Isotope Production Activities at LBNL and LANSCE-IPF:

Development of a new Nb(p,x)^{99}Mo Monitor Reaction and Fe,La(p,x) Production Cross-Section Measurements

Andrew S. Voyles

30 August 2018 – 17th International Workshop on Targetry and Target Chemistry

Berkeley UNIVERSITY OF CALIFORNIA

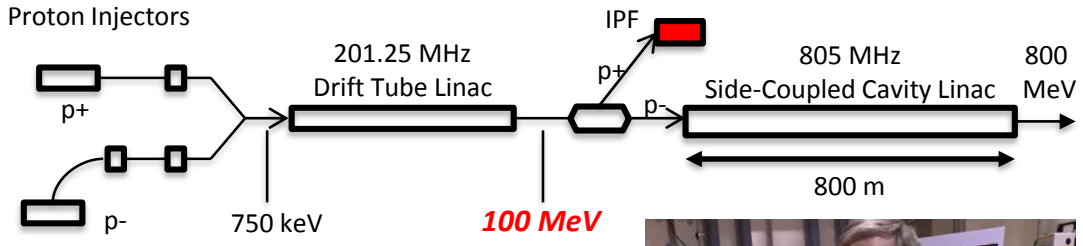
BERKELEY LAB

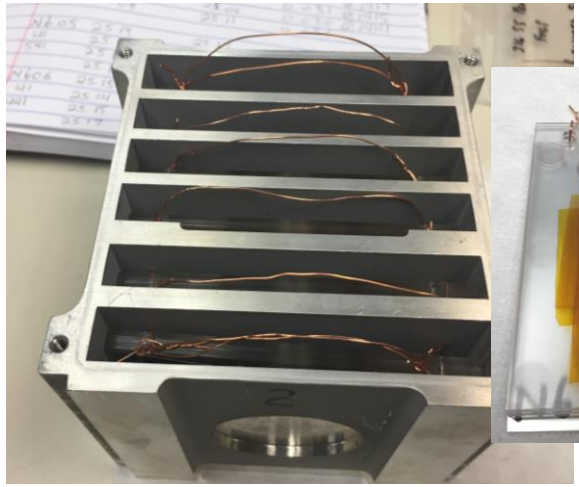
Stacked-target Charged Particle Excitation Functions

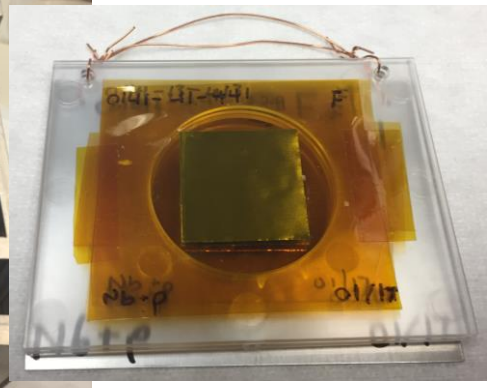
Intermediate Energy – LANL

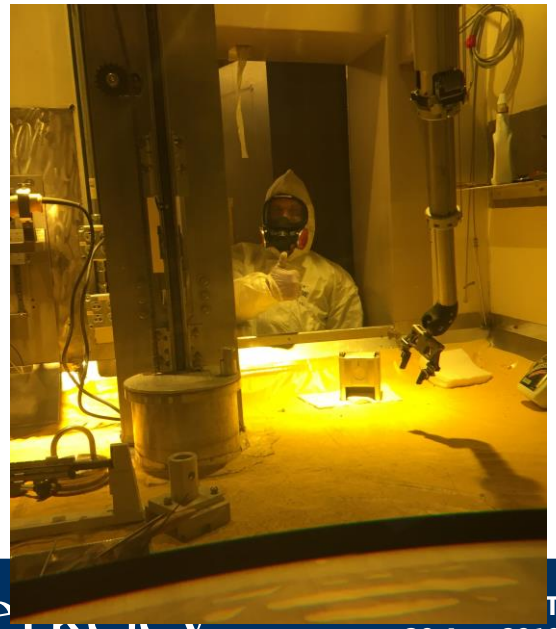
Measurements @ LANL – Nb(p,x)

- Well-characterized monitor reaction data is a top-priority objective
  - Vital for determination of fluence, energy for isotope production
  - Current data are deficient for E_p>30 MeV
- A stacked target measurement was run at LANSCE-IPF to help develop the ^{93}Nb(p,4n)^{90}Mo reaction as a new 30-200 MeV proton standard

