Correction of temperature drifts in the timing from beam scintillators and RPCs


Abstract

We present evidence for significant drifts with ambient temperature of the timing measurements by beam scintillators and barrel RPCs. The average drift of the time-of-flight measured by the barrel RPCs is $\sim 60$ ps/$^{\circ}$C. For the observed temperature variations in the 2002 data taking, this drift leads to an additional fluctuation with $\sigma \sim 200$ ps, which is large on the scale set by the intrinsic RPC time resolution of $\sigma \sim 160$ ps. For the best possible time resolution which is essential for $\pi/e$ separation by time-of-flight in the large-angle region, such drifts must be taken into account. Pertinent corrections have been developed which normalize the timing responses of detectors to $25^{\circ}$C ambient temperature.
Contents

1 Introduction 2

2 Combined timing drifts from beam scintillators and barrel RPCs 3

3 Relative timing drifts from beam scintillators 10

4 Summary 20

*******************************************************************************
The results presented in this HARP Memo can be freely used by the HARP
Collaboration at large, if correctly referenced.
*******************************************************************************
1 Introduction

Our physics goal of measuring precisely $\pi^+$ and $\pi^-$ production spectra in the large-angle region requires, *inter alia*, the best possible time-of-flight resolution of the barrel RPCs, with a view to separating charged pions from electrons produced by the conversion of photons from $\pi^0$ decay.

Given the intrinsic time resolution of $\sim 160$ ps of the RPCs [1, 2], each effect is of importance which potentially deteriorates this resolution.

One such effect is the dependence of the RPC time stamp on the ambient temperature of the experimental area. The purpose of this memo is to assess quantitatively this effect, and eliminate it through application of an appropriate correction algorithm.

To start with, Fig. 1 shows the ambient temperature during the whole HARP data-taking in the year 2002. Shown are the readings of one out of the four temperature sensors which were mounted in the four corners of the forward-RPC plane (this one sensor was mounted on the top right side when looking downstream). One observes strong variations between a minimum of $19^\circ$C and a maximum of $34^\circ$C. The readings of the four sensors show the

Figure 1: Temperature [$^\circ$C] measured by a sensor next to the forward RPCs during the whole 2002 data taking.

---

1 The intricacies of a precise time-of-flight calibration of the RPCs will be detailed in forthcoming HARP memos.
same behaviour, therefore we use throughout this memo the average of the four temperature readings, and refer to it as ‘ambient temperature’.

All corrections of temperature effects will use 25°C as ‘reference temperature’.

While the barrel RPCs were located in the temperature-stabilized interior of the solenoid magnet – by contrast to the forward RPCs –, the beam scintillators and part of the RPC readout electronics were fully exposed to changes of the ambient temperature in the experimental area.

We observe that the temperature effects of the RPCs cannot conveniently be separated from those of the beam scintillators TOFA, TOFB and TDS (for a detailed discussion of the geometric location and the time stamps obtained from these scintillators, see Ref. [3]). This is because all precision timing uses the BS scintillator as reference which has a large time jitter of $\sim 500$ ps, and possibly a strong temperature dependence. Since we have no interest to deal with effects which cancel anyway (all precise timing detectors use the same BS signal as reference, therefore any instability of the BS signal drops out in time differences between timing detectors), we ignore all differences with respect to the BS time stamp.

We consider only

1. the relative timing between RPCs and the extrapolation of the beam scintillator timing to the target position; thus we deal with the combined relative timing drifts between beam scintillators and barrel RPCs (we note that same-sign drifts with temperature will tend to compensate each other, while opposite-sign drifts will tend to enhance each other); and

2. the relative timing of the beam scintillators among each other (we ignore a potentially large common drift with temperature of TOFA, TOFB and TDS).

Sections 2 and 3 will discuss in turn our pertinent findings.

In order to correct for temperature effects, we studied specifically the data taken with a beam of $+8.9$ GeV/$c$ momentum on the 5% Be target, between 16 August 2002 at 18:00 h and 19 August 2002 at 08:00 h (Runs 17770–17897). The day–night temperature variations were $\sim 7^\circ$C during this period.

## 2 Combined timing drifts from beam scintillators and barrel RPCs

In order to study the temperature dependence of the RPC timing signal, we adopt the following procedure. We select ‘neutral’ hits, i.e. RPC hits to which no reconstructed TPC track points, while at least one reconstructed TPC track originating from the target is required.

