NEWS-G

New Experiments With Spheres-Gas

Innovative radon removal system for dark matter searches using silver-zeolite adsorbent

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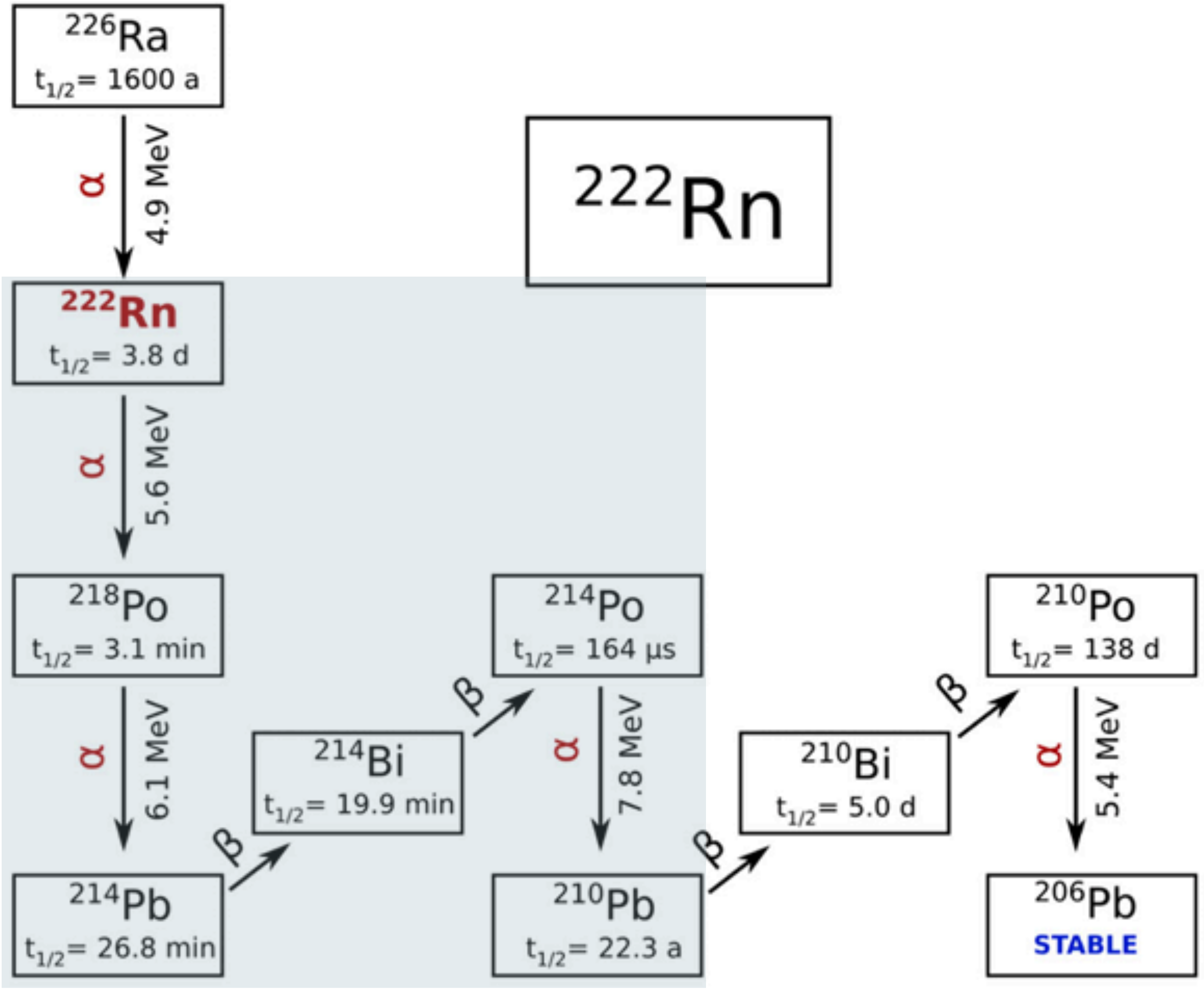
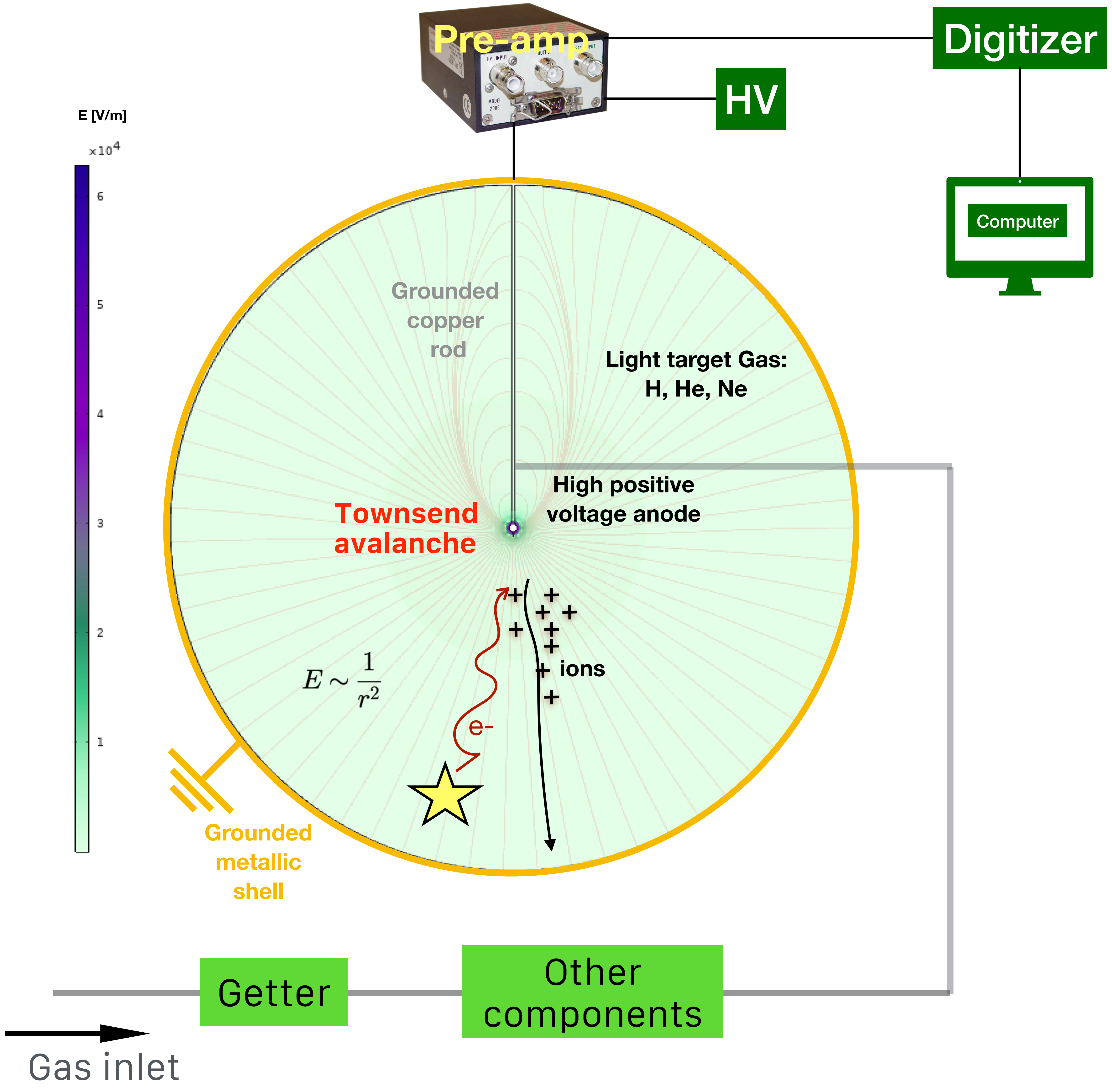
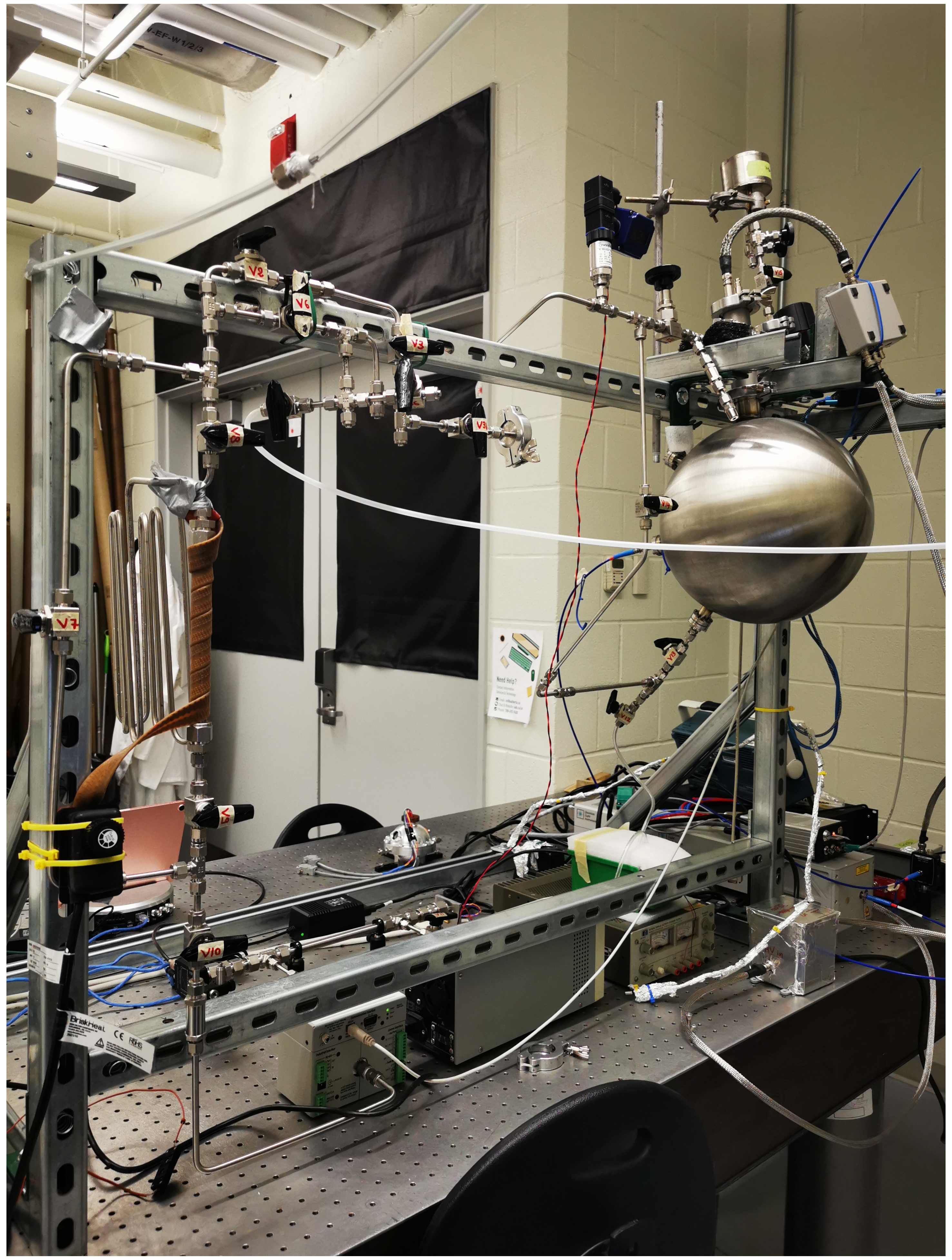
- **Rare-Event Searches:**
  - Dark matter and neutrinoless double beta decay experiments demand extremely low radioactive backgrounds
- **Radon-222:**
  - Originates from the U-238 decay chain
  - a gas of 3.82 day half-life enables it to build up in detectors and gas systems
- **Commonly used Radon Removal Techniques:**
  - Cryogenic distillation, charcoal adsorbents, etc.
  - Often **require complex setups** and continuous cooling
- **Simplified, high-efficiency radon trap developed at University of Alberta for NEWS-G**
  - Continuously remove radon while minimizing operational complexity

