Designing, Building, and Testing Components for Cosmic Ray Detectors

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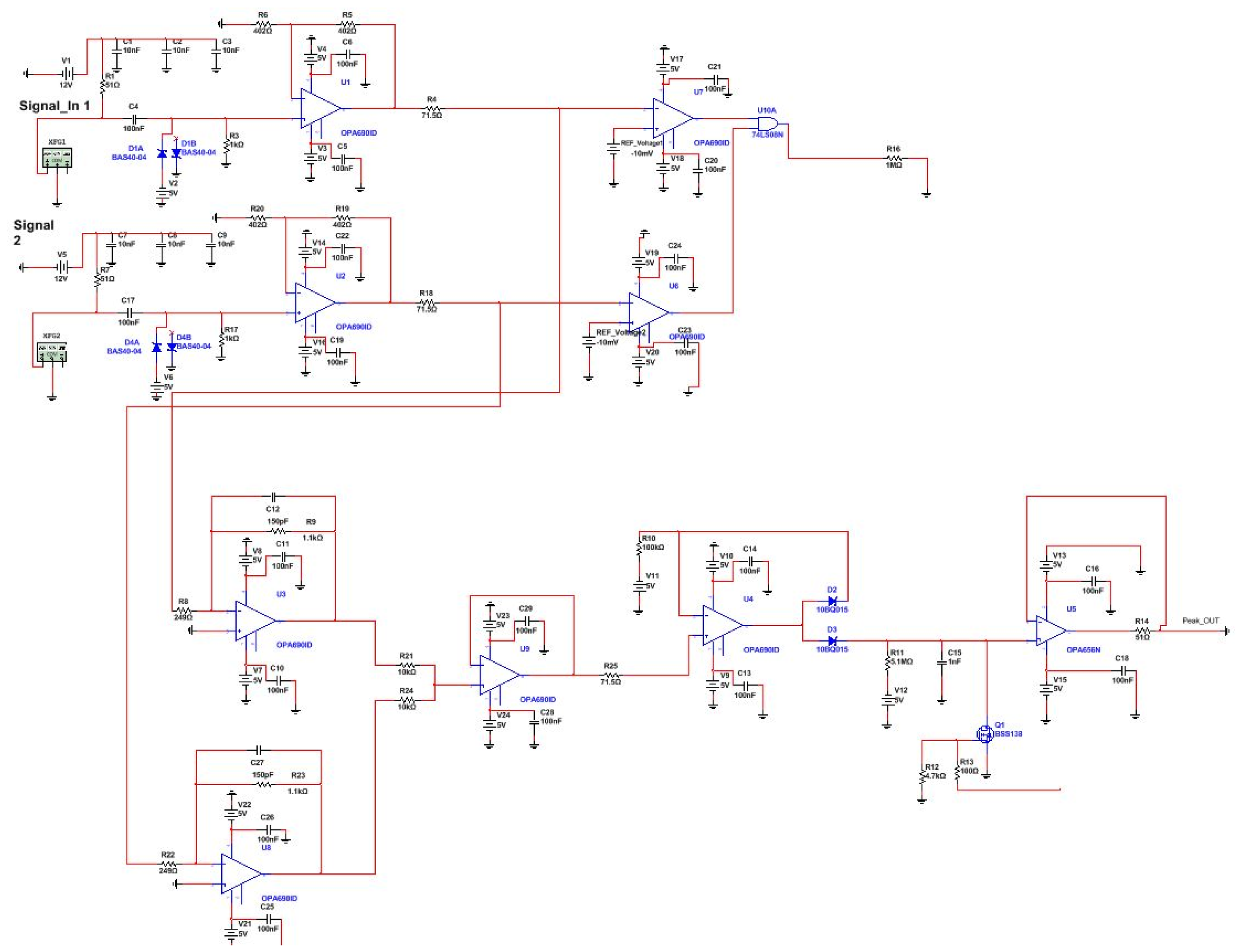
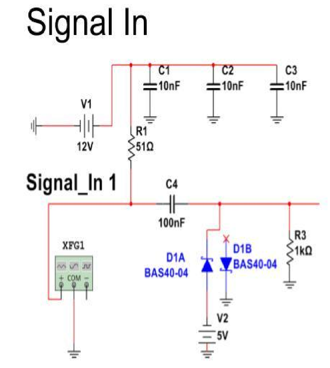
Queensborough Community College Undergraduate research day, Bayside, NY December 8th, 2017

