SASY Technical Note # 9

Calibration Transformation for SASY

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1 Introduction

The packed data for a SASY event contains raw ADC and TDC information. This document describes the transformation to an unpacked, calibrated format which describes the hits in terms of energy (MeV), time (ns), and positions (cm).

The first step in this transformation entails an intermediate format for raw unpacked data. Typically the data is simply unpacked and pedestal offsets are restored. Otherwise the raw data is just as it is read from the electronics.

In the sections below, each detector subsystem is described. There are cases where the current transformation is not the best way to proceed. I try to identify the current process and the proposed transformation for the next iteration of replay analyzer. In the process of developing this document, some changes have been implemented in STUPLE in order to proceed with the analysis. In this case, I also describe the previous form of the transformation.

2 XTAL Box Faces

The XTAL Box face crystals each have a single phototube. Only pulse height information is recorded. There is no timing information outside of the fact that the some crystal or collection of crystals in the XTAL Box should provide the start for all of the TDCs in the event.

2.1 Current Unpacking Transformation

A readout threshold is placed n channels above the pedestal. This offset is restored when the data is unpacked.

$$XT\_ADC_i = XT\_FERA\_ADC_i + XTPED_i \tag{1}$$

2.2 Current Calibration Transformation

A gain factor is then applied in converting the pulse height from raw to calibrated form:

$$XT\_EGY_i = XT\_ADC_i \times XTGAIN_i, \tag{2}$$

where

$$\begin{aligned} XT\_EGY_i &= \text{XTAL Energy (MeV)}, \\ XT\_ADC_i &= \text{XTAL Pedestal-Corrected ADC Value (chan)}, \\ XT\_GAIN_i &= \text{XTAL Gain (MeV/chan)}. \end{aligned}$$

3 XTAL Box Corners

Two phototubes are attached to each XTAL Box corner crystal. Only pulse height information is recorded, but because there are two signals, we can derive both an energy and the position of the hit along the crystal.

Given a crystal of length l and a hit which deposits an energy E_γ at the a distance z from the downstream end of the crystal, the energy seen at the down stream end is

$$E_D = E_\gamma e^{-\frac{z}{\alpha}}, \tag{3}$$

where α is the attenuation length of the crystal. The energy seen at the upstream end can be written

$$E_U = E_\gamma e^{-\frac{l-z}{\alpha}}. \tag{4}$$

The energy E_γ can be recovered by taking the square root of the product of the two energy signals.

$$\begin{aligned} \sqrt{E_D E_U} &= \sqrt{E_\gamma e^{-\frac{z}{\alpha}} E_\gamma e^{-\frac{(l-z)}{\alpha}}} \\ &= \sqrt{E_\gamma^2 e^{\frac{-l}{\alpha}}} \\ &= e^{\frac{-l}{2\alpha}} E_\gamma \qquad (5) \\ & \qquad (6) \end{aligned}$$

The position of the hit along the crystal can be determined independent of the energy of the hit by taking the ratio of the signals.

$$\begin{aligned} \frac{E_D}{E_U} &= \frac{E_\gamma e^{-\frac{z}{\alpha}}}{E_\gamma e^{-\frac{(l-z)}{\alpha}}} \qquad (7) \\ &= e^{\frac{l}{\alpha}} e^{-\frac{2z}{\alpha}} \qquad (8) \\ & \qquad (9) \end{aligned}$$

Rewriting in terms of z,

$$z = \frac{l}{2} - \frac{\alpha}{2} \ln \left(\frac{E_D}{E_U} \right) \tag{10}$$

3.1 Current Unpacking Transformation

The offset from the pedestal is added when the data is unpacked.

$$XC\_ADC_{i,j} = XC\_FERA\_ADC_{i,j} + XCPED_{i,j}, \tag{11}$$

where j is either the upstream or downstream PMT.

3.2 Current Calibration Transformation

A gain factor is applied to each PMT before the average energy is determined:

$$XC\_EGY_i = \sqrt{(XC\_ADC_{i,D} \times XCGAIN_{i,D}) \times (XC\_ADC_{i,U} \times XCGAIN_{i,U})} \tag{12}$$

where

$$\begin{aligned}
D &= \text{Downstream signal,} \\
U &= \text{Upstream signal,} \\
XC_EGY_i &= \text{XTAL Corner Energy (MeV),} \\
XC_ADC_i &= \text{XTAL Corner Pedestal-Corrected ADC Value (chan),} \\
XC_GAIN_i &= \text{XTAL Corner Gain (MeV/chan).}
\end{aligned}$$

The Z position is currently being filled by the fraction $\frac{XC\_EGY_{i,D}}{XC\_EGY_{i,U}}$ in the calibrated NTUPLE format.

