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Fermilab

THE SUPERBUCKET MONITORS IN THE PROTON AREAS

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The Superbucket

The spill structure at Fermilab has components due to the Main Ring RF of 18.9 ns apart and 1 ns in width. For a 1.2 second spill length, there are 6×10^7 RF buckets. The number of protons in one bucket varies with the beam intensity. For a beam intensity of 6×10^{10} protons per pulse there is an average of one thousand protons in each bucket.

The superbucket comes about when an RF bucket contains significantly more protons than an average bucket. The superbucket causes accidental triggers especially in the double-arm spectrometer experiments.

Figure 1 shows three types of events in a double-arm spectrometer experiment. The good event occurs when a neutral particle is created in the target by a single proton and subsequently decays into two oppositely charged particles. One spectrometer arm bends the charged particles up and the other down. The signal produced by the charged particles on the scintillation counter at each spectrometer arm is used to make a coincidental event trigger. The background related coincidence is caused by the charged particles which are created in the target by a single proton. The intensity related accidental coincidence is worsened by the superbuckets, which occurs when charged particles are created in the target by two different protons.

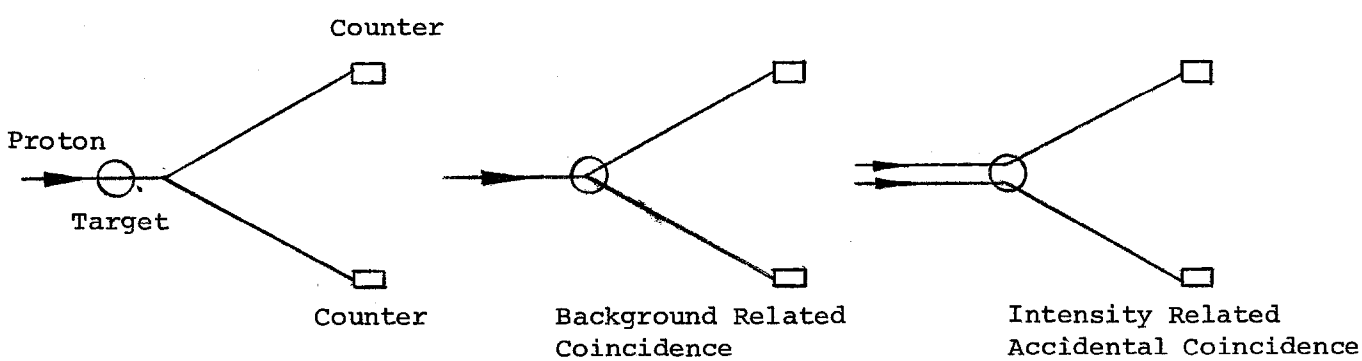


Fig. 1. Double-arm Spectrometer Events

The Cerenkov Counter

A Cerenkov counter furnishes us a good apparatus for the superbucket monitor for the following reasons:

1. It provides a fast signal
2. The signal output is proportional to the number of protons in an RF bucket.

In order to detect the fast signal an Amperez 56 AVP phototube is used. A voltage divider of 10th stage dynode output is built for preserving a fast rise time.

We have installed one Cerenkov counter each in Proton West and Proton East. For Proton West, it is located at the downstream end of the 50 foot pit; for Proton East, it is located at the upstream end of the target box. One more counter is ready to be installed in Proton Center.

The Cerenkov signal is split 1/2 each to the experimenters' porta-kamp and to the Proton Pagoda. At present, we are monitoring the percentage of superbuckets during the entire spill time. It is also possible to study the RF structure in a selected interval with proper gating signals.

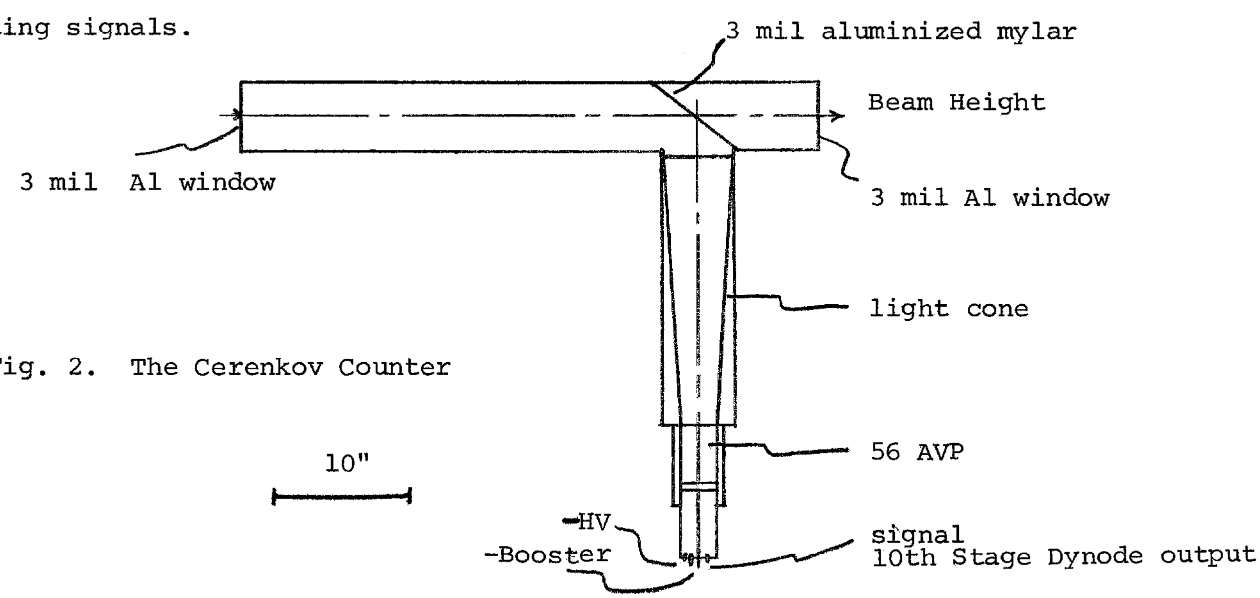


Fig. 2. The Cerenkov Counter

As shown in Figure 2, the beam passes through two 3 mil aluminum windows and a 3 mil aluminized mylar mirror which is mounted at 45°. The Cerenkov light produced by the 400 GeV proton beam traversing the one meter path length is reflected into the light cone, and is viewed by the 56 AVP cathode surface.

