

Pulse Shape Discrimination with The Neutron Walls at NCSL

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Abstract

The National Superconducting Cyclotron Laboratory at Michigan State University has recently completed the Coupled Cyclotron Upgrade. The new facility will concentrate on the study of rare isotopes produced in fragmentation reactions. Neutron-rich unstable isotopes can be investigated via break-up reactions. The resulting neutrons will be detected in two walls of position sensitive detectors. Each wall consists of glass cells filled with a liquid scintillator. Photo multipliers attached at each end of the glass cells detect light pulses created when an interaction occurs in the scintillator and the relative time of the signals can be used to extract position information. The pulse shape depends on the particle-type of the interaction and thus it is possible to distinguish neutrons from gamma rays. A new electronic circuit was designed to utilize this pulse-shape dependence to achieve neutron-gamma separation. The system was successfully tested with a single detector and is now being implemented for the whole array.

The Neutron Walls

The Neutron Walls at the National Superconducting Laboratory were designed and built to detect neutrons from break up reaction. The total detection area for one wall is 2m by 2m. The two walls can be used side by side for a greater detection angel, or be placed one in front the other for greater detection efficiency.

Each wall consists of twenty-five vertical glass cells filled with NE-213 liquid scintillator. At each end of the cells are mounted photo multiplier tubes. When an interaction occurs inside one of the cells, visual light is omitted and detected by the photo multiplier tubes. Using electronics, the entire pulse is integrated and this value is

proportional to the energy deposited in the scintillator by the incoming radiation. Since the neutrons do not deposit all their energy into the scintillator, the pulses are used just to identify that a neutron has hit the wall. The time of flight between the target and detector is used to determine the total energy of the neutron. The position of the interaction can be determined using the time difference for the light to reach the two photo multiplier tubes at each end of the cell.

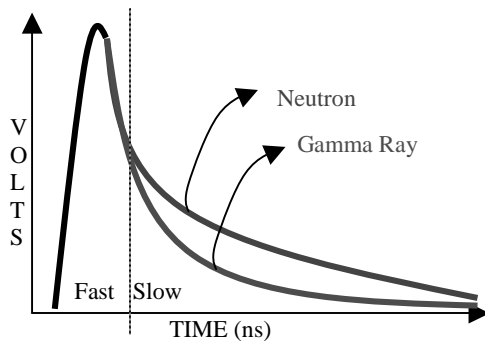
The largest problem that arises when using large area scintillators is the interference of gamma rays. When a neutron enters the scintillator, it will interact with it by hitting the proton of a hydrogen nucleus. When a gamma ray enters the scintillator, it will Compton scatter an electron. The scattered particle then excites the surrounding particles and they will emit a visible light. The light reflects down the glass cell by internal reflection where it is detected by the photo multiplier tube. Due to the size of the scintillators, background gamma rays become a very annoying problem during an experiment.

The Idea Behind the Pulse Shape Discrimination

The pulse that comes from the photo multiplier tubes is basically the sum of two exponential decays. The first one is from the initial interaction that occurs in the scintillator. This pulse usually has a high decay constant and falls off quickly (about 10ns), so this is considered as the fast signal. The second pulse comes from the secondary reactions that occur when the scattered particles bump into other particles. This pulse is smaller than the first but lasts longer due to the time of these secondary interactions. This second signal is considered the slow signal.

The traditional method of retrieving information from a pulse is to use an analog to digital converter (ADC) to record the max height of the pulse or to use a charge to digital converter (QDC) to integrate the pulse. The pulse heights and the total pulse area can be the same for both neutrons and gamma rays. Just using one of these methods can yield the same results for both interactions making it impossible to discriminate between the two.

The slow signal is not usually important for energy measurements. Except, in the NE-213 liquid scintillator, the secondary reactions depend on the scattered particle. Like described above, the scattered particles depend on the incoming radiation. This suggests a way to discriminate between the two different interactions. If the fast signal and slow signal could be integrated separately, the ratio between the two should be different depending on the interaction that took place.



Electronic Set-up

Since the two pulses come together in one pulse, there is no easy way to separate them. So we decided to integrate the entire pulse and just the beginning of the pulse (mostly the fast signal). The ratio between these two should be similar for all the same interactions.