3.3 Proposed Calibration Transformation

$$XC\_EGY_i = \sqrt{(XC\_ADC_{i,D} \times XCGAIN_{i,D}) \times (XC\_ADC_{i,U} \times XCGAIN_{i,U})} \tag{13}$$

$$XC\_Z_i = XCZSLOPE_i \times \ln \left(\frac{XC\_EGY_{i,D}}{XC\_EGY_{i,U}} \right) + XCZOFFSET_i. \tag{14}$$

4 XTAL Box Veto Paddles

The XTAL Box veto paddles each have a single phototube. Only pulse height information is recorded. There is no timing information available.

The amount of energy deposited by a particle will be dependent on the angle at the which the particle traversed the plastic. The amount of light collected will be dependent upon where the hit occured along the length of the paddle. The first effect is modelled by the monte carlo and should not be included in the calibrated form. The latter effect is not modelled and could potentially be corrected in the tranformation into the calibrated data or perhaps at a later point. This correction requires knowledge of the z position of the hit in the XTAL Box face, and thus most likely should be folded in when transforming the data into a clustered format.

4.1 Current Unpacking Transformation

A readout threshold is placed n channels above the pedestal. This offset is restored when the data is unpacked.

$$XV\_ADC_i = XV\_FERA\_ADC_i + XVPED_i \tag{15}$$

4.2 Current Calibration Transformation

A gain factor is then applied in converting the pulse height from raw to calibrated form:

$$XV\_EGY_i = XV\_ADC_i \times XVGAIN_i, \tag{16}$$

where

$$\begin{aligned} XV\_EGY_i &= \text{XTAL Veto Energy (MeV)}, \\ XV\_ADC_i &= \text{XTAL Veto Pedestal-Corrected ADC Value (chan)}, \\ XV\_GAIN_i &= \text{XTAL Veto Gain (MeV/chan)}. \end{aligned}$$

5 PN Bars

Two phototubes are attached to each PN Bar, and both pulse height and timing information are recorded. Because of this we can determine three pieces of information: the energy, the time of flight, and the position of the hit along the length of the bar.

Given a bar of length l and hit which deposits energy E at a distance x from the center of the bar, the energy seen at each end of the bar is

$$E_{\pm} = E_{TOT} e^{-\frac{\frac{l}{2} \mp x}{\alpha}}, \tag{17}$$

where $\pm$ represents signals from the positive and negative x ends of the bar. The total energy can be determined by taking the square root of the products of the signals from the two ends.

$$\begin{aligned} \sqrt{E_+ E_-} &= \sqrt{E_{TOT} e^{-\frac{\frac{l}{2}-x}{\alpha}} \times E_{TOT} e^{-\frac{\frac{l}{2}+x}{\alpha}}} \\ &= \sqrt{E_{TOT}^2 e^{-\frac{l}{\alpha}}} \\ &= e^{-\frac{l}{2\alpha}} E_{TOT} \end{aligned} \tag{18}$$

The times recorded at the two ends of such a bar are

$$T_{\pm} = TOF + \frac{\frac{l}{2} \mp x}{v}. \tag{19}$$

for a signal propogation velocity of v and an initial time for the hit of TOF.

The TOF can be recovered by averaging the two times:

$$\begin{aligned} \frac{T_+ + T_-}{2} &= \frac{\left(TOF + \frac{\frac{l}{2}-x}{v}\right) + \left(TOF + \frac{\frac{l}{2}+x}{v}\right)}{2} \\ &= TOF + \frac{l}{v}. \end{aligned} \tag{20}$$

The position x can be obtained by taking half the difference of the two times:

$$\begin{aligned} \frac{T_+ - T_-}{2} &= \frac{\left(TOF + \frac{\frac{l}{2}-x}{v}\right) - \left(TOF + \frac{\frac{l}{2}+x}{v}\right)}{2} \\ &= \frac{-x}{v}. \end{aligned} \tag{21}$$

The discriminators which provide the individual timing pulses for the PN bars are LeCroy 4413 leading edge discriminators. The closer a pulse is to the threshold, the later the timing signal comes relative to the leading edge of the pulse. Using the ADC information, one can correct for this slewing. The first step in calibrating the PN Bars is to calibrate each individual TDC channel and apply this slewing correction.

