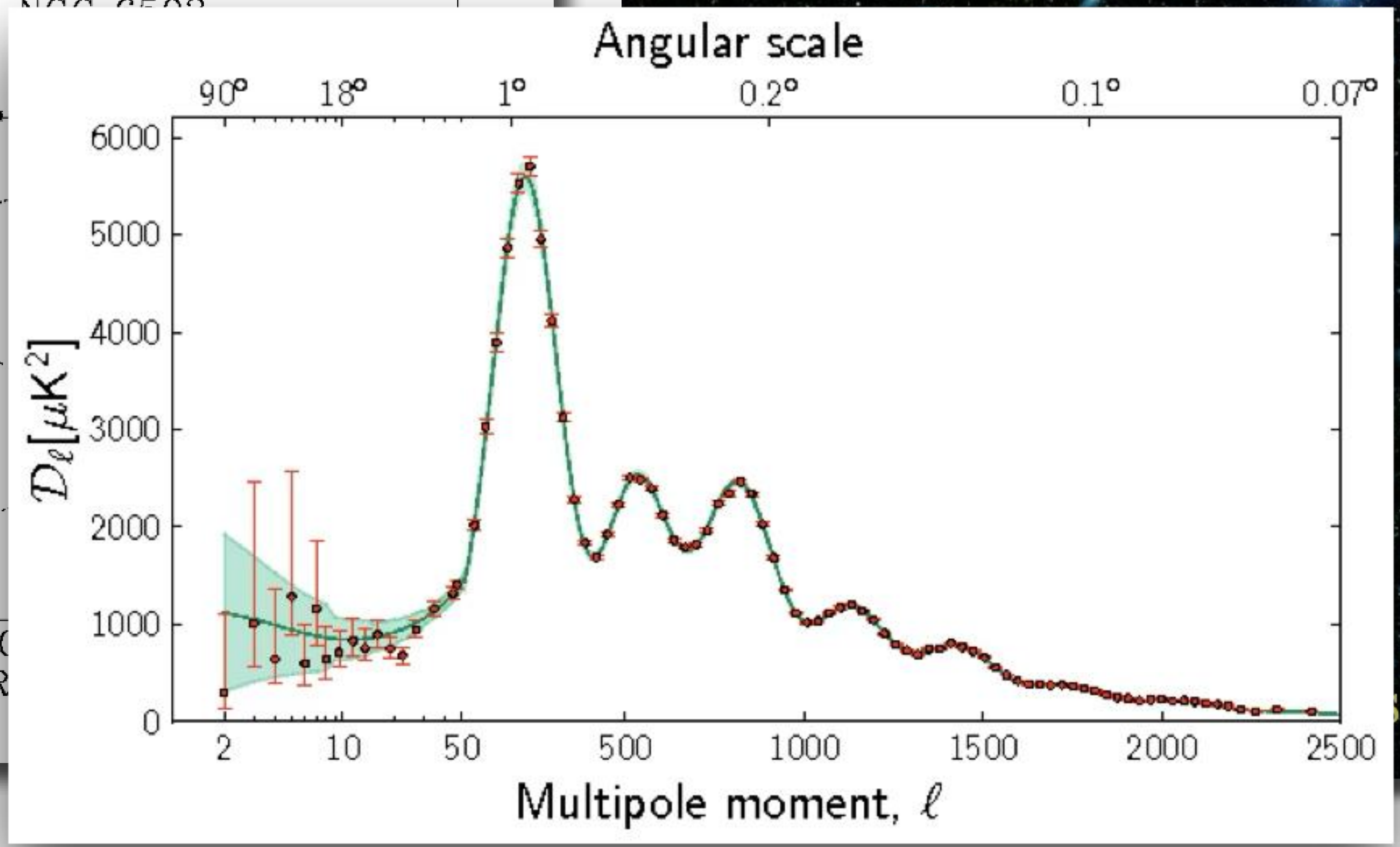
Motion of Galaxies in Clusters

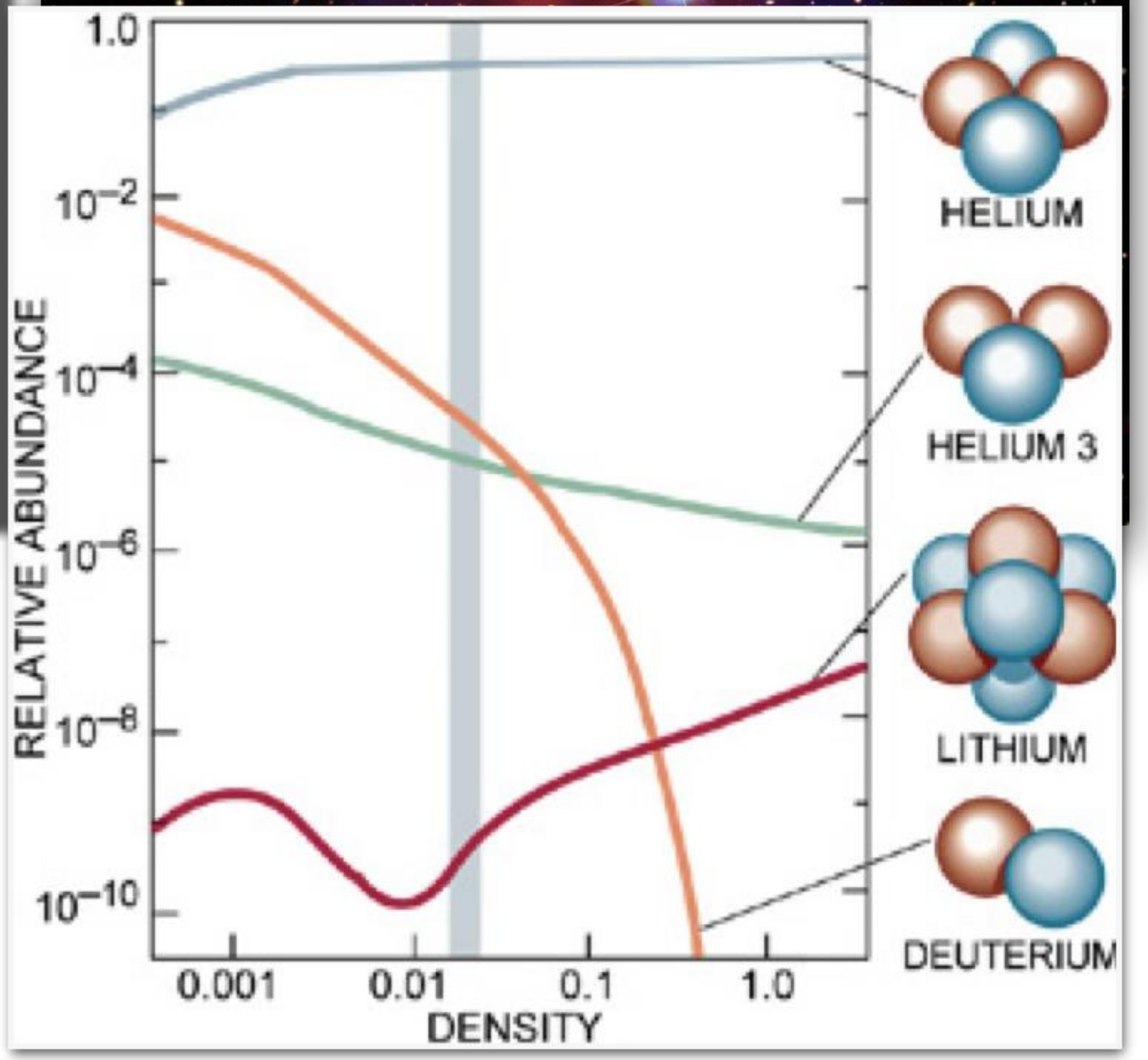
Galaxy Cluster Collisions

From the dynamics of galaxies (and larger structures)…

Dark Matter in a Nutshell





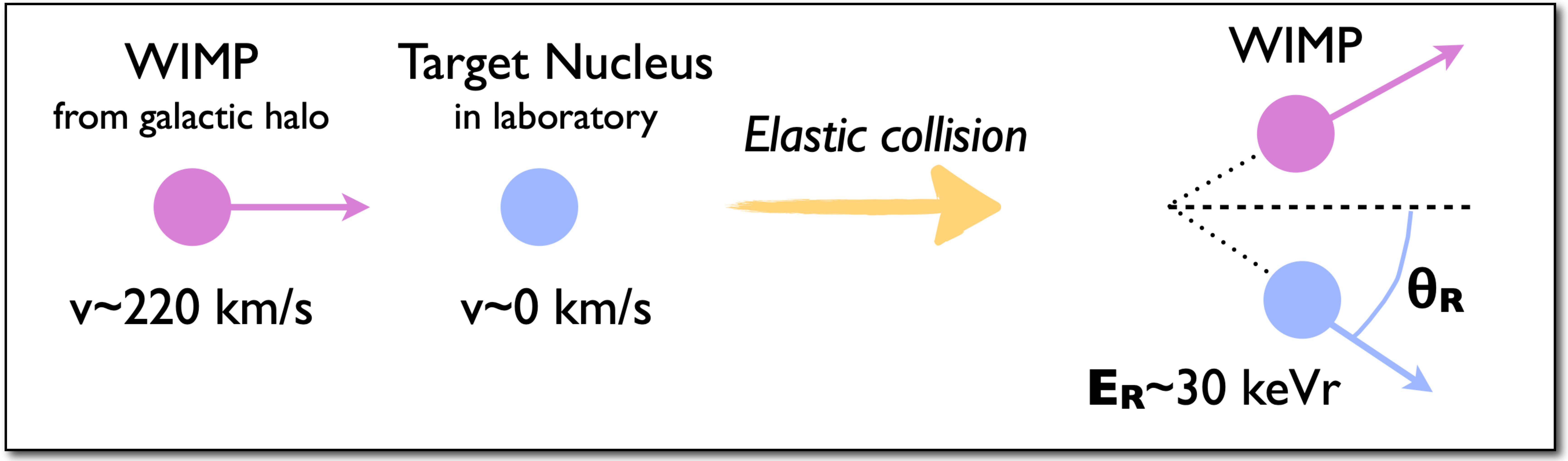


And from evidence left over from the formation of the universe itself


Ordinary Matter
4.9%
Dark Matter
26.8%
Dark Energy
68.3%

Direct Detection Event Rates

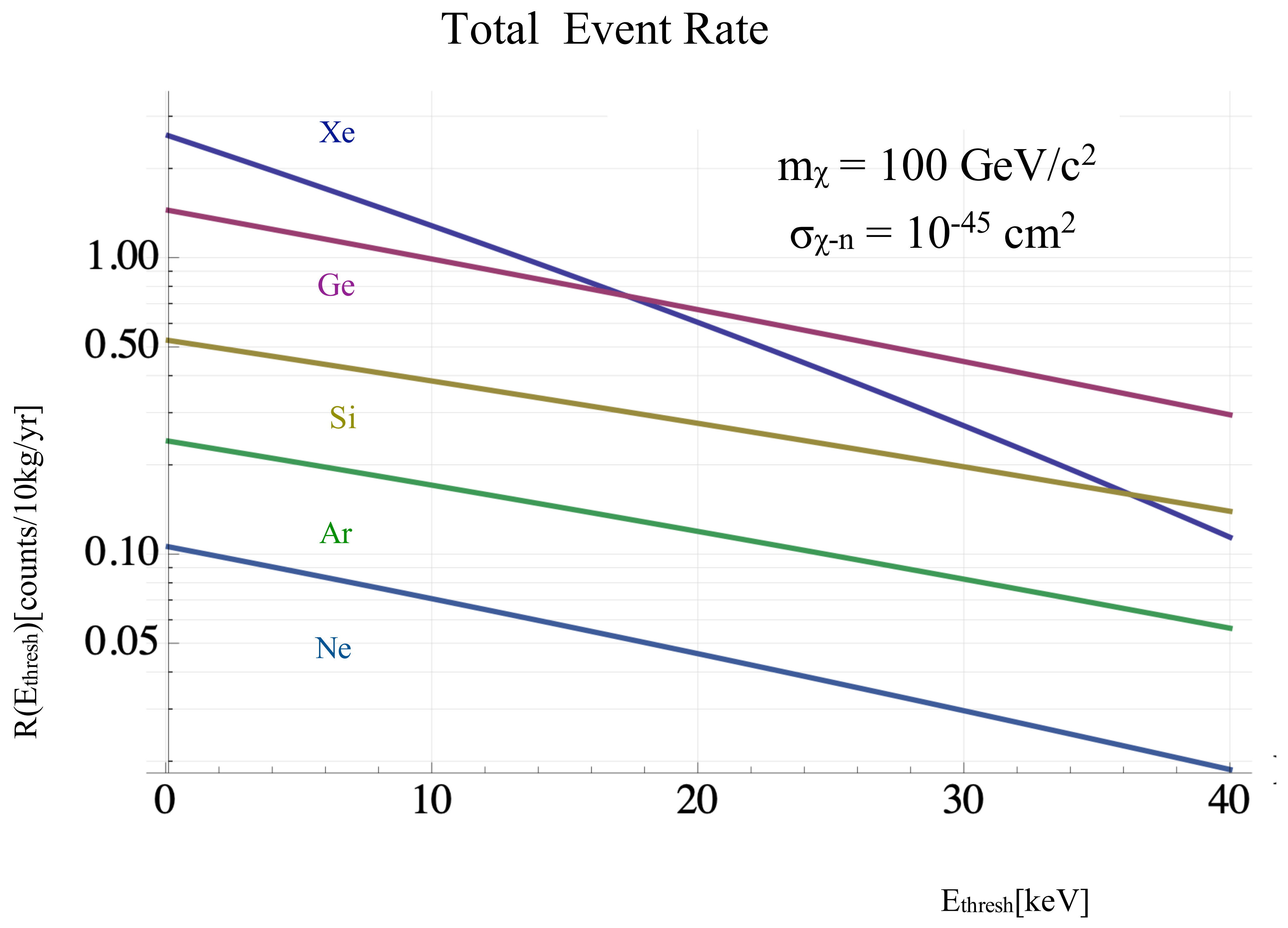
Assume that the dark matter is not only gravitationally interacting (WIMP).



- Elastic scatter of a WIMP off a nucleus
  - Imparts a small amount of energy in a recoiling nucleus
  - Can occur via spin-dependent or spin-independent channels
  - Need to distinguish this event from the overwhelming number of background events

Event Rates are Extremely Low!

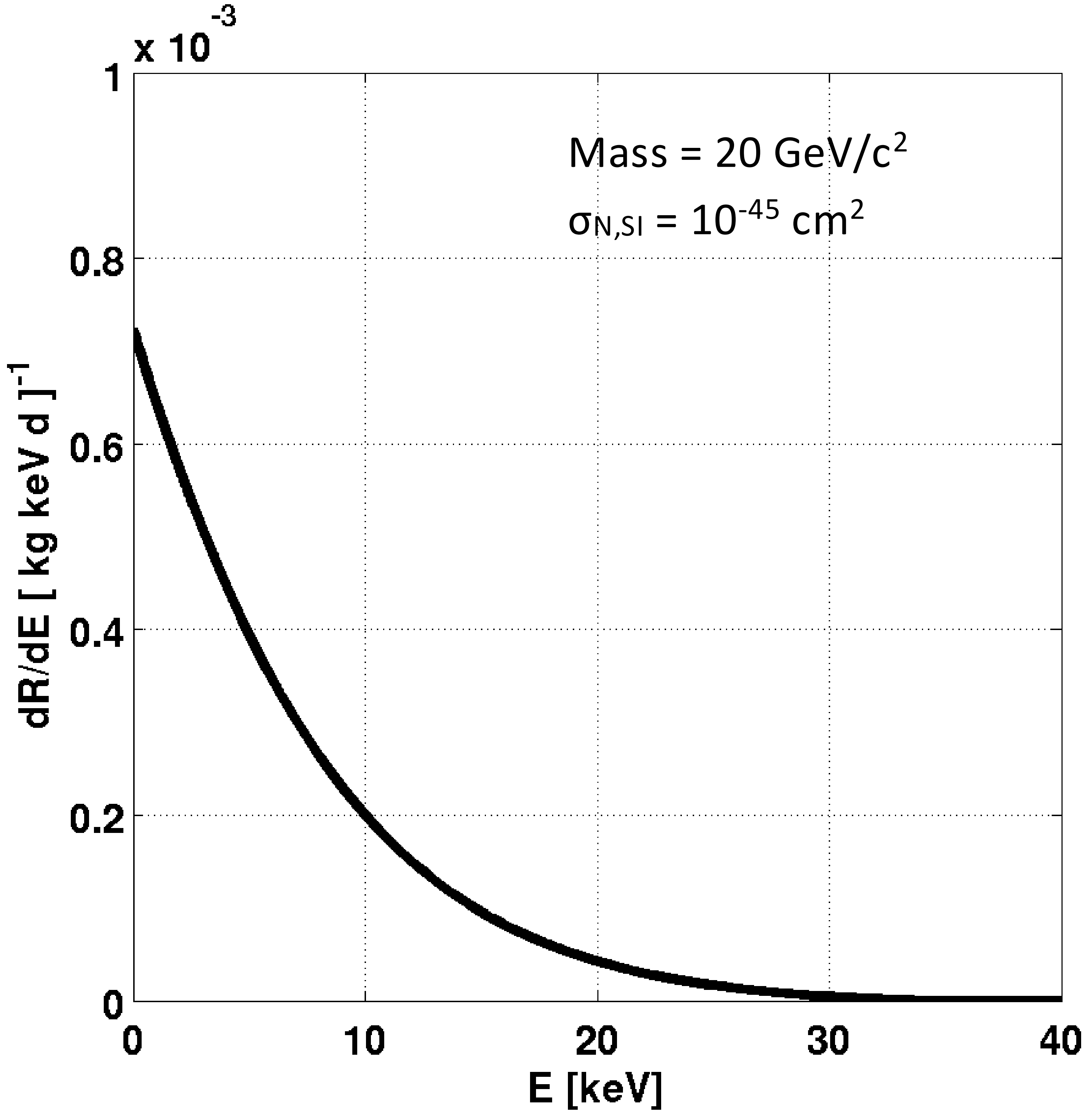
- Elastic scattering of WIMP deposits small amounts of energy into a recoiling nucleus (~few 10s of keV)
- Featureless exponential spectrum with no obvious peak, knee, break ...
- Event rate is very, very low.
- Radioactive background of most materials higher than the event rate.



Need large exposures (mass x time)!

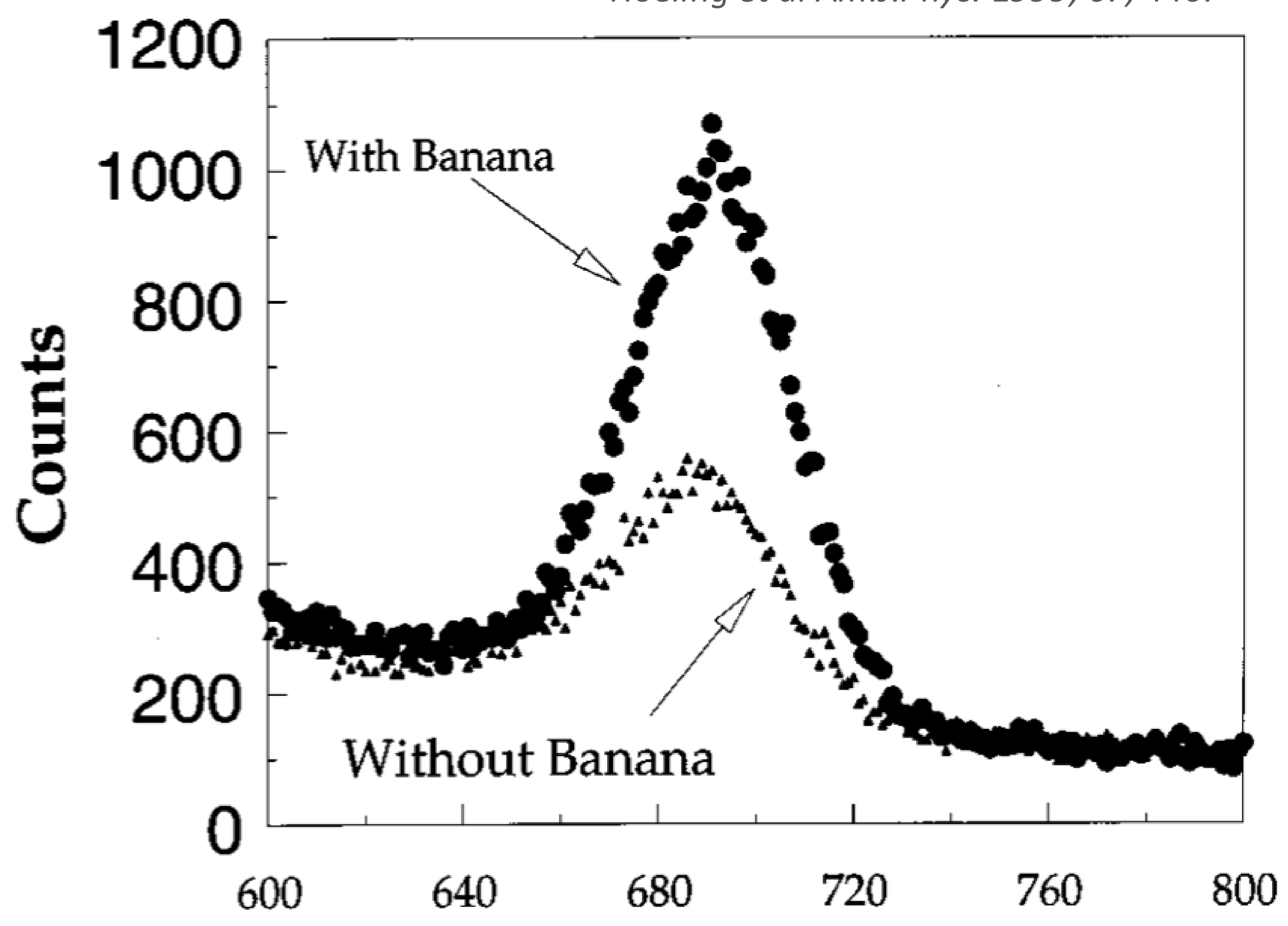
The Event Rates Are Extremely Low!

➤ Expected WIMP Spectrum



➤ Measured Banana Spectrum

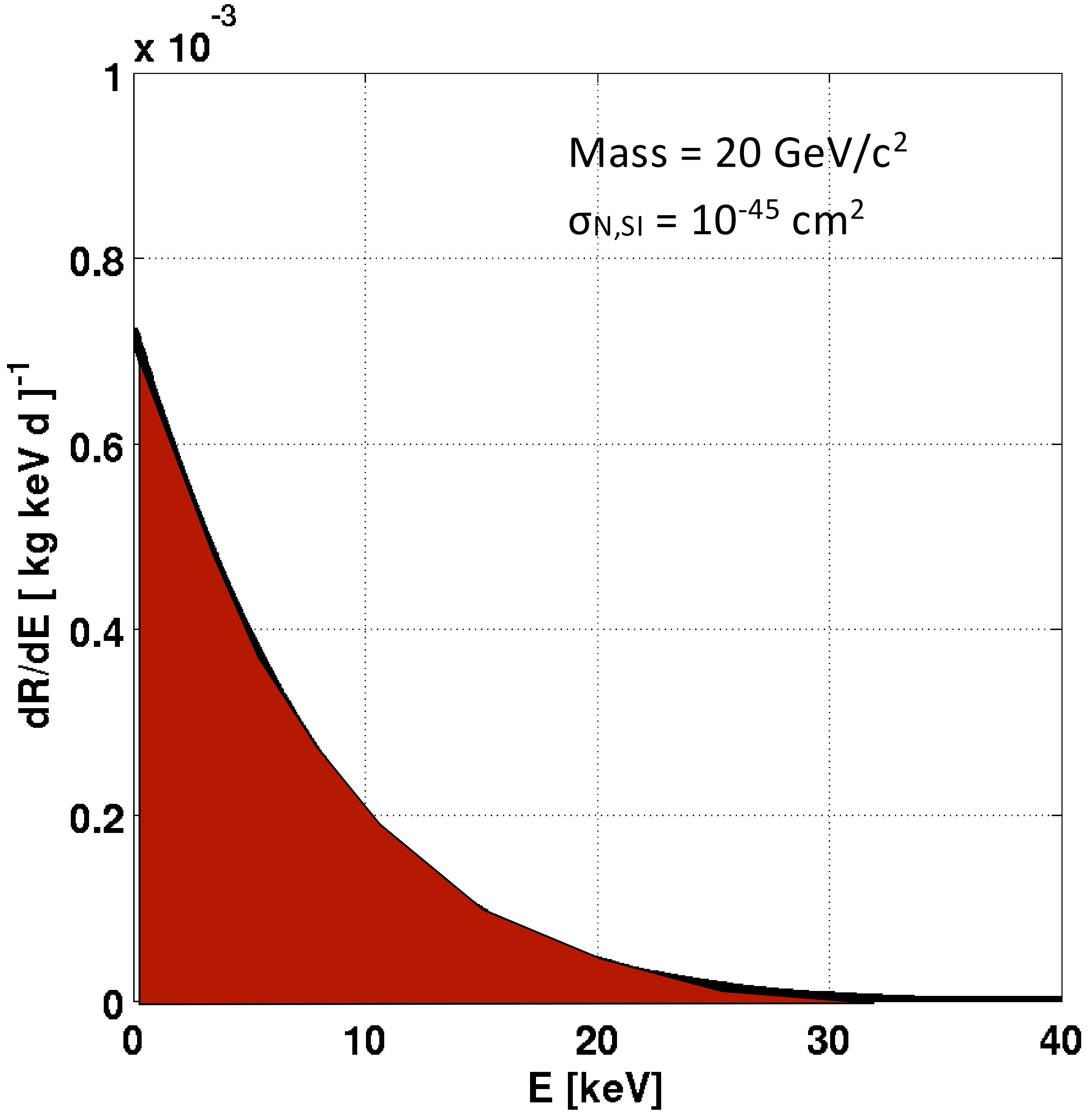
Hoeling et al Am.J.Phys. 1999, 67, 440.



Gamma measurements with a 3-inch NaI detector

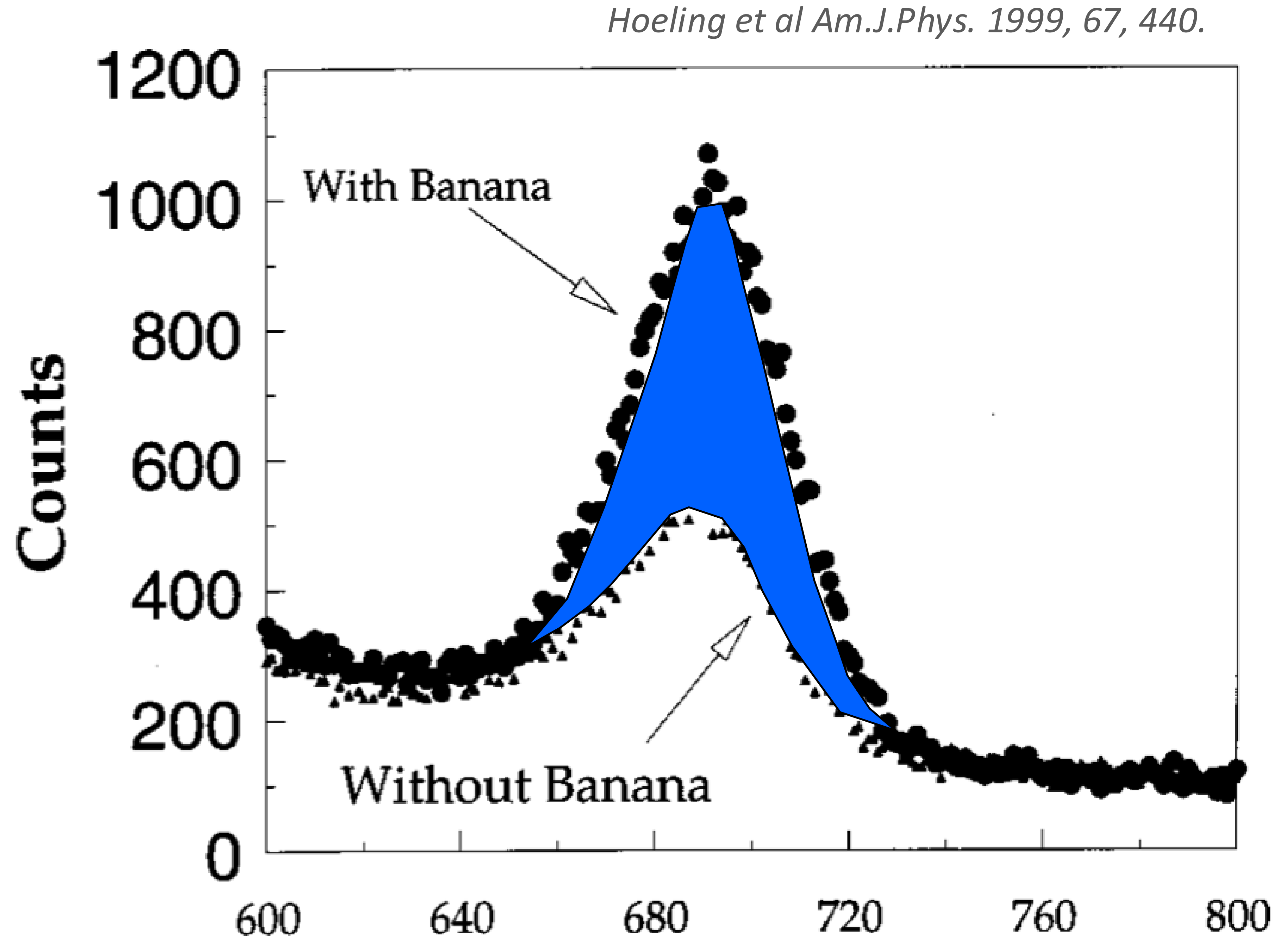
The Event Rates Are Extremely Low!

