Extracted the ratio between the charge radii of the mirror nuclei ^{3}He and ^{3}H

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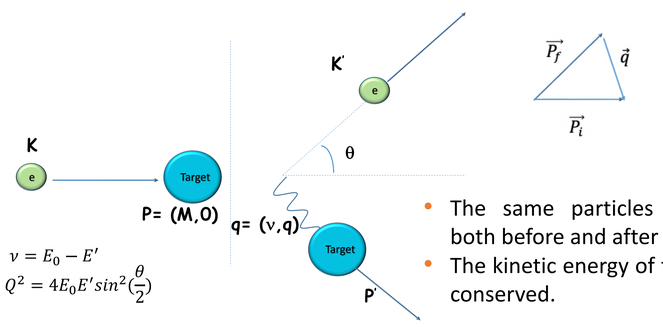
Abstract

Form factors are an essential piece of information and an intuitive and simple tool used to describe the scattering particles from nuclei and to increase understanding of the three-nucleon system. Scattering electrons from massive particles such as nucleons or nuclei is one of the most powerful tools to investigate their nature and obtain information about the internal structure of atomic nuclei and their constituents. By collecting and analyzing data from Jefferson Lab Hall A experiment E12-11-112, the nuclear charge distributions of 3He and 3H are studied in terms of the form factor at low momentum transfer around 0.1 GeV^2. The form factor is determined experimentally from the ratio of the experimental differential scattering cross section to the Mott cross section and under certain conditions (negligible recoil and validity of the Born Approximation), and it is the Fourier transform of the charge distribution $\rho(x)$. At low Q^2, the contributions of the magnetic form factor (G_M) and Coulomb corrections are minimized, which leads to an accurate extraction of the charge form factor (G_E). By measuring the form factor of a target at very low Q^2 we calculate the mean square radius by finding the slope of the form factor approaching Q^2=0. This new data point improves our knowledge of the cross section, form factors, and charge radii at low momentum transfer.

Elastic Electron Scattering



- The same particles are presented both before and after the scattering.
- The kinetic energy of the scattering is conserved.

Nuclear Form Factors and charge radii

- Cross Section is a measure of the probability of a reaction between the two colliding particles (incident electron and target's proton).
- Only a fraction of all the reactions are measured with is some of solid angle dΩ, this fraction is called "Differential Cross Section".

$$\left(\frac{d\sigma}{d\Omega}\right)^*_{\text{Mott}} = \left(\frac{d\sigma}{d\Omega}\right)_{\text{Rutherford}} \cdot \cos^2\frac{\theta}{2} = \frac{4Z^2\alpha^2(\hbar c)^2E'^2}{|qc|^4}\cos^2\frac{\theta}{2}$$

- In the case of a nucleon, the scattering cross section is given by the Rosenbluth Formula:

$$\frac{d\sigma}{d\Omega} = \sigma_{\text{Mott}}\left[G_E^2 + \frac{\tau}{\varepsilon}G_M^2\right](1+\tau)^{-1}$$

- Nuclear target is made up of atoms with differing arrangement rather than point-like particles, so the spatial extension of a nuclei and nucleons is described by a form factor.

$$F(q^2) = \frac{(d\sigma/d\Omega)_{exp}}{(d\sigma/d\Omega)_{Mott}}$$ Obtain the form factor Experimentally

The electric (magnetic) charge distribution.

$$G_{E(M)} = \int \rho_{E(M)}(\boldsymbol{r})e^{i\boldsymbol{q}\cdot\boldsymbol{r}}d^3\boldsymbol{r} \approx 1 - \frac{1}{6}\boldsymbol{q}^2\langle r^2_{E(M)}\rangle + \cdots$$

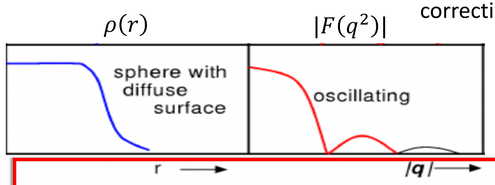
Under certain conditions

- The recoil is negligible.
- The Born approximation.

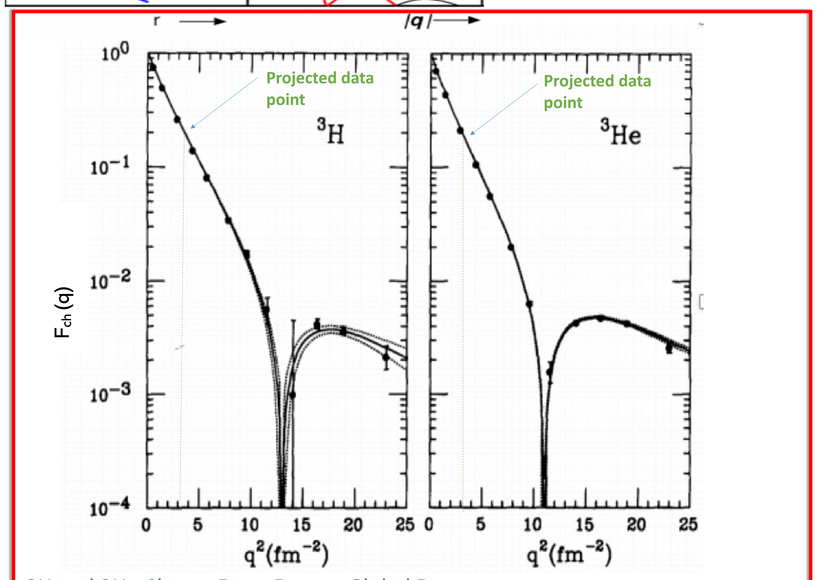
$$\langle r_E^2\rangle = -6\left.\frac{dG_E}{dQ^2}\right|_{Q=0}$$

At low momentum transfer(q2)

- The cross section is dominated by G_E .
- Minimal contribution of Coulomb corrections.



