# Design of a Gaussian Filter for the J-PARC E-14 Collaboration

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## 1 Abstract

This paper describes the design, simulation, and pulse fitting result for a Gaussian filter built for the J-PARC E-14 collaboration. The filter is a 10-pole shaper designed to produce a Gaussian-shaped output pulse in the time domain. The performance of the filter was studied for various levels of energy deposited, as well as different rates of asynchronous sampling. At a sampling rate of $125MHz$, timing resolution is better than $0.5ns$ when the energy deposited is greater than $10MeV$. For a pulse with an energy of $200MeV$, the timing resolution is approximately $110ps$.

## 2 Introduction

In the experiment, photons from $K_L^0$ decays are detected by an array of Cesium Iodide (CsI) scintillators, each connected to a photomultiplier tube (PMT). Prior to the development of the 10-pole Gaussian filter, the experiment used a 7-pole Bessel filter originally designed for use in the ATLAS tile calorimeter[1]. The Bessel filter makes the input pulse from the CsI/PMT detector into a quasi-gaussian output pulse with a FWHM of approximately $45ns$[2]. In order to improve upon the timing resolution of the Bessel filter, the 10-pole Gaussian filter was designed to produce a more symmetric, and therefore more gaussian-shaped output pulse. The 10-pole filter consists of 5 inductors, 5 capacitors, and 2 resistors. The values for each component were determined using the Accusim electronics simulation software.

The filtered output pulse is sampled at 125MHz using a technique called flash ADC sampling. Typically, timing is measured using TDC sampling and total energy is measured using ADC. However, because the filtered output is gaussian shaped, we can fit the output using the chisquare method, then use the fitted peak as the time of the hit and the height of the peak to determine the total charge. Therefore, only ADC sampling is necessary. In this paper, we examine the uncertainty in the timing resolution when the pulse timing is measured using this new method.

The fitting of the pulse depends on the starting point from which the pulse is sampled, as well as the frequency of sampling. The starting point for sampling is determined by a global trigger, which is random relative to the arrival of the pulse in the CsI scintillator. This is referred to as asynchronous sampling. This paper also examines the effect of

[1] K. Anderson, et al., Nucl. Instr. and Meth. A 551(2005) 469.
[2] J. Ma, et al., Bessel Filter Simulation. (2007)1.

asynchronous sampling and different sampling frequencies on the time resolution of the output pulse.

## 3 Design of the Gaussian Filter

The input pulse from the PMT can be approximated by a pulse with a reise time of $5ns$ and a fall comprised of two exponential functions as follows:

$$18.4e^{-t\backslash 23.6ns} + e^{-t\backslash 63.5ns}$$

The input pulse is shown below in Figure 1.

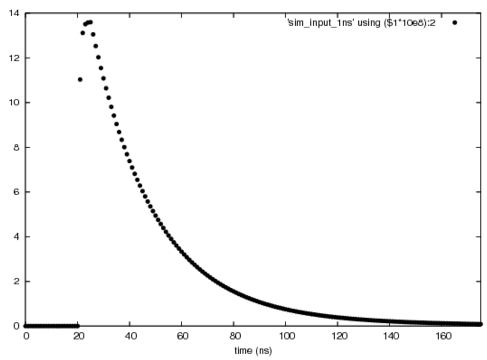


Figure 1: Input Pulse

The input pulse was run through the 10-pole Gaussian filter using the AccuSim software. Starting with values derived from Zverov's *Handbook of Filter Synthesis*, the components were modified individually to minimize the difference between the left and right side FWHM of the output pulse, while minimizing any ringing. This created a symmetric output pulse that was much closer to a true gaussian shape than the output of the 7-pole Bessel filter. The resulting schematic for the 10-pole Gaussian filter is shown in Figure 2 below. The input and output obtained from the AccuSim software is shown in Figure 3.

