

# M11 Beamline characterization experiment

*Student manual for GRIDS-TSI*

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August 1<sup>st</sup>, 2018

## INTRODUCTION

In this experiment students learn the operation of simple detectors based on conversion of scintillation light into electrical signals using photo-multiplier-tubes (PMTs). Those simple detectors are placed in the beam of particles at the end of the secondary M11 beamline at TRIUMF Cyclotron which was very recently recommissioned. A simple measurement(s) of  $dE/dx$  and Time-of-Flight of the beam particles is performed. Students are also encouraged to design and perform a measurement to determine the momentum of the beam or any other physics measurement they would like to do.

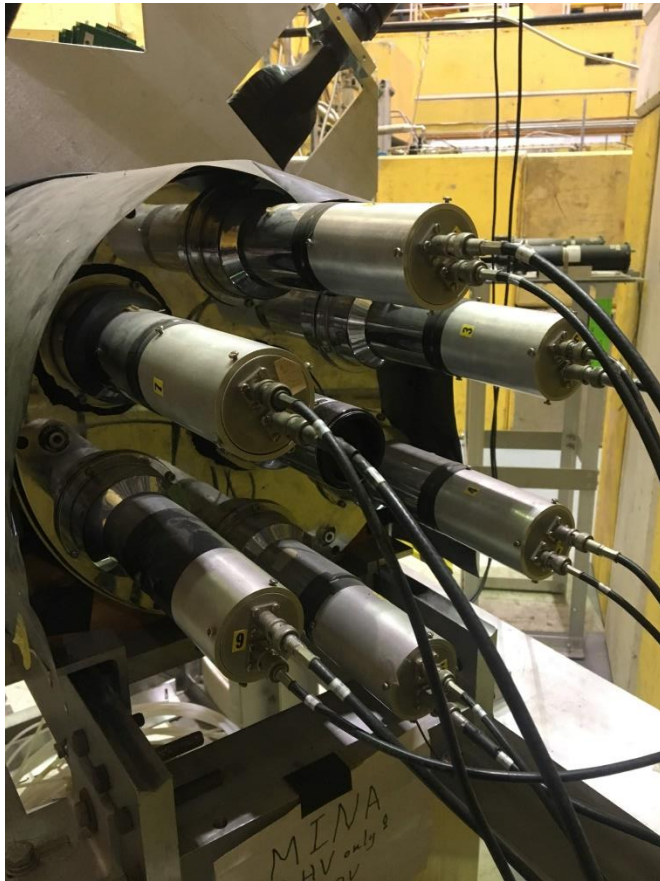
## AVAILABLE DETECTOR COMPONENTS

Scintillators: there are three plastic scintillators available. The first (BC1) is just outside the beam port (BC stands for Beam Counter). The second and third (BC2 and BC3) are mounted one after another, with their active areas completely overlapping. Scintillator dimensions are the following:  
BC1 is  $20 \times 20 \times 1.27 \text{ cm}^3$  | BC2, BC3 is  $30.5 \times 30.5 \times 1.27 \text{ cm}^3$



*Figure 1: Left: View of the BC1 scintillator outside the beam port. Right: View of the drift chambers, BC2 and BC3 scintillators, and NaI crystal on a table in the M11 area.*

The NaI crystal is a monolithic crystal, enclosed and sealed, with dimensions of 35 cm along the beam direction and 35 cm diameter. It is viewed by six phototubes at the back side. NaI crystal is mounted on a mobile table, with BC2, BC3 mounted in front of it, and 6 planar drift chambers from the TRIUMF's TWIST experiment are mounted before the BC2, BC3. For the current setup those chambers are not instrumented, and their foil windows are protected by removable aluminum plates. During the measurement all those wire chambers and protective aluminum plates can be considered as inactive material.



*Figure 2: View of the back of NaI crystal, with 6 PMTs (number 2 to 7) cabled up.*

PREPARATION: Tour of the area/introduction of the detectors:

Inside the area

- Scintillating counters (BC1, BC2, BC3)
- Drift chambers (not-instrumented)
- NaI crystal
- Distance between BC1 and BC2 is roughly 3.4m. Please measure it to confirm!

