First Evidence for Radon Daughter ~~Solubility~~ Mobility in Liquid Xenon

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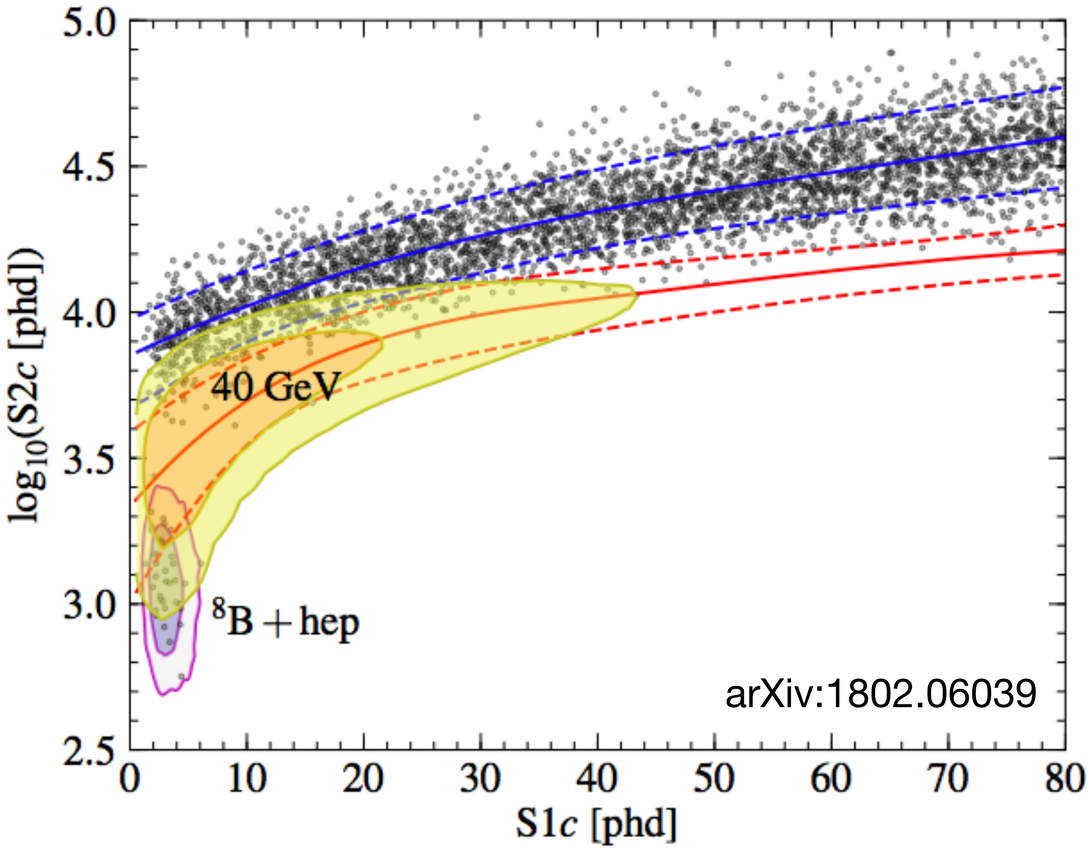
With Peter Sorensen @ LBL

Radon daughters can fake WIMP signal

LZ projected sensitivity backgrounds dominated by counts from 222Rn — we really need to know where all the radon is!



Uniform ER Internal Backgrounds

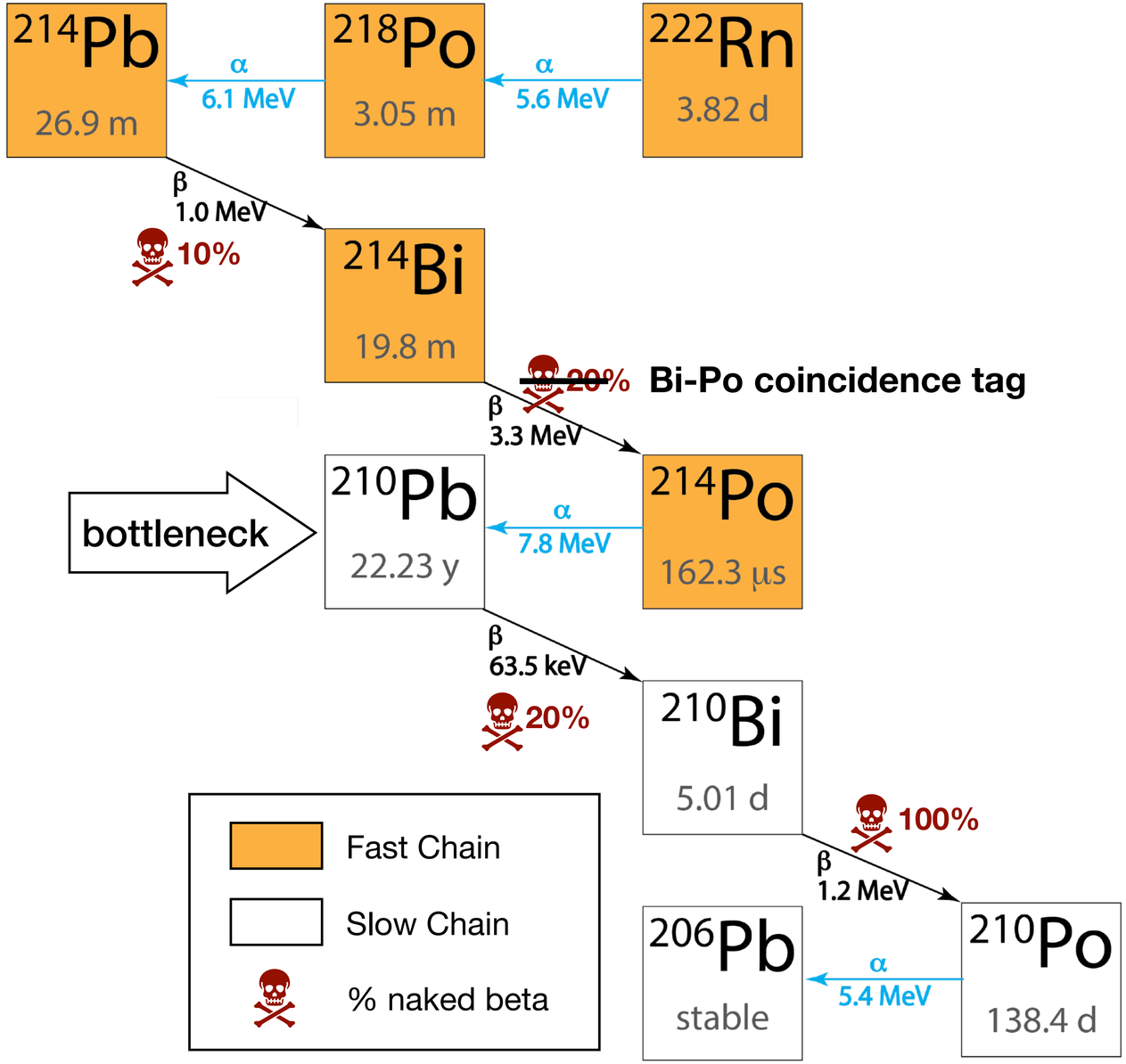
- **Expected counts in 1,000 live days in an indicative 5.6-tonne fiducial mass in [1.5-6.5] keV$_{ee}$ (ER) and [6-30] keV (NR):**

