Acceptance Study for SciBooNE Charged-Current Coherent Pion Production Technical Note Rough Draft

Jonathan Asaadi*1 and Zachary Williams $^{\dagger 1}$

¹Department of Physics, The University of Texas at Arlington

May 1, 2017

Abstract

We showed that the SciBooNE guys tried to mess physics up by cutting out all of their CC-Coh Pion events from their data that was actually there! Duh.

Do we need an abstract?

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 and linked: SciBooNE-MC and the corresponding ROOT files used in the simulation 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 steps the macros should be run in and the expected plots that each macro produces.

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 did not observe 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

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
$\bar{\bar{\nu}}$	5.3.6	Rein-Sehgal	1,000,000
$\bar{\bar{\nu}}$	5.3.6	Berger-Sehgal	1,000,000

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

3 Detector Simulation

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

3.1 The Detector

For the purposes of this acceptance study, the SciBooNE experiment is composed of two sub-detectors. The first (and the more upstream) of the sub-detectors, is the Scintillator Bar Tracker (SciBar) which was originally conceived and constructed to function as the near detector for the K2K experiment. The second (and more downstream) of the sub-detectors, is the Muon Range Detector (MRD), which is the detector designed and constructed specifically for SciBooNE for measuring the momentum of muons produced from charged-current neutrino interactions up to $1.2 \ GeV/c$ 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.

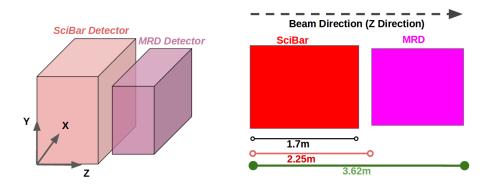


Figure 3.1: Representation of the SciBooNE detector and the coordinate frame we use in this study

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.

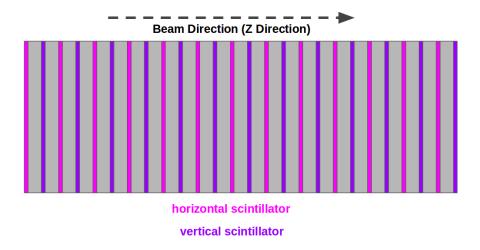


Figure 3.1.2: Depiction of the Muon Range Detector (MRD) which consists of alternating layers of horizontal scintillator (shown in pink) steel slabs (shown in grey) and vertical scintillator (shown in purple)

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.

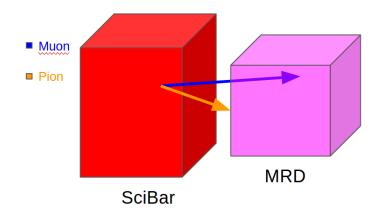


Figure 4.1: Depiction of an event that was classified as "Stopped."

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.

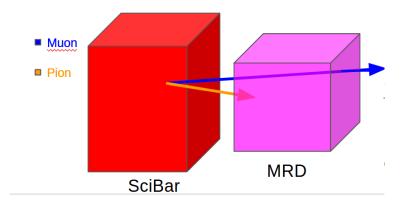


Figure 4.2: Depiction of an event that was classified as "out-the-back".

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.

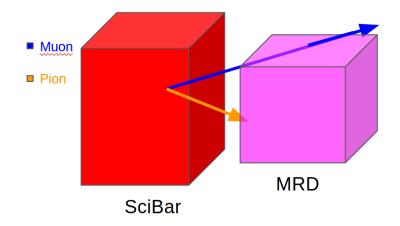


Figure 4.3: Depiction of an event that was classified as "Out-Side."

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

SciBooNE geometry.

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.

	u-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
$\mu + \text{n-other particles in SciBar}$			
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

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.

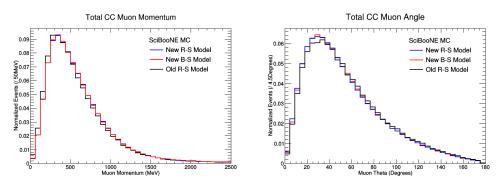


Figure 5.1: Muon Momentum (left) and Muon Angle (right) for ν -mode CC-Inclusive interactions for all three models included in this study. These samples kinematics are, unsurprisingly, very similar for the sample of CC-Inclusive

Figure 5.1 represents the one-dimensional efficiency for selecting ν -mode CC-Inclusive events for this study compared to results derived from Hirade's thesis (need proper reference) using the full SciBooNE Monte Carlo simulation. A few reference points are illustrated using dashed lines

to guide the readers eye. A few perecent difference is seen, but overall agreement between the two simulations hold.

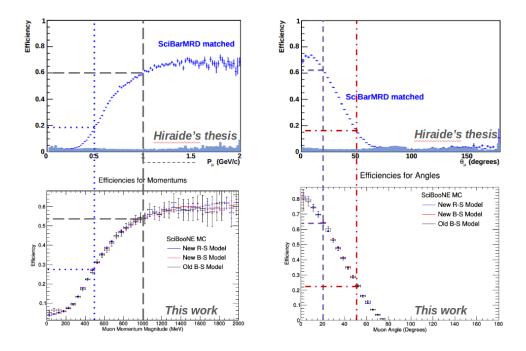


Figure 5.1: One-dimension efficiency plots for the ν -mode CC-Inclusive sample.

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.

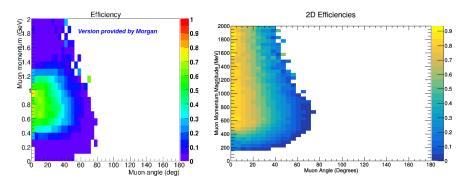


Figure 5.1: Two-dimensional efficiency plots for the ν -mode Rein-Sehgal CC-Inclusive sample.

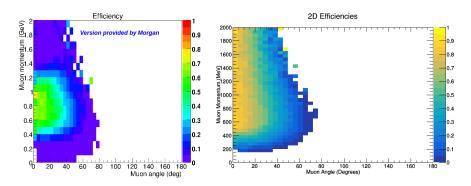


Figure 5.1: Two-dimensional efficiency plots for the ν -mode Berger-Sehgal CC-Inclusive sample.