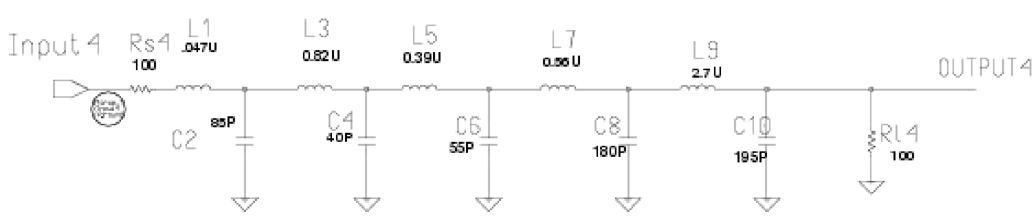


Figure 2: 10-pole Gaussian Filter

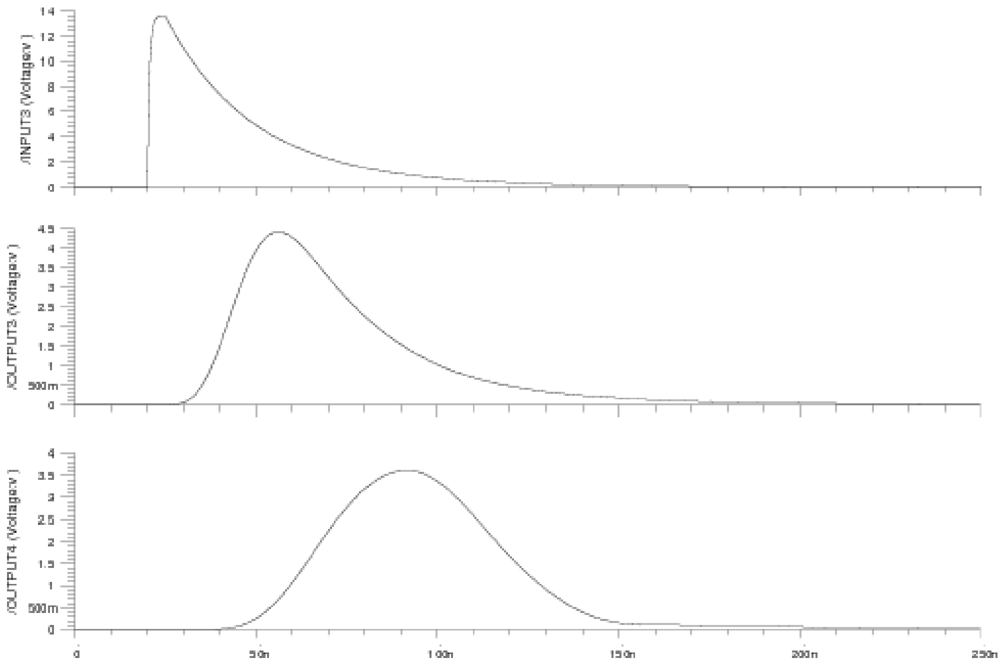


Figure 3: Input pulse (top), 7-pole output (center), and 10-pole output (bottom)

# 4 Timing Resolution for 125MHz (8ns) Sampling

To determine the arrival time of the pulse, we measure the position of the mean, or peak, of the output pulse. To test the accuracy of this measurement, we first smear each sampled output point to simulate the effect of photoelectron statistics at the PMT. We also change the starting point for sampling. Figure 4 shows a distribution of measured peak arrival times for 1600 simulated pulses. All of the pulses arrive at the same time, however, the photoelectron smearing and asynchronous sampling cause variation in the measured peak obtained from fitting. On the left, we see the distribution of measured peak timings for a pulse with a total energy of $200MeV$. The resolution of the measurement is approximately $\sigma = 110ps$. On the right is a distribution for a pulse with total energy equal to $10MeV$. The timing resolution for the lower energy pulse is about $\sigma = 500ps$. We find that as the energy of the pulse decreases, the timing resolution worsens, especially below $5MeV$. Figure 5 shows the trend in time resolution for energies less than $10MeV$.

# 5 Comparison With 7-Pole Bessel Filter

The timing resolution of the new filter was compared with that of the 7-pole Bessel filter to determine whether improving the gaussian shape improved the resolution. At $200MeV$, the resolution of the 10-pole filter was $110ps$ versus $250ps$ for the 7-pole filter[3], meaning

[3] J. Ma, et al., Bessel Filter Simulation. (2007)2.

