Fusion hindrance and SHE

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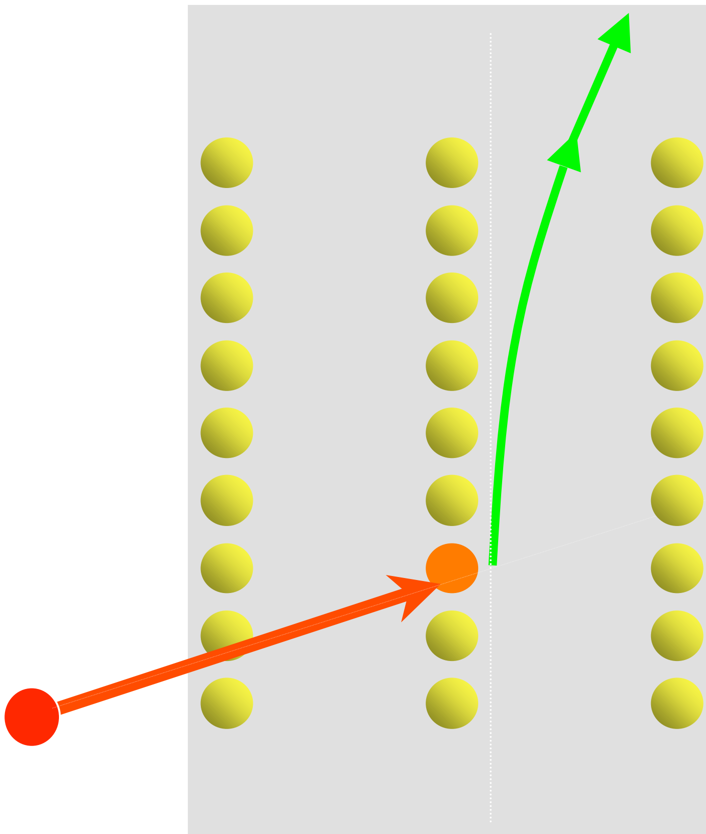
Questions for theoreticians

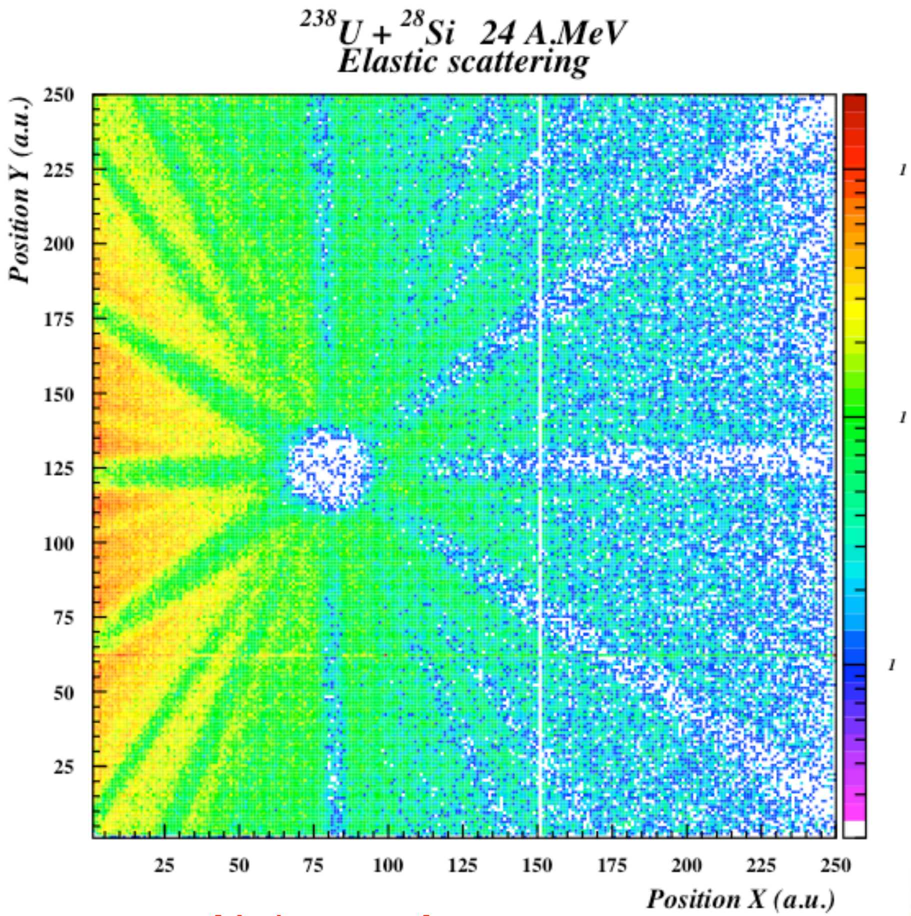
- Can we guide the experiments ?
- What is the shell correction energy ?

Difficulties

- Models cannot be extrapolated from lighter systems
  - Fusion hindrance
- Extremely low cross sections
  - Few data with few information

