

SciBooNE Charged-Current Coherent Pion Production Acceptance Study Technical Note

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1 Introduction

This document is intended to serve as a reference for the acceptance study performed for the SciBooNE charged current coherent pion production (CC-Coh $\pi^{+/-}$) re-analysis, as well as provide documentation of the code used in this study (in the event anything needs to be revisited in the future). The code resides in the github repository labeled as and linked here: [SciBooNE-MC](#). The corresponding ROOT files that were used in this acceptance study can be downloaded from here: [SciBooNE-MC-ROOTFiles](#).

The paper is structured such that Section 2 outlines Monte Carlo samples used in this study, Section 3 describes the SciBooNE detector as it was simulated in this study, Section 4 describes the various event samples that were used to both validate and generate the acceptance studies for the CC-Coh $\pi^{+/-}$ sample. Section 5 gives a high level summary of the results including the event-reduction tables as well as the CC-Coh $\pi^{+/-}$ acceptance results.

The appendix is left to explain how the code is run and the details of the scripts within. The appendix also details the order in which the macros should be run in, and the important plots that each macro produces that play a role in making the plots shown in Section 5 (the Results section).

1.1 Goal of the Re-Analysis

The goal of the re-analysis is to examine the acceptance modeling for the SciBooNE results in the presence of modern neutrino generators and updated models in order to hopefully shed light on why SciBooNE did not observe charged-current coherent pion production at low neutrino energy.

This study is intended to examine the effects of the acceptance modeling for a sample of coherent pion interactions inside the SciBooNE detector and compare what these would have been for various coherent pion production models. We utilize a simple, but robust, simulation of the SciBooNE detector and the NEUT neutrino generator to select and classify these neutrino events.

2 Samples

Five different samples were used in this study, three samples were generated in neutrino mode (ν -mode) and two samples in antineutrino mode ($\bar{\nu}$ -mode.)¹ Table 2 summarizes these samples. Details on these samples can be found in the Appendix.

¹All of these samples were generated by Callum Wilkinson (Thanks, Callum!)

Summary of Samples

Mode	NEUT version	Pion-Model	Number of simulated events
ν	5.3.6	Rein-Sehgal	1,000,000
ν	5.3.6	Berger-Sehgal	1,000,000
ν	5.0.1	Rein-Sehgal	100,000
$\bar{\nu}$	5.3.6	Rein-Sehgal	1,000,000
$\bar{\nu}$	5.3.6	Berger-Sehgal	1,000,000

Table 2: Summary of the samples used to build the acceptance model for this study.

3 Detector Simulation

This section is intended to detail the detector simulation done in this acceptance model, and to describe the assumptions made in order to accomplish accurate classifications of simulated events as charged-current coherent pion production.

3.1 The Detector

For the purposes of this acceptance study, the SciBooNE experiment is composed of two sub-detectors. The first (and the more upstream) of the sub-detectors, is the Scintillator Bar Tracker (SciBar) which was originally conceived and constructed to function as the near detector for the K2K experiment. The second (and more downstream) of the sub-detectors, is the Muon Range Detector (MRD), which is the detector designed and constructed specifically for SciBooNE for measuring the momentum of muons produced from charged-current neutrino interactions up to $1.2 \text{ GeV}/c$ by using the observed range of the trajectory of the muon. The coordinate system used throughout this study, and illustrated in Figure 3.1, puts the origin in the lower corner of the SciBar detector, has z along the beam direction, y opposite to gravity, and x to beam left.

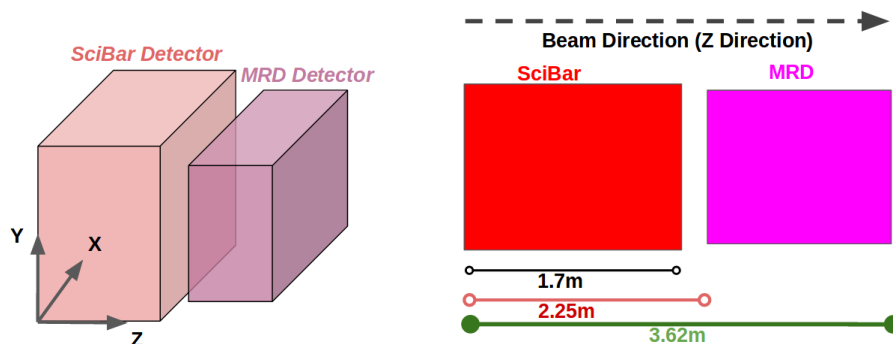


Figure 3.1: Representation of the SciBooNE detector and the coordinate frame we use in this study

3.1.1 The Scintillator Bar Tracker (SciBar)

The Scintillator Bar Tracker (SciBar) sub-detector is a scintillator detector which was used to identify neutrino interactions within SciBooNE. The dimensions of the SciBar detector used in this simulation are $0 < x < 3.0 \text{ m}$, $0 < y < 3.0 \text{ m}$, and $0 < z < 1.7 \text{ m}$. This simulation models the scintillator materials as having a constant energy deposition per unit length (dE/dx) for both

muons and pions of 2.04 MeV/cm based on previous SciBooNE analyses and on mean values for typical particle momentum listed in the particle data group (PDG).

3.1.2 The Muon Range Detector (MRD)

The Muon Range Detector (MRD), depicted in Figure 3.1.2, is located 0.55 *m* downstream of SciBar in the *z*-direction, and is a composition of two sets of thirteen alternating slabs of steel-scintillator layers, where the scintillator layers alternate between being horizontally oriented or vertically oriented, in the *xy*-plane. The steel layers have a *z*-direction thickness of 5.08 *cm* and the scintillator layers have a *z*-direction thickness of 0.6 *cm*. Combining all the layers of the different alternating materials results in 26 scintillator layers that "sandwich" twenty five steel layers in-between and gives a total *z*-direction dimension of being 1.37*m*. The *xy*-plane is modeled as a square again (as was the case with SciBar, too) with dimensions in the *x*-direction and the *y*-direction of 2.6 *m*. The energy deposition per unit length (dE/dx) of a muon penetrating the scintillator layers is assumed to be a constant 2.04 MeV/cm while the energy deposition for the muon in the steel layers is assumed to be a greater value of 11.43 MeV/cm. Both values are typical for muons at the energy range produced in SciBooNE and taken from the PDG.

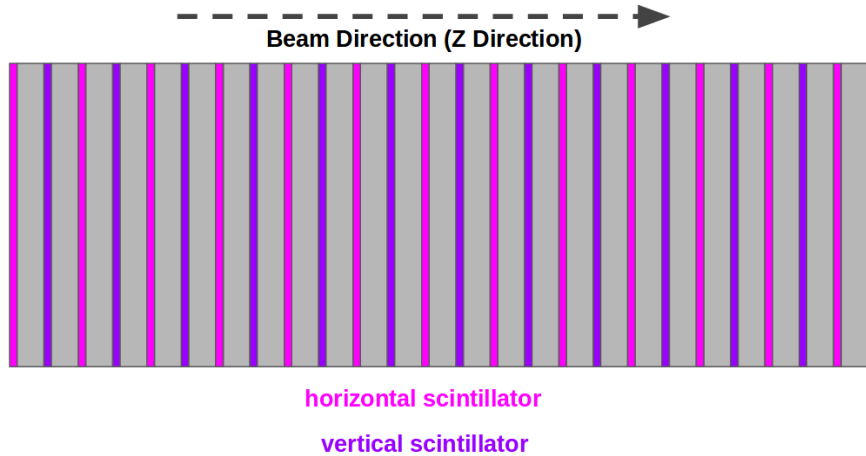


Figure 3.1.2: Depiction of the Muon Range Detector (MRD) which consists of alternating layers of horizontal scintillator (shown in pink) steel slabs (shown in grey) and vertical scintillator (shown in purple)

4 Event Selection

Two main samples are used in this study to generate the acceptance tables. The first is a charged current inclusive (CC-Inclusive) sample which requires a muon was created in the neutrino interaction and this muon intersects the MRD. This sample is described in Section 5.1 and is used to validate the building of the acceptance model by comparing it to previous SciBooNE analyses.

The second sample is the charged current coherent pion (CC-Coh $\pi^{+/-}$) sample which requires a muon and charged pion are created in the neutrino interaction exclusively (e.g. no other final state particles in the event). This sample is described in Section 5.2.

Both of these samples are selected using NEUT MC-truth flags which ensure we are treating pure samples which are classified by the neutrino generator as belonging to the appropriate sample.

Whether or not the event identified by our selection makes it into the final sample used in the acceptance study depends on the behavior of the muon with respect to the MRD. A muon which enters the MRD from a neutrino interaction will either come to stop in the MRD, exit out the back of the MRD (assuming it's momentum is great enough), or exit out the side of the MRD. In the next sections we explain this classification further.

4.1 Muon Stops within the MRD (“Stopped”)

The requirement to classify a neutrino interaction as a “stopped” event requires the muon from the interaction to have reached the MRD, penetrated at least three layers of steel (giving activity in three layers of scintillator), and to then deposit all of its remaining energy prior to reaching a boundary of the MRD. An illustration of a CC-Coh $\pi^{+/-}$ event which would be classified as “stopped” is shown in Figure 4.1.

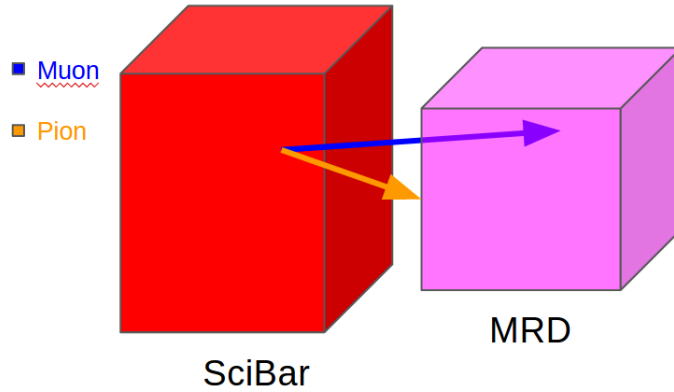


Figure 4.1: Depiction of an event that was classified as "Stopped."

These events allow for complete reconstruction of the muon's momentum based on the number of layers which the muon penetrated and the muon's incident angle.

4.2 Muon exits out the back of the MRD (“Out-the-back”)

The classification of a neutrino interaction as “out-the-back” requires that the muon from the interaction to have reached the MRD and to have had sufficient energy to have exited out the back face of the MRD without stopping. An illustration of such an event is given in Figure 4.2.



Figure 4.2: Depiction of an event that was classified as “out-the-back”.

The exact momentum of muons which pass completely through the MRD could not be made in reconstruction, so these events were classified as having the minimum energy required to penetrate all the steel and scintillator layers of the MRD.

4.3 Muon exits out the side of the MRD (“Out-the-side”)

The classification of a neutrino interaction as “out-the-side” requires that the muon from the interaction reached the MRD, penetrated at least three layers of steel, and then to have exited out the side of the active volume of the MRD (excluding the very back face). Events which are classified as “out-the-side” are excluded from this study because no accurate reconstruction of the muons momentum can be made when the muon exits out the side of the MRD. An illustration of such an excluded event which exits out the side of the MRD is given in Figure 4.3.

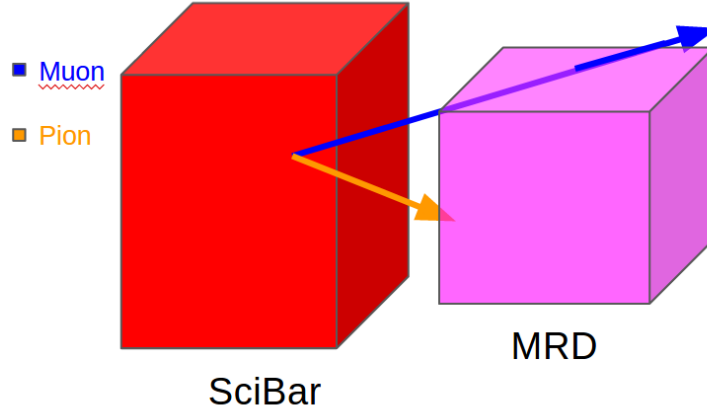


Figure 4.3: Depiction of an event that was classified as "Out-Side."

5 Results

The results of this acceptance study can be broken down into two different classification schemes of events. Those that met the conditions to qualify as CC-Inclusive events, and those that met the

conditions of classification as Charged-Current Coherent Pion events. The former is used to validate the acceptance modeling and detector simulation to reasonably reproduce previously published CC-Inclusive studies from SciBooNE, while the latter is used for the reanalysis.

5.1 Charged-Current Inclusive Events

Here we define the charged current inclusive sample (CC-Inclusive) which we use to validate our acceptance model against previously performed simulation studies.

5.1.1 ν -mode Charged-Current Inclusive Events

Table 5.1.1 goes through the event selection criteria for selecting a sample of CC-Inclusive events from the neutrino mode (ν -mode) Monte Carlo.

ν -mode CC-Inclusive Event Reduction			
Events Selection	NEUT v5.3.6 Rein-Sehgal	NEUT v5.3.6 Berger-Sehgal	NEUT v5.0.1 Rein-Sehgal
Total Sample	1,000,000	1,000,000	100,000
CC-Inclusive Interaction (μ + n-other particles in SciBar)	725,730	727,278	69,363
Muon enters the MRD	263,698	262,608	24,250
Muon enters the MRD and penetrates ≥ 3 layers of steel	231,089	230,054	21,001
“Stopped”-Events	177,406	175,799	16,062
“Out-the-back”-Events	15,389	15,952	1,421
“Out-the-side”-Events	38,294	38,303	3,518
Good CC-Inclusive Events	192,795	191,751	17,483

Table 5.1.1: Event reduction table for a sample of ν -mode CC-Inclusive events simulated in the SciBooNE geometry.

Figure 5.1.1 shows the momentum and angular (θ) distribution for the sample of ν -mode CC-Inclusive events passing all our requirements for all three models considered in this study (NEUT v5.3.6 Rein-Sehgal, NEUT v5.3.6 Berger-Sehgal, NEUT v5.0.1 Rein-Sehgal). The distributions have been normalized to the same area and show no strong differences between them.

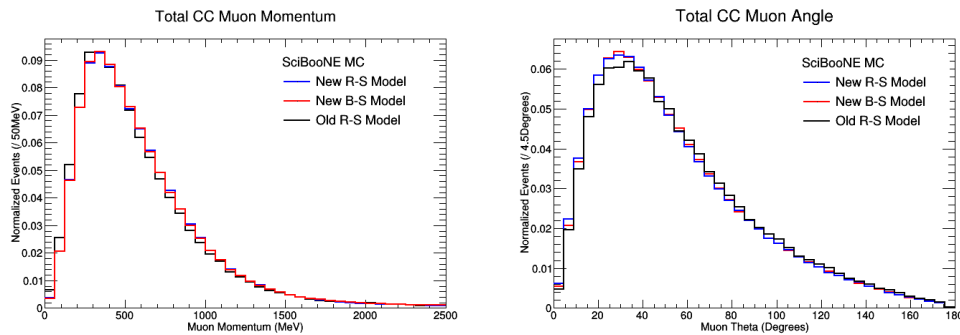


Figure 5.1.1: Muon Momentum (left) and Muon Angle (right) for ν -mode CC-Inclusive interactions for all three models included in this study. These samples kinematics are, unsurprisingly, very similar for the sample of CC-Inclusive

Figure 5.1.1 represents the one-dimensional efficiency for selecting ν -mode CC-Inclusive events for this study using all three different models compared to results derived from Hiraide's thesis² using the full SciBooNE Monte Carlo simulation. A few reference points are illustrated using dashed lines to guide the readers eye. A few percent difference is seen, but overall agreement between the two simulations hold.

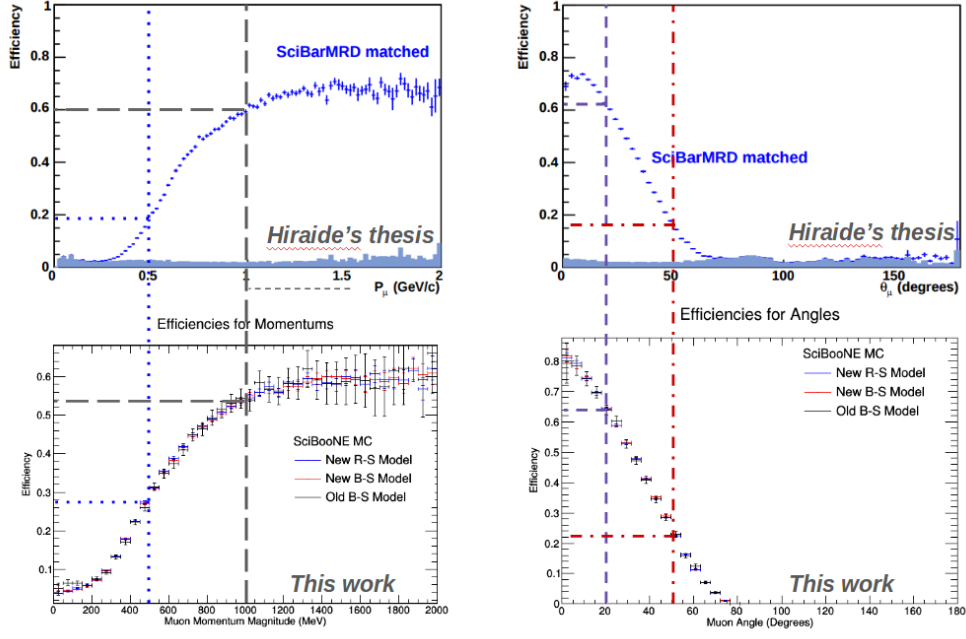


Figure 5.1.1: One-dimension efficiency plots for the ν -mode CC-Inclusive sample.

Figure 5.1.2 shows the two-dimensional efficiency for selecting ν -mode CC-Inclusive events. The left hand side is a reference plot provided by Morgan and the right hand side is for the Rein-Sehgal MC used in this study.

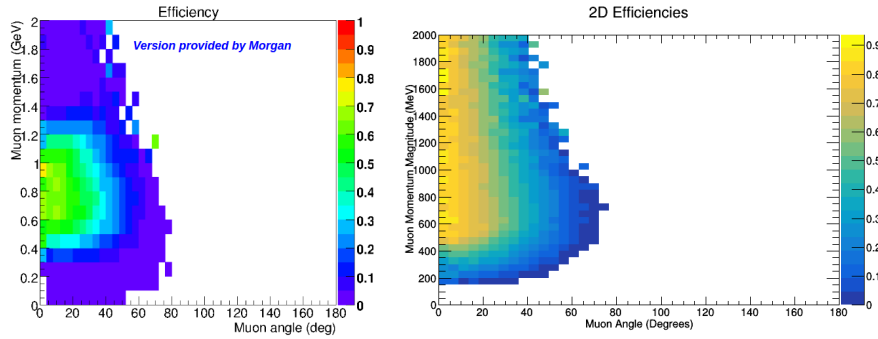


Figure 5.1.2: Two-dimensional efficiency plots for the ν -mode Rein-Sehgal CC-Inclusive sample.

²Hiraide's thesis can be found here: http://www-he.scphys.kyoto-u.ac.jp/theses/doctor/hiraide_dt.pdf

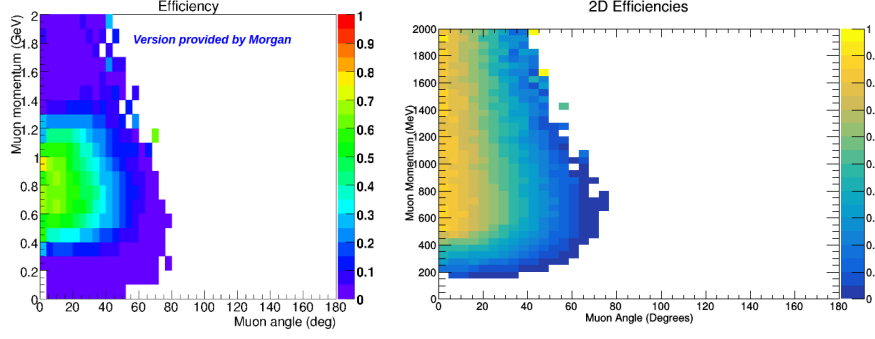


Figure 5.1.2: Two-dimensional efficiency plots for the ν -mode Berger-Sehgal CC-Inclusive sample.

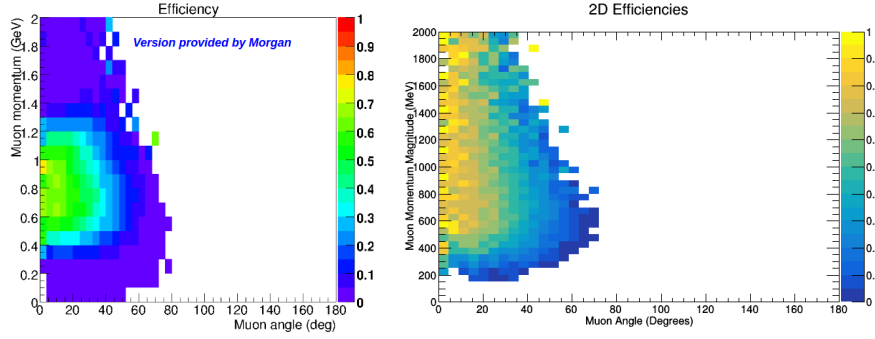


Figure 5.1.1: Two-dimensional efficiency plots for the ν -mode Old Rein-Sehgal CC-Inclusive sample.

5.1.2 $\bar{\nu}$ -mode Charged-Current Inclusive Events

Similar to before, Table 5.1.2 goes through the event selection criteria for selecting a sample of CC-Inclusive events from the antineutrino mode ($\bar{\nu}$ -mode) Monte Carlo.

$\bar{\nu}$ -mode CC-Inclusive Event Reduction

Events Selection	NEUT v5.3.6 Rein-Sehgal	NEUT v5.3.6 Berger-Sehgal
Total Sample	1,000,000	1,000,000
CC-Inclusive Interaction (μ + n-other particles in SciBar)	699,239	704,327
Muon enters the MRD	380,362	380,869
Muon enters the MRD and penetrates ≥ 3 layers of steel	336,373	337,979
“Stopped”-Events	288,289	288,206
“Out-the-back”-Events	7,608	7,857
“Out-the-side”-Events	40,476	41,916
Good CC-Inclusive Events	295,897	296,063

Table 5.1.2: Event reduction table for a sample of $\bar{\nu}$ -mode CC-Inclusive evnets simulated in the SciBooNE geometry.

Figure 5.1.1 shows the momentum and angular distribution for the sample of $\bar{\nu}$ -mode CC-Inclusive events passing all our requirements for both models considered in this study (NEUT v5.3.6 Rein-Sehgal, and NEUT v5.3.6 Berger-Sehgal). The distributions have been normalized to the same area and show no strong differences between them.

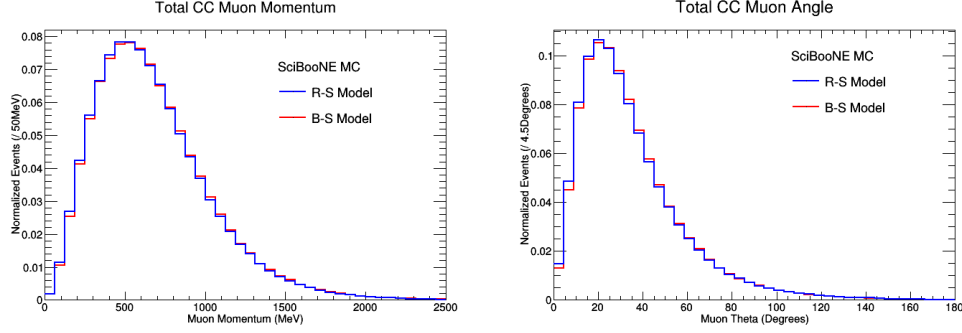


Figure 5.1.2: Muon Momentum (left) and Muon Angle (right) for $\bar{\nu}$ -mode CC-Inclusive interactions for all three models included in this study. These samples kinematics are, unsurprisingly, very similar for the sample of CC-Inclusive

Figure 5.1.2 represents the one-dimensional efficiency for selecting $\bar{\nu}$ -mode CC-Inclusive events for this study. No similar reference sample exists to be compared directly against, however we note that the shape and magnitude of the acceptance is nearly unchanged between $\bar{\nu}$ and ν -mode samples (as expected).

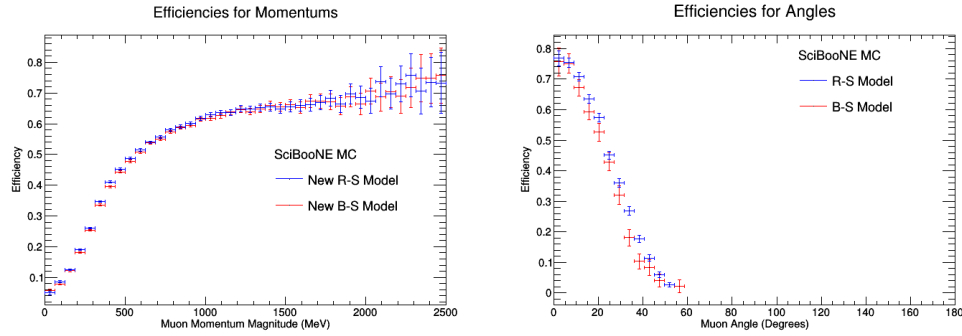


Figure 5.1.2: One-dimension efficiency plots for the $\bar{\nu}$ -mode CC-Inclusive sample. Muon's Momentums is on the right and the Muon's Angles is on the left.

Figure 5.1.2 shows the two-dimensional efficiency for selecting $\bar{\nu}$ -mode CC-Inclusive events for this study compared to results derived from Morgan's reference sample (need more words here about this....see email)

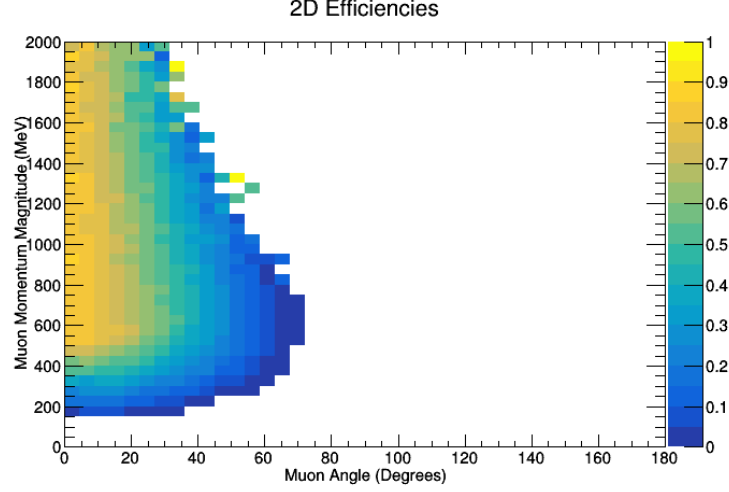


Figure 5.1.2: Two-dimensional efficiency plot for the $\bar{\nu}$ -mode Rein-Sehgal CC-Inclusive sample.

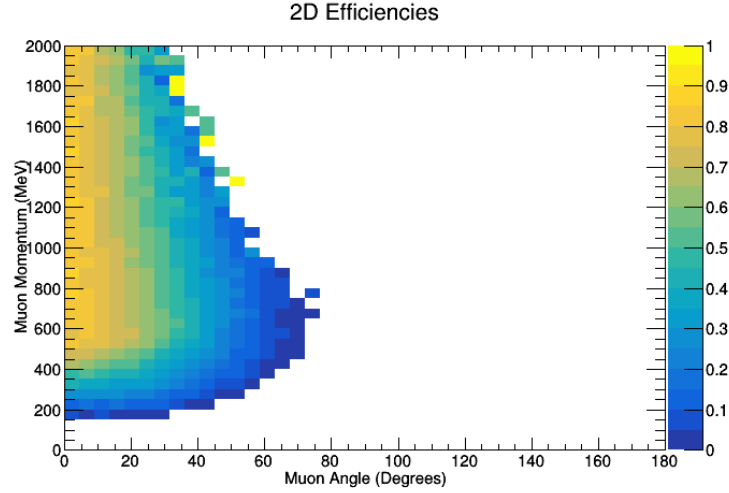


Figure 5.1.2: Two-dimensional efficiency plot for the $\bar{\nu}$ -mode Berger-Sehgal CC-Inclusive sample.