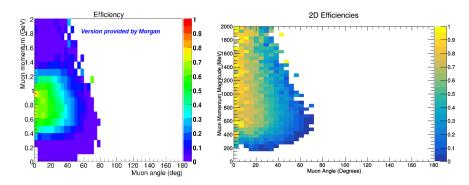


Figure 5.1: Two-dimensional efficiency plots for the ν -mode Old Rein-Sehgal CC-Inclusive sample.

Similar to before, Table 5.1 goes through the event selection criteria for selecting a sample of CC-Inclusive events from the neutrino mode ($\bar{\nu}$ -mode) Monte Carlo.

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

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

Table 5.1: Event reduction table for a sample of $\bar{\nu}$ -mode CC-Inclusive evnets simulated in the SciBooNE geometry.

40,476

295,897

41,916

296,063

"Out-the-side"-Events

Good CC-Inclusive Events

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.

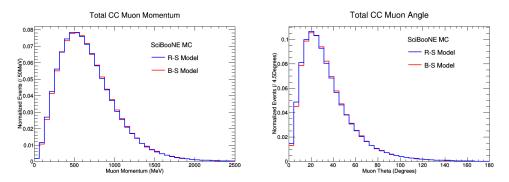


Figure 5.1: Muon Momentum (left) and Muon Angle (right) for $\bar{\nu}$ -mode CC-Inclusive interactions for all three models included in this study. These samples kinematics are, unsurprisingly, very similar for the sample of CC-Inclusive

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).

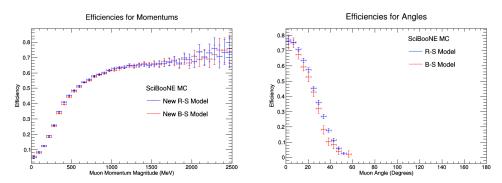


Figure 5.1: One-dimension efficiency plots for the $\bar{\nu}$ -mode CC-Inclusive sample. Muon's Momentums is on the right and the Muon's Angles is on the left.

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)

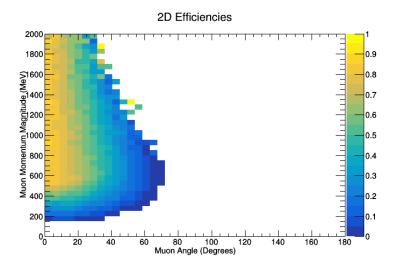


Figure 5.1: Two-dimensional efficiency plot for the $\bar{\nu}$ -mode Rein-Sehgal CC-Inclusive sample.

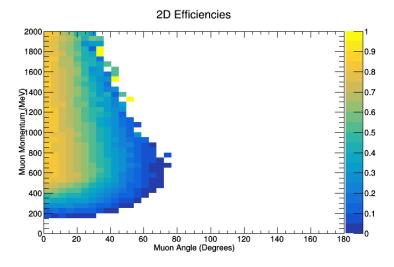


Figure 5.1: Two-dimensional efficiency plot for the $\bar{\nu}$ -mode Berger-Sehgal CC-Inclusive sample.

