Software requirements for BigBite Timing Hodoscope

R. Montgomery *, J. Annand., D. Hamilton, R. Marinaro

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1 Overview

The BigBite (BB) timing hodoscope (TH) (Fig. 1) is sandwiched between the pre-shower and shower calorimeters in BB and covers the full range of coordinates of their arrays. The main purpose of the TH is to provide a high precision timing reference, operating with high efficiency for minimum ionising particles (MIP) over the full range of particle momenta analysed by BB. This will be particularly important for two arm (e, e'N) measurements, where the e' hit time in the TH may be used as a reference for nucleon time of flight measurements in the SBS arm. It should be capable of high rate operation and not impose any significant limitation on the luminosity which can be handled by BB. The TH can also provide some pulse height information, which may be of residual use in differentiating MIP from low energy background. Furthermore, the TH can provide some hit position information which may be of use in resolving tracking ambiguities in the BB GEM systems operating at high rate.

2 Essential geometry information

The TH (Fig. 1) comprises 90 vertically stacked Eljen Technologies EJ200 plastic scintillator bars, where 'vertical' corresponds to the direction perpendicular to the spectrometer axis. The bars have dimensions $600 \times 25 \times 25$ mm^3. Each bar is read out at both ends with Electron Tubes ET 9142 single channel 29 mm total (25 mm active) diameter PMTs - resulting in 180 total readout channels. The PMTs are coupled to the bars via Eljen Technologies UVT acrylic rod light guides. The light guides have diameter 24 mm. The light guides alternate between straight and curved geometries when moving vertically through the stack of scintillators due to space constraints (see bottom Fig. 1 for a top view demonstrating this). The relevant geometry parameters are:

- the z value (on the spectrometer axis) at which the centre of the stack of scintillator bars are located;

*Rachel.Montgomery@glasgow.ac.uk

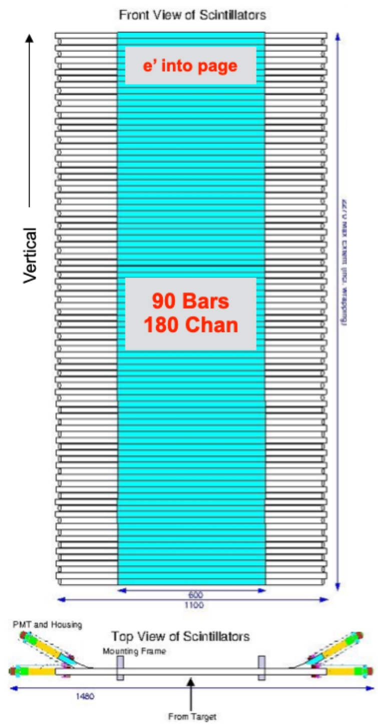

Figure 1: BigBite Timing Hodoscope components.

- the position of the centre of each of the scintillator bars in the x, y transport coordinates.

3 Key performance specifications

The achievable performance of the TH with respect to BB requirements has previously been assessed via prototyping measurements with cosmic rays [1, 2, 3] and key performance specifications are summarised below.

- Position independent timing is given by the mean time of the two PMTs which read out each bar. The mean time resolution available is $\sim 150\,\mathrm{ps}$.

- The time difference of the two PMTs which read out each bar gives the horizontal hit position along the bar. The time difference is linearly correlated with hit position. The expected time difference resolution is ~ 300 ps. The horizontal position resolution available from the time difference is therefore ~ 6 cm.

- A Landau distribution is obtained for MIP with the peak well separated from PMT noise. The position dependence of individual PMT pulse heights does not exceed a factor two and the mean pulse height varies by $\sim 11\,\%$ maximum along the length of the bar.
- Individual scintillator bars are capable of MHz operation.

These specifications can all be cross-checked via careful design of the online display distributions during calibration/commissioning.

4 Calibration and commissioning procedures with beam

The 180 signals from the PMTs are readout to two CAEN V1190A multi-hit TDCs [4] via 12 custom front end amplifier/discriminator cards [1, 2, 3] based on the NINO ASIC [5] (each front end card has 16 channels).

