Overview of Time-Dependent Energy-Density-Functional approach for heavy ion collisions

B. Avez

Centre d'Etudes Nucléaires de Bordeaux Gradignan
Université Bordeaux 1 & CNRS/IN2P3, Gradignan, France

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Weilrod, Germany

The time-dependent Hartree-Fock approach...

is a natural generalization of mean-field based methods :

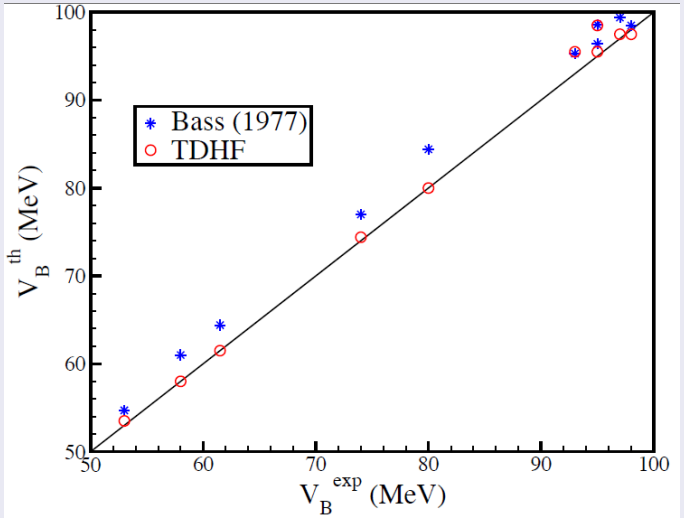
- Microscopic description of nuclear dynamics
- Unified picture of structure and dynamics
  the only parameters are the functional parametrization (Skyrme).
- Allows to investigate dynamical processes
  - small amplitude collective motion (giant resonances)
  - **Heavy ion collisions, without assumption of a particular reaction mechanism**

Bias (or simplicity of the method): "mean-field" description, wave-function approximated by a single product N-body wave-function

TDHF for fusion: successes -and limitations-

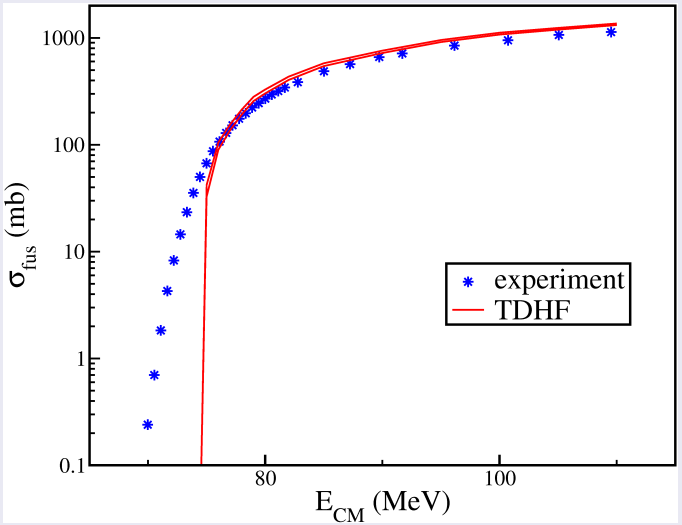
Fusion barriers

from ^{40}Ca $+^{40}$ Ca to ^{58}Ni $+^{60}$ Ni



Excitation functions

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

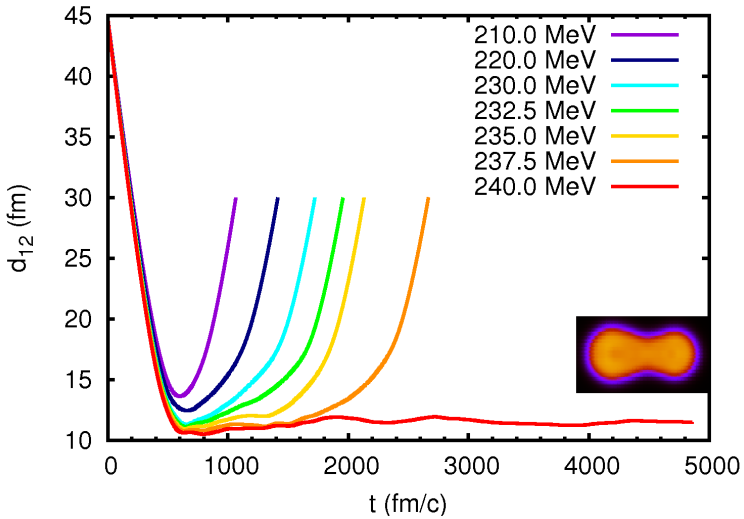


[C. Simenel et B.A., IJMP E 17, 31 (2008)]

- Good overall reproduction of fusion barriers
  including for deformed nuclei (broad barrier distributions)
- Semi-classical trajectories $\rightarrow$ no fusion below the barrier

Fusion mechanisms: Quasi-symmetric fusion and fusion hindrance (1)