- Expected WIMP Spectrum



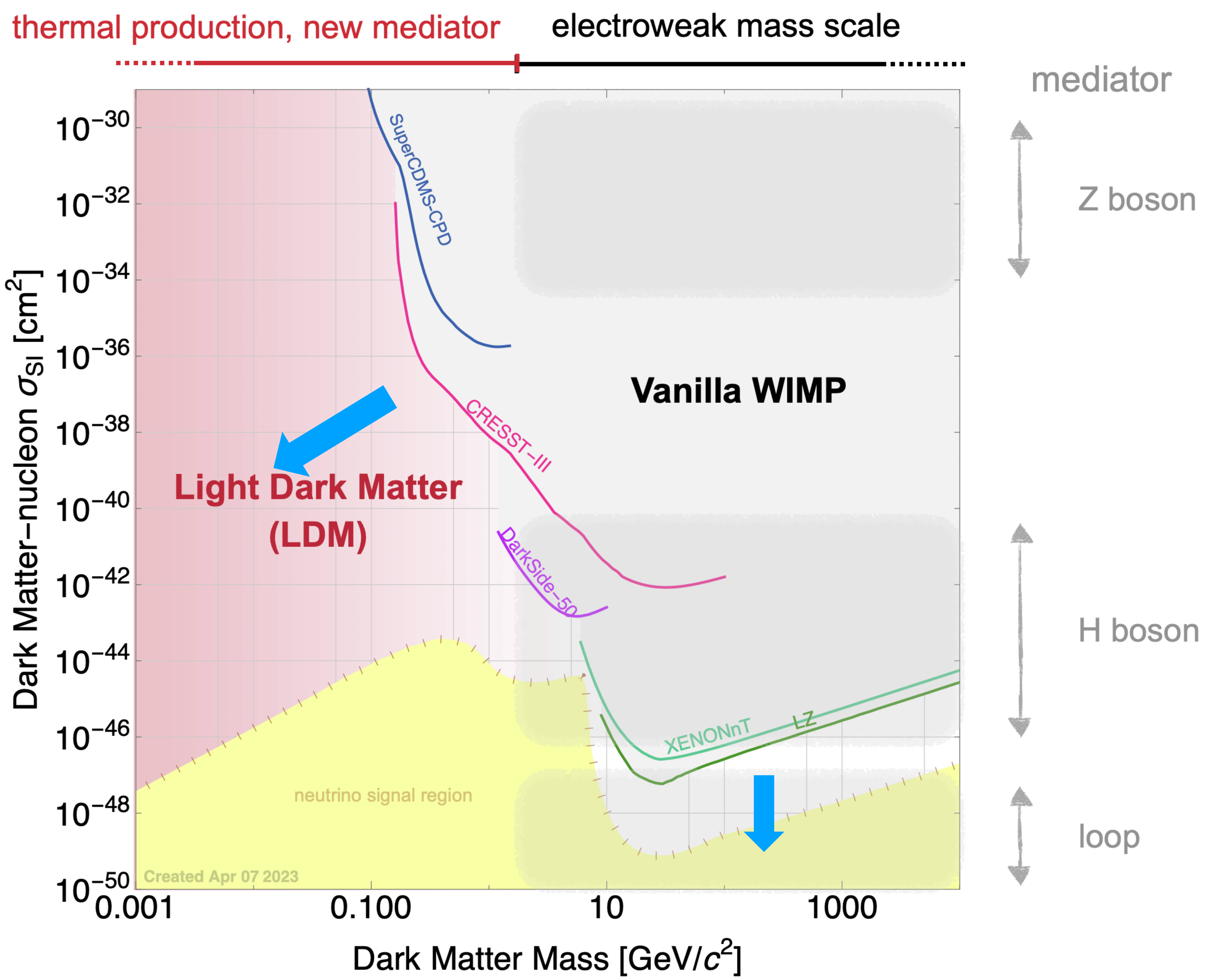
~1 event per kg per year (nuclear recoils)

- Measured Banana Spectrum



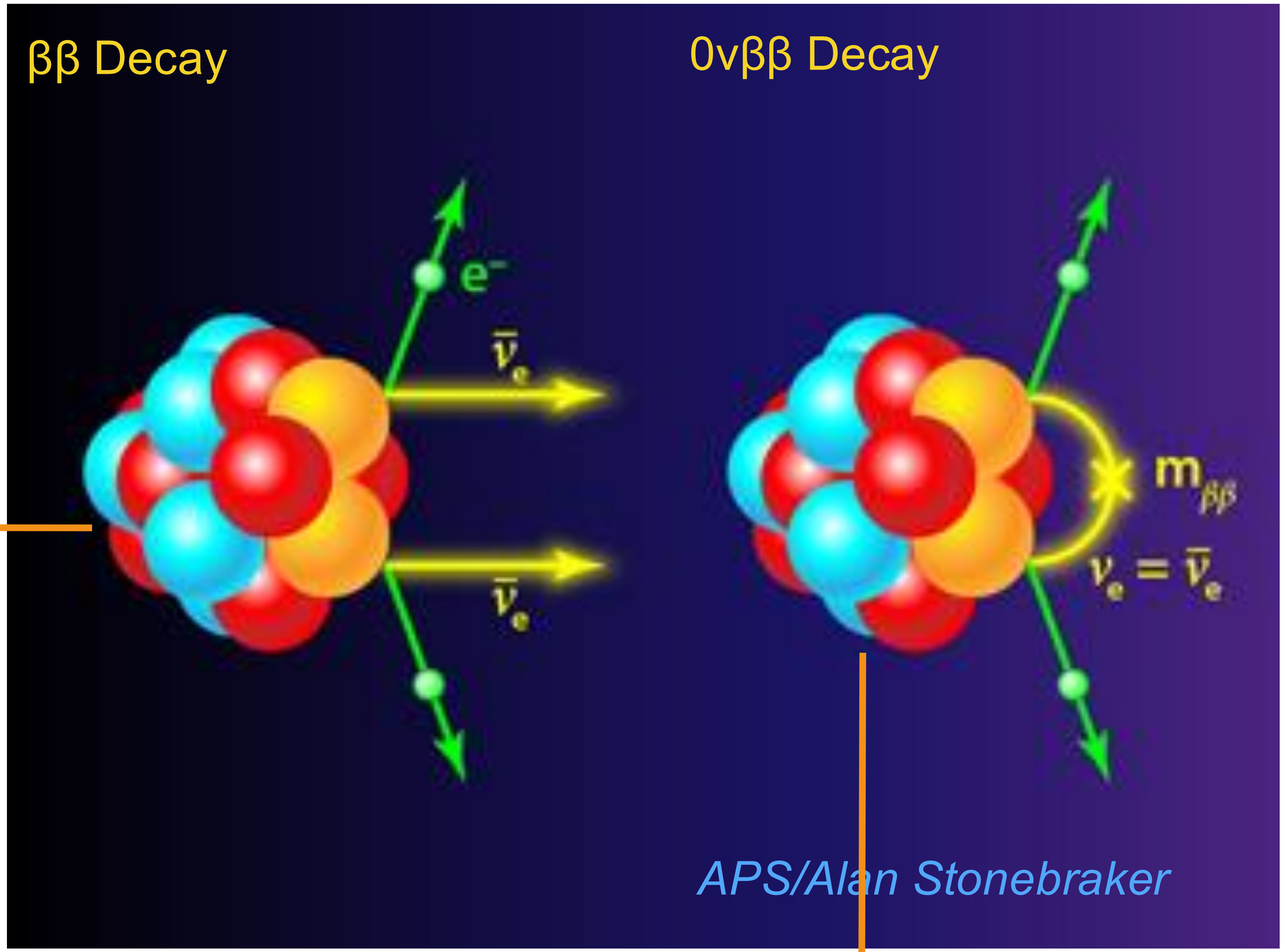
~100 events per kg per year (electron recoils)

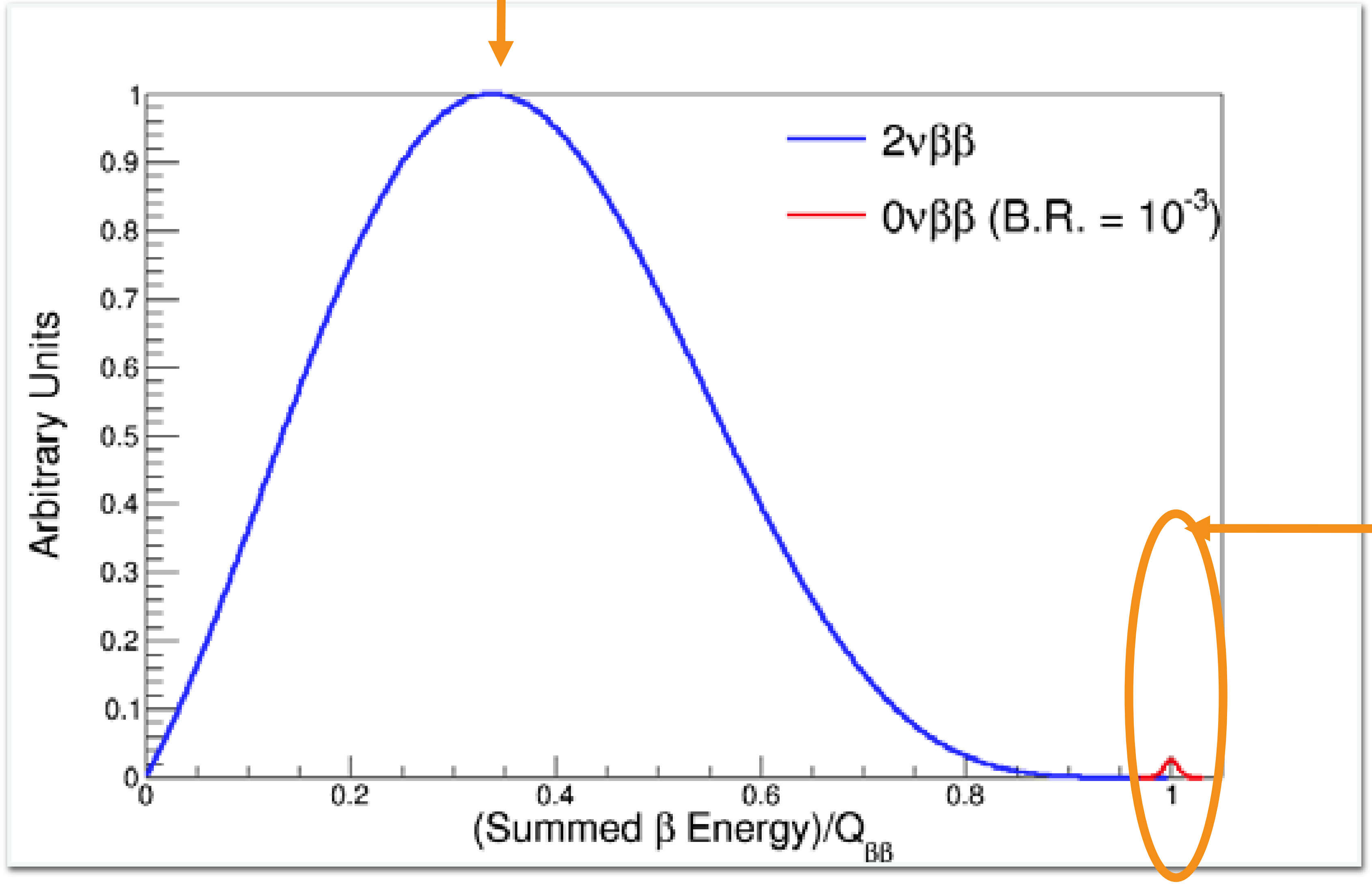
Direct Detection Landscape



Neutrinoless Double Beta Decay

Two neutrino double beta decay is allowed in some isotopes, involves transformation of 2 neutrons into two protons

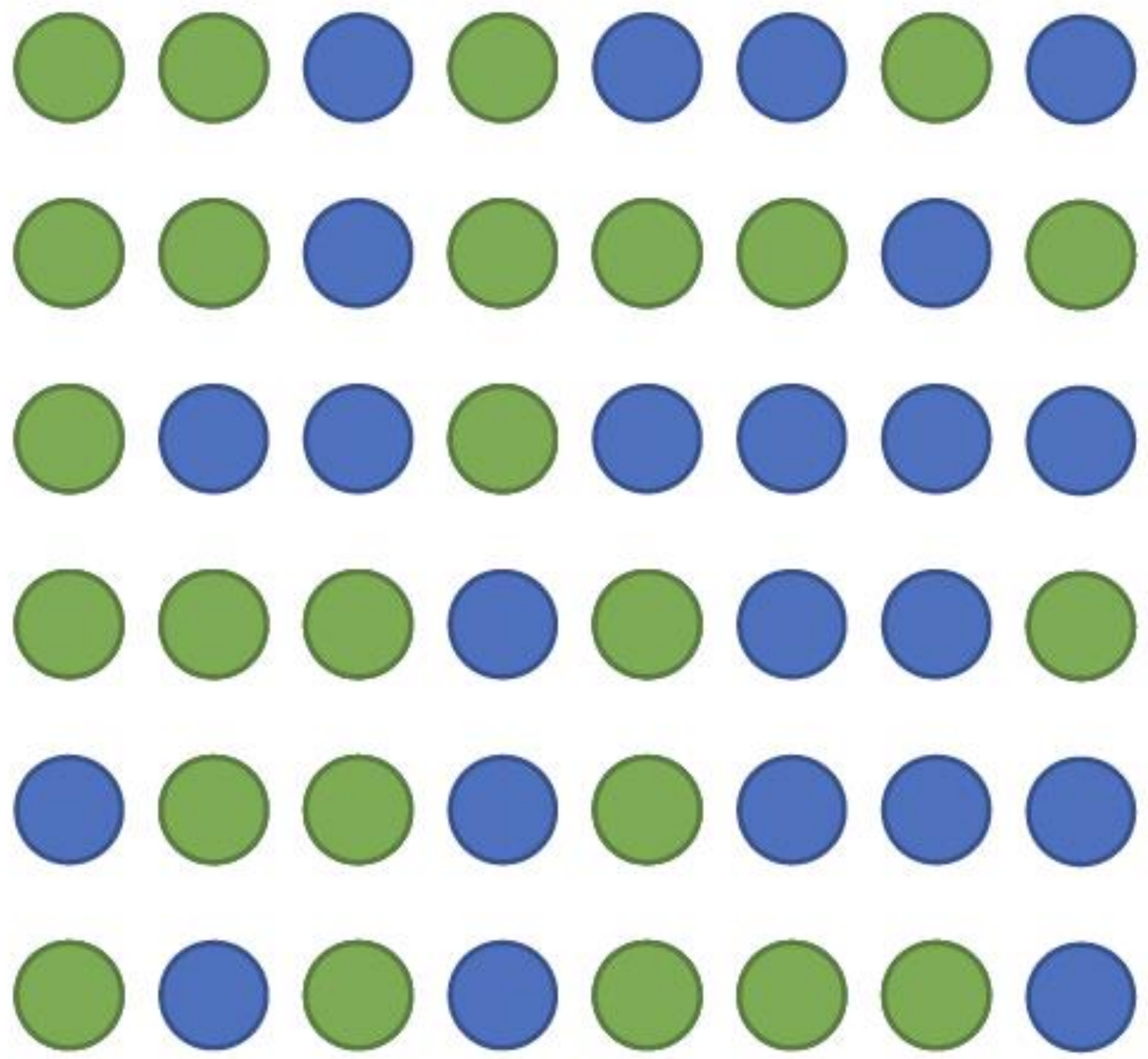




If neutrinos are Majorana particles, then 0νββ decay should be allowed.

How rare is 0νββ decay?

Half life - How long it take for half the atoms to decay



The age of the universe:

14 billion years = 1.4×10^{10} yrs

Two Neutrino Double Beta Decay:

Half life = $\sim 10^{20}$ yrs

Neutrinoless Double Beta Decay:

Half life > 10^{26} yrs

Avagodro's Number: 6×10^{23}

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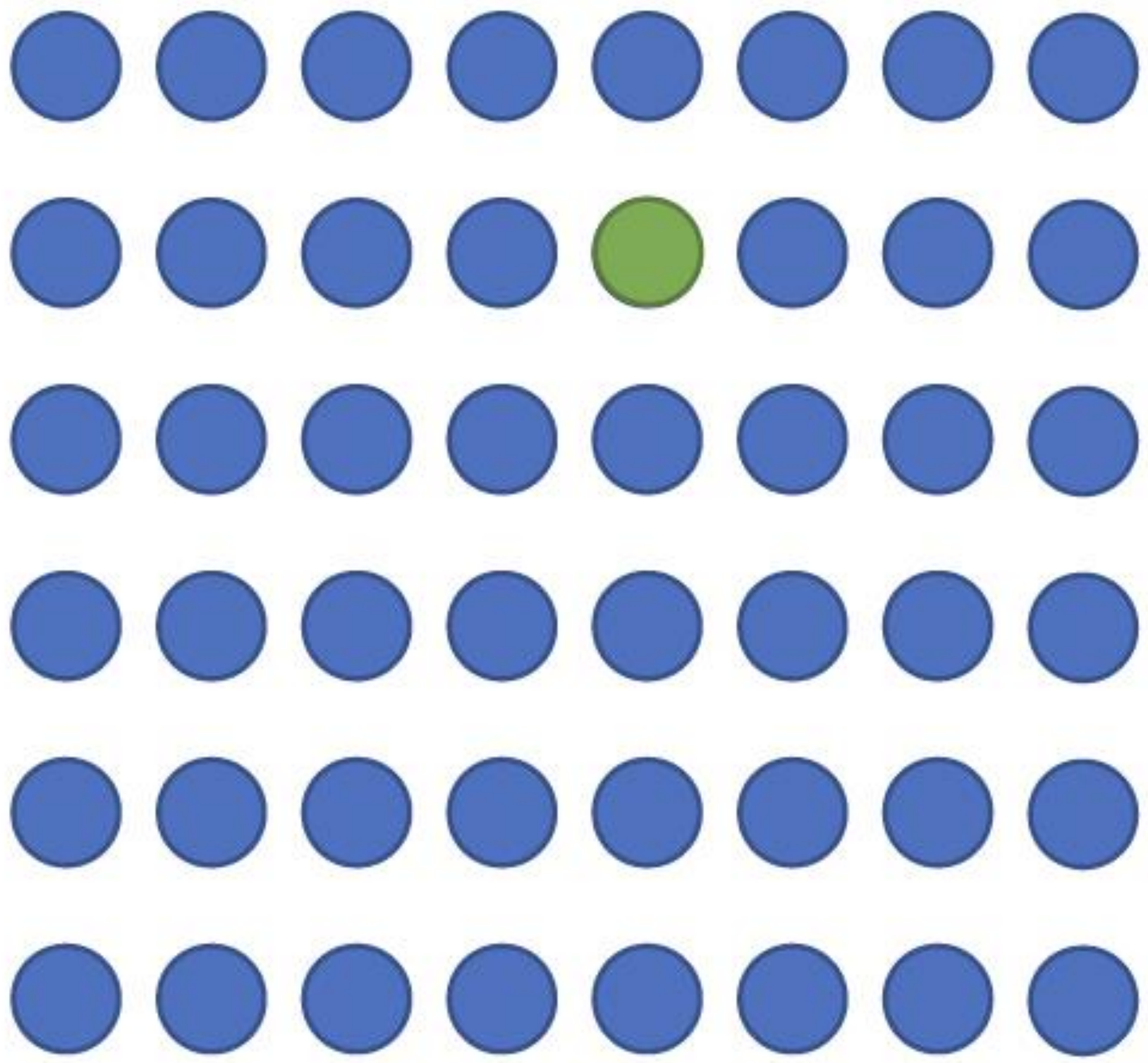

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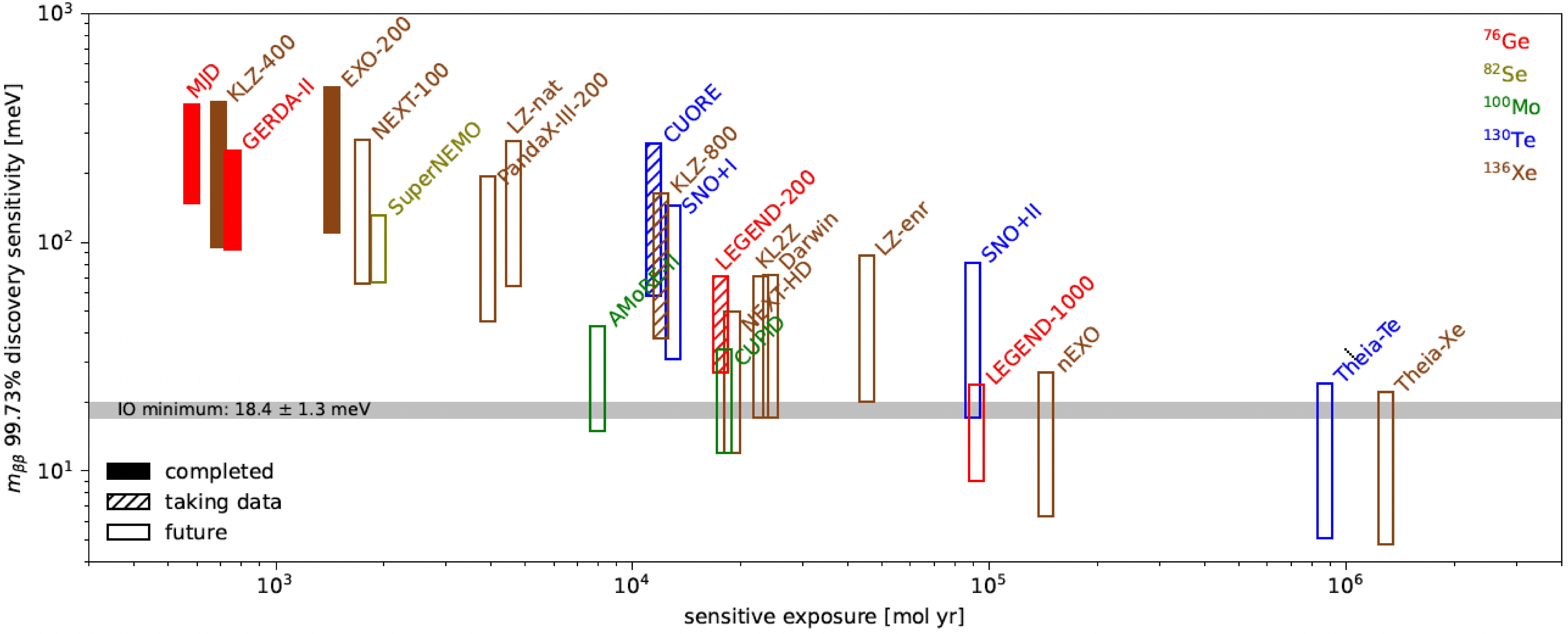
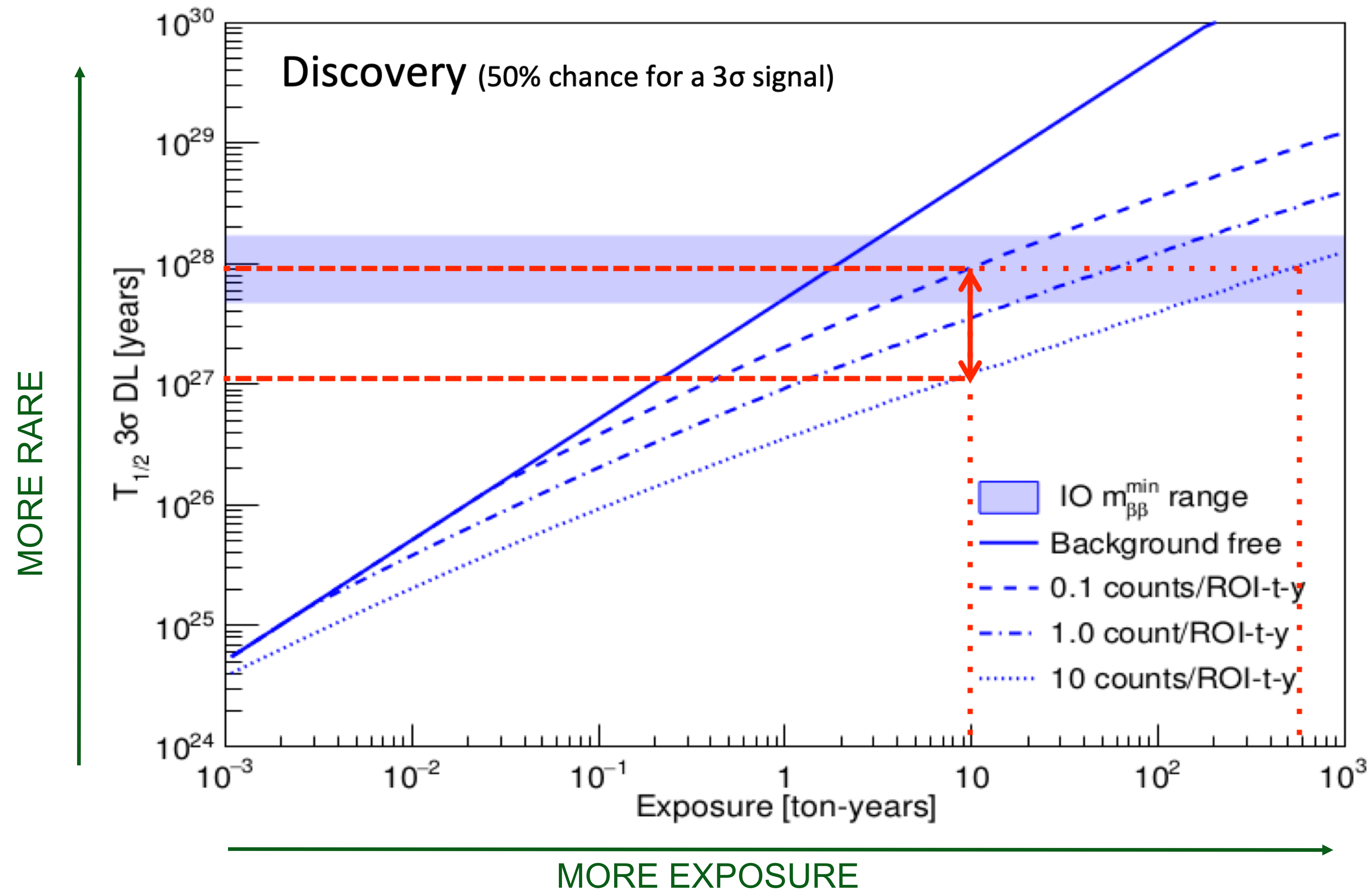
Don't wait for half to decay, wait for 1 to decay!

If you watch 50 kg of atoms for 5 years, you'll see 1 decay for a half-life of 10^{26} years

Discovery Sensitivities for Current and Next Generation $0\nu\beta\beta$ Decay Experiments



Implications on Background Requirements



J. Detwiler

Background Sources

- Environmental radioactivity
  - includes airborne radon and its daughters
- Radio-impurities in materials used for the detector construction and shield
- Radiogenic neutrons with energies below 10 MeV
  - Neutrons from (α,n) and fission reactions
- Cosmic rays and their secondaries
- Activation of detector materials near Earth's surface
- Others that we have not yet identified?

Aside: Reminder of Radioactive Decay

- Activity [decays/time] is a measure of the decay rate of a radionuclide.

$$A = \frac{dN}{dt} = \lambda N$$

λ = decay constant

N = total number of radioactive atoms

- The decay constant is the probability that a radioactive atom will decay.

$$\lambda = \frac{\ln 2}{t_{1/2}}$$

- The number of atoms of the radioisotope present is given by

$$N = \frac{Avogadro's\ Number}{atomic\ mass\ of\ the\ radionuclide} \times mass\ of\ the\ radionuclide$$

- Abundance refers to the relative portions of stable isotopes of an element.

How to Address Challenges

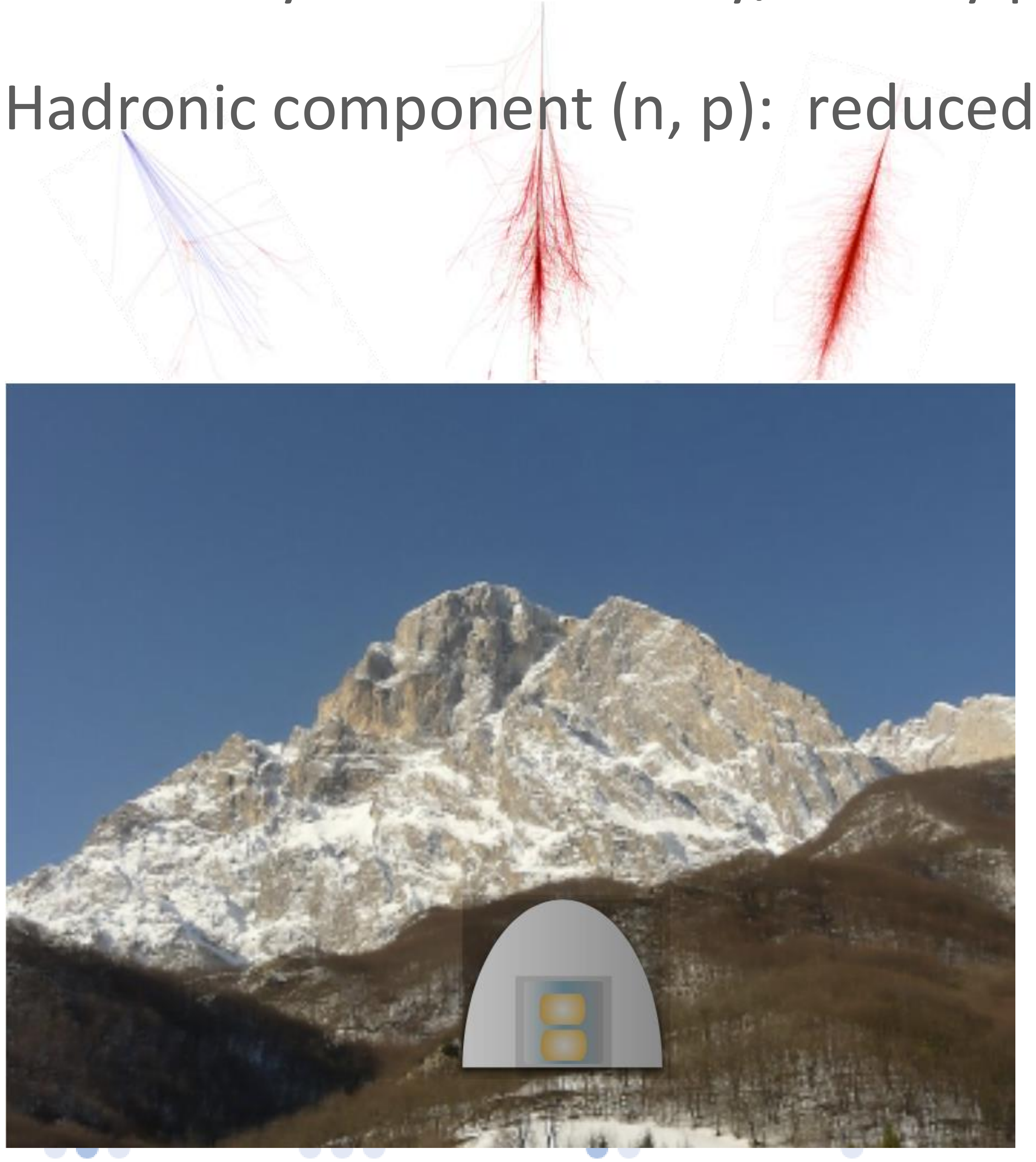
1. Insensitivity to a potential background
2. Discriminate against the background
3. Fiducial Volume Cut
4. Characterize the Background
5. Material Handling
6. Material Selection
7. Material Purification

Insensitivity to Potential Backgrounds through Design

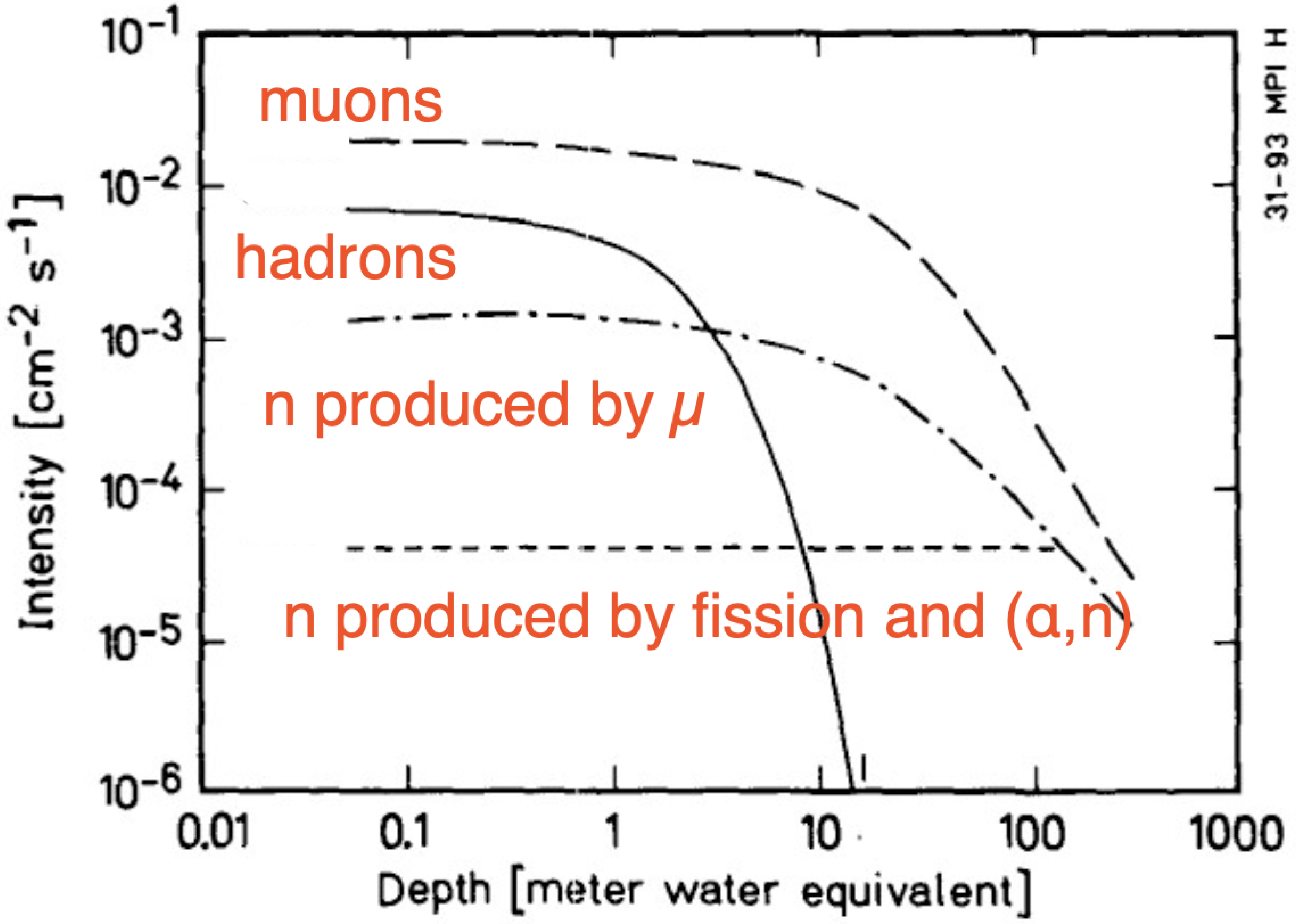
Gran Sasso, Italy

Cosmic Ray Induced Backgrounds

- Cosmic rays and secondary/tertiary particles can be problematic!
- Hadronic component (n, p): reduced by a few meters water equivalent (mew)

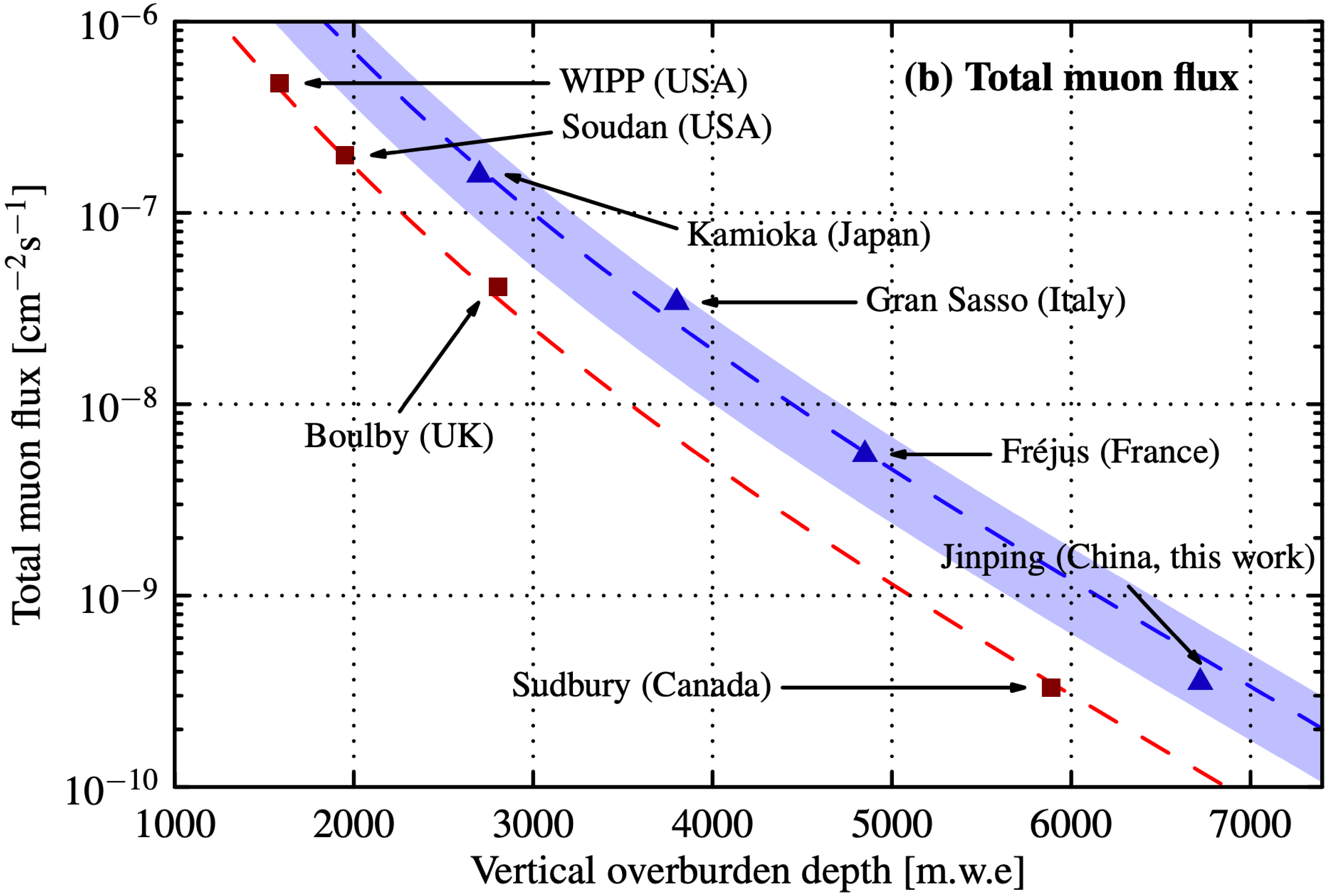


Flux of cosmic ray secondaries and tertiary-produced neutrons in a typical Pb shield vs shielding depth
Gerd Heusser, 1995



