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(FFK-2015)

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Recoil correction to the proton finite-size contribution to the Lamb shift in muonic hydrogen

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D.I. Mendeleev Institute for Metrology (St. Petersburg)

Theory of the Lamb shift in muonic hydrogen

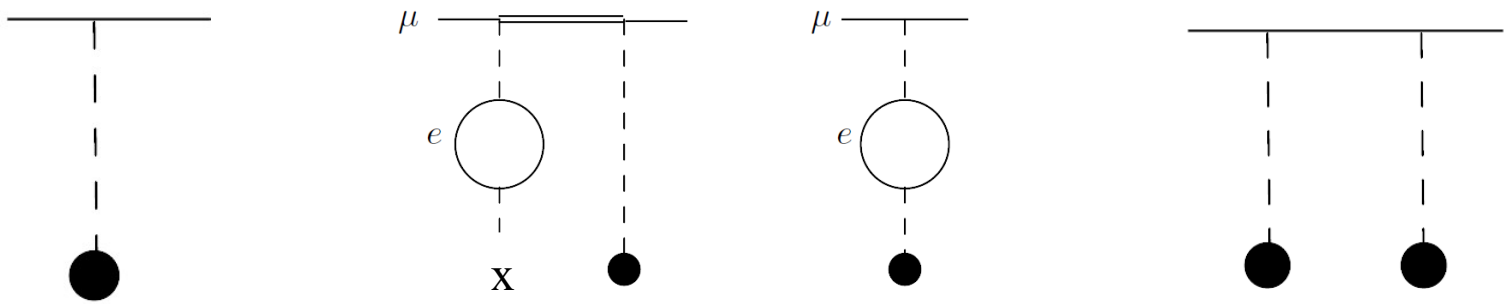
- Levels structure
- Specific QED corrections for μH
- Re-scaled hydrogenic theory
- Proton-line QED

is presented on poster:

"Theory of the Lamb shift in muonic hydrogen"

S. Karshenboim, V. Ivanov, E. Korzinin, and V. Shelyuto

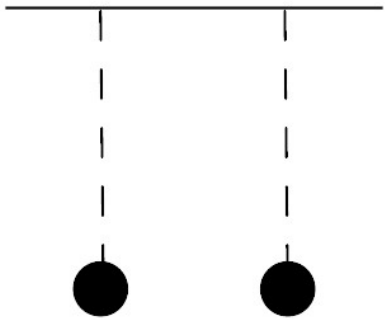
External-field proton-size contribution:



#	Designation	Order	Ref.	ΔE [meV]	
				Value	Estimation
10	PS (NR)	$(Z\alpha)^4 m$		$\mathbf{-5.1974}\ r_p^2$	$\boldsymbol{-3.7}$
11	PS (Rel)	$(Z\alpha)^6 m$	[65–67]	$-0.0016\ r_p^2 - 0.000\,04 (r_p^2)^2$	-0.0011
12	PS (eVP)	$\alpha(Z\alpha)^4 m$	Eq. (15)	$-0.0282\ r_p^2$	-0.020
13	PS (SE)	$\alpha(Z\alpha)^4 m$	[6]	$0.0006\ r_p^2$	0.0005
14.1	PS (Fri) term	$(Z\alpha)^5 m$	[69]	$-0.0251(35) + 0.062\,44\ r_p^2$	0.019

External-field proton-size contribution: problem

- Friar term



$$E(2s_{1/2}) = -\frac{2(Z\alpha)^5\, m_r^4}{\pi}\, I_{\rm Fr}\ ,$$

$$I_{\rm Fr} = \frac{\pi}{48}\int d^3r\, d^3r'\, \rho_E(\mathbf{r})\rho_E(\mathbf{r}')|\mathbf{r}-\mathbf{r}'|^3$$

$$= \frac{\pi}{48}\langle r^3\rangle_2\ ,$$

$$I_{\rm Fr} = \int_0^\infty \frac{dq}{q^4}\left[\left(G_E(q^2)\right)^2 - 1 - 2G'_E(0)\, q^2\right]$$

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FINITE-SIZE CORRECTIONS TO THE ENERGY LEVELS OF LIGHT MUONIC ATOMS ☆

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PHYSICAL REVIEW A VOLUME 53, NUMBER 4

Theory of the Lamb shift in muonic hydrogen

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(Received 28 August 1995)

