PNNL Radon Emanation System

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TAUP- Labs and Low Background

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Radon

- Radioactive noble gas
- From the decay of natural uranium and thorium

Steadily sourced and everywhere

- Radon progeny can plate-out onto surfaces

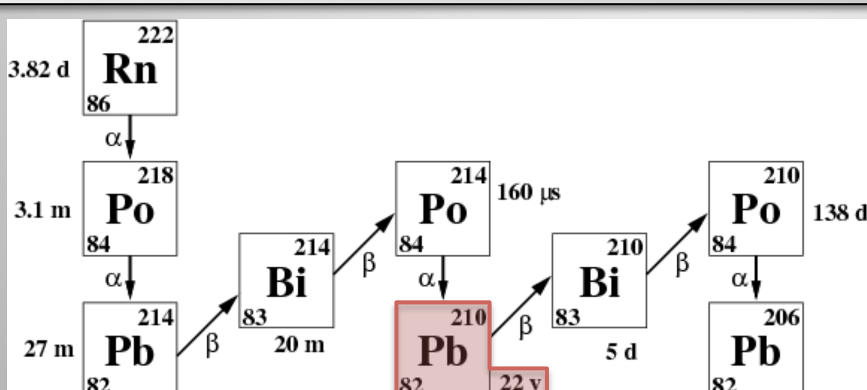
Contaminates detectors and their housings

- ^{210}Pb daughter has a 22 year half-life

Exceeds lifetime of experiments

- Decay chains emit α's, β's, γ's, and recoiling nuclei

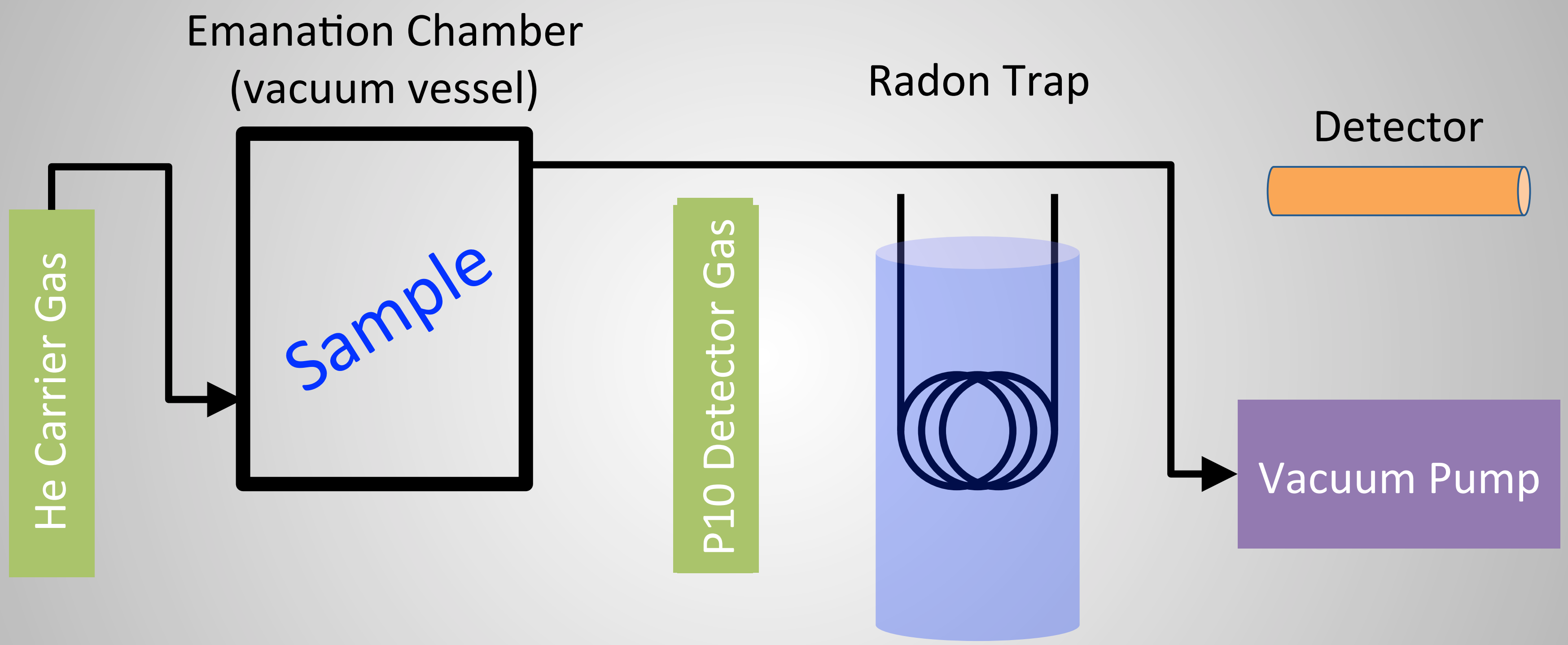
Limits dark matter and other rare-event searches



Sensitive radiopurity measurements required
(beyond commercial availability)

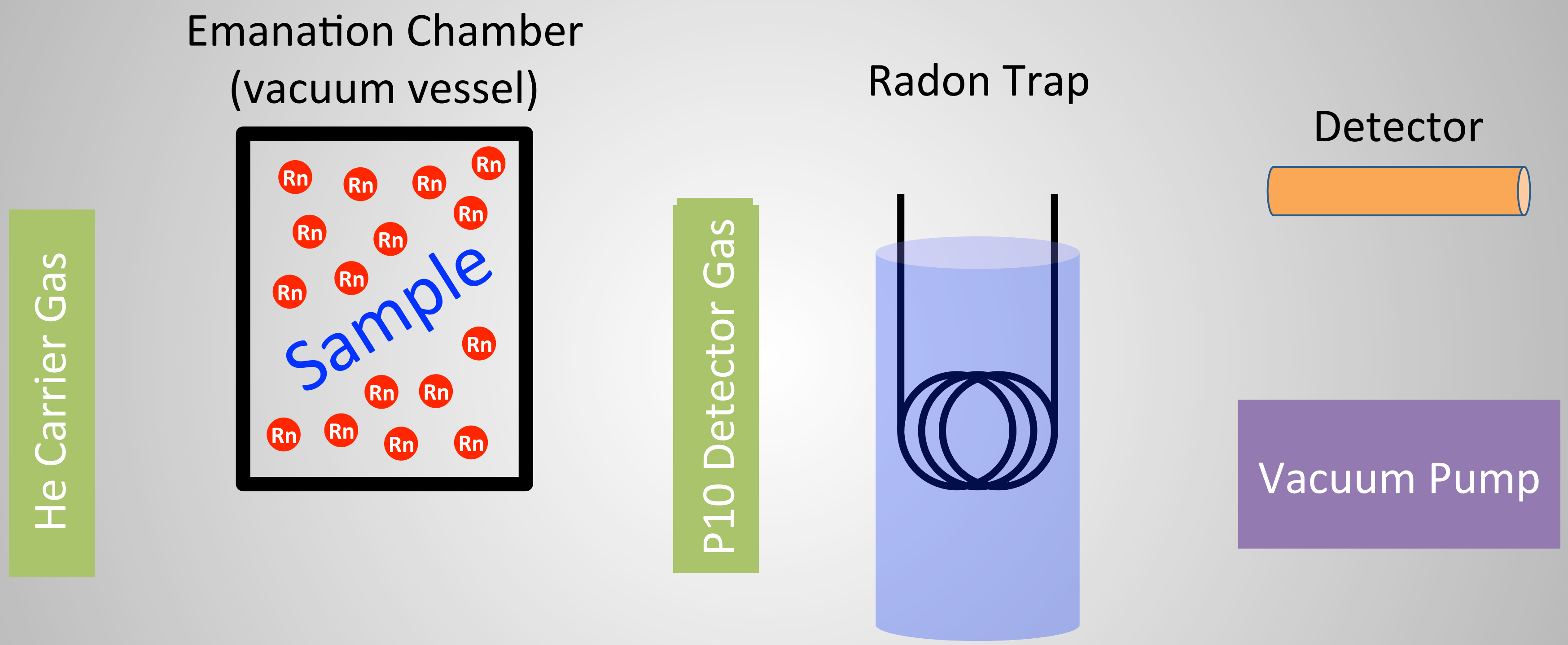
Emission Spectrum:
https://nist.gov/srd/PDFfiles/jpcrd690.pdf

Operation Premise



Step 1: "Rinse" sample (& detector) with low-Rn gas & evacuate to low pressure

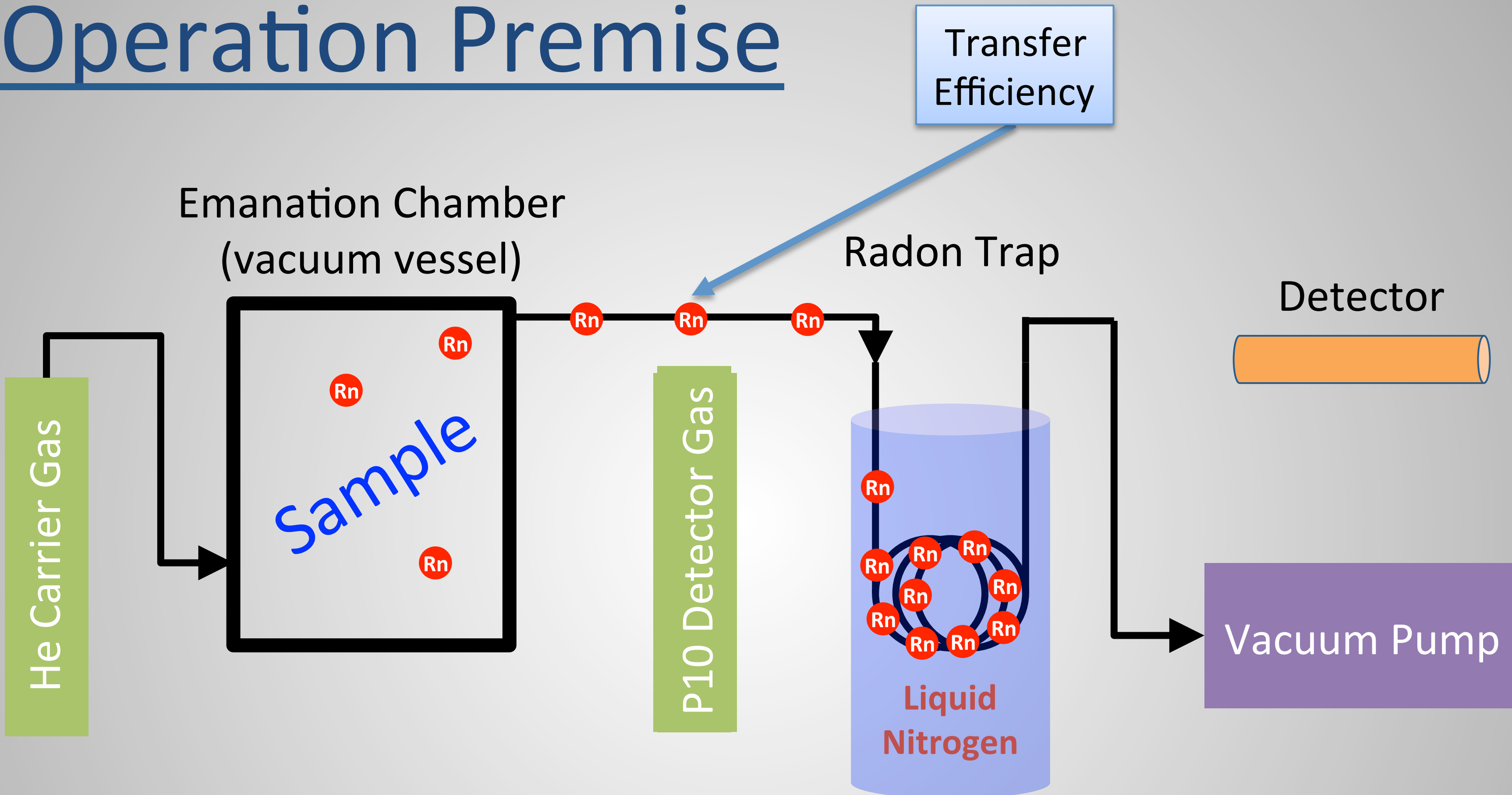
Operation Premise



Step 1: "Rinse" sample (& detector) with low-Rn gas & evacuate to low pressure

Step 2: Emanate sample for ≈1 week until Rn nears equilibrium

Operation Premise



Step 1: "Rinse" sample (& detector) with low-Rn gas & evacuate to low pressure

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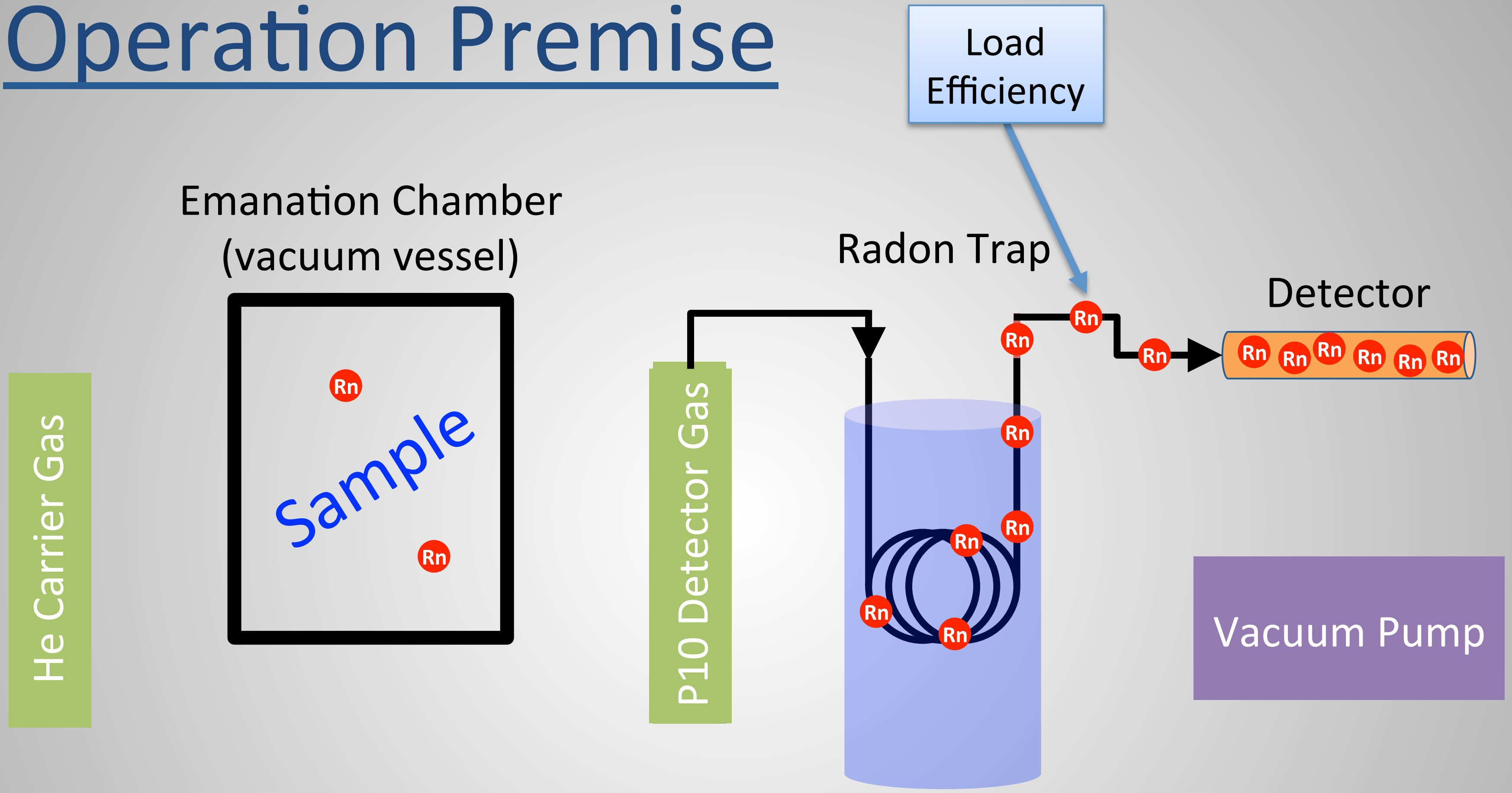
Step 3: Transfer radon sample to cryogenic trap

Operation Premise



Step 1: "Rinse" sample (& detector) with low-Rn gas & evacuate to low pressure
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Step 4: Load radon sample into detector

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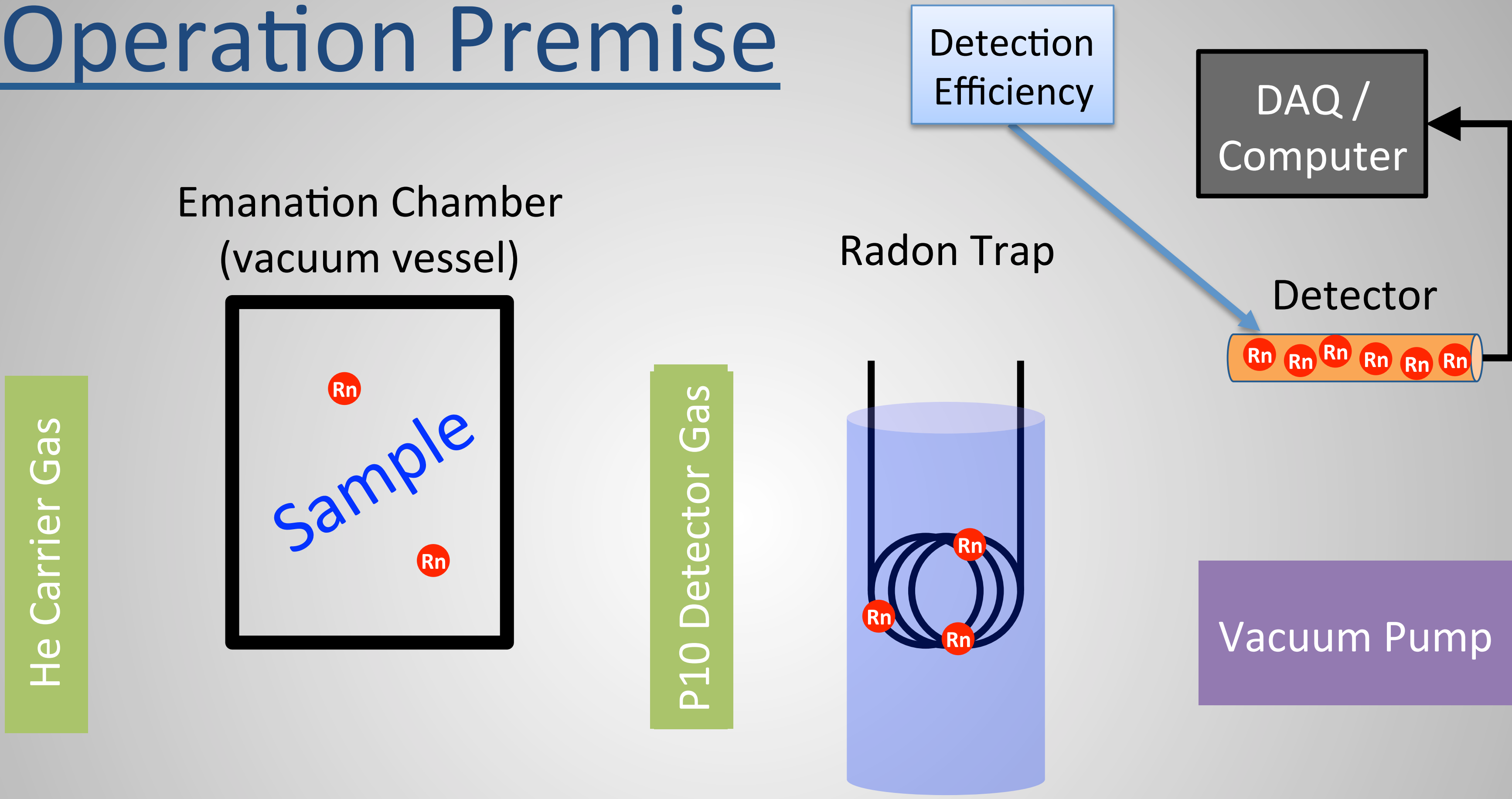


