Langevin description for evaporation-fission processes in CRISP code

Ramón Pérez

Universidade de São Paulo

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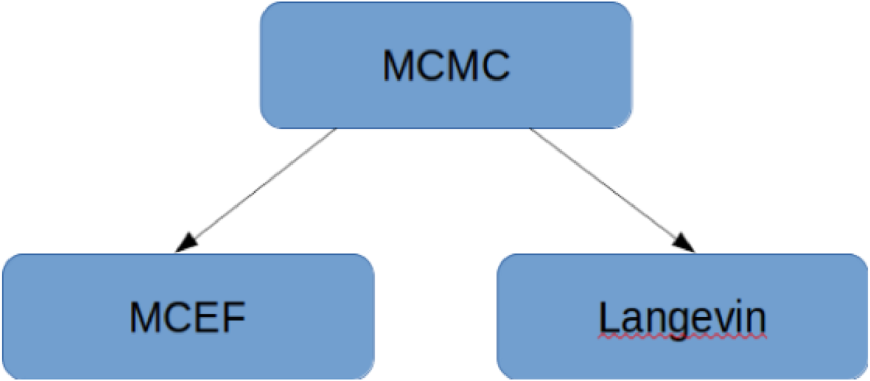
Overview

Introduction



Langevin dynamic:

- The time evolution of the nucleus is considered and friction β parameter that has a direct influence in the fission probability and evaporation multiplicity.
- This study is more interesting for ion reaction, where a considerable angular momentum is transfered to compound nucleus.

Parametrization (c,h)

- The following simple polynomial expression is in rather good agreement with the known results of exact LDM calculation:

$$\pi(u,v) = v^2 - (1-u)^2(A + Bu^2 + \alpha u) \tag{1}$$

- Volume conservation:

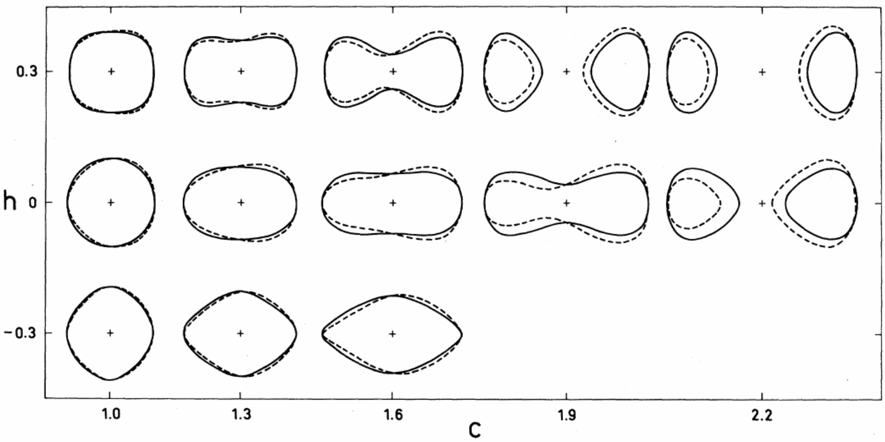
$$c = (A + \frac{1}{5}B)^{-1/3} \tag{2}$$

- Connection between the parameter sets A,B and c,h:

$$B = 2h + 1/2(c-1) \tag{3}$$

$$A = \frac{1}{c^3} - \frac{1}{5}B \tag{4}$$

Parametrization (c,h)



Langevin equation

- Langevin equation for over-damped motion:

$$\dot{q} = -\frac{1}{M\beta}\frac{dV(q)}{dq} + \sqrt{\frac{T}{M\beta}}\Gamma(t) \tag{5}$$

- Langevin discretized form:

$$q_{n+1} = q_n + \left[\sqrt{\frac{T(q)}{\beta(q)M}\frac{dS(q)}{dq}}\right]_n \tau + \sqrt{\left[\frac{T(q)}{\beta(q)M}\right]_n}\tau\omega_n \tag{6}$$

$$q(c,h) = \frac{3}{8}c(1 + \frac{2}{15}c^3)$$

Entropy and temperature

- Fermi's gas expression for the entropy:

$$S(q, E^*_{tot}, A, Z, L) = 2\sqrt{a(q, A)[E^*_{tot} - V(q, A, Z, L)]} \qquad (7)$$

