

Identification of Multinucleon Transfer Products with Short-Lived Daughter Nuclei

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Multinucleon Transfer – Transfer of Multiple Nucleons

- Two nuclei interact, transfer nucleons (neutrons and protons), detach as different species
 - Nuclear orientation, shell structure, and collision energy effect what is produced
 - Energies near the Coulomb Barrier
 - Studying many-body systems
 - Length scale: fm
 - Time scale: zs
- 1zs = 300fm/

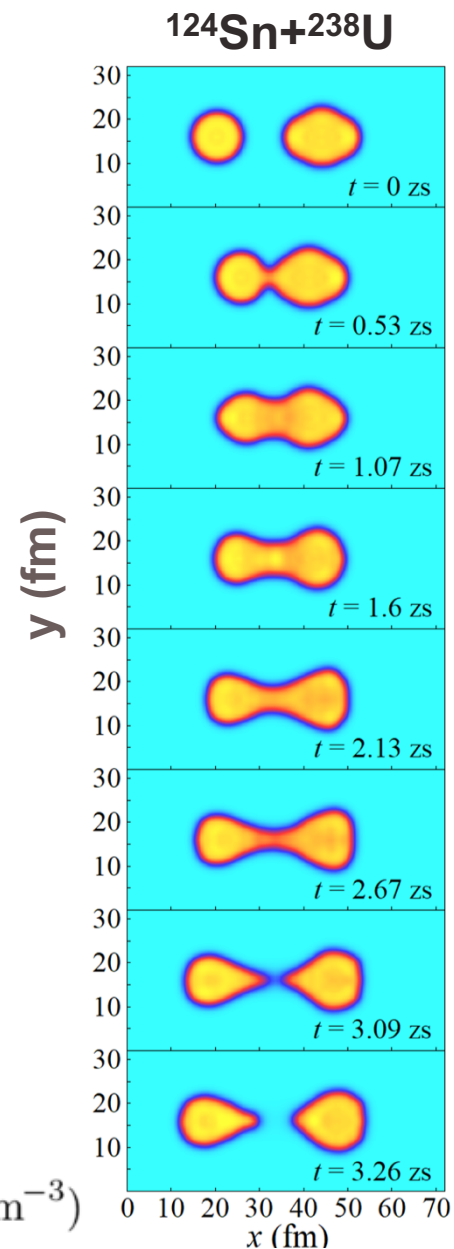
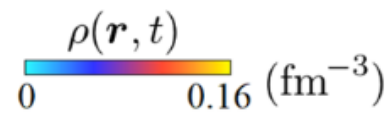
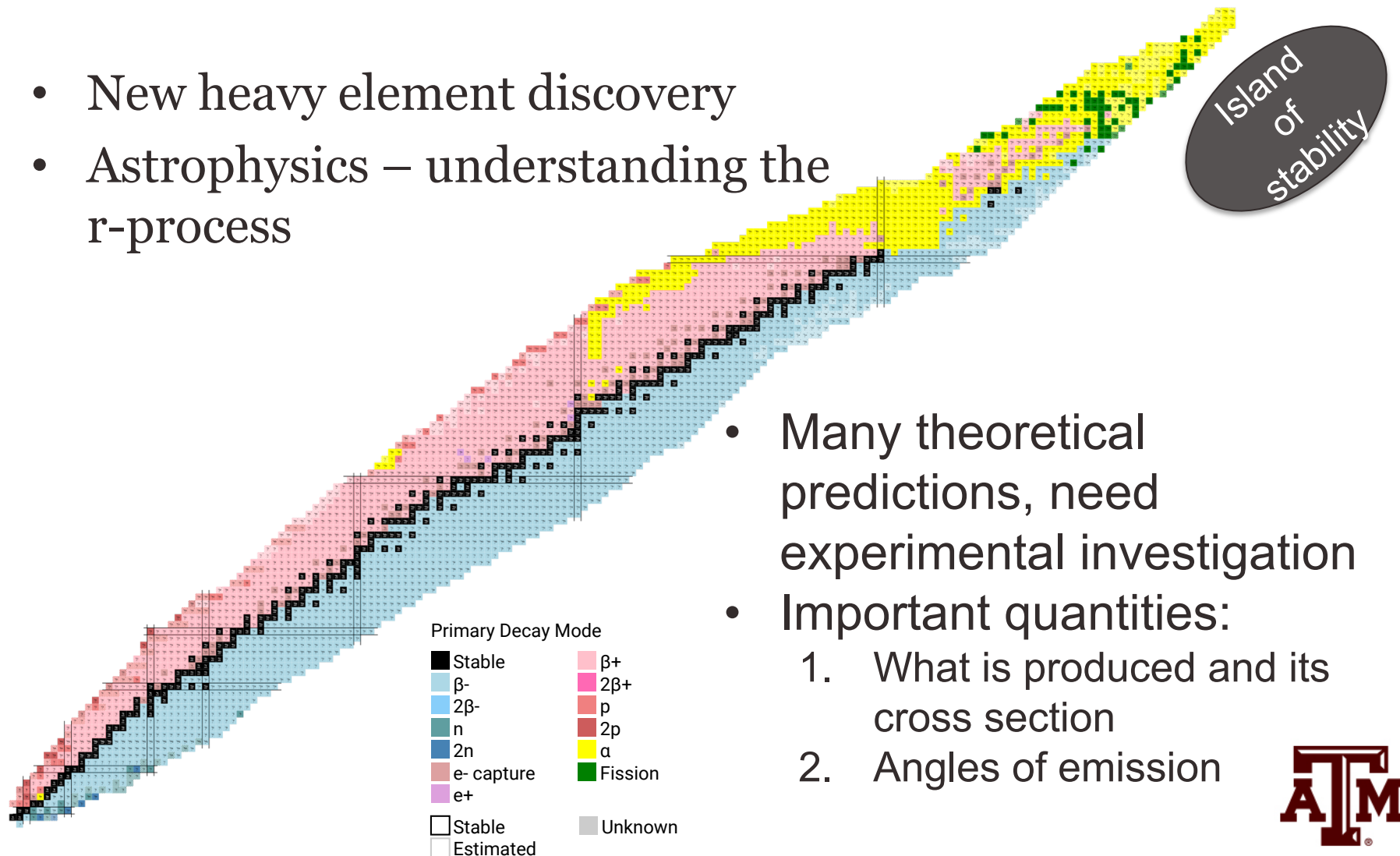
$$1\text{zs} = 300\text{fm/c}$$


Image Credit: K. Sekizawa, PRC **96**, 041601 (2017)

Why Study Multinucleon Transfer Reactions?

