

## Proposal to Measure the Flux of Circulating Muons in the Debuncher.

### 1. Summary

We request two dedicated shifts of machine study time to measure the flux of muons which circulate in the Debuncher. This measurement would be made with the Main Ring and Debuncher operating in stacking mode with standard Main Ring intensities of  $1 - 2 \times 10^{12}$  protons per pulse. The measurement would be made using existing instrumentation which can be checked out parasitically. The only additional equipment required for this measurement is a remotely controlled radiator consisting of 0.5 - 1.0 radiation lengths of lead which would be installed at the end of the AP-2 transport line.

### 2. Motivation

If the Debuncher does function as an efficient muon storage ring, then the ring can provide muon and electron neutrino beams of precisely measurable flux. This neutrino beam, if of sufficient intensity, can open new opportunities in  $\nu_e$  physics and provide the means to explore in detail  $\nu_e \rightarrow \nu_\tau$  mixing. The case for the existence of a 17 KeV neutrino has been strengthened by statistically compelling new results [1] from  $^3\text{H}$   $\beta$  decay measurements using a tritium implanted Si(Li) detector. However, measurements of this type have never been confirmed by a magnetic spectrometer experiment and seem to conflict with astrophysical and cosmological constraints [2]. The controversy over the existence of a 17 KeV neutrino has, if anything, intensified and is likely only to be resolved by setting new stringent limits on  $\nu_e \rightarrow \nu_\tau$  mixing from accelerator experiments. The storage ring approach to this study is very attractive since flux normalization can be very precise, the neutrino energy spectrum is very well understood, and backgrounds should be very small and precisely calculable.

Assuming that an experimental program using the Debuncher as a muon storage ring runs parasitically with normal Collider operation, the available neutrino beam would be  $\bar{\nu}_e + \nu_\mu$  from  $\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$  decay. However,

a large flux of  $\bar{\nu}_\mu$  would also be present from the decay of pions in the Debuncher,  $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$ . Events from  $\bar{\nu}_\mu$  interactions can be differentiated by timing from events produced by neutrinos from  $\mu$  decay.

### 3. Calculated Muon Fluxes in the Debuncher

To estimate the muon flux which is captured in the Debuncher, we use a mixture of experimental data coupled with relatively straight-forward calculations. Figure 1 shows a schematic layout of the production target, the beam transport line between the target and Debuncher (AP-2) and the Debuncher ring. During Collider running, the pion fluxes have been measured at a variety of locations shown in Figure 1, viz.: at quads 704, 728, and 733 (using ion chambers), and at location D102 in the Debuncher ring (using an rf pickup which is sensitive to, and relies upon, the bunch structure of the beam). The measured pion fluxes (per  $10^{12}$  protons on target) are summarized in Table 1.

Table 1: Measured Pion Flux (per  $10^{12}$  protons on target) at Various Locations

Location	Pion Flux $\pm 20\%$ ( $\times 10^8$ particles)
IC-704	100.
IC-728	8.7
IC-733	8.3
D102	5.2

To determine the  $\mu/\pi$  ratio at injection into the Debuncher, we have used the ray tracing program DECAY TURTLE to simulate muon/pion production, decay and transport. The simulation considers only pions produced within a transverse emittance of  $22\pi$  mm\*mrad and discards any pion or muon which strikes a magnet pole tip or any pion or muon whose momentum lies outside the momentum acceptance of the Debuncher ( $\pm 2\% \delta P/P$ ). Using this simulation we have calculated the number of pions and muons which are injected onto the closed orbit of the Debuncher, and obtain:

$$(\mu/\pi) \text{ Injected into Debuncher} = .034$$

Combining this calculated  $(\mu/\pi)$  ratio with the data of Table 1 yields:

$$\frac{\text{Muons Injected into Debuncher}}{\text{Protons on Target}} = 1.7 \times 10^{-5}.$$

We emphasize that the muon flux used for calculating this ratio includes only *those muons which are born between the target and the Debuncher; i.e., it does not include any muons which are produced by pion decay within the Debuncher.* If 5% of the muons which arise from pion decay within the Debuncher are captured, the  $(\mu/\pi)$  ratio would increase to  $4.3 \times 10^{-5}$ .

