WANDA 2021

FISSION PRODUCT YIELD MEASUREMENTS USING ^{252}CF SPONTANEOUS FISSION AND NEUTRON-INDUCED FISSION ON ACTINIDE TARGETS AT CARIBU

GUY SAVARD

ARGONNE NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.

Argonne NATIONAL LABORATORY

FISSION FRAGMENT YIELD INFORMATION

- Fission produces hundreds of neutron-rich fission fragments. These isotopes have different lifetimes and chemical properties
- The fission fragment distribution experimental information is mostly obtained on longer-lived isotopes through decay measurements. Yield for shorter-lived isotopes is mostly from modeling to reproduce the measurement on longer-lived isotopes.
- Quantitative knowledge of the decay properties of these isotopes is critical for most of these measurements.
- This data is at best unreliable … we have a number of projects using CARIBU to improve this information on medium and shorter-lived isotopes to support the measurement techniques based on decay radiation detection (see earlier talks by K. Kolos and F. Kondev), but this is not the topic of this talk.
- We have developed a new approach for these measurements that works by detecting isobarically selected ions to directly determine the yield. This technique is essentially independent from the chemical properties of the isotope and can be applied to isotopes with half-life down to ~ 25 ms.

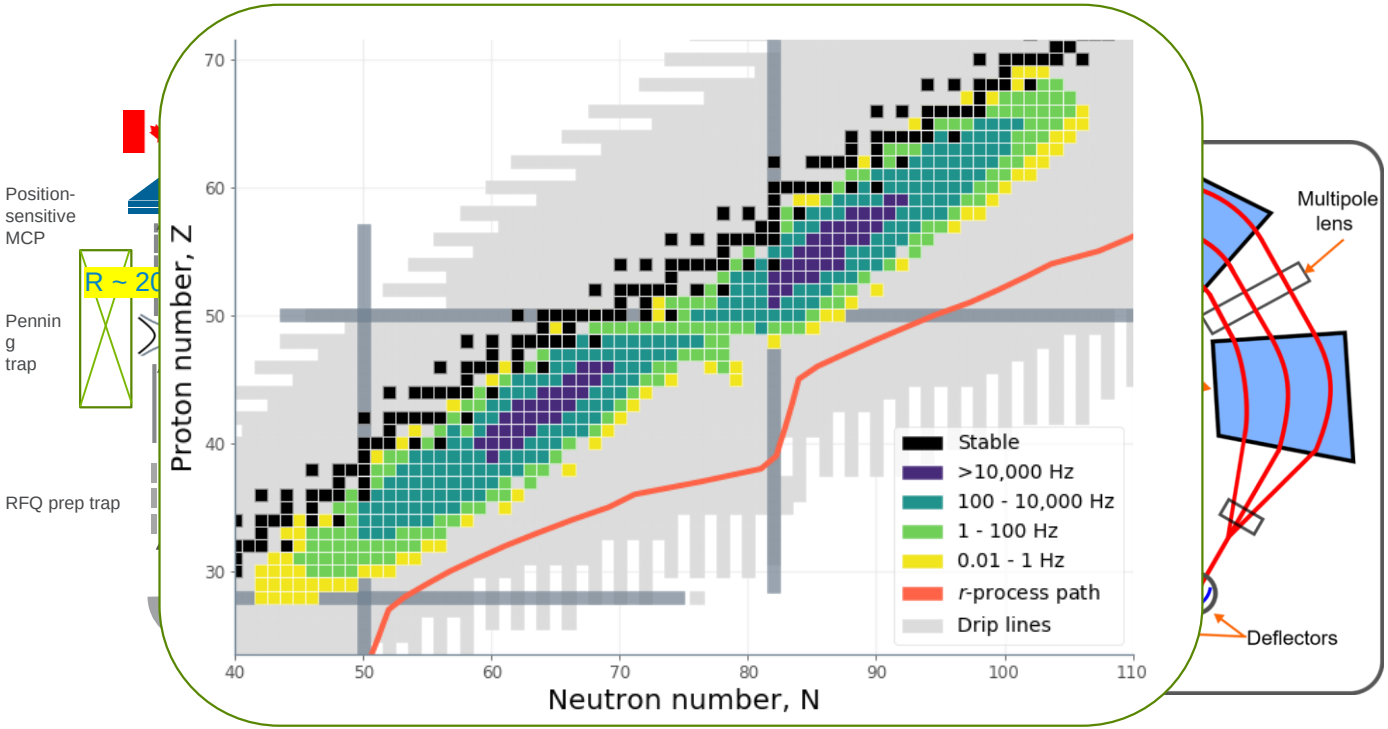
^{252}CF FISSION FRAGMENT YIELD TABLES SHOW SYSTEMATIC INCONSISTENCIES