- New heavy element discovery
- Astrophysics – understanding the r-process

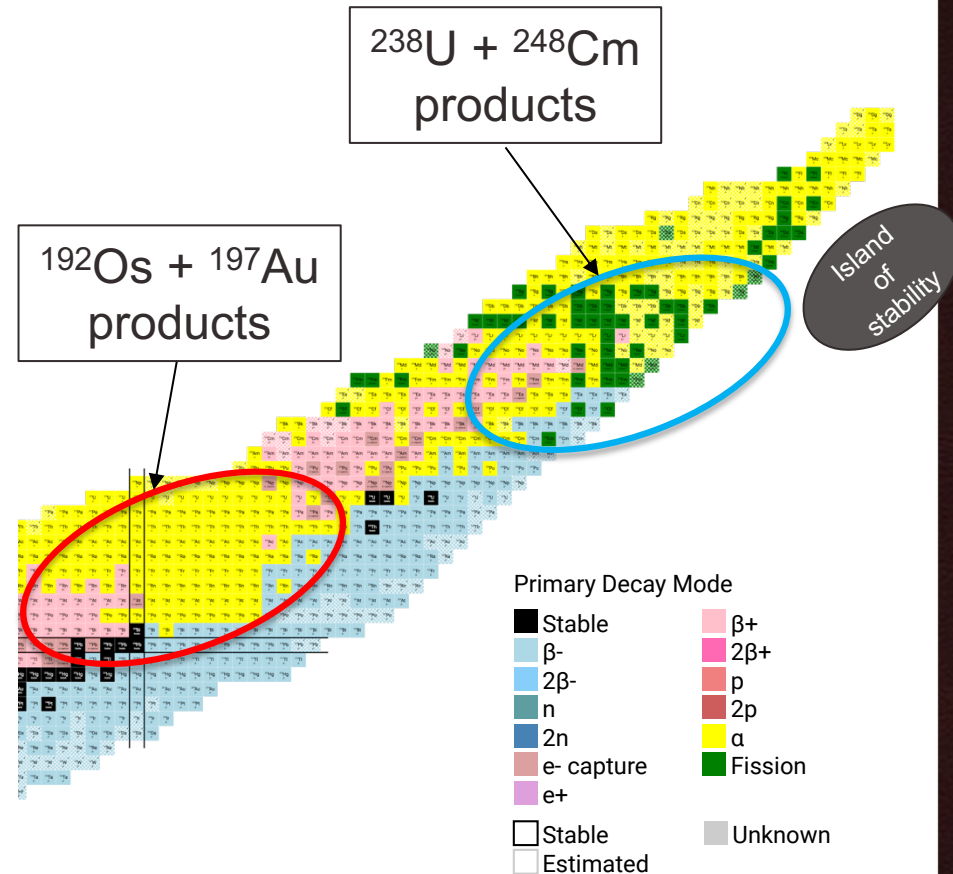


- Many theoretical predictions, need experimental investigation
- Important quantities:
 1. What is produced and its cross section
 2. Angles of emission



Understanding Trans-Target Nuclei Production

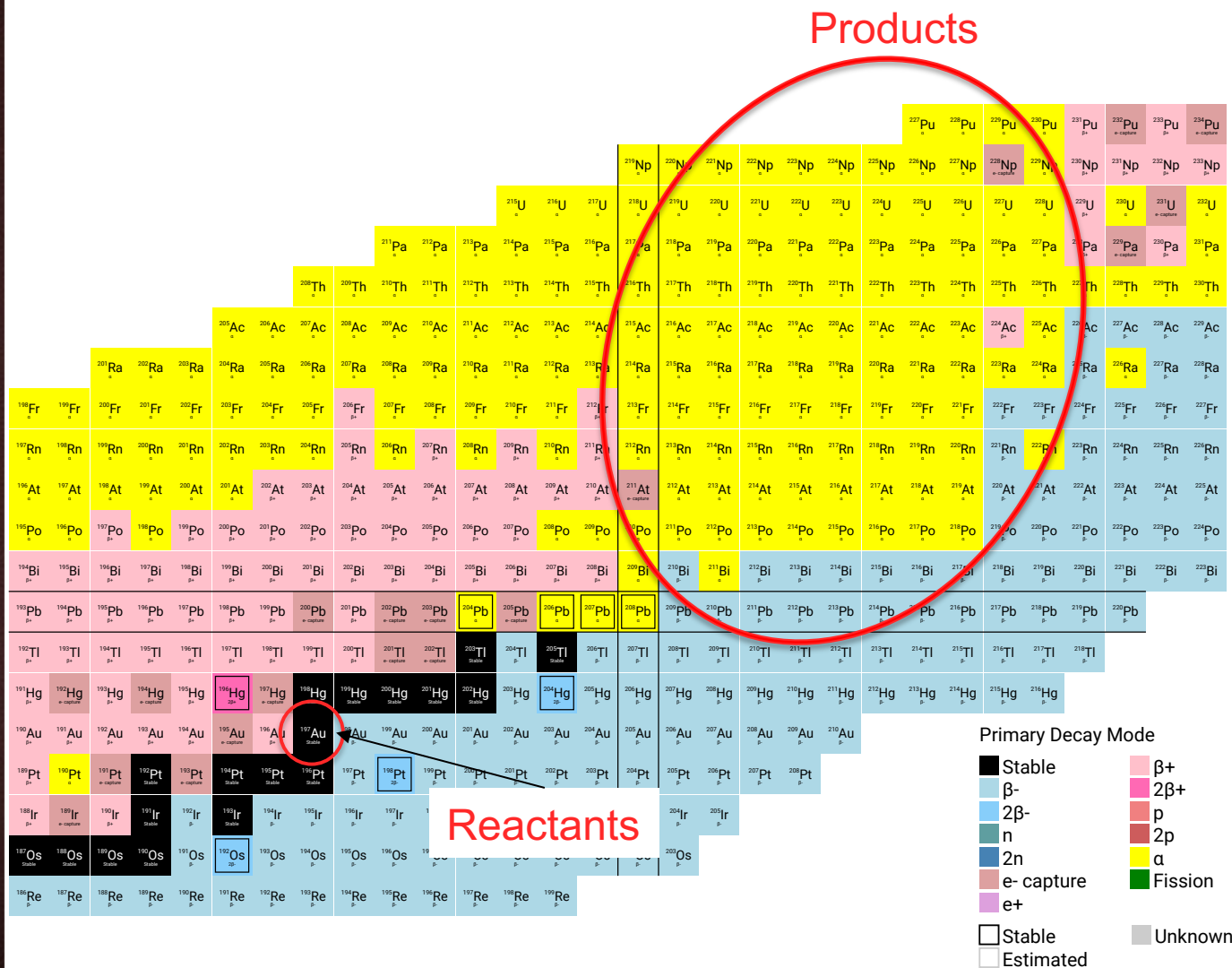
- Producing super-heavy nuclei requires production and identification of trans-target (heavier than target) nuclei
 - $^{238}\text{U} + ^{248}\text{Cm}$
 - High background – fission isomeric states
- Need to understand this process for lighter systems with less background
 - $^{192}\text{Os} + ^{197}\text{Au}$



Zagrebaev, V. & Greiner, W. PRC **87**, 034608 (2013).



Searching for α -Decaying Products of $^{197}\text{Au} + ^{197}\text{Au}$ Multinucleon Transfer

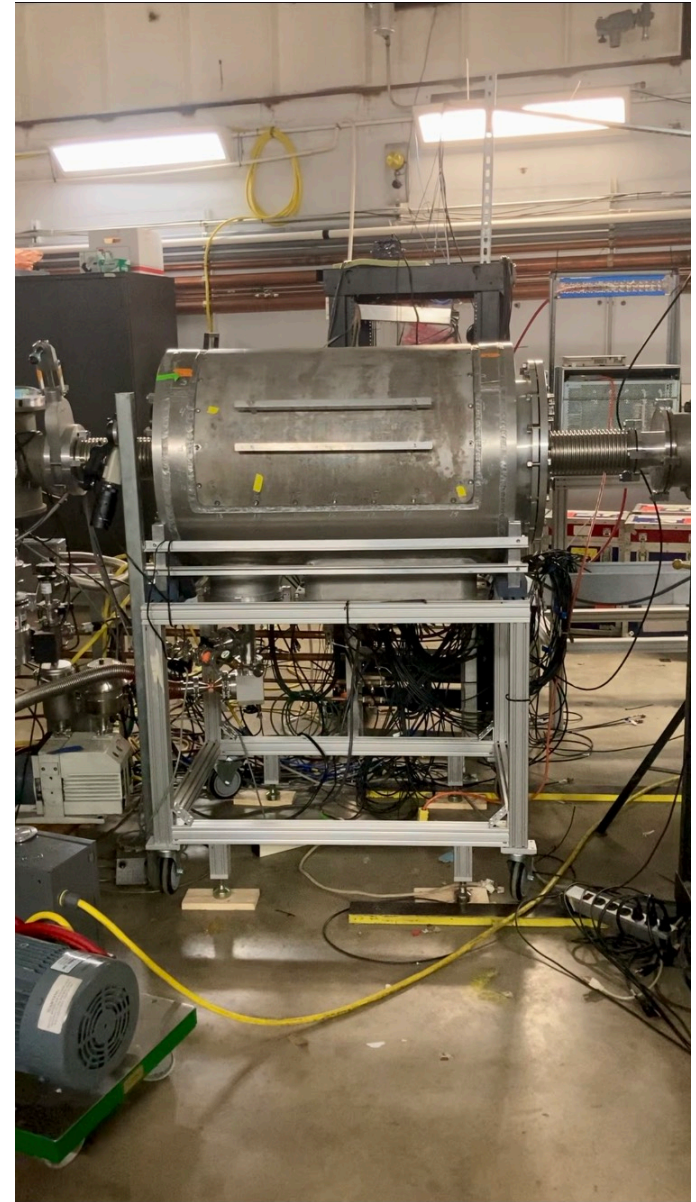


- Theoretical predictions for the $^{192}\text{Os} + ^{197}\text{Au}$:
 - 2 μb cross section
 - Ra, Ac, Th
- Search for MNT Products $85 \leq Z \leq 92$, $126 \leq N \leq 140$
- α -decaying nuclei with well-known energy and half lives
- Experiment $^{197}\text{Au} + ^{197}\text{Au}$