The number of photons produced per meter of path length in air is 23 with $n - 1 = 2.94 \times 10^{-4}$, $\beta \to 1$, and $0\ max = 1.38^{\circ}$. The sensitivity of the counter is 23 x 7% x 40% = 0.6 photoelectrons per proton, where the 7% is the quantum efficiency of the 56 AVP phototube and 40% is the light collecting efficiency.

Consider a beam intensity of 6×10^{10} protons per pulse with spill length of 1.2 second, the amplitude of the Cerenkov signal can be estimated as follows:

$$I = \frac{V}{R} = \frac{V}{50} = \frac{6 \times 10^{7} \times 10^{3} \times 1.6 \times 10^{-19} \times g \times \varepsilon}{1.2}$$

where: $g = 10^{6}$ is the gain of the 56 AVP phototube

$\varepsilon = 0.6$ is the sensitivity of the counter

Then we have v = 250mv.

We have observed the signal from -50 mv to -300 mv of 6 ns width and 20 ns apart with beam intensity from 10^{10} to 10^{11} protons per pulse correspondently as shown in Figure 3.

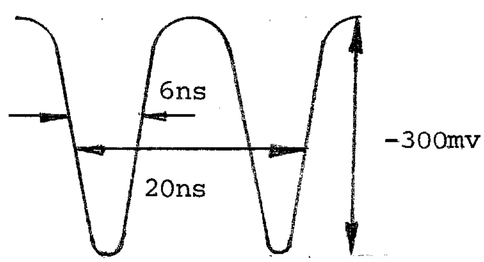


Fig. 3 Cerenkov Signal

The Scalar Outputs

The logic system is shown in Figure 4. The signal coming to the Pagoda is fed into an eight fold fanout. Each fanout signal goes to a discriminator. The discriminator threshold with 7 ns output is scaled at 30 mv per step. There are eight threshold levels from -30 mv to -240 mv. Each discriminator signal goes to a scalar.

At the -30 mv threshold level, the scalar has output only for a pulse height below the -30 mv level, similarly for the other threshold level settings. The scalar outputs can be seen on Page 14, C2 for Proton West; and on Page 14, C3 for Proton East.

The output is an exponentially decreasing function after the successive discriminator threshold level settings and in the absence of superbuckets as shown in Figure 5.

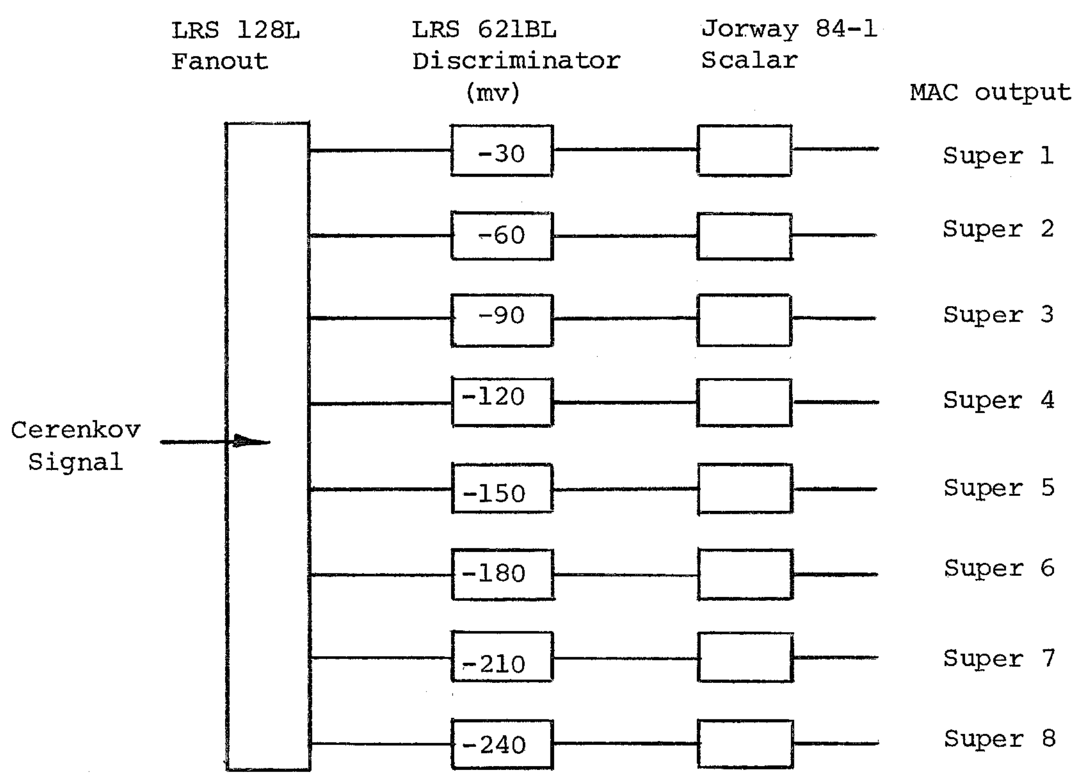


Fig. 4. The Logic System

On the other hand, in the presence of the superbuckets the scalar output will be decreasing slowly as shown in Figure 6.

