Kass, revised Spring 2012

Nuclear Spectroscopy with the PC

Read the entire document before starting lab 4!

I) Introduction:

This write-up describes the software and associated hardware that is used to turn a PC into a multi-channel analyzer (MCA). A multi-channel analyzer (MCA) is an electronic instrument which analyzes voltage pulses input into it and sorts them depending upon their respective voltages. As its name implies the MCA contains many channels. Each channel holds the count of the number of pulses which have a given voltage range. Thus the MCA generates a *histogram* of the number of pulses which fall in various voltage ranges. A typical use for the multi-channel analyzer is the measurement of the γ ray energy spectrum from a radioactive source such as Cs137.

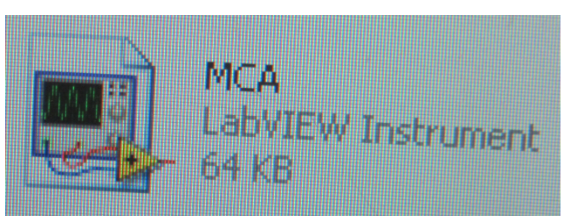
II) Software:

The PC is turned into a multi-channel analyzer using a software package called LABVIEW. LABVIEW is a product of National Instruments and is commonly used in research environments to interface computers with data collecting hardware. For the LABVIEW applications in this class you will not need to know any of the details of how to program with this software system. However, a complete set of manuals is available for those of you who are curious.

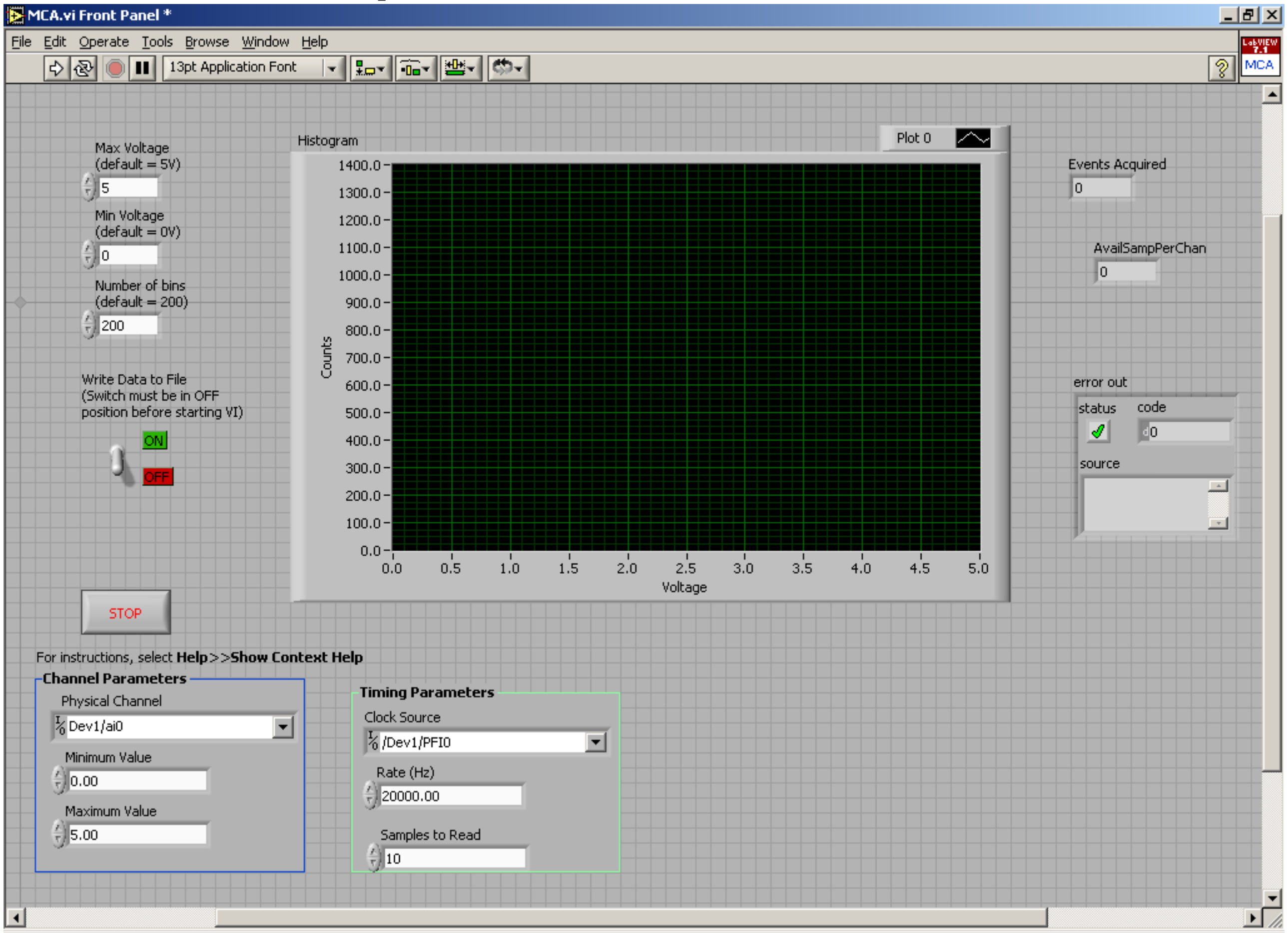
For our purposes the LABVIEW software serves two functions. First, it controls the data board (PCI-6220) inside the PC that is used to record (digitize) the electronic signals from the NaI Spectroscopy Amplifier. Second, it allows us to manipulate the recorded data and, for example, display it as a histogram.

