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Perspective studies of charmonium, exotics and flavour baryons

Mikhail Barabanov*, **Alexander Vodopyanov**

IUPAP

Fondazione Internazionale Trieste per il Progresso e la Libertà delle Scienze c/o ICTP, Strada Costiera 11, 34151 Trieste

E-mail: barabanov@jinr.ru

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

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1. Introduction

The spectroscopy of charmonium-like states together with the spectroscopy of flavour baryons is discussed. It is 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 [1 - 4]. An understanding of the baryon spectrum is one of the primary goals of non-perturbative QCD. In the nucleon sector, where most of the experimental information is available, the agreement with quark model predictions is astonishingly small, and the situation is even worse in the strange and charmed baryon sector. The experiments with hadron and proton-nuclei collisions are well suited for the spectroscopy of charmonuim-like states and flavour baryons. For this purpose an elaborated analysis of charmonium and exotics spectrum together with spectrum of charmed baryons was given. The recent experimental data from different collaborations (BaBar, Belle, BES, LHCb, CDF) were analyzed [5 - 8]. A special attention is given to the recently discovered XYZ-particles. The attempts of their possible interpretation are considered. The results of physics simulation are obtained. But much more data on different decay modes are needed before firmer conclusions can be made. The experiments planned at nuclotron-based ion collider facility (NICA) may be well suited to test these states. The NICA facility will be able collide ion beams with the luminosity 10^{27} $cm^{-2}s^{-1}$ and $\sqrt{s}$ up to 11 GeV and proton beams with the luminosity up to 10^{32} $cm^{-2}s^{-1}$ and $\sqrt{s}$ up to 27 GeV [9].

2. Reconstruction of X(3872) exotic state

The X(3872) exotic state was simulated in PYTHIA8 [10] under the assumption that it is a charmonium state and the branching ratio to $J/\psi + \rho^0$ was taken to be 5% [11, 12]. As a result, the $e^+e^-\pi^+\pi^-$ final state branching ratio $\sim 3 \times 10^{-3}$ 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.

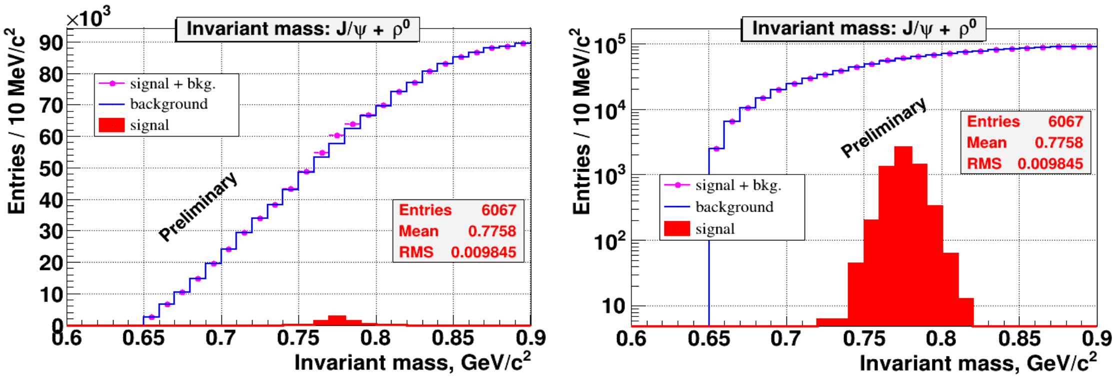

Figure 1. Invariant mass combination $M_{e+e-\pi+\pi-}$ - M_{e+e-} in linear (left) and logarithmic (right) scales.

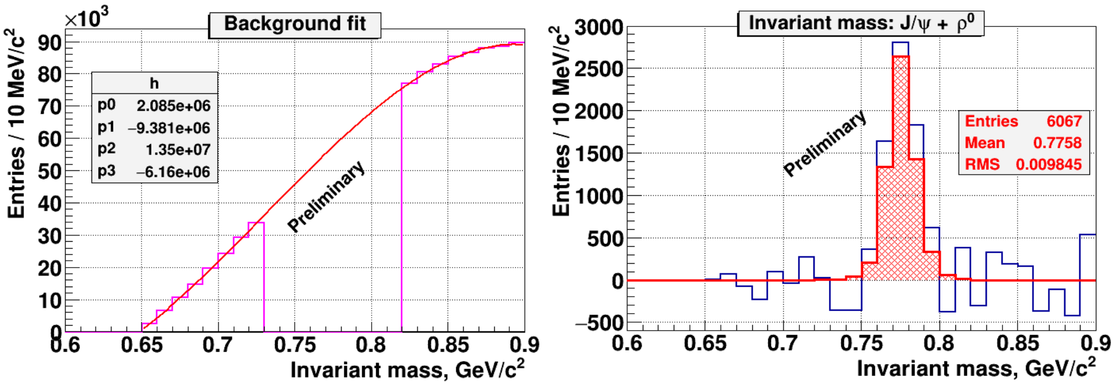

Figure 2. (Left) Background estimation using the polynomial fit of the side bands of figure 1. (Right) Background-subtracted invariant mass combination (blue line) and true X(3872) histogram (red line).

3. Study of exotic states 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 [13, 14]. 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).

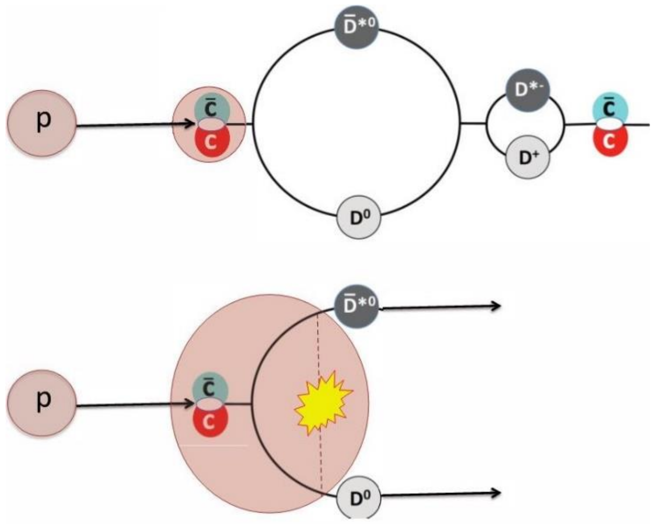

Figure 3. (Top) X(3872) production on a proton target ($r_{rms} \sim 1$ fm). Here the X(3872) escapes the target region before it can establish a significant $D\bar{D}^{(*)}$ component. (Bottom) X(3872) production on a nuclear target. Here the presence of nuclear material disrupts the coherence (< 200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

4. Conclusion

The recently observed XYZ states remain puzzling and unexplained for many years. This stimulates and motivates for new searches and ideas intended to obtain the nature of multiquark states. Physics analyses for the hadron and proton-nuclei collisions are in progress nowadays, and the 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 may be considered as one of the "pillars" for pp and pA programs at NICA.

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