Designing a Data Acquisition Board for Cosmic Ray Measurements



Signal In

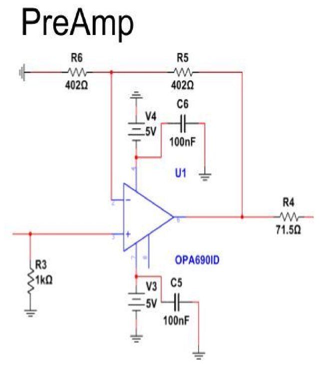


This is the beginning of the circuit and where the pulses from the photomultiplier tubes(PMTs) would enter the circuit. However we do not want to pass any random noise on top of PMT signals so we first run all pulses through a high pass filter which removes low frequency signals. A low frequency input is anything that has a frequency lower than about 1.59 kHz. We calculate this cut-off frequency using this formula:

$F_{cut\text{-}off} = 1/(2\pi RC)$

$F_{cut\text{-}off} = 1/(2*\pi*1k\Omega*100nF) \cong 1.59kHz$

PreAmp



This part of the DAQ circuit is to amplify the input pulse. To accomplish this we use a non-inverting amplifier circuit. To calculate the gain for such a circuit the following formula is used:

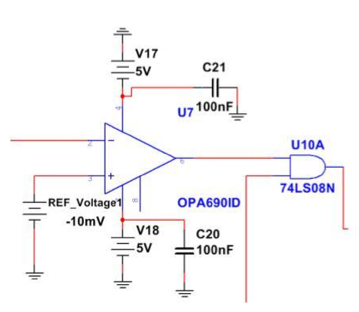
$A_v = 1 + (R5/R6)$

Example:

R5= 402Ω R6= 402Ω

$A_v = 1 + (402\Omega/402\Omega) = 1 + 1 = 2$

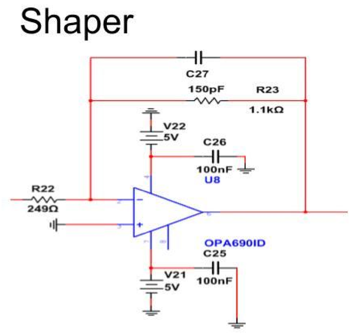
Discriminator



The discriminator sub circuit is used to set a lower limit on signal amplitude reducing noise, and to output for each pmt pulse a square wave of particular width to be read by coincidence logic. It does this by comparing the Preamp output to a reference voltage. If the signal is too low the discriminator will output a negative voltage which would result in a false or low value for the coincidence. If the signal is high the discriminator will output a positive voltage, in this case 5V, which would result in a true coincidence level. This circuit uses two discriminators and an AND Gate to calculate coincidence.

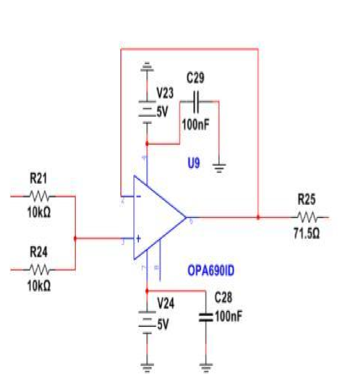
- $V_{in} <= V_{REF} \therefore V_{out} = -5V$
- $V_{in} > V_{REF} \therefore V_{out} = 5V$

Shaper



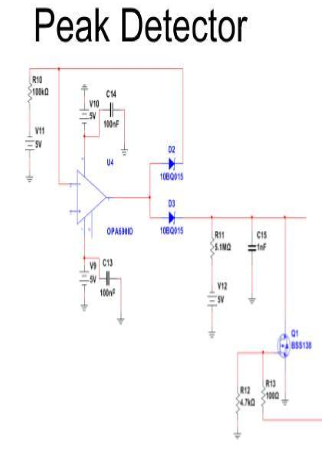
The shaper sub circuit is used to prepare the signal for the upcoming peak detector circuit. It achieves this by using a inverting op-amp circuit. The gain of this circuit will depend on the frequency of the incoming pulse or signal due to the capacitor. However, through simulation we measured a gain of about -3.4. It is important for this circuit to invert the incoming pulse because the peak detector circuit requires a positive input.