Outside the area

- Introduction of the HV power supply
- Introduction of the NIM crate and logic/analog units

ASSIGNMENTS (designed to provide hands-on experience)

1. **Cable up the PMTs that are viewing the scintillators and NaI. Cables are labelled on both ends (1 through 9). Please be aware that ‘6’ can look like ‘9’, depending on how you turn the cable though. Outside the area the cables are already connected. HV cables are connected to the High Voltage power supply. And signal cables are connected to the patch panel in the rack.**
  - i) **Locate the High Voltage power supply at the top of the rack. Look at the back of it, and you will find four HV cards. One of them has 3 cables connected to it (cables are labeled 1 through 3), reserved scintillator paddles in the beam (BC1, BC2, BC3). Check that you know which is which. Another has 6 cables (cables are labeled 4 to 9), reserved for the NaI phototubes (labeled 2 to 7 on the back of the NaI). Again, check which is which. There may be additional cables. Always be careful around high voltage equipment.**
  - ii) **Take down the keyboard from the top of the rack and use the arrow key to scroll through the channels. Locate the three scintillators (at the top) and the six NaI phototubes (about two thirds of the way down). Notice the set voltages.**



*Figure 3: The back of the HV power supply.*

2. Locate the signal cables coming from the three scintillators and the five NaI phototubes to the back of the signal patch panel in the rack. Again, make sure you know which come from the scintillators and which from the NaI crystal. The front of the patch panel is already labeled. Make sure it is all correct.

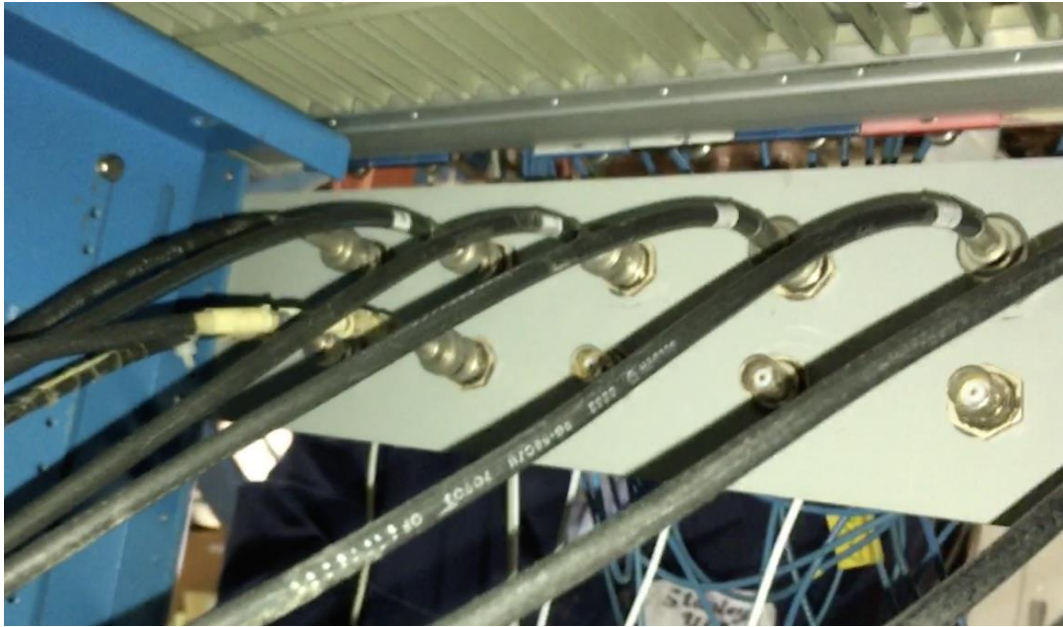


Figure 4: Back of the signal patch panel.

