Low-energy fusion dynamics with the time-dependent wave-packet method

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Example

- Weakly bound nuclei: ^{6}Li + ^{209}Bi

Wave-Packet Dynamics

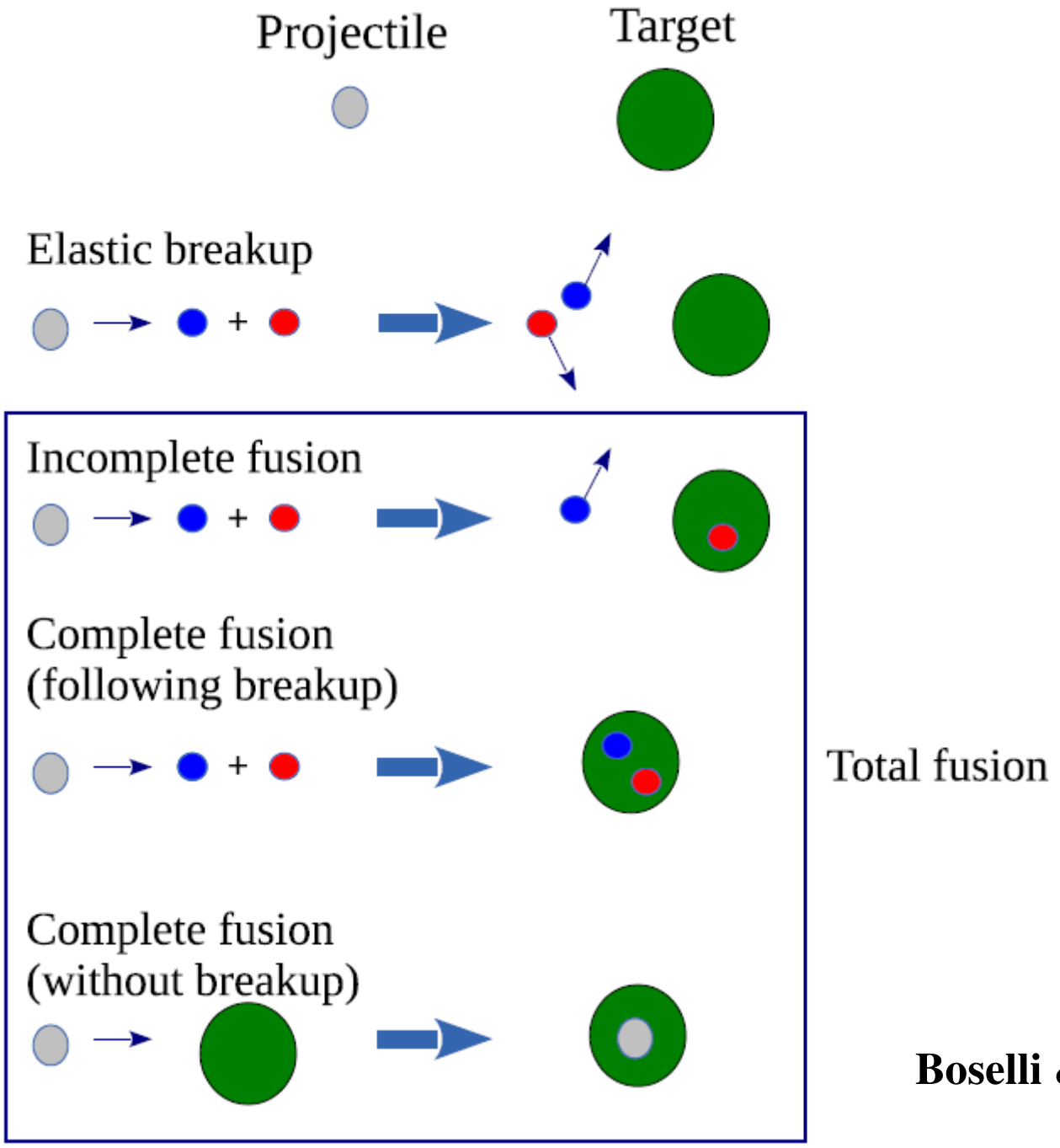
D.J. Tannor, Quantum Mechanics: a Time-Dependent Perspective, USB, 2007

- **Preparation:** the initial state $\Psi(t=0)$

- **Time propagation:** $\Psi(0) \rightarrow \Psi(t)$,
  guided by the operator, $\exp(-i\,\hat{H}\,t/\hbar)$
  $\hat{H}$ is the model Hamiltonian