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

_	_	_											_	_	_									_	_	_									_		
930.2000	823230	785714	713615	2014191	5625	0.435185	381070		_	_	_	_	_	_	_						_	_	_	_	_	_	_		_	_	_	_	_	_	_	_	
1900-1950		_	_	1,630,522	-	0.579632	_	_	-				_	_	_	_	_	_	_				_	_	_	_	_	_	_	_	_	_	_	_	_	_	
1839-1900 19	F	813733 0.7	÷	÷	=	3,462963 0.5										0				0								0		0			В				-
	-	_	_	_	=	_		_																		_											
800 1800-1850	드	_	_			129931																						=									
	=	_	4 0.70068	_	_	1,0857				0.25			_	_	_		_	_					_	_	_	_			_						_	_	
021 0E1 0E1 0E91	0.821369	_	_	_	-	0.447761	-	2 2 2	0.166667											В										В			В				
	0.921569	0.730476	0.731978	0.648718	0.546547	0.539095	23650	0.238055	0.1875																	_				В			В		_		
1609-1650	8.0	0.771642	0.704835	82581910	0.281633	0.53674	0.2573.0	0.127273	0.1875							В				В										В			В				
1530-1600	0.9365fB	1501521	525758	8501999	262025	9.513605	2000	191489	16060601	9.0			_	_	_									_	_	_		_							_	_	
300-1330	.23333	70304	89522	8578-48	799	991116	3,000	0.86556	9F																												
1420-1500 1300-1350	Н	_	_	_	-	497826	-	22	_	10769231	_	_	_	_	_	_	_	_	-		_	_	_	_	_	_	_	_	_		_	_		_	_	_	-
1400-1-50 14	98	_	72093 0.7	_	_		202130	-	_	0.1175-47 0.4	_		0	0	0	В	0	0	0	В			0	0	0	_			0	В			В		_		0.0
1320-1400 14	248	_	_	_	Ĕ	-	91208	-	_	148148 0.1						0				0						-		0		0			0				
н	321 83	_	_	_	=		0 0	-	_	_			0	0	0		0	0	В				0	0	0	_											
300 1300-1350	118 0 811	_	Ĕ	Ť	Ĕ	200000000000000000000000000000000000000		_	_	35 0.05-5161	_	_					0	0	0																		
50 1230-1300	12080 2	1 0.7389		_	_	0.498274	0 0	0.0	8 0.204918	-	0.1-2857	-	_	_	_		_	_					_	_	_	_			_						_	_	
1200-1250	0.81759	0.78947	_	Ť	Ĕ	0.550962	-	-		0.182927		11								В						_				В			В				
1130-120	0.782712	0.83027E	0.713326	0.688694	0.627978	0.533719	0.361111	0.316279	_	0.15534	_															_				В			В		_		
1100-1150	0.88785	0.80875	0.746401	0.497987	0.652881	0.364828	0.487373	0.55257	75-2472-0	78867	0.145161	0.4322581														_	_								_	_	
1020-1100	121228	0.828974	0.781633	0.713103	0.632723	0.56538	9252070	0.336748	0.2897	298910	0.178295	110																									
1000-1050	183-632	1.803922	3.74026	3.71-63-42	890098	157636	1.82253	573851	762-97	134572	911011	625-1239	_	136364	_	_	_	_		_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	
920-1000	819549	73823	778828	722747	656648	578595	459893	362308	28-258	0.221135	12-614	0814815	0.465.465	_	_									_	_	_											
E6-806	87594	=	_	Ē	=	127872	43989	-				0.122172 C		02-8902	_	_				_			_	_	_	_	_	_	_	_	_		_		_	_	
E 116-058	۲	Ï	÷	737437	-	-	-	_	-	0.239492 0.	_		0.0883721 0.		E	0	0	0	0	0			0	0	0	_			0	0			0		_	0	-
800-850 K	۲	Ï	77807	_	=	601285 0.5		_	312566 02	_	_	0.12807 0.1				0			0	8						_									_		00
	-	_	_	_	=	91210	0 0	416728 0.4	_	0.238347 0.2				0.044585 0.0	_											_				В					_		00
0.8 90	=	_	_	_	_	-		_					Ξ	_	_	165-41 0				0						_				0							
052-002 0		_	_	_	_	061255	-	-	-	92 0273593	_	_	_	=	=	0.005465						-				_									_		
659-700	-	Ï	Ĕ	0.75131	=	1098290 2		0.410602	_	-	_	228270 6	=	90.44898	Ï											_											
029-009			0.784336		0.681216	962390	2000		0.331913					8 0.033736							в																
250 600	0.82882	19827.0	0.787403	0.742788	0.7824	8 619898	48088	0.39677	0.3142	0.249649	3,000,0	0.131-69	3 0.083166	0.04336												_		=									
5HI-550	0.816092	0.824047	0.795-0.7	0.73062	0.666667	0.590321	0.44563	0.3527	0.297887	0.220634	0.165696	0.109863	0.074478	0.030608	0.0041686											_				В			В				
450-300	0.7160.49	0.785102	0.693122	0.648363	0.56578	0.513469	0.520.00	0.336716	0.249335	0.209127	241910	0.106105	0.0357781	900810	0.00228571																						
(E) (E)	1553846	9283950	1582	524072	498252	142524	322880	0.272658	0.22549	177771	1123702	0.0810889	0.0418139	90091228																							
220-400	22	_	791624	201091	_	356223			175194	0.129907 0	_		10165922 0	_		_	-	-		_	-	_				_	_	_	_		_	-	-	-	_	_	-
310.350	1707.2	9411 0	34426	8937 0.	31233	8478	15553	252	33648 0.			10248-84 01	3				0	0	8		В	В				_				0					_		-
250-310 30	282	8182 0.4	2	2,22902 0.3	9374 93	20088 02	138308 0.2	1943-4 91	10 9817186	=	=	8				_			0	0						_		_		0			0		_		00
Г	32.0	181	=	=	100	ш.	2		_		6.0															_											
200-230	8259	_	Ĕ	Ē	=	15 0.120614			0.0185547	0.002	-	-										-				_									_		
130-200	0.09375	0.123457	0.0280374	0.0696203	0.4896825	0.0341615	0.000000	0	0																												
00 100-130	_																									_		=									
PA 59-100	-	0	-						-				0	0	0		0	0	0				0	0	0	-			0	В			В			0	
S 0.30 MeV/c										-	-	-					-	-	-		-		B 250	B 250	B 250	B 25	0 26	0 20	0 26	B 26	B 26	B 26	8 26	B 26	B 26	0 26	26.2
SWAW RS	1-4.5 Deg	15-9 Deg	1435 Dag	35-18 Drg	8-25 Day	225.27 Day	15.36 Day	6-40 5 Day	405-45 Day	5-45 Deg	19554 Drg	14.28.5 Day	185.63 Day	13-67-5 Day	175-72 Day	72 75 5 Day	765.81 Drg	11-K5 5 Drg	35.90 Deg	18-945 Day	145.99 Day	19-103.5 Deg.	(B 5-1B D)	(B-1125 D)	125417 De	117-121.5 Day	(21.5-126 D.	(26.1305 D.	(3212ED)	35-1395 Dt	385141D	141-148.5 Drg	148 5-153 Day	53-1575 D.	57.5-162 D.	(62-1665 D.	18517 Deg
_	ت	-	-51	_	-	-9 5	. 00	. 00	7	7	7	177	1/2	_	_	-			æ	-50	-51	-51	_	_	_	_	_	-	_	-	_	_	-	_	_	_	

