Searching for Supernova Neutrinos with the DarkSide 20k Dark Matter Search Experiment Summary Report

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Abstract

The experiment was carried out as a part of a summer project within the Particle Physics Group under the supervision of Doctor Andrzej Szelc and Doctor Darren Price. It consisted of familiarizing myself with Linux operating system, ROOT and G4DS package, and, mainly, running simulations and analysing obtained data using the tools mentioned above in order to search for the potential new application of the DarkSide 20k detector. This report includes some instructions and advice on how to approach and use those tools, and talks about the end results.

1 Introduction

DarkSide 20k is a future dark matter detector that will be built at Laboratori Nationali del Gran Sasso between 2020 and 2021. It will consist of 2 main parts, an inner Liquid Argon Time Projection Chamber and an outer veto detector. The former's focus will be on the detection of potential dark matter candidates while the latter's primary task will be to 'veto' other electrically neutral particles entering the detector. The veto detector will also be filled up with liquid argon. However, it will not be as pure as liquid argon in the inner part as rdioactive ^{39}Ar will also be abundant there [1].
Researchers from the Manchester Particle Physics Group, who are a part of the DarkSide collaboration, came up with idea that the outer detector could be used for other purposes as well as the originially planned 'vetoing'. One of these purposes could be searching for supernova neutrinos. Testing its feasibility, and more specifically finding energy resolution of the neutrinos, was the main task of the internship. In order to do so, the G4DS package was used to run numerous simulations.

2 Instructions

As mentioned in the abstract, there are several tools that were used during the internship. For getting started with Linux terminal and ROOT online sources are recommended. There are a few sets of ROOT commands that can be used for plotting graphs from the terminal that I found very useful once they were shown to me. To draw a histogram the Draw function is generally used. The description can be found on the CERN ROOT website but in short its structure is as follows,

```
Draw("y-axis quantity:x-axis quantity","cuts","options").
```

In order to plot more than one graph on the same canvas the following should be done,

```
TFile *arbitraryname=TFile::Open("directory/name of the file you wish to use")
dstree->Draw("y-axis quantity:x-axis quantity","cuts","options")
dstree->Draw("y-axis quantity:x-axis quantity","cuts","options & same"),
```

where the first line opens the file, the second one draws the first histogram, and the third one adds another one onto the same canvas using option "same". The file has to be a ROOT one and contain a tree type data structure. The method of obtaining such a file is described in G4DS Setup and Usage Guide by Niamh Fearon and Sol Cotton. The process can be taken a step further and trees from different files can be combined into a chain, which allows, among other things, plotting data from separate files together. The commands below let the user create such a chain.

```
TChain *chainname=new TChain("dstree")
chainname->AddFile("directory/name of the file you wish to use")
```

```
chainname->Draw(),
```

where the first line creates the chain, and the second one adds a tree to it. If the chosen file has more than one tree, the top one will be added.
Information on how to use the G4DS package can be found in the guide mentioned above. Due to logistical issues I was not able to obtain access to an editable version of the guide and edit the Marley section, which could be confusing. Therefore, the instructions on how to run it are presented here.

1. Open configDarkSide_Manchester.sh
2. Uncomment the latest working version of Marley (setup marley)
3. In g4ds10 directory use the following commands
   ```
   source configDarkSide_Manchester.sh
   make
   source configDarkSide_Manchester.sh
   ```
4. In Marley directory use the following command
   ```
   marley config.js
   ```
   This will create a hepevt file
5. Go back to configDarkSide_Manchester.sh and comment out setup marley
6. In g4ds10 directory use the following commands
   ```
   source configDarkSide_Manchester.sh
   make
   ```
7. In Linux-g++ directory use the following command
   ```
   run hepevt.mac
   ```

The macro file may require some editing, make sure it operates on the right hepevt file

3 Results

The results can be divided into 2 main sections: energy resolution of electrons created in neutrino - nuclei collisions and energy resolution of neutrinos from the Marley simulation. Obtaining those results required making several small changes in the G4DS code. All those changes were commited and pushed to the Manchester Niamh branch.

3.1 Electron energy resolution

In this case energy resolution was measured as ratio of energy deposited in the materials of the veto detector (vetoene) and initial electron energy (ene0). Each simulation consisted of 10000 events (and therefore 10000 electrons, each one with the same initial energy). Each electron deposited certain fraction of this initial energy in the veto detector. This fraction was combined with the starting position of the electron in order to create 21 2-dimensionals histograms, shown in the Figure 1, Figure 2 and Figure 3. The data used to create these Figures is saved in ROOT files named outRun_electron_xxMeV.root (/pc 2014-data4/vinszym/g4ds10/Linux-g++).

