Group Meeting 11.28

COMPLEX-SCALED CDCC METHOD FOR NUCLEAR BREAKUP REACTIONS

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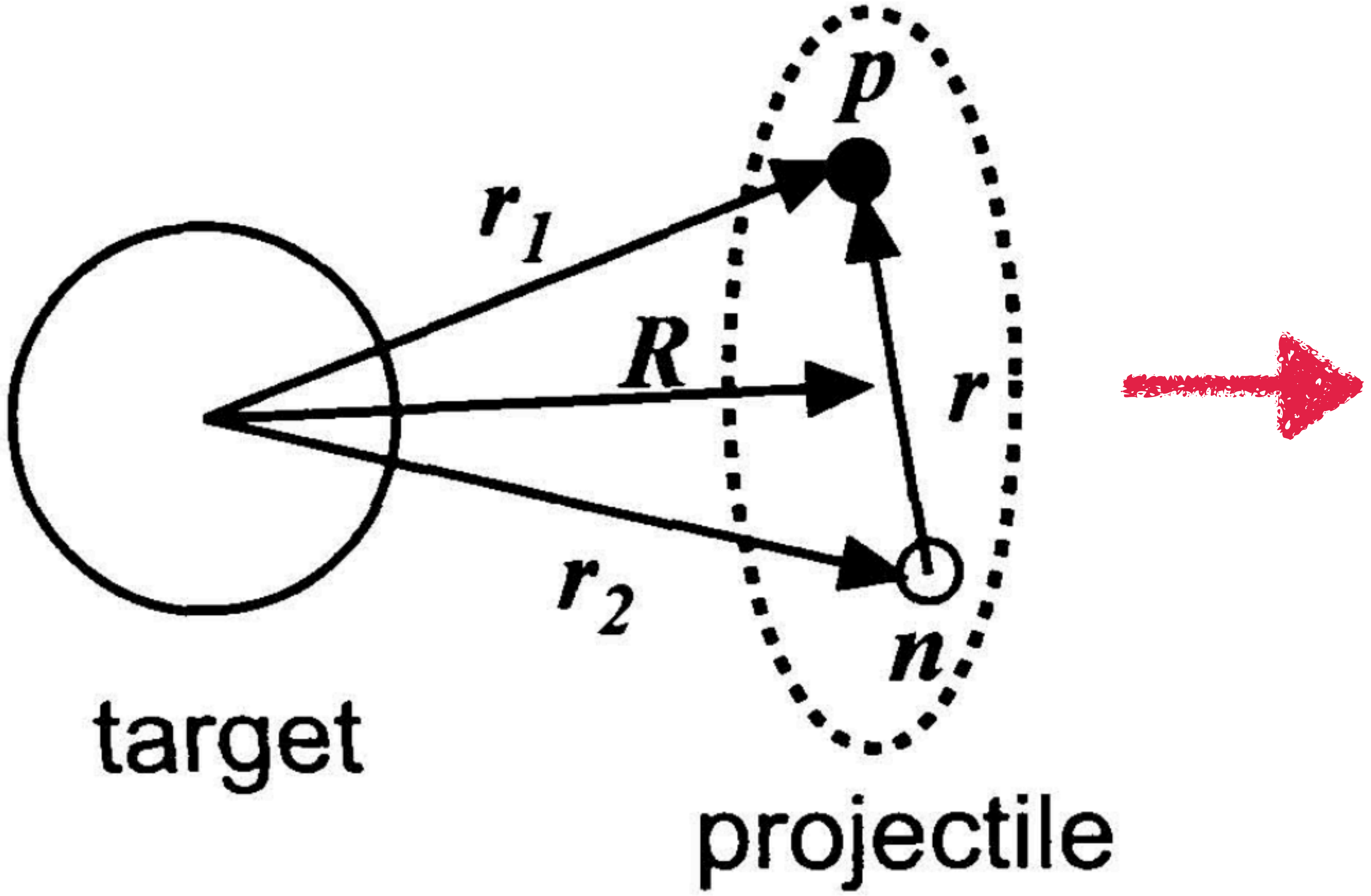
Zetian Ma