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

	_																									_												
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
4850 185		F.0 02087.	-	_	_	Ť	Ť	_	22	_	_	_	_	_	_		-	-	-	-	-	_	_	_	_	_	-	=	-	0	-	-	-	-	- 1	-	-	
1730 1800 1800 1850	24 0.86	Ť	_	Ť	Ť	ī	÷	÷	Ť	67 0.35	_	_	_	_	_		-	-	_	-	_	_	_	_	_	_	-	=	=		-	-	=	-	= :	= 1	=	
20 1730		4 0.770053			_	Ť	Ť	Ť	Ť	7 0.16565	_	_	_	_	_										_	_		-	-	_				-	- 1	- 1		
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	070657	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	_																									_		
20 12 U	7682	n zemze	-	8	Ť	÷	_	_		0.157855 0.		_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_				_	0.0
1450 14	6	0.75-4706 0.7	2832 0.7	Ť	5.09 611605.	Ī	Ī	÷		0.22222 0.1		_	_	_	_		_	_	_	_	_	_	_	_	_	_	_	-	-		-	_	-	-	= 1	-	-	
1310 1320 1320 1400 1400 1420 1420 1500	734 0.80	Ť	200 0.75	_	_	_	Ť	_				_	0.0	_	_	0	-	-	-	-	-	-	_	_	_	_	-	-	-		-	-	-	-		-	-	0 0
320 1320	33 0.898	15 0.70294	÷	_	_	_	Ť	Ť	_	÷	333 0.16656	_	_	_	_	0	_	_	_	_	_	_	_	_	_	_	_	=	=	0	_	_	=	-	= 1	= 1	=	
1300-1		5 0.813065	-	_	_	_	_	-	_	_	E 0.083232		_	_	_		_	_	_	_	_	_	_	_	_	_	-	-	-		_	-	-	-	= 1	-	-	
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	_	_	_	_	_	_	_			_	_	
	F	180-222 00	Ť	_	Ť	127275 R		_	_	_	_	_	0.0617284 0.0			0	_					_	_	_	_	_				0	_			0 1	-			0 0
Ē	F	72257	Ť	Ī	634515 0.67	Ť	Ť	÷	÷	313023 0.2	_	151292 0.13	108844 0.00		0.0-0.0567 0.0		-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	
П	-	0	0	0	_	o'	e e	ď	oʻ.	_	_	_	_	_	_		-	-				-	-	-	-	_	-	-	-		-	-	-	-	= :	= 1	-	
Ĥ	3 0.820087	8 0.82270	Ť	_	_	÷	÷	Ť	-	_	_	_	3 0.117073	_	48 0.0227273													-	-					-	- 1	- 1		
90	0.83333	0.735488	-		_	Ť	Ť	0.42864	_	_	Ť	_	Ť	Ξ	=	0.03125	_	_	_	_	_	_	_	_	_	_	_	=	=		_	_	=	- 1	= :	- 1	=	
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									_	_	_	_		_	_	_			_		
000 000		Ť	-	_	_	Ť	-	Ť	Ť	Ť	-	-	-	-	-	0.0195072 0.0	9.	_	_	_	_	_	_	_	_	_	_	_	_	-	_	_	_	-	= 1	= 1	_	0.0
	П	181 601218	-	_	Ť	-	Ť	Ť	_	_	_	_	_	_	0.0436238 0.03	Ξ	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	= 1	= 1	-	
220,600	F	_	_	_	_	_	_	_	_	Ť	_	Ť	_	Ť	Ť	387 0.01.21	-	-						-	-	_	-	-	-		-	-	-	-	= :	= 1	-	
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																							
П	F	_	_			_	_	_	_	_	=			0.0128637 0.	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	0 1		= 1	_	0 0
ĥ	22	_	Ī	23 07	Ť	2	8	2	Ī	_	_	_	_	0.00 382-17000.0	-		-	-	-	-	-	-	-	-	-		-	-	-		-	-	-	-	= 1	-	-	
300-320	0.422	0.30669	0.352953	0.3302	0.318462	0.3218	0.2533	0.2185	_	Ť	_	-	-	0.000	_									_	_	_		-	-					-	- 1	-		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	791-122101	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	-	_	_	_				_	
156-300	ĺ	0.025	÷	-	-			0.0754777	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	-	-	_	_	_	-				-	
100-150 150	=	0.0	0.0	0.0	0.0	0.0	0.0	0.0	_	_	_	_	_	_	_	0	-	-	-			-	_	_	_	_	-	-	-	0	-	-	-	-	- 1	= 1	-	
	0	0			0					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	_	_									-		
O TO A VIEW OF D							_	_	-	_	_	_	_	_	_									_	_						_							
(BS 0.5	0		- 52	- Art	Deg 0	260	D No.	D No.	D No.	Deg 0	Deg 0	Deg 0	Deg 0	Deg 0	Deg 0	O Zeo	Deg	Deg 0	Deg	Deg 0	Deg 0	Deg 0	Dog 0	8 Deg 0	5 Deg 0	7 Deg	2 Deg	e Deg	2 Deg 0	o Deg	2 Deg 0	4 Dog 0	2 Deg	a Doc	a Marie	2 Dog	2 Deg	J Deg
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

1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 -
0.00 (
0.0873333 0.077 0.077 0.077 0.073
857-84 10.08533 10.0853 10.0853 10.0853 10.08
000007 000007 00000000000000000000000
5521.74 5742.85 5453.55 55.74
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
8 8 90 90 90 90 90 90 90 90 90 90 90 90 90
0. 57. 57. 57. 57. 57. 57. 57. 57. 57. 57
1. 17 1915 1. 17
8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
1
8.55.33.33.34.8.8.8.8.3.3.3.3.8.8.3.3.3.3.3.
200 200 200 200 200 200 200 200 200 200
10 10 10 10 10 10 10 10
1.00 (
8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
8 5 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7
607 1057777 508 1051 1054 601 1057 601 1057 601 1057 601 1057 601 1057 602 1057 603 1057
7,777.7 (1970) 10,777.7 (1970)
2.00 (1975) 1.00 (
7. 7. 7. 7. 7. 7. 7. 7. 7. 7. 7. 7. 7. 7
10.00
8 77 75 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
7777778 7777778 7777778 77778 77778
1. 12 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
18.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1
9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
19
588 10.50 10
14 1738 14 1738 15 17 1738 16 17 1738 17 17 1738 17 17 1738 17 17 1738 17 17 1738 17 17 1738 17 17 1738 18 17 17 17 17 17 17 17 17 17 17 17 17 17
15. 15. 15. 15. 15. 15. 15. 15. 15. 15.
211 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
1 0.553.33 1 0.752.34 1 0.152.35 1 0.15
0.07 LESS 0.07 LESS 0.01 Misser 0.01 Misse
14.4.1 Dec. 1. Sept.

