Hidden properties of meson and baryon masses and widths

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Abstract

Regular oscillations, observed in masses and in widths in mesons and baryons, are systemically studied. The observed periods are compared and discussed. It is observed that the same fit is often able to describe different data, involving hidden properties between mesons and baryons.

1. Introduction

A new property between masses then widths of bodies, belonging to the same particle family and submitted to opposite interactions, has been recently pointed out. By analogy with classsical physics where such situation leads to oscillations, it has been shown that the same property is generally observed and is verified in very small quantum bodies like fundamental particles and also in very large bodies as astrophysical. This property was named Oscillation Symmetry.

More precisely oscillations where observed in masses and widths of mesons and baryons [1], also observed in masses and widths in fundamental and exited state nuclei [2], [3]. They were also observed in several astrophysical properties [4], [5].

Here, the same approach is applied to the systematic study of masses and widths of mesons and baryons [6], provided that the number of data is not too small. The justification of the similarity with classical physics is reasonable for the masses since they result from Schrödinger equation with two opposite interactions, namely kinetic and potential. This is not

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the case for widths but all previous studies quoted before show that they also exhibit oscillatory shapes.

We study the differences between adjacent data values versus their corresponding mean values.

$$m_{(n+1)} - m_n = f[(m_{(n+1)} + m_n)/2]$$

where $m_{(n+1)}$ corresponds to the (n+1) mass (or width) value. The function displays the successive data differences, plotted versus the mean data value of both data (n) and (n+1). The values obtained using previous equation will be named "mass data" below. When studied, the widths are plotted versus the corresponding masses. The figures show the resulting fits obtained using the following distribution with three adjustable parameters: α, M_1, and β:

$$\Delta M = \alpha(1 + cos((M - M_0)/M_1)) * exp(\beta.M)$$

The ocillation periods are P = 2 πM_1. The fit parameters are given in the forthcoming tables. M_0 is arbitrary, therefore supressed. The largest possible periods are kept.

2. Mesons

Some studies of oscillations in meson masses and widths have been presented in earlier works [1]. However slightly modified data and (or) new data justified a new improved analysis. These used data are read in [6]. Hadron spectroscopy improves constantly, especially for the heavier ones, therefore the presented analyzes are subject to possible later modifications.

2.1. Unflavoured mesons

Fig.1 shows the "mass data" of f_0 and f_2 mesons in inserts (a) and (b), and their total widths versus masses in inserts (c) and (d). The data are well fitted with nearly the same periods (see Table A1). The maximum dispersion is 5% around the mean period P=370 MeV.

Fig.2 shows the "mass data" of η and ρ mesons in inserts (a) and (b), and their total widths versus masses in inserts (c) and (d). The data are

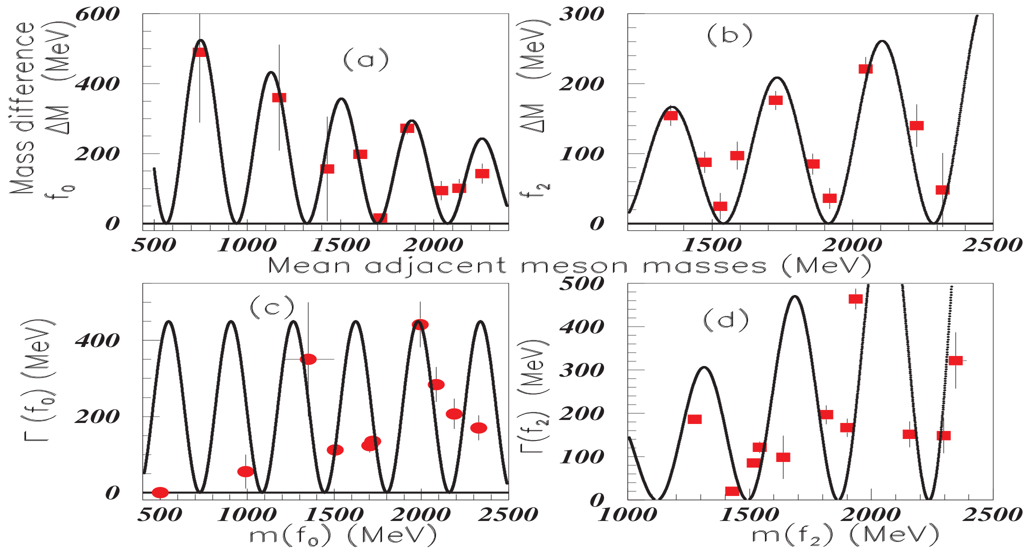

Figure 1: Color on line. Inserts (a) then (b) show the "mass data" of the f_0 then f_2 unflavoured mesons. Inserts (c) then (d) show the corresponding total widths versus masses.(See text)

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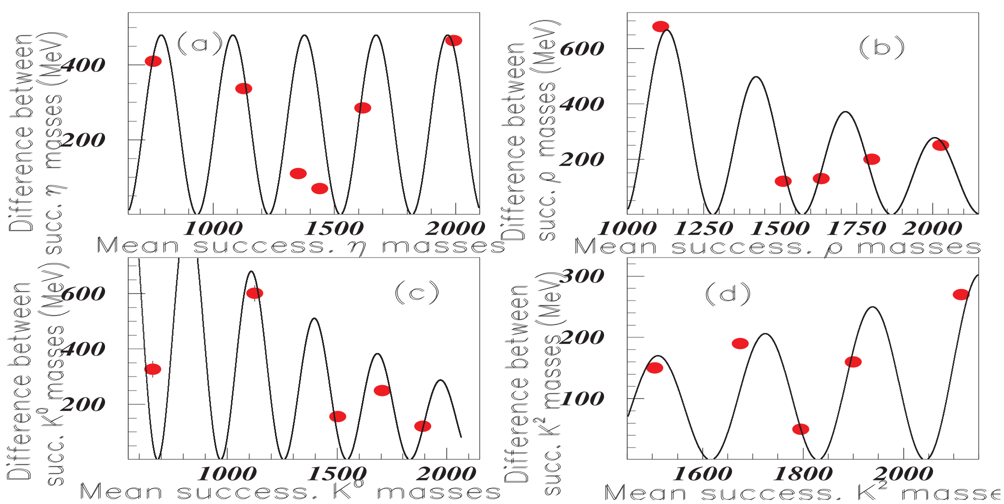

Figure 2: Color on line. Inserts (a) then (b) show the "mass data" of the η then ρ unflavoured mesons. Inserts (c) then (d) show the corresponding total widths versus masses. (See text)

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well fitted with nearly the same periods for both mesons but different for "mass data" and widths (see Table A1). The periods for masses are lower than the periods for widths, but in both cases they are nearly the same for both mesons. A peculiar relation is observed between the η and the ρ