3. Turn on the HV for the Scintillators one by one (BC1, BC2, BC3) using the space bar to toggle the ON/OFF to ON. EACH TIME(!) use the scope to confirm that the signals are present. Take the signal line coming from the front of the patch panel matching the input line on the back that you want to check, and connect it to a channel on the scope (e.g. channel 1). The scintillator signal pulses are negative, so to trigger on the rising edge, you need to select the one that slopes *down* from left to right. Adjust the vertical and horizontal scales accordingly.
4. Turn on the HV for NaI tubes, confirm signals from cosmic. These signals do not have the same shape or size as the ones from the scintillators. **IMPORTANT:** All but one of the NaI signals on the patch panel (c2-c6) will be already cabled up (they are connected to a measuring board for the data taking that will happen later). So when you want to check the signal from the NaI you will have to disconnect the small LIMO cable from the patch panel and connect the cable that goes to the scope to view it. Once you confirm that the signal is present, reconnect the LIMO cable you removed.



- Connect the outputs of the patch panel (BC1, BC2, BC3, and NaI C7 tube) to the three different inputs of the Analog Fan-In/Fan-out module (i.e. inputs in four different “sections” of the module) and confirm that the signals are still there by looking at a signal from one of the corresponding outputs in each section with the scope. The module to use for this will be the first from the left side of the rack. Adjust the Offset for each signal using a small screwdriver to turn the potentiometer on the relevant section of the fan-in/fan-out.

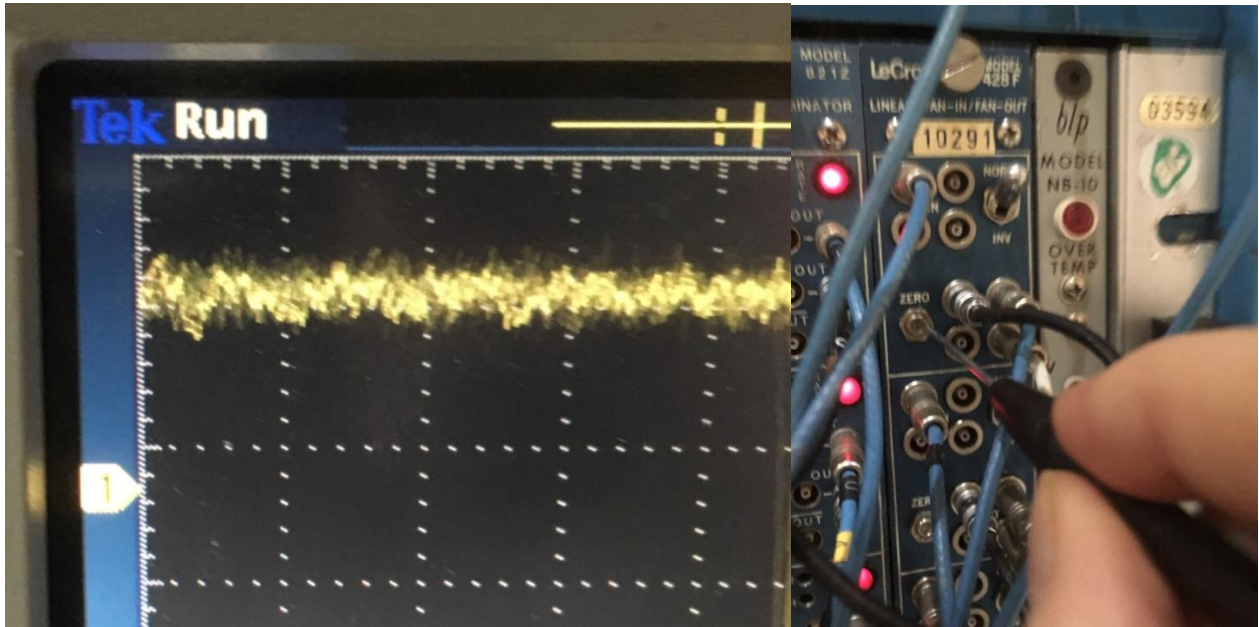


Figure 5: Left: Detail of signal from one of the scintillators. Note the little arrow marked "1" on the left side. If this is aligned with the baseline of the signal, the offset is correct. Right: Adjusting the offset of the fan-in/fan-out with a screwdriver.