- **Analysis:** extraction of probabilities from the time-dependent wave function

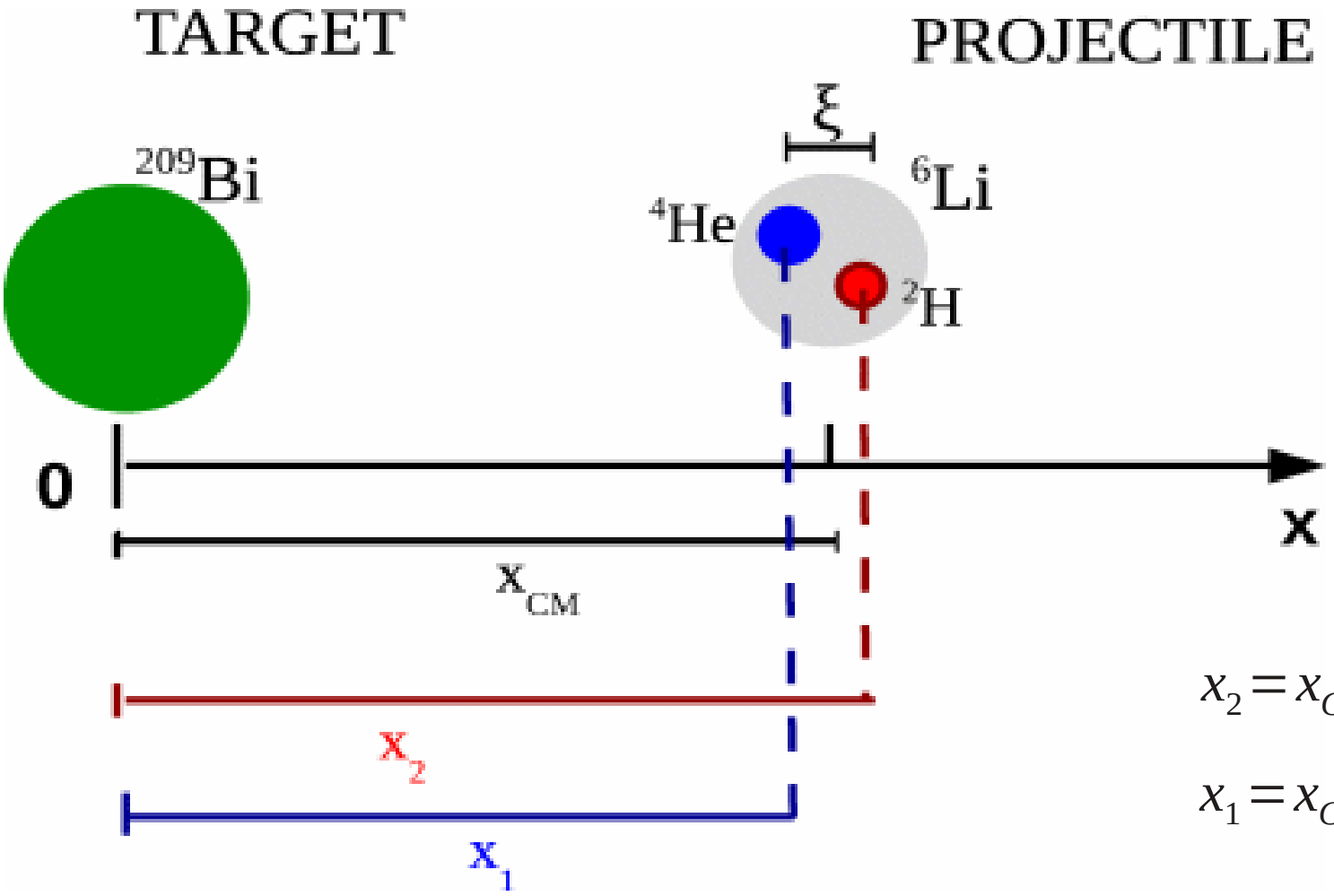
Fusion dynamics of weakly bound nuclei



