The α-quantized systematics of quark-dominated elementary particle lifetimes

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Abstract

The experimental lifetime systematics of the 36 long-lived quark and particle metastable ground states is displayed graphically on a logarithmic global α-grid spaced in powers of the fine structure constant $\alpha \sim 1/137$ and centered on the $\pi^{\pm}$ lifetime. The hadron lifetimes separate into four non-overlapping lifetime groups, each dominated by a single quark flavor. These in turn divide into slow *flavor-breaking* electroweak decays and fast *flavor-conserving* paired-quark and radiative decays, separated by α^4 lifetime gaps. The long-lived electroweak subgroups feature contral lifetime (CL) bands that map onto the α-grid lines, plus particles that are displaced by factors of 2, 3 or 4 from the CL. The quark lifetime dominance rule is $c > b > s$. The neutron and muon lifetimes lie on the global α-grid. The tauon lifetime fits into the c-quark lifetime group.

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1. Introduction and summary

Two important experimental properties of an elementary particle are its *mass m* and its *mean life* or *lifetime* τ. Experimental measurements of these quantities have become very accurate in the past few decades. The updated 2011 edition of Review of Particle Physics (RPP) [1] lists approximately 171 particle states—3 leptons, 167 hadrons, and the top quark *t*—that have well-determined mass and lifetime values. The hadron states are accounted-for as combinations of the Standard Model *u*, *d*, *s*, *c*, *b* quark flavors. The global systematics of particle and quark *masses* has been well-studied [1], but the global systematics of particle and quark *lifetimes* has received less attention. The hadron lifetimes span 28 orders of magnitude (plus the stable electron and proton), and they separate into long-lived $(\tau > 10^{-21}\,\mathrm{sec})$ quark *ground-state* configurations and short-lived $(\tau < 10^{-21}\,\mathrm{sec})$ particle *excited states*. Our analysis here is centered on the long-lived quark ground states, which contain unique information about the properties of the particles and quarks. Their lifetime regularities reveal the *s*, *c*, *b* flavor structure of the particles, and lead to the conclusion that particle lifetimes are dictated by their dominant quark flavors. In the present article, we display plots of the experimental lifetime data that illustrate and delineate important features of the quark and particle lifetime systematics. As a guide to this discussion, we summarize here the main conclusions from this global lifetime analysis.

(1) The particle mean lives [1] can be separated into metastable *unpaired-quark* ground state decays with lifetimes $\tau > 10^{-14}$ sec, *paired quark-antiquark* ground-state decays with lifetimes from 10^{-14} to 10^{-21} sec, and *excited-state* decays with lifetimes from 10^{-21} to 10^{-25} sec (Fig. 1).

(2) The unpaired-quark and paired-quark ground states are each divided into four discrete lifetime groups—(PS), (*s*), (*b*), (*c*)—in the order of decreasing lifetimes, with each group dominated by a single quark flavor, as follows: (PS), the *pseudoscalar* (*u*, *d*, *s*) *up* and *down* quark mesons and *strange* quark kaons; (*s*), the *strange* hyperons; (*b*), the *bottom* mesons and baryons; (*c*), the *charm* mesons and baryons. These groups follow the quark dominance rule *c* > *b* > *s* (Fig. 2).

(3) The $\tau > 10^{-21}$ sec ground-state lifetimes τ_i are quantized in powers of $\alpha = e^2/\hbar c \cong 1/137$ with respect to an α-spaced logarithmic lifetime grid $\tau_\mathrm{i}/\tau_{\pi^\pm} = \alpha^{x_i}$ that is anchored on the $\pi^\pm$ lifetime (Figs. 3, 4, 6-9), and is denoted here as the lifetime "global α-grid".

(4) The *flavor-conserving* paired-quark ground state lifetimes are shorter than the matching *flavor-breaking* unpaired-quark ground state lifetimes by factors of approximately α^4 (Fig. 3).

(5) Each of the four unpaired-quark (PS), (*s*), (*b*), (*c*) lifetime flavor groups has a "central lifetime" (CL) band of particles plus particles that are separated from the CL by integer lifetime ratios of 2, 3, or 4 (Figs. 4 and 5).

(6) The (PS), (*s*), (*b*) CL central lifetimes correspond to the global α-grid integers $x_\mathrm{i} \simeq 0, 1, 2,$ respectively, but the (*c*)-group CL (and the other charmed-particle ground states and the τ lepton) are shifted off the $x_\mathrm{i} \simeq 2$ grid position by a common factor of 3 (denoted here as the lifetime "charm correction factor") in the direction of shorter lifetimes (Figs. 4 and 11).

(7) The non-strange (PS) $\pi^\pm, \pi^o, \eta, \eta'$ meson lifetimes correspond to the global α-grid integer positions $x_\mathrm{i} \simeq 0, 4, 5, 6,$ respectively (Figs. 6-9).

(8) The strange (PS) $\mathrm{K}^\pm, \mathrm{K}_\mathrm{L}^o, \mathrm{K}_\mathrm{S}^o$ kaons are α-quantized on a lifetime *local* α-grid that is anchored on the $\mathrm{K}^\pm$ lifetime and is shifted from the *global* α-grid by a factor of 2 towards shorter lifetimes (Fig. 10).

(9) The neutron and the $\mu^\pm$ and $\tau^\pm$ leptons are α-quantized on another *local* α–grid that is anchored on the $\mu^\pm$ lifetime and is shifted from the *global* α-grid by a factor of ~1.6 towards shorter lifetimes (Figs. 11-12), and they exhibit the following experimental lifetime ratios:

- **(a)** $\tau_\mu/\tau_n \simeq \alpha^4$, where the muon and neutron lifetimes represent flavor-conserving and flavor-breaking decays, respectively (see conclusion (4) above and Figs. 12-13).
- **(b)** $\tau_\tau / \tau_\mu = \alpha^3/3$ (to 2% accuracy!), where the *hadronic charm correction factor* of 3 is applied here to the *leptonic* $\tau^\pm$ lifetime (see (6) above and Fig. 12).

(10) A plot of particle *lifetimes* versus particle *masses* (Fig. 14) illustrates the lifetime and mass similarities between the $\tau^\pm$ lepton and the *charmed* (*c*)-group mesons. This suggests that the weakly-interacting tauon is connected in a *generational* sense with the *c* quark family, and not with the *b* and *t* quark generation family, as is generally portrayed. This conclusion is reinforced by the accurate $\tau_\tau / \tau_\mu = \alpha^3/3$ lifetime ratio displayed in (9b) above, which uses the hadronic *charm correction factor* of 3 for the tauon lifetime.

2. The global structure of particle lifetimes

Fig. 1 shows the 170 measured particle *mean lifetimes* τ [1], together with the top quark lifetime, which are plotted on a logarithmic scale that extends from the neutron ($\tau \sim 10^3$ sec) to the W and Z gauge bosons ($\tau \sim 10^{-25}$ sec). These lifetimes divide naturally into four zones:

Zone 1. The region with lifetimes longer than 10^{-7} sec, which contains the stable proton and electron and metastable neutron and muon (and their corresponding antiparticles). These are the four lowest-mass spin ½ fermion states. The nucleons (p and n) carry the *baryon* quantum number, and the leptons (e and μ) carry the electron and muon *lepton* quantum numbers, respectively.

Zone 2. The lifetime region from 10^{-7} to 10^{-14} sec, which contains 24 hadrons and the tau lepton. The 24 hadron states are *unpaired-quark* ground states, whose decays require flavor-breaking electroweak gauge boson transformations that slow down the decay rates. The tauon (τ) carries the tau lepton quantum number.

Zone 3. The lifetime region from 10^{-14} to 10^{-21} sec, which contains 10 hadron states that are mainly *paired-quark* ground states whose decays do not require flavor-breaking transformations.

Zone 4. The 133 particles with lifetimes shorter than 10^{-21} sec (1 zeptosec), which are *excited* states that decay back down to the metastable ground states.

The experimental lifetime regularities displayed in the present article occur mainly in the metastable *ground-state* particles (including leptons), which have lifetimes $\tau > 1$ zeptosecond.

The very short Zone 4 mean lifetime τ of the top quark t is deduced from its resonance width $\Gamma = \hbar / \tau$. A crucial feature of the t quark lifetime is that it is shorter than the time theoretically required to combine with another quark and form a particle [2]. Thus this represents the direct determination of an intrinsic *bare quark* lifetime.

3. The *c* > *b* > *s* quark dominance rule and the four quark lifetime families

Fig. 2 displays the experimental flavor regularities in the lifetimes of 32 quark ground-state particles, all of which have metastable lifetimes $\tau > 10^{-21}$ sec. The 24 *unpaired-quark* ground state lifetimes in Zone 2 (top) clump into four flavor-separated groups, which are labeled (PS), (s), (b), (c), and the 10 *paired-quark* and/or *radiative decay* ground state lifetimes in Zone 3 (bottom) clump into a matching set of flavor-separated groups. These lifetime flavor groups reflect the lifetimes of *individual quarks* within the particle, which are the same for both mesons and baryons. The lifetime flavor groups are created in accordance with the quark dominance rule *c* > *b* > *s*, where the shortest quark lifetime in a particle dictates its decay. The workings of this quark dominance rule are spelled out in the caption to Fig. 2. The *c* quark has the shortest "intrinsic" lifetime, followed by *b* quark and then the *s* quark. This isn't the order we expect to find, since high-mass excitations such as the *b* quark usually are more unstable than much-lower-mass excitations such as the *c* quark. The non-strange $\pi^{\pm}$ and π^{o} pseudoscalar (PS) meson lifetimes occur in the (PS) lifetime groupings, as do the strange K_L^o and $K^{\pm}$ pseudoscalar kaon lifetimes, but the strange K_S^o kaon lifetime appears in the (*s*) flavor group.

The workings of the *c* > *b* > *s* quark dominance rule are illustrated most clearly by the $B_c^{\pm} = (c\overline{b},\ b\overline{c})$ and $B_s^o = (b\overline{s},\ \overline{b}s)$ meson lifetimes, which are labeled in Fig. 2. The $B_c^{\pm}$ meson is composed of a *b* and *c* quark-antiquark pair. The $B_c^{\pm}$ *mass* is intermediate between the $b\overline{b}$ and $c\overline{c}$ masses, but the $B_c^{\pm}$ *lifetime* is not intermediate between the *b* and *c* lifetimes: it falls squarely in the middle of the (*c*) flavor group. Similarly, the B_S meson is composed of a *b* and *s* quark-antiquark pair. The B_s^o *mass* is intermediate between the $s\overline{s}$ and $b\overline{b}$ meson masses, but the B_s^o *lifetime* falls directly in the narrow (*b*) flavor group. This same quark dominance rule carries over to the baryon lifetimes, where the $\Xi_c^o = csd$ lifetime appears in the (*c*) flavor group, and the $\Xi_b^- = bsd$ lifetime appears in the (*b*) flavor group. These two baryon states are labeled in Fig. 2. The *u* and *d* quarks also occur in particle states of the (*s*), (*b*) and (*c*) lifetime flavor groups, but any effect they have on lifetimes is superseded by the *c* > *b* > *s* quark dominance rule

As can be observed in Fig. 2, the separation distances between the matching *unpaired-quark* and *paired-quark* (PS), (*s*), (*b*), (*c*) lifetime flavor groups are somewhat larger than the factor of 10^{-7} shift that is employed between the Zone 2 and Zone 3 coordinate ranges in Figs. 1 and 2. These very large *unpaired-quark to paired-quark* separation distances are clearly of theoretical interest. As a clue to their origin, we note that the $K^{\pm}$ and K_S^o mesons displayed in Fig. 2, which both feature $K \to \pi\pi$ decay modes, and which occupy similar positions near the short-lifetime boundaries of the (PS) and (*s*) flavor groups, have the lifetime ratio $\tau_{K^{\pm}} / \tau_{K_S^o} = 138.28.$ This is within 1% of the numerical value $1/\alpha = 137.04$, where $\alpha = e^2/\hbar c$ is the fine structure constant. The occurrence of the constant α in the $\tau_{K^\pm}$ to $\tau_{K^o_S}$ lifetime ratio, and in the (PS) to (*s*) unpaired-quark flavor group separation distance, suggests that α may also play a role in the spacings of the matching unpaired-quark to paired-quark (PS), (*s*), (*b*), (*c*) flavor-group pairs of Fig. 2. This suggestion is reinforced by the experimental α^4 lifetime gaps that are observed in these matching flavor-group pairs, as discussed in the next section and displayed in Fig. 3.

