FRIB

Debugging SPACS for C++ in LISE^{++}

Hudson Miltner

New Isotope Research Group

Facility for Rare Isotope Beams, Michigan State University, East Lansing, MI 48824 USA

Date 10/23/2025

U.S. DEPARTMENT OF ENERGY | Office of Science

MICHIGAN STATE UNIVERSITY

National Science Foundation

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics and used resources of the Facility for Rare Isotope Beams (FRIB) Operations, which is a DOE Office of Science User Facility under Award Number DE-SC0023633, and by the US National Science Foundation under Grants No. PHY-20-12040 and 23-10078 "Windows on the Universe: Open Quantum Systems in Atomic Nuclei at FRIB".

SPACS Troubleshooting and Debugging

- **SPACS**
  - Spallation cross-section calculations combining EPAX and new parametrization methods for ~12-200 A nuclei and ~50MeV/U-200GeV/U projectiles on protons or neutrons
    - » Originally written in Basic, now ported to C++ for use in LISE^{++} application
  - Identified errors in C++ SPACS for mass A<~185 range calculations for most beams (see figures for ^{197}Au at 10.6 GeV/U)
  - Moving to debugging algorithm and logic of C++ port for SPACS
    - » Verified constants from Erratum and papers
    - » Comparing data points/methods from SPACS Basic to the C++ port

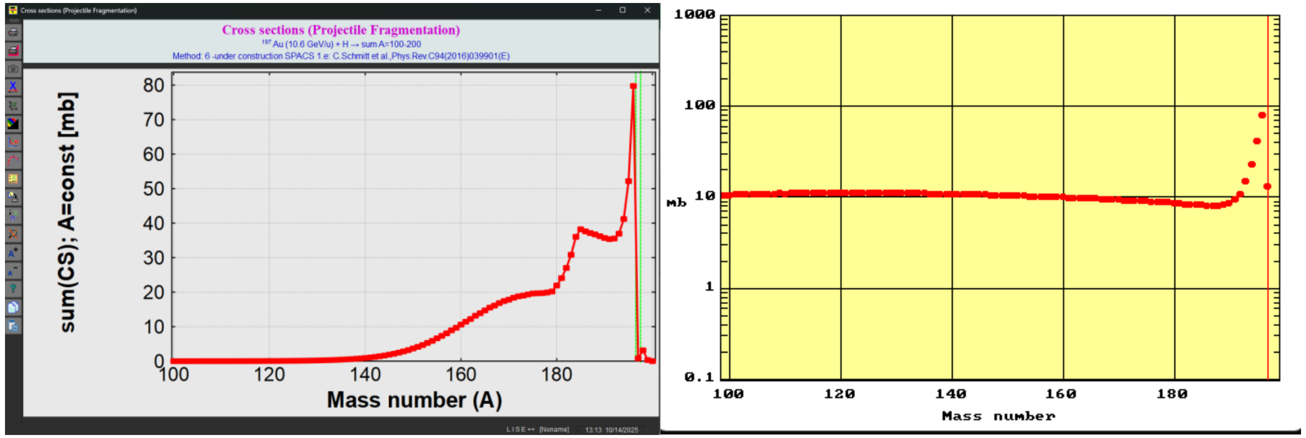


Figure 1: SPACS C++ (left) and Basic (right) isobaric distributions for ^{197}Au at 10.6GeV/U on proton target