The program used to "turn" the PC into a multi-channel analyzer is called MCA. To run the program, double click the MCA icon. The MCA program (LabView calls it an "instrument") was designed to sort "events" (actually input voltages from the spectroscopy amplifier) and display a count of them (actually a histogram) as a function of voltage. This histogram is updated as a function of time as more events are collected.

The program icon for the MCA instrument is located in C:\LabView.



Once MCA is started the computer screen will look like this:



The above will display a histogram (once data collection has started) in which the vertical (y) axis gives the number of pulses (counts) in bins of voltages. As we collect data, the number of counts in a given bin will build up on the y axis.

Starting and Stopping MCA:

To start first click on the *arrow* icon in the upper left hand corner of the display. Once the program starts to collect data an icon in the shape of a *stop* sign will appear in the upper left hand corner.

To **stop** the program click on the ***stop*** sign icon.

Writing data to a file:

After you have taken some data but **BEFORE** you click on the *stop* sign, you can record the number of counts in each bin in a data file. This is done by clicking the switch titled *Write Data to File*. After you click on this, the MCA will continue taking data for a few moments (it is designed to take data in loops of 100 events each). MCA then asks for the name of the file and writes the data to that file. This file can be opened and manipulated by other PC programs, e.g. sciDAVis.

III) Hardware:

The hardware used for the nuclear spectroscopy experiments is described below as shown in the pictures that follow.

1) NaI Calorimeter

The NaI calorimeter consists of a scintillator, a photo multiplier, and a photo multiplier base. The scintillator is a NaI crystal doped with Tl which converts γ-ray energy into many photons of light. The photomultiplier tube converts the light quanta emitted by the scintillator into photoelectrons and amplifies the number of photoelectrons, giving a current pulse proportional to the amount of energy deposited in the NaI. The photo multiplier base also distributes the necessary voltages (typically a 1000 V, total) to the photo tube itself.

2) PM Control

The blue box ("PM Control") connected to the photo tube base serves as the voltage controller for the photo tube. Here's what's what on the box:

a) ON/OFF switch: The light goes on when the power to the photo tube is turned on!

b) SET: This is a test point. You can read the "set voltage" (i.e. the voltage that the photo tube is set to) with a voltmeter by putting one voltmeter probe here and the other probe in the GND test point. The calibration is such that a reading of 10 Volts corresponds to setting the photo tube voltage to -2 kV.

c) GND: This is the ground test point.

d) MON: The voltage difference between this test point and GND is the voltage at the photo tube (actually its scaled so that -2 kV at the photo tube = 2 V on voltmeter).

e) HV SET: This is a potentiometer that sets the photo tube voltage. Turn clockwise to increase the voltage. You should always have a voltmeter reading the voltage difference between MON and GND when you adjust this pot.

