Description of fission

First comparison between microscopic and macroscopic-microscopic Potential Energy Surfaces

M. Verriere[1]

T. Kawano[1], M. R. Mumpower[1], P. Talou[1], N. Schunck[2]

[1] *Los Alamos National Laboratory, Los Alamos, NM 87545, USA*
[2] *Lawrence Livermore National Laboratory, Livermore, CA 94551, USA*

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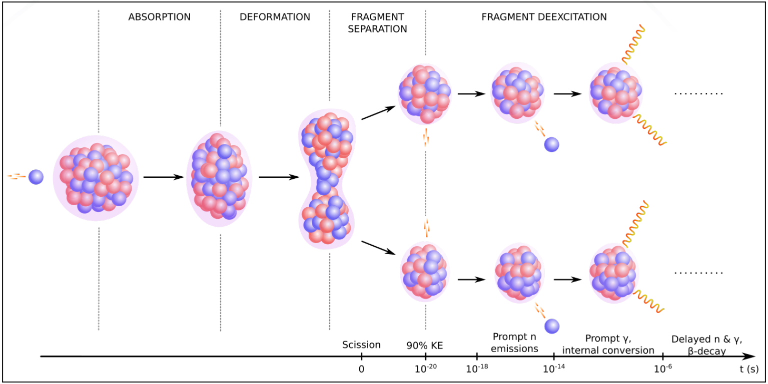
Context

1. National security
   - nuclear deterrence
   - non-proliferation

2. Energy
   - nuclear power plants

3. Fundamental Science
   - formation of elements in nucleosynthesis (r-process)
   - stability of superheavy elements

Neutron induced fission process



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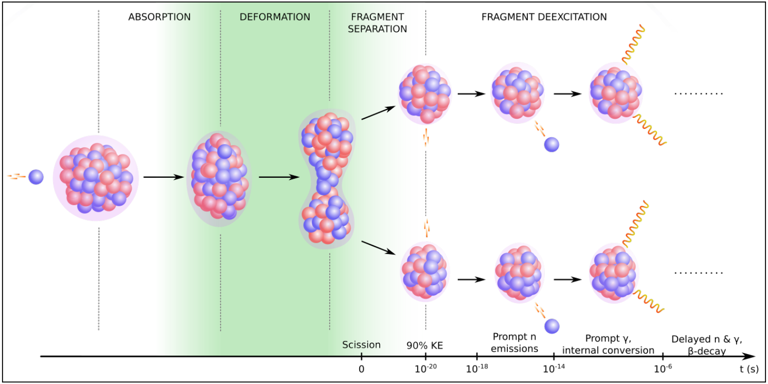
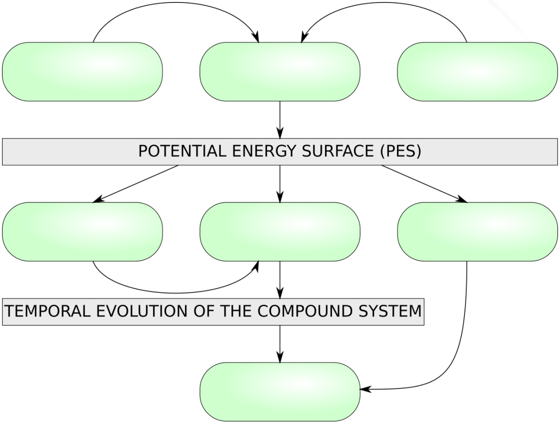


Description of the fission process



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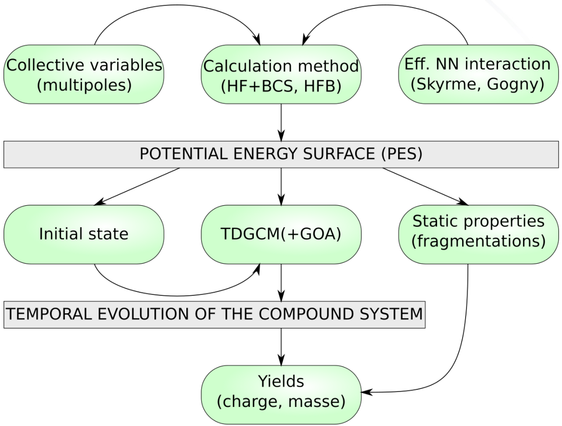