Background Source	Mass (kg)	$^{238}U_e$	$^{238}U_l$	$^{232}Th_e$	$^{232}Th_l$	^{60}Co	^{40}K	n/yr	ER (cts)	NR (cts)
		mBq/kg								
Surface Contamination										
Dust (intrinsic activity, 500 ng/cm^2)									0.2	0.05
Plate-out (PTFE panels, 50 nBq/cm^2)									-	0.05
^{210}Bi mobility (0.1 µBq/kg LXe)									40.0	-
Ion misreconstruction (50 nBq/cm^2)									-	0.16
^{210}Pb (in bulk PTFE, 10 mBq/kg PTFE)									-	0.12
(Before S2/S1 discrimination)								subtotal	**40**	**0.39**
Xenon contaminants										
^{222}Rn (1.81 µBq/kg)									681	-
^{220}Rn (0.09 µBq/kg)									111	-
^{nat}Kr (0.015 ppt g/g)									24.5	-
^{nat}Ar (0.45 ppb g/g)									2.5	-
(Before S2/S1 discrimination)								subtotal	**819**	**0**

From M. E. Monzani's LZ Sensitivity Talk

Possible backgrounds from late-chain 222Radon

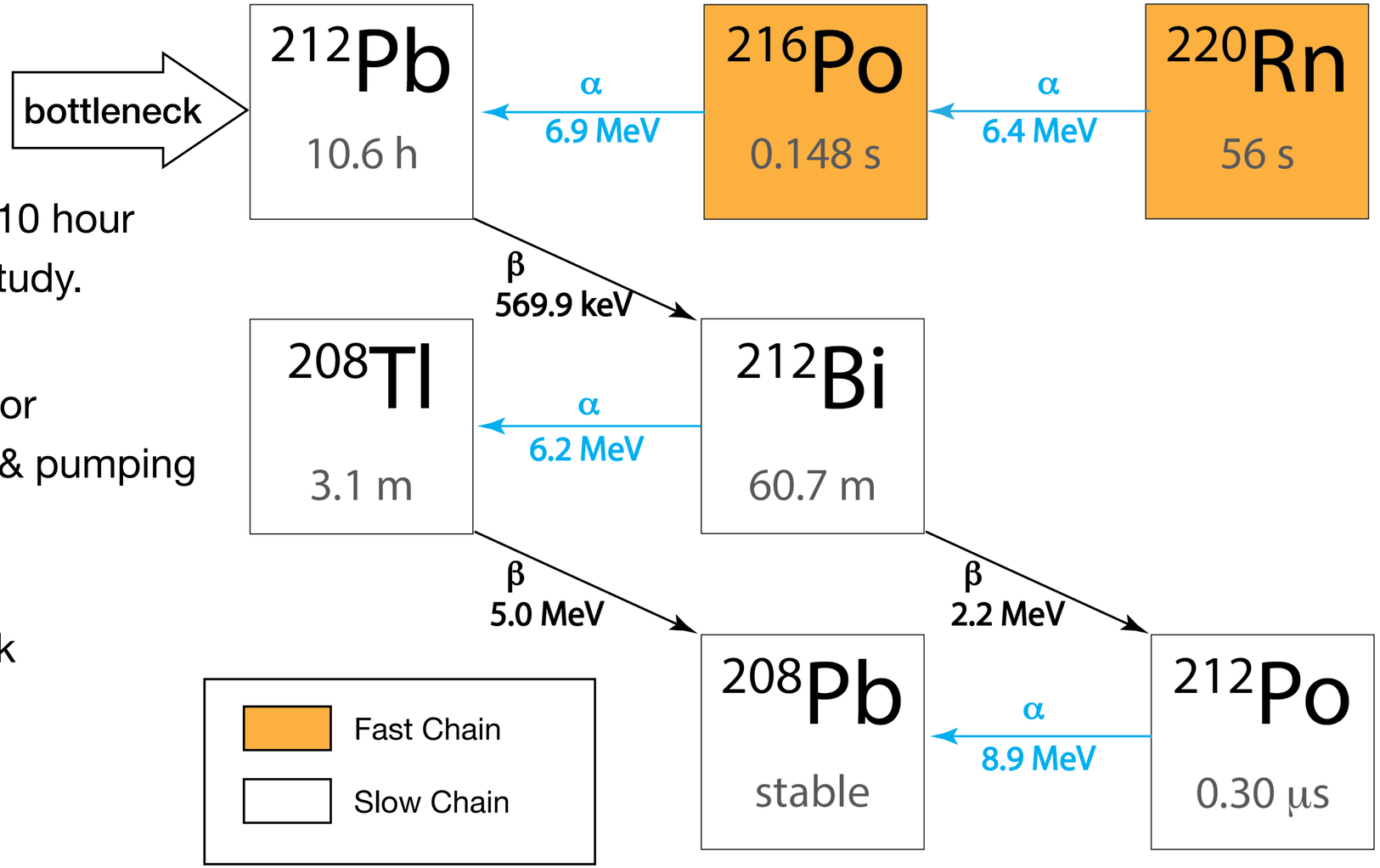
- "Naked" betas are of particular concern
- Typically, "plate out" is assumed after bottleneck
- Evidence of ^{210}Bi mobility has observed in KamLAND [1],[2] and Borexino [3]
- If radon daughters are mobile in LXe, late chain naked betas are new WIMP background in fiducial volume



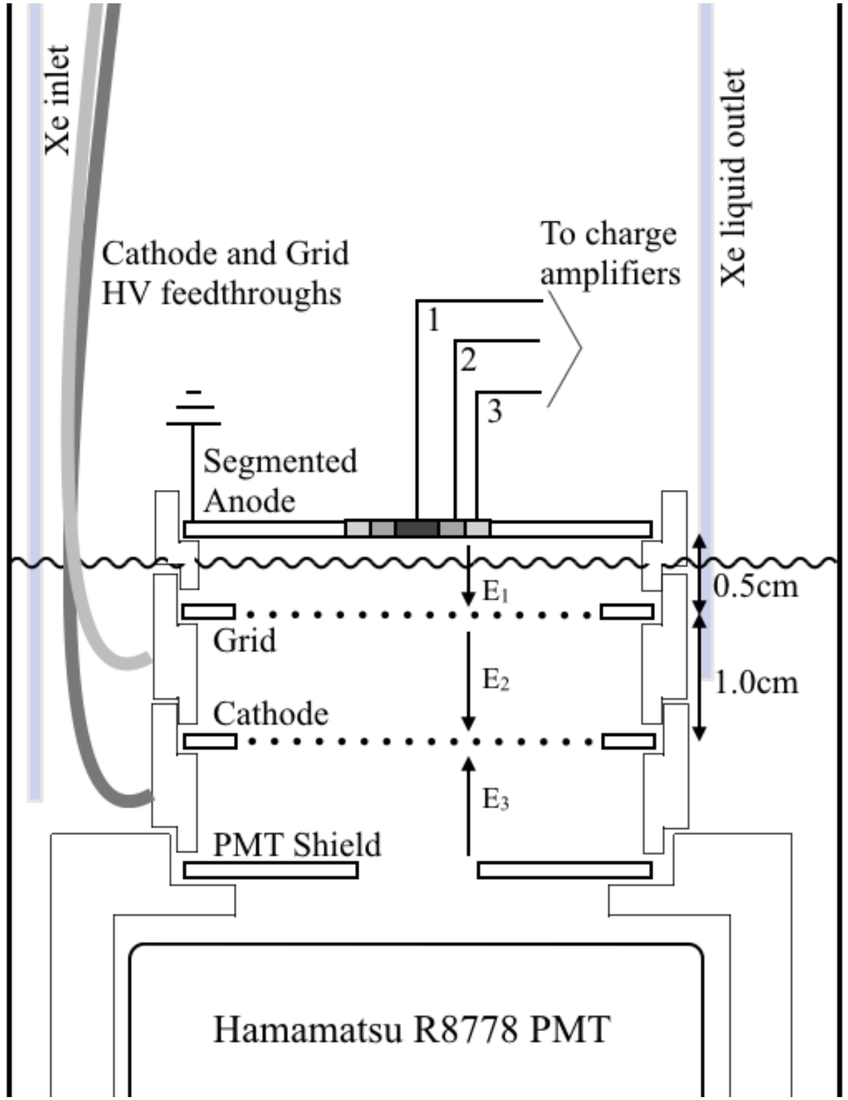
[1] Y. Takemoto et al. Nucl. Part. Phys. Proc. 265-266 (2015), pp. 139-142
[2] A. Gando et al. Phys. Rev. C 92:5 (2015) 055808
[3] G. Bellini et al. Phys. Rev. D. 89:11 (2014) 112007

