202gPb Production Cross Section Measurements via In-Beam Spectroscopy

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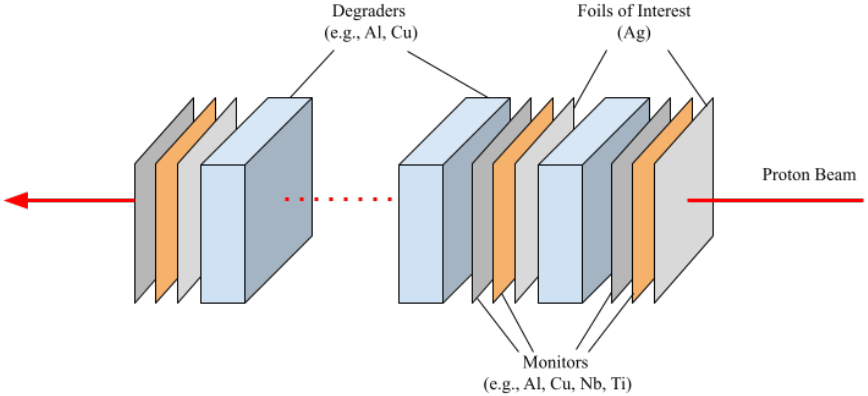
Tri-Lab Effort in Nuclear Data (TREND) -1

Stacked-target measurements and reaction modeling for Isotope Production by Lawrence Berkeley National Lab, Los Alamos National Lab, and Brookhaven National Lab. Texas A&M is a new addition to version 2.0 of the collaboration.



LBNL/TAMU
Up to 55 MeV

LANL
Up to 100 MeV

BNL
Up to 200 MeV

Tri-Lab Effort in Nuclear Data (TREND) -2

In the past we have measured cross sections for

- ^{nat}Nb(p,x)
  - ^{93}Nb(p,4n)^{90}Mo as a monitor reaction for intermediate-energy protons
- ^{75}As(p,x)
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  - ^{103}Pd as a Meitner-Auger emitter for brachytherapy

All via the stacked-target method, up to 200 MeV

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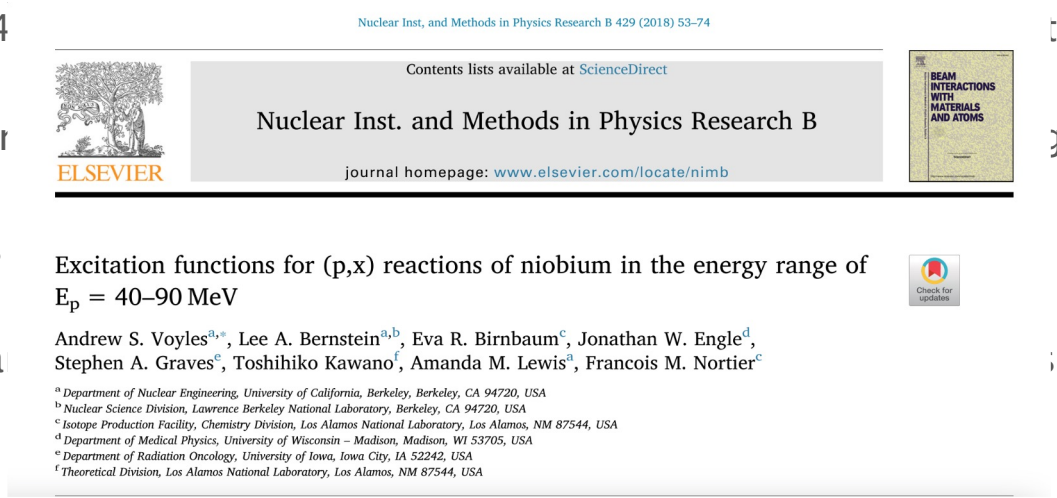

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Excitation functions for (p,x) reactions of niobium in the energy range of E_p = 40–90 MeV

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[d] Department of Medical Physics, University of Wisconsin – Madison, Madison, WI 53705, USA
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[f] Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87544, USA

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All via the stacked-target method, up to 200 MeV

PHYSICAL REVIEW C **104**, 064615 (2021)

Measurement and modeling of proton-induced reactions on arsenic from 35 to 200 MeV