Step 1: "Rinse" sample (& detector) with low-Rn gas & evacuate to low pressure
Step 2: Emanate sample for ≈1 week until Rn nears equilibrium
Step 3: Transfer radon sample to cryogenic trap
Step 4: Load radon sample into detector
Step 5: Detect radon

Front Panel

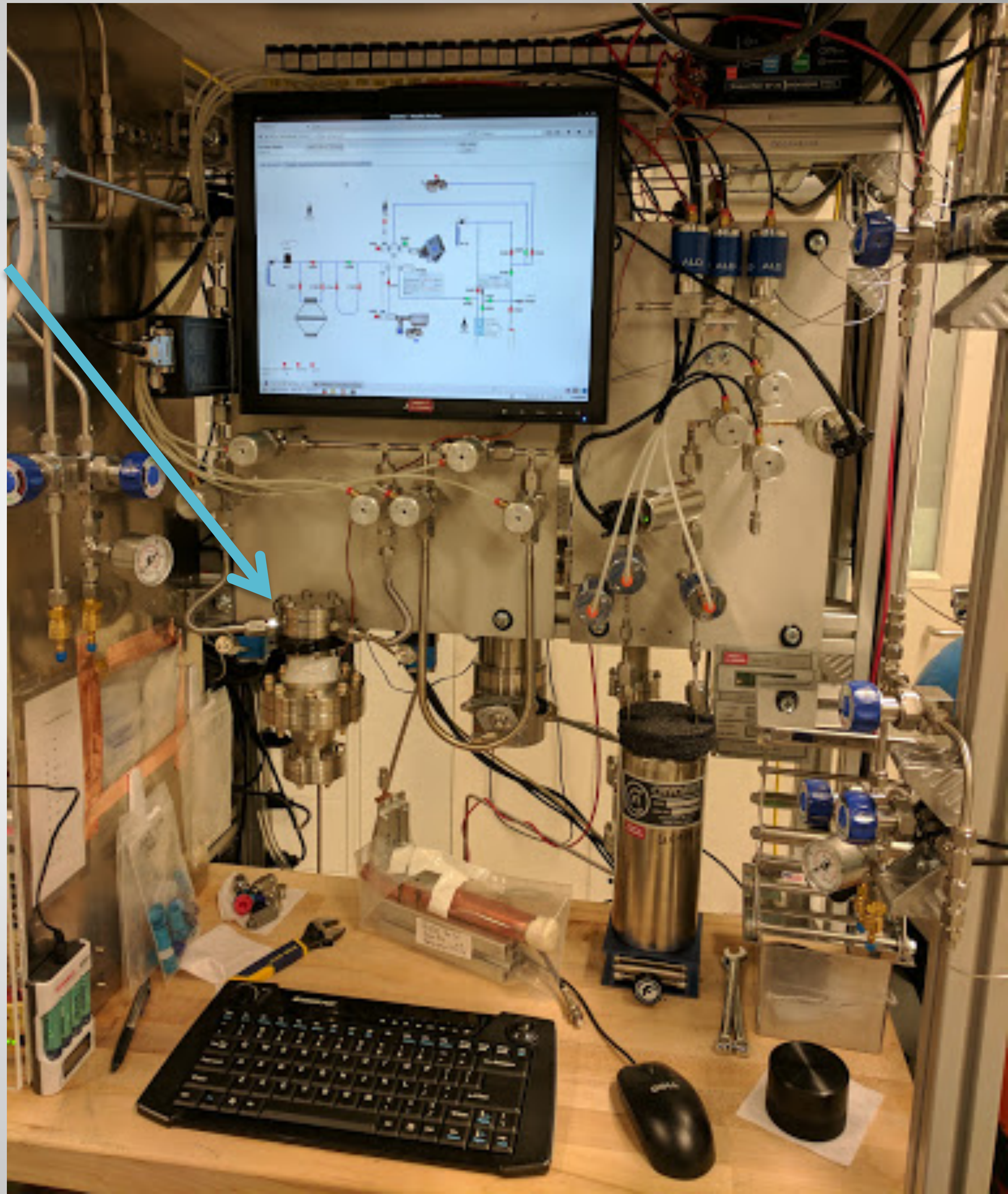
Emanation Chamber

Silica Drying Loop

Cryo Trap

Detector

Valves / Gauges



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Front Panel

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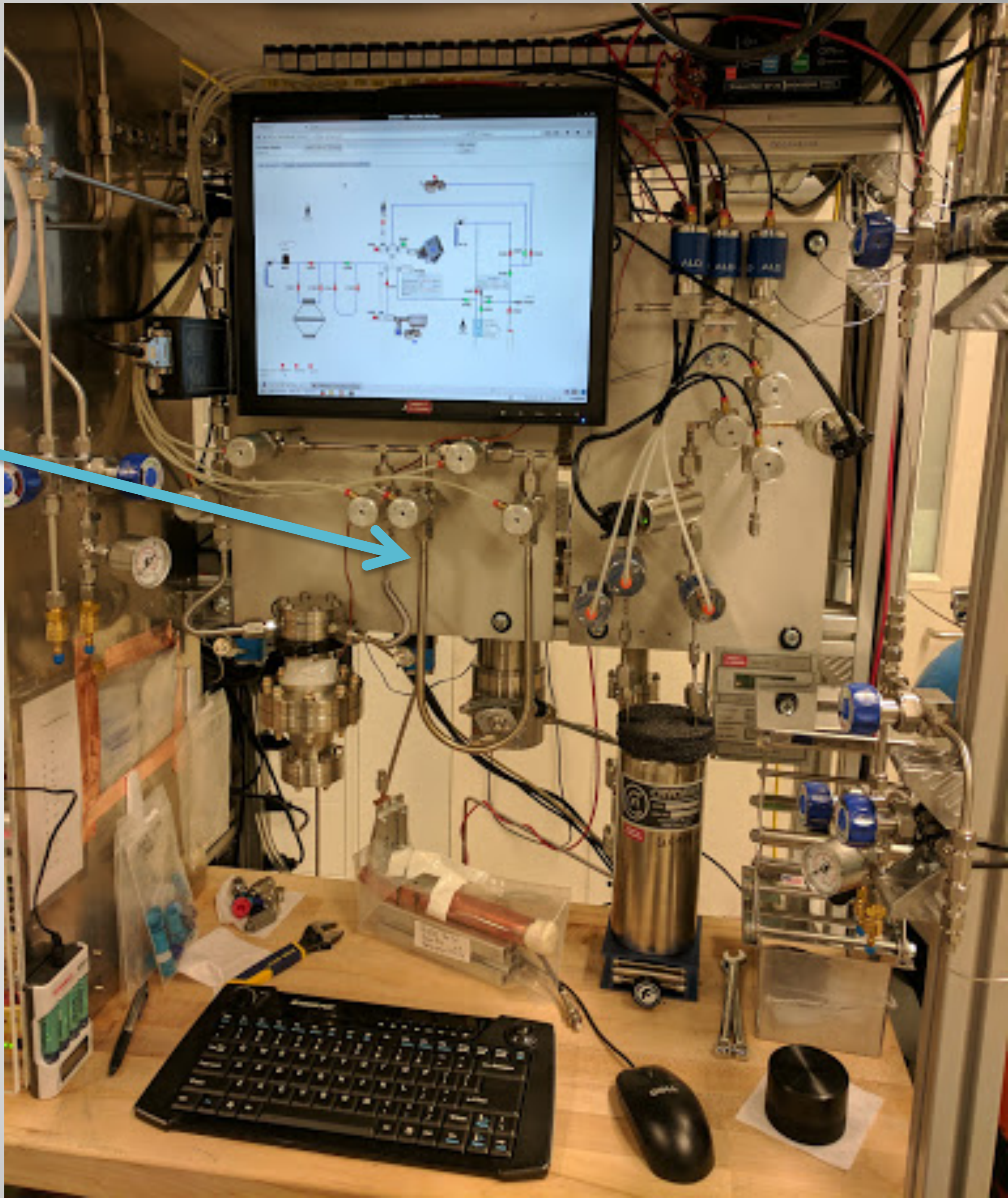

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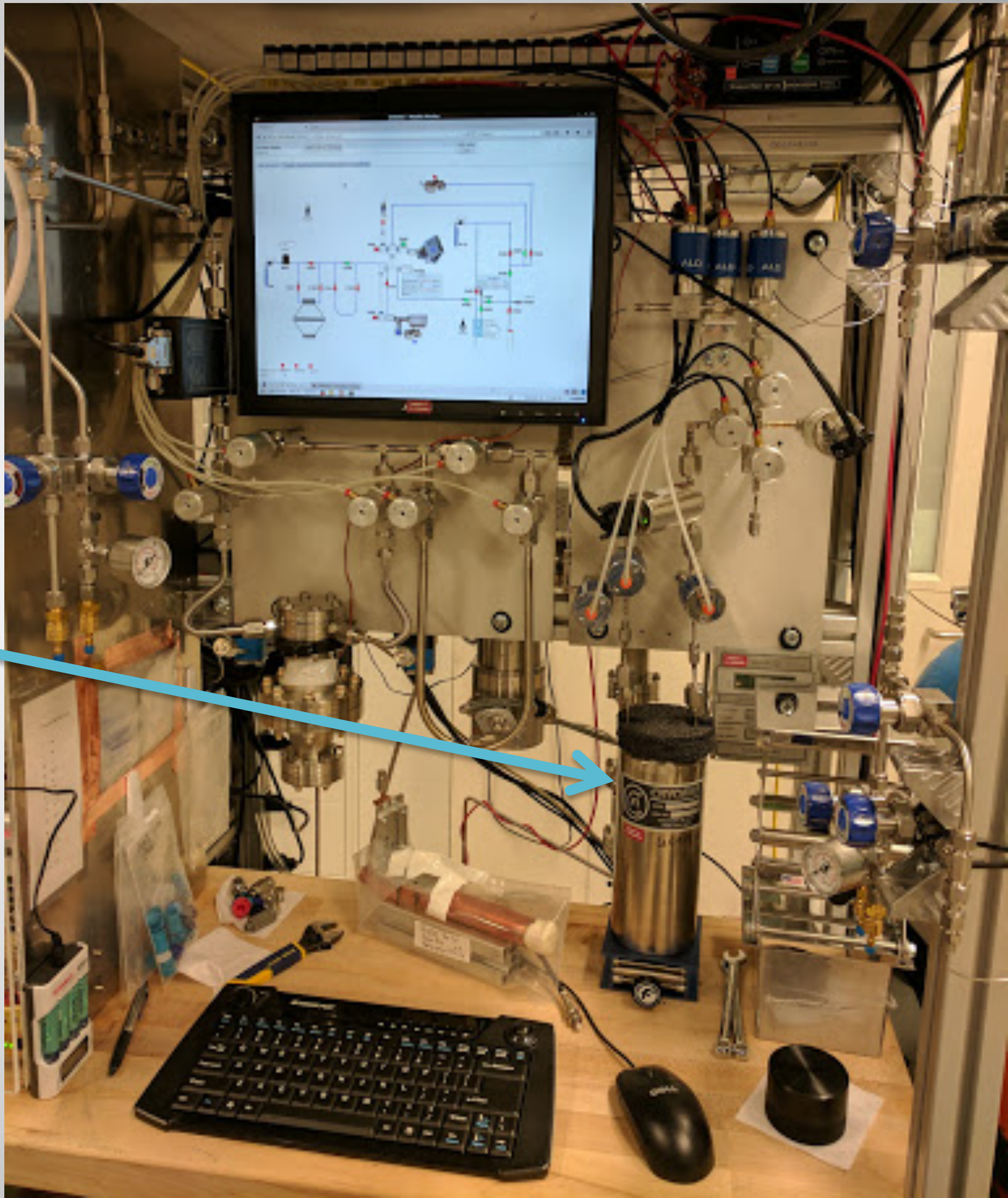

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Front Panel

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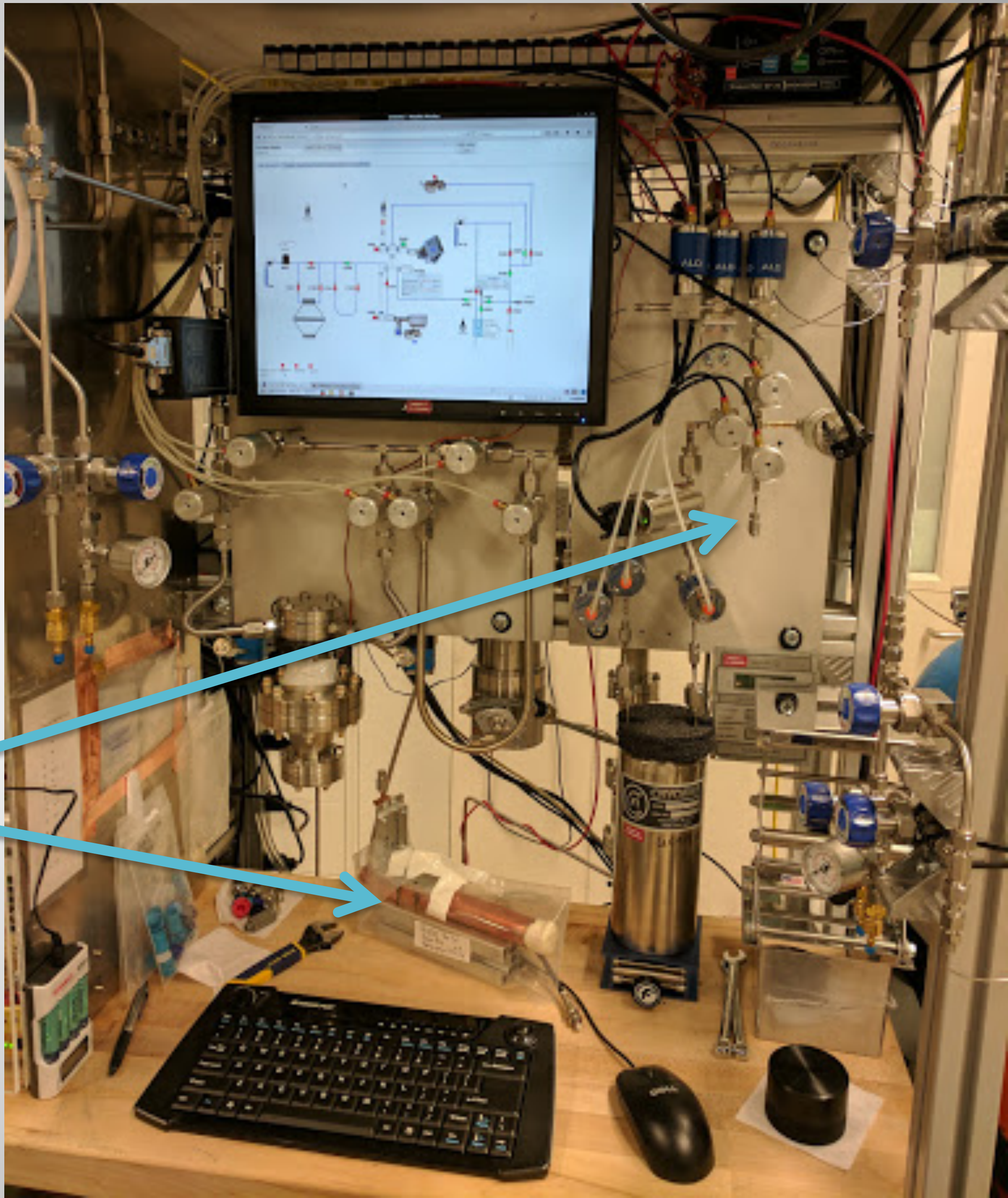

