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SHARP (e^+e^-) PAIRS: REASONS FOR CAUTION[1]

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The most recent heavy ion sharp pair experiment (APEX) reports no evidence of the sharp (e^+e^-) pairs reported in earlier (EPOS/I) work. We here attempt to place these results in the context of a search for unpredicted weak signals of great potential interest. Then caution is in order lest a discovery in progress be prematurely aborted by experimental misinterpretation. Guided by the accumulated phenomenology of the "(e^+e^-)-Puzzle", we point out that two other possible experimental mechanisms for producing the sharp (e^+e^-) lines are already under investigation in studies of $[\beta^+ + ATOM]$ collisions, and of $[\gamma + NUCLEUS]$ scattering from U targets. Evidence of sharp pairs from these studies could moot the apparent conflict in the heavy ion results. In addition, theoretical investigation of the effects upon high precision QED of the self bound Quadronium $(e^+e^+e^-e^-)$ atom could present the theoretical/experimental discrepancy in the 3γ decay of positronium as an indication of the existence of bound Q_0. Finally, we offer two possibilities for reconciling the APEX-EPOS/I results, the first based upon our ignorance of the process of Q_0 creation in the heavy ion collision, and the second, upon geometrical differences in the apparati.

1. Introduction

Surprisingly, the new APEX experiment, designed to measure the invariant mass distribution[3] of the sharp pairs previously observed [2, 3] in similar heavy ion collisions, reports null results [4, 5]. Although the APEX report asserts no direct conflict with any data reported by EPOS/I, (but only with a certain particle creation cross section inferred from the EPOS/I data under a set of very simple unverified assumptions), nevertheless it encourages speculation that the earlier (EPOS/I) observations were somehow erroneous.

We present here a rational context for caution against drawing hasty final conclusions from the present situation. In the first place, the sharp pairs were not expected, and

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[3] Unfortunately, this stated goal of the APEX project [1] was not realized.

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have no explanation within contemporary physical theory. This is consistent with their non-existence. But, if they do exist, it is also consistent with their being indicative of important new physics which we ought not allow ourselves to overlook. But our ignorance also weakens the power of our intuitions about them, inviting logical lapses[4] which may prematurely seem to foreclose certain questions.

Therefore, we hew as closely as possible to the previous experimental results. For this purpose, the "Quadronium Scenario", which describes semi-quantitatively the main features of the EPOS/I data, provides a place for the $[\beta^+ + ATOM]$ data of Sakai *et al.* [12, 13], and others[5] [16, 17], and which connects the resulting "Sharp Lepton Problem" to high precision quantum electrodynamics, provides our template for inquiry. It is outlined briefly in Section 2.

Within this framework, we suggest for further study two possibilities for reconciling the APEX and EPOS/I experiments, described in Section 3, and two alternative experimental avenues to produce the Q_0 particle and its pairs, through the $[\gamma + NUCLEUS]$ experiments of Section 4 and the $[\beta^+ + ATOM]$ studies discussed in Sections 5, 6, and 7. Section 8 outlines the effect of the hypothetical Q_0 bound state upon high precision quantum electrodynamics, and identifies the 3γ decay of orthopositronium as especially sensitive to the corresponding bound state pole.

2. The Composite Particle Q_0 Scenario

For several years the author has considered a composite particle creation/decay scenario to be the simplest framework capable of encompassing all the data of the heavy ion "(e^+e^-) Puzzle" [18, 19, 20]. About the internal structure of the composite particle, the data so far says nothing, but Occam's razor prefers a bound Quadronium $(e^+e^+e^-e^-)$ atom-without-a-nucleus, as the soundest present choice: not inadequately simple, but invoking no unecessary new hypothesis. On the other hand Q_0 is a purely phenomenological creature; no theoretical basis has yet been found to explain it strong binding. We therefore refer to the scenario as the "Composite Particle (Q_0?) Scenario".

The Composite Particle (Q_0?) Scenario allows for spontaneous Landau-Zener creation of Q_0 from the vacuum in strong enough heavy ion Coulomb fields [20, 21]. It also provides a good semiquantitative description [22] of EPOS' observed sum and difference widths as arising from Doppler and (in the U+Ta case) Coulomb broadening. The scenario also predicts [23] exotic decays of Q_0 bound in a supercomposite molecule with a nuclear ion, emitting $(e^-e^+e^+)$, (e^+e^+), (e^+), and one-γ, none of which has yet

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[4] Such lapses have already occurred twice in the the study of these sharp pairs, as follows, 1) in the premature exclusion of a new particle as a source of the pairs on the basis of the high precision agreement between QED theory [7, 8] and the experimental value of $(g_e - 2)$; and 2) in the exclusion of all possible lifetimes for a composite particle source for the sharp pairs [9]. In both cases the analyses assumed that the particle could decay *only* to (e^+e^-) pairs, and that assumption determined he conclusion. In fact neither argument speaks [10, 11] to particles with decay modes alternative to (e^+e^-), such as Q_0.