If a PMT signal charge lies above the NINO discriminator threshold, the duration of the logic LVDS output signal from the NINO is correlated with the magnitude of the input signal charge. Time over threshold (TOT) values of the NINO pulses can therefore be used to reconstruct raw pulse height information of the PMT signals. The TOT of a pulse is obtained by calculating the difference between the TDC values for its leading and trailing edges. TOT will also be used to perform time walk corrections in both calibration and production run data.

As well as it being necessary to correct TDC hits recorded in the V1190A modules via subtraction of a reference time (a copy of the trigger will be sent to a reserved channel of the inputs for this), a time walk correction must be applied. This is to correct for time walk which is correlated to input signal charge and arises in the NINO discriminator. It is highly advantageous to use the TOT information available from the NINO for this, since it is roughly linear with time [2, 3, 6], whereas ADC information, for example, is highly non-linear in its correlation with time. The time walk correction is of the form given in Equation 1.

$$t_{corrected} = t_{measured} - tc \tag{1}$$

$t_{corrected}$ is the time walk corrected value, $t_{measured}$ is the initial reference time subtracted TDC value, and $tc = (TOT - k_0)/k_1$ is the correction time.

tc is derived from the roughly linear relationship of TOT with time ($TOT = k_0+k_1*tc$), where k_0 and k_1 are constants. In reality the TOT-tc relationship is not perfectly linear and, if the ultimate TH timing resolution allows, the linear relationship may be substituted by $TOT = k_0 + k_1 * tc + k2 * tc^2$. The feasibility of using this form will be determined during commissioning, as will any dependence of the time walk correction and the constants in the TOT-tc relationship on the NINO threshold settings.

ADC modules are required for performing TOT calibrations, since TOT is non-linearly correlated with ADC values, and subsequently for setting the thresholds of the NINO discriminators. CAEN V792 [7] ADCs have been selected (although the option of moving to JLab fADCs is currently being discussed due to radiation hardness concerns). Currently there are enough CAEN V792 ADCs to instrument 64 channels of the TH simultaneously.

Before any with-beam calibrations, it will be necessary to perform initial calibrations, de-bugging and commissioning with cosmics (or a ^{90}Sr beta source e.g.). This will allow to:

- check the integrity of all readout channels and the high and low voltage systems;
- perform gain matching of the PMTs through the setting of the individual high voltage values for each PMT;
- calibrate the TOT method of pulse height reconstruction;
- set initial thresholds of the NINO front end cards;
- calibrate the time walk correction parameters.

Any malfunctioning readout or power channels should be repaired or replaced before moving to a with-beam setting. ADC spectra will be used for matching the gains of all channels of the TH, by iterating through subsets of 64 channels at a time. After gain matching, the TOT pulse height reconstructions will be calibrated for all 180 channels using distributions of TOT against ADC values, and iterating through subsets of 64 channels at a time. ADC spectra obtained with cosmics will also be used to set the initial NINO thresholds for all channels, whilst taking care not to minimise any reduction in electron detection efficiency. Setting the thresholds will require some iterations of study, since the angles of incidence of cosmics (and hence amount of TH material traversed) will be different from electrons exiting the target in the experiments. These studies would benefit from either some calculations or Geant4 simulations, to determine the expected differences between the two cases. Comparisons of ADC distributions obtained with cosmics and a ^{90}Sr (for example) may also be useful in studying these expected differences. However, the Landau distributions expected from cosmics (or a source) are not expected to be ideal and ultimately final setting of the NINO thresholds will require further testing with beam. Again, for cosmic running the thresholds will be determined for subsets of 64 channels at a time, until all 180 channels have been set. The TOT information will be used to set initial time walk correction parameters for all channels during the calibrations with cosmics, and no ADC information is required for this.

The with-beam calibrations will consist of refining the NINO threshold settings, cross-checking the TOT calibrations, and optimising the time walk corrections with scattered electrons. It is planned that the refinements of the NINO thresholds and the TOT calibration cross-checks should be checked with beam for a subset of 64 ADC channels only, to avoid Hall accesses to swap cables. In this respect, it is vital that we first have the calibrations for all channels completed during cosmic commissioning of the TH. The time walk correction checks do not require the ADC modules, and will therefore be performed for all channels in with-beam runs. With-beam runs will also be needed to optimise the V1190A window width and position with respect to the trigger signal and, if possible, a TDC calibration could also be desirable. This could be achieved by correlating hits in the TH with the microstructure of the CEBAF beam buckets (500MHz), although this is not an essential step for running the TH.

