

Pre-scission shapes of fissioning nuclei

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Collaboration:

- J.L. Egido, UAM, Madrid
- W. Nazarewicz, MSU, East Lansing
- K. Pomorski, UMCS, Lublin
- L.M. Robledo, UAM, Madrid
- A. Staszczak, UMCS, Lublin
- A. Zdeb, UMCS, Lublin



- Theoretical framework
- Symmetric and asymmetric fission ^{258}Fm
- Neutron-deficient Hg region: ^{180}Hg , ^{198}Hg , ^{196}Po , ^{174}Pt
- Cluster radioactivity in actinides
- Super-heavies
- Conclusions

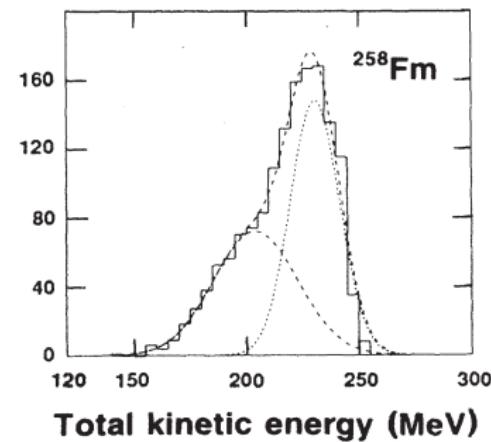
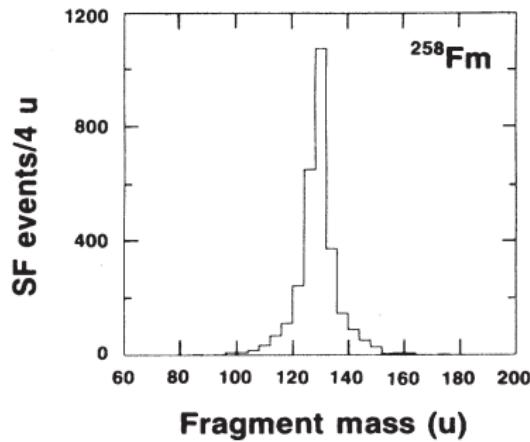


Calculations of potential energy surfaces

- Self-consistent calculations in Hartree-Focka-Bogolubov theory
- Gogny D1S parameter set
- Potential energy surfaces calculated with constrains on quadrupole, octupole and hexadecapole moments

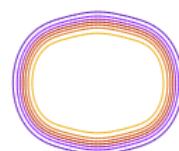
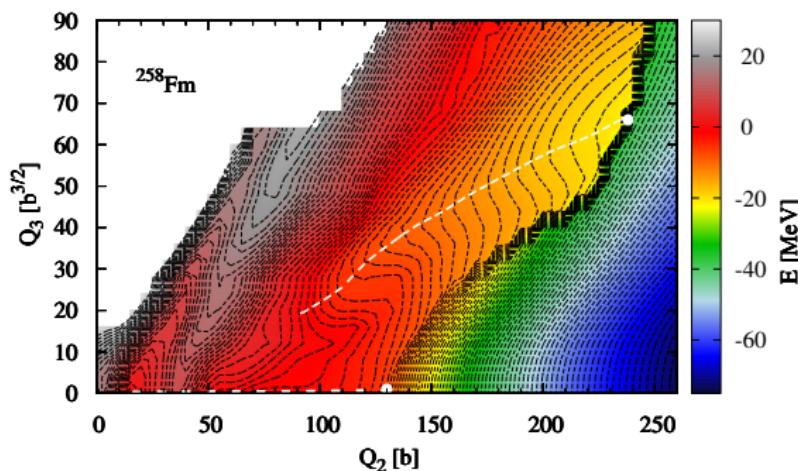
Pre-scission configuration determines properties of fission fragments



^{258}Fm - bimodal fission


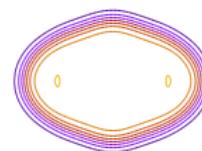
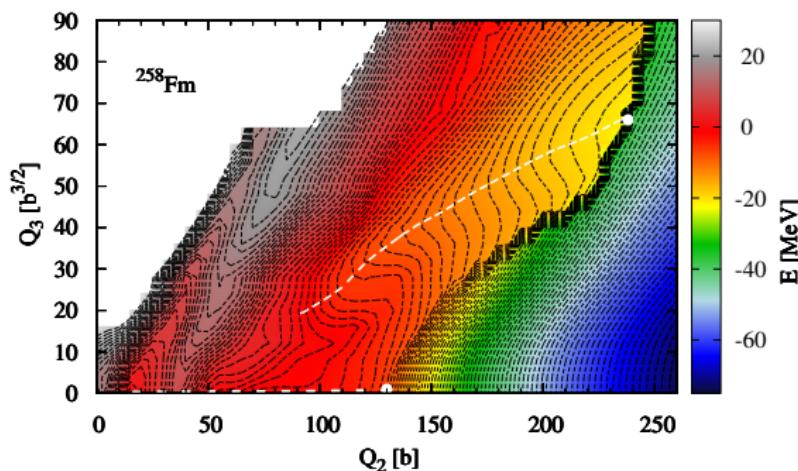
Hulet *et al.*, PRL56, 313 (1986).
 Hulet *et al.*, PRC40, 770 (1989).



 $Q_2 = 15 \text{ b}$ 

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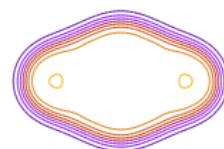
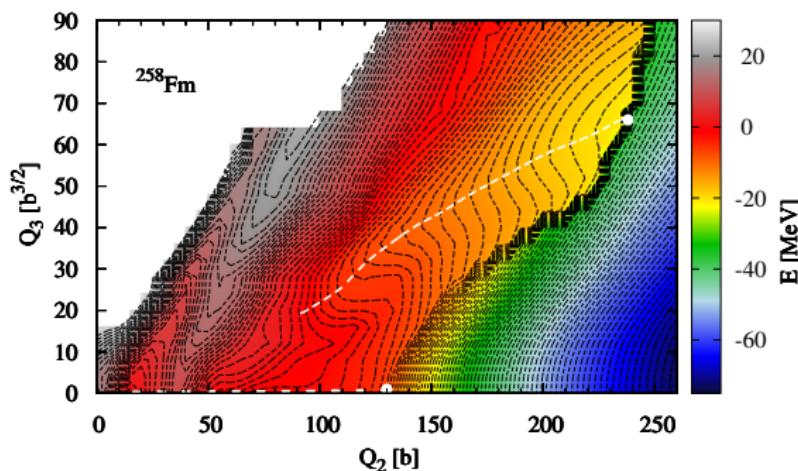


$$Q_2 = 25 \text{ b}$$



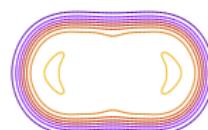
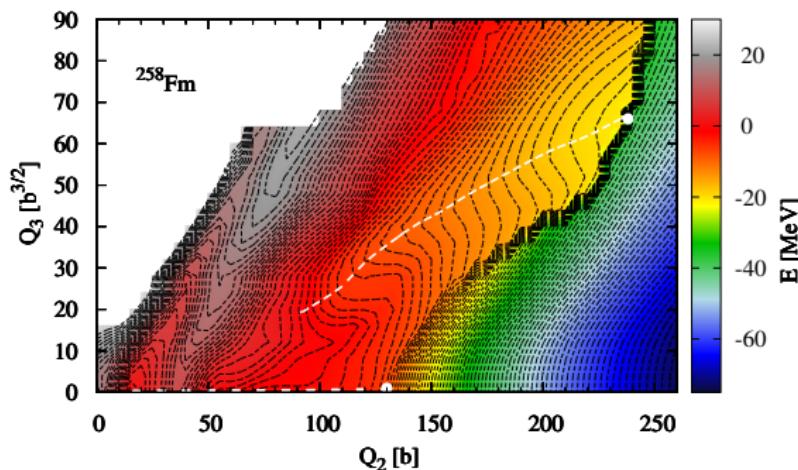
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 $Q_2 = 35 \text{ b}$ 

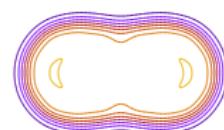
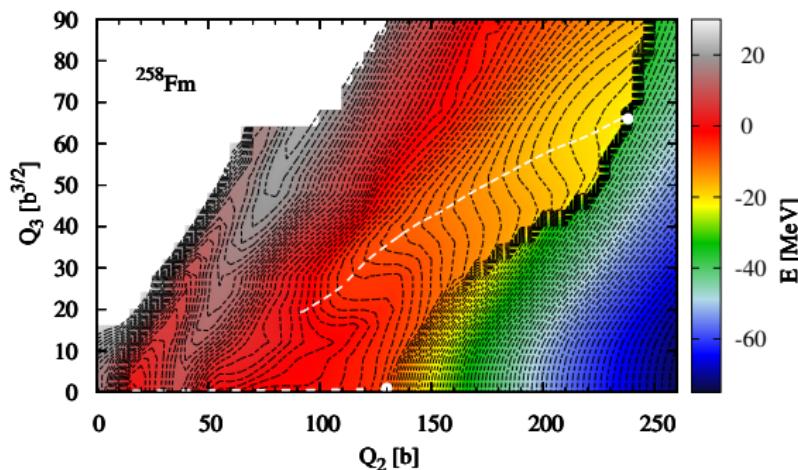
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 $Q_2 = 45 \text{ b}$ 

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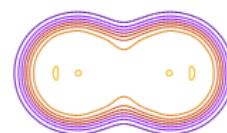
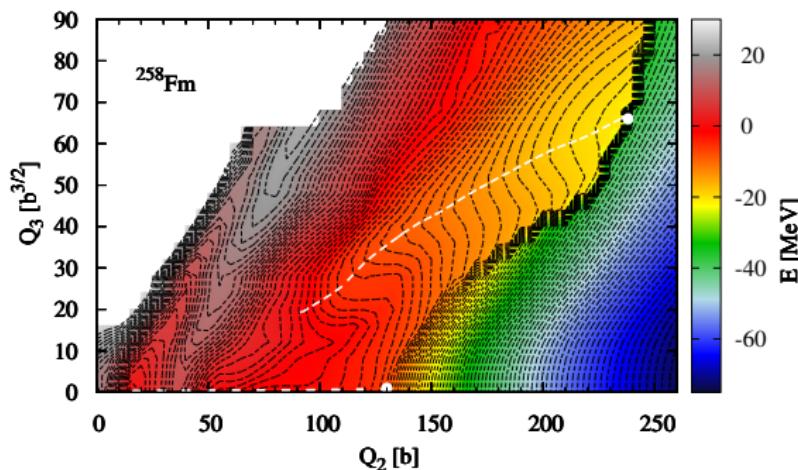


$$Q_2 = 55 \text{ b}$$



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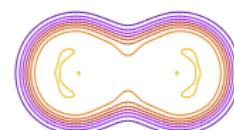
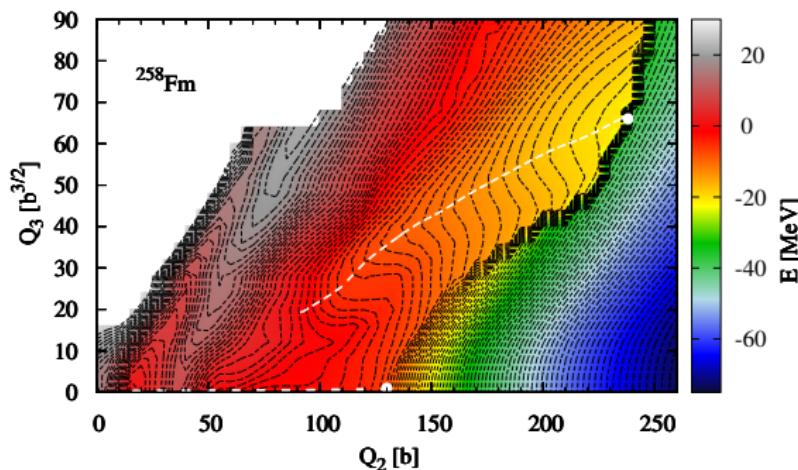


