Radon in Dark Matter Detectors

Eric Miller
Experimental Seminar
5/29/18
SLAC

Outline

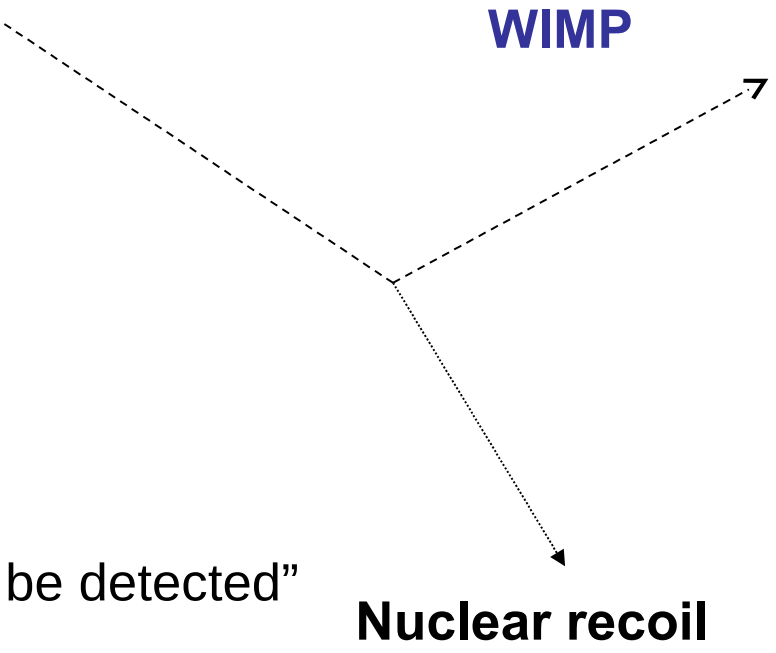
- Dark Matter
- Radon
- Radon Backgrounds – prompt
  - LZ & DRIFT
- Radon Backgrounds – long-lived
  - LZ & SuperCDMS
- Summary

Dark Matter

- Physicists' name for matter in the universe that we cannot see
- Comprises 80% of matter in universe
- Best candidate: WIMP
  - Weakly Interacting Massive Particle
  - Has no charge
  - Has mass
  - Is a new, never detected particle

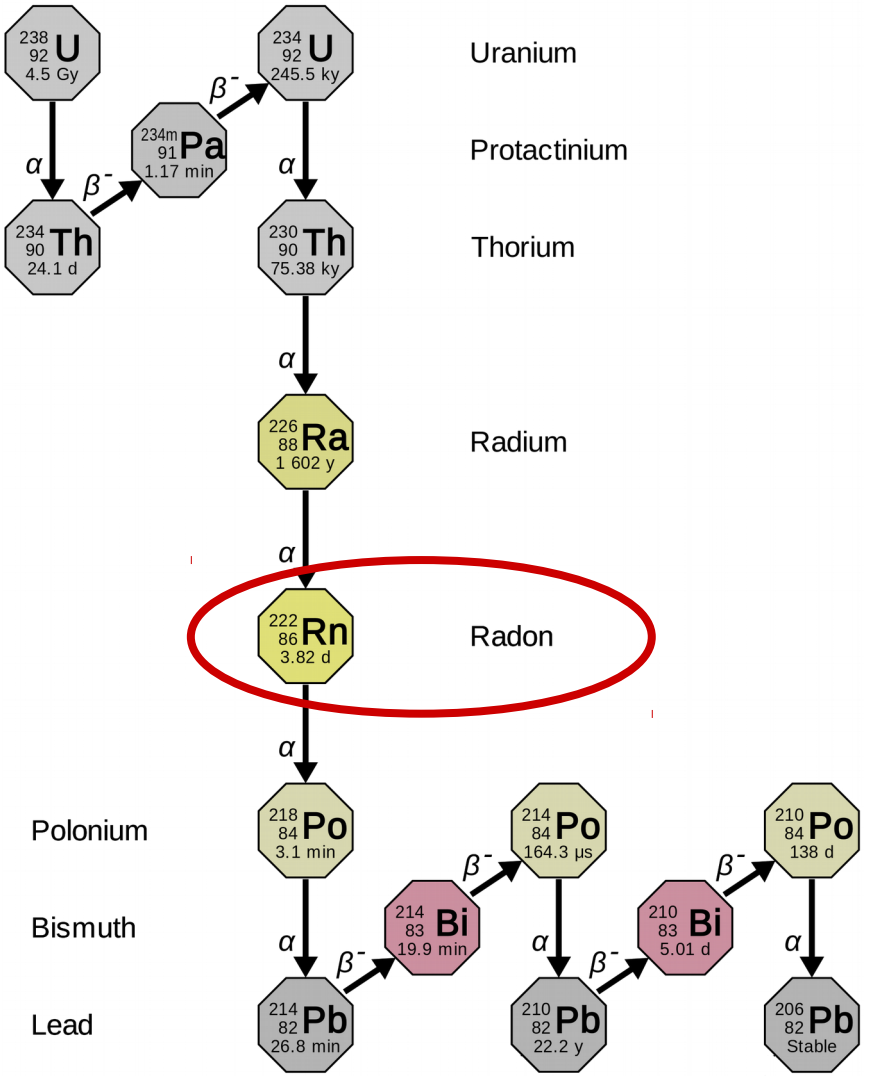
Detecting Dark Matter

- A WIMP interaction will hit a nucleus
  - Get lots of nuclei
- Wait a long time
  - WIMP interactions occur less than ~ 1/tonne/year
- Avoid WIMP-like events
  - Cosmic Rays
  - Neutrinos
    - “I have postulated a particle that cannot be detected” -Pauli
  - Radioactive decays



Radon – What is it?

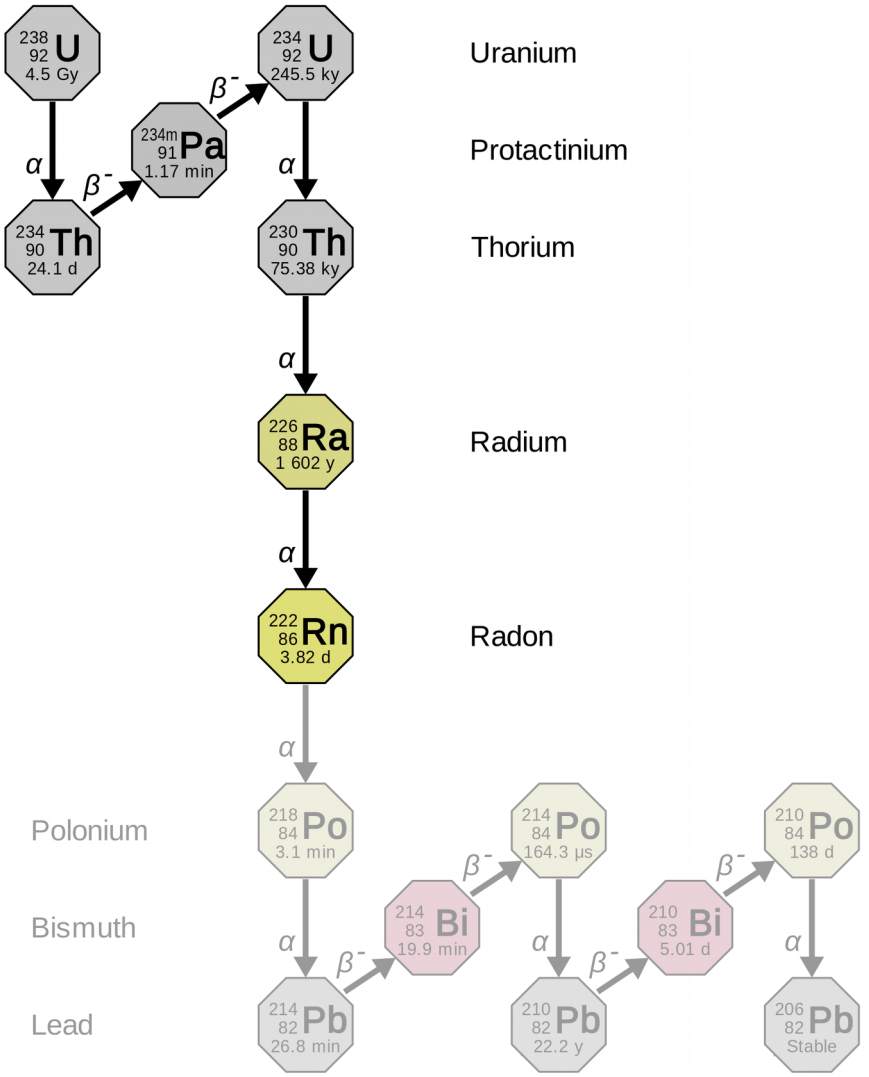
- Radioactive Noble Gas
- Radon is all around us, all the time
- Decays of Radon & daughters cause problems
  - Lung cancer
  - Rare event searches to fail



- By User:Tosaka - File:Decay chain(4n+2, Uranium series).PNG, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=33293646

Radon – Where does it come from?

- Uranium is present in all materials
- Most daughters stay put
  - Minor problems
- Radon can escape!



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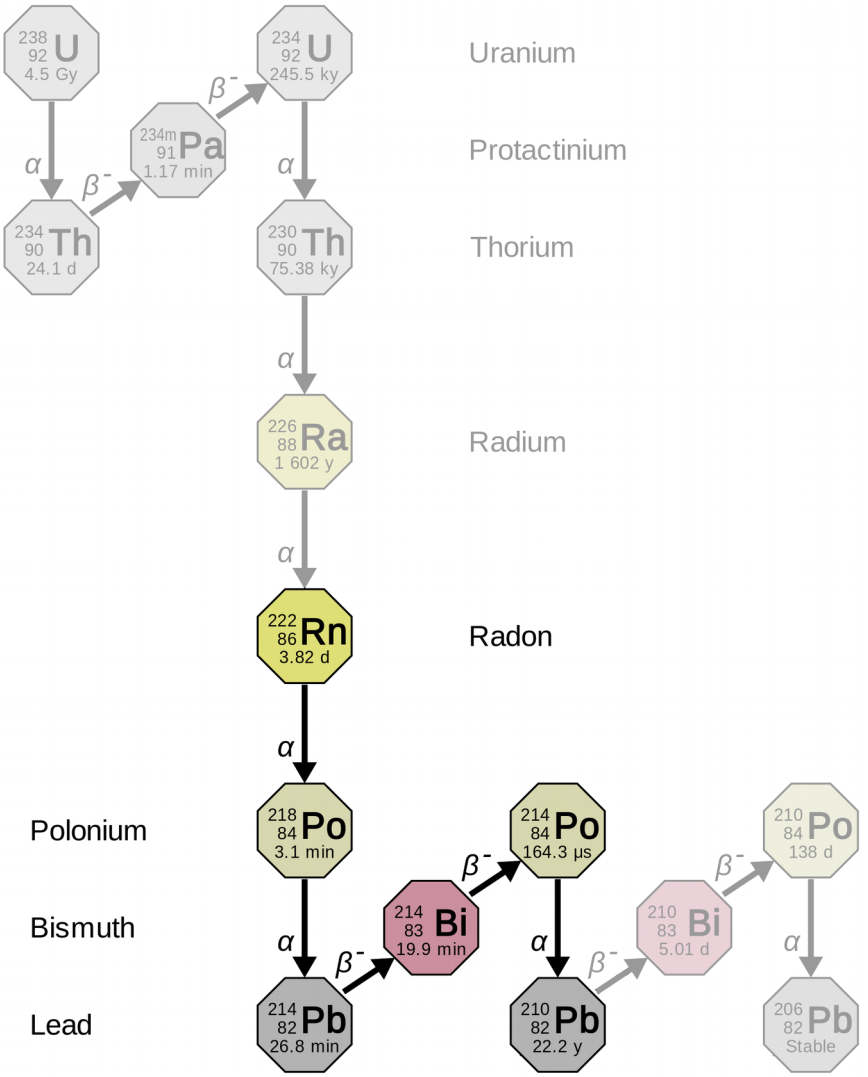
Radon – Where does it go?

- Radon is noble gas, but daughters aren't!
- After decay, metallic daughters often charged
  - Attracted to surfaces
    - Especially Teflon!
      See arxiv:1708.08534
- After decay, 4 prompt decays



