Appendix C

The Use of the LINAC for Timing

In order to collect the electrons that we measured in the majority of these experiments two strategies were employed. First, was the electron detector was positioned close to the point of collision. In addition, the electric field was kept high enough to allow measurement of electrons with energies ranging in the 10's of eV's. The drawback to this arrangement is that the electron flight time is then quite short (a few nanoseconds). The relative flight times between fast and slow electrons are even shorter, and quite difficult to measure. One of the advances made in this research was the introduction of bunched projectile beams with extremely short bunch-widths (in time). This was achieved by taking advantage of the time-focusing properties of the Linear Accelerator (LINAC) in the J.R. Macdonald Laboratory.

Before injection into the Tandem Van de Graff accelerator, the projectile beam may be compressed into ion groups or pulses with a room temperature pre-buncher. Typical bunch-widths from this buncher alone range from 1 to 2 ns. To measure the electron flight time with reasonable resolution, bunch-widths of less than 0.5 ns are required. To accomplish this, we use the LINAC to "time-focus" the projectile pulse.

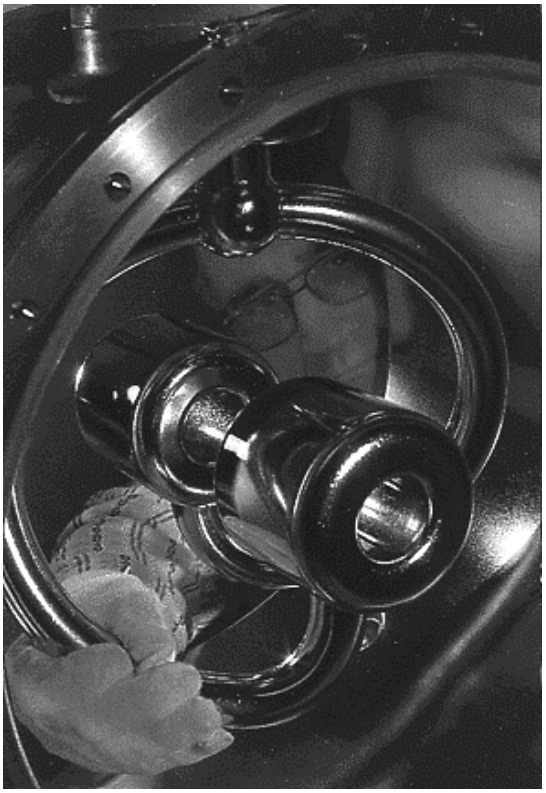

Figure C1: Super Conducting Resonator such as in KSU LINAC.

The LINAC consists of a series of split ring Niobium resonators such as shown in figure C1. These create an electric field along the beam direction, which oscillates at a frequency of 97 MHz. During normal operation, the projectile beam is first bunched with the injection buncher. It is then accelerated by the Tandem to a portion of the required beam energy before entering the LINAC. The LINAC resonators are synchronized so that when the bunch is between drift tubes, the electric field points along the beam direction, thus accelerating the pulse. (The LINAC can also be operated 180^0 out of phase so the pulse is *decelerated*;

