Microscopic description of fission mass yields

Anna Zdeb

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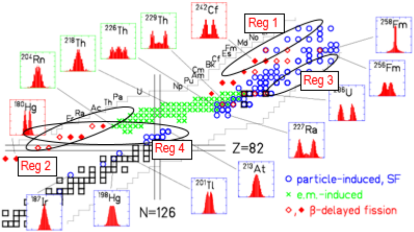
KATEDRA FIZYKI TEORETYCZNEJ UMCS LUBLIN

June 27, 2017

ECT* DTP, Trento

Motivation



K.H. Schmidt *et. al., Nucl. Phys.* **A665** *221 (2000)*

- Fission fragment mass yield is a one of the basic, measurable observable
- The shape of observed fragment mass distribution allows to determine the type of fission (symmetric, asymmetric, bimodal)
- Accuracy of reproduction of the experimental mass yields is a test of the theoretical models
- The proper theoretical description of fission mass distribution is still pending

Potential energy surface - HFB + Gogny D1S

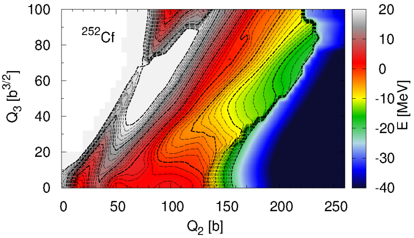
$$\delta\left[\left\langle \Phi(Q_{20},Q_{30}) \mid \hat{H} - \lambda_Z\hat{Z} - \lambda_N\hat{N} - \sum_i \lambda_i \hat{Q}_i \mid \Phi(Q_{20},Q_{30})\right\rangle\right] = 0$$

The quadrupole moment:

$$\hat{Q}_{20} = \sqrt{\frac{16\pi}{5}} \sum_{i=1}^{A} r_i^2 Y_{20}$$

The octupole moment:

$$\hat{Q}_{30} = \sqrt{\frac{4\pi}{7}} \sum_{i=1}^{A} r_i^3 Y_{30}$$



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Fission path - ^{252}Cf

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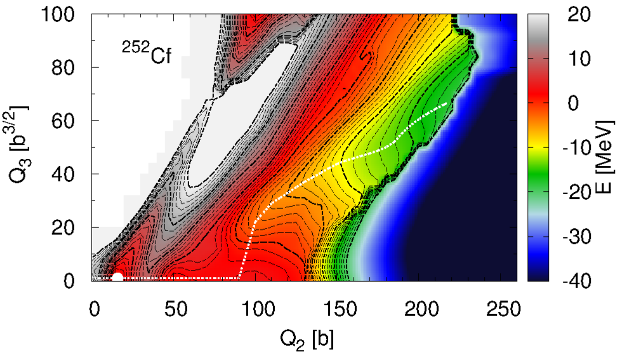

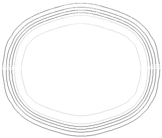

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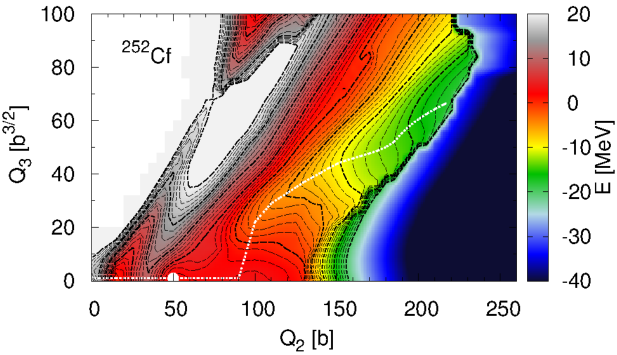

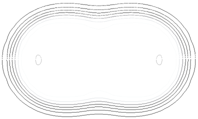

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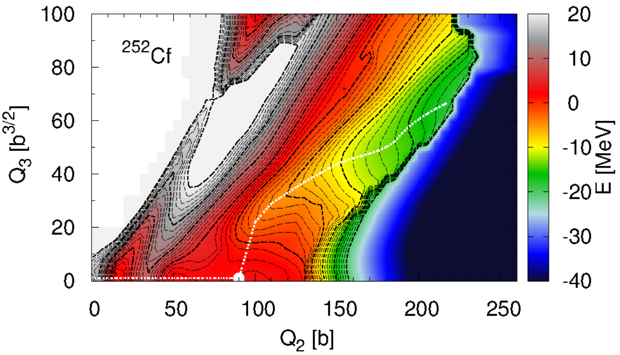

