Development of Event-Display and General Calibration Software Tools for use in Jefferson Lab's Hall A.

by

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Abstract

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by *Nandhu Sridhar*

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This thesis documents the development of an Event Display for use in the BigBite calorimeter in the Super BigBite (SBS) ecosystem of detectors in Jefferson Lab's Hall A. The development of a functional Event Display also necessitated the development of ancillary tools, namely a new Pedestal-Identifiction and Subtraction tool, as a method to Gain-Match the Photomultiplier Tubes of the BigBite calorimeter by altering the High-Voltages applied to each PMT.

All tools created in this project are generalizable and can thus potentially be applied to other detectors within the SBS ecosystem, as well as possibly other detectors within the JLab facility. The Event Display is created to aid in visualization of data, as well as providing another interface for JLab researchers to detect potential issues in the functioning of the BigBite calorimeter. The ancillary tools generated to aid in the development of the Event Display are useful not only for the development and functioning of the Event Display, but are also necessary for proper data collection and analysis.

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Chapter 1

Introduction

1.1 Research Objective

The Hall A Collaboration at Jefferson Lab is currently in the final stages of preparing a new, large experimental detector facility, collectively called the "Super BigBite Spectrometer (SBS)". The critical scientific drivers of the SBS are the measurements of electric and magnetic elastic form-factors for nucleons (both protons and neutrons) accessed in the very high momentum-transfer regime of electron-nucleon elastic scattering. The SBS facility will be comprised of many different types of radiation detection systems, each having a large number of individual readout components [2].

The Collaboration has recognized the need to develop new software tools to allow both for easier visualization to monitor the response from the many components of each detector system (so-called "event display" systems) and for more accessible calibration processes. This thesis project is therefore focused on the development of a general event-display tool that can be used for any multi-component detection system of the SBS, and demonstrate the tool's ability to monitor response and facilitate a calibration process by application on an existing detection system.

Additionally, there is a focus on building better calibration software while building these tools, which would prove important to building a good Event Display. This calibration software will be also be a general tool, like the event display and will thus be useful for other detectors within the SBS ecosystem.

1.2 Layout Of Thesis

This introductory chapter will provide the background context needed, while overviewing basic information about the experimental facility and the tools used for the thesis, as well as defining and explaining specific terms and methods related to the work. Following that, Chapter 2 will discuss the specific methods/tests done for the thesis, and the software developed to achieve the stated goals. Chapter 3 will end with showing and discussing the results of the work.

1.3 The CEBAF Accelerator and Hall A

The Continuous Electron Beam Accelerator Facility (CEBAF) is the primary particle accelerator facility at Jefferson Lab, Virginia. It uses an injector system to inject a beam of electrons into the accelerator. The photoelectric effect is one mechanism used by the CEBAF accelerator to generate the electrons to be injected using a polarized electron gun into two linear accelerators. The accelerators have a series of recirculation arcs at each end, which are magnets to re-direct the electrons for multiple passes (up to 5) through the two linear accelerators, allowing electrons to be accelerated to higher energies for use in experiments.

The beam is capable of being redirected to any configuration of the four experimental halls in the facility. While the original CEBAF facility had only three experimental halls - A, B and C -and a maximum electron energy of 6 GeV [1], recent upgrades now allow a fourth hall (D) and maximum energy of 12 GeV. [4]

The Hall A Collaboration is a Collaboration within Jefferson Lab consisting of a group of scientists from around the world focused on conducting experiments in experimental Hall A and with the equipment developed for the hall. Within the Collaboration, there are are 3 large physics-topic working groups (named BigBite, Parity Violation, and Polarized 3He); the BigBite working group is focused on experiments which can be conducted both with the "old" large-momentum-acceptance moderate-resolution BigBite spectrometer, as well as the new (still being constructed) Super-BigBite apparatus which represents an extension of the original BigBite spectrometer, which will be able to function to detect for much higher momentum scattered particles. Finally note that one component of the BigBite spectrometer, which was used in this thesis work, is the BigBite calorimeter.

1.4 The BigBite Calorimeter

The BigBite calorimeter is a calorimeter in the SuperBigBite (SBS) ecosystem of detection devices. [3] The SBS, including the BigBite calorimeter, is designed primarily to measure scattered protons following electron-proton collisions, for the purposes of studying aspects of proton structure. The BigBite calorimeter is separated into two arrays of lead glass blocks - The Pre-Shower and the Shower. The Shower is an array of 27 x 7 blocks, and is designed to provide some path/direction information (via its segmented array structure) and energy values (via stopping particles within it) of incoming high-energy protons. The Pre-Shower is an array of 27 x 2 lead glass blocks. It is also designed to give some path/direction information via its segmented array structure, but also to provide methods to both shield the shower counter from low-energy particles entering it, as well as allow for particle-identification; correlation of the signals from the Pre-Shower (energy deposited in the Pre-Shower) to the signals in the Shower (energy deposited in the thicker Shower blocks), it is possible to separate the protons of interest from lower-mass particles such as pions.

A schematic of the full BigBite detector is shown in **Figure 1.1**, illustrating the relative location of the large-momentum-acceptance magnet at the front, and the layers of various kinds of radiation detectors behind. Note that the lead-glass block arrays of the Pre-Shower and Shower are located at the end of detector layers, since the Shower is designed to stop the particles of interest.

A photograph of the as-built Pre-Shower and Shower arrays is provided in **Figure 1.2**. It is difficult to see the lead-glass blocks themselves because they are wrapped in light-tight black material, such as plastic or tape, to keep external light out of the blocks, allowing only internally created scintillation light to hit the Photo-Multiplier Tubes (PMTs) - these will be discussed later in this chapter. What is mostly visible in **Figure 1.2** are the back-ends of the PMTs where red cables are connected to provide the High Voltage needed to feed the PMTs dynode chain, and the black cables that connect the final anode of the PMT to the processing electronics (notably the Analog-to-Digital Converter modules, ADCs - also discussed later in this chapter).

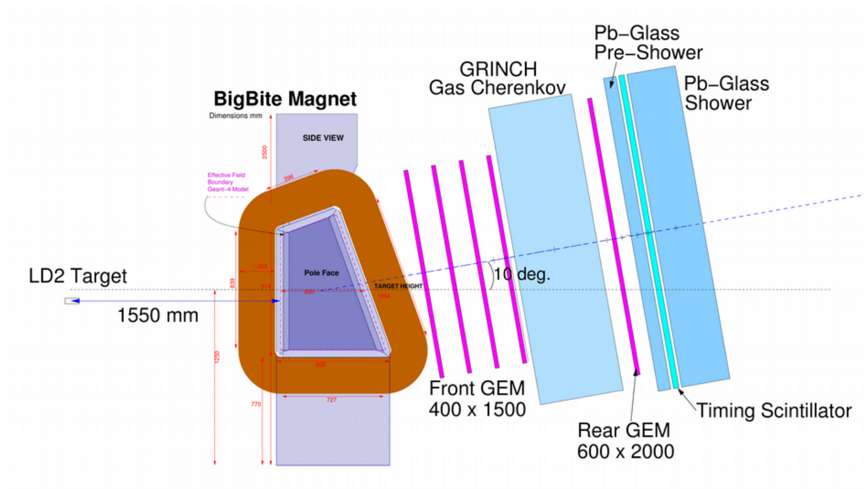


Figure 1.1: A schematic of the BigBite detector. Image used with permission from Dr. Eric Fuchey.

Lead glass blocks are a type of scintillator [6], which means that it is a material that emits a small flash of light when radiation passes through it. This is a result of molecular transition changes, induced by both excitation and ionisation, which are themselves induced by the collision of the scintillator by a nuclear particle. This light can be directed to a PMT which will convert the scintillation light to an electrical signal that allows for electronic counting [5].

Both Shower and Pre-Shower arrays in Bigbite are composed of lead glass blocks. The visible blue light emitted by scintillation within these blocks are transmitted via total internal reflection to a plastic lightguide, which guides the light towards a PMT, which then feeds the produced analog signal to an ADC, which outputs a digital value proportional to the energy deposited by the incident particle in the lead glass block.

Scintillation happens along the path of the high-energy particle, with all the emitted light constrained within the leaded glass blocks via the process of Total Internal Reflection. The total electromagnetic energy contained within the block is propor-

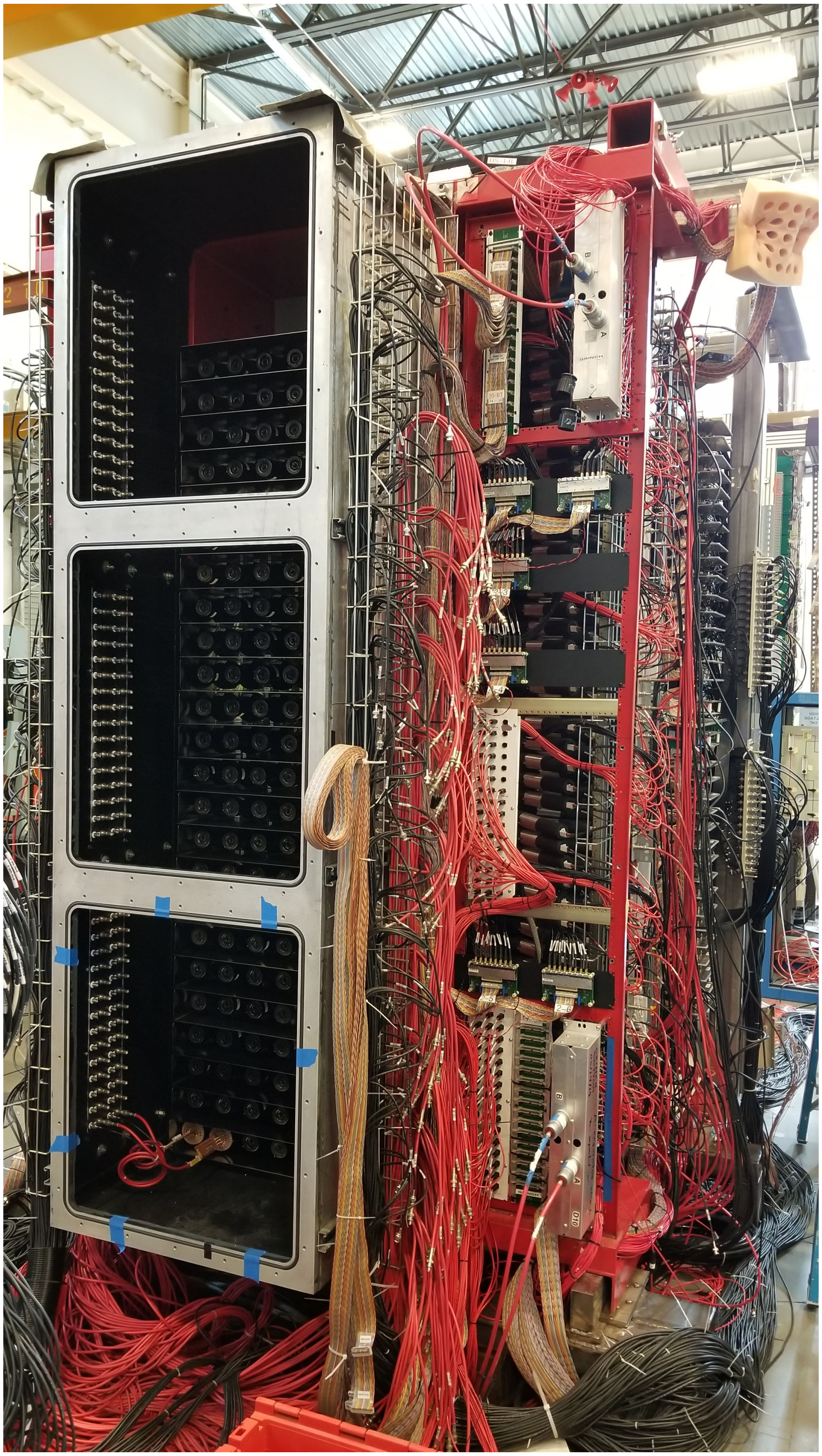


Figure 1.2: Photograph of the BigBite calorimeter. Photo Credit to Dr. Eric Fuchey.

tional to the energy deposited by the incident high-energy particle during its traversal of the block. In the case of the lead glass blocks in BigBite, the light emitted is blue.[5, Chapter 7]

This emitted visible light is then incident on the photosensitive cathode of a Photo-Multiplier Tube (PMT) via a light guide. The PMT is kept in operation at a high voltage (this is described in more detail in **Section 1.7**). The cathode of the PMT has a surface coated with a photosensitive material, which causes it to release a number of electrons proportional to the incident light ray via the photoelectric effect. The photosensitive material is especially sensitive to the blue light emitted by the lead glass blocks.

These electrons are then guided by applied voltage differences to a series of secondary emission electrodes (dynodes), releasing a larger number of electrons, proportional to the number of electrons that were incident via the process of secondary emission, which is similar to the photoelectric effect, with the exception that the role of the photon would be taken by an electron, and that an electric field must be present to guide the electrons across the device. This is then done several times, creating a cascading effect in the number of electrons.[5, Chapter 8]

When this reaches the end of the Photo-Multiplier Tube at the anode, there is a much larger number of electrons, which is still linearly proportional to the energy deposited in the lead glass block by the incident high-energy particle. This current passes through a cable as an analog signal to an Analog-Digital Converter (ADC) to generate a digital value known as the ADC value.

For this thesis work, the BigBite calorimeter was being tested using cosmic ray data. A scintillator paddle was placed on top of the detectors. It was set to trigger data collection when hit by a high energy cosmic ray particle. The subsequent data would prove useful in the testing of the event display and any further calibration.

1.5 Pedestals

A "**Pedestal**" is the name given to the feature in an ADC readout of a detector when no high energy particle has actually traversed the detector. These pedestals manifest themselves as Gaussian features in the ADC readout. As such, the pedestals represent values that will always be present in the detector response to outside charged particles, but are not themselves related to outside charged particles. Pedestals features are consistent in their position within the ADC spectrum for a given lead glass block at a given high-voltage setting (more on high-voltage in **Section 1.7**), across all the lead glass blocks.

Measuring and providing a best-fit for the centroid of the Gaussian distribution of the Pedestal features will allow for a subsequent subtraction of these Pedestal features from the ADC readout. This "**Pedestal Identification and Subtraction Process**" is an important part of the calibration process for detectors such as the lead glass blocks in the Shower and Pre-Shower, since it enables removal of any ADC response not associated with a high-energy particle of interest passing through the detector.

The pedestal can be accurately determined from test data using cosmic rays. This is because a triggering setup can be made which reads out all of the Pre-Shower or

Shower blocks when a cosmic ray would only be downward-traversing one "line" of detector blocks - leaving all the other blocks to provide pedestal ADC signals since no particle went through them.

1.6 The Event Display

Researchers in the Collaboration requested a display to easily visualize the path of a particle passing through the detector. This ability to visualize a particle path through the detectors would be in addition to, and separate from, the basic/standard readout of the ADC values from all the detector components - rather it was requested as a tool to help quickly observe the entire detector response "at a glance", and potentially diagnose performance/problems easily. For this thesis, an Event display was created to fulfil this need. Each block in the the calorimeter can be displayed in a grid-like pattern, for the Pre-Shower and Shower. The Pedestal-Normalized ADC values for each cell would then be displayed in an intuitive fashion. This will be discussed further in Chapter 2.

It is important for the display to include the Pre-Shower and Shower simultaneously in order for researchers to quickly determine whether an incoming particle was coming from the target (where the electron-proton interaction of interest takes place), as these detectors will be operating in a very high radiation environment with particles passing through them from several directions other than coming directly from the target.

An Event Display created for use with the BigBite Shower and Pre-Shower has the potential to be generalized to other calorimeters within the SBS ecosystem.

1.7 Photomultiplier Tube High Voltage and Gain matching

A High Voltage is applied to each Photo-Multiplier tube of every lead glass block in the Shower and Pre-Shower detectors. This is done so that a “potential ladder” is created, along the linear structure from the photocathode, to the dynodes, and finally to the anode. This allows for a unidirectional flow of electrons during operation.[5, Chapter 8] The applied High Voltage on each PMT determines the amplification (or “**Gain**” - see below) of the PMTs, and so also the ADC response of each lead glass block (or “channel”) of the Shower and Pre-Shower detectors. It is important to have consistent responses across channels, and therefore also consistent Gain across PMT channels.

The Gain refers to the ratio of the the charge built up at the anode of a PMT and the incoming signal at the photocathode. The average Gain of each PMT for a given applied High Voltage depends mainly on the number of dynodes, but the specific value is also dependent on the particular construction of the PMT itself. It is also important to note that each dynode has a unique secondary emission factor (equivalent to the “gain” of an individual dynode), variations of which amplify the variation in overall Gain. Every Photo-Multiplier Tube therefore has a unique value of Gain for a given High Voltage applied to it. This may then cause a variation of

Gain across the PMT channels even if the same High Voltage value is applied across all channels [5].

Correcting for the variation in the average Gain of each channel remains essential in producing well calibrated results from the Pre-Shower and Shower detectors that can be easily interpreted. As the Gain for a given voltage is a property of the Photo-Multiplier Tube, the focus is on ensuring that the overall Gain remains constant between all channels.

The mechanism by which this can be achieved is by varying the High Voltage applied to each Photo-Multiplier Tube when each detector experiences the same input - particles depositing the same amount of energy in each detector. The goal is to eliminate any variation altogether in response.

Chapter 2

Methods

2.1 Goals

For the purpose of this thesis, the goals of the project are to create a functional Event Display for the collaboration, that would be generalizable to other projects within the SBS ecosystem. Further, associated with the Event Display development, the project will create a better algorithm for identifying and subtracting the pedestals of the calorimeter array, and finally, attempting Gain Matching of the calorimeter to create well-calibrated results.

This is done with the large dataset of available test data, explained in **Section 2.2**, which was created using cosmic ray data to emulate the high energy particles expected from the accelerator when it is online. With this test data, a preliminary Event Display was created. Using the methods of Pedestal-Identification and Subtraction, explained in **Section 2.4**; and Gain matching, explained in **Section 2.5**, the Event Display was further refined and made much more useful.

All tools created for this thesis are general in use, and can thus be applied to both sets of calorimeter arrays in BigBite, other detectors in the SBS ecosstem, and potentially other detectors in the JLab facility.

2.2 Data collection

As the BigBite calorimeter was not in operation for the duration of this project, test data was obtained for the Shower and Pre-Shower using cosmic rays as a source of High-Energy particles. This provided a mechanism for creating test data to test the efficacy of the tools created for the purpose of this thesis, without need of having the Calorimeter installed in the experimental hall.

In order to begin collecting this data, a Scintillator Paddle was placed on the top of the detector, set to trigger data collection from both the Pre-Shower and Shower, whenever a high energy particle, such as a cosmic ray particle, traversed it. All of the ADC data across all channels in both calorimeter arrays is then recorded and stored. With this data further analysis is performed, as well as creating a display to visualise this data, which will be covered in the following sections.

Every time the scintillator mechanism triggers data collection, the collected data of that particular instance is stored as an "Event".This includes ADC values for both the Shower and Pre-shower arrays. A single run is a continuous stretch of time, when the calorimeters are running, and events are being recorded and stored in one computer data file. The Event Display, further discussed in **Section 2.3**, visually displays the Shower and Pre-Shower data of a single Event within a given run.

The Shower and Pre-Shower data are stored in an array with the number in the array corresponding to the specific channel, and the channel representing a single calorimeter block, as shown in Fig **Figure 2.1**. It is important to note that the Shower is the 27 x 7 array on the left hand side, whereas the Pre-Shower is the 27 x

2 grid on the right hand side. The data for the Shower is stored as an array of length 189, and the data for the Pre-Shower is stored as an array with length 54. The figure also notes the position of the scintillator paddle for triggering the mechanism for data collection in both the Shower and Pre-Shower, as a visual guide to the orientation of the scintillator paddle.

2.3 The Event Display

The Event Display was built as required by using the same template as **Figure 2.1** for the sake of forming an intuitive display that would remain as faithful to the original configuration of the Shower and Pre-Shower calorimeter arrays as much as possible; this also allows researchers at the Collaboration to easily visualize the detector responses of both the Pre-Shower and Shower “at a glance”. The Display was built using the tools that make up the ROOT library provided by CERN [7]. By design, the Display will assume that ADC values have had their Pedestal values subtracted such that the resulting value represents only above-Pedestal responses. Therefore, in order for the ADC value of an individual calorimeter block to be displayed, the calorimeter block must have an ADC value higher than the minimum count of 10. If the ADC value of this calorimeter block was below the minimum, it would not be displayed, as these values were likely values within the pedestal, rather than readings of High Energy particles. In order for this to be done, it was required to check and confirm that the Pedestals in the data were identified and subtracted, the process for which is described in **Section 2.4**.

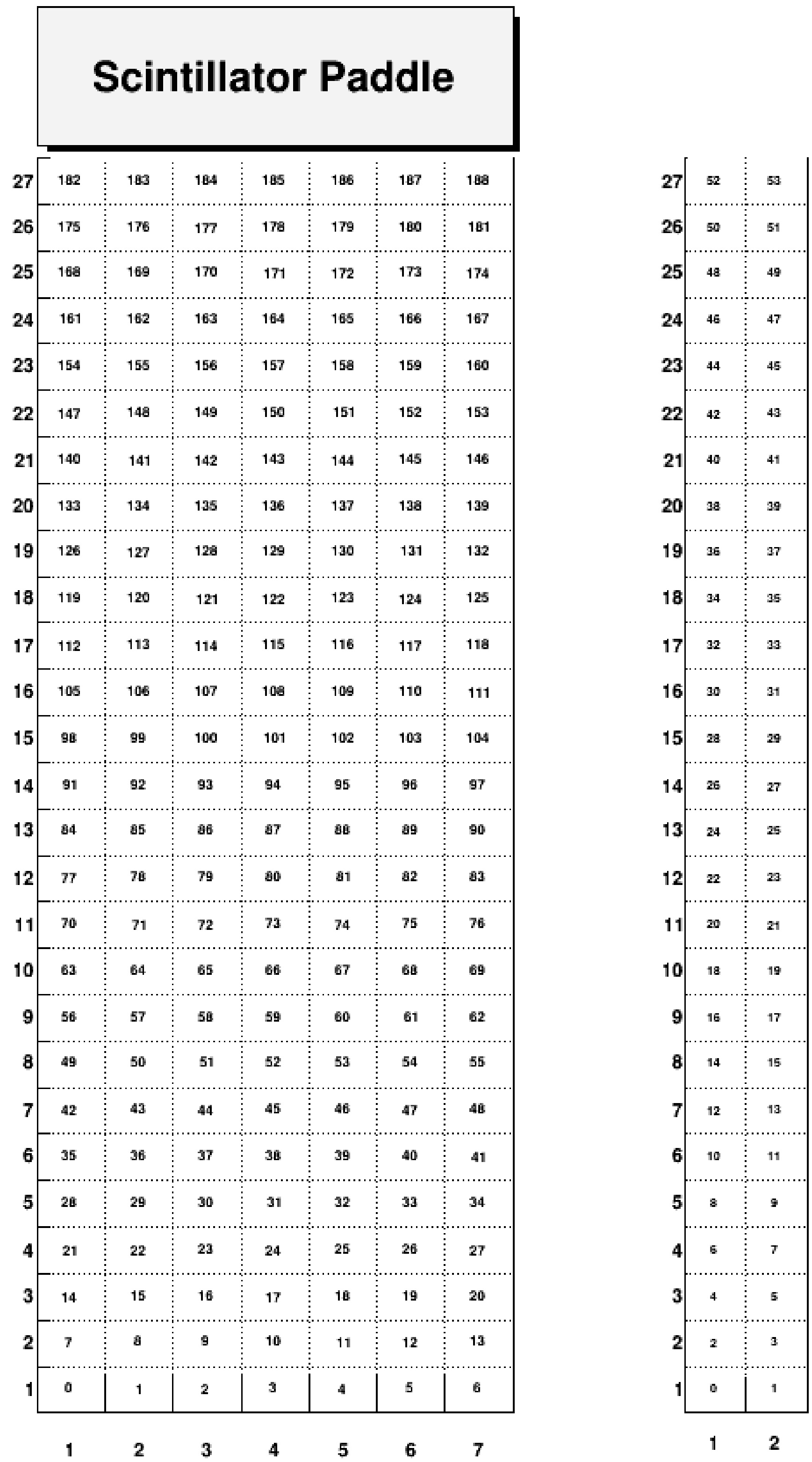


Figure 2.1: A representation of how ADC data is collected and stored.