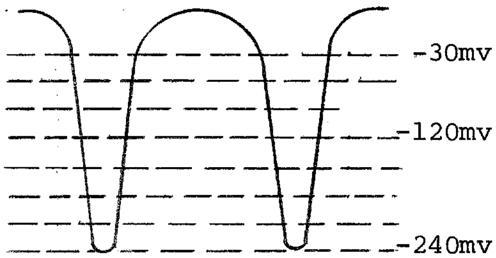


Fig. 5. Average Bucket

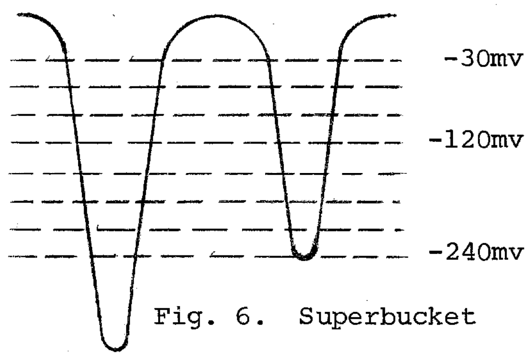


Fig. 6. Superbucket

The Superbucket Display

The differences between the scalar outputs are used to form an eight-channel pulse height analyzer. The mean pulse height in channel is defined as:

$$\text{Mean} - \frac{\Sigma(\text{Difference}) \times (\text{Threshold})}{\Sigma \text{ Difference}}$$

$$\frac{\sum_{1}^{8} \{Ni - (Ni + 1)\} (i + 1/4)}{\sum_{1}^{8} \{ Ni - (Ni + 1) \}}$$

with $N_9 = 0$

where: Ni = ith scalar output

Ni - (Ni + 1) = Difference Output

Threshold = i + 1/4, due to the exponential decay in pulse height, the average count between the channels is assumed to be 0.25 instead of 0.5.

The % of superbuckets is defined as the ratio of counts near the tail end of the differential spectrum, i.e., the overflow, to the total differential counts.

For example if the mean is found to be 1.5 and 3 times the mean is defined as the presence of superbuckets, then:

$$\text{The \% of superbuckets} = \frac{\sum_{4.5}^{8} \text{overflow}}{\sum_{1}^{8} \{Ni - Ni + 1\}} \times 100$$

Figure 7 shows the difference between the scalar outputs, the mean value in channel, and the overflows.

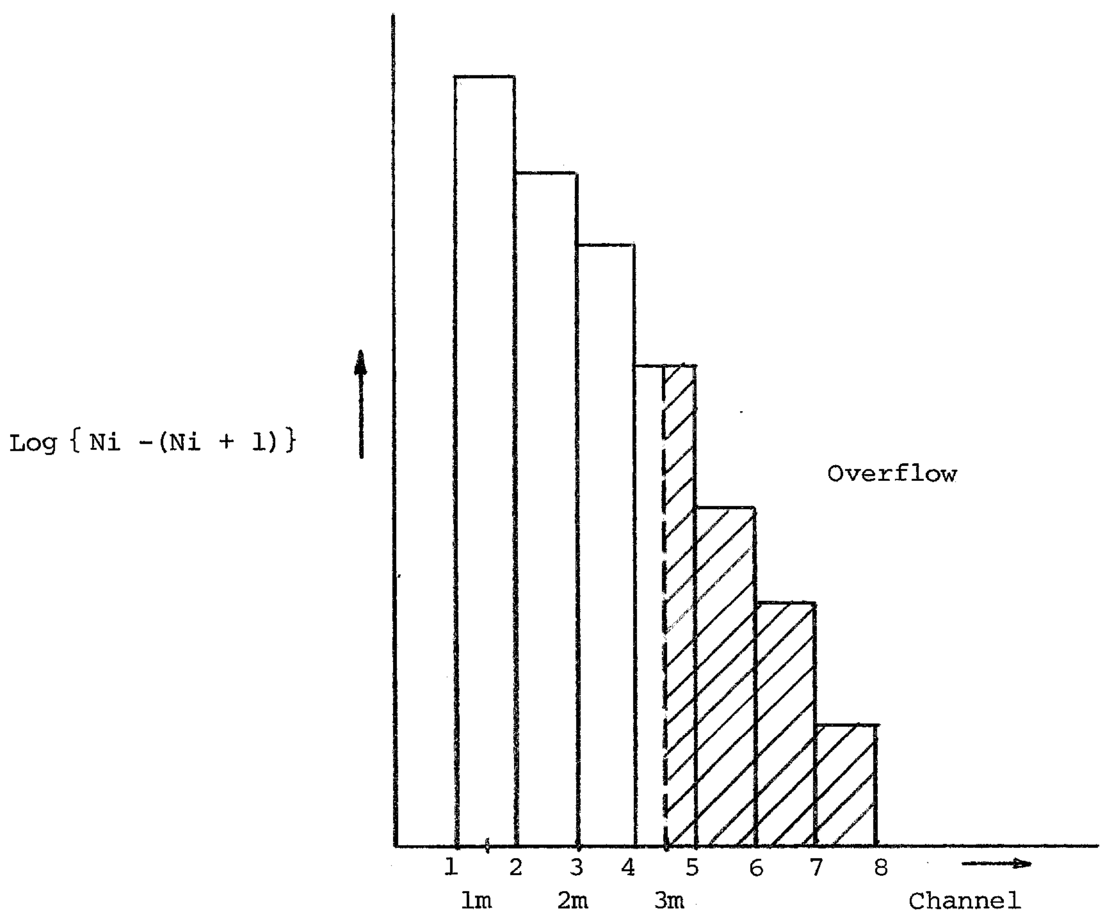


Fig. 7. The Mean Value

The computation is done by the PDP-11. The procedure is listed below:

1. Type CONTROL and C to enter PDP-11 mode
2. Exp ? Type 95 < CR >
3. RUN SUPER < CR >
4. Type CONTROL and C to exit
5. KILL TTnn, where nn is your console number
6. Type CONTROL and F to return MAC mode

A typical display for Proton West is shown in Figure 8. The first column shows the scalar output, the second column shows the differences, the bottom line shows the % of superbucket. This % should be small for a good and steady beam.

