Measurement of the neutron distribution radius in ^{208}Pb by low-energy electron scattering

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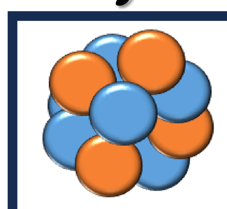
Physics motivation



Nucleus
= Proton + Neutron

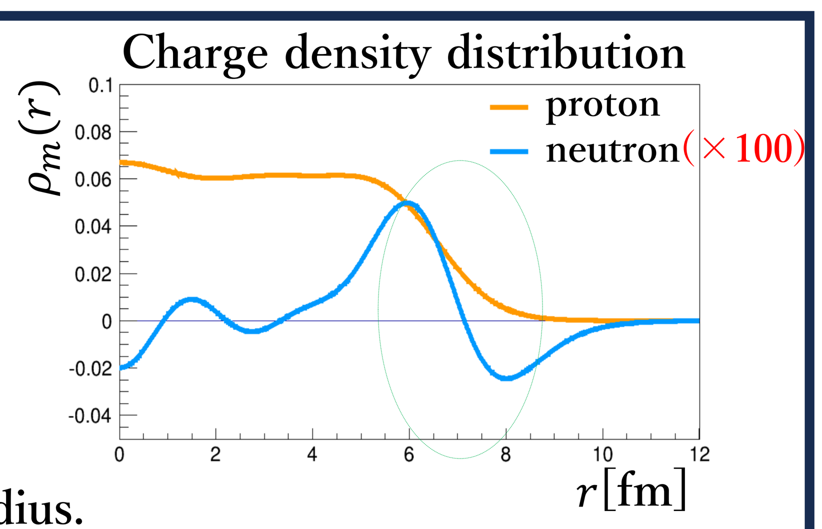
▶ Proton and neutron distribution are the fundamental quantities of nuclear structures.
Proton distribution → well known by electron elastic scattering
Neutron distribution → not well known
Electron elastic scattering (neutron charge is zero, not considered)
Hadron scattering (Model dependence)
Parity-violating electron scattering (Measure A_{PV}~10^6, very difficult)

New method shows...
➡ Possibility of accessing the neutron information through electron elastic scattering[1]

Nuclear charge density and nth moment

Nuclear charge density distribution

・Nuclear charge density distribution consists of the proton and the neutron contributions.
Theoretically the neutron contribution is known to be about 1%.



From the 2nd moment

・The 2nd moment is the square of nuclear charge radius.
・The 2nd moment is measured not only for stable nuclei but also for unstable nuclei
・The neutron distribution radius is inaccessible.

$$< r_c^2 > \equiv \int r^2 \rho_c(r) \mathrm{d}^3 r$$
$$= e_p < R_p^2 > + < r_p^2 > + e_n < R_n^2 > + \frac{N}{Z} < r_n^2 > + \text{rel. corr.}$$

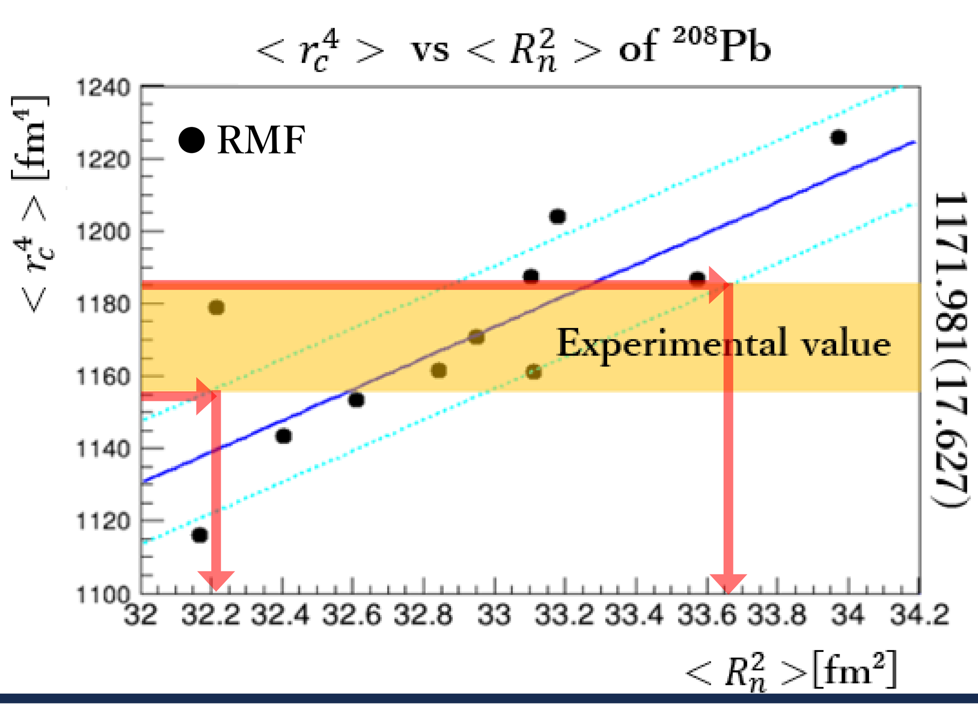
From the 4th moment

・It is possible to obtain the neutron distribution from the 4th moment.