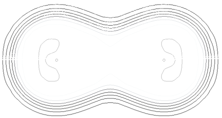

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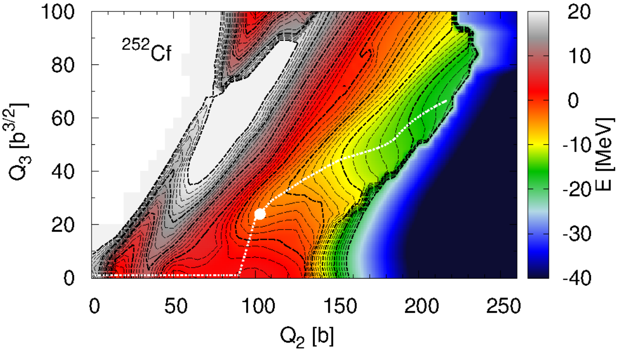

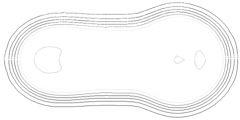

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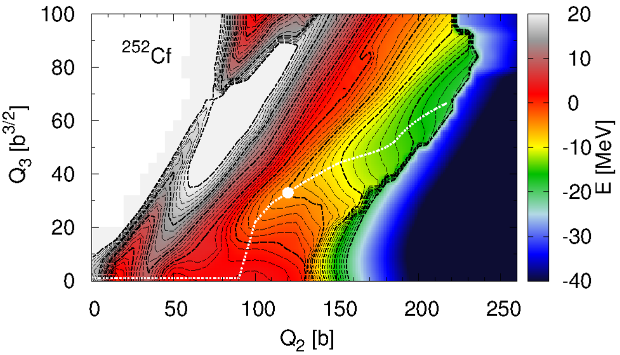

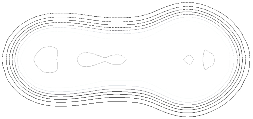

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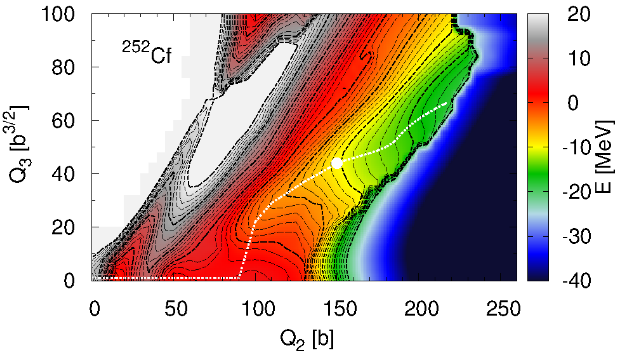

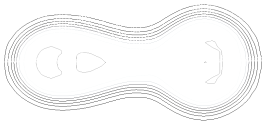

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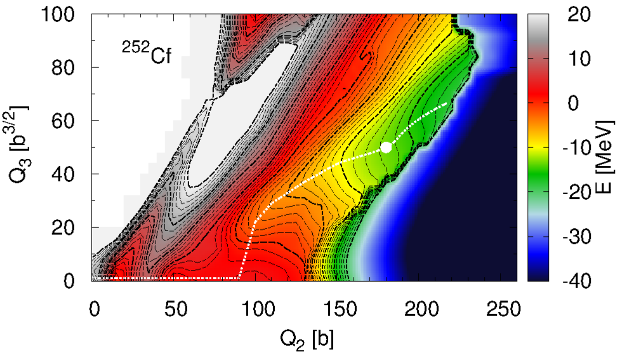

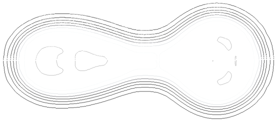

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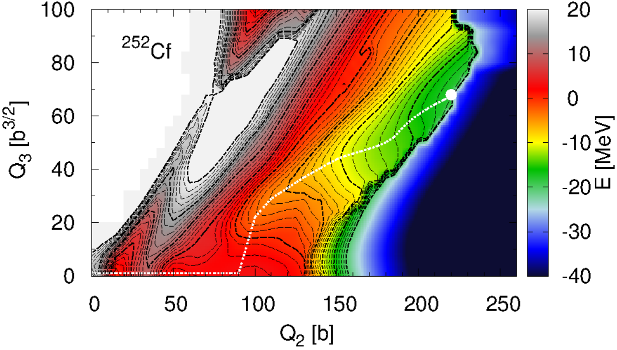