Underground Facilities

Guo et al., arXiv:2007.15925v2



- Muons that penetrate deep and produce high energy neutrons (fast neutrons) can produce keV recoils in detectors when attenuated by rock or shields.
- Processes to produce fast neutrons include:
  - negative muon capture
  - photo-nuclear reactions in associated EM showers
  - deep-inelastic muon-nucleus scatters
  - hadronic interactions of nucleons, pions and kaons

Underground Facilities

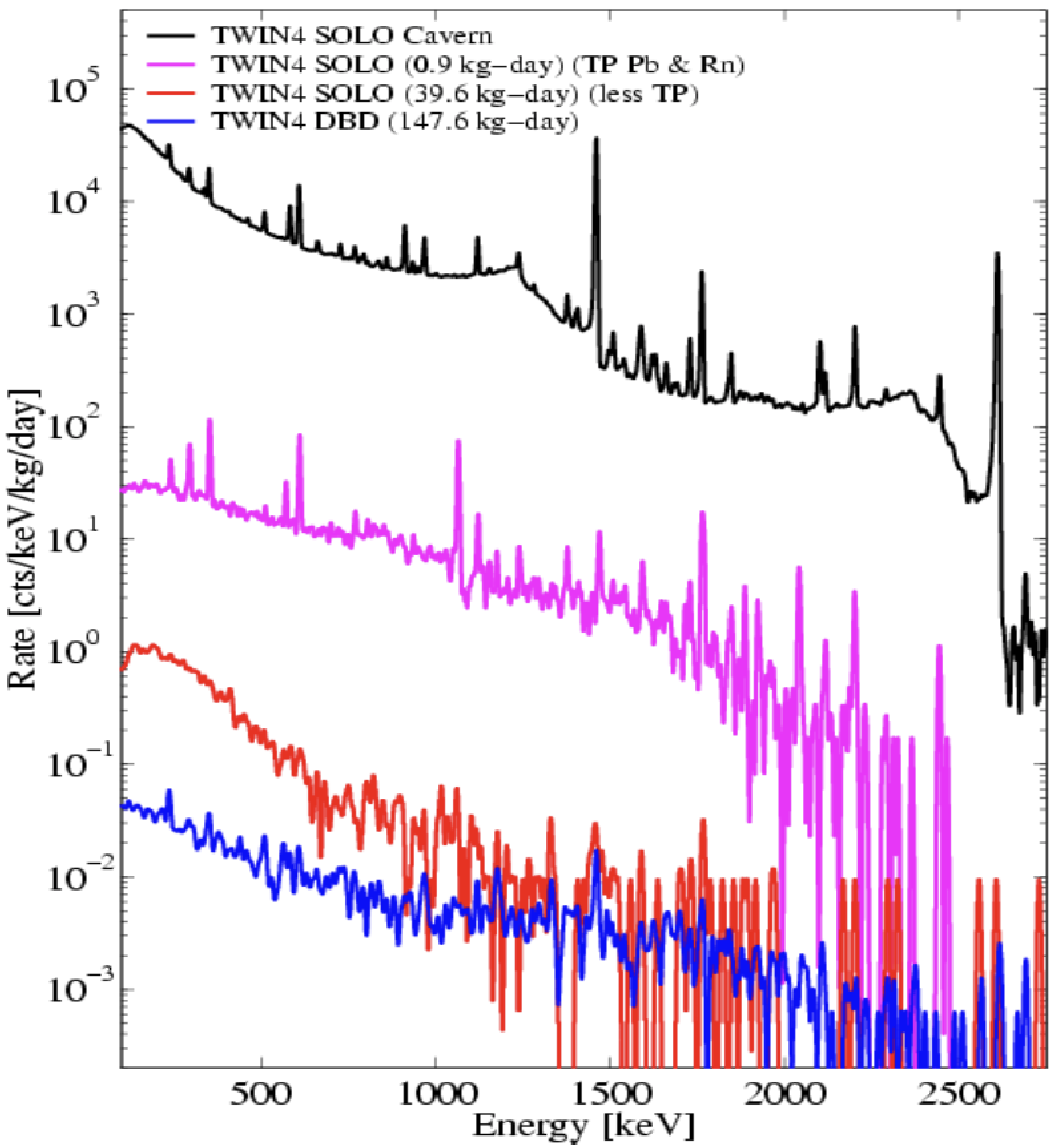
Activation of Detector Materials

- Activation of a detector or materials close to the detector during production or transportation at Earth's surface is another concern.
    - CR spectrum varies with geomagnetic latitude and the flux varies with height above Earth.
    - Cross section for production of isotopes — not all are measured
- Production is dominated by (n, x) reactions (95%) and (p, x) reactions (5%)

production in Ge after 30d exposure at the Earth's surface and 1 yr storage below ground

Isotope	Decay	Half life	Energy in Ge [keV]	Activity [μBq/kg]
^{3}H	β^-	12.33 yr	$E_{max(\beta-)}$=18.6	2
^{49}V	EC	330 d	$E_{K(Ti)}$ = 5	1.6
^{54}Mn	EC, β^+	312 d	$E_{K(Cr)}$ = 5.4, E_γ=841	0.95
^{55}Fe	EC	2.7 yr	$E_{K(Mn)}$ = 6	0.66
^{57}Co	EC	272 d	$E_{K(Fe)}$=6.4, E_γ=128	1.3
^{60}Co	β^-	5.3 yr	$E_{max(\beta-)}$=318, E_γ=1173,1333	0.2
^{63}Ni	β^-	100 yr	$E_{max(\beta-)}$=67	0.009
^{65}Zn	EC, β^+	244 d	$E^{K(Cu)}$ = 9, E_γ=1125	9.2
^{68}Ge	EC	271 d	$E_{K(Ga)}$ = 10.4	172

Environmental Backgrounds



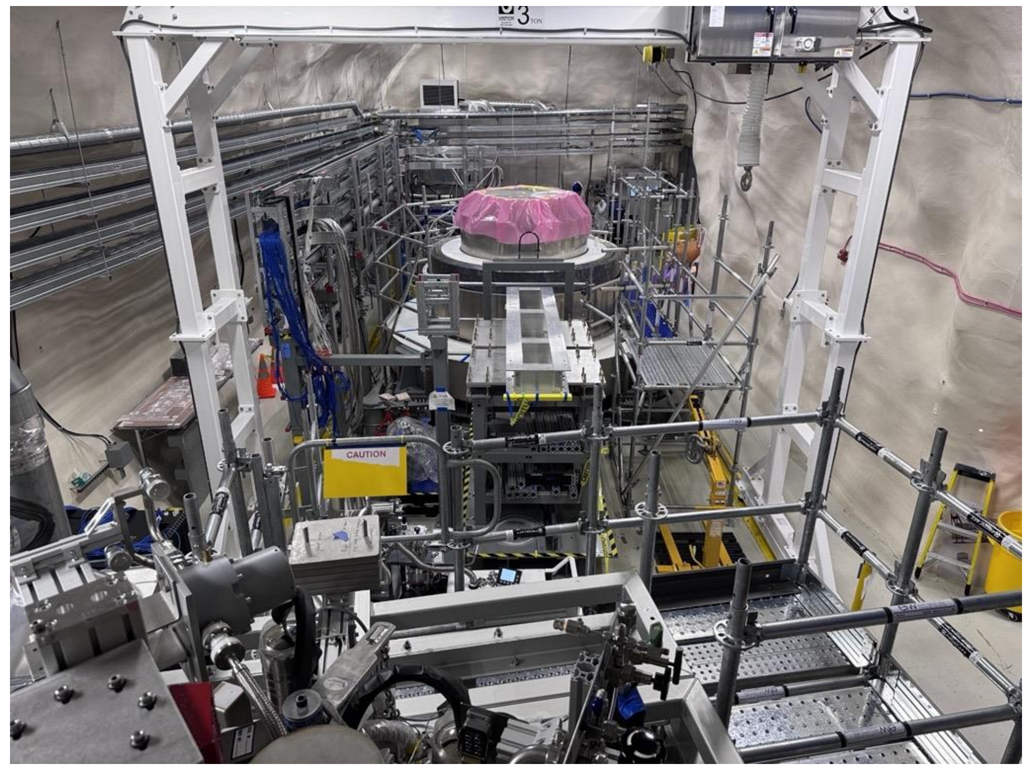
Ge detector underground, no shield

Ge detector underground, Pb shield and purge for Rn

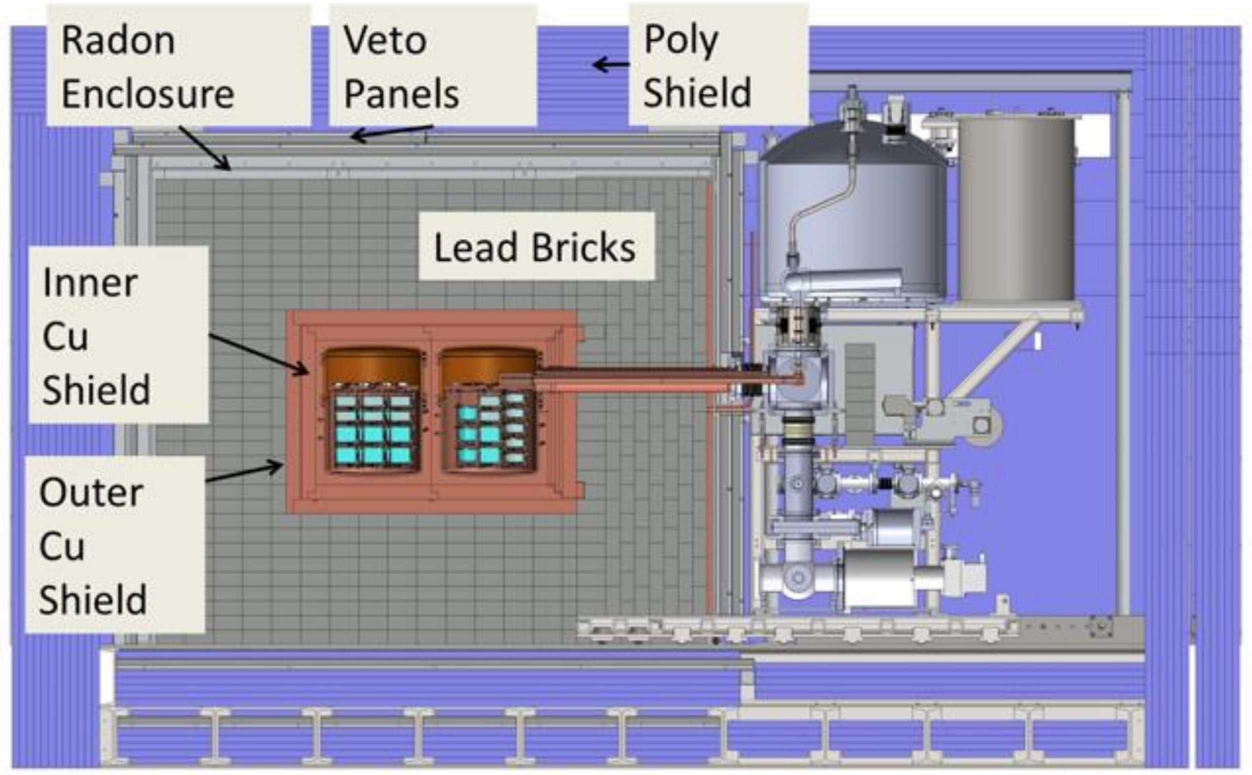
- A combination of high-Z and low-Z materials are employed to diminish the neutron and gamma fluxes.
  - Lead, polyethelyne, copper
- Nitrogen purge of shield structures to reduce backgrounds induced by airborne radon decays

Environmental Backgrounds

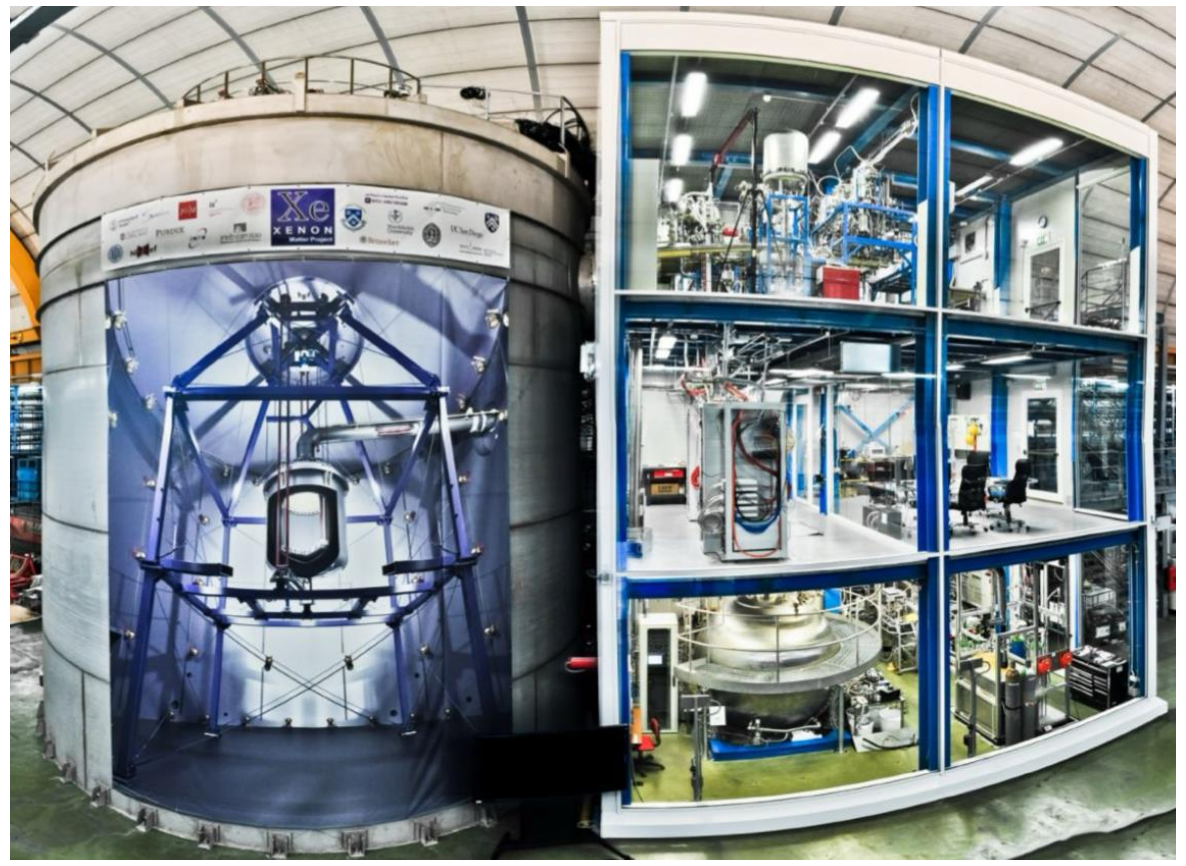
LUX/LZ Muon Veto



SuperCDMS SNOLAB Passive Shield



MAJORANA Demonstrator Passive Shield

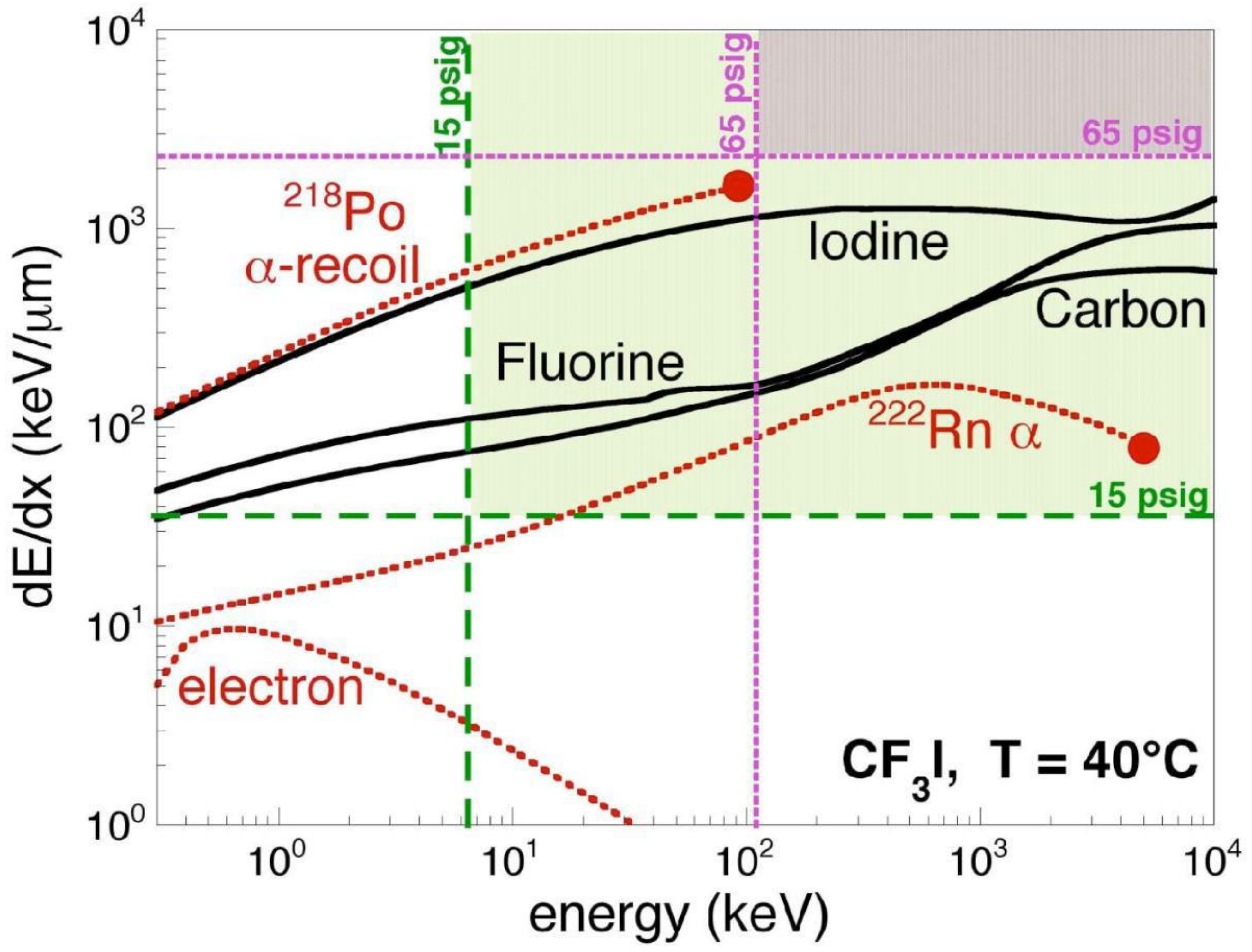


XENON1T water shield & infrastructure

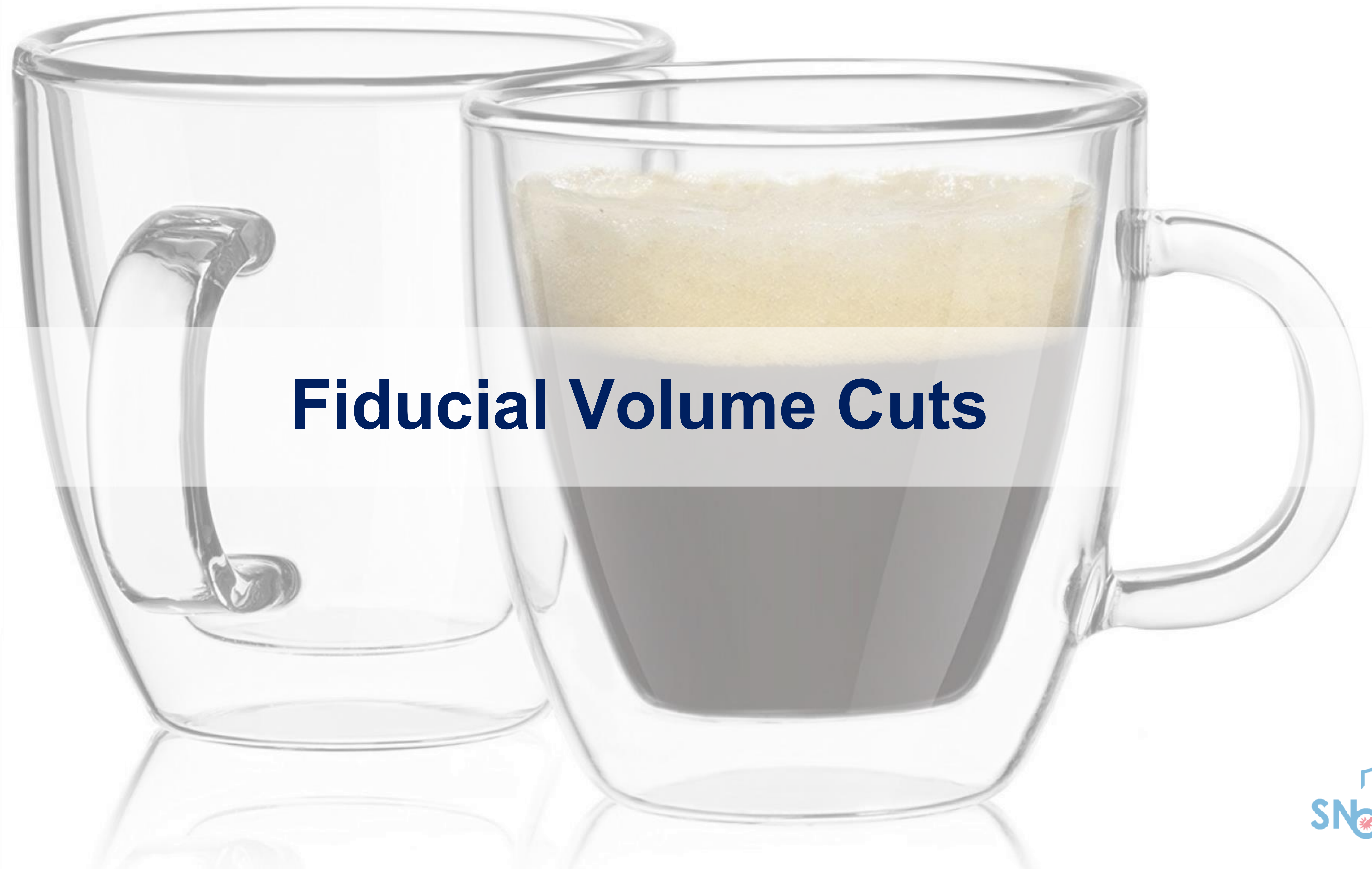
- A combination of high-Z and low-Z materials are employed to diminish the neutron and gamma fluxes.
  - Lead, polyethelyne, copper
- Nitrogen purge of shield structures to reduce backgrounds induced by airborne radon decays
- Large water shields can
  - passively reduce environmental radioactivity and muon-induced neutrons
  - can reduce underground fluxes of gamma and radiogenic fluxes by a factor of ~10^6 by employing a 1 - 3 m water shield
- Active muon vetos using doped scintillator (ie boron) can be used to identify events related to both cosmogenic and radiogenic neutrons.

Detector Design

- A bubble chamber is filled with a superheated fluid in a metastable state.
- A particle interaction with energy deposition greater than some energy threshold within a critical radius results in an expanding bubble.
- A smaller or more diffuse energy deposition will result in a bubble that immediately collapses.
- You can "tune" the chamber to make bubbles for nuclear recoils and not for electron interactions.

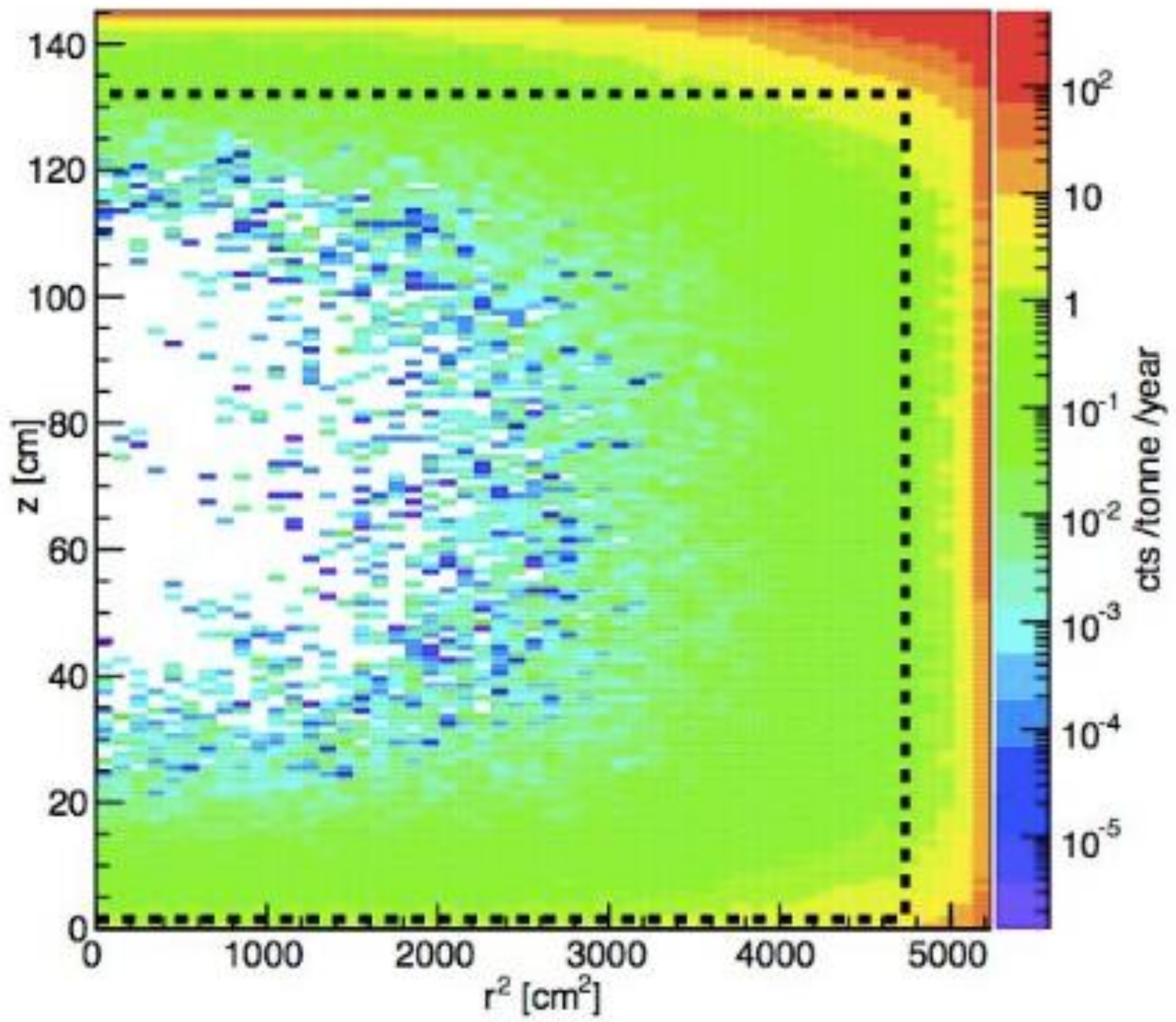


Fiducial Volume Cuts



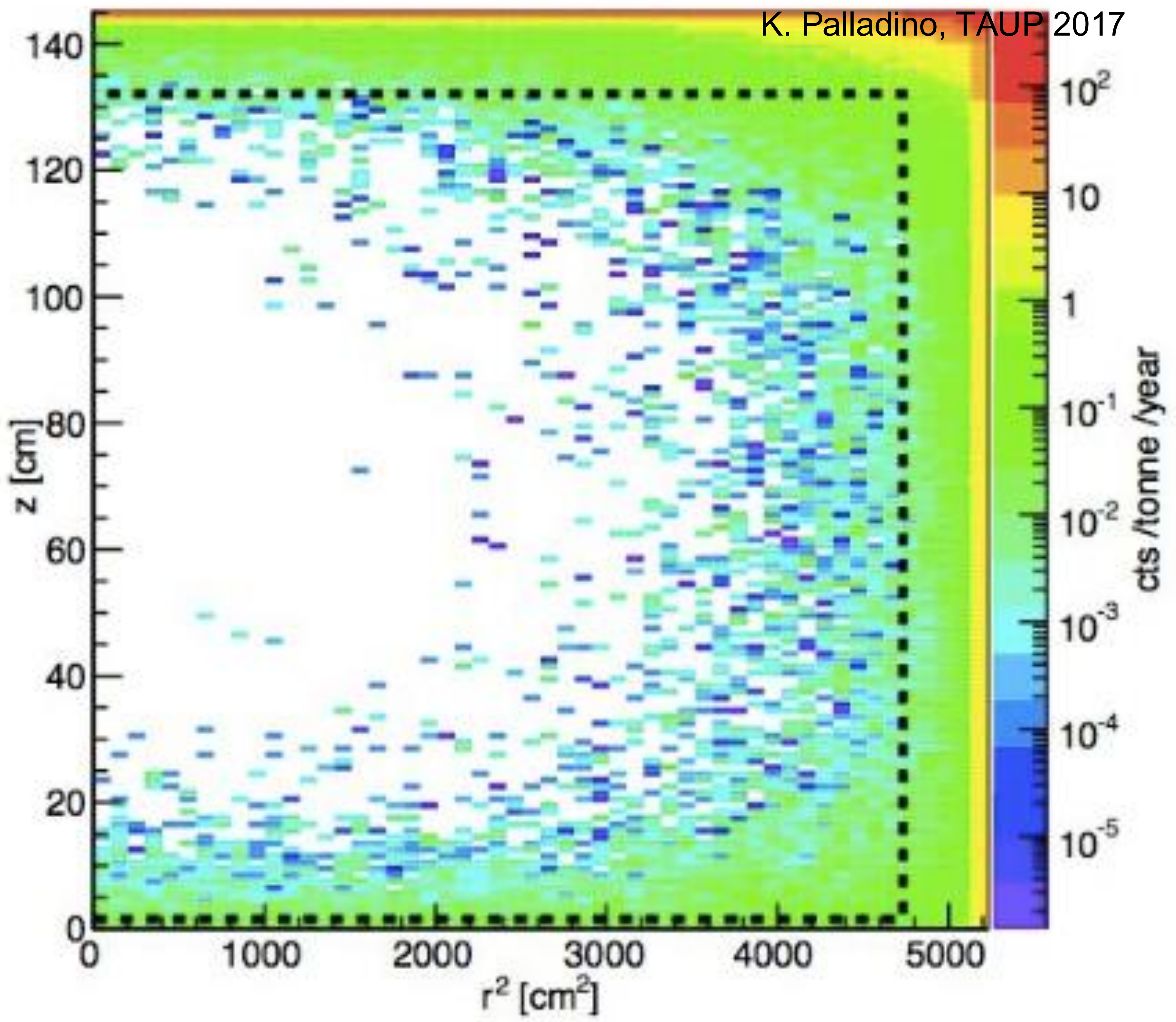
Self Shielding Properties

Example: LZ Dark Matter Experiment



LXe TPC only

3.8 T fiducial mass



LXe TPC + Skin + OD

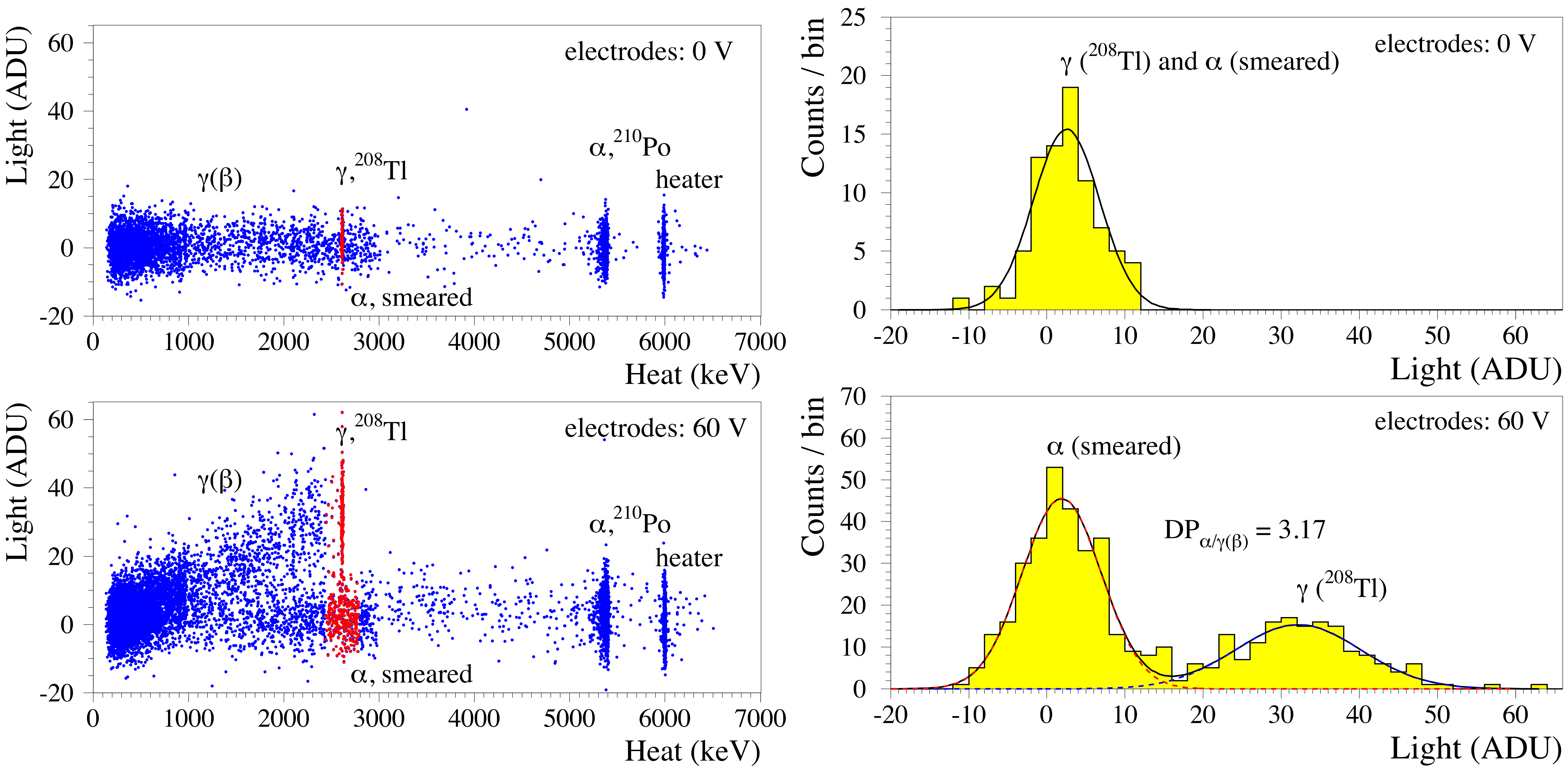
5.6 T fiducial mass

Discrimination of Backgrounds

0νββ Decay: Example COURE

- The Q-value for 0νββ decay in ^{130}Te is ~2.5 MeV.
- Surface αs dominant background (0.01 counts/keV/kg/yr)
- βs generate light at >50 keV, αs at >400 MeV

Phys. Rev. C 97, 032501 (2018)



Event Signatures: Dark Matter

The most problematic backgrounds are interactions from neutrons that result from (α,n) and fission reactions from ^{238}U and ^{232}Th decays in detector components and in close vicinity of target materials.