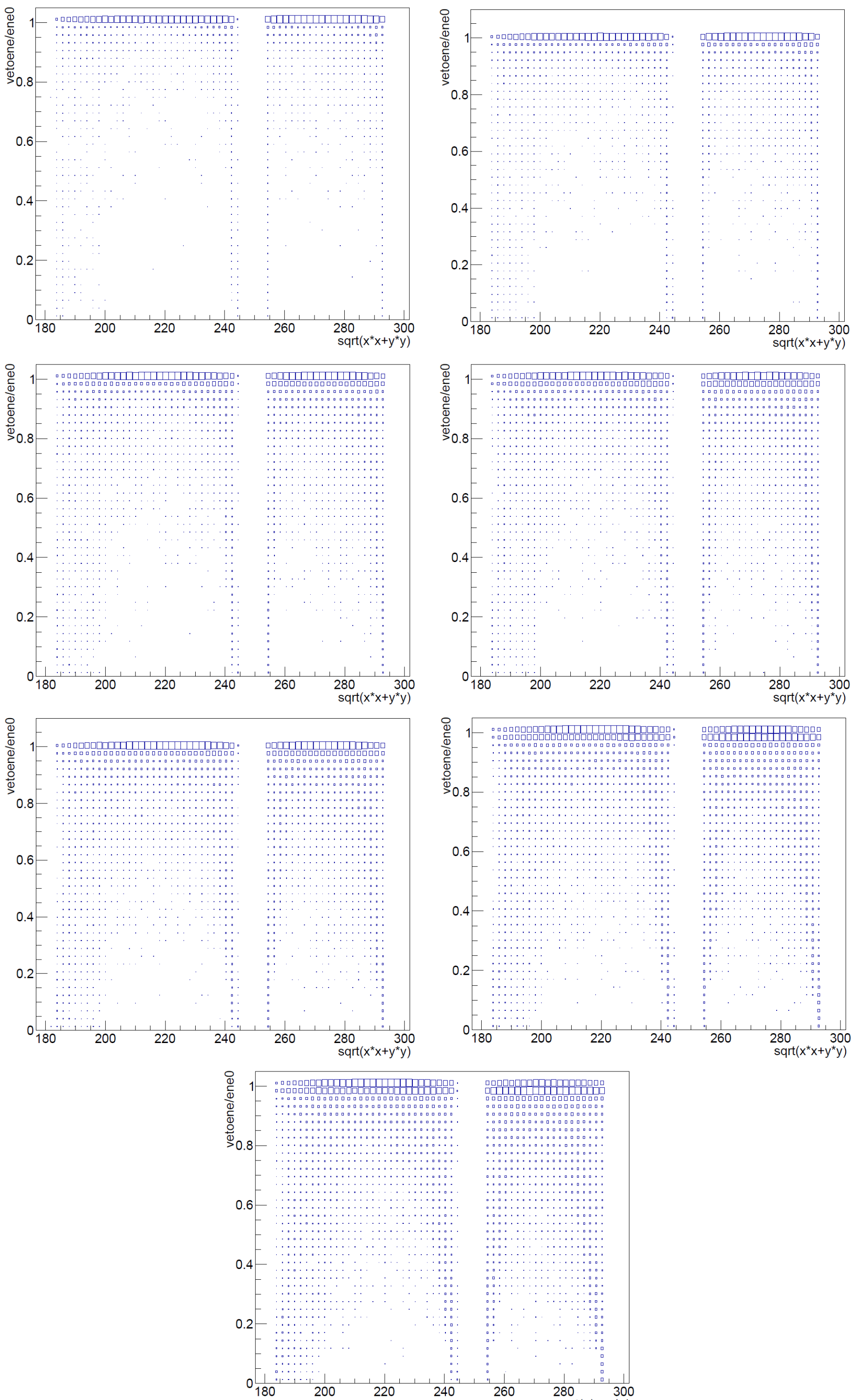


Figure 1: Values on x-axis of each histogram are initial radial electron positions in cm, while y-axis values correspond to the fraction of the energy of electron deposited in the veto detector. For each histogram the initial energy is different, starting at 5 MeV for the first one it goes up to 35 Mev with 5 MeV increments.