#### 4. Experimental Technique

We propose to measure the flux of circulating muons in the Debuncher by employing a slight modification of a technique used by G. Dugan in 1987 to measure the number of pions and electrons which get injected into the Debuncher. This technique relies upon the use of a non-destructive, rf pickup to measure the bunch structure of the beam on a turn-by-turn basis.

The beam arrives in the Debuncher, at the location of the pickup, in 84 narrow bunches ( $\approx 1$  nsec) with a spacing of about 18 nsec. The fast particles (pions, muons and electrons) are separated from the slow particles (antiprotons) by about 8 nsec and hence fast and slow particles can be separated by looking at the time structure of the output from the rf pickup on a fast scope. As the beam circulates in the Debuncher, the pions decay in a few turns ( $\gamma c \tau_{\pi} \approx 1$  turn), while the electrons spiral into the low energy edge of the machine, due to the emission of synchrotron radiation, and are lost after 14 turns. After more than 14 turns the only particles left are muons and antiprotons.

The results of turn-by-turn measurements made in 1987 are summarized in Figure 2. In these data there was no indication of a signal representing circulating, bunched muons - which are expected to be the only fast particles remaining beyond turn number 14. The absence of a bunched muon signal can be understood by calculating the muon debunching time:

$$T_D = \frac{(\Delta T)_{rf}}{\eta \frac{\delta P}{P}}$$

For muons,  $\eta = .017$  and  $T_D = 27.6 \mu\text{sec}$  ( 17 turns). The muons are completely debunched after 17 turns and, consequently, induce no signal on the rf pickup. We have checked the rate at which muons debunch by performing a simulation which uses the longitudinal difference equations to study the bunch shape as a function of turn number in the Debuncher. The results, shown in Figure 3 for a bunch injected ( $N=1$ ) with  $\Delta t = \pm 0.5 \text{ nsec}$  and  $\delta P/P = \pm 2.0\%$ , illustrate the rate at which the injected muons debunch and indicate complete debunching in 15 - 17 turns.

An examination of Figure 2 suggests that it is straight-forward to measure the bunched muon signal by killing the electrons in the beam prior to injection into the Debuncher and then measuring the number of fast particles on turns 5 - 15 using the rf pickup.

The most appealing method for killing the electrons is to insert between 0.5 - 1.0 radiation lengths of lead at the end of the AP-2 transport line. Between the last two quadrupoles in this line (IQ32 and IQ33), the betatron amplitudes are reasonably small (4 - 8m.) and the emittance blowup of the muon bunches due to multiple scattering is small. In order to verify that the radiator is not a significant secondary source it is desirable to vary the radiator thickness over the range 0.5 - 1.0 radiation lengths.

We have studied the effectiveness of radiator thicknesses of 0.25, 0.50, and 1.0 radiation lengths on removing electrons from the beam at the end of the AP-2 transport line. The program EGS was used to determine the energy of the leading (maximum energy) electron exiting the radiator for electrons of energy 9.0 GeV incident on the radiator. (The simulation was also checked analytically using a formula from Tsai [3].) The results are shown in Figures 4-6. If we impose a cut on the electron energy of 8.7 GeV for it to be captured in the Debuncher, then for radiator thicknesses of 0.25, 0.50, and 1.0 radiation length 40%, 11%, and 0.15% of the incident electrons will survive the cut. Radiator thicknesses of between 0.50 and 1.0 radiation length are therefore appropriate for this study.

## 5. Requested Resources

We estimate that two shifts of studies time would be required to measure the muon fluxes circulating in the Debuncher. Engineering support would be required to construct (from existing components) and install the remotely

controlled radiator between the last two quadrupoles in the AP-2 line.

## References

- [1] Hime, A. and Jelley, N.A., *Physics Letters B*, Vol. **257**, No. 3,4, 441, (1991).
- [2] Kolb, E.W. and Turner, M.S., *Physical Review Letters*, Vol. **67**, No. 1, 5, (1991).
- [3] Tsai, Yung-Su, *Review of Modern Physics*, Vol. **46**, No. 4, 815, (1974).