$$Q_2 = 65 \text{ b}$$



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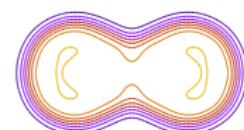
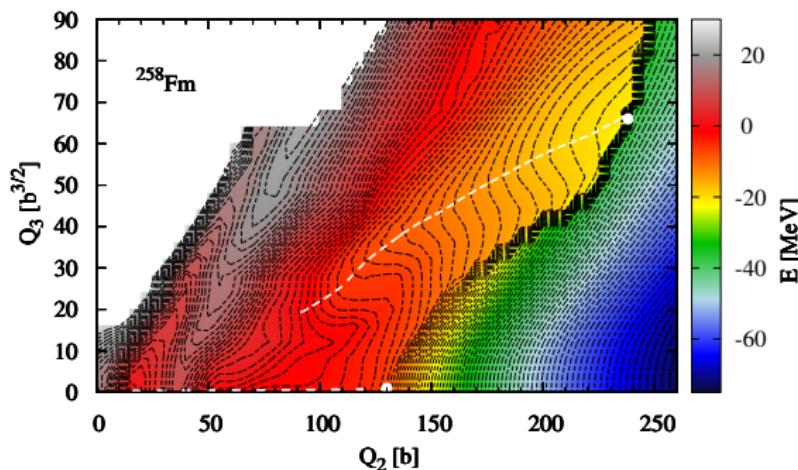


$$Q_2 = 75 \text{ b}$$



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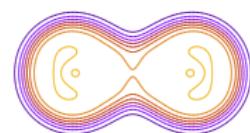
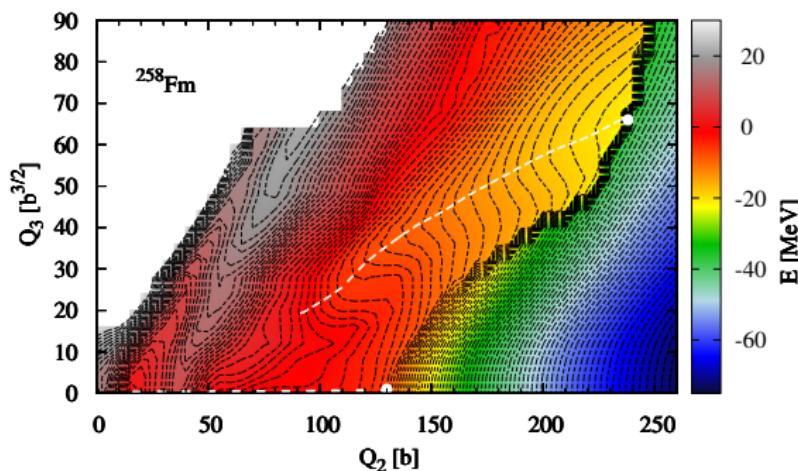


$$Q_2 = 85 \text{ b}$$



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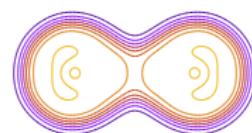
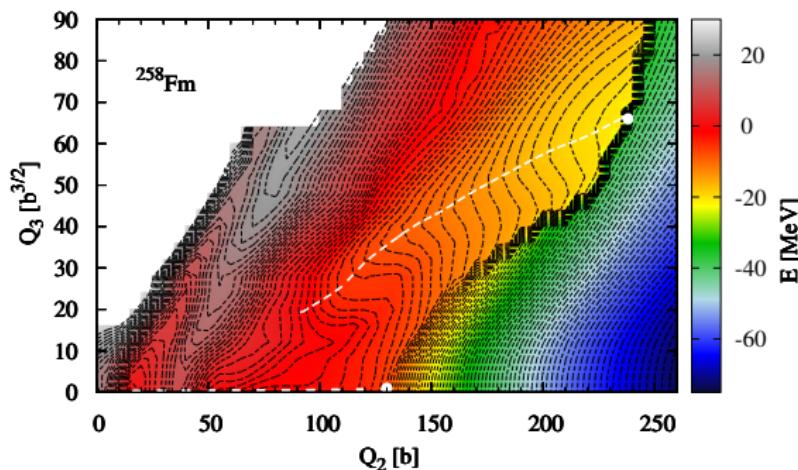


$$Q_2 = 95 \text{ b}$$



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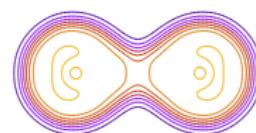
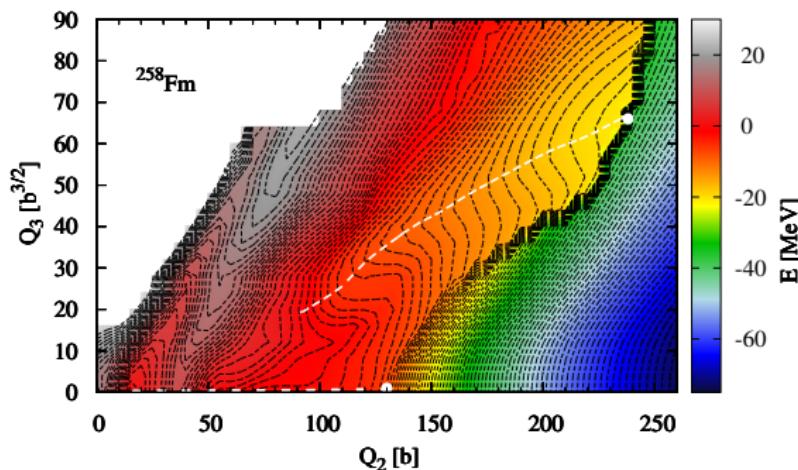


$$Q_2 = 105 \text{ b}$$



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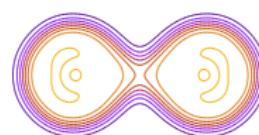
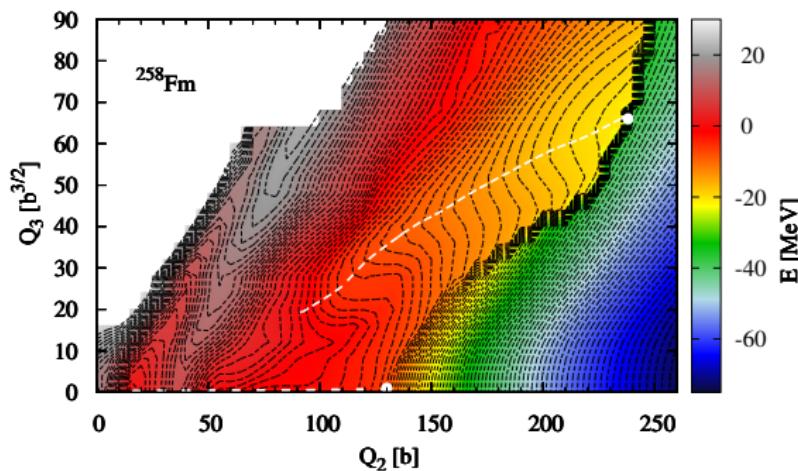


$$Q_2 = 115 \text{ b}$$



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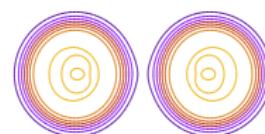
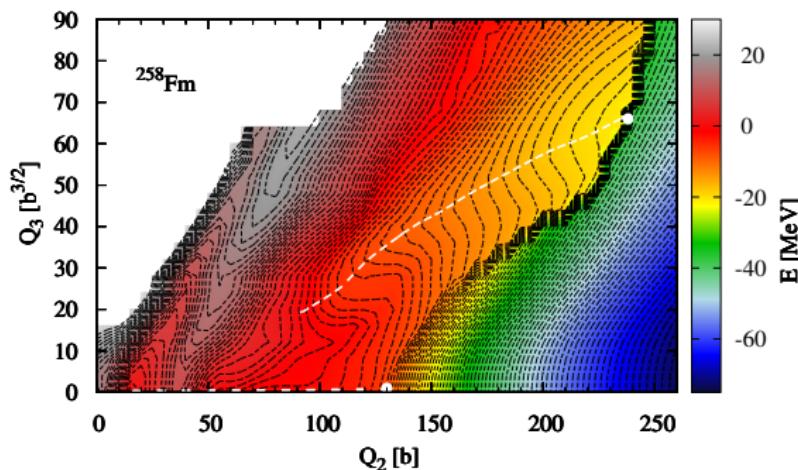


$$Q_2 = 125 \text{ b}$$



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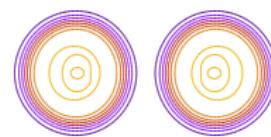
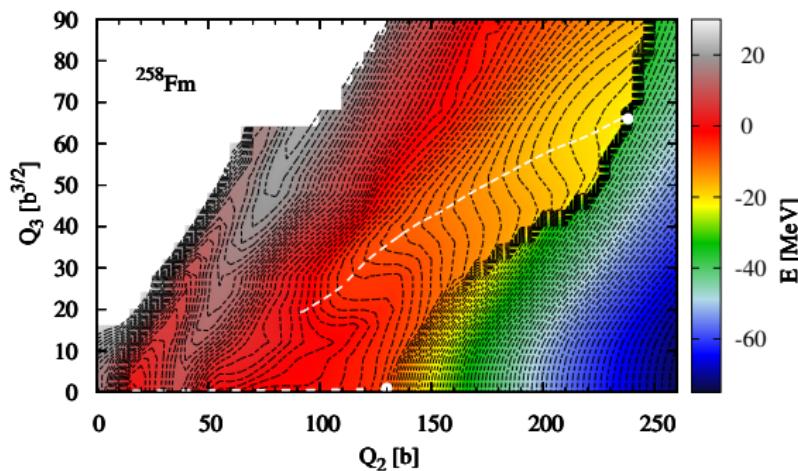


$$Q_2 = 135 \text{ b}$$



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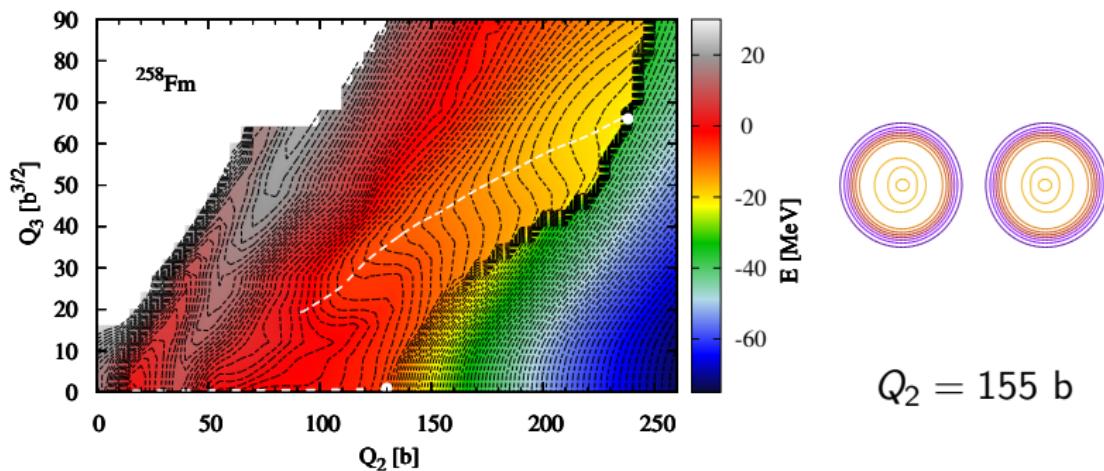