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Front Panel

Emanation Chamber

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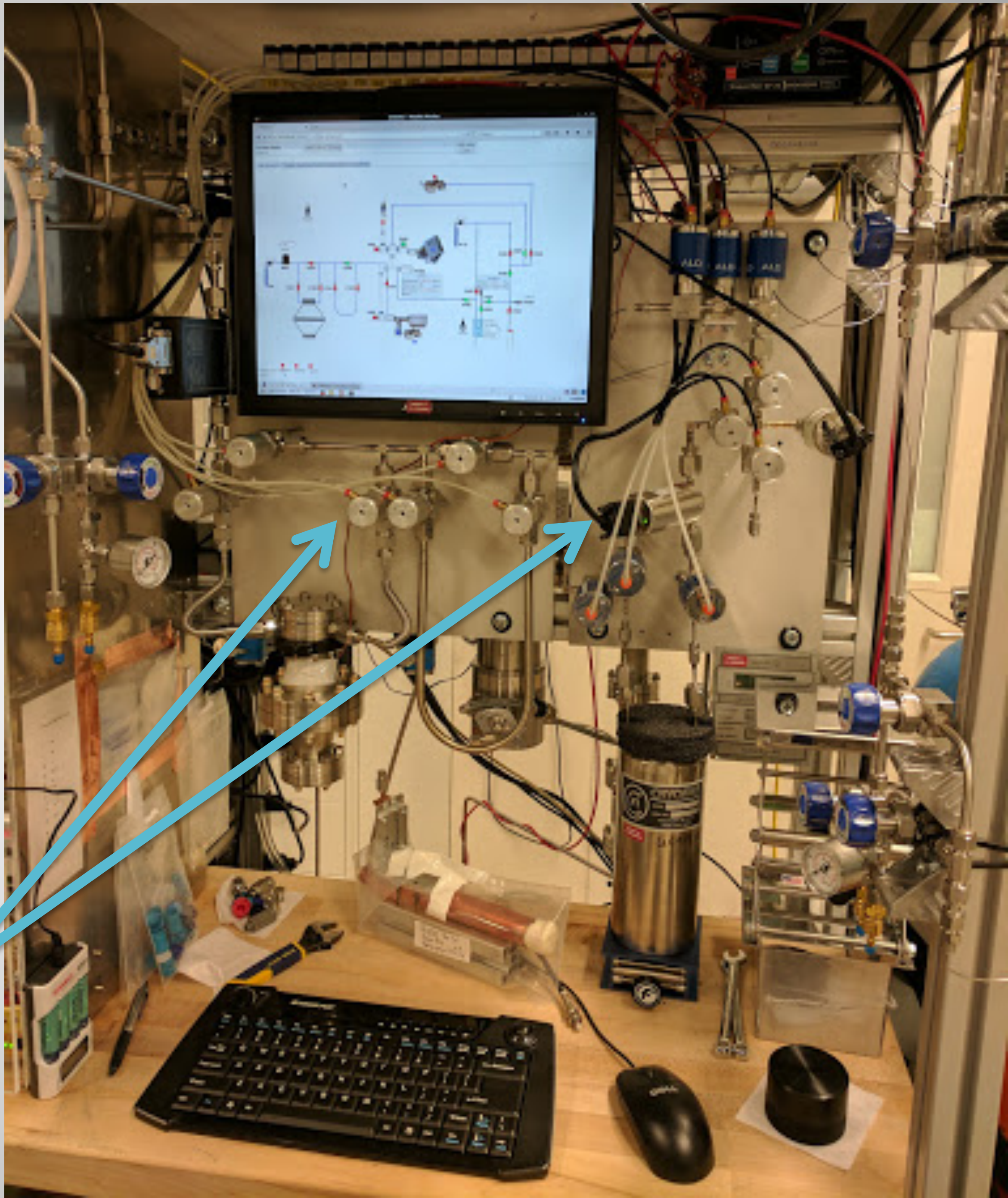
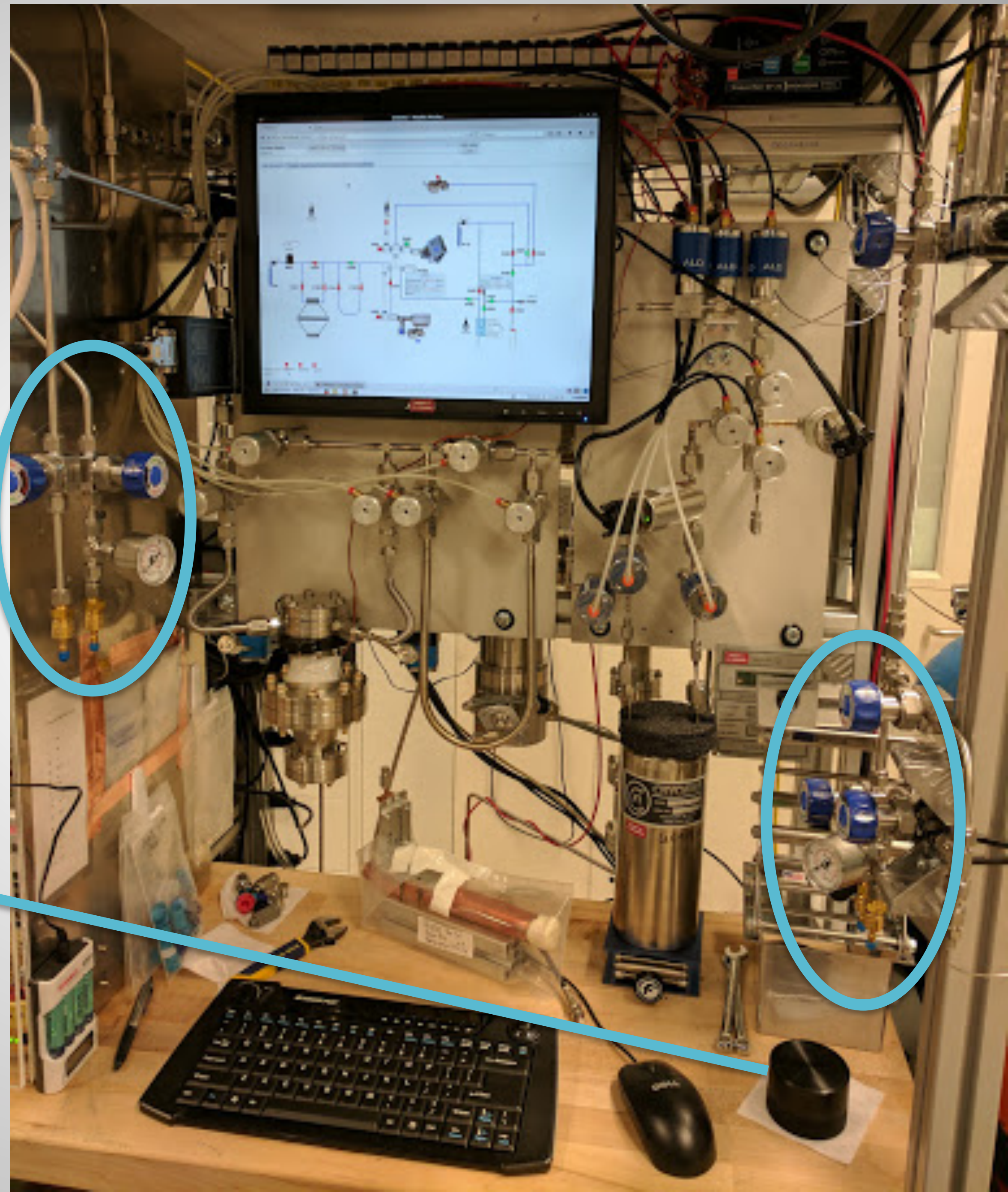


Front Panel

Acquired a
78 Bq Pylon
flow-through
source



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Ultra-Low-Background Proportional Counter

ULBPC expects high radon detection efficiency & near-zero background

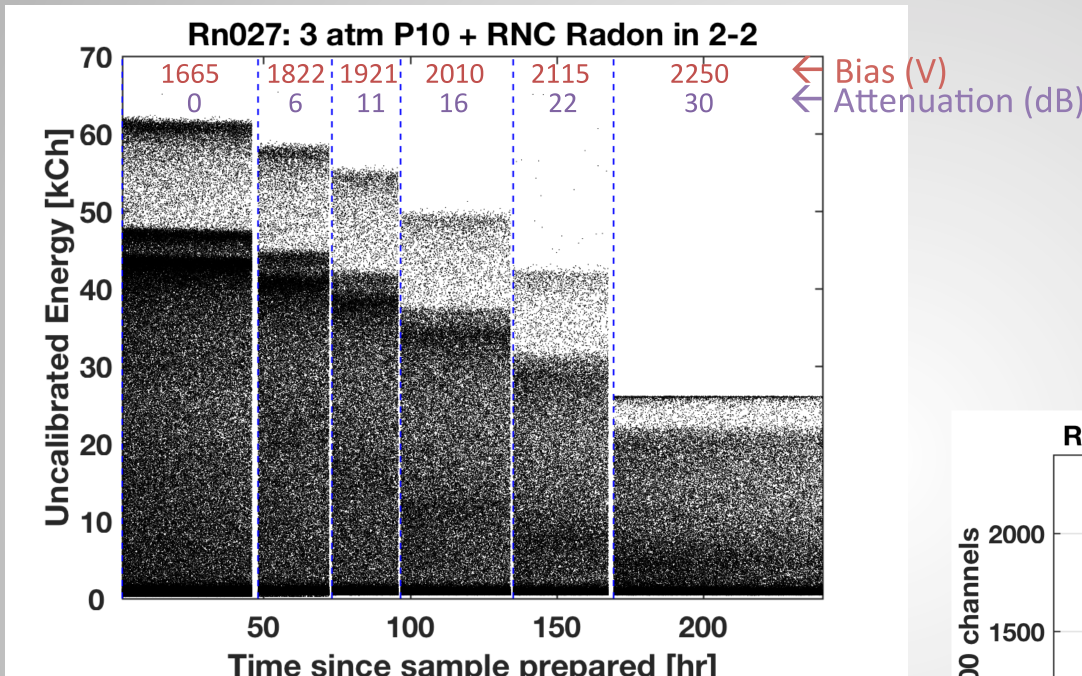
Prototype (2-2)

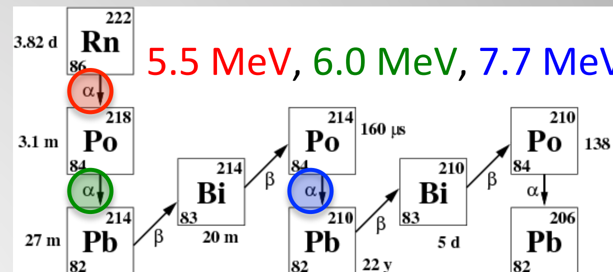
+ Electroformed Cu
− Higher background
+ No big loss if contaminated

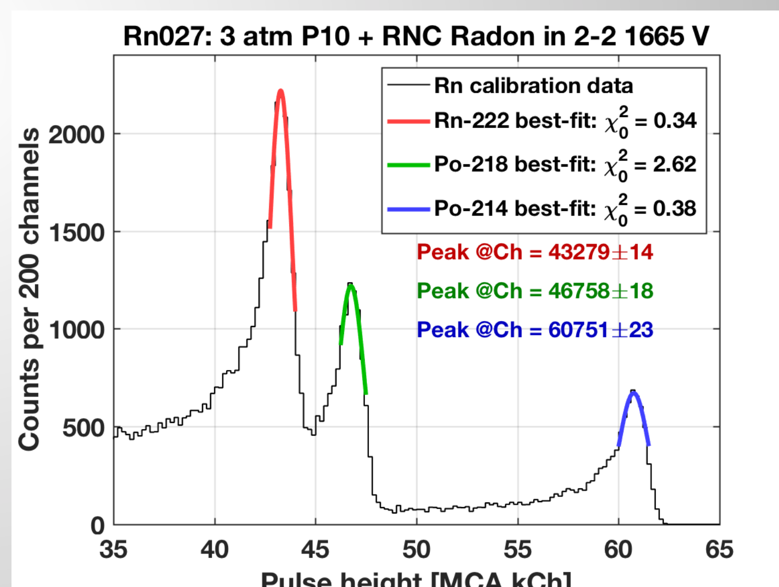
New Detector (2R01)

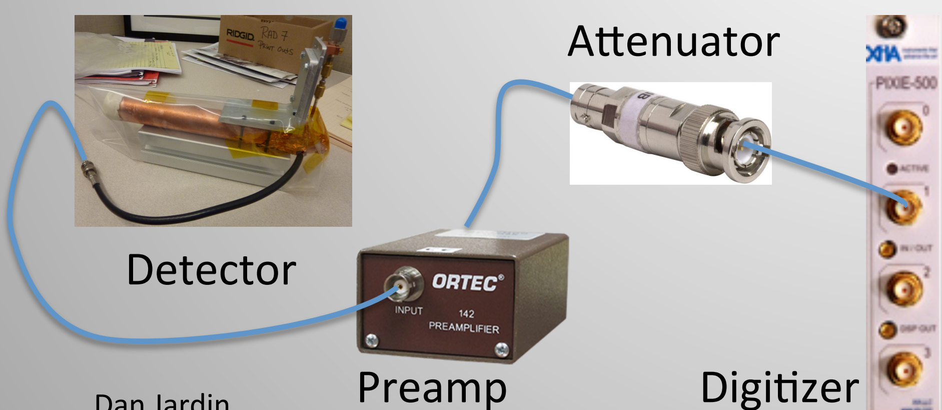
+ Electroformed Cu
+ Operation in underground
− Too valuable to contaminate

Uncalibrated Data



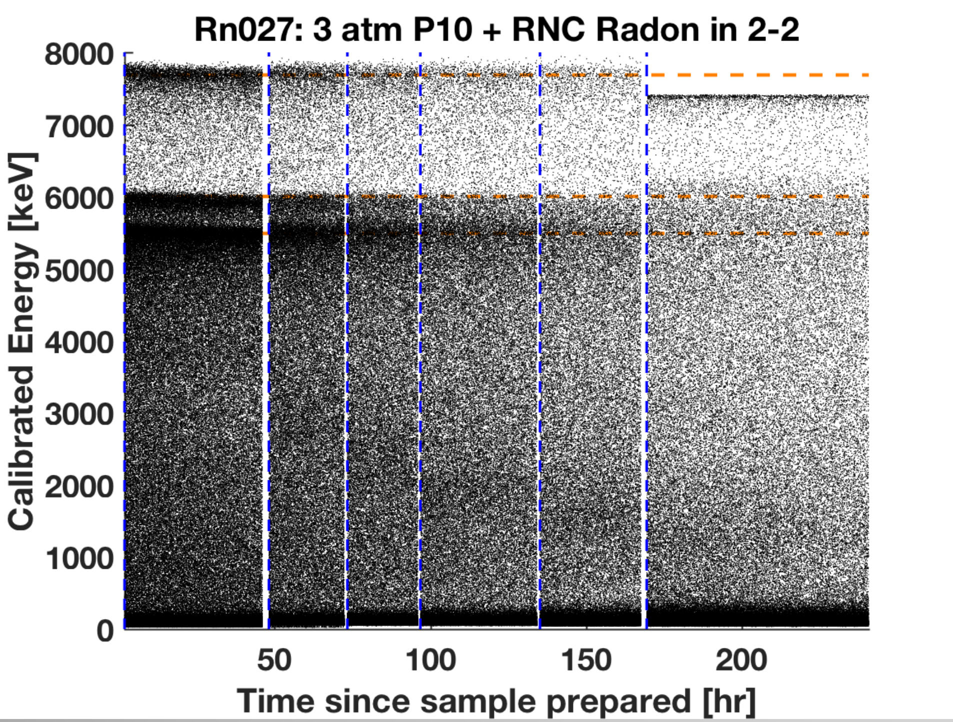


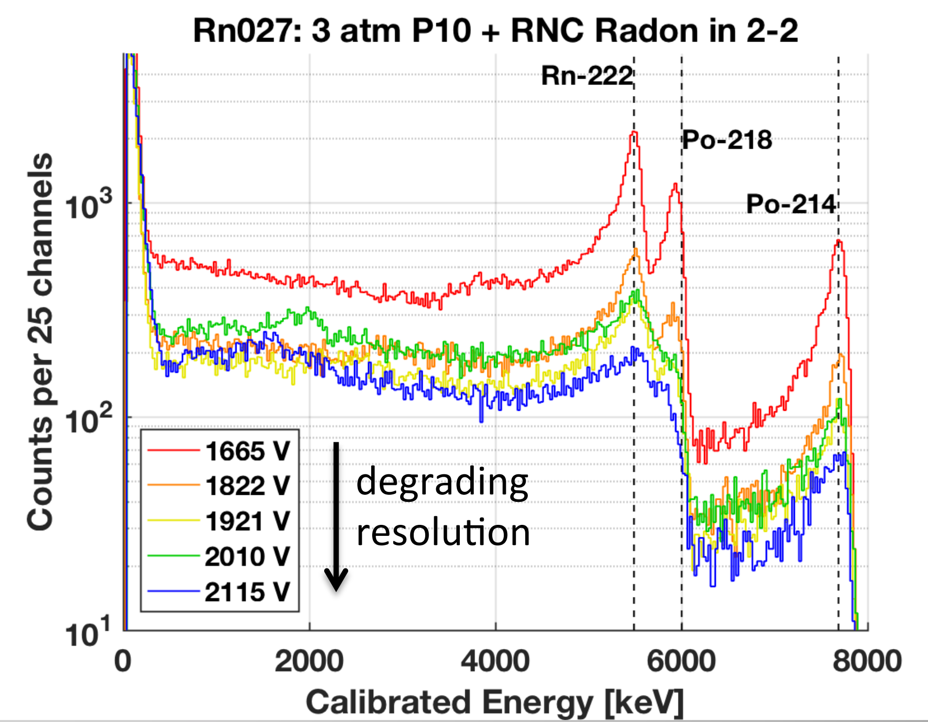




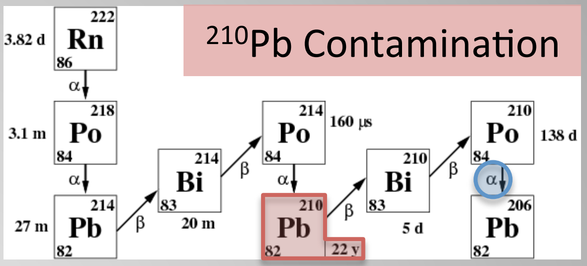
Post-Calibration

- All voltage biases on the same scale
- Peaks align as expected
- Resolution degrades as voltage increases