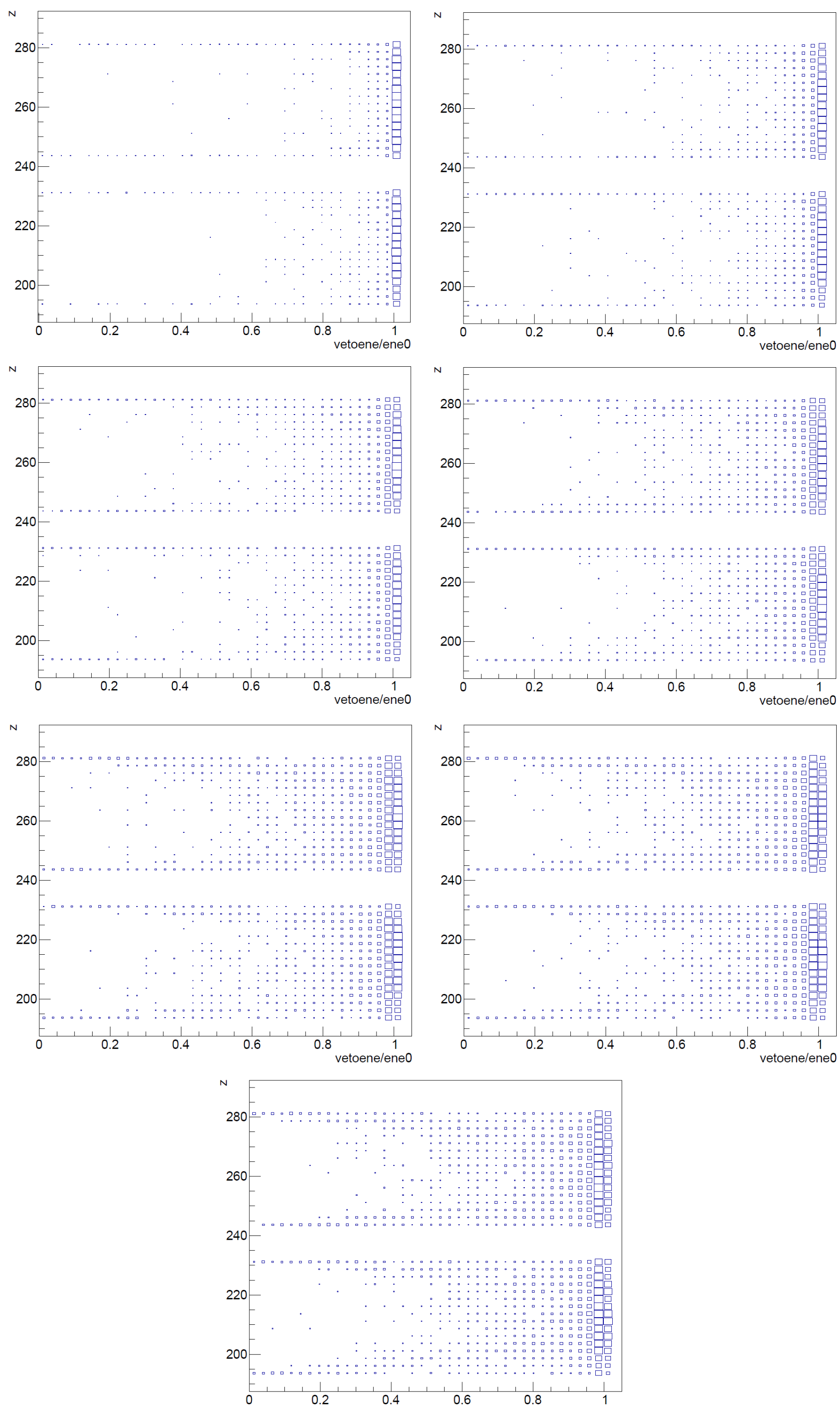


Figure 2: In this case the energy fraction is present on x-axis and y-axis values are z coordinate of the positions. Due to binning method and dimensions of the detector the histograms are much more readable if they only include positive or negative values of z. That is why only positive values are included in this Figure. Negative ones can be found in Figure 3. The initial electron energies corresponding to the graphs and their order are the same as in Figure 1.

