Constraining neutron-induced fission cross sections using surrogate reactions

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Understanding neutron-induced fission (*n,f*) cross sections of short-lived radioactive nuclei is crucial for applications in national security, nuclear energy, and astrophysics [1]. However, the direct measurement of the (*n,f*) reaction is often difficult due to the short half-lives of the isotopes of interest and the lack of free-neutron targets. To overcome these limitations, we aim to employ the surrogate reaction method, which allows the indirect measurement of (*n,f*) cross sections by populating the same compound nucleus through more accessible reactions, such as (*d, p*). The measured fission probabilities overall reaction cross section. See Figure 1 for a pictorial view of the Direct and Surrogate reactions.

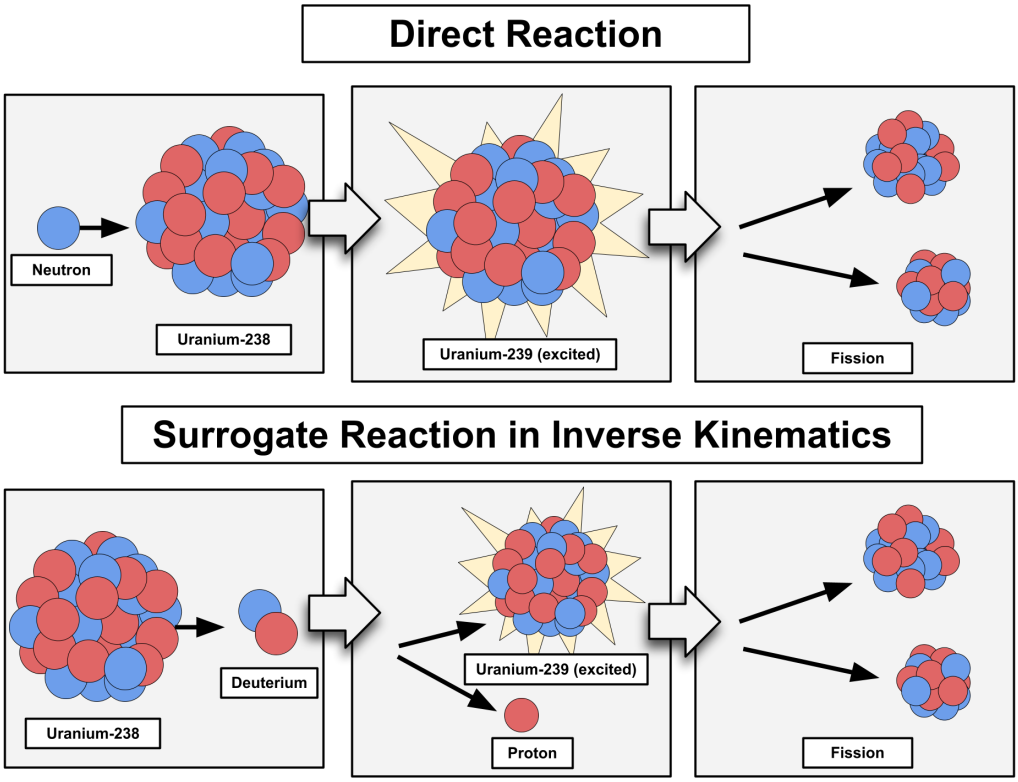

Fig. 1. Ordinarily, fission cross section measurements are made directly by impinging neutrons on a fissile target. We plan to impinge a fissile beam on a light target to induce a reaction which populates the same compound nucleus as the (*n, f*) reaction of interest.

The commissioning experiment will be the ^{238}U(*d, pf*) reaction, with the proposed detector layout shown in Figure 2. The ^{238}U beam will impinge upon a deuterium gas target within the ANASEN (Array for Nuclear Astrophysics and Structure with Exotic Nuclei) scattering chamber. ANASEN was developed by researchers at Florida State University and Louisiana State University to enable charged-particle

detection in inverse kinematics experiments with rare isotope beams [2]. It features a cylindrical geometry with concentric layers of silicon detectors that enable high-efficiency, position-sensitive detection of light recoils. In this experiment, two layers of double-sided silicon strip detectors will detect the recoiling protons, allowing for precise reconstruction of the reaction kinematics. An annular silicon array, placed at backward angles in the laboratory frame, increases angular coverage and helps capture protons emitted at more extreme angles. The fission fragments will be detected and characterized by a time-projection chamber (TPC), designed as a duplicate of the TeBAT detector currently under construction at Texas A&M University [3]. A small beamstop will be positioned at the downstream end of ANASEN to prevent unreacted beam particles from entering and saturating the TPC.

