

F-CAL LUXE

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Contents

1 Introduction

Particle physics has been studied for a long time and many of the known models today describe the behaviors of systems under no external fields, or weak fields which can be modeled by using perturbation theory and linear approximation. In LUXE, we study Quantum Electro Dynamics(QED) under strong external fields, where the behavior becomes non-perturbative. In this regime we investigate some special phenomena.

One main goal of the LUXE experiment is to study the **nonlinear Compton (NLC) process** where an electron or positron absorbs n optical photons, γ_L , from laser background and converts them into a single, high-energy gamma photon.



Another target of the LUXE experiment is the **nonlinear Breit-Wheeler process** where high energy photons produces an electron-positron pair.



To study this realm, we will experiment with high energy electron beam and high voltage lasers, the experiment system is built in collaboration with DESY where the electron accelerator is based.

2 Experiment System

A key operation for the experiment will be to capture the positrons created in the Breit-Wheeler process and determine their energies. To obtain this, we will use a sensor composed of layers of silicone semi conductors and Tungsten (W_{74}). The silicone is divided to channels connected to external voltage. When high energy charged particles interact with the silicone it causes an ionization and an electrical charge transmittance. By converting this charge into digital signal, we can learn the trajectory of a particle in the sensor by seeing which channels were creating the signal. The Tungsten, being a heavier material, is used in order to reduce the particles energy, as particles interact with it, they undergo an electromagnetic shower, in which they break down into more particles with lower momentum. The width of each tungsten layer is 3.3 mm which results with the highest probability of the particle to create only two more particles. In our sensor we will have multiple such structures of silicone and Tungsten layers, which are referred to as **Towers**. The towers will be placed next to each other in order to cover the surface area needed to capture the positrons.

3 Gap Between Towers

Between every two towers is a distance of

Ben: check dist between towers

where we have a "blind spot" in the sensor. The goal of this section is to present how this blind spots affect the accuracy of the sensor.

4 Zero Suppressed Data (ZS)

4.1 Run 1101, Zero Suppressed (Off the Gap)

Ben: Check why there are readings on the first row of the left tower

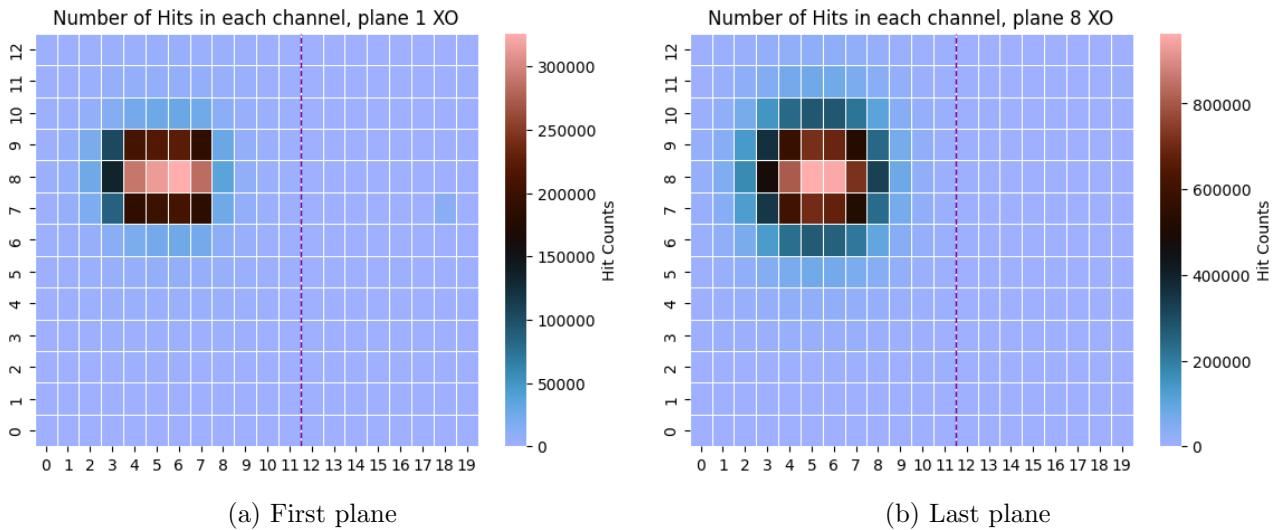


Figure 1: Run 1101. Number of hits for each channel in planes 0 (first) and 7 (last). Here we see the area where the electron beam was pointed to on the sensor, as well as the deviation from it. the difference between (a) and (b) shows the growth of particle number over the planes and also the growth of the surface area of the hits. both can be explained by the electro magnetic shower of the high energy electron in the tungsten