When an event occurs in the detector, the pulse is fed into a Pulse Discrimination Circuit (PSD), which has two outputs. The first output is the original signal, identical to the input. The second is only the beginning of the pulse or the fast part of the signal. A common gate is created about 80 ns in length. This is sent to a QDC module along with the two pulses, so both integrations can be made simultaneously.

A new Data Acquisition System was written to take data from the electronics and display them in spectra on the computer. For each event, both integrations are plotted in a 1d spectrum than they are plotted vs. each other. The ratio between the two integrations should be constant for the same reactions. So when they are plotted against each other, all events of the same type should fall on the a linear line.

PSD Circuit Problem

The PSD circuit does a good job at cutting the tail off the pulse. However, it will overshoot when it cuts the tail, leaving a small positive peak. Since the pulses are negative, we were unsure how the FERRA module would respond to this positive part during integration. So, we tried adding additional circuits after the PSD to eliminate the positive peak.

One of the things we tried, was a commercially available limiter circuit. It has a positive and negative voltage limit that can be set using adjustable resistors. If the pulse voltage exceeds the limits, than the voltage of the limit is passed thru instead of the voltage of the pulse. We set the positive limit at zero and the negative limit really low, thus only allowing a negative signal to pass threw the circuit.

Using an oscilloscope, we looked at the pulse after the limiter circuit. We had to set the positive limit a little below zero to get a clean cut. The circuit did an acceptable job of cutting out the positive peak, but there were some problems when the data was graphed. The graph appeared to have a reflection of it self, slightly shifted to the side.

We found that the limiter did not have a constant base line. When no input was supplied to the limiter circuit, a small variance of a couple mille-volts could be seen in the output signal. This did not seem like a big problem at first, but when the signal is integrated over 80ns, it would shift the results, causing a double graph.

Final Solution

After trying many different circuits and combination of circuits like the one above, we went back to not using anything at all. The FERRA module has an internal diode that protects it from positive signals. The FERRA module also injects a small negative pedestal voltage onto the input lines to protect from no signals or small positive signals. We could change the internal pedestal voltage with a small adjustable resistor inside the module. By slightly changing the pedestal voltage, we made our results a little better.

So with out using an additional circuit, we could easily distinguish between gamma rays and neutrons at an acceptable energy level. We used a ^{22}Na source to calibrate our spectra. Then we used a ^{252}Cf fission source to test for gamma ray and neutron separation. Calibration and results showing gamma ray and neutron discrimination are shown in the results section at the end of this paper.

Bibliography

[1] – Glenn F. Knoll – Radiation and Detection and Measurement (Third Edition - 2000)

