Four Dimensional Shower Profiling

Documentation, 1 Aug 2013

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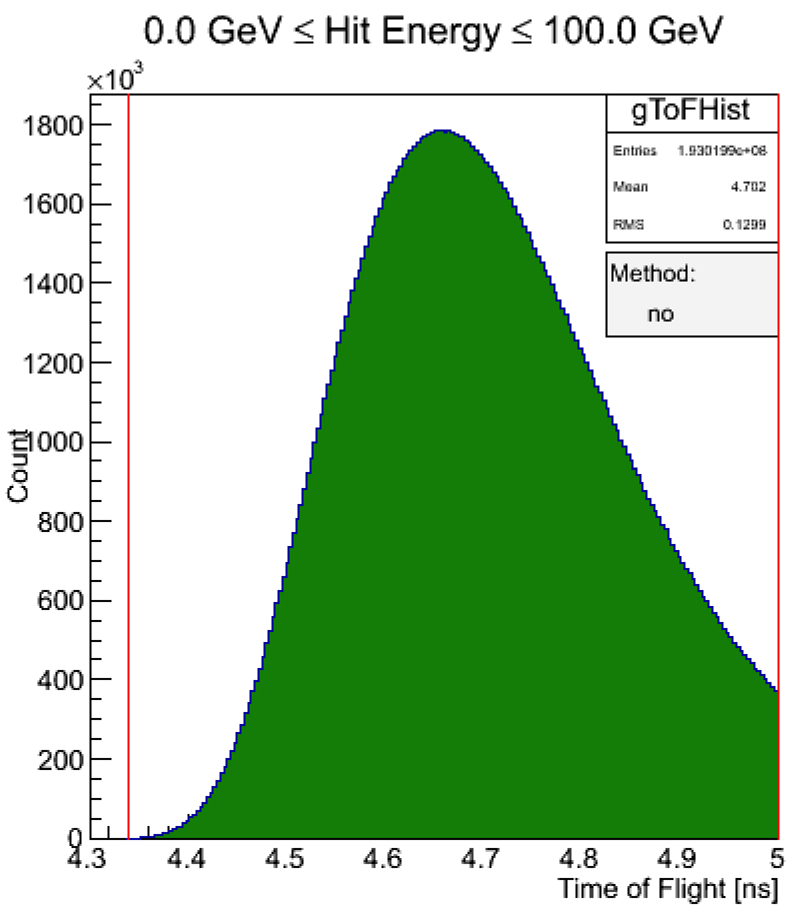
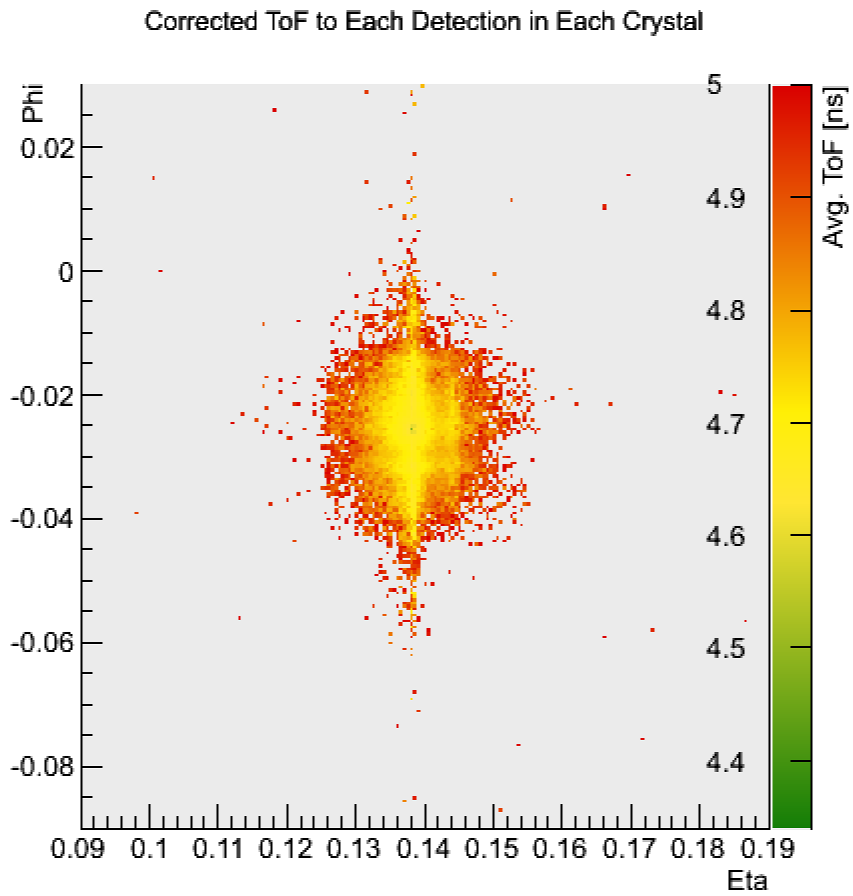
First let's go over Full Hit events

Until we reach a different section, the many plots that follow are just examinations of full hit events. There are some interesting features.

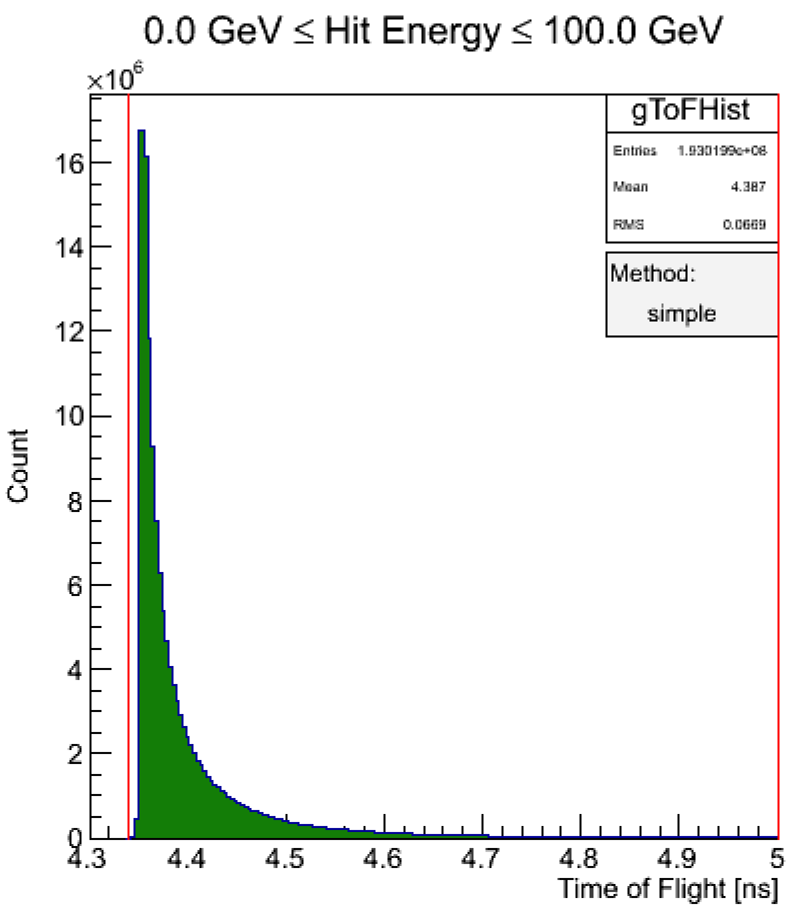
Photon 100 GeV Full

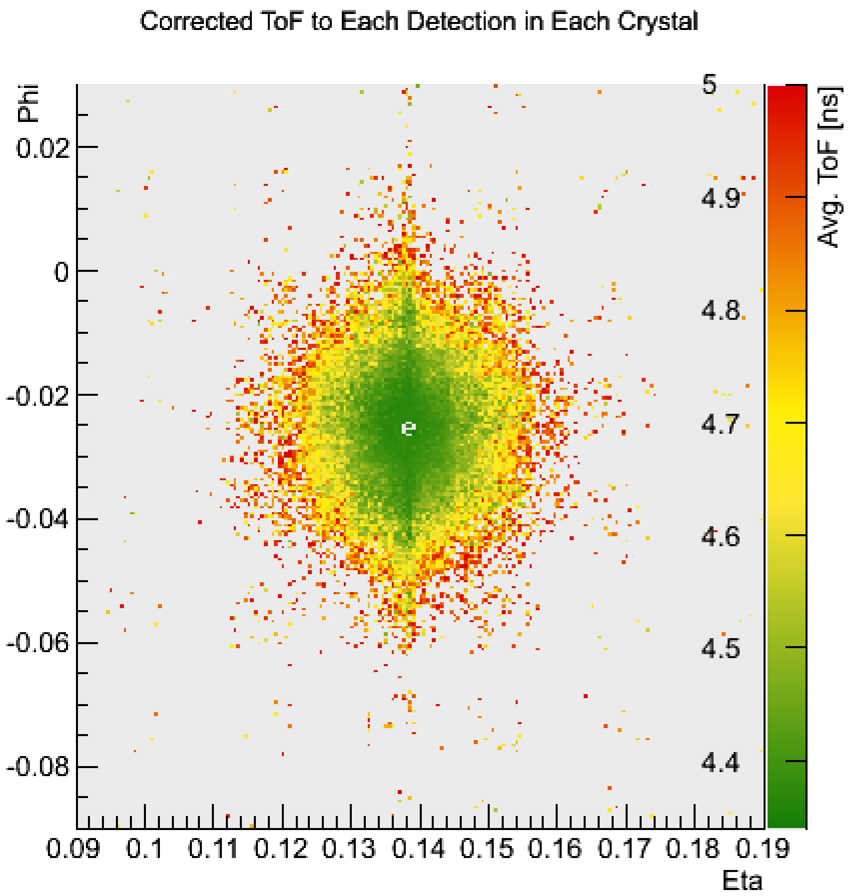




The grey area contains all the hits that are outside the time cut. Note that the method is listed on the ToF histo for all the following plots.

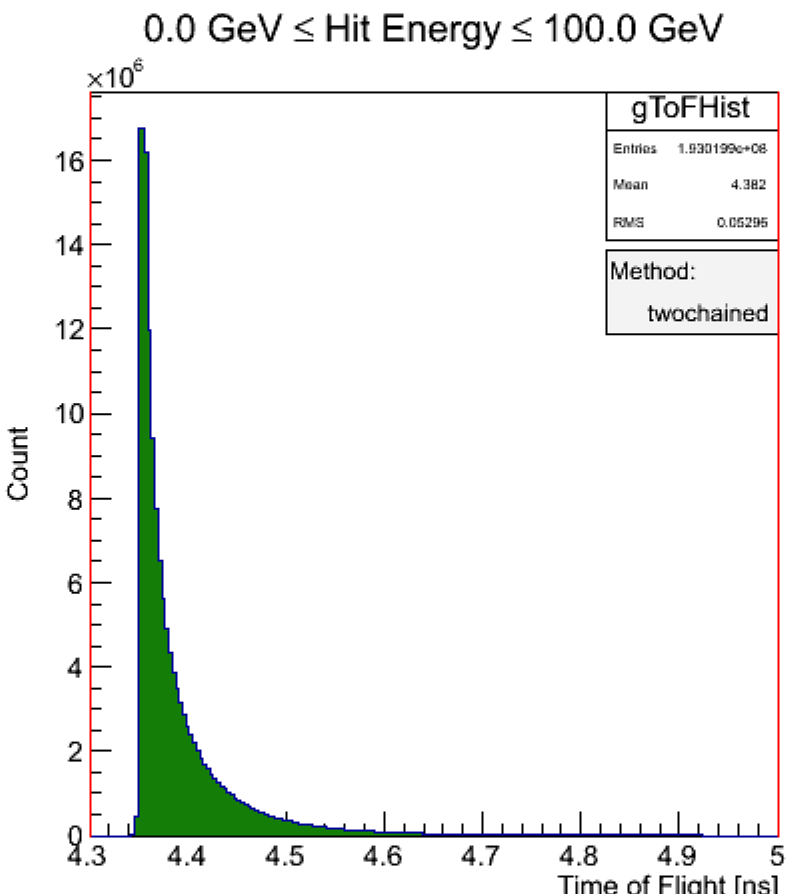
Photon 100 GeV Full

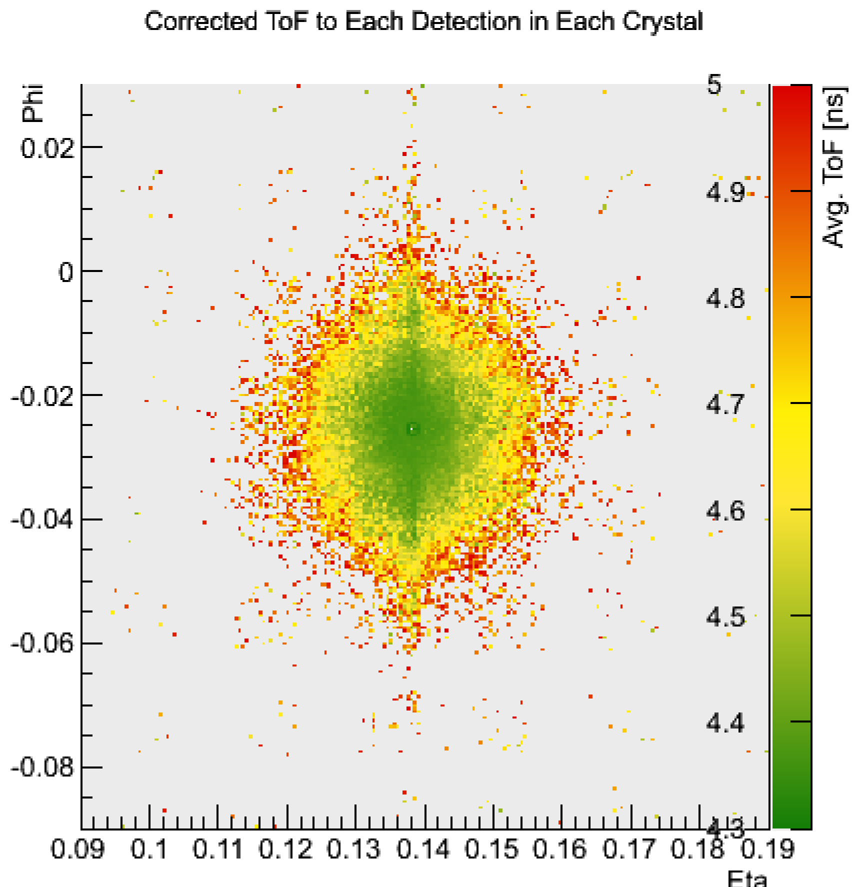




The "e" shape in the center of the eta-phi plot is due to some hits being corrected to a time earlier than the time cut.

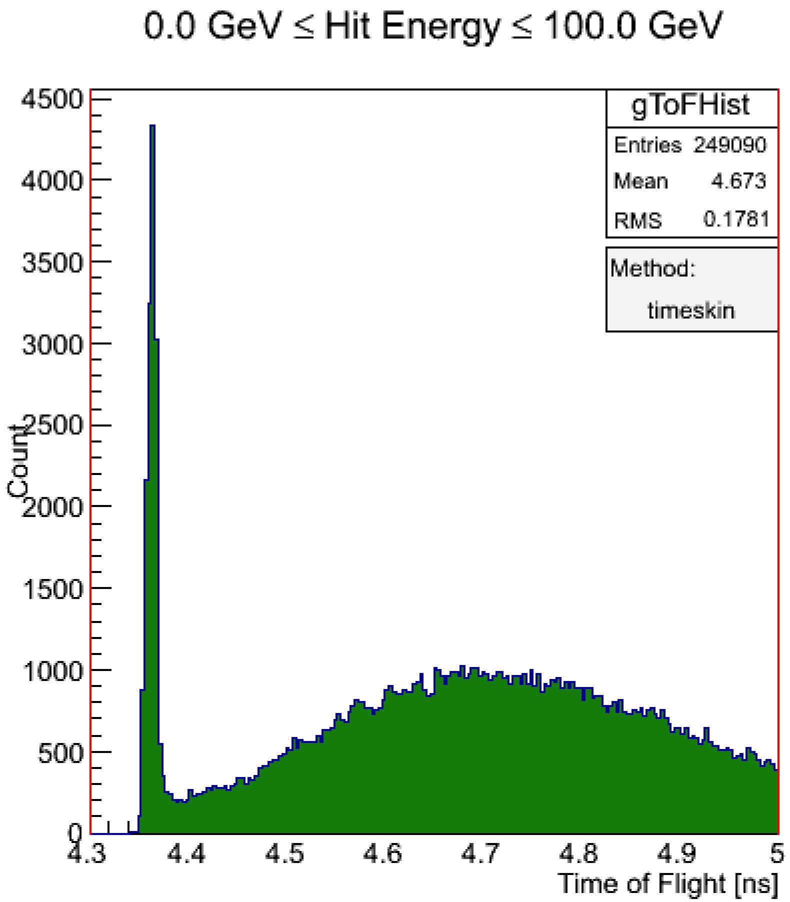
Photon 100 GeV Full

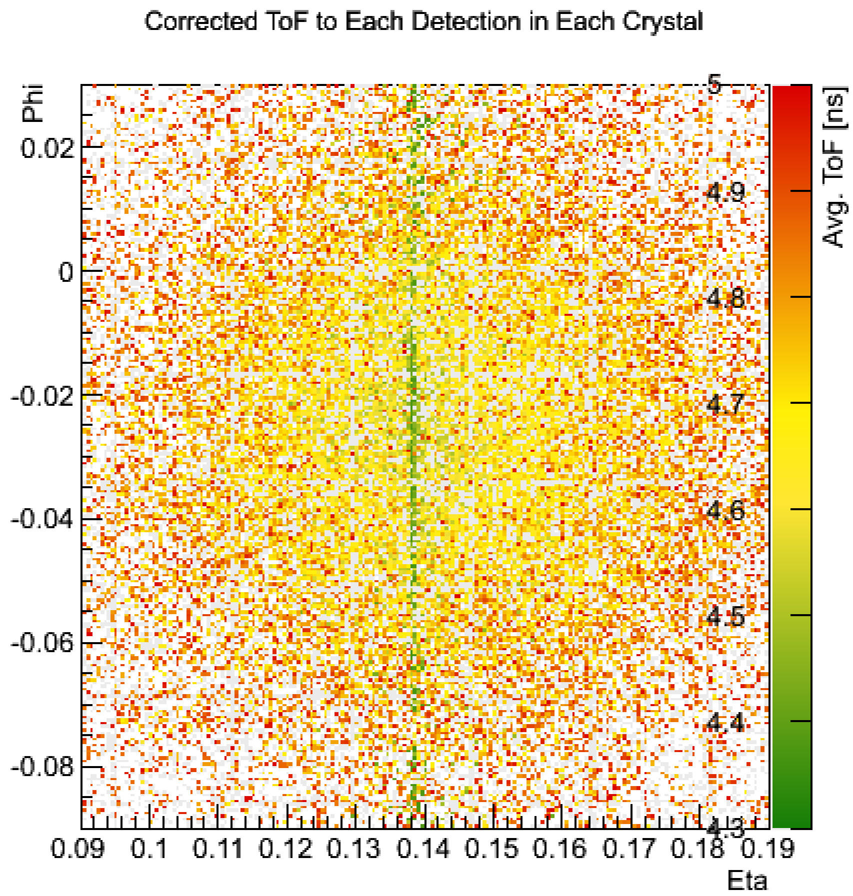




Note that the radial distance correction does not end up tightening the distribution too much. This indicates that the time smear is caused by other factors, such as a random walk effect (twochained assumes all subsequent hits are directly linked to the first hit), or delays in interactions

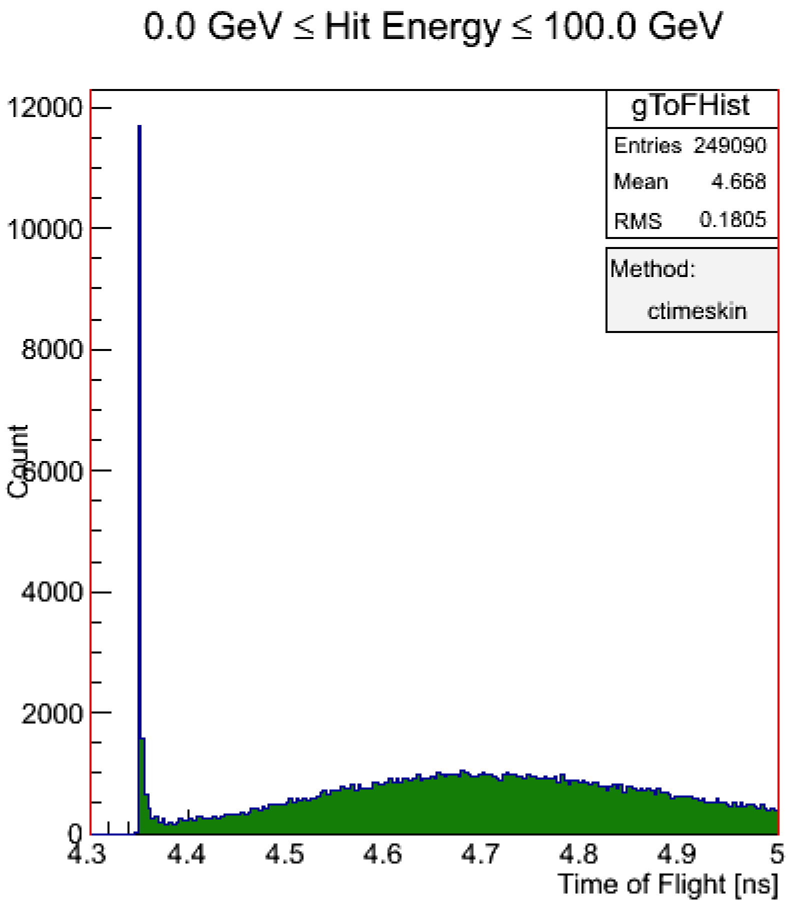
Photon 100 GeV Full

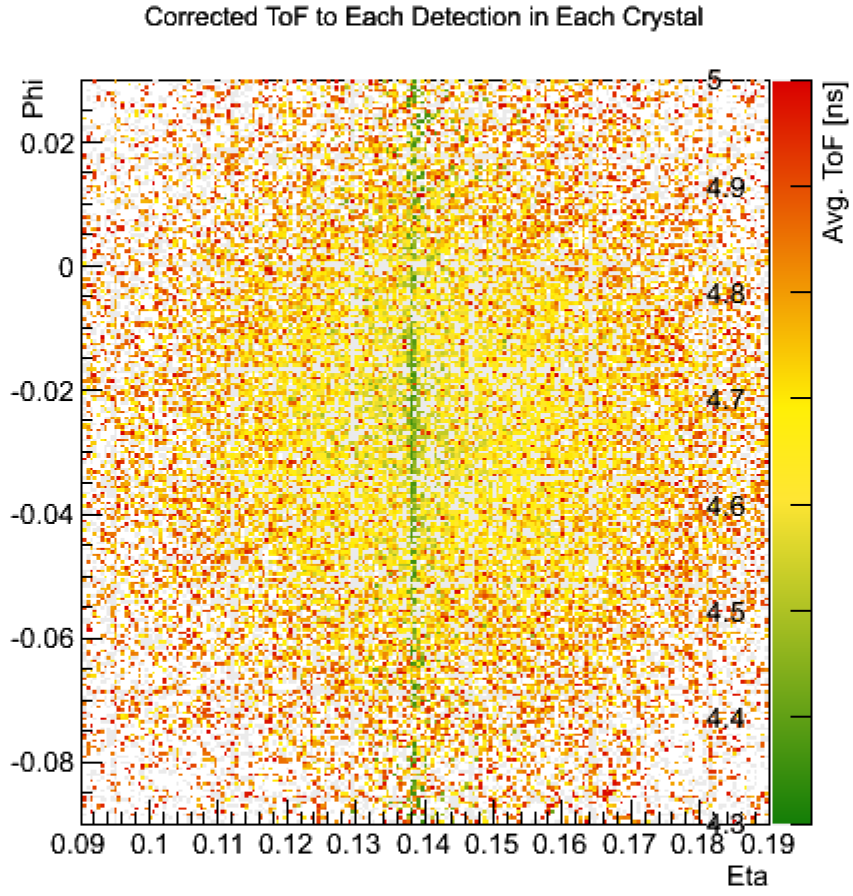




We have the first arrival peak, but with the timeskin method, we still get hits that bounce back towards the face of the crystal from the shower evolution.

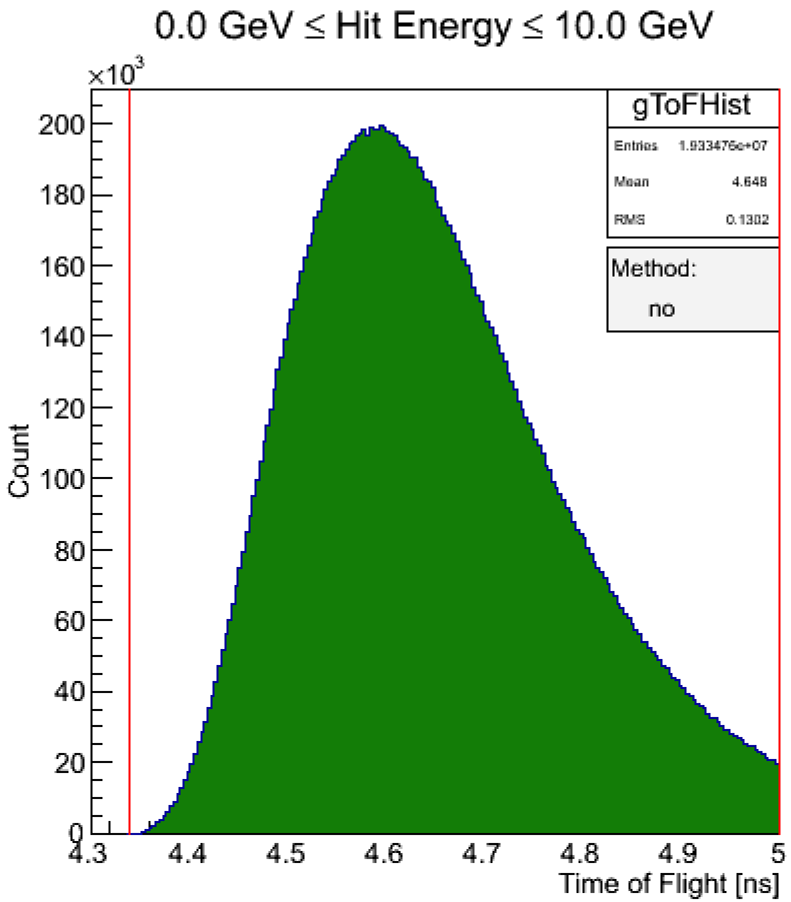
Photon 100 GeV Full

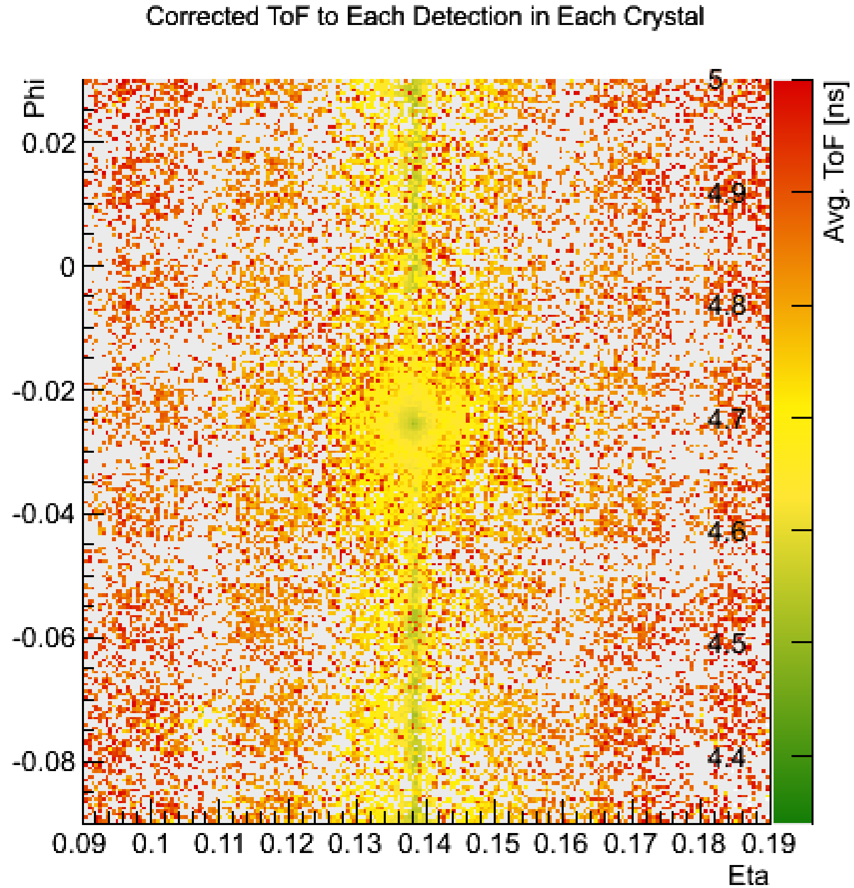




Depth correction sharpens the first arrival peak, but the effects on the second bump are somewhat minimal (although the mean of the second peak shifts up slightly)

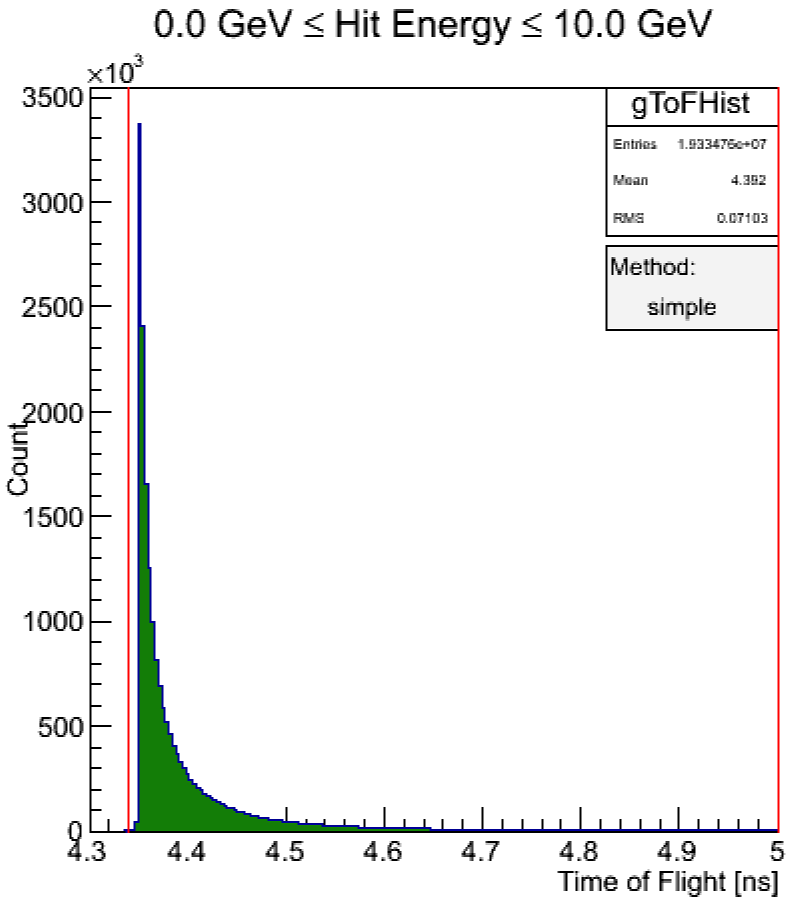
Photon 10 GeV Full

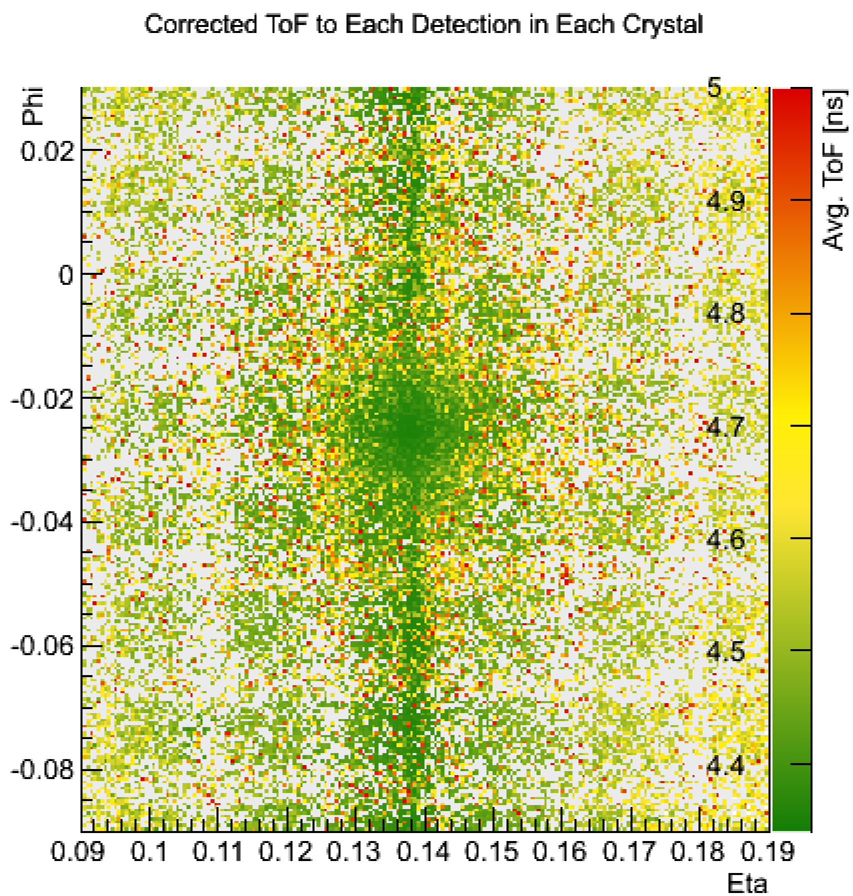




Somewhat interestingly, the peak's mean is 4.648 ns, slightly forward compared to the 100 GeV photon, with a mean of 4.702 ns (careful though – these numbers are just to accompany the visible effect of the peak leaning forward. The mean of a histo only accounts for the visible range. We've neglected the tails that come after 5 ns...). This kind of goes with the intuitive notion that a more energetic particle will penetrate deeper into the crystal, overall.