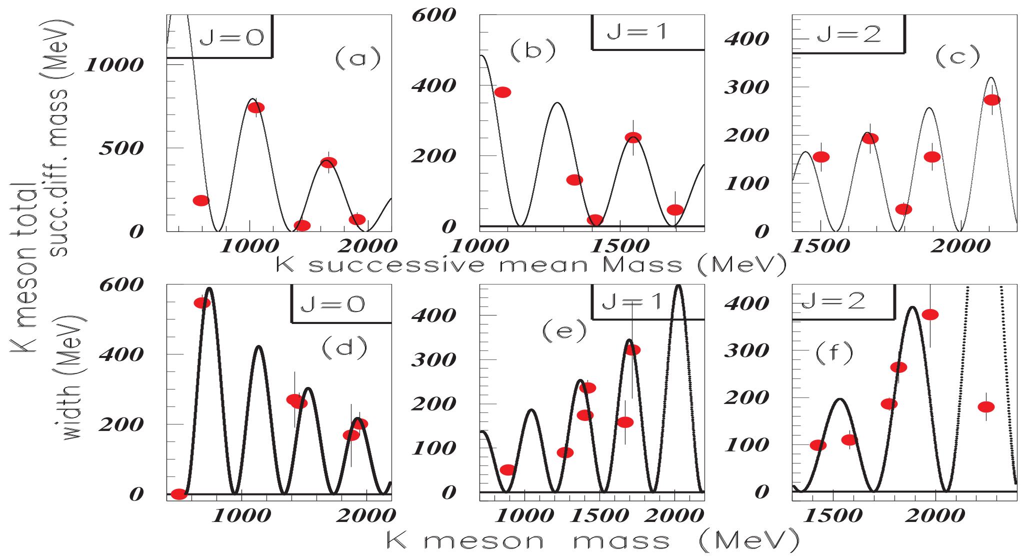

Figure 3: Color on line. Inserts (a), (b), and (c) show the "mass data" of the strange mesons with spins respectively J=0, 1, and 2. Inserts (d), (e), and (f) show the corresponding total widths versus masses. (See text)

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periods:

$$(\mathrm{P}_{\eta\ \text{"}mass\text{"}} * \mathrm{P}_{\eta\ width}) \;/\; (\mathrm{P}_{\rho\ \text{"}mass\text{"}} * \mathrm{P}_{\rho\ width}) \simeq 1$$

Only three ω meson masses are reported preventing to do the same analysis. This is also the case for other unflavoured mesons.

2.2. Strange mesons

Fig. 3 shows in inserts (a), (b), and (c) the "mass data" and fits for J=0, 1, and 2 for strange mesons, and in inserts (d), (e), and (f) the corresponding widths. The data are well fitted in all six inserts.

2.3. Charmed and Charmed strange mesons

The analysis of the Charmed and Charmed-strange mesons [6][7] are shown in fig. 4. Inserts (a) and (b) correspond to "mass data" and fits, inserts (c) and (d) show the widths and fits plotted versus their masses. The periods of Charmed-strange mesons are larger than the periods of Charmed mesons. A peculiar relation is observed between these four periods:

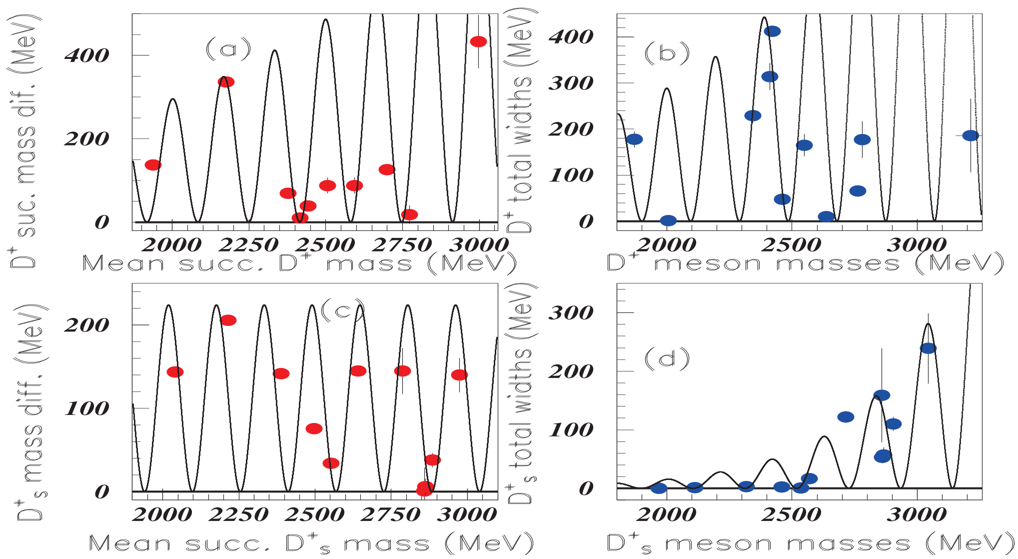

Figure 4: Color on line. (See text). Inserts (a) and (b) show the "mass data" for D^+ and D^+_S mesons. Inserts (c) and (d) show the total widths of the D^+ and D^+_S mesons versus the corresponding masses.

$$(P_{D \text{ "}mass\text{"}} * P_{D_S \text{ "}mass\text{"}}) \; / \; (P_{D\ width} * P_{D_S\ width}) \simeq 1$$

2.4. Bottom and Bottom, Strange mesons

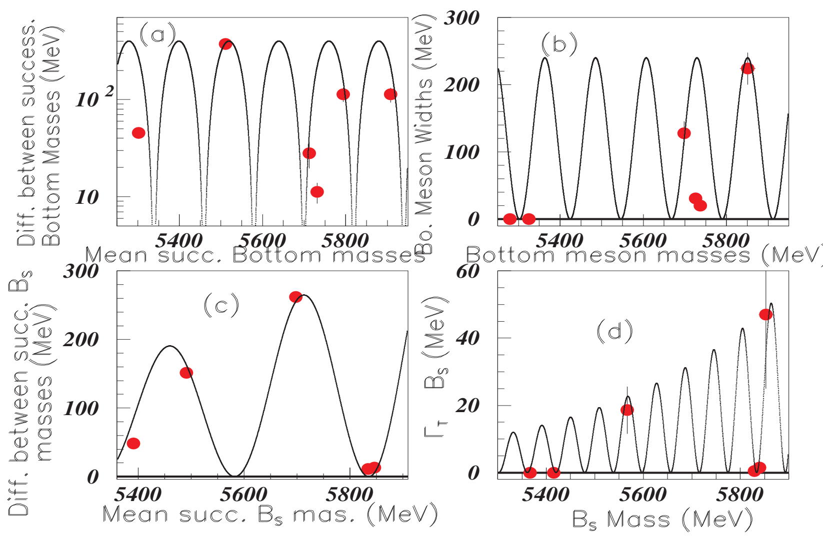

Figure 5: Color on line. (See text). Insert (a) shows the bottom "mass data", insert (b) shows the bottom widths versus the bottom masses. Inserts (c) and (d) show the "mass data", then total width for the strange bottom baryon data.