The Proton East superbucket monitor is displayed on TV channel Number 26. As shown in Figure 9, the left column shows the differences. The mean, % of superbucket and the duty factor are listed at the bottom. A fixed number of 6×10^7 is stored in the scalar channel number zero, with the assumption that there are 6×10^7 counts greater than the -30 mv threshold level. This number is also used for normalization, i.e.,

$$\text{Mean} = \sum_{0}^{8} \{ Ni - (Ni + 1) \} \ (i + 0.25)/6 \times 10^7$$

$$< \text{Mean}^2 > = \sum_{0}^{8} \{ Ni - (Ni + 1) \} \ (i + 0.25) \ (i + 0.25)/6 \times 10^7$$

$$< \text{Mean} >^2 = \text{mean} \times \text{mean}$$

$$\text{The \% of superbucket} = \frac{\Sigma \ 8 \times \text{mean} \times 100}{6 \times 10^7}$$

$$\text{The duty factor} = \frac{< \text{mean} >^2}{<\text{mean}^2>}$$

For Proton Center, E-288 displays the superbucket monitor on TV channel No. 4. is shown in Figure 9. It displays the beam quality, % of superbucket and the spill. The beam quality consists of superbuckets, slow spill and intensity with number ranges from 1 to 9 respectively.

As the proton beam hits the target, the double arm magnetic spectrometer deflects the muons vertically to the upper and lower arm. A scintillation counter V_4 detects the muon on each arm. The % of superbuckets is defined as the ratio of the out of time coincidence over the in time coincidence.

$$\text{The \% of superbuckets} = \frac{V_4^{up} \cdot V_4^{down} \text{ (delayed 4RF buckets)}}{V_4^{up} \cdot V_4^{down}} \times 100$$

The presence of a superbucket would increase the in time coincidences and in turn cause the % to go down. On the other hand, for an average RF bucket in the in time coincidental rate is low and the % is high.

The slow spill quality factor is defined as the ratio of the coincidence over the delayed 4 RF buckets single rates.

The slow spill quality factor =

$$\frac{V_4^{up} \cdot V_4^{down}}{V_4^{up}\, V_4^{down} \text{ (delayed 4 RF buckets)}} \cdot \frac{T \text{ (spill length)}}{t \text{ (18.9 ns)}} \times 10$$

The size of the RF buckets is monitored by a Cerenkov counter which is located about 30 feet upstream of the target.

Results and Comparisons

We have compared the superbucket monitors in P-E and P-W vs. P-C. As shown in Figure 10, the P-E superbucket varies from 1.1% to 2.2%, and the P-W superbucket varies from 0.02% to 1.46% while P-C changes from 88% to 76%. Quite often there is no correlation among the three monitors for an average beam.

When the superbuckets are bad, it does show on all monitors. It is interesting to note that the P-W and P-E monitors track each other more than the P-C one does.

Figure 11 shows the P-C slow spill quality factor vs. the main ring spill duty factor. The general trend is that the former varies from 1 to 9 while the later changes from 50% to 90%.

Figure 12A and 12B show the P-W trigger, slow spill and the Cerenkov signal. When the spill is bad, the Cerenkov signal shows a bunching effect, and the scalar outputs decrease slowly, which in turn causes the multiple triggers. For a good beam the trigger rate is small, the spill is good, the Cerenkov signal is small, and the scalar outputs decrease exponentially.

In order to keep the trigger rate small, it is important to maintain a steady beam intensity, since the superbucket increases quadratically with the intensity.

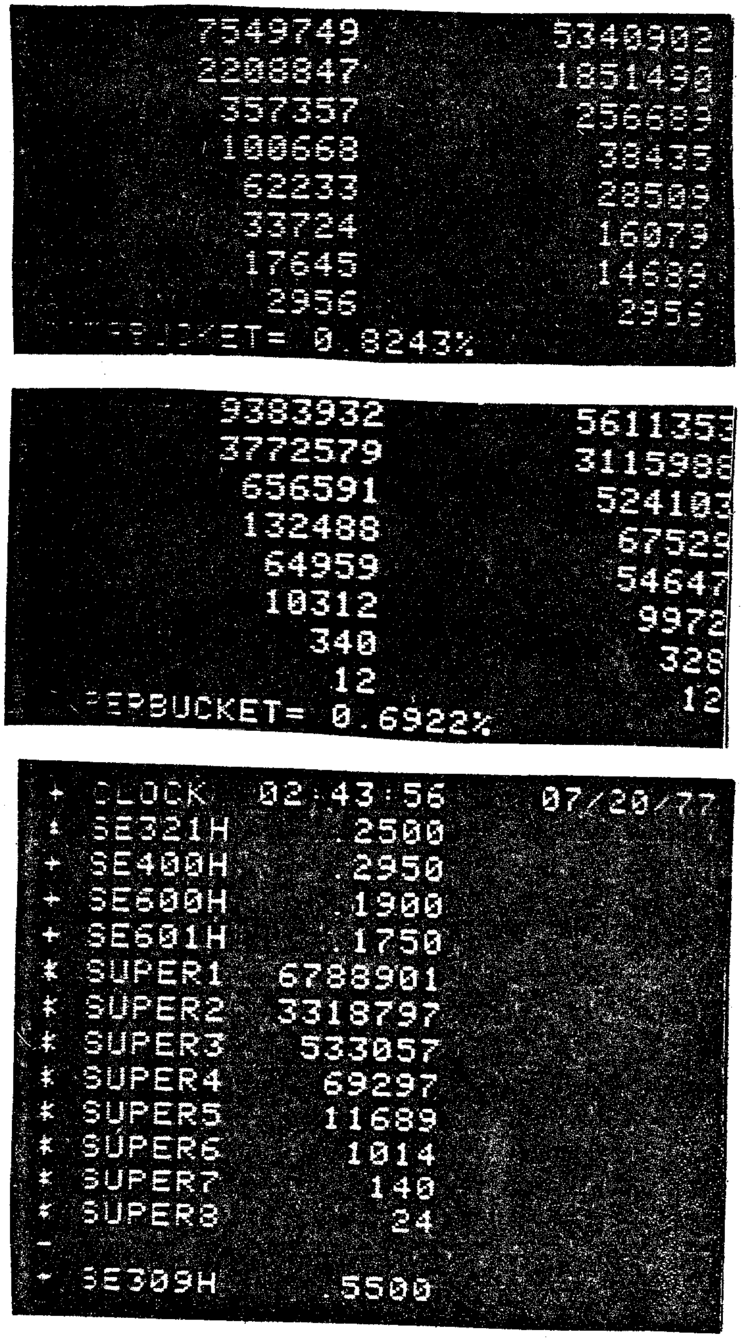
Fig. 13 shows the Cerenkov signals during E-567 runs