- The temperature is:

$$T(q, E^*_{tot}, A, Z, L) = \frac{S(q, E^*_{tot}, A, Z, L)}{2a(q, A)} \qquad (8)$$

Deformation potential

- The potential energy is given by the liquid-drop model:

$$V_s(q, A, Z) = a_2 \left[1 - k\left(\frac{N - Z}{A}\right)^2\right] A^{2/3}\left[B_s(q) - 1\right] \tag{9}$$

$$B_s(q) = \begin{cases} 1 + 0.4(64/9)(q - 0.375)^2 & \text{if } q < 0.452 \\ 0.983 + 0.439(q - 0.375) & \text{if } q \geq 0.452 \end{cases} \tag{10}$$

$$a_2 = 17.9439 MeV \qquad k = 1.7826 \tag{11}$$

Deformation potential

- The potential energy is given by the liquid-drop model:

$$V_c(q, A, Z) = c_3 \frac{Z^2}{A^{1/3}} [B_s(q) - 1] \quad (12)$$

$$B_c(x) = \begin{cases} 1 + \left(1 - B_s + \frac{B_f}{E_{ssp}}\right) / 2X & \text{if } q < 0.452 \\ 1 - 0.2\frac{64}{9}(q - 0.375)^2 & \text{if } q \geq 0.452 \end{cases} \quad (13)$$

$$\frac{B_f}{E_{ssp}}(q) = \begin{cases} 0.2599 - 0.2151X - 0.1643X^2 & \\ -0.0673X^3 & \text{if } q < 0.6 \\ 0.7259Y^3 - 0.3302Y^4 + 0.6387Y^5 & \\ +7.827Y^6 - 12.0061Y^7 & \text{if } q \geq 0.452 \end{cases}$$

$$X = 0.05ln[0.875(q_{sd} - 0.375)^{-1} - 1] + 0.74 \quad (14)$$

Deformation potential

- The potential energy is given by the liquid-drop model:

$$B_r = J_{||}^{-1} \ \textit{if} \ J_{\perp} < J_{||} \ \textit{and} \ q > 0.375$$

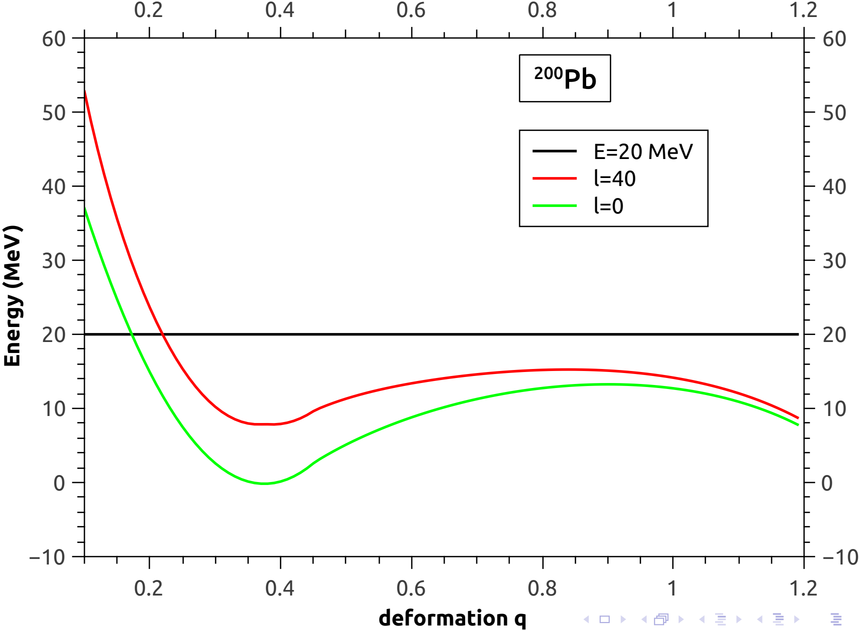
$$B_r = J_{\perp}^{-1} \ \textit{in all other cases}$$