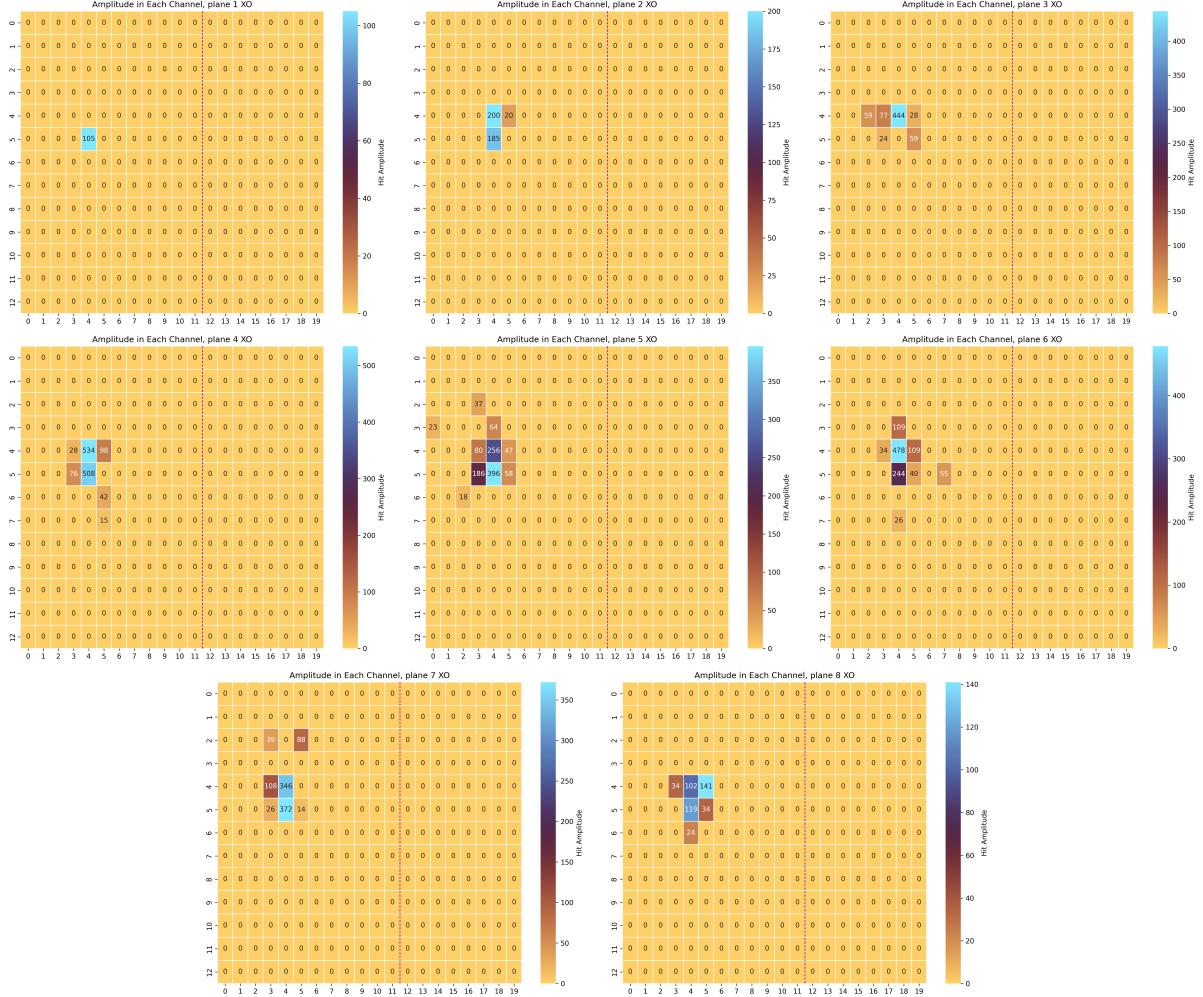


Figure 2: Run 1101. Shower of a single event, Run 1101, TLU 54106. Here each cell in the color map represents a channel in the layer of the sensor, and the presented numbers are the amplitude measured in the channel. The red dotted line marks the gap between the two towers, meaning that the right tower ends at the 11 column and the left starts at the 12 column. We see here a single electron hitting the zero plane, then it goes through the tungsten before hitting the first plane which reads 3 hits. The number of hits increases until plane 4 in this case and then starts to reduce, do to the loss of energy of the particles.

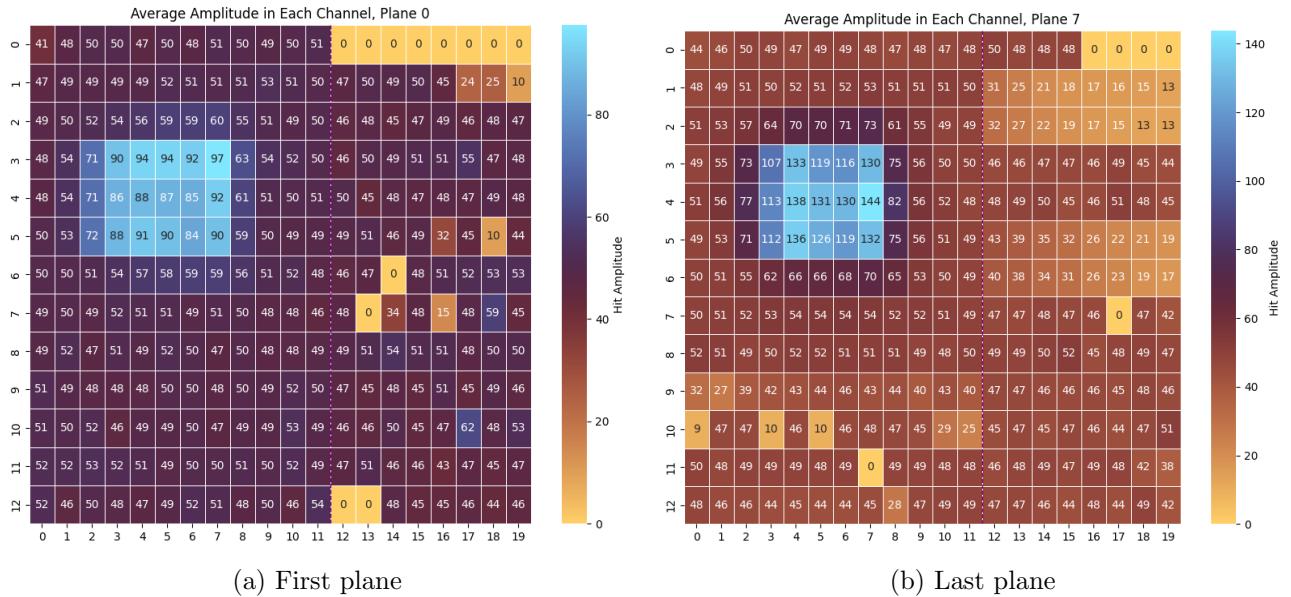


Figure 3: Run 1101. Average amplitude in each channel, planes 0 (first) and 7 (last). The average was taken by the total amplitude of each channel, divided by the total amount of hits in the channel, for the specific plane. One can notice that for the channels at the area of the electron beam, the amplitudes at plane 7 are bigger than in plane 0, while on the channels located further, there is no significant change in the reading. It is important to state that there is a tungsten layer before the first silicone layer (plane 0) and this may cause the scattering of electrons to reach the channels further from the electron beam area. However, most of the electrons that reached this far lose more energy, and in average will stamp a lower amplitude than the ones in the beam area.

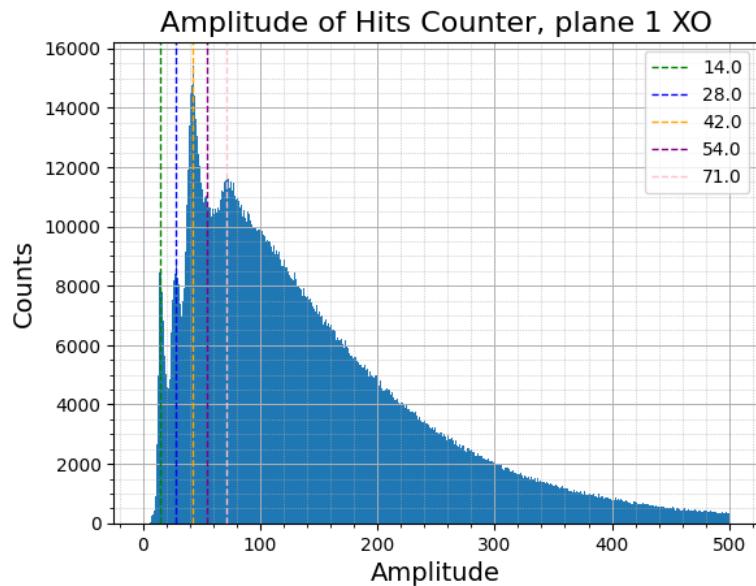


Figure 4: run 1101. Histogram of the amplitudes written in the first plane. the lines shows the peaks of the histogram

The reason for the peaks in fig (??) can be explained by the Minimum Ionizing particle (MIP), where particles of high energy will cause a minimum amount of energy loss when passing through the silicone. The amount of lost energy in such case will be translated to a digital signal with amplitude of around 15 ADC. Since the electrons also undergo a shower in tungsten before reaching the first plane, the most probable outcomes are of either 1 particle leaving 1 MIP - around 15 amp or after multiplying in the shower we will have 2 leaving 2 MIP - 30 amp or 3 particles leaving 3 MIP - 45 amp. which explains the peaks at 17, 28 and 42.

