The Albany Particle Tower: Online Access for High School Students

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Abstract

As part of the ATLAS education outreach program, the Albany Particle Tower (APT) has been made available online to students who wish to obtain experience with the different types of detectors used in particle physics. For high school students and undergraduates, the experiments provide exposure to current frontiers in physics. The online tutorial and experiment of a Time of Flight detector provides students with thorough exposure to a basic particle physics experiment. The tutorial provides a detailed discussion of how the Time of Flight detector works, and the hardware associated with it. The online access to the experiment allows students to run the detector and analyze real time data.

Introduction

The Albany Particle Tower is a Cosmic Ray Telescope containing several detectors including Time of Flight, Arogel Counter, Muon Counters, Drift Chambers, and Silicon Detectors. The Time of Flight and Muon Counter experiments have been made accessible to high school students online. High school students who access the website are sent to a tutorial that discusses the details of a Time of Flight experiment along with a Muon Counter. This tutorial begins by discussing scintillation counters, including how scintillation occurs, the path the light takes to the photomultiplier, what occurs in the photomultiplier, and how a discriminator verifies a legitimate signal. The tutorial continues on to explain the fast-logic involved in analyzing an event, and briefly touches on TDC modules. The tutorial ends with a description of how to run an experiment and do online data analysis. Before students enter the experiment they can visualize simulated particle paths through the Tower with a Java applet. This gives the students a tangible model for the experiment.

Once students have read through the tutorial, they then proceed on to the experiment. Here students are able to obtain time of flight data. They then can do analysis of the data with interactive histograms. Here students can view histograms of all scintillation counters, or view specific counters. They can also apply cuts to the data to obtain better time resolution. The data presented is preliminary.

Particle Identification Using aTOF System

Particle identification using TOF is based on the fact that particles with the same momentum but different masses will have different velocities. Classically, for velocities smaller than that of light, the momentum of a particle is defined as:

$$p=mv \qquad (1)$$

where *m* is the mass and *v* is the particle velocity. Further, the mass is a constant of motion. However, in experimental high energy physics, particles are typically close to that of the speed of light, so we have to use the relativistic definition of momentum presented below:

$$p = \frac{m}{\sqrt{1-\frac{v^2}{c^2}}}\,v \qquad (2)$$

where *m* is the rest mass and a characteristic parameter of the particle. The speed of a charged particle can be measured in a TOF system using scintillation counters. If the momentum is measured in some kind of tracking system, the mass can then be calculated using the above equation. For stable, charged particles such as the e , μ , π , K , and $p/\bar{p}$, measuring their mass is equivalent to identifying them.

If we know the momentum of a particle of mass "m" the TOF is given as:

$$T = \frac{L}{v} = \frac{L}{c}\sqrt{1+\frac{m^2c^4}{p^2c^2}} \qquad (3)$$

$$T = \frac{L}{0.2998}\sqrt{1+\frac{m^2}{p^2}} \qquad (4)$$

The fourth equation is the time of flight in nanoseconds, where *m* and *p* are in units of MeV. For *p>>m,* the time of flight can be approximated as:

$$T = \frac{L}{0.2998}\left(1+\frac{m^2}{2pc}\right) \qquad (5)$$

Figure 1 shows the time of flight versus momentum for different particle hypothesis. Clearly, as momentum increases, particle identification using TOF becomes more challenging as we approach the technological limits of timing resolution.

Time of Flight in the Albany Particle Tower

The Time of Flight experiment has three components, a basic time of flight system, a path specifier and a muon counter (Fig. 1). The basic Time of Flight system in the APT consists of two scintillators. The first scintillator is shorter than the second and is centered with respect to further detectors. Below the start scintillator is a longer scintillator, parallel to the first, with photomultipliers on each end. This provides two readouts and greater timing resolution. This second scintillator provides the stop signal for the time of flight system, where TOF is the timed difference of $(T_3\text{-}T_1) = T_3$ since T_1 is the start signal.

To create a specific flight path for the particle, or virtual beam channel, an additional scintillator is placed perpendicular to and below the first two scintillators. This reduces the flight path to a range of 4 in^2 (5 cm x 5 cm). The constrained flight path is important for subsequent experiments that require a specific flight path.