Morgan B. Fox,[1,*] Andrew S. Voyles,[1,2,†] Jonathan T. Morrell,[1] Lee A. Bernstein,[1,2] Jon C. Batchelder,[1] Eva R. Birnbaum,[3] Cathy S. Cutler,[4] Arjan J. Koning,[5] Amanda M. Lewis,[1] Dmitri G. Medvedev,[4] Francois M. Nortier,[3] Ellen M. O'Brien,[3] and Christiaan Vermeulen[3]

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[3]*Los Alamos National Laboratory, Los Alamos, New Mexico 87544, USA*
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[5]*International Atomic Energy Agency, P.O. Box 100, A-1400 Vienna, Austria*

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All via the stacked-target method, up to 200 MeV

Measurement of Proton-Induced Reactions on Lanthanum from 55–200 MeV by Stacked-Foil Activation

Jonathan T. Morrell,[1] Ellen M. O'Brien,[1] Michael Skulski,[2] Andrew S. Voyles,[3] Dmitri G. Medvedev,[2] Veronika Mocko,[1] Lee A. Bernstein,[4,3] and C. Etienne Vermeulen[1]

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[2] *Brookhaven National Laboratory, Upton, NY 11973, USA*

[3] *University of California, Berkeley, Berkeley, CA 94720, USA*

[4] *Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA*

(Dated: February 29, 2024)

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All via the stacked-target method, up to 200 MeV

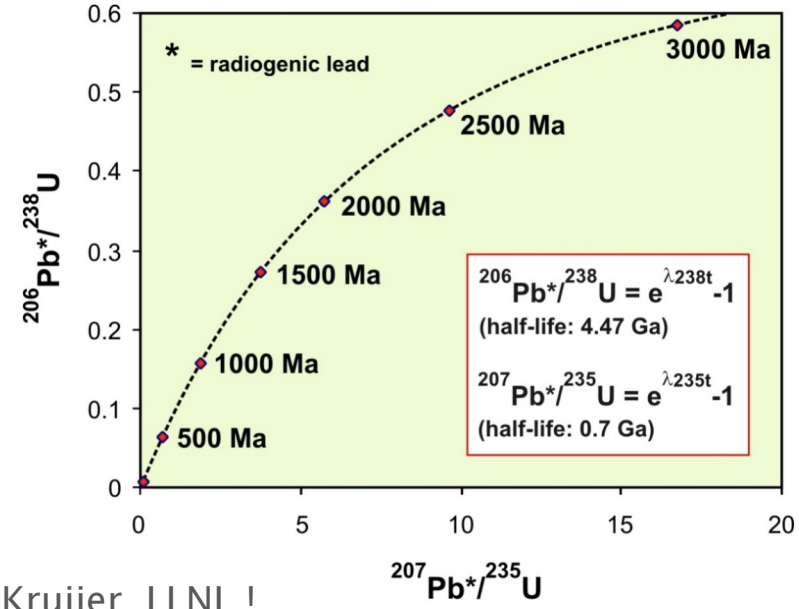
Tri-Lab Effort in Nuclear Data (TREND) -3

Stacked-target irradiation with decay gamma spectroscopy have

- Pro:
  - Measurements at multiple discrete energies without having to retune the beam
- Cons:
  - Long-lived/stable nuclei produced cannot be seen
  - Isotopes without decay gamma lines cannot be seen

^{202g}Pb production for U-Pb chronometry

- Taking advantage of the ^{238}U and ^{235}U decay chains, the U-Pb system allows studies of
  - Timings of mass extinction
  - Rate of climate change
  - 🌛Lunar formation🌜
- Thermal Ionization Mass Spectroscopy (TIMS)
  - ^{202}Pb-^{205}Pb double spike for mass fractionation correction
  - Pb isotopic analyses to sub-nanogram quantities!



Thanks to T. Kruijer, LLNL !

Y. Amelin and W. J. Davis. Isotopic analysis of lead in sub-nanogram quantities by TIMS using a ^{202}Pb–^{205}Pb spike. J. Anal. At. Spectrom., 21:1053–1061, 2006.