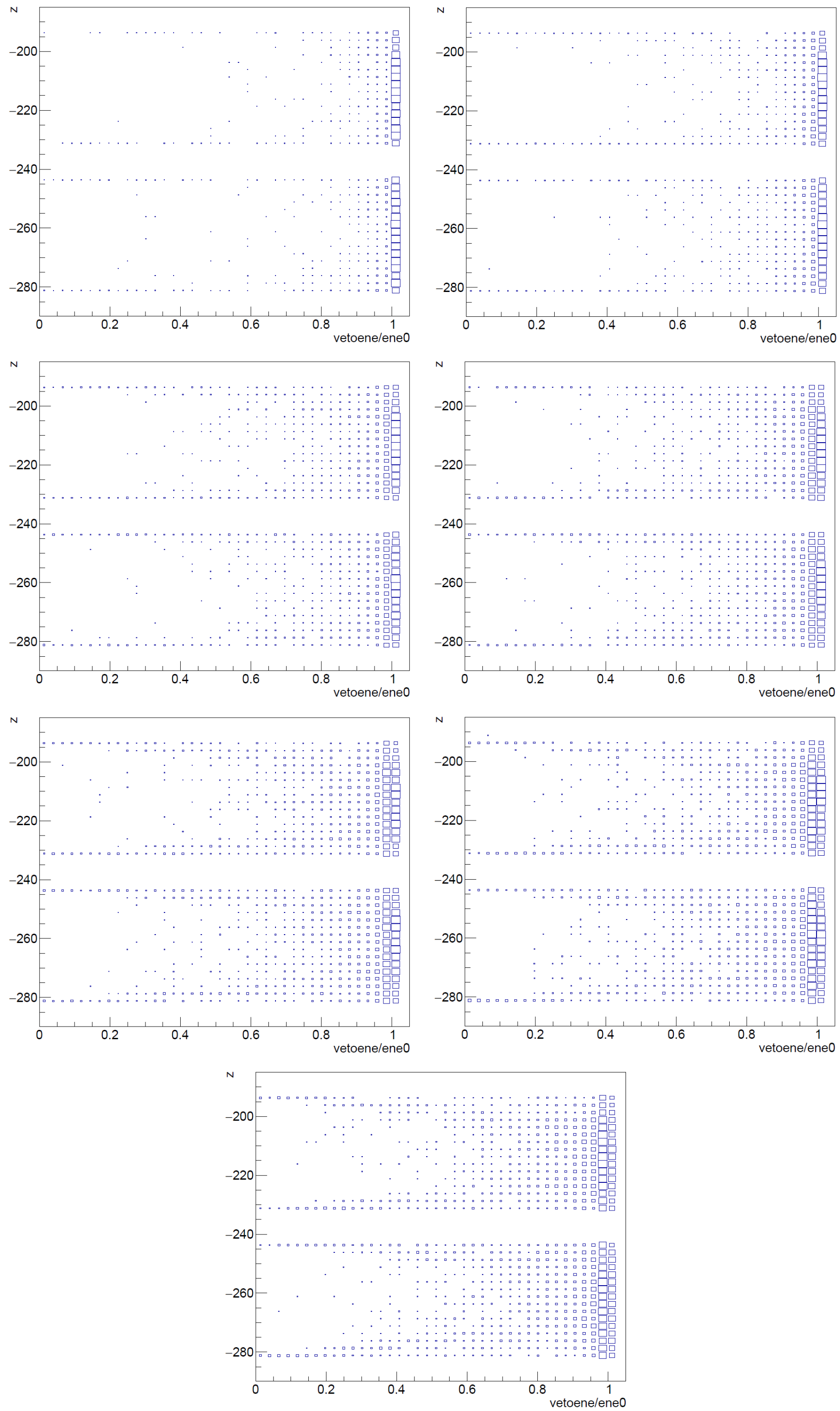


Figure 3: The same relationship as in Figure 2 is presented here but for negative z coordinate values.

The histograms clearly show that the energy resolution is the worse the closer to the boundaries of veto regions electrons are created. It can be also seen that the energy resolution gets worse as the initial energy of electrons increases. Both these conclusions are in agreement with logic. The closer to a boundary an electron is created or the higher its energy is the easier it is for some of this energy to escape the veto region in form of photons. The latter tendency can be seen more clearly in Figure 4.

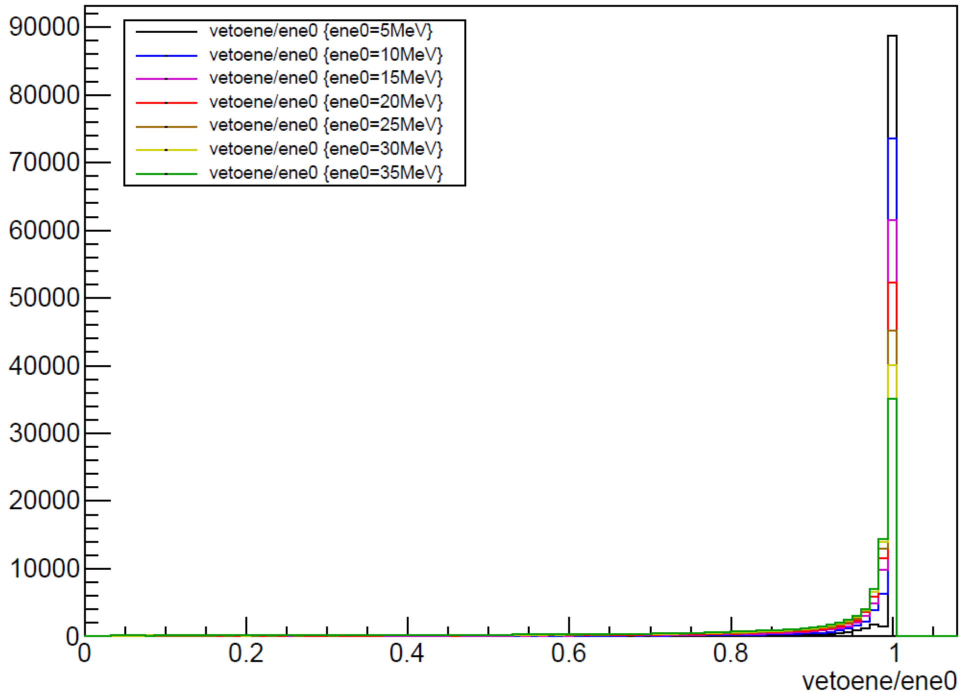


Figure 4: Superimposed histograms showing distribution of electron energy resolution for all simulated initial electron energies.

3.2 Neutrino energy resolution

Due to a big amount of time the Marley simulation takes it was run once with 10000 entries. It was ran using and MarleyEvents.hepevt file hepevt_vinszym.mac macro (both /pc2014-data4/vinszym/g4ds10/Linux-g++) with updated detector geometry, which can be found in the Manchester Niamh branch of the code. The resulting root file (outhepevt_10000_neutrinos.root, same directory) was used to plot numerous histograms which can be seen in Figures 5 - 12.