Boselli & AD-T,

PRC 92 (2015) 0446110

One-Dimensional Toy Model



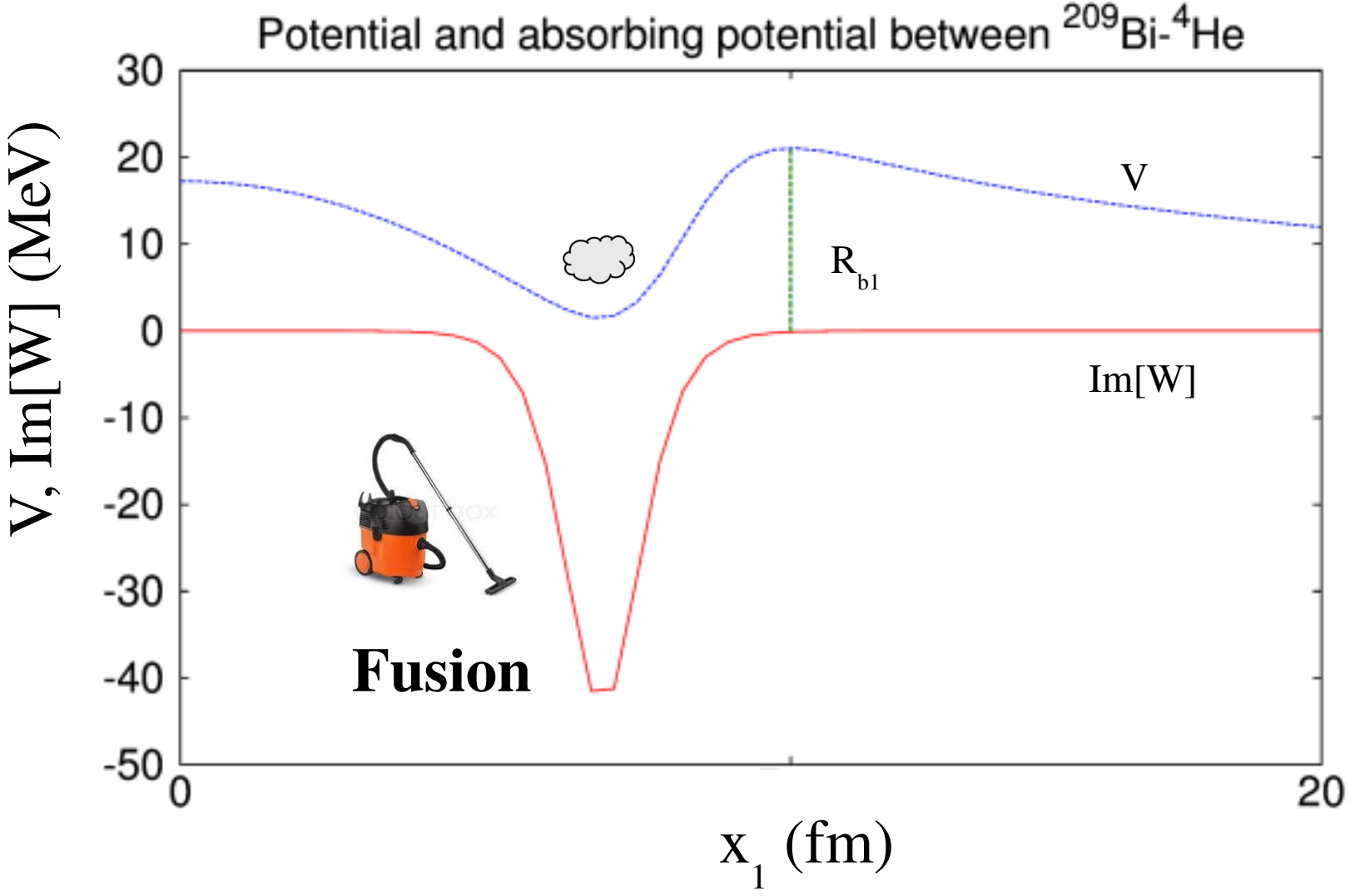
$$x_2 = x_{CM} + b\,\xi$$

$$x_1 = x_{CM} - a\,\xi$$