CSCDCC

In this article, they only apply the Complex Scaling (CS) method in the projectile.



$$\begin{cases} h = T_{\mathbf{r}} + V(\mathbf{r}) \\ h\varphi_\alpha = \varepsilon_\alpha \varphi_\alpha \\ h^\theta = U(\theta) h U^{-1}(\theta) \\ h^\theta \varphi_\alpha^\theta = \varepsilon_\alpha^\theta \varphi_\alpha^\theta \end{cases}$$

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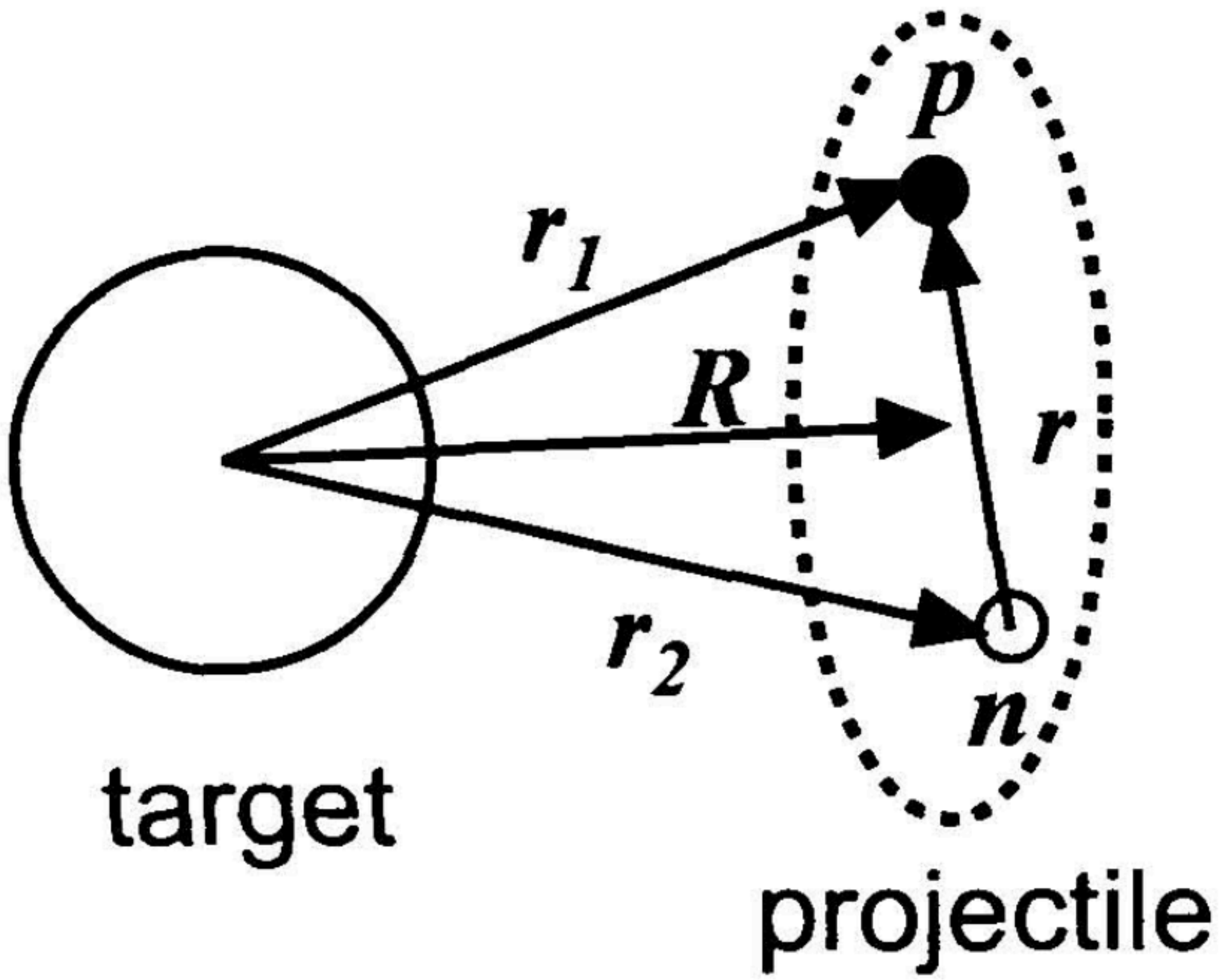
The rotated operator $U(\theta)$ only affects on $\mathbf{r}$.