(*What is the formula for this slewing and why does it take that functional form?*)

The half bars are not yet treated specially. The air gap needs to be accounted for in the timings. The signal propogation velocity will be faster through the air gap. Marvin includes code to compensate for this. I do not.

5.1 Current Unpacking Transformation

The offset from the pedestal is added to the data during the unpacking transformation.

$$PN\_ADC_i = PN\_FERA\_ADC_i + PNPED_i \tag{22}$$

The TDC value is unpacked without any changes.

5.2 Current Calibration Transformation

In the calibration transformation, the individual tubes receive a gain correction and the overall gain is adjusted by changing both factors in tandem.

$$PN\_EGY_i = \sqrt{PN\_ADC_{+,i} \times PNGAIN_{+,i} \times PN\_ADC_{-,i} \times PNGAIN_{-,i}}, \tag{23}$$

where

$$\begin{aligned} PN\_ADC_{\pm,i} &= \text{PN Bar pedestal-adjusted ADC value(chan), and} \\ PNGAIN_{\pm,i} &= \text{Calibration factor (MeV/chan).} \end{aligned}$$

The corrected TDC is calculated as such:

$$PN\_TDC\_CORR_i = PN\_TDC_i \times PNTDCSLP_i - \frac{34.5}{\sqrt{PN\_ADC_i}}, \tag{24}$$

where

$$\begin{aligned} PN\_TDC\_CORR_i &= \text{Slew-corrected PN Bar Time (ns)} \\ PN\_TDC_i &= \text{Raw PN Bar time (chan),} \\ PNTDCSLP_i &= \text{TDC Calibration factor (ns/chan), and} \\ PN\_ADC_i &= \text{Raw PN Bar pulse height (chan).} \end{aligned}$$

The corrected TDCs are then used to calculate the TOF:

$$\begin{aligned} PN\_TOF_i \;=\; & \frac{PN\_TDC\_CORR_{+,i} + PN\_TDC\_CORR_{-,i}}{2} \\ & - PNTOFOFF_i - PNGBLTOFF - TAGOFFSET, \end{aligned} \tag{25}$$

where

$$\begin{aligned} PN\_TOF_i &= \text{PN Bar TOF (ns),} \\ PN\_TDC\_CORR_{\pm,i} &= \text{PN BAR slew-corrected TDC Value (ns),} \\ PNTOFOFF_i &= \text{PN Bar detector-specific TOF Offset (ns),} \\ PNGBLTOFF &= \text{PN Bar global TOF Offset (ns),} \\ TAGOFFSET &= \text{Offset from Tagger time.} \end{aligned}$$

The corrected TDCs are also used to calculate the x position:

$$PN\_XPOS_i = -\left(\frac{PN\_TDC\_CORR_{+,i} - PN\_TDC\_CORR_{-,i}}{2}\right) \times XCAL_{Layer} - PNXOFF_i, \tag{26}$$

where

$$\begin{array}{lcl} PN\_XPOS_i & = & \text{PN Bar TOF (ns),} \\ PN\_TDC\_CORR_{\pm,i} & = & \text{PN BAR slew-corrected TDC Value (ns),} \\ XCAL_{Layer} & = & \text{Signal propagation velocity (cm/ns), and} \\ PNXOFF_i & = & \text{PN Bar detector-specific X Offset (cm).} \end{array}$$

The position of the hit along the bar is independent of the tagger times.

5.3 Proposed Calibration Transformation

The bars are still treated in groups for several constants.

We should probably introduce individual slew constants for each TDC channel.

X Calibration constants need to be introduced for each bar.

In the case of the half bars, some attempt needs to be implemented to compensate for the air gap in the energy, X position and TOF.

Currently the TOF is offset by the first tagger counter which fired. This needs to be modified so that the TOF and tagger times can be combined during the scanning of the NTUPLE.

5.4 Previous Calibration Transformation

$$PN\_EGY_i = \sqrt{PN\_ADC_{+,i} \times PNGAIN_{+,i} \times PN\_ADC_{-,i} \times PNGAIN_{-,i}}. \tag{27}$$

$$PN\_TDC\_CORR_i = PN\_TDC_i - \frac{68.7}{\sqrt{PN\_ADC_i}}. \tag{28}$$

$$\begin{aligned} PN\_TOF_i \quad = \quad & \frac{PN\_TDC\_CORR_{+,i} + PN\_TDC\_CORR_{-,i}}{4} \\ & -PNTOFOFF_i - TAGOFFSET. \end{aligned} \tag{29}$$

A Δ time was calculated for use in the conversion to Marvin's MC format.

$$PN\_DELTA_i = \frac{PN\_TDC\_CORR_{+,i} - PN\_TDC\_CORR_{-,i} - PNXOFF_i}{4} \tag{30}$$

$$PN\_XPOS_i = PN\_DELTA_i \times XCAL_{Layer} \times 4.0 \tag{31}$$

$XCAL$ was 4.18 for the bars and 4.56 for the endcap vetos.