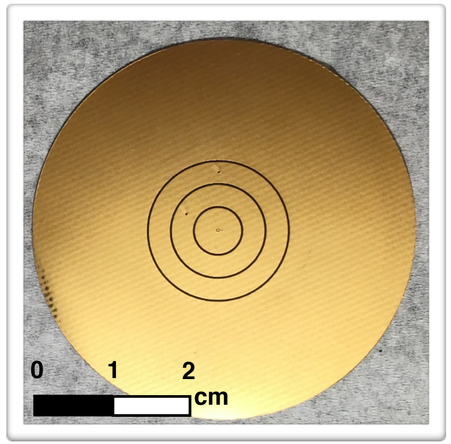
220Rn as proxy for 222Rn

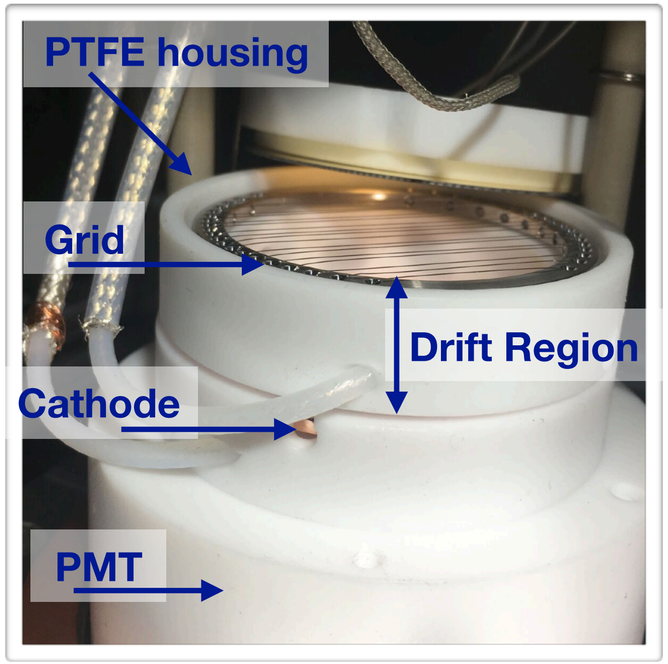
- ^{220}Rn chain bottleneck (^{212}Pb) has 10 hour half-life; well suited to laboratory study.
- Mimic conditions present in detector construction by introducing radon & pumping to vacuum.
- Search for ^{212}Bi alpha decay in bulk



TPC inner vessel







- Segmented anode instrumented with Cremat-110 charge amplifiers

Data Collection

- Direct, independent read-out of charge and light signals.
- Voltage records of PMT & charge amplifiers taken with 14 bit 125 MHz digitizer
- Triggered on coincidence between PMT and central anode segment

Procedure & data sets

Plate Out Procedure:

1. Circulate xenon gas + 220Rn
2. Pump out TPC & lines (1E-4 Torr)
3. Fill liquid Xe
4. Search for 212Bi alpha decay in bulk

Dataset ID	Plate Out #1	Plate Out #2	Background	Calibration of Signal Region
Description	Plate out w/cathode at -1 kV	Plate out w/ cathode at 0 kV	No plate out	Introduce 220Rn, 216Po into bulk LXe
Livetime (h)	12.02 ± 0.5	23.93 ± 0.5	25.02 ± 0.2	4.15 ± 0.2

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alphas of ~6MeV

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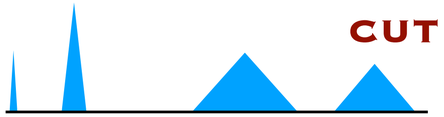
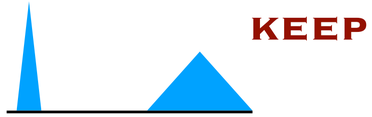
Data selection for 212Bi alpha in bulk

1. Alpha decays robustly selected by electrons/photons (S2/S1)

2.



Bi-Po topology



212 Bi alpha topology

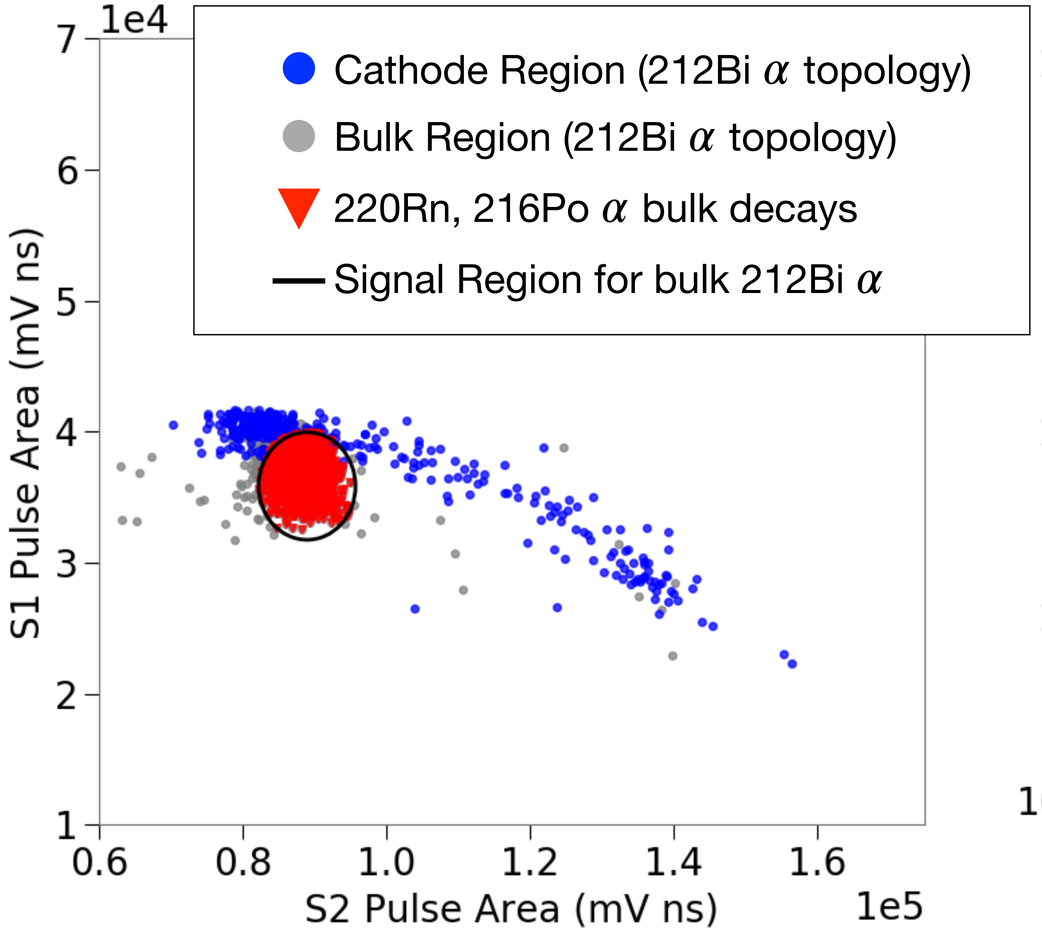
4. Is it in bulk?