Adder



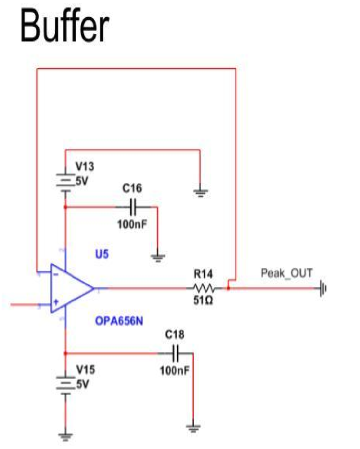
The Adder subcircuit takes in the two signals from their respective shapers an sums their averages, generating one output signal. It has a gain of 1 and does not invert the output signal.

Peak Detector



The peak detector is the heart of the circuit. It measure the amplitude of the signal. We are still working on this part of the circuit; the way it works is as follows: first the pulse runs it course through the circuit and charges up capacitor C15; once the pulse ends the capacitor discharges through the diode and enters the feedback loop of the op-amp which gives us the amplitude of the pulse. It also has a transistor which is activated by the discriminator/coincidence subcircuit which can stop, or allow, this part of the circuit to work.

Buffer



The buffer is true to its name as it acts as a buffer between the DAQ circuit and the Arduino board. This buffer is called a unity gain buffer and has a gain of 1. Another characteristic of a unity gain buffer is that it's input impedance is very high while its output impedance is very low. This allows us to connect the DAQ circuit and the arduino board together without worrying about any impedance issues.

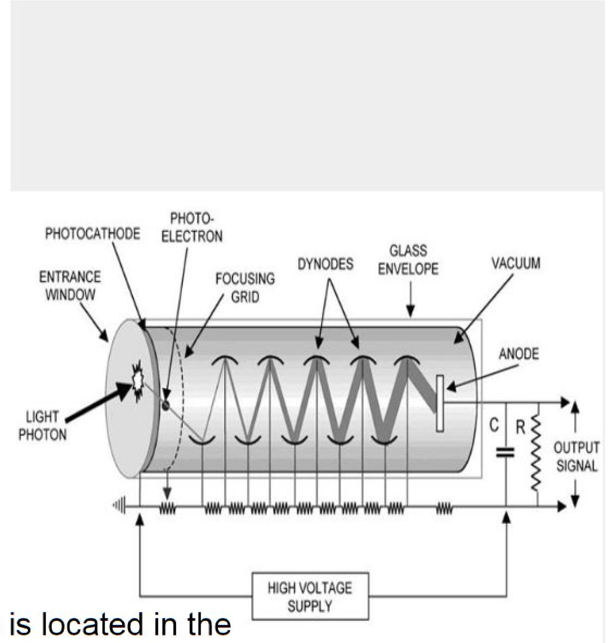
- $A_v = 1$

Method For Determining Whether a Photo-Multiplier Tube is Good or Bad

The Photo-Multiplier Tubes (PMTs) must contain 2 specific standards.

Firstly, they cannot be too noisy. A noisy PMT is like locating a bug in a sandstorm. This is called 'Dark Rate'

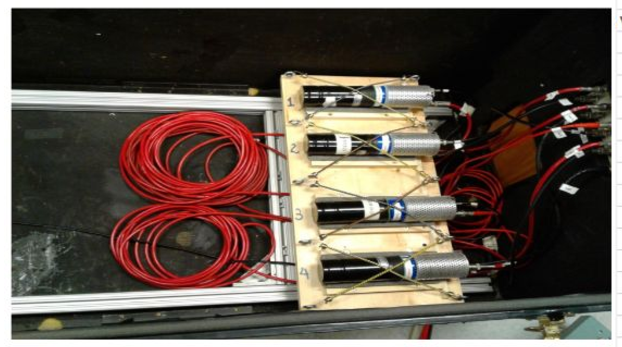
Secondly, a specific gain is wanted….



Gain - the resultant charge produced by 1 photoelectron

This resultant charge is located in the anode, that travels through the dynodes, from the photoelectron produced by a photon in the photocathode (see diagram). It travels due to an electric field supplied by a potential

Dark Rate:
PMTs are strapped into a light tight box, and the amount of charge that resides in the anode is counted.

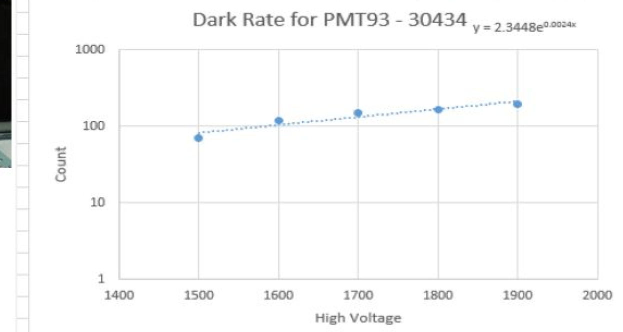


PMTs with high dark rate were rejected. Of the 77 Hamamatsu PMTs that were tested, 15 of them were rejected

The average is counted...