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

88	52	19	F	7		2	8	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_
60 1930-2	Ĭ.	5 0812155	8 0.587.7	-	-	_	9 0321429	22	=		0 0	0 0	-	=			В			0 0		-	=	Φ	8	=		0 0		= 1	=				В								
1900-19	1 0.884658	0.7333	2 0.719368	-	-	-	1 0.6-576.	0.125	=					=								= 1	=	=	0	=				= 1	=												
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	=									-	-		_
120.18	982228	0.786323	0.718579	0.648734		2000	0.472222	0.55	_					=			В						=	Ξ.	В	_				= 1	=				В					-	-		
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	0000000		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				_									_								_												_
1400-1-50	905+58-0	0.793301	919127	0.050004		2000000	69105	0.405405	20020	818.201.0		1		_									=			_				-	_												
350-140	1282121	230123	229168	68(0)22		- Haran	2332H	12824	342857	263535	1000			_	_		_	_						_								_		_	_	_	_	_	_			_	_
. SE 133	186385	92.62.0	0.25535	0.000		_	Ï	1.467192 0	137421	-	-	-		_	_	_	_		_				_	_		_					_	_	_	_	_	_							_
250-1300	829352	819324	9 662927	182003	00000	=	=	1.54704 D	0.38374	-	-	3 0		•		_			_							-							_										
200-1230 1	821846 0	799636	745802	Thurse n	-	-	23387	491838	37394	_	_	_		-		_							_	Ξ.	-	-					=		_	_									_
H215H	821212 0.	806396 0.	756.423	0 188899		-	557719	487885 0.	37473	3574.00	-	-	-	=		0	0	0					_		0					-	=			-	0	0	0	0	0			0	-
00-1150	82028	39486	.T. 6836		0 0	=		£3382 0.	393846 0		0 0	-	3 1	TRESSES II			0				0 0		=	0				0		= 1	=			В	0								
50-H(II) 11	F	780172 0.7	256151 0.2			i	200	50292 0.0	420597 0.2			0.000	-	1181818		0	В	0		0.0	0.0		=	0	8			0.0		= 1	=		0		В								
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	В		0 0	0 0		=	0	0			0.0		= 1	=			8	8	В	0	0	0			8	-
888	846791	803572 04	774887 0.	-	-	-	1259	323933 0.5	465828 D	-	-			-	=	0.0454546 04	-	8		0	0 0		=	0	0			0		= 1	=			0		0	0	0	0			0	-
E8-08		803654 0.	728919 0.	-	-	-	585787	333736 0.	500	0 09298		202204	-	=	_	2963	1.125			0.0			=	_				0.0		= 1	=			8	0								-
98 800	280028	80314 0.1	772247			,	610015	569457 0.3	A62372 10				-	_		4	0.025	0		0.0	0.0		=	0	8			0.0		= 1	=				В								
120	-	8747 04	380804 B			-	=	338364 0.3	46538		-		-	=				0.0289835 0		0.0	0.0		=	0	8			0.0		= 1	=				В								
98	265	200 08	73194 0.3	10	0 0	-	_	530737 0.5	20 89000		0 0	. 2		=	=	=	=	÷		0.0	0.0		=	=		=		0.0		= 1	=			0	Β.	0	0	0	0			0	
99	820359 0.80	812763 0.80	E827			=	9761	73181 0.53	502938 0.46			-	-	=	=	=	=	10144928 0.00	_	0 0	0 0		=	Φ		=		0 0		= 1	=						0	0	0	-	-	0	
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
200	P	_	278963 0.78		0 0	=	_	527993 056	2		0 0	-	9 1	=	_	=	=	(00215-64 0.01)	-		0 0	= 1	=			=				= 1	=									-	-		
00 200 con	325 0.812332	Ĭ	_		-	=	Φ.	_	=		0 0	040 0 2000	-	-	_	_	1,0226148 0.037	0.005				= 1	=			=		0 0		= 1	=					0							0
100	Ĭ.	6 0.722011	28 0.580187		-	-	=	4 0.65377	22 0.39-4628					-	-	_							=		0	=				= 1	=				В					-	-		
- 100 · 121		4 0.611915	0.563628		3 6	=	_	2 03833-0	3 0343522		-	-	-	-	_	_	167 0.00447928				0 0	-	=	=		=			-	= 1	=									-	-		
330-400	۴	=	220000	-	-	-	Ť	2 0.318072	0.292653	-	-	-			_	=	291801000					-	=			=				= 1	=		=		В	0				-	-		
30.30	0.398693	0.351406	1.369365	0.573.408	1000	0.00	28492	0.23752	0.21821	78087	0 0	0 0		=	_	0.0010015						= 1	=	_		=				= 1	=												
230 300	0.225352	0.254881	1,27,285.4	0.364642		1.000004	Ξ.	0.157462	0.340581		_	-	0.00	0.0114405	0.000354017		В						=	=		_				= 1	=				В								
200.250	0.173913	78-6710	0.175824	0.16291.0	0.00	nassina	0.127362	0.0779102	0.9702447	_	100000	0.00000		=				_					=			_				-	=			_			_	_	_			_	_
150-200	0.037037	0.0338922	0.0881226	0.0202050		0.000	1839200	0.0135747	75959200																																		
100-150		_	_			_		_	_					=				_				-	=			_				_	=					_	_	_	_	-	-	_	_
V/c 50-100			=			=			=					=									=			-				= 1	=									-	-		
S 0.50 MeV	0		_			-			_					=									=			_				= 1	=			_						-	-		
PWANNI RS	15 Day	45.9 Day	9435 Dev	135,18 Dec		22 C 27 C	225.27 Deg	33.5 Deg	5.36 Dec	36.40 5 Deg	1000	100 mm	1000	Wast Leg	28.5 Deg	2.63 Deg	67.5 Deg	675-72 Deg	THE DE	10 to		San Par	San Henry	98-945 Deg	945.99 Deg	99-103.5 Dev	100 C 100 Day	11.05 Day	State of the last	112.5-117 Day	Totals Deg	121 5 126 Deg	126-1385 Dry	1315-135 Dry	135-1395 Day	135-144 Day	144-148.5 Drg	148 5-133 Deg	133-1575 Deg	157.5 162 Dev	162-1665 Dev	166 5 171 Day	17-175 Day
á	Ē	-2	1.5	2		9	24	27	55	95	9 9	9 4	7	₽	'n	oći Už	63	67	8	1 2	2 2	6	20	96	76	90	100		1	= :	=	12	2.0	2	2	텀	7	77	130	15	18	g	12

Table 5: Table for 2D Histogram for New ANM-Berger-Sehgal

F	
1015-1016 1015-1	
100 170 170 170 170 170 170 170 170 170	
581-190 1-77-19-1 58-1-78-1 58-7-78-1 58	
Name of State of Stat	
2. 17. 17. 18. 18. 18. 18. 18. 18. 18. 18. 18. 18	
# DOOD OF DOOD	
C C C C C C C C C C	
10 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	
1	
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	
1.461.15(1) 1.061.16(1) 1.061.	
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	
383-1401 T	
8 10 10 10 10 10 10 10 10 10 10 10 10 10	
200 1 200 1	
10 1 1 10 10 10 10 10 10 10 10 10 10 10	
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	
11 10 10 10 10 10 10 10 10 10 10 10 10 1	
1015-1100 102-105 102-	
100-1031 100-10	
905-1100 124 26-20 124 26-20 125 26-20 125 26-20 126 26-	
80 - 200 80 - 2	
101-1010 101-10	
2016 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	
0.000,000,000,000,000,000,000,000,000,0	
1 1 1 1 1 1 1 1 1 1	
100 100	
0.831164 0.831164 0.831164 0.831164 0.83116 0.	
100 100 100 100 100 100 100 100 100 100	
101-550 201505 2	
12 12 12 12 12 12 12 12 12 12 12 12 12 1	
7	
1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	
30.2314 30.231	
2.20 (2.00 cm) (
201.23 1.44572 1.231013 1.33173 1.33173 1.44772 1.45183 1.45782 1.45782 1.45782 1.45782 1.45782 1.45783 1.4578	
1.00 - 200 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	
□ // A-4 × C	
	1375-162 Day 1375-162 Day 185-17 Day 171-175 Day
Name A 2001 144 Dec. 144 Dec. 145 Dec.	1281

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°.

