BONuS12 Calibration Constants

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This document details the calibration constants for the BONuS12 system as follows:

1 Gain calibration constants

The ionization electron collection system of the RTPC has 17280 readout pads. The gain of each pad is the ratio between the energy deposited within the track segment for which the ionization electrons will drift to that pad, and the output signal recorded value. The energy loss of a particle along its track in the RTPC, $\frac{dE}{dX}$, can be calculated from the collected ADCs as:

$$\left\langle \frac{dE}{dX} \right\rangle = \frac{\sum\limits_i \frac{ADC_i}{Gi}}{vtl}, \tag{1}$$

where the sum runs over all the pads contributing to a track. ADC_i is the recorded amplitude in each pad i, and G_i is its gain. The variable vtl is the total visible length of the track in the active drift volume.

Corresponding to the 17280 readout pads for the BONuS12 RTPC, we will need a total of 17280 constants, initially each set to 1.0.

We will extract the gains using two techniques. The first one is by comparing the experimental recorded $\frac{dE}{dX}$ to the expected values calculated from the Bethe-Bloch formula. The second technique is based on comparing the experimental ADCs to the GEANT4 simulated ones, track by track. We can refine and cross-check this second method by comparing the ADCs of each pad to the average ADCs of other, adjacent pads in the same track. These parameters will be extracted from the elastic $^1\mathrm{H}(e, e'p)$ measurements at the beginning of the BONuS12 run (at 2.2 GeV beam energy).

2 Time offset constants

These constants provide the relative timing between the signals on each pad and the vertex time of the trigger electron. They are T_{lat} and T_{rew}. Initially they will be set as $T_{lat} = \ 8\mu s$

and $T_{rew} = 9.6\mu s$.

T_{lat} is the latency of the trigger, i.e. how long after a typical electron leaves the vertex does the trigger signal reach the DREAM chips. T_{rew} is the "rewind time", i.e. how much before the trigger time do we want to start reading out the stored samples in the DREAM chips. Our first guess of these two parameters will be refined from the commissioning runs for RG-C.

3 Drift paths and Drift speed constants

In a TPC, the electrons released in an ionization drift towards the readout board following their drift paths under the effect of the applied electromagnetic field. The drift speed depends also on the gas mixture, pressure and temperature. The recorded drift time with the known drift speed of the electrons provides information on how far away from the outside surface the initial ionizations happened in the drift region, leading to reconstruct the original points of ionizations in the drift region. Furthermore, due to the Lorentz angle (the curvature of ionization tracks in the presence of the 5 T solenoid field), we also have the account for the displacement in ϕ of the position of a pad with a recorded signal and the location of the primary ionization event.

Based on our Garfield++ simulation, the best fit of the radial and the azimuthal position of a reconstructed hit can be formulated as a function of the elapsed drift time t between the ionization and the arrival of the drift electrons at the anode as:

$$r(t) = \frac{-\sqrt{a^2 + 4bt} + a + 14b}{2b} \tag{2}$$

$$\Delta\phi(r) = c(7 - \frac{r}{10}) + d(7 - \frac{r}{10})^2 \tag{3}$$

where a and b are parameters set initially by a fit in Garfield++ based on the gas, and the electromagnetic field. Because of E & B fields non-uniformity, a and b depend on z position along the detector.

Hence, to reconstruct tracks in three dimensions from the measured arrival times on each pad of a track, we will need four parameters, a, b, c, d, each of which are functions (4th order polynomials) of z (in mm) along the detector as follows (with preliminary values from the GARFIELD++ simulation), for a total of 20 calibration constants:

$$a\_t = a1 * z^4 + a2 * z^3 + a3 * z^2 + a4 * z + a5 \tag{4}$$

with
a1 = -2.48491E-4
a2 = 2.21413E-4
a3 = -3.11195E-3
a4 = -2.75206E-1
a5 = 1.74281E3

$$b = b1 * z^4 + b2 * z^3 + b3 * z^2 + b4 * z + b5 \tag{5}$$

with
b1 = 2.48873E-5
b2 = -1.19976E-4
b3 = -3.75962E-3
b4 = 5.33100E-2
b5 = -1.25647E2

$$c = c1 * z^4 + c2 * z^3 + c3 * z^2 + c4 * z + c5 \tag{6}$$

with
c1 = -3.32718E-8
c2 = 1.92110E-7
c3 = 2.16919E-6
c4 = -8.10207E-5
c5 = 1.68481E-1

$$d = d1 * z^4 + d2 * z^3 + d3 * z^2 + d4 * z + d5 \tag{7}$$

with
d1 = -3.23019E-9
d2 = -6.92075E-8
d3 = 1.24731E-5
d4 = 2.57684E-5
d5 = 2.10680E-2

These constants will be recalibrated using the elastic $^1\mathrm{H}(e, e'p)$ data from the commissioning runs by optimizing the fit between the reconstructed proton tracks and the inferred ones from the electron kinematics.

In practical terms, it will be useful to normalize all drift times to the maximum drift time, T_{max}, for an ionization event that happens right at the position of the cathode. Therefore, we will need one additional calibration constant for T_{max}. This will be set initially again from the GARFIELD++ simulation ($T_{max} \approx 6\mu s$) and then adjusted by a fit to the elastic data. Possible small shifts over time in T_{max} (due to changing gas composition, temperature, and pressure) will be monitored by the custom Drift time Monitoring System (DMS) that has been constructed for BONuS12. This will allow us to adjust the overall reconstruction from drift time to ionization point run by run without having to recalibrate all remaining 20 parameters.