[2] – Aaron Galonsky – The Neutron Wall Website

http://www.nsl.msu.edu/neutron/nw_home.html

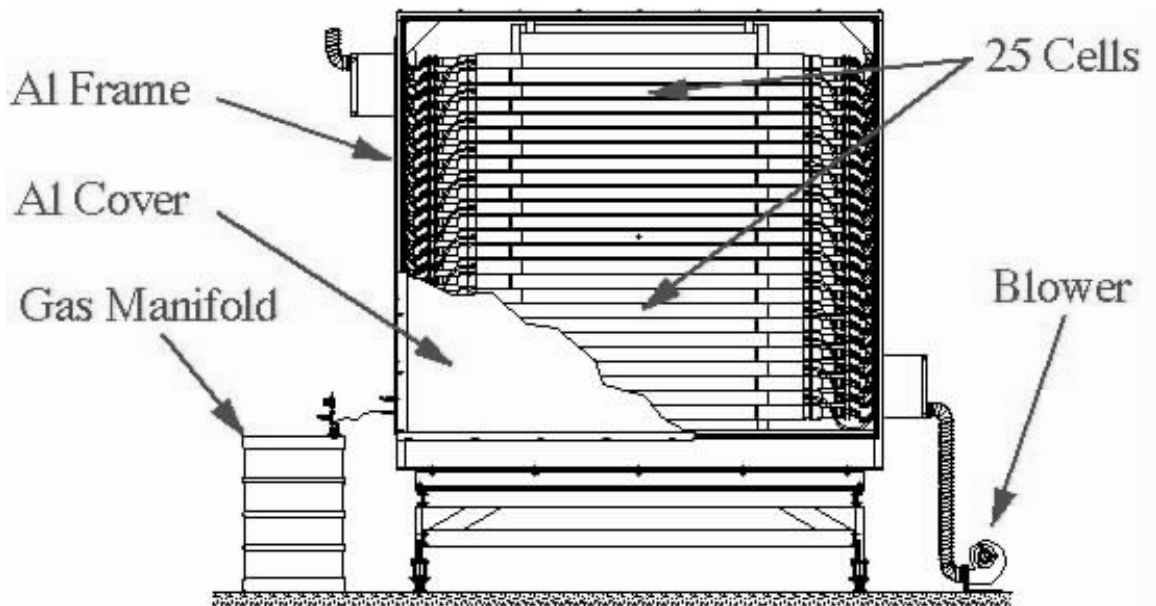


Figure 2 – Above shows a CAD drawing of one of the two neutron walls.

Results

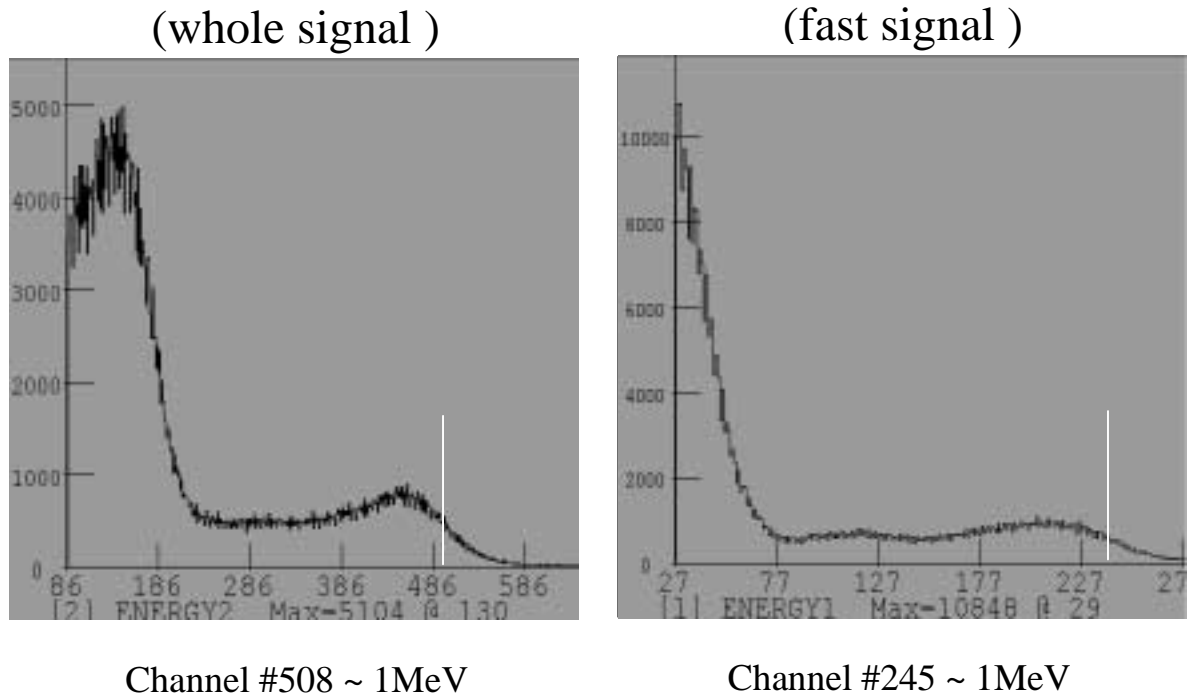


Figure 3 - Calibration Data taking with a ^{22}Na source – Above are 1D spectra showing energy detected vs. counts. The spectrum on the left is the integration of the entire signal. The spectrum on the right is the integration of just the fast signal. Both spectra show good Compton edges created when the incoming gamma ray of 1.27 MeV scatters back at 180° giving about 1 MeV of its energy to the electron. So we use these channel numbers in the middle of these edges as calibration points.

