Smashing Gold on Gold: Producing and Identifying Trans-Target Multinucleon Transfer Products

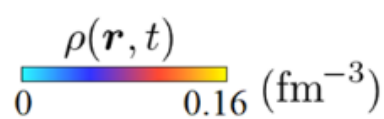
Ashley Hood
Postdoctoral Research Associate
Texas A&M University

April 09, 2021

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/c



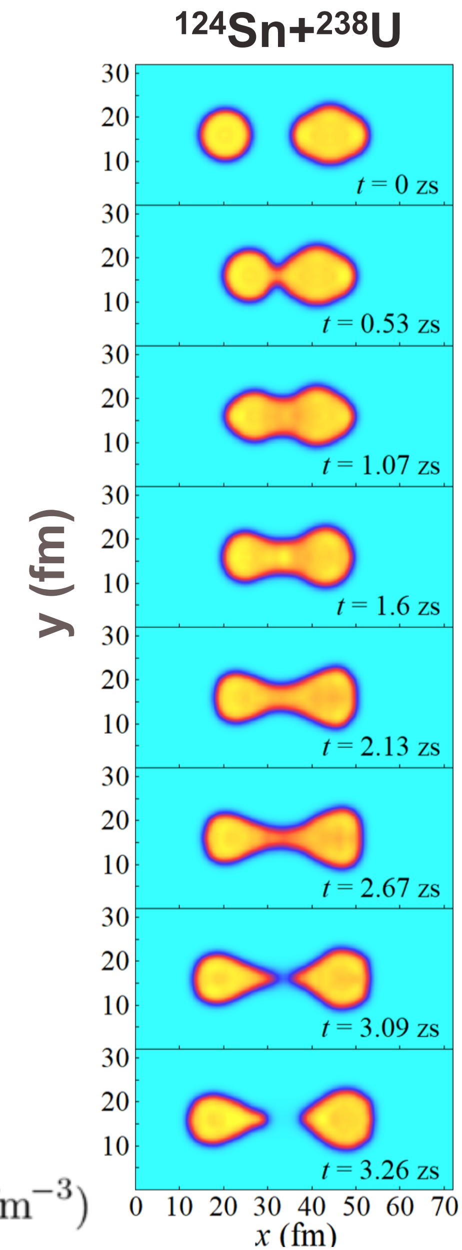
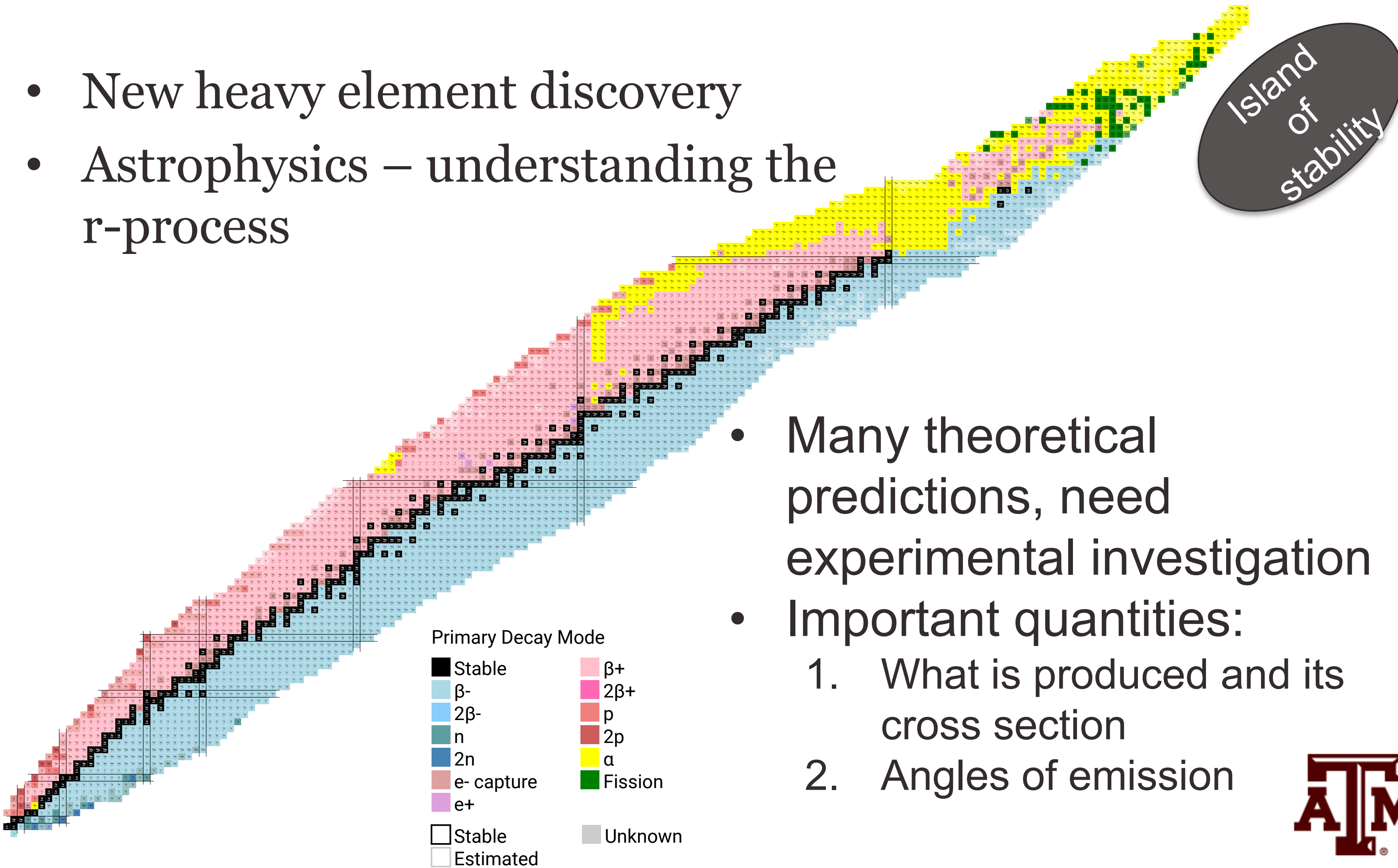


Image Credit: K. Sekizawa, PRC **96**, 041601 (2017)

Why Study Multinucleon Transfer Reactions?

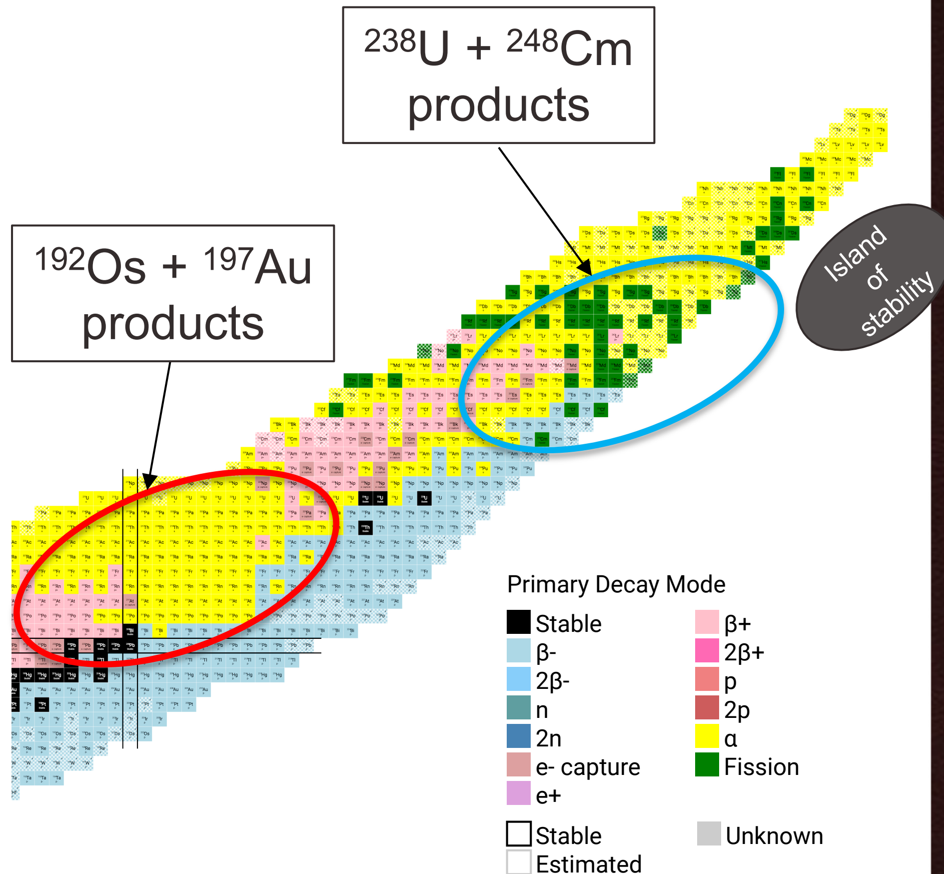
- New heavy element discovery
- Astrophysics – understanding the r-process



