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Hidden-charm and bottom meson-baryon molecules coupled with five-quark states

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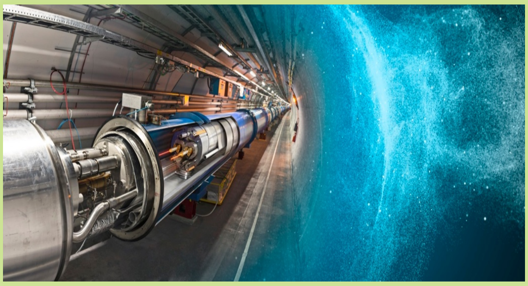
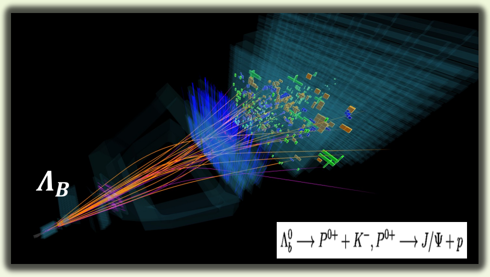
Background



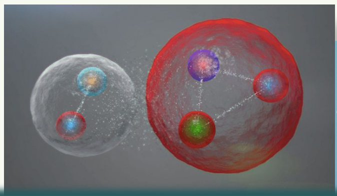
In 2015, the Large Hadron Collider beauty experiment (LHCb) collaboration observed two hidden-charm pentaquarks, $P_c^+(4380)$and $P_c^+(4450)$ in $\Lambda_B \to J/\psi K^- p$ decay [1].
These two pentaquark states are found to have masses of $4380 \pm 8 \pm 28$ MeV and $4449.8 \pm 1.7 \pm 2.5$ MeV, with corresponding widths of $205 \pm 18 \pm 86$ MeV and $39 \pm 5 \pm 19$ MeV.
The parities of these states are preferred to be opposite, and one state has J = 3/2 and the other J =5/2.

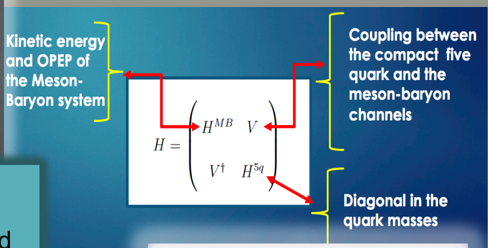


$\left(J^P_{P_c^+(4380)}, J^P_{P_c^+(4380)}\right) = \left(\frac{3}{2}^-, \frac{5}{2}^+\right)$ gives the best fit solution, but $\left(\frac{3}{2}^+, \frac{5}{2}^-\right)$ and $\left(\frac{5}{2}^-, \frac{3}{2}^-\right)$ are also acceptable.

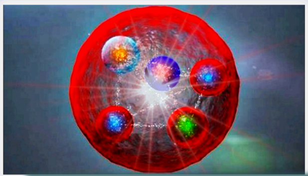
The Model

In the current problem of pentaquark, there are two competing sets of channels: the meson-baryon (MB) channels, which describe the dynamics at long distances and the five-quark (5q) channels, which describe the dynamics at short distances.





Meson-Baryon channels:
$\bar{D}\,\Lambda_c$,$\bar{D}^*\,\Lambda_c$,$\bar{D}\,\Sigma_c$,$\bar{D}^*\,\Sigma_c$,$\bar{D}\Sigma_c^*$ and $\bar{D}^*\Sigma_c^*$ **for the charmed sector and** $\bar{B}\,\Lambda_B$, $\bar{B}^*\,\Lambda_B$, $\bar{B}\,\Sigma_B$,$\bar{B}\Sigma_B^*$, $\bar{B}^*\,\Sigma_B$ and $\bar{B}^*\Sigma_B^*$ **for the bottom sector**



Compact five-quark channels

Thus, in order to take into account both the meson-baryon channels and the compact five-quark channels our model Hamiltonian, expanded by the open-charm MB and 5q channels, is written as [2]:

$$\begin{aligned} H^{MB}\psi^{MB} + V\psi^{5q} &= E\psi^{MB}, \\ V^\dagger\psi^{MB} + H^{5q}\psi^{5q} &= E\psi^{5q}. \end{aligned}$$

Solving the second equation for ψ_{5q}, $\psi_{5q} = \frac{V^+}{E-H^{5q}}$, and substituting for the first equation, we find the equation for ψ^{MB}:

$$\left(K^{MB} + V^\pi + V\frac{1}{E - H^{5q}}V^\dagger\right)\psi^{MB} = E\psi^{MB}.$$

The bound and resonant states are obtained by solving the coupled-channel Schrödinger Equation.