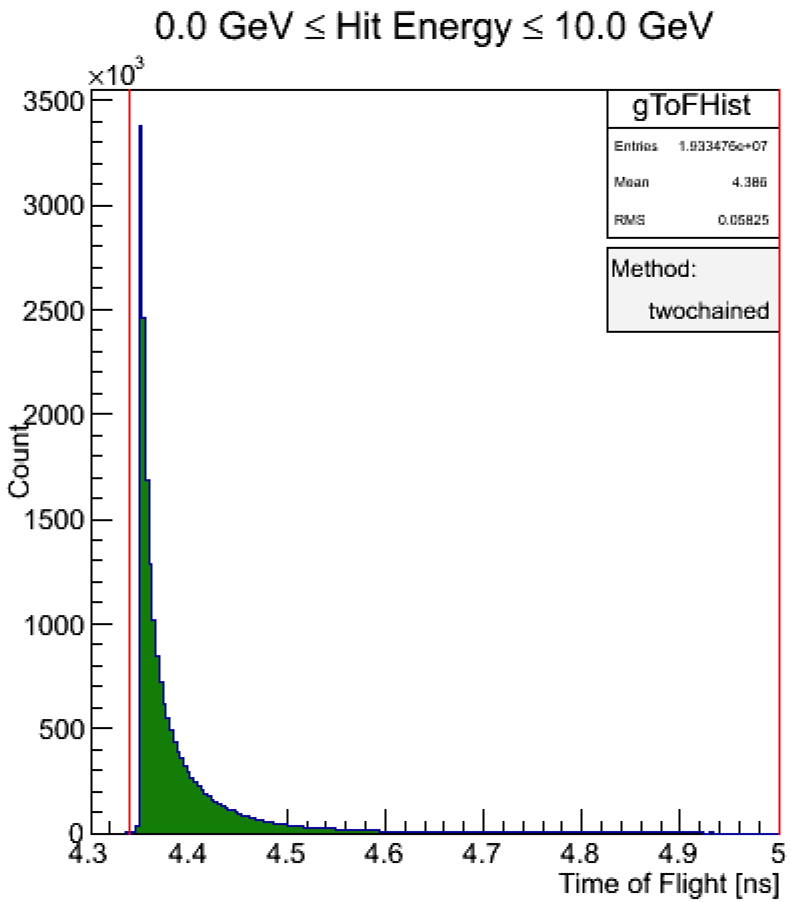
Photon 10 GeV Full

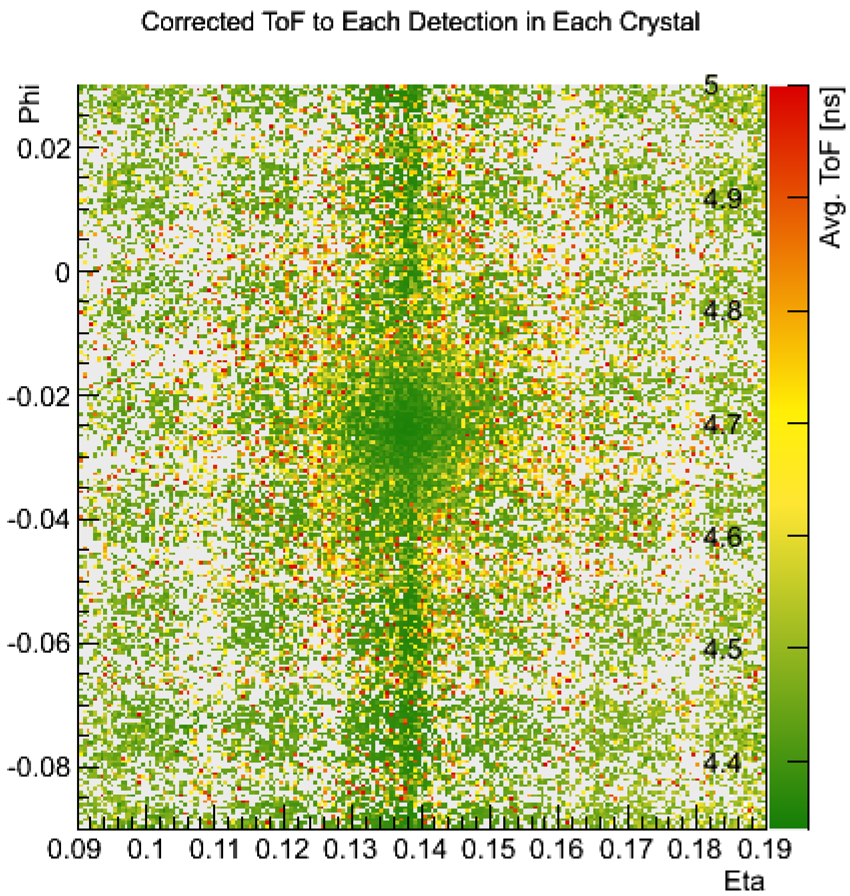




An interesting effect is the patchy look we have. It appears that the time of flights for the edges of crystals are more delayed on average, for some reason.

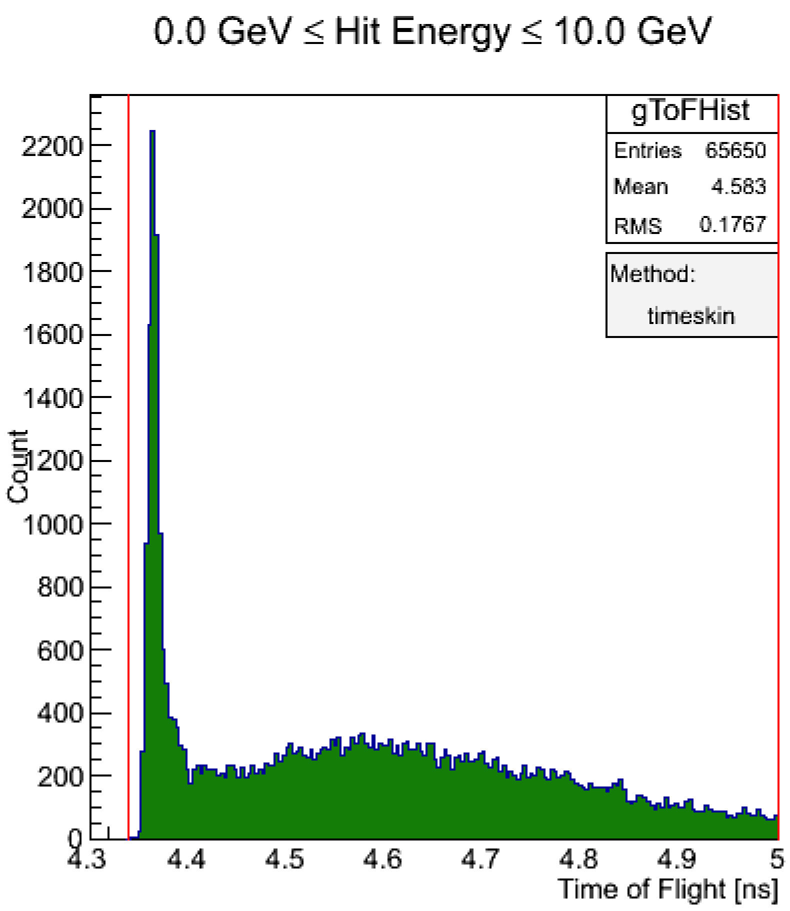
Photon 10 GeV Full

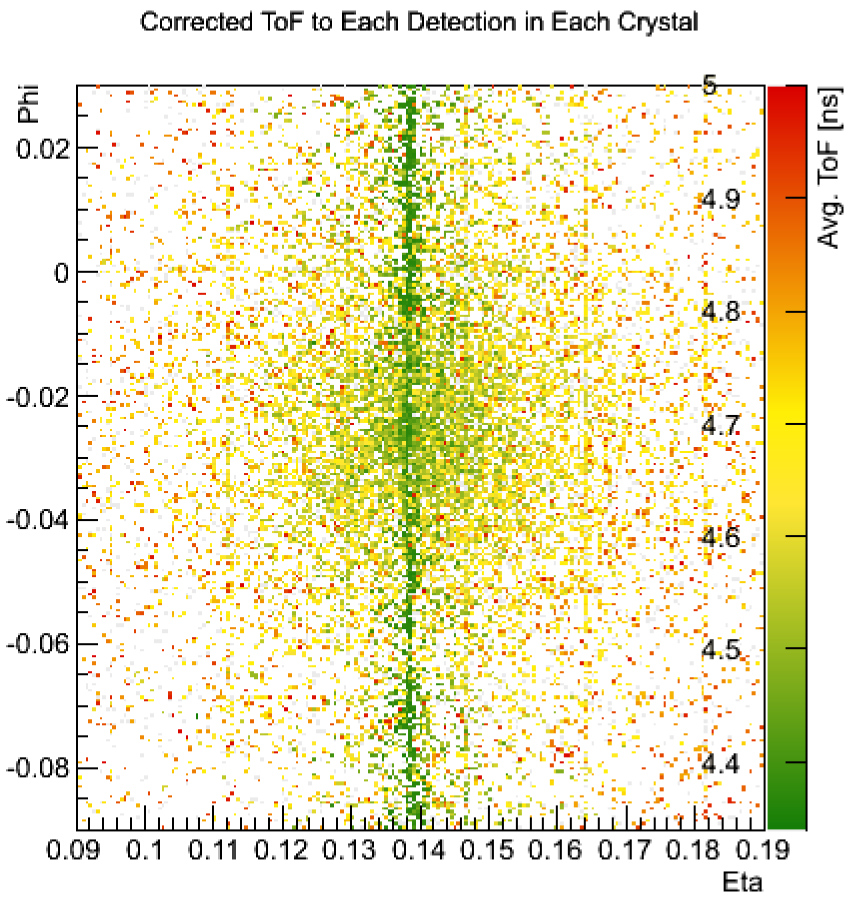




Radial correction does not seem to help much.

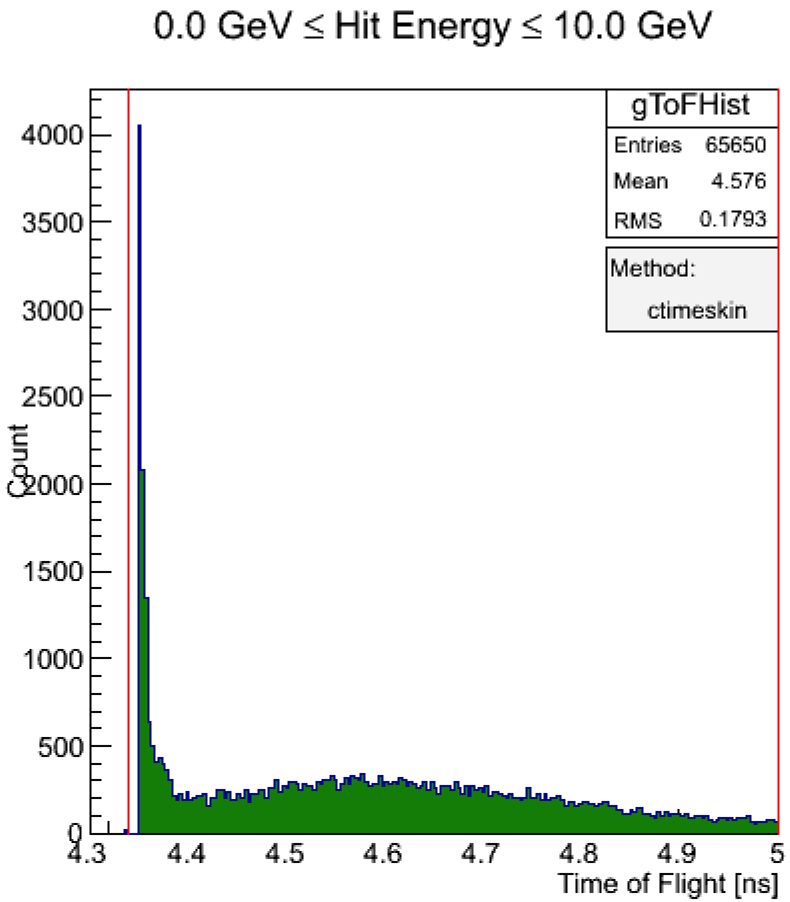
Photon 10 GeV Full

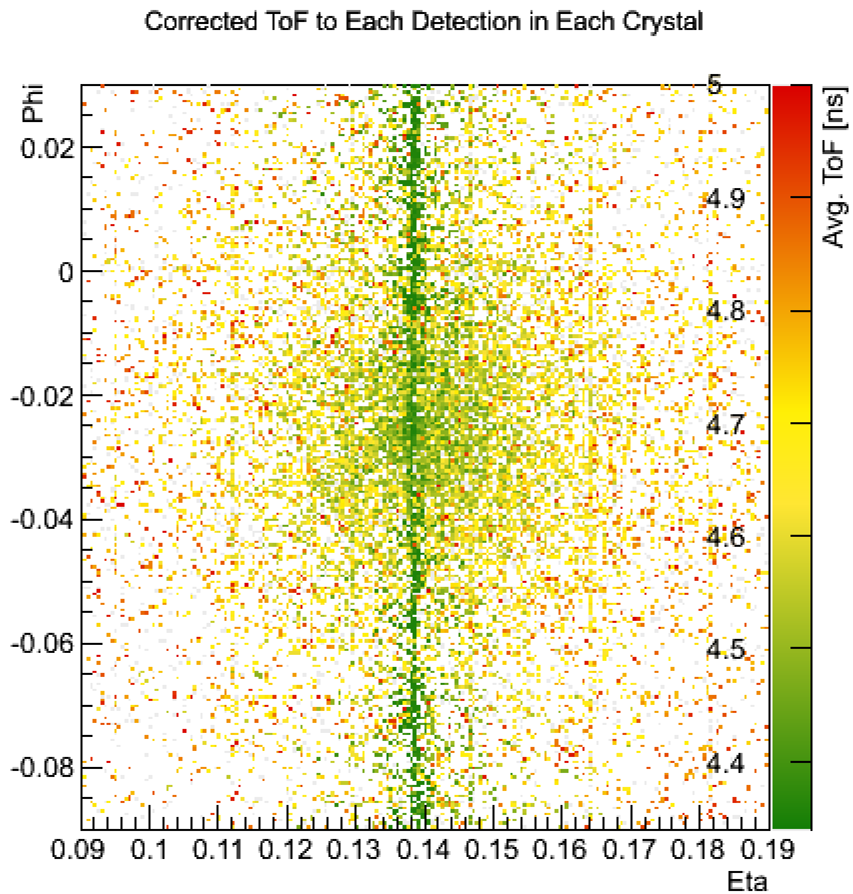




Timeskin

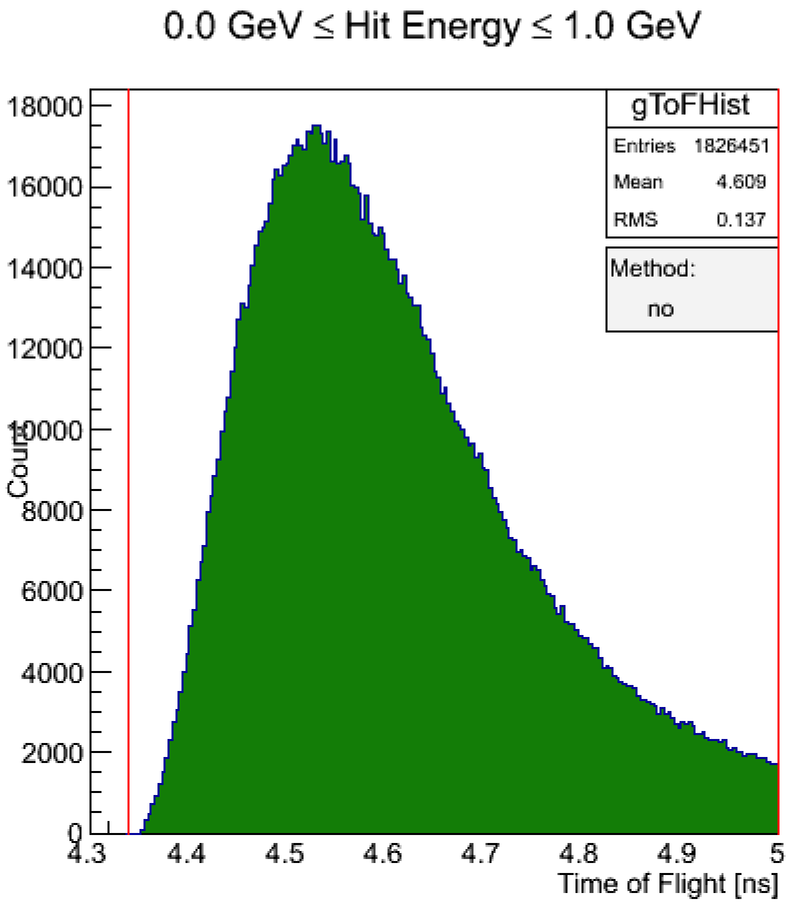
Photon 10 GeV Full

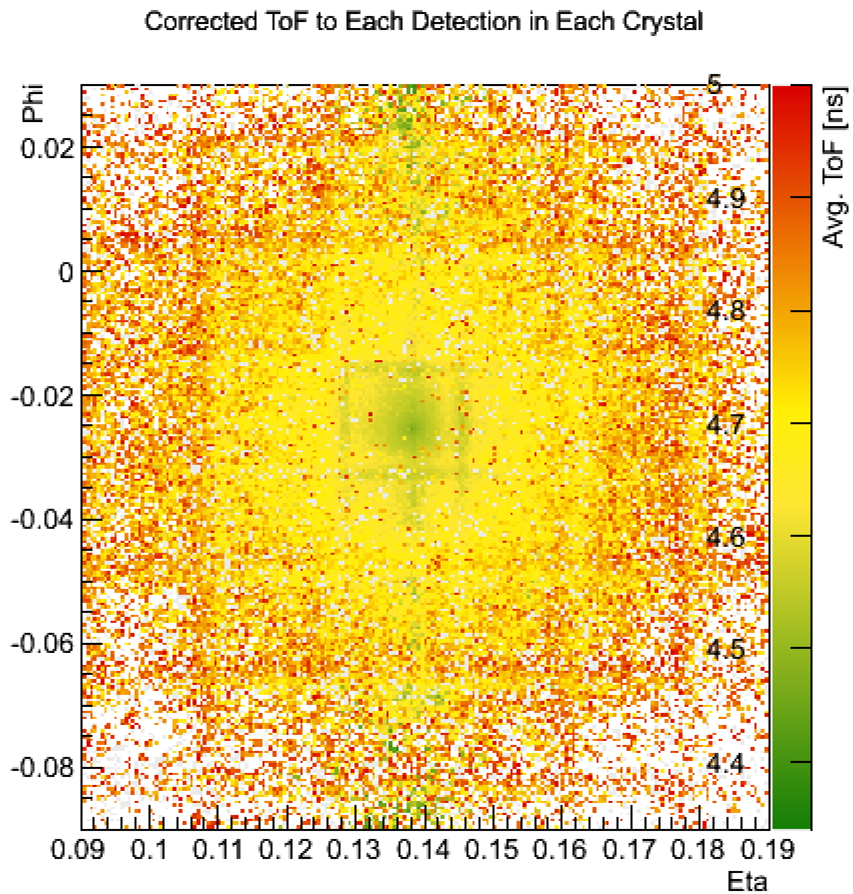




cTimeskin

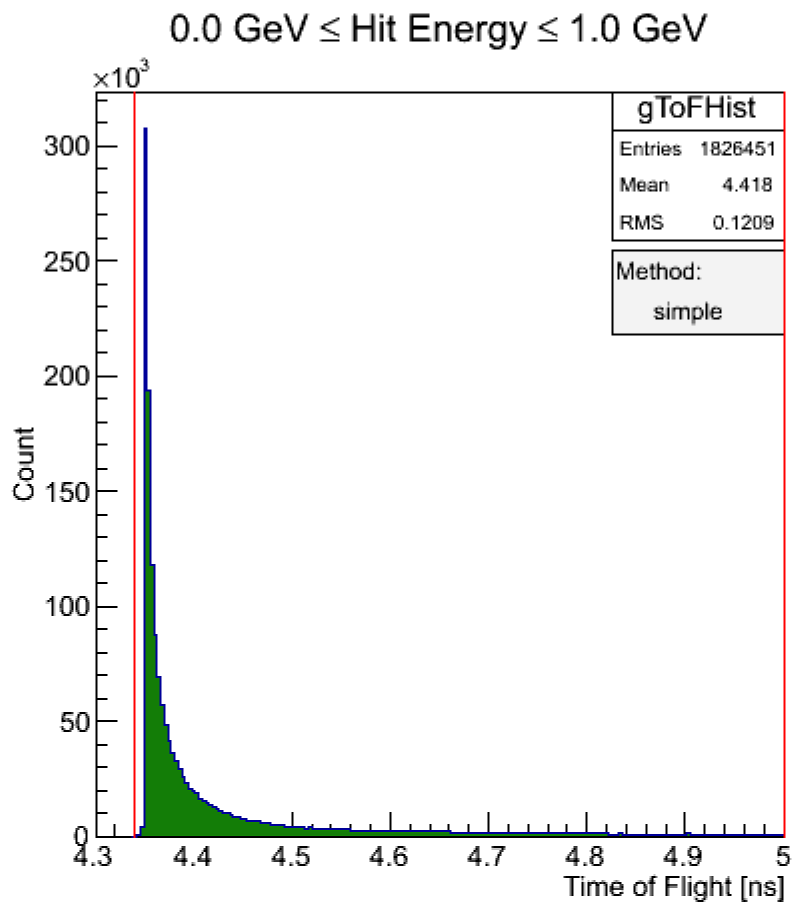
Photon 1 GeV Full

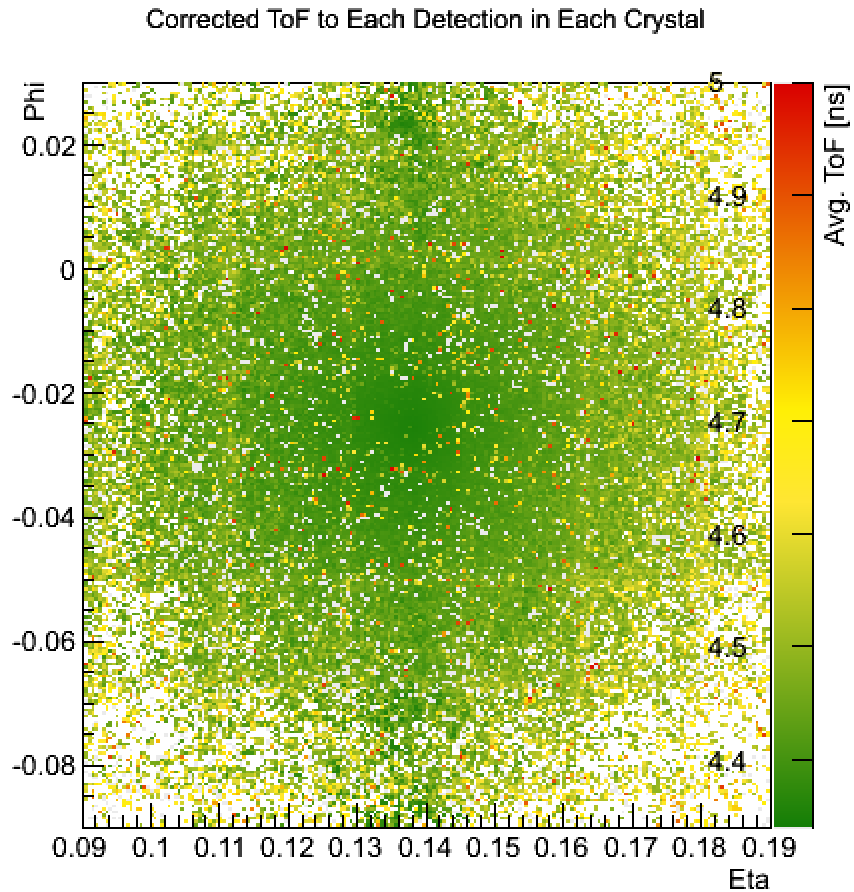




Moving to lower energy once again bumps the peak forward a bit. We also see a green square showing the edges of the crystal. This is interesting – it might be due to less shower development happening in the edges, on average. As such, the ToFs there are mostly dominated by first leaked hits.

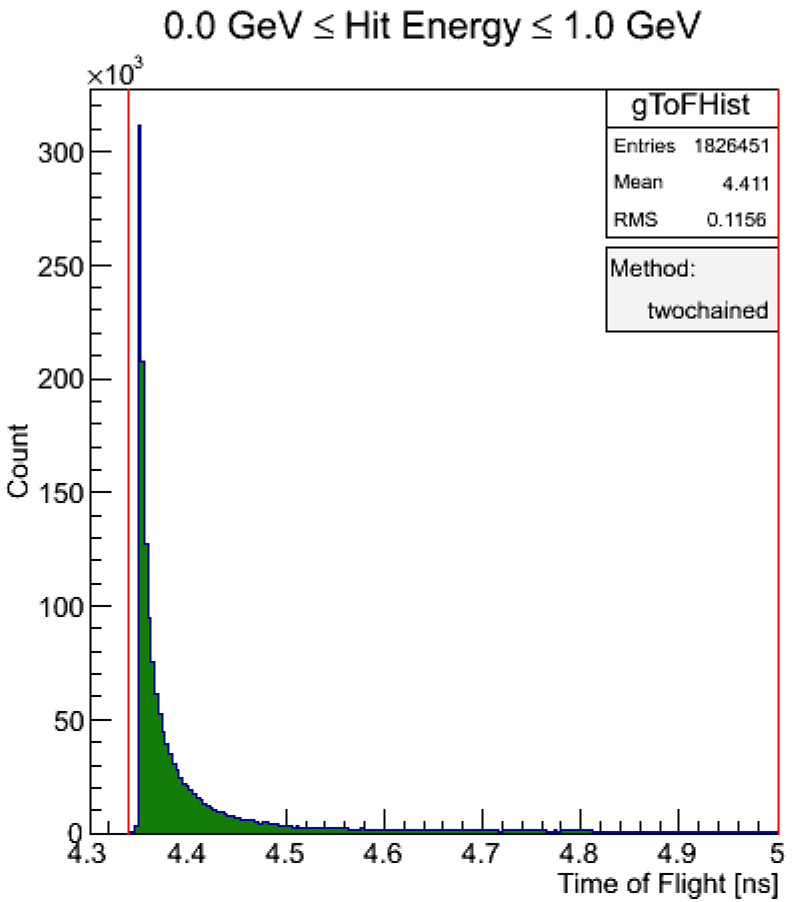
Photon 1 GeV Full

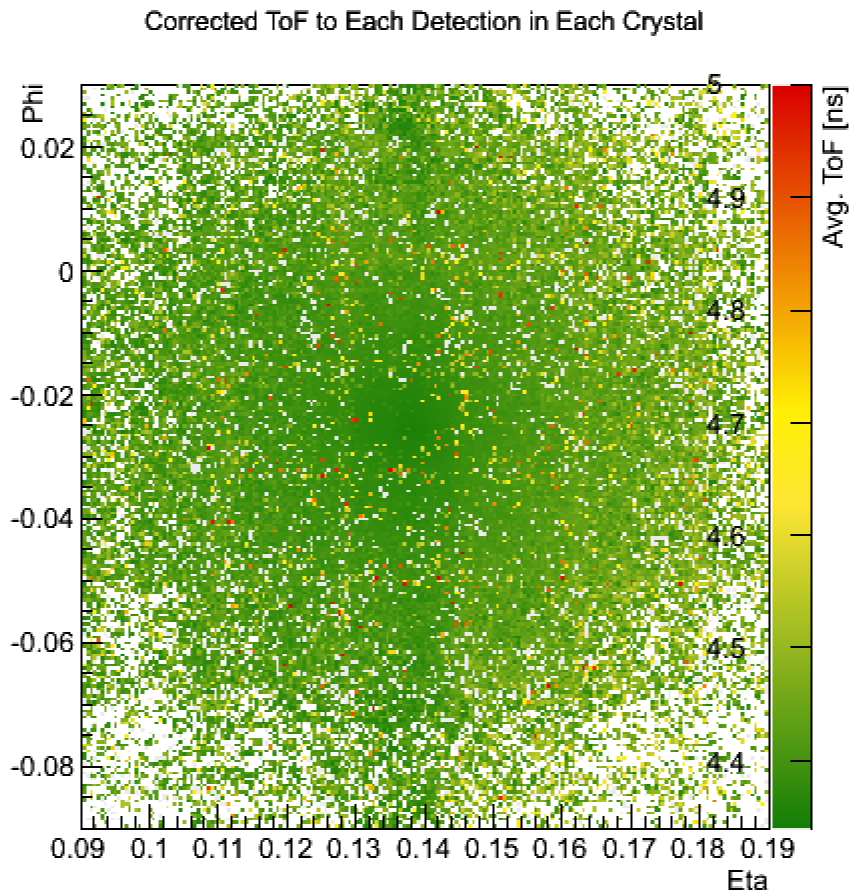




Depth correction.

