Pairing influence in binary nuclear systems

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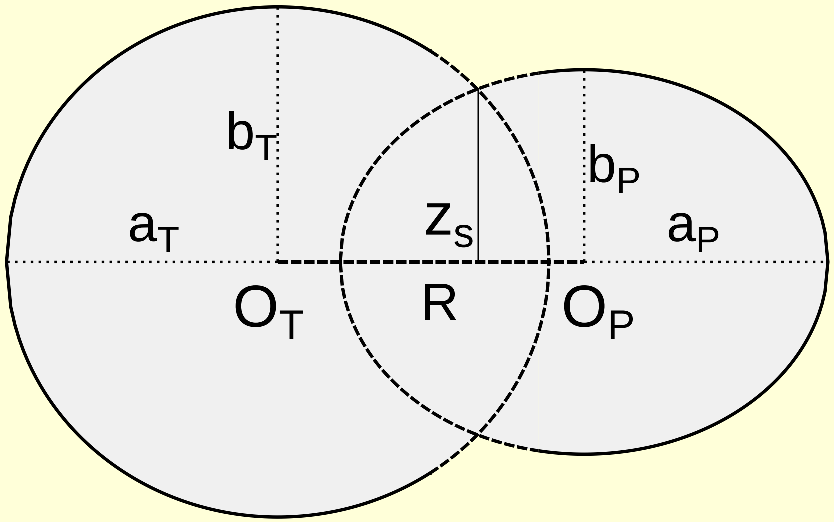
Nikola Cindro*.*

Outline

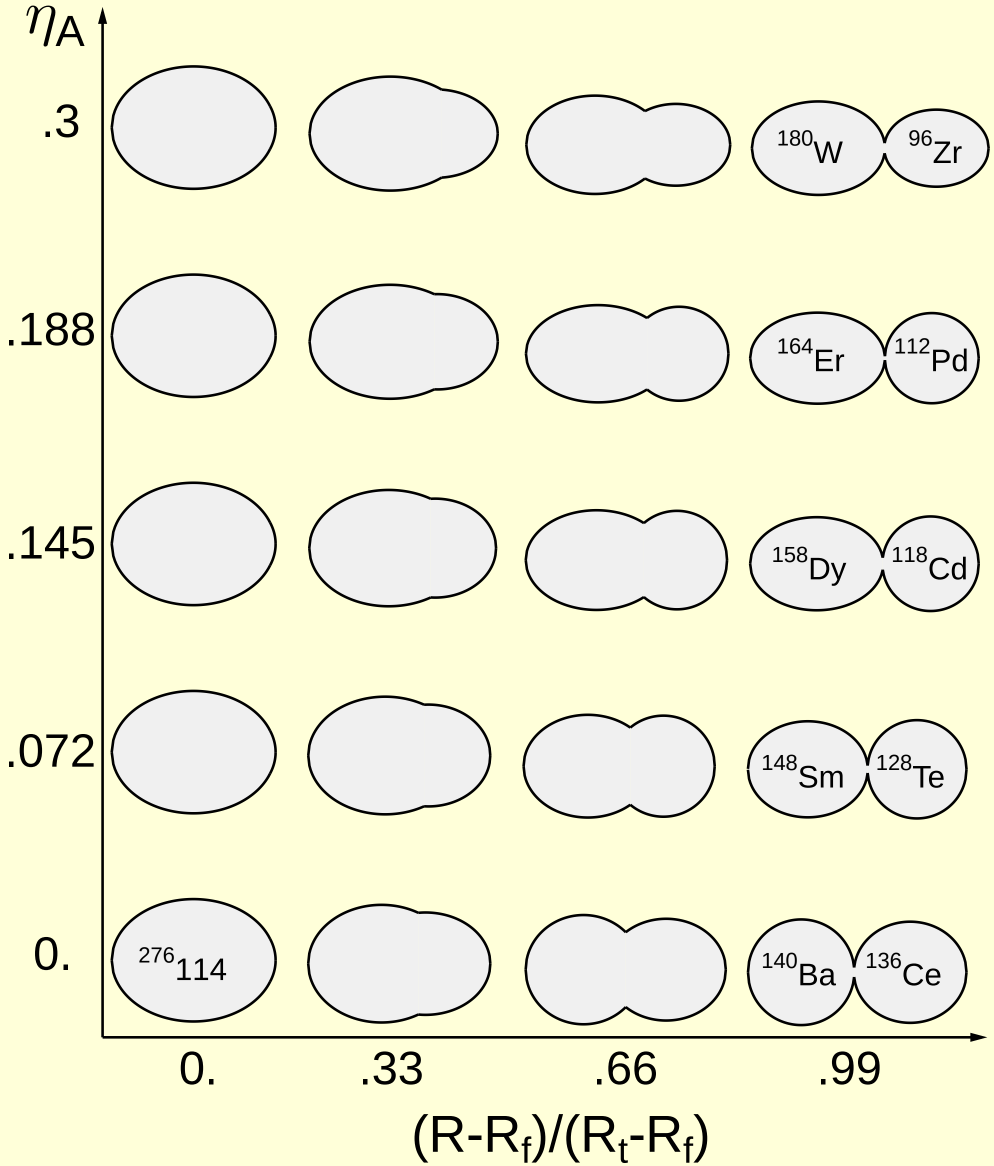
- Deformation space
- Deformed two-center shell model
- Binary macroscopic-microscopic approach
- Pairing corrections
- Mass tensor and dynamics
- Nuclear inertia
- PES, barriers and penetrabilities for synthesis of $Z\!=\!118$ isotopes

Deformation space



1. Mass asymmetry: $\eta = (A_T - A_P)/(A_T + A_P)$
2. Distance between centers: R
3. Deformation parameter of the synthesized (parent) nucleus: b_0/a_0
4. Deformation parameter of the heavy fragment (Target): b_T/a_T
5. Deformation parameter of the light fragment (Pprojectile): b_P/a_P

Deformation space



Deformed two-center oscillator potential

$$V_{DTCSM}(\rho, z) = \begin{cases} V_1(\rho, z) & , v_1 \\ V_{g1}(\rho, z) & , v_{g1} \\ V_{g2}(\rho, z) & , v_{g2} \\ V_2(\rho, z) & , v_2 \end{cases}$$

where:

$$\begin{aligned} V_1(\rho, z) &= \tfrac{1}{2} m_o \omega_{\rho_1}^2 \rho^2 + \tfrac{1}{2} m_o \omega_{z1}^2 (z + z_1)^2 \\ V_{g1}(\rho, z) &= 2V_0 - [\tfrac{1}{2} m_o \omega_g^2 (\rho - \rho_3)^2 + \tfrac{1}{2} m_o \omega_g^2 (z - z_3)^2] \\ V_{g2}(\rho, z) &= V_0 \\ V_2(\rho, z) &= \tfrac{1}{2} m_o \omega_{\rho_2}^2 \rho^2 + \tfrac{1}{2} m_o \omega_{z2}^2 (z - z_2)^2 \end{aligned}$$

$$H_{DTCSM} = -\frac{\hbar^2}{2m_0}\Delta + V_{DTCSM}(\rho,z) + V_{\mathbf{\Omega s}} + V_{\mathbf{\Omega^2}}$$

separable if $\omega_{\rho_1} = \omega_{\rho_2} = \omega_1$ for a potential:

$$V^{(d)}(\rho,z) = \begin{cases} V_1^{(d)}(\rho,z) = \frac{1}{2}m_0\omega_1^2\rho^2 + \frac{1}{2}m_0\omega_1^2(z+z_1)^2 & , z \leq 0 \\ V_2^{(d)}(\rho,z) = \frac{1}{2}m_0\omega_1^2\rho^2 + \frac{1}{2}m_0\omega_2^2(z-z_2)^2 & , z \geq 0 \end{cases}$$

Diagonalization basis:

$$\Phi_m(\phi) = \frac{1}{\sqrt{2\pi}}\exp\left(im\phi\right)$$

$$R_{n_\rho}^{|m|}(\rho) = \left(\frac{2\Gamma(n_\rho+1)\alpha_1^2}{\Gamma(n_\rho+|m|+1)}\right)^{\frac{1}{2}}\exp\left(-\frac{\alpha_1^2\rho^2}{2}\right)(\alpha_1^2\rho^2)^{\frac{|m|}{2}}L_{n_\rho}^{|m|}(\alpha_1^2\rho^2)$$

$$Z_\nu(z) = \begin{cases} C_{\nu_1}\exp\left[-\frac{\alpha_1^2(z+z_1)^2}{2}\right]\mathcal{H}_{\nu_1}[-\alpha_1(z+z_1)] & , \quad z < 0 \\ C_{\nu_2}\exp\left[-\frac{\alpha_2^2(z-z_2)^2}{2}\right]\mathcal{H}_{\nu_2}[\alpha_2(z-z_2)] & , \quad z \geq 0 \end{cases}$$

