Gogny-TDHFB calculation of ^{20}O + ^{20}O head-on collision

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1. Introduction

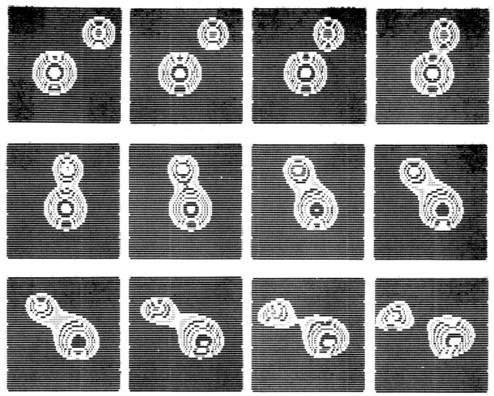
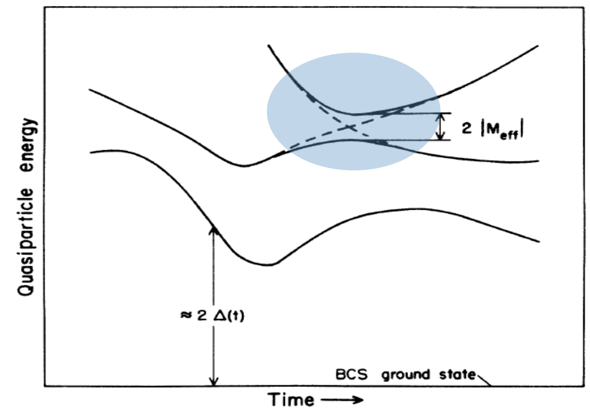


FIG. 40. Contour plots for the same reaction as in Fig. 38 with an initial angular momentum of $l = 80\hbar$.

M.S.Weiss, Fizika 9, Suppl. 3(1977), 315.



S.E.Koonin and J.R.Nix, PRC 13(1976), 209.

* nucleus-nucleus collision
  energy transfer between
  relative motion ⇔ internal excitation
  ← TDHF (P. Bonche, S. E. Koonin, and J. Negele, PRC13(1976) , 1700.)

* energy transfer with pairing correlation
  ← TDHFB (model calculation)

friction :
relative motion ⇔ internal motion

R : relative coordinate
P : relative momentum
γ : friction coefficient

$$\frac{dR}{dt} = \frac{P}{\mu},$$

$$\frac{dP}{dt} = -\frac{dV}{dR} - \frac{d}{dR}\left(\frac{P^2}{2\mu}\right) - \gamma(R)\dot{R}$$

K.Washiyama, D.Lacroix, and S.Ayik, PRC79(2009), 024609

Gogny-D1S

$$V_{12} = \sum_{i=1}^{2} \exp\left[-\frac{|\vec{r}_1 - \vec{r}_2|^2}{\mu_i^2}\right] \cdot (W_i + B_i\hat{P}_\sigma - H_i\hat{P}_\tau - M_i\hat{P}_\sigma\hat{P}_\tau) +$$

Gauss part

$$+t_3(1 + x_0\hat{P}_\sigma)\,\delta(\vec{r}_1 - \vec{r}_2)\left[\rho\left(\frac{\vec{r}_1 + \vec{r}_2}{2}\right)\right]^\gamma +$$

density dependent part

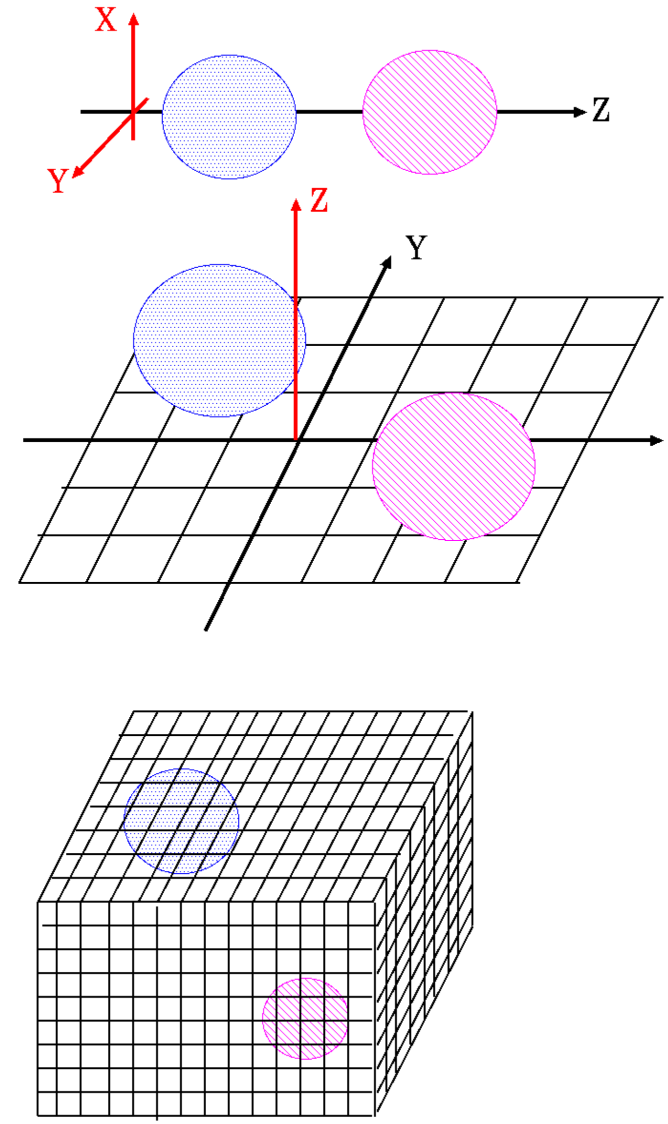
$$+iW_{\mathrm{LS}}(\vec{\sigma}_1 + \vec{\sigma}_2)\cdot \overleftarrow{\nabla}_{12} \times \delta(\vec{r}_1 - \vec{r}_2)\vec{\nabla}_{12} + V_{\mathrm{Coul.}}\,,$$

