Contribution ID: **52** Type: **not specified**

Intriguing solutions of Bethe-Salpeter equation for radially excited pseudoscalar charmonia

Friday, May 11, 2012 12:00 PM (30 minutes)

When generalizing recent various quantum mechanical models of $c-\bar{c}$ states to Quantum Filed theoretical approach based on BSE one is faced to the solutions that do not exist in non-relativistic limit. Mainly, there is unexpected doubling of the spectrum when comparing to the spectrum expected or known from the experiments as well as the ones known from the solution of the Schroedinger equation. These additional states do not belong to the known ghost and non-physical solutions as they have the same symmetry as the usual ones, however we argue they appear due to the sensitivity of BSE to the details of the analytical form of the constituents quark propagators, more specifically they are consequence of using non-confining form of the propagators. To show this explicitly we develop and describe the efficient method of the numerical solution of Q-Q BSE and numerically solve it for the case of pseudo-scalar $c-\bar{c}$ mesons. For the bare propagators of constituents we are able to find BSE solution for arbitrarily high excited state without any 3-dimensional reduction. Unlike to the Schroedinger equation the excited states are not orthogonal. Using free charm quark propagators we observe that the spin $0,1$ ground states are the only mesons left bellow naive quark threshold $2m_c$, while the all excited states are situated above this threshold. In the second part of the paper we consider the model of BSE with complex conjugated poles and show the influence on the spectrum directly in the 3+1 dimensional space.

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