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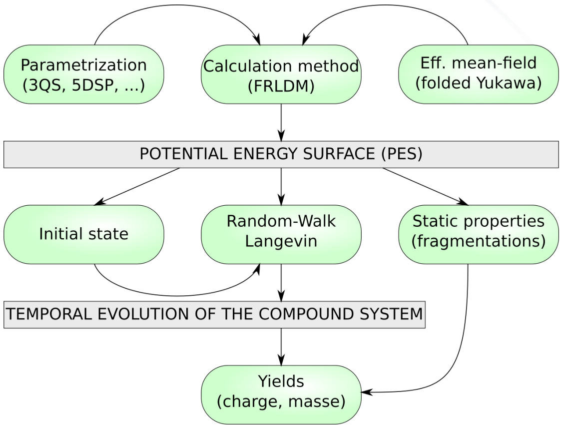

Outline

1. Presentation of the approaches
2. Comparison
3. Conclusion

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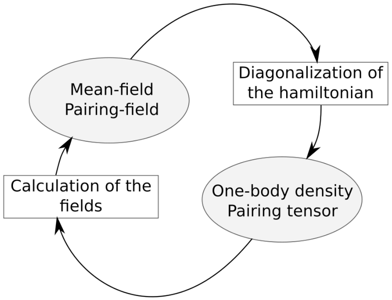
Microscopic approach

Hartree-Fock-Bogoliubov

- Minimization of the total binding energy
- Mean/pairing field from NN interaction
- Self-consistent
- Requires an important calculation power ($>$ 10min/state)



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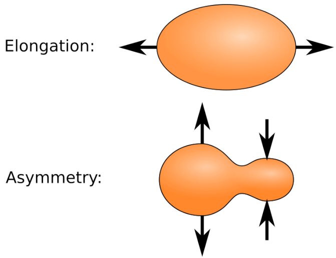
Constraints:
elongation (Q_{20}) and asymmetry (Q_{30})



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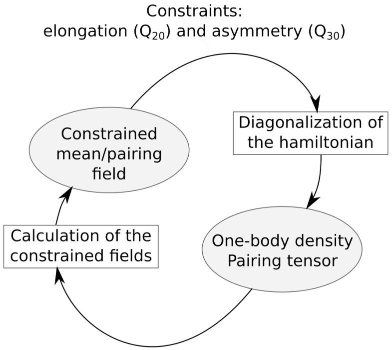


Macroscopic-microscopic approach

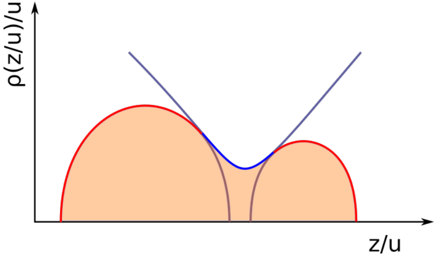
Finite Range Liquid-Drop

- Parametrization of the geometric shape
- Total binding energy E:

$$E = E_{mac} + \Delta E_{\mathrm{sh}} + \Delta E_{\mathrm{pair}}$$

- E_{mac}: Smooth energy
- ΔE_{sh}: Shell correction
- ΔE_{pair}: Pairing correction

Tri-Quadratic Surface parametrization (3QS)



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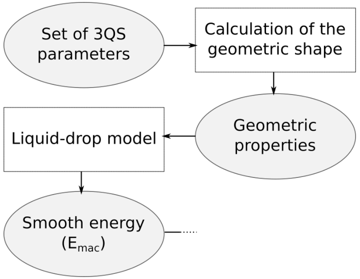
FRLDM – macroscopic part



