29th International Cosmic Ray Conference Pune (2005) **00**, 101-104

Are Elementary Particle Masses Related ?

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Most of the elementary particles discovered so far have an associated physical mass. It would be of fundamental importance to explore a possible relationship amongst the masses of these particles irrespective of their nature. Here an attempt is made to investigate this aspect on the basis of available data on the elementary particle masses. It is revealed that there is a striking tendency for successive mass differences between particles to be close integral multiple/submultiple of 29.315 MeV. The 29.315 MeV being the mass difference between a muon and a neutral pion.

1. Introduction

A large number of elementary particles and their resonances have been discovered as a result of experimental investigations with cosmic rays and in high energy nuclear collisions [1, 2, 3]. These particles have been classified into various groups on the basis of their structure, type of interaction they respond to and their associated quantum numbers [4, 5]. However, most fundamental to elementary particles is the mass they posses and the experimental observations have revealed a wide distribution in their physical masses. Irrespective of the classifications cited above it would be of fundamental importance to know if their masses are related to each other.

Some phenomenological relations have been previously worked out between masses of some specific classes of elementary particles. These include relationship between masses of some of the hadrons [5, 6] and between the masses of hadron resonance [7]. Relationships involving lepton, boson and quark masses have also been reported in the literature [8, 9]. Further, the mass differences between the individual members of baryon octet and between the members of baryon decuplet is expected to be equal for equal change in strangeness between the individual members. However, this is contrary to the observational evidence which shows large deviations from the expected values [5, 10]. The small mass difference between different charge states of a particle has been attributed to the intrinsic differences between light quark masses and to the electromagnetic interaction among constituent quarks [4, 5]. It may however be noted that no general relation that would link the masses of different elementary particles has been reported so for.

In the present study an attempt has been made to study elementary particle mass distribution in general and we reveal a greater tendency for mass differences between successive elementary particles to be close integral multiple/submultiple of mass difference between a muon and a neutral pion.

2. Data analysis and Discussion

The data source for the present study is based on the published and established list of elementary particles [1, 2, 3]. Except for the electron all classes of the stable particles decaying by weak or electromagnetic interaction i.e leptons, hadrons and massive guage bosons have been considered in the present analysis. Resonances and quarks have not been included in the present study as most of their experimentally observed features are not well understood. Reported resonance masses have large uncertainty and it has not been possible to isolate quarks [4]. The particles were tabulated in the ascending order of mass irrespective of the structure, type of interaction or their associated quantum numbers. For example, first particle in the table would be μ^- a charged lepton followed by π^0 a neutral meson. Similarly, neutron a non-strange baryon is followed by strangeness '-1' baryon i.e lambda particle and strangeness ' –3 ' baryon i.e omega particle is followed by a tau lepton.

The successive mass differences between these particles were found out and on inspection it was observed that the mass differences could be classified into two categories. Those with values of the order of a few MeV were classified as low mass differences and the remaining as the high mass differences. Out of a total of 34 stable particles leading to 33 mass differences, twenty two were having high mass difference and eleven were having low mass difference. On inspection it can easily be understood that all the low mass differences are because of the different charge states of the same particle. For example, the difference of 1.3425 MeV is the mass difference between a neutron and a proton and 4.59 MeV difference is between mass of a charged pion and a neutral pion. These mass differences are easily explainable on the basis of electromagnetic interaction [4, 5].

