Fission fragment properties from a microscopic approach

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CEA / DIF / DPTA

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Two-steps approach

1. Static method (HFB)

- calculate PES in a given subspace of collective coordinates,
- calculate exit configurations (here scission points),
- calculate fission fragment properties for each scission point.

2. Dynamical method (TDGCM)

- propagate a wave packet on the PES,
- calculate the flux across the scission line / plane,
- ponderate FF properties with corresponding exit probability.

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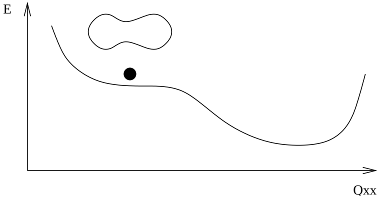
Scission mechanism

Definition

If a point A from the fission valley (non separated fragments) leads to a point B in the fusion valley (separated fragments), by a small increase of one of its deformation parameters, then A and B are called a scission point and a post-scission point, respectively.



Usually, scission is associated to:

- vanishing of the neck,
- lose of binding energy,
- drop of the mass hexadecapolar moment mean value $\langle \hat{Q}_{40} \rangle$.

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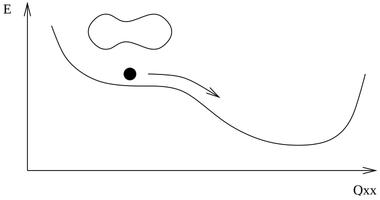

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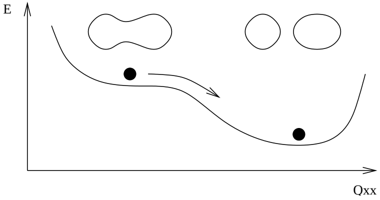

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Principle

Main hypothesis

Most of the fission fragment properties (deformation, total kinetic energy, charge and mass numbers, etc. . .) do not change too much after the scission point.

Consequence

We will localize the scission points of the fissionning system in the (elongation, asymmetry) plane, et calculate the fission fragment properties from the corresponding scission configurations.

Formalism

$$\delta\langle\varphi|\hat{H} - \lambda_N \hat{N} - \lambda_Z \hat{Z} - \sum_i \lambda_i \hat{Q}_{i0}|\varphi\rangle = 0$$

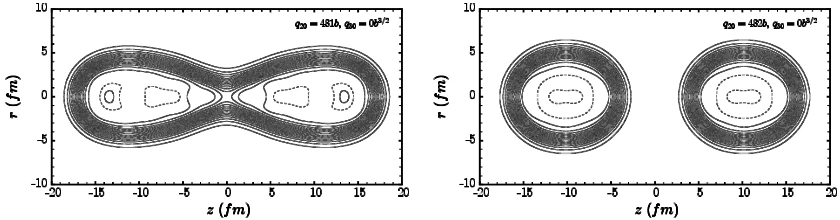
Constrained Hartree-Fock-Bogoliubov method:

- self-consistent mean-field,
- pairing included,
- nucleon-nucleon effective interaction Gogny D1S.

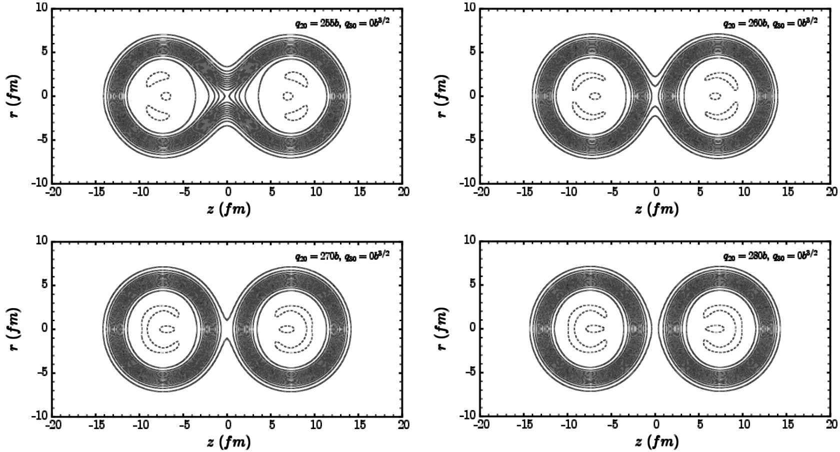
Constraints:

- charge and mass numbers Z and A,
- q_{10} to bring the center of mass of the system at the origin,
- multipolar moments q_{20} and q_{30} (elongation and asymmetry).