Fig.5 shows in inserts (a) and (b) the "mass data" then total widths of the Bottom mesons. Inserts (c) then (d) show the "mass data" then total widths of the Bottom, Strange mesons. Here a relation different from the one observed previously for η and ρ masses is observed between the four periods:

$$(\mathrm{P}_{B\ \text{"}mass\text{"}} * \mathrm{P}_{B\ width}) \ / \ (\mathrm{P}_{B_S\ \text{"}mass\text{"}} * \mathrm{P}_{B_S\ width}) \simeq 1$$

These four periods are approximately multiples of 60 MeV. As written before, we keep the largest possible periods. We observe that a reduction by a factor two of the period in fig. 5(b), will allow to describe the data around M=5740 MeV.

2.5. Charmonium and Bottomonium mesons

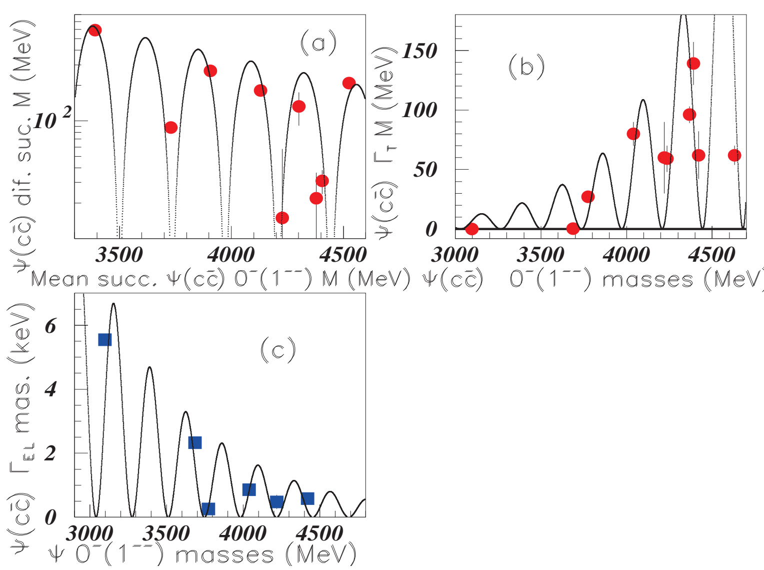

Figure 6: Color on line. (See text). Inserts (a), (b), and (c) show respectively the $c\bar{c}$ "mass data", the $c\bar{c}$ total widths, and the $c\bar{c}$ eletromagnetic widths.

Fig. 6 shows in inserts (a), (b), and (c) respectively the "mass data" of the charmonium $c\bar{c}$ $0^-(1^{--})$ mesons, their total widths versus the corresponding masses, and the electromagnetic Γ_{ee} widths versus the corresponding masses [2]. All three data are well fitted with the same period P=235.6 MeV. The total widths for masses lower than the mass of the charmonium disintegration into two charmed mesons are very small.

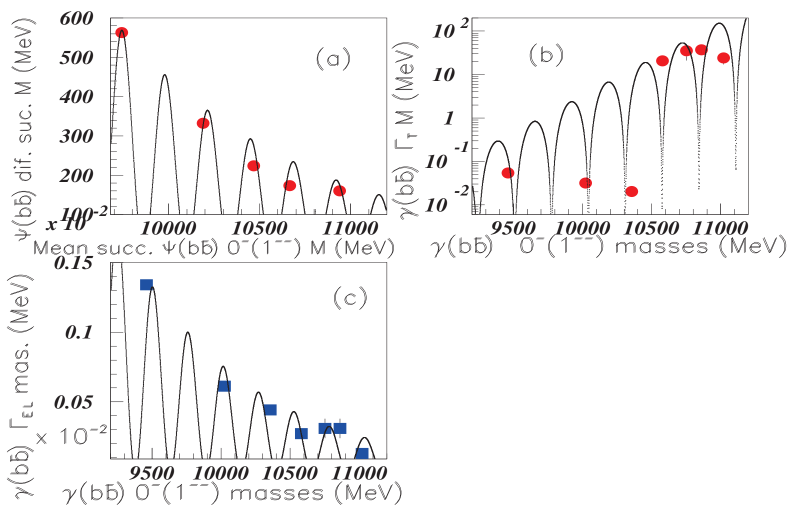

Figure 7: Color on line. (See text). Insert (a) shows the mass data of the $b\bar{b}$ $0^-(1^{--})$ mesons. Insert (b) shows the total widths of the same mesons plotted versus the corresponding masses. Insert (c) shows the electromagnetic widths of the same mesons.

Fig. 7 shows in inserts (a), (b), and (c) respectively the "mass data" of the Upsilon $b\bar{b}$ $0^-(1^{--})$ mesons, their total widths versus the corresponding masses, and the electromagnetic Γ_{ee} widths versus the corresponding masses [6] [2]. The large masses involve large α parameter value for insert (a): α=2.7 10^6.

Fig. 8 shows with red full circles the total widths of the $0^-(1^{--})$ charmoniums plotted versus the coresponding masses. In order to compare these data with bottomonium data shown with full blue squares, these last are translated by -6363 MeV, difference between fundamental $0^-(1^{--})$ $b\bar{b}$ and $0^-(1^{--})$ $c\bar{c}$ masses. The total corresponding widths are plotted versus resulting bottomonium masses. Insert (a) corresponds to $0^-(1^{--})$ mesons. Insert (b) corresponds to $1^+(1^{+-})$ mesons. The same parameters allow to fit the data in insert (b), except the α parameter which is multiplied by 1.5. All data of this fig. are well fitted. First data have very small widths, since their masses are lower than the corresponding $q\bar{q}$ masses.

Fig. 9 shows the total widths of charmonium mesons versus their masses. The quantum numbers are defined with the following markers: $\star$ $0^-(1^{--})$; $\bullet$ $0^+(1^{++})$; $\circ$ $0^+(0^{++})$; $\diamond$ $1^+(1^{+-})$; $\star$ $0^-(1^{+-})$; $\star$ $0^-(1^{+-})$; full$\triangle$ $0^+(?^?)$; full$\bigtriangledown$ $0^-(3^{--})$; $\circ$ $1^+(?^?)$; empty black square $0^-(2^{--})$; and full blue square $0^+(2^{++})$.

All data of fig. 9 are well fitted by the same curve.

The widths of other than ($b\bar{b}$) $0^-(1^{--})$ mesons are unknown.