The change from this previous format was prompted by the need to provide separation TDC calibrations for each channel. This meant the corrected TDCs needed to be in units of ns from the start. The X OFFSET was in units of channels rather than cm. The latter makes more sense.

6 Endcap Vetos

Four of the endcap vetos are treated in an identical manner to the PN Bars. The central veto is actual a pair of paddles with *no* air gap. They are treated as two independent paddles. The absence of a second signal means that the X position cannot be determined. The TOF and energy are also affected since no correction is performed for position dependence of the light attenuation. In the case of these two paddles, the X position is simply given as the center of the paddle.

6.1 Current Unpacking Transformation

Same as PN Bars.

6.2 Current Calibration Transformation

Same as PN Bars.

7 PN Bar Fingers

Each of the PN Bar fingers has a single phototube located at the top of the quarter-inch sqare scintillator. Pulse height information is read out for each finger, but no timing information is recorded.

Because of the single PMT and long length, the relation between the light output and energy is smeared by varying amounts of light attenuation. This can potentially be corrected once the center of the hit is identified in the bars.

7.1 Current Unpacking Transformation

A readout threshold is placed n channels above the pedestal. This offset is restored when the data is unpacked.

$$PF\_ADC_i = PF\_FERA\_ADC_i + PFPED_i \tag{32}$$

7.2 Current Calibration Transformation

A gain factor is then applied in converting the pulse height from raw to calibrated form:

$$PF\_EGY_i = PF\_ADC_i \times PFGAIN_i, \tag{33}$$

where

$$\begin{aligned} PF\_EGY_i &= \text{PN Bar Finger Energy (MeV)}, \\ PF\_ADC_i &= \text{PN Bar Finger pedestal-corrected ADC value (chan)}, \\ PFGAIN_i &= \text{PN Bar Finger gain factor (MeV/chan)}. \end{aligned}$$

8 Pb Glass Detectors

The Pb Glass detectors each have a single phototube per optical volume. Both the pulse height and the timing are recorded for each detector. The TDC receives the start from the SASY trigger and its stop from the individual Pb Glass signals (after passing through the LeCroy 3420 CFDs).

8.1 Current Unpacking Transformation

A readout threshold is placed n channels above the pedestal. This offset is restored when the data is unpacked.

$$PB\_ADC_i = PB\_FERA\_ADC_i + PBPEDi \tag{34}$$

The raw TDC value is not modified when unpacking the data.

8.2 Current Calibration Transformation

A gain factor is then applied in converting the pulse height from raw to calibrated form:

$$PB\_EGY_i = PB\_ADC_i \times PBGAIN_i, \tag{35}$$

where

$$\begin{aligned} PB\_EGY_i &= \text{Pb Glass Energy (MeV)},\\ PB\_ADC_i &= \text{Pb Glass Pedestal-Corrected ADC Value (chan)},\\ PBGAIN_i &= \text{Pb Glass Gain (MeV/chan)}. \end{aligned}$$

When transforming to TOF, the TDC channel is first converted to nanoseconds and then an offset is applied to align the TOF spectrum with the results from the Monte Carlo.

$$PB\_TOF_i = (PB\_TDC_i \times PBTOFSLP_i) - PBTOFOFF_i - PBGBLTOFF - TAGOFFSET, \tag{36}$$

where

$$\begin{aligned} PB\_TOF_i &= \text{Pb Glass TOF (ns)},\\ PB\_TDC_i &= \text{Pb Glass TDC Value (chan)},\\ PBTOFSLP_i &= \text{Pb Glass TDC Calibration(ns/chan)},\\ PBTOFOFF_i &= \text{Pb Glass detector-specific TOF Offset (ns)},\\ PBGBLTOFF &= \text{Pb Glass global TOF Offset (ns)},\\ TAGOFFSET &= \text{Offset from Tagger time}. \end{aligned}$$

Currently an offset is applied to each detector, then a global offset is applied to the array so that changes in the global start timing can be adjusted simply.