[5] These experiments utilized thicker targets than those used by Sakai *et al.* In addition, two other hick target experiments [14, 15] reported no supporting evidence.

been studied experimentally. All of these decays are forbidden to the isolated Q_0 atom by energy-momentum and lepton number conservation.

Among these, the single e^+ Sharp Annihilative Positron Emission (SAPosE) [24, 18] decay process, has an inverse creation process, Recoilless Resonant Positron Absorption (RRePosA), which plays a key role [25] in connecting the heavy ion "(e^+e^-) Puzzle" with Sakai's data on sharp pairs from $[\beta^+ + ATOM]$. This view identifies the $[\beta^+ + ATOM]$ process as one prospective method of producing Q_0 which is completely independent of the heavy ion studies.

In addition, the one-γ annihilation of Q_0 may already be in evidence as the 1780 keV gamma ray which occurs in the heavy ion data [26], or through its inverse creation process as one or more of the resonances in recent $[\gamma + NUCLEUS]$ studies [27] near 1.8 MeV. Thus, the creation of Q_0 in the $[\gamma + U, Th]$ process is the second alternative (to the heavy ion studies) possibility for producing Q_0.

The scenario has weathered the claim that the energetics could not allow Q_0 to be sufficiently polarized for its spontaneous creation in the high-Z Coulomb field [25, 28] of a di-ion and has survived [10, 29, 30, 31] the alleged exclusion [9] of all possible lifetimes for such composite particles by high precision Bhabha data, as well as allegedly fatal [7, 8], but in fact oversimplified [10, 11], confrontations with high precision QED, and Hartree Fock theory [32, 33]. All of these criticisms show only that Q_0, if it exists, must be strange, but never that it contradicts known physics.

3. Possibilities for Reconciling APEX and EPOS/I

As noted above we suggest for further study two possibilities for reconciling the APEX and EPOS/I experiments. The first proposes inquiries about possible unexpected effects of using thicker targets in the newer experiments.

For example, if the creation process for Quadronium were to occur only immediately after the entry of the projectile ion into the target foil, then the number of sharp pairs created might reach a maximum already for a thinner target than those used in the recent APEX experiments. Then the usual method of defining the cross section for creating the sharp pair structure becomes inapplicable: the resulting "cross section" would be proportional to the inverse of the target thickeness,and therefore not a cross section at all. (We point out that the APEX report [5] claims a conflict only with the cross section reported by EPOS/I, but does not exhibit any data to data contradiction.) In such a case, the thicker targets of the APEX experiment would not result in the intended larger number of sharp pairs, but instead would effect only an increase in the number of electrons, positrons, and coincident pairs (of which none would be the sharp energy Q_0 pairs) generated in irrelevant ion-ion collisions, and in a consequent reduction of the signal to noise quality of the measurement. For a weak signal, such degradation could render the pairs unobservable.

But by what mechanism could such an effect possibly occur? In the Quadronium Scenario, Q_0 is thought to be created in a Landau-Zener process [18, 20] in which the Coulomb field of the ionic di-nucleus binds and polarizes the Q_0 so strongly that its energy becomes negative, so that it is created spontaneously out of the vacuum.

One might reasonably imagine that the ambient electron clouds could influence such a process.

Indeed, such possibilities were considered by Cowan [34] who shows[6] that the charge on a scattered projectile ion is larger by some ~10 units (for Pb scattered from Au at 35°) in the first $\sim 20\ \mu g/cm^2$ of a target than the equilibrium value which it displays after traversing a target of $\sim 200 \mu g/cm^2$. (The Apex experiment uses targets of $\sim 10^3\ \mu g/cm^2$.) The present question therefore reopens an interesting avenue of experimental and theoretical inquiry.

The second suggestion[7] for reconciling EPOS/I and APEX stems from the fact that the APEX apparatus fails to detect leptons which fall into the range, $\sim 70° < \theta_S <\sim 110°$, in the solenoidal[8] coordinate system. A similar "Equatorial Hole" also exists for the electrons of EPOS/I. But for positrons, EPOS/I has an "Equatorial Flap" rather than a hole. It *accepts* positrons in the range, $\sim 0° < \theta_S <\sim 110°$, and in particular in the "Flap", $70° < \theta_S < 110°$. If the distribution of sharp pair leptons were such that many positrons fell into the "Equatorial Flap", then APEX would detect proportionately fewer sharp coincident pairs then EPOS/I.