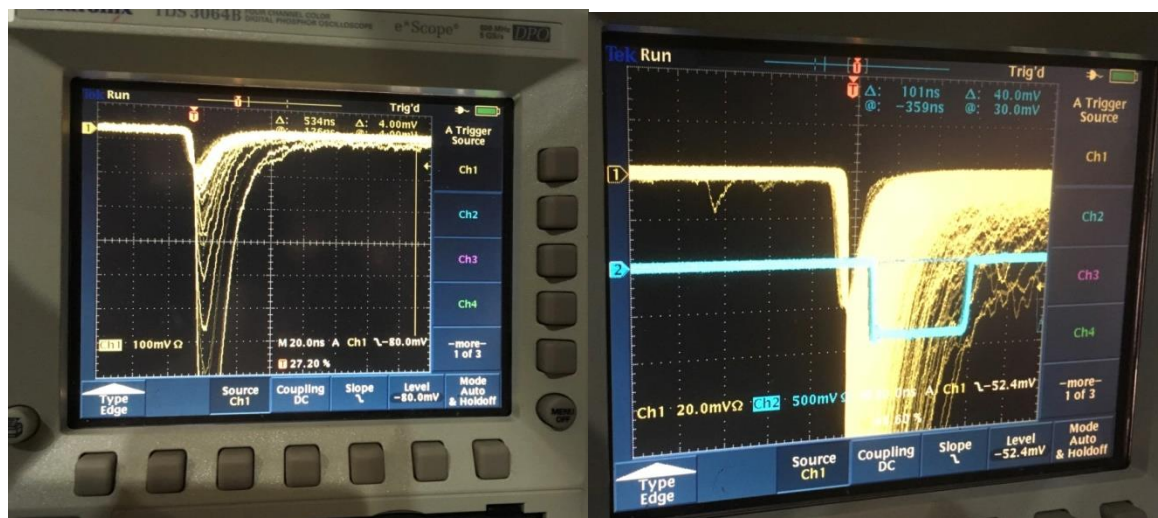


Figure 6: Left: Signal from one of the scintillators. Offset is correctly aligned (baseline of signal lines up with arrow marked "1" on left). Menus show that triggering is on the leading edge of the channel-1 signal (slope matches the shape of the left-hand part of the signal) and other settings are correct. Right: Signals from fan-out and discriminator. Notice how the top of the discriminator signal in channel 2 is just starting to fill in, as the discriminator threshold is adjusted.

- Using the scope, set discriminators for the BC1, BC2, BC3, and NaI tube and examine thresholds and length of the logical pulses produced. The goal here is to get logical signals (yes/no) as shown in sketch below. Connect the output of the fan-out module to a discriminator input. Connect a corresponding discriminator output to the scope. You may want to compare the original signal (from another of the fan-out outputs corresponding to the same input) on one scope channel with the digital signal from the discriminator on another scope channel, to get a picture like the one in the sketch. The discriminator threshold can be adjusted with a small screwdriver. To check that it is set reasonably, make sure the scope signals have a long persistency and aim for the point where the digital signal looks like the “open” well illustrated, with the top not filled in.