4. The "global α-grid" scaling and α^4 gaps of the (PS), (*s*), (*b*), (*c*) lifetime flavor groups

The lifetimes in the elementary particle displays of Figs. 1 and 2 were plotted in units of seconds. In order to investigate the quantitative nature of the elementary particle flavor groups delineated in Fig. 2, we combine the 32 hadron particle states of Fig. 2 into a single 10^{-7} to 10^{-21} sec lifetime domain, and we add in 5 closely-related hadrons. Then, in order to ascertain if the fine structure constant $\alpha = e^2/\hbar c \cong 1/137$ enters into the lifetime systematics, we select the $\pi^\pm$ meson lifetime $\tau_{\pi^\pm}$ as the reference lifetime, and we express the lifetimes τ_i of the other particles as ratios to that of the $\pi^\pm$ by means of the equation $\tau_i / \tau_{\pi^\pm} = \alpha^{x_i}$, which defines the lifetime *global α-grid*. If the logarithms x_i to the base α have integer values, then the constant α is relevant to the systematics. The results of this lifetime representation are displayed in Figure 3, which contains 37 metastable hadron states.

Evidence of an α-quantization of particle lifetimes appears most clearly in the *unpaired-quark* flavor groups. The $\pi^\pm$, π^o, η, η' non-strange pseudoscalar mesons in the (PS) lifetime region at the top of Fig. 3 provide strong evidence for a lifetime scaling in powers of α These lifetimes span 6 powers of α, or 13 orders of magnitude, and they closely match the grid lines of the superimposed lifetime α-grid, which are spaced by factors of 137. This result is reinforced by the unpaired-quark (*s*) flavor group lifetimes, which are a factor of 137 are shorter than the $\pi^\pm$ reference lifetime, and the *(b)* flavor group lifetimes, which are a factor of $(137)^2$ shorter. These two flavor groups occupy the $x_i = 1$ and $x_i = 2$ grid lines, respectively. The unpaired-group (*c*) flavor group lifetimes do not fall on an α-grid line, but are shifted by a factor of 3 past the $x_i = 2$ grid line toward shorter lifetimes. Evidence of a discrete flavor group substructure is visible in the (PS), (*s*), and (*c*) unpaired-quark lifetimes. This substructure is displayed in Fig. 4 and analyzed in detail in Sec. 4.

Figs. 2 and 3 demonstrate the manner in which the metastable ($\tau > 1$ zsec) elementary particle ground-state lifetimes sort into four flavor groups that each contain *slow* flavor-breaking unpaired-quark decays and *fast* flavor-conserving paired-quark and radiative decays. It is of interest to list the experimentally measured particles in these four flavor groups:

(PS) The pseudoscalar mesons—$\pi^{\pm}$, $K^{\pm}$, K_L^o (unpaired); π^o, η, η' (paired).

(*s*) The *s*-quark flavor groups—K_S^o, Ξ^o, Λ, Ξ^-, Σ^-, Σ^+, Ω (unpaired); Σ^o (radiative decay).

(*b*) The *b*-quark flavor groups—$B^{\pm}$, B^o, B_s, Λ_b, Ξ_b^-, Ω_b (unpaired); $\Upsilon_{1S}, \Upsilon_{2S}, \Upsilon_{3S}$ (paired).

(*c*) The *c*-quark flavor groups—$D^{\pm}$, D^o, D_s, B_c, Ξ_c^+, Λ_c, Ξ_c^o, Ω_c (unpaired);

J/ψ_{1S}, J/ψ_{2S} (paired), D^{*o}, Σ_c^o, Σ_c^{++}, Λ_c (excited states).

These lifetime flavor groups contain *mesons* and *baryons* combined together in the same lifetime patterns. This indicates that an individual flavored quark acts the same way with respect to lifetimes whether it is in a meson or a baryon. These quarks dictate the (non-overlapping) flavor group lifetimes, which are separated by factors of $\alpha \cong 1/137$.

Another salient feature in each of these flavor groups is that the ratio of the paired to unpaired lifetimes is a factor of roughly α^4, with no rogue lifetimes appearing in the intervening α^4 lifetime gaps. This is a huge leap—more than 8 orders of magnitude—and it reflects the small coupling constants of the unpaired-quark electroweak decays as compared to the much larger coupling constants of the paired-quark and radiative strong decays. These approximate α^4 lifetime gaps involve both mesons and baryons.

It is instructive to calculate the numerical values of the α^4 gaps displayed in Fig. 3, which are as follows: (PS) $(133)^4$; (*s*) $(214)^4$; (*b*) $(105)^4$; (*c*) meson $(90)^4$; (*c*) baryon $(182)^4$. These $\sim\alpha^4$ gap sizes straddle the value $(137)^4$ that represents strict α scaling. An important point to consider is that the 37 metastable hadrons represented here include all of the quark ground states, and there are no violations of the scaling systematics—no rogue particles. Historically, the overall framework for this lifetime systematics was apparent in the early experimental data, and was published prior to the discoveries of the *c* quark [3] and the *b* quark [4], which have served to flesh out the global lifetime α-grid.

The experimental lifetimes displays Figs. 2 and 3 feature an α-quantized lifetime grid that employs the *renormalized* coupling constant $\alpha = e^2/\hbar c \cong 1/137,$ and not the *running* coupling constant $\alpha(q^2)$ that is used for theoretical calculations. The running constant matches the renormalized value 1/137 at low-energy scales $(q^2 = 0),$ but increases to $\alpha(q^2) \sim 1/128$ at high-energy scales $(q^2 \approx m_W{}^2)$ [5]. The accuracy of the fit of the experimental lifetimes to the renormalized α-grid indicates that it is the renormalized coupling constant which is relevant to the decay triggering process. This conclusion will be reinforced when we extend the α-grid to encompass the long-lived muon and neutron (Sec. 7)

5. Quark flavor-group central lifetimes (CL) and factor-of-2-3-4 lifetime substructure

Figure 4 is an expanded global α-grid plot of the (PS), (*s*), (*b*), (*c*) unpaired-quark lifetime flavor groups displayed in Figs 2 and 3. It illustrates the fact that of these groups contains a clear-cut "central lifetime" (CL), together with a group substructure that brackets the CL, and which appears in the form of approximately *integer* lifetime ratios of 2, 3, or 4 between related particles. The vertical solid lines in Fig. 4 denote the average CL value for each group. These four unpaired-quark flavor groups contain the following CL particles, respectively:

(PS) The ($\pi^\pm$) pseudoscalar pion, which is bracketed between the K_L^o and $K^\pm$ kaons, and is the reference lifetime in the equation $\tau_i / \tau_{\pi^\pm} = \alpha^{x_i}$ that defines the lifetime global α-grid.

(s) The Ξ^-, Σ^- hyperons, which are bracketed between the Λ, Ξ^o hyperons and the Σ^+, Ω hyperons and K_S^o kaon. The Ξ^-, Σ^- average CL is displaced slightly from the $x_i = 1$ α-grid line in the direction of shorter lifetimes. The $K^\pm$ and K_S^o mesons both have ππ decay modes, and their lifetime ratio of 138.28 closely matches the α-grid spacing of 137.04.

(*b*) The ($B^\pm, B^o, B_s, \Lambda_b, \Xi_b^-, \Omega_b$) bottom mesons and baryons. All of the *b*-quark particles are In the CL group, which is centered on the $x_i = 2$ α-grid line.

(*c*) The (D^o, D_s, B_c, Ξ_c^+) charm mesons and baryon, which are bracketed between the $D^\pm$

charm meson and the $\Lambda_c, \Xi_c^o, \Omega_c$ charm baryons. The *c*-quark CL is displaced from the *b*-quark CL at $x_i = 2$ by a factor of 3 to the α-grid value $x_i = 2\ 2233$.

These CL groups demonstrate the workings of the quark dominance rule c > b > s. The $B_c = b\overline{c}$ meson is squarely in the *c*-quark CL group, and the $B_s = b\overline{s}$ meson is squarely in the *b*-quark CL group. The one common feature in the *b*-quark set of CL particles is the *b* quark itself, and the one common feature in the *c*-quark set of CL particles is the *c* quark. Thus it seems empirically clear that each particle lifetime is dictated by the stability of its single dominant quark.

The particle groupings displayed in Fig. 4 contain eight approximate factor-of-2 lifetime ratios among related particles, together with two factor-of-3 ratios and two factor-of-4 ratios. This brings up the question as to whether these experimental lifetime ratios represent intrinsically *integer* values, or are just coincidental results. This question is addressed in Fig. 5, where the numerical values of these ratios are arrayed so as to obtain average values for the factor-of-2, factor-of-3 and factor-of-4 lifetime intervals. As shown in Fig. 5, the average lifetime ratio for each group is within a few percent of being an exact integer. This suggests that there is a structural component of some kind which operates as a decay trigger in these decays. This decay trigger is superimposed on the overall stability of the dominant quark itself, which exhibits a dependence on the renormalized fine structure constant α. The Standard Model has worked very well in the calculation of *partial* decay channels for these particles, and it has been suggested that the *total* lifetime or decay width of an elementary particle is merely the sum over the available decay channels. However the observed global structure of these lifetimes indicates that the decay process is initiated in a manner which is to some extent independent of the decay channels and of the available phase space.

6. The α-quantization of the pseudoscalar (PS) meson lifetimes

The low-mass pseudoscalar meson family contains five nonstrange mesons $(\pi^+, \pi^-, \pi^o, \eta, \eta')$ and four strange kaons (K^+, K^-, K_L^o, K_S^o). Their lifetimes are displayed in Figs. 1-5. They provide some of the most accurate examples of global lifetime α-scaling (Fig. 3), the α^4 gap between *unpaired-quark* and *paired-quark* decays (Fig. 3), and a factor-of-2 lifetime substructure

(Figs. 4 and 5). They also exhibit a unique sequential spacing of the π^o, η, η' lifetimes by approximate factors of α (Fig. 3), and a precise α-spacing of the $K^{\pm}\rightarrow\pi\pi$ and $K^o_S\rightarrow\pi\pi$ lifetimes (Figs. 2 and 4). In Sec. 6 we evaluate the accuracy of the PS α quantizations for the $\pi^{\pm}, \pi^o, \eta, \eta'$ mesons, and in Sec. 7 we discuss the ramifications of the $K^{\pm}, K^o_L, K^o_S$ kaons.