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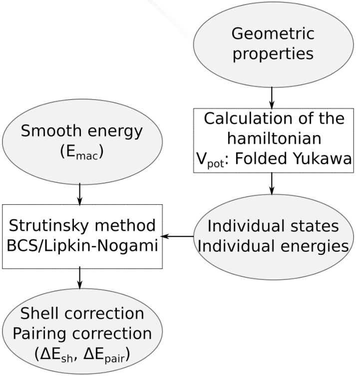
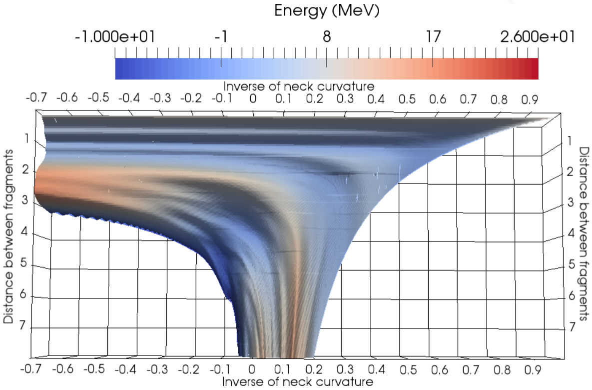
FRLDM – microscopic part



Potential energy surface of ^{236}U

3QS parametrization: $\alpha_2 = 0.0$, $\alpha_3 = 0.0$, $\sigma_3 = 1.0$



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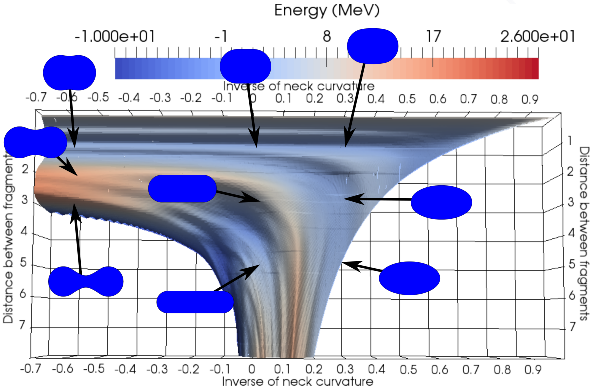

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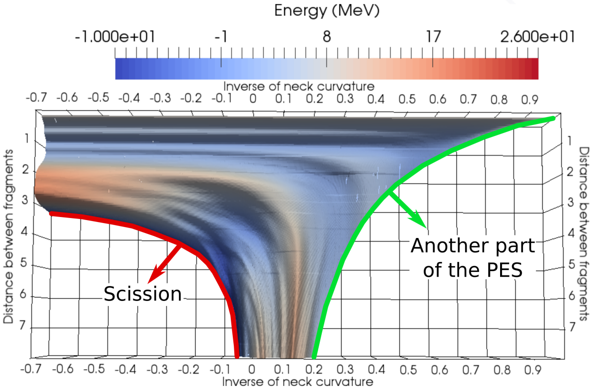
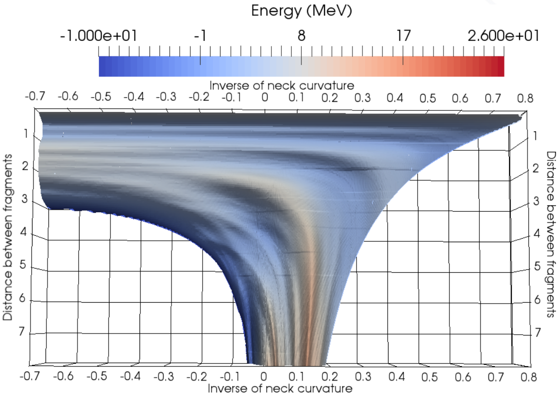