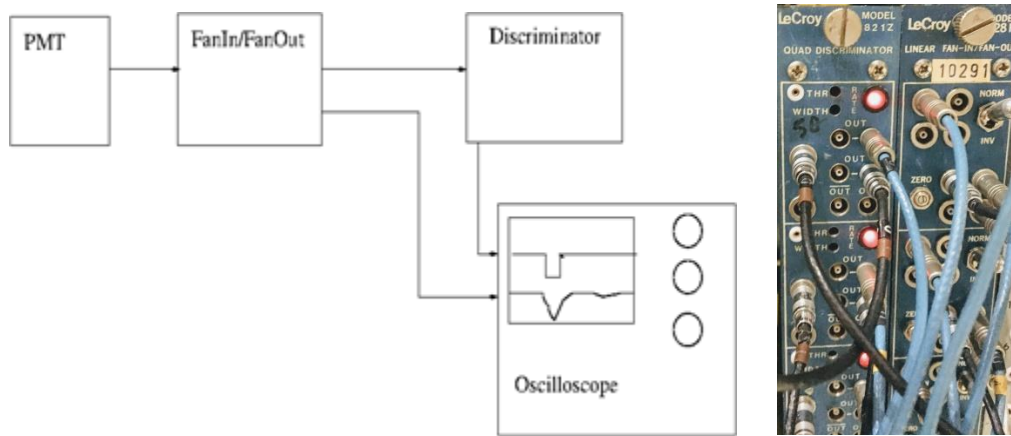


Figure 7: Left: Sketch of the setup for testing the discriminator with the scope. Right: View of the discriminator module and a Linear Fan-In/Fan-Out modules side by side. Note in the upper left corner of the discriminator there are two holes marked THR and WIDTH, using a small screwdriver threshold of the discriminator and the width of the produced logical pulse can be adjusted. A little terminal to the left of the THR is to measure the reference voltage for the set threshold.

- Using a visual scaler, observe the cosmic rate in the scintillators, and NaI. Connect one of the outputs of the discriminators for each of them to the scaler inputs. Do the rates you observe make sense?
- Set up a coincidence between BC2 and BC3 (the scintillators that are placed close together but far from the beam port) by connecting a discriminator output from each of them to the inputs of the coincidence unit, and observe the rate from the output.
- Set up a coincidence between BC1 and BC2 (scintillators that are far apart), and observe the rate. Do you expect to see many cosmic particles going through both of these scintillators? Do you expect particles to go through these two scintillators at the same time? How far apart in time would you expect the pulses to arrive, for positrons, muons and pions with momenta of  $100 \text{ MeV}/c$ ? (Masses:  $M_e=0.511 \text{ MeV}/c^2$ ,  $M_\mu=105.6 \text{ MeV}/c^2$ ,  $M_\pi=139.6 \text{ MeV}/c^2$ ). Consider if the width of the pulses is long enough to form a coincidence when you take the difference in the time of flight of the particles.

## BEAM DELIVERY

1. Secure the area – see the M11 manual (available in the counting room) and **ALWAYS MAKE SURE A QUALIFIED PERSON IS PRESENT TO ASSIST IN THIS STEP.**
2. Turn on the magnets – see the M11 manual. Do **NOT** try to change the polarity of any of the magnets. Magnets can be turned on/off manually and remotely. During normal operation beamline components are controlled remotely using EPICS controls. The proposed setting for the beamline is presented in the Figure below.

/usr1/local/epics/projects/sb/edl/m11\_devices.edl (on sbp1.triumf.ca)

Secondary Beam Line M11 Devices Status and Controls Help

Benders	PS (Digi)	Target DAC	Actual DAC	Scaled DAC	Raw R/B	R/B Current
M11:B1	on +	14277	14277	201.51 A	821	200.49 A
M11:B2	on +	5292	5292	60.56 A	165	60.44 A

Quadruples

M11:Q1	PS (Digi)	Target DAC	Actual DAC	Scaled DAC	Raw R/B	R/B Current
M11:Q1	on +	159	159	77.66 A	318	77.66 A
M11:Q2	on +	123	123	60.07 A	237	57.88 A
M11:Q3	on +	144	144	70.33 A	281	68.62 A
M11:Q4	on +	11742	11742	179.17 A	337	82.30 A
M11:Q5	on -	199	199	97.19 A	395	96.46 A
M11:Q6	on +	174	174	84.98 A	350	85.47 A