### **Figure Captions**

**Figure 1.** Debuncher and AP-2 transport line layout.

**Figure 2.** Debuncher gap-monitor analysis of circulating beam

**Figure 3.** Muon bunch shape by turn number.

**Figure 4.** Leading electron energy distribution after radiator of thickness of 1 radiation length and incident electron energy of 9.0 GeV.

**Figure 5.** Leading electron energy distribution after radiator of thickness of 0.5 radiation length and incident electron energy of 9.0 GeV.

**Figure 6.** Leading electron energy distribution after radiator of thickness of 0.25 radiation length and incident electron energy of 9.0 GeV.

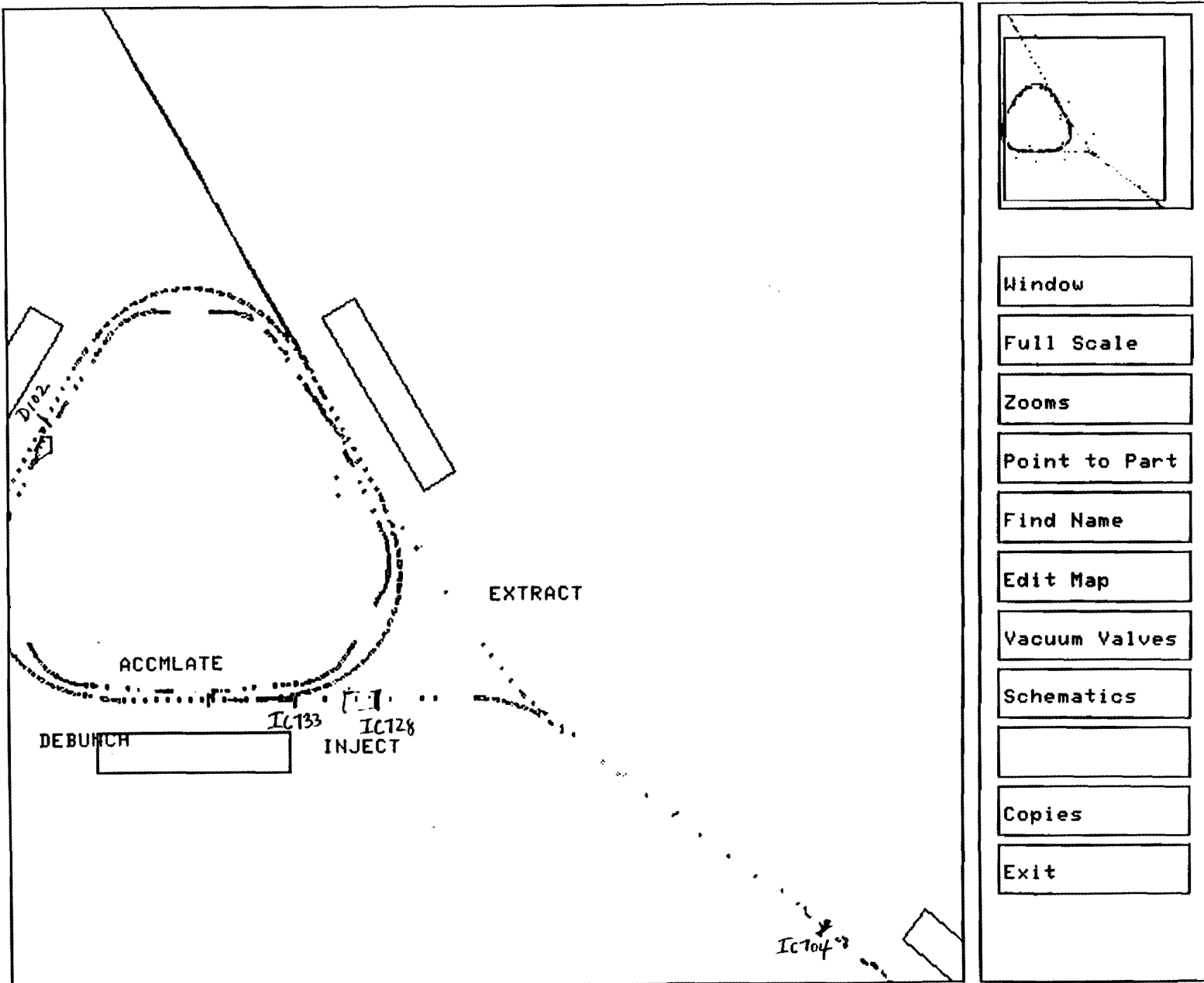


