Study hadron property and structure in high energy multiproduction process

Shi-Yuan Li*,

Institute of Theoretical Physics, Shandong University
* lishy@sdu.edu.cn

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Abstract

In high energy scattering, multiproduction process is unique in its relevance to the total cross section and in its global property such as rapidity and other kinematic distributions. If there is hard interaction, the jet rate and structure is a good arena of perturbative chromodynamics. However, once any hadron is specified, its property and structure must make sense while the global and/or perturbative chromodynamics mechanism still can put important constrains. The relation of the hadron property and structure with its production cross section, distribution etc. can be much more complex than its decay width. In one hand there are many difficulties and challenges in calculation; on the other hand, production process provides unique way to study the details of property and structure of the hadron, which is beyond the approach of its decay process. Here I review our works on such topic in recent years, mainly on the multiquark state production in multiproduction process and the Bethe-Salpeter wave function in exclusive process. For the former, I emphasize on the unitarity of hadronization process and relevant models, so that Almost No multiquark state is observed in multiproduction process; I also address how to calculate hadron molecule production in multiproduction process; the most recent observed T_{cc}^{+} is also stated with its relevance to colour and baryon number fluctuation of the preconfinement clusters. For the latter, I emphasize the Dirac structure of the hadron-quark coupling vertex.

Contents

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1 Introduction

This symposium is about multiple particle dynamics. Multiple particle system is mainly produced from the high energy scatterings, of which the multi-production process is a dominant part of the total cross section. It is also the reason of the increasing total cross section of hadronic scatterings [1]. This topic, as well as other global properties, jet observables, etc. are all important subjects in studying QCD in high energy scatterings. At the same time, multi-production process is also the copious source of various hadrons. This last fact indicates that multi-production process is a good arena to study hadron structure. Comparing other ways to study hadron structure, such as some static property if available, decay width and distribution, 'projector/probe' scattering (e.g., DIS) etc., this way is more complex. However this is why this study can provide more and more complex information, even with different physical pictures. In one hand there are many difficulties and challenges in calculation; on the other hand, production process provide unique way to study the details of property and structure of the hadron, which is beyond the approach of its decay process. This study relates the production mechanism with the structure and property of the specific hadron. Our study is in two aspects, one is the global property putting constrains on the production mechanism of hadrons; the other is the concrete details of the structure of some certain hadrons.

2 Unitarity, colour and baryon fluctuation

Prompt production of the multiquark states and/or bound states of other ingredient hadrons at high energy scattering can set a crucial point for the understanding of the hadronization mechanism, since they contain more than three constituent quarks. In any hadronization process, the produced color-singlet (anti)quark system (e.g., preconfinement cluster [2]) eventually transits to various hadron states (mesons, baryons and beyond) with the total probability exactly 1, which reflects the fact that there are no free quarks in the final states of any high energy process (confinement). In this consideration this process conserve entropy, since this process only make a unitary transition on the density matrix. This consideration is very important, since such an analysis releases and shuts down a long paradox that combination process/model will decrease the entropy and would introduce unphysical predictions. We have also pointed out that the energy conservation and the unitarity of the combination model are enough for this physical requirement. The introduction of multiquark states sets a challenge for the hadronization models/mechanism dealing with the transition from color-singlet (anti)quark system to the hadron system. With these new quark states introduced, a more detailed investigation of the whole hadron Hilbert space as well as that of the quarks is needed. As a matter of fact from experiments, the production of general mesons and baryons is dominant, so the production rate of exotic could be a small if nonvanishing. However, the present knowledge is not enough to judge how many kinds of multiquark states there are and how they 'share' the total probability of ϵ, it is not easy to predict the production rate of a specific multiquark state. What we can say, though, seems that if there are a lot of kinds of multiquark hadrons, each only shares a small part of the small ϵ. So the production rate of each is almost vanishing. This is consistent with the fact that there almost no multiquark state is observed in multiproduction process final states. Almost all the exotics are observed to produce from the decays of heavier hadrons (e.g., bottom hadrons) rather than promptly produced from multi-production processes in experiments. From the theoretical aspects, this fact is understood not only because of the unitarity constraint but also the modest mass of the preconfinement clusters [3–6], which is independent from the collision energy, and is results from the interplay between perturbative and non-perturbative QCD. So to understand this topic, the preconfinement concept [2] is also very important, especially in the cases of large number of quarks produced (e.g., in high energy nuclear collisions). This is consistent with unitarity, confinement, etc. Furthermore one has to consider the fluctuations of colour and baryon number besides the hadronization models. These fluctuations can be that of other quantum number, e.g., stangeness. The relation lies in that all kinds of the multiquark state hadrons have one common property that the bound (anti)quarks inside can be grouped into several clusters, with each cluster *possibly* in colour-singlet. But the ways of grouping these (anti)quarks are not unique; and dynamically, the colour interactions in the system via exchanging gluons can change the colour state of each individual cluster, so each kind of grouping/reduction way seems having no special physical reasons. This ambiguity has been discussed in other circumstances in name of 'colour recombination/rearrangement' [7–9]. This fact shows that multiquark hadron can not be considered in a unique and uniform way. This is a phenomenological duality: Even the production of multiquark hadron is considered as 'hadron molecule formation' ('production definition'), the subsequent colour interactions in the system can eventually transit this 'molecule' into a 'real' multiquark hadron, at least by some probability — et vice verse [10–14]. The baryon number fluctuation means some cluster can have one or more extra $qqq(\overline{qqq})$. Based on this consideration, the colour and baryon fluctuation of the preconfienment clusters has nontrivial relevance with the multiquark hadrons, and can be applied to construct various models for a specific multiquark state for comparison.

3 Bethe-Salpeter wave function in production

An example is to investigate the exclusive production ratio $\frac{\sigma(e^+e^-\to K_S K_L)}{\sigma(e^+e^-\to K^+K^-)}$ in e^+e^- annihilation continuum below the $M_{J/\Psi}$ under the spirit of Straton Model (i.e., completely relativistic Bethe-Salpeter framework), besides before applied to heavy exclusive production, e.g., $J/\Psi + \eta_c$. The coupling of the virtual photon to the Kaons is via the triangle quark loop: photon-quark-quark vertex is exactly that of standard model. The vertices between the quarks and the corresponding Kaon is the Bethe-Salpeter vertex in term of valence quark field. Hence the electromagnetic interaction and non-perturbative QCD interaction are separately assigned. The difference of these two kinds of channels lies in the electric charge. Due to the scalar wave function in Bethe-Salpeter vertex, which can be considered to regularize and renormalize the infinite integrations, the loop integral is finite. The ratio can be calculated straightforwardly [15], by adopting the vertex as $\gamma^5(1+B_1\gamma_\mu P^\mu/M)\phi(q^2)$ [16]. One gets $\frac{\sigma(e^+e^-\to K_S K_L)}{\sigma(e^+e^-\to K^+K^-)} \cong (\frac{m_s-m_d}{M})^2$. This is consistent with former experiments and can be further tested by BESIII measurements. This method also explain $e^+e^-\to J/\Psi+\eta_c$ data well.

4 Conclusion

To study the structure of hadron via production is an important view point. The recent observed T_{cc} [17,18]is investigated taking into account the colour connection and baryon number fluctuation [6], and a compact four-quark nature is favoured [19]. The interplay of multi-HEAVY-quark production and multi-HEAVY-quark bound state is a quite new and copious direction in this field. Now three pair of charm can be careful investigated in LHC (see, e.g., [20]).

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