

Amazing Patterns in the Masses of Elementary Particles

S.A. Zimov

According to the Standard Model, elementary particles are composed of quarks.

The lightest quarks are the down quark (d) and the up quark (u); they are similar in mass. The mass of the strange quark (s) is larger, and the mass of the charm quark (c) is even larger. And the largest is the bottom quark (b).

In the chemical world, the mass of molecules is equal to the mass of the atoms they are composed of. Therefore, for example, the mass of an ethanol molecule is equal to the sum of the masses of hydrogen, methane, and carbon monoxide molecules.

But the masses of elementary particles are not calculated from the mass of quarks. Therefore, it is assumed that their mass is primarily the mass of the binding energy between quarks.

Now let's take a fresh look at the masses of elementary particles. Let's use the updated list of all elementary particles (<https://pdg.lbl.gov/>). Let's select all mesons from this list. These are particles consisting of a quark and an antiquark.

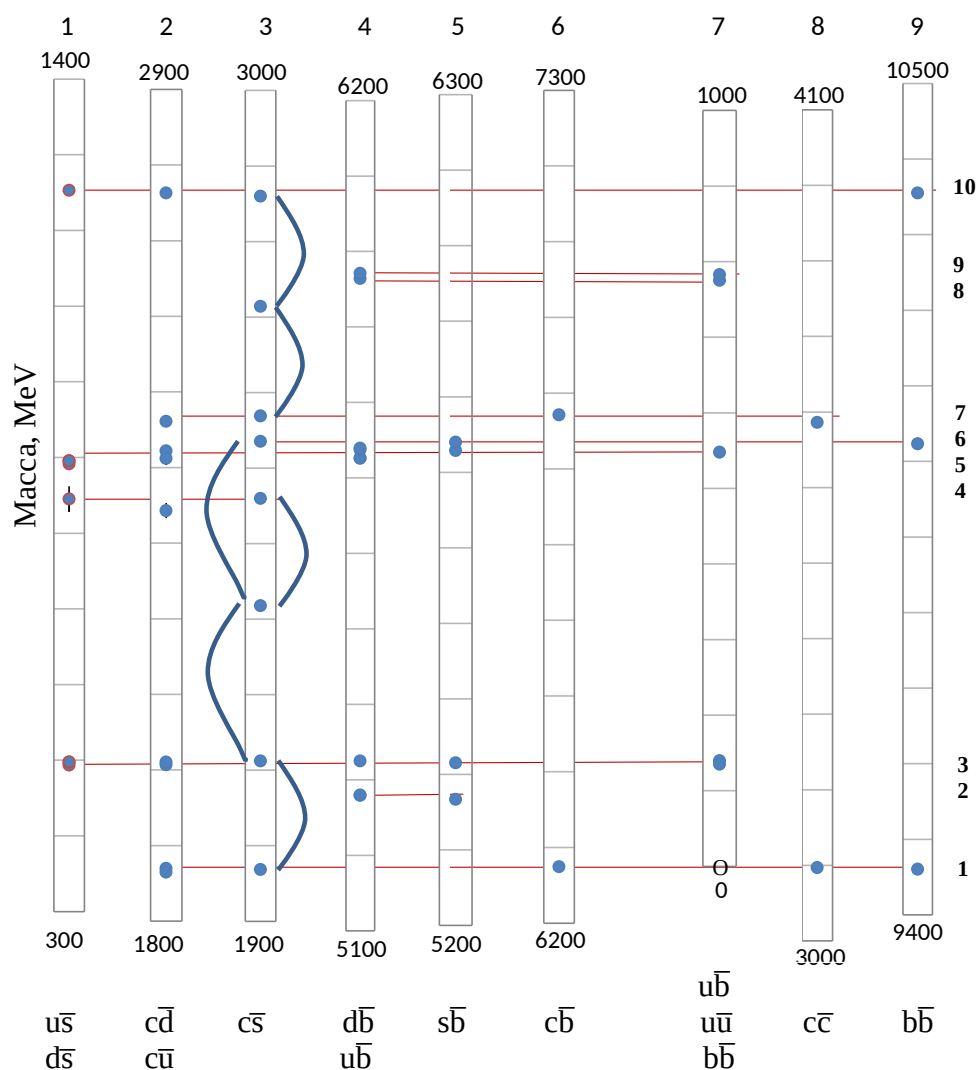


Fig. Masses of mesons and their resonances

The meson summary contains nine tables. All data from them is transferred to the figure. Each table has its own column. Below the columns, the quarks that make up the mesons in that column are shown.