All displayed values within the Event Display are displayed in boxes of variable sizes. The area of an individual box is proportional to the recorded ADC value of the individual calorimeter block it represents during this particular event. This allows for the visualization to be more intuitive, allowing researchers to quickly locate the calorimeter blocks where the ADC value is highest, and find particular patterns that may be necessary. The ADC value of that particular calorimeter block is also displayed on the box, allowing researchers to quickly pinpoint that number (which represents size of signal response) if necessary.

As the data was collected using cosmic rays that cross the scintillator paddle, the events that are most relevant for testing the Event Display would include a path of high ADC values that appear in roughly a straight line beginning at the top (shower calorimeter blocks 182 - 188), where the scintillator paddle is. Ensuring that this path is clearly visible for such events allows for demonstrating that the Event Display is a useful tool to allow researchers to easily assess whether the data collection mechanism is working correctly (and whether the Gains of the channels are well matched).

The Display's rendering of one such example straight-down event (Event 219 in run 179 of the test-data set) is shown on **Figure 2.2**. Similar to the **Figure 2.1**, the Shower is on the left hand side, and the Pre-Shower is on the right hand side. In this event, a clear linear path of a cosmic ray originating from the top is visible, the relevant boxes on the grid being larger makes it much easier to visualize those blocks that had the largest signal response to the traversing particle. Note that some blocks display ADC values somewhat smaller than would be expected if all blocks were matched to provide the same response for the same deposited energy, whereas some other blocks outside the path of this cosmic ray display much larger values than would be expected if no cosmic ray were traversing them. These are primarily artifacts of variable Gain, and the process to correct this, known as Gain-Matching, is described in **Section 2.5**.

2.4 Pedestal Identification and Subtraction

In order to ensure that the Event Display was consistently able to display channel-responses due to signals from traversing High Energy particles, it is critical that the Pedestal be identified and subtracted from the ADC values used for the Display. To identify the Pedestal quickly and efficiently, the ADC readout of a single channel was first plotted on a histogram over many recorded cosmic ray events in a given run. Such single-channel ADC spectra allow the Pedestal to be clearly displayed at the low end of the ADC values recorded, since the vast majority of triggered readouts in the cosmic ray data will correspond to events that any given Shower or Pre-Shower channel will not have had a particle traverse it (and therefore just be reading out a no-signal Pedestal related value). This is because the cosmic rays hitting the top triggering scintillator will represent particles that pass through the Calorimeter in only one particular path, but all channels are read for every event. Collecting such ADC spectra with a relatively large number of event counts allows the Pedestal to show itself easily in the form of a Gaussian response at the lowest end of the ADC values. The Gaussian shape arises from various contributions to the "noise response" in any given channel (for example, residual radiation in the lead glass block, or spurious

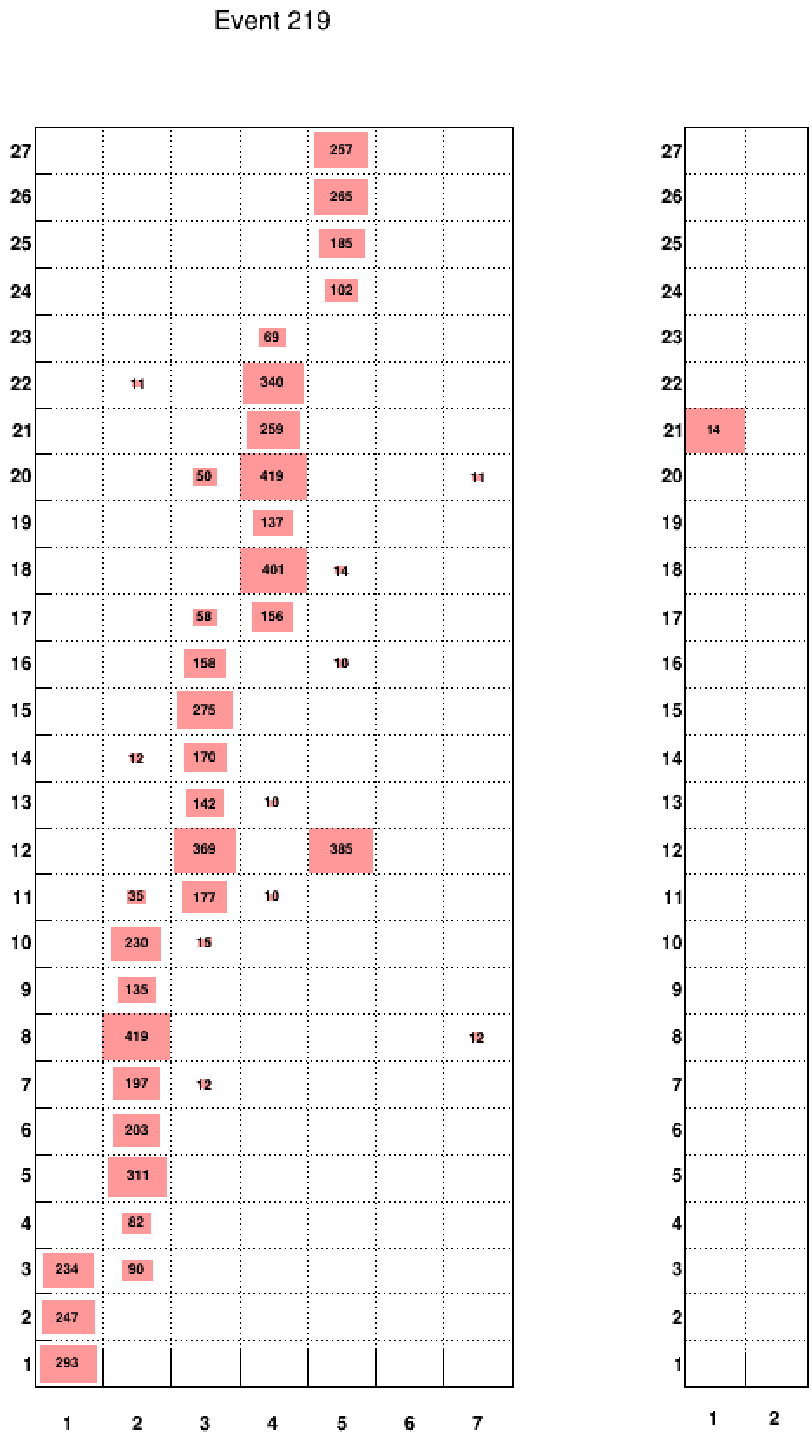


Figure 2.2: Image of the Event Display, representing Event 219, run 179.

dark-current response of the associated PMT).

To begin the process of Pedestal identification within an ADC spectrum for one channel, it was “zoomed out”, meaning that this spectrum was then rebinned into a much smaller number of bins to span across the range of possible ADC values provided by the ADC electronics. The histogram that was used for “zooming out” contained 600 bins, within a range of -1000 to 5000 ADC counts. This meant that each bin in the zoomed-out ADC spectrum contained all recorded events that lied within a range of 10 ADC values (as opposed to each bin containing all the data for each individual ACD value, as is the case in the original un-zoomed spectrum). This rebinning simply removes the statistical fluctuation from one ADC value to the next, given that the ADC’s provide charge-per-value resolution greater than is needed for use in interpreting the Calorimeter blocks’ responses, particularly for identifying the Pedestal. The rebinning process facilitates a very simple and fast method of Pedestal identification for our test data - since in the test data, most readouts correspond to no real signal in any given channel. This is discussed further below.

As the regime in which the pedestal is contained is better identified after the first rebinning to 10-ADC-channel bins, the process of “zooming in” begins. The bin containing the largest number of counts is identified, and a new ”zoomed in” ADC spectra is created using only data corresponding to events having an ADC value falling within that one largest-number bin, and one bin higher in ADC values, and one bin lower in ADC values - this new zoomed-in ADC spectra then spans a range of 30 in ADC values, and is binned back to show one bin per individual ADC value (so, the zoomed-in spectra shows 30 bins across a range of 30 ADC values, right in the regime where the large Pedestal feature exists). As the number of bins is relatively small, the mean can be found much more quickly, by iterating this simple formula across all bins of the "zoomed-in" histogram:

$$\mu = \frac{\sum\limits_{i=a}^{30} x_i n_i}{n_{tot}}$$

With μ then becoming the mean of the Pedestal for this channel, x_i representing the the ADC value of the bin (since the bin's range is only 1, for this zoomed-in spectrum, the center of the bin is taken as this value), n_i and n_{tot} representing the number of events within a particular bin and the total number of events in this zommed-in spectrum respectively, and a representing the ADC-value of the bin with the lowest ADC-value.

The Root Mean Square (RMS) of the Pedestal (to characterize the width of the Pedestal's Gaussian response) was found by a similar method, instead iterating another simple formula across all 30 bins of this "zoomed-in" histogram:

$$\sigma = \sqrt{\frac{\sum\limits_{i=a}^{30} (x_i - \mu)^2 n_i}{n_{tot}}}$$

With σ being the Pedestal's RMS for the channel and μ being the Pedestal mean for the channel, found previously.

With both the mean and the RMS known, the Pedestal is fully described for each channel, and can used in the Pedestal subtraction that is needed prior to Gain matching, and for using the channel responses in experiments. Pedestal subtraction

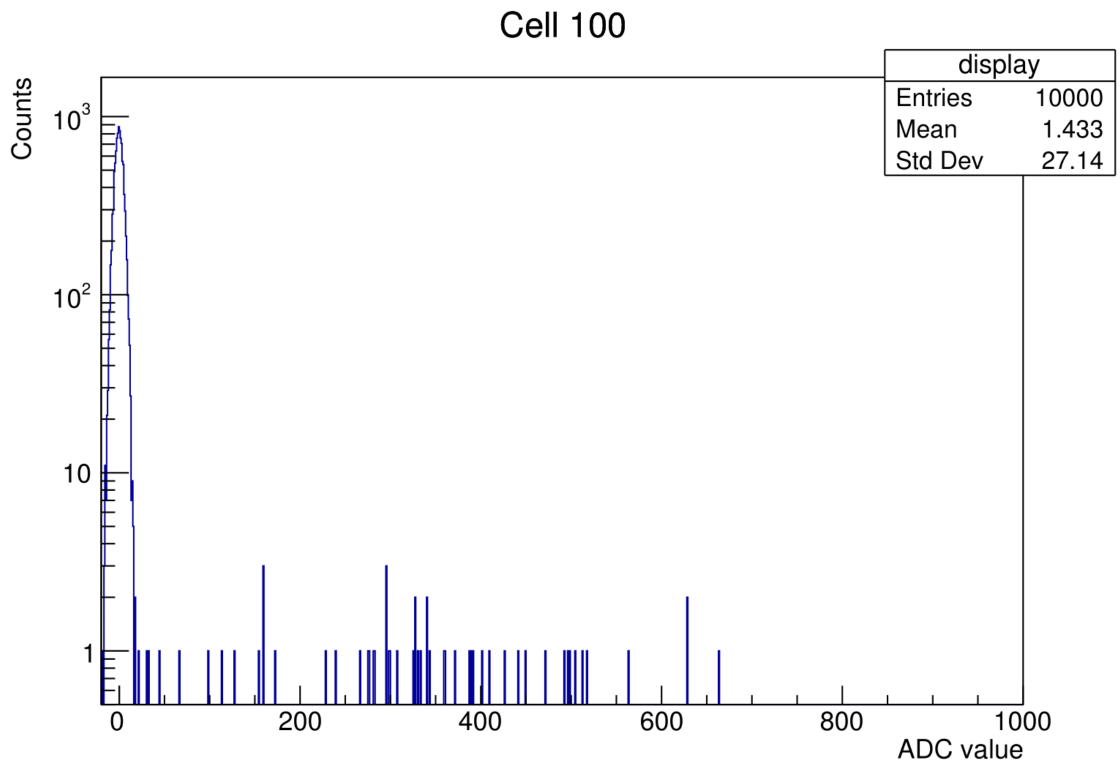


Figure 2.3: An example of a Pedestal-subtracted spectrum

is simply the process of subtracting the mean of the Pedestal from any ADC value obtained. This has the effect of centering the Pedestal at a Pedestal-subtracted ADC value of 0; this provides simplicity of interpreting recorded ADC values from every lead glass block channel as being directly proportional to the energy deposited in the block (as discussed in Chapter 1), with channel zero corresponding to zero energy deposited.

The Pedestal-subtracted spectrum of Channel 100, displaying a sample 10,000 events from a particular run, is shown in **Figure 2.3**. The x-axis represents the Pedestal-subtracted ADC value, and the y-axis represents the number of events in any given ADC-value bin. Note the large Gaussian feature in the lower end of the spectrum. This is the Pedestal, and the process of Pedestal identification and subtraction has properly caused the peak of the Pedestal to be placed at a Pedestal-subtracted ADC value of 0.

This process was done to all 189 channels within the Shower, and all 54 channels within the Pre-Shower, with significant potential to generalize this simple technique to many other detectors within the SBS ecosystem. A script was written to automate this process, allowing storage of the Pedestal mean and RMS values for every individual channel. The process need not be done again, unless the properties of the system change. As such, this will have to be done for every iteration of Gain-Matching since that process involves changing the High-Voltage applied to the PMTs, which will change the Pedestal-ADC value associated with (for example) the residual radiation in the lead-glass block or the PMT dark-current.

2.5 Gain Matching

In order to begin the process of Gain matching, cuts were made to Pedestal-subtracted ADC spectra, the cuts being that:

1. Events in which the total sum of the Pedestal-subtracted ADC value of all the channels (added together) were less than 50 (25 in the case of the Pre-Shower) were not included in the formation of these spectra.

2. Events which have a Pedestal-subtracted response less than 10 for any given channel were not included in the spectrum of that channel.

The images of the spectra with these cuts are shown in the Appendix. The mean of this spectrum, for any given single channel after applying these cuts, is known as the **Mean Cosmic Amplitude (MCA)**. The reasons these cuts were performed was in order to reduce the influence of the Pedestal on the MCA; events in which very few, or none, of the blocks were scintillated by cosmic rays were not desirable because most channels would would emit Pedestal (this was achieved by performing cut 1), and having a minimum cut-off at ADC value of 10 (cut 2) eliminates contribution from a significant portion of the Pedestal (which have had their mean located at zero through the subtraction, and the RMS values were typically less than 10), as the goal is to alter the calorimeter's response to incoming High Energy particles.

Each channel had the PMT High Voltage set to a different value and the High Voltages on which the shower was operating during the start of this experiment are shown in a graphical format in **Figure 2.4**.

After obtaining the MCA for each channel, via ROOT's default Least-Squares fit, the Gain Matching process began for the two rows at the top of the Shower, as they were exposed to the most cosmic rays, by virtue of the scintillator paddle being placed on top of them. To this end, the High Voltages of these channels, being all the channels between and including channel 168 and channel 188, were obtained, along with the MCA of these channels. The MCA was also obtained for these cells with their High Voltage reduced by 100 Volts. A Goal was set to ensure that all these channels have a MCA of 100. Note that the choice of trying to place all MCAs at a value of 100 was somewhat abitrary, but was based on the initial observation of the obtained spectra, and seeing that it was likely that aiming for MCA of 100 would ensure the High Voltage needed for all PMTs would be appropriately within

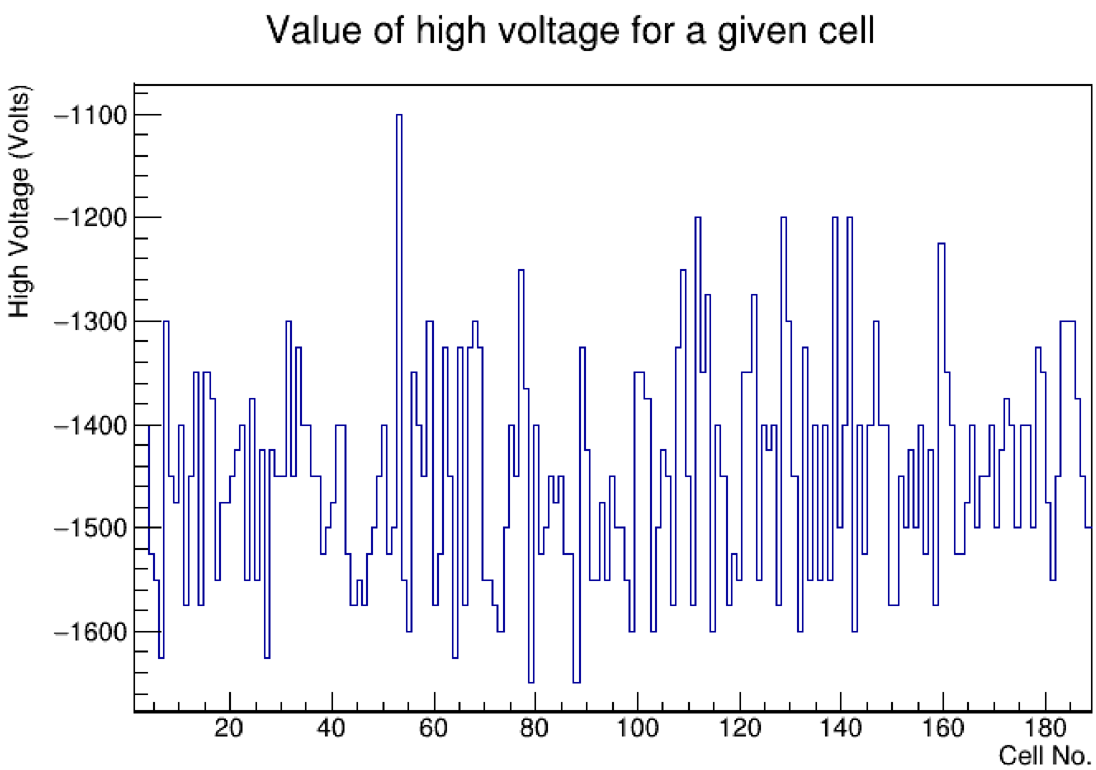


Figure 2.4: The High Voltages applied to the PMT for each channel in the Shower. Note that in this figure, the word "cell" means the same as "channel" in the text - referring to a particular lead glass block in Shower array.

the desired operating bounds (with none needing to be overly high).

In order to discover what High Voltages result in this goal amplitude, an iterative process allows for MCAs that approach the desired value. This process requires the calculation of α in the following equation:

$$\alpha = \frac{ln(\frac{\mu_{HV,R}}{\mu_{HV,O}})}{ln(\frac{HV,R}{HV,O})}$$

Where HV, R and HV, O are the reduced and original High Voltages respectively and $\mu_{HV,R}$ and $\mu_{HV,O}$ are the MCAs for those High Voltages. This value for α is then plugged into the following equation:

$$HV, 100 = HV, O \times \frac{100}{\mu_{HV,O}}^{\frac{1}{\alpha}}$$

Where HV,100 is the High Voltage value needed to be applied to that channel's PMT in order to produce an MCA value of 100. Note that these equations are exponential in nature due to the fact that the multi-dynode structure of PMTs results in an exponential relationship between the applied High Voltage and the resulting signal gain. This process is then repeated, replacing HV, O with the newly obtained value for $HV, 100$, and acquiring more cosmic ray data with the new High Voltage, until the desired outcome of MCA mean of 100 is reached.

The first trial of this process is shown in Table 2.1. The column labelled OK? refers to whether the absolute value of the change between the recommended High Voltage and the original High Voltage is too high. If the value of $\frac{\Delta abs(HV)}{HV}$ exceeds

Cell#	HV, O	$\mu_{HV,O}$	HV, R	$\mu_{HV,R}$	α	$HV, 100$	$\Delta abs(HV)$	$\frac{\Delta abs(HV)}{HV}$	OK?
188	-1500	120 ± 3	-1400	87 ± 2	4.69	-1442	-58	0.04	Yes
187	-1450	102 ± 3	-1350	76 ± 2	4.09	-1442	-8	0.01	Yes
186	-1375	168 ± 4	-1275	102 ± 2	6.58	-1271	-104	0.08	Yes
185	-1300	131 ± 3	-1200	92 ± 2	4.41	-1224	-76	0.06	Yes
184	-1300	236 ± 6	-1200	173 ± 4	3.91	-1044	-256	0.20	No
183	-1300	53 ± 2	-1200	37 ± 1	4.65	-1489	189	-0.15	No
182	-1450	89 ± 3	-1350	57 ± 2	6.12	-1479	29	-0.02	Yes
181	-1550	95 ± 3	-1450	72 ± 2	4.13	-1568	18	-0.01	Yes
180	-1475	79 ± 2	-1375	53 ± 2	5.65	-1539	64	-0.04	Yes
179	-1350	175 ± 5	-1250	124 ± 3	4.47	-1192	-158	0.12	No
178	-1325	112 ± 3	-1225	73 ± 2	5.52	-1298	-27	0.02	Yes
177	-1500	104 ± 3	-1400	64 ± 2	6.91	-1492	-8	0.01	Yes
176	-1400	202 ± 7	-1300	157 ± 5	3.41	-1139	-261	0.19	No
175	-1400	105 ± 4	-1300	73 ± 3	4.83	-1386	-14	0.01	Yes
174	-1500	70 ± 3	-1400	53 ± 2	3.99	-1638	138	-0.09	Yes
173	-1400	115 ± 4	-1300	81 ± 2	4.76	-1360	-40	0.03	Yes
172	-1375	119 ± 4	-1275	75 ± 2	6.05	-1337	-38	0.03	Yes
171	-1425	101 ± 3	-1325	71 ± 2	4.74	-1423	-2	0.00	Yes
170	-1500	174 ± 7	-1400	144 ± 5	2.81	-1230	-270	0.18	No
169	-1400	98 ± 4	-1300	72 ± 3	4.12	-1407	7	0.00	Yes
168	-1450	128 ± 6	-1350	100 ± 4	3.53	-1351	-99	0.07	Yes

Table 2.1: Recommended High Voltage values from channel 169 - 189 to get a mean cosmic amplitude A = 100.

0.1, that could damage the sensitive PMT and is thus avoided.

Chapter 3

Observations and Discussion

3.1 Mean Cosmic Amplitude variation

Figure 3.1 shows the Mean Cosmic Amplitude per channel number of the Shower, with the error bars representing the RMS of this amplitude. Clearly, the MCA varies significantly, even within error. However, this variation is not solely due to variation in Gain. In the Figure, there is a clear trend of the MCA to increase with channel number. This is due to the fact that higher Channel numbers correspond to detector blocks that are closer to the top of the array, which is where the scintillation detector is located.