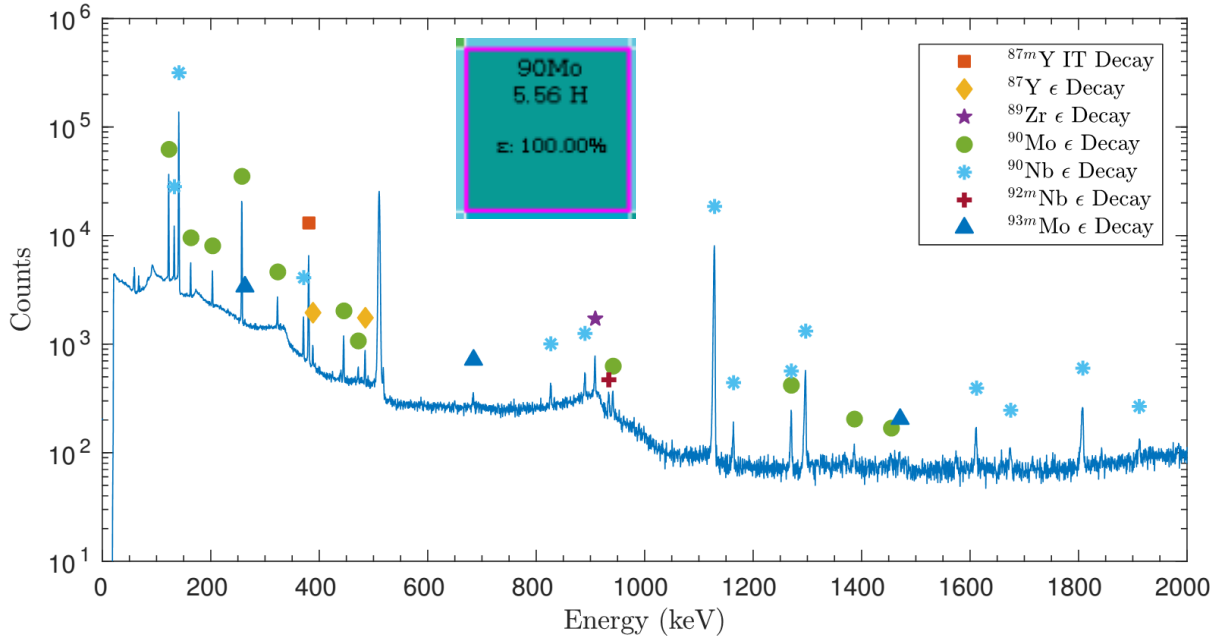






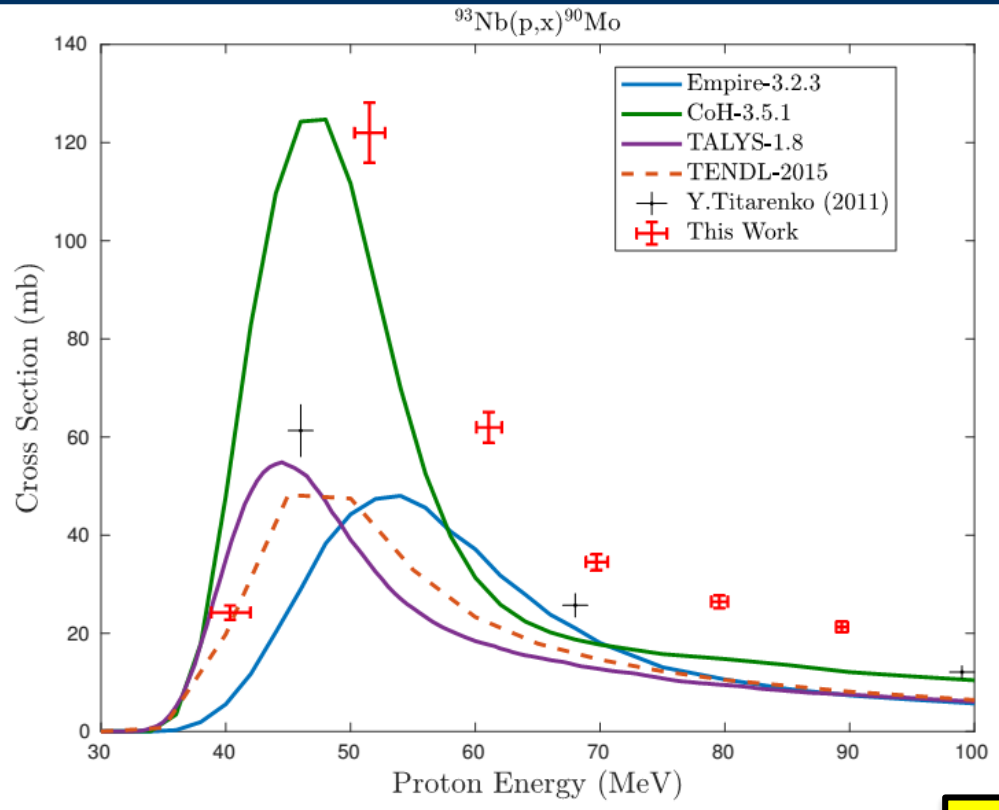


M. Nortier

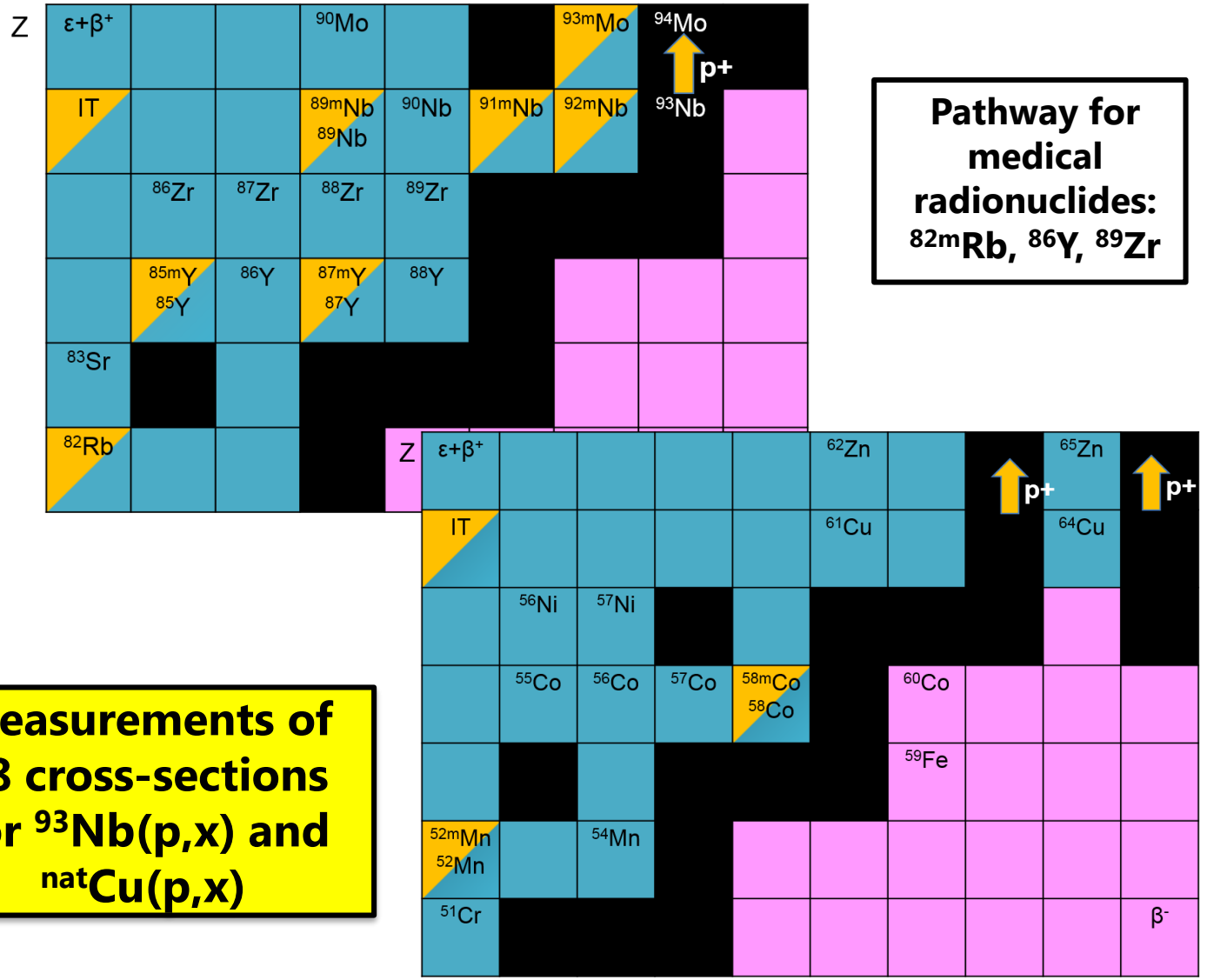


[1] A.S. Voyles, NIM B 429 (2018)

Measurements @ LANL – Nb(p,x)



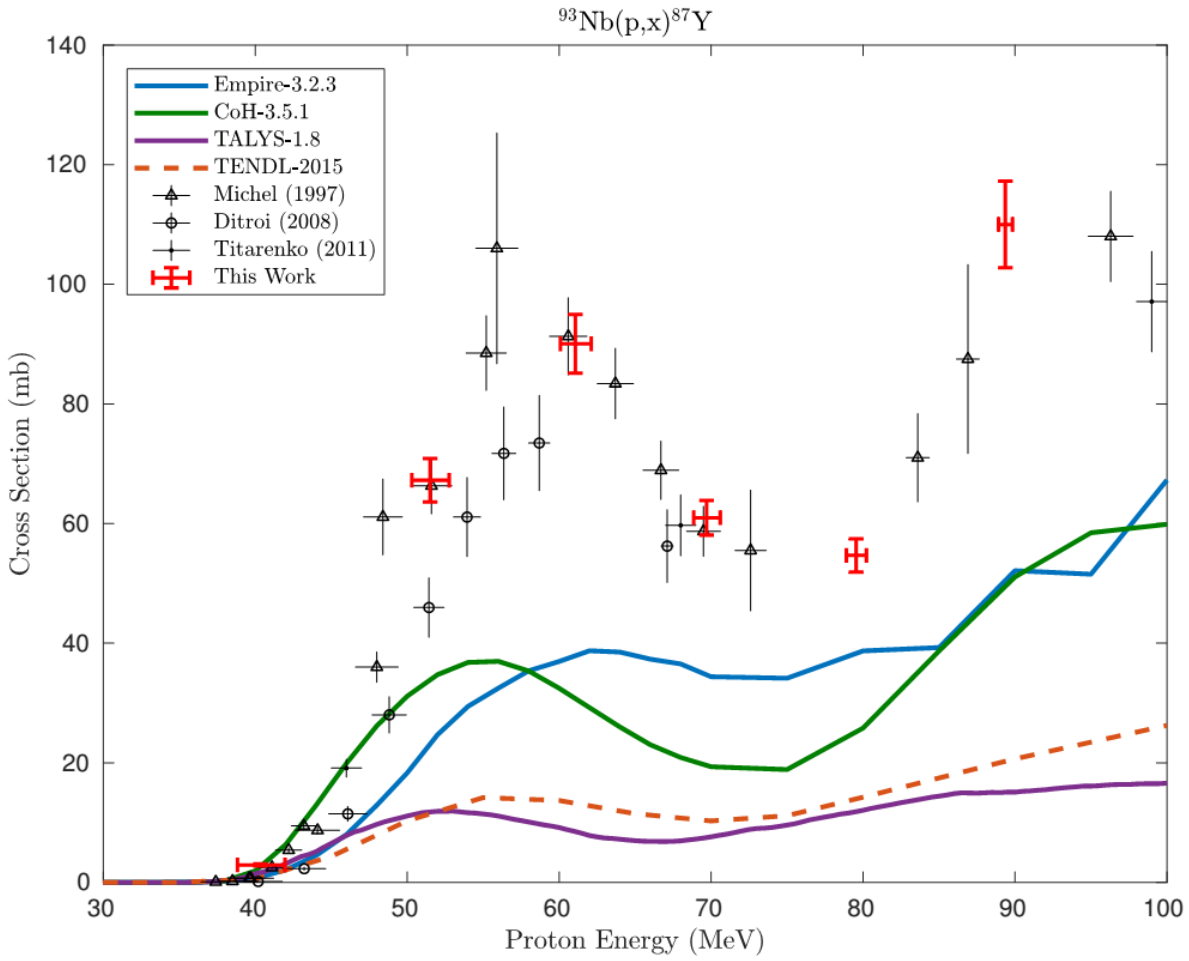
A.S. Voyles et al., "Excitation functions for (p,x) reactions of niobium in the energy range of E_p = 40–90 MeV", NIM B 429 (2018) 53–74. June 2018

