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: (insert dropbox/Google Drive Link here).

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 understand why SciBooNE had no observation of charged-current coherent pion production at low neutrino energy.

2 Samples

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

3 Detector Simulation

This section is intended to detail the nuances of detector simulation done in this acceptance model, and to describe the assumptions made in order to accomplish accurate classifications of

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

Summary of Samples

Mode	NEUT version	Pion-Model	Number of simulated events
$\overline{\nu}$	5.3.6	Rein-Sehgal	1,000,000
$\overline{\nu}$	5.3.6	Berger-Sehgal	1,000,000
$\overline{\nu}$	X.X.X	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.

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 subdetectors. 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 $1.2 \; GeV/c$ by using the observed range of the trajectory of the muon. The coordinante 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.

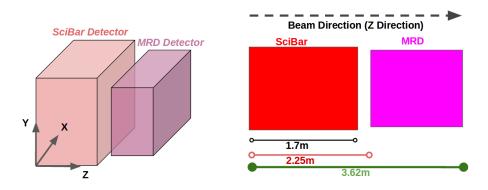


Figure 3.1: Representation of the SciBooNE detector and the coordinate frame we use in this study

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 m, 0 < y < 3.0 m, and 0 < z < 1.7 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 in the 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 inbetween and gives a total z-direction dimension of being 1.37m. 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.

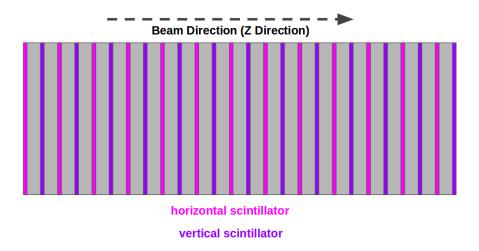


Figure 3.1.2: Depiction of the Muon Range Detector (MRD) which consists of alternating layers of horizontal scintillator (shown in pink) steel slabs (shown in grey) and vertical scintillator (shown in purple)

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.

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.

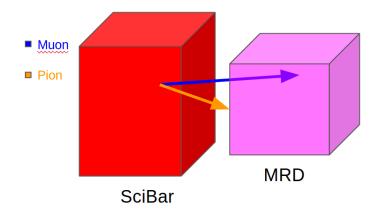


Figure 4.1: Depiction of an event that was classified as "Stopped."

These events allow for complete reconstruction of the muon's momentum based on the number of layers which the muon penetrated and the muons 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 kinematics to have exited out the back face of the MRD without stopping. An illustration of such an event is given in Figure 4.2.

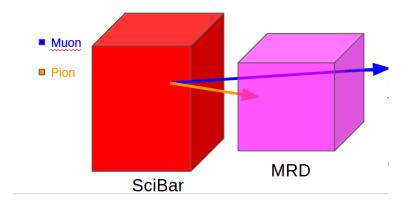


Figure 4.2: Depiction of an event that was classified as "out-the-back".

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.

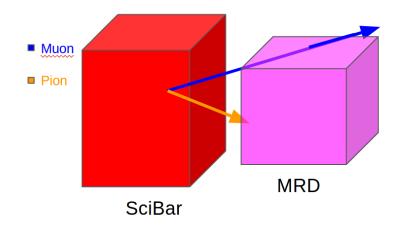


Figure 4.3: Depiction of an event that was classified as "Out-Side."

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 a CC-Inclusive event, and those that met the conditions of classification as Charged-Current Coherent Pion Production events. The plots in the two subsections below show our results.

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 previous simulation studies which were done. Table 5.1 goes through the event selection criteria for selecting a sample of CC-Inclusive events from the neutrino mode (ν -mode) Monte Carlo.

Figure 5.1 shows the momentum and angular 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 vx.x.x Rein-Sehgal). The distributions have been normalized to the same area and show no strong differences between them.

ν -mode CC-Inclusive Event Reduction

Events Selection	NEUT v5.3.6 Rein-Sehgal	NEUT v5.3.6 Berger-Sehgal	NEUT vx.x.x Rein-Sehgal
Total Sample	1,000,000	1,000,000	100,000
CC-Inclusive Interaction	725,730	727,278	69,363
μ (μ + n-other particles in SciBar)			
Muon enters the MRD	263,698	262,608	24,250
Muon enters the MRD and	231,089	230,054	21,001
penetrates ≥ 3 layers of steel			
"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: Event reduction table for a sample of ν -mode CC-Inclusive events simulated in the SciBooNE geometry.

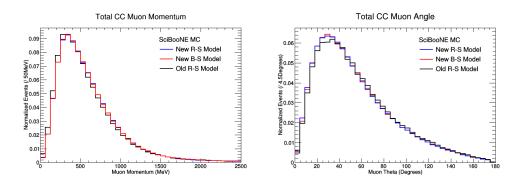


Figure 5.1: Muon Momentum (left) and Muon Angle (right) for ν -mode CC-Inclusive interactions for all three models included in this study. These samples kinematics are, unsurprisingly, very similar for the sample of CC-Inclusive

Figure 5.1 represents the one-dimensional efficiency for selecting ν -mode CC-Inclusive events for this study compared to results derived from Hiraide's thesis 2 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.

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

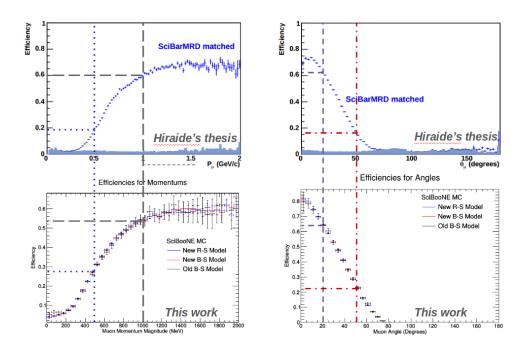


Figure 5.1: One-dimension efficiency plots for the ν -mode CC-Inclusive sample.

Figure 5.1 shows the two-dimensional efficiency for selecting ν -mode CC-Inclusive events for this study compared to results derived from Morgan's reference sample.

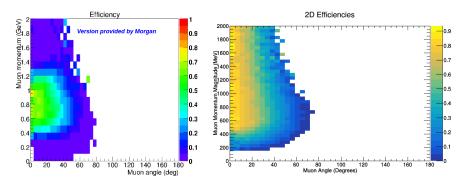


Figure 5.1: Two-dimensional efficiency plots for the ν -mode Rein-Sehgal CC-Inclusive sample.

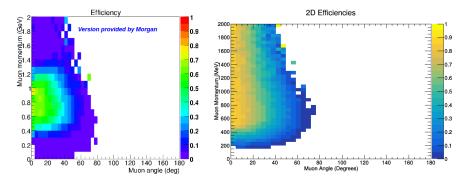


Figure 5.1: Two-dimensional efficiency plots for the ν -mode Berger-Sehgal CC-Inclusive sample.

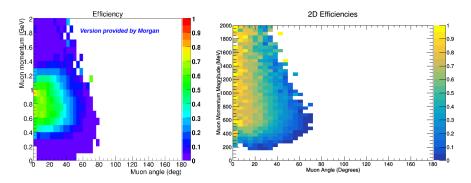


Figure 5.1: Two-dimensional efficiency plots for the ν -mode Old Rein-Sehgal CC-Inclusive sample.

Similar to before, Table 5.1 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	699,239	704,327
μ (μ + n-other particles in SciBar)		
Muon enters the MRD	380,362	380,869
Muon enters the MRD and	336,373	337,979
penetrates ≥ 3 layers of steel		
"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: Event reduction table for a sample of $\bar{\nu}$ -mode CC-Inclusive evnets simulated in the SciBooNE geometry.

Figure 5.1 shows the momentum and angular distribution for the sample of $\bar{\nu}$ -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 vx.x.x Rein-Sehgal). The distributions have been normalized to the same area and show no strong differences between them.

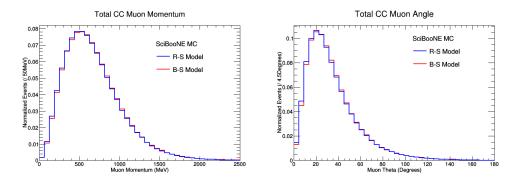


Figure 5.1: Muon Momentum (left) and Muon Angle (right) for $\bar{\nu}$ -mode CC-Inclusive interactions for all three models included in this study. These samples kinematics are, unsurprisingly, very similar for the sample of CC-Inclusive

Figure 5.1 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).

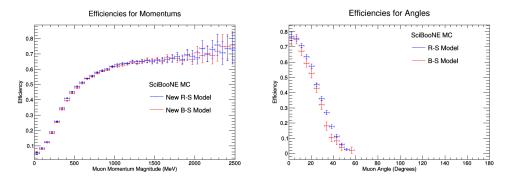


Figure 5.1: One-dimension efficiency plots for the $\bar{\nu}$ -mode CC-Inclusive sample. Muon's Momentums is on the right and the Muon's Angles is on the left.

Figure 5.1 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)

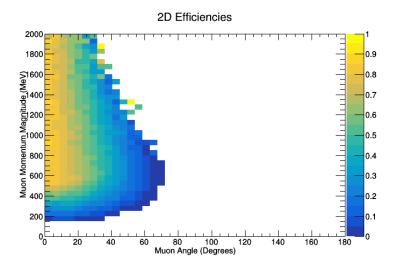


Figure 5.1: Two-dimensional efficiency plot for the $\bar{\nu}$ -mode Rein-Sehgal CC-Inclusive sample.

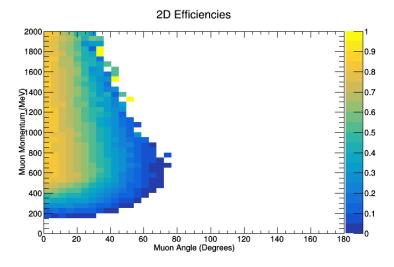


Figure 5.1: Two-dimensional efficiency plot for the $\bar{\nu}$ -mode Berger-Sehgal CC-Inclusive sample.

Below are the tables that correspond to the five 2D Efficiency CC-Inclusive histograms that are above.

Table 1: Table for 2D Histogram for New NM-Rein-Sehgal

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Table 2: Table for 2D Histogram for New NM-Berger-Sehgal

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1558-300	883838	0.794521	(B)(E)(E)(E)(E)(E)(E)(E)(E)(E)(E)(E)(E)(E)	11/272711	D.55747	999	3000	0.137931	181818		_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_		_	_	_	_		_	_	
1900-1920	277776	806162	0.745763		_	_	0.285714	0.258065	285714	_	_	_	_	_												_										_		
1856 1900 19		761905 0.	_		Ť	_	336	_	0.166667 0.0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	_	_				-			-		-		0.0
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1620 1 700 1 700 1 750	-	0.734884	_	0.6-803	0.52568	0.435681	Ť	Ť	0.285714	12	_	_	_	_	_		_	_	_	_	_	_	_	_	_	_	-	-	-		_	_	=	-	= 1	- 1	=	
1620-170	978/5/870	070057	0.747423	0.637168	0.554007	122,040	033333	0.245753	0.214286	0.078823	_	_	_	_	_		_	_	_	_	_	_	_	_	_	_	_	-	-		_	_	-		= :		-	
1600-1630	19962230	0.728643	0.664251	0.6-8629	0.538375	0.535354	1,3622-55	0.3086.22	0.181818	0.428571	173																											
1556.1600	176742	0.741784	0,71,7833	0.66548	0.587356	2	0.416567	0.2931G	0.18m/5	0.0525316	0.333333															_		_	_	_	_	_	_					
1200-123	873116	793531	0.2807	238393	1290021	148-0-6	0.433735	0.277372	0.2321-63	0.2	_																									_		
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1200-1250 1220-1300	0.78022	0.774205	0.730769	0.681775	0.579366	0.524138	0.476.556	0.405963	0.38785	0.189-474	_	0.090909	0.1111	_	_											_		-	-									
1200-1250	г.	0.78420.4	0.731677	0,700.657	0,60516	153567	0.474736	0.405531	03m654	0.233918	0.162011-4	0.0759231	_	_	_		_	_	_	_	_	_	_	_	_	_	_	_	_	-	_	_	-	-		-	-	
1130-1300	820281	0814336	0.717308	11683544	1620074	11528678	0.444332	1397764	1296117	11214286	(13857)	0.097361	0.0909091	_	_	0	_	_	_	_	_	_	_	_	_		_	_	_		_	_	_				_	
1100-1130	1813725	1611080	0,783,785	Chemin	16-0326	0202001	0.475651	0.437118	1325411	0.272981	0.180723	0.0869265	82814800	_	_	_								_	_	_	_	_	_	_	_	_				_		
1020-1100		182-0-5	9870427	_	÷	_	_	_	÷	_	_	_	0.0851054	_	29999130	Ĭ	_	_	_	_	_	_	_	_	_	Ĭ	_	_	_	_	_	_	_			_	_	
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800830	258283	0.80-211	Ť	720117.0	0.651835	0.60-228	0.54827	0.47349	0.396570	0.323815	L23597	0.161433	_	0.078078	0.0162163		_	_	_	_	_	_	_	_	_	_	-	=	=		-	-	=	-		-	=	
750 800	0.833333	0.800211	0.780287	0.732403	0.661647	0.622306	0.55257	0.494205	0.352764	0.331652	0.255.223	0.197558	0.118211	0.0845538	0.0426136		0.0123457	_	_	_	_	_	_	_	_	_	_	_	_		_	_	_	-	= 1	-	_	
700 750	1,843373	3874286	3.782736	1,752701	0.689404	0.637363	1.551801	0.479326	0.403834	330302	358858	304505	125182	0.0060020	3.0363E3E	0.0120482	.mc-p21	_	_	_	_	_	_	_	_	_	_	_	_	-	_	_	_				_	
002-009	0.486.0	1811412	527420	789-89	577215	0.615-445	0.014788	.402462	25052	785367	1.359272	237-617	135583	16060001	320620.0	0.0166667	6038300									_	_	_	_		_	_	_			_		
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200.030	0.8933	0.811448	0.78089	0.7275	0.6567	0.578365	0.406522	0.486444	0.356159	0.30273	0.2406	0.169353	0.119633	Ť	Ť	66 0.00-5035										_		-	-									
550,300	1/282/1	0.77373	0.701245	0.63450.4	0.582547	0.521715	0.405.01	0.381784	0.327/0.6	0.272-452	0.212341	0.1-185336	0.102659	0.0358421	0.0242028	0.000740-456												_	_				_				_	
400-50	.615385	1281731	5725	505116	517113	45748	355351	333753	275212	22483	781.81.	0.126334	0.0810065	0.0457005	00745573																							
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300-320	0.422	0.30669	0.352953	0.3302	0.318462	0.3218	0.253	0.2185	_	Ť	_	-	-	0.000	_										_	_		-	-					-		-		0 0
250-310	1323	0,235849	0.223329	0.200736	0.228145	0.157/451	0.152859	0.142.202	0.0817963		_	0.0110121	0.000-55620-4	_	_		_	_	_	_	_	_	_	_	_	_	_	-	-		_	_	-	-		-	-	
200-220	1107895	175471	9129213	1131222	10973451	10580736	0.085743	71221800	1032338	10139147	701231-467	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	-	_	_	_				_	
156-300	ĺ	0.025	÷	_	-			0.0754777	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	-	-	_	_	_	-					
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New NATES.	and on-to	4.50 De	9-135 Deg	135-18	18-22.5 Day	225-27 Dry	27-31.5 Day	31.5.36 Drg	36.40.5	40.5-45 1	45.40.51	49,5-541	54.58.51	585.631	63.67.51	675.721	72.75.51	765-811	81.85.51	855.00 Day	98.94.51	945.991	99-1035	103.5-108 Day	108-112.5 Day	112.5-11.7 Day	117-121.5 Dag	121.5-126 Day	125-130.5 Day	130.5-135 Deg	135 139.5 Deg	120,5-144 Deg	14118	1-8-5-153 Deg	Jon son	157.5-162 Day	162.166	100.5.171 Day