Results

Charmed sector

In figure 1 the bound and resonant state energies of the hidden-charm molecules are shown for different values of the coupling constant f/f_0.
f/f_0 is a free parameter which is proportional to the coupling strength between the Meson-Baryon and the compact five-quark channels.

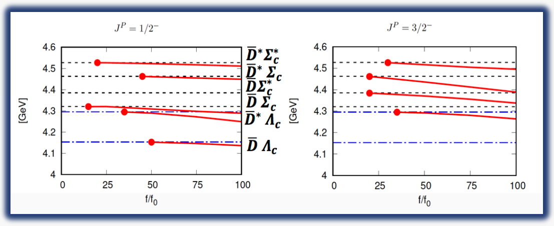


Figure 1: Bound and resonant state energies of the hidden-charm molecules (solid lines) with various coupling constants f. Dot-dashed lines are the $\bar{D}\,\Lambda_c$ and $\bar{D}^*\,\Lambda_c$ thresholds.

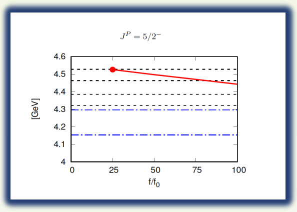


Figure 1: Dashed lines are the $\bar{D}\,\Sigma_c$,$\bar{D}\Sigma_c^*$, $\bar{D}^*\,\Sigma_c$ and $\bar{D}^*\Sigma_c^*$ thresholds. The lowest threshold $\bar{D}\,\Lambda_c$ is at 4153,46 MeV and the state whose energy is lower than the threshold is a bound state.

As one can see from Fig. 1, there are no resonant states and no bound states for $\frac{f}{f_0} = 0$.

In the hidden-charm sector the OPEP is not enough strong to produce bound and resonant P_c states.

Bottom sector

Many $\bar{B}\,\Lambda_B$ and $\bar{B}^*\,\Lambda_B$ bound states appear. Some $\bar{B}\,\Lambda_B$ bound states are produced even without introducing the five-quark potential !

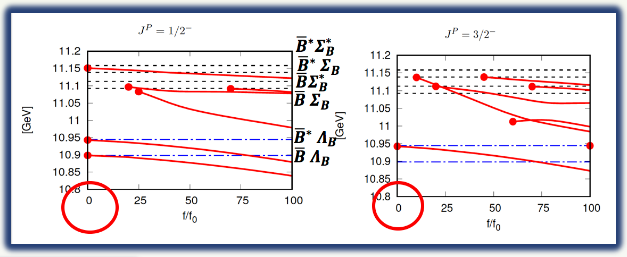
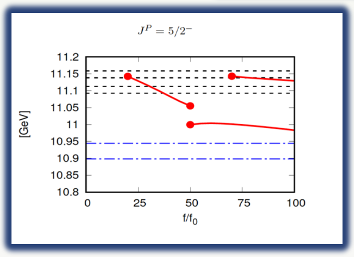


Figure 2: Dot-dashed lines are the $\bar{B}\,\Lambda_B$ and $\bar{B}^*\,\Lambda_B$ thresholds. Dashed lines are the $\bar{B}\,\Sigma_B$,$\bar{B}\Sigma_B^*$, $\bar{B}^*\,\Sigma_B$ and $\bar{B}^*\Sigma_B^*$ thresholds.



As a matter of fact in the bottom sector only the OPEP provides sufficiently strong attraction to generate several bound and resonant states. Moreover, many states appear, when the 5q potential is switched on.

Conclusion

The hidden-bottom pentaquarks are more likely to form rather than the hidden-charm pentaquarks. **The hidden-bottom sector is the more interesting environment to search the pentaquark states. For this reason, we suggested to the experimental people to look for further pentaquark states in the bottom region.**

References

[1] R. Aaij et al. (LHCb Collaboration), Phys. Rev. Lett. 115, 072001 (2015).
[2] Yasuhiro Yamaguchi, Alessandro Giachino, Atsushi Hosaka, Elena Santopinto, Sachiko Takeuchi, Makoto Takizawa, Phys. Rev. D96 (2017) no. 11, 114031.