It would be ideal to perform these above with-beam runs by correlation with particle tracks provided by the GEM system and hits in the lead glass arrays. It would also be ideal if these runs were performed at a relatively low electron beam intensity, however any other run requirements (e.g. specific beam energies/reaction channels/sieve slits/triggers etc) are flexible.

5 Requirements for online analysis/data quality monitoring/calibration

Below is the current plan for low-level histograms/plots for online analysis/data quality monitoring/calibration etc.

TDC information will be recorded for all 180 channels for all runs, i.e. both calibration/commissioning and production runs. For all runs, required TDC online display and data quality monitoring plots will include those listed below. Note that for all distributions listed below, the TDC values will first be reference time subtracted and time walk corrected.

- For each of the 180 channels:
  - Leading edge TDC spectra;
  - TOT distributions;
  - TOT against leading edge time.
- For each of the 90 bars:
  - Mean time distributions;
  - Time difference distributions;
  - Reconstructed hit position map in TH local coordinate system.

For the calibration/commissioning runs, which include ADC information in the recorded data, required online display and data quality monitoring plots will include those listed below. Again any of the distributions involving TDC values should first be reference time subtracted and time walk corrected.

- For all 180 channels during cosmic calibrations (achieved by iterating through subsets of 64 channels):
  - ADC pedestal distributions;
  - Pedestal corrected ADC spectra;
  - TOT against ADC distributions.

For the with-beam calibrations, the above ADC-related online displays will only be required for 64 channels.

6 Raw information available from detector

During production running, the TH PMTs will be connected via 12 front end NINO cards to 2 CAEN V1190 multi-hit TDCs. All TDC hits lying within the settable time window for all 180 channels of the TH will therefore be available for each event in the raw data.

For calibration runs, either in cosmic or with-beam settings, ADC information for subsets of 64 channels at a time will also be available.

7 Required database parameters

Currently, the required database parameters for the TH are expected to be (but not limited to) those listed below.

- Geometrical parameters:
  - z position of the TH in the BB spectrometer axis;
  - x and y position of the centre of each of the 90 scintillator bars in the transport coordinates.
- TDC-related parameters:
  - Mapping of TDC channels to detector elements of the TH for all 180 channels;
  - Time walk correction parameters for all 180 channels;
  - Reference channel mapping for each of the two TDC modules;
  - Time window for accepted TDC values for both TDC modules (determined by window width and position with respect to trigger);
  - Factor for converting TDC values into time in ns (either the programmed 100 ps/bin value or the TDC calibration results if performed).
- ADC-related parameters:
  - Mapping of ADC channels to detector elements of the TH for each subset of 64 channels at a time;
  - ADC to energy conversion factor for each subset of 64 channels at a time (estimated from ADC distributions obtained with MIP in cosmic running);
  - ADC pedestal positions and widths for each subset of 64 channels at a time.

8 Specialized reconstruction algorithms

For further offline processing of the data, beyond the online displays described above, there are currently no specialized reconstruction algorithms in place. However, the development of algorithms for the following reconstructions listed below (but again not limited to) may be useful:

- Reconstruction of global coordinates of the TH hits within the final spectrometer layout;
- Correlation of the TH hits with the GRINCH and GEM tracks;
- Correction of the mean hit time obtained per bar of the TH for the scattered electron flight path length after the GEM reconstruction;
- Correlation of the TH hits with the CEBAF beam bunches.

References

[1] J.R.M. Annand, Talk: BB Hodoscope, SBS Weekly Meeting, 6th April 2016

[2] J.R.M. Annand, Talk: NINO & BB Hodoscope, SBS Collaboration Meeting, July 2014

[3] J.R.M. Annand, Talk: NINO Board Status, SBS Weekly Meeting, June 2013

[4] https://www.caen.it/products/v1190a-2esst/

[5] F. Anghinolfi et al., NIM A 533 (2004) 183–187

[6] M. Cardinali et al., NIM A 766 (2014) 231–234

[7] https://www.caen.it/products/v792/