isotope	E&R lifetime	E&R direct yield (%)	JEFF 3.1 direct yield (%)	ratio
75Ge	1.380h	1.48E-07	3.36E-07	0.44
76Ge	stable	1.15E-05	2.97E-05	0.39
77Ge	11.30h	6.94E-05	0.00015	0.46
78Ge	1.45 h	0.000621	0.000866	0.72
79Ge	19.1s	0.00174	0.000338	5.15
80Ge	29.5 s	0.00291	0.00585	0.50
81Ge	7.6 s	0.0046	0.005643	0.82
82Ge	4.6 s	0.00539	0.006424	0.84
83Ge	1.9 s	0.00639	0.002605	2.45
84Ge	1.2 s	0.0024	0.000898	2.67
85Ge	0.250s	0.00106	8.36E-05	12.68
86Ge	0.247s	0.000142	7.21E-06	19.71
87Ge	0.134s	2.02E-05	2.82E-07	71.70
88Ge	0.129s	1.59E-06	7.72E-09	205.94

isotope	E&R lifetime	E&R direct yield (%)	JEFF 3.1 direct yield (%)	ratio
99Mo	2.748d	0.00114	0.00306	0.37
100Mo	stable	0.0148	0.028806	0.51
101Mo	14.6 m	0.0893	0.18531	0.48
102Mo	11.3 m	0.464	0.46562	1.00
103Mo	1.13 m	1.47	0.75505	1.95
104Mo	60 s	2.83	2.7141	1.04
106Mo	8.4 s	3.47	4.3787	0.79
107Mo	3.5 s	2.01	1.1969	1.68
108Mo	1.5 s	0.667	0.20928	3.19
109Mo	1.41 s	0.148	0.017977	8.23
110Mo	2.77 s	0.0231	0.000733	31.51
111Mo	0.466s	0.00142	2.42E-05	58.72
112Mo	0.975s	5.34E-05	5.73E-07	93.16
113Mo	#N/A	#N/A	8.82E-09	#N/A
114Mo	0.377s	6.24E-09	1.27E-10	48.99

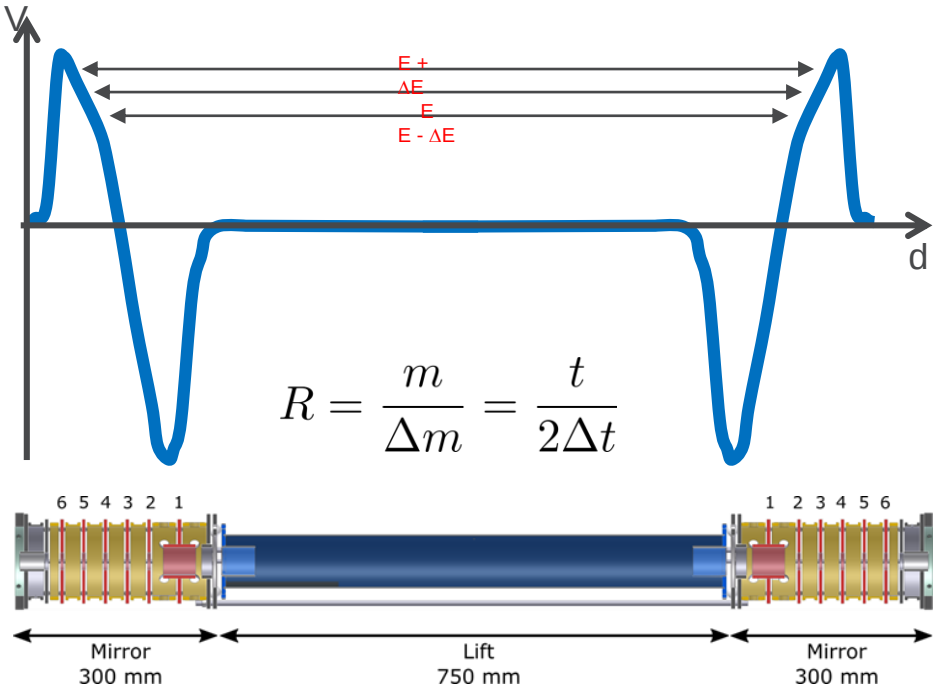
- Spontaneous fission is probably where it is easiest to do measurements but yet, we see significant differences between England & Rider and JEFF 3.1 .
- Not unexpected since for the shorter-lived isotopes, i.e. $t_{1/2}$< 1 min, most information is indirect