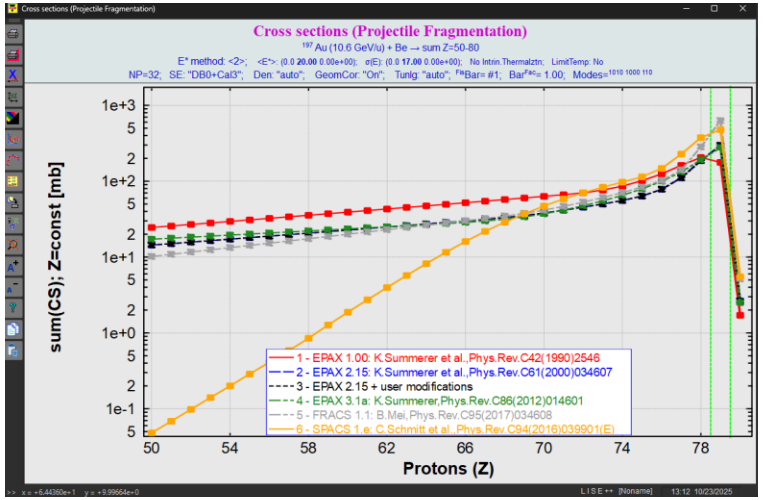


Figure 2: Comparison of C++ SPACS (orange squares) sum of Isotopic cross sections and other existing methods for ^{197}Au at 10.6GeV/U

Even-Odd Projectile Comparisons

- Note differences from SPACS predictions to other working models for both even and odd projectile cases – differences are not similar, have different behaviors around peak region.

