MARATHON Pass 2 Analysis Primer

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I. OVERVIEW

II. REPLAY

(Tyler Hague)

III. CALIBRATIONS

i. E/p

(Mike Nycz)

ii. VDC

iii. BPM

BPM Calibration

The Beam Position Monitors(BPMs) consist of four antennas that since the field produced by the beam traveling through beam line. These four wires can measure the Beam's position in a rotated frame (u/v) compared to the nominal Hall Coordinate system (x/y). These rotated positions are then transformed into the correct frame via a calibration procedure.

The BPM calibration procedure uses a technique called a Bull's eye scan to match the absolute position of the beam in the Hall's frame measured from a Harp. The harps are an intrusive way to measure the beam's absolute position. The Bull's scan is process of taking many Harp scans at many different beam positions. Data from the Harp scans and from CODA is used to solve equation 1 for the rotation matrix and the offset vector.

$$\begin{pmatrix} Beam_x \\ Beam_y \end{pmatrix} = \begin{pmatrix} BPM_u \\ BPM_v \end{pmatrix} \begin{pmatrix} C_{00} & C_{01} \\ C_{10} & C_{11} \end{pmatrix} + \begin{pmatrix} Offset_x \\ Offset_y \end{pmatrix} \quad (1)$$

During a harp scan, the (u/v) BPM positions are measured by the BPMs in Hall A and the (x/y) beam positions are measured by the harps. Expanding out equation 1,

$$\begin{aligned} Beam_x &= BPM_u * C_{00} + BPM_v * C01 + offset_x \quad (2) \\ Beam_y &= BPM_u * C_{10} + BPM_v * C11 + offset_y \end{aligned}$$

the resultant equations give three unknowns per equation. In order to solve for these three variables, we need to complete harp scans at three unique points.

iv. Raster

(Tyler Hague) The Hall A Raster system was calibrated using a combination of the BPMs, Carbon Hole target, and Carbon Single Foil target. The goal of a succesful calibration is to convert the ADC readout of the raster current into a beam position. To do this, a central position of the beam and a conversion factor from ADC readout to beam position deviation from the center.

In Hall A, we have two sets of raster coils working in tandem for the 12 GeV era. These rasters are synced to ensure that they work together, rather than against each other. With this knowledge, the Hall A Analyzer is set up so that the signals from a single raster set are used to determine the beam position. In our case, the analysis code is set up to use the upstream raster coils.

To determine the conversion from ADC to position for the horizontal direction in the hall reference frame (referred to as 'x' from here), we use the Carbon Single Foil Target. When the raster is properly calibrated in the x direction, there should be no correlation between the beam x position and the reconstructed z position of events. To do this, the z position of physics events are sliced in bins of beam x and then fit with a gaussian. The peak position of the each gaussian is then plotted versus the corresponding x position and fit with a line. Doing this method twice with two different preliminary (incorrect) calibrations allows for the slopes to be interpolated to the calibration that would yield no slope (no correlation).

This same procedure can be used with a momentum feature (e.g. the Hydrogen Elastic Peak) to calibrate the vertical direction in the hall reference frame ('y'). However, in the MARATHON kinematics there is no such momentum feature available. As an alternative, the carbon hole is fitted to determine the calibration with the knowledge that it is 2mm in diameter. The fit is done using a sigmoid function to account for smearing that occurs during reconstruction.

v. BCM

Unser and Beam Current Monitors Calibration

In order to accurately calibrate the BCM's, first the unser must be calibrated. The unser is used as an absolute reference to which the BCM's are calibrated to. The procedure to calibrate the unser involves sending a constant and known currents through a thin wire inside of the unser. A series of currents with, over a range between 2.5 - 100 μA,during 90 second intervals, as can be seen in figure (??). which shows the frequency response of the unser for the various currents. A linear fit of sent current vs the unser response, determines an overall gain factor for the unser. The gain of the unser of calibrated 4 times during MARATHON before each BCM calibration was preformed, in order to check the unser's stability. Figure(??) shows the unser was stable during the entirety of the MARATHON run.

