PROCEEDINGS OF SCIENCE

Probing of charmonium and exotic multiquark states in hadron and heavy ion collisions

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The opportunity of selected studies of multiquark exotic hadrons is discussed. The topic includes detailed analysis of their strong, weak and electromagnetic decays containing charmed quark-antiquark pair, physics analysis and events reconstruction in proton-proton and proton-nuclei collisions. These provide a good probe to test the theories of strong interactions including both perturbative and non-perturbative QCD, lattice QCD, potential and phenomenological models

41st International Conference on High Energy physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

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PoS(ICHEP2022)906

1. Introduction

The study of charmonium-like mesons is of great importance as they are among the most mysterious states ever observed in modern particle physics [1 - 4]. These states contain a hidden charm component, and therefore they are called charmonium-like exotics. Their predictions are closely linked to existing and forthcoming data of running and planned experiments like Belle, BaBar, BES, LHCb, NICA, PANDA, etc. Given the existing experience of model calculation, physics simulation and event reconstruction the detailed analysis of exotic states production may be performed. This can be pursued using well known methods based on QCD principles as well as new proposed phenomenological approaches able to describe the structure of bound state of hadrons and exotics. Chamonium-like exotics spectroscopy represents a good testing tool for the theories of strong interactions, including: QCD in both the perturbative and non-perturbative regimes, LQCD, potential models and phenomenological models. The experiments planned at the Nuclotron-based Ion Collider fAcility (NICA) [5] may be well suited to test these states. The NICA facility will be able to collide ion beams with a luminosity of 10^{27} $cm^{-2}s^{-1}$ and $\sqrt{S_{NN}}$ up to 11 GeV, and proton beams with luminosity up to 10^{32} $cm^{-2}s^{-1}$ and $\sqrt{S_{pp}}$ up to 27 GeV.

2. Reconstruction of X(3872) exotics

The X(3872) exotics was simulated in PYTHIA8 [6] under the assumption that it is a charmonium state and the branching ratio to $J/\psi + \rho^0$ was taken to be 5% [7, 8]. As a result, the $e^+e^-\pi^+\pi^-$ final state branching ratio ~ 3×10^{-3} gives the cross section for this channel of 12.2 pb, or about 10 days of running time at the luminosity of 10^{32} $cm^{-2}s^{-1}$ to produce approximately 1000 events. To better distinguish the signal peak from the background, it is better to use the invariant mass combination $M_{e+e-\pi+\pi-} - M_{e+e-}$ due to its smaller width (~10 MeV in our case, as can be seen in figure 1). Figure 1 also shows the background from events with charmonia production. The plots correspond to statistics collected during 10 months at luminosity of 10^{32} $cm^{-2}s^{-1}$. After fitting the background to the polynomial function using side bands of invariant mass distribution and subtracting it from the original distribution it is possible to observe a clear peak from the X(3872) decay (figure 2). As an extension of this topic one can consider looking at other decay modes of X(3872). Since the branching ratio of X(3872) to pairs of D-mesons is much higher (D^+D^- is ~40% and $D^{(0)}\overline{D}^{(*0)}$ is ~55%), one should try to evaluate the possibility to reconstruct this state from the hadronic decays of the D-meson pairs. For such a study, the ability to tag the D-meson decays using the silicon microvertex detector is very important.

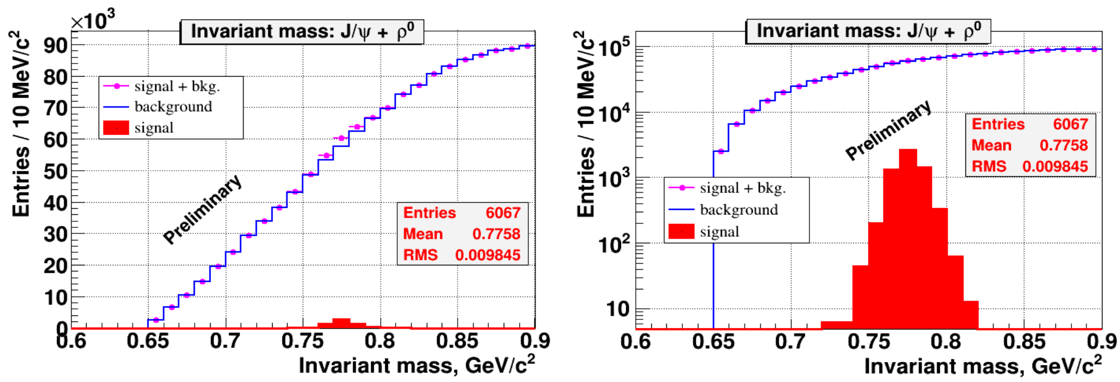

Figure 1. Invariant mass combination $M_{e+e-\pi+\pi-} - M_{e+e-}$ in linear (left) and logarithmic (right) scales.

