Imperial College London

Rayan Basu & Ewan Saw
Supervisor: Dr. Brian Appelbe
Research Group: Plasma Physics

Time-Resolving Neutron Time-of-Flight Measurements in Inertial Confinement Fusion

1. Inertial Confinement Fusion (ICF)

What is ICF?

- Recent achievements in nuclear fusion experiments have shown that we are able to attain **high yields of energy from fusion**. A recent experiment measured a yield which was ~70% of the energy delivered by its ignition laser.
- This was achieved through ICF - an approach to nuclear fusion which compresses capsules of deuterium and tritium into small, hot, and dense spheres of plasma. The fuel emits many nuclear particles, which can be used to understand properties of the fusion reaction such as the temperature of the plasma.

How Can We Improve ICF?

- Neutrons energies are measured using the time-of-flight method, which can only provide time-integrated measurements. This method suffers from a **degeneracy problem** - time-integrated measurements can only tell us about the average temperature of the experiment.
- Instead, time-resolved measurements can help us understand the temperature evolution of the plasma during the implosion. This can help with our understanding of the physics of ICF and allow us to better model the implosion.

2. Modelling the Reaction Products

1. We model the primary neutron products from DT fusion reactions over a period of burn and propagate them forwards in time. Different temperature profiles are used to create various source functions.
2. By simulating the responses of multiple detectors placed at different distances, we notice that the skewness of each signal uniquely evolve for different source functions.

I. Construct a Neutron Source

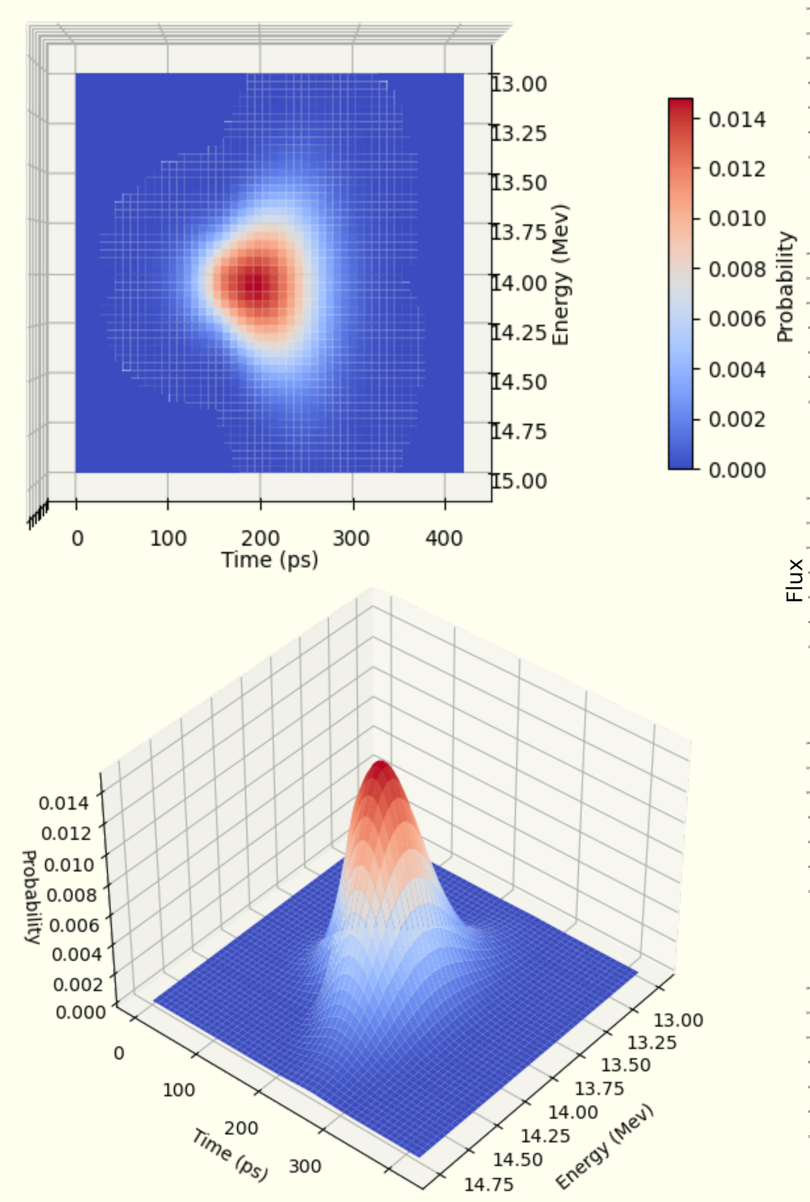

Fig. 1. Example source function of neutrons from different angles, produced with a linearly increasing temperature (4 – 15 keV) over a burn time of 100ps.