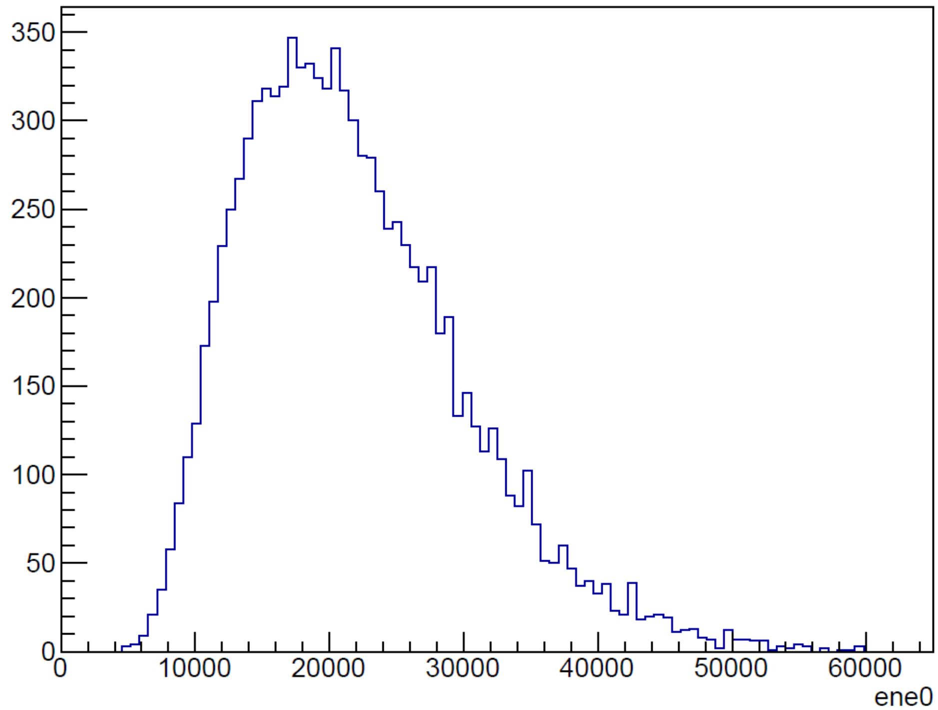
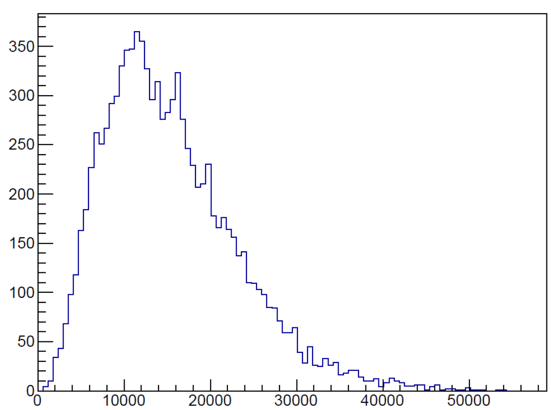


Figure 5: Neutrino energy spectrum. Energies are in keV. Y-axis corresponds to number of entries in each bin. Note that in graphs created as a result of this simulation represents the initial energy of the neutrinos, not electrons.



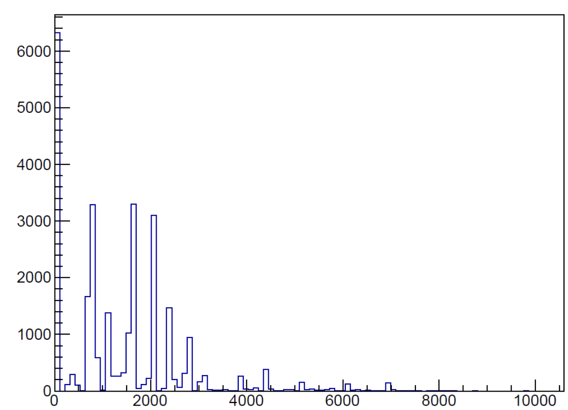


Figure 6: The left histogram shows electron energy spectrum, which confirms that the electron energies used while investigating the electron energy resolution were correctly chosen. On the right histogram photon energy spectrum can be seen. Again, the energy values on the x-axis are in keV and number of counts is on the y-axis.

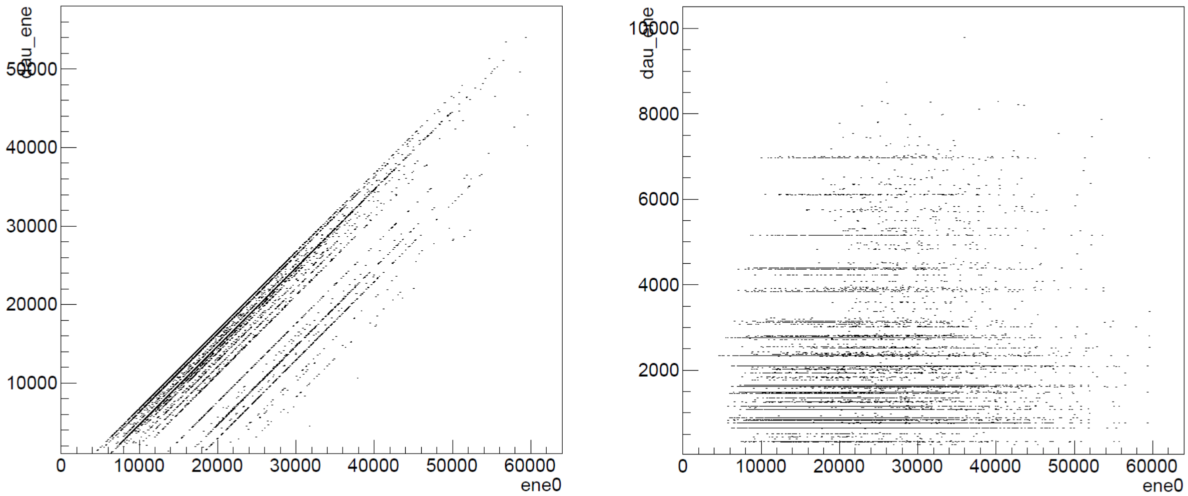


Figure 7: Both histograms show relation between energy of daugher particles and initial neutrinos. In the left histogram the daughter particles are electrons, in the right one photons. The number of entries is bigger for the graph on the right as more than one photon can be produced from neutrino - nuclei interaction. The data points create horizontal lines suggesting that photons of specific energies are most often created in the simulation. Lines of points can be also seen on the left diagram. They have gradient of 1, which is in agreement with the right histogram as in most cases the energy of the outgoing electron is the difference between energy of the neutrino and sum of photon energies which are defined in systematic way. Energies on x-axis are again in keV.