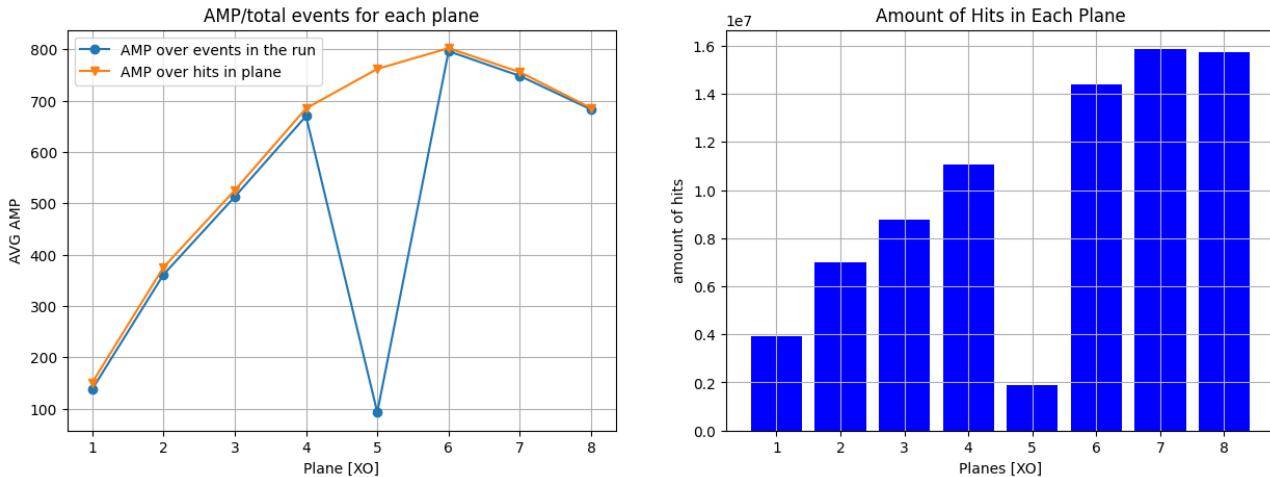


Figure 5: Run 1101. Average amp in each plane. The blue plot describe the average amplitude over the total amount of events in the run (absolute average amp), showing how much energy did each plane read over the entire run. The orange plot shows the average amplitude over the amount of events read in the plane(relative average amp), this shows the average energy of each plane solely without comparing it to the other planes. We can on the right the amount of hits in each plane, as expected, it grows bigger as the particle goes deeper in the sensor, However, in plane 4 there was probably some malfunction in the sensor as we see a major drop in comparison to the other planes. As for the energies, we see that the average amp per plane grows bigger until plane 5 and then starts to descend. The absolute average amp behave similarly, except for plane 4 which have significantly less hits and therefore lower amplitude.

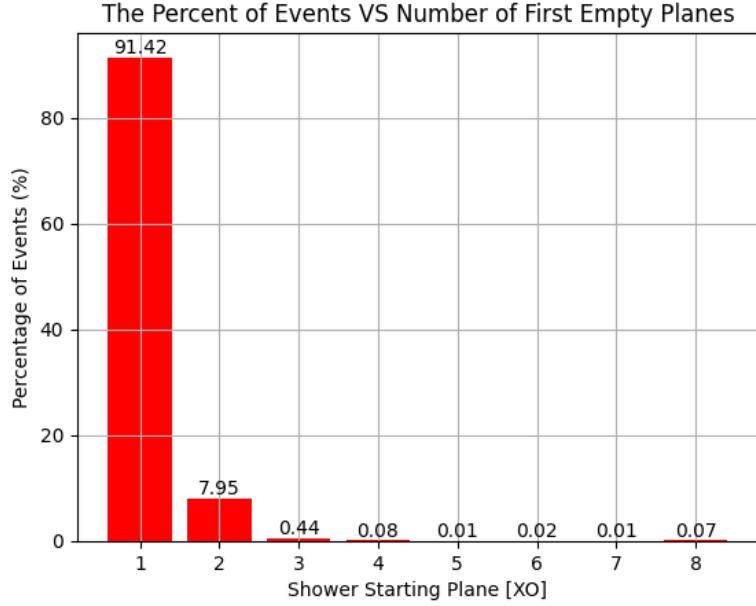


Figure 6: Run 1101. the percentage of events where the stated planes were the first ones to read data.

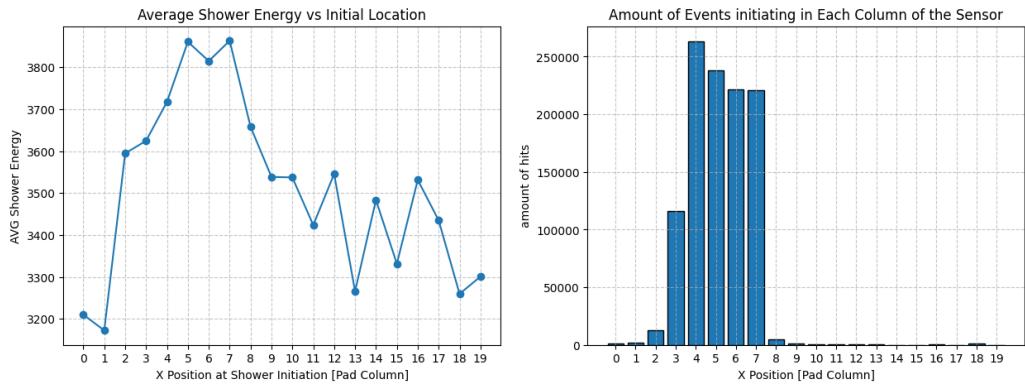


Figure 7: Run 1101. The average shower energy of an event starting in a specific column of the sensor (X position)

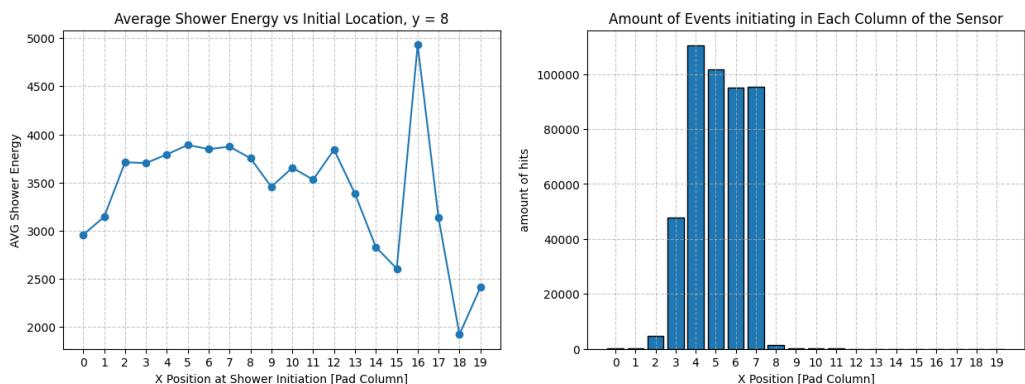


Figure 8: Run 1101. The average shower energy of events starting row y = 8 VS the initial column of the shower of the sensor (X position)

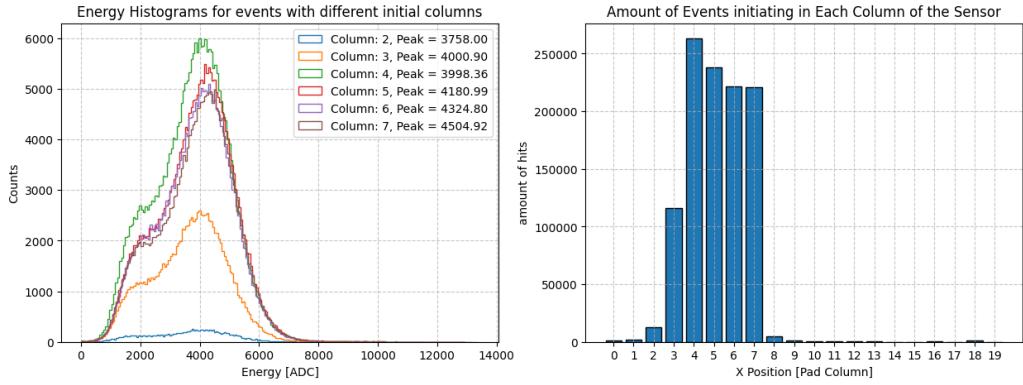


Figure 9: Run 1101. Histograms of Shower energies for events starting in different columns