Columns 1-6 contain different quarks and antiquarks. Annihilation between them is impossible, and therefore they have relatively long lifetimes. The lowest point in each of these columns is the long-lived ground state. Above these lie the resonance mesons. These are believed to be excited states of the ground particle. They are short-lived.

In column 7, the bottom two merged points represent the lightest mesons—neutral and charged pions. Their masses are 134.98 and 139.57 MeV. The neutral pion is believed to be a superposition of down and up quarks, their continuous interconversion. The dots above are their resonances. The table for column 7 and column 1 also contains more massive resonances, they are out of the figure.

The base of the two rightmost columns (8 and 9) shows the charm and bottom quarkonia, which consist of a quark and its antiquark. Therefore, they annihilate quickly, and their lifetime is only about 10^{-20} seconds. The dots above indicate their main resonances, which have the same lifetime. These mesons also have many other resonances with much shorter lifetimes. To avoid overloading columns 8 and 9, they are not shown.

All the mesons shown in the figure have very accurate mass measurements; only for two resonances (in columns 1 and 2) is the measurement error greater than the dot.

Now let's try to see patterns in this figure. Let's start by comparing columns 4 and 5. They are similar. All the dots in the fifth column correspond to the dots in the fourth. Columns 4 and 7 are also similar. Columns 2 and 3 are similar. Here, opposite all the points in the second column are points in the third column.

The figure shows that everything is interconnected. Opposite each point are one, two, three, and even five points in other columns. Only two resonances in the third column are not on the highlighted horizontal lines showing the rhythm boundaries. But they also fall within the same rhythms. To see this, move this column up and down. In the third column, four identical rhythms are shown in right brackets. It is equal to the mass of the pion. All horizontal lines are numbered. Line 3 passes through the pion points in column 7. Therefore, the width of the band between lines 1 and 3 is equal to the mass of the pion.

The distance between lines 10 and 7 is equal to the distance between lines 9 and 4. It is equal to two pions.

The distance between lines 10 and 9 is equal to the distance between lines 7 and 4, and also between 2 and 1, but with less precision. This rhythm is equal to a muon. It is equal to 105.66 MeV.

An interesting coincidence: the mass of the lepton (heavy electron) is included among the meson mass values. The figure also shows the muon mass in other cases. For example, the distance between lines 9 and 6, and 8 and 5 is the same and equals a double muon. Also visible in the third column are two rhythms equal to the mass of muon (left brackets).

The distance between lines 6 and 3 is the same as between lines 10 and 4. It is equal to four muons.

The distance between lines 4 and 3 is equal to the distance between lines 10 and 5. It is equal to the sum of two muons and a pion.

The rhythm, equal to two pions and three muons, is marked five times. Four times between lines 7 and 1, and once more, shifted by a pion, it is repeated in the third column. Random coincidences are possible in all of this, but they cannot be numerous. And among mesons, rhythms are everywhere. Moreover, all of them are numerically equal to the mass composed of the mass of the lightest particles—pions and muons.

The charm quarkonium J/Ψ , consists of a charm quark and its antiquark, according to the Standard Model (bottom dot in column 8), while bottom quarkonium $\Upsilon(1S)$, consists of a bottom quark and its antiquark, accordingly (bottom dot in column 9). We can imagine that half the mass of these mesons is attributed to the quark, and the other half to the antiquark. Let's write the masses for these halves in MeV:

$$J/\Psi:2 = 1548.45 \quad \Upsilon(1S):2 = 4730.15$$

The long-lived meson B_c^+ is the bottom dot in column 6 in the figure. According to the Standard Model, it consists of a bottom quark and a charm antiquark. Let's sum the masses of the halves of these mesons and compare them with the mass of the bottom-charm meson:

$$J/\Psi:2 + \Upsilon(1S):2 = 6278.60$$

$$6274.47 = B_c^+$$

It turns out that the mass of this meson is the sum of the masses of the halves of which it is composed.

Now let's show what elementary particles can be assembled by adding muons to the charm or bottom halves.