However, the high mass differences form the center of present investigation as they reflect the mass differences between different particles. A closer look at these mass differences have revealed that many of these differences are close multiples of 29.315 MeV which is the mass difference between π^0 and μ^-, the first two particles in the ascending order of physical mass. For example, the observed mass difference between a neutron and a lambda particle (Λ^0) is 176.0344 MeV. This value is very close to 175.89 MeV, a value obtained on multiplication of 29.315 MeV by an integer. Similarly actual mass difference between Ω^- particle and Ξ^- particle is 351.13 MeV which differs from the predicted value of 351.78 MeV by 0.65 MeV. Same is true of the mass difference between particles ($k^\pm$ & $\pi^\pm$), (Ξ^0 & Σ^-), (D^0 & τ^-), (Ω_c^0 & $\Xi_c^{0\backslash}$), ($B^\pm$ & Ω_c^0) which are very close to the integral multiples of 29.315 MeV. The difference between the observed and predicted values in case of particles (η & k^0), (p & η), (Σ^+& Λ^0), (τ^- & Ω^-), ($D_s^\pm$ & $D^\pm$), (Ξ_c^0 & $\Xi_c^{+\backslash}$), (B^* & B^0), (B_s^0 & B^*), ($B_c^\pm$ & Λ_b^0), ($W^\pm$ & $B_c^\pm$) and (Z & $W^\pm$) are however large. Many of these differences can again be accounted for if the mass difference between successive particles is considered to be integral multiple of half the mass difference between a π^0 and a μ^- i.e mass difference $(\Delta m)=N/2\ (m_{\pi^0} - m_{\mu^-})$ where N is an integer. For example the difference between mass of Σ^+ and mass of Λ^0 differs from the closest integral multiple of 29.315 MeV by 14.185 MeV whereas the difference between the observed and predicted value obtained by the integral multiplication of 29.315/2 MeV is only 0.4725 MeV. Similarly the difference between the predicted and observed mass difference between mass of τ^- and mass of Ω^- is 12.72 MeV whereas the difference obtained by choosing half integral multiple of 29.315/2 MeV is only 1.9375 MeV. Further the difference between mass of $B_c^\pm$ and mass of Λ_b^0 differs from the closest integral multiple of 29.315 MeV by 13.81 MeV whereas the difference between the observed and predicted value obtained by the integral multiplication of 29.315/2 MeV is only 0.8475 MeV. Some differences are even smaller than the inherent uncertainty in the measured masses of the particles involved. For example in the case of Ξ_c^0 and $\Xi_c^{+\backslash}$, the actual mass difference differs from the closest integral submultiple of 29.315 MeV by 0.302 MeV whereas the uncertainty in the mass of the two particles is ±1.4 MeV and ±3.3 MeV respectively.

These results are effectively presented in Figure 1 where the differences between the observed and the calculated (predicted) mass difference is plotted in the form of a histogram. It is clearly seen that a large number of differences are close to zero. Similarly in Figure 2 we show the differences between observed and predicted mass differences for successive baryons. A clear peak near the center is again visible. In case the mass differences were not integral multiple/submultiple of 29.315 MeV, distributions as shown in Figure 1 and Figure 2 would hardly be observed. In particular the successive mass differences in the baryon octet are strikingly close to the integral multiple/submultiple of 29.315 MeV. For example differences of observed and predicted mass differences between (Λ^0 & n) , (Σ^- & Λ^0) and (Ξ^0 & Σ^-) are all less than 1 MeV. These small mass differences can easily be compared with high values obtainable on the basis of difference in the strangeness of these particles [5]. Thus the mass difference between successive baryons is fully accounted in terms of the mass difference between a lepton and a meson.

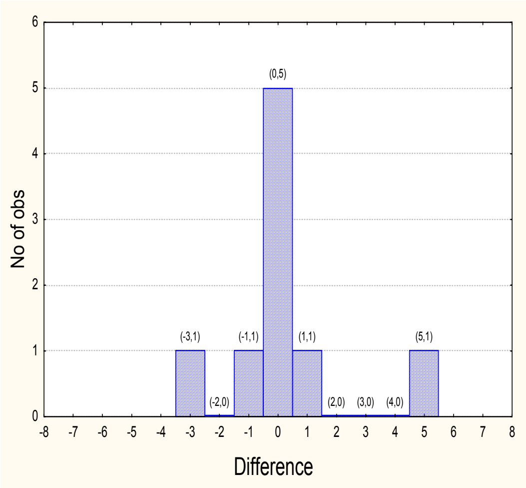

Figure 2. Difference of observed successive mass difference from closest integral multiple of 29.315/2 MeV for baryons.