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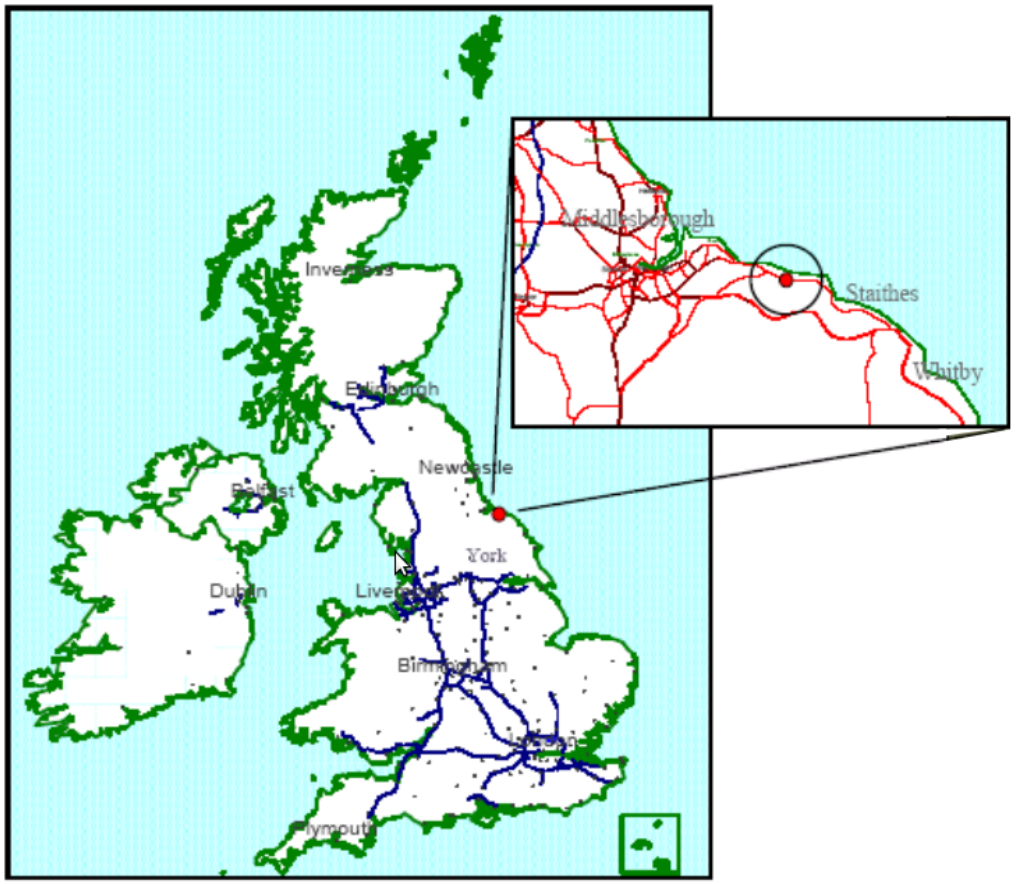
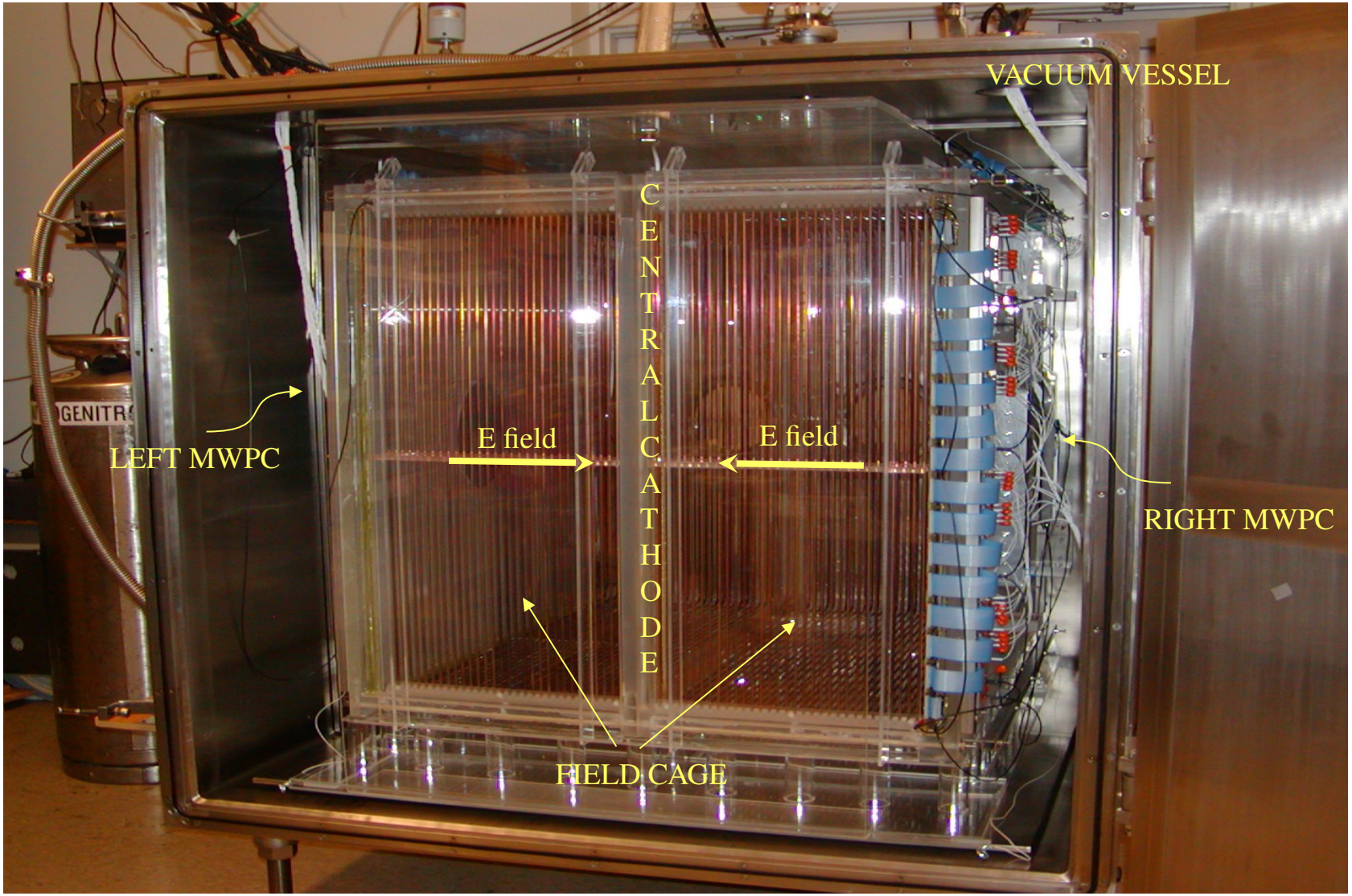
The DRIFT Experiment

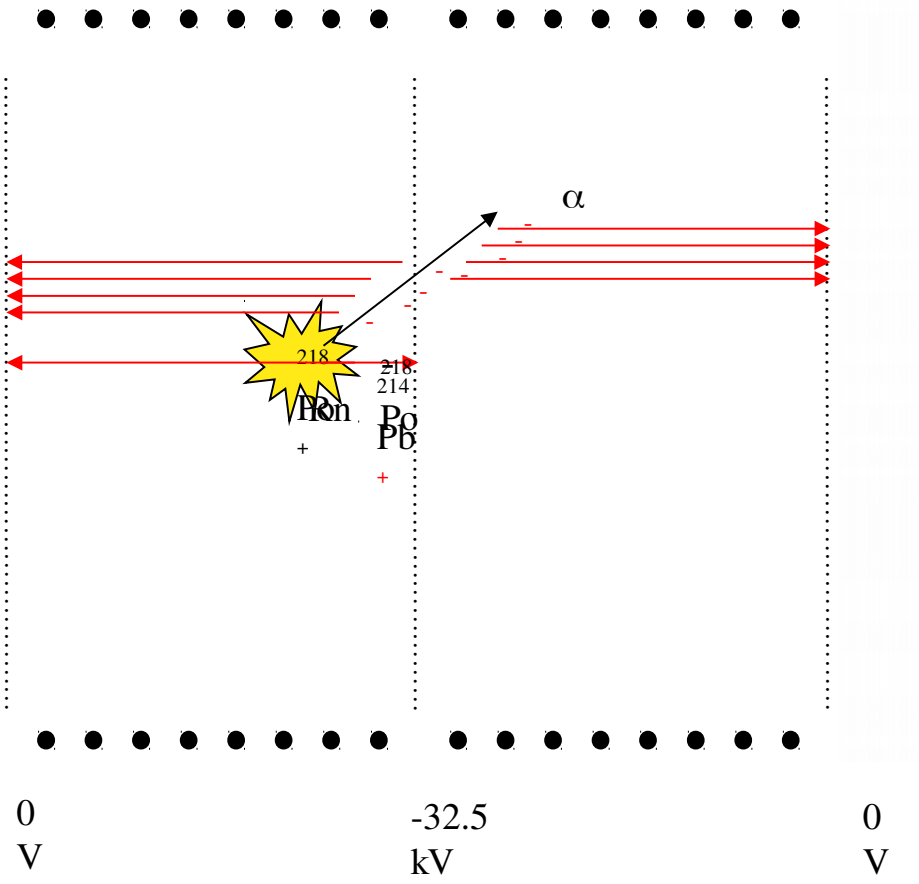
- Directional Recoil Information From Tracks
- Low-pressure gas TPC
  - 40 Torr
- 0.8 m^3 sensitive volume
- Located underground in Boulby mine, UK

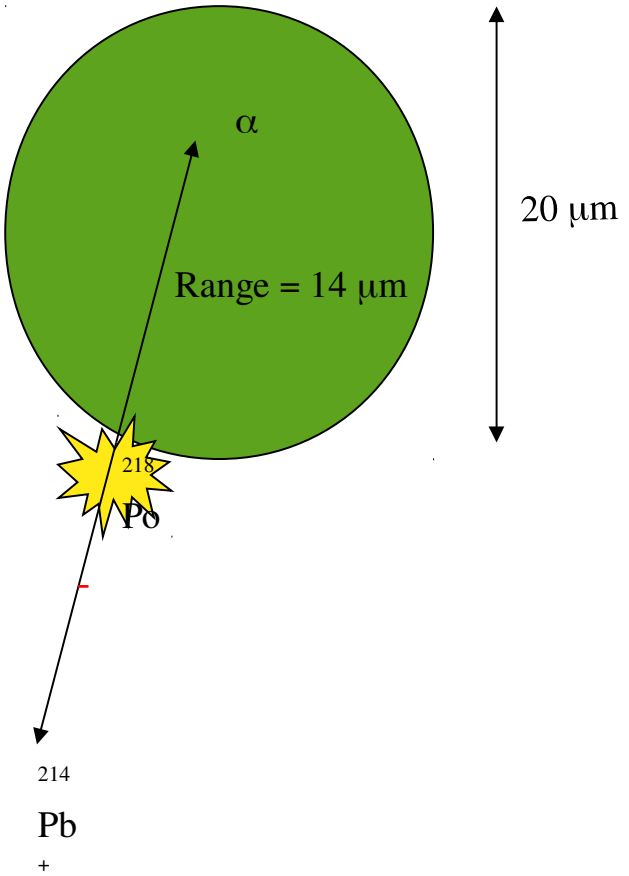


DRIFT


VACUUM VESSEL
CENTRAL CATHODE
E field
E field
LEFT MWPC
RIGHT MWPC
FIELD CAGE

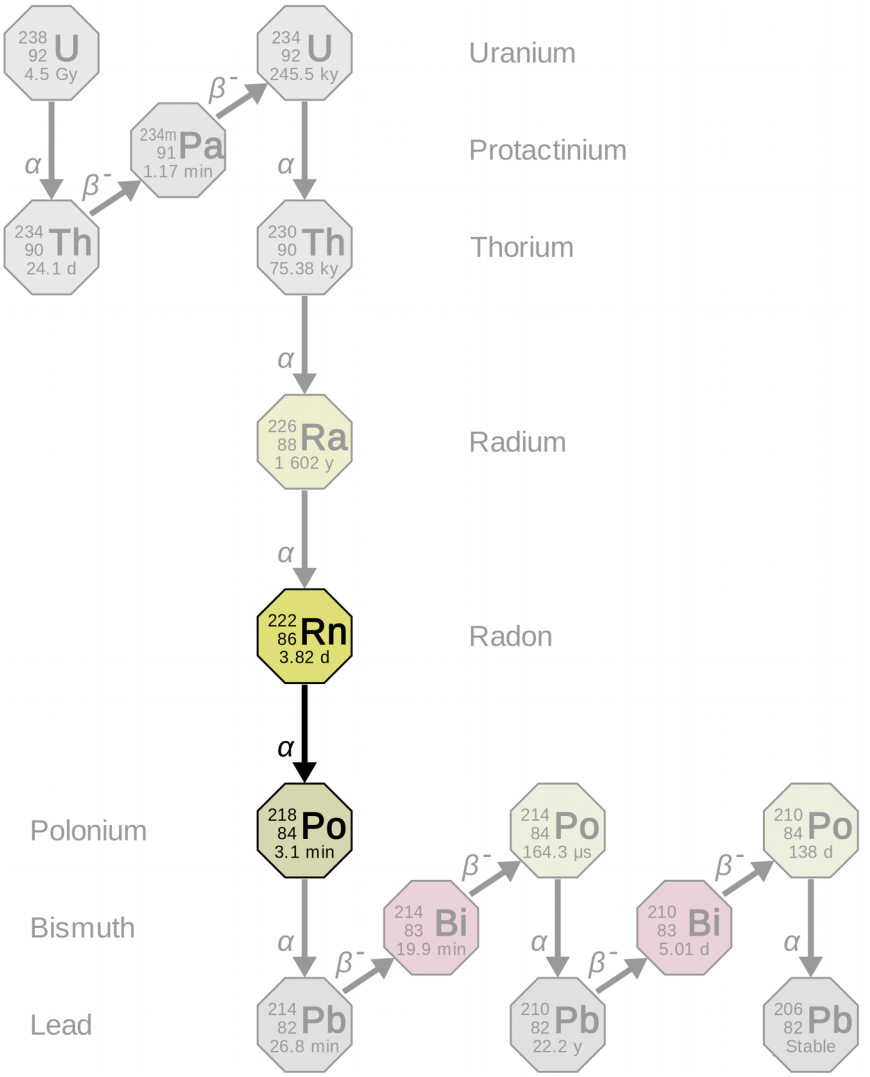
DRIFT-IId Backgrounds



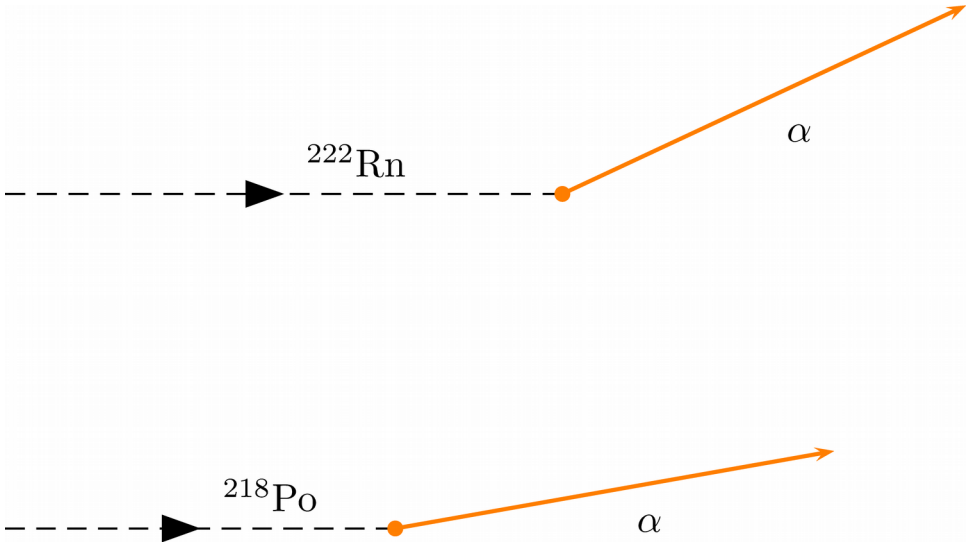


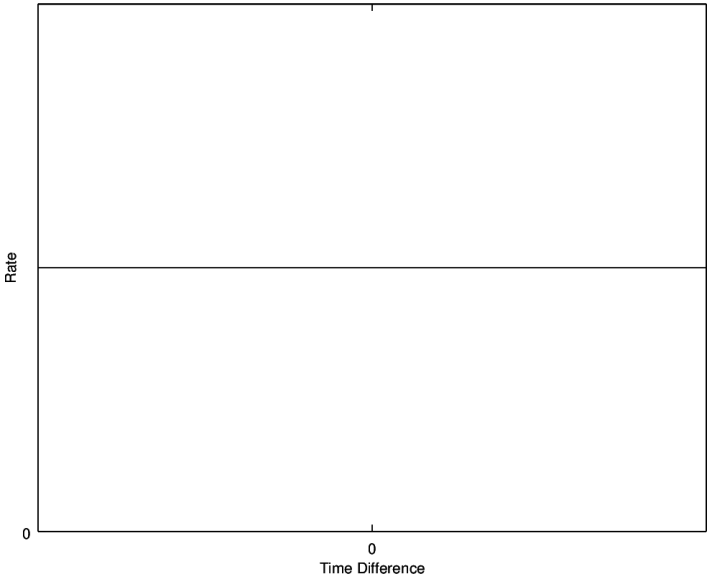
Rn Measurement Efficiency

- How to measure Rn concentration in DRIFT?
- ^{222}Rn & ^{218}Po decay by alpha emission
  - 3.1 min half-life