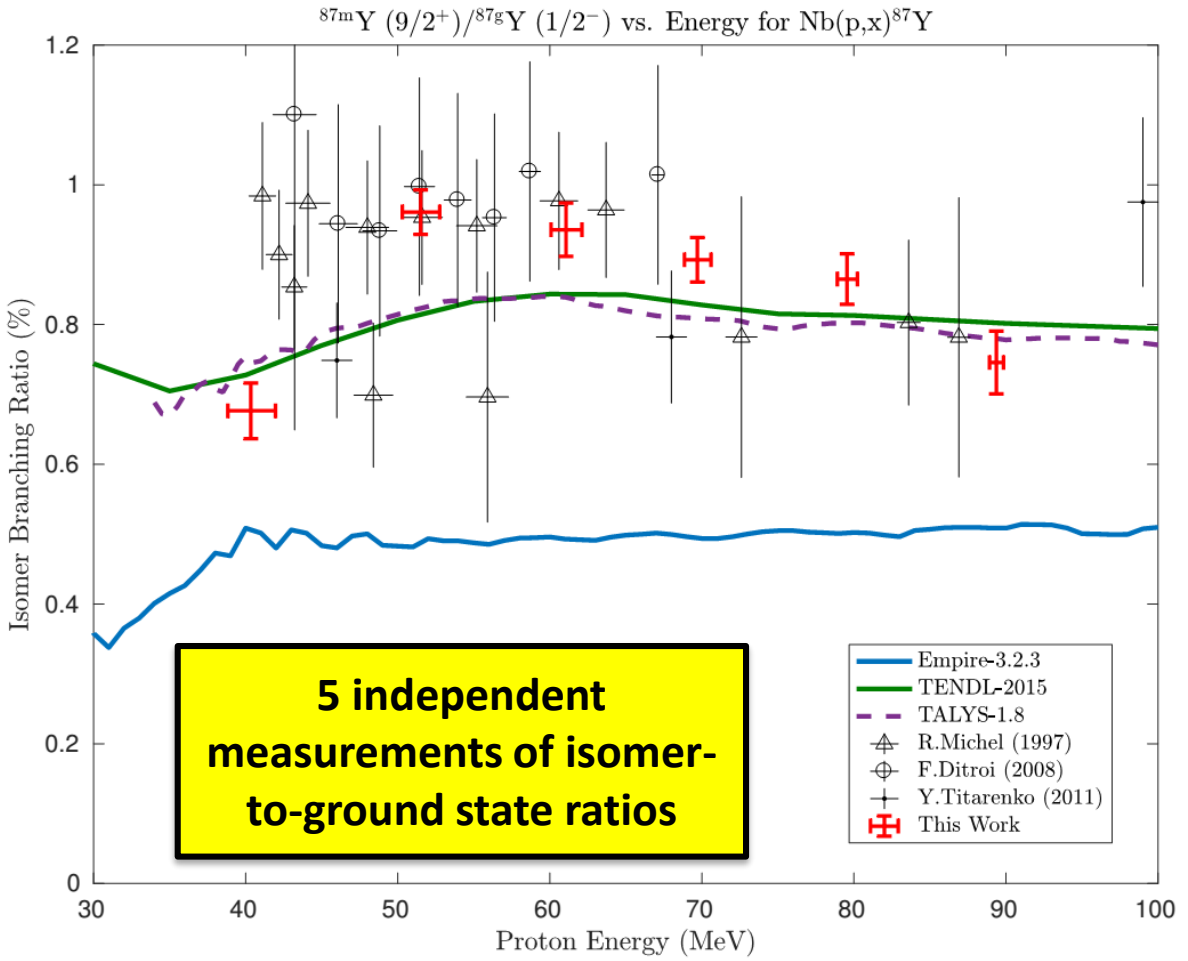


Pathway for medical radionuclides: ^{82m}Rb, ^{86}Y, ^{89}Zr

Measurements of 38 cross-sections for ^{93}Nb(p,x) and ^{nat}Cu(p,x)

Measurements @ LANL – Nb(p,x)