The Pb Glass TDC itself is not enough to provide a concrete TOF, since the start which is provided by SASY is not a solid reference point. Combining the Pb Glass TDC information with the tagger TDC information provides the most stable number for TOF. Currently only events with one tagger TDC are analyzed, therefore that TDC is used to correct the TOF.

9 In-beam Čerenkov Veto

The In-beam Čerenkov Veto has a single phototube in its prototype state. It will have up to 5 PMTs in its final state. Pulse height information is recorded for the Čerenkov counter. There is also a bit available in the event 8 coincidence register which potentially has a shorter coincidence time than the ADC gate.

Currently a simple gain factor is applied to the signal to give an 'energy.' This is inaccurate, since the amount of light depends on β of the particle and the energy of the particle depends in a non-linear way on β.

In the future, this gain factor will be necessary to equate the gains of the phototubes in software before summing the signal from the individual PMTS.

9.1 Current Unpacking Transformation

A readout threshold is placed n channels above the pedestal. This offset is restored when the data is unpacked.

$$CV\_ADC_i = CV\_FERA\_ADC_i + CVPED_i \tag{37}$$

9.2 Current Calibration Transformation

$$CV\_EGY_i = CV\_ADC_i \times CVGAIN_i, \tag{38}$$

where

$$\begin{aligned} CV\_EGY_i &= \text{Čerenkov Veto 'Energy' (AU)}, \\ CV\_ADC_i &= \text{Čerenkov Veto Pedestal-Corrected ADC Value (chan)}, \\ CV\_GAIN_i &= \text{Čerenkov Veto 'Gain' (AU/chan)}. \end{aligned}$$

9.3 Proposed Calibration Transformation

10 Tagger

Each of the tagging focal plane counters has a single phototube. No pulse height information is recorded, but the discriminated signals are used to stop a set of TDCs which are started by the SASY event strobe (in the case of an event triggered by SASY).

The tagging spectra typically show a collection of 6 peaks, crudely representing the bunch structure of the beam (electrons circle the ring in buckets which are roughly 18.9 ns long). The concidence is typically aligned such that the second peak consists of what would be called both true coincidences and accidental coincidences. The other buckets consist of hits which are deemed to be purely accidental coincidences. At the crudest level, the TDC spectrum is used to identify which 'bucket' the coincidence came from and label it as either an accidental coincidence or a combination of true and accidantals coincidences.

The tagger spectrum is used in a more refined manner to help determine TOF measures for particles seen in SASY. TOF is best measured from the time of the interaction. The start signal which is derived from SASY (typically the XTAL Box) is not well-correlated with the time of interaction. The tagger signals, on the other hand, are highly correlated with the time of interaction. The secondary electrons collected in the tagger are highly relativistic and thus have effectively constant velocity ($\beta \approx 1$). The transit time of the photon to the target is fixed. The only uncertainty in the times come from jitter in the tagger PMT signals and the extended target-size (which limits knowledge of the interaction point). When TOF is extracted, it requires the combined use of the tagger TDCs and the TDCs from the subsystem in question. Of interest is the time relative to the same point in each bucket.

Currently the tagger TDCs are assumed to have a single calibration factor. The spectra are shifted individually such that the true peaks are aligned. The boundaries of a bucket are determined and the bucket number is calculated. The offset from an arbitrary point within that bucket is then calculated and used as the tagger time.

To do this properly, first all of the individual channels need to be calibrated. They also need to be aligned. At this point, the bucket dividers can be laid out and an offset calculated.

10.1 Current Unpacking Transformation

An offset in units of channels is applied to each of the tagger TDC values when they are unpacked. A global tagger shifts allows one to easily account for a shift in the start signal.

$$TAG\_TDC_i = TAG\_TDC_i + TDCOFF_i + TAGSHIFT, \tag{39}$$

where

$$\begin{aligned} TDCOFF_i &= \text{Alignment offset (chan)}, \\ TAGSHIFT &= \text{Global Tagger shift (chan)}. \end{aligned}$$

10.2 Current Calibration Transformation

Currently, the unpacked 'raw' TDC value is passed along to the calibrated NTUPLE.

10.3 Proposed Calibration Transformation

The proper information to be passing at this point is a bucket identifier and a relative position in ns within that bucket. The bucket can be used to identify between accidentals and hits in the combined trues–accidentals peak. The time would be used to adjust TOF values for the PN bars and Pb Glass.