H_{DTCSM} operators

Oscillator operators:

$$
\begin{aligned}
\Delta V_1(\rho, z) =& \quad V_1(\rho, z) - V^{(d)}(\rho, z) &, v_1 \\
\Delta V_2(\rho, z) =& \quad V_2(\rho, z) - V^{(d)}(\rho, z) &, v_2 \\
\Delta V_g(\rho, z) =& \quad V_g(\rho, z) &, v_g
\end{aligned}
$$

Spin-orbit ls and l^2 potentials:

$$
V_{ls} = \begin{cases} -\left\{ \dfrac{\hbar}{m_0 \omega_{01}} \kappa_1(\rho, z), (\nabla V \times p) s \right\} & , A_1 - region \\ -\left\{ \dfrac{\hbar}{m_0 \omega_{02}} \kappa_2(\rho, z), (\nabla V \times p) s \right\} & , A_2 - region \end{cases}
$$

$$
V_{l^2} = \begin{cases} -\left\{ \dfrac{\hbar}{m_0^2 \omega_{01}^3} \kappa_1 \mu_1(\rho, z), (\nabla V \times p)^2 \right\} & , A_1 - region \\ -\left\{ \dfrac{\hbar}{m_0^2 \omega_{02}^3} \kappa_2 \mu_2(\rho, z), (\nabla V \times p)^2 \right\} & , A_2 - region \end{cases}
$$

Spin-orbit ls and l^2 operators

General expression:

$$ls \quad \rightarrow \quad \tfrac{1}{2}(\mathbf{\Omega}^{+}\mathbf{s}^{-} + \mathbf{\Omega}^{-}\mathbf{s}^{+}) + \mathbf{\Omega}_z\mathbf{s}_z$$

Shape dependent Ω - operators:

$$\begin{aligned}
\mathbf{\Omega}^{+}(v_1) &= -e^{i\varphi}\left[\frac{\partial V_1(\rho,z)}{\partial \rho}\frac{\partial}{\partial z} - \frac{\partial V_1(\rho,z)}{\partial z}\frac{\partial}{\partial \rho} - \frac{i}{\rho}\frac{\partial V_1(\rho,z)}{\partial z}\frac{\partial}{\partial \varphi}\right] \\
&= -e^{i\varphi}\left[m_0\omega_{\rho_1}^2\rho\frac{\partial}{\partial z} - m_0\omega_{z_1}^2(z+z_1)\frac{\partial}{\partial \rho} - \frac{i}{\rho}m_0\omega_{z_1}^2(z+z_1)\frac{\partial}{\partial \varphi}\right]
\end{aligned}$$

$$\begin{aligned}
\mathbf{\Omega}^{-}(v_1) &= e^{-i\varphi}\left[\frac{\partial V_1(\rho,z)}{\partial \rho}\frac{\partial}{\partial z} - \frac{\partial V_1(\rho,z)}{\partial z}\frac{\partial}{\partial \rho} + \frac{i}{\rho}\frac{\partial V_1(\rho,z)}{\partial z}\frac{\partial}{\partial \varphi}\right] \\
&= e^{-i\varphi}\left[m_0\omega_{\rho_1}^2\rho\frac{\partial}{\partial z} - m_0\omega_{z_1}^2(z+z_1)\frac{\partial}{\partial \rho} + \frac{i}{\rho}m_0\omega_{z_1}^2(z+z_1)\frac{\partial}{\partial \varphi}\right]
\end{aligned}$$

$$\begin{aligned}
\mathbf{\Omega}_z(v_1) &= -\frac{i}{\rho}\frac{\partial V_1}{\partial \rho}\frac{\partial}{\partial \varphi} \\
&= -im_0\omega_{\rho_1}^2\frac{\partial}{\partial \varphi}
\end{aligned}$$

Spin-orbit interaction

Total spin-orbit operators:

$$
\begin{aligned}
V_{\mathbf{\Omega s}}(v_1) &= -\frac{\hbar}{m_0\omega_{01}}\kappa_1\{\mathbf{\Omega s}(v_1),(v_1)\} \\
V_{\mathbf{\Omega s}}(v_2) &= -\frac{\hbar}{m_0\omega_{02}}\kappa_2\{\mathbf{\Omega s}(v_2),(v_2)\} \\
V_{\mathbf{\Omega s}}(v_g) &= -\frac{\hbar}{m_0\omega_{01}}\kappa_1\{\mathbf{\Omega s}(v_{g1}),(v_{g1})\} - \frac{\hbar}{m_0\omega_{02}}\kappa_2\{\mathbf{\Omega s}(v_{g2}),(v_{g2})\}
\end{aligned}
$$

DTCSM matrix

Total matrix elements:

$$\begin{aligned}\langle i|DTCSM|j\rangle = \quad E^{(d)}_{osc}(n_\rho, |m|, \nu) \quad &+ \quad \langle i|\Delta V_1|j\rangle + \langle i|\Delta V_2|j\rangle \\ &+ \quad \langle i|V_g|j\rangle + \langle i|V_{\mathbf{\Omega s}}|j\rangle + \langle i|V_{\mathbf{\Omega^2}}|j\rangle\end{aligned}$$

where $E^{(d)}_{osc}$ is the diagonalized oscillator energy:

$$E^{(d)}_{osc} = \hbar\omega_1(2n_\rho + |m| + 1) + \hbar\omega_1(\nu_1 + 0.5)$$

Diagonalization: one obtains the total binary s.p.s. energy levels $\{\epsilon_k\}$, as input data for the calculation of shell and pairing corrections.

Shell corrections

$\{E_{sp}\} \rightarrow \epsilon_i$: input data to calculate E_{shell}:

$$\delta u = \sum_i \epsilon_i - \tilde{U}$$

Smoothing $\Rightarrow$ $\tilde{U}$:
(1) smoothed level distribution $\tilde{g}(\epsilon)$:

$$\begin{aligned}\tilde{g}(\epsilon) &= \tfrac{1}{\gamma} \int_{-\infty}^{\infty} \zeta\left(\tfrac{\epsilon-\epsilon'}{\gamma}\right) g(\epsilon')d\epsilon' \\ &= \tfrac{1}{\gamma} \sum_{i=1}^{\infty} \zeta\left(\tfrac{\epsilon-\epsilon_i}{\gamma}\right)\end{aligned}$$

where the smoothing function:

$$\zeta(x) = \frac{1}{\sqrt{\pi}} \exp\left(-x^2\right) \sum_{k=0}^{m} a_{2k} H_{2k}(x)$$

(2) Then the smoothed part $\rightarrow$ smearing :

$$\tilde{U} = \hbar\omega = \int_{\infty}^{\tilde{\lambda}} \tilde{g}(\epsilon)\epsilon d\epsilon$$

(3) where the *smoothed* Fermi level comes from N_e conservation.

Pairing interaction

Normaly Z/2 levels are occupied, BUT only n levels bellow and n' levels above the Fermi energy contribute to the pairing interaction.
If Ω is the cutoff energy, $n = n' = \Omega\tilde{g}_s/2$ and $\tilde{\Delta} = 12/\sqrt{A}\hbar\omega_0^0$.
BCS equations:

$$0 = \sum_{k_i}^{k_f} \frac{\epsilon_k - \lambda}{\sqrt{(\epsilon_k - \lambda)^2 + \Delta^2}}$$

$$\frac{2}{G} = \sum_{k_i}^{k_f} \frac{1}{\sqrt{(\epsilon_k - \lambda)^2 + \Delta^2}}$$

$$k_i = Z/2 - n + 1, \;\; k_f = Z/2 + n',$$

Suppose the the pairing strength G is the same for uniform distribution:

$$\frac{2}{G} \simeq 2\tilde{g}(\tilde{\lambda}) \ln\left(\frac{2\Omega}{\tilde{\Delta}}\right)$$

Pairing interaction

As a consequence of the pairing correlation, the levels below the Fermi energy are only partially filled, while those above the Fermi energy are partially empty. IF $\{\epsilon_k\}$ are the DTCSM single particle energies, then:

$$v_k^2 = \left[1 - (\epsilon_k - \lambda)/E_k\right]/2$$

and

$$u_k^2 = 1 - v_k^2$$

where the quasi-particle energy is:

$$E_k = \sqrt{(\epsilon_k - \lambda)^2 + \Delta^2}.$$

where λ and Δ are the solutions of the BCS system of equations.