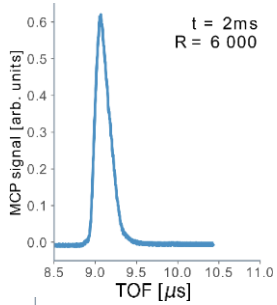
CARIBU
CALIFORNIUM RARE ISOTOPE BREEDER UPGRADE

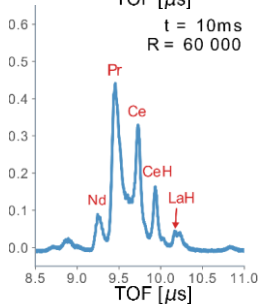


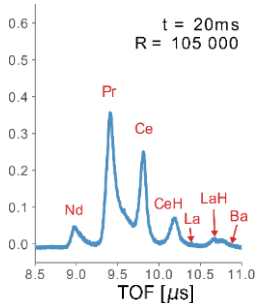
MR-TOF
MULTI-REFLECTION TIME-OF-FLIGHT MASS SEPARATOR

- System built to be isochronous with respect to energy …. i.e. $\Delta t / \Delta E = 0$
- Keep time dispersion from mass difference

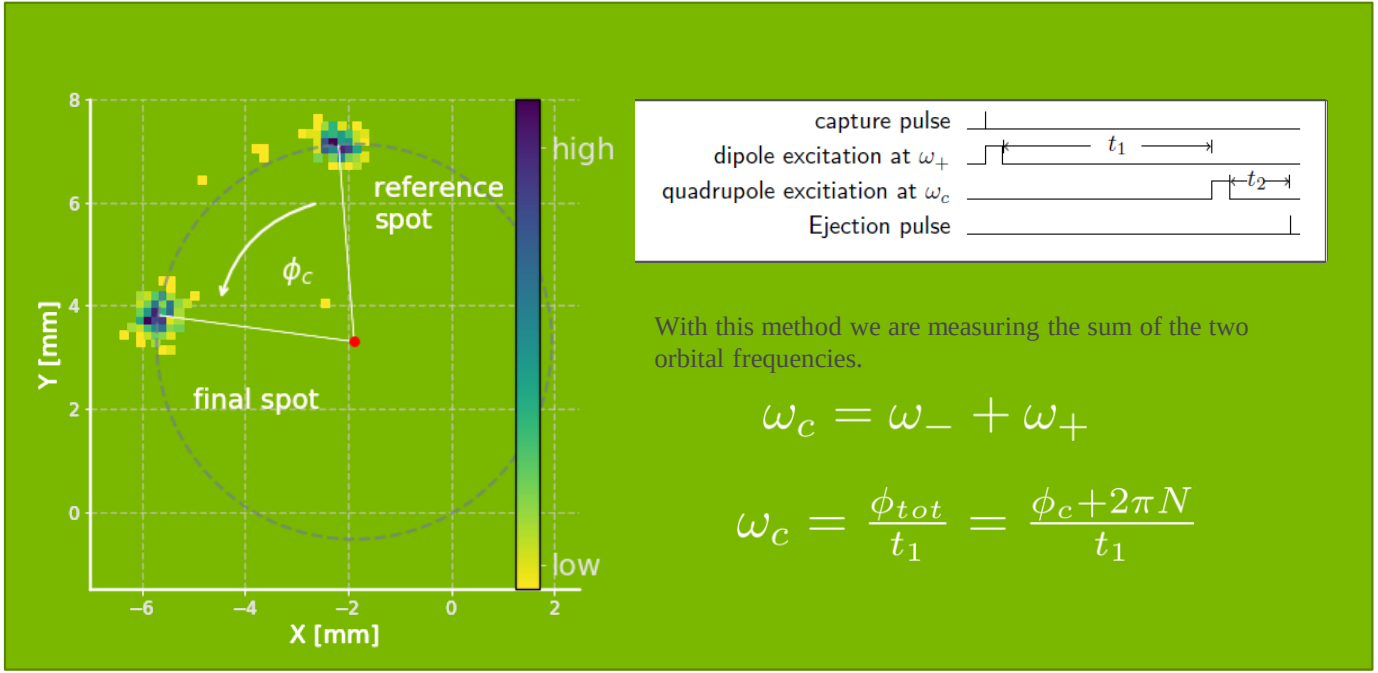