5. Is it in expected S1-S2 signal region?
Signal region is defined by bulk 220Rn, 216Po alpha decay (next slide)

Calibration of bulk signal region - 4 hours livetime

Introduce 220Rn into bulk liquid (performed after plate out)

220Rn & 216Po alpha decays fill entire bulk region. 212Bi alpha in bulk will be in same S1-S2 signal region.



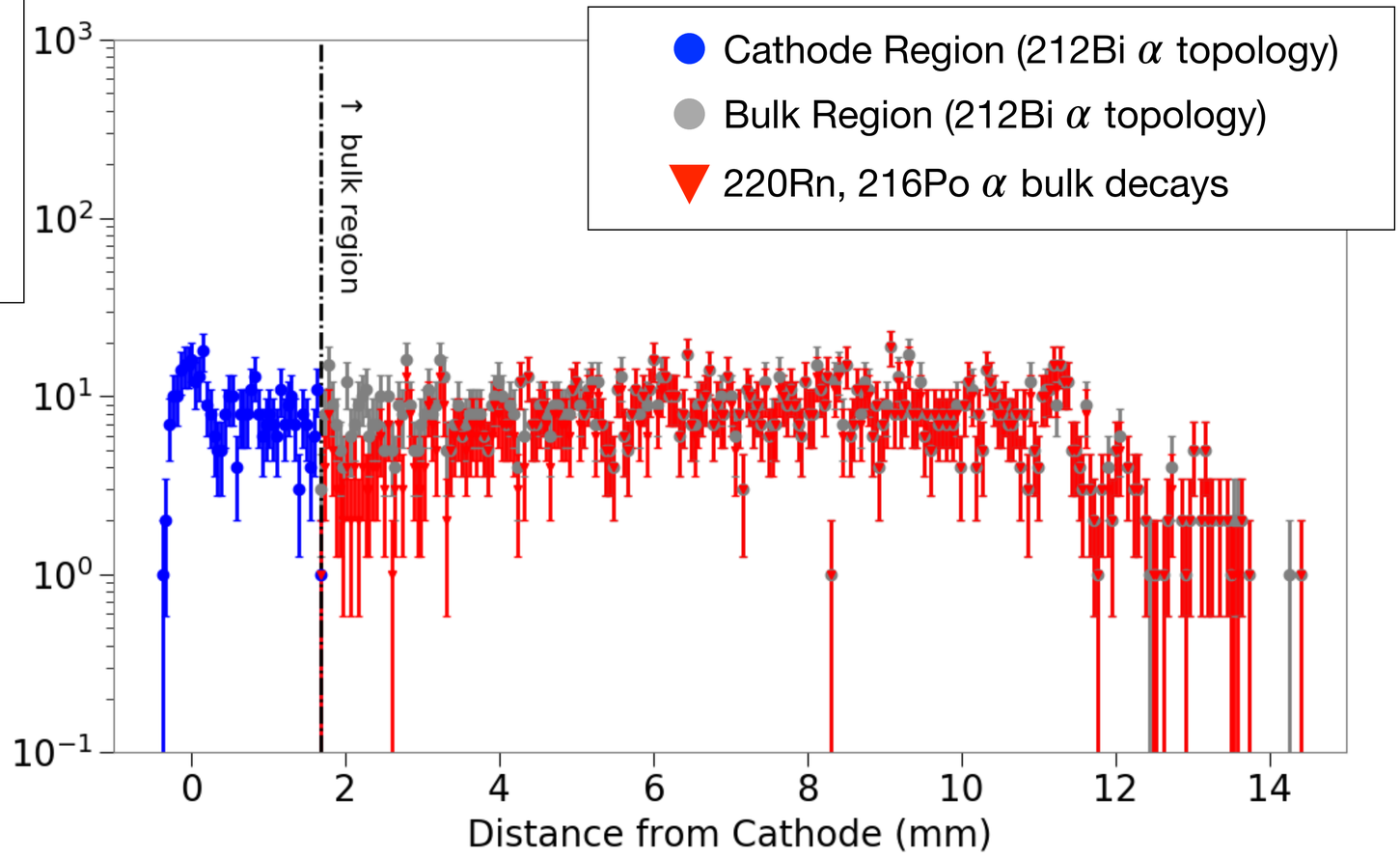
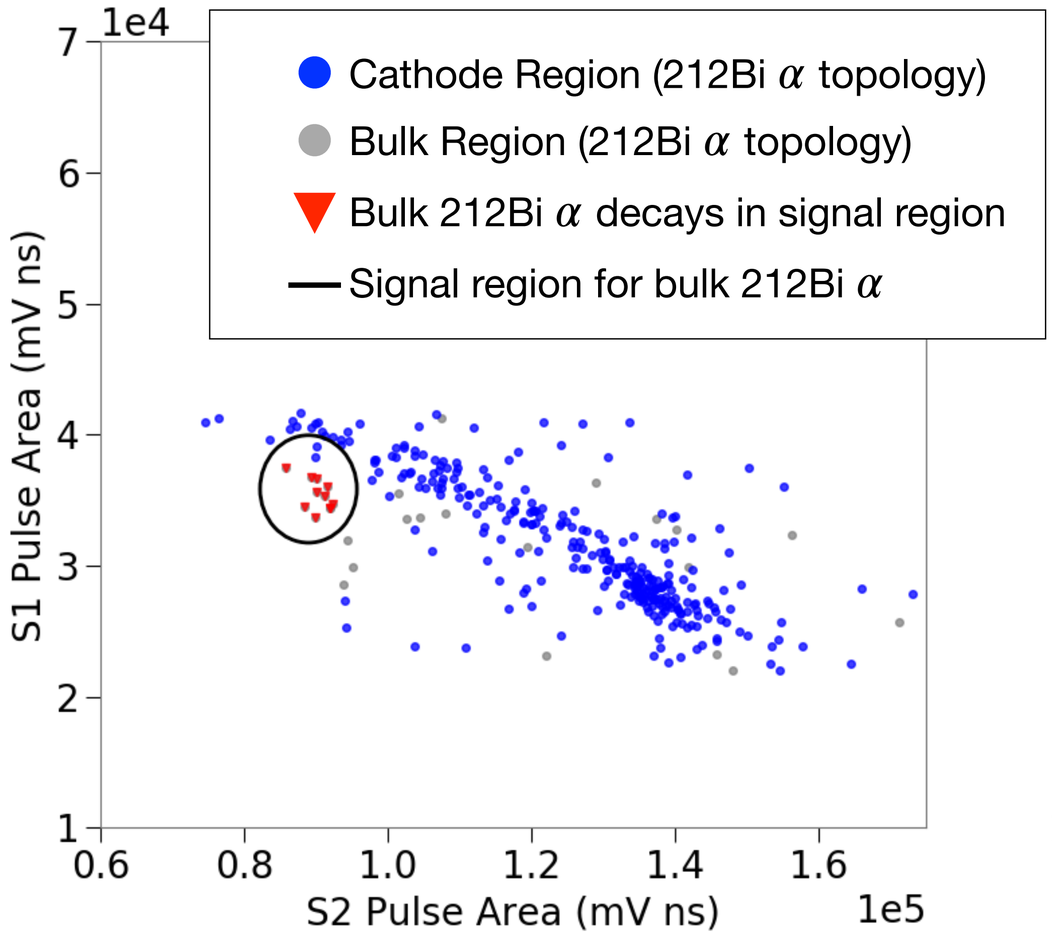