$$Q_2 = 145 \text{ b}$$



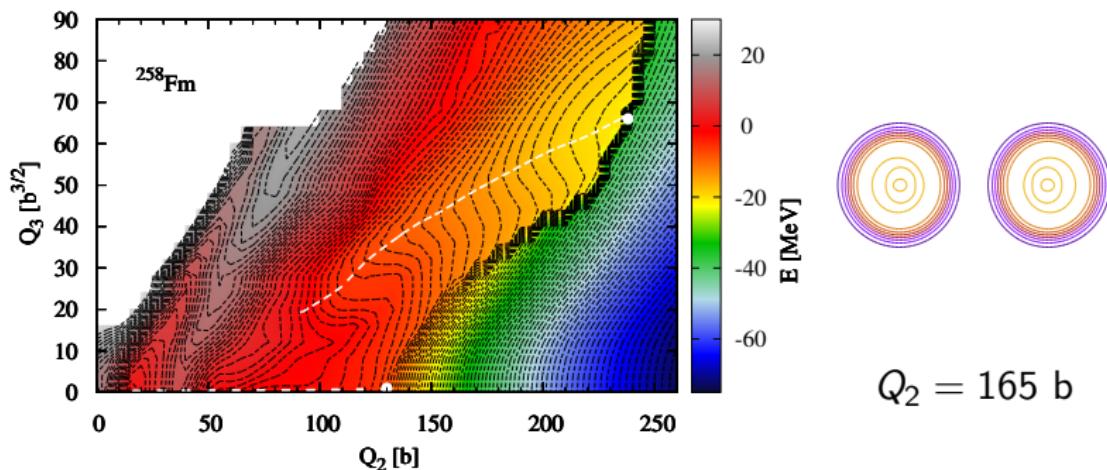
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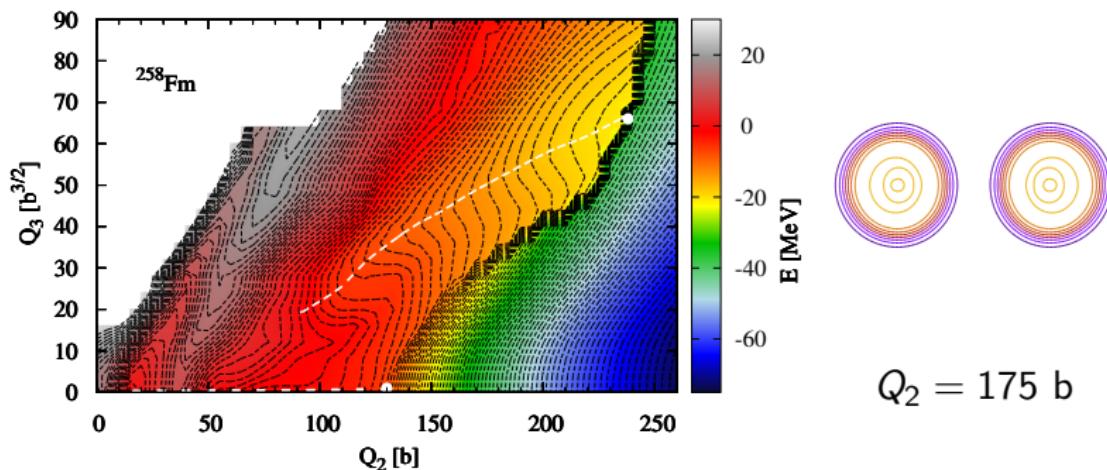
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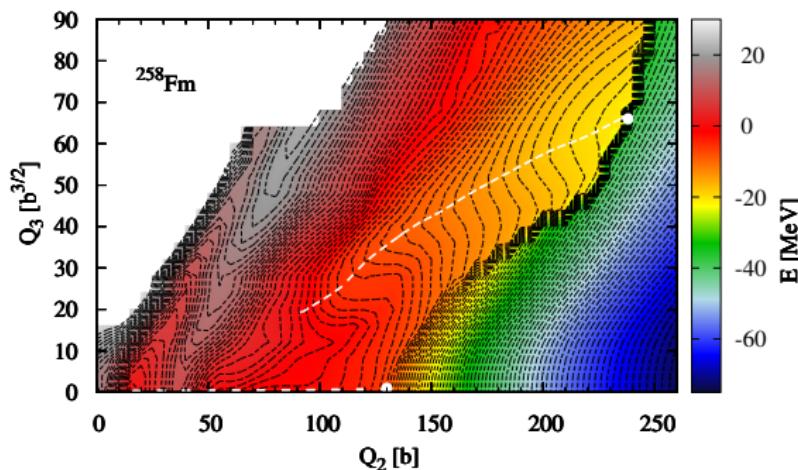


$$Q_2 = 175 \text{ b}$$

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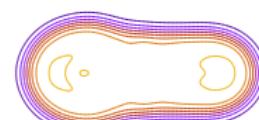
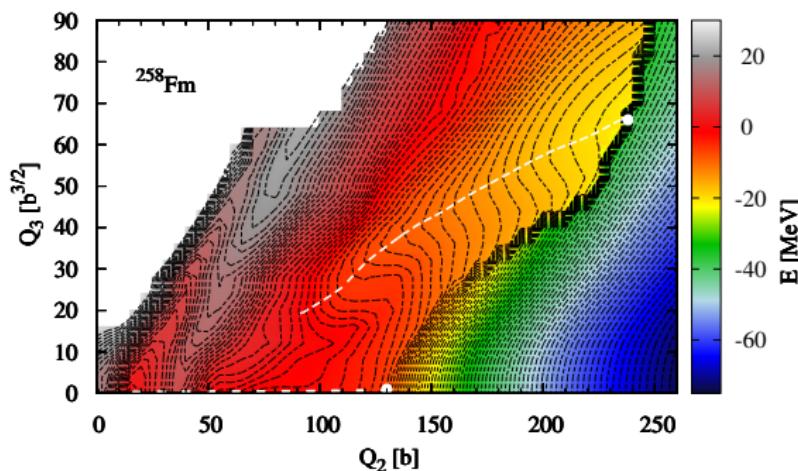




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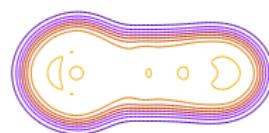
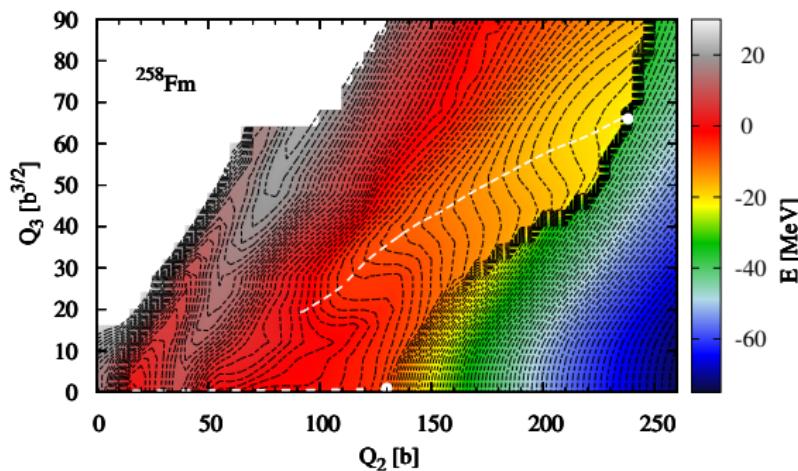
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 $Q_2 = 90 \text{ b}$ 

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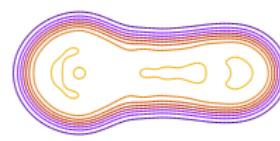
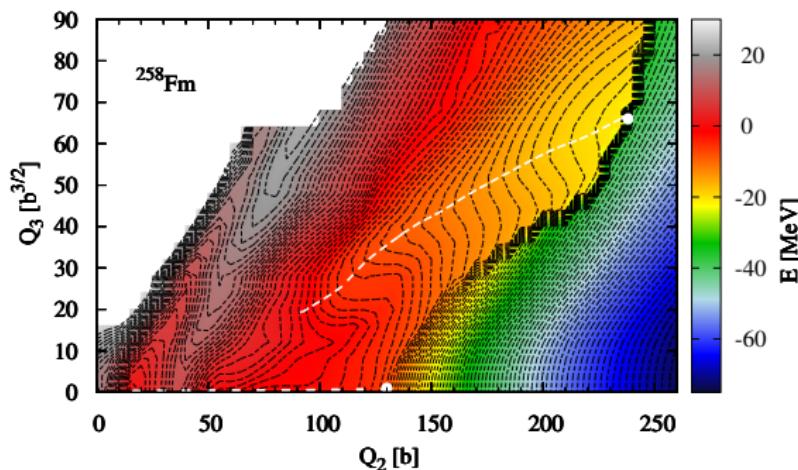


$$Q_2 = 110 \text{ b}$$



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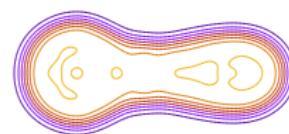
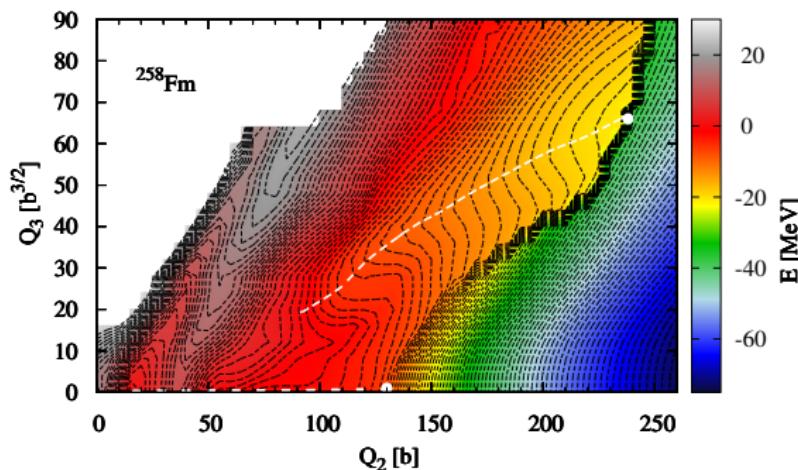


$$Q_2 = 130 \text{ b}$$



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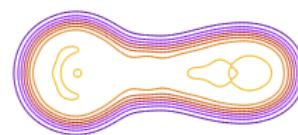
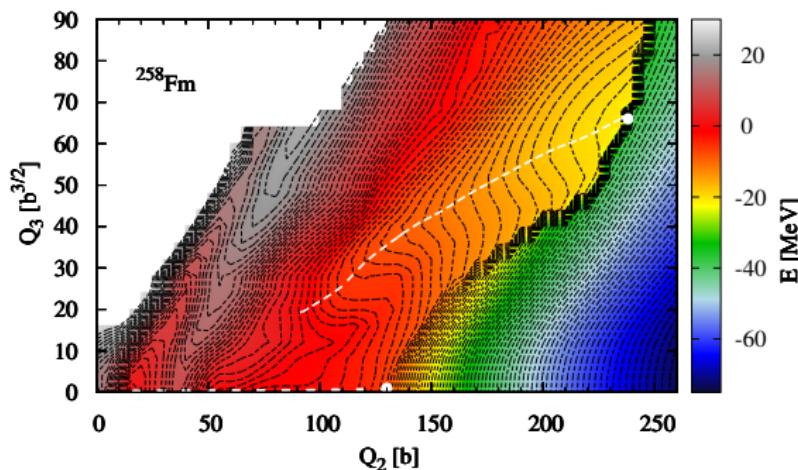