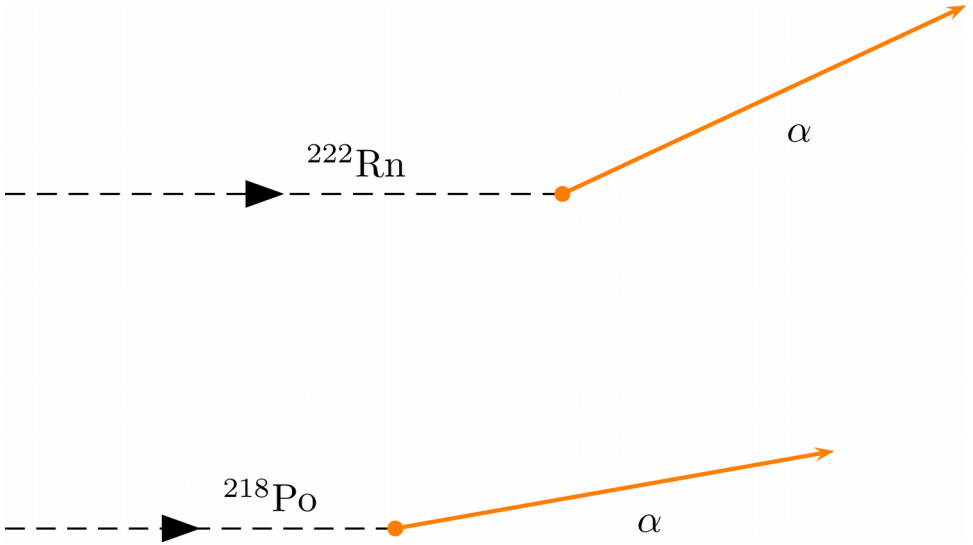


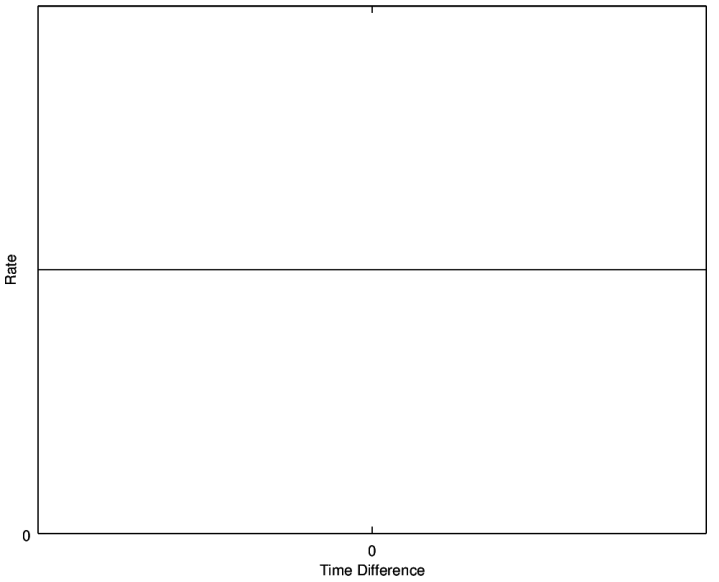
Rn Measurement Efficiency

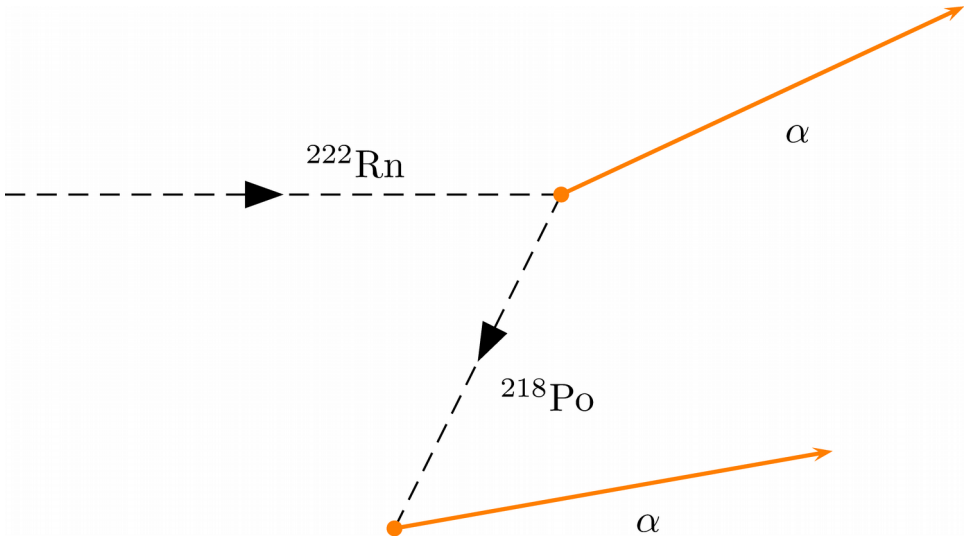


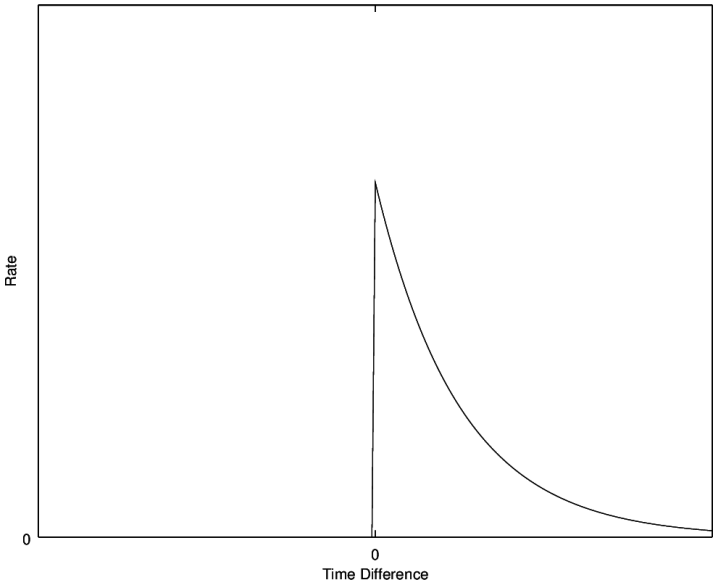


Rn Measurement Efficiency



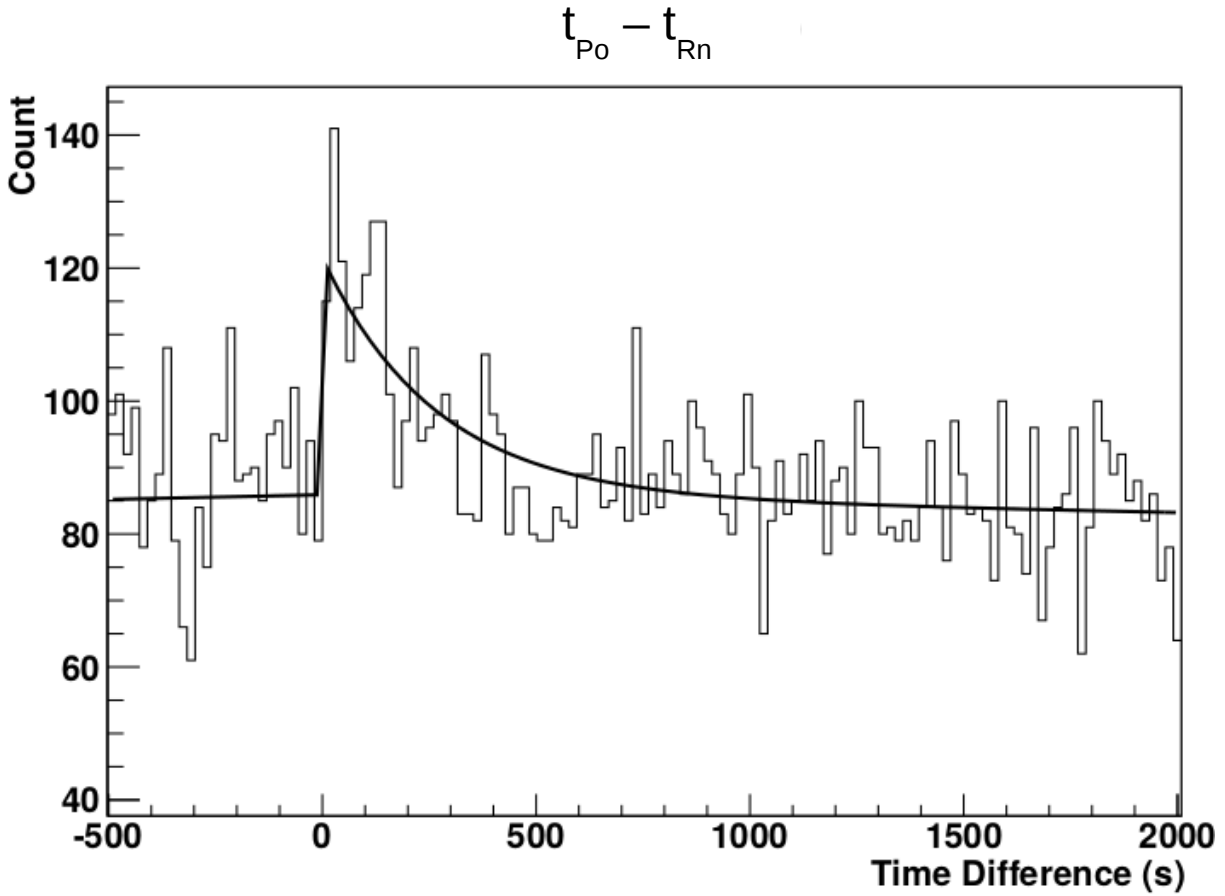






Eric Miller 5/29/18

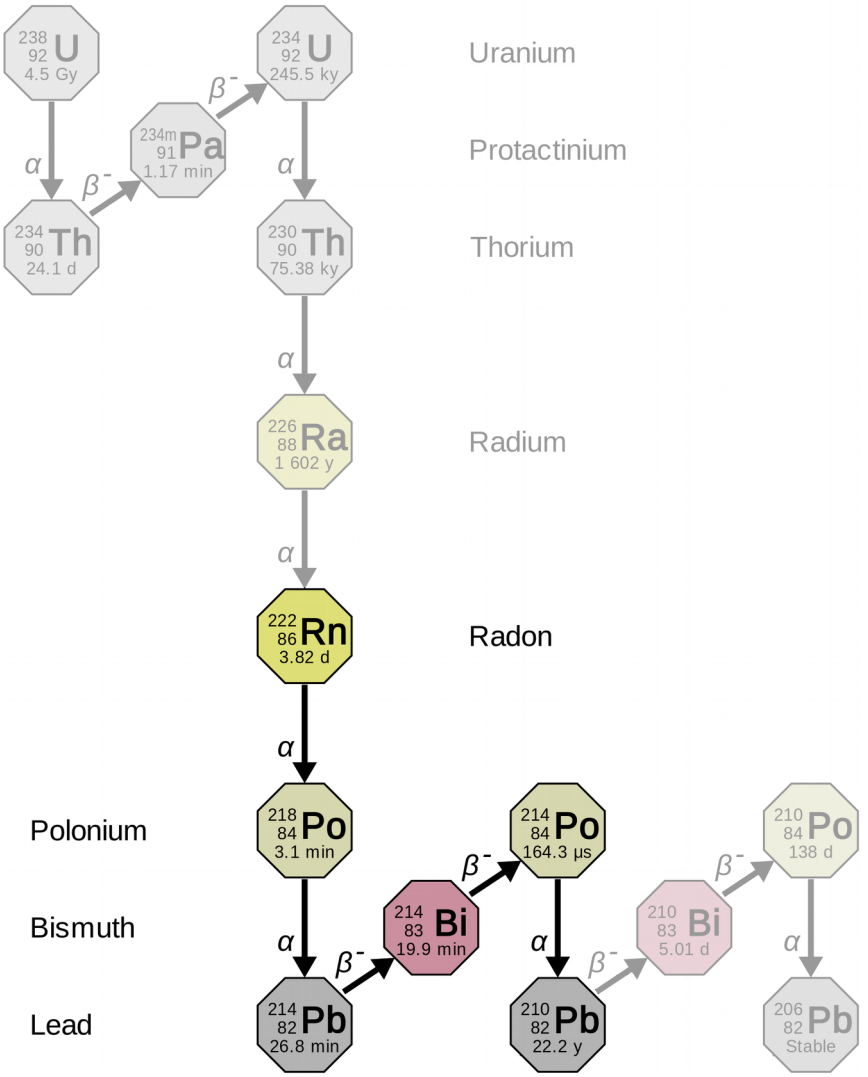
Rn Measurement Efficiency



Rn measurement efficiency = $\frac{\text{Area of exponential}}{\text{Number of Po}}$

Radon – Where does it go?

