Simulation of a new shaper for the readout of the NA62 Liquid Krypton Calorimeter

CERN summer student programme
Shusaku Arakuta
Supervised by Riccardo Fantechi

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Contents

1 Introduction

1.1 The NA62 experiment

The NA62 experiment aims to measure the branching ratio of the very rare kaon decay $K^+ \to \pi^+\nu\overline{\nu}$ at the CERN SPS(400GeV/c protons) to extract a 10% measurement of CKM parameter $|V_{td}|$. This decay is sensitive to new physics via loop processes and well predicted in the Standard Model. For this precision, the experiment have to collect about 100 events at the SM predictionwith a signal to background ratio of 10:1. As latest result, 20 signal candidates were found and the measured BR is$(10.6^{+4.0}_{-3.4}|_{stat} \pm 0.9_{syst}) \times 10^{-11}$ at 68% CL.

2 Liquid Krypton Calorimeter

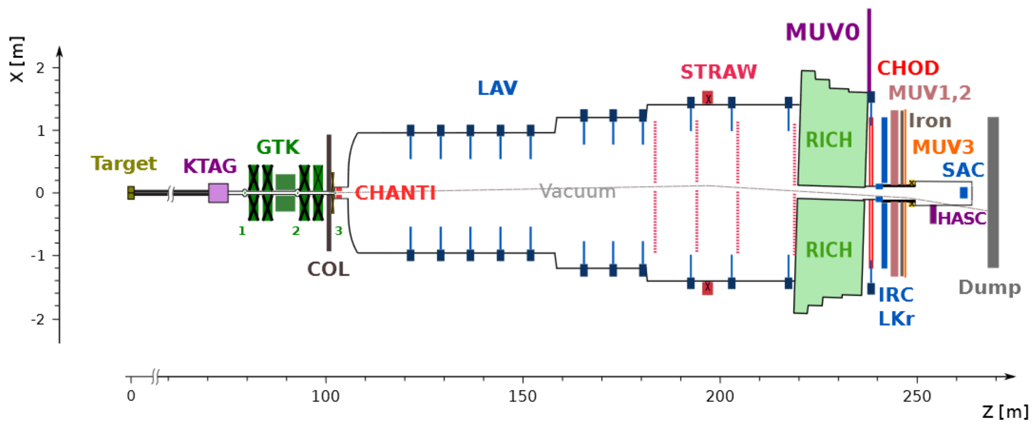

Figure 1: Overall view of NA62 detector

The NA62 detector has many components. There is a Liquid Krypton Calorimeter(LKr) downstream of the detector.[1] LKr is a electromagnetic calorimeter using liquid Krypton at 120K and used as an ionization chamber. The detector is used as part of photon veto system. Its main characteristics are good energy, spatial and time resolutions. The $\sigma_E/E = 1.4\%$ for energy deposits of 25 GeV. Its spatial and time resolutions are 1 mm and between 0.5 and 1 ns, respectively, depending on the amount and type of energy released. The resolution is derived from the structure of the detector. It is an homogenous calorimeter with a small quantity of passive material, so to get good resolutions.

2.1 Specific structure

The detector has a cylindrical volume with $5.3m^2$ cross section and 127 cm depth.The electrodes are Cu-Be ribbons and construct in the form of longitudinal towers of about 2×2 cm^2 cross section. They are stretched in slight zig-zag along the beam axis. The active volume is divided into 13248 $2 \times 2 \times 127$ cm^3 double ionization cells, with the central detector as anode. The voltage between cathode and anode is 3kV.