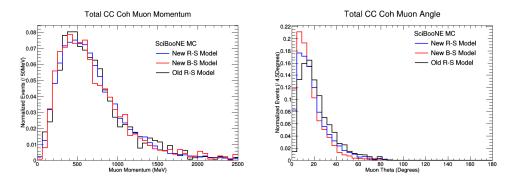


Figure 1: Muon Momentum for all of the muons of the events that made it to the MRD and penetrated at least three layers (left) and Muon Angle for the muons of the events that made it to the MRD and penetrated at least three layers (right) for ν -mode CC-Coh $\pi^{+/-}$ interactions for all three models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

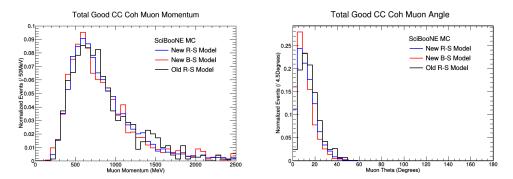


Figure 2: Muon Momentum of both the "stopped" and "not-stopped" samples (left) and Muon Angle of both the "stopped" and "not-stopped" samples (right) for ν -mode CC-Coh $\pi^{+/-}$ interactions for all three models included in this study. The "Good" classification means that only the stopped and not-stopped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

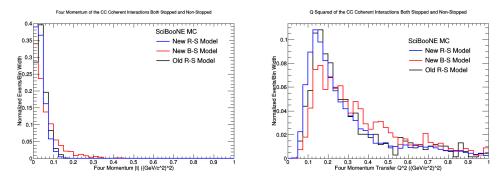


Figure 3: The |t| Momentum Transfer for the "stopped" and "not-stopped" events (left) and Q^2 Momentum Transfer for the "stopped" and "not-stopped" events (right) for ν -mode CC-Coh $\pi^{+/-}$ interactions for the three models included in this study.

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.

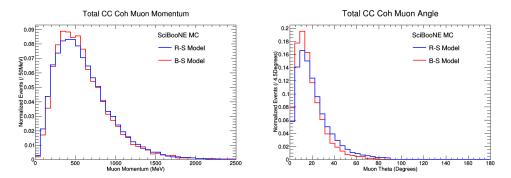


Figure 4: Muon Momentum (left) and Muon Angle (right) for ν -mode CC-Coh $\pi^{+/-}$ interactions for all three models included in this study.

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.

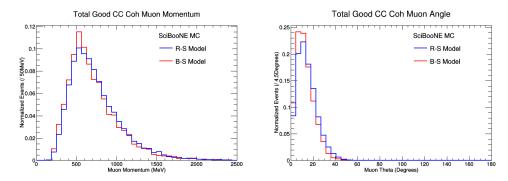


Figure 5: Muon Momentum (left) and Muon Angle (right) for $\bar{\nu}$ -mode CC-Coh $\pi^{+/-}$ interactions for both the "stopped" and "not-stopped" samples of events.

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

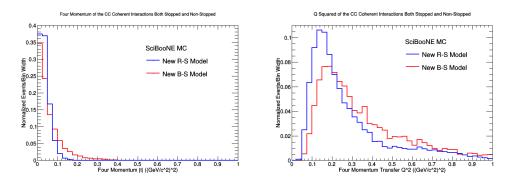


Figure 6: The |t| Momentum Transfer (left) and Q^2 Momentum Transfer (right) for $\bar{\nu}$ -mode CC-Coh $\pi^{+/-}$ interactions for both of the models included in this study which are the "stopped" and "not-stopped" events.

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 (need to put a reference) showed in his thesis. This was done by... etc.

Put in the code for how we made the vertex distributions of the interactions.

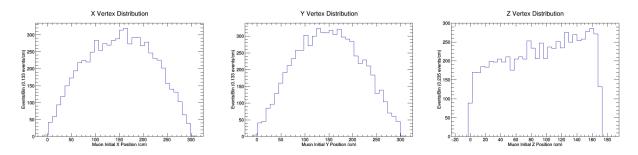


Figure 7: Vertex distributions of the events in the new Rein-Sehgal sample.

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.

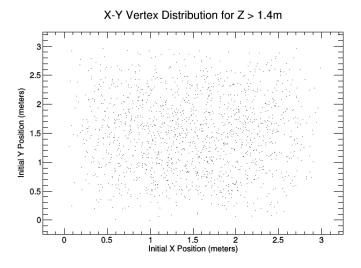


Figure 8: New ν -Mode Rein-Sehgal X-Y vertex distributions for muons that made it to the MRD and penetrated at least to the third layer of steel.

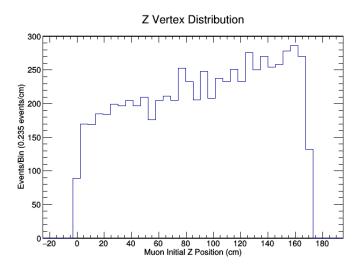


Figure 9: New ν -Mode Rein-Sehgal Z vertex distributions for the interactions.

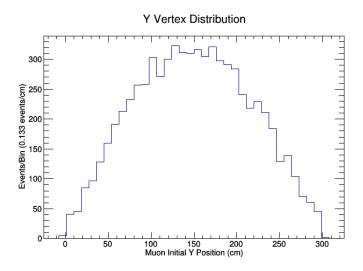


Figure 10: New ν -Mode Rein-Sehgal Y vertex distributions for the interactions.