Figure 6 shows the $\pi^{\pm}, \pi^o, \eta, \eta'$ lifetime experimental data, plotted in the form of lifetime ratios on the global α-quantized lifetime grid of Figs. 3 and 4. The accuracy of the α-scaling is visually apparent. The numerical values of the lifetime logarithms x_i are shown under the data points. Their deviations from integer 4, 5 and 6 values are all less than 0.7%. This figure demonstrates that the π^o, η, η' PS meson lifetimes accurately scale with respect to the $\pi^{\pm}$ reference lifetime by factors of S^4, S^5, S^6, respectively, where the scaling factor is S ~ 137.

Figure 7 displays calculated numerical values of the scaling factor S for the experimental lifetime ratios shown in Fig. 6. The ratios of the π^o/η and η/η' lifetimes are only qualitatively comparable to the value $S = 137$, but the global scaling factors S that employ the ratio to the $\pi^{\pm}$ lifetime and extend over several powers of S closely bracket this value.

The large span of values encompassed by the $\pi^{\pm}, \pi^o, \eta, \eta'$ PS meson lifetimes, and the accuracy with which they fall on the lifetime α-grid, can be demonstrated by writing down their experimental values, and then comparing them to the values obtained under the assumption of a precise scaling in powers of α. This comparison is as follows, where the lifetimes are quoted in zeptoseconds (10^{-21} sec):

Meson	Experimental lifetime (zsec)	Calculated α-scaled lifetime (zsec)	Accuracy
$\pi^{\pm}$	τ = 26,033,000,000,000.00		
π^o	τ = 84,000.00	73,800.00 = $\tau_{\pi^{\pm}} / (137.036)^4$	12%
η	τ = 506.00	539.00 = $\tau_{\pi^{\pm}} / (137.036)^5$	7%
η'	τ = 3.39	3.93 = $\tau_{\pi^{\pm}} / (137.036)^6$	16%

The calculated α-grid lifetimes reproduce the experimental values with a lifetime accuracy level of roughly 15% over thirteen orders of magnitude. This makes it possible to deduce the lifetime systematics in one local region of values, and then link this systematics to other local lifetime regions of the global lifetime network, as demonstrated for example in Fig. 3.

Another way to assess the accuracy of the lifetime scaling in powers of $S \approx \alpha^{-1}$ is to calculate the least-squares sum $\chi^2(S)$ of the calculated lifetimes $\tau_i(S)$ to the experimental lifetimes $\tau_i(\text{exper})$, weighted by the accuracies of the experimental values, as a function of *S*. The equation for $\chi^2(S)$ is [6

$$\chi^2(S) = \sum_i \left(\frac{\tau_i(S) - \tau_i(\text{exper})}{\Delta\tau_i(\text{exper})} \right)^2 ,$$

where $\Delta\tau_i(\text{exper})$ is the experimental error of the *i*th measurement. The calculated lifetimes have the form $\tau_i(S) = \tau_{\pi^\pm} \times S^{-x_i}$, $x_i = 4,5,6$ (see Fig. 7). The value of *S* that minimizes the chi-squared sum is the most accurate scaling factor for this data set. This method only works well in a statistical sense if all of the data have roughly comparable error limits. Otherwise, the χ^2 sum is dominated by the fits to the data that have very small error bars.[6] The results of this calculation for the $\pi^\pm$, π^o, η, η' data set are displayed in Figure 8. As can be seen, the $\chi^2(S)$ minimum occurs at the value S_{min} = 139.1, which closely agrees with the lifetime α-grid value $\alpha^{-1} \cong 137.0$. This χ^2 analysis reinforces the conclusion from Figs. 6 and 7 that these lifetimes exhibit a dependence on the renormalized fine structure constant α.

The $\chi^2(S)$ analysis is expanded in Fig. 9 to include the CL central-group *s*-quark and *b*-quark lifetimes of Fig. 4. The excluded unpaired-quark lifetimes in Fig. 4 involve either factor of 2-3-4 displacements from the lifetime α-grid, or, in the case of the *c*-quark lifetimes, an overall factor of 3 displacement. But the eleven particles that enter into the chi-square sum of Fig. 9 require no corrections to the experimental data points. As can be seen, the $\chi^2(S)$ minimum for these eleven particles is at S_{min} = 136.19, which matches the lifetime global α-grid spacing to an accuracy of 0.6%. This result indicates that the identification of the unpaired-quark central lifetimes CL in Fig. 4 as the lifetimes which are naturally spaced by factors of $\alpha^{-1} \cong 137$ relative to the unpaired-quark $\pi^\pm$ lifetime is an experimentally justified assumption.

7. The kaon "local α-grid" centered on the $K^{\pm}$ meson

The pseudoscalar meson and kaon experimental lifetimes were plotted as the (PS) unpaired-quark and paired-quark lifetime groups in Fig. 3, and the factor-of-2 spacings of the kaons were displayed in Fig. 4. In Sec. 6 we analyzed the lifetime spacings of the nonstrange $\pi^{\pm}$, π^{o}, η, η' mesons (Figs. 6-9). We now similarly analyze the strange $K^{\pm}$, K_L^o, K_S^o kaons. The kaon lifetimes are shifted by factors of 2 off the $\pi^{\pm}$-anchored *global* lifetime α-grid. Thus it seems appropriate to plot them on a "local α-grid" that is anchored on the $K^{\pm}$ lifetime. This plot is shown in Fig. 10. The $K^{\pm}$ and K_S^o kaons are related by their $\pi\pi$ hadronic decay modes, and their lifetimes fall accurately on the shifted *kaon* local α-grid. Their experimental lifetime ratio of 138.28 is within 0.9% of the value $\alpha^{-1} \cong 137.04$, which indicates that the fine structure constant α is relevant to both the kaon and pion lifetimes. The K_L^o kaon has a $\pi\pi\pi$ hadronic decay mode, and its lifetime is a factor of 4 longer than that of the $K^{\pm}$. The $\pi^{\pm}$ lifetime is the geometric mean of the K_L^o and $K^{\pm}$ lifetimes, and is the CL central lifetime of the (PS) unpaired-quark lifetime group (Fig. 2).

In Sec. 6 we demonstrated that the *nonstrange* $\pi^{\pm}$, π^{o}, η, η' pseudoscalar meson lifetimes fall accurately on the *global* α-grid that is centered on the $\pi^{\pm}$ meson. In Sec. 7 we showed that the *strange* $K^{\pm}, K_S^o$ pseudoscalar kaon lifetimes fall accurately on a *local* α-grid that is centered on the $K^{\pm}$ kaon. In Sec. 8 we extend these results to include a mixed set of particles whose lifetimes fall on a local α-grid that is centered on the $\mu^{\pm}$ muon.

8. The lifetime α-quantization of the muon, neutron and "charm-corrected" tauon

One reason for studying the experimental systematics of elementary particle lifetimes is to ascertain the requirements these results impose on theoretical lifetime formalisms. A second reason is to find out if the particle lifetimes reveal something about the nature of the particles themselves. And, as displayed here, they do. Historically, the symmetries of particle masses, spins, isotopic spins and hypercharges were used to deduce the existence of quark substates within the particles. We can see from the lifetimes displayed in Fig. 2 that the existence of quark-like objects or quark flavors can be inferred from the manner in which these particle lifetimes group together in non-overlapping flavor-group regions. This lifetime information serves to corroborate the reality of quarks as components of hadrons. The range of particle lifetimes in each of these individual flavor groups is evidently dictated by a single dominant quark flavor, which operates in the same manner in mesons as it does in baryons (Figs. 3 - 5).

A third reason for studying lifetime systematics is to see if they reveal unsuspected relationships among the particles. Our studies up to the present point have been mainly centered on the systematics of the 24 unpaired-quark *hadronic* ground states that are displayed in Fig. 4, which occupy the Zone (2) lifetime region that extends from 10^{-7} to 10^{-14} sec (Fig. 1). In the present section we expand this systematics by adding in the two long-lived Zone (1) particles—the *hadronic* neutron and *leptonic* $\mu^{\pm}$ muon—and also the Zone (2) *leptonic* $\tau^{\pm}$ tauon. The weakly-interacting $\mu^{\pm}$ and $\tau^{\pm}$ leptons are commonly regarded as being unrelated to the strongly-interacting hadrons. However, we will now demonstrate that they, and also the metastable neutron, have lifetimes that fit into and extend the $\pi^{\pm}$– anchored global α-grid systematics. Furthermore, these lifetimes furnish some information about the generational matching of the three families of quark pairs to the three families of lepton-neutrino pairs.

The neutron, muon and tauon lifetimes were displayed and labeled in Fig. 1, but have not subsequently been included. Their addition extends the observed lifetime regularities in an interesting and unique manner. Figure 11 displays the lifetimes of the 24 unpaired-quark ground-state particles of Fig. 4, together with the neutron, $\mu^{\pm}$ and $\tau^{\pm}$ lifetimes, which are all plotted on the global α-grid. The neutron and muon lifetimes occupy new positions on the α-grid, which are both close to α-quantized integer values of the lifetime logarithms x_i. Thus they extend the accurate lifetime scaling in powers of α. The tauon lifetime, however, does not match the global α-grid. Instead, it appears as a member of the *c*-quark flavor cluster, which is shifted away from the $x_i = 2$ α-grid position by a factor of 3 to $x_i = 2.2233$. The $x_i \simeq 2$ α-grid itself is occupied by the *b*-quark flavor cluster. It turns out, as we will demonstrate, that the precise lifetime positioning of the $\tau^{\pm}$ tauon leads to unexpected and phenomenologically significant results.

A subtle but important feature in Fig. 11 is the fact that the neutron and $\mu^{\pm}$ lifetimes are shifted off the global α-grid positions $x_i = -5$ and -1, respectively, and toward shorter lifetimes, by factors of 1.42 and 1.62, and the $\tau^{\pm}$ lifetime is shifted off the *factor-of-3-displaced* *c*-quark α-grid position at $x_i = 2\ 2233$ by a factor of 1.59. (Note the analogous factor-of-2 shift off the *global* α-grid and toward shorter lifetimes displayed by the pseudoscalar kaon *local* α-grid plot in Fig. 10.) This common lifetime shift suggests that the neutron, muon and tauon are in some manner related. It also indicates that the *leptonic* tauon shares the characteristic *c*-quark factor-of-3 lifetime shift (*c-quark correction factor*) of $\Delta x_i = 0.2233$ that applies to all eight *hadronic* unpaired *c*-quark ground states in Figs. 4 and 11. Thus we have the hadronic *c*-quark lifetime properties being reflected in the weakly-interacting and featureless (quarkless) tauon. To investigate these implications in more detail, we plot these lifetimes on a local α-grid that is centered on the $\mu^{\pm}$ lifetime, as shown in Fig. 12.

