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## ToF Results From Run 06C

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## ToF Results from Run 06C

On 12 September 2006, we took Time of Flight data with 1000 MeV (nominal) protons.

The MCR recorded the beam energy coming out of the booster as 1007 MeV.

We placed our two detectors (5cm x 5cm x 2mm) at the usual target location in the NSRL beam line and took events triggered by the coincidence of the two discriminators. Discriminator thresholds were set to -25 mV. The two phototubes were set to -1800 Volts for efficient triggering on protons. Event rates were very high, typically 50-100k triggers per spill, with ~600 events per spill being recorded. This did not appear to degrade the performance of the detectors significantly. Discriminator outputs were 20ns wide for ToF2, and 50ns wide for ToF1. ToF2 was cable-delayed to start in the middle of ToF1 so that ToF2 determines the TDC Start timing in most cases.

Data was taken at two locations. In Location 1, the two phototube holders were abutting each other as closely as possible, with the two scintillators separated by 3.75 inches. The rail locator indicated that the ToF1 position was 250.0 inches. Location 2 was 125 inches upstream at 125 inches.

Plots show the pulse height spectra for the two counters, and the timing distributions. For ToF analysis, we take the difference in time between the primary counter ToF2, and the secondary counter ToF1.

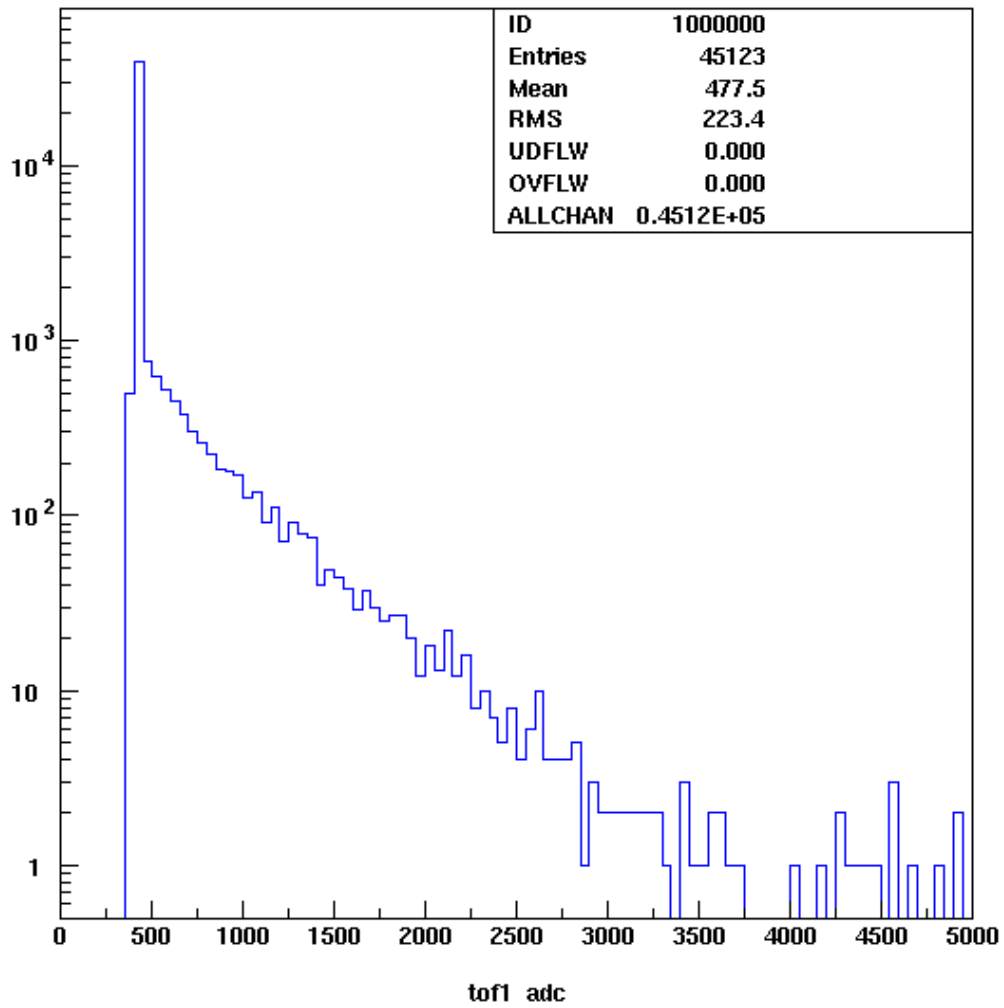


Figure 1: Pulse height distribution for ToF1 in ADC counts.

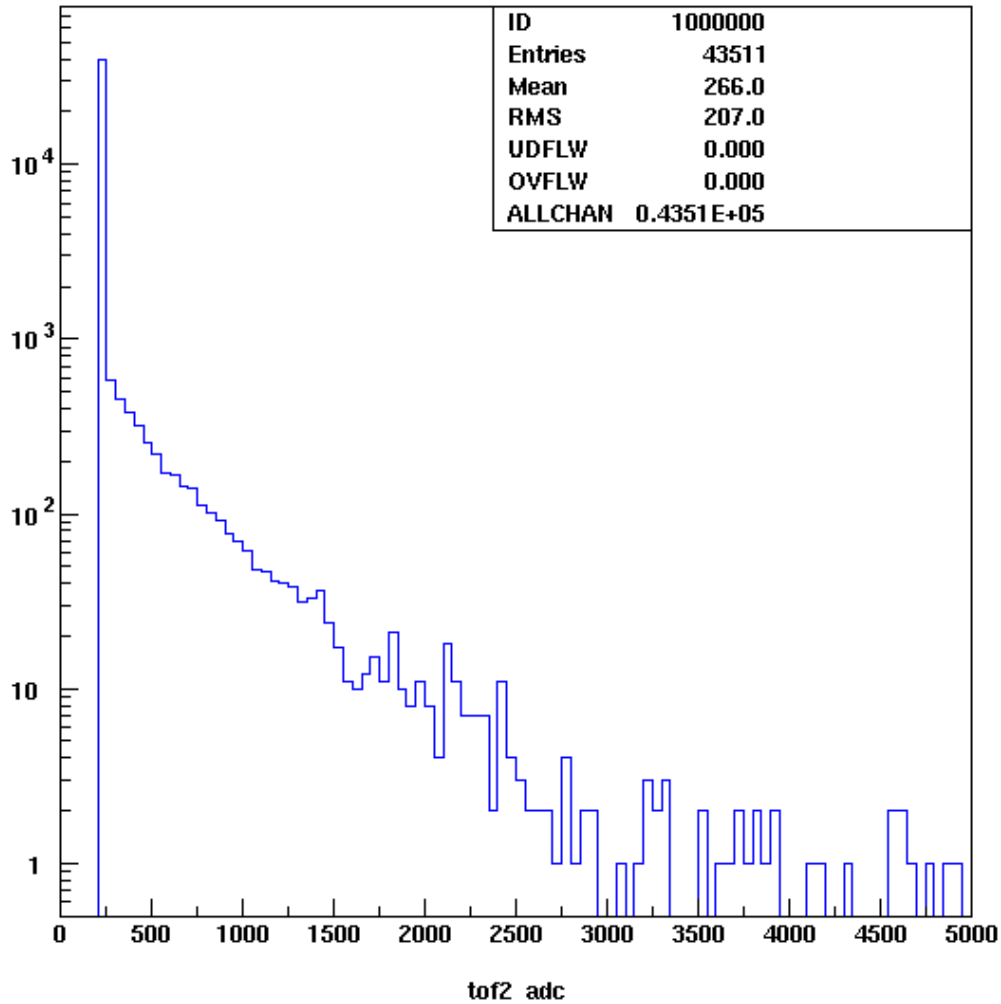


Figure 2: Pulse height distribution for ToF2 in ADC counts.

Note that there is no evidence for a peak in either of the spectra. This may be due to high levels of background from photons coming from activation in the target room. We had been running high intensity protons all day, and background levels were observed to be very high. It could be that the peak was obscured due to pile-up at these high trigger rates. Whatever the cause, we were not able to isolate a clean proton peak to do the ToF analysis on.

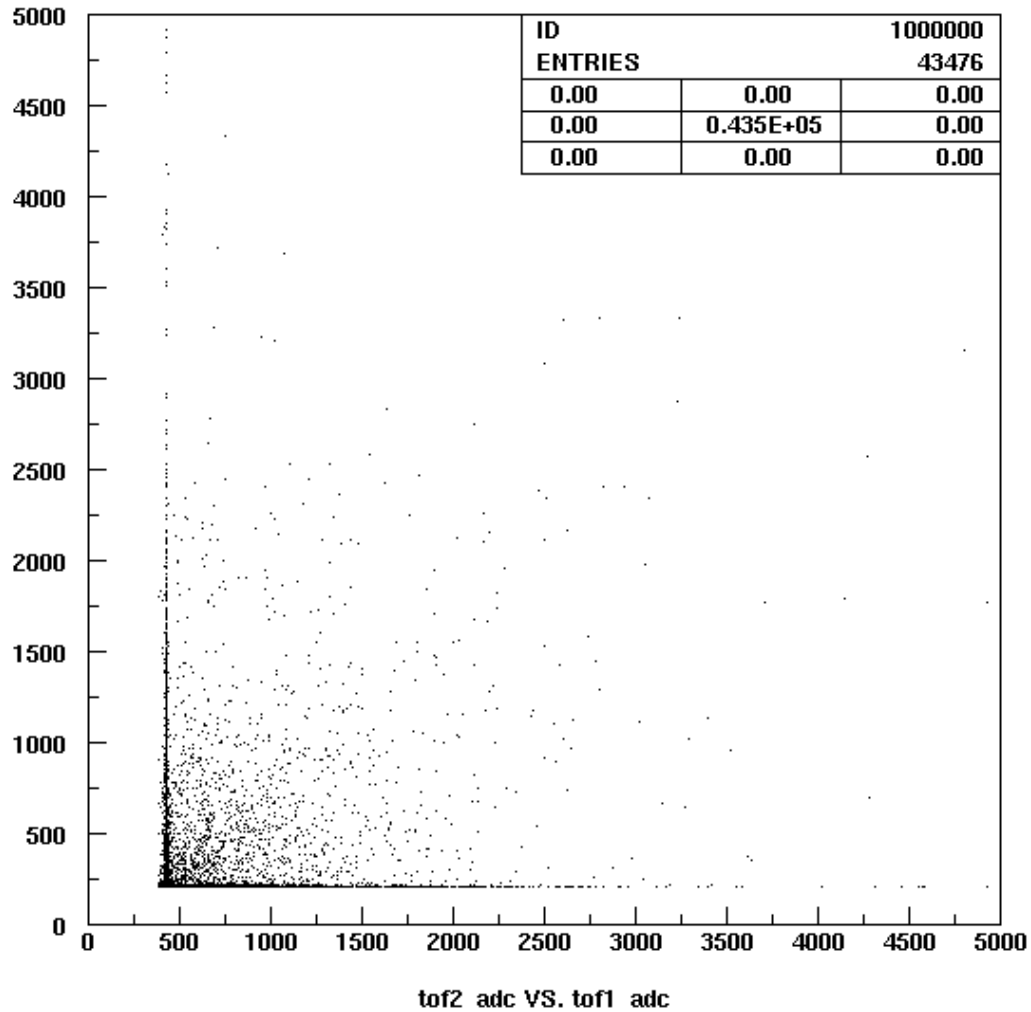


Figure 3: Pulse height distributions for ToF2 vs ToF1 in ADC counts.

The analysis was performed on 4 separate regions in the ADC scatterplot, in order to understand how the pulse height might effect the Time of Flight measurements. Region 1 was low pulse height in ToF1 and large in ToF2. Region 2 was high in ToF2 and high in ToF1. Region 3 was low in ToF2 and high in ToF1. Region 4 was low in both. Statistics were poor in all regions except Region 4, but there was no trend observed in any of the regions.

TDC distributions are also shown below.

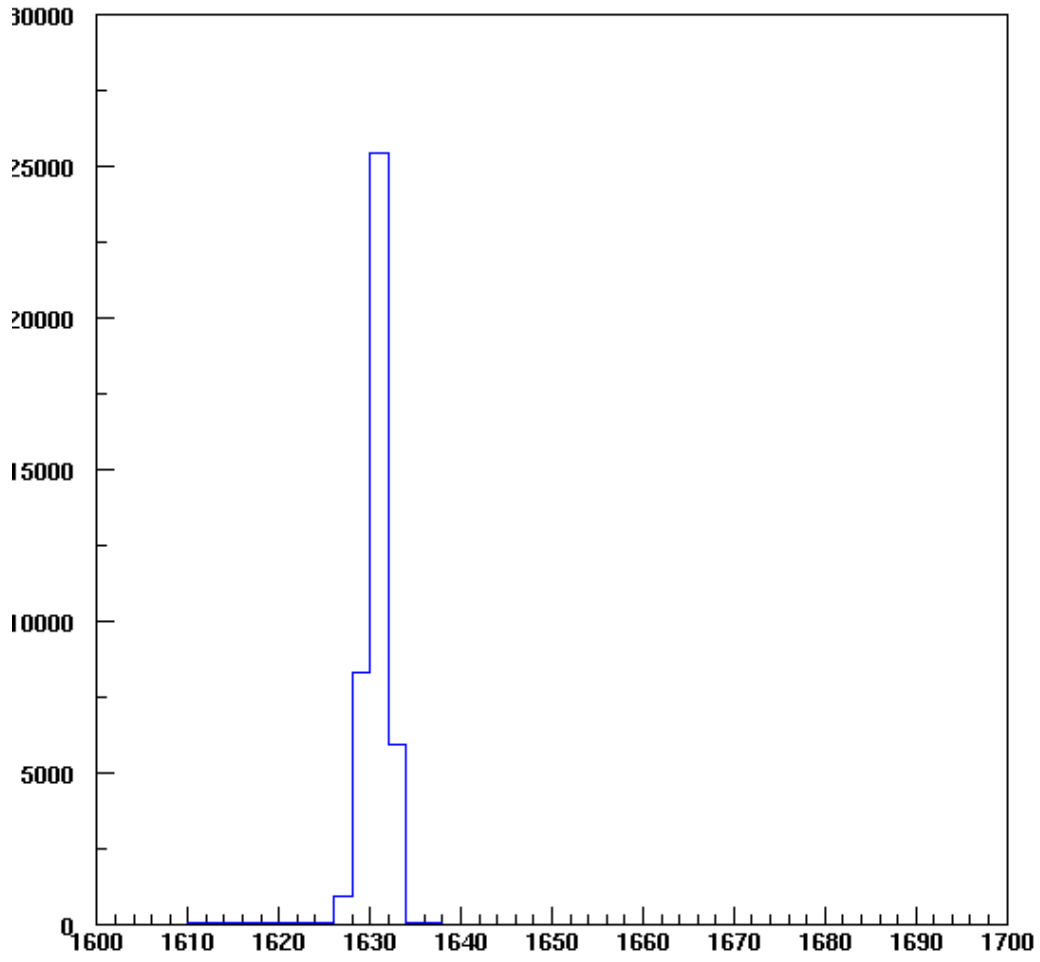


Figure 4: Timing distribution for ToF2 in TDC counts.

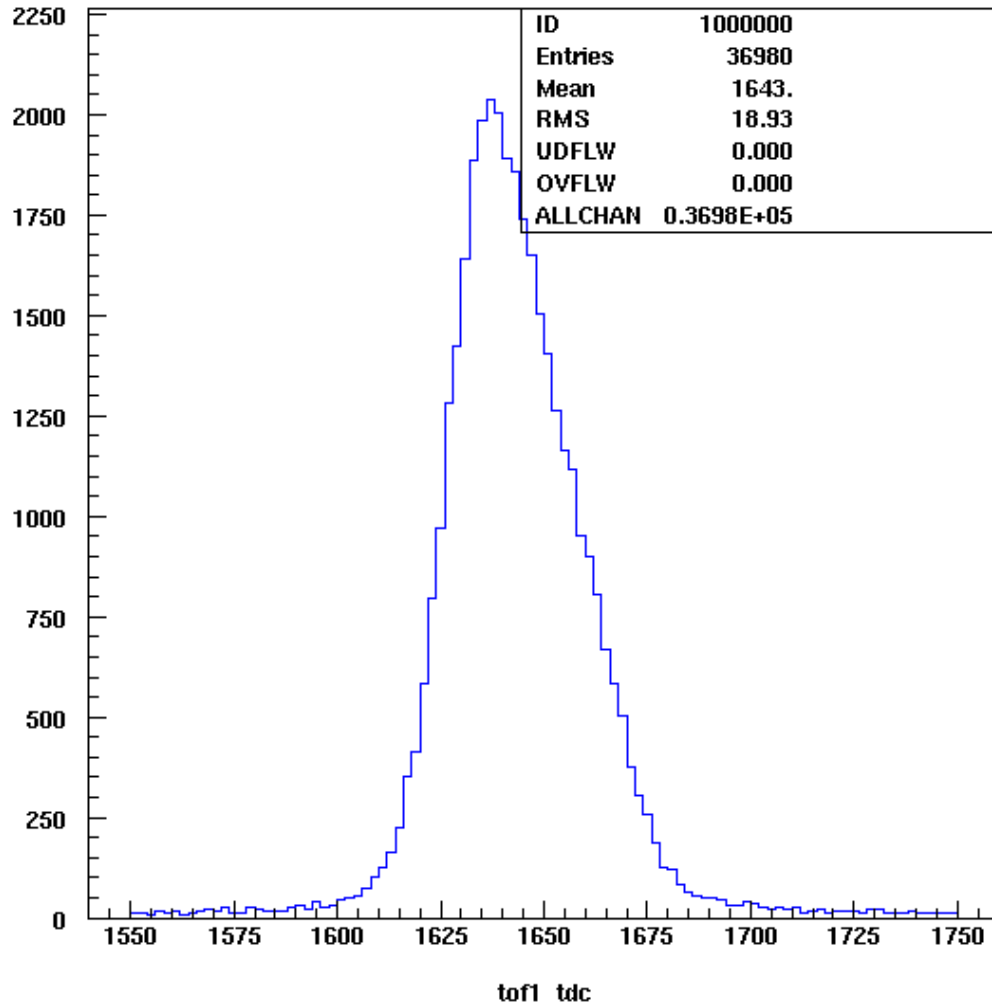


Figure 5: Timing distribution for ToF1 in TDC counts.

Note that the ToF1 TDC distribution is not symmetric. The cause of this asymmetry is not understood at this time.

When plotting ToF1 vs ToF2, there is little indication of any correlation between the two TDC values. This is different from what had been observed in earlier running where it was necessary to subtract one from the other in order to get unbiased timing.



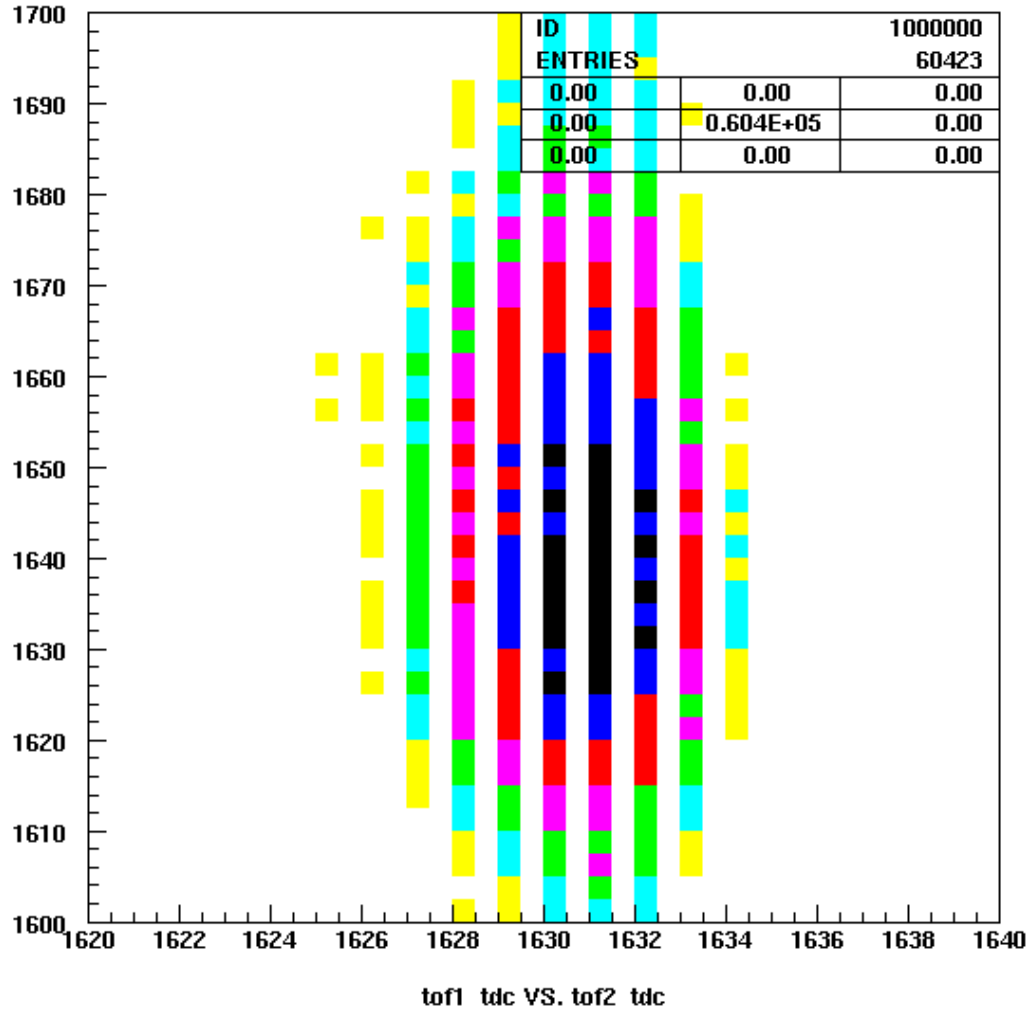


Figure 6: ToF1 TDC vs ToF2 TDC, in TDC counts. Z axis is logarithmic.

In order to obtain Time-of-Flight measurements, we made use of the TDC calibration performed several times previously. See details in [NSRL-TN-05-002](#) where the SRS Precision Pulser was used to calibrate the TDC at 35.78 ps/bin.

Fits were made to the time difference, ToF2-ToF1 (even though we saw no correlation), for the four difference regions of interest in the pulse height, giving the following results.

ADC Region	$\Delta T$ at Location 1	$\Delta T$ at Location 2	$\Delta T$
450<ADC<550	-8.48 bins	329.99 bins	337.71
550<ADC<750	-6.51	329.92	336.86
750<ADC<1000	-8.20	330.74	335.56
1000<ADC<5000	-6.26	330.28	337.24
All	-6.52	330.18	336.82

Table 1: TDC Shifts between ToF1 and ToF2 at 2 locations.

ADC Region	$\Delta T$ (ns)	$\beta$	Kinetic Energy
450<ADC<550	12.12	0.874	989
550<ADC<750	12.09	0.876	1005
750<ADC<1000	12.05	0.879	1030
1000<ADC<5000	12.11	0.875	998
All	12.09	0.876	1006

Table 2 Proton Beam Kinetic Energy from fitting to the time difference between ToF1 and ToF2 at 2 locations.

The ADC for ToF1 had a pedestal at bin 421, and the regions specified in the tables 1 and 2 are not pedestal subtracted. The four ADC regions of interest were selected to have comparable statistical significance.

The result for all the data gives 1006 MeV, to compare with the value of 1007 MeV from the RF. Although the result agrees well, the data show the extreme sensitivity of the energy to small fluctuations in  $\Delta T$  and calibration. The systematic uncertainty in these measurements comes from three sources; TDC calibration, distance between counters, and peak fitting.

The TDC calibration, as determined from pulser studies, was set to  $35.9 \pm 0.1$  ps/bin. This contributes 18 MeV to the systematic uncertainty on a kinetic energy of 1000 MeV.

The distance was measured to  $\pm 0.032$ ". This contributes 2 MeV to the error.

The peak of the timing distribution was determined by fitting a Gaussian function to the top 50% of the peak. Since some of these peaks were not symmetric, the choice of the fitting region affected the fit results. There were also small systematic variations with pulse height, as illustrated in Table 1. I have assigned an uncertainty in peak fitting of  $\pm 1$  bin based on experience fitting under a variety of conditions. This contributes 19 MeV to the error.

The statistical uncertainty in this measurement is completely negligible. The total uncertainty obtained by combining these three in quadrature is 26 MeV. Each of these uncertainties is a very steep function of beam energy.

## 200 MeV Measurement

We repeated the ToF technique with large beam protons at ~200 MeV, giving the following results.

Bin Shift	Delta t	Velocity	$\beta$	$\gamma$	$\gamma-1$	KE
632.2	22.70	17.12	0.571	1.2182	0.2182	205
632.5	22.71	17.11	0.571	1.2180	0.2180	205
632.3	22.70	17.12	0.571	1.2181	0.2181	205

Table 3: Proton Beam Kinetic Energy from fitting to the time difference between ToF1 and ToF2 at 2 locations for 200 MeV protons.

Contributions to the uncertainty were 1.5 MeV from the TDC calibration, 0.9 MeV from peak fitting, and 0.1 MeV from distance for a total of 1.8 MeV. These results should be compared to the Bragg Peak measurement of 205 MeV.

## 500 MeV Measurement

We repeated the ToF technique with large beam protons at ~500 MeV, giving the following results.

474.3	17.03	22.82	0.761	1.5422	0.5422	509
474.2	17.02	22.83	0.761	1.5427	0.5427	509
474.2	17.03	22.83	0.761	1.5425	0.5425	509

Table 4: Proton Beam Kinetic Energy from fitting to the time difference between ToF1 and ToF2 at 2 locations for 500 MeV protons.

Contributions to the uncertainty were 10 MeV from the TDC calibration, 4 MeV from peak fitting, and 0.4 MeV from distance for a total of 10.2 MeV. No Bragg Peak results could be obtained for the 500 MeV proton beam.

Both the 200 MeV and 500 MeV results were obtained with large beam at a trigger rate of ~20,000 – 50,000 coincidences per spill. The data taking took only a couple of minutes at a rate of ~600 events per spill for a total sample of ~15,000 events total at each point. It is not yet clear whether we need to take a “close” point each time, or can obtain as reproducible results with just a single “far” point. This would make ToF measurements much simpler.