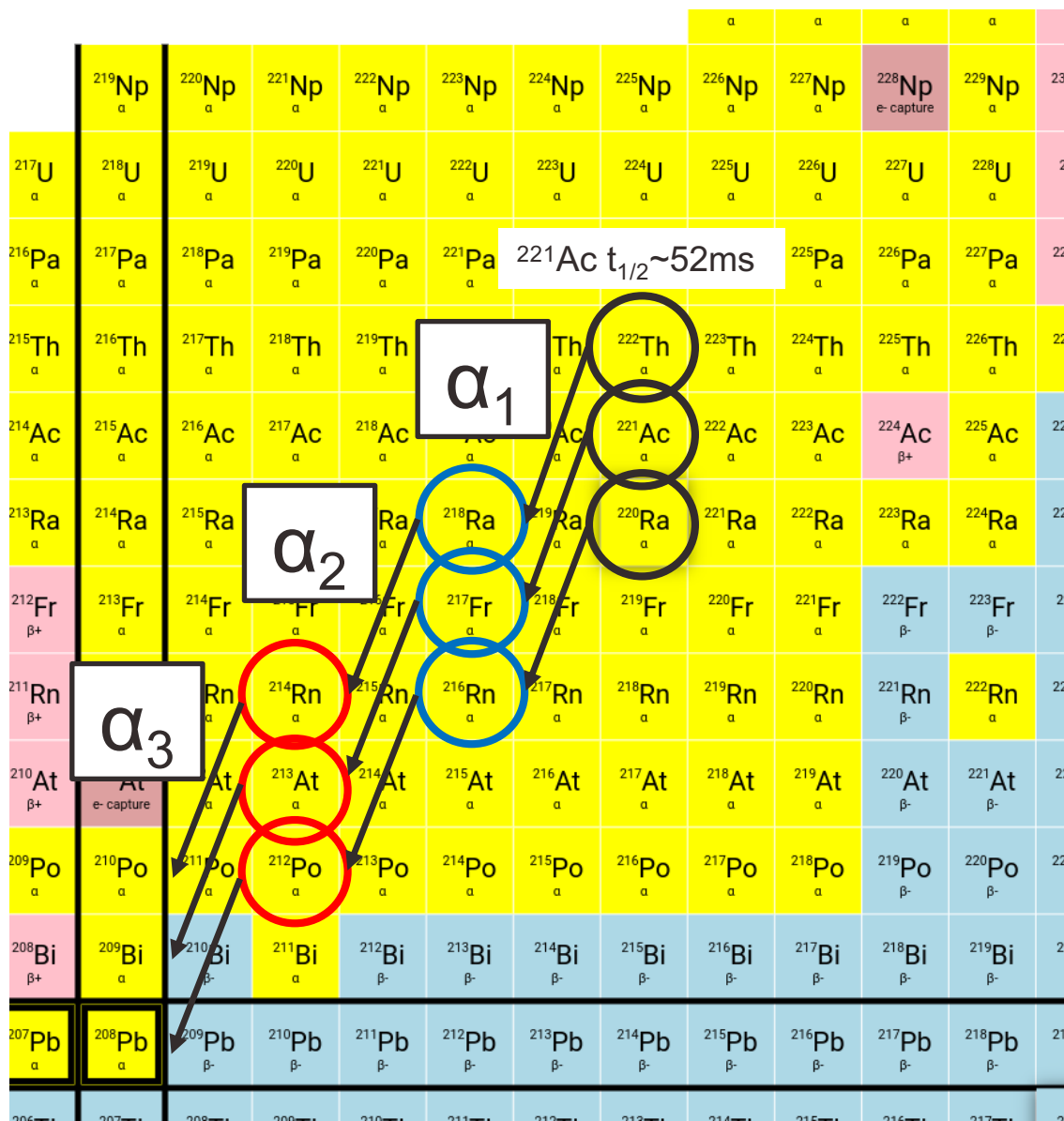


Experiment Details

- Will be conducted at the Cyclotron Institute at Texas A&M University in College Station THIS WEEK!
- Experimental chamber called the “BBQ Pit”
- ^{197}Au beam with $E_{\text{lab}} = 8.6 \text{ MeV/A}$, probing center-of-mass energies $1.3 - 0.98 V_C$ as it passes through target
- Beam pulsed on/off every few hundred ms
 - catches short-lived products
 - Nuclei produced and implanted in detectors while beam on
 - α decays detected while beam is off



Identify Nuclides Using α -Decay Chains

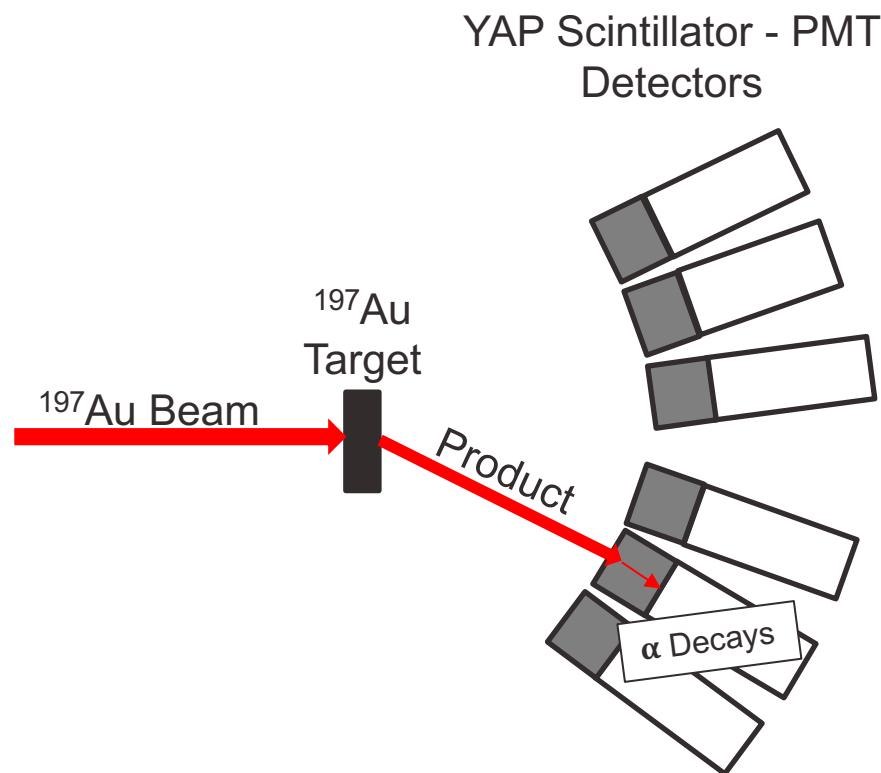


- Experiment design optimized for ^{220}Ra , ^{221}Ac , and ^{222}Th production and detection
- Short half-lives: Beam pulsed on/off for 100ms/150ms
- Identify products by establishing decay chains

