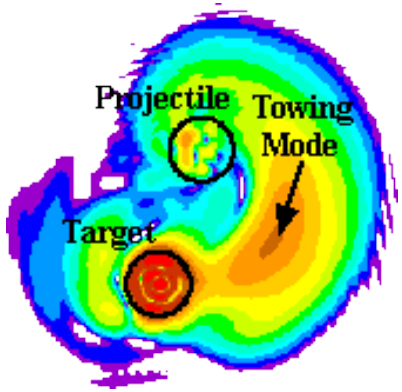


Time-Dependent approaches beyond mean-field

Denis Lacroix

GANIL-Caen

Coll: M. Assié, B. Avez, S. Ayik,
Ph. Chomaz, N. Dubray,
G. Hupin, H. Goutte
C. Simenel, R. Bernard,
J.A. Scarpaci, K. Washiyama

Microscopic theory

Challenges beyond mean-field

Beam Energy

5 MeV/A

10 MeV/A

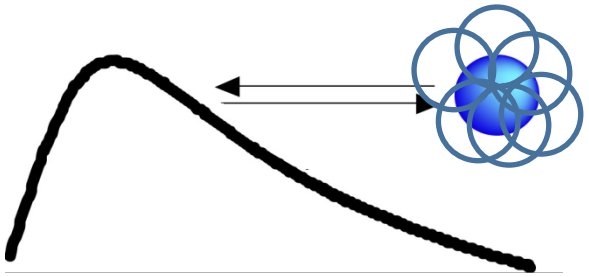
50 MeV/A

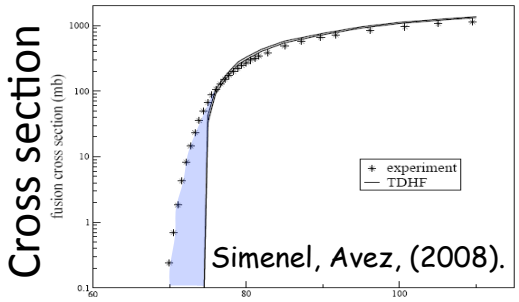
100 MeV/A

- Fusion
- Transfer★
- Break-up★ (Nuclear, Coulomb)
- Knock-out★

★**Spectroscopic tools**

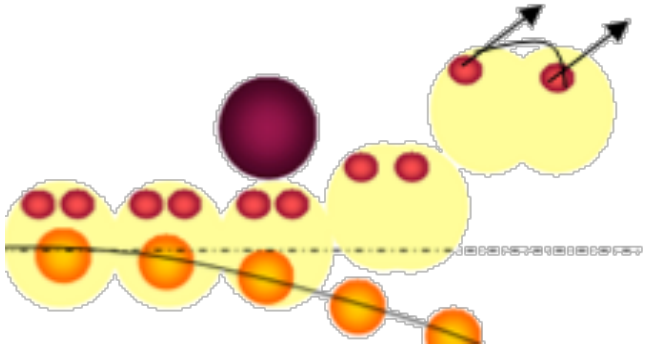
Configuration mixing



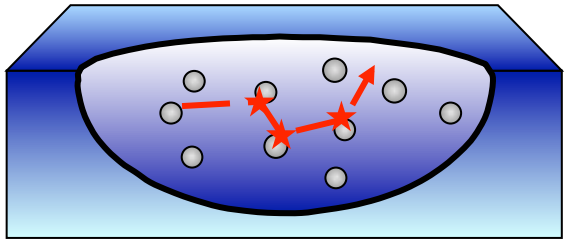


Center of mass En.

Pairing



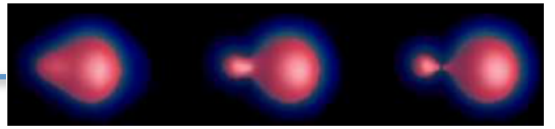
Direct NN collisions



+Enhanced effect of the continuum In exotic nuclei

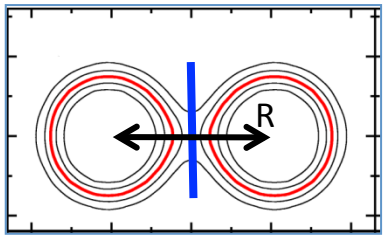
Reactions close to the Coulomb barrier

Illustration I : Fusion

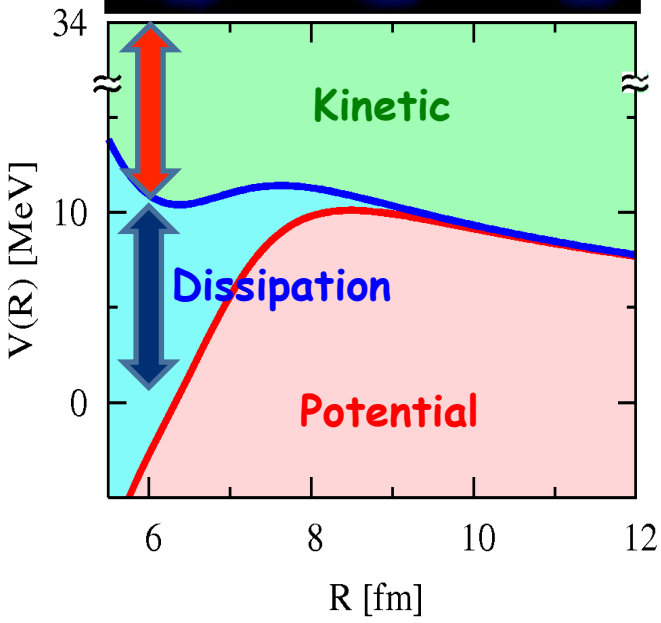


Washiyama, DL, PRC78 (2008).
Washiyama, DL, Ayik, PRC79 (2009).

