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Molecular-type hidden charm pentaquarks with an improved unitarization method

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The existence of the nucleonic pentaquark resonances $P_{c\bar{c}}(4312)^+$, $P_{c\bar{c}}(4380)^+$, $P_{c\bar{c}}(4440)^+$, $P_{c\bar{c}}(4457)^+$, $P_{c\bar{c}s}(4338)^0$ and $P_{c\bar{c}s}(4459)^0$, established by the LHCb collaboration, has been one of the major discoveries in hadron physics in the latest years. Most of these states (5 out of 6) can be understood as hadronic molecules, namely bound states of a sufficiently attractive meson-baryon interaction.

By unitarizing the scattering amplitude in the t-channel vector-meson exchange interaction model one can investigate the dynamically generated resonances. In the recent works [1,2] we revisited the procedure of the unitarized coupled-channel hidden gauge formalism, which has been a very successful approach in explaining many exotic hadrons in the charm and hidden charm sectors. Employing realistic regularization parameters, we predicted two double strangeness pentaquarks of molecular nature. Now we go further and propose an improved unitarization method. The unitarization procedure requires the regularization of the meson-baryon loop function, commonly done using either a cut-off ($G^{\rm CO}$) or dimensional regularization ($G^{\rm DR}$). Although both schemes should yield similar results, some unphysical structures in the T-matrix were found that could not be associated to any resonance or bound state. In [3] we introduce a novel hybrid loop function ($G^{\rm HY}$), which combines both dimensional and cut-off regularizations. This approach enables a cleaner analysis of the scattering amplitude by avoiding the generation of unphysical poles, while keeping the properties of the dynamically generated states unaltered. In particular, this improved procedure allows us to predict two new pentaquark states in the $S=-1$, $I=1$ sector [3,4].

These recently predicted molecular-type pentaquarks (two in $S=-2$, $I=1/2$ and two in $S=-1$, $I=1$) are dynamically generated in a very specific and unique way, via a strong non-diagonal attraction between the two heaviest meson-baryon channels [1,2]. This effect was overlooked before because other research groups were discouraged by the repulsive character of the diagonal kernel coefficients. Moreover, it is also possible that the complex structure of the scattering amplitudes obtained with both $G^{\rm DR}$ and $G^{\rm CO}$ - with unphysical structures - has obscured the physical states [3,4]. If that is the case, the hybrid loop function proposed in [3,4] proves very valuable as it simplifies the scattering amplitudes by only preserving the physical poles.

We hope that our work would stimulate experiments looking for these new pentaquark states, the discovery of which would enrich the family of observed exotic baryons.

[1] J.A. Marsé-Valera, V.K. Magas and A. Ramos, Phys. Rev. Lett. 130 (2023) no.9, 9.

[2] J.A. Marsé-Valera, V.K. Magas and A. Ramos, Phys. Rev. D 111 (2025) no.5, 5.

[3] E.E. Garcia Gonzales, Master Thesis, July 2025, U. of Sevilla & U. of Barcelona.

[4] E.E. Garcia Gonzales, V.K. Magas and A. Ramos, in preparation for publication.

Author: Prof. MAGAS, Volodymyr (University of Barcelona, Spain)

Co-authors: Mr GARCIA GONZALES, Erick (University of Barcelona, Spain); Prof. RAMOS, Àngels (University of Barcelona)

Presenter: Prof. MAGAS, Volodymyr (University of Barcelona, Spain)

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