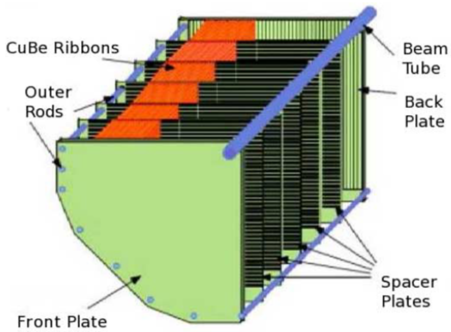

Figure 2: The structure of the LKr calorimeter

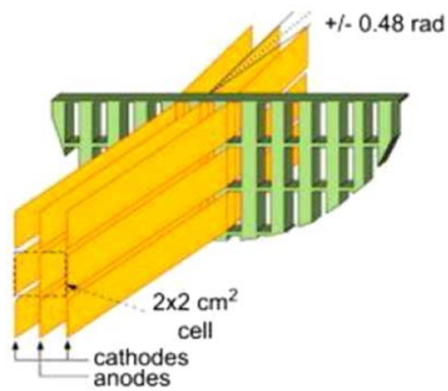

Figure 3: Detail of cells

3 The Calorimeter READout Module(CREAM)

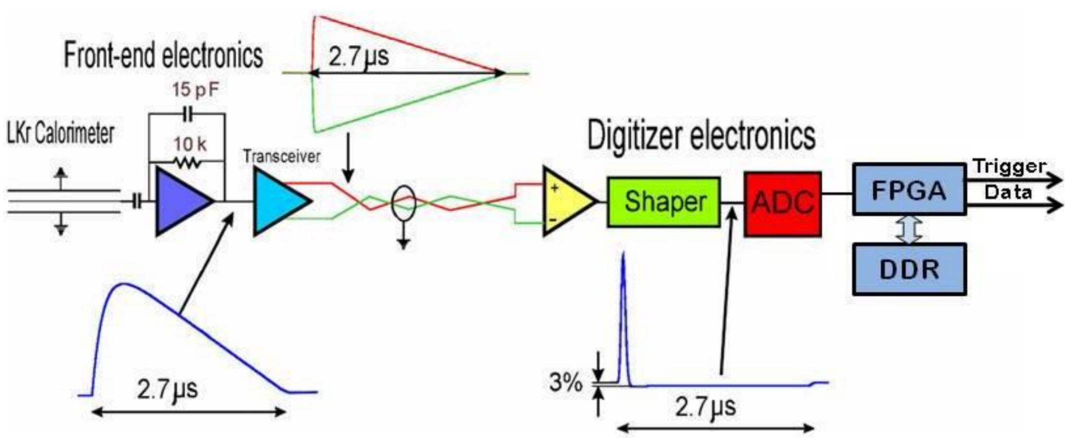

Figure 4: LKr readout system

The readout system of LKr calorimeter consists of Front-end electronics[2], Digitizer electronics and FPGA.[4] The preamplifier of Front-end electronics is inside the liquid krypton and directly connected to the anodes of the calorimeter via low inductance decoupling capacitors. The integration time constant selected for the charge preamplifier is 150ns. The preamplifier is connected to a Transceiver[6] board installed at the output of the cryostat and the output signals of the Transceiver board are differential signals. The Transceiver reshape the long signal of preamplifier in order to have a fast rising edge for fast time measurement. The rise-time and fall-time of this output are $20ns$ and $2.7\mu s$, respectively. They reach the shaper of Digitizer electronics and the shaping time is short (~65ns). The shaper is connected to FADCs for digitizing the input signal at 40 MHz. The total number of channels is 13212. The digitized voltages are analyzed and formatted for the readout by a pipeline process running on the FPGA. The basic philosophy of the readout system, as it was defined for the NA48 experiment, is described in [3][5].

4 Simulation of a New Shaper

4.1 The shaper

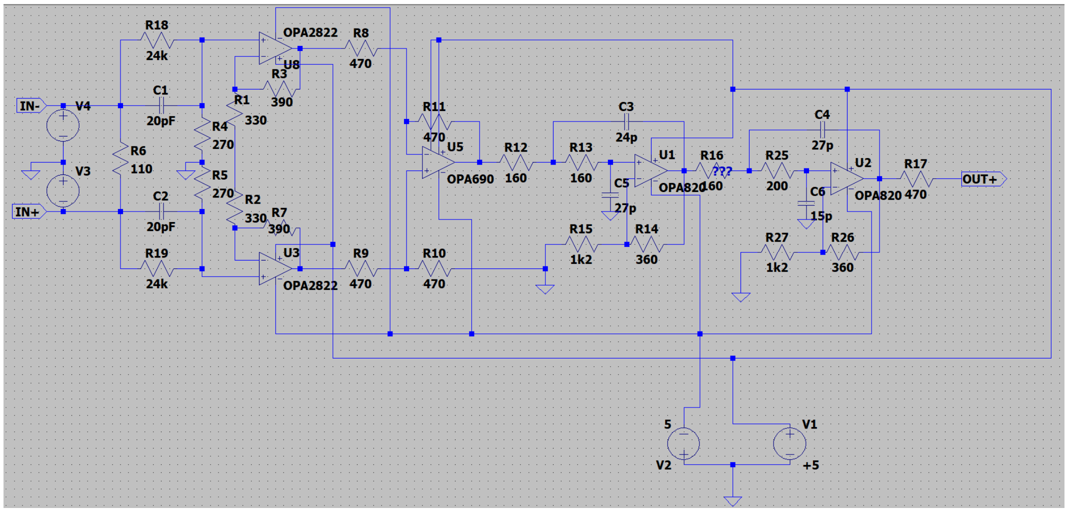

Figure 5: The schematics of the CREAM shaper

	current circuit	new circuit
C_1, C_2	39[pF]	20[pF]
R_4, R_5	510[Ω]	270[Ω]
R_{12}, R_{13}	330[Ω]	160[Ω]
C_3	47[pF]	24[pF]
C_4, C_5	56[pF]	27[pF]
C_6	33[pF]	15[pF]
R_{25}	390[Ω]	200[Ω]

Table 1: The comparison between current schematics and new schematics. The time constant is decreased by a factor of about 4.