Electron Recoils (ER)

Gamma: Most prevalent background

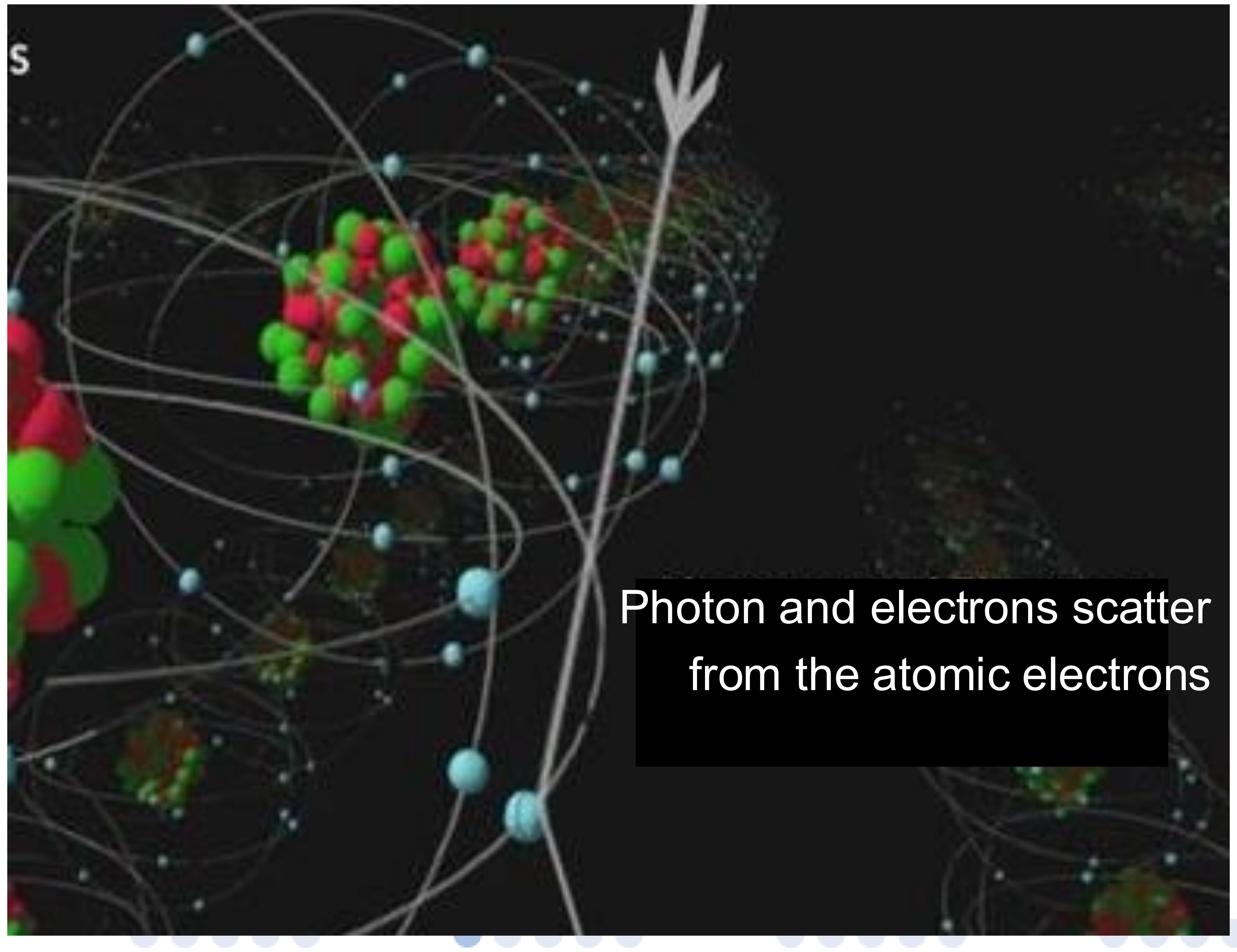
Beta: on surface or in bulk

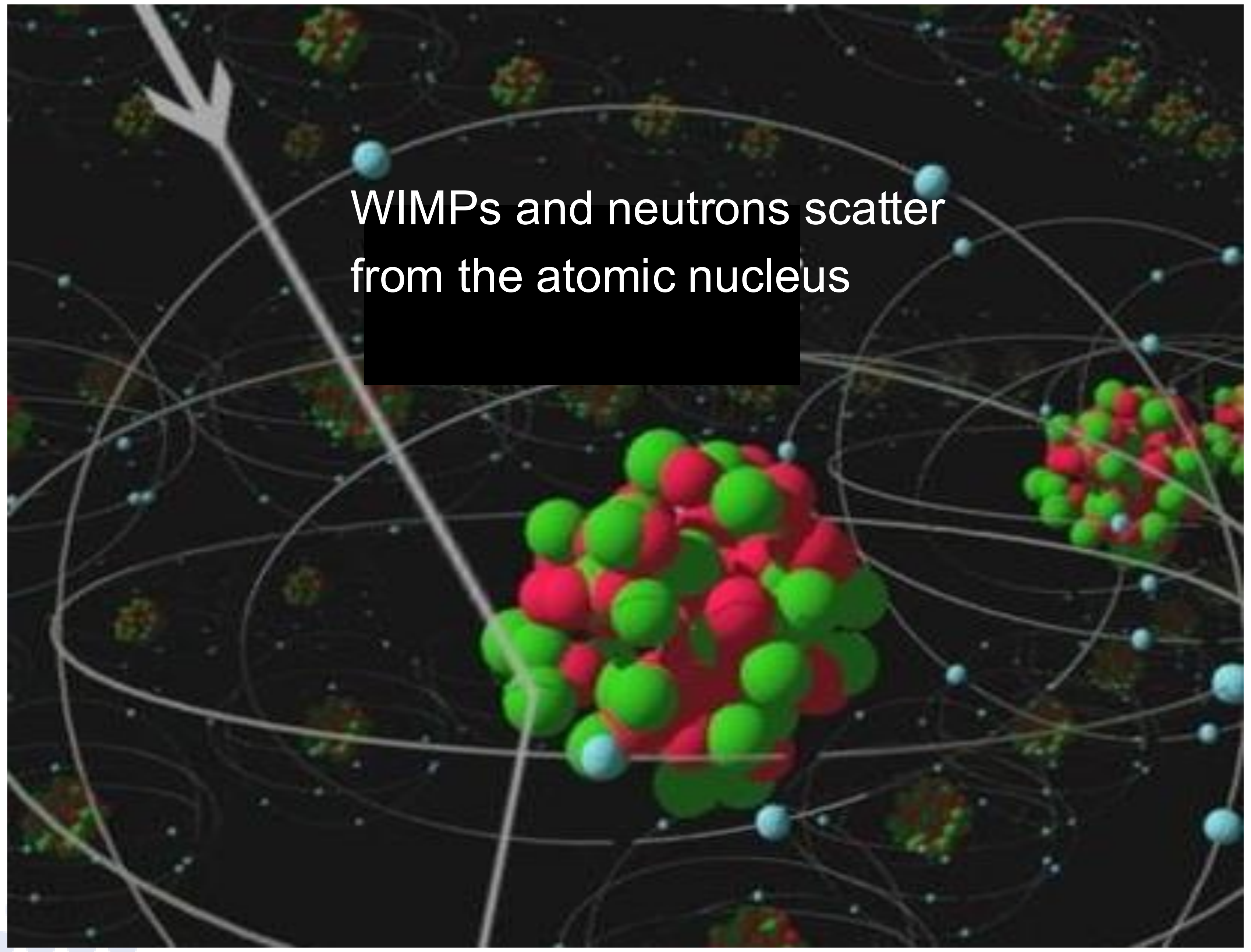
NUCLEAR Recoils (NR)

Neutron: NOT distinguishable from WIMP

Alpha: almost always a surface event

Recoiling Parent Nucleus: surface event





Event Signatures: Particle Dependent

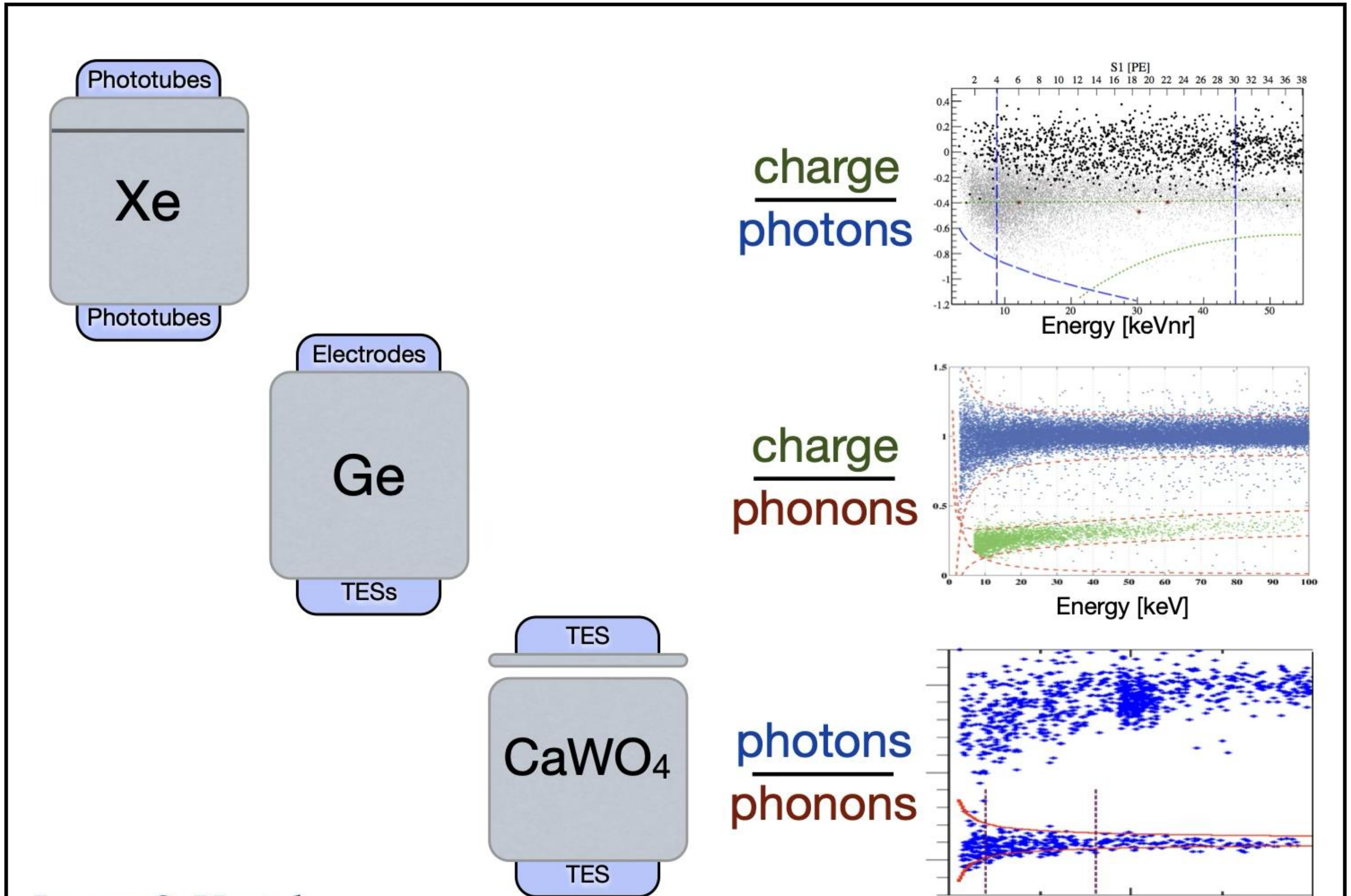
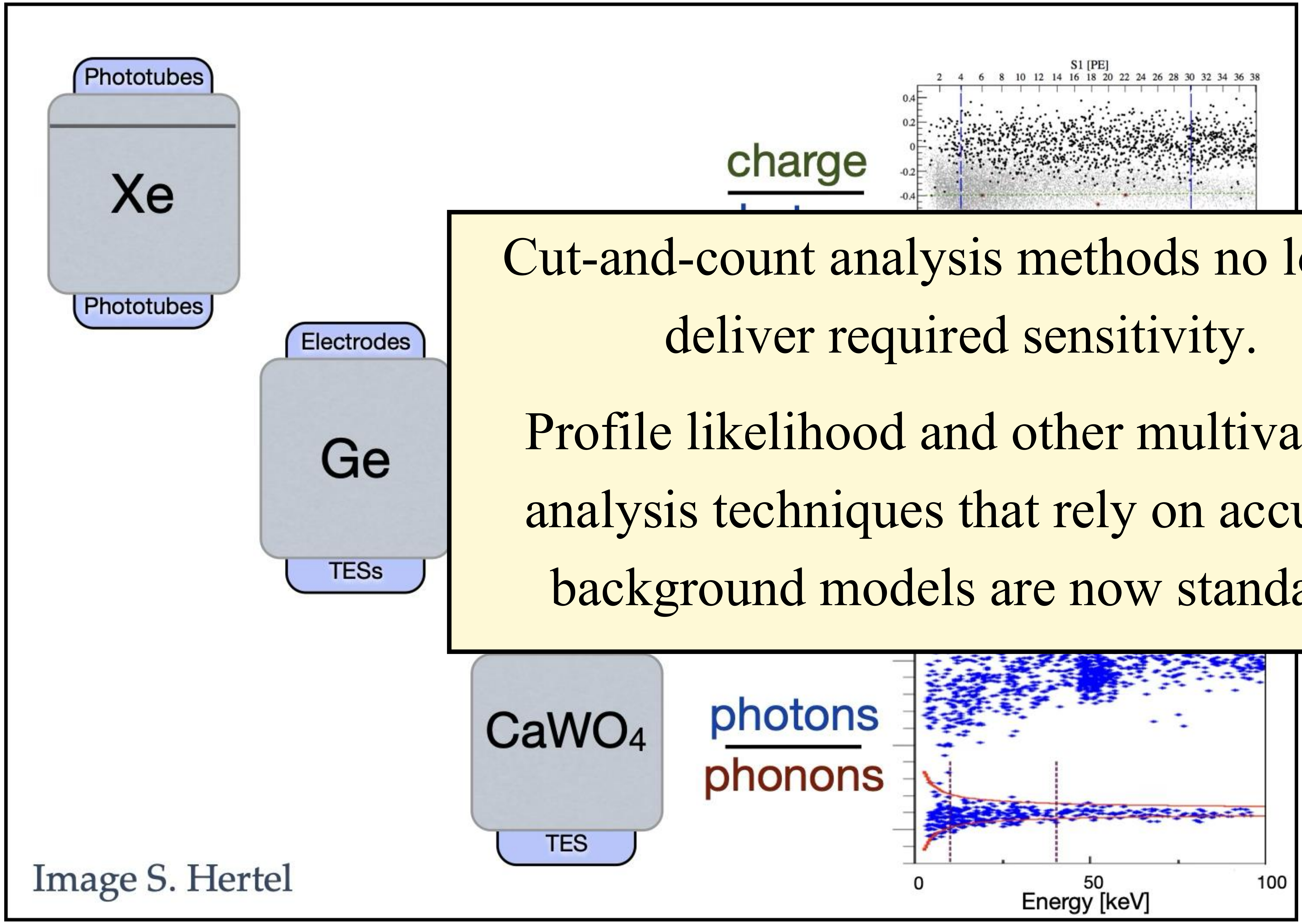


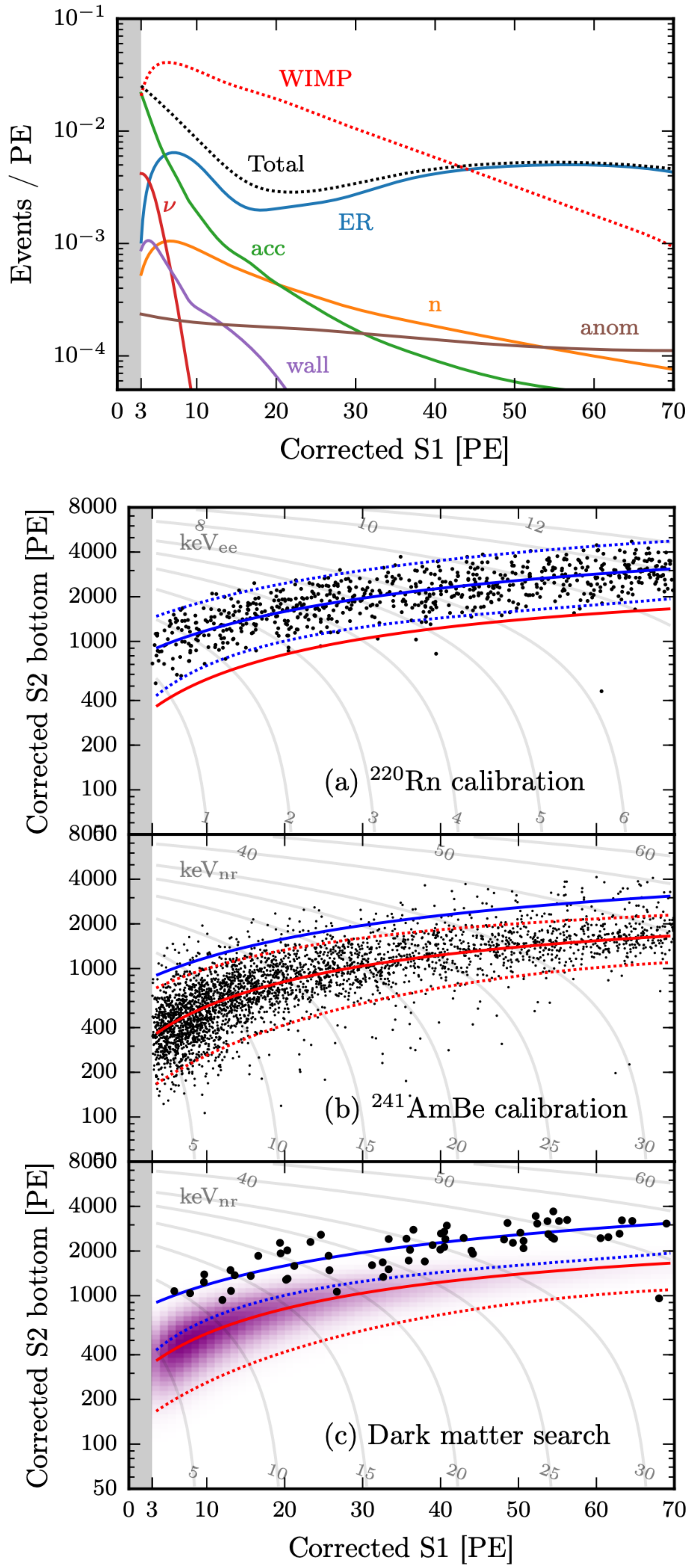
Image S. Hertel

Event Signatures: Particle Dependent



Cut-and-count analysis methods no longer deliver required sensitivity.

Profile likelihood and other multivariate analysis techniques that rely on accurate background models are now standard.



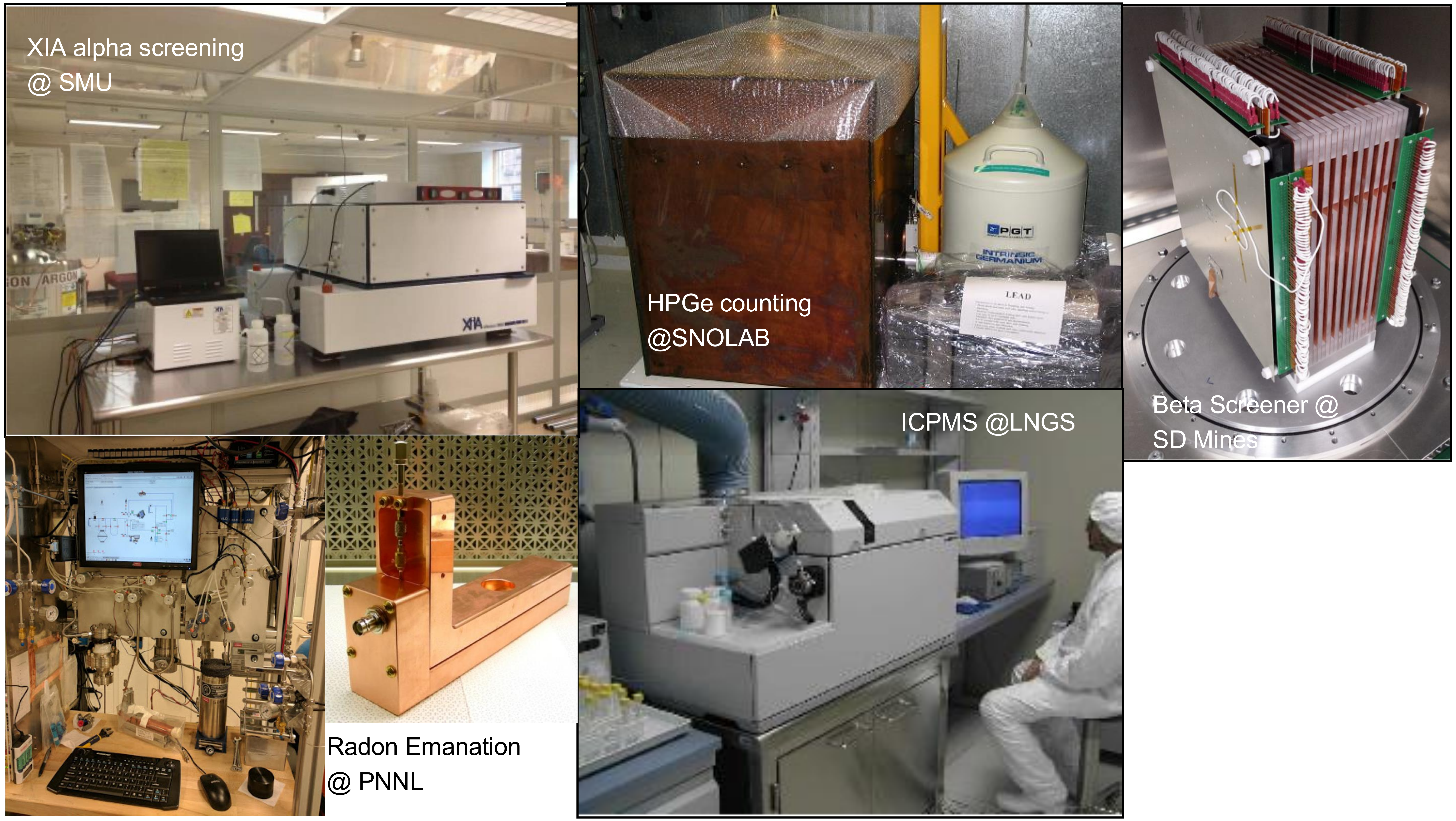
PRL 119.181301

Characterization of Backgrounds

Internal Radioactivity

- ^{238}U, ^{238}Th, ^{40}K, ^{137}Cs, ^{60}Co, ^{39}Ar, ^{85}Kr, …. decays in the detector target, materials surrounding the target medium and shield
- A number of methods are employed to characterize materials before using them as detector components.
- In most cases, looking for materials at levels of < 1 ppb.

Internal Radioactivity



In most cases, looking for materials at levels of < 1 ppb.

How Well Can We Do?

Augmented Commercial Systems:
Commercially purchased High-Purity Ge detector is placed in a custom designed shield (Pb, copper, neutron moderation and capture materials, active cosmic ray veto, underground location)

Fully Custom Systems:
In addition to a custom shield, a custom cryostat design with attention to design of and placement of electronics to minimize background sources (U/Th/K).

HPGe Counting:

Isotope/Chain	Standard Size (ppb)	(mBq/kg)	Large Size & Long Count (ppb)
^{238}U	~0.1	~1.0	0.009
^{232}Th	~0.3	~1.5	0.02
^{40}K	~700	~21	87
^{238}U	0.001	0.12	
^{232}Th	0.001	0.004	
^{40}K	1	0.031	

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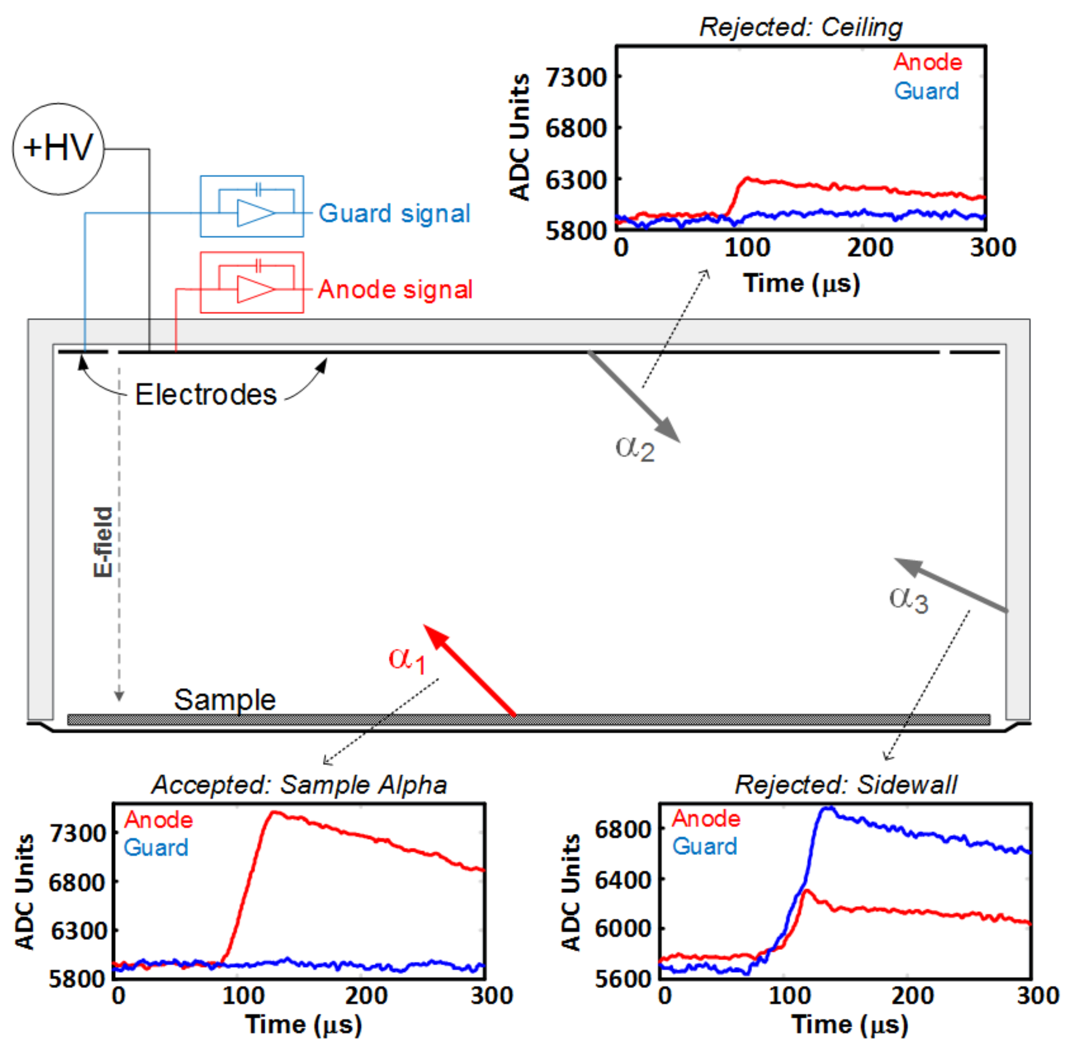
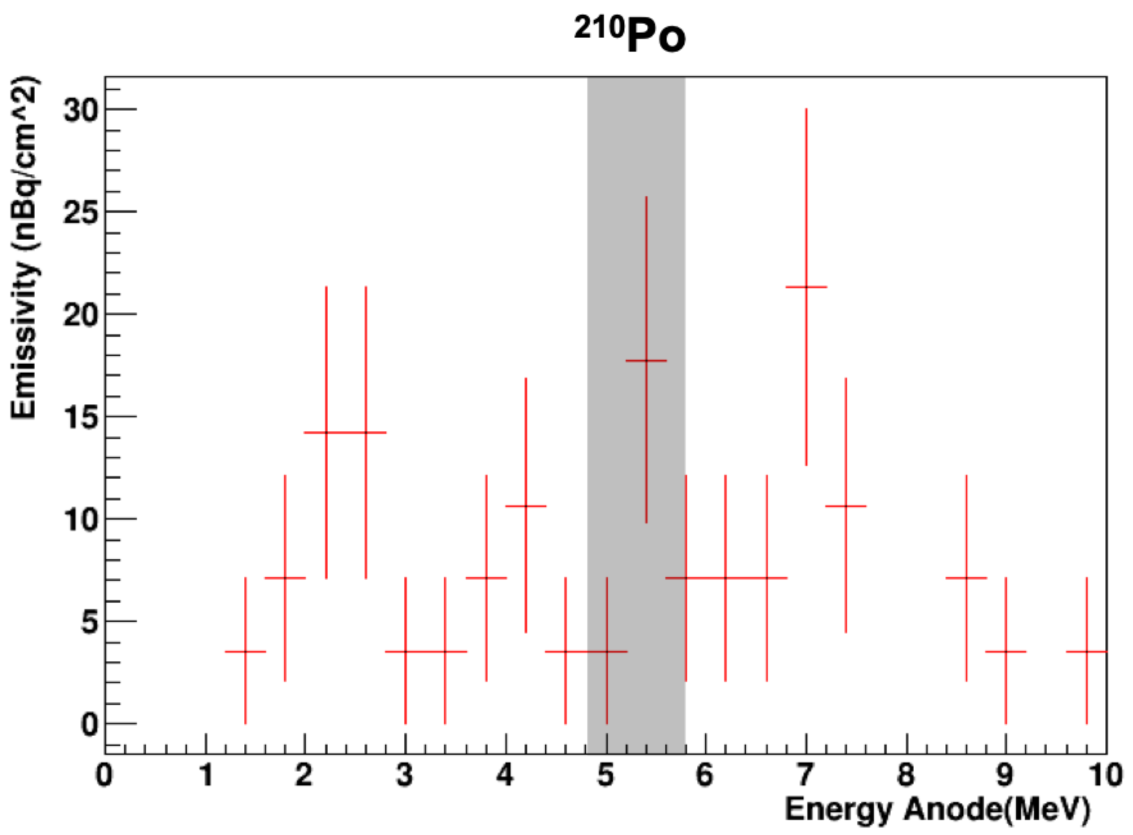
Surface Alpha Screening:



XIA uses uses pulse shape to reject events not originating from sample tray.