TABLE I: Unser Calibration Results

Date	03-05	03-28	4-03	04-06
Unser Gain	2.526e-4	2.524e-4	2.529e-4	2.527e-4

Having calibrated the unser, we can then calibrate the BCMs in a similar manner to the calibration of the unser but replacing the current from a wire with current from the electron beam. For the BCM calibrations during MARATHON and all Tritium experiments, the range in current was between 3 - 22.5 μA. Again, the procedure intervals of 90 seconds (i.e 90 seconds of continuous current to the Hall followed by 90 seconds with no beam). The Calibration procedure requires making cuts in the frequency response of the unser and BCM receiver and integrating the total amount of frequency to determine the average frequency of the receiver during the given time interval. An example of the cuts made is shown in figure 3

The unser frequency during the calibration can be related to the delivered current using the gain factor determined from the unser calibration.

$$I_{unser} = gain * f_{unser} \quad (3)$$

By then plotting $I_{unser} vs freq_{BCM}$ and fitting with a linear function, the gain and offset (which are proportional the slope and intercept of the fit respectively) of each BCM receiver can be determined. The gain

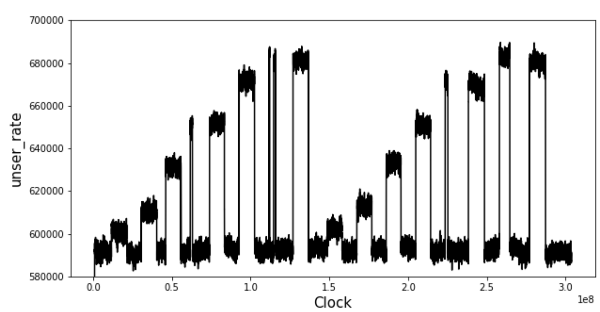

FIG. 1: BCM Calibration : unser

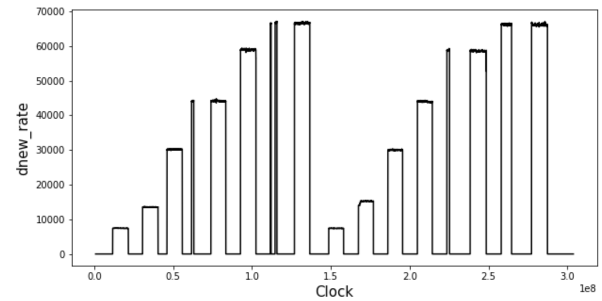

FIG. 2: BCM Calibration : dnew

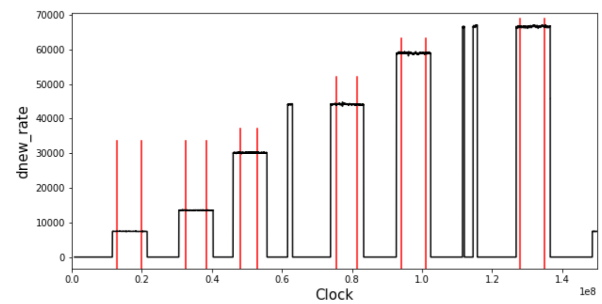

FIG. 3: Frequency cuts

Table(??) shows the result of the 3 BCM calibrations for the dnew digital BCM receiver.

TABLE II: BCM Calibration Results

	03-05	03-28	4-03
dnew Gain	3.3358e-4	3.3351e-4	3.3372e-4
dnew offset	-0.097	0.003	0.132

vi. Optics

IV. CORRECTIONS

i. PID

(Tong Su)

i. Positron Subtraction

(Tong Su)

ii. Endcap Subtraction

(Tong Su)

iii. Livetime

iv. Tritium Decay

Target composition

Tritium decays to helium via the β-decay process $^3\text{H} \to {}^3\text{He} + e^- + \overline{\nu}_e$, with a half-life of

$$\tau_{1/2} = \ln(2)\tau = (4500 \pm 8) \text{ days}$$

This results in a time-dependent target composition, with a decreasing (increasing) population of tritium (helium) nuclei. These effects must be quantified and corrected in order to accurately extract the normalized tritium yield from tritium target data.