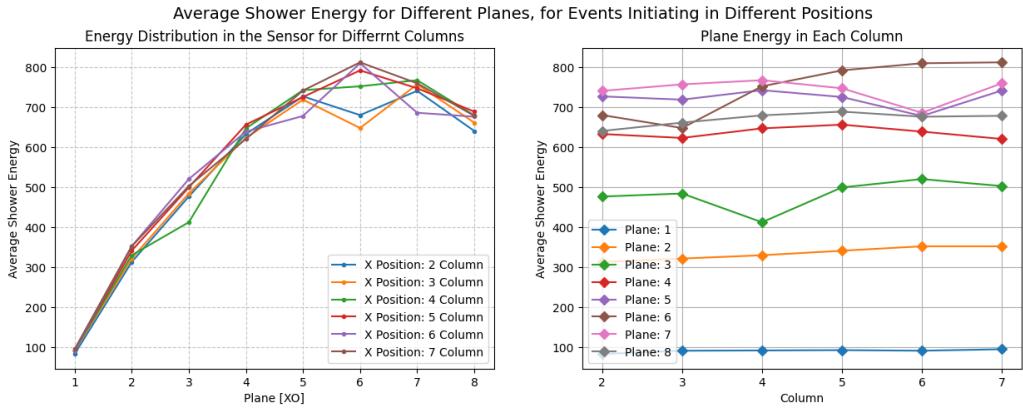
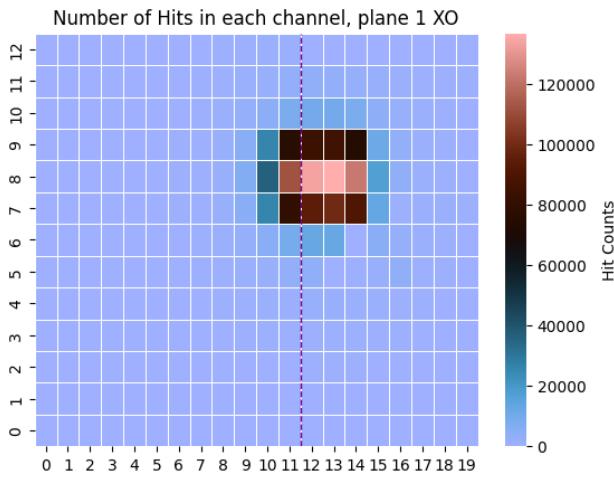
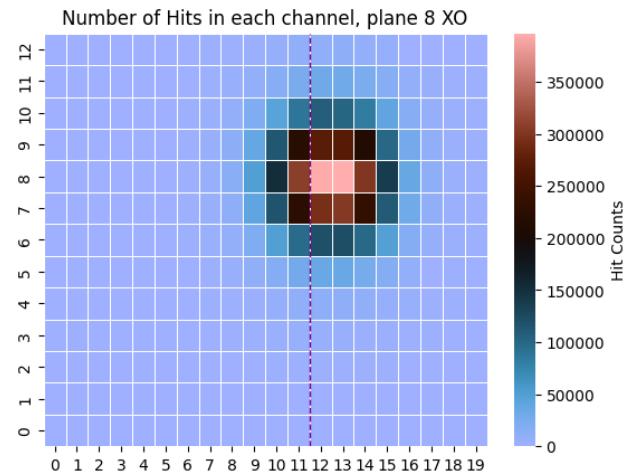


Figure 10: Run 1101. average energy in each plane for event starting in different columns

4.2 Run 1063, Zero Suppressed - On the Gap



(a) First plane



(b) Last plane

Figure 11: run 1063. Number of hits for each channel in planes 0 (first) and 7 (last). Here we see the area where the electron beam was pointed to on the sensor, as well as the deviation from it. the difference between (a) and (b) shows the growth of particle number over the planes and also the growth of the surface area of the hits, both can be explained by the electro magnetic shower of the high energy electron in the tungsten

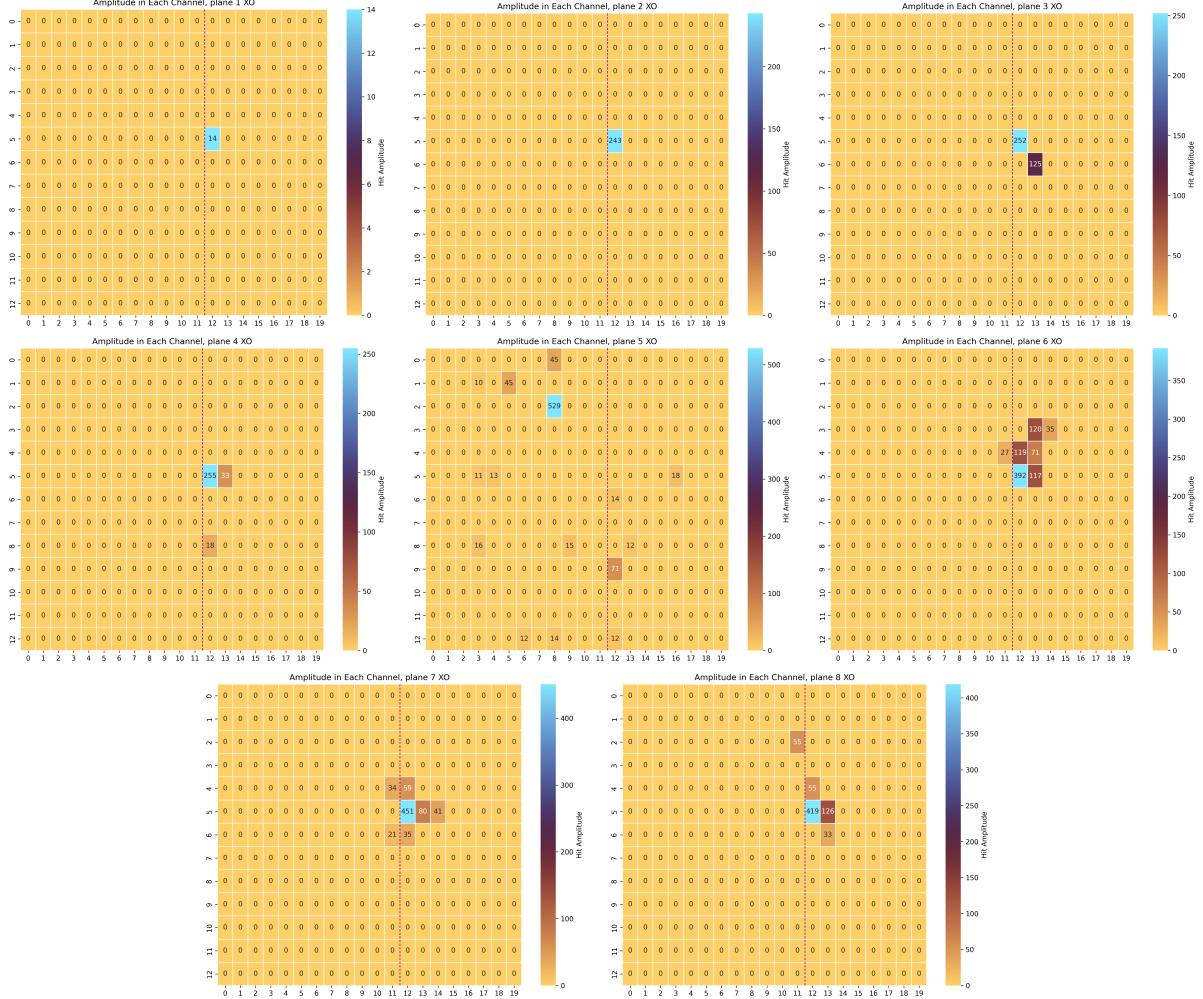


Figure 12: Run 1101. Shower of a single event, Run 1101, TLU 54106. Here each cell in the color map represents a channel in the layer of the sensor, and the presented numbers are the amplitude measured in the channel. The red dotted line marks the gap between the two towers, meaning that the right tower ends at the 11 column and the left starts at the 12 column. We see here a single electron hitting the zero plane, then it goes through the tungsten before hitting the first plane which reads 3 hits. The number of hits increases until plane 4 in this case and then starts to reduce, do to the loss of energy of the particles.

