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THEORETICAL NUCLEAR PHYSICS

Momentum Distribution of Decay Products of $K^{-}ppn$

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Abstract

We have proposed a way to deduce the size of dense nuclear system $K^{-}ppn$ from momentum distribution of three-body decay products Λ, n and p. $K^{-}ppn$ system is a four-body system, but in this investigation it is assumed as $\Lambda^{*}pn$ where Λ^{*} is considered as a bound state of $K^{-}p$. In my research work, we calculated momentum distribution of decay products Λ, p and n of $\Lambda^{*}pn$. By observing these momentum distributions, the size, density and angular momentum of $\bar{K}$ cluster are predicted. We can compare the experimental data to the theoretical calculation by using the Dalitz's variables. In the decay process $\Lambda^{*}pn \rightarrow \Lambda pn$, we treat both the p-participant (neutron spectator) and the n-participant (proton spectator) cases on equal footing. When decay protons are detected, these protons cannot be distinguished as participant protons or spectator protons. Thus, when we analyze proton data, we have to take into account not only the participant process but also spectator one where the roles of neutron and proton are exchanged. By studying the momentum distribution of decay products of $\Lambda^{*}pn$, one can deduce the size of kaon cluster, its spin and parity.

Keyword: Momentum distribution, $\Lambda^{*}pn$, Invariant mass

1. Introduction

Exotic nuclear systems involving antikaon $\bar{K}(K^{-} \text{or} \bar{K}^{0})$ as a constituent having narrow decay widths and large binding energies are called kaonic nuclear clusters or deeply bound kaonic nuclear state. The hypothesis of deeply bound kaonic nuclear states was first proposed by Akaishi e*t.al* [1].

The g-matrix method was used to determine effective $\bar{K}N$ interaction in nuclear medium. Discrete $\bar{K}$-bound states in light nuclei such as ${}^{3}_{K}H$, ${}^{4}_{K}He$, ${}^{9}_{K}Li$ [1] were predicted. The K^{-} bound states have high-nucleon density, about three times of normal nuclear density ρ_0, which could provide information concerning a modification of the kaon mass and of the $\bar{K}N$ interaction in the nuclear medium.

The first experimental search of $\bar{K}$ clusters was performed at KEK by studying the ${}^{4}He(K^{-}_{stopped}, N)$ reactions. The mass S^0 is found to be $M_{s^0} = 3117.7^{+3.8}_{-2.0}(\text{syst.}) \pm 0.9(\text{stat.})\text{MeV}$ which corresponds to binding energy $B_{s^0} = 194\ \text{MeV}$ with respect to K^{-}+p+n+n threshold. The level width Γ_{s^0} is less than 21.6 MeV [2, 3, 4]. The "strangeness exchange reaction" (K^{-}, π^{-}) was used by the FINUDA experiment at DAΦNE [5] to produce $\bar{K}$-bound states on proton-rich nuclei, such as p-p, which are unbound without the K^{-}. They found that the peak in the Λ + p invariant mass spectrum is interpreted as a kaonic bound nuclear state $K^{-}pp$ with binding energy $B_{\Lambda+p} = 115^{+6}_{-5}\ (\text{stat})^{+3}_{-4}$ (syst.) MeV and width $\Gamma_{\Lambda+p} = 67^{+14}_{-11}\ (\text{stat})^{+2}_{-3}$ (syst.) MeV respectively. Ni+Ni collisions at an incident energy of 1.93 AGeV at GSI were studied with the 4π detector FOPI [6]. The observed value for mean mass is $M_{\Lambda+d}$=3160 MeV, corresponding to a binding energy $B_{\Lambda+d}$= -149 MeV and a width $\Gamma_{\Lambda+d} \approx$ 100 MeV. It can be interpreted as a K^- nuclear cluster. It is very important to identify methods to study the characteristic features of the kaonic bound nuclear systems.

The 50 GeV PS of J-PARC will provide a unique play ground for the study of deeply bound kaonic nuclear states [7]. In the near future, dedicated experiments on search for kaonic nuclear states are also expected to be carried out in leading nuclear facilities such as J-PARC, GSI and Frascati. In parallel to this development, we are interested especially in studying the size of kaonic nuclei. In my work, I am going to analyze the size of K^-ppn system through momentum distribution of product particles proton and neutron. The decay process is $K^-ppn \rightarrow \Lambda^* pn \rightarrow \Lambda pn$ and the final decay particles would be Λ, p and n.

