Commentary: Expectations regarding exotic physics and radii measured in heavier muonic atoms

Carl Carlson
for himself and Ben Rislow
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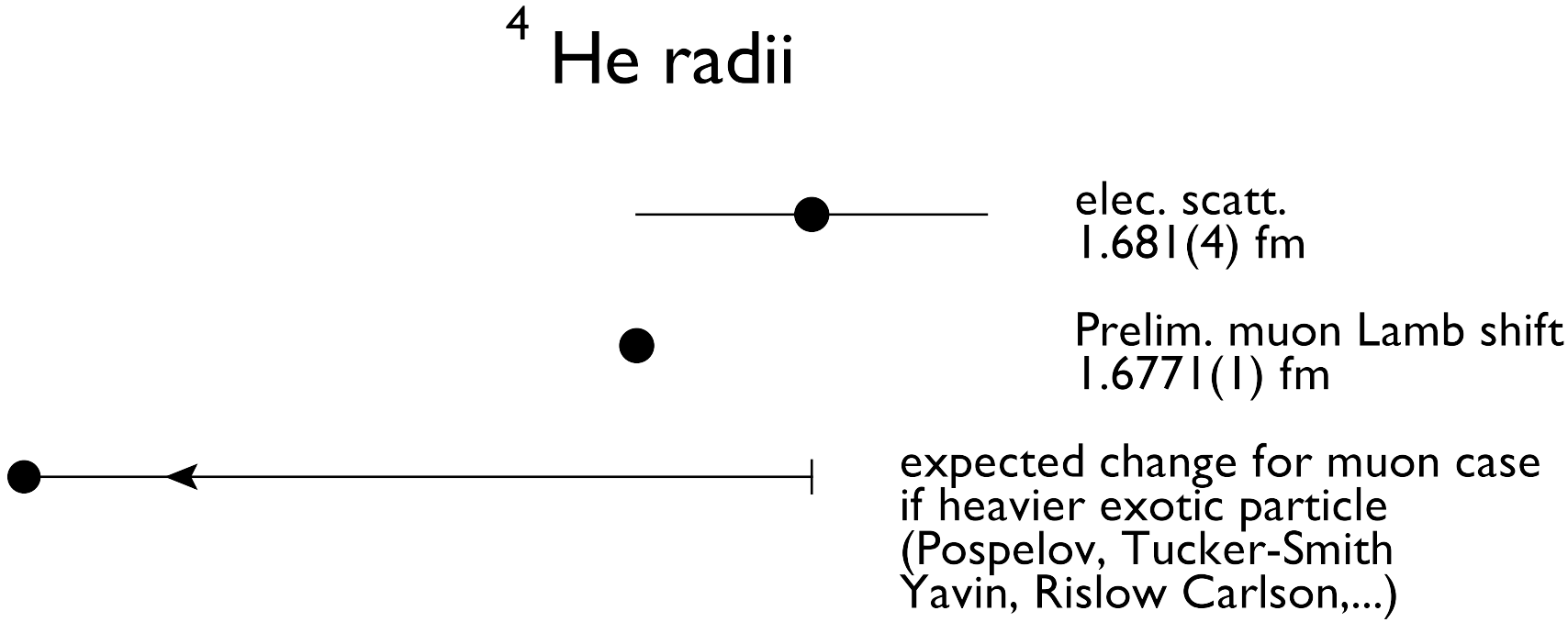
New physics and ^{4}He: intro

- The (still secret) observation: In ^{4}He, the radius from the muonic atom is 100% compatible with the known radius extracted from electron scattering.
- First look: worrisome for "new physics" explanations of proton radius puzzle.
- The message here: compatible with new physics explanations if the new exchanged particle is light (circa 1.5 MeV or less).

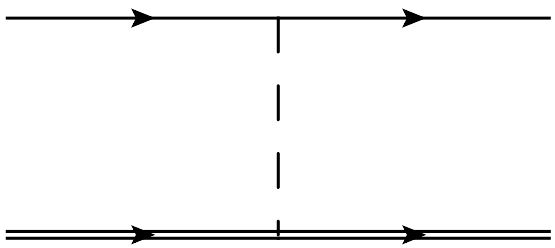
^{4}He radii

- One picture equivalent to what we have seen:



where from?