$$\sum_{\alpha,\beta} \left\langle \left[\varphi_\alpha(\mathbf{r}) \otimes y_{L_\alpha}(\hat{\mathbf{R}})\right]_{JM} \right| \left[\left(T - \left(E - \varepsilon_\alpha\right) + V\right)\right] \times \left| \left[\varphi_\beta(\mathbf{r}) \otimes y_{L_\beta}(\hat{\mathbf{R}})\right]_{JM} \right\rangle \left\langle \left[\varphi_\beta(\mathbf{r}) \otimes y_{L_\beta}(\hat{\mathbf{R}})\right]_{JM} | \Psi \right\rangle = 0$$

$$\sum_{\alpha,\beta} \left\langle \left[\varphi_\alpha(\mathbf{r}) \otimes y_{L_\alpha}(\hat{\mathbf{R}})\right]_{JM} \right| U^{-1}(\theta)U(\theta) \left[\left(T - \left(E - \varepsilon_\alpha\right) + V\right)\right] \times U^{-1}(\theta)U(\theta) \left| \left[\varphi_\beta(\mathbf{r}) \otimes y_{L_\beta}(\hat{\mathbf{R}})\right]_{JM} \right\rangle \left\langle \left[\varphi_\beta(\mathbf{r}) \otimes y_{L_\beta}(\hat{\mathbf{R}})\right]_{JM} | \Psi \right\rangle = 0$$

$$\sum_{\alpha,\beta} \left\langle \left[\varphi^\theta_\alpha(\mathbf{r}) \otimes y_{L_\alpha}(\hat{\mathbf{R}})\right]_{JM} \right| U(\theta) \left[\left(T - \left(E - \varepsilon_\alpha\right) + V\right)\right] \times U^{-1}(\theta) \left| \left[\varphi^\theta_\beta(\mathbf{r}) \otimes y_{L_\beta}(\hat{\mathbf{R}})\right]_{JM} \right\rangle \left\langle \left[\varphi_\beta(\mathbf{r}) \otimes y_{L_\beta}(\hat{\mathbf{R}})\right]_{JM} | \Psi \right\rangle = 0$$