Obviously the thin target advantage and the geometrical advantage, if both were to exist, could combine to work in EPOS/I's favor.

According to the Quadronium phenomenology, the U+Th collision creates Q_0 particles which are ejected from the collision to decay later in isolation, whereas the U+Ta collision yields Q_0 particles which remain bound to a heavy ion (and therefore exhibit the Coulomb splitting observed by EPOS/I). One must therefore anticipate possible differences in the two decays, arising from the fact that the sharp pair must in the first case have the same energy and momentum as its parent Q_0 particle, whereas in the Q_0 decay from the bound supercomposite molecule, the nucleus is available to absorb a recoil momentum, although it is so massive that the associated recoil energy is negligible, so that the pair energy remains sharp. It follows that the effect of the APEX' equatorial hole and EPOS/I's equatorial flap might be quite different in U+Th and U+Ta.

In particular, the U + Ta pairs may have smaller opening angles and larger summed pair 3-momenta than the back-to-back U + Th pairs. Then their sharp energies are especially susceptible to Doppler broadening [35]. It follows that this problem cannot be understood without consideration of the effects on the pair distribution of the Lorentz-Doppler transformation to the laboratory system.

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[6] The author wishes to acknowledge his substantial debt of gratitude to Dr. Thomas Cowan for many helpful and enlightening comments during the conversations on this topic. Dr. Cowan's recent referral of the author to Fig. 3 – 24 of his thesis was especially helpful in suggesting both the possibility of and a mechanism for such "front slice" creation of Q_0, which he also suggested might simultaneously clarify the "beam energy sensitivity". The present author's contribution is in the recognition that a sensitive Landau Zener matrix element might provide a mechanism physically to realize such a possibility.

[7] Again the author is indebted to Dr. Cowan for his suggestion that the equatorial positron flap might have given EPOS/I some advantage in detecting pairs.

[8] The solenoidal coordinates place the z-axis, whence θ_S is measured, in the direction of the magnetic B-field, which in turn is perpendicular to the beam direction.

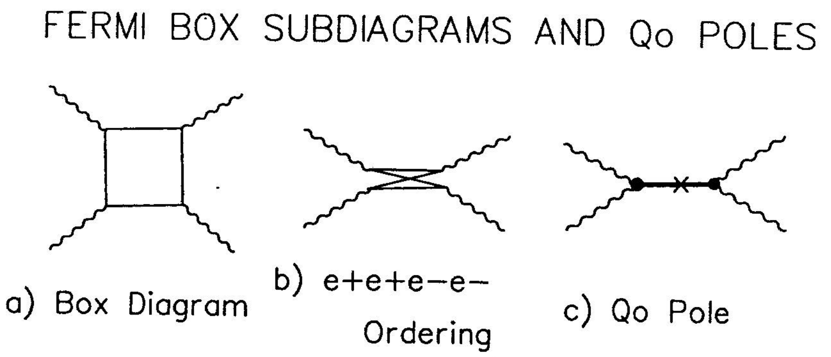

Fig. 1. Among the box diagams of part a) the continuum subset of part b) is corrected by the Q_0-pole of part c).

4. The $[\gamma + NUCLEUS]$ Alternative for Producing Q_0

Beyond the APEX-EPOS/I question, caution is also recommended by fact that other experiments now promise to speak to the "Sharp Lepton Problem" by providing alternative processes for creating Q_0.

The first is the inverse of the One-Photon decay of the bound supercomposite $\{Z^{+\prime}, Q_0\}$ molecule. Recent studies of the $[\gamma + U]$ scattering process have reported [27] three resonances in the neighborhood of 1.8 MeV, which are interpreted as evidence of excited states in the U nucleus, as they may well be. On the other hand, one or more of them may be associated, not with an excitation of U, but with the creation of a Q_0 composite particle bound in a supercomposite molecule to U. Hopefully, careful measurement, including studies of the (e^+e^-) and $(e^+e^-\gamma)$ emissions, and careful theoretical analysis can ultimately distinguish between these two hypotheses, perhaps resulting in independent evidence supporting, or ruling out, the creation here of Q_0.

We point out below that a Q_0 pole impacts QED as a correction to the four-Fermion box diagram of Fig. 1, which diagram happens also to be precisely the photon-nucleus scattering amplitude involved in the $[\gamma + U]$ scattering of Zilges *et al.* [27].

The second alternative experiment is the $[\beta^+ + ATOM]$ process, which Sakai reports to yield very sharp electrons at 330.1 keV. In the following sections we summarize briefly the present $[\beta^+ + ATOM]$ situation, its relationship to Q_0 and QED, and some other relevant implications of Q_0 for QED.