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

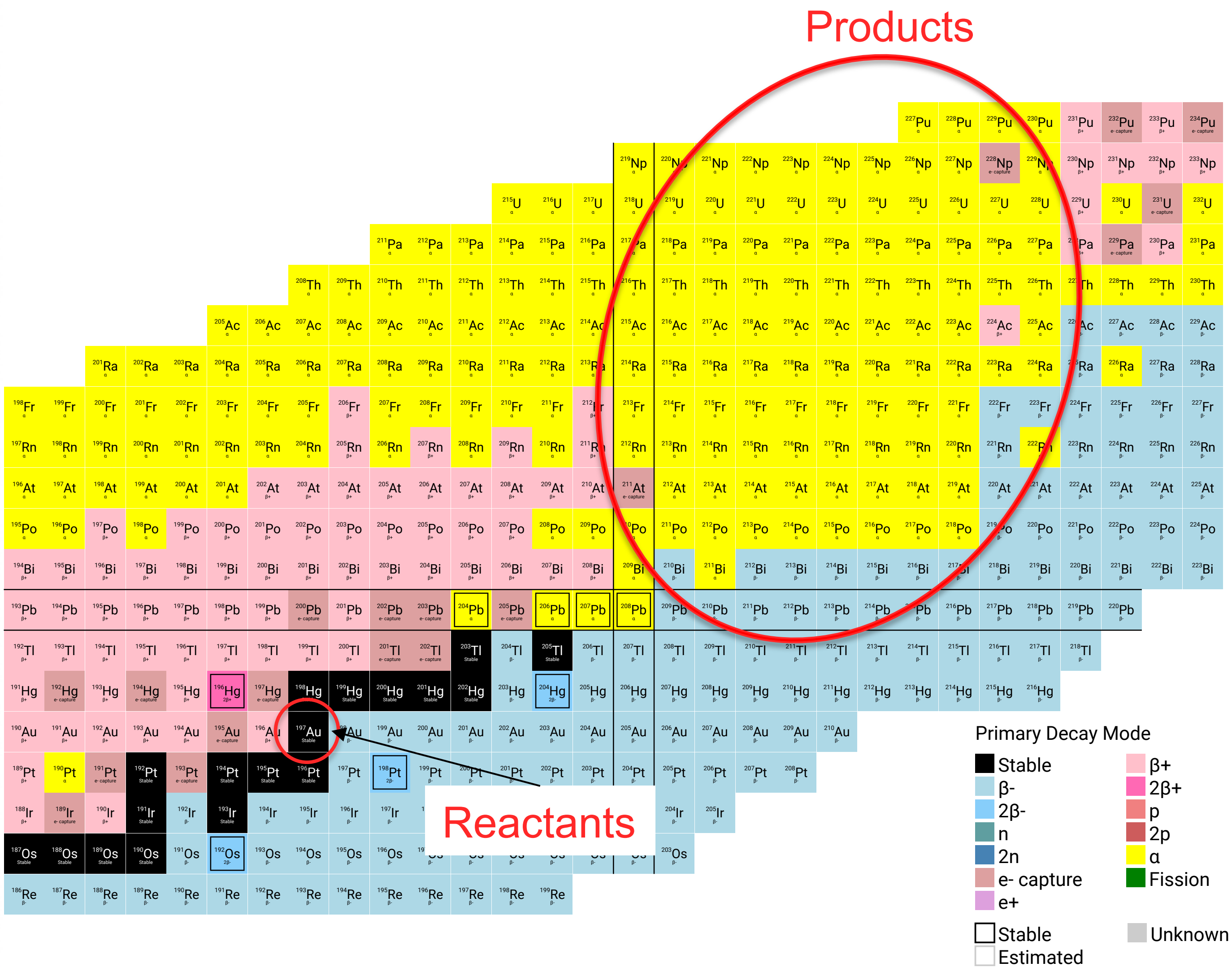
Understanding Trans-Target Nuclei Production

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



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

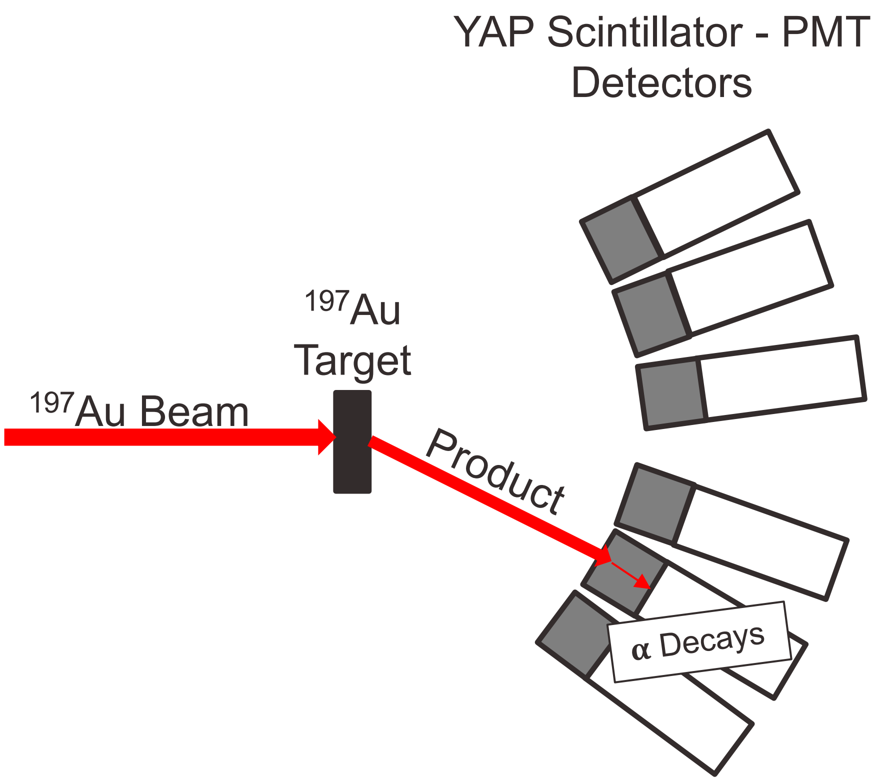
Searching for α-Decaying Products of ^{197}Au + ^{197}Au Multinucleon Transfer