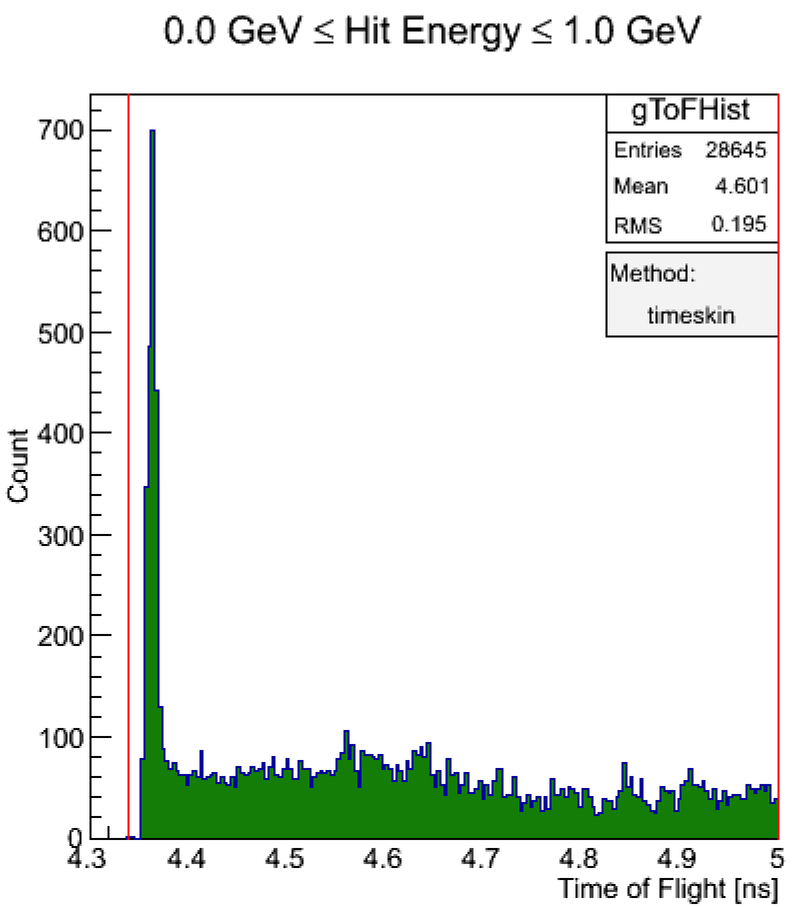
Photon 1 GeV Full

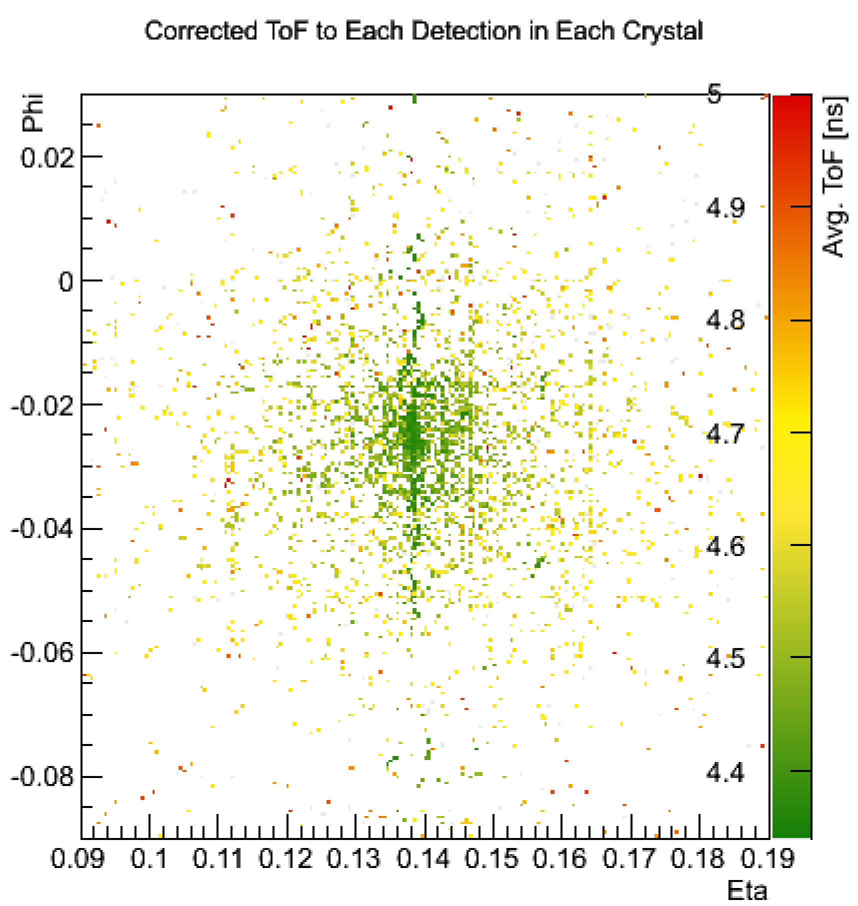




Radial correction too.

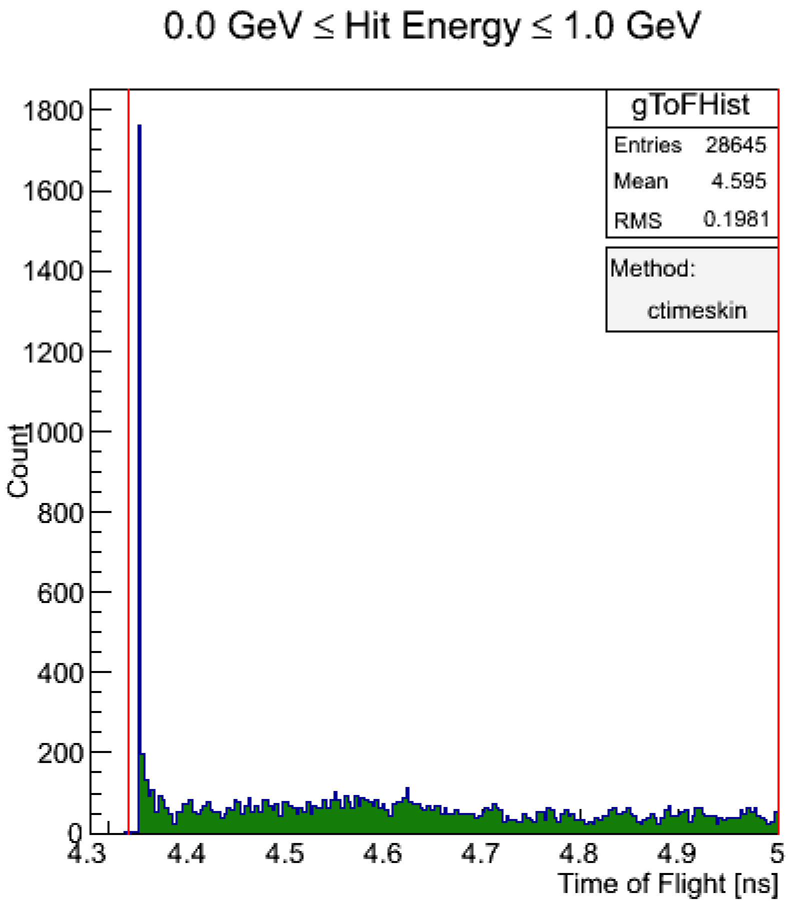
Photon 1 GeV Full

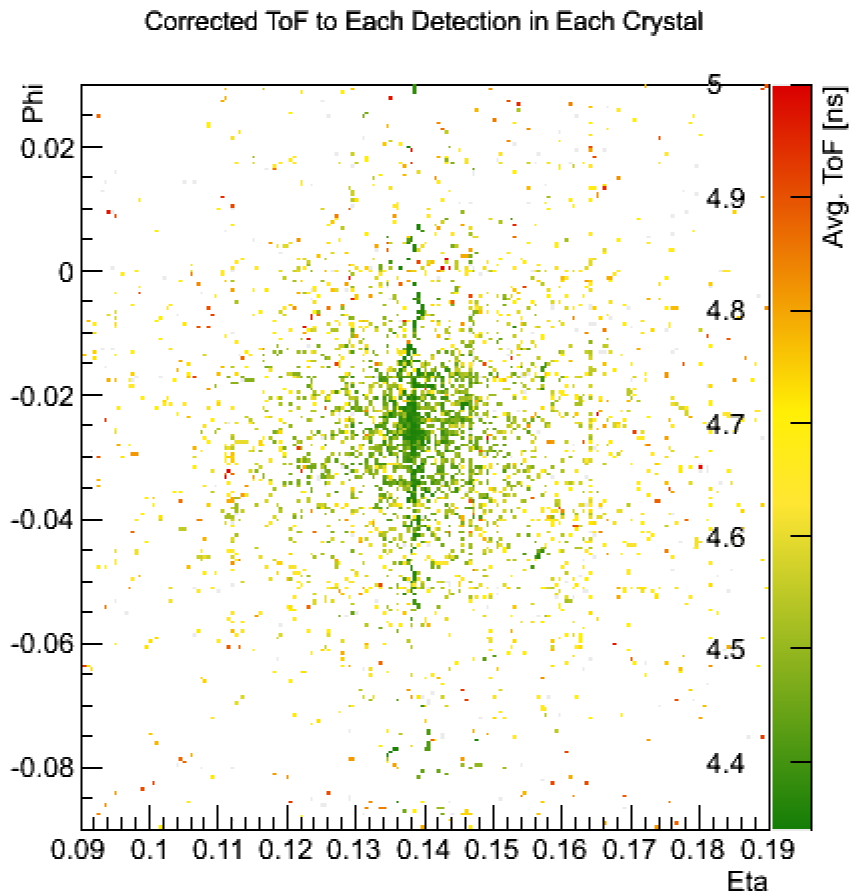




Timeskin

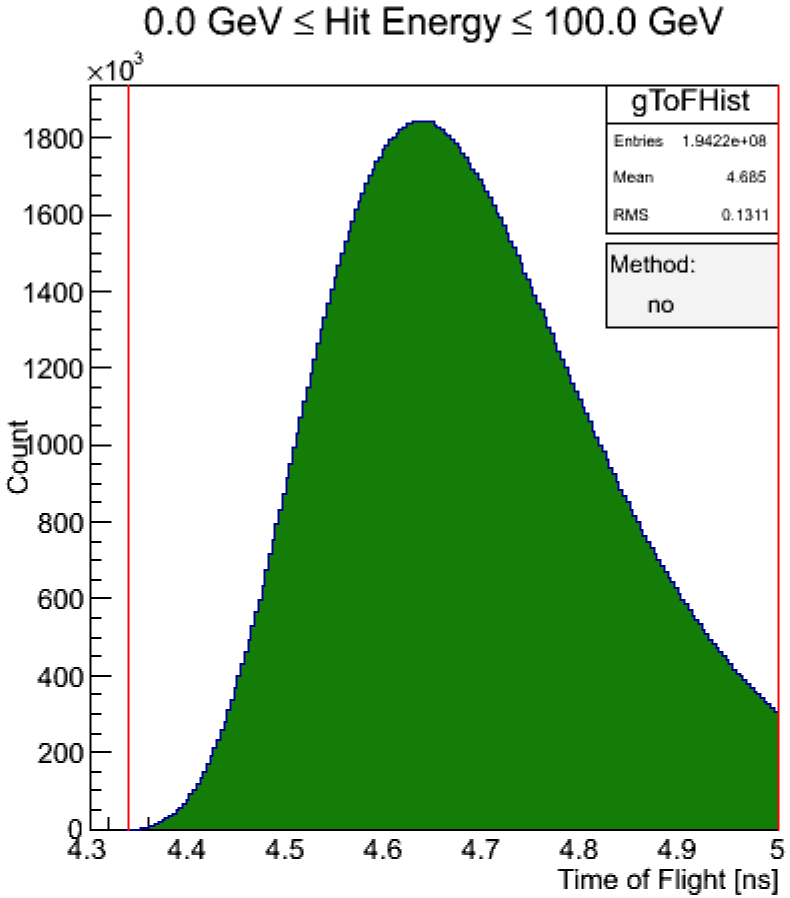
Photon 1 GeV Full

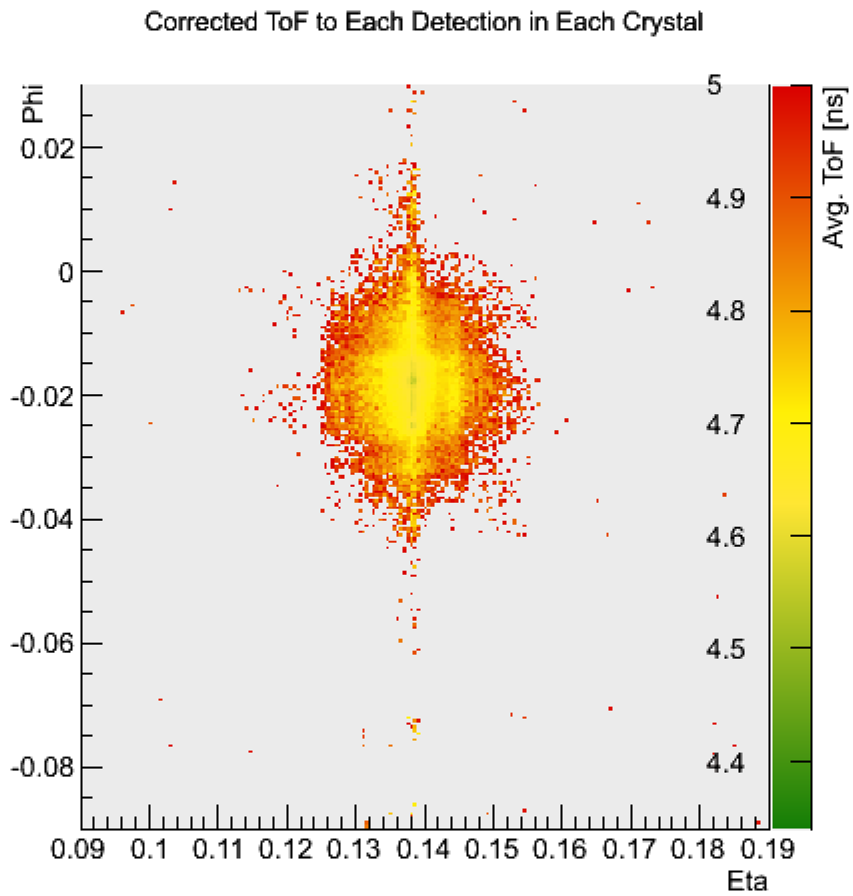




cTimeskin

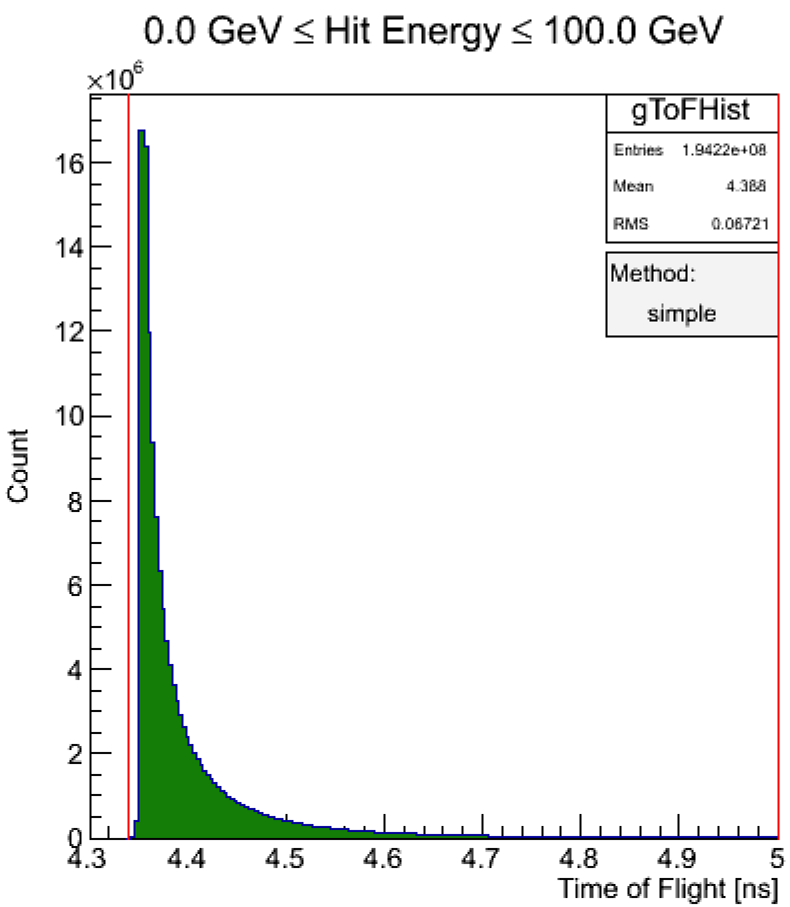
Electron 100 GeV Full

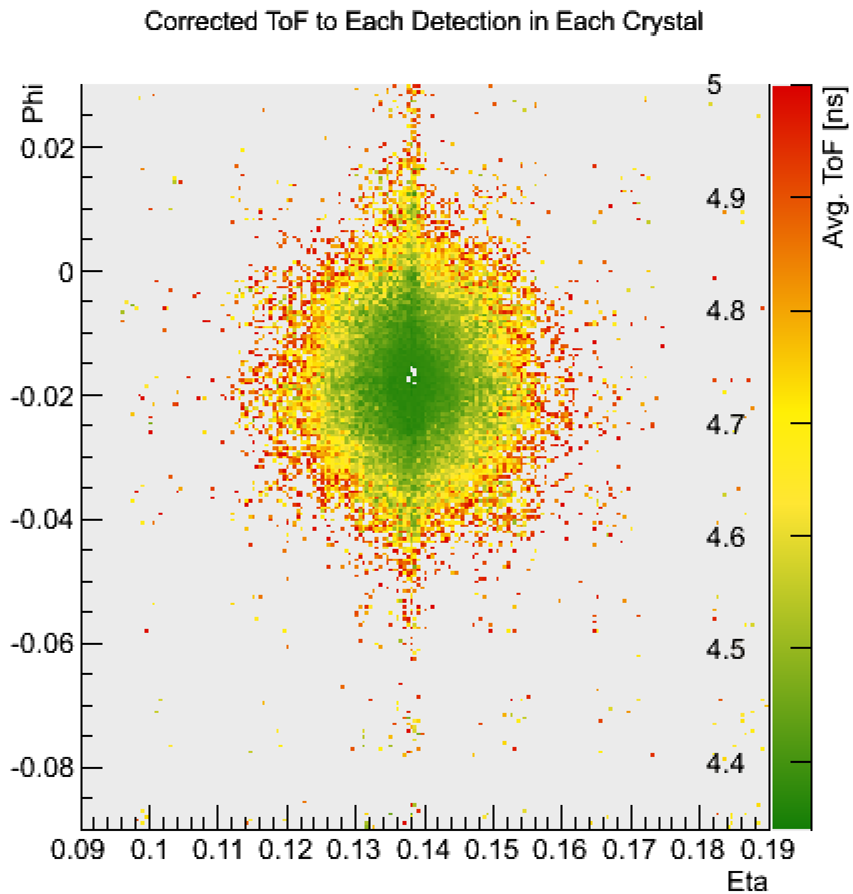




The eta-phi range were kept the same from the photon plots. Note that the beam has moved up in phi, very slightly. Other than that, the plots look very similar to the 100 GeV photon. This could be due to the photon converting to e+e- before any other interactions happen.

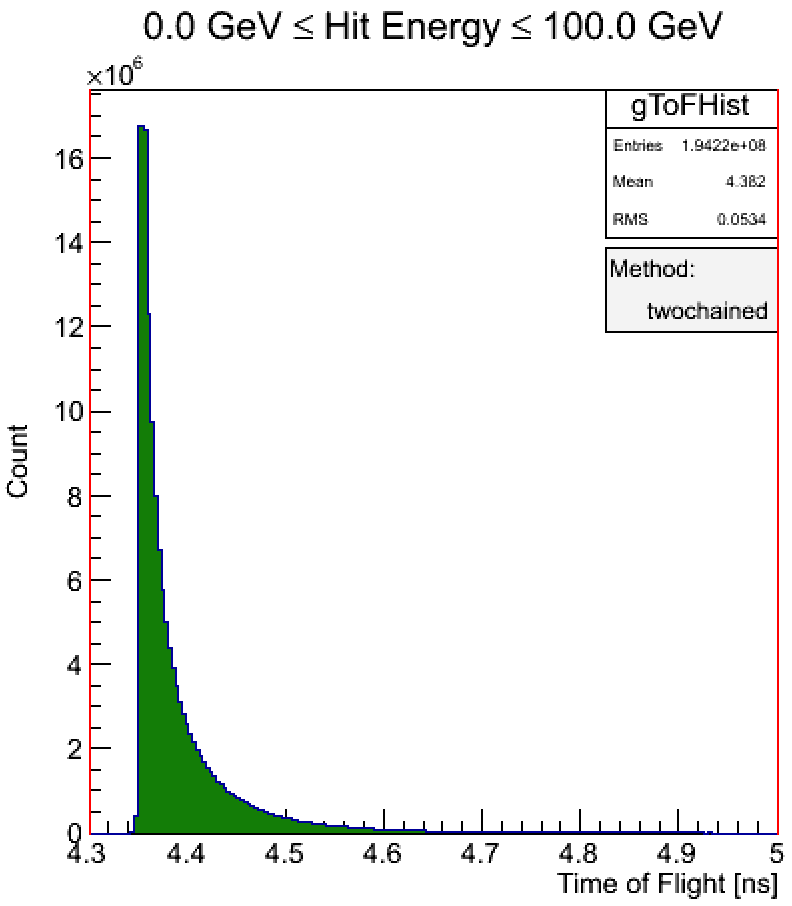
Electron 100 GeV Full

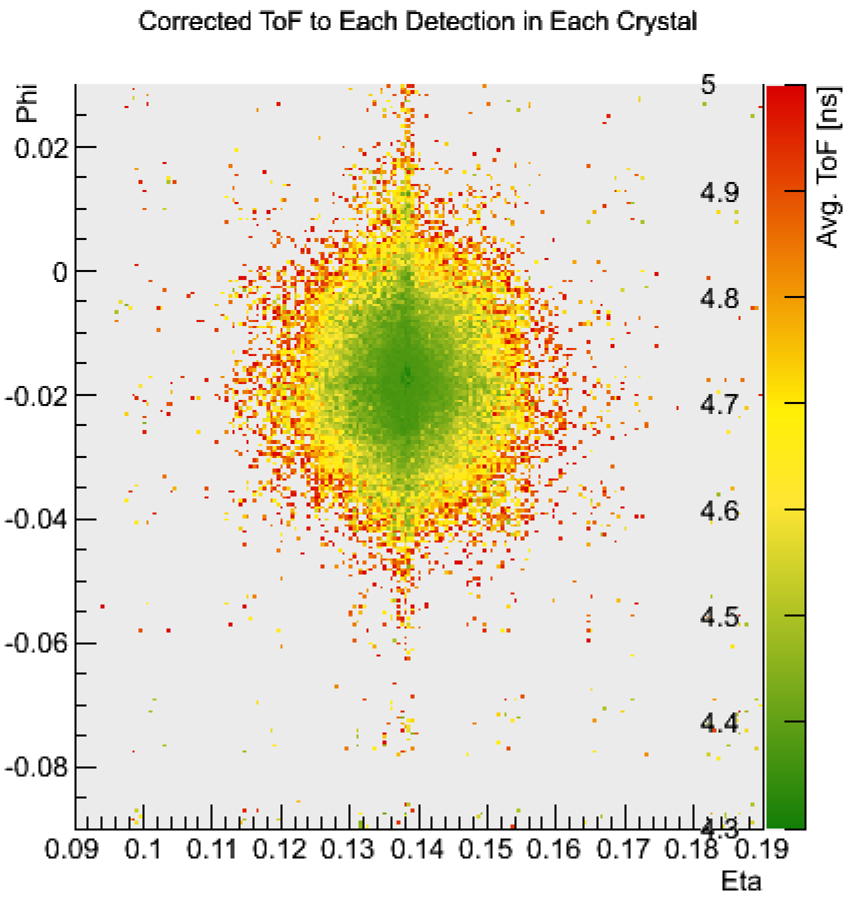




Depth Correction.

