Beam Characterization and Verification

Detector Components and Arrangement

The beam uniformity and flux are determined using an array of five particle detectors. Each detector consists of Bicron BC-400 scintillator, a Bicron BC-634A optical coupling pad, a Hamamatsu R1635 photomultiplier tube, and a Hamamatsu E1761-04 tube base. Four of the detectors are fixed in position as show in Figure 1 and set up to measure beam particle counting rates continuously at four characteristic points, each 1.64 inches (4.71 mm) away from the beam axis. A removable fifth detector is used to measure particle counts directly at the beam axis. The sensitive area of each detector is defined by a 0.1 cm^2 aperture, while the intrinsic efficiency of the scintillators is 100% for all practical purposes.

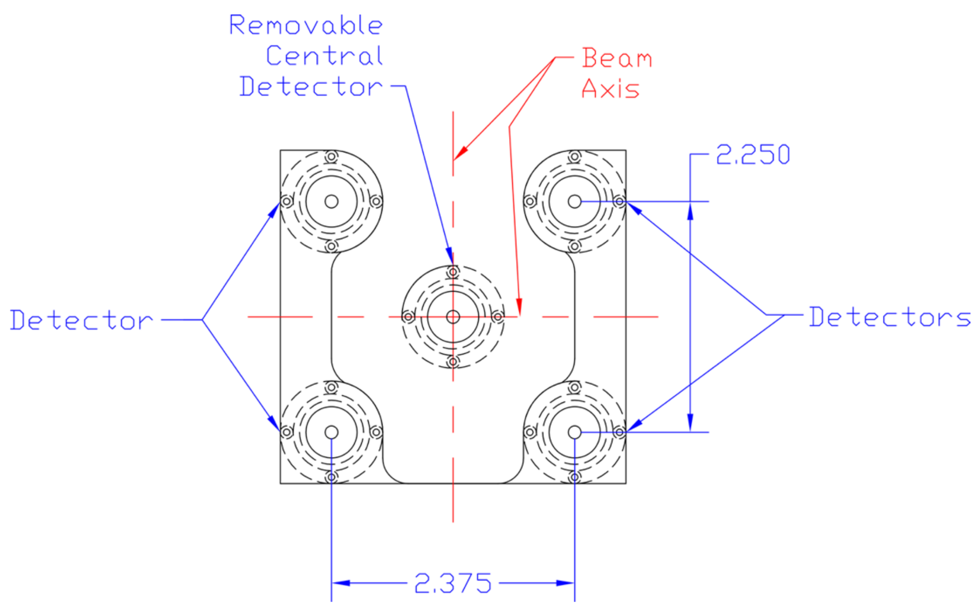

Figure 1: Detector arrangement with removable central detector also shown.

Beam Characteristics

The beam uniformity (ranging from 0 to 100%), the axial gain (%), and the beam flux (in particles/cm^2/s) are quantities used to characterize the beam. These quantities are determined by the control software and are based on the detector counting rates. The values are displayed in the SEUSS software and are updated once every second.

The beam uniformity is calculated by the following equation:

$$uniformity(\%) = 100/(1 + \frac{\sigma}{n_{av}}) \ ,$$

where

$$n_{av} = \frac{n_1 + n_2 + n_3 + n_4}{4}$$

and

$$\sigma = \sqrt{\frac{(n_1 - n_{av})^2 + (n_2 - n_{av})^2 + (n_3 - n_{av})^2 + (n_4 - n_{av})^2)}{3}}$$

Here n_{av} is the average counts per second of the four corner detectors surrounding the beam. In the equations above n_i ($i=1,2,3,4$) are the counts per second from these corner detectors. Note that when $n_1 = n_2 = n_3 = n_4 = 0$, uniformity is set to zero.

An additional gauge of beam uniformity is the central shift (cs). The central shift is a percentage of how far the beam is off from the central beam axis. It is calculated as follows:

$$cs(\%) = \frac{\sqrt{\left(\frac{n_{TL} + n_{BL} - n_{TR} - n_{BR}}{\sum n_i}\right)^2 + \left(\frac{n_{TL} + n_{TR} - n_{BL} - n_{BR}}{\sum n_i}\right)^2}}{\sqrt{2}} \times 100\%$$

Here, n_i ($i = BL, BR, TL, TR$) is the counts per second from each detector (TL=top left, BR=bottom right, TR=top right, BL=bottom right).