As such, any cosmic ray that enters the array must traverse the top detector blocks, but may pass the detector at an angle such that it does not exit the array through the bottom blocks. This results in a much higher number of counts for detector blocks in the top of the array than those further down. It was due to this reason that only the top to rows of the detector were first attempted to be Gain matched. However, compounding the issue is the fact that many of the cosmic rays which trigger the scintillator and only traverse into the top rows of the detector will be low energy particles which actually stop in these top lead glass blocks. In contrast, cosmic rays which go through the entire array and produce signals in the bottom rows

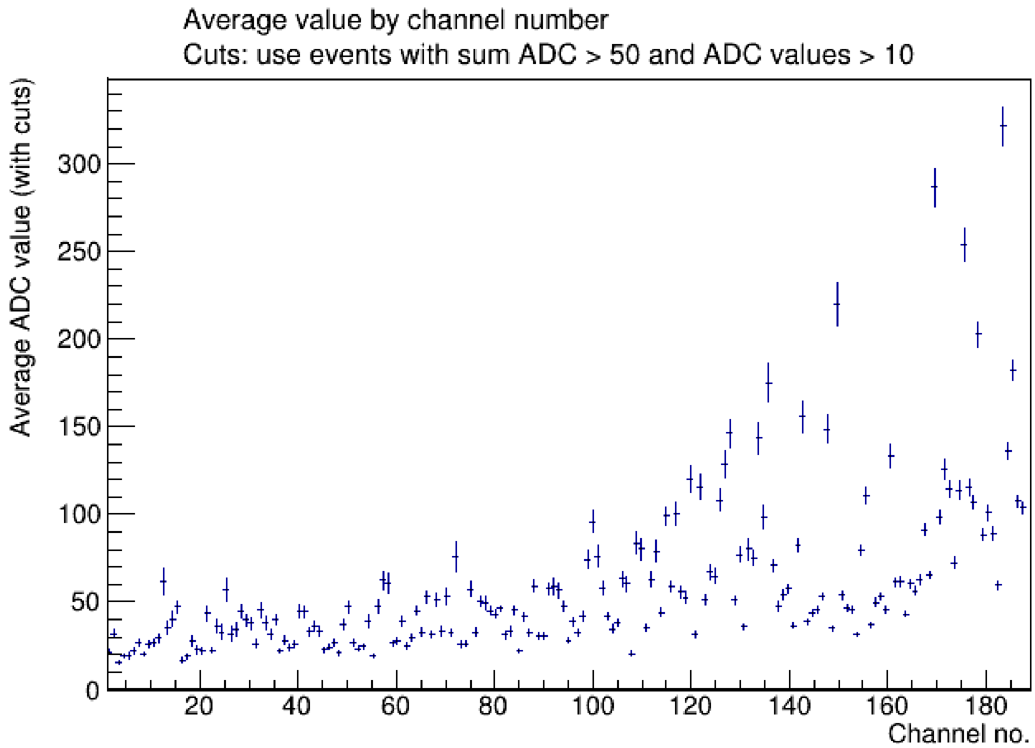


Figure 3.1: The average Mean Cosmic Amplitude for each channel.

will necessarily have been high energy cosmic rays in order to penetrate through the entire array - and these high energy cosmic rays will be definitely minimum-ionizing in character (depositing a constant, smallest, amount of energy per unit thickness of lead glass travelled through); and, in fact, ideally we would want all MCAs we measure to correspond to such minimum-ionizing high energy cosmic rays passing through the same thickness of lead glass per channel ("straight down"), since then all MCAs would be a result of the same amount of produced scintillation light. But, this wasn't the case we had for events which only went into the top rows of the detector and stopped, depositing all or most of their energy in the blocks and so producing a bigger signal (MCA) compared to minimum ionizing; or for events that may have been high energy, minimum ioninzing, but cross the top rows at angle, causing them to have a longer path through the blocks (compared to "straight down"), and so produce a bigger signal (MCA) compared to straight-down high energy particles. All of these reasons combine to give the imbalance/trend that is reflected in the Figure, going from low channel number (bottom rows) to high channel number (top rows).

A possible solution would be to place another scintillation detector at the bottom of the array and set the triggering condition to store data only when both detectors have simultaneously detected scintillation - this would guarantee that the cosmic ray particles had high enough energy to penetrate the entire lead glass array, and therefore guarantee they were minimum ionizing in nature; it would also guarantee that the particles were mostly "straight down"; those features would make a more clear argument that the measured MCAs would properly be used for Gain Matching because all would correspond to the same amount of produced scintillation light. However, this was not possible due to space constraints. Another option would be to add a third cut to the Gain Matching cuts discussed in Chapter 2, with this third cut being to only include data from events which contained both a signal in one of the top two rows and in one of the bottom two rows (to try and achieve the same effect as having a scintillator on the bottom). However, we would have needed much longer cosmic ray data-taking runs to get enough statistics for this method (our data runs had not enough events that fired the lower rows of the array). Finally, the available time I had to work directly on the project at Jefferson Lab ran out before being able to try any of these potential solutions for Gain Matching.

However, it must also be noted that there is still very significant variation in the MCA between neighbouring detectors on the figure, independent of the trend from low to high channel number discussed above. This is due to variation in Gain and highlights the importance of Gain Matching. It is due to this reason that Gain Matching was attempted only on the top two rows of calorimeter blocks, as these blocks should have very similar responses. This variation between neighboring channels can be very clearly seen in the variation of the amplitudes of spectra in Appendix A.

3.2 Results of Pedestal Identification and Subtraction

The script which I generated to perform Pedestal identification and subtraction was not the first script to do so at JLab for the BigBite Calorimeter. However, the previous script had identified Pedestals incorrectly, leading to Pedestals with mean values that were significantly distant from 0. This leads to incorrect results when trying to extract MCAs for Gain Matching, and this flaw in the previous script was only found during the development of the Event Display. As such, the project was expanded to include the development of a new Pedestal identification and subtraction system to have a functional Event Display, and allow for Gain Matching.

Figure 3.2 shows the Pedestal mean as a function the Calorimeter channel number, extracted using the script written for this project.

The results of the Pedestal RMS calculated in by this method are shown in **Figure 3.3**. Note that the mean of the RMS remains mostly consistent, save for a channel 81. This may be a result of Gain variation that creates a scintillation response that

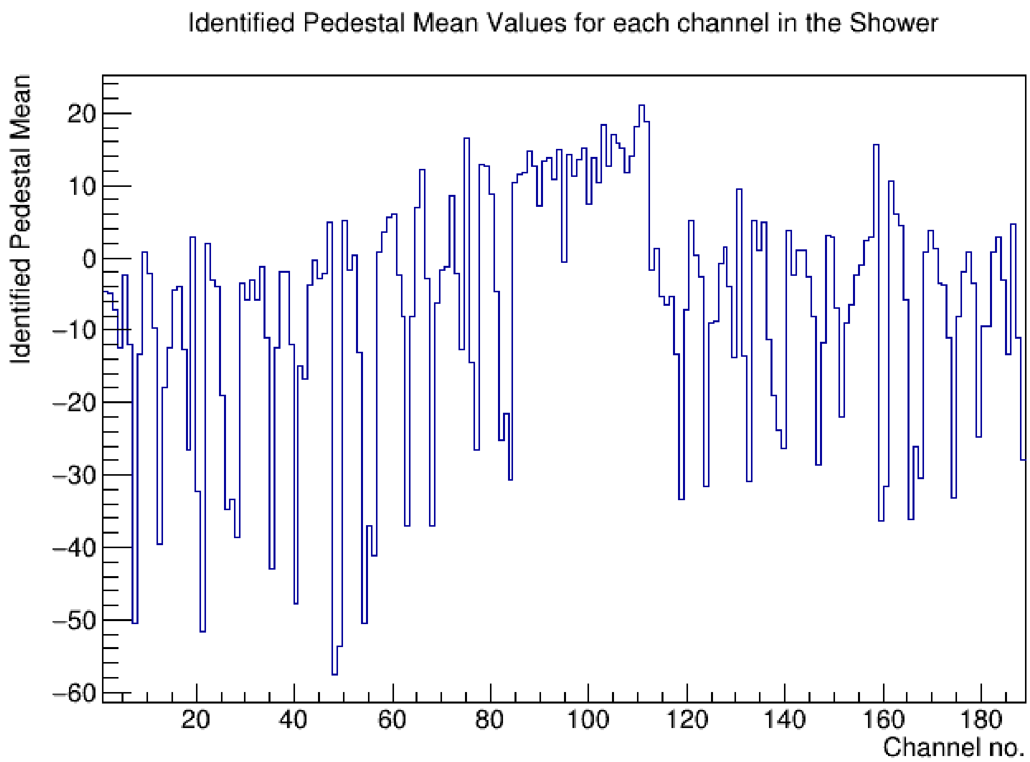


Figure 3.2: The value of the Pedestal mean as a function the Calorimeter channel number

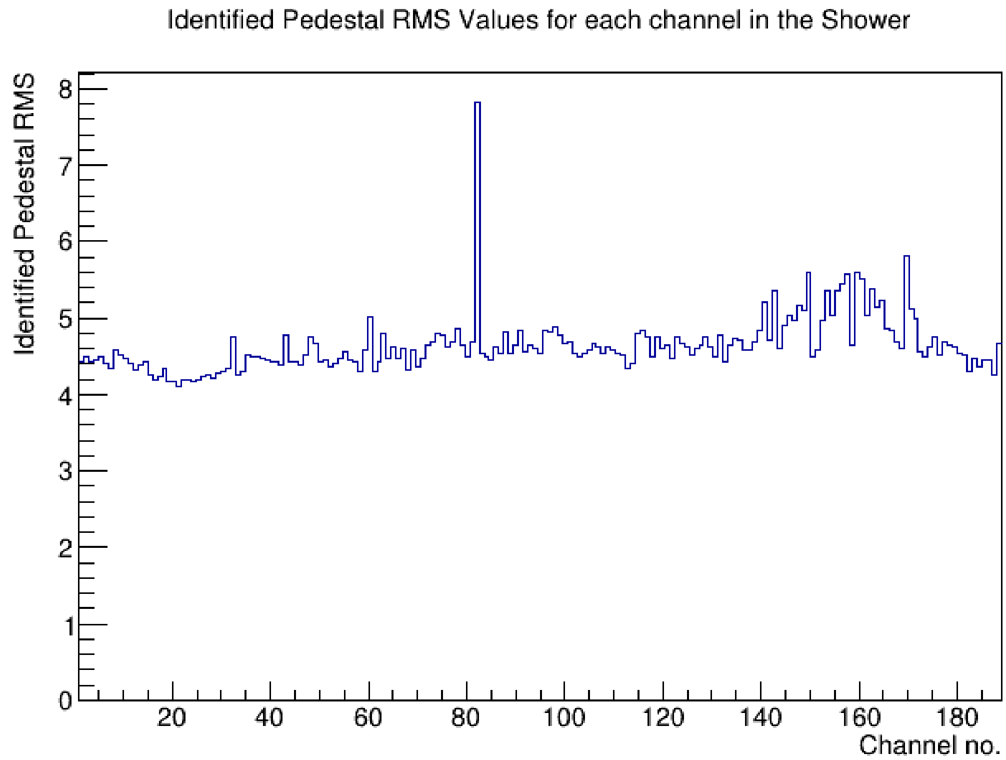


Figure 3.3: The measured value of the Pedestal Root Mean Square for all channels of the Shower.

occurs very close to the mean of the pedestal, or due to an instrumentation error that causes an unusually wide Pedestal. Looking at the response for Channel 81 in Appendix A, the latter seems much more likely.

3.3 Gain

Due to time constraints and the unforeseen, yet unavoidable addition of Pedestal Identification and Subtraction into the project, Gain Matching was not completed, and did not progress past the first iteration. However, as the process has been started, other researchers at JLab can use the same process and equation to iterate the change in High Voltage in order to create a response that is identical for all channels in the detector.

Gain Matching for the top two rows has been initiated in this project. After the process of Gain-Matching the top two rows is completed by this process, the rest of the rows can also be Gain-Matched in a similar way, ideally with the addition of the extra third cut explained earlier to help guarantee straight-down minimum-ionizing cosmic rays, and longer data taking runs to ensure enough statistics to Gain Match the bottom rows.

3.4 The Pre-Shower

In Appendix A, some channels of the Pre-shower appear to have little to no data. This may be a fault due to the instrumentation, positioning, or software. It is also important to note the large variation in the spectra from the Pre-shower in the obtained data. This was done during run 179, which was however meant to test the shower.

3.5 Event Display examples

Some examples of the Event Display in action are displayed in **Figure 3.4**. As shown, there are occasional large ADC values being displayed outside the line that the cosmic ray particle follows, due to variations in Gain. Small fluctuations that are just above the 10 Pedestal-subtracted ADC threshold are very small in the display, due to the variable sizing of the representations of each channel in the Event Display. Some

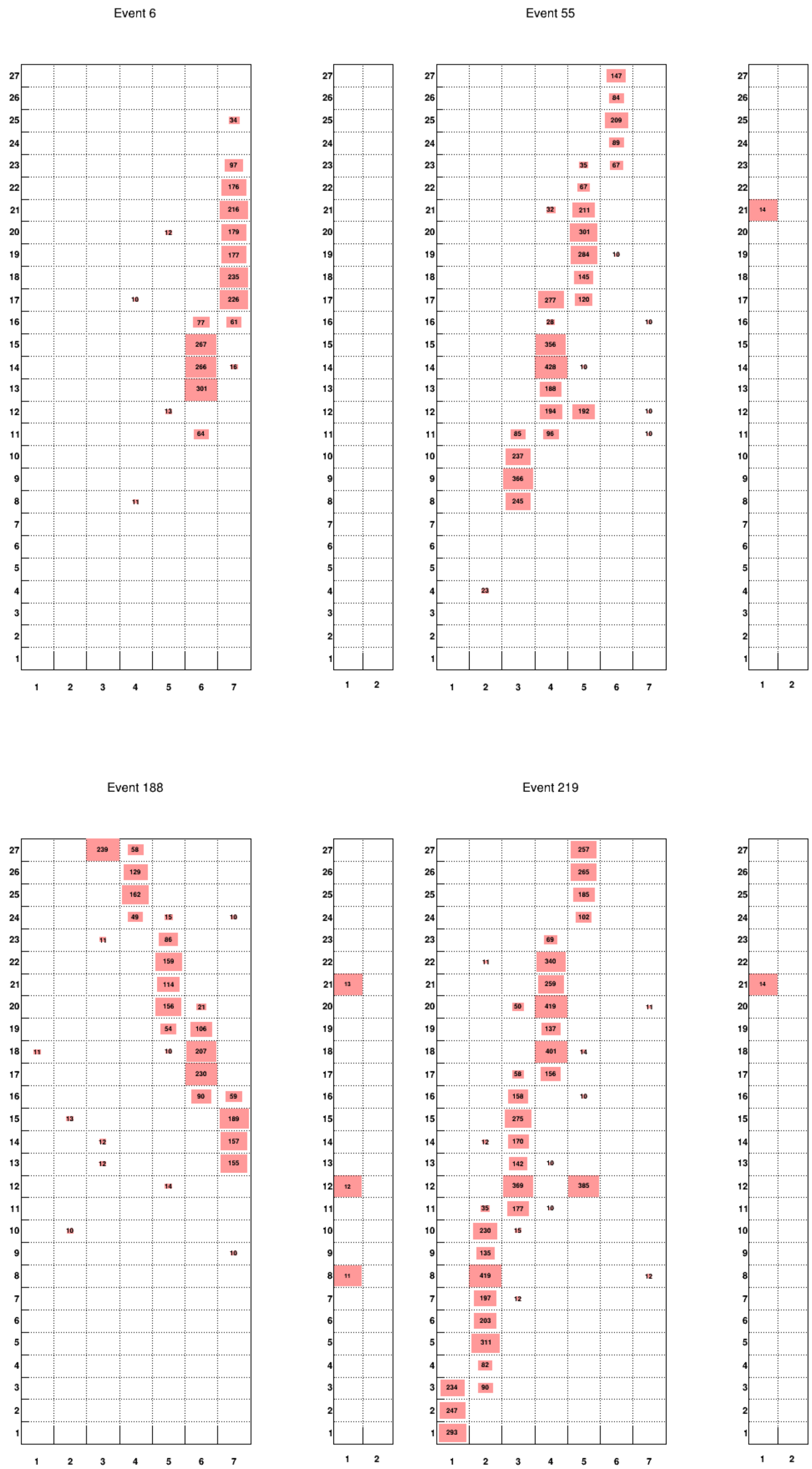


Figure 3.4: Example images of the Event Display

cosmic rays, such as those in Event 6 and Event 55, appear to leave the array in the middle of their path. However, it's important to note that the arrays are two dimensional, and the ray can appear from a different angle. This could also be an artifact of the low-energy cosmic ray particles, mentioned in **Section 3.1**, that stop in these lead blocks. This would affect Gain matching, but the scope of the issues this could generate wouldn't surpass those mentioned earlier.

Having an additional scintillator paddle at the bottom of the array could help mitigate this phenomenon as well, if feasible.

Chapter 4

Conclusions

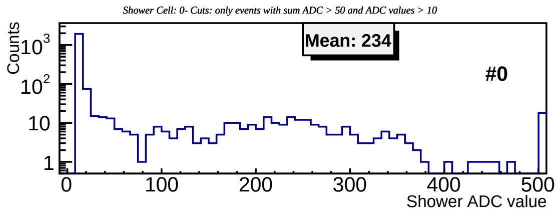
The first version of an Event Display was developed - This will be helpful for visualizing the functioning of the BigBite Calorimeter as well as diagnosing potential problems. It could also be adapted for other component detectors.

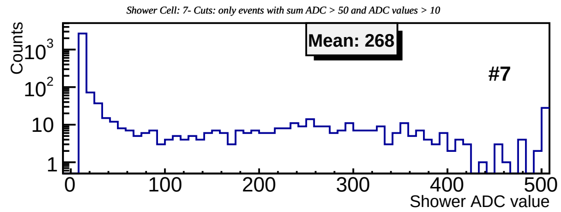
A problem was identified with the existing script for Pedestal Identification, and was fixed with a new script to Identify and Subtract Mean Pedestal values from all ADC signals. This script can also be adapted to other detectors.

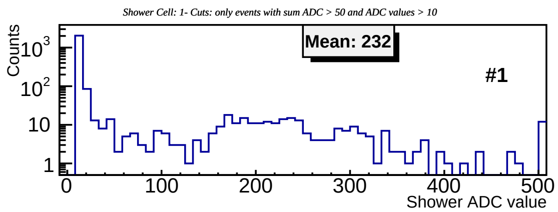
A method for Gain Matching the PMTs on the BigBite Calorimeter—using cosmic rays—was developed. An error in the initial implementation (a flawed existing Pedestal Identification script) meant that the gain matching could not be completed prior to departure from the lab due to time constraints.

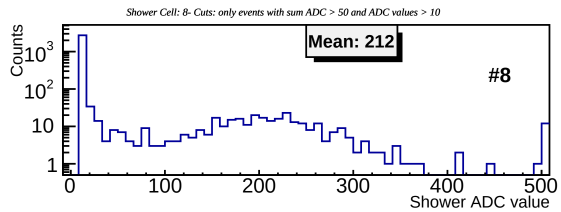
Appendix A

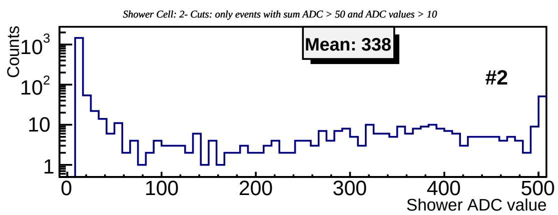
The Spectra used for calculating the Mean Cosmic Amplitude.

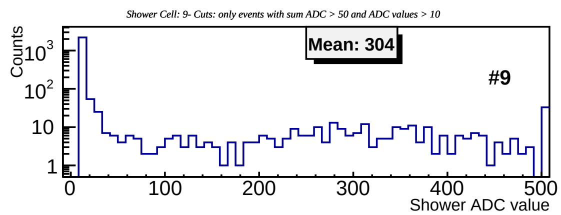

Shower Cell: 0- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 234
#0
Counts
Shower ADC value

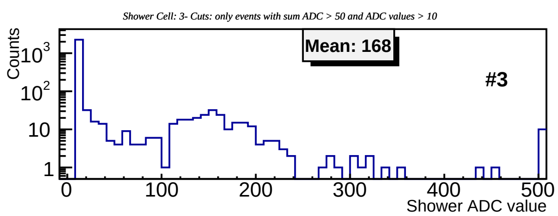

Shower Cell: 7- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 268
#7
Counts
Shower ADC value

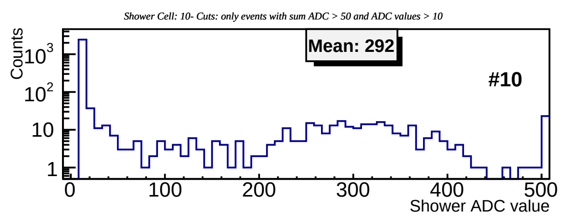

Shower Cell: 1- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 232
#1
Counts
Shower ADC value

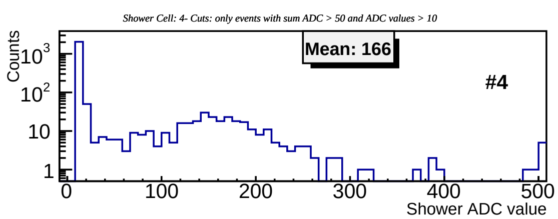

Shower Cell: 8- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 212
#8
Counts
Shower ADC value

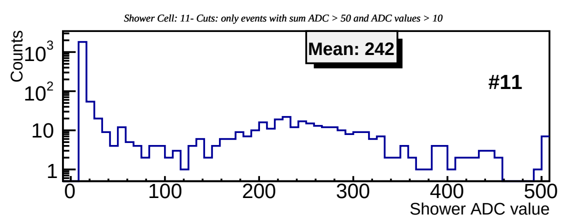

Shower Cell: 2- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 338
#2
Counts
Shower ADC value

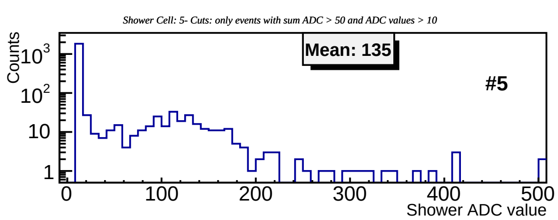

Shower Cell: 9- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 304
#9
Counts
Shower ADC value

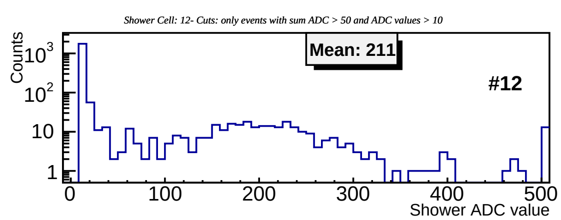

Shower Cell: 3- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 168
#3
Counts
Shower ADC value

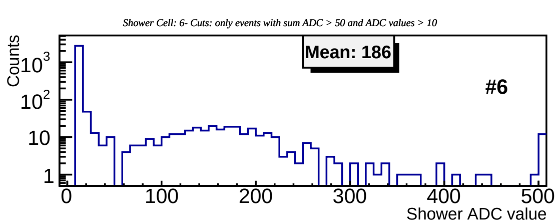

Shower Cell: 10- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 292
#10
Counts
Shower ADC value

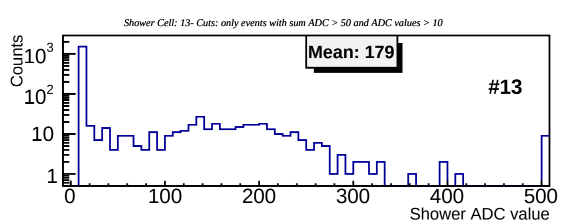

Shower Cell: 4- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 166
#4
Counts
Shower ADC value