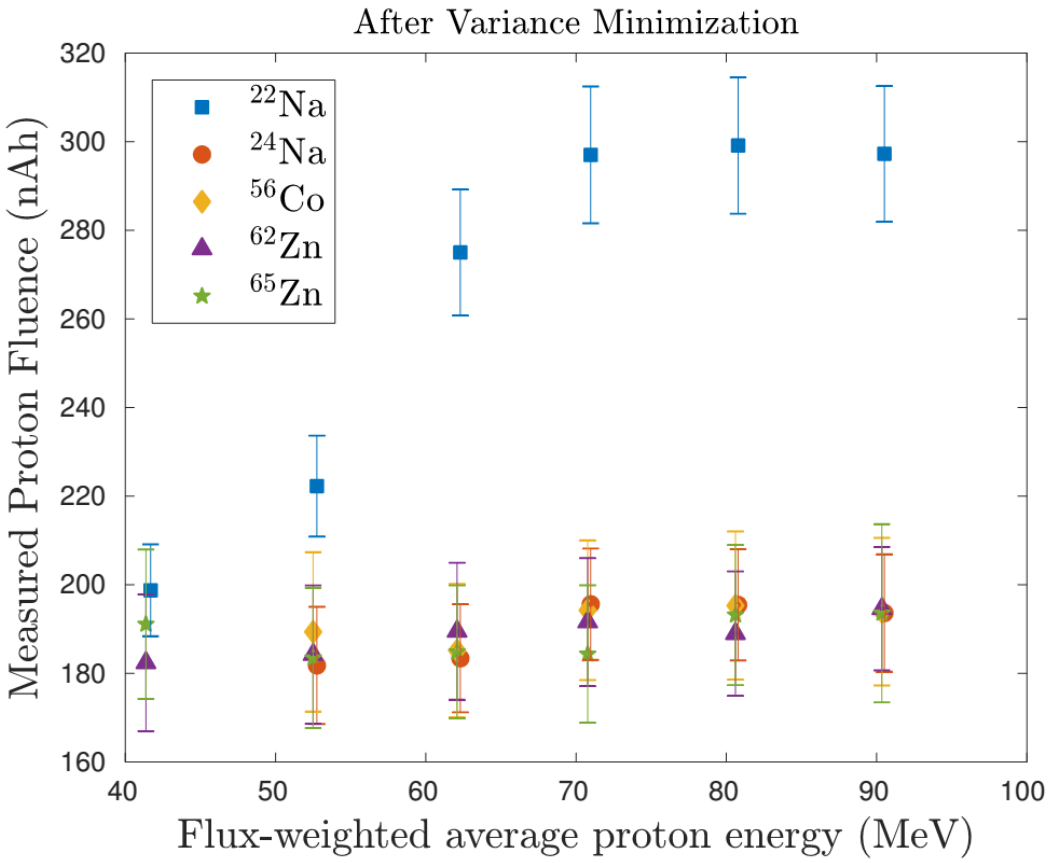


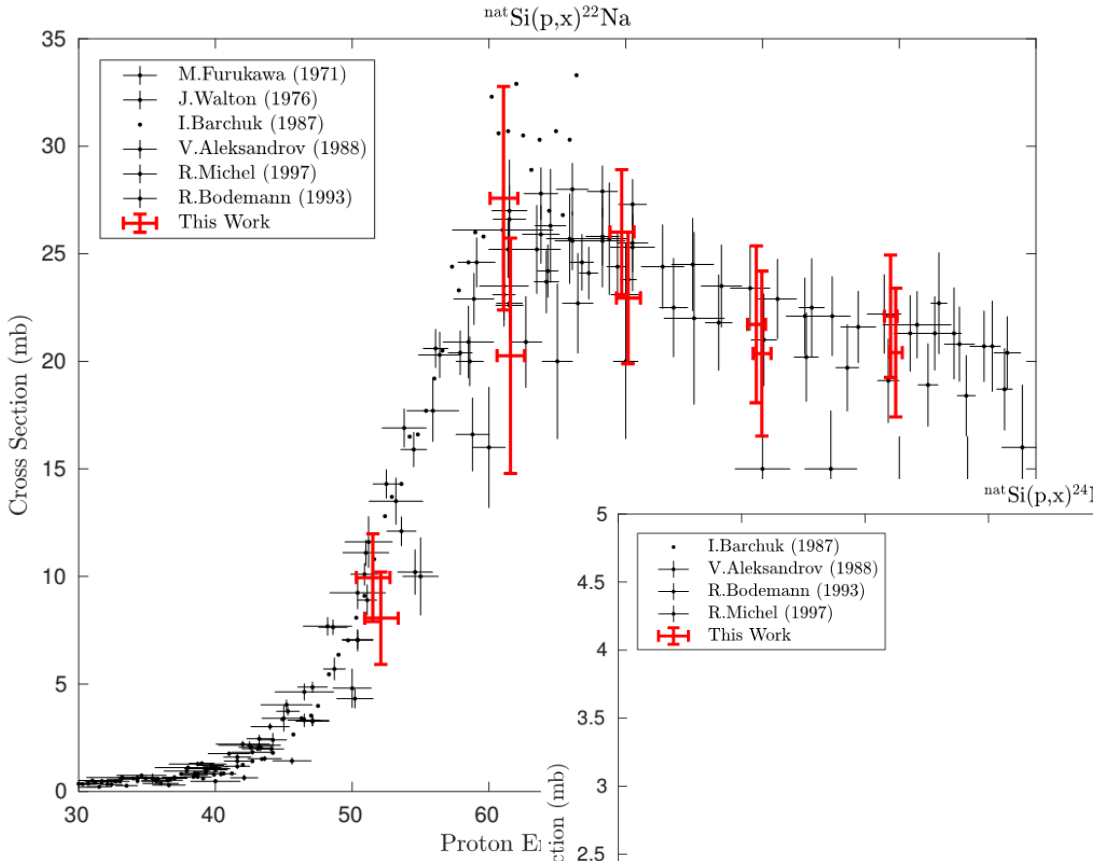


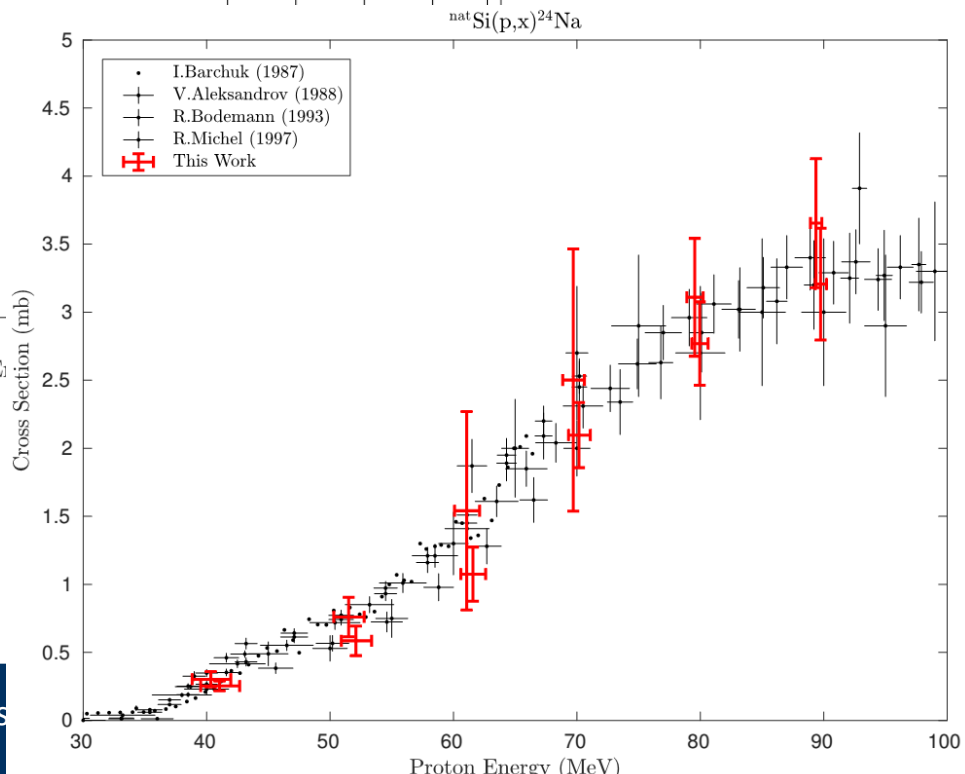
5 independent measurements of isomer-to-ground state ratios

[1] A.S. Voyles, NIM B 429 (2018)

Measurements @ LANL – Nb(p,x)







"Excess" fluence seen in ^{22,24}Na consistent with production via Si(p,x)