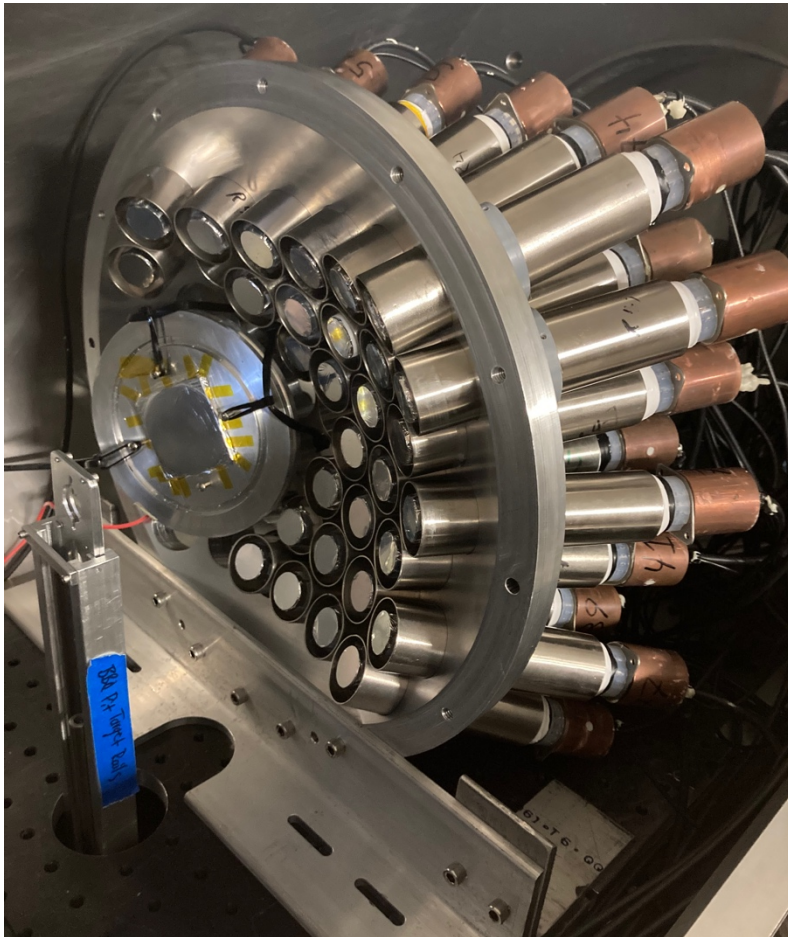


The Active Catcher Array (ACA)

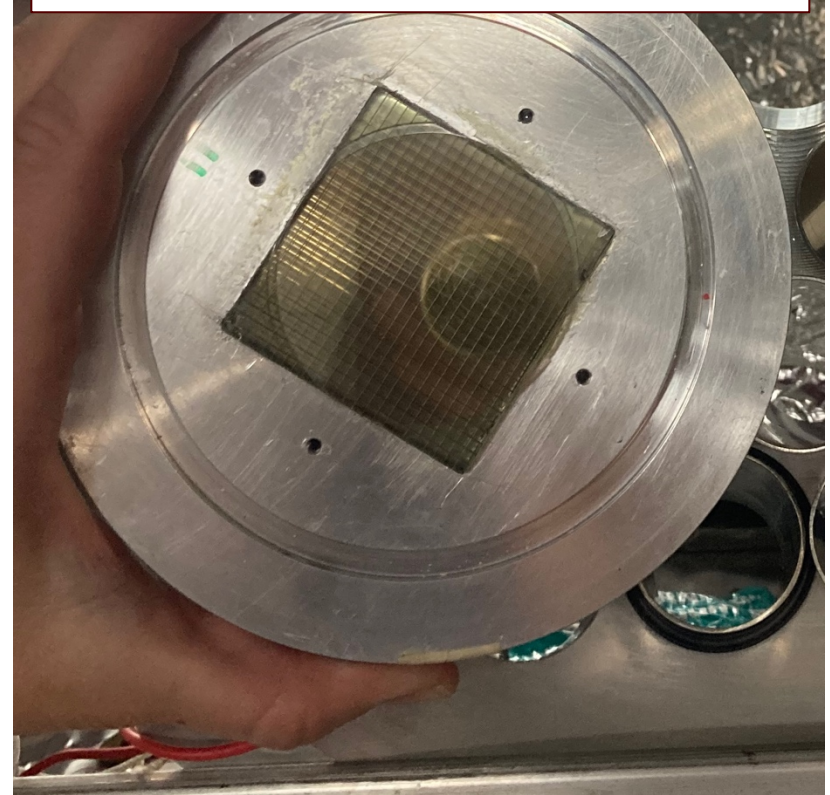
- 40 YAP scintillators coupled to photomultiplier tubes
- catches reaction products and detects α decays
- Angular range 7-60°
- Radiation hard scintillators
- Particle ID from pulse-shape discrimination
- 10% energy resolution



Position Sensitivity of the ACA



YAP scintillator and Light guide on front of position-sensitive PMT

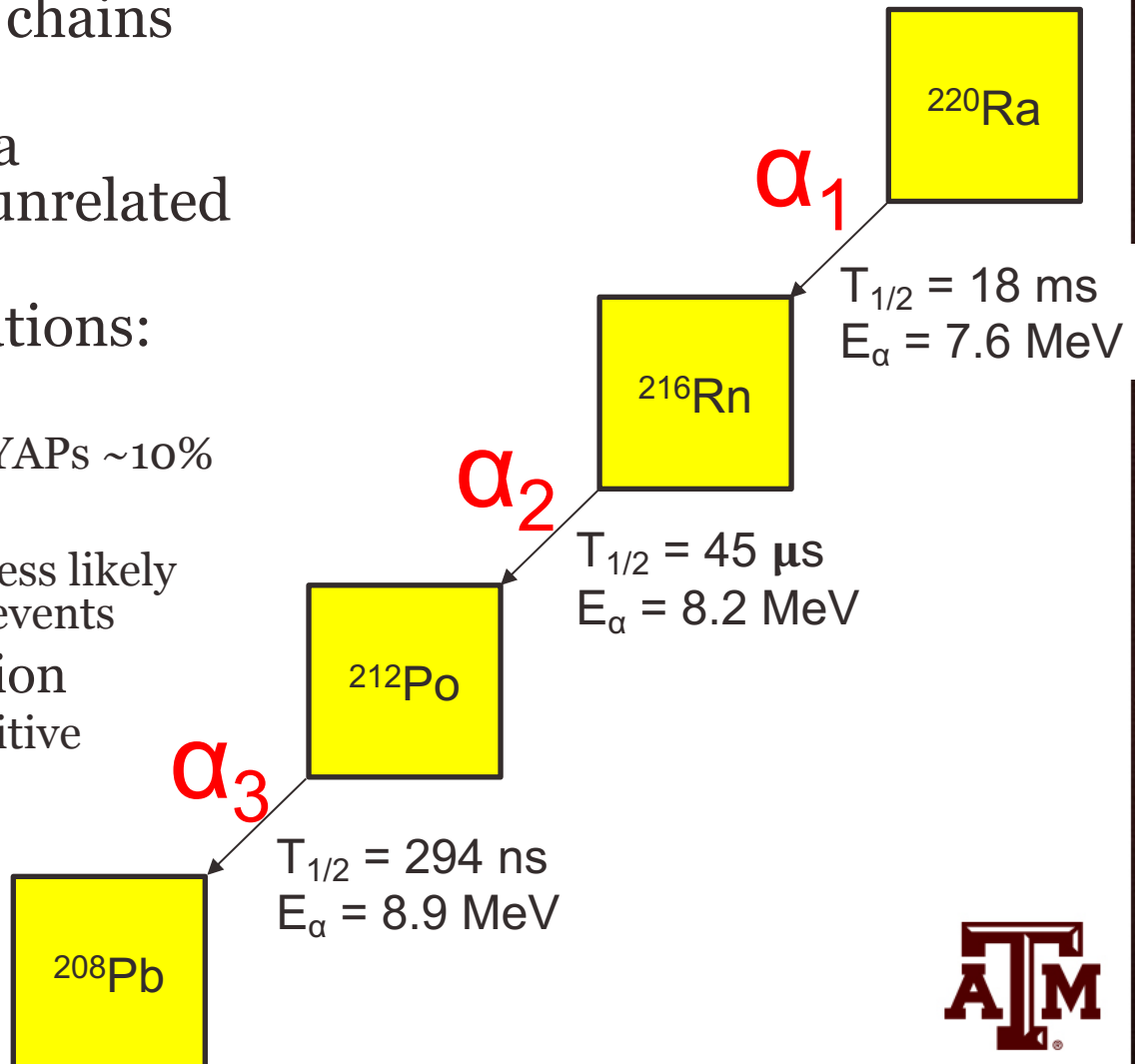


- Position resolution of YAP-PMTs - 2cm
- Replacing $\frac{1}{4}$ array with a position-sensitive PMT - 2mm spatial resolution – loaned by Robert Grzywacz