5.2 Charged-Current Coherent Pion Production Events

Here we define the Charged-Current Coherent Pion Production sample (CC-Coh $\pi^{+/-}$) which we use to validate our acceptance model against previous simulation studies which were done.

5.2.1 ν -mode Charged-Current Coherent Pion Events

Table 5.2.1 goes through the event selection criteria for selecting a sample of CC-Coh $\pi^{+/-}$ events from the neutrino mode (ν -mode) Monte Carlo.

The first quantity that is calculated for the different events is the momentum of both the muon and the pion, which are both found from the equations:

ν -mode CC-Coherent Pion Event Reduction

Events Selection	NEUT v5.3.6 Rein-Sehgal	NEUT v5.3.6 Berger-Sehgal	NEUT v5.0.1 Rein-Sehgal
Total Sample	1,000,000	1,000,000	100,000
CC-Coherent Pion Interaction ($\mu + \pi + \emptyset$ in SciBar)	12,186	2,576	1,320
Both muon and pion are forward going	8,535	1,845	884
Muon enters the MRD and penetrates ≥ 3 layers of steel	7,407	1,592	767
“Stopped”-Events	6,448	1,350	669
“Out-the-back”-Events	530	150	56
“Out-the-side”-Events	429	92	42
Good Coherent Pion Events	6,978	1,500	725

Table 1: Event reduction table for a sample of ν -mode Charged Current Coherent Pion events simulated in the SciBooNE geometry.

$$|\vec{p}_\mu| = \sqrt{P_{\mu_x}^2 + P_{\mu_y}^2 + P_{\mu_z}^2} \quad (1)$$

$$|\vec{p}_\pi| = \sqrt{P_{\pi_x}^2 + P_{\pi_y}^2 + P_{\pi_z}^2} \quad (2)$$

where $|\vec{p}_\mu|$ represents the magnitude of the momentum for the corresponding particle, and P_{μ_x} represents the component of the four momentum for the corresponding particle. The momentum is reported in units of MeV/c .

The next quantity calculated is the angle from the beam-direction for both the muon and the pion, which are labeled as either θ_μ , or θ_π , respectively. The angle from the beam-direction is the same as the angle from the z-direction, and this angle is known as the azimuthal angle. The calculation of the azimuthal angle is slightly more involved than the simple calculation used for finding the magnitude of the momentum of the two particles, and is calculated using the equations:

$$\theta_\mu = \tan^{-1} \left(\frac{\sqrt{P_{\mu_x}^2 + P_{\mu_y}^2}}{P_{\mu_z}} \right) \quad (3)$$

$$\theta_\pi = \tan^{-1} \left(\frac{\sqrt{P_{\pi_x}^2 + P_{\pi_y}^2}}{P_{\pi_z}} \right) \quad (4)$$

The angles are reported in units of $^\circ$, and should run from 0° to 180° . In the case of charged-current coherent pion production, the angle should never be larger than 90° .

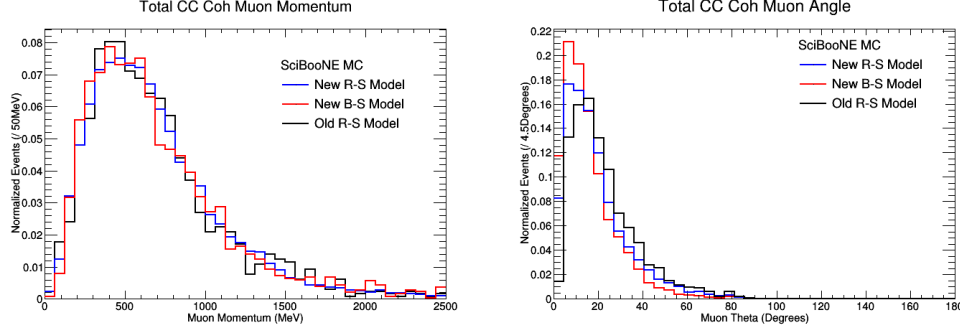


Figure 1: Muon Momentum for all of the muons of the events that made it to the MRD and penetrated at least three layers (left) and Muon Angle for the muons of the events that made it to the MRD and penetrated at least three layers (right) for ν -mode CC-Coh $\pi^{+/-}$ interactions for all three models included in this study. The "Total" classification means that all CC-Coh $\pi^{+/-}$ events are included in these histograms.

Here will be the plots for CC-Coh Pion with the good momentum efficiencies and the angle efficiencies!

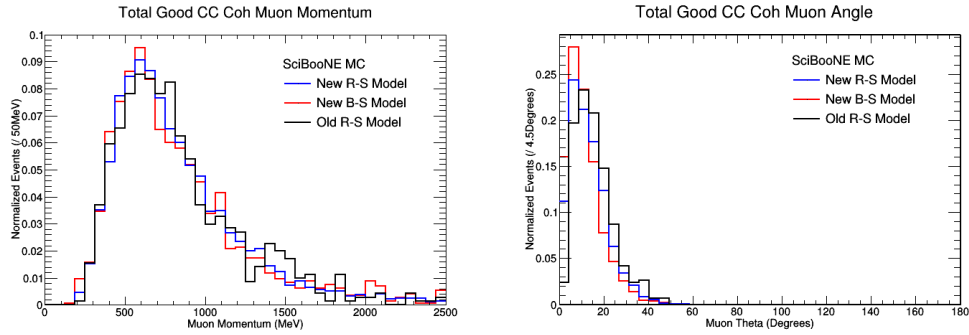


Figure 2: Muon Momentum of both the "stopped" and "not-stopped" samples (left) and Muon Angle of both the "stopped" and "not-stopped" samples (right) for ν -mode CC-Coh $\pi^{+/-}$ interactions for all three models included in this study. The "Good" classification means that only the stopped and not-stopped CC-Coh $\pi^{+/-}$ events are included for these histograms.

The last two quantities that are calculated are the two different types of four-momentum transfers specific to this interaction, which are Q^2 and $|t|$. The Q^2 corresponds to the four-momentum transfer from the neutrino and muon to the nucleus and pion, and is calculated using the equation:

$$Q^2 = |(P_{\nu_\mu} - P_\mu)^2| \quad (5)$$

This equation is the four-momentum notational form. The code follows the equation below in order to compute Q^2 :

$$Q^2 = |(P_{\nu_{\mu,x}} - P_{\mu_x})^2 + (P_{\nu_{\mu,y}} - P_{\mu_y})^2 + (P_{\nu_{\mu,z}} - P_{\mu_z})^2 + (P_{\nu_{\mu,E}} - P_{\mu_E})^2| \quad (6)$$

Q^2 is reported in units of $(MeV/c)^2$.

The $|t|$ corresponds to the four-momentum transfer from the neutrino, muon, and pion to the nucleus, and is calculated using the equation:

$$|t| = |(Q - P_\pi)^2| = |(P_{\nu_\mu} - P_\mu - P_\pi)^2| \quad (7)$$

This equation is the four-momentum notational form. The code follows the equation below in order to compute $|t|$:

$$|t| = |(P_{\nu_{\mu,x}} - P_{\mu_x} - P_{\pi_x})^2 + (P_{\nu_{\mu,y}} - P_{\mu_y} - P_{\pi_y})^2 + (P_{\nu_{\mu,z}} - P_{\mu_z} - P_{\pi_z})^2 + (P_{\nu_{\mu,E}} - P_{\mu_E} - P_{\pi_E})^2| \quad (8)$$

$|t|$ is reported in units of $(MeV/c)^2$.

ν -Mode $|t|$ and Q^2 plots are below:

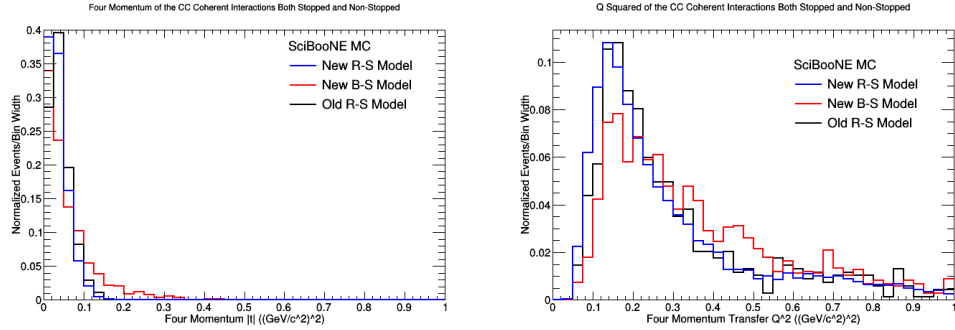


Figure 3: The $|t|$ Momentum Transfer for the "stopped" and "not-stopped" events (left) and Q^2 Momentum Transfer for the "stopped" and "not-stopped" events (right) for ν -mode CC-Coh $\pi^{+/-}$ interactions for the three models included in this study.

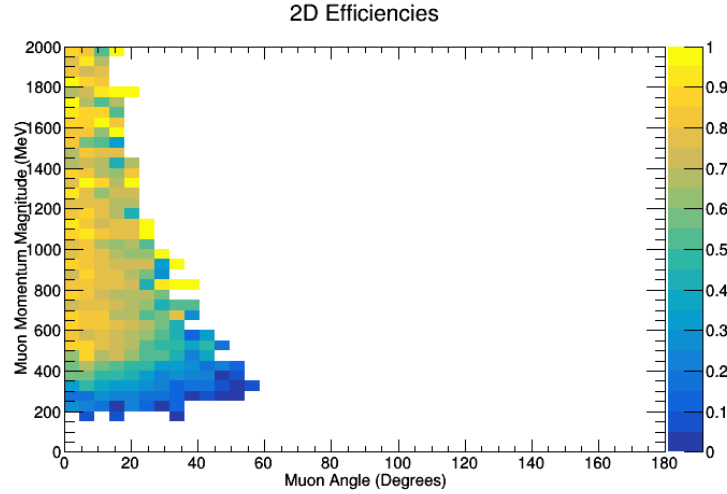


Figure 5.2.1: Two-dimensional efficiency plot for the new NEUT ν -mode Rein-Sehgal CC-Coherent sample.

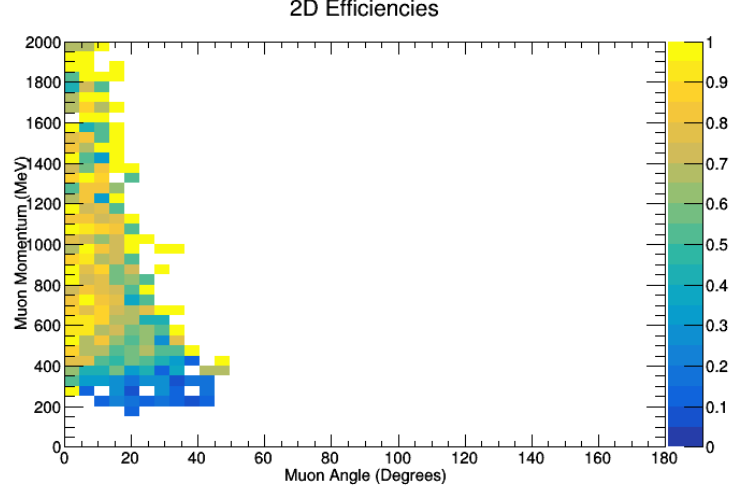


Figure 5.2.1: Two-dimensional efficiency plot for the new NEUT ν -mode Berger-Sehgal CC-Coherent sample.

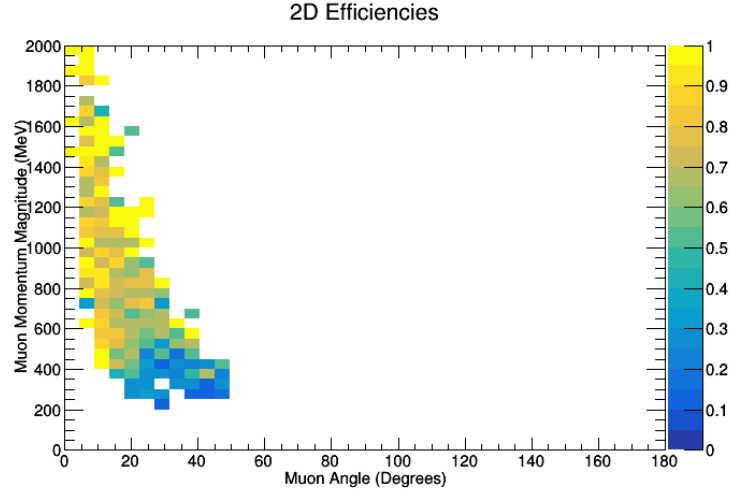


Figure 5.2.1: Two-dimensional efficiency plot for the old NEUT ν -mode Rein-Sehgal CC-Coherent sample.

5.2.2 $\bar{\nu}$ -mode Charged-Current Coherent Pion Events

Similar to before, Table 5.2.2 goes through the event selection criteria for selecting a sample of CC-Coh $\pi^{+/-}$ events from the anti-neutrino mode ($\bar{\nu}$ -mode) Monte Carlo.

Below are the plots for CC-Coh $\pi^{+/-}$ Events for $\bar{\nu}$ -mode. The layout of the rest will be very similar to ν -mode, and the equations used previously are the same equations used for the plots below.

$\bar{\nu}$ -mode CC-Coherent Pion Event Reduction

Events Selection	NEUT v5.3.6 Rein-Sehgal	NEUT v5.3.6 Berger-Sehgal
Total Sample	1,000,000	1,000,000
CC-Coherent Pion Interaction ($\mu + \pi + \emptyset$ in SciBar)	36,669	7,790
Both muon and pion are forward going	24,675	5,477
Muon enters the MRD and penetrates ≥ 3 layers of steel	20,445	4,517
“Stopped”-Events	18,935	4,203
“Out-the-back”-Events	372	82
“Out-the-side”-Events	1,138	232
Good Coherent Pion Events	19,307	4,285

Table 2: Event reduction table for a sample of $\bar{\nu}$ -mode Charged Current Coherent Pion events simulated in the SciBooNE geometry.

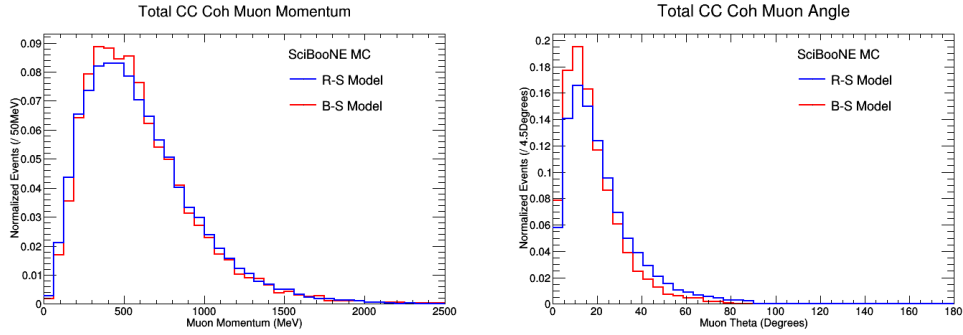


Figure 4: Muon Momentum (left) and Muon Angle (right) for ν -mode CC-Coh $\pi^{+/-}$ interactions for all three models included in this study.

The structure of the plots in Figure: 5.2.2 very closely resembles the plots for the ν -mode above, and the rest of the plots in this section have that same characteristic.

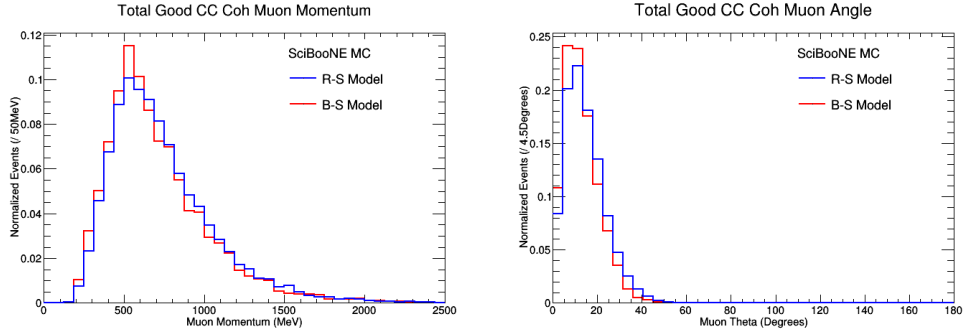


Figure 5: Muon Momentum (left) and Muon Angle (right) for $\bar{\nu}$ -mode CC-Coh $\pi^{+/-}$ interactions for both the "stopped" and "not-stopped" samples of events.

$\bar{\nu}$ -mode $|t|$ and Q^2 plots are below. They also have the same overall shape as the plots for ν -mode above.

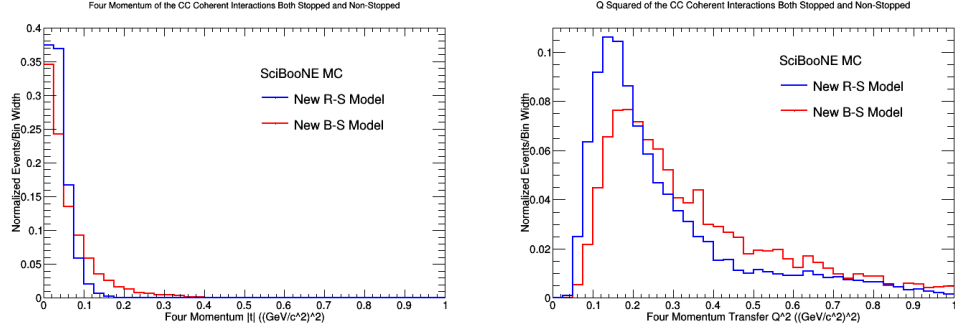


Figure 6: The $|t|$ Momentum Transfer (left) and Q^2 Momentum Transfer (right) for $\bar{\nu}$ -mode CC-Coh $\pi^{+/-}$ interactions for both of the models included in this study which are the "stopped" and "not-stopped" events.

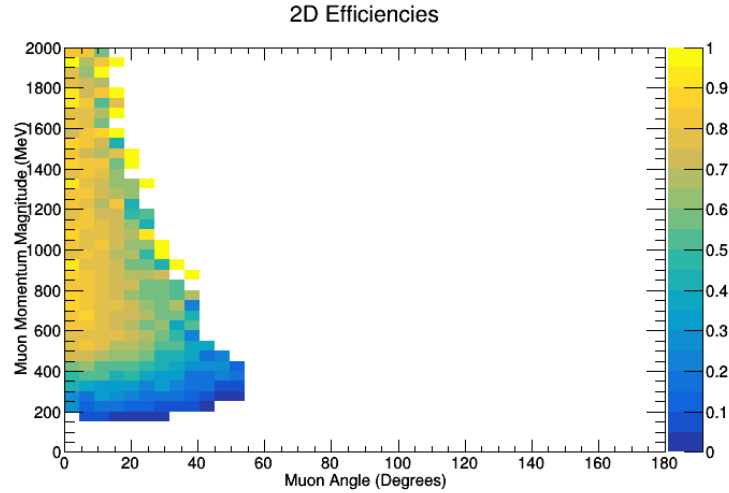


Figure 5.2.2: Two-dimensional efficiency plot for the new NEUT $\bar{\nu}$ -mode Rein-Sehgal CC-Coherent sample.

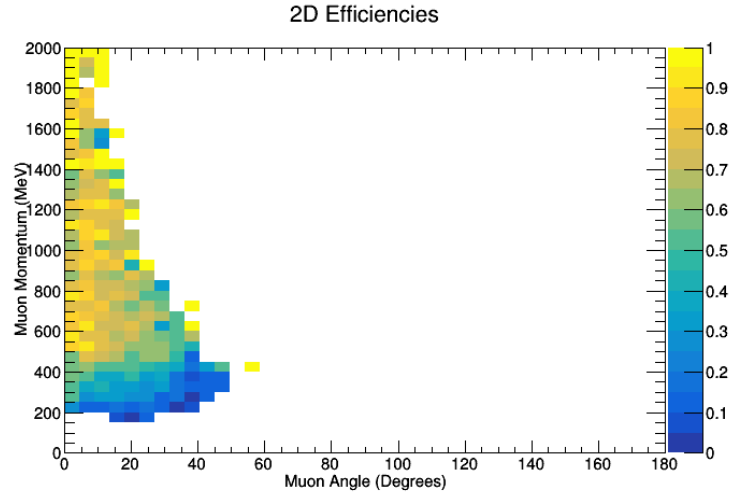


Figure 5.2.2: Two-dimensional efficiency plot for the new NEUT $\bar{\nu}$ -mode Berger-Sehgal CC-Coherent sample.

A Appendix: Sample Details

Appendix on samples

A.1 ν -Mode Rein-Sehgal NEUTv5.3.6

A sample of 1,000,000 ν interactions were simulated using the NEUT generator (v5.3.6) and the Rein-Sehgal model for coherent pion production. This sample correspond to the file labeled

`SciBooNE_numu_coh_RooTrack.root`

found at the following link (put link to sample here).

A.2 ν -Mode Berger-Sehgal NEUTv5.3.6

A sample of 1,000,000 ν interactions were simulated using the NEUT generator (v5.3.6) and the Berger-Sehgal model for coherent pion production. This sample correspond to the file labeled

`SciBooNE_numu_coh_RooTrack_NEW.root`

found at the following link (put link to sample here).

A.3 ν -Mode Rein-Sehgal NEUTv5.0.1

A sample of 100,000 ν interactions were simulated using the NEUT generator (v5.0.1, believed to be the version used by the SciBooNE collaboration in the original publication) and the corresponding older Rein-Sehgal model for coherent pion production. This sample corresponds to the file labeled

`SciBooNE_numu_coh_OLDNEUT_RooTrack.root`

found at the following link (put link to sample here).

A.4 $\bar{\nu}$ -Mode Rein-Sehgal NEUTv5.3.6

A sample of 1,000,000 $\bar{\nu}$ interactions were simulated using the NEUT generator (v5.3.6) and the Rein-Sehgal model for coherent pion production. This sample corresponds to the file labeled

`SciBooNE_numubar_coh_RooTrack.root`

found at the following link (put link to sample here).

A.5 $\bar{\nu}$ -Mode Berger-Sehgal NEUTv5.3.6

A sample of 1,000,000 $\bar{\nu}$ interactions were simulated using the NEUT generator (v5.3.6) and the Berger-Sehgal model for coherent pion production. This sample corresponds to the file labeled

`SciBooNE_numubar_coh_RooTrack_NEW.root`

found at the following link (put link to sample here).

A.6 Vertex Distributions

The events were all given a random initial point that was generated with the goal that the vertex distributions of this simulation would closely match the vertex distributions that Hiraide ³ showed in his thesis. This was done by... etc.

```
TRandom3 *randX = new TRandom3();
TRandom3 *randY = new TRandom3();
TRandom3 *flat = new TRandom3();
randX->SetSeed(jentry/2);
randY->SetSeed(jentry*jentry);
flat->SetSeed(jentry*jentry*jentry);
double Xpos = randX->Gaus(1.5,1.3);
while (Xpos<0 || Xpos>3.0) { Xpos = randX->Gaus(1.5,1.3); }
double Ypos = randY->Gaus(1.5,1.05);
while (Ypos<0 || Ypos>3.0) { Ypos = randY->Gaus(1.5,1.05); }
double Zpos = flat->Uniform(0,1.7);
```

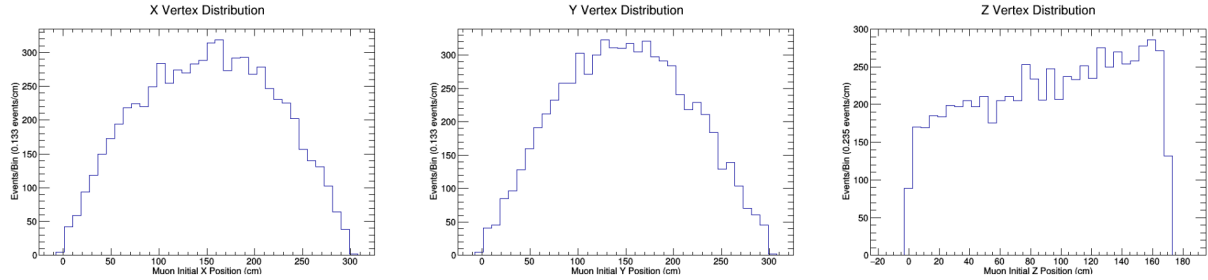


Figure 7: Vertex distributions of the events in the new Rein-Sehgal sample in ν -mode.

A.7 NewNMReinSehgal.C

This file is the macro that corresponds to the "NewNMReinSehgal.h" file, which connects with this file: "SciBooNE_numu_coh_RooTrack.root". This file performs the main analysis for this generated sample, and then organizes the information into many different histograms. The histograms are then written to a file titled "totalmuoninfoRS.root" inside the "ROOTFILES" directory. The "ROOTFILES" directory is included in the SciBooNE-MC repository (it is absolutely pertinent that this directory be located where the macro files are located due to how the calls of the combined data macros reference the now saved histograms). When this macro is run (which can take a while), it also plots a few different histograms. The histograms that are plotted are the ones shown in the figures below with descriptions included with the corresponding figures. The order that the histograms appear in this paper is the same order they will be shown when this macro is run in root.

³Hiraide's thesis can be found here: http://www-he.scphys.kyoto-u.ac.jp/theses/doctor/hiraide_dt.pdf

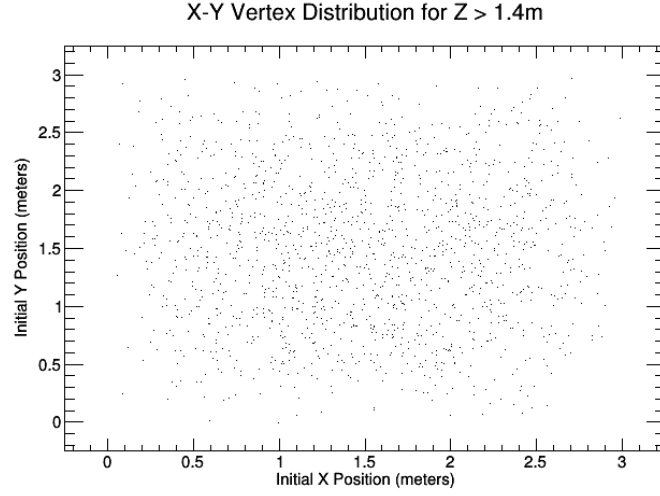


Figure 8: New ν -Mode Rein-Sehgal X-Y vertex distributions for muons that made it to the MRD and penetrated at least to the third layer of steel.

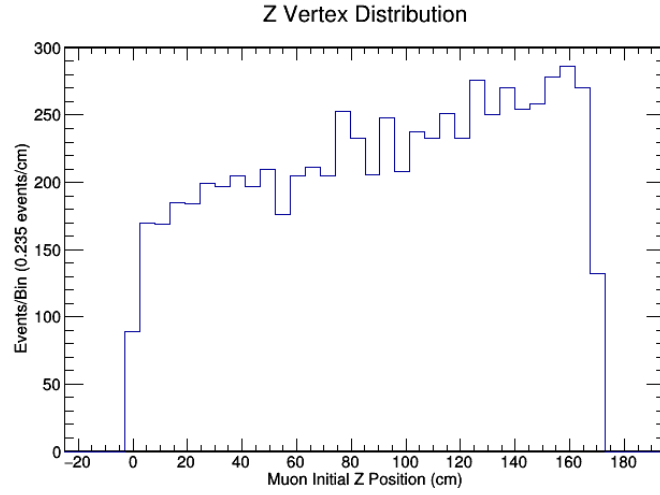


Figure 9: New ν -Mode Rein-Sehgal Z vertex distributions for the interactions.