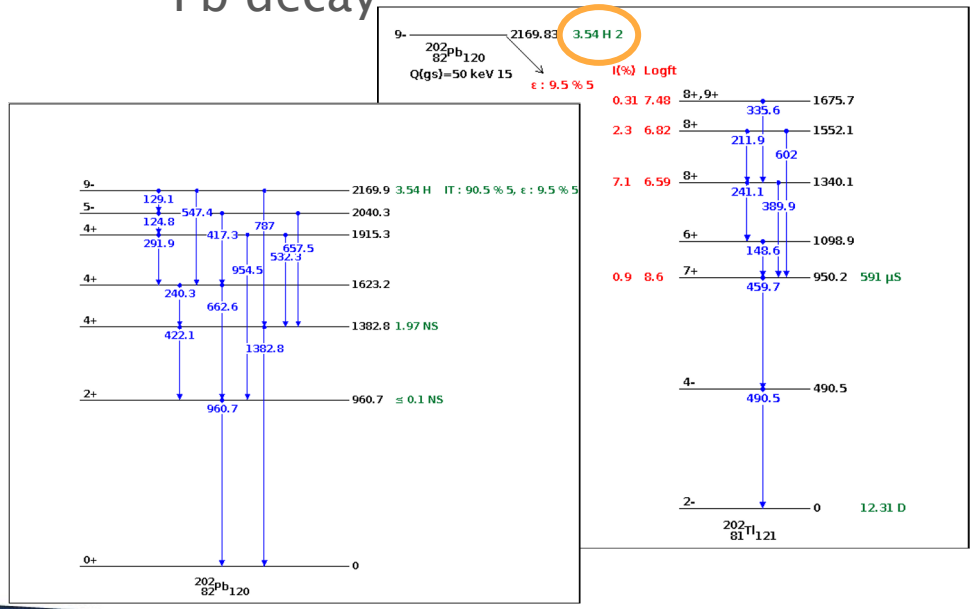
^{202g}Pb production -1

- ^{202g}Pb production cross sections
  - Only one currently available dataset from ANY reaction pathway, measured by Michel *et al.*, via secular equilibrium with ^{202}Tl
- Our proposed pathway: ^{nat}Tl(p,x)^{202g}Pb

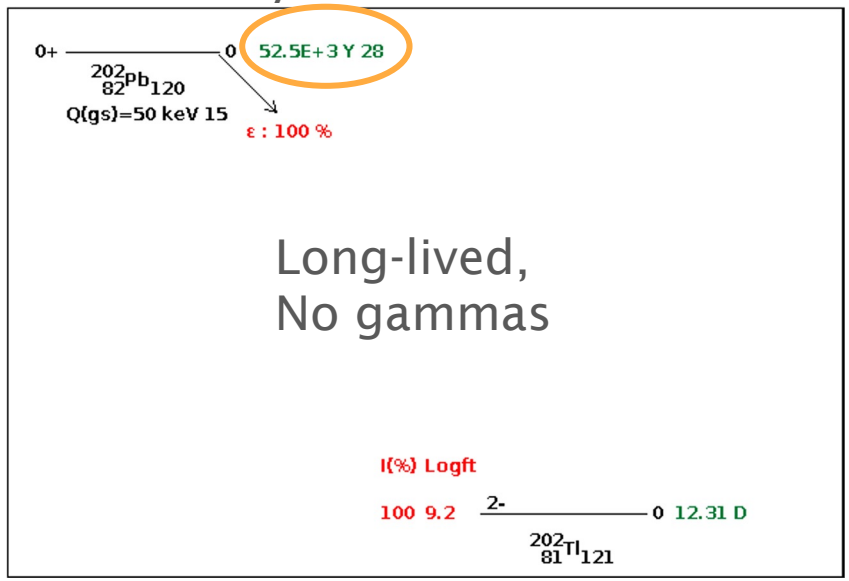
Rolf Michel *et al.* (2002) Cross Sections for the Production of Radionuclides by Proton-Induced Reactions on W, Ta, Pb and Bi from thresholds up to 2.6 GeV, Journal of Nuclear Science and Technology, 39:sup2, 242-245, DOI: 10.1080/00223131.2002.10875084

