The E866 Mark II Bull's Eye Performance and Promise

J. B. Cumming

Brookhaven National Laboratory, Upton, New York 11973, USA

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The performance of the E866 Bull's Eye during the Sept-Oct 1994 gold beam runs is examined. Multi peaked pedestal distributions and direct hits of produced or scattered particles on the PMTs are noted. A simple procedure is described to correct for the observed dependence of BE response on event position. Nonlinearity of the BE Hard Sum compared to the Soft Sum is observed and shown to lead to an artificially good resolution of the former signal which defines the INT trigger. Suggestions are made for changes and additional measurements including a "gate valve" experiment during the next running period.

I. INTRODUCTION

This Memorandum examines the performance of the E866 Mark II Bull's Eye (BE) during the Sep-Oct 1994 running period with the ^{197}Au beam at the AGS. This BE and the earlier Mark I version represent the work of R. Debbe. The primary function of the BE in E866 is to provide a minimum bias (INT) trigger indicating that a particle, identified as BEAM by the upstream B_{tot} counter, had interacted in

the target. The Bull's Eye is located in the ZCAL area of the beam line, just upstream of the hodoscope array. Its active element is a 20-cm diam, $300 \pm 1\%$ - μm thick quartz Čerenkov radiator. The large diameter should place all support materials at radii well outside of those of any beam particles. (Spectra from the smaller Mark I BE used during the 1993 run showed a satellite on the high side of the main beam peak due to interactions of beam fringe in the radiator support.) The Mark II radiator is on the upstream entrance window of an ~ 66 -cm diam, ~ 10 -cm long light-tight enclosure. Thin aluminized Mylar serves both as the exit window for the beam and as a reflector for the Čerenkov light. The front face of the quartz plate is lapped to reduce internal reflections. The reflected Čerenkov light is detected by eight photomultiplier tubes (PMTs) located at 45° intervals around the periphery of the enclosure. The PMTs view the reflector at an $\sim 15^\circ$ angle. They are sequentially numbered clockwise looking in the beam direction, starting with BE(1) at $\phi = 112.5^\circ$ in the standard coordinate system where the HH spectrometer is centered on $\phi = 0^\circ$.

Each PMT anode is bridged to provide one signal for direct input to a LeCroy 2249A Camac ADC and a second for input to a 4 channel fanin/fanout analog adder. Outputs from the two adders are summed by a third fanin/fanout to give the "Hard Sum" of the eight BE PMT signals. One output from the final fanout is digitized directly by a channel of the 2249A. A second output is delayed, then digitized to provide an event-by-event pedestal for the Hard Sum. A third output feeds a discriminator set just below the beam peak for definition of the online INT trigger. The signal to the discriminator is delay-line clipped to eliminate low frequency noise and any DC offset. Twelve words in the BEAM bank identified as RAW ADC(13) to RAW ADC(24) are reserved for BE signals. For the 1994 runs, these were assigned to the Hard Sum, the eight separate PMTs, the Hard Sum pedestal, and two spare ADCs in that order. In the present analysis of BE data, pedestals determined in a

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separate run are subtracted from the eight digitized individual PMT signals, the net signals are gain adjusted to place the beam mean for each at channel 200, and then they are added to form the BE "Soft Sum". The contribution of the individual PMTs to the Hard and Soft Sums is different since gains for the PMTs differed by as much as a factor of two. Run 14565 is taken as a typical pedestal run and Run 14535 as representative of real data.

II. PEDESTALS

A general feature is that pedestal distributions for all eight separate BE PMTs appear to have multiple peaks. Spectra for BE(1) and BE(5) are shown in Fig. 1(a) and (b). In each case satellite peaks or shoulders are present on both high and low sides of the central peak. This is not due to noise at the Camac crate since the pedestal for a spare ADC on the same card is less than one channel wide, see Fig. 1(c). There is a strong positive correlation between pedestals for any two BE ADCs, see Fig. 1(d) and, as a consequence, between the sum of eight pedestals (the Soft Sum) and any individual ADC (Fig. 1(e)). It also follows that the Soft Sum pedestal is a broad having a ragged distribution spanning some 70 channels (Fig. 1(f)). A possible source of the pedestal splitting is AC noise pickup in the cable loop extending from the fanout input in the counting hut to the PMT anode bridge on the floor and then back to the ADC input in the hut. This anode bridge reduces the effective DC source impedance seen by the ADC to 50 Ohms. Multiple peaked pedestal distributions have been observed for ZCAL PMT signals when FastBus ADCs were driven from a low impedance source. Independent of whether the present problem is due to noise or due to impedance mismatching, the presence of the positive correlations suggests it could be removed in large measure on an event-by-event basis by using one or both of the spare ADCs in combination with spare cables, PMTs, and fanin channels to

simulate an input loop without any real signal.