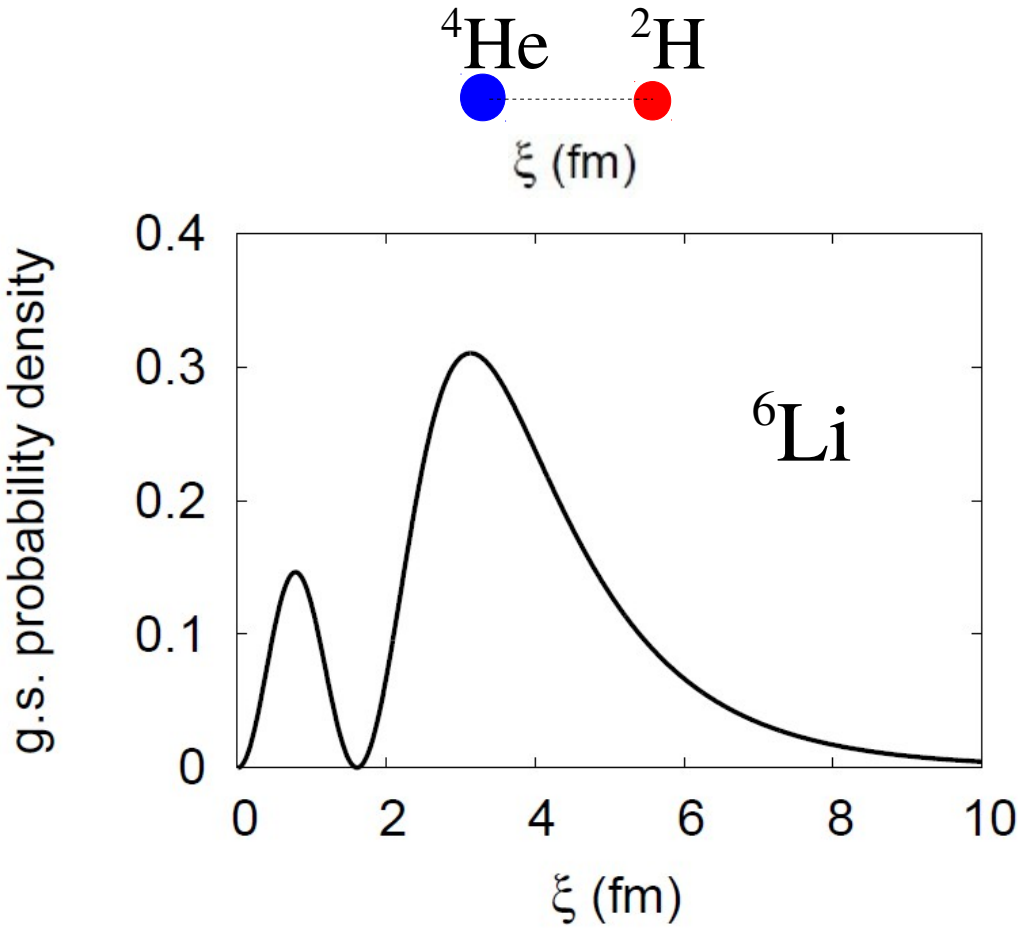
$$H = \frac{P^2_{x_{CM}}}{2M_{T12}} + \frac{P_\xi{}^2}{2m_{12}} + U_{12}(\xi) + V_{T1}(x_{CM} - a\,\xi) + V_{T2}(x_{CM} + b\,\xi)$$