Potential energy surface of ^{236}U

3QS parametrization: $\alpha_2 = 0.2$, $\alpha_3 = 0.0$, $\sigma_3 = 1.0$



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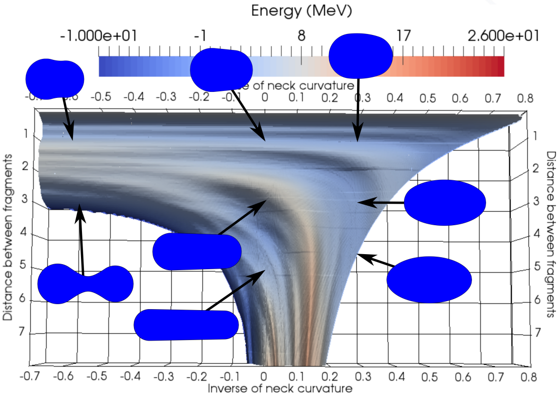
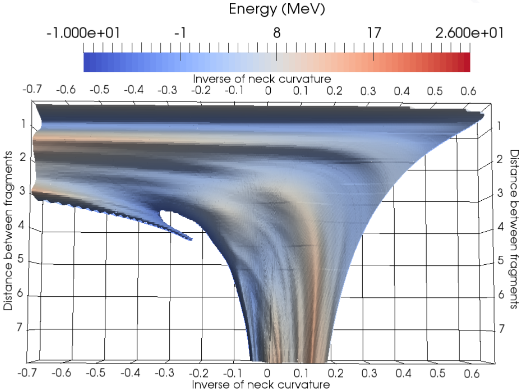


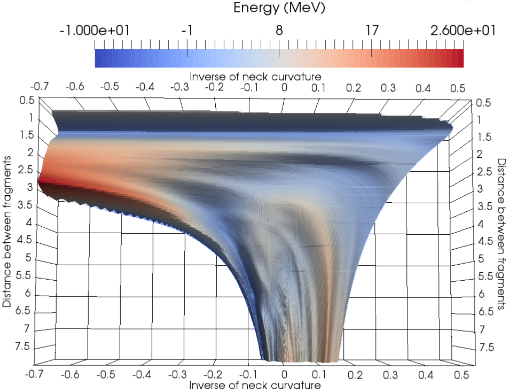
Potential energy surface of ^{236}U

3QS parametrization: $\alpha_2 = 0.4$, $\alpha_3 = 0.0$, $\sigma_3 = 1.0$



Potential energy surface of ^{236}U

3QS parametrization: $\alpha_2 = 0.6$, $\alpha_3 = 0.0$, $\sigma_3 = 1.0$



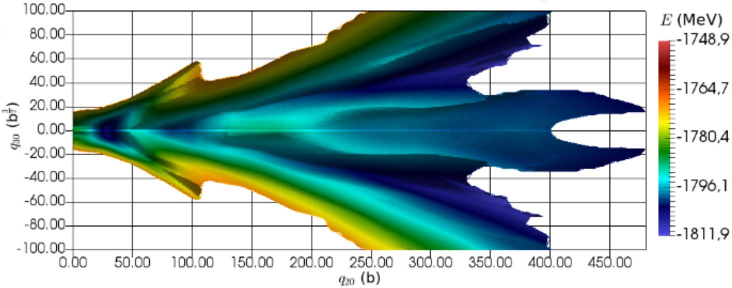
Outline

Approaches

- Calculation of microscopic potential energy surfaces
  1. few parameters (≈ 15),
  2. only 2-3 degree of freedom (usually $\hat{Q}_{20}$, $\hat{Q}_{30}$ and $\hat{Q}_{40}$),
  3. discontinuities and local minima,
  4. 10 minutes per states (≈ 100000 states in 2D).

- Calculation of macroscopic-microscopic potential energy surfaces
  1. more parameters (≈ 25),
  2. <0.2 second per states, $\approx 3000\times$ faster,
  3. possibility to include more degrees of freedom (5D),
  4. no discontinuities.

