

LISEcute Reaction Dynamics Explorer

Development report through 20 October 2026

Release 18.8.110 | Previous release 18.8.109

This cumulative report records the Reaction Dynamics Explorer through release 18.8.110. The participant Fragment and Residual buttons now open the selected transfer channel diagnostic and focus the appropriate selector. Either outgoing nucleus can be edited; the complementary A and Z follow from conservation. The previous transfer physics, mass table Q values and radial energy payment rule remain unchanged. New documentation shows the actual dialog controls and records MSVC and MinGW validation. Earlier chapters retain their original results and physical qualifications.

On 17 October we replaced the illustrative Langevin trajectories with a deterministic reaction-dynamics solver and extended it to transfer orbital angular momentum into fragment spins. The first benchmark is $48\text{Ca} + 208\text{Pb}$ at 7 MeV/u. The implementation now follows distance, radial momentum, orbital rotation, thermal heat and two fragment spins while checking total energy and angular momentum at every recorded step.

At 7 MeV/u, radial-only friction leaves the $b = 6.35\text{--}7.25$ fm band radially settled through 100 zs. Adding tangential rate $4 \times 10^{21} \text{ s}^{-1}$ sends all 37 samples into overlap after 2.50-2.85 zs. The earlier friction-rate map and the new energy-impact map examine different boundaries.

Delivered changes

- Coulomb, Woods-Saxon nuclear and centrifugal potentials with adjustable nuclear parameters.
- Dimensioned RK4 trajectories with surface-localized radial damping and tangential surface-slip drag.
- Separate thermal and rotational excitation, fragment spins, and pointwise conservation diagnostics.
- Potential, trajectory, spin and energy plots; impact-parameter ranges and outcome tables.
- Physics regression tests, numerical scan drivers, archived results and figures.
- Interactive comparison maps with progress, cancellation, trajectory inspection and CSV export.

Benchmark conclusions

Tangential rate in 10^{21} s^{-1}	Overlap outcomes	Trapped at 100 zs
0	0 of 37	37 of 37
1	19 of 37	18 of 37
4	37 of 37	0 of 37

These are results of an uncalibrated fixed-composition model. Overlap is a geometric stopping condition, not a fusion classification. For trajectories stopped at overlap or the time limit, reported energy and spin describe the state at stopping, not final outgoing fragments.

Conservative and radial dynamics

The model uses a nonrelativistic center-of-mass Hamiltonian. The dialog obtains participant masses from the current LISE mass table through ReactionCinematiqueDistribution. For the numerical studies, the bundled AME2020 entries give projectile and target masses of 44667.490028 and 193729.016188 MeV, respectively, using the LISE amu constant of 931.494061 MeV. The reduced mass is $m_P m_T$ divided by their sum. Input damping rates in zs^{-1} are divided by 299.792458 for the internal fm/c time unit.

$$E_{cm} = \frac{E_{lab} m_T}{m_P + m_T} = 273.044896808 \text{ MeV}, \quad E_{lab} = 48 \times 7 = 336 \text{ MeV}$$

Quantity	Benchmark setting
Composition	48Ca and 208Pb remain unchanged; $Q = 0$
Nuclear potential	Depth 100 MeV; radius parameter 1.2 fm; diffuseness 0.65 fm
Touching radius	11.471079987 fm
Overlap stopping radius	10.471079987 fm
Entrance surface	80 fm for the reported benchmark scans
Peak radial rate	0 or $4 \times 10^{21} s^{-1}$
Internal units	MeV, fm and fm/c; 1 zs = 299.792458 fm/c

$$V_{eff}(R, L) = V_C(R) + V_N(R) + \frac{L^2}{2\mu R^2}$$

$$V_C(R) = \frac{1.43996448 Z_P Z_T}{R}, \quad V_N(R) = -V_0 f(R)$$

$$f(R) = \frac{1}{1 + \exp[(R - R_{touch})/a]}, \quad R_{touch} = r_0(A_P^{\frac{1}{3}} + A_T^{\frac{1}{3}})$$

$$\dot{R} = \frac{p_R}{\mu}, \quad \dot{p}_R = -\frac{\partial V_{eff}}{\partial R} - \beta_R(R)p_R$$

$$\dot{\phi} = \frac{L}{\mu R^2}$$

$$\beta_R(R) = 4\beta_{R0} f(R)[1 - f(R)]$$

The entrance orbital angular momentum is the impact parameter times the asymptotic relative momentum. Initial radial kinetic energy subtracts both the potential and centrifugal terms at the entrance surface. Radial damping converts mechanical energy into thermal heat; it does not impose a prescribed energy-loss curve or a prescribed contact duration.

Fourth-order Runge-Kutta uses a maximum step of 0.5 fm/c, reduced to resolve surface motion and friction relaxation. Runs stop on outward return to the entrance surface, entry below the overlap cutoff, or the selected maximum time. Point-charge Coulomb in the small permitted overlap is an explicit approximation.

Tangential friction and fragment spins

The tangential extension is a phenomenological sliding-friction model. It uses signed angular momenta normal to the reaction plane and initially zero fragment spins. Both nuclei are rigid spheres, with radii 1.2 times the cube root of mass number in fm. Their constant moments of inertia are $I = (2/5) m r^2$.

$$a_P = \frac{R r_P}{r_P + r_T}, \quad a_T = R - a_P$$

The effective contact lever arms sum to R at each step. Scaling them with separation is an approximation for the surface tail and the small allowed overlap. Relative surface slip includes both orbital motion and fragment rotation.

$$u = \frac{L}{\mu R} - \frac{a_P S_P}{I_P} - \frac{a_T S_T}{I_T}$$

$$D = \mu \beta_T(R) u, \quad \beta_T(R) = 4 \beta_{T0} f(R) [1 - f(R)]$$

$$\dot{L} = -R D, \quad \dot{S}_P = a_P D, \quad \dot{S}_T = a_T D$$

$$\dot{E}_{\text{thermal}} = \frac{\beta_R(R) p_R^2}{\mu} + \mu \beta_T(R) u^2 \geq 0$$

Equal and opposite torques conserve total angular momentum because the lever arms sum to R . The evolving orbital L is used in the centrifugal force. Tangential drag can reverse sign if surface slip reverses; spins can return angular momentum to orbital motion while thermal production remains nonnegative.

$$J = L + S_P + S_T = J_{\text{initial}}$$

$$E_{\text{rot},P} = \frac{S_P^2}{2I_P}, \quad E_{\text{rot},T} = \frac{S_T^2}{2I_T}$$

$$E_{\text{relative}} + E_{\text{rot},P} + E_{\text{rot},T} + E_{\text{thermal}} = E_{\text{cm}}$$

Rotational energy is accounted once. For separated events, total excitation and TKE loss equal thermal heat plus both rotational energies. Thermal heat is divided in proportion to mass number; each fragment then receives its own rotational energy. For stopped or unresolved trajectories this division does not establish final fragment excitation.

Both peak rates default to zero. Setting the tangential rate to zero reproduces the radial-only model. The present model contains sliding friction but no separate rolling-resistance torque; rotating configurations may persist after surface slip vanishes.

Radial friction comparison

At 7 MeV/u, zero-friction separated trajectories conserve mechanical energy and have zero generated excitation. With radial rate $4 \times 10^{21} \text{ s}^{-1}$, the largest sampled separated-event TKE loss is 11.842 MeV at $b = 7.275 \text{ fm}$. At $b = 8 \text{ fm}$ it is 3.645 MeV, shared as 0.683 MeV in Ca and 2.961 MeV in Pb under mass-proportional thermal sharing.

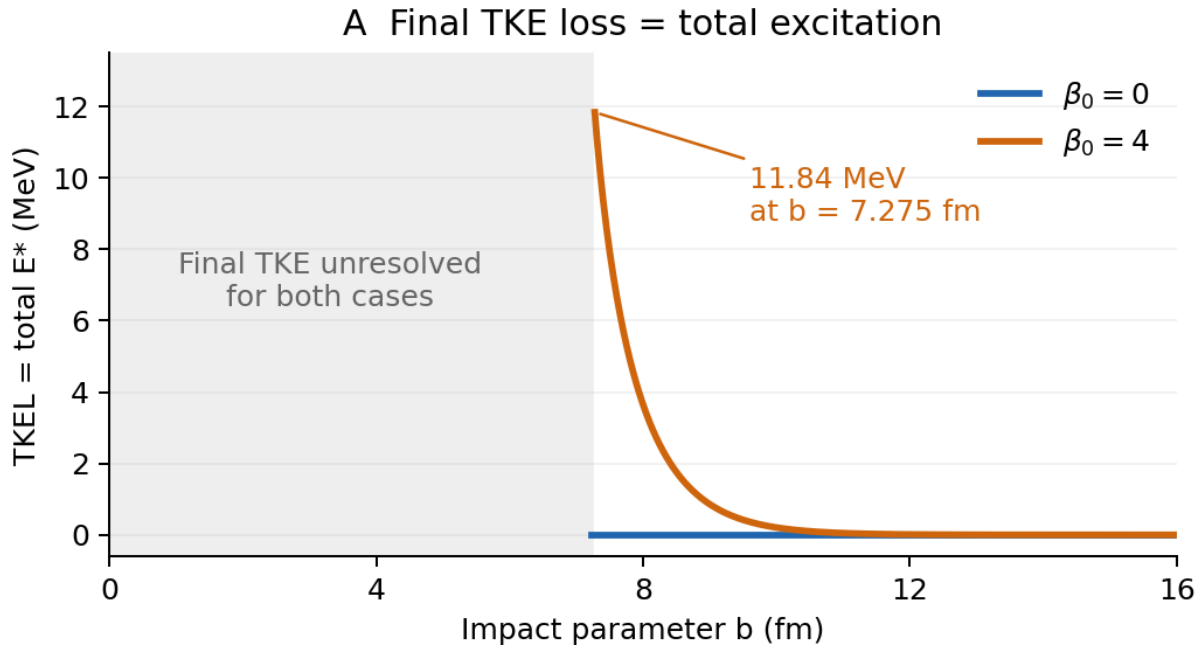


Figure 1 Separated-event TKE loss and total generated excitation versus impact parameter

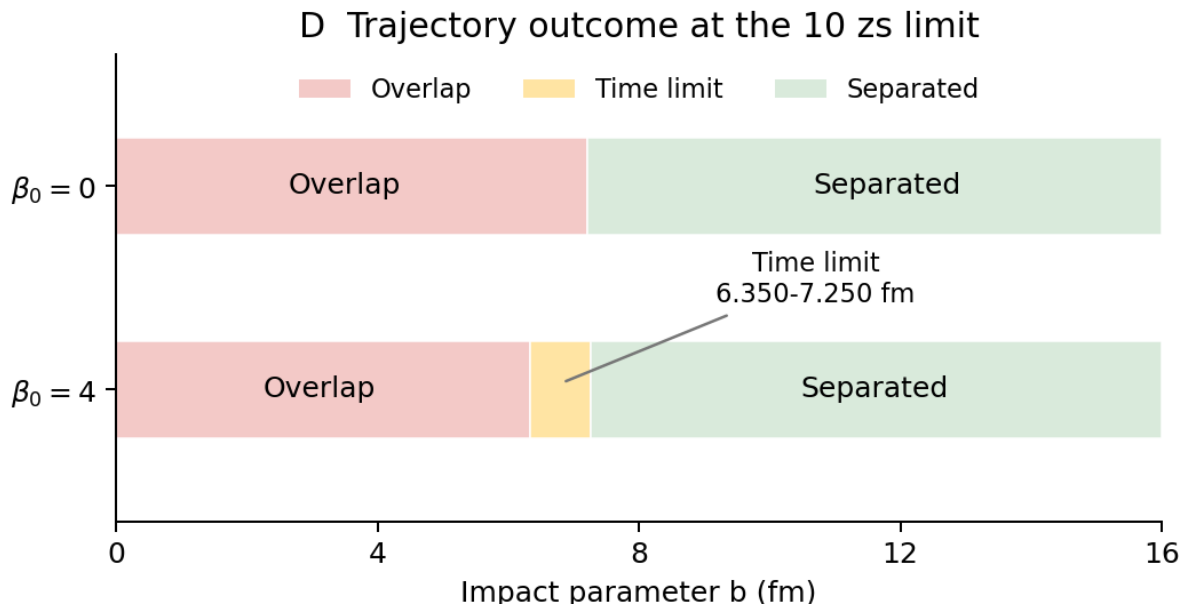


Figure 2 Outcomes with a 10 zs limit for zero and finite radial friction

On the 0.025 fm grid, zero-friction trajectories enter overlap for $b \leq 7.200 \text{ fm}$ and separate for $b \geq 7.225 \text{ fm}$. With radial friction, $b \leq 6.325 \text{ fm}$ enters overlap, $b = 6.350\text{--}7.250 \text{ fm}$ reaches the time limit, and $b \geq 7.275 \text{ fm}$ separates. Central collisions deposit 68.225 MeV before overlap stopping; that value is not an outgoing TKE prediction.

Extension to one hundred zeptoseconds

All 37 radial-only trajectories in $b = 6.35\text{--}7.25$ fm remain inside the model region through 100 zs. Radial motion damps toward effective-potential minima, while orbital rotation continues. Excitation has essentially plateaued by 10 zs. Halving the integration step preserves every outcome.

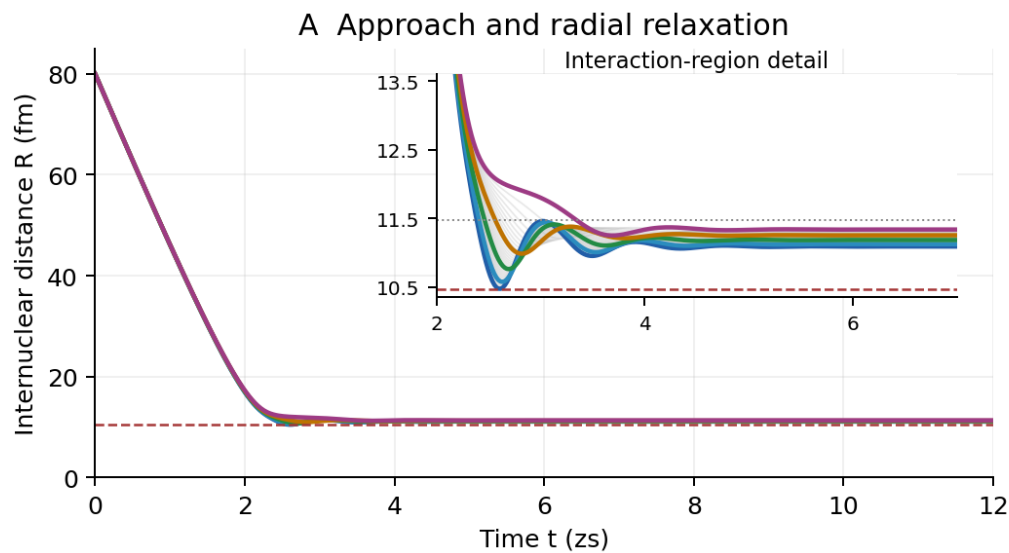


Figure 3 Radial relaxation for b 6.35 blue 6.50 cyan 6.75 green 7.00 orange and 7.25 purple in fm

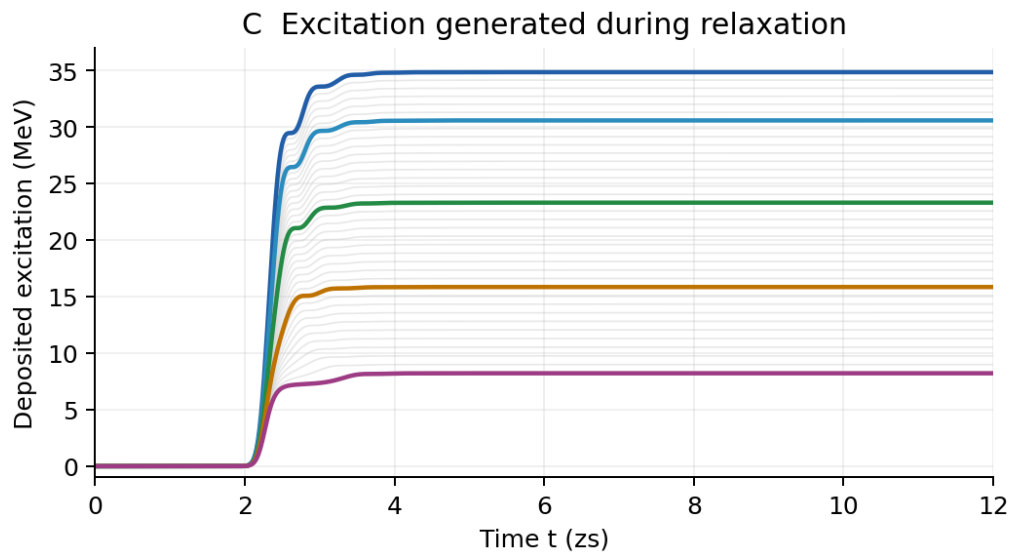


Figure 4 Excitation generated during radial relaxation

b in fm	Radius at 100 zs in fm	Excitation in MeV
6.35	11.090	34.833
6.75	11.185	23.297
7.25	11.338	8.216

The formal solver status remains time limit. Stationary radius, negligible radial velocity and the energy plateau support radial trapping within this model. This interpretation does not identify a fused compound nucleus.

Tangential friction comparison

With radial and tangential peak rates both $4 \times 10^{21} \text{ s}^{-1}$, all 37 trajectories enter the overlap stopping region after approximately 2.50-2.85 zs. At tangential rate 1, the lower 19 trajectories enter overlap and the upper 18 remain radially trapped through 100 zs.

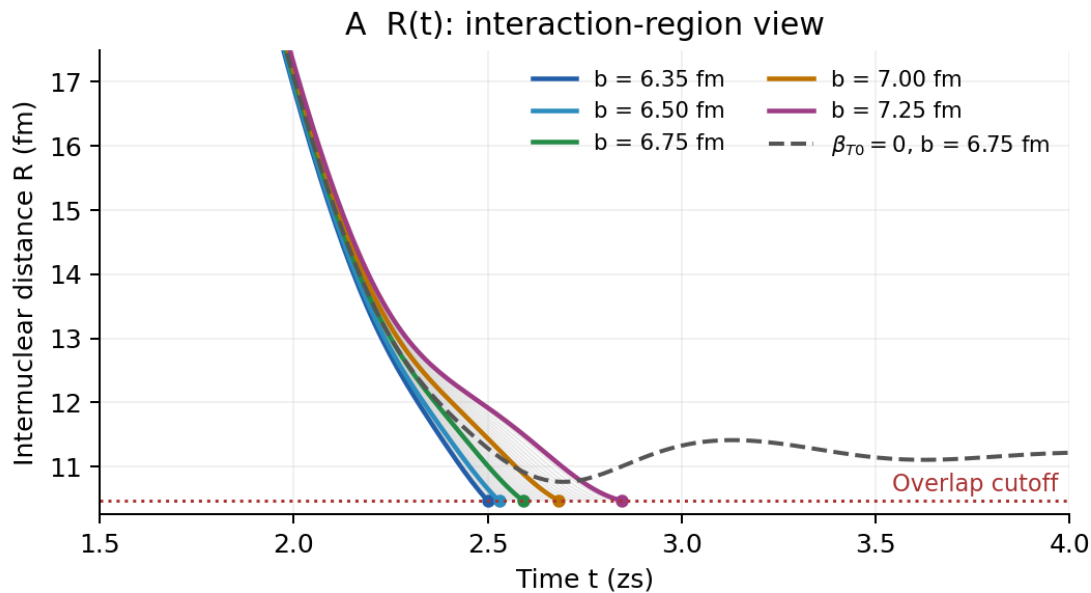


Figure 5 Surface-slip friction lowers orbital angular momentum and drives the benchmark band to overlap

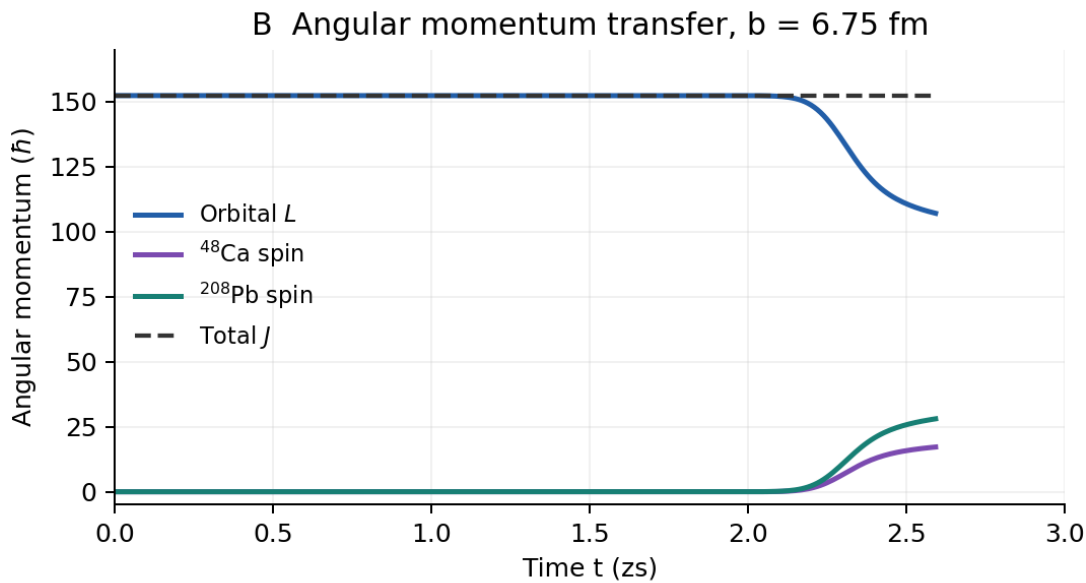


Figure 6 Orbital angular momentum transferred into Ca and Pb spins at $b = 6.75 \text{ fm}$

Initial J in $\hbar$	Orbital L at stop	Ca spin at stop	Pb spin at stop
152.297	107.055	17.200	28.042

At $b = 6.75 \text{ fm}$, excitation at overlap stopping is 48.475 MeV thermal heat plus 16.950 MeV Ca rotational energy and 3.908 MeV Pb rotational energy, totaling 69.333 MeV. These values describe the state at the cutoff. No final outgoing TKE is assigned to an overlap result.

Boundary map at one hundred zeptoseconds

The scan holds the radial rate at $4 \times 10^{21} \text{ s}^{-1}$ and samples $b = 6.350\text{-}7.250 \text{ fm}$. The main grid uses 37 impact parameters and 81 tangential rates from 0 to 4 in steps of 0.05. Another 629 weak-rate samples resolve slow relaxation near zero friction. There are 3626 parameter points plus boundary refinements.

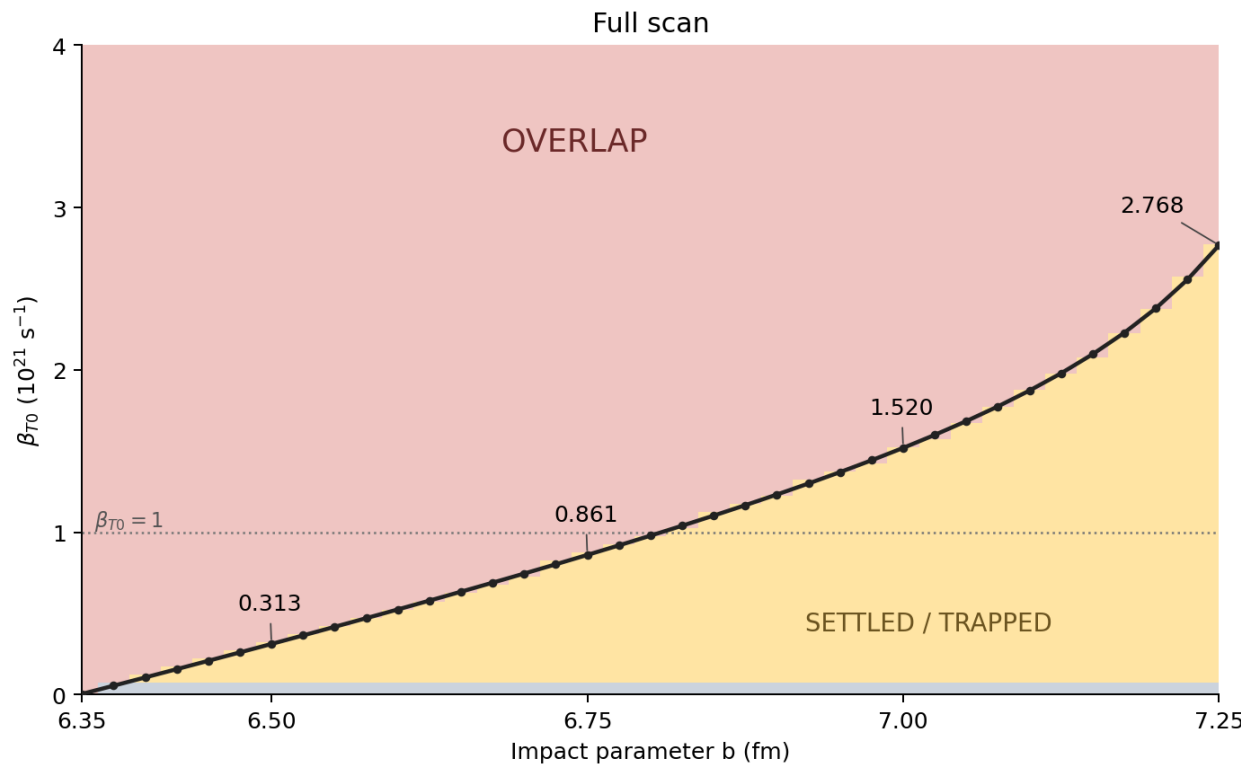


Figure 7 Refined overlap-onset curve in black with sampled overlap red settled trapping yellow and continuing relaxation gray

b in fm	Critical tangential rate in 10 ²¹ s ⁻¹
6.35	0.0049
6.50	0.313
6.75	0.861
7.00	1.520
7.25	2.768

The sampled overlap-onset boundary is monotonic. Above it, trajectories reach the 10.471 fm cutoff by 100 zs. Below it, trajectories do not reach overlap within the limit. No sampled trajectory separates. Exactly zero tangential friction leaves all 37 trajectories settled; small positive rates can leave continuing relaxation at 100 zs.

Settled classification requires, over 90-100 zs, radius span below 0.0001 fm, maximum radial speed below 0.0000001 c and total-excitation span below 0.0001 MeV. Bisection brackets are narrower than 0.00005 in rate units. Halving the time step shifts the boundary by at most 0.000104; numerical precision is not a measure of physical calibration.

Implementation and validation

Repository component	Purpose
d_Utilities/Langevin/ReactionDynamics.h	Qt-independent equations, integration, spins, energies and conservation diagnostics
d_Langevin.cpp and d_Langevin.h	Local participants, inputs, results, scanning controls and spin plots
d_LangevinPlot.cpp	Finite-data handling and gaps across unavailable outcomes
tests/reaction_dynamics_test.cpp and cmd	Standalone C++17 physics regression suite
LISEcute.pro and L_Init/lise_version.h	Version 18.8.104 and detailed dated release notes
doc/reaction_dynamics/2026-10-17	Figures, numerical evidence and portable scan sources

Physics checks

- Coulomb turning point and angular advance against analytic expectations.
- Conservative Woods-Saxon motion and zero generated heat when friction is disabled.
- Nonnegative thermal production and radial-only energy accounting.
- Transfer into both spins with pointwise conservation of L plus both fragment spins.
- Spin rotational energy included once in the total energy budget.
- Tangential-only scattering, zero tangential torque for head-on motion and time-step convergence.
- Stable classification of the 37-point tangential band under a halved integration step.

Across the 111 direct tangential-comparison runs, maximum total-energy error is below 2.2×10^{-8} MeV and maximum total-angular-momentum error is below 2.9×10^{-12} hbar. Across the larger boundary scan and refinements, the angular-momentum maximum remains below 2.8×10^{-11} hbar. The energy maximum remains below 2.2×10^{-8} MeV.

Interface changes

Model parameters now include an independent tangential rate, minimum and maximum impact parameters, and a minimum scan step of 0.025 fm. The time limit supports 100 zs. The Spins and energy tab displays orbital L, both spins, thermal heat, rotational energy and total-J error. Potential curves are labeled as entrance-L curves; trajectories use evolving L.

The dialog disables arbitrary final-channel Q values and imposed excitation inputs for this fixed-composition version. Asymptotic TKE and final fragment excitation are reported only for separated trajectories. Overlap and time-limit rows retain stopping-state diagnostics.

Reproducing the results and next steps

Reproduction

1. From the repository root, run `tests/reaction_dynamics_test.cmd` in an MSVC x64 environment to check the solver.
2. Open `doc/reaction_dynamics/2026-10-17` and run `reproduce.cmd` from an MSVC x64 Developer Command Prompt. It compiles five C++17 drivers against the repository solver.
3. The script writes fresh numerical outputs under `generated` and leaves the archived CSVs unchanged. The comparison driver reads the bundled AME2020 mass table.
4. Run the four plot Python scripts with `numpy`, `pandas` and `matplotlib` to regenerate figures from `generated`. The archived full trajectory CSVs are gzip compressed.
5. In the dialog, reproduce the coupled band with beam ^{48}Ca at 7 MeV/u, target ^{208}Pb , radial rate 4, tangential rate 4, maximum time 100 zs, `b` minimum 6.350, `b` maximum 7.250 and step 0.025 fm.

Archived numerical evidence

Artifact	Content
<code>ca-pb-comparison.csv</code>	Zero and finite radial-friction comparison
<code>ca-pb-100zs-summary.csv</code>	Long-time radial trapping and refinement
<code>ca-pb-tangential-summary.csv</code>	Rates 0 1 and 4 with spins and energy budgets
<code>ca-pb-friction-boundary.csv</code>	Coarse and refined critical-rate brackets
<code>ca-pb-friction-map-all-samples.csv</code>	All 3626 map samples and relaxation diagnostics
Compressed trajectory CSVs	Time histories behind the radial and coupled plots

Physical limits

The current model is nonrelativistic, deterministic and fixed in composition. Its supported exploratory energy range of 3-60 MeV/u is not a validated applicability range. The Woods-Saxon depth, geometry, radial damping, tangential damping and rigid-sphere inertias are illustrative and require comparison with data. Point-charge Coulomb and scaled contact lever arms are additional approximations.

Mass transfer, N/Z diffusion, evaporation, deformation, orientation-dependent interactions, stochastic forces and deep-overlap evolution remain outside this version. Residual rolling motion may survive at zero surface slip. A time-limit result does not establish permanent trapping, and an overlap result does not establish fusion.

Next priorities are calibrating potential and transport coefficients against a selected observable, testing sensitivity to the overlap cutoff and fragment inertias, and adding a physical treatment of deep-overlap configurations before making capture or fusion predictions. Comparisons with abrasion-ablation or participant-spectator dynamics remain research questions rather than assumed model limits.

Prepared for the LISEcute development record through 19 October 2026. Release notes and the archived numerical evidence accompany the source changes for version 18.8.104. The report does not depend on a machine-specific output folder.

Interactive energy and impact parameter maps

The Energy-impact map tab now compares four friction cases in two paired views: Zero and combined, and Radial and tangential only. Defaults are 3-60 MeV/u in 0.5 MeV/u steps, $b = 0$ -16 fm in 0.1 fm steps, both nonzero rates $4 \times 10^{21} \text{ s}^{-1}$, and a 100 zs limit. The default workload is 74060 trajectories. The wider dialog, minimize and maximize buttons, and illustration resizing are retained.

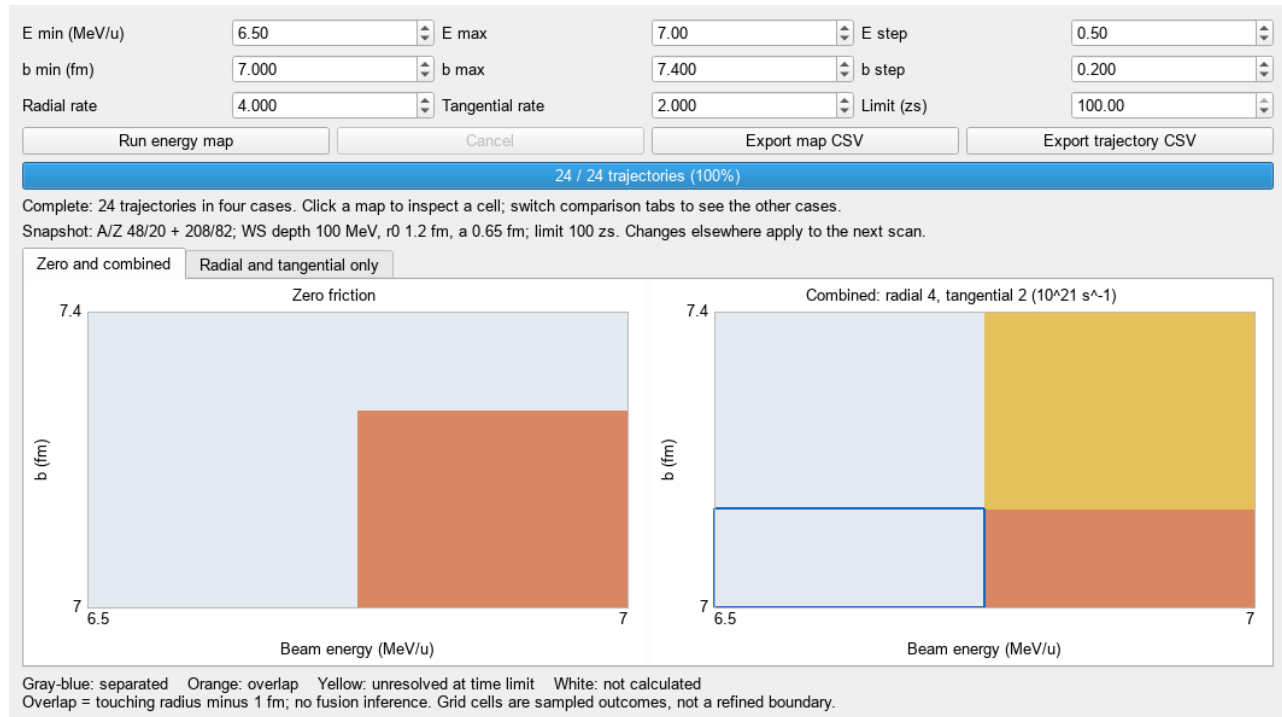


Figure 8 Four-case map controls on a small validation grid with deliberately unequal radial and tangential rates

Each scan snapshots the current participants, LISE masses and Woods-Saxon parameters. Editing other dialog controls does not change the saved inputs of existing cells. All four friction cases are interleaved at each grid point. The map supports at most 100000 trajectories and ends at the last grid coordinate not greater than the selected maximum.

The background worker publishes progress in batches. Cancel interrupts integration at a solver step and retains completed cells. Interrupted or uncomputed cells remain white. Closing the dialog requests cancellation and waits for workers to stop. These operations do not call GUI widgets from the numerical worker.

Gray-blue denotes separation, orange entry into overlap and yellow a time-limit result. The display colors sampled grid outcomes; it does not automatically refine an overlap boundary. Archived scientific boundary curves use the independent refinement described on the following page.

Energy scan from three to sixty MeV per nucleon

The archived study compares zero friction with radial and tangential rates both $4 \times 10^{21} \text{ s}^{-1}$. It contains 37030 grid trajectories at 115 energies and 161 impact parameters for each friction case, plus boundary refinements, for 41734 integrations total. Both cases use the same AME2020 masses and potential as the earlier benchmark. The integration limit is 100 zs.

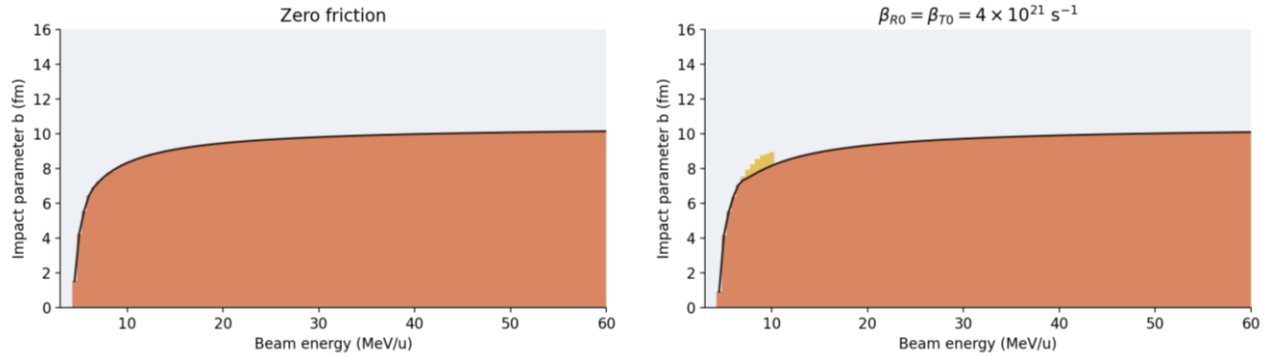


Figure 9 Energy and impact parameter outcome maps for zero and equal finite friction

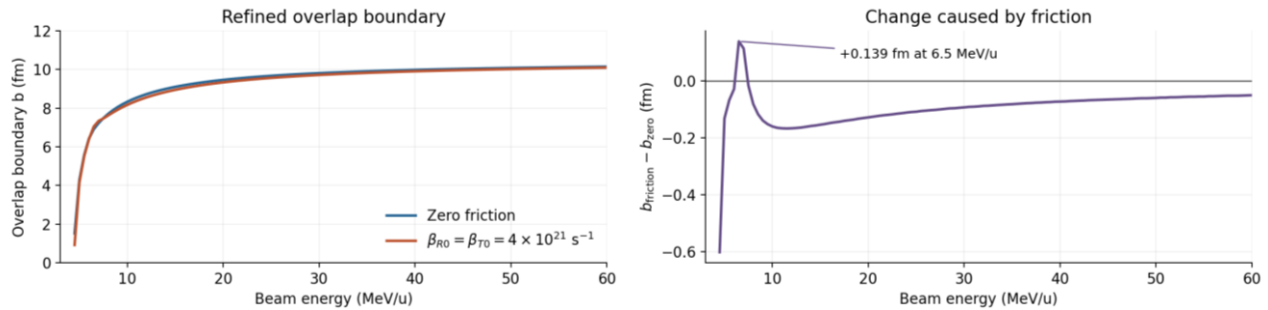


Figure 10 Refined overlap boundaries and their difference across the beam-energy scan

Energy in MeV/u	Zero friction b in fm	Equal rate 4 b in fm
4.5	1.520	0.917
6.5	6.908	7.047
7	7.220	7.334
10	8.330	8.170
20	9.461	9.333
40	9.979	9.906
60	10.146	10.095

No overlap occurs at the sampled energies 3, 3.5 and 4 MeV/u, even head-on. Both cases first overlap at 4.5 MeV/u, which brackets the onset between 4 and 4.5 without locating it exactly. Friction expands the boundary at sampled energies 6.5 and 7 MeV/u and reduces it at the other energies with overlap. At 60 MeV/u the reduction is approximately 0.050 fm.

Trajectory inspection exports and validation

Clicking a completed map cell recomputes its full trajectory from the stored input. The lower plots show $R(t)$, deposited total excitation and orbital angular momentum. A second sub-tab shows both fragment spins and total angular-momentum error. The summary separates thermal heat and spin rotation and reports status, stopping time, minimum distance and maximum conservation errors.

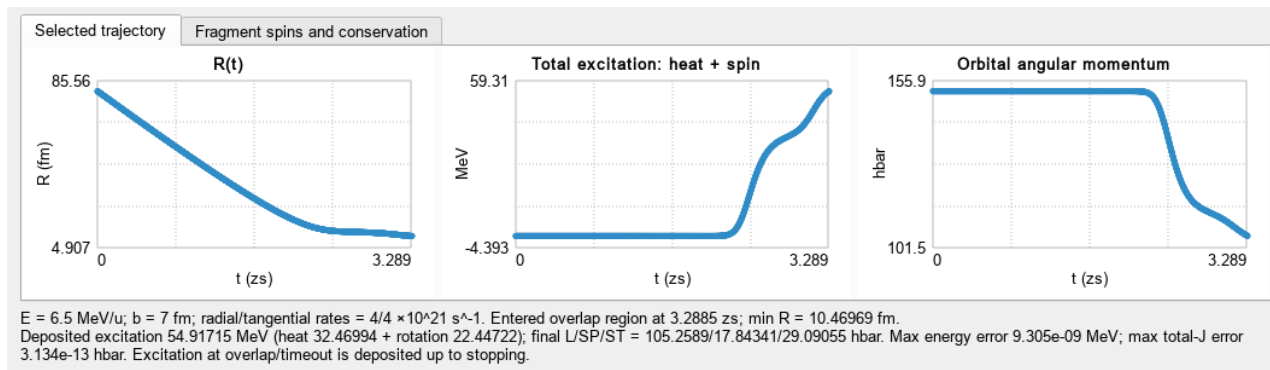


Figure 11 Selected-cell trajectory plots and stopping-state diagnostics

Export map CSV writes completed cells only, including model inputs and conservation diagnostics. Asymptotic TKE is left blank for overlap and timeout outcomes. Export trajectory CSV retains every recorded point, including velocities, heat, spin energies and momenta. Numeric output uses decimal points independent of locale, and atomic saves protect existing files from incomplete replacement.