Pairing interaction

The pairing correction:

$$\delta p = p - \tilde{p}$$

represents the difference between the pairing correlation energies for the discrete level distribution:

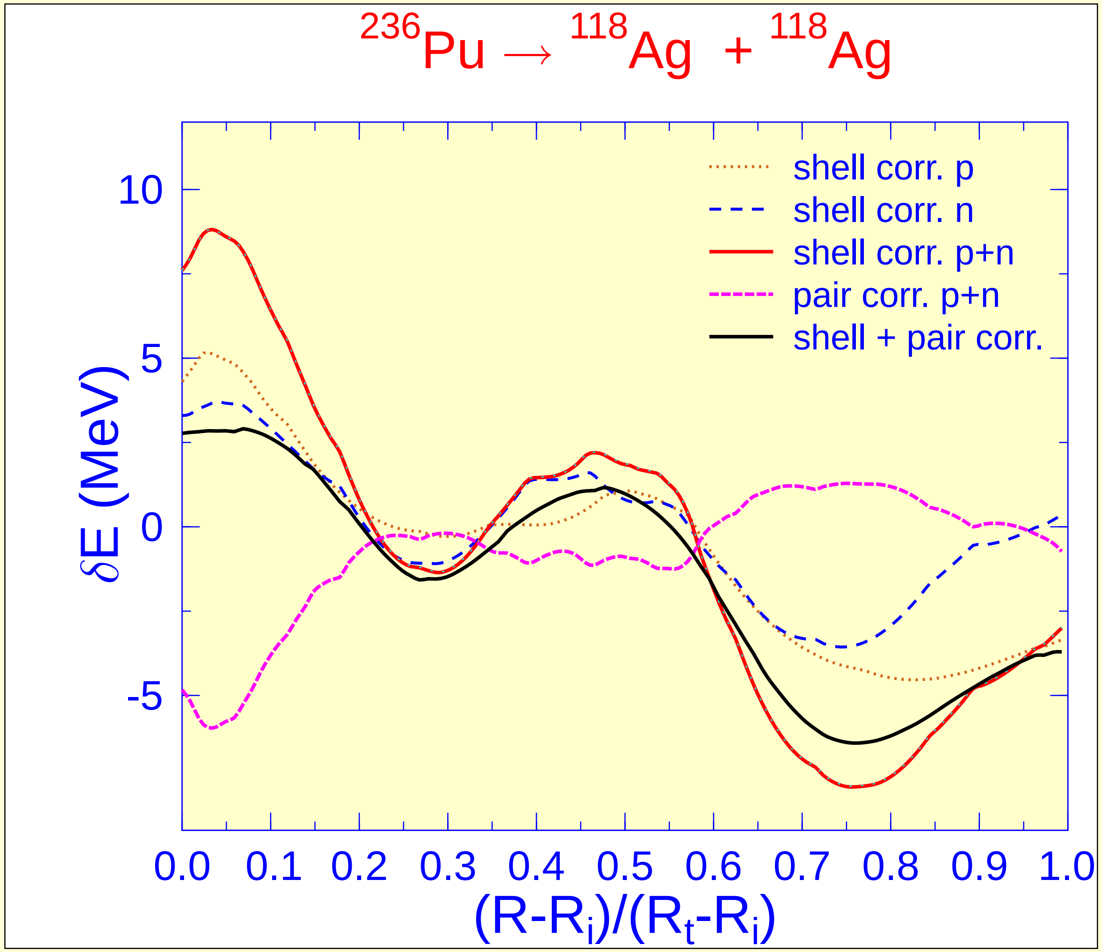
$$p = \sum_{k=k_i}^{k_f} 2v_k^2\epsilon_k - 2\sum_{k=k_i}^{Z/2} \epsilon_k - \frac{\Delta^2}{G}$$

and for the continuous level distribution

$$\tilde{p} = -(\tilde{g}\tilde{\Delta^2})/2 = -(\tilde{g}_s\tilde{\Delta^2})/4$$

Compared to shell correction, the pairing correction is out of phase and smaller. One has again $\delta p = \delta p_p + \delta p_n$, and $\delta e = \delta u + \delta p$.

Example: ^{236}Pu



Shell and pairing corrections for ^{236}Pu. The s.p.s. were obtained with the two-center shell model.

Macroscopic energy

The macroscopic energy: the sum of Coulomb E_C and Yukawa E_Y:

$$E_C = \frac{2\pi}{3}\rho_e \int_{z_{min}}^{z_{max}} dz \int_{z_{min}}^{z_{max}} dz\prime \cdot F_C(z, z\prime)$$

where $F_C(z, z')$ - shape dependent $\longrightarrow$ binary fusion configuration:

$$E_C = \frac{2\pi}{3}(\rho_{e1}^2 F_{C1} + \rho_{e2}^2 F_{C2} + 2\rho_{e1}\rho_{e2}F_{C12})$$

where ρ_{e1} and ρ_{e2} are the charge densities, and:

$$E_Y = \frac{1}{4\pi r_0^2}[c_{s1}F_{EY1} + c_{s2}F_{EY2} + 2(c_{s1}c_{s2})^{1/2}F_{EY12}]$$

The total deformation energy: $E_{def} = E_C + E_Y + \delta u + \delta p$ The surface energy constants:

$$c_{si} = a_s(1 - \kappa I_i^2) \quad where \quad I_i = (N_{ix} - Z_{ix})/A_{ix}$$

Deformation variable evolution

Variation of the semiaxis ratios: $\chi_T = b_T/a_T$ and $\chi_P = b_P/a_P$:

$$\begin{aligned}
\chi_T &= \chi_{T0} + (\chi_0 - \chi_{T0}) \exp\left[- \left(\frac{R - R_{k_T}}{R_t - R_f} k_T \right)^2 \right] \\
\chi_P &= \chi_{P0} + (\chi_{Pf} - \chi_{P0}) \exp\left[- \left(\frac{R - R_{k_P}}{R_t - R_f} k_P \right)^2 \right]
\end{aligned}$$

where:

$$\chi_{Pf} = \chi_{P0} - \frac{i_P}{10}(\chi_0 - \chi_{P0})$$

Free variables $\longrightarrow$ functions of R :

$$\begin{aligned}
b_P &= b_P(k_T, k_P, i_P; R) \\
\chi_T &= \chi_T(k_T, k_P, i_P; R) \\
\chi_P &= \chi_P(k_T, k_P, i_P; R)
\end{aligned}$$

Mass tensor and dynamics

Cranking model $\longrightarrow$ Tensor contraction along R:

$$\begin{aligned} B(R) \quad = \quad & B_{b_P b_P}\left(\frac{db_P}{dR}\right)^2 + 2B_{b_P\chi_T}\frac{db_P}{dR}\frac{d\chi_T}{dR} + 2B_{b_P\chi_P}\frac{db_P}{dR}\frac{d\chi_P}{dR} + \\ & 2B_{b_P R}\frac{db_P}{dR} + B_{\chi_T\chi_T}\left(\frac{d\chi_T}{dR}\right)^2 + 2B_{\chi_T\chi_P}\frac{d\chi_T}{dR}\frac{d\chi_P}{dR} + \\ & 2B_{\chi_T R}\frac{d\chi_T}{dR} + B_{\chi_P\chi_P}\left(\frac{d\chi_P}{dR}\right)^2 + 2B_{\chi_P R}\frac{d\chi_P}{dR} + B_{RR} \end{aligned}$$

Penetrability P for a given fusion path (fus):

$$P = \exp(-K_{ov})$$

where

$$K_{ov}(b_P, \kappa_T, \kappa_P; R) = \frac{2}{\hbar}\int_{(fus)} [2B(R)_{b_P,\kappa_T,\kappa_P} E_{def}(R)_{b_P,\kappa_T,\kappa_P}]^{1/2} dR$$

Cranking mass tensor

Cranking model $\longrightarrow$ Tensor contraction along R results in scalar forms:

$$B_\varepsilon = 2\hbar^2 \sum_{\nu\mu} \frac{\langle \nu | \partial V_{DTCSM} / \partial \varepsilon | \mu \rangle \langle \mu | \partial V_{DTCSM} / \partial \varepsilon | \nu \rangle}{(E_\nu + E_\mu)^3} (u_\nu v_\mu + u_\mu v_\nu)^2$$