The SET and MON photo tube voltages should agree with each other (after taking into account their different calibrations) to within a few volts for a working photo tube. If they do not agree to within a few volts then there is a problem with either the photo tube, photo tube base, or both. (note: some of you may not have a "blue box" but your box functions in the same manner)

3) NaI Spectroscopy Amplifier:

This box amplifies and filters the signals from the photo tube and tells the computer that there is data available to be recorded. Here's what's what with this box:

a) INPUT: The connector labeled INPUT takes the input signal from the photo tube.

b) ANALOG OUT: This connector sends the amplified signal to the INTERFACE box and ultimately to the computer.

c) TRIG OUT: The output from this connector tells the computer that an event is coming, "get ready to count".

d) GAIN: This control (potentiometer) allows you to adjust the "volume", that is, it allows you to set how much an incoming signal gets amplified. The gain is just the ratio between input and output voltages.

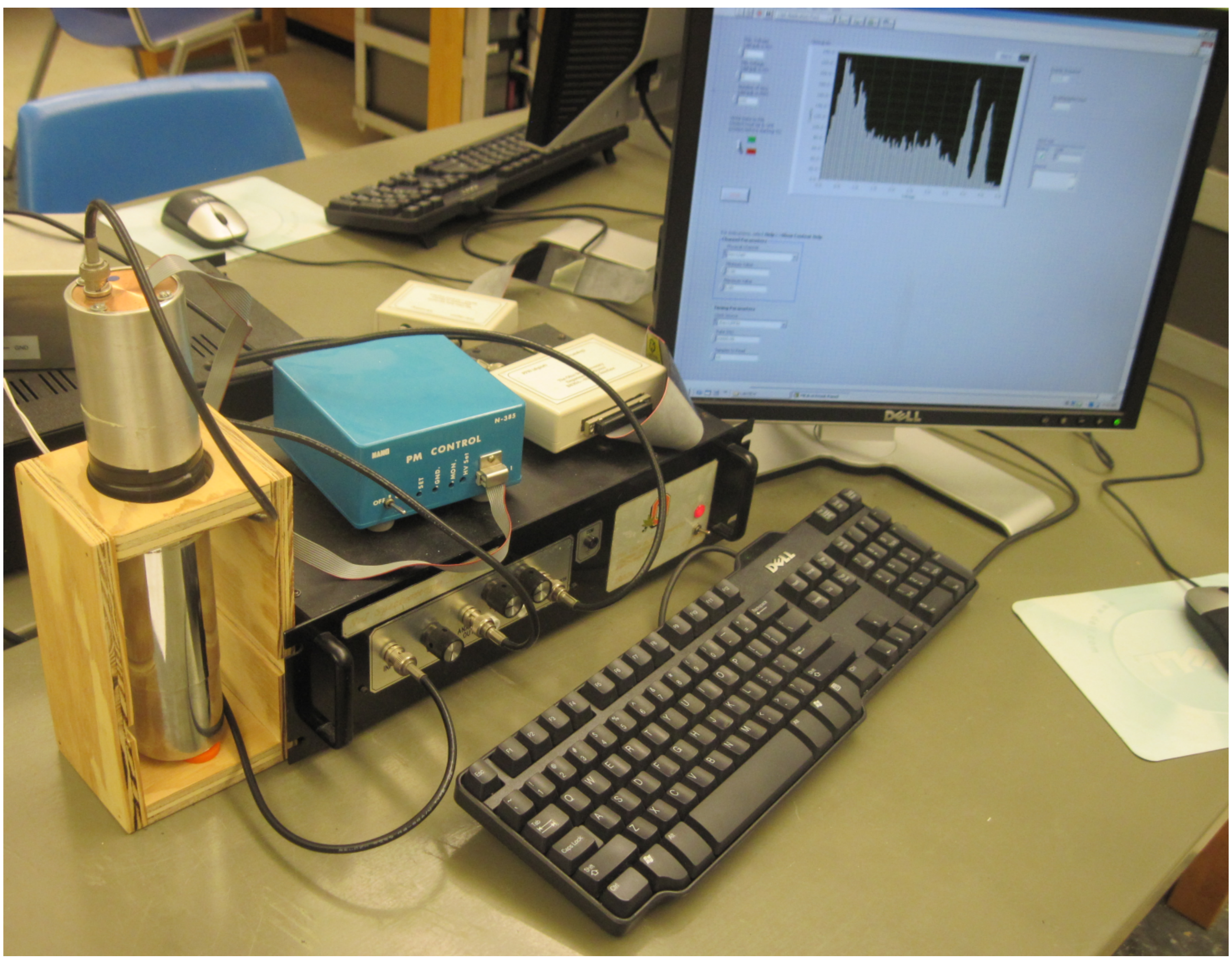
e) THRESHOLDS: Two very important dials are the upper level (labeled **UL**) and lower level (labeled **LL**) thresholds. The upper and lower level thresholds indicate the window of voltage signals that are sent out to the computer. For example if the upper level is set at 4 V and the lower level is set at 2 V then the computer will (theoretically) only receive a signal in the range 2 to 4 V, and a 1.5 or 4.2 V signal will not be counted. Note that you have to use a screw driver to turn these dials and a voltmeter to figure out what the levels actually are.