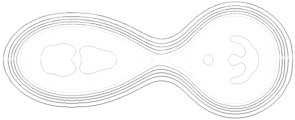

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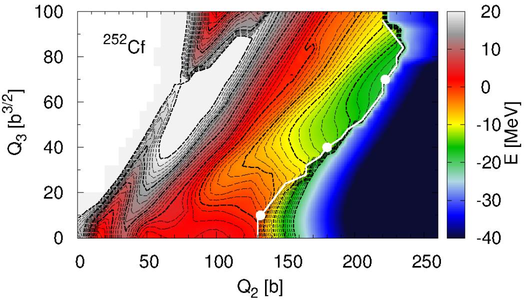
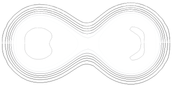
Kształty przedrozszczepieniowe

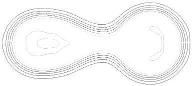


Q_2 = 130 b, Q_3 = 10 $b^{3/2}$



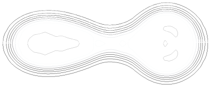
A_H / A_L = 131 / 121

Q_2= 180 b, Q_3= 40 $b^{3/2}$



A_H / A_L = 134 / 118

Q_2= 220 b, Q_3= 70 $b^{3/2}$



A_H / A_L = 142 / 110

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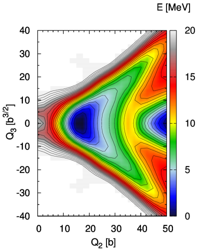
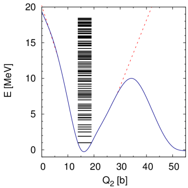
Fission dynamics

$$\widehat{H}_{coll} = -\frac{\hbar^2}{2\sqrt{\gamma}} \sum_{i,j=2}^{3} \frac{\partial}{\partial Q_{i0}} \sqrt{\gamma} B_{ij}(Q_{20}, Q_{30}) \frac{\partial}{\partial Q_{j0}} + V(Q_{20}, Q_{30})$$

$$\gamma \equiv \det G(Q_2, Q_3), \qquad B_{ij} = \mathcal{M}_{ij}^{-1}$$

$$\widehat{H}'_{\rm coll} g_n^{\pi}(Q_2, Q_3, t=0) = E_n^{\pi} g_n^{\pi}(Q_2, Q_3, t=0)$$





$$\widehat{H}_{\rm coll} g(Q_2, Q_3, t) = i\hbar \frac{\partial g(Q_2, Q_3, t)}{\partial t}$$

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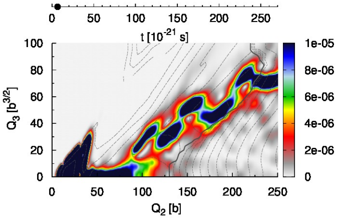
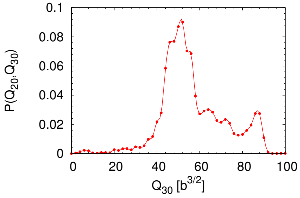
Probability current density

$$\vec{J}(Q_{20},Q_{30},t) = \frac{\hbar}{2i}\sqrt{\gamma}B(Q_{20},Q_{30})\times [g^*(Q_{20},Q_{30},t)\nabla g(Q_{20},Q_{30},t) - g(Q_{20},Q_{30},t)\nabla g^*(Q_{20},Q_{30},t)]$$

$$P(Q_{20}^{sc},Q_{30}^{sc}) = \int_{t=0}^{t=T^{propag}} \vec{J}(Q_{20}^{sc},Q_{30}^{sc},t)\cdot\vec{n}\ dt$$





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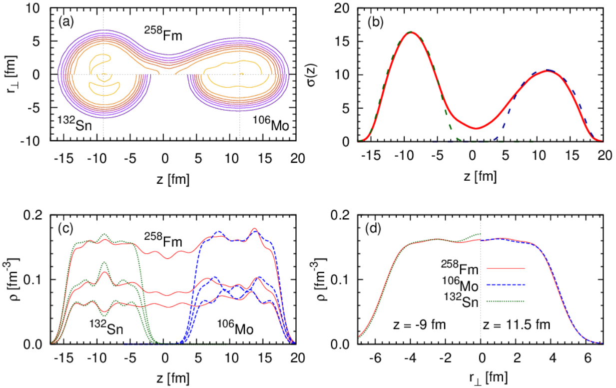
Pre-scission configuration



