Microscopic description of heavy ions collisions around the barrier

B. Avez, C. Simenel *CEA-SPhN, Saclay*

C. Golabek *GANIL, Caen*

Plan

Introduction:

Why a microscopic approach ?

I) **Time-Dependent Hartree-Fock (TDHF)**

- *formalism*
- *practical aspects*

II) **Applications to fusion**

- *light and medium-heavy systems*
- *fusion hindrance in heavy systems*
- *collision time of* $^{238}U+^{238}U$

Conclusions and perspectives

Introduction: *Why a microscopic approach ?*

Interface between structure and reactions

same formalism for both

Predictive power

heavy systems, exotic nuclei, neutron stars...

All type of reactions between two nuclei

fusion, transfer, inelastic scattering...

***N* interacting fermions (nucleons)**

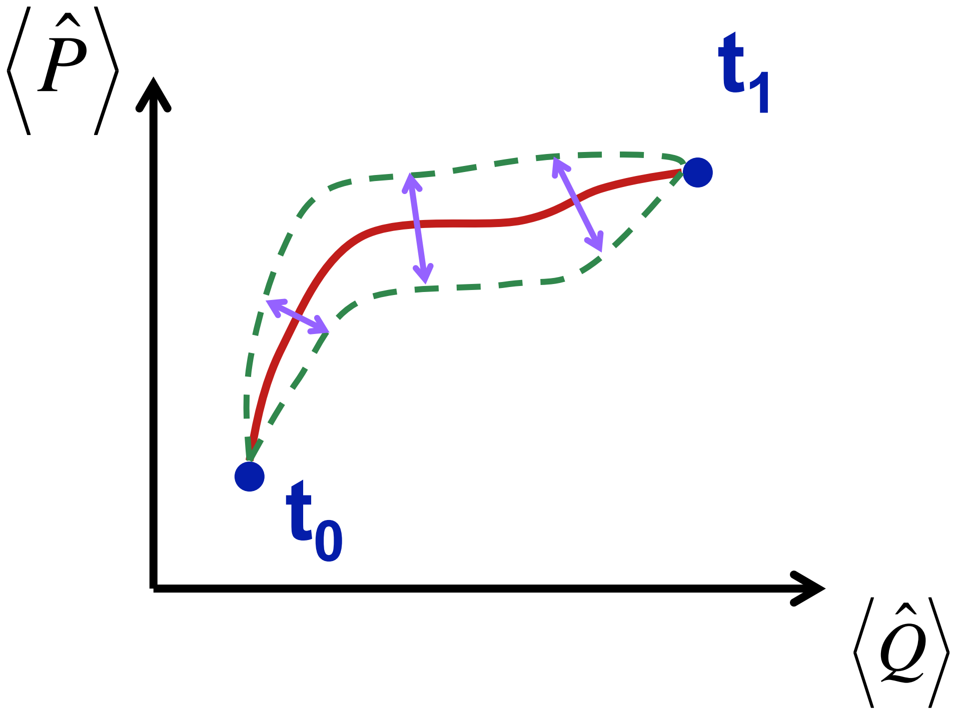
Pauli principle

I) TDHF: *Formalism*

Dirac action

$$S = \int_{t_0}^{t_1} dt \quad \langle \Psi | i\hbar \frac{\mathrm{d}}{\mathrm{d}t} - \hat{H} | \Psi \rangle$$

Variational principle $\delta S = 0$ ⇔ ***Schrödinger***



I) TDHF: *Formalism*

Dirac action $$S = \int_{t_0}^{t_1} dt \quad \langle \Psi | i\hbar \frac{\mathrm{d}}{\mathrm{d}t} - \hat{H} | \Psi \rangle$$

Variational principle $\delta S = 0$

Subspace of independent particles

➔ ***TDHF equations*** $$i\hbar \frac{\mathrm{d}}{\mathrm{d}t} |\varphi_\alpha\rangle = \hat{h}[\rho] |\varphi_\alpha\rangle$$

$$1 \leq \alpha \leq A$$

s.p. hamiltonian $$h[\rho] = \frac{\delta E[\rho]}{\delta \rho}$$

P.A.M. Dirac, Proc. Camb. Phil. Soc. **26**, 376 (1930)

I) TDHF: *practical aspects*

Skyrme functional

T. Skyrme, Phil. Mag. **1**, 1043 (1956)

$$E[\rho] \equiv E[\rho(\mathbf{r}), \mathbf{j}(\mathbf{r}), \tau(\mathbf{r}), \mathbf{s}(\mathbf{r}) \ldots]$$

10 parameters fitted on structure properties:

saturation, compressibility, neutron matter, symetry energy, few masses and radii, spin-orbit splitting...

TDHF3D (P. Bonche) + SLy4*d*

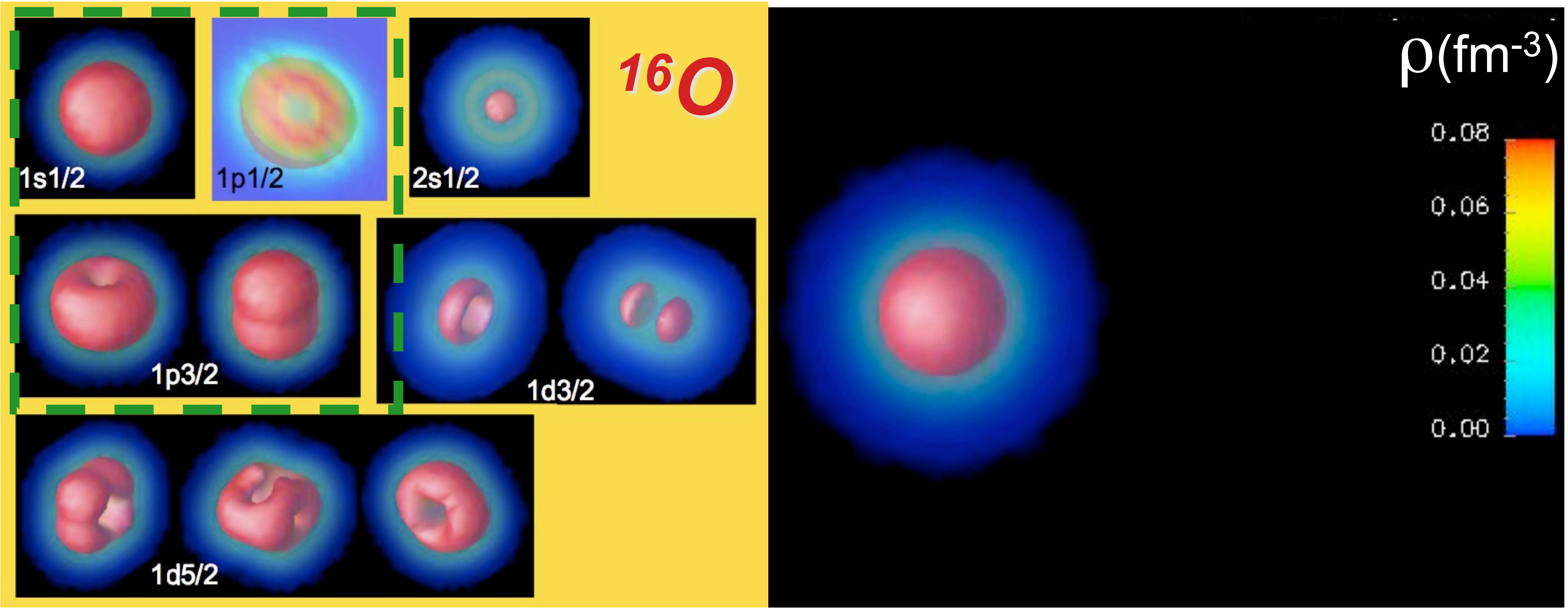
K.-H. Kim, T. Otsuka and P. Bonche, JPG **23**, 1267 (1997)

