A Few Thoughts About Injection Sources in DUNE FD

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DUNE Calibration Task Force Meeting

July 31st, 2018

From LBNC Close-Out

- The following comment was made in the LBNC close-out report:

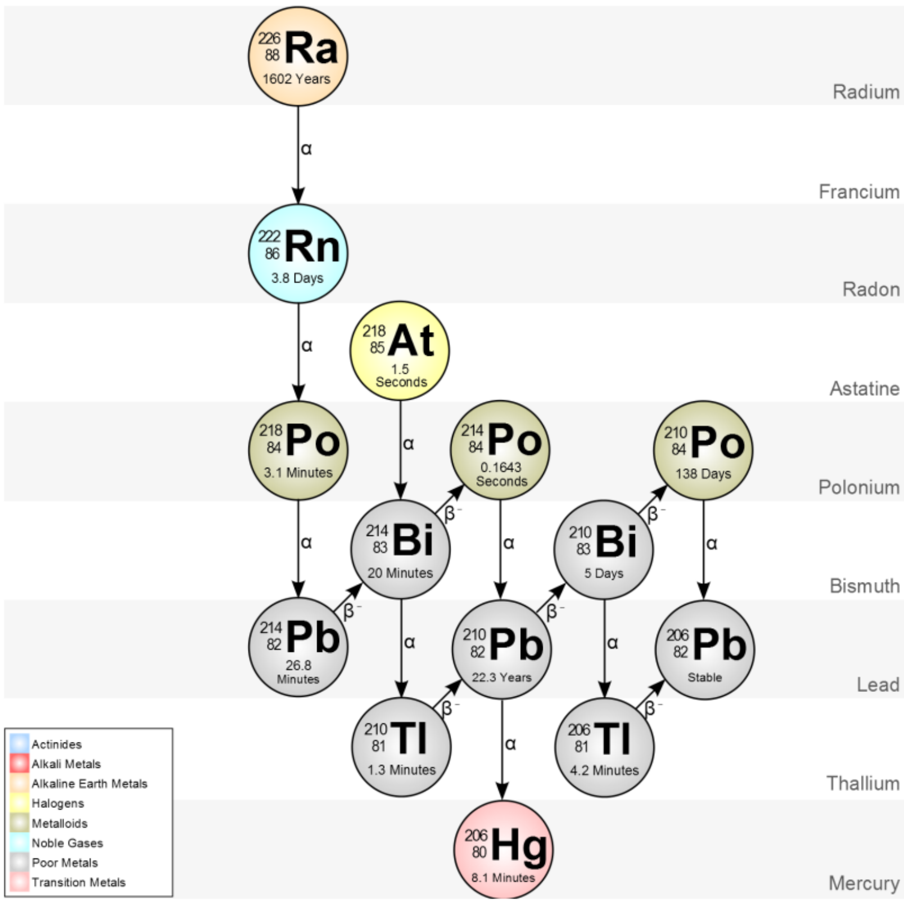
  "The liquid-noble dark matter community makes extensive use of injected radioactive sources for [electron lifetime calibrations], which have the additional advantage of mapping fluid flow in the TPC. At first glance, few-MBq flow-through 222-Rn sources are readily available and give a unique signature in the desired energy range with 214-Bi/214-Po coincidence. These sources may also be useful for understanding fluid flows in the cryostat. Other injection sources may also be appropriate."

- Also the following recommendation:

  "Evaluate the utility of internal source injection (*e.g.* 222-Rn injection, for 214-Bi/214-Po calibration) for mapping electron lifetime and fluid flow in the TPC."

- This talk: preliminary thoughts about this proposal

^{222}Rn Decay Chain



$^{222}_{86}$Rn (3.82 days) $\rightarrow$ $^{218}_{84}$Po (by α decay, 5.49 MeV)

$^{218}_{84}$Po (3.05 min) $\rightarrow$ $^{214}_{82}$Pb (by α decay, 6.00 MeV)

$^{214}_{82}$Pb (26.8 min) $\rightarrow$ $^{214}_{83}$Bi (by β decay, 1.02 MeV max)