When the Cerenkov spill signal is triggered by a line trigger, it becomes a ripple monitor for a Transrex magnet power supply. The unbalanced phase, or missing phase of the power supply produces ripple during spill time. The ripples cause 60 Hz or its multiples up to 720 Hz components in the spill structure. Whenever a poor spill occurs for the above mentioned reason, we would start plotting the power supplies and request the Main Control Crew Chief to do the same. We have localized the faulty power supplies by this means many a times.

In the future we plan to display the superbucket by 8080 or Z80 microprocessor. We are testing a new tandem Micro-channel Plate which was on loan from the Hammamatzu Corporation. We hope to use it in place of the 56AVP for detecting Cerenkov light.

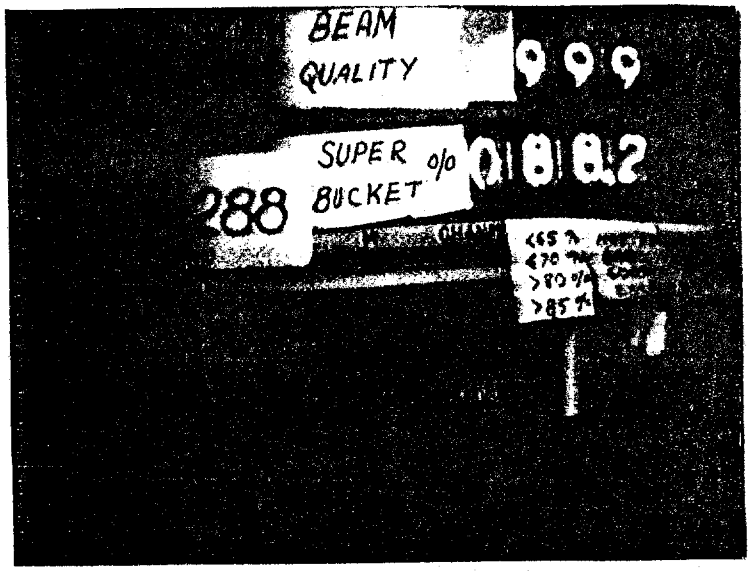
Acknowledgement

We thank Dr. B. Cox for initiating the project, and Dr. C. T. Murphy for support and encouragement. We are grateful to Dr. J. Cronin for giving us the Cerenkov counter in P-E and for useful consultation; Dr. R. Sumner for advice and for displaying the P-E superbucket. Finally we are indebted to L. Alm, R. Hawel, M. Kleczewski, B. Kramper and F. McIntosh of Proton for their technical assistance.