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

M. Warda, A. Zdeb, Physica Scripta 90 114003 (2015).

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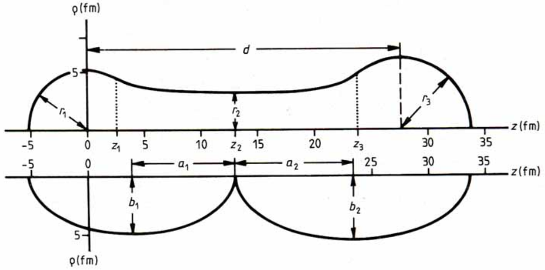
Neck rupture probability



$$P(z) \sim \exp[-\sigma(z)]$$

Brosa U., Phys. Rev. **C38** 1944 (1988).

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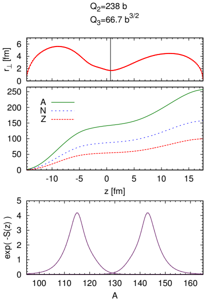
Random Neck Rupture Mechanism

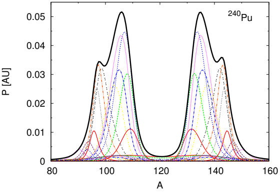
$$\sigma(z) = 2\pi \int_0^\infty r_\perp \rho(z, r_\perp) dr_\perp$$

$$P(A_1/A_2) = \exp\left[\frac{-2\gamma\sigma(z)}{T}\right] \implies$$



$$P(Q_{20}^{sc}, Q_{30}^{sc}) = \int_{t=0}^{t=T^{propag}} \vec{J}(Q_{20}^{sc}, Q_{30}^{sc}, t) \cdot \vec{n} \; dt$$

$$\implies$$



Brosa U., Phys. Rev. **C38** 1944 (1988).

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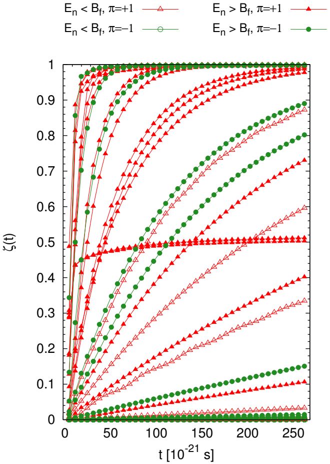
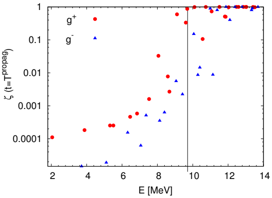
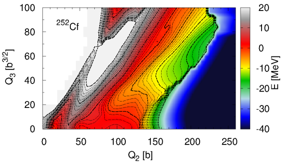
The tunneling probability







$$\zeta(t) = 1 - \int |g^{\pi}(q_{20}, q_{30}, t)|^2 dq_{20} dq_{30}$$

A. Zdeb, A. Dobrowolski, M. Warda, Phys. Rev. **C95** 054608 (2017)

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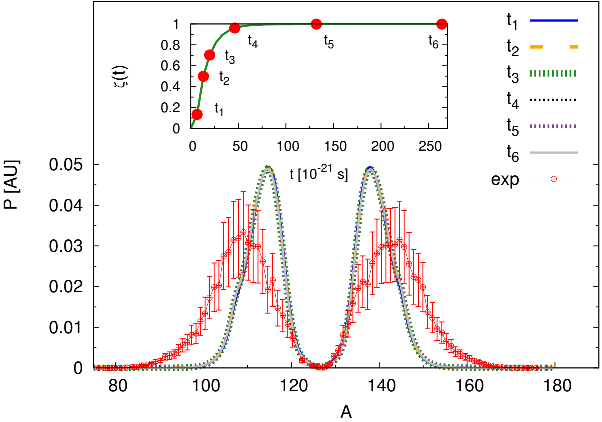
Time of evolution



A. Zdeb, A. Dobrowolski, M. Warda, Phys. Rev. **C95** 054608 (2017)

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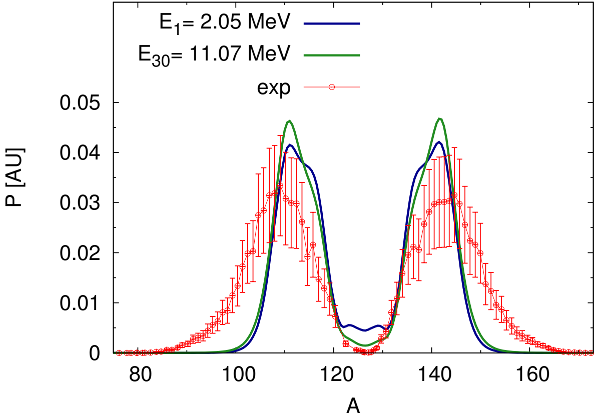
Energy dependence