Figure 1

### Gap Monitor Analysis

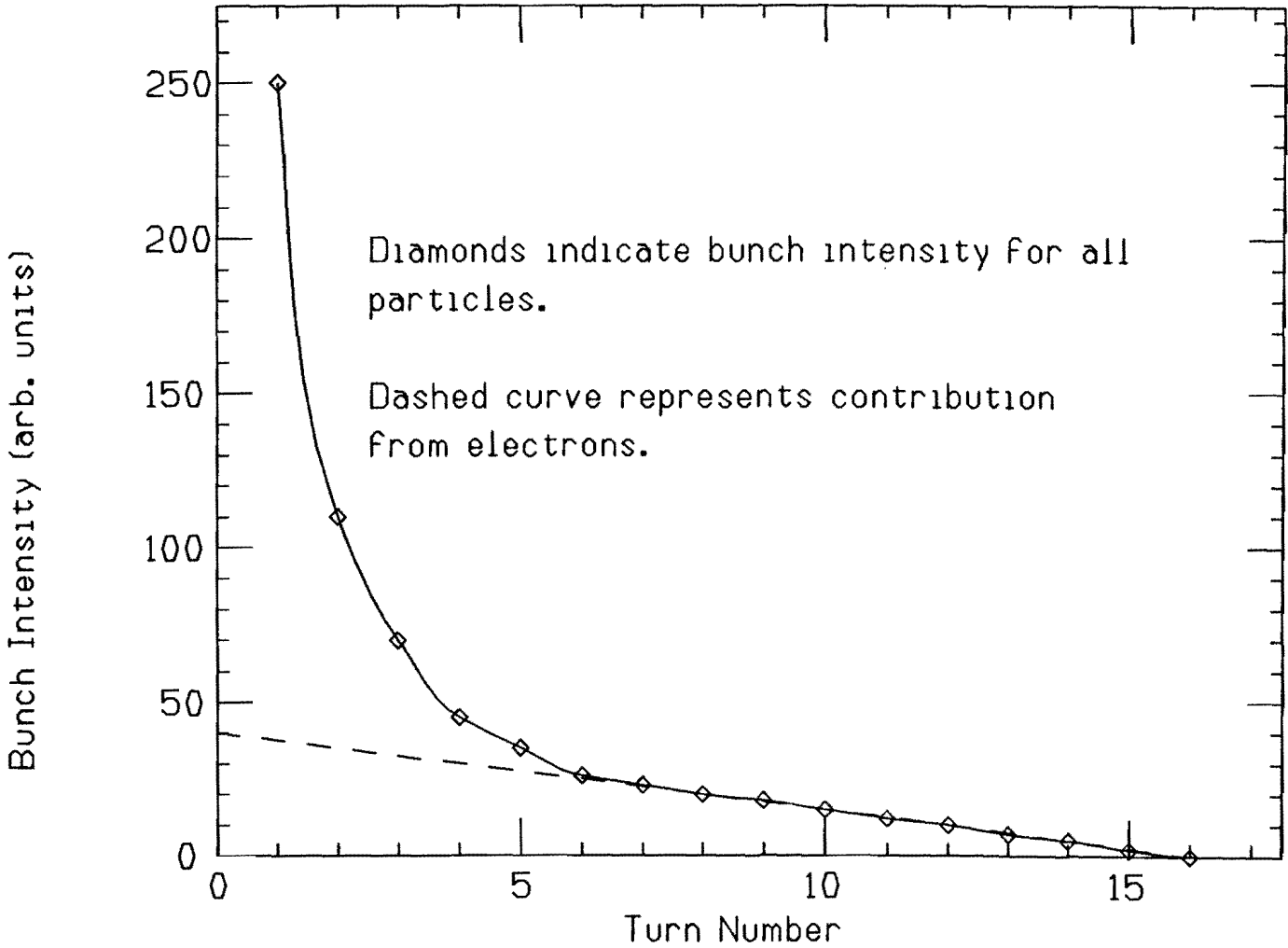


Figure 2



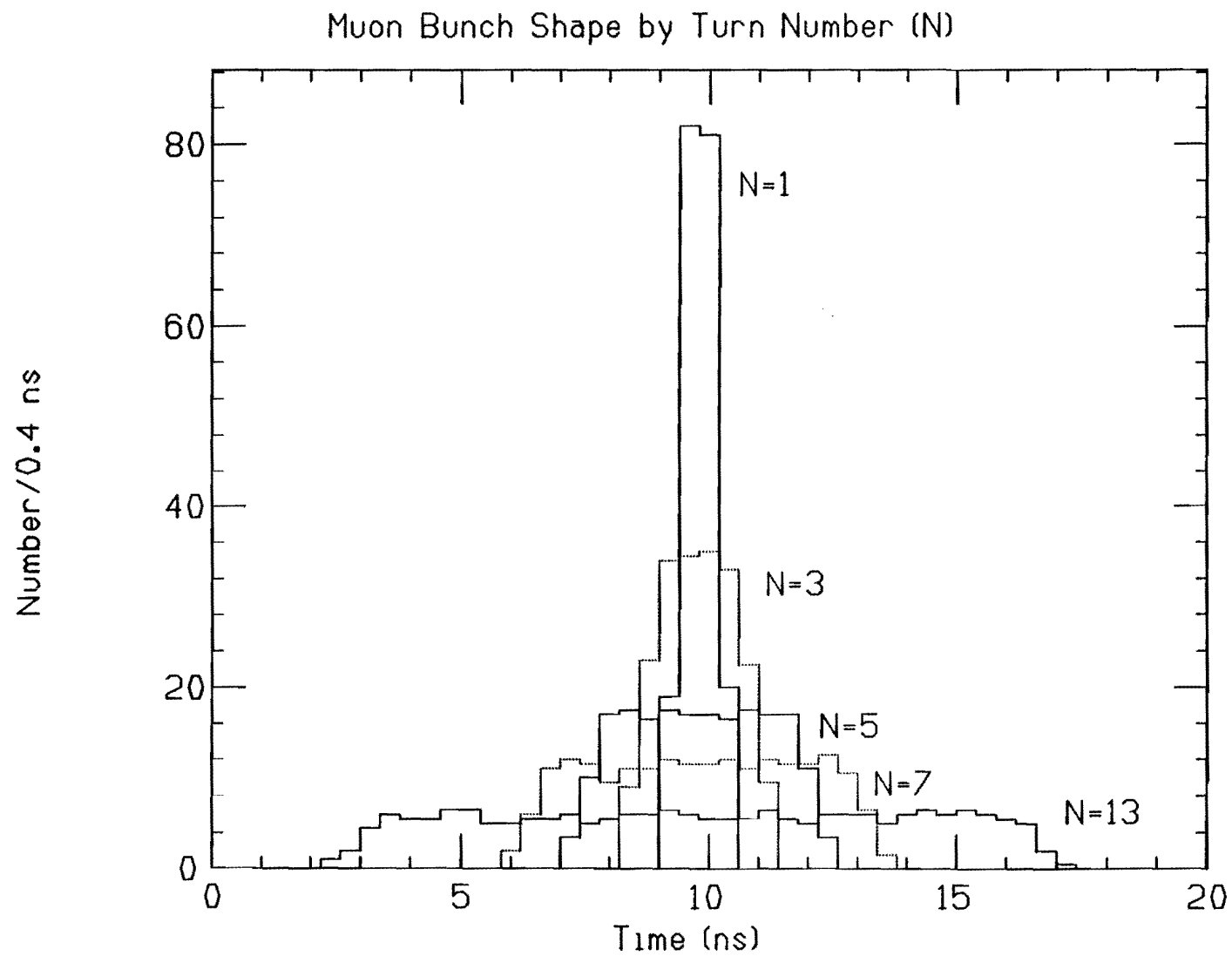