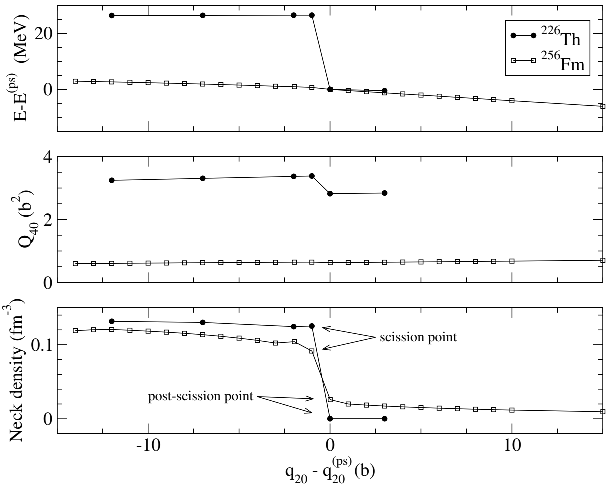
Scission criterium



Scission criterium



Scission criterium - Observables



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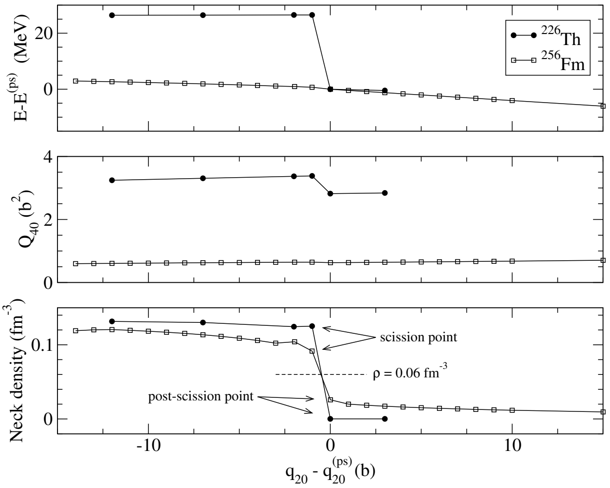

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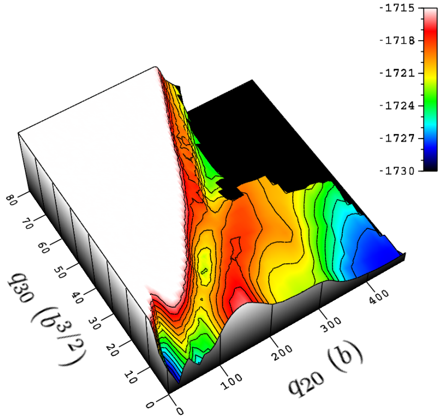
Scission lines - Choice of the nuclei

Calculated nuclei: ^{226}Th, ^{238}U, ^{240}Pu, ^{252}Cf, ^{256}Fm, ^{258}Fm, and ^{260}Fm.

- First tests for ^{238}U by H. Goutte.
- Several experimental data for ^{226}Th, ^{252}Cf and ^{256}Fm.
- Asymmetric to symmetric fission transition in ^{256}Fm to ^{260}Fm isotopic chain.
- Bimodal fission for ^{258}Fm.

Potential energy surfaces

- One-center basis calculations for $q_{20} < 200\,b$, $N = 14$.
- Two-center basis calculations for $q_{20} \geq 200\,b$, $N_1 = N_2 = 11$.
- Constant increments $\Delta q_{20} = 10\,b$ and $\Delta q_{30} = 4\,b^{3/2}$.



$^{226}_{90}\mathrm{Th}_{136}$

Potential energy surfaces

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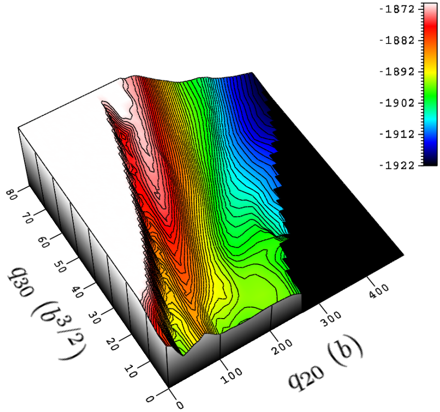

