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TITLE: RESOLUTION OF THE ARCS AND LINAC BPM
SYSTEMS

A. Introduction

On the Linac, the number of Beam Position Monitors is such that multiplexing could be avoided and each monitor is instrumented with its own electronics, a double width Camac module processing two difference signals Δx and Δy and a sum signal; a single pass of the beam yields a snap-shot picture of the trajectory. In the Arcs, the number of processing modules has been reduced by a factor of 10 with multiplexing and by the use of wide-band solid state switches. For each beam pulse, 4 monitors are "read" simultaneously, at 14 locations along each arc, and it takes 10 beam passes to reconstruct the complete e^+ and e^- trajectories. The monitors are hardwired to be "X" only or "Y" only and two signals are processed (as opposed to 3 signals for the Linac) with a single width Camac module and some additional wide-band electronics called "RF Head".

Another BPM system is being developed for the long monitors of the FF. (see J.-C. Denard's SLAC Memorandum of March 12 '86). This is a special application for measuring the position of both e^+ and e^- bunches in the neighborhood of the interaction point. This system is mentioned here for the sake of completeness but is too different to be compared to the others.

The purpose of this note is to compare the resolution obtained with two types of monitors, the Linac model and the Arcs model with their respective electronics and give the reader some basis for extrapolation when considering future monitors and processing electronics.

B. Conclusion:

The curves of figure 1 represent the expected resolution of each system as a function of the number of particles and for monitors equipped with the longest cables. (worse case)

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Below 10^{10} particles the Linac system yields a better resolution because its pick-up electrodes couple a little bit more signal and its cables are twice shorter. Beyond 10^{10} the Arcs system exhibits a resolution which is inversely proportional to the signal-to-noise ratio and decreases all the way down to the digitizer least count equivalent, whereas for the Linac, the electronics is hindered by a coarser granularity of its digitizer and a noise figure which deteriorates with increasing signal. (the attenuator is ahead of the amplifier).

C. Key to the appendix:

The appendix begins with a sketch of both systems, each element of which is characterized by an appendix item number indicated on figures 2 and 3. Figure 4 is a plot of the measured signal strength as a function of cable length, viewing the beam pulse with different filters; the 2 ns Gaussian filter is part of the trigger circuit, and the 15 ns Gaussian filter is included in the signal processing chain. Ideally this filter should be located at the output of the amplifier (an ideal amplifier). On figure 4, the signal strengths for 0 cable lengths have been calculated with the relationship of figure 5. The same relationship is also applied to the calculation of the chain output signal-to-noise ratios. (Assumptions: the beam looks like a line charge in the center of the beam pipe; the bunch length is smaller than t_0 ; electrode edge effects are ignored).

D. Appendix

	LINAC	ARCS
1	$\phi/2\pi = 0.074$ $2t_0 = 0.8 \text{ nS}$	$\phi/2\pi = 0.125$ $2t_0 = 0.35 \text{ nS}$
2	Coaxial line type RG 223 95, 121 or 145 feet	Coaxial line type RG 223 40 to 288 feet
3	Power divider loss: 3 dB	Linear resistive adder loss: 6 dB
4	Gaussian low-pass filter $\sigma = 7.5 \text{ nS}$	Gaussian low-pass filter $\sigma = 1 \text{ nS}$
5	Hybrid junction loss: 6 dB	Multiplexer (solid state switch) loss: 1 dB

6		Power combiner Loss: 3 dB
7	Solid state calibration switch; loss: 1 dB	Power divider loss: 3 dB
8	Electronic attenuator -6, -36 dB range	Gaussian low pass filter $\sigma = 7.5$ nS
9	Wideband amplifier gain: 47 dB Bandwidth: 1-50 MHz	Wideband amplifier gain: 36 dB Bandwidth: 1-50 MHz
10		Attenuator-Amplifier gain: -10 dB, +10 dB
11	Track-and-Hold switch	Track-and-Hold switch
12	Buffer (+20 dB)	Buffer (+14 dB)
13	Analog-to-digital converter. 10 bits bipolar	Analog-to-digital converter. 12 bits bipolar
14	Resolution: $\Delta x = \frac{N}{S} \frac{R}{2}$ R = 10 mm N = rms noise out of difference channel S = sum signal	Resolution: $\Delta x = \frac{\sqrt{2} N}{S+S} \frac{R}{2}$ R = 8.7 mm N rms noise and S signal out of identical channels
15	Sum signal @ 15 nS, 5×10^9 particles and with the longest cables: 257 mV	Sum signal @ 15 nS, 5×10^9 particles and with the longest cables: 53 mV
16	Amplifier maximum linear output: 500 mV	Amplifier maximum linear output: 2000 mV
17	noise at amplifier output (for minimum attenuation) 1.5 mV rms	noise at amplifier output 0.9 mV rms

18	output signal-to-noise ratio for 5×10^9 particles $S/N = 171$	output signal-to-noise ratio for 5×10^9 particles $S/N = 59$
19	Resolution @ 5×10^9 part. $\Delta x = 29\mu m$	Resolution @ 5×10^9 part. $\Delta x = 52\mu m$
20	Maximum output signal-to-noise ratio for for higher bunch charge: 333	Maximum output signal-to-noise ratio for for higher bunch charge: 2226
21	Optimum resolution of $15\mu m$ reached at 9.7×10^9 particles	Optimum resolution of $2\mu m$ reached at 1.6×10^{11} particles
21	Minimum Bunch charge for triggering 5×10^8 particles	Minimum bunch charge for triggering 1×10^9 particles

Fig. 1. System resolution as a function of the bunch number of particles and for the longest signal cables; triggering threshold: 5×10^8 Linac, 1×10^9 Arcs.

Fig. 2. Arcs BPM system

Fig. 3. Linac BPM system

Fig. 4. Arc monitors peak signal for 5×10^9 particles as observed with two filters: a 2 nS filter (trigger circuit) and a 15 nS filter (processed signal).

$$v_p = Q \frac{\phi}{2\pi} \frac{Z_0}{2\sqrt{2\pi e}} \frac{2t_0}{\sigma^2} \quad t_0 < \sigma$$

Q Bunch Charge

Z_0 Strip Impedance

t_0 Strip Electrical Length

2σ Width of Filter Impulse Response

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Fig. 5. Relationship for the calculation of the peak signal induced by the beam in a strip line and viewed with a nearly Gaussian filter.

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