5. Q_0 and Sharp Leptons from $[\beta^+ +$ ATOM]

The collisions of positrons (from various energetic beta decays) with neutral U or Th atoms has been reported by Sakai *et al.* [13] to yield a sharp (FWHM ≤ 2.1 keV) line of 330.1 keV electrons with a cross section of order $\sim 10^2$ mb in excess of the smooth background.

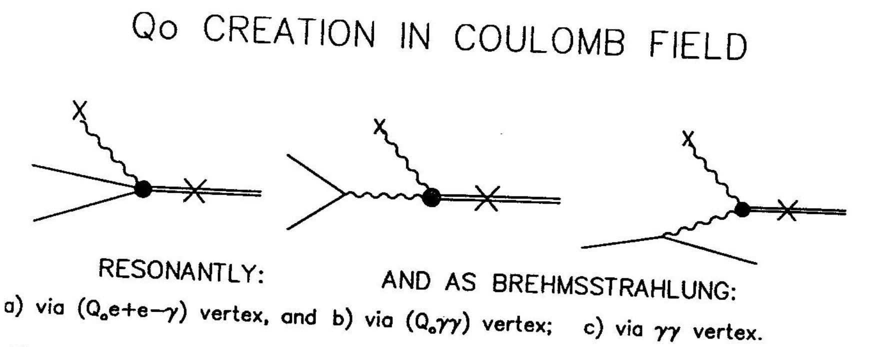

Fig. 2. Q_0 creation in a Coulomb field by: (resonant) pair annihilation, a) and b), and from the bremsstrahlung of a scattered lepton, c).

Within the Q_0 Scenario, the inverse of the single sharp annnihilative positron emission (SAPosE) occurs as follows: a positron of the correct resonant energy impinges upon an an atom (e.g., neutral U), and annihilates with one of its Bohr electrons to form a narrow eigenstate of the bound supercomposite molecule, $\{U^{+1}, Q_0\}$, analogous the $\{U^{+I}, Q_0\}$ supercomposite molecule formed in the heavy ion experiments (where I denotes the degree of ionization of the U projectile).

This molecule, which is bound by only a few keV [18] to the emergent U projectile ion, is here taken to be slightly unbound against break-up into an ion and an free Q_0 particle, perhaps due to its additional 64 ambient Bohr electrons, or perhaps due to the fact that its supercomposite molecule was created with sufficient vibrational excitation energy to break up. In the subsequent "viscous break-up" [25] of the supercomposite molecule, the Q_0 deposits the breakup kinetic energy into the electron cloud of the atom, emerging at rest later to decay in the laboratory frame, which is essentially the rest frame of the heavy target atom. Finally, Q_0 sometimes decays to yield a pair consisting of one sharp ($\Gamma \leq 2.1$ keV) electron and its sharp partner positron. Such a creation process has been labelled [25] "Resonant Recoilless Positron Absorption (RRePosA)". Such a resonant annihilation of a positron and a Bohr electron makes the leptons' rest mass energy ($2mc^2$) available to create the Q_0 particle. Resonant Q_0 creation can therefore occur at a lower incoming positron energy than the bremsstrahlung creation discussed below. It may occur either through the (Q_0, e^+, e^-, γ) effective vertex of Fig. 2a or the (Q_0, γ, γ) vertex of Fig. 2b.

Alternatively an incoming positron (or electron) with kinetic energy greater than the threshold for Q_0 creation may emit a photon in the Coulomb field of the ion leading, via the two-photon effective vertex[9] of Q_0 as shown in Fig. 2c, to the bremsstrahlung creation of Q_0 bound in the same $\{Z^{+1}, Q_0\}$ supercomposite molecule as is formed by the resonant annihilation process above. As already noted, that molecule may subsequently undergo viscous breakup, yielding an isolated Q_0 at rest which ultimately decays, sometimes to a sharp lepton pair. The cross sections reported by Sakai can be interpreted as a weighted sum of these resonant and bremsstrahlung creation processes. Knowledge of the relative importance of these two components would determine whether experimenta using positrons in the resonance energy region or positrons and/or electrons with energies above the threshold for creation are more likely to yield the sharp pairs.

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[9] Each Q_0 "effective vertex" of Figs. 1 and 2 represents the sum of the underlying QED amplitudes for the corresponding process, and is a function of the four momenta of the particles of the vertex.