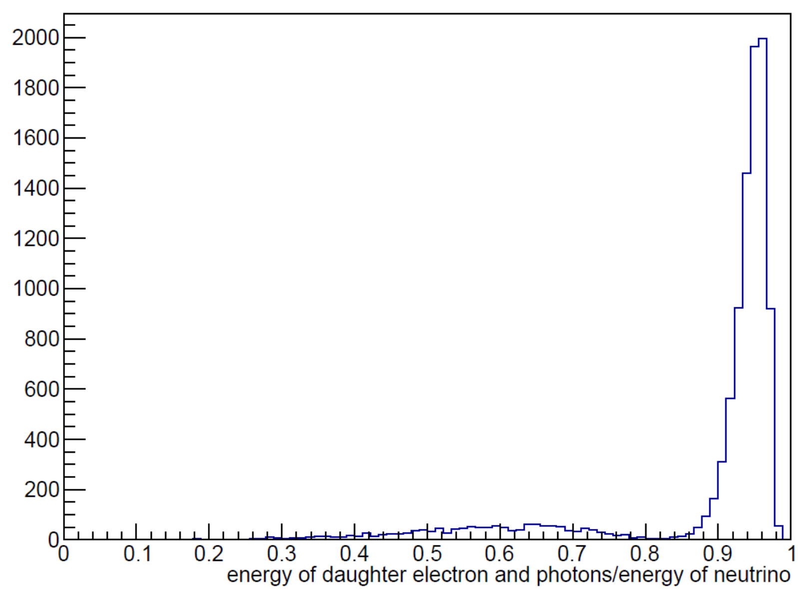


Figure 8: 1-dimensional histogram showing what fraction of neutrino energy is deposited in its daughter electron and photons.

