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THE SHARP LEPTON QUANDARY: REASONABLE CAUTIONS

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THE SHARP LEPTON QUANDARY: REASONABLE CAUTIONS

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INTRODUCTION

Apex' Null Data Surprise: The Larger View

Surprisingly, the new APEX experiment designed[1] to measure a definitive invariant mass distribution¹ of the sharp pairs previously observed[2, 3] in similar heavy ion studies reports null results[4, 5]. Although it asserts no direct conflict with any data reported by EPOS/I, and critics claim that its published analysis is inconsistent [6, 7] and not contradictory to EPOS/I, the APEX report nevertheless seems to have encouraged the view that the earlier (EPOS/I) observations were erroneous, and by extrapolation, that the whole (e^+e^-) Puzzle data set can be dismissed as an unfortunate set of physically meaningless statistical fluctuations.

We wish here to argue² that such sweeping judgements should be postponed, on the grounds that

- The published APEX analysis of their data is self-inconsistent³, and can therefore sustain no valid inference about the EPOS/I data;
- The data which supports the occurrence of sharp (e^+e^-) pairs is much more extensive than the EPOS/I data, so that the APEX surprise must be considered as one episode in a much longer struggle finally to settle the question of whether these weak signals are significant or not;
- A qualitative phenomenology exists which can organize the whole range of data of the Sharp Lepton Problem, and which suggests that

¹Unfortunately, this stated goal of the APEX project has not yet been realized.

²See also Ref.[8] where similar considerations are presented.

³The argument of Ref.[7] is simply that the APEX analysis, which utilizes a cross section ($\sigma = 5\mu\text{bn/sr}$) taken from Ref.[3] leads to an inconsistency when it is applied to the original data of Ref.[3] whence the cross section itself was derived: The APEX analysis there requires $\sim 10X$ more sharp pairs than were actually observed and used to estimate the cross section.

- certain low energy (and low cost) experiments ought to be explored for their creation of sharp pairs; as follows,
 1. The study of pairs emitted following scattering of few MeV electron and positron beams from neutral U and Th atoms;
 2. The study of pairs emitted following the resonant absorption of photons of 1.5 to 2.0 MeV on U and Th atoms.

We first present a brief data-oriented history of the Sharp Lepton Problem, to show that no single unexpected null result can provide an adequate basis for rejecting the great range and quantity of data which evidences the occurrence of sharp pairs. We then consider the Quadronium Composite Particle Scenario for these processes, and its Quantum Electrodynamical implications, in support of the above recommendations.

Sharp($\sim 80\text{keV}$) Positrons from High-Z collisions.

In 1976, the GSI Unilac acclerator delivered a U ion beam of 6.7 MeV/u, sufficient to surmount the Coulomb barrier in a U+U collision, opening the study of atomic processes in strong fields[9]. In 1983, the first report[10] of a sharp ($\sim 80\text{keV}$) positron line was published by the EPOS collaboration. In 1985, evidence from six $Z_U = Z_1 + Z_2$ combinations showed persuasively[11] that the energies of these positrons were nearly independent of Z_U , and could therefore not be the sought after positrons expected [12] from the spontaneous pair decay of the vacuum at $Z_U > Z_{crit} \approx 172$ (whose energies would increase rapidly with Z_U). By 1987, twenty three such positron lines had been measured and tabulated[13]. Their energies separated into three main groups, with mean energies of 255keV, 337KeV and 396KeV.

Very Sharp($\leq 40\text{keV}$) (e^+e^-) Pairs from High-Z Ion Collisions.

By 1986, the EPOS' solenoidal spectrometer had become a pair spectrometer and reported[2] a narrow coincident (e^+e^-) pair line with summed energies near 760 keV, of which the corresponding positron projection resembled a narrow positron singles distribution previously measured with the EPOS apparatus. In 1988, the Orange group, using its new double-orange apparatus, reported[14] evidence (4σ) for a narrow (e^+e^-) line at a summed energy 815 keV and with opening angles $\theta_{+-} \approx 180^\circ$. The positron portion of this spectrum also resembled a positron line they had measured previously. Ten additional narrow (e^+e^-) pair lines were reported by Orange[15] in 1989, five others by EPOS[3] in 1990, and another seven lines by ORANGE[16] in 1993. The six EPOS lines group into three sets, near 625, 750 and 810 keV. The seventeen Orange lines group similarly, but the energies are more scattered and additional groups occur near 560 keV (4 lines) and 895 keV (2 lines).