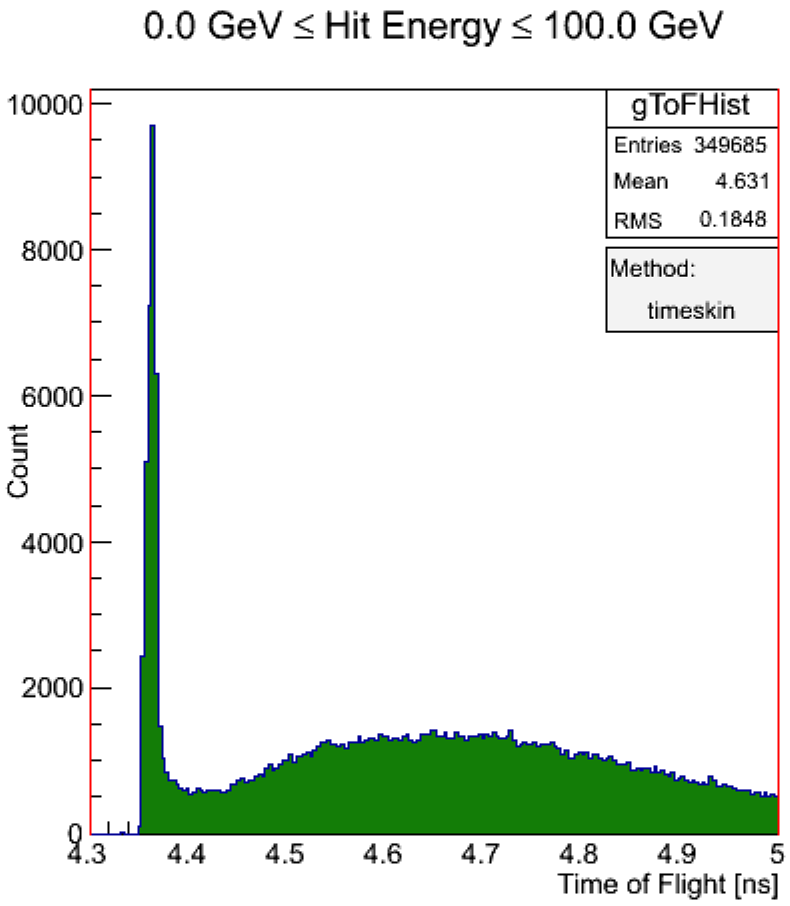
Electron 100 GeV Full

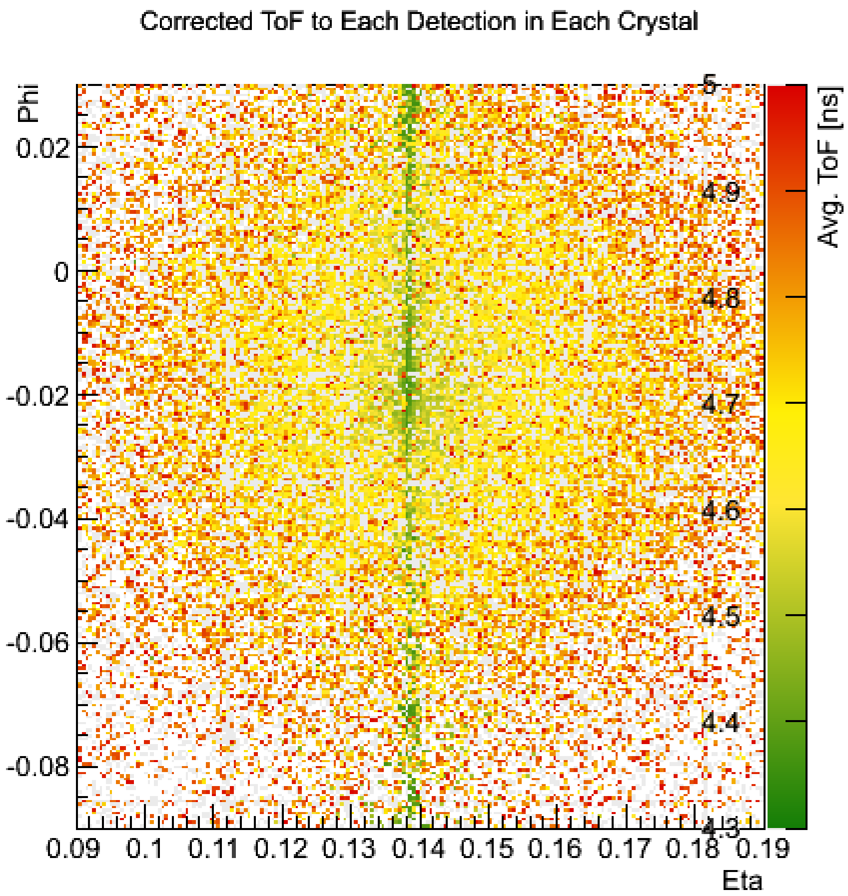




Depth Correction + Radial Correction

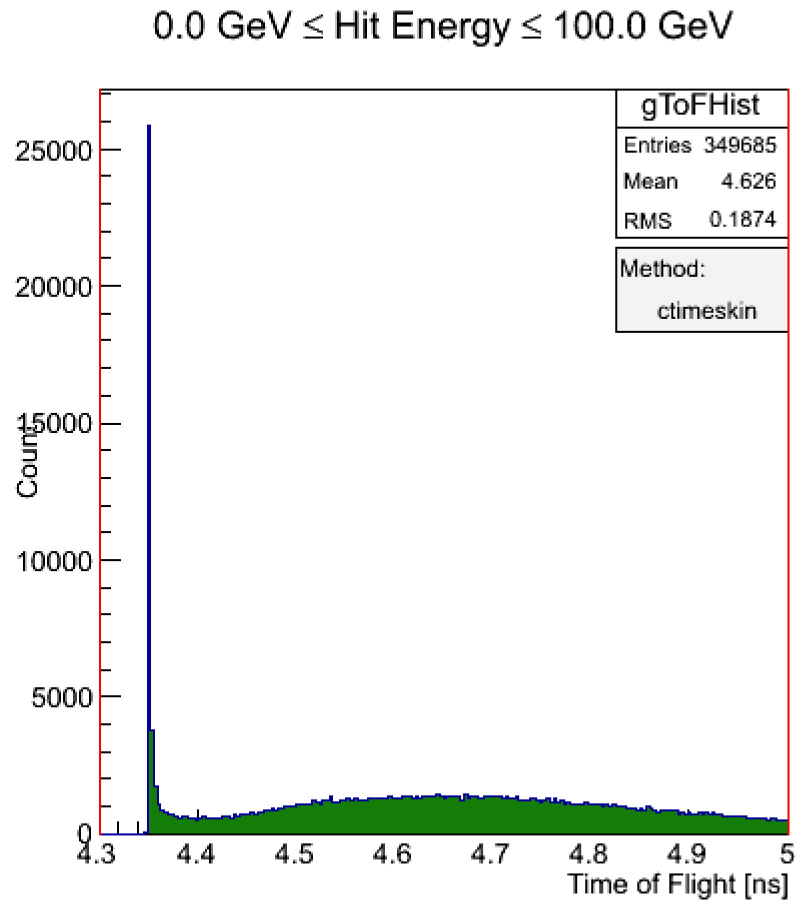
Electron 100 GeV Full

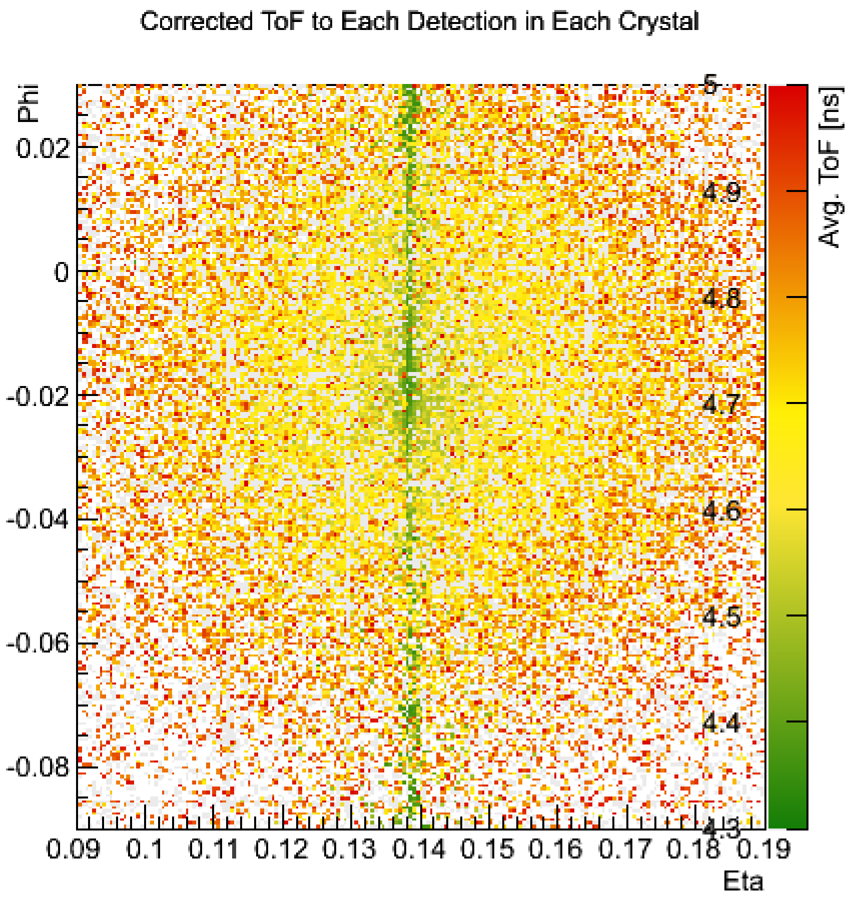




Timeskin

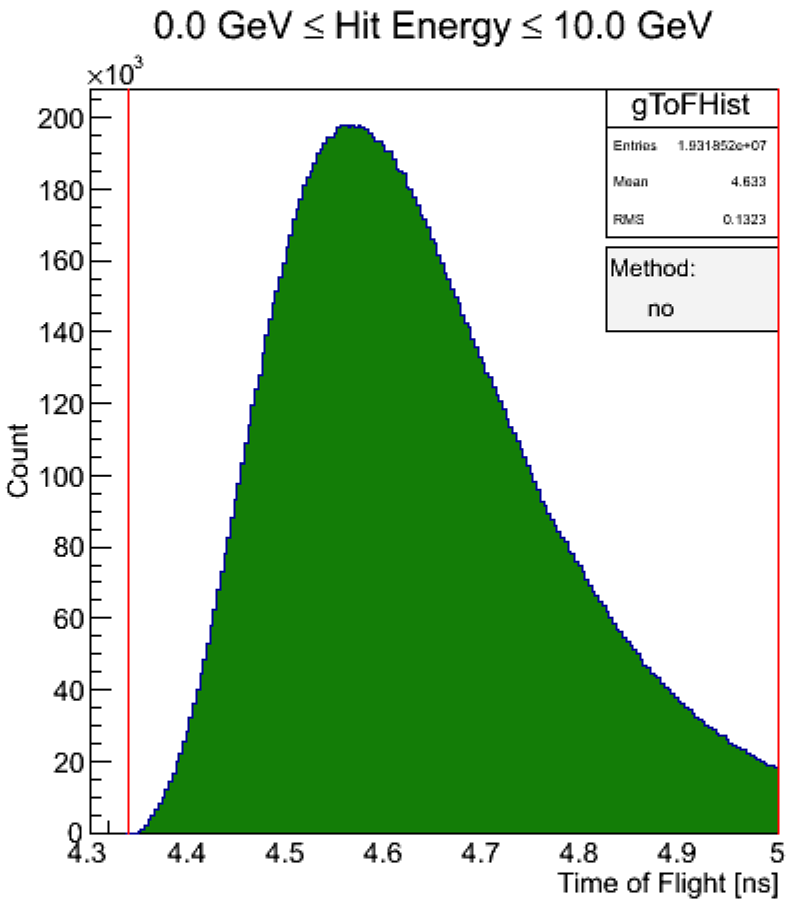
Electron 100 GeV Full

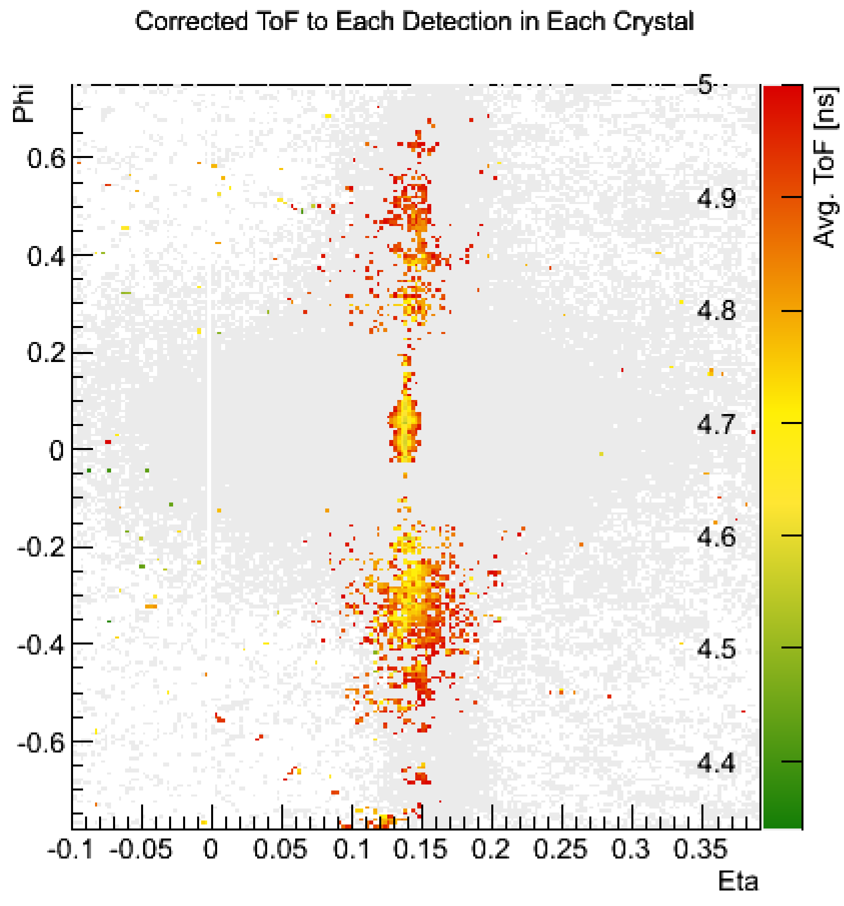




cTimeskin

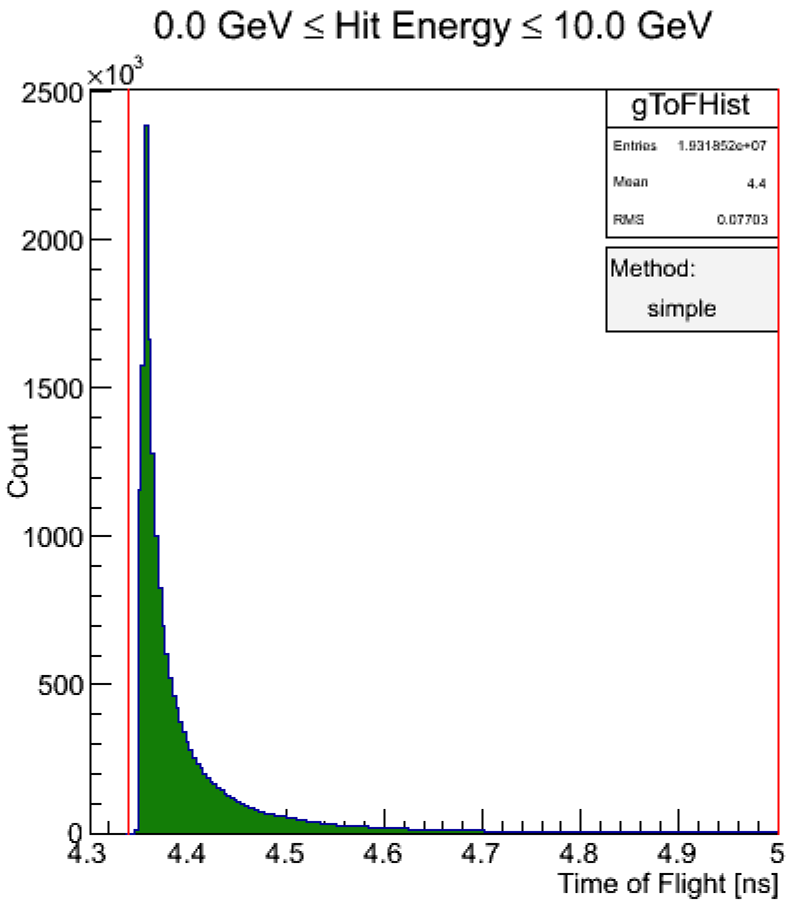
Electron 10 GeV Full

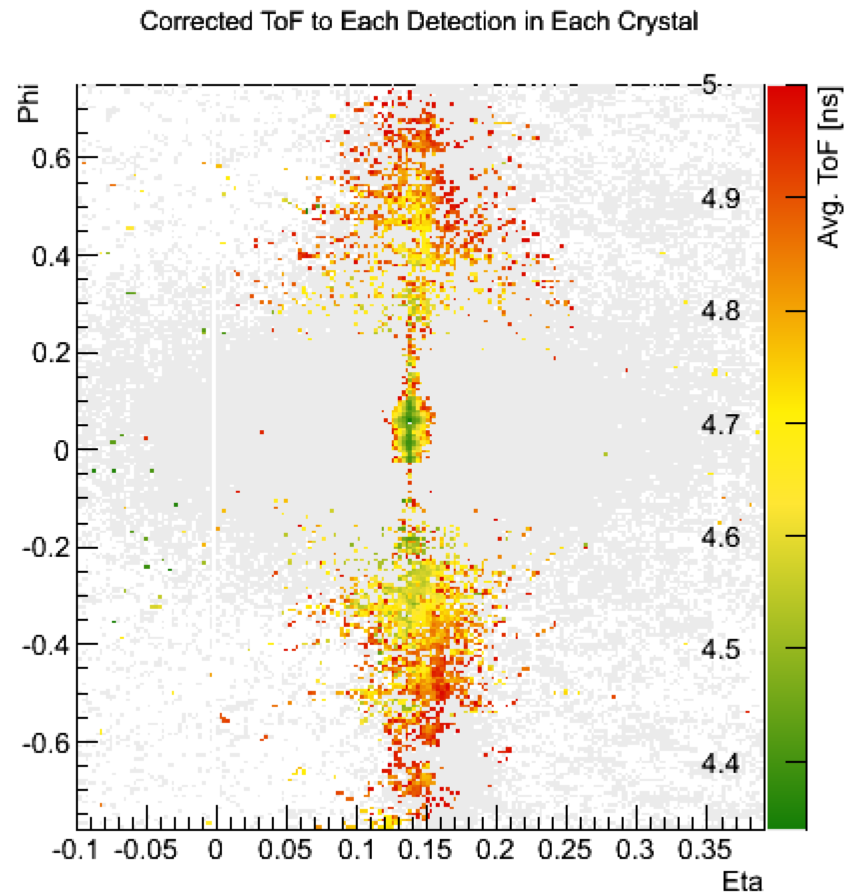




There is something interesting going on here. I'm not entirely sure what, though.

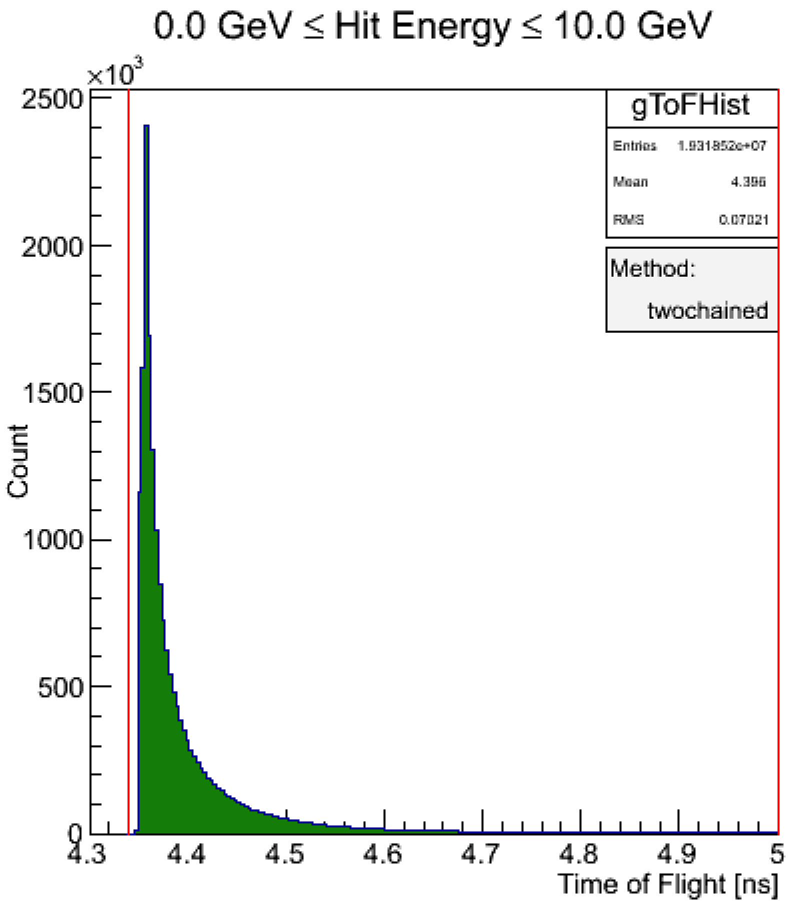
Electron 10 GeV Full

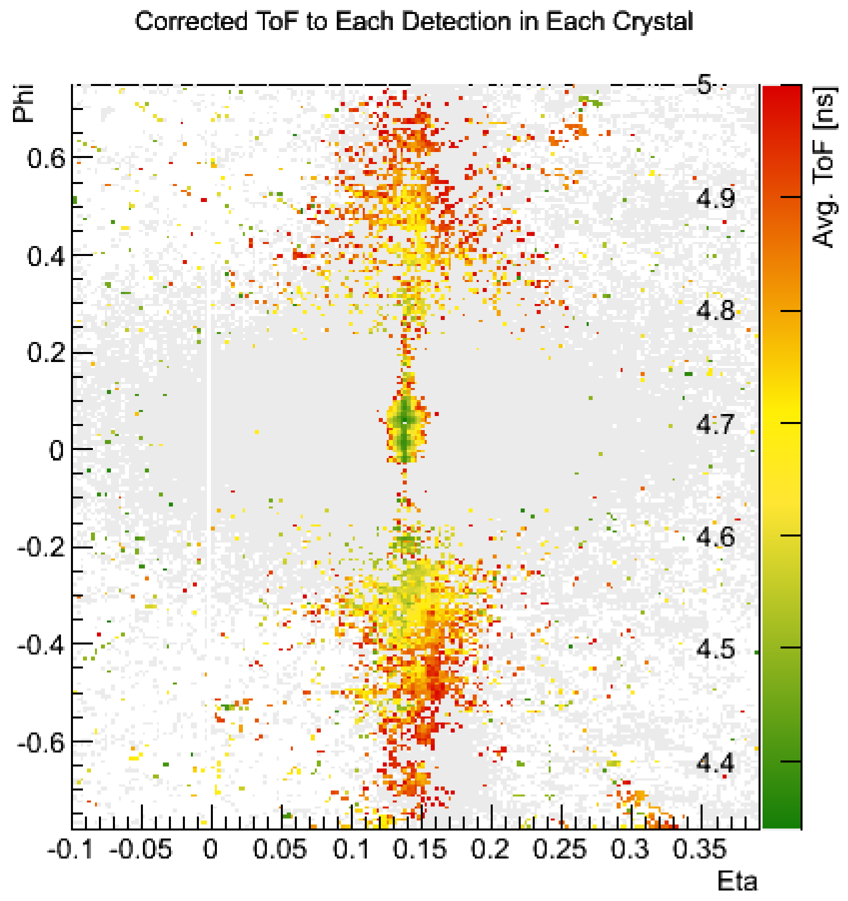




There is something interesting going on here. I'm not entirely sure what, though. Quite an interesting ToF structure.

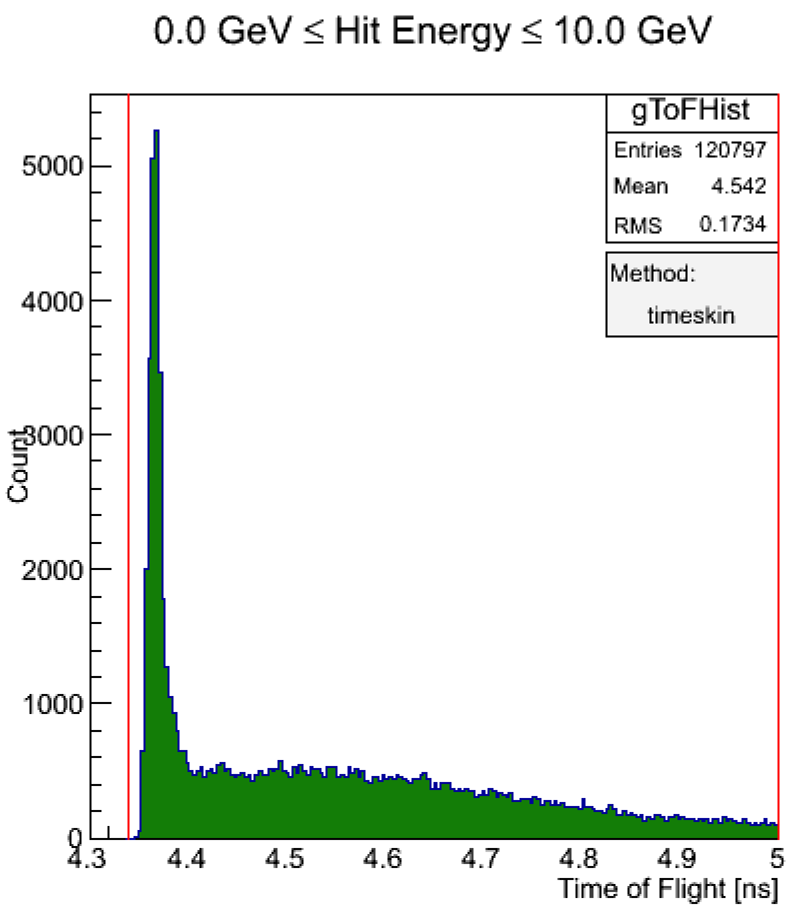
Electron 10 GeV Full

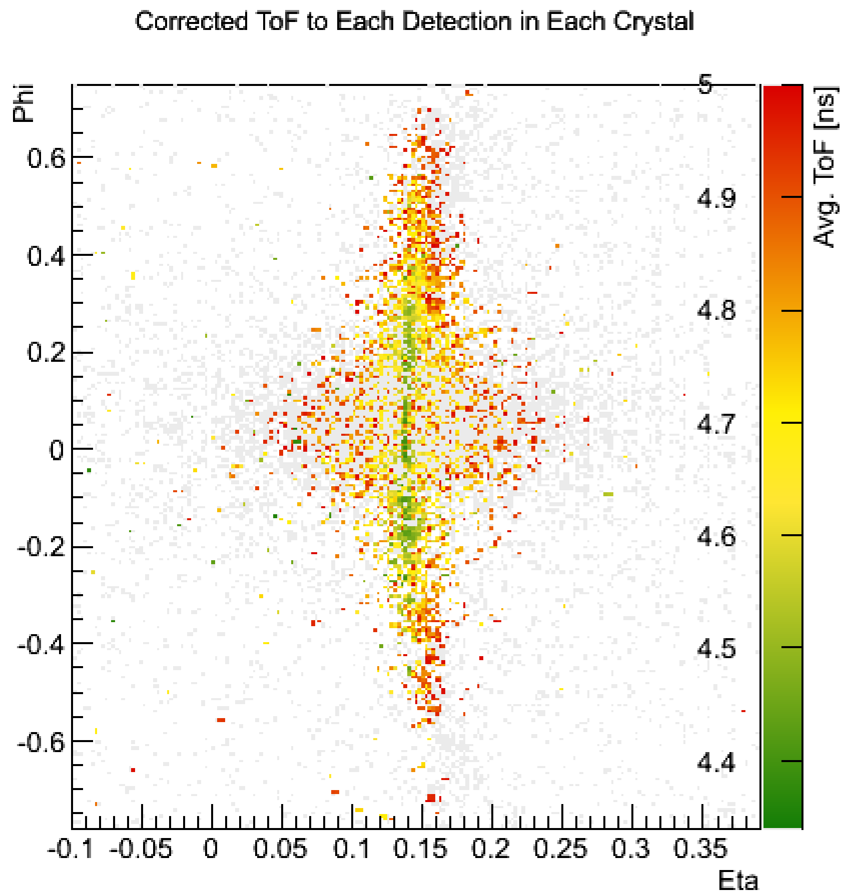




Radial correction

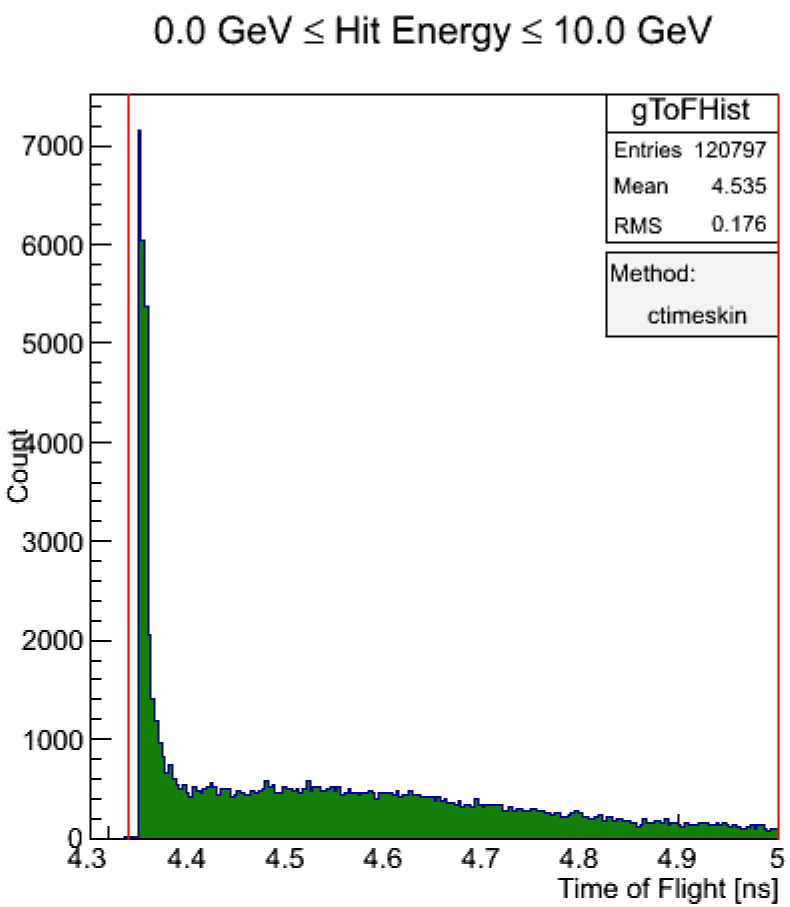
Electron 10 GeV Full

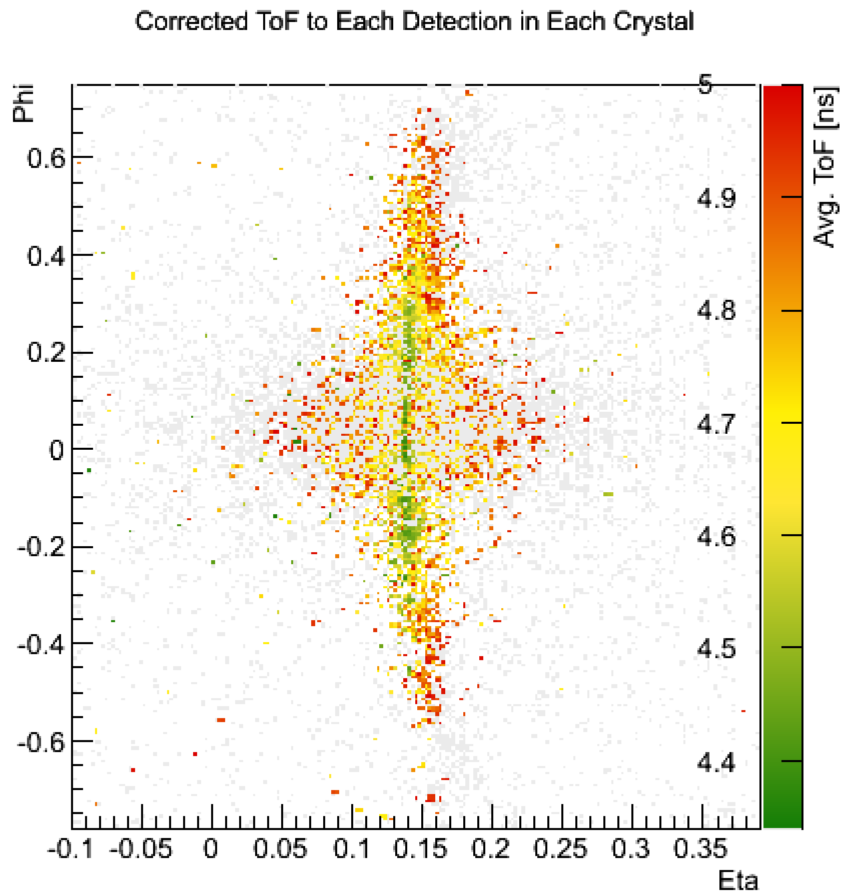




The slightly arced vertical trace is interesting.

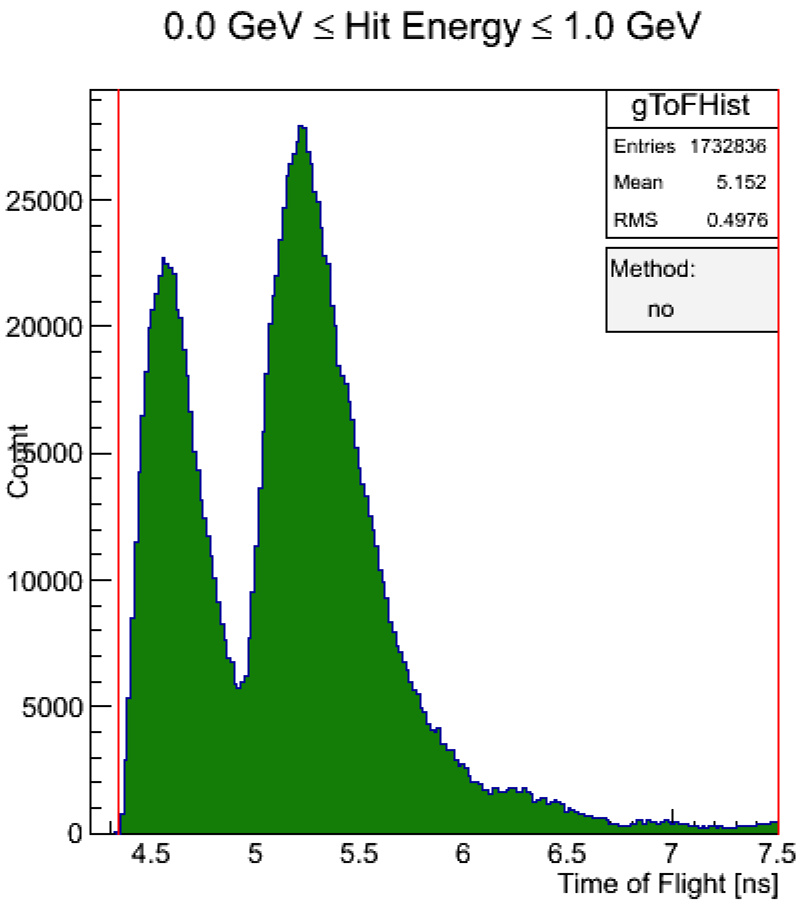
Electron 10 GeV Full

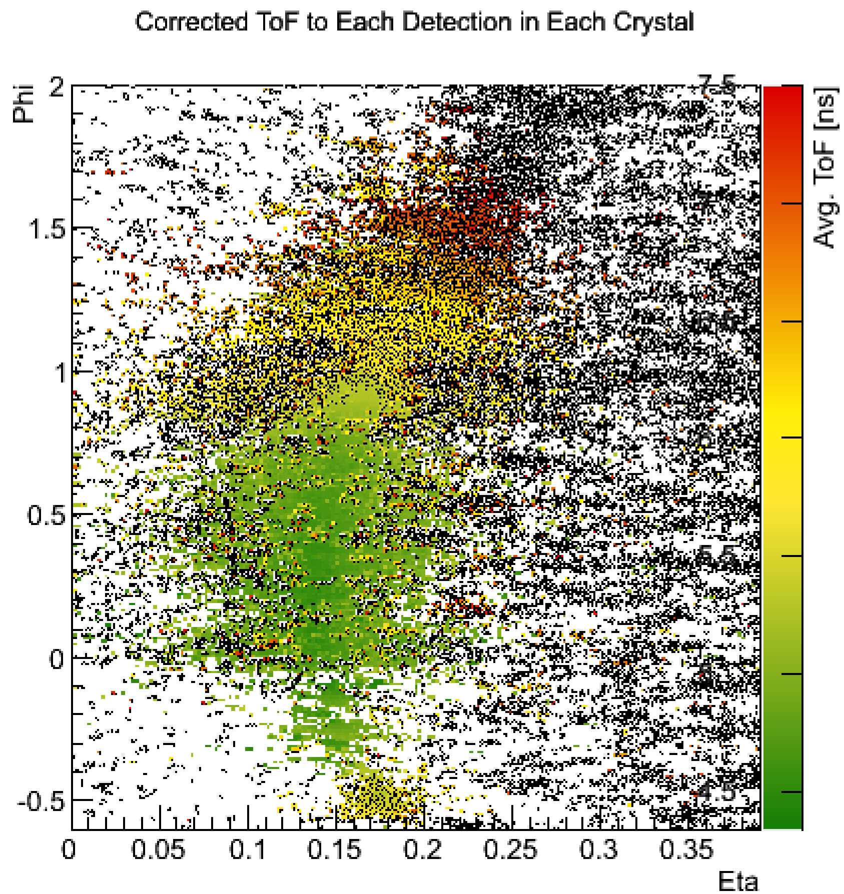




The depth correction is not as effective here as it was in previous cases. This is expected due to the increased deflection and also the more diffuse pattern.