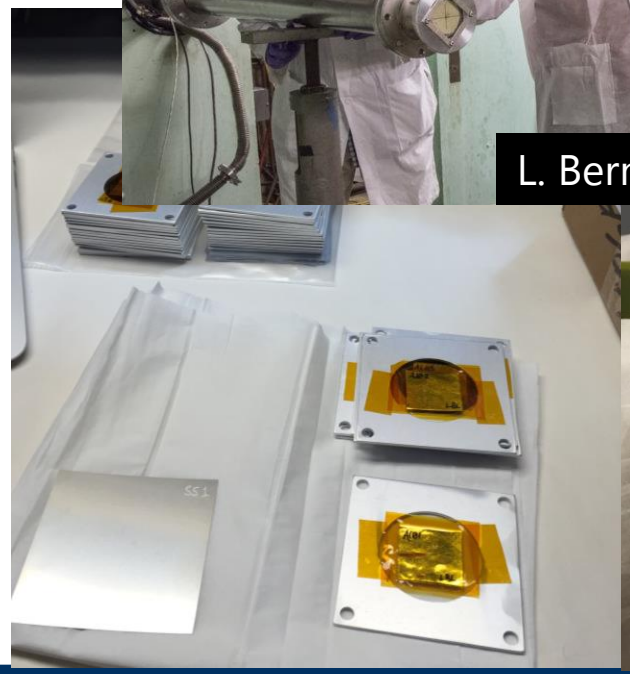
[1] A.S. Voyles

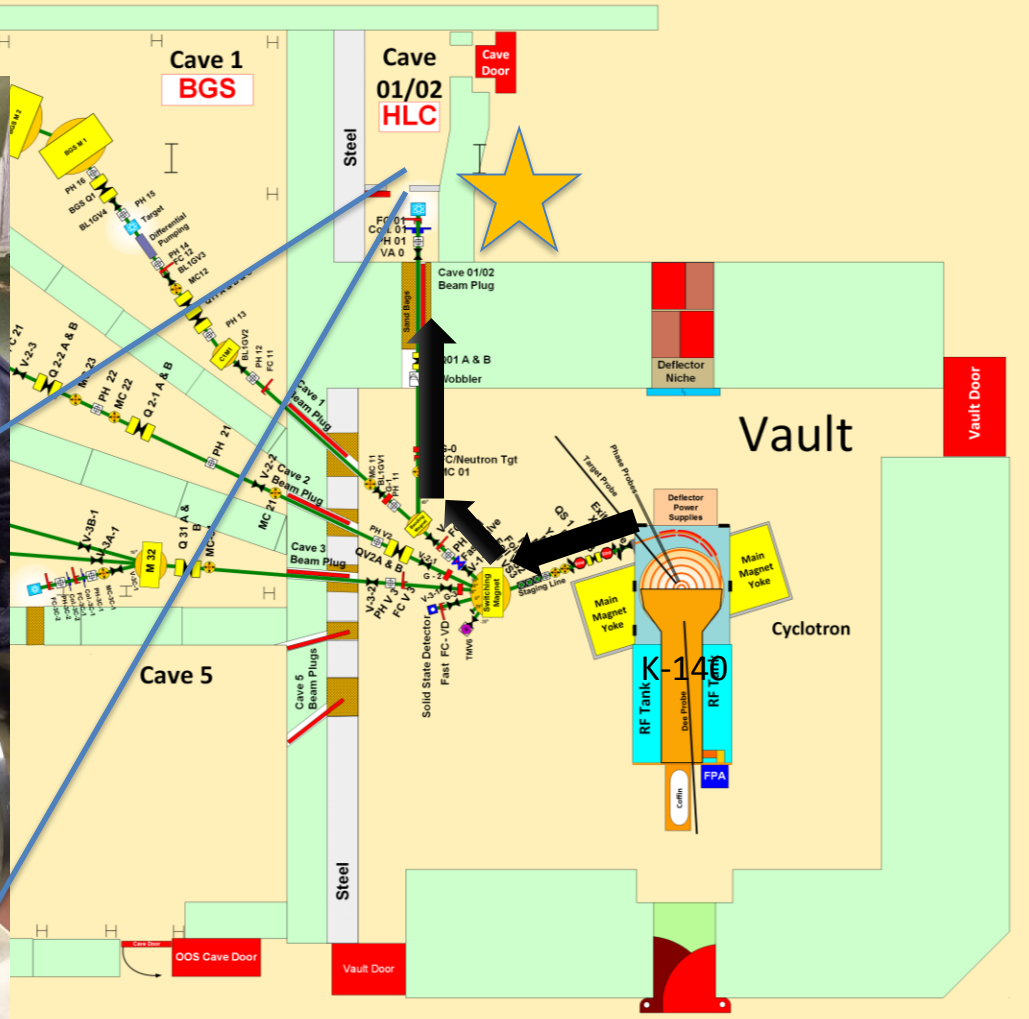
Stacked-target Charged Particle Excitation Functions