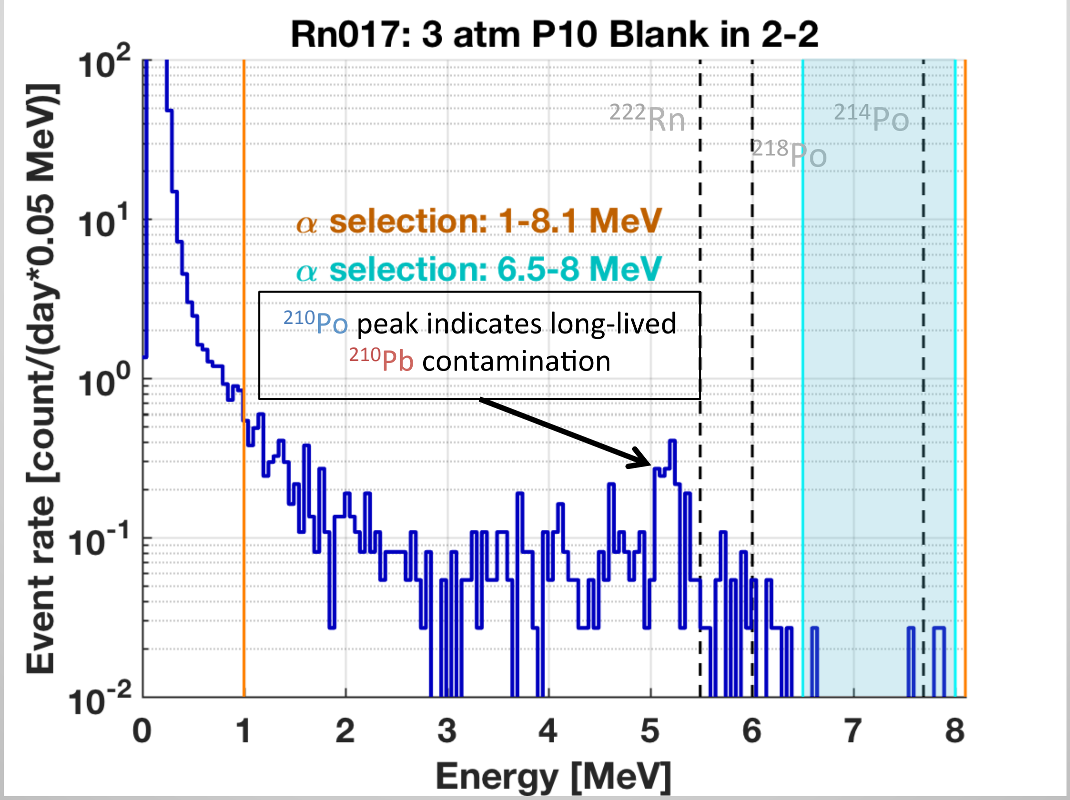




Prototype Background



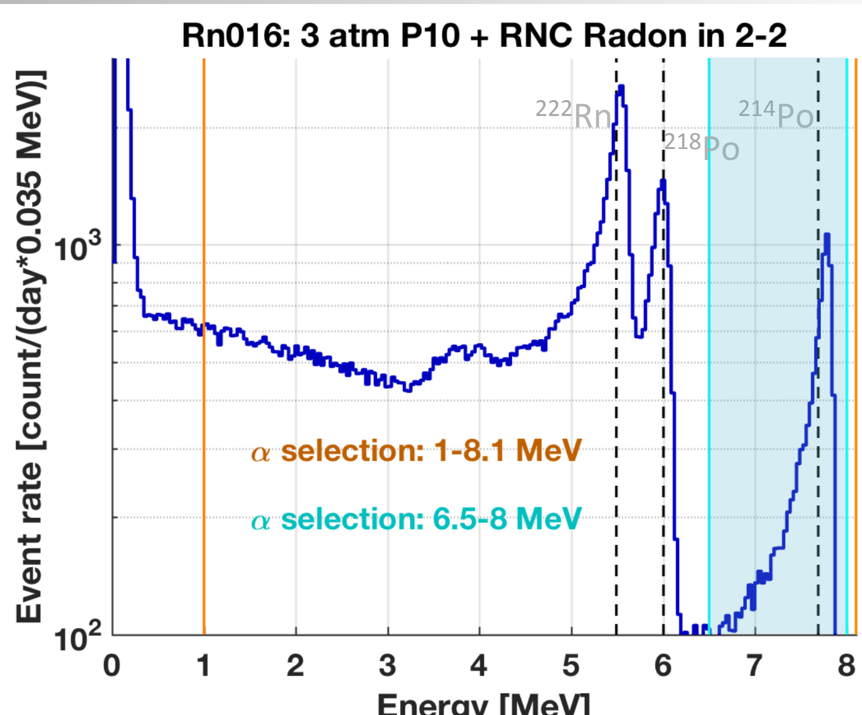
- Full ROI: 10 events/day is too high
  - Result of falling background shape and ^{210}Po peak
- Focus on cleanest part of spectrum for our tests
- ^{214}Po ROI: 4 counts / 888 hours ≈ **0.1 d^{-1}**

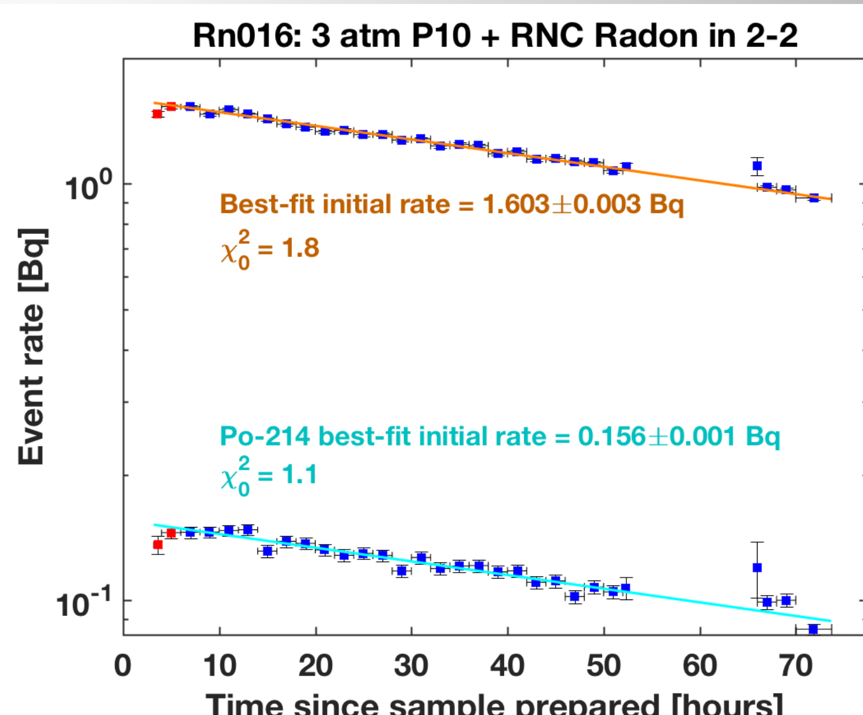


Prototype ROI

- Source Activity = 1.18 ± 0.03 Bq
- Full ROI Rate = 1.6 ± .003 Hz
- ^{214}Po ROI Rate = 0.16 ± 0.001 Hz

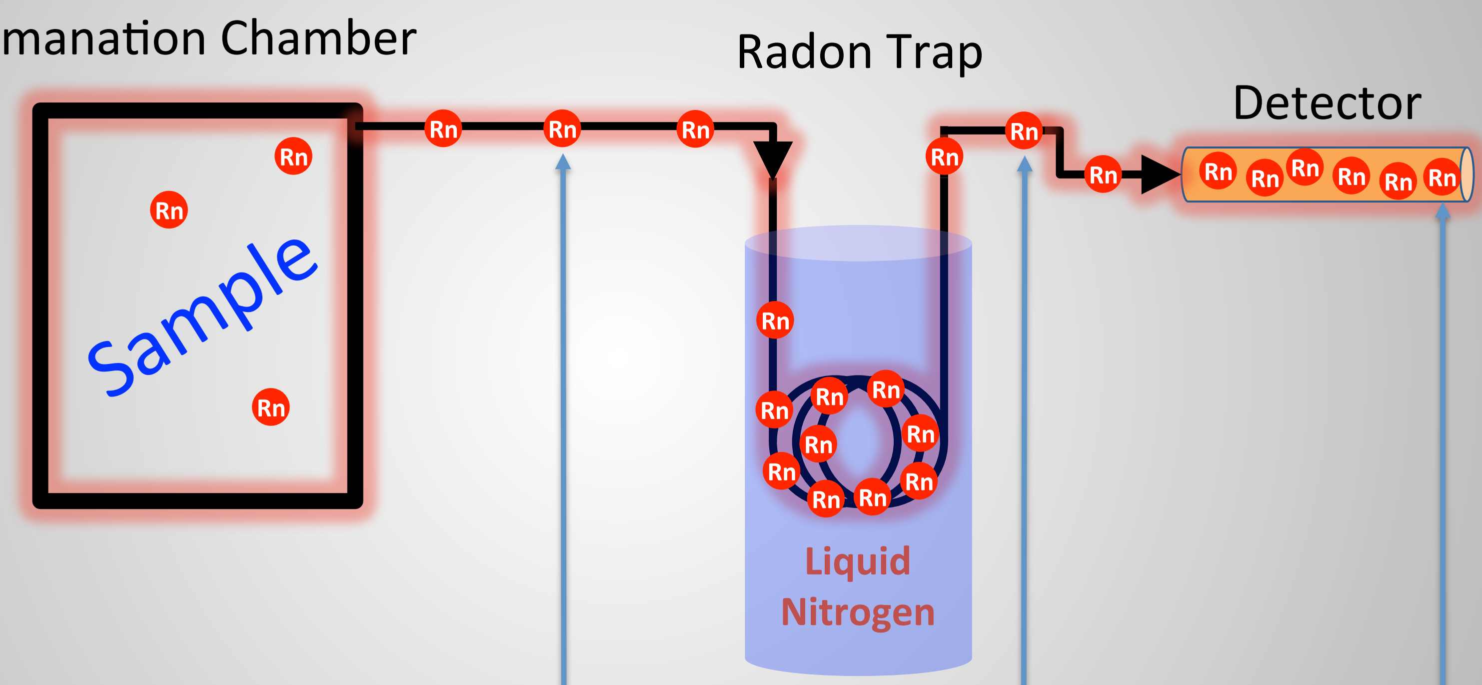
apparent efficiency > 100% means **detection efficiency is high**





Sensitivity: Background & Efficiency

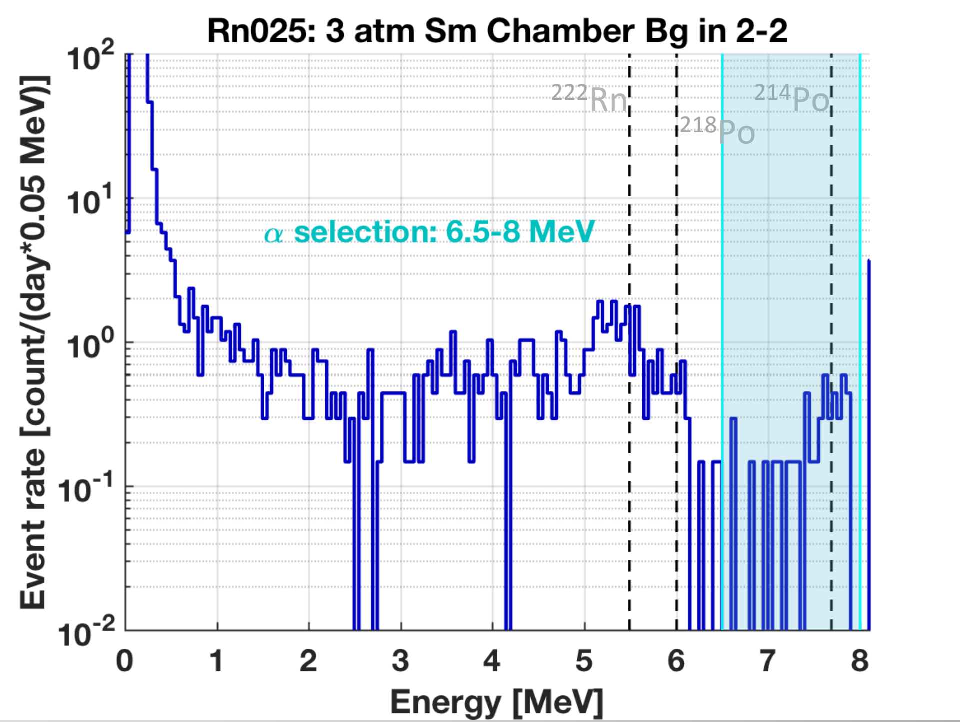
Possible background sources:
- Chamber
- Panel
- Detector



Overall Efficiency = Transfer Efficiency × Load Efficiency × Detection Efficiency

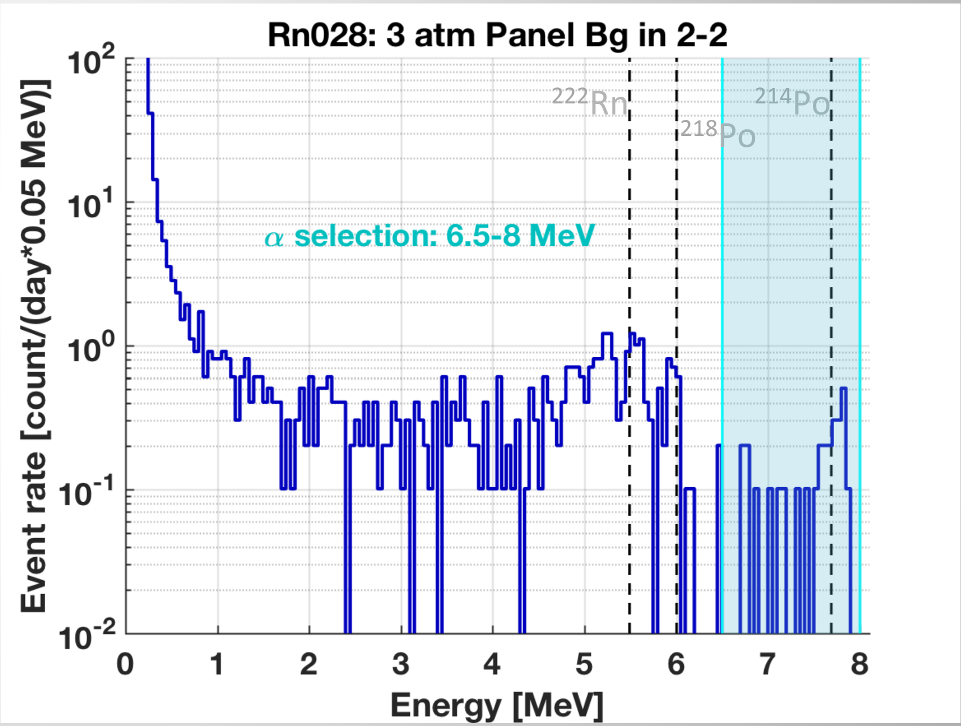
Small Chamber Background

- Chamber etched clean
  → expect low rate
- Emanated small chamber for 14 days
- ^{214}Po ROI: 34 counts / 163 hr
  = 5 d^{-1} → **50x detector bg**
- Further measurements required to establish origin
  - Chamber or panel?



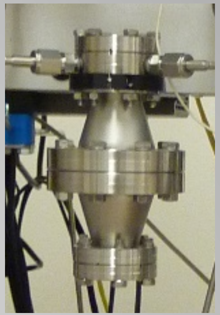
Isolated Panel

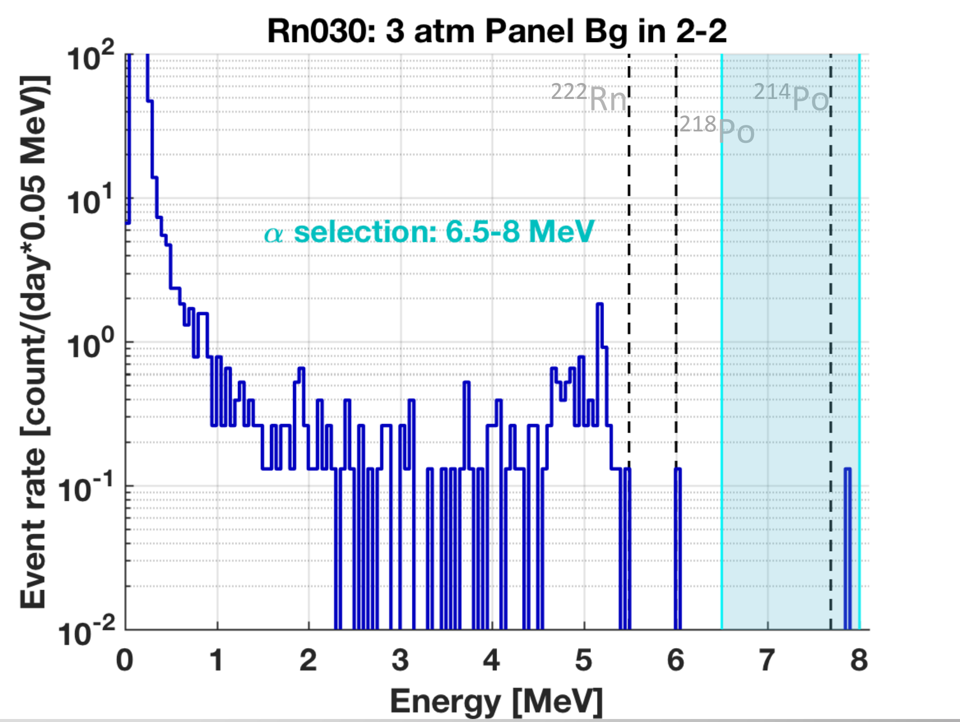
- Repeated previous procedure with no emanation time
- ^{214}Po ROI: 29 counts / 237 hr = 3 d^{-1} → **30x detector bg**
- Most of the background is from panel not the chamber
  - Anything could be a source
  - How much work will it take to identify and solve problem?



Modified Panel

- Excluded suspicious components
  - Helium triple filter
  - Silica trap
  - Small chamber
- ^{214}Po ROI: 1 count / 184 hr $= 0.13\ d^{-1}$
- Result consistent with detector background → problem removed!