Plate Out #1 - 12 hours livetime



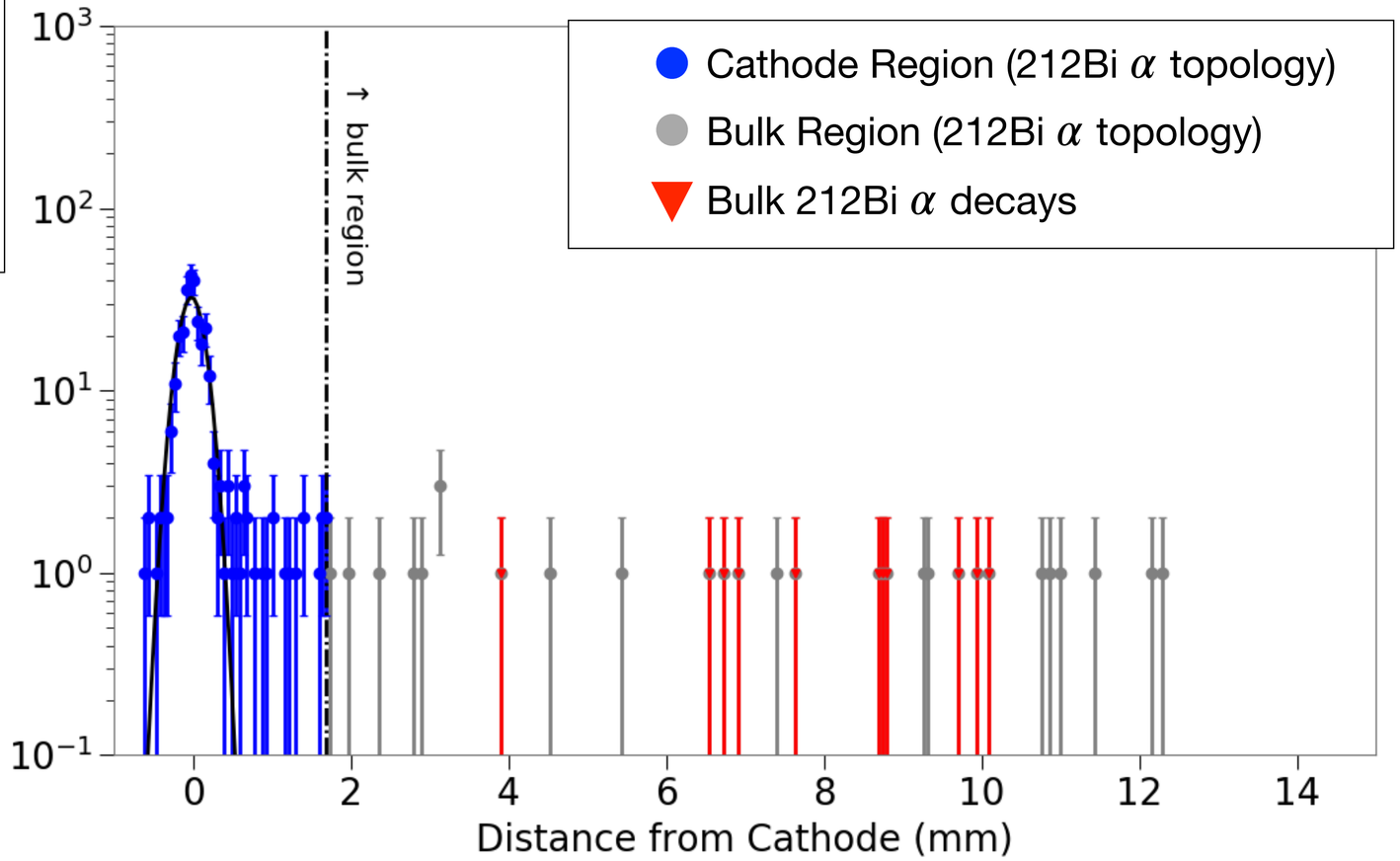
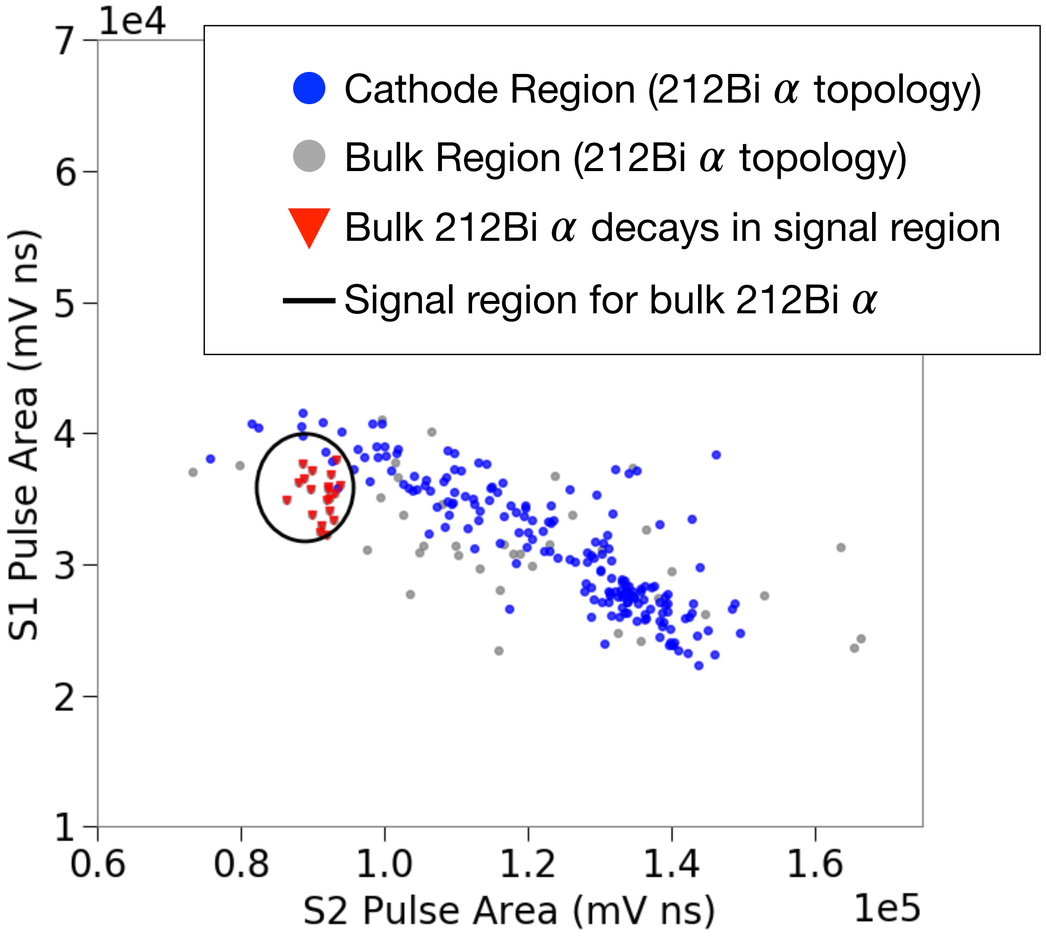