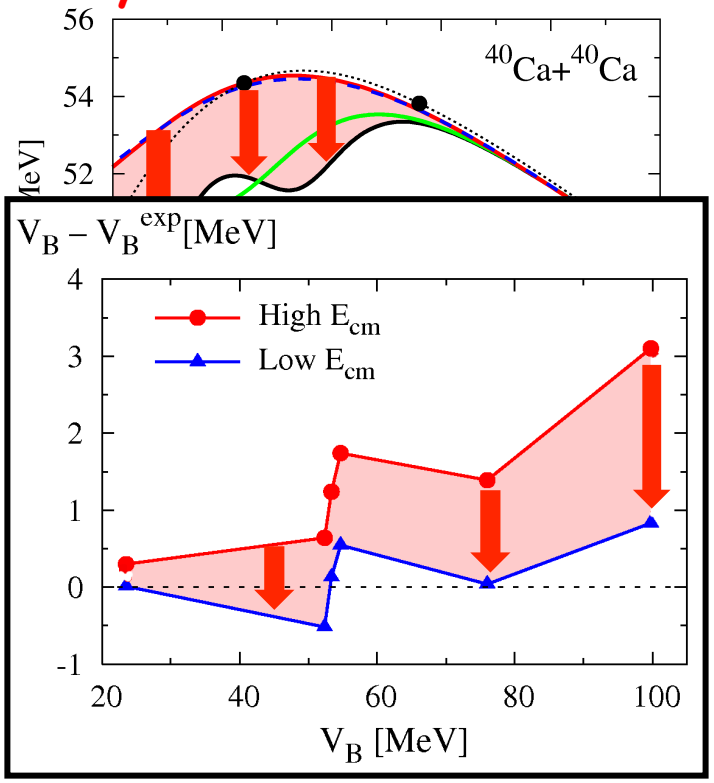
Macroscopic reduction

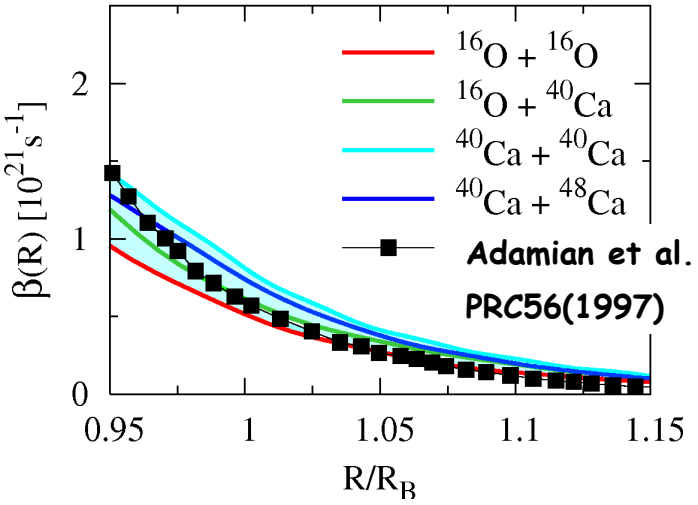


$$\frac{dP}{dt} = -\frac{dV}{dR} - \gamma(R)\frac{dR}{dt}$$



Dynamical Reduction effect

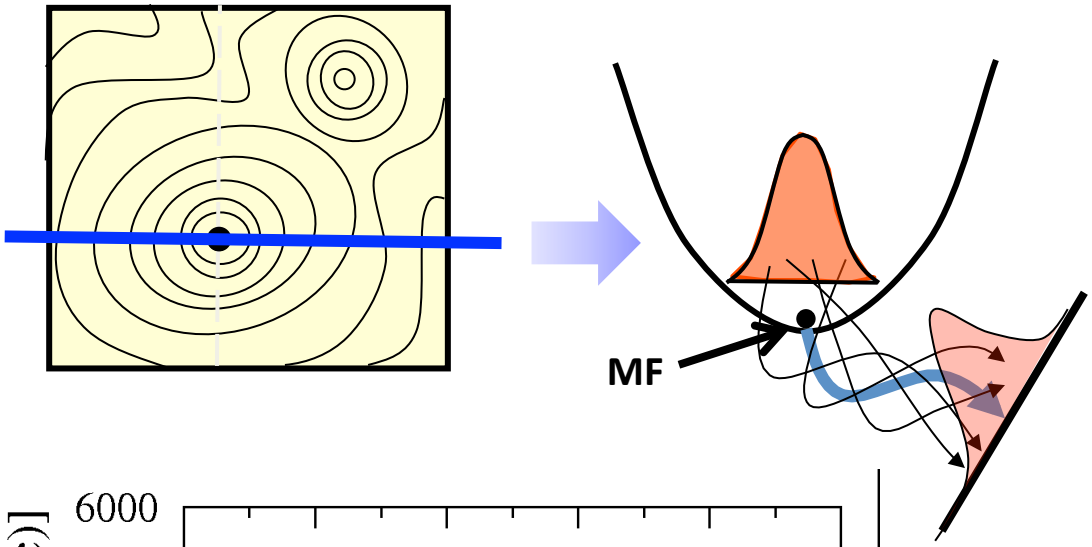


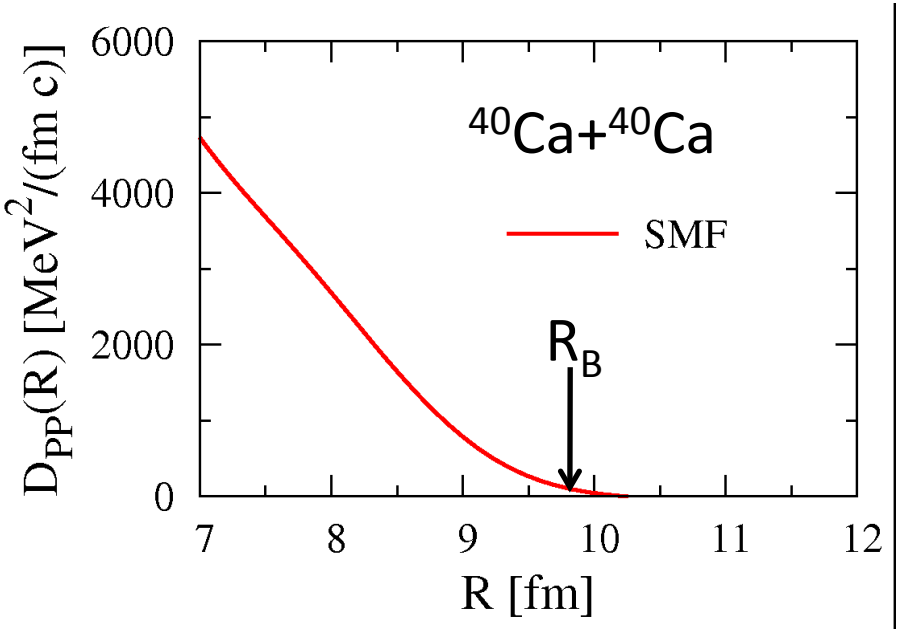


Dissipation ⇒ Internal Excitation

Toward a systematic treatment of initial correlations

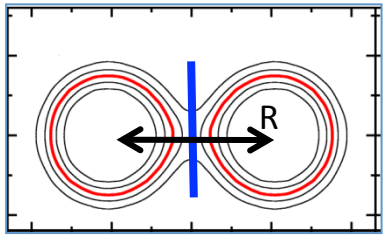
Ayik, PLB 658, (2008).