$$J_{||} = c^2 \left\{ c^{-3} + 4B_{sh}[(4/15)B_{sh}c^3 - 1]/35 \right\}$$

$$J_{\perp} = c^2 \left\{ 1 - c^{-3} + 4B_{sh}[(4/15)B_{sh}c^3 - 1]/35 \right\} /2$$

$$B_{sh}(c, h) = 2h + (c - 1)/2$$

$$q(c, h) = \frac{3}{8}c(1 + \frac{2}{15}c^3)$$



200Pb
E=20 MeV
l=40
l=0
Energy (MeV)
deformation q

Level density parameter

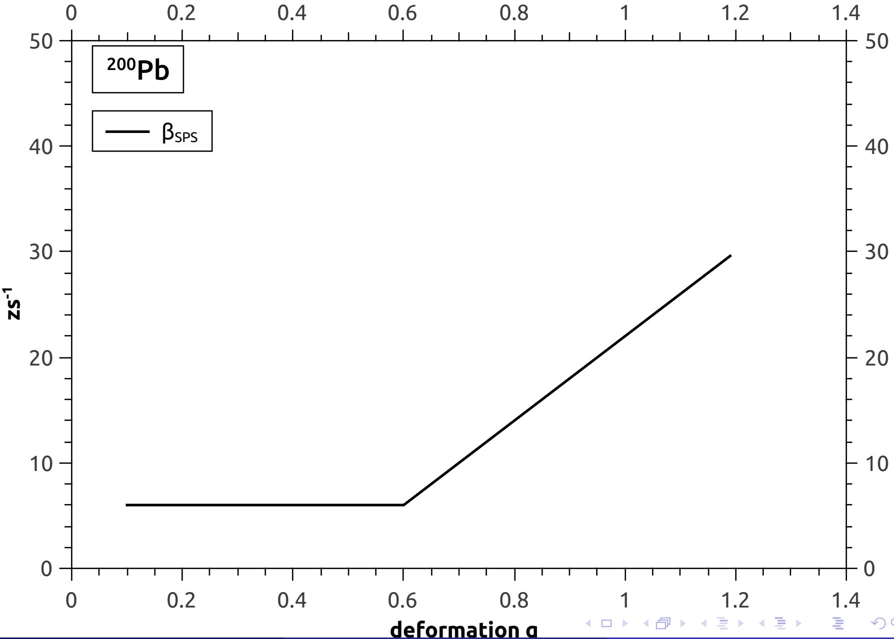
- Woods-Saxon single particle potential:

$$a(q, A) = \alpha_1 A + \alpha_2 A^{2/3} B_s(q)$$

$$\alpha_1 = 0.073 \ MeV^{-1} \quad \alpha_2 = 0.095 \ MeV^{-1}$$

- The Standard Parameter Set friction

$$\beta_{SPS}(q) = \begin{cases} \beta_0 & \text{if } q < q_{neck} \\ \beta_0 + \dfrac{\beta_{sc} - \beta_0}{q_{sc} - q_{neck}}(q - q_{neck}) & \text{if } q_{neck} \leq q \leq q_{sc} \end{cases}$$


200Pb
βSPS
zs-1
deformation q
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
10
20
30
40
50

Emission width

- The emission width of a particle of kind ν $(\nu = n, p, \alpha)$:

$$\Gamma_\nu = (2s_\nu + 1)\frac{m_\nu}{\pi^2\hbar^2\rho_c(E^*)}\int_0^{E^*-B_\nu} d\varepsilon_\nu \rho_R(E^* - \varepsilon_\nu)\varepsilon_\nu\sigma_{inv}(\varepsilon_\nu)$$