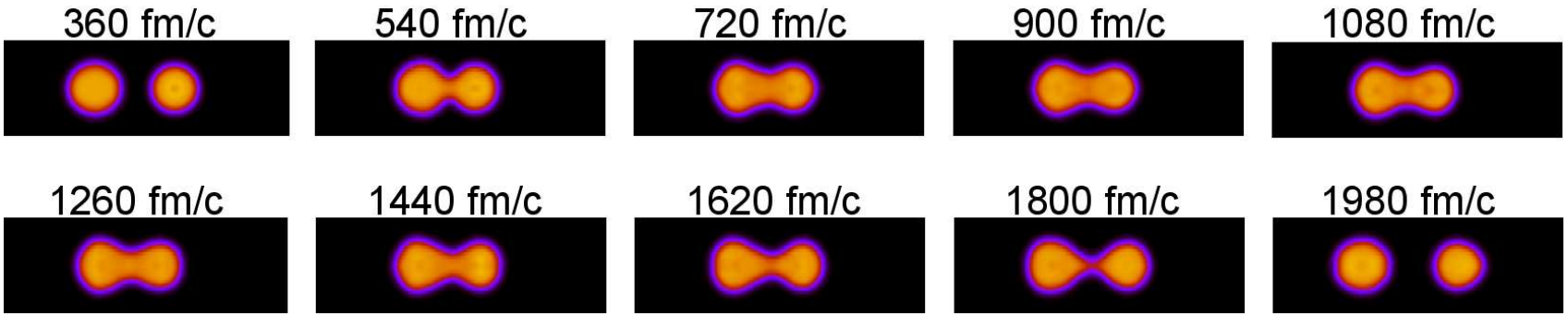
Problematic of fusion hindrance (with increasing $Z_1 \times Z_2$)
Relative CoM motion $\rightarrow$ one-body dissipation (sp degrees of freedom)



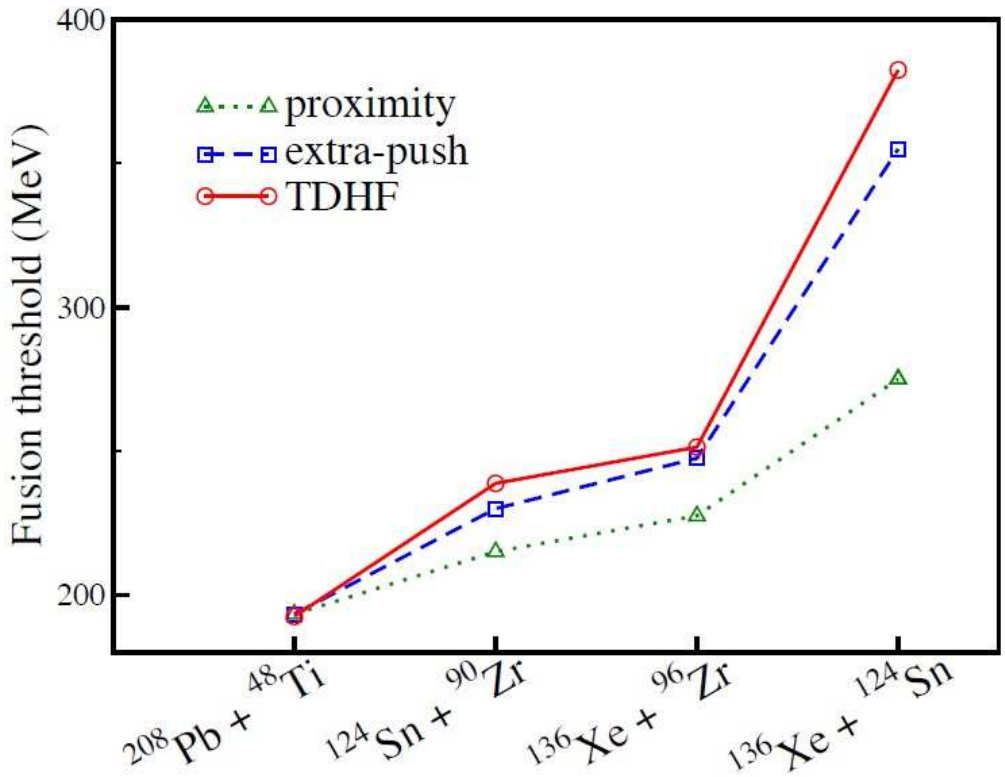
trajectories of ^{124}Sn+^{90}Zr

- $V_B^{frozen} = 218.1$ MeV
- $V_B^{dyn} = 238.75$ MeV (± 1.25)
- "extra-push" energy ≈ 20 MeV
- final system strongly deformed (not a compound nucleus)

Example of density changes: ^{124}Sn+^{90}Zr @ 235 MeV (CoM)



Fusion mechanisms: Quasi-symmetric fusion and fusion hindrance (2)