PHASE-IMAGING ION CYCLOTRON RESONANCE (PI-ICR) METHOD IN THE CPT PENNING TRAP SPECTROMETER



With this method we are measuring the sum of the two orbital frequencies.

$$\omega_c = \omega_- + \omega_+$$

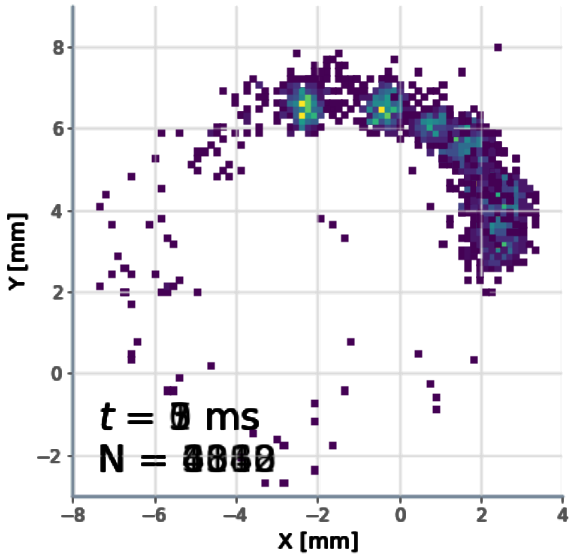
$$\omega_c = \frac{\phi_{tot}}{t_1} = \frac{\phi_c + 2\pi N}{t_1}$$

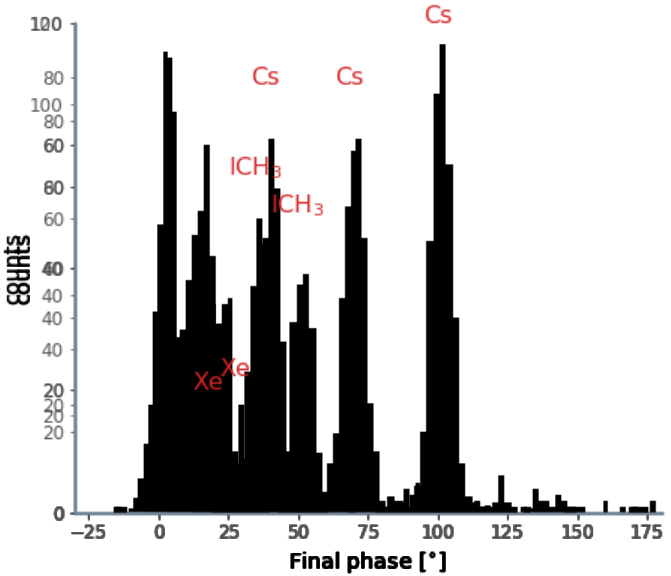
Originally developed off-line by S. Eliseev et al, PRL 110 (2013) 082501