Ultra-pure PNNL Copper

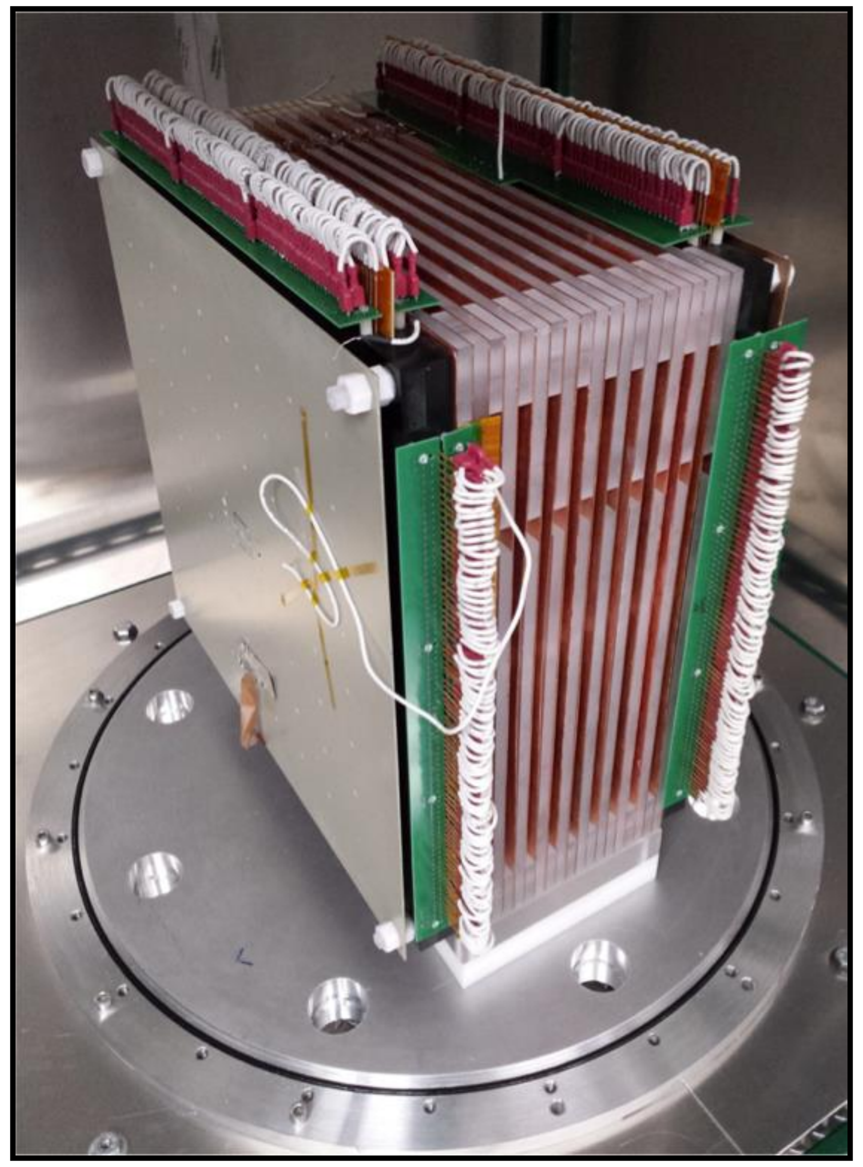
~25 nBq/cm^2 in ^{210}Po ROI

indicative of instrument background

Surface Beta Screening:

BetaCage:

South Dakota Mines, Caltech, PNNL U Alberta



Expected Sensitivity:

- *0.1 β keV^{-1} m^{-2} day^{-1}*
- *0.1 α m^{-2} day*
- *(0.1 α nBq/cm^2)*

Many other Options

Technique	Sensitivity
Radon Emanation	0.1-10 µBq/kg (Ra)
Immersion Whole Body Counters	10^{-13}-10^{-14} g/g (U/Th)
ICPMS (Inductively Coupled Plasma Mass Spectrometry)	ppt to ppt (U/Th/K)
SIMS/GDMS (Secondary Ion & Glow Discharge Mass Spectroscopy)	1 ppb (SIMS) 10-100ppt (GDMS)
AMS (Accelerator Mass Sepctroscopy)	< 1 ppt
Neutron Activation Analysis	100 pg (U), 10 ng (K)

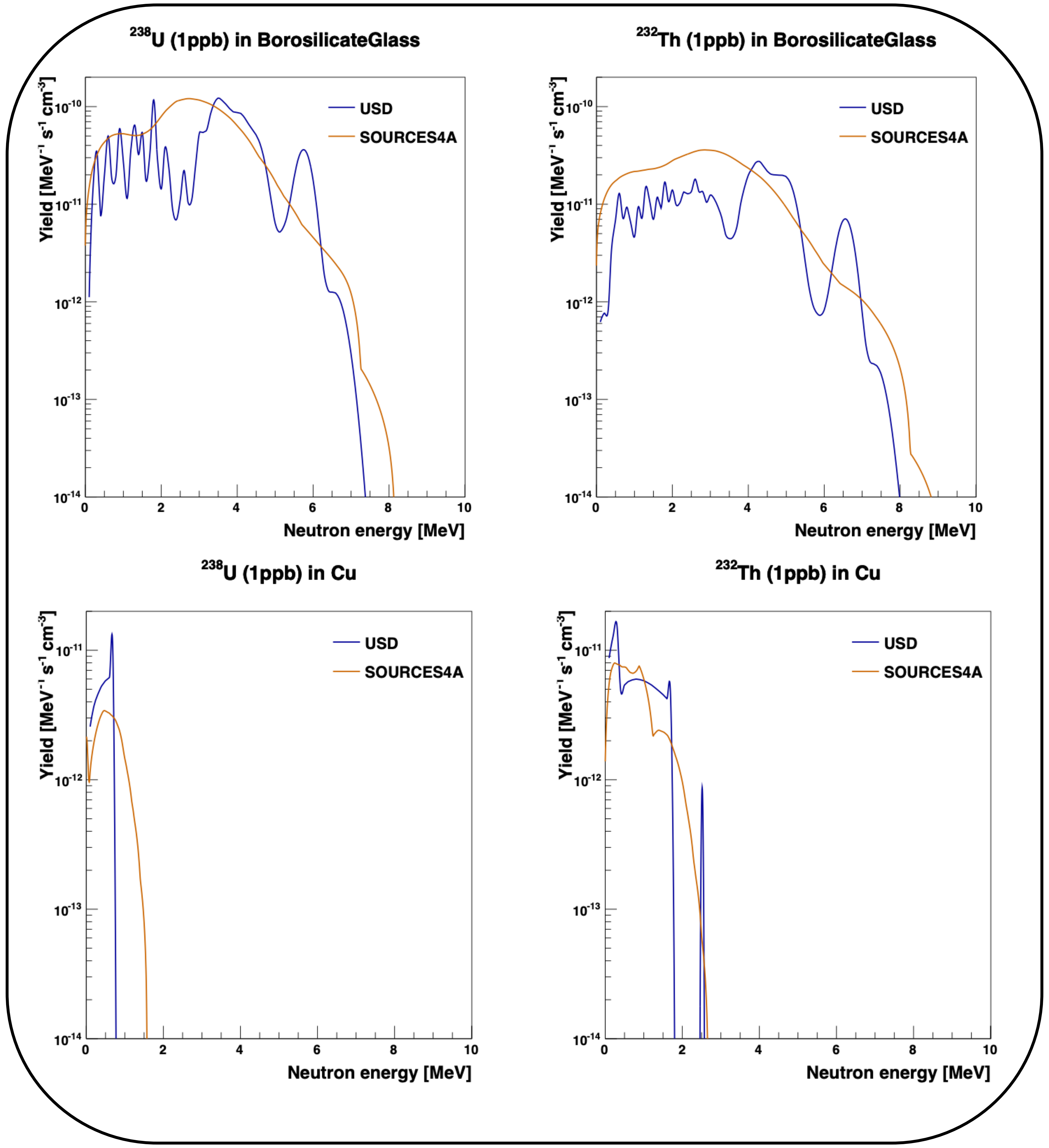
Modeling Backgrounds

- Three software frameworks exist to calculate the spectra of neutrons produced by (α-n) interactions.
  - SOURCES - (EMPIRE2.19 libraries for cross section inputs)
  - USD WebTool (TENDL 2012 libraries which are validated by TALYS for cross section inputs)
  - NeuCBOT (TALYS for cross section inputs)
- TENDL is a validated library and EMPIRE is recommended by the International Atomic Energy Agency, but neither can properly calculate all resonant behavior that is experimentally observed.
- Those spectra can be used in simulation to predict the number of background events from neutrons in an experiment.

NIM A. 888 (2018) 110-118

Framework Comparisons: USD Webtool vs Sources-4C

Calculated Radiogenic Neutron Spectra

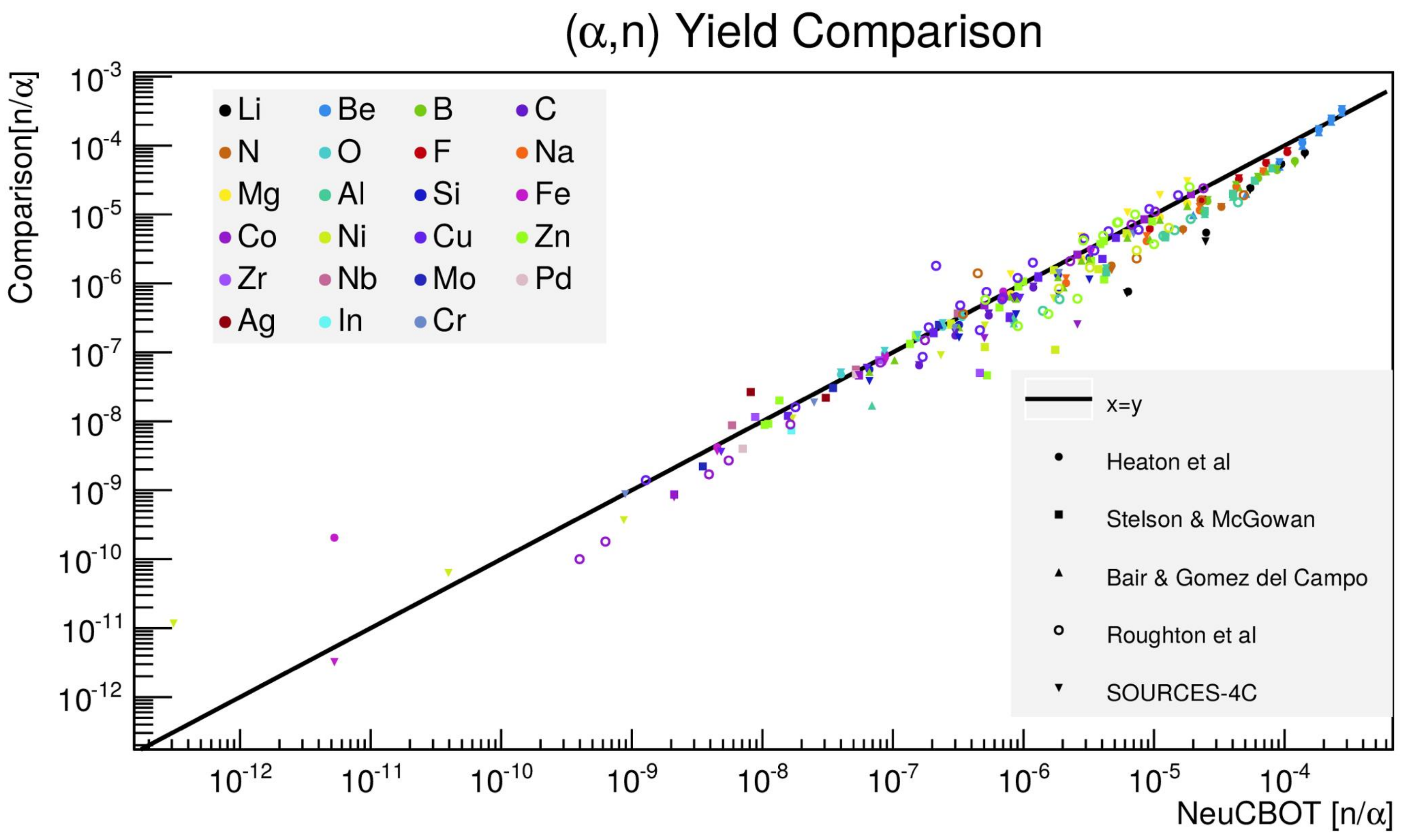


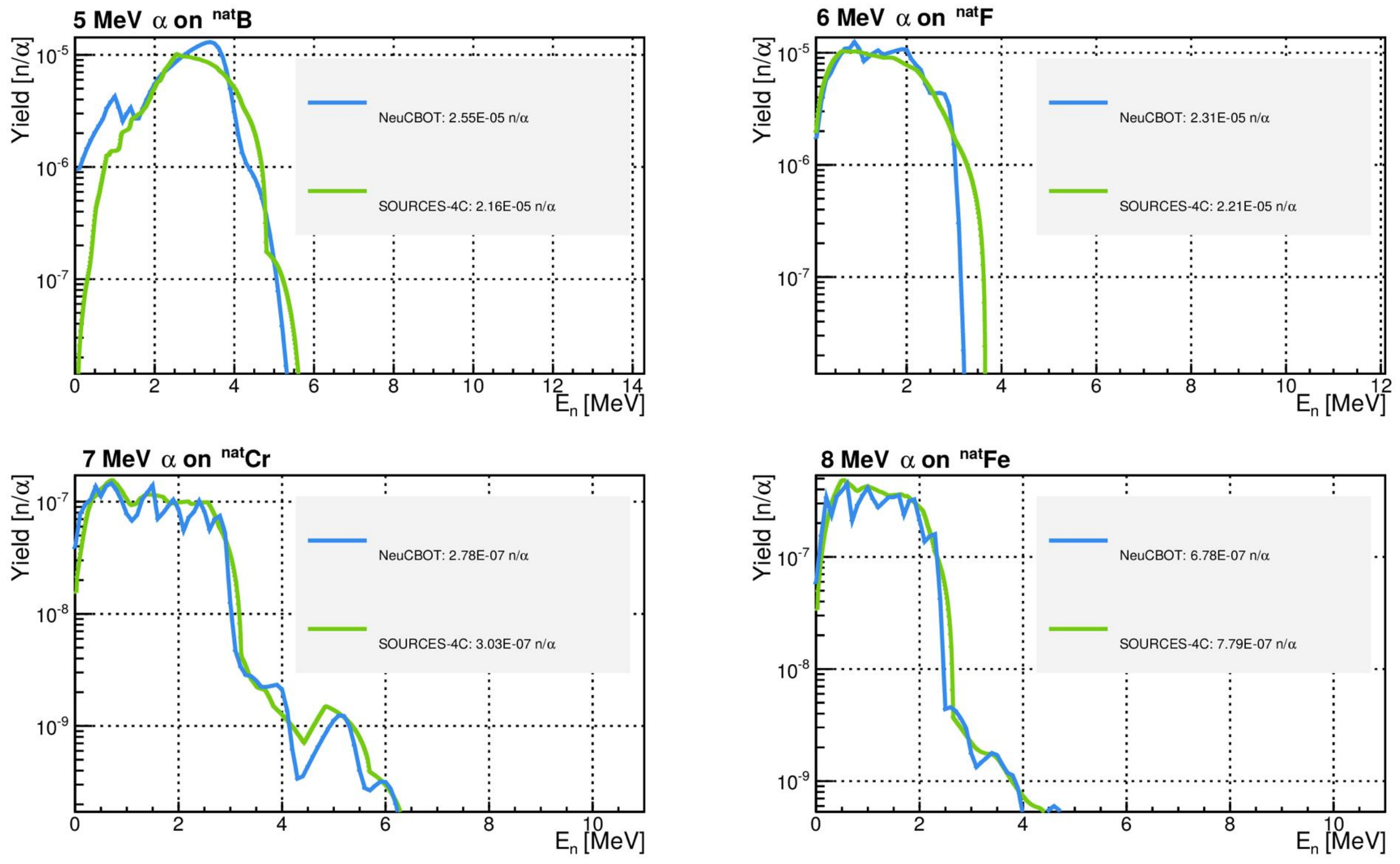
Material	Chain	Neutron Yield (n·s⁻¹·cm⁻³) SOURCES-4A	USD	Diff %
Cu	^{238}U	$2.84\ 10^{-12}$	$3.46\ 10^{-12}$	20
	^{232}Th	$9.49\ 10^{-12}$	$1.11\ 10^{-11}$	16
PE (CH_2)	^{238}U	$1.26\ 10^{-11}$	$9.56\ 10^{-12}$	-27
	^{232}Th	$5.28\ 10^{-12}$	$2.87\ 10^{-12}$	-59
Titanium	^{238}U	$1.04\ 10^{-10}$	$1.99\ 10^{-10}$	-63
	^{232}Th	$9.29\ 10^{-11}$	$1.24\ 10^{-10}$	-28
Stainless Steel	^{238}U	$3.10\ 10^{-11}$	$5.95\ 10^{-11}$	-63
	^{232}Th	$4.05\ 10^{-11}$	$6.80\ 10^{-11}$	-51
Pyrex	^{238}U	$2.30\ 10^{-10}$	$1.61\ 10^{-10}$	36
	^{232}Th	$8.66\ 10^{-11}$	$4.59\ 10^{-11}$	61
Borosilicate Glass	^{238}U	$3.48\ 10^{-10}$	$2.45\ 10^{-10}$	35
	^{232}Th	$1.27\ 10^{-10}$	$6.98\ 10^{-11}$	58
PTFE (CF_2)	^{238}U	$1.81\ 10^{-9}$	$1.60\ 10^{-9}$	12
	^{232}Th	$7.76\ 10^{-10}$	$5.42\ 10^{-10}$	36

$$\text{Diff \%} = \frac{\text{SOURCES} - \text{USD}}{(\text{SOURCES} + \text{USD})/2}$$

- Study found no major systematic differences between the two in terms input spectra, output spectra and yield.
- Both have errors in cross sections and outputs that may require a human eye to catch.

Framework Comparisons: NeuCBOT vs SOURCES-4C



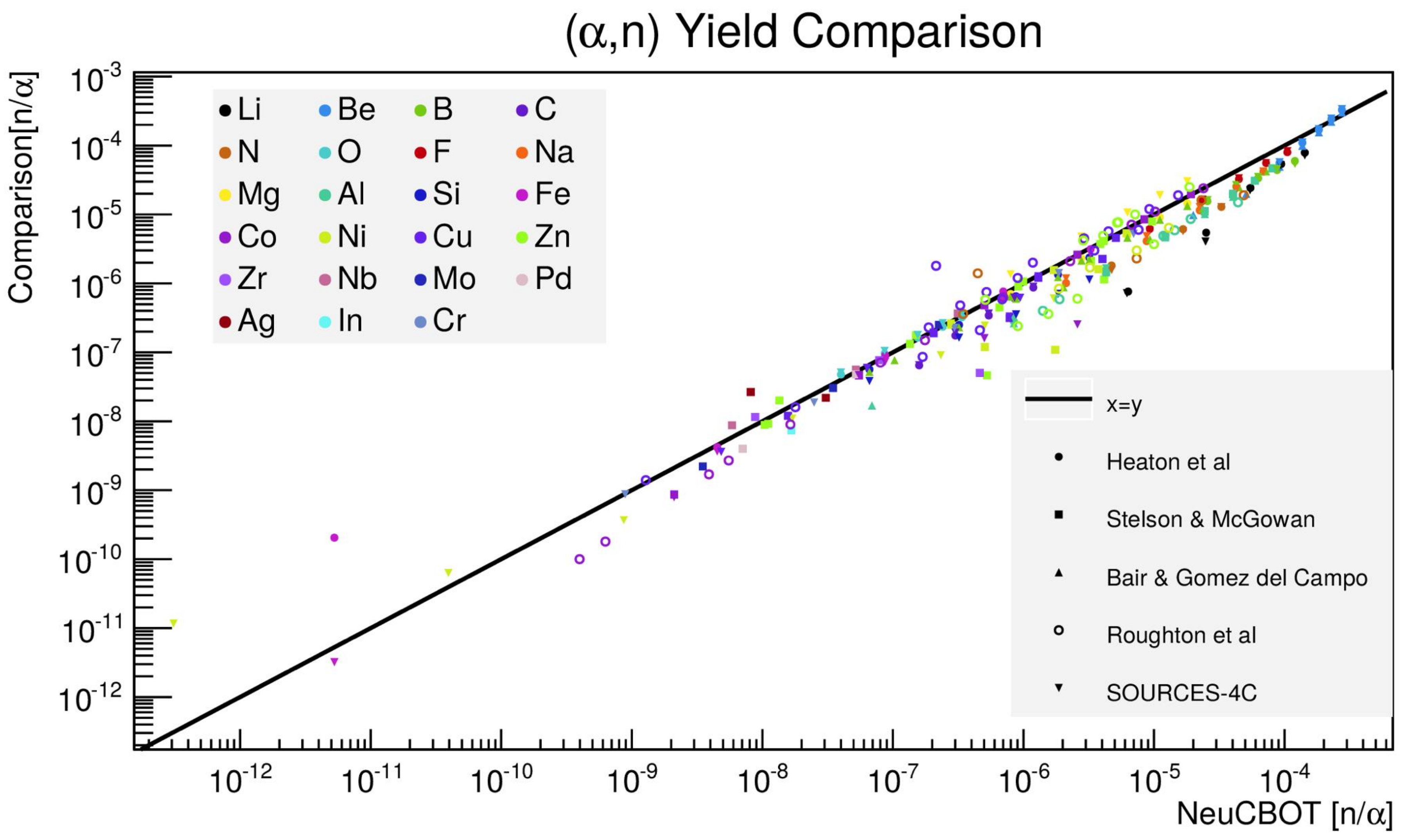


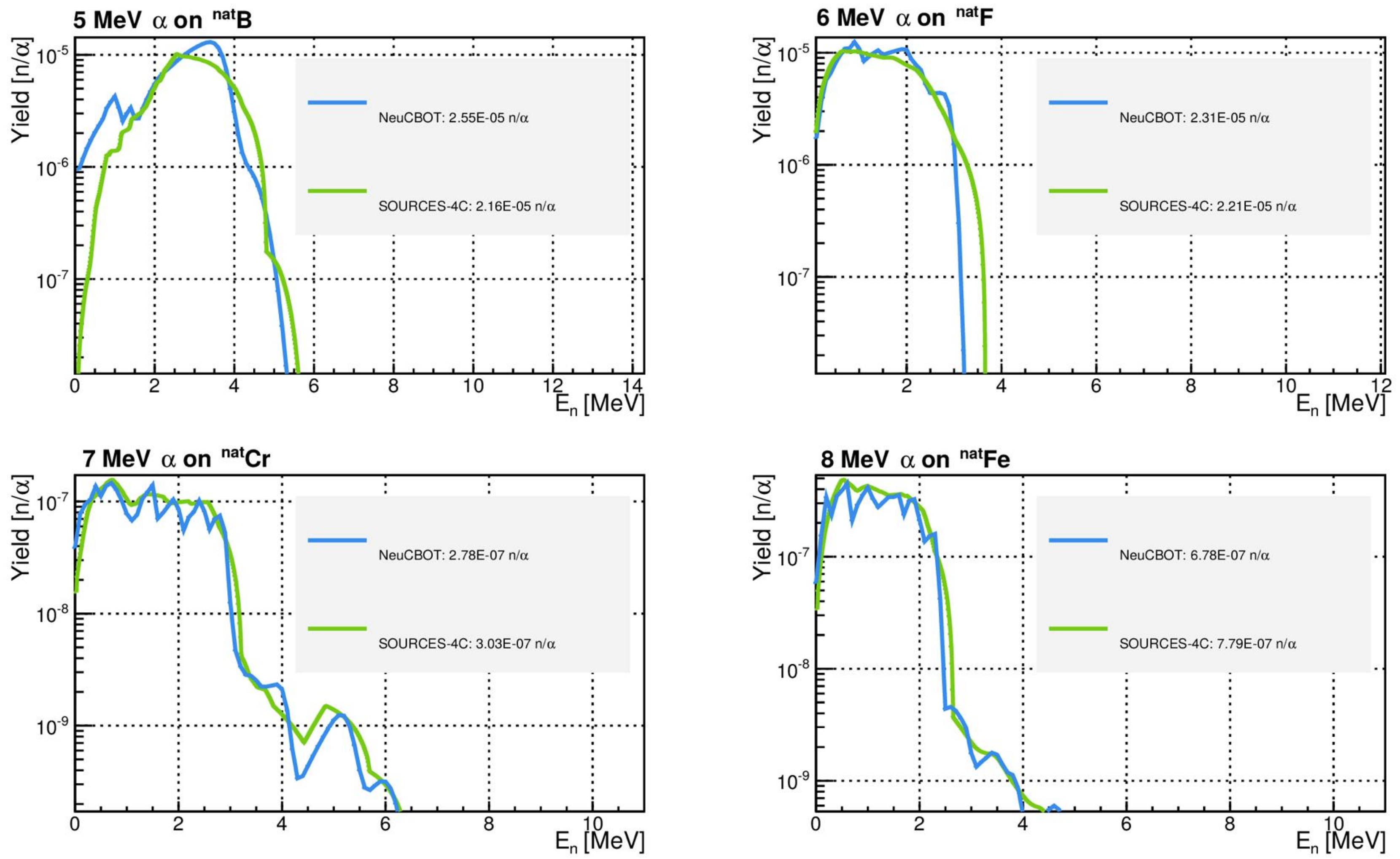
NeuCBOT used by DEAP to predict Neutrons in materials of interest.

NeuCBOT	n/s/Bq			
Material	**U238 upper**	**U238 lower**	**U235**	**Th232**
Borosilicate Glass	3.93E-06	1.76E-05	2.56E-05	2.43E-05
Acrylic	2.19E-07	9.72E-07	1.42E-06	1.33E-06
Invar	2.06E-12	2.58E-07	1.84E-07	1.08E-06
TPB	3.15E-07	1.35E-06	1.96E-06	1.84E-06
Polyethylene	2.52E-07	1.09E-06	1.58E-06	1.49E-06
Polystyrene	3.01E-07	1.29E-06	1.88E-06	1.77E-06
Stainless Steel	1.31E-09	5.52E-07	4.42E-07	1.96E-06
Argon	8.82E-08	1.41E-05	1.72E-05	2.64E-05

arXiv:1702.02465
S. Westerdale, TAUP 2017

Framework Comparisons: NeuCBOT vs SOURCES-4C





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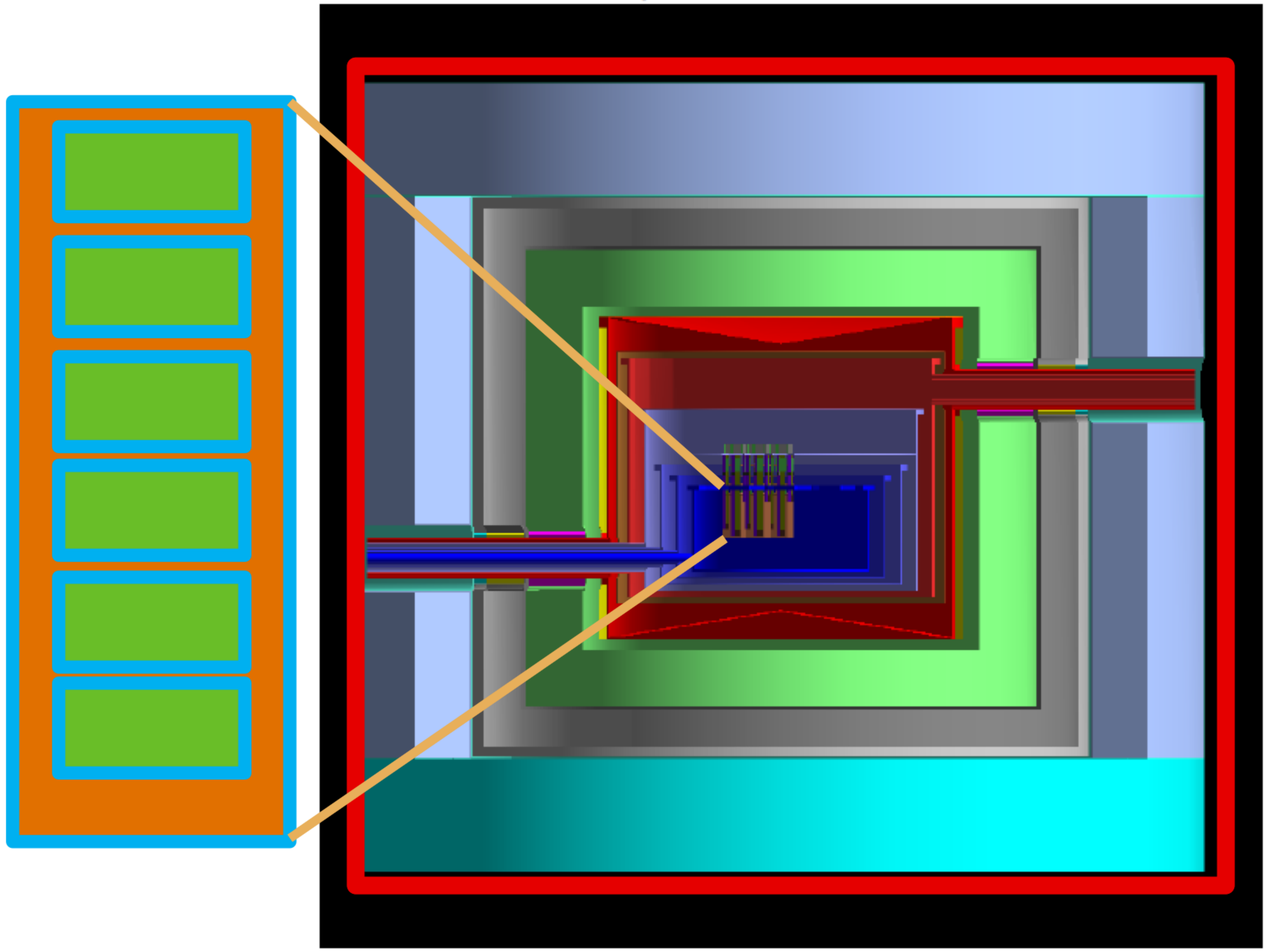
Invar	E-12			1.08E-06
TPB	E-07			1.84E-06
Polyethylene	E-07			1.49E-06
Polystyrene	E-07			1.77E-06
Stainless Steel	E-09			1.96E-06
Argon	8.82E-08	1.41E-05	1.72E-05	2.64E-05

NeuCBOT:
- 15 n/year from PMT glass
- 1 n/year from PMT ceramic
- 3 n/year from polystyrene filler foam

SOURCES-4C:
- 13 n/year from PMT glass
- 2 n/year from PMT ceramic
- 2 n/year from polystyrene filler foam

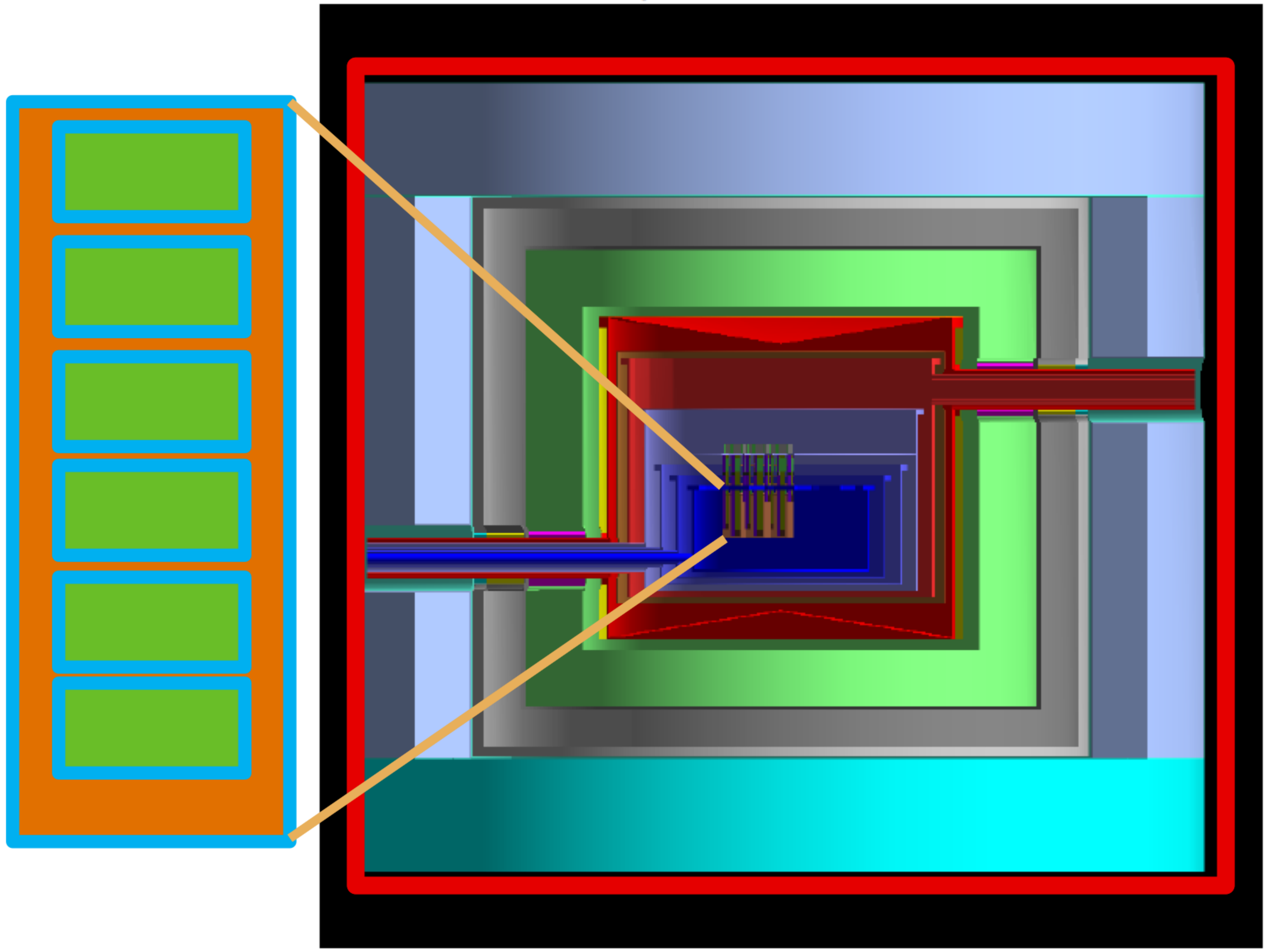
Simulation Tools



SuperCDMS Geometry in Geant4

- Geant4 simulations of backgrounds based on assay information

Simulation Tools



SuperCDMS Geometry in Geant4

- ➤ Geant4 simulations of backgrounds based on assay information
- ➤ Produce anticipated background spectra

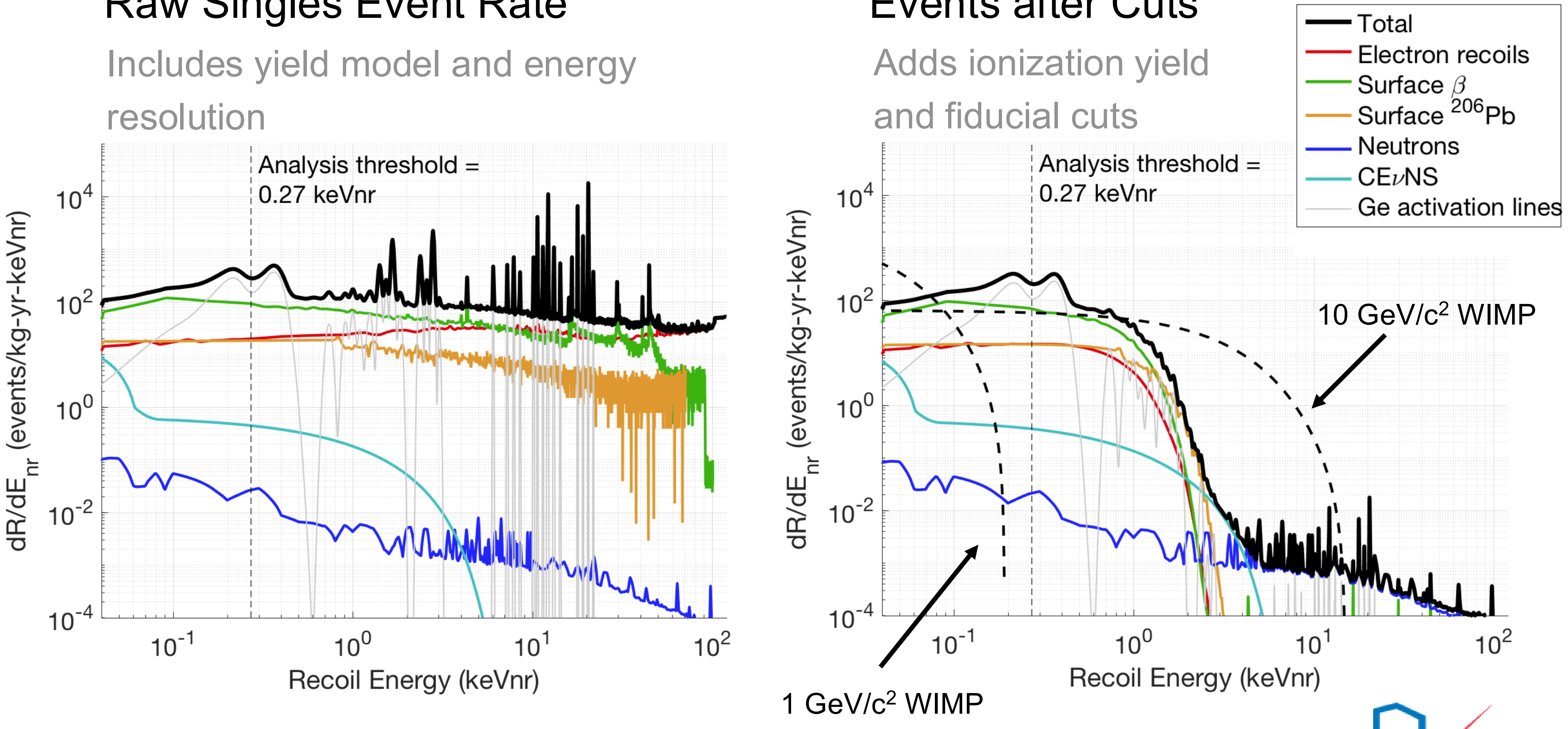
SuperCDMS anticipated background spectra (Ge iZIPs)

Raw Singles Event Rate

Includes yield model and energy resolution

Events after Cuts

Adds ionization yield and fiducial cuts



Background Inventory

SuperCDMS Background Inventory

Predicted rates in counts / kg*keVr*year

Category	Ge HV ERsingles	Si HV ERsingles	Ge iZIP ERsingles	Si iZIP ERsingles	Ge iZIP NRsingles ($x10^{-6}$)	Si iZIP NRsingles ($x10^{-6}$)
-Total	48.	360.	50.	400.	3200.	2300.
Coherent Neutrinos					2300.	1600.
-Detector Internal Contamination	24.	280.	4.7	250.	0	0
Tritium	24.	33.	4.7	6.6	0	0
Silicon-32	0	250.	0	250.	0	0
Other						
-Material Internal Contamination	17.	66.	36.	120.	370.	460.
+Housing and Towers	6.5	34.	19.	65.	51.	66.
+Readout Cables	0.31	0.46	0.39	0.80	11.	15.
+SNOBOX Cans	4.0	13.	6.5	22.	68.	75.
Kevlar Ropes	2.1	5.1	2.7	8.3	3.6	4.0
+Calibration	0.92	3.0	1.2	3.6	0.05	0.05
+Shield Materials	3.5	10.	5.3	17.	240.	300.
Bulk Pb-210 in Lead	0.07	0	0.22	0.75		
-Material Internal Activation	2.3	8.4	3.9	13.		
Housing and Towers	0.64	2.5	1.0	4.1		
+SNOBOX	1.5	5.6	2.8	8.9		
Shield	0.07	0.28	0.14	0.41		
Other						
+Non-line-of-sight Surfaces	1.6	5.0	2.9	9.3	35.	41.
Prompt Interstitial Radon	0.61	1.8	0.87	2.7		
+Cavern Environment	2.3	3.5	2.0	9.6	330.	160.
Cosmic Ray Flux	0.00	0.00	0.00	0.00	85.	99.