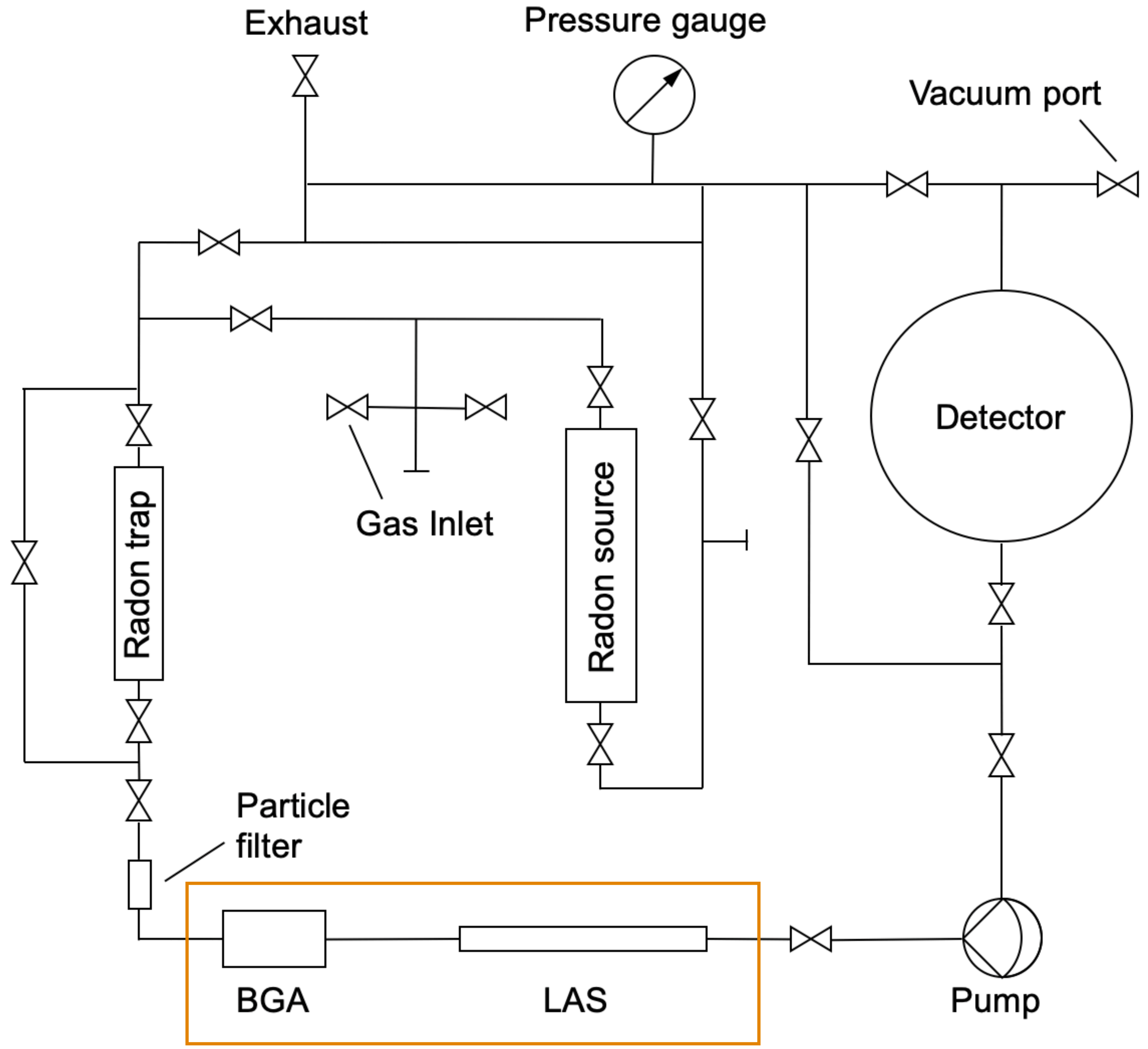


- **NEWS-G (New Experiments With Spheres-Gas)**
  - Direct dark matter experiment aiming to set **world-leading constraints** on low-mass WIMPs
  - spherical proportional counter (SPC): gaseous ionization detector with avalanche multiplication → single-electron sensitivity
- **Radon Introduction via Getter**
  - Getter removes water/oxygen but **emanates radon**
  - SPC as an *In-situ* Rn-222 monitor:
    - Alpha discrimination: distinguishes different alpha types (e.g. Rn-222, Po-218, Po-214) via pulse analysis
    - Single-Electron sensitivity: low-energy beta decays contaminating the dark matter signal region





- **Adsorbents:** Silver Zeolite vs. Activated Charcoal
  - At U of A, we tested a **silver-zeolite (Ag-ETS-10)** trap (by Extraordinary Adsorbents) at **room temperature**
  - radon capture efficiency with standard coconut-charcoal traps has been compared
- **Detector Setup at U of A:**
  - 30 cm stainless steel sphere
  - Gas mixture: 97% Ar + 3% CH_4
  - Pressure: 500 mbar
- **Radon Trap:**
  - 20 cm stainless steel tube (½ inch) filled with 10 g of adsorbent

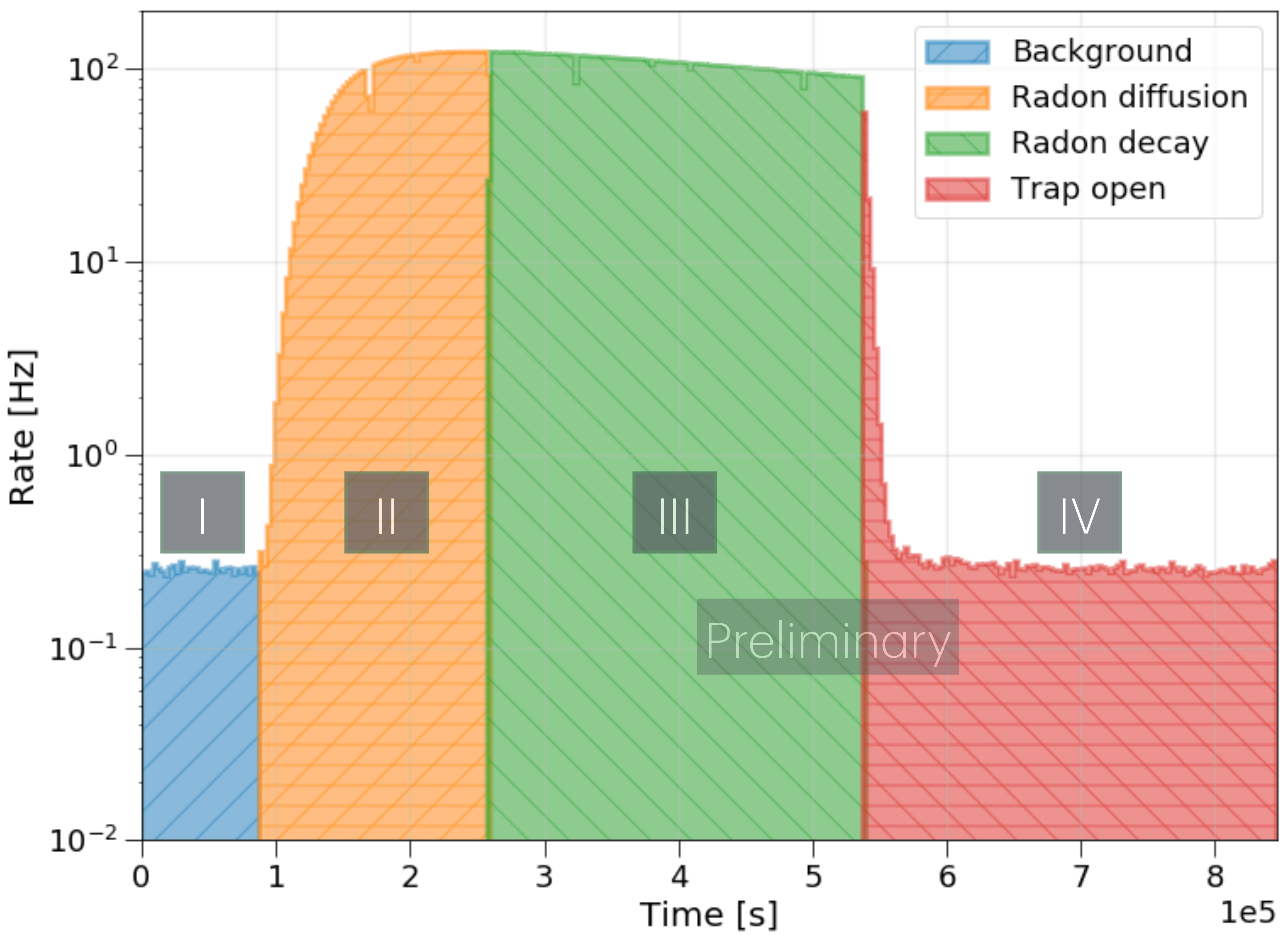


methane monitoring:

A Binary Gas Analyzer (BGA) and Laser Absorption Spectroscopy (LAS) track CH_4 levels in real time