f) WIDTH: This potentiometer controls the width of the TRIG OUT signal. Do not change this control.

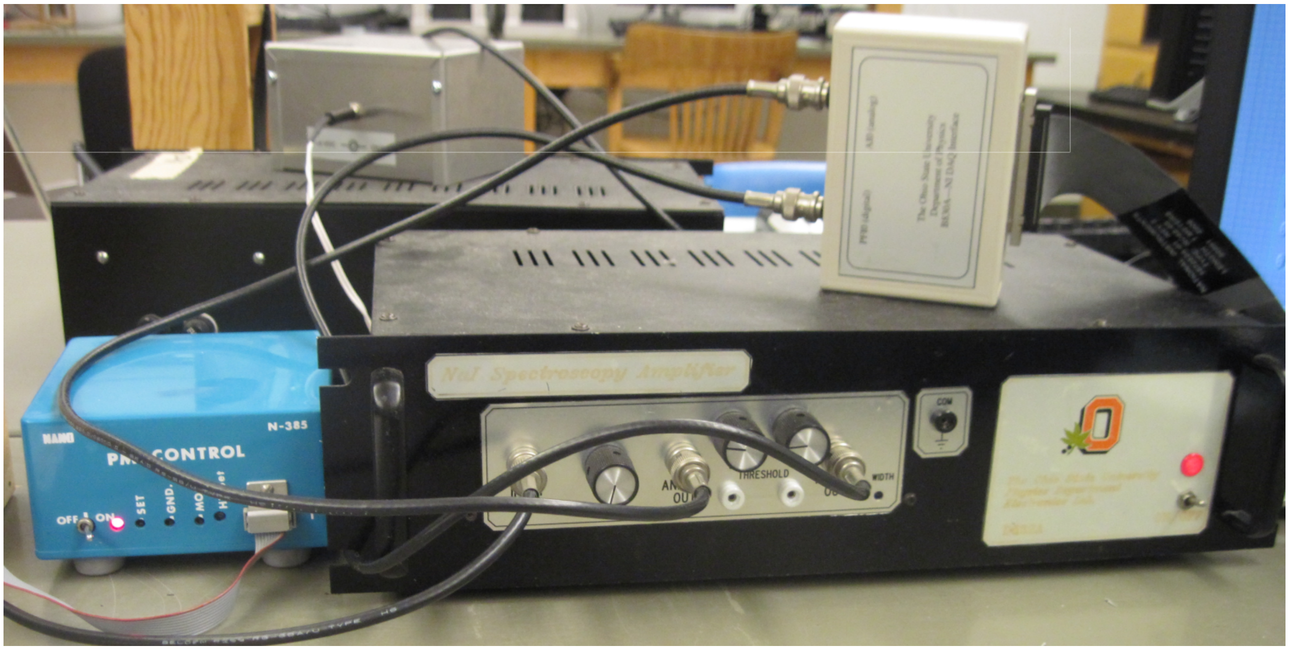
4) INTERFACE box

This box routes the signals from the NaI Spectroscopy Amplifier to the data board located inside the PC. The ANALOG OUT from the NaI Spectroscopy Amplifier should be connected to the ANALOG IN of the INTERFACE box, and the TRIG OUT of the NaI Spectroscopy Amplifier should be connected to Digital input of the INTERFACE box.

Note: The NaI Spectroscopy Amplifier and INTERFACE box were designed and built by the OSU physics department electronics shop. The spectroscopy amplifier is described in detail in a note titled D632A, which can be obtained from the electronics shop.



