RADON REDUCTION SYSTEM FOR LZ DARK MATTER EXPERIMENT

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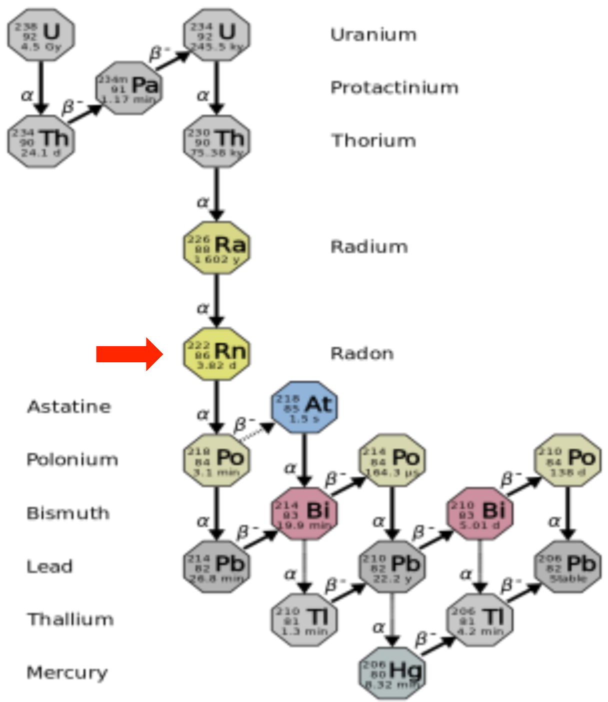
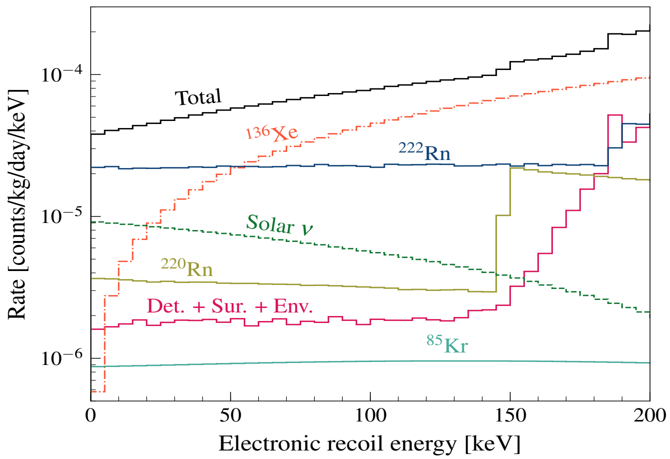
DMSS by the University at Albany, SUNY

Radon — Where From & Why Bad ?

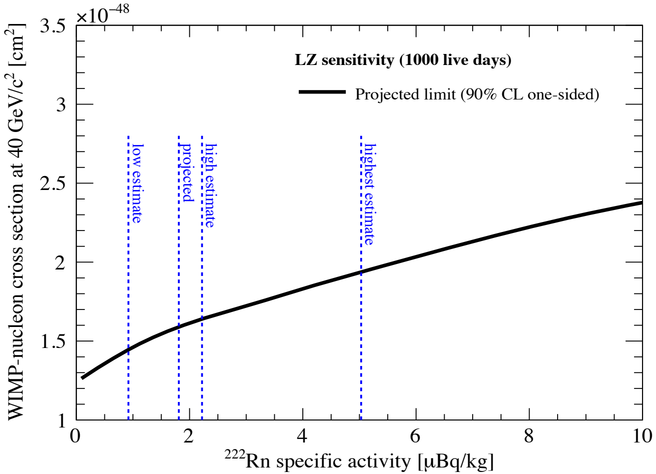


- ^{222}Rn is a decay product of ^{238}U that is everywhere
  - τ_{Rn} = 5.516 day (mean lifetime)
- Radioactive noble gas with chemistry similar to xenon
- Dissolves in liquid xenon (LXe) and isn't removed with hot gas purifying getters
- ^{222}Rn continuously emanates from detector components
- Decay products of ^{222}Rn can mimic Dark Matter signals
  - β-decay of ^{214}Pb can end up in the WIMP ROI and survive the S2/S1 discrimination cut.

