Radioactive backgrounds determination in the JUNO liquid scintillator

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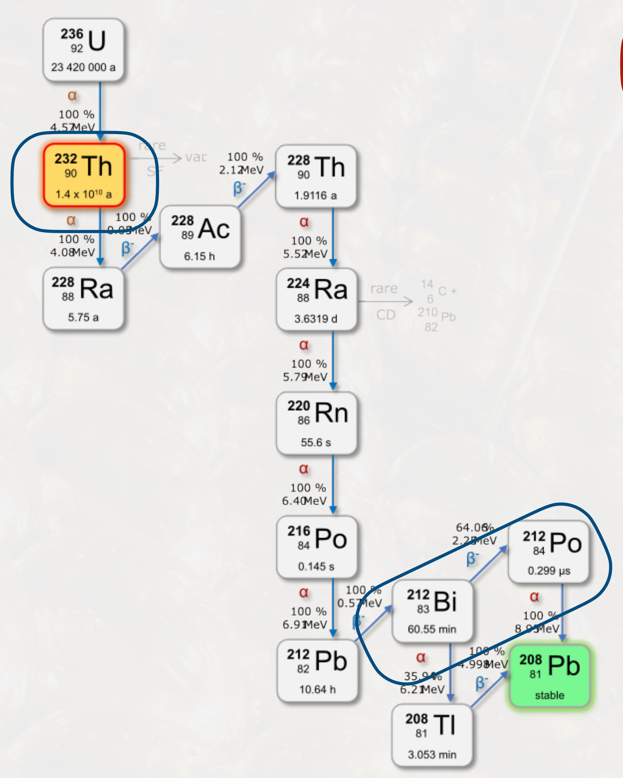
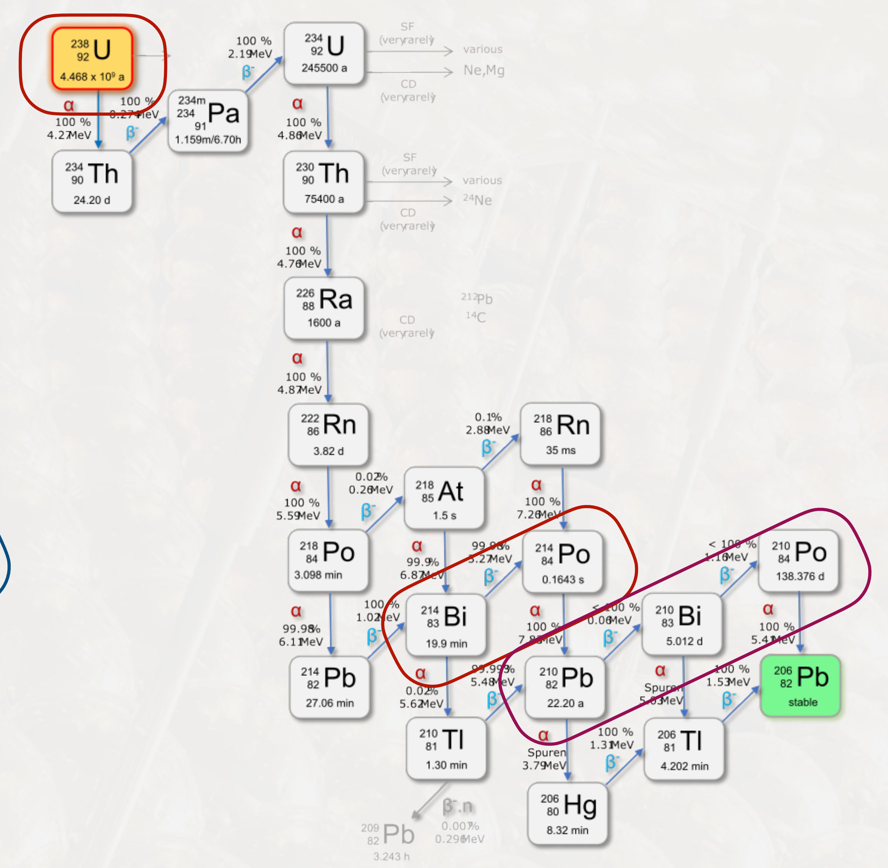
JUNO physics and backgrounds

The **J**iangmen **U**nderground **N**eutrino **O**bservatory is the largest liquid scintllator experiment with the goal of determine the **Neutrino Mass Ordering** within six year of data-taking and study neutrinos from natural sources (like **Solar**, **SuperNovae** and **DSNB**) [1].