The NaI calorimeter, PM control, spectroscopy amplifier and INTERFACE box showing all the cable connections.



Close up of the spectroscopy amplifier and INTERFACE box.

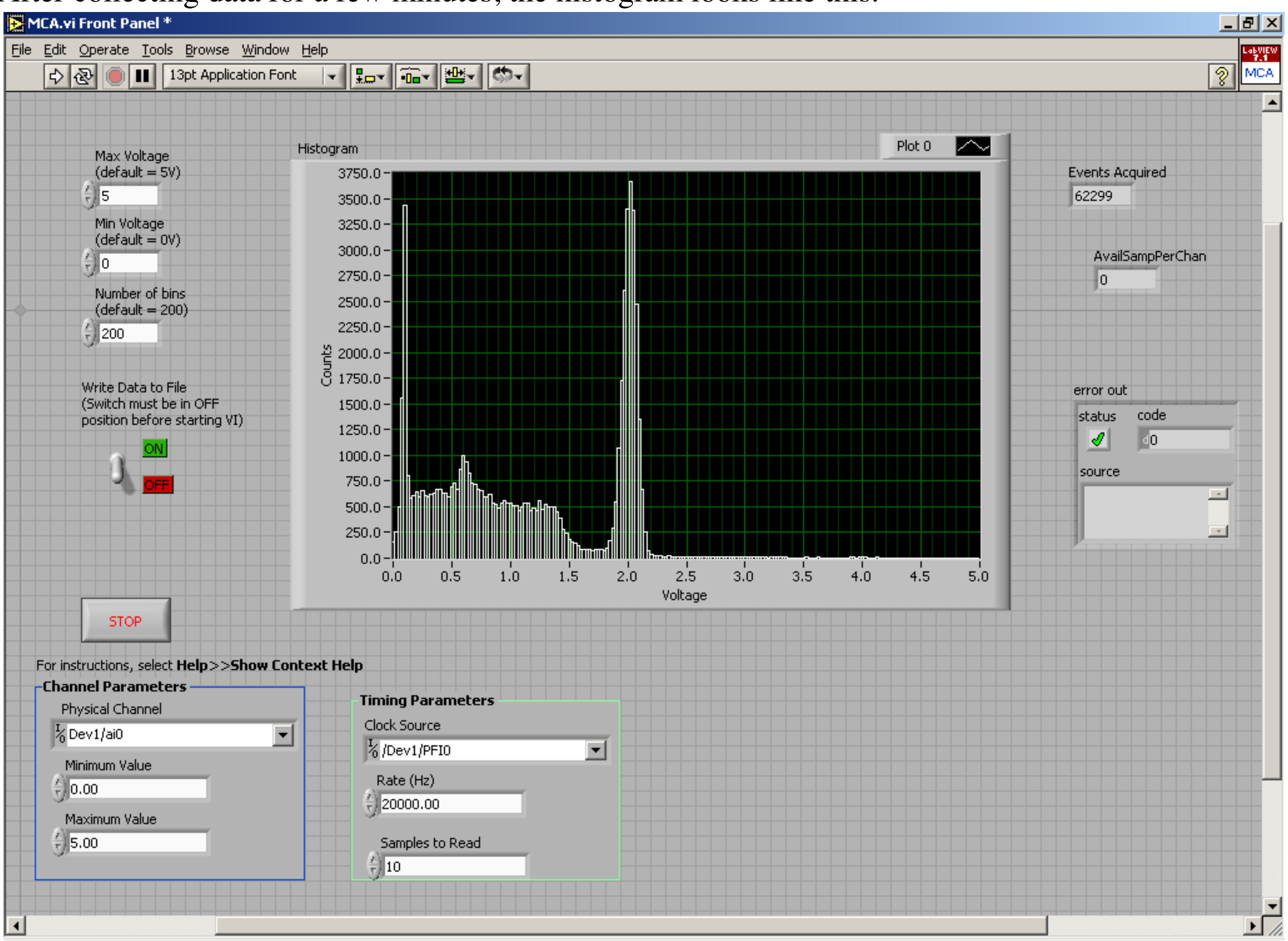
IV) Voltage to Energy Calibration:

At some point in the experiment, you will have to calibrate the horizontal axis, making a conversion from volts to keV or MeV. To do this calibration one needs several γ rays of known energy. Useful radioactive sources are Cs137 which gives off a γ ray at E = 0.662 MeV and Co60 which gives off two γ rays with E = 1.172 and 1.333 MeV. The picture below is the spectrum obtained using a Cs137. The peak at ~1.9 V corresponds to an energy of 0.662 MeV. The sharp peak on the left at ~0.1 V is a combination of the Cs137 K_α (E = 32.1 keV) and K_β (E = 36.6 keV) x-rays. One can get an accurate reading of the voltages corresponding to the peaks of the γ rays by writing the histogram to a file and then opening the file with sciDAVis to identify the voltages with maximum number of entries. Note, it is best to use at least two γ rays of known energy for the calibration as there can be a DC voltage offset so zero volts on the histogram is not zero energy!

V) Taking data with MCA:

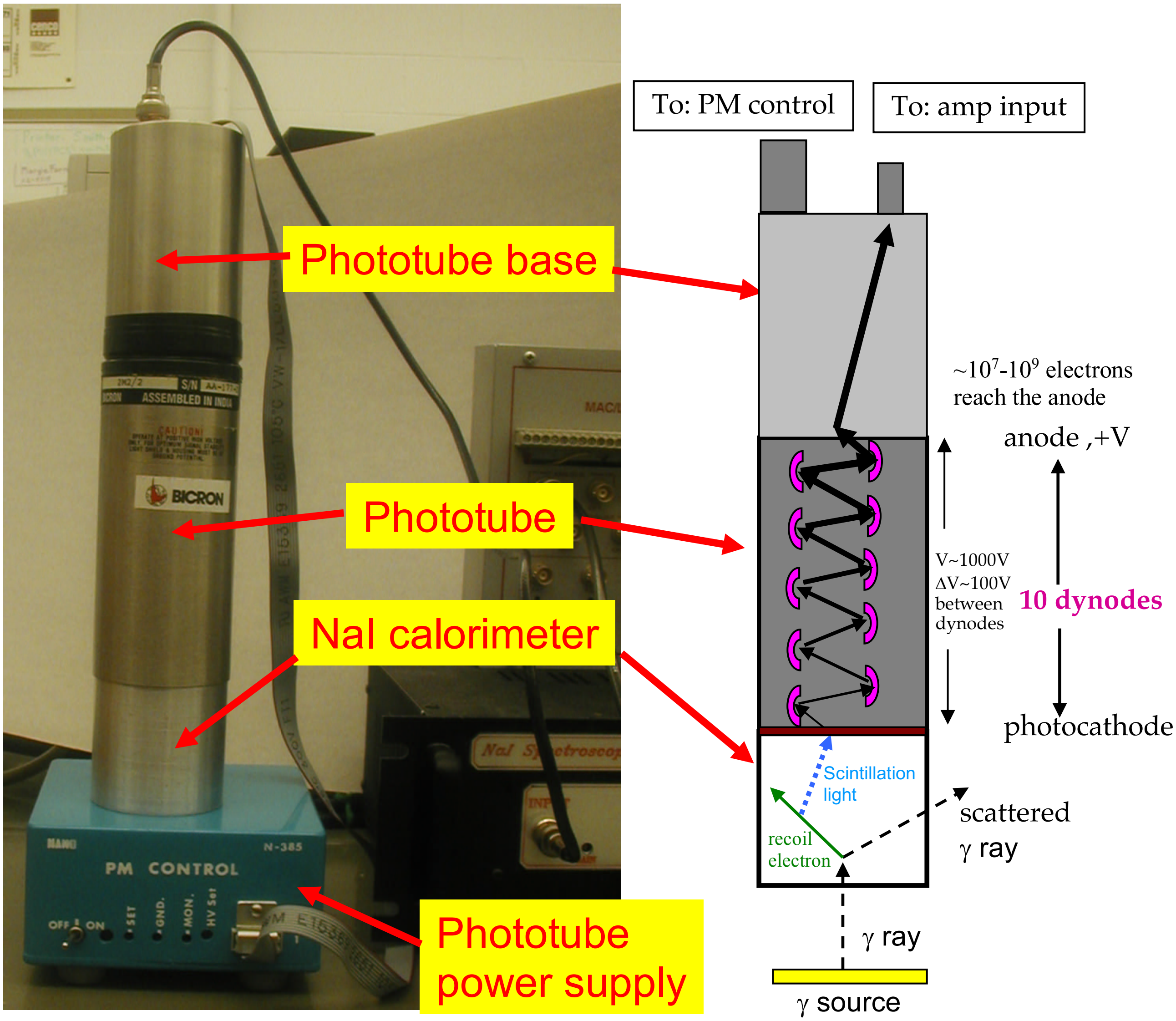
As an example of using MCA, let us go step by step through the process of measuring the γ ray energy spectrum of Cs137. After setting up the NaI calorimeter as shown in the photos in this write-up, adjusting the photomultiplier control, and making the appropriate connections between the INTERFACE box and the NaI Spectroscopy Amplifier we are now ready to take data.