Fig. 10 shows the $b\bar{b}$ "mass data" differences between successive masses versus the correponding mean masses of: $b\bar{b}$ $0^-(1^{--})$ with full black circles, $0^+(1^{++})$ with full red cirles, $0^+(2^{++})$ with blue full squares, $0^-(1^{+-})$ with green star, $0^+(0^{++})$ with red empty circle, and $1^+(1^{+-})$ with green empty diamond-shaped encircled by empty black square.

2.6. Mesons Containing Two Heavy Quarks

The spectroscopy of mesons containing two heavy quarks is presented in [6] through three tables giving the masses of new states below the open-flavour thresholds in the $c\bar{c}$, $c\bar{b}$, and $b\bar{b}$ regions, new states near the first open-flavour thresholds in the $c\bar{c}$, and $b\bar{b}$ regions, and new states above the first open-flavour thresholds. Fig. 11 use all these "data". A poor agreement between data and curve is observed, eventually related to data belonging to different families.

All meson fit parameters are reported in Table A1.

3. Baryons

3.1. N and Delta baryons

Fig.12(a) shows the "mass data" of the N* J=1/2 baryons. Fig.12(b) shows the "mass data" of the N* J=3/2 baryons. Fig.12(c) shows the total widths of Breit-Wigner data of the N* J=1/2 baryons. Fig.12(d) shows the total widths of Breit-Wigner data of the N* J=3/2 baryons.

Fig.13(a) shows the "mass data" of the Δ J=1/2 baryons. Fig.13(b) shows the "mass data" of the Δ J=3/2 baryons. Fig.13(c) shows the total widths of Breit-Wigner data of the Δ J=1/2 baryons. Fig.13(d) shows the total widths of Breit-Wigner data of the Δ J=3/2 baryons. The curves agree entirely with all data in fig.13.

Fig. 14 shows the previous values of N* and Δ baryons: "mass data" in insert (a) and widths in insert (b). Full red circles show the N* J=1/2 data, full blue squares show the N* J=3/2 data, full green stars show the Δ J=1/2 data, and purple squares show the Δ J=3/2 data. Almost all values are well fitted by unique curves. In insert (a), the curve in mass region

Table A1: Quantitative values of the mesons fit parameters

Fig.	Physics	α (MeV)	β (MeV)	P (MeV)
1(a)	f_0 "mass"	385	$-5.1*10^{-4}$	377
1(b)	f_2 "mass"	37	0.0006	373.5
1(c)	f_0 width	225	0	358.1
1(d)	f_2 width	34	$1.15*10^{-3}$	372
2(a)	η "mass"	240	0	295.3
2(b)	ρ "mass"	400	-0.001	292.2
2(c)	η width	1.0	2.7510^{-3}	345.6
2(b)	ρ width	205	0	351.9
3(a)	K^0 "mass"	1120	-0.001	622
3(b)	K^1 "mass"	813	-0.0012	270.2
3(c)	K^2 "mass"	19.5	0.001	219.9
3(d)	K^0 width	550	-0.00084	395.8
3(e)	K^1 width	35	0.00094	326.7
3(f)	K^2 width	5.1	0.00194	355
4(a)	D^+ "mass"	20	0.001	165.9
4(b)	D_S^+ "mass"	16	0.0011	194.8
4(c)	D^+ width	112	0	157.1
4(d)	D_S^+ width	0.03	0.00278	207.3
5(a)	B "mass"	200	0	120.2
5(b)	B width	120	0	121.9
5(c)	B_S "mass"	0.079	0.0013	253.2
5(d)	B_S width	$3.35*10^{-6}$	0.0027	59.1
6(a)	$c\bar{c}$ Ψ $0^-(1^{--})$ "mass"	8500	$-9.7*10^{-4}$	235.6
6(b)	$c\bar{c}$ Ψ $0^-(1^{--})$ Γ_T	$5*10^{-6}$	$2.27*10^3$	235.6
6(c)	$c\bar{c}$ Ψ $0^-(1^{--})$ Γ_E	0.38	$-1.5*10^{-3}$	235.6
7(a)	$b b$ Υ $0^-(1^{--})$ "mass"	$2.7 *10^6$	$-9.4*10^{-4}$	235.6
7(b)	$b\bar{b}$ Υ $0^-(1^{--})$ Γ_T	$1.9 * 10^{-17}$	$3.9*10^{-3}$	266.7
7(c)	$b\bar{b}$ Υ $0^-(1^{--})$ Γ_E	23	$-1.1*10^{-3}$	255.7
8(a)	$c\bar{c}$+$b\bar{b}$ width	0.12	$1.48*10^{-3}$	292.2
8(b)	$c\bar{c}$+$b\bar{b}$ width	0.18	$1.48*10^{-3}$	292.2
9	$q\bar{q}$ widths	$1.4*10^{-3}$	$2.5*10^3$	152.1
10	$b\bar{b}$ "mass"	$9.67*10^4$	$-6*10^{-4}$	326.7
11	2 Heavy quarks"mass"	96	0	169.6

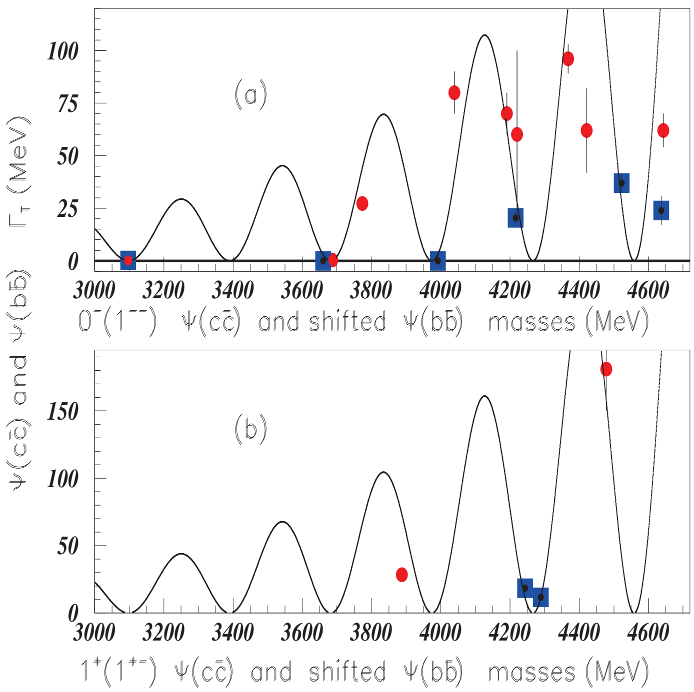

Figure 8: Color on line. (See text). Total widths of $c\bar{c}$ mesons (red full circles) and shifted $b\bar{b}$ meson masses by tr=-6363.4 MeV (blue full squares), plotted versus their corresponding masses. Insert (a) shows $0^-(1^{--})$ data, insert (b) shows $1^+(1^{+-})$ data.

