Isotope Shift

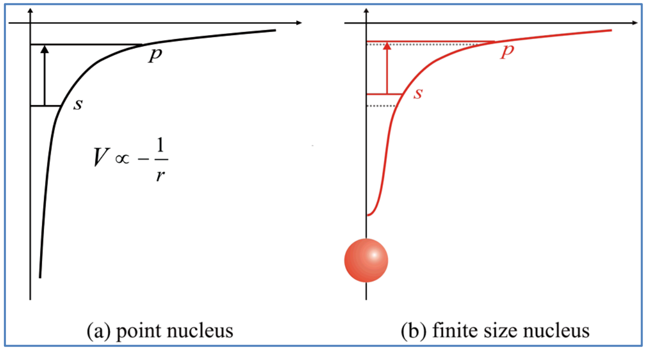
Laser trapping of exotic atoms.
RMP 85, 1383 (2013)

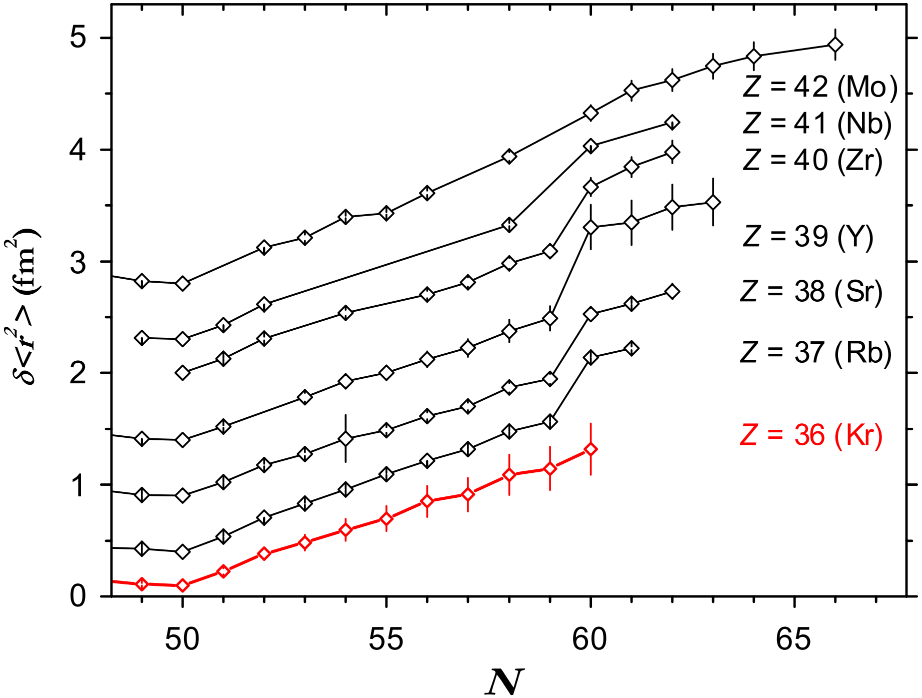
TABLE I. Contributions to the electronic binding energy and their orders of magnitude in atomic units. a_0 is the Bohr radius, $\alpha \approx 1/137$. For helium, the atomic number $Z = 2$, and the mass ratio $\mu/M \sim 1 \times 10^{-4}$. g_I is the nuclear g factor. α_d is the nuclear dipole polarizability.

Contribution	Magnitude
Nonrelativistic energy	Z^2
Mass polarization	$Z^2 \mu/M$
Second-order mass polarization	$Z^2(\mu/M)^2$
Relativistic corrections	$Z^4 \alpha^2$
Relativistic recoil	$Z^4 \alpha^2 \mu/M$
Anomalous magnetic moment	$Z^4 \alpha^3$
Hyperfine structure	$Z^3 g_I \mu_0^2$
Lamb shift	$Z^4 \alpha^3 \ln\alpha + \cdots$
Radiative recoil	$Z^4 \alpha^3 (\ln\alpha) \mu/M$
Finite nuclear size	$Z^4 \langle r_c/a_0 \rangle^2$
Nuclear polarization	$Z^3 e^2 \alpha_d/(\alpha a_0^4)$

