b Decays : a Factory for Hidden Charm Multiquarks.

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Corfu' September 1-9 2018

Summary

1) MASS SPLITTINGS FOR THE ORDINARY HADRONS DESCRIBED BY THE CHROMOMAGNETIC INTERACTION.

2) FORMATION OF THE HIDDEN CHARM MULTIQUARKS STARTING BY THE CABIBBO FAVORED DECAY : $b \to cs\bar{c}$.

3) MASS OF THE $(\frac{5}{2})^+$ DISCOVERED AT LHC_b AND SPECTRUM OF THE FOUR $(\frac{3}{2})^-$ PREDICTED BY THE CHROMOMAGNETIC INTERACTION .

4) "OPEN CHANNEL" $\Lambda_c \bar{D}_0^*$ AND $\Sigma_c \bar{D}^*$ FOR THE FOUR $(\frac{3}{2})^-$ STATES .

5) THE RELATIVE LONG LIFETIME OF PARTICLES WITH "BEAUTY" MAKES EASIER THE DISCOVERY OF MULTIQUARKS WITH HIDDEN CHARM .

6) CONCLUSIONS

HADRONS MASS DIFFERENCES DESCRIBED BY THE CHROMOMAGNETIC INTERACTION

Accepting the proposal that QCD is the theory of strong interactions, De Rujula, Georgi and Glashow realized that the fine structure, the chromomagnetic interaction (CMI) accounts for the mass differences between Δ and the nucleon and between Σ and the Λ. In this framework, there is the successful prediction :

$$M(\Xi^*) - M(\Xi) = M(Y^*) - M(\Sigma)$$

which had been previously obtained, by assuming the same coefficients for the terms transforming both as an octet for the decuplet and the octet of baryons. Applying the same approach to the charmed baryons Σ_c and Λ_c, they predicted a mass difference high enough to allow the strong decay $\Sigma_c^+ \to \Lambda_c + \pi^+$, in agreement with the discovery of both particles in a neutrino experiment .

HADRONS MASS DIFFERENCES DESCRIBED BY THE CHROMOMAGNETIC INTERACTION

Indeed, the masses of these two particles are reproduced with :
(i) the gyro-chromo-magnetic factors $k_c = 0.24$; $k_u = k_d = 1$ and
(ii) with an effective mass for the charmed quark 1715 MeV.
The Σ_b and Λ_b particles have a mass difference even larger, as expected.
A mass of 3621.40 MeV of the Ξ_{cc}^{++} recently found by $LHCb$ implies an effective mass of the constituent charmed quarks of 1665 MeV, somewhat smaller than the one found for the charmed mesons and Λ_c. This is in keeping with the fact that, for the mesons (π, K ρ, K^*), one obtains their masses with a larger effective CMI and smaller effective masses for the light and the strange quarks.

HADRONS MASS DIFFERENCES DESCRIBED BY THE CHROMOMAGNETIC INTERACTION

Both these properties can be understood by the more intense chromo-electric attraction between a quark and an antiquark, which form a color singlet with respect to two quarks, which combine in a $\bar{3}$ of SU(3) color. Indeed, the stronger attraction implies a smaller constituent mass and a larger contact interaction. In fact, for the charmed mesons D and D^*, a slightly smaller mass, 1615 MeV, and larger $k_c = 0.26$ are needed with respect to the charmed baryons. Also, the values found for the $c\ \bar{c}$ states, 1535 MeV for the mass of the charmed quark and $K_c^2 = 0.186$ for the square of the gyro chromo-magnetic factor can be understood as a consequence of the smaller distance between the constituents.

HADRONS MASS DIFFERENCES DESCRIBED BY THE CHROMOMAGNETIC INTERACTION

For the two nonets of scalar tetraquarks, where the states built with the light constituents are the $f^0(600)$ and $f^0(1370)$, their masses are reproduced with an effective chromo-magnetic interaction as for the baryons and with a larger constituent mass. Interestingly enough, this explains why the lowest one, which decays into two pions, has a very large width, while the other one decays mainly into four pions as shown by Mario Gaspero. In fact, the $SU(6)_{cs}$ Casimir, which gives the most important contribution to the masses, implies that the lighter state is almost a $SU(6)_{cs}$ singlet with an "open channel", a concept introduced by Robert Jaffe, into two pions, which are also $SU(6)_{cs}$ singlets, while the heavier one transforms mainly as a 405 and therefore has an open channel into a pair of ρ mesons, which transform as a 35 of $SU(6)_{cs}$ color spin.