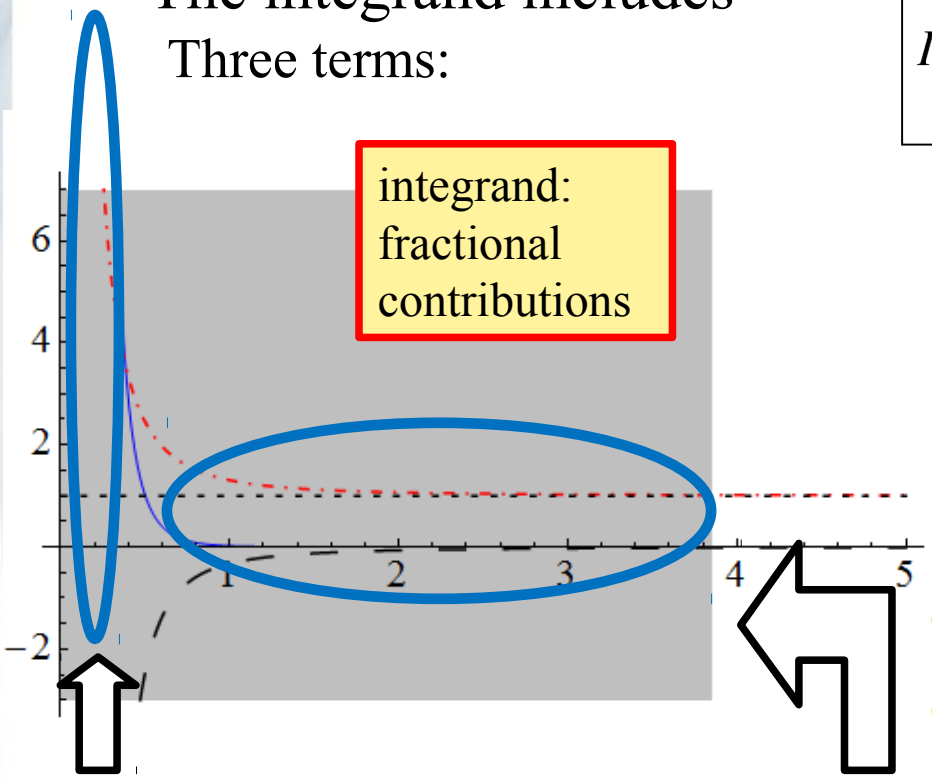
$$G'_E(0) = -\frac{1}{6}R_p^2$$

External-field proton-size contribution: Consistency problem

- The integrand includes Three terms:

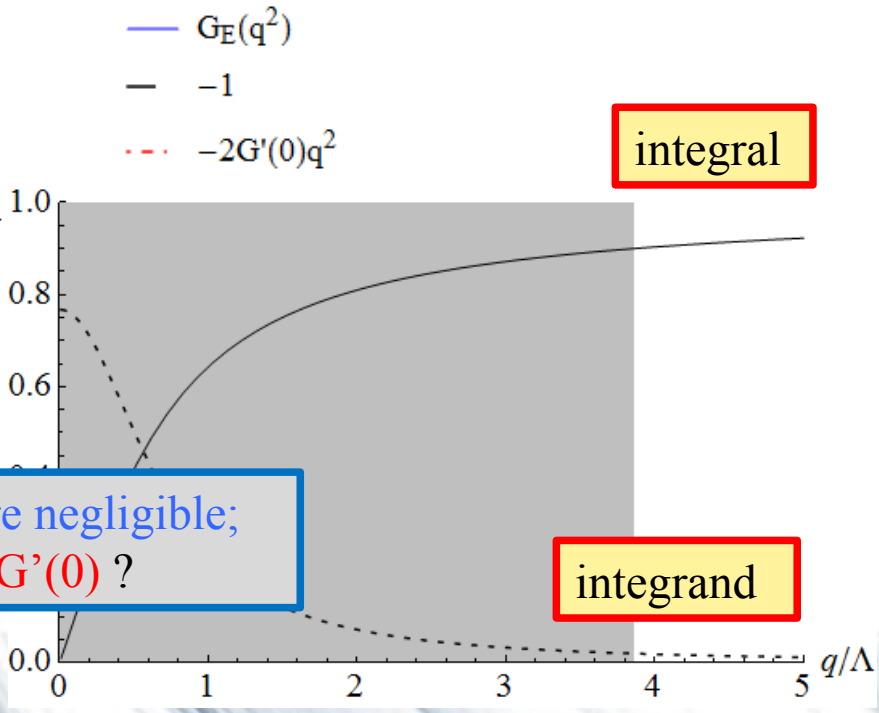
$$I_3^{\mathrm{E}} \equiv \int_0^\infty \frac{dq}{q^4}\left[\left(G_E(q^2)\right)^2 - 1 - 2G'_E(0)\,q^2\right]$$

integrand: fractional contributions



data are inaccurate; fit for G ?