CSCDCC

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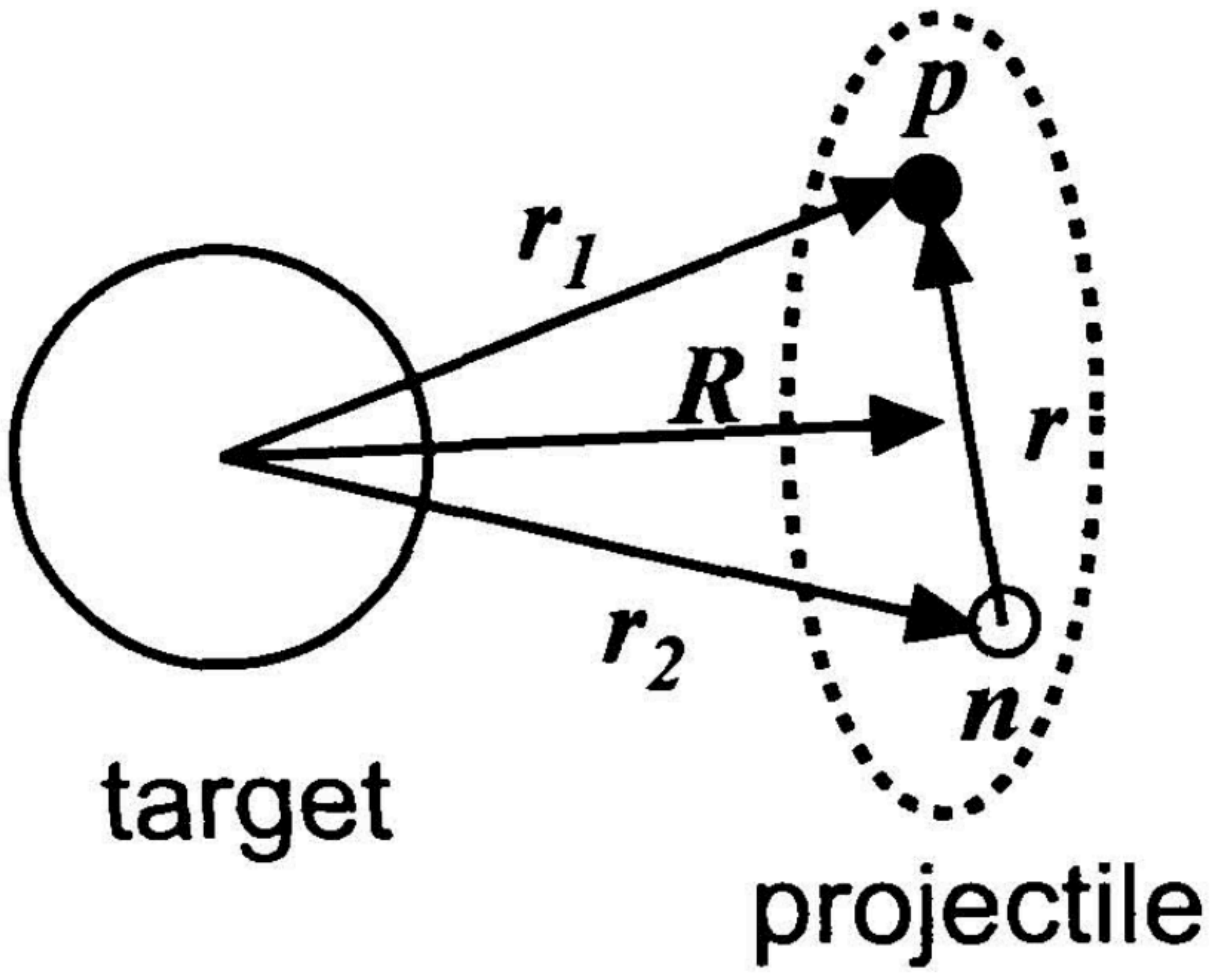

$$\sum_{\alpha,\beta} \left\langle \left[\varphi_\alpha^\theta(\mathbf{r}) \otimes y_{L_\alpha}(\hat{\mathbf{R}}) \right]_{JM} \right| U(\theta) \left[\left(T - \left(E - h_\alpha \right) + V \right) \right]$$

$$\times U^{-1}(\theta) \left| \left[\varphi_\beta^\theta(\mathbf{r}) \otimes y_{L_\beta}(\hat{\mathbf{R}}) \right]_{JM} \right\rangle \left\langle \left[\varphi_\beta(\mathbf{r}) \otimes y_{L_\beta}(\hat{\mathbf{R}}) \right]_{JM} | \Psi \right\rangle = 0$$

$$\left[\left(T - \left(E - \varepsilon_\alpha^\theta \right) \right) \right] \chi_\alpha^{(J)\theta}(R) = - \sum_{\beta \neq \alpha} F_{\alpha,\beta}^{(J)\theta}(R) \chi_\beta^{(J)\theta}(R) .$$

$$F_{\alpha,\beta}^{(J)\theta}(R) = \left\langle \left[\varphi_\alpha^\theta(\mathbf{r}) \otimes y_{L_\alpha}(\hat{\mathbf{R}}) \right]_{JM} \right| U(\theta) \left[V_1\left(r_1 \right) + V_2\left(r_2 \right) \right]$$

$$\times U^{-1}(\theta) \left| \left[\varphi_\beta^\theta(\mathbf{r}) \otimes y_{L_\beta}(\hat{\mathbf{R}}) \right]_{JM} \right\rangle .$$