Figure 12 shows the standard α-spaced logarithmic lifetime grid, but with the leptonic $\mu^{\pm}$ instead of the hadronic $\pi^{\pm}$ as the reference lifetime, and it displays just the experimental neutron and $\mu^{\pm}$ lifetimes and the "charm-corrected" $\tau_{\mathrm{corr}} \equiv \tau^{\pm}\times 3$ lifetime. As can be seen, these lifetimes are spaced by accurate powers of $\alpha^{-1} \cong 137$. The α^3 gap that separates the $\mu^{\pm}$ and τ_{corr} lifetimes is unique in the particle lifetime systematics. Using this systematics as a guide, we deduce the following lepton lifetime equation:

$$\tau_{\mu^{\pm}} = \tau_{\tau^{\pm}} \times 3 \times (137.036)^3 .$$

This equation is remarkable for both its accuracy and its implications. The equation connects two lifetimes, which are six orders of magnitude apart, to an overall accuracy of 2%. It is informative to show the numerical values from this equation, using lifetimes in microseconds (μsec):

$$\text{(experimental lifetime) } \tau_{\tau^{\pm}} = 0.0000002906\ \mu\text{sec}$$

$$\text{(experimental lifetime) } \tau_{\mu^{\pm}} = 2.197\ \mu\text{sec}$$

$$\text{(calculated lifetime) } \tau_{\mu^{\pm}} = 2.243\ \mu\text{sec (2.1\% accuracy)}$$

We can draw three conclusions from these results: *(1)* the *leptonic* tauon accurately shares the factor-of-3 "*c*-quark lifetime shift" (with respect to the *b*-quark particles on the global α-grid) that occurs for the *hadronic* *c*-quark mesons and baryons; *(2)* α^3 is a relevant scaling factor for the separation of the *leptonic* $\mu^{\pm}$ and $\tau^{\pm}$ lifetimes, in the same sense that α^4 is the relevant scaling factor for the separation of the *hadronic* unpaired-quark and paired-quark flavor-group lifetimes displayed in Fig. 3; *(3)* the *renormalized* fine structure constant $\alpha^{-1} \cong 137.036$ accurately applies to these metastable lepton lifetimes.

The other significant result we can obtain from the lifetimes displayed in Fig. 12 is the relationship it suggests between the neutron and muon lifetimes. These are separated by the same α^4 lifetime gap that is observed in each of the (PS), (s), (b), (c) flavor groups of Fig. 3. This gap is between the slow *flavor-changing* unpaired-quark decays and the fast *flavor-conserving* paired-quark or radiative decays, and it divides each flavor group into two well-separated subgroups. The *free neutron decay* into a proton, electron and electron antineutrino (which has the neutron lifetime displayed in Fig. 2) is a classic textbook example [7] of a weak-interaction flavor-transforming decay that converts a *d* into a *u* quark, as mediated by a virtual W gauge boson. Lepton number is conserved in this decay. The *muon decay* into an electron, muon neutrino and electron antineutrino conserves quark flavor (since leptons do not have quarks), and it also conserves lepton number. Thus muon decay formally serves as a flavor-conserving process. Hence the experimental α^4 gap between the neutron and muon lifetimes is in line with the α^4 gaps shown in Fig. 3, but *only if the neutron and muon are related particles*, since the α^4 gaps displayed in Fig. 3 are all within flavor-related particle groups. Thus the muon-to-neutron lifetime ratio of α^4 displayed in Fig. 12 indicates that these particles are in some sense tied together, which is also indicated by their similar lifetime displacements on the $\pi^{\pm}$-centered lifetime global α-grid of Fig. 11.

We can demonstrate the accuracy of the *low-mass* neutron-to-muon α^{-4} lifetime ratio in Fig. 12 by comparing it to the other observed *low-mass* flavor-breaking-to-flavor-conserving α^{-4} lifetime ratio, which is the $\pi^{\pm}$ to π^{0} lifetime ratio displayed in Figs. 3, 6 and 7. These two sets of lifetimes are plotted together in Fig. 13, where the long-lived flavor-changing particle decay in each case is used to anchor the lifetime *a*-grid, and the short-lived flavor-conserving decay lifetime appears at a separation distance of α^{-4} (eight orders of magnitude). These are the only examples observed below 1 GeV, and hence are logically of foundational importance. They represent the lowest-mass boson decays (the pions) and the lowest-mass fermion decays (the neutron and muon). The lifetime relationship between the $\pi^{\pm}$ and π^{0} mesons is a familiar result, but the lifetime relationship between the hadronic neutron and leptonic muon is not.

The observations we have made here with respect to the neutron, muon and tauon are based on *lifetime* systematics. Additional information can be obtained from *mass* systematics. Figure 14 displays a mass vs. lifetime plot for the unpaired-quark flavor groups of Fig. 4, with the muon and tauon added in. In Fig. 4 the particle *x*-axis logarithmic lifetimes were arbitrarily spread out along the *y* axis for comparison purposes. In Fig. 14 we use the same lifetime *x* axis as in Fig. 4, but we now employ the *y* axis to represent the particle mass. This mass-lifetime plot shows that the tau lepton $\tau^{\pm}$, which has a *lifetime* that is in the (*c*) flavor group, also has a *mass* that is right in the mass region of the *charmed* D mesons. Thus both the lifetime and mass of the tau place it as a member of the conventional (*s, c*) quark "generation" of particle states, and not as a member of the (*b, t*) quark generation (where it is customarily portrayed [8]). This mass-lifetime plot also contains an example that illustrates the workings of the $c > b > s$ quark-flavor dominance rule (Fig. 2). The B_c meson, which contains both a *b* quark and a *c* quark, has the largest mass of the unpaired *b*-quark particles, and is positioned far above the other *c*-quark masses, and yet its lifetime falls squarely on the c-quark CL central-lifetime vertical axis. Hence the $c > b > s$ quark dominance rule is independent of the mass values of the particles.

As the final result here, we cite some particle mass values that reinforce the neutron-muon relationship suggested by their lifetimes systematics. In Fig. 13 we compared the similar α^4 lifetime ratios of the $(n^o, \mu^{\pm})$ and $(\pi^{\pm}, \pi^o)$ pairs of particles. We can extend these lifetime results to include masses by comparing the linear *mass* ratios of the $(\mu^{\pm}, \mathrm{neutron}, \tau^{\pm})$ fermion lifetime triad of Fig. 12 and the $(\overline{\pi}, \eta, \eta')$ boson mass triad of Fig. 6, where $\overline{\pi} = (\pi^{\pm} + \pi^o)/2$ is the *average pion mass*. These two triads show interesting similarities, as displayed in Fig. 15:

(1) The pion is the lightest metastable *boson*, and the muon is the lightest metastable *fermion*.

(2) The heavier masses in each triad are accurate multiples of the mass of the lightest particle.

(3) The boson and fermion triads both have linear mass ratios:

$$\text{boson: } (\overline{\pi}, \eta, \eta') = 1::4::7; \quad \text{fermion: } (\mu, \mathrm{n}, \tau) = 1::9::17.$$

(4) The experimental accuracies of these mass ratios are:

$$\eta = 4\overline{\pi}\ (0.2\%);\ \eta' = 7\overline{\pi}\ (0.3\%); \quad n = 9\mu\ (1.2\%);\ \tau = 17\mu\ (1.1\%).$$

The $(\overline{\pi}, \eta, \eta')$ triad contains three closely-related hadron states, whereas the (μ, n, τ) triad has a hadron interspersed between two leptons, and yet their numerical accuracies are remarkably similar. The mass systematics of Fig. 15 reinforces the lifetime systematics of Figures 6 and 12. In particular, the close interrelationship between the *muon* and the *neutron* emerges from both their mass and their lifetime systematics. It does not appear in the current formulations of Standard Model theories. This suggests that in assessing theories and models for elementary particles, both masses and lifetimes (mass stability) need to be taken into consideration.

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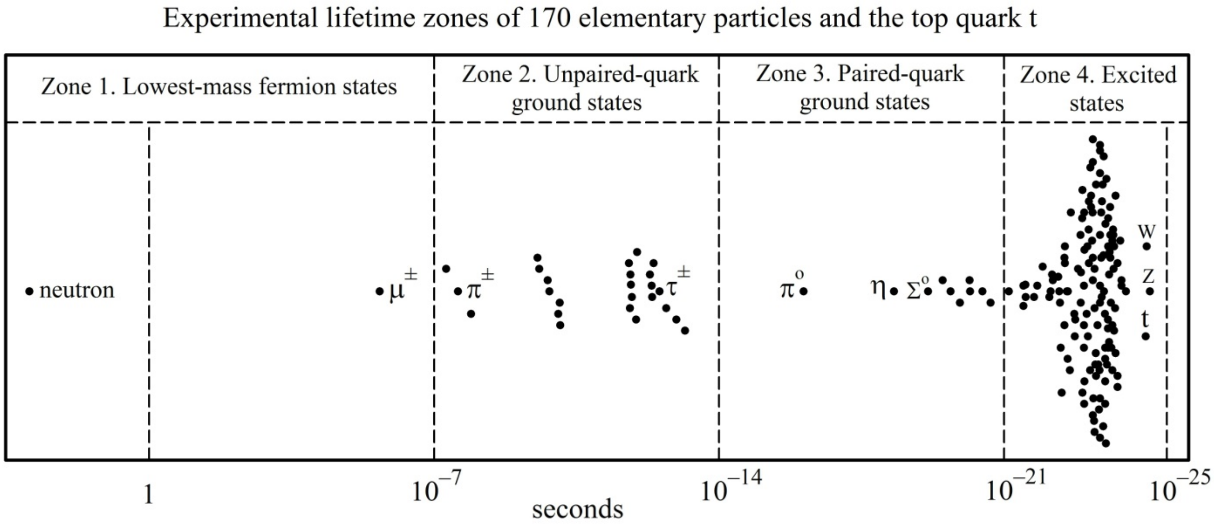

Figure 1. The measured lifetimes of 171 particle states, as listed in RPP 2011 [1]. The lifetimes in seconds are plotted on a logarithmic scale that spans 28 orders of magnitude, and that separates into four distinct lifetime zones. The Zone 4 hadron *excited states* decay down to the ground states via strong decays that conserve flavor, and they have short lifetimes of less that 10^{-21} sec (1 zsec). The hadron *ground states* divide into two factor-of-10^{7} lifetime zones, which reflect the flavor-breaking that is involved in the decay process. The *paired-quark* meson ground states, and the $\Sigma^{o}-\Lambda^{o}$ hyperon state, all of which *conserve flavor* and/or have radiative decays, are in the 10^{-14} to 10^{-21} sec Zone 3 lifetime range. The *unpaired-quark* hadron ground states, which require *flavor-changing* electroweak decays, are all in the 10^{-7} to 10^{-14} sec Zone 2 lifetime range. The only massive elementary particles with lifetimes longer than 10^{-7} sec are the Zone 1 metastable muon and neutron and the stable electron and proton. The shorted-lived excitations are the very massive Zone 4 W and Z gauge bosons and top quark *t*.

