LIÈGE INTRANUCLEAR CASCADE MODEL

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PHYSICAL REVIEW C 66, 044615 (2002)

PHYSICAL REVIEW C 87, 014606 (2013)

PHYSICAL REVIEW C 90, 054602 (2014)

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Outline

General hypothesis

Initialization

General workflow

General hypothesis

$$\boxed{\lambda/2\pi} << \boxed{d} < \boxed{\Lambda} < \boxed{R}$$

reduced de Broglie wavelength

distance

mean free path

radius

$\lambda/2\pi << d$: The size of the wave packet describing the particle is much lower than the distance. So all nucleons appear distinct and well defined in momenta and positions for the incoming projectile. This means a classical treatment of the particles propagation.

$\lambda/2\pi < \Lambda$: The scattered wave reaches its asymptotic state before the next interaction and interactions can be treated in a classical approach.

$d < \Lambda$: Interactions are **independent** from each other (assuming that the time between two collisions is larger than the interaction time scale). Interactions and transport can be treated independently.

$\Lambda < R$: The possible interferences between the scattered waves **cancel out** due to the large number of interactions.

General hypothesis

$$\boxed{\lambda/2\pi} << \boxed{d} < \boxed{\Lambda} < \boxed{R} \xrightarrow{\text{limit}}$$

much lower energy ×

high energy ×

reduced de Broglie wavelength

distance

mean free path

radius

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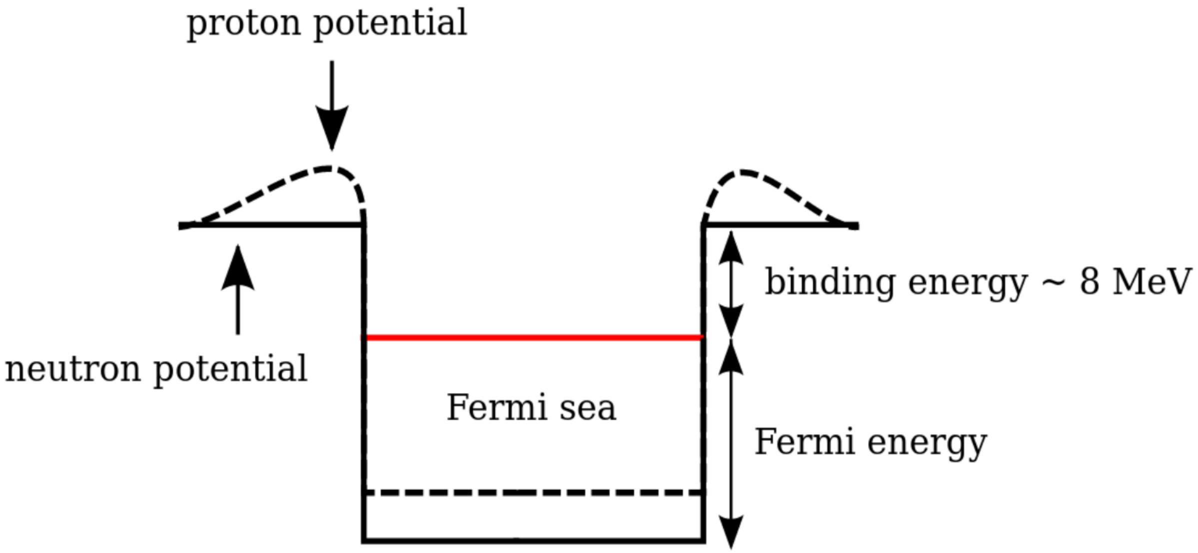
Initialization

Initialize projectile : An impact parameter (b) is assigned at **random**, which undergoes adjustments due to the **Coulomb force**. When the projectile penetrates the target nucleus, its energy is adjusted based on the **nuclear potential**.