Main sources of internal backgrounds are the secular chains of ^{238}U and ^{232}Th secular chains detectable via BiPo coincidences and possible out-of-equilibrium isotopes (^{210}Po; ^{210}Pb) [4, 5].



^{232}Th decay chain

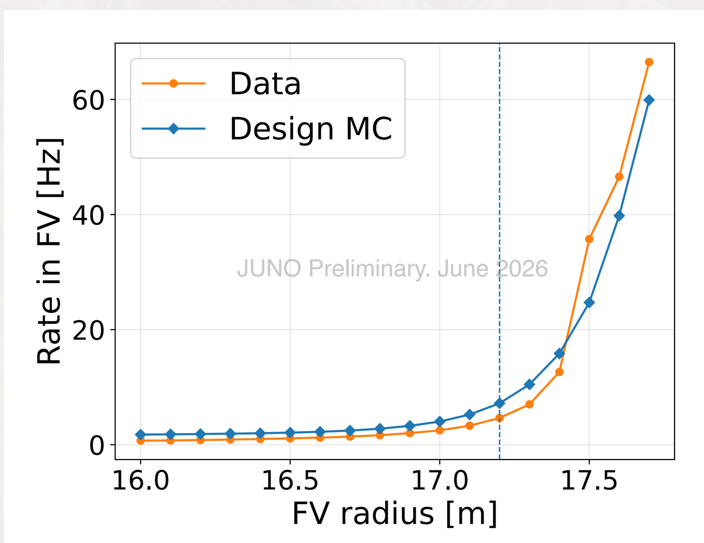


^{238}U decay chain

Rate of events above 0.7 MeV

The contribution to the event rate above 0.7 MeV (minimal threshold for antineutrino analysis) is mostly due to **radioactivity:**

- **Internal** (Liquid scintillator);
- **External** (PMT glass, stainless steel structure and acrylic).



Requirement: Rate < 7.2 Hz (FV < 17.2 m; E > 0.7 MeV) [3]
Measured: Rate < 6 Hz (FV < 17.2 m; E > 0.7 MeV);

^{238}U secular chain

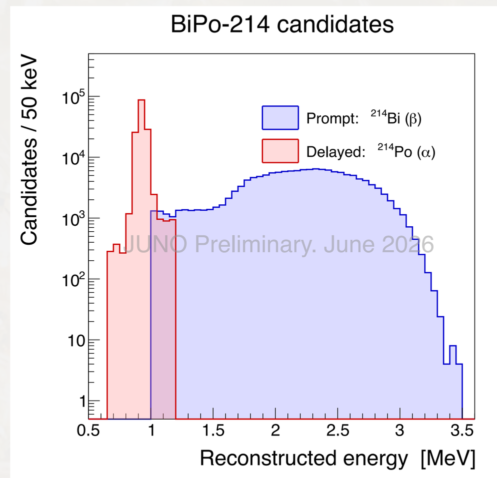
The ^{238}U analysis uses the coincidence between the ^{214}Bi and ^{214}Po.
Only period after filling were considered when ^{222}Rn was fully decayed [5].
Main selection strategy:

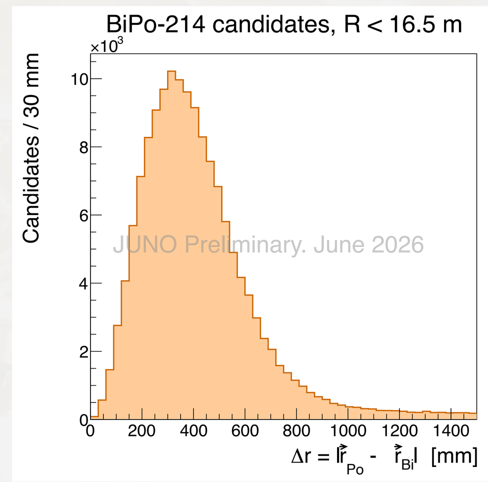
1. **Seach for ^{214}Po candidate** (0.65 < E_{Po} < 1.15 MeV; efficiency ~100%)
2. **Open dt window to search for ^{214}Bi** (10 - 1200 μs; efficiency ~95%)
3. **Open dR position cut** (dR_{BiPo} < 1.5 m; efficiency ~99%)
4. **Search for ^{214}Bi candidate** (0.80 < E_{Bi} < 3.50 MeV; efficiency ~93%)