I) TDHF: *practical aspects*

Initial condition

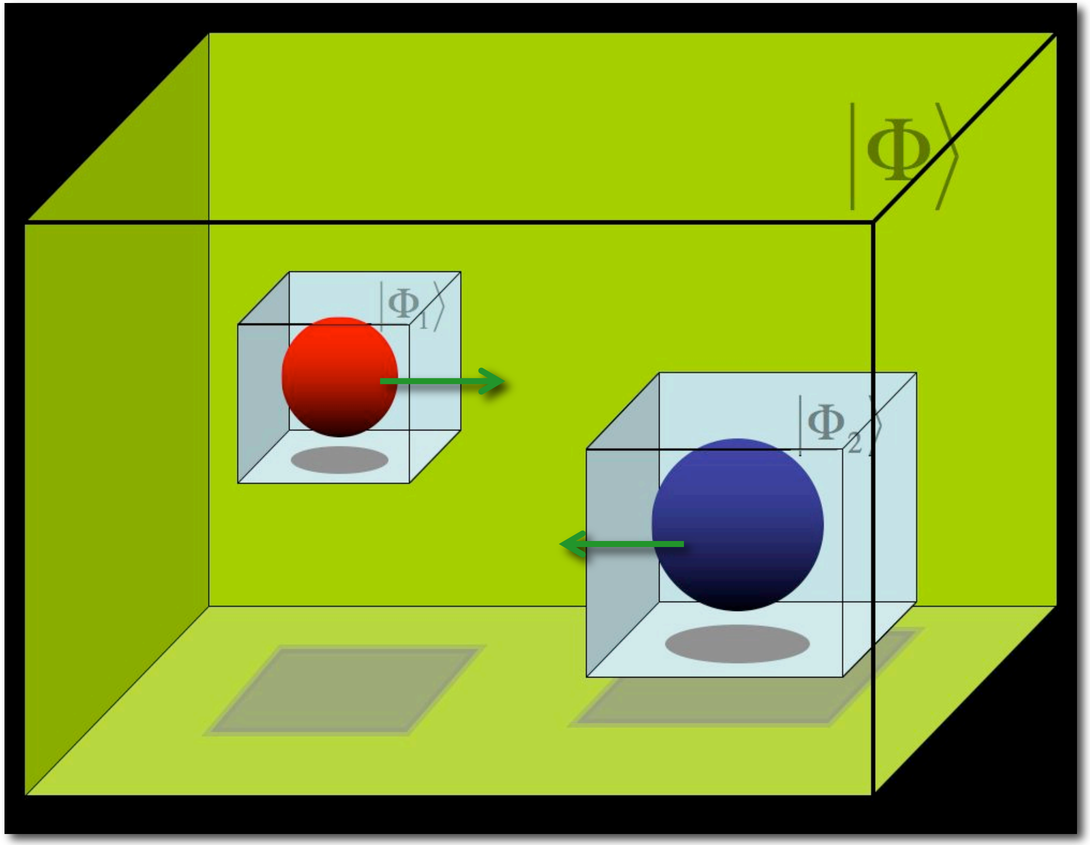
- *Rutherford trajectory from ∞ to D_0 ~ 40 fm*
- *HF ground state at D_0*

neutron occupied w.f.



I) TDHF: *practical aspects*

Initial state



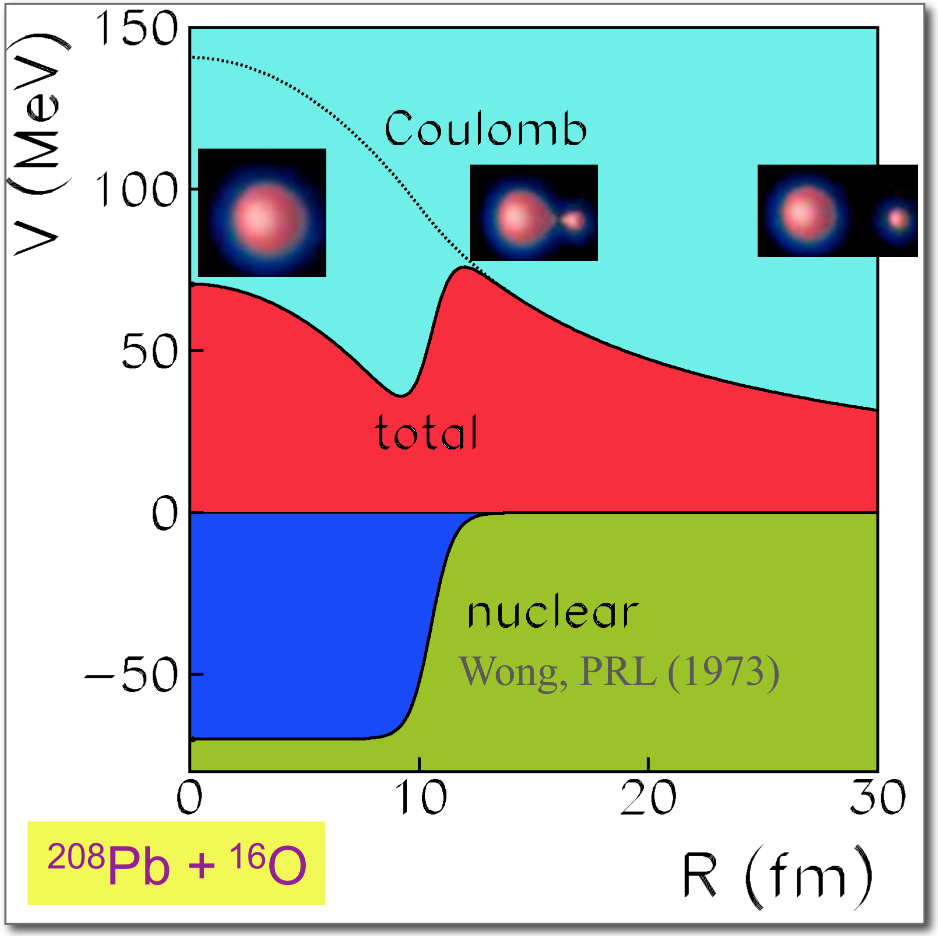
Galilean boost

$$|\psi(0)\rangle = \exp\left(-i\mathbf{P}\hat{\mathbf{R}}\right)|\psi_{HF}\rangle$$

D.J. Thouless and J.G. Valatin, NPA **31**, 211 (1962)

