

Predicting fusion rate self-consistently

Consistent workflow for evaluating beam-target fusion rate with the orbit-following code ASCOT5

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ASCOT5 offers state-of-the-art EP simulations

- ✓ Guiding centre and full gyro-orbit
- ✓ Collisions
- ✓ 3D inputs
- ✓ Open source
- ✓ Hybrid parallelisation + vectorisation
- ✓ GPU porting
- ✓ Post-processing tools
- ✓ Award-winning¹ tutorials, support sessions

¹Self-given.



Used to study energetic particles in several devices

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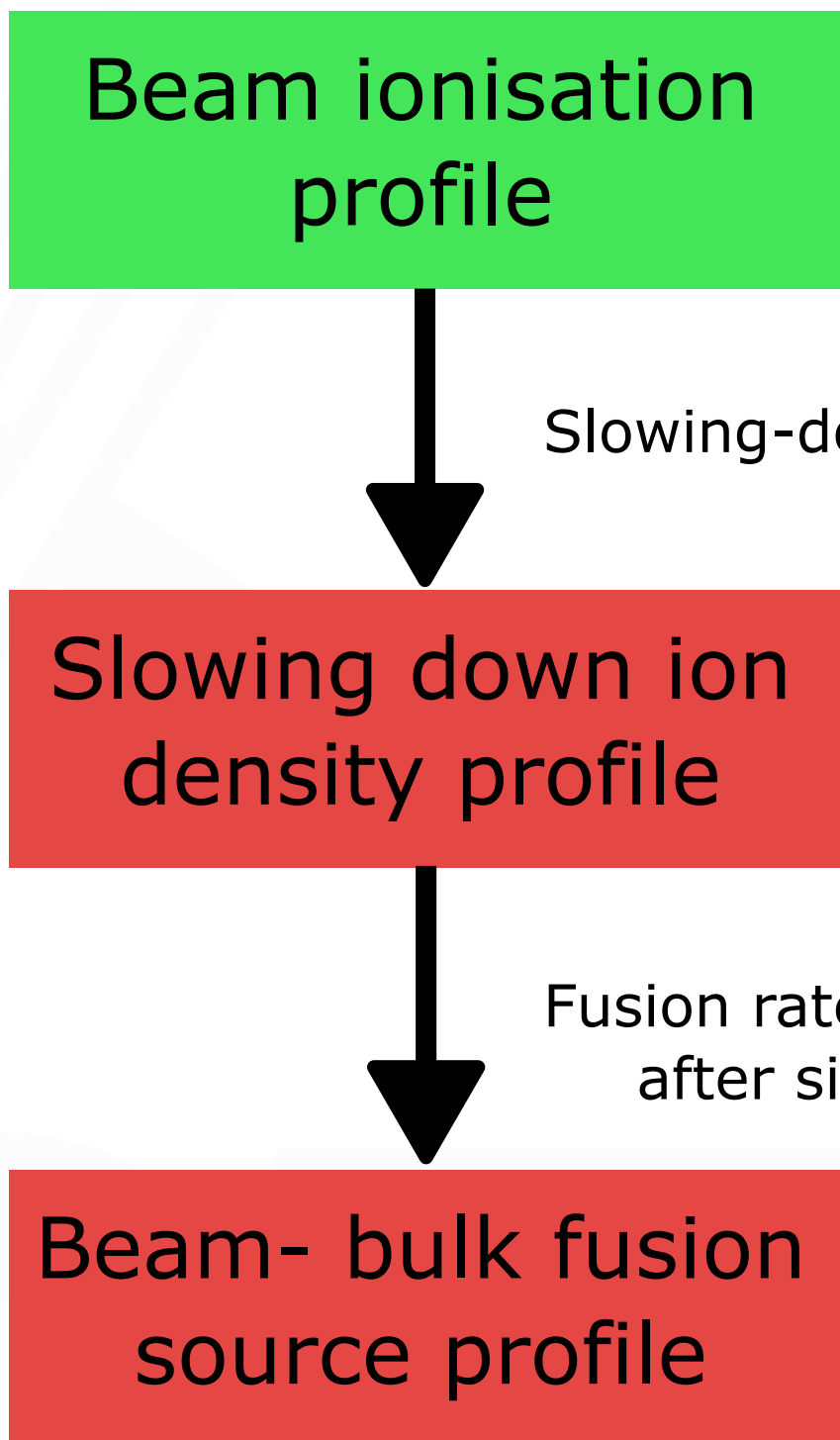
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R. Coelho et al., "Alpha particle generation and confinement in D-3He scenarios in JT-60SA," Nucl. Fusion, vol. 66, no. 8, p. 086029, Jul. 2026, doi: 10.1088/1741-4326/ae7e06.