The rationale behind these requirements is to select hits from the conversions of photons from $\pi^0$ decays, with a view to (i) being independent of the effects from finite mass on the
particle time-of-flight, and (ii) being independent of effects from static and dynamic track distortions; the requirement of at least one reconstructed track not pointing to the ‘neutral’ hit strongly reduces background from $\sim 1$ MeV photons which stem from scattered remnants of electromagnetic showers.

For each pad, the time distribution of ‘neutral’ hits with respect to the time of arrival of the beam particle at the target (which is extrapolated from the TOFA, TOFB and TDS time stamps, and therefore imports its own drift with temperature) is plotted and the time at 50% of the maximum at the rising slope is taken.

Figure 2 shows such time distributions, separately for low and high ambient temperatures. It is apparent that the 50% point can be easily determined from the fit of a smooth function.

The RPC time is given here in picoseconds on a relative time scale, which is sufficient since we deal here only with relative time differences (the precise determination of absolute time differences will be dealt with in forthcoming HARP memos). The upper plot in Fig. 3

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Time distribution of ‘neutral’ hits in a single pad, at low (upper plot; runs 17817–17823) and high (lower plot; runs 17835–17841) ambient temperature.}
\end{figure}
shows the dependence on temperature of the 50% point as a function of astronomical time between 16 and 19 August 2002. The strong day–night variation and its correlation with the ambient temperature, shown in the lower plot, is apparent. Note that the timing drift with temperature spans $\sim 500$ ps, equivalent to a fluctuation with $\sigma \sim 200$ ps.

Figure 4 shows that the observed drift with temperature is not the property of a single selected pad but rather the typical behaviour of all pads. We further observe that the temperature dependence is not uniform across pads. That calls for a pad-specific correction algorithm for timing drifts with ambient temperature. Figure 5 shows the observed temperature dependence of the points of 50% of the maximum at the rising slope of the time distribution of ‘neutral’ hits, for a single pad. The dependence can be adequately approximated as linear which suggests its characterization by a pad-specific ‘temperature slope’. Figure 6 shows the distribution of the such determined ‘temperature slopes’ across the 180 pads in the padrings 3 to 8 of the barrel RPCs (padrings 1 and 2 are poorly populated, therefore the average correction from padrings 3 to 8 is applied for them). One observes the average slope of $\sim 60$ ps per degree, while there is non-negligible variation among the pads.

We emphasize again that the observed effect is the combined temperature drift of the difference between the time stamp from the barrel RPCs, and the time of arrival of the beam particle at the target as extrapolated from the beam timing scintillators.

We conjecture that the bulk of the observed drift with temperature results from a temperature drift of the readout electronics which was located in racks inside the experimental area.

The question arises whether the same correction for timing drift with temperature also holds for other running periods. We checked that by analysing in the same fashion $-8$ GeV/$c$ data on the 5% Be target (runs 13391–13421, taken on 20 May 2002). Figure 7 suggests that the ‘temperature slope’ was the same in May and in August 2002, which supports the conjecture that the same ‘temperature slope’ can be used for all data for the correction of timing drifts with temperature.

However, Fig. 7 also shows clearly that there is a shift of order 200 ps between analogous time references, which are in all cases the points of 50% of the maximum at the rising slope of the time distribution of ‘neutral’ hits. That means that the time reference changes with time and must be determined individually for each data set which exhibits enough stability so as not to deteriorate significantly the RPC time-of-flight resolution.

Figure 8 shows finally the result of the operation: the temperature dependence, or rather the independence of temperature, of the points of 50% of the maximum at the rising slope of the time distribution of ‘neutral’ hits, for a single pad, after application of the correction algorithm. It appears that any residual timing drift with temperature is less than 6 ps/$^\circ$C. That is more than one order of magnitude smaller than before correction, hence the impact on time-of-flight resolution from the RPCs is negligible.

The calibration constants for the correction of the RPC timing drift with temperature are available from the authors, upon request.
Figure 3: Time-dependence of the point of 50% of the maximum at the rising slope of the time distribution of ‘neutral’ hits in a single pad (top); variation of the ambient temperature in the same period (bottom).
Figure 4: Time dependence of the points of 50% of the maximum at the rising slope of the time distribution of ‘neutral’ hits, for many pads.

Figure 5: Temperature dependence of the points of 50% of the maximum at the rising slope of the time distribution of ‘neutral’ hits, for a single pad.
Figure 6: Distribution of the ‘temperature slopes’ (see the text) across the 180 pads in the padrings 3 to 8 of the barrel RPCs.