Ayik, Washiyama, DL, PRC (2009)

Application to fusion

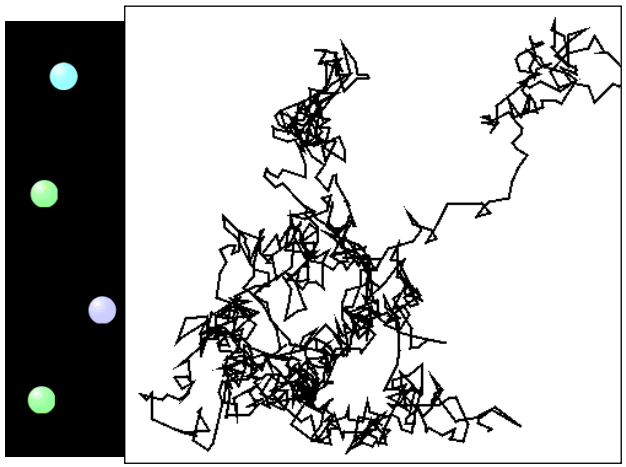


Mean-field

$$\frac{d}{dt}P = -\frac{d}{dR}U(R) - \gamma(R)\dot{R}$$

Mean-field+Initial fluct.

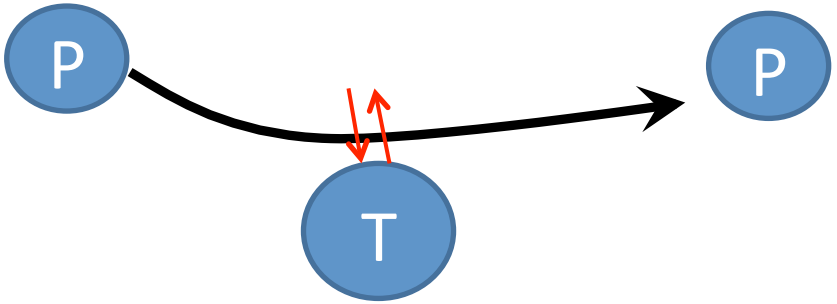
$$\frac{d}{dt}P^{\lambda} = -\frac{d}{dR^{\lambda}}U(R^{\lambda}) - \gamma(R^{\lambda})\dot{R}^{\lambda} + \xi_P^{\lambda}(t)$$

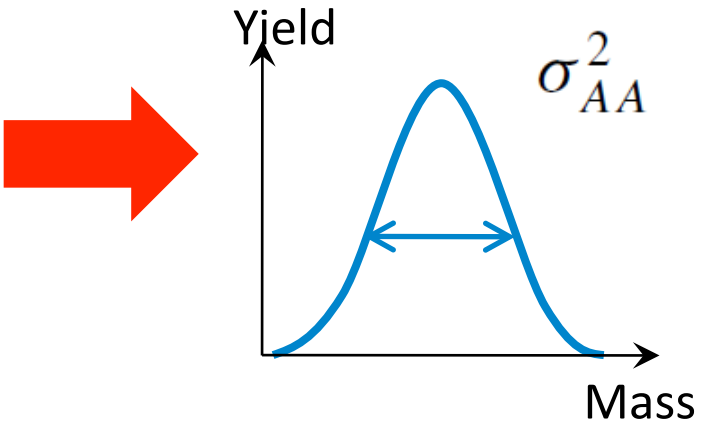


$$\overline{\xi_P^{\lambda}(t)\xi_P^{\lambda}(t')} = 2\delta(t-t')D_{PP}(R)$$

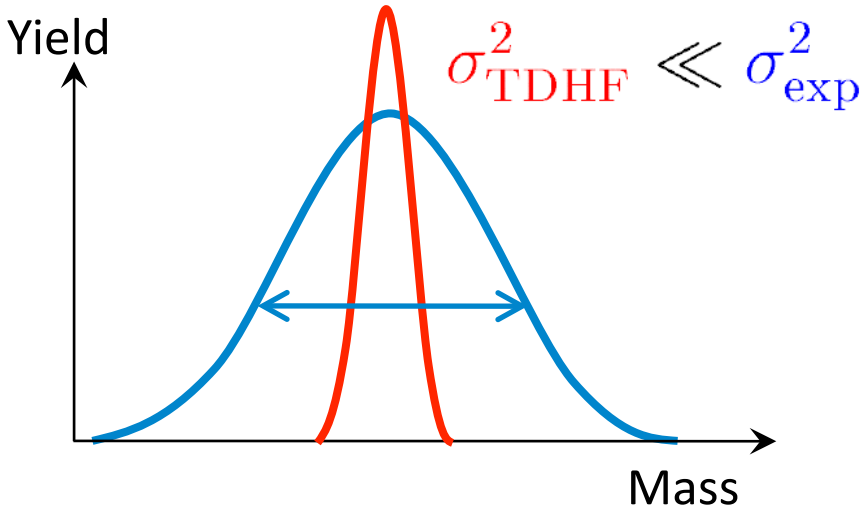
Toward a systematic treatment of initial correlations

Ayik, PLB 658, (2008).





Width of mass distribution in DIC



● Long standing problem

- Davies et al., PRL41 (1978)
- Negele, Rev.Mod.Phys.54 (1982)
- Abe et al., Phys.Rep.275 (1996)
- Lacroix et al., Prog.Part.Nucl.Phys. (2004)