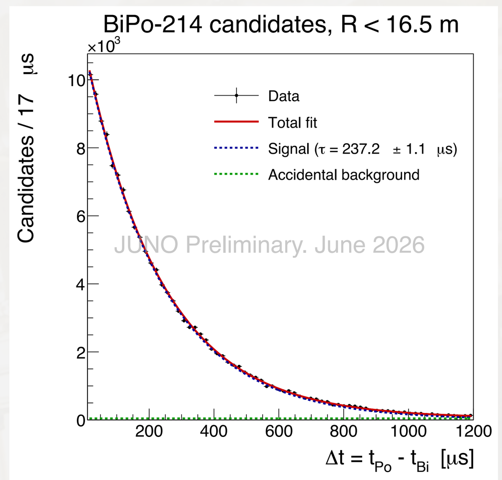
Requirement: $< 1 \times 10^{-15}$ g/g [2]

^{238}U (R < 16.5 m): $(8.22 \pm 0.03^{stat} \pm 0.68^{sys}) \times 10^{-17}$ g/g

^{238}U (R < 15.0 m): $(7.79 \pm 0.03^{stat} \pm 0.70^{sys}) \times 10^{-17}$ g/g





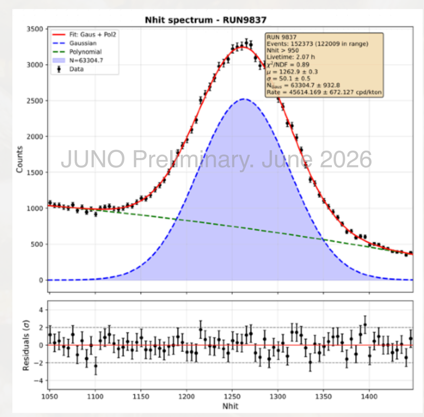


Decaying ^{210}Po contribution

There are three possible scenarios:

1. ^{210}Po concentration equal to ^{238}U → no out-of-equilibrium isotopes
2. ^{210}Po concentration higher than ^{238}U and stable → ^{210}Pb out-of-equilibrium
3. ^{210}Po concentration higher than ^{238}U and decaying → ^{210}Po out-of-equilibrium

The time evolution of ^{210}Po rate shows a decay consistent with ^{210}Po lifetime. However, the constant plateau is larger than the one expected from ^{238}U only, ndicating the presence of out-of-equilibrium ^{210}Pb (option 2).



^{210}Po (Intial rate - Sep. 25): $(4.78 \pm 0.02^{stat} \pm 0.14^{sys}) \times 10^{4}$ cpd/kton

^{210}Po **(Current rate):** $(2.28 \pm 0.01^{stat} \pm 0.07^{sys}) \times 10^{4}$ cpd/kton

^{232}Th secular chain

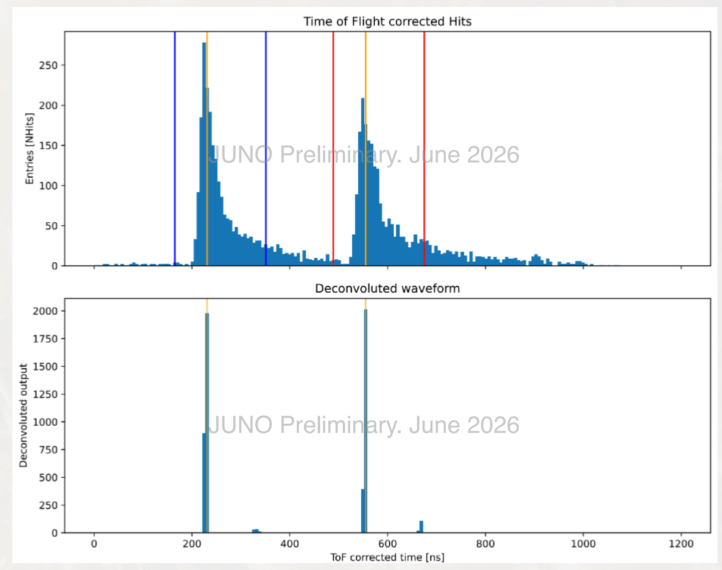
Very fast coincidence between ^{212}Bi and ^{212}Po ($\tau \sim$ 430 ns).