Blocking technique in crystals

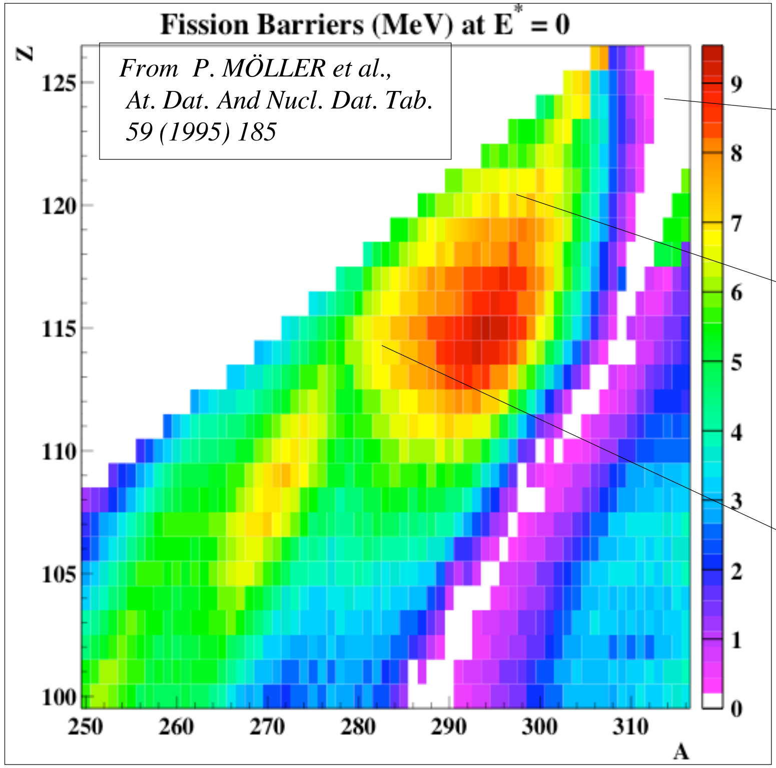




F. Goldenbaum et al., PRL 82 (1999) 5012

Direct evidence for long fission times

Fission barriers



M. Morjean et al, Eur. Phys. J. D45 (2007) 27 & PRL101, 072701 (2008)

Mesurements at GANIL by crystal blocking techniques

Z = 124 A = 312

At least 12 % of the capture events with a life time longer than 10^{-18} s

Z = 120 A = 296

At least 10 % of the capture events with a life time longer than 10^{-18} s

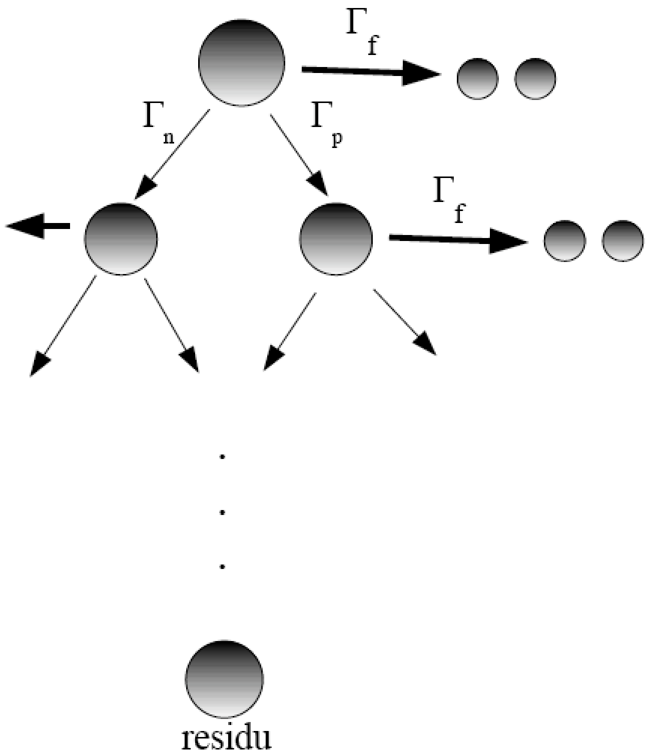
Z = 114 A = 282

Very low statistic or no events with a life time longer than 10^{-18} s

$$1/\Gamma_f \approx 10^{-21} s$$

KEWPIE 2

Main ingredients



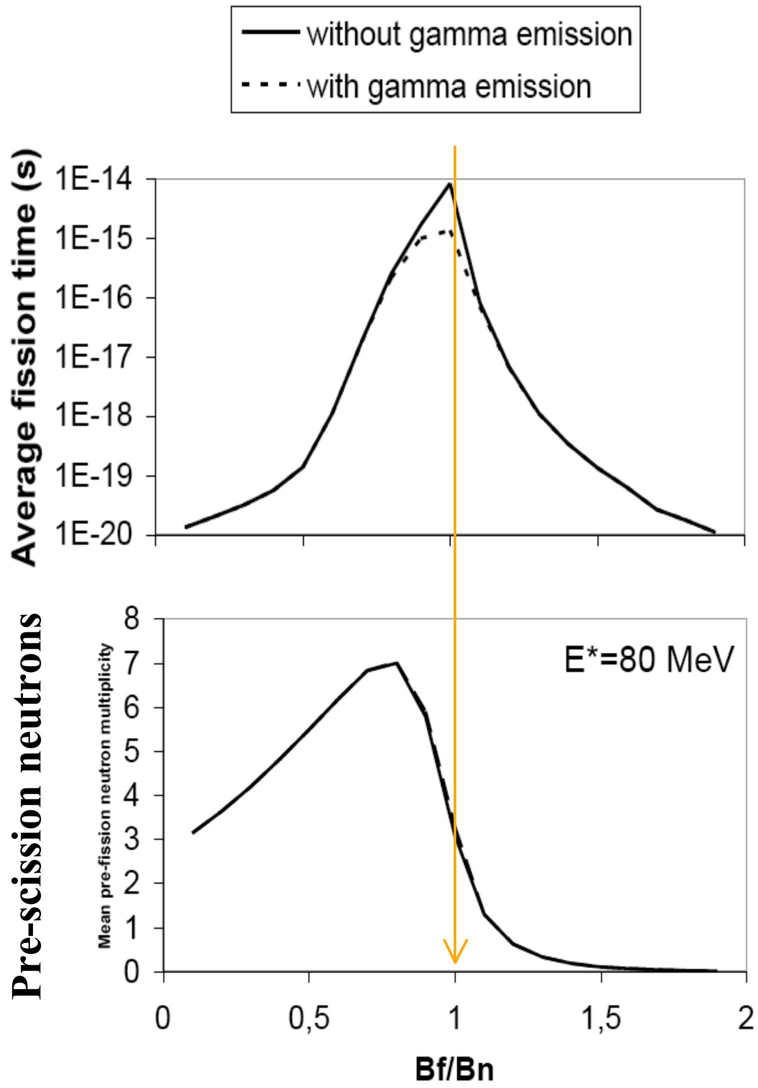
$$\frac{dP_i}{dt} = \Gamma_{i-1}^{n} P_{i-1}(t) - (\Gamma_i^f + \Gamma_i^n) P_i(t)$$

- **Formalism:**
  - Weisskopf or Hauser-Feshbach
  - Bohr-Wheeler
- **Level density:**
  - Bohr-Mottelson with angular dependence
- **Level density parameter:**
  - Töke-Swiatecki
  - Suppression of shell energy corrections according to Ignatyuk
- **Collective enhancement included**

A. Marchix, PhD thesis, Univ. Caen (2007)

Simplified model

- Fission vs neutron evaporation
- Bn=6 MeV & Bf constant along the chain
- Long fission times mean:
  - $B_f \approx B_n$
  - Long fission time events occur after evaporation of several neutrons
  - We cannot extract Bf of each isotope



D.B. et al, IJMP E17 (2008) 1681-1693

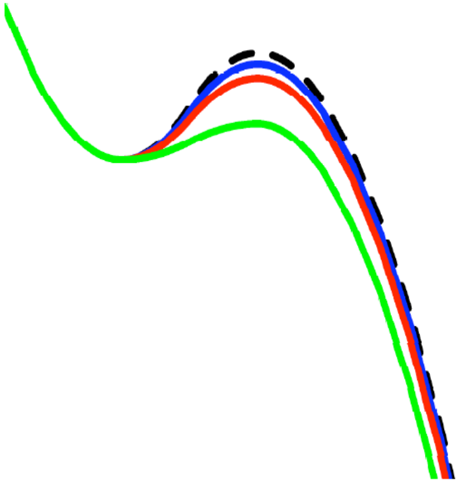
What about ΔE_{shell}?

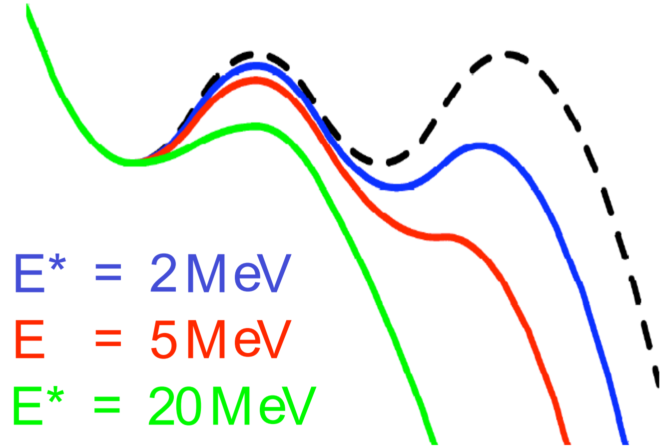
$$a_{ground} = a.\left(1 + \frac{(1 - e^{-E^*/E_d}).\Delta E_{shell}}{E^*}\right)$$

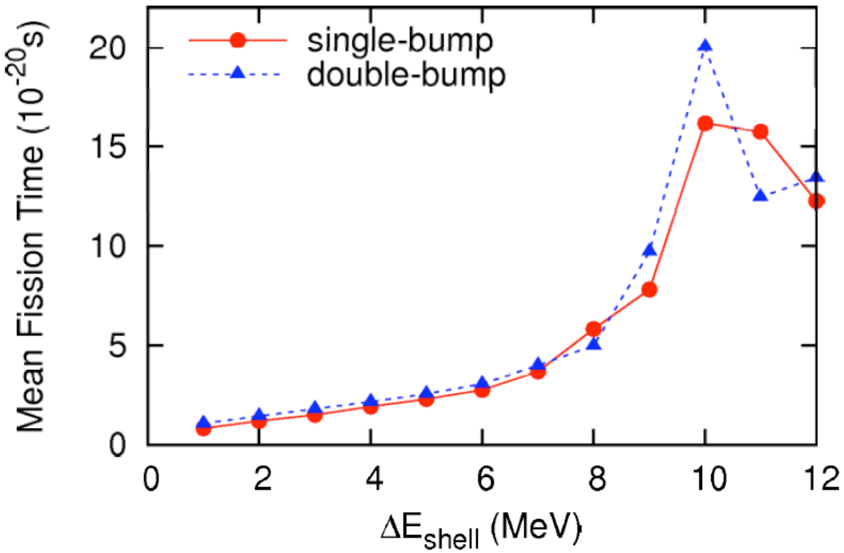
$$B_f \approx e^{-E^*/E_d}.\left|\Delta E_{shell}\right|$$