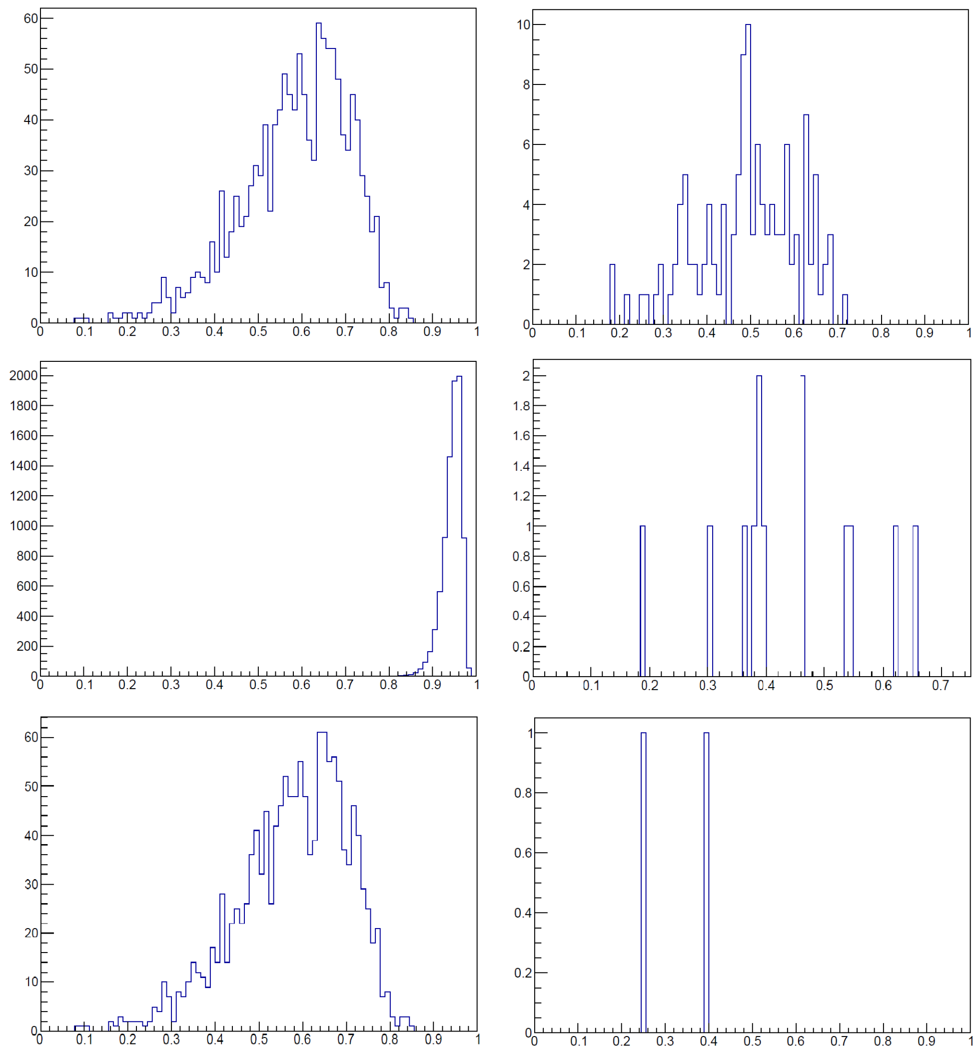


Figure 9: In Figure 8, apart from the tall peak close to 1, another, much wider, peak can be seen. For that reason a more detailed analysis of this spectrum was done. It was realised that some of the events created in the simulation result in protons and neutrons being freed up. The top left histogram shows entries involving a neutron. As can be seen these entries have smaller maximal combined daughter energy of photons and electrons and the spectrum peaks outside of the tall peak seen in Fig 8. The same is true, to even bigger extent, for events involning a proton, which are presented on the top right histogram. The middle left diagram displays the entries that produce neither a proton nor a neutron. Those entries contribute to the tall peak the most and have a much smaller contribution to the wide peak. However, they do contribute as can be seen in the middle right histogram which displays events from the same set but in the energy fraction range of 0 to 0.7. There are few such events and bad energy resolution of neutrinos corresponding to them is likely due to them occuring close to the veto region boundaries. The two bottom diagrams show events involving either a proton or a neutron, on the left, and both, on the right.

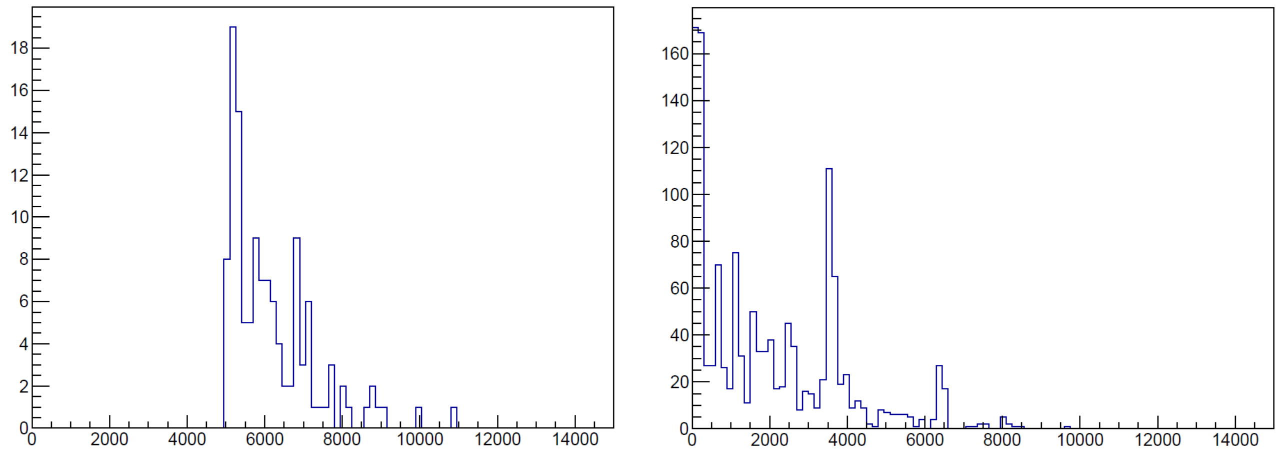


Figure 10: Graphs presenting kinetic energy of the protons, on the left, and the neutrons, on the right, in keV.

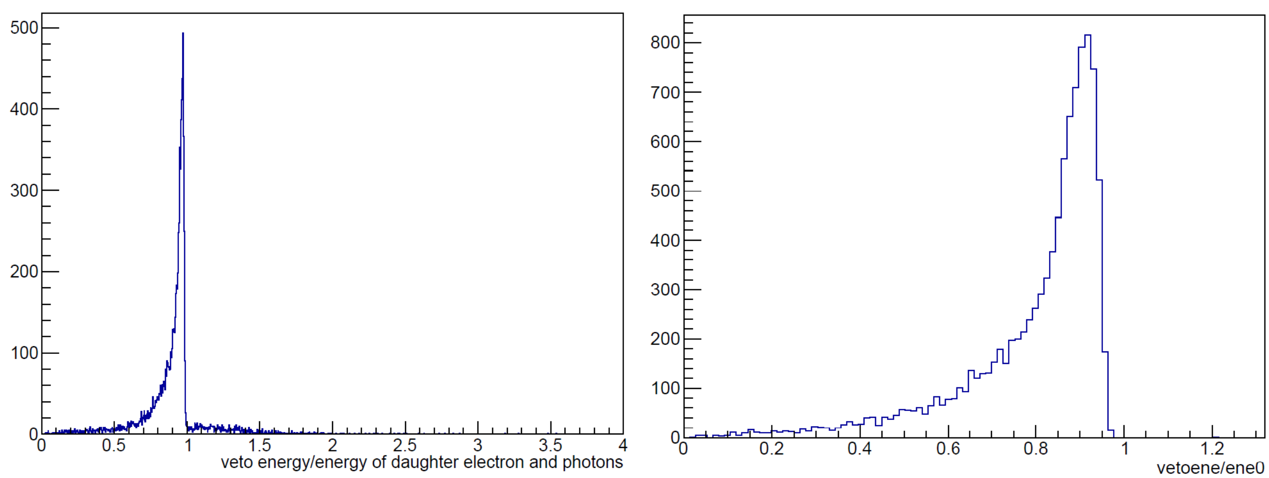


Figure 11: Relations of energy deposited in the veto materials with the combined energy of daughter photons and electrons and with the energy of neutrino are shown on the left and right, respectively. Due to some processes, that were not determined during the internship in some cases the veto energy is greater than the daughter energy. One entry has its veto energy greater even than the initial energy of the neutrino, which is the reason for the x-axis upper limit of the right histogram being greater than 1 (the energy ratio for this entry is 1.208).