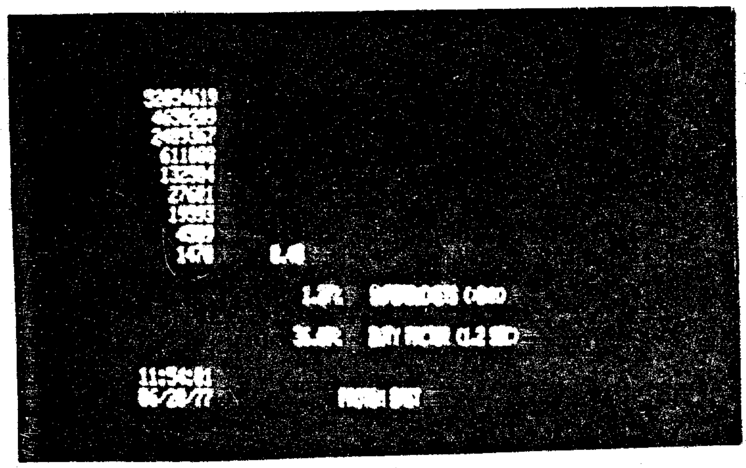


Page 14, C2 - PW

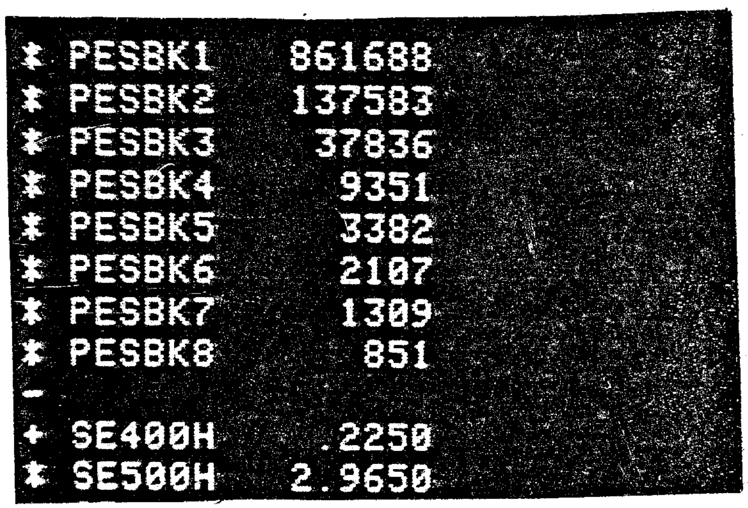
Fig. 8 PW Monitor



Channel #4
PC



Channel #26
PE



Page 14, C3 - PE

Fig. 9 PC and PE Monitors

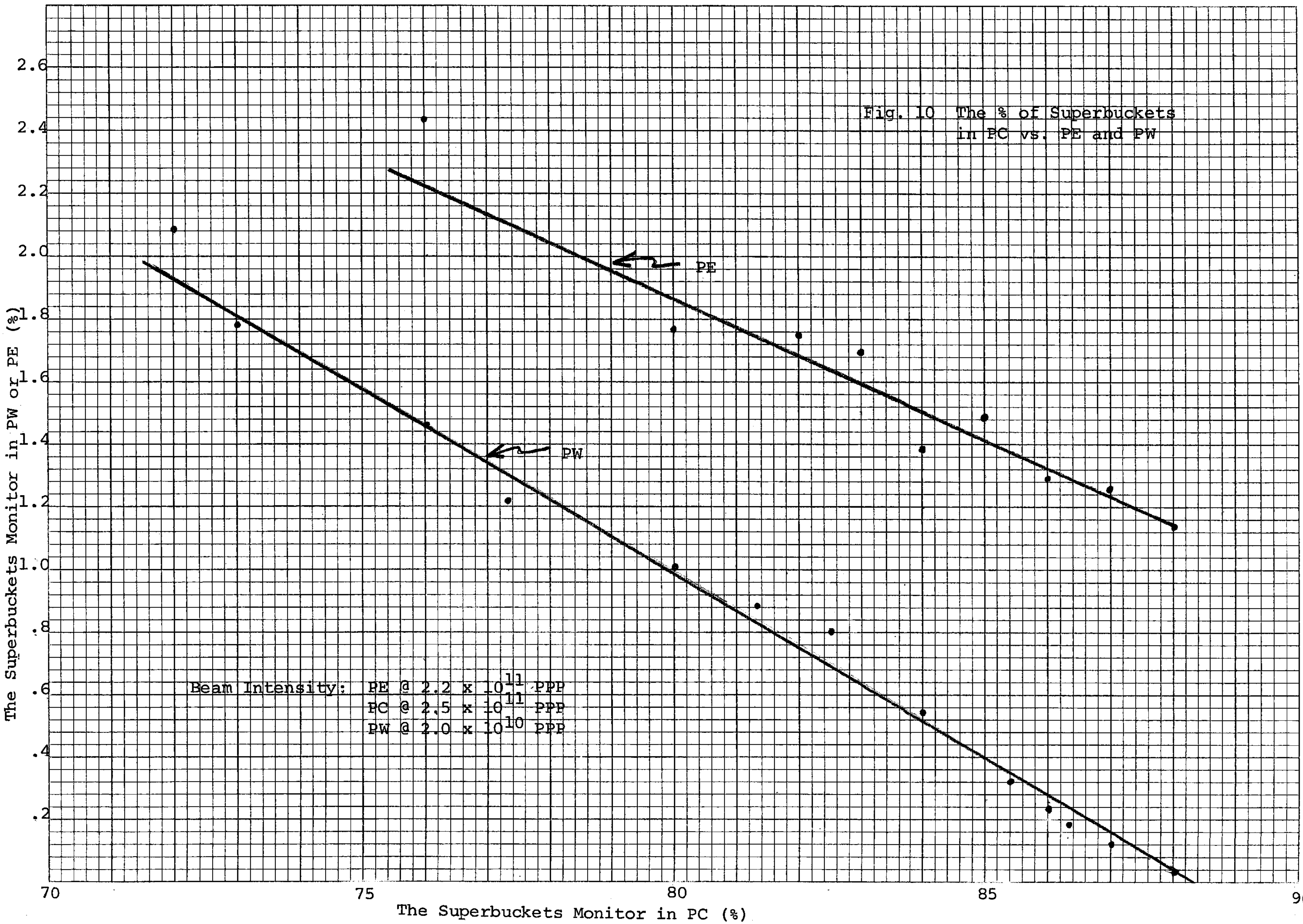


Fig. 10 The % of Superbuckets
in PC vs. PE and PW
PE
PW
Beam Intensity: PE @ 2.2 x 10^11 PPP
PC @ 2.5 x 10^11 PPP
PW @ 2.0 x 10^10 PPP
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
70
75
80
85
90
The Superbuckets Monitor in PW or PE (%)
The Superbuckets Monitor in PC (%)