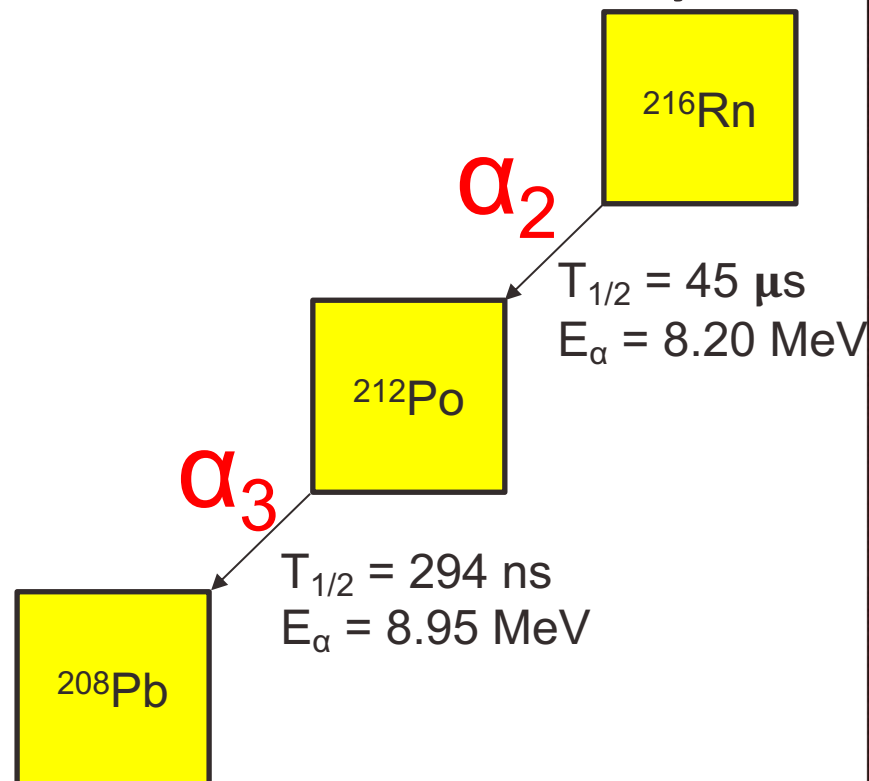
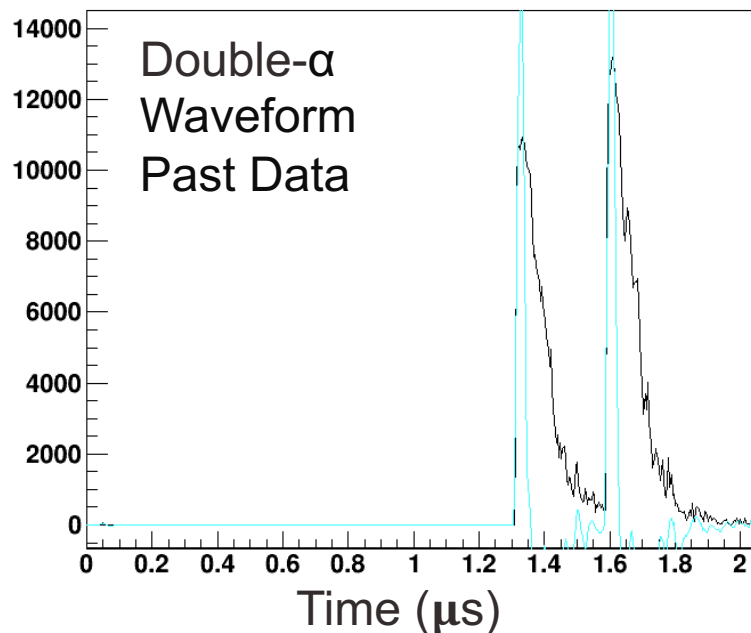


Keep Random Correlations Low

- Small number of decay chains observed
- chain could arise from a random correlation of unrelated events
- Reduce random correlations:
 - Small energy window
 - Energy resolution of YAPs $\sim 10\%$
 - Small time window
 - Decays close in time less likely randomly correlated events
 - Finer position resolution
 - Testing position-sensitive photomultiplier tube



Single Digitized Waveform - 2 α Decays



- SIS 3316 digitizers
 - 2,000 ns waveform length
- Trigger on α -decay of ^{216}Rn (with pre-trig delay of 400ns)
- ~ 4 half lives of ^{212}Po captured in the rest of the digitized waveform



Summary

- This week, we will be conducting the $^{197}\text{Au} + ^{197}\text{Au}$ multinucleon transfer experiment
- Searching for production of trans-target nuclei by detecting α -decay chains
- Past data have shown detections of double α decays in a single waveform, indicating detections of desired products



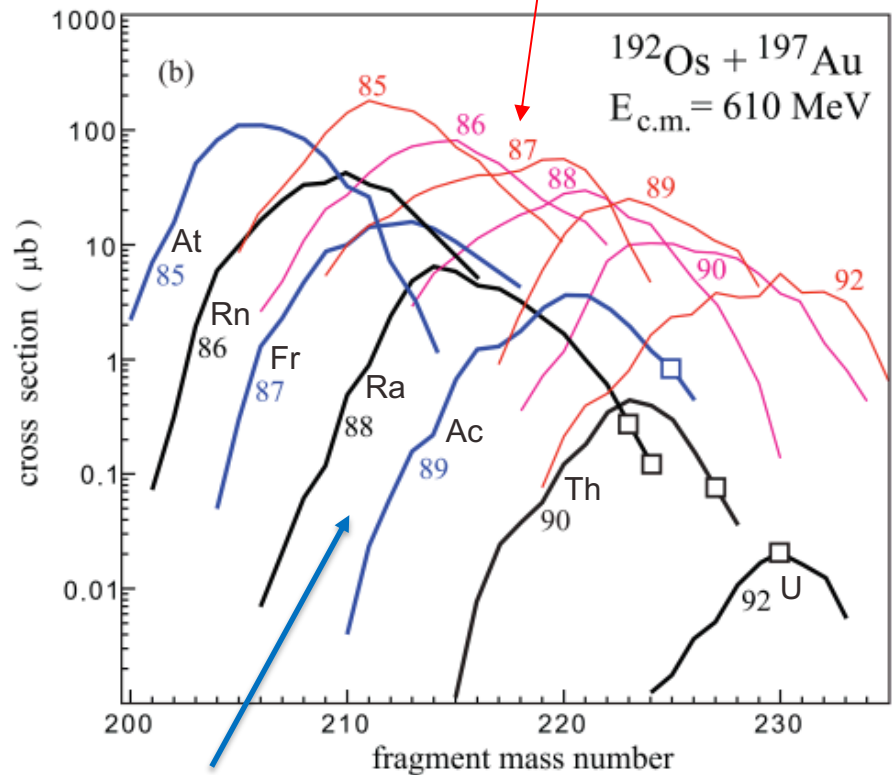
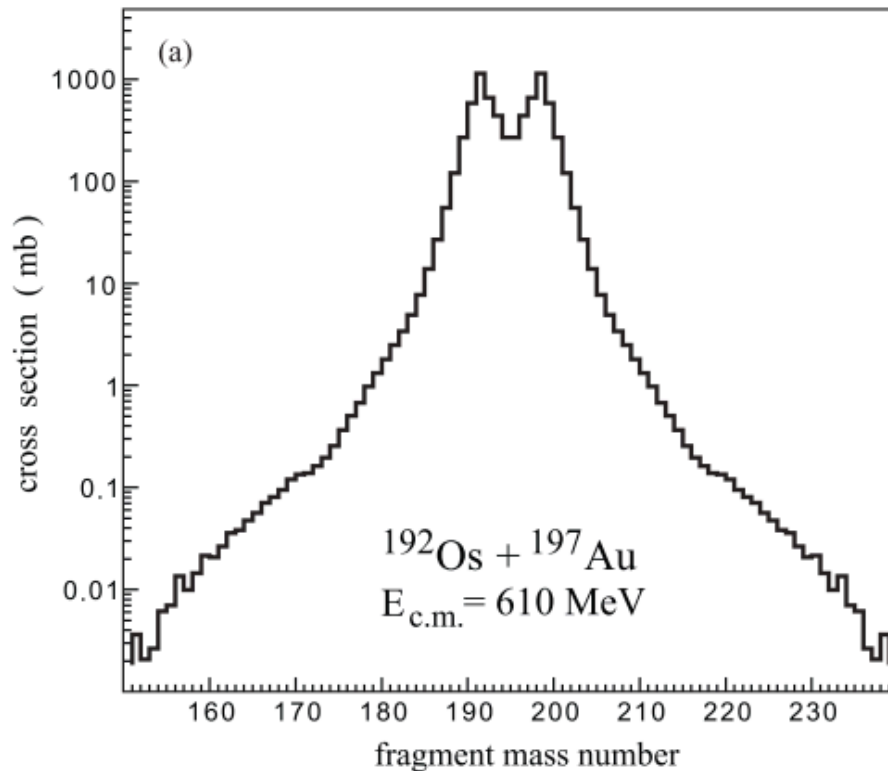
Acknowledgements