Numerical validation

Check	Result
Grid classification	15870 separated; 21115 overlap; 45 unresolved
Unresolved grid cells	All with friction; energies 7-10 MeV/u; b bounding range 7.4-8.9 fm
Boundary refinement	Every row with overlap has a single transition; final b brackets below 0.001 fm
Half step comparison	Maximum boundary midpoint shift 0.000684 fm
Total energy	Maximum error 5.076×10^{-6} MeV over grid and refinement runs
Total angular momentum	Maximum error 6.343×10^{-12} hbar over grid and refinement runs
GUI integration checks	Actual map clicks; direct-solver agreement; immutable snapshots; complete and partial CSV; cancellation and shutdown

Run tests/reaction_energy_map_test.cmd for the offscreen Qt integration check and tests/reaction_dynamics_test.cmd for the physics regression suite. Run reproduce-energy-scan.cmd in the dated archive directory to regenerate grid, boundary and diagnostics CSVs under generated. The plotting script reads CSVs beside itself; copy it into generated to plot fresh results. ENERGY_SCAN.md records the full protocol and interpretation limits.

Isolating the two friction channels

The new comparison view separates the radial and tangential channels while keeping the participants, potential, scan coordinates and time limit identical. Radial-only uses the selected radial rate and exactly zero tangential rate. Tangential-only does the reverse. The combined case uses both rates. Distinct case labels remain available even when a user selects a zero rate.

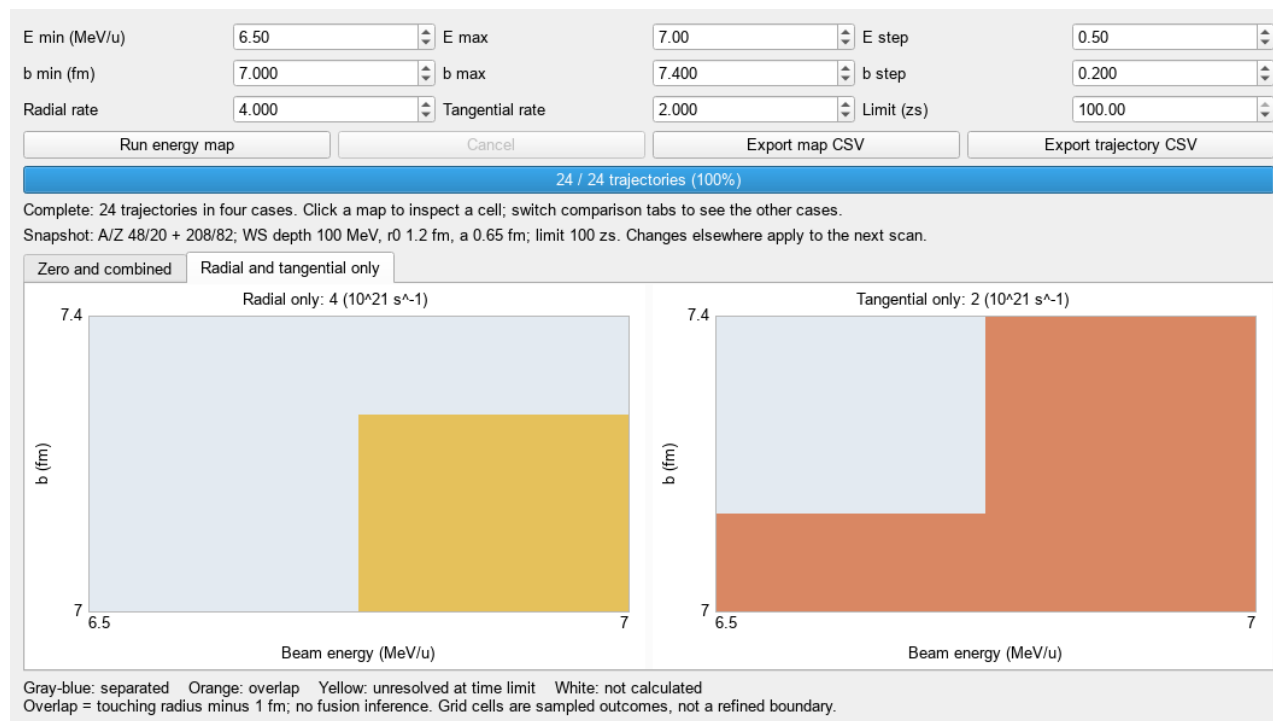


Figure 12 Radial-only and tangential-only maps on the same unequal-rate validation grid

Case	Radial rate	Tangential rate
Zero friction	0	0
Radial only	Selected radial rate	0
Tangential only	0	Selected tangential rate
Combined	Selected radial rate	Selected tangential rate

The two rate controls are shared across the isolated and combined cases. The four maps have identical axes and retain clickable point inspection, background progress, cooperative cancellation and partial-map export. The total scan cap remains 100000 trajectories. Both CSV formats append `friction_case` without moving the existing numeric columns.

The selected-trajectory summary explicitly identifies its friction case, so switching comparison views does not obscure which saved point produced the lower plots. Qt integration tests use unequal rates to detect crossed channel wiring, click all four maps and compare exported outcomes and excitation with direct solver calculations.

Four case overlap boundaries

The focused study uses $^{48}\text{Ca} + ^{208}\text{Pb}$ at nine energies from 6 to 60 MeV/u, with each nonzero rate fixed at $4 \times 10^{21} \text{ s}^{-1}$. It retains the earlier AME2020 masses, $Q = 0$, Woods-Saxon depth 100 MeV, $r_0 = 1.2 \text{ fm}$, diffuseness 0.65 fm, entrance radius 80 fm and overlap cutoff 10.471079987 fm. The time limit is 100 zs.

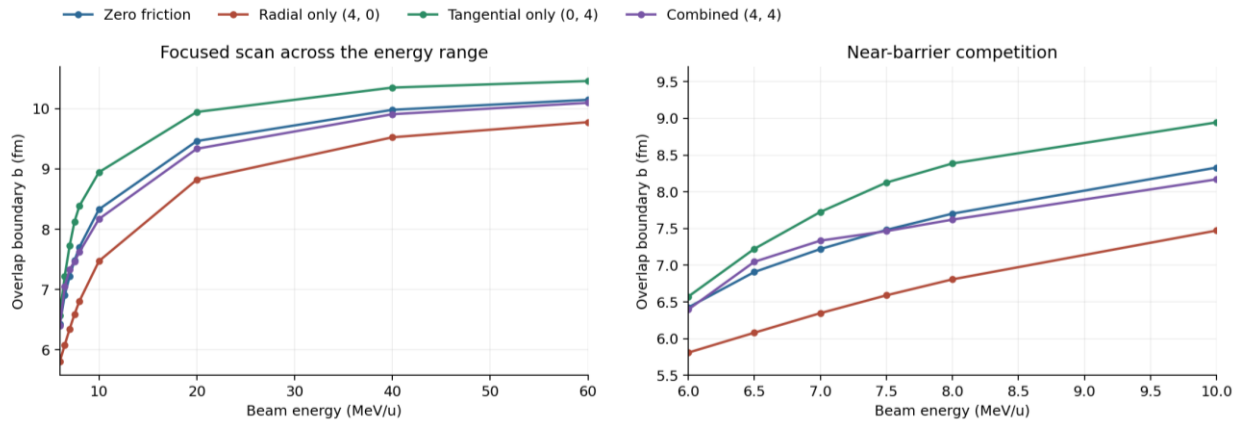


Figure 13 Four friction cases across the energy range and a near-barrier zoom with the same case colors

Energy in MeV/u	Zero b in fm	Radial b in fm	Tangential b in fm	Combined b in fm
6	6.426	5.810	6.573	6.397
6.5	6.908	6.081	7.223	7.047
7	7.220	6.347	7.726	7.334
7.5	7.481	6.590	8.126	7.464
8	7.702	6.808	8.386	7.621
10	8.330	7.472	8.945	8.170
20	9.461	8.820	9.943	9.333
40	9.979	9.523	10.347	9.906
60	10.146	9.774	10.457	10.095

At each energy and in each case, 161 impact parameters from 0 to 16 fm in steps of 0.1 resolve one overlap-to-nonoverlap transition. There are 5796 grid integrations and 6564 integrations including boundary refinements and twelve probe trajectories. Each boundary is refined below 0.001 fm and independently checked with a half time step.

The largest half-step boundary shift is 0.0004883 fm; maximum total-energy error is $5.076 \times 10^{-6} \text{ MeV}$ and maximum total- J error is $5.605 \times 10^{-12} \text{ hbar}$. The zero and combined boundaries reproduce the earlier two-case scan. Connecting lines guide the eye between the nine sampled energies and do not locate the crossover exactly.

Why the combined overlap boundary changes

Radial drag opposes incoming radial momentum and generates heat without changing orbital L . Tangential drag transfers L into fragment spins and lowers centrifugal repulsion. The same-coordinate probes below show how these mechanisms change the outcome when combined.

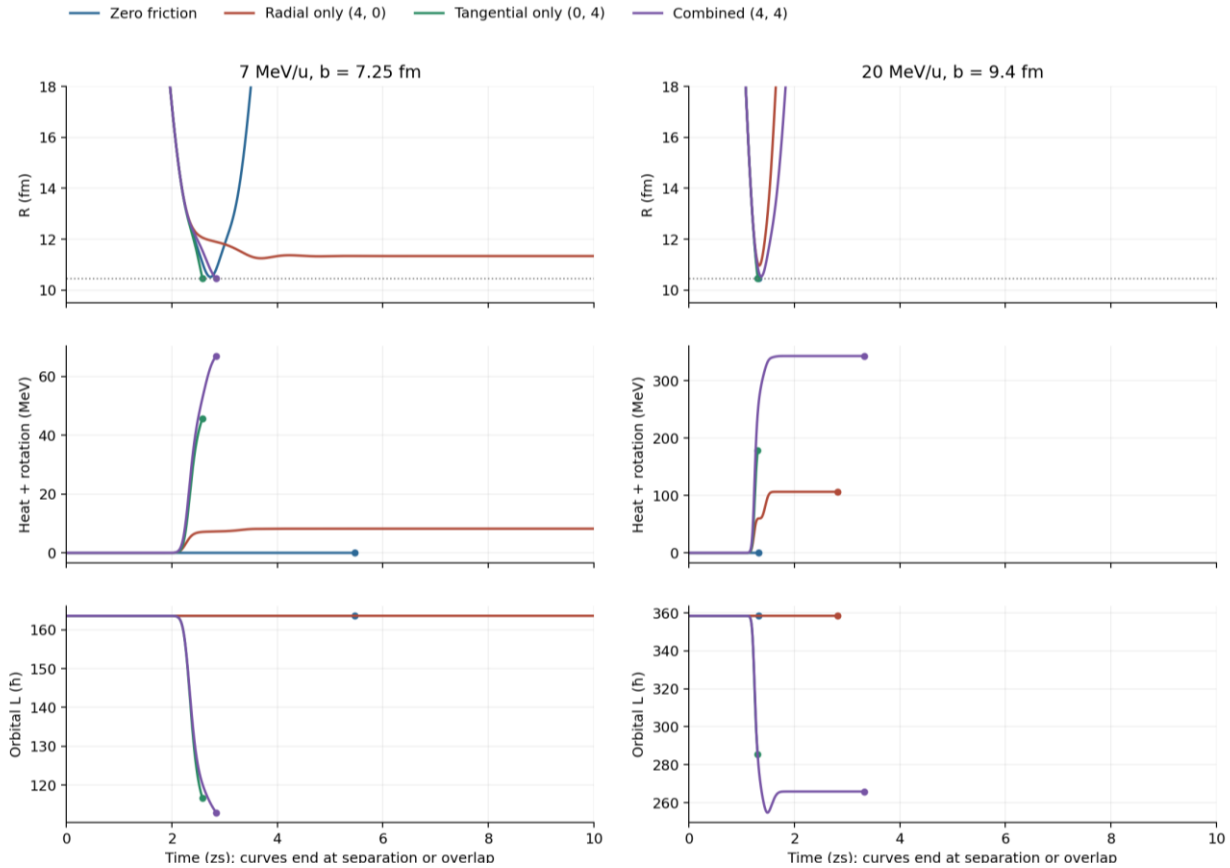


Figure 14 Distance excitation and orbital angular momentum for identical impact parameters within each energy panel

At 7 MeV/u and $b = 7.25$ fm, zero friction separates and radial-only reaches 100 zs outside overlap with 8.216 MeV deposited. Tangential-only and combined enter overlap after 2.580 and 2.844 zs. Orbital L starts at 163.579 hbar and reaches 116.700 and 112.937 hbar at the respective overlap stops.

At 20 MeV/u and $b = 9.4$ fm, zero and tangential-only enter overlap, while radial-only and combined separate. Combined friction still reduces orbital L from 358.495 to 265.847 hbar and deposits 342.982 MeV of excitation. The high-energy reduction therefore does not mean tangential transfer has vanished. Radial slowing changes surface exposure and slip history, so isolated-case effects cannot be added linearly.

Run reproduce-channel-comparison.cmd in the dated archive to regenerate CSVs under generated. Copy plot-channel-comparison.py there to regenerate figures and the gzip trajectory archive. CHANNEL_COMPARISON.txt records settings, outcomes and interpretation limits. The study remains an uncalibrated nonrelativistic model; neither overlap nor timeout establishes fusion or permanent trapping.

Contact time definition and map controls

Contact time is the cumulative duration for which the internuclear separation R is at or below the touching radius. For this system the touching radius is 11.471079987 fm and the overlap cutoff is 10.471079987 fm. Contact may comprise more than one interval. Surface friction has a finite tail outside touching, so zero geometric contact does not imply zero energy dissipation.

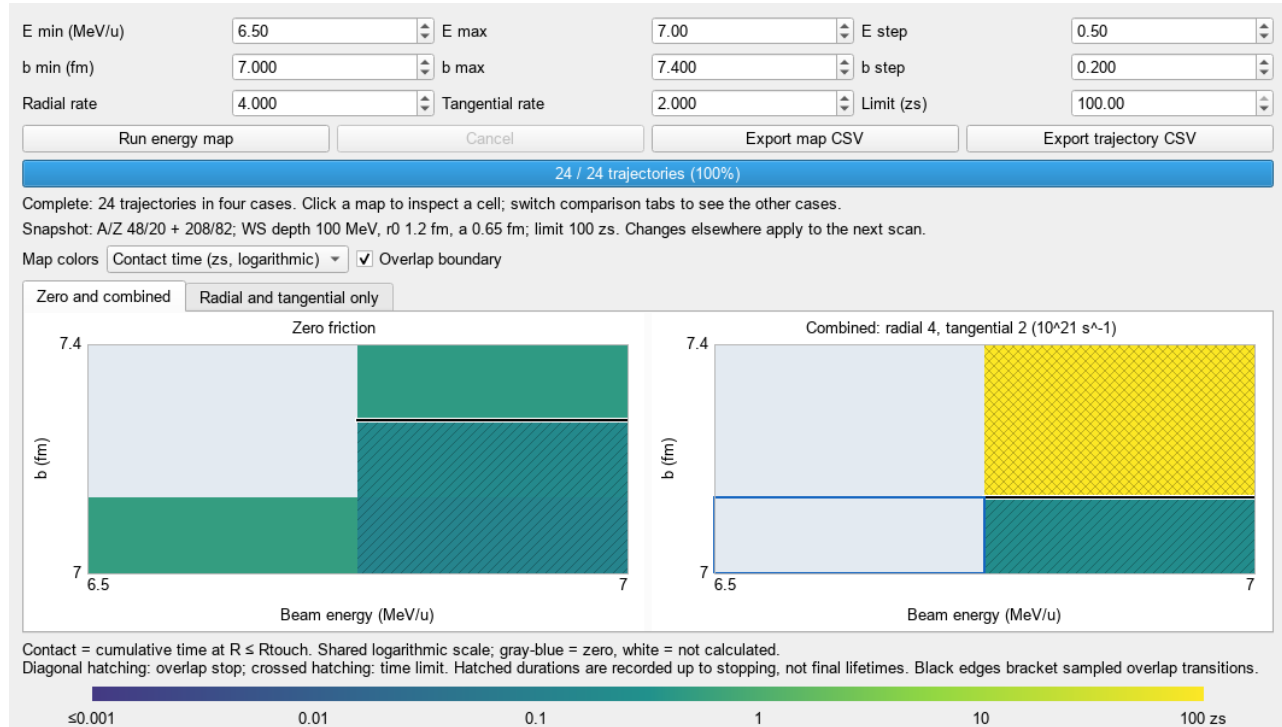


Figure 15 Contact duration view with a shared logarithmic scale and optional sampled overlap edges

The map color selector switches between outcomes and contact time without repeating the scan. All four cases share a logarithmic scale from 0.001 to 100 zs; smaller positive values use the first color. Gray-blue marks zero contact and white marks uncomputed cells. A single diagonal hatch marks an overlap stop and crossed hatching marks a time-limit stop. Both durations are recorded only up to the stopping event and are censored.

Black and white edges mark transitions between adjacent sampled impact parameters with different overlap classification. They are grid edges, not refined boundaries, and are not extended across uncomputed cells. Hovering displays energy, impact parameter, duration and outcome. Clicking retains trajectory, excitation, orbital momentum and spin inspection. The map page scrolls when the window is small.

Map CSV export appends contact_censored and contact_radius_fm after friction_case, preserving every earlier numeric column. Selected-point diagnostics show the touching radius and distinguish a completed contact history from a duration censored by overlap or the integration limit.

Contact duration over the full energy range

The full atlas uses $^{48}\text{Ca} + ^{208}\text{Pb}$ at 58 energies from 3 to 60 MeV/u in 1 MeV/u steps and 161 impact parameters from 0 to 16 fm in 0.1 fm steps. Four friction cases give 37352 integrations. Nonzero radial and tangential rates are each $4 \times 10^{21} \text{ s}^{-1}$; every calculation has a 100 zs limit and maximum step 0.5 fm/c.

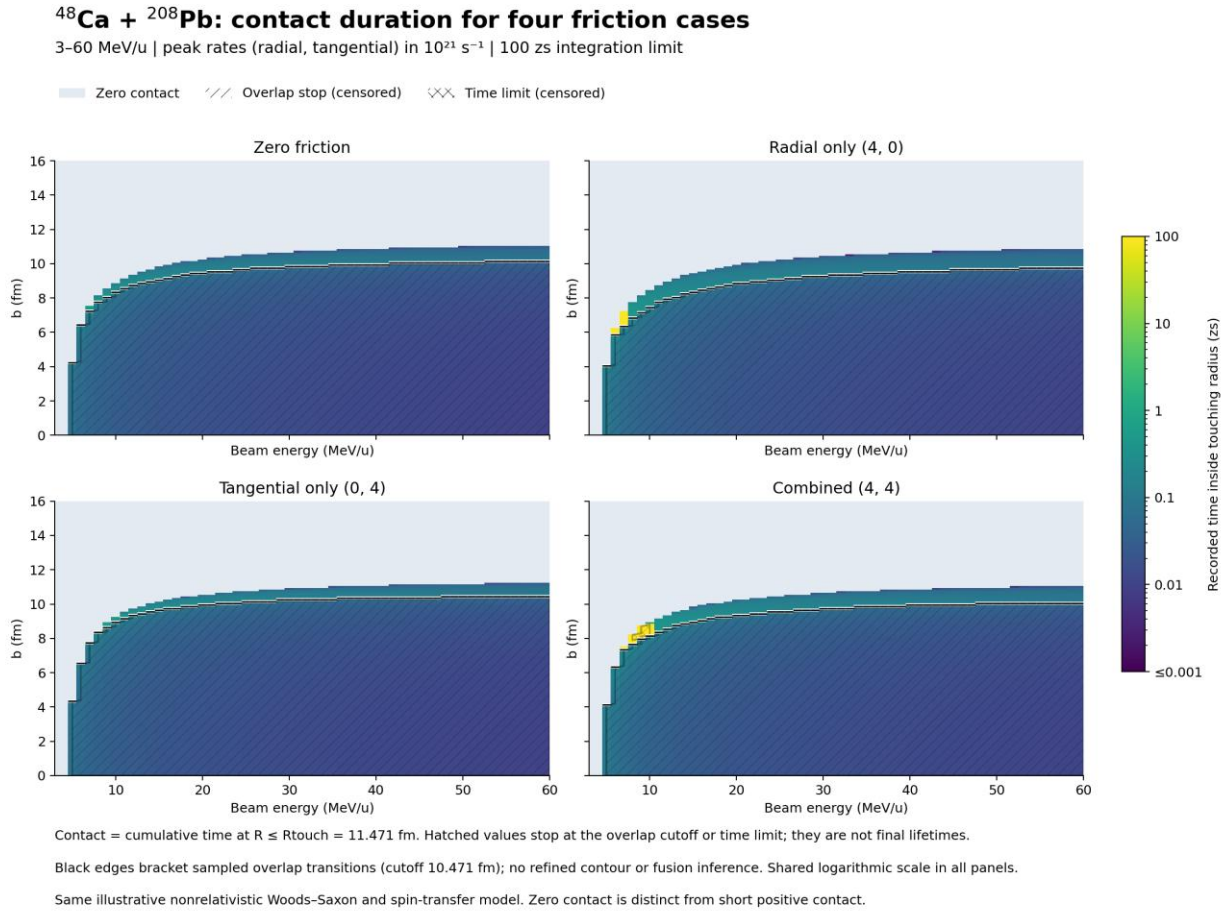


Figure 16 Full contact-time atlas for zero radial tangential and combined friction

The archived atlas uses the same AME2020 masses, $Q = 0$ and Woods-Saxon parameters as the earlier studies: depth 100 MeV, $r_0 = 1.2 \text{ fm}$ and diffuseness 0.65 fm. The entrance radius is at least 80 fm and grows when required by energy and impact parameter, matching the GUI. This scientific grid is distinct from the finer default GUI energy step of 0.5 MeV/u.

There are 23088 cells with positive geometric contact. The largest recorded duration is 97.932177 zs. Long durations concentrate near the transition between overlap and separation; their interpretation depends on the stopping outcome. Hatching must be read together with color because early overlap termination can produce a short recorded contact duration.

Contact duration near the overlap boundary

The zoom resolves 17 energies from 6 to 10 MeV/u in 0.25 MeV/u steps and 91 impact parameters from 5.5 to 10 fm in 0.05 fm steps. The four cases give 6188 integrations. With the full atlas there are 43540 runs; repeated coordinates between grids are included in this total.

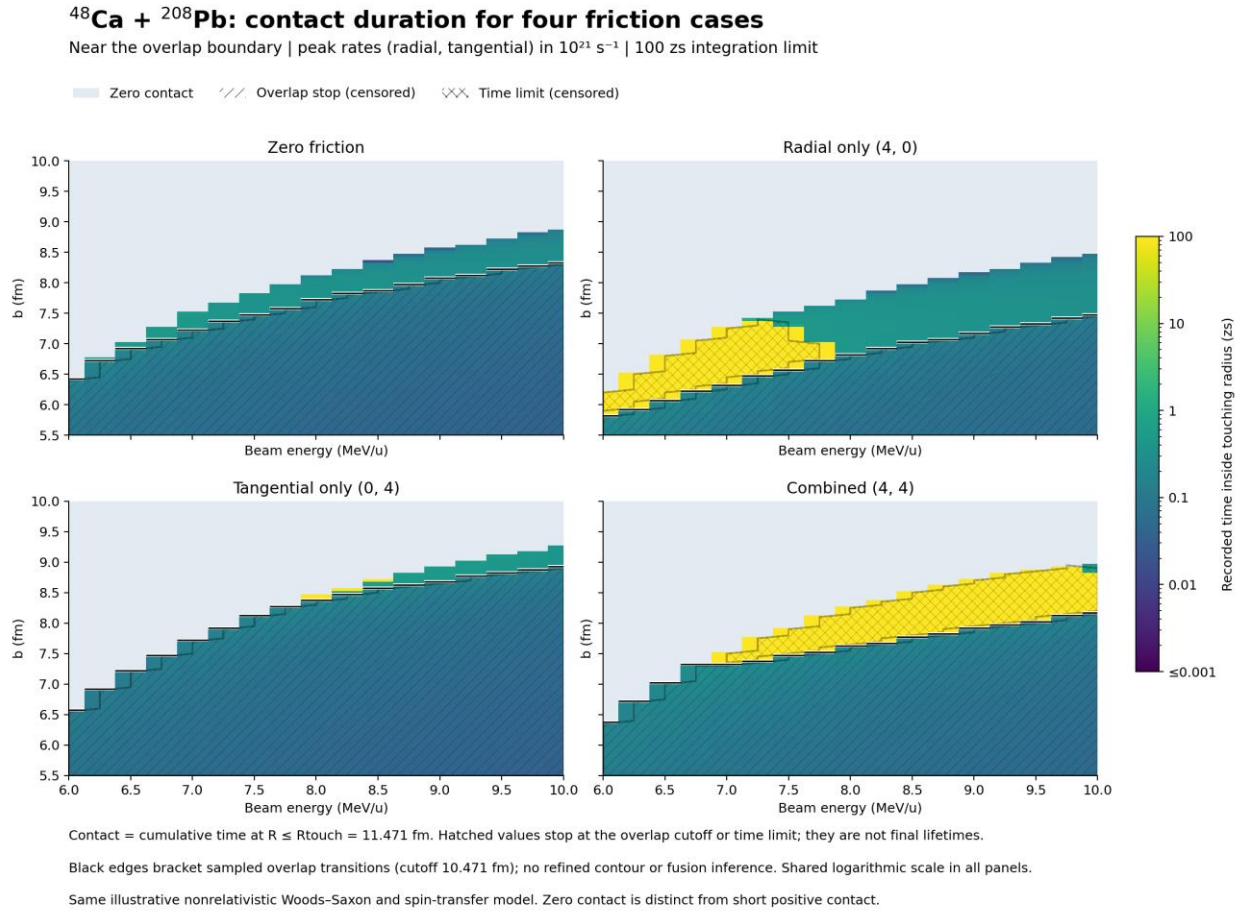


Figure 17 Near-boundary contact-time atlas with the same scale and censoring conventions

The zoom contains 3402 positive-contact cells and a largest recorded duration of 97.984985 zs. Radial damping can sustain long contact outside the overlap cutoff. Tangential transfer can instead bring the same entrance conditions into overlap after a short recorded contact interval. These are stopping-state comparisons, not rankings of final lifetimes.

The color scale is shared across both atlases and all four cases. The boundary edges reflect sampled outcomes at the stated grid spacing; the maps do not add new sub-grid boundary refinement. The deterministic fixed-composition model does not evolve deep-overlap configurations and does not classify fusion.

Selected contact times and release validation

The selected coordinates reproduce the earlier channel probes using the contact-aware accumulator. The table reports cumulative contact in zs, rather than total elapsed trajectory time. Overlap and time-limit entries are censored; separated entries have completed contact histories.

Energy MeV/u	b fm	Friction case	Outcome	Contact zs
7	7.25	Zero	Separated	0.431715
7	7.25	Radial only	Time limit	96.651413
7	7.25	Tangential only	Overlap	0.104230
7	7.25	Combined	Overlap	0.248134
20	9.4	Zero	Overlap	0.067029
20	9.4	Radial only	Separated	0.137449
20	9.4	Tangential only	Overlap	0.048628
20	9.4	Combined	Separated	0.234375

At 7 MeV/u and $b = 7.25$ fm the radial-only trajectory reaches the 100 zs limit with 96.65 zs recorded contact, whereas tangential-only and combined trajectories enter overlap. At 20 MeV/u and $b = 9.4$ fm radial-only and combined trajectories separate after completed contact intervals. A short overlap entry does not establish a shorter physical lifetime than a separated event.

Numerical and interface checks

Touching-crossing steps contribute a linearly interpolated fraction rather than a whole midpoint-classified step. This changes the diagnostic accumulator without changing the equations of motion, energies, spins or classifications. Analytic free head-on and grazing-chord tests, including a half-step check, validate the contact measure. Overlap termination remains at the first recorded step inside the cutoff.

Across both contact atlases the maximum total-energy error is 5.075987×10^{-6} MeV and maximum total-J error is 6.342086×10^{-12} hbar. The standalone physics and offscreen Qt integration suites pass. GUI checks cover cached display switching, all four case clicks, CSV censoring and radius fields, cancellation, partial exports and shutdown.

Reproduction and archived evidence

Run reproduce-contact-map.cmd in the dated archive to write fresh CSVs under generated. Copy plot-contact-map.py into generated and run it with numpy, pandas and matplotlib to regenerate the figures. CONTACT_MAP.txt records the protocol and interpretation limits. contact-map-manifest.json records normalized text and raw binary SHA-256 hashes. Source CSVs, selected probes, diagnostics, PNG and PDF figures accompany this release.

Extension to one thousand zeptoseconds

All 6188 near-boundary coordinates were re-integrated from the original entrance conditions through 1000 zs. The grid covers 6-10 MeV/u in 0.25 MeV/u steps and $b = 5.5$ -10 fm in 0.05 fm steps, with four friction cases at every point. Each nonzero damping rate remains $4 \times 10^{21} \text{ s}^{-1}$. The 289 histories unresolved at 100 zs were independently repeated with a half time step, giving 6477 scientific integrations.

Friction case	Unresolved at 100 zs	Later separation	Later overlap	Settled at 1000 zs
Zero	0	0	0	0
Radial only	112	0	0	112
Tangential only	4	0	0	4
Combined	173	0	0	173

All 289 remain outside overlap and satisfy the settling criteria over 900-1000 zs. The sampled overlap boundary is unchanged. The 5899 histories already separated or stopped at overlap by 100 zs reproduce their earlier outcome, stopping time and excitation. This extension covers the near-boundary grid, rather than the full 3-60 MeV/u atlas.



Figure 18 The 1000 zs limit and extended contact scale on the radial and tangential comparison view

Single collisions and energy-impact maps now accept limits up to 1000 zs while retaining the 100 zs default. Saved limits above 100 zs use a shared 0.001-1000 zs logarithmic contact scale. Editing the next scan limit does not recolor cached results. The formal solver status remains TimeLimit; settled_at_limit is an additional diagnostic in the archived study.

Comparing outcomes at the two time limits

The left column shows the original 100 zs outcomes. The right column distinguishes the histories that remain at the 1000 zs limit and pass the late-time settling checks. No sampled trajectory changes between overlap and nonoverlap.

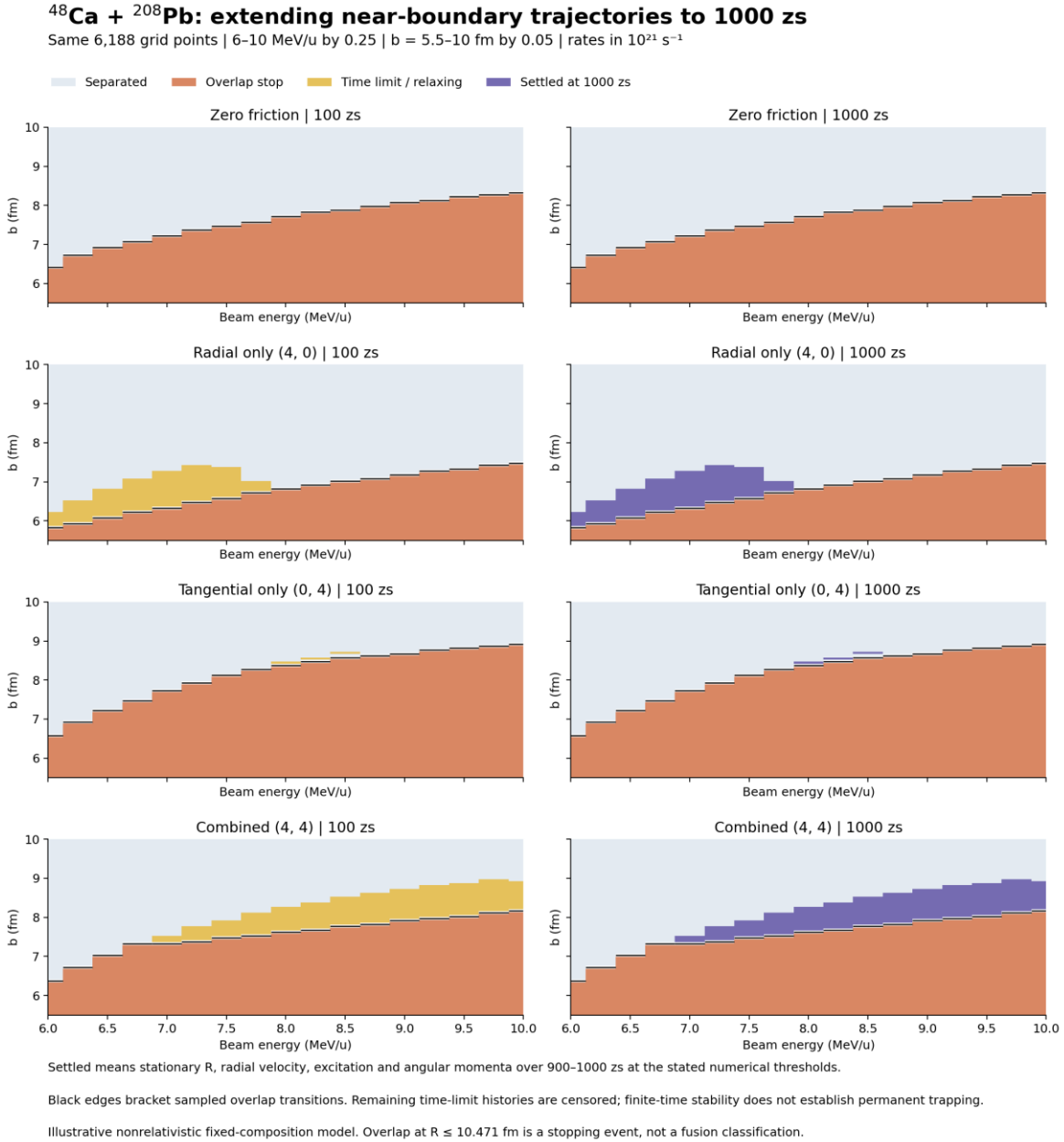


Figure 19 All four friction cases at 100 and 1000 zs with identical coordinates and sampled overlap edges

Purple denotes a settled state through 1000 zs. It does not assign an infinite lifetime or identify a fused compound nucleus. Black edges bracket transitions between adjacent sampled impact parameters; no new sub-grid boundary refinement is implied.

Contact duration through one thousand zeptoseconds

The extended atlas uses the same definition of cumulative contact at $R \leq R_{\text{touch}}$, with $R_{\text{touch}} = 11.471079987$ fm. All four cases share the extended 0.001-1000 zs scale. Overlap and time-limit durations remain censored at stopping, regardless of whether the late-time motion has settled.

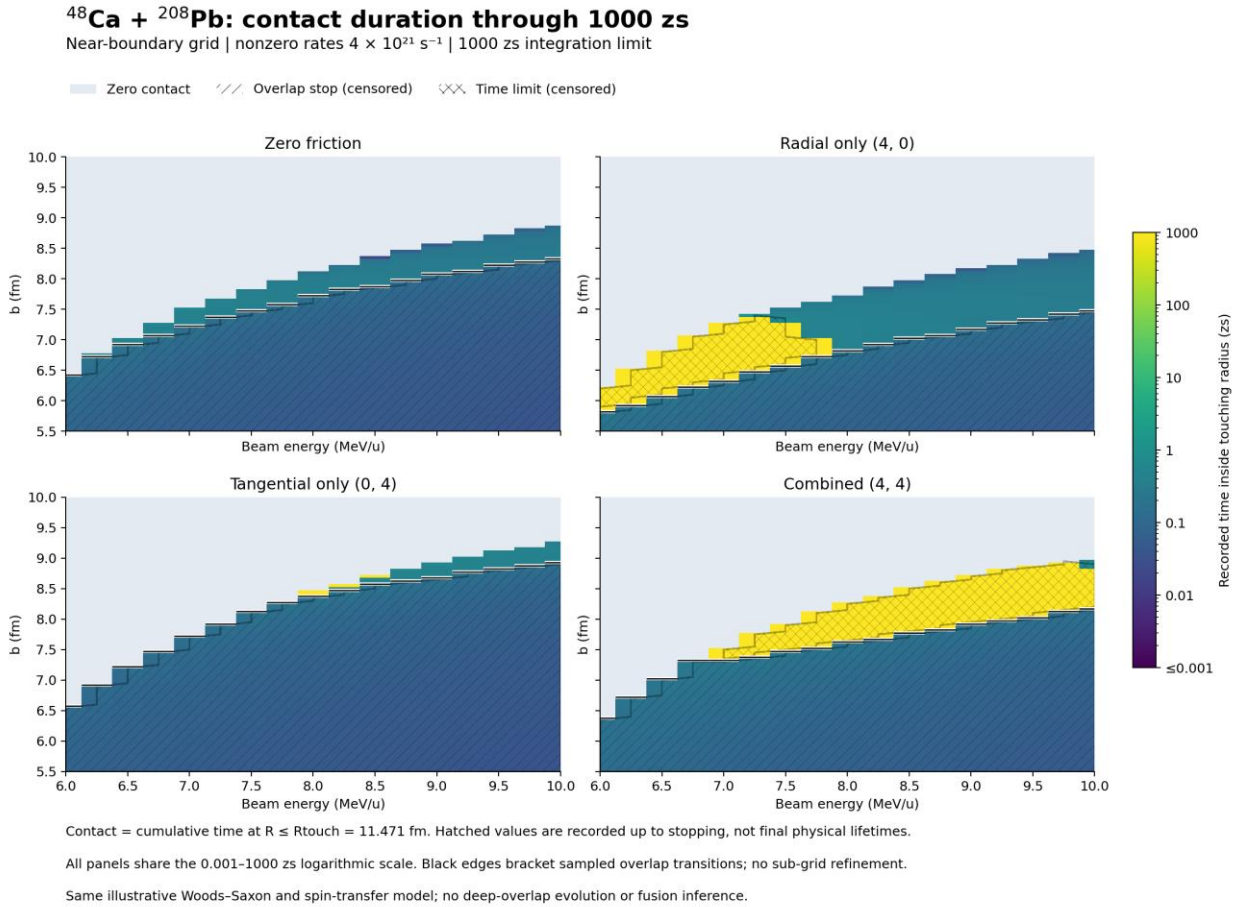


Figure 20 Recorded contact duration through 1000 zs for the four friction cases

At 7 MeV/u and $b = 7.25$ fm, the radial-only trajectory records 996.651413 zs of contact by the new limit, compared with 96.651413 zs at 100 zs. It remains near $R = 11.338218$ fm with total excitation 8.215529 MeV. At the same coordinate, zero friction separates, while tangential-only and combined friction enter overlap before 3 zs.

Across the 289 remaining time-limit histories, final separations range from 10.858495 to 11.551513 fm. Some stationary states lie outside touching but inside the friction tail. Thus the absence of geometric contact does not imply an absence of dissipative evolution.

Long time motion excitation and angular momentum

Every originally unresolved history is shown in gray, with one labeled reference per nonzero friction case. The coordinates differ between columns. Zero friction has no unresolved point at 100 zs. The dashed vertical line marks the previous integration limit.

What happens to the 289 histories unresolved at 100 zs

Gray: every originally unresolved history in that case. Color: one labeled reference; coordinates differ between columns.

Zero friction has no unresolved points at 100 zs. Dashed vertical lines mark the old limit.

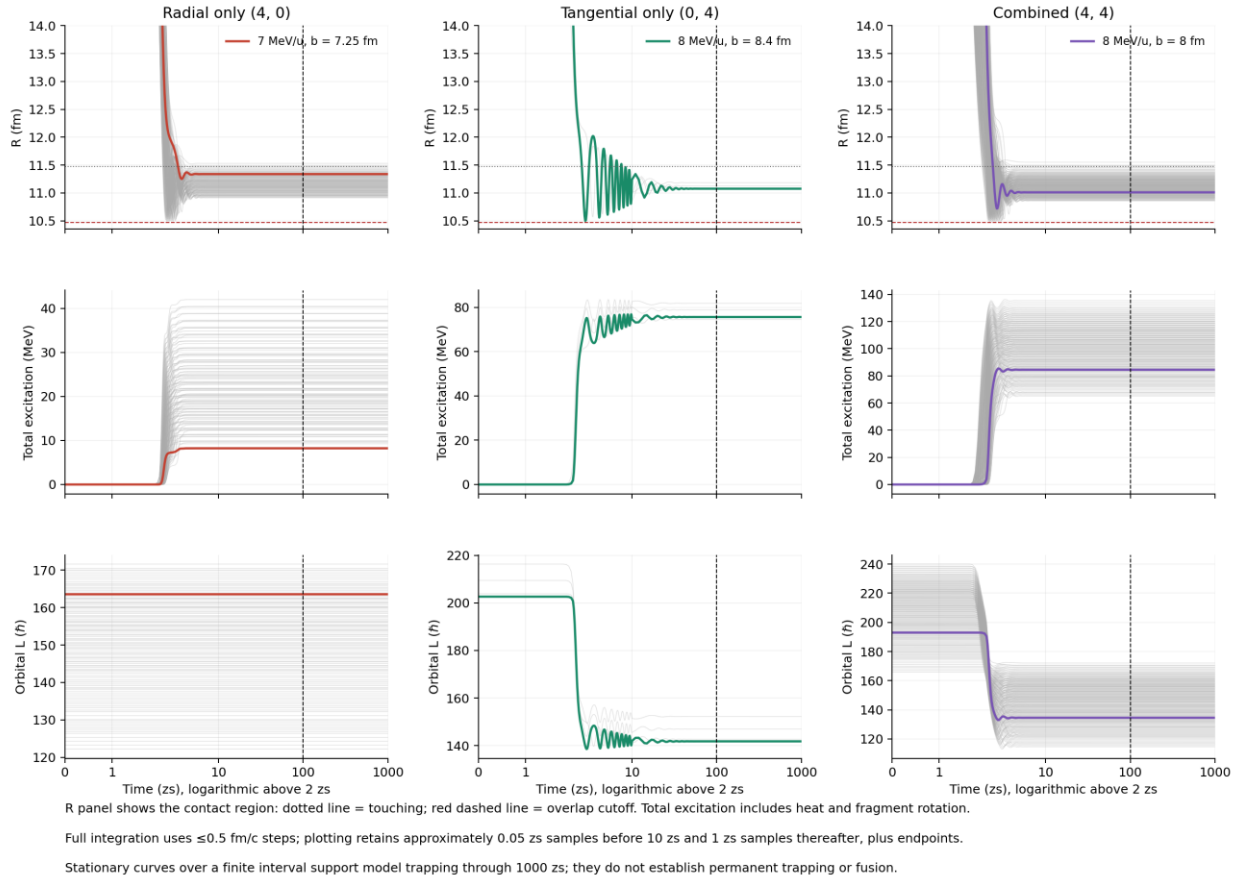


Figure 21 Separation total excitation and orbital angular momentum through 1000 zs

Radial-only damping leaves orbital L unchanged while radial motion settles. Tangential transfer redistributes L into fragment spins, and its coupling to radial motion can produce oscillatory relaxation. The combined cases settle with both damping channels active. The largest additional total-excitation change from 100 to 1000 zs is only $1.678 \times 10^{-5} \text{ MeV}$; the largest orbital- L change is $1.347 \times 10^{-5} \text{ hbar}$.