$$Q_2 = 150 \text{ b}$$

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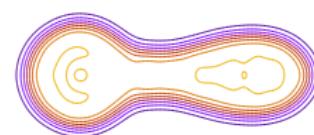
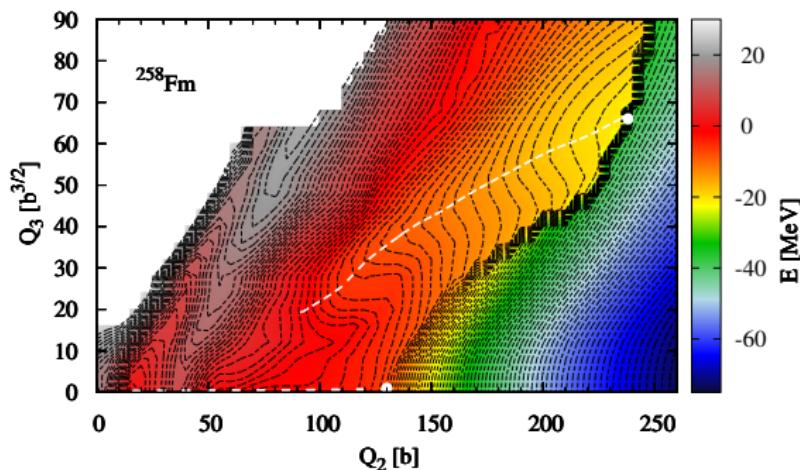


$$Q_2 = 170 \text{ b}$$



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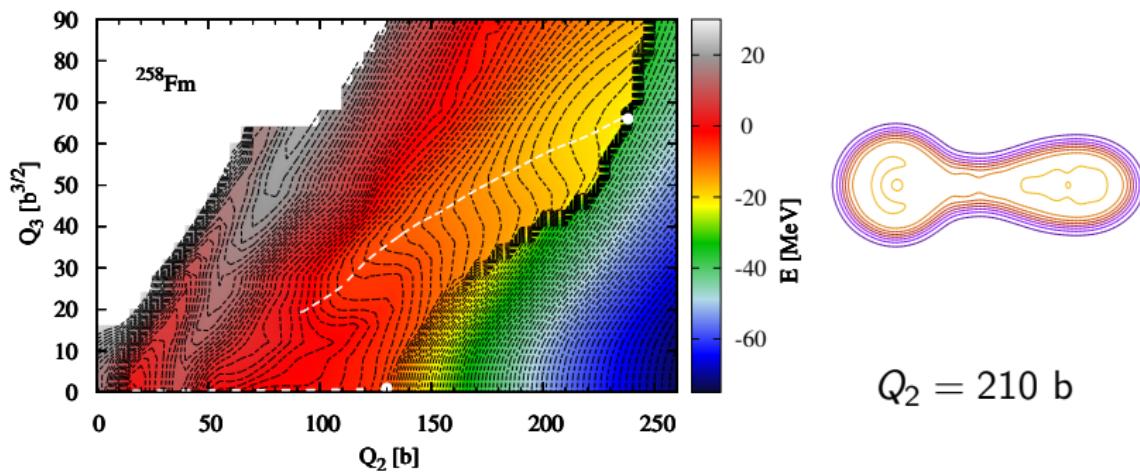


$$Q_2 = 190 \text{ b}$$



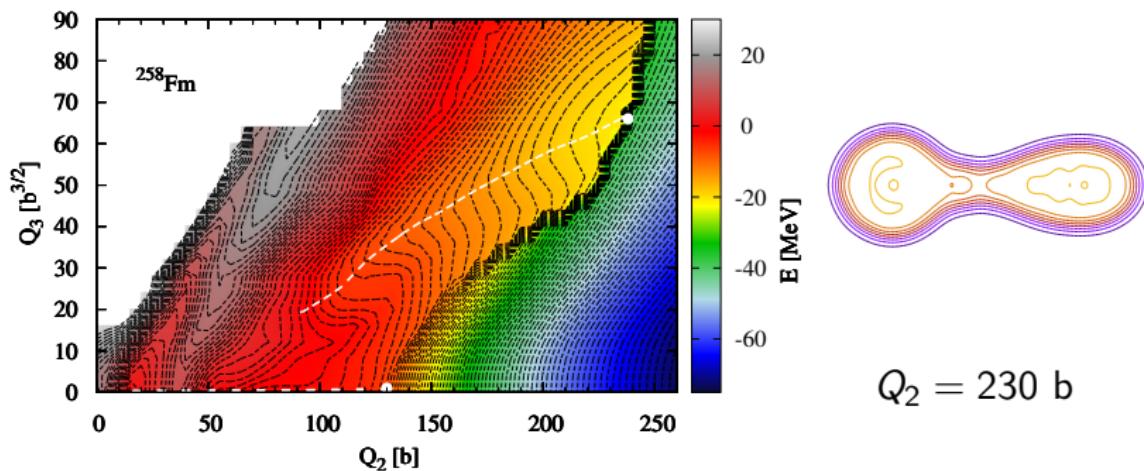
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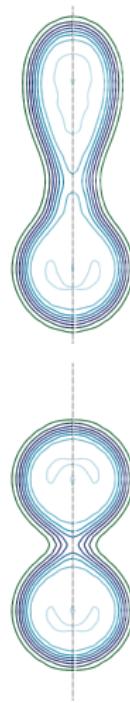
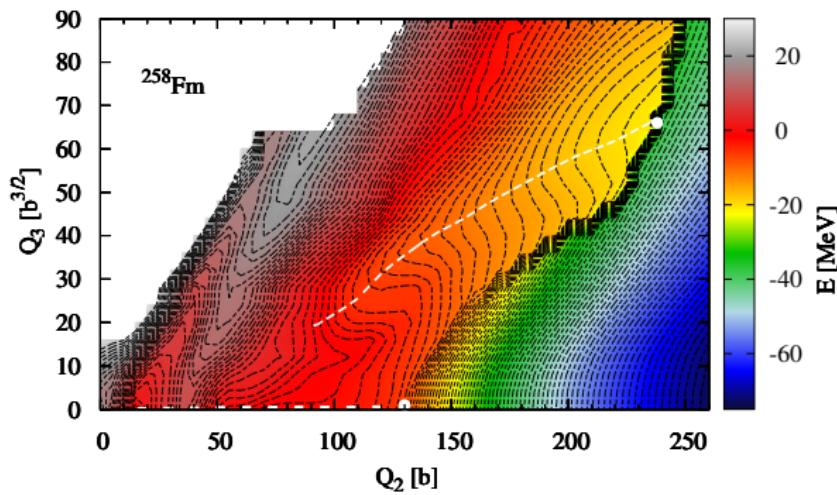
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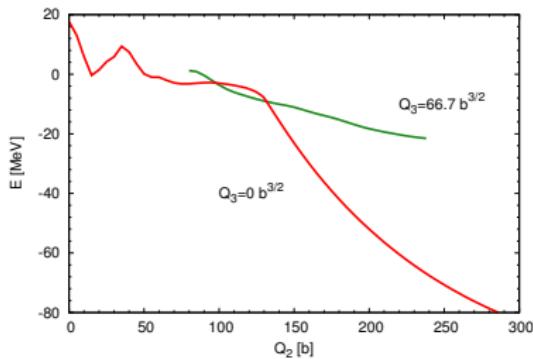
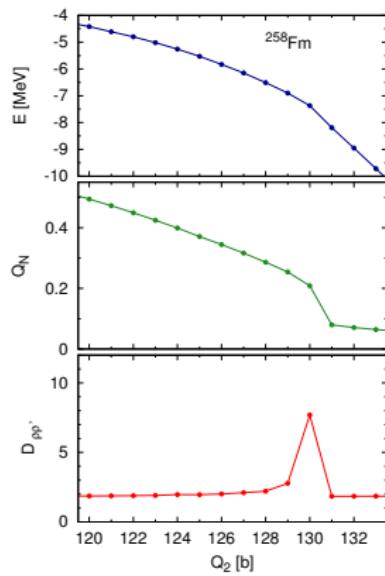


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^{258}Fm – pre-scission point


Neck parameter:

$$Q_N = \exp\left(\frac{-(z-z_0)^2}{a_0^2}\right)$$

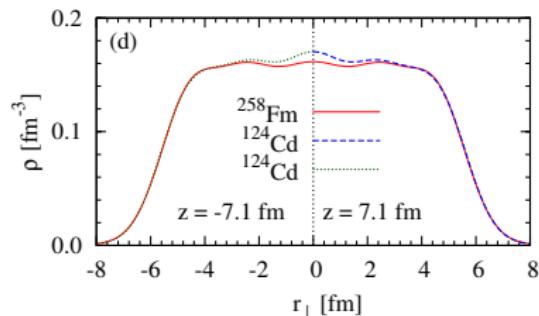
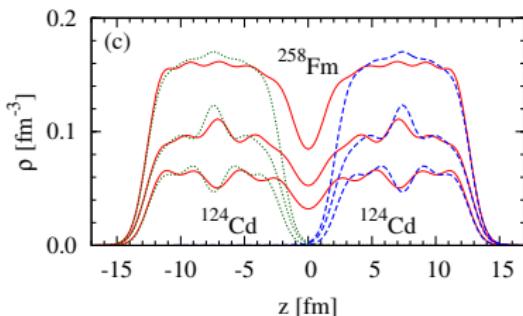
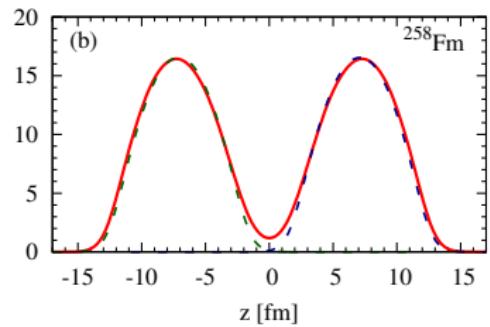
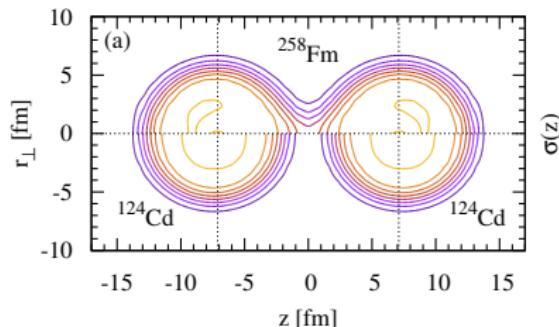
Density distance:

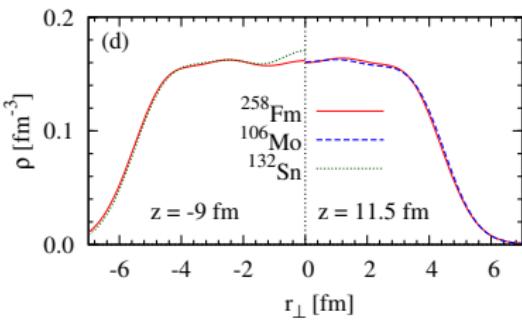
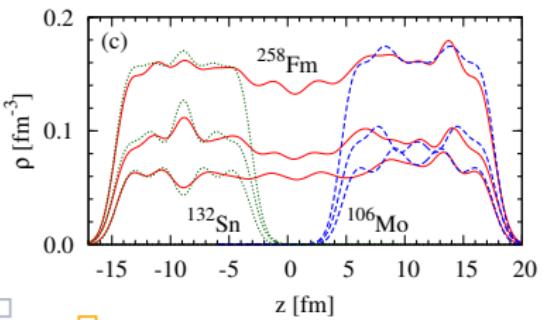
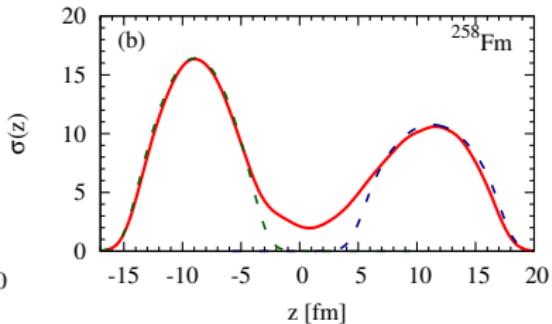
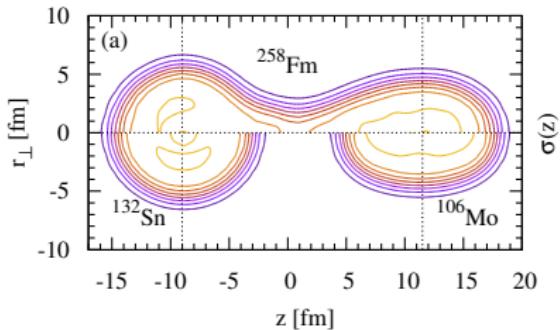
$$D_{\rho\rho'} = \int |\rho(\vec{r}) - \rho'(\vec{r})| d\tau$$

N. Dubray, D. Regnier, CPC183, 2035 (2012).
M. Warda, A. Zdeb, Phys. Scr. 90, 114003 (2015).

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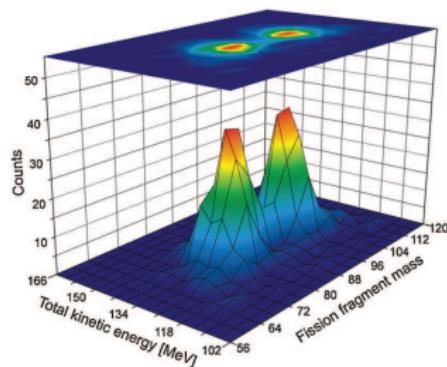


FIG. 4 (color online). The derived fission-fragment distribution of ^{180}Hg as a function of the fragment mass and the total kinetic energy.