An additional scintillator at the bottom of the APT serves as a Muon Counter. This scintillator is below several lead blocks, which stops all particles except muons. To look at the flight time of a muon, the muon must pass through the Time of Flight system and Muon Counter within the Virtual Beam Channel.

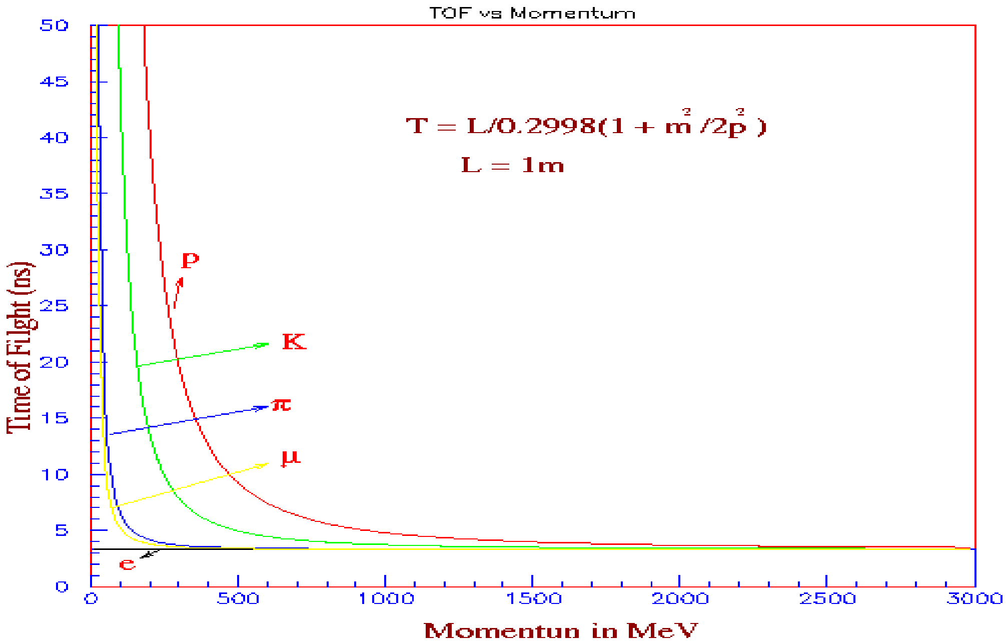

FIGURE 1. TOF of different particle hypothesis as a function of momentum.

Software

The software used for the Albany Particle Tower is *LabVIEW* by National Instruments. *LabVIEW* is a general-purpose programming system, using graphical programming language to create programs in block form. It contains extensive libraries for a variety of programming tasks including; data acquisition, GPIB and serial instrument control, data analysis, data presentation, and data storage. *LabVIEW* is a "virtual instrument," its appearance and operation imitate actual instruments. With this component, users are faced with an interactive user interface called the front panel. The front panel simulates the panel of a physical instrument. It can contain knobs, buttons, graphs, and other controls and indicators. The program *BridgeVIEW* allows for online interactive access to the Albany Particle Tower.

Experimental Procedure

Once a high school student completes the tutorial, he/she will then proceed to the experiment. At the experiment page, the student is able to login, create a data file, take data over a specified time, and later analyze the data. While the data is acquired, the student can view tables keeping tallies of hits and a histogram that is continuously updated.

Following data collection, students can manipulate the histograms by using switches and buttons to require specific triggers and apply cuts. Buttons along the left side of each histogram allow you to view specific plots. To apply cuts, the top window is used. The range for cuts can be set by specifying numbers in the top "Select" box and then clicking on the corresponding minimum or maximum range box. The maximum and minimum parameters can then be applied by clicking on the trigger's slide bar in the appropriate area. The slide bar can perform three functions; it can "Require" or "Exclude" a specific range, or not apply any cuts.