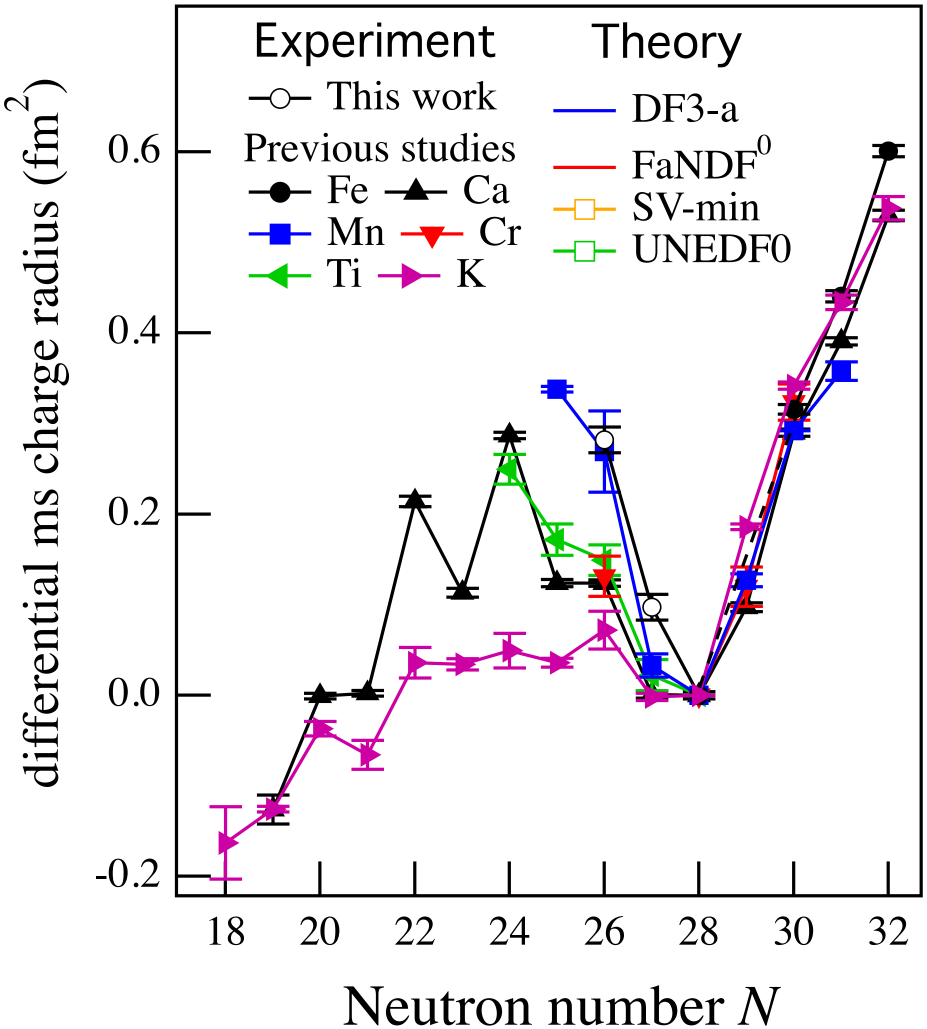
$$\alpha = \frac{1}{137}$$

μ=reduced electron mass



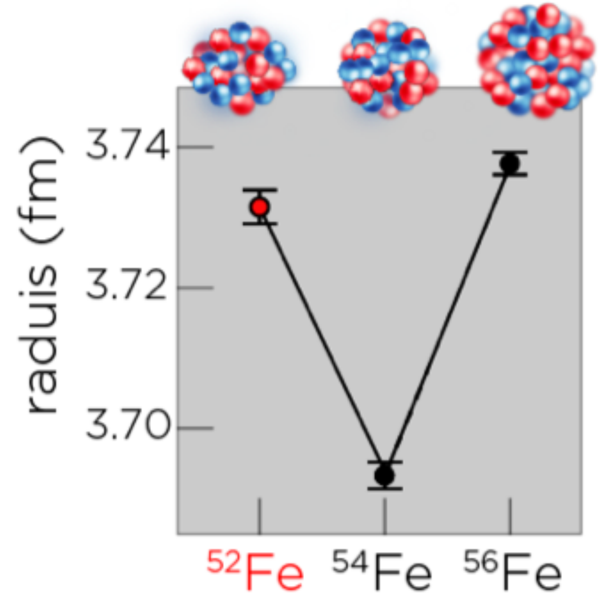


Difference in mean-square charge radii for the N~60 region, PRL 105, 032502 (2010)

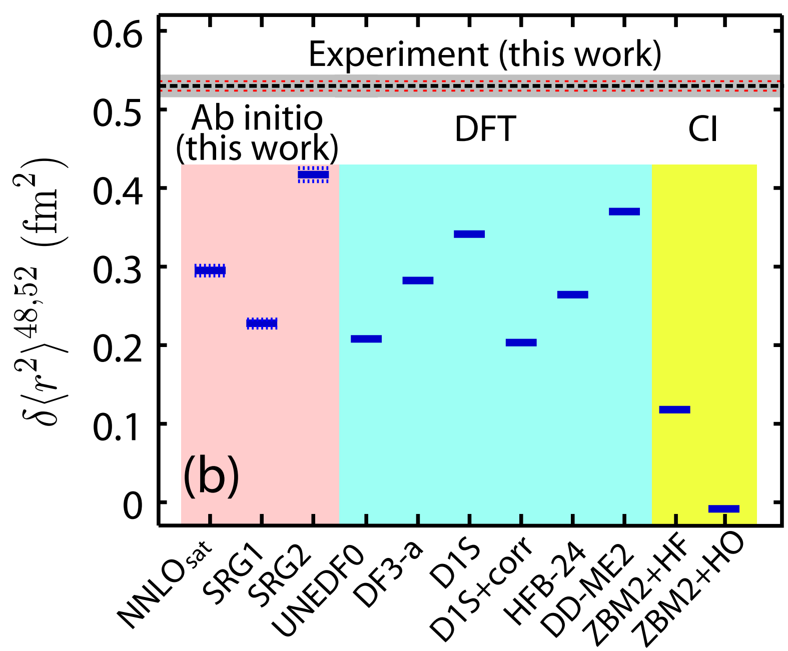


Phys. Rev. Lett. 117, 252501 (2016)

BECOLA @ NSCL



Nature Physics 12, 594 (2016)



Neutron radii

- Proton-Nucleus elastic
- Pion, alpha, d scattering
- Pion photoproduction

} Involve strong probes

Phys. Rev. Lett. 112, 242502 (2014)

http://physics.aps.org/synopsis-for/10.1103/PhysRevLett.112.242502

Parity-violating electron scattering

Z_0 of Weak Interaction

M_Z=90.19 GeV!

Parity Violating Asymmetry

$$A = \frac{\left(\frac{d\sigma}{d\Omega}\right)_R - \left(\frac{d\sigma}{d\Omega}\right)_L}{\left(\frac{d\sigma}{d\Omega}\right)_R + \left(\frac{d\sigma}{d\Omega}\right)_L} = \frac{G_F Q^2}{2\pi\alpha\sqrt{2}}\left[\underbrace{1 - 4\sin^2\theta_W}_{\approx 0} - \frac{F_n(Q^2)}{F_P(Q^2)}\right] \sim 7\cdot 10^{-7}$$