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

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14.4.1 Dec. 1. Sept.

Table 4: Table for 2D Histogram for New ANM-Rein-Sehgal

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1850-19	0.78378	0.75999	0.998053	-	-	-	172007	15	_	-				=				0				-	=	=	0	_				= 1	=					0	0	0	0	-	-	0	
1800-185	0.808989	0.734082	0.711409	0.6098.48		0.303634	0.49(8(8	0307692	90					=									=	-		_				- 1	=									-	-		_
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17001750	0.836538	0.73-5798	1997020	0.681818		0.04(0.02)	0.494382	0.358974	19					=									=			_				= 1	=												
1650-17III	80	0.733146	0,71537	0.628507		0.505094	05133K	0348837	053333	22	2 .			=					-			-	=		0	_				= 1	=									-	-		_
1600-1650	0.80315	0.732-84	0.724876	0.677481		0.000000	0.469388	0.346154	0.333333					=			В						=		В	_				= 1	=				В								
1350-1600	0.802721	980080	719977	0.50027	1	100/00	1606050	0.402062	0.592593	78867				=									=			_					=												
1500-1530	292180	820020	10000000	0.63144	10000	20,50	0.4813-6	6291820	0.282051	0.142857	0000000	-		=									=			_					=												
1450-1500	0.820896	0.770154	0.712513	818189	000000000000000000000000000000000000000	997369	0.488-62	0.464286	0.290323	0.0				_									_								_												_
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00-1150	82028	39486	359636		0 0	=		£3382 0.	393846 0		0 0	-	3 1	- TRESSESSES			0				0 0		=	0				0		= 1	=			В	0								
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E 1831	811494 08	808895 0.7	64215 0.7	218.415 0.6			28082	498878 0.5	25238 0.4	35745		-	-	_	157856		0	0		0.0	0.0		=	=	0	=		0 0		= 1	=				0	0	0	0	0	-	-	0	-
9-1000 100	814732 118	79961 0.8	7.0 0.27			Ĕ.	é	51392 0.4	439291 0.4	-	0 0	0 0	9 1	Ξ.	114285 0.1				-	0	0 0		=	_		=		0		= 1	=						В	В	В	-	-	В	-
93	849776 04	816404 07	76928 0.			-	588134 0.5	509007 03	128421 D	-	-	-	-	Ξ.	=	0.0525536	0.125	8		0 0	0 0		=	0	8			0.0		= 1	=			8	8	В	0	0	0			8	-
888	846791	803572 04	774887 0.	-	-	-	1259	323933 0.5	465828 D	-	-			-	=	0.0454545	-	8		0	0 0		=	0	0			0.0		= 1	=			0		0	0	0	0			8	-
SE 52		803654 0.	728919 0.	-	-	-	585787	333736 0.	500	0 09588		202204	-	=	_	2963	1.125			0.0			=	_				0.0		= 1	=			8	0								-
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120	-	8747 04	380804 B			-	<u>.</u>	338364 0.3	46538		-		-	=				0.0289835 0		0.0	0.0		=	0	8			0.0		= 1	=				В								
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909	808989 082	806912 0.812	78-8609 0.77	ė	1 6	3	641457 0.60	220 82999	18047 0.58		0 0	0 0	-	=	=	=	10423729 0.04	10103093 001	-		0 0		=	0		-				= 1	=		_	0	В	0	0	0	0			0	0
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Table 5: Table for 2D Histogram for New ANM-Berger-Sehgal

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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. Table 5.2 goes through the event selection criteria for selecting a sample of CC-Coh $\pi^{+/-}$ events from the neutrino mode (ν -mode) Monte Carlo.

	v mode ee concrem 1	on Brone Readerson	
Events Selection	NEUT v5.3.6 Rein-Sehgal	NEUT v5.3.6 Berger-Sehgal	NEUT vx.x.x Rein-Sehgal
Total Sample	1,000,000	1,000,000	100,000
CC-Coherent Pion Interaction	12,186	2,576	1,320
$(\mu + \pi + \varnothing \text{ in SciBar})$			
Both muon and pion are	8,535	1,845	884
forward going			
Muon enters the MRD and	7,407	1,592	767
penetrates ≥ 3 layers of steel			
"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

 ν -mode CC-Coherent Pion Event Reduction

Table 6: Event reduction table for a sample of ν -mode Charged Current Coherent Pion events simulated in the SciBooNE geometry.

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:

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

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

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:

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

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

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

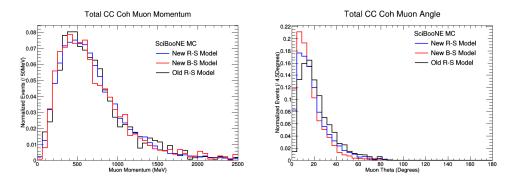


Figure 1: Muon Momentum for all of the muons of the events that made it to the MRD and penetrated at least three layers (left) and Muon Angle for the muons of the events that made it to the MRD and penetrated at least three layers (right) for ν -mode CC-Coh $\pi^{+/-}$ interactions for all three models 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!

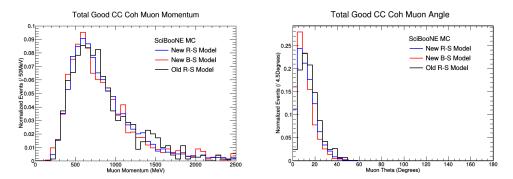


Figure 2: Muon Momentum of both the "stopped" and "not-stopped" samples (left) and Muon Angle of both the "stopped" and "not-stopped" samples (right) for ν -mode CC-Coh $\pi^{+/-}$ interactions for all three models included in this study. The "Good" classification means that only the stopped and not-stopped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

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

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

$$Q^{2} = |(P_{\nu_{\mu,x}} - P_{\mu_{x}})^{2} + (P_{\nu_{\mu,y}} - P_{\mu_{y}})^{2} + (P_{\nu_{\mu,z}} - P_{\mu_{z}})^{2} + (P_{\nu_{\mu,E}} - P_{\mu_{E}})^{2}|$$

$$(6)$$

 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:

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

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

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

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

 ν -Mode |t| and Q^2 plots are below:

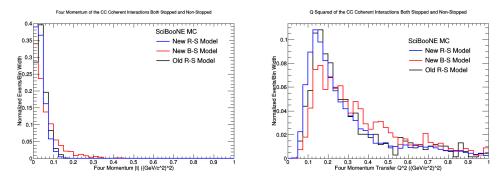


Figure 3: The |t| Momentum Transfer for the "stopped" and "not-stopped" events (left) and Q^2 Momentum Transfer for the "stopped" and "not-stopped" events (right) for ν -mode CC-Coh $\pi^{+/-}$ interactions for the three models included in this study.

Similar to before, Table 5.2 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.

$\bar{\nu}$ -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	36,669	7,790
$(\mu + \pi + \varnothing \text{ in SciBar})$		
Both muon and pion are	24,675	5,477
forward going		
Muon enters the MRD and	20,445	4,517
penetrates ≥ 3 layers of steel		
"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 7: Event reduction table for a sample of $\bar{\nu}$ -mode Charged Current Coherent Pion events simulated in the SciBooNE geometry.

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.

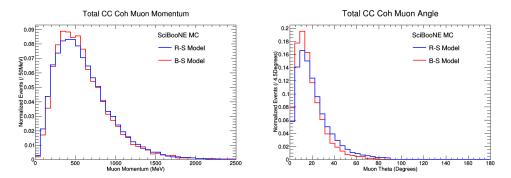


Figure 4: Muon Momentum (left) and Muon Angle (right) for ν -mode CC-Coh $\pi^{+/-}$ interactions for all three models included in this study.

The structure of the plots in Figure: 5.2 very closely resembles the plots for the ν -mode above, and the rest of the plots in this section have that same characteristic.

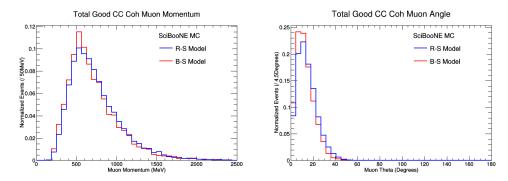


Figure 5: Muon Momentum (left) and Muon Angle (right) for $\bar{\nu}$ -mode CC-Coh $\pi^{+/-}$ interactions for both the "stopped" and "not-stopped" samples of events.

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

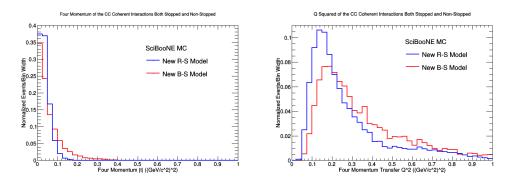


Figure 6: The |t| Momentum Transfer (left) and Q^2 Momentum Transfer (right) for $\bar{\nu}$ -mode CC-Coh $\pi^{+/-}$ interactions for both of the models included in this study which are the "stopped" and "not-stopped" events.