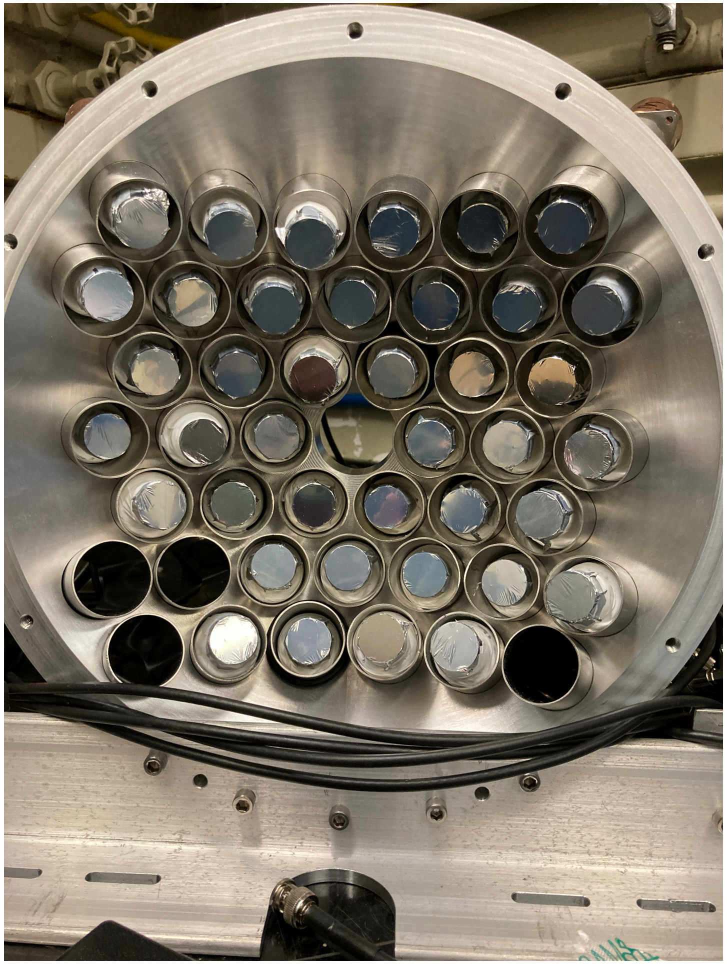
- Theoretical predictions for the ^{192}Os + ^{197}Au:
  - 2 μb cross section
  - Ra, Ac, Th
- Search for MNT Products 85 ≤ Z ≤ 92, 126 ≤ N ≤ 140
- α-decaying nuclei with well-known energy and half lives
- Experiment ^{197}Au+^{197}Au

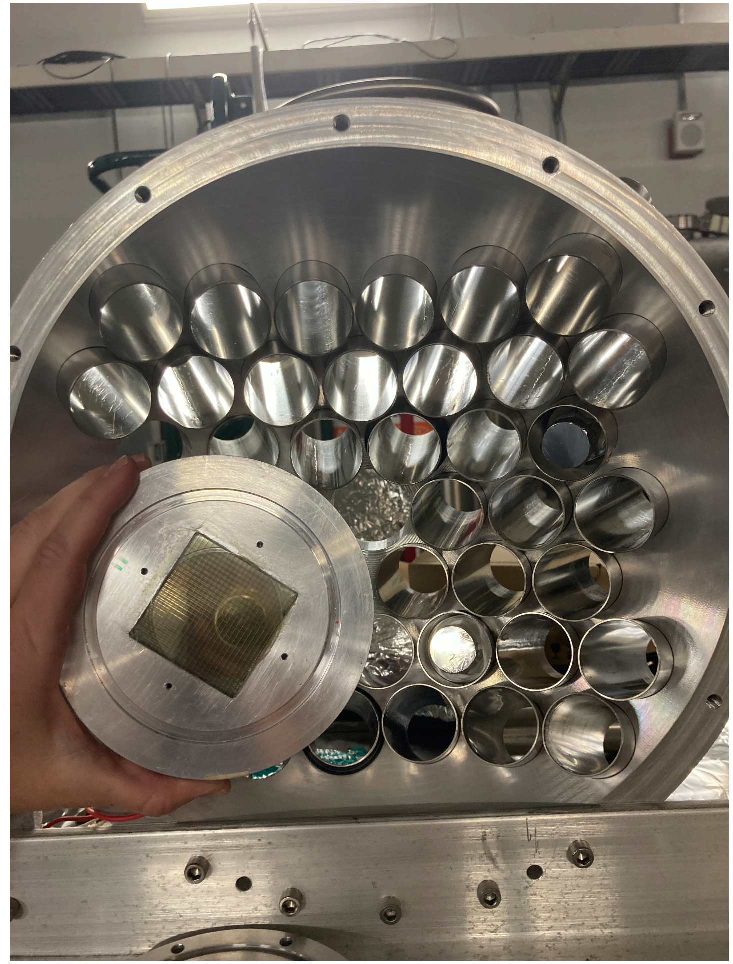
The Active Catcher Array (ACA)