◆ (semi-)Classical

- Feldmeier, Rep.Prog.Phys.50(1987)915
- Chomaz et al., Phys.Rep. 389(2004)263

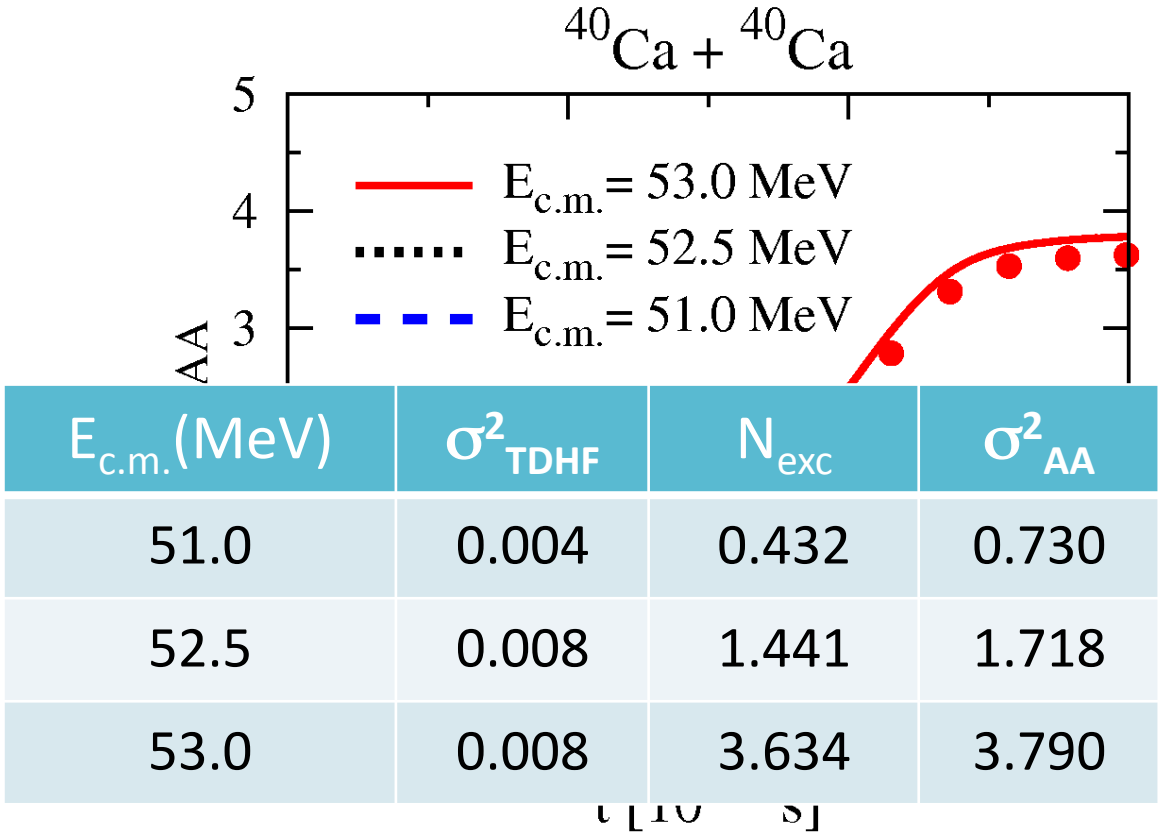
Mass fluctuations and exchanged nucleons

Stochastic mean-field

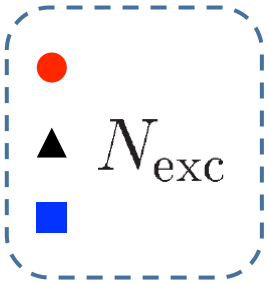
$$\frac{d}{dt}A_P^\lambda = v(A_P^\lambda, t) + \xi_A^\lambda(t)$$

$$\overline{\xi_A^\lambda(t)\xi_A^\lambda(t')} = 2\delta(t-t')D_{AA}$$

$$\sigma_{AA}^2(t) \simeq 2\int_0^t D_{AA}(s)ds$$



E$_{c.m.}$(MeV)	σ$^2_{TDHF}$	N$_{exc}$	σ$^2_{AA}$
51.0	0.004	0.432	0.730
52.5	0.008	1.441	1.718
53.0	0.008	3.634	3.790



Washiyama, Ayik, DL, PRC (2009).

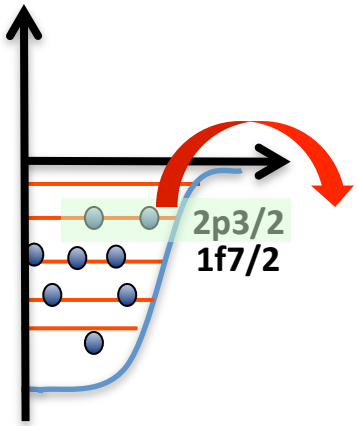
Nuclear Break-up

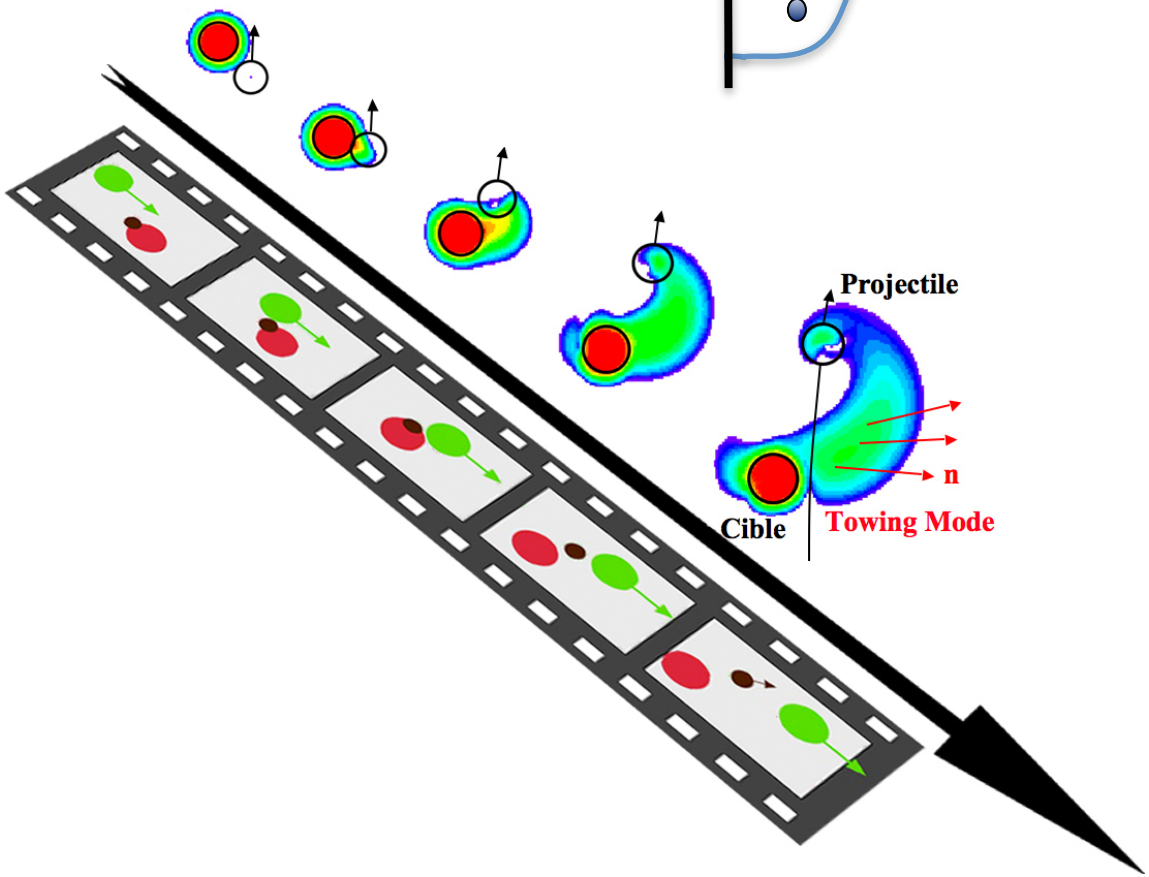
Application III: Time-Dependent Schrödinger approach on a 3D mesh