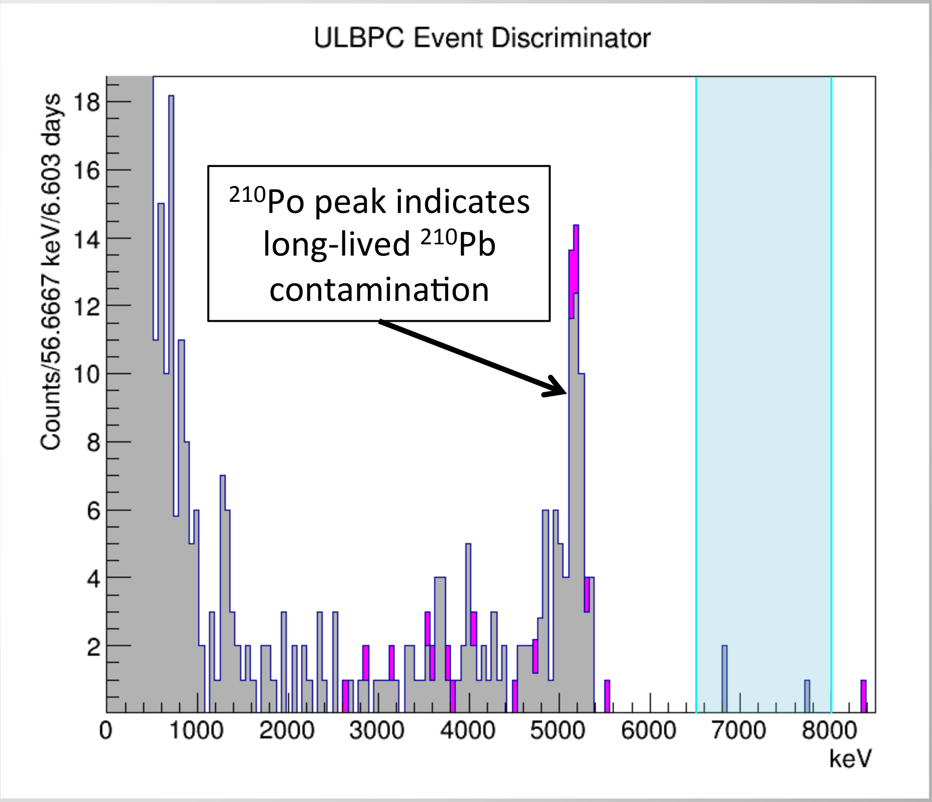




Panel background is small

Small Chamber Background (retry)

- Emanated small chamber for 18 days
- ^{214}Po ROI: 3 counts / 160 hr
  = 0.45 d^{-1}
  - Not as high as panel background before modification
- Strange timing for 3 events in ROI
  - Expect exponential rate
  - Evidence of radon carryover

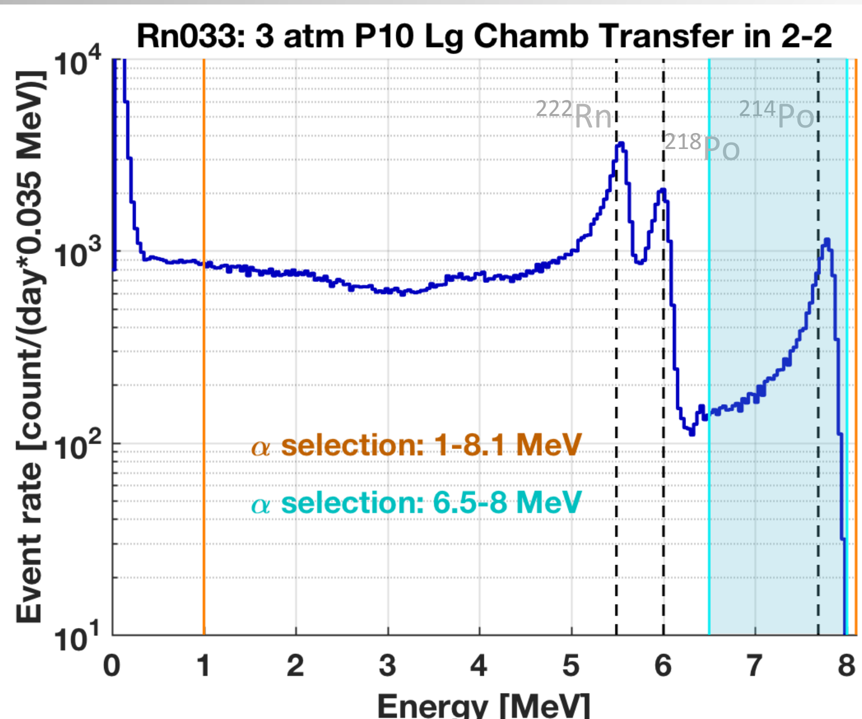


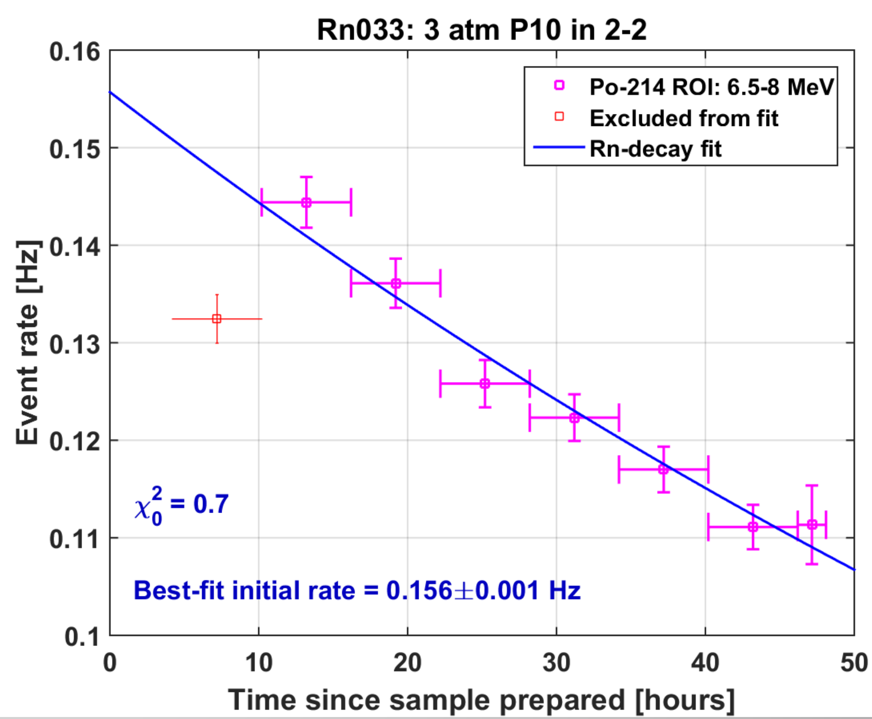
Suggests Blank Rate of 100-200 µBq

Large Chamber Efficiency

- Source Activity = 1.98±0.05 Bq
- Full ROI Rate = 1.56±0.001 Hz
- ^{214}Po Overall Efficiency = **8.08±0.14 %**

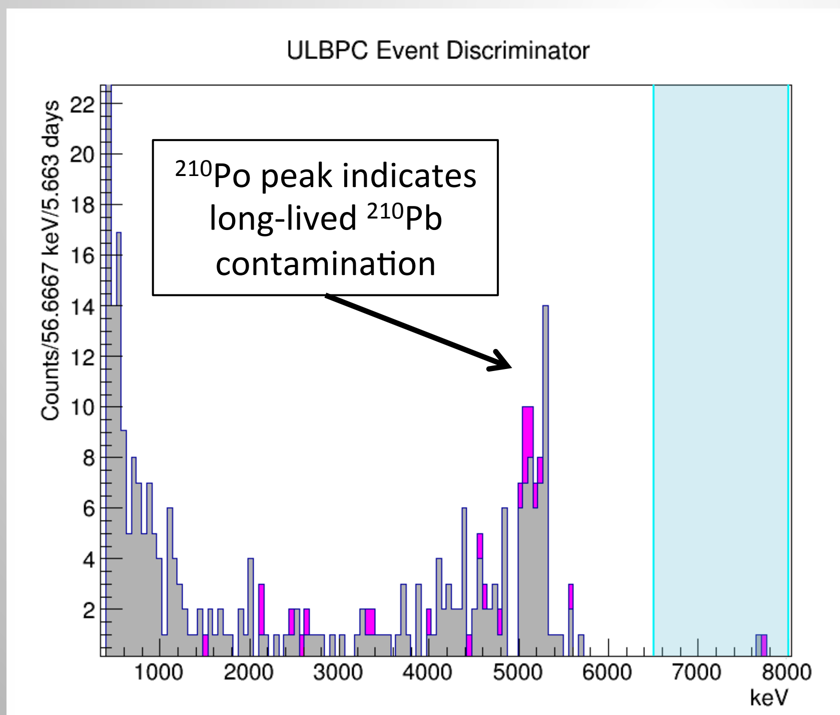
} apparent efficiency < 100% indicates transfer/load efficiency is lower, believe we can improve this





Large Chamber Background

- Emanated large chamber for 13 days
- ^{214}Po ROI: 1 counts / 5.7 days ≈ 0.18 d^{-1}
  - Assume 100% uncertainty for upper bound



Blank Rate

<100 µBq

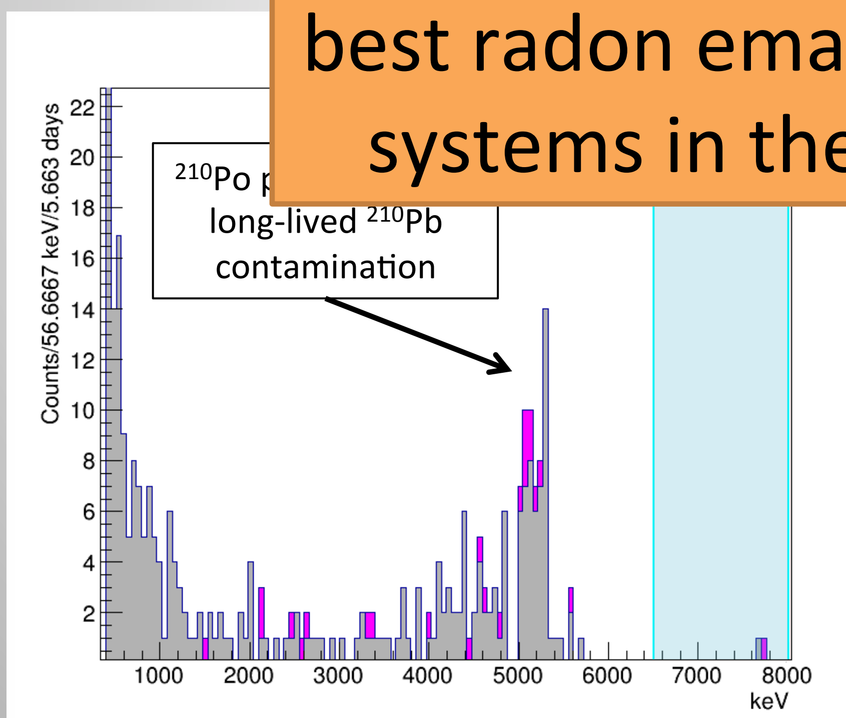
or

<50 Rn atoms in equilibrium

Large Chamber Background

- Emanated large chamber for 13 days
- ^{214}Po ROI: 1 counts / 5.7 days ≈ 0.18 d^{-1}
    - Assume 10

Comparable to the best radon emanation systems in the US!



Blank Rate

<100 µBq

or

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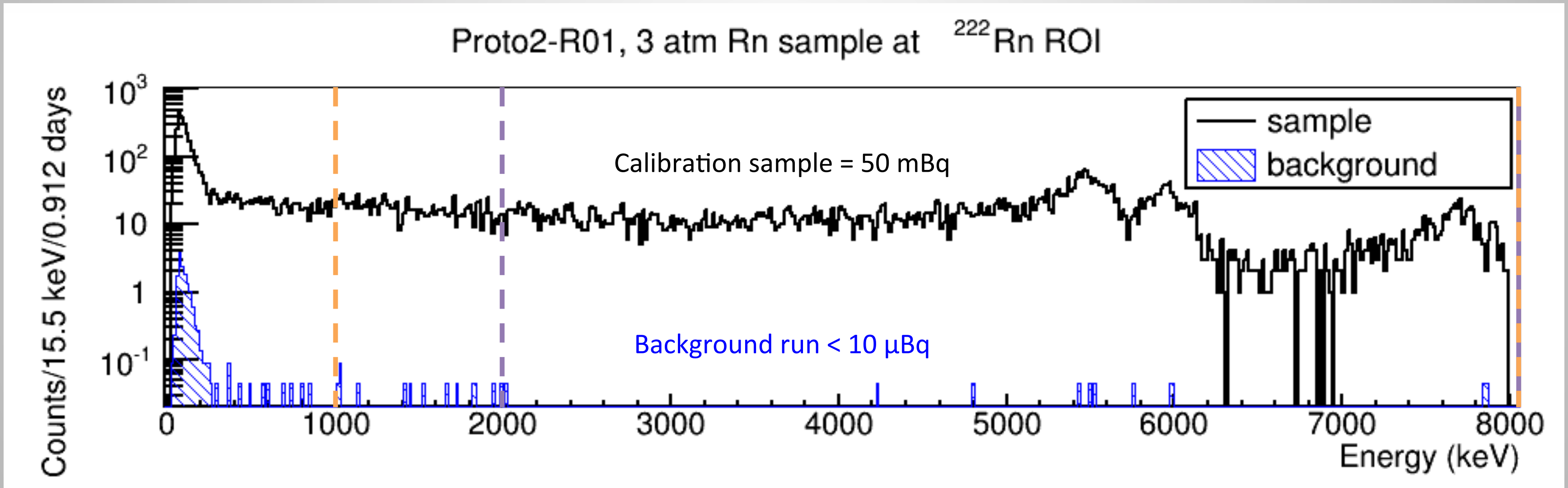
Room to Improve

- New detector operated underground
- Suggests optimal energy range



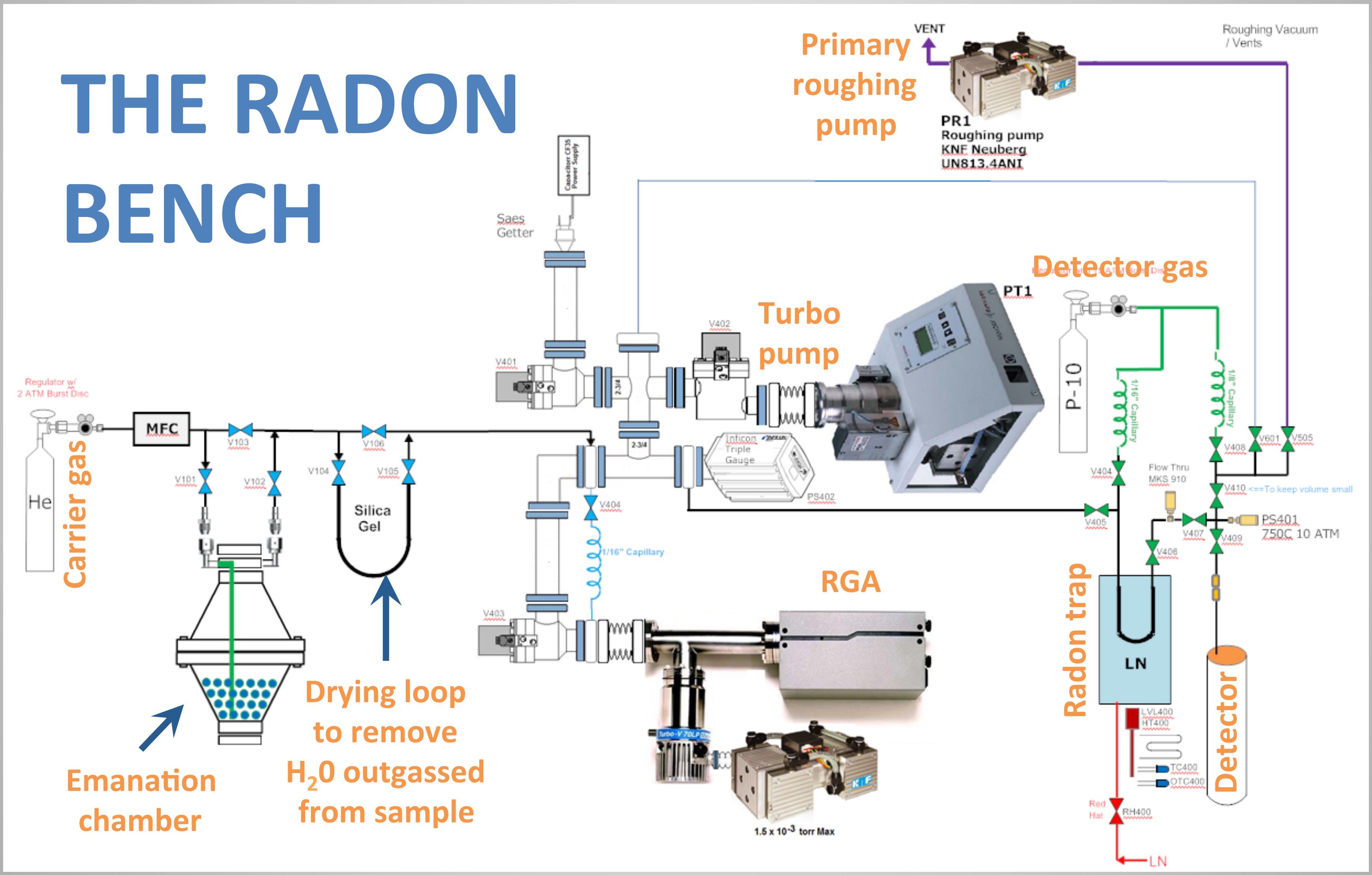
Energy ROI	Background	Signal
1-8 MeV	1.07±0.27 d^{-1}	86.8±0.9 mHz
2-8 MeV	0.56±0.21 d^{-1}	72.0±0.8 mHz

Summary

- The PNNL Radon Emanation System works!
- Can now do radon assays at a competitive sensitivity level
  - Using ^{214}Po ROI in prototype operated above ground
- Either the silica trap or the helium filter is a hot background source
- New ULBPC operated underground shows potential for further improvement