The target cell was filled with an initial tritium number density n_T^0, and initial helium number density n_H^0. As tritium decays to helium, these number densities evolve in time as

$$n_T = n_T^0 \, e^{-t/\tau} \tag{4}$$

$$n_H = n_H^0 (1 - e^{-t/\tau}), \tag{5}$$

where t is the number of days since the target was filled. Since the decay process preserves the total number of nuclei, the total number density n_{tot} is constant in time:

$$\begin{aligned} n_{tot} &= n_T + n_H \\ &= n_T^0 + n_H^0 \end{aligned} \tag{6}$$

With these quantities, the helium fraction can be defined:

$$f_H = \frac{n_H}{n_T + n_H} = \frac{n_H}{n_{tot}} \tag{7}$$

Given an infinite amount of time, all of the tritium will decay to helium. Therefore $f_H \to 1$ as $t \to \infty$.

Normalized yield correction

The normalized yield is defined as:

$$Y = \frac{N}{Qn}, \tag{8}$$

where N is the number of detected electrons, Q is the beam charge incident on the target, and n is the target number density. Assume that N includes all corrections (deadtime, efficiency, endcap contamination, etc.) *not* related to tritium decay. In practice, the yield is extracted from multiple runs, so the number of detected electrons and luminosity must be summed over run number i:

$$Y = \frac{\sum N_i}{\sum Q_i n_i}, \tag{9}$$

The required correction must account not only for the evolution of the target composition (quantified in the previous section), but also for the fact that some of the detected electrons N will have actually scattered from a helium nucleus instead of a tritium nucleus. Begin by expressing the raw, uncorrected normalized yield (which is measured) as

$$Y_{raw} = \frac{\sum (T_i + H_i)}{\sum Q_i (n_{T,i} + n_{H,i})} \tag{10}$$

where T and H are the number of detected electrons scattered by tritium and helium, respectively. For time-dependent quantities (such as $n_{T,i}$ and $n_{H,i}$, given by Equations 4 and 5), the subscript indicates the value of the quantity at the time of run i. The goal is to obtain the normalized tritium yield Y_T in terms of Y_{raw} and correction factors, where

$$Y_T = \frac{\sum T_i}{\sum Q_i n_{T,i}}. \tag{11}$$

Due to the helium contamination, the correction factor will depend on the normalized helium yield

$$Y_H = \frac{\sum H_i}{\sum Q_i n_{H,i}}. \tag{12}$$

From equation (10), only a few steps of algebra are required to obtain Y_T. Recall that the total number density $n_{tot} = n_T + n_H$ is constant in time, and note that the tritium fraction $n_{T,i}/n = 1 - f_{H,i}$, where f_H is the helium fraction defined by Equation 7.

$$\begin{aligned} Y_{raw} &= \frac{\sum (T_i + H_i)}{\sum Q_i (n_{T,i} + n_{H,i})} \\ &= \frac{\sum T_i}{n_{tot} \sum Q_i} + \frac{\sum H_i}{n_{tot} \sum Q_i} \\ &= \left(\frac{\sum_i T_i}{\sum_i Q_i n_{T,i}} \right) \left(\frac{\sum_i Q_i n_{T,i}}{n_{tot} \sum_i Q_i} \right) + \left(\frac{\sum_i H_i}{\sum_i Q_i n_{H,i}} \right) \left(\frac{\sum_i Q_i n_{H,i}}{n_{tot} \sum_i Q_i} \right) \\ &= Y_T \left(\frac{\sum Q_i (1 - f_{H,i})}{\sum Q_i} \right) + Y_H \left(\frac{\sum Q_i f_{H,i}}{\sum Q_i} \right) \end{aligned}$$

To simplify notation, define the charge-averaged helium fraction:

$$\langle f_H \rangle \equiv \frac{\sum Q_i f_{H,i}}{\sum Q_i} \tag{13}$$

Thus,

$$Y_{raw} = Y_T(1 - \langle f_H \rangle) + Y_H \langle f_H \rangle, \tag{14}$$

and finally,

$$Y_T = Y_{raw} \left(\frac{1}{1 - \langle f_H \rangle} \right) - Y_H \left(\frac{\langle f_H \rangle}{1 - \langle f_H \rangle} \right) \tag{15}$$

Uncertainty propagation

Pending

v. Boiling

(Tong, Mike)

vi. Radiative Corrections

(Hanjie Liu)

V. BINNING AND COMBINING

Bin width Choice

Bin Centering

Combining Kinematic Overlap