The mass of mesons with a charm quark (these are the bottom points in columns 2) is obtained by adding three muons to the charm half:

$$J/\Psi:2 + 3\mu = 1865.43$$

$$1864.84 = D^0$$

The mass of mesons with a charm and strange quarks (these are the bottom points in columns 3) is obtained by adding four muons to the charm half:

$$J/\Psi:2 + 4\mu = 1971.09$$

$$1968.35 = D_s^+$$

The mass of a meson with a bottom quark (the bottom point in column 5) is obtained by adding six muons to the bottom half.

$$\Upsilon(1S):2 + 6\mu = 5364.11$$

$$5366.92 = B_s^0$$

A baryon with a charm quark is made up of a charm half and 7 muons.

$$J/\Psi:2 + 7\mu = 2288.07$$

$$2286.46 = \Lambda_c^+$$

A baryon with two charm quarks is made up of two charm half with the addition of 5 muons.

$$J/\Psi:2 + J/\Psi:2 + 5\mu = 3625.2$$

$$3621.6 = \Xi_{cc}^{++}$$

There are only seven basic mesons and baryons with charm or bottom quarks. And for five of them, as we see, the mass is composed by adding muons to these heavy halves.

And now another example. In the figure, columns 8 and 9, the top dots are meson resonances, which contain charm and bottom quarks, their antiquarks, and something else. Here are the masses of their halves:

$$\Psi(2S):2 = 1843.05 \qquad \Upsilon(3S):2 = 5177.6$$

Now let's write down the masses of baryons with charm and bottom quarks. They also contain charm and bottom quarks, and something else.

$$\Lambda_c^+ = 2286.46 \qquad \Lambda_b^0 = 5619.6$$

Now, let's write a simple relationship for these halves of mesons and baryons:

$$\Upsilon(3S):2 - \Psi(2S):2 = 3334.55$$

$$\Lambda_b^0 - \Lambda_c^+ = 3333.14$$

This precise coincidence implies that mesons and baryons, in addition to the charm and bottom quark, also share something else of equal mass.

Column 7 shows three pion resonances. They can also be divided into halves:

$$\eta:2 = 273.93 \qquad \rho:2 = 387.63 \qquad \omega:2 = 391.33$$

We can also attempt to assemble mesons and baryons from these.

The lightest mesons-kaons are the bottom points in the first column. They are obtained by adding the mass of one muon to the meson halves:

$$\rho:2 + \mu = 493.29 \qquad \omega:2 + \mu = 497.00$$

$$493.677 = K^+$$

$$497.611 = K^0$$

According to the Standard Model, the proton and neutron are composed of three light quarks. Their masses are trivially composed of the halves of three light mesons—three "quarks."

$$\eta:2 + \eta:2 + \rho:2 = 935.49$$

$$\eta:2 + \eta:2 + \omega:2 = 939.19$$

$$938.27 = p$$

$$939.57 = n$$

The proton mass was calculated with less accuracy than the neutron mass. However, the proton is a charged particle, and its mass consists of its own mass and the mass of its electric field. Taking this into account, we obtained a very close match.

And this is the numerical match for a baryon with a bottom quark:

$$\Upsilon(1S):2 + \omega + \mu = 5618.47$$

$$5619.6 = \Lambda_b^0$$

And this is the match for a meson with a bottom quark (this is the bottom dot in the fourth column in the figure):

$$\Upsilon(1S):2 + \eta = 5278.01$$

$$5279.34 = B^+$$

As a result, it turns out that the masses of all long-lived mesons and baryons can be assembled, in some cases trivially, in others more complexly, from a small set of masses of half-mesons, and muons. Since the η meson is close in mass to four pions, and two muons are close in mass to three half-pions, other combinations are possible.

And now for the most massive particles.

These are the intermediate vector bosons $W = 80377+12$ and $Z = 91187.6+2.1$;

The Higgs boson $H = 125250+170$;

And the top quark $t = 172690+300$.

The masses of these particles and their halves are related, not very precisely, but quite simply:

$$W + Z = 171564.6$$

$$W + Z:2 = 125970.8$$

$$172690.0 = t$$

$$125250.0 = H$$

Another example demonstrating the similarities in the mass ratios of different particle classes. Besides the electron and muon, there is another, the heaviest lepton, the tau lepton: $\tau = 1776.86 + 0.12$. We divide its mass by the proton mass, and below we write the ratio for superheavy particles—the top quark and the Z boson:

$$\tau:p = 1.89376$$

$$t:Z = 1.893788$$

It turns out to be a coincidence. Other coincidences can be cited, such as the neutron - neutral kaon ratio and the charm meson-charged kaons ratio:

$$n:K^0 = 1.88816$$

$$D^0:2K^+ = 1.88872$$

The set of elementary particles is small, but the coincidences are numerous. They can't all be random coincidences.

Look again at columns 4 and 5 in the figure. They are clearly similar. Columns 4 and 7 are also similar, as are columns 2 and 3. And the mass of the charm-bottom meson is trivially equal to the sum of the masses of charm and bottom halves. These examples alone show that the masses of elementary particles can be composed of the masses of simpler elements.