238U + 238U Collisions
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SUMMARY
We examine the collision of two Uranium 238 nuclei using the time-dependent superfluid local density approximation (TD-SLDA). We set out four various initial relative orientations (below), while varying the initial boost energy of the nuclei as well as setting the relative phases of the pairing gaps to be in or out of phase. After completing the calculations we calculate various observables. Note, all calculations were performed at zero impact parameter, but will eventually be extended to finite impact parameters.

Motivation:
A big motivation for the collision of heavy elements is to produce heavy elements (SNE) and create rich nuclei close to the neutron drip line via multi-nucleon transfer (MNT) reactions. An example, consider the following figure.

![Graph](Image)

which shows that the probability of producing super heavy nuclei is indeed present in the case of colliding two heavy nuclei when compared to colliding one heavy and one light nuclei.

In our project we will also focus on extending traditional approaches such as TDHF or TD-HF-SCF to TD-SLDA to see if pairing plays a role in these types of collisions.

METHOD
Theoretical framework:
The quasiparticle-phonon ansatz
\[
\rho_{\sigma}(\mathbf{r}, t) = \sum_{\mathbf{k}, \alpha} \rho_{\sigma, \mathbf{k}, \alpha}(t) \langle \alpha | \mathbf{r} | \sigma \rangle
\]
satisfies the following evolution equation:
\[
\frac{\partial \rho_{\sigma, \mathbf{k}, \alpha}(t)}{\partial t} = \sum_{\sigma'} \sum_{\mathbf{q}} \langle \sigma' | v | \sigma \rangle \langle \alpha | \mathbf{r} + \mathbf{q} | \sigma \rangle \frac{\rho_{\sigma', \mathbf{k}', \alpha'}(t)}{\rho_{\sigma, \mathbf{k}, \alpha}(t)}
\]
for any local density functional (EDF). Here we focused on the Skx1.1 NEQ4 [2].

These solutions can then be used to construct various quantities,
\[
\begin{align*}
\rho_{\sigma, \mathbf{k}, \alpha}(t) &= \rho_{\sigma, \mathbf{k}, \alpha}(t) \\
\rho_{\sigma, \mathbf{k}, \alpha}(t) &= \rho_{\sigma, \mathbf{k}, \alpha}(t) \\
\rho_{\sigma, \mathbf{k}, \alpha}(t) &= \rho_{\sigma, \mathbf{k}, \alpha}(t) \\
\rho_{\sigma, \mathbf{k}, \alpha}(t) &= \rho_{\sigma, \mathbf{k}, \alpha}(t) \\
\end{align*}
\]

which turn out to be a tool to calculate the energy density functional, various observables, such as kinetic energy, quadrupole and octupole moments, etc.

RESULTS
Multi-nucleon transfer in case of tip to waist collisions:

![Graph](Image)

We plot the change in particle number for the left WS, YI, WL, WL, YI, WS. TDSLDA shows the largest amount of transfer along the collision axis.

Orientations:

![Graph](Image)

Ternary quasifusion:

![Graph](Image)

The observed ternary collisions where a light fragment was formed.

Examples:

![Graph](Image)

The neutron density matrix (upper half) and proton (lower half) as a function of time at center of mass energies 850 MeV (left panel) and 1000 MeV (right panel) respectively with the pairing gap set to zero. The curve indicates the time at which the tip was finally 1800 MeV.

Other quantities:

![Graph](Image)

The comparative distance between the two fragments, given by:
\[
\Delta_{\text{tip}} = \frac{1}{2} \left( \rho_{\text{tip}}(\mathbf{r}, t) - \rho_{\text{waist}}(\mathbf{r}, t) \right)
\]
was plotted as a function of time for all cases, and used to extract the minimum separation between the two nuclei.

REFERENCES

FUTURE OUTLOOK
Above is the before and after of a preliminary 238U+238U collisions.

Mass widths of reaction products:

We will be applying the Itakura-Tomseth prescription for calculating the mass widths. This means we need to consider a smooth transition, that either our mass flow will well-separated nuclei at 50 MeV. Then we apply the following transformation to the observables:
\[
\rho_{\sigma, \mathbf{k}, \alpha}(t) \to \rho_{\sigma, \mathbf{k}, \alpha}(t) + \rho_{\sigma, \mathbf{k}, \alpha}(t)
\]
where \( \alpha \) is a small positive number [1].

Theoretical framework:

Post collision decay modes:

We will calculate the decay products for the excited nuclei after the collision, either by using the GEMC code or another code.

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DEFINITIONS

Space discretization:
\[
\begin{align*}
\Delta x &= \Delta y = \Delta z = 1, \\
\Delta x &= \Delta y = \Delta z = 1, \text{ in MeV}, \\
\text{and R} &= 80 \text{ MeV}, \text{in MeV}, \\
\text{and R} &= 80 \text{ MeV}, \text{in MeV}, \\
\text{and R} &= 80 \text{ MeV}, \text{in MeV}, \\
\end{align*}
\]

The simulations were run on Oak Ridge National Lab’s Summit supercomputer.

Additionally, the total energy, TKE before and after the collision, maximum density, and so forth, are used in this paper.