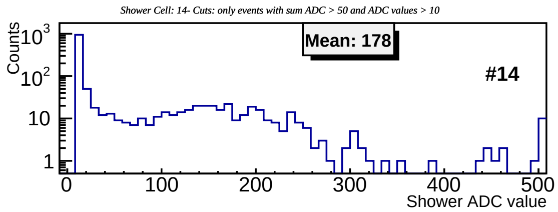

Shower Cell: 11- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 242
#11
Counts
Shower ADC value

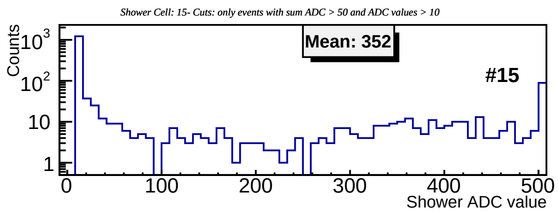

Shower Cell: 5- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 135
#5
Counts
Shower ADC value

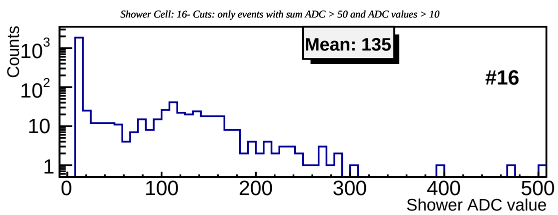

Shower Cell: 12- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 211
#12
Counts
Shower ADC value

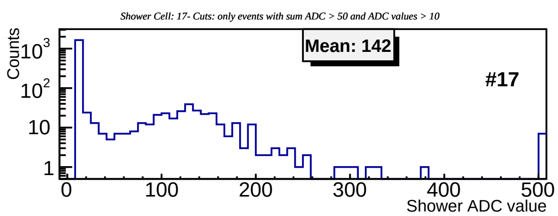

Shower Cell: 6- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 186
#6
Counts
Shower ADC value

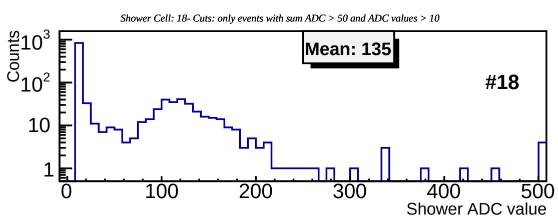

Shower Cell: 13- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 179
#13
Counts
Shower ADC value

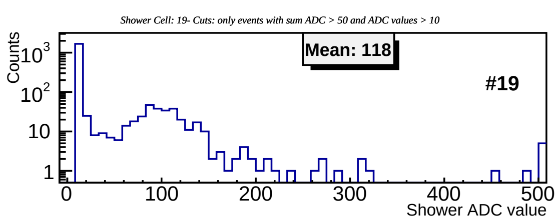

Shower Cell: 14- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 178
#14
Counts
Shower ADC value

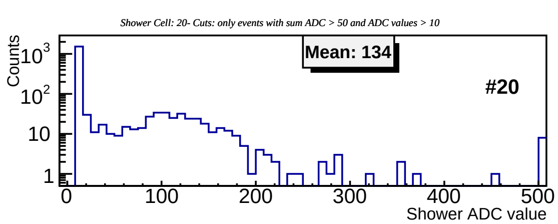

Shower Cell: 15- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 352
#15
Counts
Shower ADC value

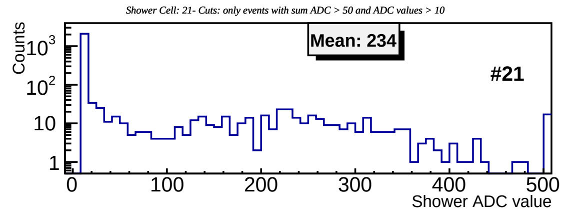

Shower Cell: 16- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 135
#16
Counts
Shower ADC value

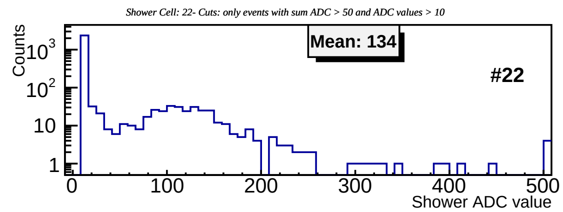

Shower Cell: 17- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 142
#17
Counts
Shower ADC value

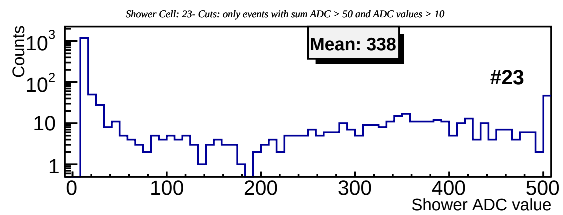

Shower Cell: 18- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 135
#18
Counts
Shower ADC value

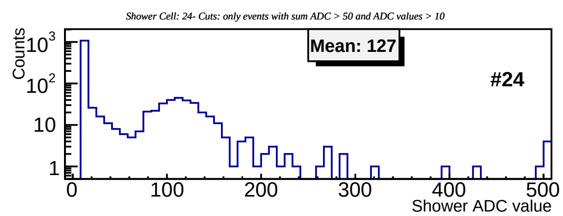

Shower Cell: 19- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 118
#19
Counts
Shower ADC value

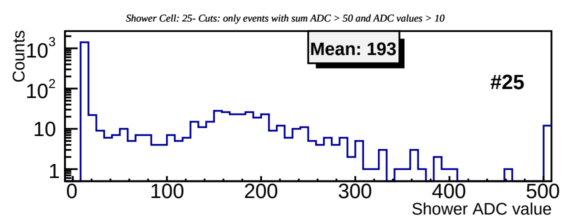

Shower Cell: 20- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 134
#20
Counts
Shower ADC value

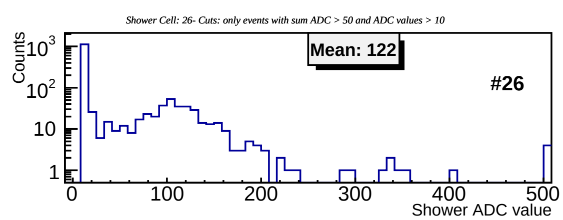

Shower Cell: 21- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 234
#21
Counts
Shower ADC value

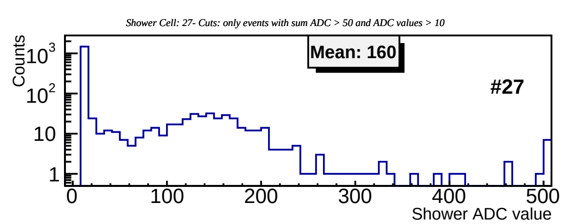

Shower Cell: 22- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 134
#22
Counts
Shower ADC value

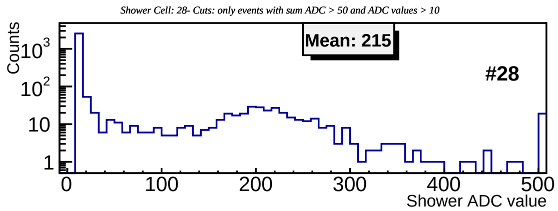

Shower Cell: 23- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 338
#23
Counts
Shower ADC value

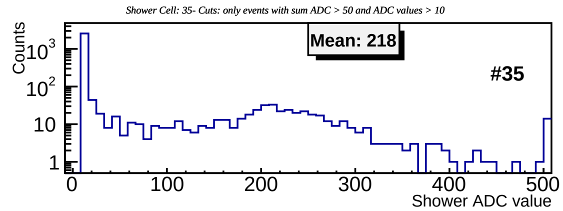

Shower Cell: 24- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 127
#24
Counts
Shower ADC value

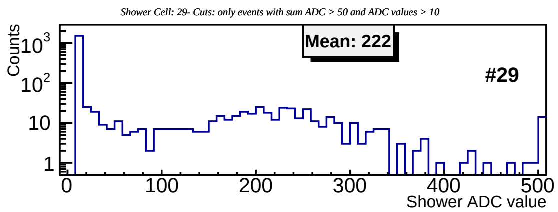

Shower Cell: 25- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 193
#25
Counts
Shower ADC value

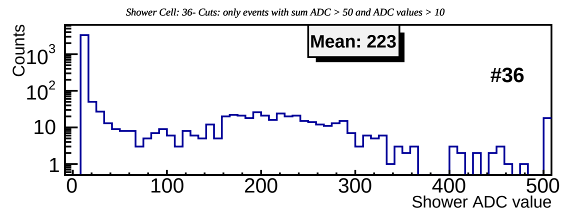

Shower Cell: 26- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 122
#26
Counts
Shower ADC value

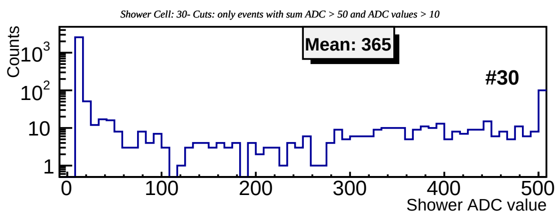

Shower Cell: 27- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 160
#27
Counts
Shower ADC value

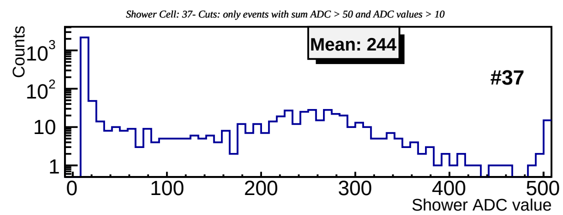

Shower Cell: 28- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 215
#28
Counts
Shower ADC value

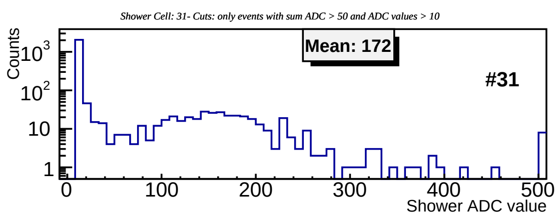

Shower Cell: 35- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 218
#35
Counts
Shower ADC value

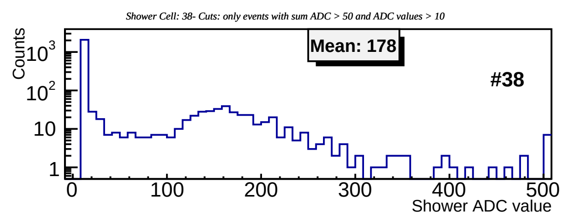

Shower Cell: 29- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 222
#29
Counts
Shower ADC value

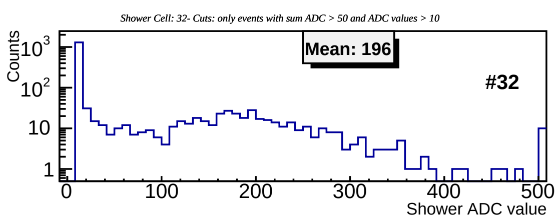

Shower Cell: 36- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 223
#36
Counts
Shower ADC value

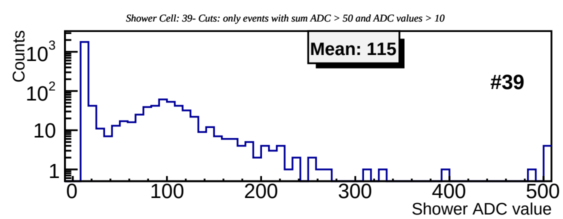

Shower Cell: 30- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 365
#30
Counts
Shower ADC value

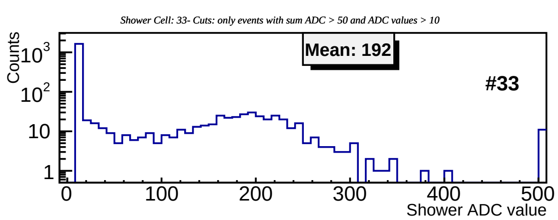

Shower Cell: 37- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 244
#37
Counts
Shower ADC value

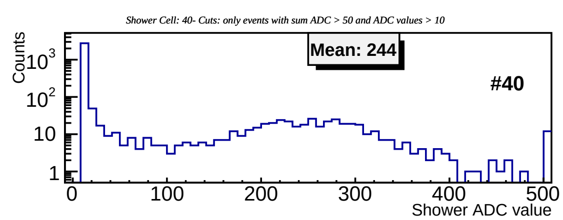

Shower Cell: 31- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 172
#31
Counts
Shower ADC value

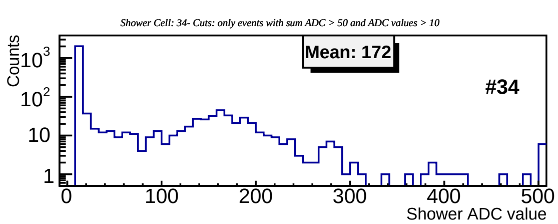

Shower Cell: 38- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 178
#38
Counts
Shower ADC value

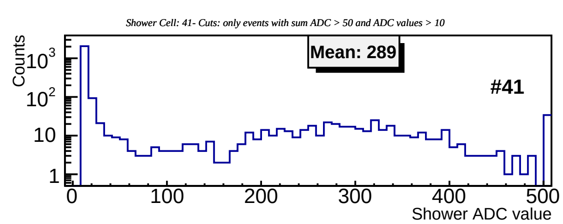

Shower Cell: 32- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 196
#32
Counts
Shower ADC value

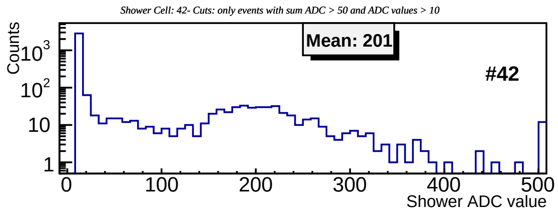

Shower Cell: 39- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 115
#39
Counts
Shower ADC value

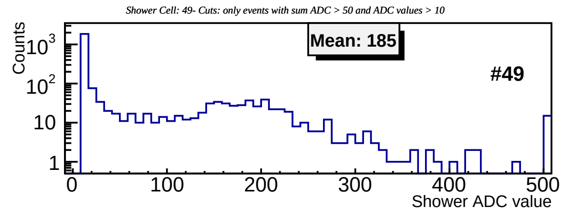

Shower Cell: 33- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 192
#33
Counts
Shower ADC value

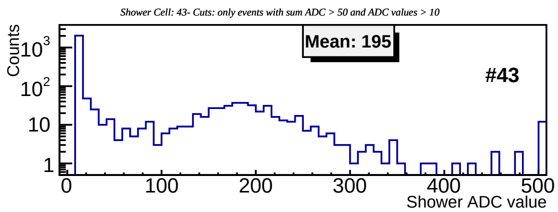

Shower Cell: 40- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 244
#40
Counts
Shower ADC value

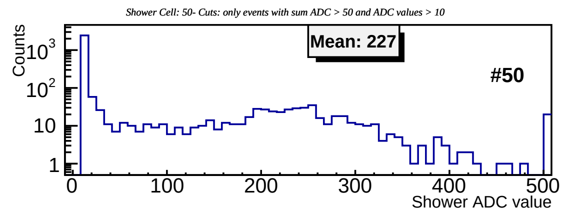

Shower Cell: 34- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 172
#34
Counts
Shower ADC value

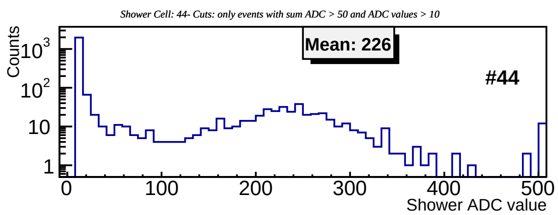

Shower Cell: 41- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 289
#41
Counts
Shower ADC value

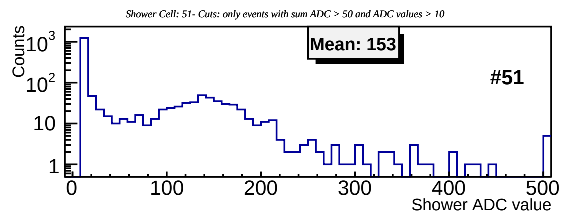

Shower Cell: 42- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 201
#42
Counts
Shower ADC value

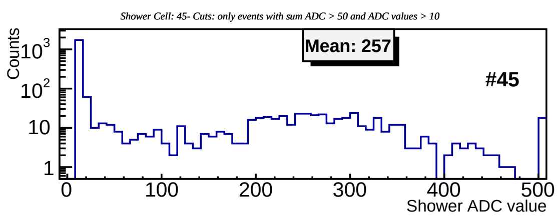

Shower Cell: 49- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 185
#49
Counts
Shower ADC value

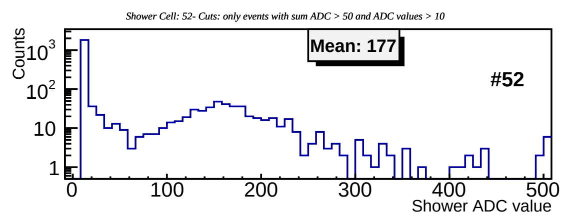

Shower Cell: 43- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 195
#43
Counts
Shower ADC value

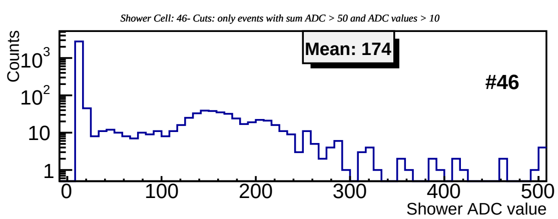

Shower Cell: 50- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 227
#50
Counts
Shower ADC value

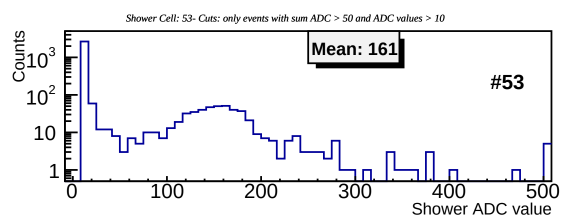

Shower Cell: 44- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 226
#44
Counts
Shower ADC value

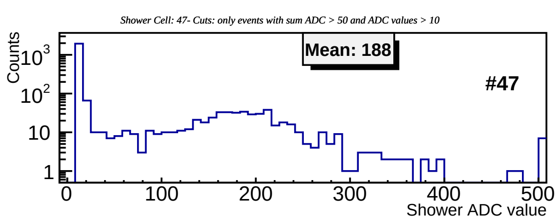

Shower Cell: 51- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 153
#51
Counts
Shower ADC value

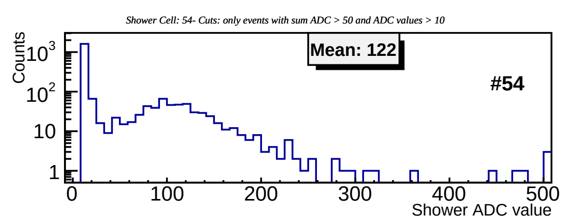

Shower Cell: 45- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 257
#45
Counts
Shower ADC value

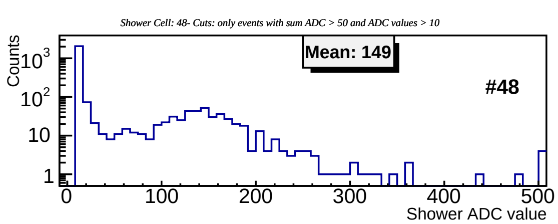

Shower Cell: 52- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 177
#52
Counts
Shower ADC value

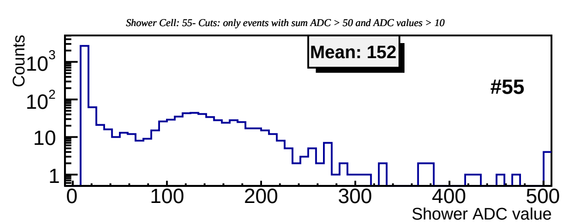

Shower Cell: 46- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 174
#46
Counts
Shower ADC value

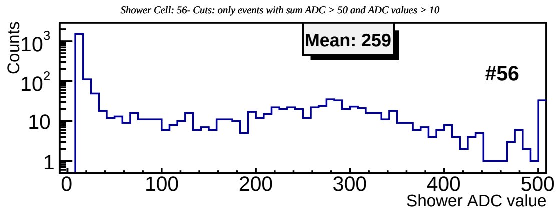

Shower Cell: 53- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 161
#53
Counts
Shower ADC value

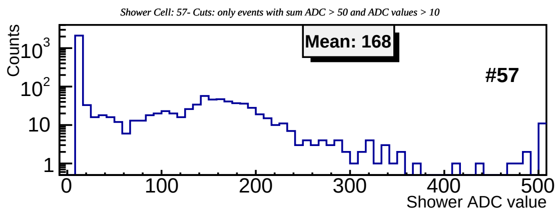

Shower Cell: 47- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 188
#47
Counts
Shower ADC value

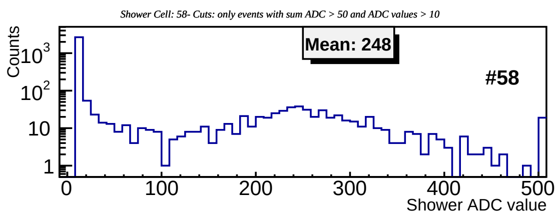

Shower Cell: 54- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 122
#54
Counts
Shower ADC value

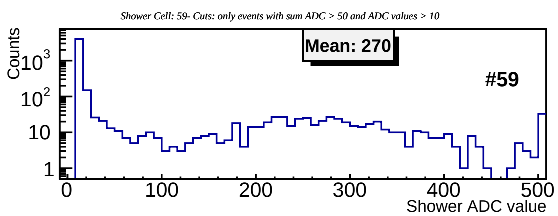

Shower Cell: 48- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 149
#48
Counts
Shower ADC value

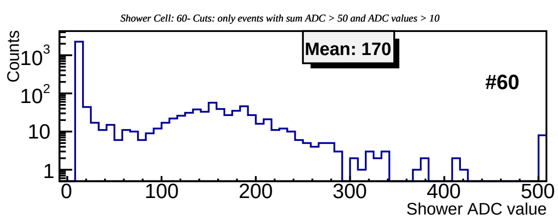

Shower Cell: 55- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 152
#55
Counts
Shower ADC value

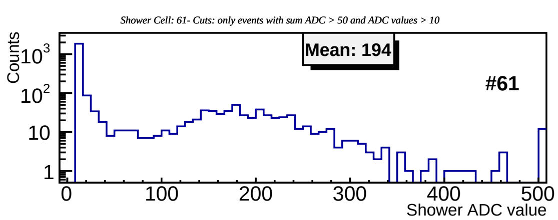

Shower Cell: 56- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 259
#56
Counts
Shower ADC value

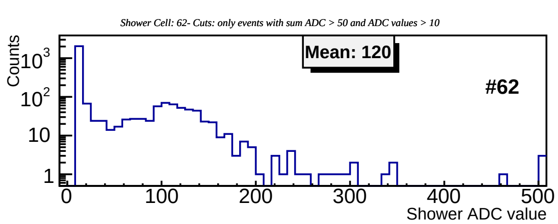

Shower Cell: 57- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 168
#57
Counts
Shower ADC value

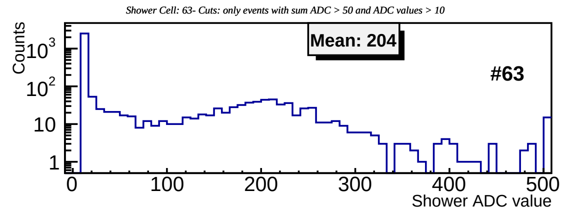

Shower Cell: 58- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 248
#58
Counts
Shower ADC value