$^{256}_{100}\mathrm{Fm}_{156}$

Potential energy surfaces

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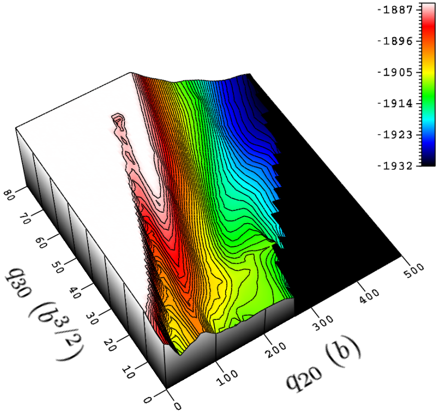

$^{258}_{100}\mathrm{Fm}_{158}$

Potential energy surfaces

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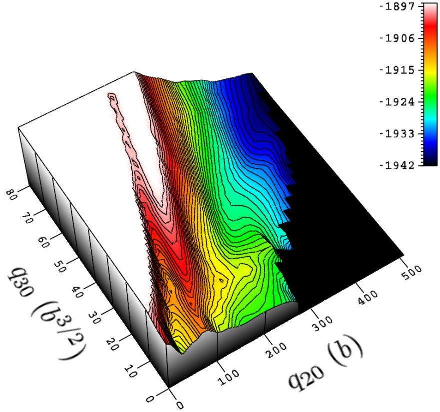
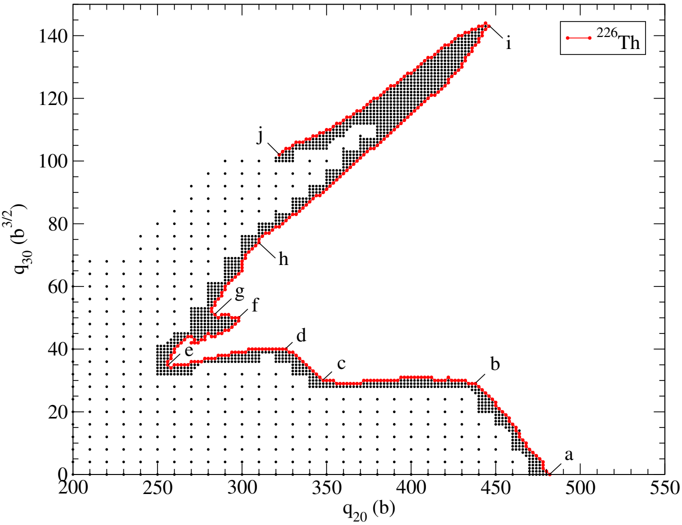
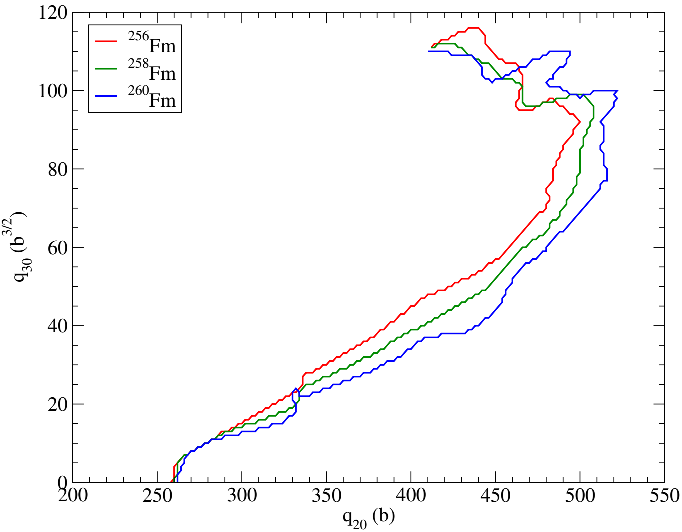