Table I: Summary of the Sakai Data

β^+Source(K^+_{MAX})	Sharp E_-	$\overline{\sigma}_S$	f_B	f_R
1) ^{82}Rb(3.37 MeV)	330 keV	159 mb	0.16	0.08
2) ^{118}Sn(2.66 MeV)	330 keV	158 mb	0.36	0.05
3) ^{118}Sn(2.66 MeV)	410 keV	212 mb	0.10	0.08

6. Two Component (Resonant + Brehmsstrahlung) Analysis

To answer this question, we have re-analysed Sakai's cross sections for the 330 keV line, measured with two different positron emitters, by assuming a two component (resonant + bremsstrahlung) creation process. We take the resonant creation to be described by a constant average resonant cross section, $\overline{\sigma}_R$, for positrons in the resonant energy range, 660 keV $< E_+ <$ 995 keV, and the bremsstrahlung creation, by a constant average bremsstrahlung cross section, $\overline{\sigma}_B$ for positrons from the creation threshold energy of 1682 keV up to the endpoint energy, $K^{\beta^+}_{MAX}$, of the relevant β^+-decay distribution. Then the number of sharp electrons observed, which is reported by Sakai in terms of an isotropic cross section, $\overline{\sigma}_S$, assumed constant over the bremsstrahlung energy range from threshhold to $K^{\beta^+}_{MAX}$, must be equal to the number from Q_0 particles created by resonance plus the number from Q_0 particles created by bremsstrahlung:

$$f_B \, \overline{\sigma}_S = f_R \, \overline{\sigma}_R + f_B \, \overline{\sigma}_B \, , \qquad (1)$$

where f_R and f_B are the β^+ fractions for the resonance and bremsstrahlung ranges, respectively. We have also applied the same approach to a second line reported by Sakai *et al.* [36] at 410 keV. Then these three data sets are analyzed pairwise, yielding three pairs of values for these two average cross sections, $\overline{\sigma}_R$, and $\overline{\sigma}_B$.

Sakai's results are summarized in Table I, together with calculated values of the two β^+ fractions. The average resonant and bremsstrahlung cross sections which follow from fits to the three possible pairings of the data are given in Table II. These fits indicate consistently that the bremsstrahlung cross section is roughly (i.e., within a factor of two) $\sigma_B \sim 10^2$ mb: σ_B = (158, 147, and 87 mb). However, the wide range of values (1, 71, and 144 mb) for the resonant cross section, σ_R, indicates that this cross section is essentially undetermined by this data.

Table II: Extracted Values of $\overline{\sigma}_B$ and $\overline{\sigma}_R$

Data Pair from Table I	$f_B\sigma_S$	$\overline{\sigma}_B$	$\overline{\sigma}_R$
1), 2)	(25.9, 56.9)	158 mb	1.5 mb
2), 3)	(56.9, 21.2)	147 mb	71 mb
3), 1)	(21.2, 25.9)	87 mb	144 mb

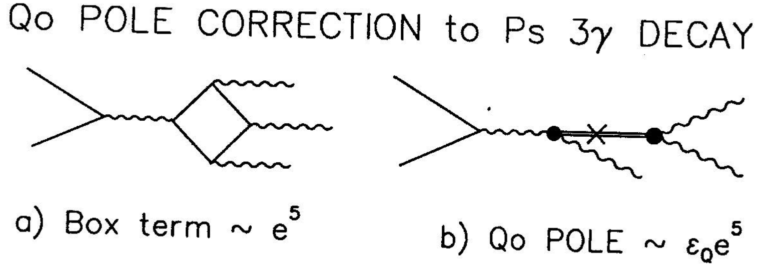

Fig. 3. A box diagram first contributes to the 3γ decay of orthopositronium in $O(e^5)$. The Q_0-pole correction to such terms might well be larger than the present uncertainties, of $O(e^7 \ln \alpha)$, and could perhaps ameliorate the 10σ discrepacy which presently exists between experiment and QED theory.

7. Needed: e^+ (or e^-) MeV Beam Experiments

This situation strongly recommends experiments with beams of positrons and (equally well) of electrons in the energy range from 2 to 4 MeV, which can reliably measure a cross section of 10^2 mb to yield a separately sharp ($\Gamma \leq 2.1$ keV) 330.1 keV electrons and positrons. Such a project could verify Sakai's sharp line, and guarantee that it arises, at least in part, from the bremsstrahlung process. A supplementary experiment, with positrons (only) of kinetic energy in the range, $660 \leq K^+ \leq 795$ keV, could measure the same line from decay of Q_0 formed by the Recoilless Resonant Positron Absorption process. Here, however, Sakai's results offer less assurance about the magnitude of the cross section.