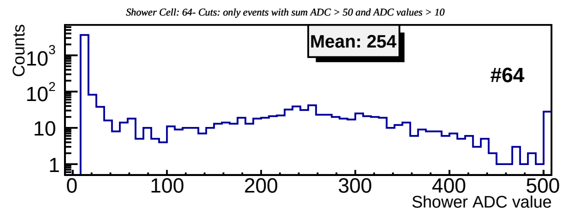

Shower Cell: 59- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 270
#59
Counts
Shower ADC value

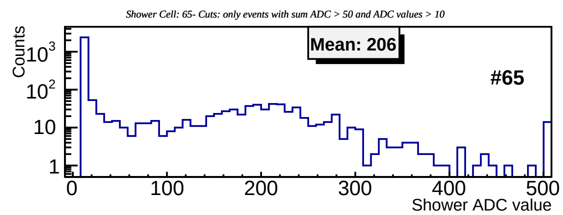

Shower Cell: 60- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 170
#60
Counts
Shower ADC value

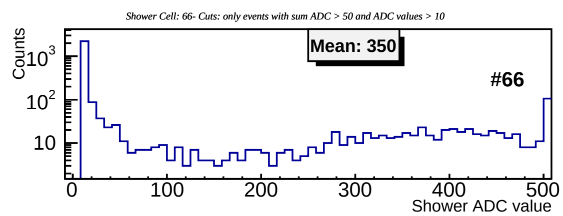

Shower Cell: 61- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 194
#61
Counts
Shower ADC value

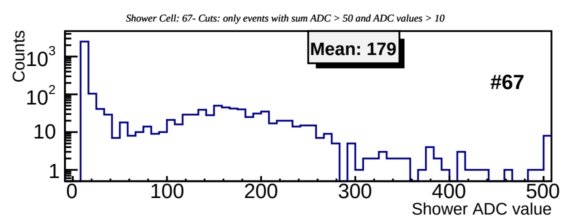

Shower Cell: 62- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 120
#62
Counts
Shower ADC value

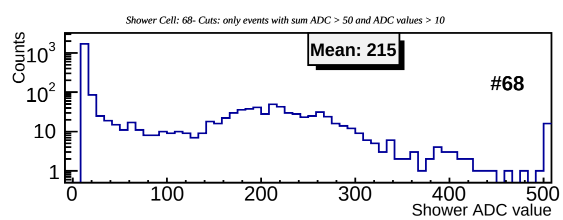

Shower Cell: 63- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 204
#63
Counts
Shower ADC value

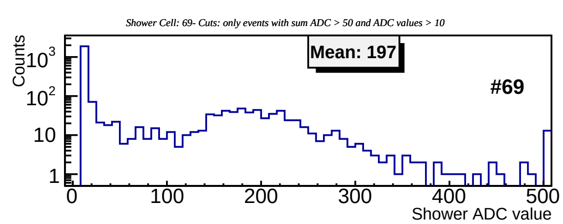

Shower Cell: 64- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 254
#64
Counts
Shower ADC value


Shower Cell: 65- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 206
#65
Counts
Shower ADC value

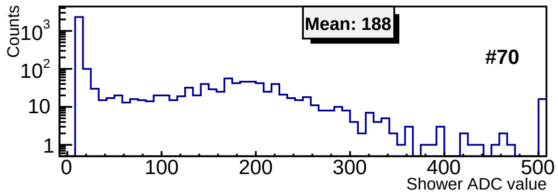

Shower Cell: 66- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 350
#66
Counts
Shower ADC value


Shower Cell: 67- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 179
#67
Counts
Shower ADC value

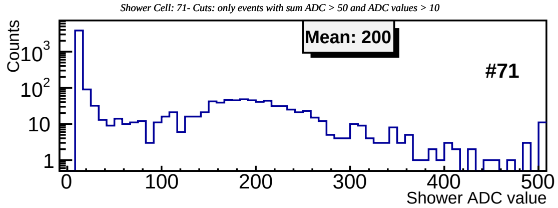

Shower Cell: 68- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 215
#68
Counts
Shower ADC value


Shower Cell: 69- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 197
#69
Counts
Shower ADC value

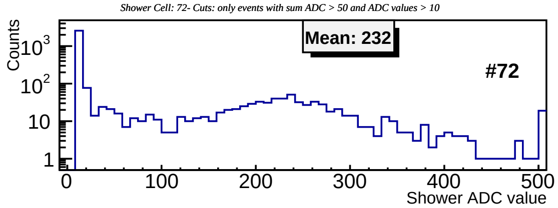
Shower Cell: 70- Cuts: only events with sum ADC > 50 and ADC values > 10



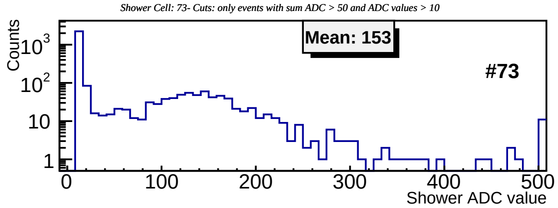
Shower Cell: 71- Cuts: only events with sum ADC > 50 and ADC values > 10



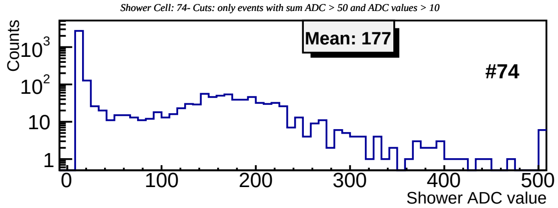
Shower Cell: 72- Cuts: only events with sum ADC > 50 and ADC values > 10



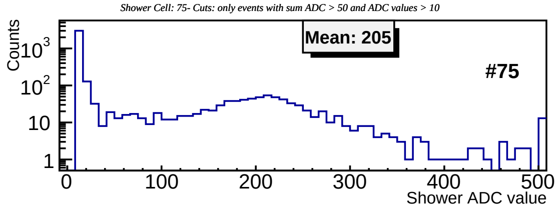
Shower Cell: 73- Cuts: only events with sum ADC > 50 and ADC values > 10



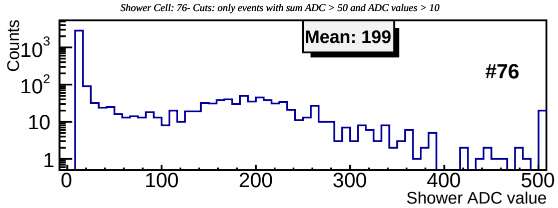
Shower Cell: 74- Cuts: only events with sum ADC > 50 and ADC values > 10



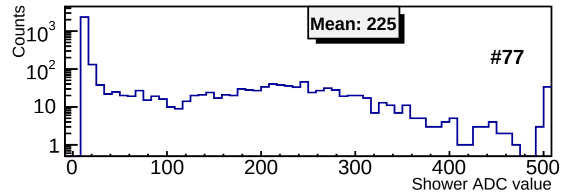
Shower Cell: 75- Cuts: only events with sum ADC > 50 and ADC values > 10



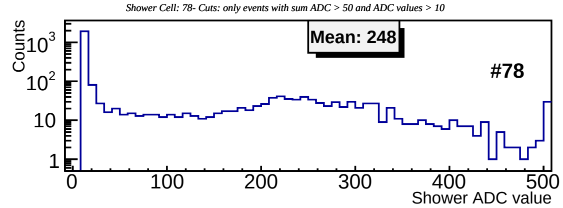
Shower Cell: 76- Cuts: only events with sum ADC > 50 and ADC values > 10



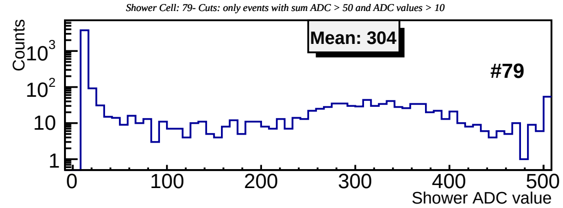
Shower Cell: 77- Cuts: only events with sum ADC > 50 and ADC values > 10



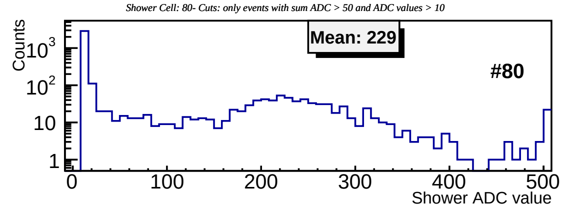
Shower Cell: 78- Cuts: only events with sum ADC > 50 and ADC values > 10



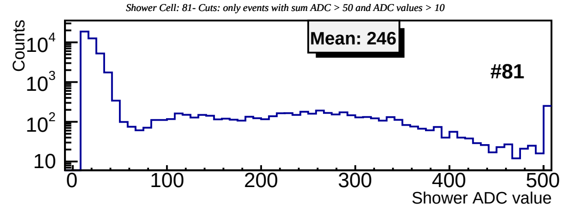
Shower Cell: 79- Cuts: only events with sum ADC > 50 and ADC values > 10



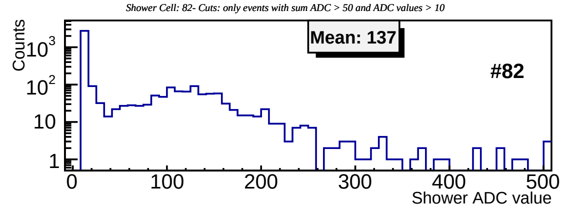
Shower Cell: 80- Cuts: only events with sum ADC > 50 and ADC values > 10



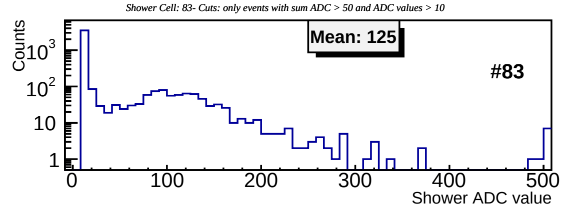
Shower Cell: 81- Cuts: only events with sum ADC > 50 and ADC values > 10

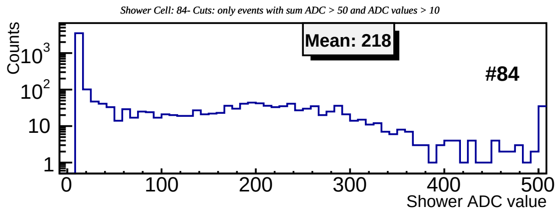


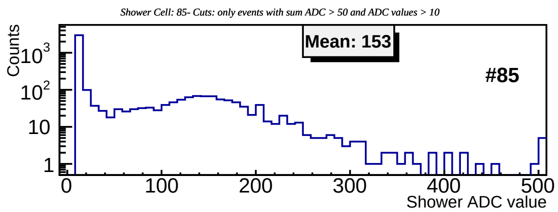
Shower Cell: 82- Cuts: only events with sum ADC > 50 and ADC values > 10

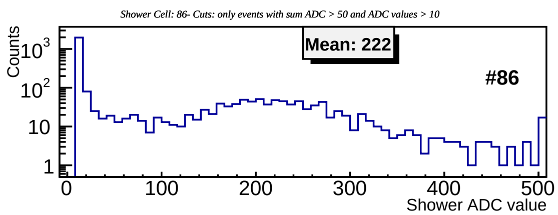


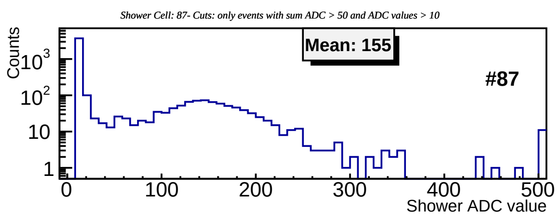
Shower Cell: 83- Cuts: only events with sum ADC > 50 and ADC values > 10

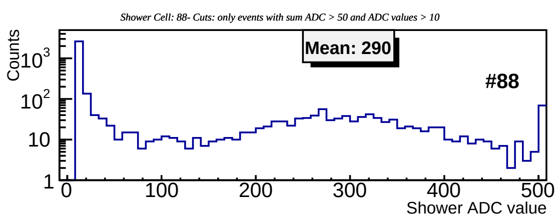


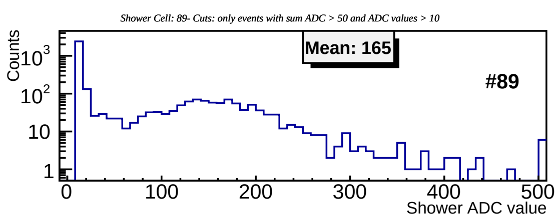

Shower Cell: 84- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 218
#84
Counts
Shower ADC value

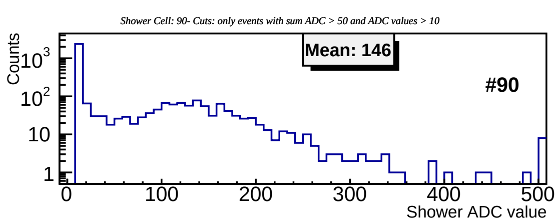

Shower Cell: 85- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 153
#85
Counts
Shower ADC value

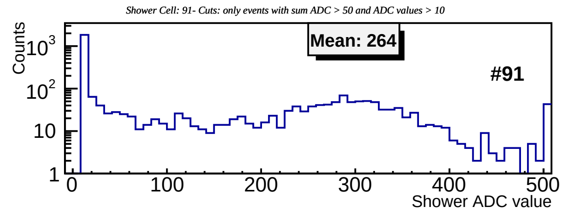

Shower Cell: 86- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 222
#86
Counts
Shower ADC value

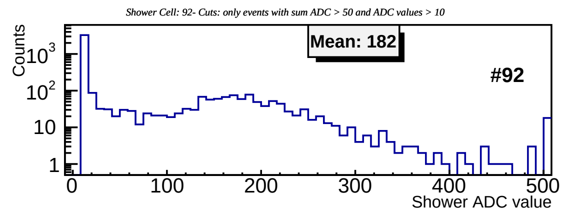

Shower Cell: 87- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 155
#87
Counts
Shower ADC value

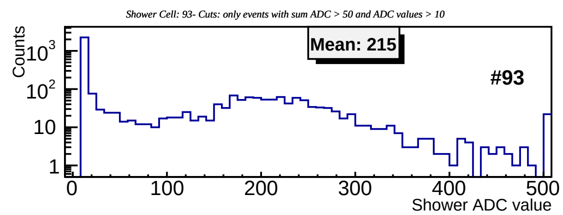

Shower Cell: 88- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 290
#88
Counts
Shower ADC value

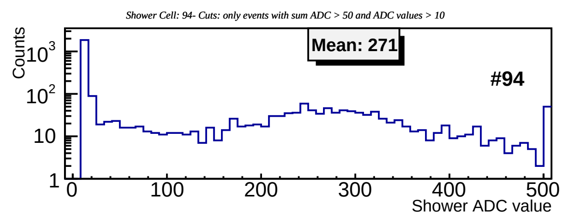

Shower Cell: 89- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 165
#89
Counts
Shower ADC value

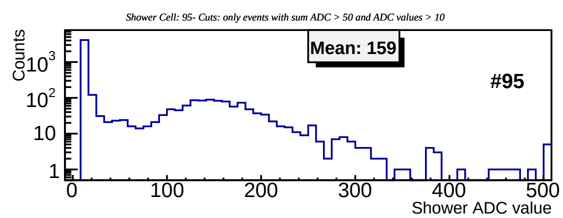

Shower Cell: 90- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 146
#90
Counts
Shower ADC value

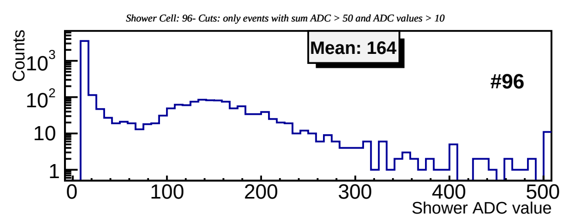

Shower Cell: 91- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 264
#91
Counts
Shower ADC value

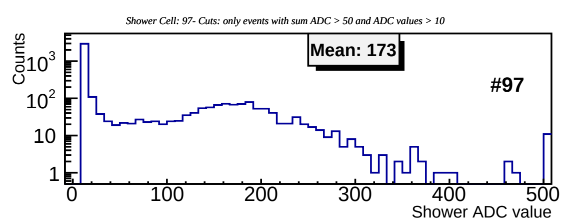

Shower Cell: 92- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 182
#92
Counts
Shower ADC value

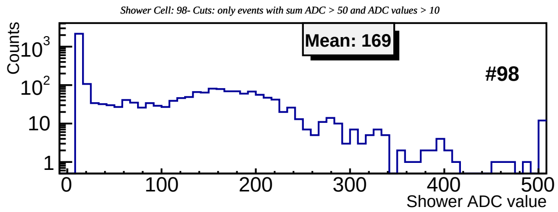

Shower Cell: 93- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 215
#93
Counts
Shower ADC value

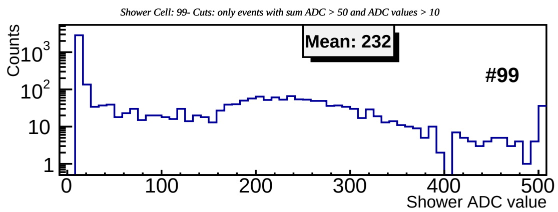

Shower Cell: 94- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 271
#94
Counts
Shower ADC value

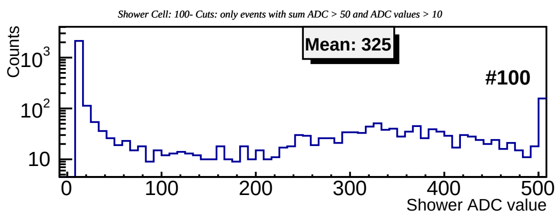

Shower Cell: 95- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 159
#95
Counts
Shower ADC value

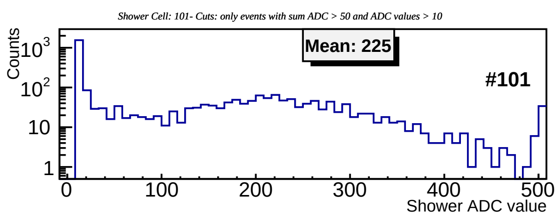

Shower Cell: 96- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 164
#96
Counts
Shower ADC value

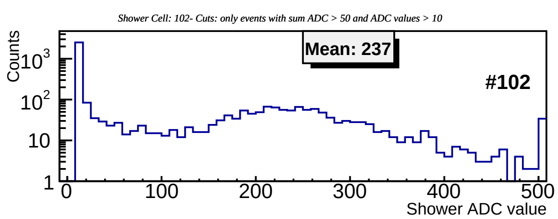

Shower Cell: 97- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 173
#97
Counts
Shower ADC value

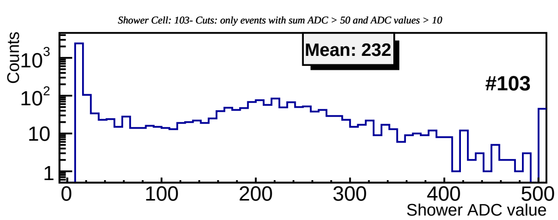

Shower Cell: 98- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 169
#98
Counts
Shower ADC value

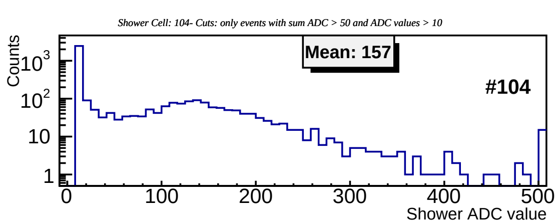

Shower Cell: 99- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 232
#99
Counts
Shower ADC value

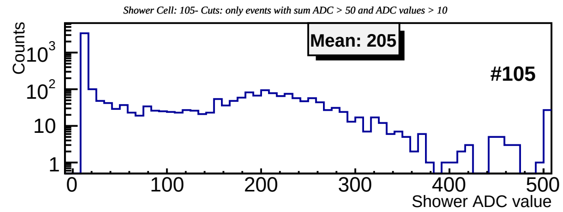

Shower Cell: 100- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 325
#100
Counts
Shower ADC value

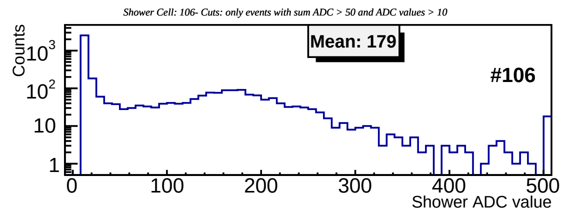

Shower Cell: 101- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 225
#101
Counts
Shower ADC value

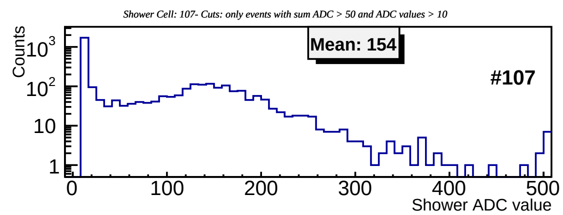

Shower Cell: 102- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 237
#102
Counts
Shower ADC value

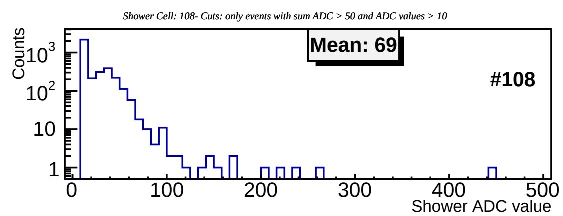

Shower Cell: 103- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 232
#103
Counts
Shower ADC value

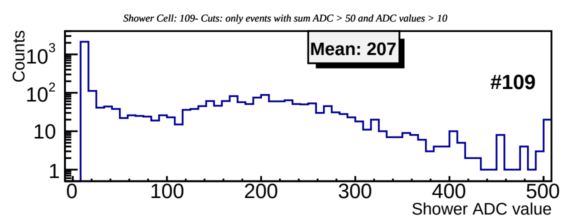

Shower Cell: 104- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 157
#104
Counts
Shower ADC value

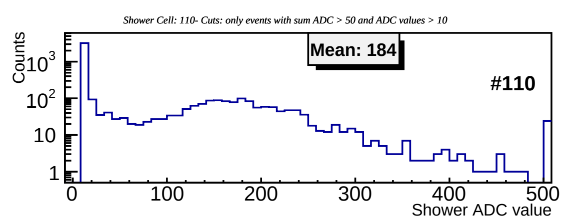

Shower Cell: 105- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 205
#105
Counts
Shower ADC value

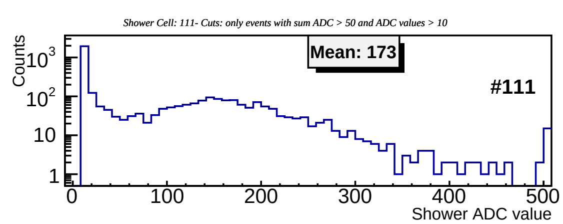

Shower Cell: 106- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 179
#106
Counts
Shower ADC value

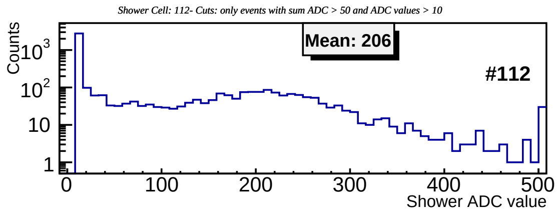

Shower Cell: 107- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 154
#107
Counts
Shower ADC value

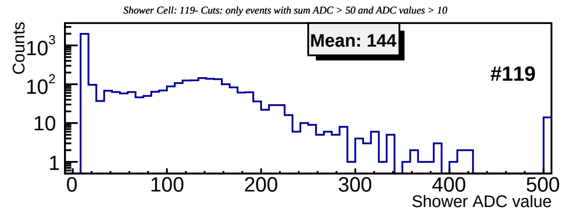

Shower Cell: 108- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 69
#108
Counts
Shower ADC value