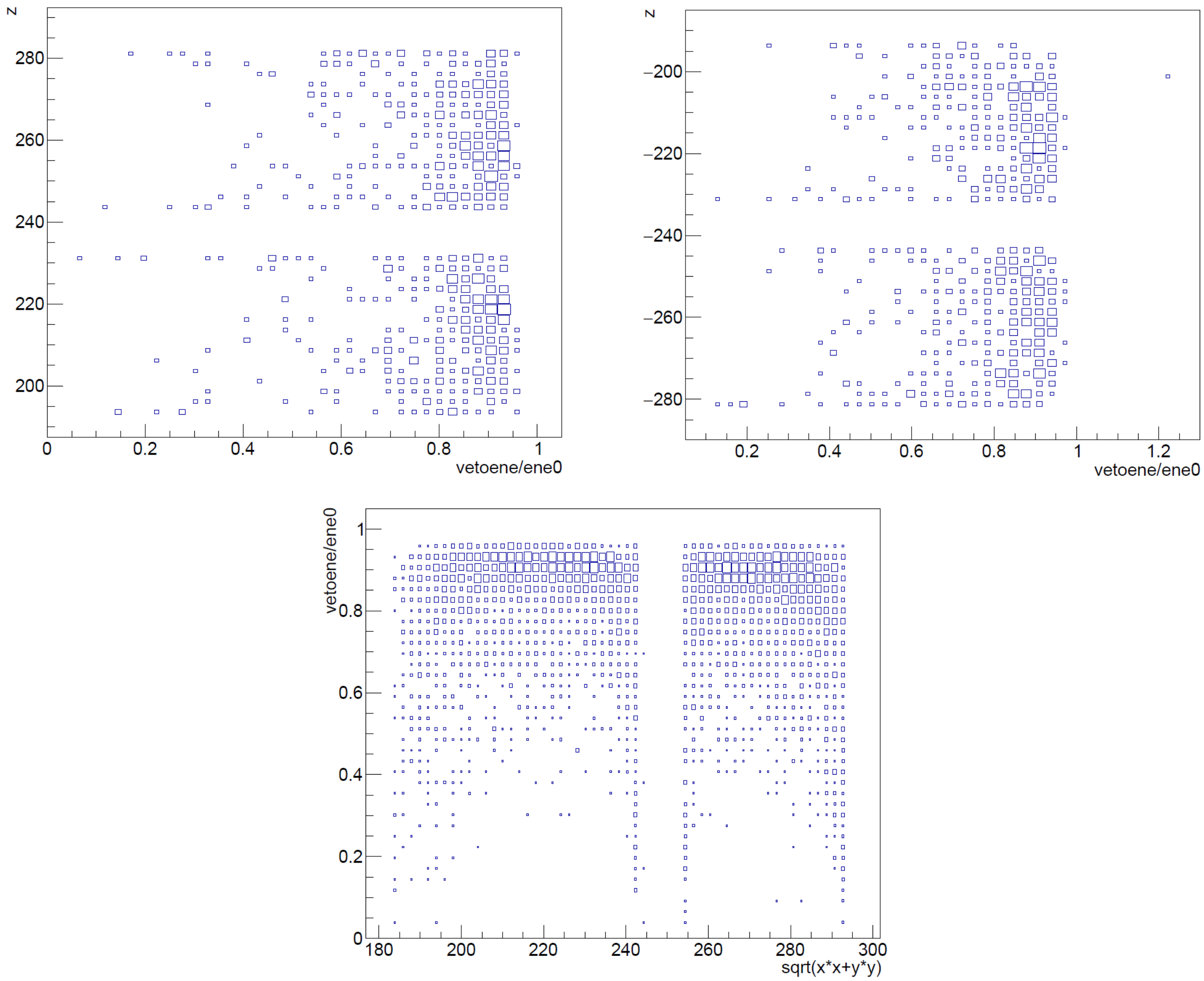


Figure 12: This set of histograms displays relationship between the energy resolution and the starting position of the neutrino, similarly to what can be seen in Figures 1, 2 and 3. However, in this case entries has different energies defined by the energy spectrum from Figure 5. The tendency for the energy resolution to worsen closer to the boundaries of the veto region is preserved.

4 Conclusions

During the internship several important steps towards determining how feasible using the veto detector for the discussed purpose is were taken. The changes made in code should be fine to be incorporated indefinitely, apart from one. The way the code determines the energy deposited in the veto materials is rather robust and likely requires revisiting. The electron energy resolution was graphically analysed with no suprising behaviour occuring and is ready for further analysis. There are a few issues with the neutrino energy resolution, discussed in the previous section.

Some of the events demonstrates unexpected behaviour, like the one whose veto energy is greater than the initial energy, and should be subject to more detailed analysis. A Marley simulation incorporating light was also run (outhepevt_150_neutrinos_light.root), however, little progress was made with it. The light count was behaving in rather unexpected manner and probably requires some further changes being made in the code.

References

[1] Niamh Fearon, *Direct Dark Matter Detection with the DarkSide-20k Detector*, December 2018.