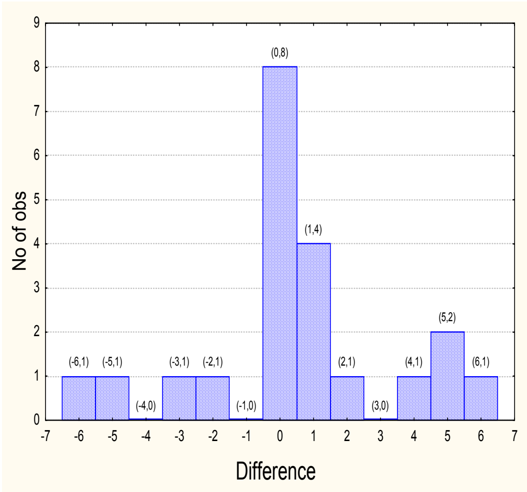

Figure 1. Difference of observed successive mass differences from closest integral multiple of 29.315/2 MeV for stable particles.

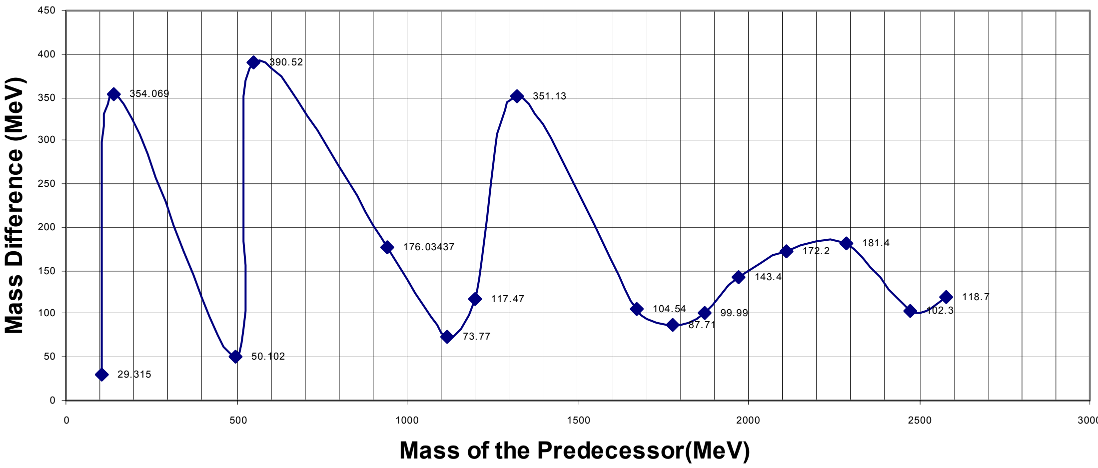

Figure 3. Periodic variation of mass difference in case of stable particles.

Further actual mass difference between two leptons μ^- and τ^- differs from the closest integral multiple/submultiple of 29.315 MeV, by 0.376 MeV. Keeping in view the nature and structure of leptons, mesons and baryons together with our above cited results it is concluded that a basic relation exists between particles responding to different types of interactions and having completely different structures.

In Figure 3 we plot mass of the predecessor elementary particle against the mass difference with it's successor. For the purpose of clarity, the maximum mass considered in Figure 3 is 2697.5 MeV i.e mass of Ω_c^0. The small mass differences due to the electromagnetic interaction have been excluded as they lie very close to the mass axis. The plot reveals some regularity in variation of mass differences and tends to suggest a periodic variation of mass difference.

3. Conclusions

Our results show that observed mass differences between elementary particles can be explained in terms of the mass difference between a neutral pion and a muon. This is important in view of the fact that mesons and leptons have different structure and undergo different interactions. That the mass differences are integral multiples of a basic mass tends to indicate quantized nature of mass.

4. Acknowledgements

The authors wish to thank Aatif Nabi Shah for contributing to intresting discussions in the initial phase of this work.

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