L-S part, Coulomb

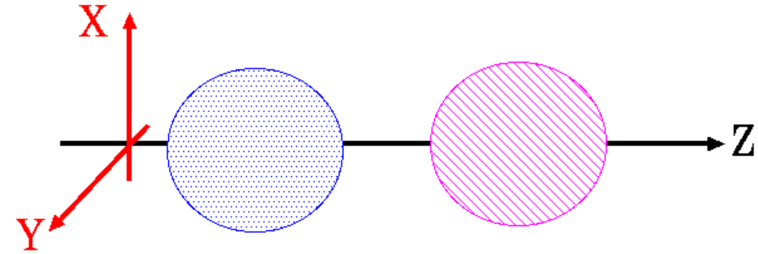
harmonic oscillator	Lagrange mesh
x, y	z

harmonic oscillator	Lagrange mesh
z	x, y

harmonic oscillator	Lagrange mesh
———	x, y, z



harmonic oscillator	Lagrange mesh
x, y	z



$$\left\{\phi_{n_x}(x), \phi_{n_y}(y), \phi_{n_z}(z)\right\} \Rightarrow \left\{\phi_{n_x}(x), \phi_{n_y}(y), \underline{f_{n_z}(z)}\right\}$$

harmonic oscillator

Lagrange mesh

$$f_l(z) = \frac{1}{N}\frac{\sin\left(\pi\left(z - z_l\right)/h\right)}{\sin\left(\pi\left(z - z_l\right)/L\right)}$$

$$L = Nh$$

$$f_k(z_{k'}) = \delta_{kk'}$$

$$\int_{-L/2}^{L/2} f_l(z) f_{l'}(z) dz = h\,\delta_{ll'}$$

$$\int_{-L/2}^{L/2} f_l(z) W(z) f_{l'}(z) dz = h\,W(z_l)\,\delta_{ll'}$$

D. Baye and P. Heenen,
J. Phys. A 19, 2041 (1986).

2． Basic equation

cf. Ring & Schuck, The Nuclear Many-Body Problems

Bogoliubov 変換：
$$\begin{cases} \beta_k^\dagger = \sum_\alpha (U_{\alpha k} C_\alpha^\dagger + V_{\alpha k} C_\alpha), \\ \beta_k = \sum_\alpha (U_{\alpha k}^* C_\alpha + V_{\alpha k}^* C_\alpha^\dagger). \end{cases}$$

$$i\hbar \frac{\partial}{\partial t} \begin{pmatrix} U(t) \\ V(t) \end{pmatrix} = \mathcal{H} \begin{pmatrix} U(t) \\ V(t) \end{pmatrix} \qquad \mathcal{H} = \begin{pmatrix} h & \Delta \\ -\Delta^* & -h^* \end{pmatrix}.$$

$$h_{\alpha\beta} = T_{\alpha\beta} + \Gamma_{\alpha\beta},$$

$$\Gamma_{\alpha\beta} = \sum_{\nu\delta} \mathcal{V}_{\alpha\gamma\beta\delta} \rho_{\delta\gamma}, \quad \Delta_{\alpha\beta} = \frac{1}{2} \sum \mathcal{V}_{\alpha\beta\gamma\delta} \kappa_{\gamma\delta},$$

$$\rho_{\alpha\beta} = (V^* V^T)_{\alpha\beta}, \quad \kappa_{\alpha\beta} = (V^* U^T)_{\alpha\beta}.$$

time translation（with predictor-corrector method）

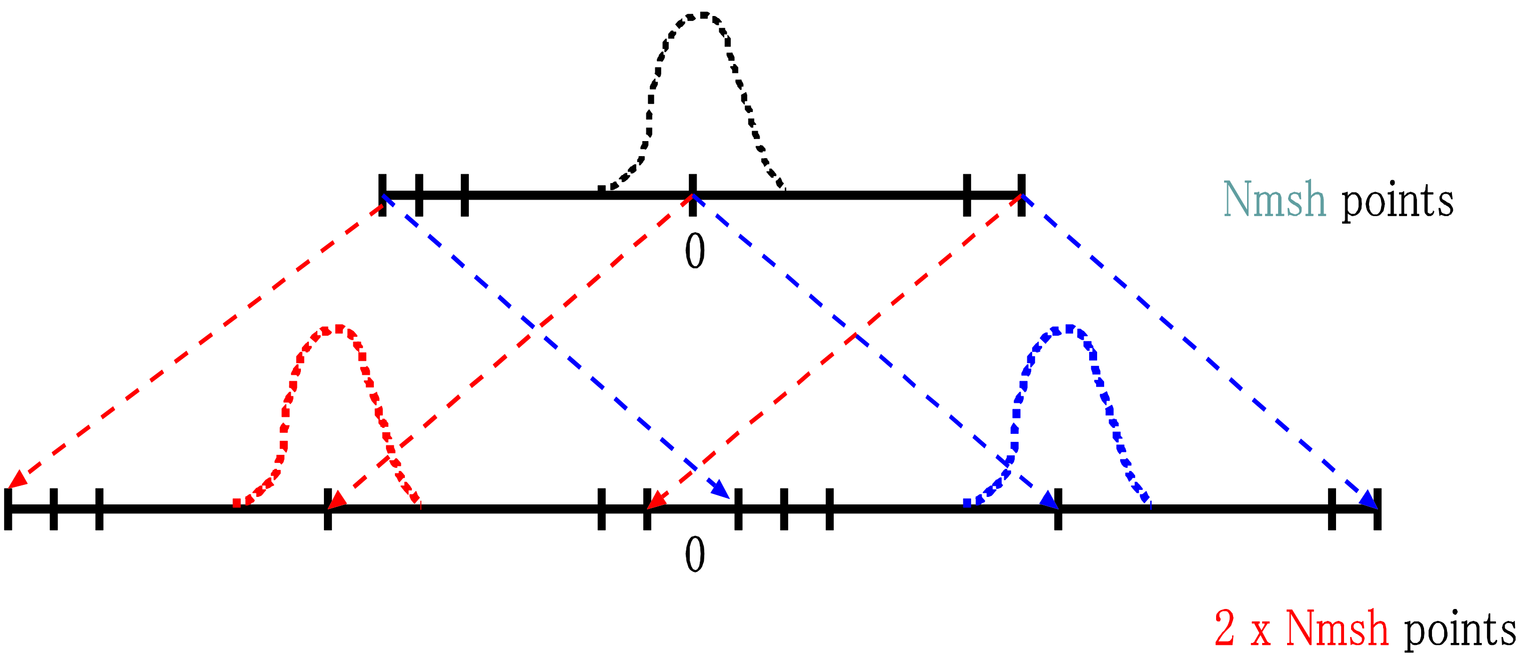
$$\begin{pmatrix} U(t) \\ V(t) \end{pmatrix}^{(n+1)} = \exp\left(-i \frac{c\Delta t}{c\hbar} \mathcal{H}^{(n+\frac{1}{2})}\right) \begin{pmatrix} U(t) \\ V(t) \end{pmatrix}^{(n)}$$

3． Numerical results:

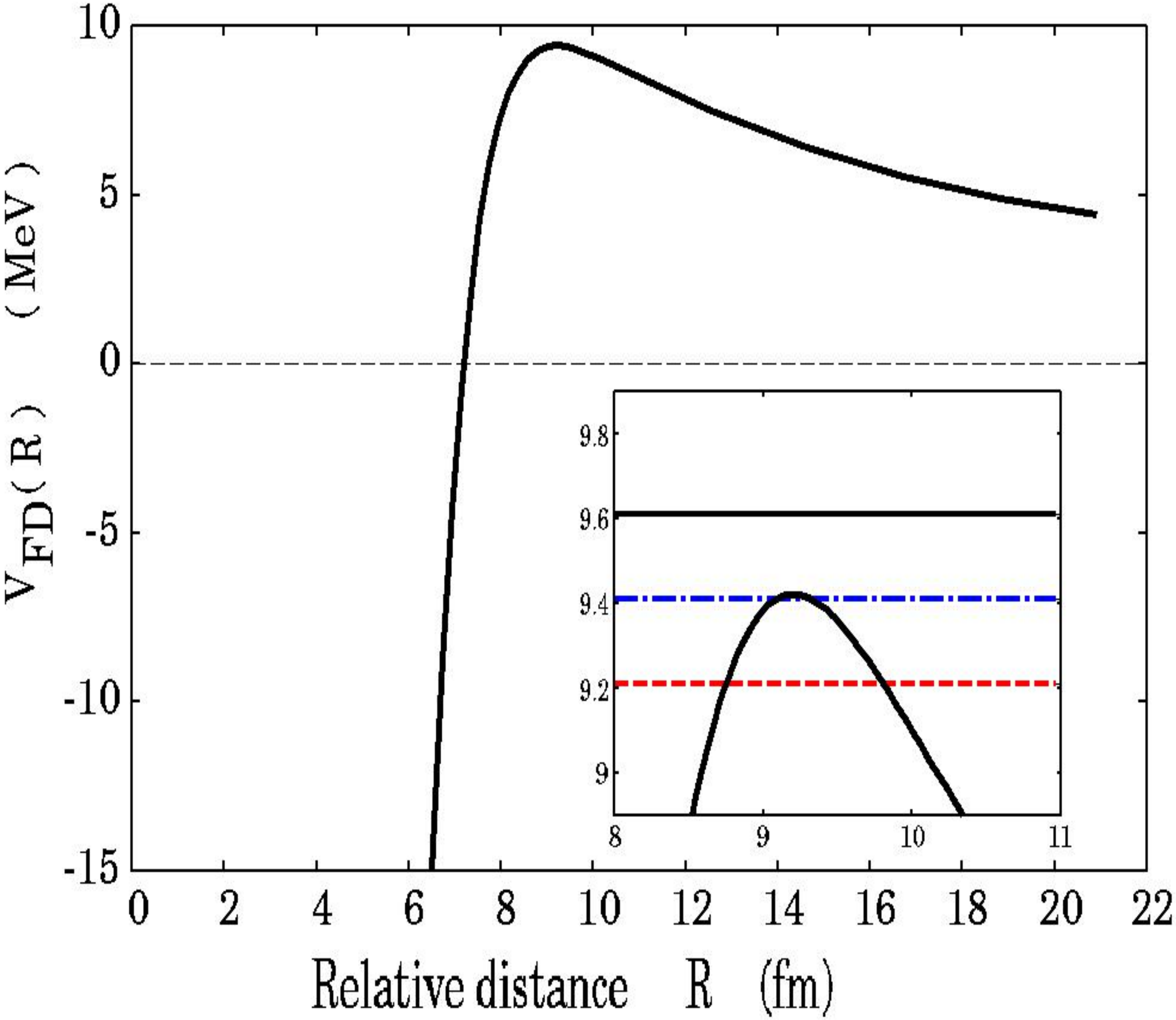
$^{20}O + ^{20}O$ with Ecm = 9.2, 9.4, 9.6 MeV etc

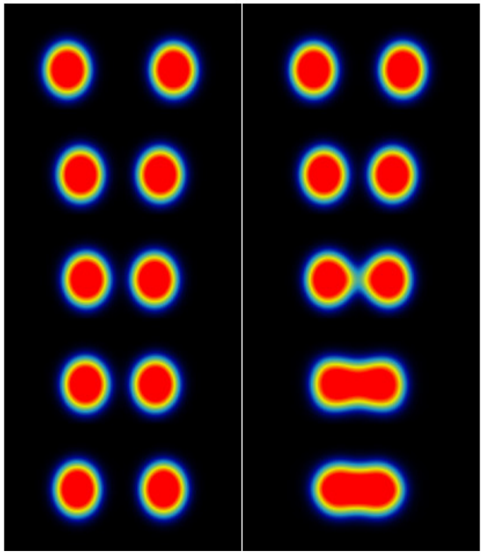
≪ initial condition and parameters≫

- harmonic oscillator shell Nsh= 4
- number of mesh points: **23 x 2 = 46**
- time step c⊿t = 0.3 fm
- ⊿x = 0.91 fm
- initial separation **: 21 fm**