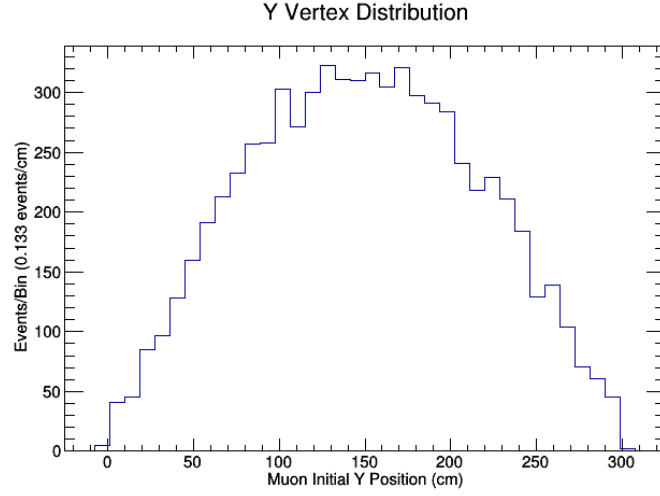


Figure 10: New ν -Mode Rein-Sehgal Y vertex distributions for the interactions.

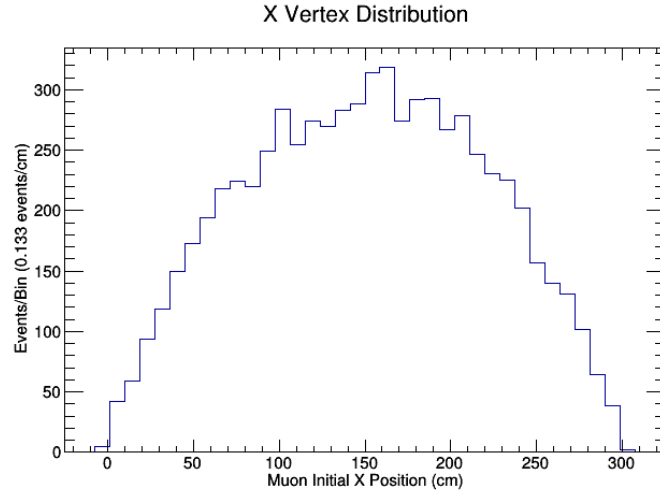


Figure 11: New ν -Mode Rein-Sehgal X vertex distributions for the interactions.

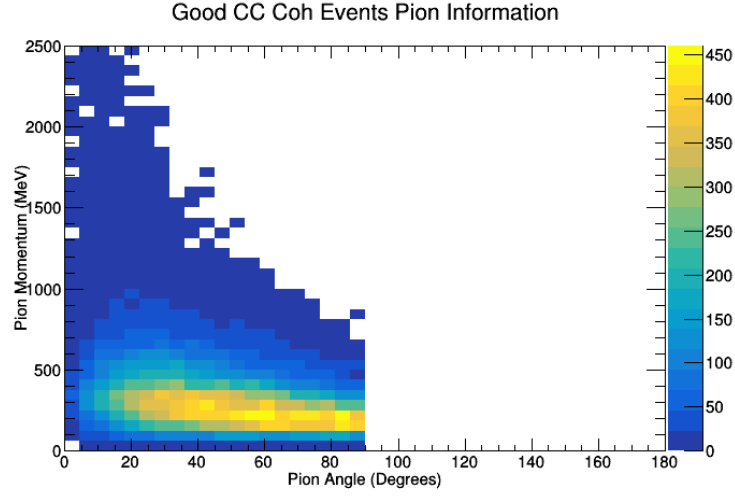


Figure 12: This is a 2D histogram for the momentum and angle of the pion in the CC Coh Pion events that met the qualification of being "good".

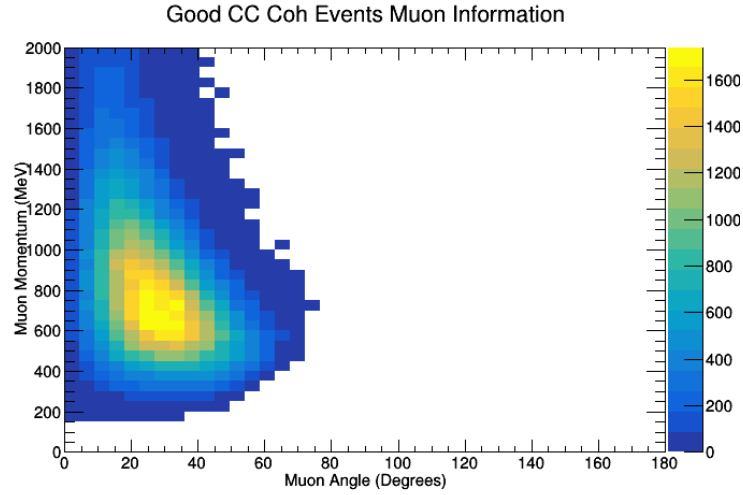


Figure 13: This is a 2D histogram for the momentum and angle of the muon in the CC Coh Pion events that met the qualification of being "good".

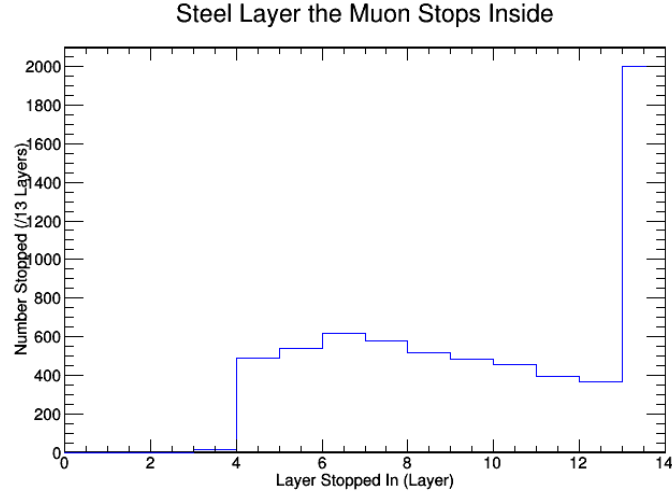


Figure 14: This histogram shows the amount of muons that embedded (or "Stopped") in a corresponding layer of steel in our simulation.

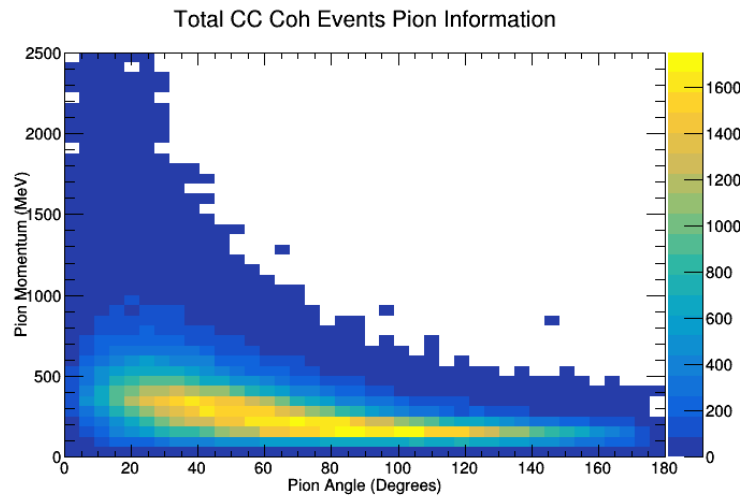


Figure 15: This is a 2D histogram for the momentum and angle of the pion in the total CC Coh Pion events.

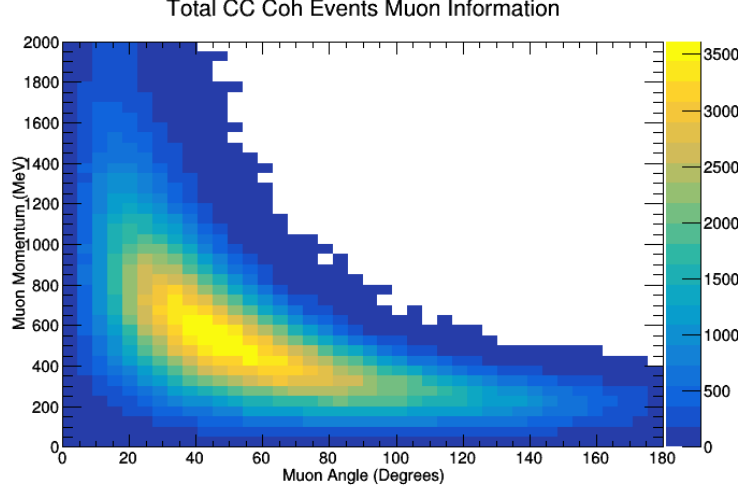


Figure 16: This is a 2D histogram for the momentum and angle of the muon in the total CC Coh Pion events.

The NewNMReinSehgal.C macro also calculates many different quantities for the generated simulation of the events and saves the information in histograms that are later called upon through the plotting macros (which are after all of the analysis macros). The first quantity that is calculated for the different vertexes is the momentum of both the muon and the pion, which are both calculated using the equations:

$$|\vec{p}_\mu| = \sqrt{P_{\mu_x}^2 + P_{\mu_y}^2 + P_{\mu_z}^2} \quad (9)$$

$$|\vec{p}_\pi| = \sqrt{P_{\pi_x}^2 + P_{\pi_y}^2 + P_{\pi_z}^2} \quad (10)$$

The momentum is reported in units of MeV/c .

The next quantity that is calculated in the macro is the angle from the beam-direction for both the muon and the pion, which are labeled as either θ_μ , or θ_π , respectively. The angle from the beam-direction is the same as the angle from the z-direction, and this angle is known as the azimuthal angle. The calculation of the azimuthal angle is slightly more involved than the simple calculation used for finding the magnitude of the momentum of the two particles, and is calculated using the equations:

$$\theta_\mu = \tan^{-1}(\sqrt{P_{\mu_x}^2 + P_{\mu_y}^2}/P_{\mu_z}) \quad (11)$$

$$\theta_\pi = \tan^{-1}(\sqrt{P_{\pi_x}^2 + P_{\pi_y}^2}/P_{\pi_z}) \quad (12)$$

The angles are reported in units of $^\circ$, and should run from 0° to 180° . In the case of Charged-Current Coherent Pion Production, the angle should never be larger than 90° .

The last two quantities that this analysis macro calculates are the two different types of four-momentum transfers specific to this interaction, which are Q^2 and $|t|$. The Q^2 corresponds to the four-momentum transfer from the neutrino and muon to the nucleus and pion, and is calculated using the equation:

$$Q^2 = |(P_{\nu_\mu} - P_\mu)^2| \quad (13)$$

This equation is the four-momentum notational form. The code follows the equation below in order to compute Q^2 :

$$Q^2 = |(P_{\nu_{\mu,x}} - P_{\mu_x})^2 + (P_{\nu_{\mu,y}} - P_{\mu_y})^2 + (P_{\nu_{\mu,z}} - P_{\mu_z})^2 + (P_{\nu_{\mu,E}} - P_{\mu_E})^2| \quad (14)$$

Q^2 is reported in units of $(MeV/c)^2$.

The $|t|$ corresponds to the four-momentum transfer from the neutrino, muon, and pion to the nucleus, and is calculated using the equation:

$$|t| = |(Q - P_{\pi})^2| = |(P_{\nu_{\mu}} - P_{\mu} - P_{\pi})^2| \quad (15)$$

This equation is the four-momentum notational form. The code follows the equation below in order to compute $|t|$:

$$|t| = |(P_{\nu_{\mu,x}} - P_{\mu_x} - P_{\pi_x})^2 + (P_{\nu_{\mu,y}} - P_{\mu_y} - P_{\pi_y})^2 + (P_{\nu_{\mu,z}} - P_{\mu_z} - P_{\pi_z})^2 + (P_{\nu_{\mu,E}} - P_{\mu_E} - P_{\pi_E})^2| \quad (16)$$

$|t|$ is reported in units of $(MeV/c)^2$.

A.8 NewNMBergerSehgal.C

This file is the macro that corresponds to the "NewNMBergerSehgal.h" file, which connects with this file: "SciBooNE_numu_coh_RooTrack_NEW.root". This file performs the main analysis for this generated sample, and then organizes the information into many different histograms. The histograms are then written to a file titled "totalmuoninfoBS.root" inside the "ROOTFILES" directory. The "ROOTFILES" directory is included in the SciBooNE-MC repository (it is absolutely pertinent that this directory be located where the macro files are located due to how the calls of the combined data macros reference the now saved histograms).

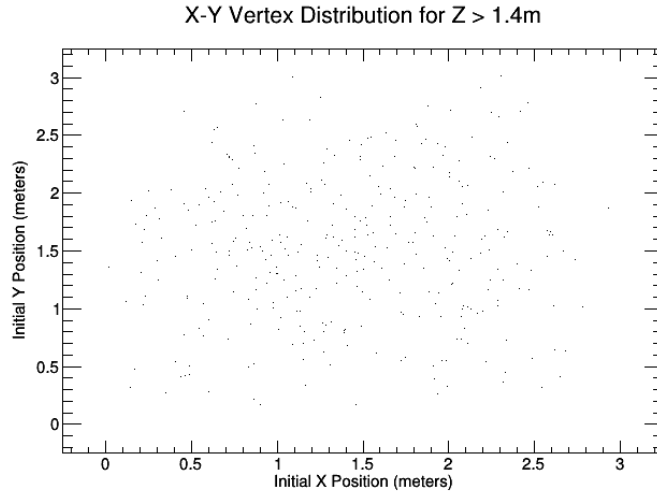


Figure 17: New ν -Mode Berger-Sehgal X-Y vertex distributions for muons that made it to the MRD and penetrated at least to the third layer of steel.

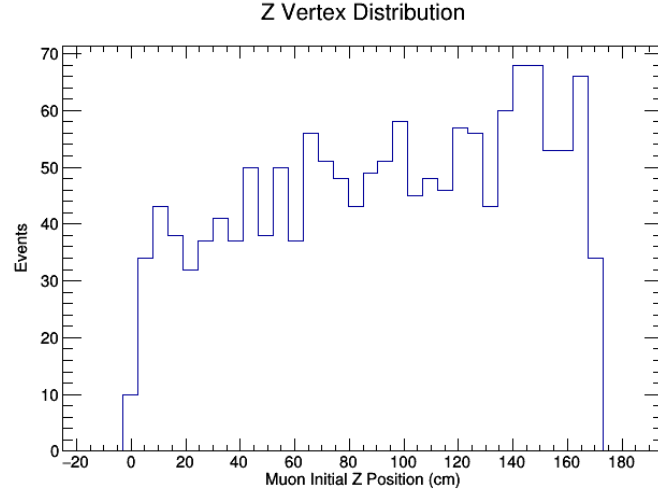


Figure 18: New ν -Mode Berger-Sehgal Z vertex distributions for the interactions.

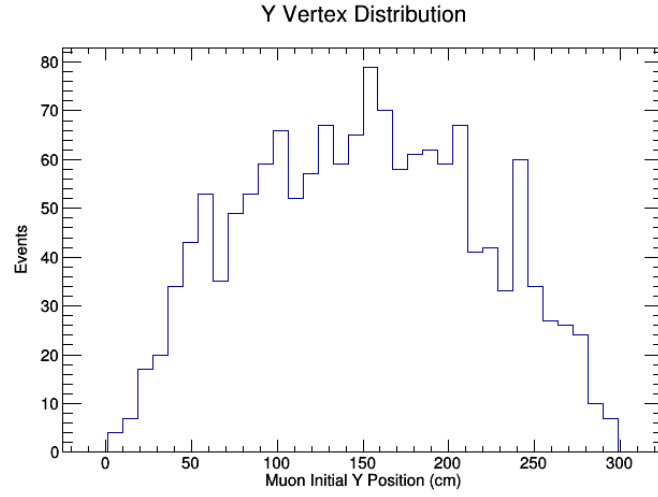


Figure 19: New ν -Mode Berger-Sehgal Y vertex distributions for the interactions.

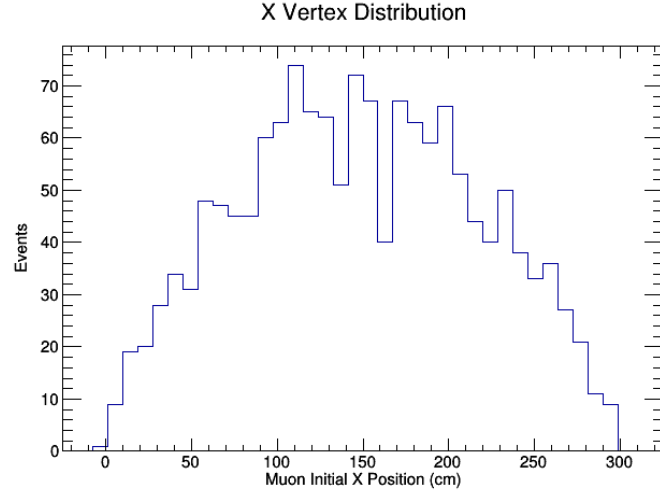


Figure 20: New ν -Mode Berger-Sehgal X vertex distributions for the interactions.

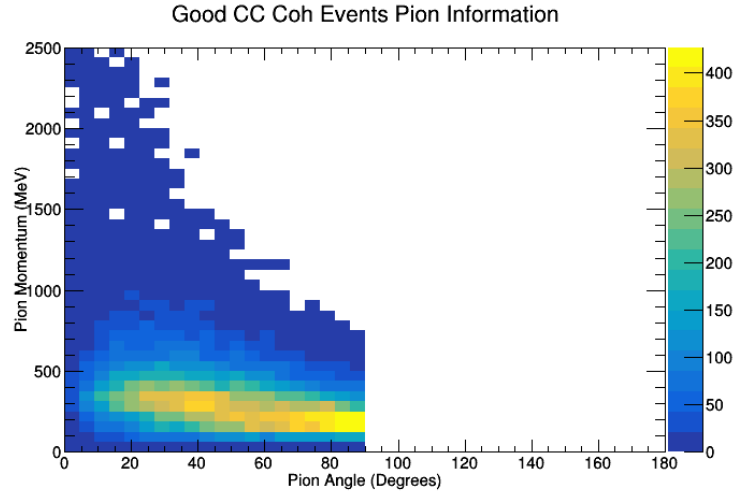


Figure 21: This is a 2D histogram for the momentum and angle of the pion in the CC Coh Pion events that met the qualification of being "good".

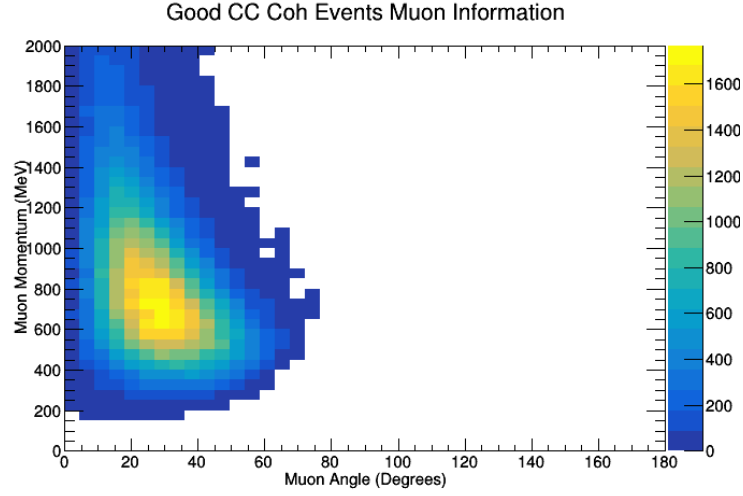


Figure 22: This is a 2D histogram for the momentum and angle of the muon in the CC Coh Pion events that met the qualification of being "good".!

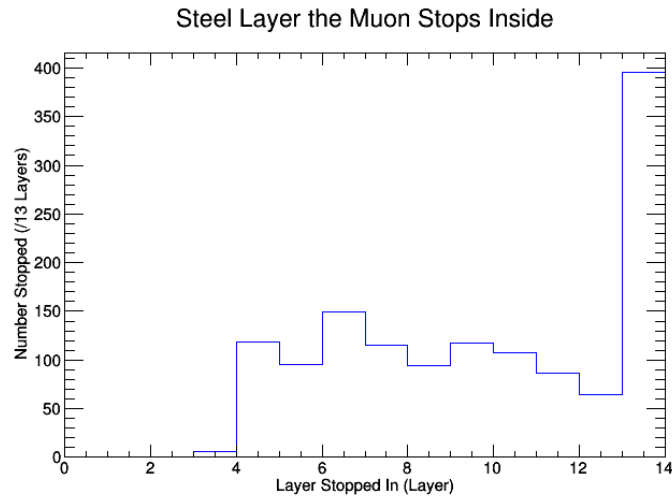


Figure 23: This histogram shows the amount of muons that embedded (or "Stopped") in a corresponding layer of steel in our simulation.

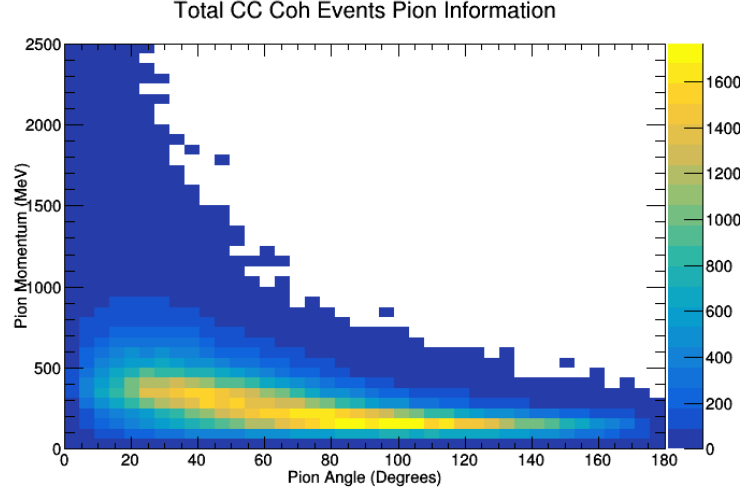


Figure 24: This is a 2D histogram for the momentum and angle of the pion in the total CC Coh Pion events.

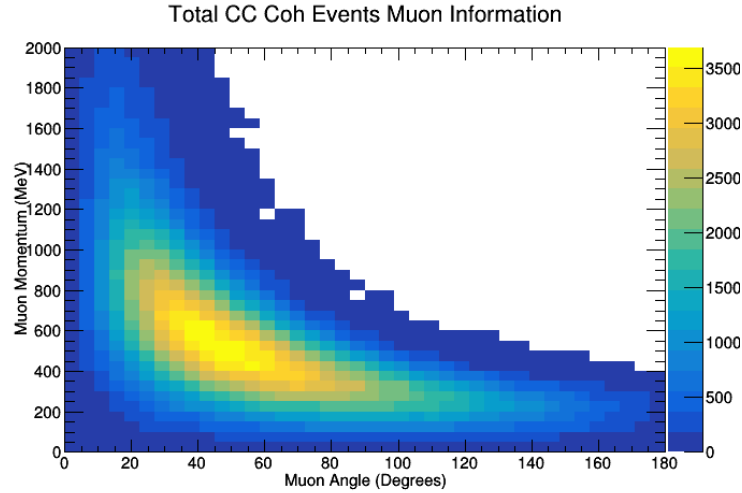


Figure 25: This is a 2D histogram for the momentum and angle of the muon in the total CC Coh Pion events.

A.9 OldNMReinSehgal.C

This file is the macro that corresponds to the "OldNMReinSehgal.h" file, which connects with this file: "SciBooNE_numu_coh_OLDNEUT_RooTrack.root". This file performs the main analysis for this generated sample, and then organizes the information into many different histograms. The histograms are then written to a file titled "totalmuoninfoOBS.root" inside the "ROOTFILES" directory. The "ROOTFILES" directory is included in the SciBooNE-MC repository (it is absolutely pertinent that this directory be located where the macro files are located due to how the calls of the combined data macros reference the now saved histograms).

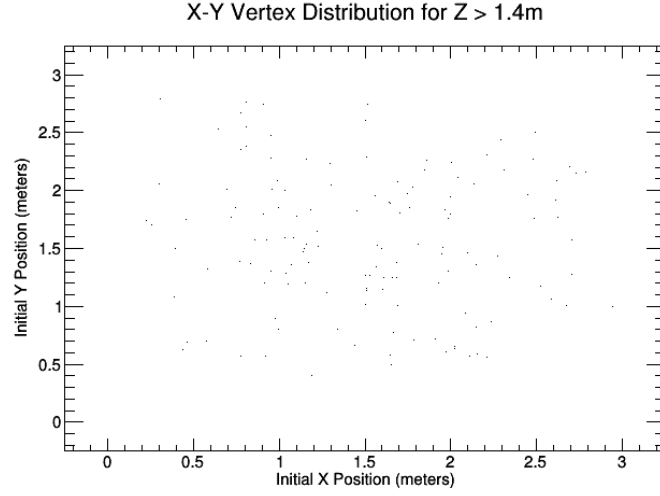


Figure 26: Old ν -Mode Rein-Sehgal X-Y vertex distributions for muons that made it to the MRD and penetrated at least to the third layer of steel.

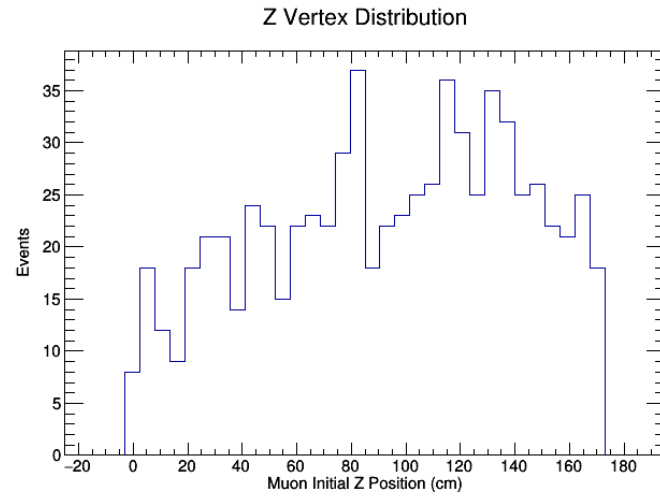


Figure 27: Old ν -Mode Rein-Sehgal Z vertex distributions for the interactions.

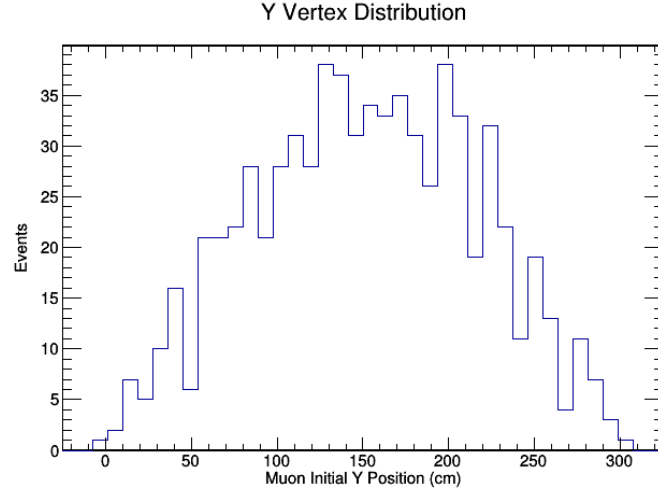


Figure 28: Old ν -Mode Rein-Sehgal Y vertex distributions for the interactions.

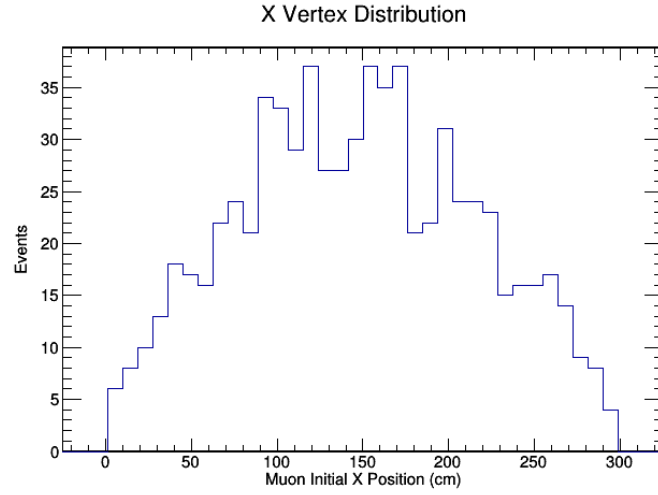


Figure 29: Old ν -Mode Rein-Sehgal X vertex distributions for the interactions.