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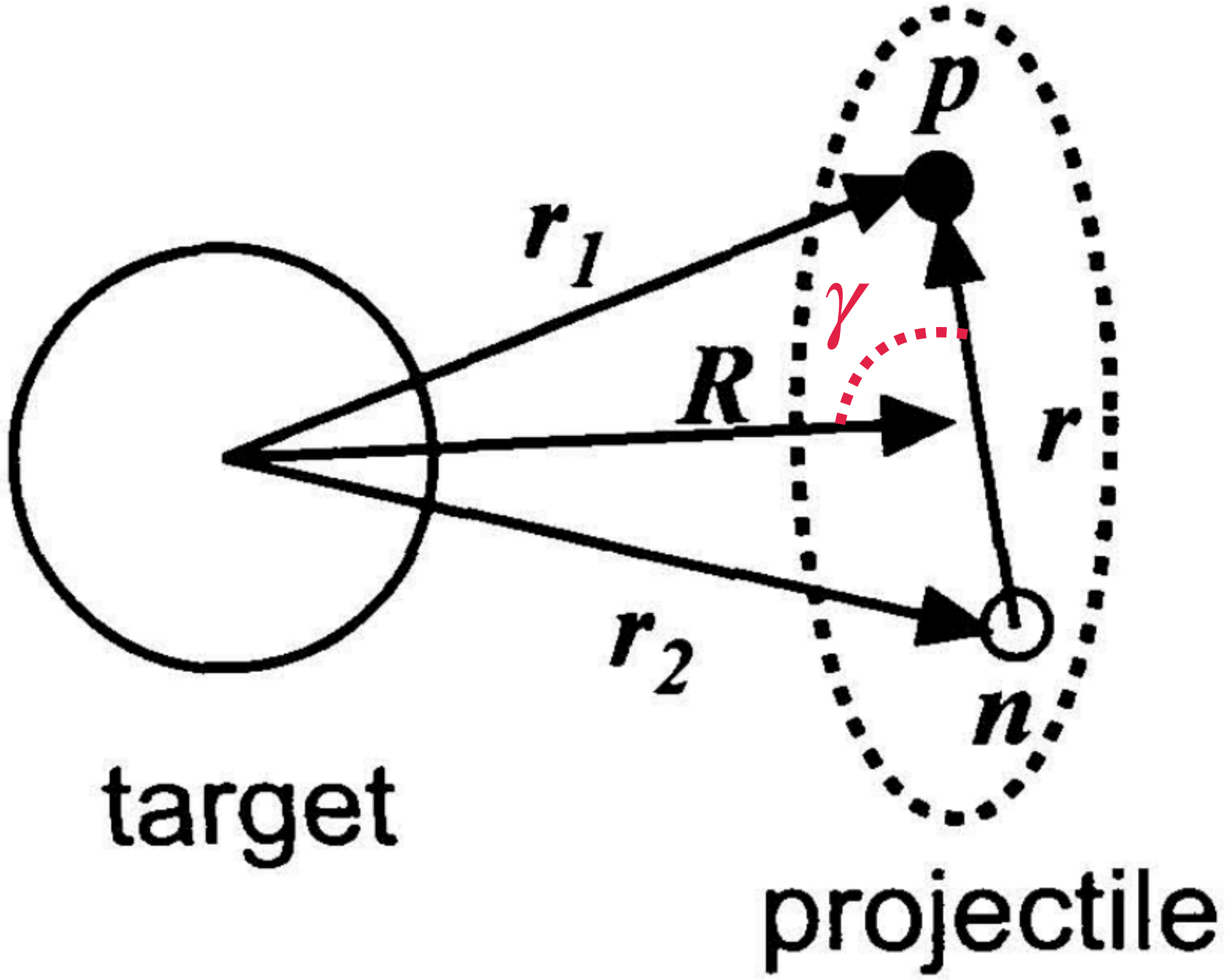
In the coupling potential, there may be some problems when r becomes complex.