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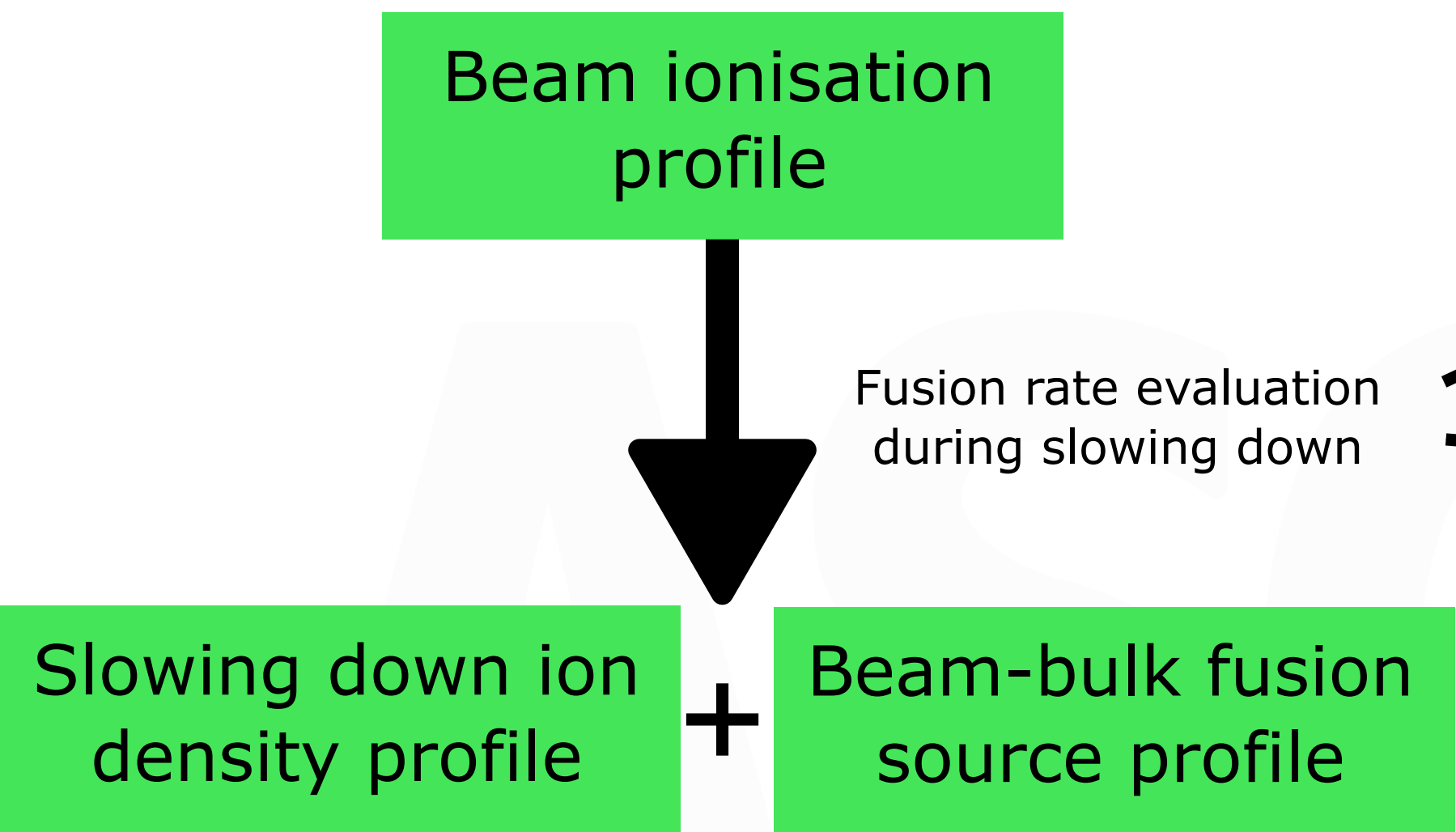
Inconsistent fusion source



Construct a histogram by adding on each time step ($+ w_{\text{marker}} \Delta t$) to the corresponding bin. The resulting histogram approximates $f_{\text{beam}}(\mathbf{x}, \mathbf{v}_{\text{beam}})$.

$$\iint f_{\text{bulk}}(\mathbf{x}, \mathbf{v}) f_{\text{beam}}(\mathbf{x}, \mathbf{v}_{\text{beam}}) \sigma(v_{\text{rel}}) v_{\text{rel}} d^3 \mathbf{v} d^3 \mathbf{v}_{\text{beam}}$$

Consistent fusion source



On each time step, **decrease marker weight according to local fusion rate**.

Construct a histogram by adding on each time step ($+ w_{\text{marker}} \Delta t$) to the corresponding bin. The resulting histogram approximates $f_{\text{beam}}(\mathbf{x}, \mathbf{v}_{\text{beam}})$. **This time the distribution is consistent.** Now the fusion rate is obtained from the change in the marker weights.

How much does the inconsistent workflow overestimate slowing down density and beam-bulk fusion rate?

CASE 1: Tokamak with 150 keV passing T ion at axis

Overestimation of density in the inconsistent workflow	Higher beam energy, longer slowing down time	
	$E_{\text{beam}} = 120 \text{ keV}$	$E_{\text{beam}} = 150 \text{ keV}$
$T_i = T_e = 9 \text{ keV}$	+0.2 %	+0.3 %

Fusion rate will be overestimated by +0.1 % Fusion rate will be overestimated by +0.2 %

CASE 2: Tokamak with 1 MeV passing D ion at axis

Overestimation of density in the inconsistent workflow	Higher beam energy, longer slowing down time	
	$E_{\text{beam}} = 500 \text{ keV}$	$E_{\text{beam}} = 1 \text{ MeV}$
$T_i = T_e = 10 \text{ keV}$	+0.8 %	+0.9 %
$T_i = T_e = 20 \text{ keV}$	+1.2 %	+1.5 %

Fusion rate will be overestimated by +1.8 %

- Conclusions**
- 1) The discrepancy grows with slowing-down time as more fusion reactions occur.
 - 2) The errors are at most of the order 2%