The Hard Sum pedestals, prompt in Fig. 2(a) and delayed in Fig. 2(b), while spread over more channels than those of any individual BE PMT, appear much better behaved than the Soft Sum pedestal (Fig. 1(f)). The prompt and delayed signals are positively correlated, Fig. 2(c), and their event-by-event difference, Fig. 2(d), is reasonably narrow with a FWHM of ~ 5 channels. It would appear that the use of the delayed pedestal to correct the Hard Sum for real events should be successful.

There is some tendency for both an individual BE PMT pedestal (Fig. 2(e)) and the Soft Sum pedestal (Fig. 2(f)) to be anticorrelated with the delayed Hard Sum pedestal. The highest BE(1) or Soft Sum signals are associated with low Hard Sum pedestals, but this trend does not continue beyond the most probable values. There is no clear reason to expect an anticorrelation.

III. DIRECT HITS ON PHOTOMULTIPLIERS

Examination of spectra from the individual BE PMTs for BEAM, INT, Spec2, and FSpec triggers from Run 14535 provides evidence for what we term "direct hits" of scattered or produced particles on the PMTs. We compare BEAM and Spec2 spectra from BE(1) in Fig. 3(a). The BEAM peak falls at channel 200 as a consequence of the gain adjustment procedure. Although the resolution from a single PMT is poor, there are no BEAM events above channel 400. While most Spec2 events fall below the beam peak as expected, there is a tail extending well above all BEAM events. Because of the Z^2 dependence of Čerenkov light, these events correspond to nonphysical charges. We postulate they arise from interactions in the photocathode or other parts of the PMTs when they are struck by scattered or produced particles.

The saturation peak in Fig. 3(a) and saturation peaks in spectra from the other BE PMTs occur at channel ~ 1175 in the raw data from the BEAM bank. The

LeCroy 2249A is normally considered to be a 10 bit ADC. While it is specified to be linear over the 10 bit range, it actually digitizes by counting a 20 MHz oscillator through a gate whose width is proportional to the charge of the input pulse. For overloading input pulses, the gate is forced closed at 55-60 μ sec giving a saturation peak in the range from channels 1100 to 1200, consistent with the observed values.

The high channel tail for Spec2 events is much reduced, if not eliminated completely, when outputs from all eight BE PMTs are added to form the Soft Sum, see Fig.3(b). This suggests that at most a few PMTs are directly hit to produce a signal ≥ 400 channels in a given Spec2 event. The actual multiplicity of hits on the PMTs is tabulated in Fig. 4 for the triggers used during Run 14535. Single hits dominate, rising from 0.6% for BEAM events to 3.3% for Spec2 and FSpec triggers. Double hits are somewhat less common than expected and no events with three or more large hits were observed. The azimuthal angular distribution of the hits is also shown in Fig. 4. They appear more frequently on the side of the BE toward the Forward Spectrometer ($\phi = \pm 180^\circ$).

While the influence of large direct hits is apparent in spectra from the single BE PMTs, the general shapes of the spectra suggest that direct hits may produce spurious signals of all sizes. This is apparent if one examines the pattern of signals from the BE PMTs for individual events: the order of 30% of the nonbeam events have one PMT giving a signal grossly larger than the rest. A correction procedure was developed to remove or reduce the influence of direct hits on the PMTs on an event-by-event basis. First, the PMT giving the largest signal is ignored and a mean is calculated for the remaining seven. Then, all BE signals are compared to the provisional mean. If an individual signal is twice the mean, that PMT is flagged and its contribution removed from the mean. Because of pedestal uncertainties, any PMT with a signal ≤ 20 channels, *i.e.*, 10% of the response to beam, is not flagged. Finally,

the output for all flagged PMTs is replaced by the mean of the unflagged channels. Representative events influenced by this "fix" are shown in Fig. 5. The first line for each event gives the input BE signals resulting from pedestal subtractions and gain adjustments, the second line, the values after correction. The first two examples, events 13 and 125, illustrate events with single large direct hits where the correction is obvious. The next five events illustrate single smaller direct hits. Correction in the case of the first three of these is straight forward. However, in the case of event 5, the replacement of the raw 20.2 for BE(5) by the mean, 9.3, is near the threshold of the correction procedure. While rejection of the 217.0 for BE(2) in event 164 seems reasonable, the twice mean rejection criterion leaves the 101.8 for BE(7) untouched.