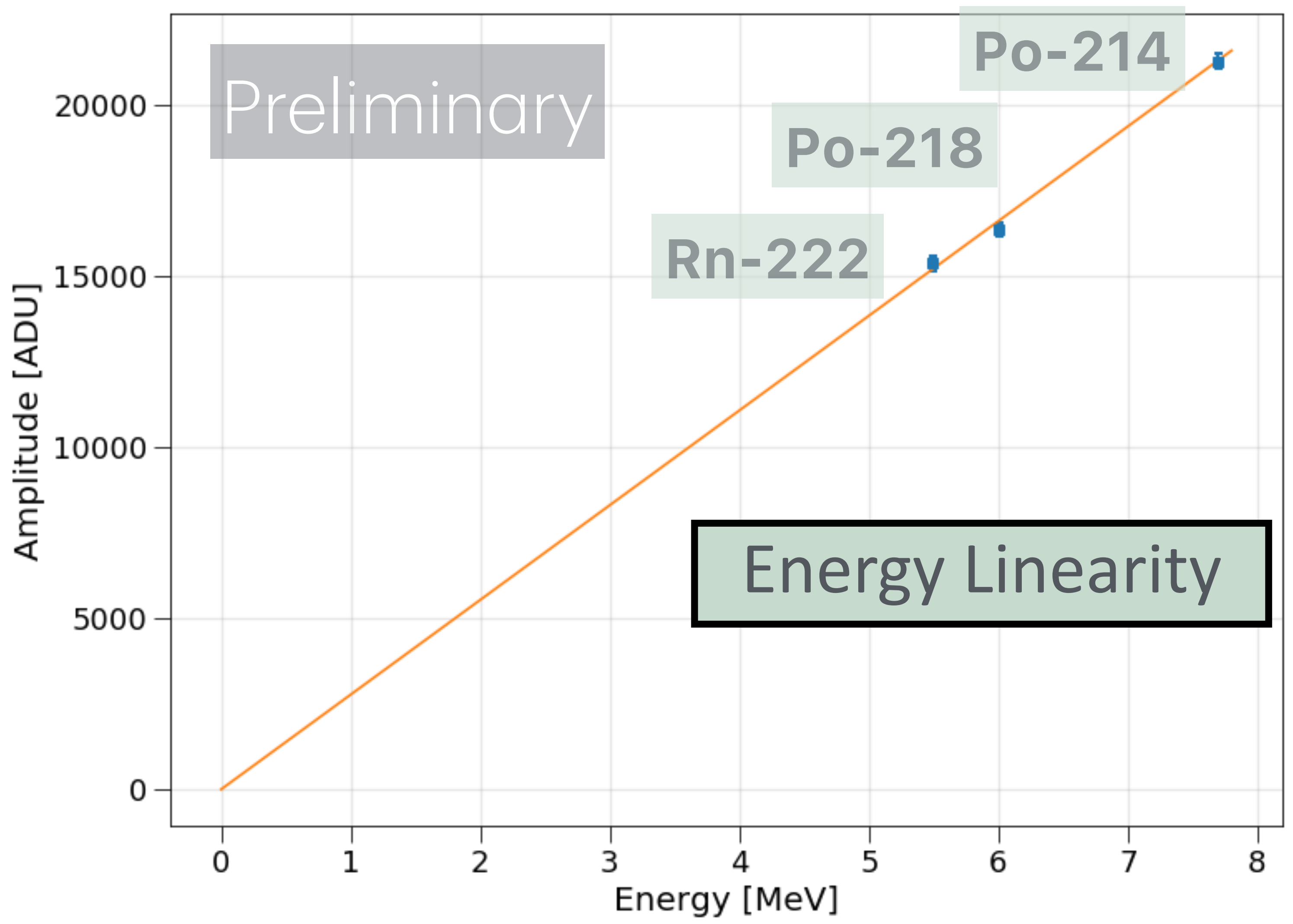
- **<u>Three runs conducted at U of A to test trap performance with 4 phases each:</u>**
  - I. Background (~ 24 hrs)
  - II. Radon Injection (until rate ~ 75 Hz)
  - III. Radon decay (exponential over 2 days)
  - IV. Trap open (closed-loop circulation)

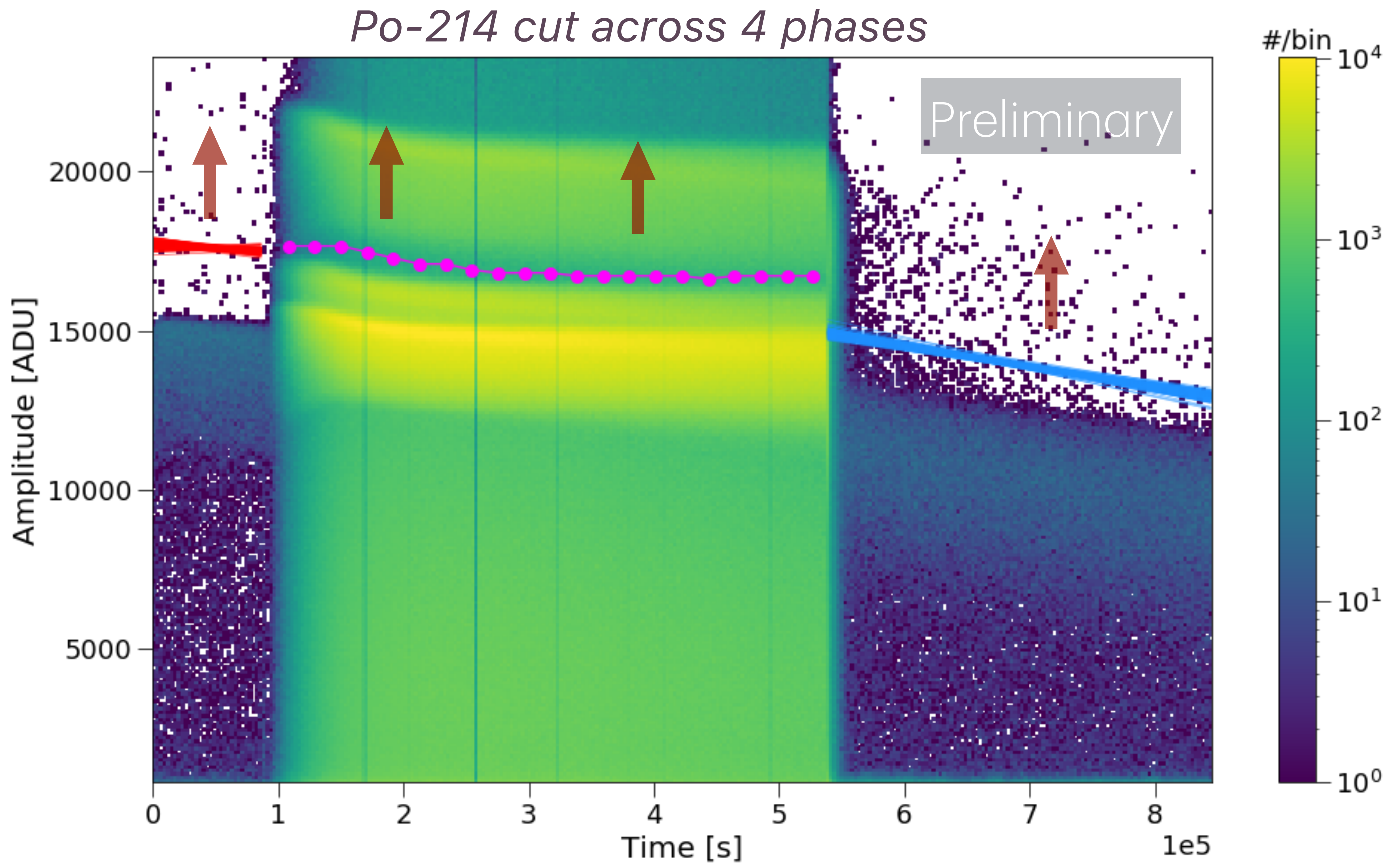
SZ: silver zeolite
AC: activated charcoal
RT: room temperature

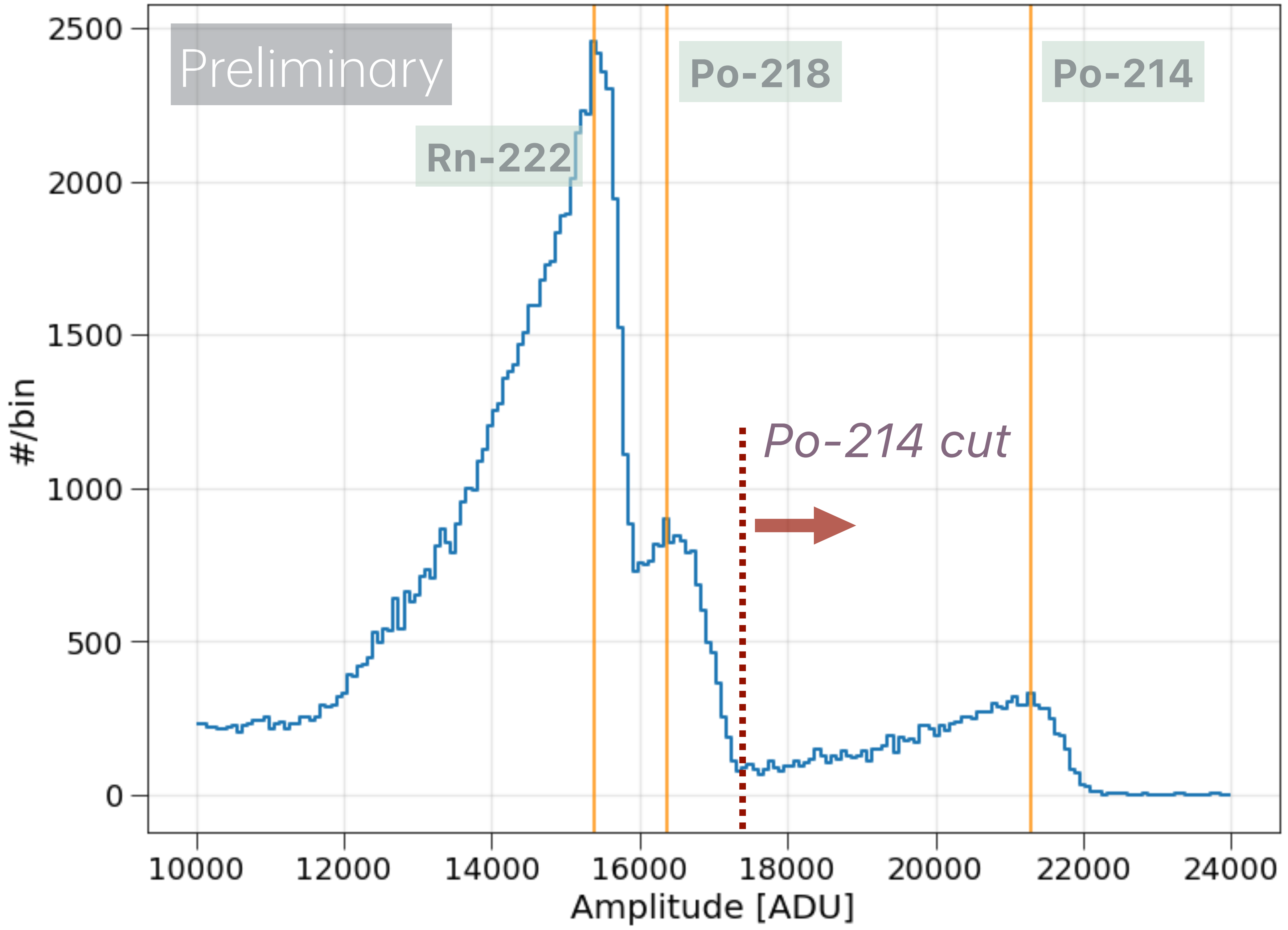


Run #	adsorbent	temperature	gas	pressure (mbar)	voltage (V)
1	**SZ**	**RT**	Ar + 3% CH_4	500	1180
2	**SZ**	**RT**	Ar + 3% CH_4	500	1180
3	**AC**	**RT**	Ar + 3% CH_4	500	1180