^{202g}Pb production -2

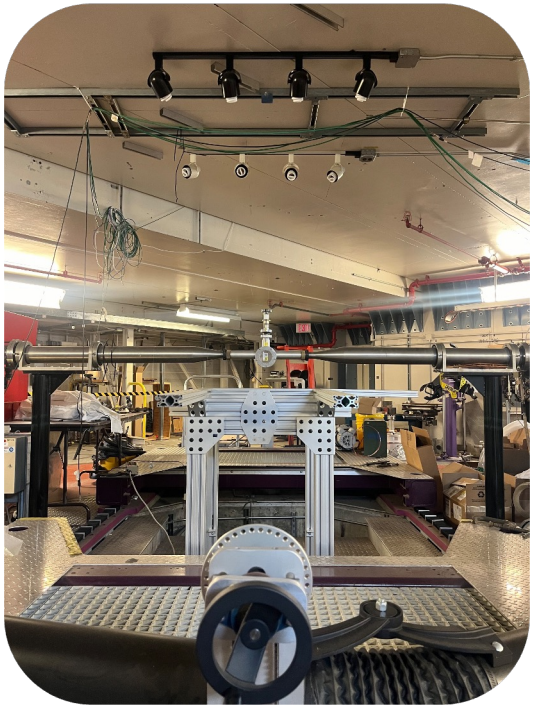
^{202m}Pb decay

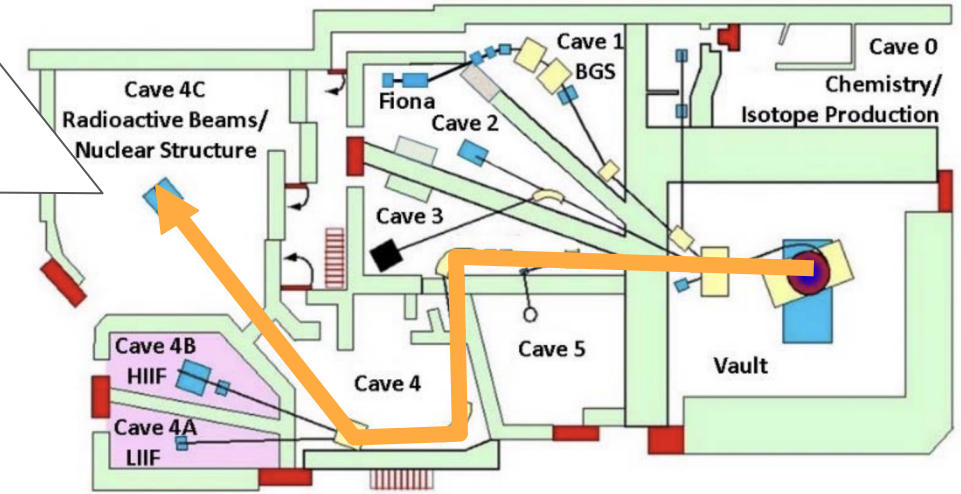


^{202g}Pb decay



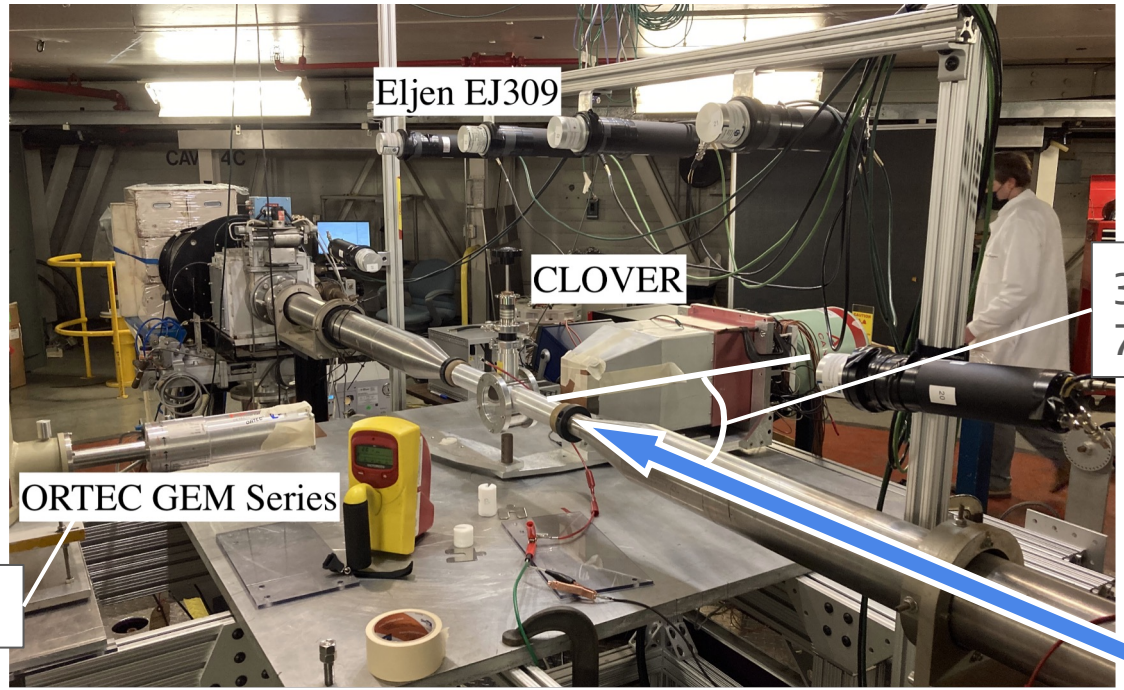
Cave 4C at LBNL's 88-Inch Cyclotron