$$< r_c^4 > \equiv \int r^4 \rho_c(r) \mathrm{d}^3 r$$
$$= e_p < R_p^4 > + \frac{10}{3} < R_p^2 >< r_p^2 > + e_n < R_n^4 > + \frac{10}{3} < R_n^2 >< r_n^2 > + \frac{N}{Z} + \text{rel. corr.}$$

Neutron distribution radius of ^{208}Pb from 4th moment within RMF

・The figure below plots $< r_c^4 >$ vs $<R_n^2>$ obtained from relativistic mean field models.
・11 models are fitted as a straight line.
・From the measured 4th moment, the neutron distribution radius can be determined.
・The result from the models is in agreement with the previous experiment (PREX).

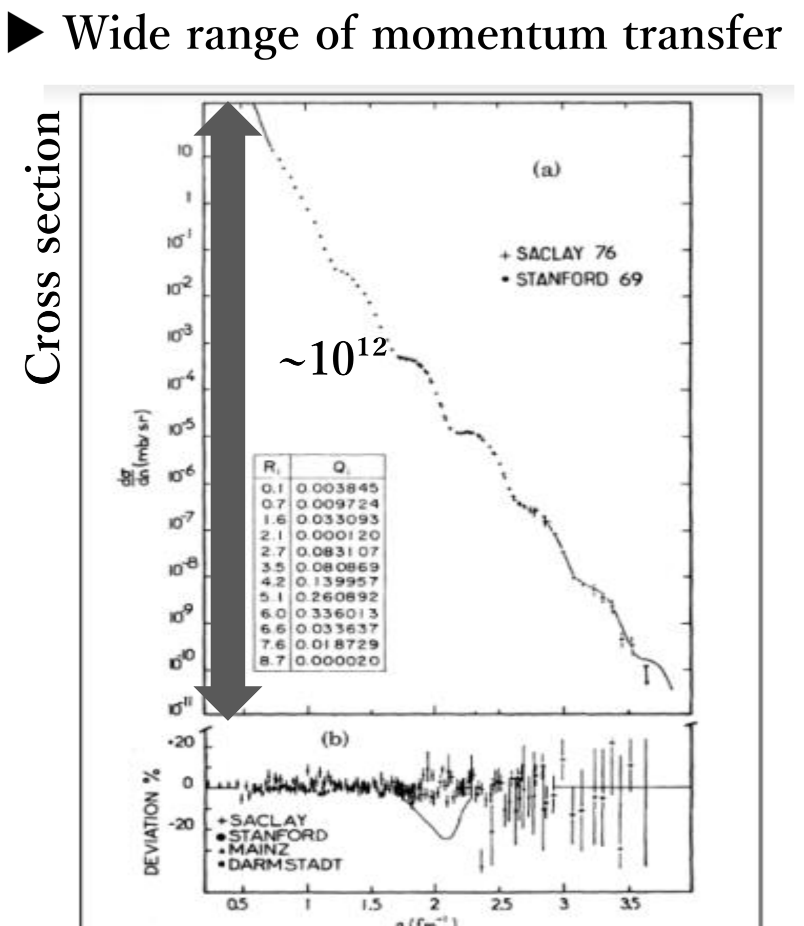


		R_n[fm]
^{208}Pb	$< r_c^4 >$theory	5.728(57)
	PREX	5.737(84)