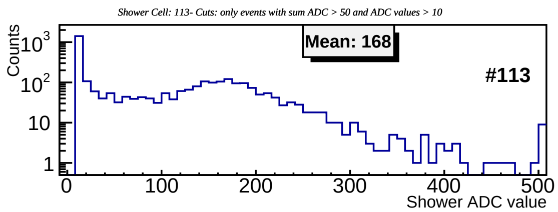

Shower Cell: 109- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 207
#109
Counts
Shower ADC value

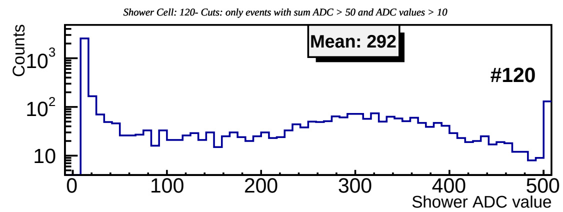

Shower Cell: 110- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 184
#110
Counts
Shower ADC value

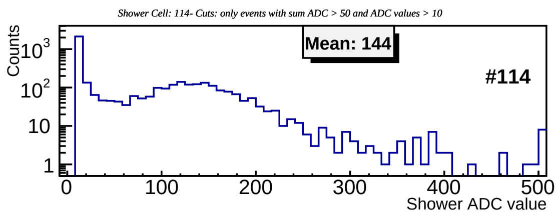

Shower Cell: 111- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 173
#111
Counts
Shower ADC value

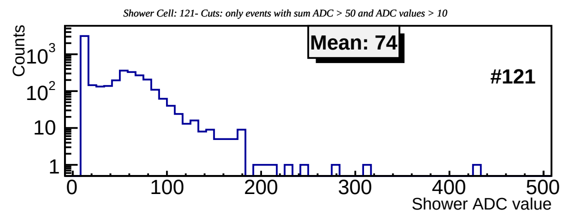

Shower Cell: 112- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 206
#112
Counts
Shower ADC value

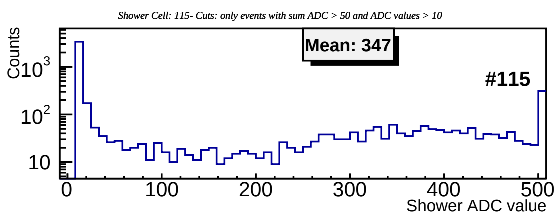

Shower Cell: 119- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 144
#119
Counts
Shower ADC value

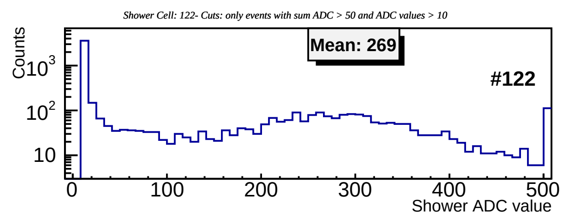

Shower Cell: 113- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 168
#113
Counts
Shower ADC value

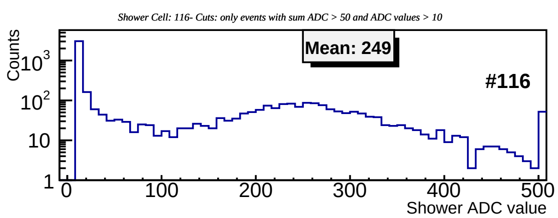

Shower Cell: 120- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 292
#120
Counts
Shower ADC value

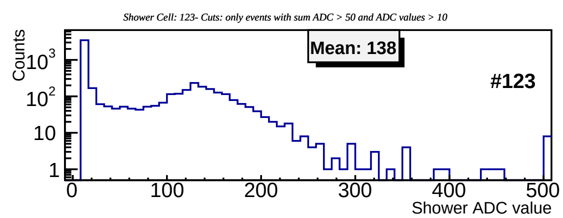

Shower Cell: 114- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 144
#114
Counts
Shower ADC value

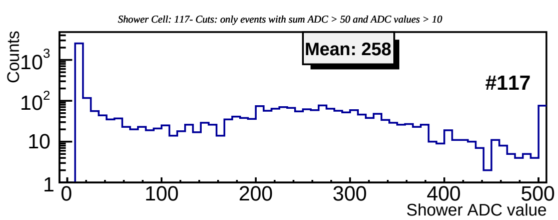

Shower Cell: 121- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 74
#121
Counts
Shower ADC value

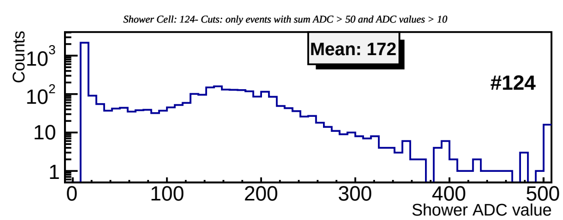

Shower Cell: 115- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 347
#115
Counts
Shower ADC value

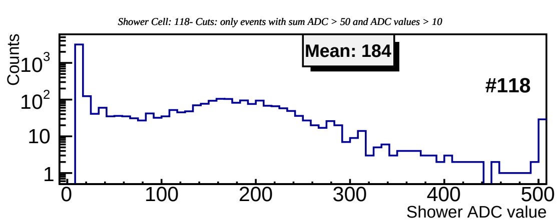

Shower Cell: 122- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 269
#122
Counts
Shower ADC value

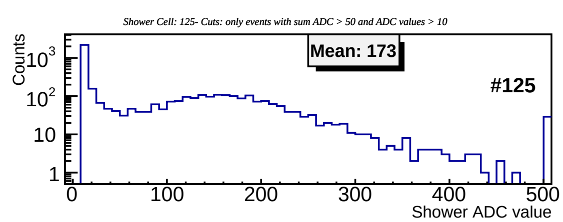

Shower Cell: 116- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 249
#116
Counts
Shower ADC value

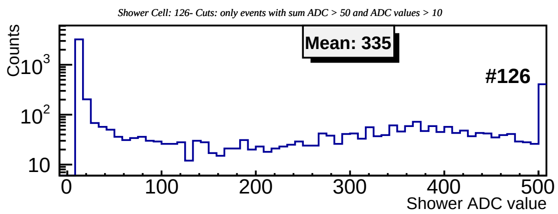

Shower Cell: 123- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 138
#123
Counts
Shower ADC value

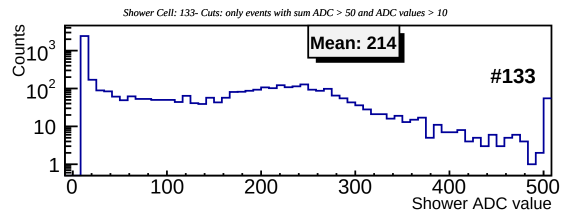

Shower Cell: 117- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 258
#117
Counts
Shower ADC value

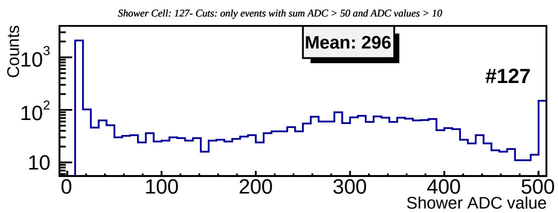

Shower Cell: 124- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 172
#124
Counts
Shower ADC value

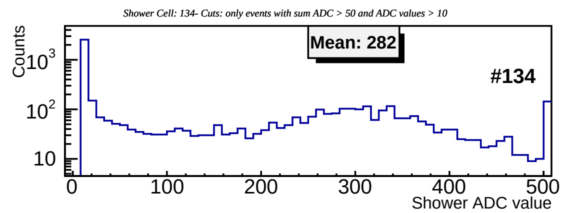

Shower Cell: 118- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 184
#118
Counts
Shower ADC value

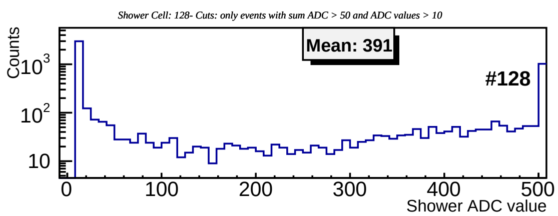

Shower Cell: 125- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 173
#125
Counts
Shower ADC value

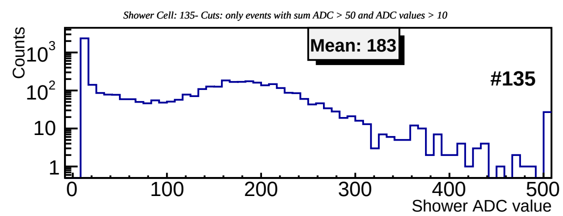

Shower Cell: 126- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 335
#126
Counts
Shower ADC value

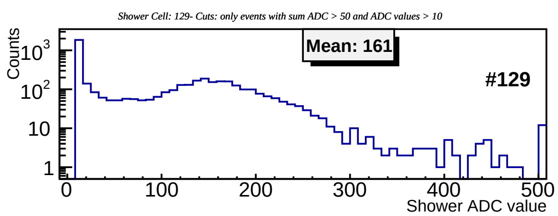

Shower Cell: 133- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 214
#133
Counts
Shower ADC value

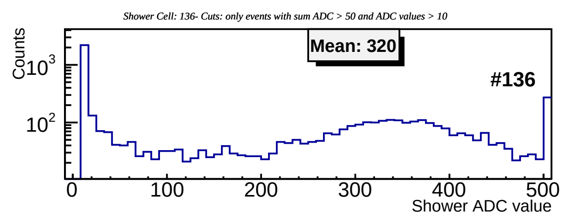

Shower Cell: 127- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 296
#127
Counts
Shower ADC value

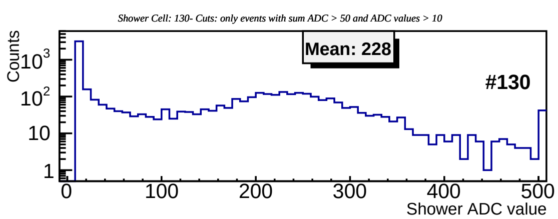

Shower Cell: 134- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 282
#134
Counts
Shower ADC value

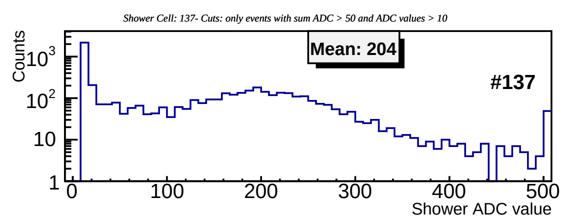

Shower Cell: 128- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 391
#128
Counts
Shower ADC value

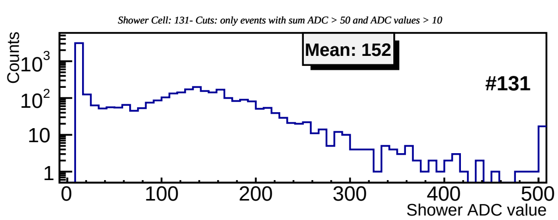

Shower Cell: 135- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 183
#135
Counts
Shower ADC value

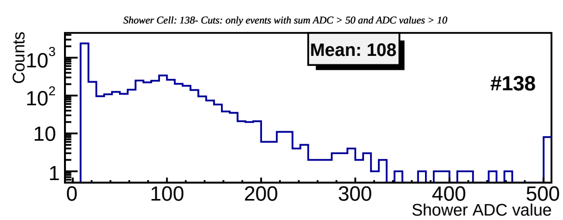

Shower Cell: 129- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 161
#129
Counts
Shower ADC value

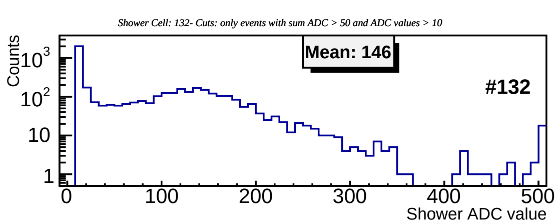

Shower Cell: 136- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 320
#136
Counts
Shower ADC value

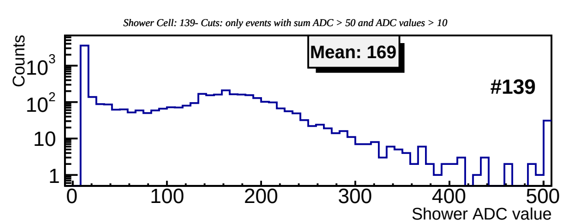

Shower Cell: 130- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 228
#130
Counts
Shower ADC value

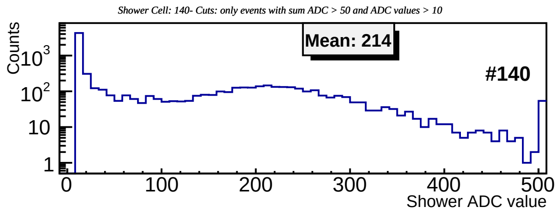

Shower Cell: 137- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 204
#137
Counts
Shower ADC value

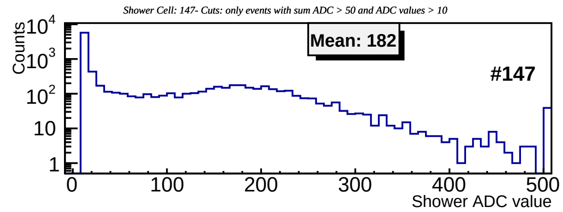

Shower Cell: 131- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 152
#131
Counts
Shower ADC value

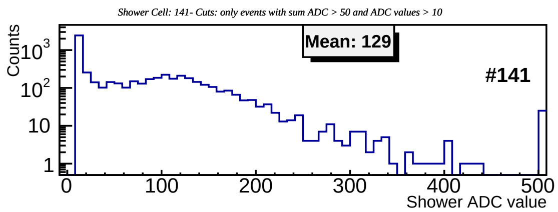

Shower Cell: 138- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 108
#138
Counts
Shower ADC value

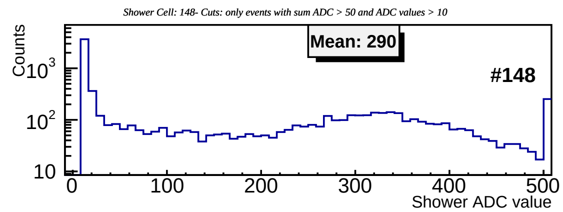

Shower Cell: 132- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 146
#132
Counts
Shower ADC value

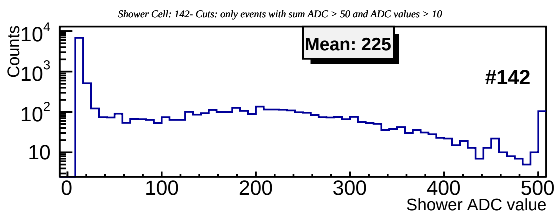

Shower Cell: 139- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 169
#139
Counts
Shower ADC value

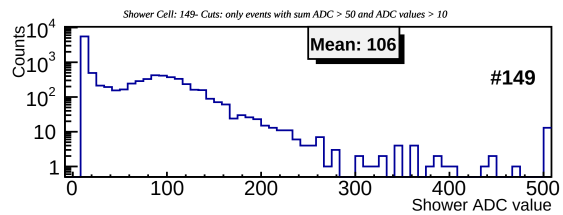

Shower Cell: 140- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 214
#140
Counts
Shower ADC value

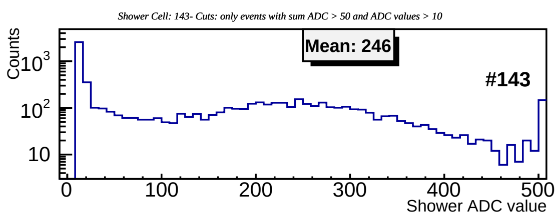

Shower Cell: 147- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 182
#147
Counts
Shower ADC value

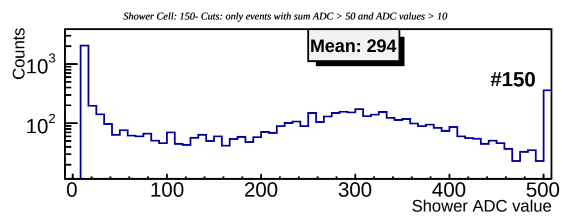

Shower Cell: 141- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 129
#141
Counts
Shower ADC value

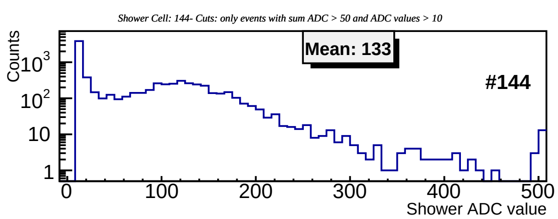

Shower Cell: 148- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 290
#148
Counts
Shower ADC value

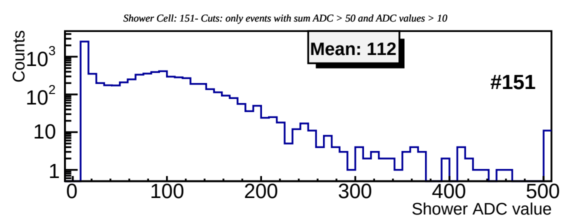

Shower Cell: 142- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 225
#142
Counts
Shower ADC value

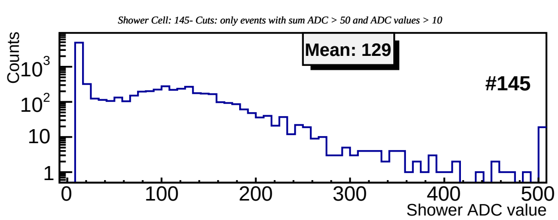

Shower Cell: 149- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 106
#149
Counts
Shower ADC value

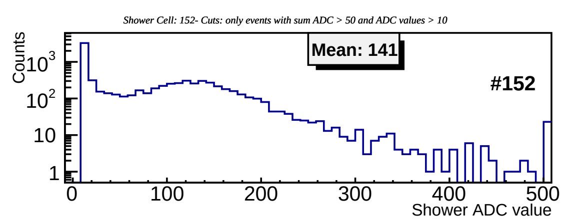

Shower Cell: 143- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 246
#143
Counts
Shower ADC value

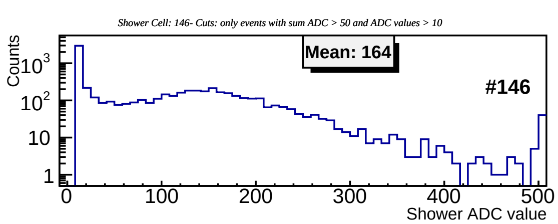

Shower Cell: 150- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 294
#150
Counts
Shower ADC value

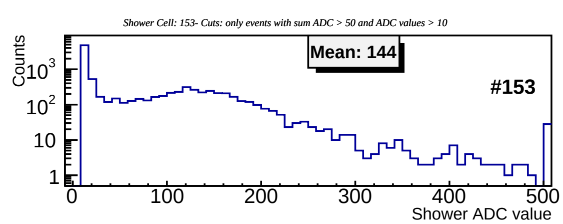

Shower Cell: 144- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 133
#144
Counts
Shower ADC value

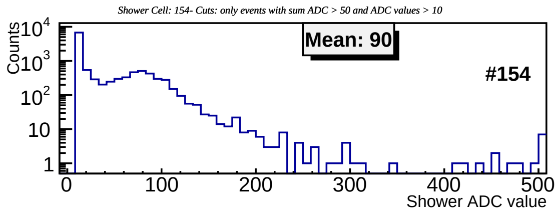

Shower Cell: 151- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 112
#151
Counts
Shower ADC value

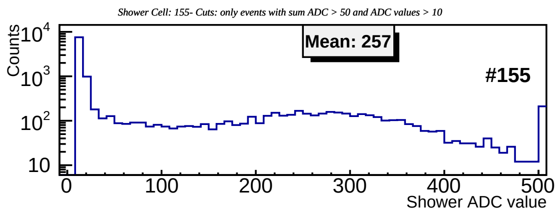

Shower Cell: 145- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 129
#145
Counts
Shower ADC value

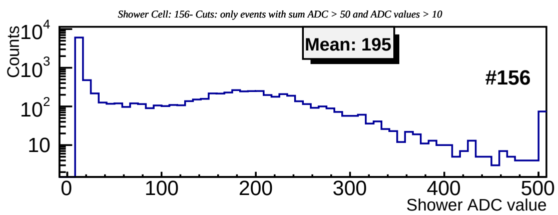

Shower Cell: 152- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 141
#152
Counts
Shower ADC value

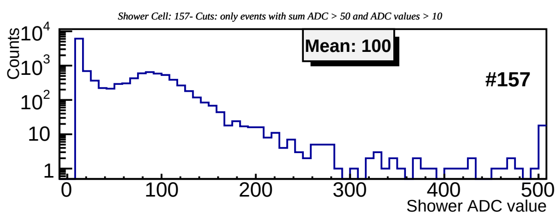

Shower Cell: 146- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 164
#146
Counts
Shower ADC value

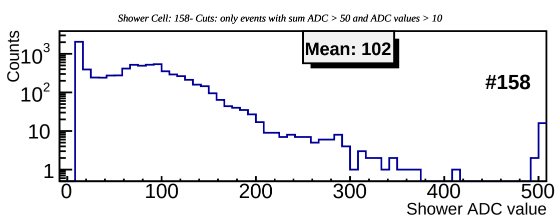

Shower Cell: 153- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 144
#153
Counts
Shower ADC value

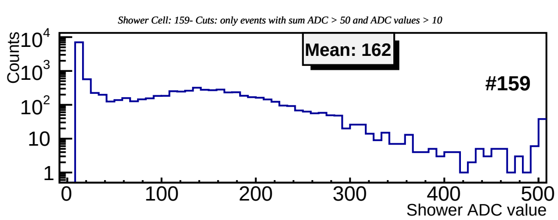

Shower Cell: 154- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 90
#154
Counts
Shower ADC value

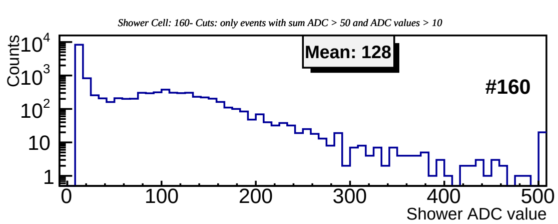

Shower Cell: 155- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 257
#155
Counts
Shower ADC value

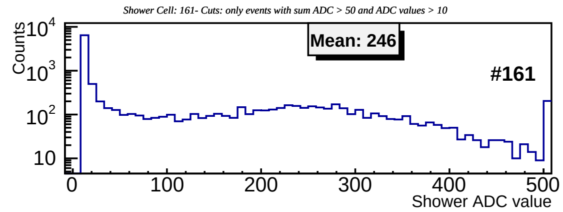

Shower Cell: 156- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 195
#156
Counts
Shower ADC value

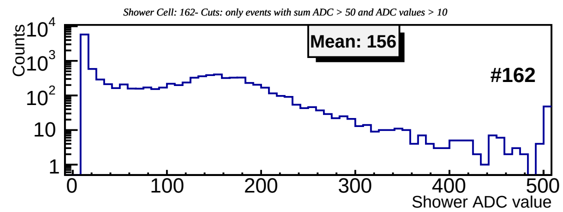

Shower Cell: 157- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 100
#157
Counts
Shower ADC value

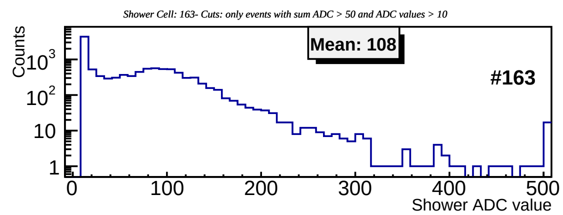

Shower Cell: 158- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 102
#158
Counts
Shower ADC value