Figure 7: Slopes in the ‘time vs temperature’ diagram for a single pad, in May (dark points) and in August (open points) 2002; the two slopes were fitted independently of each other.
Figure 8: Independence of temperature of the points of 50% of the maximum at the rising slope of the time distribution of ‘neutral’ hits after application of the correction algorithm, for a single pad.
3 Relative timing drifts from beam scintillators

The time reference for all HARP time-of-flight detectors is provided by three scintillation counters, referred to as TOFA, TOFB and TDS, which together permit to determine the time of arrival at the target of the incoming beam particle. Because of the stringent requirements on time resolution, it is of interest to check the stability of time measurement by these scintillators against temperature.

However, for the reasons outlined in Section 1, we shall study in this Section only the time differences TOFA–TOFB, TOFA–TDS, and TOFB–TDS, and therefore only the possible impact of timing drifts with temperature on beam particle identification.

Figures 9–11 show the distributions of time differences between the three scintillators. The data correspond to run 17897 (20 minutes long).

![Figure 9: Distribution of the time difference [ps] between the scintillators TOFA and TOFB.](image)

One can see two distinct time distributions in $t_{\text{TOFA}} - t_{\text{TOFB}}$ and in $t_{\text{TOFA}} - t_{\text{TDS}}$. The separation between the averages of the two distributions corresponds to the time-of-flight delay of 8.9 GeV/c protons with respect to ultra-relativistic charged pions, muons and electrons. If the beam composition is unstable, then the mean time difference will be unstable too, even if the scintillators themselves are stable. Hence the following approach was adopted. For every run the full histogram of time difference was saved and fitted, and the stability of fit parameters against the run number (or astronomical time) was checked. The histograms were fitted by a sum of two Gaussians, with the constraint that the resolutions of the two peaks are the same.

In the distribution of $t_{\text{TOFB}} - t_{\text{TDS}}$ the two-distribution structure is not resolved since the

---

10
flight distance between TOFB and TDS (2885 mm) is too short. In this case the stability was checked for the the average peak position. The effect of beam content variation is less then 10 ps if the fraction of protons is stable within 20% or so.

The stability of the beam content versus the astronomical time is presented in Fig.12. No variation is observed which would appreciably impact the study of temperature drift of the timing differences TOFA–TOFB, TOFA–TDS, and TOFB–TDS.

Figure 13 shows the time dependence of the resolution of the time difference between two scintillators. The values were extracted from the fit which assumed that the resolutions are identical for protons and ultra-relativistic particles. One can see that the resolution is reasonably stable with time, although \( t_{TOFA} - t_{TOFB} \) shows a small oscillation with a period of 12 hours.

Finally, Figs. 14–16 show the (in-)stability of the time difference for all three possible pairs of scintillators (beware that only two out of the three plots are independent of each other).

The time-dependence of the difference \( t_{TOFB} - t_{TDS} \) was determined as the time dependence of the average of the respective distribution. For the other two combinations the fitted centres of the Gaussians were used. To improve the precision, a weighted mean of the two Gaussians was calculated for each histogram.

Every one of the three time dependences shows a clear oscillation with a period of one day. The positions of the respective extrema correspond to 0, 24, and 48 hours after the beginning of data taking, i.e. approximately to 18:00 h at the then August evenings when the ambient temperature was highest.
The range of instability over 3 days is 140 ps for $t_{\text{TOFA}} - t_{\text{TOFB}}$, 80 ps for $t_{\text{TOFA}} - t_{\text{TDS}}$, and 180 ps for $t_{\text{TOFB}} - t_{\text{TDS}}$. We reiterate again that we are looking only at the instability of the time difference between scintillators. It is quite possible that a large genuine temperature dependence distorts the timing in much the same way for every scintillator, however this common drift effect cancels in the time differences. The instability of time differences might be much smaller than the instability of absolute times.

Figures 17–19 show the same data as Figs. 14–16, but plotted against the ambient temperature (beware again that only two out of the three plots are independent of each other). The observed dependence is consistent with the simple assumption of a linear dependence which permits quantifying the drift of the timing differences with temperature in terms of a slope in the ‘time vs temperature’ plot.

(We note in passing that five data points in Figs. 17 and 18, distinguished as open rather than dark circles, are slightly off the track; that is apparently the result of an instability in the timing scintillator TTA which lasted for several hours from 18:00 h onwards on 16 August; the net effect of this instability is small enough not to worry about; however, these five points were disregarded in fits.)

