PHYS4175 - Nuclear Physics

Midterm Assignment 1

Due **Thursday, October 8th**, at 17:00 EDT

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Introduction

The proton's radius, while known approximately to be about 0.9 fm, is the subject of a major on-going debate in nuclear physics. Measuring the proton's radius with high-energy electron scattering is challenging because the proton's charge distribution seems to be diffuse, and as a result, the proton's electric form factor, G_E, has no wiggles. Instead, the proton's charge radius is measured using the following relation:

$$r_p \equiv \sqrt{\langle r^2 \rangle} = \lim_{Q^2 \to 0} \sqrt{-6 \frac{dG_E}{dQ^2}}$$

This presents an extrapolation problem. Experiments can measure G_E^2 when $Q^2 = 4EE' \sin^2 \frac{\theta}{2}$ is greater than 0, but to estimate the radius, the data must be extrapolated to $Q^2 = 0$, where one can't measure.

In this assignment, you are provided with data from five fictional experiments, and your goal is to analyze the data and estimate the proton radius. (The fictional data has been produced in a way such that there is a correct answer. No, it is not 0.877 fm. And no, it is not 0.84 fm.)

Requirements

Write a paper describing your analysis and what you believe is the proton radius is, given the data. For full credit, this paper must fulfill or answer the following requirements and questions.

- Graph the raw data, and comment on what you notice.
- Develop a computer program to "fit" (or apply regression techniques) to the data to determine the radius from a data set. Describe your approach.
- Apply your program to each experiment separately. Produce graphs comparing the best-fit function and the data. Produce graphs showing the residuals, i.e., the difference between the best fit function and the data. Comment on what you observe in the residuals.
- Produce a table of results on the proton radius *and uncertainty on that radius* for each of the experiments. Comment on the whether or not the experiments are consistent with each other.
- Do a combined analysis of all of the experiments, and determine your best estimate for the proton radius, and the uncertainty on that radius. How does your number compare with an average of the results in your table.
- Offer commentary on how one could do an even better analysis on the data you are given. (Do not say, get more data at lower Q^2.)

Other questions you may want to tackle:

- Is it better to fit the entire data set, or merely a subset of the data at low Q^2?
- Does the choice of regression model introduce any uncertainty?
- How should the "normalization uncertainty" be handled?

The paper should end up being 5–10 pages in length, including figures, but I am not grading for length. The pdf document must be produced by a computer (LaTeX, MS Word, Open Offce, Mac Pages are all fine, scans of hand-written notes are not acceptable).

About the data

The data file provided has the results of five independent fictional experiments. All five sets are grouped in the same file (you may want to edit, and break them up into multiple files). The data are arranged in three columns:

Q^2 [GeV^2]	$\lvert G_E^p\rvert^2$ [unitless]	$\delta\lvert G_E^p\rvert^2$ [unitless]
⋮	⋮	⋮

which are closest to what one would measure in an experiment. Notice that the uncertainty in the third column is the uncertainty on $|G_E|^2$, not G_E.

In addition, all five experiments have a "normalization uncertainty," i.e., they quote an uncertainty on how well the constants in the formula:

$$N = \frac{d\sigma}{d\Omega} \cdot \Omega \cdot I \cdot \alpha \cdot t$$

are known. An error in this normalization would shift *all* of the data in a given experiment up or down by a constant factor. Different experiments might shift in different directions, up or down, independent of each other. For the sake of this problem, the five fictional experiments have a 1% normalization uncertainty.