Collaborators:

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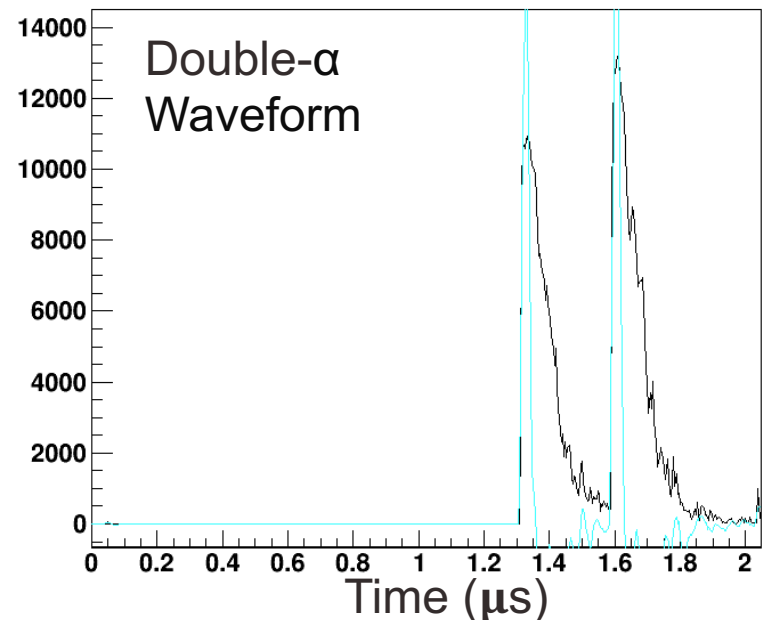
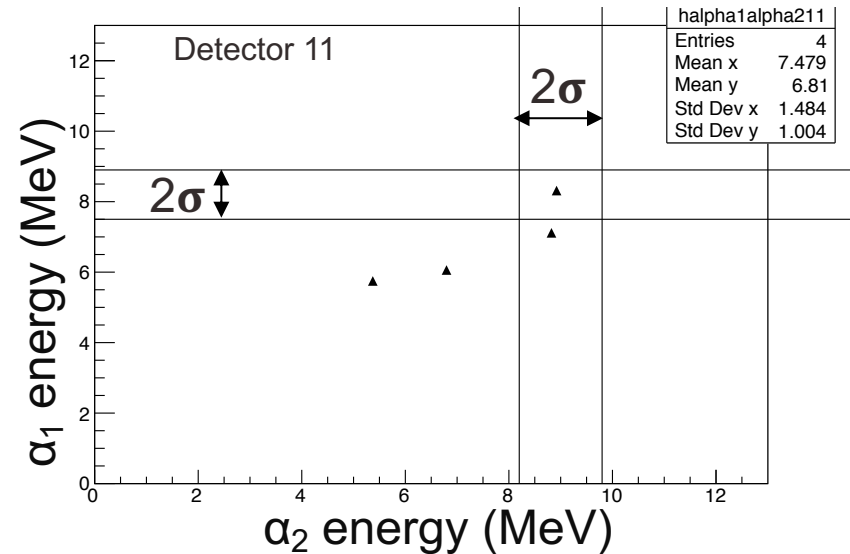


Zagrebaev, V. & Greiner, W. PRC **87**, 034608 (2013).



MNT Products of $^{208}\text{Pb} + \text{natPb}$

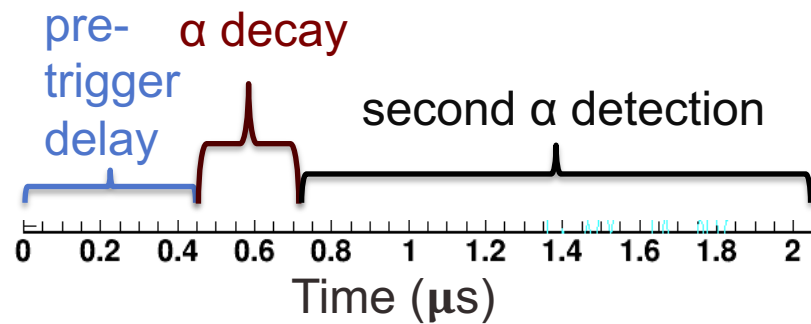
- MNT experiment ran in 2018 with $^{208}\text{Pb} + \text{natPb}$
- Experiment Goal: Benchmark the active catcher array for super heavy element studies
- My Goal: Find double- α decays in single waveform
- Digitizer settings caused issues
 - Long pre-trigger delay 1,300 ns
 - 2,000 ns no-trigger window after waveform capture
- Learning from this for next experiment



Future Work: Detector Improvements

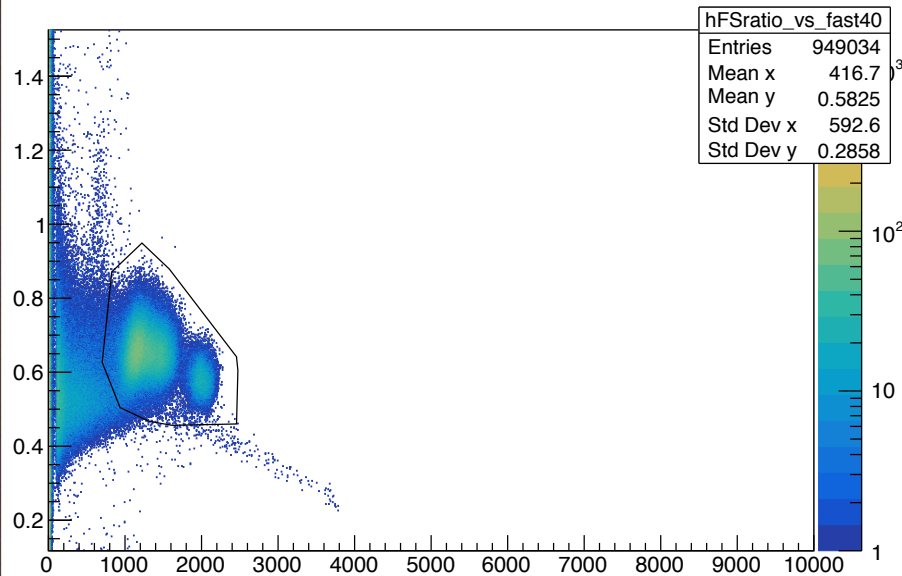
- Improve ACA by lowering possible random correlations
 - Better position Resolution
 - Position-sensitive Photomultiplier Tubes
 - Better energy resolution
 - Must be radiation hard
 - Investigated using diamond detectors, not radiation hard



