Lambda-Lambda correlation in (K^-, K^+) reaction — Is there a virtual pole ?

A. Ohnishi[a], Y. Hirata[ab], Y. Nara[bc], S. Shinmura[d] and Y. Akaishi[e]

[a] Division of Physics, Graduate School of Science,
Hokkaido University, Sapporo 060-0810, Japan

[b] Advanced Science Research Center, Japan Atomic Energy Research Institute,
Tokai, Ibaraki 319-11, Japan

[c] Physics Department, Brookhaven National Laboratory, Upton, N.Y. 11973, U.S.A.

[d] Faculty of Engineering, Gifu University, Yanagido 1-1, Gifu 501-1193, Japan

[e] Institute of Particle and Nuclear Study, High Energy Accelerator Research
Organization (KEK), Oho 1-1, Tsukuba 305-0801, Japan

Hyperon momentum distribution and correlation in (K^-, K^+) reactions are analyzed in a microscopic transport model with correlation effects generated by the final state interaction. It is shown that K^+ and Λ momentum distributions are well reproduced with the dynamical transport followed by the statistical evaporation of Λ from hyperon compound nuclei. In the correlation analysis of $\Lambda\Lambda$, we can well reproduce the observed strong enhancement at low energies with reasonably attractive $\Lambda\Lambda$ interactions. The relation of this enhancement to the virtual pole is discussed.

1. INTRODUCTION

The interaction between $\Lambda\Lambda$ is very important in many fields of physics. For example, the hyperon-nucleon and hyperon-hyperon interaction is one of the most exciting topics in this conference, and the $\Lambda\Lambda$ pair is the lowest mass threshold channel in the flavor singlet BB pair, where the theoretical uncertainty is the largest. It is also closely related to the existence of the H particle, which is discussed in connection with the neutron star and in the context of its production.

Despite of its importance, information of the $\Lambda\Lambda$ interaction has been limited only to that from the three double Λ hypernuclei observed in these 40 years. Therefore the recent measurements of $\Lambda\Lambda$ invariant mass spectra in KEK-E224 and BNL-E906 experiments [1–3] have made a great impact. Both of the measured data show enhancement just above the $\Lambda\Lambda$ threshold compared to the results of the IntraNuclear Cascade (INC) model, which well reproduces the (K^-, K^+) specta on various targets [4]. This strong enhancement implies the existence of some kind of correlation between $\Lambda\Lambda$. One of the candidates to generate this correlation is the pairwise $\Lambda\Lambda$ final state interaction (FSI). In the case of a chaotic source, the enhancement (or suppresson) coming from FSI can be well described by using the Koonin-Pratt correlation function theory [5]. This theory takes into accout of both effects of the nuclear FSI and the HBT correlation. In few-body systems, more rigorous treatments have been applied to extract nuclear interactions [6], but the essential mechanism of enhancement is the same: when the interaction is attractive, the wave function rapidly grows within the interaction range and the transition matrix element is enhanced.

In order to extract useful information on $\Lambda\Lambda$ interaction by using the correlation function theory, it is necessary to have a reliable source function of Λ particle. Hadronic cascade models have been applied and have met some successes in describing high-energy nuclear reactions, especially for meson spectra. However, when low-energy baryon spectra are addressed, mean field effects become essential. In addition, if the particle under consideration is stable enough in the nuclear environment, later evaporations from residual nucleus may contribute significantly in the low-energy region. The framework including these ingredients — hadronic cascade (two-body collisions), mean field effects, and later evaporation processes — is now a standard treatment in studying the whole history of nuclear reactions, and referred to as a microscopic transport model or a nuclear microscopic simulation.

In this paper, we apply this microscopic transport model to $(K^-, K^+\Lambda\Lambda)$ reactions on ^{12}C and ^{9}Be. Then we utilize the phase space information of Λ from these simulations to evaluate the $\Lambda\Lambda$ correlation. We show that by evaluating the dynamical transport and the Λ evaporation from hyperon compound nuclei [7,8], we can simultaneously reproduce K^+ and Λ momentum distribution. In addition, $\Lambda\Lambda$ invariant mass spectra can be well *fitted* with reasonably attractive $\Lambda\Lambda$ interactions. Then we discuss the mechanism of this enhancement in connection with the pole position of the $\Lambda\Lambda$ system.