To study the performances of a new shaper, we started from the actual circuit. The values of the components are written in Figure.5 and Table.1. The output signal can be simulated with LTspice. The schematics is basically same as the current one and the difference between the current one and this one is a shorter shaping time. If the input voltage is +1V and -1V at t=0 with 20ns risetime, the output will be as the red line at Fig.6. For comparison the blue line shows the actual signal shape. The FWHM is about 20ns and is decreased by a factor of about 3 with respect to the current circuit. It is important for getting time resolution and time capability. The current sampling rate is 40MHz, but considering 20ns FWHM, we need higher frequency. In this project, we generated 50ps sampled data as raw data and reduced to 160MHz(6.25ns) sampled data for using as the simulated data.

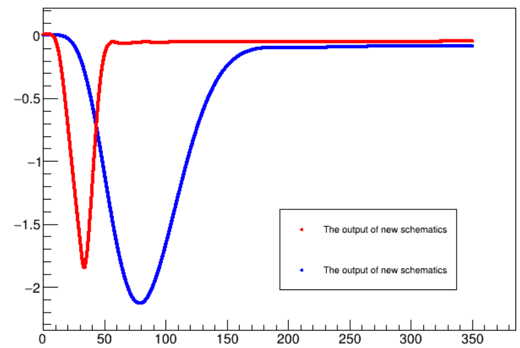

Figure 6: A comparison of output signal of current schematics and new one when the input voltage is $\pm 1V$

4.2 The Goal of this project

The goal of this project is to verify the performance of a new schematics with a shorter shaping time and higher sampling frequency, for having better time resolution and time separation at larger event rates. If a pulse is close in time and space to a good event, we have to separate the superposition to reject the accidental events. For the separation, better time resolution is very useful.

4.3 Conditions of the two pulses

To study superposition, we consider a fixed pulse at time 0 and a subsequent one with different amplitude and delay. The different parameters are:

	risetime[ns]	input voltage[V]	delay time[ns]
1st Signal	20	$\pm$1.0	0
2nd Signal	20	$\pm$0.3,0.5,0.8,1.0	10,20,30

Table 2: The condition of the two pulses

The delay time is the time that the signal comes to this schematics. The condition of 1st signal is fixed and the one of 2nd signal is changed because the time relation of two signals are basically specular.

4.4 Other Products

For pulse reconstruction in MonteCarlo simulation, I produced two kinds of files which have the amplitude and its derivative in time steps of 1ns. They are produced for the current schematics and the new one.

5 How to separate Two Pulses

The pulse reconstruction has to get the maximum voltage and the time of the signals from LKr calorimeter. As you can see in Fig.6, around the maximum amplitude the signal can approximated by a parabola. For that reason, in this project, I fitted the peak by parabola with 4 points or calculated the shape with 3 points. For separation of the superposition, it has one or two peaks. If the signal has

one peak like Fig. 7 which is a superposition of Fig.6 and 10ns delay and 0.5V input , it is difficult to separate. All we can do is getting the information of the peak. If the signal has two peaks like Fig. 8 which is a superposition of Fig.6 and 30ns delay and 0.5V input , it is relatively easy to separate. For example, the derivative of two points changes three times between positive and negative, and the first and third time will be first peak and second peak, respectively.
Basically, I use the three points composed maximum point and two neighbour points for getting the parabola. Assuming the coodinate of the points are $(t_1, V_1), (t_2, V_2), (t_3, V_3)\ :\ (t_1 < t_2 < t_3)$, the parabola become

$$V = \frac{V_3 - \frac{V_2 - V_1}{t_2 - t_1}(t_3 - t_2) - V_2}{(t_3 - t_1)(t_3 - t_2)}(t - t_1)(t - t_2) + \frac{V_2 - V_1}{t_2 - t_1}(t - t_2) + V_2.$$

You can calculate at $t = t_1, t_2, t_3$ easily. By the way, the maximum voltage and the voltage of neighbour point may be close. In that case, I should use also the other point that 6.25ns ahead the neighbour point and then fit by parabola. The criteria whether the points are close or not is $0.95 \times$ maximum voltage. For the Fit, I used ROOT.[7]
Looking at the FWHM of the sampled pulse is another possible way of spotting superposition. The FWHM should be different from the one of the single pulse.

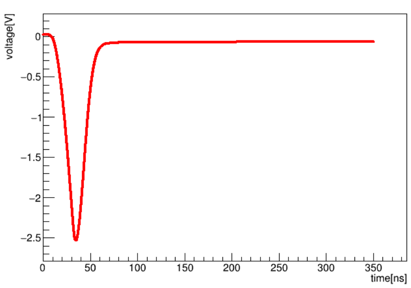

Figure 7: A signal with one peak. This is a superposition of Fig.6 and 10ns delay and 0.5V input.