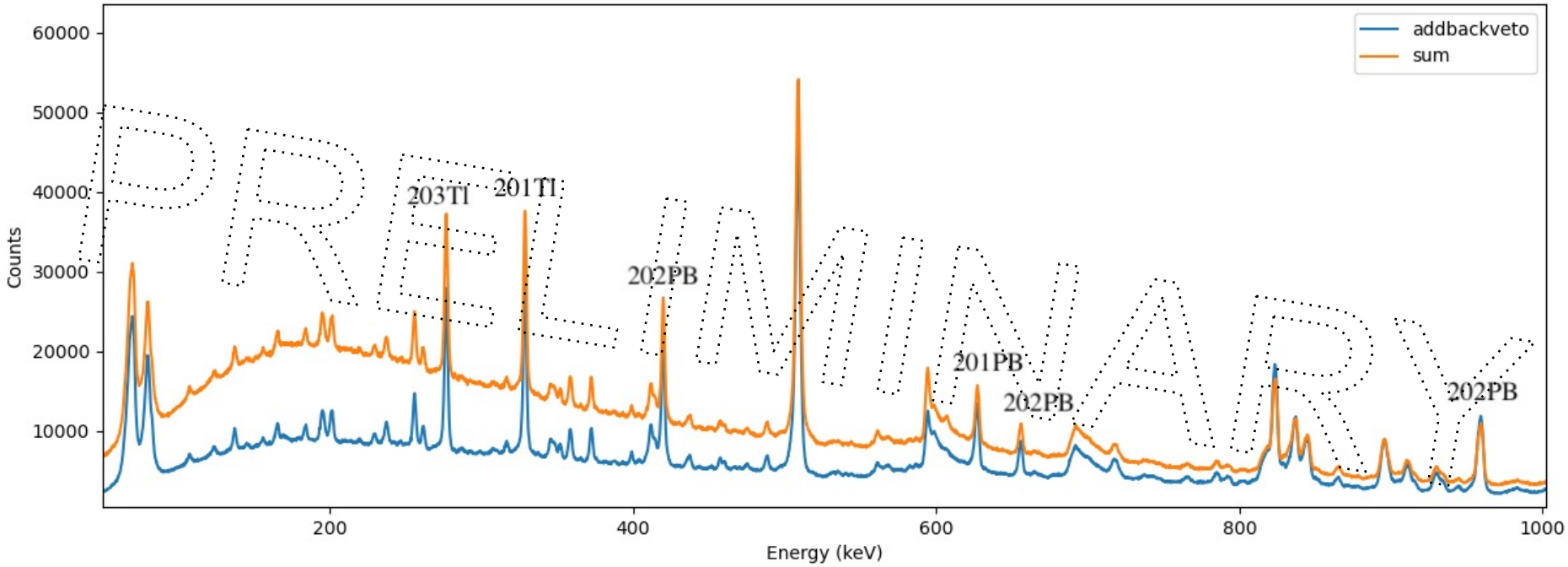


The 88-Inch Cyclotron: A one-stop facility for electronics radiation and detector testing. M.Kireeff-Covo *et al.*,. Measurement, 127, (2018), p. 580-587. https://doi.org/10.1016/j.measurement.2017.10.018