- 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

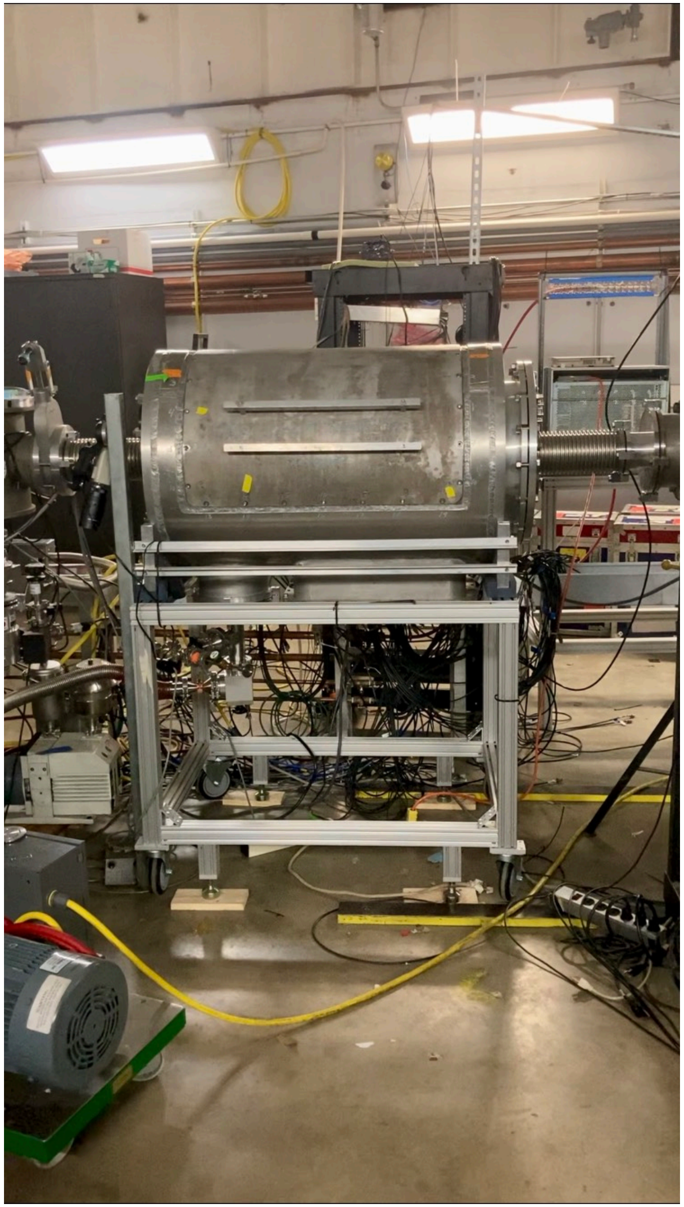




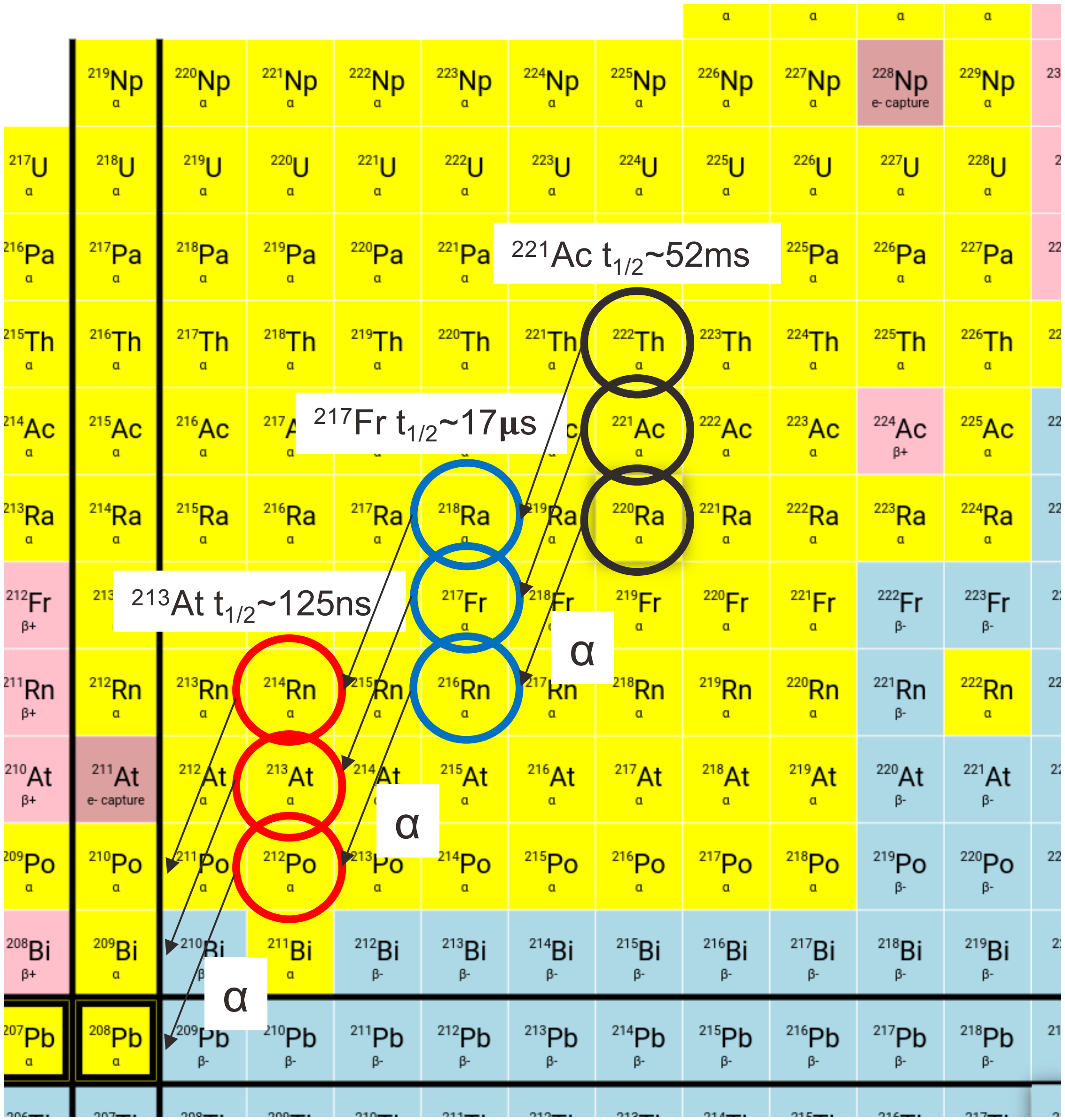
- Position resolution of YAP-PMTs - 2cm
- Replacing ¼ array with a position-sensitive PMT - 2mm spatial resolution

Experiment Details

- Will be conducted at the Cyclotron Institute at Texas A&M University in College Station
- Experimental chamber called the "BBQ Pit"
- ^{197}Au beam with E_{lab}=8.6 MeV/A, probing center-of-mass energies 1.3-0.98V_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

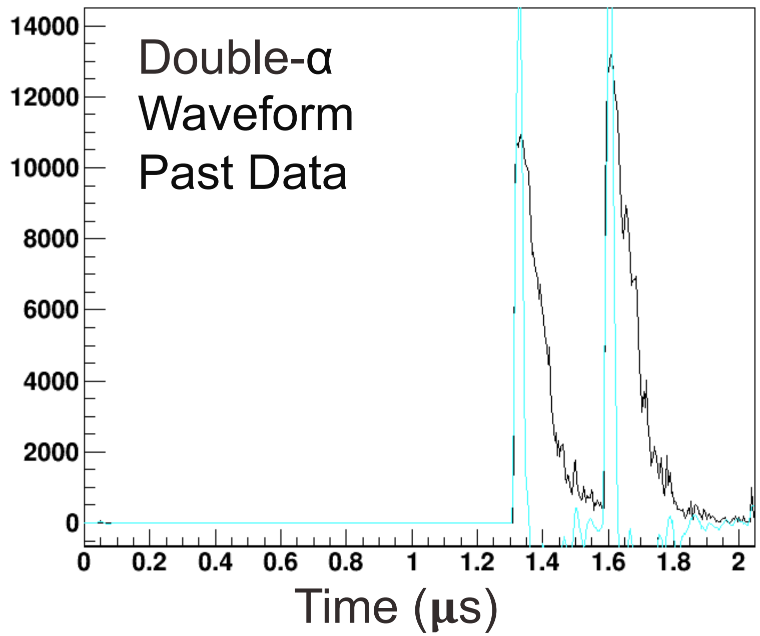


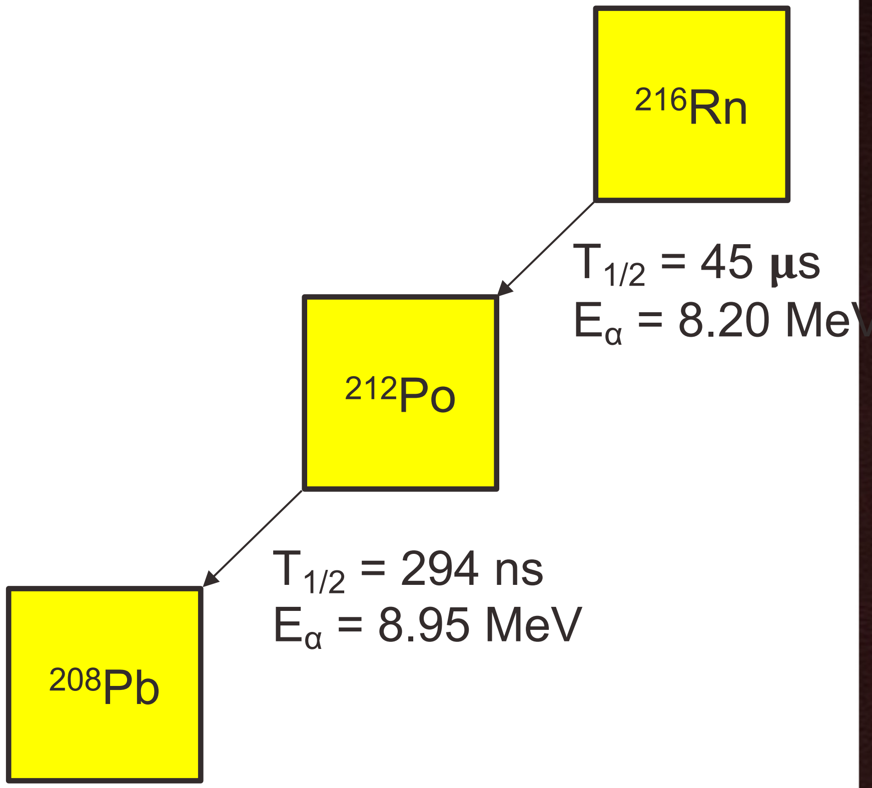
Identify Nuclides Using α-Decay Chains



- Identify products by establishing 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