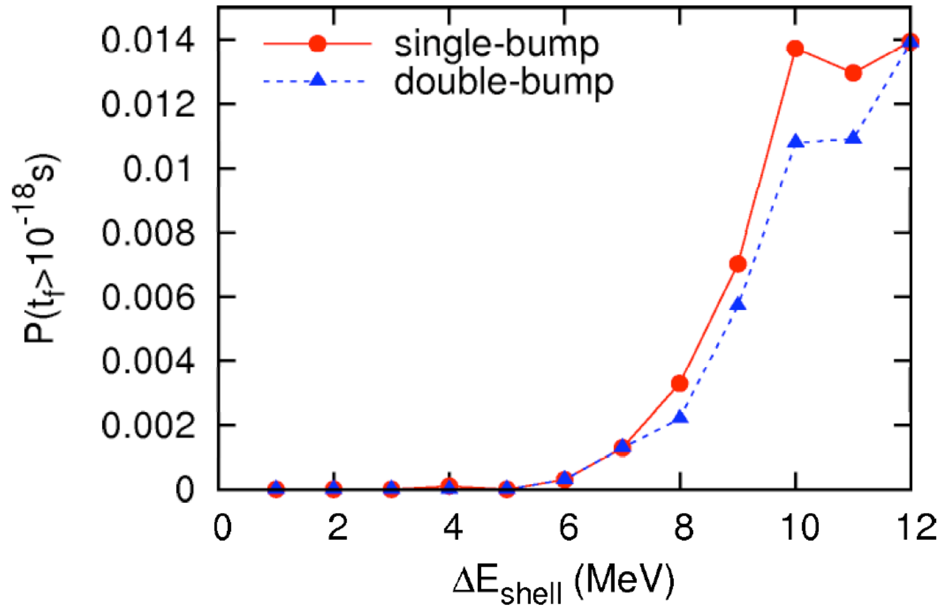
- **Experimental results for Z=120 and 124 cannot be reproduced with Möller's table**
- **Very large ΔE_{shell} for the first isotopes of the evaporation chain**
- **Potential structure effects ?**

Structure effect 2



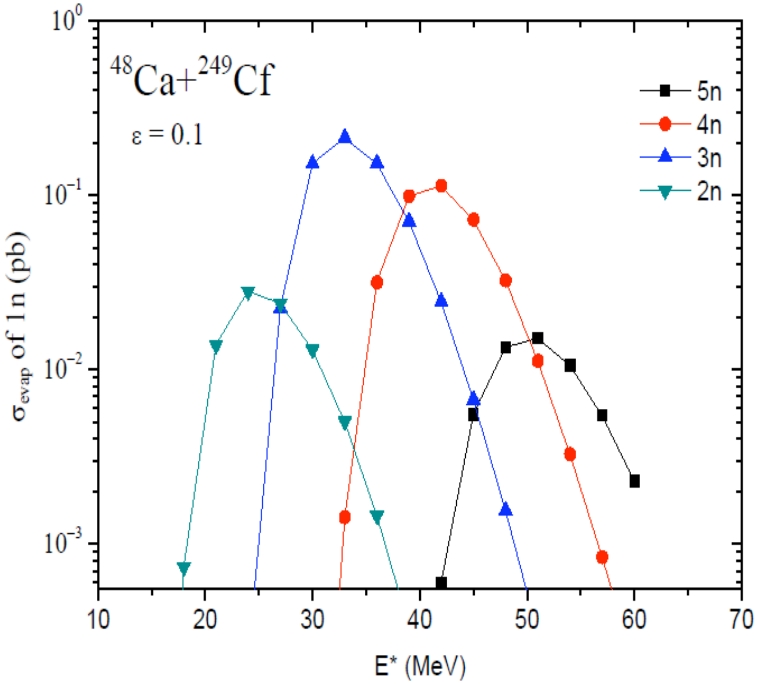






Preliminary

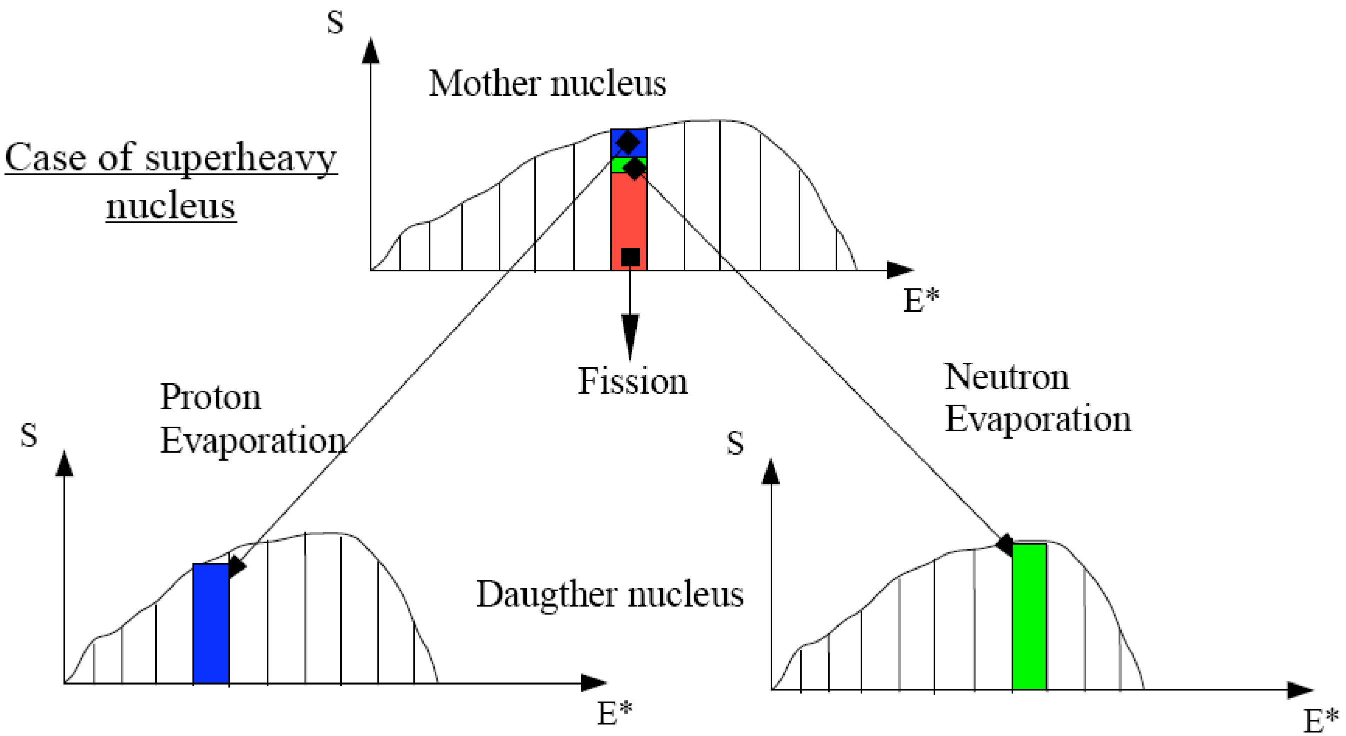
Residue cross sections



KEWPIE 2

Specificity

- It is **not** a Monte-Carlo code to calculate very low probabilities
- It is based on a **discretisation** in bins of the energy spectra:



Residue cross sections

Important parameters of KEWPIE2

- Shell correction energy -> correction factor

$$\Delta E_{shell} = f.\Delta E_{Moller}$$

- Damping Energy E_d

$$a_{ground} = a.(1 + \frac{(1 - e^{-E^*/E_d}).\Delta E_{shell}}{E^*})$$

$$B_f \approx e^{-E^*/E_d}.|\Delta E_{shell}|$$

  - Originally, *Ed*=18.5 MeV

- Reduced friction

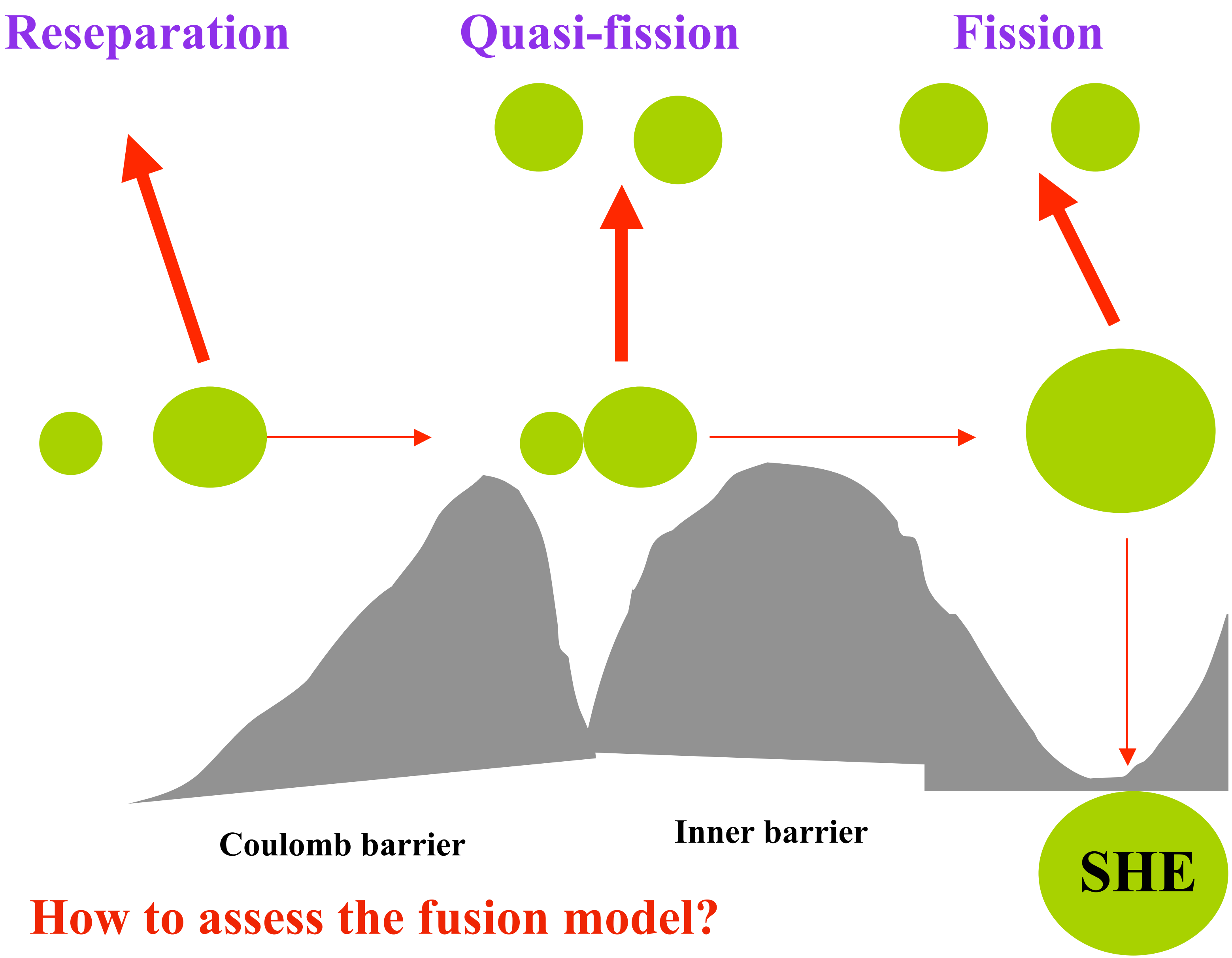
β=2.10^{21}s^{-1}

A. Marchix, PhD thesis, Univ. Caen (2007)

Results

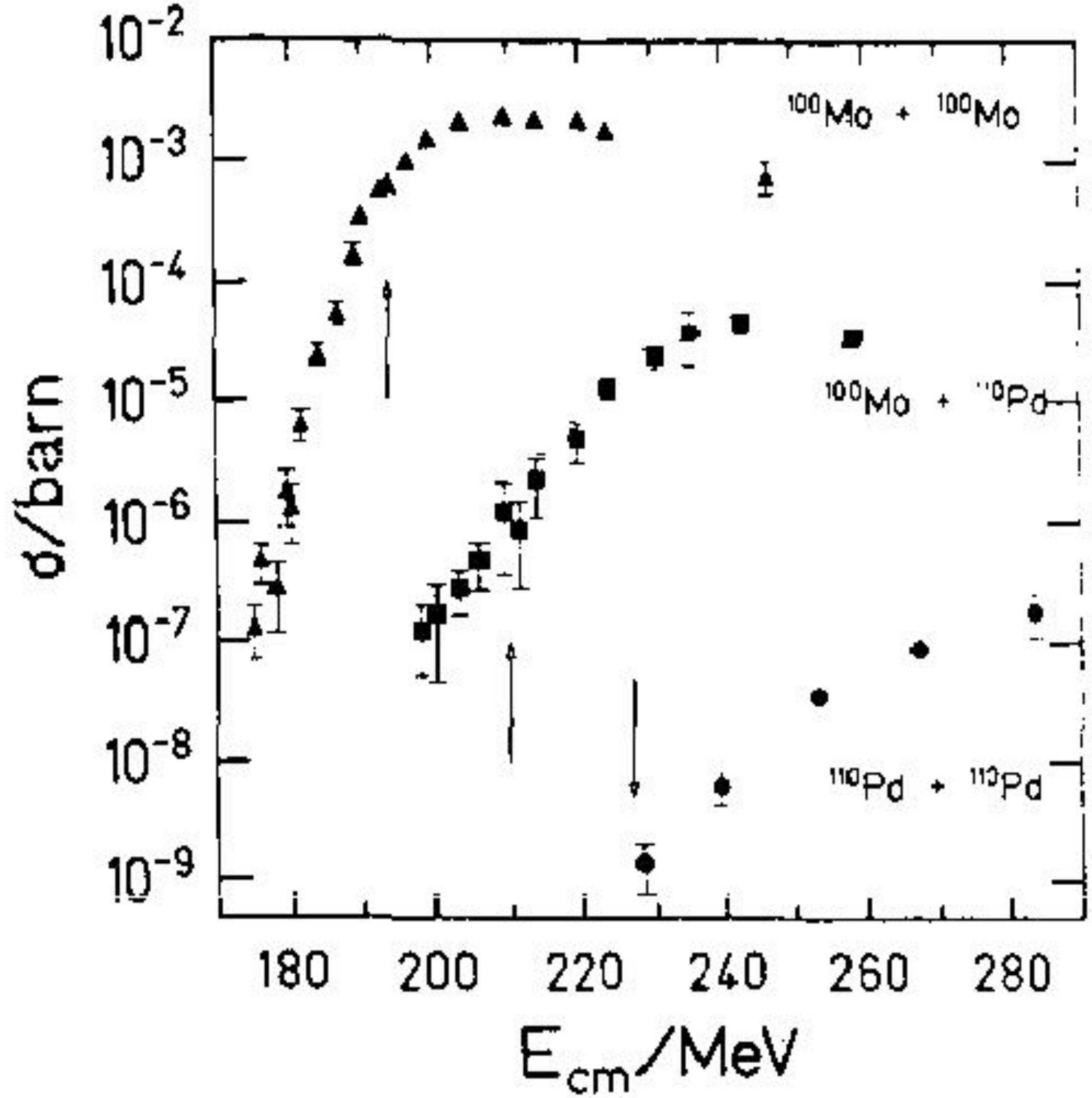
- Fitting the residue cross sections gives very strong constraint on ΔE_{shell}…
  - Precision of 1 MeV
- … if we know the fusion cross section