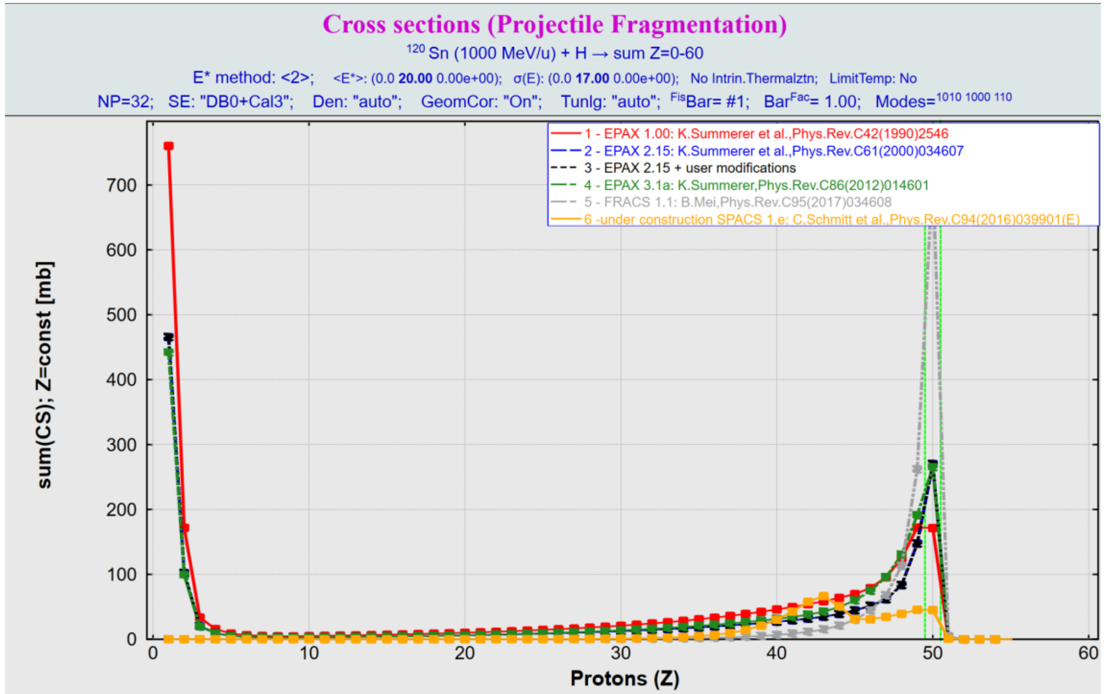


Figure 3: Even Mass ^{120}Sn at 1GeV/U sum of isotopic