Single Digitized Waveform - 2 α Decays

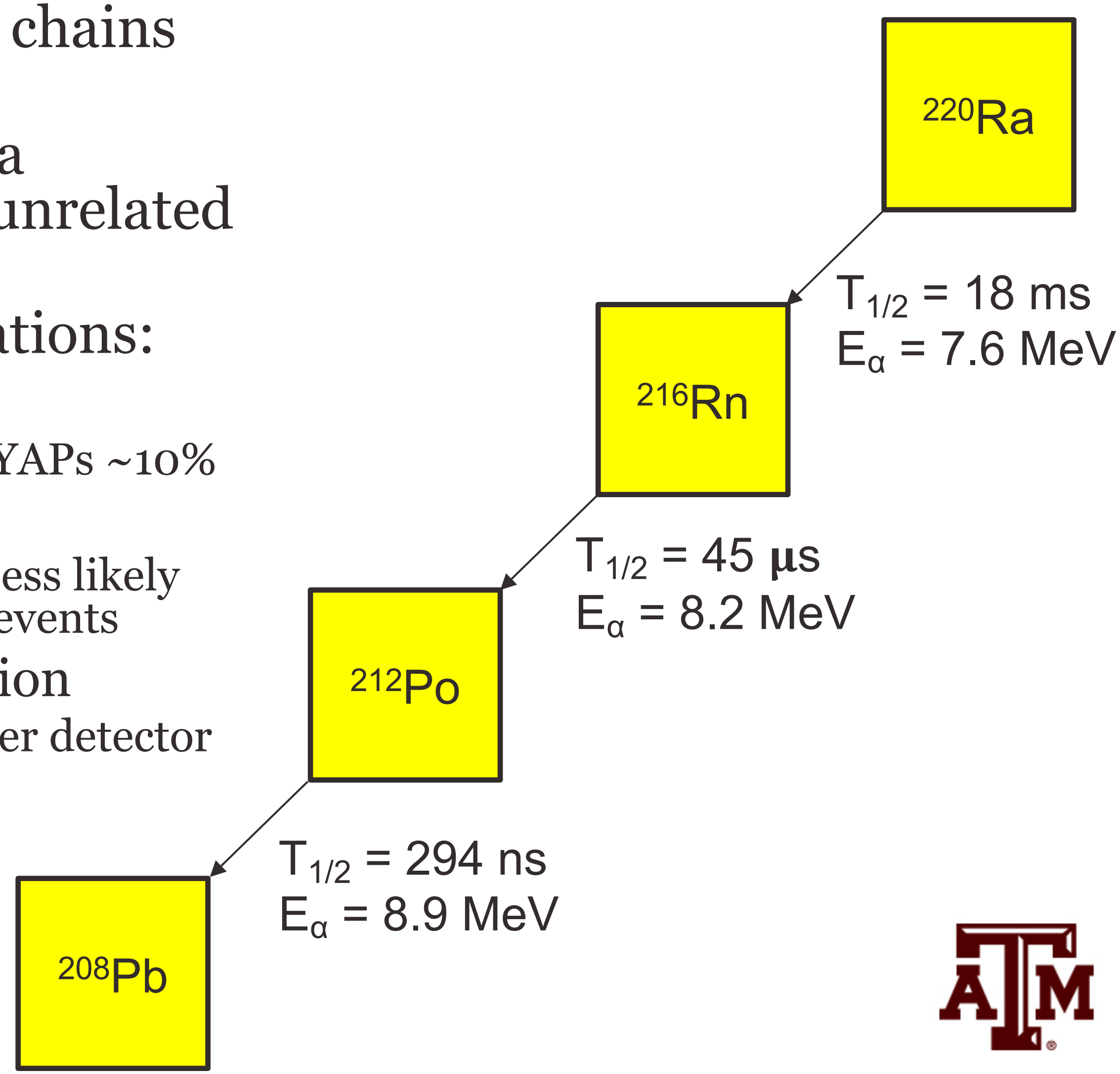




- SIS 3316 digitizers
  - 2,000 ns waveform length
- Trigger on α-decay of ^{216}Rn (with pre-trig delay of 400ns)
- ~4 half lives of ^{212}Po captured in the rest of the digitized waveform

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 ~10%
  - Small time window
    - Decays close in time less likely randomly correlated events
  - Finer position resolution
    - Look at 1 active catcher detector at a time



Summary

- This month, we will be conducting the ^{197}Au + ^{197}Au multinucleon transfer experiment
- Searching for production of trans-target nuclei by detecting α-decay chains
- Good timing and position resolution will help accomplish are essential to accomplish this
- If this research sounds interesting, check out more of what we do at the Cyclotron Institute at Texas A&M University!

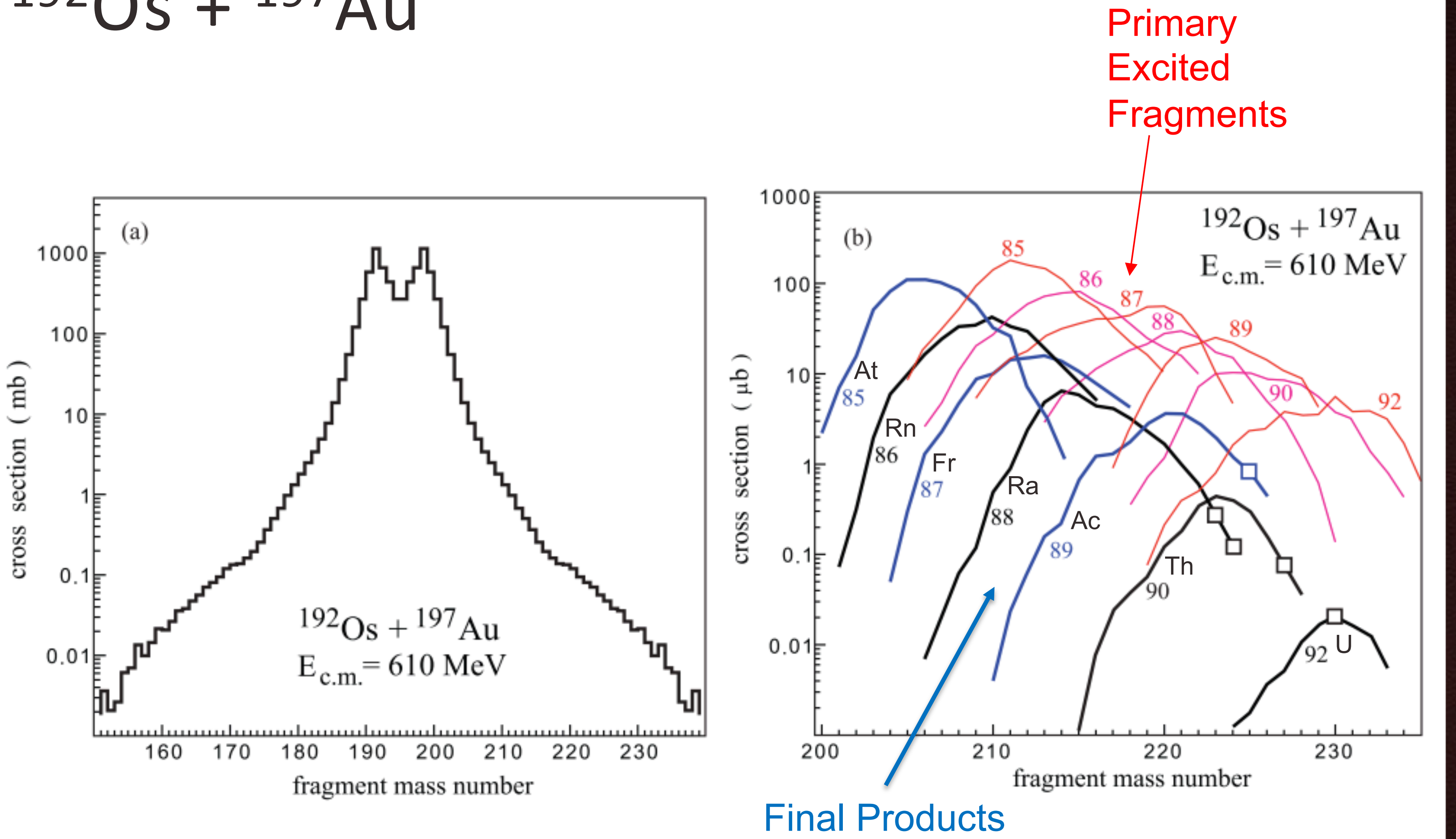
Acknowledgements

Collaborators:

Austin Abbott, Jerome Gauthier, Kris Hagel, Bryan Harvey, Andy Hannaman, Andrea Jedele, Yiu-Wing Lui, Alan McIntosh, Lauren McIntosh, Maxwell Sorensen, Zach Tobin, Roy Wada, Adi Wakhle, and Sherry Yennello

This work is supported by the Department of Energy and the National Nuclear Security Administration under award number DE-NA0003841, the Center for Excellence in Nuclear Training And University-based Research (CENTAUR), and the Department of Energy award DE-FG02-93ER40773.