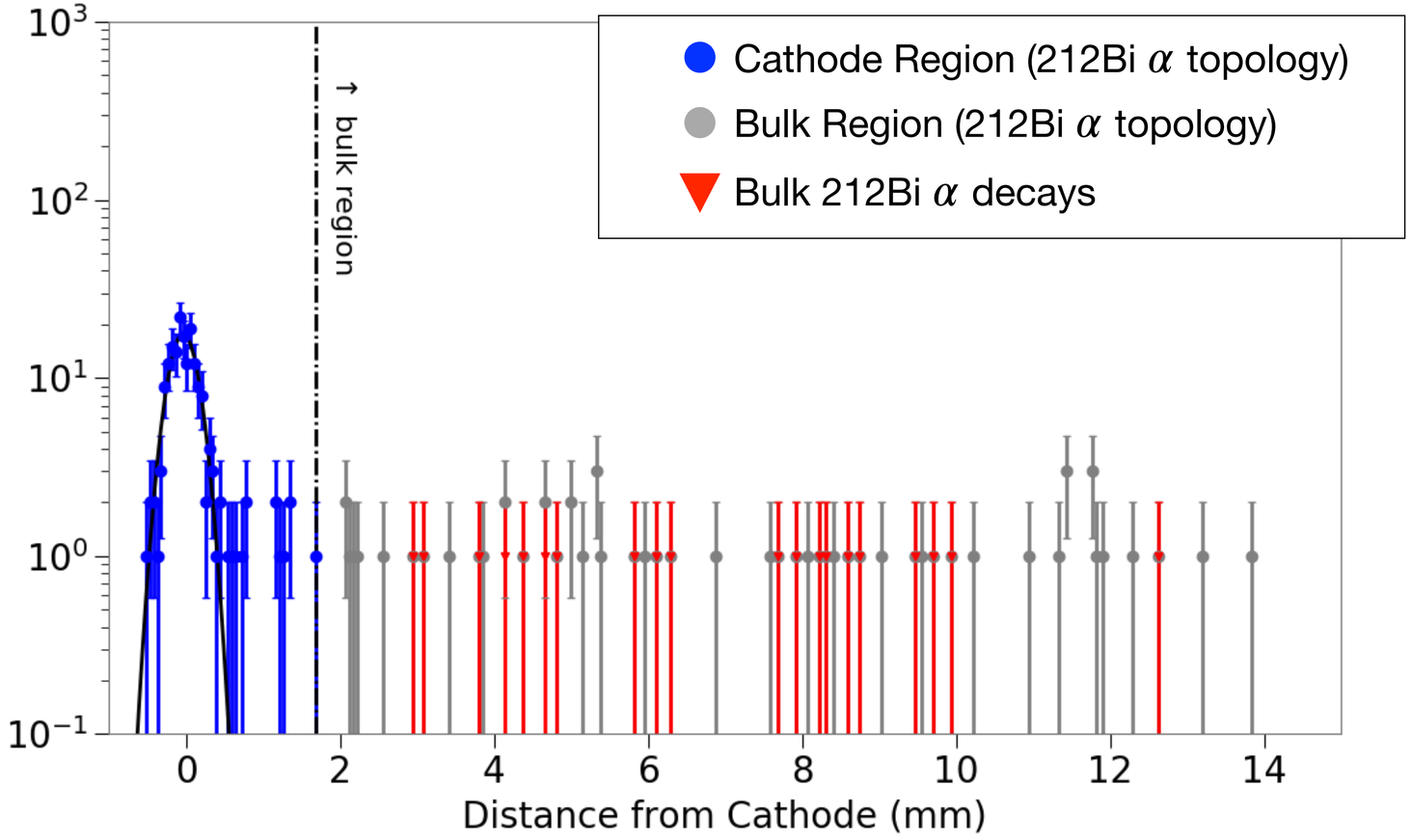
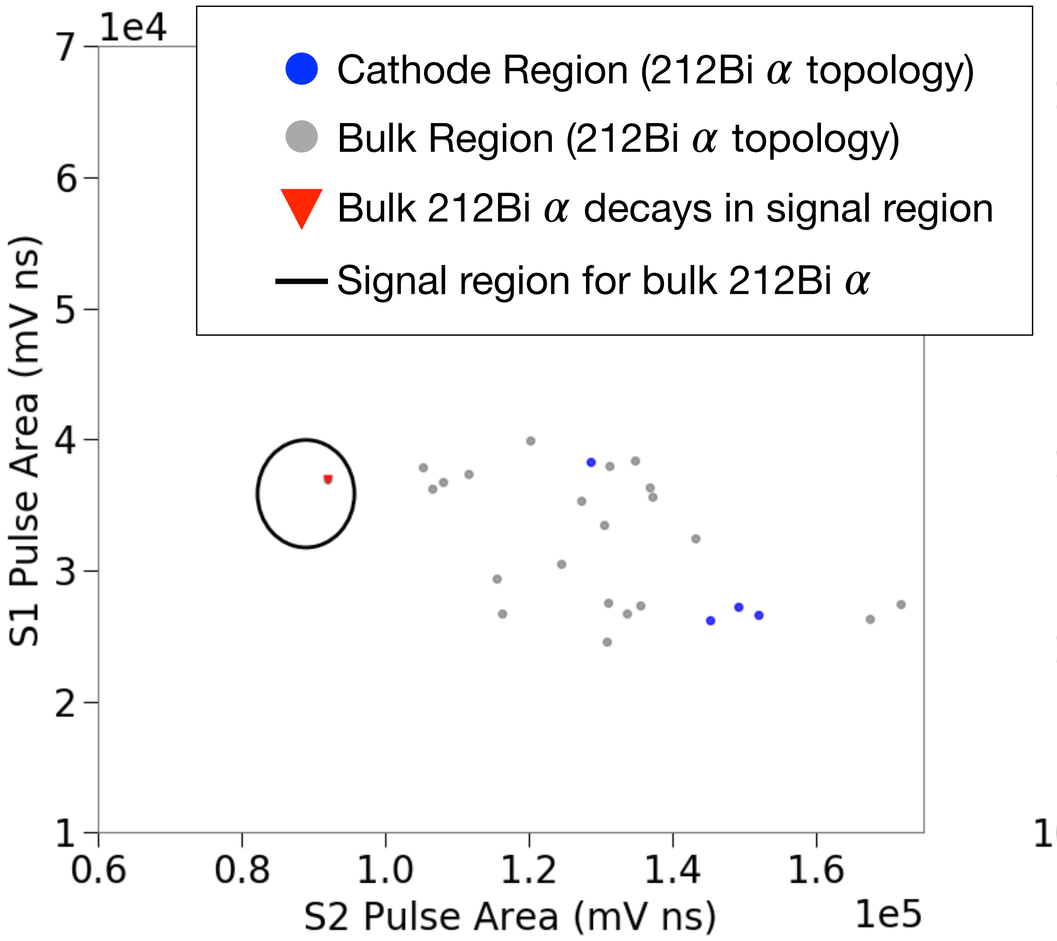