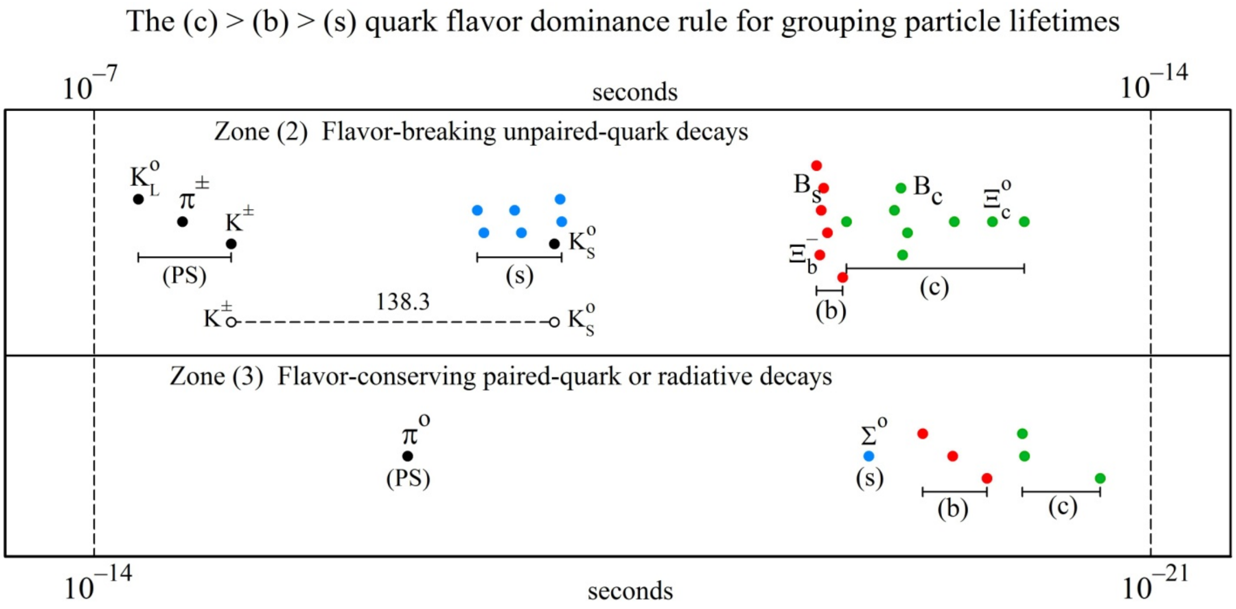

Figure 2. A lifetime plot of 32 metastable hadronic *quark flavor ground states*, with each hadron labeled by its dominant quark substate. The Zone 2 top section displays the *unpaired-quark* lifetimes in the 10^{-7} to 10^{-14} sec range, and the bottom section displaying the corresponding *paired-quark* lifetimes in the 10^{-14} to 10^{-21} sec range. The lifetimes in each section separate into four non-overlapping quark flavor groups, labeled as (PS) black, (*s*) blue, (*b*) red, (*c*) green, with mesons and baryons grouped together. The flavored quarks each have a characteristic range of lifetime values, and the shortest flavor range is dominant. The quark dominance rules are as follows:

(1) All particles that contain a *c* quark are in the (*c*) flavor group .

(2) All particles that contain a *b* quark but no *c* quark are in the (*b*) flavor group.

(3) The hyperons, which contain *s* quarks but no *b* or *c* quark, are in the (*s*) flavor group.

(4) The non-strange pseudoscalar (PS) *mesons* are in the (PS) flavor group, whereas the strange PS *kaons* appear in both the (PS) group $(\mathrm{K}^{\pm},\mathrm{K}_{\mathrm{L}}^{\mathrm{o}})$ and the (*s*) group $(\mathrm{K}_{\mathrm{S}}^{\mathrm{o}})$.

These results establish the empirical quark flavor dominance rule *c* > *b* > *s* for hadron lifetimes, with the pseudoscalar mesons forming a slightly more complex subset of particles. The $\mathrm{K}^{\pm}/\mathrm{K}_{\mathrm{S}}^{\mathrm{o}}$ lifetime ratio of 138.3 matches the fine structure constant value $\alpha^{-1} \cong 137.0$.

Figure 3. The lifetimes of 37 metastable quark ground states, showing the α-quantization of the *unpaired-quark* (PS) black, (*s*) blue, (*b*) red, and (*c*) green flavor groups, and the α^4 lifetime gaps between the *unpaired-quark* and corresponding *paired-quark* and *radiative* flavor groups. The 32 metastable hadron ground states of Fig. 2 are displayed here, together with the η and η' pseudoscalar mesons and three *c*-quark baryon excited states that have lifetimes slightly shorter than 1 zsec. The lifetimes are plotted as ratios to the $\pi^{\pm}$ reference lifetime, using a logarithmic representation with the base $\alpha \cong 1/137$. The non-strange $\pi^{\pm}, \pi^{o}, \eta, \eta'$ pseudoscalar meson lifetimes match x_i = 0, 4, 5, 6 α-grid lines, respectively. The unpaired-quark (*s*) and (*b*) flavor groups match the x_i = 1 and 2 α-grid lines, and the unpaired-quark (*c*) group is displaced by a factor of 3 from x_i = 2 in the direction of shorter lifetimes (see Fig. 4). Another prominent feature in Fig. 3 is the division of the (PS), (*s*), (*b*), (*c*) flavor-group lifetimes into long-lived and short-lived components. The lifetimes in the *paired quark* flavor groups are shorter than the lifetimes in the corresponding *unpaired-quark* groups by factors of approximately α^4. The intervening α^4 gaps form a *lifetime desert region* where no particle states have been observed. The results displayed in Fig. 3 demonstrate that an α-spaced lifetime grid anchored on the $\pi^{\pm}$ lifetime is an appropriate framework (a *global* α-grid) on which to combine the 37 ground-state hadrons into a unified global lifetime pattern. They also show that *mesons* and *baryons* occur together in the same pattern flavor-groupings, which are dictated by individual flavored quarks within the particles.

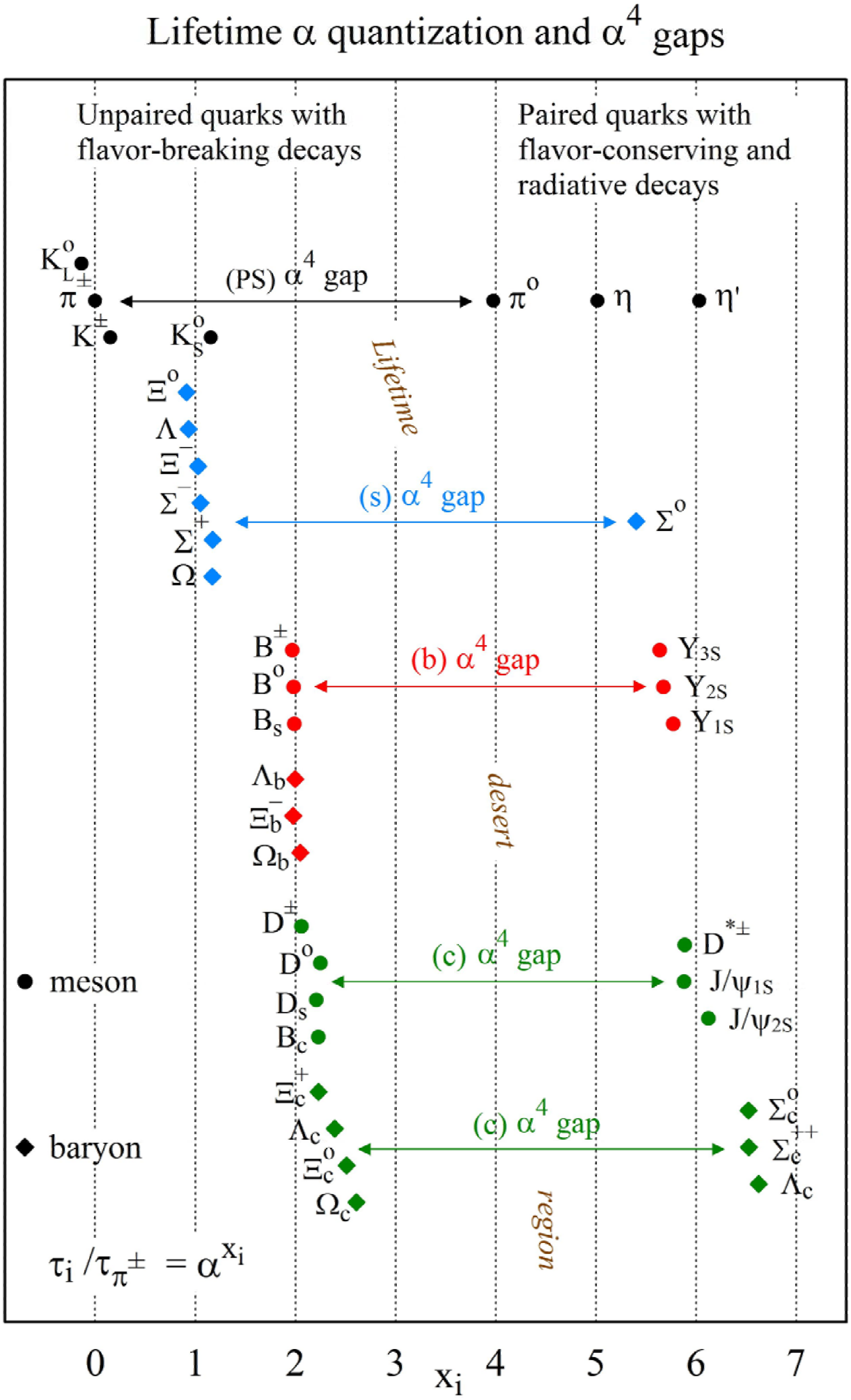
Lifetime α quantization and α^4 gaps
Unpaired quarks with flavor-breaking decays
Paired quarks with flavor-conserving and radiative decays
K_L^o
π^±
K^±
K_s^o
(PS) α^4 gap
π^o
η
η'
Lifetime
desert
region
Ξ^o
Λ
Ξ^−
Σ^−
Σ^+
Ω
(s) α^4 gap
Σ^o
B^±
B^o
B_s
(b) α^4 gap
Υ_3S
Υ_2S
Υ_1S
Λ_b
Ξ_b^−
Ω_b
D^±
D^o
D_s
B_c
(c) α^4 gap
D^*±
J/ψ_1S
J/ψ_2S
Ξ_c^+
Λ_c
Ξ_c^o
Ω_c
(c) α^4 gap
Σ_c^o
Σ_c^++
Λ_c
● meson
◆ baryon
τ_i /τ_π± = α^x_i
0
1
2
3
4
5
6
7
x_i

Fig. 3

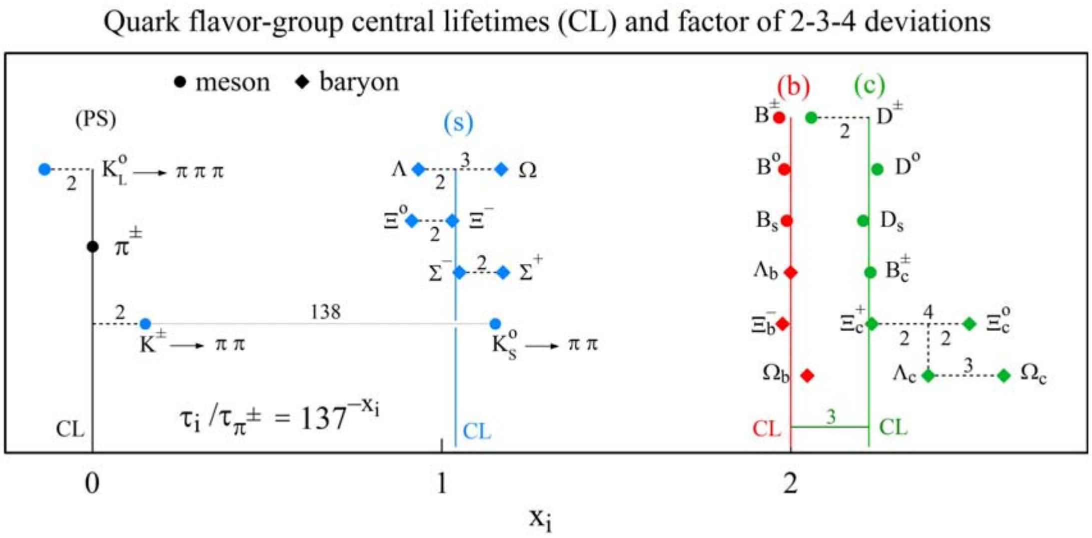
Quark flavor-group central lifetimes (CL) and factor of 2-3-4 deviations

Figure 4. Unpaired-quark (PS) black, (*s*) blue, (*b*) red, (*c*) green flavor-group CL central lifetimes and factor of 2-3-4 group substructures. This figure displays the 24 unpaired-quark ground-state lifetimes of Figs. 2 and 3, shown plotted on a global lifetime α-grid centered on the $\pi^\pm$ meson. The vertical lines denote the CL central lifetime in each quark flavor group The (PS) group CL (the $\pi^\pm$) defines the $x_i = 0$ α-grid line The (*s*) group CL is slightly off the $x_i = 1$ α-grid line. The (*b*) group CL is accurately placed on the $x_i = 2$ α-grid line. The (*c*) group CL is displaced toward shorter lifetimes by a factor of 3 with respect to the (*b*) group CL. The B_c meson is a member of the (*c*) group CL particles, and the B_s meson is a member of the (*b*) group CL particles, in accordance with the c > b > s quark dominance rule. The lifetimes that do not fall on the central lifetimes exhibit a lifetime substructure in which the lifetime ratios between related particles occur with approximately integer values of 2, 3 or 4. There are eight factor-of-2 ratios, two factor-of-3 ratios, and two factor-of-4 ratios (including $K^o_L / K^\pm$) displayed in Fig. 4. These lifetime ratios are also displayed graphically in Fig. 5, where they are grouped together and averaged.

