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Probing of X, Y, Z exotics with hadron and heavy ion collisions

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Summary. — The possibility of selected studies of heavy exotic hadrons called X, Y, Z states is considered. The topic includes detailed analysis of their strong, weak and electromagnetic decays containing $c\bar{c}$ pair, physics simulations and event reconstruction at NICA facility.

1. – Physics case

The study of X, Y, Z 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 therefore 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 can 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 nuclotron-based ion collider facility (NICA) are well suited to test these states. NICA facility will be able to collide ion beams up to heavy ones as gold-gold with the luminosity 10^{27} cm^{-2}c^{-1} and $\sqrt{s}$ up to 11 GeV and proton (deuteron) beams with the luminosity 10^{32} cm^{-2}c^{-1} and $\sqrt{s}$ up to 26 GeV. Two detectors are foreseen at NICA. The first one is multi-purpose detector (MPD) aimed for experiments with ion beams. The second one is spin physics detector (SPD) aimed for experiments with polarized proton and deuteron beams [5].

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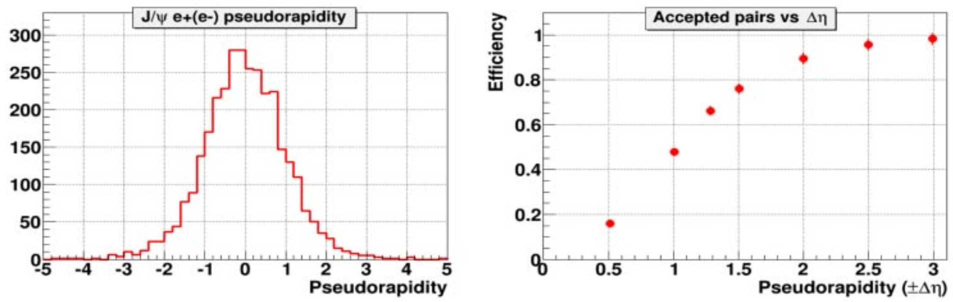

Fig. 1. – Left) Pseudorapidity distribution of electrons and positrons from J/ψ decays; right) percentage of $J/\psi \to e^-e^+$ decays with both the electron and positron within the pseudorapidity window of $\pm\Delta\eta$.

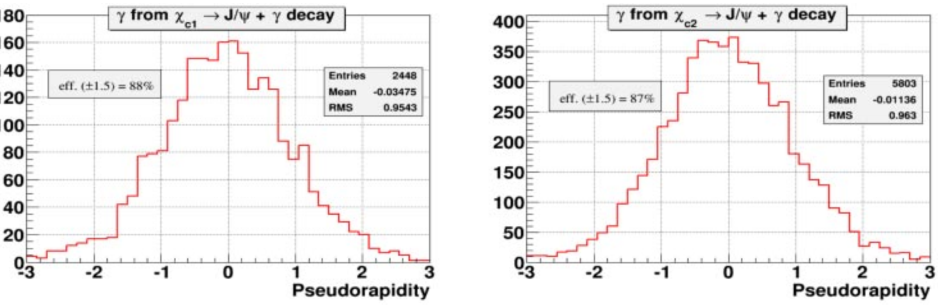

Fig. 2. – Left) Pseudorapidity distributions of the photons from charmonia decays: left) χ_{c1}, right) χ_{c2}.

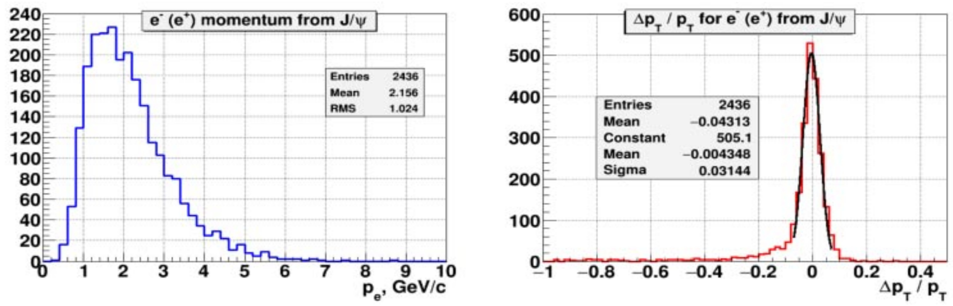

Fig. 3. – Left) Momentum spectrum of electrons and positrons with $|\eta|$ <1.5 from J/ψ decays; right) $\Delta p_T/p_T$ - distribution for decay products, where Δp_T is the difference between reconstructed and true transverse momentum.