Reaction



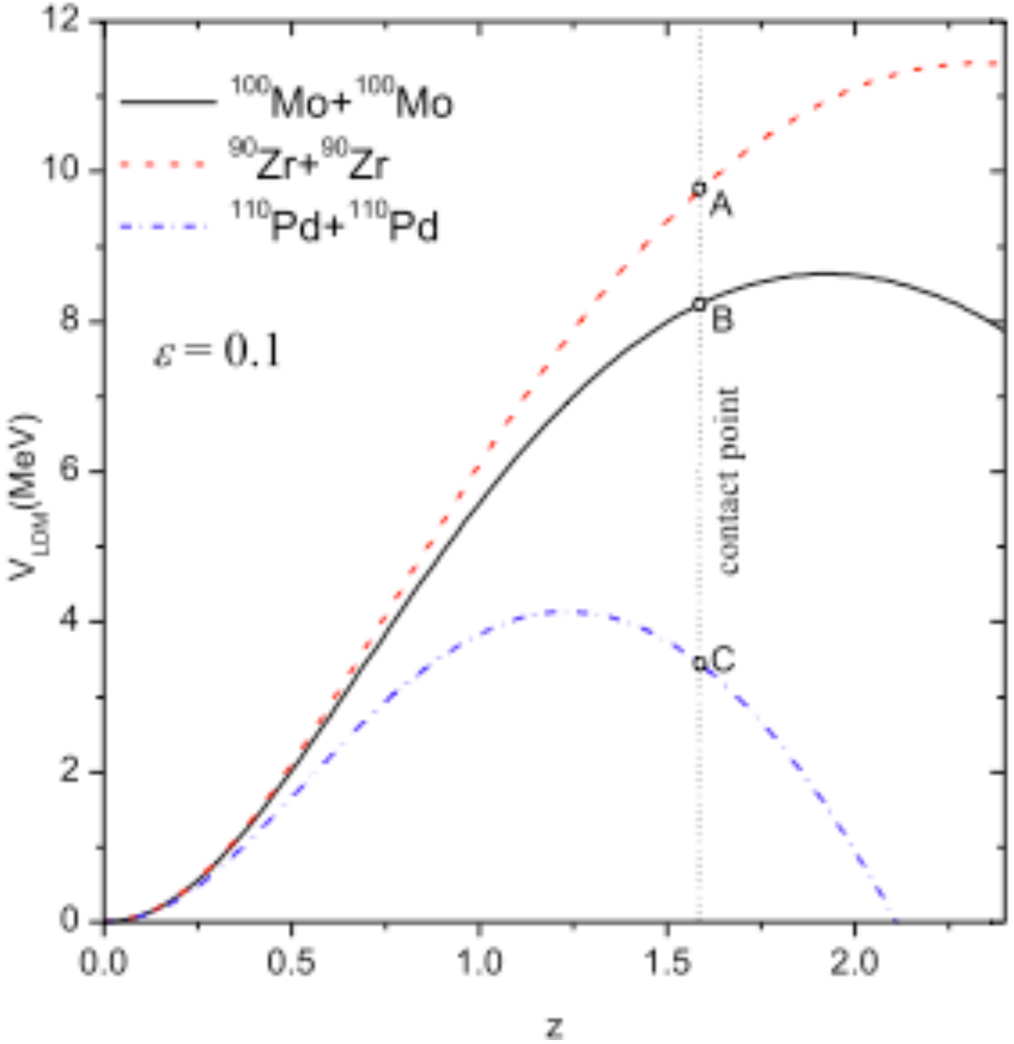
How to assess the fusion model?