Late-time radial force balance and vanishing surface slip support stationary rotating states. The potential curvature under the appropriate conserved angular-momentum constraints is positive for every former timeout, with a minimum of 2.75661 MeV/fm^2 . These checks support finite-time model trapping and do not establish permanent trapping in a physical collision.

Long time validation and reproduction

Settling check over 900-1000 zs	Required threshold
Separation span	Less than 0.0001 fm
Maximum absolute radial velocity	Less than 1×10^{-7} c
Total excitation span	Less than 0.0001 MeV
Each orbital and fragment-spin momentum span	Less than 0.0001 hbar

All 289 former timeouts satisfy every condition. The largest measured late-time separation span is 1.297×10^{-13} fm and largest radial speed is 2.165×10^{-15} c. The original 0.5 fm/c maximum step and independent 0.25 fm/c runs agree on every outcome and settled classification.

Numerical comparison	Maximum
Total-energy error over both step sizes	1.267×10^{-7} MeV
Total-angular-momentum error	8.223×10^{-12} hbar
Half-step excitation difference	6.60×10^{-8} MeV
Half-step contact-duration difference	1.320×10^{-5} zs
Final radial force magnitude	1.363×10^{-9} MeV/fm
Final surface slip with tangential friction	7.936×10^{-13} c

Final radius and orbital momentum agree at the stored CSV precision of 12 significant digits. Zero differences at that precision do not imply exact real arithmetic. Settling diagnostics use every integration point, while the plotted gzip histories retain approximately 0.05 zs spacing before 10 zs and 1 zs thereafter, including endpoints.

Reproduction

Run reproduce-contact-1000zs.cmd in the dated archive from an MSVC x64 Developer Command Prompt. It writes fresh coarse and half-step CSVs under generated. Copy plot-contact-1000zs.py there and run it with numpy, pandas and matplotlib to produce figures, validation metrics and compressed histories. The plotting script reads the original 100 zs baseline from the parent archive.

CONTACT_1000ZS.txt records the complete protocol and interpretation. contact-1000zs-former-timeouts.csv includes the late-time spans, force, slip and constrained-potential curvature. contact-1000zs-manifest.json records solver, baseline, source and result hashes. Both compressed history files contain 289 histories through 1000 zs, each with 344199 rows in total.

Release checks and limits

The application compiles with the extended limits. The physics regression and Qt integration suites pass, including the saved contact scale, 1000 zs CSV metadata and radial long-contact benchmark. The model remains deterministic and fixed in composition, without stochastic forces, evaporation, mass transfer or deep-overlap evolution. Neither overlap nor absence of a late event through 1000 zs establishes fusion or a physical lifetime.

Equilibrium potential diagnostics

The new Equilibrium / potential tab compares the final trajectory radius with minima of the appropriate constrained potential. It is available after a single collision and in the selected-point tabs after clicking a completed energy-map cell. All friction cases use the saved trajectory inputs. The diagnostic does not alter the integration or assign a new outcome.

Conserved quantities determine the curve

Without tangential friction, orbital angular momentum L remains fixed and both fragment spins remain zero. The radial-only potential is the Coulomb plus Woods-Saxon potential with the fixed- L centrifugal term.

$$V_{\text{radial}} = V_C + V_N + \frac{L^2}{2\mu R^2}$$

With tangential friction, the solver preserves total J and the spin-sharing relation imposed by its constant lever-arm fractions. Let $f_P = A_P^{1/3}/(A_P^{1/3} + A_T^{1/3})$ and $f_T = 1 - f_P$. Starting from zero spins gives $SP = f_P(J-L)$ and $ST = f_T(J-L)$. Minimizing orbital plus spin energy at fixed J and this ratio gives zero surface slip.

$$\frac{1}{I_s} = \frac{f_P^2}{I_P} + \frac{f_T^2}{I_T}$$

$$V_{\text{constrained}} = V_C + V_N + \frac{J^2}{2(\mu R^2 + I_s)}$$

$$L_{\text{eq}} = \frac{J\mu R^2}{\mu R^2 + I_s}$$

Tangential-only and combined friction therefore have the same constrained curve for identical entrance conditions. Radial damping changes the approach to this rotational envelope. A transient with finite surface slip need not lie on it. Freezing the final orbital L would impose the wrong constraint on a spin-coupled equilibrium.

Finding and interpreting minima

The diagnostic samples force at spacing no greater than $\text{diffuseness}/80$, brackets positive-to-negative force crossings and bisects each bracket 60 times. It excludes boundary roots and requires positive potential curvature. The search covers the cutoff to $\max(\text{start}, b+40, \text{final } R, \text{cutoff}+30)$ in fm. A missing exterior minimum is reported explicitly. The curve is never continued below the overlap cutoff.

The surface view spans the cutoff to $R_{\text{touch}}+8$ fm. A checkbox shows the full range. Red dashes mark the cutoff, purple dashes the final radius and green lines the minima. Final radii inside overlap are reported numerically without a marker in the excluded domain. The closest minimum is listed with curvature and final-radius difference. Final radial speed, conservative radial force and surface slip help assess whether the trajectory has relaxed.

Stationary references and contrasting outcomes

Six reference integrations use the existing $^{48}\text{Ca} + ^{208}\text{Pb}$ masses and Woods-Saxon parameters, nonzero damping rates of $4 \times 10^{21} \text{ s}^{-1}$, a 1000 zs limit and maximum step 0.5 fm/c. The first three reproduce settled states at deliberately different entrance coordinates. The second three compare the same entrance conditions. They supplement the archived 6188-point study rather than repeat the full scan.

$^{48}\text{Ca} + ^{208}\text{Pb}$: Stationary reference trajectories at constrained potential minima

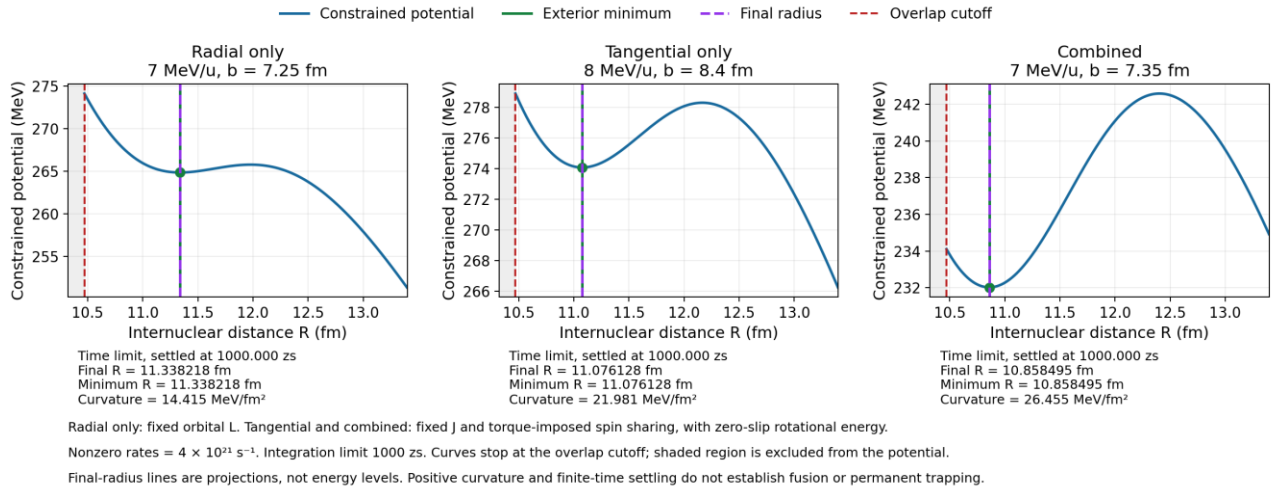


Figure 22 Exterior minima and final radii for three settled reference trajectories

Case	Energy MeV/u	b fm	Final R and minimum fm	Curvature MeV/fm ²
Radial only	7	7.25	11.338218	14.414817
Tangential only	8	8.40	11.076128	21.981119
Combined	7	7.35	10.858495	26.454579

All three final radii agree with their exterior minima within $1 \times 10^{-12} \text{ fm}$. Their conservative radial force magnitudes are below $2 \times 10^{-12} \text{ MeV/fm}$. Tangential-only and combined surface slips are below $5 \times 10^{-16} \text{ c}$. Radial-only slip remains finite because that case has no tangential damping.

Exterior minima and overlap outcomes

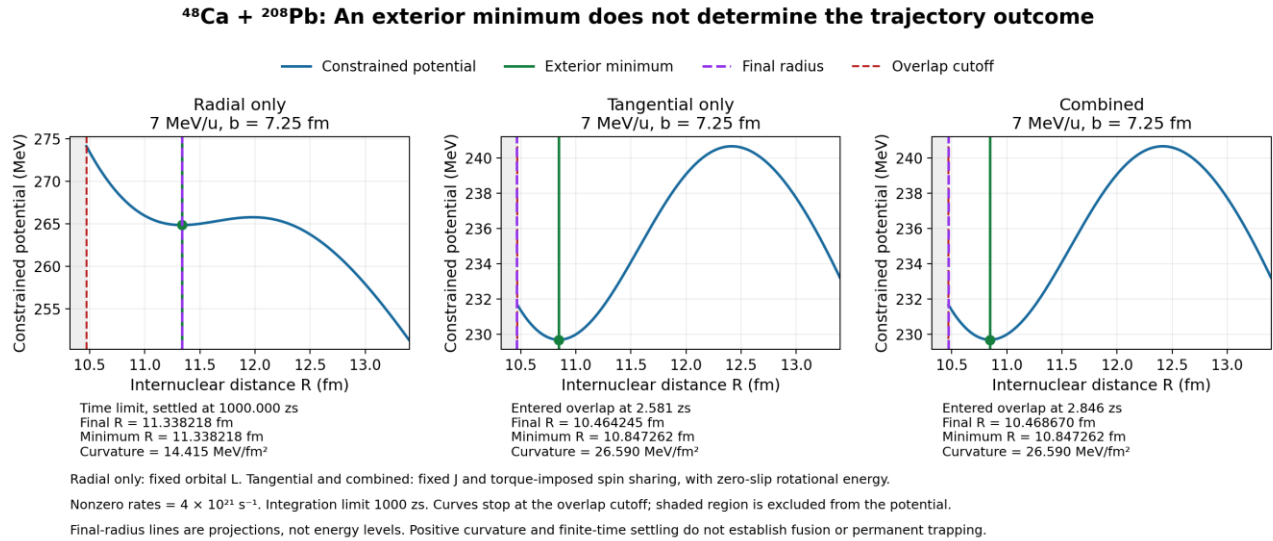


Figure 23 Identical entrance conditions can cross overlap despite an exterior potential minimum

At 7 MeV/u and $b = 7.25$ fm, radial-only motion settles. Tangential-only reaches overlap at 2.580554 zs and combined at 2.845746 zs, although both curves have a minimum at 10.847262 fm. Their inward radial velocities and nonzero slip show that they have not reached the equilibrium envelope. The existence of a minimum alone cannot classify the outcome.

Reproduction and limits

The 2026-10-18 archive contains equilibrium-study.cpp, reproduce-equilibrium.cmd, six endpoint records, 7206 potential samples, PNG/PDF figures and three interface captures. Run the command file to write fresh CSVs under generated. Copy plot-equilibrium.py into generated and run it with numpy and matplotlib. The manifest records source and output hashes. The original 1000 zs histories remain in the 2026-10-17 archive.

The constrained potential is a diagnostic of this deterministic fixed-composition model with rigid fragment inertias and its prescribed torque ratio. Positive curvature and finite-time relaxation do not establish permanent trapping or fusion. Stochastic forces, mass transfer, evaporation and deep-overlap evolution remain outside the current model.

Diagnostic interface and release validation

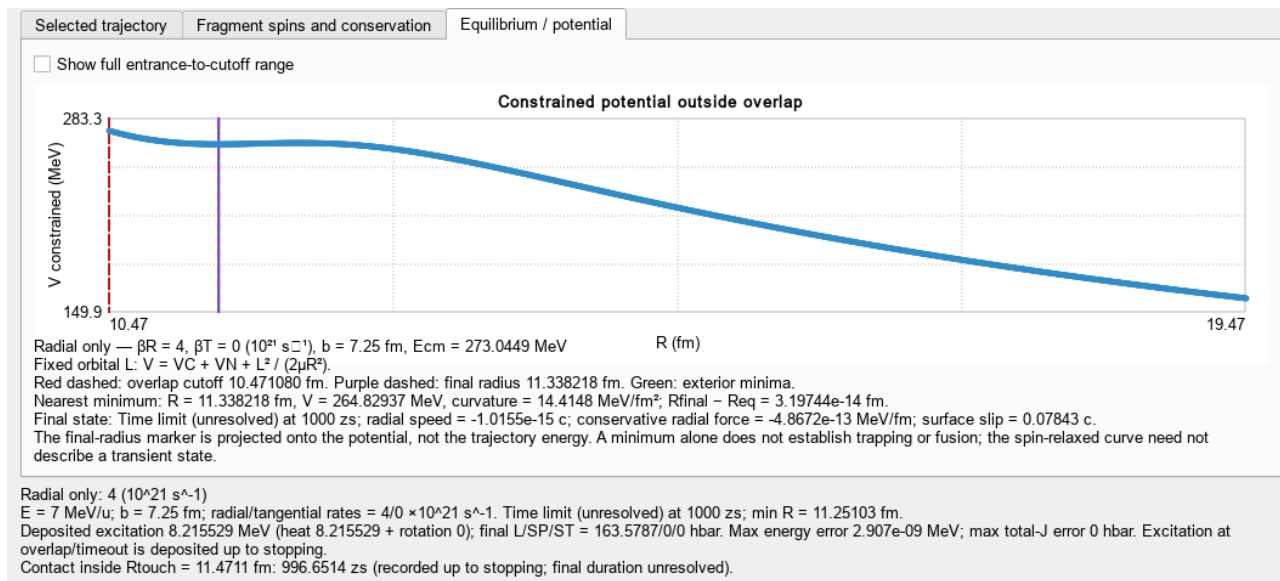


Figure 24 Selected radial-only map point showing coincident final-radius and equilibrium markers

Single-collision input changes clear its diagnostic. Map inspection retains the completed cell snapshot, including masses, potential parameters, rates, energy and impact parameter. Starting a new scan clears the previous diagnostic. Switching between surface and full range changes only the displayed interval, without reintegrating a trajectory.

Check	Evidence
Potential derivative	Central differences agree with the negative constrained force at four radii in each of three cases
Rotational constraint	Independent orbital-plus-fragment-spin energy is minimized at the zero-slip partition
Integrated references	Three settled trajectories approach the independently located minima and orbital momenta
No exterior minimum	Repulsive Coulomb test excludes a spurious boundary equilibrium
Qt interaction	All four map cases select the appropriate constraint and populate the diagnostic; range switching and screenshots checked
Release build	MSVC x64 Release and physics/Qt regression suites pass

Convergence and local stability checks

The Convergence / stability tab adds fifteen reproducible checks for the three settled reference cases. All nine entrance runs agree under time-step refinement, and all six displaced states return within the configured settling thresholds by 1000 zs. These are local numerical checks of this deterministic model, rather than a new energy-impact scan or a proof of permanent capture.

Reference	Energy MeV/u	b fm	Radial rate	Tangential rate
Radial only	7	7.25	4	0
Tangential only	8	8.40	0	4
Combined	7	7.35	4	4

Rates are in 10^{21} s^{-1} . The archived masses, Woods-Saxon parameters, rigid fragment inertias and overlap cutoff remain unchanged. These fixed benchmarks are independent of the dialog controls for the next collision. The integration limit is 1000 zs in every run.

Time step comparison

Each entrance trajectory uses maximum steps 0.5, 0.25 and 0.125 fm/c. The existing surface and damping safeguards can shorten a step. Adjacent refinements must agree on stopping outcome and settling classification, with final-radius difference below 0.001 fm, contact-time difference below 0.01 zs and total-excitation difference below 0.001 MeV. These are agreement tolerances, not an inferred convergence order.

Late time criteria

Maximum over 900 to 1000 zs	Threshold
Radial span and distance from equilibrium	0.001 fm each
Absolute radial velocity	$1 \times 10^{-6} \text{ c}$
Absolute conservative radial force	0.001 MeV/fm
Absolute surface slip with tangential damping	$1 \times 10^{-6} \text{ c}$

Settling requires a complete 100 zs window and formal TimeLimit status. The diagnostics inspect every integration sample. Radial-only motion may retain nonzero surface slip because it has no tangential damping. Other time-limit states remain unresolved. These thresholds differ from the stricter radius and velocity criteria of the earlier full 1000 zs study, and this new tab also requires distance, force and active slip checks.

Perturbation protocol

At each constrained minimum, two additional runs displace the radius by minus or plus 0.01 fm. They start with zero radial momentum and zero thermal heat, retaining the orbital and fragment angular momenta. Total J is unchanged. The imposed displacement supplies mechanical energy, so each run measures its energy error relative to its own displaced initial state. The step cap is 0.125 fm/c. Generated heat plus spin rotation is reported as total excitation.

Time step agreement for the settled references

All three step caps preserve the settled classification in every reference case. Contact duration and total excitation differences decrease with refinement. Radius differences are close to floating-point and CSV precision, so a convergence order cannot be inferred from their ratios.

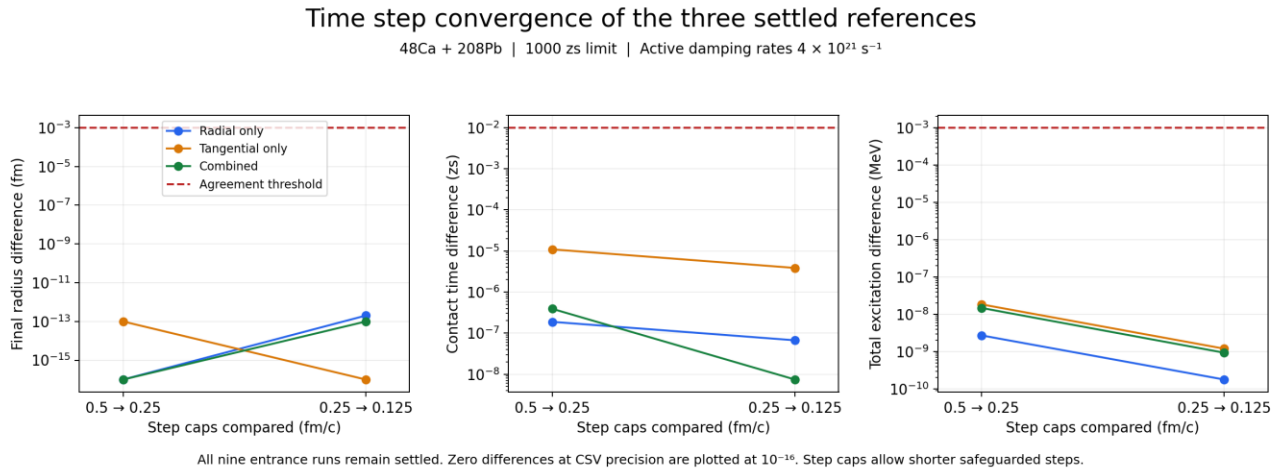


Figure 25 Adjacent time step differences compared with the configured agreement thresholds

Quantity	Maximum adjacent difference	Threshold
Final radius	$2.01 \times 10^{-13} \text{ fm}$	0.001 fm
Contact duration	$1.094 \times 10^{-5} \text{ zs}$	0.01 zs
Total excitation	$1.846 \times 10^{-8} \text{ MeV}$	0.001 MeV

Values use the archived CSV precision of fifteen significant digits. Zero radius differences at that precision appear at 10^{-16} fm on the logarithmic figure. They do not mean exact equality in real arithmetic. The larger contact-time differences arise in the tangential-only reference, yet remain about three orders of magnitude below the configured tolerance.

The maximum total-energy error across all fifteen runs is $1.9724 \times 10^{-8} \text{ MeV}$. The maximum total-angular-momentum error is $7.412 \times 10^{-12} \text{ hbar}$. The perturbed states use their own initial energy and J as conservation references. The shared integration path preserves the original entrance-run regression results.

Response to small radial displacements

The first 20 zs reveal oscillatory return following a displacement of the equilibrium radius. Radial-only and combined damping relax more rapidly than tangential-only damping in these selected cases. All six runs meet the late-time criteria over 900-1000 zs. This comparison uses different entrance coordinates in each column.

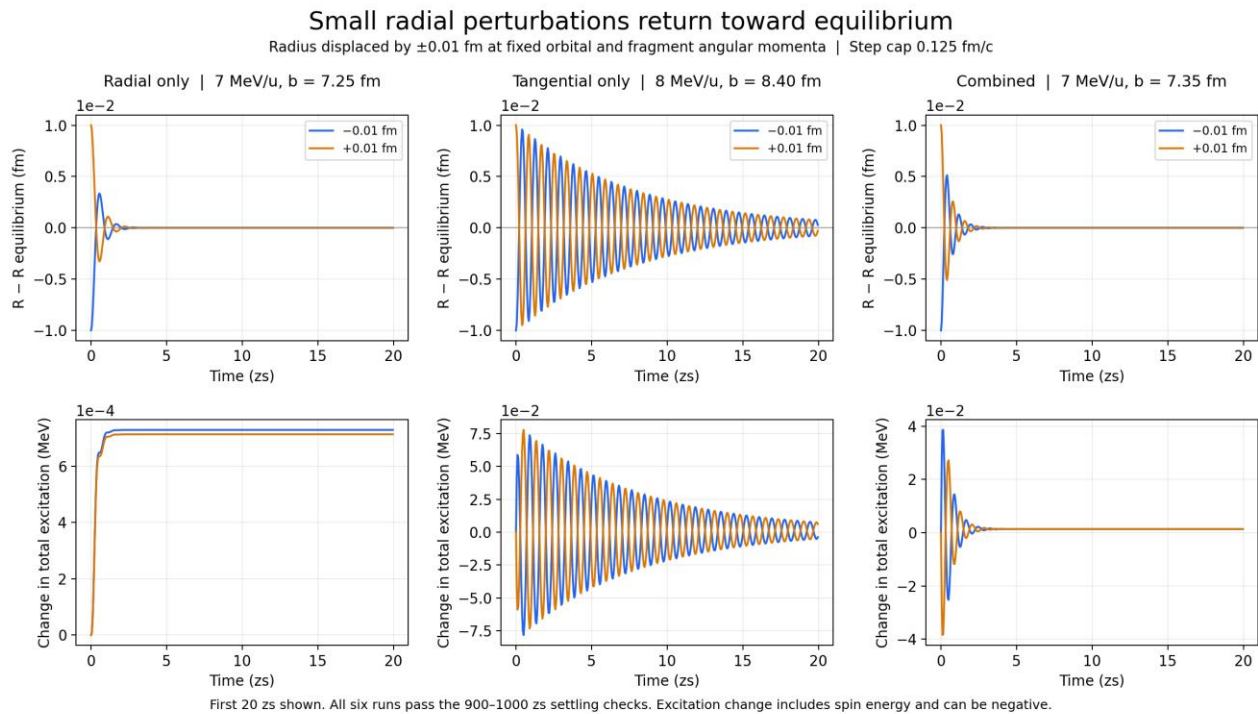


Figure 26 Radius displacement and change in total excitation after inward and outward perturbations

Total excitation includes spin rotational energy. Its change from the perturbed initial state can be negative during oscillations because spin and orbital energy exchange, even though dissipative heat production remains nonnegative. The three cases have different initial spin energies. These excitation increments are not a second estimate of the original collision excitation.

The perturbations test attraction near the chosen minimum at one amplitude and two radial directions. They do not cover large disturbances, arbitrary spin perturbations, thermal fluctuations or alternative potential parameters. The local return supports stability within the specified deterministic equations and observation time.

Settling margins and interpretation

For each case, the figure takes the maximum of each diagnostic across all five runs and divides it by the applicable threshold. Every required ratio is below one. All calculations use the complete final 100 zs window rather than the endpoint alone.

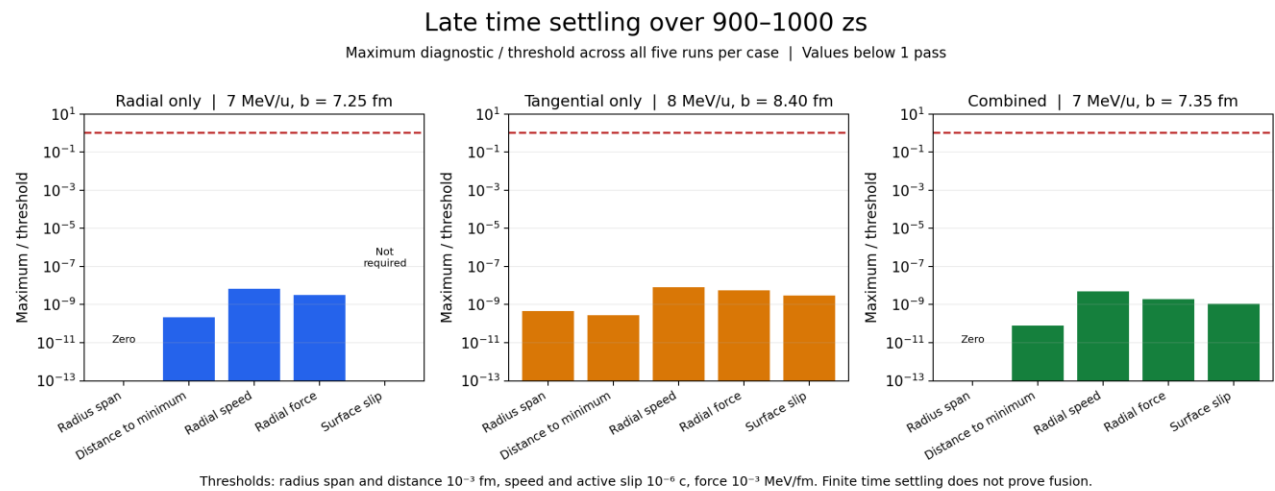


Figure 27 Late time diagnostics normalized by their settling thresholds

Reference	Equilibrium radius fm	Runs passing settling	Perturbations returning
Radial only	11.338218186	5 of 5	2 of 2
Tangential only	11.076127713	5 of 5	2 of 2
Combined	10.858495202	5 of 5	2 of 2

Radial-only surface slip is deliberately excluded from the settling criterion. With no tangential torque, a finite slip can persist at a stable radial minimum. With tangential friction, both radial force balance and small slip are required. Zero late-time radial spans at stored precision reflect numerical stationarity, not a physical statement about thermal fluctuations.

The formal solver outcome remains TimeLimit for all fifteen runs. The interface adds the finite-time description Settled near minimum. It does not relabel those states as fusion, assign an infinite lifetime or validate the potential and damping parameters against experiment.

Stability interface and reproducible evidence

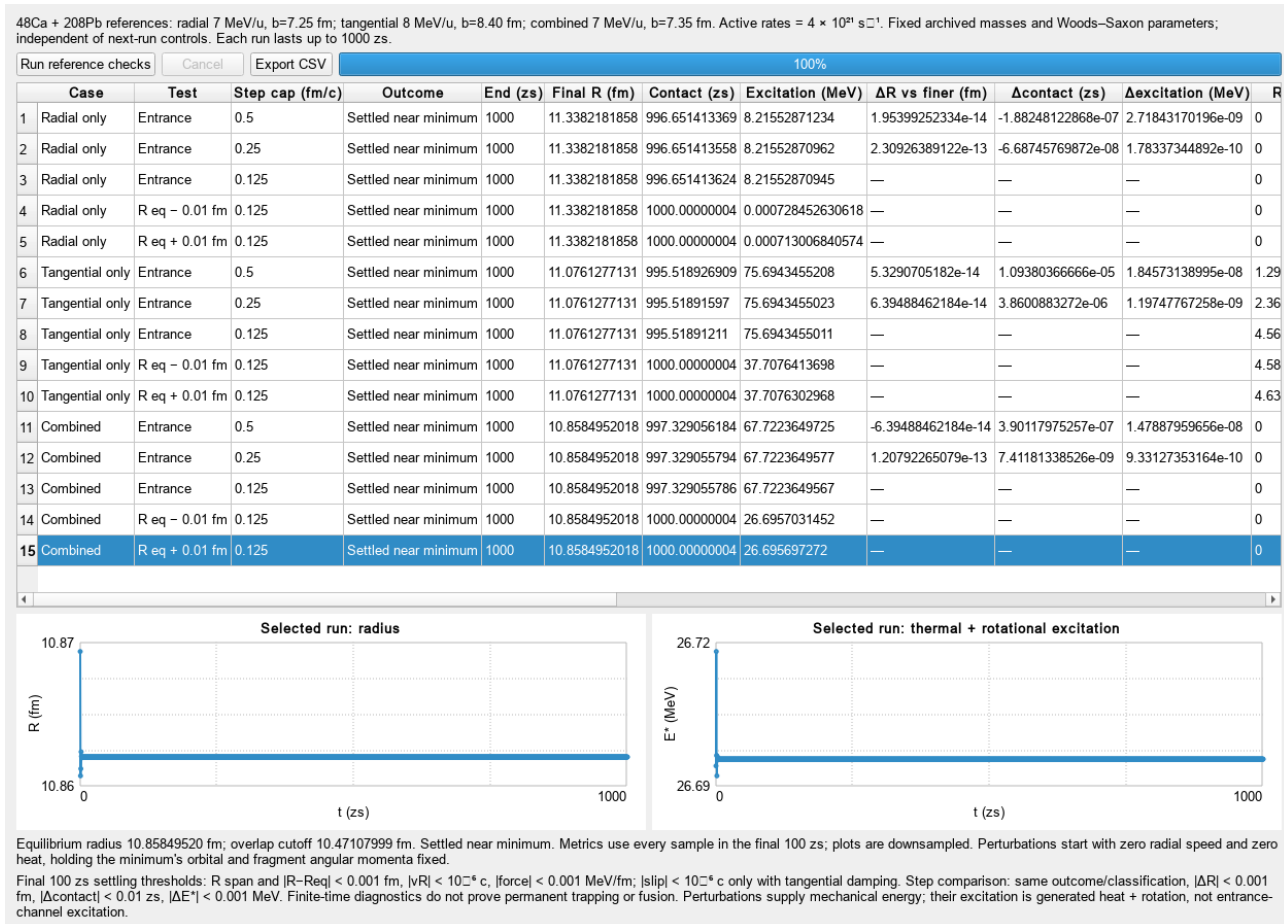


Figure 28 Convergence and stability tab with selectable traces and completed reference checks

The table shows the step cap, stopping outcome, final radius, contact duration, total excitation, adjacent-refinement differences and late-time diagnostics. Additional columns report energy and angular-momentum errors. Select a row for radius and excitation traces. Progress, cancellation and CSV export operate on completed rows, and closing the widget cancels and joins the worker.

Reproduction and validation

In doc/reaction_dynamics/2026-10-18, run reproduce-stability.cmd to regenerate the fifteen-run summary and sampled trajectories under generated. Copy plot-stability.py into that directory to regenerate the scientific figures and validation JSON. The archive includes 20715 plotted trajectory samples; the settling summary uses every integration point. Sampling is approximately 0.05 zs through 20 zs and 1 zs thereafter, with endpoints retained.

The full MSVC release build and physics and Qt integration tests pass. Tests cover reference convergence, both perturbation directions, conservation relative to displaced initial states, incomplete-window rejection, invalid overlap starts, all fifteen GUI rows, CSV export, cancellation and worker shutdown. Source and evidence hashes accompany the release. Earlier versioned reports, presentations and simulation data are retained.

Potential and friction sensitivity: protocol

Release 18.8.99 adds independent lower, baseline and upper comparisons for six model parameters. Each comparison contains all four friction cases. Click a map point or boundary-table row to inspect its saved trajectory, potential, excitation and angular momentum. Progress, cancellation and CSV export retain completed results.

Parameter	Lower / baseline / upper
Woods–Saxon depth	90 / 100 / 110 MeV
Woods–Saxon radius parameter	1.08 / 1.20 / 1.32 fm
Woods–Saxon diffuseness	0.585 / 0.650 / 0.715 fm
Radial friction rate	3.6 / 4.0 / $4.4 \times 10^{21} \text{ s}^{-1}$
Tangential friction rate	3.6 / 4.0 / $4.4 \times 10^{21} \text{ s}^{-1}$
Overlap allowance	0.90 / 1.00 / 1.10 fm

The archived study uses $^{48}\text{Ca} + ^{208}\text{Pb}$ at 6, 7, 8, 9 and 10 MeV/u, $b = 5.5\text{--}10$ fm in 0.25 fm steps, a 100 zs time limit and a 0.5 fm/c step cap. Thirteen unique configurations share one baseline: 13×95 coordinates $\times$ four cases = 4940 integrations. $Q=0$ and composition remains fixed. Each variant changes only one input; inactive friction channels remain zero.

All 251 sampled overlap/nonoverlap transitions are retained as brackets. Nine energy/case/configuration slices contain no transition in the sampled range. Missing markers do not give a measured boundary. Vertical bars indicate the sampled 0.25 fm interval, not a confidence interval. Contact and excitation refer to stopping; overlap and time-limit contact durations remain censored.

Changing r_0 changes touching geometry and the overlap cutoff as well as the nuclear potential. The overlap allowance is subtracted from the touching radius. The study is a one-at-a-time model sensitivity comparison, not a calibrated parameter uncertainty estimate.

Woods–Saxon depth

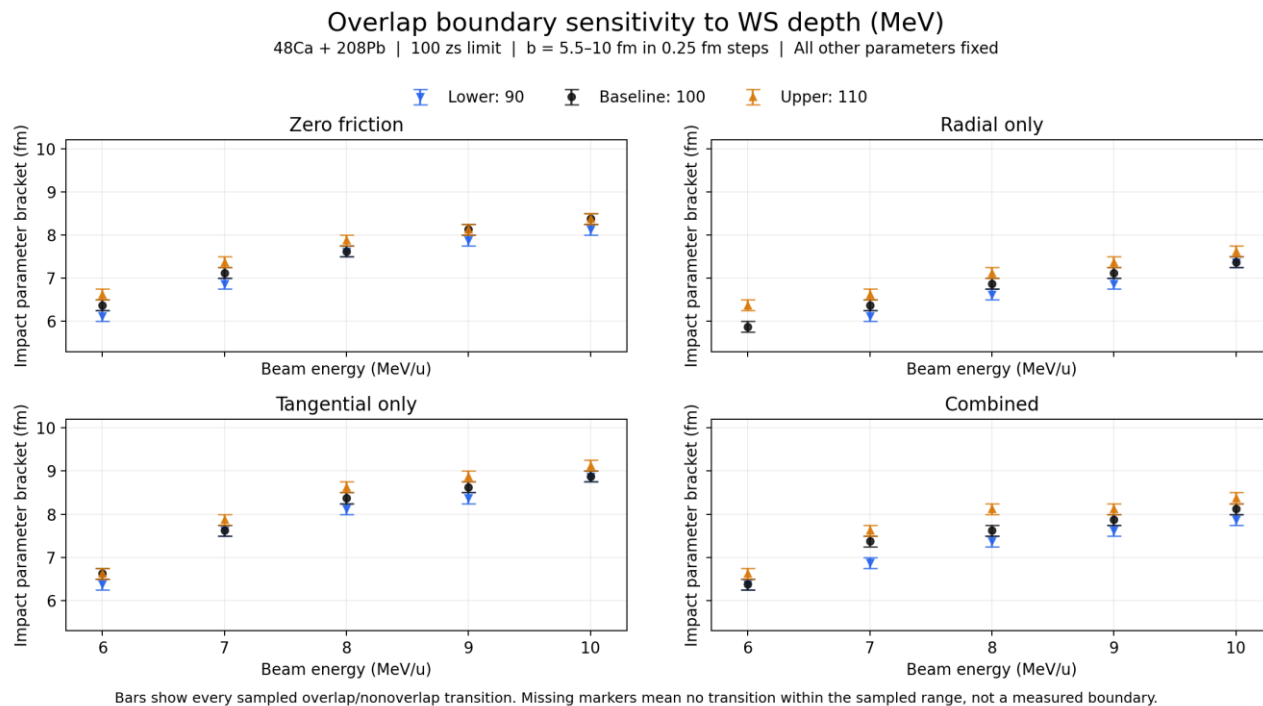


Figure 29 Woods–Saxon depth: lower, baseline and upper overlap brackets

Parameter values: 90 / 100 / 110 MeV. The four panels isolate friction channels. Only adjacent sampled outcomes define a bracket; no boundary is extrapolated beyond the scan.

Woods–Saxon radius parameter

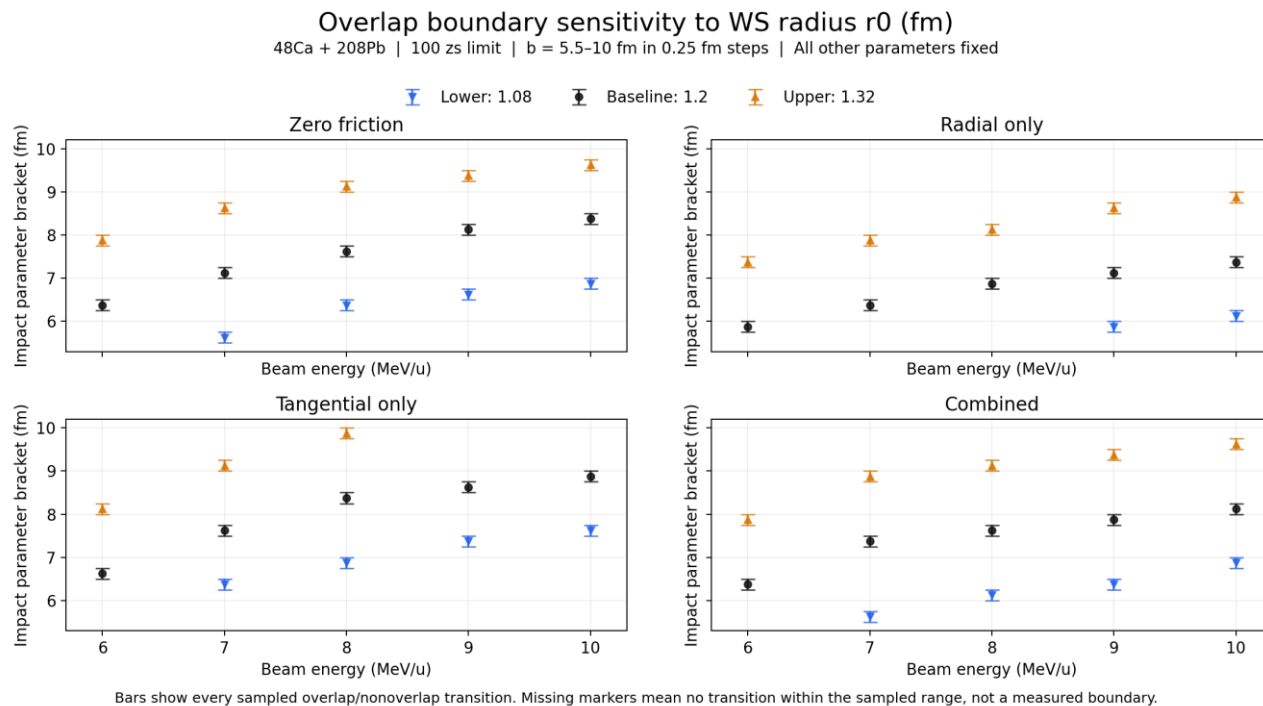


Figure 30 Woods–Saxon radius parameter: lower, baseline and upper overlap brackets

Parameter values: 1.08 / 1.20 / 1.32 fm. The four panels isolate friction channels. Only adjacent sampled outcomes define a bracket; no boundary is extrapolated beyond the scan.