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 NEUTvx.x.x

A sample of $100,000 \nu$ interactions were simulated using the NEUT generator (vx.x.x, 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 correspond 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 correspond 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 correspond 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);
```

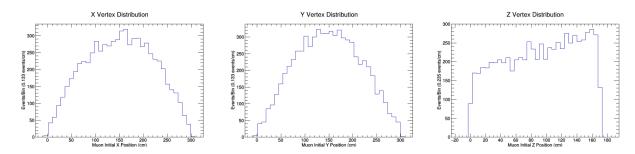


Figure 7: Vertex distributions of the events in the new Rein-Sehgal sample in ν -mode.

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

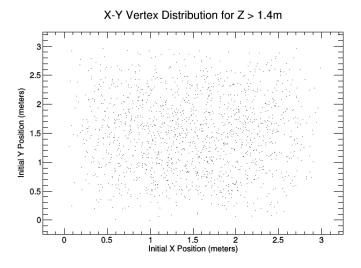


Figure 8: New ν -Mode Rein-Sehgal X-Y vertex distributions for muons that made it to the MRD and penetrated at least to the third layer of steel.

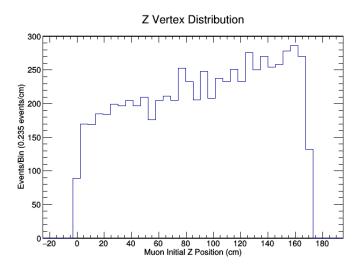


Figure 9: New ν -Mode Rein-Sehgal Z vertex distributions for the interactions.

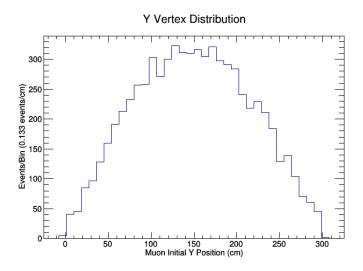


Figure 10: New ν -Mode Rein-Sehgal Y vertex distributions for the interactions.

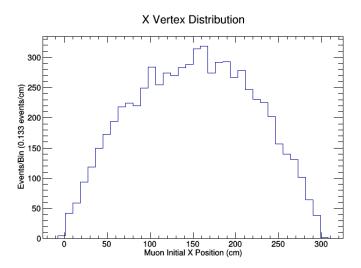


Figure 11: New ν -Mode Rein-Sehgal X vertex distributions for the interactions.

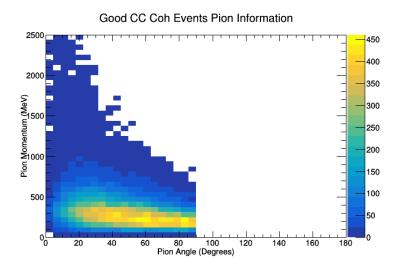


Figure 12: This is a 2D histogram for the momentum and angle of the pion in the CC Coh Pion events that met the qualification of being "good".

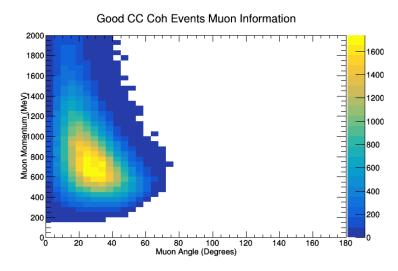


Figure 13: This is a 2D histogram for the momentum and angle of the muon in the CC Coh Pion events that met the qualification of being "good".

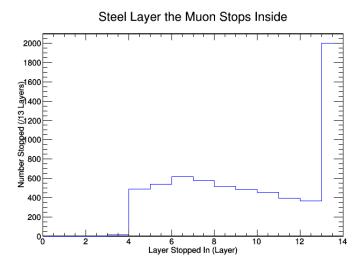


Figure 14: This histogram shows the amount of muons that embedded (or "Stopped") in a corresponding layer of steel in our simulation.

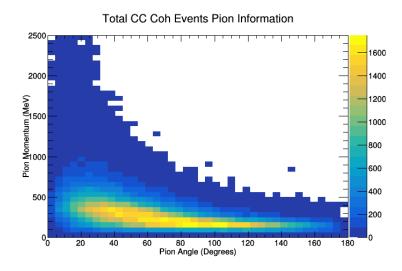


Figure 15: This is a 2D histogram for the momentum and angle of the pion in the total CC Coh Pion events.

Total CC Coh Events Muon Information Muon Momentum (MeV) Muon Angle (Degrees)

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:

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

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

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:

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

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

The angles are reported in units of °, 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:

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

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

$$Q^{2} = |(P_{\nu_{\mu,x}} - P_{\mu_{x}})^{2} + (P_{\nu_{\mu,y}} - P_{\mu_{y}})^{2} + (P_{\nu_{\mu,z}} - P_{\mu_{z}})^{2} + (P_{\nu_{\mu,E}} - P_{\mu_{E}})^{2}|$$
(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:

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

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

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

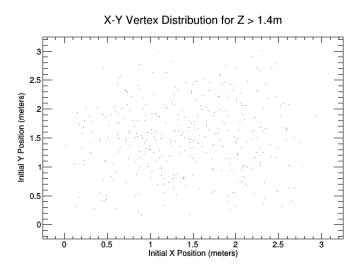


Figure 17: New ν -Mode Berger-Sehgal X-Y vertex distributions for muons that made it to the MRD and penetrated at least to the third layer of steel.

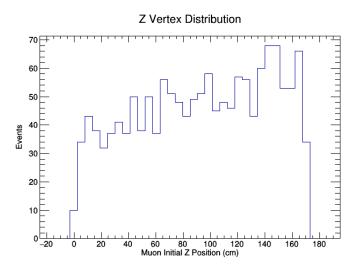


Figure 18: New ν -Mode Berger-Sehgal Z vertex distributions for the interactions.

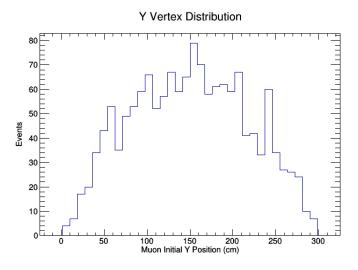


Figure 19: New ν -Mode Berger-Sehgal Y vertex distributions for the interactions.

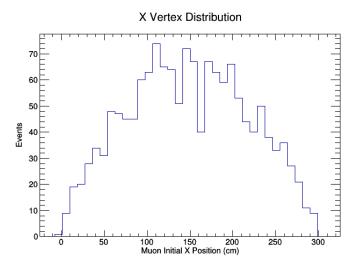


Figure 20: New ν -Mode Berger-Sehgal X vertex distributions for the interactions.

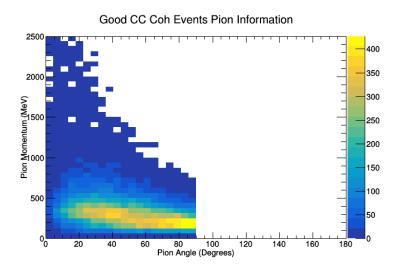


Figure 21: This is a 2D histogram for the momentum and angle of the pion in the CC Coh Pion events that met the qualification of being "good".

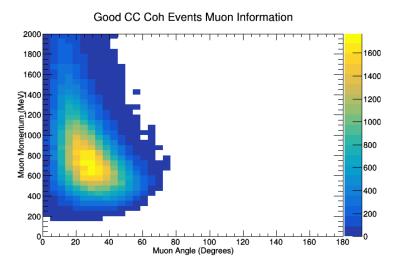


Figure 22: This is a 2D histogram for the momentum and angle of the muon in the CC Coh Pion events that met the qualification of being "good".!

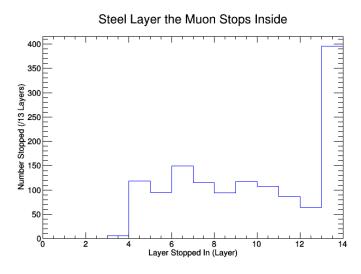


Figure 23: This histogram shows the amount of muons that embedded (or "Stopped") in a corresponding layer of steel in our simulation.

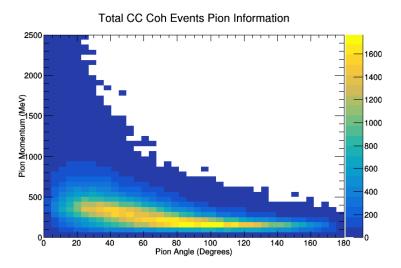


Figure 24: This is a 2D histogram for the momentum and angle of the pion in the total CC Coh Pion events.

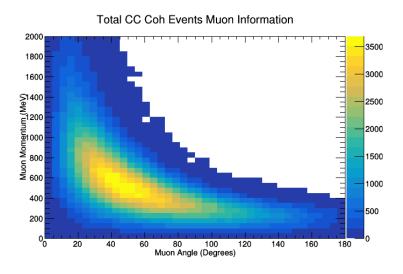


Figure 25: This is a 2D histogram for the momentum and angle of the muon in the total CC Coh Pion events.

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).

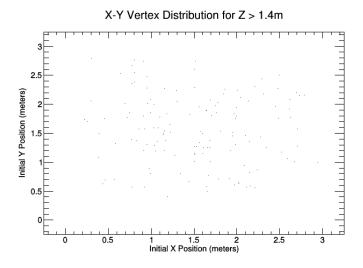


Figure 26: Old ν -Mode Rein-Sehgal X-Y vertex distributions for muons that made it to the MRD and penetrated at least to the third layer of steel.

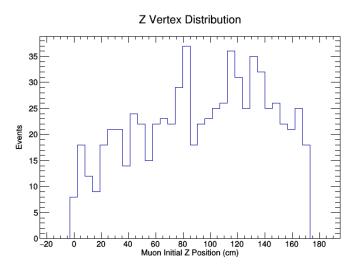


Figure 27: Old ν -Mode Rein-Sehgal Z vertex distributions for the interactions.

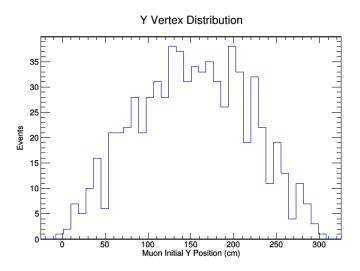


Figure 28: Old ν -Mode Rein-Sehgal Y vertex distributions for the interactions.

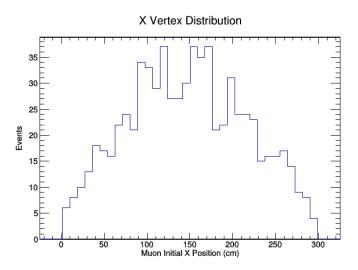


Figure 29: Old ν -Mode Rein-Sehgal X vertex distributions for the interactions.

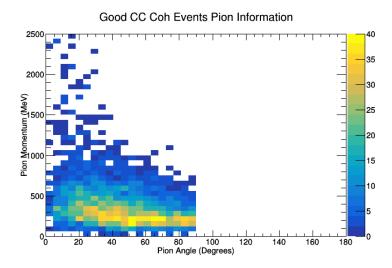


Figure 30: This is a 2D histogram for the momentum and angle of the pion in the CC Coh Pion events that met the qualification of being "good".

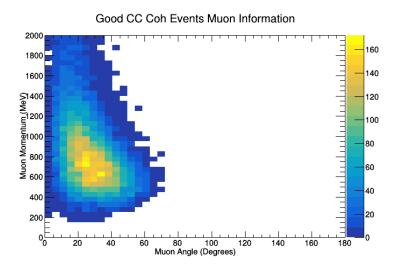


Figure 31: This is a 2D histogram for the momentum and angle of the muon in the CC Coh Pion events that met the qualification of being "good".

Steel Layer the Muon Stops Inside

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

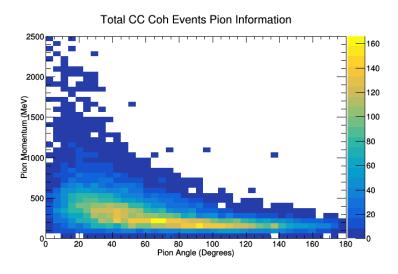


Figure 33: This is a 2D histogram for the momentum and angle of the pion in the total CC Coh Pion events.

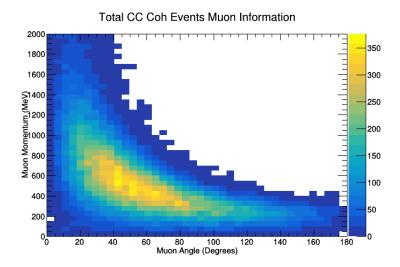


Figure 34: This is a 2D histogram for the momentum and angle of the muon in the total CC Coh Pion events.

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).

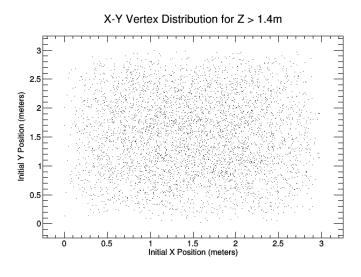