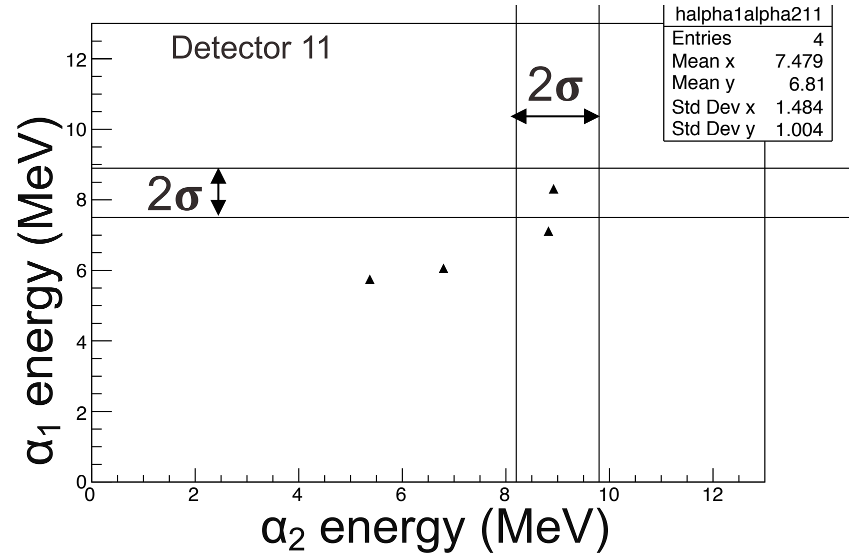
$^{192}Os + ^{197}Au$

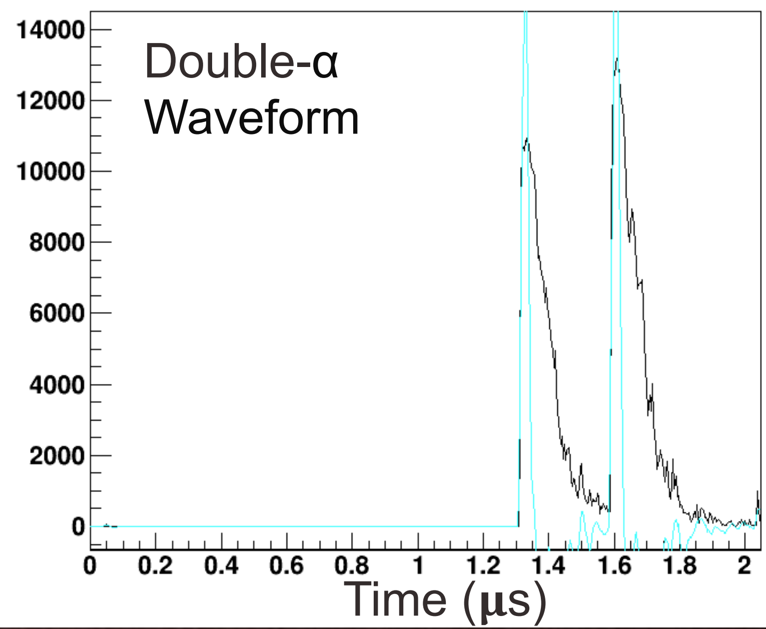


Zagrebaev, V. & Greiner, W. PRC **87**, 034608 (2013).

MNT Products of $^{208}Pb + ^{nat}Pb$

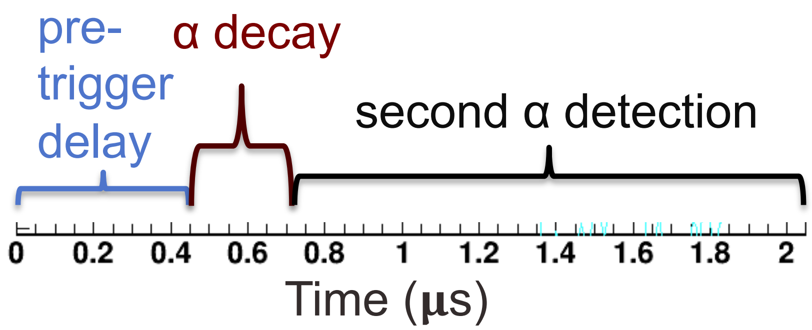
- MNT experiment ran in 2018 with $^{208}Pb + ^{nat}Pb$
- Experiment Goal: Benchmark the active catcher array for super heavy element studies
- My Goal: Find double-α decays in single waveform
- Digitizer settings caused issues
  - Long pre-trigger delay 1,300 ns
  - 2,000 ns no-trigger window after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





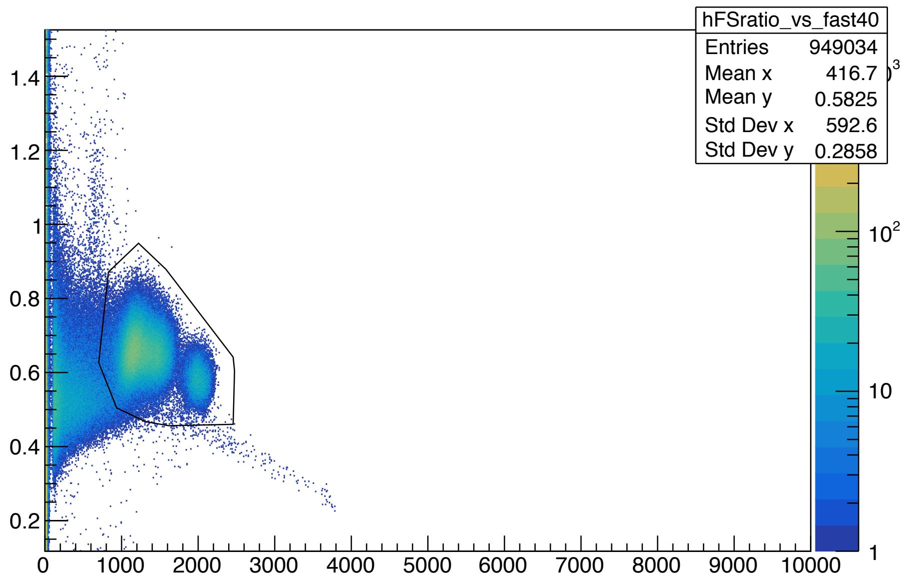
Future Work: Detector Improvements

- 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

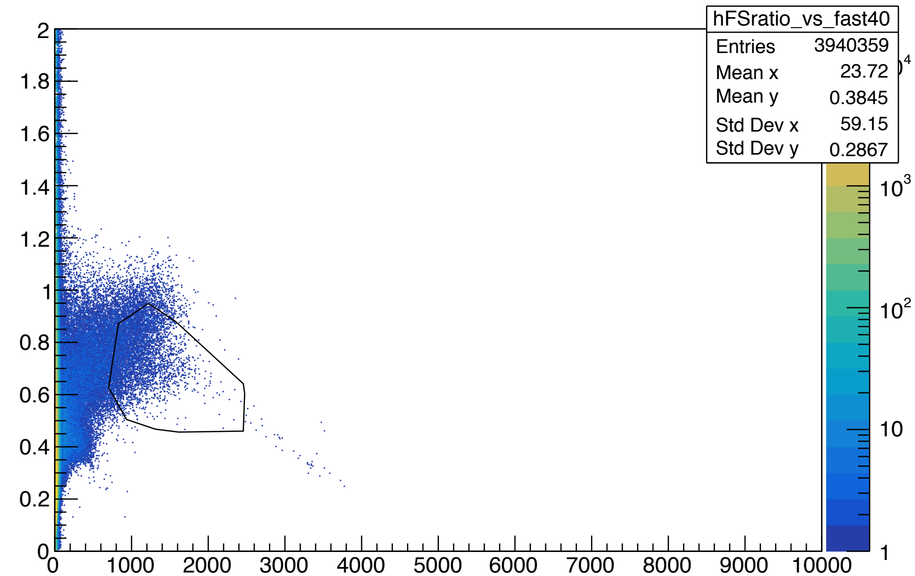

pre-
trigger
delay
α decay
second α detection
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Time (μs)