While the central detector is in place along the central beam axis, the beam flux (particles/s/cm^2) is determined solely by the counts per second measured by the central detector. Once the central detector is removed from the central beam axis the following equation is used to determine the beam flux:

$$flux(particles/s/cm^2) = \frac{n_{av} \cdot ag}{A}$$

Where n_{av} is the average counts per second from the four corner detectors (equation given above), A is the sensitive area of each detector (A=0.1 cm^2) and ag is the axial gain. The axial gain is the ratio of the counts per second of the central detector to the average counts per second of the four corner detectors and is given by the following:

$$ag = \frac{n_{cen}}{n_{av}}$$

The equation for n_{av} is previously given above. When the central detector is in place the axial gain is updated every time the central detector has accumulated at least 10,000 counts. While the central detector is taken out of the beam axis, the SEUSS software will use the last value calculated for the axial gain in determining the beam flux (unless otherwise specified) during each run.

The fluence, or total particle count per unit area (counts/cm^2), is determined by the following:

$$fluence = N_{av} \cdot ag$$

Where N_{av} is the average of the total counts from each of the corner detectors for the duration of a run and ag is the axial gain.

The average total counts from the four corner detectors can be expressed as:

$$N_{av} = \frac{\sum N_i}{4}$$

Where N_i (i=1 to 4) is the total number of counts from each detector for the duration of the run.

Electronics Verification

A simple electronics set-up is used for beam dosimetery in the Radiation Effects Facility beam-line. The output from each of five detectors is input into a separate channel on a LeCroy Model 428F Fan In/Fan Out NIM module. Each detector signal is split two ways, with one signal output going to the K500 control room to be viewed during detector bias adjustment, and a second signal output sent to a channel in a Phillips Scientific Model 710 eight channel discriminator. Each channel of the discriminator has its threshold set near 30 mV to remove false counts due to electronic noise. The discriminator output is forwarded to a LeCroy Model 2551 scaler. The SEUSS software interfaces with this module to retrieve counts viewed on-screen. An electronics diagram for particle detection is shown below in Figure 2.

Figure 2. Detector electronics diagram.

To verify the electronics set-up is working properly, a signal from a BNC model BH-1 Tail Pulse Generator is used in place of detector signals. The signal from the pulse generator is shaped to resemble the actual detector pulse. It is given an amplitude of approximately 70 mV and is split five-ways using a Lecroy Model 428F Fan In/Fan Out module. The split signal outputs take the place of detector inputs in the fan in/fan out module described is the previous paragraph. The signal frequency is measured using a Tektronix 2445 oscilloscope. The electronics are verified to be working correctly when this frequency equates with the counts per second observed using the SEUSS software. For further verification, the SEUSS software is used to take fluence measurements over 1-, 5-, and 15- minute durations. Results from a test taken at a pulser frequency of 1112 Hz are show in Table 1 below. In all instances the percent difference between measured counts and the counts calculated from the scaler frequency is less than %1.

	SEUSS Fluence	Counts from pulser	% difference
1 minute	66310	66720	0.6
5 minute	333900	333600	0.1
15 minute	1000000	1000800	0.1

Table 1. Comparison of pulser rate counts to counts seen by SEUSS software with pulser inputs placed directly into the fan in/fan out module.

This same procedure is then repeated with the pulser inputs being directly attached to the ends of the detector signal cables located in the beam line cave. Fluence measurements were taken with SEUSS at 1-, 5-, and 15-minute durations. The pulser frequency in this case was measured to be 1336 Hz. The percent differences in all instances were again less than %1. Results are shown in Table 2.

	SEUSS Fluence	Counts from pulser	% difference
1 minute	79530	80160	0.8
5 minute	401400	400800	0.1
15 minute	1202000	1202400	0.03

Table 2. Comparison for pulser rate counts and counts read by SEUSS software with pulser inputs placed in beam line cave.

PMT Efficiency

A stroboscope (General Radio 1531-AB Strobotac) is used to test photomultiplier tube (PMT) efficiency. The stroboscope is placed in front of the five beam line detectors and set to a known frequency. This frequency is calibrated using the stroboscope's calibrations procedure from the user manual. The uncertainty is also determined as described in the stroboscope user's manual. Using the SEUSS software, total-count measurements at various frequencies are taken for 1-minute, 5-minute, and 15-minute intervals. Frequencies sampled are 3600 and 24000 flashes per minute. A sample of such data is show in Table 3. In all cases, the measured counts are within the uncertainty of the flashes per minute produced by the stroboscope.

	SEUSS Fluence	Flashes per minute	% difference
1 minute	3571	3600 (+/- %1.2)	0.8
5 minute	17920	18000 (+/- %1)	0.4
15 minute	53840	54000 (+/- %1)	0.3

Table 3. Comparison for flashes per minute from stroboscope and counts read by SEUSS software at increasing time intervals.