- Radon is noble gas, but daughters aren't!
- After decay, metallic daughters often charged
  - Attracted to surfaces
    - Especially Teflon!
      See arxiv:1708.08534
      by Eric Morrison
- After decay, 4 prompt decays
  - **^{214}Pb beta decay is "naked"**



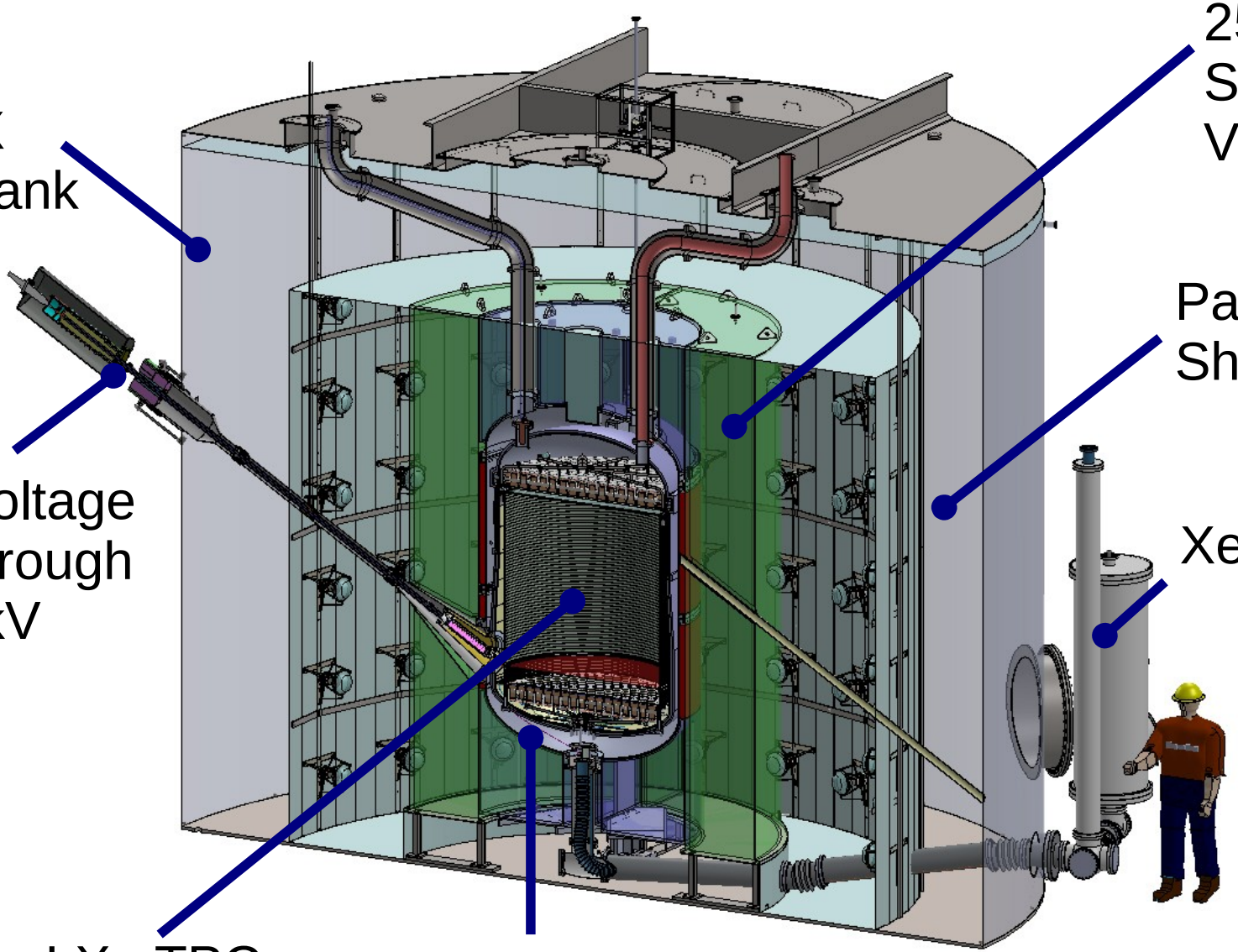
- By User:Tosaka - File:Decay chain(4n+2, Uranium series).PNG, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=33293646

The LZ Dark Matter Detector

Located in the Davis Cavern
4850' level in Homestake Mine, SD

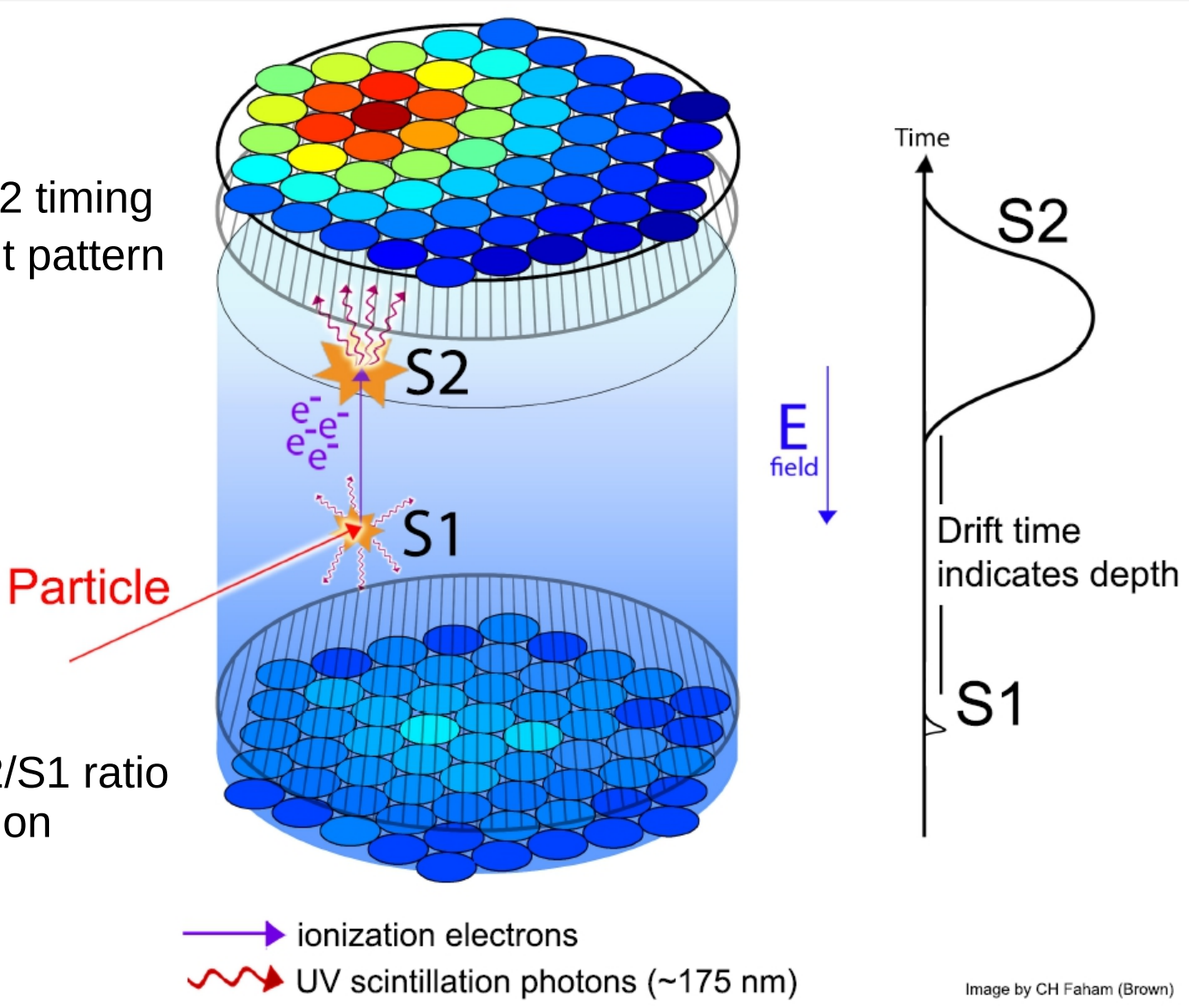
LUX has been removed
Water tank remains

The LZ Dark Matter Detector



The LZ Dark Matter Detector

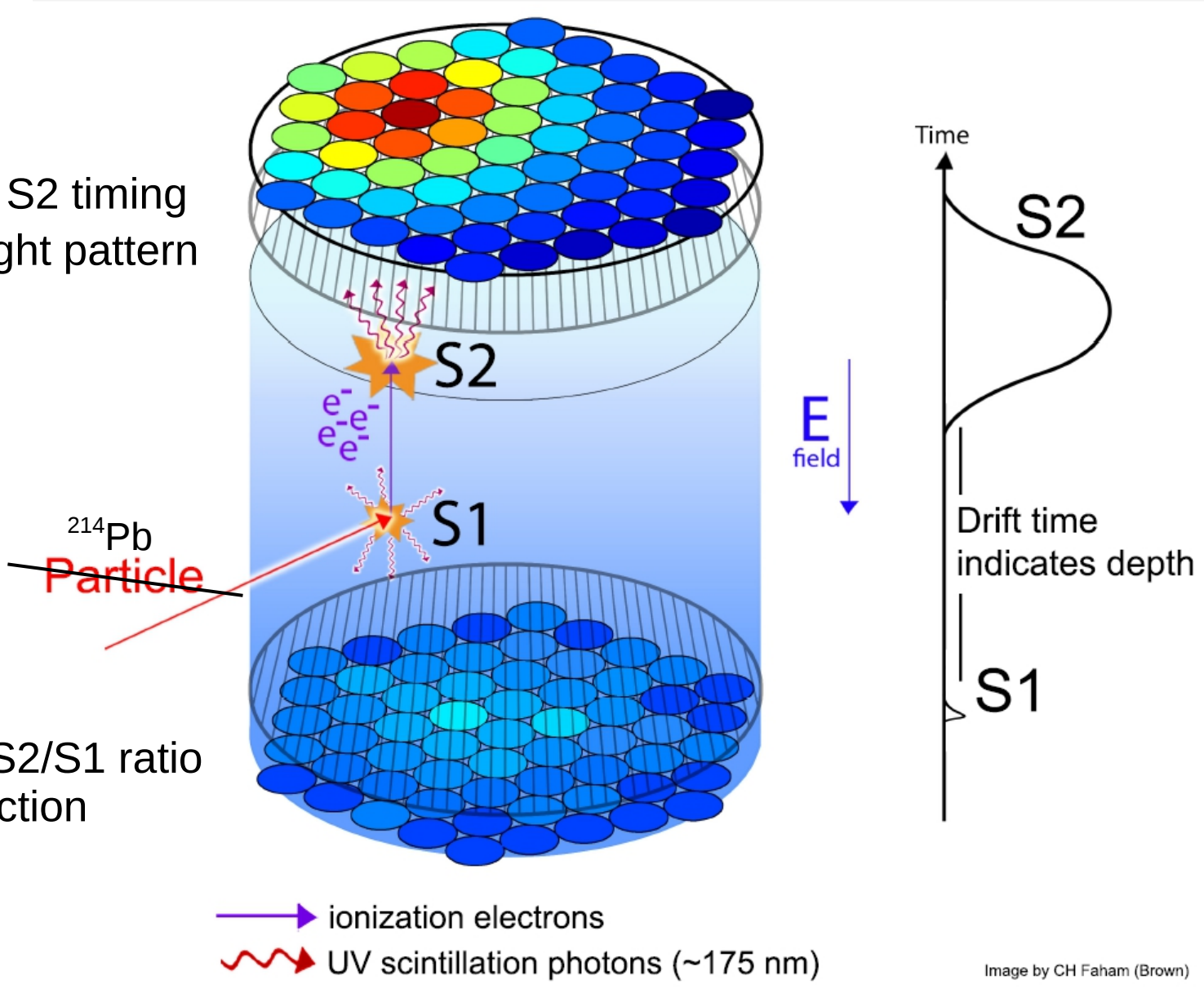
Z position from S1 – S2 timing
X-Y positions from light pattern



Reject electrons by S2/S1 ratio
Expect > 99.5% rejection

The LZ Dark Matter Detector

Z position from S1 – S2 timing
X-Y positions from light pattern



Reject electrons by S2/S1 ratio
Expect > 99.5% rejection

Radon Backgrounds in LZ

- ^{214}Pb “naked” beta
  - Expects 700 of these decays over experiment lifetime
  - Looks like 3.5 WIMPs
- More than all other backgrounds combined!
- Radon levels are already below 1 atom / kg Xe

Environmental	0.05
Argon + Krypton	0.13
^{210}Bi Migration	0.20
Material Contamination	0.28
^{136}Xe	0.34
Neutrinos	1.64
Radon & Daughters	3.49
Total	**6.12**

Radon Screening Program

- Limit introduction of Rn to LZ
- 4 institutions
- ~50 atom sensitivity
- Measured >100 samples