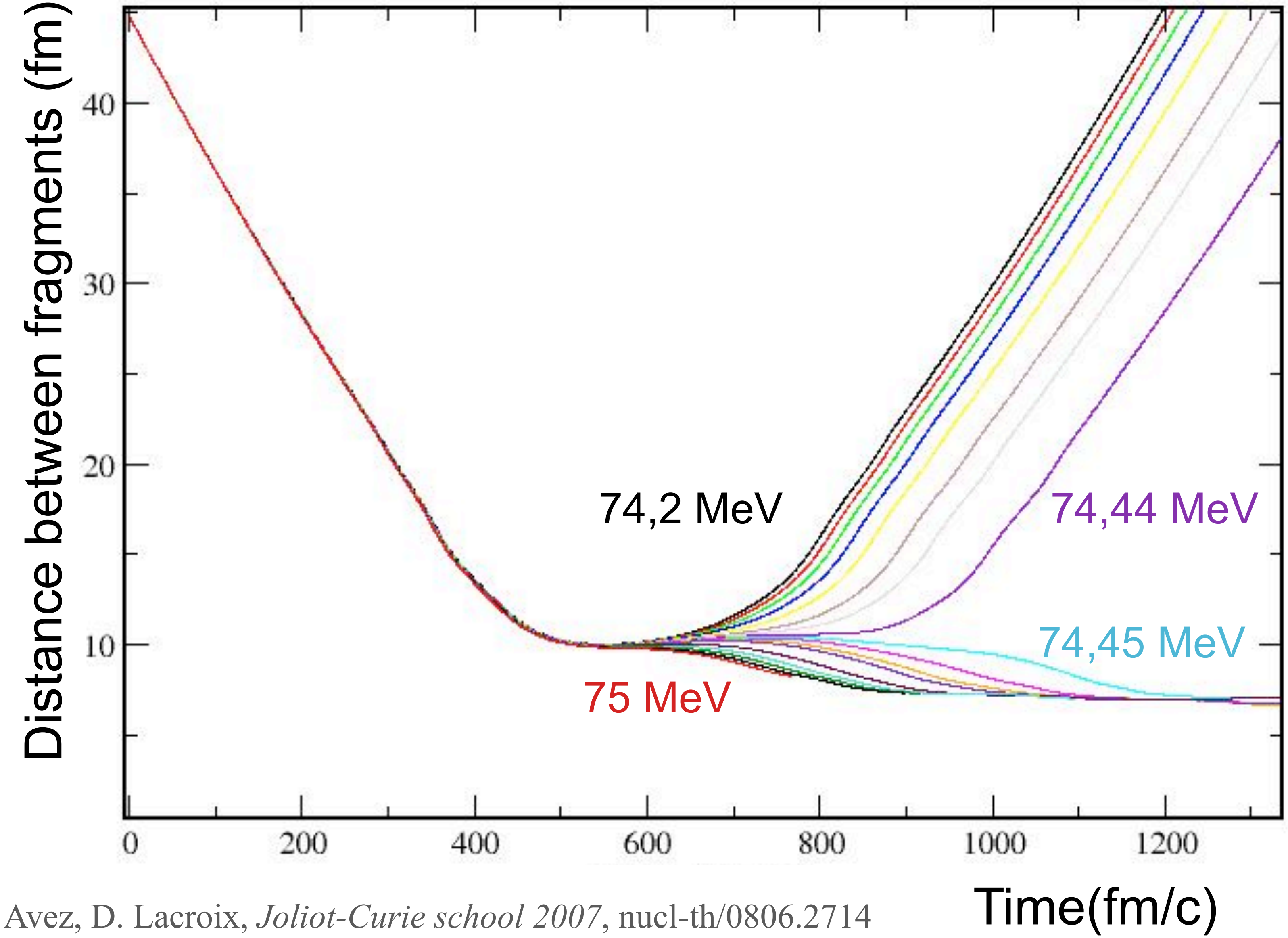
II) Applications to fusion:
light and medium-heavy systems

