Beam Aborts in PEP-II rings and lingering Drift Chamber currents

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ABSTRACT

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The BABAR detector at SLAC was designed to study CP-violation in B-meson decays from electron-positron collisions in the PEP-II electron-positron storage rings. Background radiation in the High Energy Ring (HER) and Low Energy Ring (LER) of PEP-II has the potential to damage the sensitive equipment in the BABAR detector. As a result, the beams in the HER and LER can be aborted to prevent such damage. In the span of a few microseconds, the HER and LER currents drop from, for example, 1450 micro Amps and 2300 micro Amps, respectively, to zero. At this time the voltage in the Drift Chamber is rapidly ramped down from a potential of 1930 V to a safe potential of 800 V, thus we would expect the currents in the Drift Chamber to quickly go to zero once the beams are aborted. However, we observe an average 15 second delay in the measured time it takes for all current in the Drift Chamber to fall below 1 micro Amp. This delay has been hypothesized as an instrumentation issue and not as a physical phenomenon. The specific sources of this error are still not completely known, but analysis suggests

that it results from the interplay of the CAEN High Voltage supplies and the EPICS system and/or limitations within those systems.

INTRODUCTION

Data collection has changed dramatically over the last 100 years. In the past, a large amount of a scientist's time was spent directly working with the apparatus and recording each measurement by hand. Today, advanced electronics and computers allow us to store large amounts of data efficiently so that, ideally, the scientist can spend less time on data retrieval and more time on data analysis. An example of this is BABAR's online detector control system, called the Experimental Physics and Industrial Control System (EPICS), used to monitor data and record quantities such as current in the Drift Chamber [1]. The analog current values get digitized and recorded into the Ambient database, so that the information is accessible with computers for analysis. There are custom-made programs at SLAC, such as OdcNtupleMaker and Ambient Explorer, in which one can attain quantities of interest for any time period from the beginning of the experiment (1999) through the present. Using OdcNtupleMaker, we looked at instances of so-called "beam aborts", i.e. when the beams in the HER and LER are dumped, and the effect this has on the Drift Chamber (DCH) current. During beam aborts, the sources from which we get currents in the DCH, i.e., the HER and LER currents, drop instantaneously. Thus we expect the DCH current to also drop to zero instantaneously. Instead, the DCH has been observed to take, on average, 14-19 seconds to drop to zero. This is an anomaly. In this paper, we analyze this behavior of DCH current after beam

aborts to investigate this issue. The leading hypothesis for this irregularity is a combination of factors involving sampling times, EPICS, and the high voltage system.

BACKGROUND

There are several ways in which the HER/LER beams can be aborted. If sensors within the PEP-II rings detect sufficiently high radiation, the beams are ejected out of the rings, in order to prevent them from entering the BABAR detector. The DCH can also protect against high radiation by limiting injection rates whenever an instantaneous dose limit is exceeded. Likewise, PIN diodes near the Silicon Vertex Tracker (SVT) monitor both very high, instantaneous doses of radiation and moderately high doses that accumulate over time which can also be harmful. This can occur during an injection of current into the PEP-II rings, or during a period of stable beams. In this paper, only the aborts of stable beams are of interest because only then is the DCH is ramped up to 1930 V at the time of abort. From May 1999 until present, stable beam aborts are triggered 3 times a day on average.

Voltages are supplied to sense, field, guard, and clearing wires of the DCH by a CAEN SY527 High Voltage (HV) mainframe [2]. The CAEN system contains 7 service boards, labeled B0 through B6, which are connected to the wires. The mainframe communicates with the EPICS driver via the “CAENnet”. The values of the currents in the HER, LER, and DCH are periodically measured by EPICS and stored in a database. Today, the sum of the currents in the DCH is recorded with a maximum sampling frequency of once every 2 seconds. However, intervals between measurements can be

multiples of two seconds if the values are not changing significantly. Ideally, a changing current will prompt a new value to be recorded every two seconds.

Before October 23, 2003, the DCH currents were recorded at a different frequency than they are today. In the past, the 44 individual groups of HV currents were sampled every 2 seconds and the sum of all HV currents (which we refer to as HV sum) was recorded every 5 seconds. After October 23, 2003, the individual HV groups, which are used to generate the HV sum, were recorded every second and the HV sum was recorded every 2 seconds. It will be shown that this increase in frequency had an effect on the reported average delay in DCH current dropping to zero.