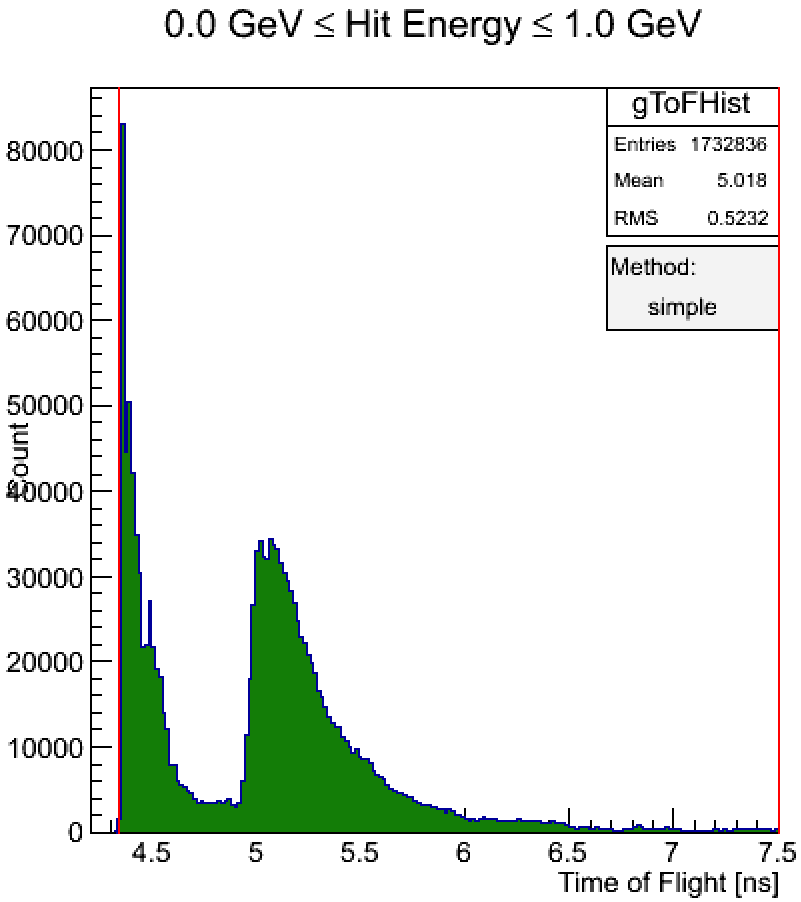
Electron 1 GeV Full

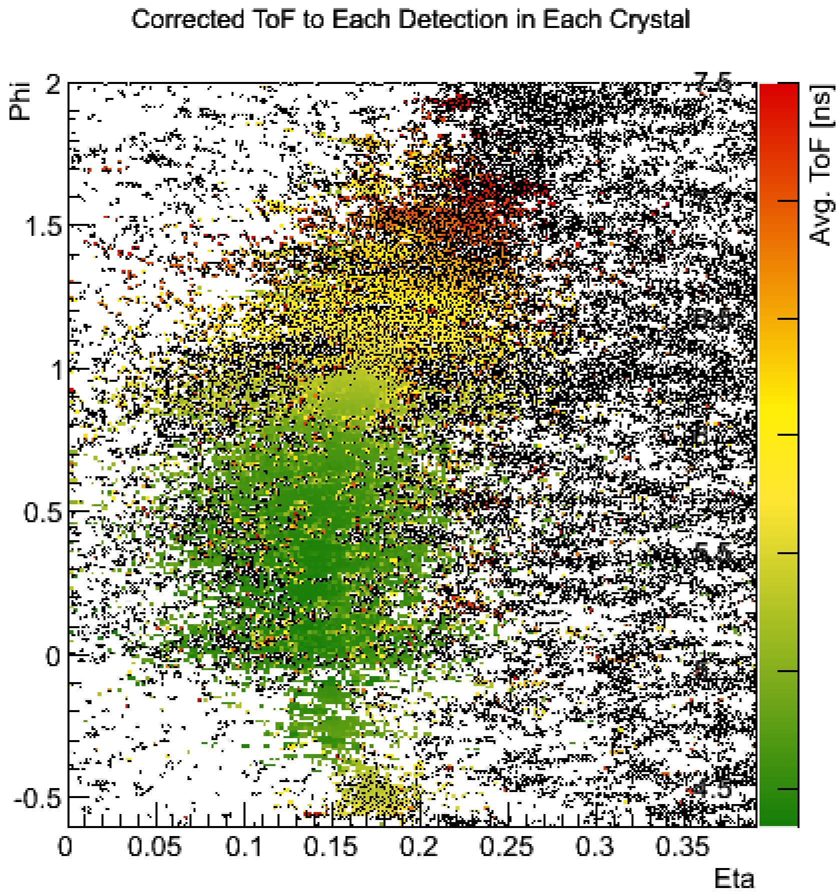




This is the raw electron data. The black spots everywhere are due to some sort of ROOT glitch – It's showing actual hits, but the regions aren't being greyed-out like they are supposed to be. Regardless, all the black dots are events that fall outside of the ToF cut.

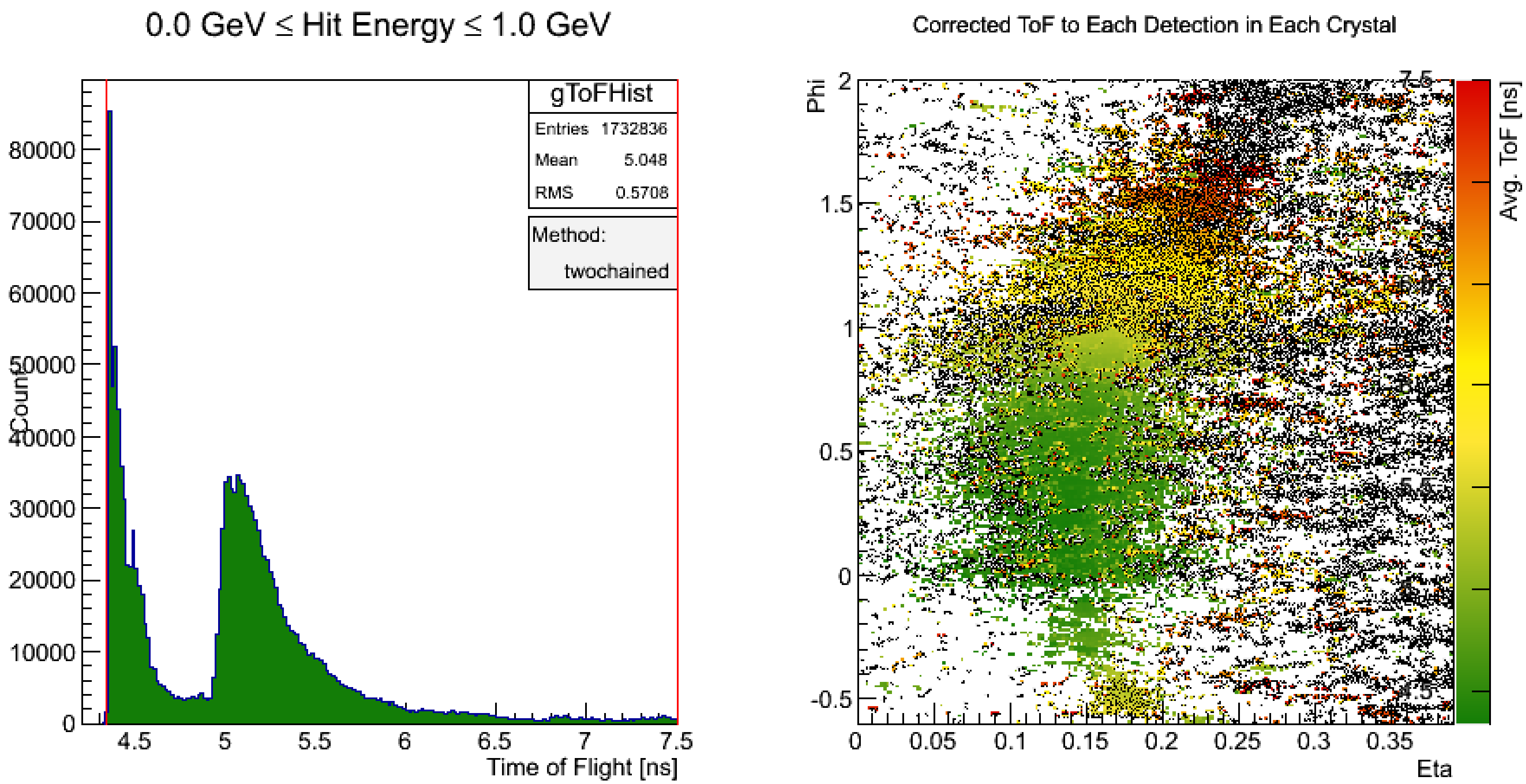
Electron 1 GeV Full





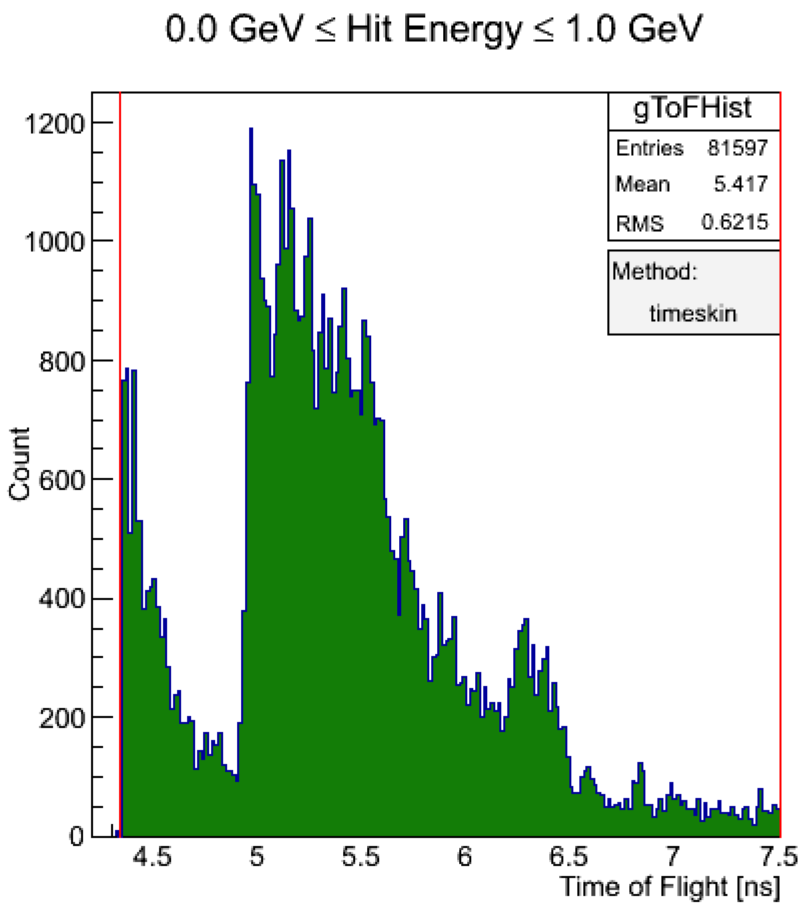
Simple depth correction. Perhaps the lead arrival of the photon emitted by bremsstrahlung is a good measure of arrival? It would be emitted earlier in the deflection so less of its path will be curved, albeit only slightly.

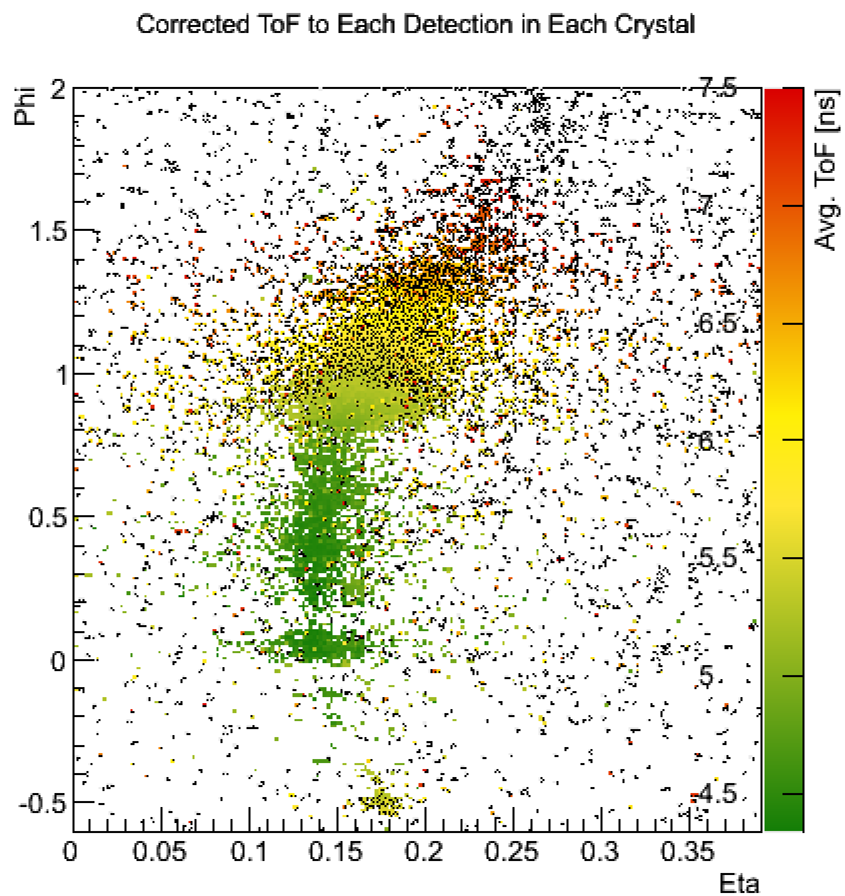
Electron 1 GeV Full



Radial distance correction does not help too much.

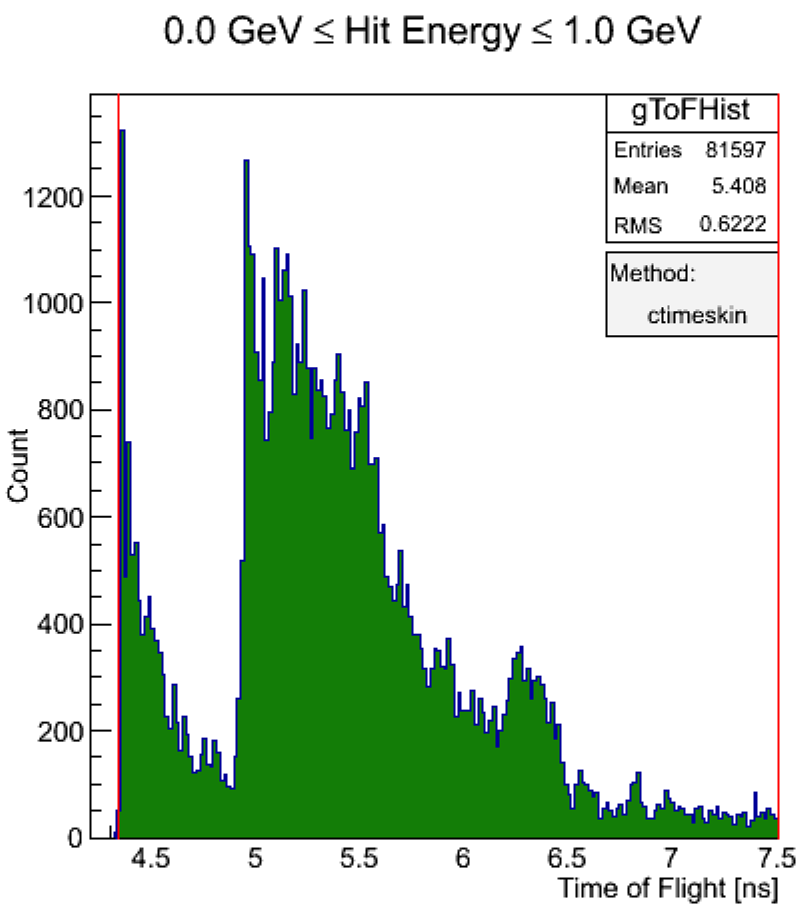
Electron 1 GeV Full

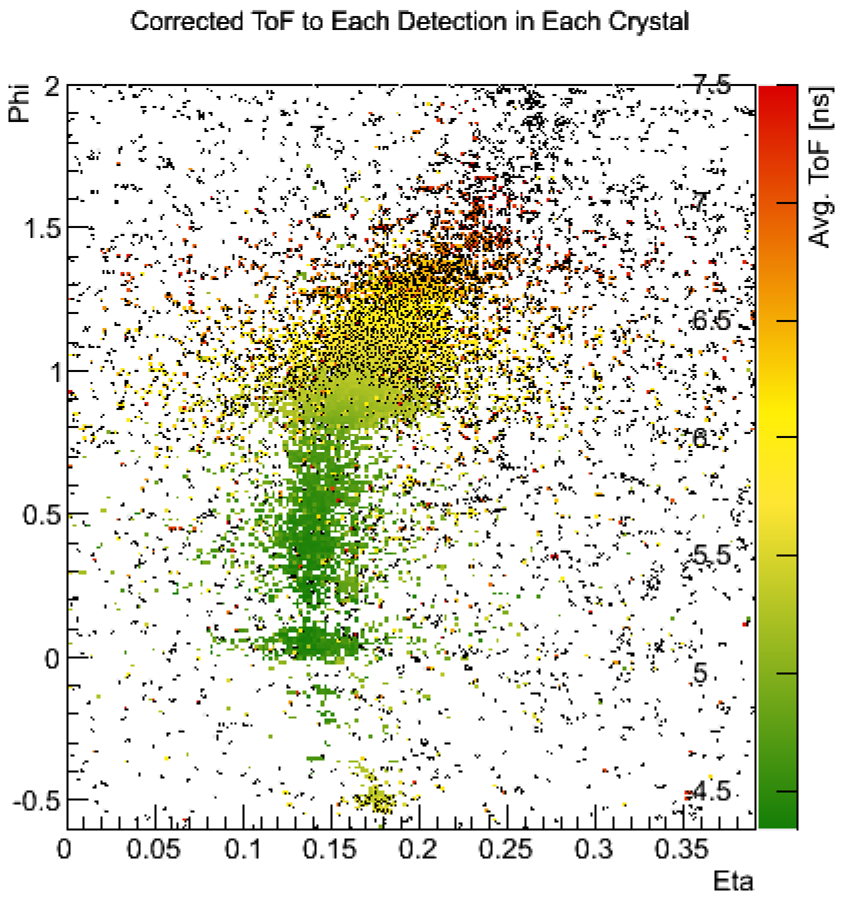




Interestingly, by applying the 5mm timeskin, the electron arrival gets further emphasized while the photon arrivals decrease. Perhaps this may indicate that electrons react faster when entering the crystal? After all, the photon usually undergoes conversion first, which may reduce the efficiency of detection within such a thin layer.

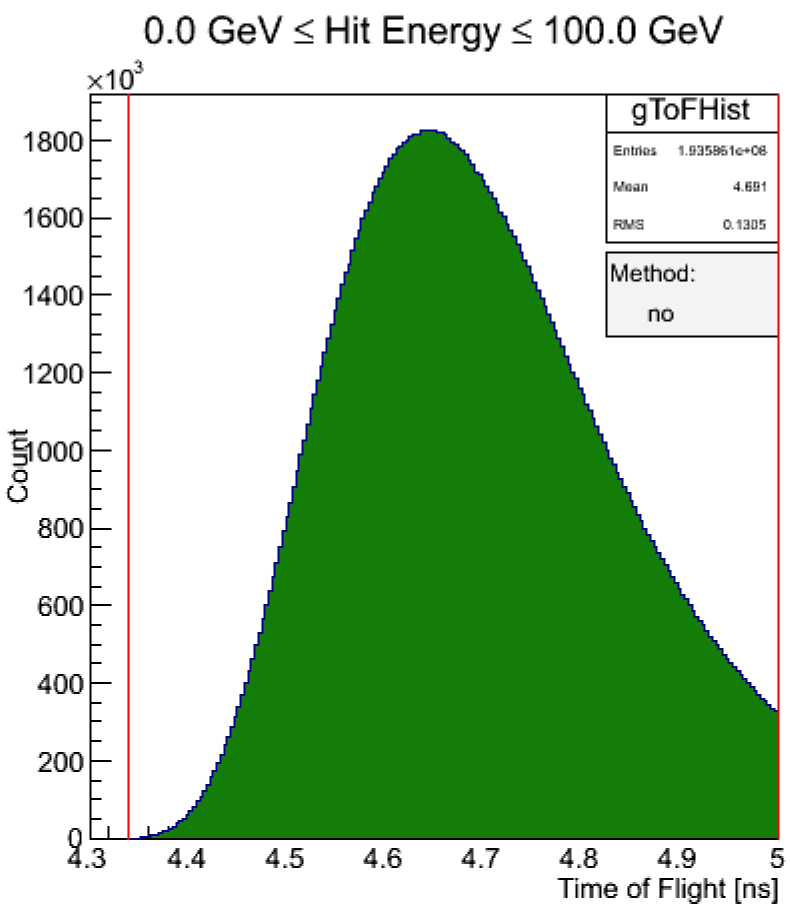
Electron 1 GeV Full

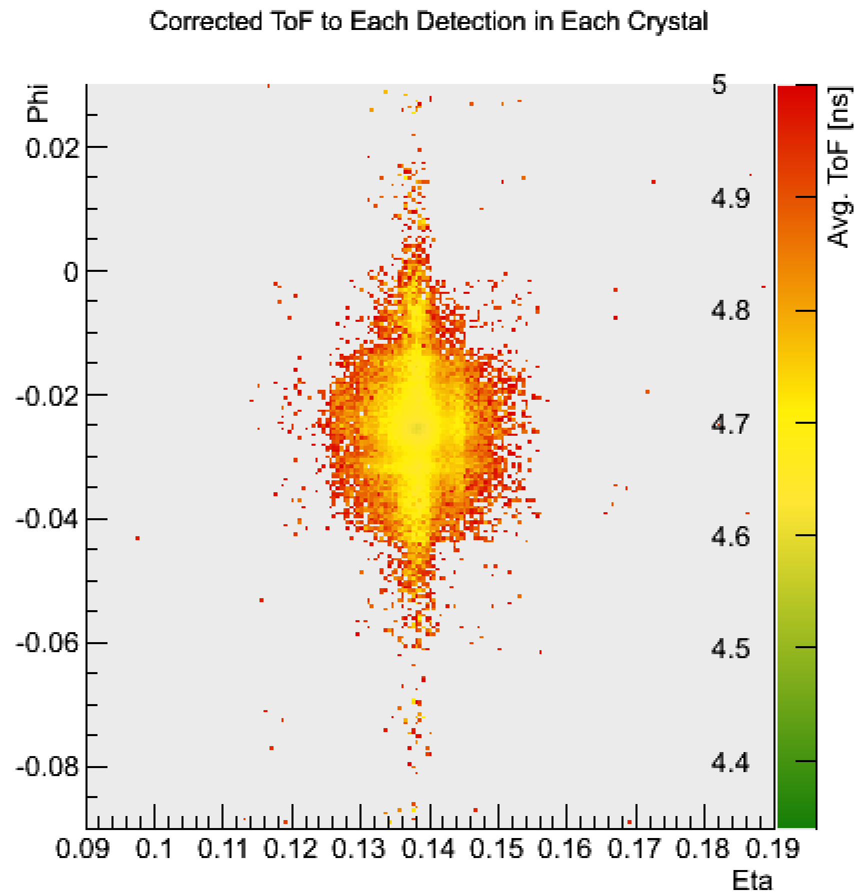




Depth correction does not help with the timeskin too much. This indicates that the time spread has quite a lot to do with the diffuseness of the pattern, and not so much with the depth.

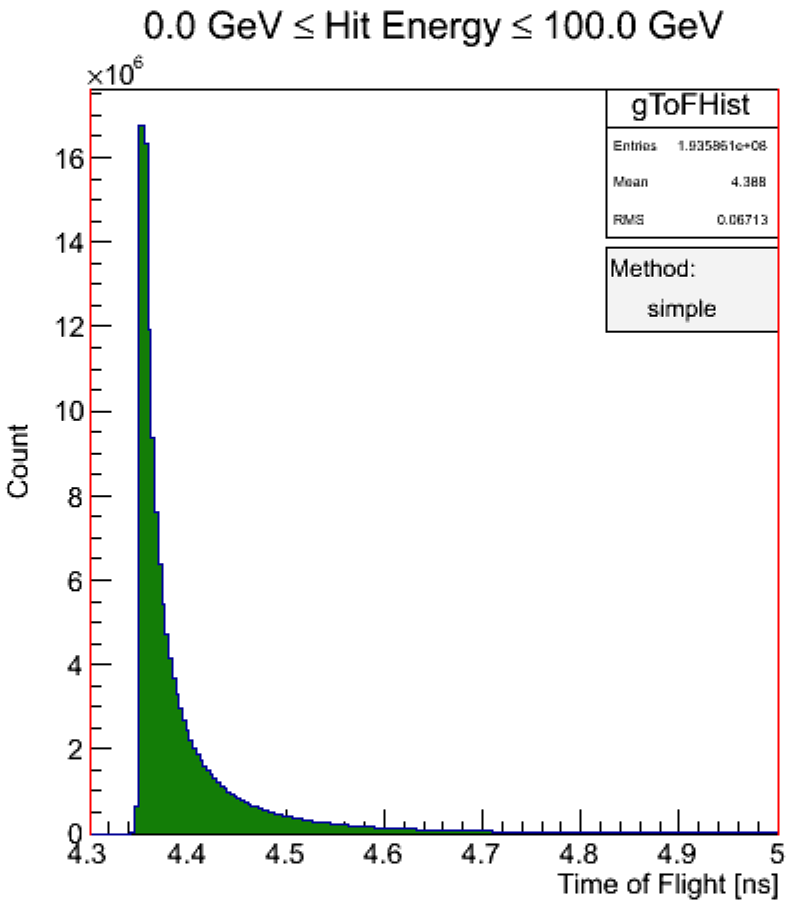
Pi0 100 GeV Full

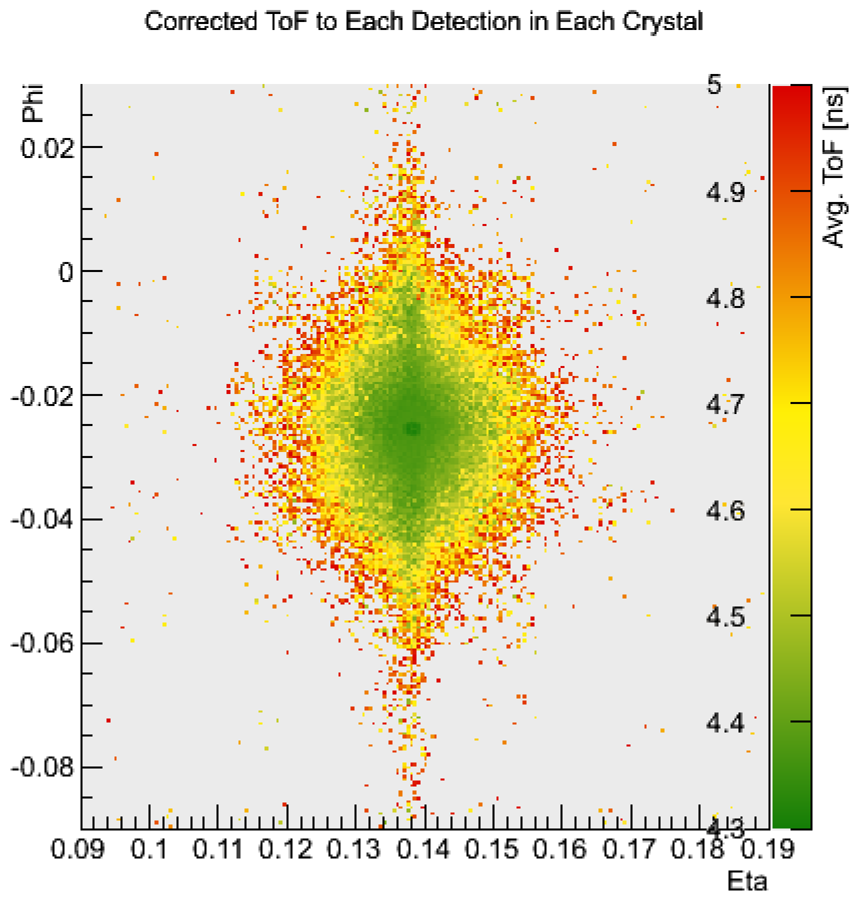




The pattern looks extremely similar to that of the 100 GeV photon, which could be a problem if we want to tell the difference between the two.

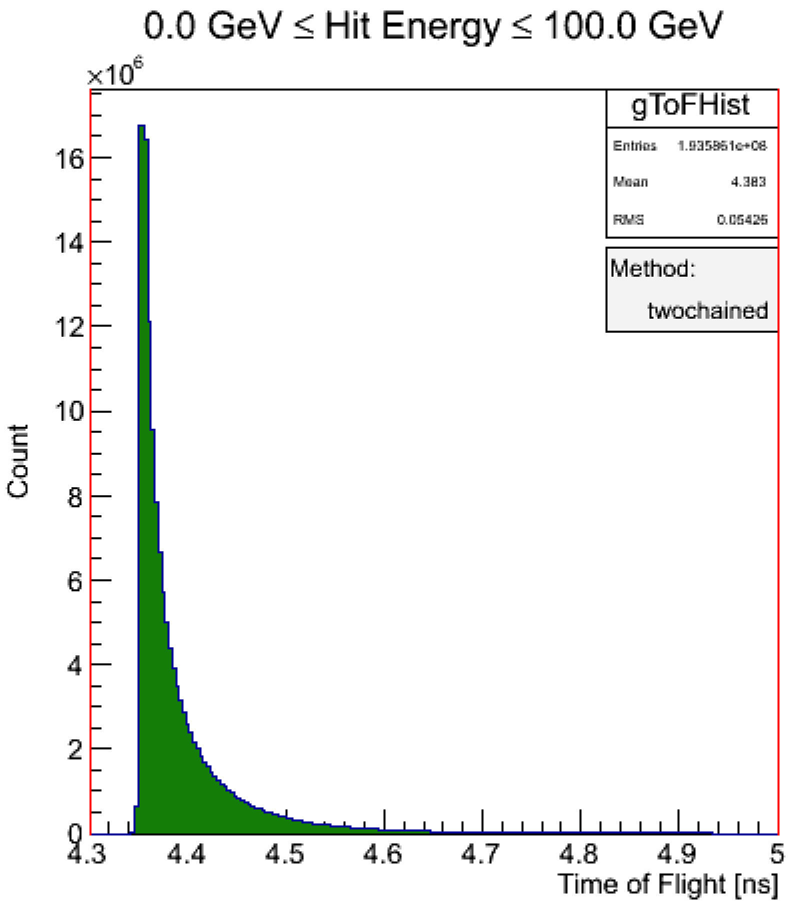
Pi0 100 GeV Full

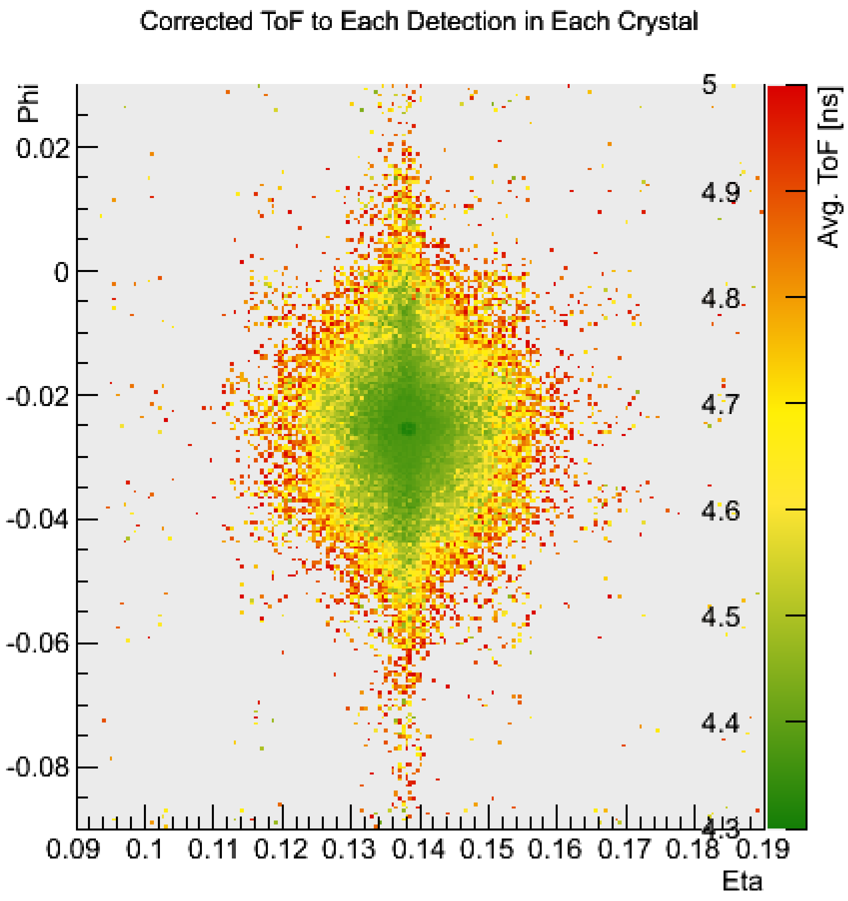




If compared to the photon 100 GeV depth corrected plot, you would notice that this pattern looks a little more spread in the phi. Interesting.