2. Using Dalitz's Variables in Momentum Distribution

2.1 Momentum Distribution of Spectator Neutron

The theoretical formulation of our decay momentum distribution is given in the center of mass frame of K^-ppn, while experimental data is generally a collection of decay product from variously moving K^-ppn systems. Now, problem is how to apply the theoretical formula to the analysis of experimental data. We can solve this problem by introducing Dalitz's variables, which are Lorentz invariant quantities.

The Transition matrix element T_{fi} of the $\Lambda^* pn$ decay process can be expressed in terms of the following form, $T_{fi} = \frac{1}{L^6}\int d\xi\, e^{-i\mathbf{k}_{\Lambda p}\cdot\xi} V(\xi)\Phi(\xi) \int d\mathbf{r}\, e^{-i\mathbf{k}\cdot\mathbf{r}} \phi(\mathbf{r}) \int d\mathbf{R} e^{-i(\mathbf{K}-\mathbf{0})\cdot\mathbf{R}}$

We can get the decay rate W_{fi} by using the Fermi's Golden Rule,

$$\int d^9R\, d\mathbf{k}_\Lambda = \frac{1}{\hbar(2\pi)^5}\delta(E_f - E_i)\left|\bar{V}(k_{\Lambda p})\right|^2 \left|\bar{\phi}(\mathbf{k})\right|^2 d\mathbf{k}_p\, d\mathbf{k}_n \int d\mathbf{k}_\Lambda \delta(\mathbf{k}_p + \mathbf{k}_\Lambda + \mathbf{k}_n) \tag{2.1}$$

The invariant mass 'M' of a set of N particles is defined as

$$M = \left(\sum_{i=1}^{N} E_i\right)^2 - \left(\sum_{i=1}^{N} p_i\right)^2$$

We calculated the momentum distribution of spectator neutron from the decay process $K^-ppn \rightarrow \Lambda^* pn \rightarrow \Lambda pn$ by solving numerically the following equation.

$$d(\hbar R_n) = \frac{1}{4\pi^3}\frac{1}{\hbar^6}\frac{1}{4M^2} E_n dX \int_0^\infty E_\Lambda dY \sum_i E_p(x_i) v_c^2 g_c k_{\Lambda p}^2(x_i) e^{-(\frac{2a^2b^2}{4a^2+b^2}k_{\Lambda p}^2(x_i)) - \frac{3}{2}a^2k^2} \tag{2.2}$$

where, M is the mass of the mother nucleus K^-ppn system. X_{max} and X_{min} are determined from the following equation.

$$X = m_{\Lambda p}^2 = (E_\Lambda + E_p)^2 - (p_\Lambda + p_p)^2 \tag{2.3}$$

X_{max} is obtained when p_n= 0.

$$X_{max} = (M - m_n)^2 \tag{2.4}$$

Similarlay, Y_{max} and Y_{min} are obtained to be

$$Y_{min} = (m_{pn}^2)_{min} = (m_p + m_n)^2 \text{ and } Y_{max} = (M - m_\Lambda)^2 \tag{2.5}$$

The integral of Y in equation (2.2) is computed with upper limit Y_{max} and the lower limit Y_{min}. We calculated the various momentum distribution of spectator neutron which correspond to various size parameters. The size parameter a = 0.87 fm is obtained from theretical prediction of shrunk K^-ppn system and a=1.61 fm is obtained from the normal ^3He[8]. Another size parameter is chosen to be 1.24 fm which is between the above two values. The momentum distribution of spectator neutron for three size parameters are shown in figure (2.1). It is found that the distribution is shifted to higher momentum region when the mother nuclear size becomes smaller.