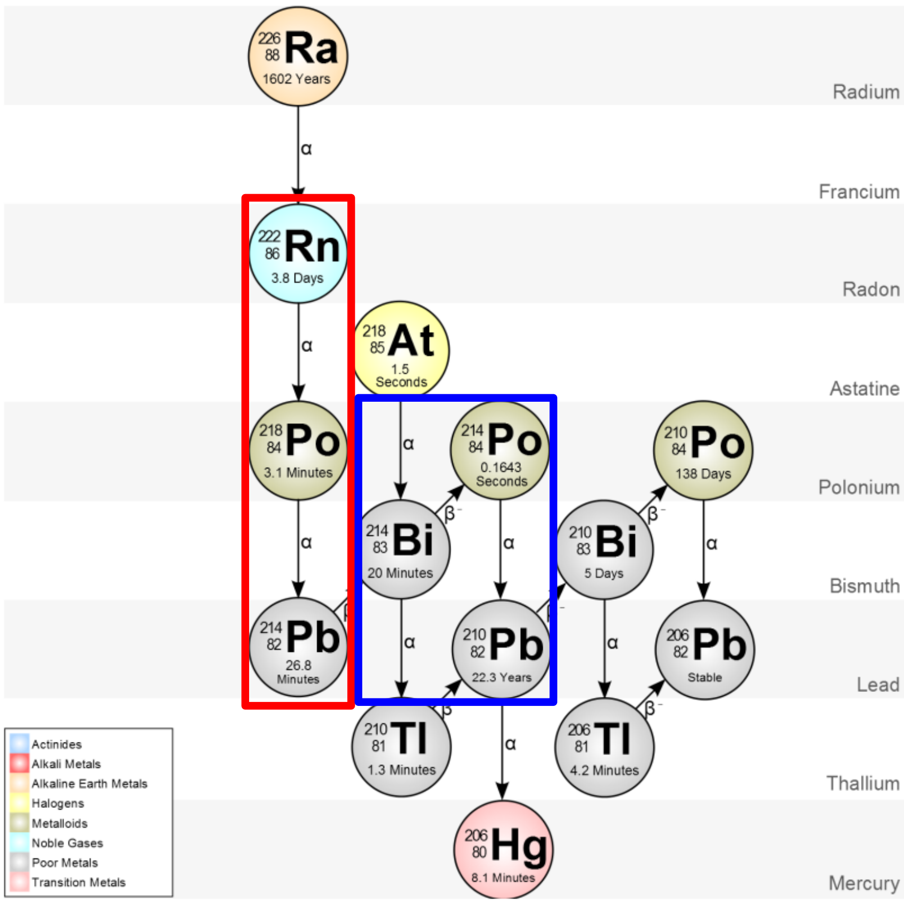
$^{214}_{83}$Bi (19.7 min) $\rightarrow$ $^{214}_{84}$Po (by β decay, 3.27 MeV max)

$^{214}_{84}$Po (164 μs) $\rightarrow$ $^{210}_{82}$Pb (by α decay, 7.69 MeV)

$^{210}_{82}$Pb (22.3 years) $\rightarrow$ $^{210}_{83}$Bi (by β decay, 0.017 MeV max)

etc. down to stable $^{206}_{82}$Pb

^{222}Rn Decay Chain



Fluid Flow Mapping?

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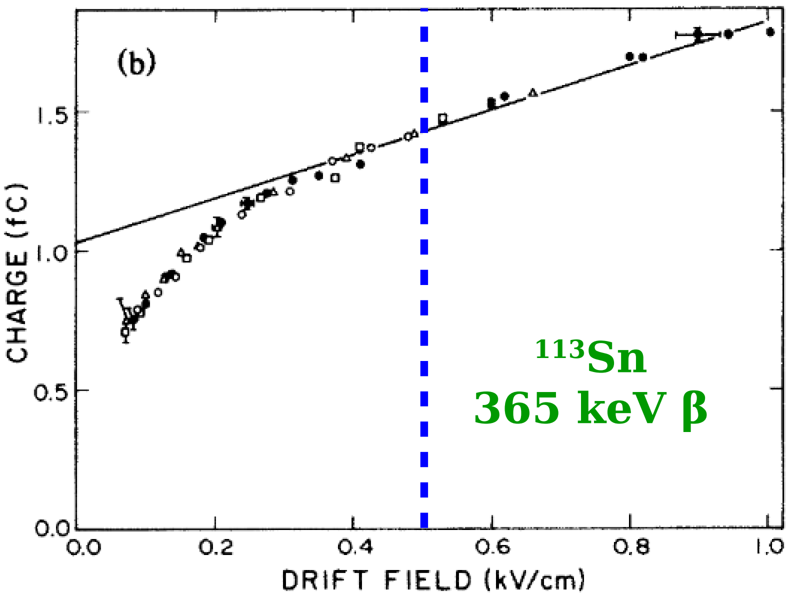
Electron Lifetime Calibration?