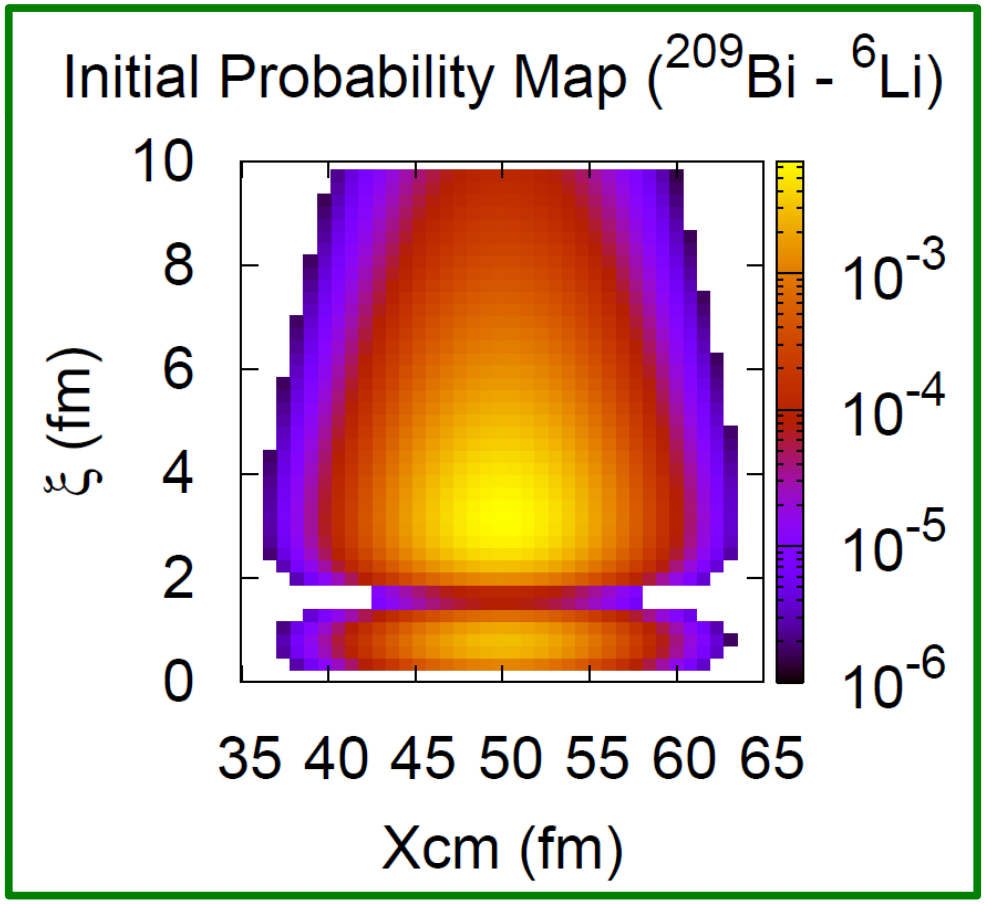
Describing Fusion

♦ To simulate fusion (**irreversibility**): acting inside the Coulomb barrier $-iW_{T1}(x_1)$ & $-iW_{T2}(x_2)$



Preparing the Initial State





Time Propagation

R. Kosloff, Ann. Rev. Phys. Chem. **45** (1994) 145

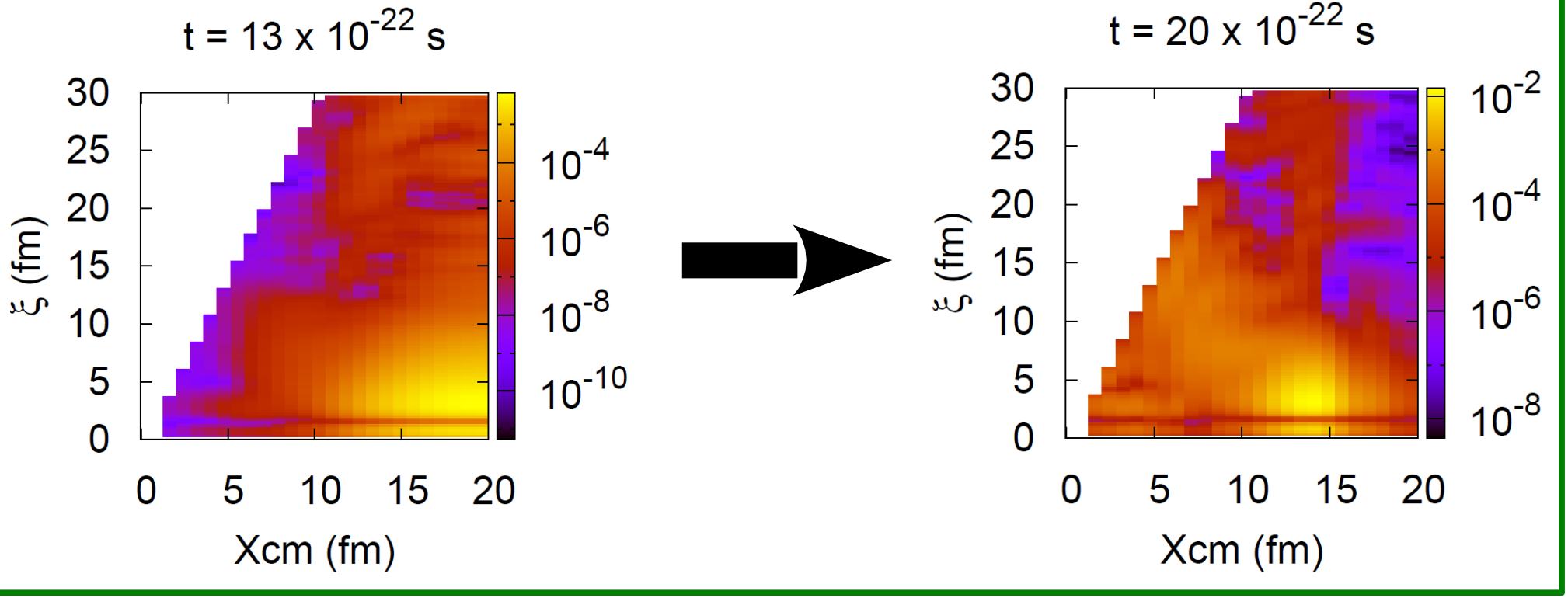
$$\Psi(t+\Delta t) = \exp\left(-i\frac{\hat{H}\,\Delta t}{\hbar}\right)\Psi(t)$$