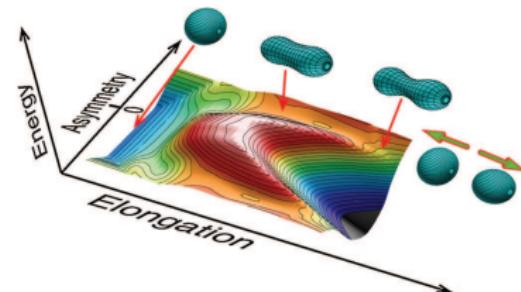
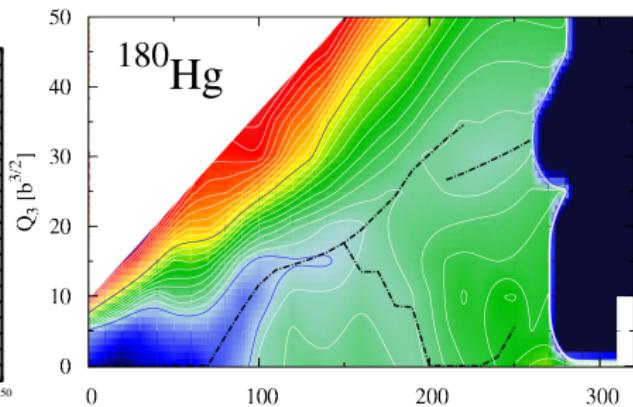
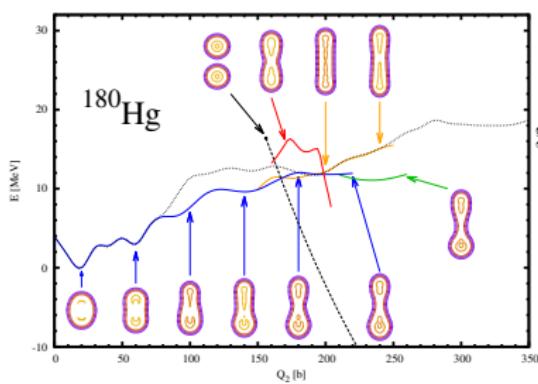


FIG. 5 (color online). A schematic representation of the potential-energy surface for ^{180}Hg in two dimensions (elongation and asymmetry) resulting from a five-dimensional analysis. The shapes shown, connected by arrows to their locations, are the ground state, the saddle point, and the point where the asymmetric valley disappears.

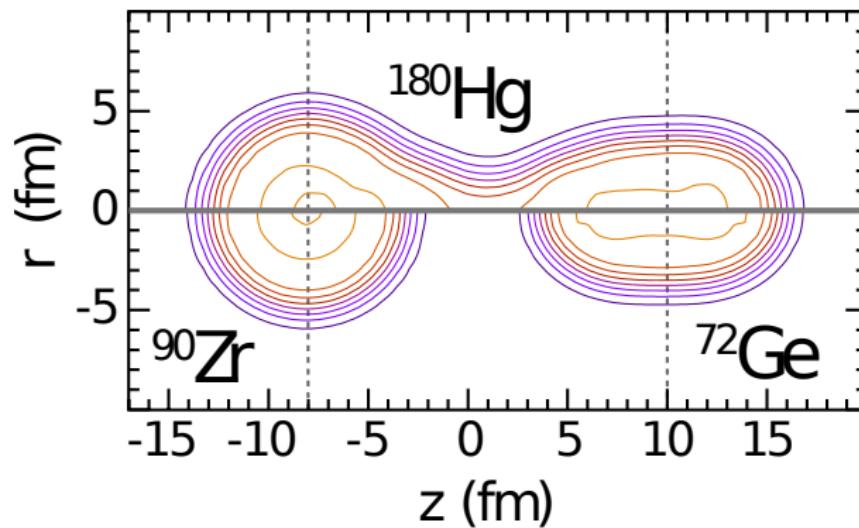
A.N. Andreyev, et al., Phys. Rev. Lett. 105 (2010) 252502
 J. Elseviers, et al., Phys. Rev. C 88 (2013) 044321





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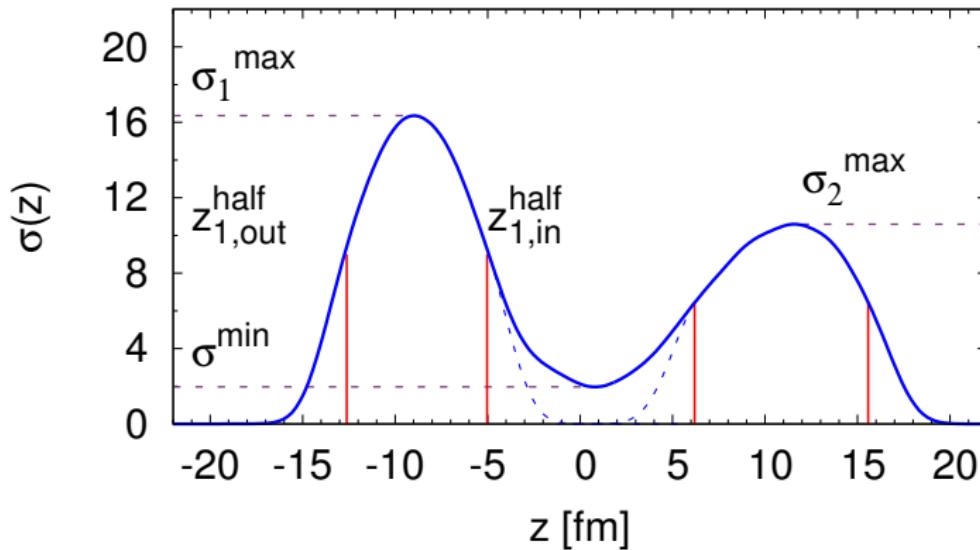


M. Warda, A. Staszczak, W. Nazarewicz, Phys. Rev. C 86 (2012) 024601



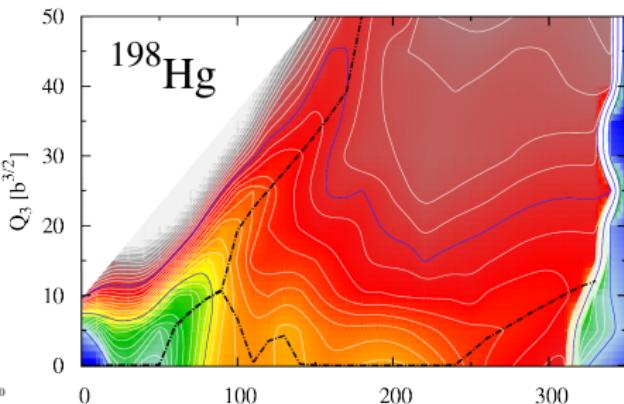
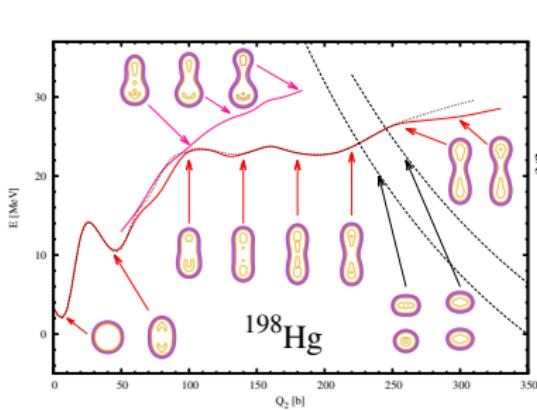
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$$\sigma(z) = 2\pi \int_0^\infty dr_\perp r_\perp \rho(z, r_\perp)$$



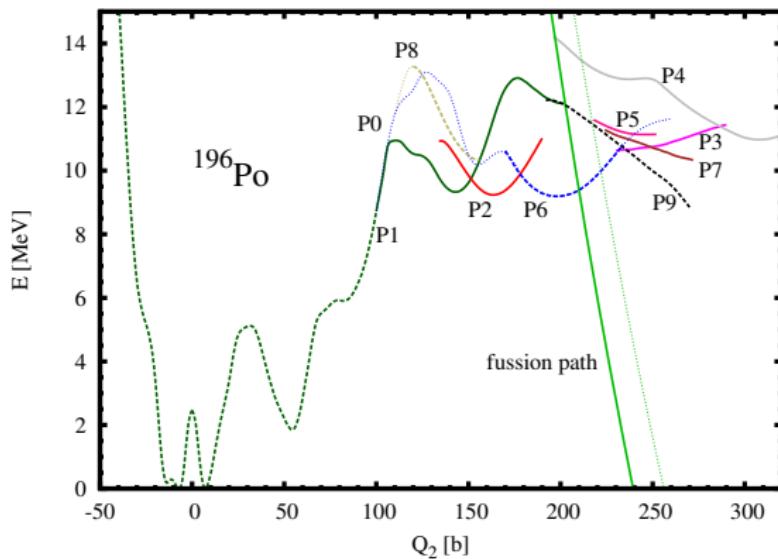
M. Warda and A. Zdeb, Phys. Scr. 90 (2015) 114003