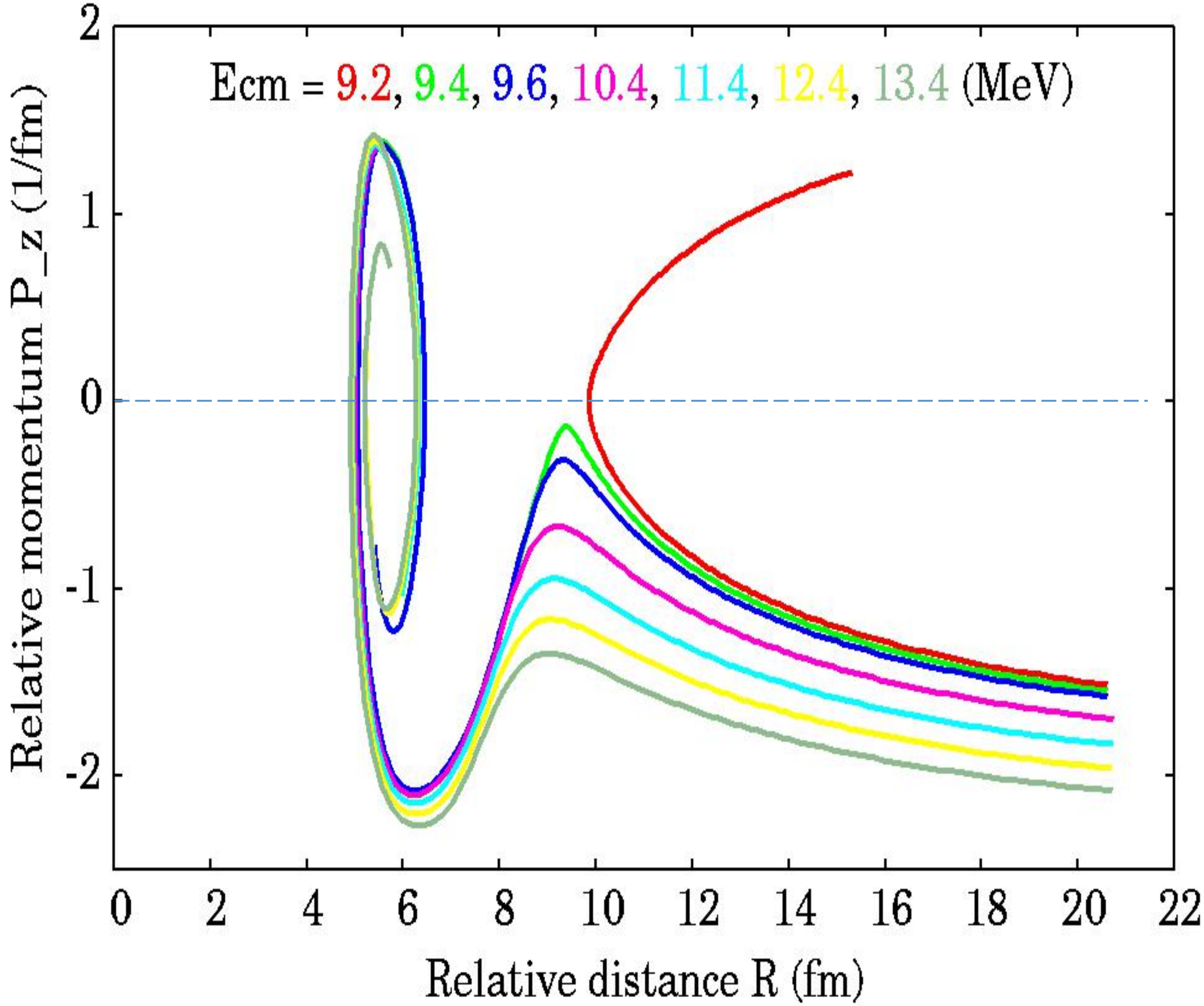


≪ frozen density potential≫





≪ Phase space：relative distance R and relative momentum P_Z ≫



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