- Level densities of the compound and residual nuclei are:

$$\rho \sim (2L+1)exp(S)$$

- Inverse cross sections are:

$$\sigma_{inv}(\varepsilon_\nu) = \begin{cases} \pi R_\nu^2(1 - V_\nu/\varepsilon_\nu) & \text{for } \varepsilon_\nu > V_\nu \\ 0 & \text{for } \varepsilon_\nu < V_\nu \end{cases}$$

Emission width

- The barriers for the charged particles are:

$$V_\nu = \frac{(Z - Z_\nu)Z_\nu K_\nu}{R_\nu + 1.6}$$

$$R_\nu = 1.22\left[(A - A_\nu)^{1/3} + A_\nu^{1/3}\right] + \frac{3.4}{\varepsilon_\nu^{1/2}\delta_{\nu,n}}$$

$$K_\nu = 1.32 \; for \; \alpha \; K_\nu = 1.15 \; for \; proton$$

Emission width

- For giant dipole $\gamma - quanta$:

$$\Gamma_\gamma = \frac{3}{\rho_C(E^*)} \int_0^{E^*} d\varepsilon \rho_C(E^* - \varepsilon) f(\varepsilon)$$

$$f(\varepsilon) = \frac{4}{3\pi} \frac{1+k}{m_n c^2} \frac{e^2}{\hbar c} \frac{NZ}{A} \frac{\Gamma_G \varepsilon^4}{(\Gamma\varepsilon)^2 + (\varepsilon^2 - E_G^2)^2}$$

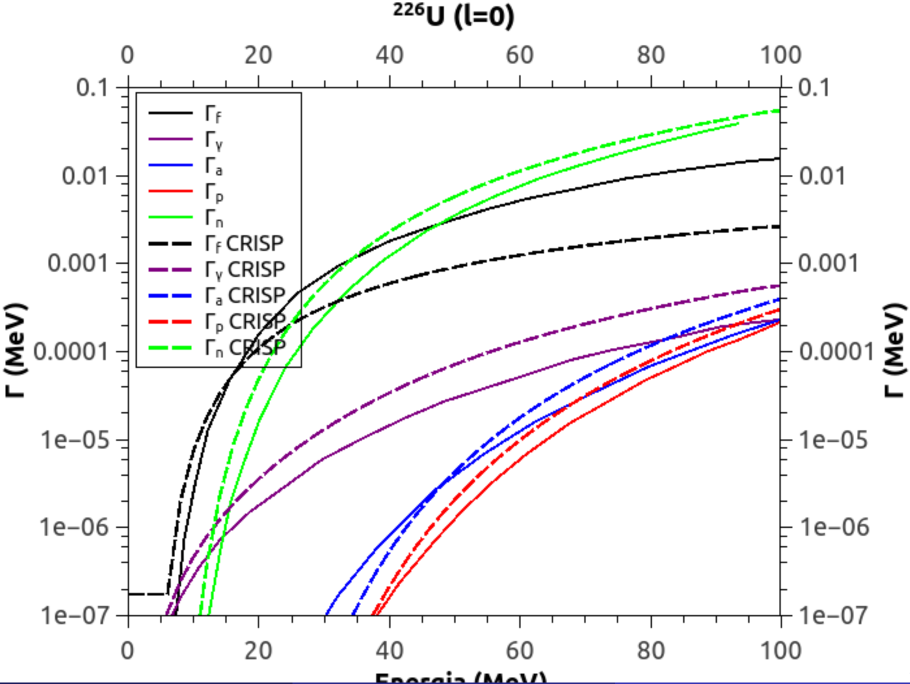
with k=0.75, E_G=80/$A^{1/3}$ MeV, Γ_G=5 MeV

Fission width

- For fission:

$$\Gamma_f = \hbar \frac{T_{gs}}{\beta_{gs}} \frac{\sqrt{\left|S''_{gs}\right| S''_{sd}}}{\pi M} exp(S(q_{sd}) - S(q_{gs}))\ x$$

$$x \left\{ 1 + erf\left[(q_{sc} - q_{sd}) \sqrt{S''_{sd}/2}\ \right] \right\}^{-1}$$