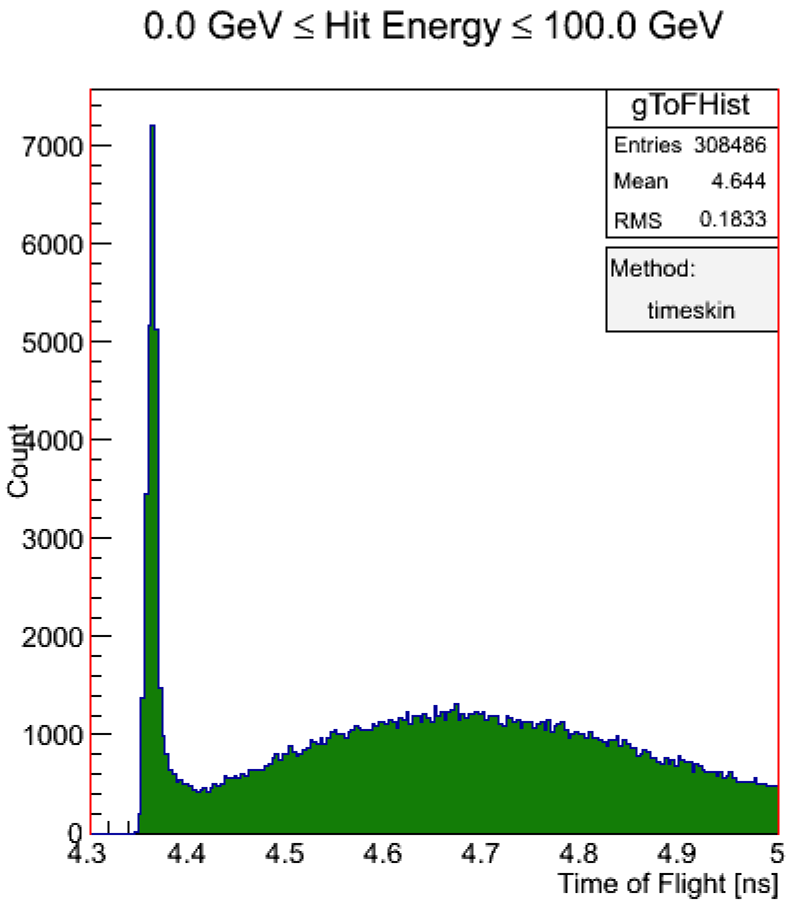
Pi0 100 GeV Full

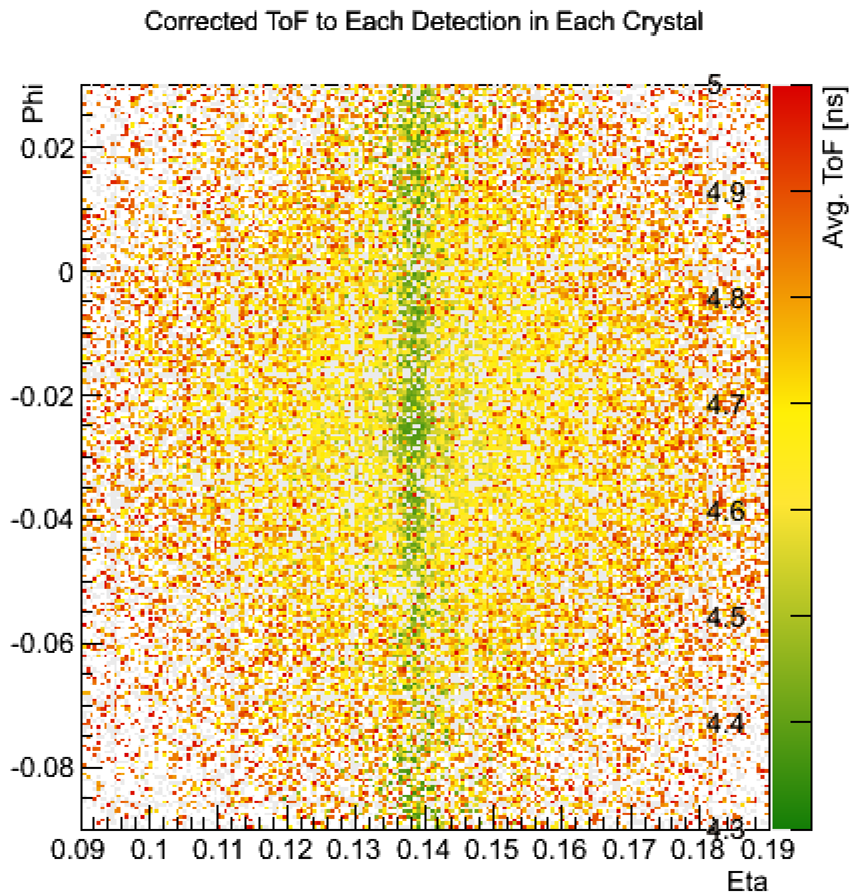




Radially corrected.

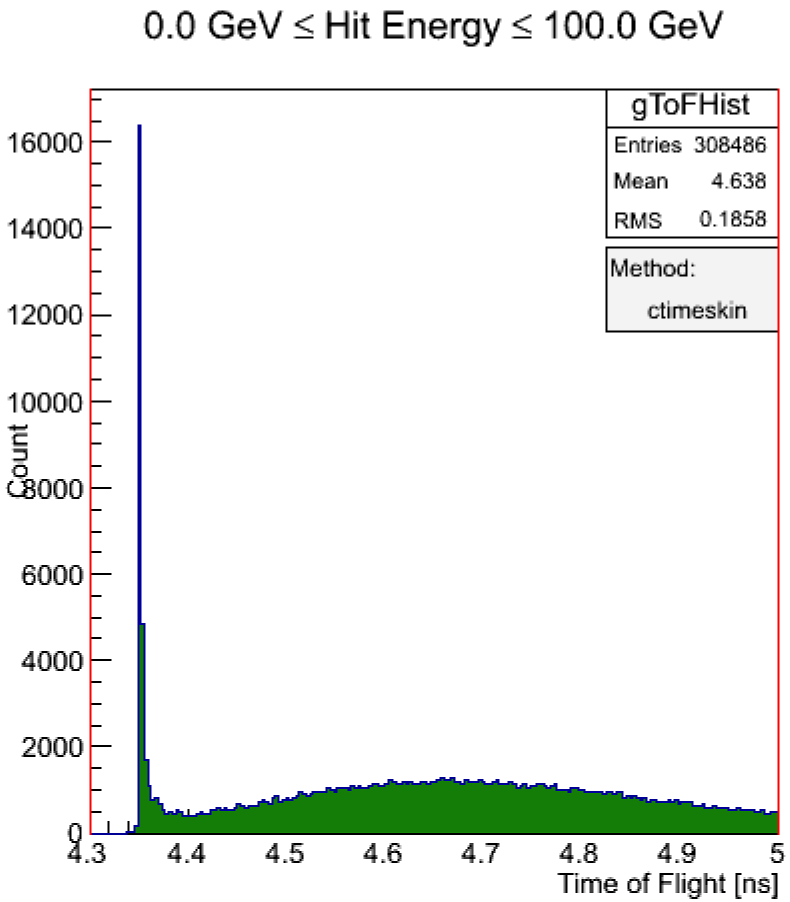
Pi0 100 GeV Full

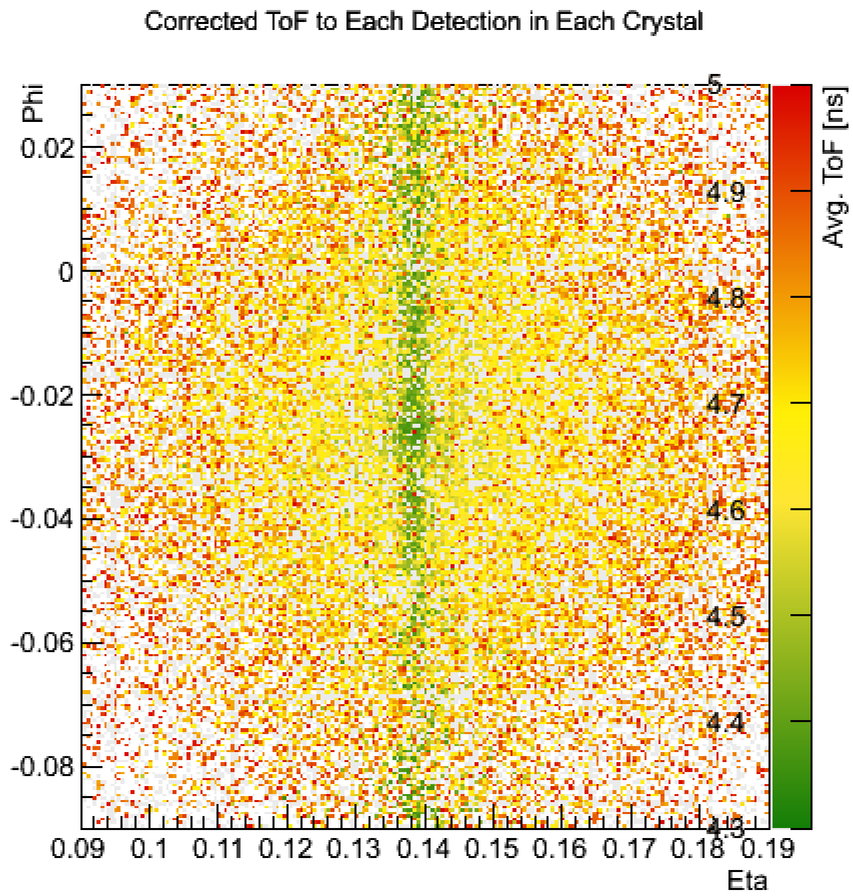




Still looks similar to the 100 GeV photon

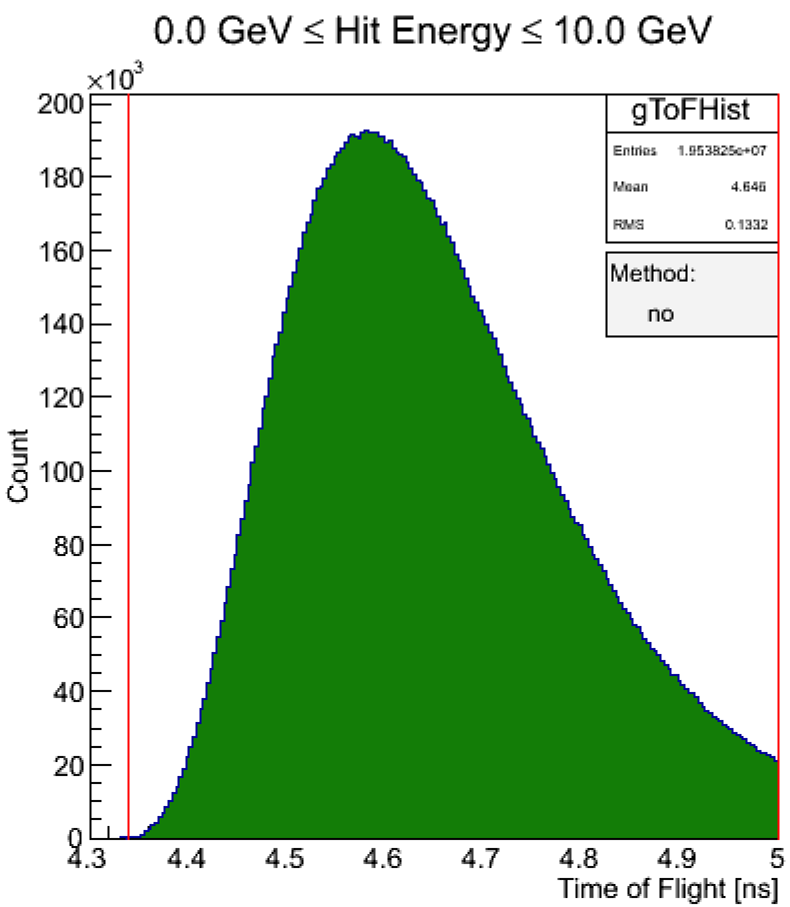
Pi0 100 GeV Full

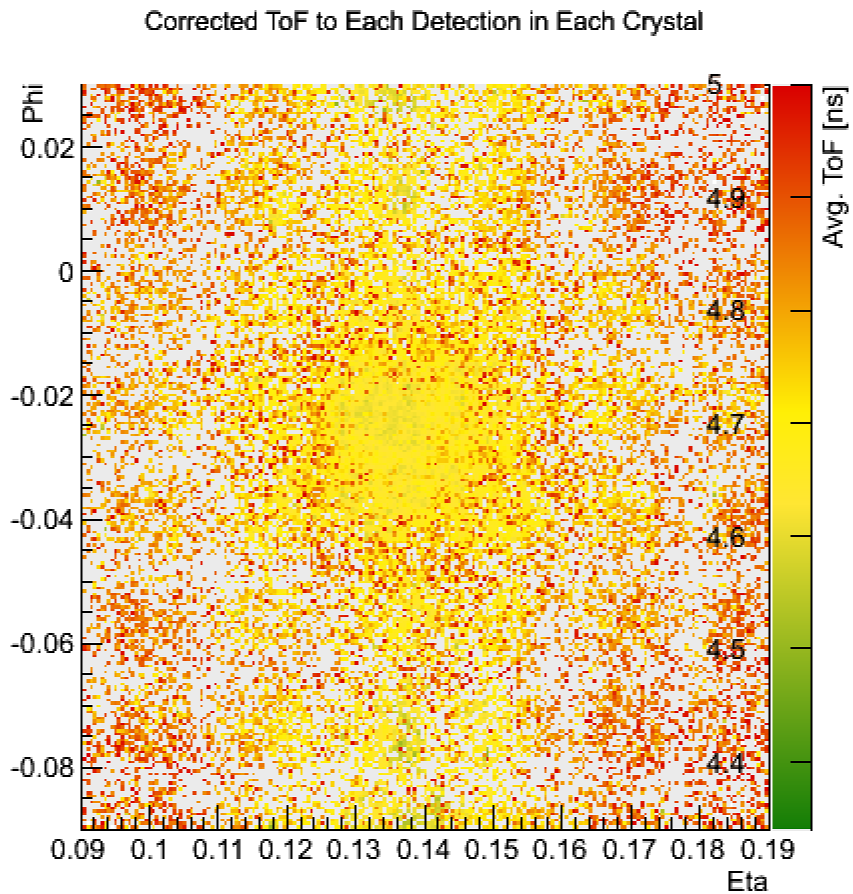




cTimeskin

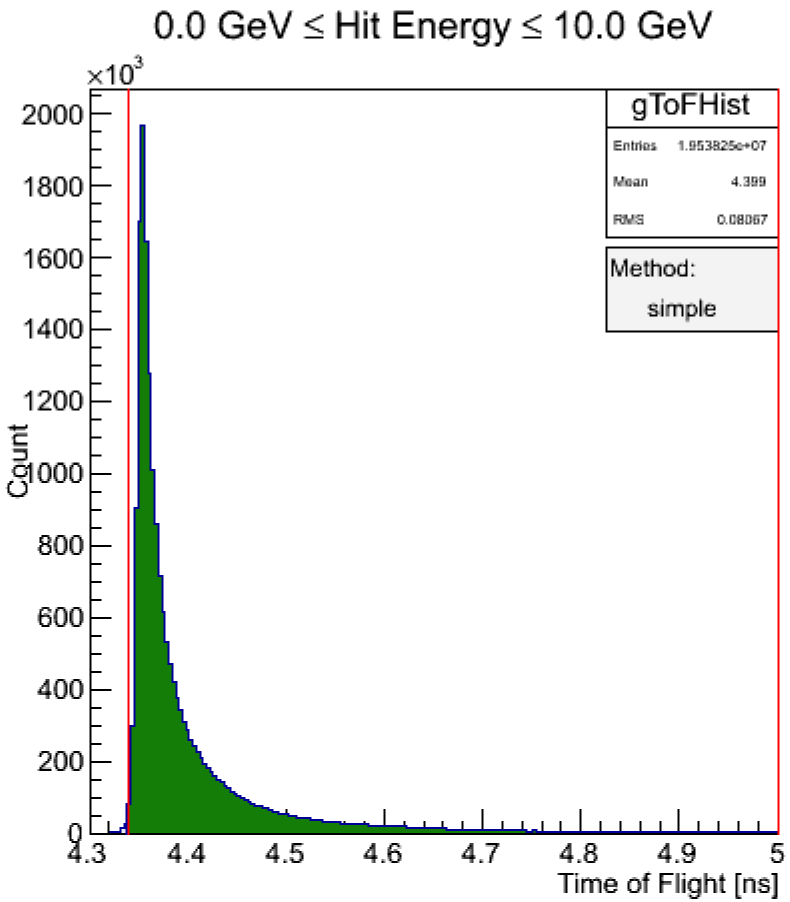
Pi0 10 GeV Full

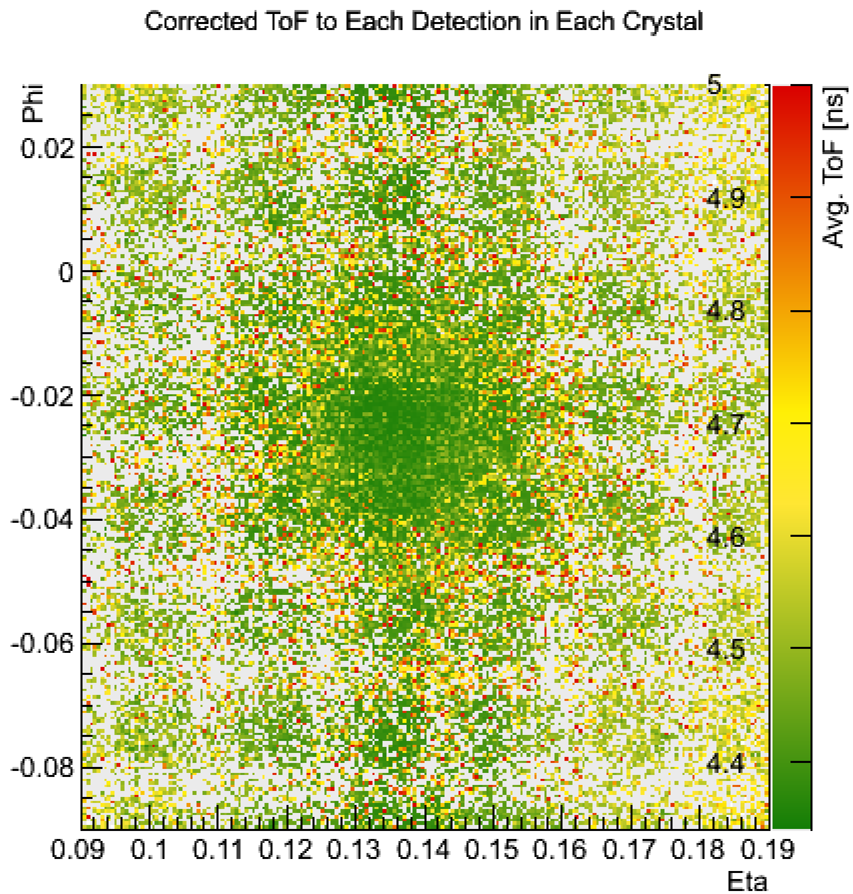




Not sure there's much to notice other than the eta-phi pattern looks a bit different from the 10 GeV photon. The yellow center band is thicker, essentially.

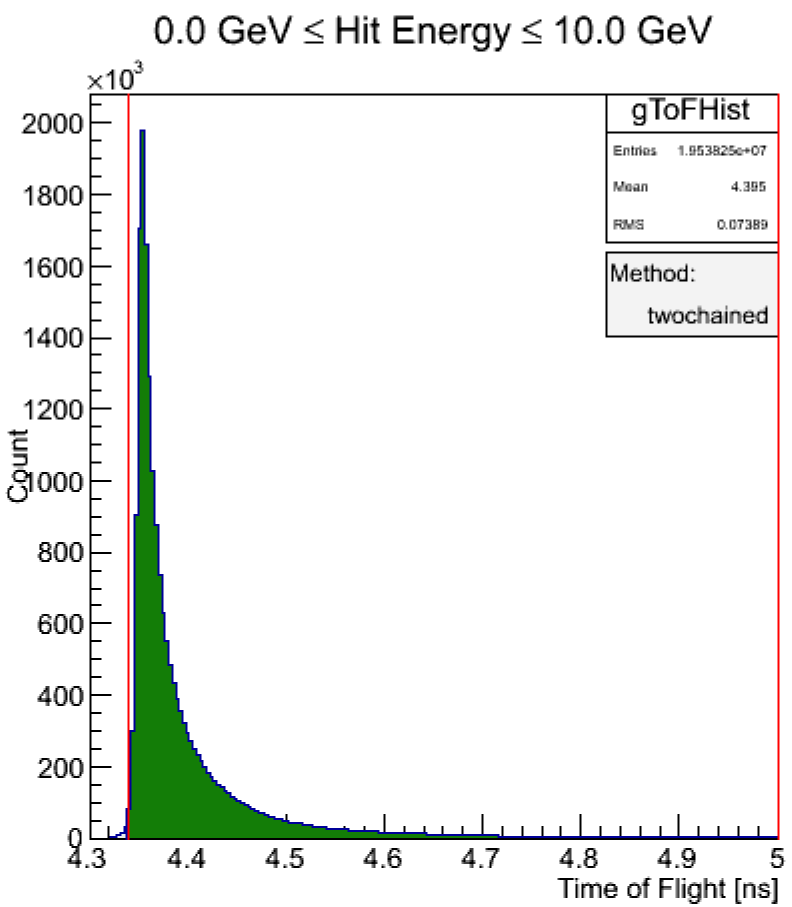
Pi0 10 GeV Full

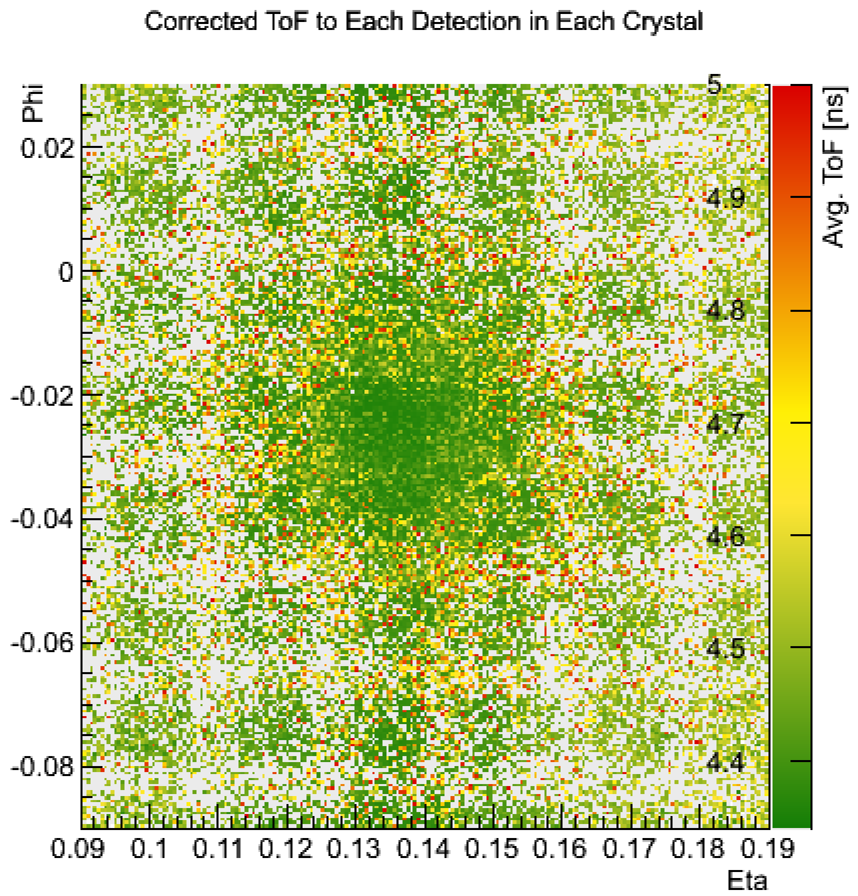




Interestingly, unlike the 10 GeV photon, the ToF is less tight, and so is the eta-phi pattern. This may be due the Pi0 converting into 2 photons, each separating by a small angle, increasing the path length by making it nonlinear

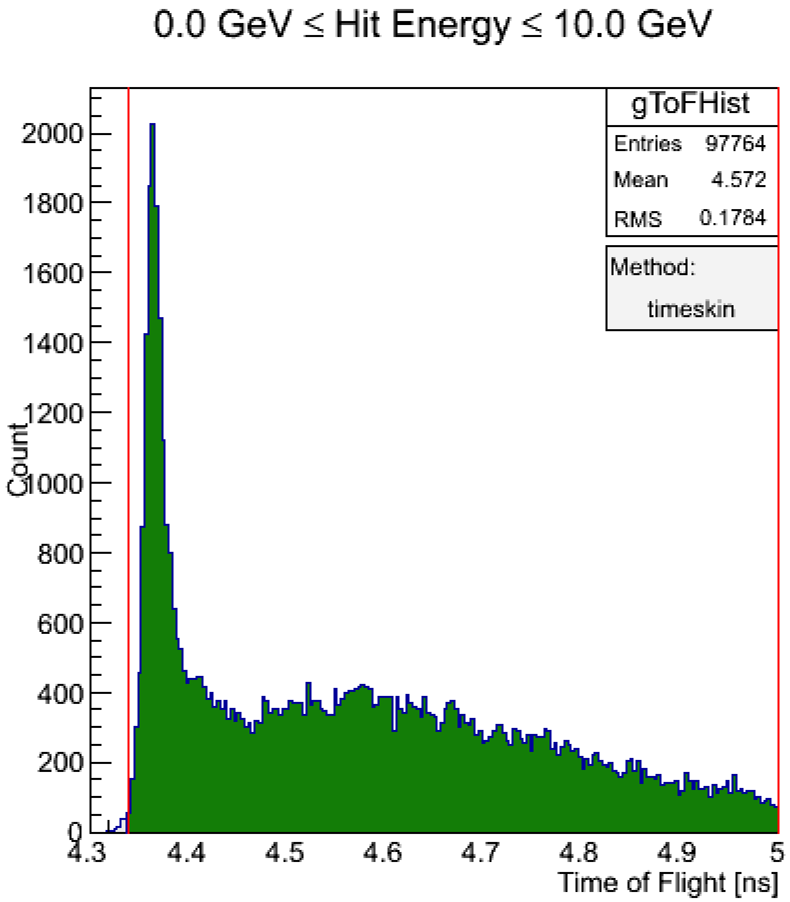
Pi0 10 GeV Full

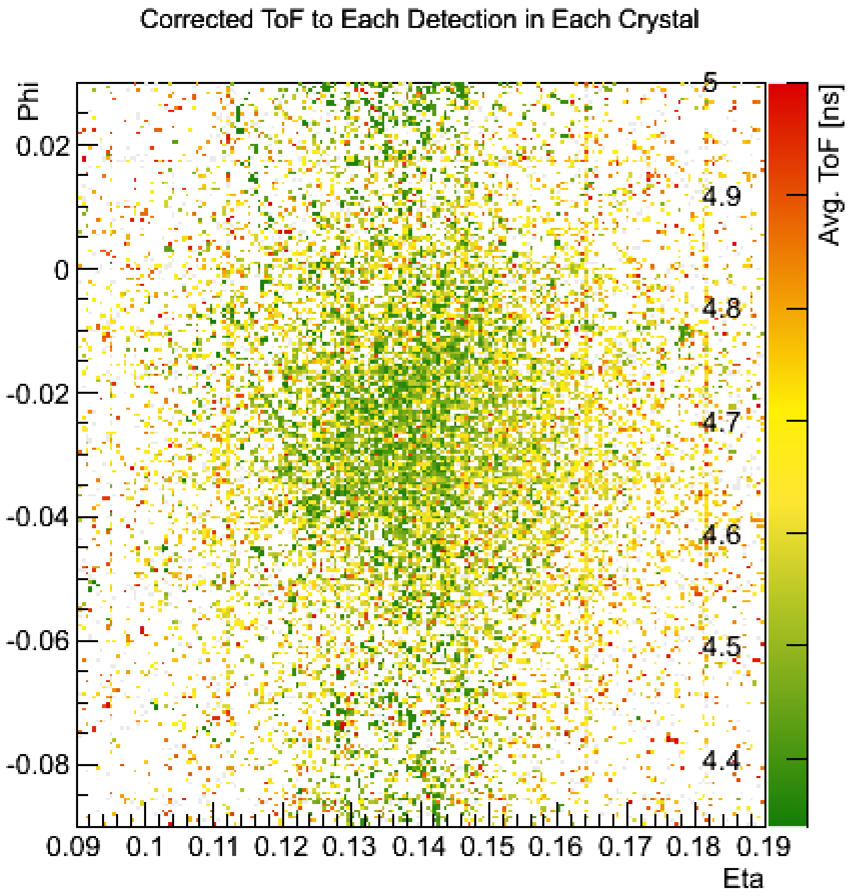




Radial corrections hardly make a difference.