We may be confident that also the pentaquark states are eigenvectors of the chromo-magnetic interaction.

A general analysis of the spectrum of negative and positive pentaquarks built with the three lightest quarks and the study of $3q\ 3\bar{q}$ hexaquarks can be found in previous works .

THE b DECAY INTO A PAIR $c\bar{c}$ AND A STRANGE QUARK

The decays :

$B^- \rightarrow J/\psi + \rho^0(\omega) + K^-$

$\Lambda_b \rightarrow p + J/\psi + K^-$

start from the Cabibbo allowed non-leptonic decay :

$b \rightarrow c + s + \bar{c}$

and to produce the needed number of constituents followed by the emission by the strange quark of a gluon, which gives rise to a pair of light $q\bar{q}$ pair in the first case and to a $u\bar{u}$ pair in the second case.

THE b DECAY INTO A PAIR $c\bar{c}$ AND A STRANGE QUARK

In the first case the s produced in the weak decay combines with the spectator $\bar{u}$ to form the final K^-, while the $c\bar{c}$ pair and the light pair, octets of color, give rise to the $3872, 1^+$ tetraquark with hidden charm . In the second case the strange quark forms the K^- together with the $\bar{u}$ produced by the gluon, while the u together with the spectator scalar diquark in the Λ_c forms an octet of color with isospin $\frac{1}{2}$, which together with the $c\bar{c}$ color octet forms the hidden charm pentaquarks seen by LHC_b

THE b DECAY INTO A PAIR $c\bar{c}$ AND A STRANGE QUARK

In fact the current × current product :

$\bar{c}_L\gamma_\mu b_L\bar{s}_L\gamma^\mu c_L$

is a combination of :

$\bar{c}_L\gamma_\mu c_L\bar{s}_L\gamma^\mu b_L$

and

$\bar{c}_L\gamma_\mu\lambda_a b_L\bar{s}_L\gamma^\mu\lambda_a c_L$

giving rise to the amplitude for the "golden decay" for CP violating asymmetries and to the first step of the production of the hidden charm multiquarks, respectively.

THE FORMATION OF THE MULTIQUARKS

The mechanism proposed for the formation of the $3872, 1^+$ holds only for its neutral components and indeed its charged partners have not been seen. As long as for the hidden charm multiquarks we assume that the $(\frac{3}{2})^-$ and the $(\frac{5}{2})^+$ are formed by the two color octets built with the light quarks and with the $c\bar{c}$ pair in S-wave or in P-wave, respectively. In the first case we look for the eigenvectors of the chromomagnetic interaction in a space of dimension 4, since the total spin $\frac{3}{2}$ can be obtained with a spin $\frac{3}{2}$ for the light quarks or with a spin $\frac{1}{2}$ for the light quarks and 1 for the $c\bar{c}$ pair. In this case one has both the possibility of $(8 \times 8)_1$ and the "open channel" for the decay into $p + J/\psi$ 1×1 for the color.

THE 4 $\frac{3}{2}^-$ STATES

Isospin conservation requires that the three light quarks in the pentaquark with hidden charm have isospin $\frac{1}{2}$, whic corresponds to a mixed symmetry. Therefore, if their spatial wave function is symmetric, they should transform under $SU(6)$ color spin as a 70, which has a mixed symmetry, in order that their total wave function is totally antisymmetric.
Remember the rules for the permutation group of three objects :
$S \times M = M$, $M \times M = S + M + A$ and $A \times M = M$

The 70 of $SU(6)$ decomposes under $SU(3) \times SU(2)$ as $10 + 8 + 1, \frac{1}{2}$ $+\ 8, \frac{3}{2}$. The pair $c\bar{c}$ may transform as $35 + 1$ decomposing as $8 + 1, 3 + 1$.

THE 4 $\frac{3}{2}^-$ STATES

To build a color singlet total spin $\frac{3}{2}$, one has the following 4 possibilities :

$8, \frac{3}{2} \times 8, 1 \ \ 8, \frac{3}{2} \times 8, 0 \ \ 8, \frac{1}{2} \times 8, 1$

and the "open channel" for the decay into $p + J/\psi$:

$1, \frac{1}{2} \times 1, 1$

We shall diagonalize the chromomagnetic interaction in that basis.

THE 4 $\frac{3}{2}^-$ STATES

We shall keep into account the different strength of the chromomagnetic interaction between the light quarks, of their interaction with the charm quark ant its antiparticle and of the interaction between c and $\bar{c}$ with the factors k_1, k_2 and K_c^2 introduced for the charmed baryons, the charmed mesons and the charmonia. As a result we get the following eigenvalues (in MeV) and eigenvectors.