2.2 Momentum Distribution of Participant Proton

We also calculated the momentum distribution of participant proton by solving numerically the following equation,

$$d(\hbar R_p) = \frac{1}{4\pi^3}\frac{1}{\hbar^6}\frac{1}{4M^2}E_p dX \int E_n dY \sum_i E_\Lambda(x_i) V_c^2 \times g_c k_{\Lambda p}^2(x_i) e^{-\left(\frac{2a^2b^2}{4a^2+b^2}K_{\Lambda p}^2(x_i)+\frac{3}{2}a^2k^2\right)} \quad (2.6)$$

The binding energy, interaction range parameter 'b' and the size parameter 'a' are the same as the computation of neutron momentum distribution. After the necessary calculation, we have solved equation (2.6) numerically. We obtained the momentum distribution of participant proton corresponding to the various size parameters and the results are shown in figure (2.2). It is found that the momentum of participant proton is sensitive to the size of mother nucleus.

When we analyze proton data, we have to take into account not only the participant process but also the spectator one where the roles of n and p are exchanged. By averaging both the processes we get decay proton distribution formula for experimental data analyses. Thus, the total momentum distribution is the sum of momentum distributions of spectator neutron and participant proton. It is expressed as the following equation,

$$d(\hbar R) = \frac{1}{2}\left[d(\hbar R_{spectatorn}) + d(\hbar R_{participant\ p})\right]. \quad (2.7)$$

Therefore, we solved the equation (2.7) to obtain the total momentum distribution for various root mean square distance. These results are shown in figure (2.3). Figure (2.3) shows both "shrunk" and "normal" cases. In the normal case, the distributions show clearly separated two components. The lower peak corresponds to the participant proton case. This peak indicated that the spectator neutron is emitted with a low momentum. The higher peak corresponds to spectator neutron. This peak indicates that the participant proton take out most of the momenta.

On the other hand, in the "shrunk core" case, the distributions are significantly broadened. This means that even the "spectator" neutron is allowed to carry a large momentum and the participants cannot take out large momenta.

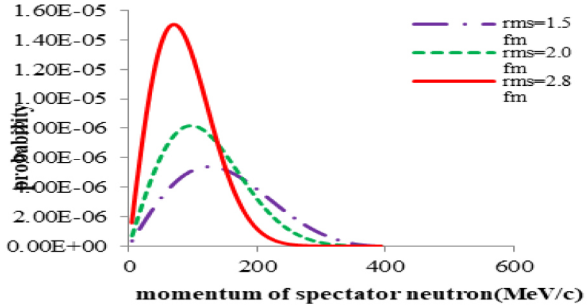

Fig. (2.1)Momentum distribution of spectator neutron for various root mean square distances

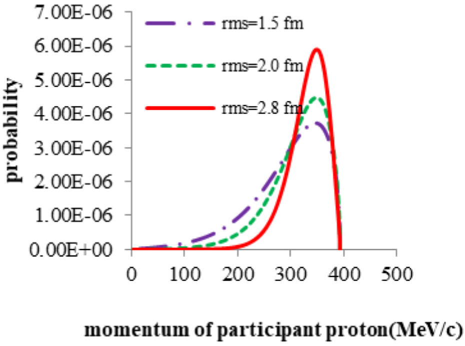

Fig. (2.2) Momentum distribution of participant proton for various root mean square distances

2.3 Invariant-mass Spectra

The invariant mass 'M' of a set of N particles is defined as $M = \left(\sum_{i=1}^{N} E_i\right)^2 - \left(\sum_{i=1}^{N} p_i\right)^2$.

The theoretical formulation of equation (2.2) is in the centre of mass frame while the experimental data is measured in laboratory frame. Since the invariant masses are the same in any reference frame, we can directly compare the distribution curves which are plotted versus invariant masses. Distribution of invariant mass versus energy distribution of neutron is shown in figure (2.4). The $m^2_{\Lambda p}$ distribution is effected by the core size of the $\Lambda^* pn$ system. In figure (2.4) both "shrunk" and "normal" cases are shown. In the normal case, the distributions show clearly separated two components. The higher one is peaked toward the upper limit, $(M\text{-}m_n)^2 = 4.732\ \mathrm{GeV}^2/c^4$, which corresponds to the participant proton case. This peak indicated that the spectator neutron is emitted with a low momentum. The other peak, near the lower limit, $(m_n + m_p)^2 = 4.218\,\mathrm{GeV}^2/c^4$, results from the spectator particle. On the other hand, in the "shrunk core" case, the distributions are significantly broadened. This means that even the "spectator" neutron is allowed to carry a large momentum because of the internal momentum. In balance, the participants cannot take out large momenta. This marked difference between the shrunk and normal case can be detected experimentally.