II. Propagate the Source Function

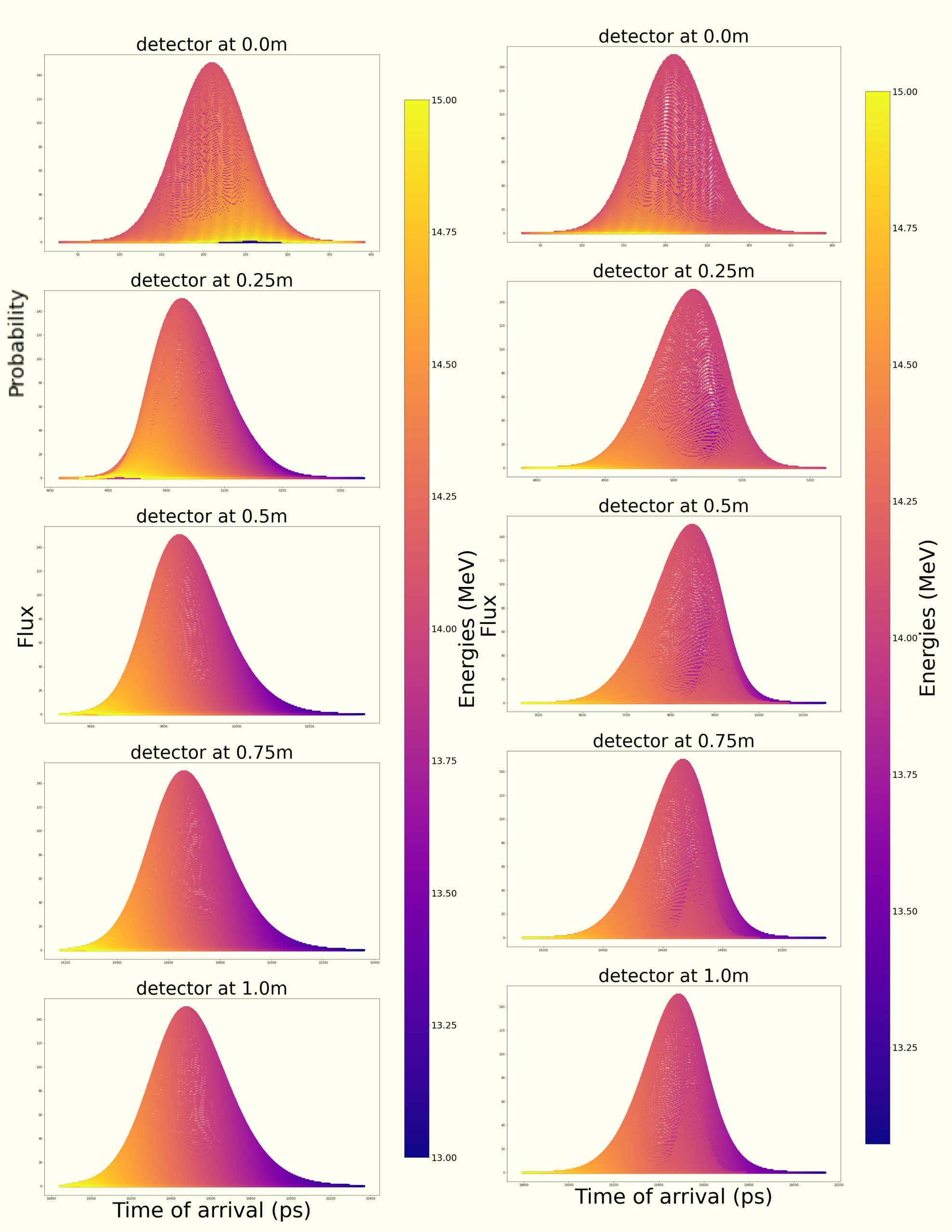

Fig. 2. Plotting time of arrival of neutrons for a linearly increasing temperature from 4-15 keV (left) and linearly decreasing temperature from 10-1 keV (right).

3. Preliminary Results

1. Shape of skewness curve varies greatly depending on if temperature increases or decreases throughout burn.
2. The peak skewness occurs at predictable distances from the detector.
3. Regression models can be used to classify increasing and decreasing temperature profiles in certain cases.

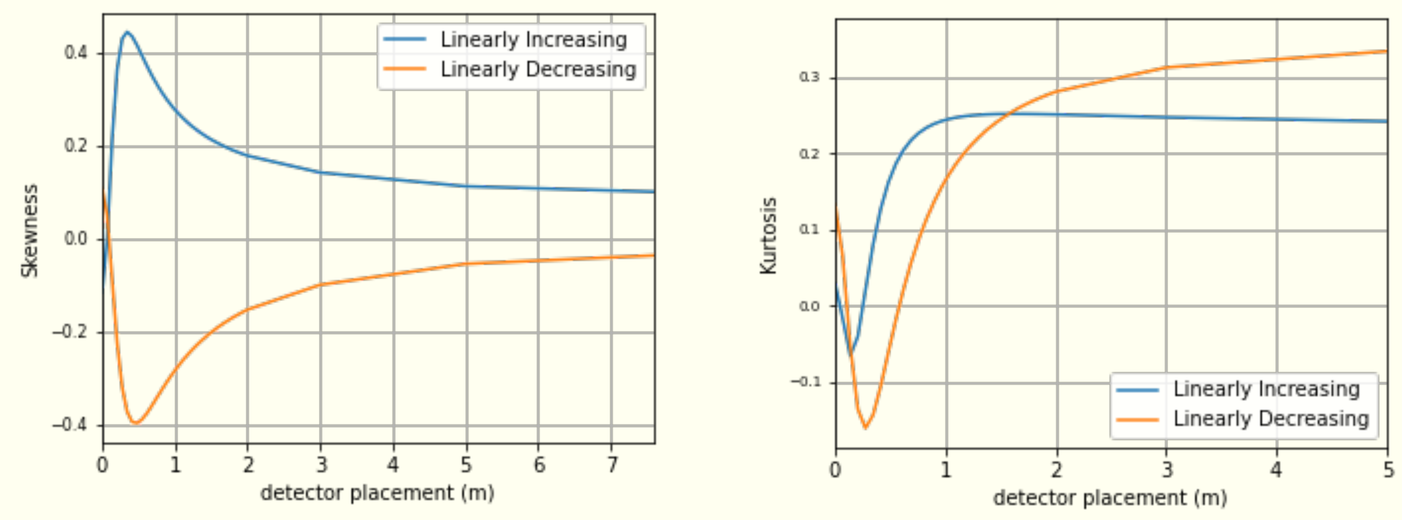

Fig. 3. Plots of skew (left) and kurtosis (right) values for the linearly increasing and decreasing neutron sources in Section 2.

Key Takeaway: Skewness and Kurtosis of the neutron yield are an effective way of understanding the time-evolution of the averaged plasma temperatures

4. Comparison to Simulated Data

We classify three different regimes for burn: **self-heating**, **ignited hotspot**, and **propagating burn** which correspond to differing magnitudes of yield in this simulated data.