Alpha Gate from ^{228}Th Spectrum

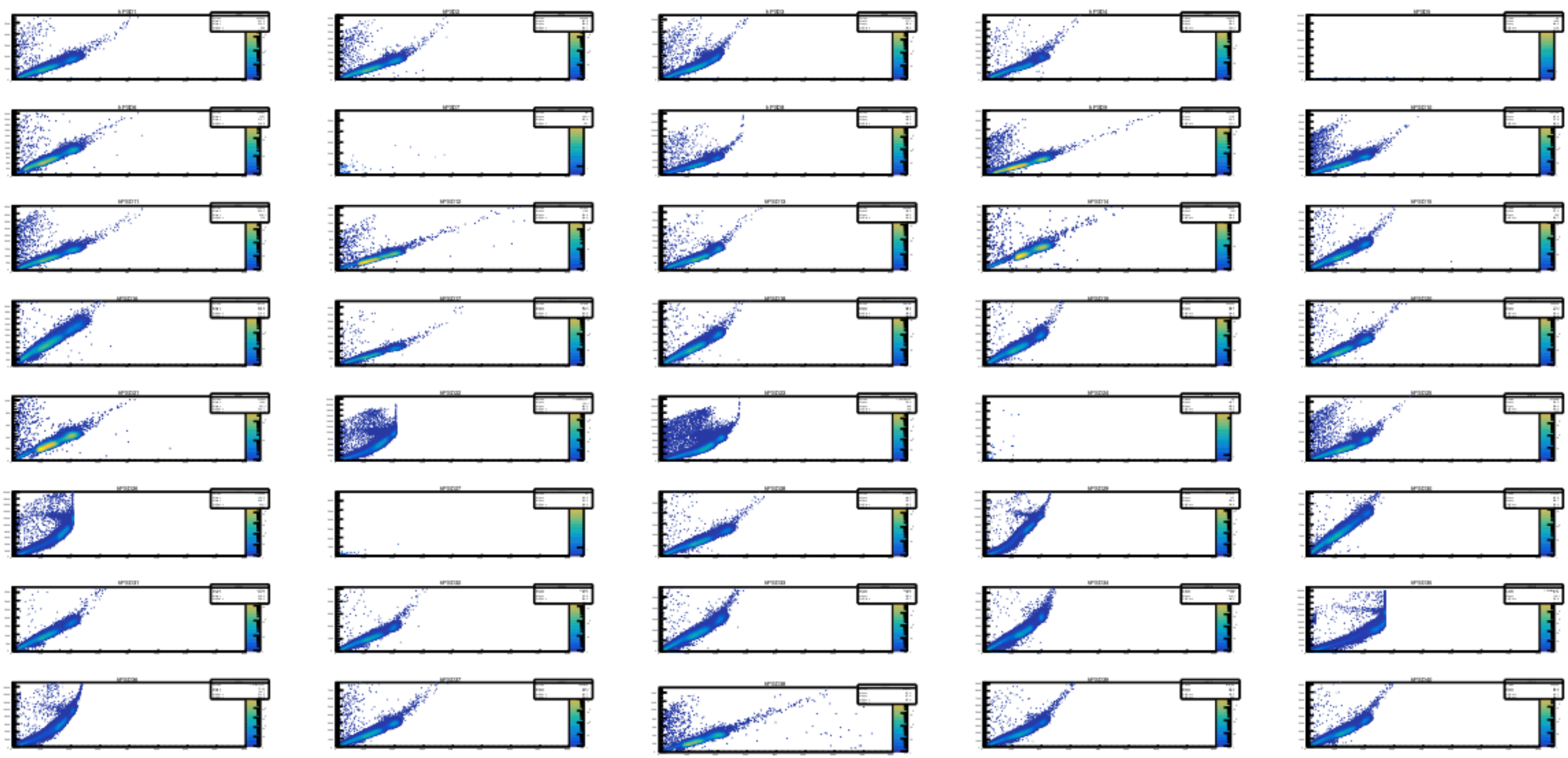
^{228}Th Calibration Run with Graphical Cut