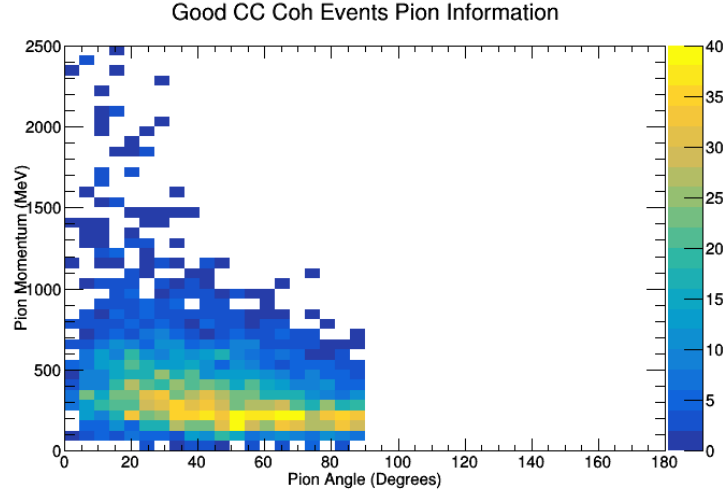


Figure 30: This is a 2D histogram for the momentum and angle of the pion in the CC Coh Pion events that met the qualification of being "good".

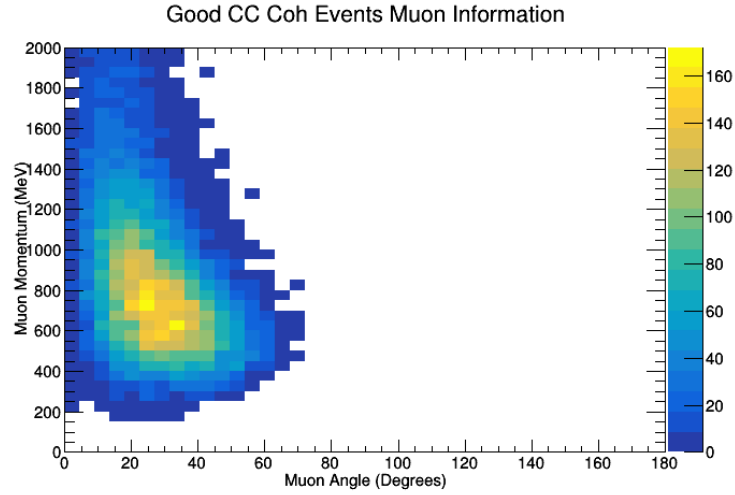


Figure 31: This is a 2D histogram for the momentum and angle of the muon in the CC Coh Pion events that met the qualification of being "good".

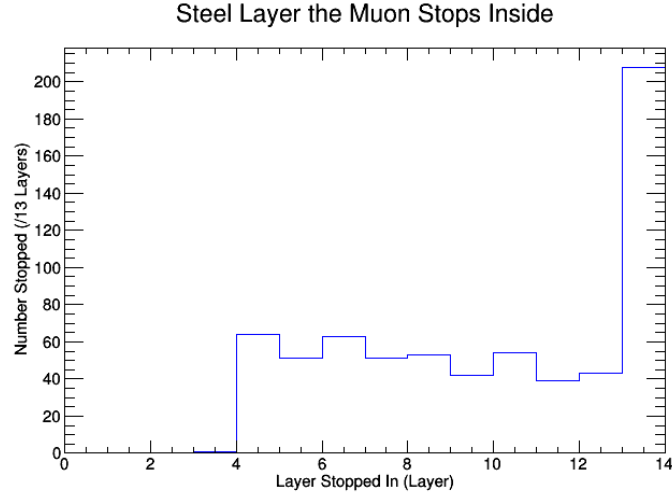


Figure 32: This histogram shows the amount of muons that embedded (or "Stopped") in a corresponding layer of steel in our simulation.

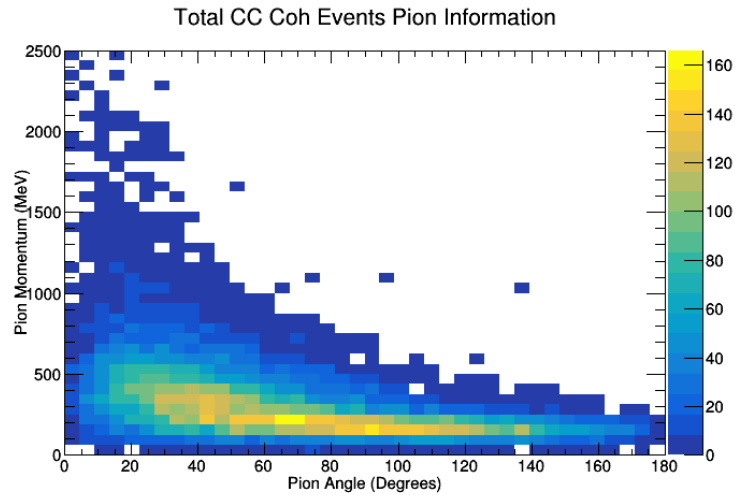


Figure 33: This is a 2D histogram for the momentum and angle of the pion in the total CC Coh Pion events.

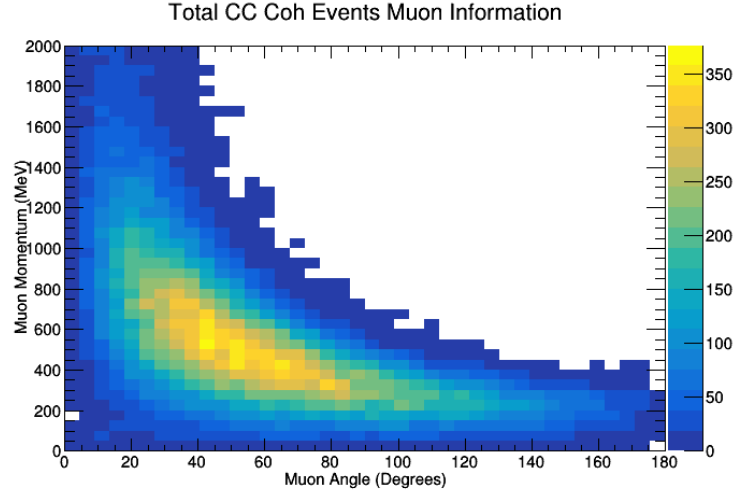


Figure 34: This is a 2D histogram for the momentum and angle of the muon in the total CC Coh Pion events.

A.10 NewANMReinSehgal.C

This file is the macro that corresponds to the "NewANMReinSehgal.h" file, which connects with this file: "SciBooNE_numubar_coh_RooTrack.root". This file performs the main analysis for this generated sample, and then organizes the information into many different histograms. The histograms are then written to a file titled "totalmuoninfoRSBar.root" inside the "ROOTFILES" directory. The "ROOTFILES" directory is included in the SciBooNE-MC repository (it is absolutely pertinent that this directory be located where the macro files are located due to how the calls of the combined data macros reference the now saved histograms).

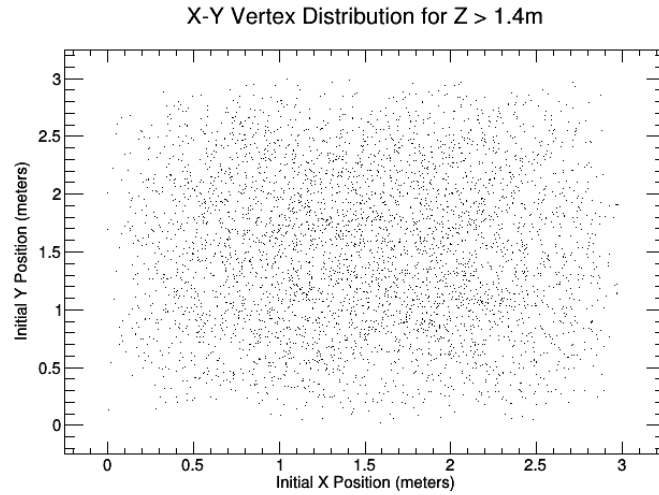


Figure 35: New $\bar{\nu}$ -Mode Rein-Sehgal X-Y vertex distributions for muons that made it to the MRD and penetrated at least to the third layer of steel.

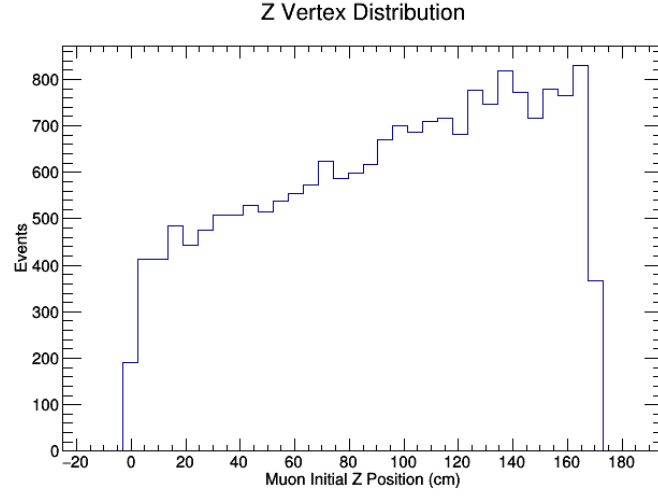


Figure 36: New $\bar{\nu}$ -Mode Rein-Sehgal Z vertex distributions for the interactions.

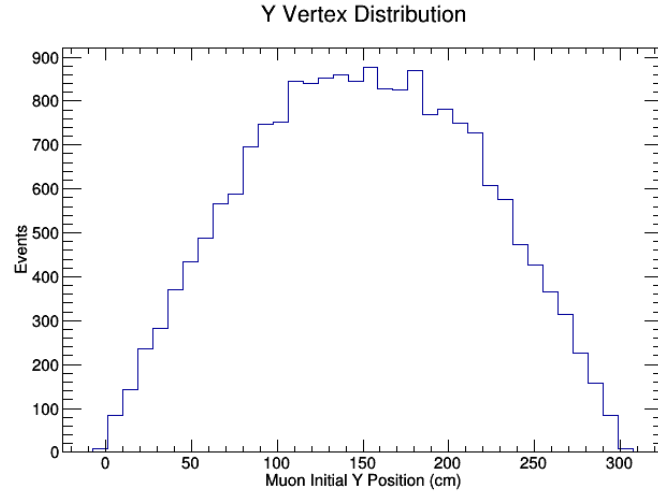


Figure 37: New $\bar{\nu}$ -Mode Rein-Sehgal Y vertex distributions for the interactions.

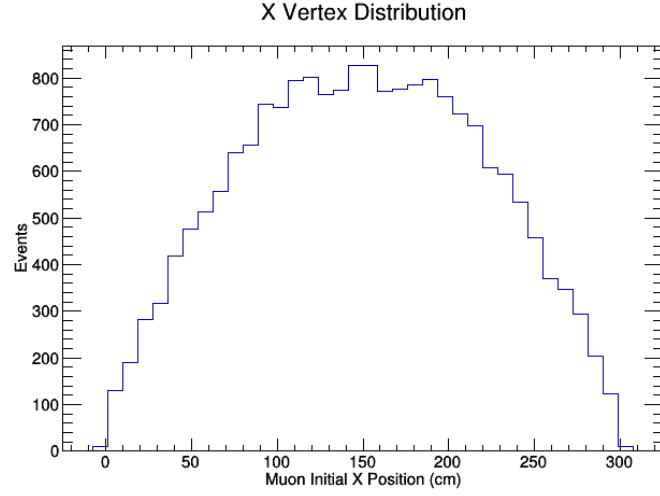


Figure 38: New $\bar{\nu}$ -Mode Rein-Sehgal X vertex distributions for the interactions.

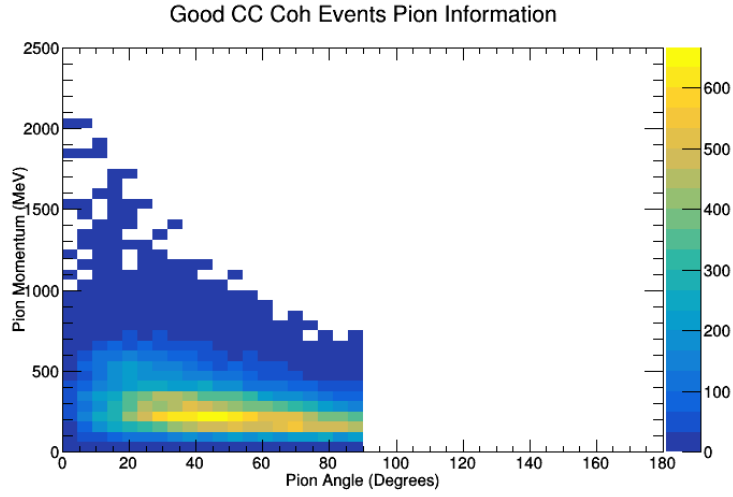


Figure 39: This is a 2D histogram for the momentum and angle of the pion in the CC Coh Pion events that met the qualification of being "good".

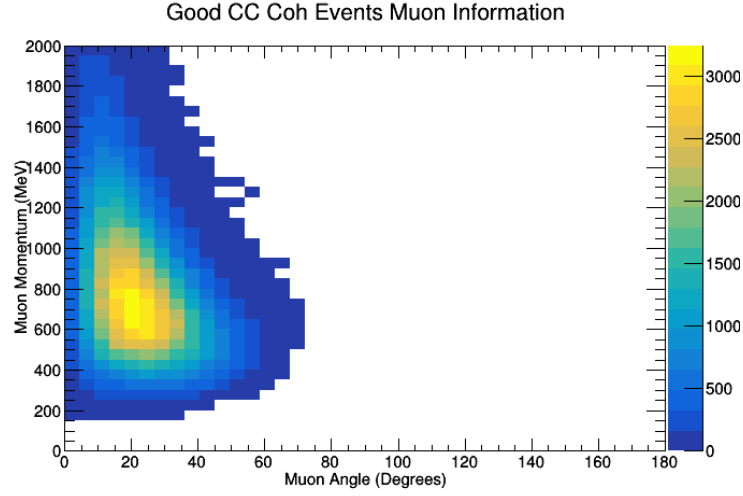


Figure 40: This is a 2D histogram for the momentum and angle of the muon in the CC Coh Pion events that met the qualification of being "good".

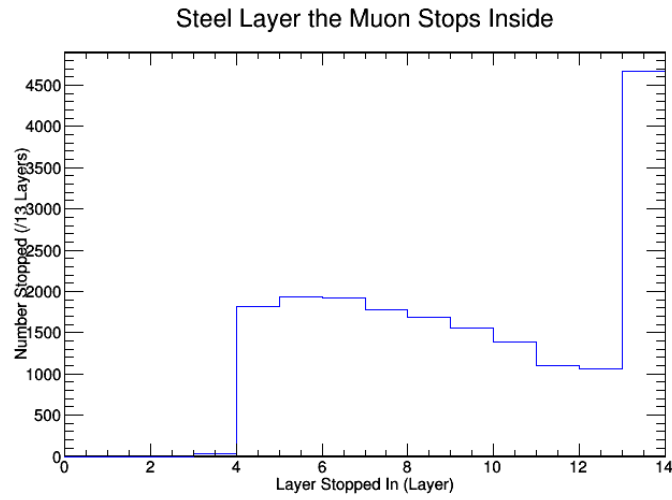


Figure 41: This histogram shows the amount of muons that embedded (or "Stopped") in a corresponding layer of steel in our simulation.

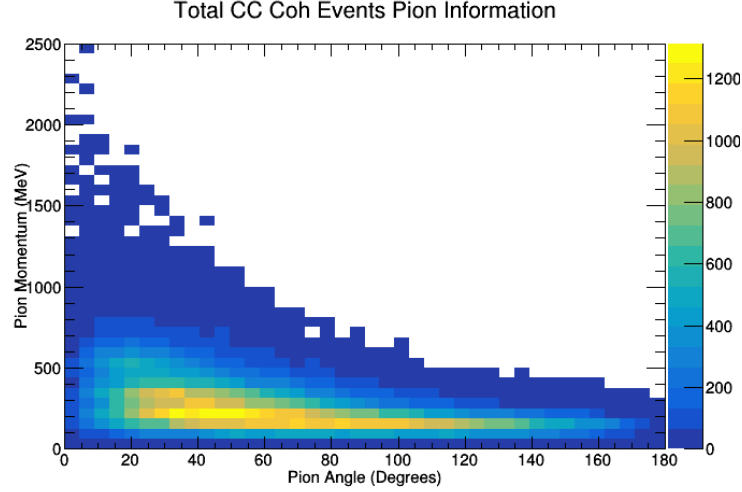


Figure 42: This is a 2D histogram for the momentum and angle of the pion in the total CC Coh Pion events.

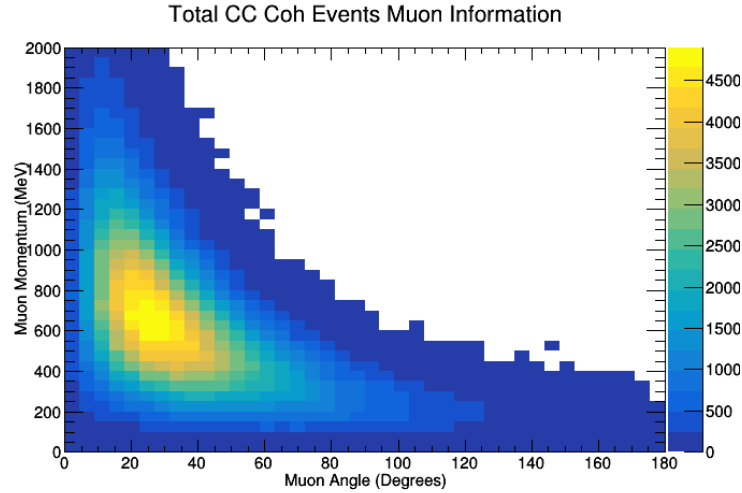


Figure 43: This is a 2D histogram for the momentum and angle of the muon in the total CC Coh Pion events.

A.11 NewANMBergerSehgal.C

This file is the macro that corresponds to the "NewANMBergerSehgal.h" file, which connects with this file: "SciBooNE_numubar_coh_RooTrack_NEW.root". This file performs the main analysis for this generated sample, and then organizes the information into many different histograms. The histograms are then written to a file titled "totalmuoninfoBSBar.root" inside the "ROOTFILES" directory. The "ROOTFILES" directory is included in the SciBooNE-MC repository (it is absolutely pertinent that this directory be located where the macro files are located due to how the calls of the combined data macros reference the now saved histograms).

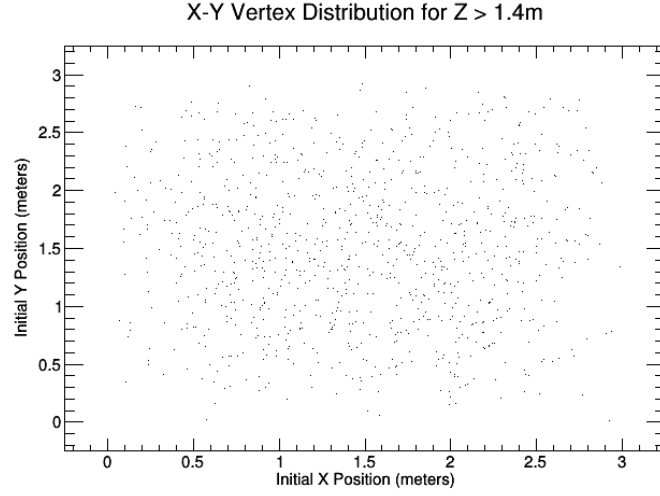


Figure 44: New $\bar{\nu}$ -Mode Berger-Sehgal X-Y vertex distributions for muons that made it to the MRD and penetrated at least to the third layer of steel.

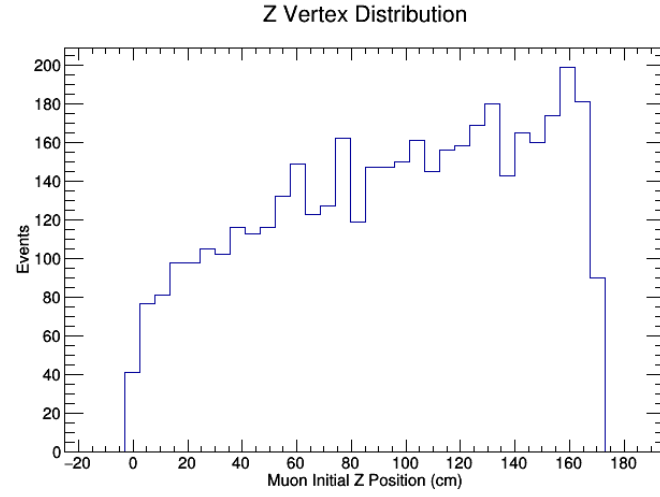


Figure 45: New $\bar{\nu}$ -Mode Berger-Sehgal Z vertex distributions for the interactions.

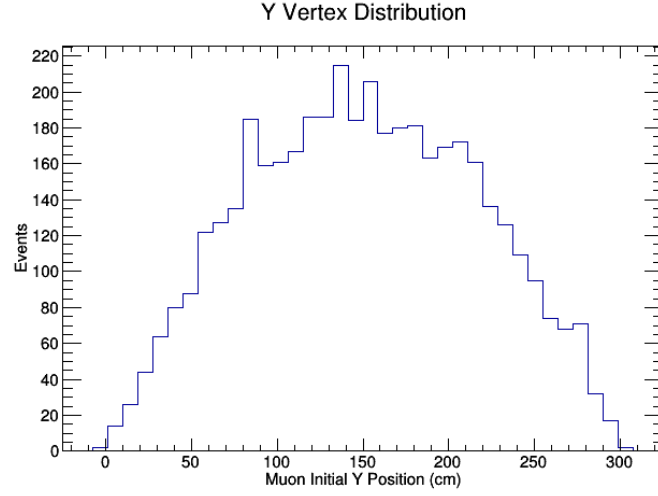


Figure 46: New $\bar{\nu}$ -Mode Berger-Sehgal Y vertex distributions for the interactions.

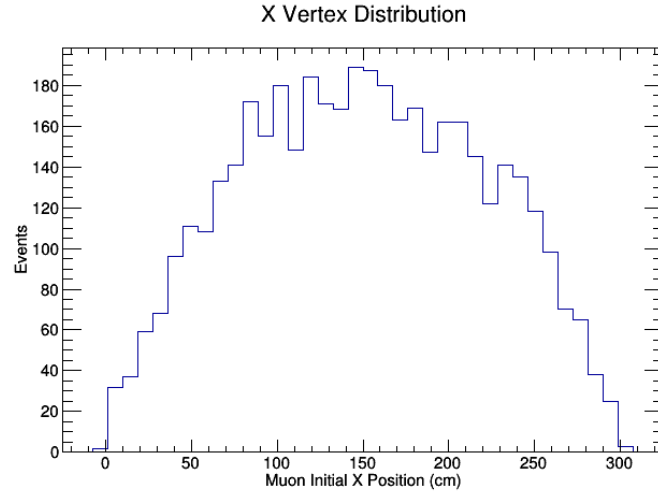


Figure 47: New $\bar{\nu}$ -Mode Berger-Sehgal X vertex distributions for the interactions.

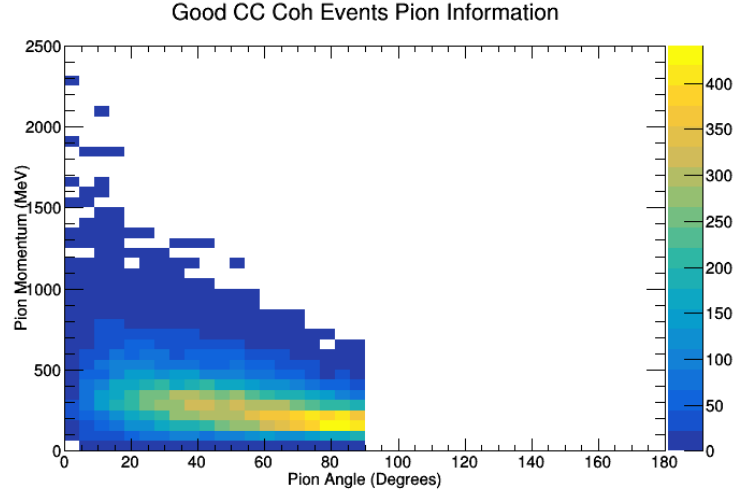


Figure 48: This is a 2D histogram for the momentum and angle of the pion in the CC Coh Pion events that met the qualification of being "good".

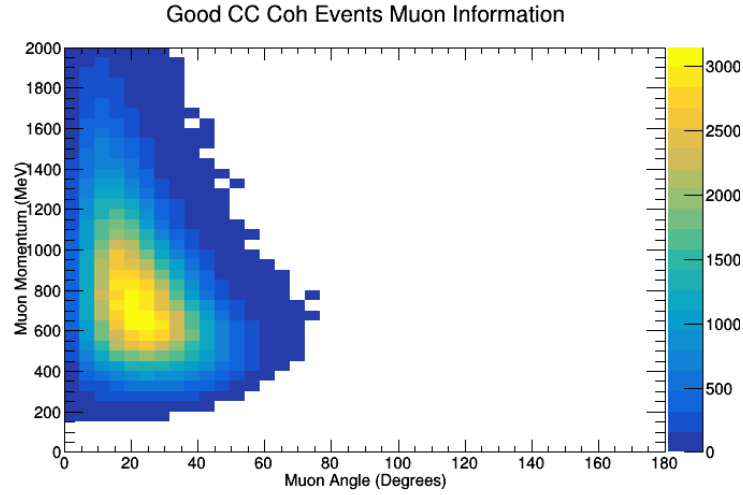


Figure 49: This is a 2D histogram for the momentum and angle of the muon in the CC Coh Pion events that met the qualification of being "good".

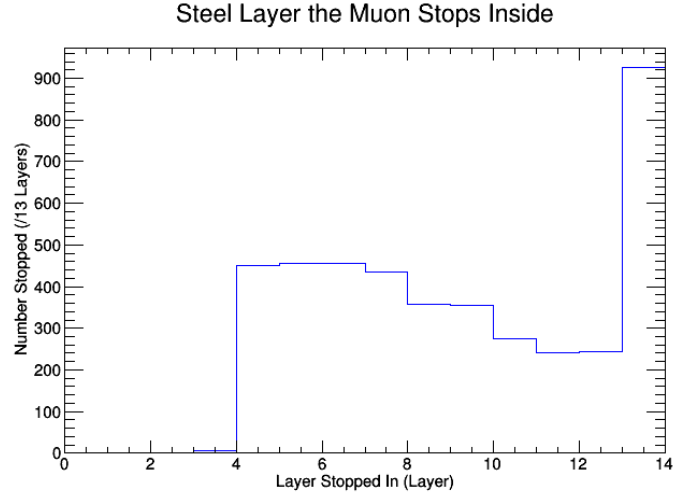


Figure 50: This histogram shows the amount of muons that embedded (or "Stopped") in a corresponding layer of steel in our simulation.

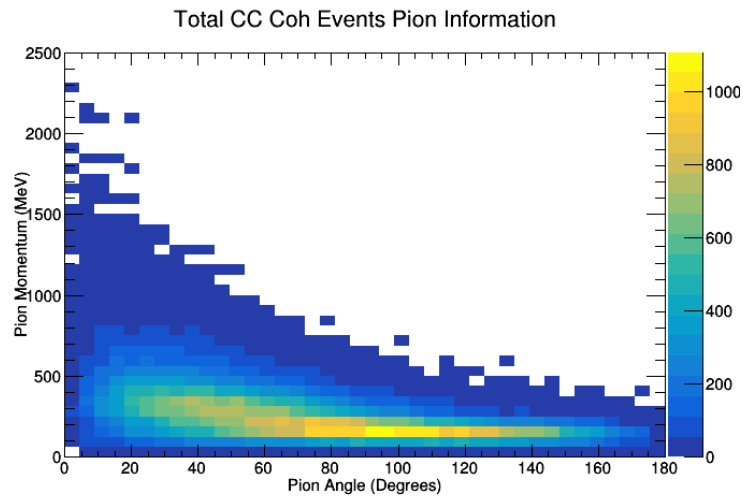


Figure 51: This is a 2D histogram for the momentum and angle of the pion in the total CC Coh Pion events.