fusion barriers



II) Applications to fusion:
light and medium-heavy systems

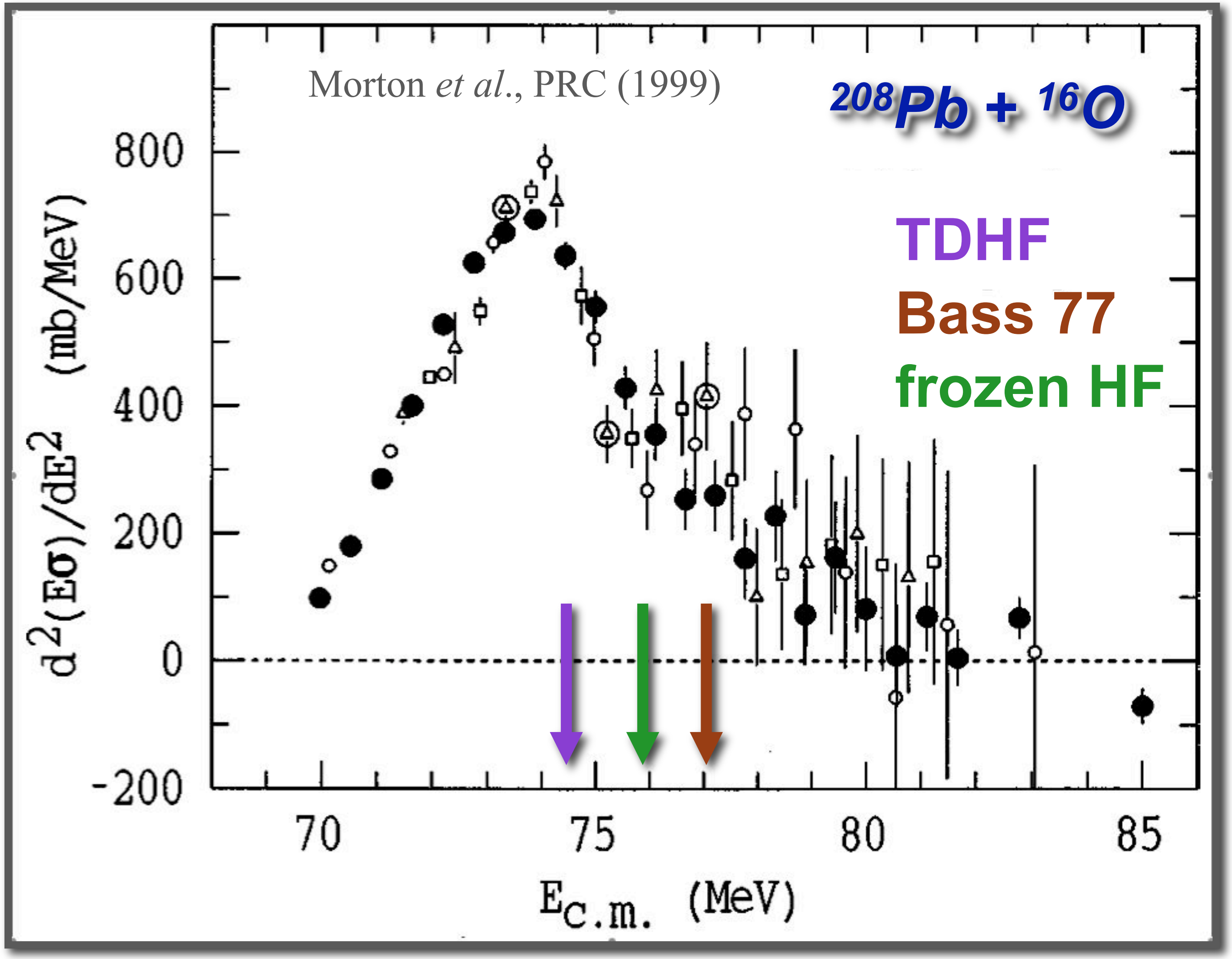
$^{208}Pb + ^{16}O$



C.S., B. Avez, D. Lacroix, *Joliot-Curie school 2007*, nucl-th/0806.2714

II) Applications to fusion:
light and medium-heavy systems

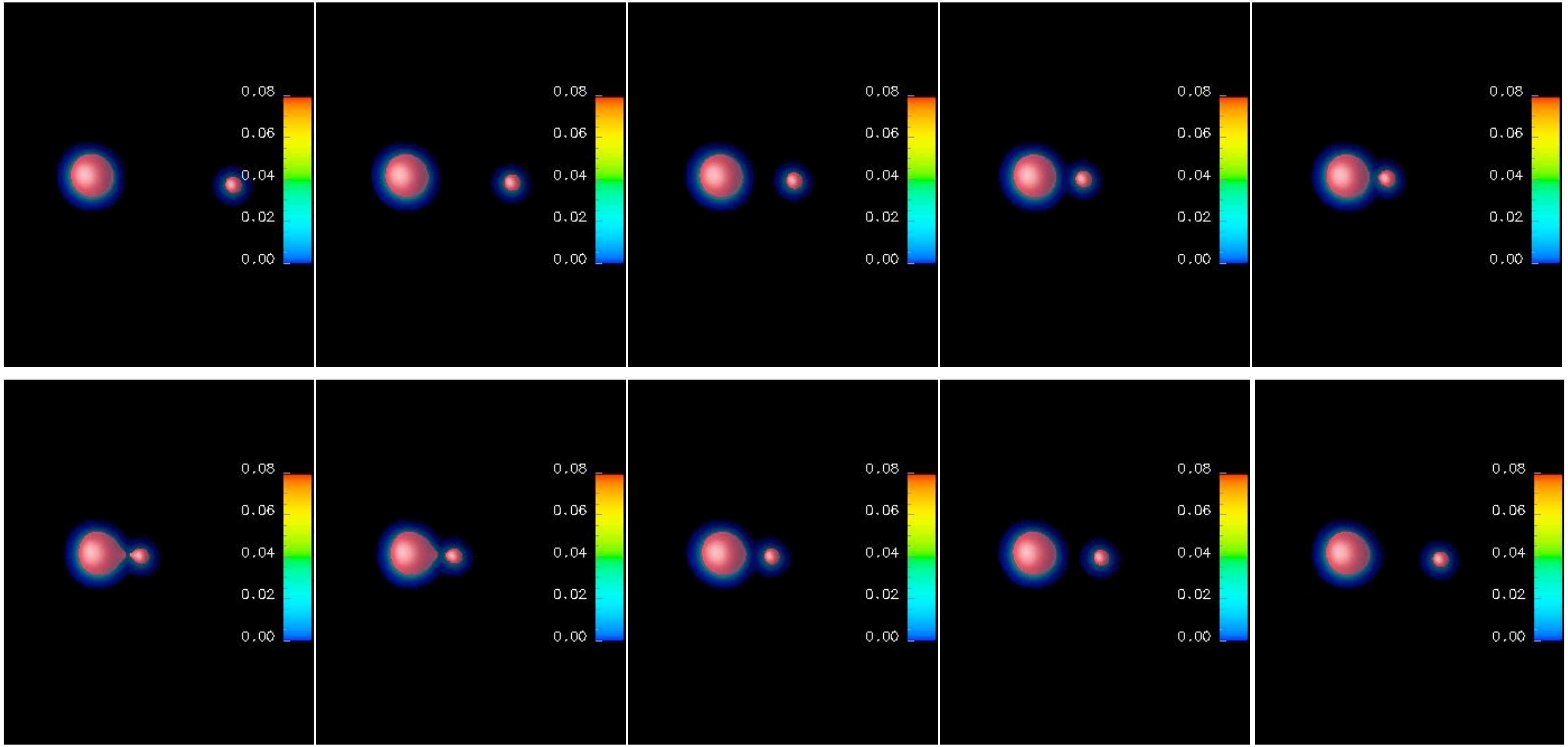
Fusion barriers



II) Applications to fusion:

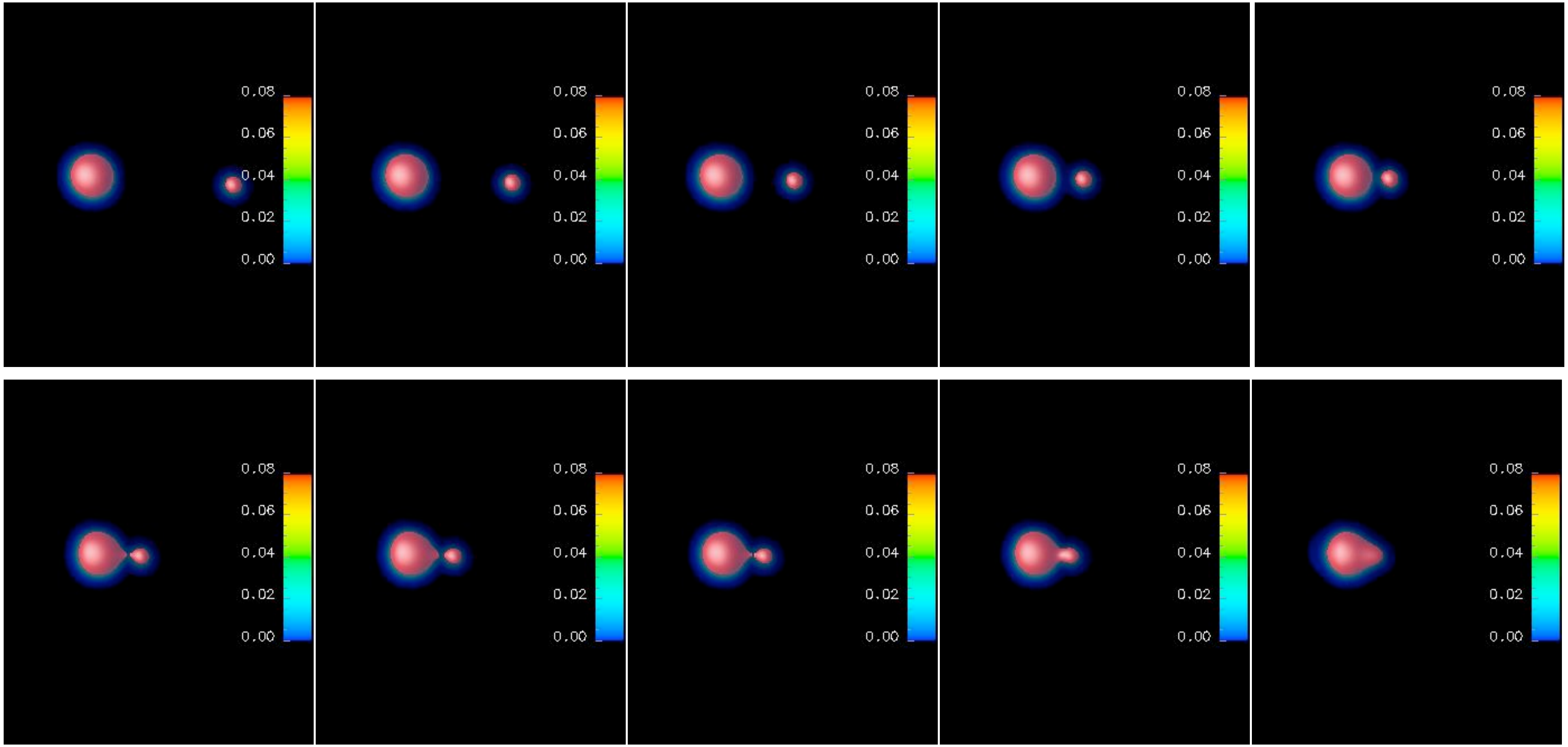
light and medium-heavy systems

$^{208}Pb + ^{16}O$ 74.44 MeV



II) Applications to fusion:
light and medium-heavy systems

$^{208}Pb + ^{16}O$ 74.45 MeV

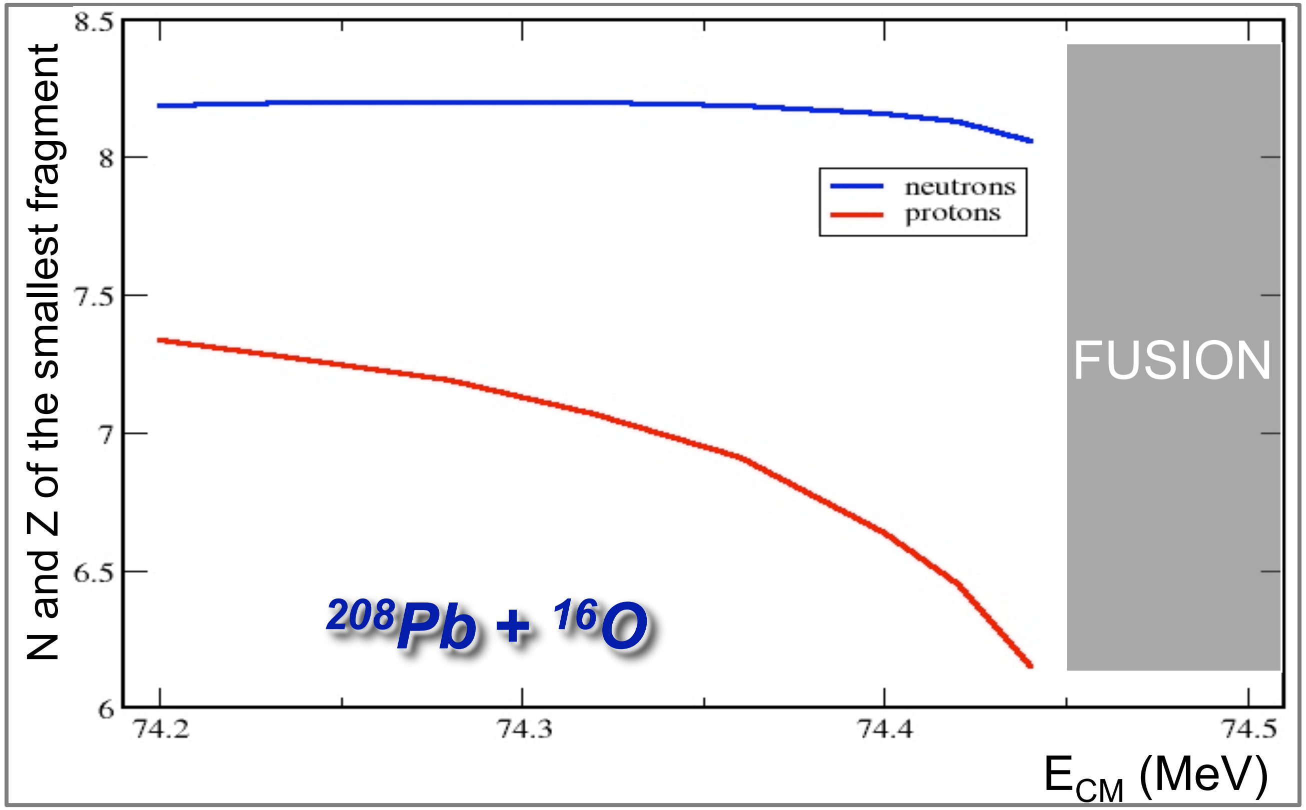


II) Applications to fusion:
light and medium-heavy systems

couplings to transfer in $^{16}O+^{208}Pb$

CRC calculations I.J. Thompson *et al.*, NPA **505**, 84 (1989).

TDHF:

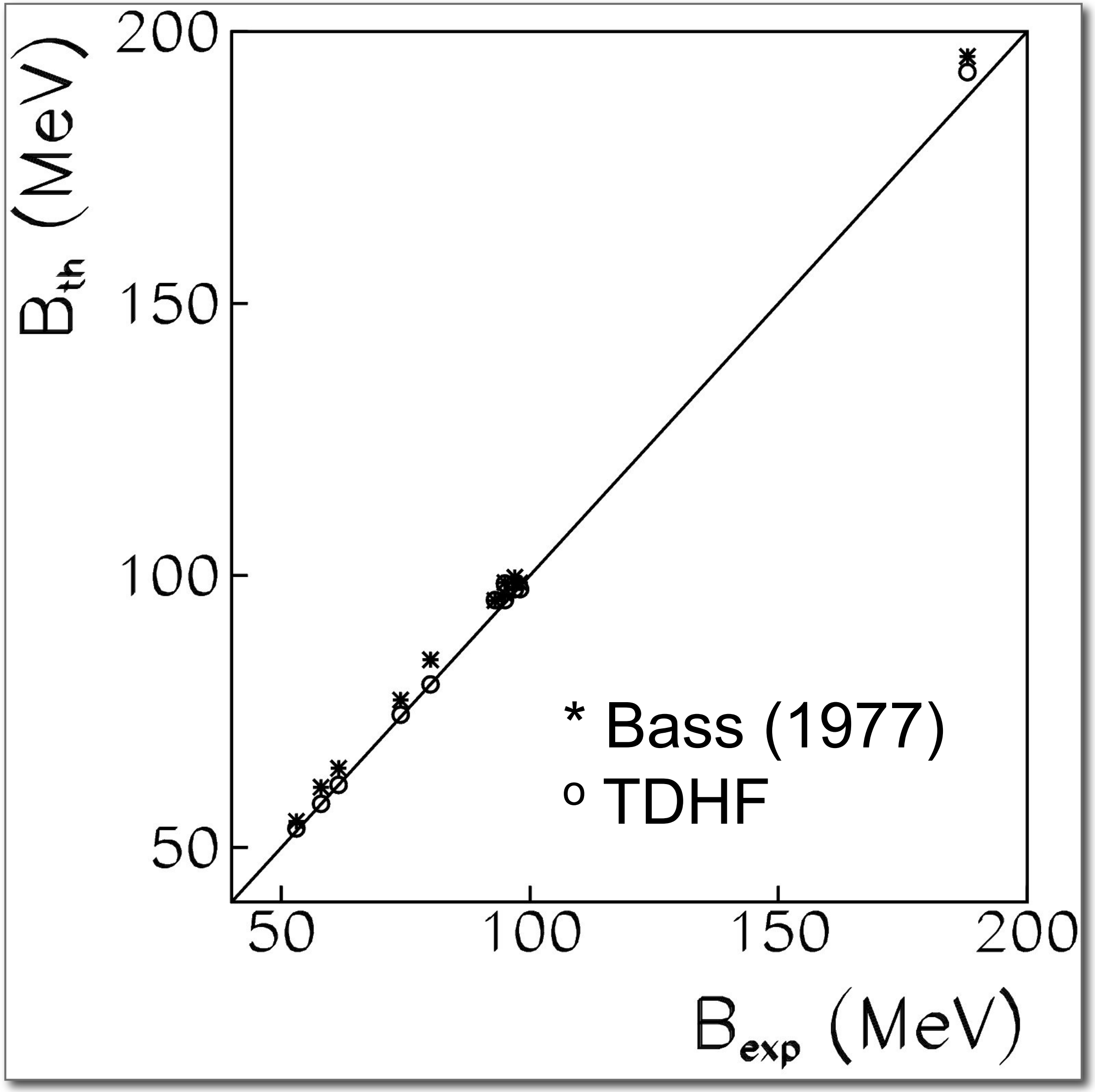


isovector restoring force because of N/Z asymetry

C. S., Ph. Chomaz and G. de France, PRL (2001) and PRC (2007)

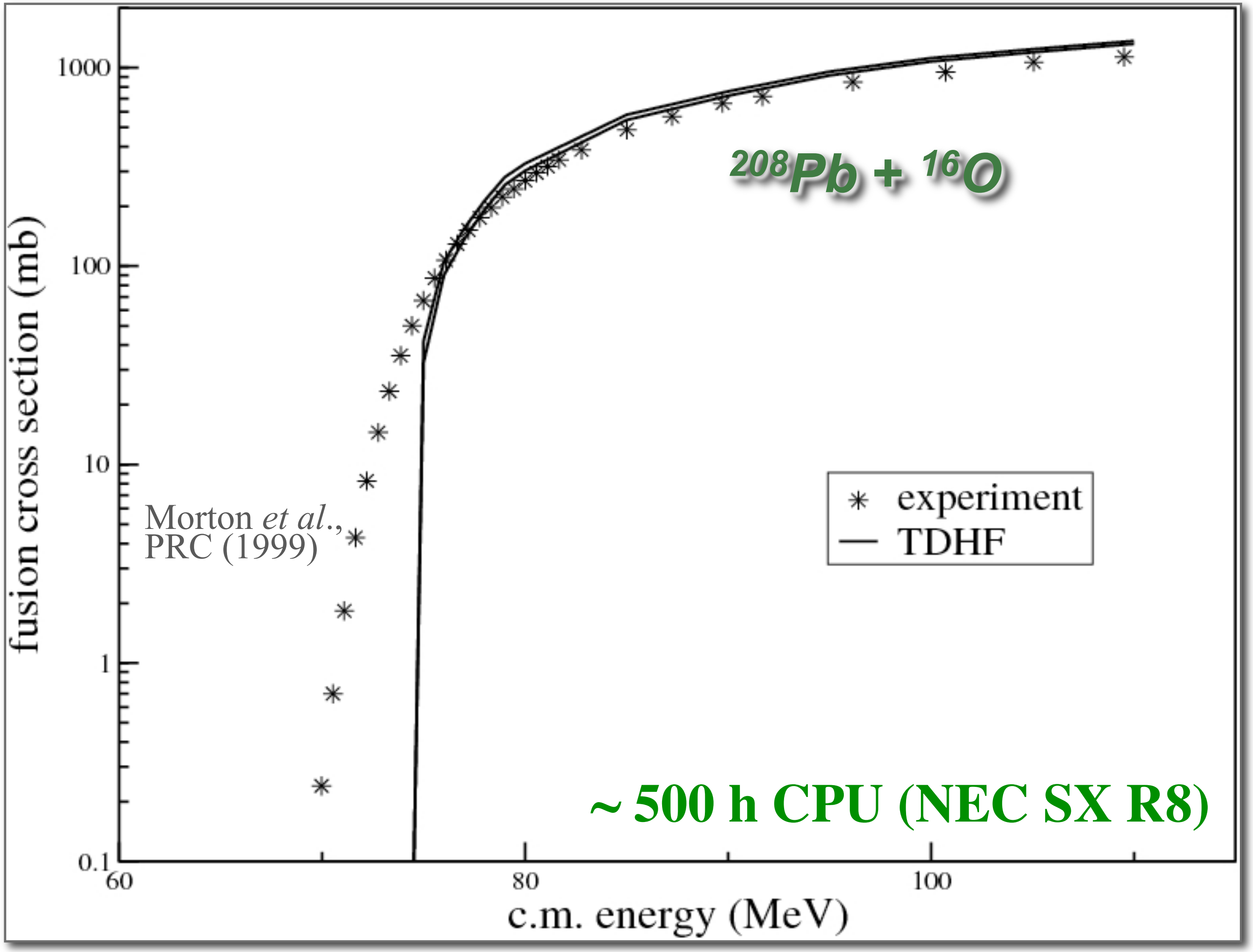
II) Applications to fusion:
light and medium-heavy systems

systematics



C.S. and B. Avez, Int. J. Mod. Phys. E **17**, 31 (2008)

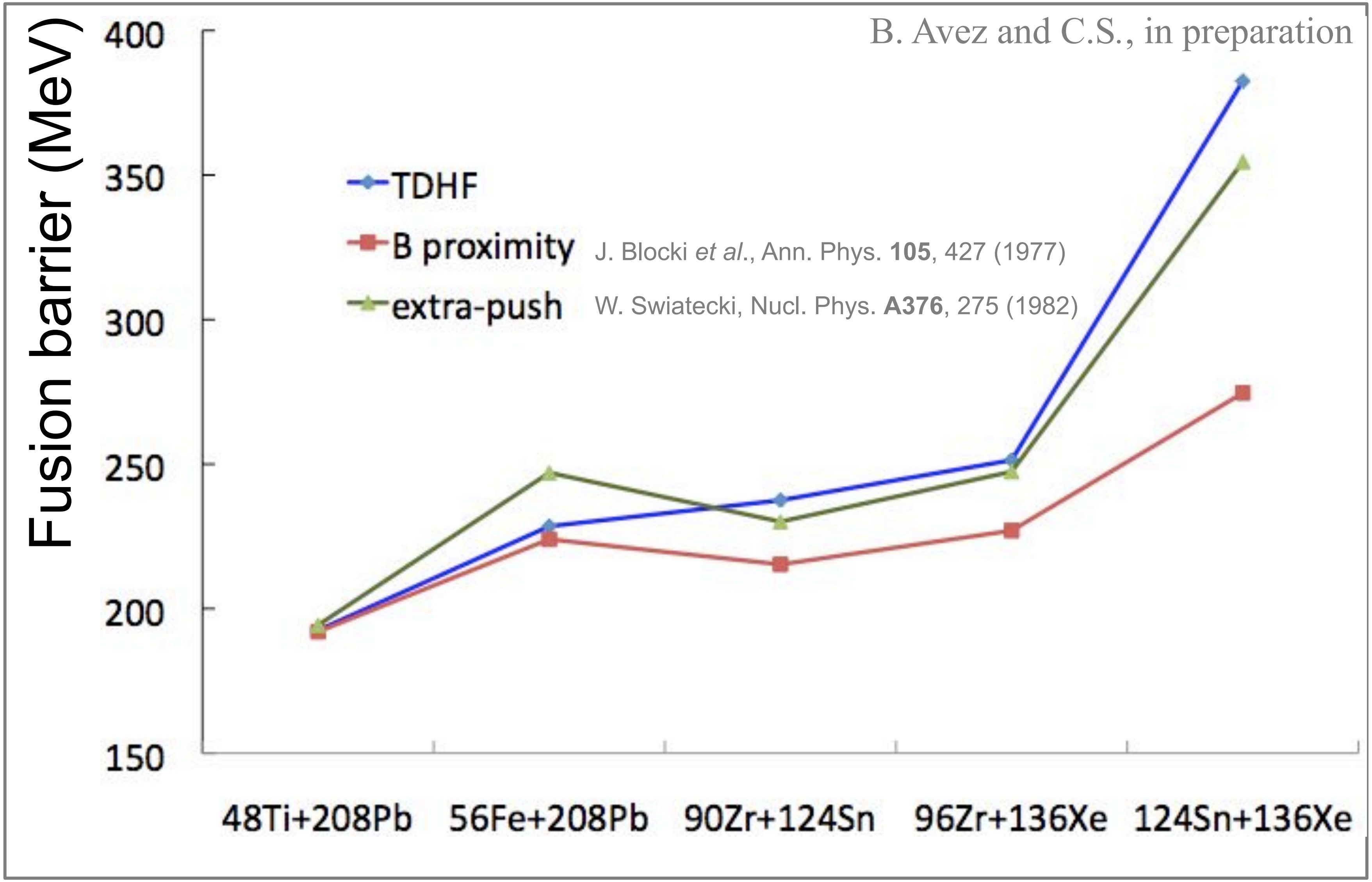
II) Applications to fusion:
light and medium-heavy systems