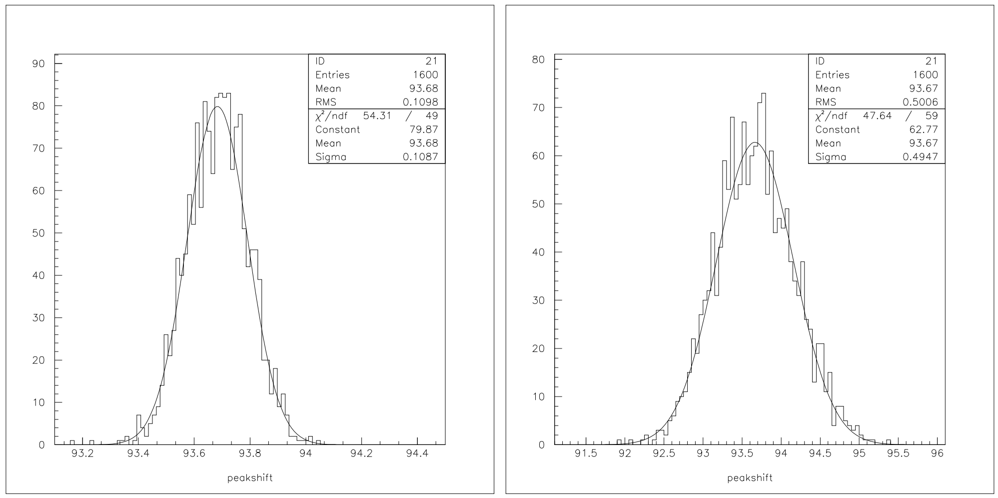


Figure 4: Timing Resolution: 200MeV pulse (left) and 10MeV pulse (right)

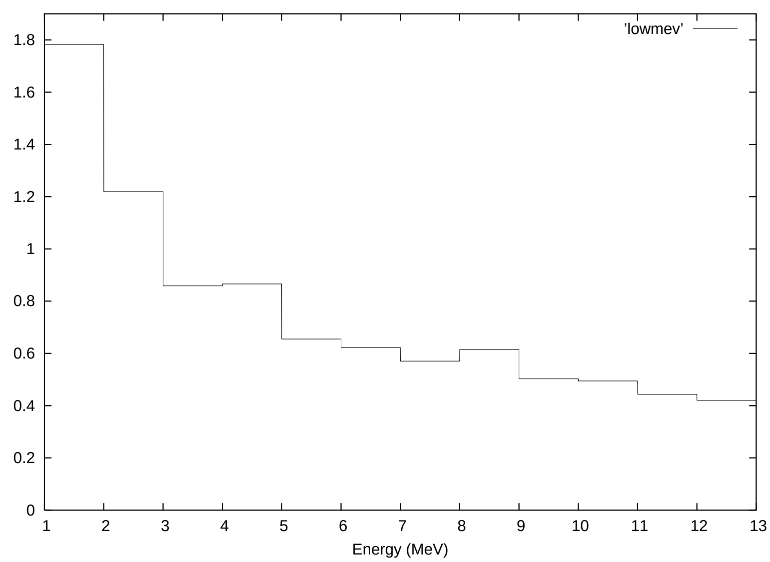


Figure 5: Timing Resolution, Low Energy Pulses

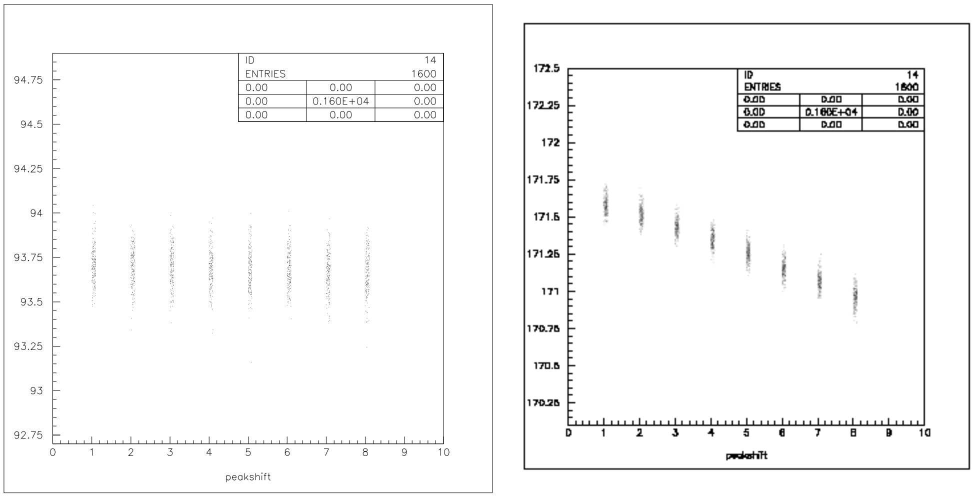


Figure 6: Time Resolution Histogram: 10-pole filter (left) and 7-pole filter (right)

that at high energies, the new filter cuts the uncertainty in time measurement in half. For low energies, the performance of the two filters is comparable, with the 10-pole filter having slightly better resolution.