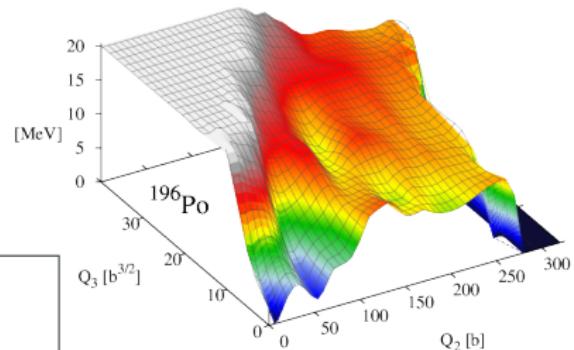
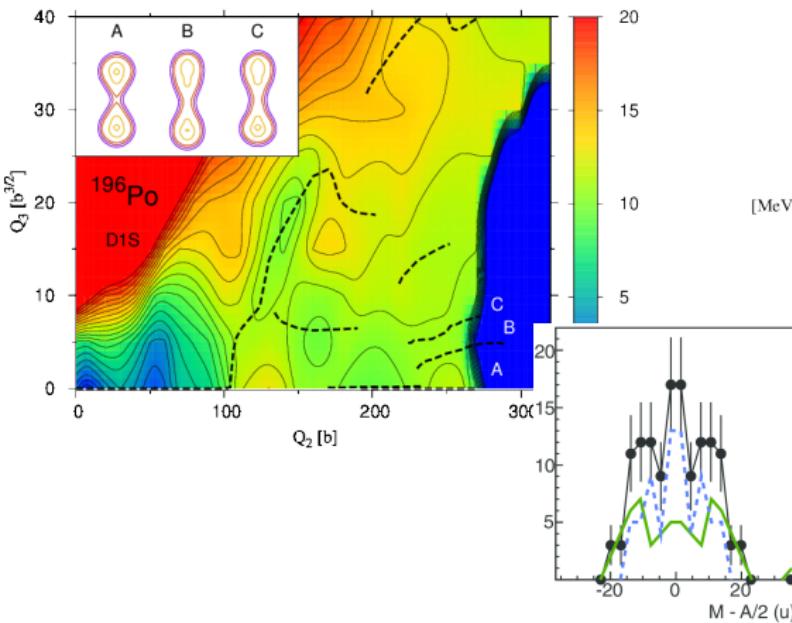




M. Warda, A. Staszczak, W. Nazarewicz, Phys. Rev. C 86 (2012) 024601
 M.G. Itkis, et al., Yad. Fiz. 52, 944 (1990)

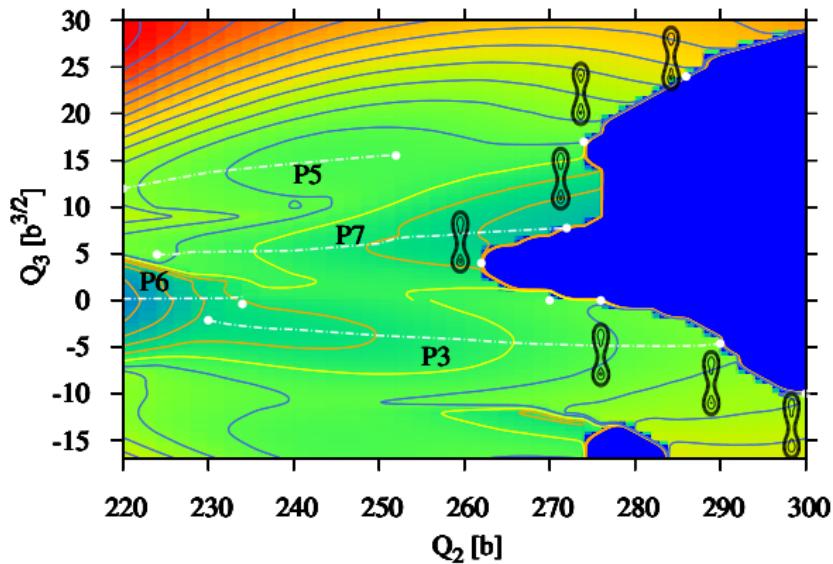
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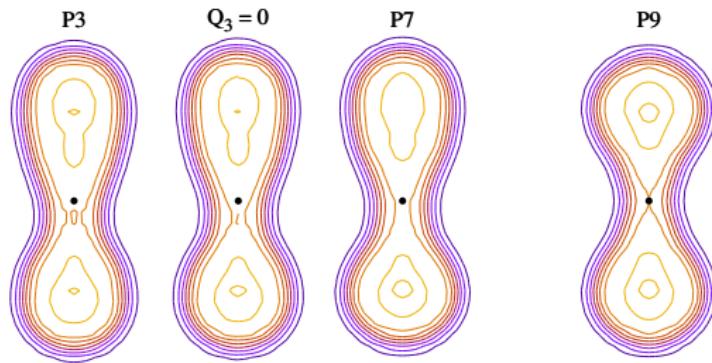




L. Ghys, et al. Phys. Rev. C 90 (2014) 041301R

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$Q_2 = 250 \text{ b}$



Cluster radioactivity

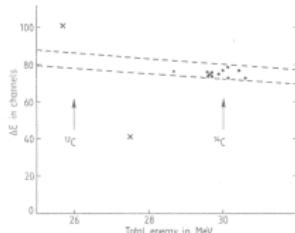


Fig. 1 Contents of the two-dimensional array ΔE versus E_{tot} after a run of 189 days. The dotted line indicates the allowed region of calibration and the arrows indicate the total energies expected for ^{14}C and ^{209}Pb emissions from the decay of ^{223}Ra . The lower of the two crosses represents a quadruple pile-up. Below the total energy displayed, large numbers of triple and double α -pile-ups were recorded. Single α -events (and, in part, even double α -pile-ups) were biased out on the analogue side to avoid deadtime problems on the digital side. The upper cross is an event which was recorded during a thunderstorm which affected the main body. A run of 189 days was made with this filter, yielding 8 events and, in addition, a run of approximately half a year was performed to investigate possible cosmic ray-induced events. Channel 77 in $\Delta E = 6.7 \text{ MeV}$, which is exactly as expected for ^{14}C . Detector characteristics: The dead layer of the ΔE detector (200 mm^2 active area, $8.2 \mu\text{m}$ sensitive thickness) was determined to lie between $3 \text{ and } 8 \mu\text{m}$. In addition, a thin layer of gold ($1 \mu\text{m}$ thickness, $20 \mu\text{g cm}^{-2}$) was evaporated on the source and $15 \mu\text{g cm}^{-2}$ carbon film inserted between the source and the ΔE detector. An extra $30\text{--}40 \mu\text{g cm}^{-2}$ of gold is present on the E -detector (300 mm^2 active area). This gives a total of $150\text{--}250 \mu\text{g cm}^{-2}$ of effective dead layer (Si equivalent) and an energy loss of ^{14}C ions of $0.5\text{--}0.8 \text{ MeV}$. The source of strength $3.3 \mu\text{Ci}$ gave a counting rate of $\sim 4,000 \text{ s}^{-1}$, corresponding to an effective solid angle of detection of $\sim 1/3 \text{ sr}$.

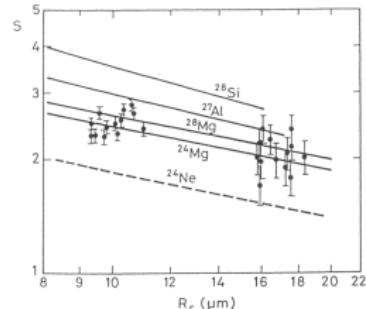
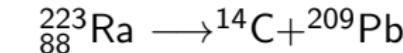


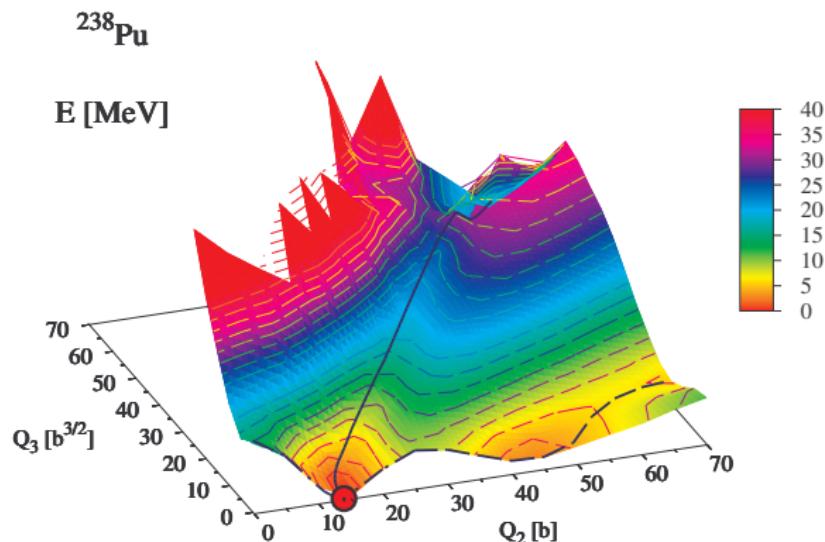
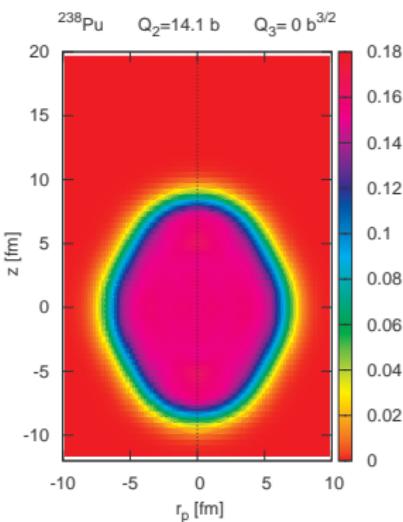
Fig. 6. Comparison of the sensitivity S measured at two stages of the etching process for the 15 events from the decay of ^{238}Pu with accelerator calibrations. Reprinted with permission from M. Hussonnien et al., "Cluster decay of ^{238}Pu and correlations of the probabilities of α decay, cluster decay and spontaneous fission of heavy nuclei" JETP Letters 62 (1995) p 701. Copyright 1995 American Institute of Physics.

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R. Bonetti, A. Guglielmetti, in *Heavy Elements and Related New Phenomena Vol II*, ed. W. Greiner and R.K. Gupta, p.634, Word Scientific, 1999



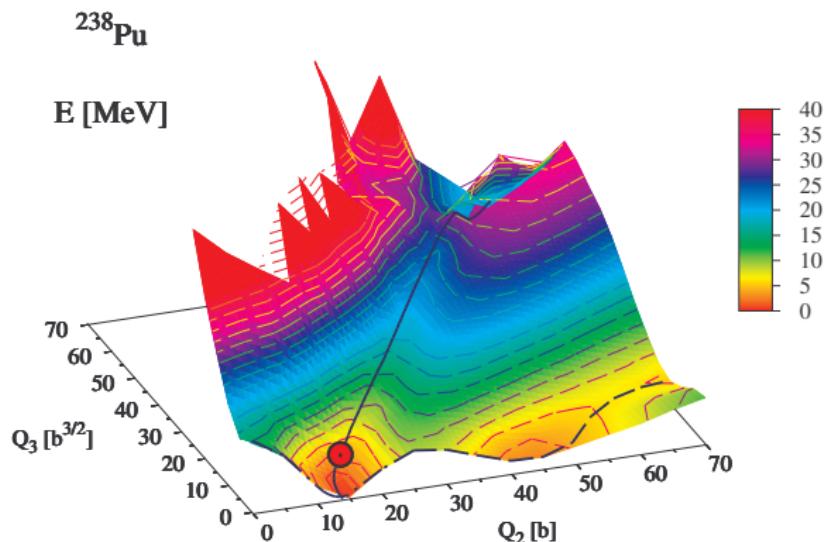
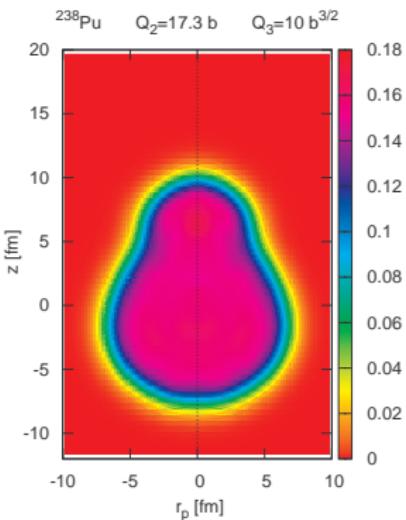
Cluster radioactivity: ^{238}Pu