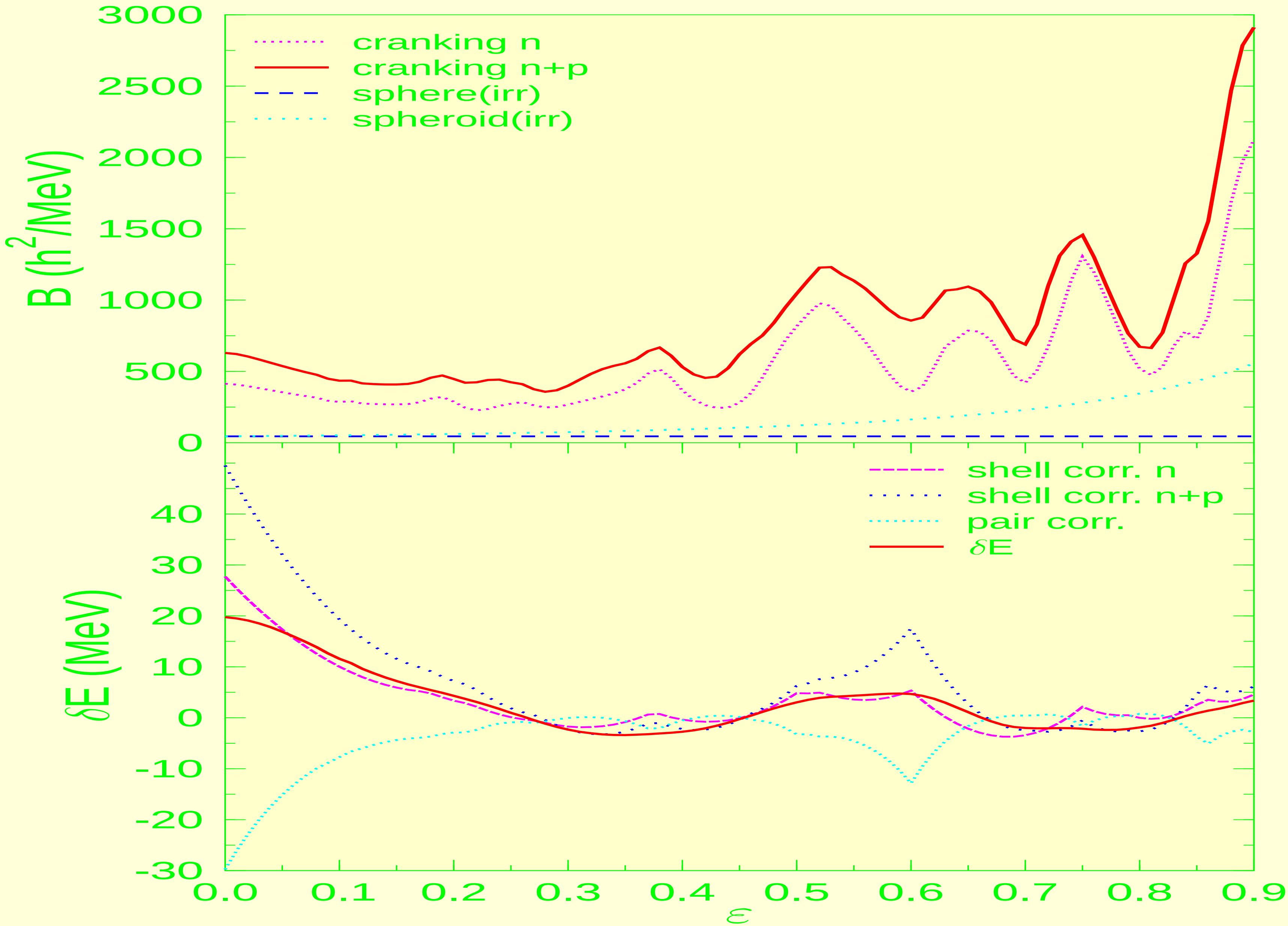
where:

$$V_{DTCSM} = V_{DTCSM}^{2osc} + V_{ls} + V_{l^2}$$

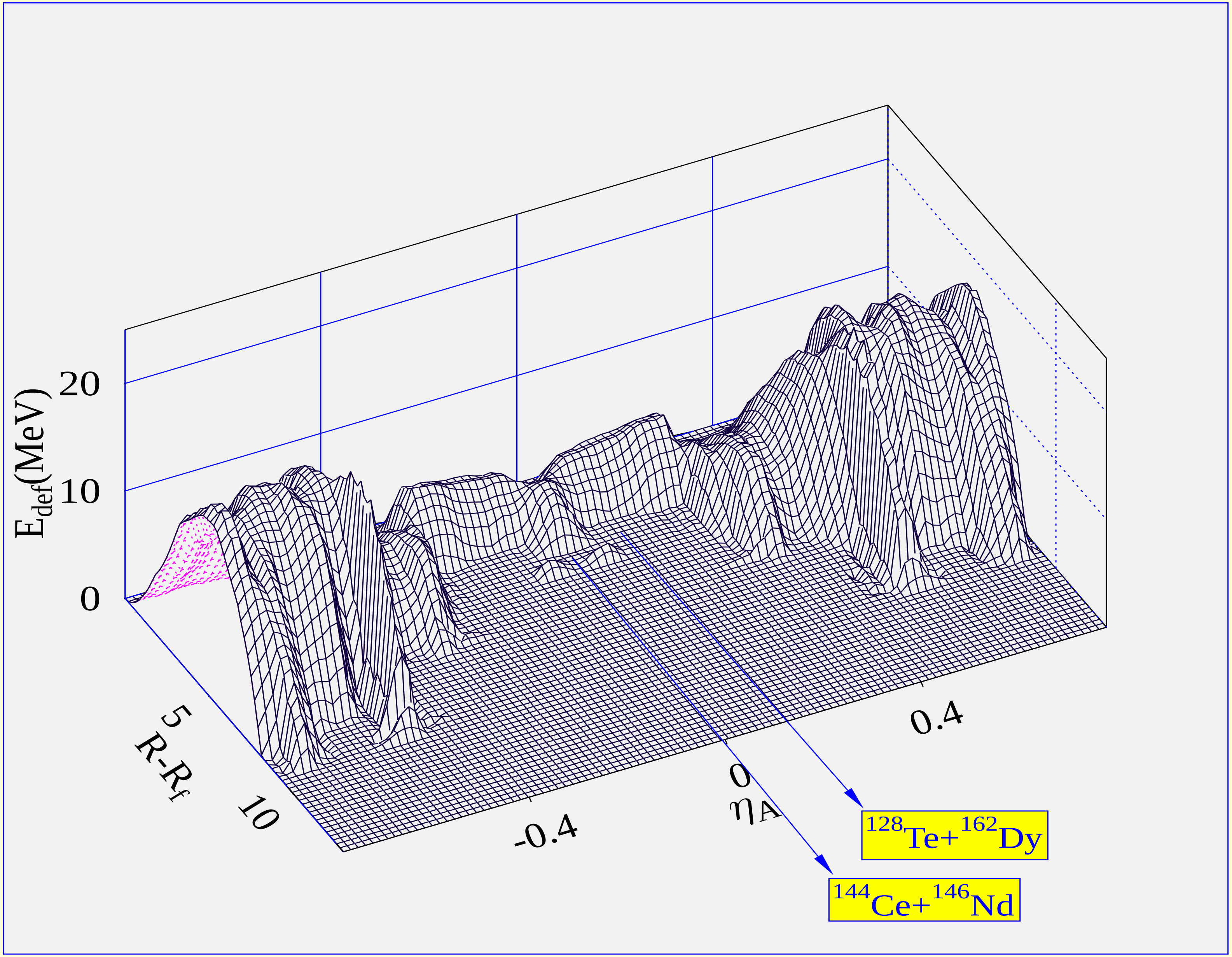
and the s. p. s. are the DTCSM wave functions.