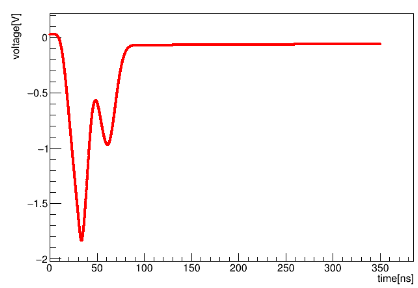

Figure 8: A signal with two peaks. This is a superposition of Fig.6 and 10ns delay and 0.5V input.

6 Results

The Table.3 shows the comparison between the parameters gotten from Fit and Raw data (original data from LTspice). For 20ns delay and 0.8V, I couldn't find the 2nd peak because the peak is too small. The ratio of the two parameters is within $100 \pm 7\%$.The Table.4 shows the FWHM of superpositions and the single pulse. Those are calculated by selecting the two samples around half amplitude, let a straight line pass through them and find the time for which the line gives you half the amplitude.If the signal have more than two timings of half amplitude, I calculated the FWHM by subtraction with the first timing and the last timing.

The FWHM of 30ns delay and 0.3V is close to the one of single pulse. The reason is the second peak doesn't take over the FWHM of the first peak. About the other FWHM using 0.3V, the distance of the two pulse is close and the FWHM gets larger.

Single pulse	Fit or Raw	peak's time[ns]	peak's amplitude[V]		
	Fit	32.78	-1.75		
	Raw	33.35	-1.85		

2nd input	Fit or Raw	1st peak's time[ns]	1st peak's amplitude[V]	2nd peak's time[ns]	2nd peak's amplitude[V]
10ns delay	Fit	34.25 ± 0.06	-2.15 ± 0.01	——	——
0.3V	Raw	34.05	-2.25	——	——
10ns delay	Fit	35.24	-2.45	——	——
0.5V	Raw	34.55	-2.53	——	——
10ns delay	Fit	36.45	-2.85	——	——
0.8V	Raw	35.75	-2.87	——	——
10ns delay	Fit	37.36	-2.93	——	——
1.0V	Raw	35.95	-2.96	——	——
20ns delay	Fit	34.09 ± 0.01	-1.807 ± 0.002	——	——
0.3V	Raw	33.85	-1.91	——	——
20ns delay	Fit	35.06 ± 0.01	-1.867 ± 0.001	——	——
0.5V	Raw	34.15	-1.96	——	——
20ns delay	Fit	36.50	-1.96	Not found	Not found
0.8V	Raw	34.85	-2.02	50.25	-1.61
20ns delay	Fit	36.96	-2.01	49.62 ± 1.58	-1.87 ± 0.12
1.0V	Raw	35.00	-2.06	53.2	-1.92
30ns delay	Fit	32.81	-1.74	60.91	-0.594
0.3V	Raw	33.40	-1.84	61.05	-0.595
30ns delay	Fit	32.83	-1.74	60.96	-0.967
0.5V	Raw	33.40	-1.83	60.95	-0.969
30ns delay	Fit	32.85	-1.74	61.79	-1.55
0.8V	Raw	33.40	-1.84	61.70	-1.56
30ns delay	Fit	32.86	-1.74	62.81	-1.88
1.0V	Raw	33.40	-1.84	63.45	-1.91

Table 3: The upper table is parameter of the first pulse. The lower table is the comparison between Fit(Calculated) Parameter and Raw data Parameter(Caluculated with the data every 50ps from LTspice).

Configuration	FWHM[ns]
Single pulse	20.34
10ns delay 0.3V	21.27
10ns delay 0.5V	21.72
10ns delay 0.8V	22.50
10ns delay 1.0V	24.16
20ns delay 0.3V	24.11
20ns delay 0.5V	30.25
20ns delay 0.8V	36.22
20ns delay 1.0V	38.25
30ns delay 0.3V	20.66
30ns delay 0.5V	42.31
30ns delay 0.8V	48.67
30ns delay 1.0V	49.54

Table 4: The comparison of FWHM.

7 Conclusions

The difference between the pulse of current schematics and a new one is not only shaping time but also the amplitude. The ratio of the amplitudes is $\frac{A\ new\ one}{The\ current\ one} = 0.868$. The parabolic fit has some effect because the difference is within $\pm 10\%$, but there are some problems and plans to improve. First, the pulse with one peak may be able to separate or, at least, judge as a superposition from the FWHM of the pulse. The FWHM is larger than single pulse's one which is about 20ns. That can be a criteria for small delay time. With 10ns delay, the FWHM increase a few ns. Second, the derivative may be useful for getting 2nd peak. If a pulse is superposition, the derivative at 2nd peak is smaller than one of the standard shape.

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