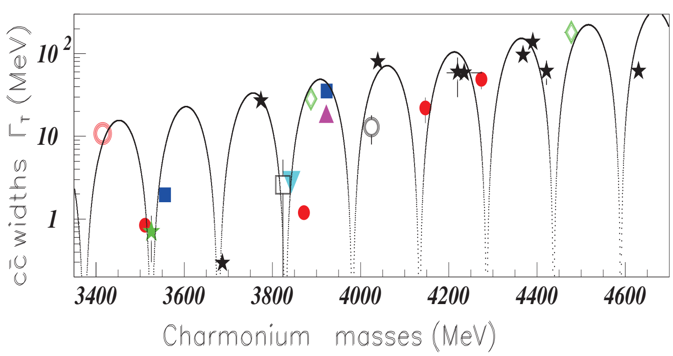

Figure 9: Color on line. (See text). Total widths of $q\bar{q}$ mesons plotted versus their corresponding masses.

around M=1600 MeV describes poorly the data. However the "global fits" display clear connexions between "mass data" then widths of both spins and both isospins of unflavoured baryons. The width periods are smaller than those obtained for separated N* and Δ, a consequence of more and

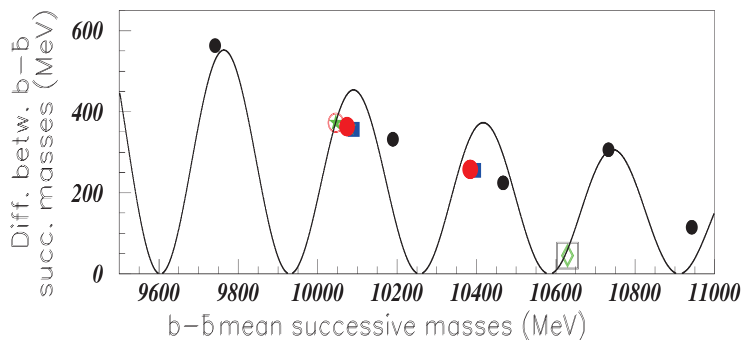

Figure 10: Color on line. "Mass data" for several $b\bar{b}$ meson quantum numbers (See text).

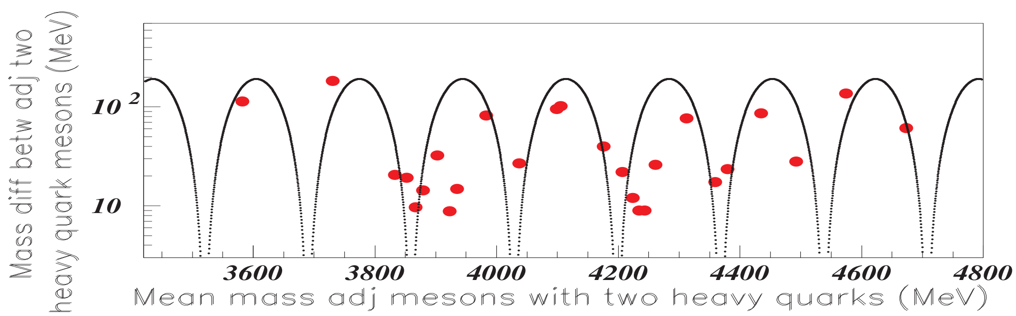

Figure 11: Color on line. (See text). Mean mass adj. mesons with two heavy quarks (MeV).

dispersed data. The α and β values in both inserts are obtained with a translation in fits by -900 MeV in order to get not too small (less precises) values.

3.2. Charmed Baryons

3.3. Λ and Λ_C baryons

Fig. 15 shows the "mass data" (in insert (a)) and widths spectra (in insert (b)) of Λ (full red circles) and Λ_C (full blue squares).

3.4. Ξ and Ξ_C baryons

Fig.16 shows for Ξ and Ξ_C baryons the "mass data" (in inserts (a) and (b)) then widths (in inserts (c) and (d)), and fits. The periods of Ξ_C M and Γ are quite the same and are lower than the periods for Ξ M and Γ.

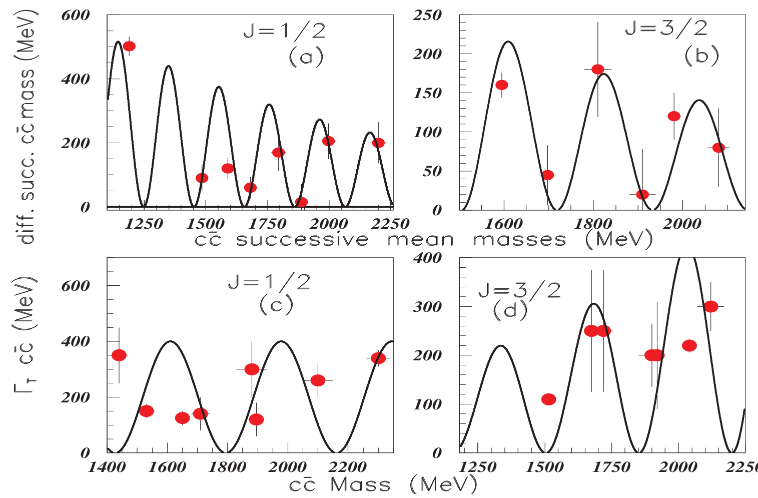

Figure 12: Color on line. "Mass data" of J=1/2 and J=3/2 N^* baryons in inserts (a) and (b). Widths versus masses of J=1/2 and J=3/2 baryons in inserts (c) and (d).(See text).

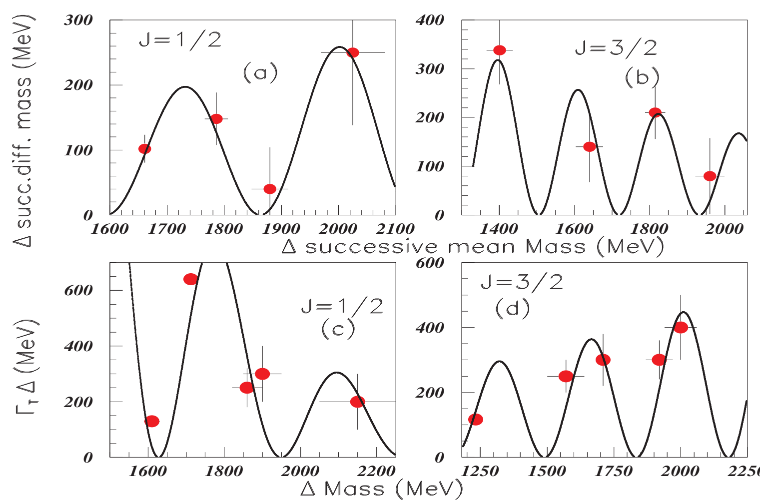

Figure 13: Color on line. "Mass data" for J=1/2 and J=3/2 Δ baryons in inserts (a) and (b). Widths versus masses in inserts (c) and (d).(See text).

