THE INCREDIBLE SHRINKING PROTON
(A HAND-WAVING ANALYSIS)

I. Potential Energy of a Point Muon

Take the proton charge to be uniformly distributed on a spherical shell of radius a_p in the proton rest frame. Let $e < 0$ be the charge of thr electron, so the charge of the proton is $-e$. Then, the proton charge density is $\rho(r) = -e\delta(r-a_p)/(4\pi a_p^2)$ where δ is the delta function, and r is the distance of a point from the center of the proton. The Coulomb potential of the proton is $\phi = -e/r$ for $r > a_p$ and $\phi = -e/a_p$ for $r < a_p$. Suppose a negatively charged point muon orbits the proton at a distance r from the center of the proton. The potential energy of this system is $V = -e^2/r$ for $r > a_p$, and $V = -e^2/a_p$ for $r < a_p$. The energy levels will be dependent on the potential energy, which is dependent on the proton radius. Notice that the largest value of r for which $V = -e^2/a_p$ is a_p.

II. Potential Energy of an Extended Muon

Same proton, but take the muon charge to be uniformly distributed on a spherical shell of radius $a_\mu < a_p$. The center of the orbiting muon

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is a distance r from the center of the proton. The potential energy of this system is $V = -e^2/r$ for $r > a_p + a_\mu$ when all of the muon is outside the proton, and $V = -e^2/a_p$ for $r < a_p - a_\mu$ when all of the muon is inside the proton.. For $a_p - a_\mu < r < a_p + a_\mu$, some of the muon charge is inside the proton and some of the muon charge is outside the proton. The potential energy goes from $-e^2/(a_p + a_\mu)$ at $r = a_p + a_\mu$ to $-e^2/a_p$ at $r = a_p - a_\mu$, so The largest value of r for which $V = -e^2/a_p$ is $r = a_p - a_\mu$.

III. Conclusion

If the muon is extended as in the second section, but we apply the analysis of the point muon as in the first section; then, we incorrectly conclude that the radius of the proton is $a_p - a_\mu$. Certainly, muon size will affect the energy levels for any muon charge distribution. So the solution to the incredible shrinking proton problem may be that the muon is extended in space.

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