break-up as a spectroscopic tool

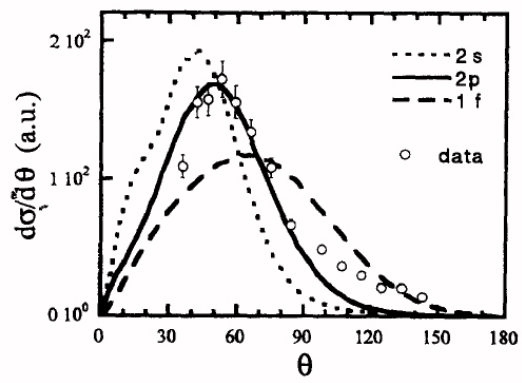
First example:

^{58}Ni break-up @44 MeV/A

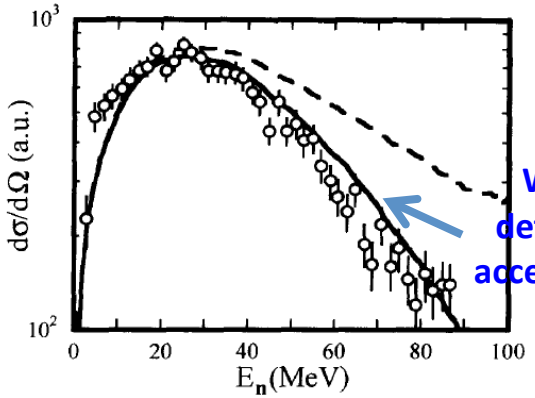




Angular distribution:



Kinetic Energy distribution:



With detector acceptance

DL, Scarpaci, Chomaz, NPA658 (1999)

Configuration Mixing from a different perspective

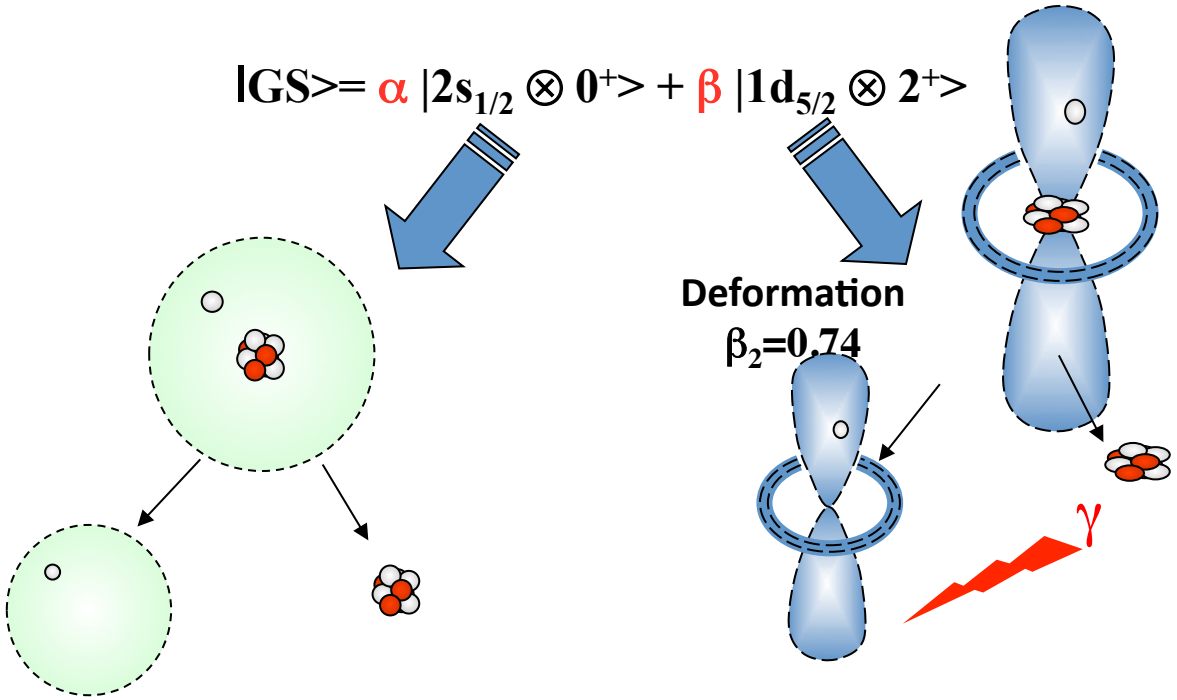
Time-Dependent Generator Coordinate Method (TDGCM)

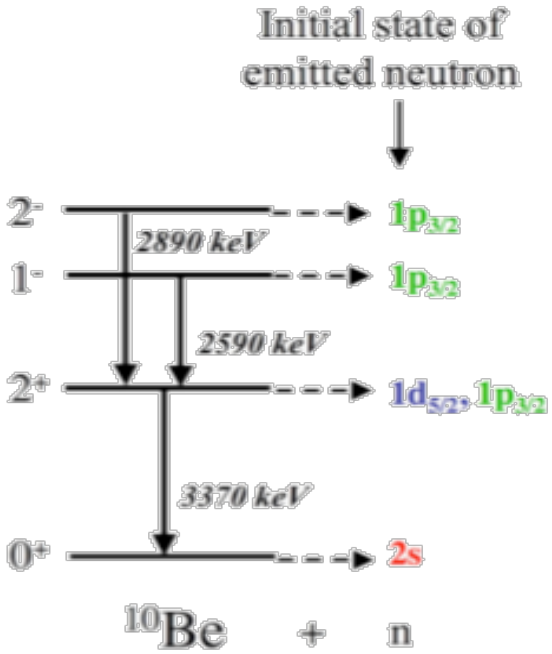
$$i\hbar\frac{d|\Psi\rangle}{dt} = \cancel{\int dQ\left\{i\hbar\frac{\partial f(Q)}{\partial t}\right\}|\Phi(Q)\rangle} + \int dQ f(Q)\left\{i\hbar\frac{\partial}{\partial t}|\Phi(Q)\rangle\right\}$$

Application: break-up of ^{11}Be

Lima et al., NPA795 (2007) 1

$|GS\rangle = \alpha\,|2s_{1/2}\otimes 0^+\rangle + \beta\,|1d_{5/2}\otimes 2^+\rangle$