$$F_{\alpha,\beta}^{(J)\theta}(R) = \left\langle \left[\varphi_\alpha^\theta(\mathbf{r}) \otimes y_{L_\alpha}(\hat{\mathbf{R}})\right]_{JM} \middle| U(\theta)\left[V_1(r_1) + V_2(r_2)\right] \right.$$
$$\left. \times U^{-1}(\theta) \middle| \left[\varphi_\beta^\theta(\mathbf{r}) \otimes y_{L_\beta}(\hat{\mathbf{R}})\right]_{JM} \right\rangle .$$

In the integral, the angle γ couldn't be gotten from the law of cosine. They may use the multi-expansion here.

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With the boundary condition, the relative wave function is written by,

$$\chi_{\alpha}^{(J)\theta}(R) \to \left[\delta_{\alpha 0} u_{L_0}^{(-)}\left(K_0 R\right) - \sqrt{\frac{v_0}{v_{\alpha}^{\theta}}} S_{\alpha 0}^{(J)\theta} u_{L_\alpha}^{(+)}\left(K_{\alpha}^{\theta} R\right)\right]$$

Project onto the real energy ε

$$\left|S^{(J)}(\varepsilon)\right|^2 = \frac{1}{\pi} \mathscr{I}m \left[\sum_{\alpha} \frac{\tilde{S}_{\alpha 0}^{(J)\theta *} S_{\alpha 0}^{(J)\theta}}{\varepsilon_{\alpha}^{\theta} - \varepsilon}\right]$$

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The result is very close to the PS-CDCC.