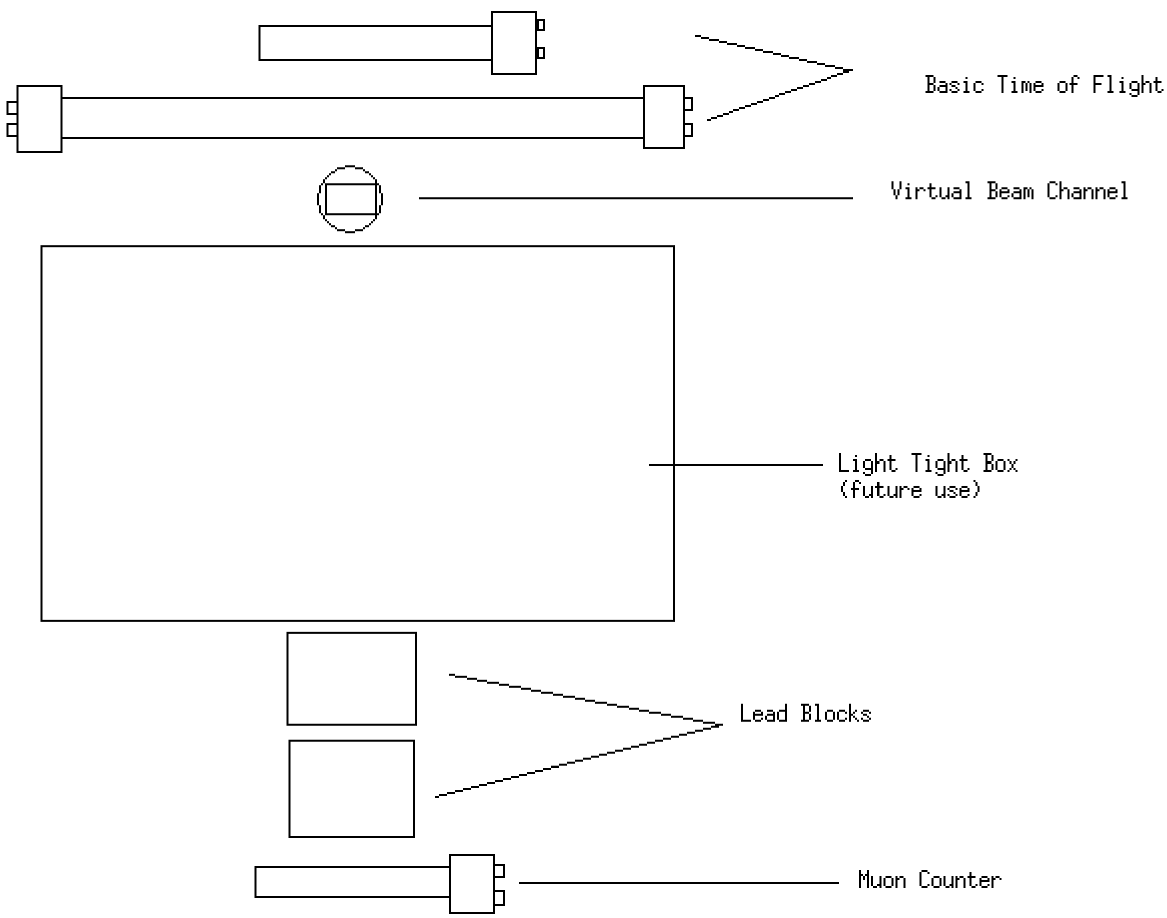

FIGURE 2. The Albany Particle Tower. The time of flight system has scintillators one meter apart. A virtual beam channel is created by placing an additional scintillator perpendicular to the Time of Flight system. The Muon Counter completes the experiment. Note: Not drawn to scale. The counters are numbered in numerical order.

TOF Online Analysis

To analyze the flight time of a muon, from the front panel, the "TDC Values" histogram and the "TDC Differences" histogram should be selected. The flight time of muons is found by requiring only muon triggers, thereby excluding invalid events. This is done by, while in the "Cuts" of the TDC Values window (top third), moving the muon switch to "Require." By doing this, both histograms adjust accordingly. The "TDC Differences" histogram is then used to find the time of flight. The blue histogram, (T_1-T_3), gives a Gaussian plot of the time difference as the particle travels one meter between the two scintillators. This process has not yet been perfected.

TOF Offline Analysis

Because the online analysis process has yet to be perfected, time of flight data was analyzed offline. The goal of initial offline analysis was to improve timing resolution due to the set up, and to then apply these calibrations to the software.