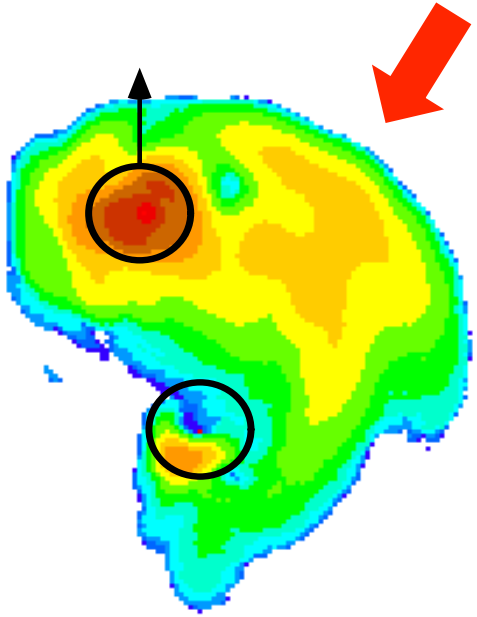


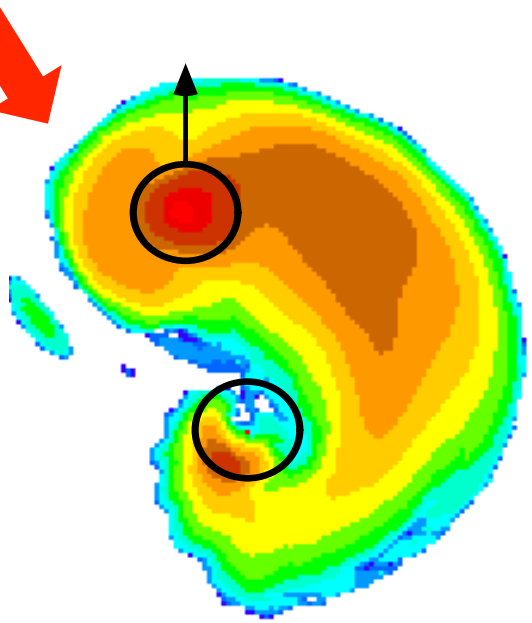


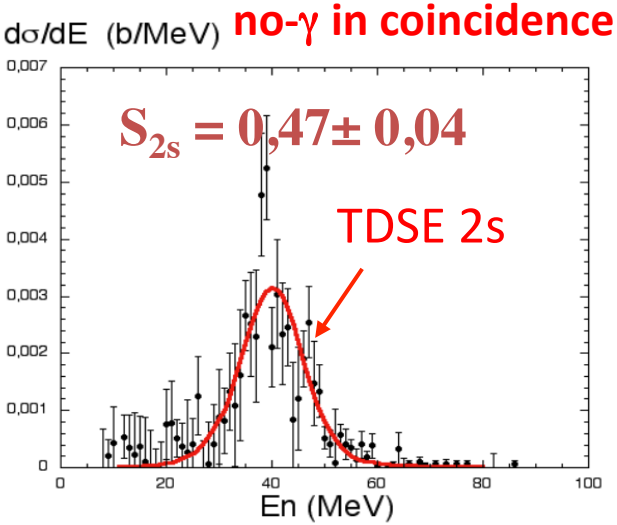
Configuration Mixing in Time-dependent approaches

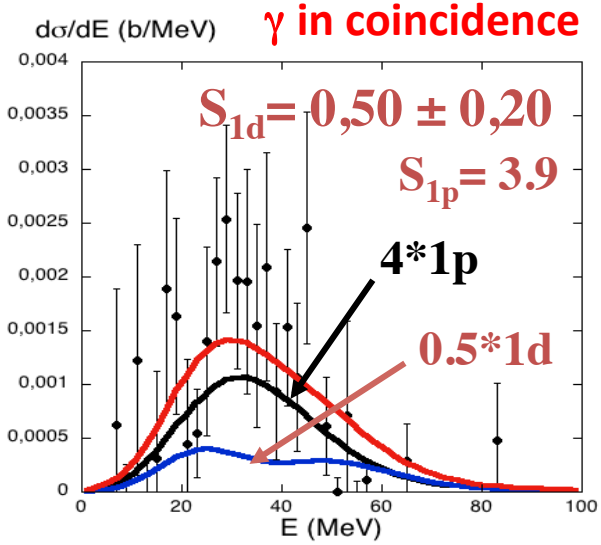
Lima et al., NPA795 (2007) 1

Configuration mixing in ^{11}Be: $|GS\rangle = \alpha\,|2s_{1/2} \otimes 0^+\rangle + \beta\,|1d_{5/2} \otimes 2^+\rangle$