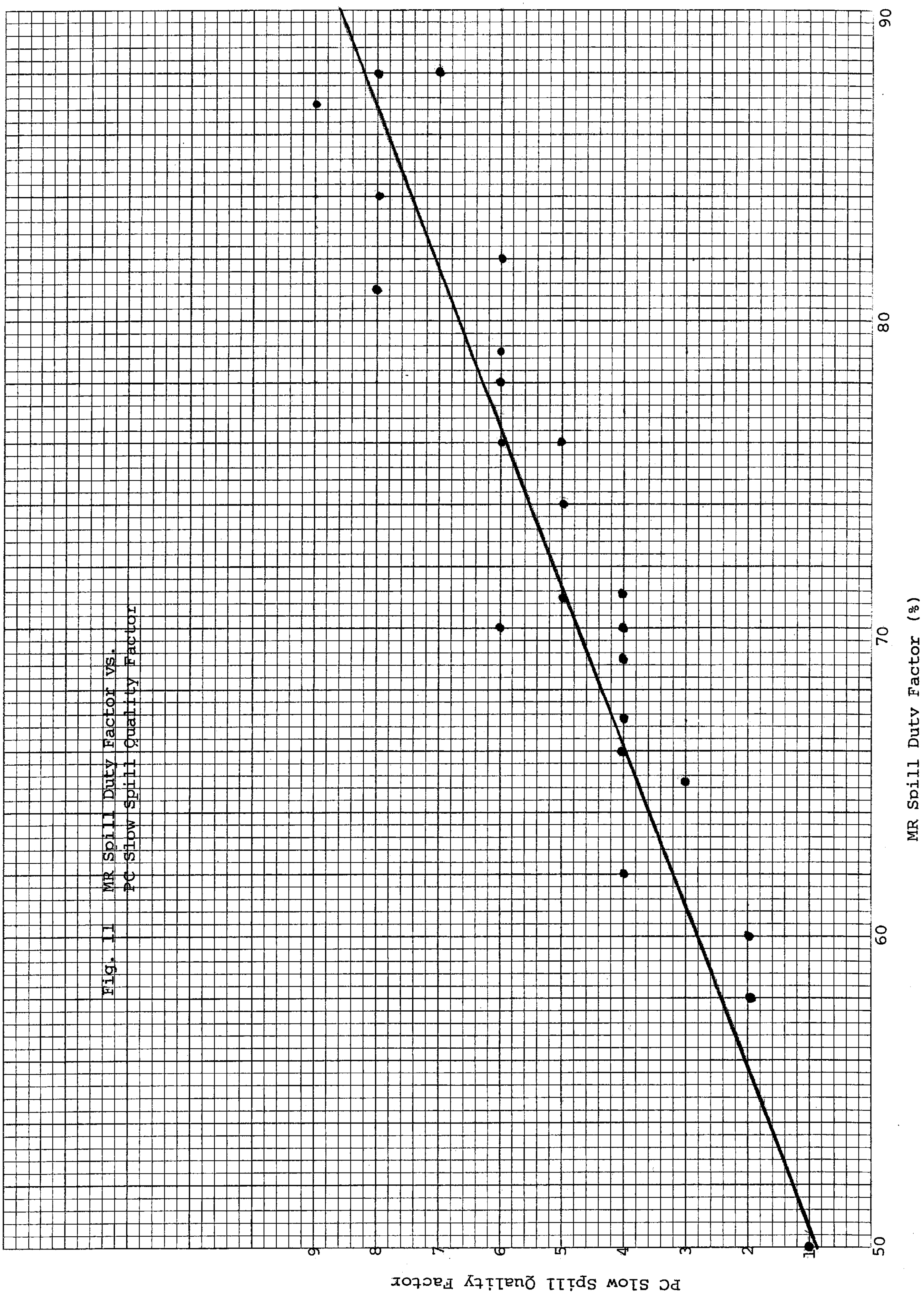
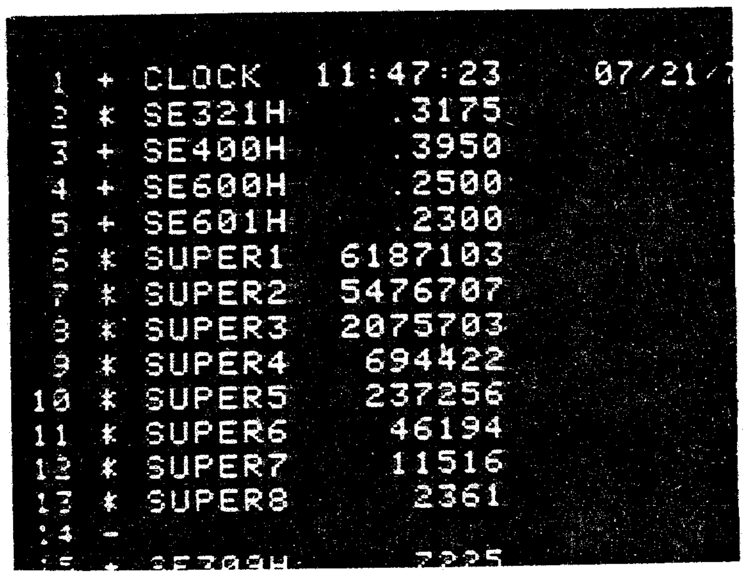