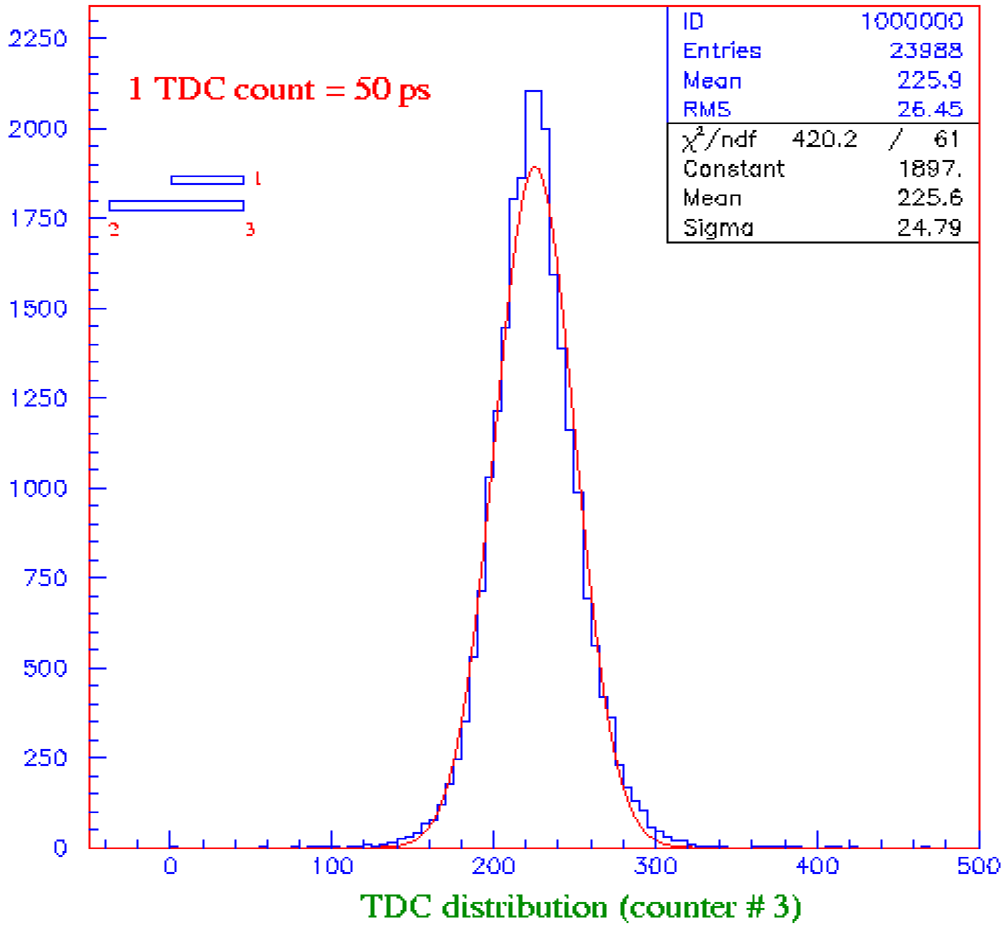

FIGURE 3. T_3-T_1 distribution.

In the following analysis, we assume all photomultipliers are identical. Here we show the systematic improvement study of our timing resolution with changed conditions and cuts. From T_3-T_1 timing distribution (Figure 3), our upper limit on our timing resolution was obtained. Figure 3 shows the measured resolution σ^m_{3-1}.

$$\left(\sigma^m_{3-1}\right)^2 = \sigma_1^2 + \sigma_3^2 + \sigma_{pos}^2 \qquad (6)$$

Assume $\sigma_{pos} = 0$, and $\sigma_1 = \sigma_3 = \sigma_{pmt}$ (identical photomultipliers), then the σ_{pmt} = 870 ps.

This resolution is further improved for straight tracks going through the center of the 2/3 counter by requiring the fourth counter (Virtual Beam Channel). Figure 4 shows the measured T_3-T_2 distribution, σ^m_{2-3}.

$$\left(\sigma^m_{2-3}\right)^2 = \sigma_2^2 + \sigma_3^2 + \sigma_4^2 \qquad (7)$$

$$\sigma_4 = \frac{5n}{c\sqrt{12}} = 72 \text{ ps} \qquad (8)$$

(where n = 1.5, c = 30 cm/ns)

Assume $\sigma_1 = \sigma_3 = \sigma_{pmt}$, then σ_{pmt} = 242 ps, where 242 ps is the timing resolution on either end, improving the resolution by 70%.