- **Basic cut:** Amplitude > 1200 ADU to remove muons and non-physical events
- **Po-214 cut:**
  - Po-214 (7.7 MeV) is the highest-energy alpha in the Rn-222 decay chain
  - Short half-life (164 μs) + secular equilibrium with Rn
    - → **ideal proxy** for radon rate







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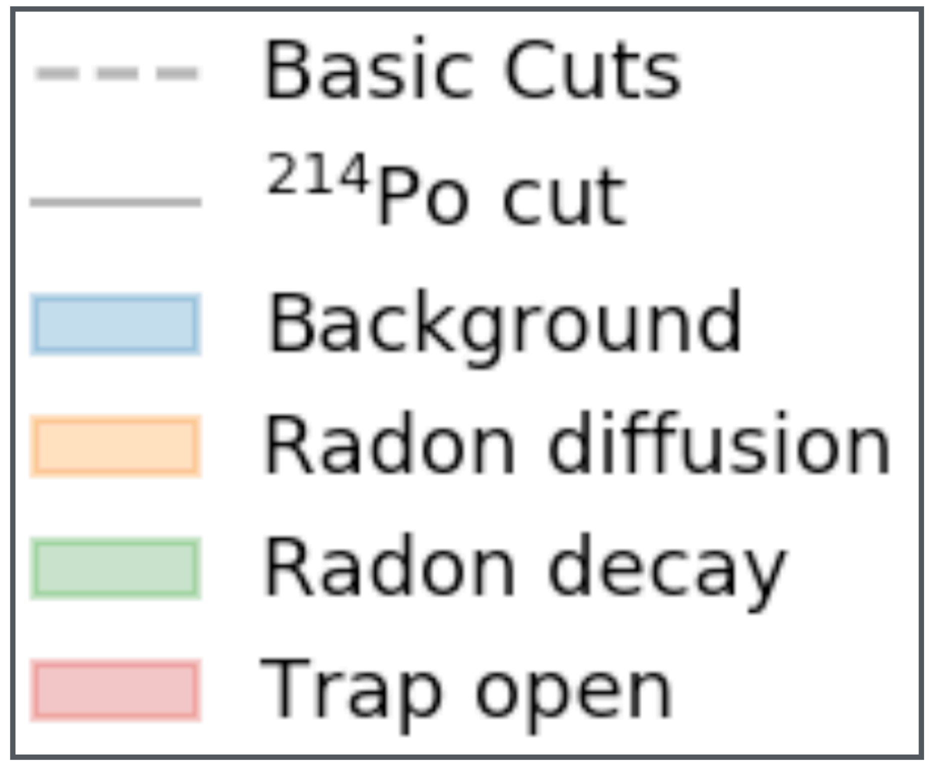
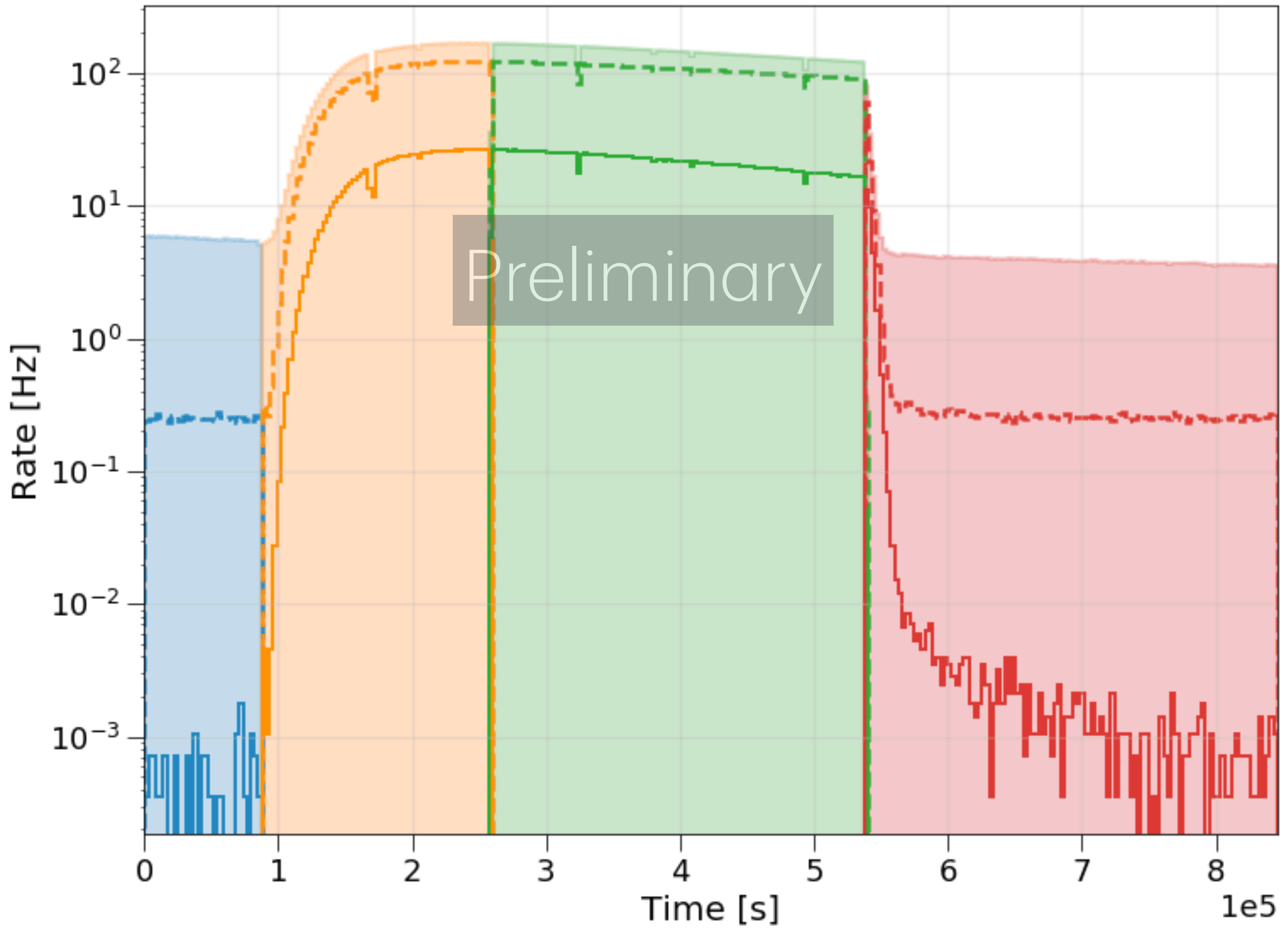
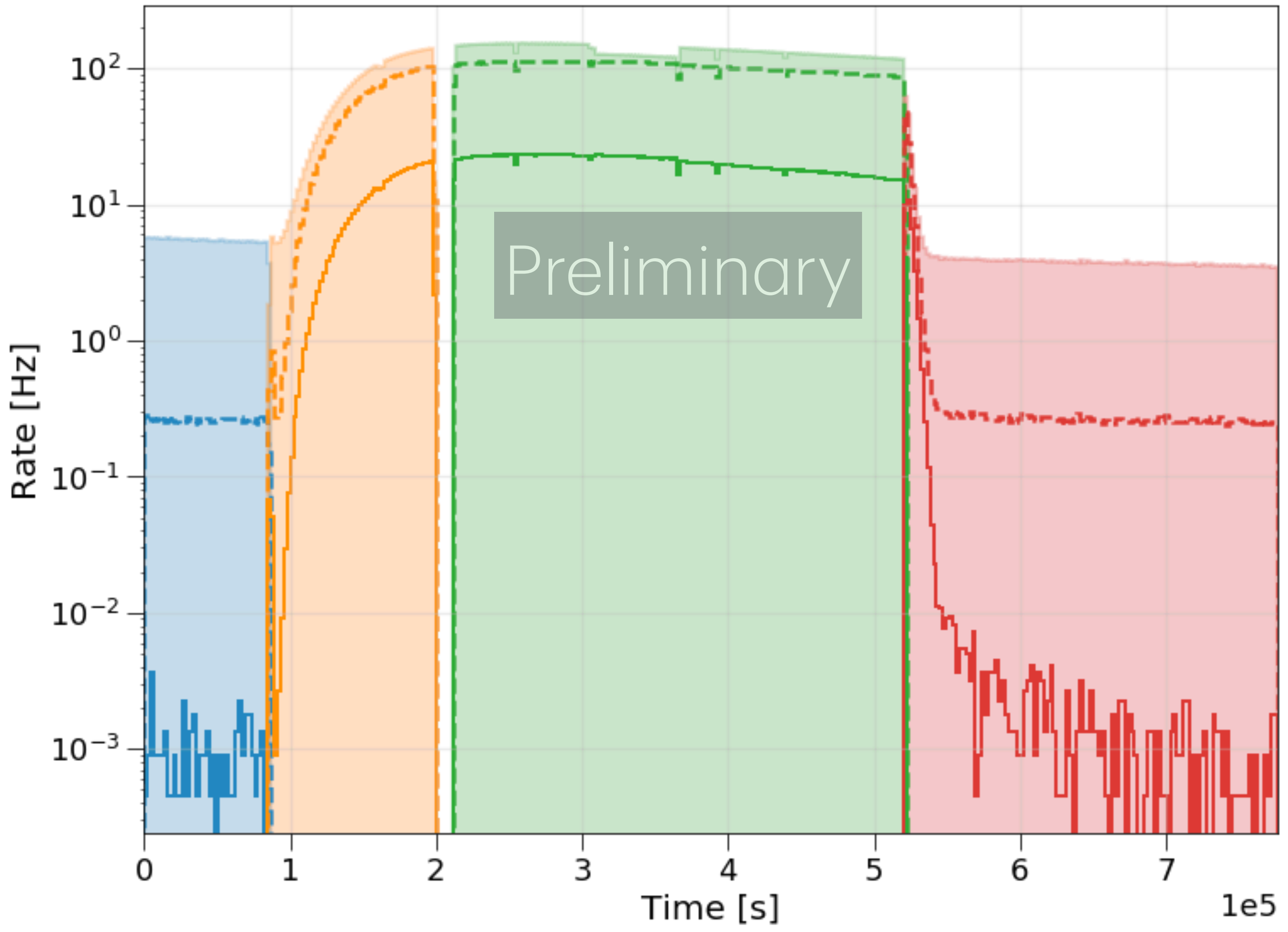