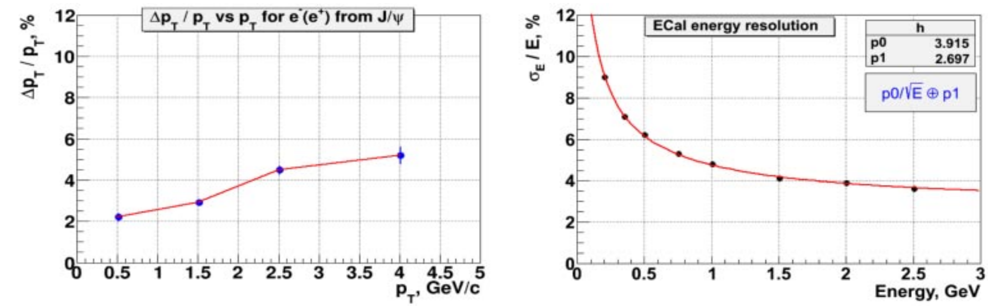

Fig. 4. – Left) $\Delta p_T/p_T$ versus p_T for electrons and positrons with $|\eta|$ <1.5 from J/ψ decays; right) energy resolution ($\sigma E/E$) of the EMC for photons and electrons as a function of their energy.

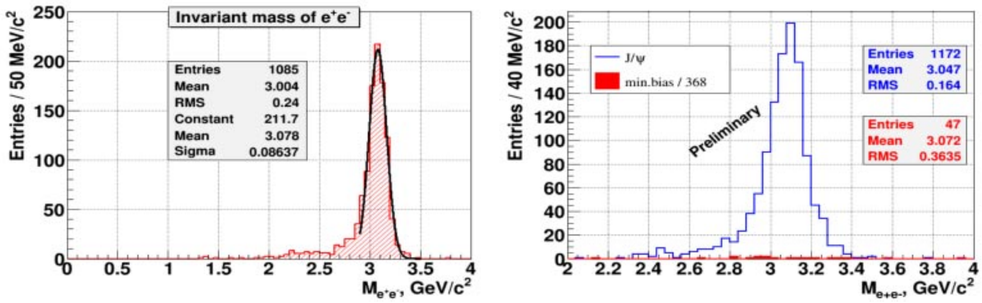

Fig. 5. – Left) reconstructed invariant mass of electron-positron pairs from J/ψ decays (signal); right) the same and minimum bias events (background), remaining after applying selection cuts (red). Note that only 1/368 part of all the minimum bias statistics was processed.

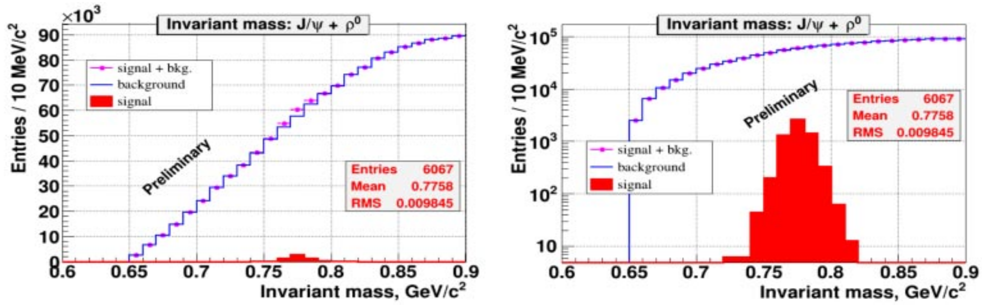

Fig. 6. – Invariant mass combination $M_{e^+e^-\pi^+\pi^-}$ - $M_{e^+e^-}$.