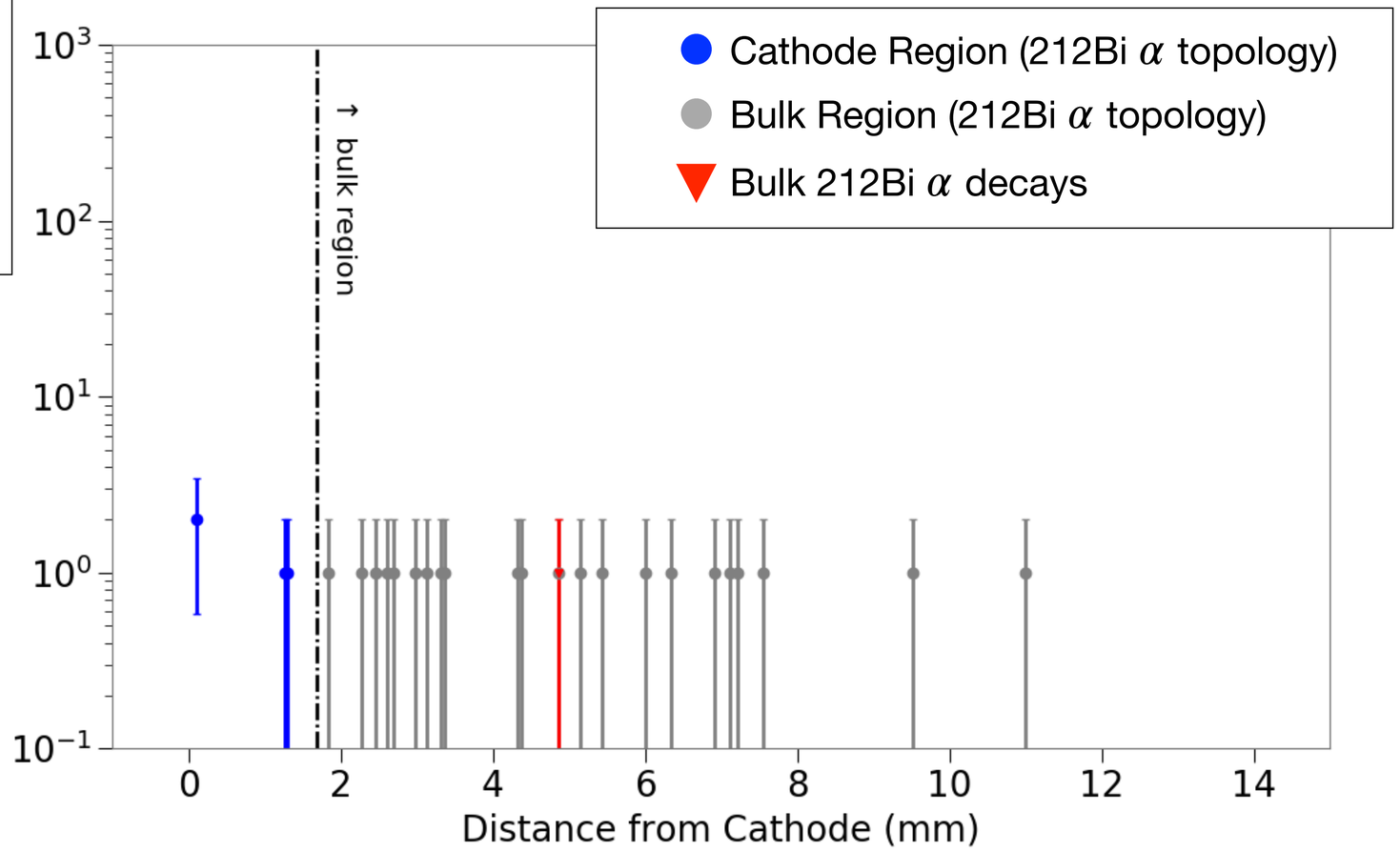
Plate Out #2 - 24 hours livetime





Background - 24 hours livetime





Clear evidence for radon daughters leaving walls

Number of events consistent with 212Bi alpha decay to 208Tl

Dataset ID	Plate Out #1	Plate Out #2	Background
Bulk events	**11**	**20**	**1**
Cathode events	**300**	**183**	**4**
Livetime	12.02 ± 0.5	23.93 ± 0.5	25.02 ± 0.2

In both plate out data sets, events consistent with 212Bi alpha decay were observed in the LXe bulk at counts above background.

Very preliminary Rn-daughter mobility ESTIMATE

To put these counts into context of LXe dark matter experiments, define mobility:

$$\text{mobility} = \frac{\text{Bq 212Bi dissolved / kg LXe}}{\text{Bq 212Pb plated out / cm}^2\text{ detector surface}}$$

atoms/kg/cm²

Mobility Estimate of 212Bi alpha in LXe atoms/kg/cm²

Dataset ID	Plate Out #1	Plate Out #2
Mobility Range Estimate	0.1–84	0.1—58

Significant uncertainties in test bed volume & plate-out area

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Mobility Range Estimate	0.1–84	0.1—58

Significant uncertainties in test bed volume & area

This is a very large and interesting difference

210Bi mobility: ~ 1.0 E -5 atoms/kg/cm²

LUX Preliminary (K. Oliver-Mallory's Talk):

210Pb in bulk < 0.099 uBq / kg LXe

210Pb on PTFE > 9.8 mBq / cm²

Why are there events in the bulk?

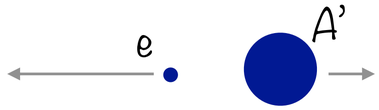
Some % of plated-out daughters = Physisorption binding energy ~1 eV or less (e.g Van der Waals)

Hypothesis 1: Early in detector lifetime, may expect physisorbed species to easily ‘wash off’ in LXe

Hypothesis 2: Beta ejection of Bi daughter nucleus

→ gives rise to innate difference between 212Bi (laboratory) and 210Bi (late 222Rn-chain) mobility

	210Pb (222Rn chain - reality)	212Pb (220Rn chain - laboratory)
Decay Q	63.5 keV	569.9 keV
Max. Bi daughter nucleus recoil	0.006 eV	0.6 eV



$$(E_{A'})_{recoil} = p_{A'}^2 / 2m_{A'}$$
$$= p_e^2 / 2m_{A'}$$

Conclusions

Clear evidence for 212Bi mobility was observed.

Our calculated 212Bi mobility in lab is much greater than LUX preliminary 210Bi measurement

→ Two hypothesis why:

1. Chemistry: Increased mobility/solubility in early times due to physisorbed species
2. Particle Physics: Natural difference between 220Rn and 222Rn chains
   - Would be a boon for LZ and company (Late-chain naked betas of 222Rn chain very unlikely to dissolve into bulk)