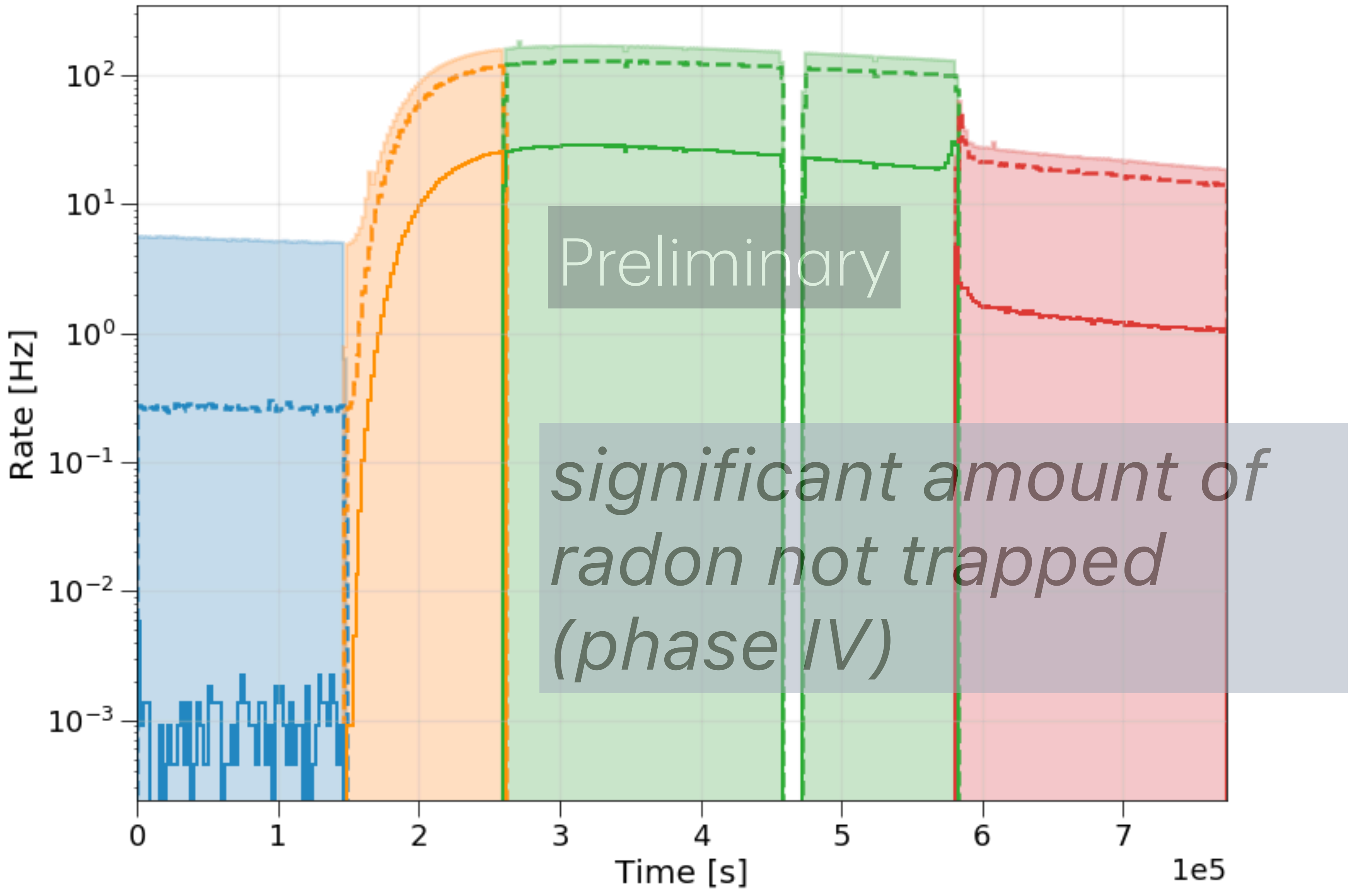
Run 1: SZ



Run 2: SZ

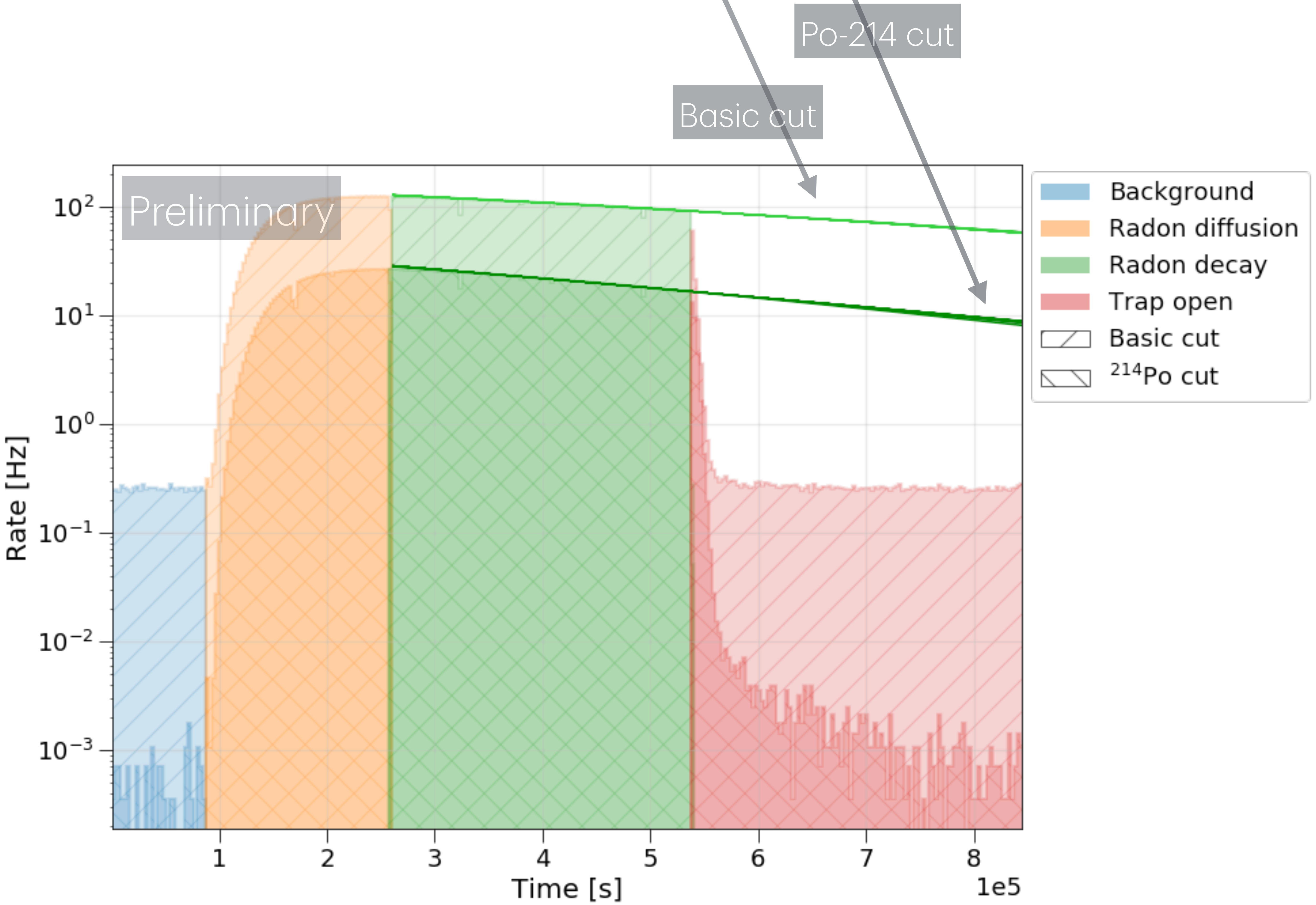


Run 3: AC



- **Pileup Simulation & MCMC Fitting:**
  - Pileup & Dead time:
    - Monte Carlo model that includes possible pileup between alpha decays and missed events due to data acquisition deadtime
  - Markov Chain Monte Carlo (MCMC) fit:
    - optimizes radon decay parameters (initial activity rate, the fractional of different type of events remained post-cuts) by comparing simulated results and measured data on phase III
- **No-Trap Prediction:**
  - Derived from best-fit simulation of phase III radon decay
  - Provides predictive curves on phase IV to later compare **actual vs expected radon rate without trap intervention**

Multiple near-overlapping curves reflect different MCMC samples, capturing our model's full range of uncertainties.



- **Definition of R-value (R_r) to evaluate trap performance:**

$$R_r(t) = \frac{R_{expected}(t)}{R_{observed}(t)}$$

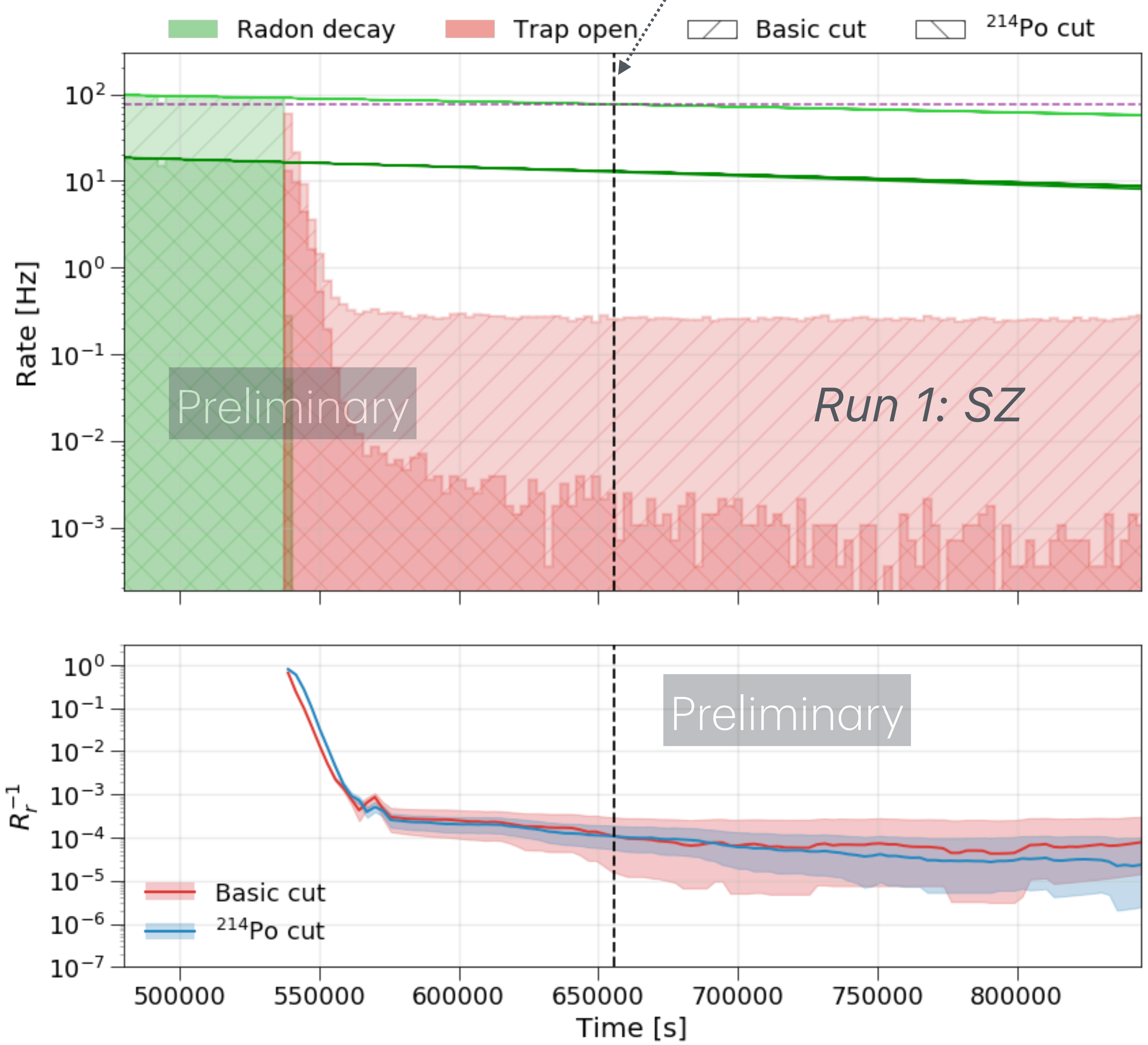
  - $R_{expected}(t)$: predicted radon rate from MCMC-based no-trap model
  - $R_{observed}(t)$: Measured radon rate after the trap is opened
  - Higher $R_r(t)$ → better radon reduction

