Multidimensional PES in spontaneous fission

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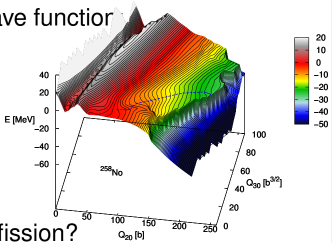
ESNT, Saclay

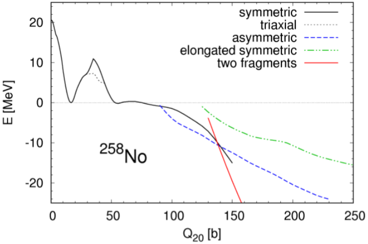
Motivation

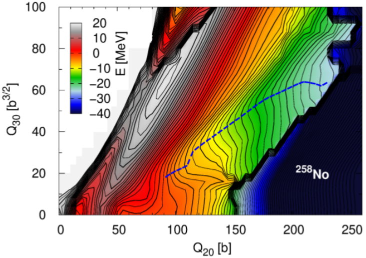
1. **Potential Energy Surface** (PES) - basic ingredient in description of fission observables
   - **Spontaneous fission half-lives** $\longrightarrow$ shape of fission barrier
   - **Fission dynamics** $\longrightarrow$ topography of PES
2. In **self-consistent** models PES is defined as a function of **constraints** (not deformation parameters) $\Longrightarrow$ The self-consistent solutions are not always univocal
   - Dependence on the starting wave function: 2 minima with different value of the non-constraint collective coordinate
3. **Which** (and **how many**) **collective degrees of freedom** in the deformation space allows to obtain an accurate description of fission?
4. Can one obtain **a continous PES at scission**?



2D PES: Fission paths of ^{258}No

^{258}No - **bimodal** fission type



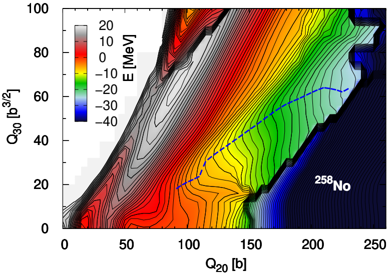


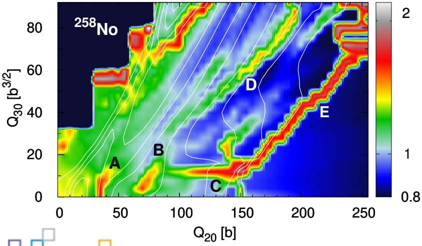
Considered degrees of freedom:

- **Elongation**: $\widehat{Q}_{20} = \frac{1}{2}\sqrt{\frac{16\pi}{5}}\sum_{i=1}^{A} r_i^2 Y_{20}(\theta)$
- **Mass asymmetry**: $\widehat{Q}_{30} = \sqrt{\frac{4\pi}{7}}\sum_{i=1}^{A} r_i^3 Y_{30}(\theta)$

A. Zdeb, M. Warda, L.M. Robledo, PRC 104, 014610 (2021).

2D PES of ^{258}No: Discontinuities





Density distance[1]**:**

$$D_{\rho\rho'} = \int |\rho(\vec{r}) - \rho'(\vec{r})| d\vec{r}$$

- **A**: first barrier
- **B**: the second minimum region
- **C**: between symmetric and asymmetric valley
- **D**: bordering asymmetric valley at large octupole deformation
- **E**: scission line

1. N. Dubray, D. Regnier, CPC **183** 2035 (2012).

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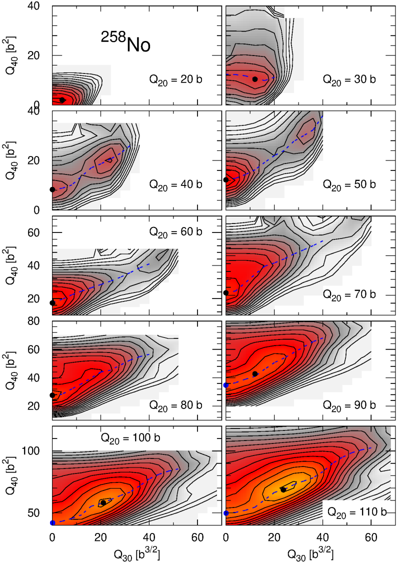
3D PES of ^{258}No : (Q_{20}, Q_{30}, Q_{40})