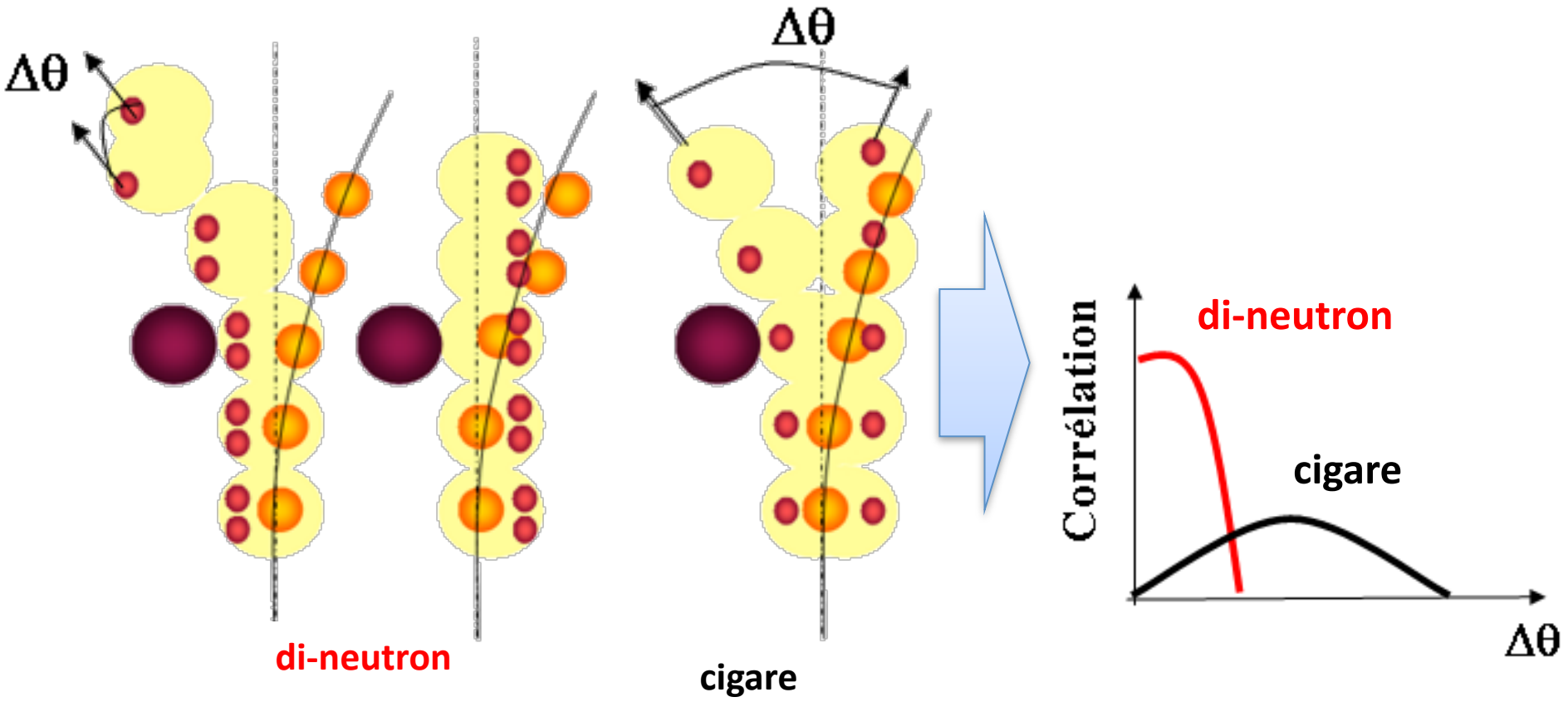






First application : Nuclear break-up of correlated systems

Physical Intuition



General strategy

Starting point

$$H = \sum_{ij} \langle i|T|j\rangle a_i^+ a_j + \frac{1}{2}\sum_{ijkl}\langle ij|v_{12}|lk\rangle a_i^+ a_j^+ a_l a_k$$

Static

$$E_{\text{Exact}} = \langle\Psi|H|\Psi\rangle = E_{\text{MF}}[\rho] + E_{\text{Corr}}[C_{12}]$$

$$\rho = \sum |\varphi_i\rangle n_i \langle\varphi_i|$$

$$C_{12} = \rho_{12} - \rho_1\rho_2(1 - P_{12})$$

Relevant parameters

$$\{\varphi_i, n_i, C_{ij;kl}\}$$

Dynamic (BBGKY hierarchy)

$$i\hbar\tfrac{\partial}{\partial t}\rho_1 = [h_1[\rho], \rho_1] + \tfrac{1}{2}\text{Tr}_2[\bar{v}_{12}, C_{12}]$$

$$i\hbar\tfrac{\partial}{\partial t}C_{12} = [h_1[\rho] + h_2[\rho], C_{12}]$$

$$+\tfrac{1}{2}\left\{(1-\rho_1)(1-\rho_2)\bar{v}_{12}\rho_1\rho_2 - \rho_1\rho_2\bar{v}_{12}(1-\rho_1)(1-\rho_2)\right\} \Longleftrightarrow B_{12}$$

$$+\tfrac{1}{2}\left\{(1-\rho_1-\rho_2)\,\bar{v}_{12}C_{12} - C_{12}\bar{v}_{12}\,(1-\rho_1-\rho_2)\right\} \Longleftrightarrow P_{12}$$

$$+\text{Tr}_3\left[\bar{v}_{13}, (1-P_{13})\,\rho_1 C_{23}\,(1-P_{12})\right]$$
$$+\text{Tr}_3\left[\bar{v}_{23}, (1-P_{23})\,\rho_1 C_{23}\,(1-P_{12})\right] \Longleftrightarrow H_{12}$$

~~+ 3-body~~

N-N collisions

Pairing

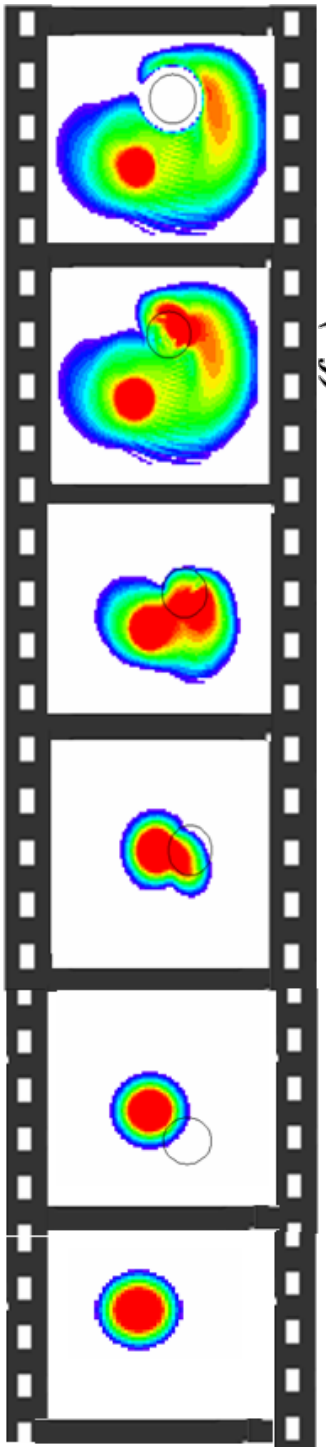
Higher order

⇨ **Time Dependent Density Matrix (TDDM)**

Lacroix , Ayik, Chomaz , Prog. Part. and Nucl. Phys. (2004)
Simenel, Avez, Lacroix, (2008) arXiv:0806.2614.

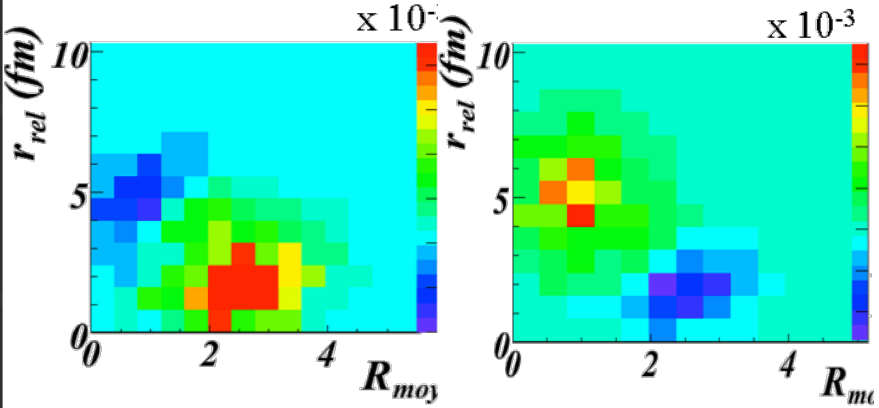
Nuclear break-up of correlated systems

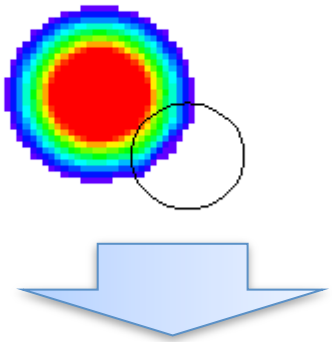
Assié, DL, PRL (2009)