We have demonstrated resolution of over 10,000,000 allowing to easily separate isomers

PI-ICR MASS SEPARATION

$$\nu_c = \frac{\phi_{tot}}{2\pi t} = \frac{\phi_c + 2\pi N}{2\pi t}$$

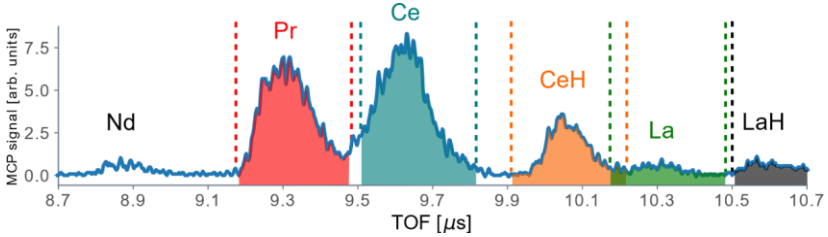


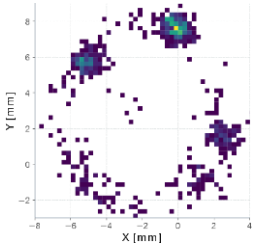


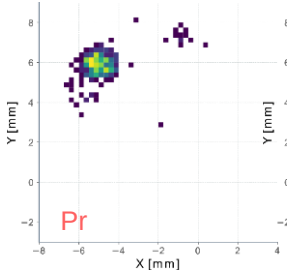
MR-TOF + PI-ICR

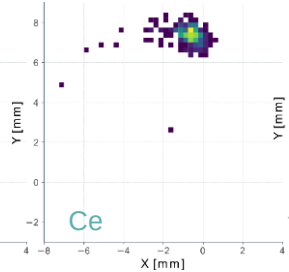
BEAM OF A/Q = 150/2+

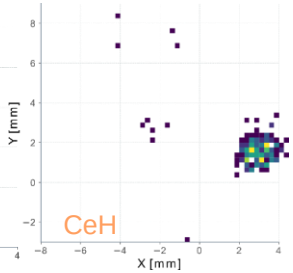
- MR-TOF is a crucial device for the CPT
- What does R = 100,000 really mean?
- Moving 300ns BNG window around allows us to select a single isobar and suppress others