LZ Background Inventory

Intrinsic Contamination Backgrounds	Mass (kg)	Composite	U early (mBq/kg)	U late (mBq/kg)	Th early (mBq/kg)	Th late (mBq/kg)	Co60 (mBq/kg)	K40 (mBq/kg)	n/yr (inc. S.F. rej.)	ER (cts)	NR (cts) (w/ SF rej.)
Upper PMT Structure	46.7	Y	5.32	0.80	1.08	0.72	0.03	3.81	5.23	0.14	0.001
Lower PMT Structure	71.7	Y	2.62	0.24	0.41	0.30	0.00	1.33	6.57	0.08	0.001
R11410 3" PMTs	91.9	Y	71.63	3.20	3.12	2.99	2.91	15.41	[illegible]	1.47	0.013
R11410 PMT Bases *	2.8	Y	369.62	75.87	38.91	33.07	0.97	50.58	[illegible]	0.37	0.003
R8778 2" PMTs	6.1	Y	138.02	59.39	16.93	16.90	16.25	412.67	[illegible]	0.13	0.008
R8520 Skin 1" PMTs	2.1	Y	62.17	5.29	4.91	4.85	24.44	[illegible]	53.71	0.02	0.006
R8520 Skin PMT Bases *	0.2	Y	212.95	108.46	42.19	37.62	2.23	[illegible]	3.62	0.00	0.000
PMT Cabling	62.5	Y	5.81	7.05	1.24	1.62	[illegible]	6.30	0.75	0.68	0.000
TPC PTFE	184.0	N	0.02	0.02	0.03	0.03	[illegible]	0.12	22.54	0.06	0.008
Grid Wires	0.18	N	1.20	0.27	0.33	[illegible]	1.60	0.40	0.00	0.00	0.000
Grid Holders	92.3	Y	2.86	0.83	0.94	[illegible]	1.42	2.82	20.71	0.97	0.008
Field Shaping Rings	92.5	Y	5.49	1.14	0.72	[illegible]	0.00	2.00	41.04	0.98	0.016
TPC Sensors	4.45	Y	21.17	5.04	[illegible]	1.56	1.36	9.36	4.96	0.02	0.000
TPC Thermometers	0.57	Y	26.57	11.84	[illegible]	4.31	0.99	462.60	1.79	0.06	0.000
Xe Recirculation Tubing	15.1	Y	0.79	0.18	0.23	0.33	1.05	0.30	0.64	0.00	0.000
HV Conduits and Cables	137.7	Y	3.6	[illegible]	0.6	0.8	1.4	2.5	26.5	0.05	0.006
HX and PMT Conduits	199.6	Y	3.36	[illegible]	0.48	0.58	1.24	1.47	5.23	0.05	0.001
Cryostat Vessel	2705.0	Y	[illegible]	0.11	0.40	0.40	0.18	0.54	159.44	0.94	0.017
Cryostat Seals	33.7	Y	[illegible]	27.56	3.50	5.93	9.76	140.80	127.08	0.54	0.006
Cryostat Insulation	13.8	Y	85.84	36.55	11.44	9.15	3.40	78.87	35.33	0.48	0.004
Cryostat Teflon Liner	26.0	[illegible]	0.02	0.02	0.03	0.03	0.00	0.12	3.18	0.00	0.000
Outer Detector Tanks	4299.3	[illegible]	3.28	0.60	0.54	0.57	0.03	4.78	200.65	0.96	0.002
Liquid Scintillator	17640.3	Y	0.01	0.01	0.01	0.01	0.00	0.00	14.28	0.03	0.000
Outer Detector PMTs	204.7	Y	570	470	395	388	0.00	534	7 587	0.01	0.000
Outer Detector PMT Supports	770.0	N	12.35	12.35	4.07	4.07	9.62	9.29	258.83	0.00	0.000
Subtotal (Detector Components)										8.01	0.101
222Rn (1.63 μBq/kg)										588	-
220Rn (0.08 μBq/kg)										99	-
natKr (0.015 ppt g/g)										24.5	-
natAr (0.45 ppb g/g)										2.47	-
210Bi (0.1 μBq/kg)										40.0	-
Laboratory and Cosmogenics										4.3	0.06
Fixed Surface Contamination										0.19	0.39
Subtotal (Non-ν counts)										767	0.55
Physics Backgrounds											
136Xe 2νββ										67	0
Astrophysical ν counts (pp+7Be+13N)										255	0
Astrophysical ν counts (8B)										0	0**
Astrophysical ν counts (Hep)										0	0.21
Astrophysical ν counts (diffuse supernova)										0	0.05
Astrophysical ν counts (atmospheric)										0	0.46
Subtotal (Physics backgrounds)										322	0.72
Total										1 090	1.27
Total (with 99.5% ER discrimination, 50% NR efficiency)										5.44	0.63
										6.08	

Detector components from assays

Xenon contaminants

External backgrounds

Physics: Neutrinos!

- ➤ Background inventories of components and their required purity can be made.
- ➤ Provides a tool that can be used for material and vendor selection.

Material Selection

Community Assays

Pacific Northwest NATIONAL LABORATORY

radiopurity.org

SNOLAB

documentation

GitHub

about | search | advanced search | insert | update

Query Assistant

1 Bq U-238/kg	=	81 ppb U	(81 x 10^{-9} gU/g)
1 Bq Th-232/kg	=	246 ppb Th	(246 x 10^{-9} gTh/g)
1 Bq K-40/kg	=	32300 ppb K	(32300 x 10^{-6} gK/g)
1 Bq U-235/kg	=	1.76 ppm U	(1.76 x 10^{-6} gU/g)

Search for records containing the term...

Copper

include synonyms

search

advanced search

RESULTS

num records: 139

Units:

Units Convert

name: Copper	**grouping:** ILIAS UKDM	**published**	**U-238**: 0.5 ppb **Th-232**: 0.5 ppb **K-40**: 0.01 ppm
name: Copper	**grouping:** ILIAS UKDM	**published**	**U-238**: 0.005 ppb **Th-232**: 0.004 ppb **Rb**: 2.6 ppb **K-40**: 0.01 ppm
name: Copper, screens, support	**grouping:** EDELWEISS (2011)	**published**	**Ra-226**: 0.016 mBq/kg **Th-228**: 0.012 mBq/kg **K-40**: 0.11 mBq/kg **Co-60**: 0.018 mBq/kg

User Interface

name: Au-plated Cu rods **grouping:** XENON1T **published**

U-235: 0.94 mBq/kg **U-238**: 20.4 mBq/kg **Ra-226**: 1.1 mBq/kg
Ra-228(Th-232): 1.6 mBq/kg **Th-228**: 1.1 mBq/kg **K-40**: 83 mBq/kg
Co-60: 0.49 mBq/kg **Cs-137**: 0.3 mBq/kg

database id: 60e5f48705b060b951dbf398
grouping: XENON1T
data reference (publication): Aprile, E., Aalbers, J., Agostini, F. et al., Eur. Phys. J. C 77, 890 (2017)

sample info

- **name:** Au-plated Cu rods
- **description:** Au-plated Cu rods, 2.4 kg, Copper
- **source:** Dörrer

measurement info

- **institution:** Gator
- **values:**

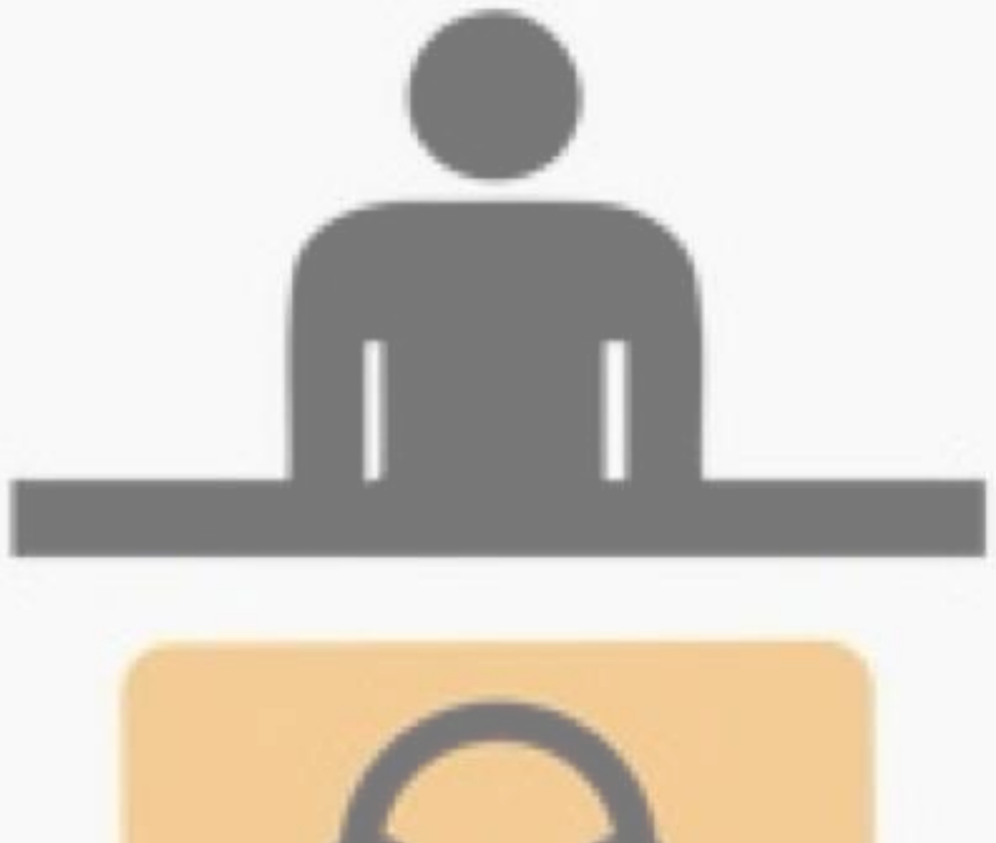
U-235	<	0.94	mBq/kg
U-238	<	20.4	mBq/kg
Ra-226	<	1.1	mBq/kg
Ra-228(Th-232)	<	1.6	mBq/kg
Th-228	<	1.1	mBq/kg
K-40	=	83	mBq/kg ± 9 mBq/kg
Co-60	<	0.49	mBq/kg
Cs-137	<	0.3	mBq/kg

data input

- **name:** Arsalan Khuwaja
- **contact:** akhuwaja@ryerson.ca
- **data input date:** 2020-08-29



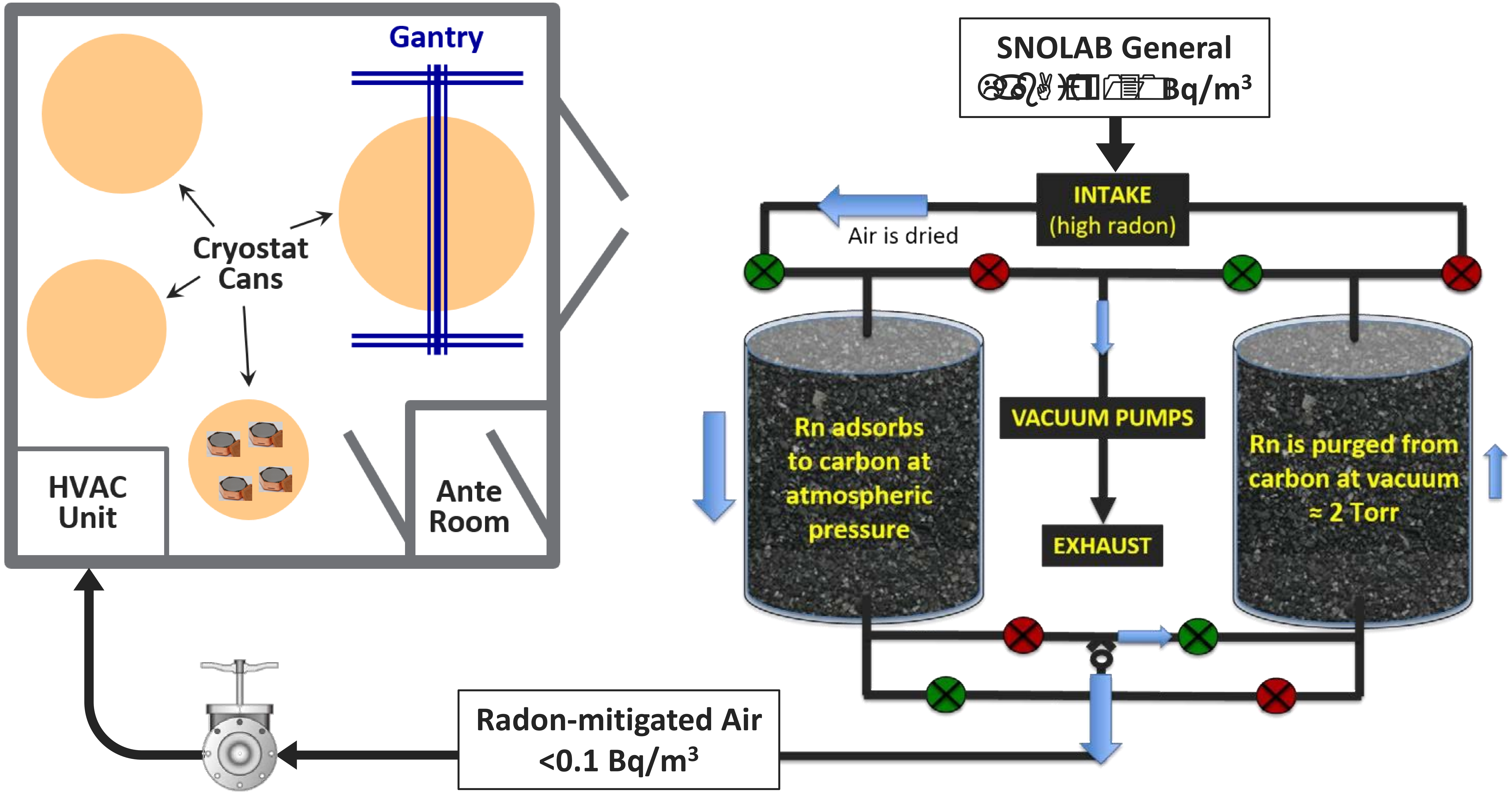
Material Handling

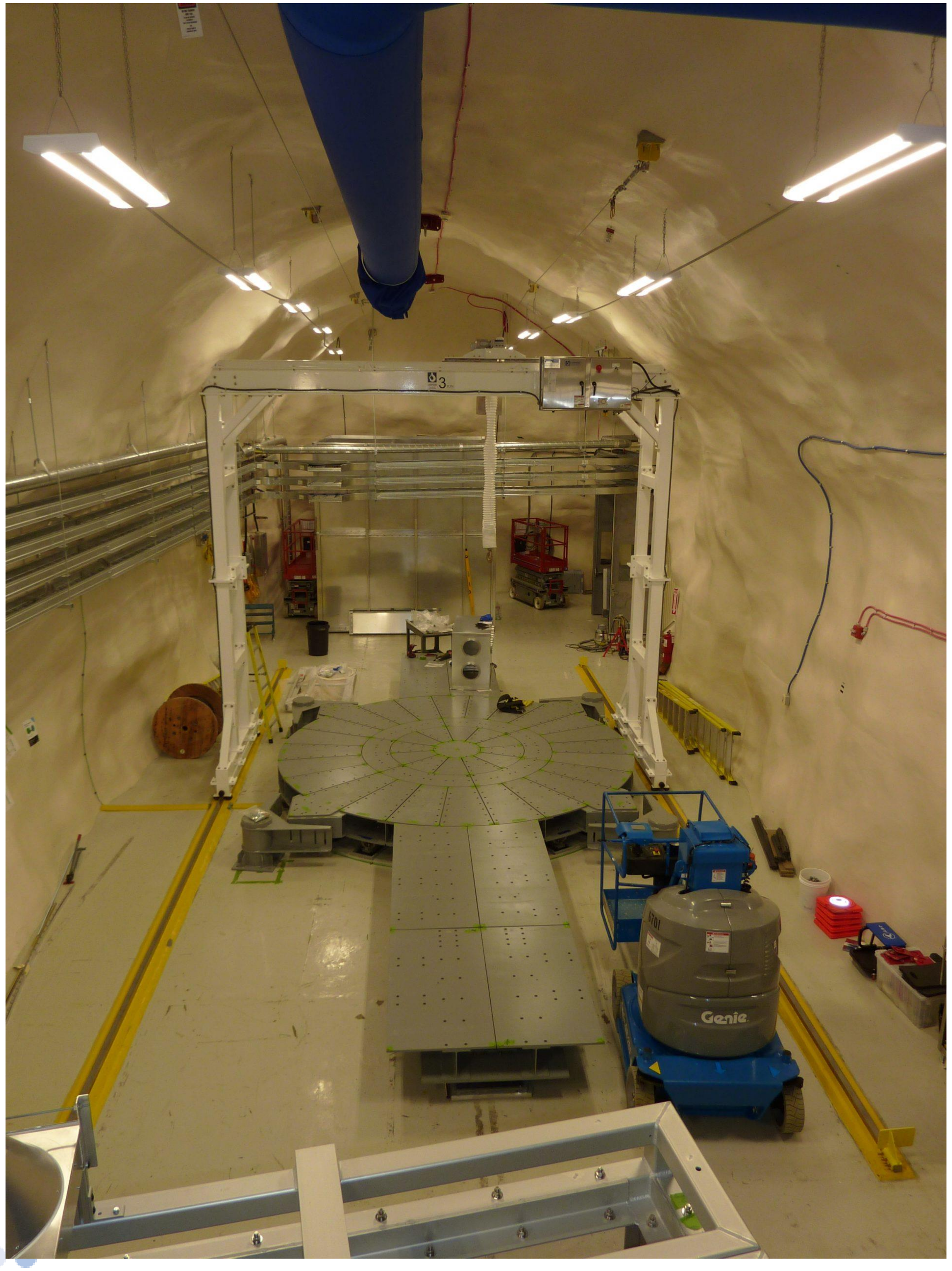

Low Radon Cleanroom @ SNOLAB via Vacuum Swing Absorption (VSB)

Class-100 Low-radon Cleanroom

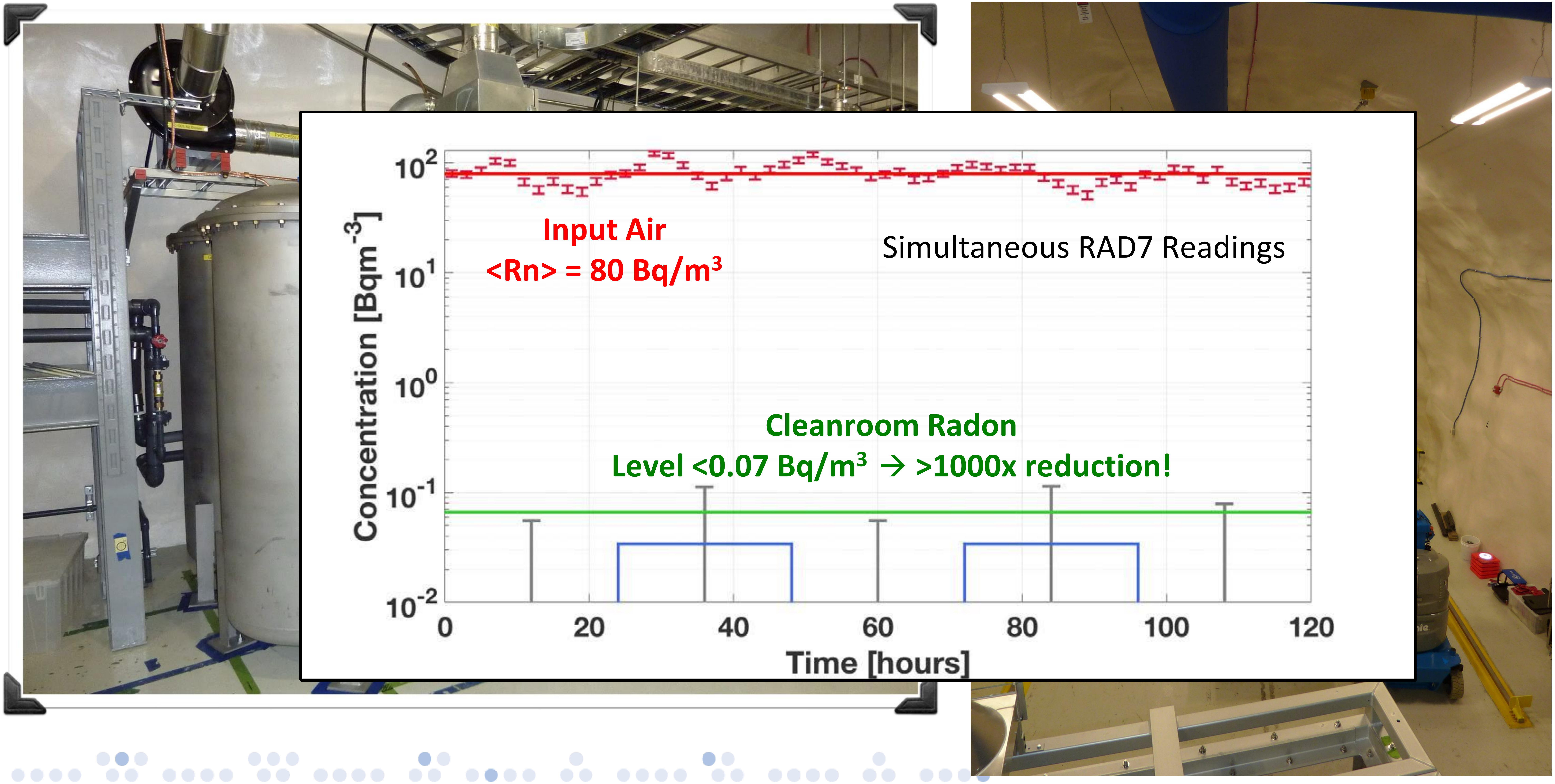
Custom-built Radon Mitigation System



VSA Radon System at SNOLAB



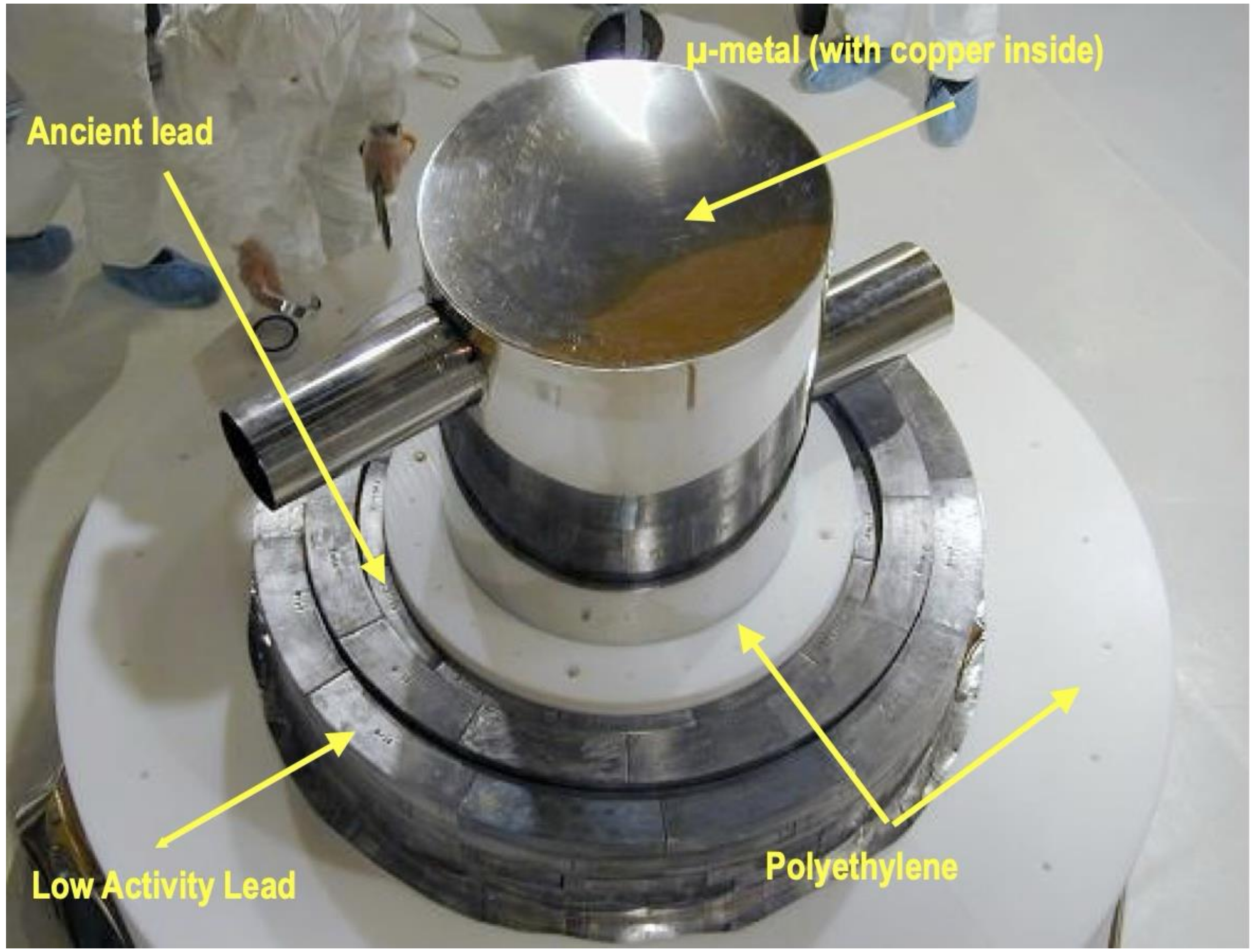
VSA Radon System at SNOLAB



VSA Radon System at SNOLAB

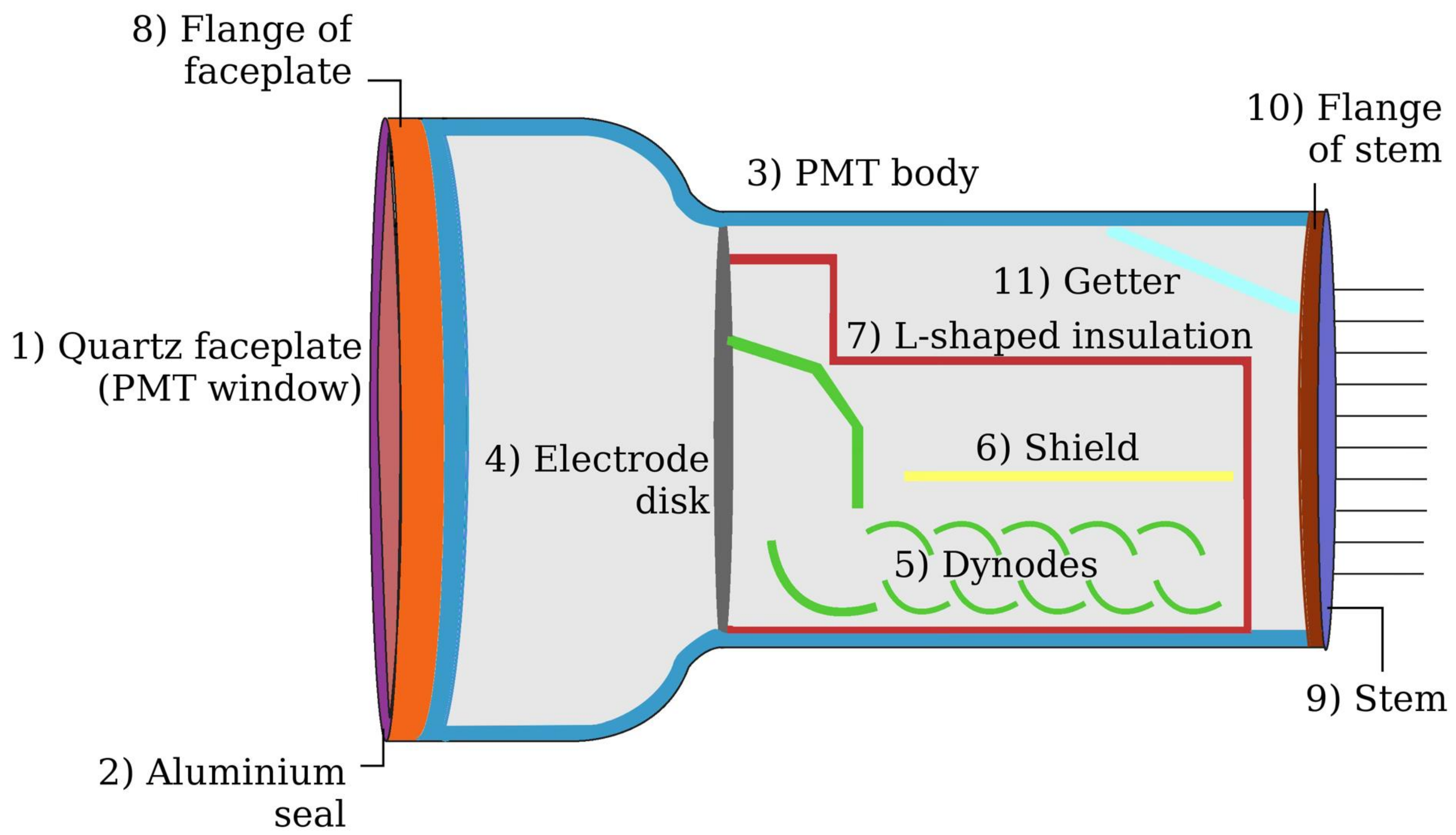
Material Purification

Use Cleanest Materials Possible



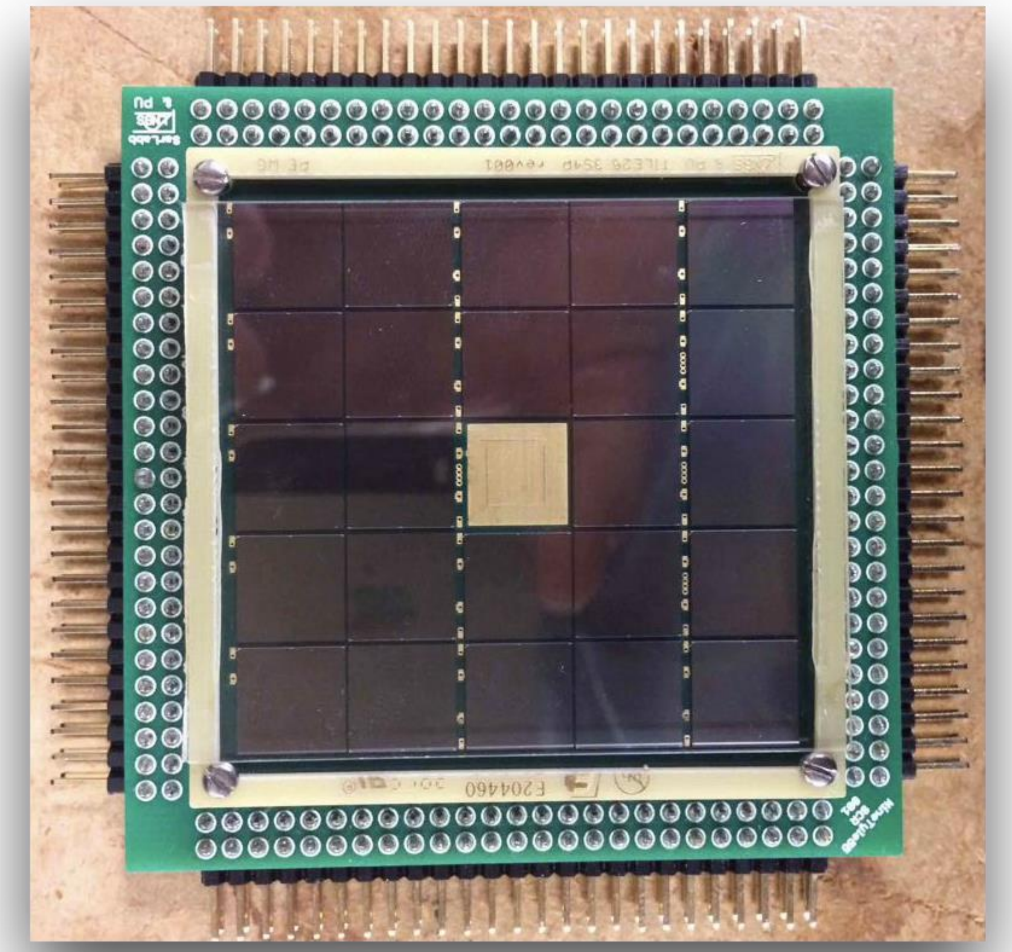
Shield made from Low Activity and Ancient Lead (SuperCDMS Soudan)