Figure 5 concludes with six examples of events with two direct hits on BE PMTs. Corrections in the first two of these are again straight forward. Events 45 and 47 are of interest because the direct hits ride on a significant background typical of a less central event. The direct hits are on separated PMTs in event 45, on adjacent ones in event 47. Event 82 was included as an example of possibly three direct hits. Signals for BE(2) and BE(5) are corrected but the original 93.1 for BE(1) is left unchanged.

While results for events such as 82 and 164 suggest some fine tuning of the rejection procedure might be desirable, the present method leads to much improved BE spectra, as illustrated in Fig. 6. Figure 6(a) shows the BE vs ZCAL correlation for nonbeam events, essentially the sum of fragment Z^2 vs the sum of fragment A and Fig. 6(b) gives the BE spectra for those events having ZCAL energies ≤ 500 GeV, both prior to fixing the BE. This energy cut translates to fragment masses ≤ 47 amu. The occurrence of central events based on ZCAL associated with apparently large charges in the BE, charges even larger than would be expected for any reasonable single fragment, had been noted early-on and was an unsolved puzzle. The corresponding spectra after correction of the BE for direct hits are shown in Fig. 6(c) and

(d). Comparison with the uncorrected data indicates that major distortions caused by direct hits on the BE PMTs can be removed. Particularly striking is the BE soft sum spectra for central events which collapses to a Gaussian spike centered near zero with a sigma of 22 channels.

IV. BULL'S EYE RESPONSE VS POSITION

An ideal Bull's Eye would have at most a weak dependence on the impact position of a particle so that day-to-day shifts in mean beam position or sweeping during the spill would not significantly change the position its output relative to the fixed INT discriminator or degrade its resolution. This section examines the actual dependence of Mark II BE signals using ZCAL to determine a beam particle's position. Note that the (x, y) coordinates from ZCAL are the mass weighted centroid of an event while the response of the BE is Z^2 weighted: these should be the same for a beam particle.

A set of clean BEAM events falling within ± 1 -cm of the line connecting BE(1) and BE(5) was selected on the basis of coordinates from ZCAL, and BE signals were examined as a function of distance along this line. The signal from BE(1) is shown in Fig. 7(a). The origin here is at the center of the BE and positive distances are directed toward BE(1). A monotonic fall of the response might be expected as the source recedes from the PMT: this is observed between 6 and 0 cm. The rise of response in moving still further away (from 0 to -6 cm) was unexpected.

BE(3) is located perpendicular to the selected line of motion. It might be expected that its response would be highest when the source was directly in front of the PMT along that line, *i.e.*, at distance zero, and fall off to either side. While approximate symmetry is observed, see Fig. 7(b), the response is *lowest* for the source at the BE center. Since the thickness of the quartz radiator was specified to be uniform to $\pm 1\%$, the dependence of Čerenkov light on position should be negligible. Either this is not

the case, or there are some geometrical effects in the reflective collection of light by the PMTs. The influence of radiator thickness can be removed by taking the ratio of two BE outputs, in particular, the BE(5)/BE(1) ratio should be a monotonic function of source position. Figure 7(c) indicates that this is the case.

The data shown in Fig. 7 give little hope that adding outputs to form the Soft Sum would remove the dependence on position. The normalized Soft Sum for clean BEAM events is shown as a function of the (x, y) position of the interaction in Fig. 8(a): central y and x slices through this distribution are shown in Fig. 8(b) and (c), respectively. While the beam probes only a fraction of the radiator area, substantial variations in the response are apparent. Whether these can be described as an azimuthally symmetric hole at the center as suggested by the slices and Fig. 7, or have a more complicated dependence, *e.g.*, some sort of valley in the surface of Fig. 8(a), requires more extensive mapping of the response vs position.

V. RESOLUTION

It had been observed during and after the 1994 runs that the Hard Sum spectra for BEAM events in the Bull's Eye appeared to have better resolution than the Soft Sum spectra. However, both had tailing on their high sides. The previous section has shown there is a positional dependency of the BE response which might broaden and distort observed spectra from their true shapes. In the absence of more extensive mapping of the BE response, we assume azimuthally symmetry and plot mean efficiency vs source radius in Fig. 9(a). A beam particle at the center of the beam distribution ($r = 0$ cm) gives an $\sim 5\%$ lower signal compared to the mean. The response in the beam fringe ($r = 9$ cm) is $\sim 25\%$ higher. A Gaussian plus constant parameterization of the data, shown as the curve in the figure, provides a convenient correction procedure for BEAM and nonBEAM events over the whole Bull's Eye

aperture. This represents an approximate correction since the region of the BE which has been mapped is limited, particularly in the x direction, and even in the mapped regions there is a suggestion of an azimuthal asymmetry (Fig. 8(a)).