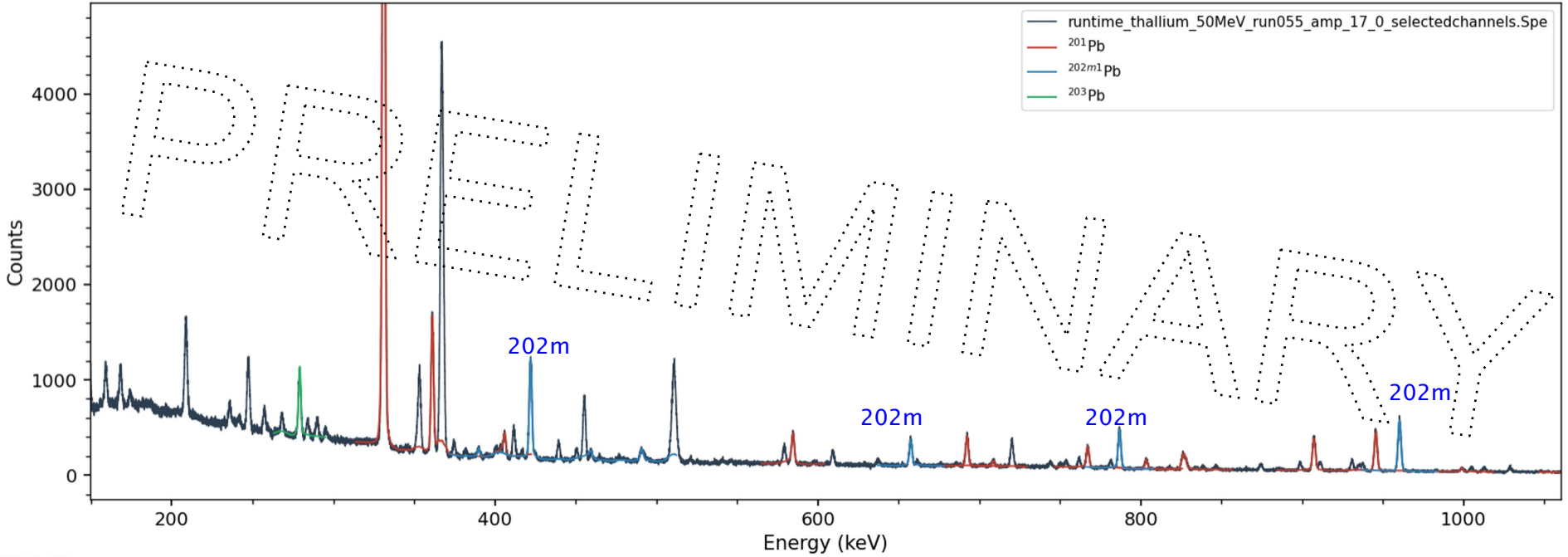
Experimental setup: in-beam spectroscopy



In-beam gamma spectrum (48°)

