Light nuclei production from nonlocal many-body scatterings

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arXiv:2106.12742(2021)

A novel approach

Impulse approximation (IA):

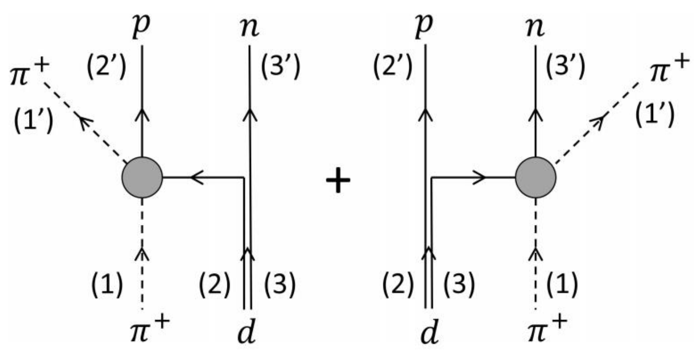


FIG. 1. Diagrams for the reaction $\pi^+ d \leftrightarrow \pi^+ np$ in the impulse approximation. The filled bubble indicates the intermediate states such as a Δ resonance.

Relativistic kinetic equation for $\pi NN \leftrightarrow \pi d$

$$\frac{\partial f_d}{\partial t} + \frac{\mathbf{P}}{E_d} \cdot \frac{\partial f_d}{\partial \mathbf{R}} = -\mathcal{K}^{>} f_d + \mathcal{K}^{<}(1+f_d)$$

with collision integral:

$$\text{R.H.S.} = \frac{1}{2g_d E_d} \int \prod_{i=1'}^{3'} \frac{\mathrm{d}^3\mathbf{p}_i}{(2\pi)^3 2E_i} \frac{\mathrm{d}^3\mathbf{p}_\pi}{(2\pi)^3 2E_\pi} \frac{E_d \mathrm{d}^3\mathbf{r}}{m_d}$$
$$\times 2m_d W_d(\tilde{\mathbf{r}}, \tilde{\mathbf{p}}) \left(\overline{|\mathcal{M}_{\pi^+ n \to \pi^+ n}|^2} + n \leftrightarrow p \right)$$
$$\times \Big[-\Big(\prod_{i=1'}^{3'} (1 \pm f_i) \Big) g_\pi f_\pi g_d f_d + \frac{3}{4} \Big(\prod_{i=1'}^{3'} g_i f_i \Big)$$
$$\times (1+f_\pi)(1+f_d) \Big] \times (2\pi)^4 \delta^4(p_{\text{in}} - p_{\text{out}})$$

Nonlocal collision integral to take into account of finite nuclei size.
W_d denotes deuteron Wigner function.

Solving kinetic equations with the stochastic method

Relativistic kinetic equation for $\pi NN \leftrightarrow \pi d$

$$\frac{\partial f_d}{\partial t} + \frac{\mathbf{P}}{E_d} \cdot \frac{\partial f_d}{\partial \mathbf{R}} = -\mathcal{K}^{>} f_d + \mathcal{K}^{<}(1 + f_d)$$

with nonlocal collision integral:

$$\text{R.H.S.} = \frac{1}{2g_d E_d} \int \prod_{i=1'}^{3'} \frac{d^3\mathbf{p}_i}{(2\pi)^3 2E_i} \frac{d^3\mathbf{p}_\pi}{(2\pi)^3 2E_\pi} \frac{E_d d^3\mathbf{r}}{m_d} \times 2m_d W_d(\tilde{\mathbf{r}}, \tilde{\mathbf{p}}) \left(\overline{|\mathcal{M}_{\pi^+ n \to \pi^+ n}|^2} + n \leftrightarrow p\right) \times \Big[-\Big(\prod_{i=1'}^{3'}(1 \pm f_i)\Big) g_\pi f_\pi g_d f_d + \frac{3}{4}\Big(\prod_{i=1'}^{3'} g_i f_i\Big) \times (1 + f_\pi)(1 + f_d) \Big] \times (2\pi)^4 \delta^4(p_{\rm in} - p_{\rm out})$$

Stochastic method with test particles

Probability for reaction $\pi d \leftrightarrow \pi NN$ to take place in volume ΔV and time interval Δt are given by

$$P_{23}\big|_{\rm IA} \approx F_d v_{\pi^+ p} \sigma_{\pi^+ p \to \pi^+ p} \frac{\Delta t}{N_{\rm test} \Delta V} + (p \leftrightarrow n)$$

$$P_{32}\big|_{\rm IA} \approx \frac{3}{4} F_d v_{\pi^+ p} \sigma_{\pi^+ p \to \pi^+ p} \frac{\Delta t W_d}{N_{\rm test}^2 \Delta V} + (p \leftrightarrow n)$$