$$|\mu\rangle = |DTCSM(n_\rho, n_z, m | \rho, z, \phi)\rangle$$

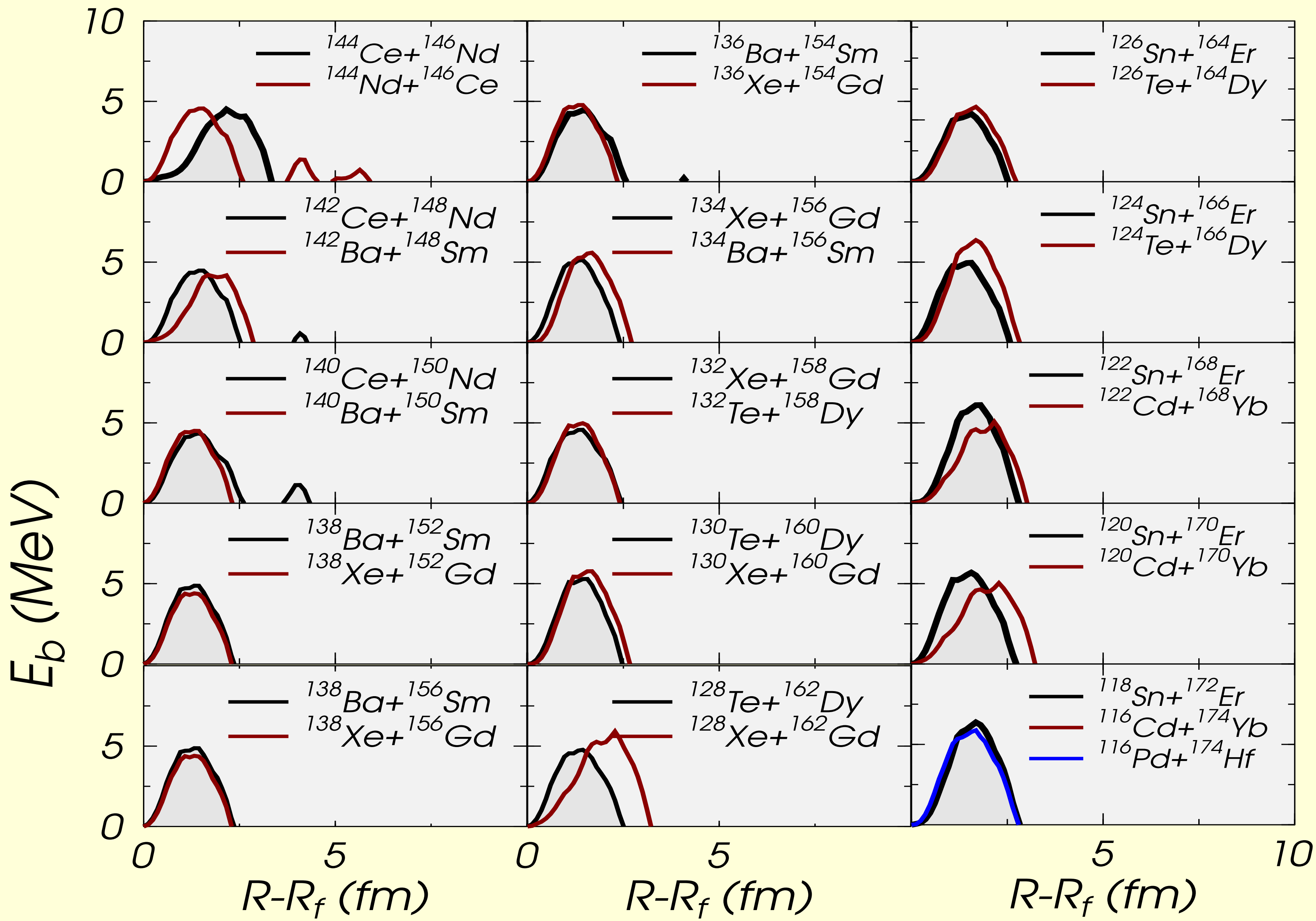
Cranking inertia for ^{236}Pu



PES for $^{290}118$



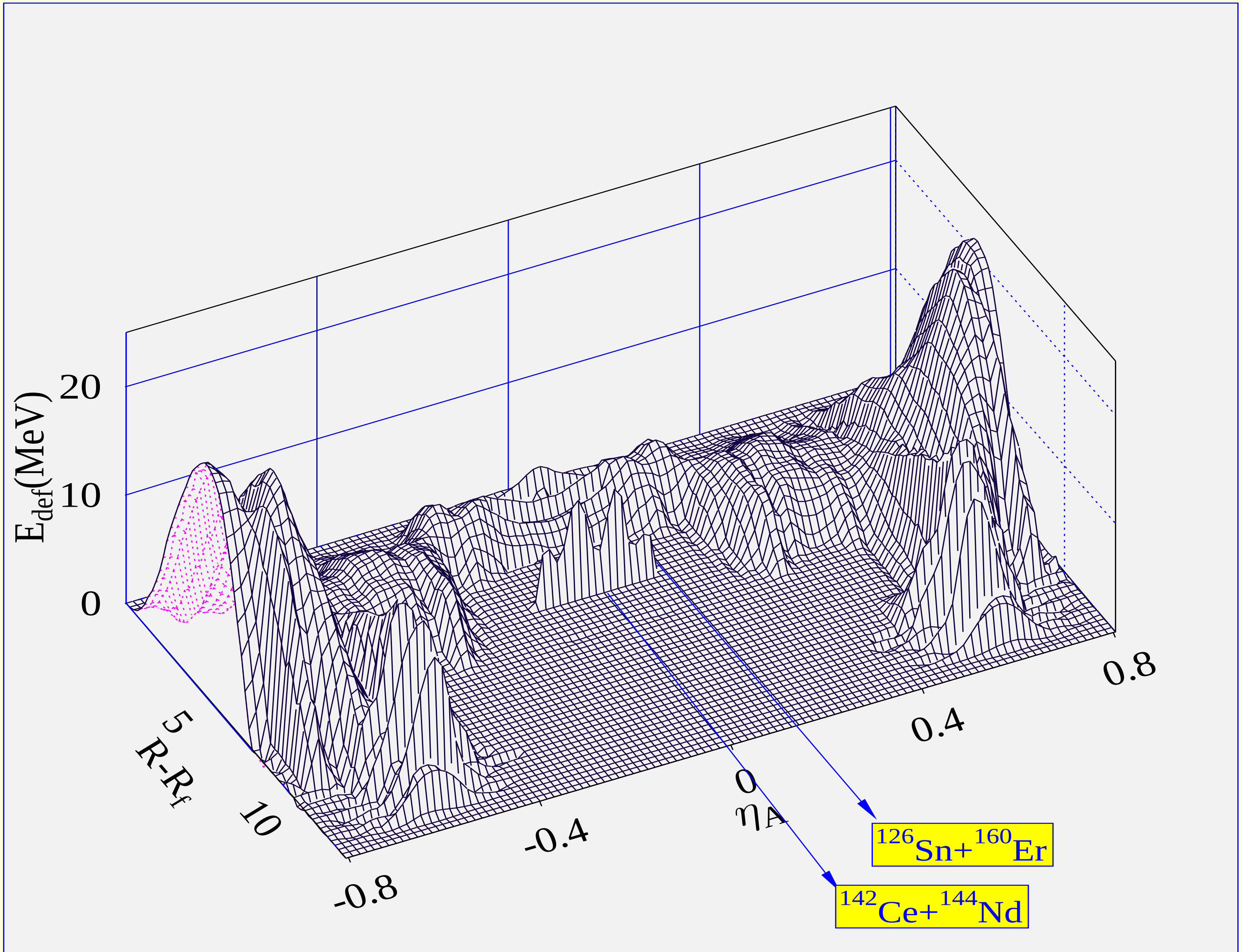
Isobaric channel cold fusion barriers for $^{290}118$