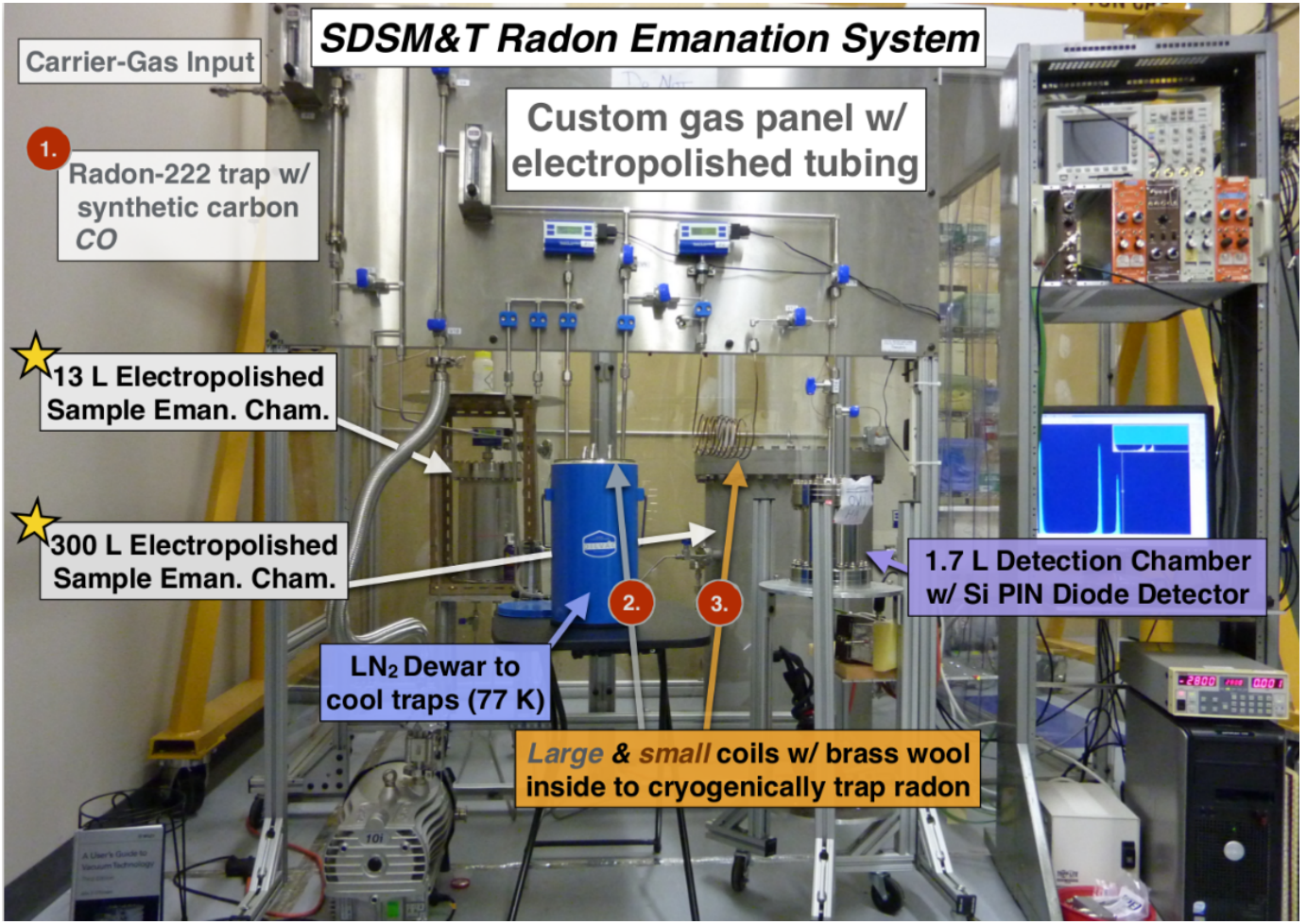


Image by M. Bowles

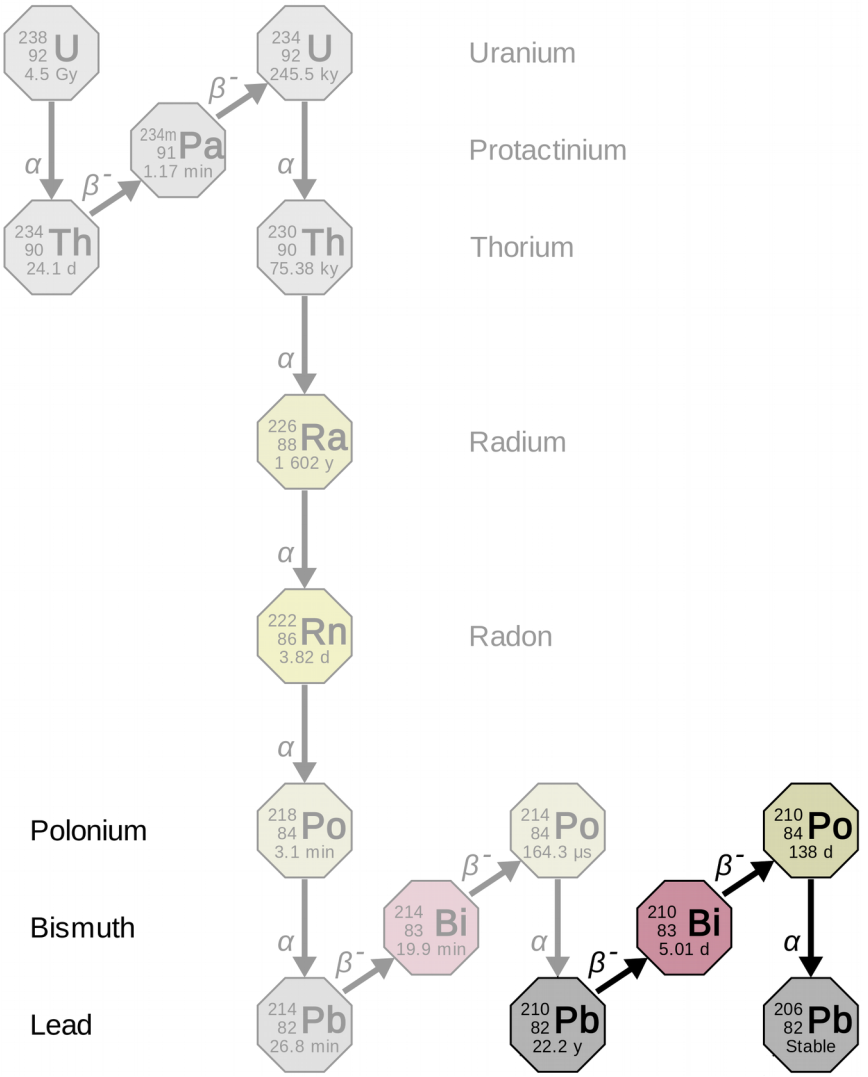
Radon Screening Program

- Screening program gives complete picture of Rn sources in LZ
- Identifies components to replace/improve
- Expectation of meeting detector requirements

Material	Component(s)	Quantity	Unit	Estimate (mBq)
Al_2O_3 resistor	PMT Bases	9790	#	**0.58***
$BaTiO_3$ capacitor	PMT Bases	3010	#	**0.016***
Cirlex	PMT Bases	6000	cm^2	**0.37***
Titanium	Cryostat, PMT Mounts, Field Rings, Grid Supports	412,000	cm^2	0.41
PTFE	Reflectors, HV Umbilical	840,000	cm^2	**<1.3***
PMT Cabling†	PMT Cabling	17,000	m	0.09
PMT Feedthrough†	Signal Flange	88	#	**<0.24**
Steel Conduit†	Cabling Conduit	100,000	cm^2	0.055
R11410 PMT	R11410 PMT	488	#	1.26
R8520 PMT	R8520 PMT	90	#	0.15
R8778 PMT	R8778 PMT	36	#	0.09
Polyethylene	HV Umbilical	4200	cm^2	0.10
Tin-coated copper	HV Umbilical	11,000	cm^2	0.002
Tivar	HV Umbilical	3894	cm^2	0.004*
Acetal	HV Umbilical	195	cm^2	0.0002*
Copper	HV Umbilical	39	cm^2	0.000007
Epoxy	HV Umbilical	1000	cm^2	0.0001*
Steel	Cryostat Seals, Xe Recirculation	135,000	cm^2	0.104
Recirculation Pump	Xe Recirculation	1	#	0.1
Purification Getter	Xe Recirculation	2.5	kg	1.34
Transducers & Valves	Xe Recirculation	30	#	0.17
Welds	Recirculation System, Cryostat	32.3	m	**0.11**
Dust				10.0
Total				<16.5

Radon & Long-lived daughters

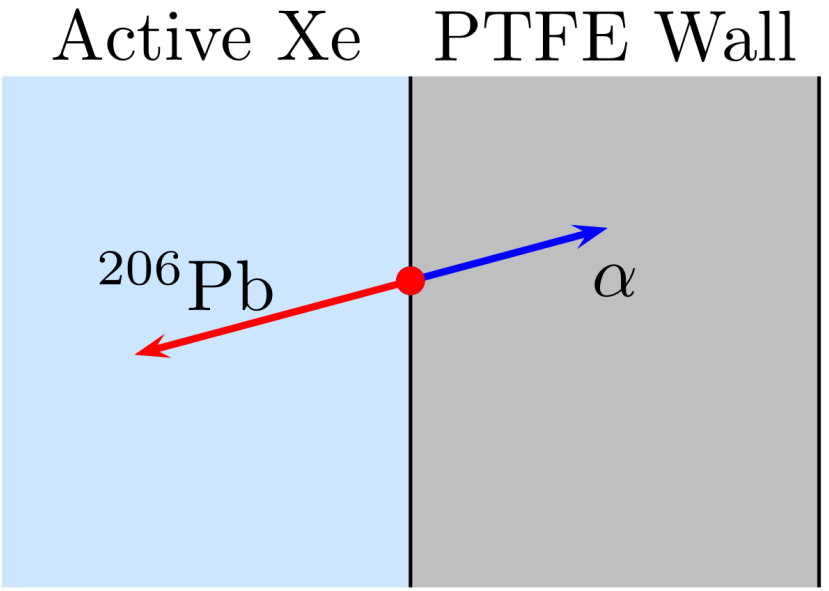
- 210Pb has 22.2 year half-life
- Exposure to atmospheric radon can leave radioactive daughters on detector components



- By User:Tosaka - File:Decay chain(4n+2, Uranium series).PNG, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=33293646

Radon's long-lived daughters

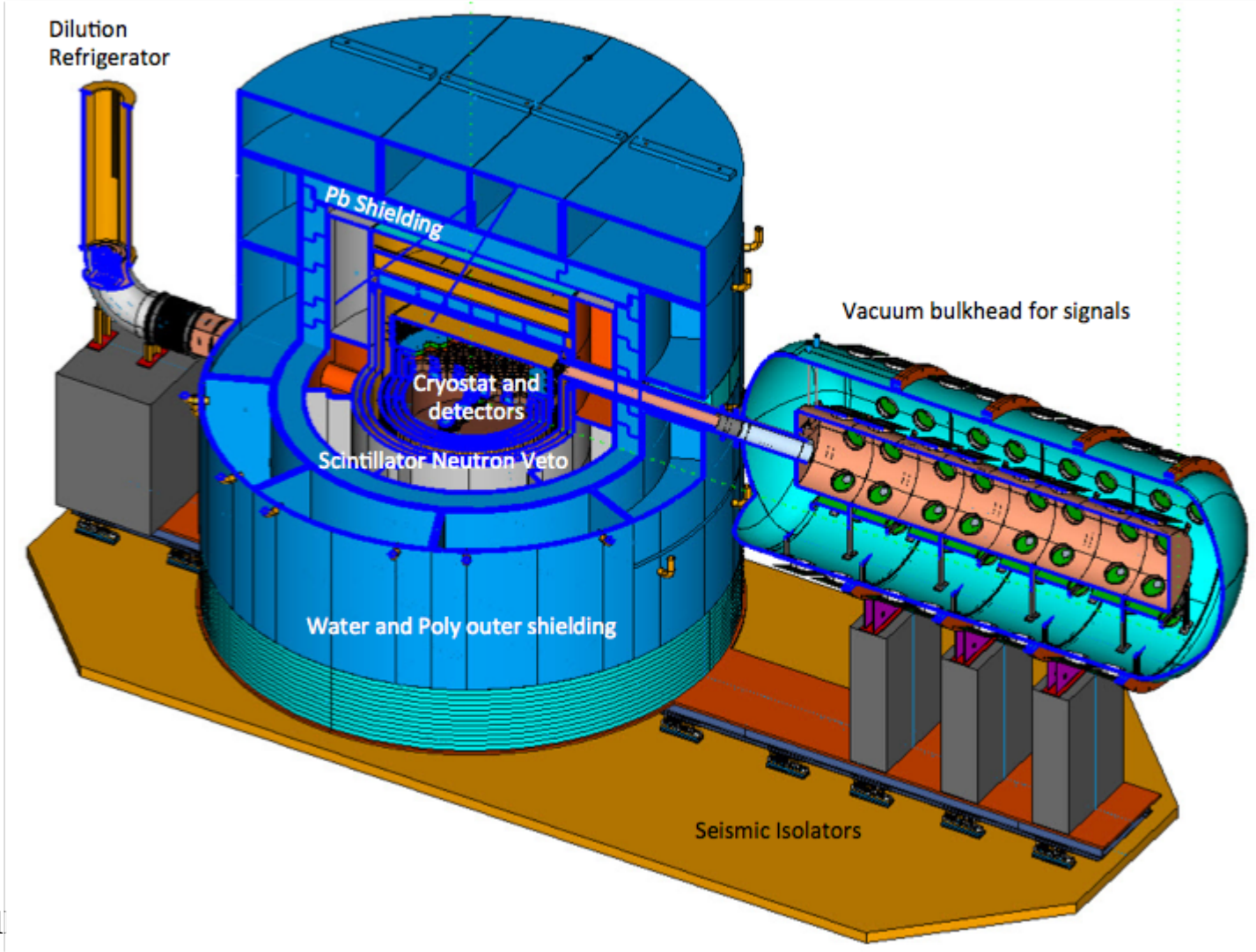
- 210Pb sticks around
  - Populates 210Po daughter
  - 210Po decays by alpha
- 210Po decay can create nuclear recoils into Xe
- 210Po alpha can create (alpha, n) backgrounds



- Must limit Rn exposure to reduce these backgrounds!