PMT93 30434
Dark count in 8 sec, 10* amplification, -30 mV threshold discrimination

Voltage	Count 1	Count 2	Count 3	Count 4	Count 5	Average (Hz)
1400	139	143	116	120	134	16.3
1500	507	597	550	603	553	70.25
1600	973	981	931	1027	944	121.4
1700	1160	1147	1124	1243	1250	148.1
1800	1377	1310	1358	1410	1276	168.275
1900	1616	1581	1523	1593	1514	195.675

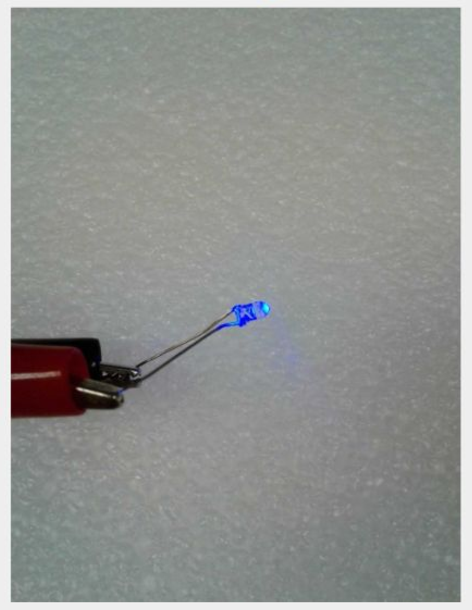


Gain:
In a light tight box, a pulse generator allows the LED light to flash at a specific rate, even in nanoseconds at a time!

This also allows us to control a specific potential, to the hundredths place

1 photoelectron can be produced with this method.

A Blue LED light is used

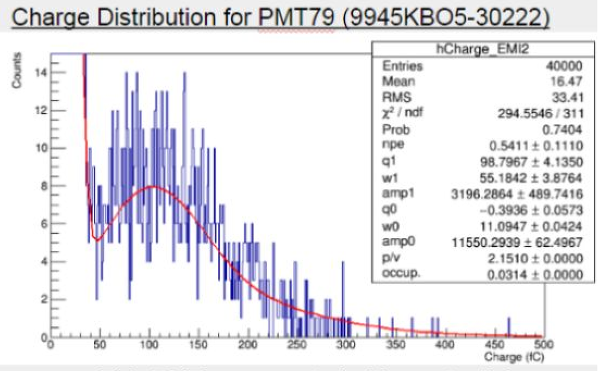


This line is derived from a Poisson Distribution. Notice the similarities.

It is fit about a histogram

key: q1 - peak

Charge Distribution for PMT79 (9945KBO5-30222)



This PMT was counted with a potential of 1600V

This means that the gain at 1600V is approximately...

q1(peak) / e

$98.7967\text{x } 10^{-15}C / 1.609\text{x } 10^{-19}C$

=

$6.14 \text{ x } 10^5$

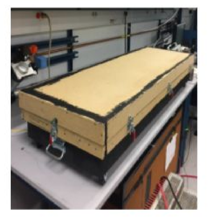
Designing a Box Light Tight and NE-114 Scintillator Efficiency Tests

Making a Dark box Light Tight.

We designed and built a dark box, and improved the dark box by making it impermeable to light. Our goal was to make the box completely light tight. To test its light tightness a Hamamatsu H2431-50 PMT (s/n AA720) was placed in the box and its dark rate recorded with the room lights on, and then off. If the box is completely light tight we expect the PMT dark rate would be the same with the box completely covered with a black tarp and lights off, as when left uncovered with room light on.

The PMT "dark rate" is a form of noise due to the PMT's cathode emitting thermionic electrons; the PMT powered up at a high operating voltage creates strong electric fields across its dynodes which produce a large gain in the number of electrons emitted off the anode. By counting PMT dark rate under different room lighting condition we were able to test the dark box.