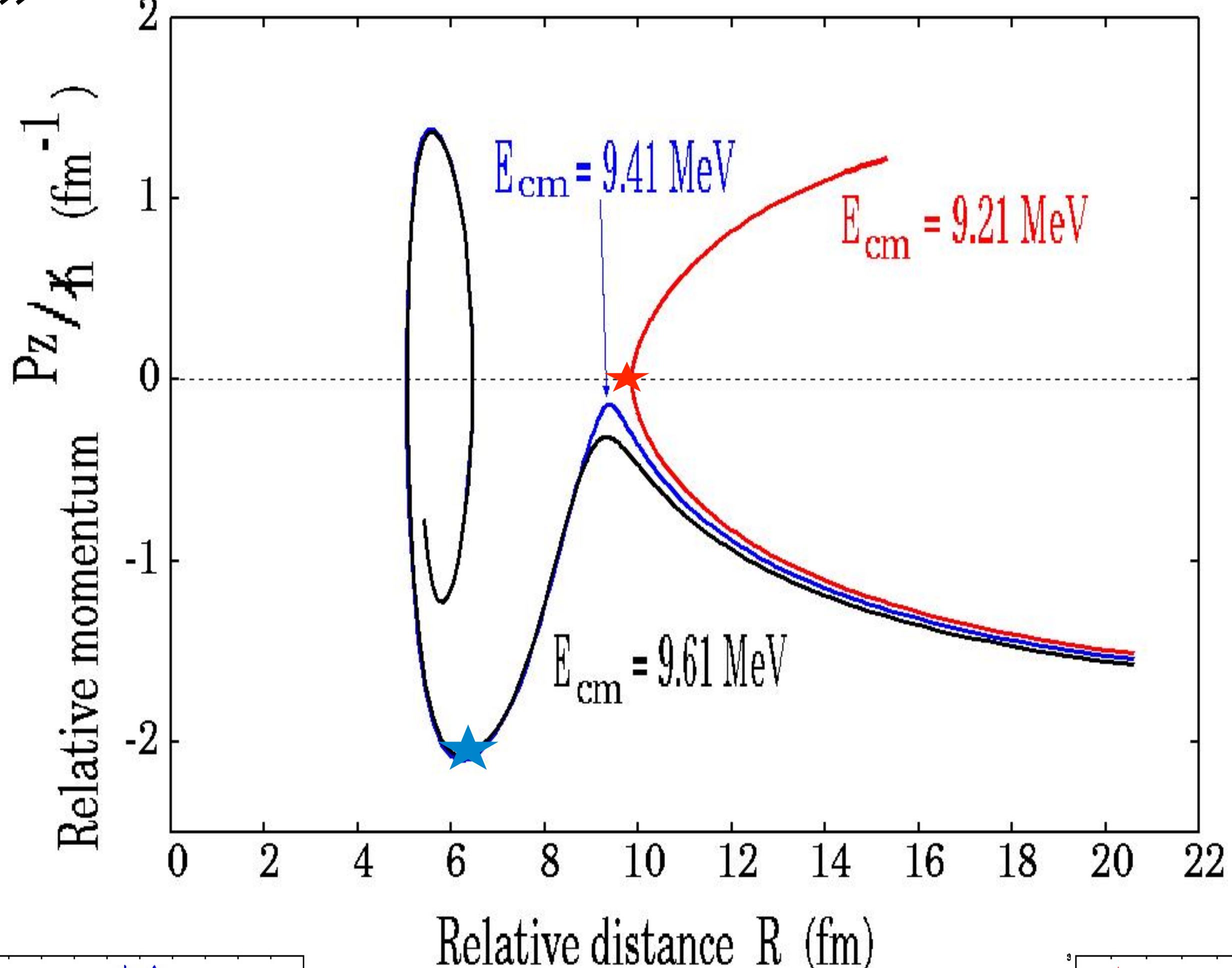
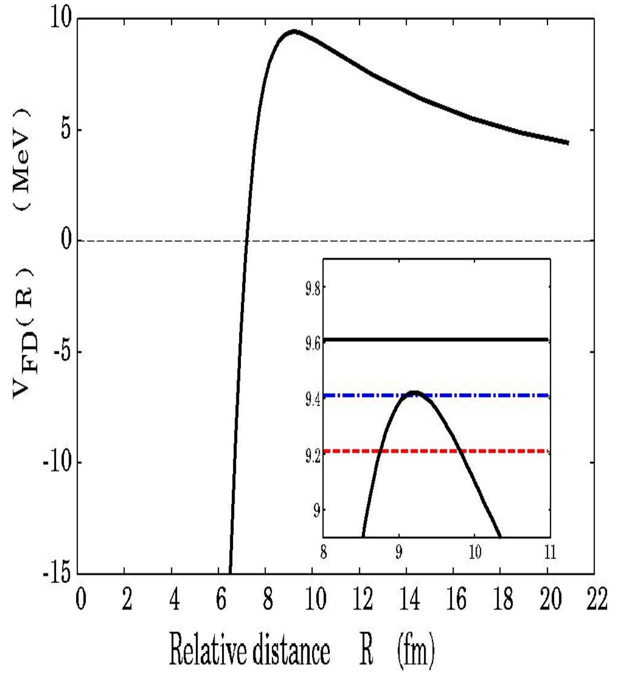
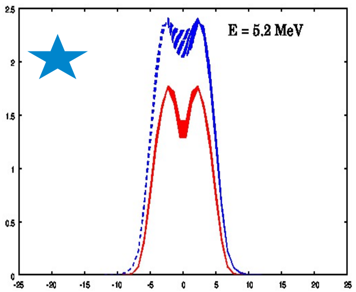
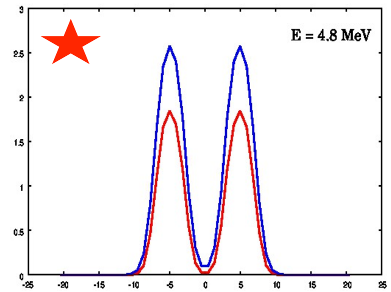
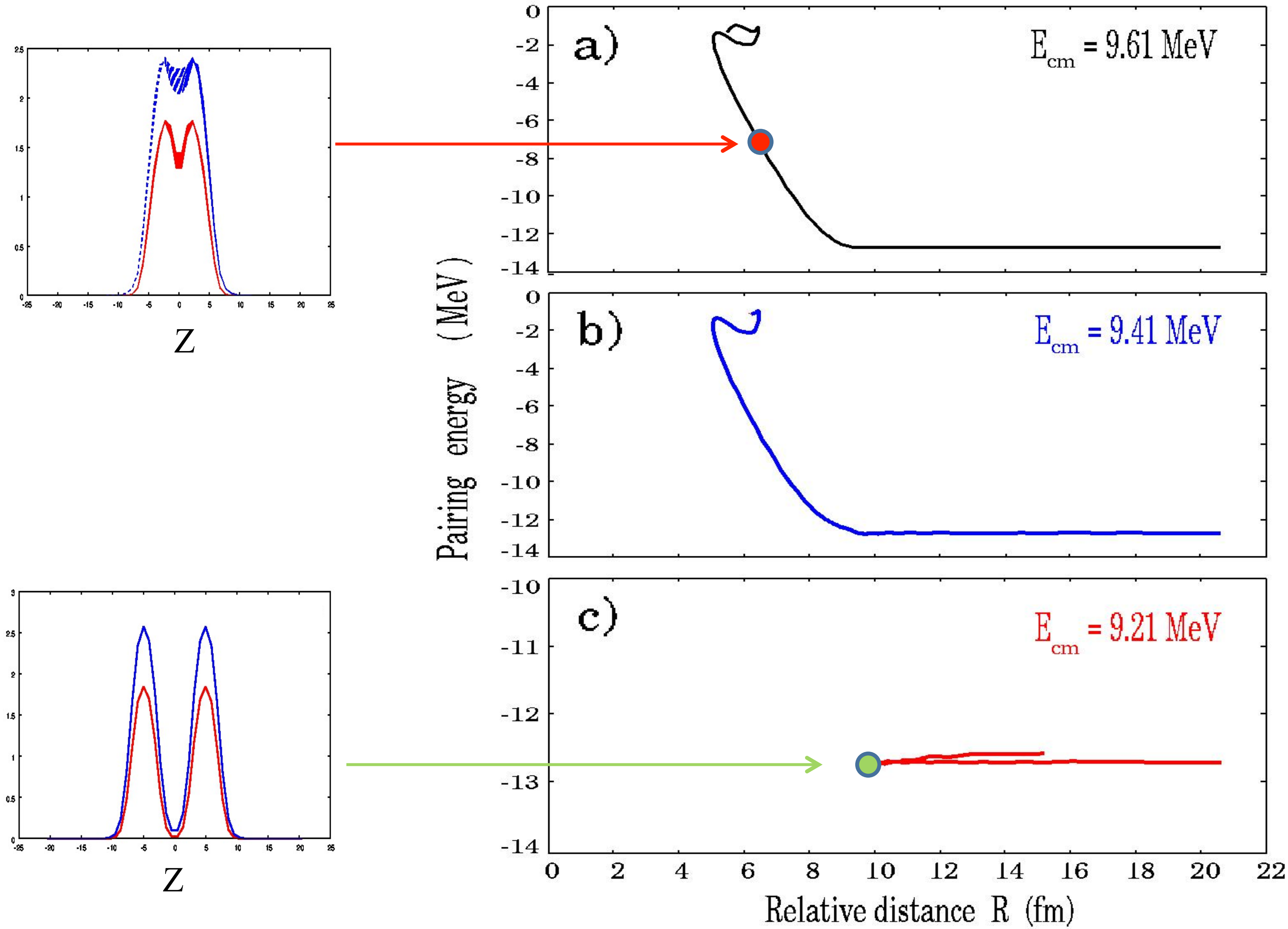




