

PROBING OF MULTIQUARKS STRUCTURE IN HADRON AND HEAVY ION COLLISIONS

The spectroscopy of charmonium-like mesons with masses above the $2m_D$ open charm threshold has been full of surprises and remains poorly understood [1]. The currently most compelling theoretical descriptions of the mysterious XYZ mesons attribute them to hybrid structure with a tightly bound $c\bar{c}$ diquark [2] or $cq(cq)\bar{c}$ tetraquark core [3 - 5] that strongly couples to S-wave $D\bar{D}$ molecular like structures. In this picture, the production of a XYZ states in high energy hadron collisions and its decays into light hadron plus charmonium final states proceed via the core component of the meson, while decays to pairs of open-charmed mesons proceed via the $D\bar{D}$ component.

These ideas have been applied with some success to the XYZ states [2], where a detailed calculation finds a $c\bar{c}$ core component that is only above 5% of the time with the $D\bar{D}$ component (mostly $D_0\bar{D}_0$) accounting for the rest. In this picture these states are composed of three rather disparate components: a small charmonium-like $c\bar{c}$ core with $r_{rms} < 1$ fm, a larger $D+D-$ component with $r_{rms} = \hbar/(2\mu+B)^{1/2} \approx 1.5$ fm and a dominant component $D_0\bar{D}_0$ with a huge, $r_{rms} = \hbar/(2\mu_0B_0)^{1/2} > 9$ fm spatial extent. Here μ and μ_0 and B and B_0 denote the reduced mass for the $D+D-$ ($D_0\bar{D}_0$) system and the relevant binding energy $|m_D + m_{\bar{D}} - M_X(3872)|$ ($B = 8.2$ MeV, $B_0 < 0.3$ MeV). The different amplitudes and spatial distributions of the $D+D-$ and $D_0\bar{D}_0$ components ensure that the $X(3872)$ is not an isospin eigenstate. Instead it is mostly $I = 0$, but has a significant ($\sim 25\%$) $I = 1$ component.

In the hybrid scheme, XYZ mesons are produced in high energy proton-nuclei collisions via its compact ($r_{rms} < 1$ fm) charmonium-like structure and this rapidly mixes in a time ($t \sim \hbar/\delta M$) into a huge and fragile, mostly $D_0\bar{D}_0$, molecular-like structure. δM is the difference between the XYZ meson mass and that of the nearest $c\bar{c}$ mass pole core state, which we take to be that of the $\chi_{c1}(2P)$ pure charmonium state which is expected to lie about 20 - 30 MeV above $M_X(3872)$ [6, 7]. In this case, the mixing time, $c\tau_{mix} \sim 10$ fm, is much shorter than the lifetime of $X(3872)$ which is $c\tau_{X(3872)} > 150$ fm [8].

The experiments with proton-proton and proton-nuclei collisions with $\sqrt{s_{pN}}$ up to 26 GeV and luminosity up to $10^{32} \text{ cm}^{-2}\text{s}^{-1}$ planned at NICA are well suited to test this picture for the $X(3872)$ and other XYZ mesons. In near threshold production experiments in the $\sqrt{s_{pN}} \approx 8$ GeV energy range, XYZ mesons can be produced with typical kinetic energies of a few hundred MeV (i.e. with $\gamma\beta \approx 0.3$). In the case of $X(3872)$, its decay length will be greater than 50 fm while the distance scale for the $c\bar{c} \rightarrow D_0\bar{D}_0$ transition would be 2 - 3 fm. Since the survival probability of an $r_{rms} \sim 9$ fm "molecular" inside nuclear matter should be very small, XYZ meson production on a nuclear target with $r_{rms} \sim 5$ fm or more ($A \sim 60$ or larger) should be strongly quenched. Thus, if the hybrid picture is correct, the atomic number dependence of XYZ production at fixed $\sqrt{s_{pN}}$ should have a dramatically different behavior than that of the ψ' , which is long lived compact charmonium state.

The current experimental status of XYZ mesons together with hidden charm tetraquark candidates and present simulations what we might expect from A-dependence of XYZ mesons in proton-proton and proton-nuclei collisions are summarized.

References

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