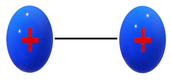
Connection between charge distributions and form factors for spherically symmetric charge distribution in Born approximation.

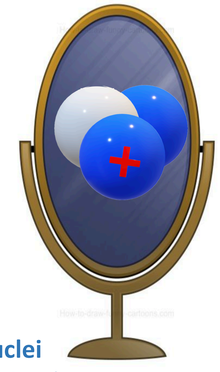


3H and 3He Charge Form Factors Global Data A. Amroun et al., Nucl. Phys. A579, 596 (1994).

Mirror nuclei

- "Mirror nuclei" are pairs of nuclei in which the proton number in one equals the neutron number in the other and vice versa.
- The same spin and parity.

^{3}H nuclei	3He nuclei
	
n-n interaction has only a strong interaction due to isospin symmetry.	P-P interaction has the same strong interaction and the electromagnetic interaction.

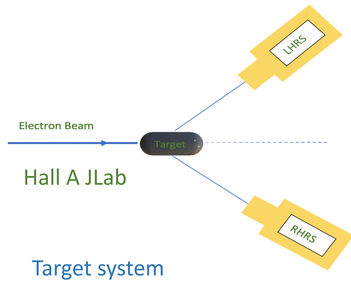


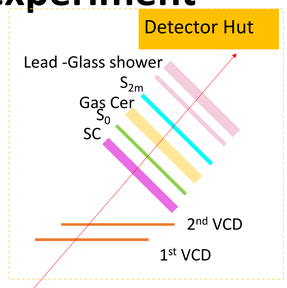
3H and 3He nuclei are the simplest pair of mirror nuclei.

E12-11-112 experiment

Experimental setup

- Standard Hall A LHRS configuration.
- Gas Cerenkov + Calorimeter PID.



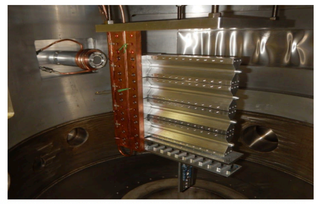


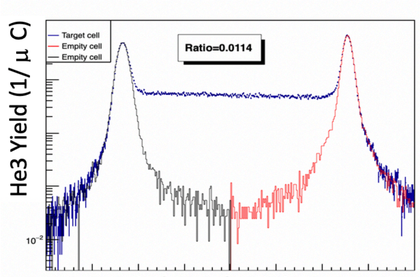
Kinematic

- Beam current: 5μA
- Beam energy: 1.171 GeV
- Momentum: 1.12798 GeV
- Angle: 17.009 degree
- Q^2 = 0.12 GeV^2

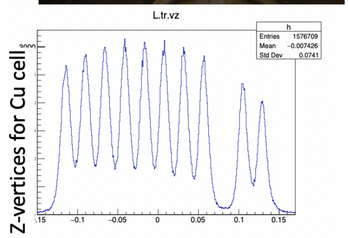
Target system

- Consisted of five identical aluminum cells.
- Each 1.25 cm in diameter, 25 cm long.
- Four cells were filled with 1H, 2H, 3H, and 3He gas while the fifth cell was empty.
- Empty cell for window subtraction (check software cut on windows, subtract residual contribution).



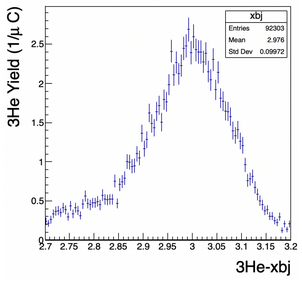


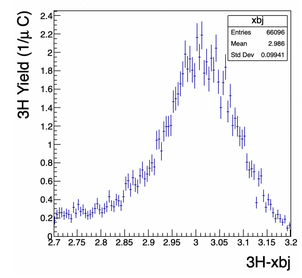
window subtraction



Optics calibration

From yield to charge radius





Yield

$$Y_i = \frac{\#\ of\ observed\ events}{Effective\ Luminosity} = \frac{C_i}{Q_i \cdot \rho_i \cdot Boiling_i \cdot eff_i \cdot LT_i/PS_i}$$

Cross Section

$$\left(\frac{d\sigma}{d\Omega}\right)_{exp} = \frac{ps\ N_e}{N_{in}\ \rho\ LT\ \epsilon_{det}}\frac{1}{\Delta\Omega\Delta P\Delta Z}$$

Form Factors

$$\left(\frac{d\sigma}{d\Omega}\right)_{exp} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott}\frac{1}{1+\tau}\left[G_E^2(Q^2) + \frac{\tau}{\epsilon}G_M^2(Q^2)\right]$$

Electric From Factor

$$G_{E(M)} = \int \rho_{E(M)}(\boldsymbol{r})e^{i\boldsymbol{q}\cdot\boldsymbol{r}}d^3\boldsymbol{r} \approx 1 - \frac{1}{6}\boldsymbol{q}^2\langle r^2_{E(M)}\rangle + \cdots$$

Charge Radius

$$\langle r_E^2\rangle = -6\left.\frac{dG_E}{dQ^2}\right|_{Q=0}.$$