^{226}U (l=0)
Γ (MeV)
Energia (MeV)
0 20 40 60 80 100
0.1 0.01 0.001 0.0001 1e−05 1e−06 1e−07
Γ_f
Γ_γ
Γ_a
Γ_p
Γ_n
Γ_f CRISP
Γ_γ CRISP
Γ_a CRISP
Γ_p CRISP
Γ_n CRISP

Initial conditions

- The total initial excitation energy is:

$$E^*_{tot} = E_{cm} + Q$$

  where:

$$E_{cm} = E_{lab} A_T / (A_T + A_P)$$

- The angular momentum $L = \hbar l$ is sampled from the spin distribution:

$$\sigma(l) = \frac{2\pi}{k^2} \frac{2l+1}{1 + exp\left[(l - l_c)/\delta l\right]}$$

- The quantity l_c scales as

$$l_c = \sqrt{A_p A_T / A}\left(A_P^{1/3} + A_T^{1/3}\right)\left(0.33 + 0.205\sqrt{E_{cm} - V_c}\right)$$

Initial conditions

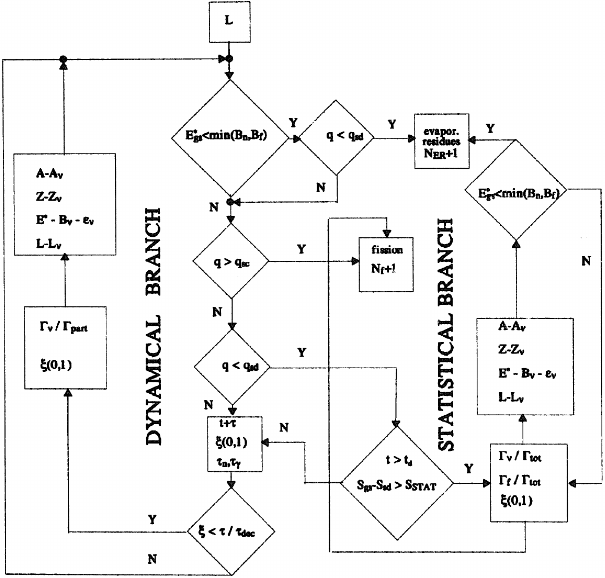
- The barrier V_c is:

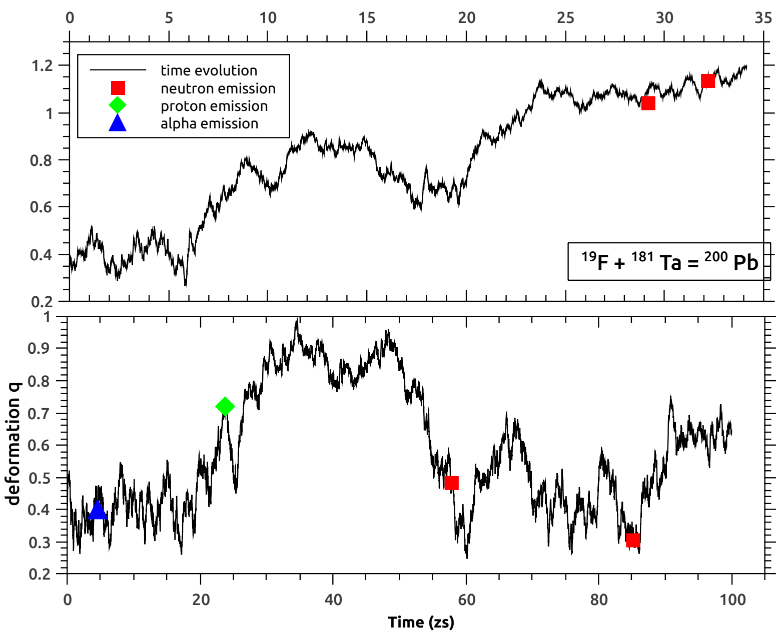
$$V_c = 5/3 c_3 Z_P Z_T / \left(A_P^{1/3} + A_T^{1/3} + 1.6 \right)$$