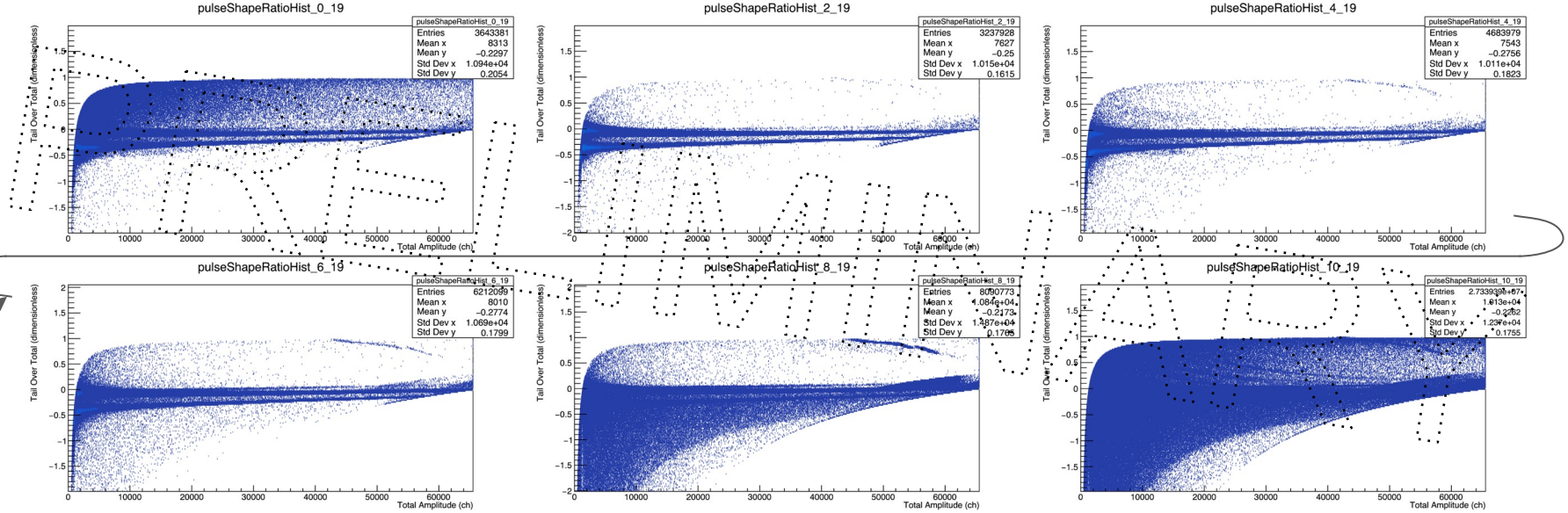


Decay gamma spectrum



Neutron detection at 6 angles

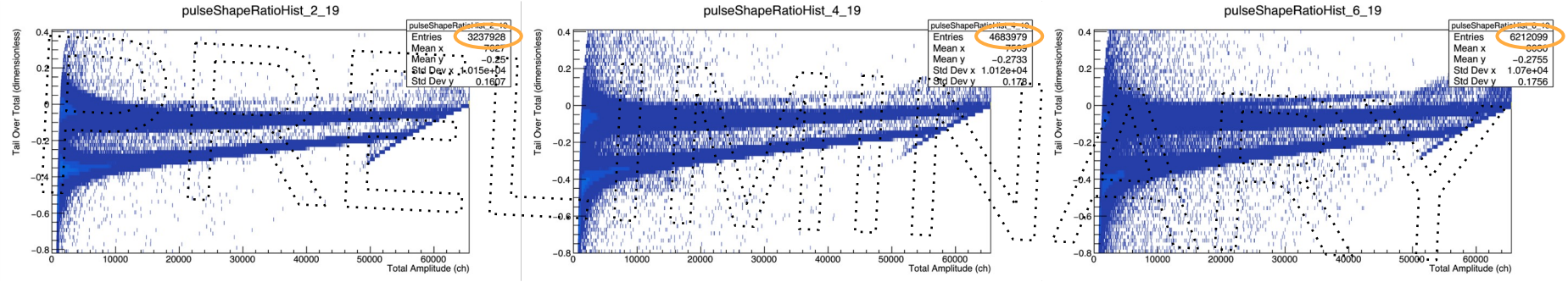
Upstream of target



Downstream of target

Neutron detection

Upstream of target → Downstream of target



Proton energy = 50 MeV

Future plans

Building on other works[1, 2] of the Tri-Lab Effort in Nuclear Data (TREND) –

- The partial cross section measurements of this work are complemented by results of a ^{nat}Tl(p,x) stacked-target irradiation
- Double-differential cross section measurements enable further adjustments of TALYS or CoH parameters
  - Gammas - level density, ɣ strength function, …
  - Neutrons - optical model, pre-equilibrium, …

[1] M. Fox *et al.* Investigating high-energy proton-induced reactions on spherical nuclei: Implications for the preequilibrium exciton model. Phys. Rev. C, 103:034601, Mar 2021.
[2] C. Apgar *et al.* Investigation of the production of ^{117m}Sn and ^{119m}Te via proton bombardment on natural antimony: Implications for charged particle reaction modeling. in preparation, 2024.

Collaborators and acknowledgement

Y.-H Lee[1], A.S. Voyles[1], C.E. Apgar[1], M.S. Basunia[2], J.C. Batchelder[1], L.A. Bernstein[1,2], J.A. Brown[1], C.S. Cutler[4], J.M. Gordon[1], T.A. Laplace[1], W. Lin[4], D.G. Medvedev[4], J.T. Morrell[3], E.M. O'Brien[3], K. Rector[3], M. Skulski[4], C.E. Vermeulen[3]

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