$^{260}_{100}\mathrm{Fm}_{160}$

Scission lines - ^{226}Th



Scission lines - $^{256-260}$Fm



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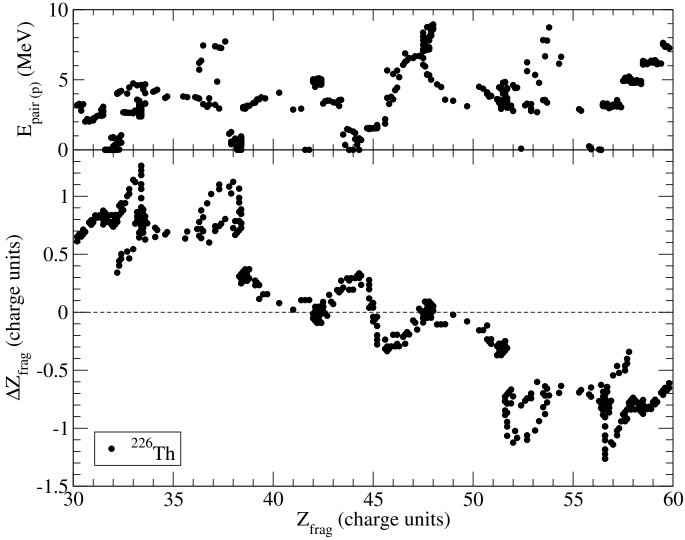
Deviations $\Delta Z_{\text{frag}} = Z_{\text{frag}} - Z_{\text{UCD}}$

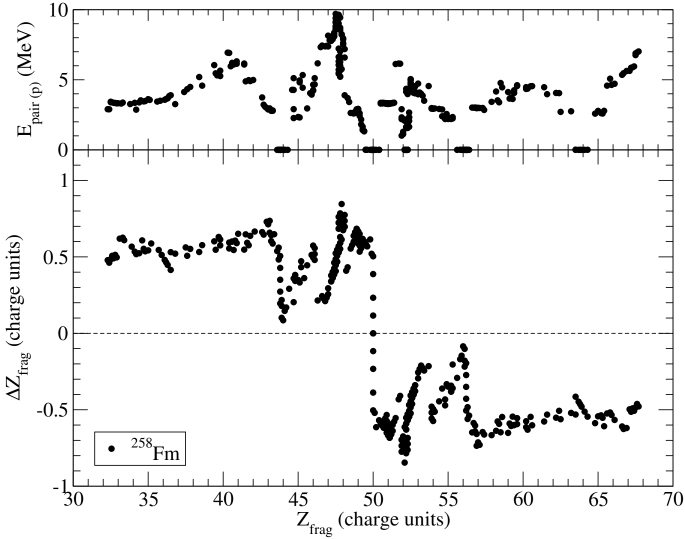
$$Z_{UCD} \equiv \frac{Z_{\text{fs}}.A_{\text{frag}}}{A_{\text{fs}}}$$

- UCD = Unchanged Charge Distribution.

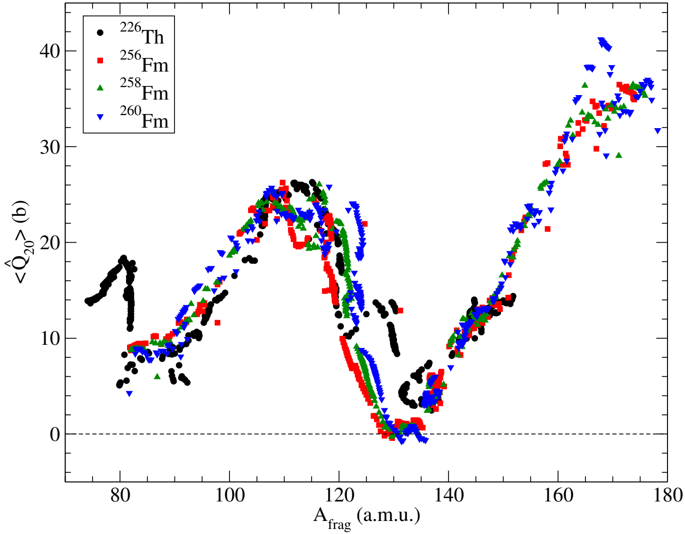
Deviations $\Delta Z_{\mathrm{frag}} = Z_{\mathrm{frag}} - Z_{\mathrm{UCD}}$ for ^{226}Th