Raw and response corrected Soft Sum spectra are shown in Figs. 9(b) and (c), respectively. Resolution (σ/E) for the raw spectrum is 7.9% and skewing from the Gaussian fit is apparent. Resolution is improved to 6.7% and the corrected spectrum is Gaussian over a wide range. Note that the effective $\sigma = 20$ channels for the ill-behaved pedestal distribution is not a major contributor to the width, $\sigma = 107$ channels, of the corrected Soft Sum spectrum for BEAM events. It is, however, of much more significance in case of more central events. It is problematic if the resolution of the BE could ever be improved to approach the 3.8% obtained without any correction for position dependence, for the smaller B_{tot} during the representative run. An improvement in resolution of the Hard Sum spectra is also achieved by applying the same correction for position dependence, see Figs. 10(a) and (b), where σ/E decreases from 5.5 to 4.7%.

VI. LINEARITY

It would be desirable that the Soft Sum from a Bull's Eye detector be proportional to the Hard Sum. Differences in weighting contributions of the individual signals to the two sums and nonlinearities in the two stages of fanin/out adders which generate the Hard Sum might lead to less than ideal behavior. That this is the case can be seen in Fig. 11 where the Hard Sum is shown as a function of the Soft Sum for BEAM, INT, and Spec2 events. A gradual bending-over of the main locus of events is observed. Straight lines indicate the slope in the BEAM region and for the more central events. A calibration of the Hard Sum based on clean BEAM events will underestimate charges of fragments with lower Z^2 if proportionality is assumed. When

the measured resolution of the Hard Sum for clean BEAM events is corrected for this nonlinearity, σ/E increases from the 4.7% seen in Fig. 10(b) to 8.0%, appreciable poorer than that of the Soft Sum. It is still reasonable to use the Hard Sum to build the INT trigger, however, claims as to how sharp the cut is must be appropriately softened.

An interesting feature is the occurrence of events above and to the left of the main sequence in Fig. 11, events where the Hard Sum is much larger than expected from the Soft Sum. These artifacts are particularly frequent for low values of the Soft Sum. They show the influence of direct hits on the BE PMTs. Soft Sums were corrected for this effect in preparing Fig. 11, but the Hard Sums were not.

VII. SUMMARY AND SUGGESTIONS

A detailed examination of the performance of the Mark II Bull's Eye used during the Sep-Oct 1994 gold runs has shown a number of deviations from behavior which might be expected from an ideal device. Correction procedures have been or can be developed for some of these. In this category are problems with pedestals for the individual BE PMTs. The pedestal correlations suggest that using spare cables and circuits to simulate a real data channel, but without a PMT signal, would give a good event-by-event measure of pedestals. Direct hits on PMTs and the resulting distortion of spectra is a problem which appears to have been solved.

It does not appear that physical dependence of the Bull's Eye response on position could be removed without a major redesign. Present off-line correction procedures are partially successful, and a more extensive mapping, either by moving the beam position or by physically moving the BE is clearly practical. While removing the nonlinearity of the Hard Sum by using different summing circuits is a possibility, justification of the required effort is problematical as the nonlinear output can still

reasonably define the INT trigger, and more reliable information on fragment charges can be obtained from the Soft Sum if needed.

A major motivation for the present work was to understand the Bull's Eye's performance and capabilities so that it might be used in a "gate valve" experiment to calibrate ZCAL's response to the gold beam. In such an experiment, a target is introduced into the beam line well upstream of the normal target position, and the line is used for momentum selection of the projectile fragments transported to the target area and thence to ZCAL. In gate valve experiments with oxygen and silicon beams, the combination of charge information from the B_{tot} , B_{tof} , and BE counters with mass information from ZCAL permitted the unique identification of single fragments and confirmed the linearity of ZCAL's response with fragment mass.