Hexadecapole moment:

$$\hat{Q}_{40} = \sqrt{\frac{4\pi}{9}} \sum_{i=1}^{A} r_i^4 Y_{40}$$

Visible 1-2 minima in the region below the second fission barrier

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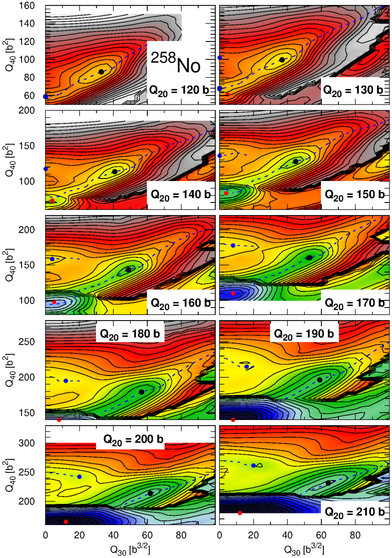
3D PES of ^{258}No : (Q_{20}, Q_{30}, Q_{40})



$Q_{20} \geq 130$ b - 3 fission valleys spread

- asymmetric mode
- symmetric mode
- symmetric elongated

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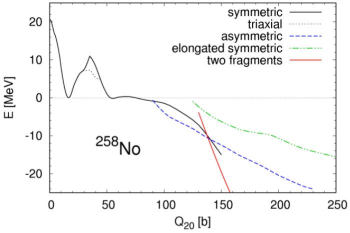
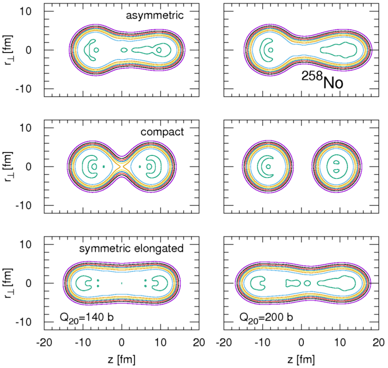
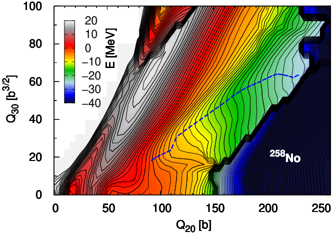
2D PES: Fission channels of ^{258}No

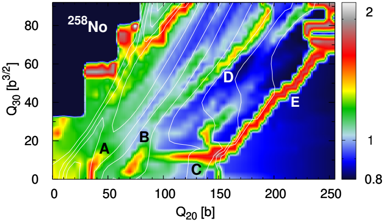


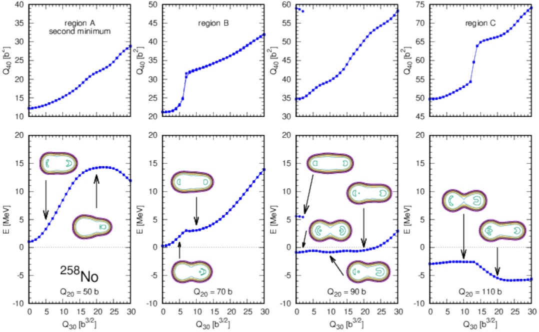


- multiplication of the surfaces on the 2D PES $\Longrightarrow$ misinterpretation of the results from different valleys
- possible accidental change of the configuration

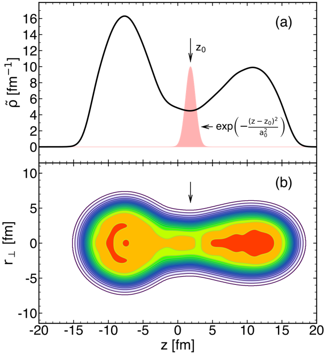
Nuclear shape evolution on the way to fission





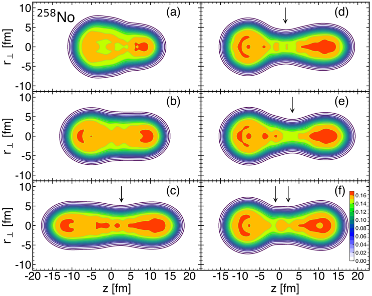


Neck constraint



$$\hat{Q}_N = \exp\left[-\frac{(z-z_0)^2}{a_0^2}\right]$$

z_0 - positioned at the local minimum of the linear density

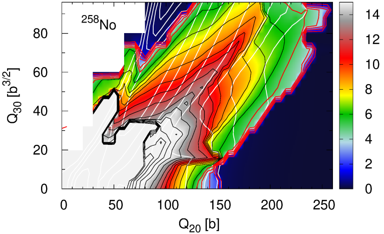


Possible problems:

- No reduction of the linear density
- Neck as thick as fragment
- Symmetric-elongated shape
- Rapid change of z_0 position
- Double minimum of the linear density