with $c_3 = 0.7053$ MeV

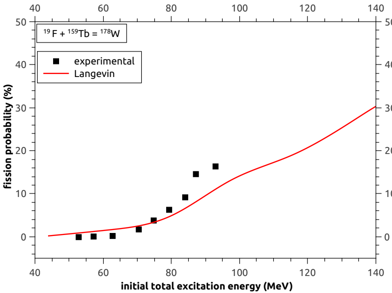
- The diffuseness δl is:

$$\begin{cases} (A_P A_T)^{3/2} * 10^{-5} \left[1.5 - 0.02 \left(E_{cm} - V_c - 10\right)\right] & \text{for } E_{cm} > V_c + 10 \\ (A_P A_T)^{3/2} * 10^{-5} \left[1.5 - 0.04 \left(E_{cm} - V_c - 10\right)\right] & \text{for } E_{cm} < V_c + 10 \end{cases}$$

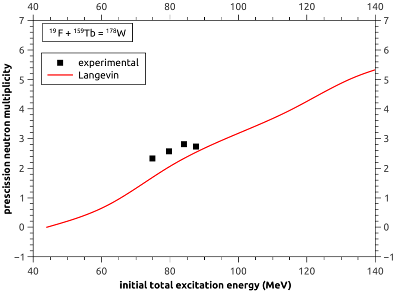

L
E*gs<min(Bn,Bf)
q < qsd
evapor. residues
NER+1
E*gs<min(Bn,Bf)
A-Av
Z-Zv
E* - Bv - εv
L-Lv
DYNAMICAL BRANCH
q > qsc
fission
Nf+1
STATISTICAL BRANCH
Γv / Γpart
ξ(0,1)
q < qsd
A-Av
Z-Zv
E* - Bv - εv
L-Lv
t+τ
ξ(0,1)
τn,τγ
t > td
Sgs-Ssd > SSTAT
Γv / Γtot
Γf / Γtot
ξ(0,1)
ξ < τ / τdec
Y
N



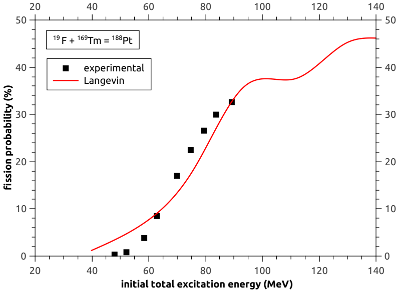
time evolution
neutron emission
proton emission
alpha emission
$^{19}F + ^{181}Ta = ^{200}Pb$
deformation q
Time (zs)



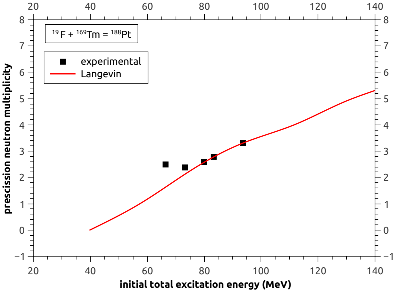
19 F + 159Tb = 178W
experimental
Langevin
fission probability (%)
initial total excitation energy (MeV)



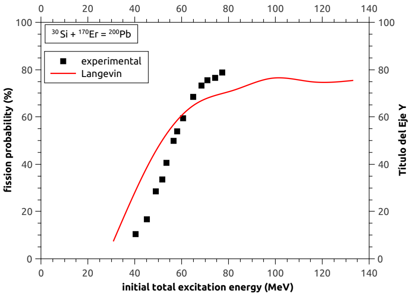
19 F + 159Tb = 178W
experimental
Langevin
prescission neutron multiplicity
initial total excitation energy (MeV)