Microscopic PES, ^{240}Pu

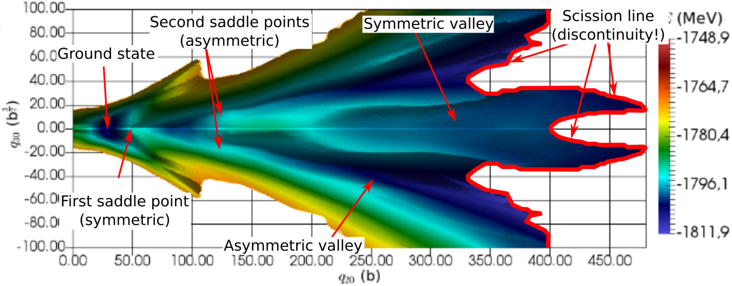


2-dimensional Potential Energy Surface of $^{240}\mathrm{Pu}$

PES propagation code: M. Verriere, N. Dubray

HFB code: J.-F. Berger, N. Dubray, M. Verriere, (axial, 2 centers HO basis)

Microscopic PES, ^{240}Pu



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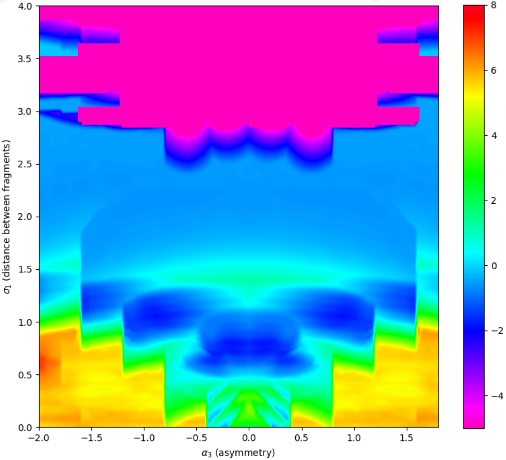
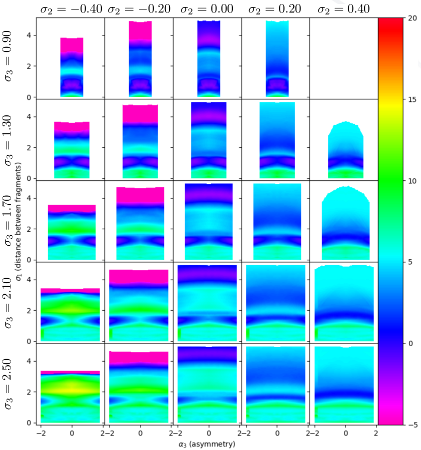


2-Dimensional Potential Energy Surface of $^{240}\mathrm{Pu}$ (preliminary)

Macroscopic-microscopic PES, ^{240}Pu



4-Dimensional Potential Energy Surface of $^{240}\mathrm{Pu}$ (preliminary)

Outline

Conclusion

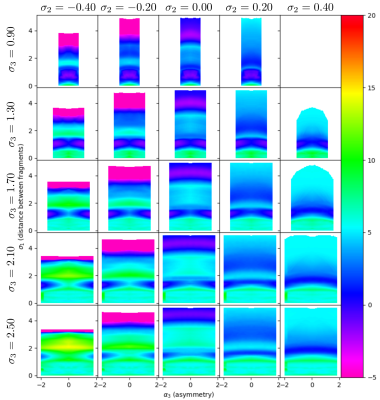
- The macroscopic-microscopic approach offers more collective degrees of freedom (5-D)
- Microscopic effects are important for the dynamics (tunneling, collective correlations)

Project

Construct a new approach:

- using a macroscopic-microscopic PES (with FRLDM)
- and a microscopic method for the description of the dynamics (with TDGCM+GOA)

Thank you!


$\sigma_2 = -0.40$
$\sigma_2 = -0.20$
$\sigma_2 = 0.00$
$\sigma_2 = 0.20$
$\sigma_2 = 0.40$
$\sigma_3 = 0.90$
$\sigma_3 = 1.30$
$\sigma_3 = 1.70$
$\sigma_3 = 2.10$
$\sigma_3 = 2.50$
σ_1 (distance between fragments)
α_3 (asymmetry)
20
15
10
5
0
−5