3.5. Ω_C baryons

The eight known Ω_C masses are read in [6].

Fig. 17(a) shows the oscillation symmetry study applied to the eight experimental Ω_C "mass data". Insert(b) shows the data and same fit when the two theoretically predicted masses [9] at M=3146 $\pm$12 MeV and M=3182 $\pm$12 MeV are introduced . Insert(c) shows the data and same fit when the predicted mass at M=3182 $\pm$12 MeV is introduced but not the M=3146

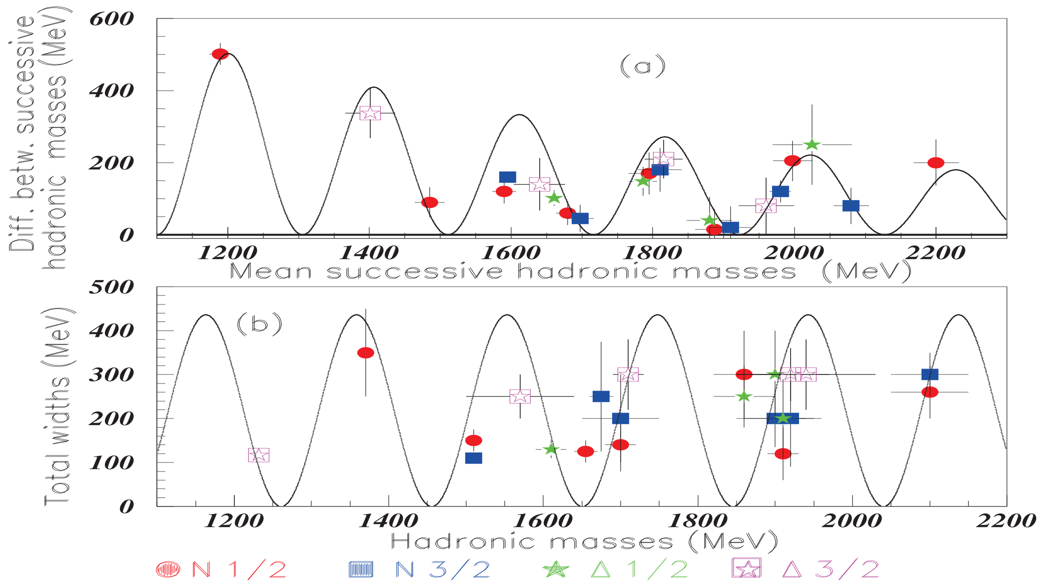

Figure 14: Color on line. (See text). "Mass data" of N^* and Δ baryons (J=1/2 and J=3/2) are shown in insert (a). Corresponding widths are shown in insert(b).

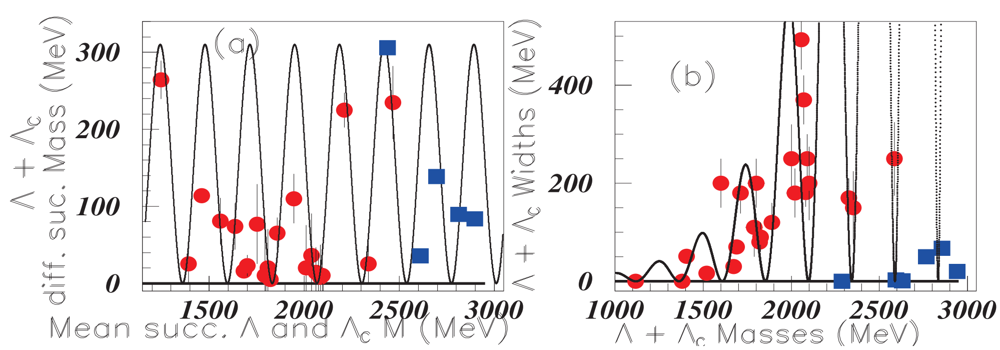

Figure 15: Color on line. (See text). Insert (a) shows the variation of the differences between successive Λ (red full circles) and Λ_C (blue full squares) "mass spectra" versus their corresponding mean masses. Insert (b) shows the widths of the corresponding Λ and Λ_C versus their masses.

$\pm$12 MeV. This choice is favoured. Insert (d) shows the total widths plotted versus their corresponding masses. Four widths are known,and two others are reported with a maximum value only. In insert (d), the width for M=3050.2 MeV: $\Gamma \leq 1.2$ MeV is taken to be 0.8$\pm$0.4 MeV, and the width for M=3119.1 MeV is indicated as $\Gamma \leq 2.6$ MeV and is introduced as 2.0$\pm$0.6 MeV. The width of the first Ω_C and the fit below M=2800 MeV are arbitrarily enhanced by 10^3 in order to avoid a large compression of

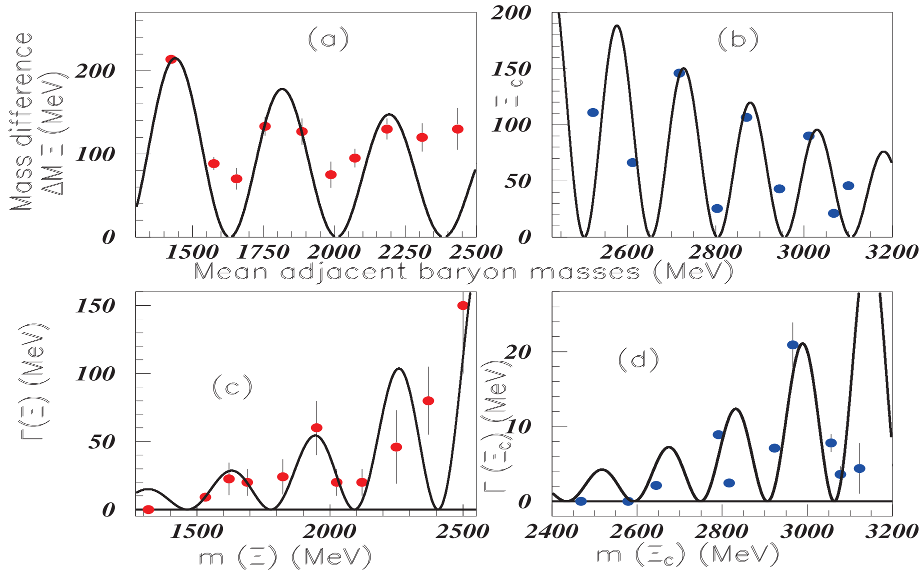

Figure 16: Color on line. (See text). Inserts (a) and (b) show the variation of the difference between successive Ξ and Ξ_C "mass spectra" versus their corresponding mean masses. Inserts (c) and (d) show the widths of the same baryons versus their masses.