cross sections

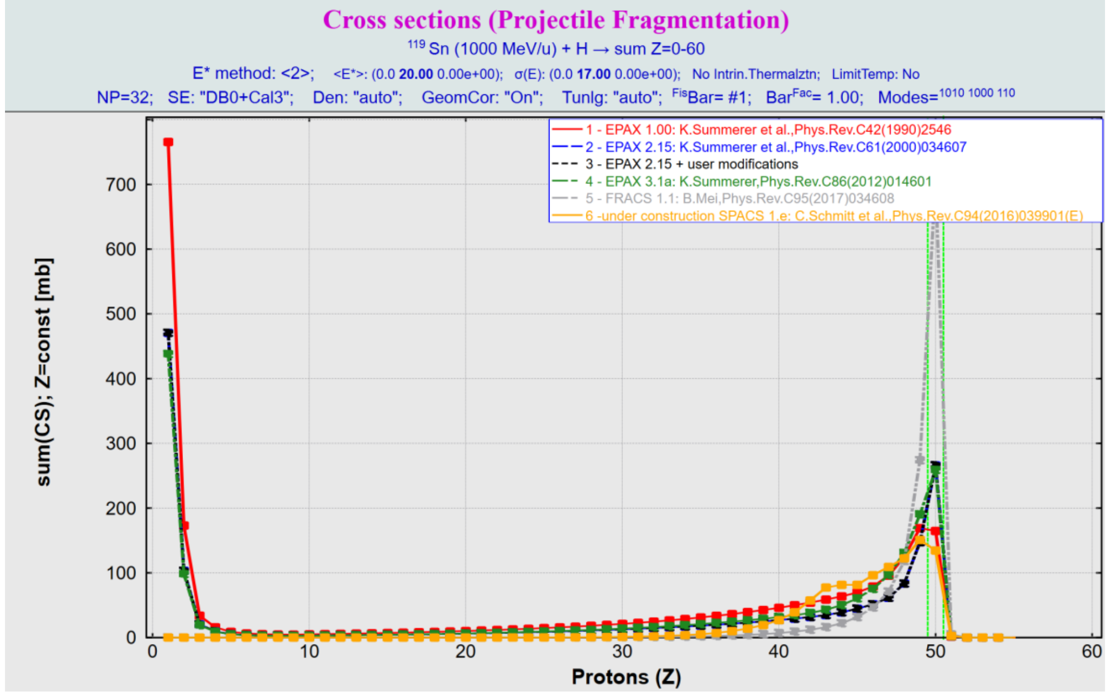
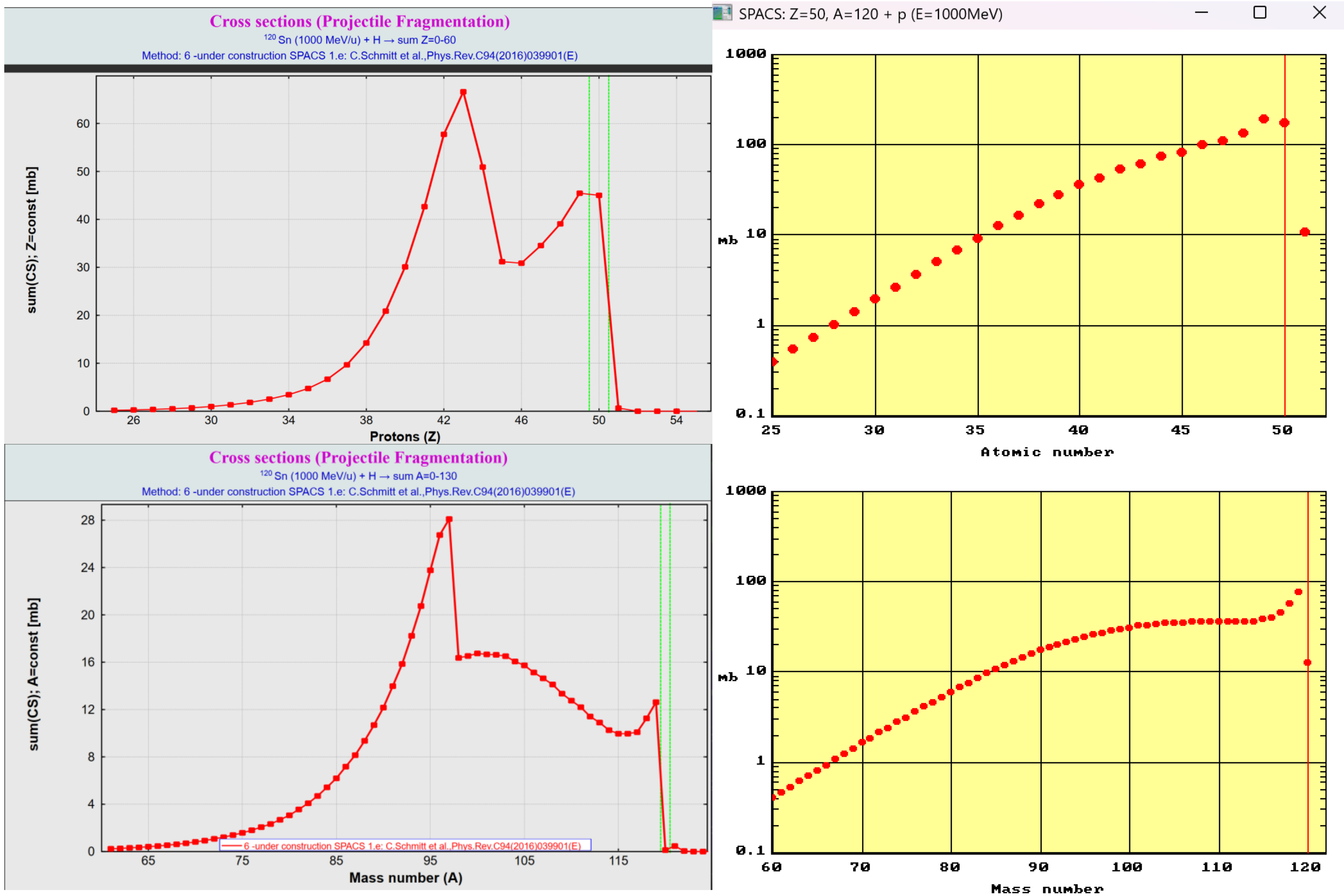