$$\exp\left(-i\frac{\hat{H}\,\Delta t}{\hbar}\right) \approx \sum_n a_n\, Q_n(\hat{H}_{norm})$$

$$\hat{H}_{norm} = \frac{(\bar{H}\,\hat{1} - \hat{H})}{\Delta H}$$

The Chebyshev Propagator

$$a_n = i^n(2-\delta_{n0})\exp(-i\frac{\bar{H}\,\Delta t}{\hbar})\,J_n(\frac{\Delta H\,\Delta t}{\hbar})$$

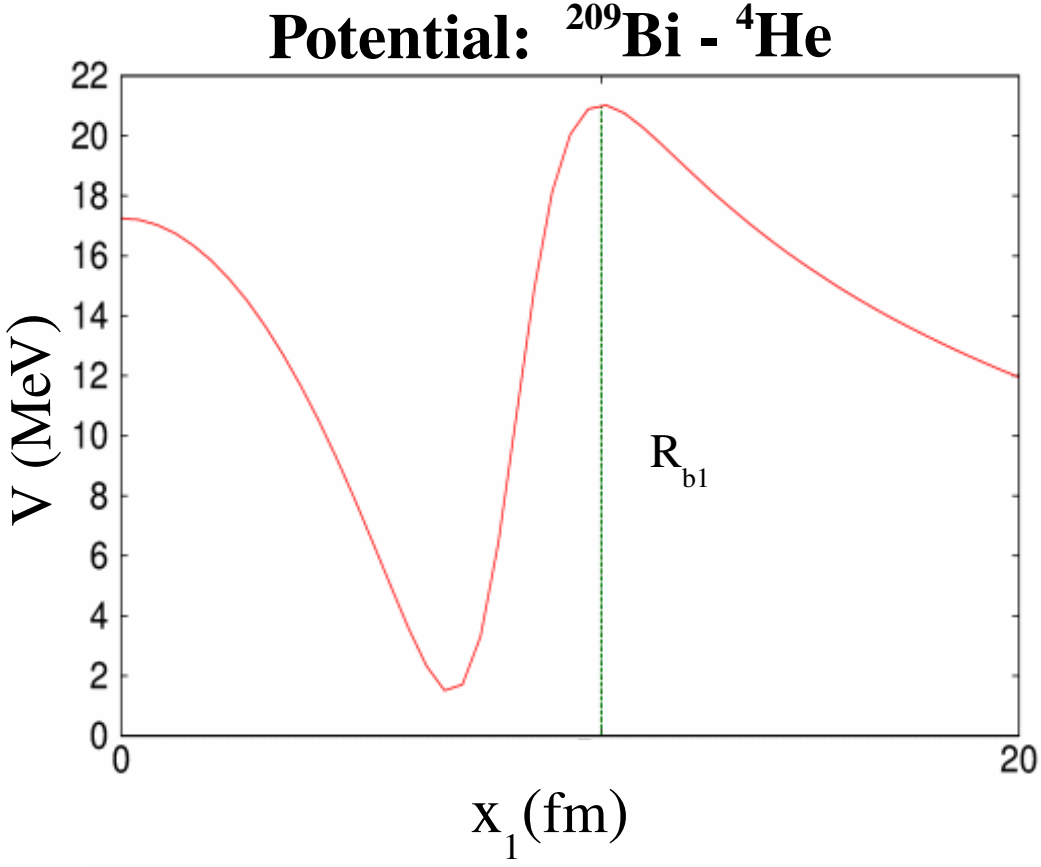


Slicing the Wave Function: A Novel Idea

♦ Projection operator acting on the position x_i of the fragment relative to the target