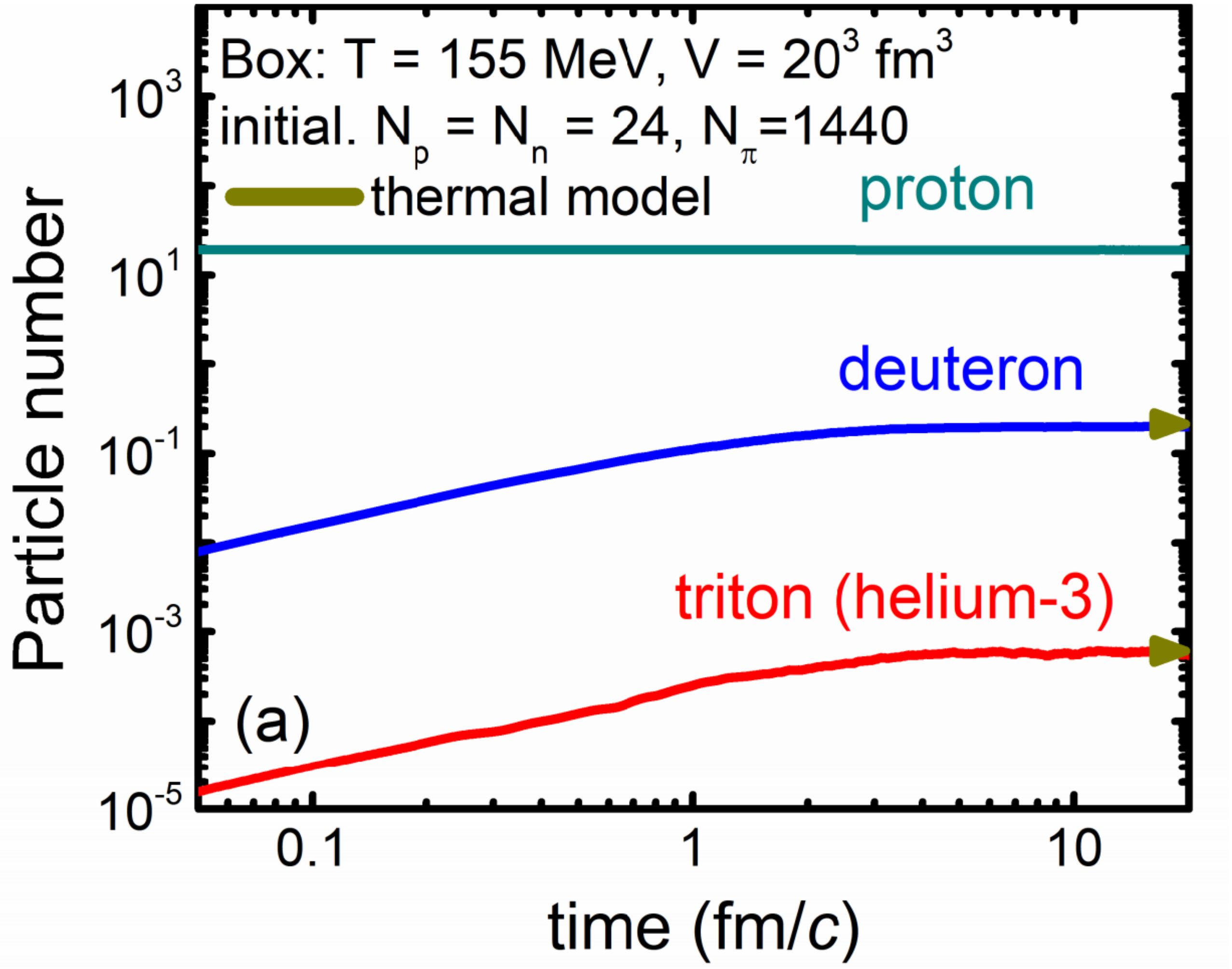
For triton or helium-3:

$$P_{42}\big|_{\rm IA} \approx \frac{1}{4} F_t \frac{v_{\pi N} \sigma_{\pi N \to \pi N} \Delta t}{N_{\rm test}^3 \Delta V} W_t$$

'renormalization' factor F_d, F_t

Validation in box calculation

Thermal limits are well reproduced



Results for high-energy nuclear collisions: