CENTER FOR EXCELLENCE IN NUCLEAR TRAINING AND UNIVERSITY-BASED RESEARCH

Constraining neutron-induced fission cross sections using surrogate reactions with radioactive beams

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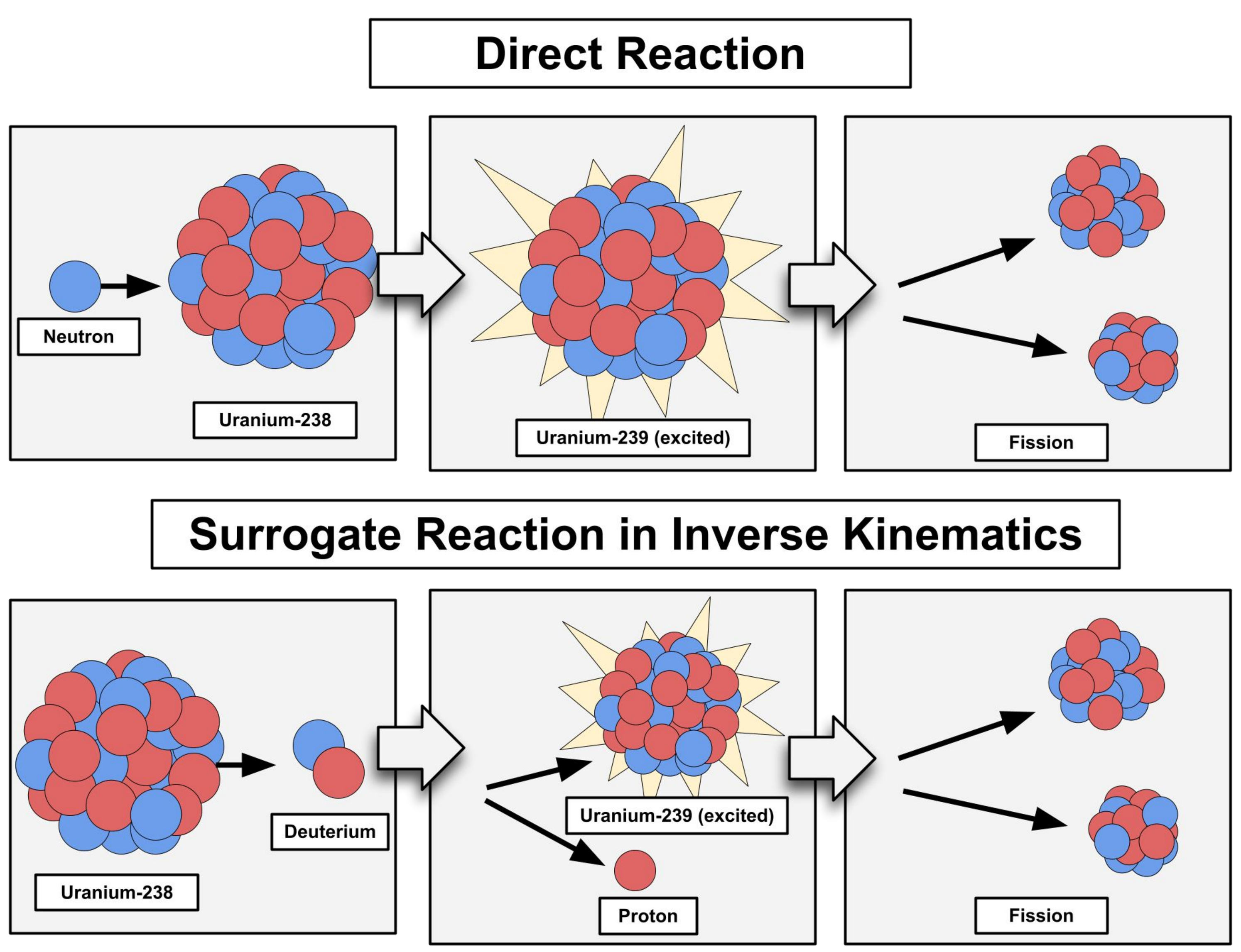
Introduction

Neutron-induced fission (n,f) cross sections of radioactive nuclei are important for national security, nuclear energy, and astrophysics applications. [1] However, directly studying the (n,f) reaction on radioactive nuclei is difficult due to the short lifetime of the nucleus of interest and the current infeasibility of free-neutron targets. To overcome these problems, we aim to study the processes via surrogate nuclear reactions. Our experiment will utilize a radioactive beam incident on a gas target to induce surrogate reactions that are analogous to the (n,f) processes of interest. The resulting fission fragments will be detected and characterized using a time projection chamber.

Surrogate Reactions

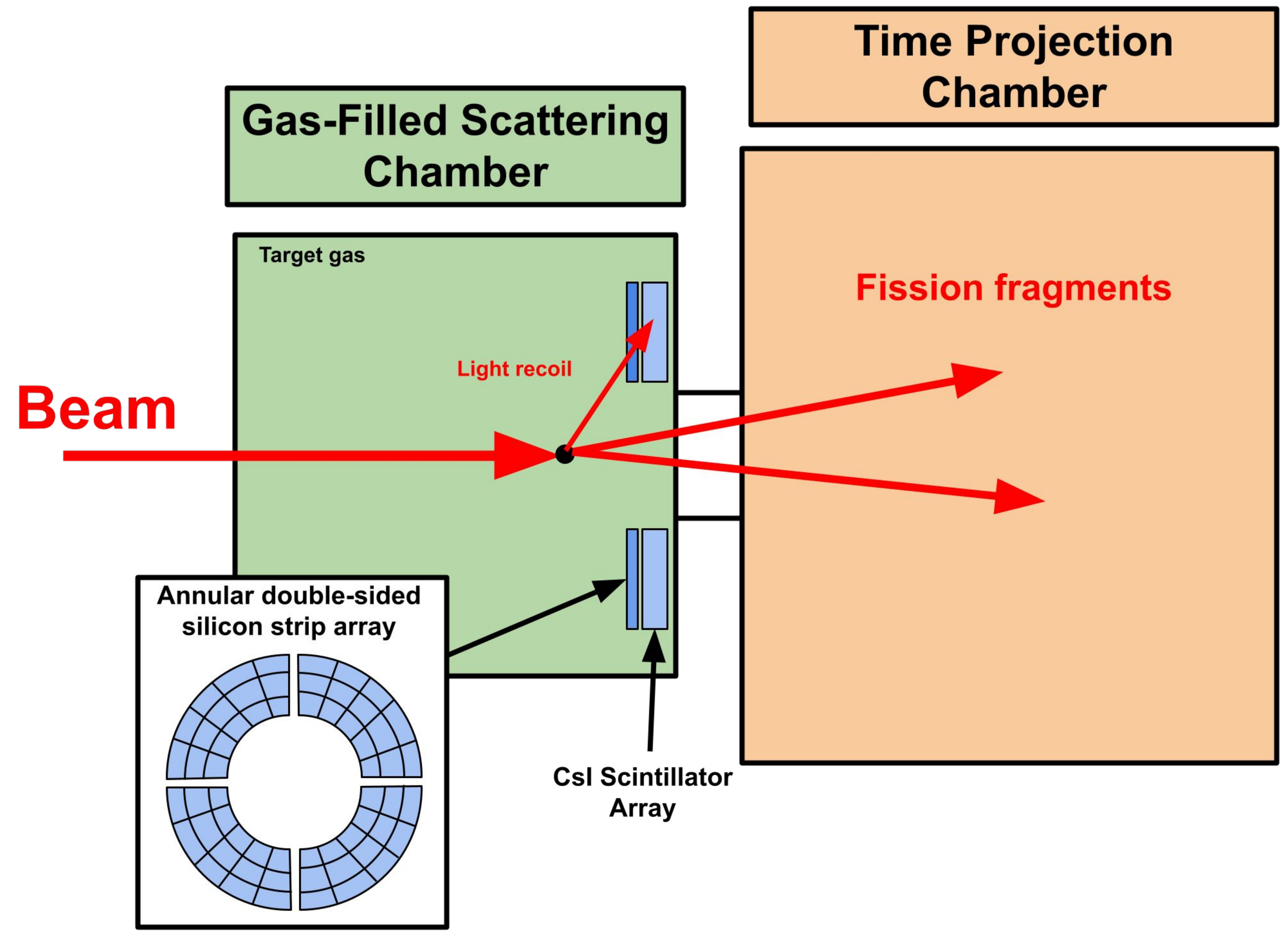
The *surrogate nuclear reaction method* will allow us to populate the same compound nucleus as the *(n,f)* reaction of interest, but through a more easily accessible pathway, for example (*d,p*). The compound nucleus fission probabilities can then be combined with known formation cross sections to determine the overall reaction cross section. [1] The *inverse kinematics method* will allow for the study of radioactive nuclei through the use of *rare isotope beams.*



Above: a comparison of the direct reaction ^{238}U(*n,f*) with the surrogate reaction ^{238}U(*d,pf*). Both reactions populate the excited compound nucleus ^{239}U via different mechanisms, ultimately leading to fission.

Experimental Setup

The commissioning experiment will be the ^{238}U(*d,p*) reaction. The beam will react with a deuterium gas target inside the gas-filled scattering chamber. Light recoils will be detected using an annular silicon-CsI(Tl) telescope array, while fission fragments will be detected and tracked using a gas-filled time projection chamber (TPC). The TPC design will be a duplicate of the TeBAT TPC currently under construction at Texas A&M University. [2]