Weinberg angle: $\sin^2\theta_W = 0.23120 \pm 0.00015$

	proton	neutron
Electric charge	1	0
Weak charge	0.08	1

A comment: Yukawa potential

$$V_Y(r) = -g^2 \frac{e^{-\mu r}}{r}$$

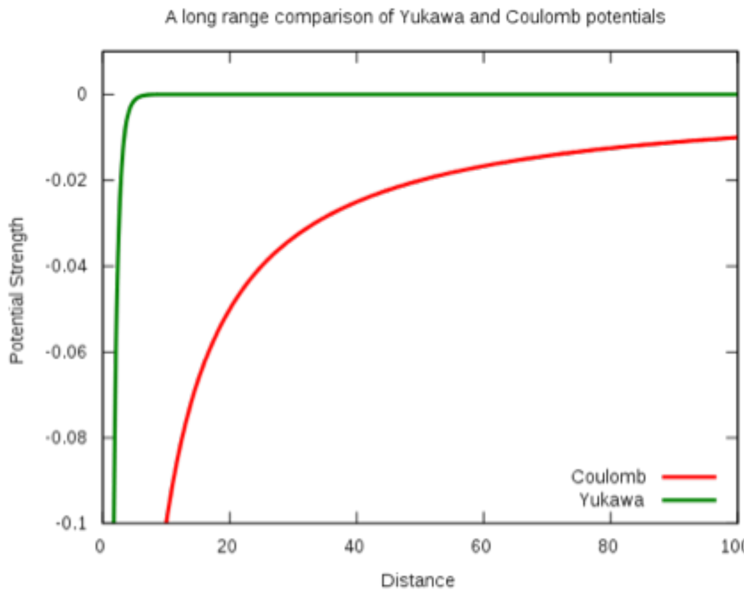
$$\lambda_B = \frac{1}{\mu} = \frac{\hbar}{m_B c}$$

Compton wavelength of the boson (force carrier)

Mass of the boson

$$-\frac{1}{c^2}\frac{\partial^2 \Psi}{\partial t^2} + \nabla^2 \psi = \mu^2 \Psi$$

Klein-Gordon equation



Lead (^{208}Pb) Radius Experiment : PREX

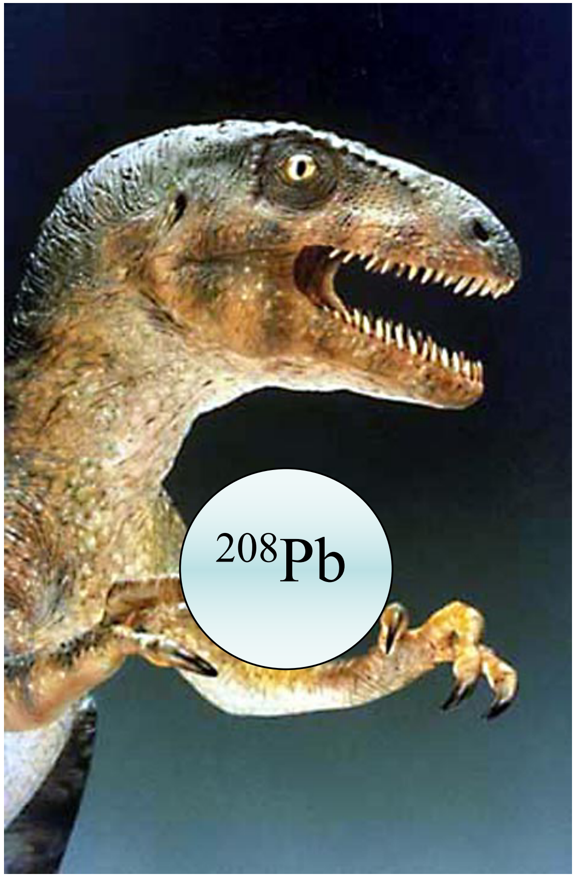
Analysis is clean, like electromagnetic scattering:

1. Probes the entire nuclear volume
2. Perturbation theory applies

E = 850 MeV, $\theta = 6^0$
electrons on lead

Phys. Rev. Lett. 108, 112502 (2012)

http://physics.aps.org/synopsis-for/10.1103/PhysRevLett.108.112502

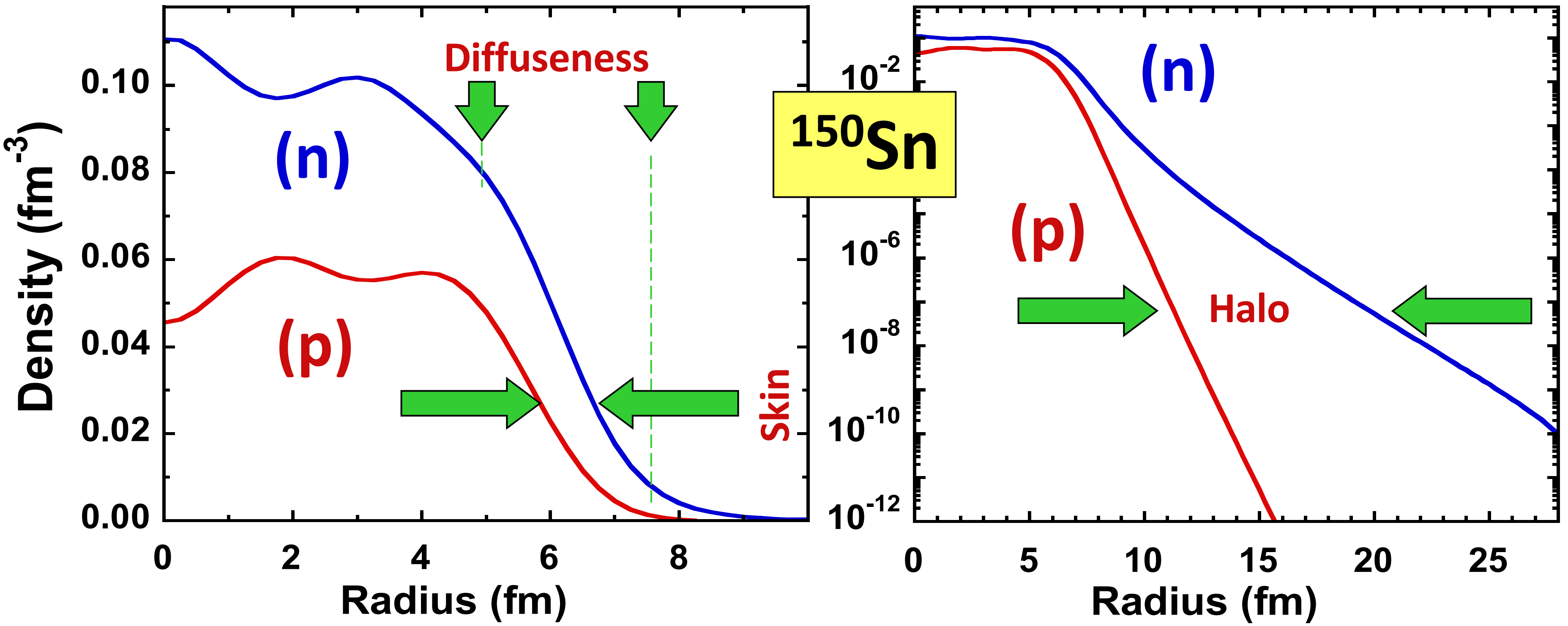


$$R_{skin} = R_n - R_p$$

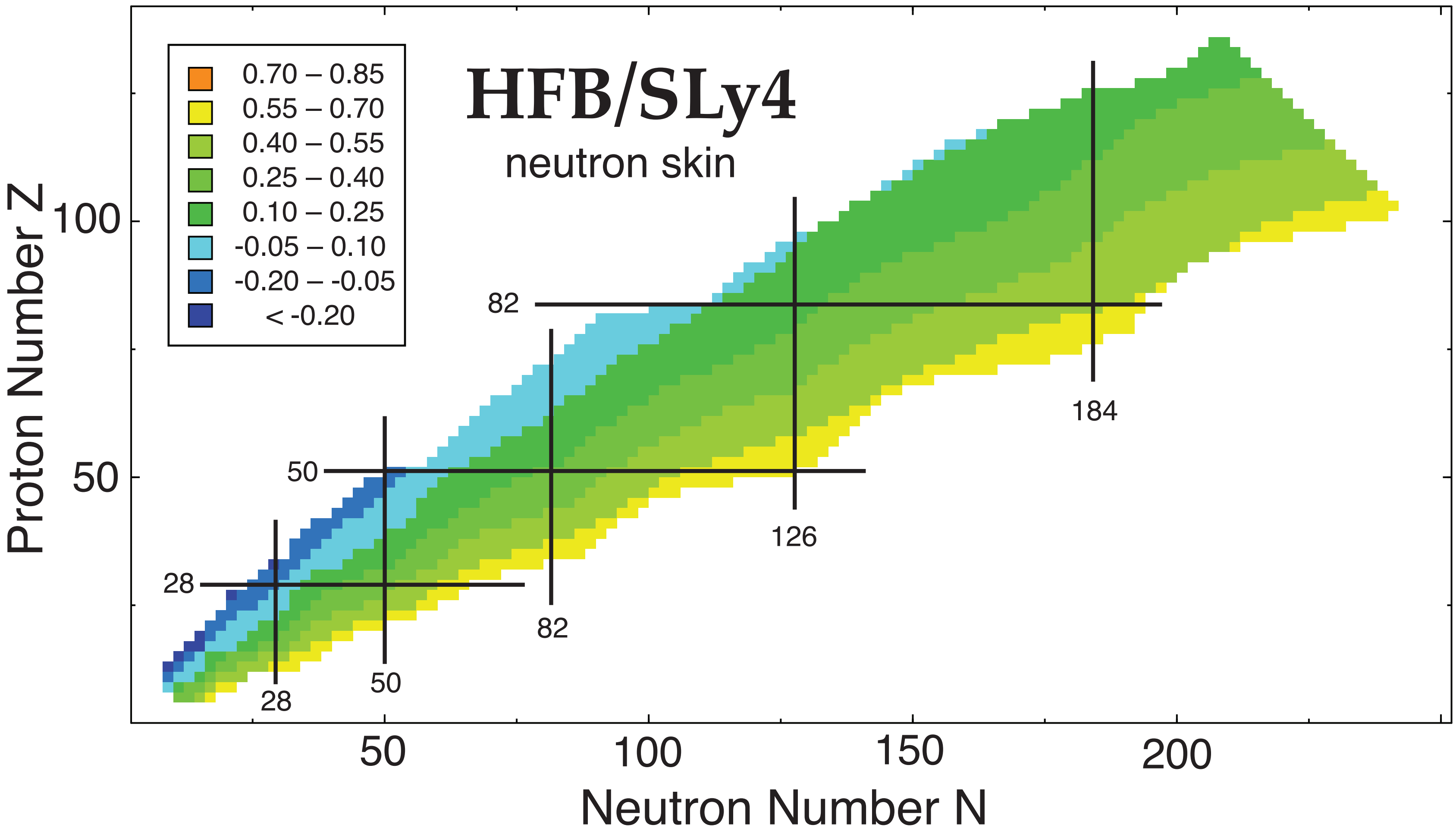
PREX: $0.34^{+0.15}_{-0.17}\, fm$

Theory: $0.168 \pm 0.022\, fm$

Neutron & proton density distributions



S. Mizutori et al., Phys. Rev. C61, 044326 (2000)



HW: Assuming the nucleus of mass number *A* to be a spherical object with a sharp surface and constant nucleonic density ρ_0= 0.16 nucleons/fm^3, find the relation between nuclear radius and *A*.

Test the performance of the resulting expression by comparing with experimental data for charge radii:
http://www.sciencedirect.com/science/article/pii/S0092640X12000265
Assume that the radius of the mass distribution is the same as the radius of the charge distribution. Note that this reference discusses root-mean-square (rms) nuclear charge radii not geometric radii.