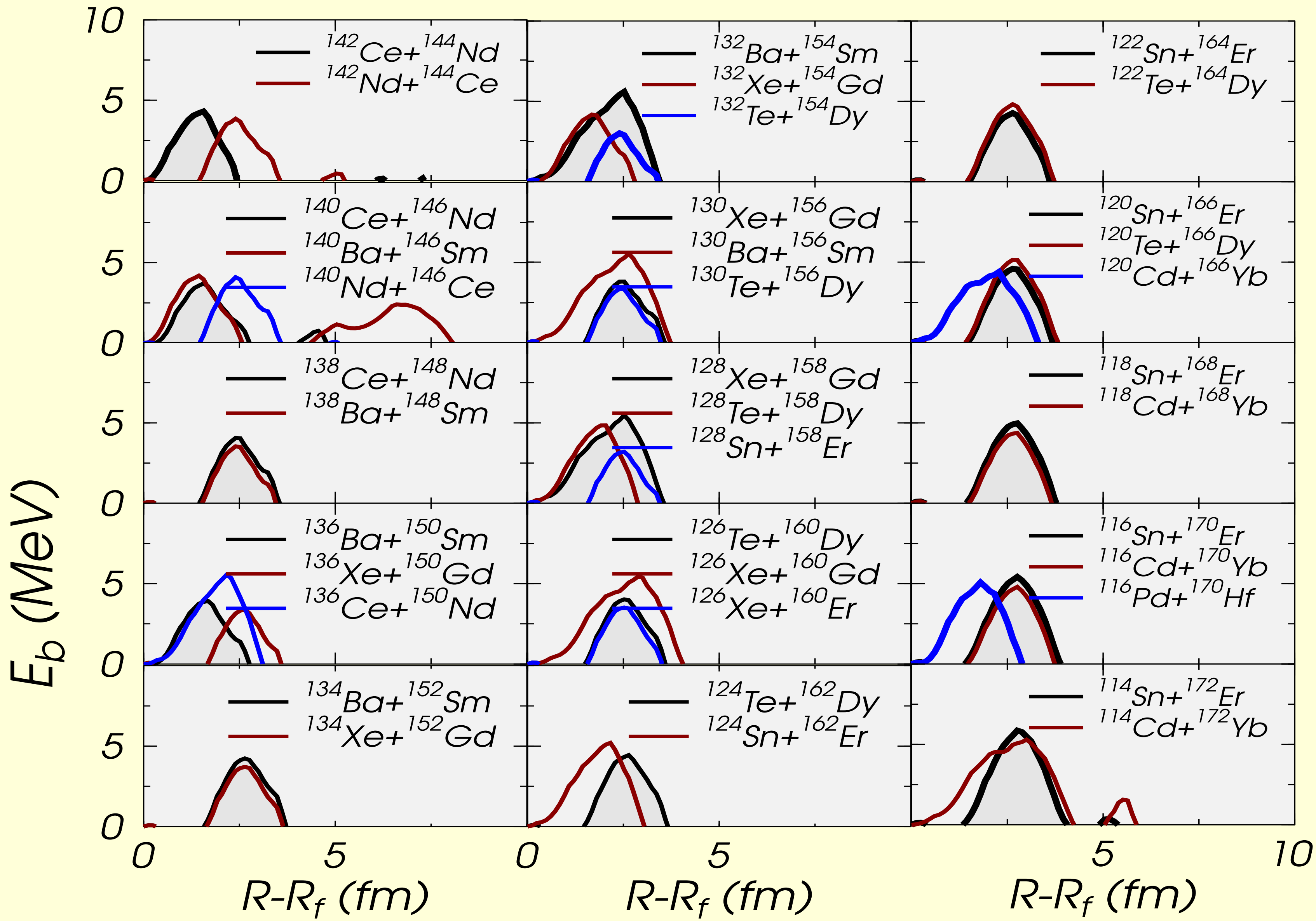
Cold fusion channels for ^{290}118

Reaction	E_b (MeV)	$log_{10}P$	Reaction	E_b (MeV)	$log_{10}P$
^{144}Ce+^{146}Nd	4.4	-5.	^{132}Xe+^{158}Gd	4.57	-4.31
^{144}Nd+^{146}Ce	4.56	-5.89	^{132}Te+^{158}Dy	4.98	-4.49
^{142}Ce+^{148}Nd	4.47	-4.51	^{130}Xe+^{160}Gd	5.77	-5.19
^{142}Ba+^{148}Sm	4.2	-4.52	^{130}Te+^{160}Dy	5.29	-4.76
^{140}Ce+^{150}Nd	4.35	-4.91	^{128}Te+^{162}Dy	4.77	-4.44
^{140}Ba+^{150}Sm	4.5	-4.17	^{128}Xe+^{162}Gd	5.91	-6.27
^{138}Ba+^{152}Sm	4.86	-4.42	^{128}Sn+^{162}Er	5.19	-4.6
^{138}Xe+^{152}Gd	4.4	-4.04	^{126}Te+^{164}Dy	5.87	-5.32
^{136}Ba+^{154}Sm	4.44	-4.33	^{126}Sn+^{164}Er	5.48	-4.81
^{136}Xe+^{154}Gd	4.66	-4.33	^{124}Sn+^{166}Er	4.96	-4.64
^{134}Ba+^{156}Sm	5.58	-5.02	^{124}Te+^{166}Dy	6.37	-5.68
^{134}Xe+^{156}Gd	5.13	-4.61	^{122}Sn+^{168}Er	6.12	-5.5
^{132}Xe+^{158}Gd	4.57	-4.31	^{122}Cd+^{168}Yb	5.07	-5.39

PES for $^{286}118$



Isobaric channel cold fusion barriers for $^{286}118$



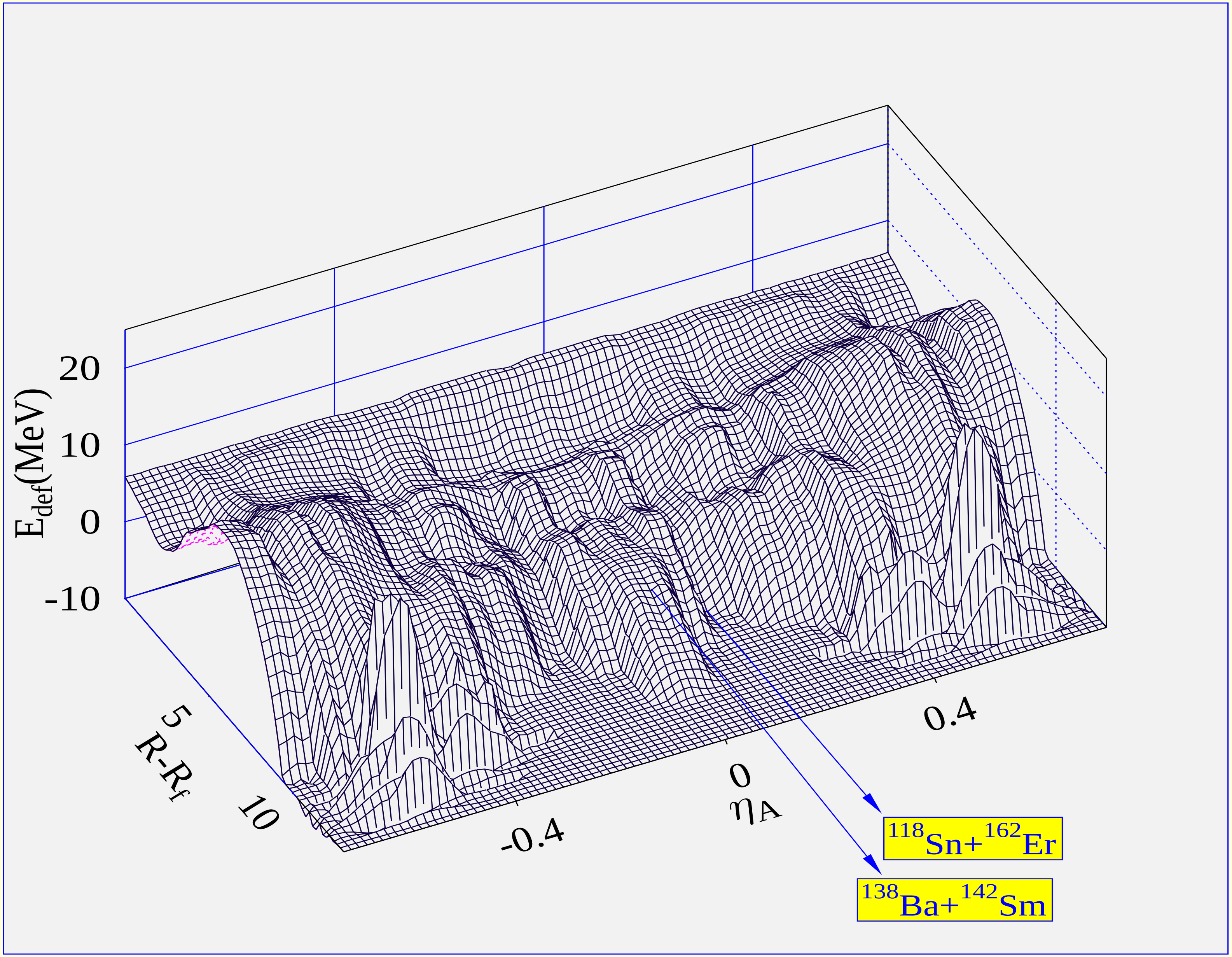
Cold fusion channels for ^{286}118

Reaction	E_b (MeV)	$log_{10}P$	Reaction	E_b (MeV)	$log_{10}P$
^{142}Ce+^{144}Nd	4.3	-3.48	^{132}Ba+^{154}Sm	5.6	-5.55
^{142}Nd+^{144}Ce	3.85	-3.53	^{132}Xe+^{154}Gd	4.18	-3.63
^{140}Ce+^{146}Nd	3.7	-3.7	^{132}Te+^{154}Dy	3.02	-2.4
^{140}Nd+^{146}Ce	4.1	-3.4	^{130}Ba+^{156}Sm	5.52	-6.25
^{140}Ba+^{146}Sm	4.19	-8.71	^{130}Xe+^{156}Gd	3.79	-3.18
^{138}Ce+^{148}Nd	4.06	-3.35	^{130}Te+^{156}Dy	3.34	-2.71
^{138}Ba+^{148}Sm	3.54	-2.83	^{128}Sn+^{158}Er	3.2	-2.56
^{136}Ba+^{150}Sm	3.92	-3.39	^{128}Xe+^{158}Gd	5.48	-5.82
^{136}Ce+^{150}Nd	5.54	-4.86	^{128}Te+^{158}Dy	4.85	-4.22
^{136}Xe+^{150}Gd	3.37	-2.69	^{126}Xe+^{160}Gd	5.44	-6.58
^{134}Ba+^{152}Sm	4.23	-3.49	^{126}Te+^{160}Dy	4.02	-3.33
^{134}Xe+^{152}Gd	3.71	-3.06	^{126}Sn+^{160}Er	3.51	-2.9