Development of Low Radioactivity PMTs (XENON1T)



arXiv:1503.07698

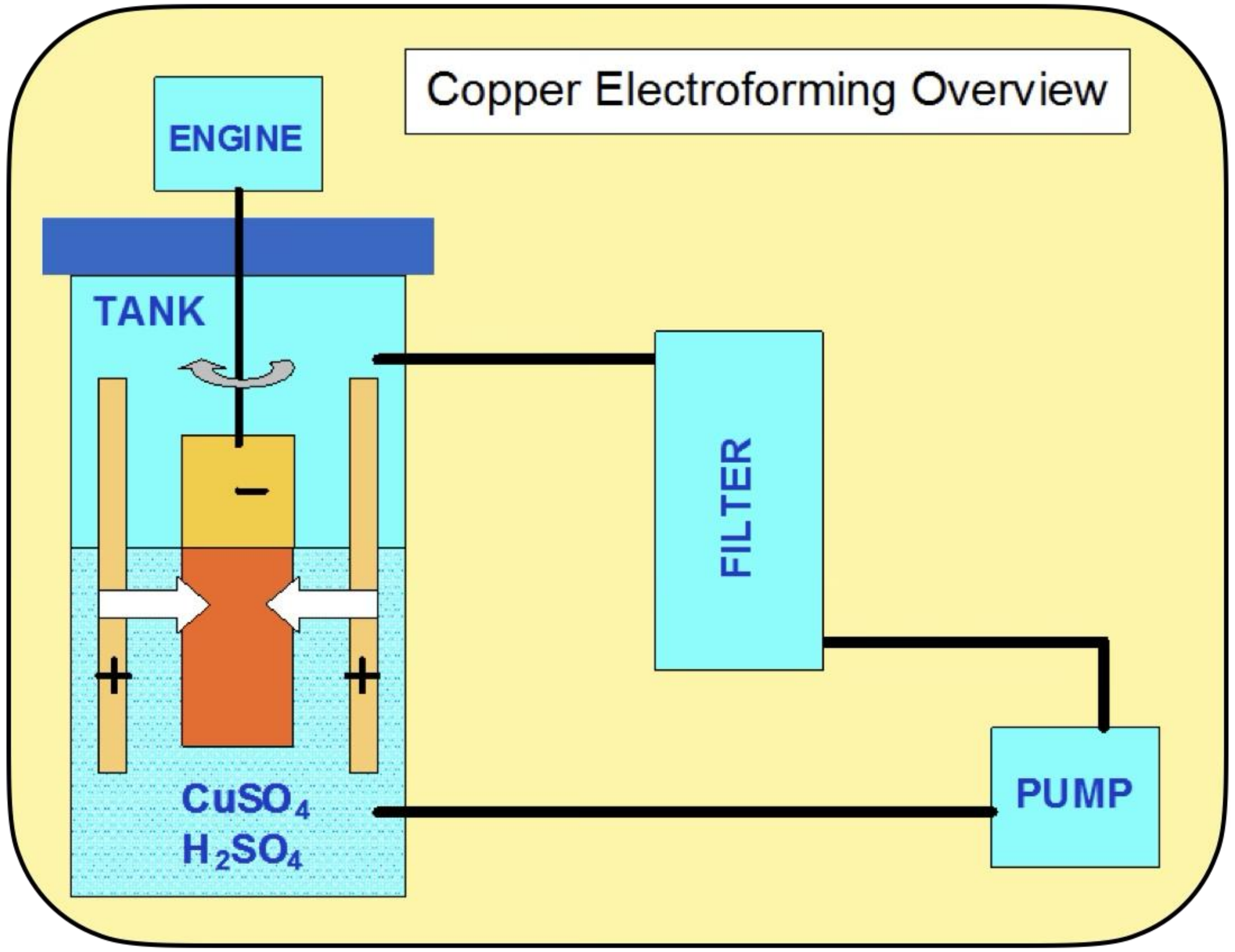
SiPMs replace PMTs (Darkside)



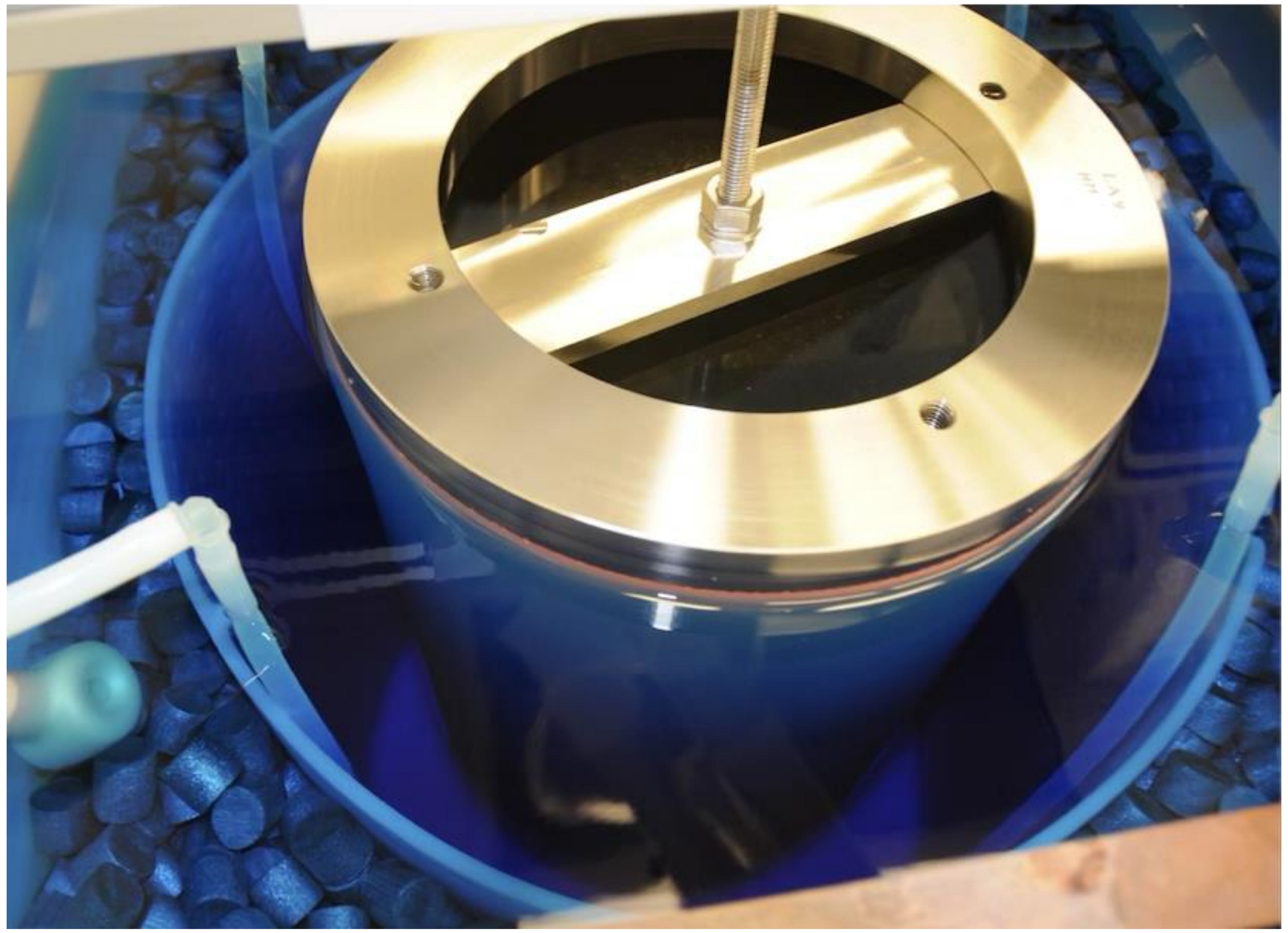
arXiv: 1706.04220

Make what you can't find

Electroforming is a method of producing pieces by the deposition of a metal onto a mold, which is subsequently removed.



Electroforming of copper at PNNL

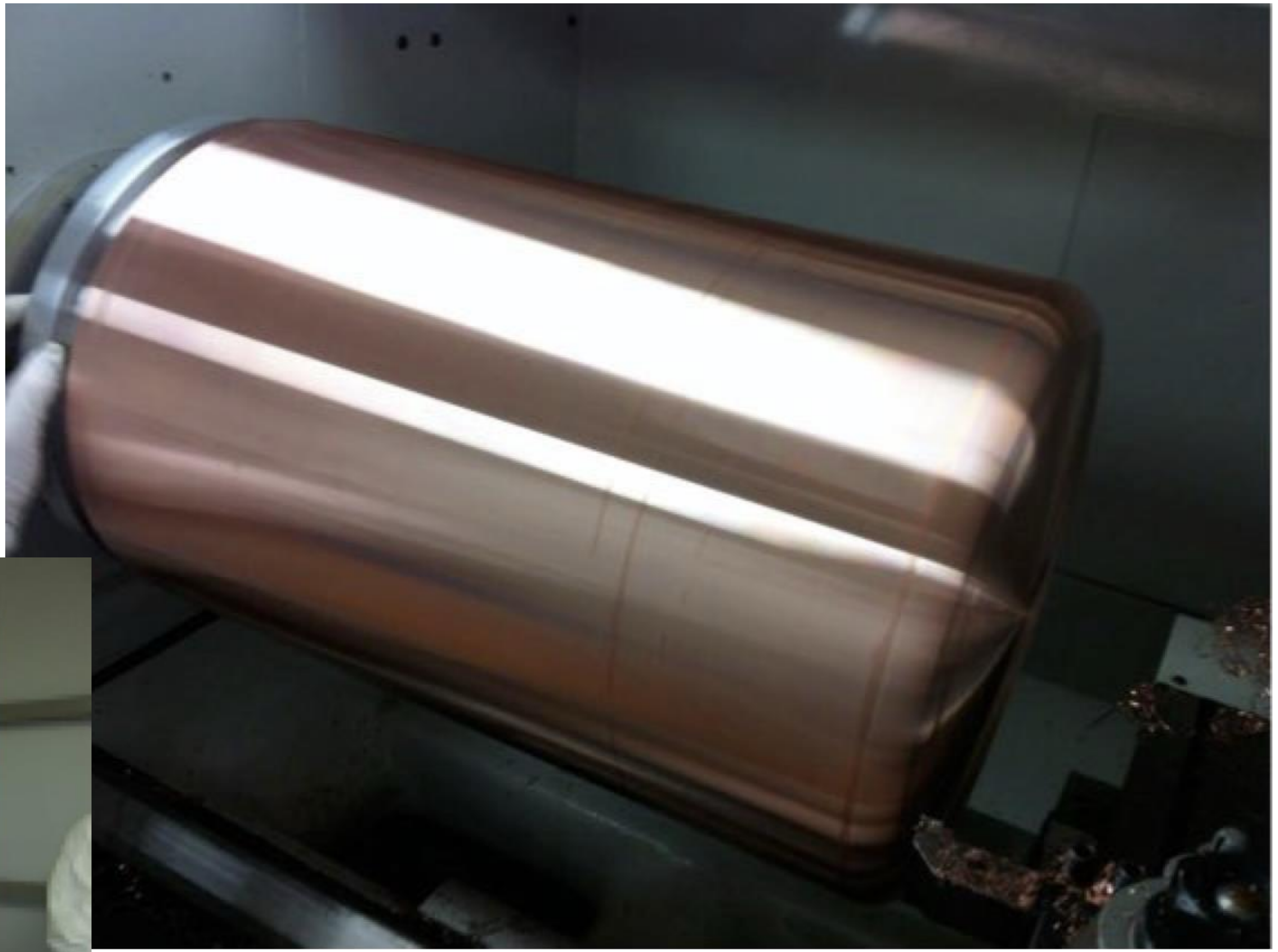


Th decay chain (ave) ≤ 0.1 μBq/kg
U decay chain (ave) ≤ 0.1 μBq/kg

MAJORANA copper was electroformed copper by PNNL at its shallow site.

Electroforming Baths

Inspection of Mandrels



Electroformed copper after turning on lathe.

Remove Contaminants

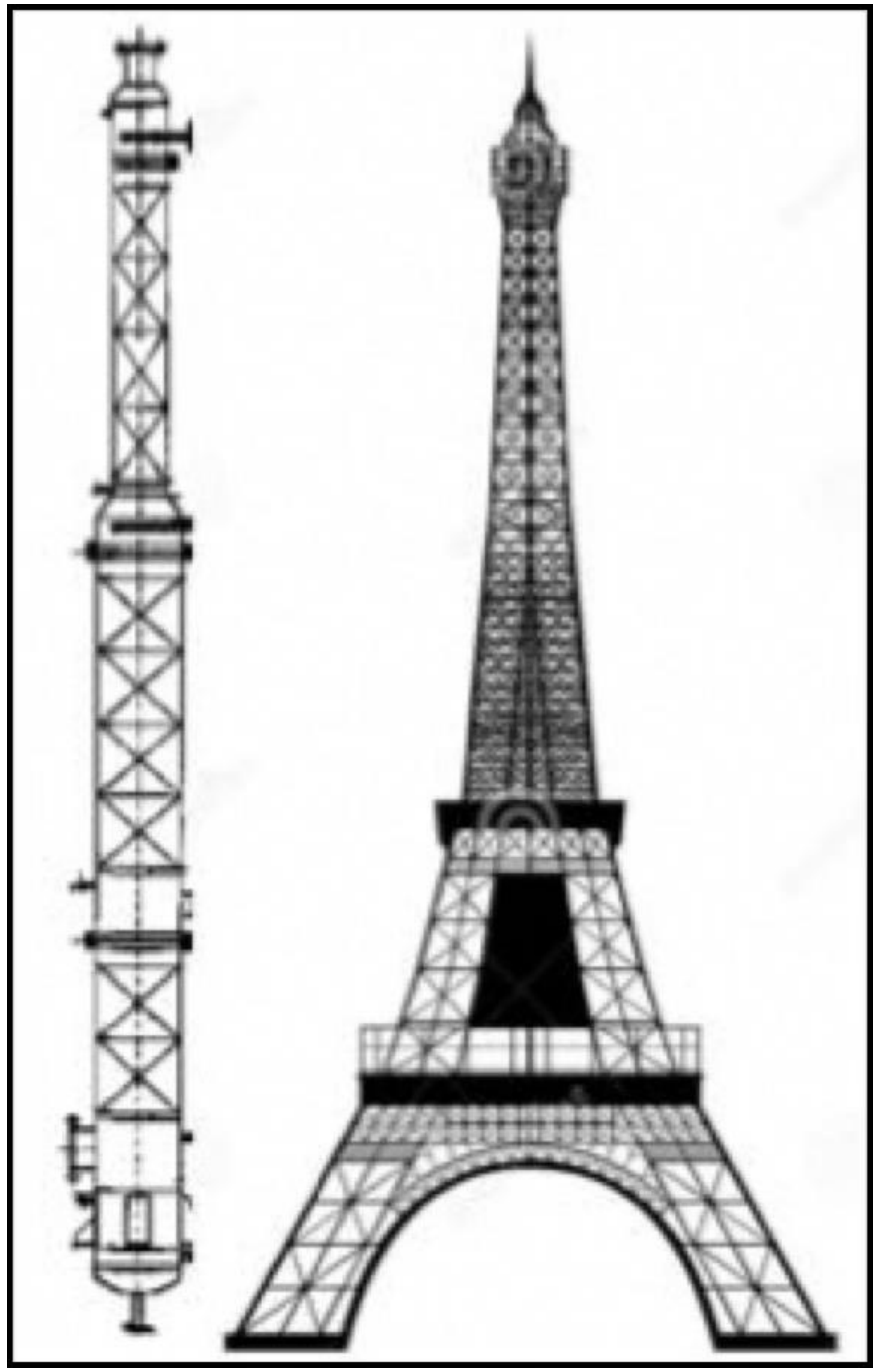
XENON1T Gas Purification System and Distillation Column

Continuous gas purification through heated getters

- Commercial Xe:
  1 ppm - 10 ppb of Kr
- XENON1T sensitivity demands: 0.2 ppt
- 5.5 m distillation column, 6.5 kg/h throughput

Purify what you can

DarkSide Cryogenic distillation column for purification of ^{39}Ar



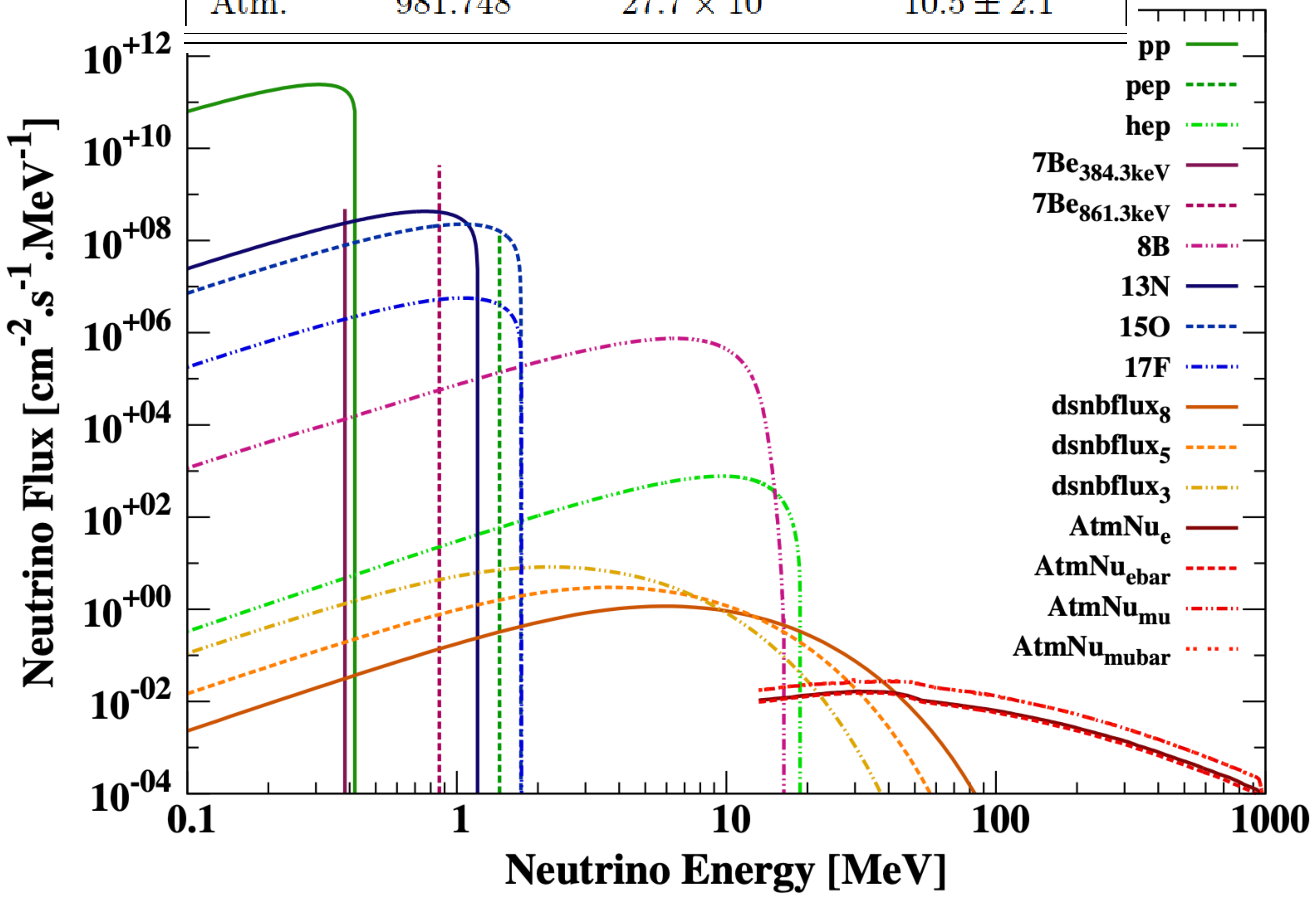
Future experiments will require a massive effort to extract and distill ^{39}Ar — plans for a 350 m distillation column are underway.
(Aria - Sardinia, Italy)

Irreducible & Unexpected Backgrounds

Neutrino Backgrounds

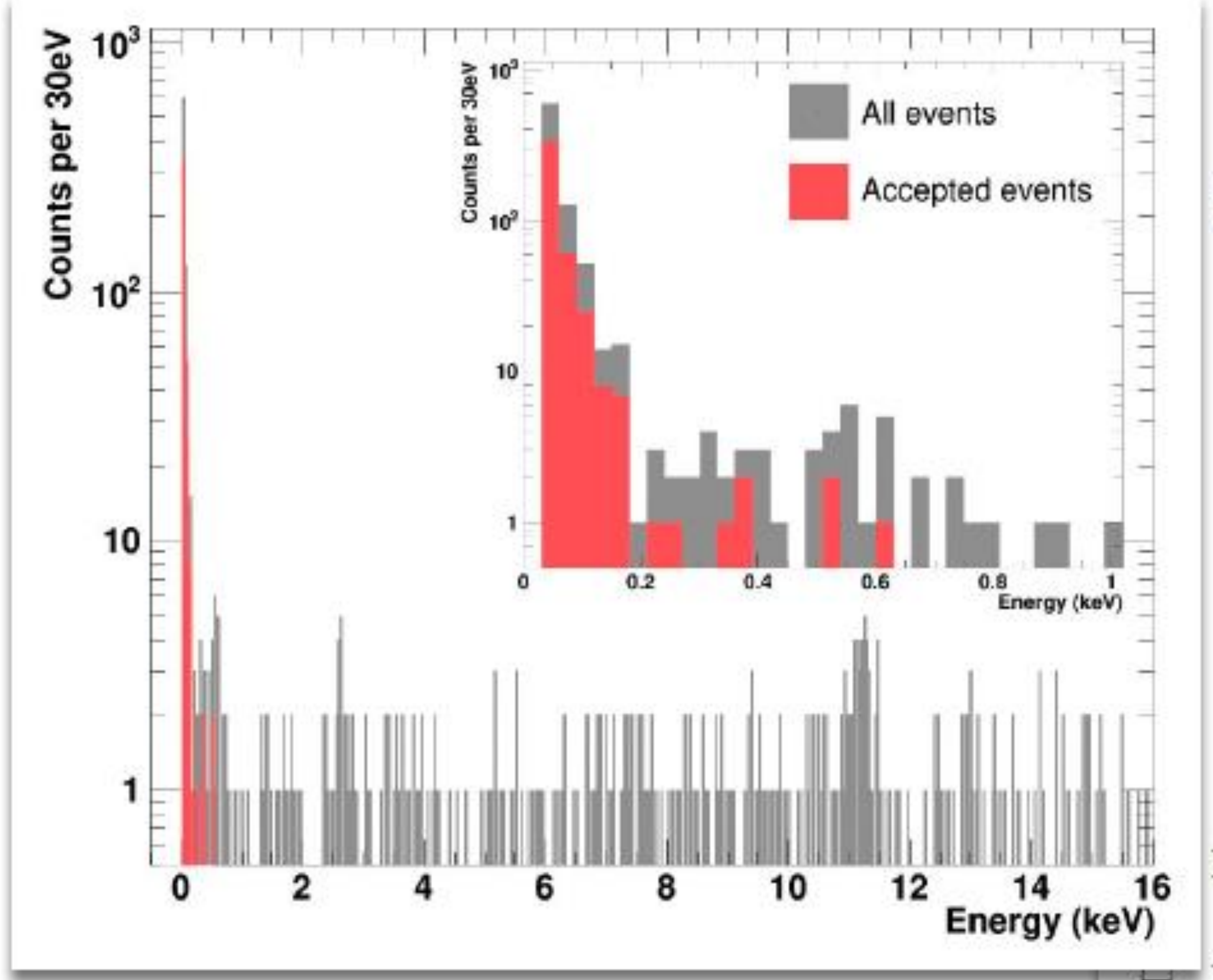
- Solar pp-neutrinos
  - low energies, high fluxes
  - contribute to the ER background via ν-e scattering at a level of 10 - 25 event per(ton x year)at low energies
- Neutrino-induced NR can not be distinguished from WIMP signals (8B solar neutrinos)
  - $\sim 10^3$ events per(ton x year) for heavy targets
  - Atmospheric Neutrinos and Diffuse Supernovae Neutrinos
    - ~1-5 events per (100 ton x year)

ν type	E_ν^{max} (MeV)	$E_{r_{Ge}}^{max}$ (keV)	ν flux ($cm^{-2}.s^{-1}$)
pp	0.42341	5.30×10^{-3}	$5.99 \pm 0.06 \times 10^{10}$
^{7}Be	0.861	0.0219	$4.84 \pm 0.48 \times 10^{9}$
pep	1.440	0.0613	$1.42 \pm 0.04 \times 10^{8}$
^{15}O	1.732	0.0887	$2.33 \pm 0.72 \times 10^{8}$
^{8}B	16.360	7.91	$5.69 \pm 0.91 \times 10^{6}$
hep	18.784	10.42	$7.93 \pm 1.27 \times 10^{3}$
DSNB	91.201	245	85.5 ± 42.7
Atm.	981.748	27.7×10^3	10.5 ± 2.1

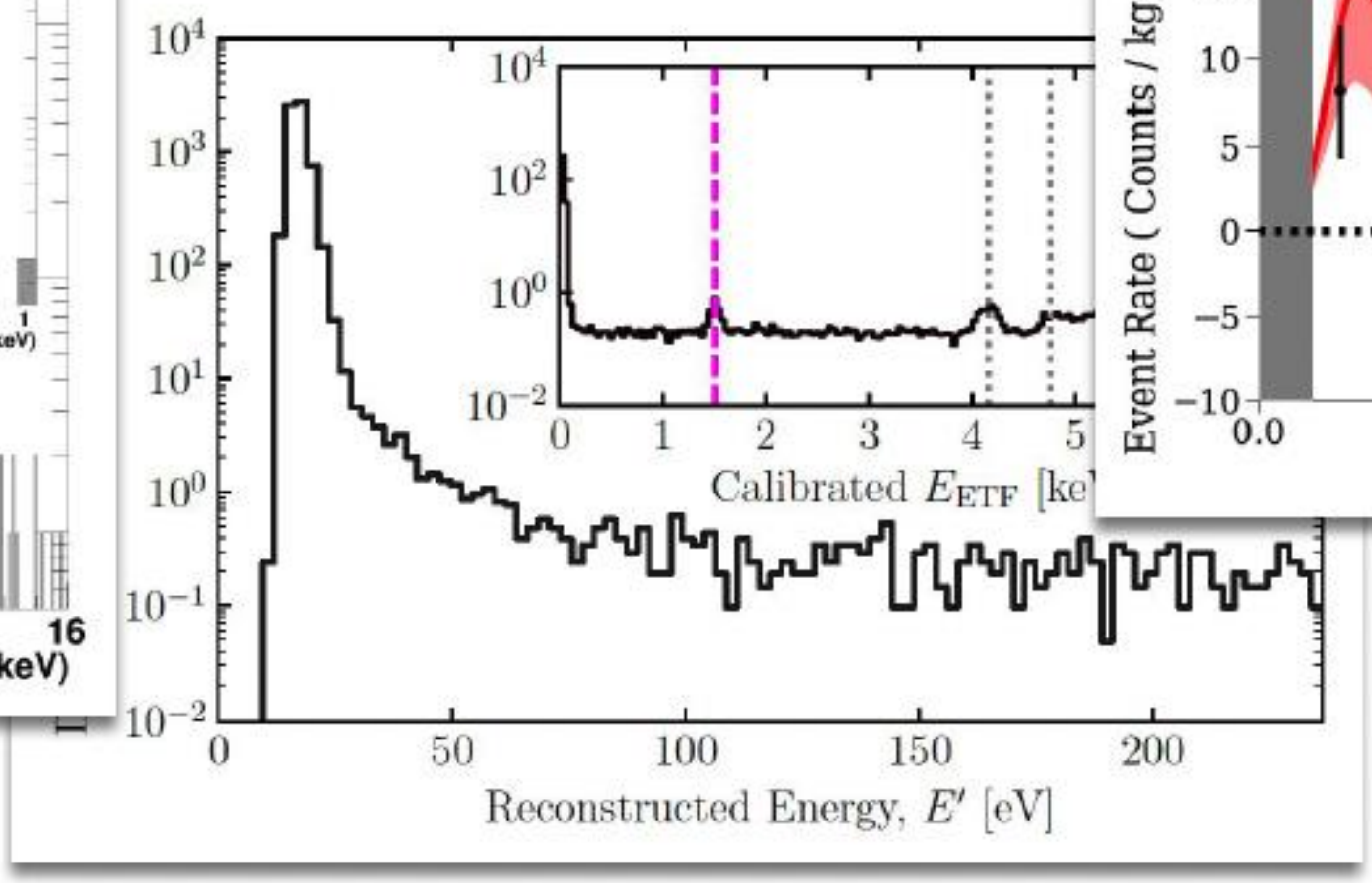


Unexpected Low Energy Excess (2020)