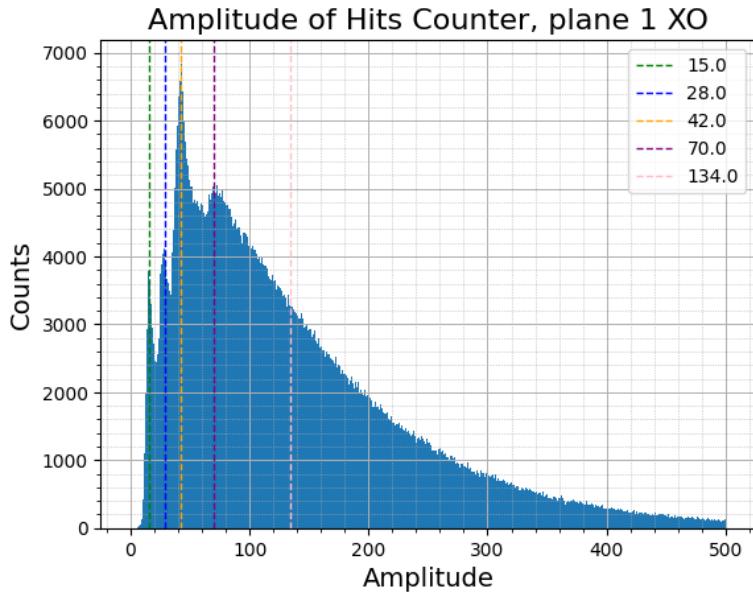


Figure 13: run 1063. Histogram of the amplitudes written in the first plane. the lines shows the peaks of the histogram

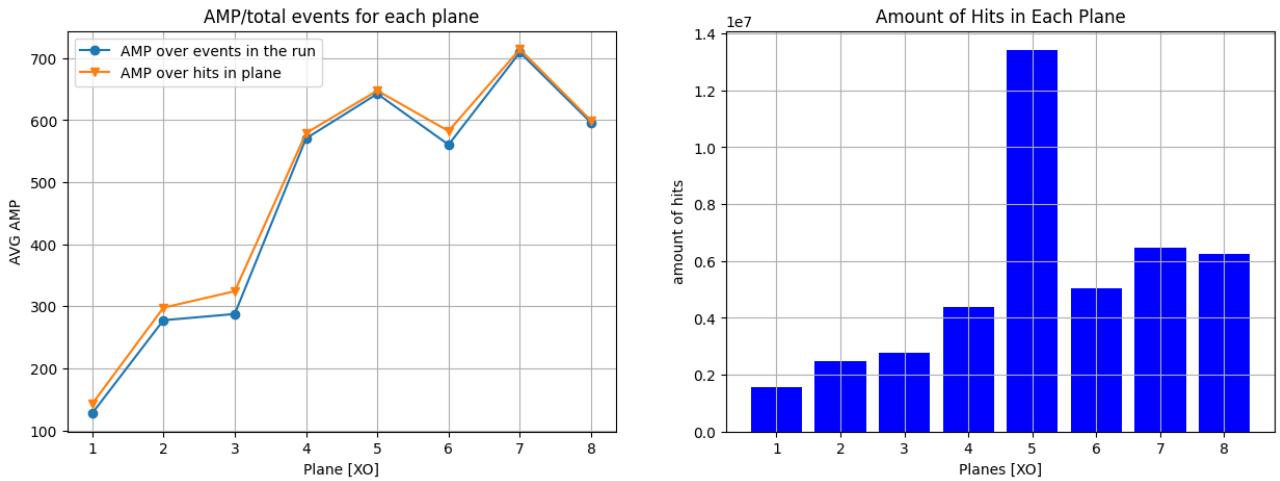


Figure 14: run 1063. Average amp in each plane. The blue plot describe the average amplitude over the total amount of events in the run (absolute average amp), showing how much energy did each plane read over the entire run. The orange plot shows the average amplitude over the amount of events read in the plane(relative average amp), this shows the average energy of each plane solely without comparing it to the other planes. We can on the right the amount of hits in each plane, as expected, it grows bigger as the particle goes deeper in the sensor, However, in plane 4 there was probably some malfunction in the sensor as we see a major drop in comparison to the other planes. As for the energies, we see that the average amp per plane grows bigger until plane 5 and then starts to descend. The absolute average amp behave similarly, except for plane 4 which have significantly less hits and therefore lower amplitude.

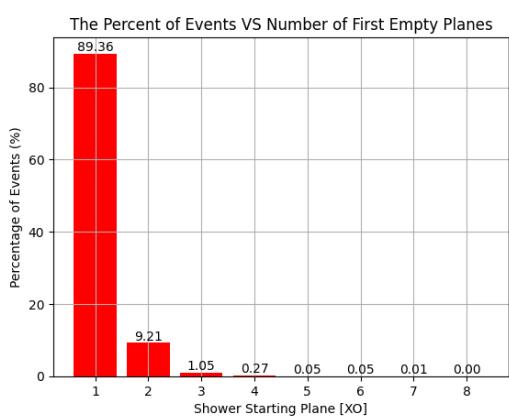


Figure 15: run 1063. the percentage of events stating the shower on different planes.

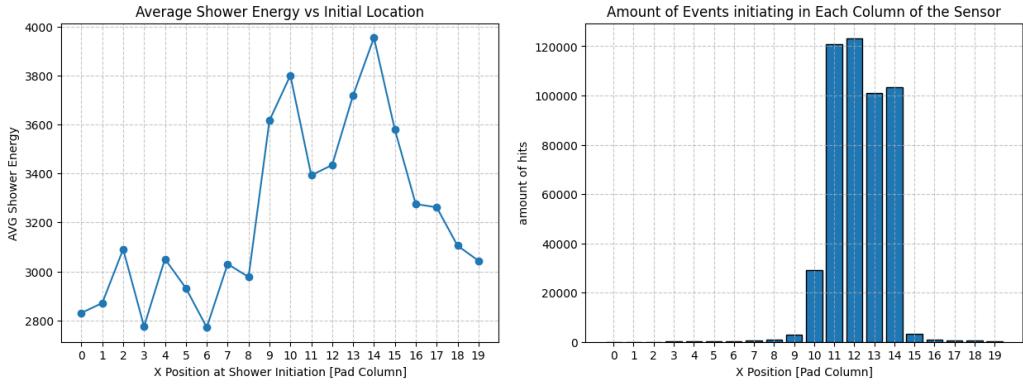


Figure 16: run 1063. The average shower energy of an event starting in a specific column of the sensor (X position)

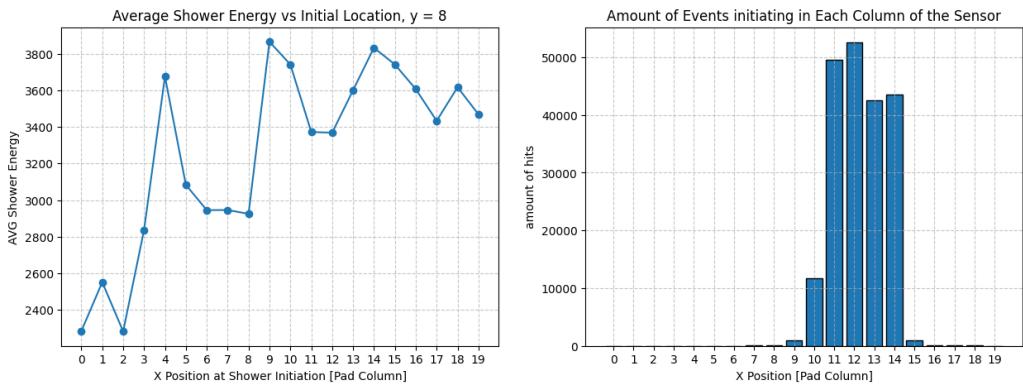


Figure 17: run 1063. The average shower energy of events starting in a row $y = 8$ VS the initial column of the shower in the sensor (X position)

In figure (??) we see the average energy of an event given the column of the first pad that was activated. This run occurs close to the Gap (between columns 11 and 12) and we see indeed how the energy is decreased for the events starting in these columns.