PROCESS

To understand the anomaly of the lagging DCH current, we first needed to find instances of beam aborts. We found recent instances from a BABAR website [3]. Once the beam aborts were selected, we examined the BABAR Ambient database and looked at 4 minute intervals around each event, (2 minutes before and 2 minutes after) to study the behavior of the DCH currents during this time. The quantities studied were the HER and LER currents, as well as the HV sum and groups of DCH HV current. For most of the events, the HV sum took 12-23 seconds to decay down to a value close to zero. In general, the HER, LER, and HV sum did not decrease to exactly 0 micro Amps, so we chose to approximate this as any value less than 1 micro Amp. Henceforth, the phrase “drop to zero” will signify a drop to a value below this threshold. For many events, the HV sum dropped to a value around 6 micro Amps in a short time period (approximately

30 seconds or less), but did not drop below 1 micro Amp for one or two minutes after the beams were aborted. We thus added the condition that if the time intervals for the HV sum to drop to zero is greater than 25 seconds, then we calculate the time interval to drop below 7 micro Amps. We found that most of the data fell within a 10 to 25 second range.

The delay in DCH current to drop to zero follows two types of behavior. The first observed pattern is a simple drop in current after beam abort, as shown in Figure 1. The second observed pattern is an initial rapid spike in current after beam abort followed by an abrupt decrease, as shown in Figure 2. Initially, we distinguished these two types of behavior and calculated the time intervals to drop to zero for each independently.

However, as can be seen from Figures 3 and 4, both of these patterns result in similar time delays. We see a normal distribution, skewed to the left, with an average delay of 15 seconds for both “drops” and “spikes”. Both Figures 3 and 4 show most events in the range 12 to 23 seconds. We can deduce that the two types of behavior, drops and spikes, fall to zero in approximately the same amount of time and thus we see there is no need to separate the two patterns in this analysis.

We examined the intervals to drop to zero as a function of time, from February 2001 to July 2004. We found that the average time interval for the HV sum to drop to zero after a beam abort did change throughout the lifetime of BABAR. Figure 5 shows that the most frequent delay interval, i.e., *mode delay*, was 19 seconds for the year 2001. For the year 2002 through October 23, 2003, the mode delay was 17 seconds. This is demonstrated in Figures 6 and 7, which show a normal distribution with a skew to the left. After the sampling frequency change on October 23, 2003, the mode delay was 14-15 seconds. Figures 8 and 9 show the distribution for this time period, which is again

normal and skewed to the left, but with a much smaller standard deviation. Since the HV sum sampling interval decreased from 5 to 2 seconds, it makes sense that the mode delay would decrease.

We then decided to examine the 44 groups of individual DCH sense currents more closely to determine their average delay. First, we examined the sampling intervals for the period November 2002 to October 23, 2003. Figure 10 shows a distribution of the sampling intervals for this period, with peak intervals at 6 and 4 seconds. This agrees with the minimum sampling interval of 2 seconds for this period. When the minimum sampling interval was changed to 1 second after October 23, 2003, the average sampling interval stayed about the same. Figure 11 shows a distribution of sampling intervals for October 23, 2003 through July 2004, with a peak at 5 seconds. Thus we see that the change in maximum sampling frequency had a bigger effect on the HV sum than on the 44 individual HV groups.

As noted with the HV sum, the 44 groups also showed significant time delays in returning to zero current after beam aborts. However, we noticed that the 44 groups fall to zero much faster than the HV sum. As seen from Figure 12, the majority of the 44 groups of sense wires go to zero 8 seconds before the HV sum for the period November 2002 – October 23, 2003. Figure 13 shows that the majority of the 44 groups of sense wires go to zero 4-5 seconds before the HV sum for the period October 23, 2003 – May 2004.

Thus we decided to determine the time intervals of the 44 groups to fall to zero after beam aborts. The sense wires are not all digitized simultaneously, but in fact are sampled in three groups based on the different CAEN boards that connect to them. These

three boards are called B0, B1 and B6. Figures 14 - 19 show the time intervals to drop to zero for these three groups for both the 2 second sampling interval (shown for November 2002-October 23, 2003) and the 1 second sampling interval (October 23, 2003 – July 2004). Unlike the HV sum, the mode delay did not change significantly for the three groups after the sampling rate increased. We noticed that the group B6 has much longer time intervals, around 10 seconds, compared to the 7-8 second intervals for groups B0 and B1. Because the boards have been replaced and switched throughout the BABAR experiment, and yet we consistently see B6 with longer delays, we can not attribute the delay to the board itself. In addition, the fact that the delay is different for B6 excludes the possibility that the delay was a physical phenomenon. Instead, we ascertain that this must be a problem with the way that the CAEN High Voltage supplies read the HV boards. Also, we can attribute part of the HV sum delay to the time it took EPICS to compute the value of this sum. Assuming that EPICS does not start computing the sum until the last values of current are recorded, we see that for the period before October 23, 2003, there was a 2 – 7 second summing delay and a 3 – 5 second summing delay for the period after. This is shown in more detail in Table 1.