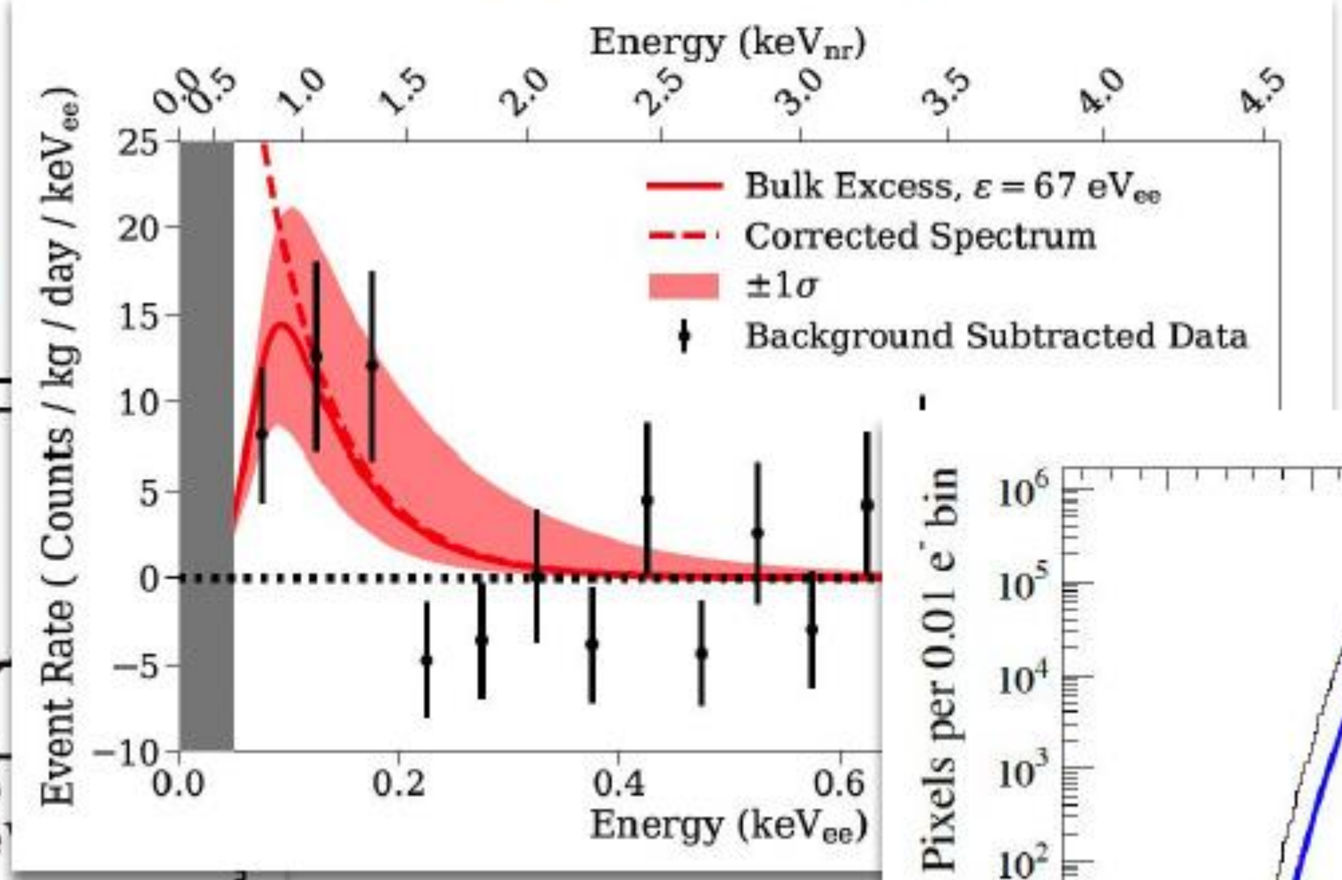
CRESST, Phys. Rev. D 100, 102002



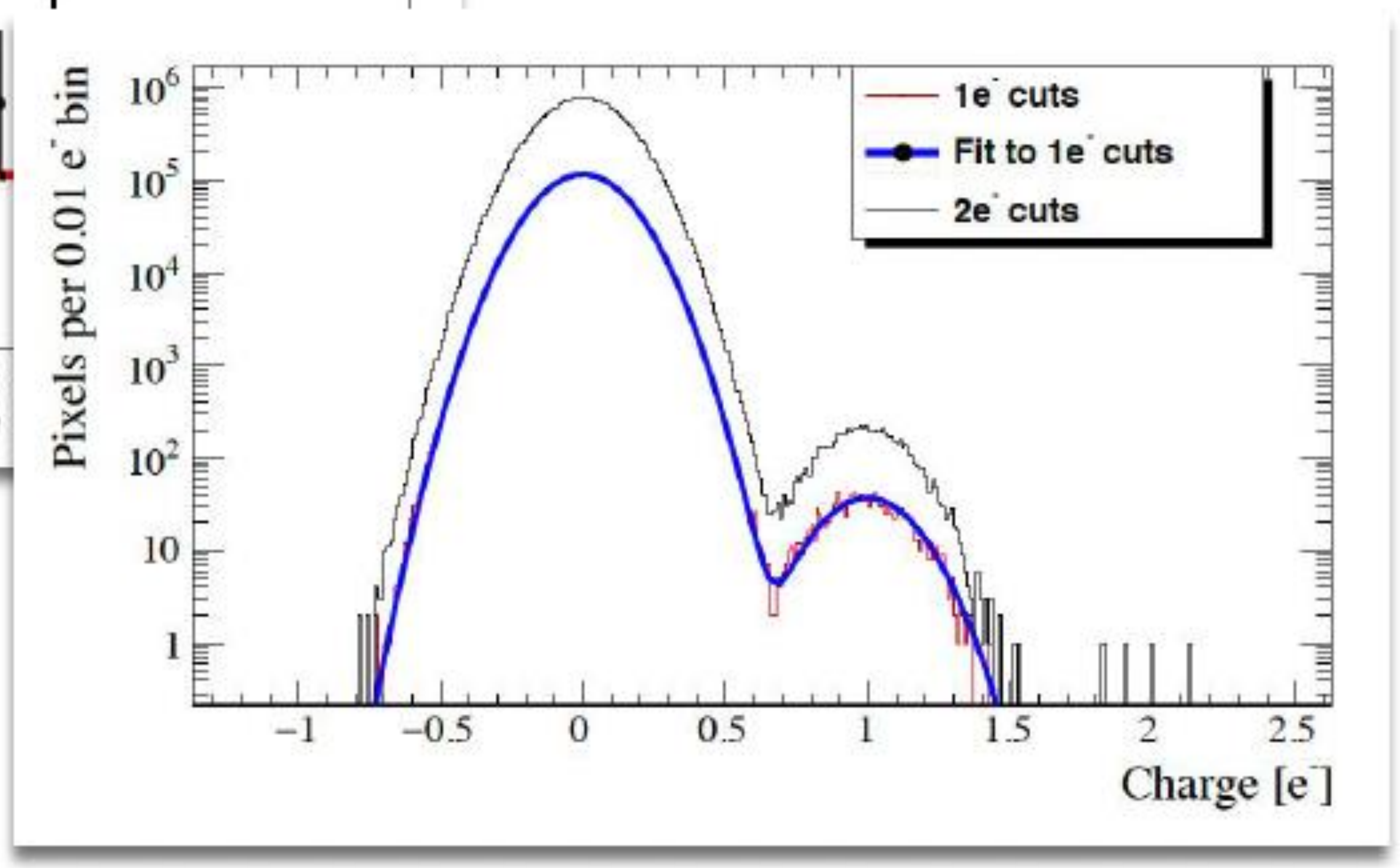
SuperCDMS, Phys. Rev. Lett. 127, 061801



DAMIC, Phys. Rev. Lett. 125, 241803

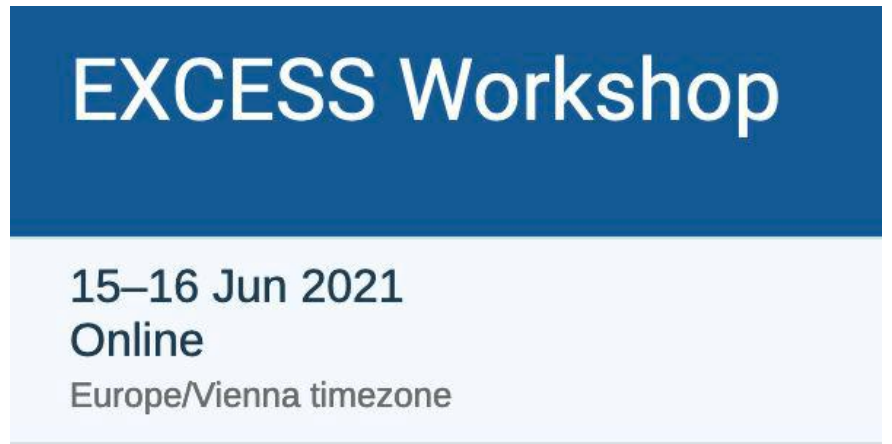


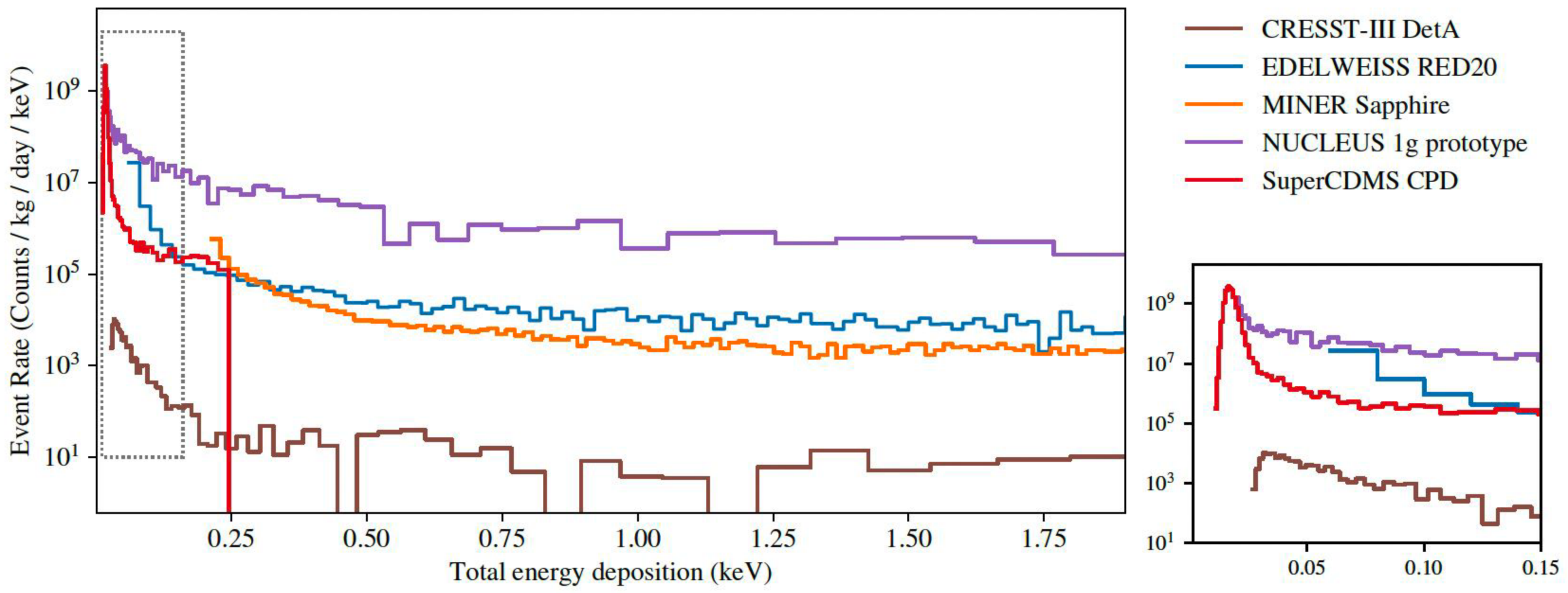
SENSEI, Phys. Rev. Lett. 125, 171802



- Cryogenic, CCD-like and gaseous ionization detectors had successfully lowered their recoil energy thresholds, down to ~10 eV
- Steeply rising excesses above known backgrounds were observed

EXCESS Workshop Series Began



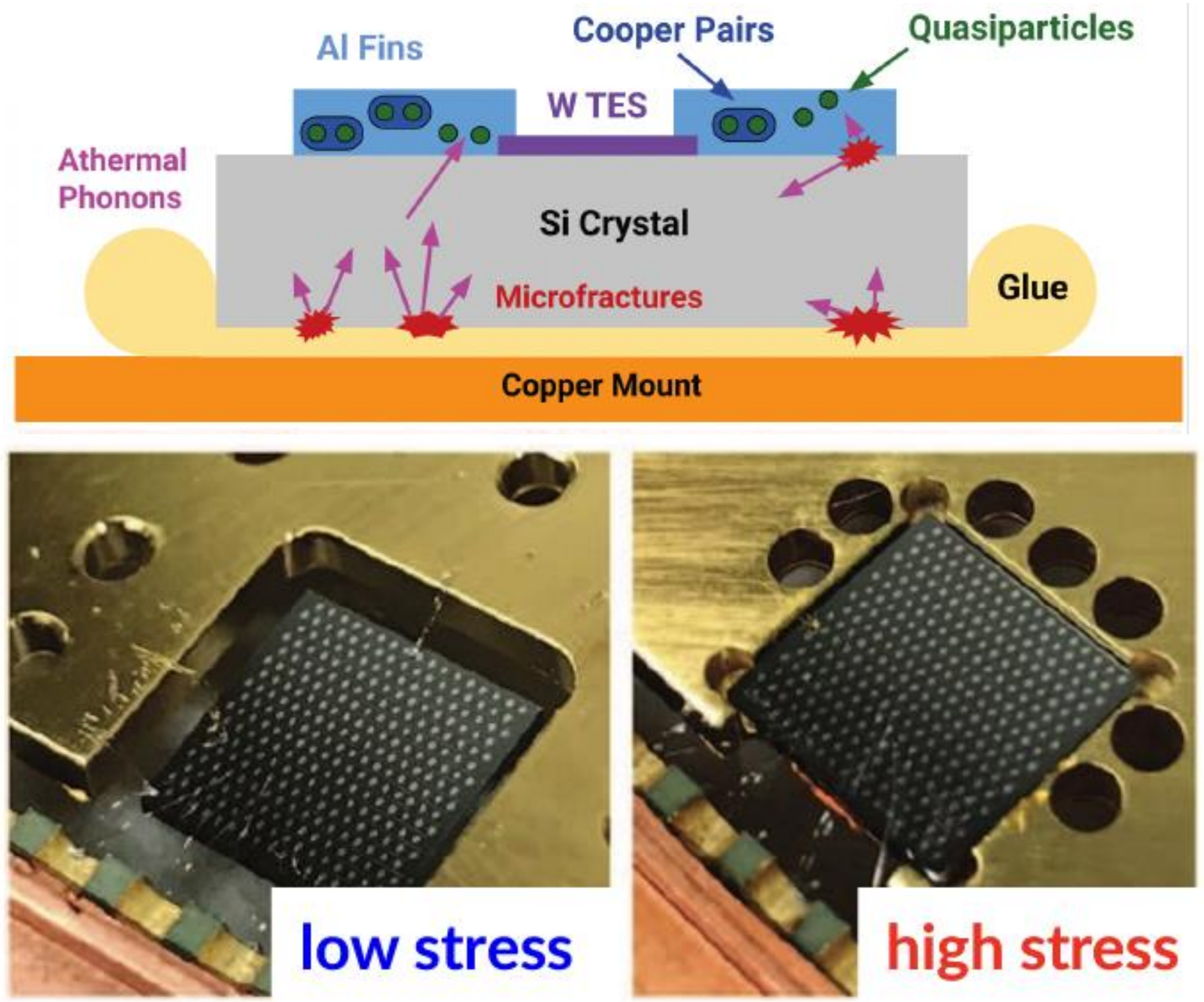


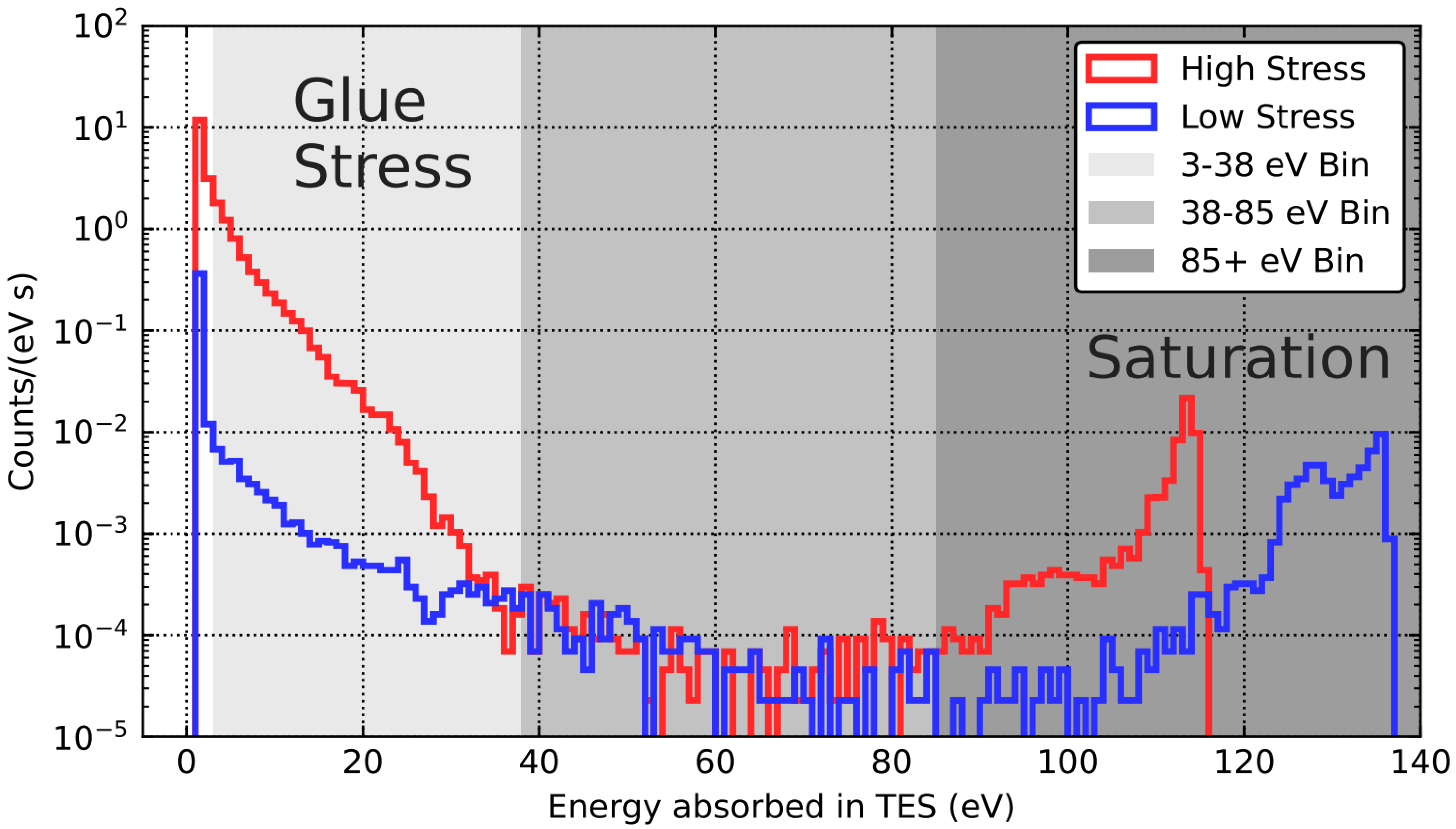
Contents

- In 2021, **community effort** was started to study the observations & learn more about the new backgrounds.
- “New physics” origin of excesses mostly excluded - but possibly **“previously not directly observed physics phenomena”** at (partially) low temperatures and energies.

Some Key Findings

Excess events can be caused by external stress!

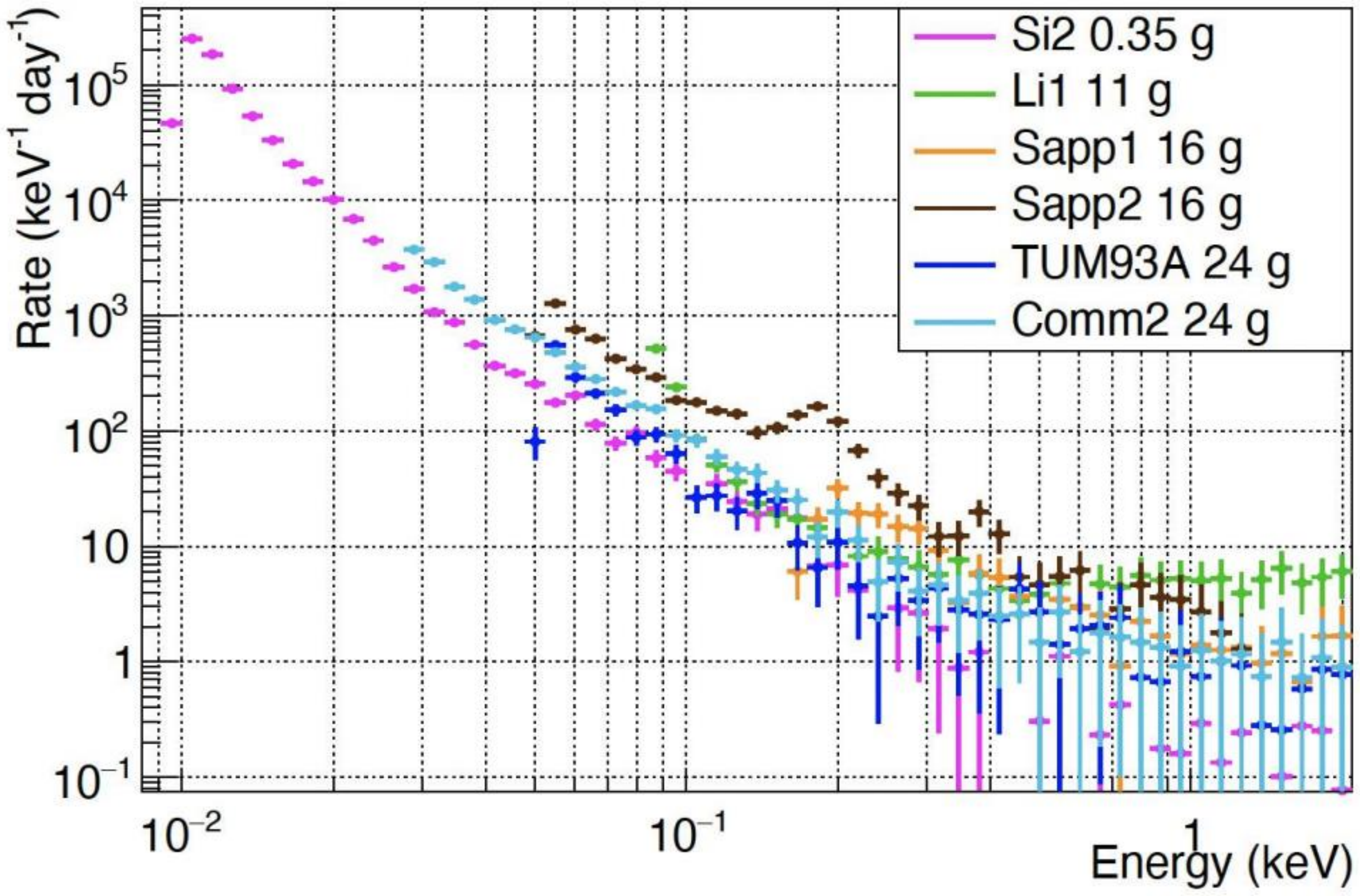




Some Key Findings

- CRESST observed **vastly different excess rates** in detector modules, with no obvious dependence on material and target size.
- The **event rate decays after the cooldown** of the experiment.
- ***Hypothesis:***
  Differential thermal expansion in the various layers of a sensor could introduce stress during thermal cycles

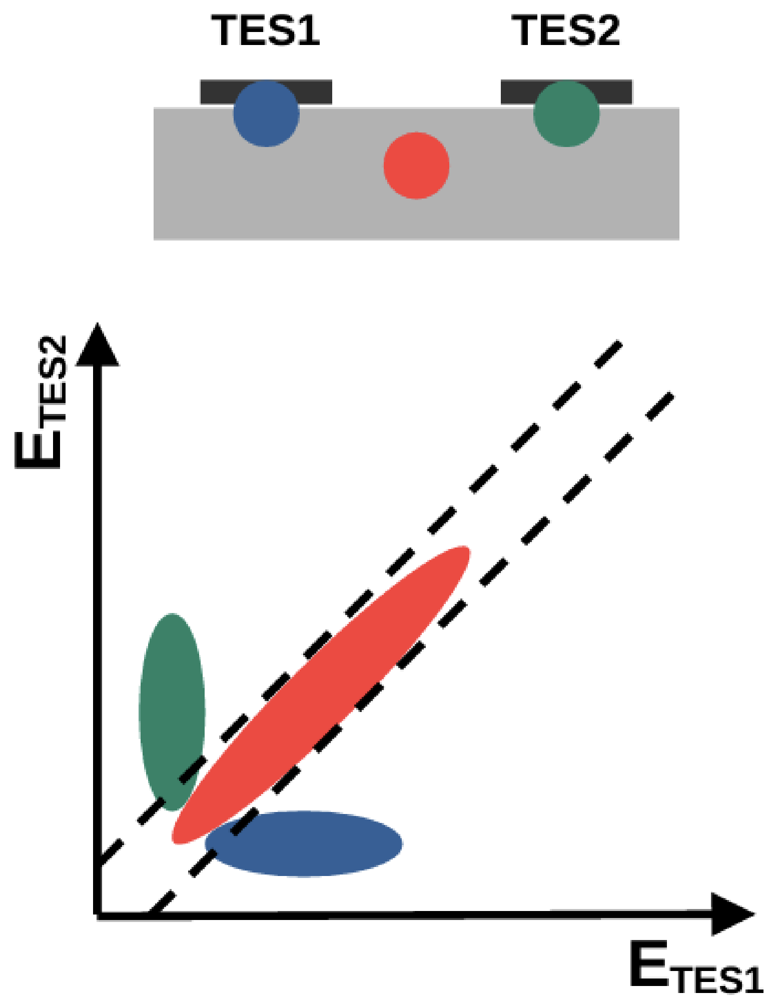
CRESST, SciPost Phys. Proc. 12, 013 (2023)

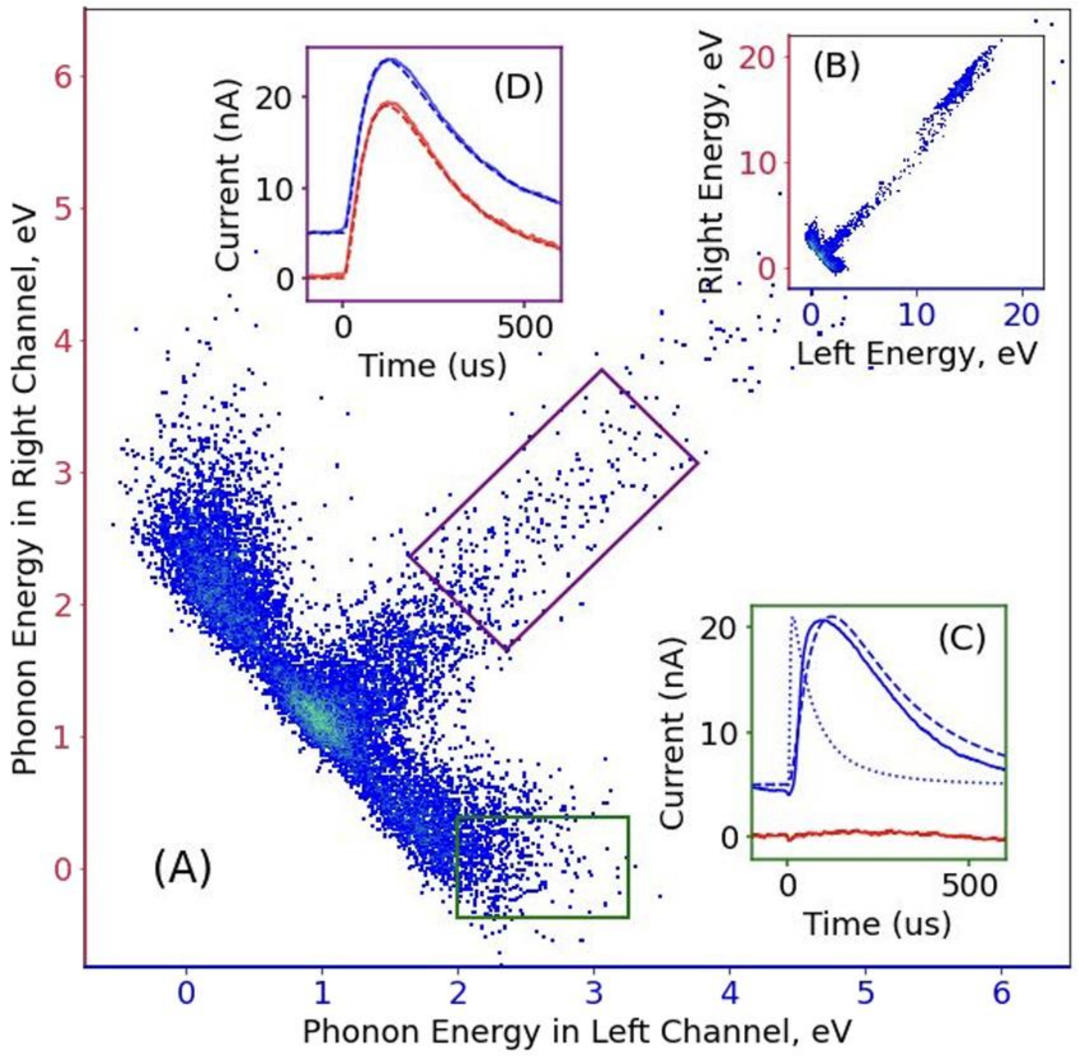


Some Key Findings

Use multiple sensors to identify sensor events

- Singles: events from sensor itself should only show up in that sensor
- Shared: bulk events should be seen by all sensors
- First prototypes tested by CRESST and SPICE

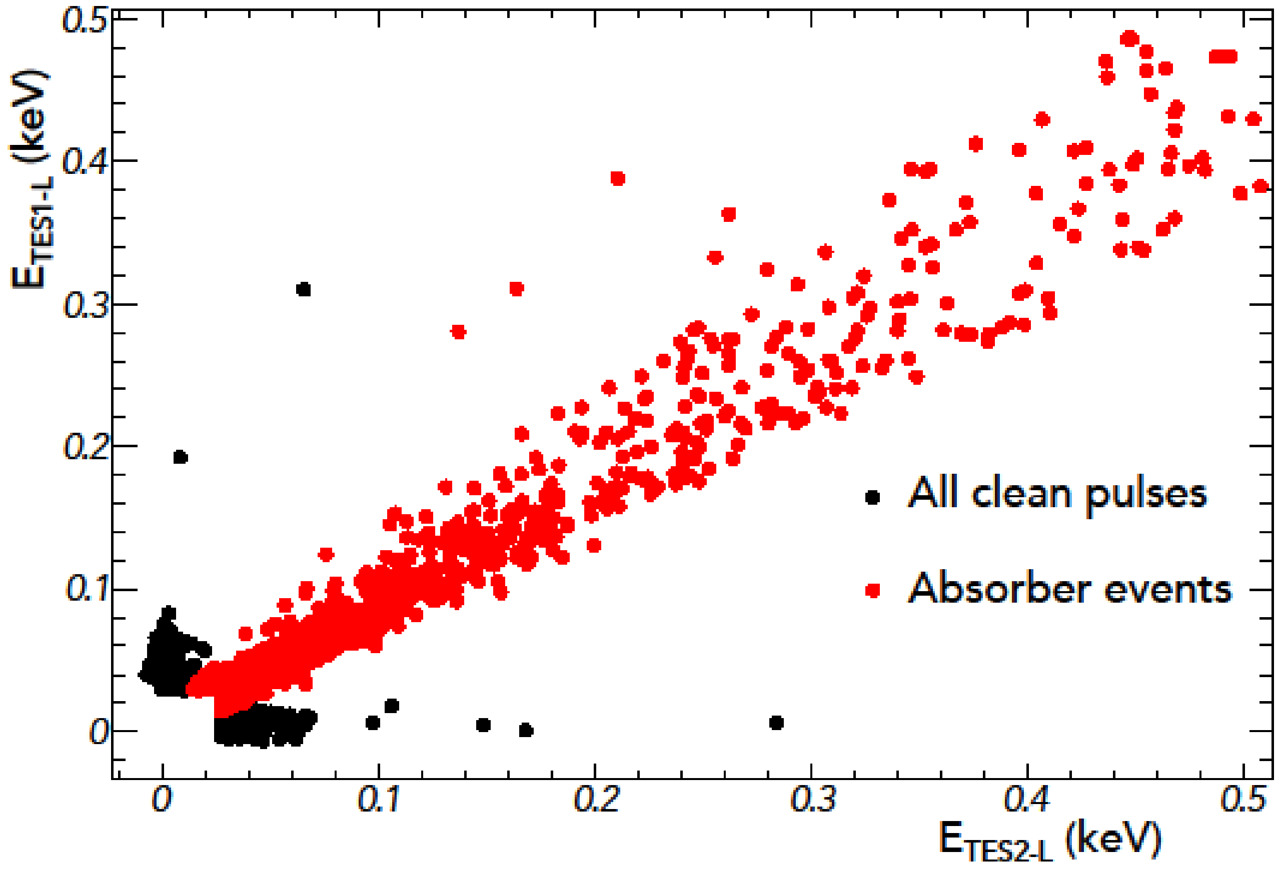




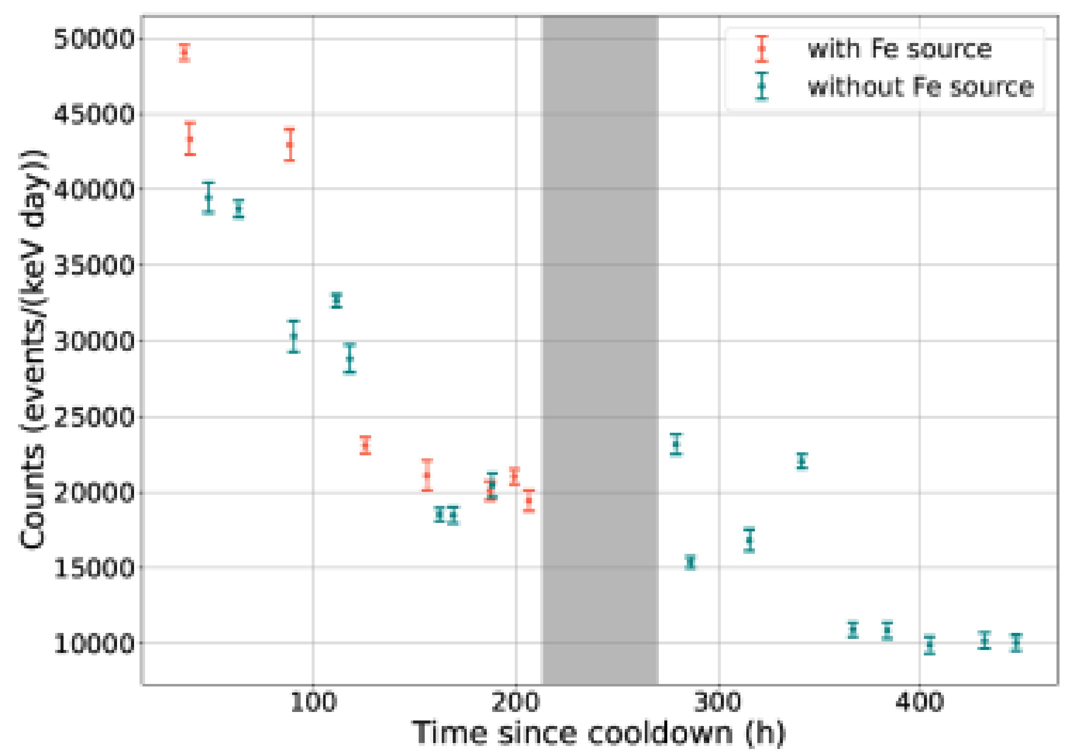
Romani, EXCESS 2023

Recent **CRESST results** from observations for shared event low energy excess (LEE):

- decays with time
- is not compatible with noise
- External radiation does not impact the LEE



CRESST, arXIv:2404.02607v1



Concluding Thoughts

- A decade ago as we were planning for the experiments in underground science that we are now conducting and building, we faced great challenges in terms of how to handle the radio purity demands required to do the science.
- To achieve our goals, we developed new detectors and methods for cleaning and handling materials. We developed new analysis techniques and protocols.
- This was achieved through collaboration: AARM, LRT conferences, joint working groups between collaborations (MOUs), etc.
- Knowing your backgrounds is crucial for the success of rare event searches.
- As we plan for the needs of the next decade opportunities are abundant — some of the challenges are known (the neutrino background, cosmic activation of isotopes, surface alpha backgrounds, etc), others are yet to be discovered. We will need techniques to clean, purify and manufacture materials and equipment that can validate the radiopurity of these materials at the required levels.