Very Very Sharp($\leq 3\text{keV}$) (e^+e^-) Pairs from [$\beta^+ + ATOM$].

Several investigators have reported⁴ that β^+ decay distributions of positrons incident upon neutral *U* and *Th* atoms produce electrons and positrons [20, 21, 22, 23, 24, 25] with kinetic energies of $\sim 330\text{keV}$. Sakai reports a width, $\Gamma_{e^-} < 3\text{keV}$. No such leptons were observed in irradiations of lower Z Ta atoms.

⁴Although others[17, 18] reported no success in observing such features, we adopt the positive results reported as the basis for the present discussion on the general grounds that a reported positive signal is more significant than a reported null signal. We note also that Sakai et al. have argued [19] that because of the experimental arrangements, these failures to observe the leptons can not be taken as evidence *against* the processes observed in other experiments.

We include these [$\beta^+ + \text{ATOM}$] results within the Sharp Lepton Problem because the Quadronium Composite Particle Scenario can, via the substantial flexibilities which adhere to a polarizable composite particle, encompass[26] the very very narrow widths of these lines as resulting from a Q_0 creation process which utilizes the ion's large mass to reduce the recoil energy to zero. In this way Sakai's sharp electrons obtain a direct relationship with the pairs from the high-Z heavy ion collisions, and escape the criticism of Tsertos[27], that the (e^+e^-) line width from an object created in a $(\beta^+ + e^-)$ collision could never, when the electron is bound in a high-Z atom, be as narrow as Sakai has measured the line to be.

The Importance of Explicit Phenomenology. Just as the phenomenology guided the resolution of Tsertos' paradox on the narrowness of Sakai's line, so it did also in the case of the null Bhabha results[28] (which were claimed [29] to exclude the entire range of lifetimes for a composite particle whose decay might provide the sharp (e^+e^-) pairs). In this case the $(e^+e^+e^-e^-)$ structure of Q_0 suggested that its $(e^+e^-\gamma)$ decay should be more probable than its (e^+e^-) decay, in contradiction to the one channel decay assumed in the analysis of Ref.[29]. Indeed, under further scrutiny[30], it emerged that the limitations on the lifetime were artifacts of that very assumption, and not at all empirical inferences from the null data.

These examples emphasize the crucial role of an organizing phenomenology in a complicated problem involving unknown physics, such as the Sharp Lepton Problem. For Tsertos' criticism, the Q_0 phenomenology had already provided the bound "supercomposite molecule" to describe the EPOS/I U+Ta Coulomb shifts. It remained only to recognize that the very large nuclear mass could render the recoil energy of such a molecule negligible. Likewise, the $Q_0 (e^+e^+e^-e^-)$ structure provided the clue to defeating the claims of the null Bhabha results, as noted above.

Above all, a mechanistic phenomenology can provide predictions which suggest new inquiries, either to extend the range of its assumptions or force their alteration. Moreover when its assumptions are restrained by Occam's razor, the phenomenology may at a given stage be virtually unique. This seems currently to be the case for the Q_0 Composite Particle Scenario. In short, although two phenomenologies for any given problem are better than one, one phenomenology is infinitely better than none at all.

THE QUADRONIUM COMPOSITE PARTICLE SCENARIO

For some time[31, 32] we have considered a composite particle creation/decay scenario to be the simplest framework capable of encompassing[33] all the data of the heavy ion " (e^+e^-) Puzzle". 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 unnecessary new hypotheses. On the other hand Q_0 is so far a purely phenomenological creature; no theoretical basis has yet been found to explain its strong binding.

The property of compositeness substantially enriches the phenomenology because a composite particle is polarizable by an external field, and a neutral polarizable particle can be bound in a Coulomb field. Furthermore a composite particle exhibits a spectrum of internal eigenstates, as required by the several observed pair lines.