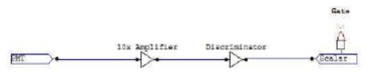
Outside dimensions: ($68\frac{1}{4}$" x $23\frac{3}{4}$" x $11\frac{5}{16}$")
Inner dimensions: (60" x $16\frac{1}{4}$" x 6")



Setup used in experiment

1. Power supply (to power PMT)
2. Sixteen channel amplifier (to amplify the pulses x10)
3. Six channel discriminator (to filter dark rate pulses and detect muon pulses)
4. Quad gate/ delay generator (timer)
5. Visual scaler

Block diagram:



In testing the dark box we found out that it was not light tight. To improve its light tightness the following improvements were made:

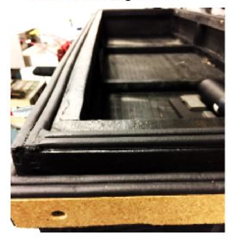
1. Lid replaced with more solid wood, 3 hinges replaced with 8 compression loaded latches.
2. Areas around screws filled with black silicone.
3. Porous gasket replaced with non-porous foam rubber gasket.
4. Bulkhead panel connectors and metal plate interfaces sealed with black silicone inside and outside.
5. Unused bulkhead connectors covered.

Dark box before improvement

Dark box after improvement

Old foamy gasket.

New rubber gasket.



Open connectors and unsealed connector plate.

Covered connectors and sealed connector plate.

After replacing the lid, hinges, gasket, and installing the additional wood liners and gasket, DYNAFLEX 230 black silicon was used to fill in all corners, gaps on the inside and outside of the box. The box was measured to be 92% light tight.

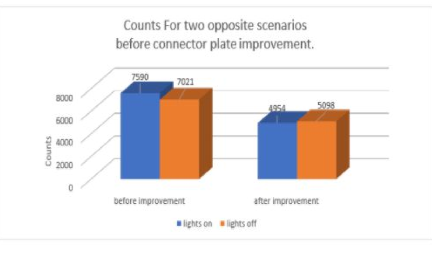
The leaks were found to be through the bulkhead connector panel.

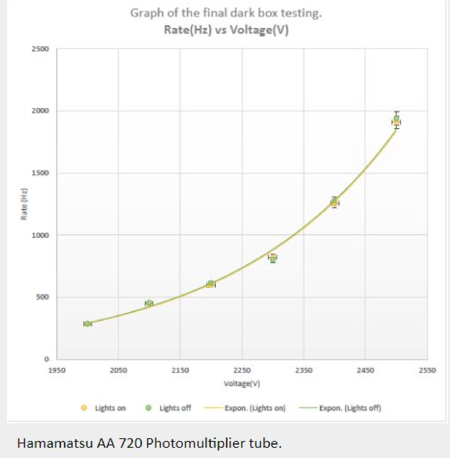
DYNAFLEX 230 black silicon was used to fill around all SHV and BNC connector interfaces through the metal bulkhead panel, and the unused bulkhead connectors were covered, after the box was measured to be 99.6% light tight.

Final light tight tests

There are 2 graphs included on on the plot. The yellow fit represents the dark rate of the Hamamatsu pmt with lights on, the green fit is with the lights off.

In analyzing this graph we see the box is light tight due to the fact that PMT dark rate is the same with the box completely covered with a black tarp and lights off, as when left uncovered and room light on.



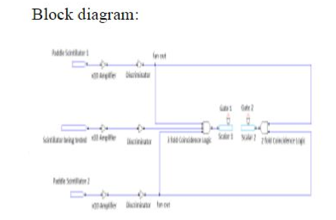


Hamamatsu AA 720 Photomultiplier tube.

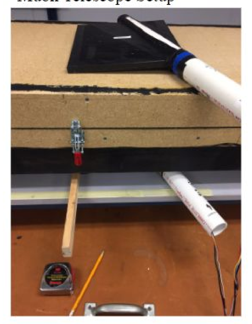
Efficiency tests on scintillator

The scintillator output was tested along it's length as a measure of its attenuation. Two small QuarkNet scintillator counters with photomultiplier tubes sandwiched the NE-114 scintillator counter under test (with Hamamatsu PMT s/n AA1071 attached) in a "muon telescope" setup. The 2-fold coincidence and 3-fold coincidence were measured simultaneously at different distances from the scintillator under test's PMT. In order for the scintillator to appear perfectly uniform and 100% efficient along its distance the ratio of 3-fold counts to 2-fold must be equal 1.

Block diagram:



Muon Telescope Setup

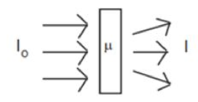


NE-114 scintillator about 40 inches long.