Radon—Largest Background Source in LZ



The background spectra in the 5.6 ton fiducial volume of the LZ LXe TPC for single scatter events



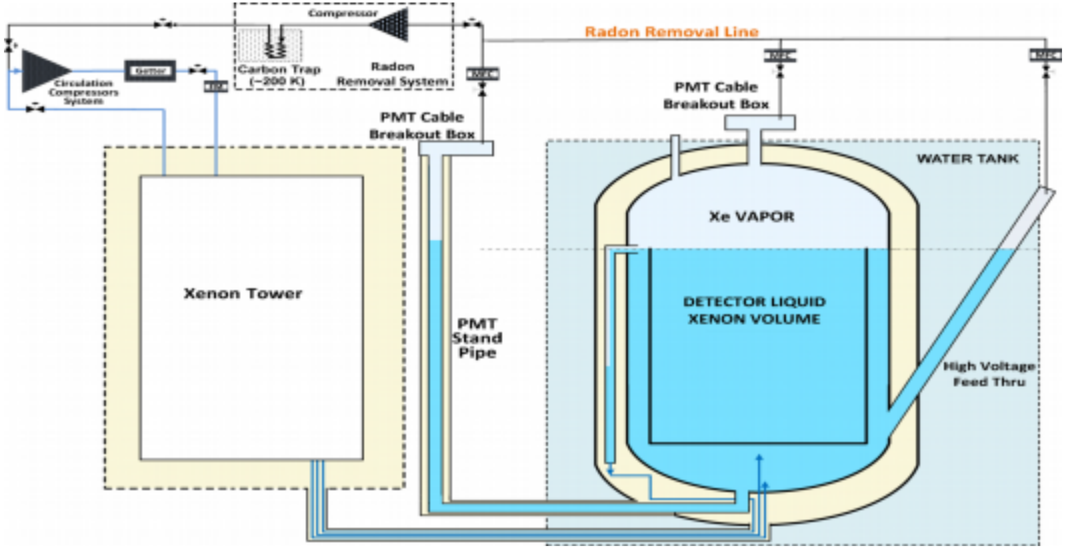
High and low correspond +1σ and -1σ of all ^{222}Rn screening measurements, respectively.

- The highest scenario assumes no reduction in emanation rate at LZ operating temperatures, 175K
- ^{222}Rn emanation rates from warm cables and feedthroughs of LZ detector components estimated to be in 8.3-20 mBq range

In-line Radon Reduction System for LZ

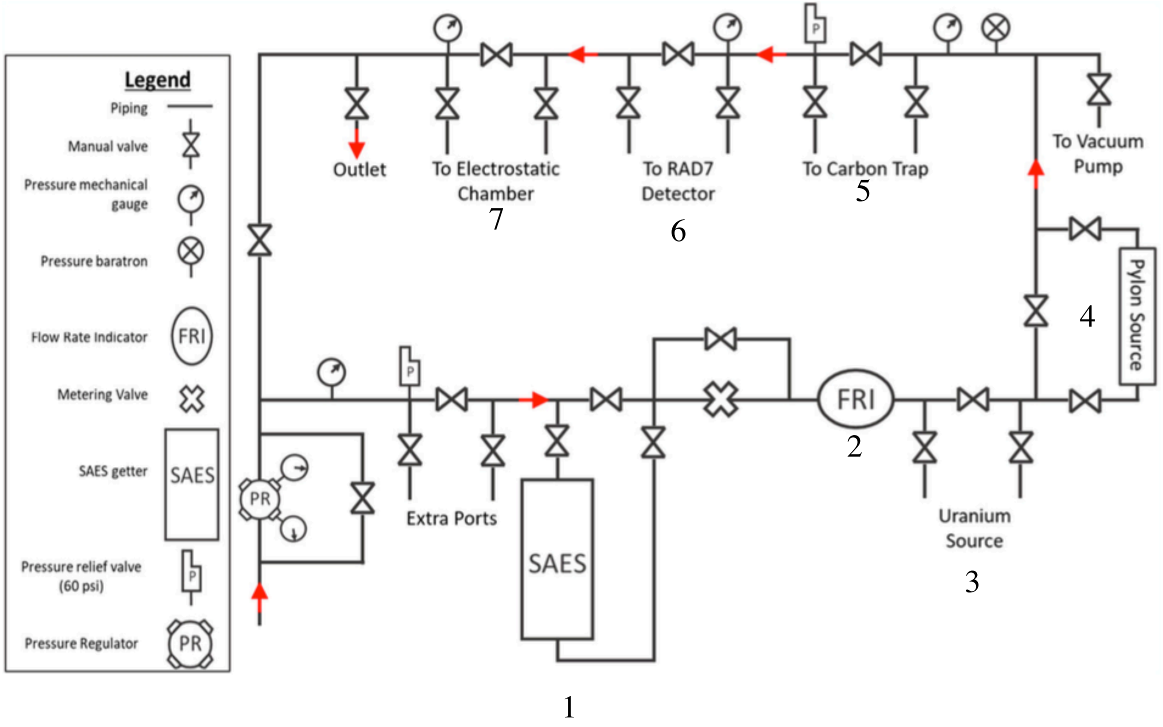
The LZ goal is to reduce ^{222}Rn background of the warm section (cables and feedthroughs) below 1 mBq, about an order of magnitude reduction from current estimates, 8.3-20mBq.