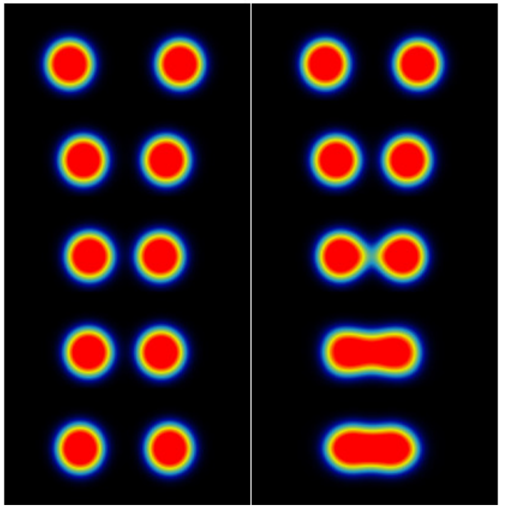




≪ Pairing energies vs relative distance ≫



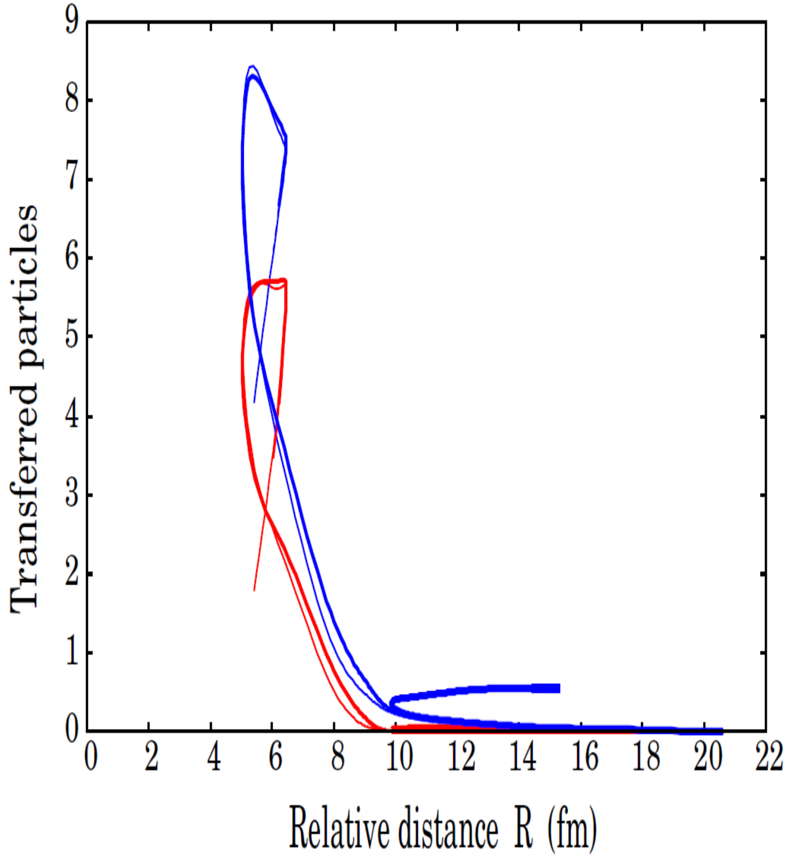
≪ Number of transferred particles ≫

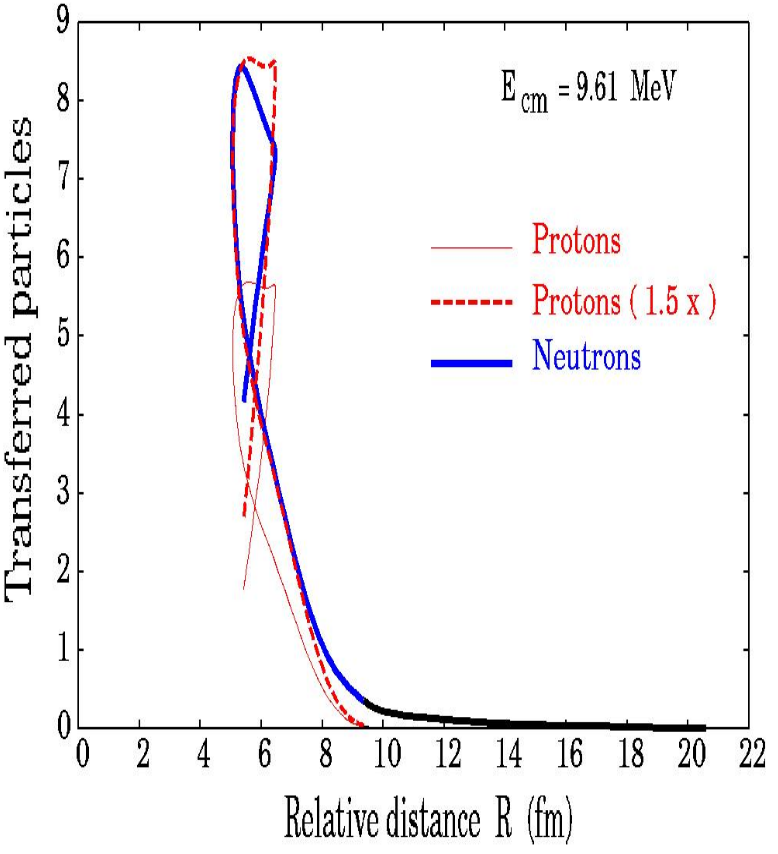


$$N^P_{\text{trans}}\left[R(t)\right] = \int d^3x \rho_P(\mathbf{r},t)\theta(x)$$

$$\rho_{P/T}(\mathbf{r},t) = \sum_{i\in P/T} |\phi_i(\mathbf{r},t)|^2$$

Eq. (3) in
K. Washiyama, D. Lacroix,
and S.Ayik, PRC79 024609(2009)





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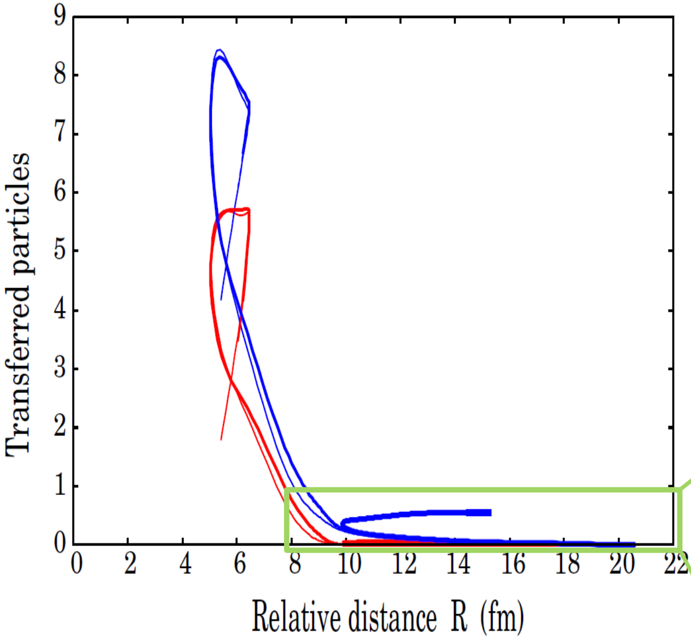
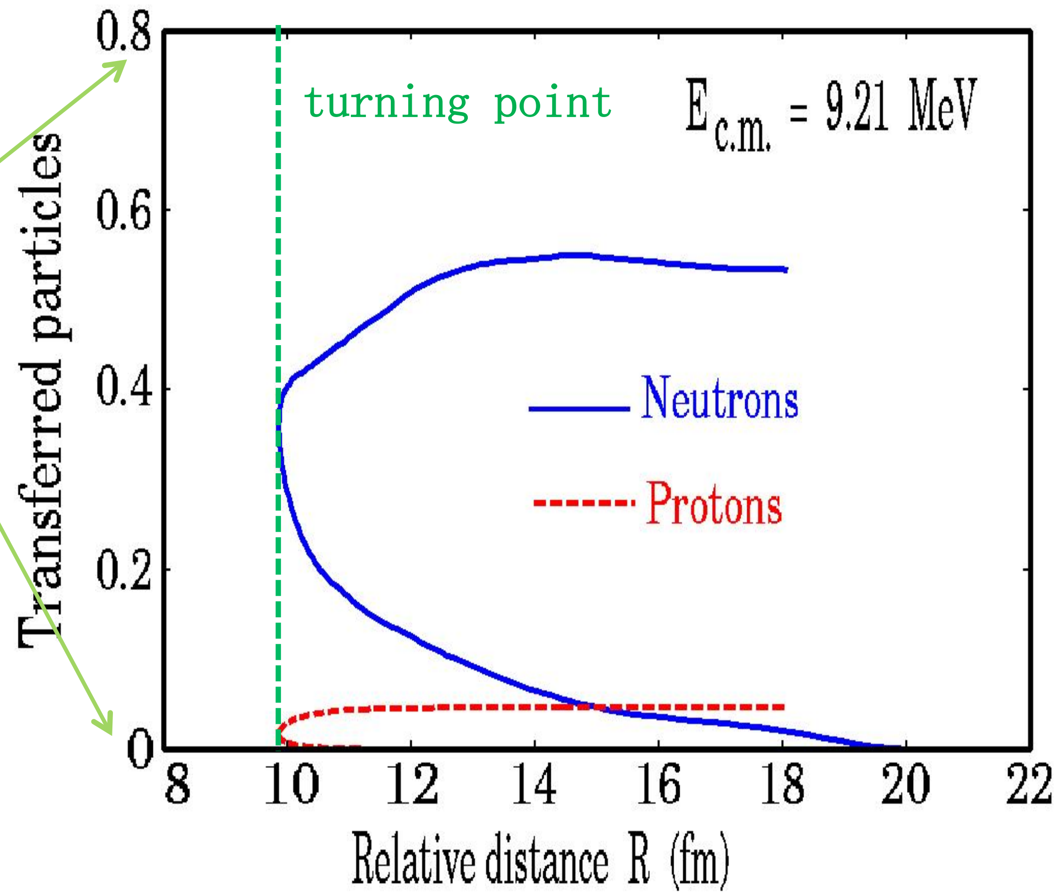
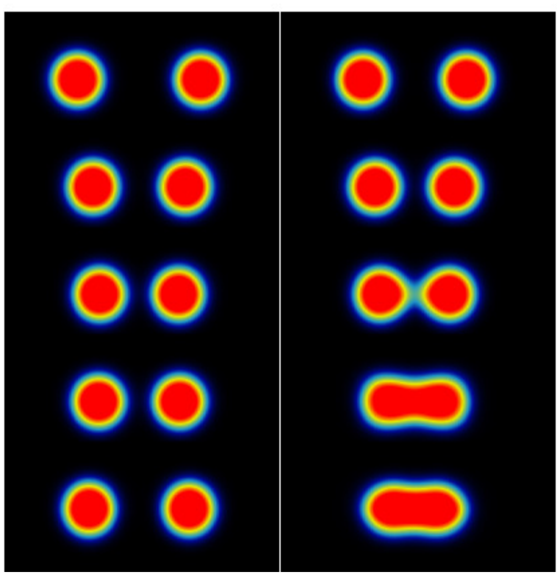