Experimental fusion hindrance

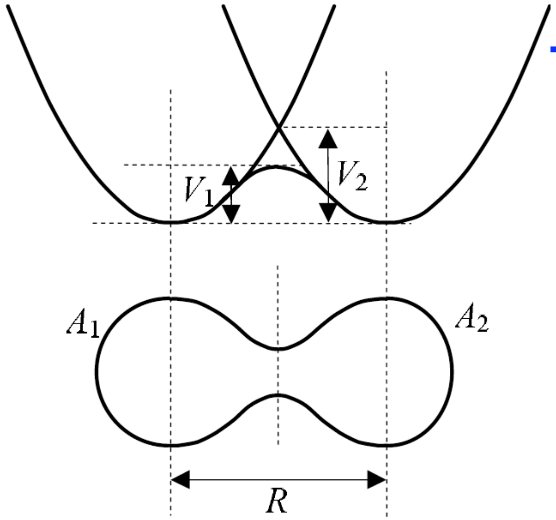


K.-H. Schmidt & W. Morawek *Rep. Prog. Phys.* **54** (1991) 949

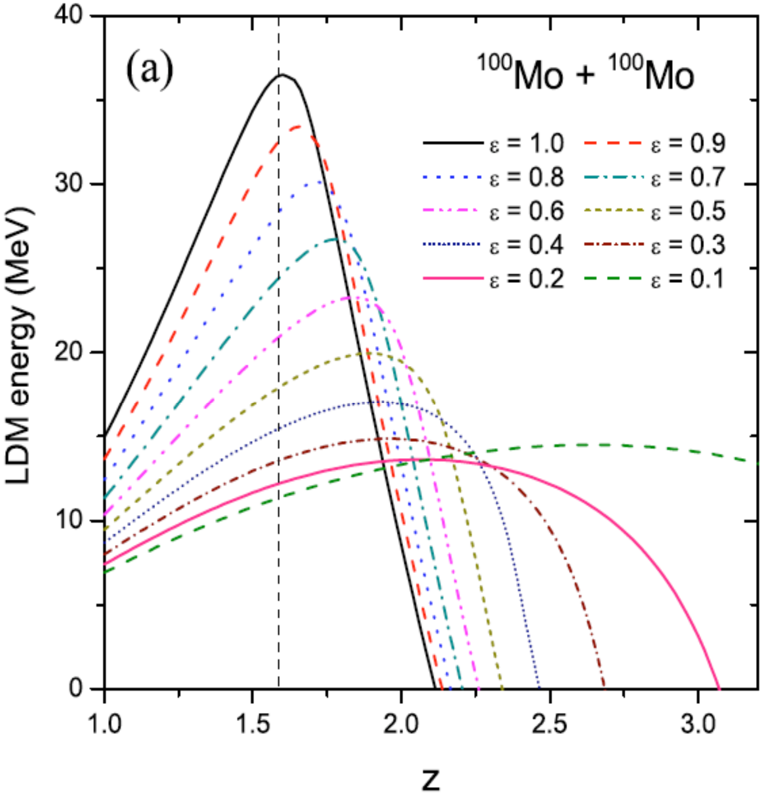
Position of the inner barrier

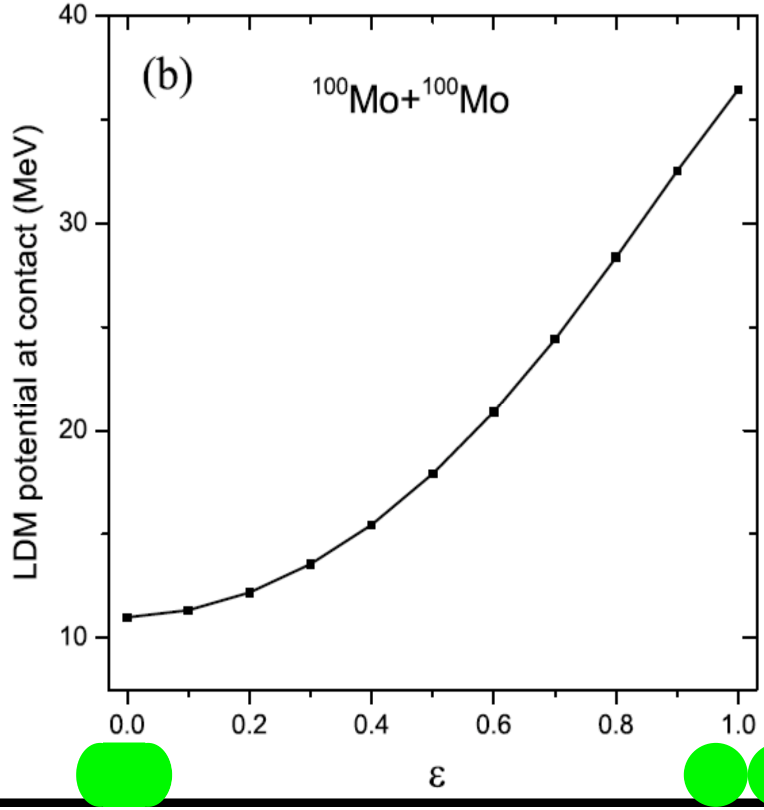


Importance of the neck

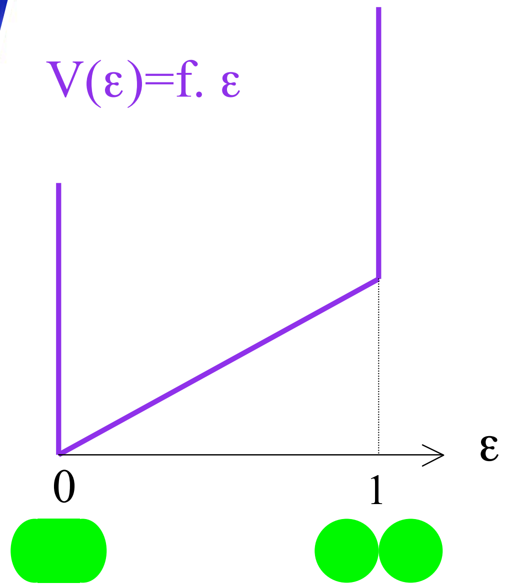