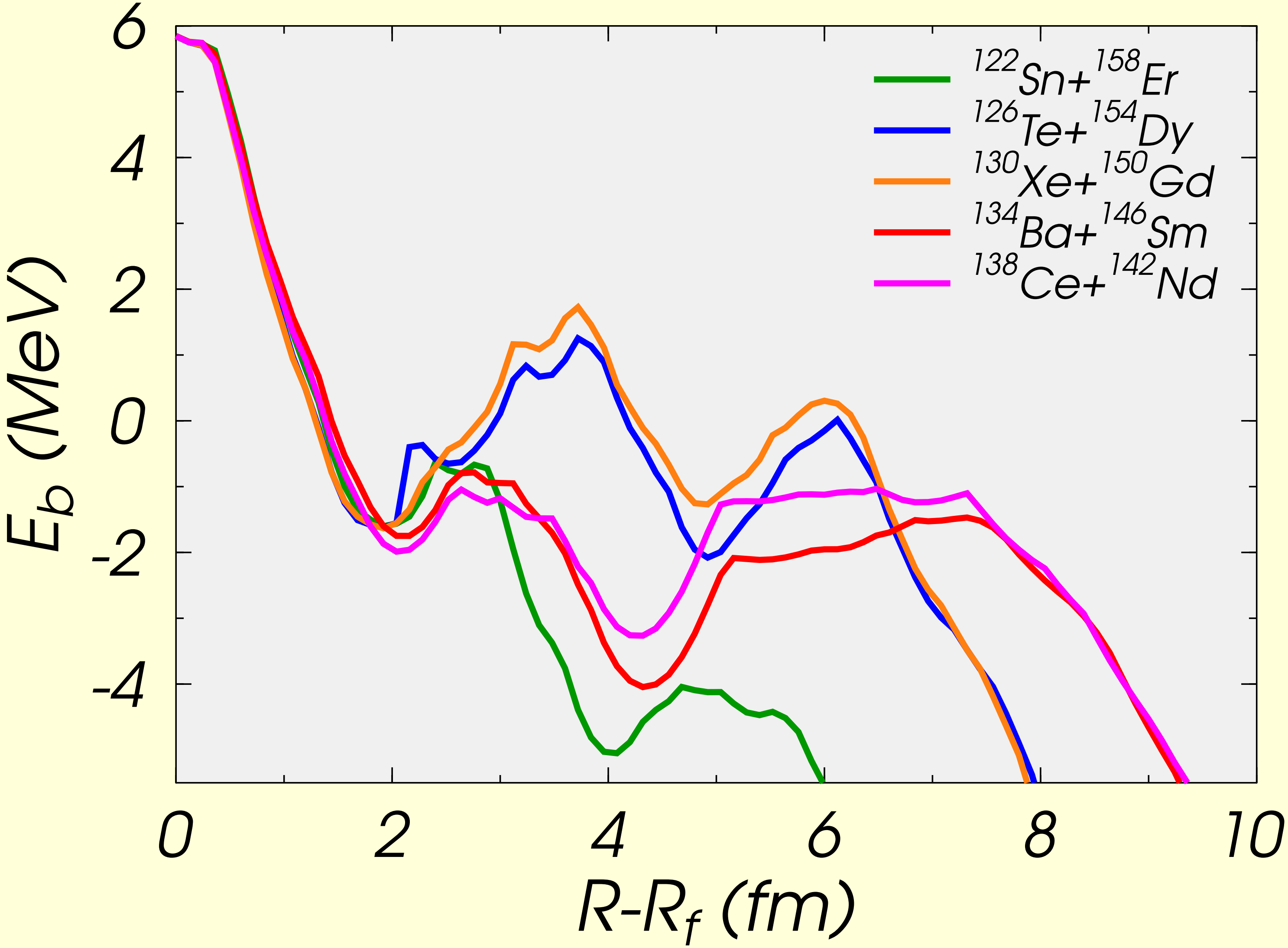
Cold fusion channels for ^{286}118

Reaction	E_b (MeV)	$log_{10}P$	Reaction	E_b (MeV)	$log_{10}P$
^{124}Sn+^{162}Er	5.2	-4.55	^{118}Sn+^{168}Er	4.98	-4.11
^{124}Te+^{162}Dy	4.44	-3.65	^{118}Cd+^{168}Yb	4.37	-3.6
^{122}Te+^{164}Dy	4.82	-3.93	^{116}Sn+^{170}Er	5.42	-4.5
^{122}Sn+^{164}Er	4.27	-3.47	^{116}Cd+^{170}Yb	4.8	-3.93
^{120}Te+^{166}Dy	5.14	-4.28	^{116}Pd+^{170}Hf	5.08	-4.6
^{120}Sn+^{166}Er	4.59	-3.75	^{114}Sn+^{172}Er	5.87	-5.27