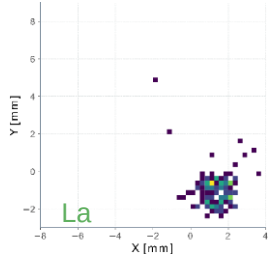


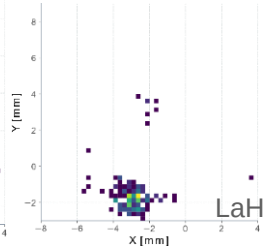




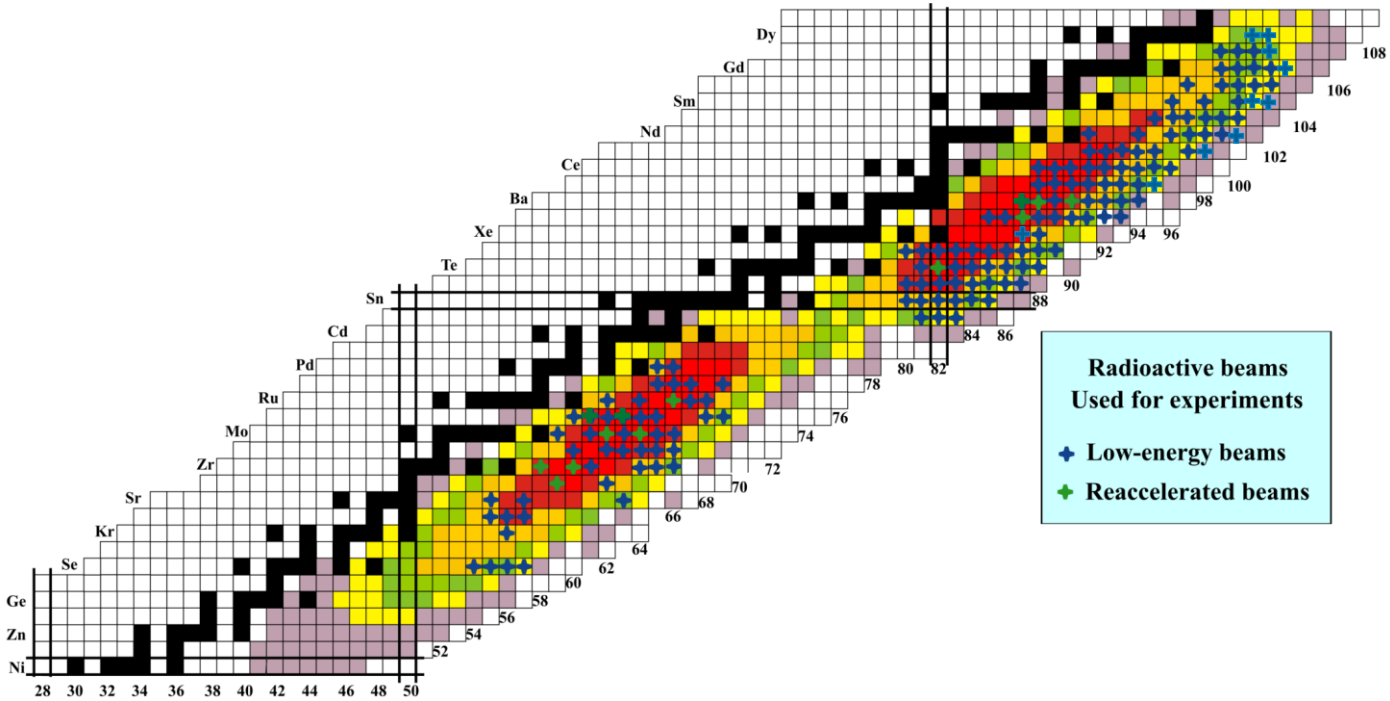






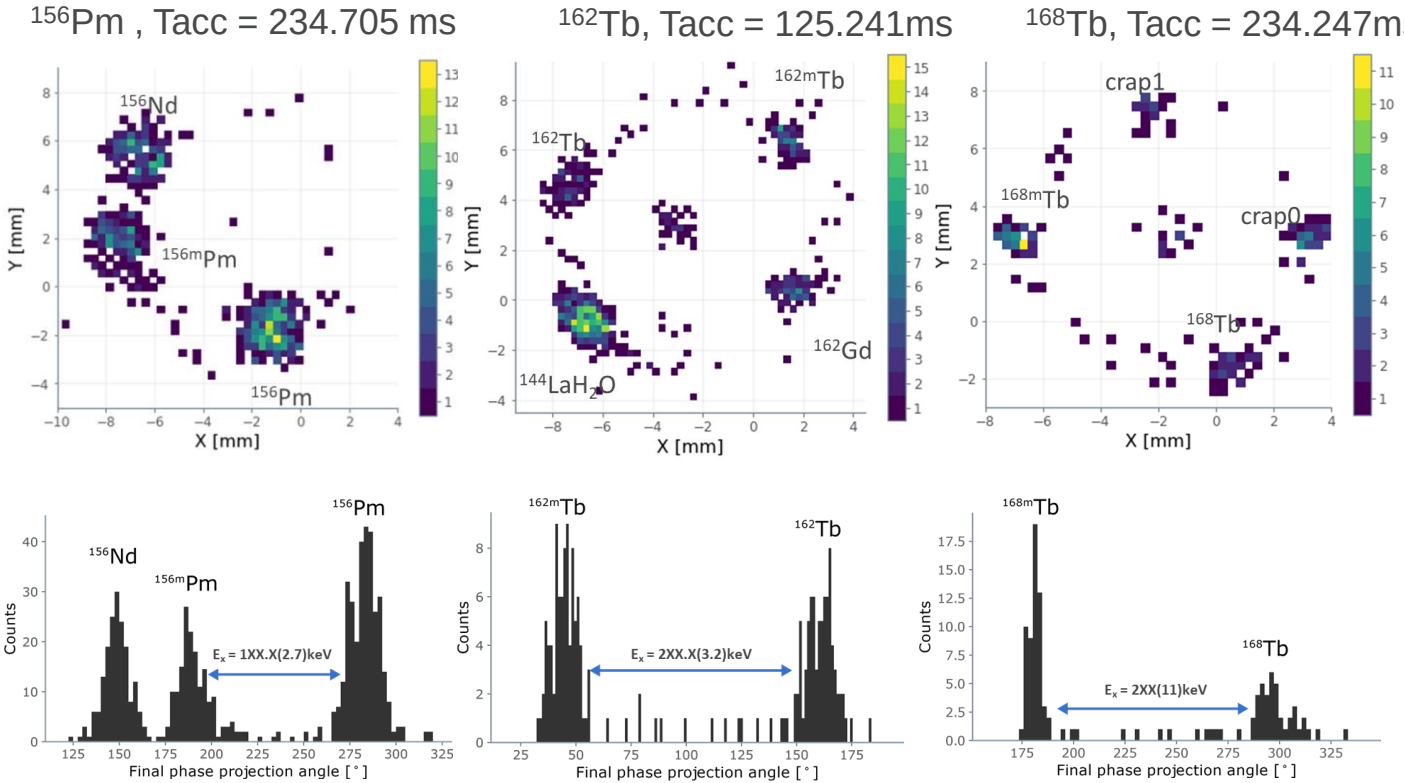


CARIBU BEAMS DELIVERED TO EXPERIMENTS SO FAR



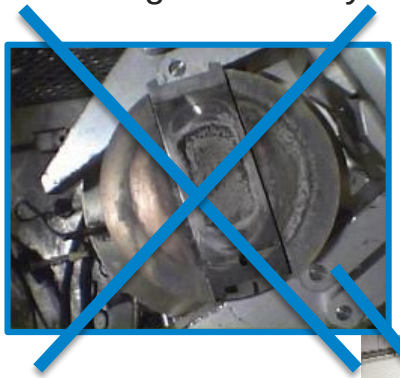
All of these beams now available in the new low-background low-energy area (Area 1)

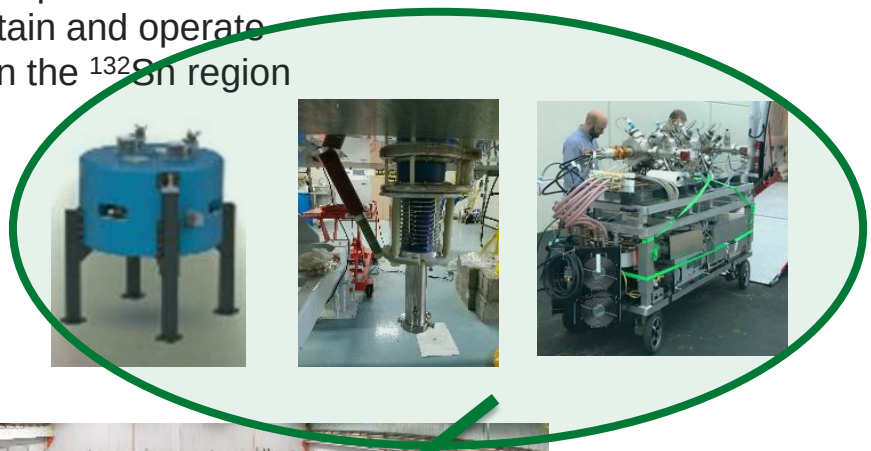
ION COUNTING ISOMER MEASUREMENTS: FISSION YIELD, EXCITATION ENERGY, …



NEUTRON GENERATOR UPGRADE TO CARIBU

- Replace ^{252}Cf source by neutron-induced fission on actinide foils. For the facility it provides
  - More reliable source of fission products
  - Operationally easier to maintain and operate
  - Higher fission yield feeding in the ^{132}Sn region