90% of the integral



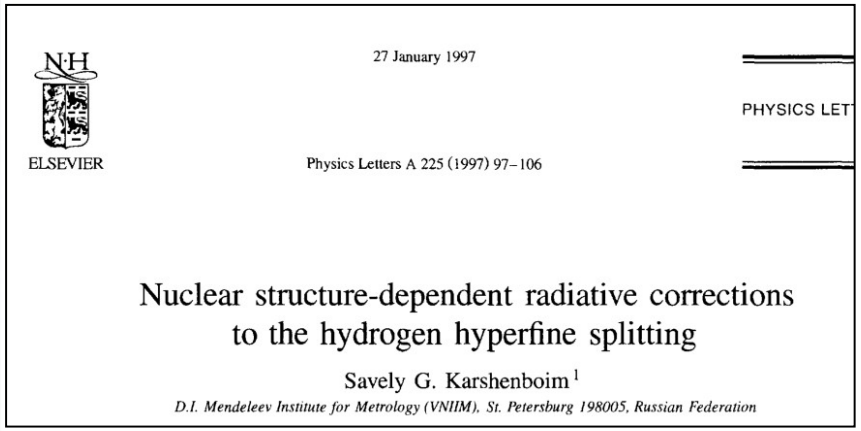
integral

data are negligible; fit for G'(0) ?

integrand

External-field proton-size contribution: method

$$I = \int_0^\infty dq... \equiv I_< + I_> \equiv \int_0^{q_0} dq... + \int_{q_0}^\infty dq...$$



27 January 1997

PHYSICS LET

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Physics Letters A 225 (1997) 97–106

Nuclear structure-dependent radiative corrections to the hydrogen hyperfine splitting

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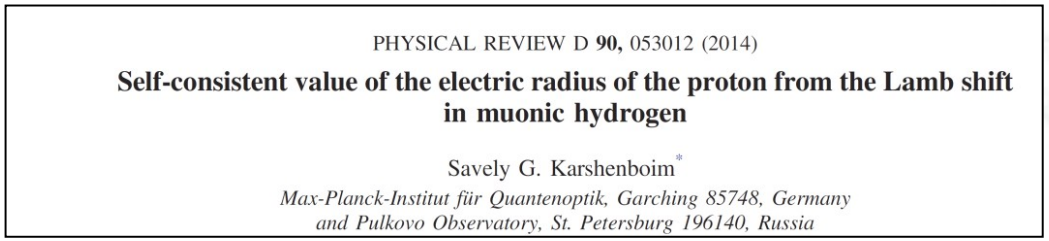

PHYSICAL REVIEW D **90,** 053012 (2014)

Self-consistent value of the electric radius of the proton from the Lamb shift in muonic hydrogen

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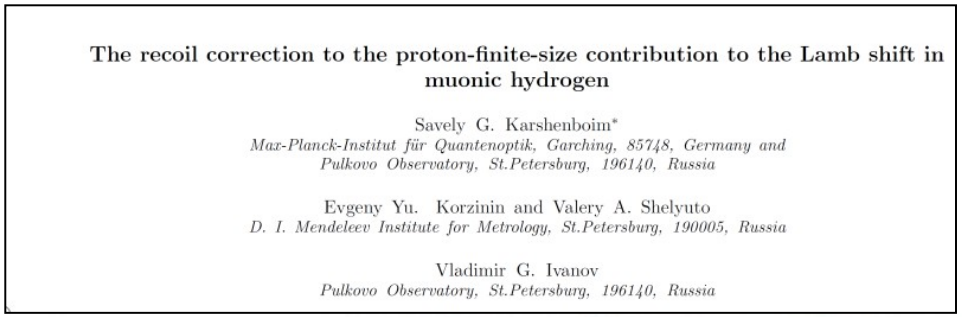

The recoil correction to the proton-finite-size contribution to the Lamb shift in muonic hydrogen

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External-field proton-size contribution: Strategy of the evaluation

- Split the integral

$$I = \int_0^\infty dq\ldots \equiv I_< + I_> \equiv \int_0^{q_0} dq\ldots + \int_{q_0}^\infty dq\ldots$$