In figure (??) we have the histograms of energies of all showers which activated only a single pad in the first plane, for different columns of initiation. we see a difference in the center of the peak, as for the columns closer to the gap the energies are lower. we remind that in run 1101 (fig. ??) all energies are around 4220.

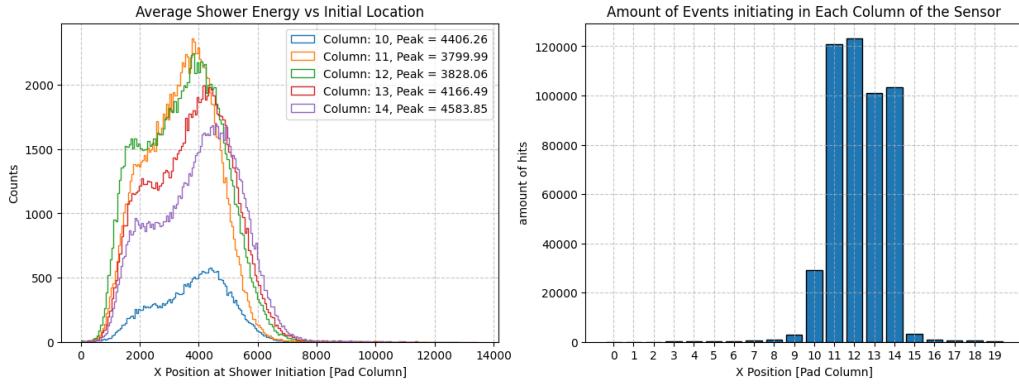


Figure 18: run 1063. Histograms of Shower energies for events starting in different columns

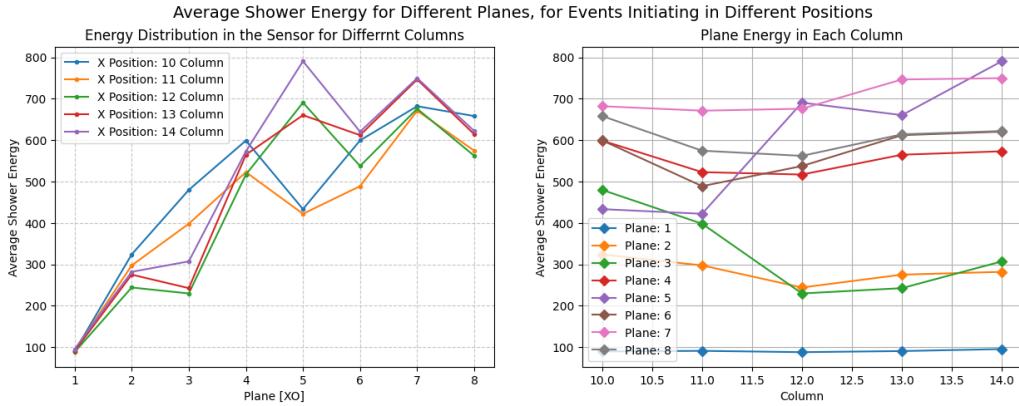


Figure 19: run 1063. Average energy in each plane for event starting in different columns

In figure (??) we have the average energy in a plane, for events starting in different columns, we see from fig. (??) that plane 4 was problematic and many false pads were activated in it, and indeed get some random results in fig.?? as well. We also see a drop in plane 2 for some of the columns. There is also a drop in plane 5, this might occur because this is at a depth of the sensor where the shower is close to its peak, meaning that we also have a large amount of leakage to the Gap.

5 Reconstructed Data

This is updatated data with better signal analysis and thresholds.

5.1 Choosing Runs to Analayze the Gap

Choosing the best runs to study the uncertainties of the sensor around the gap is a crucial step to achieve percise results. We will observe the runs that are expeericieng the least amount of leakege, and also have the least defected pads.

In the following table we will present some of the candidates runs:

To choose our reference runs, we want the least leakege well-behaving shower, we want the center to be as far as possible from the boundaries and the gap. The dimensions of the left tower is 13 rows and 20 columns as can be seen in figure (??). Hence, the best runs will be 1093 and 1094.

To choose our runs for gap analysis we want to be as close to the gap but as far from the boundaries as possible. Since the gap is between columns 11,12, according to table(??) the best runs will be the ones also located in the middle rows of the sensor. Therefore we will check runs 1080 and 1081.

Next Lets observe this runs:

Run Number	Location on Sensor		Location in Logbook	
	Column	Row	X	Y
1079	12,13	10	20.1	29.9
1080	12,13	8	20.1	20.1
1081	12,13	6	10.1	20.1
1088	12,13	4	0.1	20.1
1089	12,13	2,3	-9.8	20.1
1093	5,6	6	-20	10.1
1094	5,6	6	-20	10.1

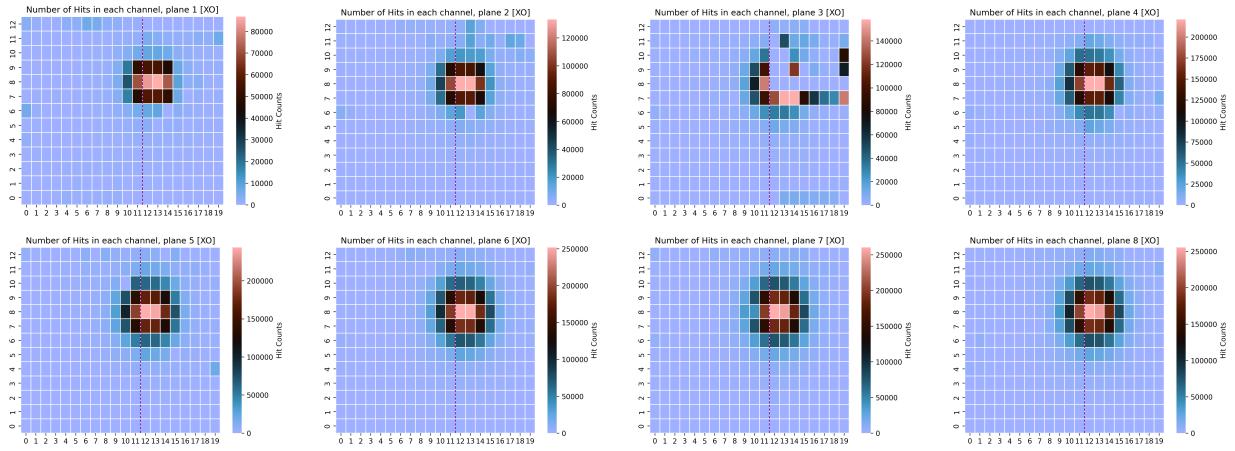


Figure 20: Run 1080 Reconstructed, Hits amount in Each Channel in Every Plane.