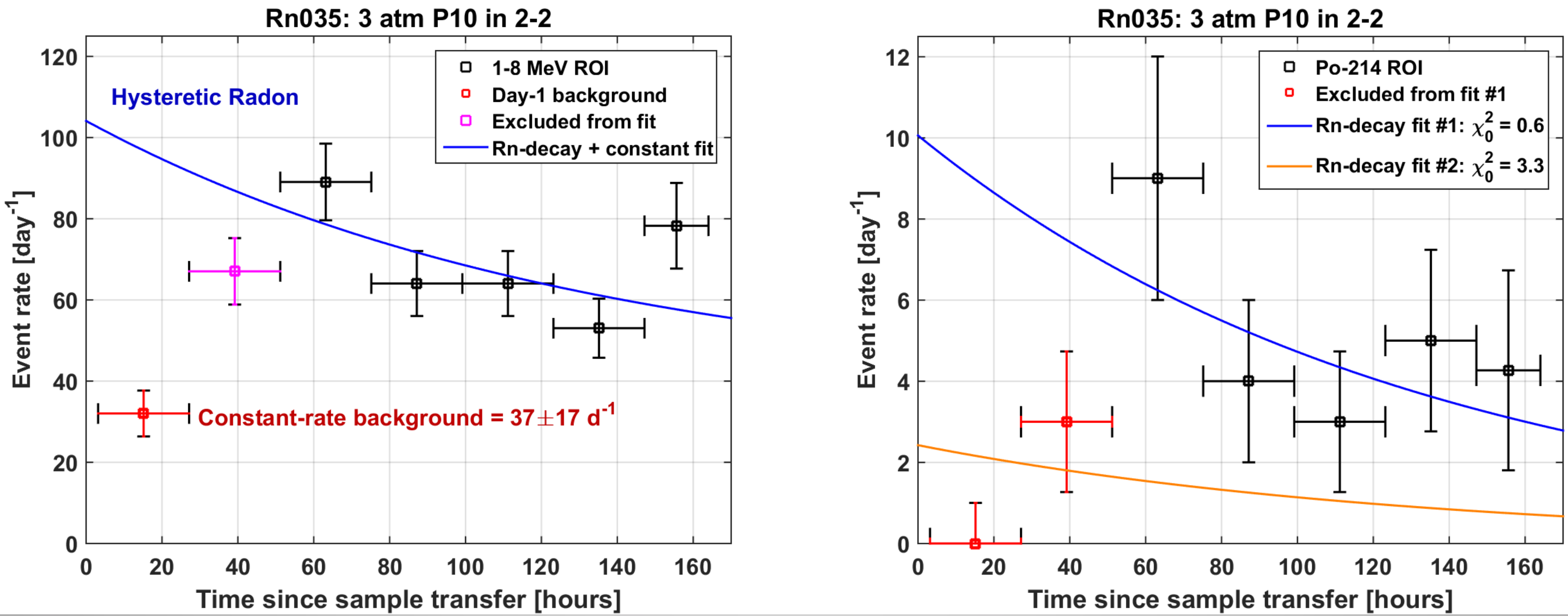
Backup Slides

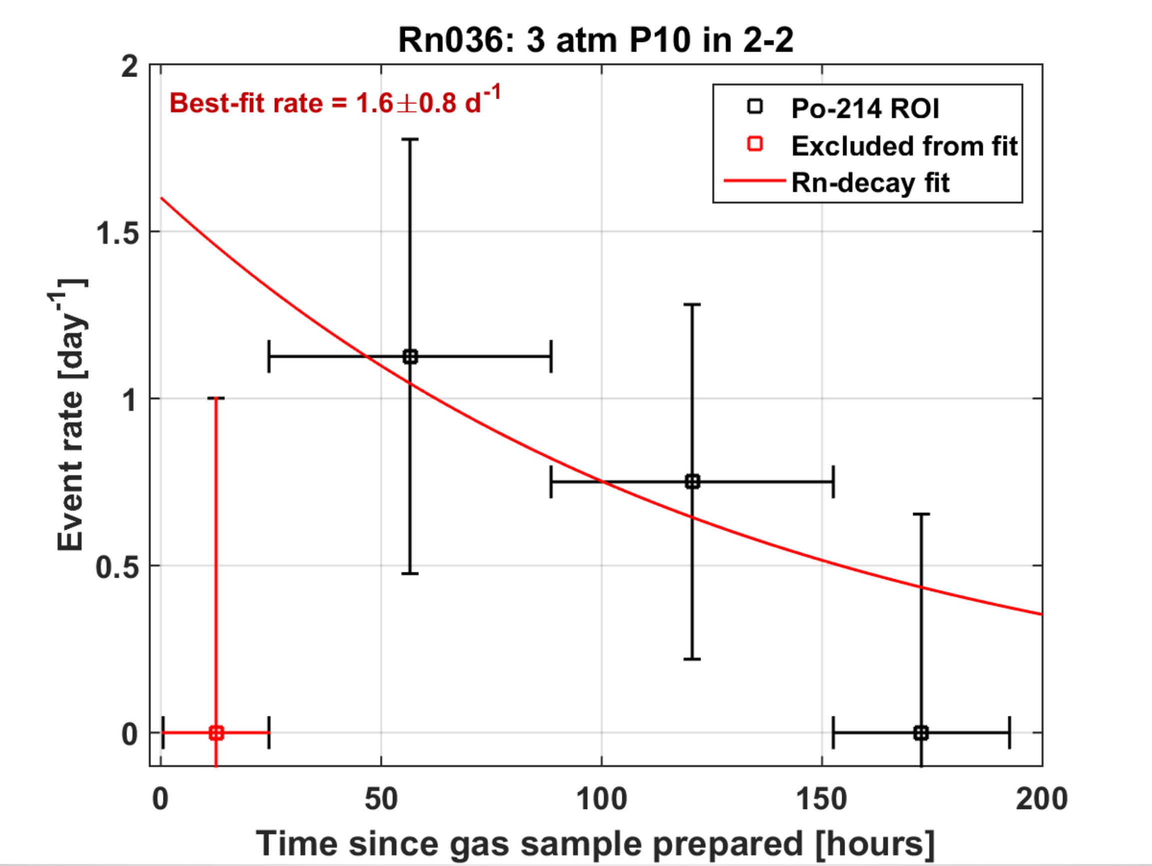
Schematic


THE RADON BENCH
Primary roughing pump
VENT
PR1
Roughing pump
KNF Neuberg
UN813.4ANI
Roughing Vacuum / Vents
Saes Getter
Detector gas
PT1
Turbo pump
V401
V402
V403
V404
V405
V406
V407
V408
V409
V410 <==To keep volume small
V505
V601
Regulator w/ 2 ATM Burst Disc
MFC
V101
V102
V103
V104
V105
V106
He
Carrier gas
Silica Gel
Inficon Triple Gauge
PS402
P-10
1/16" Capillary
1/8" Capillary
Flow Thru MKS 910
PS401
750C 10 ATM
RGA
Radon trap
LN
LVL400
HT400
TC400
OTC400
Red Hat
RH400
Detector
Emanation chamber
Drying loop to remove H_2O outgassed from sample
1.5 x 10^{-3} torr Max

Inter-run Carryover?

- Interesting result: small chamber background run immediately after high-Rn efficiency transfer shows strange time signature
- Hypothesis: caused by Rn diffusing into detector parts
  - Plastic parts and o-rings most likely candidates





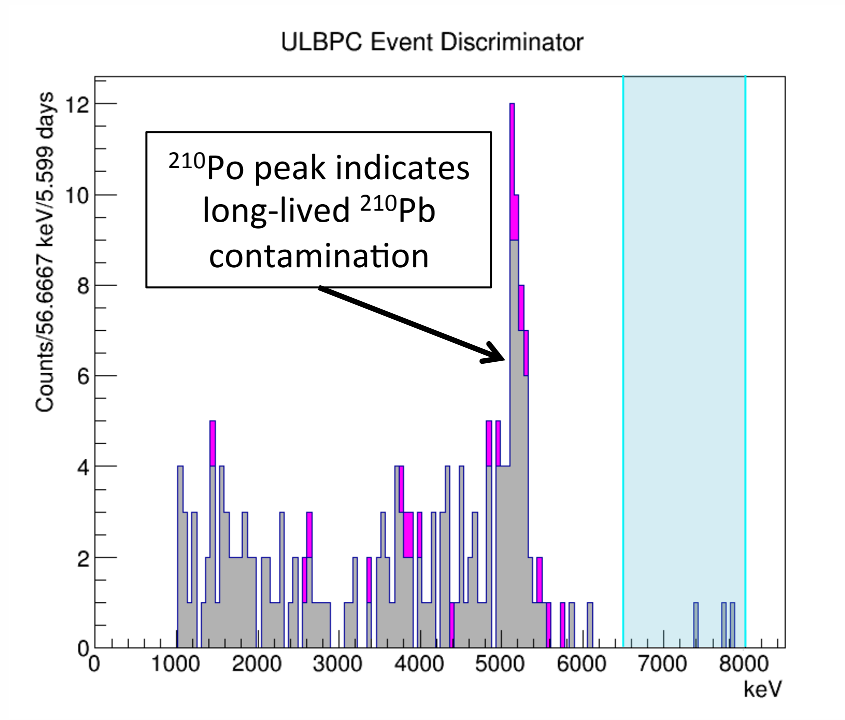
Measuring Carryover

Stopped previous run, rinsed detector and loaded with P10 blank for background run.

Goal was to let the diffusion finish and then watch the Rn decay away

Large Chamber Background

- Emanated large chamber for 18 days
- ^{214}Po ROI: 3 counts / 5.5 days ≈ 0.55 d^{-1}
  - None in first 2.4 days → evidence of something else
  - Conservatively assume all 3 are from chamber



Blank Rate

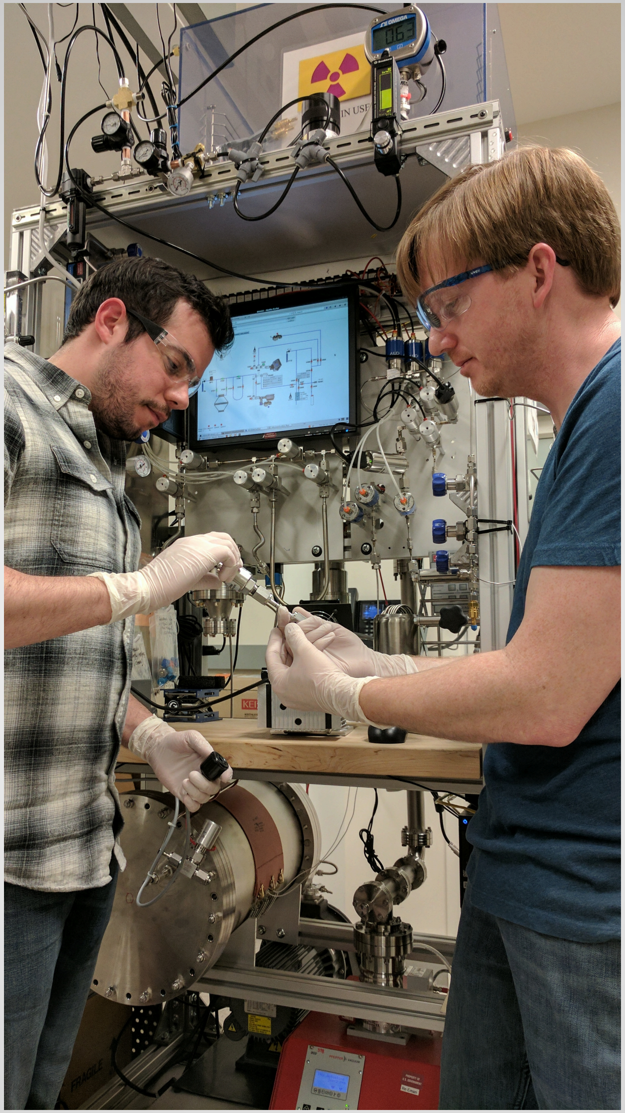
100-200 µBq

or

50-100 Rn atoms in equilibrium

Future Plans

- Optimize assay
  - Transfer efficiency
  - Demonstrate reproducibility
  - Automate the procedure
- Additional background measurements of each chamber
- Characterization of detection efficiency
- Perform first radon emanation assays
  - Materials of construction for low-radon storage and shipping containers for SuperCDMS detectors
  - Wetted components for large liquid noble detectors



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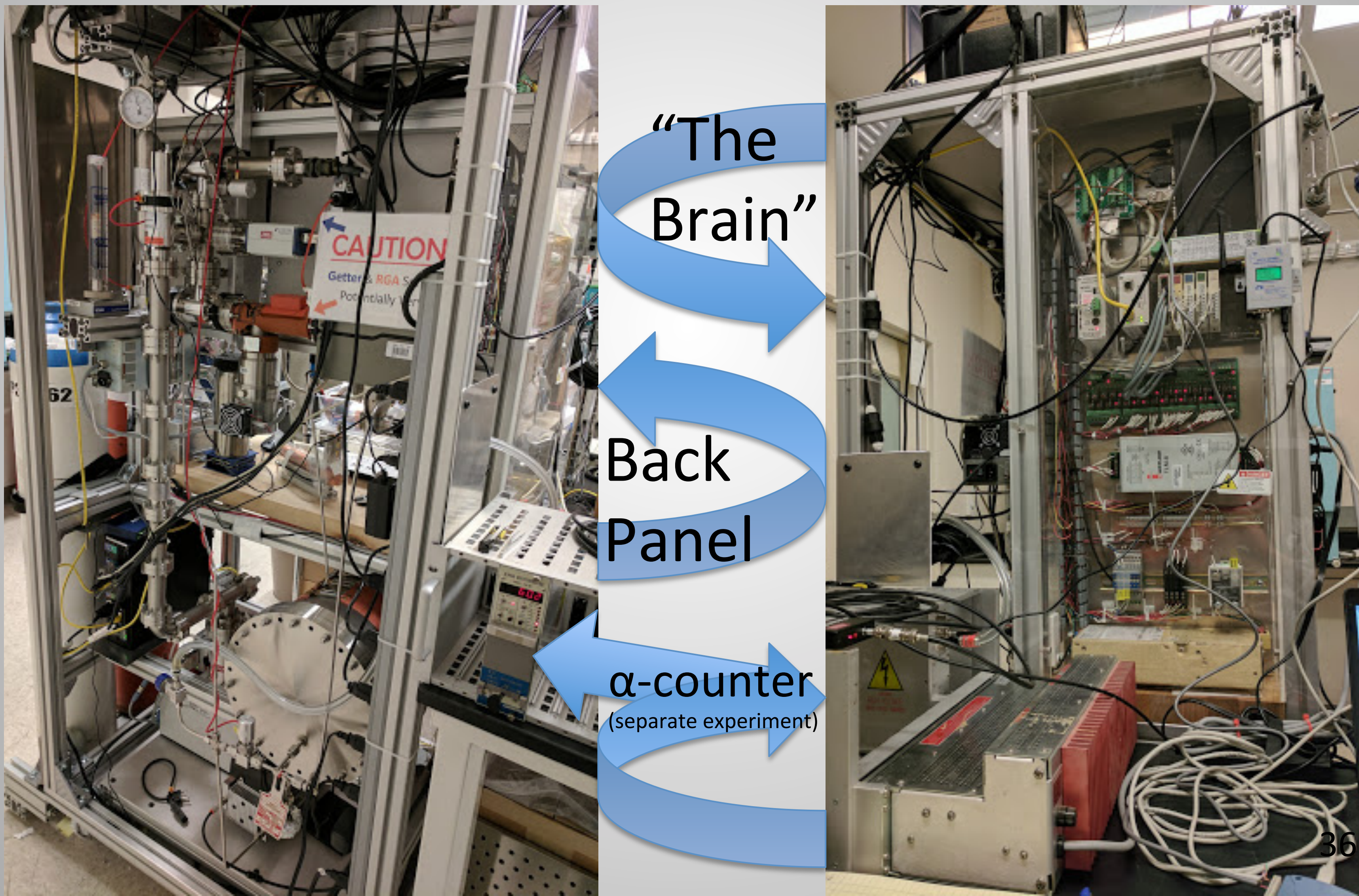
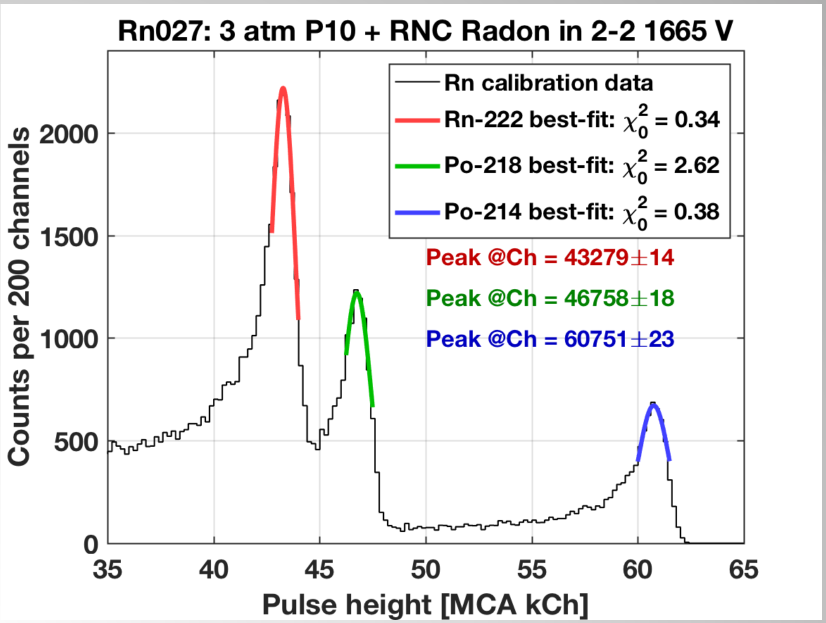
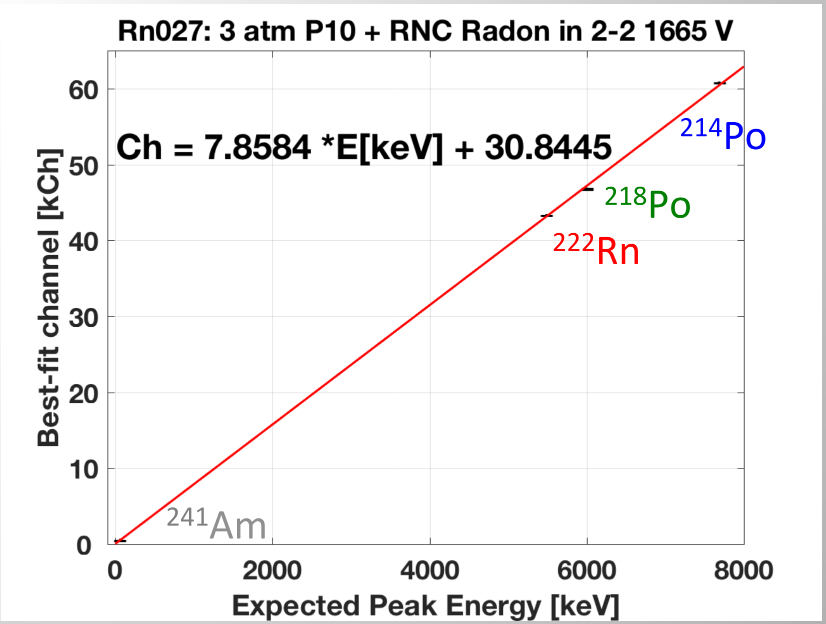
Other Angles

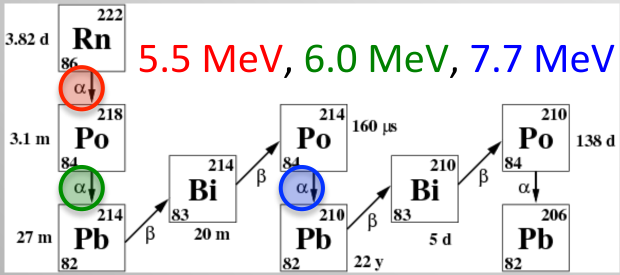


Energy Calibration

1. Fit each peak with a Gaussian function
2. Plot center of peaks against expected energy
   - Include ^{241}Am peak to constrain low energy
3. Linearly fit and extract parameters