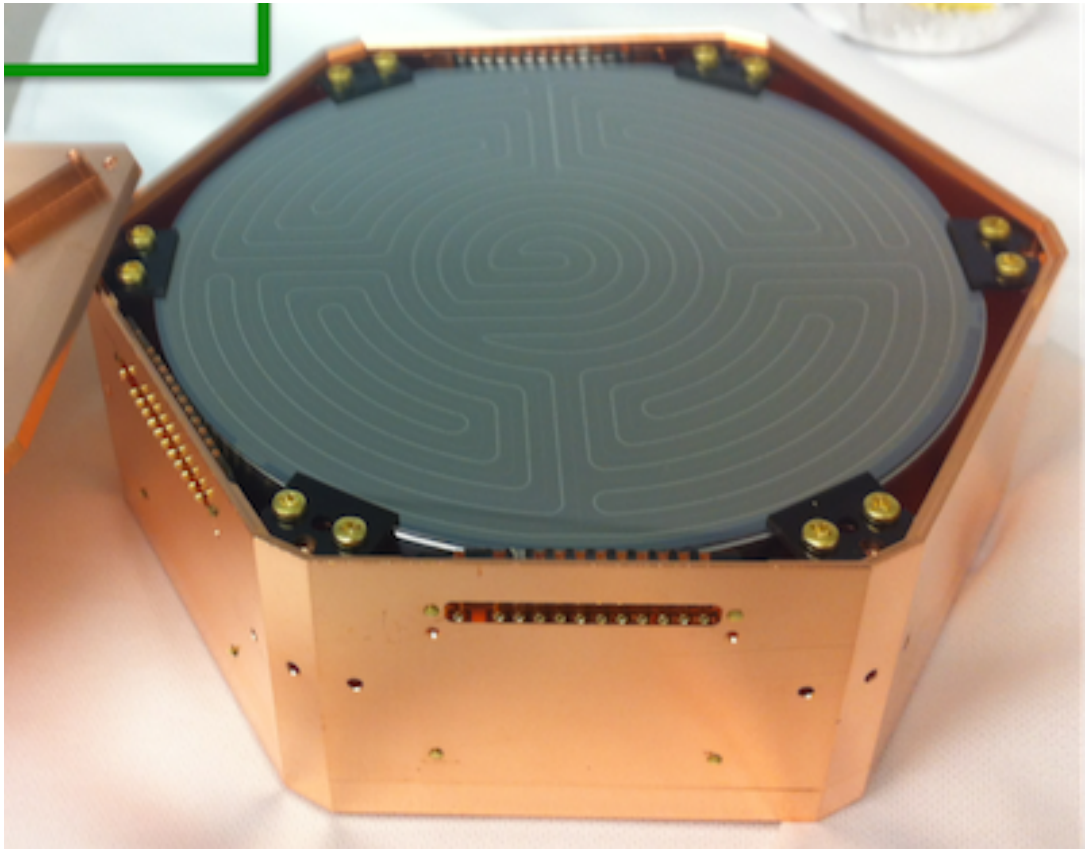
SuperCDMS SNOLAB

- To be located in SNOLAB, Canada

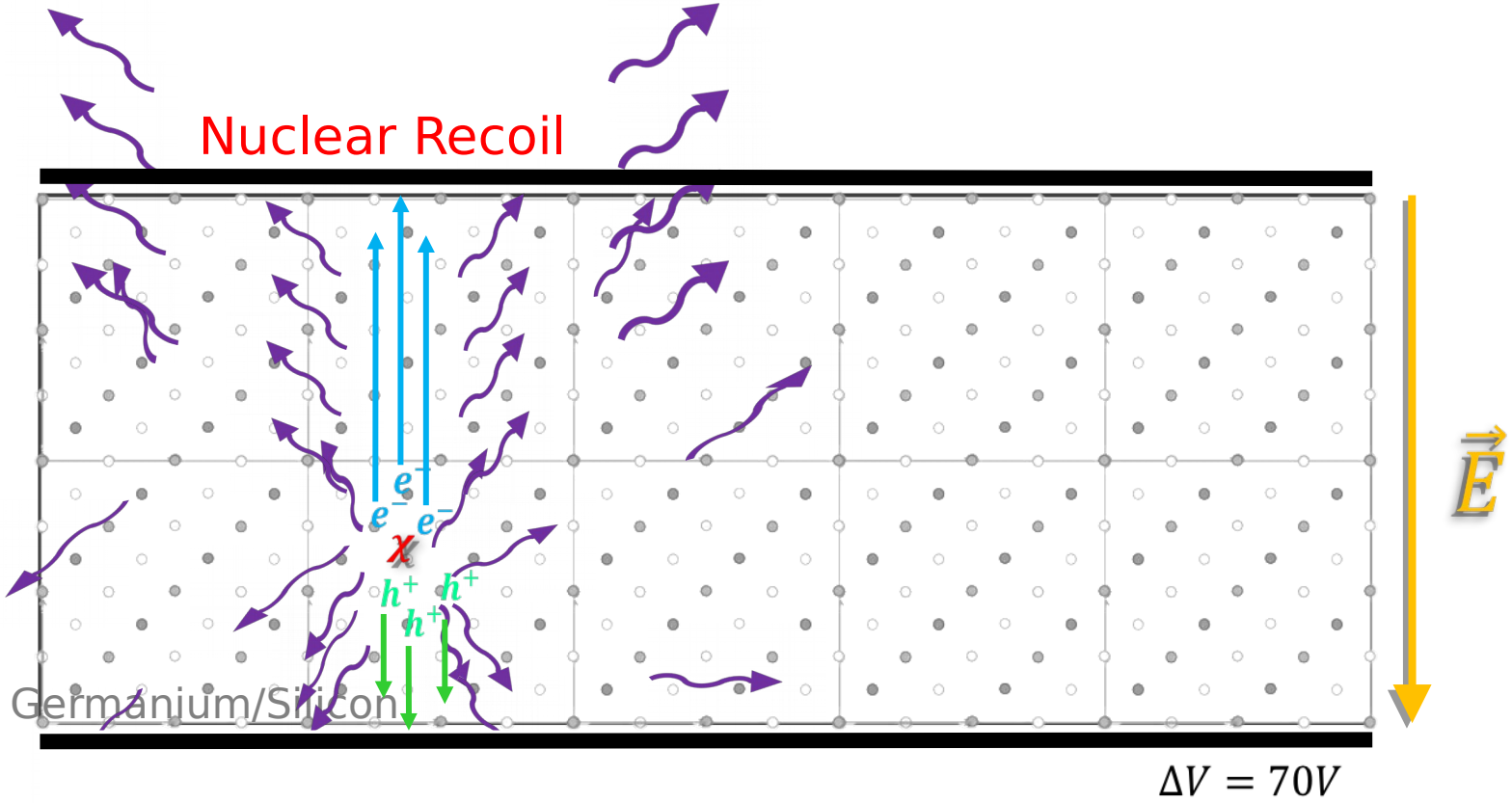


SuperCDMS SNOLAB

- Semiconductor technology: Ge or Si
- Measures ionization & heat (phonons)



SuperCDMS Operation - HV



χ Dark Matter Particle (WIMP)

↘ ↔ phonons

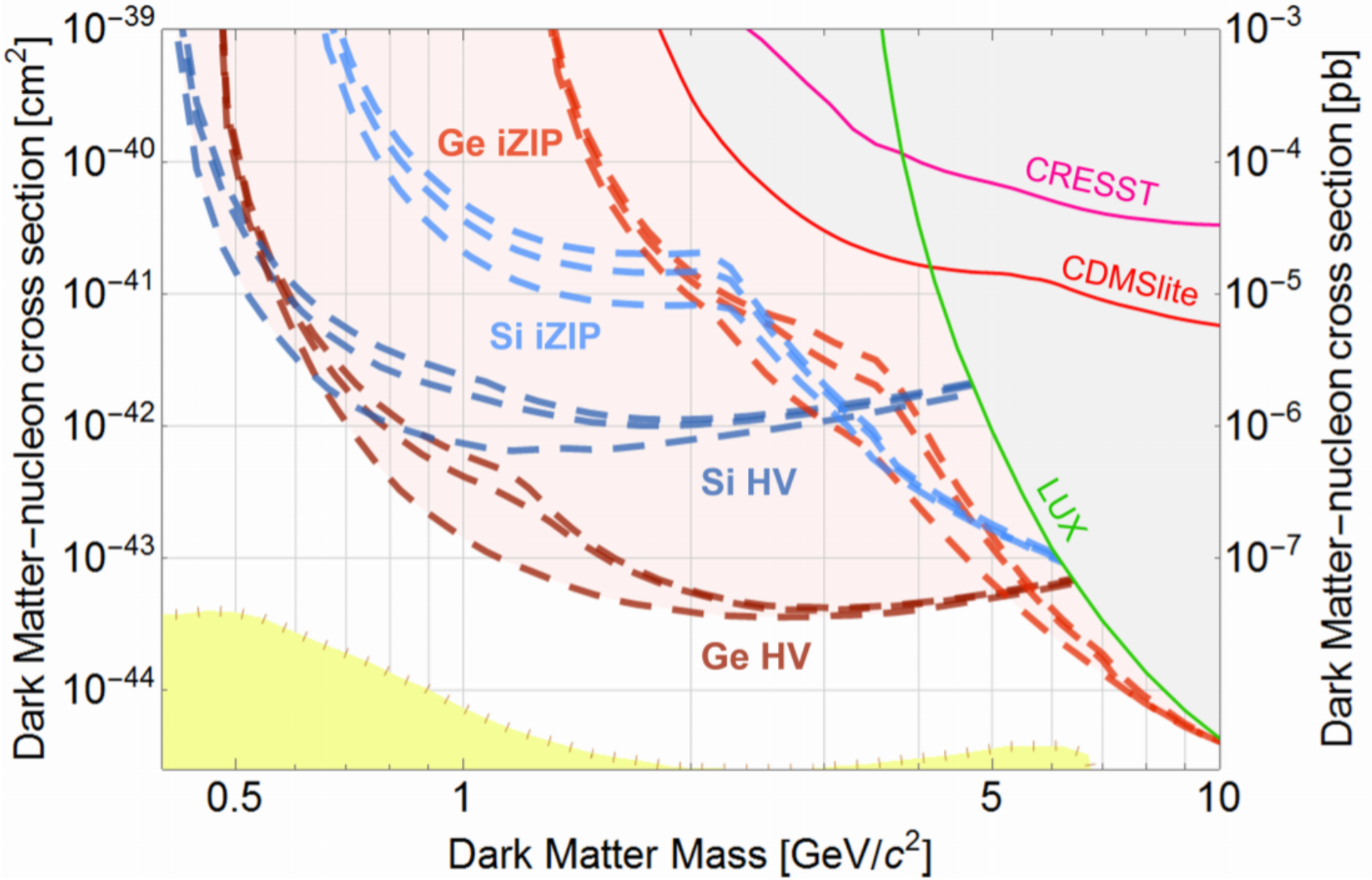
Animation by Joseph Street

Radon backgrounds in CDMS

- Backgrounds from long-lived radon daughters on detectors
  - Other areas with line-of-sight to detectors
- Byproducts from decays hit detector surfaces

Effect of Radon on CDMS Sensitivity

1x, 6x & 10x the 50 nBq/cm^2 ^{210}Pb Specification

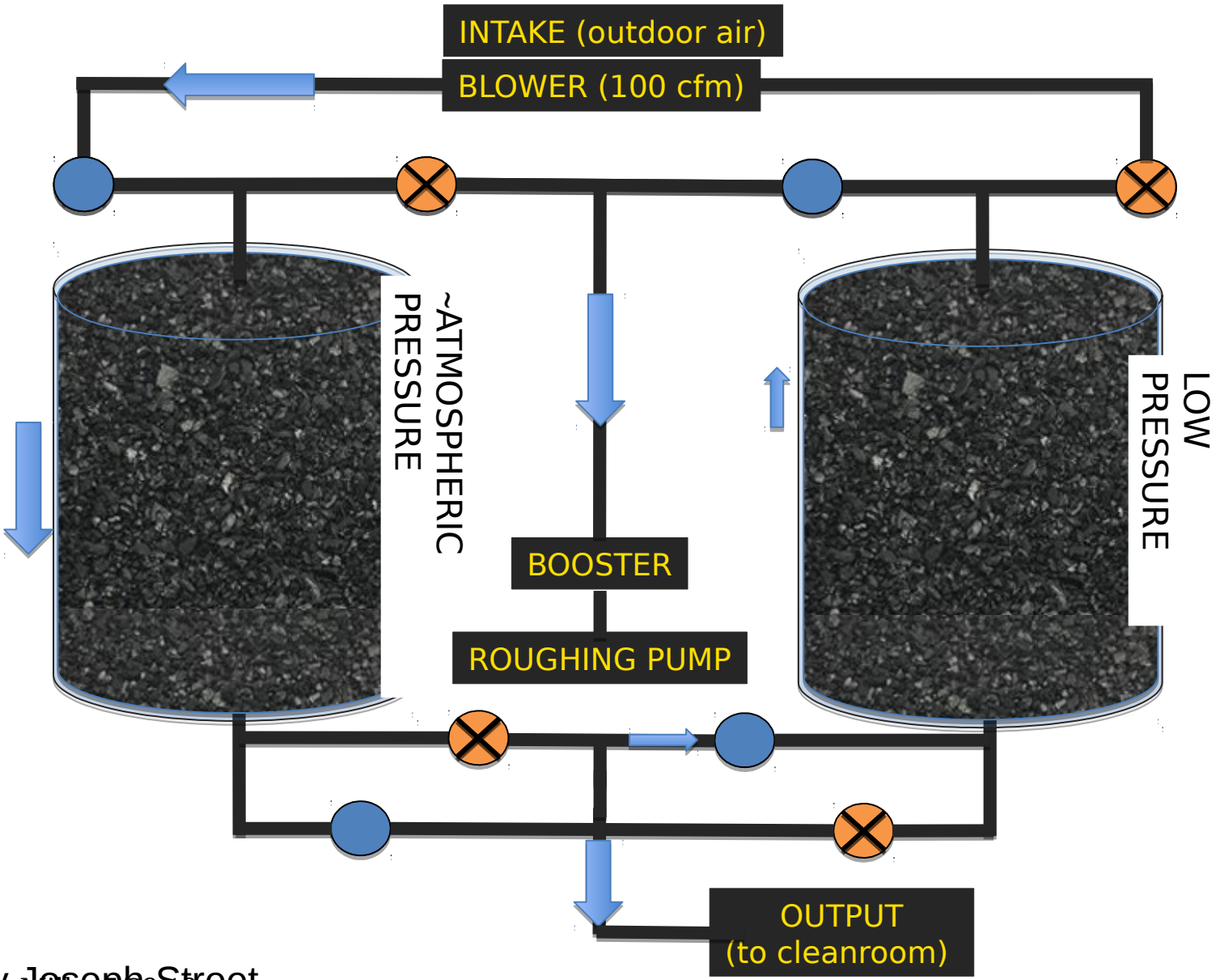


Radon-Free Environment

- These experiments must be constructed in radon-free environments
  - ~10,000 x lower radon than safe for humans!
- Impractical to build in glove-boxes
- Hard to breathe nitrogen purge