- $N = \tau_{Rn} A$ (= 5.516 d * 1 mBq) = 476 Rn atoms (steady-state population)
- Sequestration of atoms in activated carbon trap until most ^{222}Rn nuclei decay
  - Analogous to gas chromatography: v(Xe)/ v(Rn) (-85 C) ≈ 1000
- In order to obtain removal of 90%, sequestration time must be greater than $\ln(10) \cdot \tau_{Rn} = 12.7$ days



Michigan Radon Reduction R&D

- 1: SAES high temperature gas purification getter
- 2: Gas flow meter
- 3: Emanation chamber with ^{238}U ores
- 4: Radon source (Pylon source (103.6 kBq))
- 5: Cryostat with charcoal trap
- 6: RAD7 radon detector
- 7: In-house radon detector

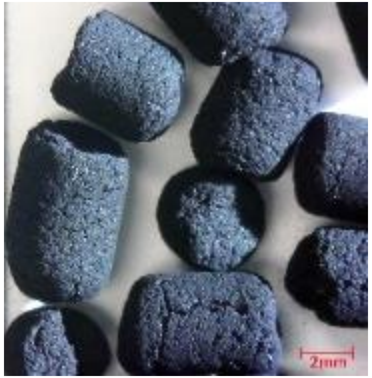


Different Activated Charcoals Tested

Saratech

CarboAct

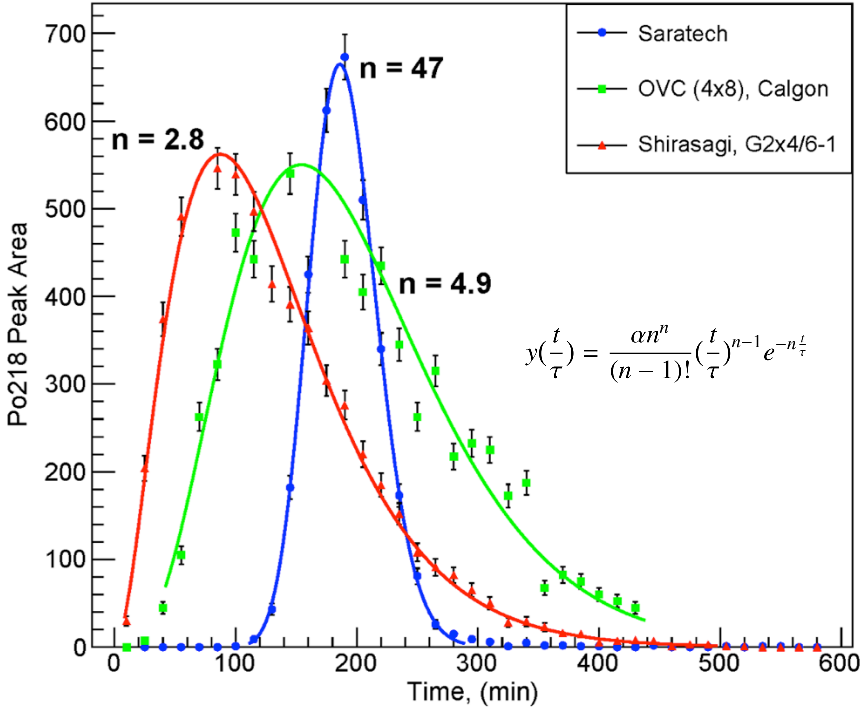
Shirasagi



Charcoal	Density (g/cm^3)	Surface area (m^2/g)	Spec. activity (mBq/kg)	Price ($/kg)
Calgon OVC 4x8	0.45	1,100	53.6 ± 1.3	6
Shirasagi	0.45	1,240	101 ± 8	27
Saratech	0.60	1,340	1.71 ± 0.20	35
Saratach (HNO_3)	0.60	1,340	0.51 ± 0.09	135
CarboAct	0.28	1,000	0.23 ± 0.19	15,000