Methods to obtain 4th moment

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} |F(q)|^2$$ in PWBA, 0$^+$

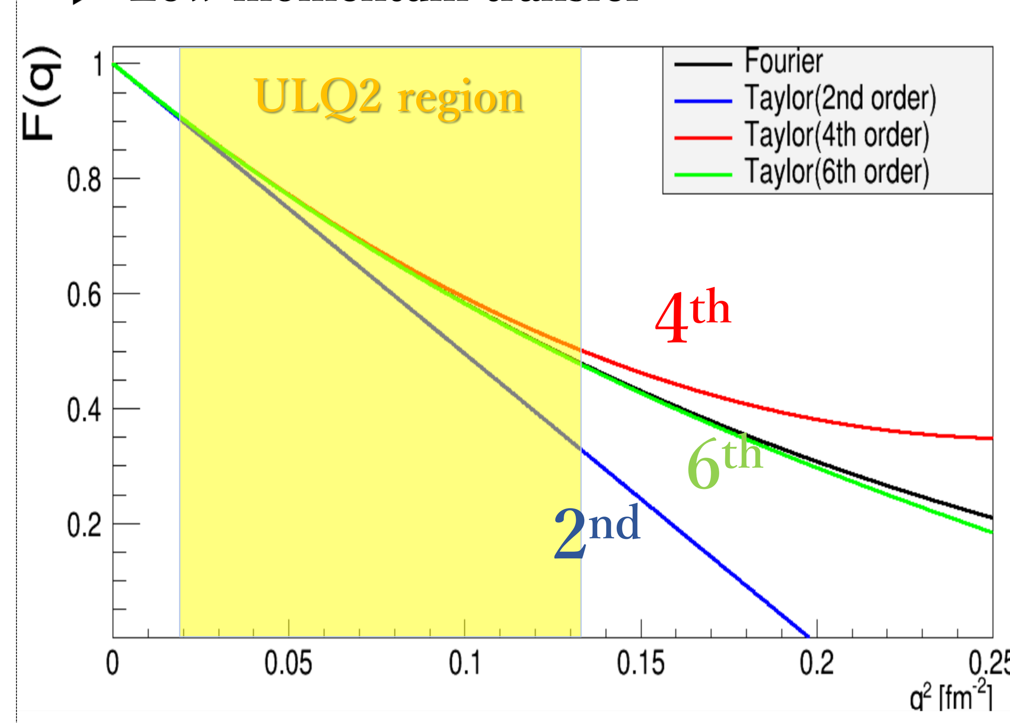
▶ Wide range of momentum transfer



B. Frois *et al.*, Phys. Rev. Lett. **38**, 152(1977).

$$F(q) = \int \rho_c(r) e^{-iq\cdot r} dr$$
$$< r_c^4 > = \int r^4 \rho_c(r) d^3 r$$

▶ Low momentum transfer



$$F(q) = 1 - \frac{<r_c^2>}{3!} q^2 + \frac{<r_c^4>}{5!} q^4 \ldots$$

・The cross section is very large at low-q.
・This method makes it possible to measure the neutron distribution of unstable nuclei with collaboration of SCRIT facility.

Reference
[1] H. Kurasawa and T. Suzuki, Prog. Theor. Exp. Phys. 2019, 113D01(2019)

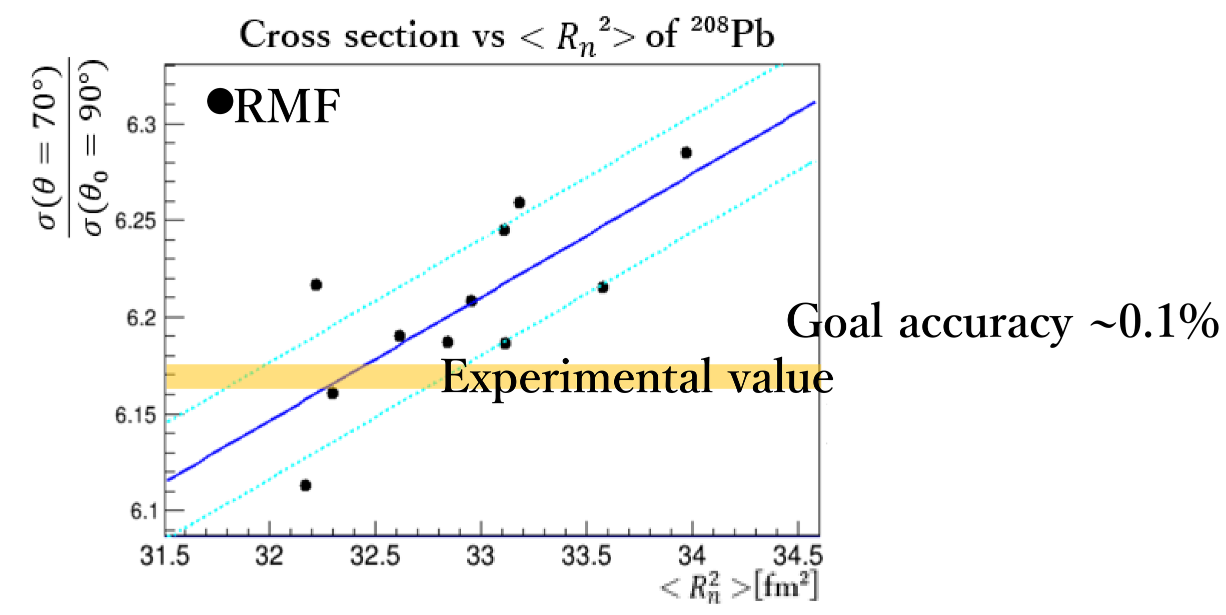
LEEP(Low Energy Electron Scattering for ^{208}Pb)

▶ Why low-q?
・The cross section is very large.