8. Quadronium and Quantum Electrodynamics

The central fact of the present discussion [11] of Q_0 and QED is illustrated in Fig. 1, which shows that a Q_0 bound state pole is simply a specific time ordering of a Feynman four Fermion "box" subdiagram. Then each such pole modifies the calculation of every such subdiagram by adding to its four fold integral the Q_0-pole term diagrammed in Fig. 1c. In the present first outline of the problem, we assume crudely that if a box diagram occurs among diagrams of $O(e^N)$, then the corresponding Q_0-pole correction will be equal to ϵ_Q times this correction, and therefore of $O(\epsilon_Q e^N)$. The (presumably) small quantity ϵ_Q is to be taken here as a semi-quantitative indicator of the magnitude of the Q_0 correction to the set of terms corrected, rather than as a quantity expected to have specific numerical value.

We also take as the relevant scale for the corresponding Q_0-pole correction the (larger of the theoretical and experimental) uncertainties of the electron magnetic moment anomaly, $a(e) = (g_e - 2)/2$, of the decay rates, $\lambda_{\gamma\gamma}$ and $\lambda_{\gamma\gamma\gamma}$ (for para and orthopositronium respectively), and of the Delbruck photon-nucleus scattering cross section, $\sigma_{\gamma\gamma}$.

The columns of Table III presents for each of these four quantities, the leading order value, the Q_0-pole correction, the larger uncertainty, and (in column 5) the ratio of the correction to the uncertainty. Table III shows that for small values of ϵ_Q, the three quantitities, $\lambda_{\gamma\gamma}$, $\sigma_{\gamma\gamma}$, and especially, $a(e) = (g_e - 2)/2$, are insensitive[10] to this correction, and that only the 3γ decay rate of orthopositronium is sensitive to the presence of a Q_0-pole pole correction on this decay rate. Remarkably, all of these quantities are in excellent theoretical/experimental agreement, except for the 3γ decay rate, which currently exhibits a discrepancy between the theory and the experiment which is some 10 times larger than the error in either. In that case, as illustrated in Fig. 3, a Q_0-pole corrects a term of $O(e^5)$ while current theory and experiment are uncertain in $O(e^7 \ln \alpha)$. This situation encourages further investigation of the possible effect of the Q_0-pole correction. We hope in the future to study such corrections to this decay rate more quantitatively.

Table III: SOME MAGNITUDES FOR Q_0-CORRECTIONS IN QED[a]

Process[b]	T_0	$(Q_0\text{-P})/T_0$	Υ^{Th}_{Ex}/T_0	$(Q_0\text{-P})/\Upsilon^{Th}_{Ex}$
1) $a(e) = (g_e - 2)/2$	$\alpha/2\pi \simeq 10^{-3}$	$\approx 4.0 \times 10^{-8} \epsilon_Q$	$\sim 2.7 \times 10^{-8}$	$\sim 1\, \epsilon_Q$
2) $Ps\,(1^1S_0):\ \lambda_{\gamma\gamma}$	$\sim 8 \times 10^9/sec$	$\sim \epsilon_Q \alpha^2$	$\sim 1.4 \times 10^{-3}$	$\sim 0.04\, \epsilon_Q$
3) $Ps\,(1^3S_1):\ \lambda_{\gamma\gamma\gamma}$	$\sim 7 \times 10^6/sec$	$\approx 2.4 \times 10^{-2} \epsilon_Q$	$\sim 1.8 \times 10^{-4}$	$\sim 10^2\, \epsilon_Q$
4) Delbruck[c]: $\sigma_{\gamma\gamma}$	$\propto (Z^2 e^4)$	$\sim \epsilon_Q$	$\sim 5 \times 10^{-1}$	$\sim 2\, \epsilon_Q$

[a] The quantity (Q_0-P) denotes the Q_0-Pole correction, and Υ^{Th}_{Ex} is the magnitude of the (larger of the) current theoretical and experimental uncertainties. As a fraction of the leading order term, T_0, it provides the scale of significance for any discrepancy between experiment and theory.

[b] The data for $a(e)$ is from Ref. [37]; for Ps decays, from Ref. [38].

[c] The generic Delbruck scattering amplitude is here assigned a nominal 50% uncertainty on the basis of Ref. [39]. However, as discussed in the text this process is of special interest in the resonance region, near $E_\gamma = M_Q c^2$ where (photon+ nucleus) can create a real Q_0particle, either free or bound to the nucleus.