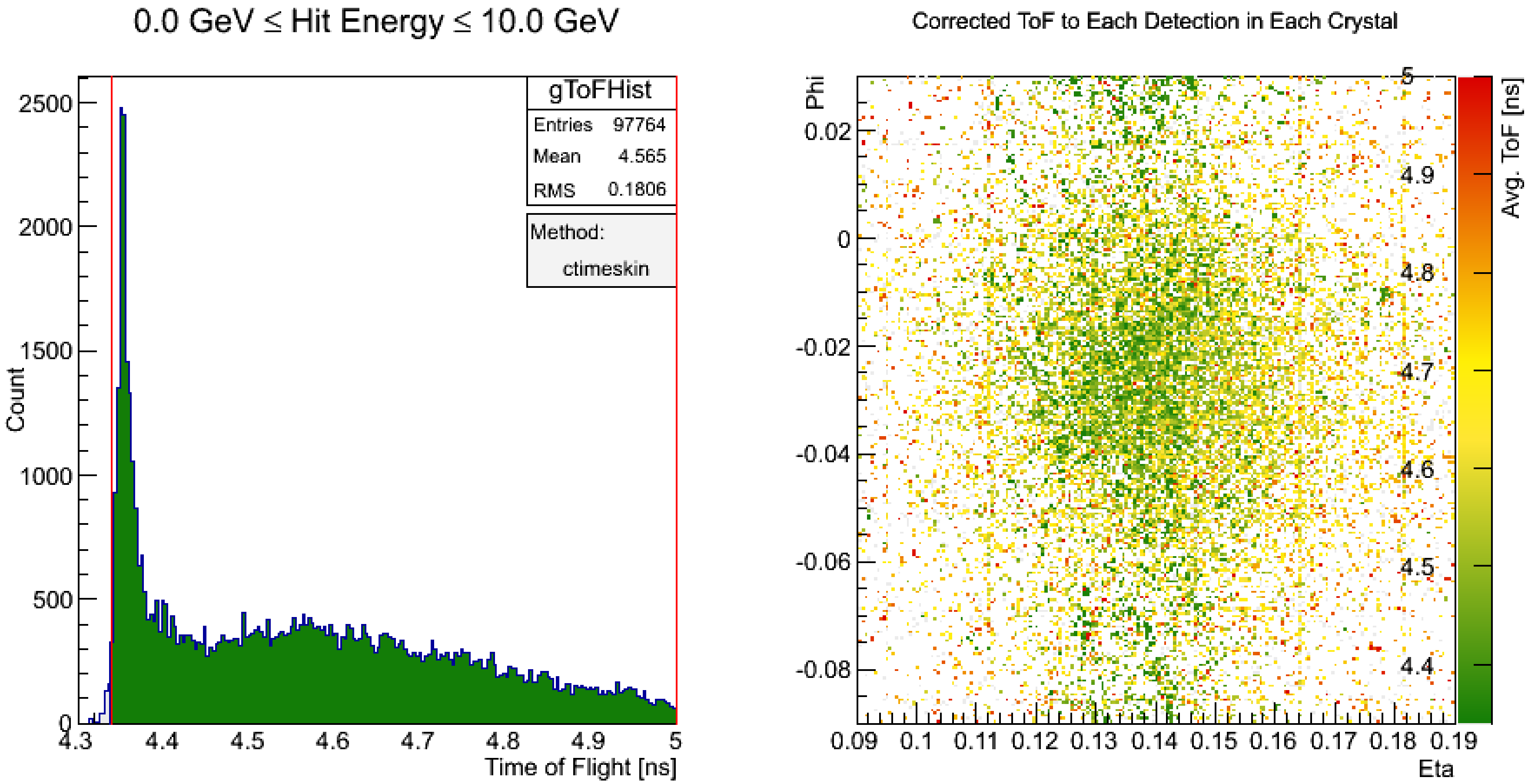
Pi0 10 GeV Full





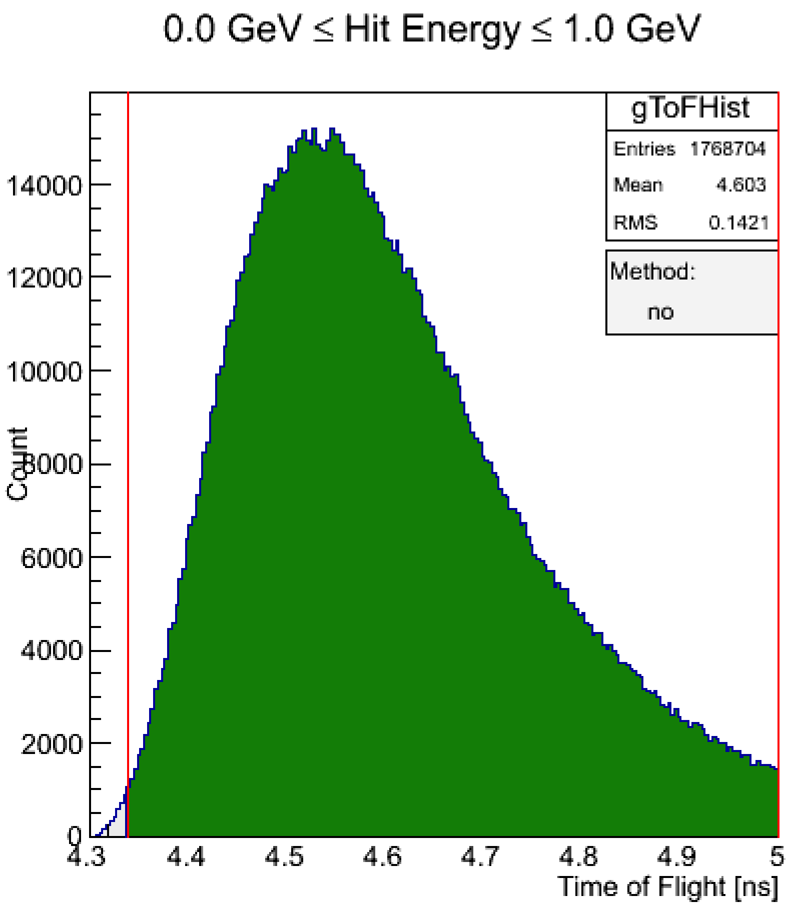
timeskin

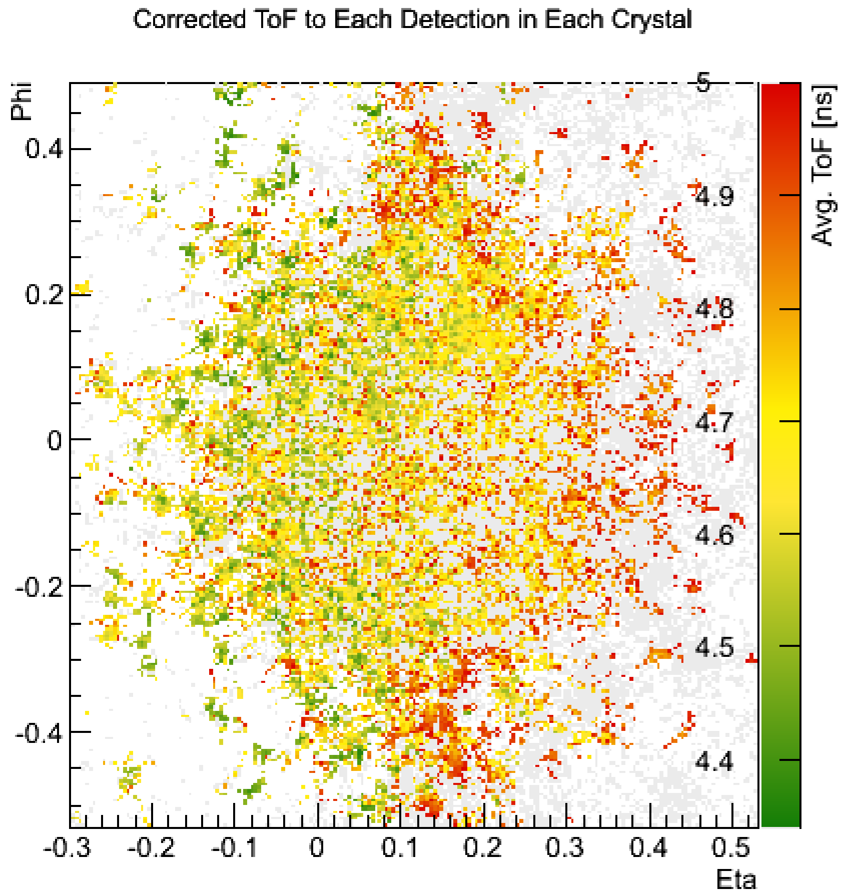
Pi0 10 GeV Full



Depth correction does not help too much, with the timeskin. It's probably because the hits are so diffuse that the additional ToF smearing due to depth does not make too much of a difference.

Pi0 1 GeV Full

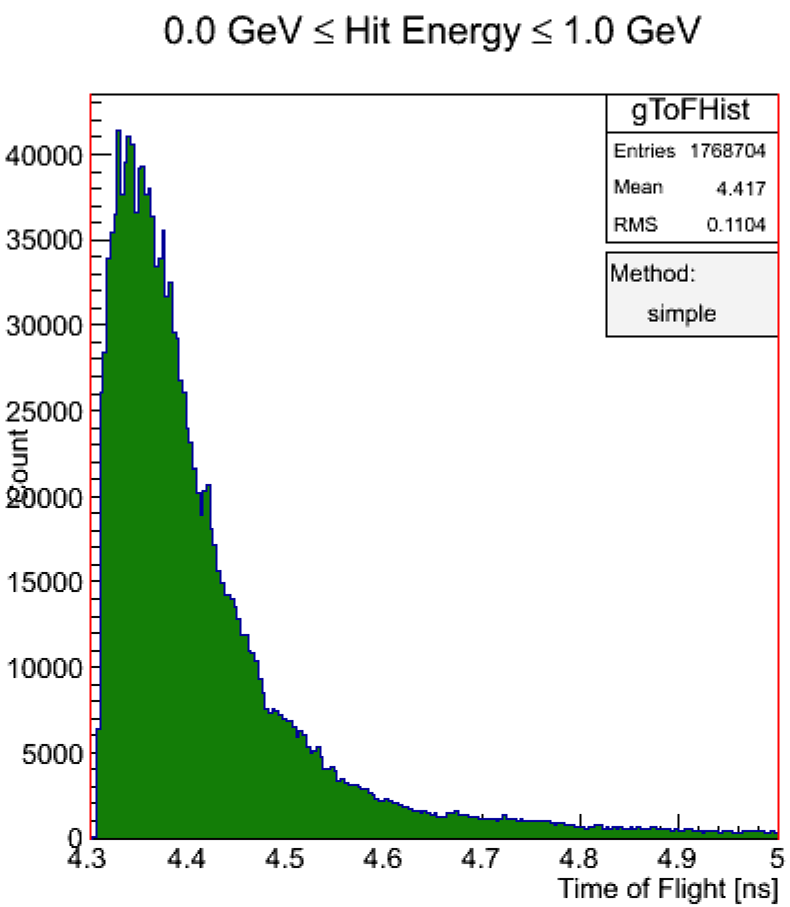


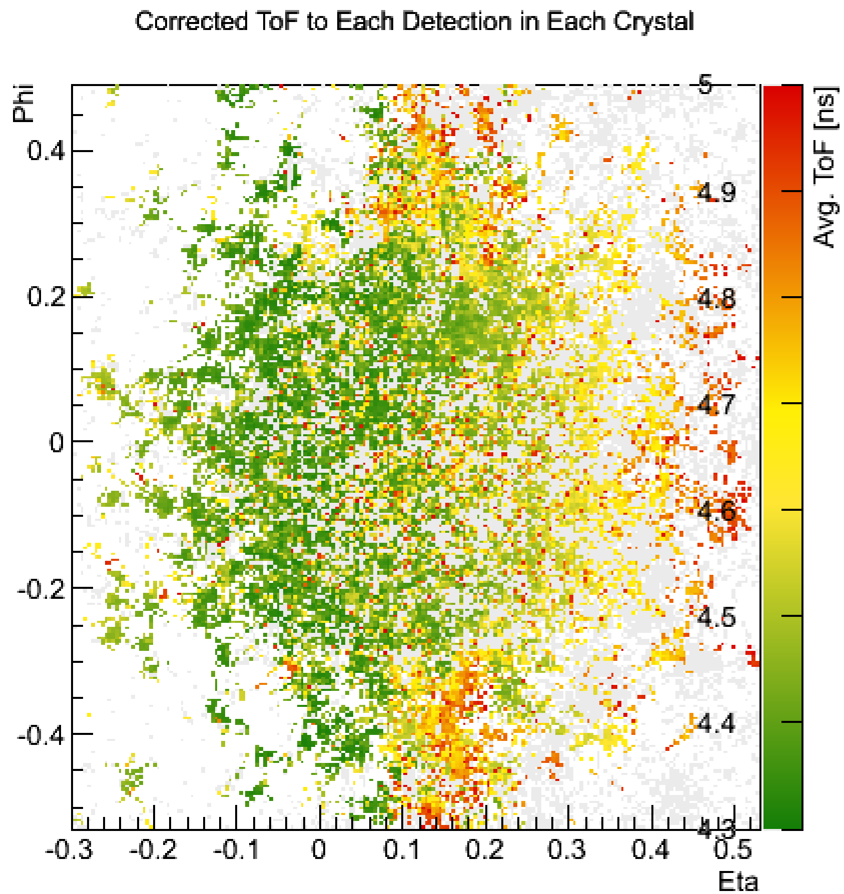


This photon separating effect spurred the idea of shooting low energy pi0s, which convert to 2 photons very early, in order to simulate a vertex. The two photons going off in different directions could be used to test Sepehr's zvertexing algo, using ToFs

The cauliflower shape of the hit pattern is very intriguing. Each little splotch is probably one of the photons shed by the pi0. Due to the lower energy, the angle between the photons is larger than in previous plots. Overall, the shift from green to red from left to right in the eta-phi plot is simply due to increased path length in the barrel as eta increases (also explains why the majority of the grey regions {which happen later than 5ns} are at high eta).

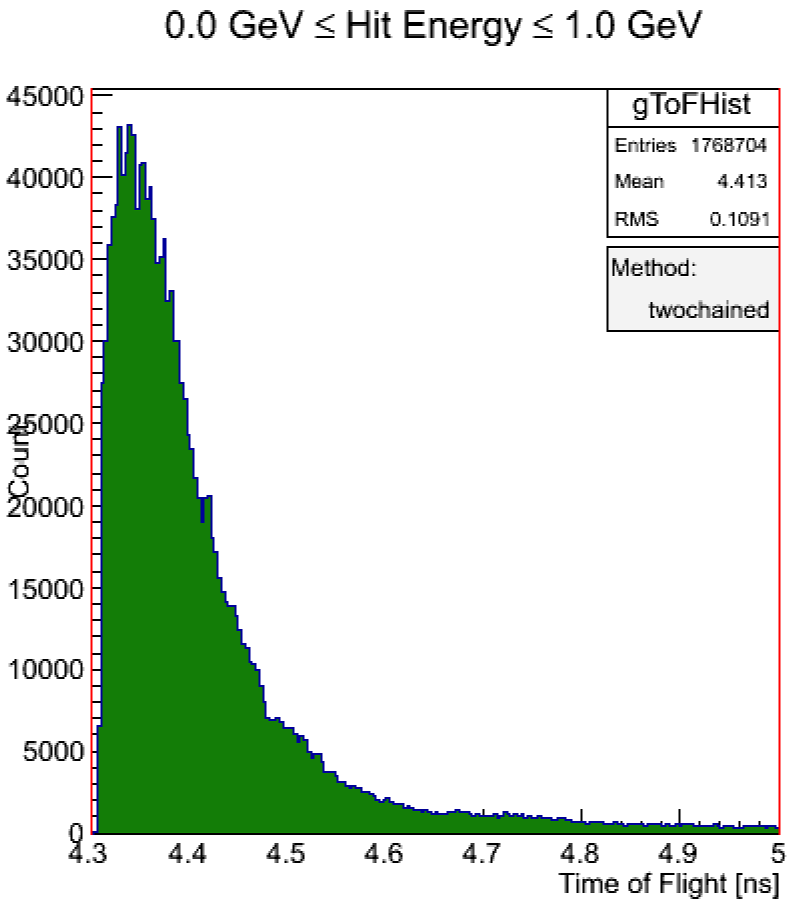
Pi0 1 GeV Full

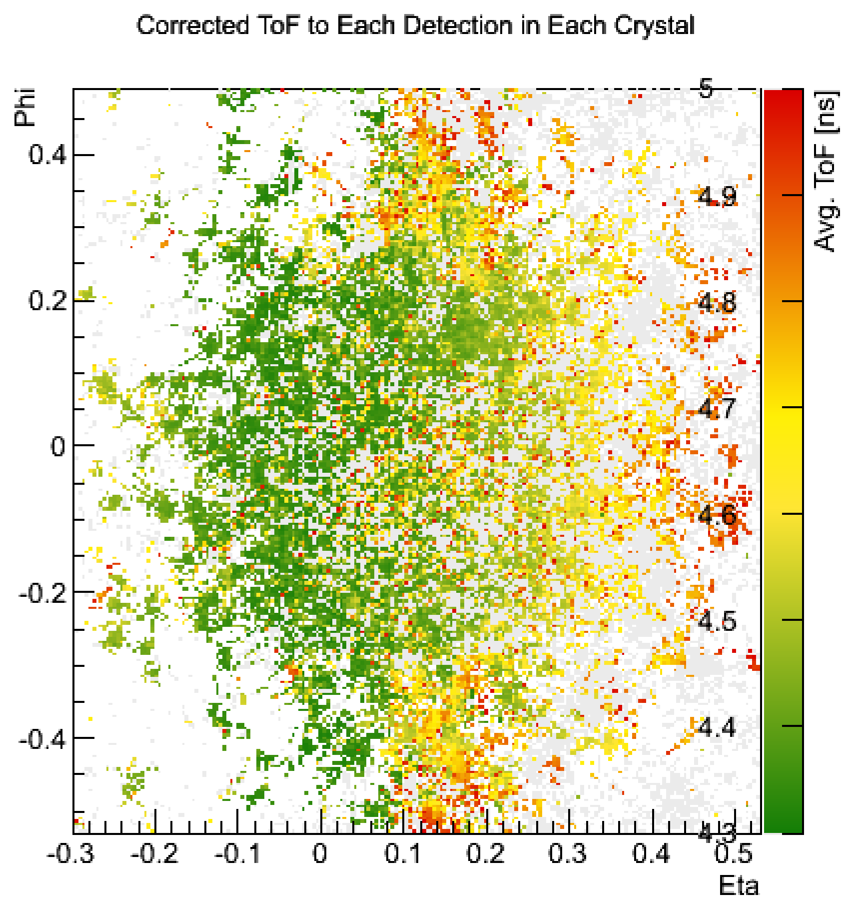




Depth correction does not help too much. However, this is expected. Due to the photons moving off to slightly different places, we expect a distribution of path lengths, which directly leads to a spread in ToFs.

Pi0 1 GeV Full





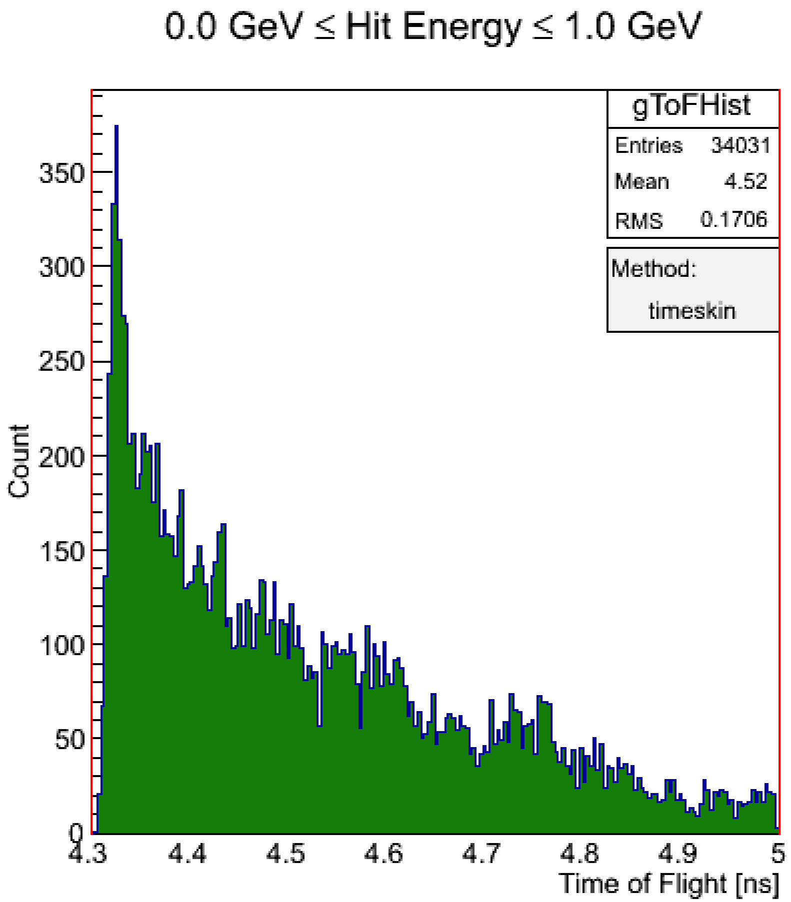
Radial correction barely helps. This is because it's not radial correction from where it was supposed to hit – such a correction *would* help. Remember that this particular algorithm just takes the first hit of an event and assumes all subsequent hits are straight-line following the first hit. Since each event produces 2 photons that hit different places, the twochained method actually does particularly poorly – it assumes the first photon to hit is the first hit for the whole event! It tries to associate the shower of the second photon back to the first hit. A lot of hits are not spacetime compatible with being linked (spacelike separated) due to the hits belonging to the other photon's shower. For such points, the algorithm does not apply any radial correction (as it was written to do). This leads to an interesting digression, so the next slide will be about chaining hits.

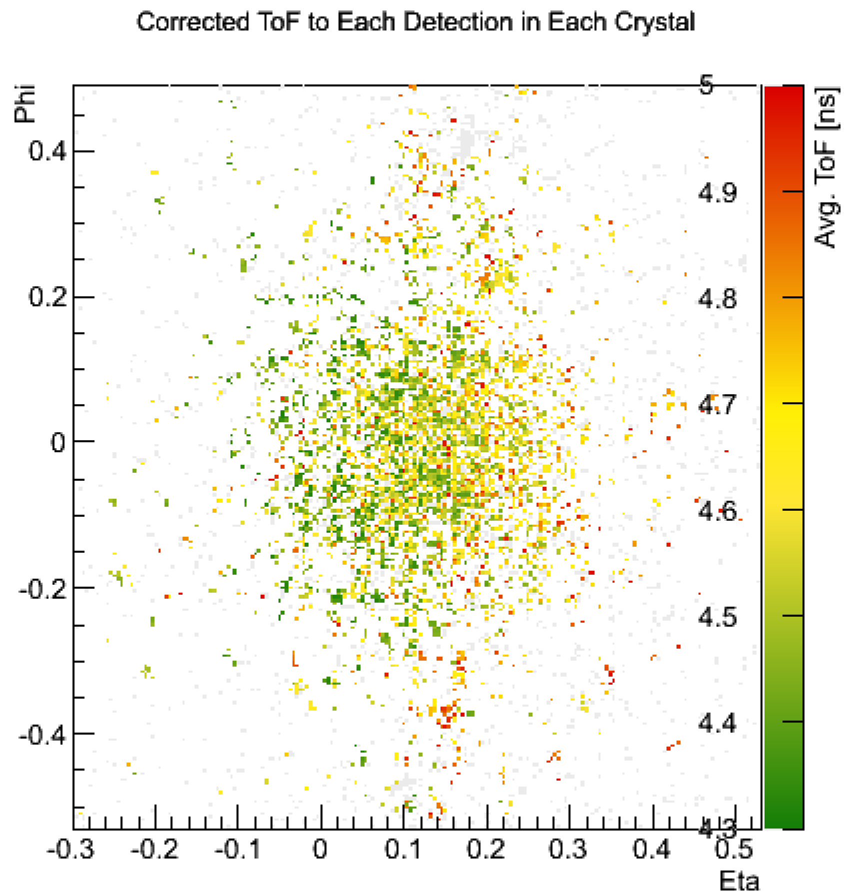
Pi0 1 GeV Full

The twochained method only attempts to directly link subsequent hits to the first. We've seen how this fails when two particles are produced, such as when a photon or a pi0 converts since it incorrectly assumes that all hits from the shower of the second particle are linked to the first hit of the first particle.

A second shortcoming of this method is that very rarely are the subsequent hits directly coming from the first hit. On average, they are at least a few dozen hits separated from the first hit. Instead of being linked by a straight path back to the first hit, they are linked by some sort of random walk with each deflection or curve due to some sort of interaction of hits that happened in between. Theoretically, if we knew enough, we would be able to produce the whole shower and we'd be able to trace back the path of every single hit. It is safe to say that this is impossible, for all intents and purposes, due to the absurd amount of knowledge you would need. Simply knowing the position and time of each hit would not come close to being enough. To determine the whole causal relationship through the shower (or to produce some probabilistic determination of the most likely causal relationship) , you would need to at least know the angle of a hit, (the angle it arrives at), and potentially the momentum vector. A bit too crazy.

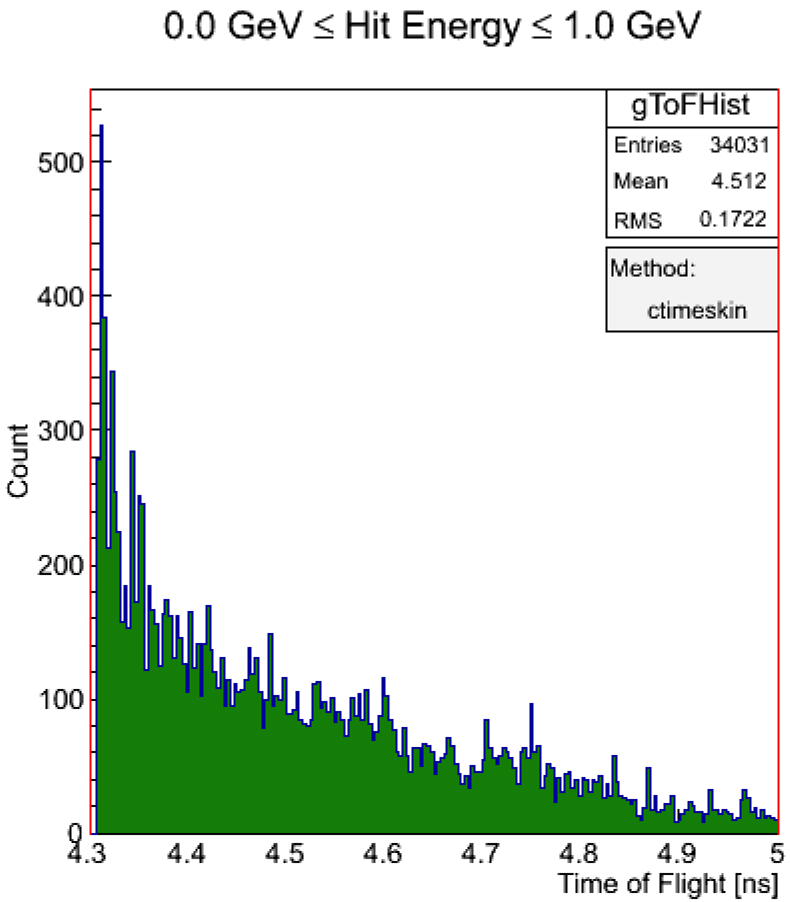
Pi0 1 GeV Full

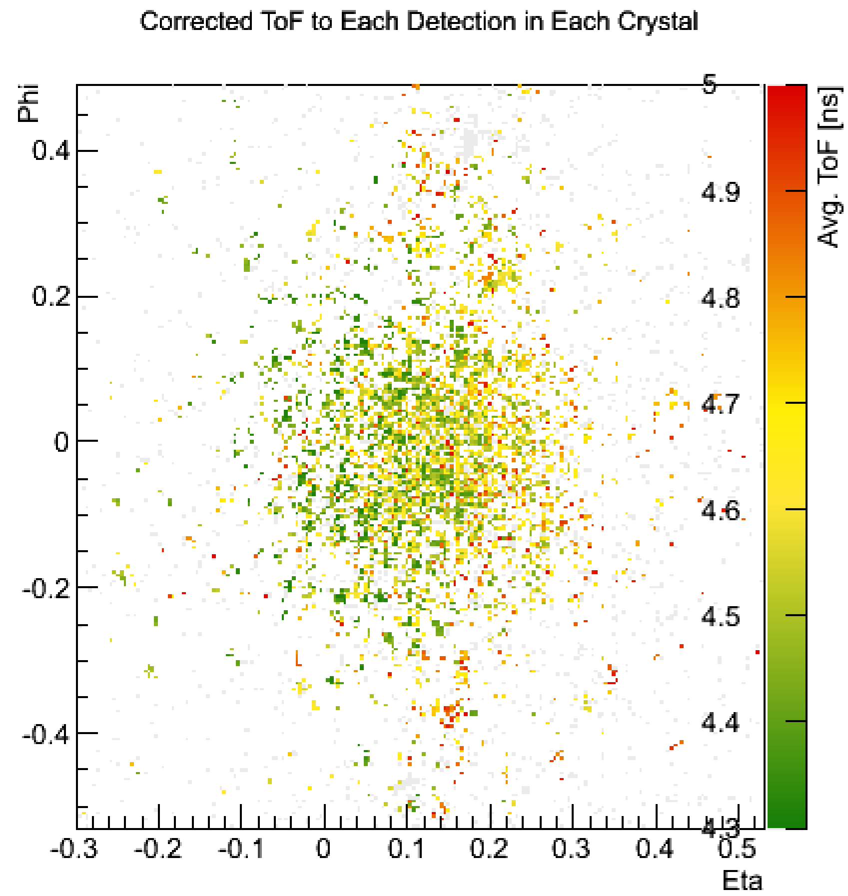




The timeskin produces quite an interesting ToF histo. Not sure what it means yet.

Pi0 1 GeV Full



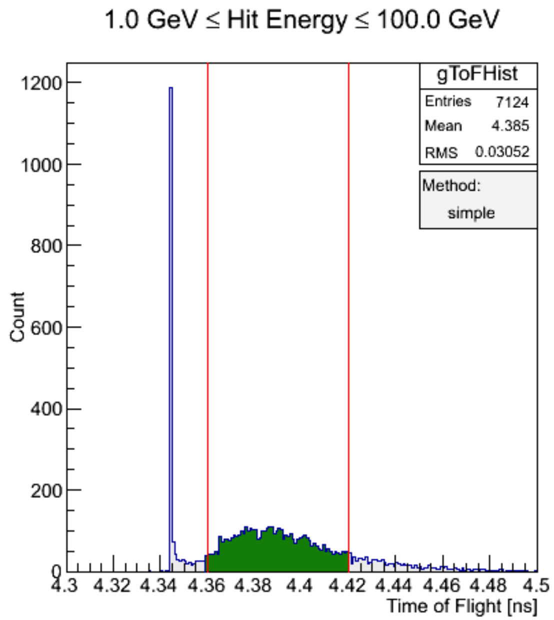


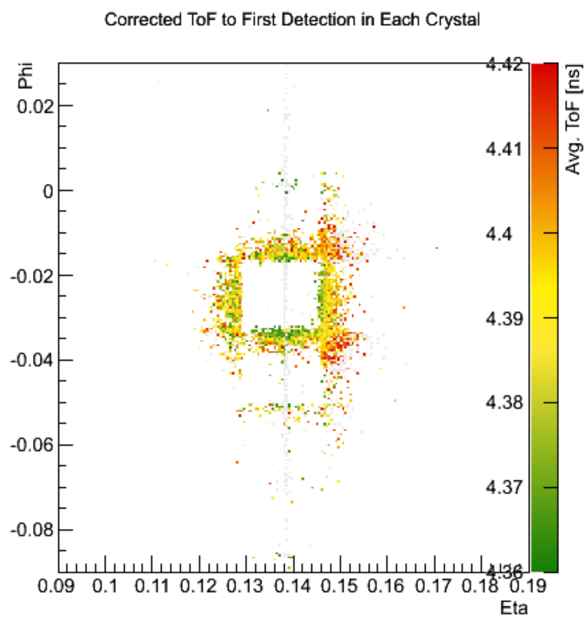
Depth correction does not help too much.