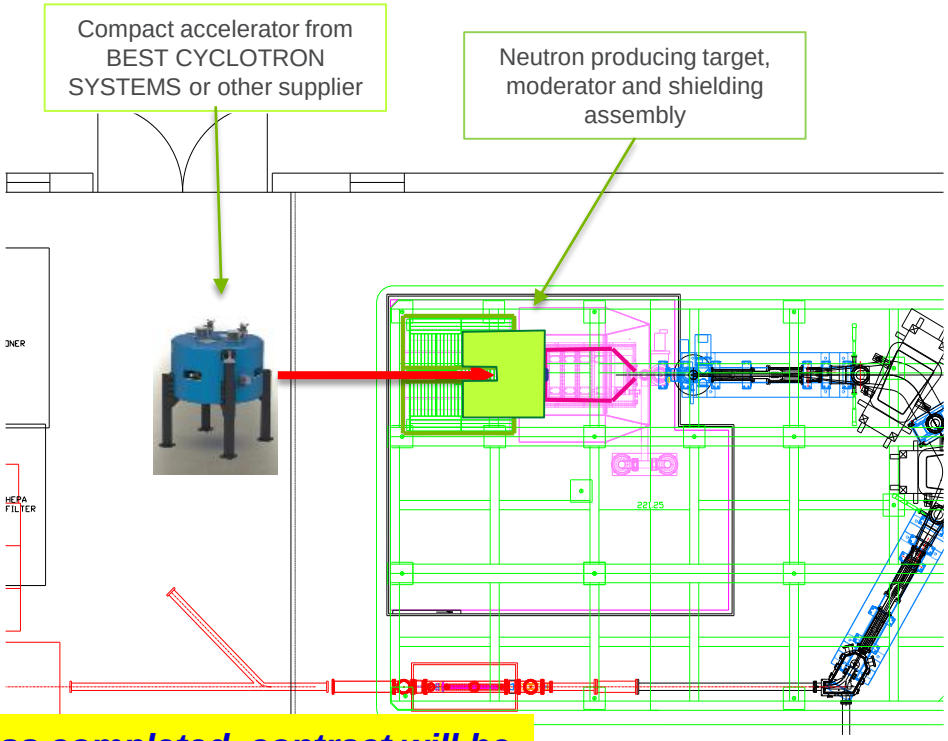




SELECTED P-7LI OPTION FOR NUCARIBU

Low-energy cyclotron/linac

- 6 MeV compact proton accelerator (cyclotron or linac)
- Can obtain sufficient current and higher energy so can afford to put it off the platform (lose 150 keV in energy)
- Is the less expensive option
- Easier to bring in services since off of HV platform
- Space available
- CARIBU shutdown shorter since less work on platform



Selection process completed, contract will be awarded this week

STATUS

- **CARIBU can provide pure, mass separated, low-energy beams of any fission product to various experimental stations … no chemical limitations, essentially no lifetime limitations ($t_{1/2}$ > 25 ms)**

Note: next ATLAS/CARIBU PAC deadline is March 1 2021

- **CARIBU currently using spontaneous fission of ^{252}Cf to produce fission fragments but will be upgraded to use neutron-induced fission on thin actinide foils**
- **Currently completing the analysis of fission-product isomer-to-g.s. ratios measurement for ^{252}Cf spontaneous fission**
- **CARIBU was off for a large part of CY2020 due to COVID-19 shutdown/restrictions but restarting now. Fission fragment branching ratios in ^{252}Cf spontaneous fission will be measured in CY2021 using the ion counting method to resolve discrepancies between LANL and European tables.**
- **nuCARIBU project is started and installation of neutron-induced fission setup is expected in FY2022.**
- **Measurements on neutron-induced fission on ^{235}U and other actinides using counting system developed for ^{252}Cf will proceed in FY2023 and following years.**

This work is a collaboration between ANL and LLNL, with co-PIs Guy Savard (ANL) and Nick Scielzo (LLNL).