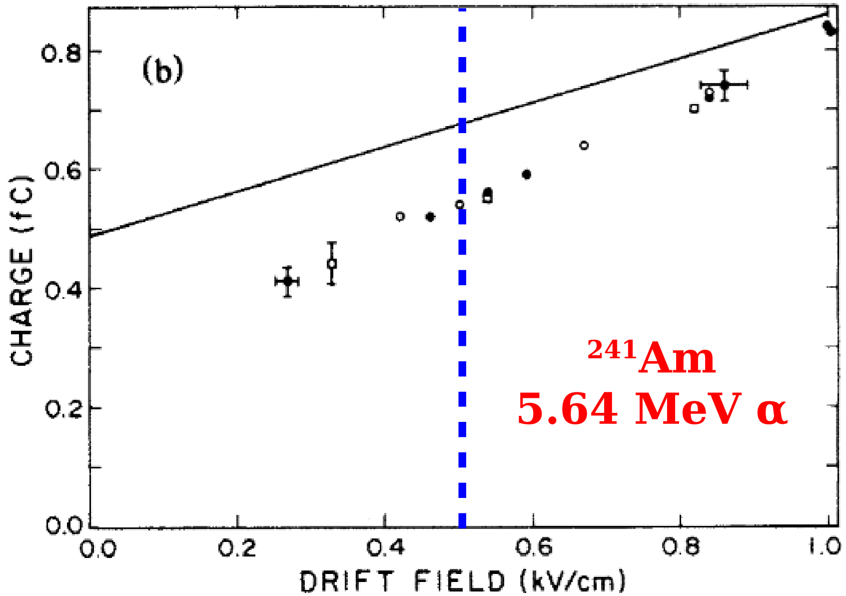
Comparing Sources

- ^{39}Ar beta decays were identified by the LBNC as "not an optimal internal source for the goals stated"
  - I personally think it is because the LBNC did not fully understand the methodology, as opposed to the calibration idea being flawed in some serious manner
  - No discussion on specific shortcomings of method
- That being said, let's compare different sources:
  - **^{39}Ar beta decay**: broad energy distribution, low free charge, but "comes for free"
  - **^{222}Rn → ^{218}Po → ^{214}Pb**: narrow energy distributions, low free charge, needs light for t_0 tag, injection source, requires continuous readout stream
  - **^{214}Bi → ^{214}Po → ^{210}Pb**: broad and narrow energy distributions, higher free charge (beta), needs light for t_0 tag, injection source, two decays in same readout window

Free Charge

Scaletter, R.T. et al. Phys.Rev. A25 (1982) 2419-2422





- Free charge from alphas is a lot smaller due to enhanced recombination, despite higher energies
  - At 500 V/cm: **R_β ~ 0.55**, **R_α ~ 0.015**
  - 5.5 MeV α (^{222}Rn): **~3500 e^-** (ideal Y plane ENC ~ 500 e^-)
  - 7.7 MeV α (^{214}Po): **~5000 e^-**
  - For reference, 565 keV β (^{39}Ar end point): **~13000 e^-**

Free Charge

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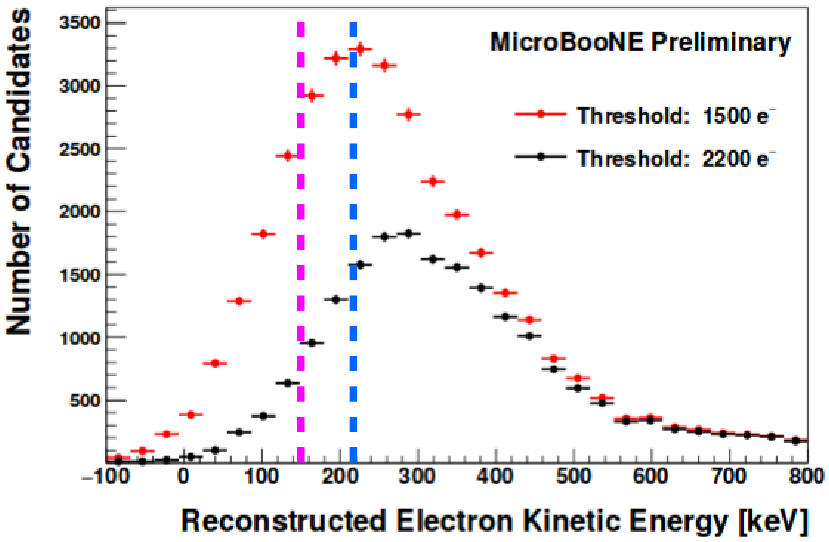