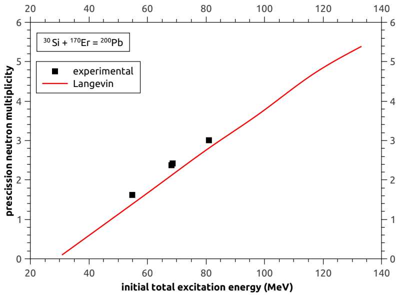
19 F + 169Tm = 188Pt
experimental
Langevin
fission probability (%)
initial total excitation energy (MeV)



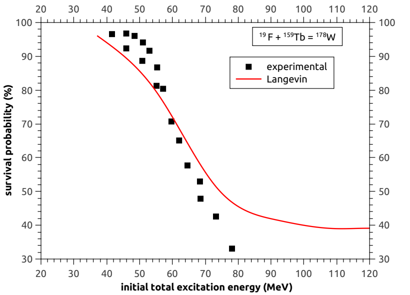
19 F + 169Tm = 188Pt
experimental
Langevin
prescission neutron multiplicity
initial total excitation energy (MeV)



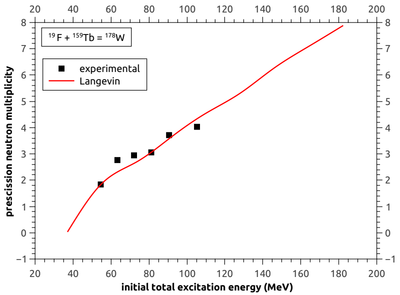
$^{30}Si + ^{170}Er = ^{200}Pb$
experimental
Langevin
fission probability (%)
Título del Eje Y
initial total excitation energy (MeV)



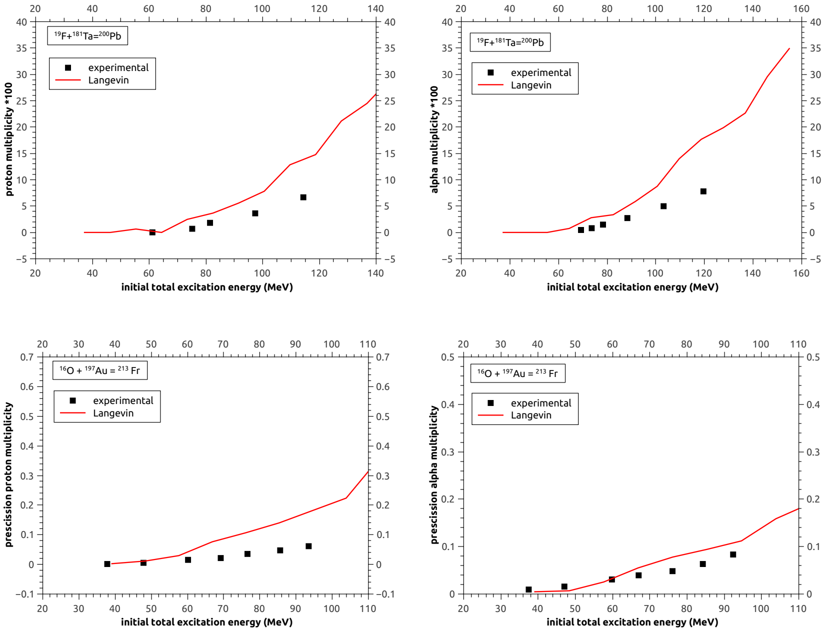
$^{30}Si + ^{170}Er = ^{200}Pb$
experimental
Langevin
prescission neutron multiplicity
initial total excitation energy (MeV)