Woods–Saxon diffuseness

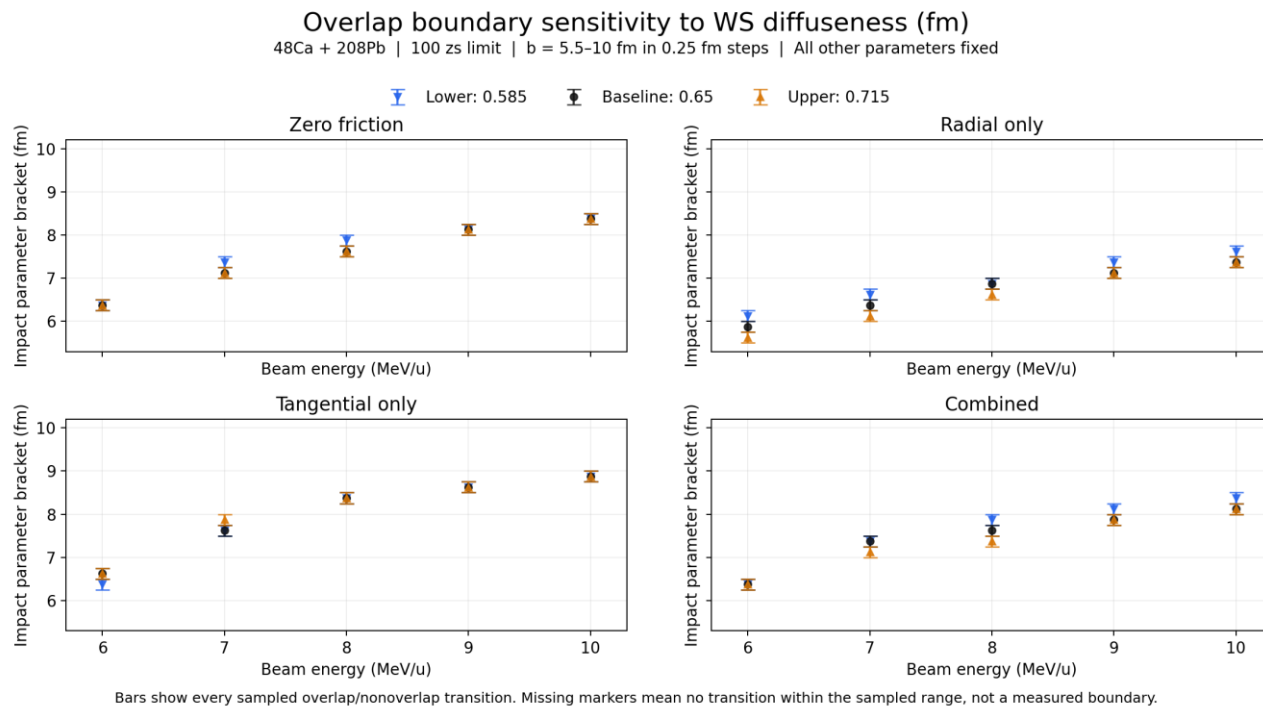


Figure 31 Woods–Saxon diffuseness: lower, baseline and upper overlap brackets

Parameter values: 0.585 / 0.650 / 0.715 fm. The four panels isolate friction channels. Only adjacent sampled outcomes define a bracket; no boundary is extrapolated beyond the scan.

Radial friction rate

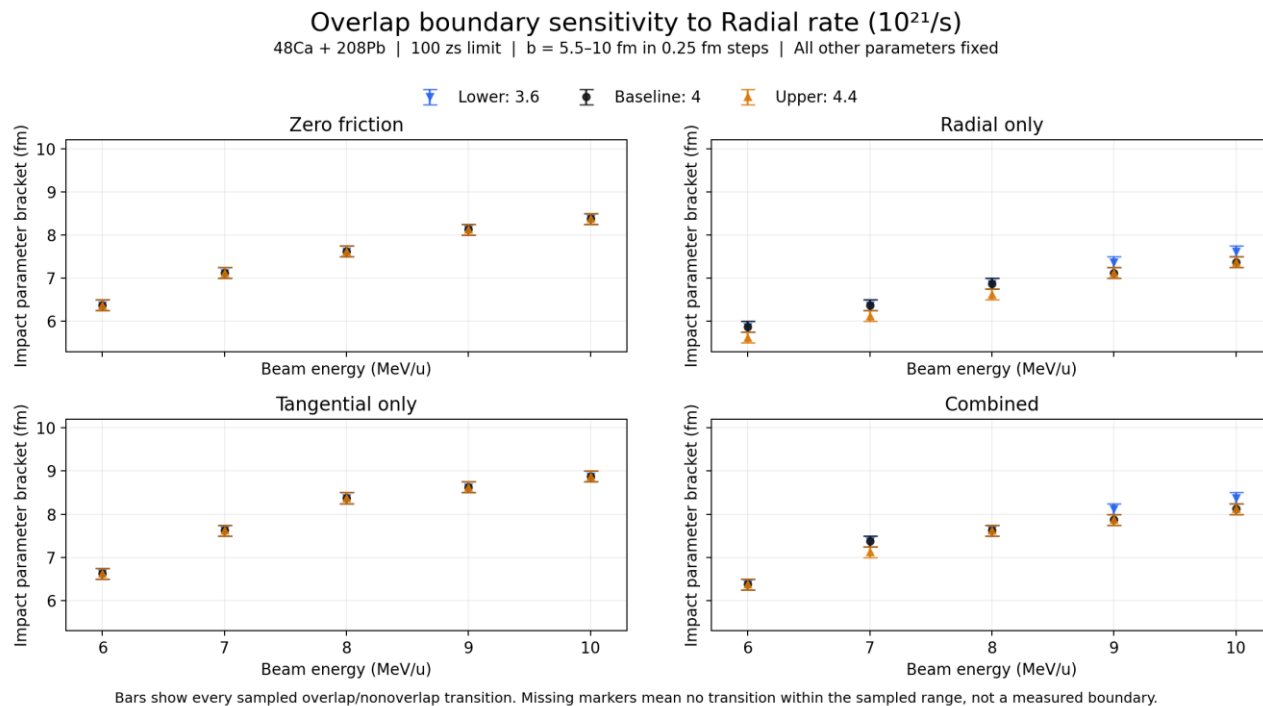


Figure 32 Radial friction rate: lower, baseline and upper overlap brackets

Parameter values: $3.6 / 4.0 / 4.4 \times 10^{21} \text{ s}^{-1}$. The four panels isolate friction channels. Only adjacent sampled outcomes define a bracket; no boundary is extrapolated beyond the scan.

Tangential friction rate

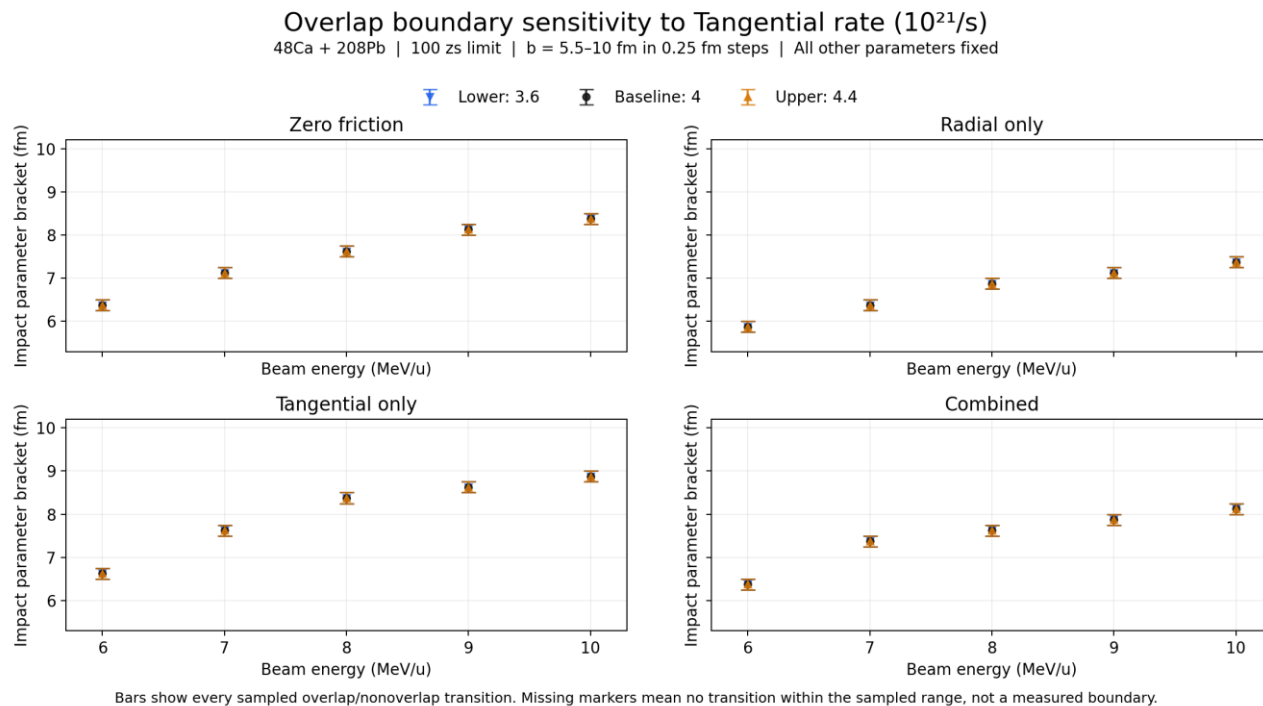


Figure 33 Tangential friction rate: lower, baseline and upper overlap brackets

Parameter values: $3.6 / 4.0 / 4.4 \times 10^{21} s^{-1}$. The four panels isolate friction channels. Only adjacent sampled outcomes define a bracket; no boundary is extrapolated beyond the scan.

Overlap allowance

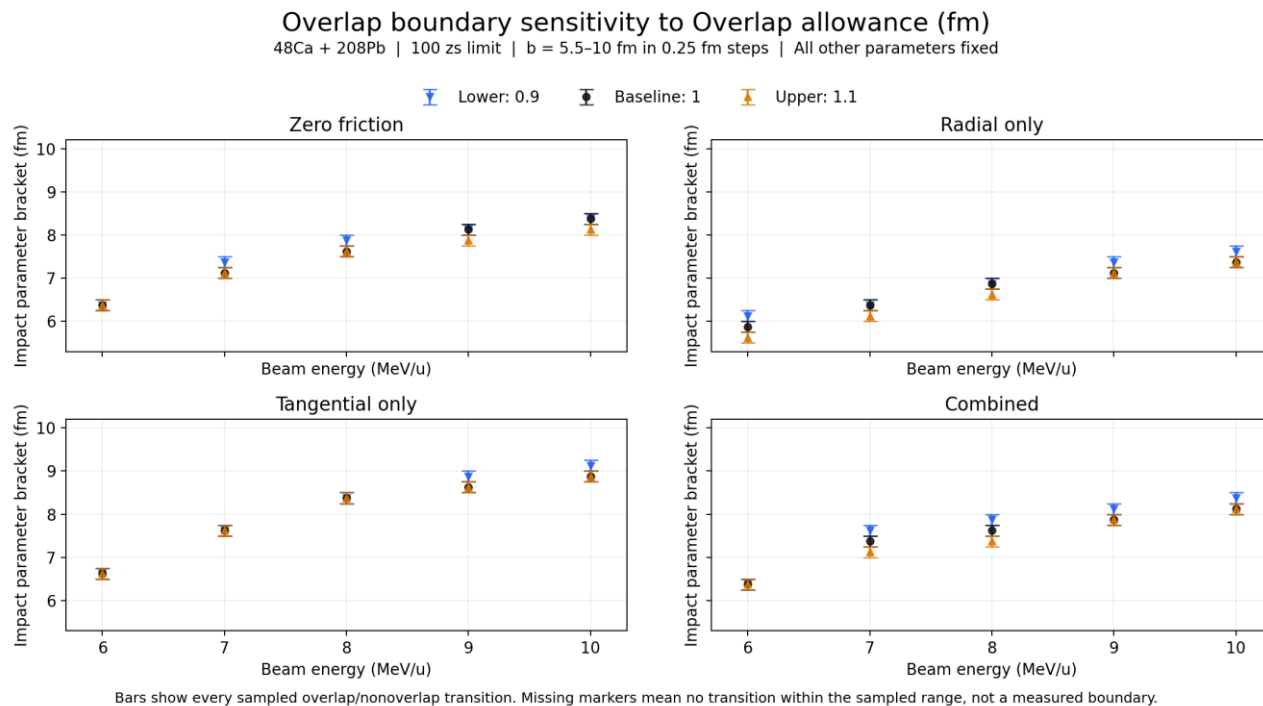


Figure 34 Overlap allowance: lower, baseline and upper overlap brackets

Parameter values: 0.90 / 1.00 / 1.10 fm. The four panels isolate friction channels. Only adjacent sampled outcomes define a bracket; no boundary is extrapolated beyond the scan.

Sensitivity results and numerical checks

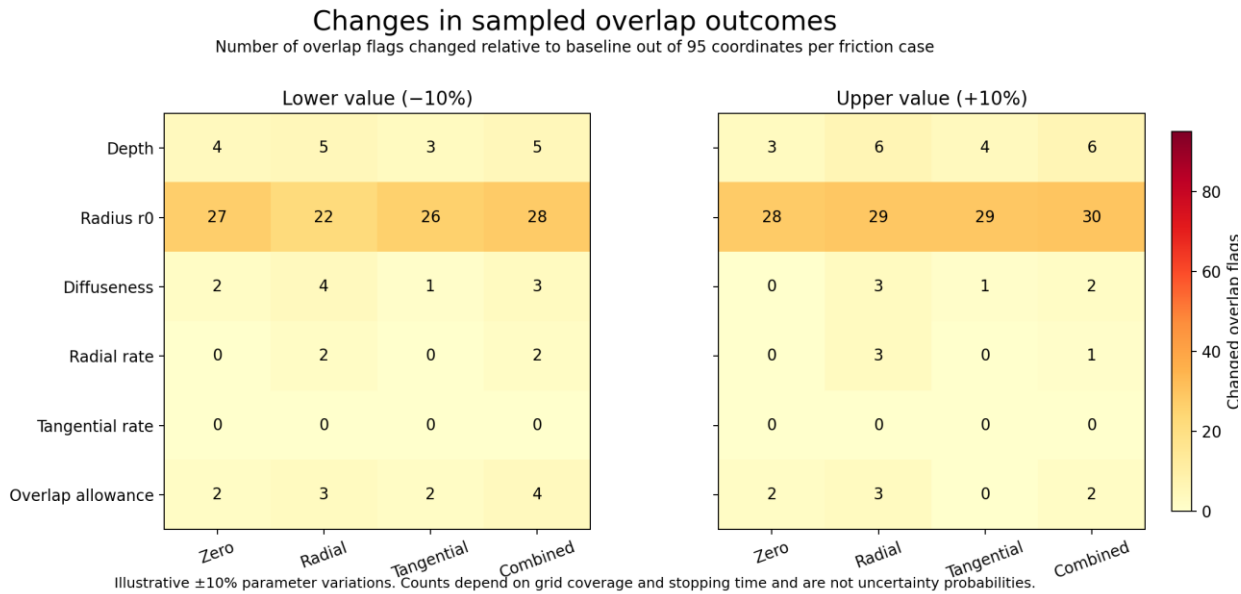


Figure 35 Changed overlap flags relative to the shared baseline, out of 95 coordinates per cell

The radius parameter gives the largest response: 22–30 changed flags per case and variant. Depth changes 3–6 flags, diffuseness 0–4 and overlap allowance 0–4. Radial-rate changes affect 1–3 flags in active cases. Tangential-rate changes produce no sampled flag changes. This does not rule out boundary shifts below 0.25 fm or changes in contact time, excitation and the trajectories.

Maximum conservation errors across 4940 runs are 1.464×10^{-7} MeV in energy and 4.093×10^{-12} hbar in total angular momentum. Cases with the varied friction channel disabled reproduce the baseline outputs exactly. No multiple transitions occur in this archive; the interface and exporter retain all transitions if present.

Sensitivity interface and reproducibility

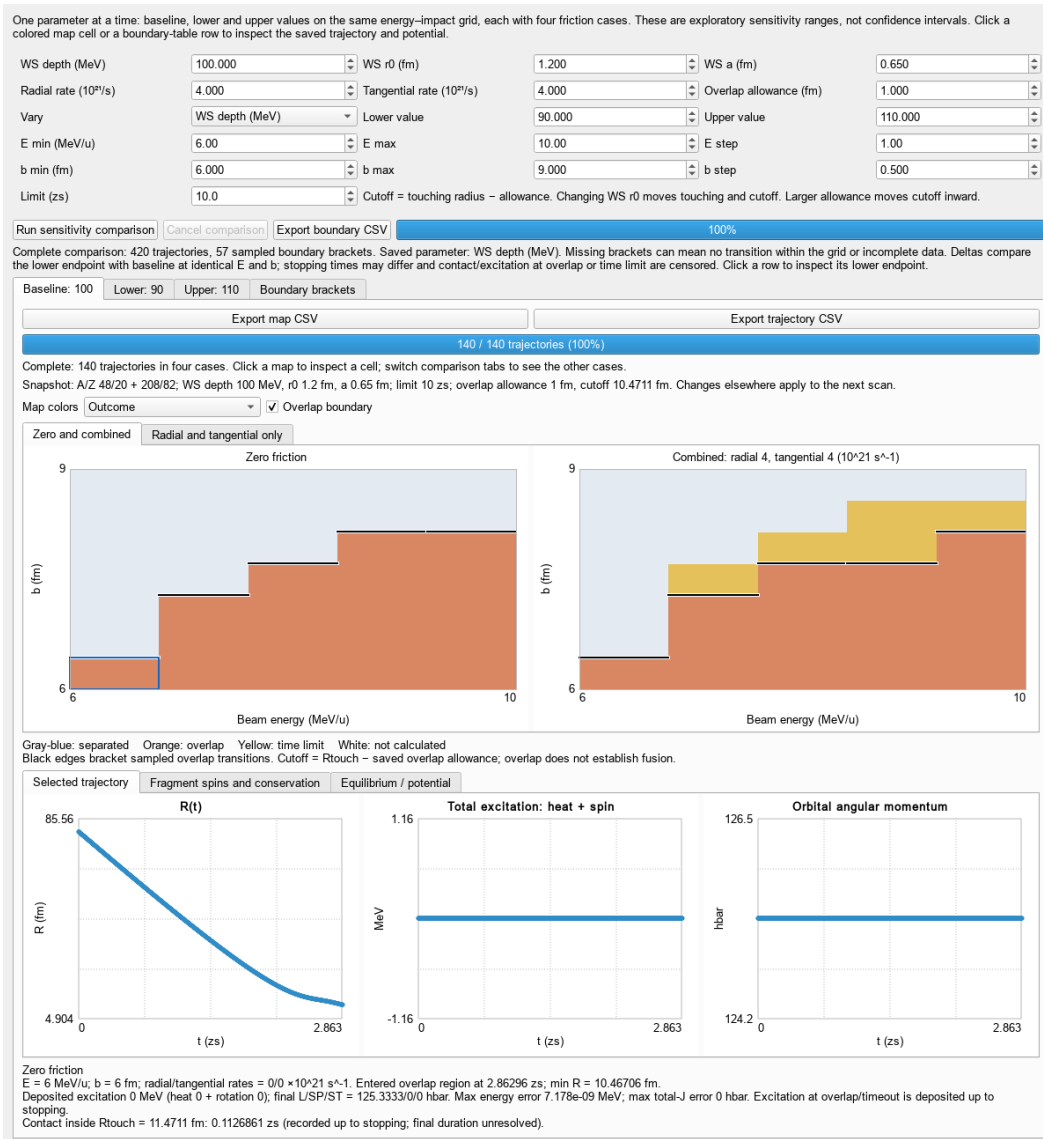


Figure 36 Sensitivity interface: separate 420-run GUI validation at 10 zs

This interface capture uses a smaller validation grid and a 10 zs limit. The scientific figures on the preceding pages use 4940 integrations with a 100 zs limit. Boundary rows expose contact-time and excitation differences against the same baseline coordinate. Selecting a row opens its lower-b endpoint in the trajectory inspector.

The archive doc/reaction_dynamics/2026-10-18 contains SENSITIVITY.txt, sensitivity-study.cpp, reproduce-sensitivity.cmd, sensitivity-grid.csv, boundary and coverage tables, validation JSON and plot-sensitivity.py. The GUI suite covers all six parameters, channel isolation, saved-point inspection, CSV export, cancellation and worker destruction. Full release compilation is recorded alongside the source and evidence hashes.

Adaptive overlap boundary protocol

The adaptive tab refines every overlap/nonoverlap transition found by a 0.25 fm coarse search to a width no greater than 0.01 fm. All four friction cases are evaluated at 6, 7, 8, 9 and 10 MeV/u over $b=5.5\text{--}10$ fm. Baseline potential and friction values match the preceding sensitivity study. The baseline and twelve independent $\pm 10\%$ variants form thirteen configurations.

Each trajectory first runs to separation, overlap or 100 zs. Every timeout is re-integrated from its original entrance state to 1000 zs. This preserves the initial heat, phase and angular momentum references. Settling is evaluated over the final 100 zs using every integration point and the existing equilibrium, radial span, speed, force and active surface-slip criteria. Settled and unresolved timeouts remain distinct from separated and overlap outcomes.

Study quantity	Result
Completed slices	260
Evaluated coordinates	6195
1000 zs extensions	387
Total integrations	6582
Refined brackets	251
Slices without a transition	9
Maximum bracket width	0.0078125 fm

Bisection resolves detected transitions; it cannot rule out narrower islands between coarse points with equal outcomes. Every detected transition is retained. Missing transitions are recorded as coverage gaps, not inferred boundaries. The model remains deterministic, nonrelativistic and fixed in composition. Overlap is a geometric stop, not a fusion classification.

Adaptive boundaries and sensitivity envelopes

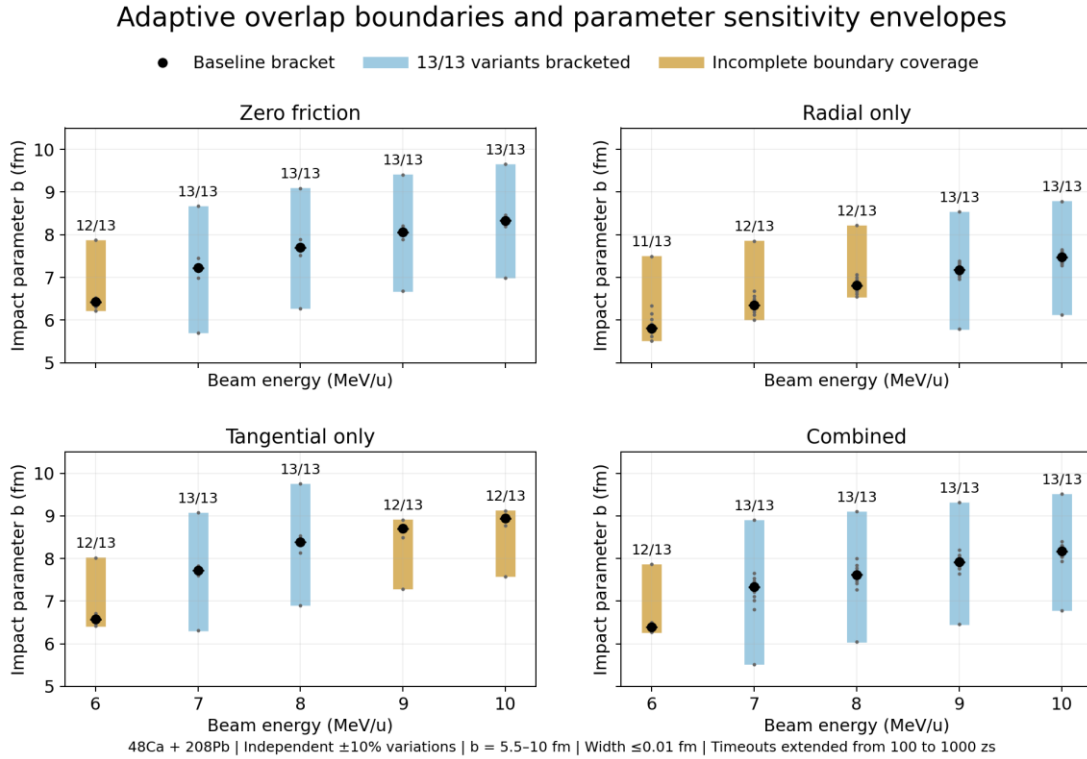


Figure 37 Baseline boundaries and outer extents of the thirteen tested parameter configurations

Black markers show baseline bracket midpoints with their numerical widths. Each vertical range encloses the outer endpoints of the observed parameter-variant brackets at that energy. Blue indicates all thirteen variants have a sampled boundary; amber indicates incomplete coverage. The labels give the number of variants with measured brackets.

These ranges describe the tested model parameters and are not statistical confidence intervals. Missing boundaries cannot be replaced by scan endpoints when constructing a complete physical envelope. Radius variations change the touching radius and overlap cutoff as well as the nuclear potential. All sampled transitions would be pooled; this archive has at most one per slice.

Resolved parameter effects on the boundary

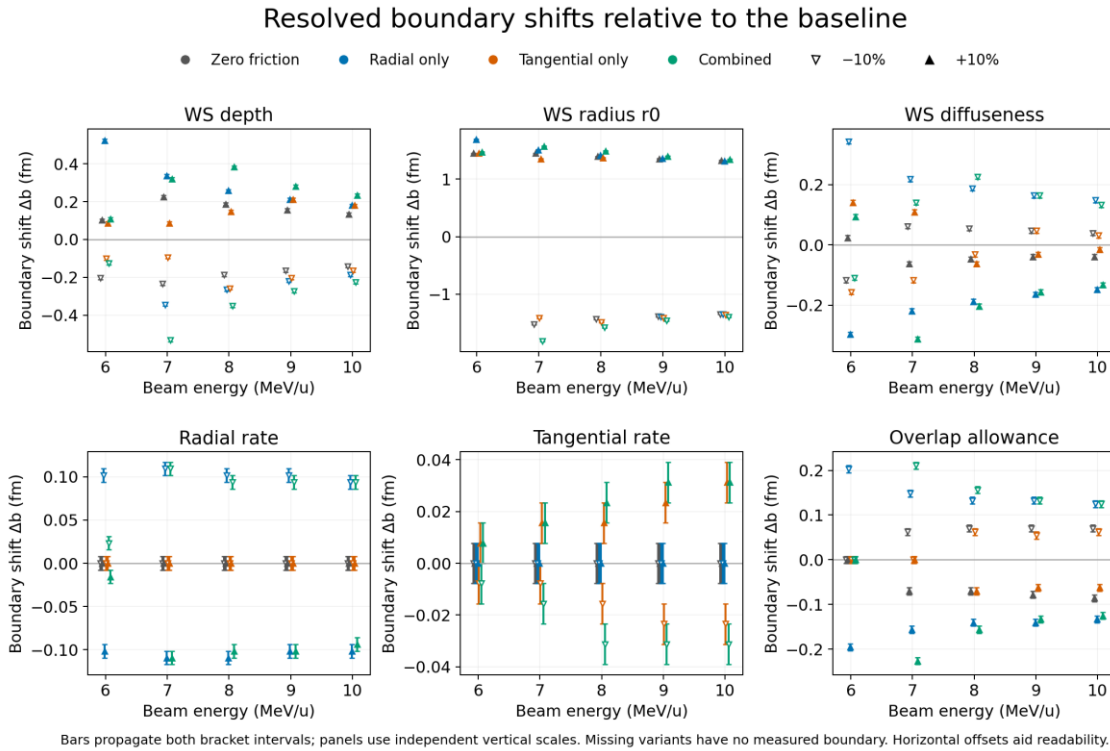


Figure 38 Refined shifts relative to baseline for each parameter and friction case

Each shift interval subtracts the baseline bracket from the variant bracket: its limits are variant lower minus baseline upper, and variant upper minus baseline lower. A shift interval containing zero does not establish a resolved displacement at this tolerance. Vertical scales differ between panels to expose small friction effects. The plotted horizontal offsets only separate cases visually.

The tangential-rate variants, which changed no overlap flags on the earlier 0.25 fm grid, now show a maximum absolute midpoint displacement of 0.031250 fm among the measured boundaries. The refined brackets quantify effects that a coarse overlap flag can miss. The interval bounds, rather than the midpoint alone, determine whether an individual shift excludes zero.

Trajectories on opposite sides of the boundary

Boundary pairs at 7 MeV/u reveal different stopping outcomes

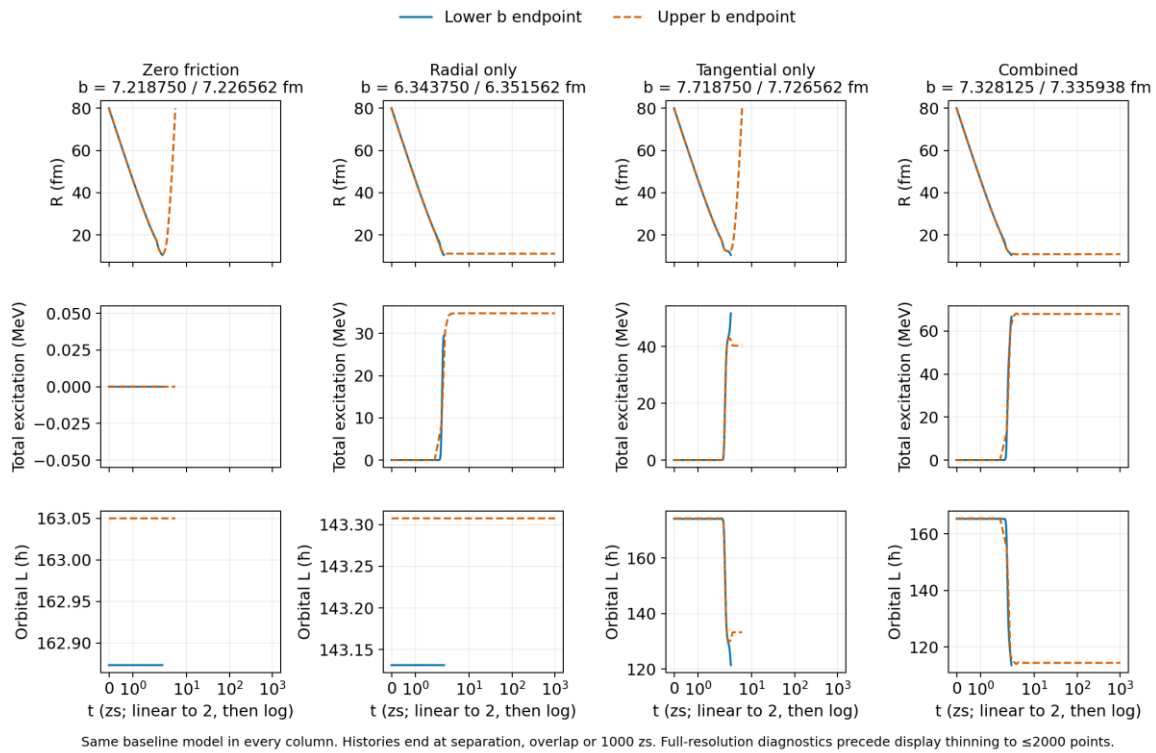


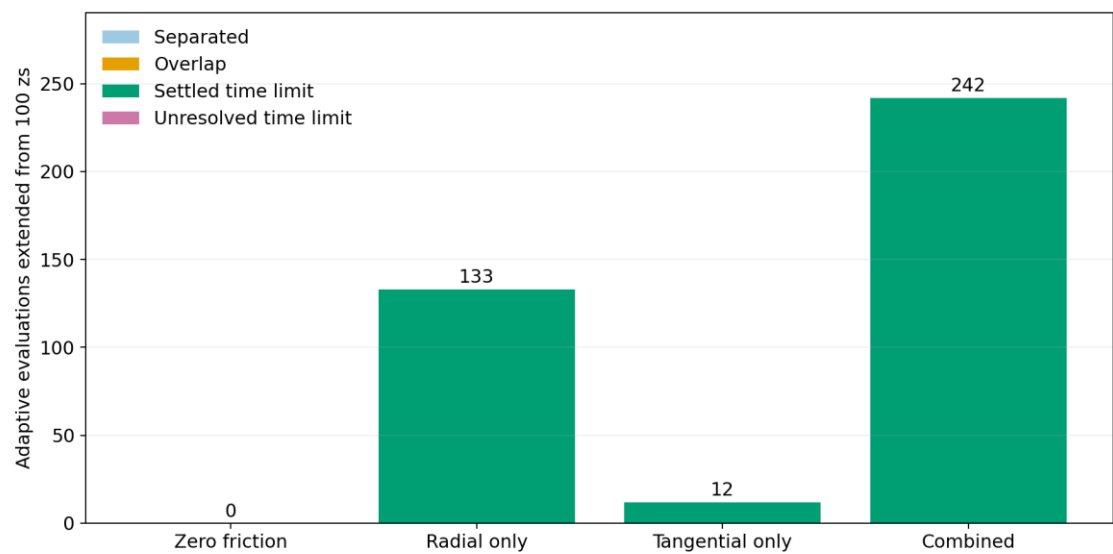
Figure 39 Saved baseline boundary pairs at 7 MeV/u with radius, total excitation and orbital momentum

The lower and upper impact parameters differ by at most 0.01 fm. Their histories stop at the physical stopping condition implemented by the model or at the integration limit. The time axis is linear to 2 zs and logarithmic thereafter, allowing early contact and late settling to share the figure. Total excitation includes thermal heat and both fragment rotational energies.

The interactive tab also shows the projectile and target spins. Up to 2000 display samples are retained per endpoint, including both ends of the history. Conservation maxima and settling checks use every integration point before display thinning. Reported contact times at overlap or timeout remain censored.

Outcomes of the extended trajectories

Outcomes after extending ambiguous trajectories to 1000 zs



Counts include coarse samples and refinement probes across 13 configurations; repeated physical inputs across configurations are counted. Adaptive sampling concentrates near boundaries: these counts are not physical outcome probabilities. Settling does not prove permanent trapping.

Figure 40 Final outcomes of all adaptive evaluations that reached the initial 100 zs limit

Outcome at 1000 zs	Number of extended evaluations
Separated	0
Overlap	0
Settled time limit	387
Unresolved time limit	0

These counts include coarse points and refinement probes across all thirteen configurations. Repeated physical inputs across configurations are counted. The adaptive search deliberately concentrates evaluations near boundaries, so the counts cannot be interpreted as event probabilities, reaction cross sections or an unbiased impact-parameter sample.

The maximum energy error over evaluated trajectories is 1.464e-07 MeV and the maximum total-angular-momentum error is 4.388e-12 hbar. Settling through 1000 zs does not establish an infinite lifetime. Unresolved timeouts remain explicitly unresolved.

Adaptive interface and reproducible evidence

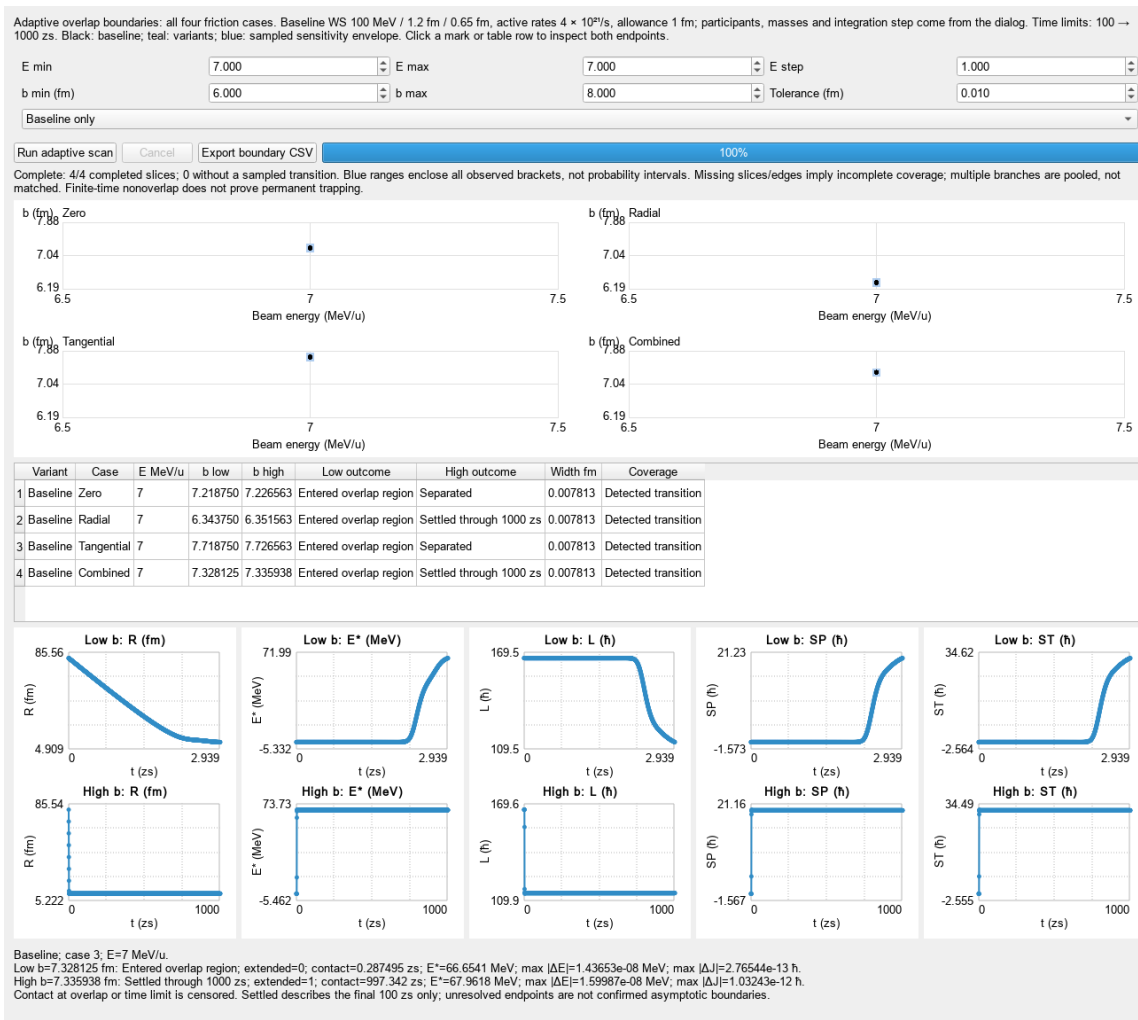


Figure 41 Baseline GUI validation at 7 MeV/u with selectable boundary pairs

The controls select the energy and impact-parameter ranges, bracket tolerance and parameter variants. Clicking a plotted bracket or table row loads both saved endpoint histories. Progress and cancellation retain completed slices. The CSV contains outcomes, extension flags, contact, excitation, saved physical inputs and coverage. This screenshot uses $b=6\text{--}8$ fm; the scientific study uses $b=5\text{--}10$ fm.

Reproduce the archive with `reproduce-adaptive.cmd` and `plot-adaptive.py` in `doc/reaction_dynamics/2026-10-18`. `ADAPTIVE.txt` specifies the protocol. The archive retains every evaluated coordinate, all boundary brackets, coverage and sampled reference histories. Tests cover multiple transitions, missing boundaries, 1000 zs settling, all four cases, sensitivity variants, pair selection, exports, cancellation and shutdown.

Dissipation and prefragment excitation

Release 18.8.101 separates thermal energy into projectile and target reservoirs. Friction-only and combined cases use the same mechanical damping. Heat-exchange-only sets both damping rates to zero. Initial thermal energies are identical across cases and are added to the entrance energy budget. The partners retain their input masses and charges; the hot projectile is an illustrative prefragment proxy.

$$U_i = a_i T_i^2, \quad a_i = \frac{A_i}{k}, \quad w(R) = 4f(R)[1 - f(R)]$$

$$\dot{U}_P = \eta \dot{Q}_{\text{fric}} - q, \quad \dot{U}_T = (1 - \eta) \dot{Q}_{\text{fric}} + q$$

$$q = \lambda w(R) \frac{a_T U_P - a_P U_T}{a_P + a_T}$$

Positive q transfers heat from projectile to target. This phenomenological exchange law relaxes the reservoirs toward equal temperatures. Its equivalent conductance is $\lambda w a_P a_T (T_P + T_T) / (a_P + a_T)$. The common level-density scale k changes the inferred temperatures but cancels from the energy-relaxation fraction. The surface factor extends beyond geometrical touching and is not an independent contact-area calculation.

Input	Illustrative reference
Partners and kinetic energy	48Ca + 208Pb; $E_{\text{cm}} = 272.56$ MeV; $b = 7.35$ fm
Thermal initial state	$U_P = 40$ MeV; $U_T = 0$; $k = 8$ MeV
Friction and heat sharing	Active radial and tangential rates 4 zs^{-1} ; $\eta = 48/256$
Exchange	Peak $\lambda = 4 \text{ zs}^{-1}$ when enabled
Integration	100 zs; 1000 zs extension; step caps 0.5 and 0.25 fm/c

The mechanical solver remains unchanged. Thermal postprocessing uses every solver step: half the generated heat, exact exchange at the trapezoidal surface exposure, then the remaining half heat. Exchange preserves $U_P + U_T$ and cannot overshoot thermal equilibrium. Temperature and thermal energy do not feed back on force, potential or friction.