So far we have not accounted for pulse height correction and proper calibration. Part of the long tail in Figure 4 can be reduced by applying pulse height cuts on the corresponding ADCs. Figure 5 shows pulse height distribution of counters 2, 3, and 4.

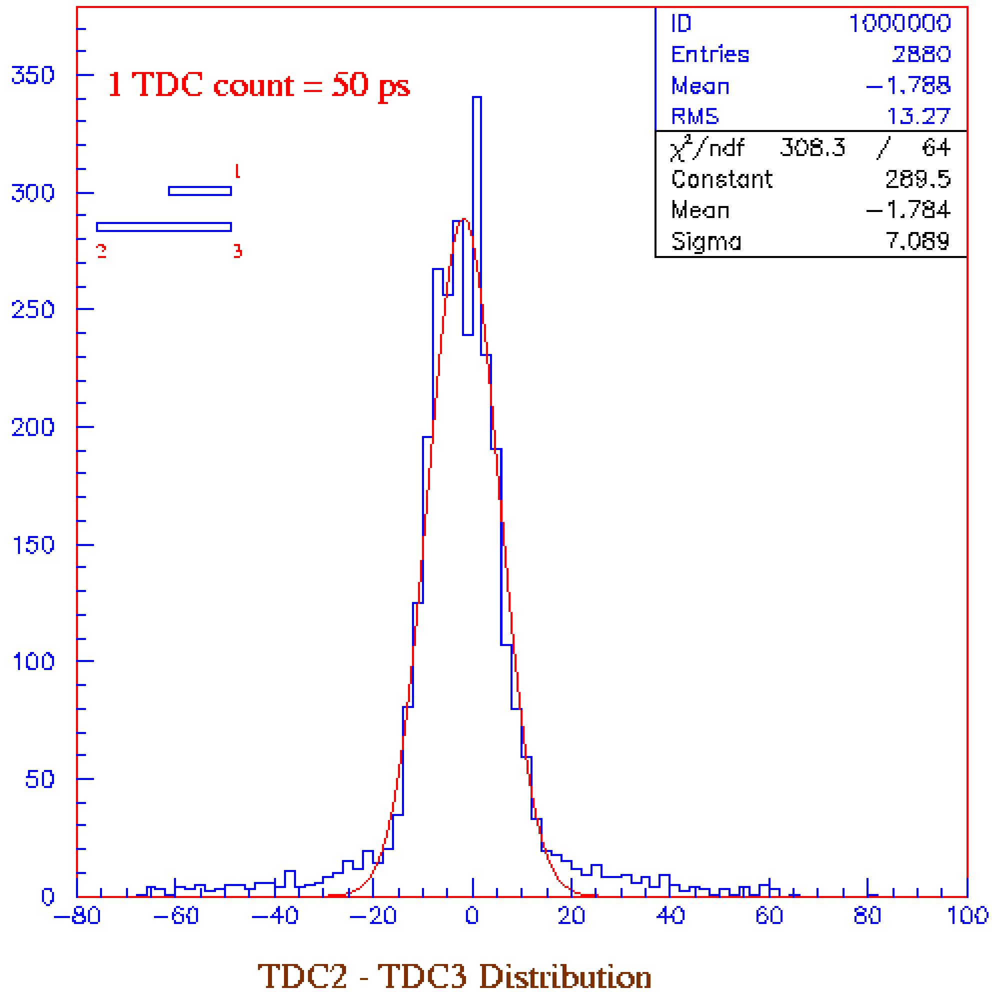

FIGURE 4. Timing distribution of tracks going through the center of the counter 2/3.

Figure 6 shows T_3-T_2 distribution after pulse height cut greater than 100, 130, and 100 ADC counts for the 2, 3, and 4 counters, respectively. The background decreases and the timing resolution on either side of the counter improves by 7%.