DISCUSSION AND CONCLUSION

The nature of this delay in recorded HV current in the Drift chamber is still a subject of speculation. My mentor, Thomas Glanzman, had examined a similar type of delay during the ramping up of voltage from 800 to 1930 V in the Drift Chamber [4]. Using an oscilloscope to directly measure the DCH currents, he noticed a difference of about 13 seconds between his measurement and the EPICS data. Another study was done

by Mike Kelsey [5], who examined a continuous display of DCH analog current and found a 5-15 second delay between the analog trace versus the EPICS data during ramp downs.

An EPICS specialist, Vincent Poireau, claims that instead of the expected 1 second sampling interval, EPICS is actually updating only once every 4 seconds [6]. When he examined the current read directly from the CAEN High Voltage supplies, he saw that the current is actually updated roughly every 4 seconds. On the other hand, EPICS is scanning for the current once every second. Thus, the effective sampling rate is once every 4 seconds for EPICS. The reason behind the CAEN mainframe's slow sampling rate remains a mystery.

To summarize, we started off with a 17-19 second delay before October 23, 2003 and a 14-15 second delay after this date. We then divided the sense wires into the three groups and found that the B6 board is consistently read last, with a mode delay of 10 seconds to drop to zero after beam abort compared to 7-8 seconds for boards B0 and B1. Thus we attributed 2-7 seconds as a summing delay for the time before October 23, 2003 and 3-5 seconds after this date. Based on work from Poireau, we can attribute at most 4 seconds of this delay to the CAEN sampling rate. This still leaves 3-4 seconds for B0 and B1. More study is needed to explain those mysterious remaining seconds in detail, but they have been isolated between the CAEN HV supplies and EPICS.

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Tables

	5 s sampling for HV sum	2 s sampling for HV sum
HV sum drop to 0	17	15
B6 drop to 0	10	10
Difference	7	5
Summing delay	2 - 7	3 - 5

Table 1. Average delay, given in seconds, in calculating the HV sum value by EPICS.

Figures

Figure 1. Plot of a beam abort with a drop in Drift Chamber current for June 12, 2004. The blue line represents the electron beam, the red line represents the positron beam, and the green line represents the HV sum current in the Drift Chamber.

Figure 2. Plot of a beam abort with a dramatic spike in Drift Chamber current for June 20, 2004. The blue line represents the electron beam, the red line represents the positron beam, and the green line represents the HV sum current in the Drift Chamber.

Figure 3. Time intervals for the High Voltage sums of the Drift Chamber currents to simply drop to zero after beam aborts for November 2002 – July 2004.

Figure 4. Time intervals for the High Voltage sums of the Drift Chamber currents to spike up and then drop to zero after beam aborts for the November 2002 – July 2004.

Figure 5. Time intervals for the High Voltage sums of the Drift Chamber currents to drop to zero after beam aborts for the year 2002.

Figure 6. Time intervals for the High Voltage sums of the Drift Chamber currents to drop to zero after beam aborts for the year 2002.

Figure 7. Time intervals for the High Voltage sums of the Drift Chamber currents to drop to zero after beam aborts for January – October 23, 2003.

Figure 8. Time intervals for the High Voltage sums of the Drift Chamber currents to drop to zero after beam aborts for October 23, 2003 – April 2004.

Figure 9. Time intervals for the High Voltage sums of the Drift Chamber currents to drop to zero after beam aborts for May – July 2004.

Figure 10. Time intervals between recorded measurements for 44 HV groups.

Figure 11. Time intervals between recorded measurements for 44 HV groups.

Figure 12. Intervals between the times that the High Voltage sums of the Drift Chamber currents and the currents in the majority of 44 individual groups of sense wires drop to zero for November 2002 – October 23, 2003.

Figure 13. Intervals between the times that the High Voltage sums of the Drift Chamber currents and the currents in the majority of 44 individual groups of sense wires drop to zero for October 23, 2003 – May 2004.

Figure 14. Time intervals for the B0 section of DCH currents to drop to zero after beam aborts before the change in sampling frequency.

Figure 15. Time intervals for the B0 section of DCH currents to drop to zero after beam aborts after the change in sampling frequency.

Figure 16. Time intervals for the B1 section of DCH currents to drop to zero after beam aborts before the change in sampling frequency.

Figure 17. Time intervals for the B1 section of DCH currents to drop to zero after beam aborts after the change in sampling frequency.

Figure 18. Time intervals for the B6 section of DCH currents to drop to zero after beam aborts before the change in sampling frequency.

Figure 19. Time intervals for the B0 section of DCH currents to drop to zero after beam aborts after the change in sampling frequency.