Thermal histories in the three comparison cases

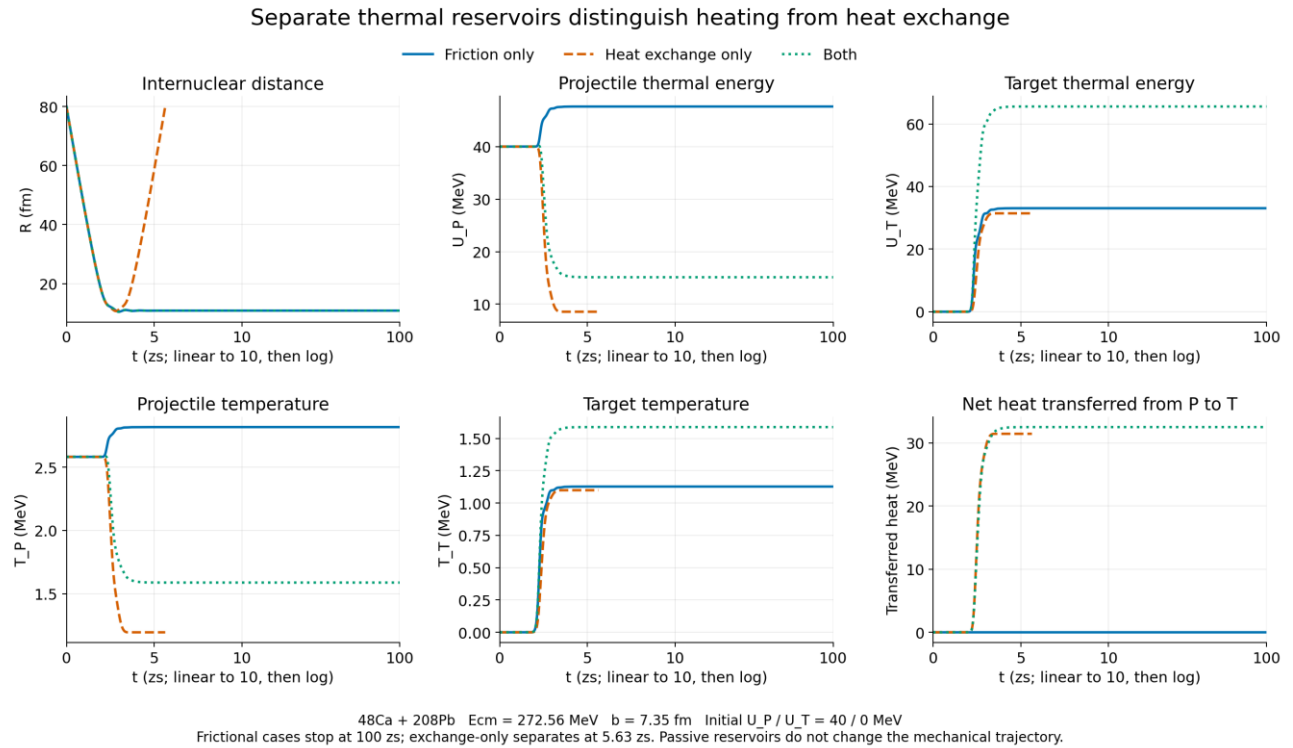


Figure 42 Radius, separate thermal energies, temperatures and net heat exchange

Case	Final U_P MeV	Final U_T MeV	Net P to T MeV
Friction only	47.6306	33.0661	0
Heat exchange only	8.56387	31.4361	31.4361
Both	15.1306	65.5661	32.5000

The two frictional cases generate the same 40.6968 MeV of heat and follow identical mechanical histories. Their different projectile excitations isolate heat redistribution. With both mechanisms, the reservoir temperatures approach 1.58801 MeV. Heat-exchange-only separates at 5.63046 zs, before complete temperature equilibration; the frictional cases reach the 100 zs limit at $R = 10.85776$ fm.

The reference uses default numerical masses 48×931.49410242 and 208×931.49410242 MeV, with E_{cm} specified directly. It is near 7 MeV/u but is not an exact reproduction of the earlier mass-table benchmark. All constants are archived in THERMAL.txt. Curves end at their actual stopping times.

Energy accounting and the intermediate dissipation stage

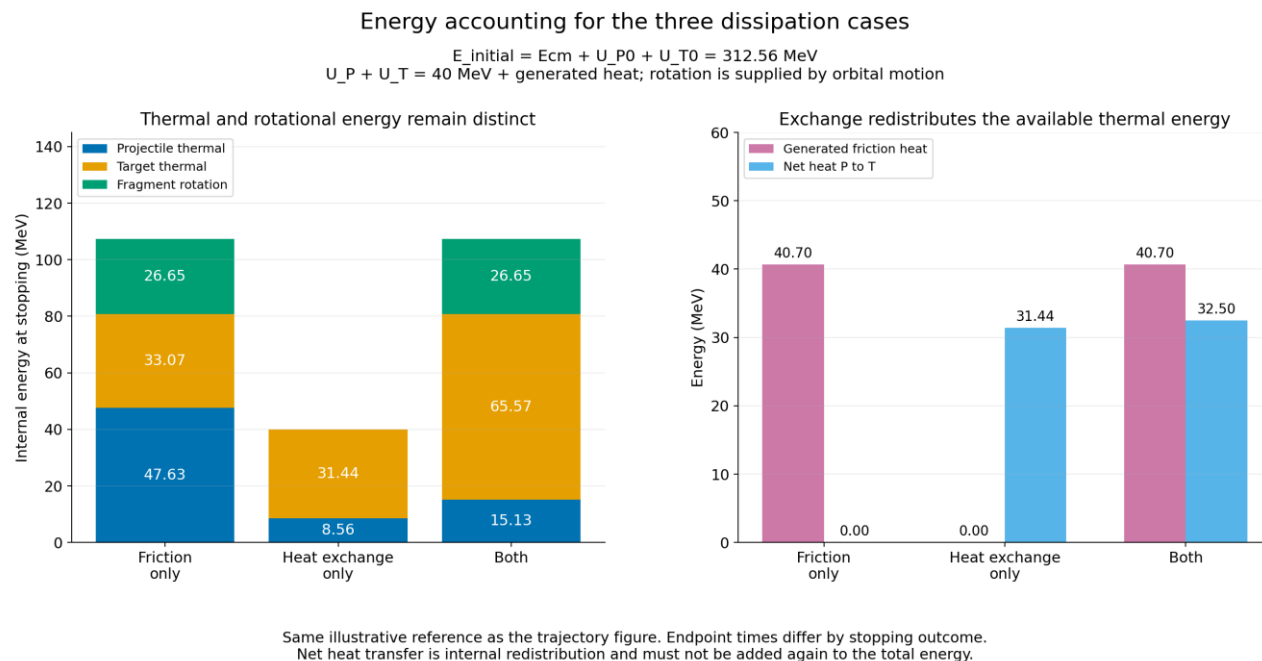


Figure 43 Separate thermal reservoirs and fragment rotation in the energy balance

The conserved energy is radial kinetic energy plus Coulomb, nuclear and centrifugal terms, both rotational energies and $U_{\text{P}} + U_{\text{T}}$. Its reference is $E_{\text{cm}} + U_{\text{P0}} + U_{\text{T0}} = 312.56 \text{ MeV}$. Friction produces 40.6968 MeV of thermal heat and transfers 26.6519 MeV into rotation in the two frictional cases. Exchange moves existing thermal energy between reservoirs; adding its net transfer to the energy sum would count it twice.

The 2006 abrasion–friction–ablation proposal motivates separating mechanical heating from thermal redistribution. This diagnostic demonstrates that a hotter total system can coexist with a cooler projectile reservoir. An initial excitation distribution, abrasion-generated masses and charges, nucleon exchange and evaporation are still needed to test neutron-rich residue survival or the low-excitation tail. No exponential momentum-loss distribution follows from this deterministic reference alone.

Source context: O. Tarasov, Projectile fragmentation aspects to produce neutron-rich isotopes, 2006, slides 8–9:
https://lise.frib.msu.edu/paper/2006_09_acs_pf.pdf

The APF/UP excitation update exposes fixed-slope or current-AA excitation choices. Coupling the new heating to those prescriptions requires checking for double counting:
https://lise.frib.msu.edu/18/18_04_09_UP_APF_ExcitationEnergy_Update.pdf

Thermal convergence and long time checks

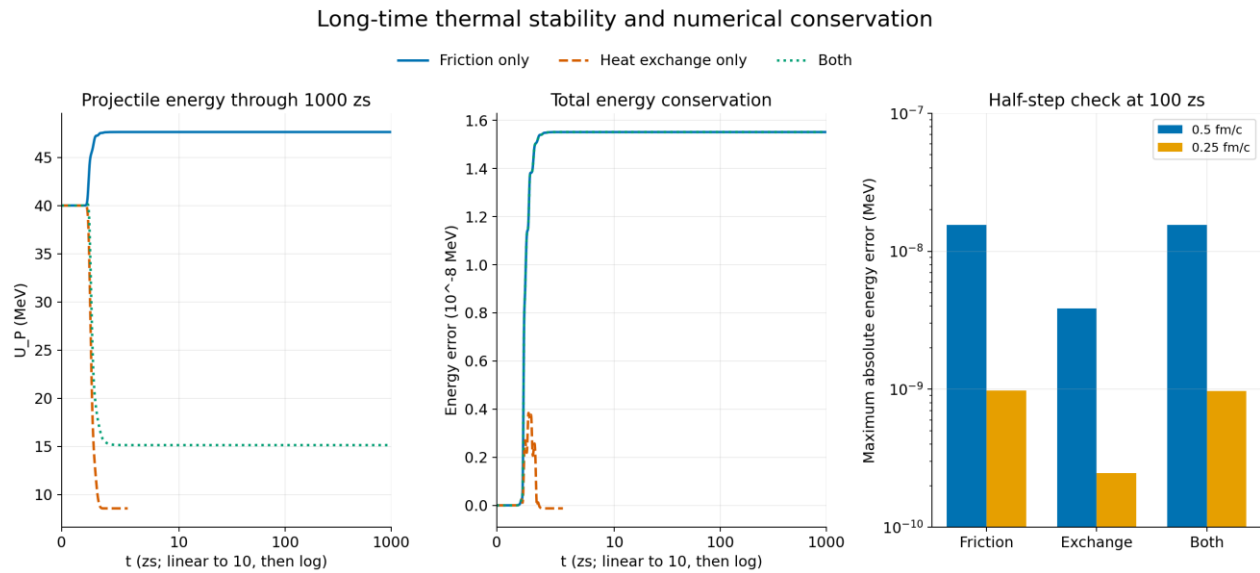


Figure 44 Three cases through 1000 zs and independent half-step comparisons at 100 zs

Diagnostic over nine runs	Maximum
Total energy residual	1.5514×10^{-8} MeV
Thermal partition residual	7.0557×10^{-12} MeV
Total angular momentum residual	3.4292×10^{-12} hbar
Half-step final UP change	9.2148×10^{-9} MeV
Half-step stopping-time change	1.0248×10^{-4} zs

Nine integrations comprise three 100 zs baselines, three 1000 zs runs and three half-step 100 zs runs. The exchange-only path exits early in every calculation. The frictional paths remain outside overlap through 1000 zs with unchanged final thermal partition. Their formal status remains TimeLimit; this check does not establish an infinite lifetime.

The test suite additionally covers the analytic exchange solution, reverse heat flow, equal temperatures, cold reservoirs, zero exchange, strong exchange with one-sided heating, invalid inputs and an independent reconstruction of total energy. Conservation maxima use all integration points. These are numerical validations of the chosen closure, not experimental validation.

Thermal diagnostic interface and reproducibility

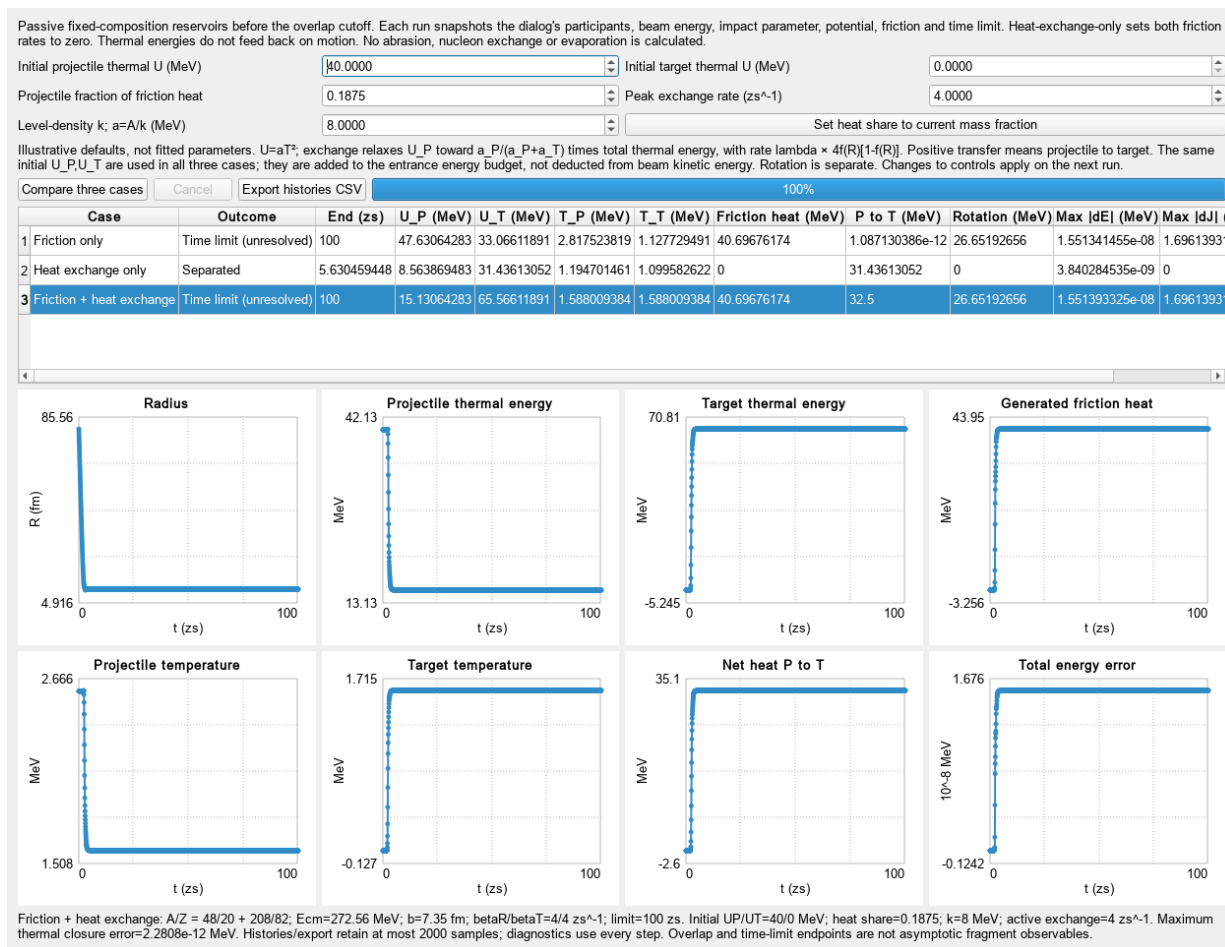


Figure 45 The dissipation and excitation tab with the combined reference selected

A run snapshots the current participants, kinetic energy, impact parameter, potential, friction and time limit. The tab provides initial thermal energies, the projectile share of generated heat, level-density scale and exchange rate. Selecting a result row restores its saved parameters and histories. Progress, cancellation and safe shutdown preserve completed cases.

CSV export contains physical inputs, effective case settings, separate energies and temperatures, rotations, angular momenta and conservation errors. GUI traces retain at most 2000 samples per case. The scientific archive retains every sample through 10 zs and uniformly sampled later points. Earlier versioned reports and all previous figures remain available.

Reproduce this study with thermal-study.cpp and reproduce-thermal.cmd, then plot-thermal.py, in doc/reaction_dynamics/2026-10-18. THERMAL.txt defines the protocol. The summary, histories, validation JSON and source hashes accompany the release. The independent GUI and numerical suite is tests/reaction_thermal_test.pro.

Prefragment ensembles and conditional ablation response

Release 18.8.102 adds a prefragment A/Z selector and the existing surface, Gaimard, simplified, exponential and lognormal AA excitation models. Positive-energy intervals of each finite AA density become weighted centroids. Their weights sum to one over the retained support. Every case uses the same initial distribution; missing tails are not extrapolated. The selected prefragment A sets the projectile thermal heat capacity, while the mechanical trajectory retains the entrance nuclei.

$$P_c(A_r, Z_r | A_{pf}, Z_{pf}) = \sum_j D(A_r, Z_r | U_{P,c,j}, J = 0)$$

The ablation tab snapshots a completed four-case ensemble. LISE point decay supplies the conditional response D at the exact thermal energy of each discrete member. It does not rerun abrasion or apply a second thermalization correction. Initial thermal U enters decay; entrance-channel rotational energy and spins are not assigned to the prefragment. Other residues remain competing outcomes. Numerical omitted and excess probabilities are displayed separately and are not renormalized away.

Production study input	Value
Entrance and reference	48Ca + 208Pb at 7 MeV/u; Ecm = 273.044896 MeV; b = 7.35 fm; current LISE masses
Prefragment and residues	46Ar parent; conditional 46Ar, 45Ar and 44Ar probabilities
Mechanics	WS depth 100 MeV; r0 1.2 fm; diffuseness 0.65 fm; 100 zs limit; step 0.5 fm/c
Thermal transfer	UT0 = 0; projectile friction share 0.18110; k = 8 MeV; active rates 4 zs ⁻¹
AA and decay	AA thermalization preparation off; fast 2T decay; J = 0; fission and breakup disabled
Sampling	100 source intervals for all five AA models; exponential quadrature also subdivided to 200 and 400

The explicit transfer study switches AA thermalization preparation off to avoid that particular second correction. Empirical excitation prescriptions may still absorb dissipation, so double counting remains a physical modeling issue. The post-abrasion mass, participant and Q-value energy ledger is not implemented. Overlap and time-limit endpoints are conditional inputs, not identified asymptotic fragments.

Excitation ensembles before and after transfer

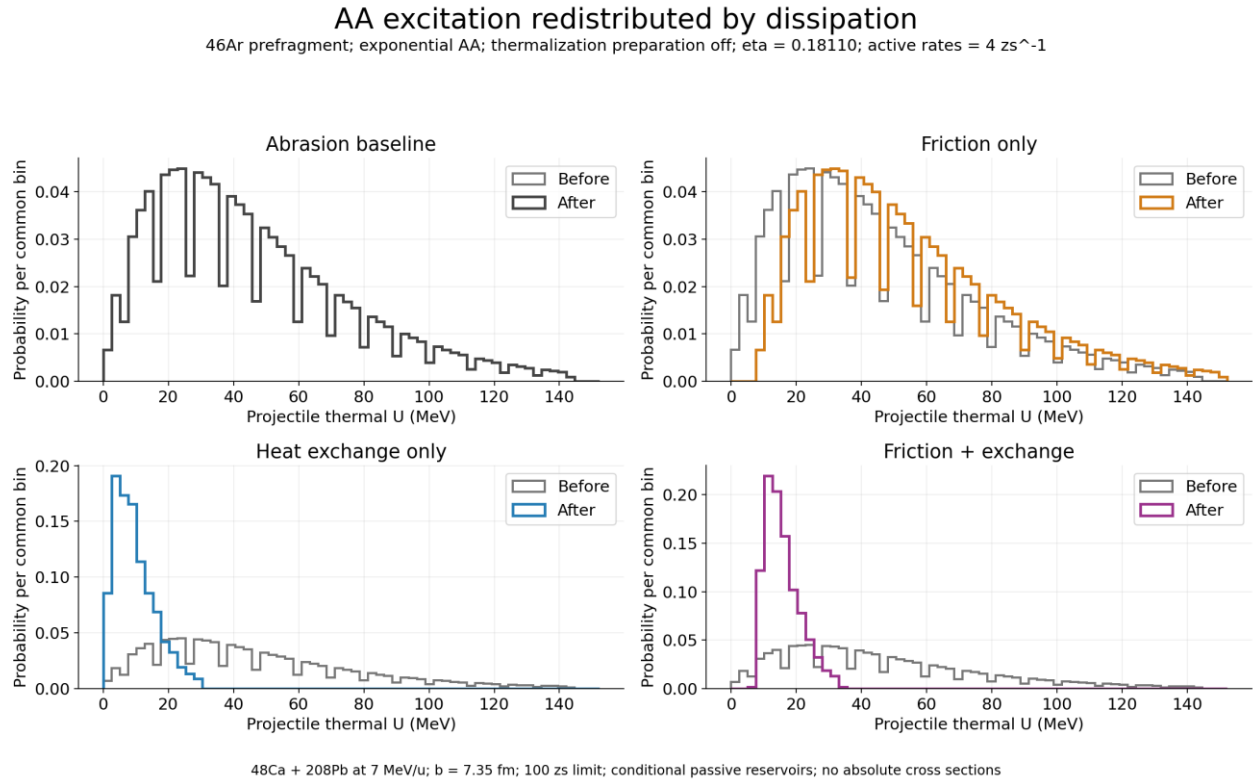
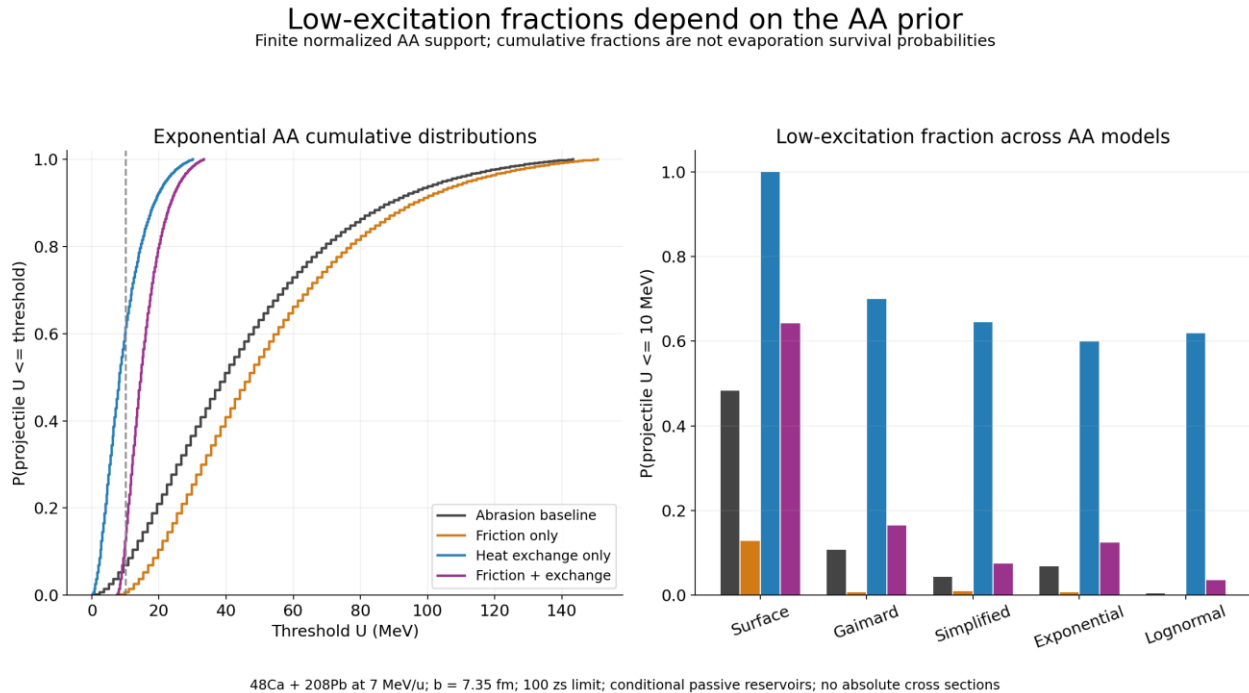


Figure 46 Exponential AA distribution before and after each thermal-transfer case

The baseline preserves the AA excitation ensemble. Friction alone translates each member by its share of generated heat. Exchange redistributes energy between projectile and target reservoirs; in this passive model the map is affine in initial projectile U. The two frictional cases share the same mechanical trajectory and heat generation. Probability weights remain attached to their original members.

All curves use common histogram edges, and ordinates are probability per bin rather than density. The archive records every member, its initial and final projectile energies, target energy and net transfer. The source is an actual LISE AA calculation, not the synthetic distribution used by the GUI regression test.

Low excitation cumulative probabilities



Conditional residue probabilities

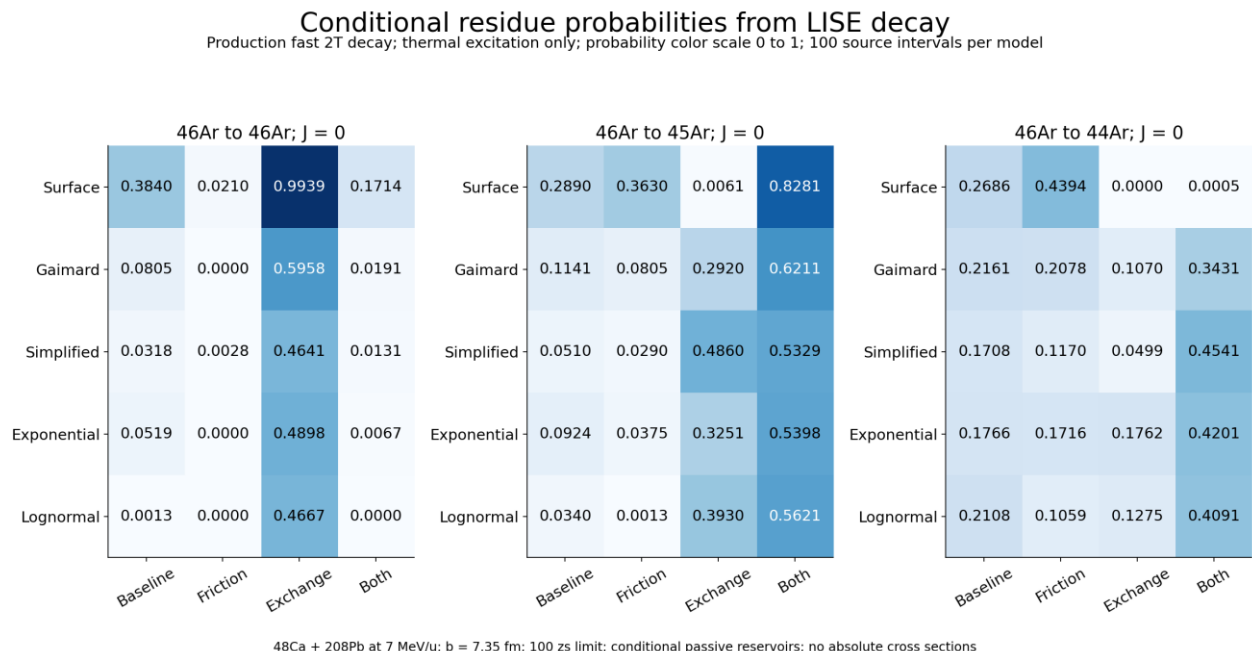


Figure 48 Production LISE conditional decay probabilities for three argon residues

Each cell is the weighted probability for one residue from the selected 46Ar prefragment. These three residues are not an exhaustive final-state set; their probabilities need not sum to one. In the exponential case, the combined response raises P(44Ar) from 0.176607 to 0.420109, while exchange alone gives 0.176159. For the surface model, exchange instead almost entirely retains 46Ar. The direction and size of the response depend on the residue and AA prior, not solely on the mean excitation.

Exponential AA case	P 46Ar	P 45Ar	P 44Ar
Baseline	0.051921	0.092420	0.176607
Friction	0.000000	0.037462	0.171609
Exchange	0.489826	0.325086	0.176159
Both	0.006706	0.539774	0.420109

The two frictional mechanical paths reach the time limit in this reference; the baseline and exchange-only paths separate. Comparing their terminal conditional distributions does not establish an observed fragmentation cross section.

Excitation contributions to the selected residue

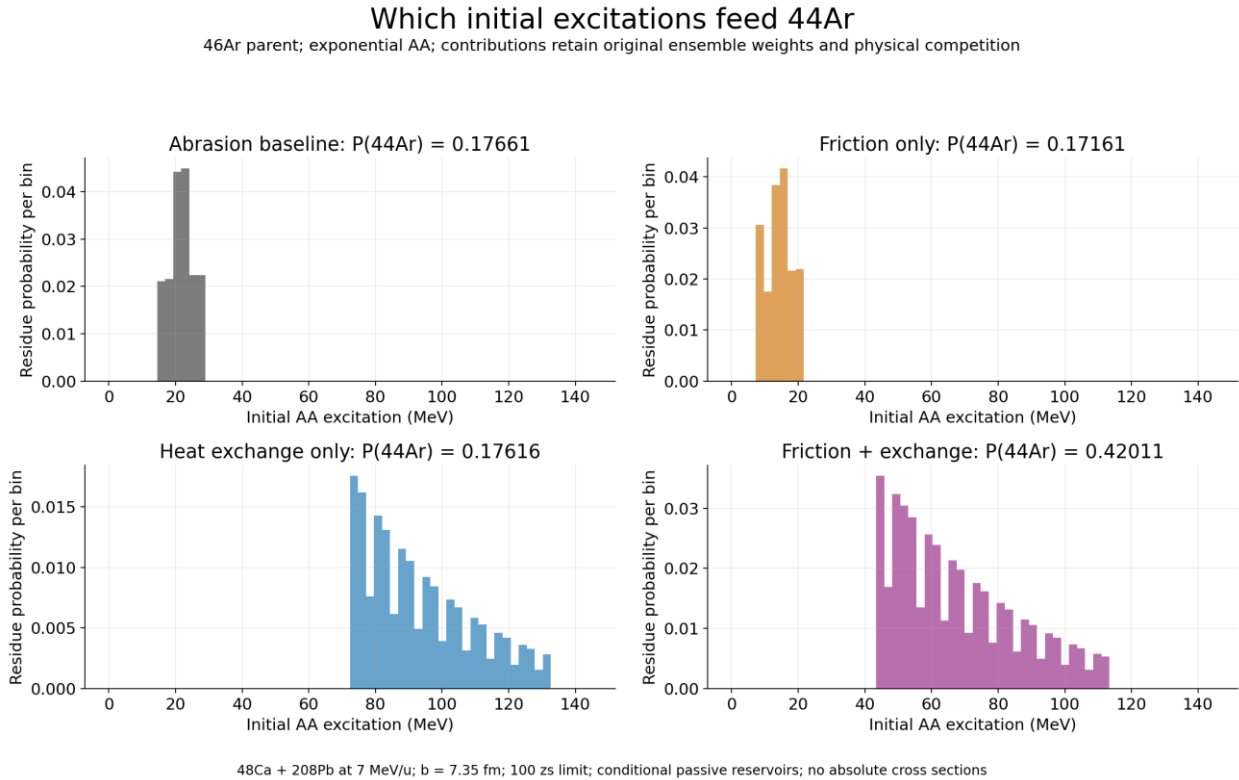


Figure 49 Initial-excitation contributions feeding 44Ar in the exponential AA comparison

The horizontal axis tracks initial AA excitation, preserving the ancestry of every member. The plotted weight is its source probability multiplied by the LISE decay probability at its after-transfer thermal U . The integral of the weighted contributions equals the corresponding case probability. A zero contribution can reflect either small source population or an inaccessible/competing decay path; clicking the response plot separates these effects.

The interface reports conditional probability ratios to the abrasion baseline. A zero baseline produces an undefined ratio rather than a fabricated enhancement. CSV export retains both probabilities, the original member weights, the individual decay response and numerical omitted/excess diagnostics.

Quadrature refinement and production validation

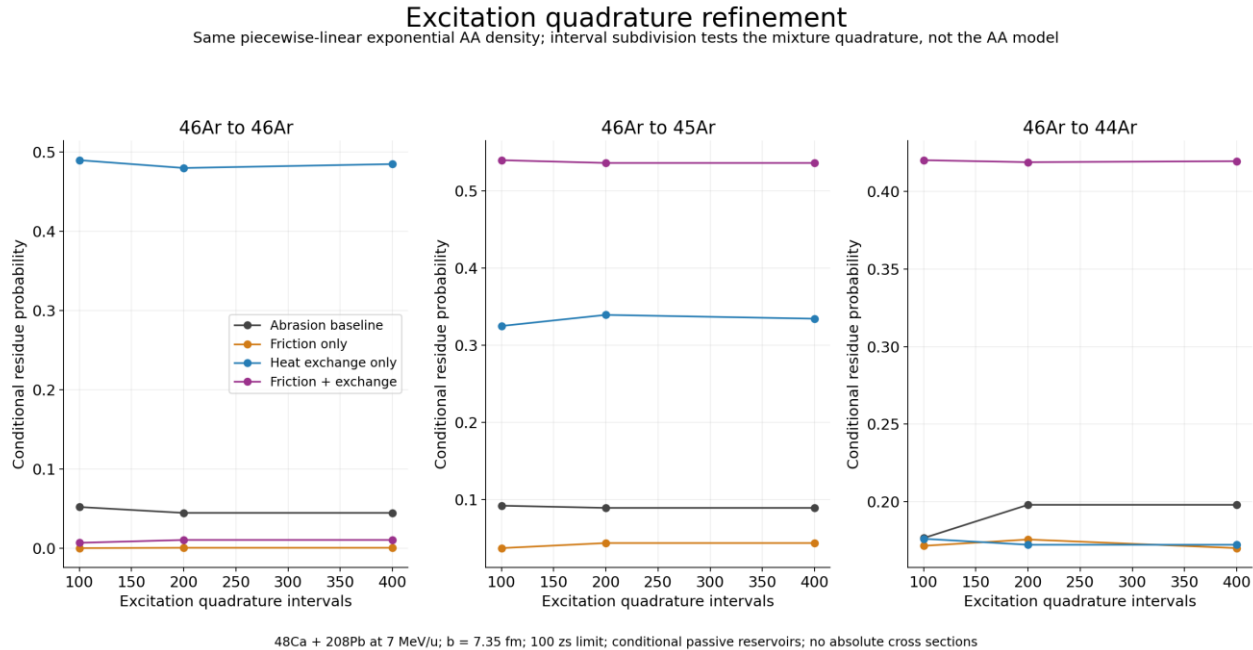


Figure 50 Exponential AA mixture evaluated with 100 200 and 400 quadrature intervals

The largest absolute probability change from 200 to 400 intervals is 0.00555431. This refines integration over the same linearly interpolated AA density; it does not change or validate the AA prescription itself. The 100-interval results remain explicitly identified as the interface-resolution study. Further refinement may be needed near sharp decay thresholds.

Validation quantity	Result
Mixture reconstruction	Every archived case equals the sum of its exported weighted contributions
Maximum mechanical energy residual	1.57815e-08 MeV
Maximum angular momentum residual	1.23523e-12 hbar
Maximum weighted omitted probability	7.92494e-17
Maximum weighted numerical excess	5.11069e-17

Production-library tests cover all five AA generators, cold-parent survival and forbidden neutron emission at zero excitation, independent point-decay weighted sums, suppression isolation and cancellation. Separate GUI tests cover selections, CSV snapshots and failed/cancelled result retention. Numerical consistency does not establish experimental accuracy.

Prefragment ensemble interface

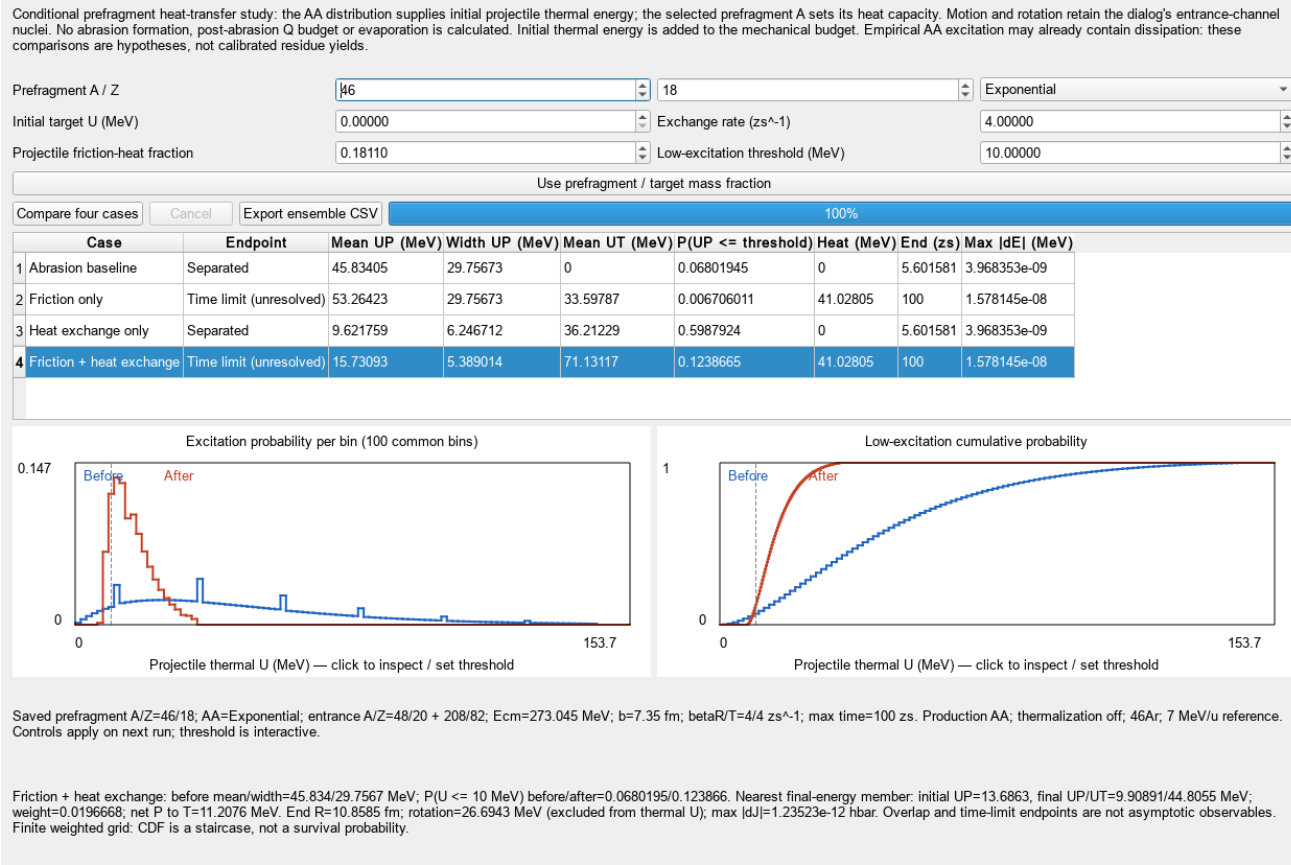


Figure 51 Production exponential AA ensemble with the combined case selected

Complete all four ensemble cases before opening Ablation response. The ensemble tab provides model and prefragment selection, before/after histograms, cumulative curves and a clickable low-excitation threshold. A private AA object uses the Explorer participants rather than unrelated main-window beam settings. Controls apply on the next run; exported values belong to the saved snapshot.

Progress and cancellation retain complete ensemble cases. Ablation requires a complete four-case input. Its statistical engine reads shared LISE settings, so decay runs under an application-modal progress dialog rather than concurrently on a worker thread.

Ablation interface and two row navigation

Results	Trajectory table	Plots	Model parameters	Potential	Impact parameter scan	Spins and energy	Equilibrium / potential
Convergence / stability	Energy-impact map	Potential/friction sensitivity	Adaptive overlap boundary	Dissipation / excitation	Prefragment ensemble	Ablation response	

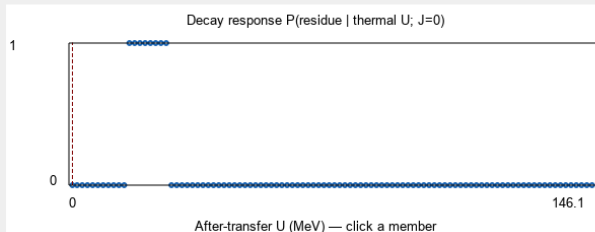
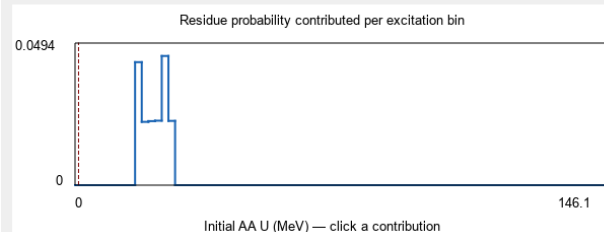
Figure 52 Two-row Explorer navigation including the new ablation response tab

First complete the four cases in Prefragment ensemble for a 48Ca projectile. This tab takes a copy of that saved ensemble and applies LISE statistical decay to each member's projectile thermal energy. It computes conditional residue probabilities, not production cross sections. Decay uses $J=0$; entrance-channel rotation is not assigned to the prefragment. Overlap/time-limit endpoints are conditional scenarios, not measured outgoing fragments.