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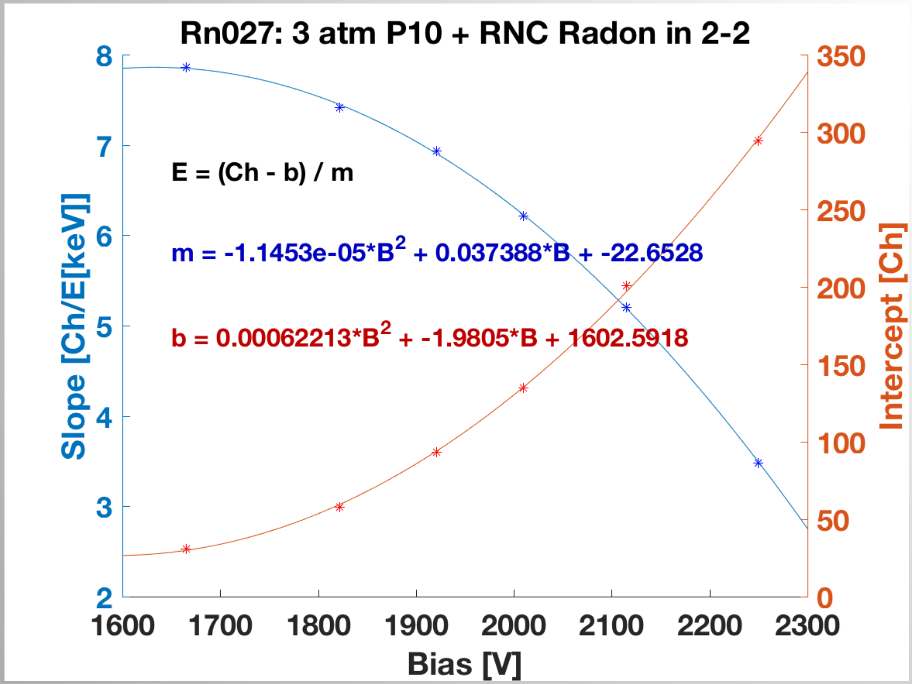
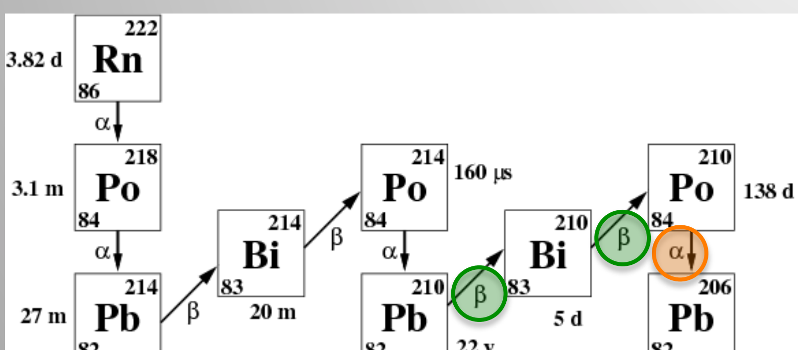
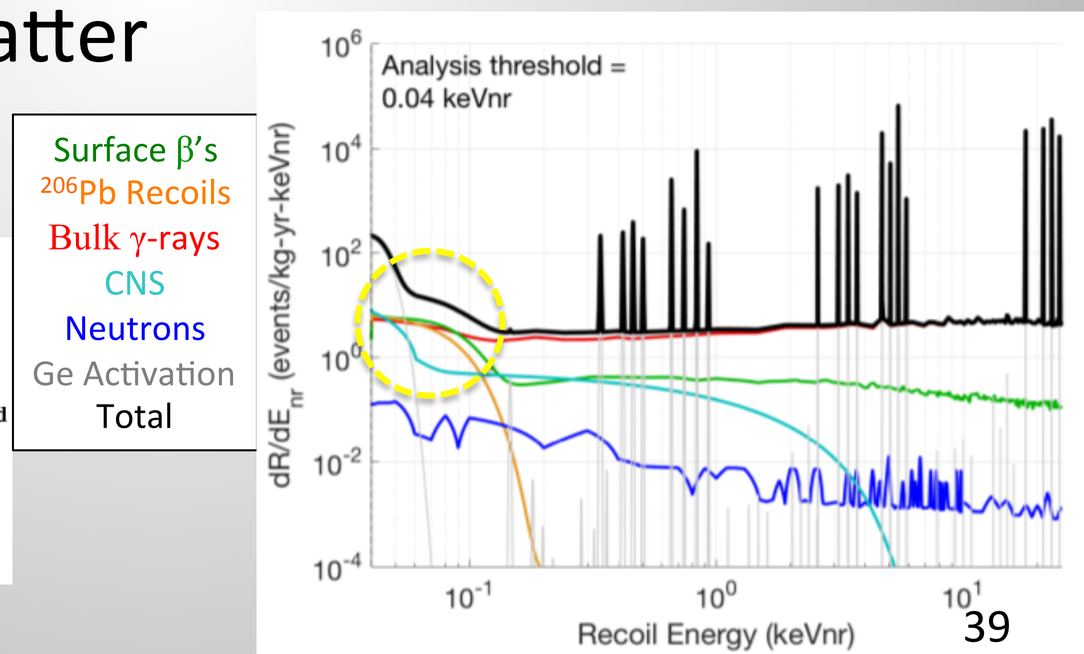


1. Fit each peak with a Gaussian function
2. Plot center of peaks against expected energy
   - Include ^{241}Am peak to constrain low energy
3. Linearly fit and extract parameters
4. Extract linear parameters and plot for each bias
5. Describe fit parameters as function of bias

Radon in SuperCDMS

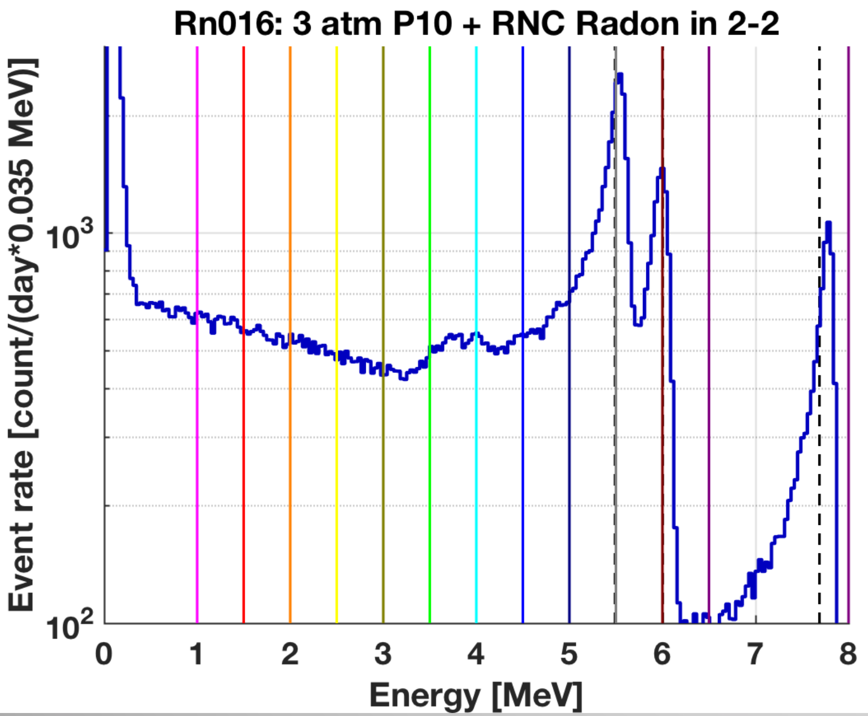
- Recoil events on/near surface of SuperCDMS detectors can mimic dark matter signal
- Increase in ^{210}Pb background from radon could be dominant and limit sensitivity for low-mass dark matter

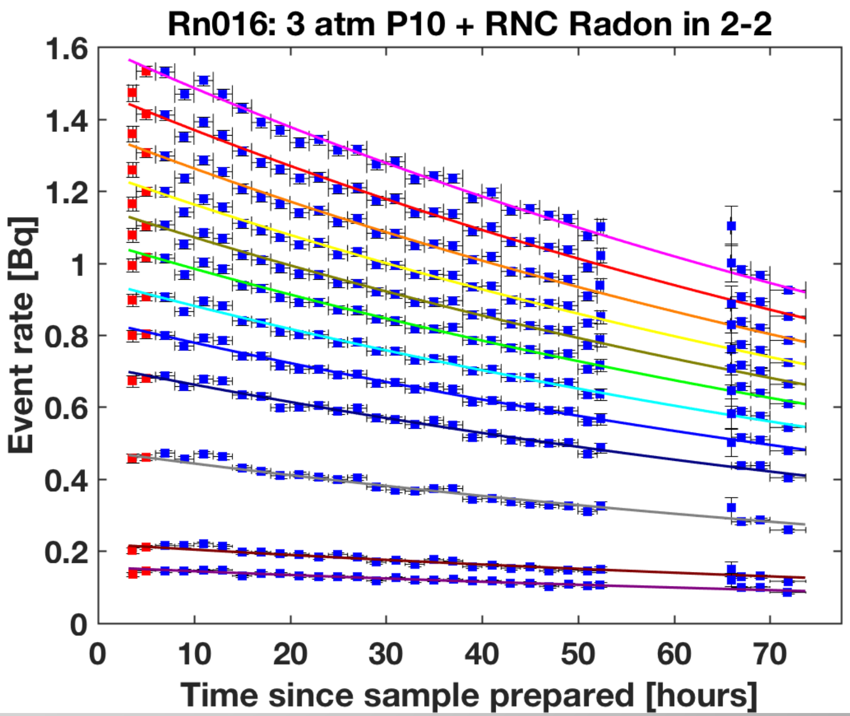




Closer look at Rn016 efficiency

- Showing efficiency as a function of lower energy cutoff – high end is always 8 MeV





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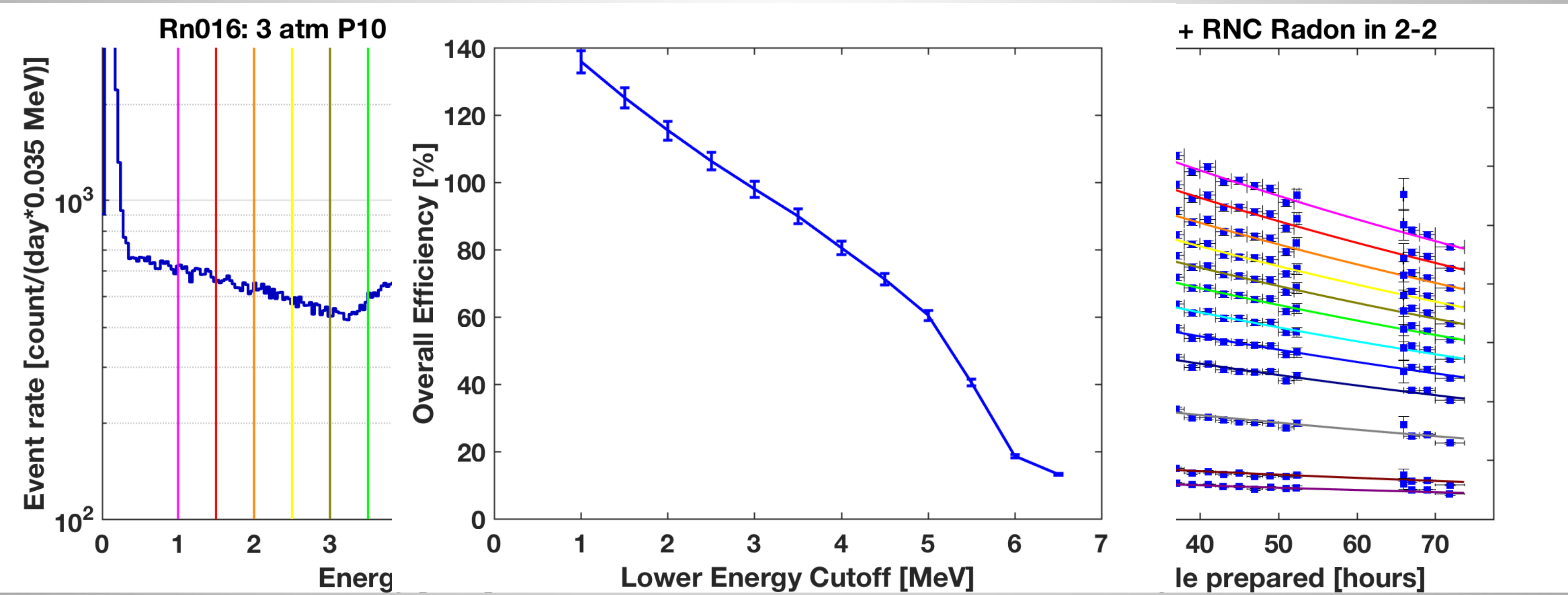
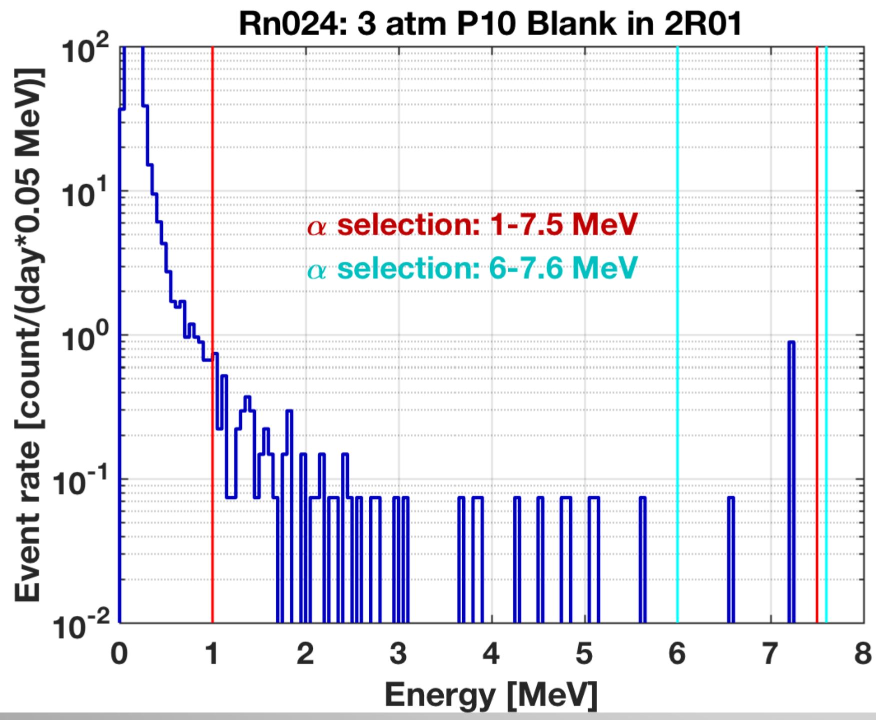
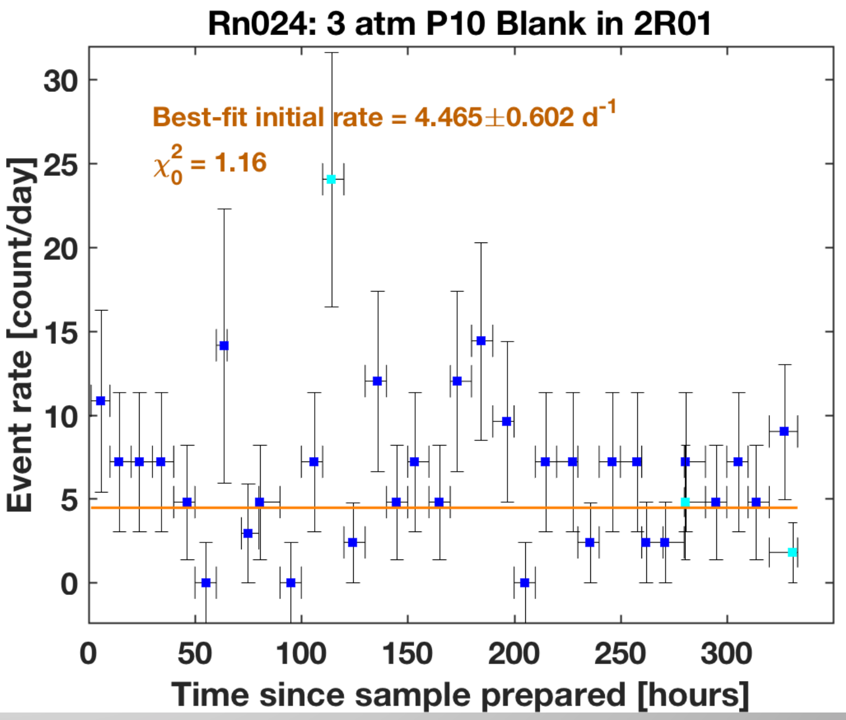


Rn024: bg of new detector

- Above ground, uncalibrated
- Difference from Rn022 is raw traces were saved → 2 high energy pulses were removed using PNNL ROOT tools