Two techniques were developed:

In-window analysis:

1. Search for **two waveforms** in the same readout window
2. **Correct the time of flight** for the reconstructed position
3. **Extract the time** for the two waveforms
4. **Apply energy and time cuts**

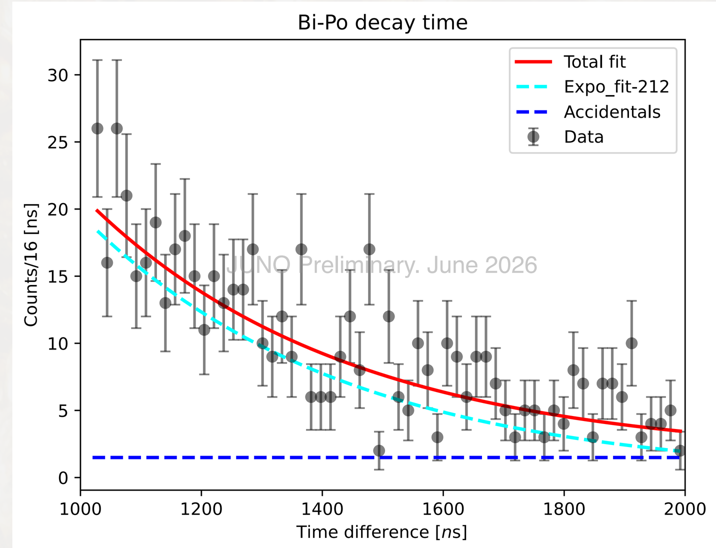
Total selection **efficiency: ~13%**



Off-window analysis:

1. Seach for **^{212}Po candidate**
2. **Open dt window** to search for ^{212}Bi
3. Open dR **position cut**
4. Search for **^{212}Bi candidate**

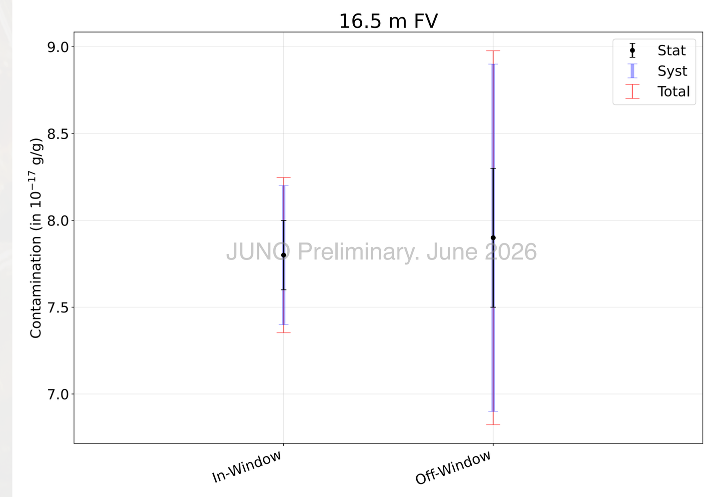
Total selection **efficiency: ~3%**



Requirement: $< 1 \times 10^{-15}$ g/g [2]

^{232}Th (R < 16.5 m):
$(7.8 \pm 0.1^{stat} \pm 0.4^{sys}) \times 10^{-17}$ g/g

^{232}Th (R < 15.0 m):
$(7.8 \pm 0.2^{stat} \pm 0.4^{sys}) \times 10^{-17}$ g/g



Conclusion

JUNO had stringent requirement on the radioupritу of the liquid scintillator and the surrounding material. During construction and filling a huge effort of the collaboration was done to control radioactive contaminants. JUNO matched requirements for both internal and external radioactive backgrounds for the main radioactive chains for NMO nalysis.

References

[1] 10.1088/1674-1137/ad7f3e; [2] 10.1140/epjc/s10052-025-14333-4
[3] 10.1007/JHEP11(2021)102]; [4] 10.1088/1674-1137/ae3dc1
[5] https://hdl.handle.net/2434/1202479;