Without loss of generality, we make now the assumption that the TDS scintillator is stable with time. The three measured slopes in the ‘time vs temperature’ diagrams of $-16.5$ ps/°C (TOFA–TOFB), $+7.2$ ps/°C (TOFA–TDS) and $+23.5$ ps/°C (TOFB–TDS) then translate into the following drifts with temperature:
Figure 12: The fraction of ultra-relativistic particles in the incoming beam versus the astronomical time of data taking. The values were extracted from the distributions of \( t^{\text{TOFA}} - t^{\text{TDS}} \).

<table>
<thead>
<tr>
<th></th>
<th>( t^{\text{corr}} )</th>
<th>( t^{\text{meas}} )</th>
<th>( \Delta T )</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOFA</td>
<td>( t^{\text{TOFA}} )</td>
<td>( t^{\text{TOFA}} )</td>
<td>( -7.0 \cdot \Delta T )</td>
</tr>
<tr>
<td>TOFB</td>
<td>( t^{\text{TOFB}} )</td>
<td>( t^{\text{TOFB}} )</td>
<td>( -23.5 \cdot \Delta T )</td>
</tr>
<tr>
<td>TDS</td>
<td>( t^{\text{TDS}} )</td>
<td>( t^{\text{TDS}} )</td>
<td>( t^{\text{TDS}} )</td>
</tr>
</tbody>
</table>

In these formulae, \( \Delta T \) refers to the difference of the ambient temperature to the reference temperature of 25°C.

Numerically, it turns out that the large negative coefficient of TOFB is effectively reduced to half of its value by the coefficient of TDS which is zero, because TOFB and TDS are physically located very close to each other whereas TOFA is far upstream. Therefore, the resulting effective average coefficient of \( \sim -12 \text{ ps}/^\circ\text{C} \) is not very different from the TOFA coefficient of \(-7.0 \text{ ps}/^\circ\text{C} \) so that, incidentally, we expect that the slope in the ‘time vs z’ diagram of the beam particle is little affected.

We emphasize once more that for the correction of the drift with temperature of the time-of-flight of a secondary particle, it is important to correct the \textbf{combined} effect from the difference in the respective detector’s response (e.g. the RPCs as discussed in Section 2). Considering the drift of time differences between the beam scintillators in their own right is primarily an academic exercise and makes sense only with a view to beam particle identification.

Figure 20 shows the slopes from the beam timing scintillators in nanoseconds per metre, in the ‘time vs z’ diagram [3] separately for protons and pions, as a function of astronomical time. One sees clearly a drift with temperature, however it is apparent that this drift has
Figure 13: Time dependence of the resolution of the time difference between two scintillators; open circles correspond to the difference $t^{\text{TOFA}} - t^{\text{TDS}}$ and black points to the difference $t^{\text{TOFA}} - t^{\text{TOFB}}$.

esentially no impact on the separation between protons and pions.

The above conclusion is corroborated by Fig. 21 which shows the slopes from the beam timing scintillators in nanoseconds per metre in the ‘time vs $z$’ diagram, before (top) and after (bottom) correction for drift with ambient temperature. The two plots are practically indistinguishable.
Figure 14: Time dependence of the time difference [ps] between the beam scintillators TOFA and TOFB.

Figure 15: Time dependence of the time difference [ps] between the beam scintillators TOFA and TDS.
Figure 16: Time dependence of the time difference [ps] between the beam scintillators TOFB and TDS.

Figure 17: Temperature dependence of the time difference [ps] between the scintillators TOFA and TOFB.
Figure 18: Temperature dependence of the time difference [ps] between the scintillators TOFA and TDS.

Figure 19: Temperature dependence of the time difference [ps] between the scintillators TOFB and TDS.
Figure 20: Time dependence of the slopes [ns/m] in the ‘time vs z’ diagram for protons and pions.
Figure 21: Slopes [ns/m] in the ‘time vs z’ diagram before (top) and after (bottom) correction for drift with ambient temperature.
4 Summary

It is shown that changes in the ambient temperature in the experimental area during data taking lead to strong drifts of the timing response of the RPCs with ambient temperature, which must be corrected to comply with the stringent requirements on time-of-flight resolution in the large-angle region.

Correction algorithms have been developed and implemented in our RPC data analysis.

As for the timing scintillators in the beam line, their drift with ambient temperature is lumped together with the respective drifts of the RPCs. The timing differences between beam scintillators show an unambiguous dependence on ambient temperature, however that would solely impact the identification of beam particles. It is shown that beam particle identification is not significantly deteriorated by temperature drifts in the beam scintillators.

References