- **The determination of R-value for each time bin:**
  - maximizing a likelihood function that compares the expected rate, derived from MCMC simulations, against the observed experimental data on phase IV:

$$L = \sum_i P\left(c_i \,\middle|\, R_{expected}(i) \times R_r^{-1} + B\right)$$

  - *P* denotes the Poisson probability of observing c_i counts given the expected counts $R_{exp}(i) \times R_r^{-1} + B$, with *B* representing the background radiation observed on phase I.

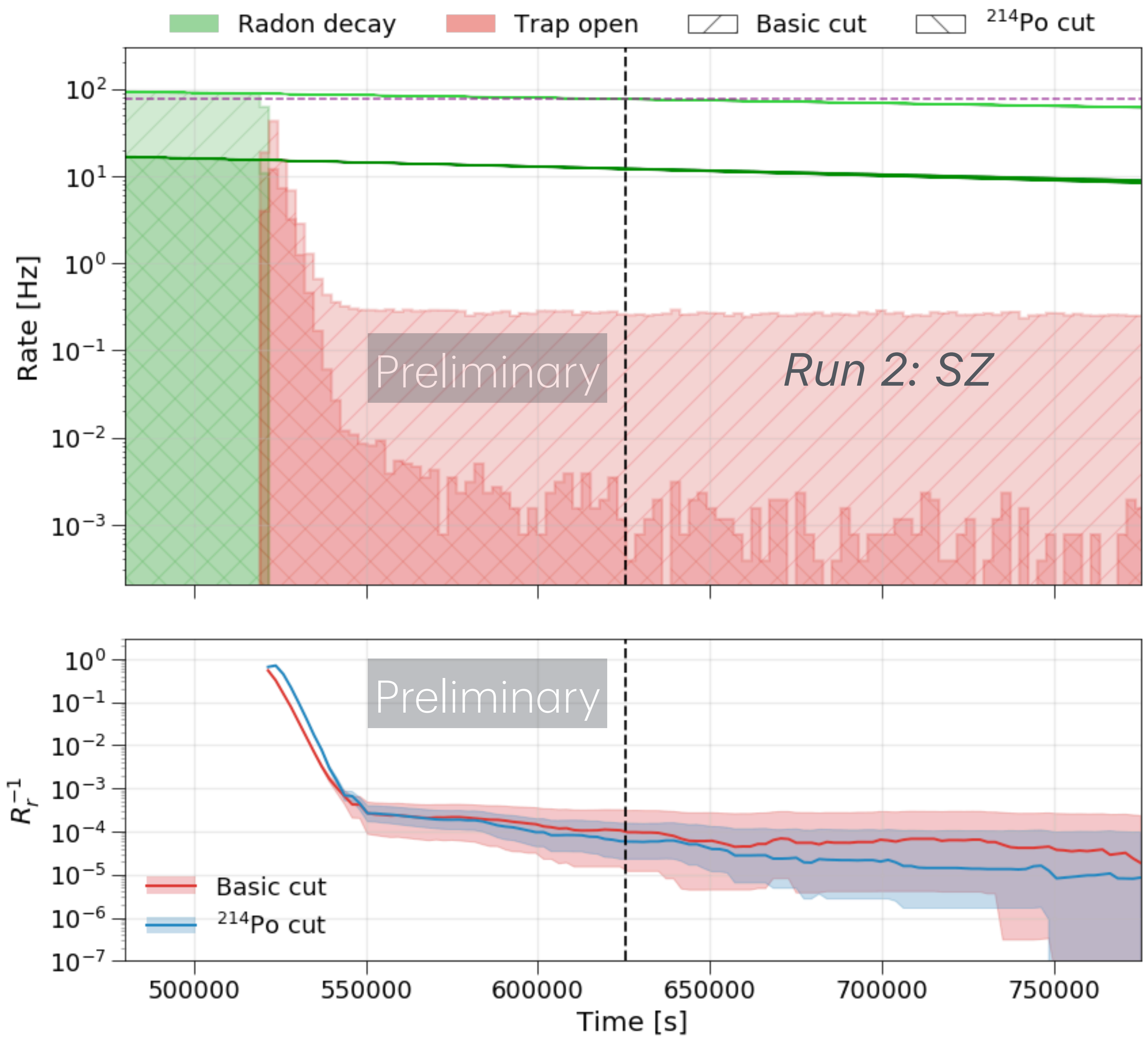
The R-value with its 90% confidence interval at the time corresponding to the chosen reference rate of 76.5 Hz (black dashed line) is reported. This rate level serves as a consistent benchmark, enabling us—and others—to cross-check the trap's performance under comparable operational conditions.

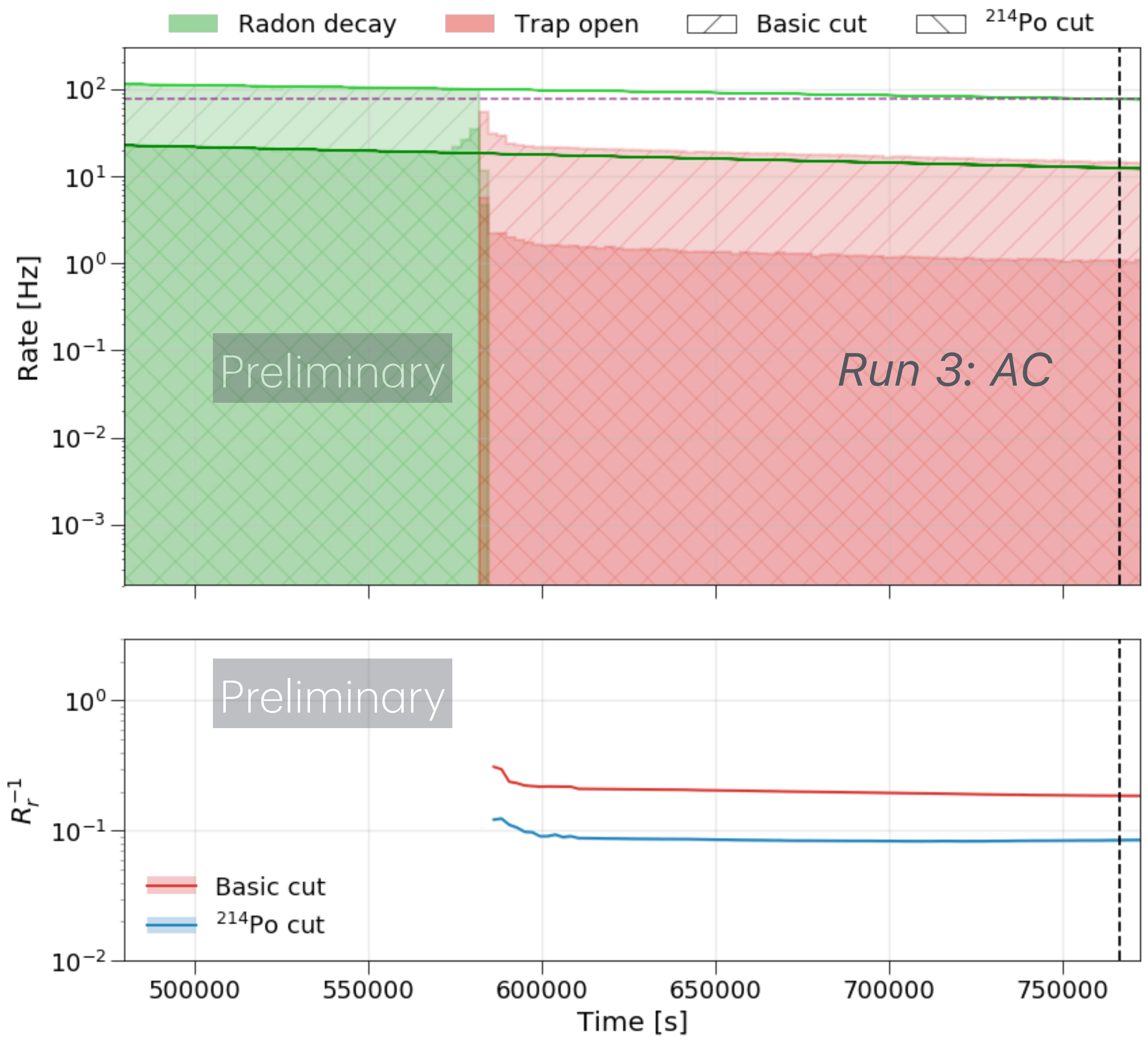


- **Silver zeolite outperforms activated charcoal at room temperature**
- **Run 1 and 2 show similar results**