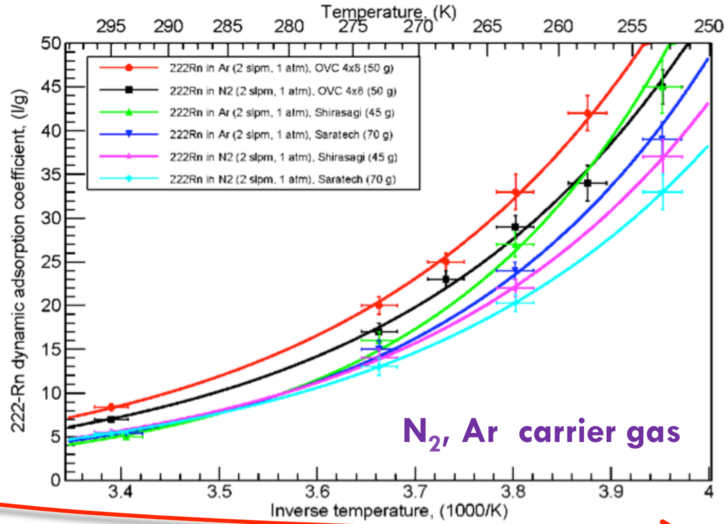
Elution Curves for Ar in a 0.1l Trap at 293K

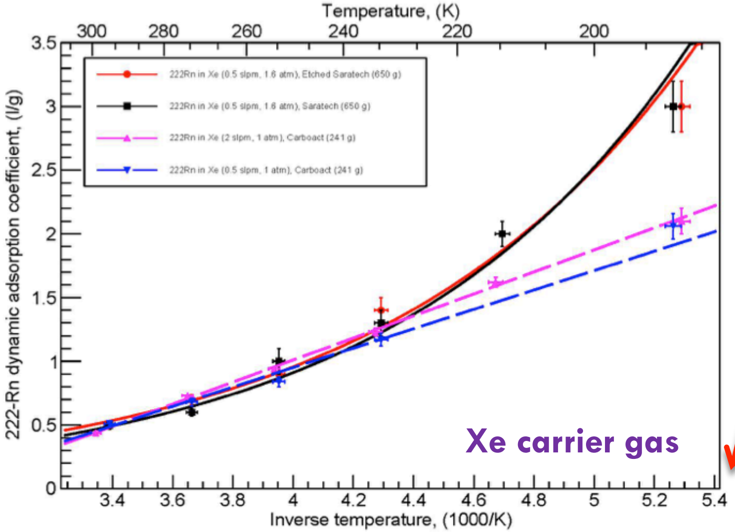
- ^{222}Rn adsorption characteristics on various charcoals were studied in N_2, Ar, and Xe carrier gases.
- Vastly different transition times for various charcoal types.
- By measuring the ^{218}Po spectra after ^{222}Rn injection, elution curves were obtained using the chromatographic plate model—the charcoal trap is divided into stages of equal volume where the gas and charcoal are in equilibrium.



k_a—The Dynamic Adsorption Coefficient

- τ, the average breakthrough time for radon is related to the absorption coefficient by $\tau = \frac{k_a m}{f}$, obtained from the fit of the elution curves.
- k_a-values for N_2 and Ar as a function of the inverse temperature of the trap follow Arrhenius law for the tested charcoals.