- New particle exchange gives Yukawa potential and energy difference for 2S - 2P states,



$$V(r) = -\frac{C_S^{\mu} C_S^{p}}{4\pi r} e^{-Mr}$$

$$\Delta E_{\text{new exch.}} = -\frac{C_S^{\mu} C_S^{h}}{M_\phi^2} |\phi_{2S}(0)|^2 f(x)$$

where $x = M_\phi a = M_\phi / (Z m_r \alpha)$ and $f(x) = x^4/(1+x)^4$

- Physics of *f(x)*: light particle, $x \approx 0$, long range, no energy diff. between 2S and 2P small; heavy particle, short range, only 2S affected and $f(x) \approx 1$. Range is relative to size of atomic state.

formulas

- Idea: $$\Delta E_{\text{new exch.}} = -\frac{C_S^{\mu} C_S^{h}}{M_{\phi}^2} |\phi_{2S}(0)|^2 f(x)$$

- Is mimicking change in nuclear radius:

$$\Delta E_{\text{finite size}} = \frac{2\pi Z\alpha}{3} |\phi_{2S}(0)|^2 \delta R_h^2$$

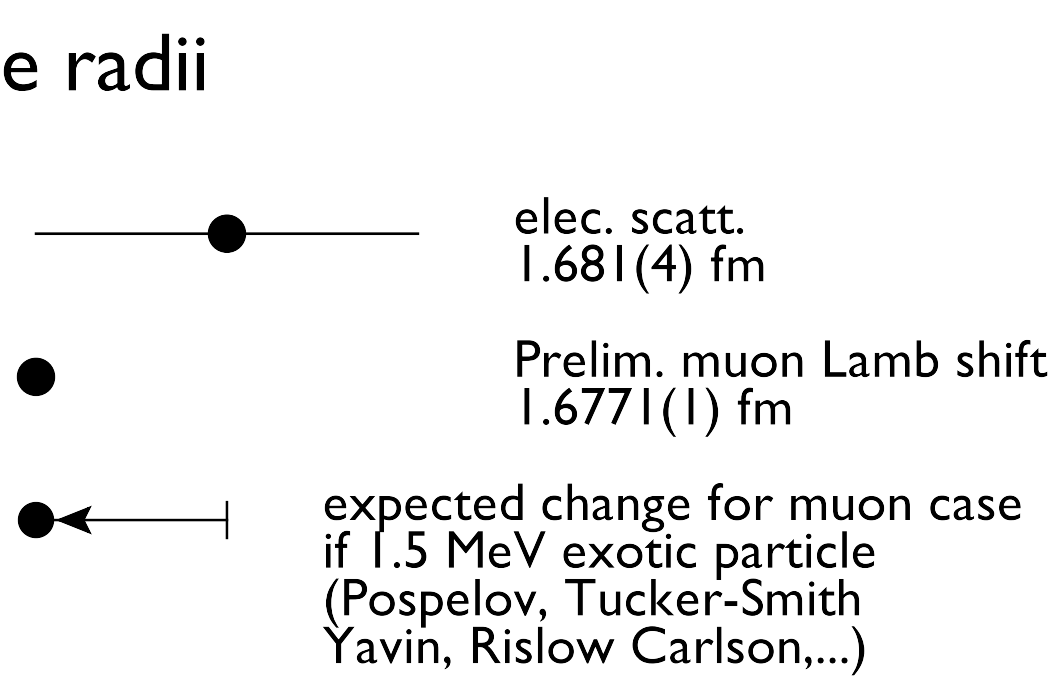
- One more thing: say new coupling to hadron prop. to Z, whence

$$\frac{\delta R_h}{R_h} = \frac{\delta R_p}{R_p} \frac{R_p^2}{R_h^2} \frac{f(x_h)}{f(x_p)}$$

and x_h is smaller than x_p because of $1/Z$

^{4}He radii

- The ratio $f(x_h)/f(x_p)$ — the cancellation between 2S and 2P energy shifts — matters for low masses of the exchange particle. For M above 10 MeV get figure like that before. For M lighter, have



Finish

- Ending message: new physics still o.k. if exchange particles light.
- Note especially Tucker-Smith & Yavin 2011 paper.
- Similar comments apply to Carbon, where
  - electron scattering gives r(C) = 2.478(9) fm [0.4%] (Offermann et al., 1991)
  - muonic atom gives r(C) = 2.483(2) fm [0.08%] (Ruckstahl et al., 1984)