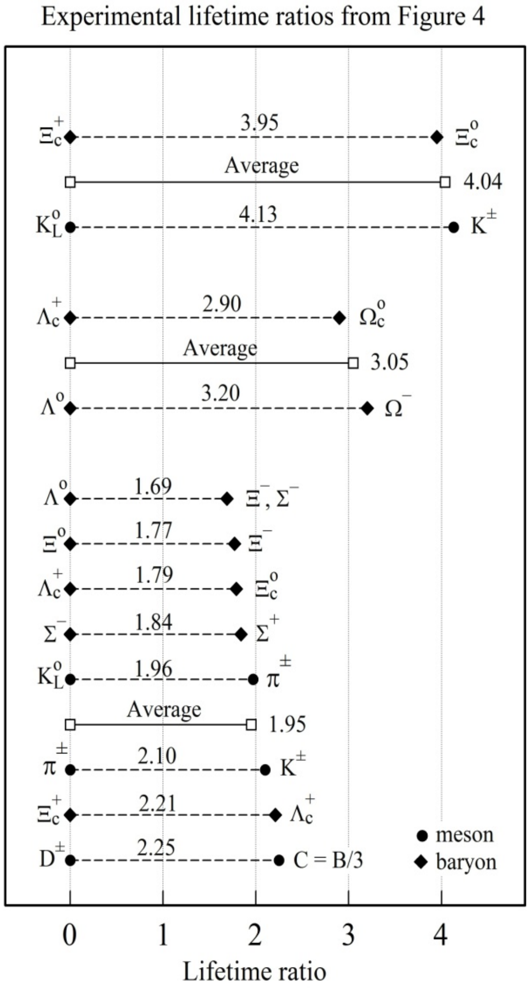

Figure 5. The factor of 2-3-4 integer lifetime ratios that were displayed and labeled in Fig. 4 are shown here in Fig. 5, where they are grouped together by integer value and averaged. The eight factor-of-2 lifetime ratios are between related particles except for the $\Lambda^{o}/(\Xi^{-},\Sigma^{-})$ ratio, which employs the (*s*) flavor group CL central lifetime, and the $D^{\pm}/(C=B/3)$ / ratio, which employs the (*c*) flavor group CL central lifetime. The two factor-of-3 lifetime ratios are between Λ particles (which feature one flavored quark) and Ω particles (which feature three flavored quarks). Although the experimental lifetime ratios 2, 3, and 4 are only approximately equal to integers, the average over all of the measured ratios for a given integer type is within a few percent of being an exact integer. This suggests an underlying particle integer decay mechanism that has smaller effects as perturbations. In addition to the integer lifetime ratios displayed here, the ω/ϕ vector meson lifetime ratio is 1.993. The ω and φ have lifetimes slightly shorter than 1 zsec, and hence are not included in the present metastable particle compilation.

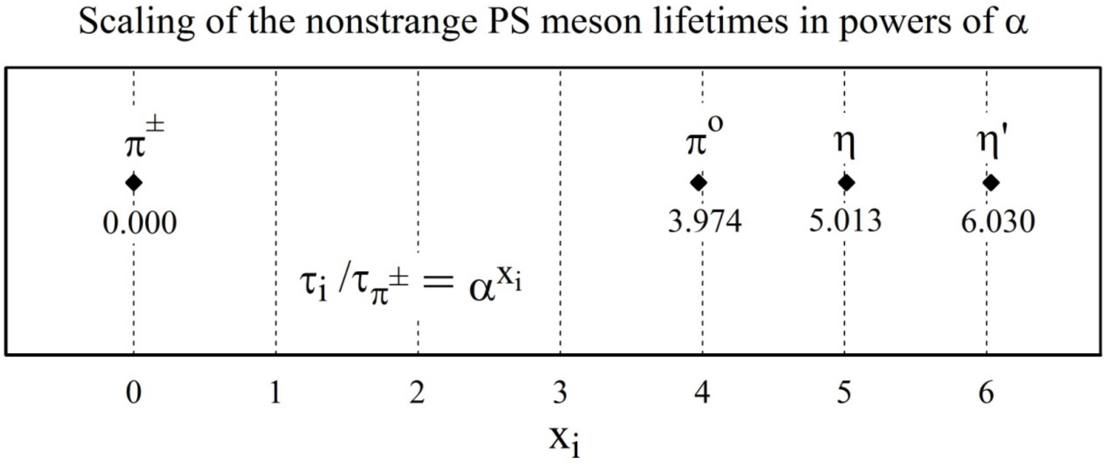

Figure 6. The accurate global α quantization of the nonstrange pseudoscalar mesons, whose lifetimes extend over 6 powers of α, or 13 orders of magnitude. The $\pi^{\pm}$ meson, the lowest-mass and the longest-lived (except for K_L^o) hadron state, serves as the reference lifetime for this global α-grid. The numerical values of the lifetime logarithms x_i are displayed below the experimental data points, and are close to the integer values that denote precise α-scaling. In detail, the deviations of the logarithms x_i from the exact integers 4, 5 and 6 are 0.65%, 0.26% and 0.50%, respectively. The α^4 lifetime gap between the unpaired-quark $\pi^{\pm}$ and paired-quark π^o mesons is also displayed in Fig. 3, where it is compared to similar α^4 gaps in the other lifetime flavor groups. The factor of ~α lifetime spacings in the π^o, η, η' excitation sequence are unique in the elementary particle lifetime data set, as can be seen in Fig. 3.

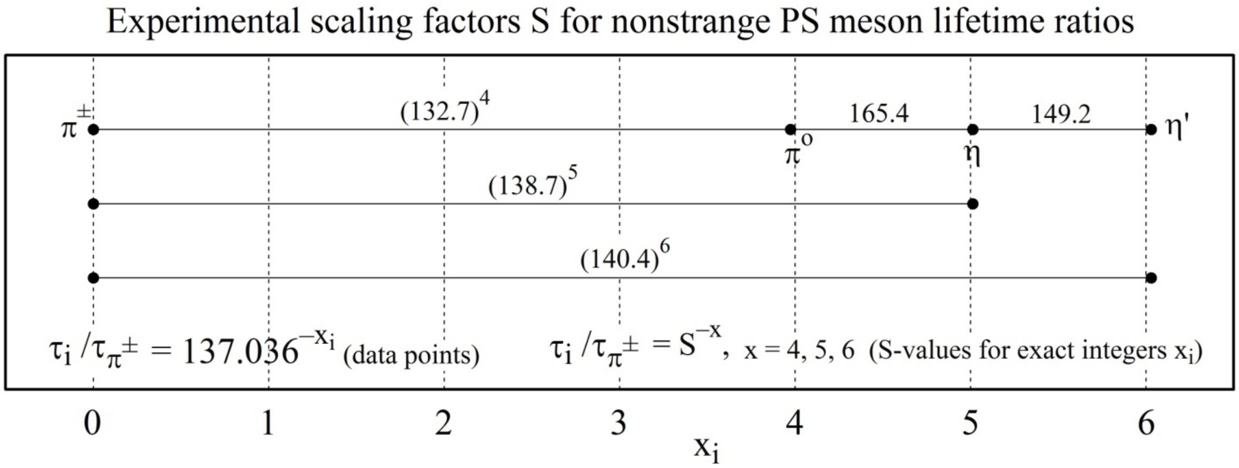

Figure 7. Experimental values of scaling factors S for the $\pi^{\pm}$, π^{o}, η, η' pseudoscalar meson lifetimes, plotted against the global α-grid framework of Fig. 6. The left equation defines the x_i data points on the lifetime α-grid, and the right equation defines the scaling factor S under the assumption that the x_i are exact integers. As can be seen, the local lifetime ratios π^{o}/η and η/η' are only qualitatively comparable to the α-quantized value $\alpha^{-1} \cong 137$, but the S values for the π^{o}, η, η' lifetimes when they are expressed as ratios to the $\pi^{\pm}$ lifetime closely match the α-grid scaling. This agreement demonstrates the usefulness of the lifetime global α-grid for correlating the systematics of the metastable ground-state hadron lifetimes over many orders of magnitude.

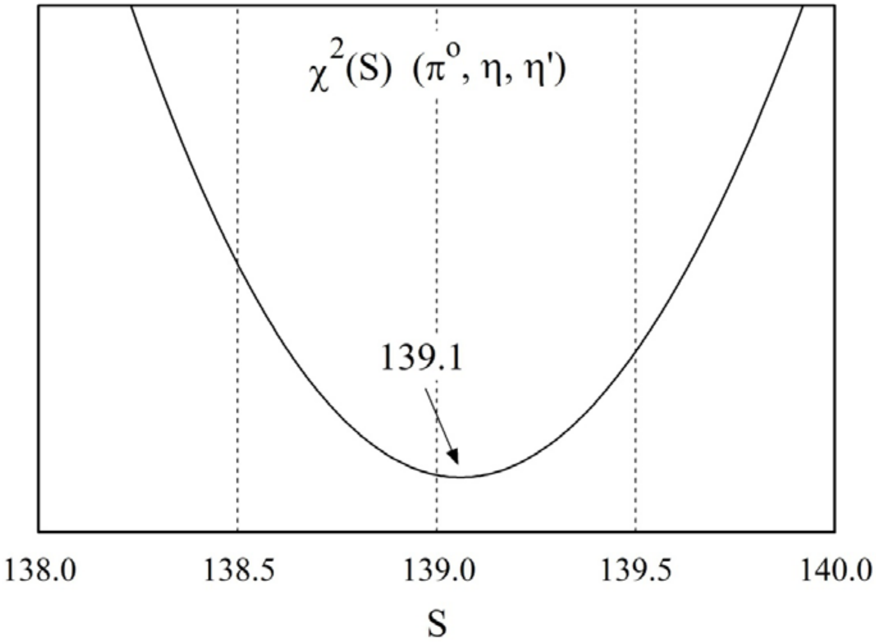

Figure 8. The least-squares sum $\chi^2(S)$ for the nonstrange π^o, η, η' pseudo-scalar mesons, plotted as a function of the scaling factor S (see Fig. 7). The chi-squared minimum at S = 139.1 gives the best fit of the theoretical S-scaled lifetimes to the experimental lifetimes, which are weighted by the accuracy of the experimental data. [6] This scaling factor closely matches factor-of-137 grid lines of the global α- grid that is employed in Figs. 3, 4 and 6.