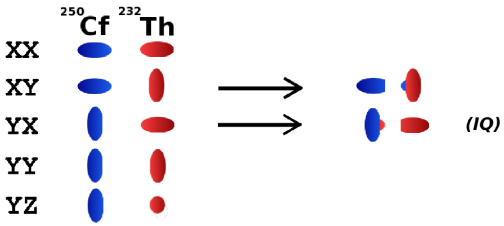


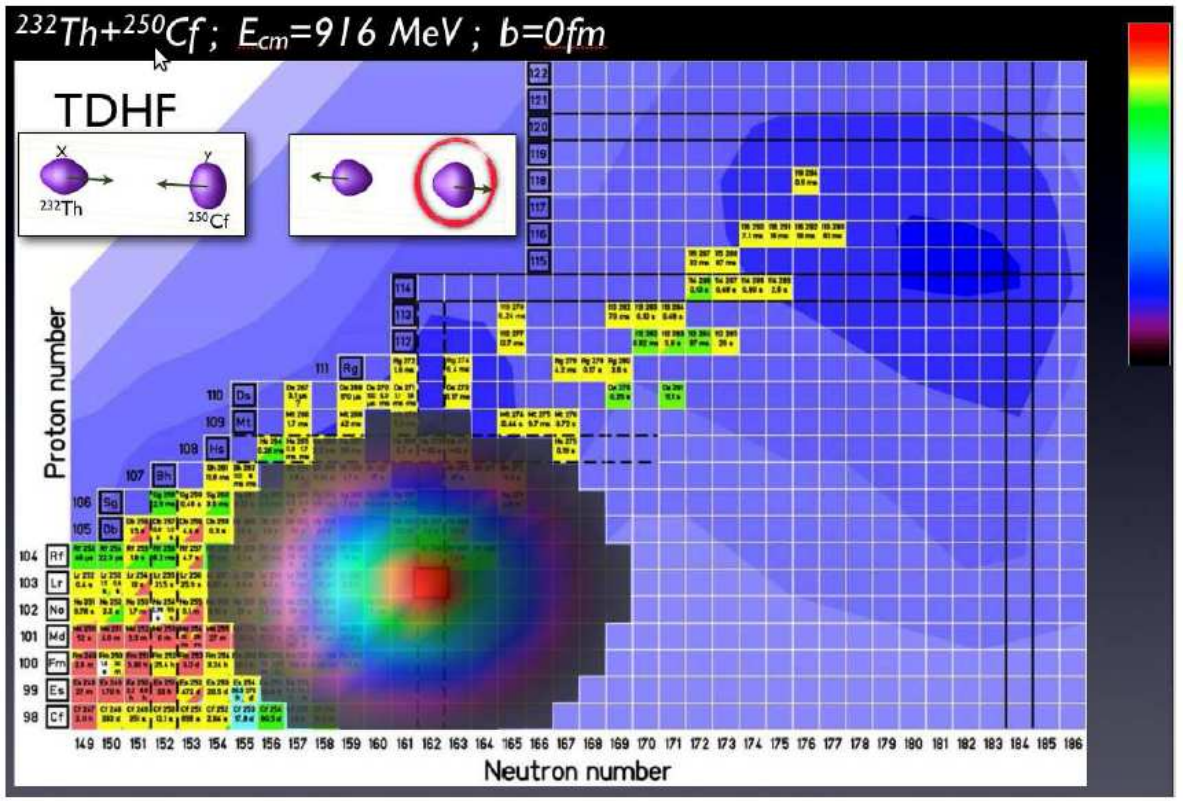
TDHF naturally accounts for the one-body dissipation in quasi-symmetric entrance channels

$\rightarrow$ further studies needed to scrutinize the mechanisms in the "extra-push" window

Collision of actinides: "Inverse Quasifission"

Inverse quasifission mechanism feeding very heavy elements
allowed by side-tip orientation of actinides
From ^{250}Cf to the neighborhood of ^{265}Lr





[D.J. Kedziora and C. Simenel, PRC 81, 044613 (2010)]

TDHF: promising results towards mechanisms leading to SHE/VHE

Promising results for the study of fusion/DIC mechanisms

- Charge and mass equilibration/tranfer,
  energy transfer from CoM $\rightarrow$ sp degrees of freedom
- Extraction of macroscopic quantities from a microscopic approach:
  ion-ion potentials, shape evolution, excitation of the dinuclear system...
  Cf. Lacroix, Washiyama, Ayik
  Cf. Umar, Oberacker, Maruhn, Reinhard
- Capture cross-sections
  recent TDHF applications for SHE (Umar, Oberacker, Maruhn, Reinhard, PRC 81, 064607 (2010))
- Quasifission mechanisms
  Cf. Simenel and Kedziora

Such studies should also benefit from new Skyrme parametrizations coming from time-independent EDF developments

Improving TDHF: Challenges for the future

Improving the model is needed...

- ...by including pairing correlations (TDHF-Bogoliubov)
- ...by including fluctuations (better reproduction of the opened exit channels)
  $\rightarrow$ Balian-Véneroni variational principle
- ...to account for tunneling of the N-body wave-function (fusion below the barrier)
- ...to account for thermal equilibration of the compound nucleus

$\rightarrow$ Need to go explicitely beyond the mean-field (Trajectory mixing, nucleon-nucleon collisions, stochastic mean-field approaches)