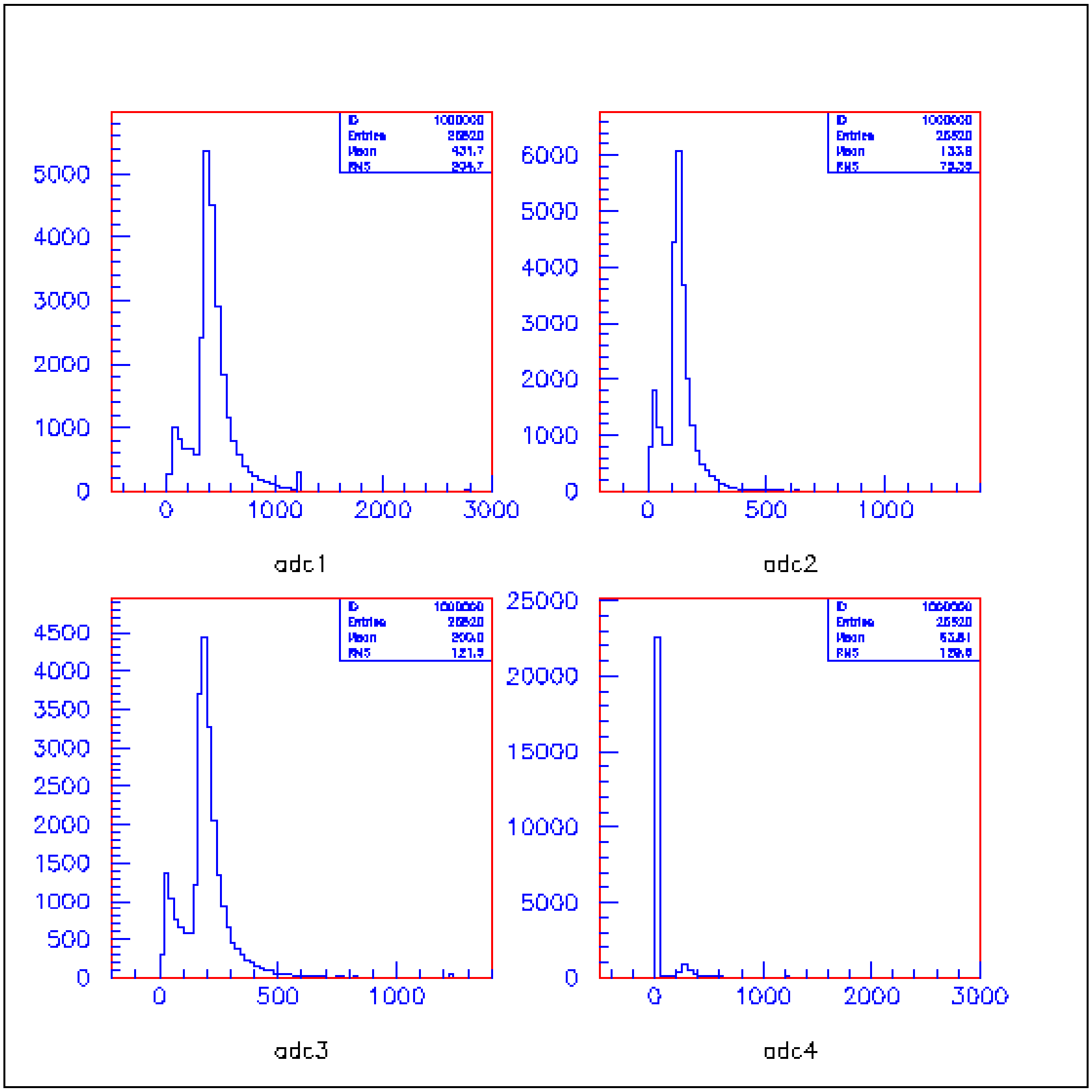

FIGURE 5. Pulse height correction values for the 2, 3, and 4 counters. This calibration has yet to be applied.

Conclusions

The Albany Particle Tower, the experiment and tutorial, has wonderful potential to be a powerful learning tool in the high school classroom. It can take students from the world of textbook mechanics directly into the realm of particle physics. The tutorial provides a very detailed description of all components of the experiment in a technical manner. This may need to be adjusted in the future so that the tutorial better enhances student learning. The tutorial should possibly be written in a less technical manner with a dialogue, or question-and-answer approach, with quite less detail.

The front panel of the experiment is complex, as it has been broken down into several frames, some with additional windows. It is strongly advised that teachers run the experiment and obtain time of flight results, with thorough understanding, before introducing it to the class.