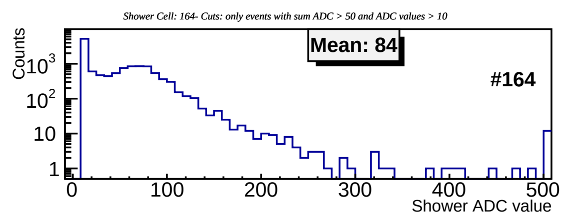

Shower Cell: 159- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 162
#159
Counts
Shower ADC value

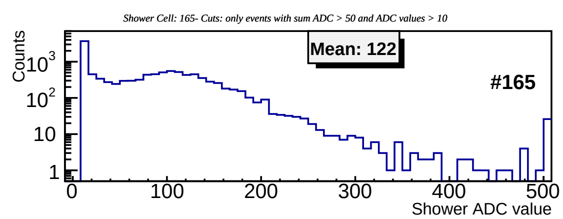

Shower Cell: 160- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 128
#160
Counts
Shower ADC value

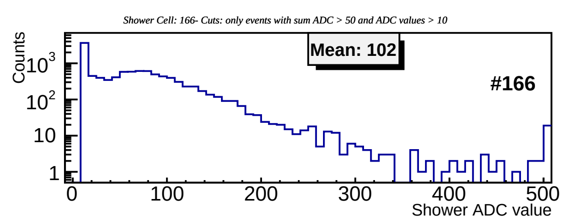

Shower Cell: 161- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 246
#161
Counts
Shower ADC value

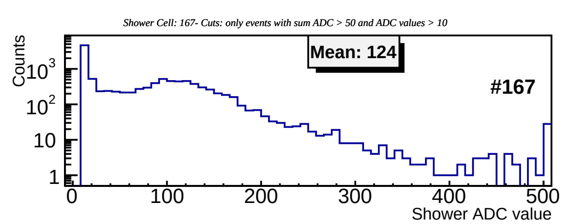

Shower Cell: 162- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 156
#162
Counts
Shower ADC value

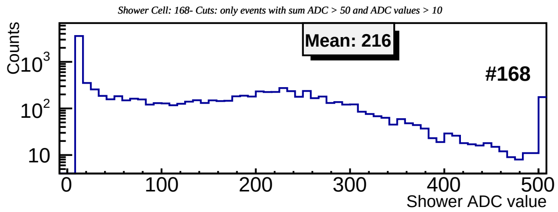

Shower Cell: 163- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 108
#163
Counts
Shower ADC value

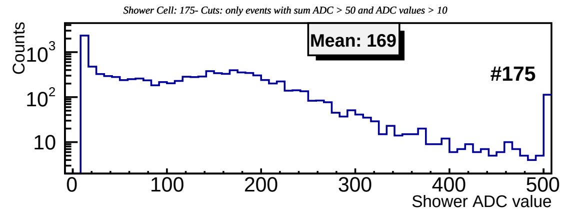

Shower Cell: 164- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 84
#164
Counts
Shower ADC value

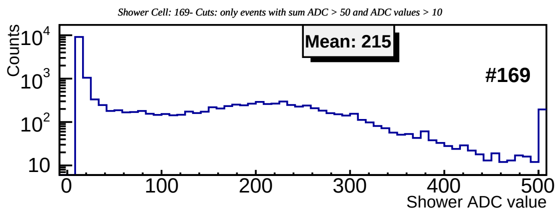

Shower Cell: 165- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 122
#165
Counts
Shower ADC value

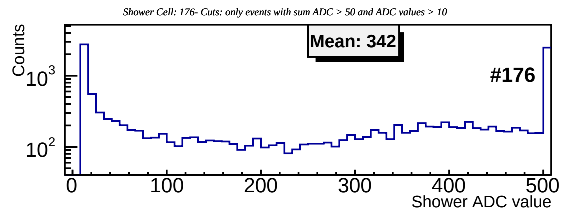

Shower Cell: 166- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 102
#166
Counts
Shower ADC value

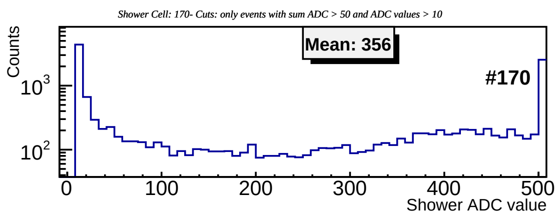

Shower Cell: 167- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 124
#167
Counts
Shower ADC value

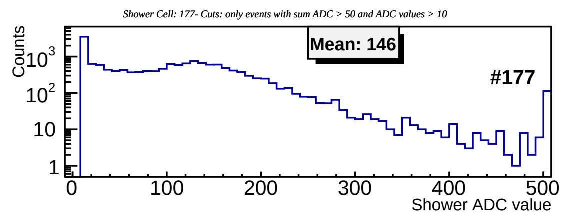

Shower Cell: 168- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 216
#168
Counts
Shower ADC value

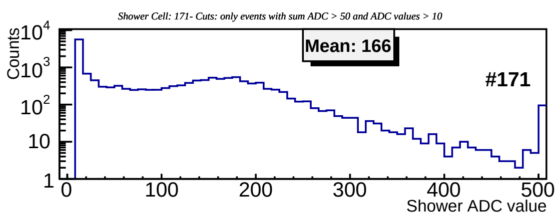

Shower Cell: 175- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 169
#175
Counts
Shower ADC value

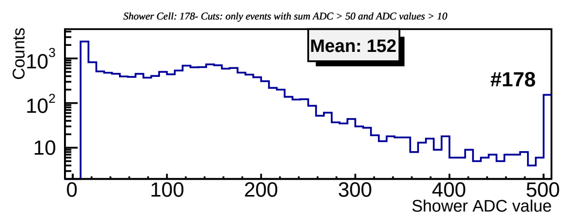

Shower Cell: 169- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 215
#169
Counts
Shower ADC value

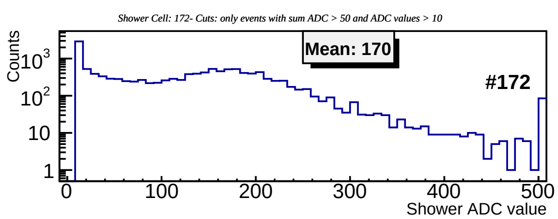

Shower Cell: 176- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 342
#176
Counts
Shower ADC value

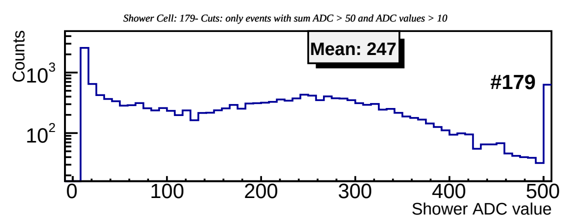

Shower Cell: 170- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 356
#170
Counts
Shower ADC value

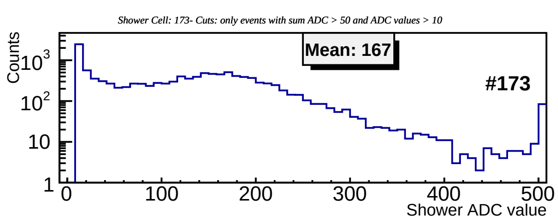

Shower Cell: 177- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 146
#177
Counts
Shower ADC value

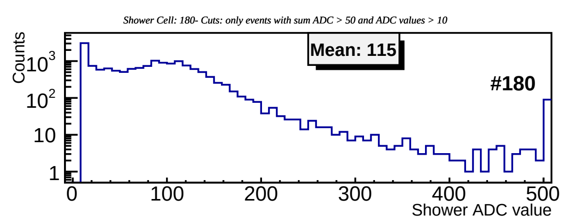

Shower Cell: 171- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 166
#171
Counts
Shower ADC value

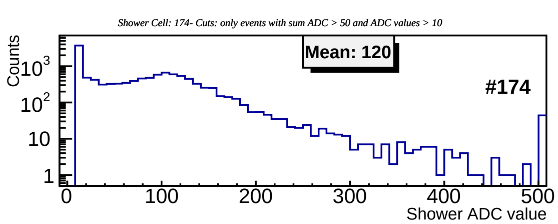

Shower Cell: 178- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 152
#178
Counts
Shower ADC value

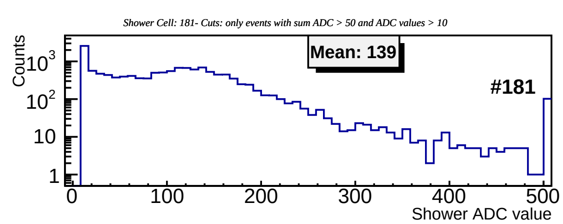

Shower Cell: 172- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 170
#172
Counts
Shower ADC value

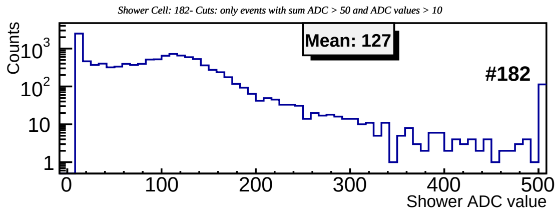

Shower Cell: 179- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 247
#179
Counts
Shower ADC value

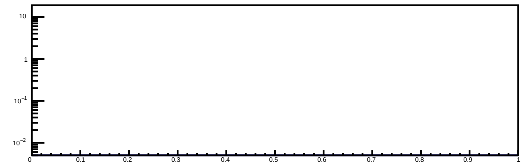

Shower Cell: 173- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 167
#173
Counts
Shower ADC value

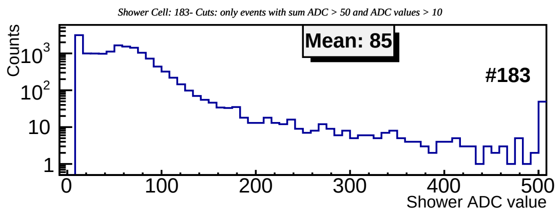

Shower Cell: 180- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 115
#180
Counts
Shower ADC value

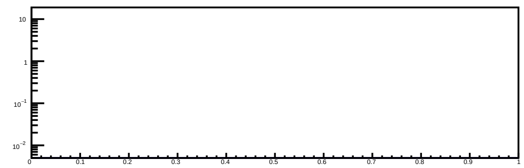

Shower Cell: 174- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 120
#174
Counts
Shower ADC value

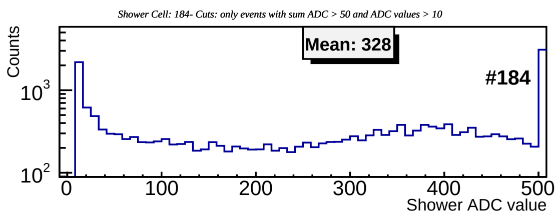

Shower Cell: 181- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 139
#181
Counts
Shower ADC value

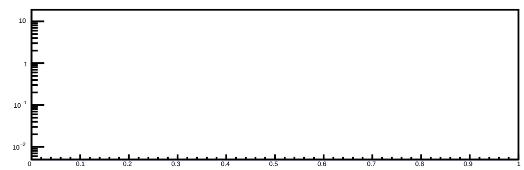

Shower Cell: 182- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 127
#182
Counts
Shower ADC value

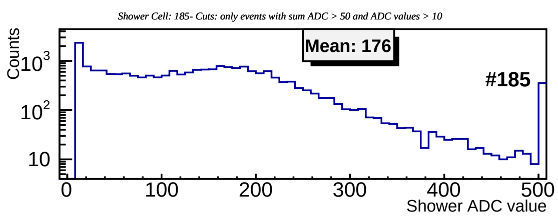


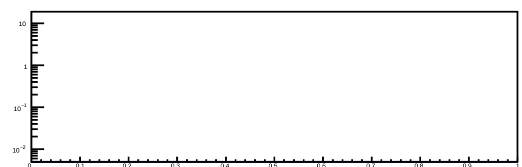

Shower Cell: 183- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 85
#183
Counts
Shower ADC value

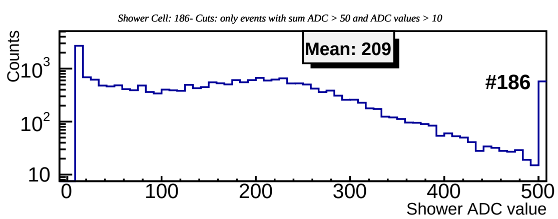


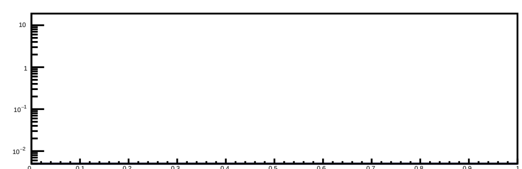

Shower Cell: 184- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 328
#184
Counts
Shower ADC value

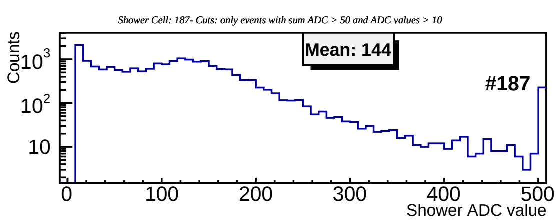


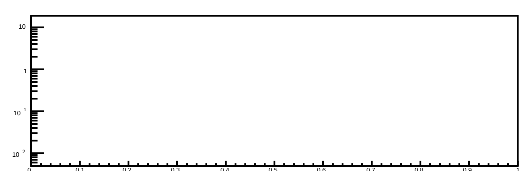

Shower Cell: 185- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 176
#185
Counts
Shower ADC value

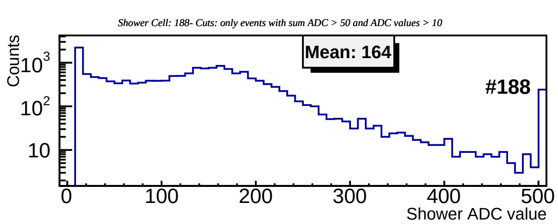


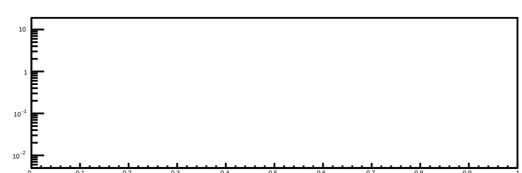

Shower Cell: 186- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 209
#186
Counts
Shower ADC value

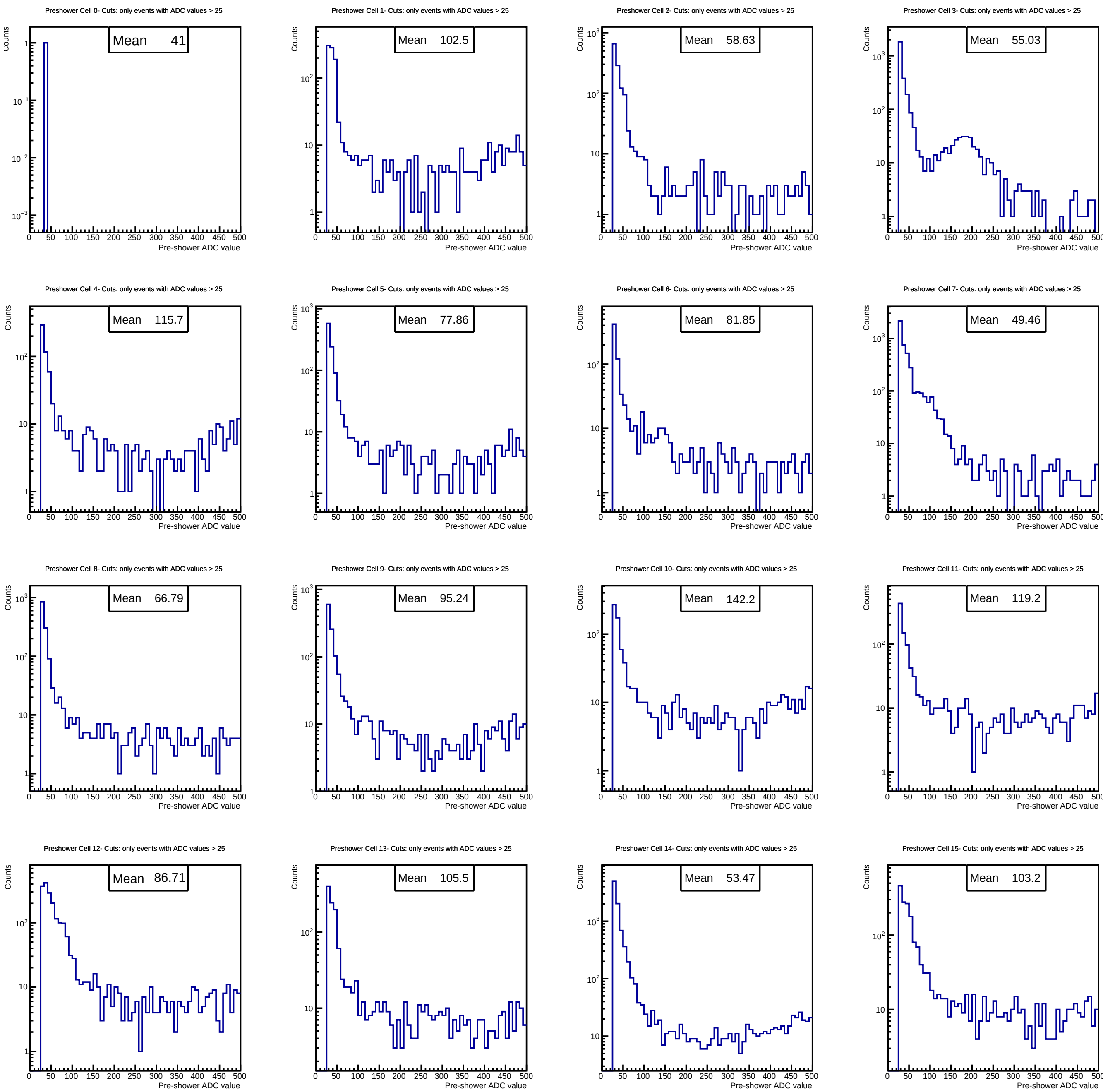


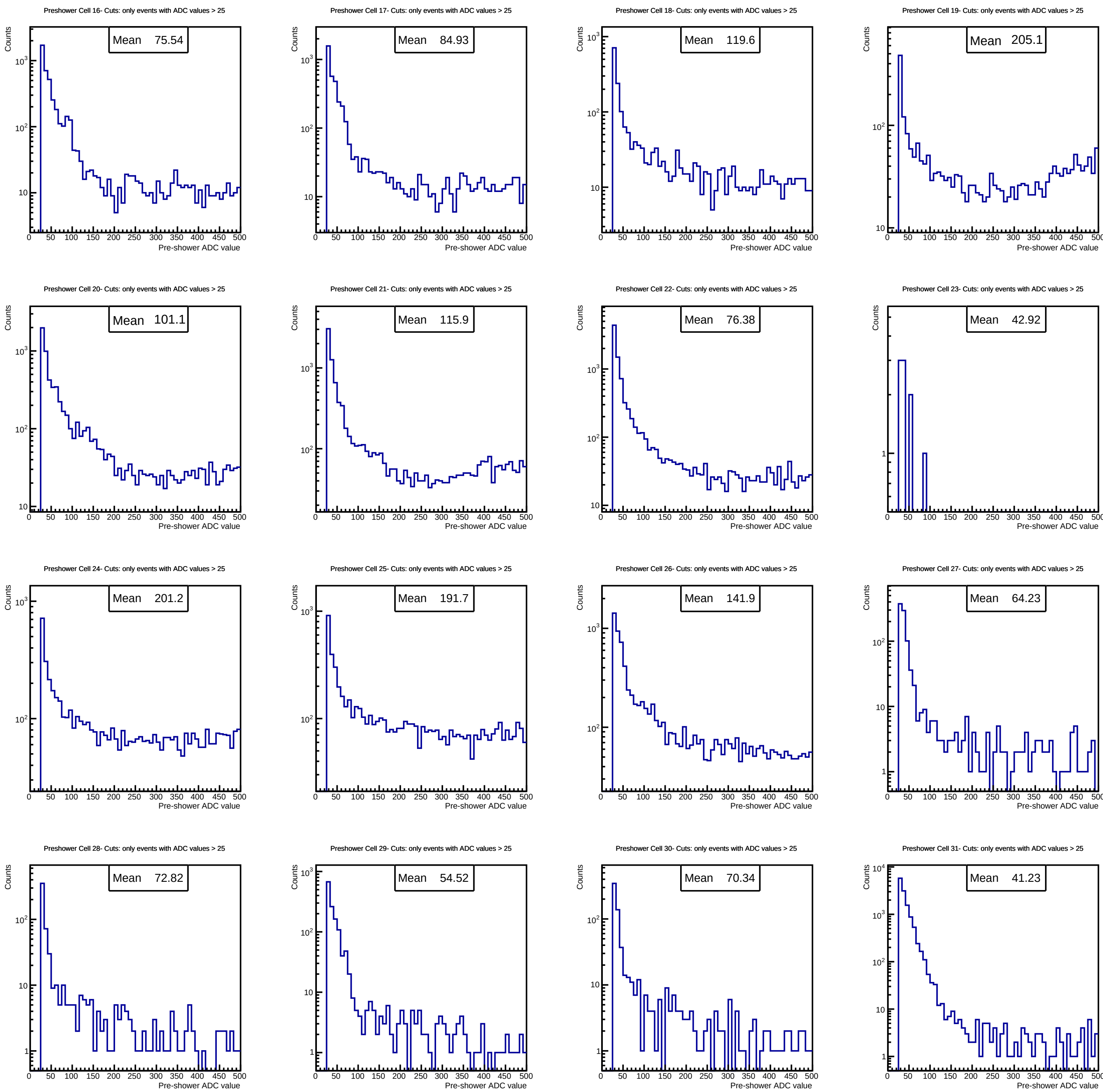

Shower Cell: 187- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 144
#187
Counts
Shower ADC value

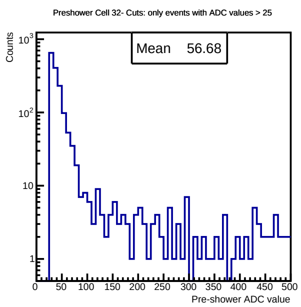


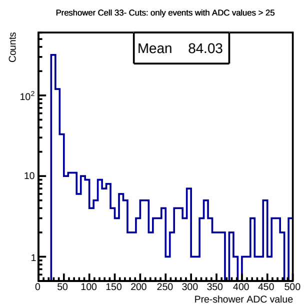

Shower Cell: 188- Cuts: only events with sum ADC > 50 and ADC values > 10
Mean: 164
#188
Counts
Shower ADC value