▶ Why ^{208}Pb?
・The nuclear charge density distribution is well known.
・It is a doubly magic nucleus.
・There are many theoretical models.

Method 1: measure R_n from the cross section ratio

・We use DWBA instead of PWBA, and directly relate the cross section ratio and the neutron distribution radius.
・The cross section ratio will be measured with an accuracy of 0.1% to extract the neutron distribution radius with an accuracy of less than 1%.



Method 2: measure R_n from the 4th moment

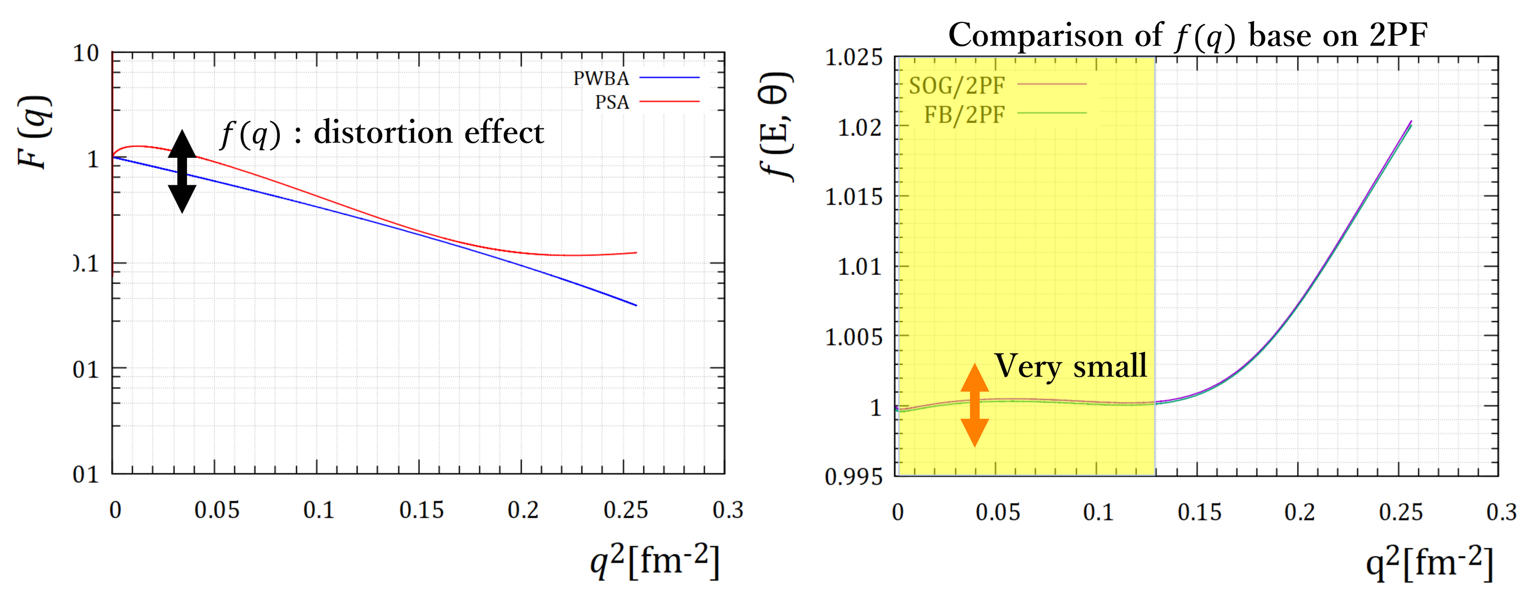
・W assume that the cross section can be expressed including distortion effect $f(q)$ based on PWBA formula.

$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{exp}} = f_{\text{exp}}(q) \left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}} |F(q)|^2, \quad \left(\frac{d\sigma}{d\Omega}\right)_{\text{model}} = f_{\text{model}}(q) \left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}} |F(q)|^2$$

・$f(q)$ are no difference between some distributions, even if 2PF, at low-q.