C.S., B. Avez, D. Lacroix, *Joliot-Curie school 2007*, nucl-th/0806.2714

II) Applications to fusion:
fusion hindrance of heavy systems

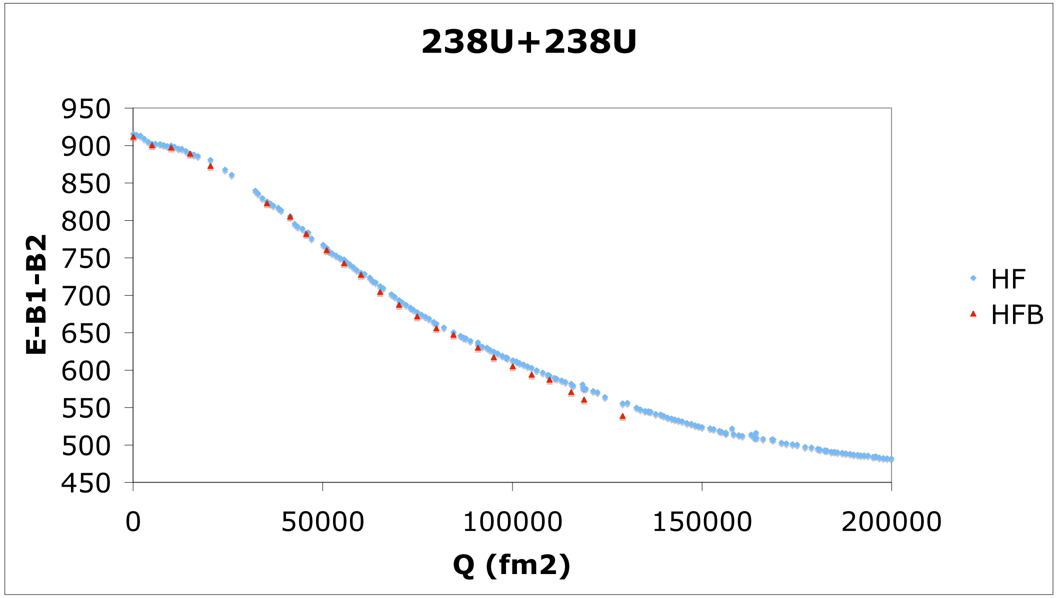
J.R. Nix and A.J. Sierk, PRC **15**, 2072 (1977)



II) Applications to fusion: *collision time of $^{238}U+^{238}U$*

No pocket for fusion

J.F. Berger *et al.*, PRC **41**, 2483R (1990)

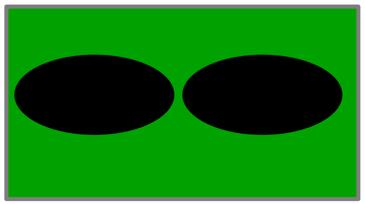


Collision time

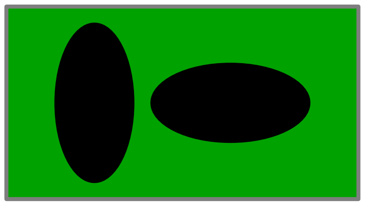
SHE formation, super-strong electric fields

(e^+e^- production if $T_{coll} \geq$ **1000 fm/c** J. *Reinhart et al.*, ZPA **303**, 173 (1981)*)*