Low(er) Energy – LBNL

Stacked-target Charged Particle Excitation Functions

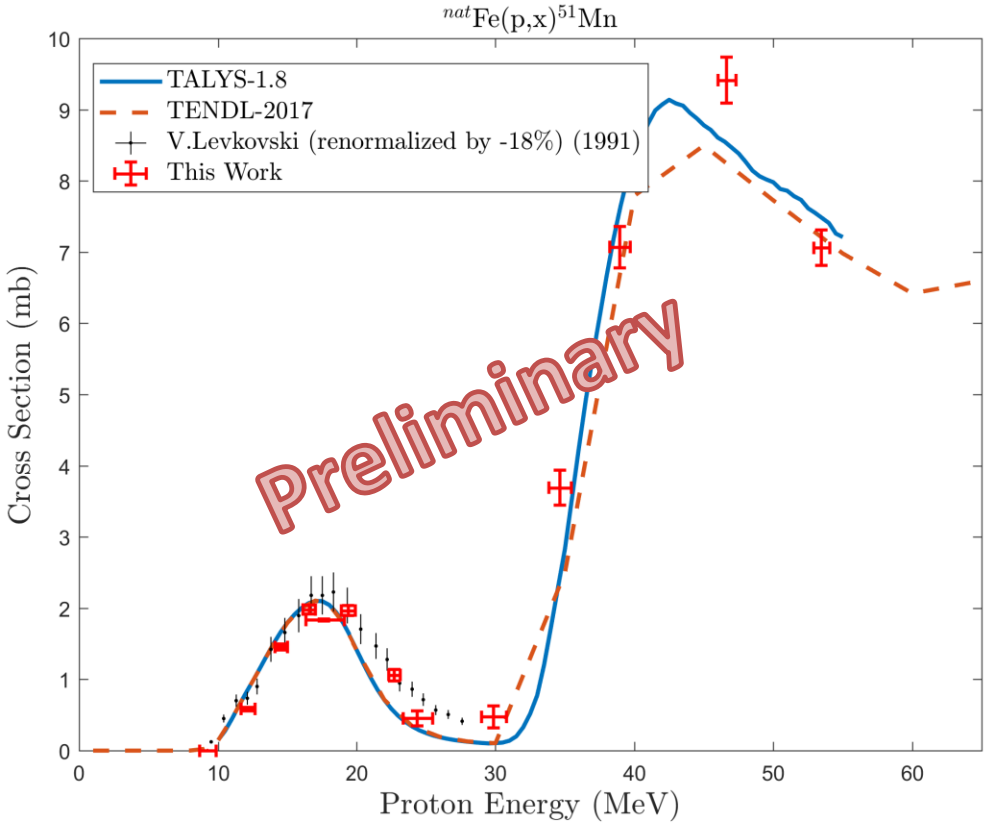
88-Inch Cyclotron



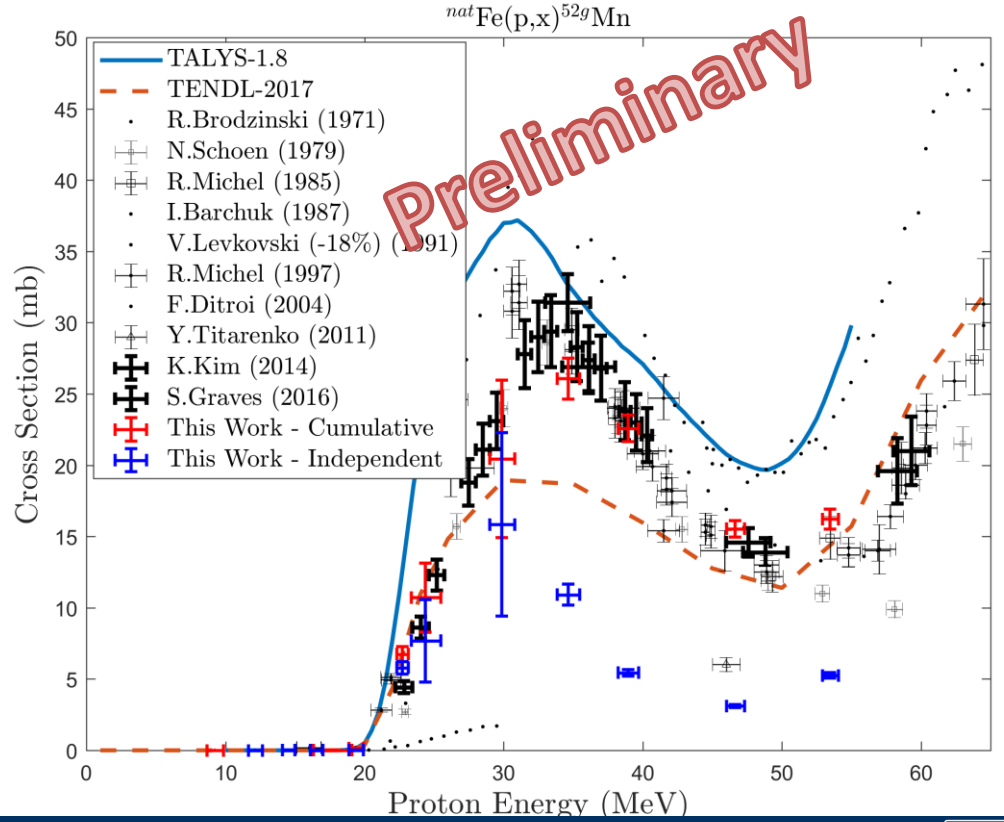


2016: Launched a complementary nuclear data measurement campaign at the LBNL 88-Inch cyclotron to address gaps in reaction data at E<60 MeV/A

$^{nat}Fe(p,x)^{51,52}Mn$ – Novel PET imaging

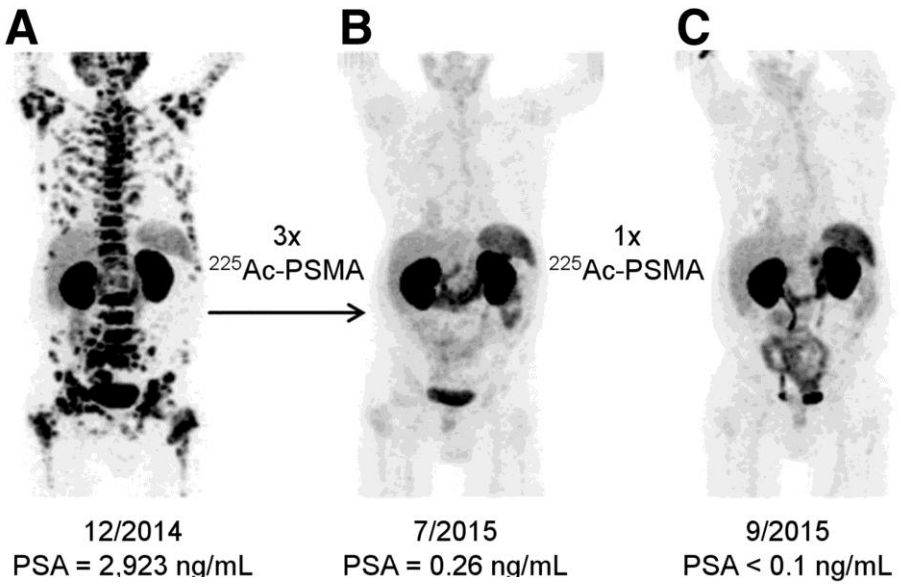


- Emerging medical radionuclides
  - ^{51}Mn ($t_{1/2}$ = 46 min, 97% β^+) – short-lived PET tracer for metabolic studies
  - ^{52g}Mn ($t_{1/2}$ = 5.6 d, 29% β^+) – long-lived PET tracer for neuron tracking, immune studies

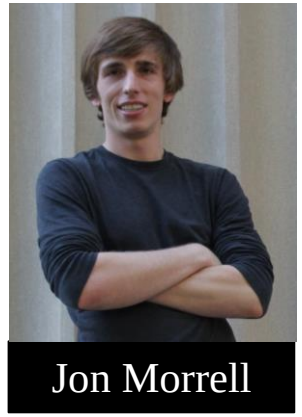


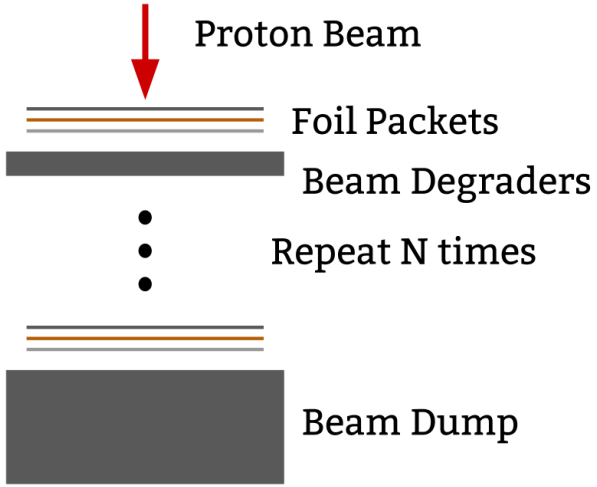
Two overlapping stacks: E_p= 55→15 MeV, 25→0 MeV (120 nA@10 min, 100 nA@20 min)

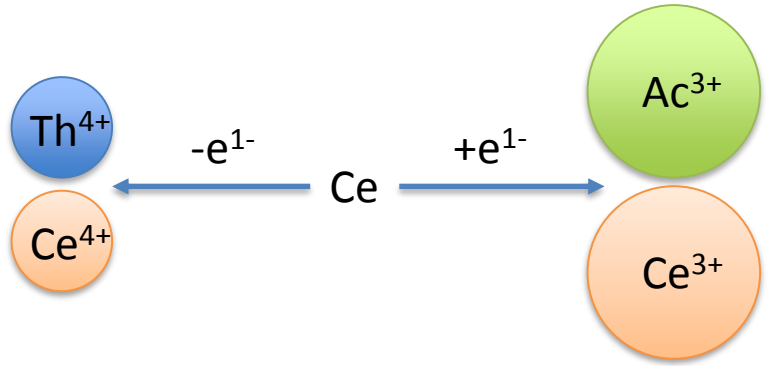
$^{140}La(p,6n)^{134}Ce$ - a PET analogue for ^{225}Ac



- ^{225}Ac decay chain lacks sufficient positrons to produce a signal that can be detected by PET.
  - In order to employ PET to explore new uses of alpha emitters, positron-emitting, surrogate radionuclides will have to be developed.
  - $^{134}Ce/^{134}La$: $t_{1/2}$ = 75.9 h / 6.67 m, 2.7 MeV β^+ (62.0%)
- Cross sections un-measured and reaction modeling predictions (EMPIRE/TALYS) differ by >10x