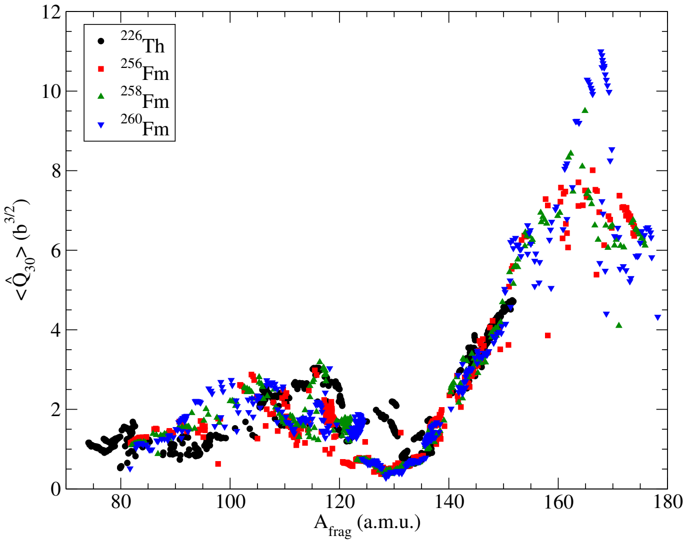
Deviations $\Delta Z_{\mathrm{frag}} = Z_{\mathrm{frag}} - Z_{\mathrm{UCD}}$ for ^{258}Fm



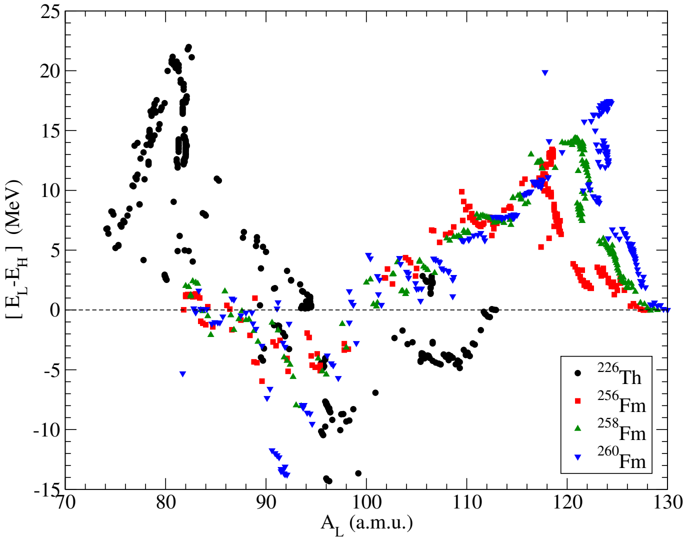
Fragment deformations - $\langle \hat{Q}_{20} \rangle$



Fragment deformations - $\langle \hat{Q}_{30} \rangle$



Fragment deformation energy



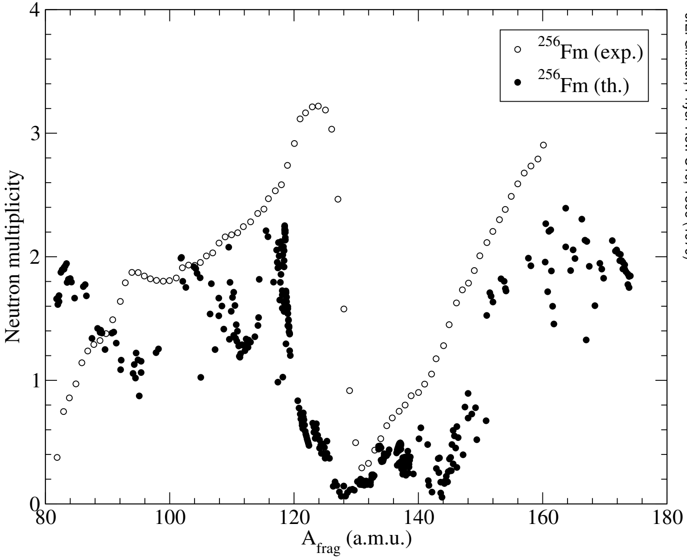
Neutron multiplicity

As a first estimate:

$$\nu_{\text{frag}} = \frac{E_{\text{def}}}{\langle E_k \rangle + B_n^*}$$

- B_n^* is the one-neutron binding energy in the deformed fragment.
- $\langle E_k \rangle = 2$ MeV for ^{226}Th and $\langle E_k \rangle = 1.5$ MeV for $^{256-260}$Fm.