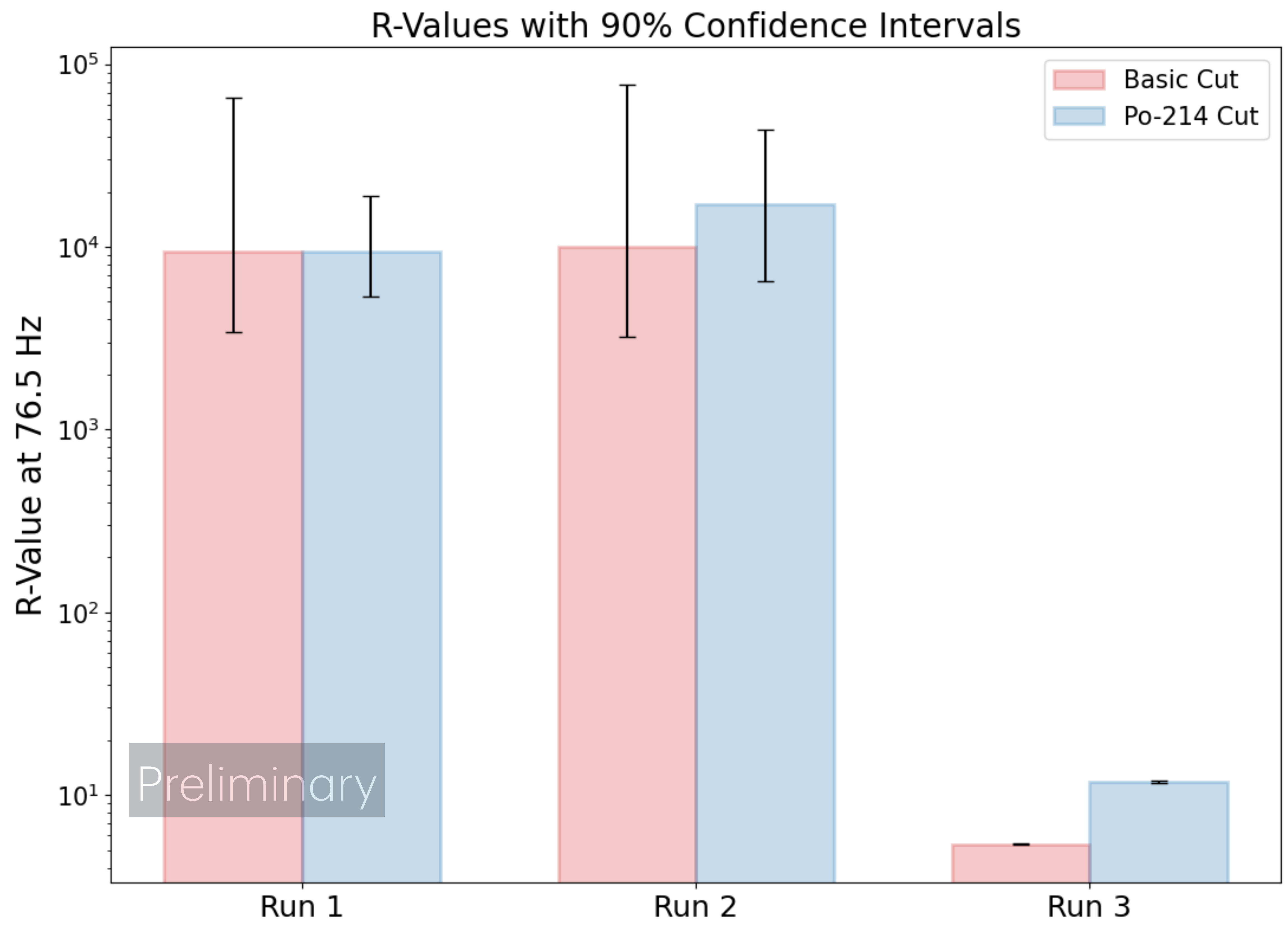
Horizontal dashed line: a rate at 76.5 Hz

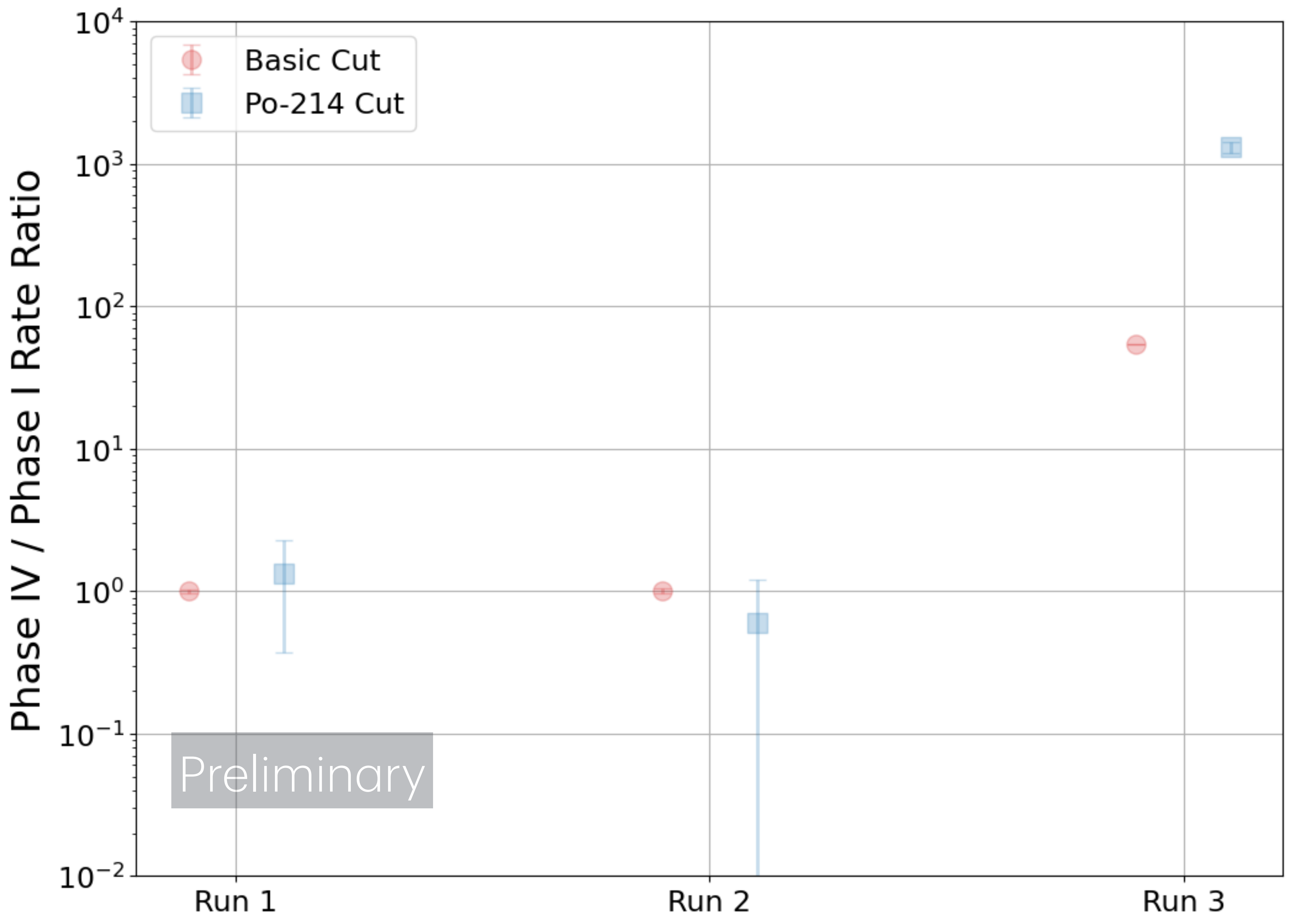
Vertical dashed line: marks the time when MCMC-based no-trap model reaches 76.5 Hz





R-value at Predefined rate = 76.5 Hz	Run 1: SZ	Run 2: SZ	Run 3: AC
Basic cut	9367.56 [3432.47, 65126.5]	10027.4 [3235.36, 76748.4]	5.37948 [5.33629, 5.42327]
Po-214 cut	9420.72 [5337.88, 19115.2]	17059.1 [6449.7, 43815.8]	11.8137 [11.6235, 11.9976]