Jon Morrell



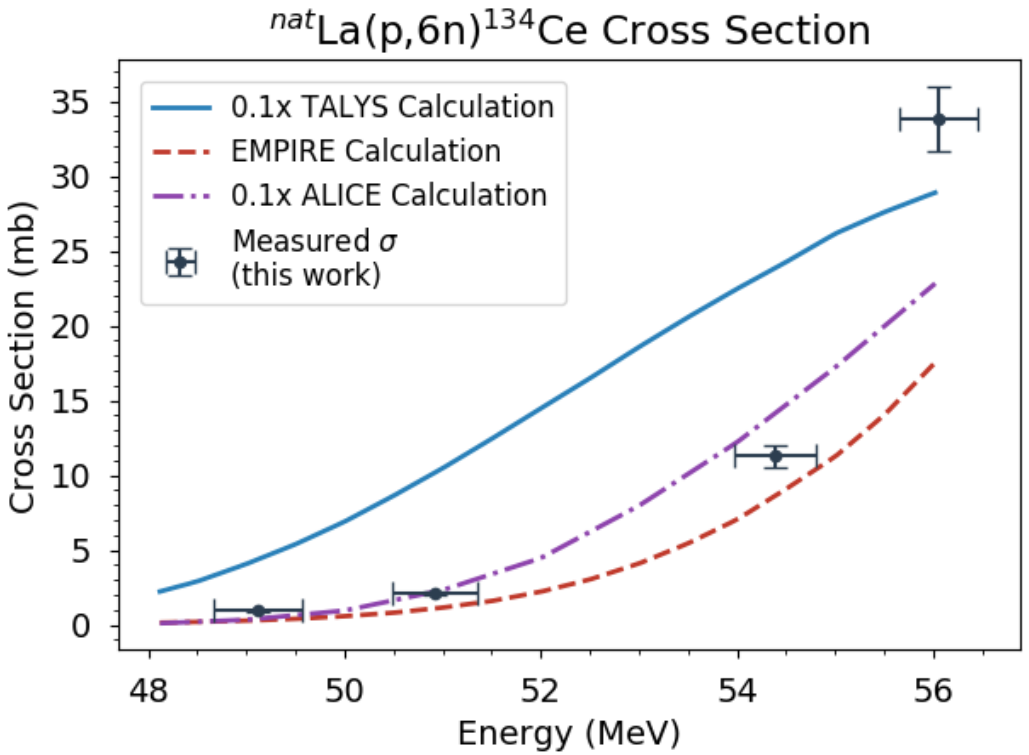


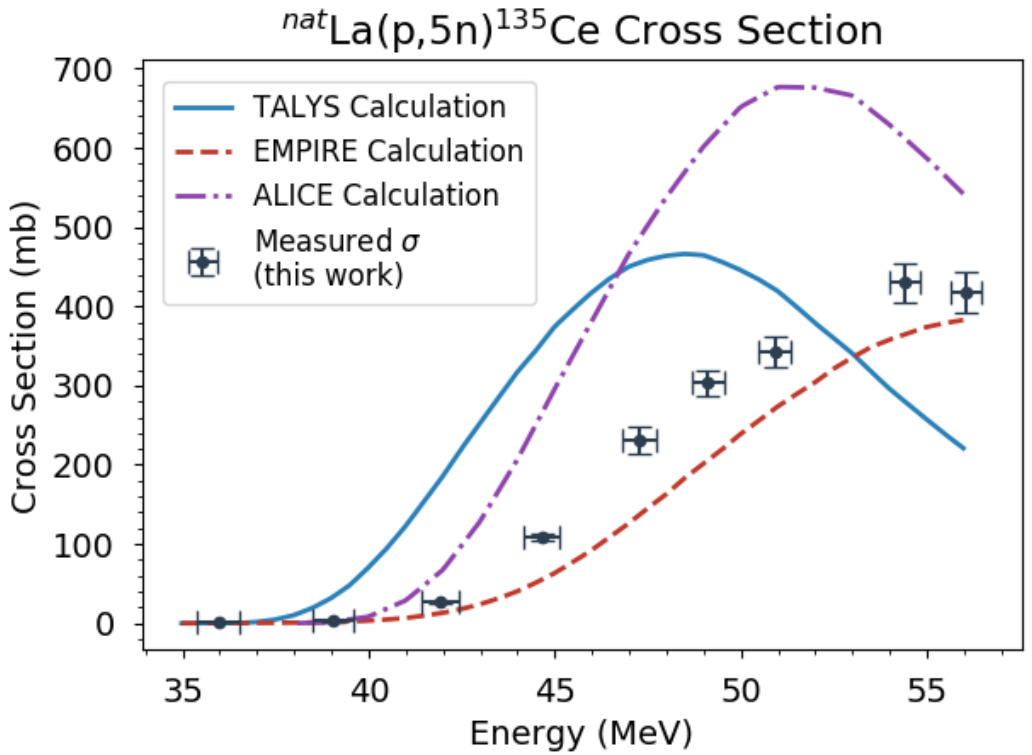
^{134}Ce as a ^{227}Th mimic

^{134}Ce as an ^{225}Ac mimic

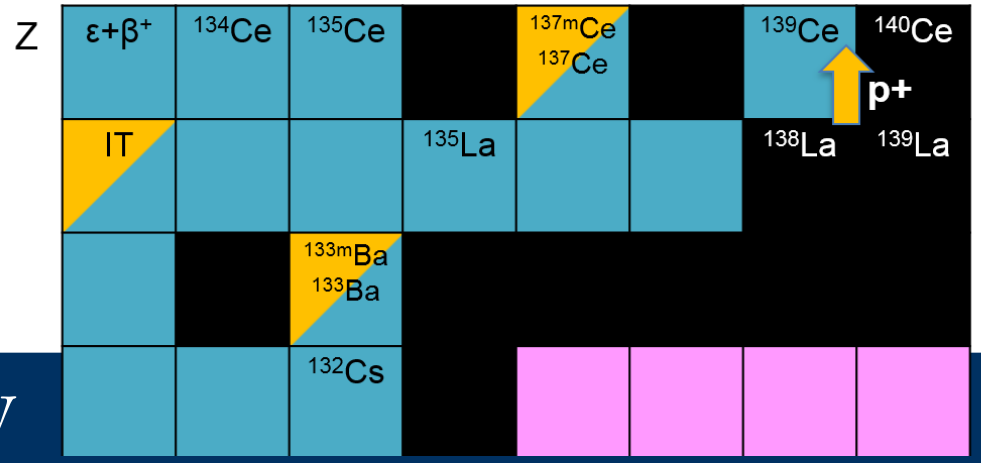
[2] Kratochwil, Clemens, *Journal of Nuclear Medicine* 57.12 (2016).

^{140}La(p,6n)^{134}Ce - a PET analogue for ^{225}Ac





^{135}Ce is major contaminant: higher-energy ≈70 MeV beam required for clean production of ^{134}Ce

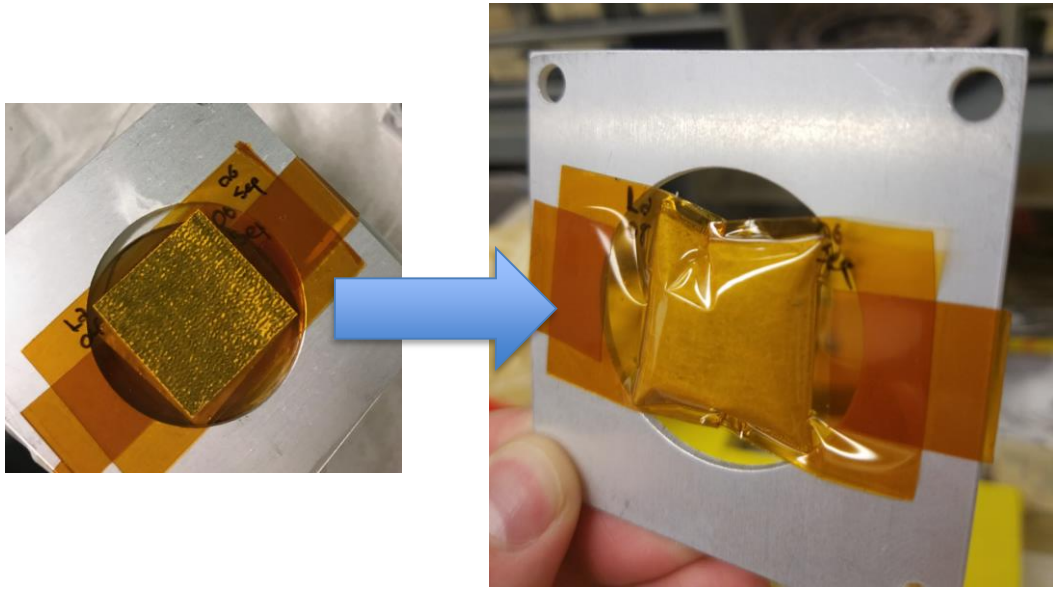


- TALYS and ALICE overpredict (p,6n) cross section by >10x, XS peaks 8-10 MeV higher than predicted
- Reaction code differences: Hybrid Monte-Carlo pre-equilibrium (EMPIRE) vs. Exciton model (TALYS, ALICE)