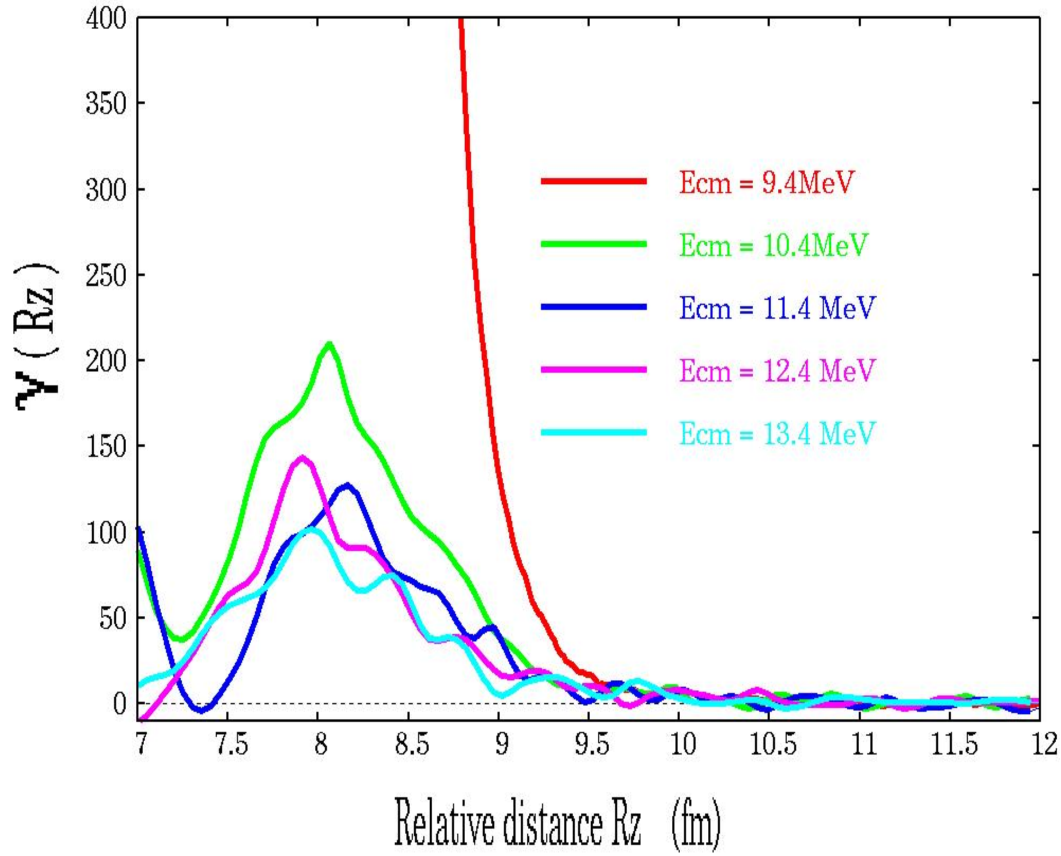
≪ Friction coefficient γ (R) ≫

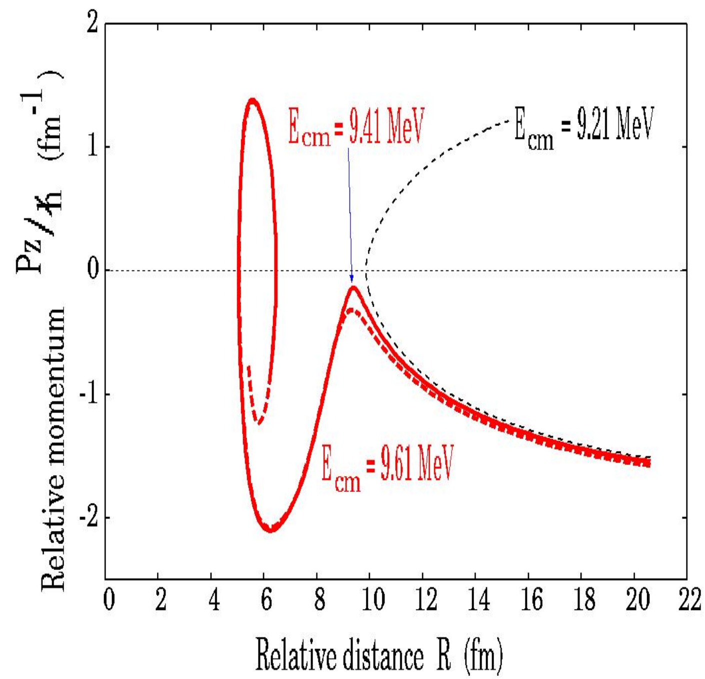
$$\frac{dR}{dt} = \frac{P}{\mu},$$
$$\frac{dP}{dt} = -\frac{dV}{dR} - \frac{d}{dR}\left(\frac{P^2}{2\mu}\right) - \gamma(R)\dot{R}$$