Figure 4: Odd mass ^{119}Sn at 1GeV/U sum of isotopic cross sections

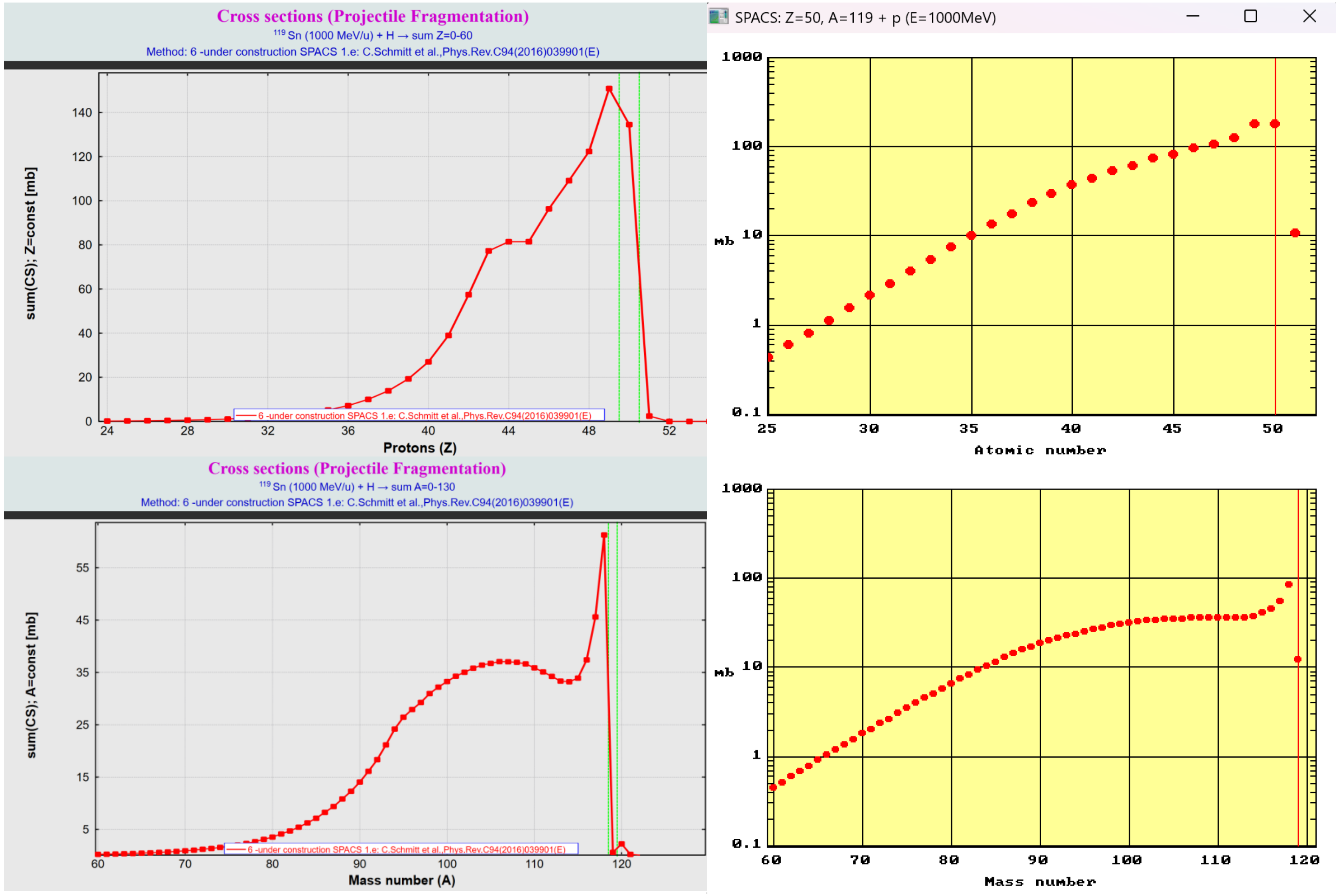
^{120}Sn + p 1GeV/*u*



- Focusing on peak regions for even A mass projectile, notice discontinuities for both isotopic and isobaric cross section sums
  - Both cases, sum rises too early and grows uncontrolled before discontinuities reduce cross section
  - For isobaric sums, complete breakdown around 100 A

Fig 5: Even mass ^{120}Sn at 1GeV/U comparison of C++ (left) and Basic (right) calculations

^{119}Sn + p 1GeV/*u*



- Again, focusing on the peak for even A projectile, notice trends:
  - Sum begins to rise early again for isobaric and isotopic sums
  - Now, peaks are shifted rightwards, closer to actual expected curve
  - Some clear discontinuity counting even-odd mass number

Figure 6: Odd mass ^{120}Sn at 1GeV/U comparison of C++ (left) and Basic (right) calculations

^{120}Sn and ^{119}Sn Comparison

- Here is an additional print of the even and odd tin isotopes next to each other.
  - This result suggests some error in the calculations for even-odd projectiles, and is found to be consistent in additional isotopes (not only tin)