FERMI BOX SUBDIAGRAMS AND Q_0 POLES

Figure 1. Among the box diagrams of part a), the 4-lepton continuum integral of time ordering b) is corrected by the Q_0 -pole part in part c).

Landau Zener Q_0 Creation; Novel Decay Modes of Q_0 Bound to Nucleus.

The Composite Q_0 Particle Scenario allows for spontaneous Landau-Zener creation of Q_0 from the vacuum in strong enough heavy ion Coulomb fields[32, 34]. For Quadronium states below the breakup energy ($4mc^2$), three decays, $(e^+e^-\gamma)$, $(\gamma\gamma)$, and (e^+e^-) , are obvious possibilities. Each can be described by an effective vertex whose perturbative⁵ leading order diagrams are $\propto e$, $\propto e^2$, and $\propto e^2$, respectively. In its simplest form it provides a good semiquantitative description[35] of EPOS' observed sum and difference widths as arising from Doppler broadening (alone in the Free Annihilative Pair Emittive (FAPE) decay) and from the combined Coulomb and Doppler broadening (in the Bound Annihilative Pair Emittive (BAPE) decay of the U+Ta case)⁶.

The scenario also predicts[37] exotic decays of Q_0 bound in a supercomposite molecular state, $\{Z^I, Q_0\}$, with a nuclear ion, emitting $(e^-e^+e^+)$, (e^+e^+) , (e^+) , and One-Photon, none of which has yet been studied experimentally. In the decay of an isolated Q_0 atom all of these decays are forbidden by energy-momentum and lepton number conservation, and become allowed only by virtue of the capacity of the nucleus to capture electrons, and to absorb momentum. However, the summed energy of the emitted particles remains sharp because the massive nucleus can absorb as much momentum as necessary without taking up any significant recoil energy.

Of these exotic decays, the One-Photon emissive decay of Q_0 may already be in evidence as the 1780 keV gamma ray which occurs in the APEX heavy ion data[38]. Or its inverse creation process may already have been seen as one or more of the resonances in recent $[\gamma + \text{NUCLEUS}]$ studies[39] near 1.8 MeV. We discuss these possibilities further below.

⁵Caution: such perturbative characterizations are potentially misleading for the decay of a bound state because they take no cognizance of the form factors of the effective vertices and do not consider the possible occurrence in the decaying state of a substantial amplitude in some other (than the $(e^+e^+e^-e^-)$) sector, such as the $(e^+e^-\gamma)$ sector or the $(\gamma\gamma)$ sector.

⁶The beginnings of an analogous treatment for the Orange data has been reported in Ref.[36]

In addition, the single (e^+) emission (earlier labelled “Sharp Annihilative Positron Emission (SAPosE)”) defines an inverse process in which a supercomposite $\{Z, Q_0\}$ state can be created resonantly when a positron of nearly the correct energy annihilates with a Bohr electron, (earlier called “Recoilless Resonant Positron Absorption(RRePosA)”), which may contribute to Sakai’s sharp leptons.

Q_0 So Far: Strange, But Not Unphysical. The Quadronium scenario has weathered the claim that Q_0 could not be sufficiently polarized for its spontaneous creation in the high-Z Coulomb field[26, 40] of a di-ion and has survived[30, 41, 42, 43] the alleged exclusion[28] of all possible lifetimes for such composite particles by high precision Bhabha data (as discussed above), as well as allegedly fatal[44, 45], but in fact oversimplified[30, 46], confrontations with high precision QED, and Hartree Fock theory[47, 48]. All of these criticisms show only that Q_0 , if it exists, must be strange, but never that it contradicts known physics.

QUADRONIUM AND QUANTUM ELECTRODYNAMICS

If Q_0 is a bound state of $(e^+e^+e^-e^-)$, then it is essentially a quantum electrodynamical object, and one can ask what effects it might have upon the physical phenomena of QED. Fig.(1) illustrates the key to such a discussion[46]: each Q_0 bound state is a pole in the $(e^+e^+e^-e^-)$ spectrum of the Feynman four-Fermion “box” subdiagram of Fig.(1b). Then Q_0 modifies every such Feynman subdiagram by adding to its four-fold integral the pole term diagrammed in Fig.(1c).