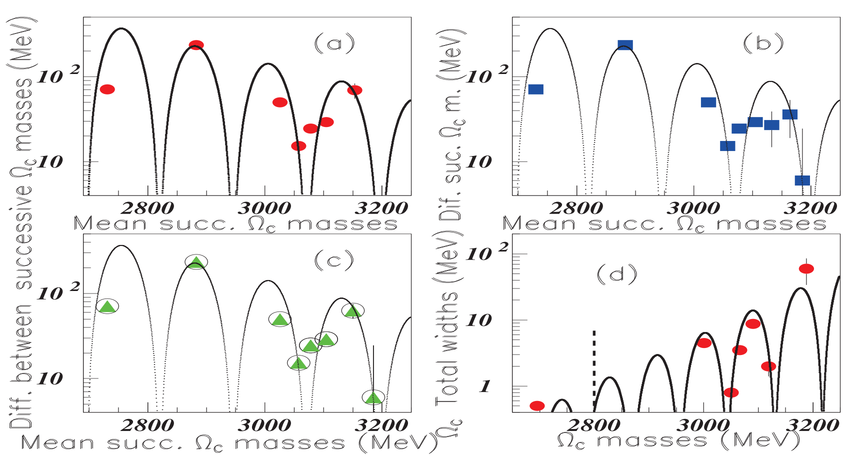

Figure 17: Color on line. (See text). Inserts (a), (b), and (c) show the eight Ω_C "mass data" and the two other possible theoretically predicted masses. Insert (d) shows the total widths ploted versus the correponding masses.

the figure describing larger masses. Indeed the mean life of Ω_C lower mass baryon is $0.821 \pm 0.011 * 10^{-10}$ s. Insert (d) allows to predict possible widths of the M=3146 and 3182 MeV Ω_C baryons. They are $\Gamma_T(3146) \approx 10$ MeV, and $\Gamma_T(3182) \approx 56$ MeV.

Fig. 18 shows the "mass data" of Charmed, Strange mesons in insert (a), and Bottom, Strange mesons (full red circles) and Bottom, Charmed meson (full blue square) in insert(b).

3.6. Bottom Baryons

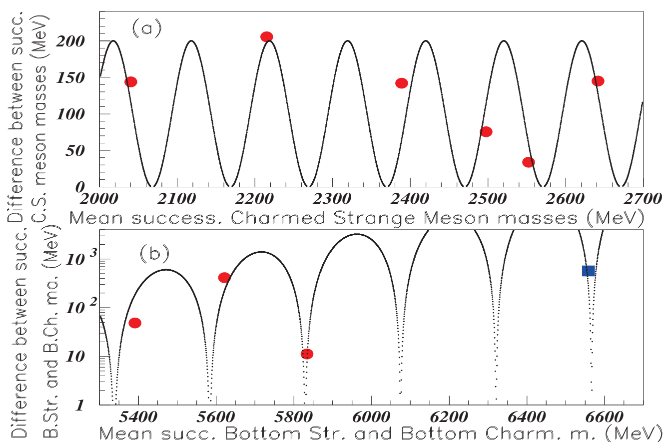

Figure 18: Color on line. (See text).Insert (a) shows the "mass data" of the Charmed Strange meson masses. Insert (b) shows the Bottom Strange et Bottom Charmed "mass data".

3.7. Λ_B, Σ_B, and Ξ_B baryons

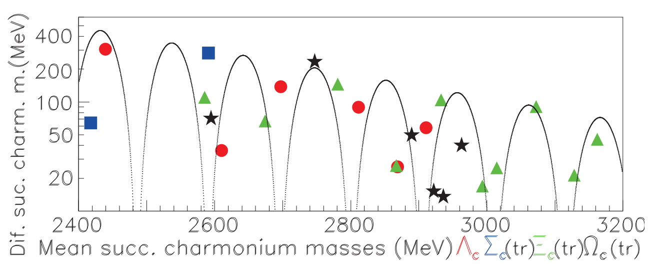

Figure 19: Color on line. (See text). "Mass data" of Λ_C (full red circles), Σ_C (full blue squares), Ξ_C (full green triangles), and Ω_C (full black stars).

Fig.19 shows the "mass data" of the Charmonium baryons. In order to show to what extent the different "mass data" can be dispayed in a common fig., the masses of the "mass data" are translated by "tr" Mev. Λ_C is exhibited by full red circles (tr=0), Σ_C is exhibited by full blue squares (tr=-68), Ξ_C is exhibited by full green triangles (tr=62), and Ω_C is exhibited by full black stars (tr=-136). The fit is done on Ξ_C data. The

Table A2: See text. Quantitative values of the baryons fit parameters, and parameters from general discussion.

Fig.	Name	α	β	P
12(a)	N^* 1/2 "M"	630	-7.8$*10^{-4}$	204.2
12(b)	N^* 3/2 "M"	540	-1.0$*10^{-3}$	213.6
12(c)	N^* 1/2 Γ	200	0	367.6
12(d)	N^* 3/2 Γ	31	9.5$*10^{-4}$	348.1
13(a)	Δ 1/2 "M"	17.5	0.001	270.2
13(b)	Δ 3/2 "M"	643	-0.001	213.6
13(c)	Δ 1/2 Γ	67800	-0.0029	321.7
13(d)	Δ 3/2 Γ	67	0.0006	344.3
14(a)	N* and Δ "mass"	340	-1$*10^{-3}$	205.5
14(b)	N* and Δ Γ	218	0	408.4
15(a)	Λ "M"	155	0	235.6
15(b)	Λ Γ	0.23	3.6$*10^{-3}$	245
16(a)	Ξ "M"	221	-5$*10^{-4}$	377
16(b)	Ξ_C "M"	4500	-1.5$*10^{-3}$	150.8
16(c)	Ξ Γ	0.51	2.05$*10^{-3}$	314.2
16(d)	Ξ_C Γ	4.1$*10^{-4}$	3.4$*10^{-3}$	157.1
17(a)	Ω_C"M"	6.5*10^6	-0.0038	125.3
17(b)	Ω_C"M"	6.5*10^6	-0.0038	125.3
17(c)	Ω_C"M"	6.5*10^6	-0.0038	125.3
17(d)	$\Omega_C G_T$	8.0$*10^{-12}$	8.9$*10^{-3}$	87.3
18(a)	Ch.Str. Meson "mass"	100	0	100.5
18(b)	B.S.+ B.C. Mes. "mass"	2.3*10$-$6	3.42$*-$3	245.7
19	$\Lambda_C, \Sigma_C, \Xi_C$ "masses"	9.9$*10^4$	$-2.5 * 10^{-3}$	104.9
20	$\Lambda_B, \Sigma_B, \Xi_B$ "masses"	126	0	267.0
21(a)	"mass"P Me.+Bar.fund.Ma	400	-4.24$*10^{-4}$	289.0
21(b)	width P Me.+Bar.fund.Ma	250	-2.1$*10^{-4}$	289.0

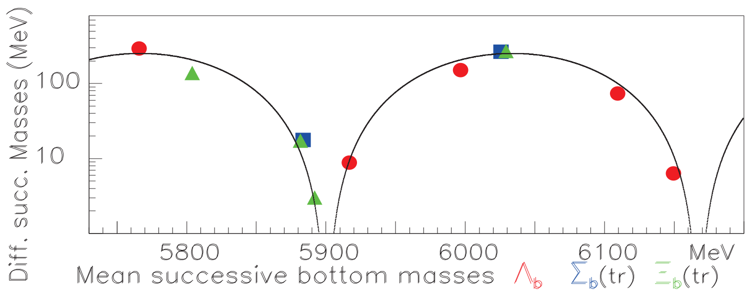

Figure 20: Color on line. (See text). "Mass data" of Λ_B (full red circles), Σ_B (full blue squares), and Ξ_B (full green triangles).

agreement between data and fit is passable for Σ_C and describes rather well the Λ_C and the Ω_C data.