Figure 35: New $\bar{\nu}$ -Mode Rein-Sehgal X-Y vertex distributions for muons that made it to the MRD and penetrated at least to the third layer of steel.

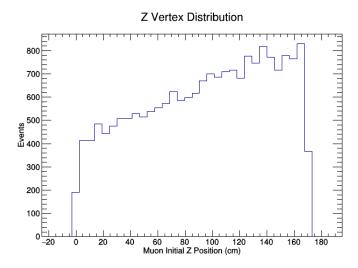


Figure 36: New $\bar{\nu}$ -Mode Rein-Sehgal Z vertex distributions for the interactions.

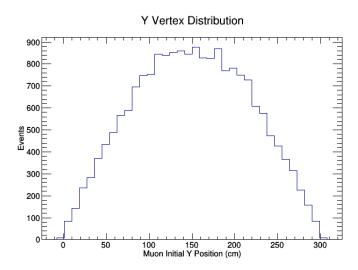


Figure 37: New $\bar{\nu}$ -Mode Rein-Sehgal Y vertex distributions for the interactions.

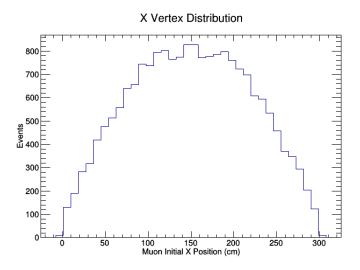


Figure 38: New $\bar{\nu}$ -Mode Rein-Sehgal X vertex distributions for the interactions.

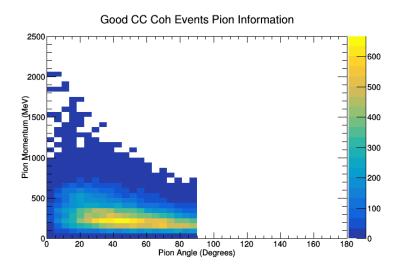


Figure 39: This is a 2D histogram for the momentum and angle of the pion in the CC Coh Pion events that met the qualification of being "good".

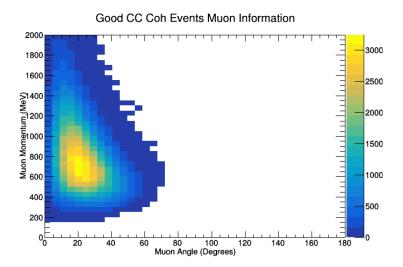


Figure 40: This is a 2D histogram for the momentum and angle of the muon in the CC Coh Pion events that met the qualification of being "good".

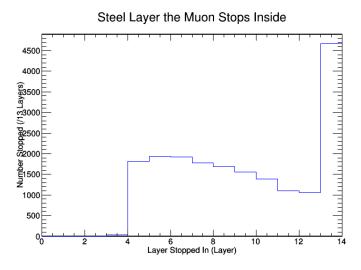


Figure 41: This histogram shows the amount of muons that embedded (or "Stopped") in a corresponding layer of steel in our simulation.

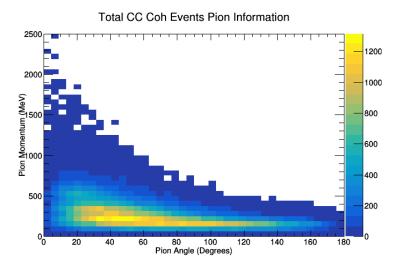


Figure 42: This is a 2D histogram for the momentum and angle of the pion in the total CC Coh Pion events.

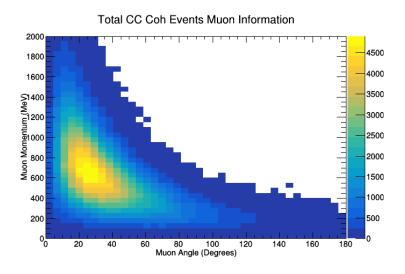


Figure 43: This is a 2D histogram for the momentum and angle of the muon in the total CC Coh Pion events.

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).

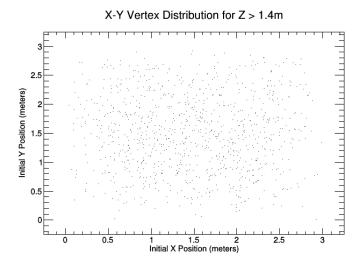


Figure 44: New $\bar{\nu}$ -Mode Berger-Sehgal X-Y vertex distributions for muons that made it to the MRD and penetrated at least to the third layer of steel.

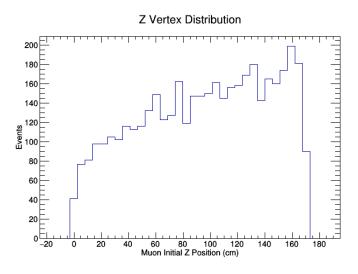


Figure 45: New $\bar{\nu}$ -Mode Berger-Sehgal Z vertex distributions for the interactions.

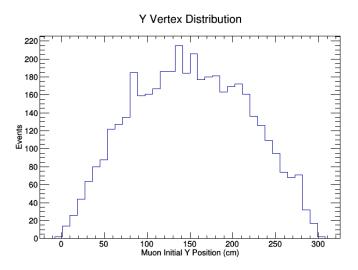


Figure 46: New $\bar{\nu}$ -Mode Berger-Sehgal Y vertex distributions for the interactions.

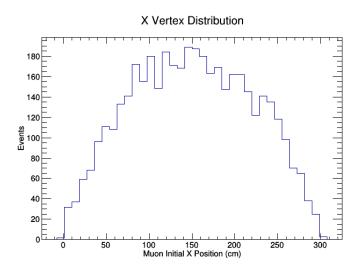


Figure 47: New $\bar{\nu}$ -Mode Berger-Sehgal X vertex distributions for the interactions.

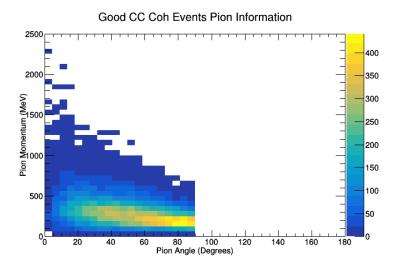


Figure 48: This is a 2D histogram for the momentum and angle of the pion in the CC Coh Pion events that met the qualification of being "good".

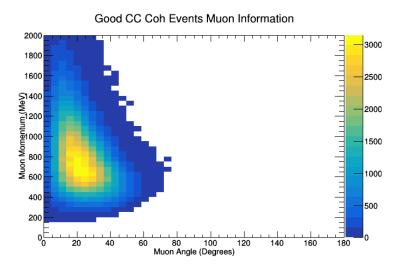


Figure 49: This is a 2D histogram for the momentum and angle of the muon in the CC Coh Pion events that met the qualification of being "good".

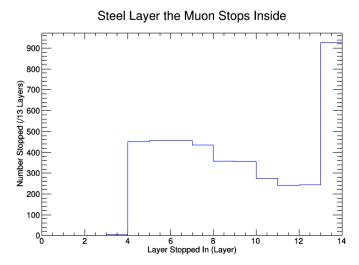


Figure 50: This histogram shows the amount of muons that embedded (or "Stopped") in a corresponding layer of steel in our simulation.

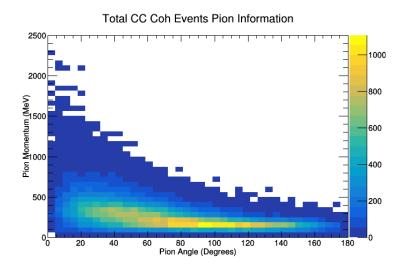


Figure 51: This is a 2D histogram for the momentum and angle of the pion in the total CC Coh Pion events.

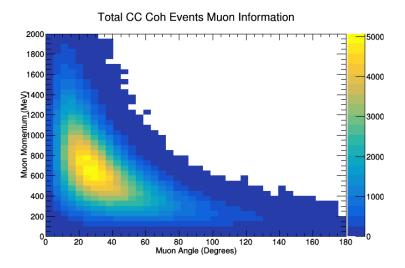


Figure 52: This is a 2D histogram for the momentum and angle of the muon in the total CC Coh Pion events.

A.12 NMCombinedPlots.C

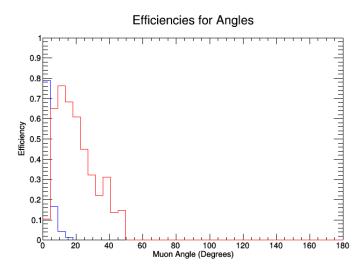


Figure 53

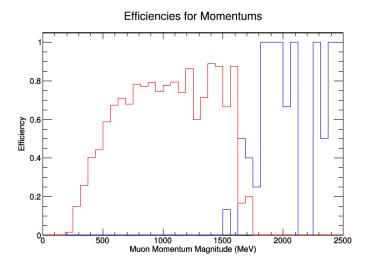


Figure 54

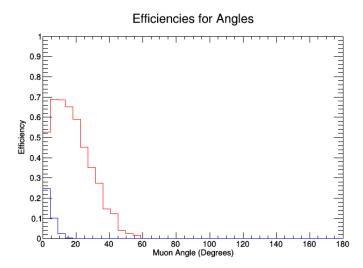


Figure 55

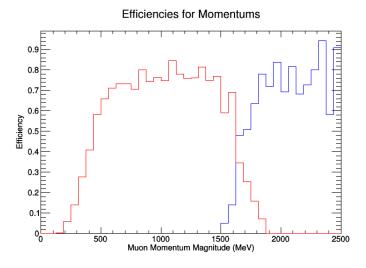


Figure 56

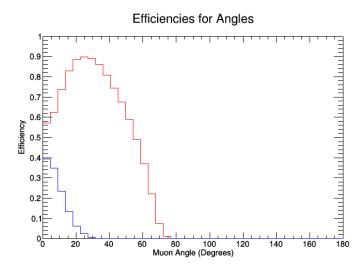


Figure 57

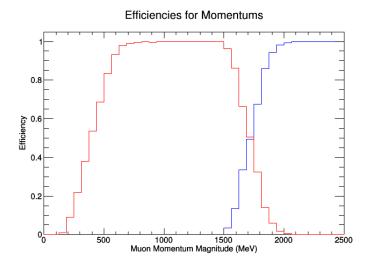


Figure 58

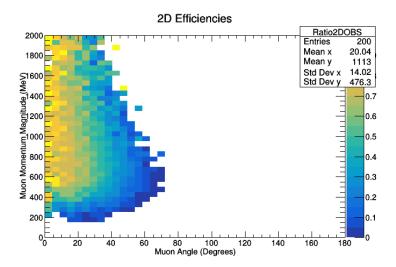


Figure 59

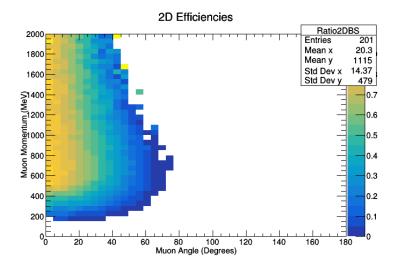


Figure 60

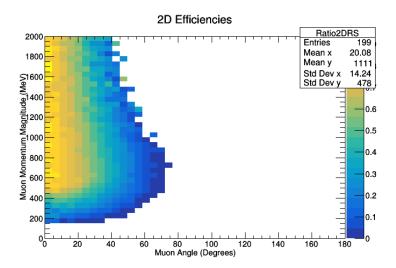


Figure 61

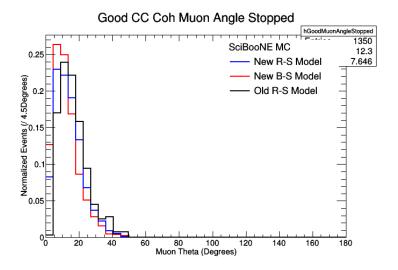


Figure 62

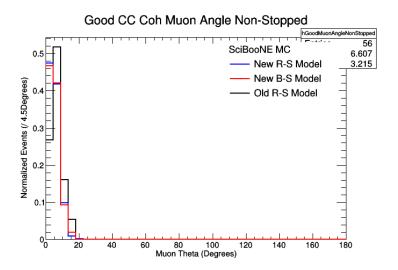


Figure 63

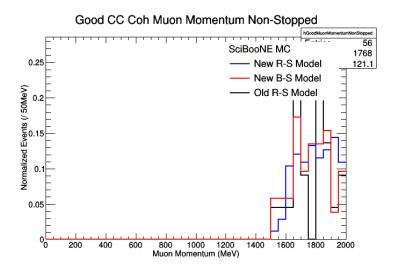


Figure 64

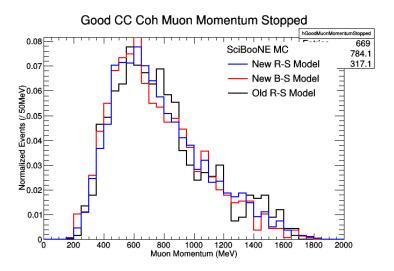


Figure 65

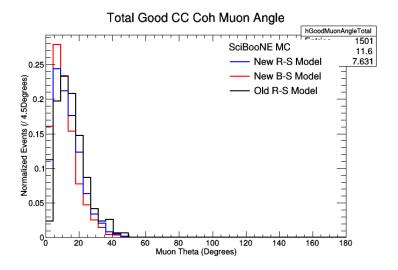


Figure 66

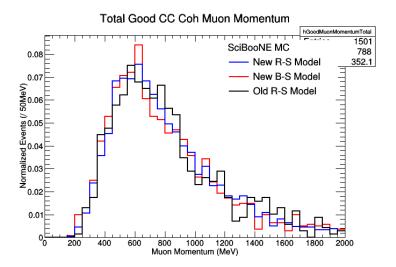


Figure 67

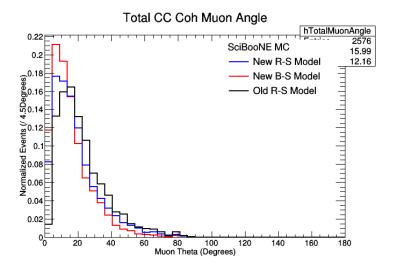


Figure 68

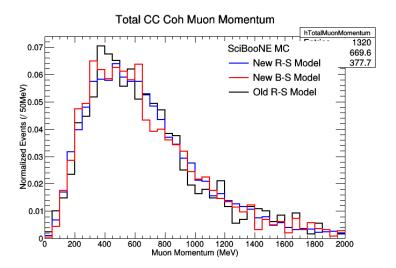


Figure 69

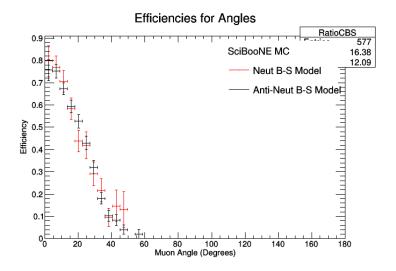


Figure 70

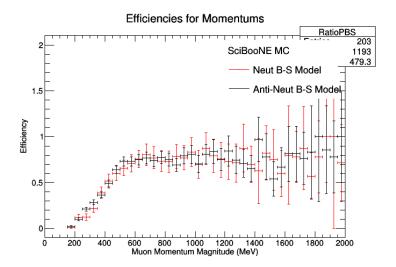


Figure 71

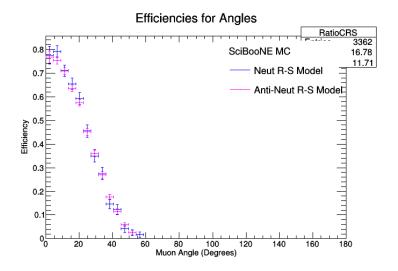


Figure 72

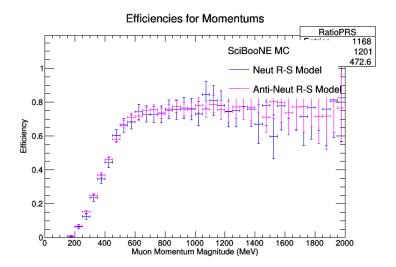


Figure 73

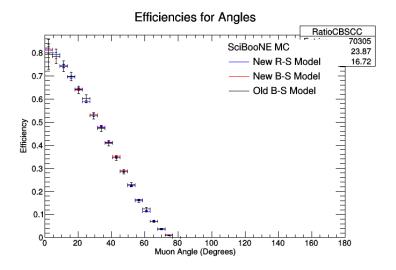


Figure 74

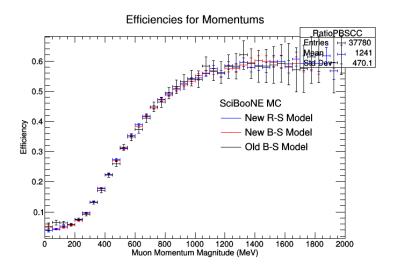


Figure 75

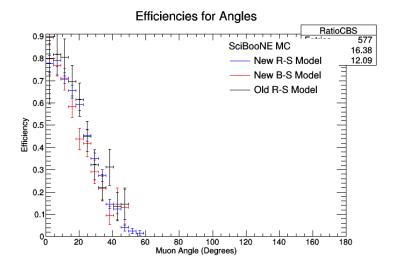


Figure 76

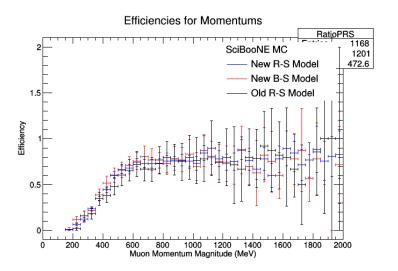


Figure 77

A.13 NMPionPlotting.C

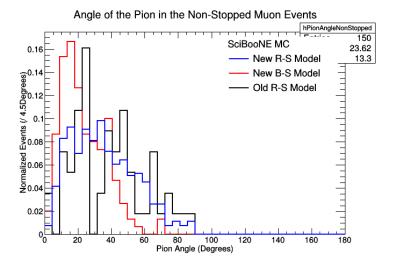


Figure 78

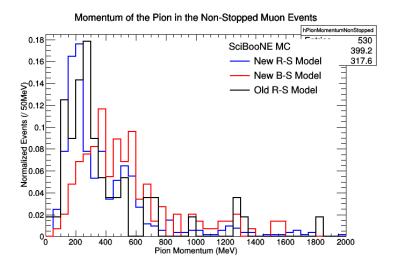


Figure 79

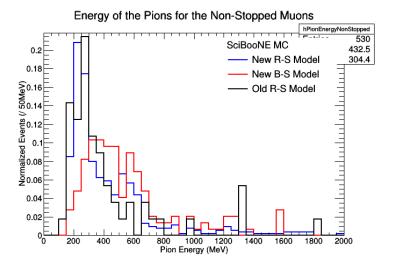


Figure 80

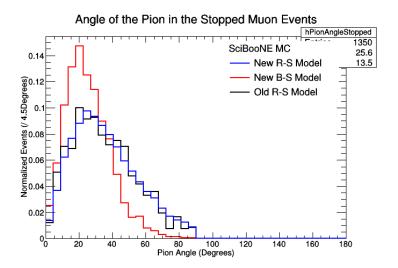


Figure 81

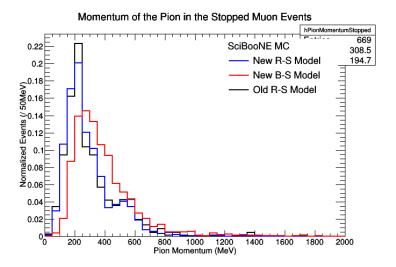


Figure 82

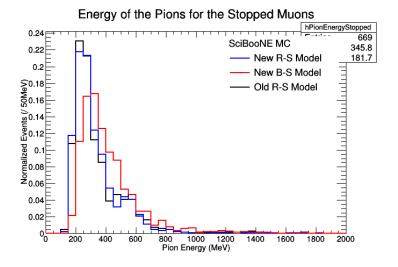


Figure 83

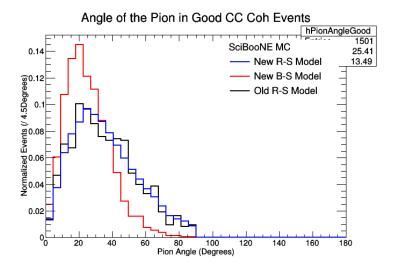


Figure 84

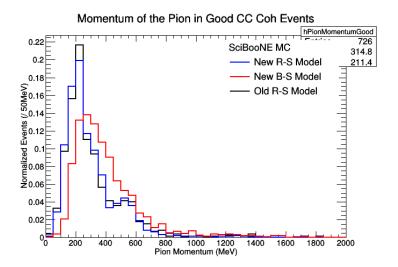


Figure 85

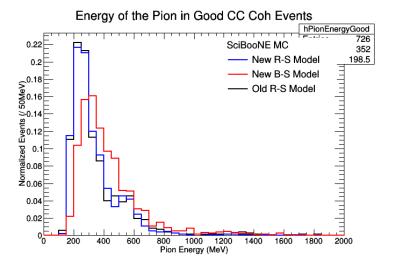


Figure 86

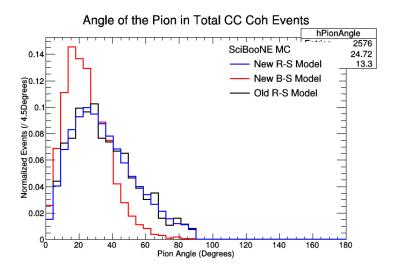


Figure 87

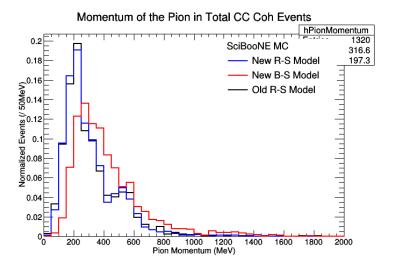


Figure 88

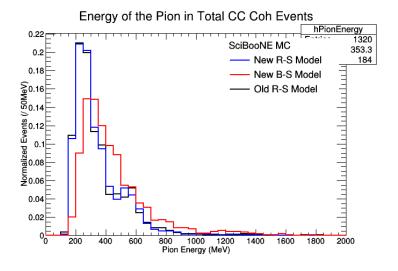


Figure 89

${\bf A.14 \quad NMFour Squared Plotting.C}$

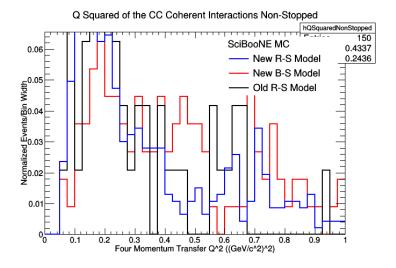


Figure 90

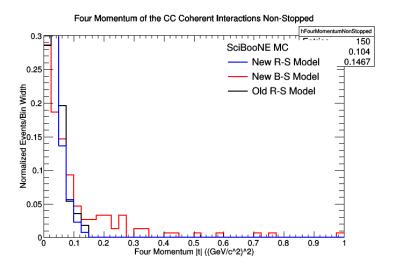


Figure 91

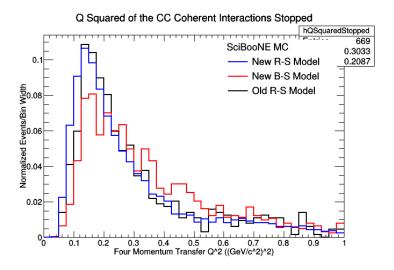


Figure 92

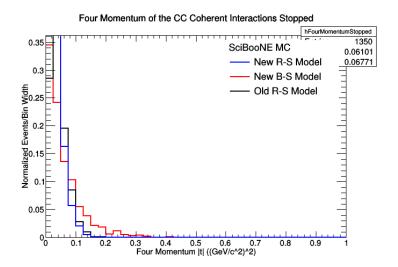


Figure 93

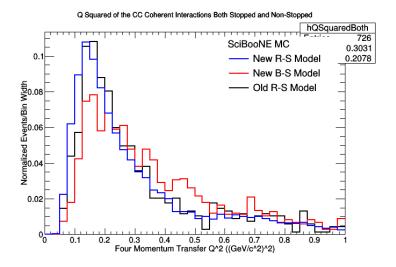


Figure 94

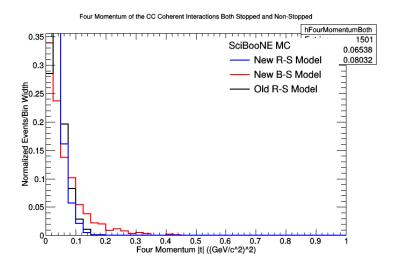


Figure 95

A.15 ANMCombinedPlots.C

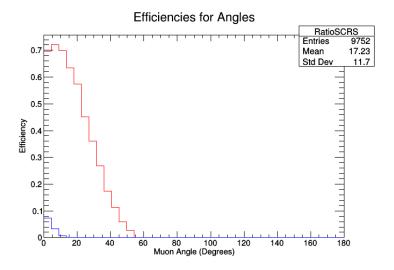


Figure 96

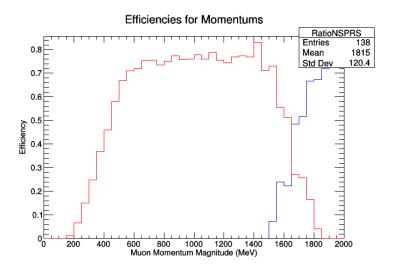


Figure 97

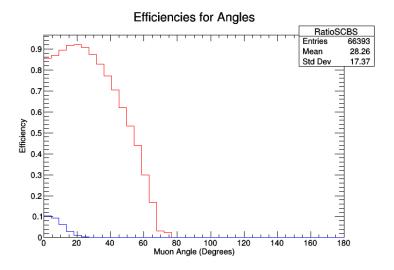


Figure 98

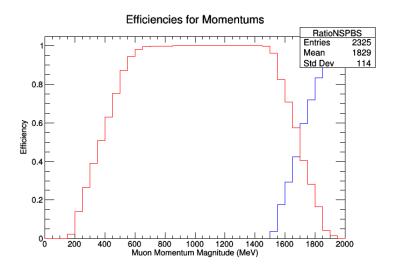


Figure 99

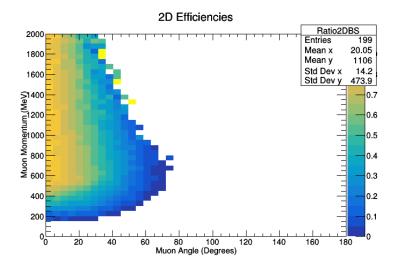


Figure 100

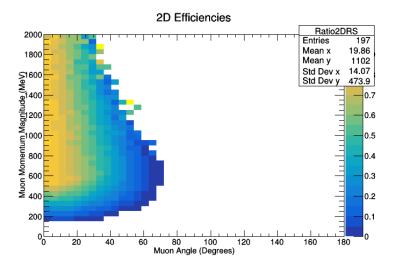


Figure 101

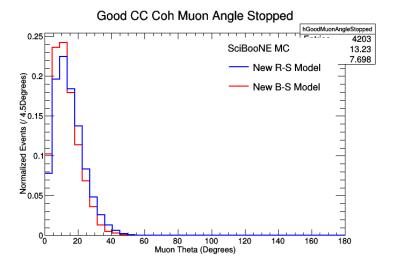


Figure 102