R. Han, M. Warda, A. Zdeb, L.M. Robledo, PRC104,064602 (2021).

Neck thickness



$$Q_N(Q_{20}, Q_{30})$$

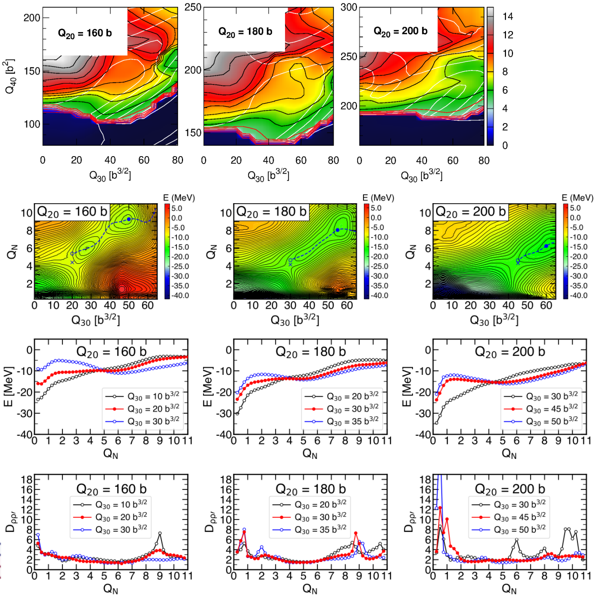
$$\Delta Q_N = 1$$

- $Q_N = 4 - 5 \Longrightarrow$ **Pre-scission** shape
- Neck radius (def. as r of a cylinder with a height $\sqrt{\pi} a_0$):

$$r_{NECK} = \sqrt{Q_N/(\rho_0 \pi^{3/2} a_0)} = 1.059\sqrt{Q_N} \Longrightarrow \text{rms radius of:}$$

- deuteron: 2.76 fm
- α particle: 2.13 fm

^{258}No - scission region in asymmetric valley



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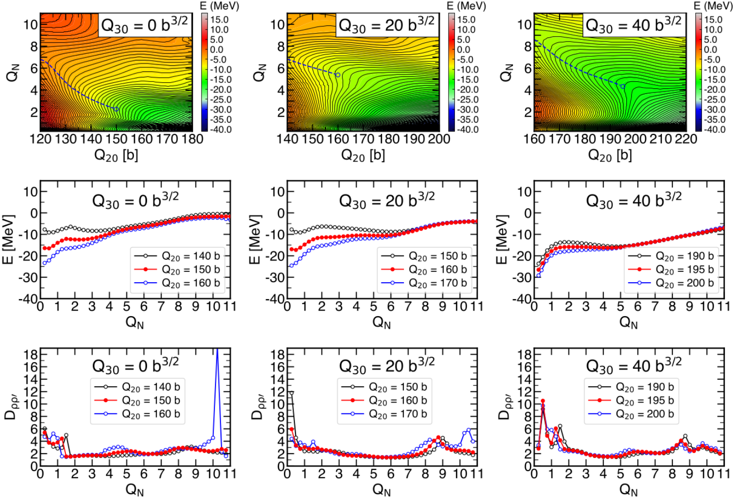
^{258}No - scission region in symmetric valley



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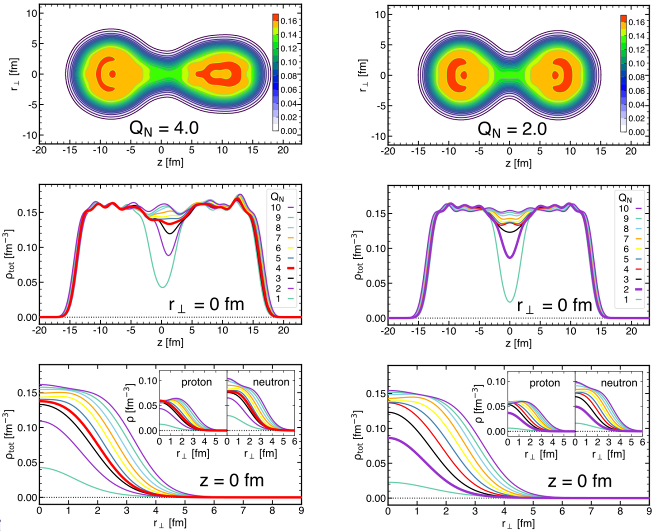
Scission point



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Summary & Conclusions

1. The HFB model with well-reputed Gogy D1S interaction was applied in order to investigate self-consistent PES' in fission.
2. For high Q_{20} values a complicated topography was found and analyzed.
3. The **competing fission channels** responsible for observed **bimodal** mass yield in fission of ^{258}No were discussed: asymmetric, symmetric compact and elongated modes.
4. One can obtain **a continous PES in the scission region** when Q_N is considered as a collective degree of freedom.
5. There is a **limit** value of the neck parameter after which the system becomes **unstable**: 2 in symmetric mode, 4 in asymmetric.

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Thank you!

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