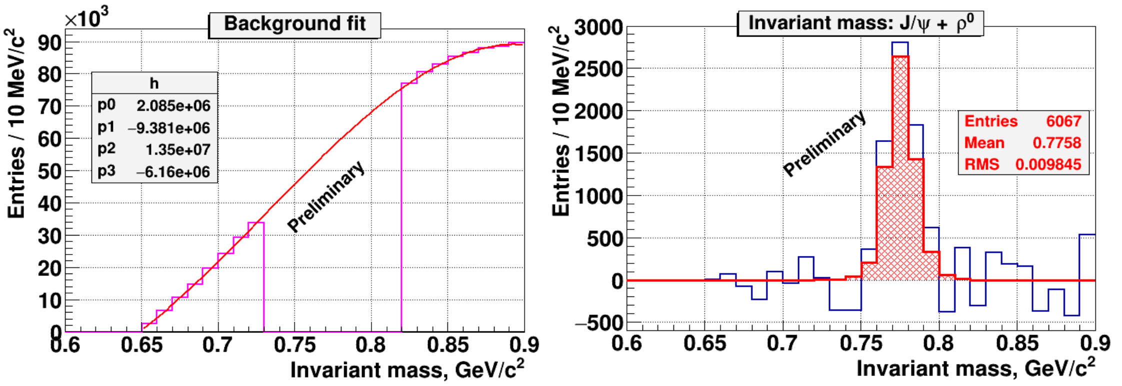

Figure 2. (Left) Background estimation using the polynomial fit of the side bands of figure 1. (Right) Background-subtracted invariant mass combination (blue line) and true X(3872) histogram (red line).

3. Study of exotics in proton-nuclei collisions

The experiments with proton-nuclei collisions planned at NICA may be suited to test the structure of the X(3872) and, possibly, some other XYZ mesons. In near threshold production experiments in the $\sqrt{S_{pN}} \approx 8$ GeV energy range, these states can be produced with typical kinetic energies of a few hundred MeV in the centre of mass system. Following the most democratic interpretation, X(3872) represents a hybrid structure with a dominant molecular component [9, 10]. Since the survival probability of an $r_{rms} \sim 9$ fm "molecule" inside nuclear matter should be very small, its production on a nuclear target with $r_{rms} \sim 5$ fm or more (A ~ 60 or larger) is expected to be strongly quenched. Thus, if the hybrid picture is correct, the atomic number dependence of X(3872) production at fixed $\sqrt{S_{pN}}$ should have a dramatically different behaviour than that of the ψ', which is a long lived compact charmonium state (Fig.3).

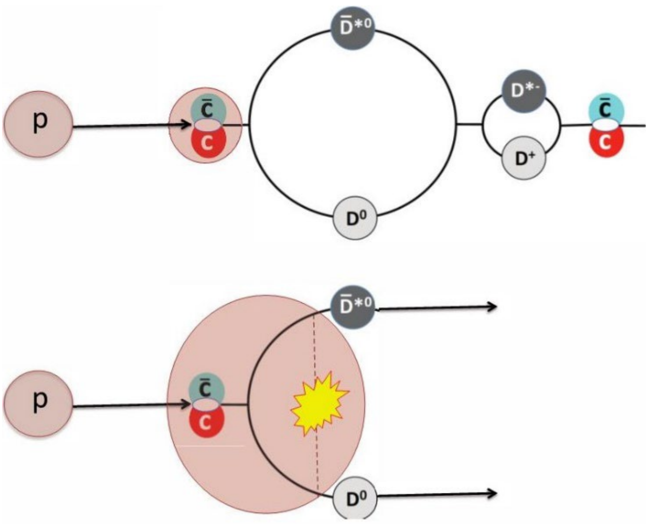

Figure 3. (Top) X(3872) production on a proton target ($r_{rms} \sim 1$ fm). Here the X(3872) escapes the target region before it can establish a significant $D\overline{D}^{(*)}$ component. (Bottom) X(3872) production on a nuclear target. Here the presence of nuclear material disrupts the coherence (< 200 keV) between the well separated $D^{(0)}$ and $\overline{D}^{(*0)}$ states (represented by the dashed line).

4. Conclusion

Several observed stated remain puzzling and will likely remain unexplained again for many years. This stimulates and motivates for new searches and ideas intended to obtain the nature of multiquark states. Physics analyses for the proton-proton and proton-nuclei collisions are in progress nowadays, and a few preliminary results have been obtained. The experiments with pp and pA collisions can obtain some valuable information on charm production. Measurements of charmonium-like states should therefore be considered as one of the "pillars" of pp and pA programs.

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