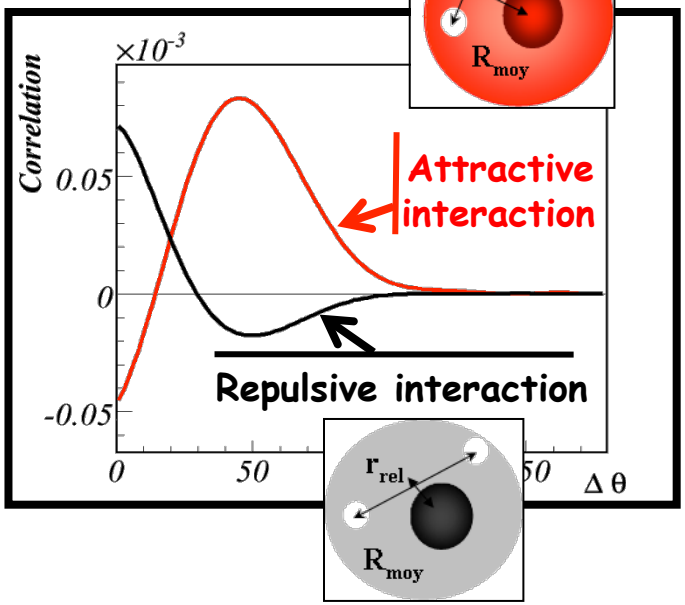
attractive int.

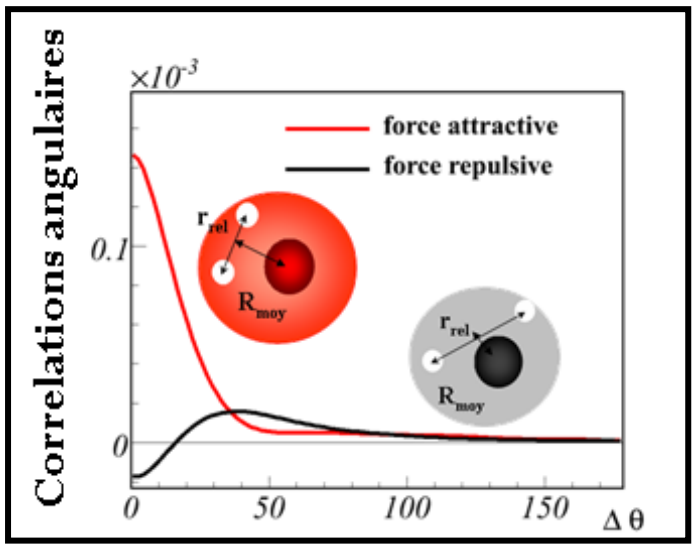
répulsive int.





Different initial correlations

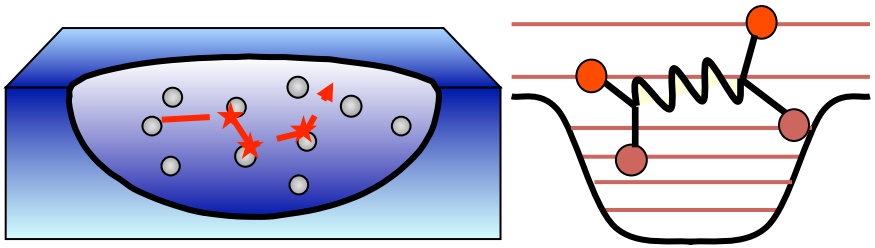




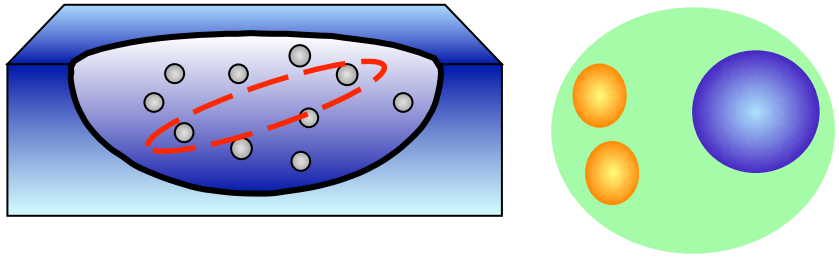
Conclusion and summary

Challenges beyond mean-field

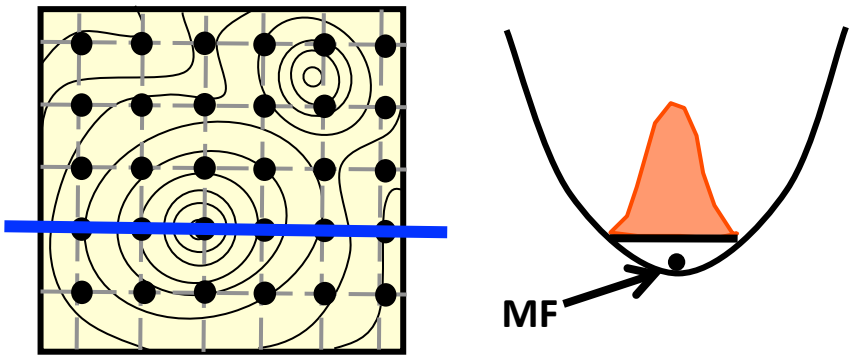
In-medium nucleon-nucleon collisions



Pairing correlation



Configuration mixing



Extended TDHF (vibration)

TDHFB (vibration)

TDDM or TDDM^P (breakup, vibration)

TDGCM (Fission)

Stochastic Mean-Field (Fusion, transfer)

Quantum Monte-Carlo (path integrals) (Simple Bose or Fermi systems)

Now under development

- TDDM^{P}: nuclear structure, giant resonances, transfer with (M. Assié)

- Time-Dependent EDF with pairing
  1-TDHF+BCS (K. Washiyama)
  2-Beyond BCS (G. Hupin)

- Alpha clustering in N=Z nuclei (pn pairing) through break-up with (J.-A. Scarpaci)