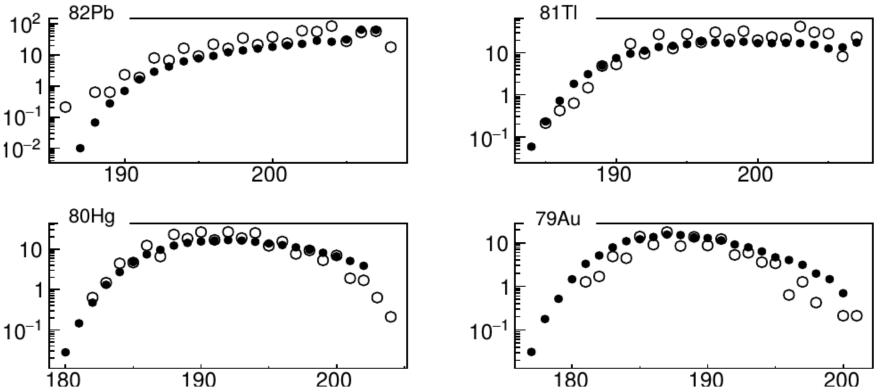
$^{19}F + ^{159}Tb = ^{178}W$
experimental
Langevin
survival probability (%)
initial total excitation energy (MeV)

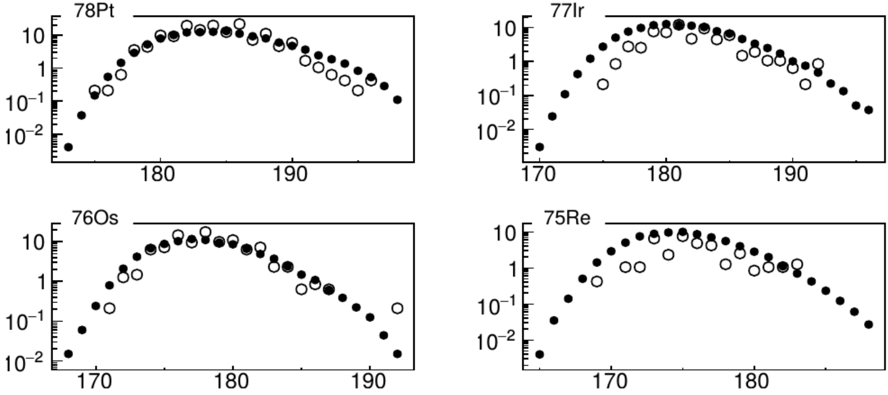


$^{19}F + ^{159}Tb = ^{178}W$
experimental
Langevin
prescission neutron multiplicity
initial total excitation energy (MeV)

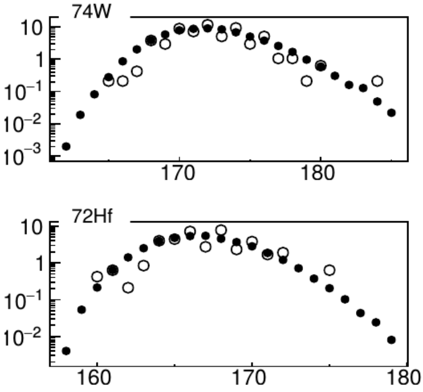


$^{19}F+^{181}Ta=^{200}Pb$
experimental
Langevin
proton multiplicity *100
initial total excitation energy (MeV)
$^{19}F+^{181}Ta=^{200}Pb$
experimental
Langevin
alpha multiplicity *100
initial total excitation energy (MeV)
$^{16}O + ^{197}Au = ^{213}Fr$
experimental
Langevin
prescission proton multiplicity
initial total excitation energy (MeV)
$^{16}O + ^{197}Au = ^{213}Fr$
experimental
Langevin
prescission alpha multiplicity
initial total excitation energy (MeV)


82Pb
81Tl
80Hg
79Au
10^2
10
1
10^{-1}
10^{-2}
180
190
200



78Pt
10
1
10^{-1}
10^{-2}
180
190
77Ir
10
1
10^{-1}
10^{-2}
170
180
190
76Os
10
1
10^{-1}
10^{-2}
170
180
190
75Re
10
1
10^{-1}
10^{-2}
170
180


74W
10
1
10⁻¹
10⁻²
10⁻³
170
180
73Ta
10
1
10⁻¹
10⁻²
160
170
180
72Hf
10
1
10⁻¹
10⁻²
160
170
180
71Lu
1
10⁻¹
10⁻²
160
170

Conclusions

Conclusions

Thanks