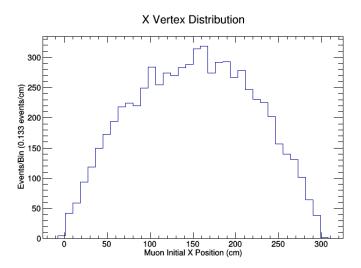


Figure 11: New ν -Mode Rein-Sehgal X vertex distributions for the interactions.

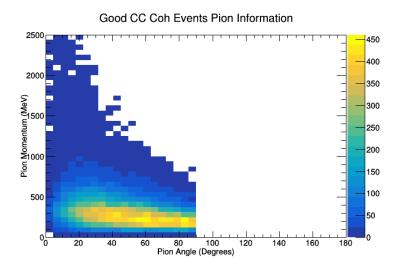


Figure 12: This is a 2D histogram for the momentum and angle of the pion in the CC Coh Pion events that met the qualification of being "good".

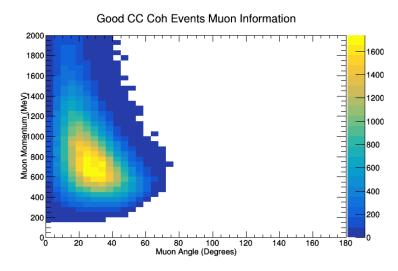


Figure 13: This is a 2D histogram for the momentum and angle of the muon in the CC Coh Pion events that met the qualification of being "good".

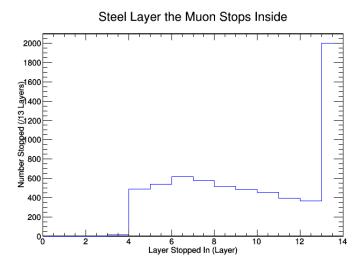


Figure 14: This histogram shows the amount of muons that embedded (or "Stopped") in a corresponding layer of steel in our simulation.

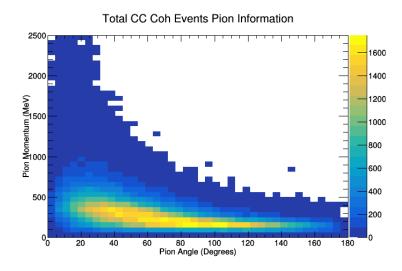


Figure 15: This is a 2D histogram for the momentum and angle of the pion in the total CC Coh Pion events.

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).

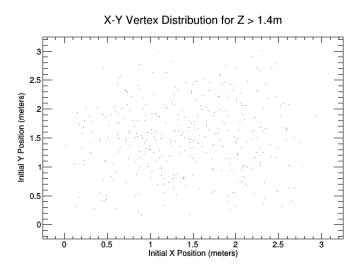


Figure 17: New ν -Mode Berger-Sehgal X-Y vertex distributions for muons that made it to the MRD and penetrated at least to the third layer of steel.

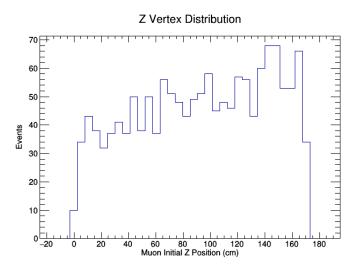


Figure 18: New ν -Mode Berger-Sehgal Z vertex distributions for the interactions.

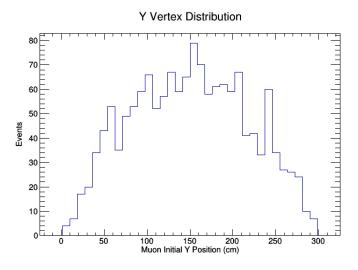


Figure 19: New ν -Mode Berger-Sehgal Y vertex distributions for the interactions.

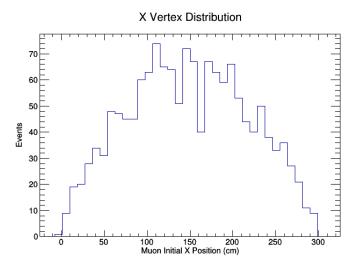


Figure 20: New ν -Mode Berger-Sehgal X vertex distributions for the interactions.

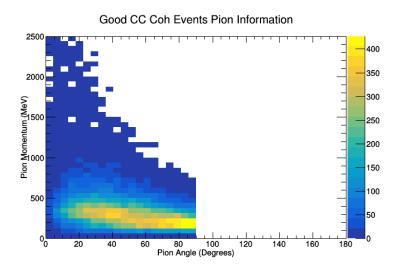


Figure 21: This is a 2D histogram for the momentum and angle of the pion in the CC Coh Pion events that met the qualification of being "good".

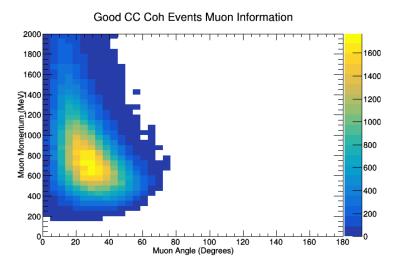


Figure 22: This is a 2D histogram for the momentum and angle of the muon in the CC Coh Pion events that met the qualification of being "good".!

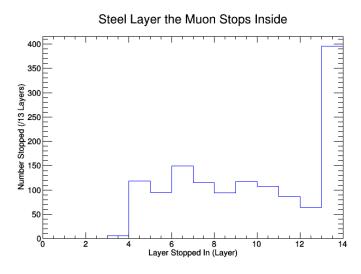


Figure 23: This histogram shows the amount of muons that embedded (or "Stopped") in a corresponding layer of steel in our simulation.

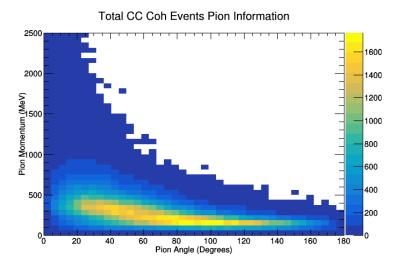


Figure 24: This is a 2D histogram for the momentum and angle of the pion in the total CC Coh Pion events.

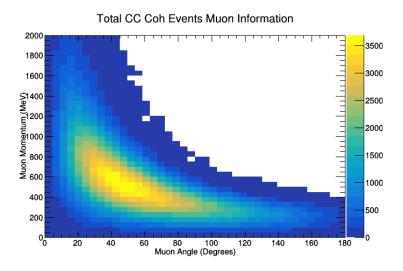


Figure 25: This is a 2D histogram for the momentum and angle of the muon in the total CC Coh Pion events.