In the first classification of the problem, we assumed crudely that if a box diagram occurs among diagrams of $O(e^N)$, then the corresponding Q_0 -pole contribution will be equal to ϵ_Q times their contribution, 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, rather than as a quantity expected to have specific numerical significance.

The columns of Table I present (for four physical QED quantities) the leading order QED value, the magnitude of the Q_0 -pole correction, the larger (of the theoretical and experimental) uncertainty, and (in column 5) the ratio of the correction to the uncertainty. Table I shows that for small values of ϵ_Q , the quantities, $\lambda_{\gamma\gamma}$, $\sigma_{\gamma\gamma}$ and $a(e) = (g_e - 2) / 2$, are generally insensitive⁷ to this correction, but that the 3γ decay rate of orthopositronium is sensitive to Q_0 -pole pole correction. Remarkably, of these four quantities only the 3γ decay rate of orthopositronium currently exhibits a significant (10σ) discrepancy between theory and the experiment. In that case, current theory and experiment are uncertain in $O(e^7 \ln \alpha)$, while a Q_0 -pole corrects a term of $O(e^5)$. This situation encourages the hope that further quantitative investigation of the effect of the Q_0 -pole correction may allow QED data to speak to the existence of Q_0 .

⁷These results provide the clearest contradiction to the claim[44] that QED and, especially, the value of $(g_e - 2)$, precludes a composite particle scenario. However, that claim was based on an analysis of a hypothetical X_0 particle and upon the assumption that X_0 decays *only* to (e^+e^-) . The claim is therefore not applicable to the Q_0 particle, which should prefer the $(e^+e^-\gamma)$ decay over the (e^+e^-) pair decay. See also the earlier comment under Explicit Phenomenology about how the same multi-channel decay property of Q_0 enables it to escape the drastic consequences for the composite particle lifetimes claimed to follow from the null results of the high precision Bhabha studies.

Table I: SOME MAGNITUDES FOR Q_0 -CORRECTIONS IN QED^a

Process ^b	T_0	$(Q_0 - P)/T_0$	Υ_{Ex}^{Th}/T_0	$(Q_0 - P)/\Upsilon_{Ex}^{Th}$
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) $Ps(1^1S_0) : \lambda_{\gamma\gamma}$	$\sim 8 \times 10^9 / \text{sec}$	$\sim \epsilon_Q \alpha^2$	$\sim 1.4 \times 10^{-3}$	$\sim 0.04 \epsilon_Q$
3) $Ps(1^3S_1) : \lambda_{\gamma\gamma\gamma}$	$\sim 7 \times 10^6 / \text{sec}$	$\approx 2.4 \times 10^{-2} \epsilon_Q$	$\sim 1.8 \times 10^{-4}$	$\sim 10^2 \epsilon_Q$
4) Delbruck ^c : σ_{DEL}	$\propto (Z^2 e^4)$	$\sim \epsilon_Q$	$\sim 5 \times 10^{-1}$	$\sim 2 \epsilon_Q$

^aThe quantity $(Q_0 - P)$ denotes the Q_0 -Pole correction, and Υ_{Ex}^{Th} 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.

^bThe data for $a(e)$ is from Ref.[49]; for Ps decays, from Ref.[50].

^cThe generic Delbruck scattering amplitude of a photon from a Coulomb field is here assigned a nominal 50% uncertainty on the basis of Ref [51]. 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_0 particle, either free or bound to the nucleus.

TWO LOW ENERGY ALTERNATIVES TO HIGH-Z HEAVY IONS

These considerations suggest two types of low energy non-heavy-ion experiment as alternative means to produce the composite Q_0 particle.

1st: Q_0 from $[\gamma + \text{NUCLEUS}]$

The first alternative method for producing Q_0 arise directly from the diagram of Fig.(1c) when it is applied to the Delbruck scattering of photons from a nuclear Coulomb field. In that case two of the external photon lines are replaced by Coulomb interactions (x) and each of the two vertices becomes $(\propto Ze^2)$, instead of $(\propto e^2)$. If Q_0 can bind to the involved ion, then the Q_0 creation can lead to a supercomposite molecular bound state, and a resonance occurs in the Delbruck scattering when the incoming photon energy is near the supercomposite eigenenergy. Clearly, the decay of this resonance by emission of a photon yields precisely the exotic One-Photon decay of Q_0 bound to an ion which was discussed above.