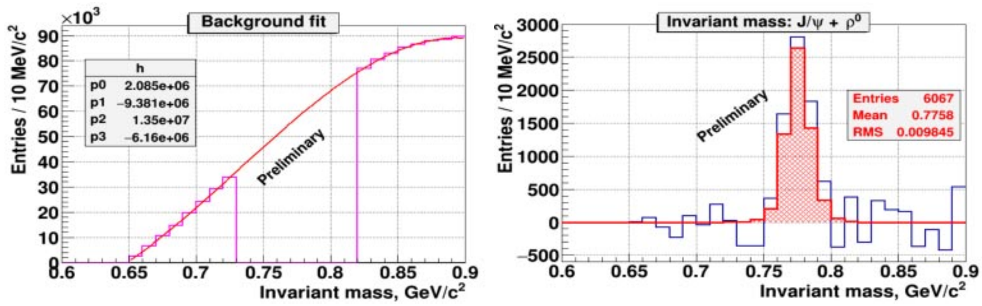

Fig. 7. – Left) Background estimation using the polynomial fit of the side bands of Fig. 6 (left); right) background - subtracted invariant mass combination from Fig. 6 (left) (blue line) and true X(3872) histogram (red line).

2. – Heavy flavor studies

Good tracking and particle identification performance of NICA SPD, estimated over a significant fraction of the final state phase-space events, can provide a good opportunity to extend its ambitious physics program to studies of heavy charmed objects via their decays to electrons, hadrons or photons. This can be illustrated by the PYTHIA8 [6] simulated data of heavy quarkonia production in p-p collisions at $\sqrt{s}$ ∼26 GeV. One can see from Fig. 1 that the detector acceptance for electron-positron pairs from J/ψ decays is quite high (∼80% for $|\eta|$ <1.5). The detector acceptance for photons from electromagnetic decays of heavy quarkonia can be seen in Fig. 2. It exceeds 80% for χ_{c1} and χ_{c2} decays. The momentum resolution for electrons and photons is presented in Figs. 3, 4. One can see that it will be possible to combine the momentum measurement of electrons in tracking detectors with energy measurement in the electromagnetic calorimeter to obtain better accuracy for fast particles. Signal reconstruction performance of the detector for $J/\psi \to e^-e^+$ decays was evaluated using the full simulation / reconstruction chain. As can be seen in Fig. 5, the J/ψ invariant mass peak is clearly visible.

3. – Reconstruction of X(3872) exotics

The exotic state X(3872) was simulated in PYTHIA8 under the assumption that it is a charmonium state and the branching ratio to $J/\psi + \rho^0$ was taken to be 5% [7]. As a result, the $e^+e^-\pi^+\pi^-$ final state branching ratio $\sim 3 \times 10^{-3}$ gives for the cross section of this channel the value of 12.2 pb which corresponds to ∼10 days of running time at the luminosity of 10^{32} cm^{-2}c^{-1} to produce ∼1000 events. To better separate 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 Fig. 6). Figure 6 also shows the background from events with charmonia production. The plots correspond to the statistics that will be collected in 10 months at 10^{32} cm^{-2}c^{-1}. After fitting the background in the side bands of the invariant mass distribution with a polynomial function and subtracting it from the original distribution it is possible to observe a clear peak from the X(3872) decay (Fig. 7).

As an extension of this topic one can consider to search for other decay modes of X(3872). Since the branching ratio of X(3872) to pairs of D-mesons is much higher (for D^+D^- it is ∼40% and for $D^0\bar{D}^{*0}$ it is ∼55%) one should try to evaluate the possibility to reconstruct this state from the hadronic decays of D-meson pairs. For such a study, the ability to tag the D-meson decays using the silicon microvertex detector is very important. Thus, this physics topic becomes synergetic to the heavy ion charm program of NICA.

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