Figure 12 shows the correlation between BE fragment rms charge, Z , and ZCAL fragment mass, A , for BEAM and Spec2 events. The various corrections discussed above have been applied. The most peripheral events tend to define a vertical band due to multifragmentation in which several fragments carrying most of the projectile mass and energy fall into the ZCAL acceptance. Because of the Z^2 weighting, rms Z in the BE is substantially lower than 79. This band is more heavily populated in INT events, not shown in the figure. The more central events define a horizontal band in this figure characterized by rms $Z \leq 15$ and ZCAL masses approaching, but not reaching zero. (These data are for Au+Au interactions where the nuclear halo gives some transparency even in zero impact collisions.) Shown in Fig. 12 is the approximate line of stability defined by the masses of odd Z nuclei. The largest yields for *single* projectile fragments are expected to fall slightly to the left of this line for heavy fragments, slightly to the right for lighter ones. The purpose of Fig. 12 is to show that if single fragments from an upstream target can be selected by the beam line, they should fall into an (Z,A) region reasonable free from background arising

from interactions in the normal target region. The high resolution signals from B_{tot} should provide a significant further cleanup from background in such a measurement.

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Bull's Eye Pedestals

Figure 1

Bull's Eye Pedestals

Figure 2

Bull's Eye, BE(1) and Soft Sum Comparison of Spec2 and BEAM Triggers

Figure 3

E866 Mark II Bull's Eye Events with Large PMT Signals

Events with one or more PMTs > 400 as a function of trigger

Trigger	Beam	Int	Spec2	FSpec
Events	3045	8963	76177	28720
1 hit	18	199	2491	945
2 hits	0	2	37	21
1 hit %	0.6	2.2	3.3	3.3

Angular Distribution of Hits on PMTs

Figure 4

E866 Bull's Eye

Representative Events with Hits on PMTs

Event	BE(1)	BE(2)	BE(3)	BE(4)	BE(5)	BE(6)	BE(7)	BE(8)
Large Single Hits								
13*	16.1	27.0	25.8	531.5	17.0	17.2	17.2	13.2
	16.1	27.0	25.8	19.1	17.0	17.2	17.2	13.2
125*	0.1	547.7	5.2	2.6	4.7	0.1	5.5	4.9
	0.1	3.3	5.2	2.6	4.7	0.1	5.5	4.9
Smaller Single Hits								
144*	1.7	11.8	1.5	6.4	4.7	2.7	15.7	265.0
	1.7	11.8	1.5	6.4	4.7	2.7	15.7	6.4
191*	3.4	2.9	-1.3	0.8	119.3	-1.6	-0.3	2.1
	3.4	2.9	-1.3	0.8	0.9	-1.6	-0.3	2.1
157*	0.6	-0.9	-0.4	-1.1	-0.2	-0.8	24.5	-0.6
	0.6	-0.9	-0.4	-1.1	-0.2	-0.8	-0.5	-0.6
5*	3.4	15.6	12.7	14.9	20.2	6.1	4.1	8.3
	3.4	15.6	12.7	14.9	9.3	6.1	4.1	8.3
164*	90.4	217.0	74.5	84.5	65.3	75.6	101.8	84.2
	90.4	82.3	74.5	84.5	65.3	75.6	101.8	84.2
Double Hits								
6*	7.3	152.4	1.5	3.6	2.2	2.7	164.5	0.8
	7.3	3.0	1.5	3.6	2.2	2.7	3.0	0.8
70*	0.1	38.4	-4.1	-2.1	38.2	1.8	2.6	2.1
	0.1	0.1	-4.1	-2.1	0.1	1.8	2.6	2.1
45*	192.8	51.1	39.9	103.3	22.7	33.5	28.9	42.2
	36.4	51.1	39.9	36.4	22.7	33.5	28.9	42.2
47*	20.0	29.5	34.3	34.6	392.1	163.1	9.9	31.1
	20.0	29.5	34.3	34.6	26.6	26.6	9.9	31.1
176*	11.1	10.5	23.0	5.5	4.7	26.7	5.5	2.1
	11.1	10.5	6.6	5.5	4.7	6.6	5.5	2.1
82*	93.1	412.2	1.5	4.5	208.6	6.1	11.4	4.2
	93.1	20.1	1.5	4.5	20.1	6.1	11.4	4.2

Figure 5

Bull's Eye Soft Sum

Raw

Corrected

Figure 6

E866 Bull's Eye PMT Response vs Distance

Figure 7

Bull's Eye, Run 14535

Figure 8

Bull's Eye, Run 14535

Figure 9

Bull's Eye, Run 14535

Figure 10

Bull's Eye, Run 14535

Figure 11

Bull's Eye, Run 14535

RMS Z from BE vs A from ZCAL, Spec2 and Beam Triggers

Figure 12