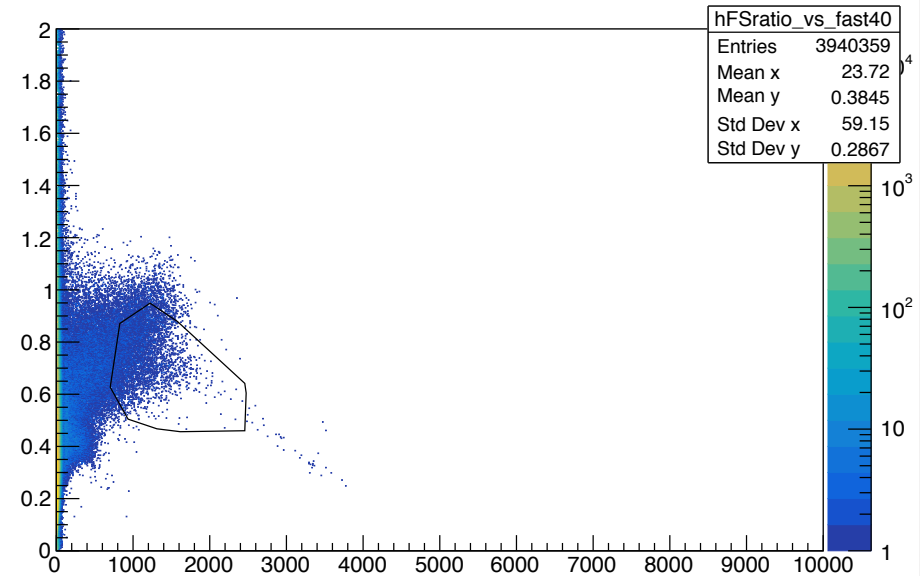


Alpha Gate from ^{228}Th Spectrum

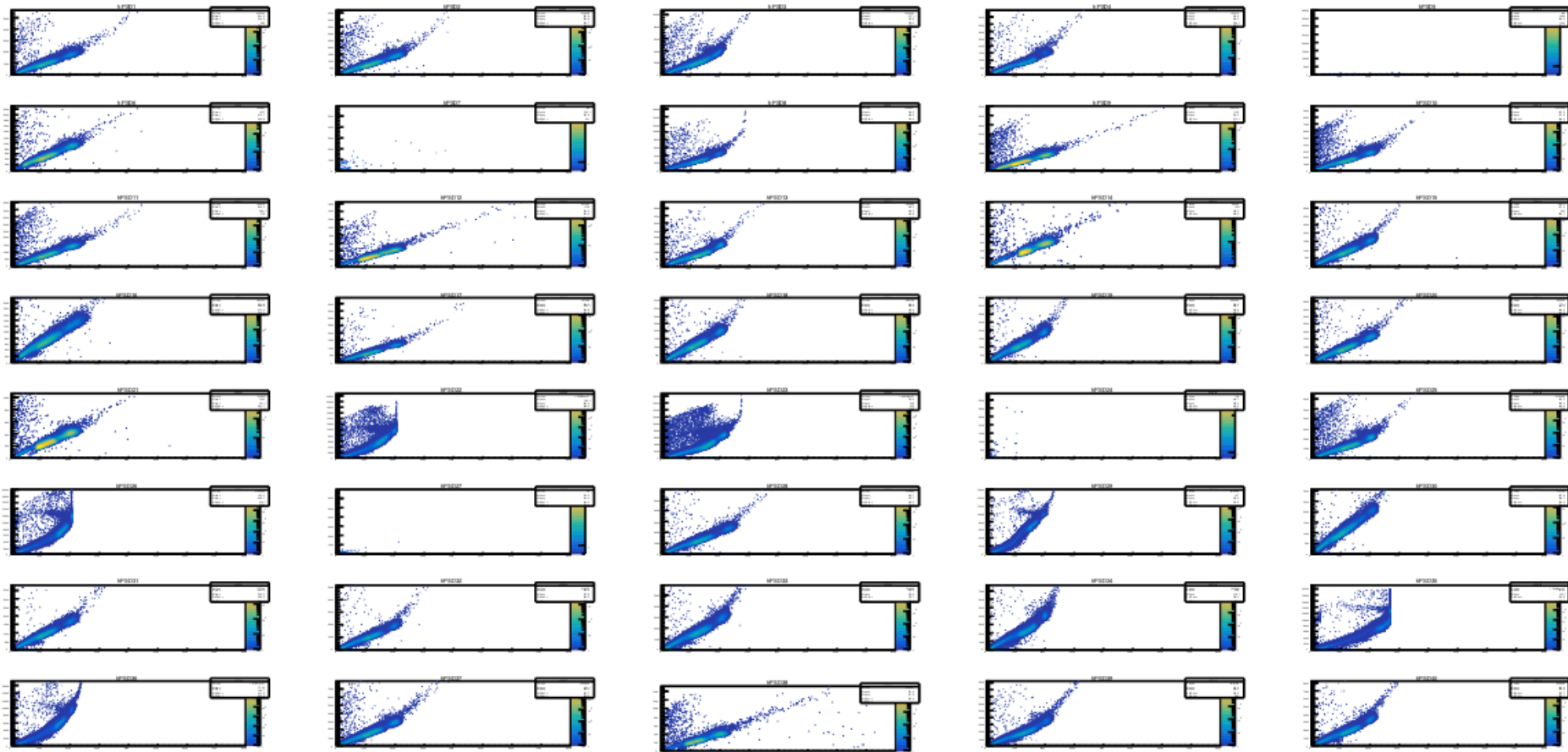
^{228}Th Calibration Run with Graphical Cut