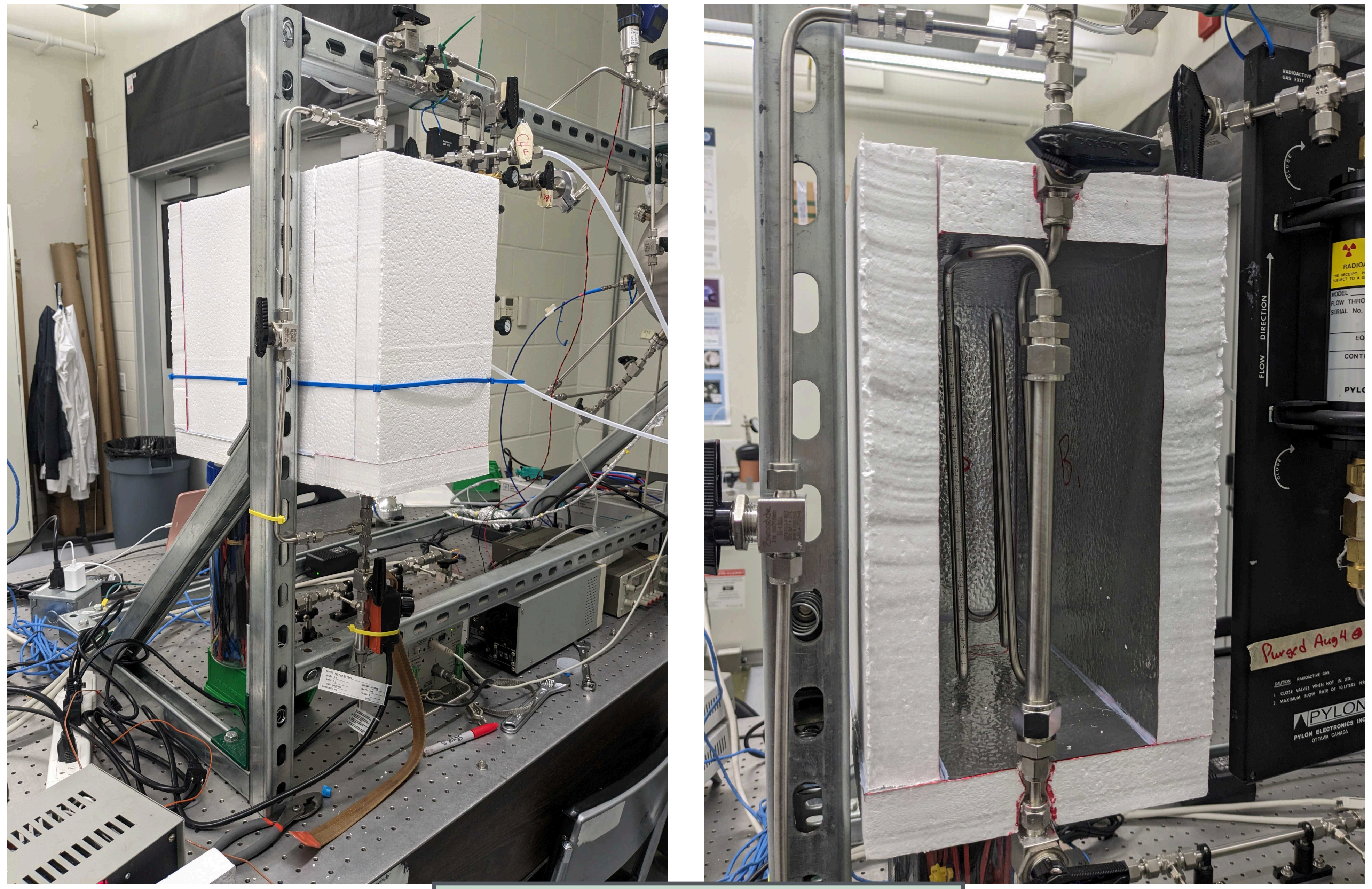




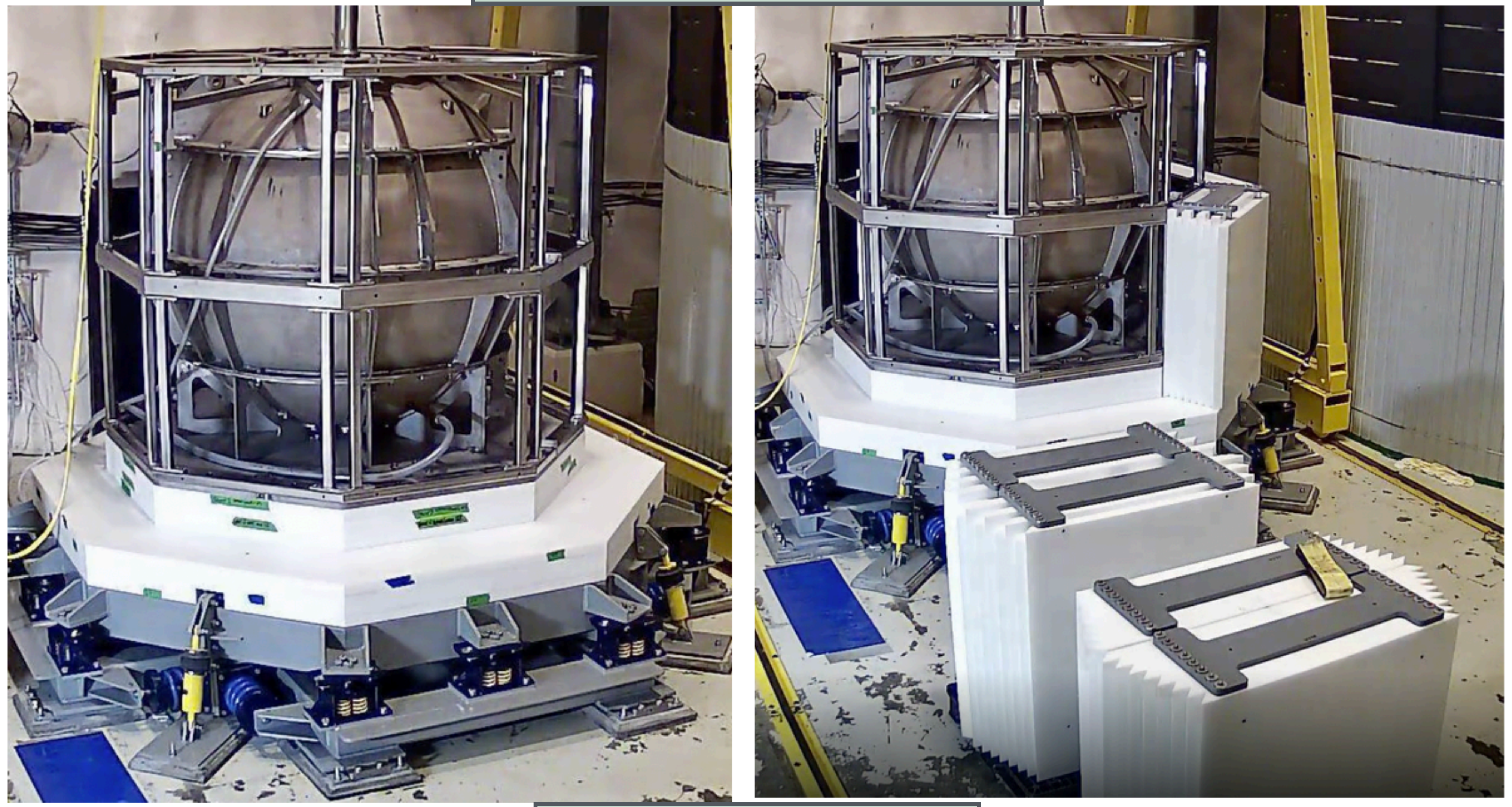
- **Key Findings:** *SZ at RT is more efficient on removing radon than AC.* —> ***paper submission soon on this study and results***

- **Future steps at U of A:**
  - Cool the trap: Investigate lower temperatures (e.g. dry ice) for potential effect in radon capture
    - **Preliminary tests** show reduce in gain on phase IV because a lot of CH_4 is adsorbed
  - Detector Upgrades in dry ice run:
    - **Add a getter** to remove water and oxygen (current gain drop suggests moisture/oxygen intrusion);
    - **CH_4 Pre-spiking** to compensate for CH_4 absorption in the trap

- **SNOLAB Deployment:**
  - SZ trap is also currently installed for NEWS-G at SNOLAB
  - Dedicated analysis are planned to quantify radon reduction under real operating conditions



U of A radon trap



SNOLAB SPC

Acknowledgments

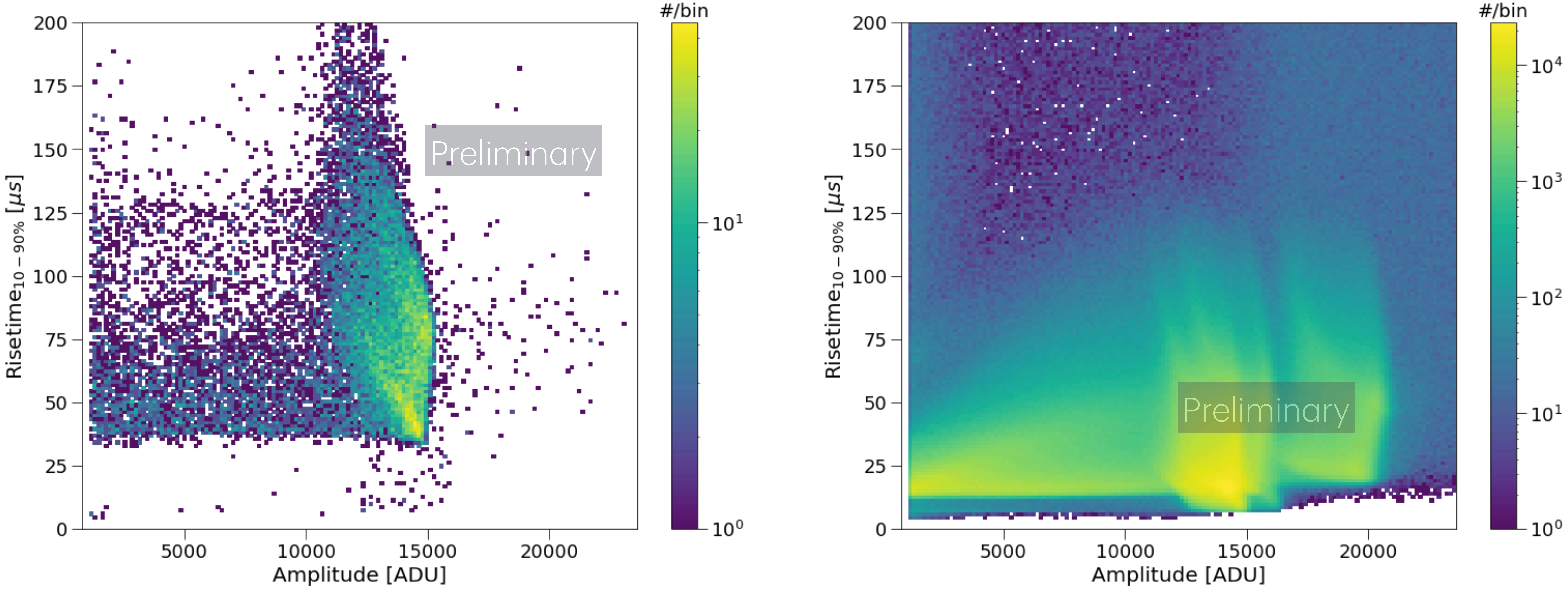
Thank you!

- I acknowledge the support and contributions of the NEWS-G Collaboration.
- Special thanks to my supervisor and the Piro group for their guidance and assistance!

extra slides

- The MCMC analysis targeted the following key parameters, each fundamentally influencing the modeling of radon decay within our experimental setup:
  - True Radon Activity Rate (True rate): This parameter represents the intrinsic decay rate of radon at a specific initial time during Phase 3, which serves as the starting point for simulating radon decay in the pileup simulation. This rate is crucial for accurately modeling the radon dynamics as observed in the experimental data.
  - Total Pileup Fraction (Pileup_fraction total): Represents the fraction of observed events that are actually pileups in the data selected after basic cuts.
  - Alpha Decay Retention Fraction (Alpha_frac total): The fraction of all alpha decays (including those from radon and its immediate decay products) that remain in the dataset after basic cuts.
  - Specific Po214 Retention Fraction (Po214 frac): The fraction of 214Po specific events retained after Po214 cuts.
  - Pileup Fraction in Po214 Selected Data (Pileup fraction cut): The proportion of pileup events retained in the dataset filtered through Po214-specific cuts

- Core Idea of MCMC
  - Construct a Markov chain that *samples* the posterior distribution of parameters.
  - Each step proposes new parameters, evaluates how likely they are (likelihood), then accepts or rejects them based on a probabilistic criterion.
  - Over many iterations, samples cluster in regions of high posterior probability, revealing both best-fit values and their uncertainties.
- Integrating MCMC with Pileup Simulation
  - **Monte Carlo Pileup Simulation** generates realistic radon events, including coincident (pileup) and deadtime-affected signals.
  - A **Poisson likelihood** compares simulated rates to observed data.
  - MCMC explores parameter space (e.g., radon activity, pileup fraction, alpha retention) to find the combination that best fits the data.
- Running the Chain
  - **Initialize** multiple "walkers" with random parameter guesses.
  - **Propose new parameter sets** (e.g., slight changes in radon rate, pileup fraction).
  - **Evaluate likelihood** (how well simulation matches data).
  - **Accept or reject** proposed parameters based on a Metropolis-like criterion.
  - **Converge** to a steady-state distribution (the posterior).
- In summary, MCMC leverages multiple walkers to thoroughly explore parameter space and uses an acceptance/rejection scheme (Metropolis-like criterion) to build a *chain* of parameter sets that reflect the likelihood of the underlying data model. It's particularly helpful for complex, multi-parameter problems—such as modeling radon decays with pileup and deadtime—where standard fitting methods can struggle.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