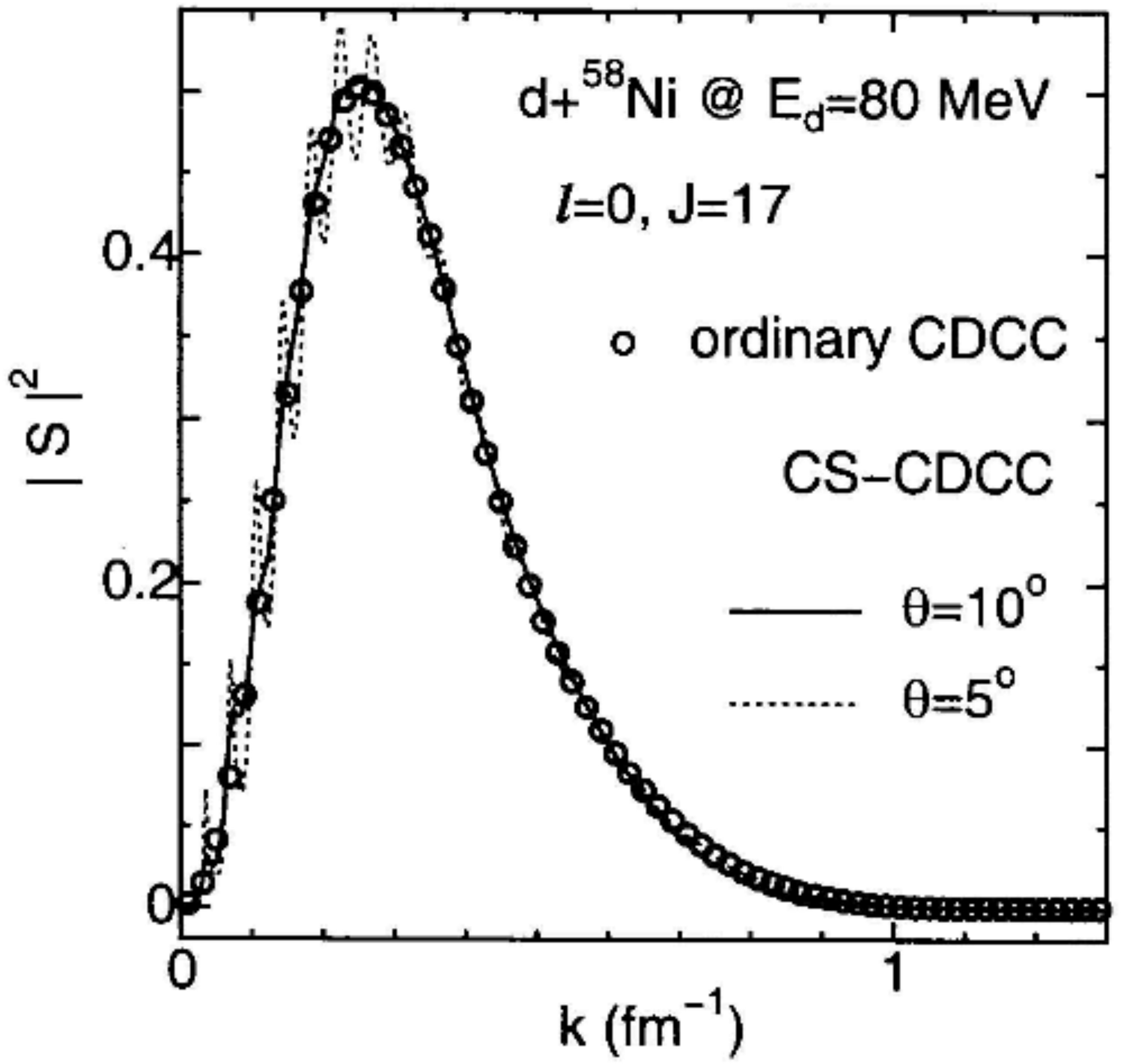

Fig. 2. Squared modulus of S matrix element as a function of k.

Method

In another paper, they introduced the CS to solve the coupled channel problem.

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Three-body model analysis of $\alpha + d$ elastic scattering and the $^2H(\alpha,\gamma)^6Li$ reaction in complex-scaled solutions of the Lippmann-Schwinger equation

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We investigate the $\alpha + d$ elastic scattering and the radiative capture reaction of $^2H(\alpha,\gamma)^6Li$ based on the $\alpha + p + n$ three-body model. The $\alpha + d$ scattering states are described by using the complex-scaled solutions of the Lippmann-Schwinger equation. We calculate the elastic phase shifts for the $\alpha + d$ scattering and the radiative capture cross section of ^6Li. We evaluate the contributions of the $\alpha + p + n$ structures in those observables. It is found that in the $\alpha + d$ scattering process, the deuteron breakup and the rearrangement to the $^5He + p$ and $^5Li + n$ channels play prominent roles in reproducing the observed phase shifts and radiative capture cross section.

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Continuum Level Density of a Coupled-Channel System in the Complex Scaling Method

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We study the continuum level density (CLD) in the formalism of the complex scaling method (CSM) for coupled-channel systems. We apply the formalism to the $^4He = [^3H+p] + [^3He+n]$ coupled-channel cluster model where there are resonances at low energy. Numerical calculations of the CLD in the CSM with a finite number of L^2 basis functions are consistent with the exact result calculated from the S-matrix by solving coupled-channel equations. We also study channel densities. In this framework, the extended completeness relation (ECR) plays an important role.

Method

They treated different channels like this.