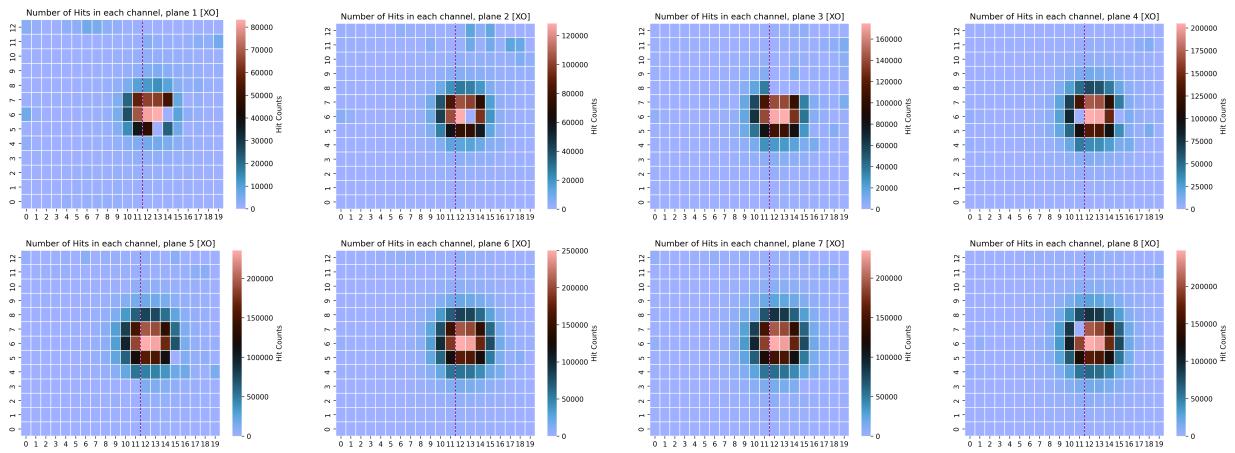


Figure 21: Run 1081 Reconstructed, Hits amount in Each Channel in Every Plane.

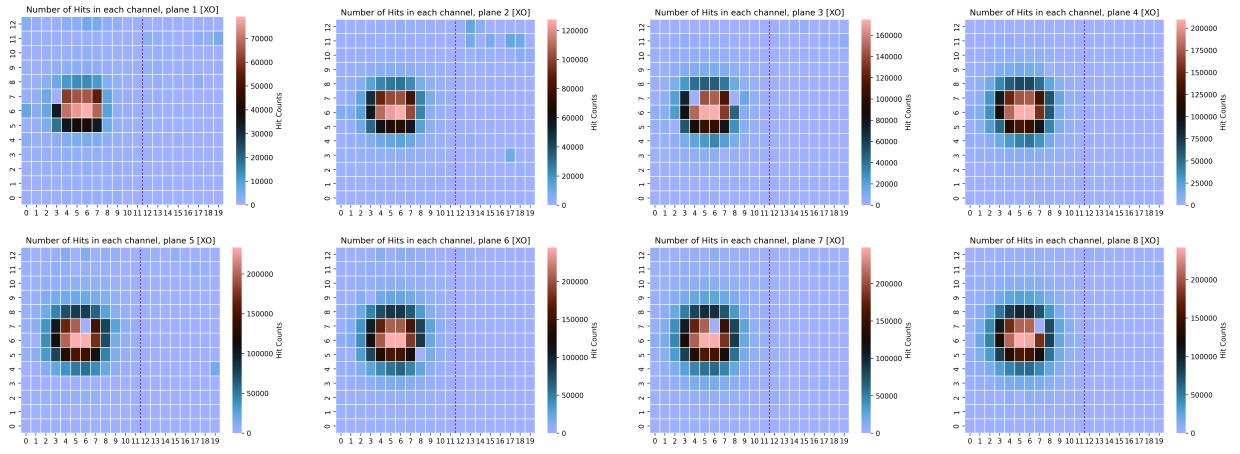


Figure 22: Run 1093 Reconstructed, Hits amount in Each Channel in Every Plane.

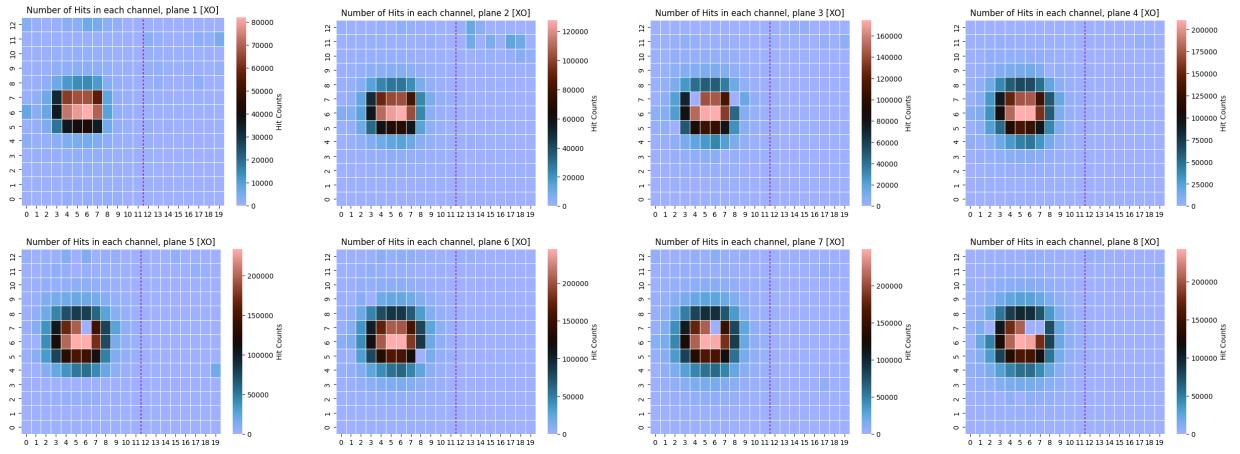


Figure 23: Run 1094 Reconstructed, Hits amount in Each Channel in Every Plane.

Comparing the runs on the gap 1080(??) and 1081(??) we see that in run 1080 the data from plane 3 is completely disordered. While some dead channels are ok as we can reconstruct the loss data by analyzing their surrounding channels (as can be seen in further chapters), we will not be able to compensate such inaccuracy as in run 1080, plane 3. **Hence for our "Gap run" we shall choose run 1081**

For our off gap run we see a relatively similar performances, the main differences are the dead channel in run 1093, plane 1 which does not appear in 1094, and the dead channel in 1094, plane 8 which does not appear in 1093. Since the deposited energy in the deeper planes is higher, the dead channels in plane 8 are more problematic than the ones on the initial planes, together with the dead channel on plane 8 of run 1094 being very close to the center of the beam, **for our "Reference run" we will use run 1093**

5.2 statistics

Some important note on analyzing large probabilistic data sets is to understand how to determine the accuracy and relevance of our results, when we measure many values, we want to assess the mean of these values its uncertainties and other statistic parameters. We will present here how to determine such values.

Mean Value - the probability weighted average of a random variable

$$\mu = E[x] = \sum_i x_i \cdot p(x_i) \quad (3)$$

If all events have equal probabilities:

$$\mu = E[x] = \frac{1}{N} \sum_i x_i \quad (4)$$

Standard Deviation - the distance from the mean where we have an effective quantity of events

$$\sigma = std = \sqrt{Var[x]} = \frac{1}{N} \sum_i (x_i - \mu)^2 \quad (5)$$

Standard Deviation Error Mean - the uncertainty of the mean value

$$\sigma_\mu = \sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n-1}} \quad (6)$$

Skewness - Asymmetry of the distribution

$$\gamma_1 = Skewness = E[(\frac{X-\mu}{\sigma})^3] \quad (7)$$

Some important distributions that our data follows:

Gaussian Distribution

$$f(x) = A \cdot e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (8)$$

In the Gaussian distribution, the mean and std values appear explicitly.