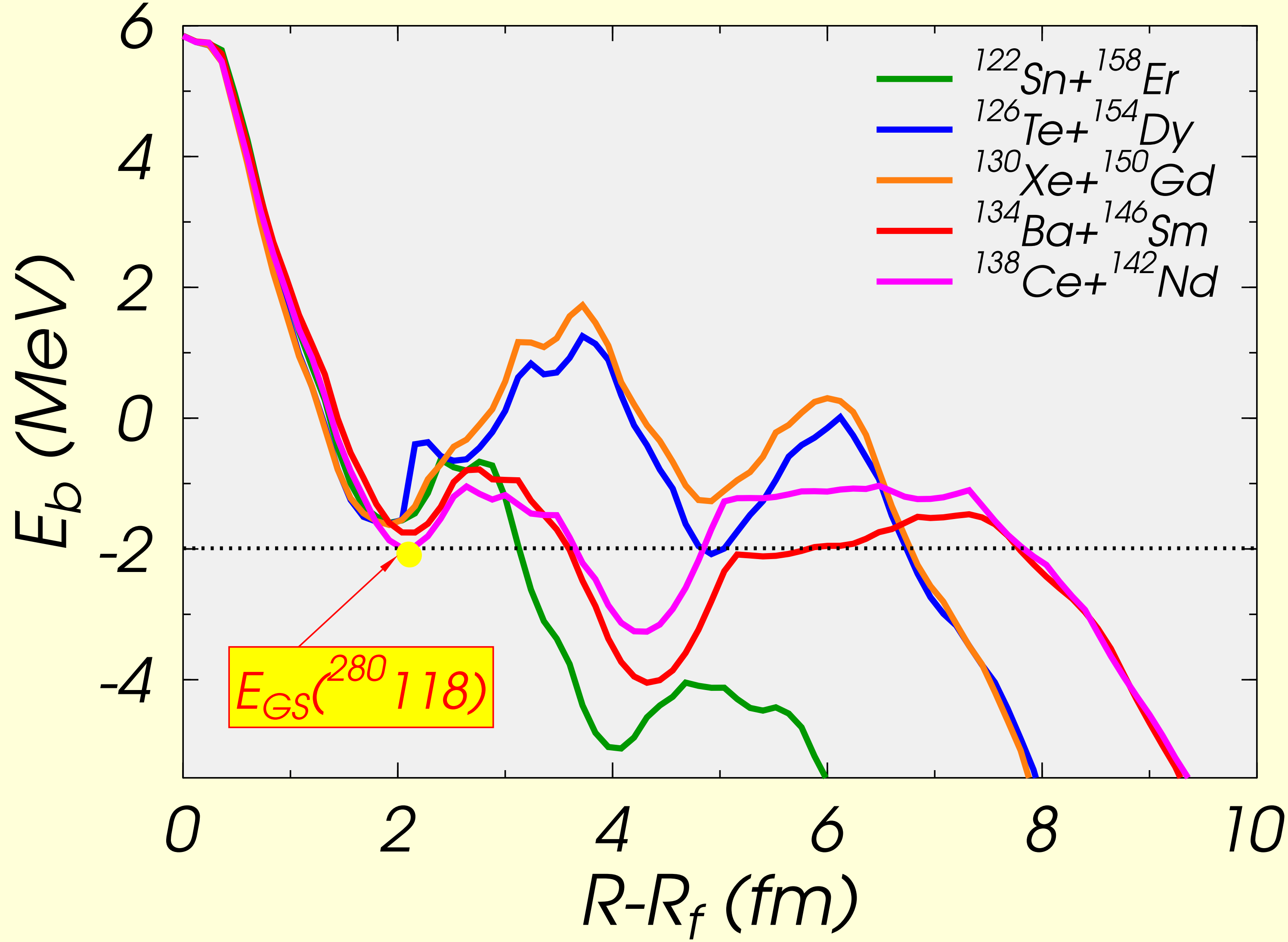
PES for $^{280}118$



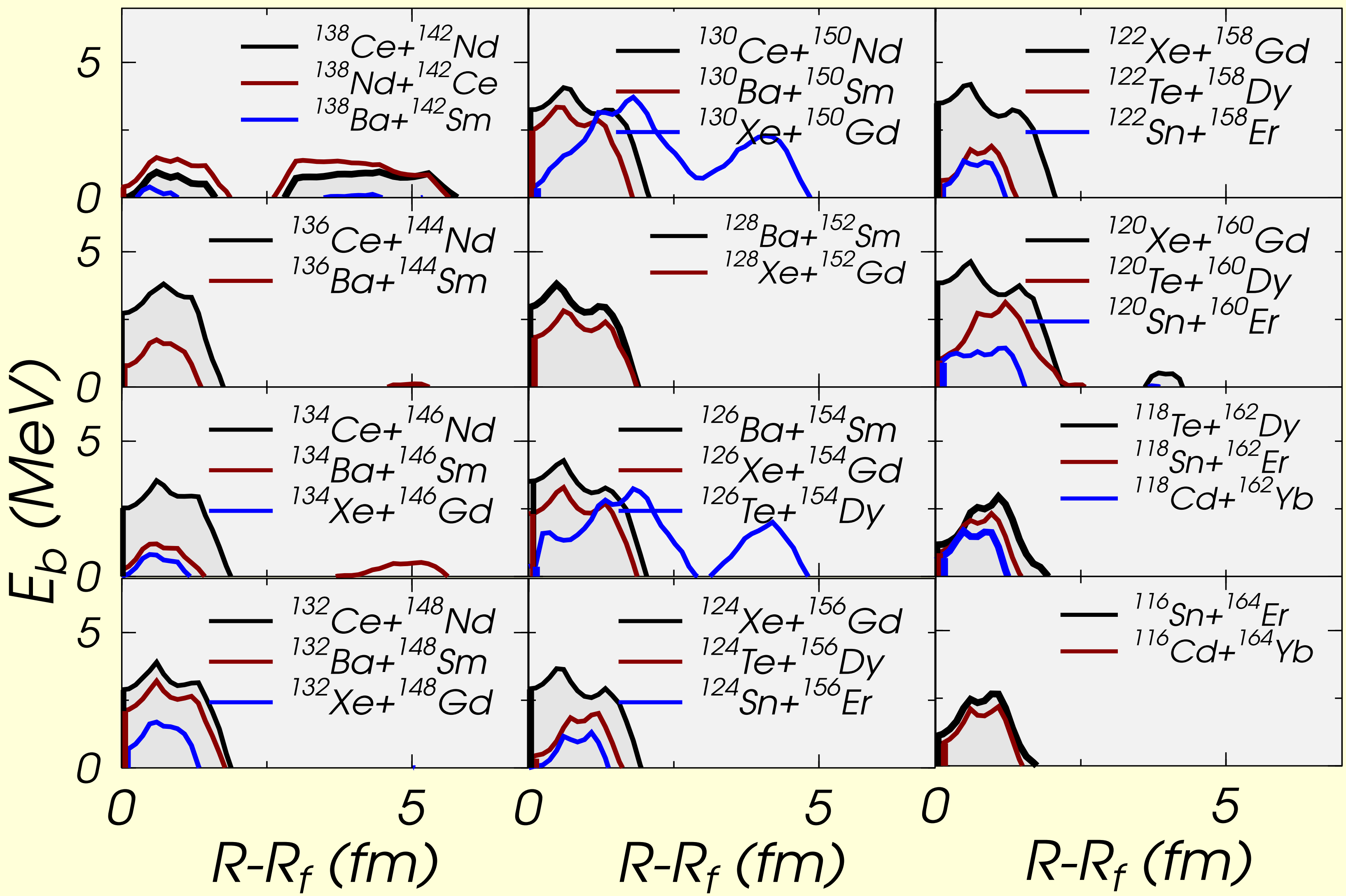
Cold fusion barriers for $^{280}118$



Cold fusion barriers for ^{280}118



Isobaric channel cold fusion channels for ^{280}118



Cold fusion channels for ^{280}118

Reaction	E_b (MeV)	$log_{10} P$	Reaction	E_b (MeV)	$log_{10} P$
^{138}Nd+^{142}Ce	1.48	-5.22	^{130}Ce+^{150}Nd	4.07	-4.32
^{138}Ce+^{142}Nd	0.95	-3.94	^{130}Ba+^{150}Sm	3.34	-3.28
^{138}Ba+^{142}Sm	0.39	-0.59	^{130}Xe+^{150}Gd	3.71	-7.87
^{136}Ce+^{144}Nd	3.81	-3.31	^{128}Ba+^{152}Sm	3.8	-3.7
^{136}Ba+^{144}Sm	1.61	-1.91	^{128}Xe+^{152}Gd	2.82	-3.
^{134}Ce+^{146}Nd	3.54	-3.56	^{126}Ba+^{154}Sm	4.28	-4.34
^{134}Ba+^{146}Sm	1.2	-2.4	^{126}Xe+^{154}Gd	3.29	-3.32
^{134}Xe+^{146}Gd	0.81	-0.77	^{126}Te+^{154}Dy	3.24	-6.72
^{132}Ce+^{148}Nd	3.9	-3.81	^{124}Xe+^{156}Gd	3.67	-3.79
^{132}Ba+^{148}Sm	2.88	-3.09	^{124}Te+^{156}Dy	2.01	-1.9
^{132}Xe+^{148}Gd	1.69	-1.58	^{124}Sn+^{156}Er	1.17	-1.15

Cold fusion channels for $^{280}118$

Reaction	E_b (MeV)	$log_{10}P$	Reaction	E_b (MeV)	$log_{10}P$
^{122}Xe+^{158}Gd	4.18	-4.38	^{118}Te+^{162}Dy	2.95	-2.83
^{122}Te+^{158}Dy	1.9	-1.75	^{118}Sn+^{162}Er	2.32	-2.07
^{122}Sn+^{158}Er	1.32	-1.31	^{118}Cd+^{162}Yb	1.68	-1.57
^{120}Xe+^{160}Gd	4.63	-5.37	^{116}Sn+^{164}Er	2.66	-2.53
^{120}Te+^{160}Dy	3.13	-3.43	^{116}Cd+^{164}Yb	1.99	-2.04
^{120}Sn+^{160}Er	1.31	-1.86			

Possible conclusions

- A specialized binary macroscopic-microscopic model is applied to calculate the deformation energy.
- Cranking mass tensor and multidimensional minimization of action integral is used to obtain WKB penetrabilities.
- For $^{294}118$:
  ^{136}Te+^{158}Dy $\rightarrow$ $logP$=-5.97
  ^{126}Sn+^{168}Er $\rightarrow$ $logP$=-6.55

  For $^{290}118$:
  ^{140}Ba+^{150}Sm $\rightarrow$ $logP$=-4.17
  ^{128}Te+^{162}Dy $\rightarrow$ $logP$=-4.44
  ^{116}Pd+^{174}Hf $\rightarrow$ $logP$=-4.6
- For $^{286}118$:
  ^{138}Ba+^{148}Sm $\rightarrow$ $logP$=-2.83
  ^{132}Te+^{154}Dy $\rightarrow$ $logP$=-2.4
  ^{126}Pd+^{160}Hf $\rightarrow$ $logP$=-2.9

  For $^{280}118$:
  ^{138}Ba+^{142}Sm $\rightarrow$ $logP$=-0.59
  ^{134}Xe+^{146}Gd $\rightarrow$ $logP$=-0.77
  ^{124}Sn+^{156}Er $\rightarrow$ $logP$=-1.15
  ^{122}Sn+^{158}Er $\rightarrow$ $logP$=-1.31