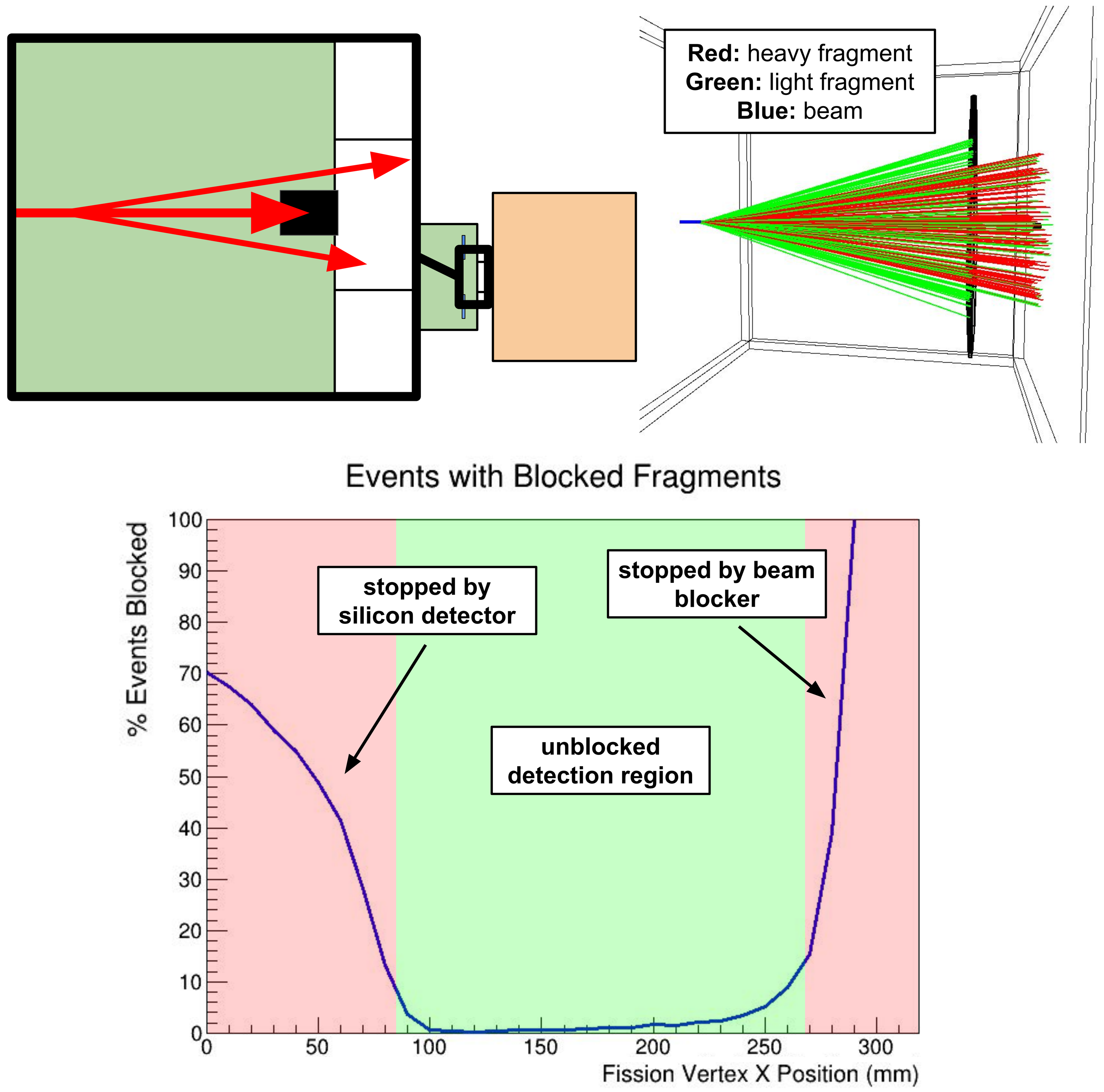
Above: a schematic of the proposed experimental setup. The light recoil particles will be detected and identified using a Si-CsI(Tl) telescope, enabling the identification of the surrogate reaction. Fission fragment trajectories will be captured by the TPC.

References

[1] J. Escher et. al. (2012). Compound-nuclear reaction cross sections from surrogate measurements. *Rev. Mod. Phys., 84, 353–397.*
[2] S. Ahn et. al. (2022). Status of Texas Birmingham Active Target (TeBAT) development. *Texas A&M University.*
[3] Plompen, A.J.M., Cabellos, O., De Saint Jean, C. *et al.* The joint evaluated fission and fusion nuclear data library, JEFF-3.3. *Eur. Phys. J. A* 56, 181 (2020).

Beam Blocker/Annular Silicon Simulation

A small beam blocker will be placed along the beam axis at the end of the scattering chamber to stop unreacted beam particles from entering the TPC. A Monte Carlo simulation was performed to optimize the blocker's size, ensuring it effectively prevents TPC overload while maximizing fission fragment detection. The simulation will also guide the optimal placement of the silicon detector to effectively detect light recoils while minimizing the obstruction of fission fragments. Fission fragment mass distributions in the simulation are sourced from JEFF-3.3. [3]



Top-left: a schematic of the beam blocker, designed to block unreacted beam while allowing fission fragments to pass around
Top-right: 3D visualization generated by the simulation
Bottom: percentage of fission events with at least one blocked fragment as a function of fission vertex position

Future Steps

- Simulation of light recoils
- Order parts and construct Si-CsI(Tl) array
- Complete TeBAT and construct new TPC
- Collect and analyze data on the ^{238}U(*d,p*) reaction

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