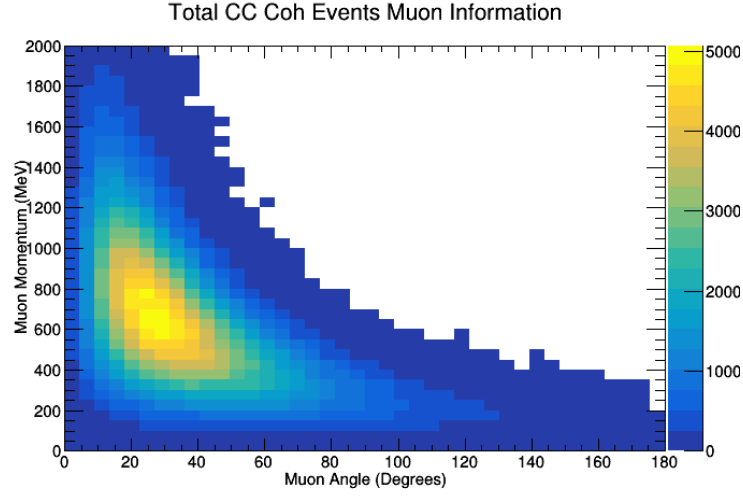


Figure 52: This is a 2D histogram for the momentum and angle of the muon in the total CC Coh Pion events.

A.12 NMCombinedPlots.C

This is the file that performs the main plotting operations for the neutrino mode samples using the muon's information. All of the muon efficiency plots for neutrino mode are made with this file.

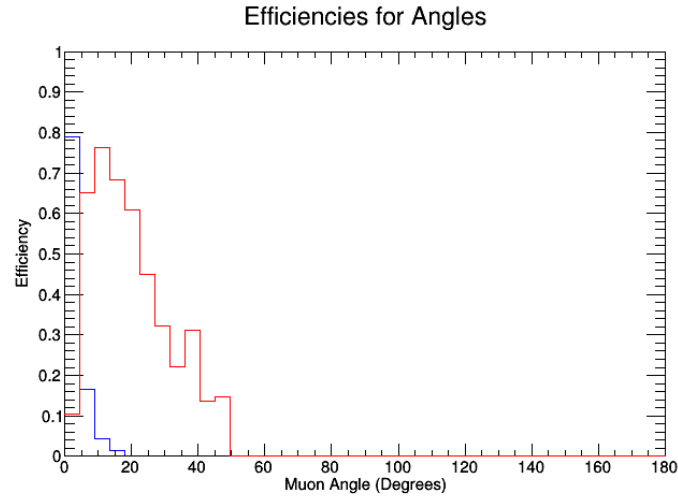


Figure 53

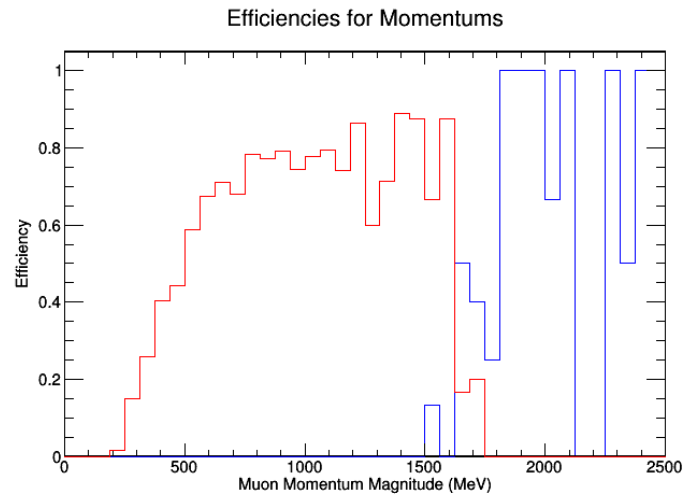


Figure 54

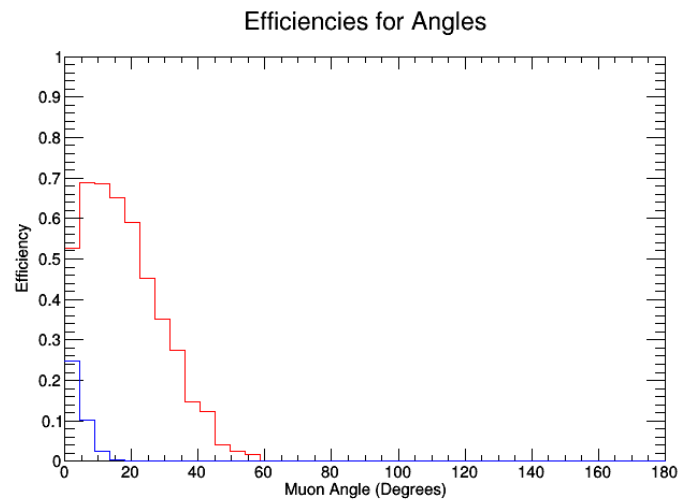


Figure 55

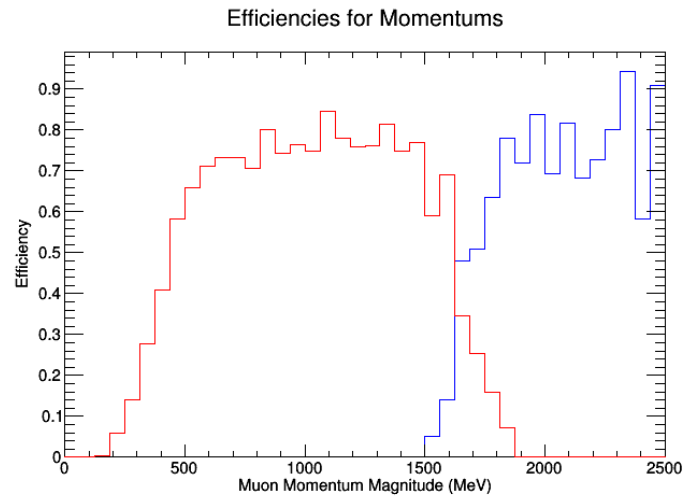


Figure 56

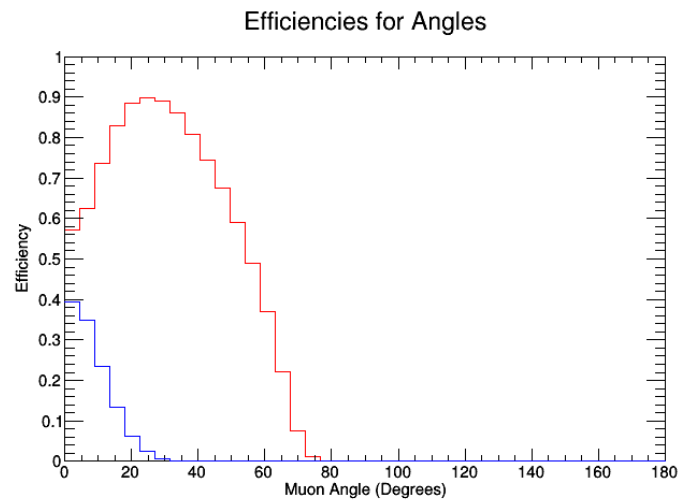


Figure 57

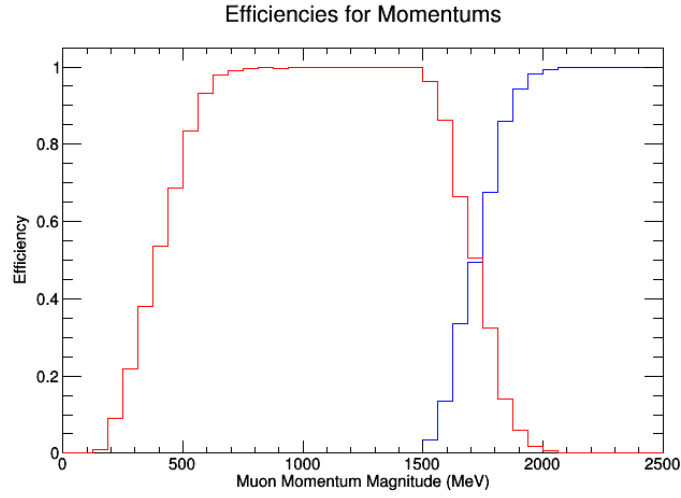


Figure 58

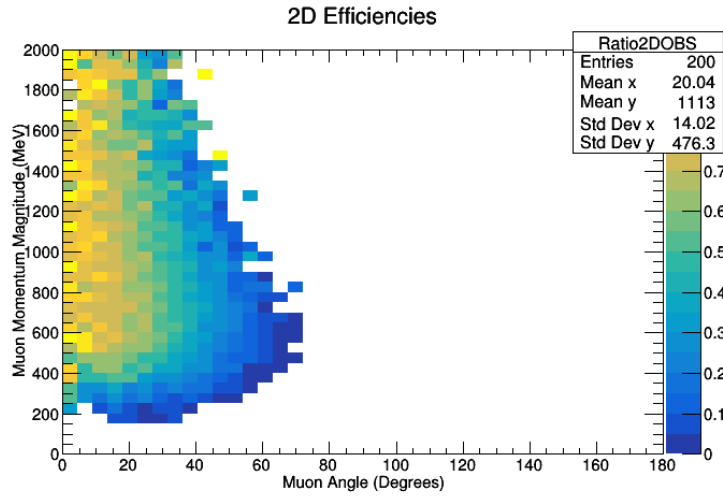


Figure 59

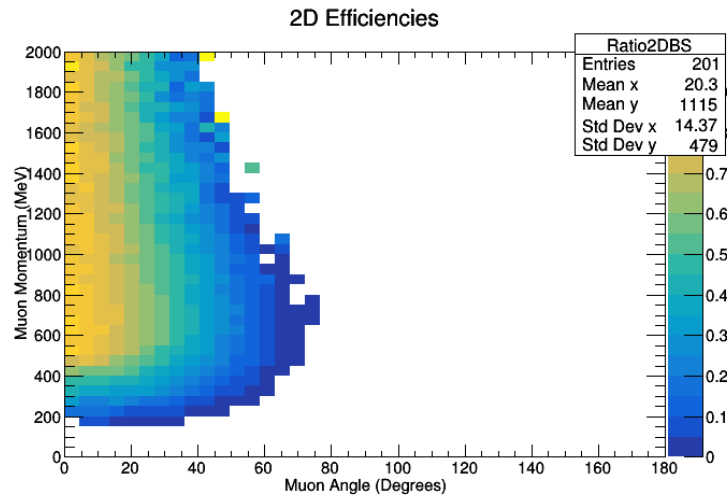


Figure 60

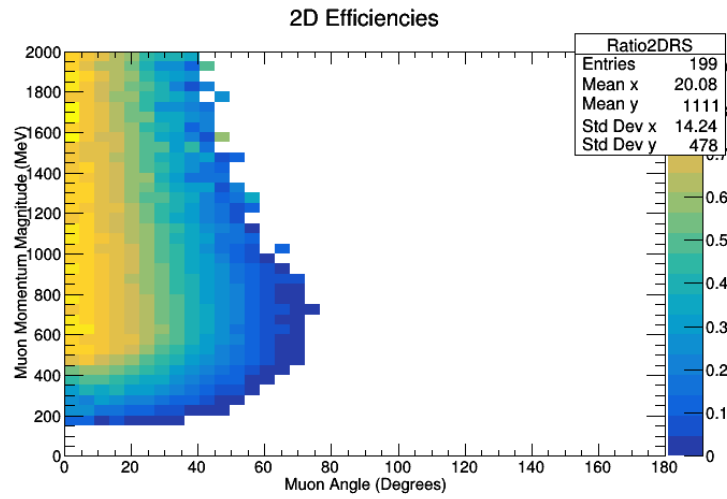


Figure 61

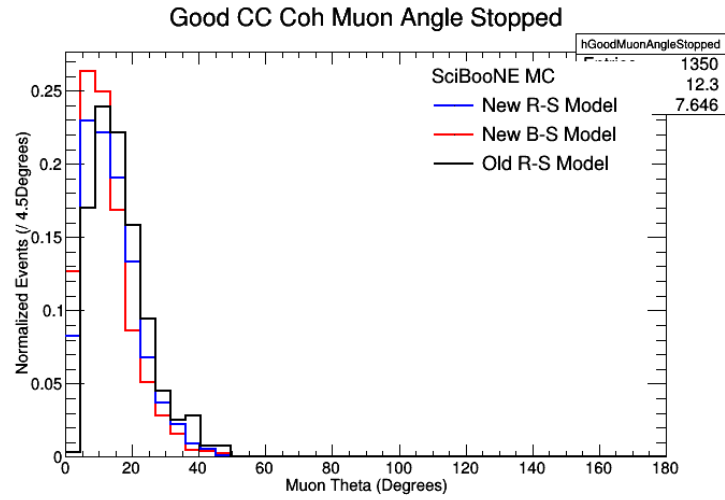


Figure 62

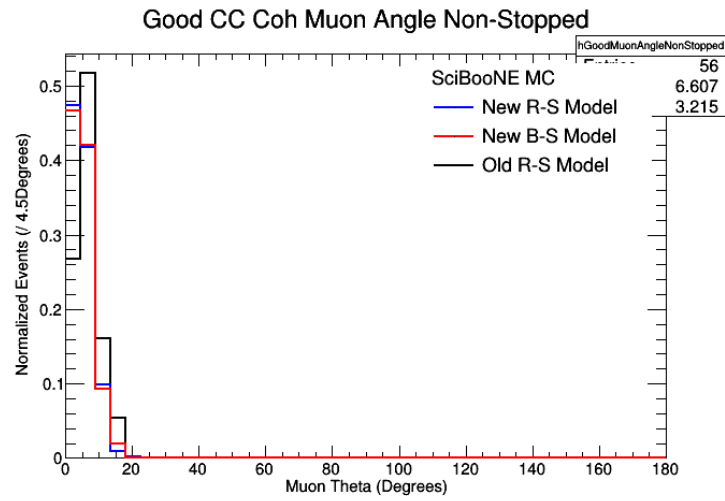


Figure 63

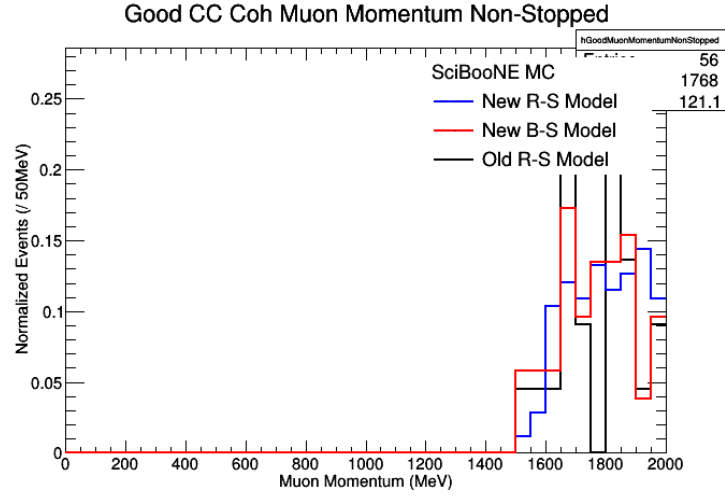


Figure 64

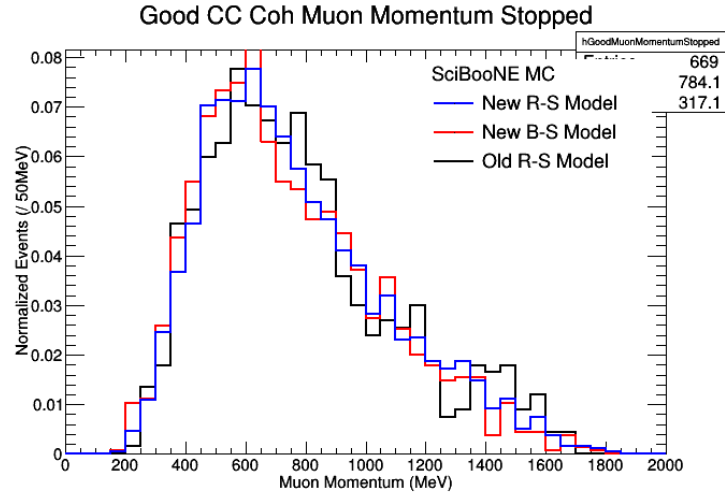


Figure 65

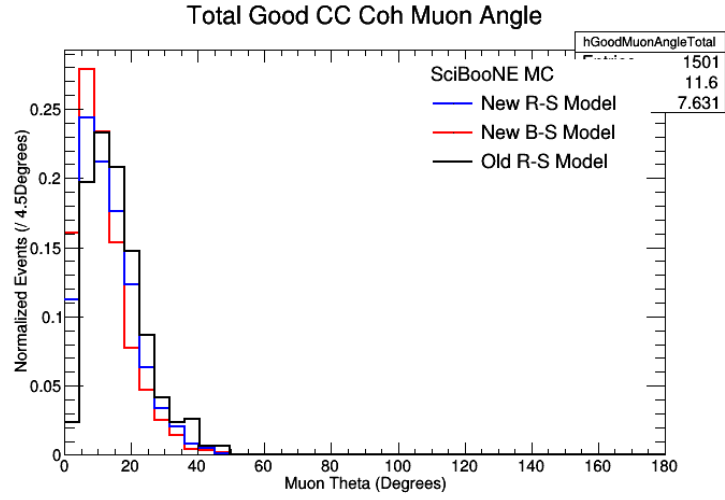


Figure 66

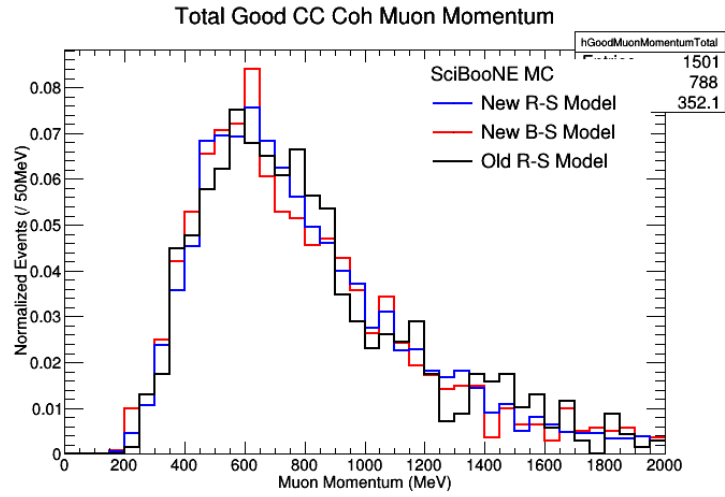


Figure 67

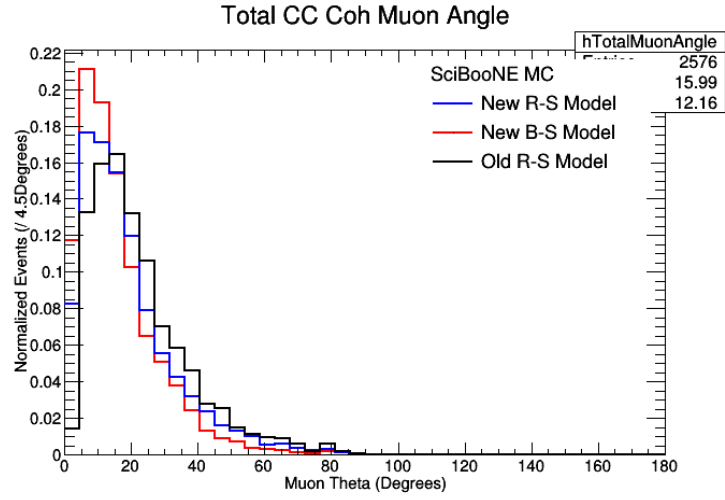


Figure 68

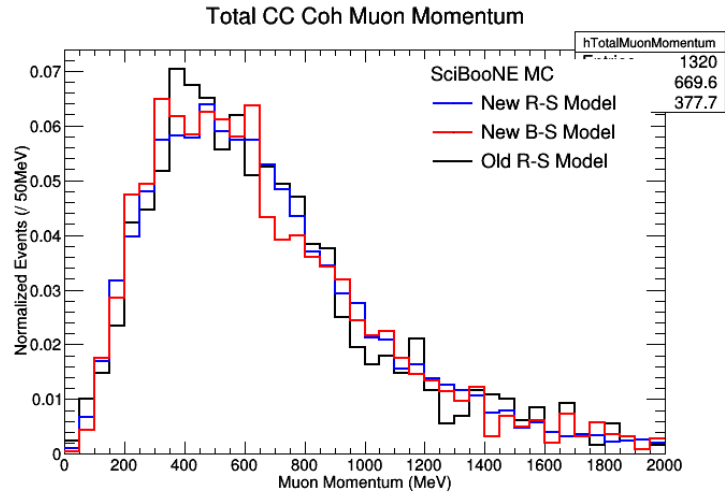


Figure 69

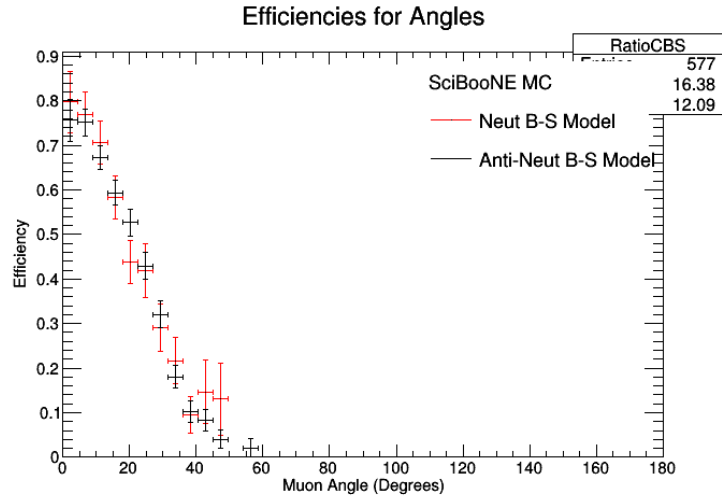


Figure 70

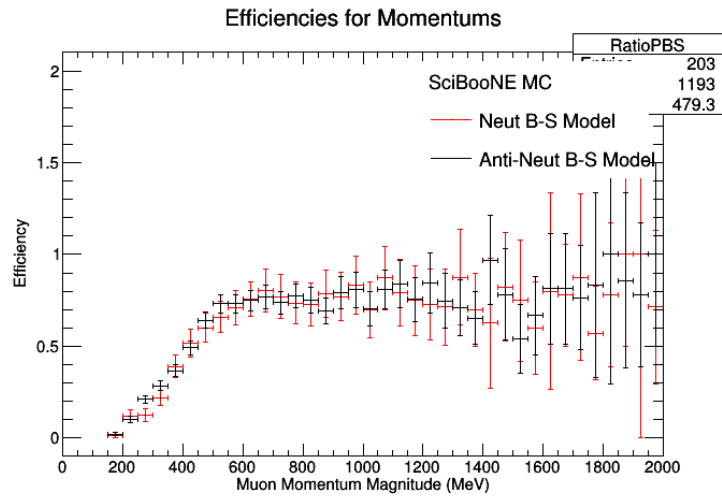


Figure 71

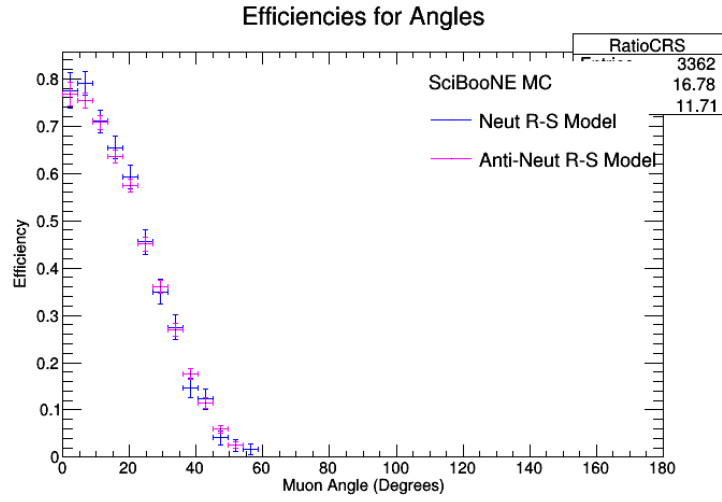


Figure 72

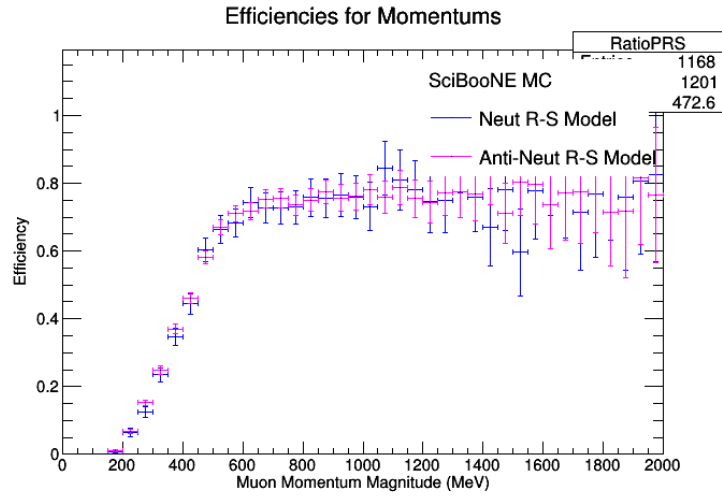


Figure 73

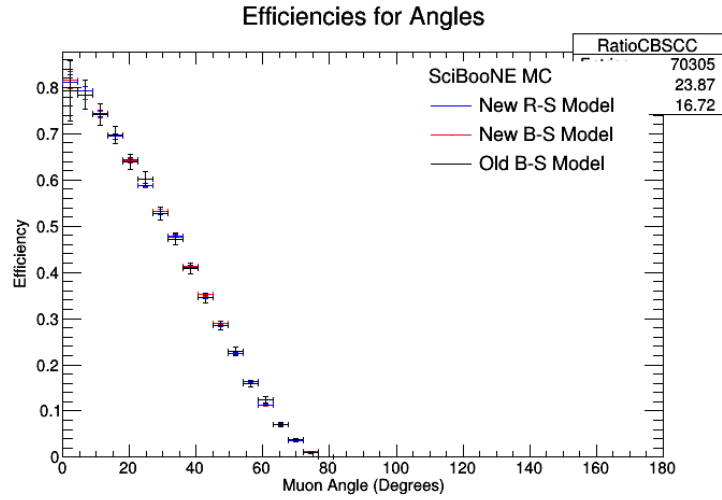


Figure 74

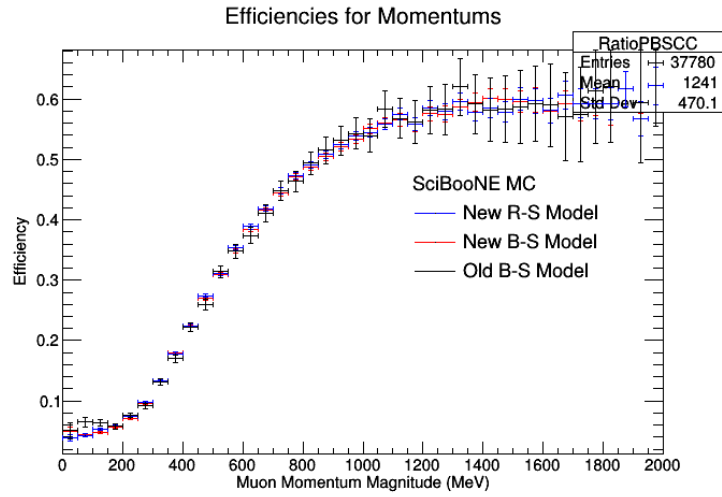


Figure 75

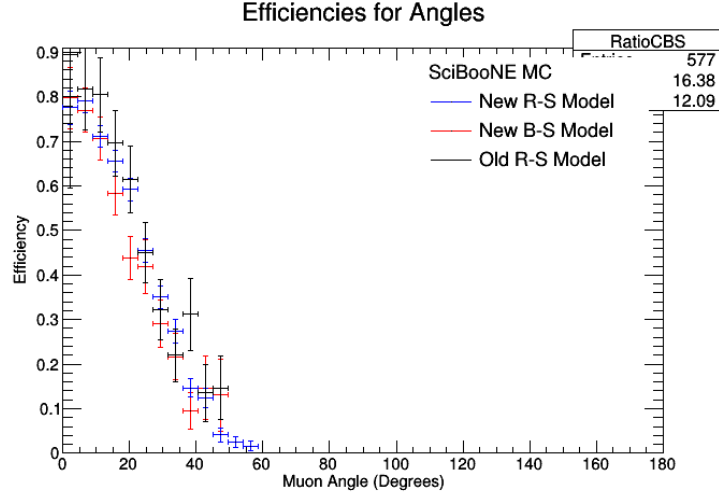


Figure 76

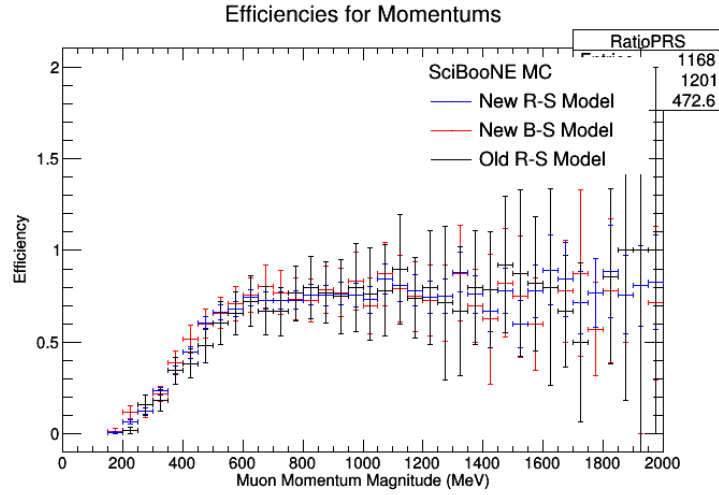


Figure 77

A.13 NMPionPlotting.C

This is the file that performs the main plotting operations for the neutrino mode samples using the pion's information. All of the pion efficiency plots for neutrino mode are made with this file.