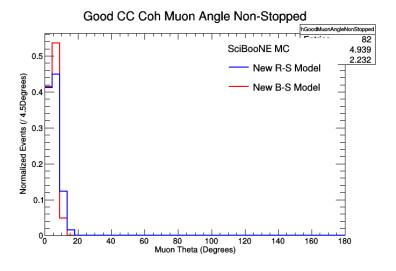


Figure 103

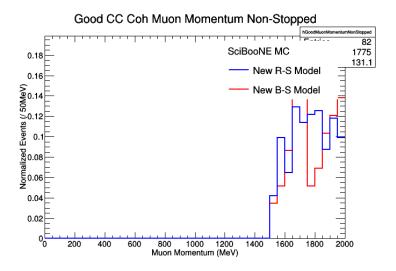


Figure 104

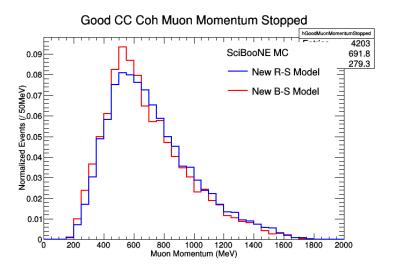


Figure 105

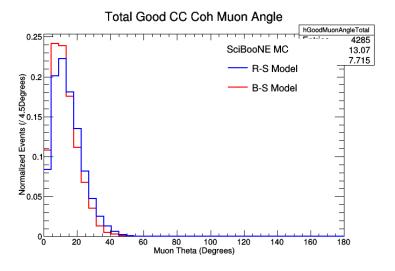


Figure 106

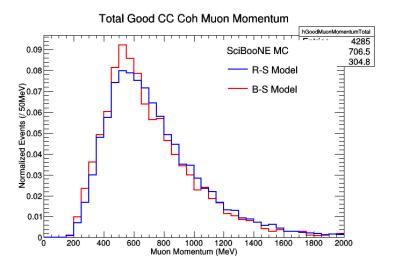


Figure 107

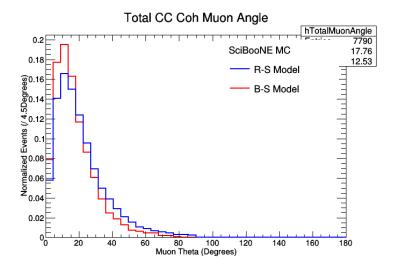


Figure 108

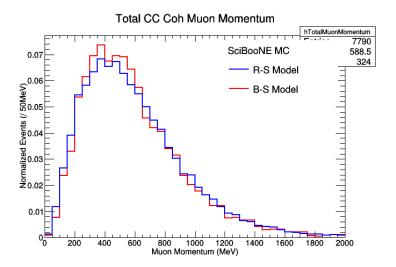


Figure 109

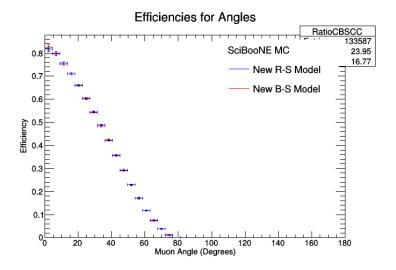


Figure 110

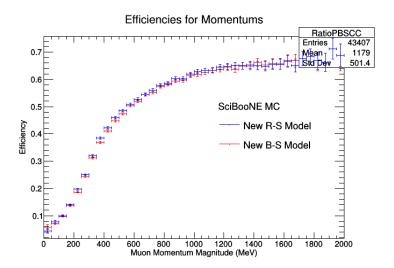


Figure 111

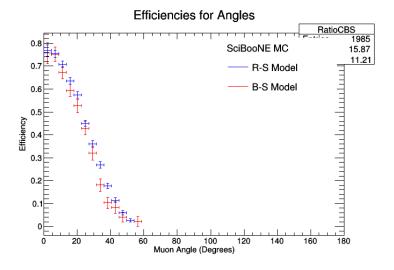


Figure 112

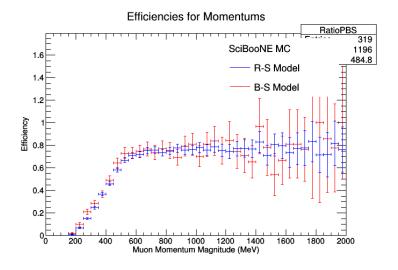


Figure 113

A.16 ANMPionPlotting.C

I need to come back and insert all of my images here.

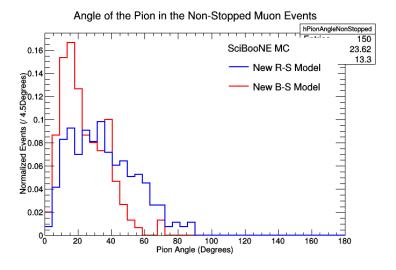


Figure 114

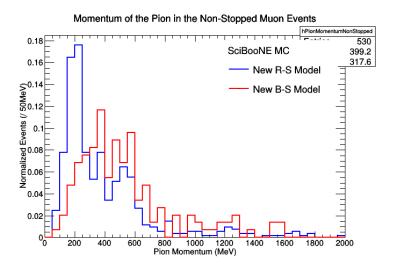


Figure 115

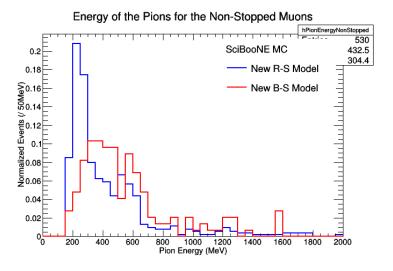


Figure 116

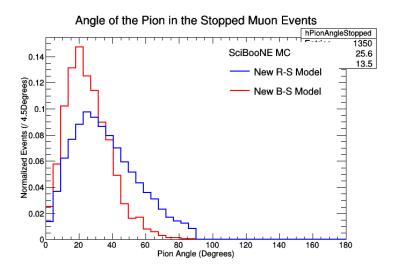


Figure 117

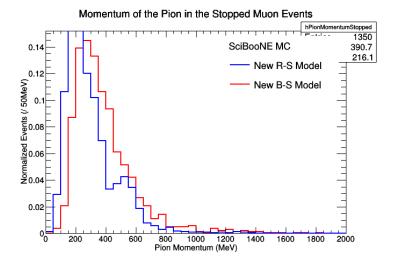


Figure 118

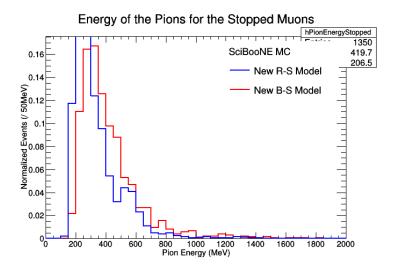


Figure 119

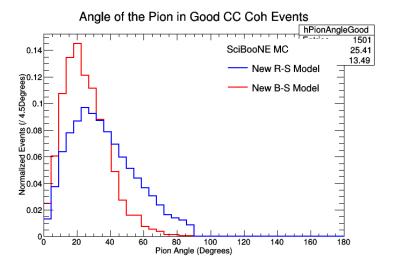


Figure 120

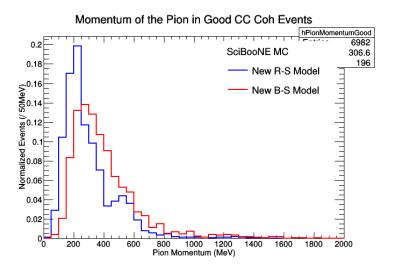


Figure 121

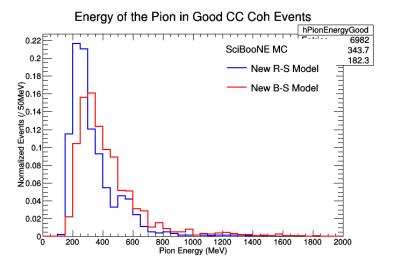


Figure 122

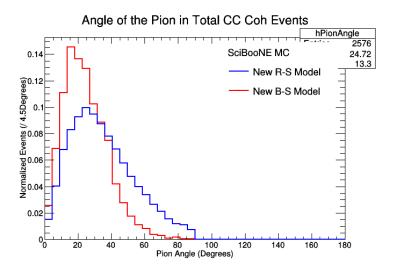


Figure 123

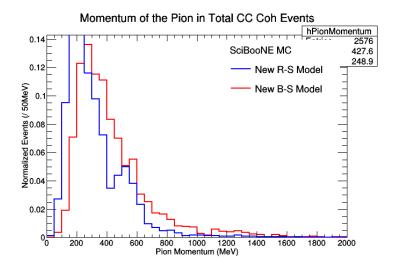


Figure 124

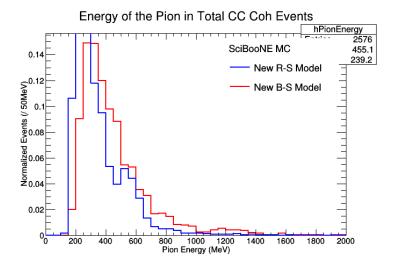


Figure 125

A.17 ANMFourSquaredPlotting.C

I need to come back and insert all of my images here.

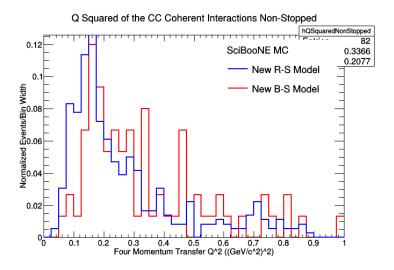


Figure 126

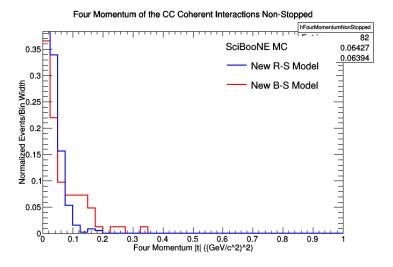


Figure 127

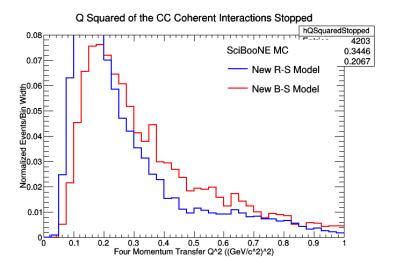


Figure 128

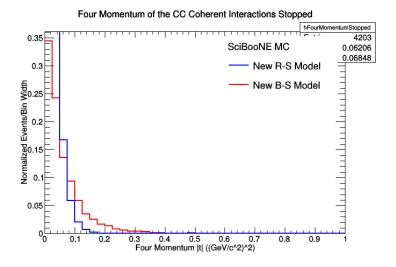


Figure 129

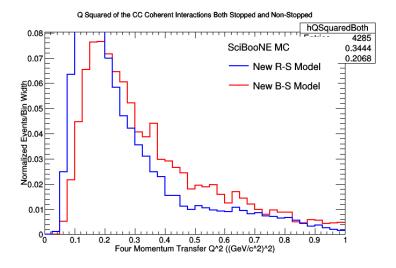


Figure 130

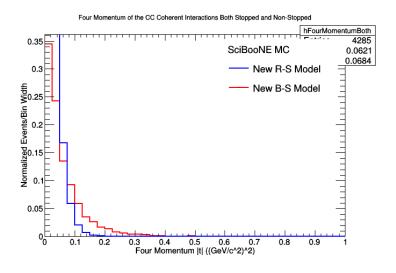


Figure 131

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 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 suuuuuuuper patient...)

D Figures and Tables

D.1 List of Figures

There will eventually be a huge list of figures here.

D.2 List of Tables

There will eventually be the event reduction tables and 2D histogram tables here.

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

300	- R	7.5	312	218	_	12	9	25	. 19	-	-	-	_	_	-	_	_	-	_	_	_	_	_	-	-	_	_	-	_	-	-	_	_	_	_	_		_	_	_	_
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1908-1	_	G 0.78387	0.62385	8 0.83025		-	0.2597	5	7	22								-			0.0			= 1	= 1	=	=					=		-					= 1	- 1	= 0
1830-16	2	81378	0.7302	89889	=	_					В	в	В	в		В	В				0 0			= 1	= 1	=	=		В			_				0.0					= 0
1800-1K	0.848483	0.79375	0.684982	0.63871	-	-	_	_	0.071-286	27											0 0			= 1	= 1	=	=					=							-	-	
1730-180	0.7793	0.774194	890020	0.598291	11582717	0.42857	0.416667	0.34875	0.25		8.25		В			В	В							= 1	= 1	=	=					_									= 0
130.150	0.921369	1.74777	0.747774	1,634561	0.532(61	0.447351	0.242901	0.272727	2	75999L0														= 1	= 1	=	=					_									= 0
1630-1700	0.921569	0.730476	8,739,78	0.648718	75450	53905	0.34058	0.32857	0.238095	0.1875					В									= 1	= 1	=	=		В		В	_									= 0
1600-1650	8.8	0.770642	0.704835	8558191	0.581633	0.63674	0.04634	0.337349	0.127273	0.1875		В		В										-	-	=	_					_									
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0-1250 125	SUZ92 0.80	39474 8-7.	7,6803 0.72	318895 n.68	53-4488 II.61	TH62 0.4	A63785 0.45	-	0	22(238 0.20	182927 0.11	1 0.1	6.5			0	0	-		0	0 0		0 0	= 1	= 1	=	=			0		=			0		-	0		= 1	= 0
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950-1m	0816248	0.79823	0.77828	0.722747	_	_			-	0.28-258	0221135	÷	0.0814815	11 0.0465465	B B			-		0 0	0 0			= 1	= 1	=	=					=			0 0				-	-	
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820-900	0.798611	0.820840	0.784038	0.71437	-	-	_	_	-	0299735	0.239492	_	Ŧ	-	2 0.0641026	9 0075					0 0			= 1	= 1	=	=					=							-	-	= =
800-820	0.796748	0.816514	0.77907	=	=	=		0.465472		0.312566	0.252889	Ĕ	0.12807		0.0347222	0.0131579	В				0 0			-	-	=	=					_					-		-	-	= 0
220-800	8.2	0.80777	0.757746	0.713192	0.676.0	0.617100	0.5-6332	0.4852-22	0.416728	0.324022	0.2583-5	0.153939	0.133188	0.0654045	0.0458	0.0121212								= 1	= 1	=	=					_							-	-	= =
200-220	B-773458	0.828302	95222	0.70711	0.67305	0.61255	0537204	0.512734	0.420808	033975	0273593	0.188506	0.135764	0.08-5225	88982200	0.0234114	0.00546541							= 1	= 1	=	=		В			_									= 0
659-700	18-5-455	0.80404	0.785013	0.755131	2011690	0.628604	0538199	- 5	0.410602	03-2802	0.269592	0.214009	2282210	0.083686	0.0-44898	0.020155										_	_					_									
600-650	8.2975	8.44185	0.784336	1,257	0.581216	2968396	0.57336	9583	176	9.331915	0.260561	2212810	0.132230	0.0781828	0.033736	0.0173-0										=	_					_									
550-600	0.828829	719827-0	0.787402	172788	7826	88861910	53869	1,48985	399772	3142	0.248649	0.190045	0.131-69	7991880	0.0483498	0.0121873		_	-			-				_	_	_	_	_	_		-	_				_			
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320 320-40	_	_	334426 0.475	-		528 0.35	10	553 0.26	1678-5 1228	_	9081688 0.129	_	10248494 0.04	0.01,						0 0	-		0 0	= 1	= 1	=	=			0		=			0 0	- 0	-			= 1	= =
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139.200	0.49375	0.123457	0.0280374	0.0696203	0.7896825	0.78-0.615	0.0128535	755879070										-						=	=	=	=		В			_		-							= 0
100-130			0	_	-	-	-	-			0		0		0	0	0	-	-		0 0			= 1	= 1	=	=				0	_	-	-			-				= 0
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S 0-30 MeV			0	_	-	-	-	-			0		0		0	0	0	-	-		0 0			= 1	- 15 A	= 25	= 25	0 25	0 26	0 %	0					0 0		0 25	25	25	26.1
New NATRS	0-45 Deg	15-9 Deg	1435 Day	35-18 Day	8 22 5 Day	125.27 Day	77.31.5 Dov	15.36 Dev	36-40.5 Day	405-45 Day	5-85 Drg	19554 Drg	4.38.5 Day	185.63 Drg	13 675 Day	775-72 Day	72.75.5 Day	765.81 Dev	81.85 5 Day	2 00 Day	The state of	945.09 Dec	0.100	99-103 S LON	165 3-168 Day	(B-1125 D)	12 3 417 Deg	17-1215 Deg	21.5-126 D.	126-1385 Dag	130 5 135 Day	135-1395 Dev	130 5-144 Day	144.148.5 Dev	1.00 C 170 Day	To the Day	or particular.	157.5-162 Drg	162-1665 Day	1665-171 Day	10 00 10 10 10 10 10 10 10 10 10 10 10 1