M. Warda, L.M. Robledo, Phys. Rev. C 84 (2011) 044608

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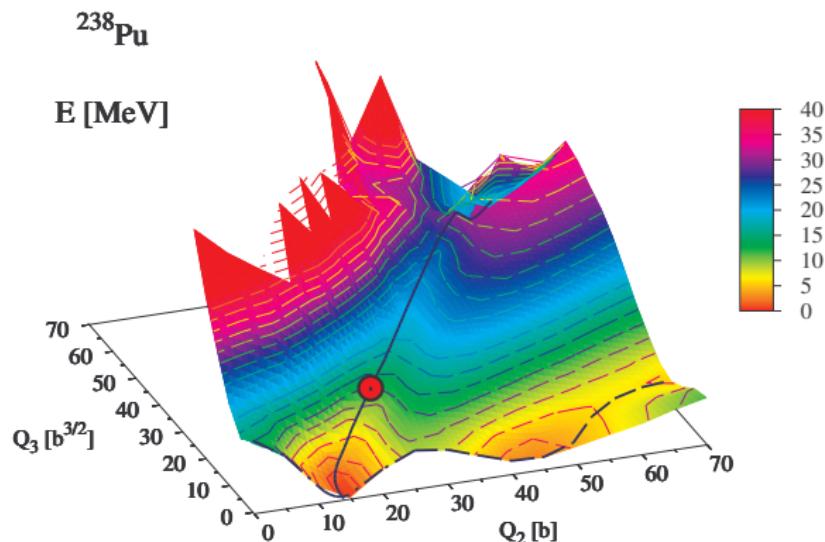
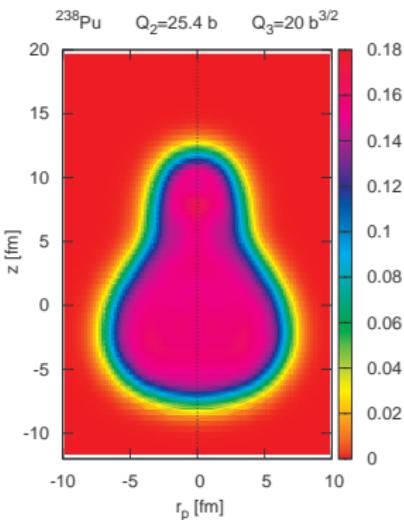
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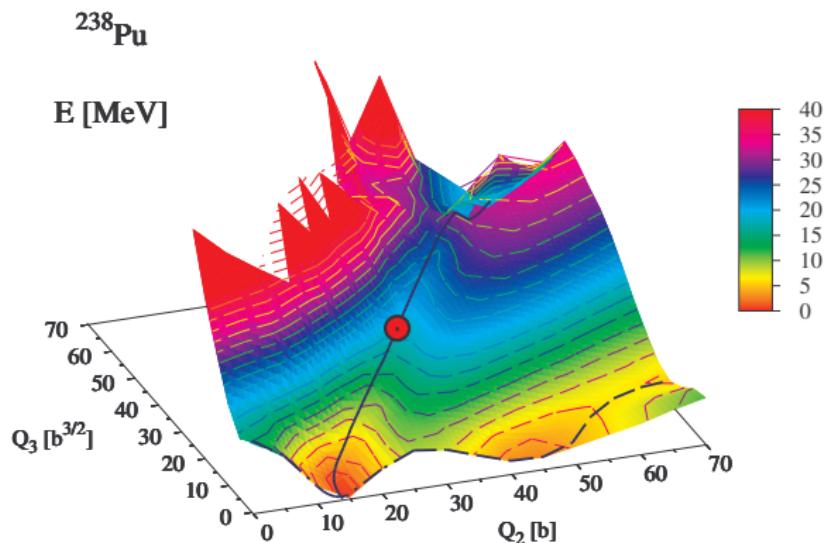
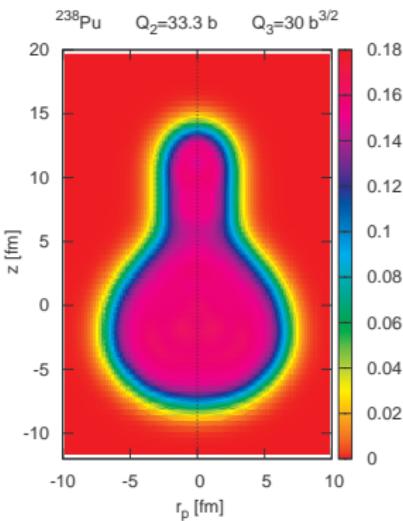
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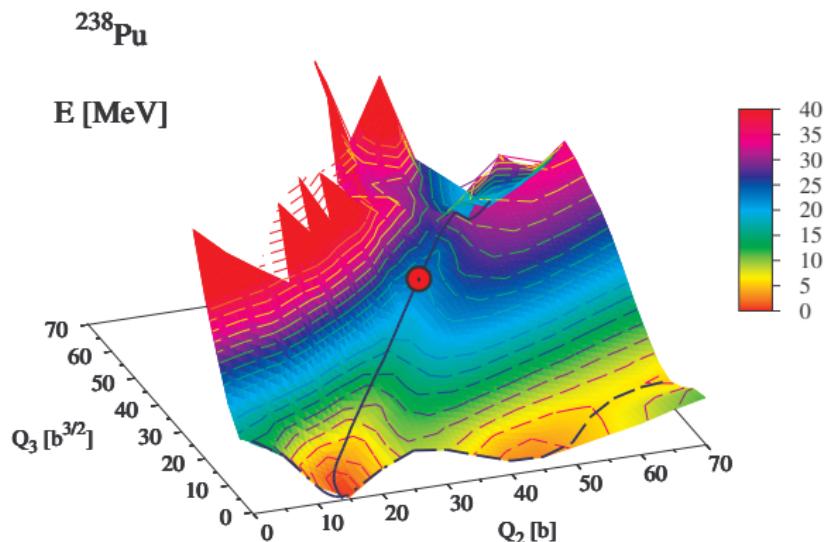
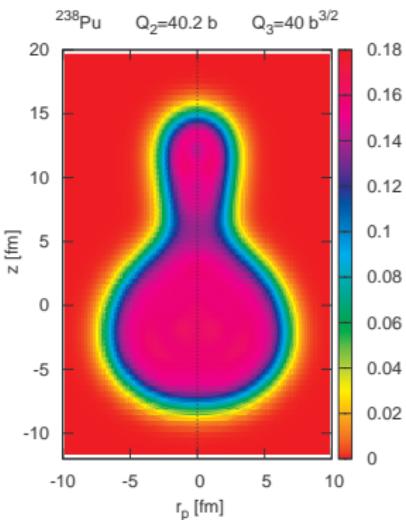
Cluster radioactivity: ^{238}Pu



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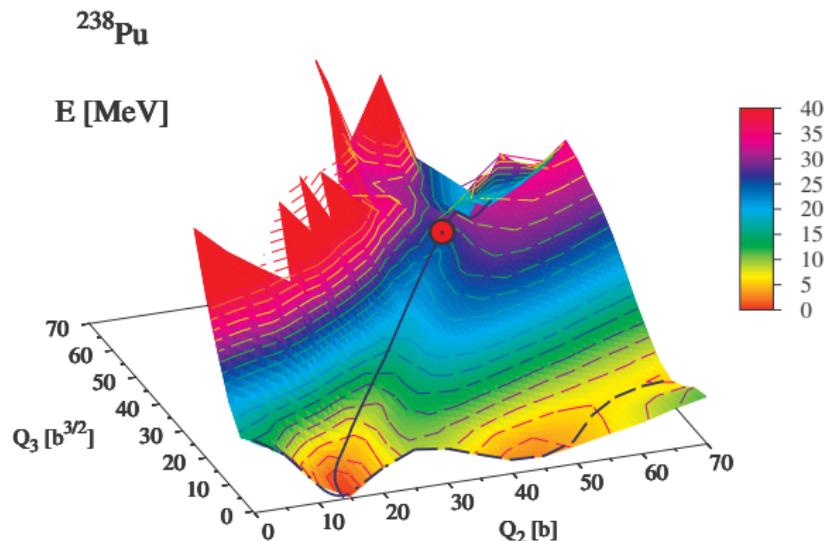
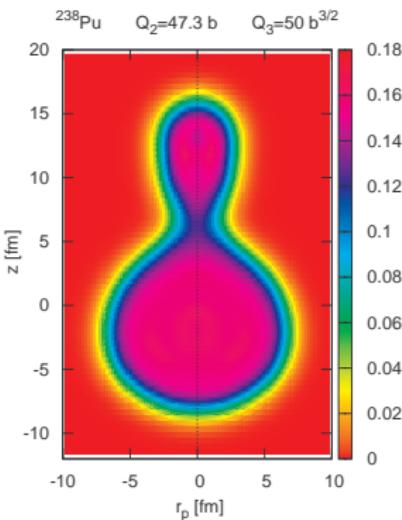
Cluster radioactivity: ^{238}Pu



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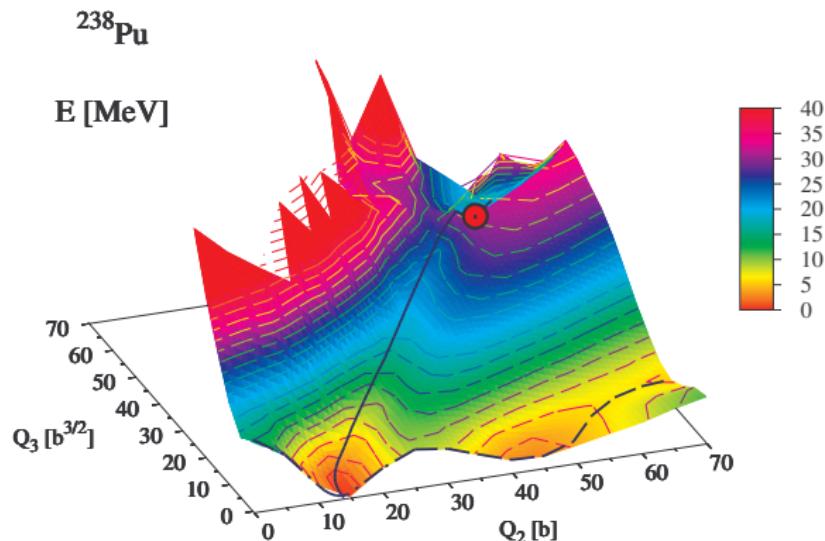
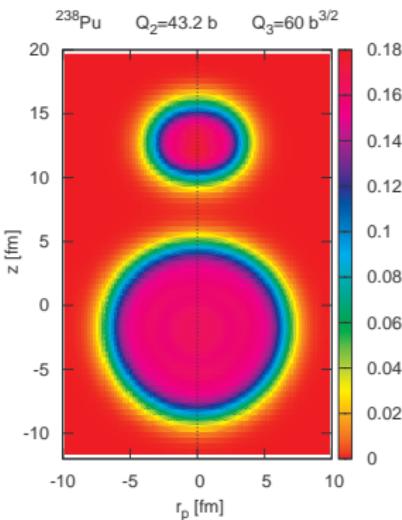
Cluster radioactivity: ^{238}Pu