The ^{222}Rn α will be very hard to observe! Highly susceptible to threshold effects

The ^{214}Po α is very borderline, too close to call…

Remember: dark matter experiments use both S1 and S2 to separate α and β

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Readout Mode

- ^{222}**Rn** → ^{218}**Po** → ^{214}**Pb** can, in principle, be used for fluid flow studies given the time between the two alpha decays: **Δt ~ 3 min.**
  - Expected fluid flow velocities: O(10) mm/s
  - Injection rate would need to be adjusted to ensure no ambiguity between unrelated decays (no "pile-up")
- This pretty much requires continuous readout in order to make work → added complication
- On the other hand, ^{214}**Bi** → ^{214}**Po** → ^{210}**Pb** yields a beta followed by an alpha with **Δt ~ 160 μs**
  - Both decays in same readout window (most of the time)
  - Can use fact that they should be detected with same wires to loosen threshold criteria → can be helpful for tagging

Tagging t_0 w/ Light

- Unlike ^{39}Ar beta decay electron lifetime calibration method, both decay doublets of interest require tagging light of individual decays to know position in x
  - *This has never been demonstrated in a **large** LArTPC*
  - Must tag light of both alphas in case of $^{222}Rn \rightarrow {}^{218}Po \rightarrow {}^{214}Pb$
  - Can in principle tag light from either beta or alpha in case of $^{214}Bi \rightarrow {}^{214}Po \rightarrow {}^{210}Pb$ (more light from higher-energy alpha)
- This seems very hard and will be a challenge…
  - … but then again supernova/solar neutrino program requires tagging of low-energy activity such as this
  - From DUNE IDR: requirement of PDS is to tag t_0 of 10 MeV energy deposition without ambiguity
    - I would assume this is for electron from supernova ν_e
    - Same light yield as for 6 MeV α… so we have the same goals

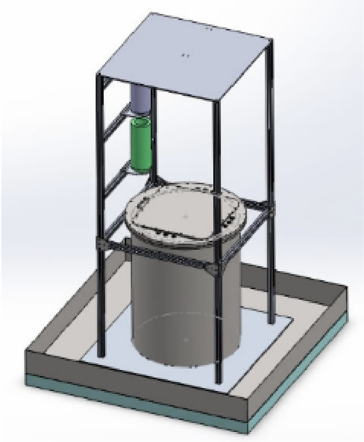
Closing Thoughts

- My personal opinions on the two decay doublets of interest that we get out of the ^{222}Rn decay chain:
  - **^{222}Rn → ^{218}Po → ^{214}Pb:** very hard and probably too much trouble for our time – do we need to map fluid flow in FD?
  - **^{214}Bi → ^{214}Po → ^{210}Pb:** hard, but feasible, and could have utility in electron lifetime measurement and other calibrations – worth studying further
- Investigating use of ^{226}Ra as injection source for ^{222}Rn
  - More on quantities and hardware later
- Discussing possibility of a full-scale test with MicroBooNE, LArIAT, and DUNE (e.g. FNAL Test TPC)
  - Probably will want to study effects of e.g. Pb plating out on detector surfaces in dedicated smaller setup – cryogenic setup being constructed at CSU can be used for this

BACKUP SLIDES

Small Underground TPC

- Lack of knowledge of recombination will complicate use of spectrum for nailing down electron lifetime
  - Need to know both mean recombination and fluctuations in recombination at this energy scale
  - Chatting with experts (Flavio, Stephen Pordes, Masayuki Wada, Peter Meyers, Matt Szydagis, Ben Jones) and conclusion is that we don't know this very well for argon, needs study for precision calib.
- Ahead of DUNE, **measure Ar-39 charge spectrum**
  - At MicroBooNE
  - In separate setup for precision measurement
    - Underground
    - Short drift
    - t_0 tag from light



M. Mooney, D. Warner

Conceptual design for portable cryostat