But such a state, once created, can also decay to products other than $(\gamma\gamma)$; e.g., to $(e^+e^-\gamma)$, and to (e^+e^-) . In these decays external photon lines may again be replaced by Coulomb interactions, with each inserting a factor (Ze) into the amplitude in place of a factor, (e) . Then the leading perturbative terms⁸ for various decays are as follows: $(e^+e^-x) \propto (Ze)$, $(e^+e^-\gamma) \propto (e)$, $(\gamma x) \propto (Ze^2)$, $(\gamma\gamma) \propto (e^2)$, and $(e^+e^-) \propto (e^2)$, where x denotes an external photon line replaced by a Coulomb interaction. One therefore expects the (e^+e^-x) sharp pair decay, rather than the Delbruck photon re-emission, to dominate the decay.

$[\gamma + U]$ Resonances and 1.8 MeV Gammas in Heavy Ions.

Recent experimental studies of $[\gamma + U]$ scattering have reported[39] three Delbruck resonances in the neighborhood of 1.8 MeV, which are there interpreted as evidence of excited dipole states in the U nucleus, as they may well be. On the other hand, according to the present discussion 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

⁸See the caution in footnote No. 5 about perturbative discussions of bound states.

supercomposite molecule to U. In that case a study of the resonant gamma induced (e^+e^-) emission should exhibit an excess of pairs over photons. Such an excess would be qualitatively opposite to the behaviour expected from the conventional internal pair creation (IPC) associated with the decay of an excited nuclear state, where perturbatively the pair decay amplitude is smaller than the photon decay by a factor, (e).

We note also that an excess of gamma rays near 1.8 Mev was observed by the Orange group [52] (which they argue is not consistent with IPC), and that a 1780 keV gamma line was observed in the APEX experiments[38], which is also discussed only in terms of the IPC process. Whether these data can help to clarify whether any of the $[\gamma + U]$ resonances is due to a $\{Z, Q_0\}$ bound state is an interesting open question.

Also, if the pairs from the $[\gamma + U]$ resonances were measured to be excessive by IPC standards, then the suspicion that a supercomposite $\{Z, Q_0\}$ state is involved could be checked by using a different isotope of Uranium in the experiment: The QED Q_0 processes should hardly be affected at all, but a nuclear excitation is unlikely to remain the same from one isotope to another.

It seems reasonable to expect that careful measurement of the (e^+e^-) and ($e^+e^-\gamma$) emissions, plus careful analysis, can distinguish between the IPC and $\{Z, Q_0\}$ alternatives for each line (Two phenomenologies are better than one!), providing new evidence supporting, or ruling out, the creation of Q_0 .

2nd: Q_0 from $[\beta^+(\text{or } e^+) + ATOM]$

The second alternative method for producing Q_0 arises from the application of the diagram of Fig.(1c) to the lepton scattering process, as illustrated in Fig.(2c). There lepton scattering creates a brehmsstrahlung photon which, together with a Coulomb interaction creates the $\{Z, Q_0\}$ bound state resonantly. Figs.(2a) and (2b) display other mechanisms for creating the same supercomposite state at lower energies by annihilating an incoming positron of the correct resonant energy with a Bohr electron of the target atom to form the supercomposite $\{Z, Q_0\}$ state. (These latter two processes are inverse to the exotic single Sharp Annihilative Positron Emittive (SAPosE) decay predicted by the phenomenology, as discussed above.)

However it is formed, the sharp pair decay of this supercomposite state is expected to dominate over the One-Photon decay (and also over the ($e^+e^-\gamma$), and ($\gamma\gamma$) decays) and therefore to contradict the γ dominance expected for a conventional IPC process.

Sharp Leptons from $[\beta^+ + ATOM]$. The collisions of positrons (from various energetic beta decays) with neutral U or Th atoms has been reported[25] by Sakai, et al. to yield a sharp ($FWHM \leq 2.1$ keV) line of 330.1 keV electrons with a cross section of order $\sim 10^2 mb$ in excess of the smooth background.