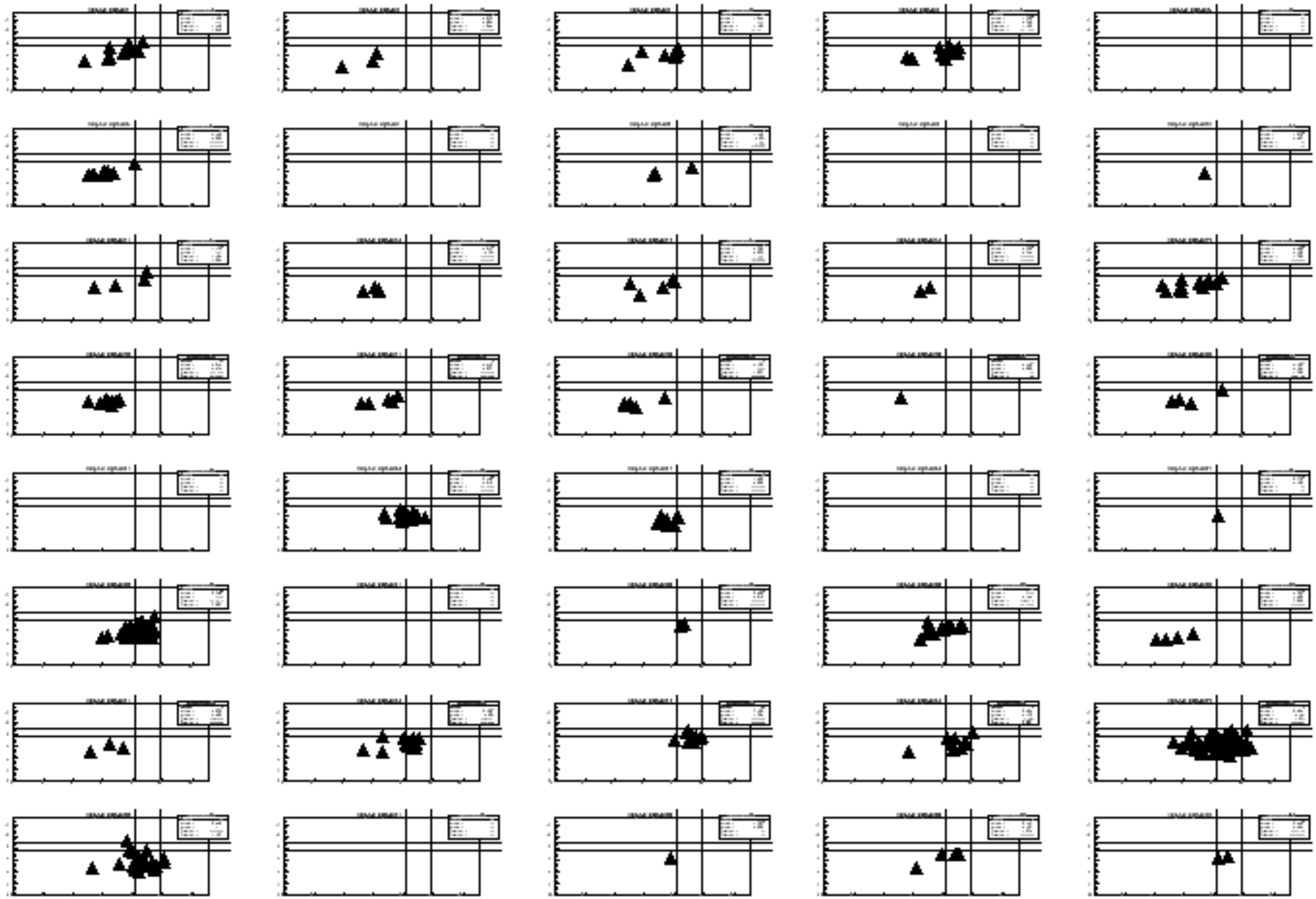
Graphical Cut with Reaction Data



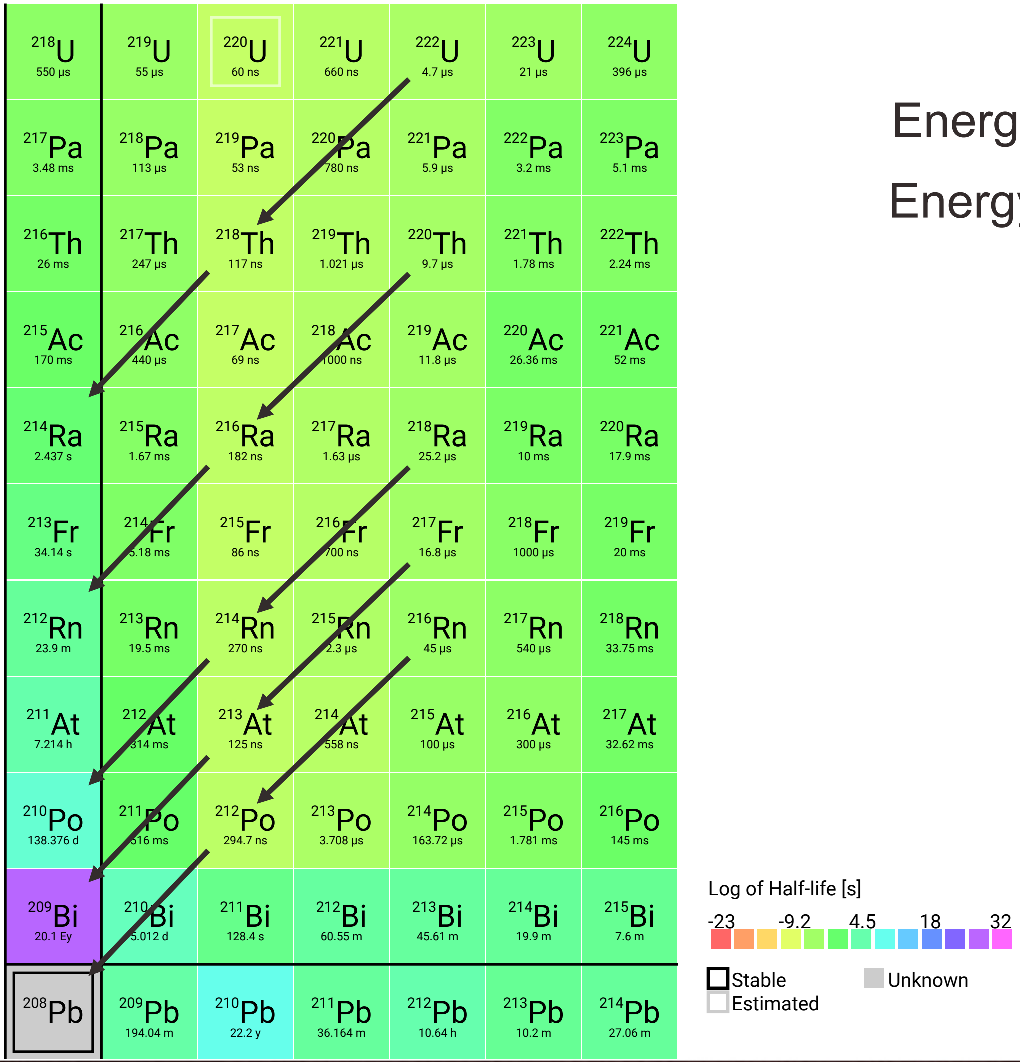
Fast vs. Slow, All Detectors, ^{228}Th spectrum



Double Alpha Waveform All Detectors



Other Candidates for Single Waveform Decay Chains

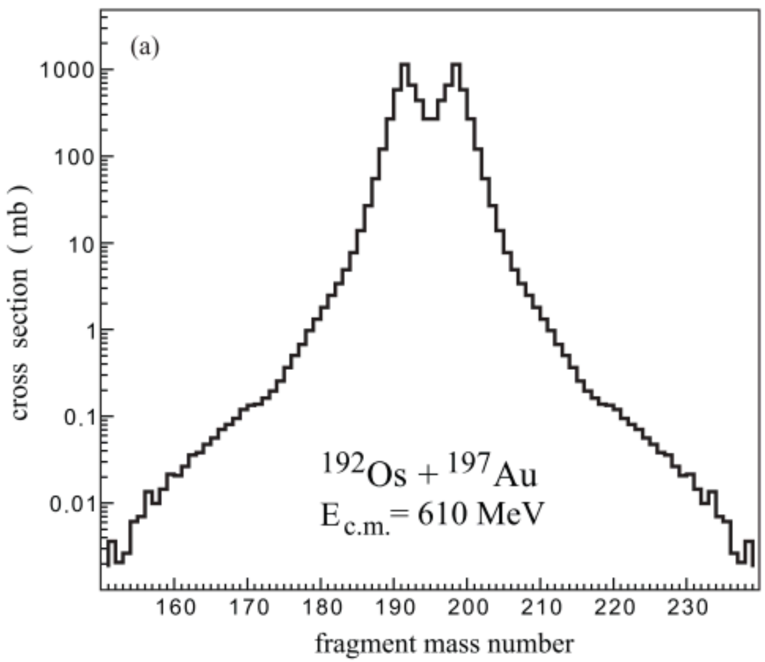


Energy α_1 ~ 8.2-9.5 MeV

Energy α_2 ~ 9.0-10.0 MeV

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

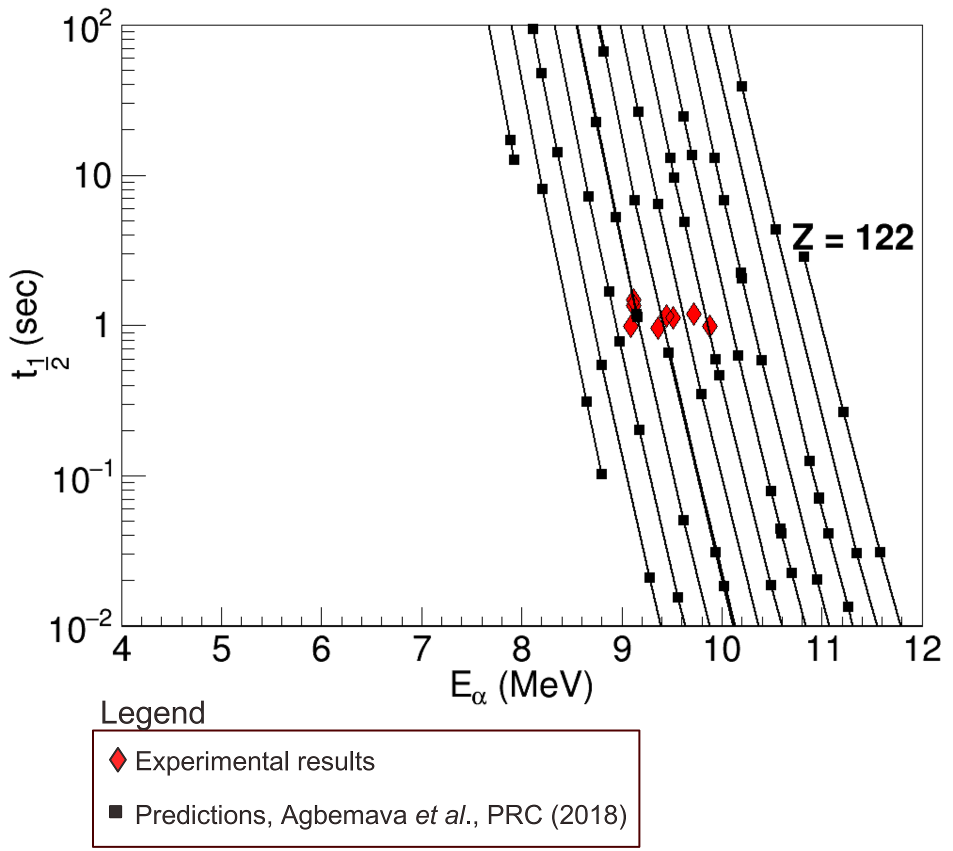
$^{192}Os + ^{197}Au$



(a)
1000
100
10
1
0.1
0.01
cross section (mb)
192Os + 197Au
Ec.m.= 610 MeV
160
170
180
190
200
210
220
230
fragment mass number

Previous Study of $^{238}U + ^{232}Th$ 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).