Final residue A / Z: 44 / 18

Saved prefragment A/Z=46/18 -> residue 44/18; AA=Exponential; Ecm=273.045 MeV; b=7.35 fm. Production LISE fast 2T; J=0; thermal U only. Numerical omitted/excess diagnostics are reported separately; other physical residues are not renormalized away. Ratios are undefined when the baseline is zero.

Case	Endpoint	Residue probability	Ratio to baseline	Weighted omitted	Weighted excess
1 Abrasion baseline	Separated	0.1766066219	1	6.09806e-17	4.21939e-17
2 Friction only	Time limit (unresolved)	0.1716093946	0.97170419	6.54156e-17	3.06356e-17
3 Heat exchange only	Separated	0.1761589181	0.99746497	3.41653e-18	1.63569e-18
4 Friction + heat exchange	Time limit (unresolved)	0.4201086806	2.3787822	7.77395e-18	6.93813e-18



	Initial U (MeV)	After U (MeV)	Ensemble weight	Decay probability	Weighted contribution	Cumulative contribution	Omitted	Excess
1	0.960639894	0.960639894	0.001728017763	0	0	0	0	0
2	2.234484109	2.234484109	0.004977993271	0	0	0	0	0
3	3.64200966	3.64200966	0.007843583382	0	0	0	0	0
4	5.068162436	5.068162436	0.0103585358	0	0	0	0	0
5	6.500484695	6.500484695	0.01255397121	0	0	0	0	0
6	7.935602493	7.935602493	0.01445857478	0	0	0	0	0
7	9.372222735	9.372222735	0.01609877431	0	0	0	0	0
8	10.8097433	10.8097433	0.01749890585	0	0	0	0	0
9	12.24784588	12.24784588	0.0186813677	0	0	0	0	0
10	13.68634642	13.68634642	0.01966676359	0	0	0	0	0
11	15.12513104	15.12513104	0.02047403571	0	0	0	0	0
12	16.56412556	16.56412556	0.02112058836	1	0.02112058836	0.02112058836	0	0
13	18.00327954	18.00327954	0.02162240284	1	0.02162240284	0.04274299119	0	0

Abrasion baseline; member 1: initial AA U=0.96064 -> thermal U=0.96064 MeV. Weight=0.00172802; decay probability=0; contribution=0 to total 0.176607. Target U=0 MeV; net projectile-to-target heat=0 MeV. Click a plot or contribution row to inspect another member. Finite AA-grid quadrature; narrow decay thresholds may require finer excitation sampling.

Figure 53 Production 46Ar to 44Ar response and clickable excitation contributions

Archive: ensemble-ablation-study.cpp, reproduce-ensemble-ablation.cmd, three CSV tables, settings, validation JSON, source manifest and plot-ensemble-ablation.py. ENSEMBLE.txt and ABLATION.txt describe the interfaces. Earlier figures and release reports remain retained. The next physical step is an explicit post-abrasion initialization and angular-momentum prescription before absolute yields or UP momentum comparisons.

Residue feeding and Universal Parameterization

Release 18.8.103 connects the excitation ensemble to 44Ar feeding from eight reachable abrasion parents: 44–46Ar, 45–47K and 46–47Ca. The unabraded 48Ca projectile is excluded. Each parent uses its production geometrical abrasion weight and AA isotopic factor, multiplied by its weighted LISE conditional decay response. All four cases retain the same finite AA source weights.

$$W_{c,i} = \sigma_{abr,i} \sum w_{i,j} D(44Ar | U_{c,i,j}, J = 0)$$

$$f_{c,i} = \frac{W_{c,i}}{\sum W_{c,k}} \quad S_c(p) = \sum f_{c,i} K_i(p)$$

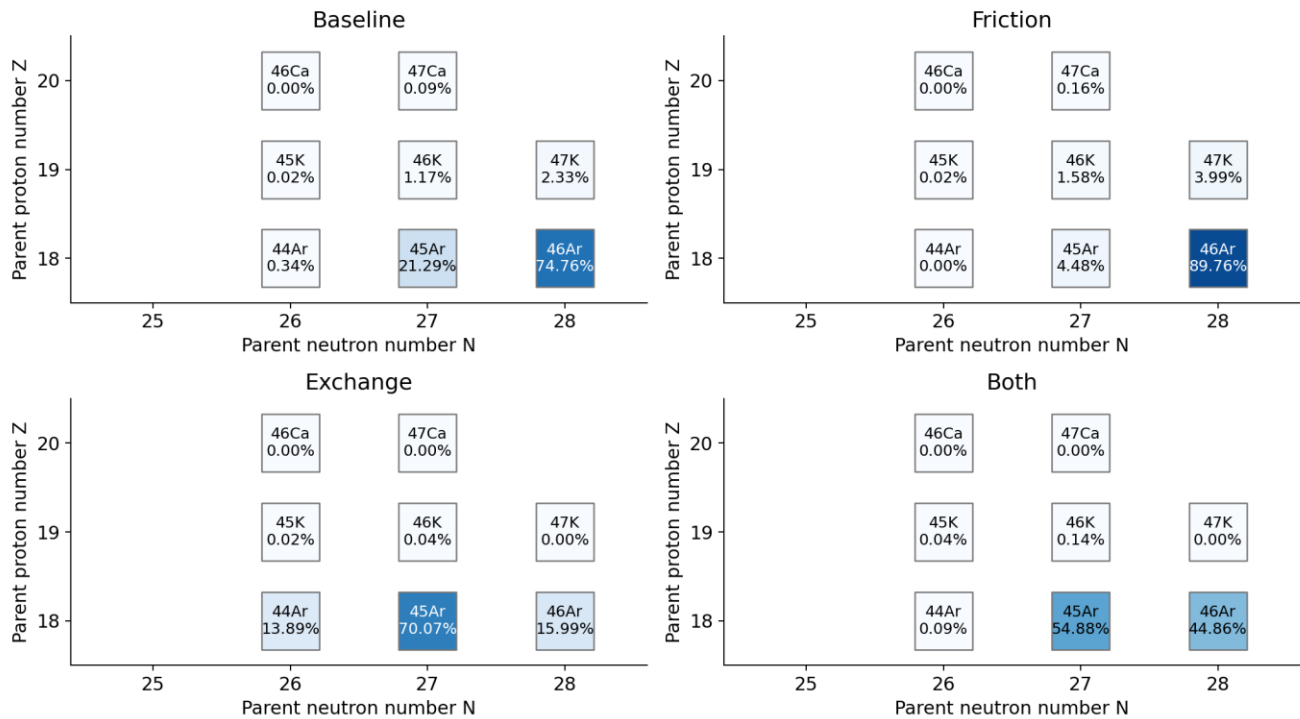
Raw W values retain inherited mb units, but they combine an integrated abrasion weight with a fixed-b response and therefore do not define production cross sections. Only the parent fractions used for the momentum mixture are normalized. Competing residues and numerical omitted or excess probability remain separate.

Reference input	Setting
Entrance	48Ca + 208Pb, 7 MeV/u; Ecm 273.044896 MeV; b 7.35 fm
Mechanics	WS 100 MeV, 1.2 fm, 0.65 fm; active radial/tangential rates 4 zs ⁻¹ ; 100 zs; step 0.5 fm/c
Thermal	Initial target U=0; fixed projectile heat share 0.18110; k=8 MeV; exchange 4 zs ⁻¹
Source and decay	Exponential AA mean 24 MeV, 100 intervals per parent; preparation thermalization off; fast 2T at J=0
UP	Mode 2; sigma0=160 MeV/c; coefficient 1.25; shift=-1; fixed mode-2 excitation 14 MeV per removed nucleon
Standard parent	Private-context APF method C selects 46Ar, effective A=46

Selected parent mass changes thermal heat capacity, while mechanical masses remain the entrance masses. The saved heat share is fixed for all parents. Fragment rotation is excluded from decay excitation. The post-abrasion Q, momentum and spin ledger remains an open modeling step.

Parent contributions feeding argon 44

Parent fractions feeding 44Ar



48Ca + 208Pb, 7 MeV/u, $b = 7.35$ fm; conditional fixed-b feeding; frictional cases end at 100 zs

Figure 54 Normalized parent fractions in the four thermal cases

^{46}Ar supplies 74.76% of baseline feeding and 89.76% with friction alone. Heat exchange shifts the leading contribution to ^{45}Ar : 70.07% for exchange and 54.88% with both mechanisms. These fractions combine parent formation weights with decay response; the largest conditional decay probability need not identify the largest contributor.

Baseline and exchange-only trajectories separate. The friction and combined cases reach 100 zs unresolved. Their endpoint excitation distributions are diagnostic scenarios and do not identify outgoing residues.

Conditional decay and formation weights

Decay response and parent population weights

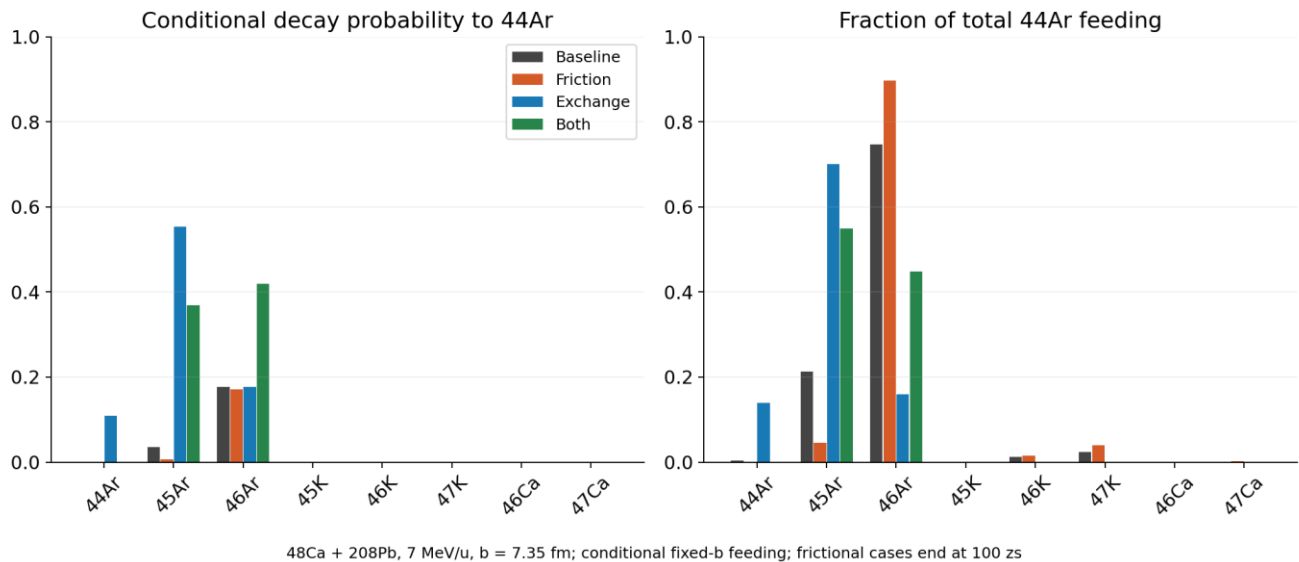


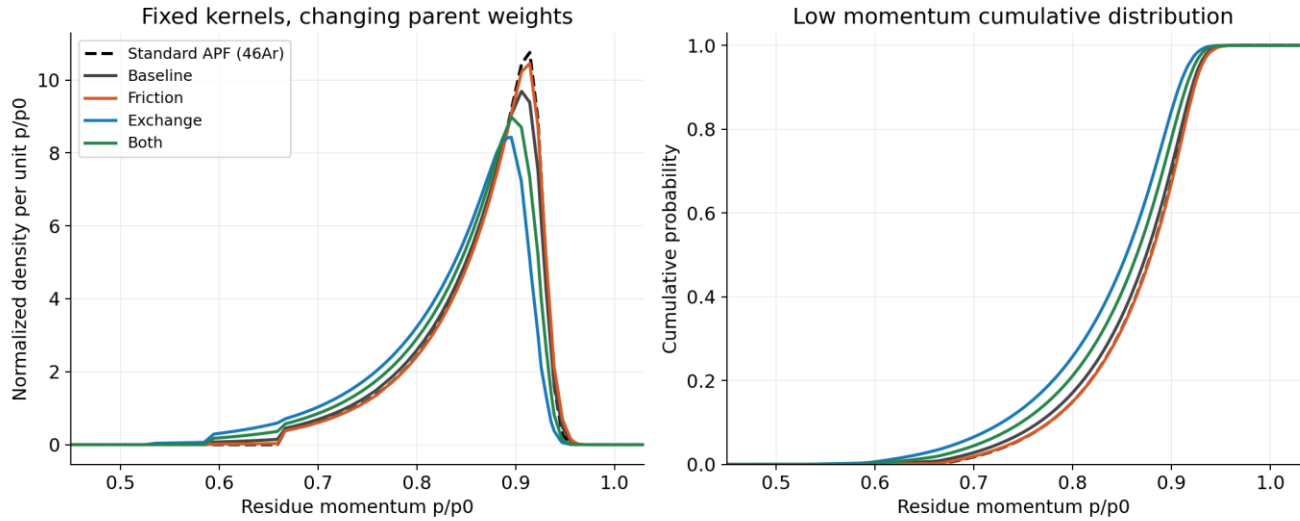
Figure 55 Conditional decay probabilities and normalized feeding fractions

Case	Raw conditional weight	Dominant parent	Fraction
Baseline	8.661884	46Ar	0.747591
Friction	7.010139	46Ar	0.897603
Exchange	40.406181	45Ar	0.700680
Both	34.337597	45Ar	0.548812

Raw totals are 8.66, 7.01, 40.41 and 34.34 in inherited abrasion-weight units. Their increase under exchange is a response of the selected finite excitation prior and decay model. No impact-parameter-dependent parent formation probability has been applied, so these totals must not be interpreted as absolute yields or measured cross sections.

Single parent and mixed momentum spectra

Single-parent and mixed Universal Parameterization spectra



48Ca + 208Pb, 7 MeV/u, $b = 7.35$ fm; conditional fixed-b feeding; frictional cases end at 100 zs

Figure 56 Standard APF spectrum and four mixtures with fixed parent kernels

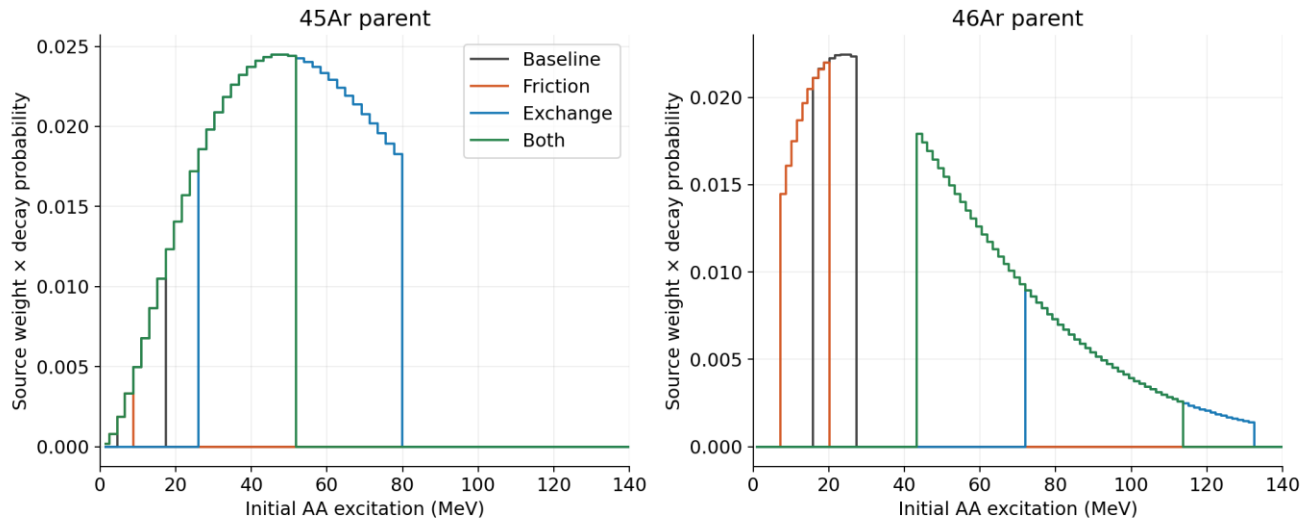
Case	Mean p/p_0	RMS MeV/c	$P(p < 0.95 p_0)$
Baseline	0.857208	315.558	0.998349
Friction	0.863114	298.369	0.997452
Exchange	0.834352	363.646	0.999858
Both	0.846333	338.694	0.999662

The shared production convolution evaluates every parent with the same UP options. Kernels remain fixed across cases. Mixture widths include the spread of parent centroids. Each finite-support kernel is normalized, and the union of its knots preserves the piecewise-linear mixture. Exact interval integrals supply moments and cumulative probabilities.

The implemented mode-2 excitation is removed mass times DefaultExEnerAA (14 MeV here). It is distinct from the 24 MeV exponential AA mean and from dissipated thermal heat. This comparison changes feeding populations without adding a new momentum-loss or evaporation-recoil prescription.

Excitation ancestry and interpretation

Excitation members feeding ^{44}Ar from the dominant parents



$^{48}\text{Ca} + ^{208}\text{Pb}$, 7 MeV/u, $b = 7.35$ fm; conditional fixed-b feeding; frictional cases end at 100 zs

Figure 57 Discrete excitation-member contributions from ^{45}Ar and ^{46}Ar

Each ordinate is the original member probability multiplied by its after-transfer decay response. The sum for a parent equals its conditional probability. Multiplication by that parent abrasion weight gives its raw contribution to residue feeding. Initial excitation on the horizontal axis preserves ancestry as exchange moves thermal energy into the target reservoir.

The diagnostic can test how an intermediate dissipation stage changes parent populations and therefore a UP mixture. It does not yet derive UP asymmetry from a dynamical momentum distribution. Experimental comparison requires a consistent abrasion geometry, post-abrasion energy and momentum initialization, and a prescription for emitted-particle recoil.

Residue feeding interface and validation

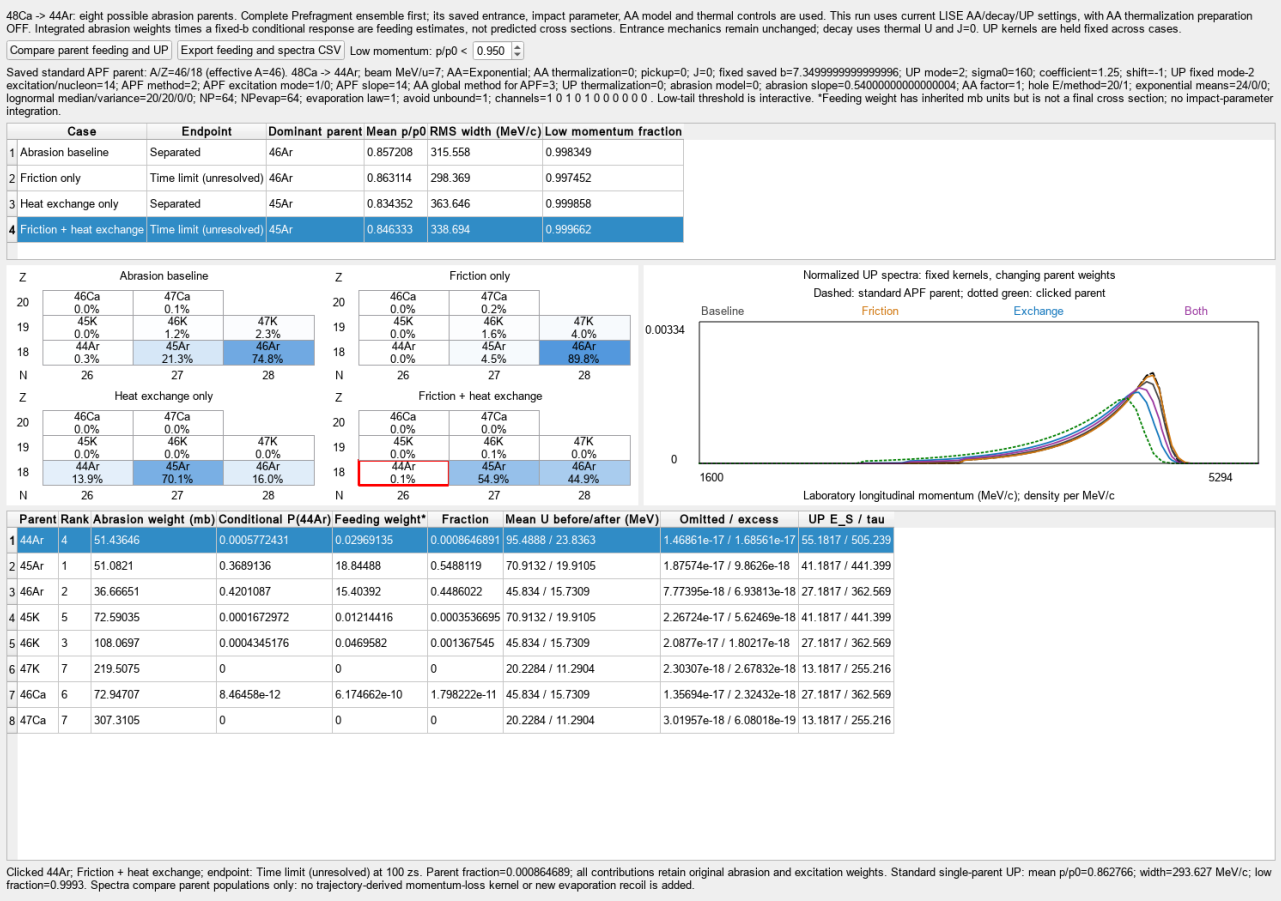


Figure 58 Production residue feeding tab with parent maps and UP spectrum inspection

Run from a completed four-case ensemble. Click a parent map or table row to inspect its contribution and fixed kernel. The summary compares mean momentum, width and low-tail fraction. Progress and cancellation preserve the previous complete snapshot. CSV records saved settings, cases, parents, excitation members and normalized spectra in one rectangular table.

Production checks cover independent decay responses, APF search methods A/B/C, UP modes 0/1/2 at 7 MeV/u and mode 2 at 60 MeV/u, context isolation and cancellation. Independent CSV reconstruction validates 4893 rows, 32 parent records, 3200 members and 13 spectra. GUI tests cover selection, progress, cancellation and failed-run retention. The unsupported low-separation DJM Gaussian fallback is explicitly rejected when enabled.

Reproduction: tests/reaction_feeding_integration.cpp with tests/reaction_ablation_integration.py and the release MSVC objects. The archive contains the production CSV, protocol, summary, plot script and validation logs. Numerical checks establish consistency of this implementation, not calibration of the underlying physics.

Post abrasion initialization and conservation

Release 18.8.104 changes the mechanical system to the selected parent plus 208Pb after a prescribed sudden abrasion step. All eight 44Ar-feeding parents are included. A free packet of removed nucleons initially shares the projectile-center velocity and position. It retains its momentum and orbital angular momentum. Its intrinsic excitation and spin are zero, and its residual interactions are neglected.

$$\Delta M = ME(\text{parent}) + \Delta Z ME(1H) + \Delta N ME(n) - ME(48Ca)$$

$$E_{\text{ref}} = \Delta M + K_{\text{packet}} + K_{\text{pair CM}} + K_R + K_t + V_C + V_N + E_{\text{rot}} + U_P + U_T$$

$$J_{\text{ref}} = J_{\text{packet}} + J_{\text{pair CM}} + L_{\text{relative}} + S_P + S_T$$

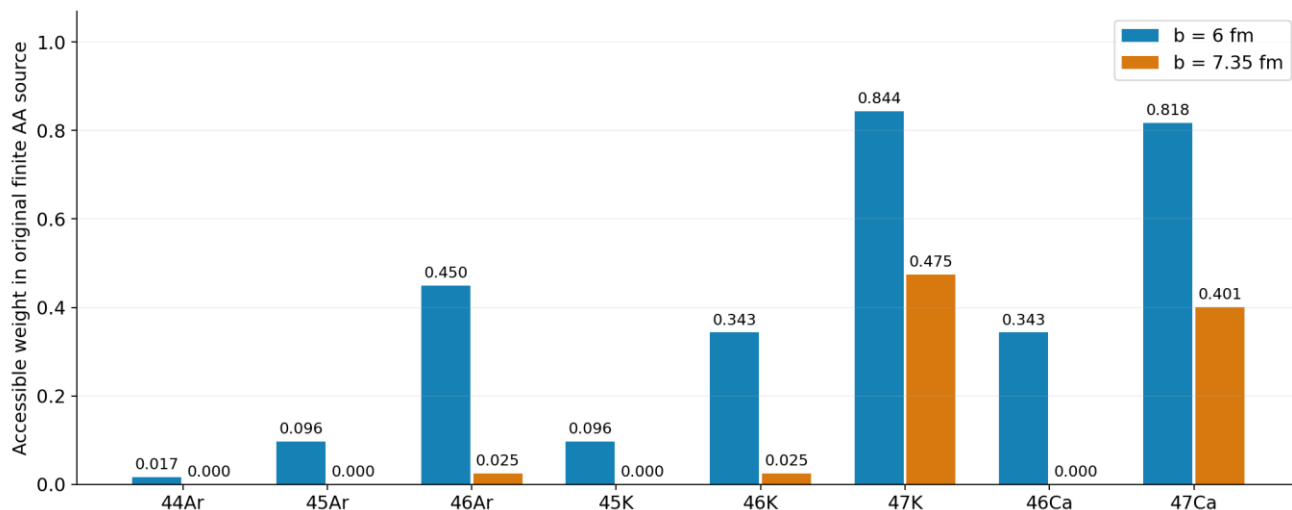
Common $A \times u$ inertias define a Galilean split, while physical atomic mass excesses determine the rest-energy cost ΔM . Atomic electron counts balance through the removed hydrogen atoms. At 7 MeV/u this inertia convention gives $E_{\text{cm}}=273$ MeV, distinct from the 273.044896 MeV production-mass feeding reference. Initial target thermal energy is included in the reference. The AA projectile excitation is paid from mechanical energy, rather than added as an external source.

Reference setting	Value
Entrance and parents	48Ca + 208Pb at 7 MeV/u; eight Ar/K/Ca parents
Abrasion prescription	Rinit = entrance touching + 2 fm = 13.47108 fm; zero initial fragment spins
Energy payment	Keep relative tangential velocity; adjust pair radial kinetic energy for ΔM , AA U and potential change
Source	Exponential AA; preparation thermalization and pickup off; 24 groups per parent, original weights retained
Propagation	b=6 fm primary reference; b=7.35 fm comparison; 100 zs after abrasion; 0.5 fm/c step
Active rates	Radial, tangential and exchange 4 zs^{-1} ; projectile heat share 0.18110; initial target U=0

The radius and radial-payment rule are model choices. Source grouping preserves weight and mean excitation, but it can move threshold acceptance. These checks establish conservation within this closure; they do not calibrate abrasion geometry, participant transport or the AA prior.

Accessible AA support after the energy payment

Energy accessibility after abrasion at 7 MeV/u



Gap 2 fm; 24 AA groups per parent. Rejected weight remains explicit. This is a closure-dependent quadrature result.

Figure 59 Original AA weight with positive remaining radial energy at two impact parameters

Parent	Separation cost MeV	Accessible b=6 fm	Accessible b=7.35 fm
44Ar	42.27188	0.016838	0.000000
45Ar	37.10306	0.096376	0.000000
46Ar	29.02964	0.449793	0.024908
45K	31.04061	0.096376	0.000000
46K	24.17099	0.343125	0.024908
47K	15.80157	0.844125	0.474825
46Ca	17.22784	0.343125	0.000000
47Ca	9.95152	0.817571	0.401187

All eight parents have some accessible sampled support at $b=6$ fm. At $b=7.35$ fm the 44Ar, 45Ar, 45K and 46Ca sources have none under this closure. A zero here describes the sampled finite source and the radial-energy constraint; it does not establish that physical production is forbidden. Inaccessible members retain their weight and are not propagated. Means shown elsewhere condition on the accessible weight.

Correlated excitation and parent momentum

46Ar excitation and momentum before and after dissipation

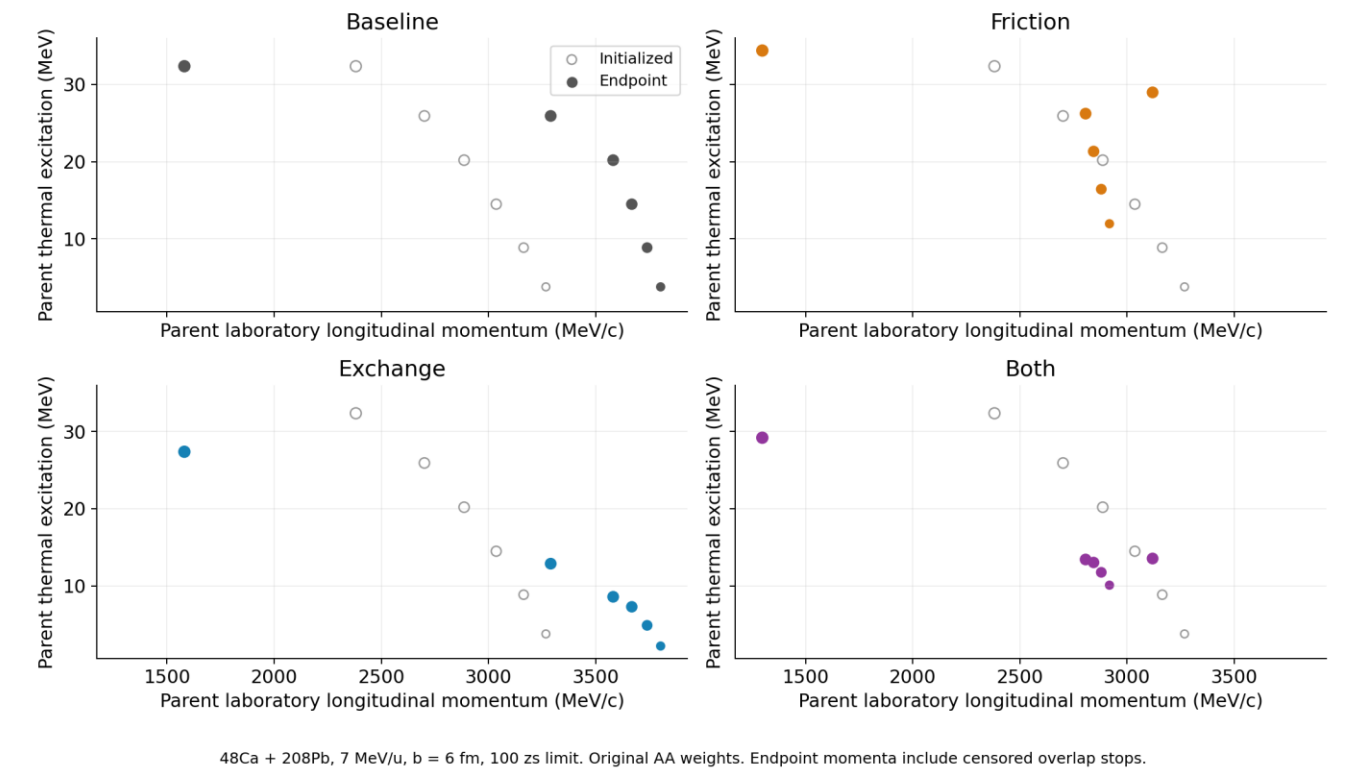


Figure 60 Initialized and endpoint ensembles for 46Ar at b=6 fm

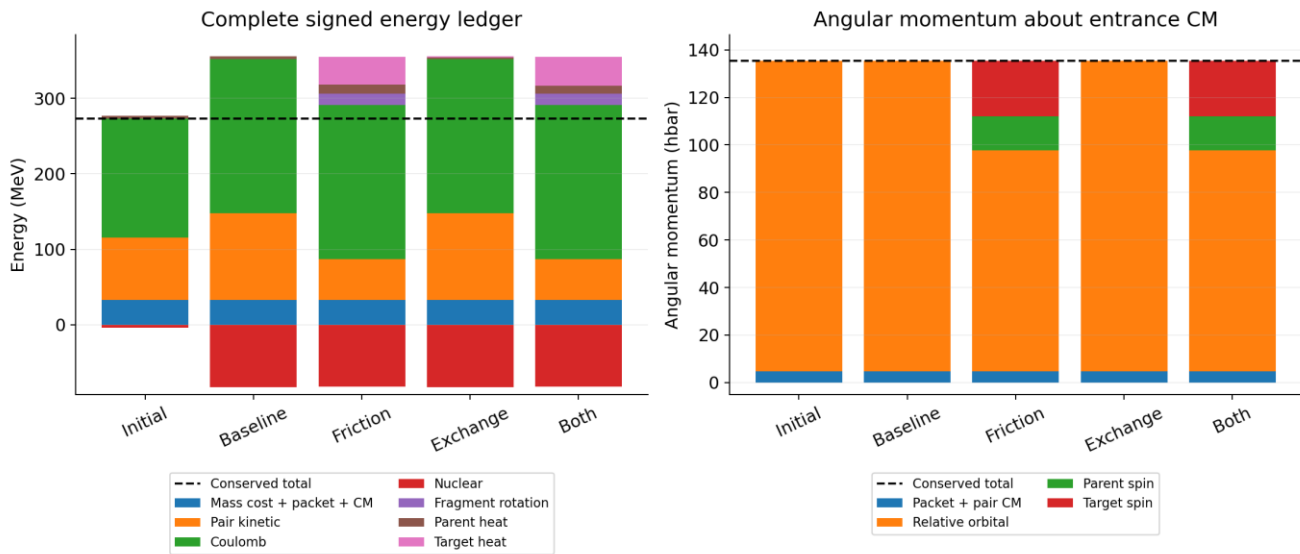
Case	Conditional mean U MeV	Conditional mean p MeV/c
Baseline	20.75835	3098.471
Friction	25.71874	2533.408
Exchange	12.80436	3098.471
Both	16.70000	2533.408

Each marker retains its original AA probability weight. Paying a different excitation cost gives each member a different initial radial momentum, so the excitation–momentum correlation exists before friction is applied. Exchange changes the thermal partition on the same mechanical path. Friction changes the motion and generates heat; the combined case shares that mechanical path while redistributing the heat.

Longitudinal momentum is the parent laboratory momentum at stopping, projected on the asymptotic incident axis with a Galilean boost. Separated paths still stop at a finite exit radius. Overlap and time-limit points are censored. These are parent ensembles, not evaporated-residue UP spectra.

Energy and angular momentum budgets

46Ar member 0 conservation budgets



$b = 6$ fm; initial AA $U = 3.76778$ MeV. Negative nuclear energy is shown below zero. Dashed line is the signed sum.

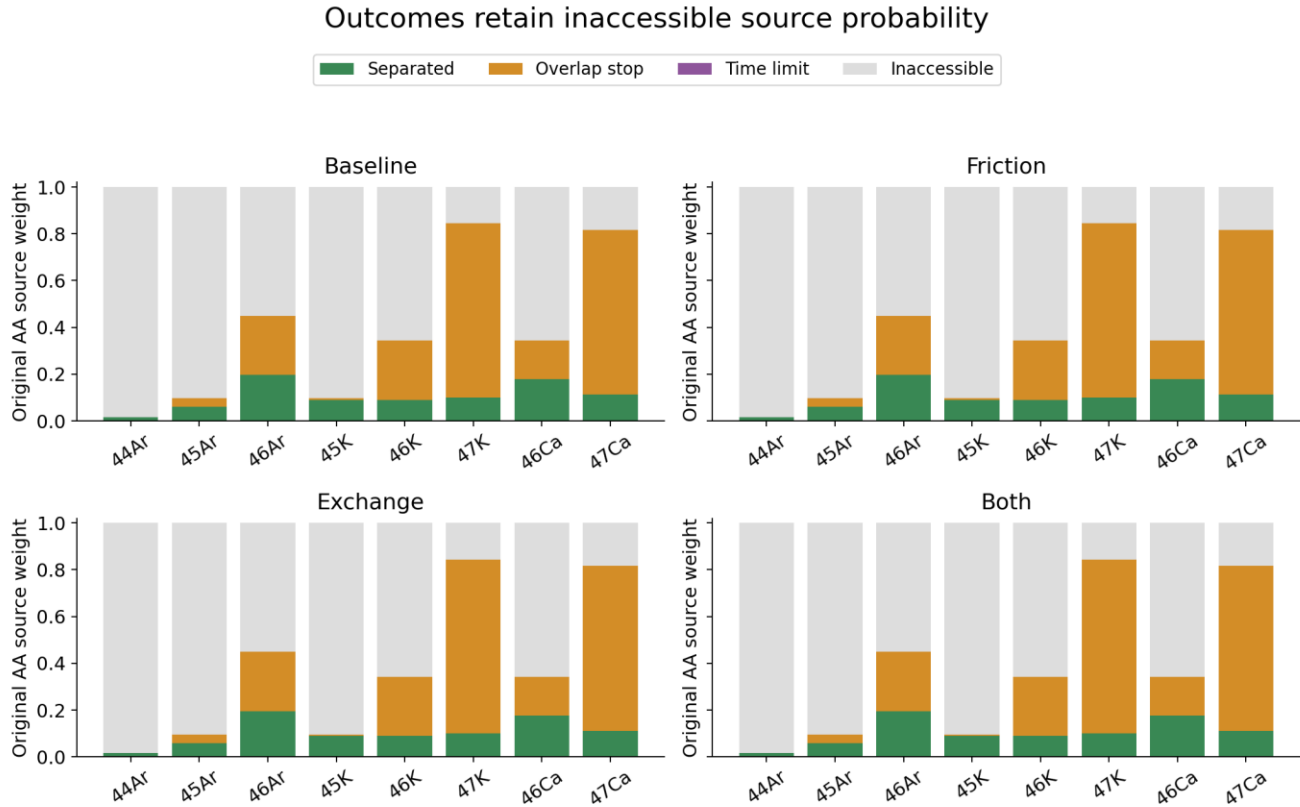
Figure 61 Signed energy and angular momentum terms for one 46Ar source member

The selected member starts at AA $U=3.767782$ MeV. The physical separation cost for 46Ar is 29.029643 MeV. The full energy sum includes that cost, the free packet kinetic energy, pair-CM recoil, relative motion, the changed potential, fragment rotation and both thermal reservoirs. The negative nuclear contribution is retained with its sign. A positive-stack height alone is not the conserved energy.

Removing a co-moving packet also removes orbital angular momentum. The surviving pair CM is displaced and recoils. Both contributions remain in the total about the original entrance CM. Tangential friction transfers relative orbital angular momentum into fragment spins without changing that total. Initial fragment spins remain zero in this first prescription.

A member with nonpositive remaining radial energy is explicitly inaccessible. The central impulse does not alter the retained tangential velocity. An alternative prescription that assigns intrinsic spin, participant recoil or noncentral impulses could change this boundary and requires its own energy and angular-momentum ledger.

Outcomes and interpretation of the four cases



7 MeV/u, $b = 6$ fm, gap 2 fm, 24 groups. No renormalization. Overlap and time-limit stops do not identify final fragments.

Figure 62 Endpoint outcomes and inaccessible weight for all eight parents at $b=6$ fm

Each bar sums to one over the original finite AA source, including inaccessible inputs. Baseline and exchange share outcomes because exchange is passive. Friction and both likewise share mechanical outcomes. At this sampled reference the accessible states separate or enter overlap; no time-limit weight appears. Outcome weights are conditional on the imposed abrasion radius and energy-payment rule, not physical channel probabilities or cross sections.

This initialization exposes an energy constraint absent from the earlier feeding comparison, which reused entrance-channel mechanics. It supplies a conservation framework for a future abrasion–friction–ablation calculation. A consistent next coupling would propagate the initialized parent ensemble through decay while retaining its excitation, momentum and spin correlations. A formation probability versus impact parameter and an emitted-particle recoil model are still required before absolute yields or dynamical UP predictions.

Initialization interface and production validation



Figure 63 Production initialization diagnostic with a selected 46Ar member and combined case

Validation over primary reference	Maximum
Path energy residual	2.20785×10^{-8} MeV
Path total-J residual	4.15584×10^{-13} hbar
Endpoint linear-momentum residual	3.29618×10^{-13} MeV/c

Independent CSV reconstruction validates 535 records from 192 grouped source members and all eight parents. Tests also cover zero-rate identities, the analytic straight-line momentum axis, half-step outcome and thermal agreement, inaccessible weights, private production context, cancellation and saved result retention. The interface permits parent selection, clickable endpoints and inaccessible-member inspection. CSV exports full saved inputs and initialized/endpoint budgets.

Archive: INITIALIZATION.txt, two reference CSVs, validation JSON, source manifest, production interface capture, four scientific PNG/PDF figures, plot-initialization.py and reproduce-initialization.cmd. The 24-group study is not a source-quadrature convergence claim. Numerical conservation does not establish the physical validity of the free-packet or radial-payment assumptions.