The value of the neck parameter differs from authors

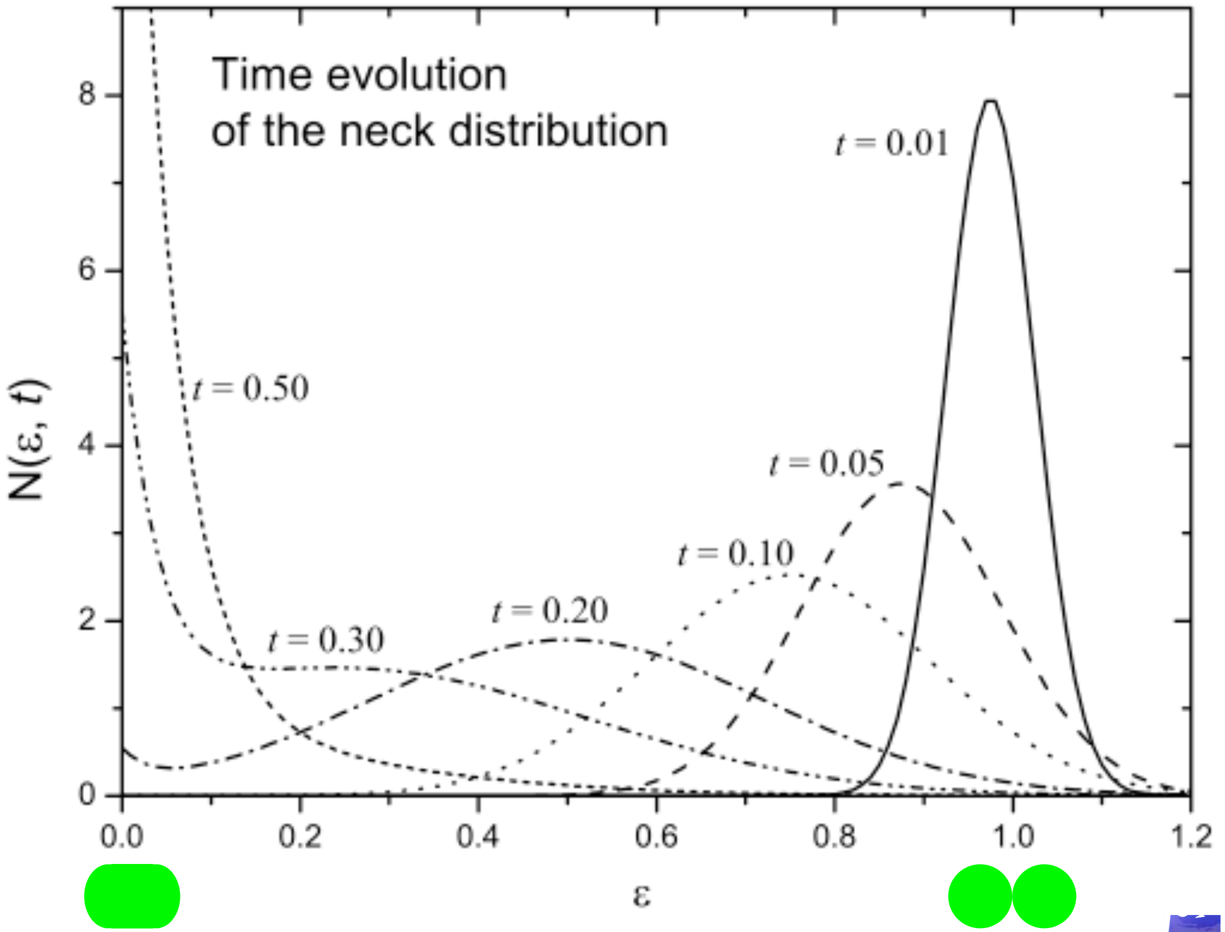




Neck dynamics

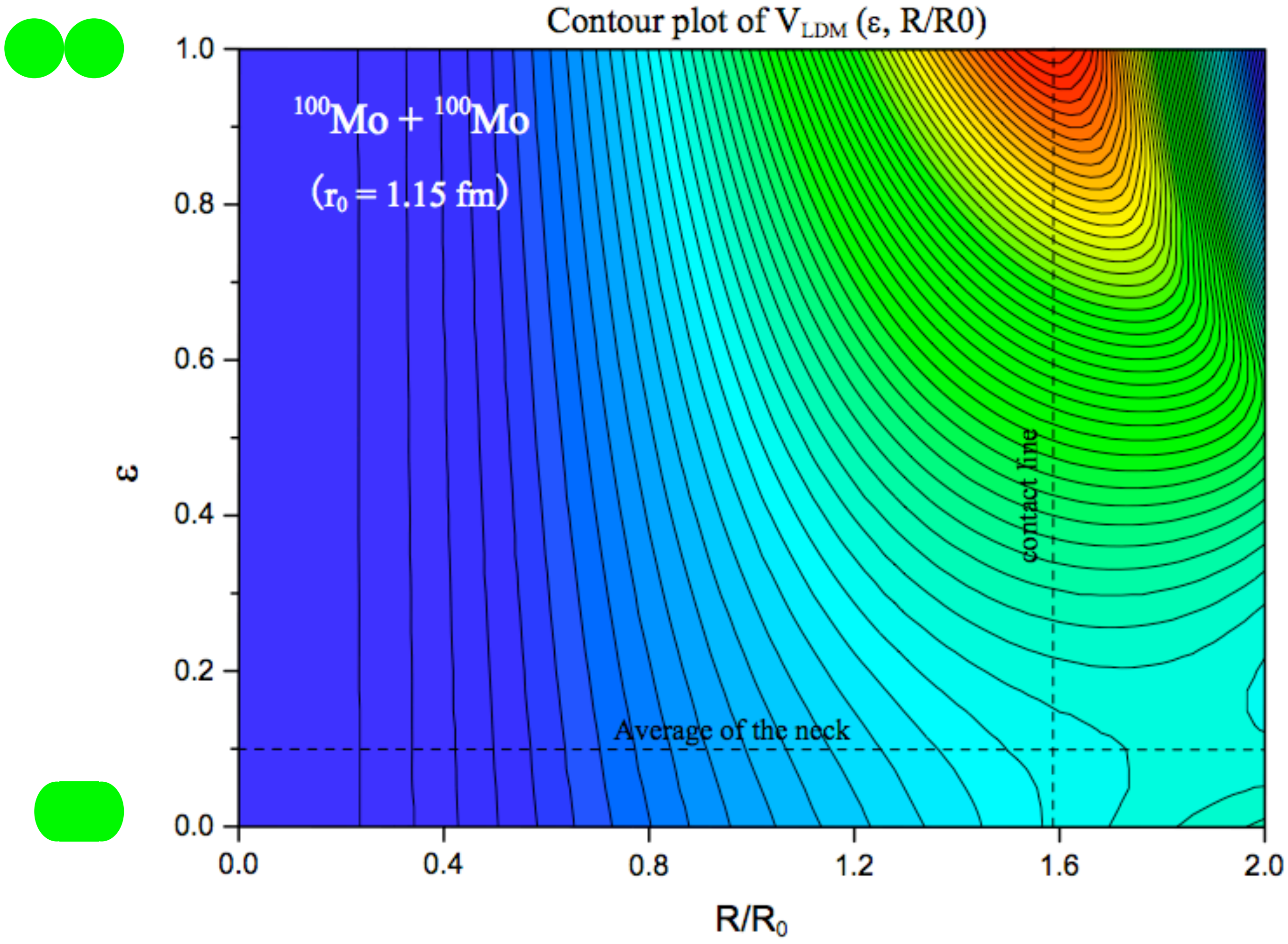


We solved the
Smoluchowski equation

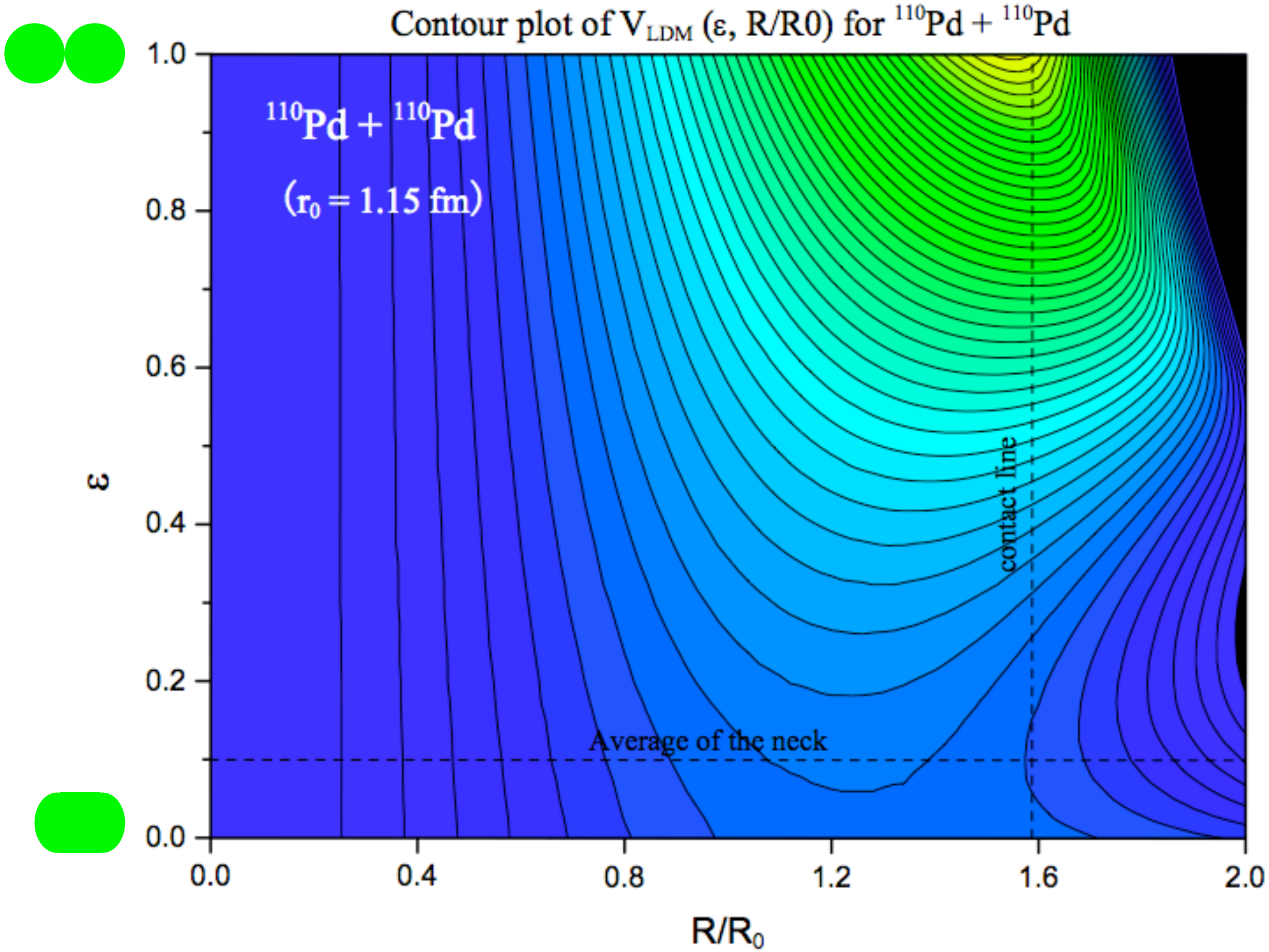


➡**Neck equilibrates very quickly**
➡ **<ε> ≈ 0.1**

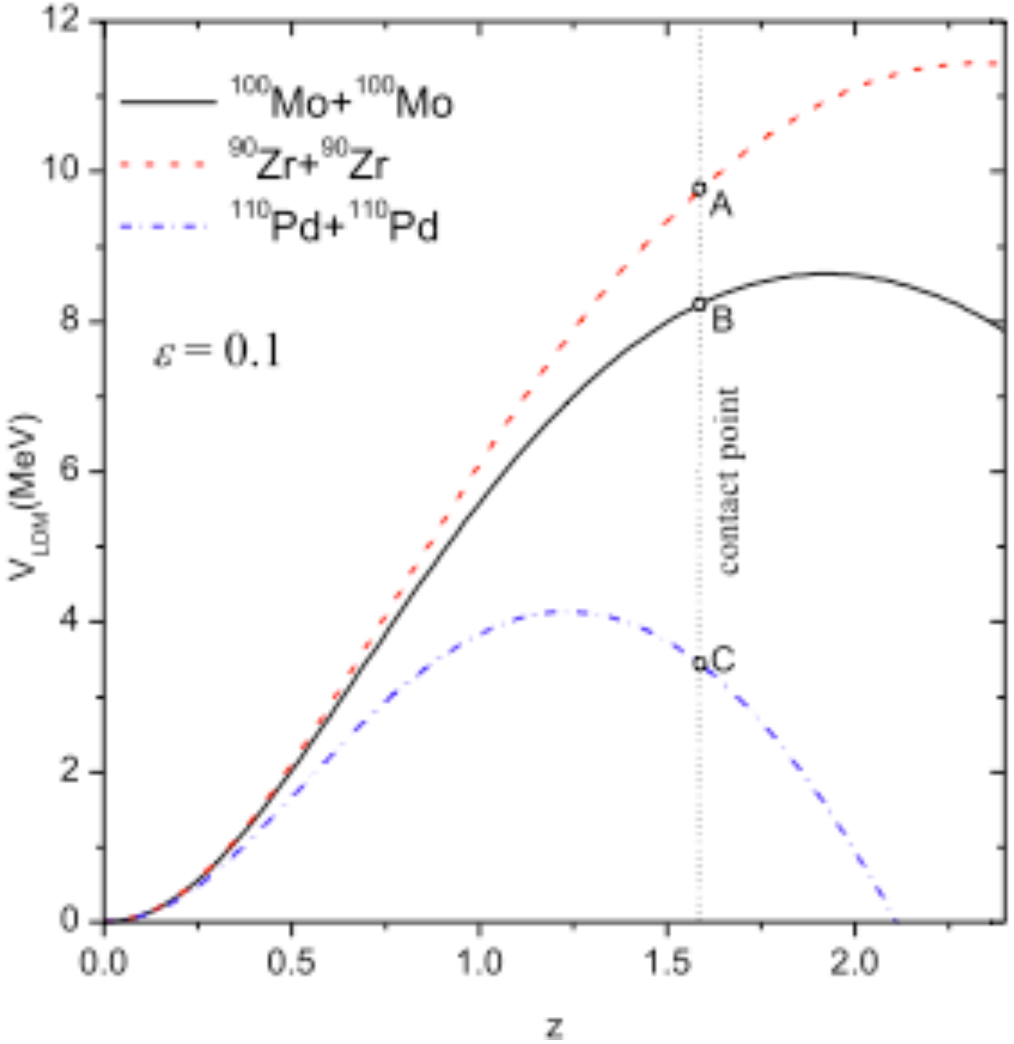
Fusion hindrance for symmetric reactions