Gamma Distribution

$$f(x) = A \cdot \frac{1}{\Gamma(\alpha) \theta^\alpha} x^{\alpha-1} e^{-x/\theta} \quad (9)$$

In Gamma distribution, the mean and std read:

$$\mu = \alpha \cdot \theta \quad , \quad \sigma = \sqrt{\alpha} \cdot \theta \quad (10)$$

we can rewrite in our variables

$$\alpha = (\frac{\mu}{\sigma})^2 \quad , \quad \theta = \frac{\sigma^2}{\mu} \quad (11)$$

and write the Gamma distribution in terms of μ and σ

$$f(x) = A \cdot \frac{1}{\Gamma((\frac{\mu}{\sigma})^2) \frac{\sigma^2}{\mu}} x^{(\frac{\mu}{\sigma})^2-1} e^{-x/\frac{\sigma^2}{\mu}} \quad (12)$$

5.3 Analyzing the Shower Energies and Positions in our Reference Run - Run 1093 Reconstructed, 8 layers of tungsten

We will observe the data of the shower energies in 8 plane of silicone, for events starting at column 6 of the detector for our Reference Run (1093)

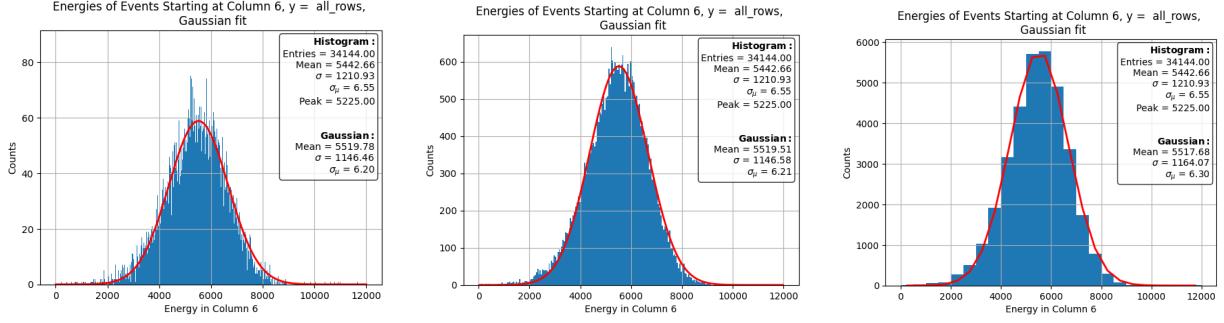


Figure 24: Run 1093 Reconstructed, Histogram of shower energies of events starting at column 6, the bin size from left to right are 5, 50, 500. fit to Gaussian distribution

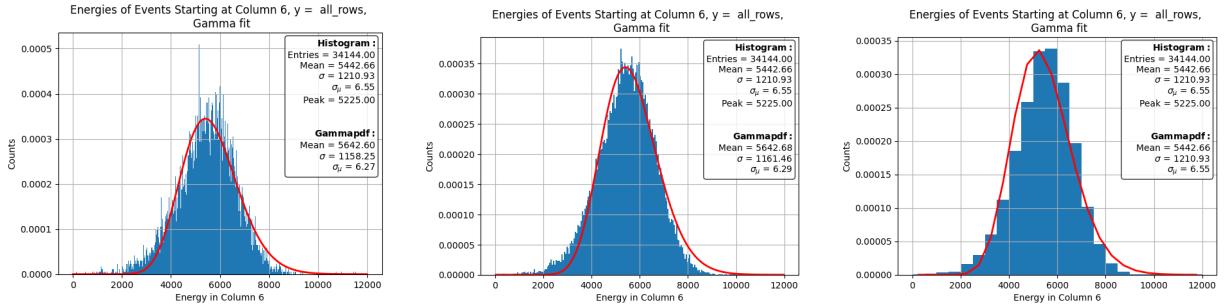


Figure 25: Run 1093 Reconstructed, Histogram of shower energies of events starting at column 6, the bin size from left to right are 5, 50, 500. Fit to Gamma distribution.

We see that the Gaussian fit is more accurate than the Gamma, this is because we observe the total shower energy, and since all electron arrive with the same energy of 5 GEV, the maximum deposited energy in the calorimeter is limited. Hence we do not get a right tail as in the Gamma distribution.

Now we can take the mean of all columns in the detector and get the relation between shower energy of events and their initial column.

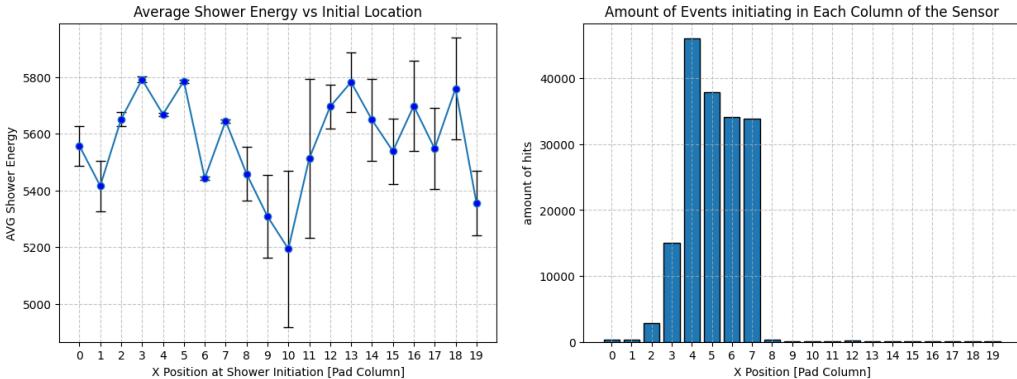


Figure 26: run 1093 Reconstructed, Average Shower Energy vs the Initial column of an Event. Events from all rows

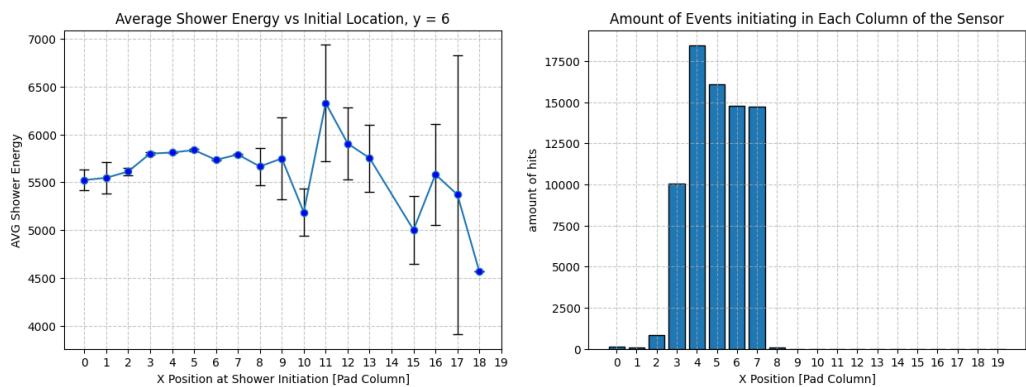


Figure 27: run 1093 Reconstructed, Average Shower Energy vs the Initial column of an Event. Events from row 6 only