2. HYPERON DISTRIBUTION AND CORRELATION

In Fig. 1 we show the calculated results of K^+ and hyperon momentum distributions and $\Lambda\Lambda$ invariant mass spectra, in comparison with available data. In the calculation, we have incorporated the hadron-hadron cross sections [4], mean field effects to baryons ($U(Y) = -30, -16$, and -10 MeV at normal nuclear density for $Y = \Lambda, \Xi$, and Σ, respectively) as an external potential, and Λ evaporation from hyperon compound nuclei [8]. In addition, we have applied the FSI correlation function theory to the $\Lambda\Lambda$ invariant mass spectra. By assuming a two-range gaussian (trg) form for the $\Lambda\Lambda$ interaction, we evaluated the residual error to the KEK-E224 data. The calculated invariant mass spectrum is sensitive to the interaction, and reasonably but strongly attractive interactions are preferred to reproduce E224 data. In Fig. 2, we show this and χ^2 contour map. By using the same interaction, BNL-E906 data of the $\Lambda\Lambda$ invariant mass spectrum is also well reproduced.

In these figures, we find that the yield of produced Λ particle is much larger (around twice) in the case of ^{12}C target. There are some reasons for this, such as the two-step contribution, incident energy, and hyperon compound nuclear formation probability. In order to study the correlation effects clearly, it will be better to make an experiment at around $P(K^-) = 1.65$ GeV on a heavier target (enhanced two-step contributions), and select Λ particles at higher momenta (to reduce evaporation contribution).

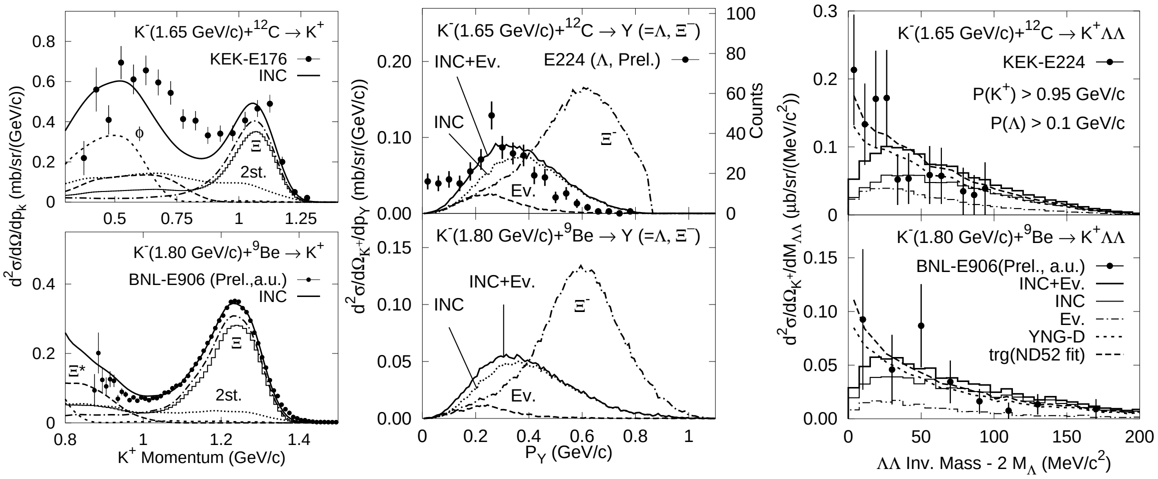

Figure 1. Calculated K^+ momentum spectra (left), hyperon momentum spectra (middle), and $\Lambda\Lambda$ invariant mass spectra (right) in (K^-, K^+) reactions on ^{12}C and ^{9}Be targets in comparison with data [9,2,10]. The E906 data are shown in an arbitrary unit. The Λ spectrum of KEK-E224 is preliminary, and it is shown in counts (right axis). In the correlation calculation, we have adoped the YNG-D [11] interaction and the fitted trg interaction.

Unfortunately, statistics of the data is not enough to exclude any of the presently proposed $\Lambda\Lambda$ interactions. As shown in Fig. 2, almost all the Nijmegen model interactions and Ehime potentials are within the range of $\chi^2/\mathrm{DOF} < 1$ in $(1/a_0, r_{\mathrm{eff}})$ plane. However, if the statistics is increased by 50 %, the limitation to the interaction becomes severe, assuming that the mean values of data are unchanged. We find only several sets of potential parameters in the range of $\chi^2/\mathrm{DOF} < 2/3$.

3. VIRTUAL POLE

At around the resonance pole, we frequently observe strongly enhanced cross sections. On the other hand, it is not usual to observe strong enhancement of momentum correlation near threshold, where s-wave is dominant. Therefore, the present enhancement of $\Lambda\Lambda$ correlation, which amounts to 3-6 near threshold, is not a usual phenomenon.