To determine why the 10-pole filter performs so much better than the 7-pole filter at high energies, we examined a two-dimensional histogram of the resolution. The historgram shows the measured peak position on the y-axis and the starting point for asynchronous sampling on the x-axis. Two-dimensional histrograms for each filter are shown in Figure 6. While the histrogram for the 7-pole filter shows a downward trend in the measured peak position as the sampling points change, the measurements for the 10-pole filter remain consistent. This means that improving the gaussian shape of the pulse eliminated statistical walk due to asynchronous sampling, which caused much of the improvement in the timing resolution.

# 6 Effects of Asynchronous Sampling & Sampling Rate

As discussed in Section 5, the histogram of measured peak times for variations of asynchronous sampling showed no walk at $200 MeV$. Similar plots made for low energy pulses (energies less than $10 MeV$) show similarly level distribution, leading us to conclude that the technique of asynchronous sampling has little to no effect on the timing resolution of the 10-pole filter.

Next we wanted to examine the effect of varying the sampling frequency on the timing resolution. Simulation was repeated for reates ranging from 83.33 MHz (12ns) to 333.33MHz (3ns). As expected, the accuracy of measurement increases with the sampling frequency. Timing resolutions at $200 MeV$ ranged from approximately $130 ps$ at 83.33MHz to $65 ps$ at 333.33MHz. Unfortunately, as the rate of sampling increases, so does the cost of the experiment. Therefore, it is likely that the experiment will be conducted using the current 125MHz sampling rate. A plot of the timing resolution versus the rate of asynchronous sampling is shown in Figure 7.

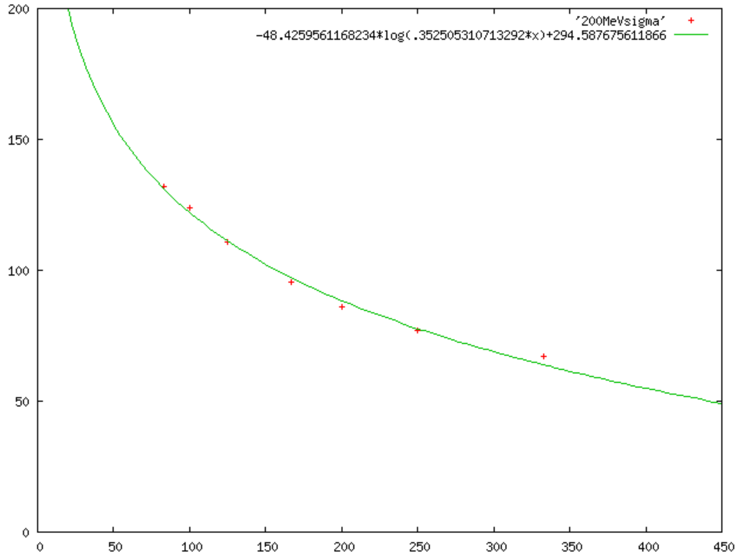


Figure 7: Timing Resolution for Different Rates of Sampling

# 7 Conclusions

Simulation for the 10-pole Gaussian filter shows that improving the gaussian fit of the output pulse significantly improves the timing resolution of the filter. We found that at high energies, the timing resolution of the 10-pole filter was double that of the old 7-pole filter originally intended for use with the experiment. At $200MeV$, the 10-pole filter has a resolution of $110ps$, whereas the 7-pole filter had a resolution of $250ps$. We were able to test the performance of the filter at low energy, and also confirm that the use of asynchronous sampling does not negatively effect the filter's performance. Finally, we confirmed that the performance of the filter can be improved even further by increasing the rate of asynchronous sampling. These simulations show that time measurement for the experiment can be performed using only ADC, eliminating the need for TDC measurement.