Initialize target nucleus : 1) Sample the momentum for each nucleons which satisfies uniformly distributed with a maximum (Fermi momentum)

$$p_F = \left(\frac{9\pi}{8}\right)^{1/3} \frac{\hbar}{r_0} \qquad\qquad E_F = p_F^2/2M$$

potential well for neutrons and protons :



Initialization

Initialize target nucleus : 2) Sample the position for each nucleons in a Monte-Carlo way

$$\rho = \begin{cases} \dfrac{\rho_0}{1+\exp\left(\frac{r-R_0}{a}\right)}, & A > 19 \quad \text{Woods-Saxon distribution} \\ \rho_0 \dfrac{1+\alpha\left(\frac{r^2}{a^2}\right)}{\exp\left(\frac{r^2}{a^2}\right)}, & 6 < A \leq 19 \quad \text{Harmonic-oscillator distribution} \\ \dfrac{\rho_0}{\exp\left(\frac{r^2}{a^2}\right)}, & A \leq 6 \quad \text{Gaussian density distributions} \end{cases}$$

ρ_0 : nucleon density constant

R_0 : averaged radius of nucleus $r_0 A^{1/3}$

$r_0 \approx 1.25 fm$

a : skin depth of nuclear

Limit of volume : $R_{max} = R_0 + 8a$

General workflow

Participants and Spectators

Why ? → "spontaneous Fermi sea boiling"

interaction and exchange energy in the nucleus

⬇

gaining momentum beyond the Fermi level

⬇

some nucleons leave a stable nucleus

General workflow

Participants and Spectators

1) Only projectile particles are particles

2) Spectator nucleons are, limiting interactions only between **participant-participant** and **spectator-participant** nucleons.

3) As interactions occur, a spectator nucleon that interacts with a participant becomes a participant itself, along with any new particles formed.

4) If a participant nucleon’ s energy drops below a **threshold**, it will become a spectator

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randomly

7 MeV

General workflow

Binary cascade

a three-step cycle :

1) Particles within the nucleus are advanced until a pair collisions; multi-particle aren’ t accommodated, except for the **Pauli blocking**. In the INCL framework, a collision is recognized when the distance drops below **the minimum approach distance** derived from their total interaction cross-sections, defined as $d_{min} = \sqrt{(\sigma_{tot}/\pi)}$;

2) To address binary collisions, selecting the kind of the impending binary collision **randomly**, based on pertinent **reaction cross-sections**, for example, the reaction NN → NNπ;

3) Creating the phase space and the charge distribution of particles in the end state.