Attenuation in the scintillator can be quantified using the following formula:

Photons are absorbed in matter by statistical processes that lead to an exponential absorption that is a function of position. This function is normally written as:

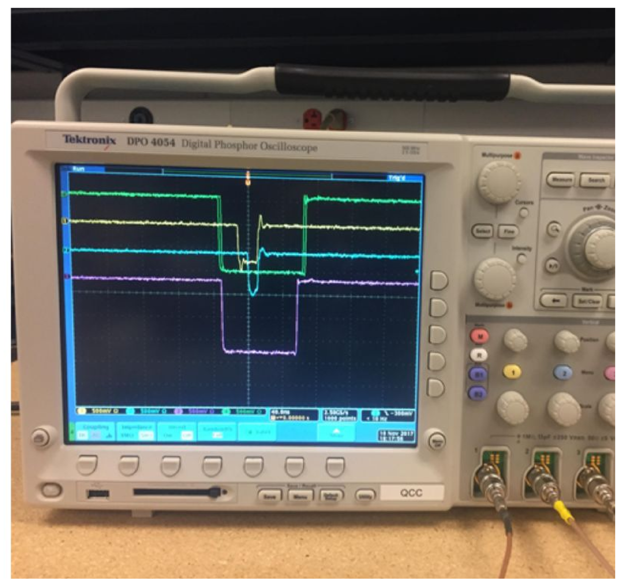
$$I = I_o e^{-\mu x}$$



Where:
I_o = the number of photons of a certain energy incident or entering the sheet of material,
x = the thickness of the sheet,
I = the number of photons that have passed through a layer of thickness x,
µ = the linear attenuation coefficient of the material for photons of this particular energy

The photons that do not get through have interacted within the sheet of material and are either absorbed or scattered. In this case, photons have interacted in the sheet. The number of photons transmitted by a certain thickness is the value of *I*.

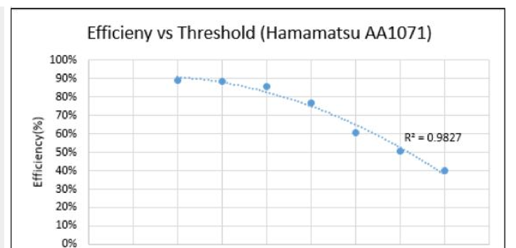
- Green and Purple graphs represent discriminator unit signals for two small muon detectors the width of the gate approximately 85(ns) and an amplitude is 1.5 (V)
- Yellow and blue graphs represent the width of 2 fold and 3 fold coincidence signals after coincidence unit.



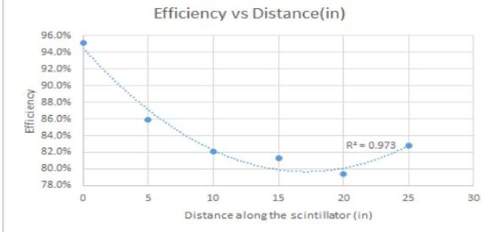
Gate Width
Voltage
Random "noise" pulses

The rate of noise depends on the voltage applied to the photomultiplier tubes – Higher voltage produces more random pulses.
– Rate on channel 1 is R_1
– Rate on channel 2 is R_2
– Accidental rate when channel 1 fires first: R_1R_2*w
– Accidental rate when channel 2 fires first: $R_2 R_1*w$
– Total accidental rate: $2 R_1R_2*w$= 2*300*300*85*(10^-9)= 0.0153
– Three-fold accidental rate: $R_1R_2R_3*w^2$ =4500*300*300*85*85*(10^-9)^2= 3*(10^-6).

– Gate width was set to 85 ns for all three discriminators.
– Accounts for different lengths of cables, different "transit times" in photomultiplier tubes.



The NE-114 scintillator efficiency was measured as a function of discriminator threshold which sets a lower limit on PMT signal amplitudes.The discriminator on the PMT attached to the NE-114 scintillator under test was adjusted while keeping the discriminator thresholds for the small reference QuarkNet counter PMTs fixed at an 8 mV equivalence voltage. As expected efficiency decreases with increasing threshold. When the threshold is 2mV the number of 3-fold counts is largest, with higher thresholds more NE-114 signals are filtered out.



The NE-114 scintillator efficiency was measured at 79% at distances between 15 and 20 inches from the PMT. However we plan to verify this again and investigate why this graph turns upward after 15 inches.