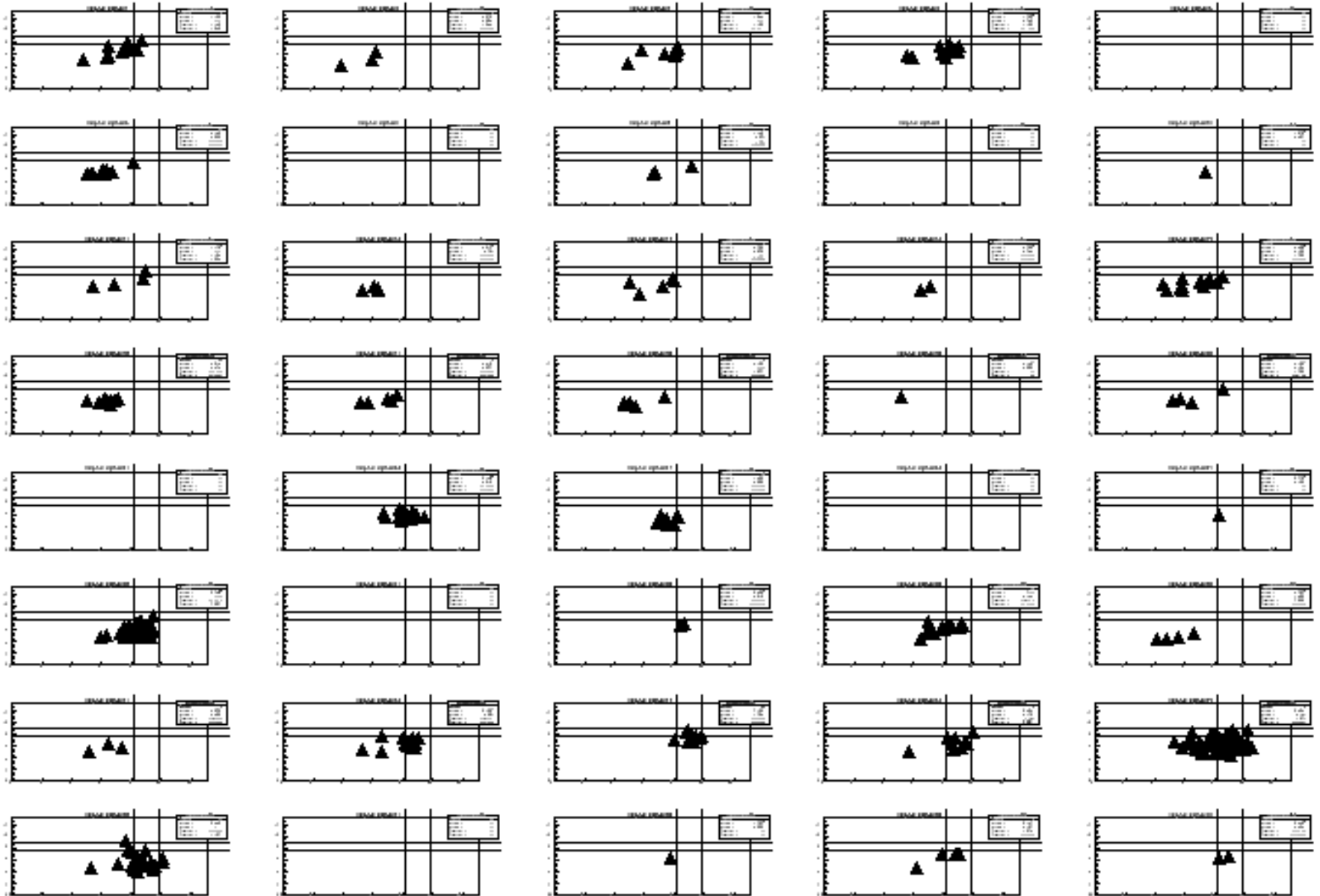
Graphical Cut with Reaction Data



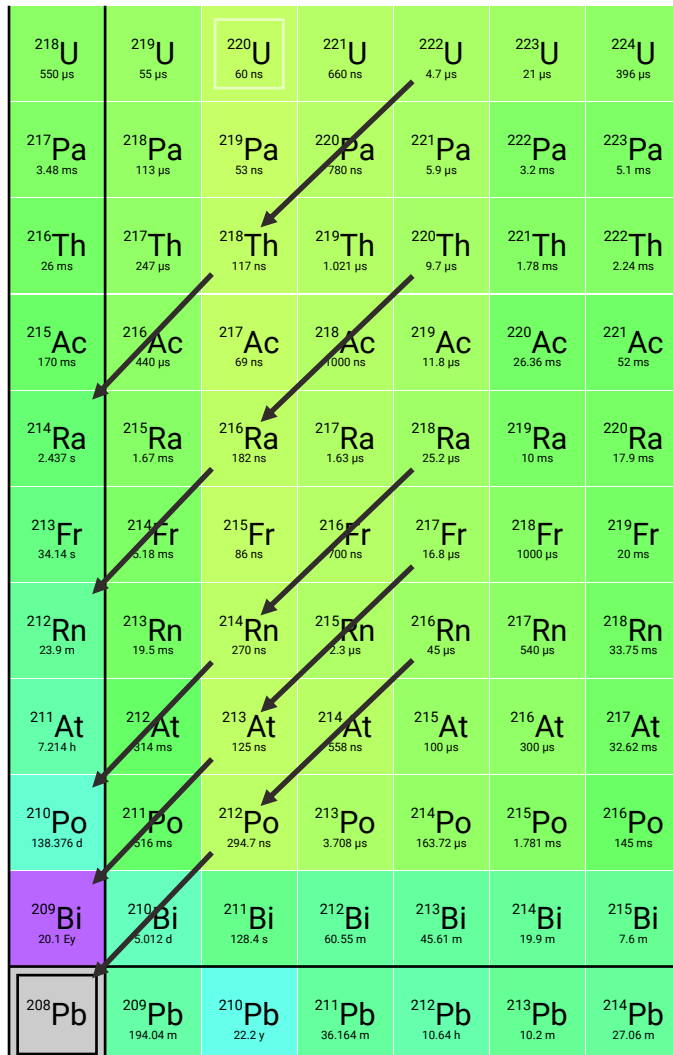
Fast vs. Slow, All Detectors, ^{228}Th spectrum



Double Alpha Waveform All Detectors

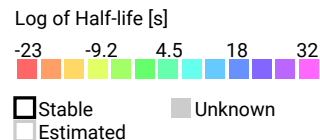


Other Candidates for Single Waveform Decay Chains



Energy $\alpha_1 \sim 8.2\text{-}9.5$ MeV

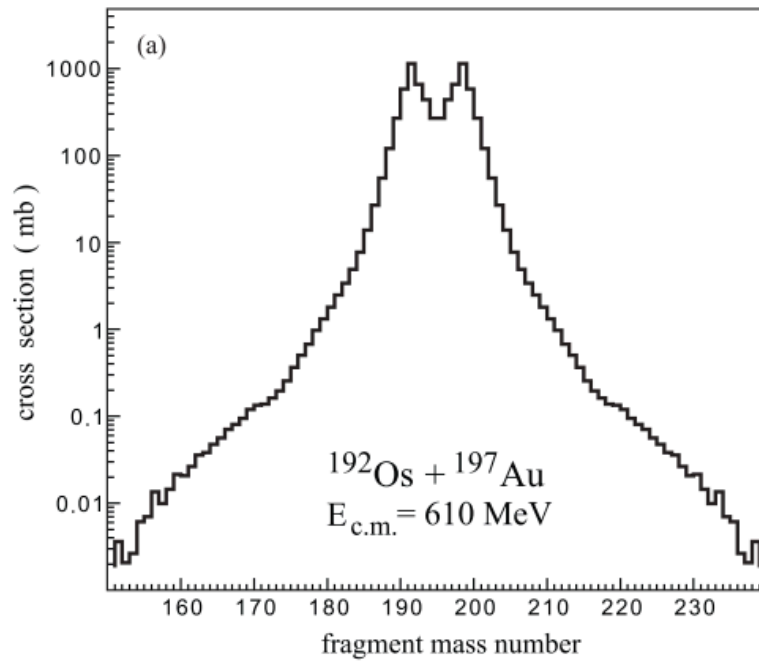
Energy $\alpha_2 \sim 9.0\text{-}10.0$ MeV



$^{197}\text{Au} + ^{192}\text{Os}$ Products Predicted

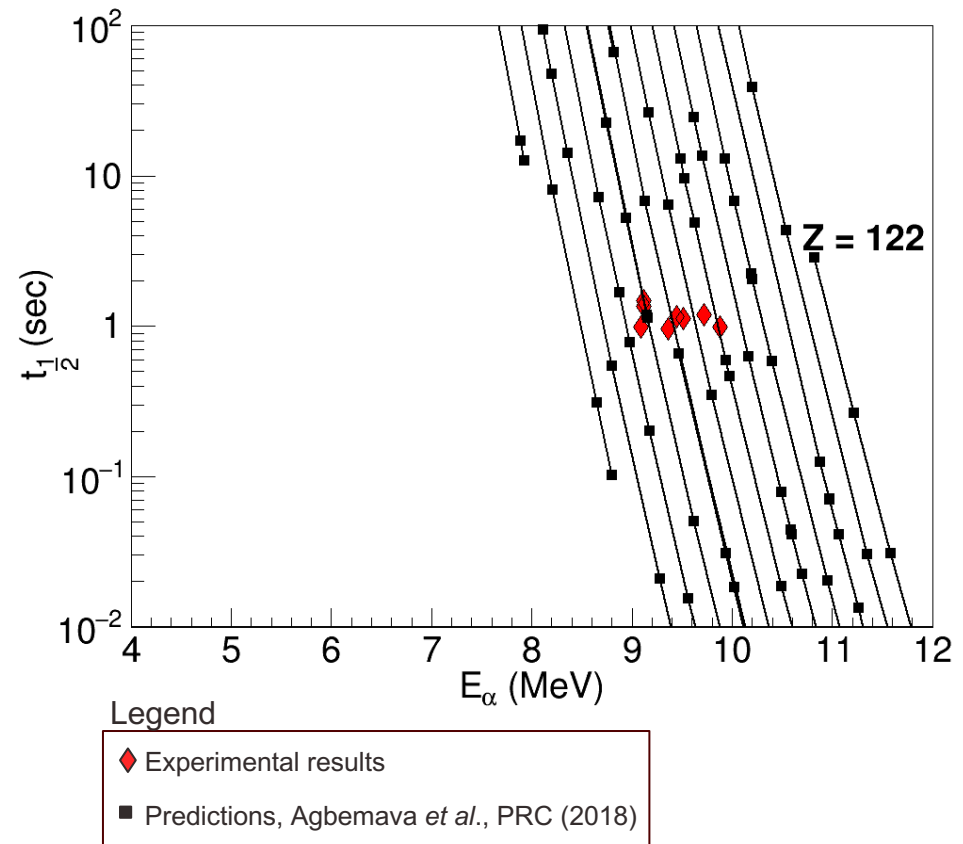


$^{192}\text{Os} + ^{197}\text{Au}$



Previous Study of $^{238}\text{U} + ^{232}\text{Th}$ MNT

- Experiment performed at Texas A&M University using the active catcher array, looking for super-heavy elements
- Results of a correlated pair search show half-life and alpha energy in red diamonds
- Comparison with theoretical predictions made via the Viola-Seaborg approach suggests the identification of nuclei with $Z = 112$
- Couldn't identify any specific isotopes
 - High Background



Wuenschel, S., et al., PRC 90, 011601 (2014).