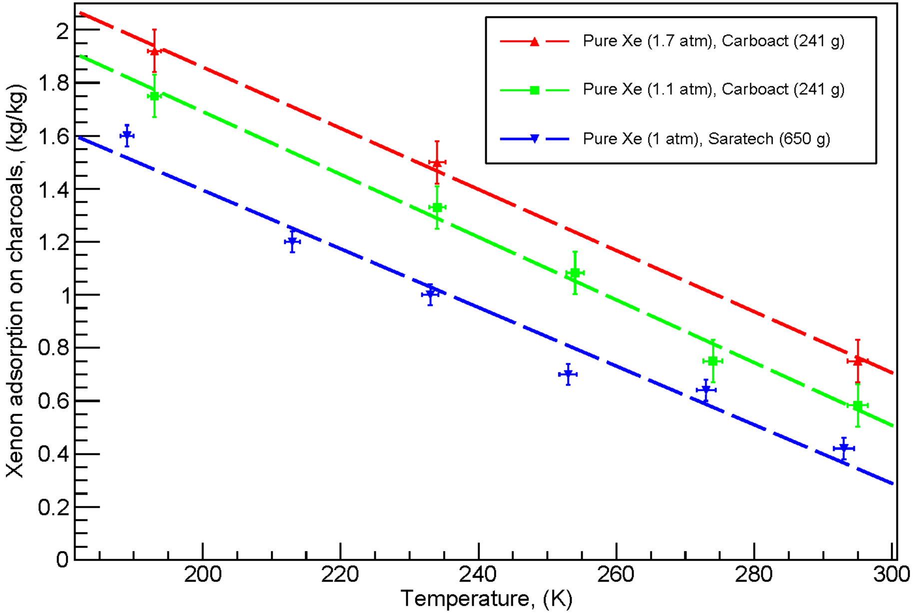
Different Ranges

ka-values for 222Rn range from 5-45 l/g in N_2 and Ar carrier gases, while in Xe they are an order of magnitude lower, 0.5-3 l/g.

For Xe as the carrier gas the k_a-values in Saratech and etched (HNO_3) Saratech consistent with Arrhenius law, however in CarboAct, violates it.

Adsorption of Xenon gas on Charcoal

- Xe atoms have high polarizability and tend to occupy the charcoal adsorption sites much faster resulting in the short ^{222}Rn breakthrough times.
  - Increases linear with decreasing temperature
  - Increases only slightly with pressure
- Saratech adsorbs on average about 30% less Xe than CarboAct at atmospheric pressures .
- Adsorption of N_2 and Ar gases was below detection limit of the scale, (below 20 g of charcoal)