As noted, a bound $\{Z, Q_0\}$ supercomposite state can be created in the $[\beta^+ + ATOM]$ process either resonantly as in Figs.(2a) and (2b) or by brehmsstrahlung, as in Fig.(2c), and its Q_0 will decay primarily to sharp (e^+e^-) pairs. But because the decay occurs in the nuclear Coulomb field, pairs with sharp leptons of equal energy are improbable, and the difference energy width is Coulomb broadened[35] to $\sim 100 keV$. Clearly, Sakai's very very sharp electrons are not produced by such decays.

In fact, under the Q_0 scenario Sakai's sharp electron line must be the e^- partner of a sharp 660 keV back-to-back equal-energy pair decay of an free isolated Q_0 at rest in the laboratory. How can the process create such an object? The Q_0 phenomenology allows an answer: consider the creation of a slightly unbound supercomposite state

Q₀ CREATION IN COULOMB FIELD

Figure 2. In the presence of a nuclear Coulomb field, Q_0 may be created by resonant annihilation of a pair, as in a) and b), or by a brehmsstrahlung photon from a scattered lepton, as in c).

which recoils as a unit before breaking up. (We recall that the EPOS/I data indicated that the supercomposite molecule is very weakly ($\sim 1\text{keV}$) bound against breakup[33]. It is therefore plausible either that a small excitation energy delivered in the creation process might produce an unbound supercomposite molecule, or that the lowest energy state might become slightly unbound under altered circumstances.) In addition, allow the Q_0 during the breakup process to deposit its kinetic energy entirely into the electron cloud of the atom. Then the Q_0 emerges at rest in the laboratory frame later to decay in isolation[26], and its decay pairs have the properties observed by Sakai, et al.

One sees that the scenario must exploit extensively the possibilities offered by its substantial complexity in order to encompass Sakai's phenomenon. But it is able to do so without new assumptions, and so it survives until the next test.

Two Component (Resonant + Brehmsstrahlung) Analysis. We have carried out a two-component analysis[46] of Sakai's data to determine what it implies for the average values of the separate resonance and brehmsstrahlung creation cross sections. The data indicates a brehmsstrahlung cross section of $\sim 10^2\text{mb}$ for the sharp e^- production, but tolerates a broad range of resonant cross sections.

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 10^2mb for separately sharp ($\Gamma \leq 2.1\text{keV}$) 330.1 keV electrons and positrons. Such experiments could verify Sakai's sharp line, and guarantee that it arises, at least in part, from the brehmsstrahlung process. A supplementary experiment, with positrons (only) of kinetic energy in the range, $660 \leq K^+ \leq 795\text{keV}$, 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.

Note that decay pairs sharp in total energy, but with Coulomb split and Coulomb broadened e^+ and e^- distributions, should also be expected to occur in these experiments due to decays of the truly bound supercomposite state, whenever the bound state exists.

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 on sharp 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 [$\beta^+ + \text{ATOM}$] processes, currently under study[25] by Sakai, et al., and the [$\gamma + \text{NUCLEUS}$] studies[39] of Zilges, et al.

Furthermore, the Quadronium ($e^+e^+e^-e^-$) structure for the composite particle leads one to consider the implications for high precision Quantum Electrodynamics. One finds that the Q_0 -Pole corrections to the conventional QED predictions are insignificantly small, except 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 [$\gamma + \text{U}$] scattering discussed above[39].

The upshot of our analysis is that excessive pessimism about the sharp pairs is unwarranted at the present time, particularly

- a) because the APEX data does not actually contradict the EPOS/I data, and cannot even speak to the ORANGE pair data and the earlier sharp positron lines of the ORANGE, EPOS, and TORI groups, and
- b) because other studies may soon provide data on the composite particle and its pairs which are independent of the heavy ion processes used so far, and perhaps more easily repeated and verified.

We believe that one should wisely withhold judgement while these alternatives are traced out and understood in detail. In summary, a continuing post-APEX interest in the "Sharp Lepton Problem", and especially one which emphasizes data sources alternative to high-Z heavy ion collisions, seems both appropriate and inevitable.

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