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Table 9: Table for 2D Histogram for New NM-Berger-Sehgal

	_																												_										
1558-300	2020	0.794521	083030	112220	D.557477	253.	30835	0.137931	181818																														
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1620 1 700 1 700 1 750	0.836733	0,734884	0.700381	0.6-8138	0.52568	0.435081	0.411755	0.34875	0.28574	0.165657	_	_	_	_	_	_		_	_	_	_	_	_	_	_	_	_	_	_		_	_	_	_	_	_	_		_
1620-1700	978/5/810	72067	0.747423	891/2910	1000000	757.04.0	0,333333	0.245753	0.214286	0.0788235	_																												
	19962	528648	1664231	16-8620	1538375	1522334	0.3622-E	0.3086.22	8181813	G-428571	173																												
_	37/2/	1741784 0	1717833	166548	1587136	Ť	_	_	_	9	0.33333	_	_	_	_	_	_	_	_	-	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	-	
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1400514	0.85	0.76-5706	0,7533	0.05925	0.309419	0.409093	0.45179	0,381397	0.348624	0.22222	0.13636	_	0.0	_	_	_		_				_	_	_	_	_	_	_	_		_	_	_	_					-
1350-140	0.808734	0,79294	0.728296	0.08171	0.612863	0.309404	0.453169	0.33354	0.328	0.231884	0.166667	_	_	_	_	_		_	_		_	_	_	_	_		_	_	_		_	_	_	_	_		_		_
1310 1320 1320 1400 1400 1420 1420 1500	0.783133	0.813665	0,708861	0.08321	0.307805	0.529101	0.431408	0.389305	0.356279	0.197368	0.0833333																												
220-1300	22187	7500	22 (E)	681775	52026	524138	426.556	.405963	38785.	189-54	0.0388235	0.0909091	11111																										
1200-1250 1220-1300	0 2/8°	(78420.4 D	0 229157	700.07	0 91319	535057	-	406551	Ť	Ť	-	0.0752231 0	_	_	_	_				_			_	_	_	_	_	_	_		_	_				_			
1139-1300 120	831 896	_	5308 0.7	-	7	20	444332 0.4	754 0.4	-	_	_	_	0 1606	-	-	-	-	-	-		-	-	-	-	-	-	-	-	_		-	-	-	-	-		-		-
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1020-1100	87)	0.82-20-55	0.7772.85	0.7086	0.633392	0.571780	0.490654	0.411755	0.357923	0.26-576	0.213839	_	0.0851054		0.166667	_		_	-		-	-	_	_	_		_	_	_		_	_	-	_	-		-		-
1000 102	3-88/2 H	0.80-225	0.756738	0,703534	0.653195	0.571275	0.515236	0.42383	0.342320	0.29-2294	0.236700	0.132184	0.0617284	0.033333	0.071428	_		_	_	_	_	_	_	_	_	_	_	_	_		_	_	_	_	_	_	_		_
920 1000 1000 1020	0.814815	7,0007	0,720384	0.683544	0.634515	0.500778	0.518553	0.451835	0.368859	0.313023	0.205285	0.151292	0.108844		0.0-0.0567																								
000-020	1820187	1822710	5000	1702804	165554	157899	1517520	3461108	13699-12	1312284	0.219613	0.142512	2211	0438716	0.0227273	_	_	_	_	_	_	_	_	_	_	_	_	_	_		_	_	_	_	_	_	_	_	
П	833333	÷	773-806	Sugar.	661634	÷	6	Ť	400812	_	_	_	Ξ	_	50	0.03125	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	
	1858333	180-211 0.	-	C711937 0.	-	Ť		_	_	12	Ť	Ť	_	0.0780781 0.	0.0162162 0.	0		_	_		_	_	_	_	_		_	_	_	0	_	_	_	_	_		_		-
П	833333 (18)	800211 0.8	Ť	7.0 800-227	÷	10	Ť	÷	÷	÷	÷	÷	_	_	0.026135 0.0	-	0123457 0							-	_		_	_	-	0	_	-				-		0	0
15	3 0.83	_	0	_	0		_		_	_	_	_		_	0	-	ď							_	_	-	_	_	_		_	_							=
700.750	0.8433	0.81.4286	0.78270	0.752791	_	0.637363	0.55189	0.49320	0,40383	0.330302	0.258858	0.204505	0.125182	0.006002	0.036353	÷	9 0.00G-2035										_	_	_										=
002,029	0.864865	0.801402	0.794369	0.749489	0.677215	0.615-445	0.054788	0.402462	0.425845	0.345987	0.359272	0.19-403	0.135503	0.0003091	0.039056	0.0166667	0.00280805												_										_
000.650		0.805305	0.801724	0,730102	1207830	0.629688	1264264	0.488325	0.419254	03-55679	0.261-486	1,213213	0.120520	0.0780856	0.0367232	0.0195072																							
230 600	П	6012187	78354	736387	.02331	700700	354516	472969	387314	2816187	1344831	_	_		8223810	0.011-213													_							_			
200200	Т	1.811448	28189	25.45	2020	378365	.406522	36444	386159	1,30273	_	_	-	0.0634228	811987	730370	_	_	_	_	_	_	_	_	_	_	_	_	Ĭ	_	_	_	_	_	_	_	_	_	
	77	_	_	_	_	_	_	_	97	52 0.3	Ī	Ī	Ť	Ť	Ť	3000700466 0.0					-		_	_	_	-	_	_	_		_	_	-	_			-		0
200.300	117383	0.773273	0,701.245	0.63459.4	11582547	0.521715	0.405-0	0.381784	0.3274	0.272.4	0.2122	÷	÷	_	=	00007		-	-		-	-	-	-	-		-	-	_		-	-	-	-	-		-		-
400-550	0.615385	0.581731	0.5725	0.565116	0.517013	0.447548	0.355351	0.333753	0.275212	0.22483					0.00745573	_						_	_	_	_		_	_	_		_	_	_	_					_
330-400	9350650	0.478261	0,4633-43	0,448833	0.41500	0.381265	0312166	0.283494	0.233583	0.192308	0.141328	0.0928814	0.05522683	76382100	_	_		_	_		_	_	_	_	_		_	_			_	_	_	_	_		_		_
300.350	22222	200004	82563	230233	118-452	221873	25338	12221	170164	129657	0.0040285	0.0531873	0.0199623	282°C'000'1																									
	0	_	620	736	145 0.	461	829 0.	202	_	Ť	_	-	0.000-55334 0.		_	_	0						_	_	_	-	_	_	_	0	_	_		-					-
256-310	11325	1 0235845	1 0.223	0.20	51 0.228147	36 0.197	43 0.172	17 0.1.222			_	100	8	-	-											-	-	-	_				-						-
200.250	0.075780	125-57.10	013676	0.131225	0.097345	_		_	0.032338	0.01391.47	701231467																		_										=
156.200		0.0625	0.09375	0.0382166	0.039014	0.0354035	0.00485618	0.00754717																									_						_
100-150	0				_	_		_												_						_			_										
B 20 MeV/c 20 100								-																		-			_										=
OCCUPATION OF CO.																																							
SS	Dog	4.5.0 Deg	9-13.5 Deg	18 Day	18-22.5 Day	225.27 Day	27-31.5 Day	31.5-36 Day	To Day	to Dog	To Day	24 Dog .	O Dog	53 Deg	To Day	72 Dog 5	2 Day	No 18	O Day	70 Deg	Co Dog	30 Deg	35 Dag	103.5-108 Dag	108-112.5 Dag	112.5-117 Dag	17-121.5 Day	121.5-126 Dag	125 130.5 Day	130,5 135 Day	135-130,5 Deg	130,5-144 Dag	48.5 Dag	148.5-153 Dag	123-157.5 Day	157.5 162 Day	162-166.5 Deg	471 Day	To Day
New.	0-45 Day	4.50	9430	1354	18-22	2254	27.3	31.54	36-40	40.5	45.0	45.5	89	5854	63-67	675	2	7654	81.85	85.54	98-94	9452	99-10	168.5	108.1	112.5	17.1	121.5	136.1	130.5	135.1	130.5	7	1.8.5	182	157.5	162.1	166.5	5