Regarding the effect of a Q_0-pole on the box diagram, which defines the leading order amplitude for photon photon scattering, we note that neither the measured nor the calculated values of the generic Delbruck cross sections are currently very precise. On the other hand, a Q_0-pole implies a (perhaps narrow) *resonant* amplitude at the

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[10] These results provide the clearest contradiction to the claims [7] that QED and, especially, the value of $(g_e - 2)$, precludes a composite particle scenario. But that claim was based on an analysis of a hypothetical X_0 particle which depended essentially upon the assumption that it decays *only* to (e^+e^-). The claims can therefore can not be considered applicable to the Q_0 particle. See also footnote 4 above.

pole energy, defined by an eigenenergy of the Q_0 particle. Then $(\gamma\gamma)$ scattering from a nucleus would exhibit resonance behaviour there, which may be especially narrow when the Q_0 particle can be bound to the nucleus in the supercomposite molecule of the Q_0 Scenario. One is lead therefore to look for a resonance in the scattering of photons of about 1.8 MeV from high-Z ions, and especially from U and Th, for which the Sakai results suggest a nearly bound Q_0 state.

Remarkably, Zilges *et al.* [27] have recently reported three such resonances in the scattering of photons from Uranium targets. (We note that these authors analyse their resonances in terms of excited states of the U nucleus, and seem unaware of the alternative possibility that such a resonance might arise from the creation of the Q_0 particle.)

Thus, we can hope that, as the details of the matrix elements and the branching ratios, particularly to the three particle $(e^+e^-\gamma)$ continuum and to sharp (e^+e^-) pairs, emerge under further experimental study, each line will be recognized as involving either an excited state of U or a supercomposite bound state. One qualitative distinction between the two is the fact that Q_0 creation is not specific to the particular nucleus, as are the nuclear excited states. Thus if the same lines were seen in another isotope of U or in another (e.g., Th) target, Q_0 creation would be indicated. Also, the branching ratios of Q_0 need have no resemblance to those of a nuclear resonance. In particular for the Q_0 resonance, the branching to $(e^+e^-\gamma)$ is likely to be the largest[11], while those to (e^+e^-) and $(\gamma\gamma)$ could be smaller, and without any expectation that the (e^+e^-) branching should be weaker than the $(\gamma\gamma)$ branching. Needless to say clear evidence either here or in the $[\beta^+ +$ ATOM] case might establish the occurrence of Q_0 and its sharp pairs independently of the heavy ion ambiguities.

9. Summary and Conclusions

We have presented an analysis of the quandary posed by the APEX' failure to corroborate the sharp (e^+e^-) pairs of the earlier EPOS/I experiments. Our view is strongly influenced by the fact that for some years we have been evolving a certain composite particle phenomenology and adapting it with some success to the growing body of data related to these pairs. The resulting "Quadronium Scenario" provides an organizing template for this intricate set of data, gives a good semi-quantitative phenomenology of the EPOS/I measurements, and predicts decay processes yet to be studied.

But most important for the present discussion, the Scenario shows how Q_0 might be created in processes other than high-Z heavy ion collisions; specifically, in the $[\beta^+ +$ ATOM] processes, currently under study [13] by Sakai *et al.*, and the $[\gamma + NUCLEUS]$ studies [27] of Zilges *et al.*

Furthermore, the Quadronium $(e^+e^+e^-e^-)$ structure for the particle leads one to consider the implications of Q_0 for high precision quantum electrodynamics. One finds that the scaled Q_0 corrections are quite small, except perhaps for the 3γ decay of orthopositronium (currently in 10σ disagreement with experiment),and the resonant photon-NUCLEUS scattering amplitude, which will dominate the creation of Q_0 in the $[\gamma + U]$ scattering discussed above [27].

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[11] This expectation is supported by the preliminary data on $(e^+e^-\gamma)$ reported by Widmann *et al.*[40] as discussed in Ref. [10].

The upshot of our analysis is that excessive pessimism about the sharp pairs is unwarranted at the present time, because other studies are in progress which may offer alternative channels for creating the the composite particle which provides them. One might wisely suspend judgement while these alternatives are traced out and understood in detail.

In addition, we have suggested two possibilities for reconciling the APEX data with the EPOS/I experiments. Both ought to be excluded before any final conclusions are drawn. Of these one invokes the possible influence of ambient electrons upon the Q_0 creation process; it could also at last explain the mysterious "beam energy sensitivity" of the EPOS/I experiments, and at the same time imply a degradation of the the pair signal measured from thick targets, providing thereby a reason why APEX is less sensistive to the pairs than was EPOS/I.

The second notes that the "Equatorial Hole" of the APEX geometry, remains a rejecting "hole" for for EPOS/I electrons, but becomes an accepting "flap" for EPOS/I positrons. Then the APEX apparatus would be far less sensistive than would the EPOS/I to angular dependences of the emitted lepton pairs which frequently place positrons into this flap .

In summary, a continuing post-APEX interest in the "Sharp Lepton Problem" seems both proper and inevitable.