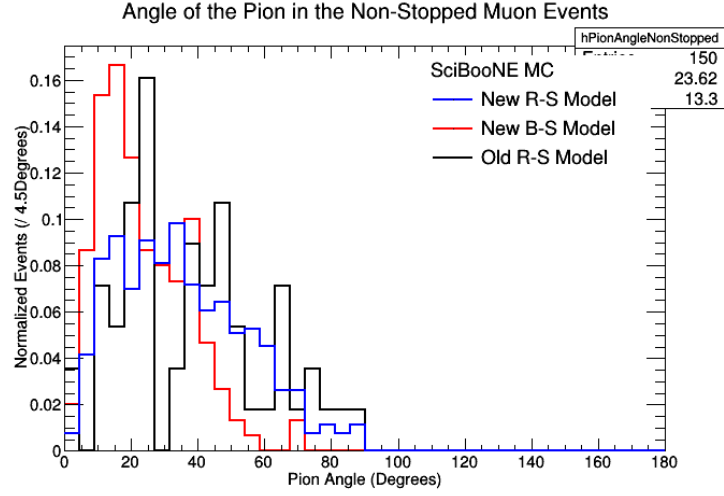


Figure 78

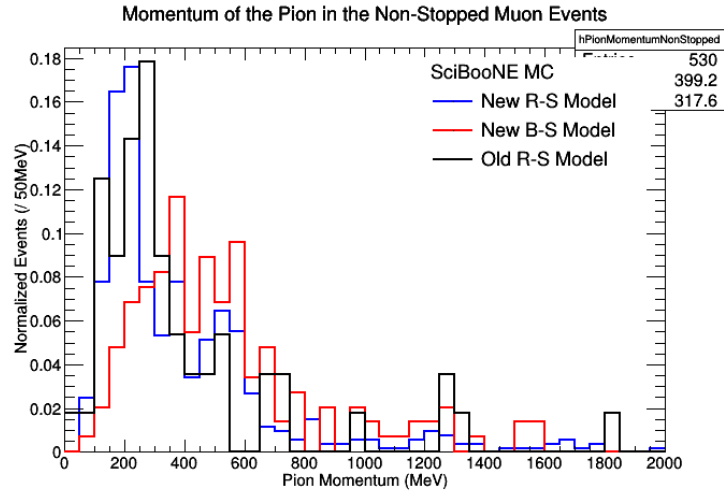


Figure 79

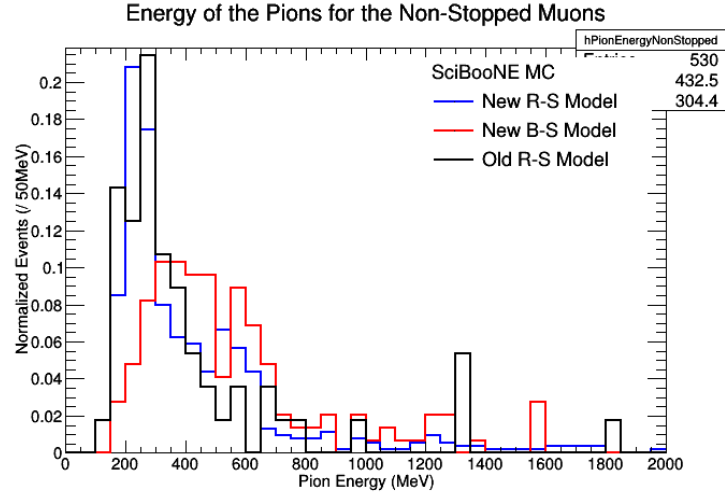


Figure 80

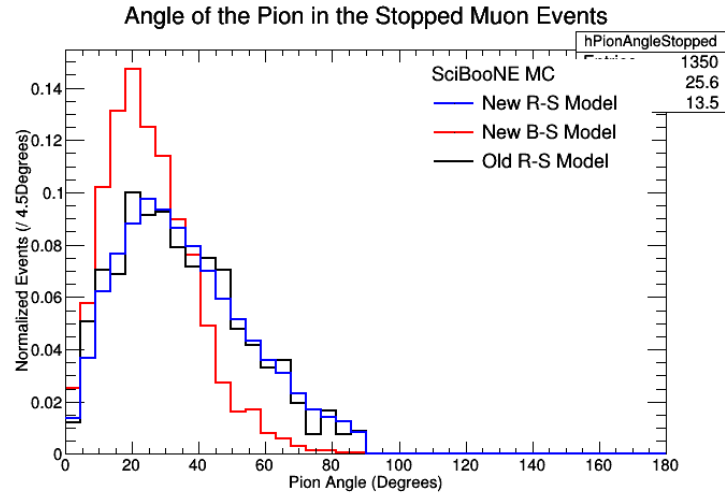


Figure 81

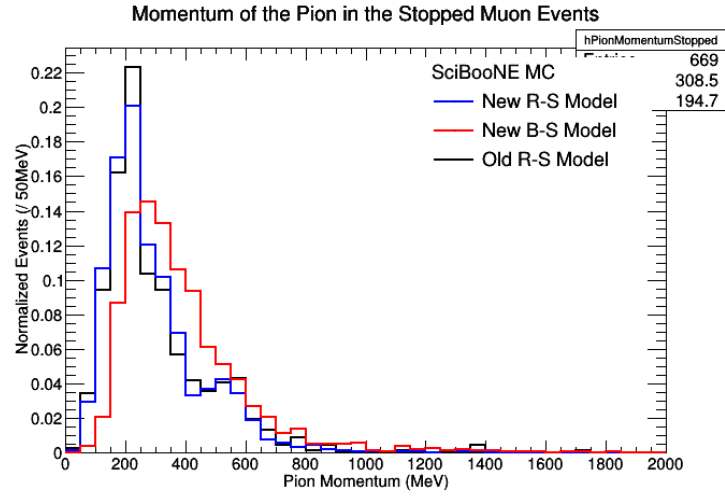


Figure 82

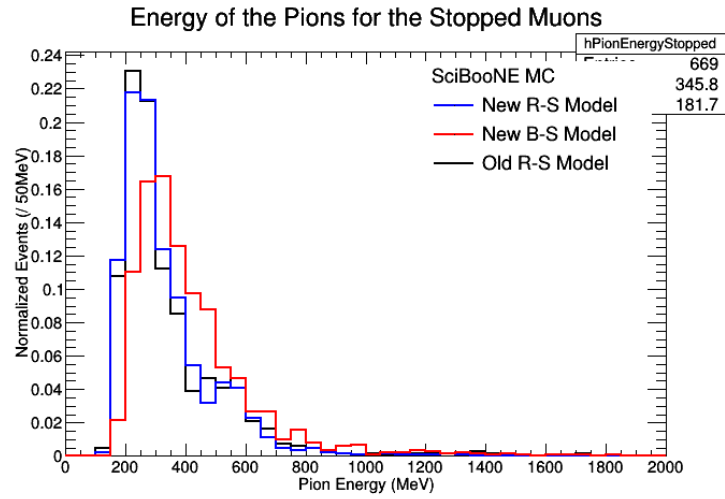


Figure 83

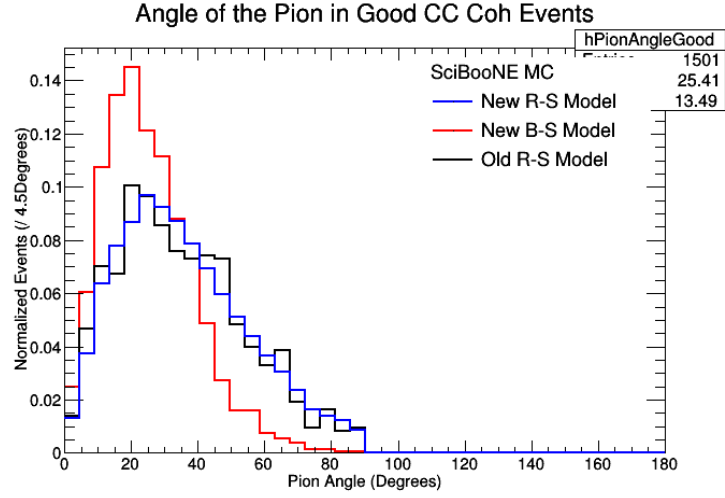


Figure 84

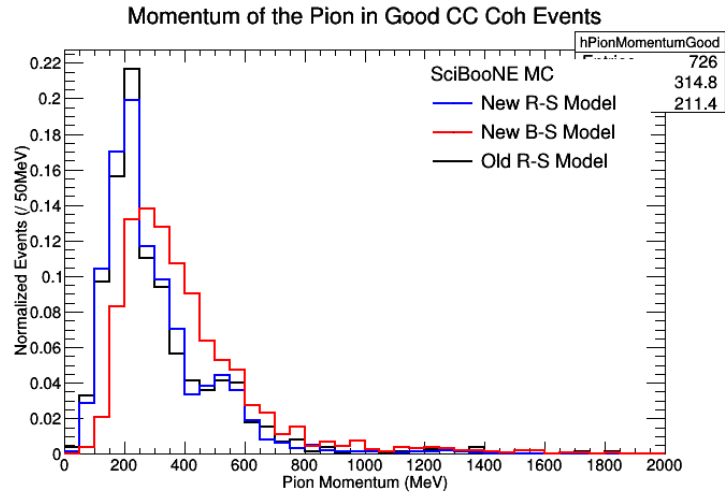


Figure 85

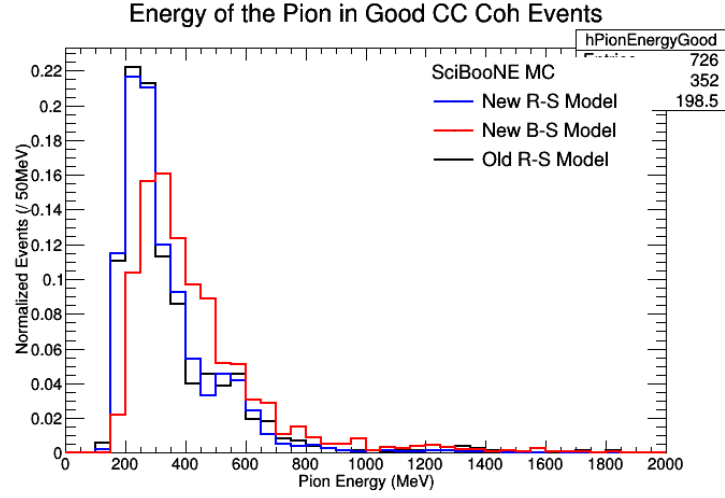


Figure 86

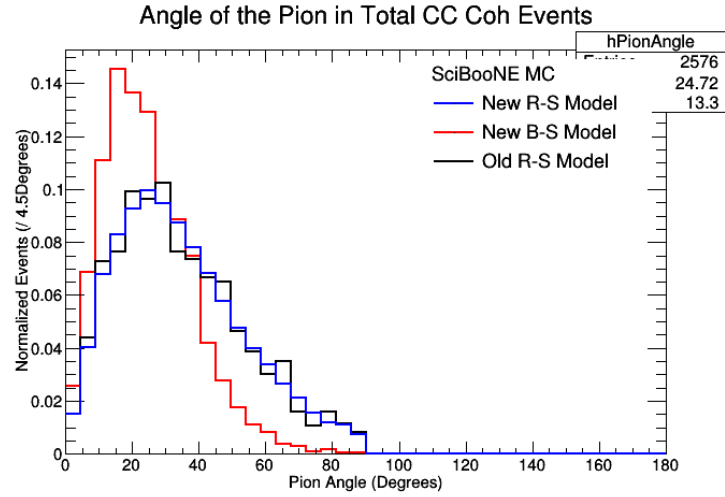


Figure 87

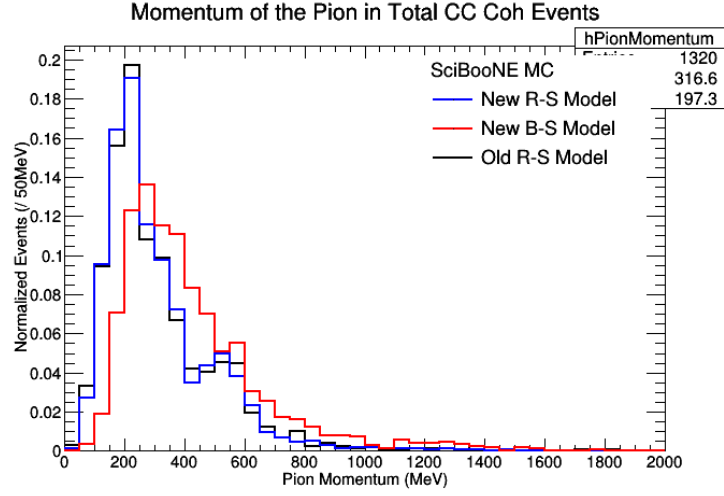


Figure 88

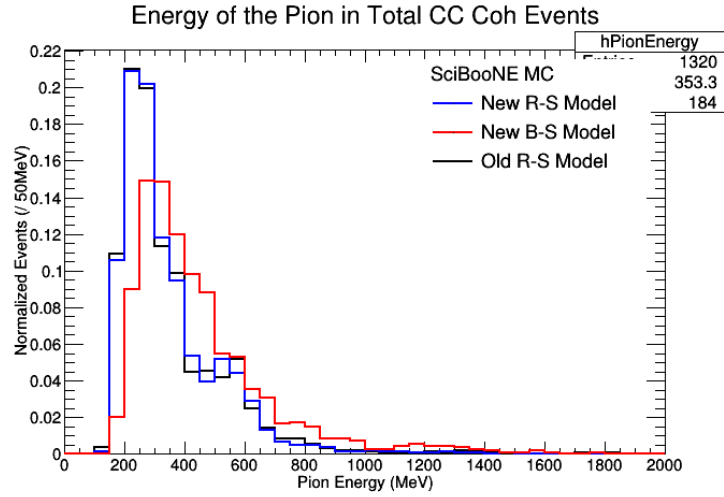


Figure 89

A.14 NMFourSquaredPlotting.C

All of the four-momentum transfer (both $|t|$ and Q^2) combined plots are made with this file for neutrino mode.

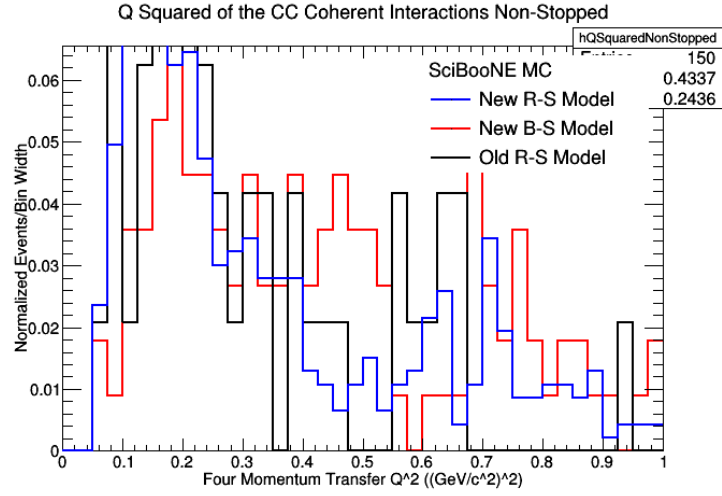


Figure 90

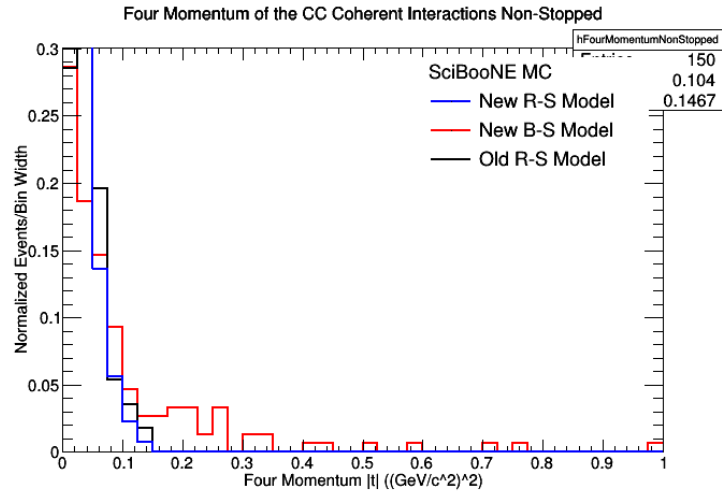


Figure 91

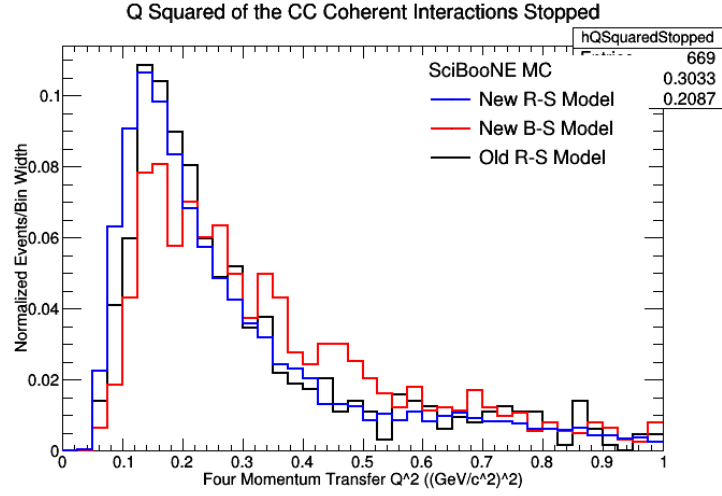


Figure 92

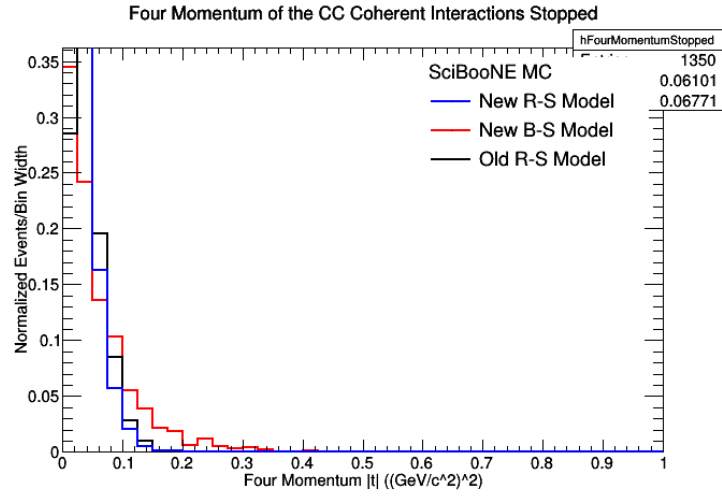


Figure 93

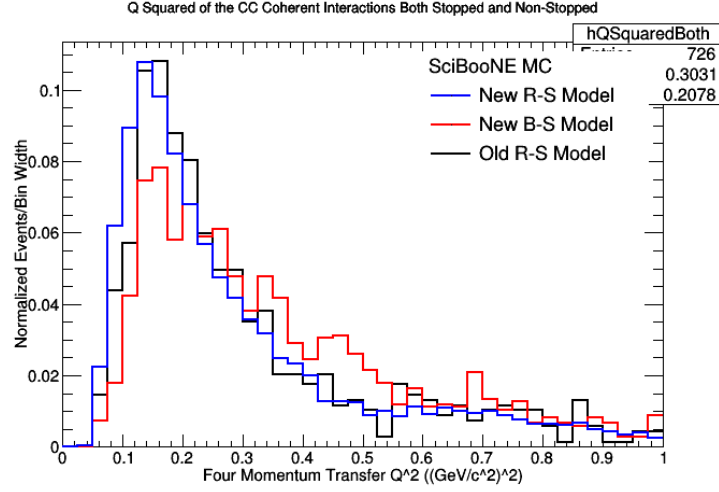


Figure 94

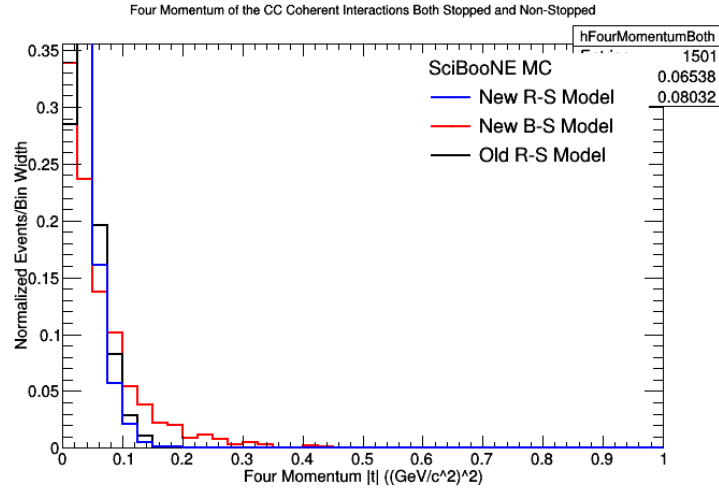


Figure 95

A.15 ANMCombinedPlots.C

This is the file that performs the main plotting operations for the anti-neutrino mode samples using the muon's information. All of the muon efficiency plots for anti-neutrino mode are made with this file.