Table 10: Table for 2D Histogram for Old NM-Rein-Sehgal

1950-2000	1.718333	0.265217	0.33333	F .	2								= 0				= 0													
1988-1958	0.533333	1111	7.0	9.2	n-telebrasis																			_						
859-1900	0.882353	88	142	625																				_						
-	0857143		_	_	79999	_	_				_			-	_			-	_					_		_	_			_
= .	820087 02		0.647059 0.0	_		0						-	= 0			-	= 0	0.00		-	= =			_				-	-	0
===			_	-	-							-	= 0	-			= 0	-	0		= =	-		_						
-		5 888		9								-	= =			-	= =		в		= =	-		_						
7 1	0.82528		_		0.285714								= 0				= 0								0			-		
1600-16		0.612245		_		12							= 0				= 0				= =									
156.16	189461	0.653846	2	_	0.505.00	_							= 0				= 0							_						
1500-1550	0.781905	0.386957	299999-0	0.380952	0.33333								= 0				= 0							_						
1450-1500	0.755556	992230	8377778	0347826	799950		_												В											
1400-1450	0.875	998	998999	0.44444	11347	7	0.333333																	_						
833333	825 706897	694444	4137333	_	223893 2 23893	22																		_						
13ff 1358 1 0.6 8	862069	670588 0	1578947		==	15	E							-	_			-			20			_		_	_			
_		1,716882 0.6 1,51875 0.6			1346837			0 0	a con				= 0	0.00			= 0	0.00			= =			_	0			-		
7	0.791045 0.61	_			28574 13				2 -				= 0	-			= 0	-			= =	-		-				-		
150 1200 75 0 75			_	_		_	800						= 0				= 0				= =	-						-		
	89 0.8 16 0.683544	57 0.88679	-	_	==	92 0.208333	11	E 0					= 0			-	= 0			-	= =	-						-		
= -		0.705357	-	=		_	=	0.1428				-	= 0				= 0							_						
_	0807002		-	12		_	_	3.					= 0				= 0													
1000-165	0.747253	0.70068	0529801	-			878	0.071428	1 -				= 0		_		= 0		В		= =			_						
60 00	0.810811	0.735099			0.360825		_	0.129032	2777				= 0				= 0							_						
6 -		0.736115		0.513228	1,417417	0.29661	_	0.236364					= 0				= 0				= =									
850-900 0.777778	0 0	0.753425		-	0.394537			0.122807	=				= 0				= 0							_						
1606060	0.574681	0.711656	191191	0.592437	269878	0.337423	0.273973		0.15625		0.111111	-	= =		_		= 0		В					_						
20-800	0.77361	0.719178	0.659574	0.516981	1376318	031672	0270115	0.15942	0.054217	0.0689655			= 0				= 0				= =			_						
0.777.0	0.732539	0.70229	0.632930	0.550781	0.42222	0.266534	206277	0.220238	0.0487805		В													В						
37	7347	6,68036	1668234	1244061	45474	340557	285136	22058	103742	10869365	1,022222				_	_			_	_			_	_	_	_	_			
1857143	0.65	722222	628291	522727	41195	291545	263699	1212996	10.00 pt	75	6860100																			
1 0 0		0.773109	_		==	=	_	0.169381	M7692	1381952	_			-	_			-	_					_		_	_			
299		25928	_	_		_	_	7588		125523 0.4	6	-	= 0	0.00	0	0	= 0	0.00			= =				0		-	-	-	
900 200	30 998 20 25	630952 0.61	989 898	1981	200 900	1875	1322 0.7	144	655556 0.0	6241379 0.0	0 SS88800	-	= 0			-	= 0			-	= =			0				-		-
1.8 8.5	667 0.601	622	797 0.463	863	100	128	462 0.151	160819 0.133			0.002	-	= =			-	= 0		-	-		-					-	-	-	
1280	13 0.625	160	54 8518	96 030	1 22		<u></u>	0 0	-	-	0		= 0		В		= 0		0		= =	-		0				-	-	
-	14 0.470588	4 0.560	19 8 19 401	0.2962	2 1235			364 0.0816327	0.0				= 0				= 0													
988 928	0.28571	3 0365854		976	-		_	96 00636364	- 177		0	-	= -		_		= 0		0					0		0			-	
230 300	0.25	5 0 18 4211		_	0.07	0.0869565	0.0434783	9698010 0					= 0				= 0											_		
0.33333	0.0769231	0.15		_	0.097361 0.014								= 0				= 0		В											
158-200 8		0.0774286	299917-00	0.0217391	0.008.0522						0		= 0				= 0							0						
100-150										_									_				_			_	_			
8.8					==						8		= 0			-	= 0			-					0			_		
D-30 MeV					==							-	= 0				= 0		_	_				_				_		
5 Deg	15.9 Dog 13.5 Deg	13.5.18 Day	24 De	31.5 Deg	2 De 18 De 1	Set Deg	49.5 Deg	Basil Day	See Dec	63-675 Day	67.5-72 Day	765 Day	Charles Day	55.5 M Day	90-945 Deg	945-99 Deg	Series Deg	168 112 5 Deg	112 5-117 Deg	7121.5 Deg	121 3-126 Day 126-130 5 Dec	5-135 Dev	135 139 5 Deg	5.144 Dog	144-148 5 Drg	5-153 Deg	133-157.5 Dog	5.462 Day	166 5 171 Day	7-175 Deg
8 6	9 13	25.5	22.2	12	3 %	9	ğ	9	2 06	9.29	67.5	i i		175	98-8	945	66	9 9	112,	211	1 8	Ē	13	ē	7	2	ġ	157	1 12	Ę

Table 11: Table for 2D Histogram for New ANM-Rein-Sehgal

_																																	_			
1930-20EB	0.715882	0.68877B	9635714	218190	1321439	22																														
1900-1920	88468	89261210	0.648275	0.635394	0.647169	125	_	_								_	_	_	_	_						_	_		_		_		_	_	_	
1850 1900	0.783784	0.698952	0.615385	0.52553	1720071	1.55	_	-																		_			_		_		_			
1800-1830	0808080	0711409	8-85090	0.569231	0.491818	0307692	9.0																				_		_		_		_			
739-1890	825356	718379	1648734	57377	472222	13	_	_	_	_	_	_	_	_		_	_	_					_		_	_	_		_	_	_	_	_	_	_	
400 1750	20038	701461	818189	APR52 (78.685	128821	F.	_	_	_	_	_	_	_		_	_	_	_						_	_	_	_	_	_	_	_	_			
120 170	8 233.46	71337	628592	Ť	_	÷	53333	17	_	_	_	_	_	_							_	_	_	_	_	_	_		_	_	_	_	_	-		
H-1650 P	80315 0	-	_	-	_	Ï	33333	_			_	-	-	-							_	_	8	_		_	_		_		_		_	-		
59-1600 1	802721 B	718917	_	_	=	=	Ξ.	169667 B	0	0													0		0	_		0	_	0	_	0	_			-
00-1530	813642	_	_	Ť	_	Ï	1282051 0	=	33333	0	-	0	0	0	-								0		0	_		0	_	0	_	0	_	-		
31.1310	820896 08	_	631818 0.6	_	_	÷	290323 02	2	8	0													0		0	_		В	_	0	_	0	_	0 1	-	0.0
0-1-50 1-4	834906 0.8		=	_	_	_	2000 00	32308 0.2							-	-	-	-										0	_		_		_	-	0.0	
0-1400 1-40	785124 0.8	-	_	_	_	Ť	=	1263625 0.1	27.27							-	-	-	-										_		_		_	-	0.0	
1330 135.	8G85 878 8C90 8E80	-	_	-	_	Ĕ	Ť	_	nnn 927	0	0	0	0	8	0						8	8	0	8	0	8	0	В	8	0	8	0	8	0 1	0 0	
130 130	829352 0.863 810724 0.700		_	_	_	÷	_	_	22222 0.111	70	-					-	-	-	-		В	В		В				В							0.0	
1230 1258			-	_	_	_	_	_	_	294 0		22			-	-	-	-	-														_	-	= 0	
1200	212 0.82(0.4)	-	Ĕ	_	_	6	-	-	=	392 0.233294	2					=	=	=	=		0	0		0											= 0	
158 1158-1	28 0.821212		_	_		_	_	_	_	0.307692	0 22					=	=	-	-				0		0					0		0	_	-	- 0	