Strong enhancement comparable to this case can be found in the nn correlation in heavy-ion collisions [5], and ^{9}Li-n correlation in ^{11}Li breakup. In both of the cases, it is expected that a virtual pole might exist. A virtual pole is defined as a pole in the complex momentum plain having $k = k_R + ik_I$ with $k_R = 0$ and $k_I < 0$, thus the pole energy becomes negative, but the wave function (whose asymptotic form is $\exp(ikr)/r$) diverges. When a virtual pole exist near threshold, it will enhance the strength most strongly at zero momentum (threshold), which is the closest along the physical momentum trajectory to the pole. Thus we can naturally understand the strong enhancement near threshold.

We have searched for the virtual poles with two-range gaussisan interactions by using the Jost function method [12], and find that the present $\Lambda\Lambda$ enhancement is consistent with the vitual pole with $k_I \sim 0.3$ fm^{-1}. However, since the existence of virtual poles

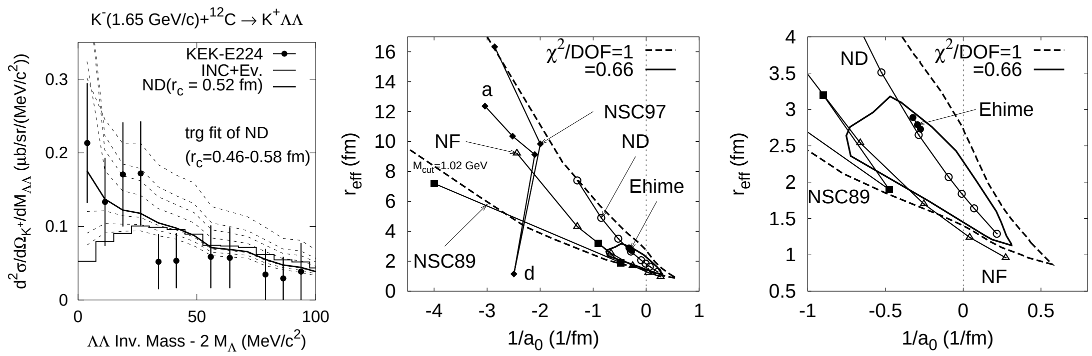

Figure 2. Left: interaction dependence of the invariant mass spectrum. Two-range gaussian interactions fitted to the low-energy ND model behavior are used. Middle and Right: χ^2 contour map in the scattering length (a_0) and the effective range (r_{eff}) plain.

strongly depends on the potential form, further study with different interaction form will be necessary in order to confirm the existence of the virtual pole.

4. CONCLUSION

In this paper, we have studied the hyperon momentum distribution and correlation between $\Lambda\Lambda$ in (K^-, K^+) reactions. Global understanding of K^+ and Λ momentum distribution is achieved in a microscopic transport model. The correlation function analysis suggests that attractive $\Lambda\Lambda$ interaction is necessary, and the best fit interaction makes $\Lambda\Lambda$ system barely unbound. It may be possible that a virtual pole of $\Lambda\Lambda$ system would exist. Higher statistics data is desired to determine $\Lambda\Lambda$ interaction more precisely.

REFERENCES

1. J.K. Ahn et al. (KEK-E224 collab.), Phys. Lett. **B444** (1998), 267.
2. T. Fukuda for BNL-E906 collab., Nucl. Phys. **A639** (1998), 355; in this proceedings; T. Tamagawa et al. (BNL-E906 collab.), in this proceedings.
3. T. Tamagawa (BNL-E906 collab.), private communications.
4. Y. Nara et al., Nucl. Phys. **A614** (1997), 433.
5. W. Bauer et al., Ann. Rev. Nucl. Part. Sci. **42**, 77 (1992), and references therein.
6. I. Slaus, Y. Akaishi and H. Tanaka, Phys. Rep. **173** (1989), 257.
7. T. Yamazaki, Nuovo Cim. **103A** (1989), 78.
8. Y. Hirata et al., Prog. Theor. Phys. **102** (1999), 89.
9. T. Iijima et al. (KEK-E176 collaboration), Nucl. Phys. **A546** (1992), 588.
10. J.K. Ahn (KEK-E224 collab.), private communications.
11. Y. Yamamoto et al., Prog. Theor. Phys. Suppl. **117** (1992), 361.
12. S. A. Rakityansky and S. A. Sofianos, J. Phys. **A31** (1998), 5149.
    H. Masui, S. Aoyama, T. Myo, K. Kato, and K. Ikeda, Nucl. Phys. **A673** (2000), 207.