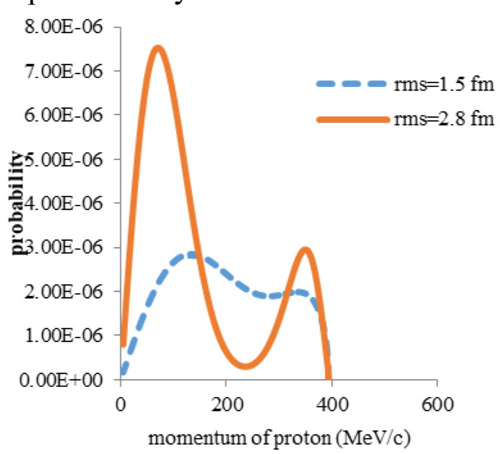

Fig. (2.3) Momentum distribution of proton for shrunk core and normal core

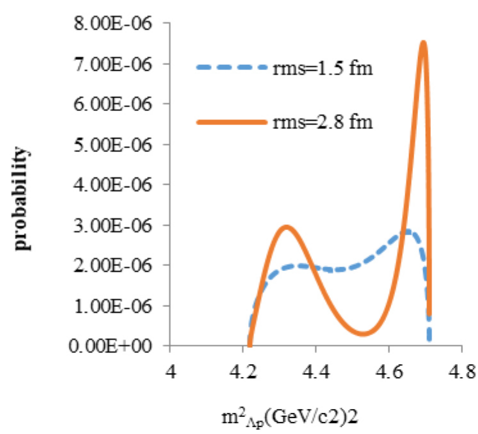

Fig. (2.4) Invariant mass ($m^2_{\Lambda p}$) spectra for shrunk core and normal core

3. Conclusion

In my research work, we calculated momentum distribution of decay products of $\Lambda^{*}pn$ using Fermi Golden rule. The theoretical formulation is in the centre of mass frame while the experimental data is measured in laboratory frame. Therefore, if we want to compare the theoretical curve with the experimental plot, we have to change centre of mass momentum to laboratory frame. However, if we use invariant mass of particle pairs, it is not necessary to change the physical quantities from lab frame to centre of mass frame.

In the decay processes, we consider both the p-participant and n- participant case on equal footing. When decay protons are detected, these protons cannot be distinguished as participant protons or spectator protons. Thus, when we analyze proton data, we have to take into account not only the participant process but also spectator one where the roles of neutron and proton are exchanged.

By studying the momentum distribution of decay product of $K^{-}ppn$, one can deduce the size of the kaon cluster system, and its spin and parity. We also found that the momentum distribution of spectator neutron is shifted to higher momentum region when the mother nuclear size becomes smaller and momentum of participant proton is sensitive to the size of mother nucleus.

On the other hand, in the "shrunk core" case, the distributions are significantly broadened. This means that even the "spectator" neutron is allowed to carry a large momentum and the participants cannot take out large momenta. The invariant mass plots enable us to directly compare with the experimental plots. It is found that momentum distributions of decay particles are sensitive to the size of the mother nucleus and this is a possible analysis to determine the size of kaonic nuclei.

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References

[1] Y. Akaishi and T. Yamazaki, Phys. Rev. **C65** (2002) 044005.
[2] T. Suzuki *et al.,* Phys. Lett. **B597** (2004) 263.
[3] M. Iwazaki *et al.,* http: xxx. lanl. Gov, nucl-ex/0310018, (2003).
[4] M. Iwazaki (KEK PS-E471 Collaboration), Proceedings EXA05, (2005) 191.
[5] M. Agnello *et al.,* Phys. Rev. Lett. **94** (2005) 212303.
[6] N. Hermann (FOPI Collaboration), Proceedings EXA05, (2005)61.
[7] S. Sawada, Proceedings EXA05, (2005) 413.
[8] Y. Akaishi, A. Dote, T. Yamazaki, Phys. Lett. **B613** (2005) 140.