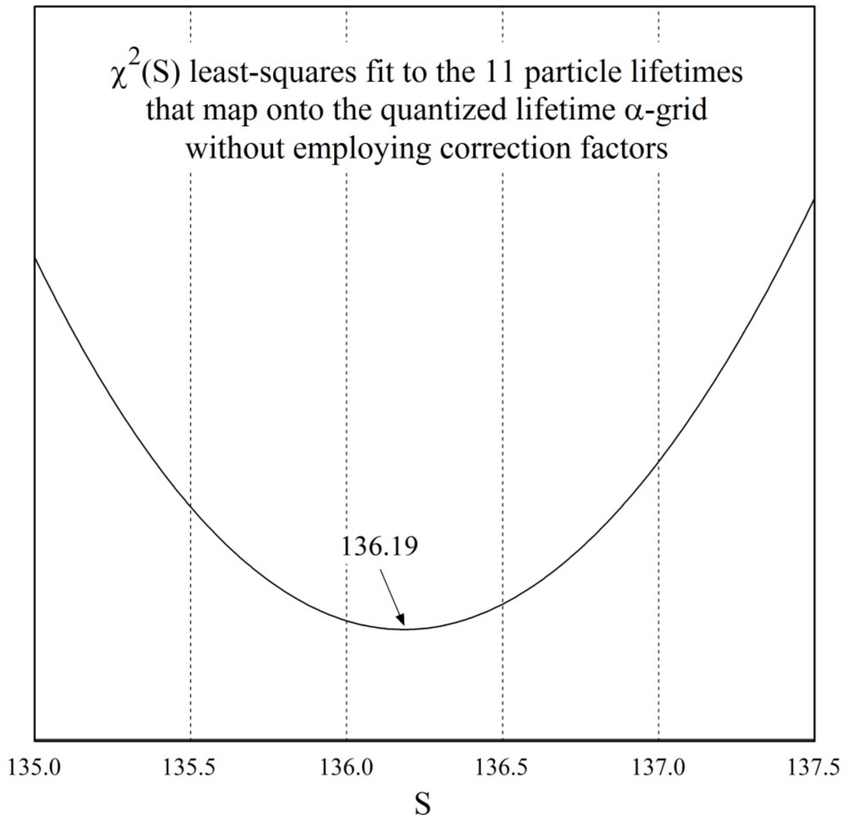

Figure 9. The $\chi^2(S)$ sum for eleven metastable particles, plotted as a function of *S*. These eleven particles are the π^o, η, η' mesons of Fig. 8, the CL central-group Ξ^-, Σ^- *s*-quark hyperons of Fig. 4, and the CL central-group $B^\pm, B^o, B_s, \Lambda_b, \Xi_b^-, \Omega_b$ *b*-quark mesons and baryons of Fig. 4. None of these particles involve factor of 2-3-4 integer displacements from the lifetime α-grid. As can be seen, the shape of the $\chi^2(S)$ curve is similar to that of Fig. 8, but the minimum has been shifted to the value $S_{\min} = 136.19$. This matches the α-grid spacing of 137.04 to an accuracy of 0.6%. Hence the concept of unpaired-quark lifetime quantization in powers of α, which is visually apparent in the global lifetime plots of Figs. 3, 4 and 6, is quantitatively borne out by the least-squares plots of Figs. 8 and 9. This χ^2 minimum also substantiates the use of the $\pi^\pm$ meson to anchor the global lifetime α-grid, and it verifies that this grid is based on the *renormalized* fine structure constant $\alpha^{-1} \cong 137$, and not the running constant $\alpha(q^2)$ that increases from $\alpha(q^2) \cong 1/137$ at $q^2 = 0$ to $\alpha \cong 1/128$ at $q^2 \approx m_W^2$ [5].

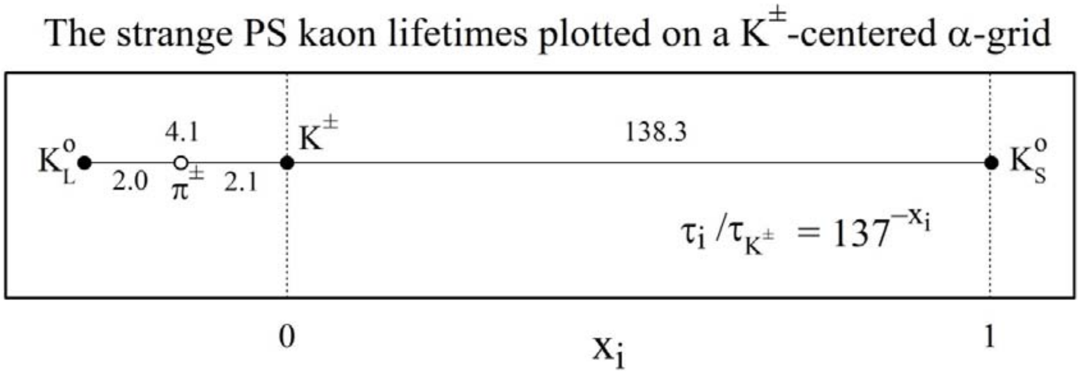

Figure 10. The strange $K^{\pm}$, K_L^o, K_S^o pseudoscalar kaon lifetimes, shown plotted on an α-quantized *local* α-grid that is anchored on the $K^{\pm}$ lifetime. Both the $K^{\pm}$ and K_S^o lifetimes match α-grid lines, which demonstrates the relevance of local α-grids for shifted as well as central lifetimes. The nonstrange $\pi^{\pm}$ lifetime is also displayed here to illustrate how it serves as the central lifetime of the K_L^o, $\pi^{\pm}$, K_S^o lifetime triad, which forms the unpaired-quark (PS) subgroup in Fig. 2. This mixed kaon and meson triad contains two accurate factor-of-2 lifetime ratios, as well as a factor-of-4 ratio between the two kaons (see Figs. 4 and 5).

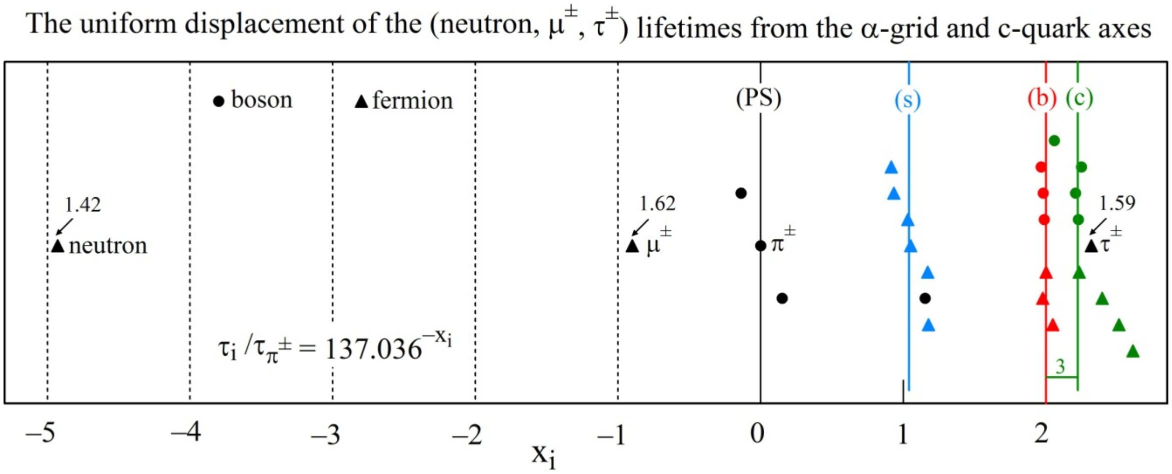

Figure 11. The *hadronic* unpaired-quark lifetime plot of Fig. 4 with the *hadronic* neutron and *leptonic* $\mu^\pm$ muon and $\tau^\pm$ tauon added in. The vertical solid lines through the (PS), (*s*), (*b*) and (*c*) flavor-group data points denote the *central lifetimes* CL for each group. The (PS) and (*b*) CL's lie on the $x_i = 0$ and $x_i = 2$ α-grid lines, respectively, but the (*s*) CL is slighter shorter than the $x_i = 1$ α-grid line. The (*c*) flavor group has four particles on the CL at $x_i = 2.2233$, and four particles with integer-displaced lifetimes (see Fig. 4), all of which are shifted toward shorter lifetimes by a common factor of 3 (the *c-quark correction factor* $\Delta x_i = 0.2233$) with respect to the $x_i = 2$ α-grid line. The neutron and muon lifetimes occupy the $x_i = -5$ and $x_i = -1$ global α-grid lines, but are shifted toward shorter lifetimes by factors of 1.42 and 1.62, respectively. The tauon is similarly shifted with respect to the *c*-quark CL by a factor of 1.59. This suggests that these three lifetime shifts may be related. In Fig. 12 we replot these three lifetimes on a *local* α-grid that is anchored on the $\mu^\pm$ lifetime instead of the $\pi^\pm$ lifetime.

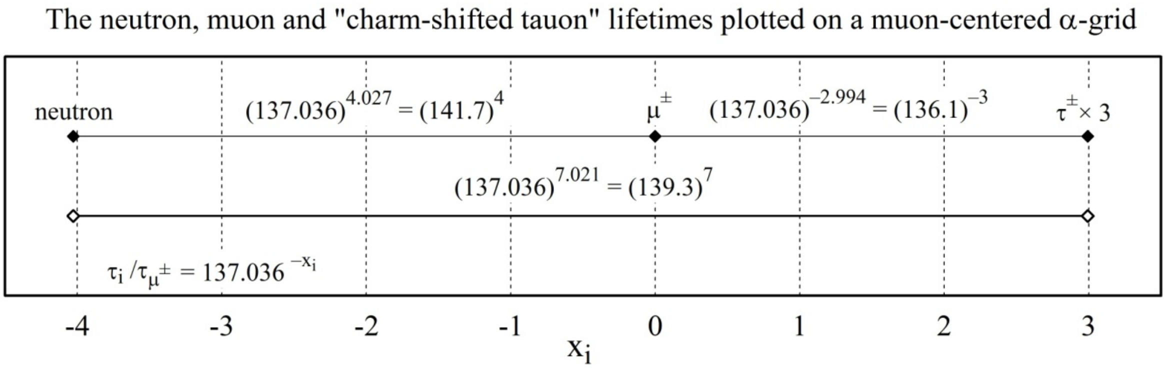
The neutron, muon and "charm-shifted tauon" lifetimes plotted on a muon-centered α-grid

Figure 12. The neutron and $\mu^{\pm}$ lifetimes, shown plotted together with the $\tau^{\pm}_{corr} \equiv \tau^{\pm} \times 3$ lifetime (using the *c*-quark *charm correction factor* 3 shown in Fig.4), and displayed on an α-quantized lifetime grid that is anchored on the $\mu^{\pm}$ lifetime. The leptonic $\mu^{\pm}$ to $\tau^{\pm}_{corr}$ lifetime ratio is α^{-3} (to 2% accuracy over a span of 6 orders of magnitude). This suggests that the tau lepton, which does not contain a *c* quark, nevertheless carries the *c*-quark lifetime flavor systematics. This surprising link between hadronic and leptonic lifetime behavior can also be inferred, although in a somewhat different form, from the neutron to $\mu^{\pm}$ lifetime ratio of α^{-4}. This is the lifetime ratio that occurs between the *slow* flavor-breaking and *fast* flavor-conserving hadronic decays displayed in Fig. 3. The slow neutron-to-proton decay involves a flavor-breaking *d* to *u* quark conversion. The fast $\mu^{\pm}$ to $e^{\pm}$ decay conserves quark flavors (it has none). Thus the neutron to $\mu^{\pm}$ lifetime ratio of α^{-4} formally follows the *flavor-breaking* to *flavor-conserving* rule of Fig. 3, but here one particle is a *hadron* and the other is a *lepton*. Hence the observed lifetime factor of α^{-4} conceptually links the hadronic neutron to the leptonic muon. Similarly, the observed lifetime factor of $3\,\alpha^{-3}$ links the leptonic tauon to the hadronic charm family (if we assume that the lifetime factor of α^{-3} represents an appropriate leptonic lifetime interval). Hence the experimental lifetime systematics of Figs. 11 and 12 suggests a commonality of some hadron and lepton lifetime properties.