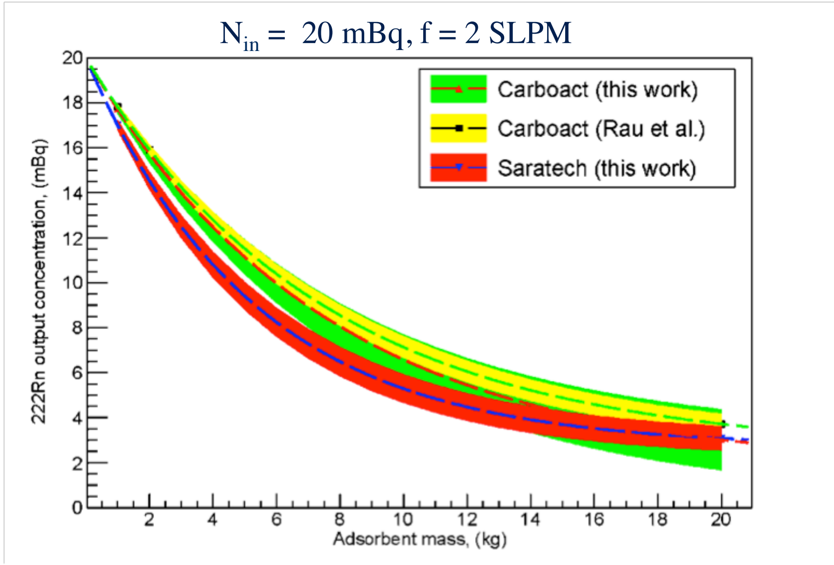


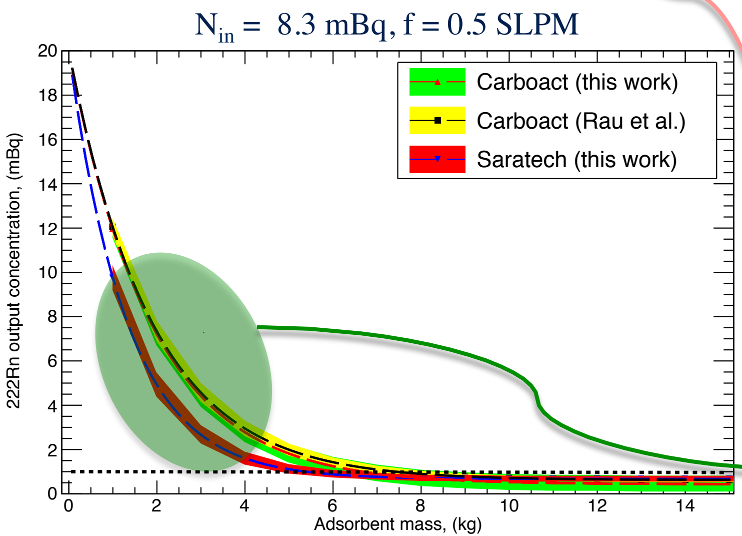
Building a Radon Trap

$$N_{out} = N_{in} e^{-\frac{k_a \cdot m}{f \cdot \tau_R}} + s_0 f \frac{\tau_R}{k_a}\left(1 - e^{-\frac{k_a \cdot m}{f \cdot \tau_R}}\right)$$

Due to Rn in GXe

Due to activity of the charcoal





- Lowest achievable Rn concentration is limited by specific activity (s_0) of charcoal
- Need 5 – 7 kg of etched Saratech to reduce Rn concentration from warm cables and feedthroughs at the output of the trap below 1 mBq
- Even though CarbAct has lowest s_0, not most efficient trap material for low(ish) mass

Conclusion & Acknowledgments

- ^{222}Rn breakthrough times in N_2 and Ar carrier gases are significantly longer than in Xe carrier gas.
  - This may be attributed to the lower polarizabilies of N_2 and Ar compared to Xe
- Among the investigated charcoals, Saratech appears to be the most efficient ^{222}Rn reduction material.
  - Chemical etching of Saratech with HNO_3 acid reduced the intrinsic radioactivity (^{238}U) by about a factor of three.
  - Etching did not affect the ^{222}Rn adsorption characteristics of Saratech making it a strong candidate for a trap.
- Published in NIM journal: A 903 (2018) 267–276

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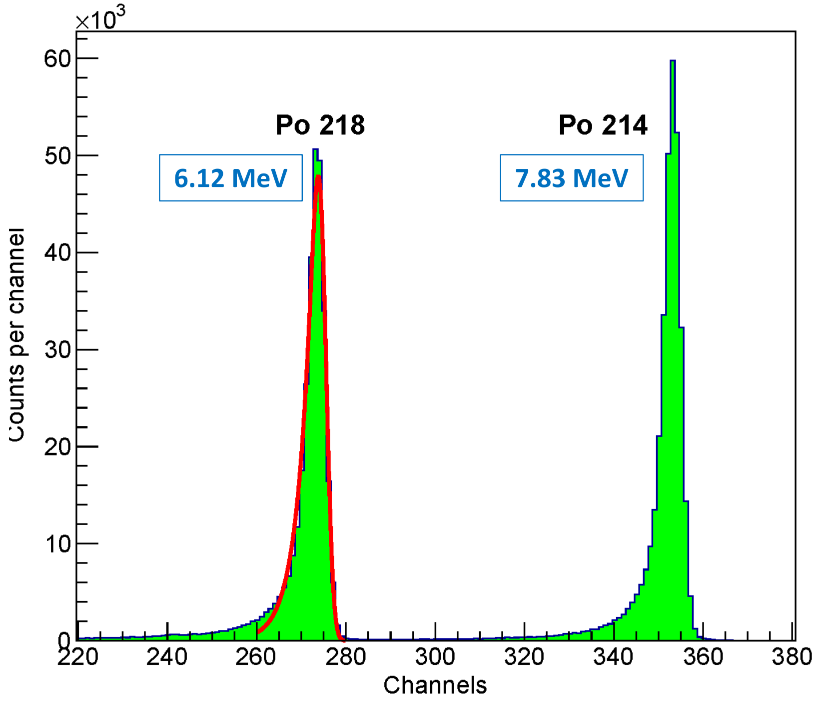
Backup Slides

^{218}Po and ^{214}Po peaks



$$f(x,\mu,\sigma,\nu) = \frac{A}{2\nu} e^{\left(\frac{x-\mu}{\nu} + \frac{\sigma}{2\nu^2}\right)} erfc\left(\frac{1}{\sqrt{2}}\left[\frac{x-\mu}{\sigma} + \frac{\sigma}{\nu}\right]\right),$$

- Fitted to this analytical function for alpha spectra from which the area of the peak can be determined.

Arrhenius Law

$$k = Ae^{\frac{-E_a}{k_b T}}$$

- Describes the rate of chemical reactions
- k: rate constant
- E_a: activation energy (J)
- k_b: Boltzmann constant (J/K)
- T: temperature (K)