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References

[1] APEX: (February, 1989), A USDOE Proposal for an Atlas Positron Experiment.
[2] T.E. Cowan *et al.*: *Phys. Rev. Lett.* **56** (1986) 444
[3] P. Salabura *et al.*: *Phys. Lett. B* **245** (1990) 153 *(see also references therein)*
[4] I. Ahmad *et al.*: *Nucl. Phys. A* **583** (() 1 995) 247.
[5] I. Ahmad *et al.*: *Phys. Rev. Lett.* **75** (1995) 2658
[6] R. Baer *et al.*: *Nucl. Phys. A* **583** (1995) 237
[7] J. Reinhardt *et al.*: *Phys. Rev. C* **33** (1986) 194
[8] J. Reinhardt *et al.*: *Z. Phys. A* **327** (1987) 367
[9] H. Tsertos *et al.*: *Phys. Lett. B* **266** (1991) 259 *and earlier referecnces cited there*
[10] J.J. Griffin: *Phys. Rev. C* **47** (1993) 351
[11] J.J. Griffin: *Can. J. Phys.* **74** (1995) *(in press)*
[12] M. Sakai *et al.*: *Phys. Rev. C* **44** (1991) R944
[13] M. Sakai *et al.*: *Phys. Rev. C* **47** (1993) 1595 *and earlier referecnces cited there*
[14] T.F. Wang *et al.*: *Phys. Rev. C* **36** (1987) 2136
[15] R. Peckhaus *et al.*: *Phys. Rev. C* **36** (1987) 83

[16] K. Erb *et al.*: *Phys. Lett. B* **181** (1986) 52

[17] C. Bargholz *et al.*: *Phys. Rev. C* **40** (1989) 1188 *and and earlier referecnces cited there*

[18] J.J. Griffin: *Intl. J. Mod. Phys. A* **6** (1991) 1985

[19] J.J. Griffin: *in Proc. 5th Int. Conf. on Nuclear Reaction Mechanisms, Varenna 1988 (Ed. E. Gadioli)*. U. of Milano, p. 669

[20] J.J. Griffin: *J. Phys. Soc. Jpn.* **58** (1989) S427 *and earlier referecnces cited there*

[21] J.J. Griffin: Univ. Maryland Report PP 89-053, (DOE/ER/40322-052) Oct. 1988

[22] J.J. Griffin: *Phys. Rev. Lett.* **66** (1991) 1426

[23] J.J. Griffin: *in Proc. 6th Int. Conf. on Nuclear Reaction Mechanisms, Varenna 1991 (Ed. E. Gadioli)*. Univ. of Milano, p. 758

[24] J.J. Griffin, T.E. Cowan: Univ. Maryland Report PP 90-060 (DOE/ER/40322-088) Nov. 1989

[25] J.J. Griffin: *in Topics in Atomic and Nuclear Collisions, Predeal 1992 (Eds. A. Calboreanu, V. Zoran)*. Plenum Press, 1994, p. 419

[26] K.C. Chan: PhD thesis, Yale University, 1995.

[27] A. Zilges *et al.*: *Phys. Rev. C* **52** (1995) R468

[28] X. Jin: Univ. Maryland Report *(to be published)*;
X. Jin: *Bull. Am. Phys. Soc.* **36** (1991) 1244

[29] J.J. Griffin: *Phys. Rev. Lett.* **70** (1993) 4158

[30] S.D. Henderson *et al.*: *Phys. Rev. Lett.* **69** (1992) 1733

[31] X.Y. Wu *et al.*: *Phys. Rev. Lett.* **69** (1992) 1729

[32] D. Ionescu, B. Mueller, W. Greiner: *J. Phys. G: Nucl. Phys.* **15** (1989) L103

[33] J.J. Griffin: *J. Phys. G: Nucl. Phys.* **15** (1989) 925

[34] T.E. Cowan: PhD thesis, Yale U., 1988 *(see especially Sec 3.4.2.5 and Figure 3-24)*

[35] J.J. Griffin: *Acta Phys. Pol. B* (1995, *(in press)*)

[36] M. Sakai *et al.*: *in Nuclear Physics of Our Times (Sanibel Island, Florida, Nov. 1992), (Ed. A.V. Ramayya). World Sci., Singapore, p. 313*;
M. Sakai *et al.*: Univ. Tokyo, I.N.S. Report No. 957 (1992)

[37] T. Kinoshita, D.R. Yennie: *in* Quantum Electrodynamics *Ed. T. Kinoshita)*. World Sci., Singapore 1990, p. 1

[38] A.P. Mills, S. Chu in *Quantum Electrodynamics*, edited by KINOSHITA, T., page 774, (World Scientific, 1990).

[39] R. Moreh, S. Kahana: *Phys. Lett. B* **47** (1973) 351

[40] E. Widmann *et al.*: *Z. Phys. A* **340** (1991) 2091