Neutron multiplicity for ^{256}Fm



J.E. Gindler, Phys. Rev. C19, 1806 (1979)

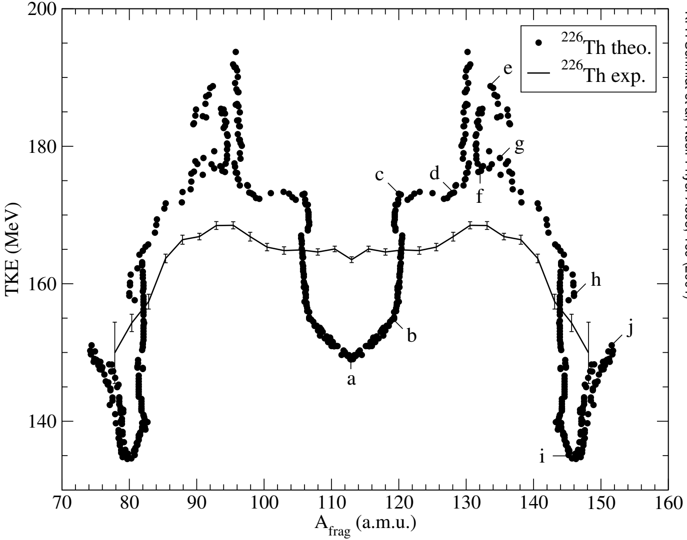
Total kinetic energy

As a first estimate:

$$E_{\text{TKE}} = \frac{e^2 Z_1 Z_2}{d_{\text{charg.}}}$$

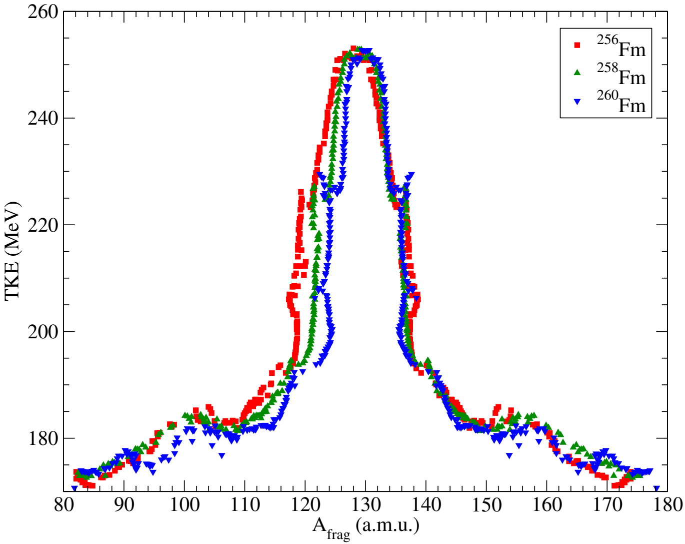
$d_{\text{charg.}}$ is the distance between fragments centres of charge.

Total kinetic energy - ^{226}Th

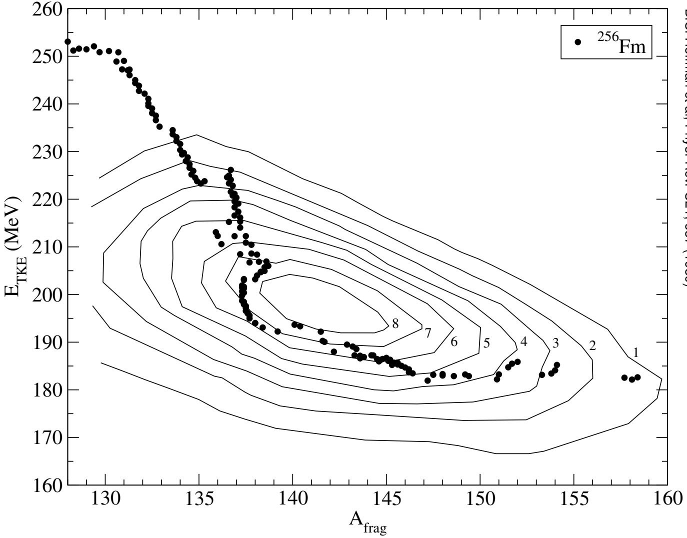


K.-H Schmidt et al, Nucl. Phys. A693, 169 (2001)

Total kinetic energy - $^{256,258,260}Fm$



Total kinetic energy - ^{256}Fm



D.C. Hoffman et al, Phys. Rev. C21, 637 (1980)

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Conclusion

- Full coherent microscopic method from PES to FF properties.
- Lot of new results obtained.
- On-going calculations (^{236,238}U, ^{240}Pu, ^{252}Cf…).
- Possible extensions :
  - additional contraints (q_{40}, q_{neck}),
  - study of the continuity of the observables across the scission,
  - validation of the approach for highly asymmetric systems,
  - dynamical calculations (TDGCM+GOA).

Collaborators: H. Goutte, J-P. Delaroche, J-F. Berger