Fig.20 shows the "mass data" of the following Bottom baryons. In order to show to what extent the different "mass data" can be dispayed in a common fig., the masses of the "mass data" are translated by "tr" MeV: Λ_B (tr=0) exhibited by full red circles, Σ_B (tr=62 MeV) exhibited by full blue squares, and Ξ_B (tr=-62 MeV) exhibited by full green triangles. It is noteworthy that in these conditions, all these bottom baryons are very well fitted by an unique fit.

4. Discussion

The meson and baryon "mass data" and widths oscillate, more especially when they belong to lower mass families. These oscillations are reproduced by simple equation with three adjustable parameters. The corresponding periods are discussed, on the contrary of the two other parameters α and β, since these two are connected and depends on the starting mass value used for the fit.

Several relations between different periods are observed:

- between η and ρ mesons, between Charmed and Charm, Strange mesons, and between Bottom and Bottom, Strange mesons;

- the widths of $c\bar{c}$ and $b\bar{b}$ display the same fit, provide the introduction of a constant shift on the $b\bar{b}$ masses (fig. 8);

- the widths of $q\bar{q}$ charmonium and bottomonium mesons are well described by the same curve (fig. 9 and 10);

- the "mass data" for J=1/2 and J=3/2 N^* and Δ are rather well described by the same period. This is also true for the corresponding widths (fig. 14);

- the same observation applies for Λ and Λ_C baryons (fig. 15);

- the same observation is also observed for the "mass data" of the Λ_C, Σ_C, Ξ_C, and Ω_C (fig. 19) and for Λ_B, Σ_B, and Ξ_B (fig. 20).

Another property is illustrated in fig. 21. This fig. shows the mass oscillatory periods (in insert (a)) and width oscillatory periods (in insert (b)), versus the fundamental mass of all families. Full red circles show the meson data, full blue squares show the baryon data. The same period allows to describe correctly the data of both inserts.

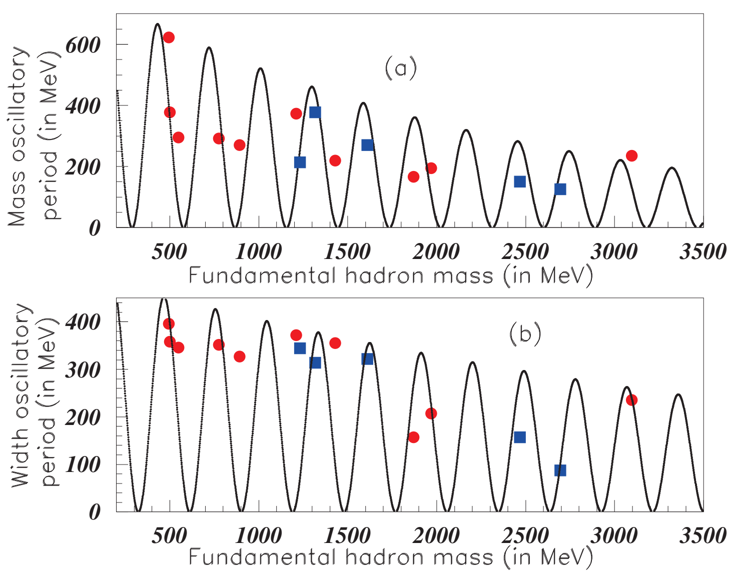

Figure 21: Color on line. (See text). Insert (a) shows the Mass oscillatory periods versus the fundamental masses of meson families in full red circles and baryon families in full blue squares. Insert (b) shows the width oscillatory periods versus the corresponding fundamental masses of meson families.

5. Conclusion

The first result highlighted in this paper is the confirmation that the oscillation properties are widely observed in nature. This paper shows that they are systematically observed in masses and widths of mesons and baryons.

The second result is the observation that the "same" oscillatory periods, may describe the different properties of different bodies. Previous section summarizes these properties.

These observations needs theoretical approaches which are clearly outside the scope of the present work.

References

[1] B. Tatischeff, "0scillation symmetry applied to: 1)hadronic and Nuclear Masses and widths 2)astrophysics, and used to predict unknown data", Proceedings of the 15^{th} International Conference on Nuclear Rection Mechanisms, Varenna (Italy) June 2018.

[2] B. Tatischeff, "Application of the Oscillation Symmetry to the Electromagnetic Interactions of Some Particles, Nuclei, and Atoms", Journal of Advances in Applied Mathematics, Vol. 6, N. 2, 2021. doi.org/10.22606/jaam.2021.62003.

[3] B. Tatischeff, "Observation of oscillation symmetry in nuclei excited state masses and widths", viXra:2111.0010 [pdf] (2021).

[4] B. Tatischeff, "Oscillation symmetry applied to several astrophysical data. Attempt to predict some properties of the putative ninth and tenth new solar planets", Phys. Astron. Int. J. 2019;3(6):267-274. DOI:10.15406/paij.2019.03.00193.

[5] B. Tatischeff, "Oscillation symmetry applied to several astrophysical masses, and allowing to highlight remarkable relations between masses", Phys. Astron. Int. J. 2020;4(62):93-105. DOI:10.15406/paij.2020.04.00206.

[6] P.A. Zyla *et al.*, (Particle Data Group), "The Review of Particle Physics (2021)", Prog. Theor. Exp. Phys. 2020, 083C01 (2020) and 2021 update.

[7] M.Batra and A.Upadhayay, "Strong decay widths and coupling constants of recent charm meson states", Eur. Phys. J. C (2015) 75:319 DOI 10.1140/epjc/s10052-015-3516-4.

[8] R. Aaij *et al.* (LHCb Collaboration),"Observation of New Ξ_C^0 Baryons Decaying to $\Lambda_C^+ K^-$", Physical Review Letters **124**, 222001 (2020).

[9] E. Ortiz-Pachecs *et al.* "Heavy Ω_C and Ω_B baryons in the quark model", arXiv:2004.09409 (nucl-th).