Now for other stuff

That's it for the full hit patterns. Next we have some miscellaneous items.

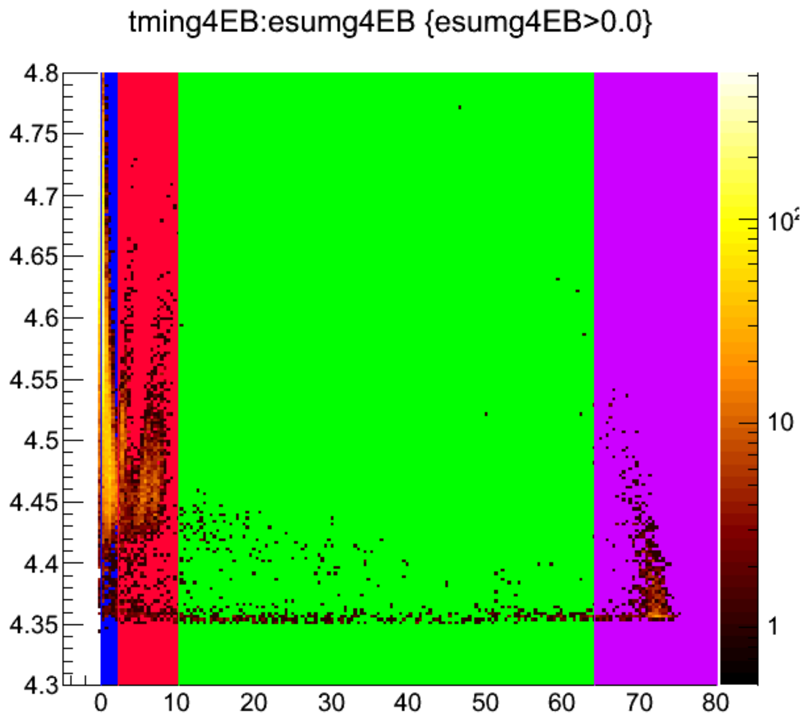
Esum is Total Energy Deposited in Crystal. Different From eg4EB, which is HitE

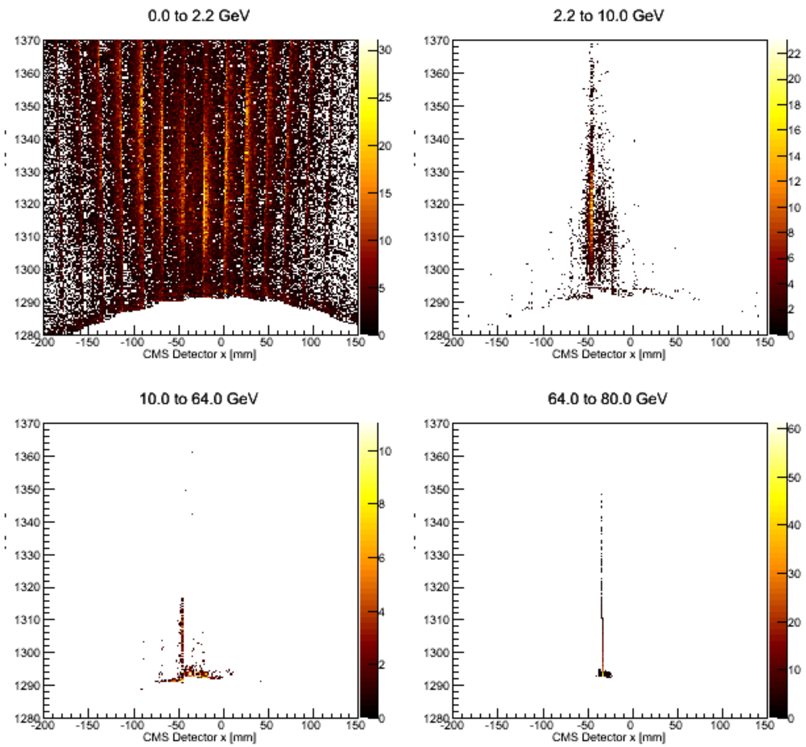




So, the plot above is inaccurate. The cut applied is not on Hit Energy, it's actually on Esum, the total energy deposited in a crystal. So, in some sense, it's like a geometric cut on the distance from the central hit since the energy falls off radially. Esum might still be useful in some ways; by cutting out crystals that are farther away from the initial hit, you can potentially clean up the ToF histogram a bit.

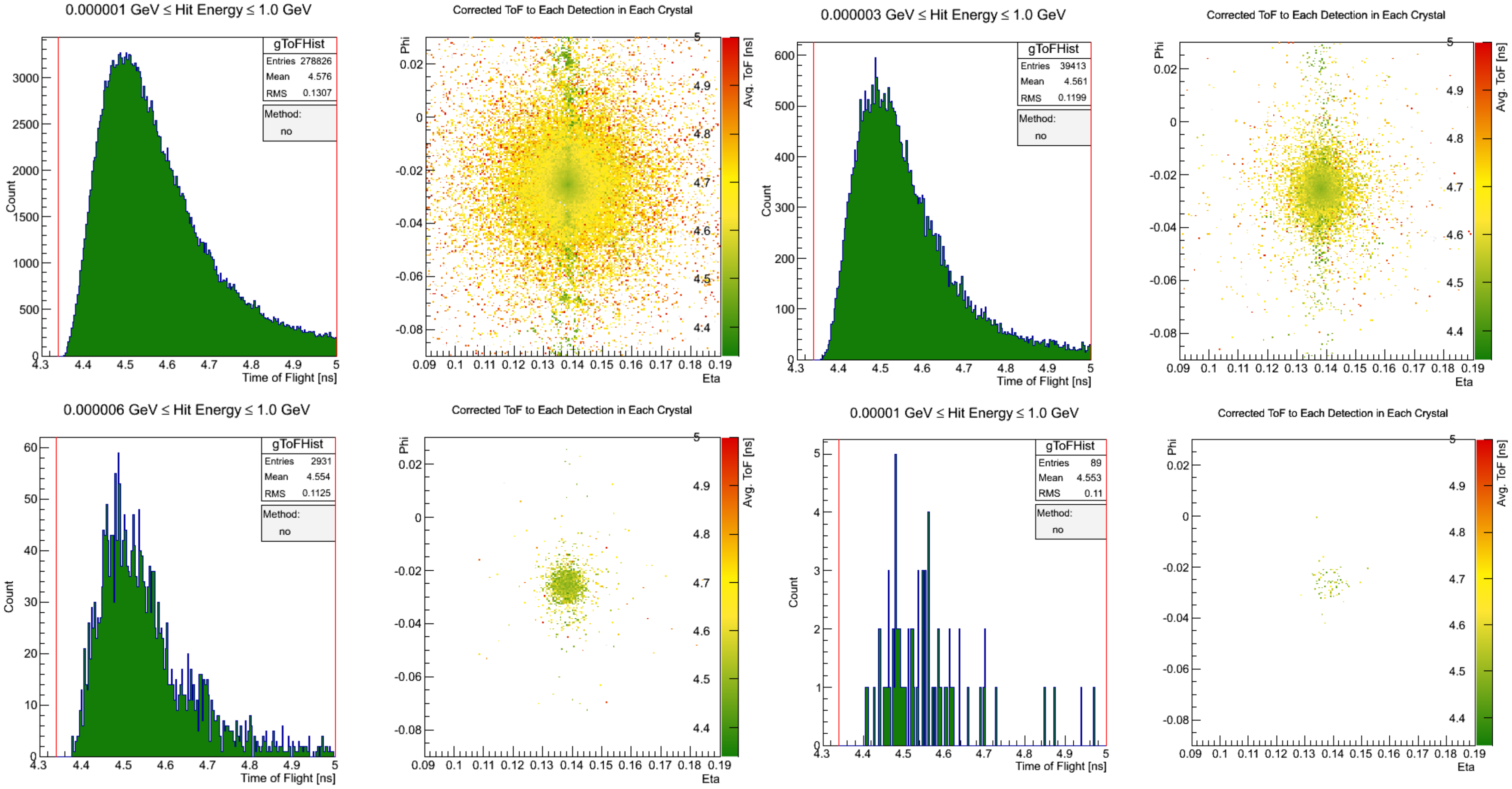
Esum is Total Energy Deposited in Crystal. Different From eg4EB, which is HitE





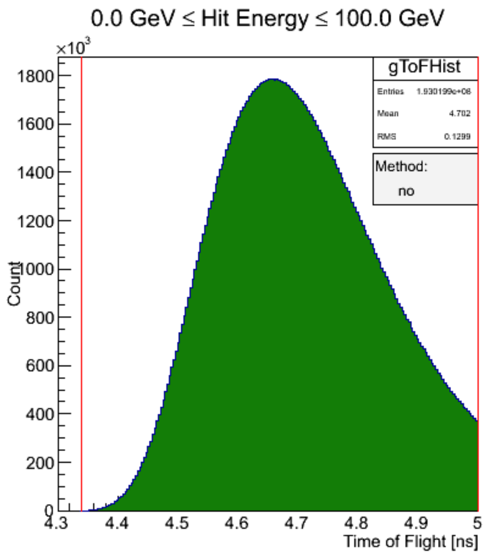
Now that we know what Esum is, the plots we wondered about earlier make a lot more sense. The plume at 70% of the total energy is the first crystal hit, which takes the majority of the detection's energy. The other plumes around 10% of the total energy are likely the surrounding layers of neighboring crystals. These absorb a good deal of energy, but not as much as the central crystal. Also note that the 10% - 60% range is likely to contain the events when the photon → e+e- deposit in different crystals, each taking half the energy on average.

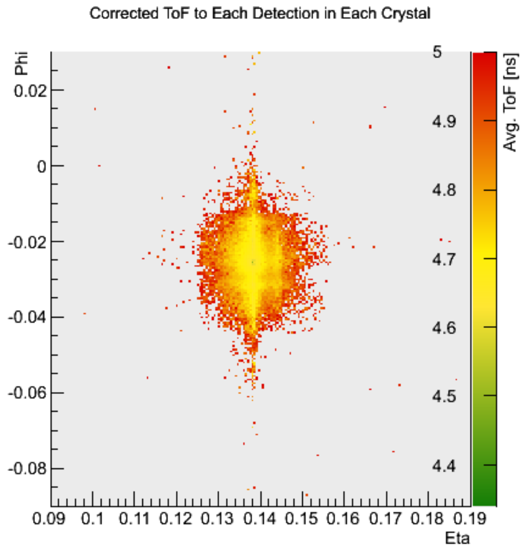
Photon 1GeV – Cutting Hit Energy Doesn't Change Much...

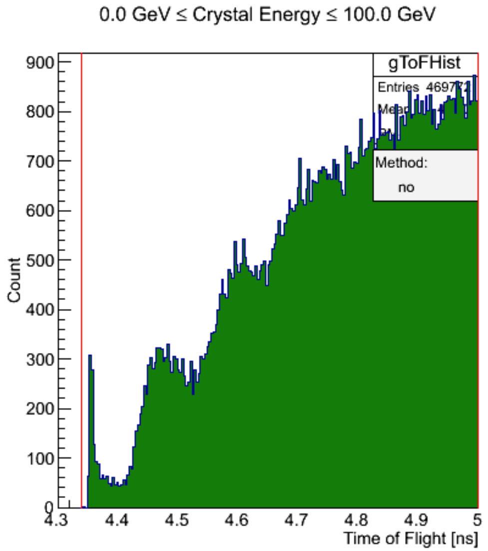


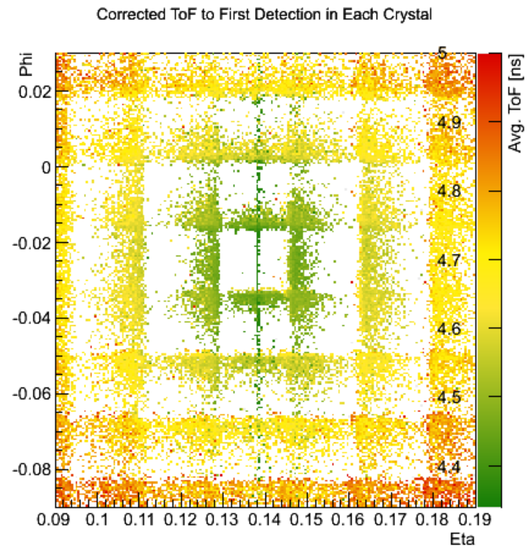
Note that raising the lower bound on the hit energy does not appear to improve the tightness of the ToF distribution (at least, not by much). Instead, you begin to cut hits very quickly.

Difference Between Looking at First Hits and All Hits









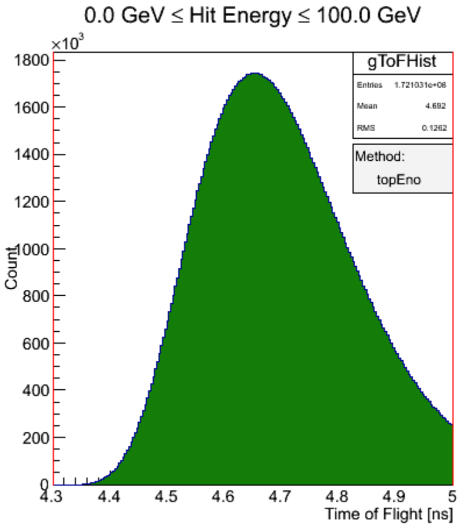
On the left we have all the hits, on the right we have just the first hits. In the ToF histograms, necessarily we have the right ToF histo inside the left histo. As for why the eta-phi plots look different, it's because the ToFs are *averaged* for each eta-phi location. The grey surrounding the pattern on the left eta-phi just means that the ToF average is outside the time cut applied with the red vertical lines.

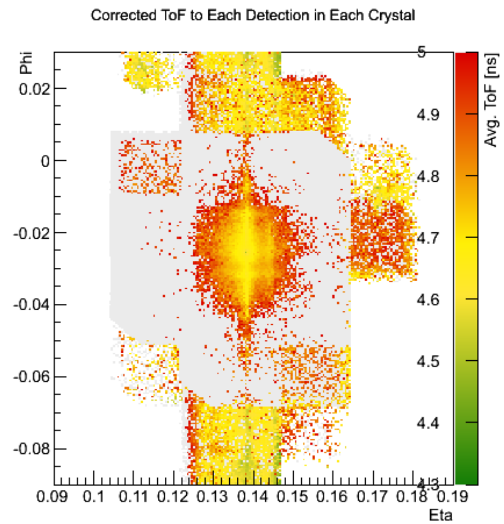
It is also interesting to note that the bumps in the right ToF histo probably correspond to the shower arriving at the different levels of surrounding crystals. First it reaches the 8 neighboring crystals, then the 16 surrounding those.

TopE* methods

The confusion we had between Esum and hitE made us realize that Esum might still be useful. This led me to writing methods with the prefix “topE-” to signify that only n crystals with the highest Esum were considered. Typically, the n used was 9, but for some plots I used n = 1.

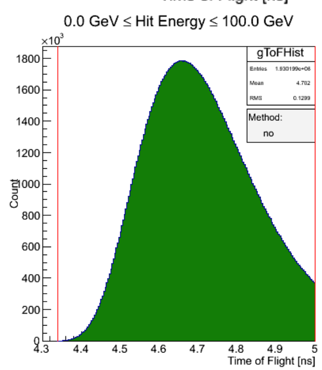
TopEno →
N = 9

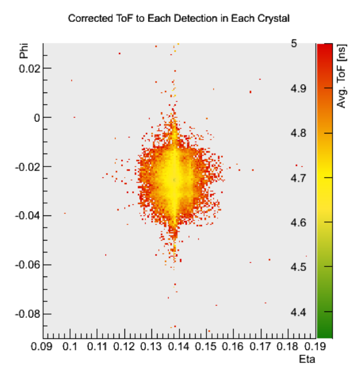




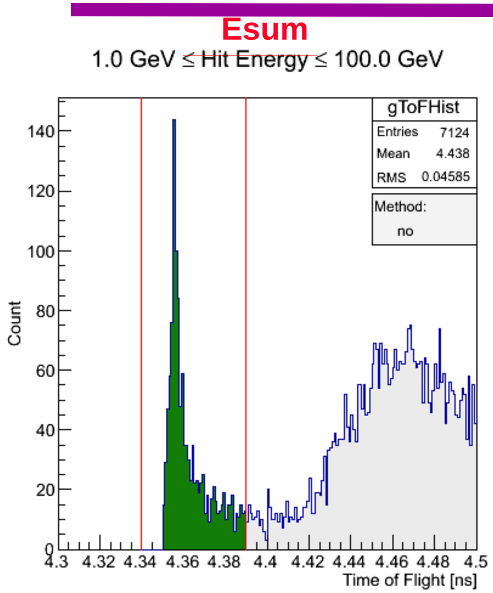
From the patches, it's quite clear how the method works. For this, n=9. Note that it hardly improves the ToF distribution, at least when no correction is applied.

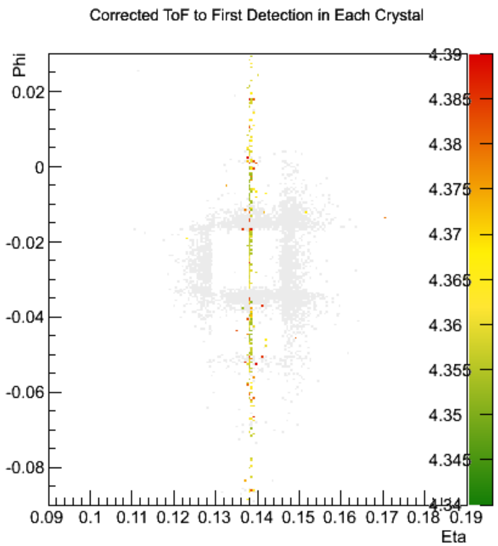
No method →

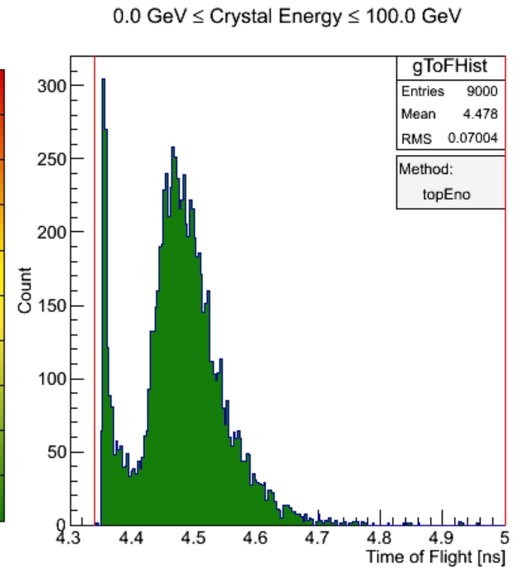


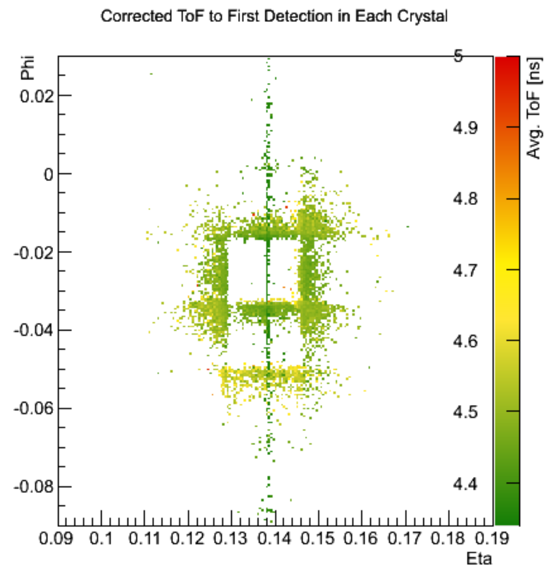


TopE method on First Hits produces similar plots to when we were using Esum as a cut



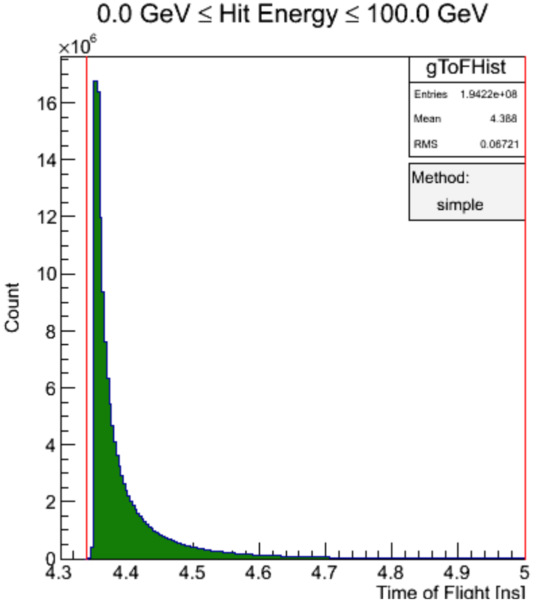


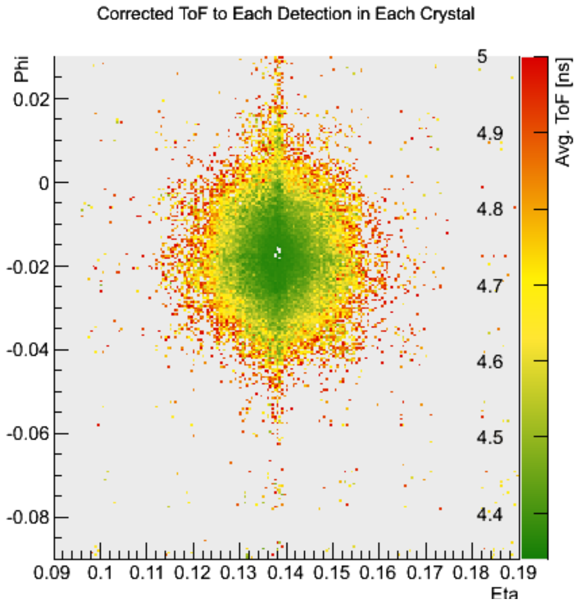


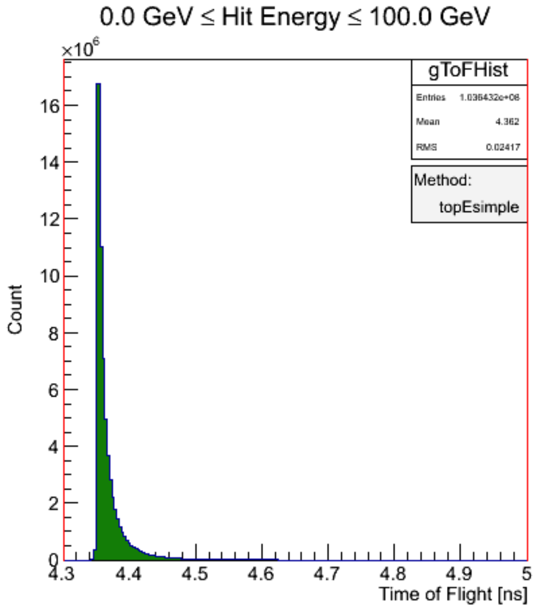


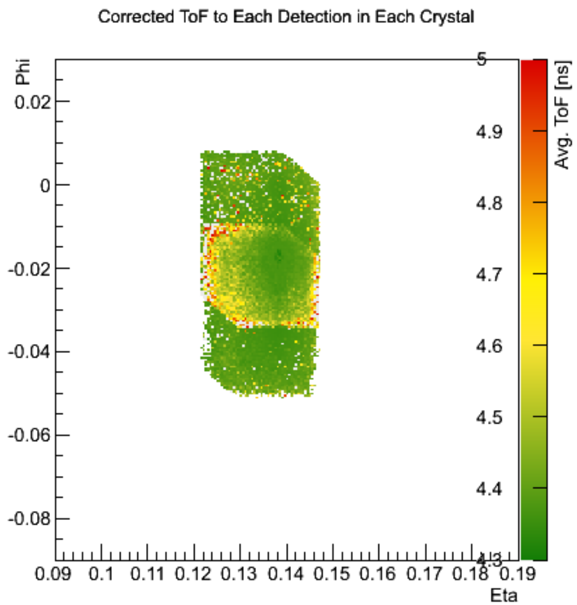
Note the similarity in the plots (the shape of the ToF is actually supposed to look more similar – notice the x-scale difference. Both second beaks have approximately the same mean and width). This isn't supposed to be too surprising – after all, they are both cuts on Esum. However, TopE methods are more specific since they would technically work for any energy particle. Cutting Esum directly would require knowing the energy of the particle beforehand (since obviously a 1GeV Esum cut on a 0.8 GeV photon event would cut out everything, while such a cut would work well for a 100GeV photon event).

TopEsimple – TopE applied to depth correction. (Full Hits)









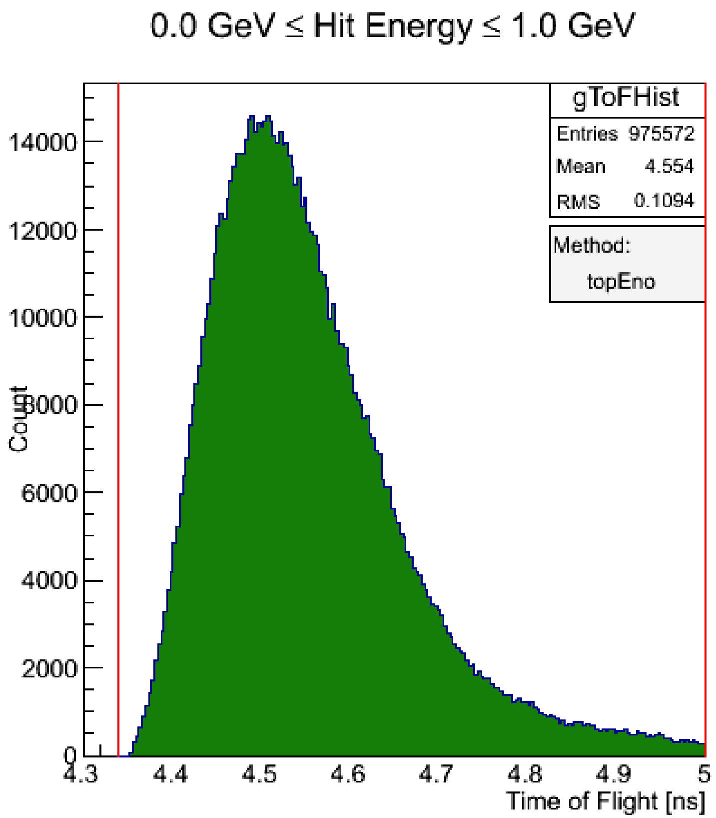
Encouragingly, for events like 100GeV Electrons, using topEsimple with n = 1 (just highest energy crystal considered) tightens up the ToF distribution.

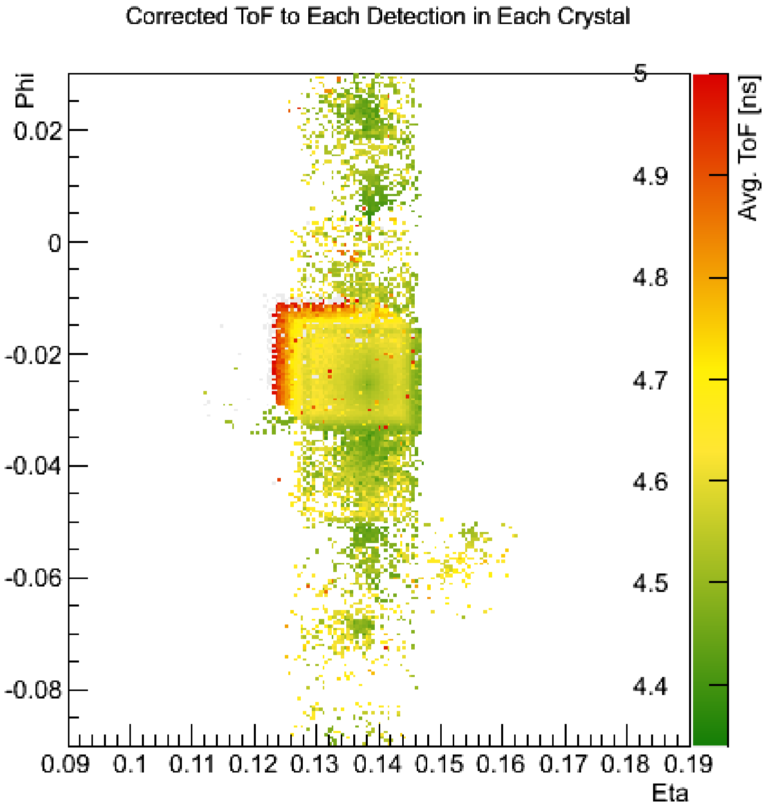
(RMS 67ps → 24ps)

Note that the electron doesn't always deposit the majority of its energy in the crystal it is aimed at. Here there are clearly 3 crystals. Also, the hits in the center crystal tend to happen at slightly higher eta and phi, even though it was aimed at the center of that crystal. This is due to the B-field curling it up in phi, and due to the increased path length, the electron has more time to move forward in the barrel (hence higher eta).

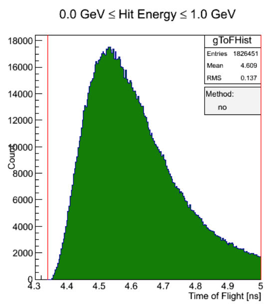
Cedric Flamant – 1/Aug/2013

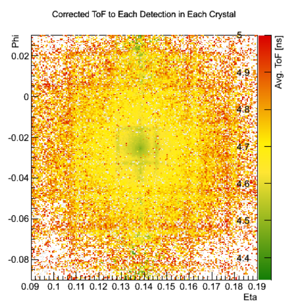
TopEno applied to photon 1GeV





Here n = 1, so we are only looking at the crystal with the most energy. For photons, such an n is highly deceptive in occasions where it undergoes conversion, since only one of the two crystals (positron in one crystal, electron in the other) are chosen, even if the energy difference is very small, and totally arbitrary.





← the full event, raw.

What's Next

- Compute the RMS and mean of the direct hit arrival peak, as well as the more diffuse second peak which is caused by crystal leaking.
- Compute the RMS and mean of all hits.
- Do the two measurements listed above for many individual events. The goal is to see what fluctuations exist in the means and widths of these peaks. If the patterns are fairly consistent, especially for the full hits, it may indicate the feasibility of using the entire hit ToF pattern instead of just the first hits, which is the traditional thinking.
- Run more smeared events – find out how to simulate timing that is characteristic of a real collision sequence.
- Shoot low energy pi0, use photon arrival times to attempt to zvertex reconstruct using Sepehr's method.
- The big question right now is whether it is more feasible to use the first few hits to characterize the time of arrival, or if it is better to simply integrate the whole ToF distribution and use some defining characteristic, such as its mean, to determine the “true ToF” which could be used for vertex reconstruction.
    - Additional small goals/questions:
    - If the timeskin option is to be used, a penetration depth study should be performed to measure the efficiency of detections based on various timeskin thicknesses. More generally, efficiency tests need to be performed for whatever idea we settle on further exploring.