Initialization radius and sampling sensitivity

Release 18.8.105 studies initialization inside the utility before adding another physical assumption. The radial energy-payment prescription, free removed packet and common A times u inertia convention remain unchanged. The same finite production AA source is reused for every radius, grouping cap and thermal case. Only the prescribed abrasion radius and grouping change within a study.

$$R_{init} = R_{touch\ entrance} + gap$$

Reference control	Saved value
Reaction and energy	48Ca + 208Pb at 7 MeV/u
Parent domain	44Ar 45Ar 46Ar 45K 46K 47K 46Ca 47Ca
Radius gaps	1 1.5 2 2.5 3 fm above entrance touching
AA grouping caps	24 50 100; original finite interval source
Mechanical controls	b=6 fm; radial and tangential active rates 4 zs ⁻¹
Thermal controls	Exchange active rate 4 zs ⁻¹ ; projectile share 0.1811; initial target U=0
AA source and time	Exponential; preparation thermalization and pickup off; 100 zs after abrasion
Four cases	Baseline; friction only; heat exchange only; friction and heat exchange

The gap is not a Woods-Saxon radius parameter. Incoming conservative reachability is tested before applying the abrasion step. A radius that cannot be reached is shown separately from a reachable radius with zero accessible AA weight. Numerical failures or cancellation retain the preceding complete scan.

Caps regroup the existing positive-energy interval centroids. They preserve source normalization and mean excitation, but threshold acceptance need not be preserved. Cap 100 retains the current production grid; this study does not increase the underlying density resolution or invent an unrepresented tail.

Radius dependence and finite source sampling

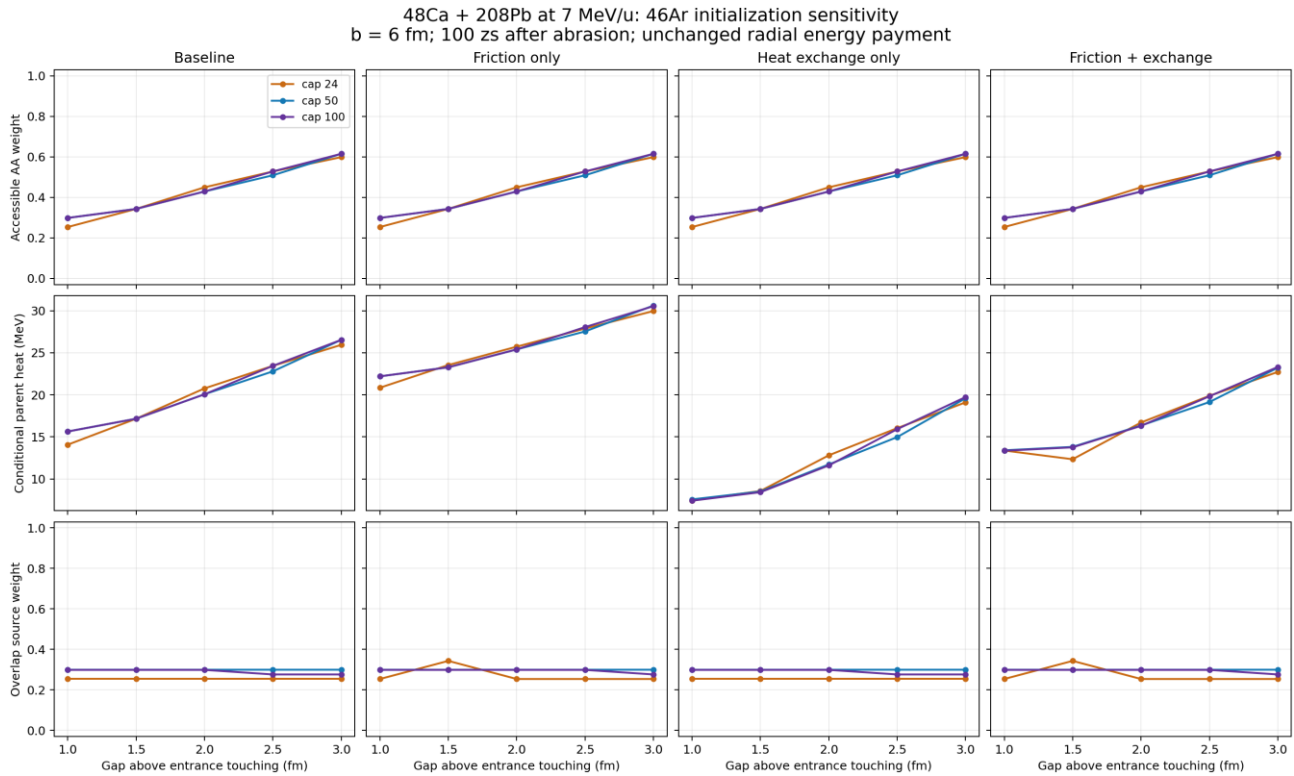


Figure 64 46Ar accessible source weight conditional parent heat and overlap source weight across all four cases

At cap 100, accessible 46Ar weight increases from 0.298618 at a 1 fm gap to 0.615242 at 3 fm. Accessibility is identical in all four columns because the common radial-energy test occurs before the subsequent dynamics. Friction and heat exchange then change the conditional excitation and, where friction acts, the mechanical outcome.

The largest absolute accessible-weight change from cap 100 is 0.047833949 across the eight-parent reference. This is 4.78 percentage points of the original source. Differences measure sensitivity to regrouping a finite AA grid; they are neither confidence intervals nor a demonstration of full physical convergence.

Accessible source weight across eight parents

Parent	Gap 1 fm	Gap 2 fm	Gap 3 fm	Max sampling shift pp
44Ar	0.000577	0.010873	0.058671	0.951
45Ar	0.026544	0.096376	0.223345	4.783
46Ar	0.298618	0.429153	0.615242	4.489
45K	0.017903	0.063450	0.200108	3.841
46K	0.209078	0.365077	0.581848	4.465
47K	0.753876	0.850280	0.947932	1.589
46Ca	0.187084	0.343125	0.564409	3.634
47Ca	0.705565	0.824511	0.934613	1.025

All entries use original AA normalization. Inaccessible members retain their weights, while separated, overlap and time-limit weights sum to accessible weight. Only conditional means divide by accessible weight. Missing conditional means remain undefined. All 15 coordinate pairs are reachable for this $b=6$ fm reference; the 480 summary records cover eight parents and four cases.

$$W_{\text{separated}} + W_{\text{overlap}} + W_{\text{time limit}} = W_{\text{accessible}}$$

Radius dependence is substantial under the retained prescription. It reflects how the chosen abrasion location changes the available radial-energy budget and which part of the AA prior is admitted. These quantities are conditional diagnostics of the stated closure, not absolute formation probabilities. No beamline transmission calculation or decay coupling is introduced.

Independent validation	Maximum or count
Path energy residual across the scan	2.95112 times 10^{-8} MeV
Path total J residual across the scan	7.65874 times 10^{-13} hbar
Selected detail endpoint linear momentum residual	4.32907 times 10^{-13} MeV/c
Selected detail export	2200 records; 800 source members; eight parents
Summary reconstruction	480 rows; 32 selected parent and case means checked against members

Saved boundary maps and trajectory selection

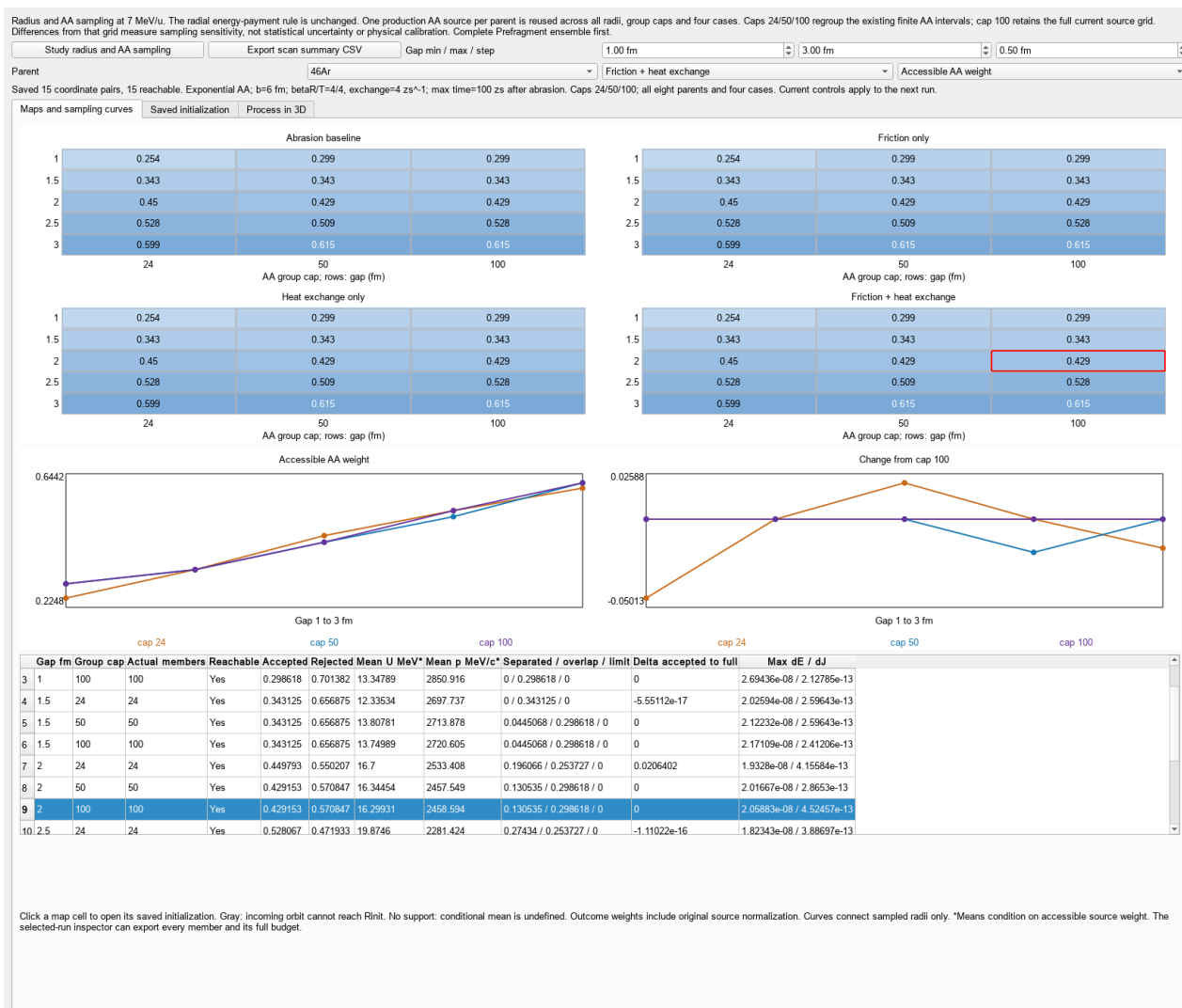


Figure 65 Radius and sampling maps with a shared scale clickable coordinates and saved results

Choose a parent and metric, then click a map cell to open its saved initialization and conservation ledger. The table retains an overview of all coordinates. Export the scan summary for comparisons; the selected-run inspector exports individual source members and complete initialized and endpoint budgets. No propagation is repeated when inspecting these saved endpoint results.

Abrasion geometry and energy flow

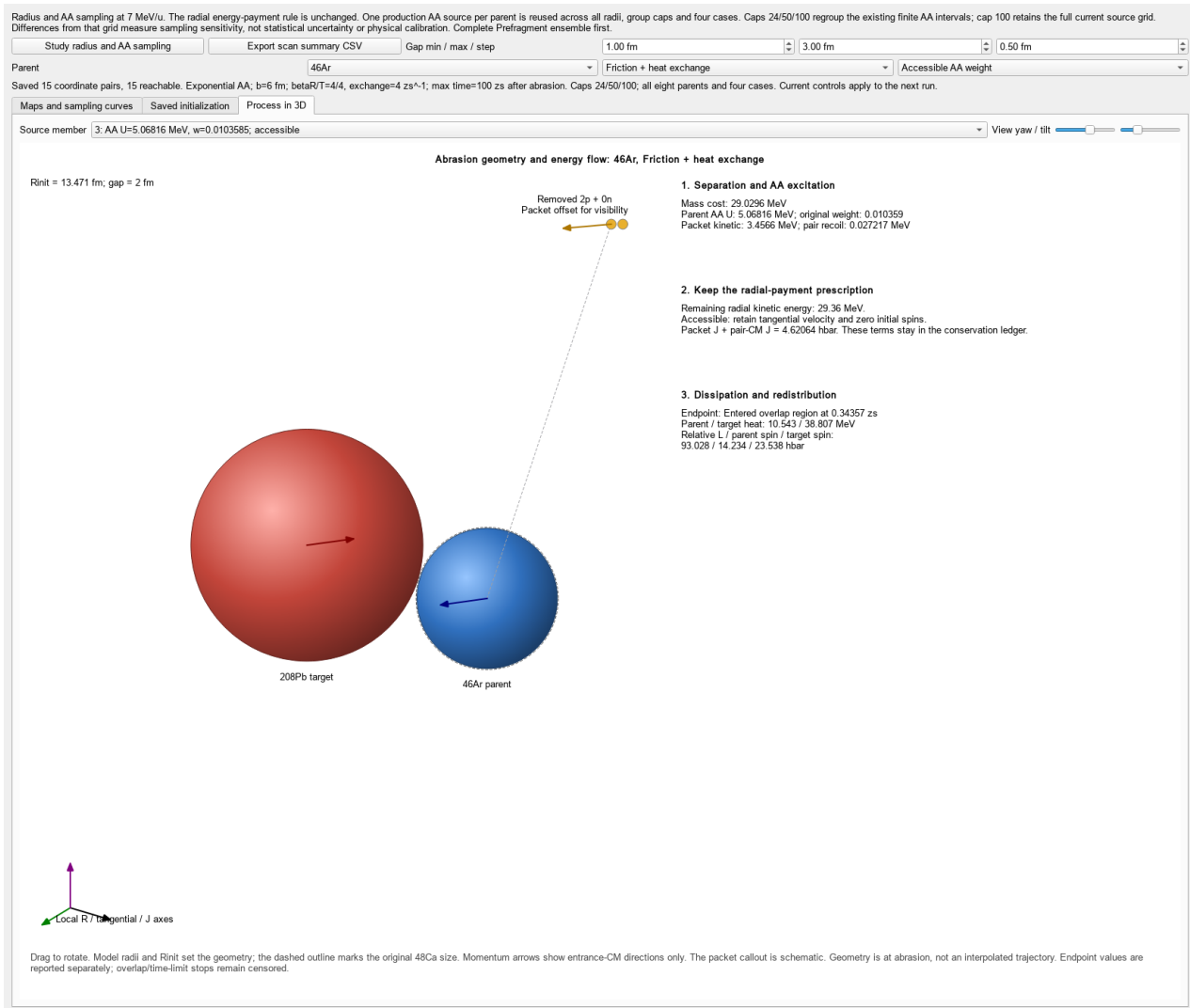


Figure 66 Retained rotatable 3D schematic for the gap 2 fm cap 100 combined 46Ar reference

This is an explanatory drawing at the abrasion instant. Sphere sizes and separation use saved model radii. The detached removed-nucleon packet is a visibility callout, not a transported object at that offset. Momentum arrows show entrance-CM directions with independent display normalization. Endpoint heat and spins are listed separately; the view does not interpolate a physical 3D trajectory.

Four case time histories and phase portraits

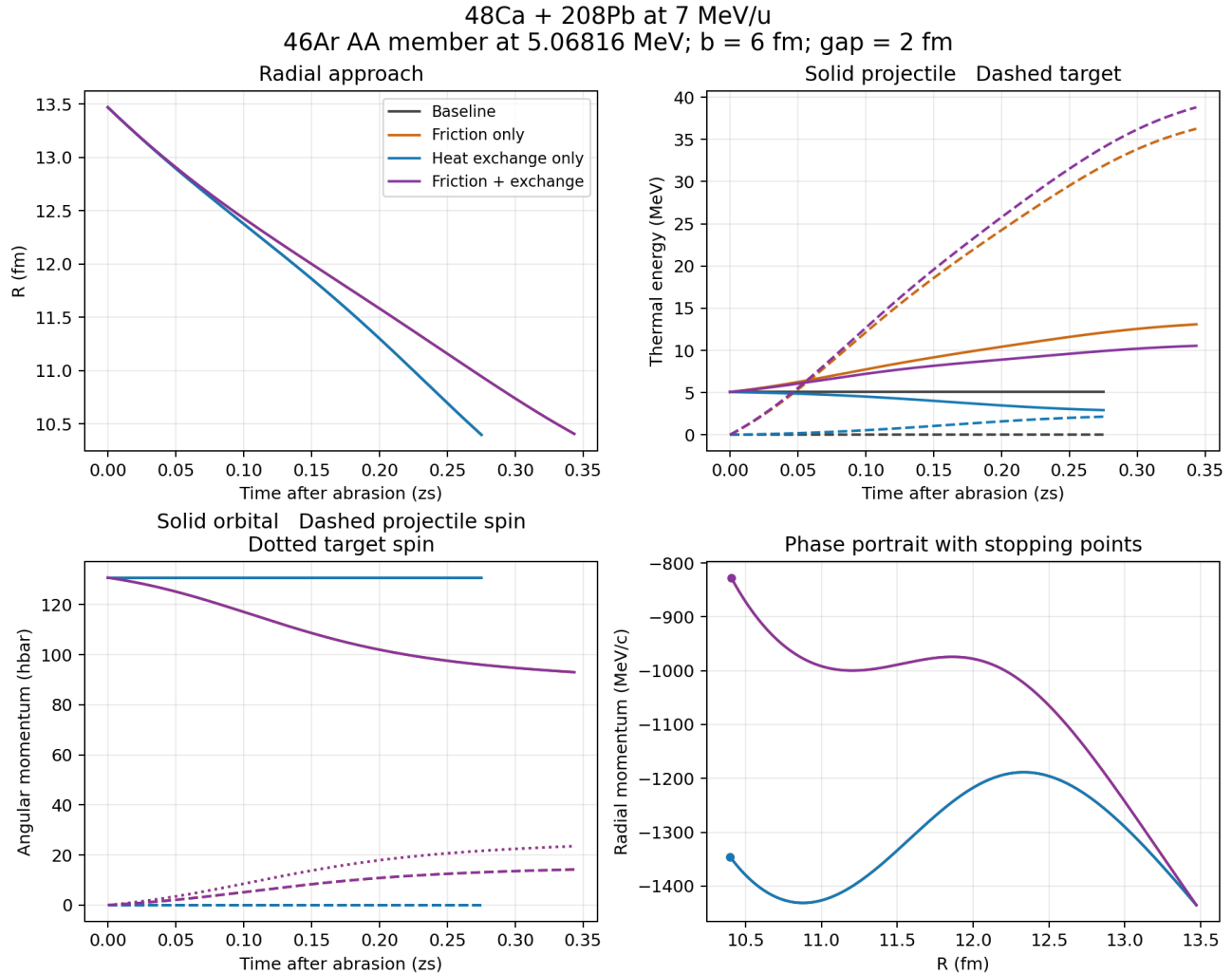


Figure 67 Production 46Ar time histories and phase portraits for all four thermal cases

The selected member has AA $U=5.06816$ MeV at gap 2 fm and cap 100. Heat exchange changes the reservoir partition on the same mechanical path: baseline and exchange share R and pR, while friction and both share their dissipative path. Tangential friction transfers relative orbital momentum into the two spins. Dots in the phase portrait mark the stopping points; these reference trajectories enter overlap and are not continued past it.

Synchronized dynamic trajectory plots

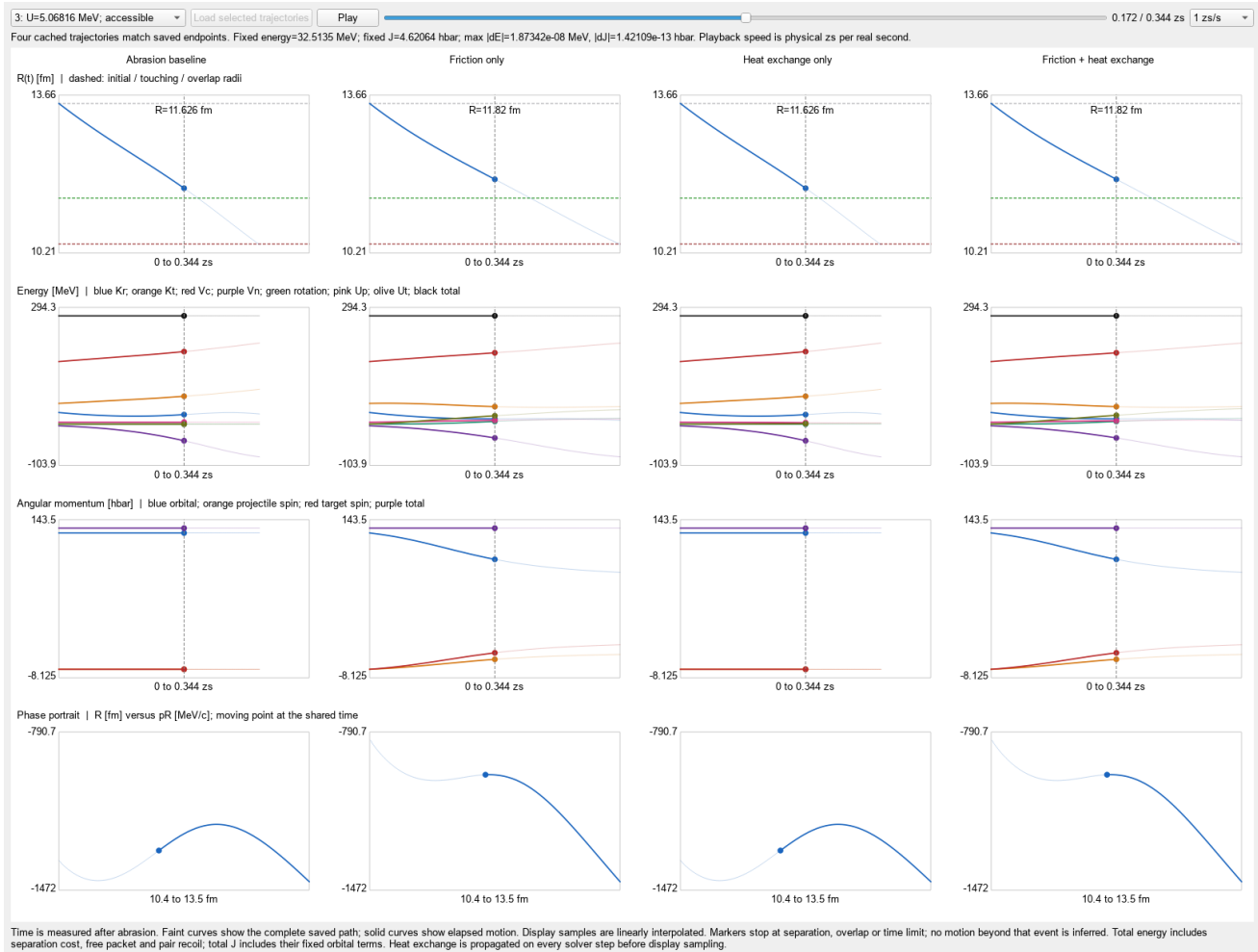


Figure 68 Dynamic plots paused at the shared half-time cursor with all four cases visible

The dynamic view adds $R(t)$, signed kinetic and potential contributions, rotational energy, both thermal reservoirs, the complete energy ledger, orbital angular momentum, both spins and total J. The last row shows R versus radial momentum. Axis ranges are common across the four cases. Fixed separation, free-packet and pair-recoil terms remain in the conserved totals.

Play and pause, the time slider and speeds from 0.1 to 10 physical zs per real second control one shared cursor. Each marker stops at its own separation, overlap or unresolved time-limit event. Faint curves show the complete cached path; solid curves show elapsed motion. The 3D schematic remains a separate explanatory tab.

Playback reconstruction and release validation

The scan stores endpoint budgets. Opening Dynamic trajectories reconstructs only the selected accessible member from its saved initialized state and model controls. It does not regenerate the AA source. The two mechanical paths and four thermal mappings are checked against the saved endpoint times, radii, excitations, orbital momenta, spins and statuses before being cached. Loading is cancellable. Playback itself never reruns the equations of motion.

Heat exchange and conservation checks use every original solver step. At most 1025 display samples per case are retained, combining uniform and logarithmic early-time coverage so a long settled tail does not hide rapid approach and spin transfer. The displayed cursor interpolates linearly between these samples. It does not extrapolate beyond a stopping event. Leaving the tab pauses playback; playing from the final time restarts at abrasion.

Release check	Result
Version metadata	18.8.105; Windows resource 18.8.105.1
MSVC release compilation	Passed with Qt 6.7.0
MinGW release compilation	Passed with Qt 6.7.0 and GCC 13.1
Playback reference maximum energy residual	1.87342 times 10^{-8} MeV
Playback reference maximum total J residual	1.42109 times 10^{-13} hbar
Longest reference trajectory	0.343571 zs after abrasion
Scan summary after adding playback	Byte identical to the prior saved study
Automated checks	Endpoints; full E and J ledgers; interpolation; event clamps; timing and speed; pause and restart; inaccessible members; cancellation
Presentation	PowerPoint unchanged by request

The archive includes original-weight summaries, selected member budgets, sampled playback paths, independent validation JSON, figures, interface captures, build and test logs, and reproduction sources. Reproduce the study with `reproduce-initialization-sensitivity.cmd` and the figures with `plot-initialization-sensitivity.py` and `plot-playback.py`. This release keeps the investigation within Reaction Dynamics Explorer; physical calibration of the AA initialization and energy-payment rule remains open.

Energy dependent initialization and dissipation

Release 18.8.106 extends the controlled initialization study across five energies. The scientific question is how the available radial energy, the admitted AA source and the subsequent frictional heating change as the encounter becomes faster. The same prescription is applied at each energy so its consequences can be examined inside the utility.

Control	Production reference
Reaction and energies	48Ca + 208Pb; 7 15 30 40 60 MeV/u
Parent domain	44Ar 45Ar 46Ar 45K 46K 47K 46Ca 47Ca
Impact parameter and radius gaps	b=6 fm; gaps 1 1.5 2 2.5 3 fm above entrance touching
Excitation source	Exponential AA, prepared privately at each energy; cap 100
Active friction and exchange	Radial 4 zs^{-1} ; tangential 4 zs^{-1} ; heat exchange 4 zs^{-1}
Four cases	Baseline; friction only; heat exchange only; both
Thermal and numerical controls	Projectile heat share 0.1811; initial target excitation 0; step 0.5 fm/c; limit 100 zs after abrasion
Retained initialization	Free co-moving removed packet; zero initial spins; separation and AA excitation paid from radial kinetic energy
Kinematics	Common A times u inertias with physical mass-excess separation costs; Galilean energy and momentum closure

The 7 MeV/u point remains a numerical and low-energy reference. The 15 MeV/u point explores the transition, and 30 to 60 MeV/u provides the higher-energy comparison requested for the abrasion interpretation. This design does not assign 30 MeV/u a sharp validity threshold. Preparation at each energy also does not force an energy dependence into an AA parametrization that has none for these controls.

All comparisons preserve original source weights. Conditional means divide by accessible weight; inaccessible members remain recorded. Contact time counts only time inside the actual post-abrasion pair touching radius and ends at separation, overlap or the time limit. The subsequent evolution inside overlap is outside this calculation.

Reference trends across the five energies

The tables use ^{46}Ar at $b=6$ fm, a 2 fm gap and cap 100. Every tabulated mean is conditional on accessible AA weight. Contact durations are post-abrasion intervals in zs; projectile excitations are in MeV.

MeV/u	Accessible weight	Baseline contact	Friction contact	Generated heat
7	0.429153	0.0783547	0.101927	29.4519
15	1	0.0325711	0.0402481	127.26
30	1	0.0186501	0.0210408	224.223
40	1	0.0155117	0.0171403	271.631
60	1	0.0122024	0.0131928	349.091

MeV/u	Baseline UP	Friction UP	Exchange UP	Both UP
7	20.06	25.3937	11.6038	16.2993
15	45.834	68.8807	36.971	58.8735
30	45.834	86.4409	40.6599	80.8848
40	45.834	95.0264	41.5007	90.4278
60	45.834	109.055	42.3967	105.452

The finite ^{46}Ar AA source has mean initial excitation 45.8340 MeV at every energy for the selected Exponential settings. At a 2 fm gap, only 0.429153 of that source is accessible at 7 MeV/u; its conditional baseline mean is consequently 20.0600 MeV. The whole finite source is accessible at 15 to 60 MeV/u at this gap. The change in the baseline mean therefore includes a change in admitted support, rather than an imposed change in the AA source distribution.

Friction-generated heat increases while recorded contact decreases. The mechanical work depends on velocities and slip as well as duration; the retained fixed friction rates do not imply a fixed energy loss per unit contact time. Heat exchange only redistributes excitation. It shares the baseline mechanical path, while the combined case shares the friction-only path and generated heat.

Across all eight parents and sampled gaps, every accessible 30, 40 and 60 MeV/u member reaches the overlap cutoff. Some lower-energy members separate or reach the 100 zs limit. Thus the high-energy contact values describe approach up to overlap, not the total lifetime of an interacting participant system.

Contact time maps across energy and radius

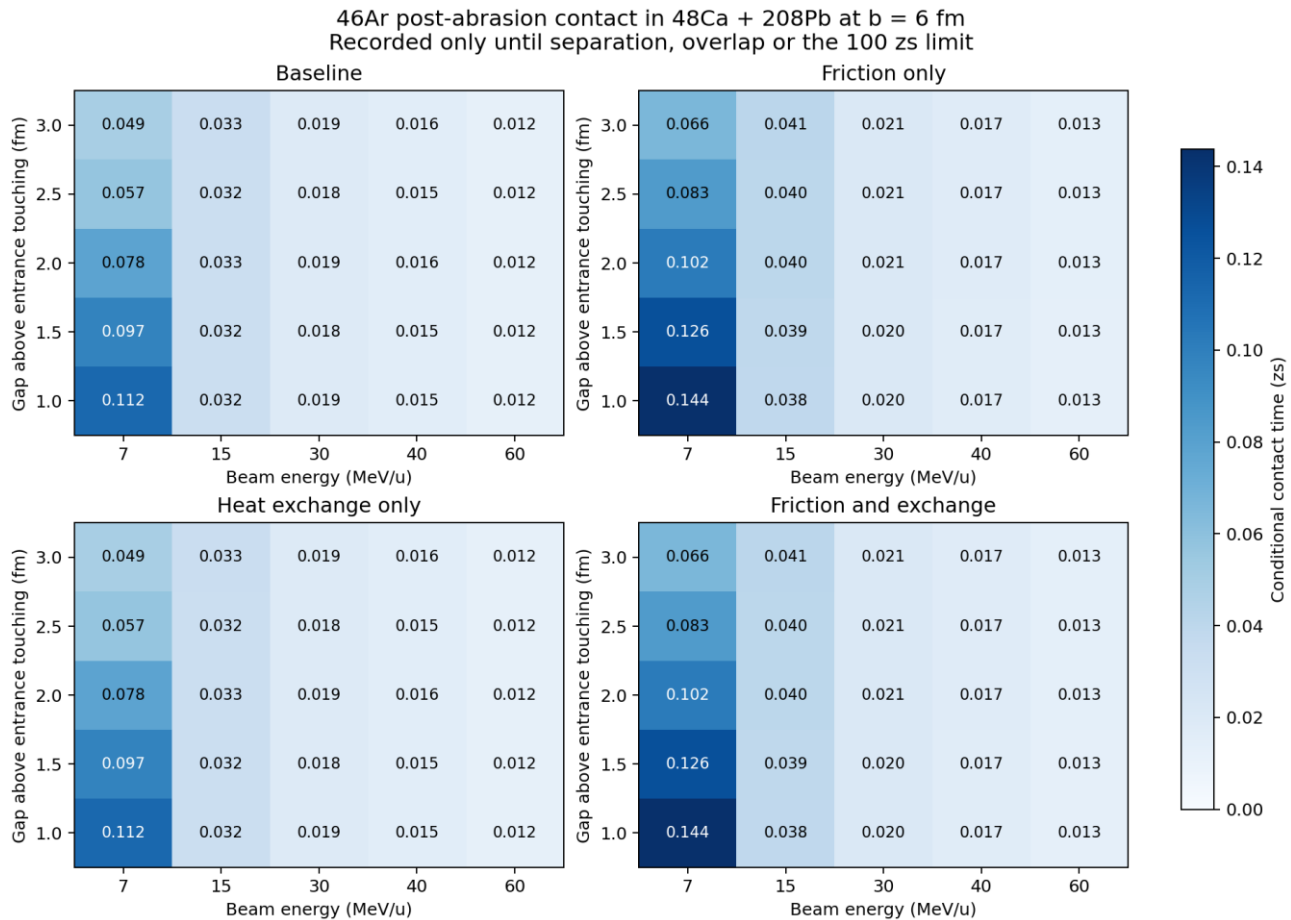


Figure 69 Four case maps of conditional recorded contact for 46Ar

Map cells use the same color scale. At fixed energy and gap, baseline and exchange-only contact are identical; friction-only and combined contact are identical. Passive heat exchange does not feed back into the mechanical equations in this model. The longer frictional approach at a given energy coexists with the strong decrease in duration as beam energy increases.

At 7 MeV/u, changing the abrasion gap alters both the propagation interval and which AA members pass the radial-energy test. At higher energies the source is much more accessible, and the recorded interval becomes less sensitive to the gap. Outcome and accepted-weight columns must be considered alongside a conditional contact mean.

Excitation and heat across beam energy

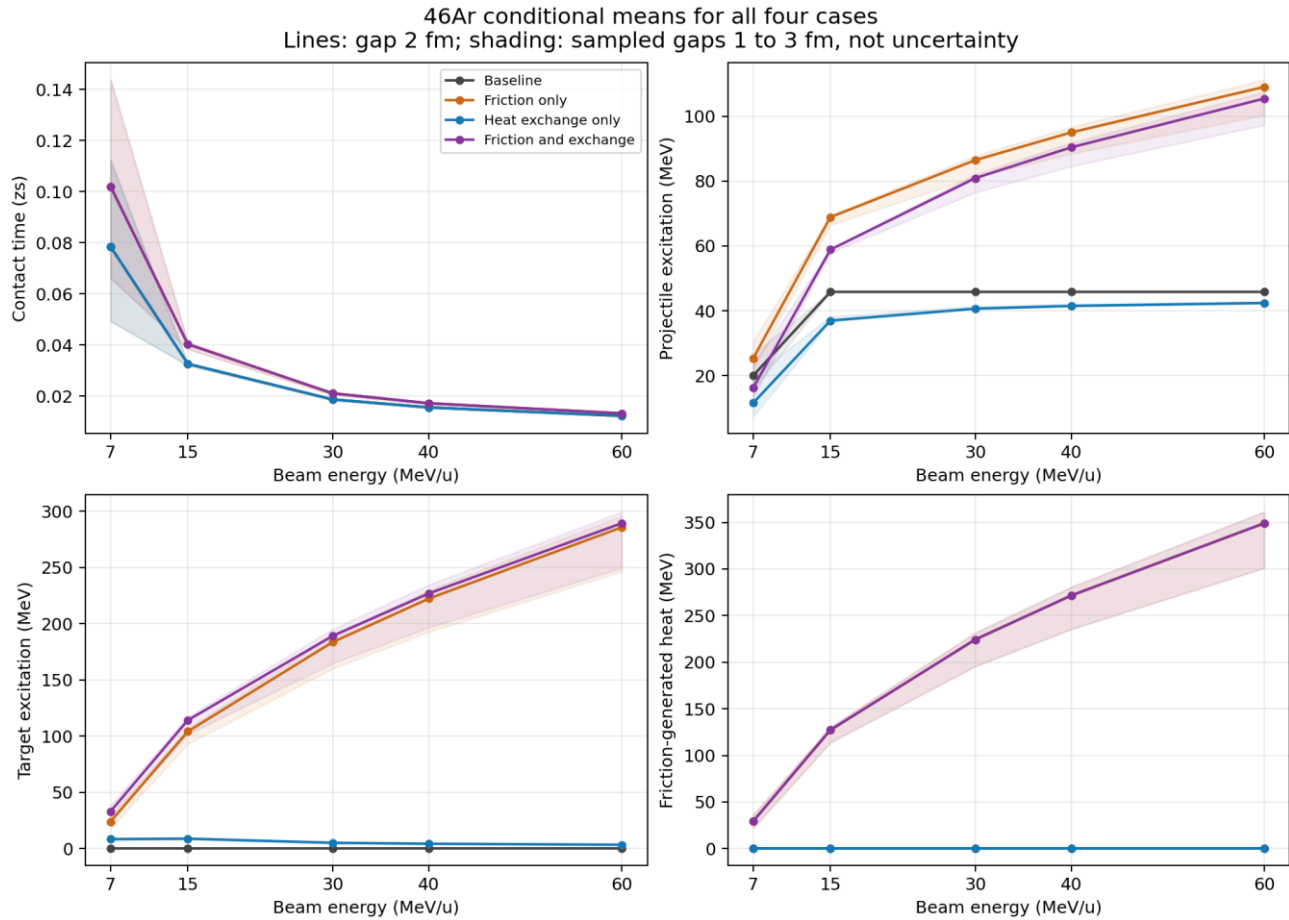


Figure 70 Contact and thermal reservoirs at gap 2 fm with the sampled radius envelope

Lines identify the selected 2 fm gap; shading gives the minimum and maximum across five sampled gaps. These bands describe sensitivity of the stated prescription, with potentially changing support. They are not statistical confidence bands. Projectile and target excitations include the initial AA reservoir and its subsequent redistribution; generated heat isolates the mechanical dissipation.

At 7 MeV/u, combined-case projectile excitation can lie below the baseline because heat is transferred to the target even while friction generates additional heat. At 60 MeV/u, the combined-case mean projectile excitation reaches 105.452 MeV and generated heat reaches 349.091 MeV for the selected gap. These quantities are sampled at overlap or the other stopping event and are not a prediction of an outgoing evaporated residue.

Sensitivity to the prescribed abrasion radius

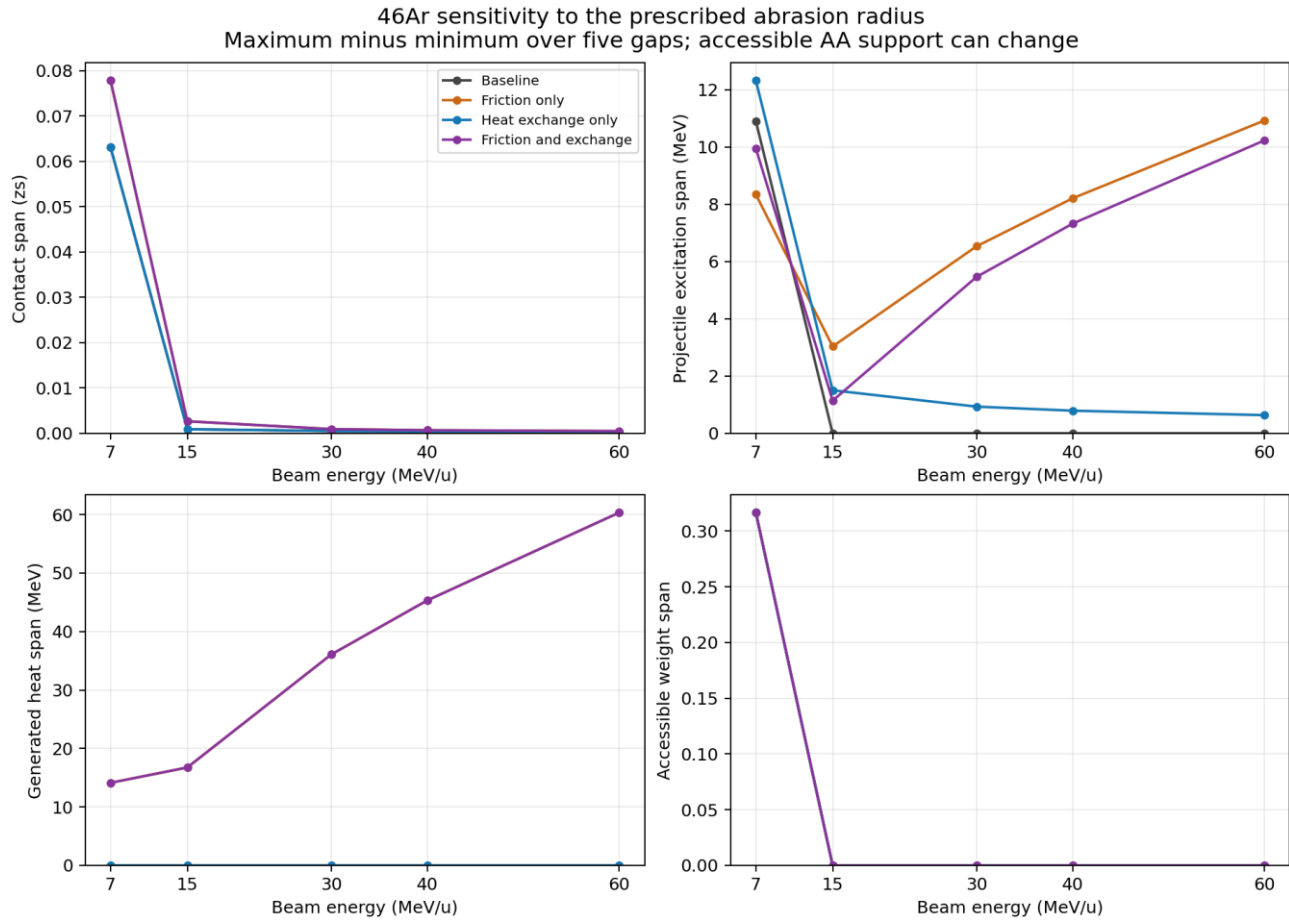


Figure 71 Maximum minus minimum over gaps 1 to 3 fm for 46Ar

For 46Ar at 7 MeV/u, accessible source weight spans 0.316624 across the five gaps. That span is zero at 15 to 60 MeV/u for this finite source. Combined-case contact span falls from 0.0778411 zs at 7 MeV/u to 0.000482593 zs at 60 MeV/u. Increased accessibility removes one source of sensitivity but does not remove the effect of the chosen abrasion location on subsequent dissipation.