General workflow

Binary cascade

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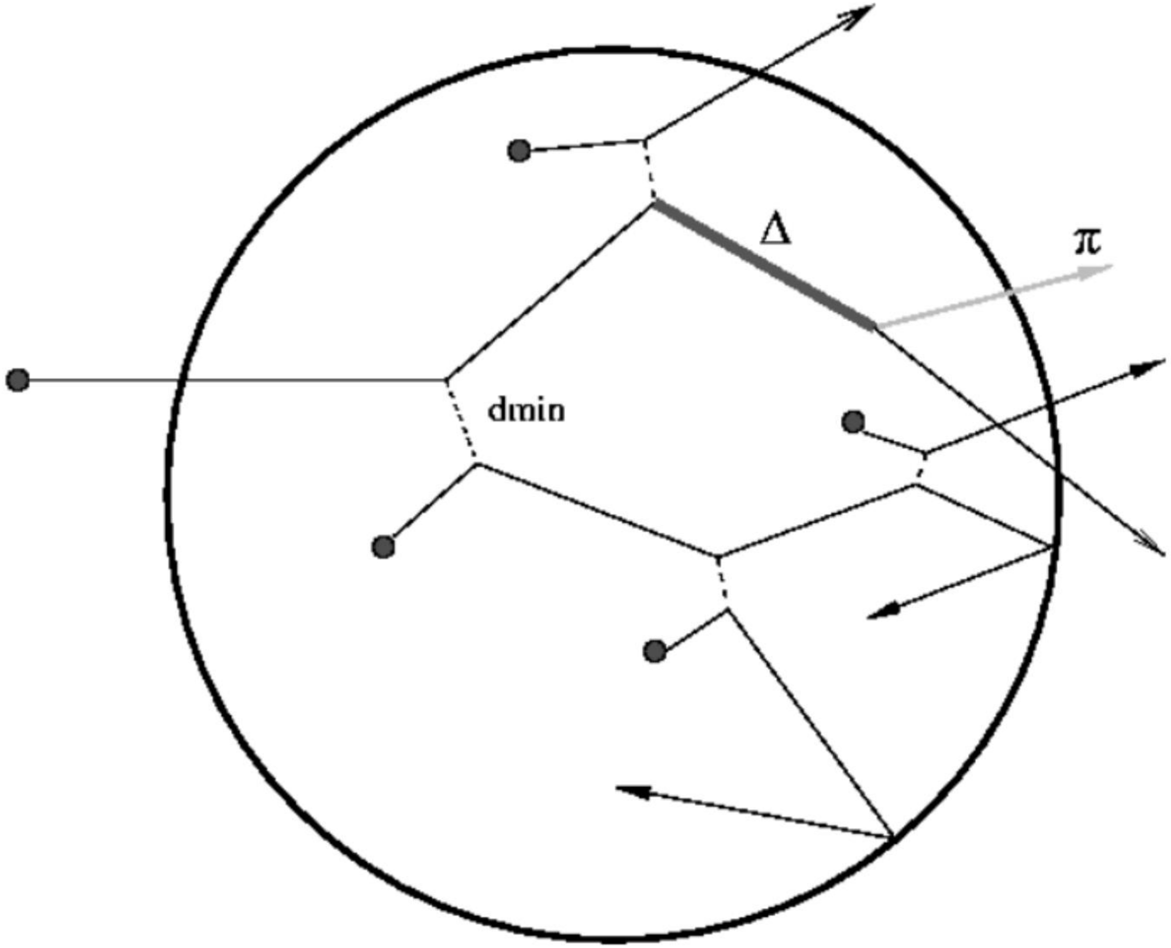

Representation of an intranuclearcascade

General workflow

Pauli blocking   Avoid producing states prohibited by the Pauli principle

two Pauli-blocking tests :

1) Appling to all interactions **except the initial one.** This test monitors the existence of similar nucleons in the final state of an interaction within **a defined phase space** (with Δr = 3.185 fm and Δp = 200 MeV/c), the phase-space occupation probabilities f_i are evaluated by counting nearby nucleons in a small phase-space volume :

$$f_i = \frac{1}{2} \frac{(2\pi\hbar)^3}{\frac{4\pi}{3} r_{PB}^3 \frac{4\pi}{3} p_{PB}^3} \sum_{k \neq i} \theta(r_{PB} - |\vec{r}_k - \vec{r}_i|)$$

$$\times \theta(p_{PB} - |\vec{p}_k - \vec{p}_i|),$$

The collision between i and j nucleons is allowed or forbidden following the comparison of a random number with the product $(1-f_i)(1-f_j)$

General workflow

Pauli blocking Avoid producing states prohibited by the Pauli principle

two Pauli-blocking tests :

2) Applicable to all collisions, checks for vacancies in the Fermi sea that could cause the nucleus to have **negative excitation energy**.

Both tests should be negative in order for the interaction to occur.

General workflow

Cascade stopping

If all energetic particles are emitted and only those with **low momenta** are still wandering around reflecting from the surface, they set certain value of time period:

$$t_{stop} = 29.8 \times A_T^{0.16}$$

A: the initial baryonic number of the target nucleus.

Also the cascade will stop if no nucleus-contained particle exceeds the Fermi energy by **at least 10 MeV** in order to optimizing computation time

Deexcitation

Thanks!