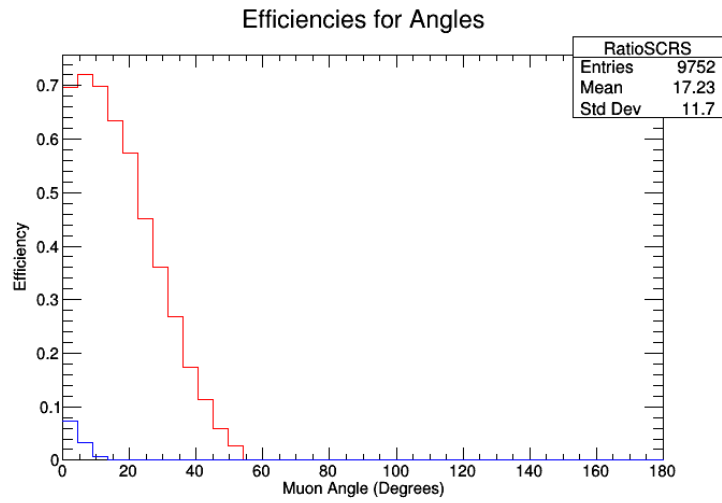


Figure 96

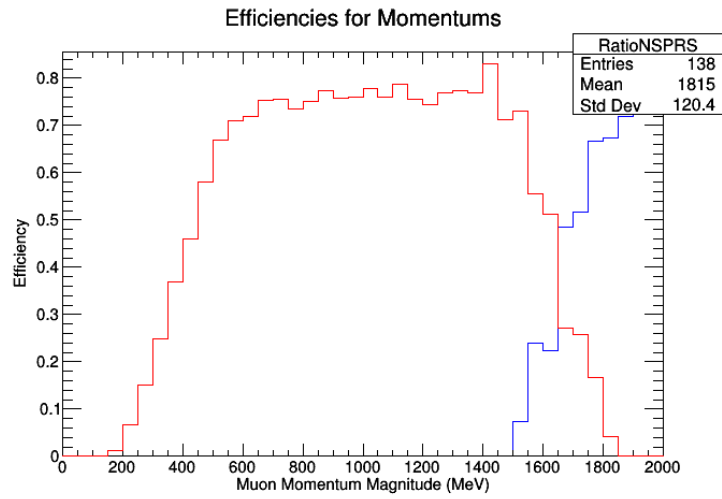


Figure 97

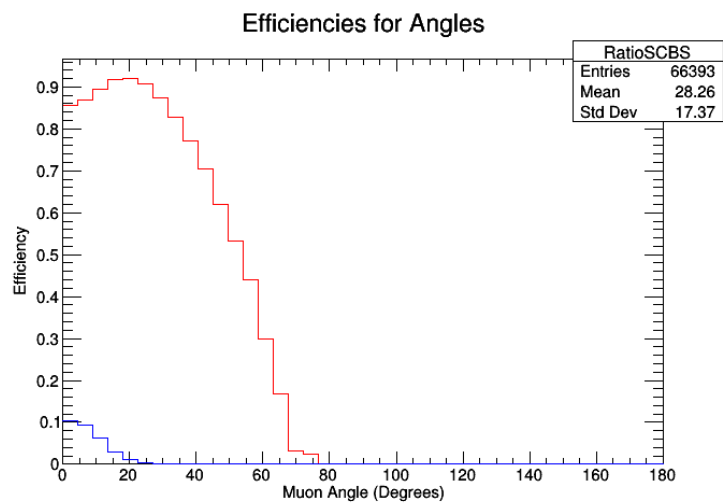


Figure 98

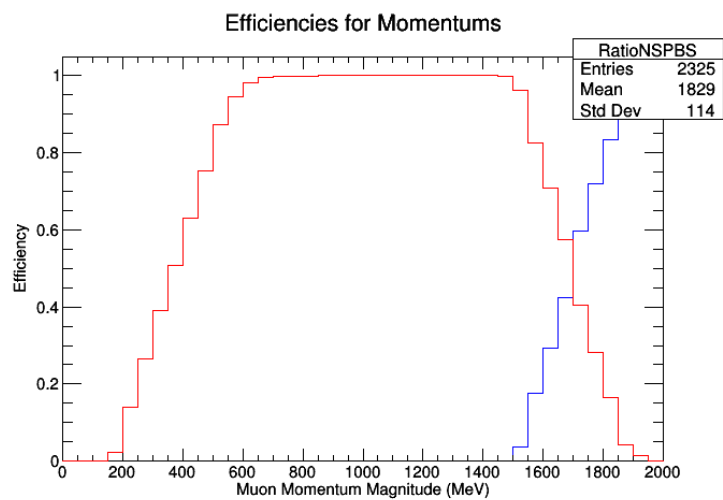


Figure 99

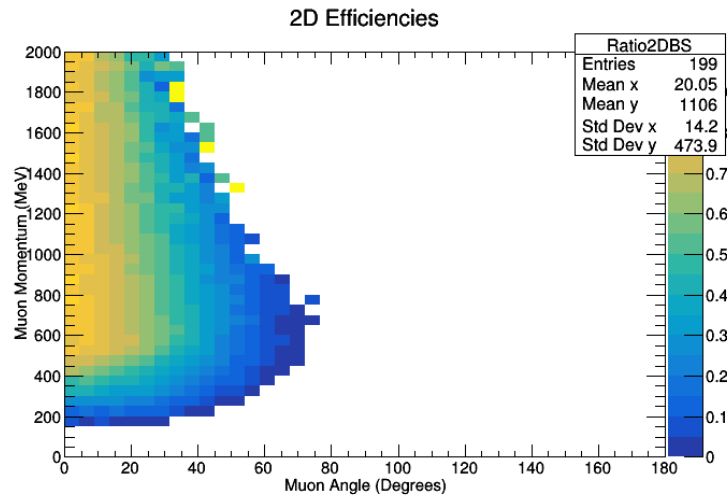


Figure 100

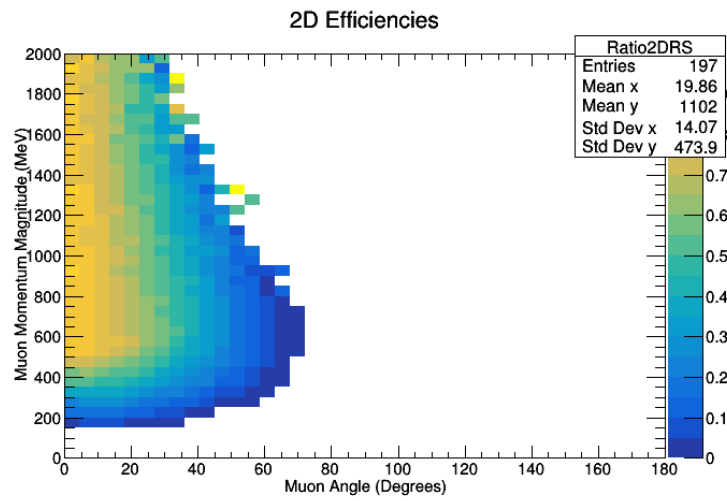


Figure 101

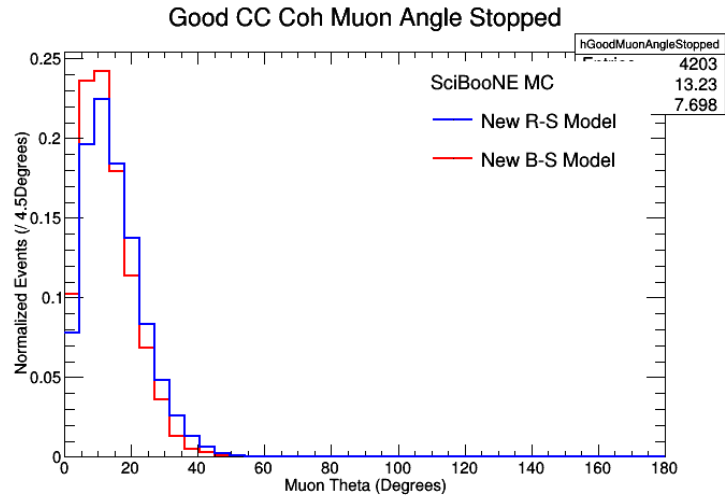


Figure 102

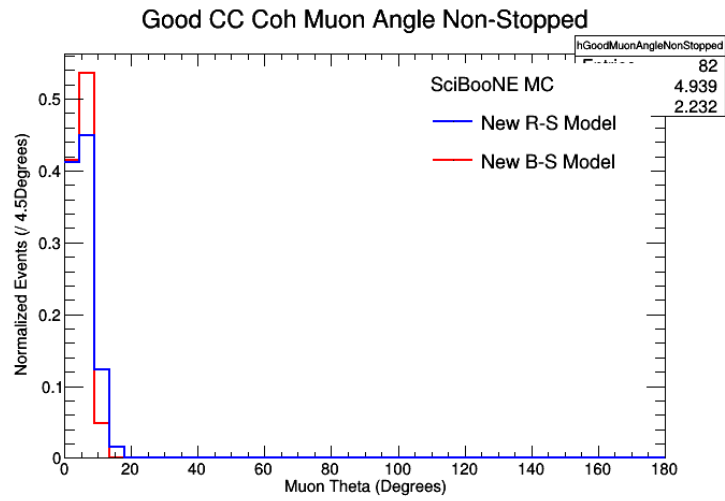


Figure 103

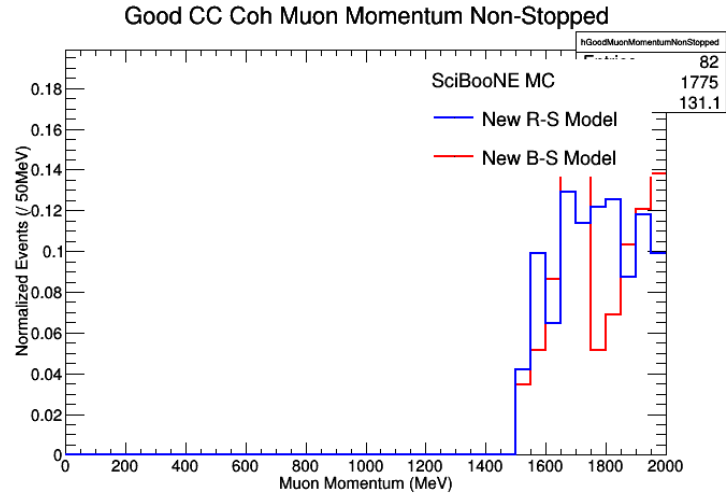


Figure 104

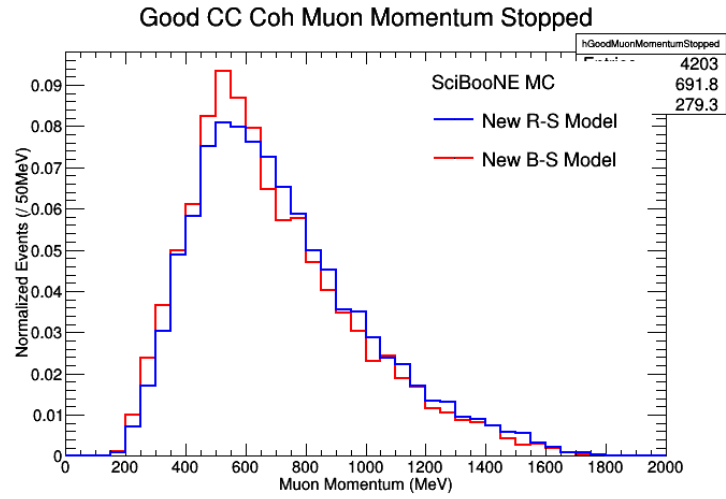


Figure 105

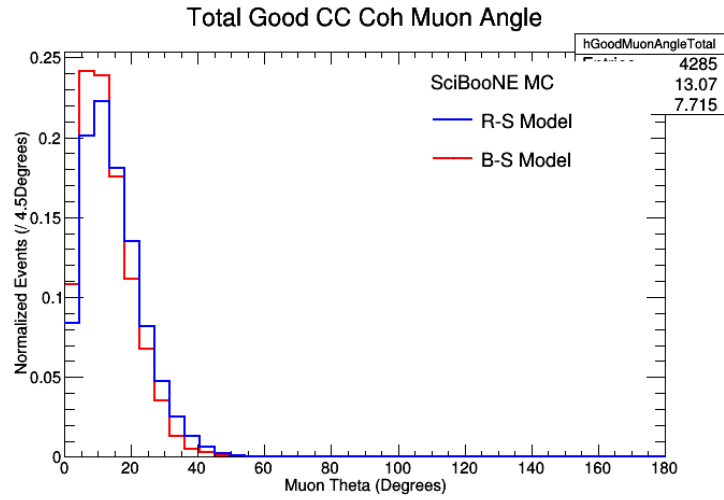


Figure 106

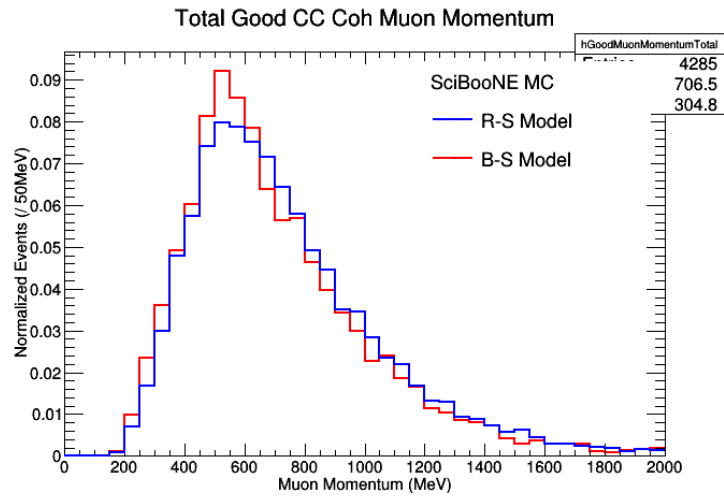


Figure 107

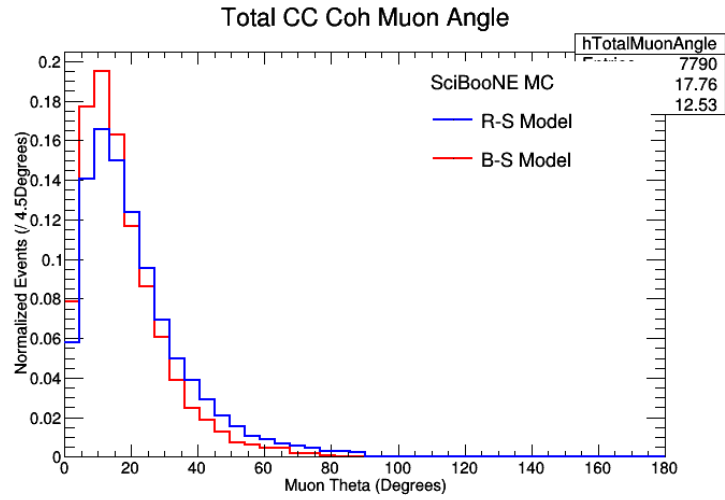


Figure 108

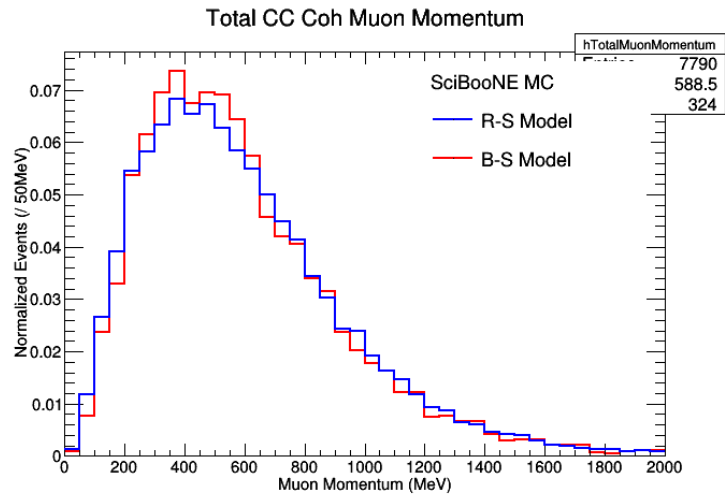


Figure 109

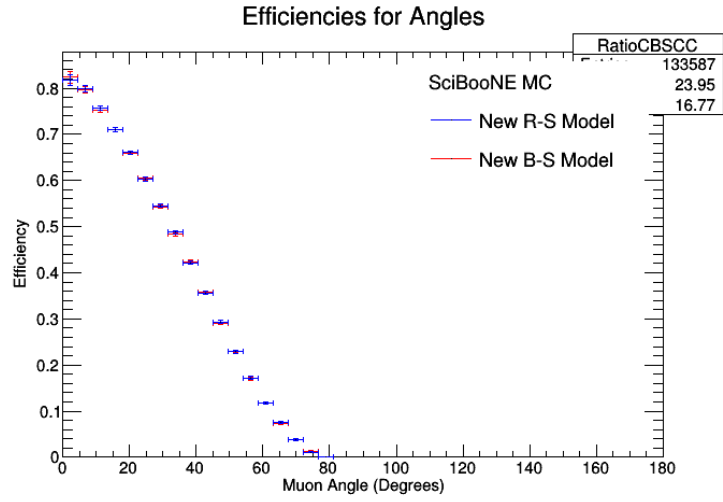


Figure 110

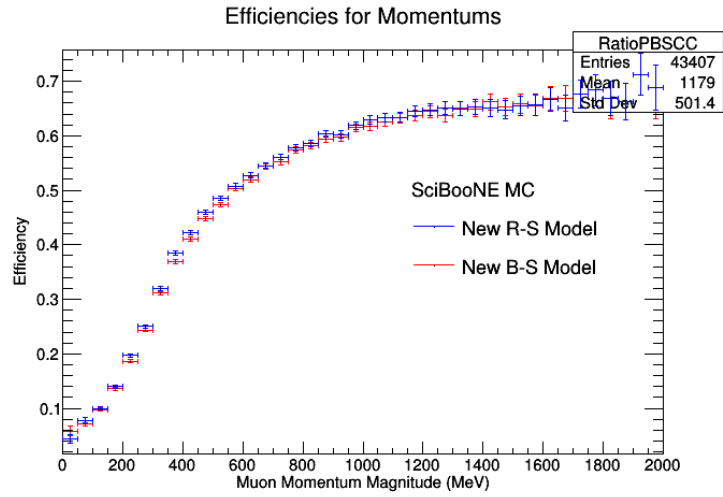


Figure 111

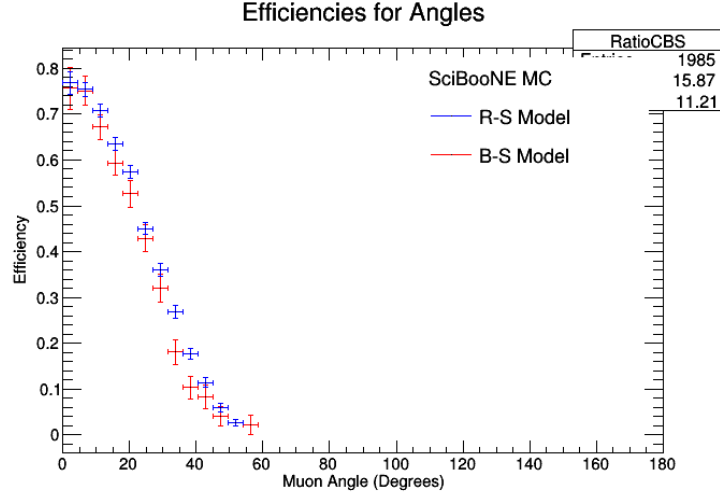


Figure 112

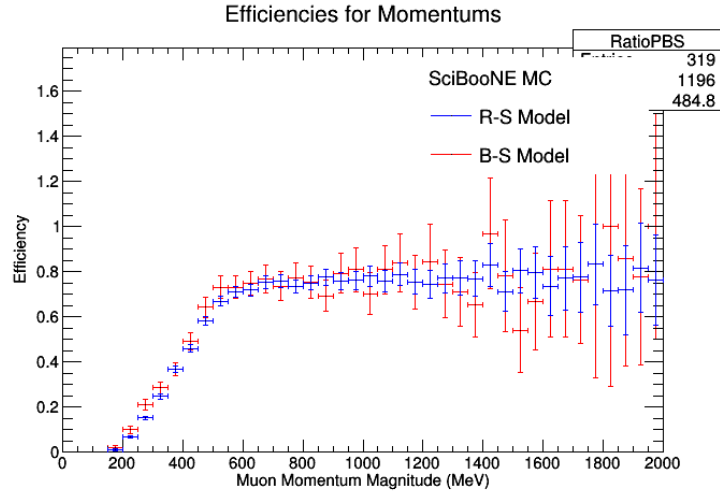


Figure 113

A.16 ANMPionPlotting.C

This is the file that performs the main plotting operations for the anti-neutrino mode samples using the pion's information. All of the pion efficiency plots for anti-neutrino mode are made with this file.

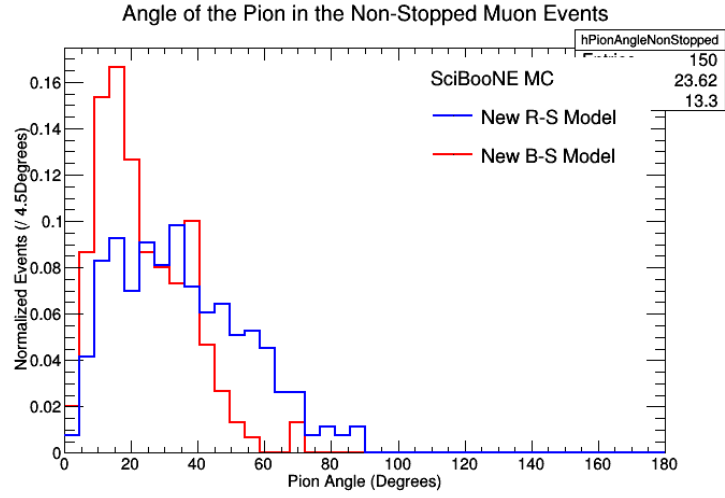


Figure 114

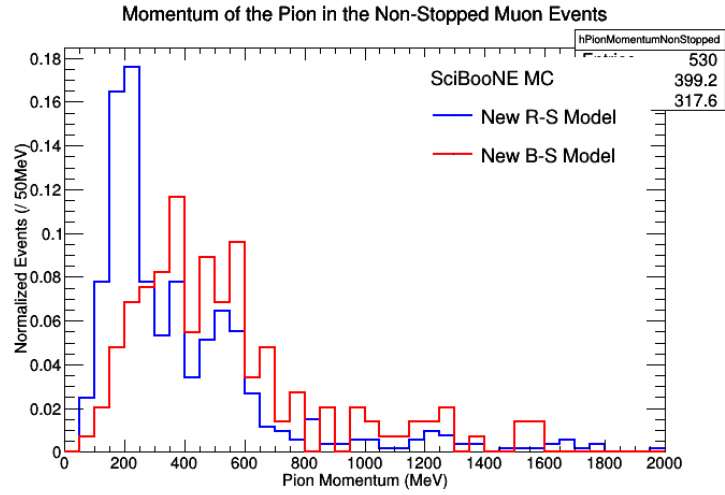


Figure 115

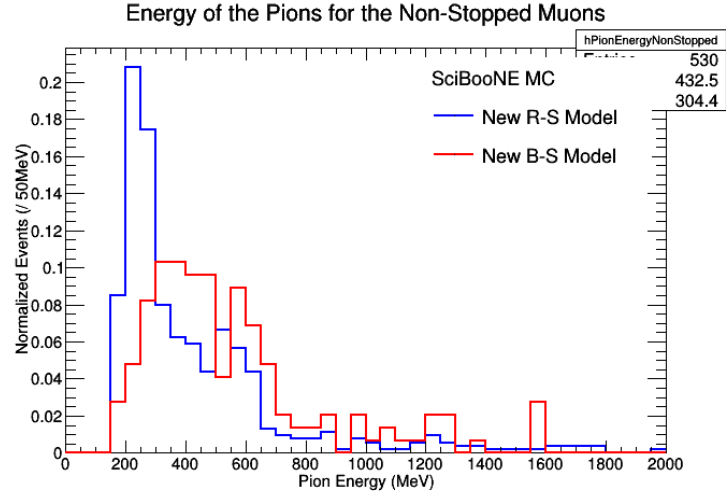


Figure 116

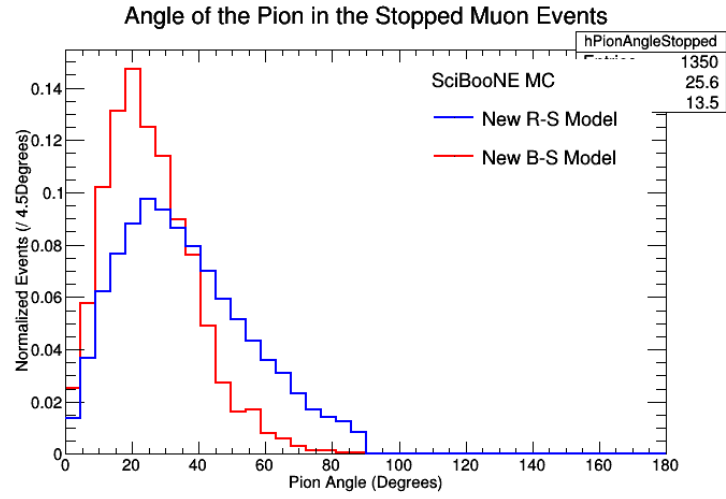


Figure 117

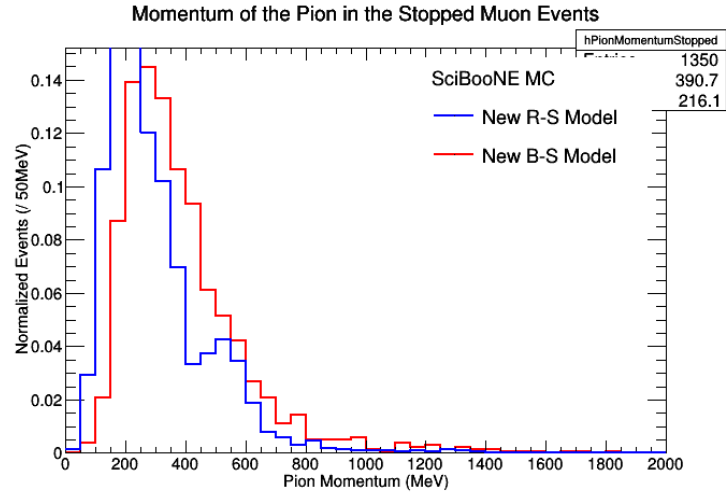


Figure 118

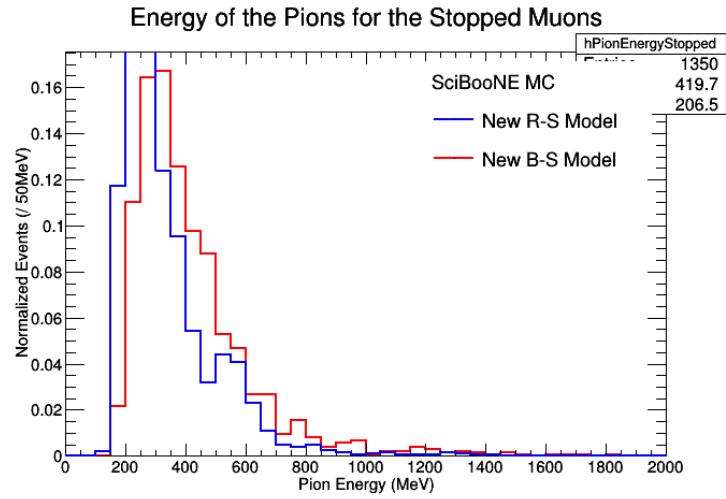


Figure 119

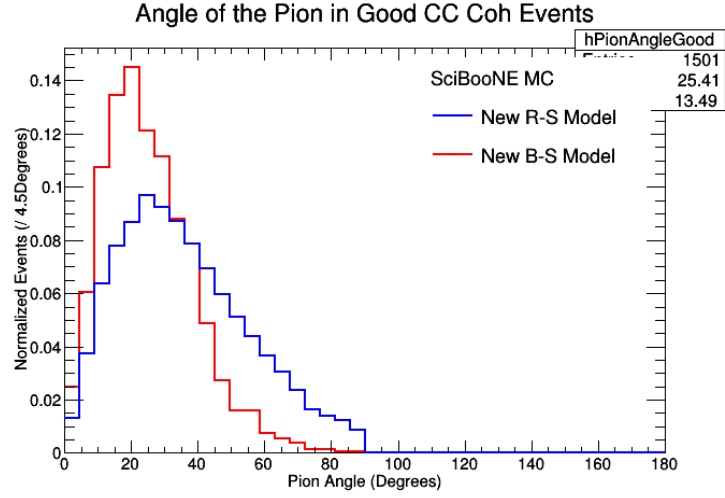


Figure 120

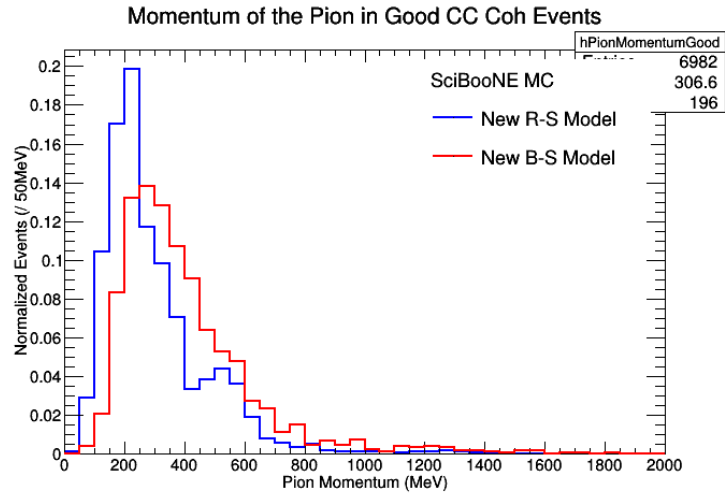


Figure 121

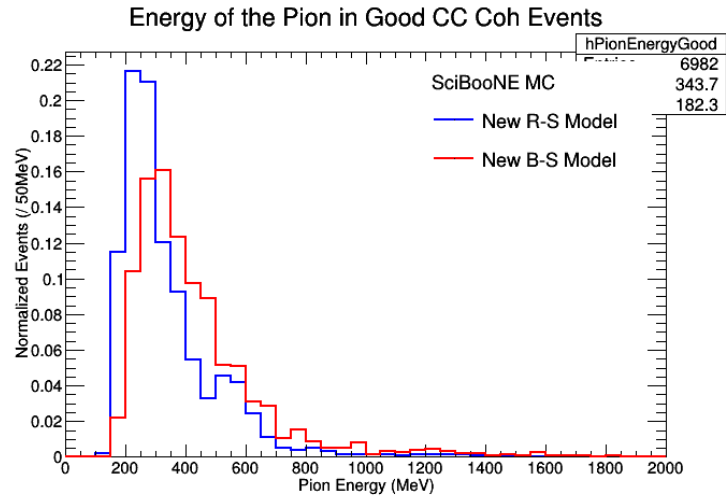


Figure 122

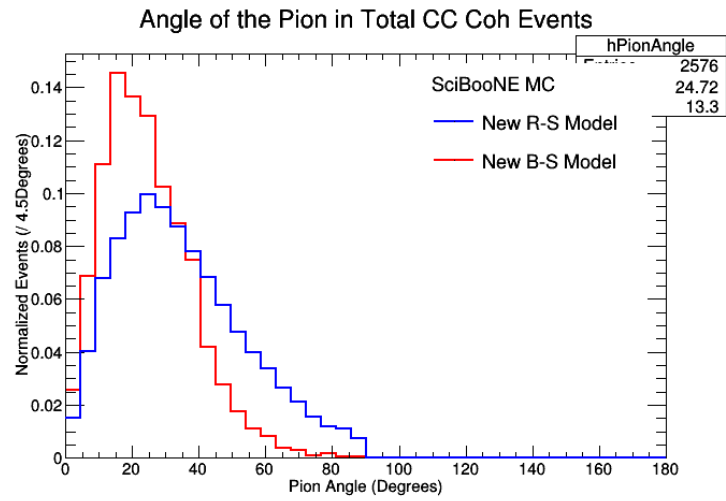


Figure 123

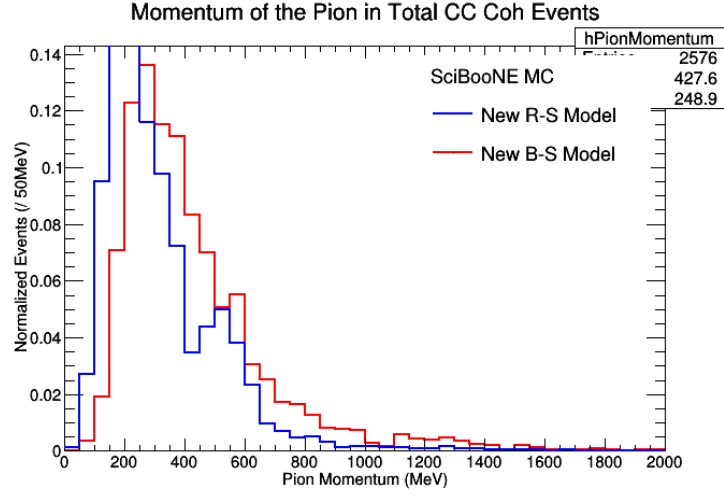


Figure 124

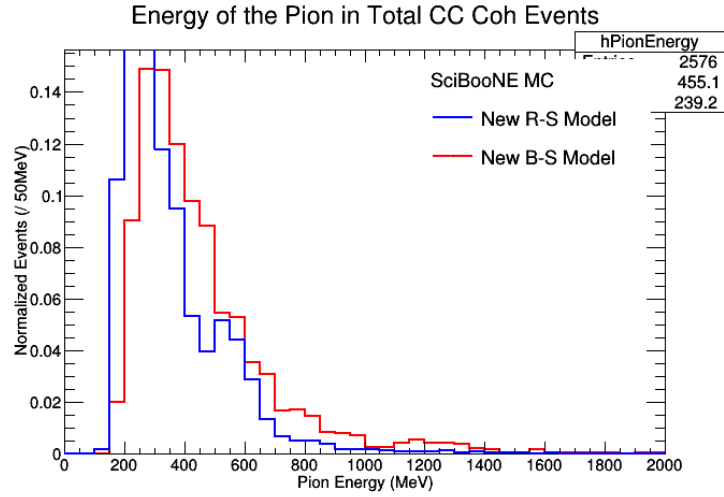


Figure 125

A.17 ANMFourSquaredPlotting.C

All of the four-momentum transfer (both $|t|$ and Q^2) combined plots are made with this file for anti-neutrino mode.