To start collecting data with MCA, click on the arrow button in the upper left corner of the display screen. Make sure that the *Write Data to File* switch is in the down position. MCA then begins to collect data, 1000 events at a time (this number is set by the software and can be changed). The program will continue to take data until the user stops it. The box labeled **[Total data points read]** gives the total number of events recorded so far. As this number increases, our histogram will (hopefully) form to indicate a few definite peaks in the energy spectrum. After collecting data for a few minutes, the histogram looks like this:



In this example 62,299 events (pulses) have been collected so far. To stop counting events, we click on the stop sign in the upper left corner of the screen. **Remember:** If you want to write your data to a file, you need to click on the *Write Data to File* switch **before** clicking on the stop sign. **Note:** each time MCA is started it re-initializes all variables to their default values therefore the histogram starts off with zeros in all bins. The data from a previous run will be lost unless you saved the data to a file.

Details of the NaI calorimeter and phototube



For every 100 eV deposited in NaI we get 1 scintillation photon

1 MeV =10,000 photons produced,

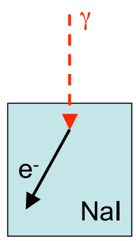
But not all of these photons are collected.

efficiency of photocathode ~20%

Basic Physics Processes in a Sodium Iodide (NaI) Calorimeter

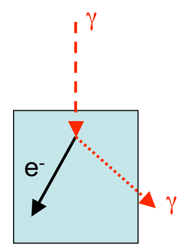
NaI is a "scintillator". As a charged particle traversing the NaI it loses energy. The energy is absorbed by the molecules and puts the NaI molecules into an excited state. NaI gives off light ("scintillates") when it de-excites back to the ground state.
The amount of light given off by NaI is proportional to the amount energy absorbed.
The light yield is ~ 1 photon produced per 100 eV deposited in NaI (1 MeV = 10^4 γ's).
However, not all γ's are collected as the efficiency of the photocathode is ~ 20%.

Photoelectric Effect
γ absorbed by material
electron ejected



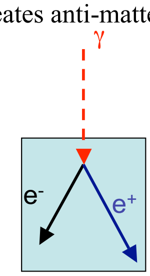
hv < 0.05 MeV

Compton Scattering
$\gamma e^- \rightarrow \gamma e^-$
"elastic scattering"



0.05 < hv < 10 MeV

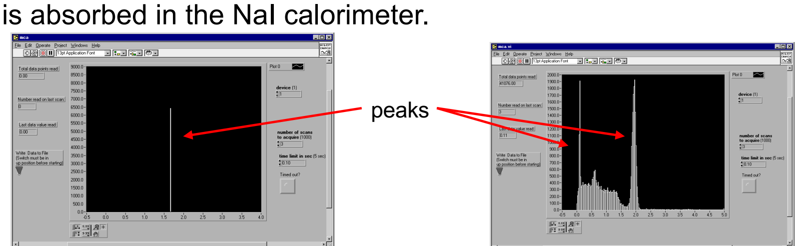
Pair Production
$\gamma \rightarrow e^+ e^-$
creates anti-matter



hv > 10 MeV
γ-ray must have E > $2m_e$

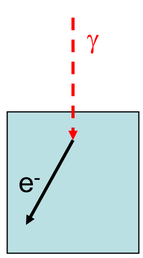
How do we get a PEAK in the energy spectrum?