The time of flight of a particle is important so that the velocity of a particle can be calculated. In a real particle physics experiment, the momentum is measured independently. With these two parameters known, the mass of the particle can be determined. This is not necessary for muon identification, but with the implementation of a drift chamber, other particles can be identified.

Current time of flight values do not reflect correction for timing resolution. Time of Flight experiments will continue to be run to perfect the online experimental process as well as improving the timing resolution by pulse height correction and calibration.

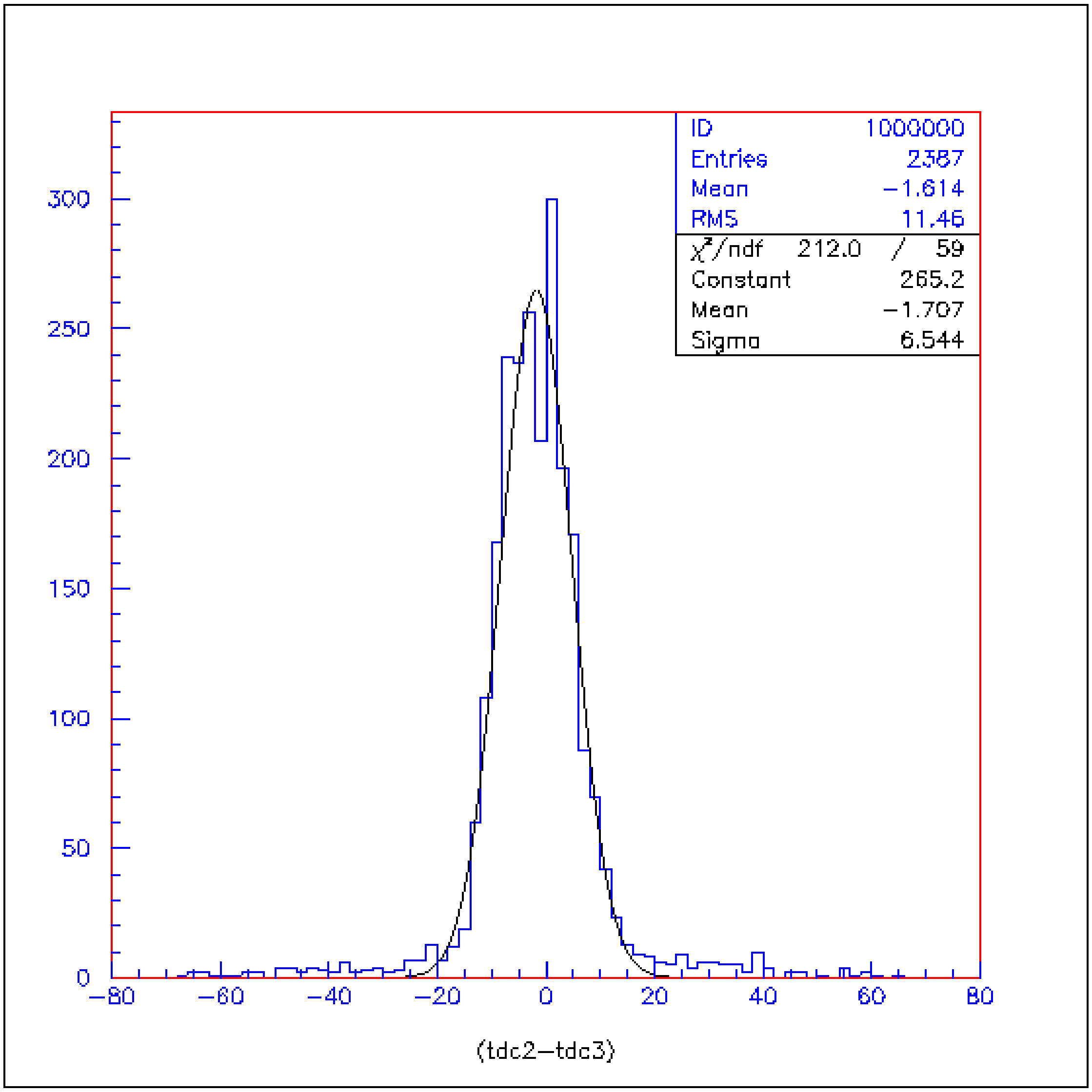

FIGURE 6. Resolution of time of flight requiring the Virtual Beam Channel.

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