Sextuples

M11:SX1	PS (Digi)	Target DAC	Actual DAC	Scaled DAC	Raw R/B	R/B Current
M11:SX1	off	0	0	0.00 A	0	0.00 A
M11:SX2	off	0	0	0.00 A	0	0.00 A
M11:SX2.5	off	9	9	1.76 A	0	0.00 A
M11:SX3	off	8	8	1.56 A	0	0.00 A
M11:SX4	off	8	8	1.56 A	0	0.00 A

Jaws & Slits

Device	Width	Position	Communication	Status
M11:FDVJAWS (Vert)	98.4 mm		ack	N/A
M11:FDHJAWS (Horz)	150.0 mm		ack	N/A
M11:MIDSLITS (Horz)	98.2 mm	1.0 mm	ack	N/A
M11:MIDVJAWS (Vert)	100.8 mm		ack	N/A

Device	Position	Communication	Status
BEAMBLOCKER	out		
M11:ABSORBER	0	ack	at position

VA1

M11:VA1	open
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Save / Restore / Scale    Archiver    Diag Tools    Utilities    Alarm Handler    Overview

Figure 8: Snapshot of the EPICS control. Please notice the setting for the magnets as well as slits and jaws. **B1-14227; B2-5292; Q1-159; Q2-123; Q3-144; Q4-11742; Q5-199; Q6-174; F0VJ-100mm; F0HJ-150mm; MIDS-100mm; MIDVJ-100mm.**

## USING OSCILLOSCOPE:

- 3. Observe different particles in the beam using the scope and persistency mode (visual). How can you tell which signals correspond to which particle types?**
- 4. Trigger on BC1 and check if you can see the time of flight (TOF) difference between those pulses and the pulses of BC2 and BC3. Do you expect to see a difference?**
- 5. Observe difference in pulses in NaI tubes. Can you explain the differences between the scintillation signals in the (thin) scintillator paddles and the (thick) NaI crystal?**

## DAQ (Automated data taking)

Data can be digitized through the use of a charge integrating Analog-to-Digital Converter (ADC) and a Time-to-Digital Converter (TDC). A charge integrating ADC: The module receives a logical pulse, which also denotes the integration window. ADC starts integrating the analog signal and then does the conversion of the integral into a digital format, which can be read out and stored for data analysis (offline) or viewed on-the-fly (online).

In order to select when to record analog signals one has to set up trigger logic. In the case of the M11 setup, the easiest is to trigger on the coincidence of the BC1 and BC2. Triggering on such coincidences will ensure that signals from the beam particles can be recorded. Next page contains the trigger diagram for the M11 beamline characterization.

Notice that the BC1, BC2, BC3 signals go through delay lines before going into a Fan In/Fan out module and then to the ADC. This is done to ensure that the whole pulse is within the integration window of the ADC.

Another detail is that in order to record time, a logical pulse from an associated discriminator is sent to the TDC module, but first it goes through a NIM/ECL converter, which converts NIM signal into an ECL signal, accepted by the TDC.

Finally, there is a part of the diagram that is enabling 'dead time' in the formation of the trigger signal (which also served as the integrating window for the ADC). It is done through the use of the gate and delay generator and ensures that once the coincidence of BC1, BC2 occurs and the trigger is produced, no other coincidence will be accepted for 2ms. That limits the rate of the data-taking. The RF signal, which corresponds to the cyclotron is gate with the coincidence of the BC1 & BC2, this is implemented to ensure that only one RF pulse is recorded. Otherwise RF pulses come with a periodicity of the 43ns.





In order to start the display, please use the terminal in the counting room. Change to the directory: **/home/m1daq/online/fevme/analyzer/** and start the program called: **anaDisplay.exe**

By issuing command:

**./anaDisplay.exe**

if everything looks good, you can proceed to the next step.