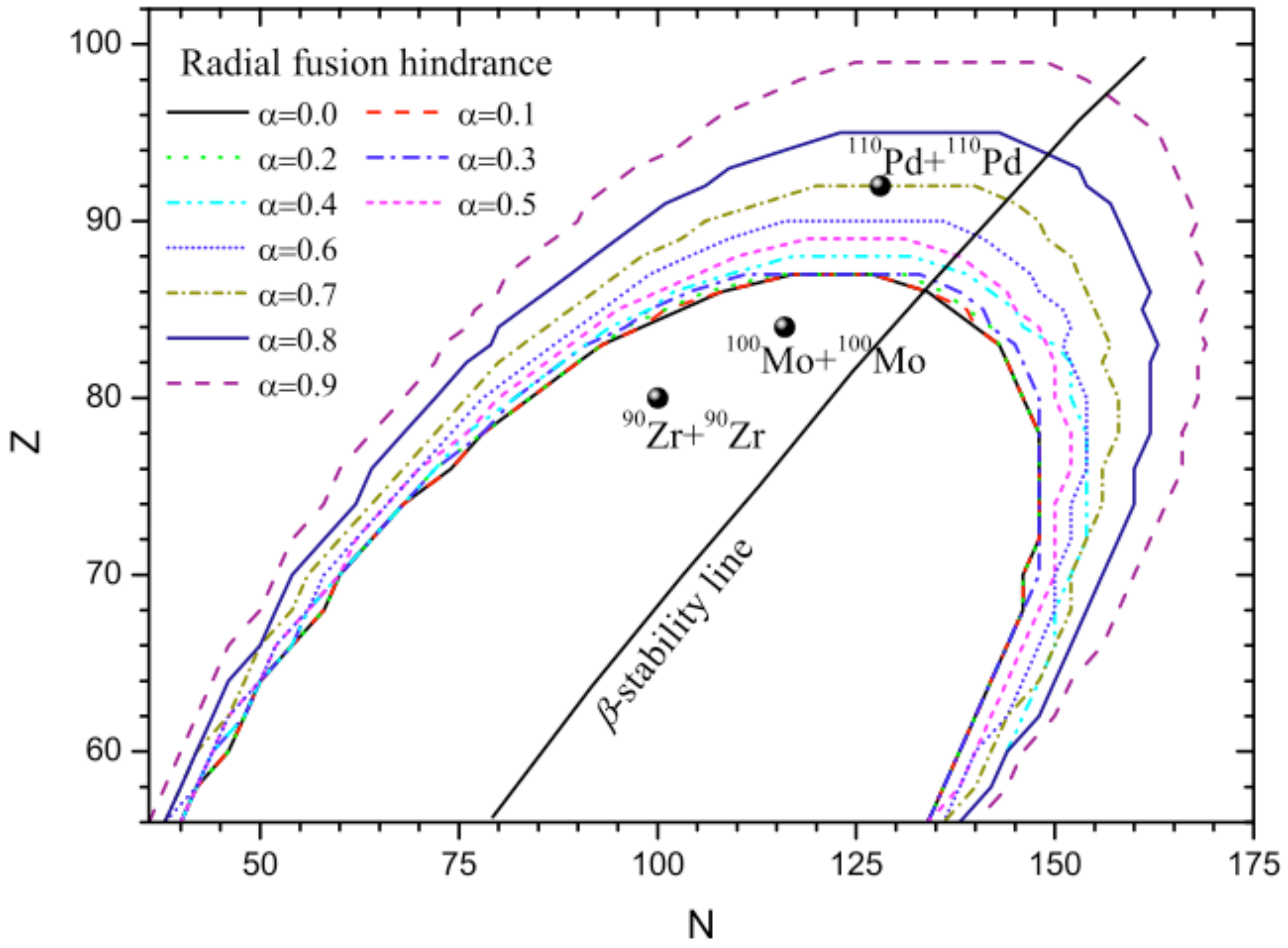
Fusion hindrance for symmetric reactions



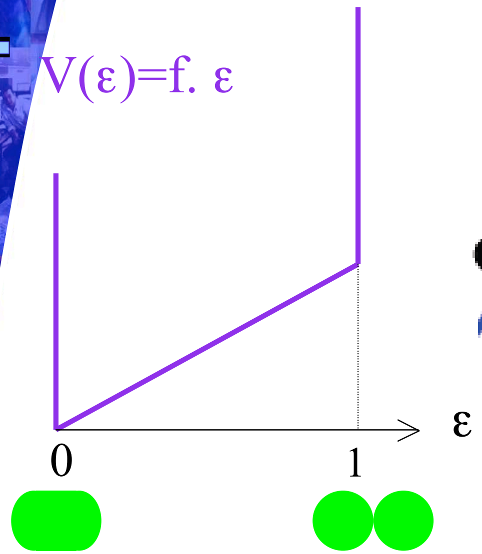
Influence of the shift

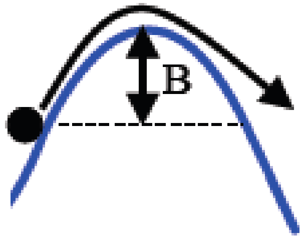


Borderline between hindered and non hindered reactions



Adiabatic approximation





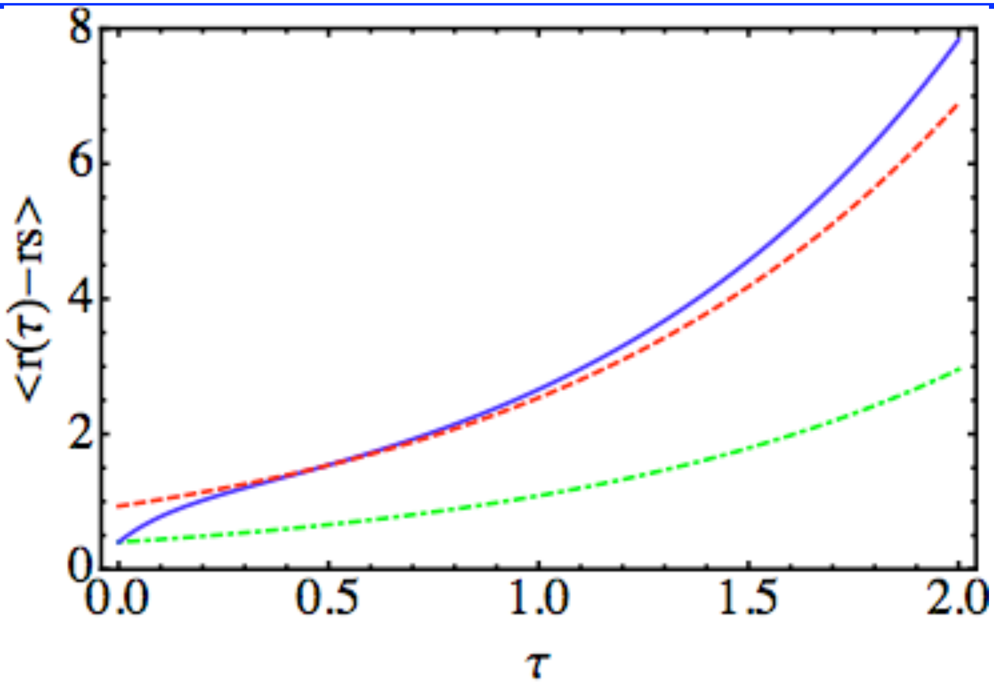
- Fast degree of freedom (neck) vs slow degree of freedom (r)
- Tensor coupling
- Shift of the initial condition in r
- Larger hindrance due to dynamical coupling!

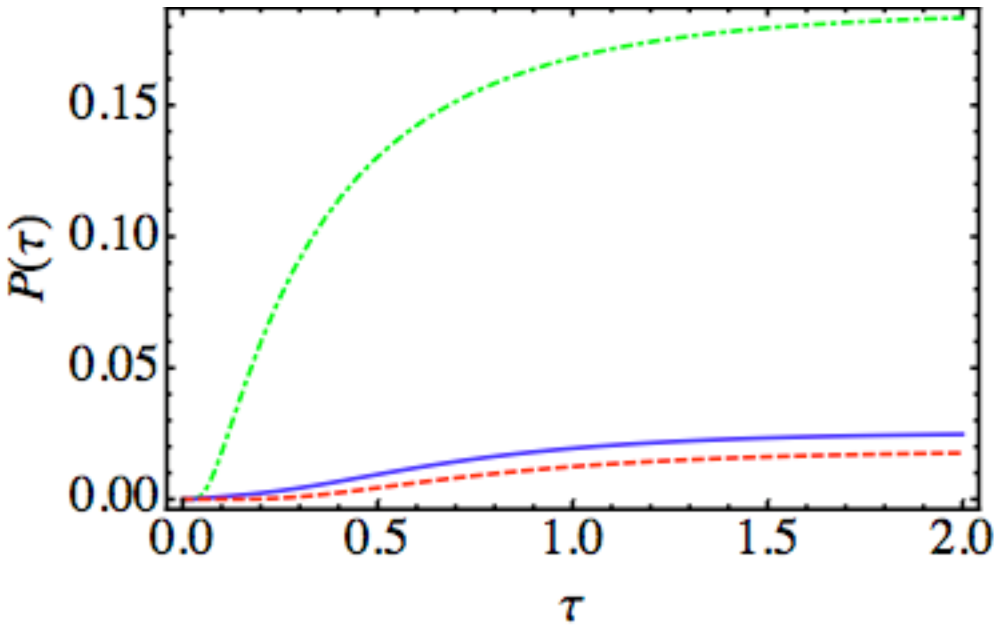
$$[\gamma]\begin{bmatrix}\dot{\varepsilon}\\ \dot{r}\end{bmatrix} = -\begin{bmatrix}\partial V/\partial\varepsilon\\ \partial V/\partial r\end{bmatrix} + \begin{bmatrix}\rho_1(t)\\ \rho_2(t)\end{bmatrix},$$

$$\Delta r \simeq -\frac{\gamma_{r\varepsilon}}{\gamma_{rr}}\Delta\varepsilon.$$

Test on a simple case

Exact solution for a saddle made with 2 parabolas





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