EIGENVALUES AND EIGENVECTORS OF THE CMI

- 120 for (.057, .08, .59, .624)

- 71 for (.225, .063, .604, -.762)

+ 11 for (.39, .847, .35, -.094)

+ 80 for (.736, -.522, -.041, -.15)

The "open channel" $p+J/\psi$ corresponds to the fourth state and has negligible components along the two eigenvectors corresponding to the two higher eigenvalues and substantial along to the two lower ones. This agrees with the mass of the $\frac{3}{2}^-$ if the sum of the constituent masses is 4480 MeV with the consequence of predicting the spectrum :

4360, 4409, 4491 and 4560 MeV.

OPEN DECAYS INTO $\Lambda_c + \bar{D}^{*0}$ and $\Sigma_c + \bar{D}^*$

The two lower states have components mainly along the states with total spin of the light quarks $\frac{1}{2}$. Therefore, if we consider the combinations $qqc\ q\bar{c}$, for the state $\Lambda_c + \bar{D}^{*0}$ the total spin of the light quarks is $\frac{1}{2}$ (the total spin of two light quarks in the Λ_c is 0) and it will be an "open channel" for the two lighter states, the same with "open channel" $p + J/\psi$. Instead it can been shown that the $\Sigma_c + \bar{D}^*$ has components mainly along the states with total spin of the light quarks $\frac{3}{2}$ and therefore will be an open channel for the two heavier states.

As long for the $(\frac{5}{2})^+$ it is expected to be narrow, since its decay into $p + J/\psi$ needs the exchange of a gluon, as it is the case for the decay of the $3872, 1^+$ into $J/\psi + \rho_0(\omega)$.

ADVANTAGE OF THE LONG LIFETIME OF THE BEAUTIFUL PARTICLES

The long lifetime of the beautiful particles has the consequence that they decay at a distance from the point, where they are produced, sufficient to the extent that the quarks produced by their decay are not surrounded by the pairs produced by the gluons created in the interaction.

Therefore the recombination of the spectator quarks of the weak decay $b \to c + s + \bar{c}$, the quarks and the antiquark produced in the decay and the pair produced by the gluon emitted from one of them may combine to form hidden charm multiquarks and not to form ordinary hadrons with the quarks and the antiquarks produced in the interaction.

CONCLUSIONS

1) The mechanism proposed for the production of the hidden charm pentaquarks produced at LHC_b implies the existence of four $(\frac{3}{2})^-$, the two lower with "open channel" into $p + J/\psi$ and $\Lambda_c + \bar{D}^{*0}$ and the two higher with "open channel" into $\Sigma_c + \bar{D}^*$.

2) The long lifetime of the beautiful particles allows the final constituents of their decay with a production of a single gluon to give rise to hidden charm multiquarks far from the quarks and the antiquarks produced in the interaction point.

3) The small width of the $(\frac{5}{2})^+$ and the small branching ratio of the $3872, 1^+$ into $J/\psi + \rho_0(\omega)$ are explained by the gluon exchange necessary to produce the final states. The mechanism for the production of the $3872, 1^+$ works only for the production of the neutral vector mesons.

SUMMARY

We assume that the two hidden charm pentaquark states discovered at $LHCb$ are built from three light quarks and a $c\bar{c}$ pair. Further assumed is that the three light quarks and the $c\bar{c}$ pair are both in color octet states. Thus, for the final $J^P = \frac{5}{2}^+$ state, the three light quarks and the $c\bar{c}$ pair are in a relative P-state, whereas the five constituents are in a relative S-state forming the four $J^P = \frac{3}{2}^-$ states, the four eigenstates of the chromo-magnetic Hamiltonian with masses 4360, 4409, 4491 and 4560 MeV. The "open channel" $[p+ J/\psi]$ has *large* components along the two lower mass states and they thus appear as a resonance with a mass 4380 MeV, whereas $[\Lambda_c \bar{D}^*]$ and $[\Sigma_c \bar{D}^*]$ are "open channels" respectively for the two lowest and the two highest mass resonances, respectively. The small width of the 5/2$^+$ state is due to the fact that its decay requires one-gluon exchange. The decays of particles with beauty furnish the best experimental technique for discovering multi-quark states with hidden charm. Also, the mechanism of production proposed here explains why only a few states with non-minimal constituents have been discovered so far.