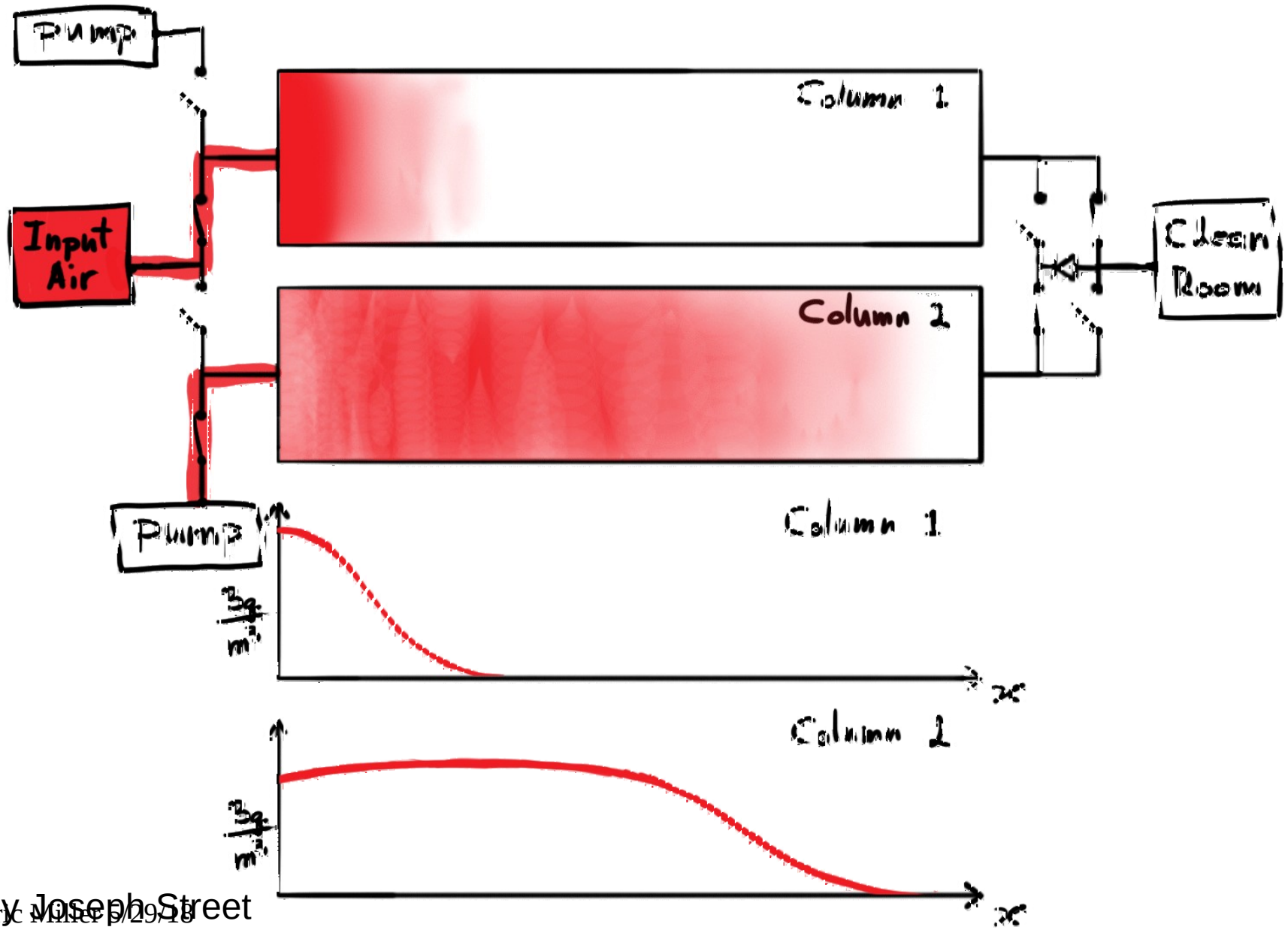
- Need to produce radon-free, breathable air

Vacuum-Swing Adsorption



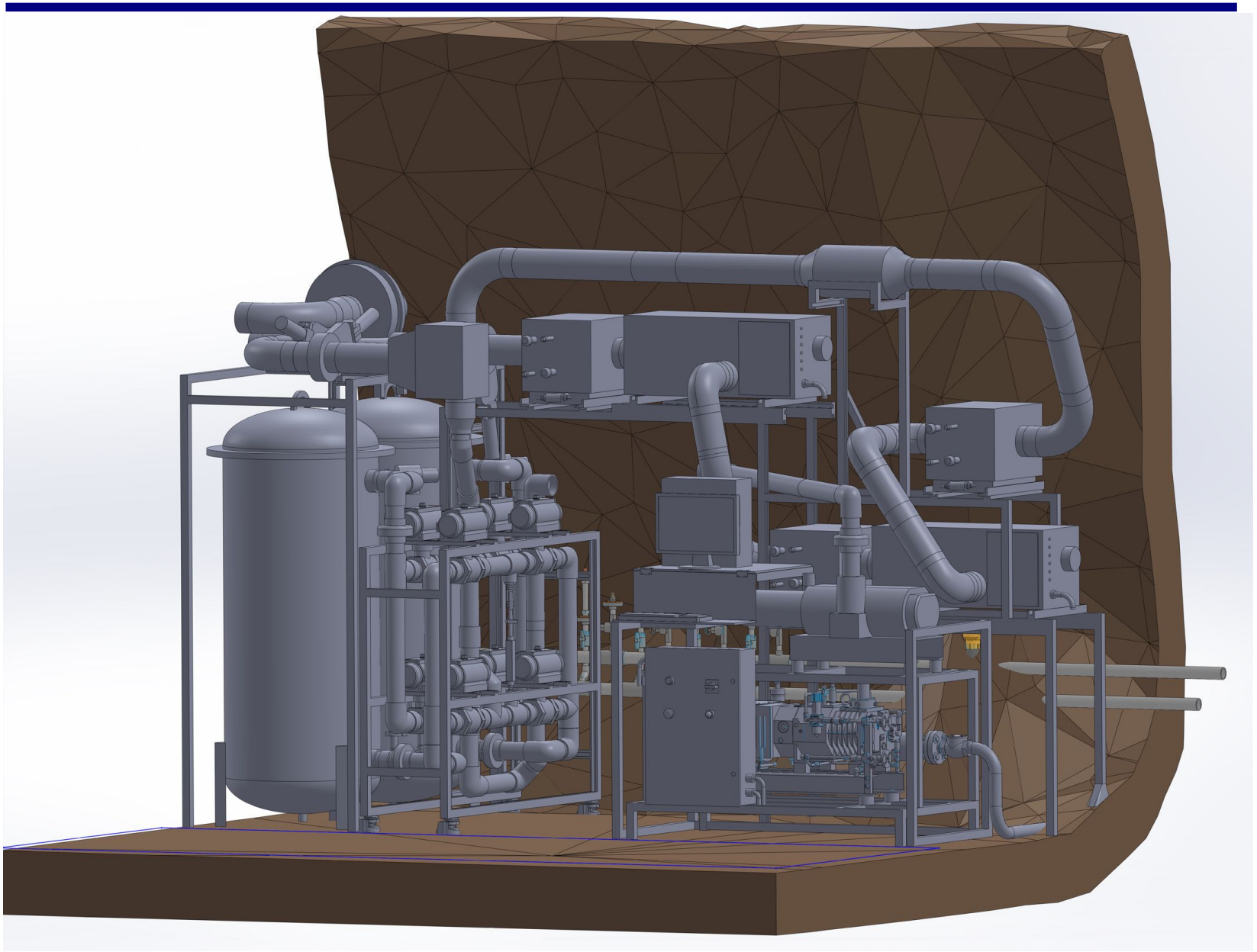
Graphic by Joseph Street
SDSM&T

Vacuum-Swing Adsorption



Graphic by Joseph Street

VSA for CDMS



VSA for SURF

Summary

- Radon is an increasingly serious background for rare event searches
- Many detector technologies have problems with radon
- Work at SDSM&T addresses these backgrounds on multiple fronts

- Thanks to Schnee group for their hard work!

Bonus Slides!

Effect of Radon on LZ Sensitivity

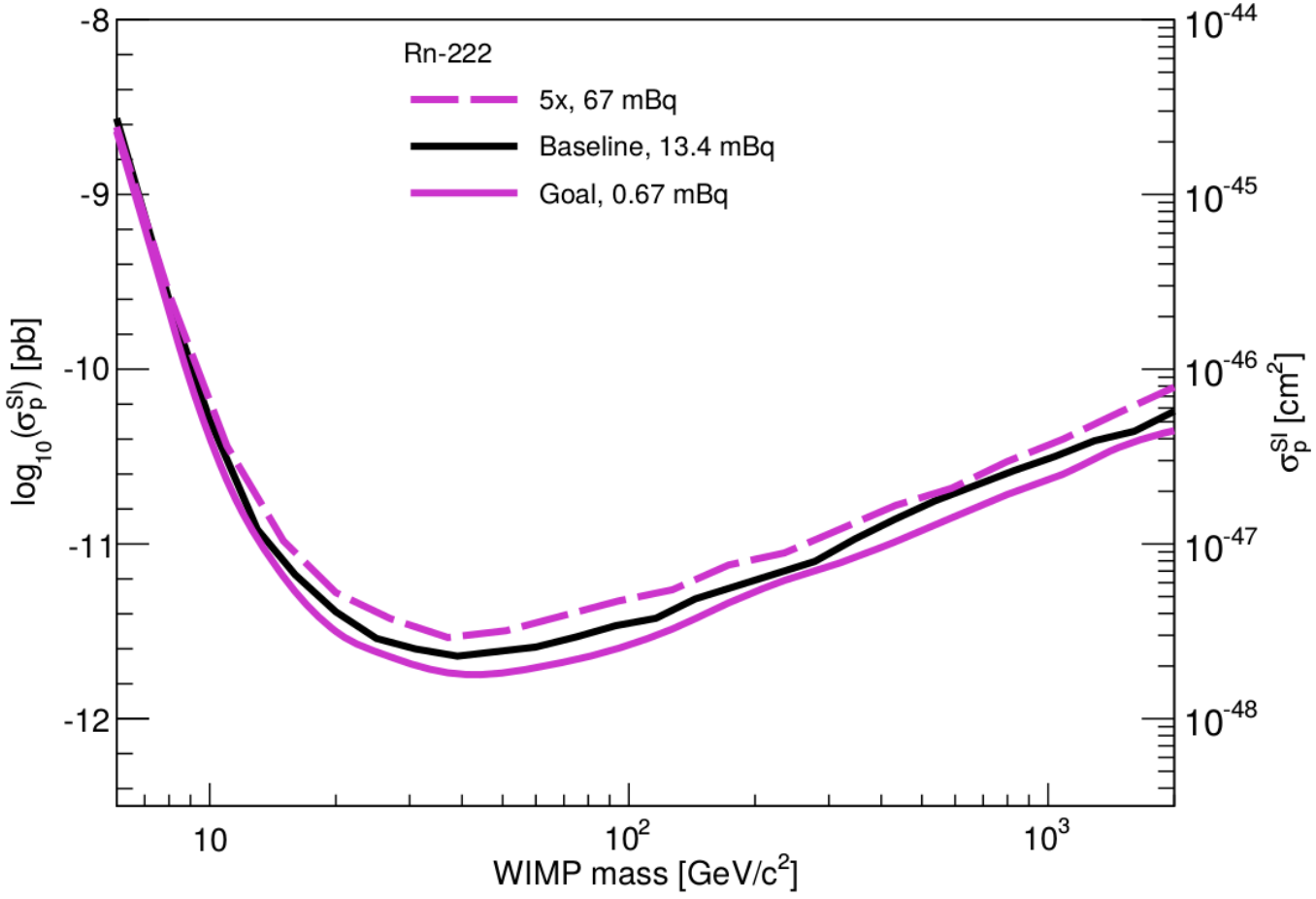
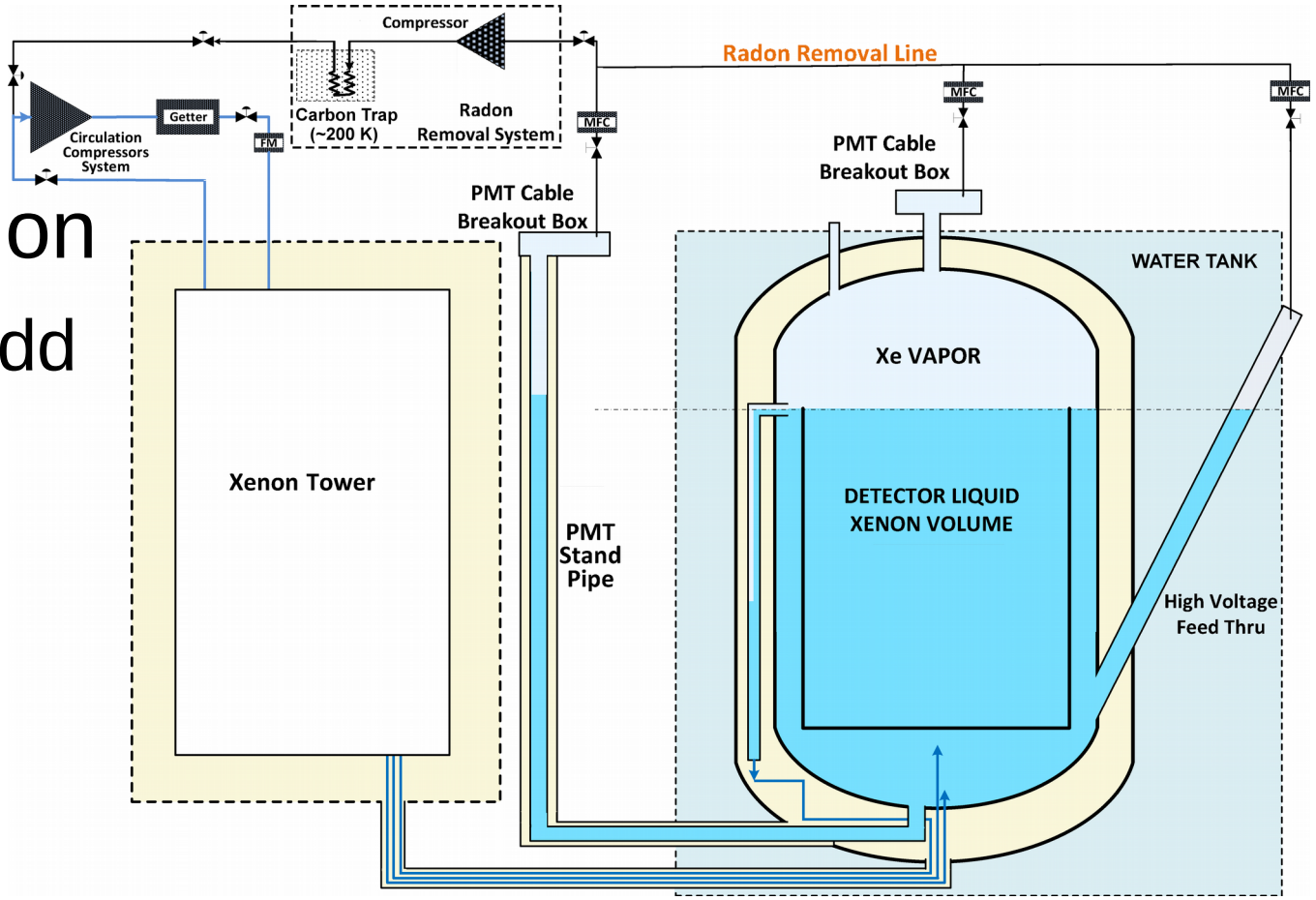
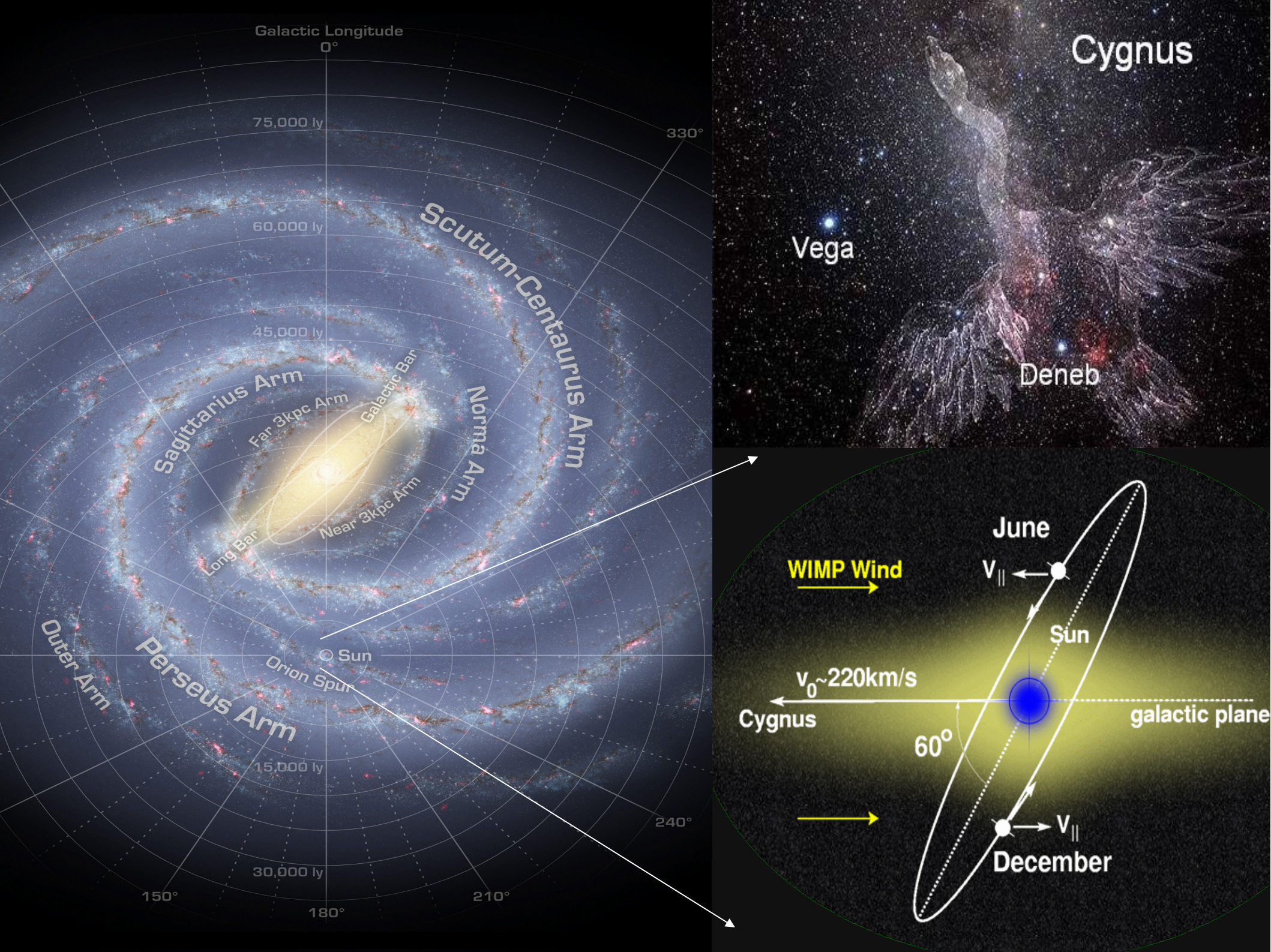