A peak in the energy spectrum corresponds to the case when all of the γ-ray's energy is absorbed in the NaI calorimeter.

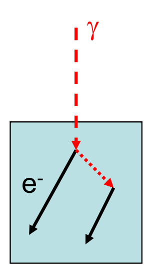


perfect energy resolution
all γ energy totally absorbed

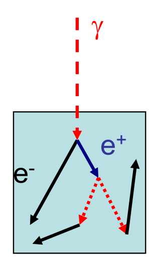
actual energy resolution
not all γ energy totally absorbed



Photoelectric effect and electron stops in NaI.

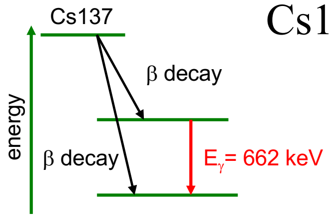


Compton scatter followed by photoelectric effect

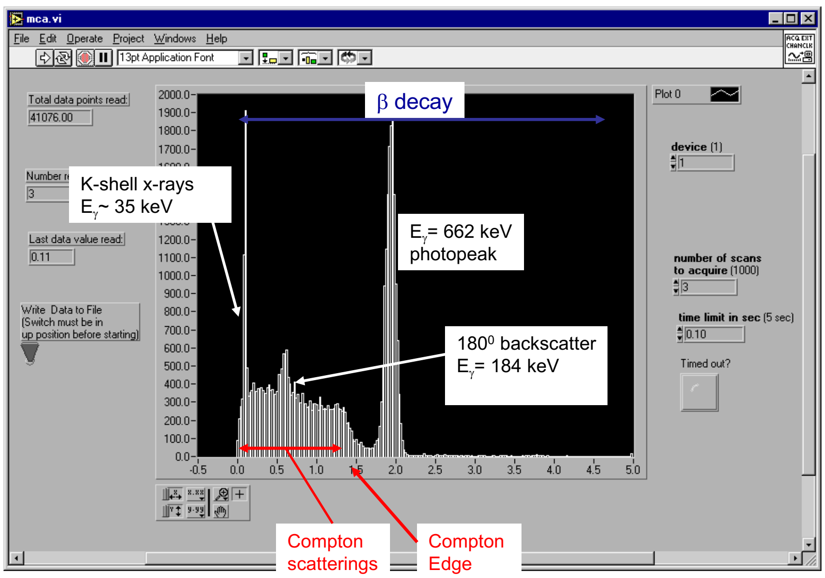


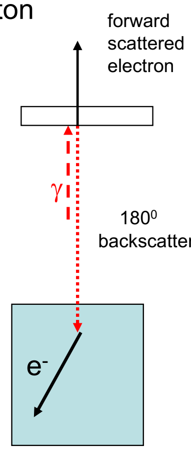
Pair production
e^- is absorbed in NaI
e^+ annihilates into 2 γ's
γ's undergo photoelectric effect

Cs137 γ-ray Spectrum



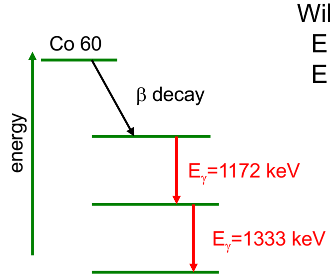
β decay gives off electrons with a range of energies
Emax = 514 keV, 1170 keV
γ decay gives off a monchromatic photon
E = 662 keV



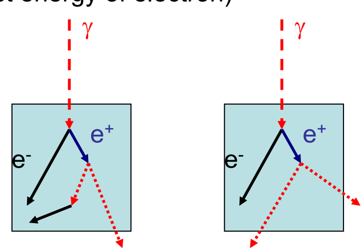


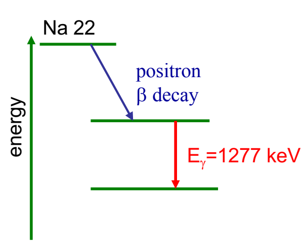
Co60 and Na22

Both Co60 and Na22 have complicated spectra since their γ's have enough energy to undergo pair production.



Will have "escape" peaks from positron annihilation
E = E_γ- (rest energy of electron)
E = E_γ- 2x(rest energy of electron)





Na22 gives off a positron which will annihilate and produce 2 γ's. But only one γ will be detected!