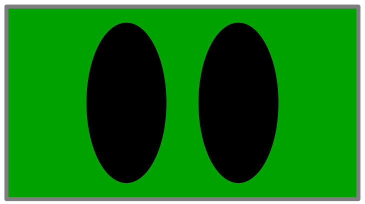
Role of orientation



top on top



top on side

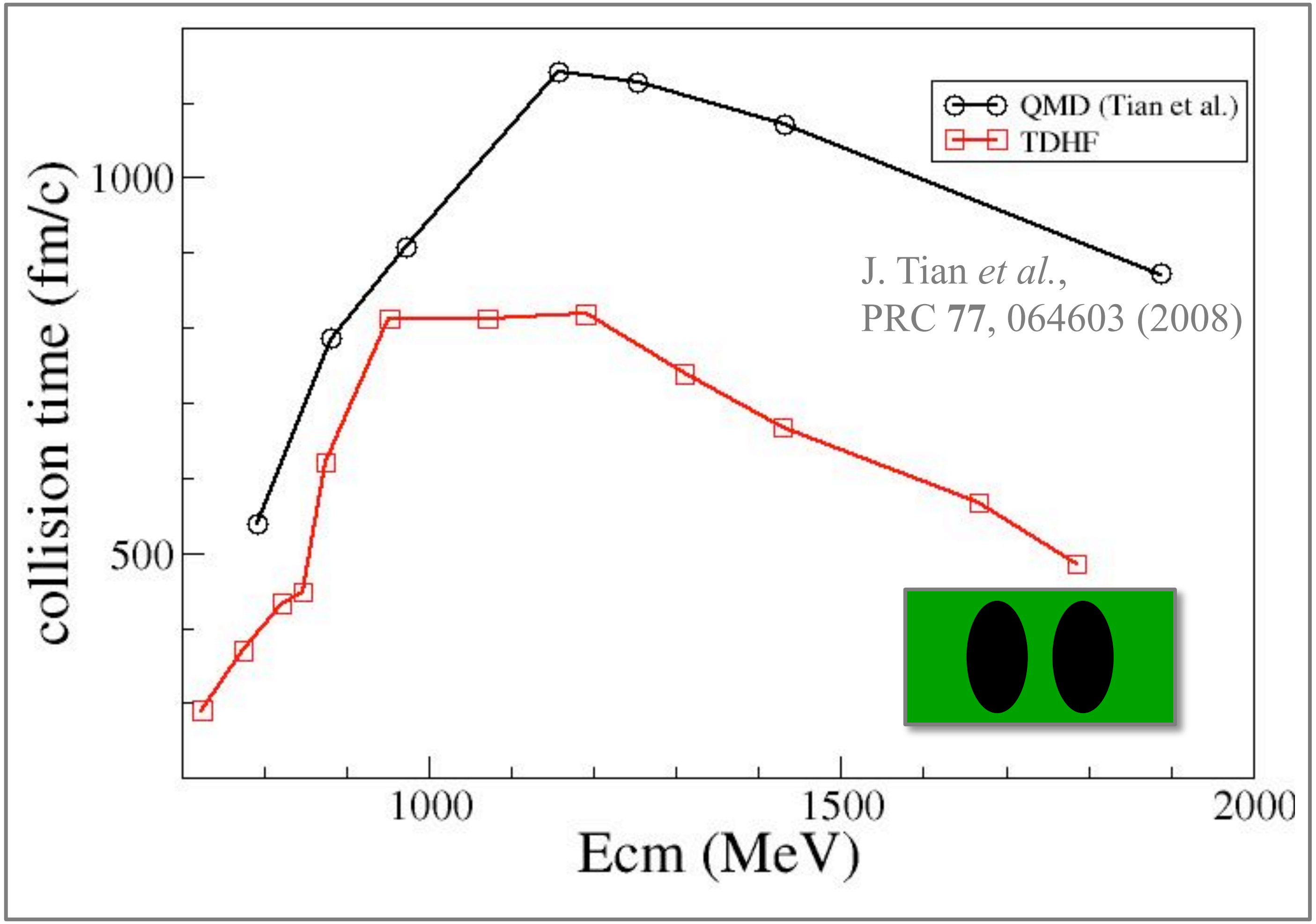


side on side

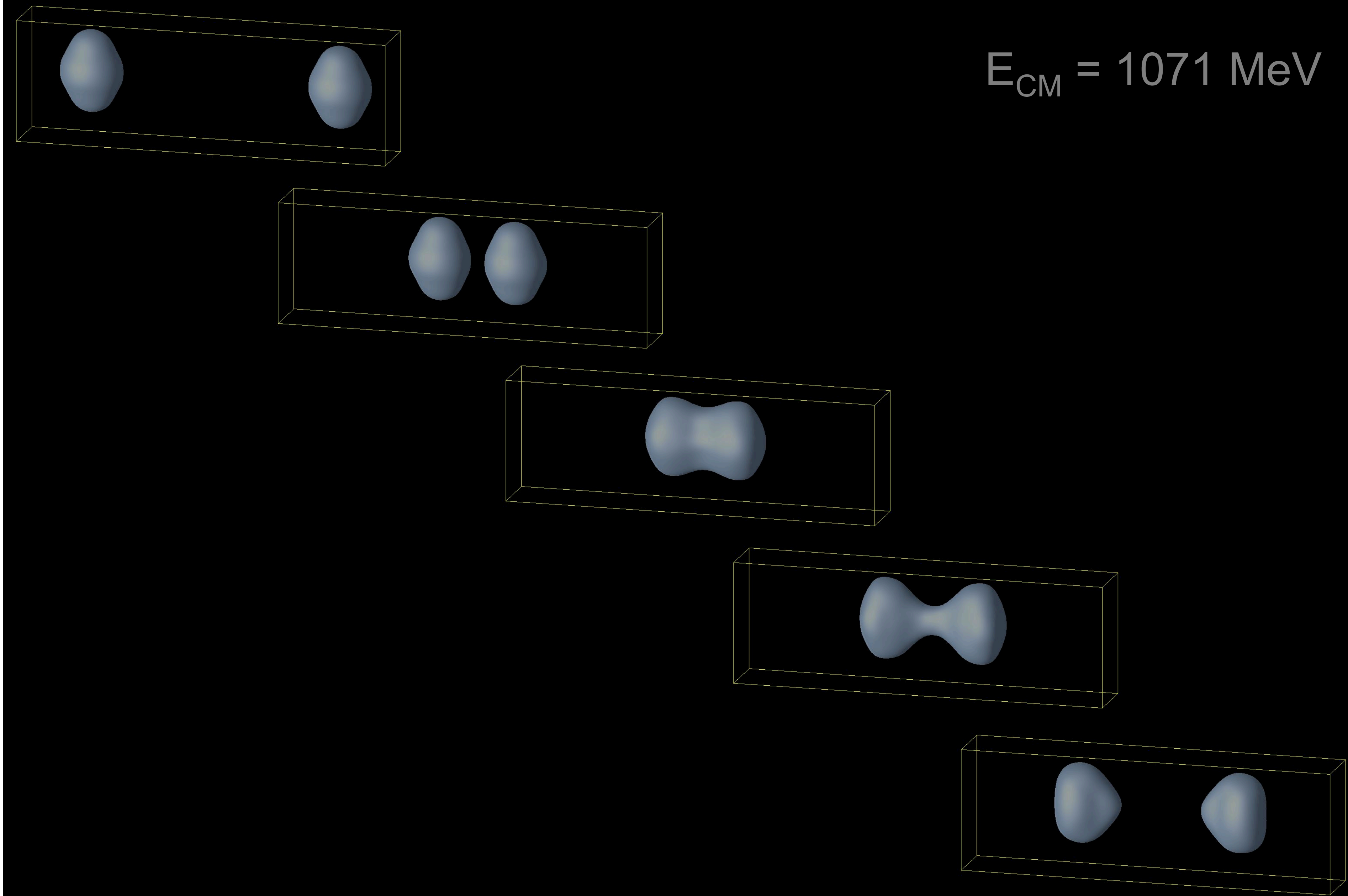
II) Applications to fusion: *collision time of* $^{238}U+^{238}U$

collision time maximum for side on side

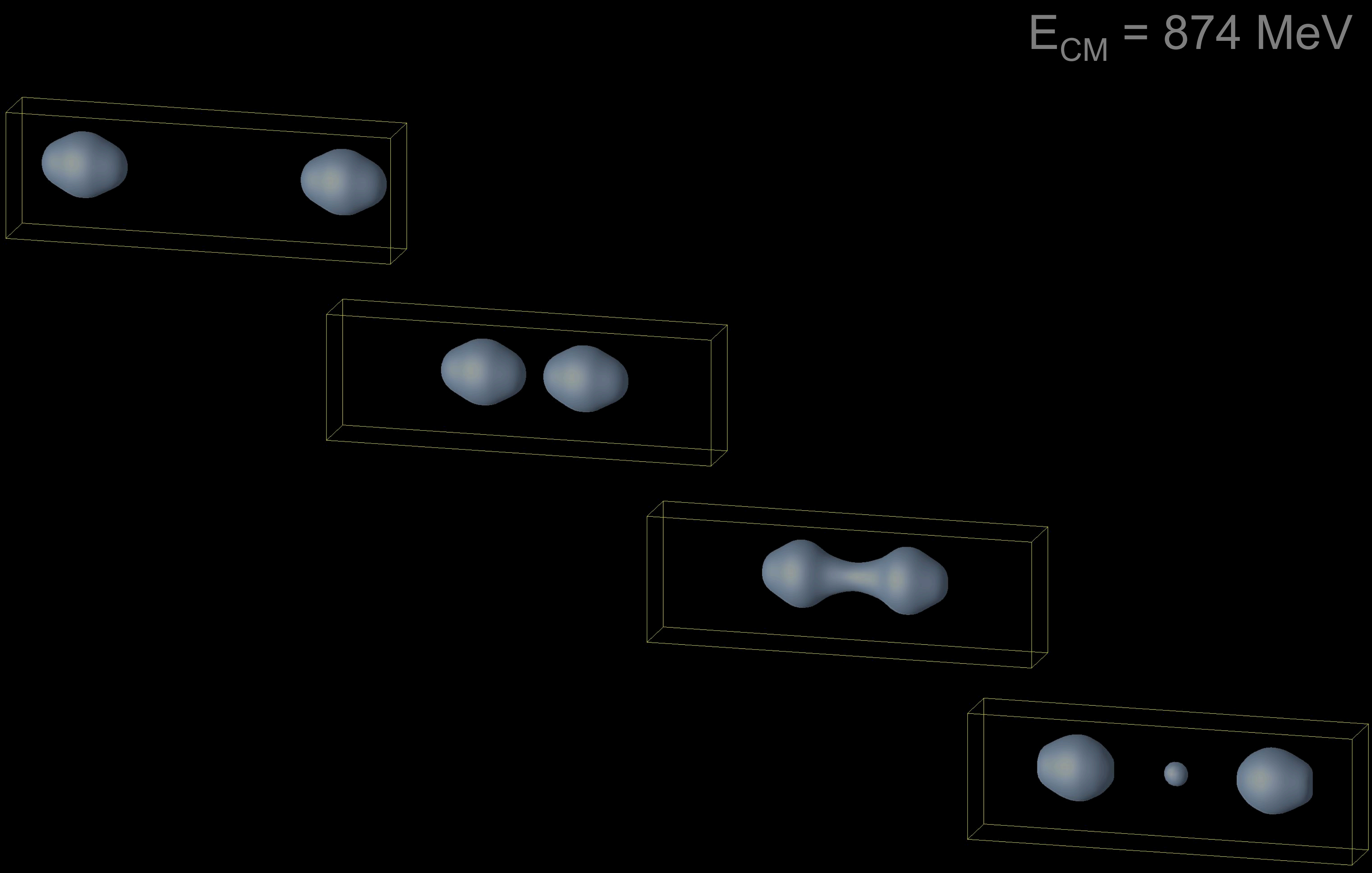
C. Golabek and C.S., in preparation



II) Applications to fusion: *collision time of* $^{238}U+^{238}U$



II) Applications to fusion: *collision time of $^{238}U+^{238}U$*



Conclusions

- **TDHF ok for fusion barriers and cross sections above B**
- **Fusion hindrance for heavy systems**
- **$^{238}U+^{238}U$ collision time might be to short for e^+e^- production**

Perspectives

- **Fusion with exotic nuclei: *role of symetry energy ?***
- **Mechanisms responsible for fusion hindrance ?**
- **Effect of pairing ? *TDHFB*** B. Avez, C.S. and Ph. Chomaz, PRC 2008.
- **Beyond TDHF to go below the barrier.**

Perspectives

TDHF publications in nuclear physics