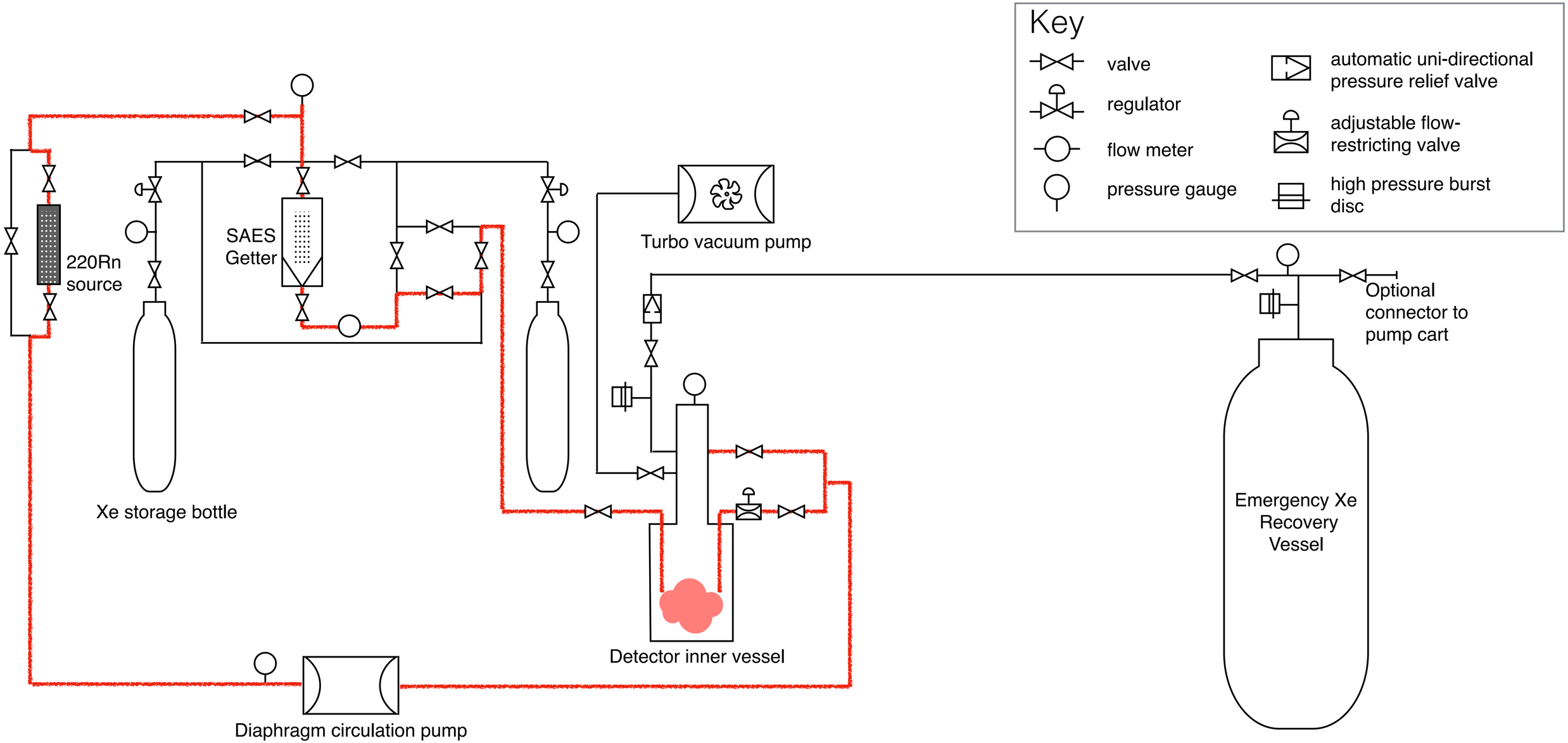
Further study desired! We can start to answer: hypothesis 1 or 2?

Extra Slides

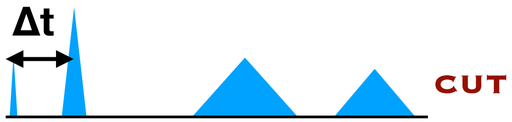
Data sets & conditions

	Dataset ID	A	B	C	D
Plate-out conditions	description	plate out	plate out	background	calibration
	220Rn rate	4.5 ± 0.5 Hz	4.5 ± 0.5 Hz	0 Hz (source bypassed)	-
	Circulation Time (h)	24	48	24	-
	Cathode Voltage (kV)	-1	0	0	-
Data-taking conditions	Getter purification	yes	yes	yes	yes
	220Rn introduced	no	no	no	yes
	Cathode Voltage (kV)	-6	-6	-6	-6
	Grid Voltage (kV)	-4	-4	-4	-4
	Livetime (h)	12.02 ± 0.5	23.93 ± 0.5	25.02 ± 0.2	4.15 ± 0.2

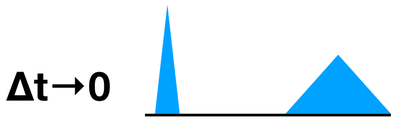
Example radon circulation path for plate out



Defining cathode region



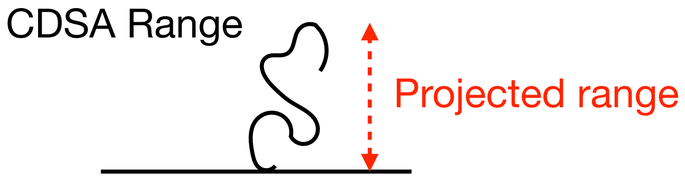
Bi-Po topology



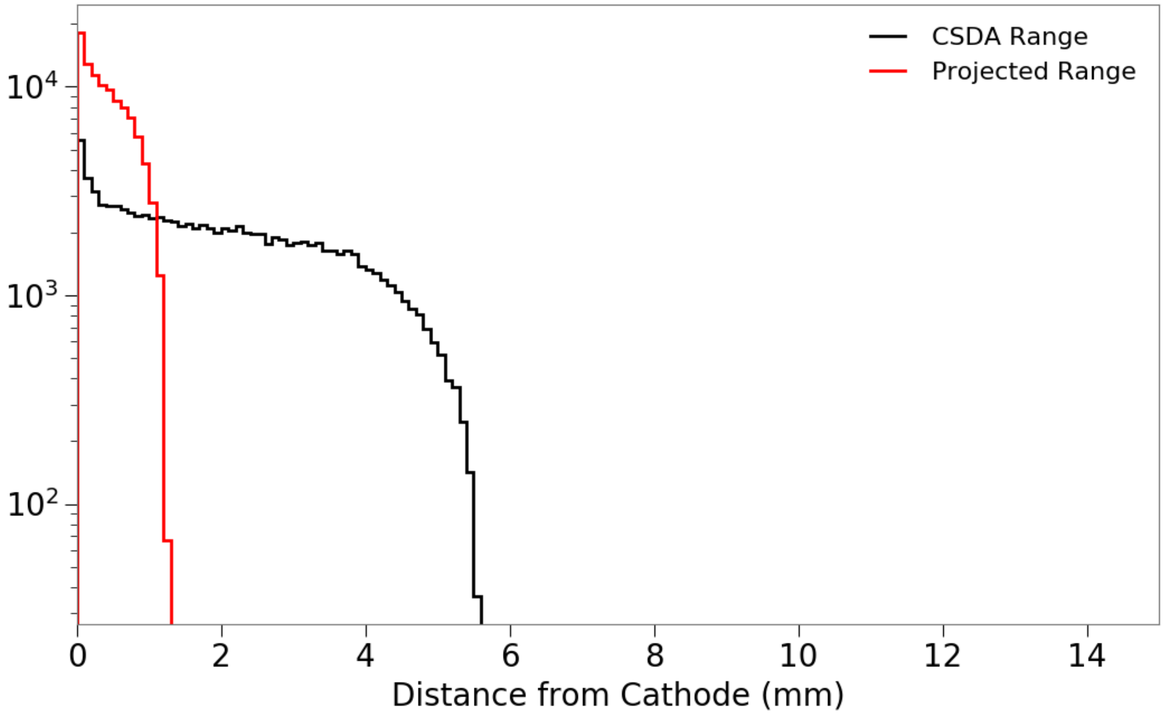
Bi-Po topology→ 212 Bi alpha topology

If it's consistent with cathode position, if β penetrates into bulk region could mimic signal.

How far can (2.2MeV) β penetrate into bulk region?



Monte Carlo Study to find maximum distance 212Bi β on cathode could penetrate into drift region



CDSA to projected range conversion from Tabata, T., et al. NIM Phys Research B 108 (1996) 11–17

Cathode alpha decay populations