The combined-case projectile excitation span is 9.95271 MeV at 7 MeV/u, 1.14099 MeV at 15 MeV/u, and 10.2304 MeV at 60 MeV/u. Excitation sensitivity need not track contact sensitivity monotonically. Each radius span requires at least two supported gaps; the exported coverage columns identify how many gaps contribute. A radius that is not reached is distinct from a reached radius with zero accessible source weight.

Selected high energy trajectories

60 MeV/u selected 46Ar member 3 at $b = 6$ fm and gap 2 fm
Trajectories stop at the recorded event

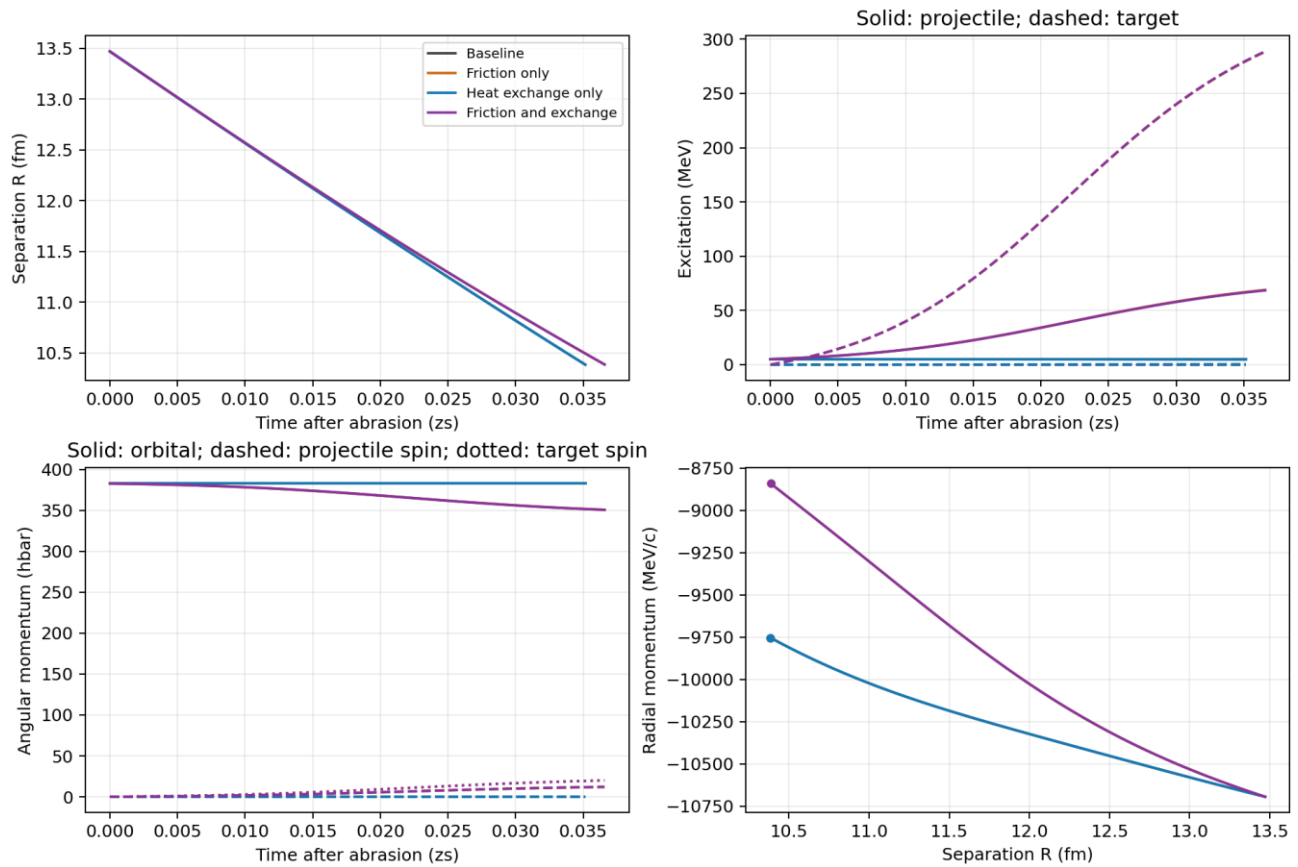


Figure 72 Saved 60 MeV/u 46Ar member 3 at gap 2 fm for all four cases

The selected trajectory is reconstructed from saved initialization data and checked against the recorded endpoint before playback. The same mechanical and thermal equations supply the plotted samples. The phase portrait ends at the overlap event; no continuation is inferred. Tangential friction transfers orbital angular momentum into fragment spins while the free packet and pair recoil remain in the complete angular momentum budget.

The utility retains synchronized play and pause, a common time slider and speed control. Each case stops its marker at its own endpoint. Energy and angular momentum views include all fixed and evolving terms needed for conservation. The separate rotatable 3D schematic continues to explain the initialized geometry.

Energy study interface and validation

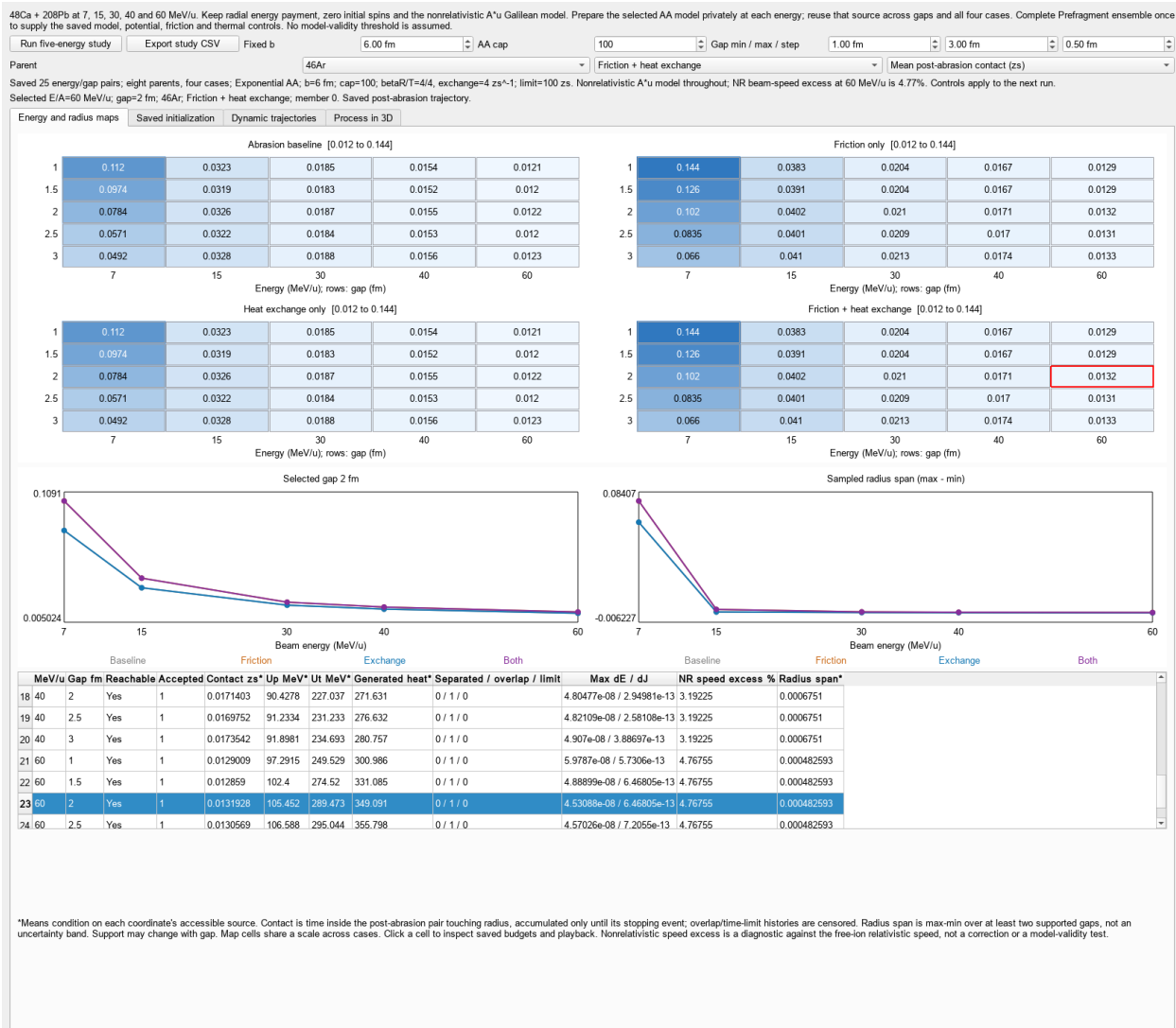


Figure 73 Clickable energy and radius maps with saved inspection and CSV export

The production scan contains 800 summary rows, covering 25 coordinates, eight parents and four cases. Independent CSV checks reconstruct conditional means, radius spans, conserved ledgers and selected contact duration. The 6400 selected 60 MeV/u member records and 384 path samples pass. All 7 MeV/u member records agree exactly with the archived release 18.8.105 reference.

Maximum scan energy residual is 1.16994e-07 MeV and maximum total angular momentum residual is 2.76544e-12 hbar. Selected endpoint linear momentum residual is 1.67182 times 10^-12 MeV/c. MSVC numerical and interface tests, legacy initialization checks and the MSVC release build pass. PowerPoint remains unchanged; future MinGW builds require an explicit request.

The common nonrelativistic model is retained throughout. Its free-ion speed exceeds the relativistic comparison by about 4.77 percent at 60 MeV/u; the exported diagnostic does not correct the dynamics. Conservation establishes internal numerical consistency, while the physical applicability of the initialization and collective friction at decreasing contact time remains to be investigated. Reproduction scripts, logs, CSV data and figures are archived with this release.

Three decimal numerical displays

Release 18.8.107 reduces long numerical strings in tables, result text, plots and inspection details. Fixed notation and the mantissa of scientific notation use three digits after the decimal point. This is display rounding: the solver state is unchanged, and table delegates leave the original item text available for export.

	Stored reference text	Displayed value
1	11.0761277131	11.076
2	1000.00000004	1000.000
3	-6.39488462184e-14	-6.395e-14
4	3.90117975257e-07	3.901e-07
5	46Ar	46Ar

Figure 74 Implemented table delegate with representative fixed and scientific values

Reference value	Displayed value
11.0761277131	11.076
1000.00000004	1000.000
-6.39488462184e-14	-6.395e-14
3.90117975257e-07	3.901e-07

Nonzero magnitudes below 0.001 or at least one million use scientific notation; zero displays as 0.000. This avoids hiding a small conservation residual as zero merely because the interface uses three decimal places. Integer identifiers, source counts and labels such as 46Ar retain their identity formatting. Undefined diagnostic values remain distinct from numerical zero.

The examples illustrate formatting, not a new convergence calculation. Complete numerical values remain in the stored records. CSV exports continue to use their existing numerical data and precision; the table display delegate does not overwrite raw table contents. Input controls retain their established precision so displaying results does not silently round physical parameters.

Tabs linked to the single collision action

Left portion of the two row navigation

Results	Trajectory table	Plots	Model parameters	Potential
Potential/friction sensitivity	Adaptive overlap boundary	Dissipation / excitation	Prefragment ensemble	Ablation response

Grey tabs: Run single collision results. Potential follows current inputs; other studies have their own Run buttons.

Right portion of the same navigation

Impact parameter scan	Spins and energy	Equilibrium / potential	Convergence / stability	Energy-impact map
Residue feeding / UP	Post-abrasion initialization	Initialization radius / sampling	Initialization energy / dissipation	Collision animation

Figure 75 Left and right portions of the same two row navigation stacked for readability

A slightly darker grey background identifies pages updated by Run single collision. The currently selected tab keeps its blue highlight. Tooltips identify the action, and a legend beneath the navigation explains the grouping. The Potential page follows current inputs rather than a saved trajectory. Other studies retain their own run actions.

Grey result tab	Content from the saved single collision
Results	Stopping status, excitation, energy and angular momentum summaries
Trajectory table	Time samples of distance, velocity, heat, rotation and angular momentum
Plots	Separation, relative speed and total generated excitation versus time
Spins and energy	Orbital momentum, both spins, heat, rotation and total J error
Equilibrium / potential	Constrained potential, final radius, equilibrium minima and overlap cutoff
Collision animation	Calculated center of mass motion with synchronized time and readouts

To inspect a chosen impact parameter, set b and the other collision controls, click Run single collision, and select any grey result page. The Plots page still opens automatically after the run. Changing the collision inputs clears old trajectory results and the animation so a previous run cannot be mistaken for the new settings.

Calculated collision animation at the selected impact parameter

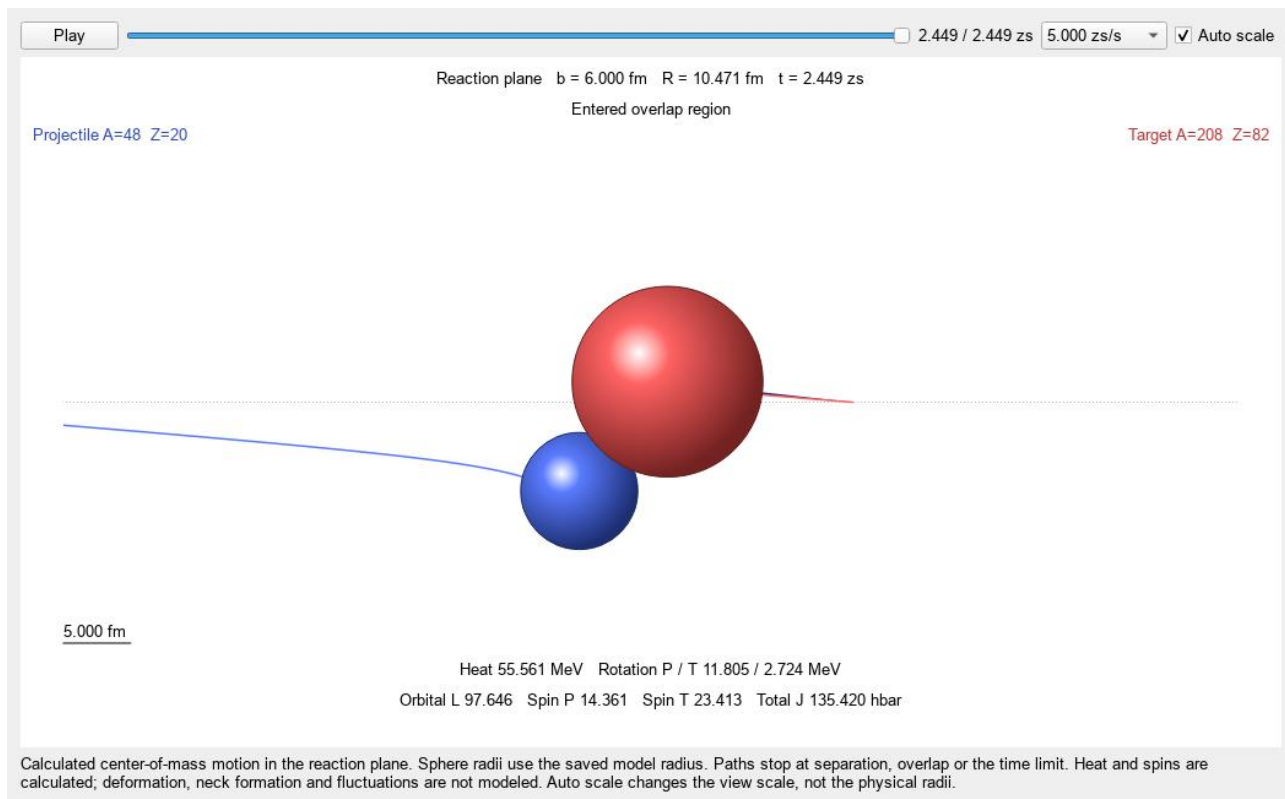


Figure 76 Saved 48Ca plus 208Pb reference at b 6.000 fm paused at its overlap endpoint

The animation uses the completed solver trajectory. At each displayed time it interpolates the recorded separation and orbital angle and positions the two centers about their common center of mass using the saved masses. Sphere radii use the model radius coefficient times A to the power one third. The trails show calculated center paths in the reaction plane. There is no additional integration during playback.

Play and Pause control the saved run; the time slider scrubs from zero to the endpoint. Speed is physical zs per real second and ranges from 0.100 to 100.000 zs/s. Each readout follows the same cursor: separation, time, thermal heat, each fragment rotational energy, orbital momentum, both spins and total J . Playing from the final time restarts at zero. Leaving the tab pauses playback.

Auto scale fits the current separation while keeping the two nuclei on one physical scale. Turning it off uses the complete saved trajectory range. The scale bar labels the current spatial scale. The pictured reference uses the deterministic default A times u masses, E_{cm} 273 MeV, b 6 fm, radial and tangential rates 4 zs^{-1} and a 5 zs limit. It is a solver reference capture, not a newly calibrated reaction model.

Animation scope and release validation

The displayed motion ends at the recorded separation, overlap or time-limit event. A time-limit endpoint remains unresolved. The spheres visualize fixed composition and the center separation; deformation, neck formation, fluctuations, transfer and evolution beyond overlap are not supplied by this solver. The earlier rotatable initialization schematic remains available in its own diagnostic views.

Validation	Result
Release metadata	18.8.107; Windows file and product version 18.8.107.1
MSVC release compilation	Passed with Qt 6.7.0
Fixed and scientific display	Three decimal places; integer identity and labels retained
Stored numerical precision	Display delegate leaves original reference item text unchanged
Saved trajectory	Impact parameter and endpoint match loaded solver result; interpolation stays between adjacent radius samples
Playback behavior	Speed, pause, restart, endpoint clamp, input invalidation and pause on leaving pass
Navigation	Six related tabs identified; clicking animation selects and highlights its page
Energy study regression	Five energies, conservation, contact, radius spans, clicks, CSV, cancellation and saved-state retention pass
Visual checks	Formatting, tab grouping and animation widget captures reviewed
Other deliverables	PowerPoint unchanged; no MinGW build

This release changes presentation and adds a view of existing trajectories. The physics solver and its conservation equations are unchanged. The previous energy-study production results remain the numerical reference; no new production scan or parameter calibration is claimed. The archive contains widget captures, focused tests, regression and build logs, and scripts for reproducing the report and checking the release.

The local review executable was built with the concurrent APF working-copy edit already present in this workspace. That source edit, the unrelated installed executable change and unrelated document deletions are excluded from this release commit. MSVC remains the default toolchain for subsequent work; MinGW requires an explicit request.

Selected transfer channel diagnostic

The new independent tab explores a prescribed transfer channel for ^{48}Ca plus ^{208}Pb at 7 MeV/u. Selecting fragment A and Z fixes the complementary residual to $A = 256$ minus fragment A and $Z = 102$ minus fragment Z. The preview reads the current LISE mass tables through `W_ME` with `DefaultMassOption` and calculates Q from atomic mass excesses. Electron counts balance between entrance and exit. Missing masses or invalid nuclei reject the channel.

The diagnostic answers a conditional question: how would this specified channel alter a calculated trajectory if it occurred at the selected incoming radius? It does not predict nucleon transfer probabilities, rates or cross sections. The main participant panel and Run single collision remain fixed composition; this tab has its own comparison action.

Reference control	Value
Entrance	$^{48}\text{Ca} + ^{208}\text{Pb}$ at 7 MeV/u
Impact parameter and transfer radius	6.000 fm and 12.000 fm
Radial and tangential peak rates	4.000 zs^{-1} each = $4 \times 10^{21} \text{ s}^{-1}$
Woods Saxon depth radius diffuseness	100.000 MeV; 1.200 fm; 0.650 fm
Spin radius coefficient	1.200 fm
Start radius and overlap multiplier	80.000 fm and 1.000
Step cap and total time limit	0.500 fm/c and 10.000 zs
Galilean inertias and entrance energy	A times u; u = 931.49410242 MeV; $E_{\text{cm}} = 273.000 \text{ MeV}$

The adjustable transfer radius must be outside both entrance and exit overlap cutoffs and inside the starting radius. The first incoming crossing is located by partial RK4 reintegration and bisection. A trajectory turning outside that radius is reported as not reaching transfer. The original time limit includes the incoming approach; propagation after transfer uses only the remaining time.

Mass table channels and matching prescription

Fragment	Residual	Q MeV	Outcome
48Ca	208Pb	0.000	Overlap
49Ca	207Pb	-2.221	Overlap
50Ca	206Pb	-2.598	Overlap
49Sc	207Tl	1.623	Overlap
47Ca	209Pb	-6.014	Overlap

The identity channel gives exactly zero Q. These five production checks share the incoming approach and reach the transfer radius at 2.293814 zs. Every listed outgoing trajectory subsequently reaches its overlap cutoff. These are selected channels at one reference point, not a channel yield scan.

At the event, separation R, orbital angle, thermal heat, orbital angular momentum L and both fragment spins are continuous. The exit masses, reduced mass, charges, Woods Saxon radius and spin inertias change. The required exit radial kinetic energy is $E_{\text{before}} + Q$ minus exit potential including centrifugal energy minus heat minus exit rotational energy. A nonpositive radial allowance is reported as energetically closed under this matching rule; the code does not propagate an imaginary radial momentum.

The full accounted energy is $K_r + K_t + V_c + V_n + \text{heat} + \text{rotationP} + \text{rotationT}$ minus Q. It remains equal to the original 273 MeV reference. Total angular momentum is $L + SP + ST$ and remains equal to 135.420 hbar. Conservation residuals are measured against the original entrance references throughout the complete path, so matching cannot hide accumulated incoming integration error.

Common A times u inertias provide one consistent Galilean closure across the event; Q retains the physical atomic mass information separately. Opposite fragment momenta preserve the pair center of mass momentum. Centers are reassigned about that center when masses change. This instantaneous point mass prescription does not resolve neck dynamics, microscopic transferred nucleon trajectories, recoil sharing or fragment deformation.

Selected channel trajectories and excitation

48Ca + 208Pb at 7 MeV/u $b = 6$ fm $\beta_R = \beta_T = 4/zs$
Incoming transfer at $R = 12$ fm; trajectories stop at overlap

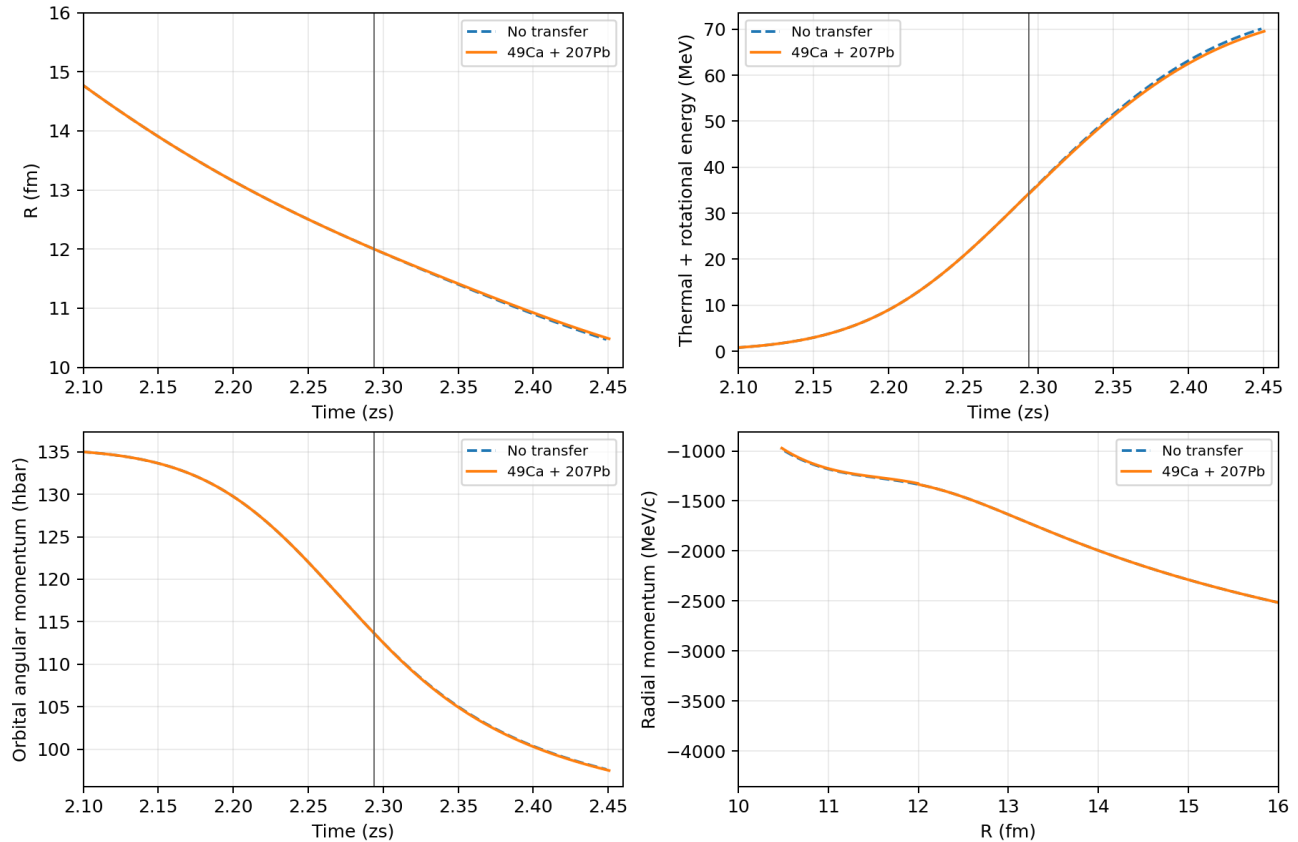


Figure 77 Production trajectory comparison near transfer and overlap. The vertical line marks transfer at 12 fm. The phase portrait includes the radial momentum jump required by the matching rule.

For 49Ca plus 207Pb, $Q = -2.221$ MeV. The no transfer trajectory reaches overlap at about 2.449 zs and the selected channel at about 2.451 zs. Their endpoint radii are 10.471 and 10.483 fm respectively because the composition dependent overlap cutoff changes. The small separation between the curves is expected for this prescribed single neutron pickup at the chosen radius.

The endpoint no transfer heat is 55.561 MeV and rotational energy is 14.529 MeV. The selected channel has 55.241 MeV of heat and 14.300 MeV of rotation. Excitation here denotes generated thermal plus rotational energy in the recorded two fragment model. Propagation stops at overlap; these values do not establish asymptotic fragment excitation or a measured residue yield. Outgoing TKE is only reported for trajectories that actually separate.

Matching energy and angular momentum budgets

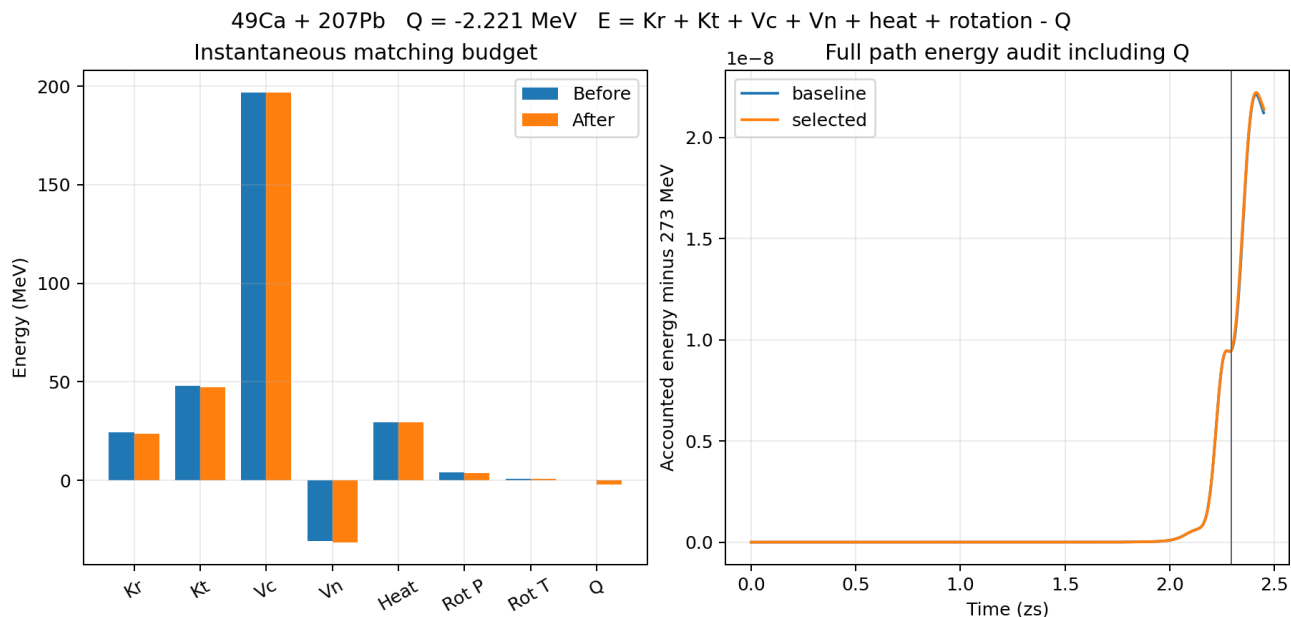


Figure 78 Before and after energy ledger for 49Ca plus 207Pb and the full path energy conservation residual. Q is subtracted in the accounted energy.

Energy term MeV	Before	After
Radial kinetic energy	24.505	23.777
Tangential kinetic energy	48.080	47.327
Nuclear potential	-30.710	-31.324
Thermal heat	29.509	29.509
Projectile rotation	3.916	3.784
Target rotation	0.904	0.911
Accounted energy	273.000	273.000

Heat and all three angular momentum components are continuous at transfer. Rotation and tangential kinetic energy can change because their inertias change. The selected endpoint has $L = 97.507$ hbar, $SP = 14.446$ hbar and $ST = 23.467$ hbar, compared with 97.646, 14.361 and 23.413 hbar without transfer.

Using the selected transfer tab

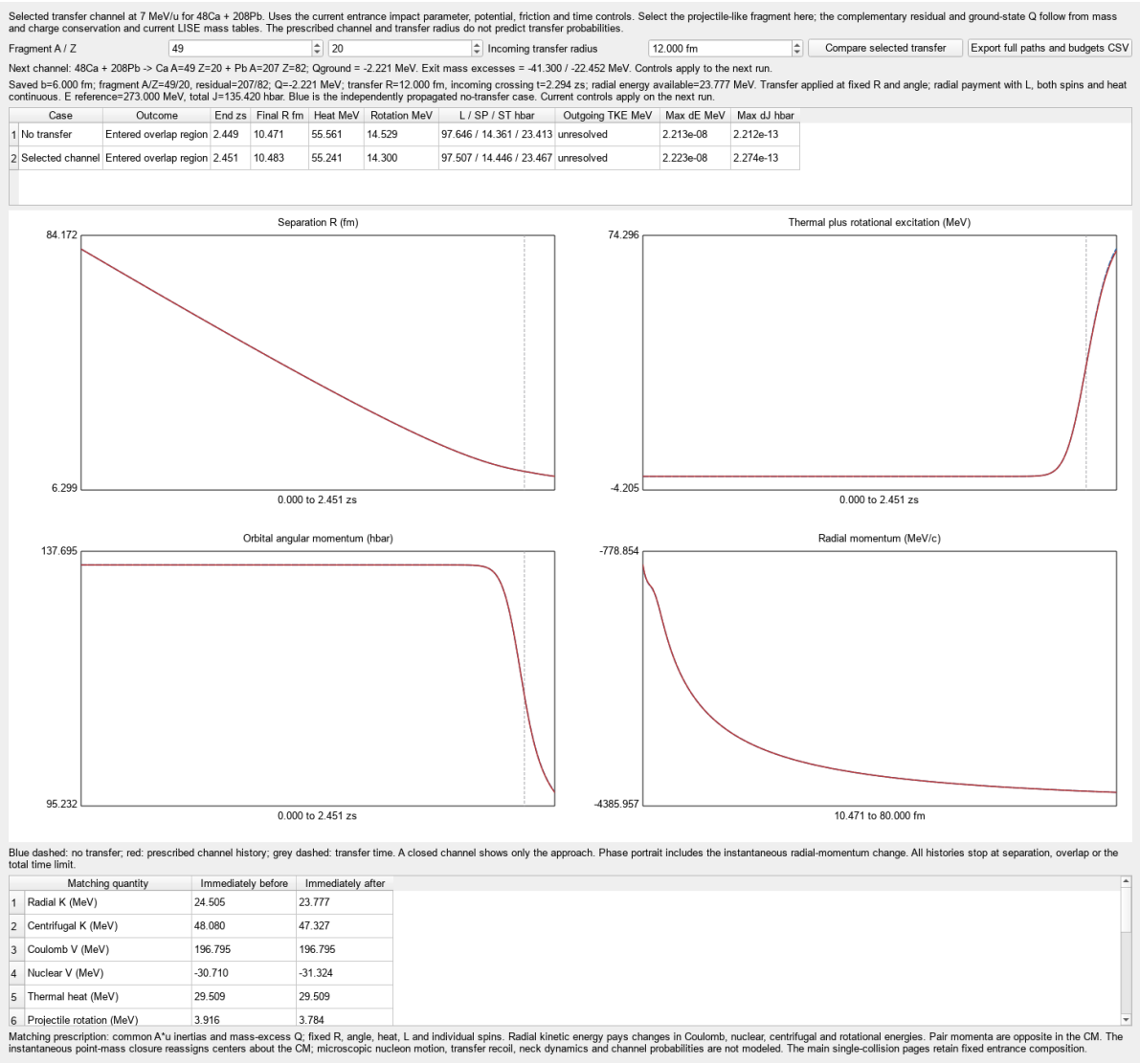


Figure 79 Actual production widget with the selected 49Ca plus 207Pb reference, comparison curves and matching ledger.

Set b and the collision controls, open Selected transfer channel, choose fragment A and Z, set the radius and click Compare selected transfer. The residual and mass table Q preview update with the fragment selection. The summary separates radius not reached, energetically closed and applied channels. Cancellation or a failed run preserves the previous complete comparison.

The four plots show separation, thermal plus rotational excitation, orbital angular momentum and the R versus pR phase portrait. The ledger lists every matching energy term and angular momentum component. Displayed numbers use three decimal places; CSV retains full precision, metadata and every recorded sample. Duplicate event times before and after transfer are intentional and preserve the matching discontinuity.

Transfer validation and release record

The MSVC release build uses Qt 6.7.0 with application version 18.8.109 and Windows file version 18.8.109.1. Focused transfer tests cover eighteen channel and friction combinations, independent energy and angular momentum reconstruction, the incoming event radius, an identity channel, step refinement, closed and unreachable channels, cancellation, UI behavior and CSV export. The existing five energy initialization regression also passes.

The production fixture loads the actual LISE mass tables and validates the five channels listed above, independently checking atomic mass Q values, conservation and isolation from global participant selections. The archived CSV contains 4439 rows with 27 columns. Independent reconstruction finds maximum absolute energy residual 2.223×10^{-8} MeV and angular momentum residual 2.274×10^{-13} hbar for the selected ^{49}Ca channel. Across all five production channels the largest energy residual is 2.257×10^{-8} MeV. Pair momentum closure is exact in the exported Galilean construction.

The archive includes full precision production data, the channel summary, validation receipts, scientific figures, the actual widget capture and scripts for reproduction. Release 18.8.108 moved the module into ReactionDynamics.pri; this release adds the transfer source and headers to that same module. PowerPoint is unchanged and no MinGW compilation was requested.

The local review executable includes the concurrent APF working copy edit already present in this workspace. That source edit, installed executables and unrelated document deletions are excluded from this release commit. The model remains a selected channel diagnostic with an explicit energy payment assumption. Radius sensitivity, alternative recoil sharing and a probabilistic transfer model remain future studies.

Fragment and residual participant controls

The selected transfer diagnostic was introduced with fragment selection inside its own tab, while the participant panel Fragment and Residual buttons remained disabled. Release 18.8.110 enables both buttons and connects them to the dedicated transfer controls. This makes the selected channel accessible from the participant panel without changing the single collision physics.

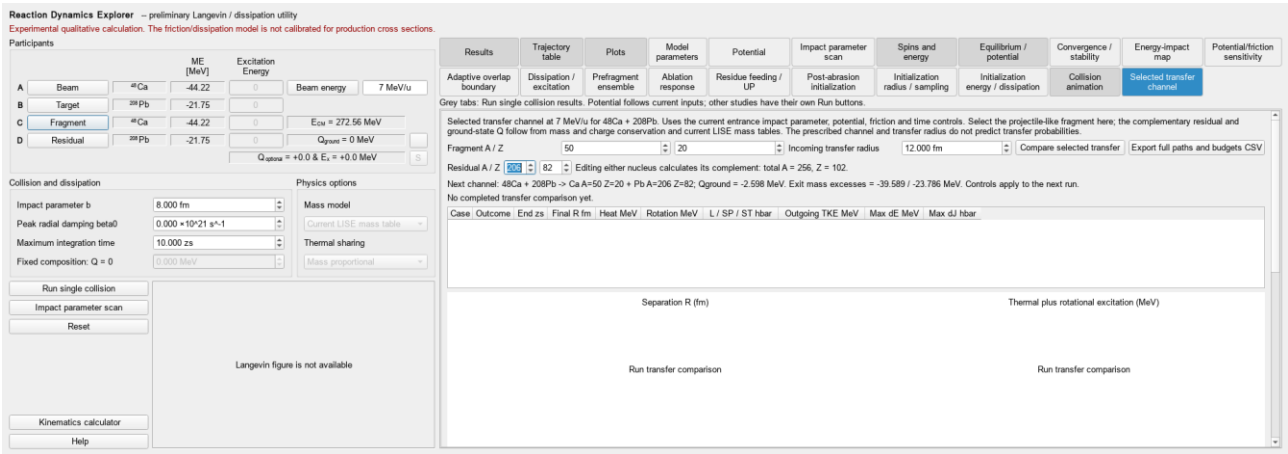


Figure 80 Actual main dialog after clicking Residual and selecting A = 206. Fragment A updates to 50, with total A = 256 and Z = 102. This integration fixture omits the decorative image resource; the transfer controls are the production widgets.

Participant button	Action
Fragment	Open Selected transfer channel and focus fragment A
Residual	Open Selected transfer channel and focus residual A

The transfer tab now contains editable A and Z controls for both outgoing nuclei. Editing either nucleus updates the other using $A_{\text{residual}} = 256 - A_{\text{fragment}}$ and $Z_{\text{residual}} = 102 - Z_{\text{fragment}}$. Signal blocking prevents recursive updates. The complementary controls stay synchronized even when a temporarily invalid A and Z combination causes channel validation to reject the selection.

The mass table preview and Q value update with the selected channel. For example, residual 206Pb implies fragment 50Ca and $Q = -2.598$ MeV in the reference mass tables. After selection, click Compare selected transfer to calculate the trajectory using the chosen radius and current impact parameter, potential, friction and time controls. Changing a selector prepares the next run; it does not relabel a previously completed result.

The left participant labels continue to describe the entrance composition used by Run single collision. Its result pages retain that fixed composition. The transfer tab labels and summary identify the selected outgoing channel, while the original prescribed energy payment and conservation checks remain in force. No transfer probability or cross section is inferred from enabling the controls.

Selector regression and toolchain validation

Check	Result
MSVC release	18.8.110.1 compiled with Qt 6.7.0
MinGW release	18.8.110.1 compiled with Qt 6.7.0 and MinGW 13.1
Focused tests on MSVC and MinGW	Complement selection in both directions, initial residual and correct field focus
Actual dialog production test on MSVC	Both buttons enabled; clicks select transfer tab and focus the intended control
Production channel checks	Real mass tables, neutron pickup and stripping, proton pickup, atomic mass Q parity, conservation and CSV
Report validation	Opening and two added pages visually inspected; retained page bodies compared with release 18.8.109

The focused tests exercise fragment and residual A and Z edits, not just the enabled state of a button. The production fixture constructs `TLangevinDlg` after loading actual LISE mass tables, clicks each participant button and verifies the selected tab and focused field. Selecting residual A = 206 must update fragment A to 50. The reviewed screenshot records that interaction. The existing transfer tests also check full path energy and angular momentum, event location, identity channels, closed and unreachable channels, cancellation and saved CSV behavior.

This release fixes access to the transfer controls and adds complementary selection. It does not introduce a new scan or change the dynamics equations. The five reference channel results and numerical conservation bounds documented in the previous chapter remain applicable. The MinGW focused test repeats the numerical and selector checks with the second compiler; the full application build verifies production source and link compatibility.

The cumulative report contains 100 pages and preserves the thirty native equations in earlier chapters. The archive includes build and test logs, a dialog capture, release receipts and scripts. The initial release commit recorded MSVC validation without a report update. This follow up adds the requested Word report and MinGW build to the same application version 18.8.110; PowerPoint remains unchanged.

Both local review executables include the concurrent APF working copy edit already present in this workspace. That source edit, installed executables and unrelated document deletions remain excluded from these commits. The usual MSVC default remains in effect for future work; this MinGW build was explicitly requested.