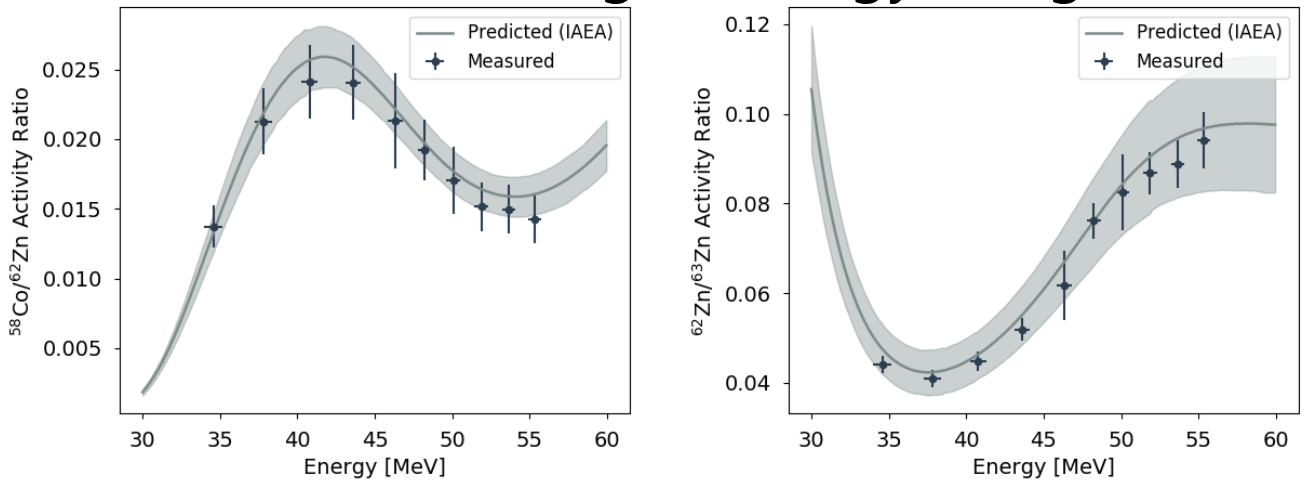
$^{140}La(p,6n)^{134}Ce$ - a PET analogue for ^{225}Ac

Major takeaways:

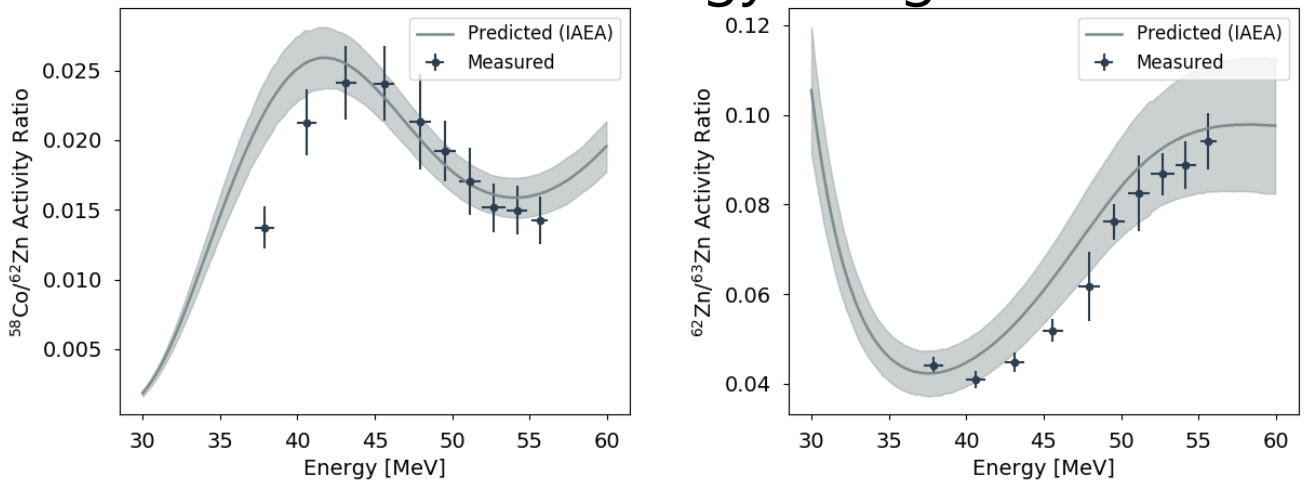
- Significant deviation (>20%) between Anderson & Ziegler and MCNP6/X
  - Future work: explore in depth with other stacked target data
- La metal targetry concerns:
  - Significant decomposition, outgassing post-EoB



Anderson & Ziegler Energy Assignment



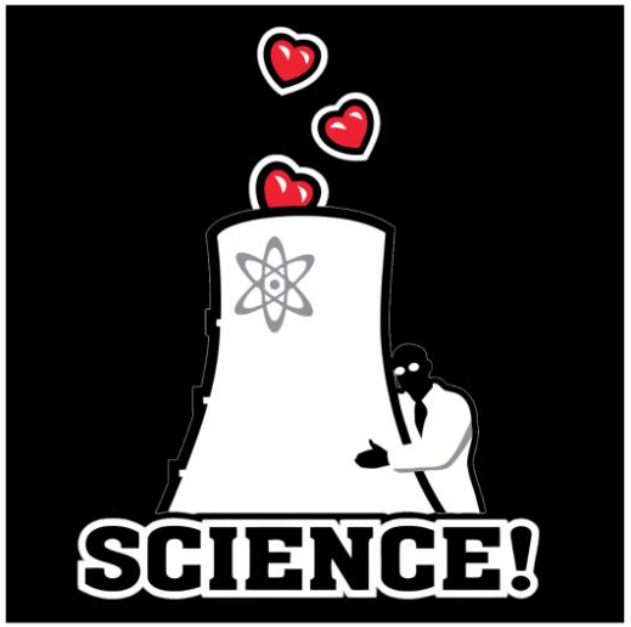
MCNP6 Energy Assignment



Collaborators on this work

M.S. Basunia[1], L.A. Bernstein[1,2], E.R. Birnbaum[3], J.W. Engle[3,4], S.A. Graves[5], T. Kawano[3], A.M. Lewis[2], E.F. Matthews[2], J.T. Morrell[2]. F.M. Nortier[3]. A. Springer[6], A.S. Voyles[2]

[1] *Lawrence Berkeley National Laboratory*
[2] *University of California-Berkeley Dept. of Nuclear Engineering*
[3] *Los Alamos National Laboratory*
[4] *University of Wisconsin – Madison*
[5] *University of Iowa – Department of Radiation Oncology*
[6] *Karlsruhe Institute of Technology*



We gratefully acknowledge support from:

- U.S. Department of Energy, Office of Science via the Isotope Development and Production for Research and Applications subprogram in the Office of Nuclear Physics
- Lawrence Berkeley National Laboratory and the U.S. Nuclear Data Program under contract # DE-AC02-05CH11231
- U.S. Nuclear Regulatory Commission
- U.S. Department of Energy grant #DE-SC0019238 – Support for Students, Postdoctoral Fellows, and Trainees to Attend the 17th International Workshop on Targetry and Target Chemistry


Questions?
Berkeley
UNIVERSITY OF CALIFORNIA
BERKELEY LAB