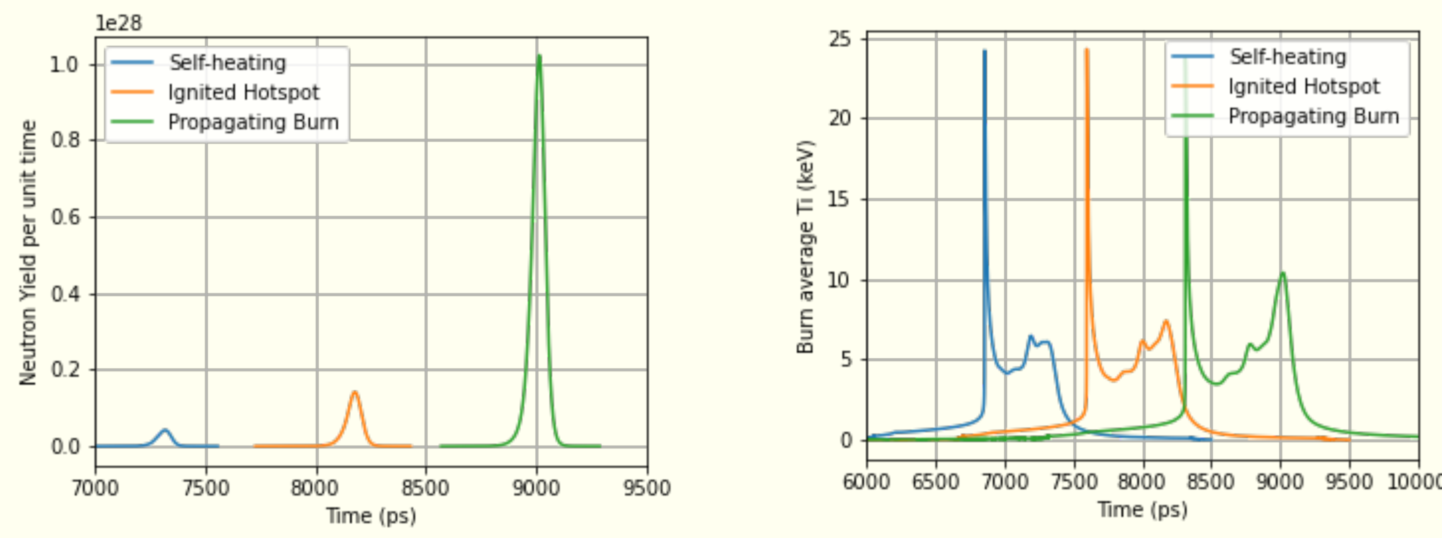

Fig. 4. Simulated neutron yields per unit time (left) and temperature profiles (right) for self heating, ignited hotspot, and propagating burn regimes.

These sources are then propagated, and the skewness and kurtosis curves of the simulations can be compared against our models.

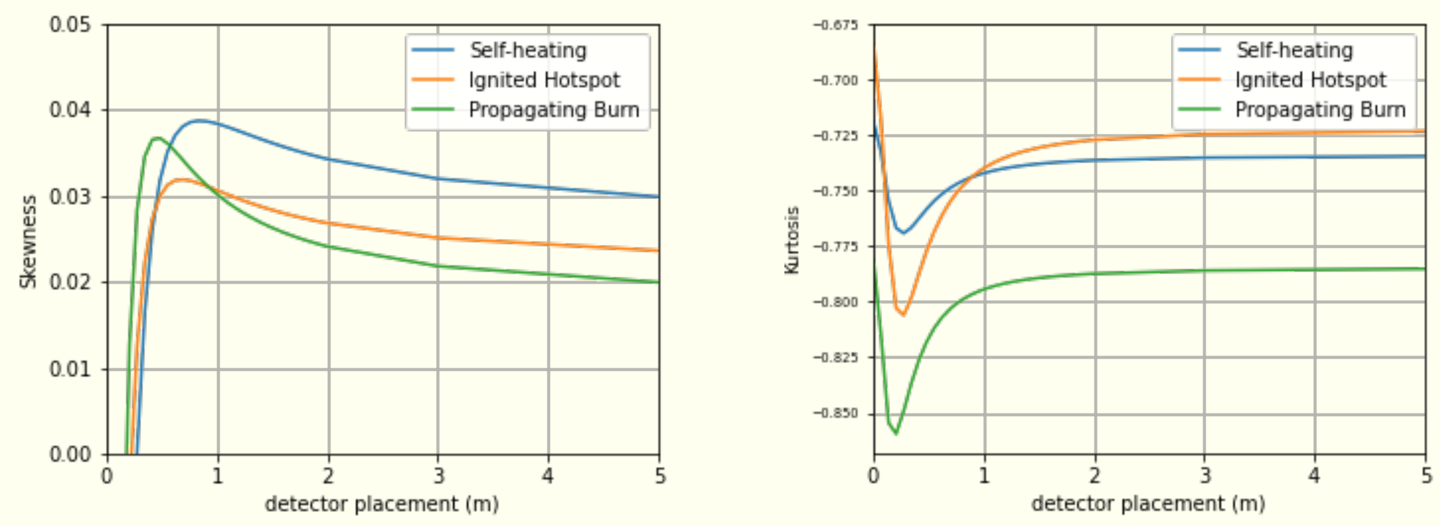

Fig. 5. Skewness and kurtosis curves corresponding to the neutron yields and temperature profiles in figure 4.

The skewness and kurtosis curves mimic the increasing temperature profile. There is also a clear difference in the location of the peaks which can help classify the regime.

5. Further Work

1. Determine optimal detector placement for making time-resolved temperature measurements.
2. Investigate the physical reason behind these results.
3. Develop more advanced modelling techniques using regression methods to predict exact temperature profiles.
4. Understand the relationship between skew and temperature for a skewed neutron flux at 0m.

References: Tollefson, Jeff. "US Achieves Laser-Fusion Record: What It Means for Nuclear-Weapons Research." *Nature News*, Nature Publishing Group, 27 Aug. 2021, https://www.nature.com/articles/d41586-021-02338-4.