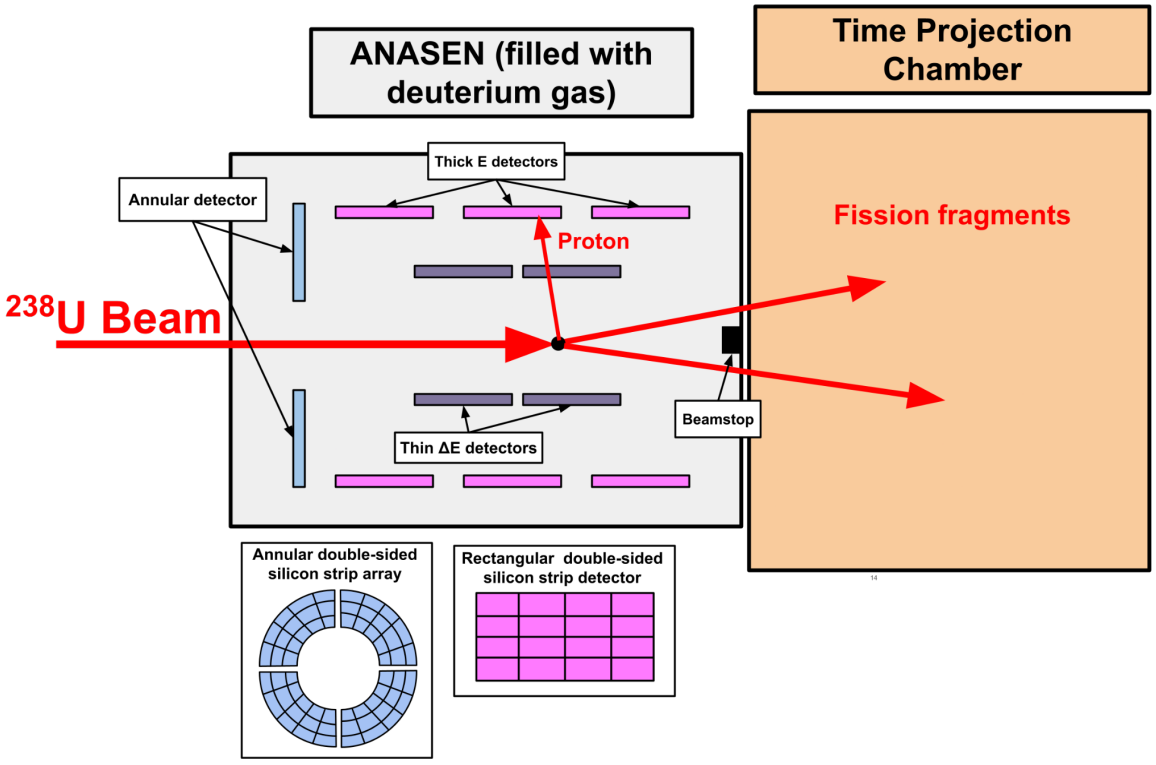

Fig. 2. Schematic of the proposed experimental setup for the ^{238}U(*d, pf*) reaction.

A lightweight Monte Carlo simulation, written in ROOT, was used to estimate detection efficiency across different geometries and inform the experimental setup. An example 3D event display is shown in Figure 3. A "good event" requires that the proton be detected with sufficient energy and that both fission fragments reach the TPC. The silicon detectors were arranged to create a large region of uniform efficiency.