Figure 3

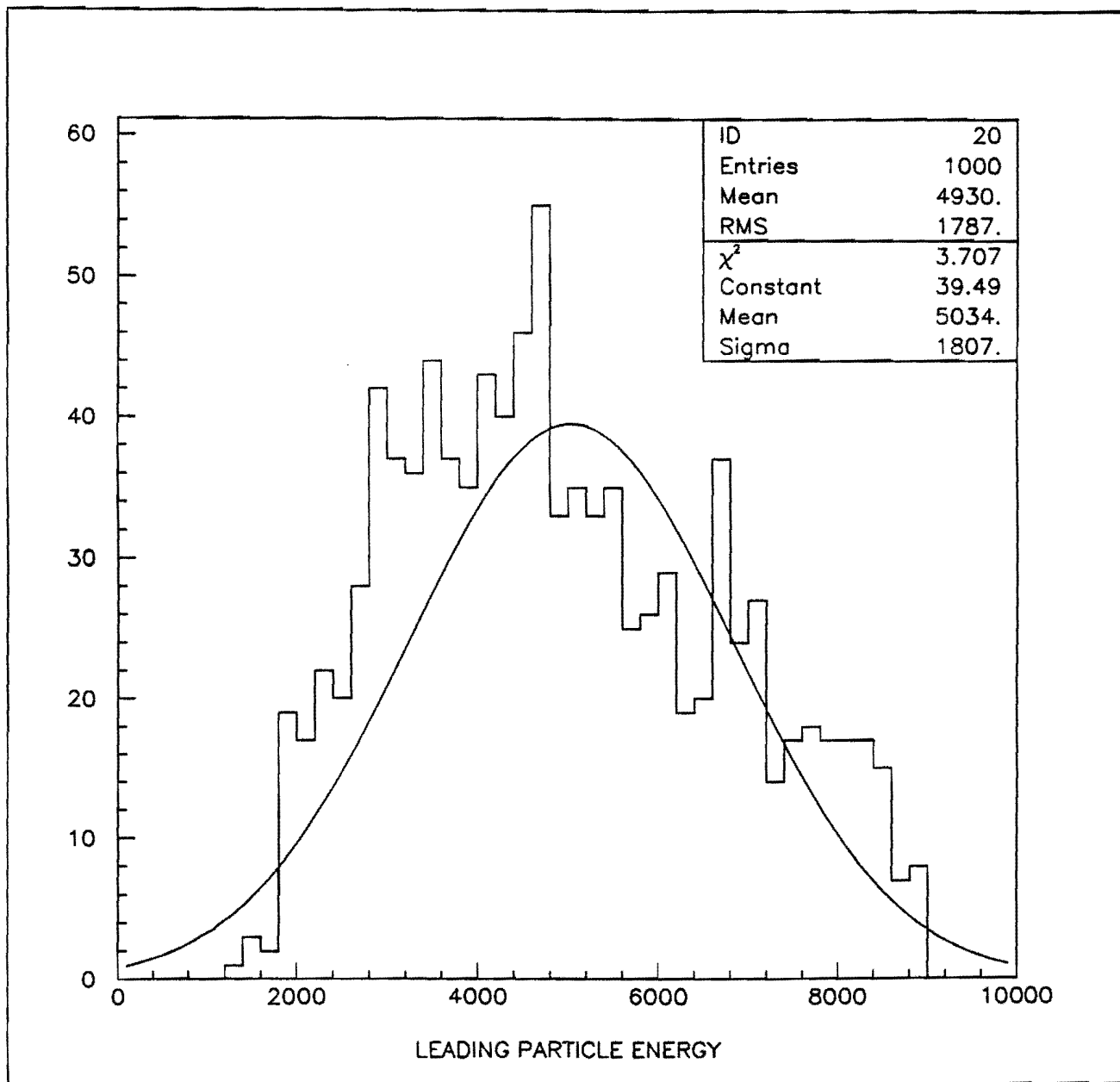


Figure 4

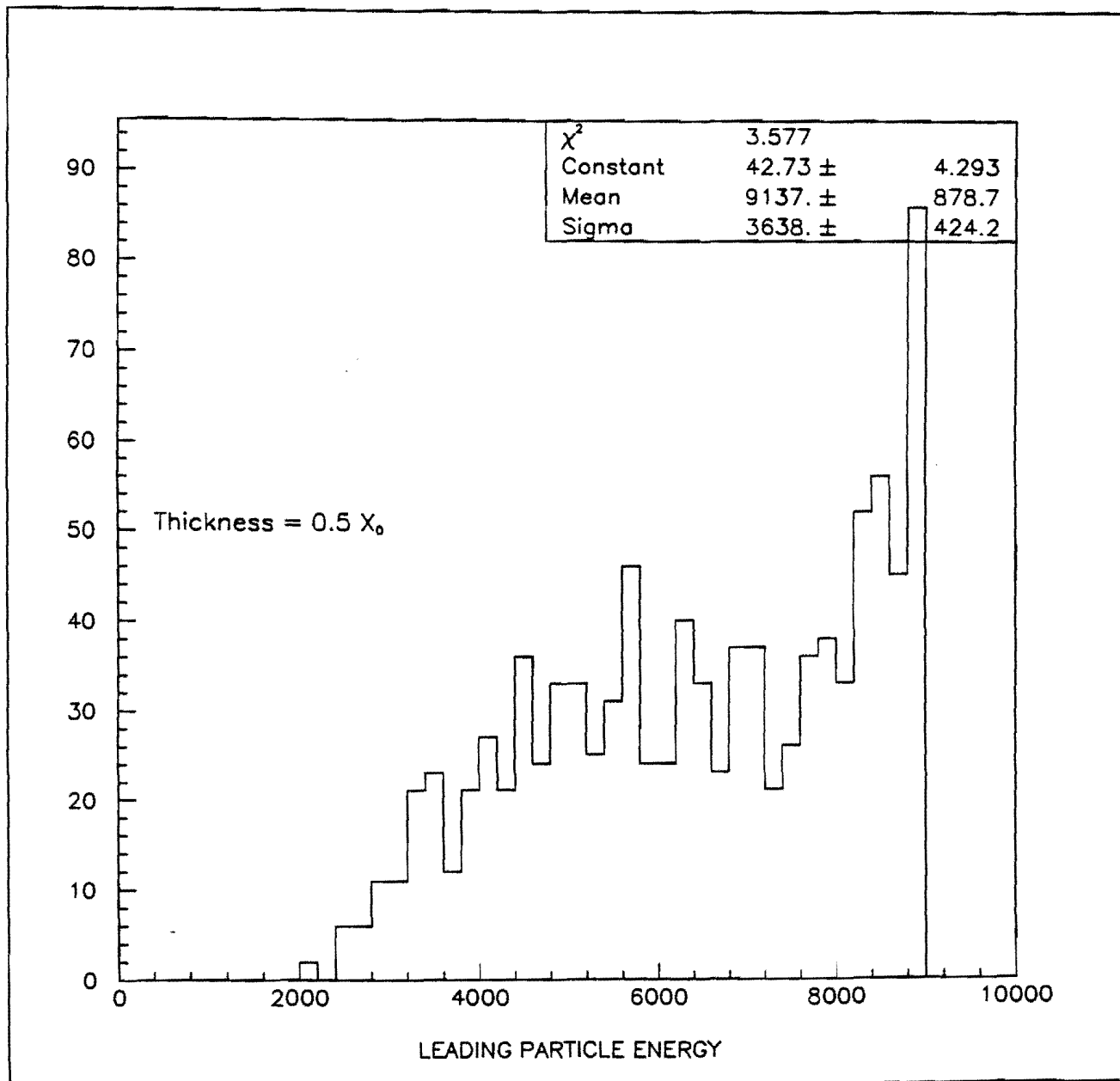


Figure 5

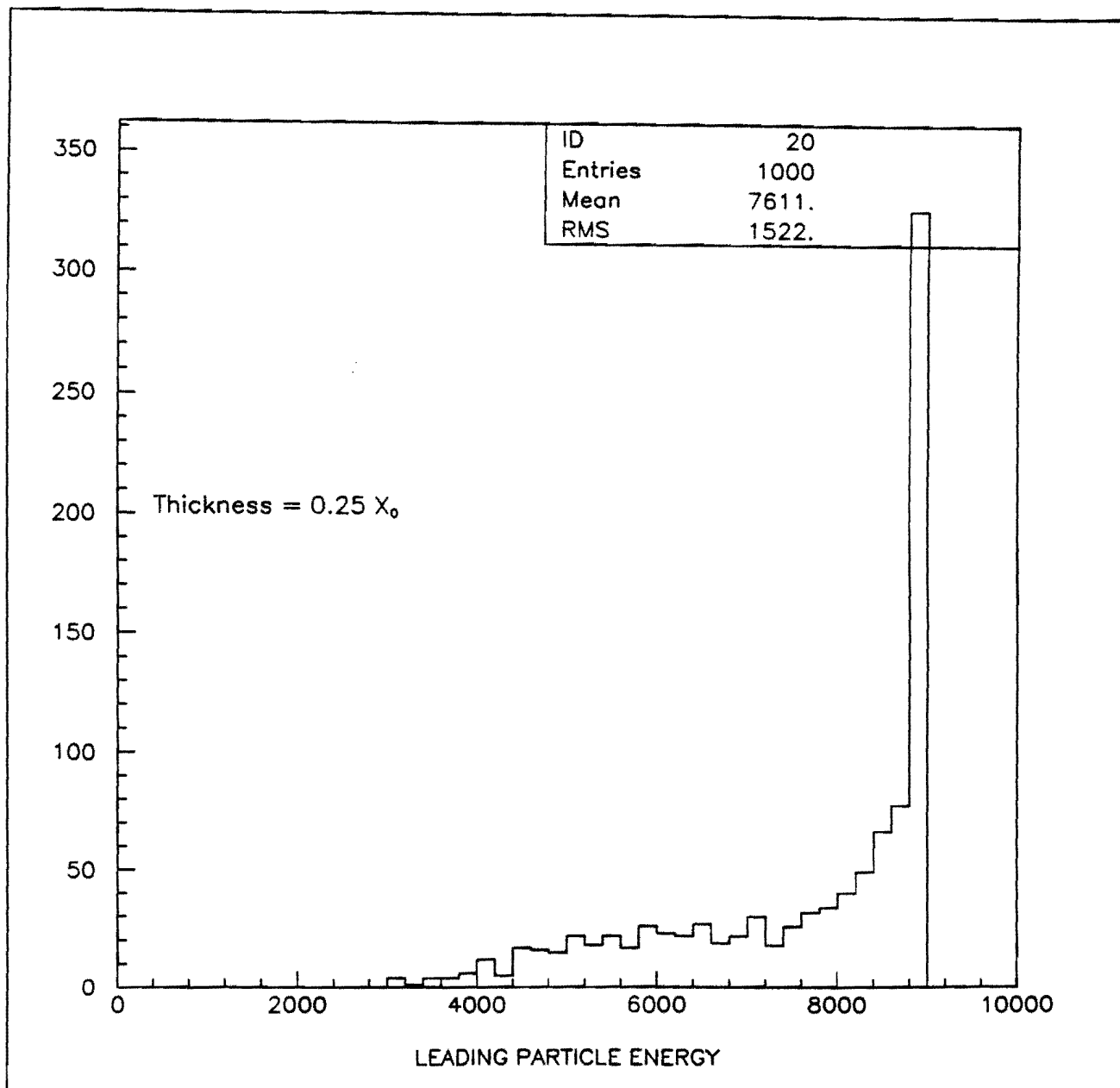


Figure 6