(Heaviside function)

$$P_i = \Theta(R_{bi} - x_i)$$
$$Q_i = 1 - P_i$$



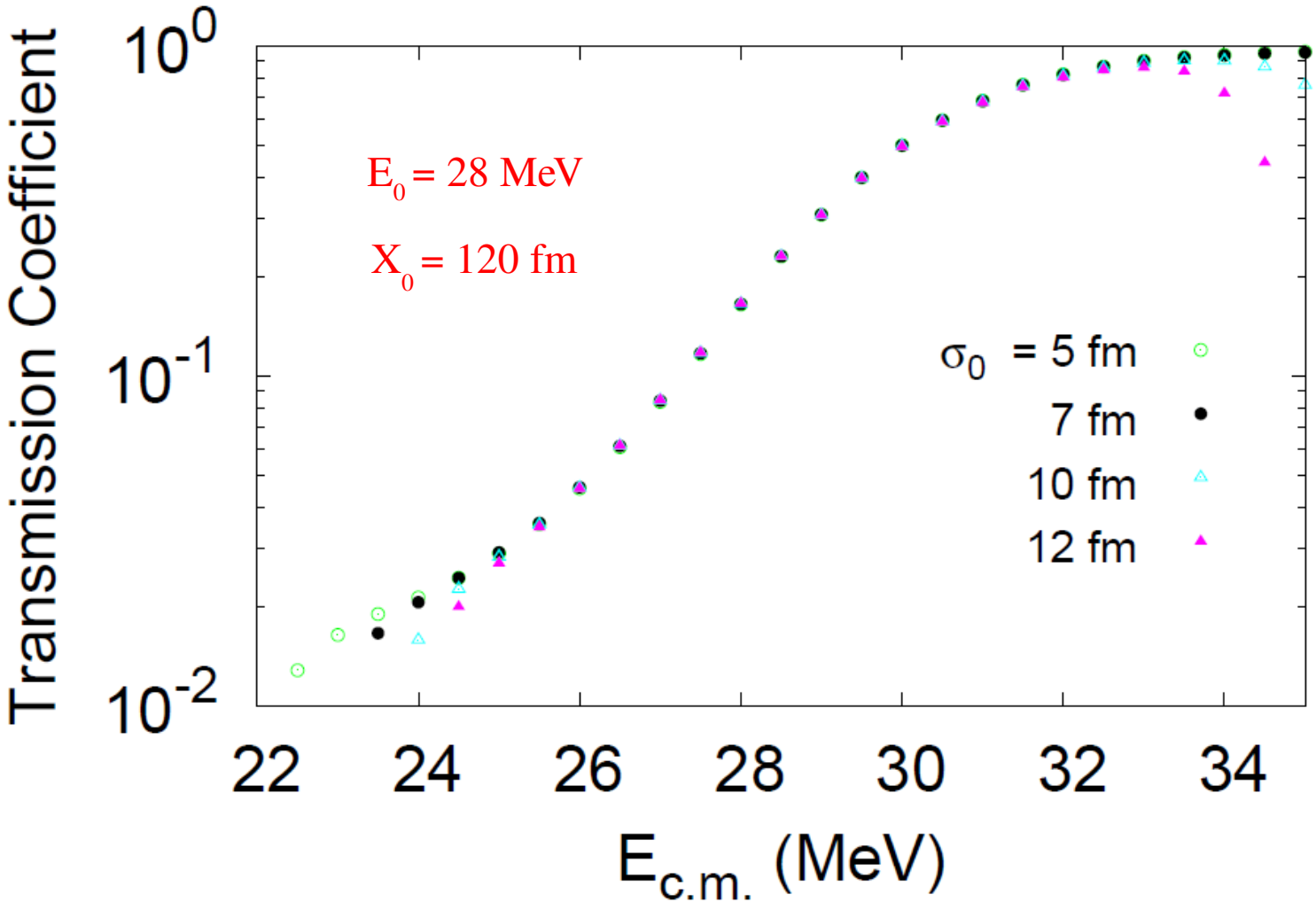
	CAPTURED	NON CAPTURED
CF	● ●	
ICF	●	●

♦ Act with $(P_1+Q_1)(P_2+Q_2)=1$ on the wave function:

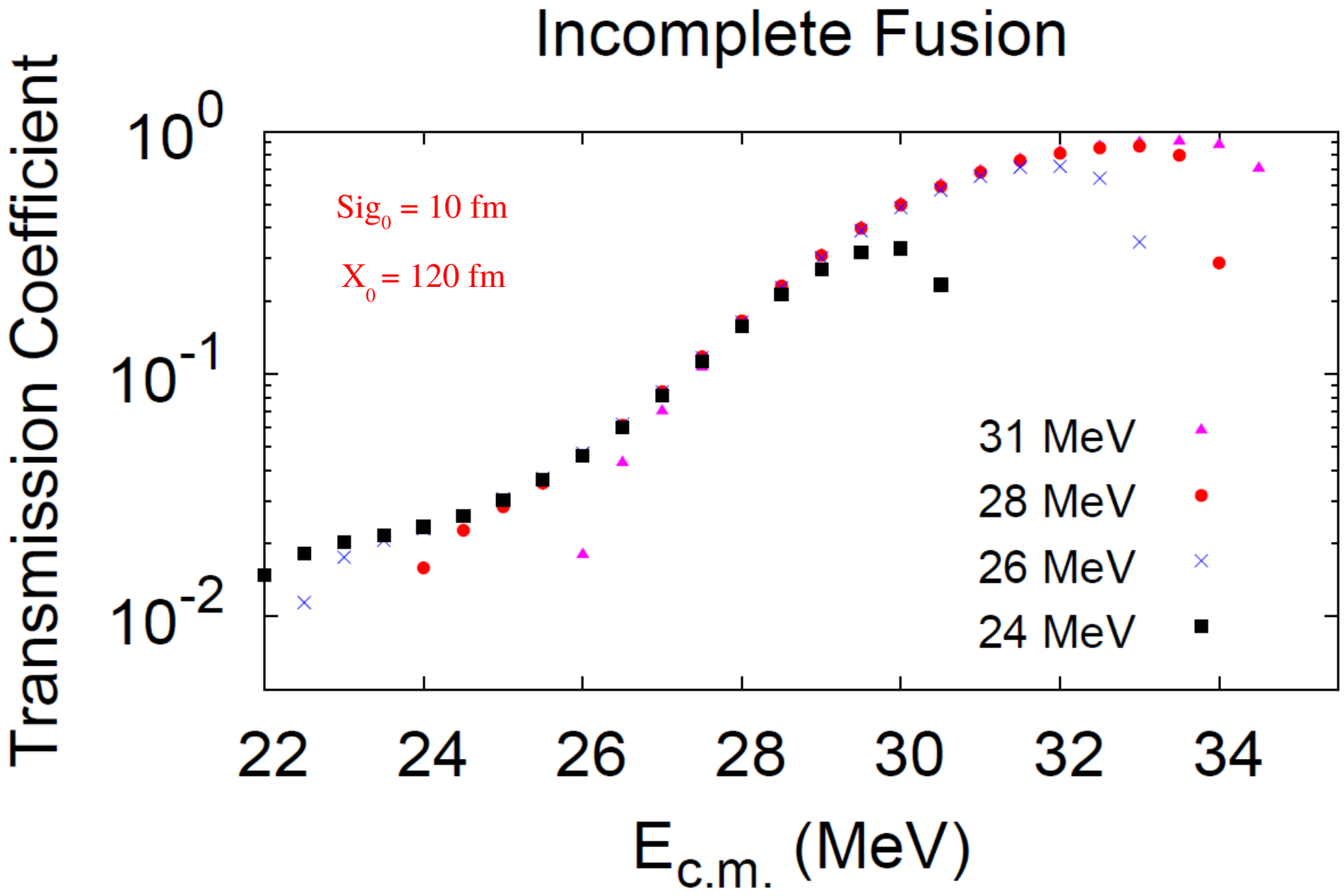
$$\tilde{\Psi}(x_1,x_2,t)=(P_1P_2+P_1Q_2+Q_1P_2+Q_1Q_2)\tilde{\Psi}(x_1,x_2,t)=\Psi_{CF}+\Psi_{ICF}+\Psi_{SCATT}$$

Results

- Energy-resolved **total transmission** for different values of the **width** of the **initial wave packet**



Results


Incomplete Fusion
Transmission Coefficient
10^0
10^{-1}
10^{-2}
Sig_0 = 10 fm
X_0 = 120 fm
31 MeV
28 MeV
26 MeV
24 MeV
22
24
26
28
30
32
34
$E_{c.m.}$ (MeV)

Conclusions

Boselli & AD-T, Physical Review C **92** (2015) 044610

- **Wave-packet dynamics** is a useful tool for modelling low-energy fusion dynamics of weakly bound nuclei.

- **Complete & incomplete fusion processes** can unambiguously be separated in the configuration space.

- **A three-dimensional quantum dynamical model** using wave-packet dynamics is being developed.