⇒

$$\gamma(R) = -\frac{\left[\dot{P}_I\right]_{R_I=R} - \left[\dot{P}_{II}\right]_{R_{II}=R}}{\left[\dot{R}_I\right]_{R_I=R} - \left[\dot{R}_{II}\right]_{R_{II}=R}}$$

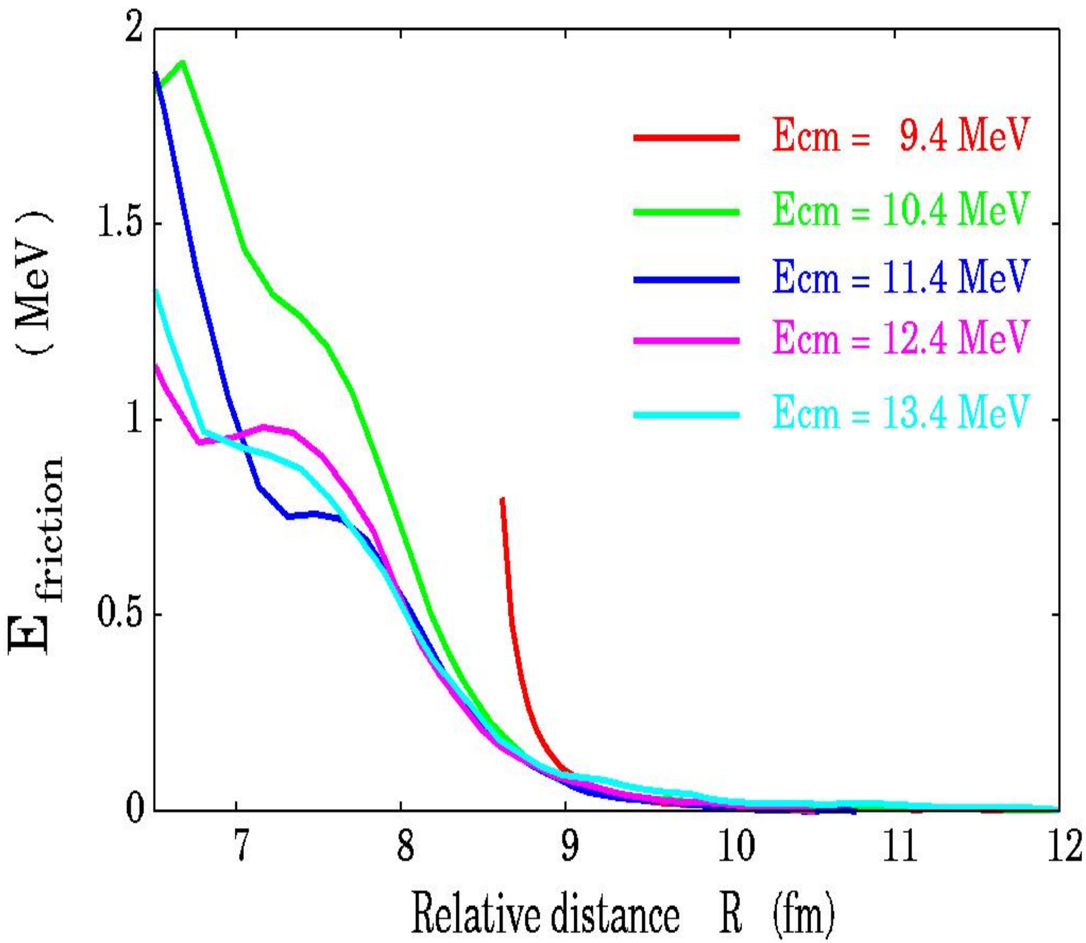
Eq.(9) in PRC78, 024610(2008)
by Washiyama & Lacroix

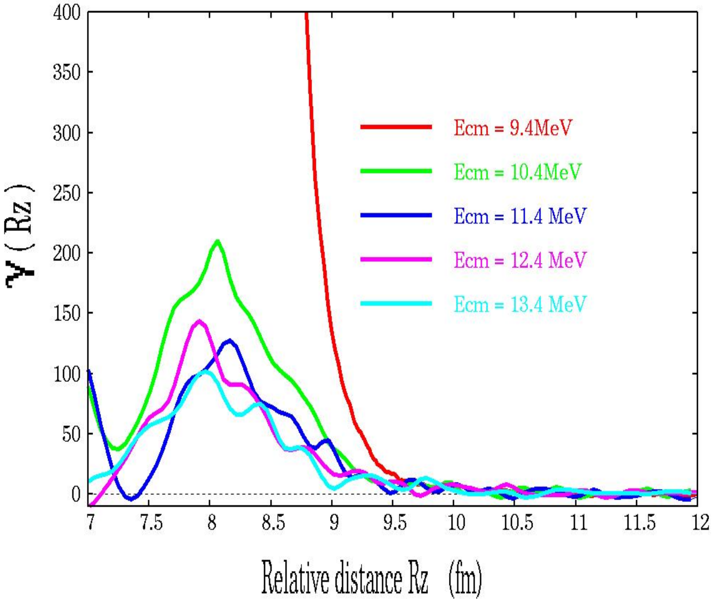




≪ energy dissipation ≫

$$E_{\mathrm{friction}}(t) = \int_0^t \gamma(t)\ \dot{R}(t)^2\ dt$$





4. Summary

i) Gogny-TDHFB calculation of $^{20}O + ^{20}O$ head-on collisions.

ii) Friction coefficient γ(R), number of transferred particles, change of pairing energy, and so on are presented.

iii) γ(R) will be calculated in the combinations as

1) $^{20}O + ^{20}O$,

2) $^{16}O + ^{20}O$ (no pairing + pairing),

3) $^{20}O + ^{34}Mg$ (spherical + deformed),

and in more larger systems.

iv) Combinations of nuclei with finite impact parameter.

v) Refined method of calculating the numbers of transferred nuclei.

- ***Many thanks to***

  G. Scamps san and K. Washiyama san

  for their discussions and comments.