M. Warda, L.M. Robledo, Phys. Rev. C 84 (2011) 044608

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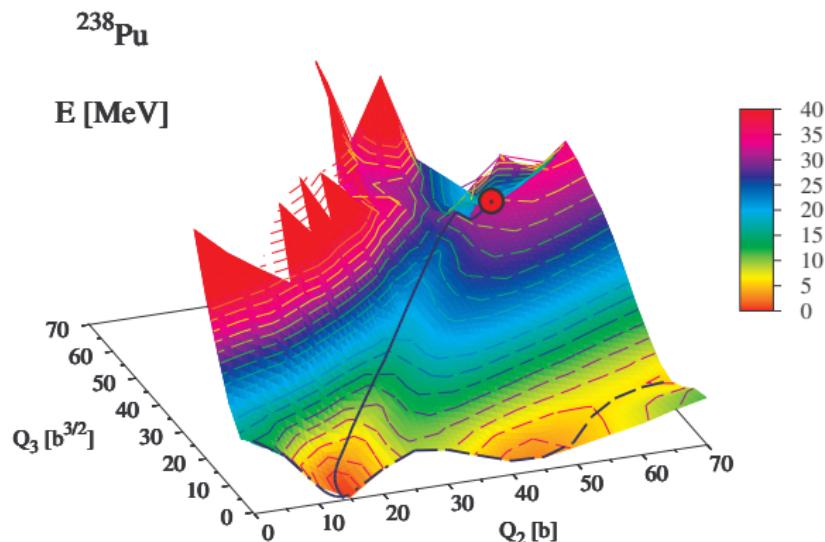
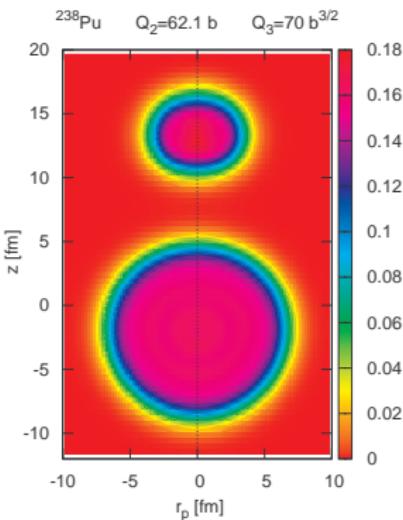
Cluster radioactivity: ^{238}Pu



M. Warda, L.M. Robledo, Phys. Rev. C 84 (2011) 044608

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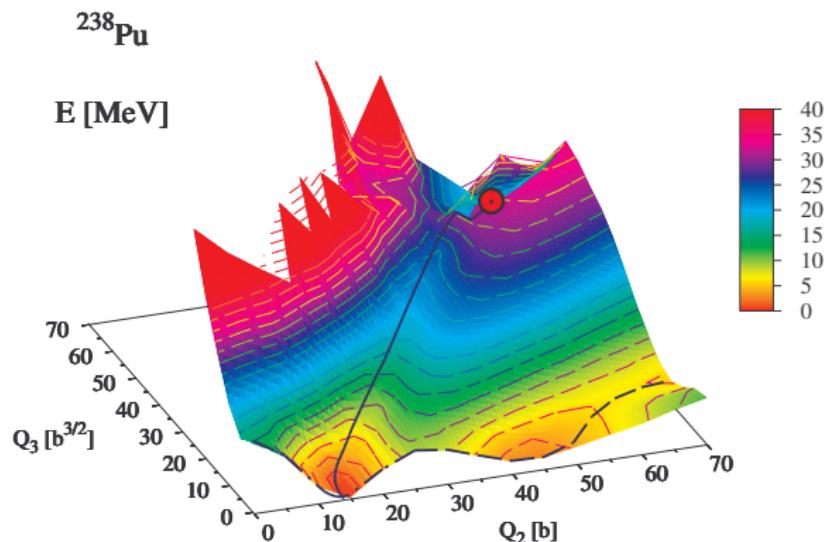
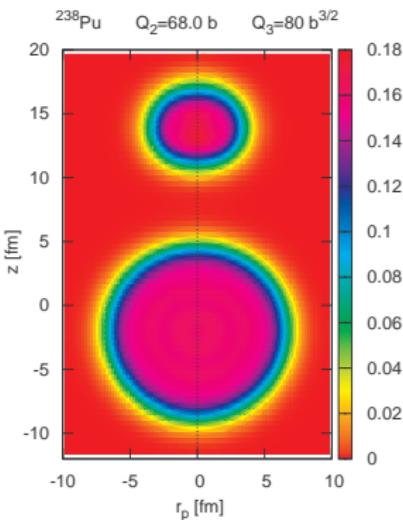
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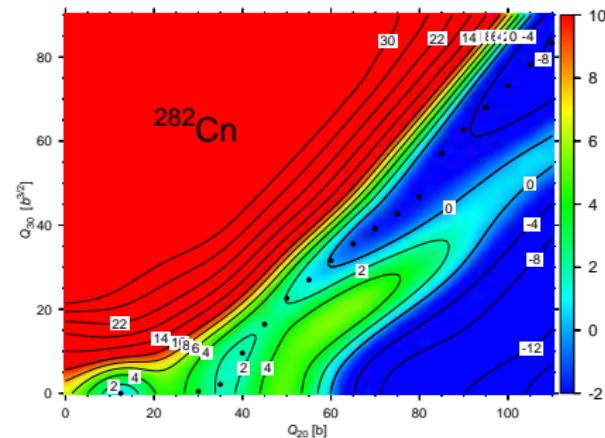
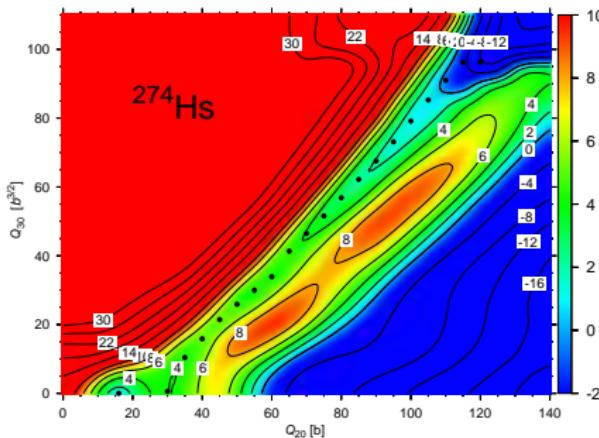
Cluster radioactivity: ^{238}Pu



M. Warda, L.M. Robledo, Phys. Rev. C 84 (2011) 044608

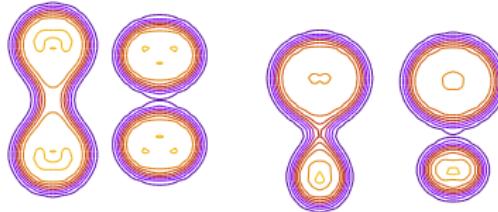
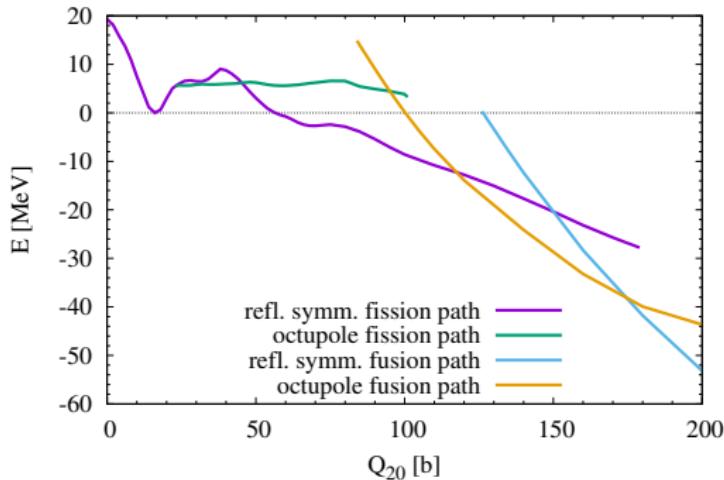
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Super-heavy nuclei

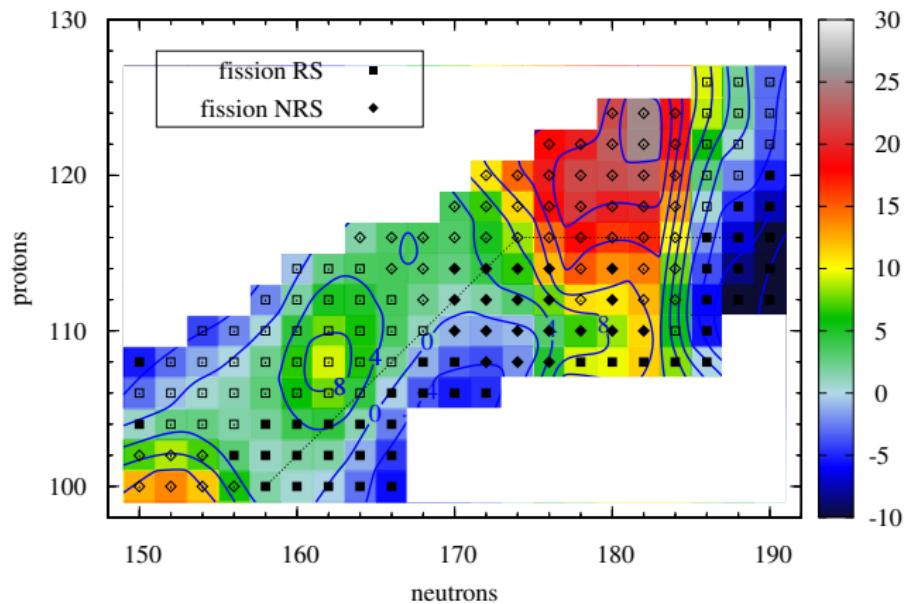


M. Warda, J.L. Egido, Phys. Rev. C 86 (2012) 014322

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Fission half-lives



A. Baran, M. Kowal, P.G. Reinhard, L.M. Robledo, A. Staszczak, M. Warda, Nucl. Phys. A 944 (2015) 442



- Pre-scission shapes have been determined in self-consistent procedure in HFB theory with Gogny D1S force
- The fragment mass asymmetry reproduces experimental observations
- Shell structure of the fragments can be seen before the neck rupture



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and Jie Meng on chirality

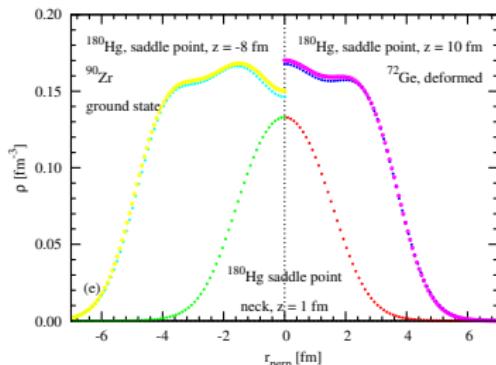
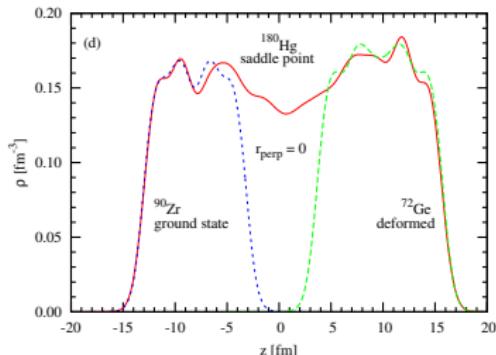
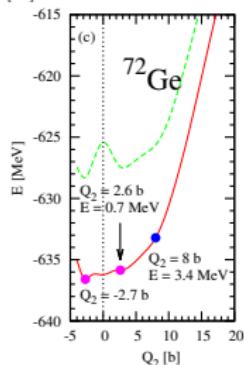
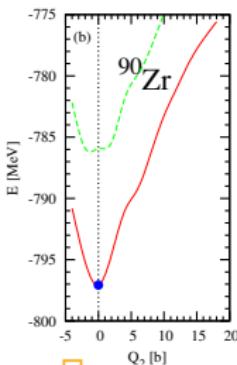
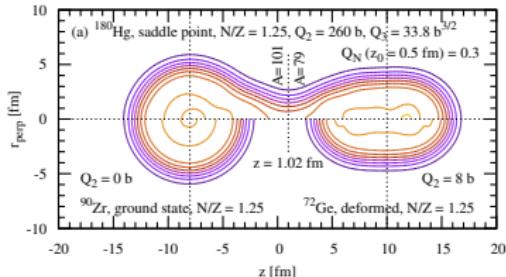
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^{180}Hg





^{198}Hg