#### **4. Look at the charge vs time-of-flight offline. Confirm that it makes sense.**

This has to be done offline. In order to do this, make sure that the run you were taking has stopped. Note the run number. For example the run you took was number **98**. You will change to the directory:

**/home/m1daq/online/fevme/analyzer/**

And you will analyze the data to convert it into a root file, by issuing the command:

**./midas2root.exe ../../data/run00098.mid.gz**

This will produce a file:

**output\_000098.root** in the same directory (**/home/m1daq/online/fevme/analyzer/**)

Now you can open it using command:

**root -l output\_000098.root**

Once in root, you will have access to the root tree (structure that holds the data). You can view what data is available with issuing command: **midas\_data->Print()** when in root.

**root [3] midas\_data->Print()**

```
*****
*Tree :midas_data: MIDAS data *
*Entries : 210586 : Total = 84517003 bytes File Size = 12936122 *
* : : Tree compression factor = 6.54 *
*****
*Br 0 :timestamp : timestamp/I *
*Entries : 210586 : Total Size= 845408 bytes File Size = 9233 *
*Baskets : 27 : Basket Size= 32000 bytes Compression= 91.47 *
*.....*
*Br 1 :serialnumber : serialnumber/I *
*Entries : 210586 : Total Size= 845501 bytes File Size = 296216 *
*Baskets : 27 : Basket Size= 32000 bytes Compression= 2.85 *
*.....*
*Br 2 :nchannels : nchannels/I *
*Entries : 210586 : Total Size= 845408 bytes File Size = 7304 *
*Baskets : 27 : Basket Size= 32000 bytes Compression= 115.63 *
*.....*
*Br 3 :adc_value : adc_value[nchannels]/I *
```

```

*Entries : 210586 : Total Size= 27896762 bytes File Size = 8718638 *
*Baskets : 900 : Basket Size= 32000 bytes Compression= 3.20 *
*.....*
*Br 4 :tdc_value : tdc_value[64]/I *
*Entries : 210586 : Total Size= 54083632 bytes File Size = 3882168 *
*Baskets : 1699 : Basket Size= 32000 bytes Compression= 13.92 *
*.....*

```

Note that you are interested in the variables `adc_value` and `tdc_value`. For the `adc_value`:

```

BC1 : adc_value[0]
BC2 : adc_value[1]
BC3: adc_value[2]
NaI C2: adc_value[3]
..
...
...
NaI C6: adc_value[7]

```

as for TDCs they should be as follows:

```

BC1: tdc_value[1]
BC2: tdc_value[2]
BC3: tdc_value[3]
trigger pulse: tdc_value[4]
gated RF: tdc_value[0]

```

A few examples on how to plot histograms using root:  
To plot a histogram of the charge collected by BC1:

```

root [8] midas_data->Draw("adc_value[0]")

```

if you want to impose a condition, then do:

```

root [8] midas_data->Draw("adc_value[0]","adc_value[0]<400")

```

If you want to see the correlation of BC1 and BC2 signals you can do a scatter plot:

```

root [8] midas_data->Draw("adc_value[0]:adc_value[1]")

```

or you can do a scatter plot with a condition:

```
root [8] midas_data->Draw("adc_value[0]:adc_value[1]", "adc_value[0]<1000 &&  
adc_value[1]<1000")
```

same logic goes for `tdc_value[]` array, however there should always be a reference signal, so only differences should be examined. Note though that `tdc_value` arrays is measuring TDC counts, and each count is 100ps. So if you want to gauge the time you have to take that into account. For example time difference between BC2 and BC1 would be:

$(\text{tdc\_value}[2]-\text{tdc\_value}[1])*0.1$  if you want to see time in ns.

Please try to see the charge collected in BC1, BC2, BC3 versus the Time-of-Flight between BC1 and BC2.

to exit root type command:

**•q**

If you would like to analyze the data offline, consider saving the root file to a USB disk or discuss getting remote access to data with the experiment's supervisor.

## DETERMINATION OF MOMENTUM | OTHER QUESTIONS

Discuss with your experiment supervisor a possibility of determining the momentum of the beam you just observed. Can you do it with the data you took? Can you think of setting up another test?

How would you use the information from 5 NaI tubes that were recorded?

Can you determine the time resolution of the plastic scintillators?