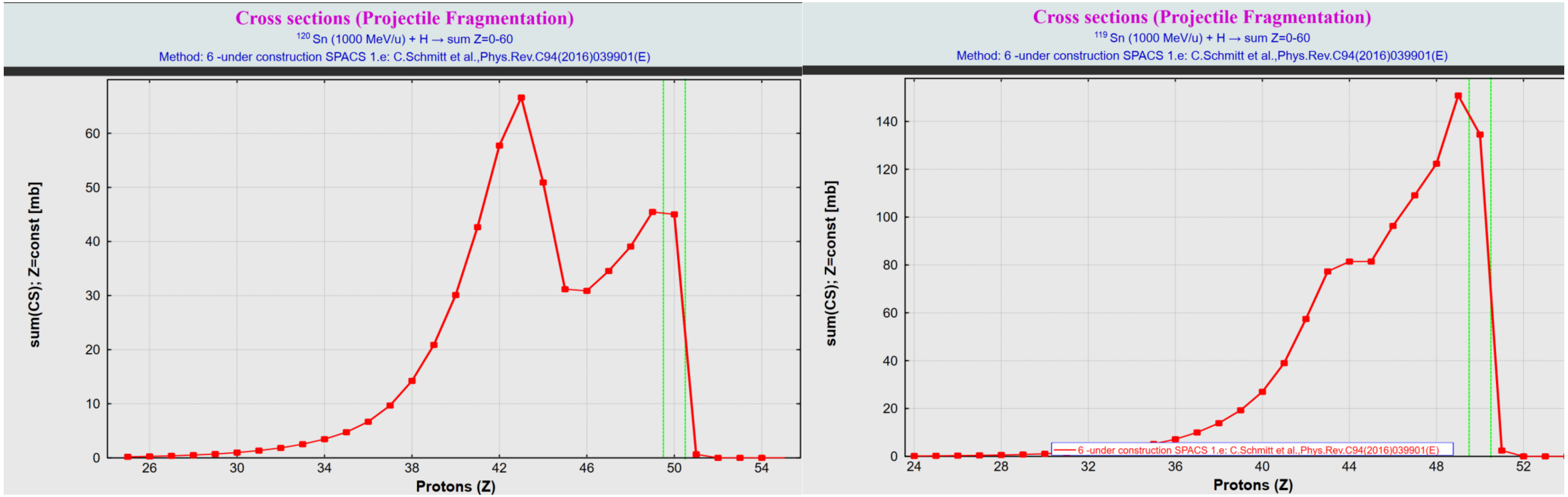


Figure 7: Even mass ^{120}Sn (left) and ^{119}Sn at 1GeV/U side by side

Ansatz Considerations

- The Erratum includes Ansatz that prevent escaping values/divergence of functions.
- For central collisions, provided some ratio of projectile, target and product mass greater than 19, fix to be 19 to prevent numeric error (Fig. [])
  - Ansatz not originally considered in SPACS C++ version, but no clear numerical errors encountered

Ansatz:
for $[(A_{\mathrm{proj}} - A_{\mathrm{cent}} - A)/A_{\mathrm{cent\_fluct}}] > 19$: $[(A_{\mathrm{proj}} - A_{\mathrm{cent}} - A)/A_{\mathrm{cent\_fluct}}] = 19$ in Eq. (A6).

Figure 8: Ansatz for central mass contributions

- For even-odd corrections, additional Ansatz (Fig. [+1])
  - Not included in SPACS C++, large candidate for gamma even-odd miscalculations

Ansatz:
if $F_{e\text{-}o}(A,Z) > 2$: $F_{e\text{-}o}(A,Z) = 2$ in Eq. (A35).

Figure 9: Ansatz for even-odd corrections

- For gamma attenuation, additional Ansatz (Fig. [+2])
  - Not included in SPACS C++, additional large candidate for $F_{e\text{-}o}(A,Z)$ corrections

Ansatz,
if $T \leqslant 0$, $S_n \geqslant 50$, or $A \leqslant 1$: $\Gamma_n = 0$ in Eq. (A39b),
if $T \leqslant 0$, $S_p \geqslant 50$, or $A \leqslant 1$: $\Gamma_p = 0$ in Eq. (A39c),
if $T \leqslant 0$, $S_\alpha \geqslant 50$, or $A \leqslant 4$: $\Gamma_\alpha = 0$ in Eq. (A39c).

Figure 10: Ansatz for gamma attenuation