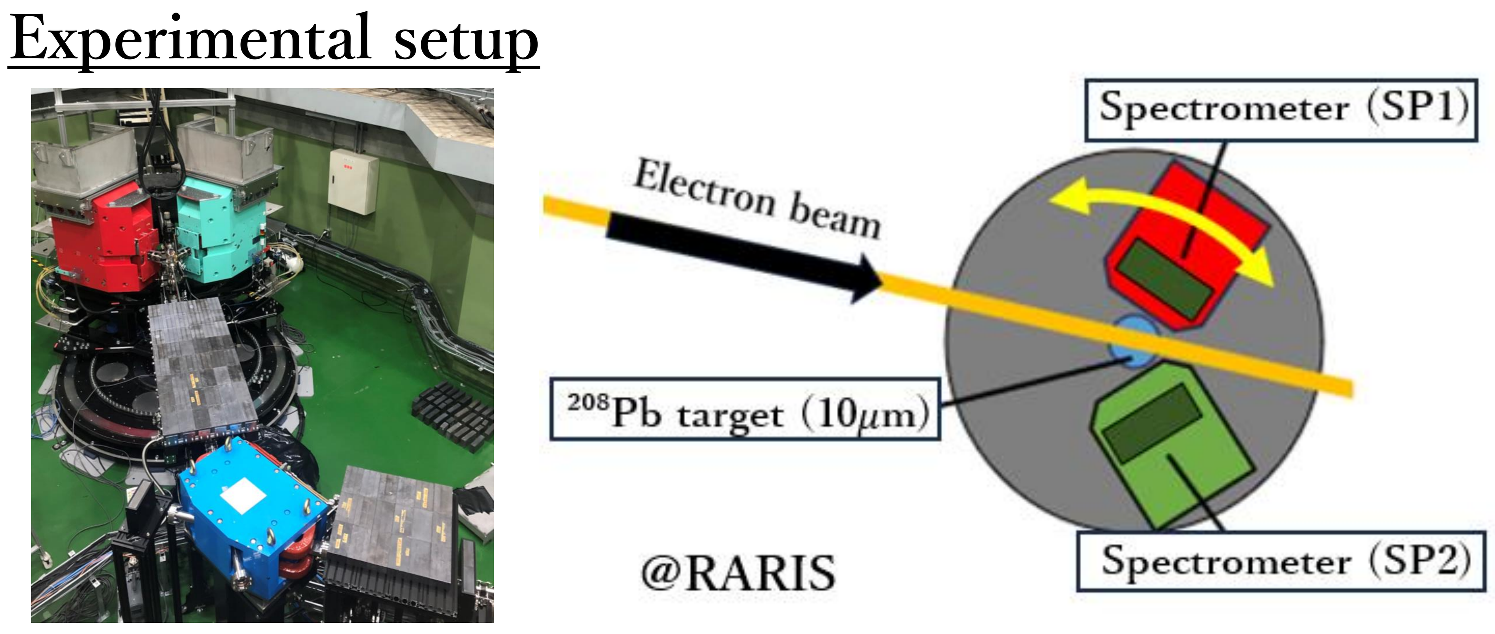
$$f_{\text{exp}}(q) \approx f(q) \approx f_{\text{model}}(q) \;\; (f_{\text{exp}}(q)\text{: SOG, FB、} f_{\text{model}}(q)\text{: 2PF})$$

・We calculate $f(q)$ using 2PF and measure the cross section. Then we can get the form factor $F(q)$ and the 4th moment. (cf. Methods to obtain 4th moment ▶ Low momentum transfer)



Experimental setup and current status (ULQ2)

Experimental setup



・The figure above shows the experimental facility at RARIS, which we call the "Ultra Low Q2" facility, designed to measure the proton radius.
・The twin spectrometers can rotate from 30 to 150 degrees and the momentum resolution is less than 0.1%.
・We use 10μm thickness ^{208}Pb target.
・We use silicon strip detectors a as focal plane detectors on top of the spectrometers.

Current status

・We conducted the test experiment.
・We will start to acquire the physics data this year.

Summary

・Electron scattering can determine $<R_n^2>$ from $< r_c^4 >$.
・$< r_c^4 >$ can be measured not only from a wide-q range but also at low-q. This is a possible application for unstable nuclei.
・We are currently studying the relationship between the cross section ratio and $<R_n^2>$ using ^{208}Pb target. (LEEP exp.)
・LEEP exp. needs ~0.1% cross section ratio accuracy to extract the $<R_n^2>$ with an accuracy of less than 1%. (Stay tuned to see the result!!)