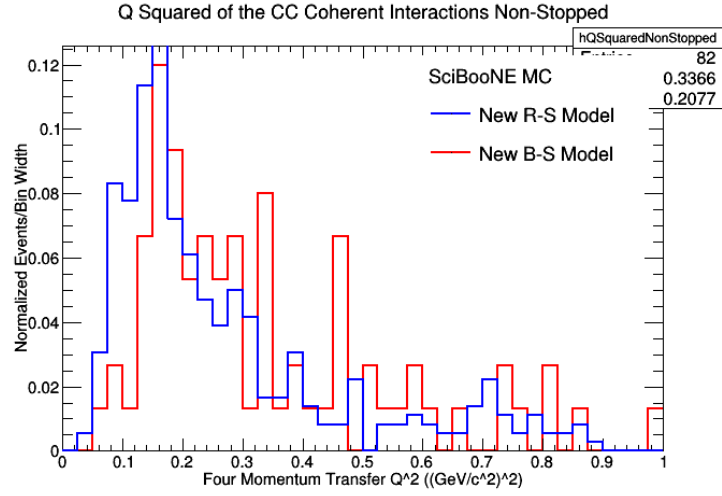


Figure 126

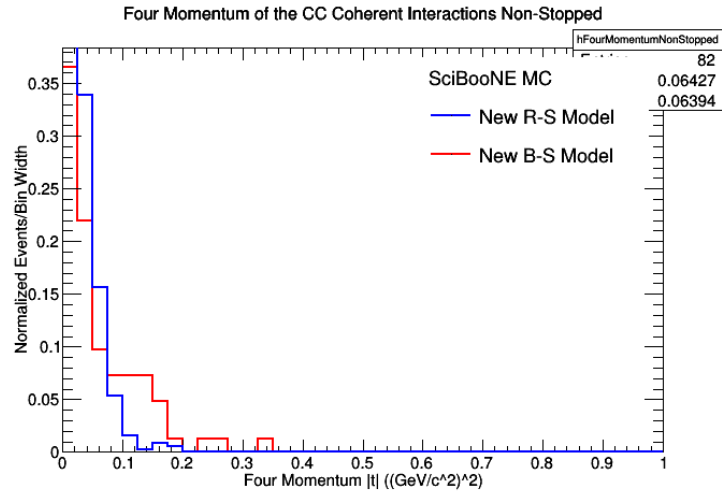


Figure 127

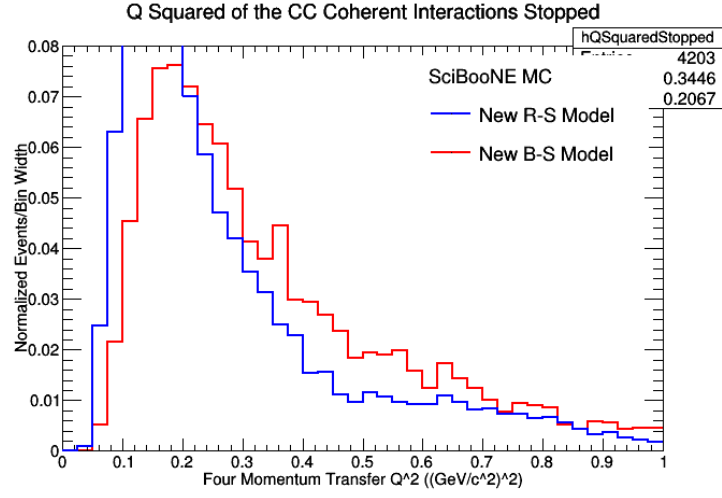


Figure 128

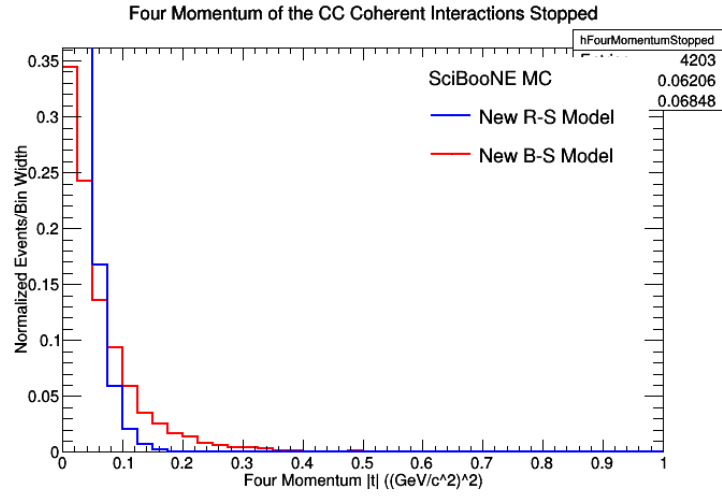


Figure 129

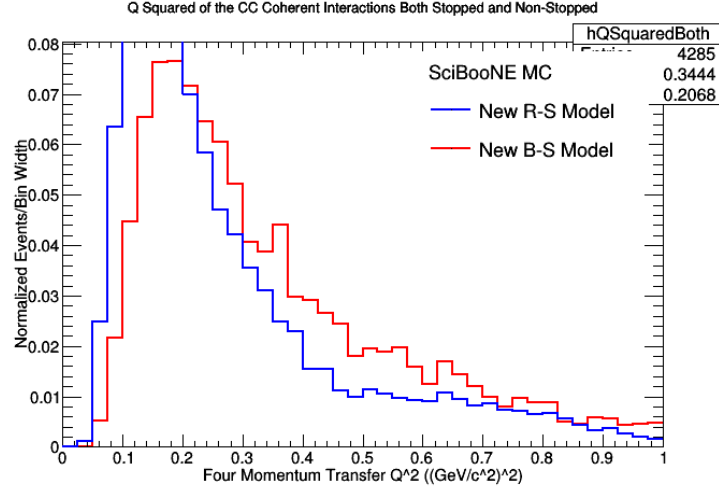


Figure 130

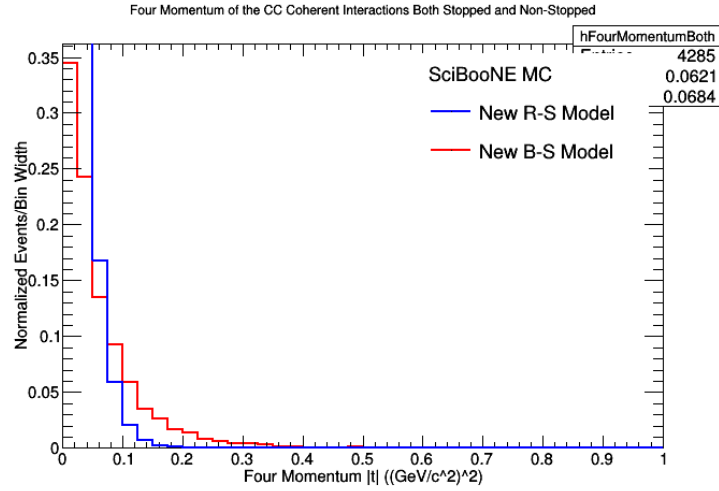


Figure 131

B Steps for Running the Code

The instructions on how to run the code and the order the files need to run in so that there are no resulting error messages, or other issues while running the code, are detailed in this section.

Step 1: This is the first step. (Run the NewNM macros and the NewANM macros and the OldNM macro.)

Step 2: This is the second step. (Run the combined plotting macros.)

Step 3: This is the third step. (Run the Pion Plotting macros.)

Step 4: Etc. (Run the FourSquaredMomentum macros.)

C Efficiency Tables

These are the corresponding tables to the 2D Efficiency plots for CC-Inclusive events.

Table 3: Table for 2D Histogram for New NM-Rein-Sehgal

Wavelength	1.5-1.94	1.94-2.14	2.14-2.34	2.34-2.54	2.54-2.74	2.74-2.94	2.94-3.14	3.14-3.34	3.34-3.54	3.54-3.74	3.74-3.94	3.94-4.14	4.14-4.34	4.34-4.54	4.54-4.74	4.74-4.94	4.94-5.14	5.14-5.34	5.34-5.54	5.54-5.74	5.74-5.94	5.94-6.14	6.14-6.34	6.34-6.54	6.54-6.74	6.74-6.94	6.94-7.14	7.14-7.34	7.34-7.54	7.54-7.74	7.74-7.94	7.94-8.14	8.14-8.34	8.34-8.54	8.54-8.74	8.74-8.94	8.94-9.14	9.14-9.34	9.34-9.54	9.54-9.74	9.74-9.94	9.94-10.14	10.14-10.34	10.34-10.54	10.54-10.74	10.74-10.94	10.94-11.14	11.14-11.34	11.34-11.54	11.54-11.74	11.74-11.94	11.94-12.14	12.14-12.34	12.34-12.54	12.54-12.74	12.74-12.94	12.94-13.14	13.14-13.34	13.34-13.54	13.54-13.74	13.74-13.94	13.94-14.14	14.14-14.34	14.34-14.54	14.54-14.74	14.74-14.94	14.94-15.14	15.14-15.34	15.34-15.54	15.54-15.74	15.74-15.94	15.94-16.14	16.14-16.34	16.34-16.54	16.54-16.74	16.74-16.94	16.94-17.14	17.14-17.34	17.34-17.54	17.54-17.74	17.74-17.94	17.94-18.14	18.14-18.34	18.34-18.54	18.54-18.74	18.74-18.94	18.94-19.14	19.14-19.34	19.34-19.54	19.54-19.74	19.74-19.94	19.94-20.14	20.14-20.34	20.34-20.54	20.54-20.74	20.74-20.94	20.94-21.14	21.14-21.34	21.34-21.54	21.54-21.74	21.74-21.94	21.94-22.14	22.14-22.34	22.34-22.54	22.54-22.74	22.74-22.94	22.94-23.14	23.14-23.34	23.34-23.54	23.54-23.74	23.74-23.94	23.94-24.14	24.14-24.34	24.34-24.54	24.54-24.74	24.74-24.94	24.94-25.14	25.14-25.34	25.34-25.54	25.54-25.74	25.74-25.94	25.94-26.14	26.14-26.34	26.34-26.54	26.54-26.74	26.74-26.94	26.94-27.14	27.14-27.34	27.34-27.54	27.54-27.74	27.74-27.94	27.94-28.14	28.14-28.34	28.34-28.54	28.54-28.74	28.74-28.94	28.94-29.14	29.14-29.34	29.34-29.54	29.54-29.74	29.74-29.94	29.94-30.14	30.14-30.34	30.34-30.54	30.54-30.74	30.74-30.94	30.94-31.14	31.14-31.34	31.34-31.54	31.54-31.74	31.74-31.94	31.94-32.14	32.14-32.34	32.34-32.54	32.54-32.74	32.74-32.94	32.94-33.14	33.14-33.34	33.34-33.54	33.54-33.74	33.74-33.94	33.94-34.14	34.14-34.34	34.34-34.54	34.54-34.74	34.74-34.94	34.94-35.14	35.14-35.34	35.34-35.54	35.54-35.74	35.74-35.94	35.94-36.14	36.14-36.34	36.34-36.54	36.54-36.74	36.74-36.94	36.94-37.14	37.14-37.34	37.34-37.54	37.54-37.74	37.74-37.94	37.94-38.14	38.14-38.34	38.34-38.54	38.54-38.74	38.74-38.94	38.94-39.14	39.14-39.34	39.34-39.54	39.54-39.74	39.74-39.94	39.94-40.14	40.14-40.34	40.34-40.54	40.54-40.74	40.74-40.94	40.94-41.14	41.14-41.34	41.34-41.54	41.54-41.74	41.74-41.94	41.94-42.14	42.14-42.34	42.34-42.54	42.54-42.74	42.74-42.94	42.94-43.14	43.14-43.34	43.34-43.54	43.54-43.74	43.74-43.94	43.94-44.14	44.14-44.34	44.34-44.54	44.54-44.74	44.74-44.94	44.94-45.14	45.14-45.34	45.34-45.54	45.54-45.74	45.74-45.94	45.94-46.14	46.14-46.34	46.34-46.54	46.54-46.74	46.74-46.94	46.94-47.14	47.14-47.34	47.34-47.54	47.54-47.74	47.74-47.94	47.94-48.14	48.14-48.34	48.34-48.54	48.54-48.74	48.74-48.94	48.94-49.14	49.14-49.34	49.34-49.54	49.54-49.74	49.74-49.94	49.94-50.14	50.14-50.34	50.34-50.54	50.54-50.74	50.74-50.94	50.94-51.14	51.14-51.34	51.34-51.54	51.54-51.74	51.74-51.94	51.94-52.14	52.14-52.34	52.34-52.54	52.54-52.74	52.74-52.94	52.94-53.14	53.14-53.34	53.34-53.54	53.54-53.74	53.74-5
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Table 5: Table for 2D Histogram for Old NM-Rein-Sehgal

[illegible]

Table 6: Table for 2D Histogram for New ANM-Rein-Sehal

Age	ANM	Rein	Sehal	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99	100-104	105-109	110-114	115-119	120-124	125-129	130-134	135-139	140-144	145-149	150-154	155-159	160-164	165-169	170-174	175-179	180-184	185-189	190-194	195-199	200-204	205-209	210-214	215-219	220-224	225-229	230-234	235-239	240-244	245-249	250-254	255-259	260-264	265-269	270-274	275-279	280-284	285-289	290-294	295-299	300-304	305-309	310-314	315-319	320-324	325-329	330-334	335-339	340-344	345-349	350-354	355-359	360-364	365-369	370-374	375-379	380-384	385-389	390-394	395-399	400-404	405-409	410-414	415-419	420-424	425-429	430-434	435-439	440-444	445-449	450-454	455-459	460-464	465-469	470-474	475-479	480-484	485-489	490-494	495-499	500-504	505-509	510-514	515-519	520-524	525-529	530-534	535-539	540-544	545-549	550-554	555-559	560-564	565-569	570-574	575-579	580-584	585-589	590-594	595-599	600-604	605-609	610-614	615-619	620-624	625-629	630-634	635-639	640-644	645-649	650-654	655-659	660-664	665-669	670-674	675-679	680-684	685-689	690-694	695-699	700-704	705-709	710-714	715-719	720-724	725-729	730-734	735-739	740-744	745-749	750-754	755-759	760-764	765-769	770-774	775-779	780-784	785-789	790-794	795-799	800-804	805-809	810-814	815-819	820-824	825-829	830-834	835-839	840-844	845-849	850-854	855-859	860-864	865-869	870-874	875-879	880-884	885-889	890-894	895-899	900-904	905-909	910-914	915-919	920-924	925-929	930-934	935-939	940-944	945-949	950-954	955-959	960-964	965-969	970-974	975-979	980-984	985-989	990-994	995-999	1000-1004	1005-1009	1010-1014	1015-1019	1020-1024	1025-1029	1030-1034	1035-1039	1040-1044	1045-1049	1050-1054	1055-1059	1060-1064	1065-1069	1070-1074	1075-1079	1080-1084	1085-1089	1090-1094	1095-1099	1100-1104	1105-1109	1110-1114	1115-1119	1120-1124	1125-1129	1130-1134	1135-1139	1140-1144	1145-1149	1150-1154	1155-1159	1160-1164	1165-1169	1170-1174	1175-1179	1180-1184	1185-1189	1190-1194	1195-1199	1200-1204	1205-1209	1210-1214	1215-1219	1220-1224	1225-1229	1230-1234	1235-1239	1240-1244	1245-1249	1250-1254	1255-1259	1260-1264	1265-1269	1270-1274	1275-1279	1280-1284	1285-1289	1290-1294	1295-1299	1300-1304	1305-1309	1310-1314	1315-1319	1320-1324	1325-1329	1330-1334	1335-1339	1340-1344	1345-1349	1350-1354	1355-1359	1360-1364	1365-1369	1370-1374	1375-1379	1380-1384	1385-1389	1390-1394	1395-1399	1400-1404	1405-1409	1410-1414	1415-1419	1420-1424	1425-1429	1430-1434	1435-1439	1440-1444	1445-1449	1450-1454	1455-1459	1460-1464	1465-1469	1470-1474	1475-1479	1480-1484	1485-1489	1490-1494	1495-1499	1500-1504	1505-1509	1510-1514	1515-1519	1520-1524	1525-1529	1530-1534	1535-1539	1540-1544	1545-1549	1550-1554	1555-1559	1560-1564	1565-1569	1570-1574	1575-1579	1580-1584	1585-1589	1590-1594	1595-1599	1600-1604	1605-1609	1610-1614	1615-1619	1620-1624	1625-1629	1630-1634	1635-1639	1640-1644	1645-1649	1650-1654	1655-1659	1660-1664	1665-1669	1670-1674	1675-1679	1680-1684	1685-1689	1690-1694	1695-1699	1700-1704	1705-1709	1710-1714	1715-1719	1720-1724	1725-1729	1730-1734	1735-1739	1740-1744	1745-1749	1750-1754	1755-1759	1760-1764	1765-1769	1770-1774	1775-1779	1780-1784	1785-1789	1790-1794	1795-1799	1800-1804	1805-1809	1810-1814	1815-1819	1820-1824	1825-1829	1830-1834	1835-1839	1840-1844	1845-1849	1850-1854	1855-1859	1860-1864	1865-1869	1870-1874	1875-1879	1880-1884	1885-1889	1890-1894	1895-1899	1900-1904	1905-1909	1910-1914	1915-1919	1920-1924	1925-1929	1930-1934	1935-1939	1940-1944	1945-1949	1950-1954	1955-1959	1960-1964	1965-1969	1970-1974	1975-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019	2020-2024	2025-2029	2030-2034	2035-2039	2040-2044	2045-2049	2050-2054	2055-2059	2060-2064	2065-2069	2070-2074	2075-2079	2080-2084	2085-2089	2090-2094	2095-2099	2100-2104	2105-2109	2110-2114	2115-2119	2120-2124	2125-2129	2130-2134	2135-2139	2140-2144	2145-2149	2150-2154	2155-2159	2160-2164	2165-2169	2170-2174	2175-2179	2180-2184	2185-2189	2190-2194	2195-2199	2200-2204	2205-2209	2210-2214	2215-2219	2220-2224	2225-2229	2230-2234	2235-2239	2240-2244	2245-2249	2250-2254	2255-2259	2260-2264	2265-2269	2270-2274	2275-2279	2280-2284	2285-2289	2290-2294	2295-2299	2300-2304	2305-2309	2310-2314	2315-2319	2320-2324	2325-2329	2330-2334	2335-2339	2340-2344	2345-2349	2350-2354	2355-2359	2360-2364	2365-2369	2370-2374	2375-2379	2380-2384	2385-2389	2390-2394	2395-2399	2400-2404	2405-2409	2410-2414	2415-2419	2420-2424	2425-2429	2430-2434	2435-2439	2440-2444	2445-2449	2450-2454	2455-2459	2460-2464	2465-2469	2470-2474	2475-2479	2480-2484	2485-2489	2490-2494	2495-2499	2500-2504	2505-2509	2510-2514	2515-2519	2520-2524	2525-2529	2530-2534	2535-2539	2540-2544	2545-2549	2550-2554	2555-2559	2560-2564	2565-2569	2570-2574	2575-2579	2580-2584	2585-2589	2590-2594	2595-2599	2600-2604	2605-2609	2610-2614	2615-2619	2620-2624	2625-2629	2630-2634	2635-2639	2640-2644	2645-2649	2650-2654	2655-2659	2660-2664	2665-2669	2670-2674	2675-2679	2680-2684	2685-2689	2690-2694	2695-2699	2700-2704	2705-2709	2710-2714	2715-2719	2720-2724	2725-2729	2730-2734	2735-2739	2740-2744	2745-2749	2750-2754	2755-2759	2760-2764	2765-2769	2770-2774	2775-2779	2780-2784	2785-2789	2790-2794	2795-2799	2800-2804	2805-2809	2810-2814	2815-2819	2820-2824	2825-2829	2830-2834	2835-2839	2840-2844	2845-2849	2850-2854	2855-2859	2860-2864	2865-2869	2870-2874	2875-2879	2880-2884	2885-2889	2890-2894	2895-2899	2900-2904	2905-2909	2910-2914	2915-2919	2920-2924	2925-2929	2930-2934	2935-2939	2940-2944	2945-2949	2950-2954	2955-2959	2960-2964	2965-2969	2970-2974	2975-2979	2980-2984	2985-2989	2990-2994	2995-2999	3000-3004	3005-3009	3010-3014	3015-3019	3020-3024	3025-3029	3030-3034	3035-3039	3040-3044	3045-3049	3050-3054	3055-3059	3060-3064	3065-3069	3070-3074	3075-3079	3080-3084	3085-3089	3090-3094	3095-3099	3100-3104	3105-3109	3110-3114	3115-3119	3120-3124	3125-3129	3130-3134	3135-3139	3140-3144	3145-3149	3150-3154	3155-3159	3160-3164	3165-3169	3170-3174	3175-3179	3180-3184	3185-3189	3190-3194	3195-3199	3200-3204	3205-3209	3210-3214	3215-3219	3220-3224	3225-3229	3230-3234	3235-3239	3240-3244	3245-3249	3250-3254	3255-3259	3260-3264	3265-3269	3270-3274	3275-3279	3280-3284	3285-3289	3290-3294	3295-3299	3300-3304	3305-3309	3310-3314	3315-3319	3320-3324	3325-3329	3330-3334	3335-3339	3340-3344	3345-3349	3350-3354	3355-3359	3360-3364	3365-3369	3370-3374	3375-3379	3380-3384	3385-3389	3390-3394	3395-3399	3400-3404	3405-3409	3410-3414	3415-3419	3420-3424	3425-3429	3430-3434	3435-3439	3440-3444	3445-3449	3450-3454	3455-3459	3460-3464	3465-3469	3470-3474	3475-3479	3480-3484	3485-3489	3490-3494	3495-3499	3500-3504	3505-3509	3510-3514	3515-3519	3520-3524	3525-3529	3530-3534	3535-3539	3540-3544	3545-3549	3550-3554	3555-3559	3560-3564	3565-3569	3570-3574	3575-3579	3580-3584	3585-3589	3590-3594	3595-3599	3600-3604	3605-3609	3610-3614	3615-3619	3620-3624	3625-3629	3630-3634	3635-3639	3640-3644	3645-3649	3650-3654	3655-3659	3660-3664	3665-3669	3670-3674	3675-3679	3680-3684	3685-3689	3690-3694	3695-3699	3700-3704	3705-3709	3710-3714	3715-3719	3720-3724	3725-3729	3730-3734	3735-3739	3740-3744	3745-3749	3750-3754	3755-3759	3760-3764	3765-3769	3770-3774	3775-3779	3780-3784	3785-3789	3790-3794	3795-3799	3800-3804	3805-3809	3810-3814	3815-3819	3820-3824	3825-3829	3830-3834	3835-3839	3840-3844	3845-3849	3850-3854	3855-3859	3860-3864	3865-3869	3870-3874	3875-3879	3880-3884	3885-3889	3890-3894	3895-3899	3900-3904	3905-3909	3910-3914	3915-3919	3920-3924	3925-3929	3930-3934	3935-3939	3940-3944	3945-3949	3950-3954	3955-3959	3960-3964	3965-3969	3970-3974	3975-3979	3980-3984	3985-3989	3990-3994	3995-3999	4000-4004	4005-4009	4010-4014	4015-4019	4020-4024	4025-4029	4030-4034	4035-4039	4040-4044	4045-4049	4050-4054	4055-4059	4060-4064	4065-4069	4070-4074	4075-4079	4080-4084	4085-4089	4090-4094	4095-4099	4100-4104	4105-4109	4110-4114	4115-4119	4120-4124	4125-4129	4130-4134	4135-4139	4140-4144	4145-4149	4150-4154	4155-4159	4160-4164	4165-4169	4170-4174	4175-4179	4180-4184	4185-4189	4190-4194	4195-4199	4200-4204	4205-4209	4210-4214	4215-4219	4220-4224	4225-4229	4230-4234	4235-4239	4240-4244	4245-4249	4250-4254	4255-4259	4260-4264	4265-4269	4270-4274	4275-4279	4280-4284	4285-4289	4290-4294	4295-4299	4300-4304	4305-4309	4310-4314	4315-4319	4320-4324	4325-4329	4330-4334	4335-4339	4340-4344	4345-4349	4350-4354	4355-4359	4360-4364	4365-4369	4370-4374	4375-4379	4380-4384	4385-4389	4390-4394	4395-4399	4400-4404	4405-4409	4410-4414	4415-4419	4420-4424	4425-4429	4430-4434	4435-4439	4440-4444	4445-4449	4450-4454	4455-4459	4460-4464	4465-4469	4470-4474	4475-4479	4480-4484	4485-4489	4490-4494	4495-4499	4500-4504	4505-4509	4510-4514	4515-4519	4520-4524	4525-4529	4530-4534	4535-4539
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These are the corresponding tables to the 2D Efficiency plots for CC-Coherent Pion events.

Table 8: Table for 2D Histogram for New CC-Coh Pion NM-Rein-Sehgal

[illegible]

Table 9: Table for 2D Histogram for New CC-Coh Pion NM-Berger-Sehgal

[illegible]

D Acknowledgements

Thank everyone who helped, and thank everyone who gave their inputs into your acceptance study. YOU NEED TO GIVE A HUGE AND SPECIAL THANKS TO DR. ASAADI RIGHT HERE! (He has been suuuuuuper patient...)