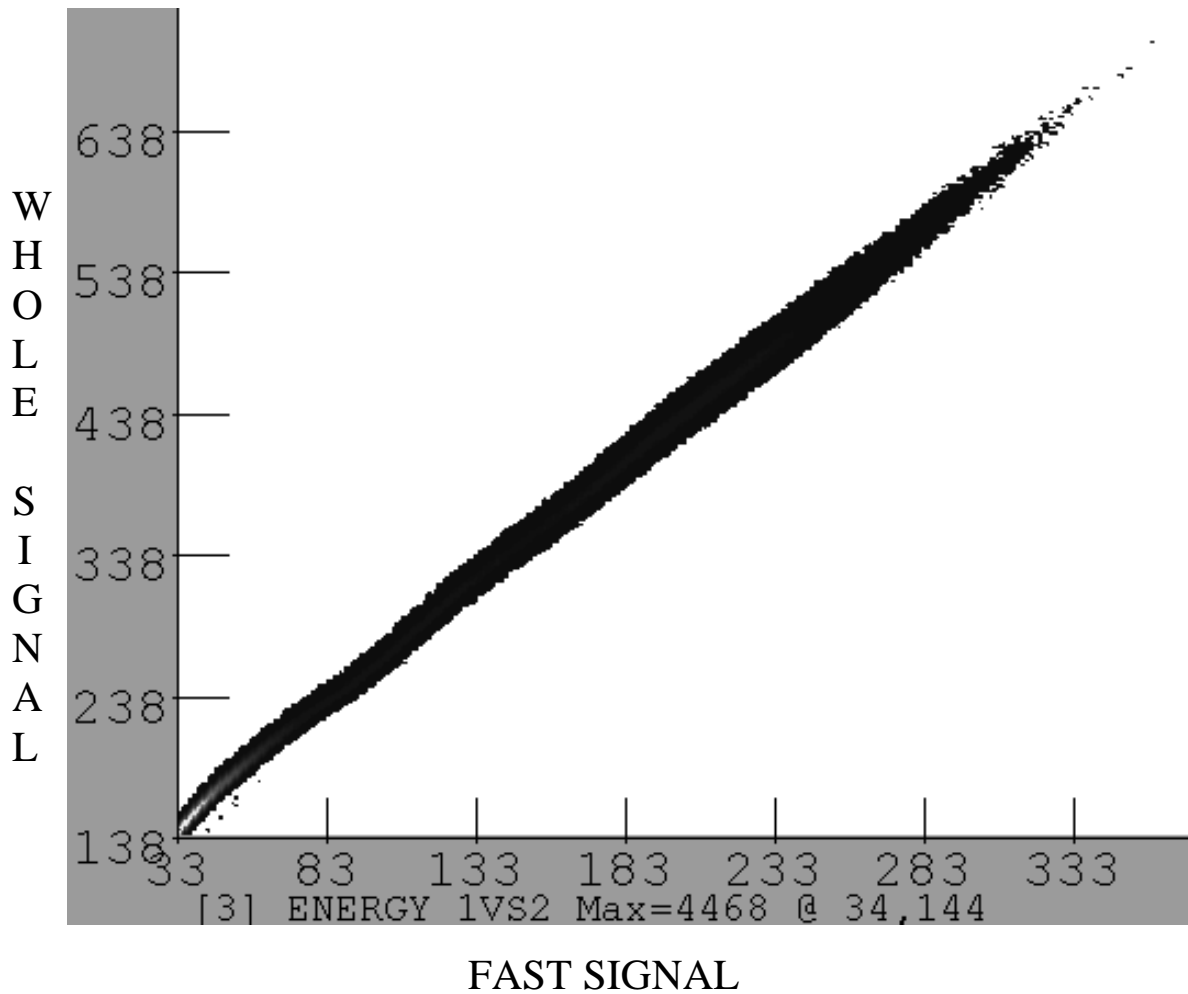


Figure 4 - Calibration Data taking with a ^{22}Na source - The above is a 2D graph of the two spectra in figure 3. The ratio between the whole signal and the fast signal are constant because all the points fall on a linear line.