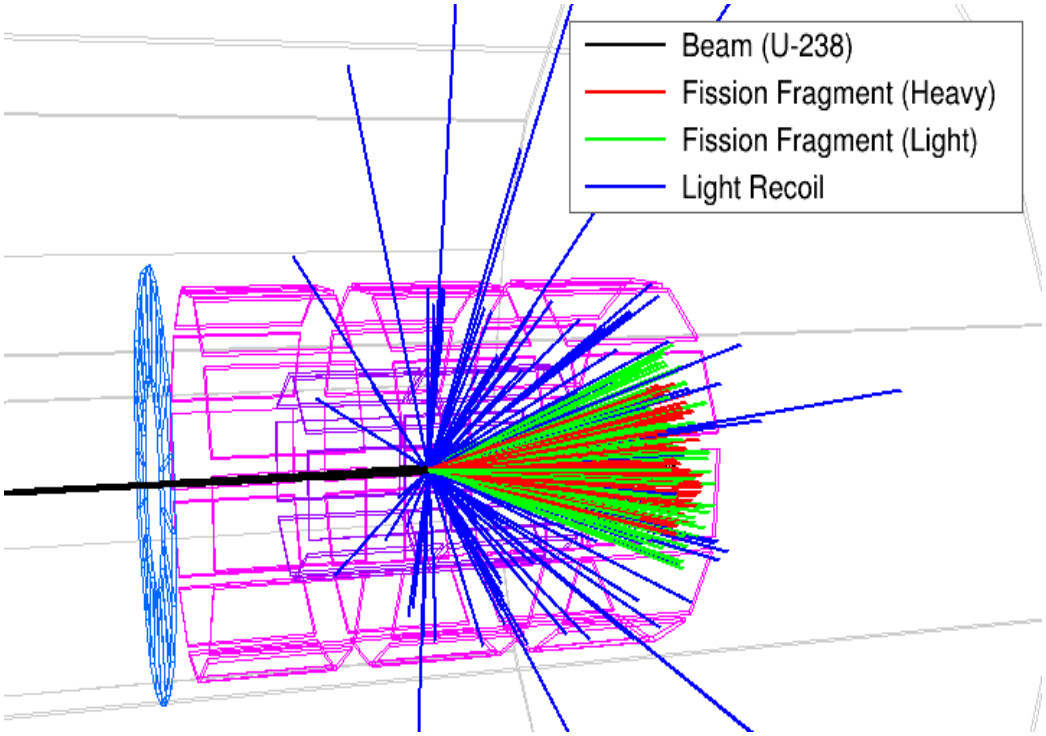

Fig. 3. A 3D visualization generated by the simulation showing 100 fission events generated at a location of 250mm in the ANASEN chamber.

Fig. 4 shows the results of the efficiency simulation assuming a 5 MeV excitation energy in the pre-fission ^{239}U compound nucleus. Events where the proton has a center of mass recoil angle of less than

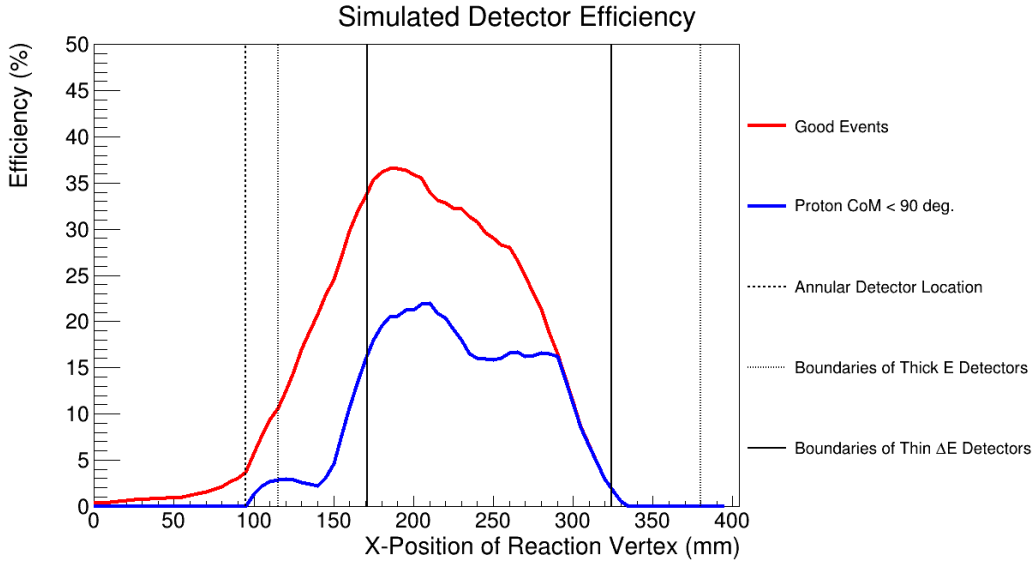

Fig. 4. Efficiency as a function of the X-position of the reaction vertex in the ANASEN chamber.

90 degrees are of particular interest because these events are populated by the direct (*d, p*) reaction rather than by compound fusion-evaporation, and therefore have a spin-parity distribution that is predictable by theoretical models such as DWBA. The spin-parity distribution of the compound nucleus

can be used to correct for differences between the direct (*n, f*) reaction and the surrogate reaction, allowing for a more accurate reproduction of the (*n, f*) cross section of interest [1].

Notably, this project will involve the first use of a uranium beam at the TAMU Cyclotron Institute in over two decades. Additionally, the use of the ANASEN detector marks the beginning of a new collaboration between Texas A&M University, Louisiana State University, and Florida State University. Future steps include finalizing the TPC construction, implementing a more detailed Geant4 simulation for full detector response modeling, and collecting and analyzing experimental data from the ^{238}U(*d, pf*) reaction.

[1] J. Escher *et al.* Rev. Mod. Phys. **84**, 353 (2012).

[2] E. Koshchiy *et al*., Nucl. Instrum. Methods Phys. Res. **A870**, 1 (2017).

[3] S. Ahn *et al.*, Status of Texas Birmingham Active Target (TeBAT) development. *Progress in Research*, Cyclotron Institute, Texas A&M University (2022-2023), p. IV-48.