Parity Violation in Electron Scattering

Goals:

- Gain experience in data analysis using a data sample from the E158 experiment at SLAC
- Introduce the concept of a parity violating asymmetry
- Explore strategies for correcting measurements for systematic variations. Use the measured correlations to translate between a "raw" (aka "measured") asymmetry and a "corrected" (aka "true") asymmetry
- Learn how to determine confidence intervals for measured quantities

The E158 experiment at SLAC measured a parity-violating asymmetry in Møller (electron-electron) scattering. This was a fixed-target experiment, which scattered longitudinally-polarized electrons off atomic (unpolarized) electrons in a 1.5m liquid hydrogen target. The files provided here contain a snapshot of 10,000 "events" from this experiment (overall, the experiment collected almost 400 million such events over the course of about 4 months). Each event actually records a pair of pulses: one for the right-handed electron and one for the left-handed electron. For each event, 4 variables are recorded:

- **Counter:** A unique number labeling the event
- **Asym:** The "raw" cross section asymmetry from one of the detector channels (there are 50 of these overall). The cross section asymmetry is defined as

  $$A_{raw} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

  The asymmtry is recorded in units of PPM (parts per million). It is called "raw" because corrections due to the difference in beam properties at the target are not yet applied (see below).
- $\mathbf{\Delta X}$: The beam position at the target in the x-direction in microns (with the convention that the beam is traveling along Z).
- $\mathbf{\Delta Y}$: The beam position at the target in the y-direction in microns

The data sample is provided in internal ROOT format (asymdata.root) and in plain text format (asymdata.txt). You are free to use either to answer the questions below.

1. Compute the mean of the raw asymmetry, Asym, distribution and its statistical uncertainty.

2. Compute the correlation coefficients: $\mathrm{Corr}(Asym, \Delta X)$, $\mathrm{Corr}(Asym, \Delta Y)$, and $\mathrm{Corr}(\Delta X, \Delta Y)$. Which variables are approximately independent of each other?

3. A better estimator of the parity-violating asymmetry is the quantity that corrects for possible differences in the right- and left-handed electron pulses. We want to define a quantity

$$A_{PV} = A_{raw} - a_x \Delta X - a_y \Delta Y$$

   with coefficients a_x and a_y defined in such a way that A_{PV} is independent of ΔX and ΔY. This is called a linear regression. For now, we will assume that a_x is negligible (how good is this assumption?) and compute a_y. Compute a_y and its uncertainty using:

   (a) A binned least squares fit, using a profile histogram

   (b) An unbinned least squares fit

4. Compute the mean of the regressed asymmetry distribution A_{PV} and its statistical uncertainty.

5. Compute the 90% confidence interval for the true value of A_{PV}

6. Check the hypothesis that the distribution of A_{PV} is Gaussian. For this, you can bin the distribuition of A_{PV} in a reasonable number of bins (e.g. 100) and compute the goodness-of-fit (or p) value for the Gaussian distribution. Estimate the confidence level (or probability that the hypothesis is correct).