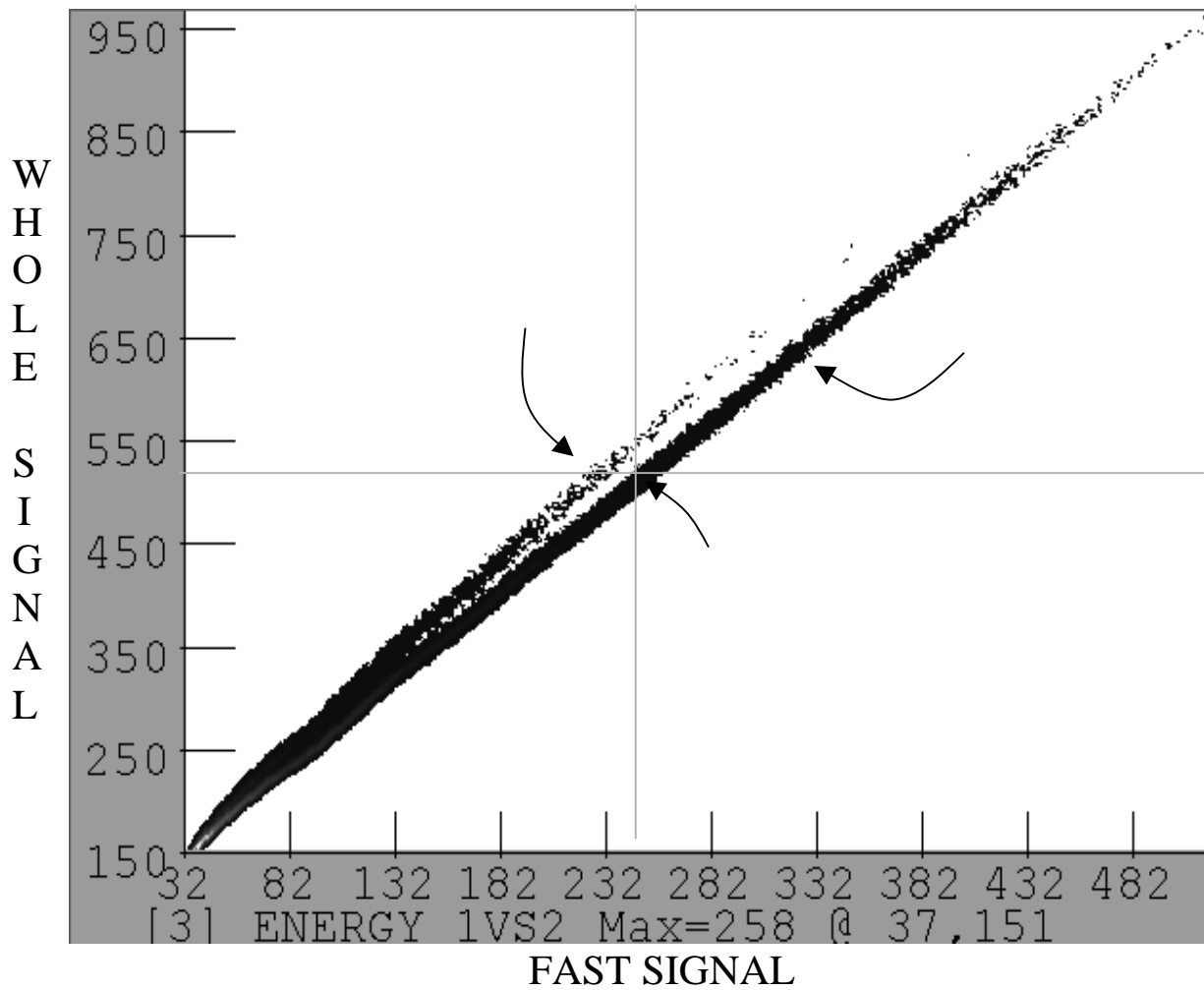


Figure 5 - Discrimination data taking with a ^{252}Cf source - The above is a 2D graph like that of figure 4, except a fission source is being used. The two data lines represent the neutrons and gamma ray interactions. Its easy to see discrimination between the two lines below the 1MeV lines we found.