- Low momentum

$$\left(G_E(q^2)\right)^2 \simeq 1 - \frac{R_E^2}{3}q^2 + C^{\rm dip}(1\pm 1)\,q^4$$

- High momentum

$$I^{\rm E}_{3>} = \int_{q_0}^\infty \frac{dq}{q^4}\left(G_E(q^2)\right)^2 - \frac{1}{3q_0^3} + \frac{1}{3}\frac{R_E^2}{q_0}$$

PHYSICAL REVIEW C **83**, 015203 (2011)

Realistic transverse images of the proton charge and magnetization densities

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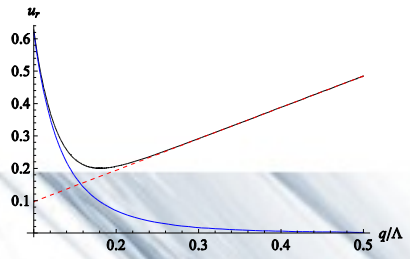
[2]*Department of Physics, University of Washington, Seattle, Washington 98195-1560, USA*
[3]*Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*

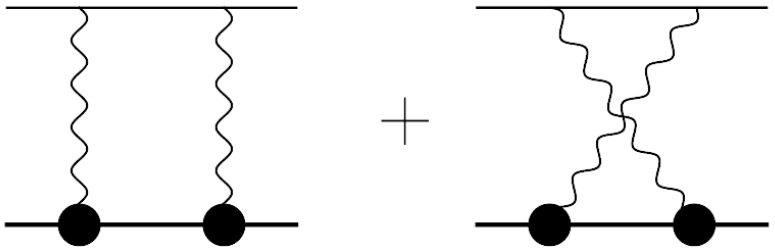
$$\delta I^{\rm E}_{3>} = \frac{1}{3q_0^3}\frac{2\delta G_E(q_0^2)}{G_E(q_0^2)}\left(G_{\rm dip}(q_0^2)\right)^2$$

- Minimization of the uncertainty

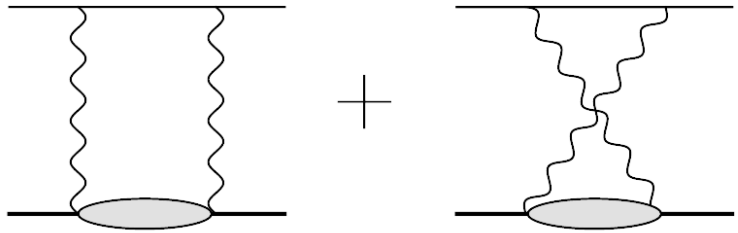


Two photon exchange proton-size contribution:

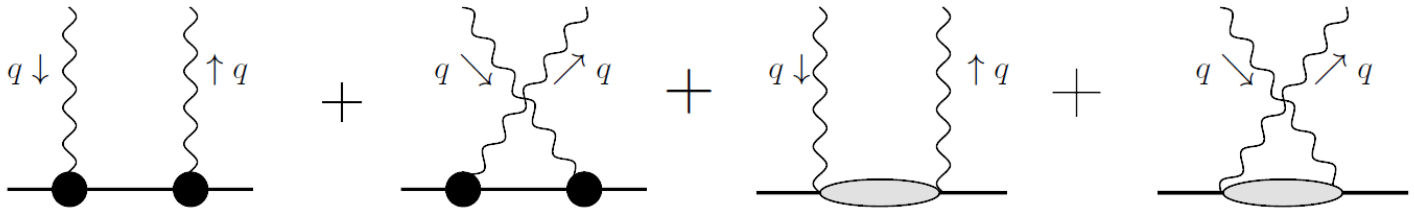
- Elastic



- Inelastic

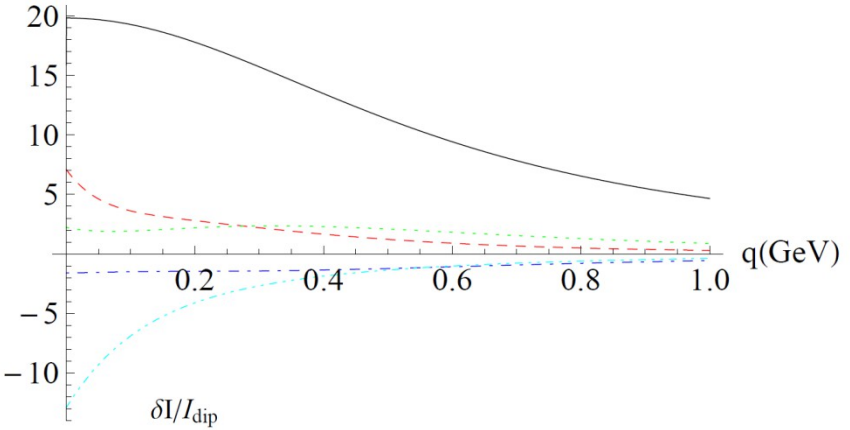


- Virtual Compton amplitude



Two photon exchange proton-size contribution: Elastic recoil and finite size

$$
\begin{aligned}
I_{\rm rec} &= I_\kappa + I_{\rm EF} + I_{\rm M1} + I_{\rm M2}\ , \\
I_\kappa &= \kappa \int_0^\infty \frac{dq}{q^4}\left\{(2+\kappa) f_{M1} + f_{M2}\right\}\ , \\
I_{\rm EF} &= \int_0^\infty \frac{dq}{q^4} f_{EF}(m,M;q^2)\left[\left(G_E(q^2)\right)^2 - 1\right]\ , \\
I_{\rm M1} &= \int_0^\infty \frac{dq}{q^4} f_{M1}\left[\left(G_M(q^2)\right)^2 - (1+\kappa)^2\right]\ , \\
I_{\rm M2} &= \int_0^\infty \frac{dq}{q^4} f_{M2}\left[G_M(q^2)G_E(q^2) - (1+\kappa)\right]\ , \qquad (21)
\end{aligned}
$$



PHYSICAL REVIEW A VOLUME 53, NUMBER 4

Theory of the Lamb shift in muonic hydrogen

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(Received 28 August 1995)

Proton Polarizability and Lamb Shift in the Muonic Hydrogen Atom

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PHYSICAL REVIEW A **84**, 020102(R) (2011)

Higher-order proton structure corrections to the Lamb shift in muonic hydrogen

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[2]*Department of Physics, College of William and Mary, Williamsburg, Virginia 23187, USA*
[3]*Institut für Kernphysik, Johannes Gutenberg-Universität, D-55099 Mainz, Germany*

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Proton polarisability contribution to the Lamb shift in muonic hydrogen at fourth order in chiral perturbation theory

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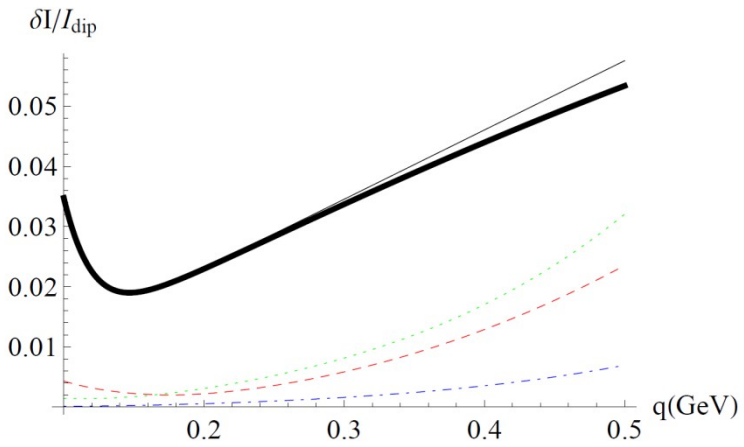

PHYSICAL REVIEW D **91,** 073003 (2015)

Recoil correction to the proton finite-size contribution to the Lamb shift in muonic hydrogen

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Two photon exchange proton-size contribution: Elastic recoil and finite size

#	Designation	ΔE [meV]	
		Value	Estimation
14.1	eTPE:Fri	$0.062\ r_p^2 - 0.025(4)$	*0.019*
14.2	eTPE:κ^*	$-0.003\,05$	*−0.003*
14.3	eTPE:EF*	$0.001\,07\ r_p^2 + 0.001\,36(4)$	*0.002*
14.4	eTPE:M1*	$0.001\,88(3)$	*0.002*
14.5	eTPE:M2*	$-0.000\,016\ r_p^2 - 0.000\,90$	*−0.0009*
14	eTPE	$0.064\ r_p^2 - 0.026(4)$	*0.019*

Two photon exchange proton-size contribution: Elastic recoil and finite size

More information one can find in poster:

"*Recoil correction to the proton finite-size contribution to the Lamb shift in muonic hydrogen*"

S. Karshenboim, V. Ivanov, E. Korzinin, and V. Shelyuto

Thank You for attention!