Figure 12.3.9: LZ sensitivity projections for three different assumptions on the concentration of radon in the active volume.

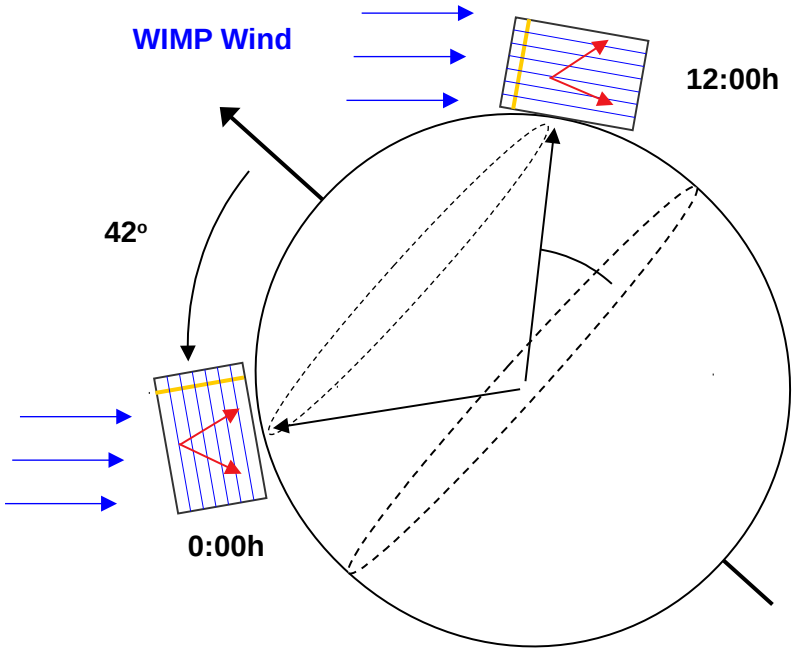
Radon Filter in LZ

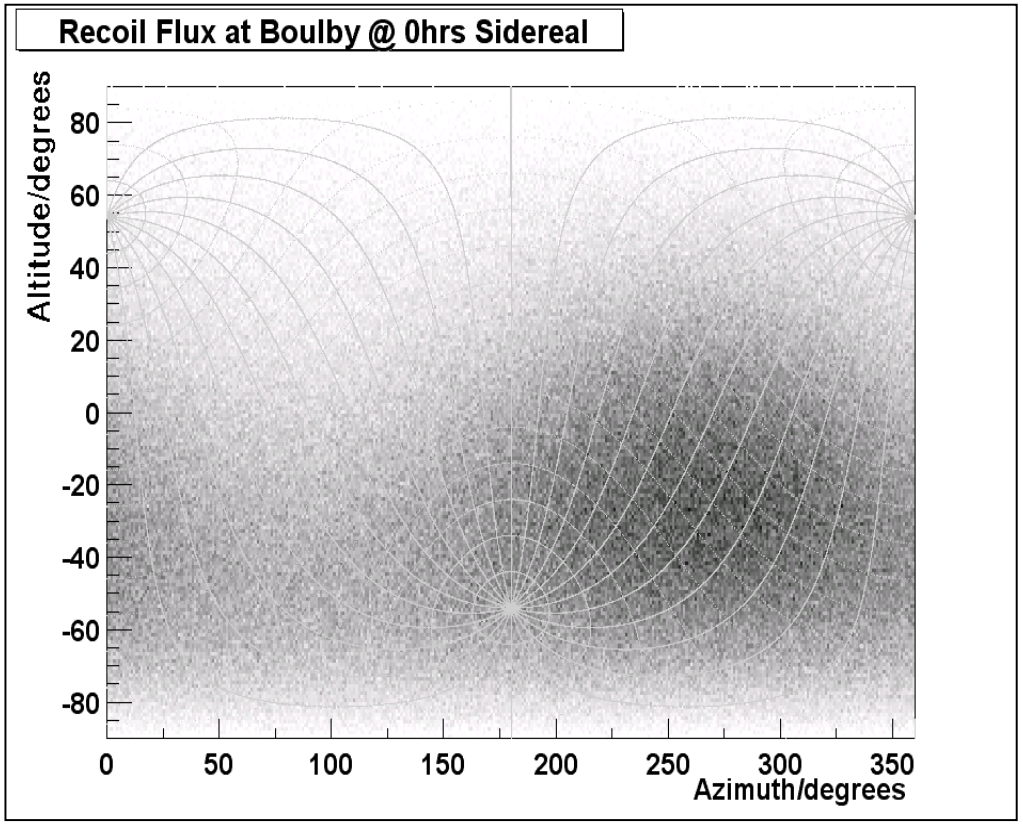
- Radon sticks to carbon – can we make a Rn filter?
- Too expensive for **full** circulation
  - ...and would add more Rn!
- Certain areas purified




Galactic Longitude
0°
330°
240°
210°
180°
150°
75,000 ly
60,000 ly
45,000 ly
30,000 ly
15,000 ly
Scutum-Centaurus Arm
Sagittarius Arm
Perseus Arm
Norma Arm
Outer Arm
Far 3kpc Arm
Near 3kpc Arm
Galactic Bar
Long Bar
Orion Spur
Sun
Cygnus
Vega
Deneb
June
December
WIMP Wind
$V_{||}$
Sun
v_0~220km/s
Cygnus
galactic plane
60°

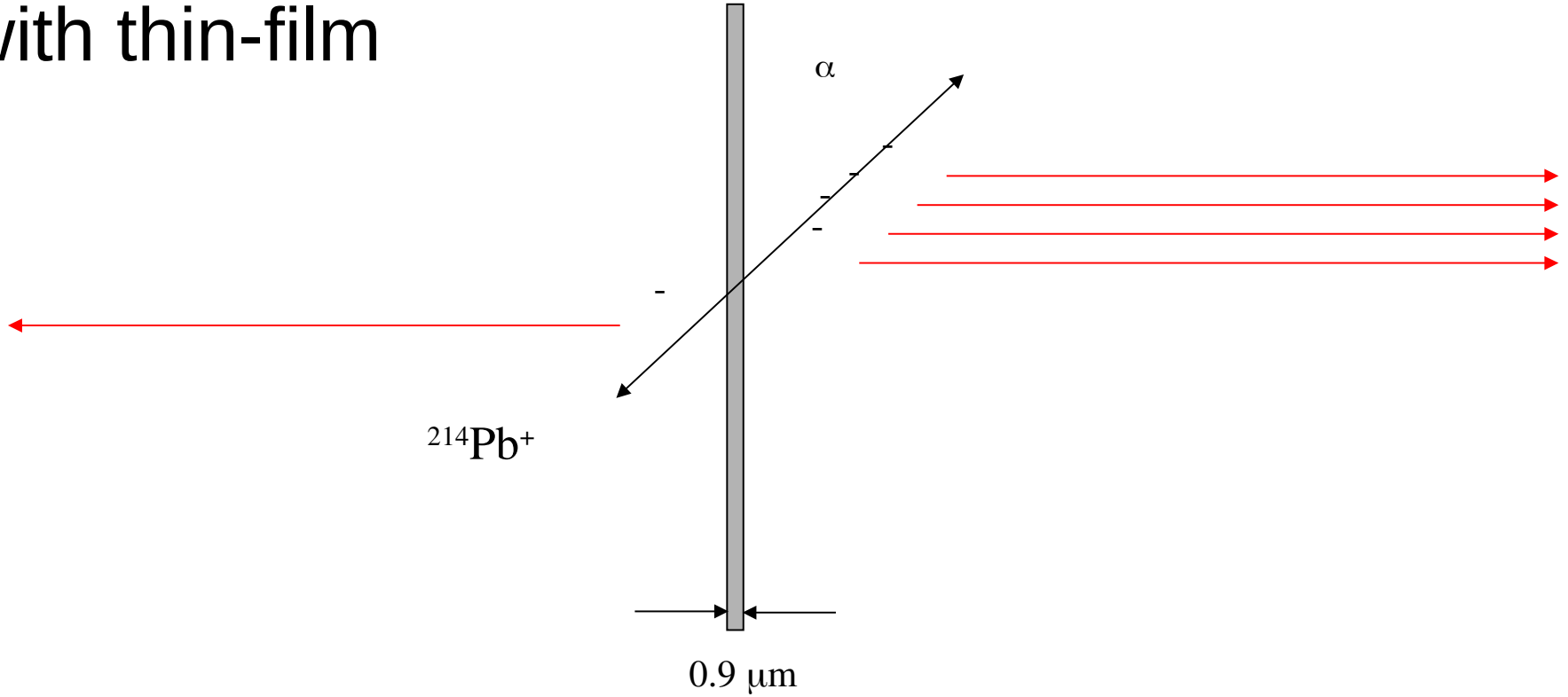
Sidereal Modulation





DRIFT Backgrounds

- DRIFT Backgrounds ONLY from Rn daughters
  - Rates as high as 130/day
- Reduced 40x by replacement of wire cathode with thin-film



Thin-Film Cathode Installation