A. Zdeb, A. Dobrowolski, M. Warda, Phys. Rev. **C95** 054608 (2017)

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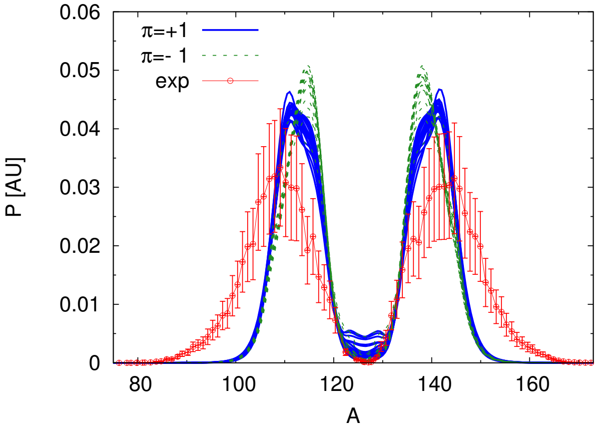
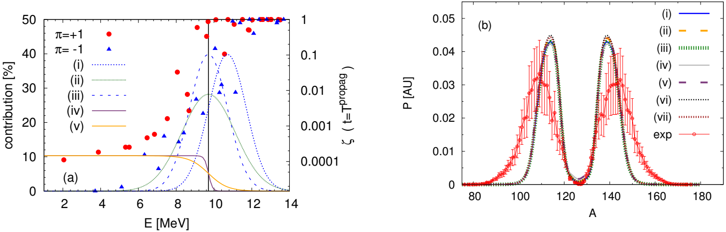
Parity dependence



A. Zdeb, A. Dobrowolski, M. Warda, Phys. Rev. **C95** 054608 (2017)

Mixed states



A. Zdeb, A. Dobrowolski, M. Warda, Phys. Rev. **C95** 054608 (2017)

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Conclusions and perspectives

- The peaks positions are well reproduced
- There is no strong correlation between mass distribution and initial conditions
- Theoretical mass yields are too narrow in comparison to the experimental ones
- To improve the accuracy of data reproduction model extensions are required

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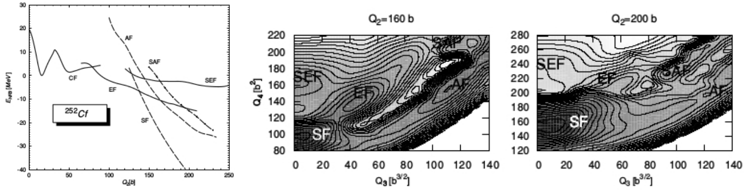
Third dimension - Q_{40}

The hexadecapole moment: $\widehat{Q}_{40} = \sqrt{\frac{4\pi}{9}} \sum_{i=1}^{A} r_i^4 Y_{40}$



$\Longrightarrow$ **Super-asymmetric fission path**

M. Warda, K. Pomorski, J.L. Egido, L.M. Robledo, J. Phys. G: Nucl. Part. Phys. 31, S1555 (2005).

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Thank you!

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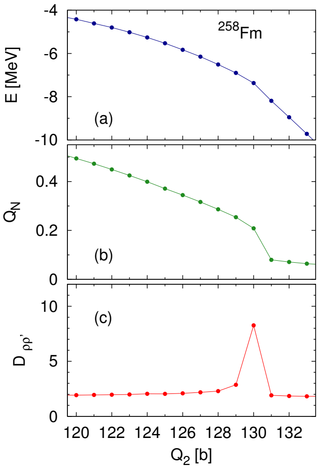
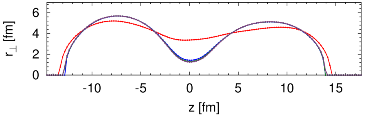
Searching for pre-scission points





$$D_{\rho\rho'} = \int_0^\infty |\rho(\vec{r}) - \rho'(\vec{r})| d\tau$$

M. Warda, A. Zdeb, Physica Scripta **90** 114003 (2015)
N. Dubray et al., Comp. Phys. Comm. **183** (2012) 2035.

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