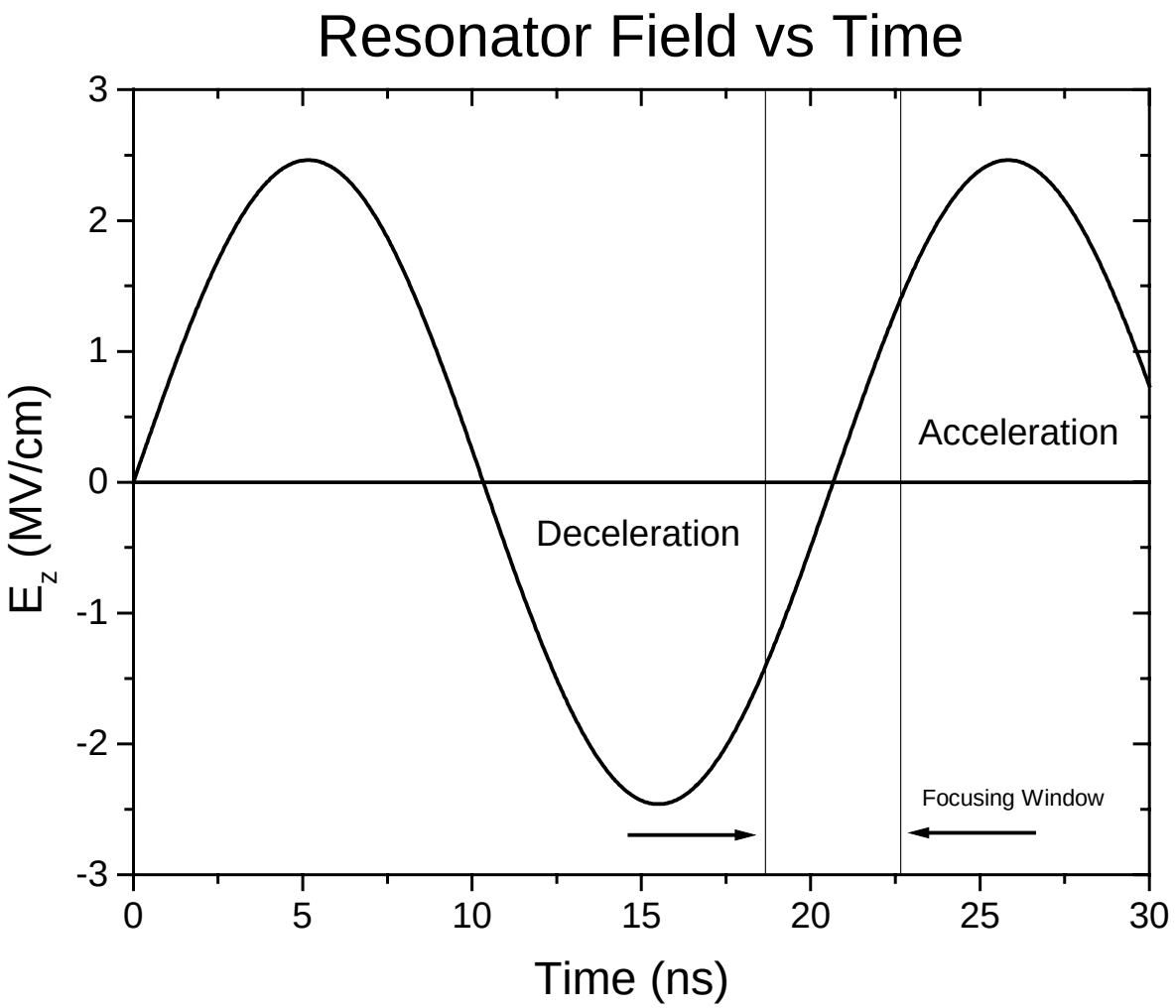

Figure C2: Time dependence of LINAC resonator electric field. Shown is the "crossover" region in which the focusing must take place.

however, this mode is seldom used). This process continues through the series of resonators, effectively increasing the projectile's energy.

When using the LINAC as a time-focusing device, only one resonator is in operation. There are two parameters that are varied when tuning the resonator: its phase relative to that of the beam bunch, and its electric field strength. By adjusting the phase of the resonator so that the pulse is between the drift tubes during a crossover (i.e. the time at which the field changes from negative to positive), the early pulses can be decelerated, while the late ones are accelerated (Fig. C2). Because projectiles within the pulse now have different velocities, the late ones catch up with the centroid, and the early ones lag behind. Therefore, at some "focal point," they all pass the same position at the same time. By tuning the field strength of the resonator, we adjust the focal length so that a focus occurs at the collision point in the spectrometer. Of course, after the beam passes through the point at which the bunch-width is a minimum, the bunch spreads out again. This is directly analogous to classical optics. Therefore, in order to get the best magnification, or smallest bunch-width, it was necessary to locate the experiment as close as possible to the resonator in use. For our measurements, the last available resonator in the series was always used, and the experiment was placed in what was once a diagnostic cube immediately after the LINAC. The distance from the resonator varied from approximately one to four meters.

The bunch-width was measured with the following procedure. A gold foil near the experiment was placed in the path of the beam. The scattered beam was then detected with a surface-barrier detector. Another signal was taken from the master

clock, which sychronizes the resonators, chopper, and pre-buncher. We then minimized the width of a peak produced in the time-difference measurement of the coincidence of these two signals. This width is due to the bunch-width of the beam, as well as the resolution of the measurement. The minimum width ever measured for our experiments was ~150 ps. which is of the order of the expected resolution for the detector and electronics. This width was also strongly dependent upon the beam energy, charge, and mass. For all of our measurements, the bunch width was less than 1 nanosecond, and usually less than 400 ps.