100 1100	0.820728	_	Ť	Ť	_	_	_	_	35 0.211338	Ť	18 0.0833333																	В	_		_		_	-	0.0	
030 1050 1	94 0835	_	15 0.69735	_	N 15533	_	-	_	Ĕ	Ē	8181818	98				=	=	=	=							_			_		_		_	-	= 0	
1009-1	32 0.811494		78 0.718415	ė	_	ė	Ξ.	Ξ.	_	=	2 B.125	=																В	_		_		_	-	0.0	
958-10	76 0814732	_	Ĕ	-	_	_	_	_	=	_	_	_	999	0	-	-	-	-								_			_		_		_	-	0.0	
900.93	91 0849776 0816404		Ť	Ť	=	-	_	Ξ	Ť	Ť	÷	63 0.05-479-6	5-6 0.0535536	0.125		=	=	=	=							_			_		_		_	-	= 0	
820-90	1 0.846791	_	Ĕ	-	-	Ξ	Ť	-	Ĕ	_	_	6 0.105263	163 0.04545-E			-	-	-	-															= 1	= 0	
8 E8 E8	7 0.834821	_	1 0.72291	_	_	ď	=	~	_	_	Ť	4 0.121076	47 0.0462963	_														В	_		_		_	-	0.0	
730-800	1 0.82608	-		_	_	÷	_	_	_		-	0.13664	3 0.07729-57	_		-	=	=	-															-	= 0	
788-758	0.846154	0.780604	_	_	0.616002	0.538364	0.0538	_	_	_	_	0.133106	2 0.4868263	_	95 0 4289835	-	=	=	=															-	= 0	
659-700	792080	0.77894	0.739165	0.686785	0.631832	0.530737	0.499168	0.431897	033394	0.270336	0.191678	0.1390-6	0.0850662	0.0482759	_	_	-	-	-							_	_		_		_		_	-	= 0	
999	0820390	0.77573	0.746173	7615590	1928191	0.573181	0.502938	0.418154	_	_	=	0.1-6336	2062280	0.0439122	_		-	-	-							_			_		_		_	= 1		
220.600	0.808989	0.784609	0.754711	0.700024	0.641457	0.566528	0.48047	0.382382	0.32(273	0.250172	0.178536	0.124613	1821800	0.0423729	0.0103093	-	-	-	-							_		В	_		_		_		- 0	
500 550	0.812332	0.778963	0.7420	0.669713	0.587/83	0.527303	0.29639	0.351301	0.30581	0.222903	0.172282	0.122696	0.072-0.61	0.037-084	0.00515464																					
450 500	0.741325	781089.0	0.642998	0.578125	0.511835	0.455377	8.294628	0.333169	0.268313	0.212046	0.149639	6899110	0.4526316	0.0226148																						
00-450	1583034	1562628	1529018	500719	346546	13833-0	1342622	129-621	1226718	117744	1127891	1288360	10405544	100-447928		_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_		
939-400	510304	200	627	802	28182	318072	292653	2223E2	200825	13113	103003	4637772	020202	79180103												_			_		_		_			
B-350	208603 0	_	372408 0.	_	_	24	_	÷	131676	_	_	0170428 0.	_	-												_			_		_		_	-	0.0	0.0
300	225352 B.	_	264642 0.		_	_	В	_	_	_	_	0 2100354017	-													_			_		_		_	-	0.0	0.0
530	123913 0.22	-	_	_	=	=	=	=	2010 1200-910	10.0	19:0	0.00	0	0		-	-	-	-				0		0					0		0		-	= 0	
200.52	. 0		_	_	=	Ť	100 LEGERAL 0 1070	0.68	9.016							-	-									_		В	_		_		_	-	= 0	
150 150 20	0.037037	0.0881226	0.0302959	0.0457273	0.0256881	0.0135747	0.0026	0	0	0	0	0	0	0		=	=	=	=		8	8	0	8	0	0			0	0	0	0	0	0 1	-	
59-100 100-150	-	-				_	_	_								=	=	=	=	-																
0.50 MeV/c 50	00				-						_	-	-	-							8	8		8			-	0						201	2 0	- 0
			Bac Bac	n sac	n sa	B Sac	B Sac	B Sac	Bac Bac	Bac Bac	B Sac	B B B B B B B B B B B B B B B B B B B	B B B B B B B B B B B B B B B B B B B	B B B B B B B B B B B B B B B B B B B	6					E S	n sac	Dec	8 Deg B	1 Deg B	7 Deg B	1 Deg B	i Deg i	2 Dog 0	1 Deg B	Dog B	1 Deg B	Dog B	3 Deg B	Dog C	2000	Dog .
New ANM R-S	8.45 Day 450 Day	9-135 Drg	135-18 E.	18-22.5 Deg	225.27 L	27-31 5 De	315 36 L	36-40.5 L	485-45 E.	45-85 E	495-54 Deg	5438.5 D	585 63 D	63.675 D	675-72 D	72 H 5 D	765.81 Dec	81.85.5 D	855.90 Dec	98 94 5 Deg	945.99 E.	99-103.5 Day	165 5 168 Day	108-1125 Deg	112.5-117 Dog	117-121.5 Deg	121.5-126 Dry	126-1385	1315-135 Deg	135,1395	1285144 Dry	144-148-5 Dag	148.5-133 Day	153-1575 Deg	107.07.00	105 5 17 Day

Table 12: Table for 2D Histogram for New ANM-Berger-Sehgal

0.000	180924	0.663507	0613924	675737	0.482730				_	_	_	_	_		_												_							_		
1900,1950	82329	3,653/0	88099	352632	0.405405	.7	_	_	_	_	_	_	_	_	_	_	_	-	-	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	
0.000	-	60,007	62857	_	297297	-			_	_	_	_	_	_	_	_											_	_						_		
0.80.081	1	038802	182737	1,525641 0	136364				_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_		_		_	-	
202180	+	777.488	_	_	-	_			_					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0		_	-	-
120	824074 0			_	0.443299 0.0	1 29	0		_					Φ																	0		0		0	= =
200	82226			÷	445800			-	_					0														0			-				-	= =
291	871795 0.8	0.0		_	363889 0.4		2			0	0	0	0	В	0	0	0	0	0	0	0	0	0	0	0	0	0	В	0	0		0			-	==
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21170111	998908	0.730656	0.895486	0.638889	0.543849	19890	0.323529	97	0.196429	_				В					0																	==
0.00	18.0.432	0.7864	801690	9.624197	0.583187 0.5	0.394628	0.347664	0.283262	0.195632	0.130435	0.0769231																									==
10001050	0.818653	0.26873	1.07.0	0.636641	0.269439	8928870	_	_	0.229299	0.145455																										
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220.800	0.866324	100100	0.7337	0.673-64	0.545275		1229620	0.320774	0.259352	0.210306	9626110	Φ.	0.0933333		0.0833333																				-	
20,250	78728.0	0.723730	99-92-0	0.686069	0.604635	0.55983	0.407023	0.337821	0.267346	0.176355	0.12-426	0.0946372	0.057847	0.0136986																						==
650, 310	20814-8 0	0.285367	0.748866	0.689579	0.53535	798967-0	0.422945	0.3-8088	161-127-191	0.26357	0.1-0563	7326180.0	0.0387354	0.01652486	786667																					
029,009	0.834184	0.77411.4	0.745335	12198910	0.567878	0.500339	7478747	0.337145	0.232955	0.189664	0.1-6609	0.088785	0.0446927	8121648																						==
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Arw A NAC	0-45 Deg	4.2.9 Leg	135-18 Dec	18-22 5 Deg	225.27 Drg	315.36 Dec	36-40.5 Dry	485-45 Day	45-49.5 Drg.	495.54 Drg.	5438.5 Dry	585.63 Dry	63-67-5 Dry,	675-72 Dry	72 H 5 Deg	765-81 Deg.	81-85.5 Dry	855.90 Deg.	90-94.5 Deg	945.99 Drg	99-103 5 Deg	103 5 108 Deg	108-1125 Deg	112 5 117 D	117-1215 D	121 5 126 Deg	126-1305 Dag	1315-135 D	135-1395 D	135.14tD	144-1485 Day	148 5-153 Day	153-1575 Deg	157.5-162 E	162-1665 E	12 12 12 Dev
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