Fig. 11 MR Spill Duty Factor vs. PC Slow Spill Quality Factor

Trigger

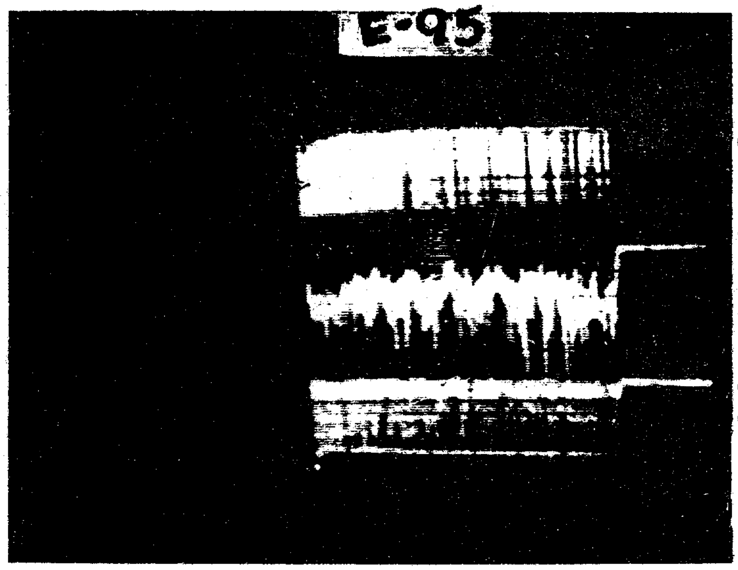
Spill

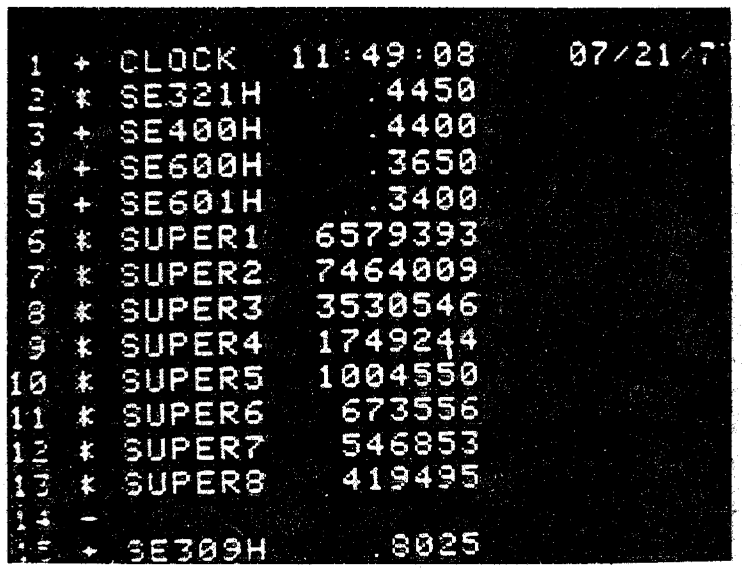
Cerenkov
Counter



PW Good Beam

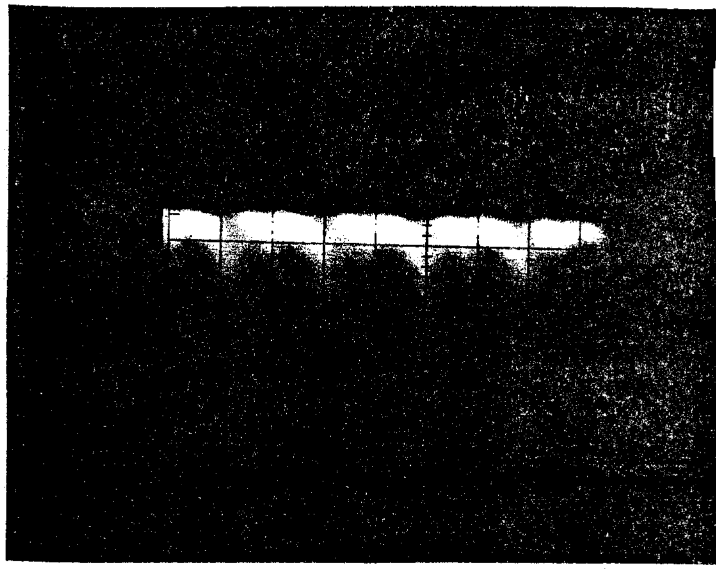
Fig. 12a. Good Beam - PW



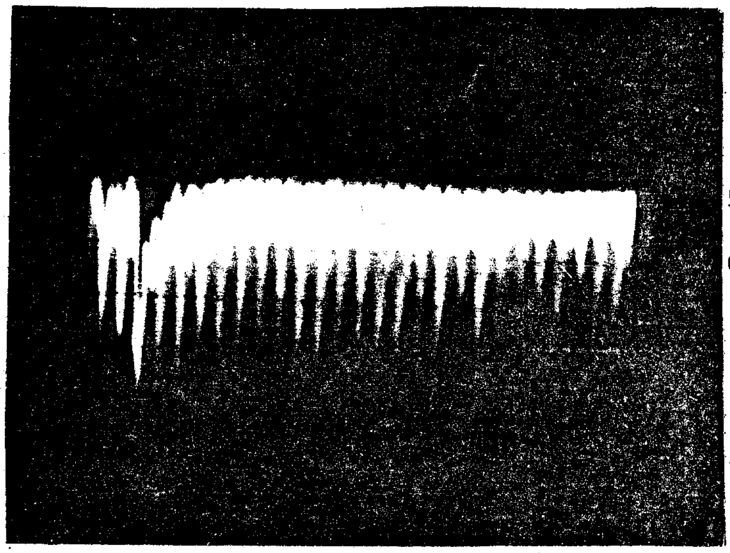


PW Poor Beam

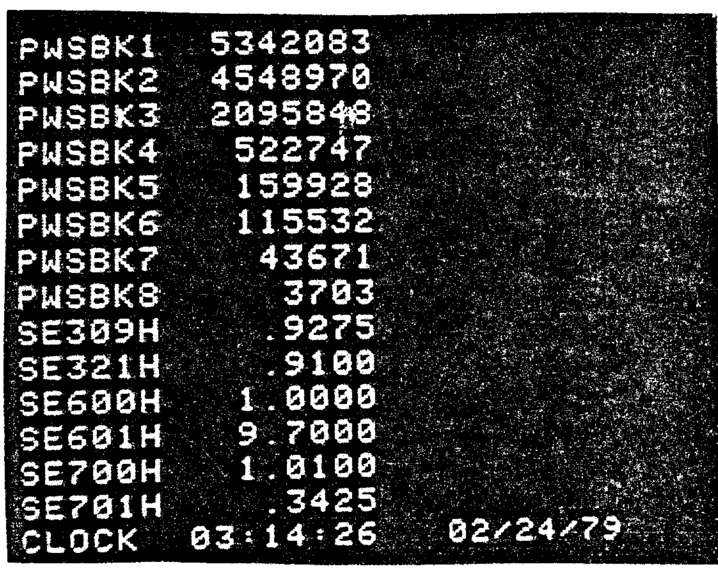
Fig. 12b Poor Beam - PW



10ns/cm
50mv/cm



50μs/cm
0.2v/cm



PW Superbucket
Monitor during
E-567 runs

Fig. 13 Cerenkov Signals