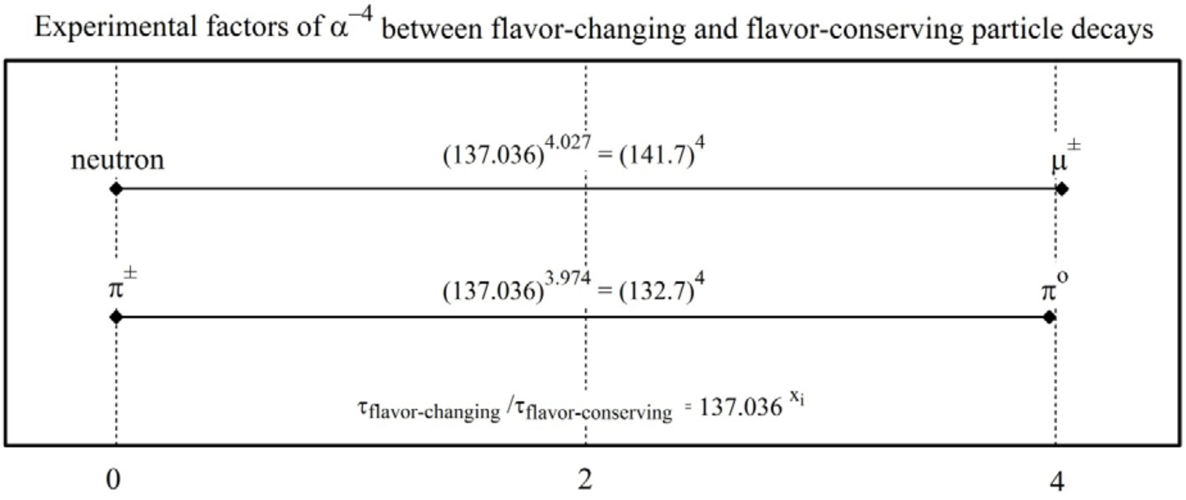

Figure 13. A comparison of the flavor-changing neutron and charged pion lifetimes with the flavor-conserving muon and neutral pion lifetimes, which are each a factor of α^4 shorter. As can be observed, the paired neutron-muon and $\pi^{\pm}/\pi^{o}$ lifetime ratios, which each span eight orders of magnitude, are accurately quantized in powers of α. These two sets of lifetimes are displaced from each other by a factor of α^5 (Fig. 1). The surprising result here is that whereas the $\pi^{\pm}$ and π^{o} are clearly-related particles, the n^{o} and $\mu^{\pm}$ are commonly assumed to be unrelated. In addition to the neutron-muon lifetime relationship displayed here, there is also a mass relationship that involves the neutron, muon, and tauon, as described in the text and displayed in Fig. 15.

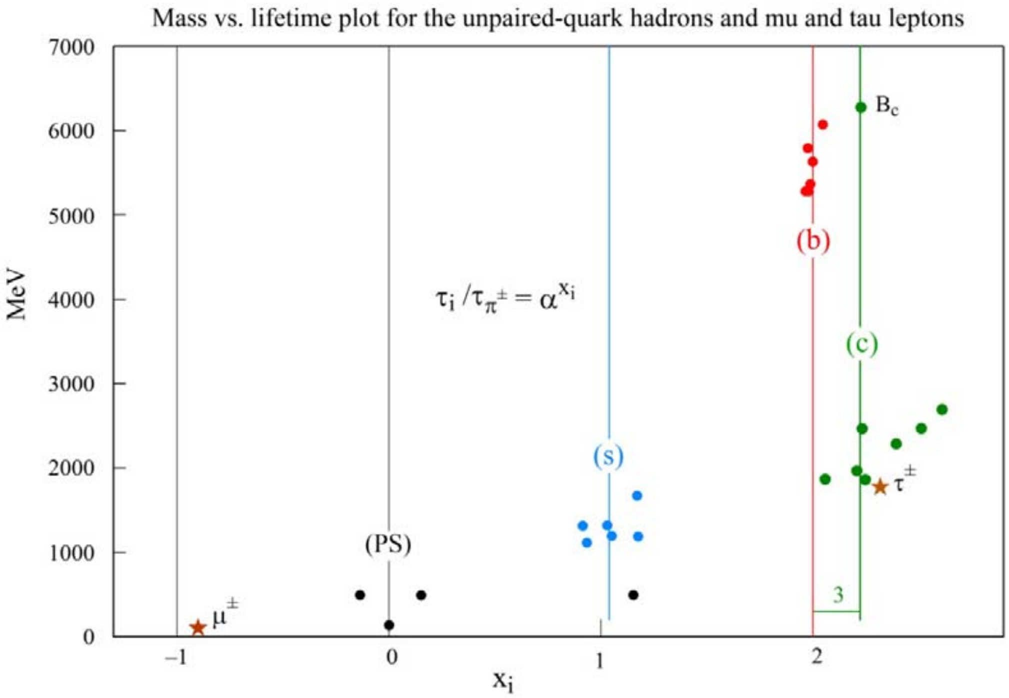

Figure 14. The 24 unpaired-quark hadron ground states of Fig. 4 plus the $\mu^\pm$ and $\tau^\pm$ leptons, shown on a mass-lifetime plot that has the logarithmic lifetime α-grid as the abscissa and the linear masses in MeV as the ordinate. The vertical solid lines indicate the "central lifetime" in each flavor group region (Fig. 4). The close association of the $\tau^\pm$ lepton mass with the mass group of *c*-quark D mesons and *charm* baryons is consistent with the fact that its lifetime carries the factor-of-3 "charm" correction factor. However, the close association of the $B_c = b\overline{c}$ meson mass with the mass group of *b*-quark B mesons and *bottom* baryons is *not* consistent with its lifetime, which falls squarely on the central lifetime (vertical line) of the charm flavor family. This shows that the $c > b > s$ quark dominance rule (Fig. 2) for dictating particle lifetimes supersedes the effects of the particle mass values. Particle mass groupings do not necessarily lead to corresponding lifetime flavor groupings.

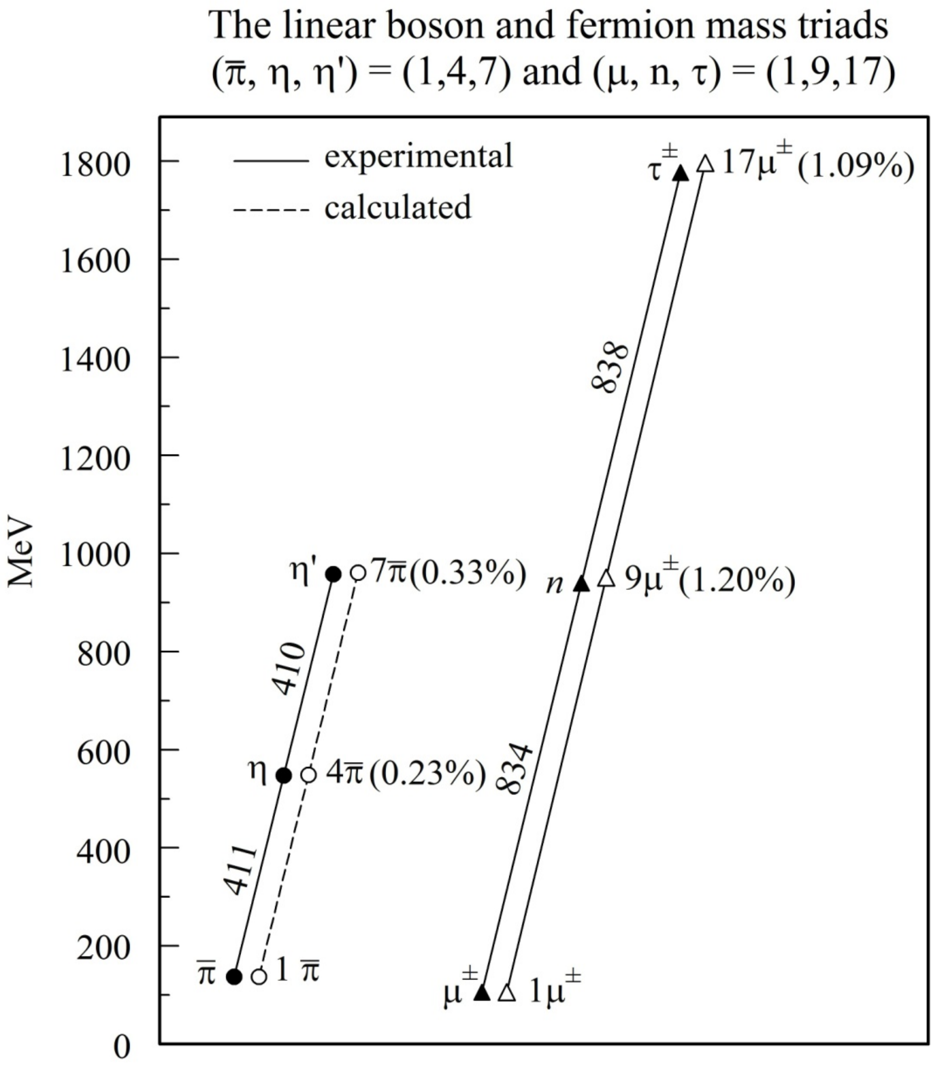

Fig. 15. The linear $(\bar{\pi}, \eta, \eta') \propto (1, 4, 7)$ boson and $(\mu, n, \tau) \propto (1, 9, 17)$ fermion mass triads, where $\bar{\pi} = (\pi^{\pm} + \pi^{o})/2$ denotes the average value of the closely-spaced $\pi^{\pm}$ and π^{o} masses. The pseudoscalar $\bar{\pi}, \eta,$ and η' mesons are clearly-related hadronic particles, but the weakly-interacting μ and τ leptons bear no obvious relationship to the hadronic neutron *n*. However, these boson and fermion triads share three common features: (1) they are accurately linear (~1%); (2) each lowest-energy particle state serves as the unit energy; (3) the ~836 MeV fermion excitation interval is approximately twice the ~410 MeV boson excitation interval. This suggests that the μ, *n*, and τ fermions have features in common, as do the matching $\bar{\pi}, \eta,$ and η' bosons.