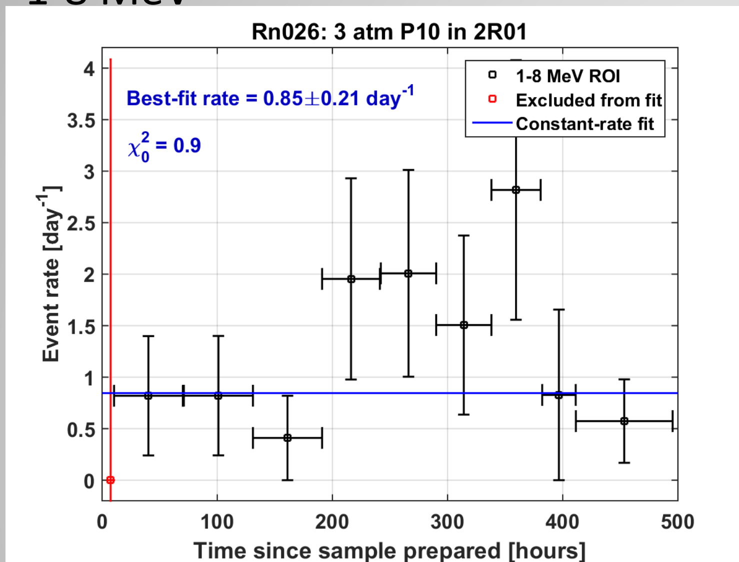


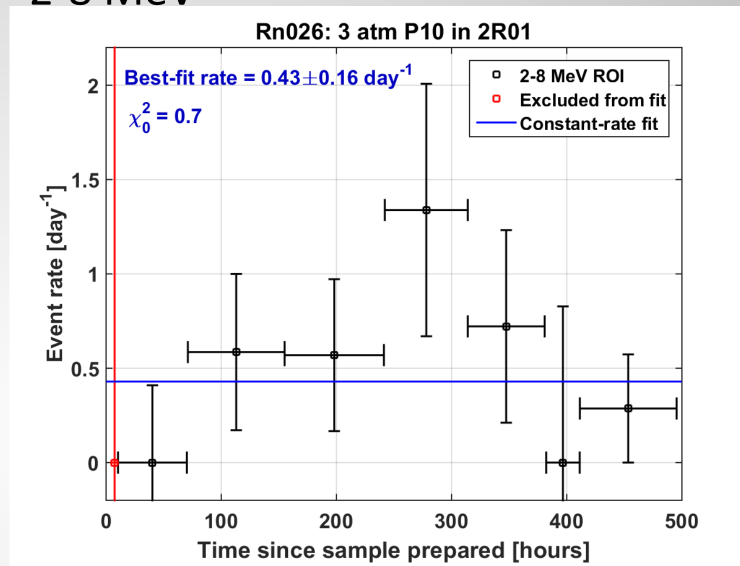


Rn026: new det bg rates undgd

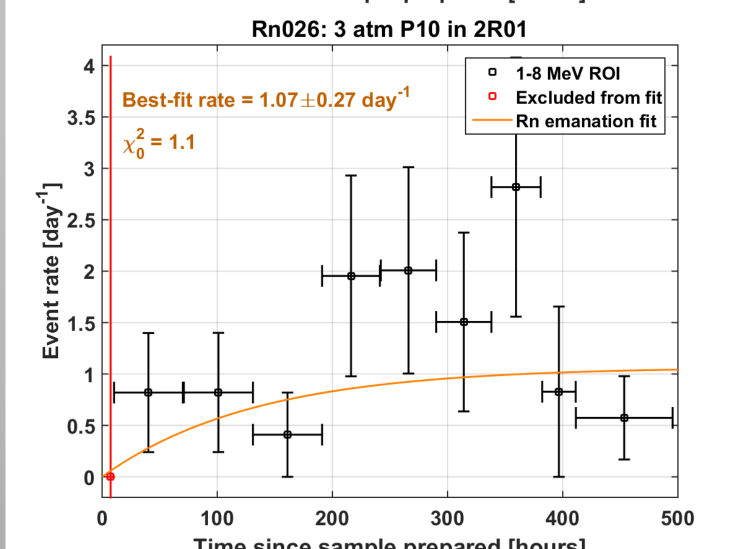
1-8 MeV | 2-8 MeV

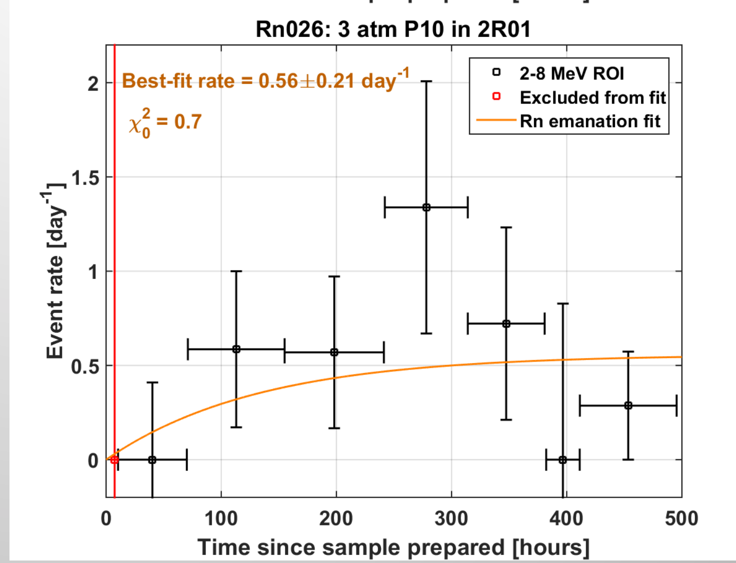
Flat Fit





Grow-in Fit

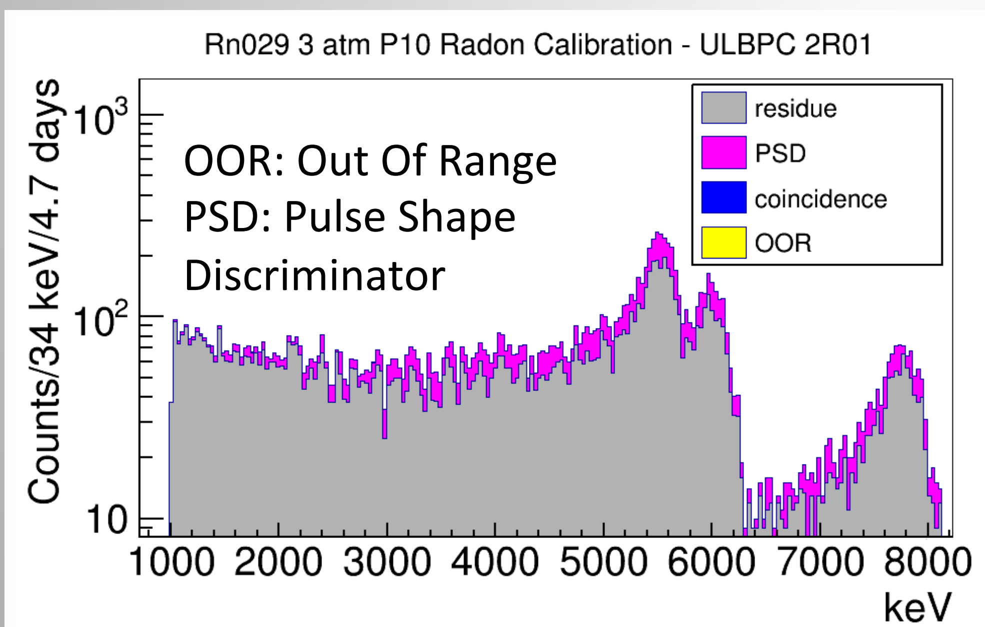


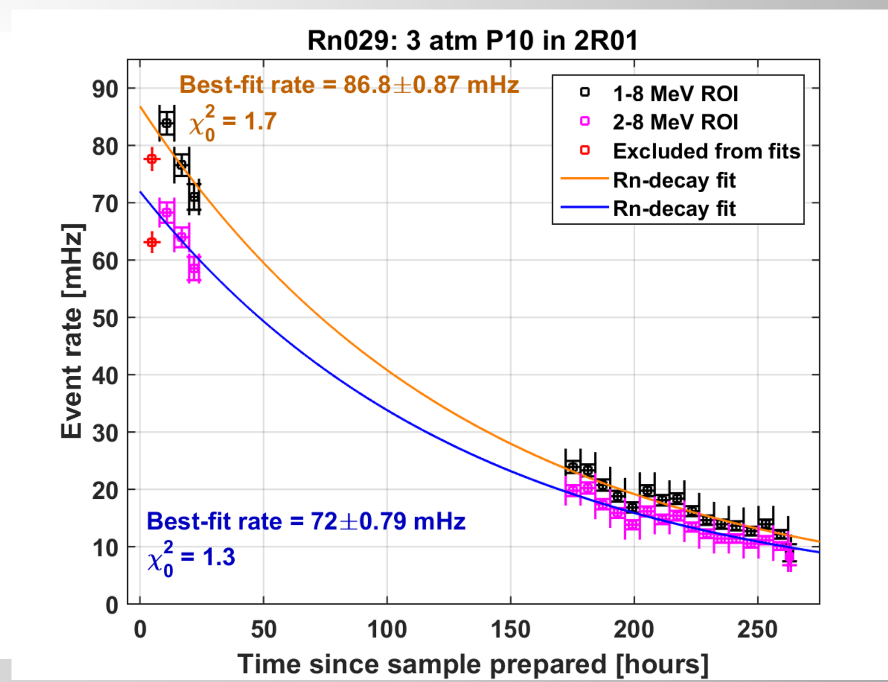


More conservative & more accurate if detector is source

Rn029: new det undgd eff

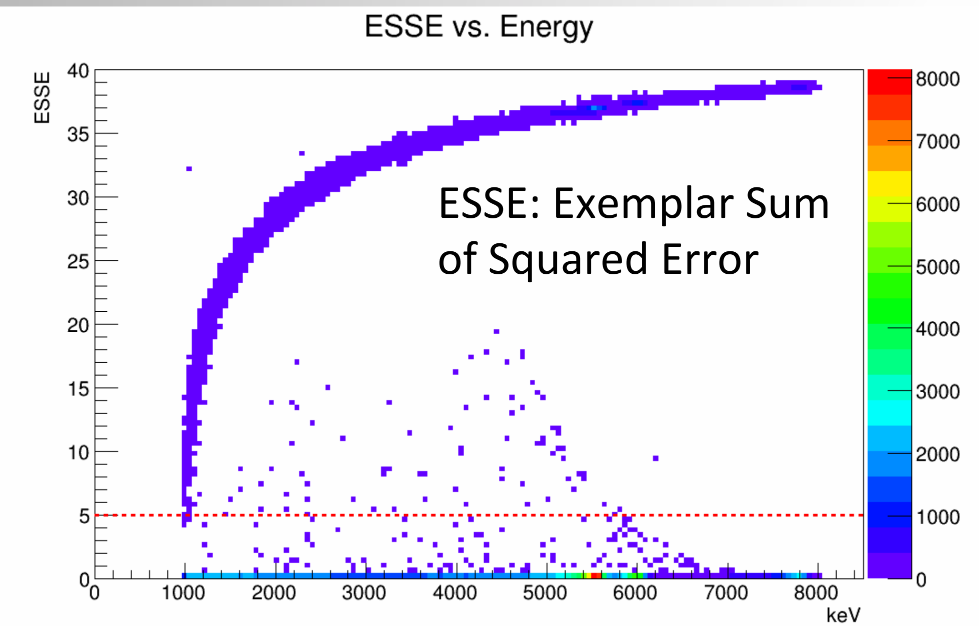
- Selecting 2-8 MeV instead of 1-8 MeV is only a small hit in efficiency

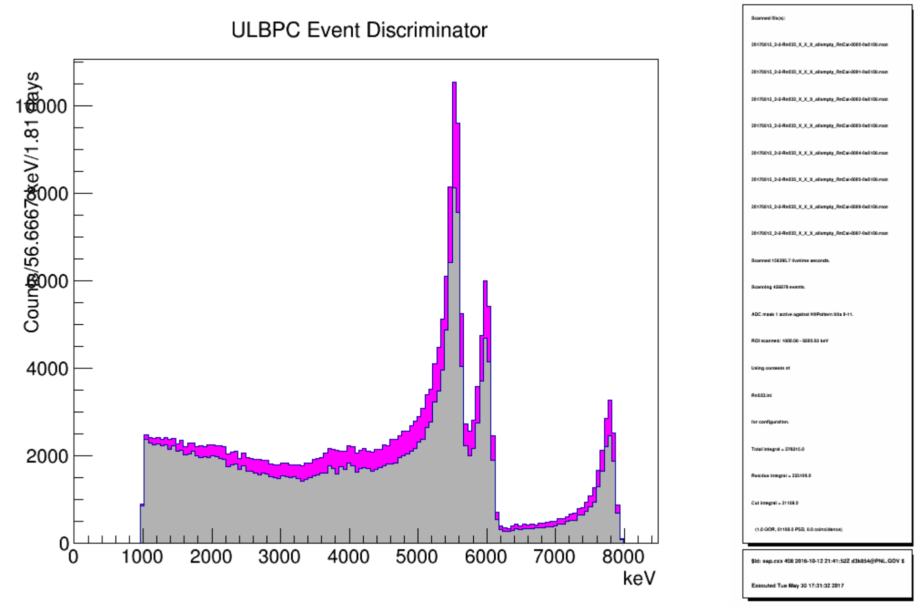




Rn033: lg chamber eff

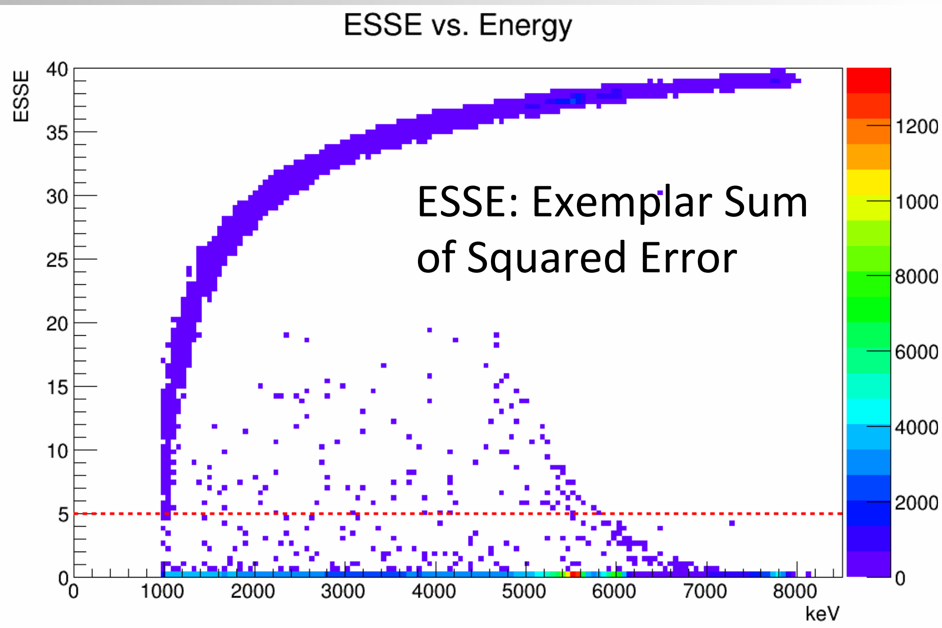
- Left is pulse shape parameter
  - Events above the line were removed
- Right is resulting spectrum
  - Magenta events were removed, gray events remain

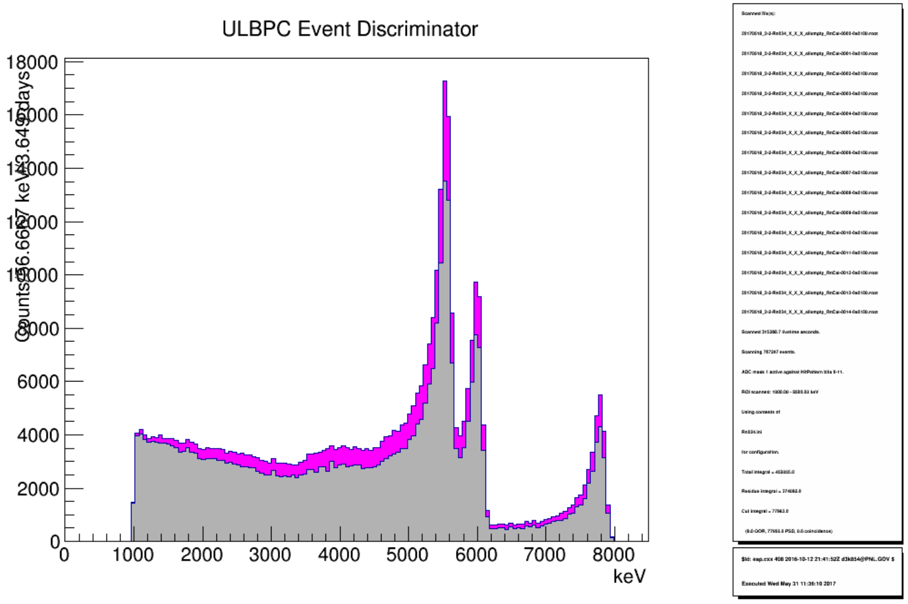




Rn034: lg chamber eff

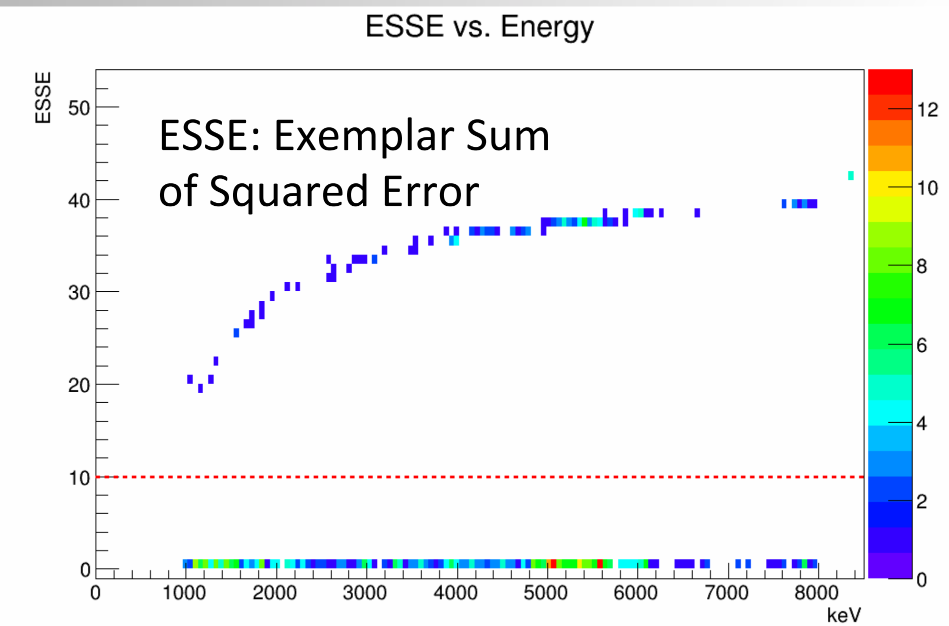
- Left is pulse shape parameter
  - Events above the line were removed
- Right is resulting spectrum
  - Magenta events were removed, gray events remain

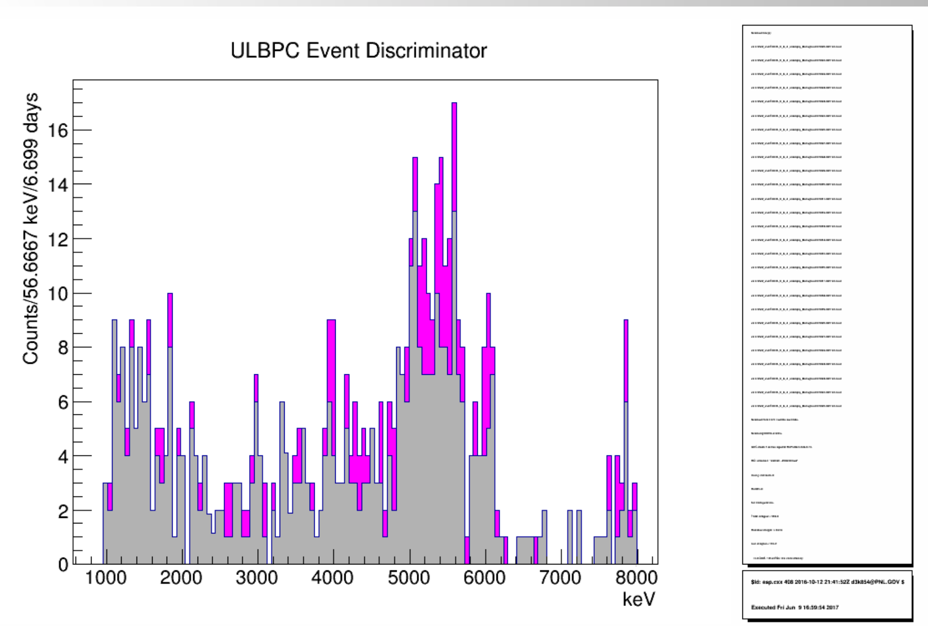




Rn035: sm chamber bg

- First time we saw evidence of hysteretic background
- Left is pulse shape parameter
  - Events above the line were removed
- Right is resulting spectrum
  - Magenta events were removed, gray events remain





Rn036: detector carryover

- Left is pulse shape parameter
  - Events above the line were removed
- Right is resulting spectrum
  - Magenta events were removed, gray events remain