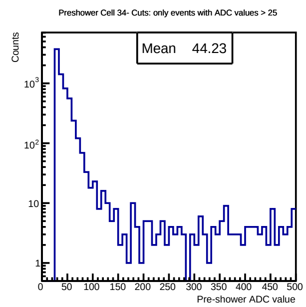


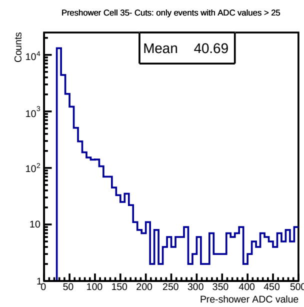

Preshower Cell 0- Cuts: only events with ADC values > 25
Mean 41
Preshower Cell 1- Cuts: only events with ADC values > 25
Mean 102.5
Preshower Cell 2- Cuts: only events with ADC values > 25
Mean 58.63
Preshower Cell 3- Cuts: only events with ADC values > 25
Mean 55.03
Preshower Cell 4- Cuts: only events with ADC values > 25
Mean 115.7
Preshower Cell 5- Cuts: only events with ADC values > 25
Mean 77.86
Preshower Cell 6- Cuts: only events with ADC values > 25
Mean 81.85
Preshower Cell 7- Cuts: only events with ADC values > 25
Mean 49.46
Preshower Cell 8- Cuts: only events with ADC values > 25
Mean 66.79
Preshower Cell 9- Cuts: only events with ADC values > 25
Mean 95.24
Preshower Cell 10- Cuts: only events with ADC values > 25
Mean 142.2
Preshower Cell 11- Cuts: only events with ADC values > 25
Mean 119.2
Preshower Cell 12- Cuts: only events with ADC values > 25
Mean 86.71
Preshower Cell 13- Cuts: only events with ADC values > 25
Mean 105.5
Preshower Cell 14- Cuts: only events with ADC values > 25
Mean 53.47
Preshower Cell 15- Cuts: only events with ADC values > 25
Mean 103.2
Counts
Pre-shower ADC value

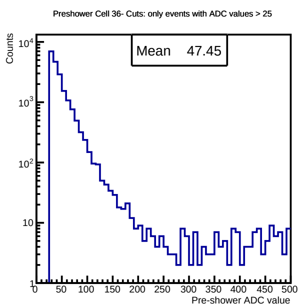

Preshower Cell 16- Cuts: only events with ADC values > 25
Mean 75.54
Preshower Cell 17- Cuts: only events with ADC values > 25
Mean 84.93
Preshower Cell 18- Cuts: only events with ADC values > 25
Mean 119.6
Preshower Cell 19- Cuts: only events with ADC values > 25
Mean 205.1
Preshower Cell 20- Cuts: only events with ADC values > 25
Mean 101.1
Preshower Cell 21- Cuts: only events with ADC values > 25
Mean 115.9
Preshower Cell 22- Cuts: only events with ADC values > 25
Mean 76.38
Preshower Cell 23- Cuts: only events with ADC values > 25
Mean 42.92
Preshower Cell 24- Cuts: only events with ADC values > 25
Mean 201.2
Preshower Cell 25- Cuts: only events with ADC values > 25
Mean 191.7
Preshower Cell 26- Cuts: only events with ADC values > 25
Mean 141.9
Preshower Cell 27- Cuts: only events with ADC values > 25
Mean 64.23
Preshower Cell 28- Cuts: only events with ADC values > 25
Mean 72.82
Preshower Cell 29- Cuts: only events with ADC values > 25
Mean 54.52
Preshower Cell 30- Cuts: only events with ADC values > 25
Mean 70.34
Preshower Cell 31- Cuts: only events with ADC values > 25
Mean 41.23
Counts
Pre-shower ADC value

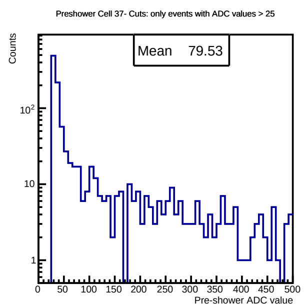

Preshower Cell 32- Cuts: only events with ADC values > 25
Mean 56.68
Counts
Pre-shower ADC value

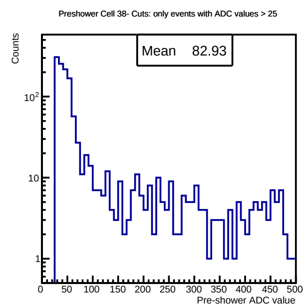

Preshower Cell 33- Cuts: only events with ADC values > 25
Mean 84.03
Counts
Pre-shower ADC value

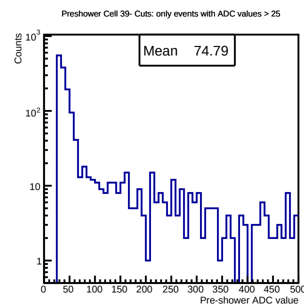

Preshower Cell 34- Cuts: only events with ADC values > 25
Mean 44.23
Counts
Pre-shower ADC value

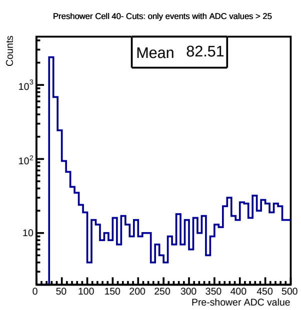

Preshower Cell 35- Cuts: only events with ADC values > 25
Mean 40.69
Counts
Pre-shower ADC value

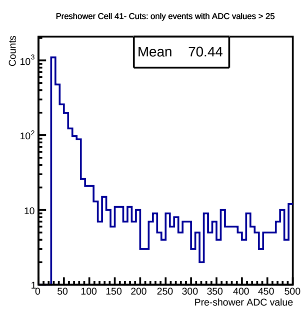

Preshower Cell 36- Cuts: only events with ADC values > 25
Mean 47.45
Counts
Pre-shower ADC value

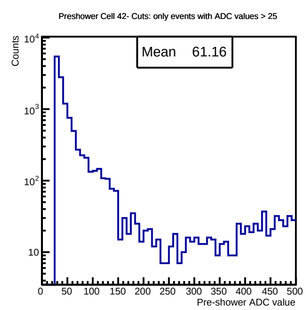

Preshower Cell 37- Cuts: only events with ADC values > 25
Mean 79.53
Counts
Pre-shower ADC value

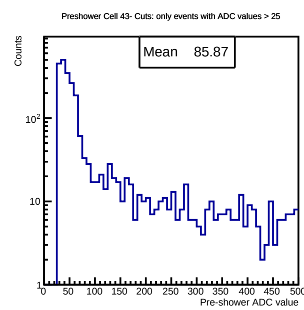

Preshower Cell 38- Cuts: only events with ADC values > 25
Mean 82.93
Counts
Pre-shower ADC value

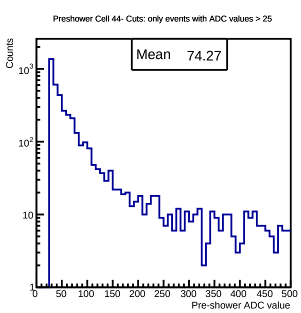

Preshower Cell 39- Cuts: only events with ADC values > 25
Mean 74.79
Counts
Pre-shower ADC value

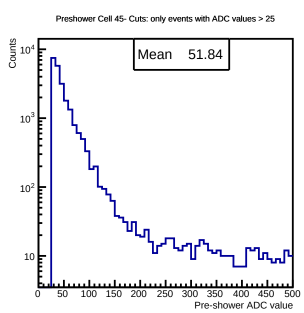

Preshower Cell 40- Cuts: only events with ADC values > 25
Mean 82.51
Counts
Pre-shower ADC value

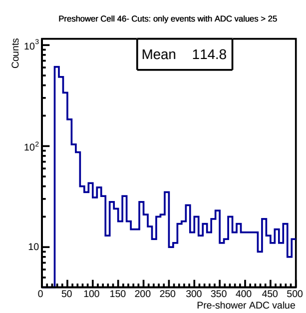

Preshower Cell 41- Cuts: only events with ADC values > 25
Mean 70.44
Counts
Pre-shower ADC value

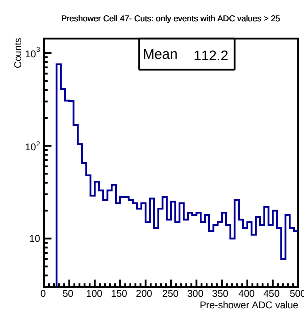

Preshower Cell 42- Cuts: only events with ADC values > 25
Mean 61.16
Counts
Pre-shower ADC value

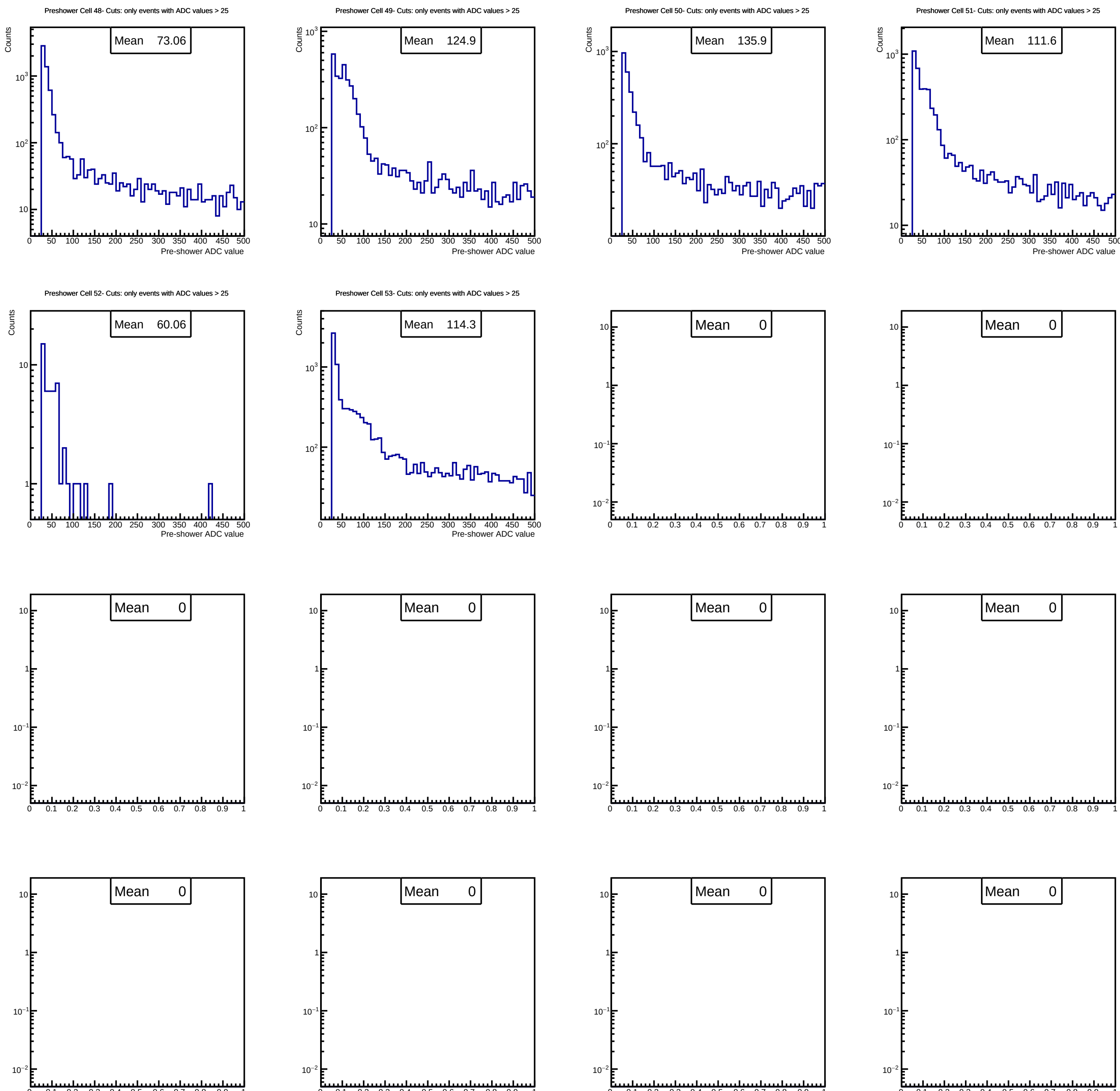

Preshower Cell 43- Cuts: only events with ADC values > 25
Mean 85.87
Counts
Pre-shower ADC value


Preshower Cell 44- Cuts: only events with ADC values > 25
Mean 74.27
Counts
Pre-shower ADC value


Preshower Cell 45- Cuts: only events with ADC values > 25
Mean 51.84
Counts
Pre-shower ADC value


Preshower Cell 46- Cuts: only events with ADC values > 25
Mean 114.8
Counts
Pre-shower ADC value


Preshower Cell 47- Cuts: only events with ADC values > 25
Mean 112.2
Counts
Pre-shower ADC value


Preshower Cell 48- Cuts: only events with ADC values > 25
Mean 73.06
Preshower Cell 49- Cuts: only events with ADC values > 25
Mean 124.9
Preshower Cell 50- Cuts: only events with ADC values > 25
Mean 135.9
Preshower Cell 51- Cuts: only events with ADC values > 25
Mean 111.6
Preshower Cell 52- Cuts: only events with ADC values > 25
Mean 60.06
Preshower Cell 53- Cuts: only events with ADC values > 25
Mean 114.3
Counts
Pre-shower ADC value
Mean 0

Appendix B

ROOT code examples

B.1 The code used to create the Event Display

```
#include "Riostream.h"
#include <TFile.h>
#include <TF1.h>
#include <TH1.h>
#include <TH2.h>
#include <TGraphErrors.h>
#include <TTree.h>
#include <TROOT.h>
#include <TLegend.h>
#include <string>
#include <TCanvas.h>
#include <TStyle.h>

//Display an array, set a minimum value to display.
void Draw(Double_t data[], vector<Double_t>* means, Double_t min, const char*
title, Int_t rows = 27, Int_t cols = 7){

	//Create a 2D histogram to store the data.
	auto display = new TH2I("display",title,cols,0,cols,rows,0,rows);



	//Fill the bins with data.
	for(int i = 0; i < cols; i++){
		for(int j = 0; j < rows; j++){
```

```
                //Only display if value(channel) > min.
                if(data[(j*cols)+i] - means->at((j*cols)+i) > min){

                        //Fill the bins
                        display->SetBinContent(i+1,j+1,(Int_t)(data[i+
                        (j*cols)] - means->at(i+(j*cols))));
                } else {
                        //Else display 0.
                        display->SetBinContent(i+1,j+1,0);
                }
        }
}
display->GetYaxis()->SetNdivisions(rows);
display->GetXaxis()->SetNdivisions(cols);

//Have to completely replace axes to position axis labels where they are
display->GetYaxis()->SetLabelSize(0);
display->GetXaxis()->SetLabelSize(0);

//Let's make a function to set the axis values
TF1 *xfunc = new TF1("xfunc","x",1,cols+1);
TF1 *yfunc = new TF1("yfunc","x",1,rows+1);

//Set colour, box text size and remove the stats box.
display->SetFillColor(kRed-9);
display->SetStats(0);
display->SetMarkerSize(1.2+((7-cols)/1.7));

//Have to make the old axis labels invisible (unable to edit some axis
//properties directly).
display->GetYaxis()->SetLabelSize(0);
display->GetXaxis()->SetLabelSize(0);
display->SetTitleSize(1/cols);

//Display the event.
display->Draw("box,text");
```

```
        //Create completely new axes to get label in the middle of the
        //divisions)
        TGaxis *x = new TGaxis(0,0,cols,0,"xfunc",cols+1,"M");
        x->SetLabelSize(0.25/cols);
        x->SetLabelOffset(0.015*(cols-7));
        x->Draw();

        TGaxis *y = new TGaxis(0,0,0,rows,"yfunc",rows+1,"M");
        y->SetLabelSize(0.25/cols);
        y->Draw();



        //Vertical lines.
        for (int i = 1; i < cols; i++){
                TLine *line = new TLine(i,0,i,rows);
                line->SetLineStyle(kDotted);
                line->Draw();
        }

        //Horizontal lines.
        //Vertical lines.
        for (int i = 1; i < rows; i++){
                TLine *line = new TLine(0,i,cols,i);
                line->SetLineStyle(kDotted);
                line->Draw();
        }

        //Memory clean up.
        //delete gROOT->FindObject("display");
}

void eventDisplay(){

        //Get the mean and RMS values.
        vector<Double_t>* rmsValues;
```

```
vector<Double_t>* meanValues;

vector<Double_t>* rmsValuesPS;

vector<Double_t>* meanValuesPS;

TFile *calibration = TFile::Open("pedestalcalibrated.root");

meanValues = (vector<Double_t>*)calibration->Get("Mean");

rmsValues = (vector<Double_t>*)calibration->Get("RMS");

meanValuesPS = (vector<Double_t>*)calibration->Get("MeanPS");

rmsValuesPS = (vector<Double_t>*)calibration->Get("RMSPS");

calibration->Close();


//Create a Canvas

auto c1 = new TCanvas("c1","Event␣Display",500,1200);

TPad *shower = new TPad("shower","Shower",0.01,0.01,0.7,0.99);

shower->Draw();

TPad *preshower = new TPad("preshower","Pre-Shower",.8,.01,.99,.99);

preshower->SetLeftMargin(0.15);

preshower->Draw();


//Open the file.

TFile *events = TFile::Open("bbcal_179.root");


//Get the Tree.

TTree* tree = 0;

events->GetObject("T",tree);


//Set the variable to hold the values.

Double_t data[189];

Double_t dataPS[54];

tree->SetBranchAddress("bb.sh.a_p",&data);

tree->SetBranchAddress("bb.ps.a_p",&dataPS);


//Get the number of events.

Int_t nEvents =(Int_t) tree->GetEntries();


Int_t event = 0;

Int_t cell = 0;
```

```
        for(Int_t event = 0; event < nEvents; event++){

                //Clear the data array
//              for(int i = 0; i < 189;i++){
//                      data[i] = 0.0;
//                      if(i < 54){
//                              dataPS[i] = 0;
//                      }
//              }
                //Read in that data.
                tree->GetEntry(event);

                //Get the total calibrated ADC value
                Double_t sum = 0;
                for(int i = 0; i < 189; i++){
                        sum += data[i]-meanValues->at(i);
                }

                //Don't display events with a total ADC value < 50
                if(sum < 50){
                        continue;
                }

                //Create the histogram to draw this event.
                std::string title = "Event␣";
                title += std::to_string(event);

                //Display the event
                //c1->cd(1);
                shower->cd();
                Draw(data,meanValues, 10, title.c_str(),27,7);
                //c1->cd(2);
                preshower->cd();
                Draw(dataPS,meanValuesPS, 10, "" ,27,2);
                gPad -> WaitPrimitive();
```

```
                //Memory clean up
                delete gROOT->FindObject("display");
        }
}
```

B.2 The Code used for Pedestal Identification and Subtraction

```
#include "Riostream.h"
#include <TFile.h>
#include <TF1.h>
#include <TH1.h>
#include <TH2.h>
#include <TGraphErrors.h>
#include <TTree.h>
#include <TROOT.h>
#include <TLegend.h>
#include <string>
#include <array>
#include <vector>

void CalibratePedestal(const char* filename = "bbcal_179.root"){
        //const Int_t entrySize = rows * cols;
        //Open the file.
        TFile *events = TFile::Open(filename);

        //Get the Tree.
        TTree* tree = 0;
        events->GetObject("T",tree);

        //Set the variable to hold the values.
        Double_t data[189];
        tree->SetBranchAddress("bb.sh.a_p",&data);
```

```
//Get the number of events.
Int_t nEvents =(Int_t) tree->GetEntries();

//c1->SetLogy();
vector<Double_t> rmsValues;
vector<Double_t> meanValues;

for(Int_t cell = 0; cell < 189; cell++){
        //Zoom out
        auto outDisplay = new TH1D("outDisplay","Cell",600,-1000,5000);

        //Put in the values here.
        vector<Double_t> values;

        //Read in data
        for(int event = 0; event < nEvents; event++){
                //Read in that data.
                tree->GetEntry(event);
                //Fill the bins with content.
                values.push_back(data[cell]);
                event++;
        }

        //Put data on the zoomed-out histogram.
        for(int event = 0; event < values.size(); event++){
                outDisplay->Fill(values[event]);
        }

        //Find max so we know where to zoom in.
        auto zoomBin = outDisplay->GetMaximumBin();
        auto zoomMaxLow = outDisplay->GetBinLowEdge(zoomBin-1);
        auto zoomMaxHigh = outDisplay->GetBinLowEdge(zoomBin+1)
                + outDisplay->GetBinWidth(zoomBin);

        //Zoom in.
```

```
        auto inDisplay = new TH1D("inDisplay","Cell",30,zoomMaxLow,zoomMaxHigh);

        delete gROOT->FindObject("outDisplay");

        //Fill in this histogram.
        for(int event = 0; event < values.size(); event++){
                inDisplay->Fill(values.at(event));
        }

        //Get the sum of all values within the histogram
        Double_t sum = 0;
        Double_t squareSum = 0;
        Double_t entries = 0;
        for(int i = 1; i < 30; i++){
                entries+=inDisplay->GetBinContent(i);
                Double_t area = inDisplay->GetBinCenter(i)*inDisplay->
                        GetBinContent(i);
                sum += area;
        }

        //Calculate the mean of the histogram
        meanValues.push_back(sum/entries);

        //Calculate the RMS of the histogram
        for(int i = 1; i < 30; i++){
                squareSum+=pow(inDisplay->GetBinCenter(i)-
                        meanValues[cell],2)*inDisplay->GetBinContent(i);
        }
        rmsValues.push_back(sqrt(squareSum/entries));

        //Memory Clean up
        delete gROOT->FindObject("inDisplay");
}

//Do the same for the pre-shower.
//Set the variable to hold the values.
```

```
Double_t data1[54];
tree->SetBranchAddress("bb.ps.a_p",&data1);
vector<Double_t> rmsValues1;
vector<Double_t> meanValues1;

for(Int_t cell = 0; cell < 54; cell++){
        //Zoom out
        auto outDisplay = new TH1D("outDisplay","Cell",600,-1000,5000);

        //Put in the values here.
        vector<Double_t> values;

        //Read in data
        for(int event = 0; event < nEvents; event++){
                //Read in that data.
                tree->GetEntry(event);
                //Fill the bins with content.
                values.push_back(data1[cell]);
                event++;
        }

        //Put data on the zoomed-out histogram.
        for(int event = 0; event < values.size(); event++){
                outDisplay->Fill(values[event]);
        }

        //Find max so we know where to zoom in.
        auto zoomBin = outDisplay->GetMaximumBin();
        auto zoomMaxLow = outDisplay->GetBinLowEdge(zoomBin-1);
        auto zoomMaxHigh = outDisplay->GetBinLowEdge(zoomBin+1) +
        outDisplay->GetBinWidth(zoomBin);

        //Zoom in.
        auto inDisplay = new TH1D("inDisplay","Cell",30,zoomMaxLow,
                zoomMaxHigh);
```

```
        delete gROOT->FindObject("outDisplay");

        //Fill in this histogram.
        for(int event = 0; event < values.size(); event++){
                inDisplay->Fill(values.at(event));
        }

        //Get the sum of all values within the histogram
        Double_t sum = 0;
        Double_t squareSum = 0;
        Double_t entries = 0;
        for(int i = 1; i < 30; i++){
                entries+=inDisplay->GetBinContent(i);
                Double_t area = inDisplay->GetBinCenter(i)*inDisplay->
                        GetBinContent(i);
                sum += area;
        }

        //Calculate the mean of the histogram
        meanValues1.push_back(sum/entries);

        //Calculate the RMS of the histogram
        for(int i = 1; i < 30; i++){
                squareSum+=pow(inDisplay->GetBinCenter(i)-
                        meanValues1[cell],2)*inDisplay->
                        GetBinContent(i);
        }
        rmsValues1.push_back(sqrt(squareSum/entries));

        //Memory Clean up
        delete gROOT->FindObject("inDisplay");
}

//Write this to a file.
TFile outputFile ("pedestalcalibrated.root","RECREATE");
outputFile.WriteObjectAny(&meanValues,
```

```
        "std::vector<Double_t>", "Mean");
    outputFile.WriteObjectAny(&rmsValues, "std::vector<Double_t>", "RMS");
    outputFile.WriteObjectAny(&meanValues1,
        "std::vector<Double_t>", "MeanPS");
    outputFile.WriteObjectAny(&rmsValues1,
        "std::vector<Double_t>", "RMSPS");
    outputFile.Close();
}
```

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