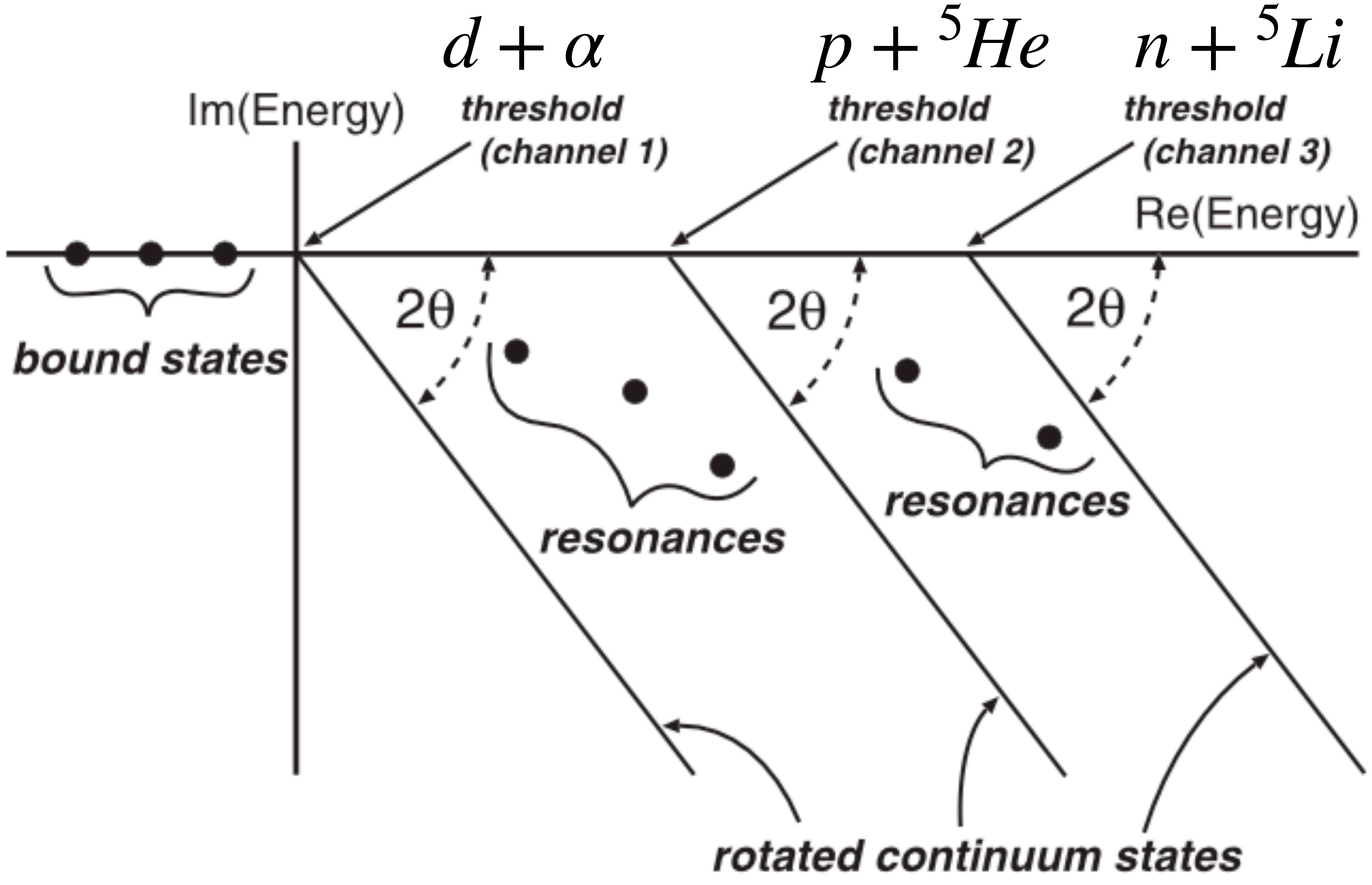

Fig. 1. Schematic energy eigenvalue distribution of a complex scaled Hamiltonian.