The NewNMBergerSehgal.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:

$$|\vec{p}_{\mu}| = \sqrt{P_{\mu_x}^2 + P_{\mu_y}^2 + P_{\mu_z}^2} \tag{17}$$

$$|\vec{p}_{\pi}| = \sqrt{P_{\pi_x}^2 + P_{\pi_y}^2 + P_{\pi_z}^2} \tag{18}$$

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:

$$\theta_{\mu} = tan^{-1}(\sqrt{P_{\mu_x}^2 + P_{\mu_y}^2}/P_{\mu_z}) \tag{19}$$

$$\theta_{\pi} = tan^{-1} \left(\sqrt{P_{\pi_x}^2 + P_{\pi_y}^2} / P_{\pi_z} \right) \tag{20}$$

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:

$$Q^2 = |(P_{\nu_{\mu}} - P_{\mu})^2| \tag{21}$$

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

$$Q^{2} = |(P_{\nu_{\mu,x}} - P_{\mu_{x}})^{2} + (P_{\nu_{\mu,y}} - P_{\mu_{y}})^{2} + (P_{\nu_{\mu,z}} - P_{\mu_{z}})^{2} + (P_{\nu_{\mu,E}} - P_{\mu_{E}})^{2}|$$
(22)

 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:

$$|t| = |(Q - P_{\pi})^{2}| = |(P_{\nu_{\mu}} - P_{\mu} - P_{\pi})^{2}| \tag{23}$$

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

$$|t| = |(P_{\nu_{\mu,x}} - P_{\mu_x} - P_{\pi_x})^2 + (P_{\nu_{\mu,y}} - P_{\mu_y} - P_{\pi_y})^2 + (P_{\nu_{\mu,z}} - P_{\mu_z} - P_{\pi_z})^2 + (P_{\nu_{\mu,E}} - P_{\mu_E} - P_{\pi_E})^2|$$
(24)

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

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).

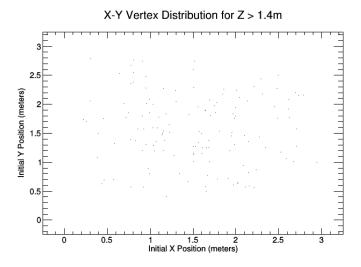


Figure 26: Old ν -Mode Rein-Sehgal X-Y vertex distributions for muons that made it to the MRD and penetrated at least to the third layer of steel.

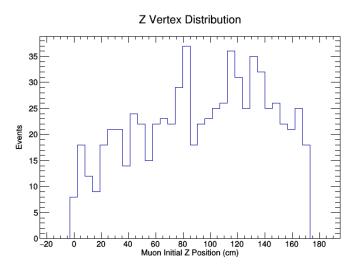


Figure 27: Old ν -Mode Rein-Sehgal Z vertex distributions for the interactions.

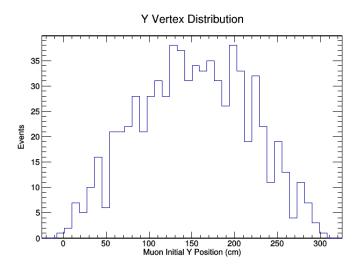


Figure 28: Old ν -Mode Rein-Sehgal Y vertex distributions for the interactions.

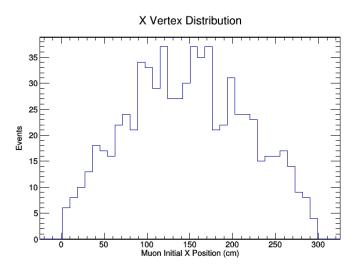


Figure 29: Old ν -Mode Rein-Sehgal X vertex distributions for the interactions.

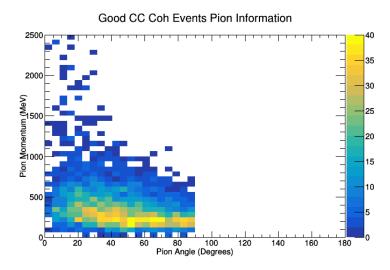


Figure 30: This is a 2D histogram for the momentum and angle of the pion in the CC Coh Pion events that met the qualification of being "good".

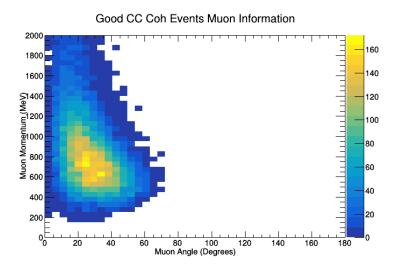


Figure 31: This is a 2D histogram for the momentum and angle of the muon in the CC Coh Pion events that met the qualification of being "good".

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.

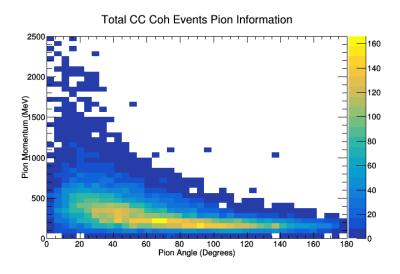


Figure 33: This is a 2D histogram for the momentum and angle of the pion in the total CC Coh Pion events.

Total CC Coh Events Muon Information Muon Momentum (MeV) 1200 800 800 800 Muon Angle (Degrees)

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

The OldNMReinSehgal.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:

$$|\vec{p}_{\mu}| = \sqrt{P_{\mu_x}^2 + P_{\mu_y}^2 + P_{\mu_z}^2} \tag{25}$$

$$|\vec{p}_{\pi}| = \sqrt{P_{\pi_x}^2 + P_{\pi_y}^2 + P_{\pi_z}^2} \tag{26}$$

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:

$$\theta_{\mu} = tan^{-1}(\sqrt{P_{\mu_x}^2 + P_{\mu_y}^2}/P_{\mu_z}) \tag{27}$$

$$\theta_{\pi} = tan^{-1}(\sqrt{P_{\pi_x}^2 + P_{\pi_y}^2}/P_{\pi_z}) \tag{28}$$

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:

$$Q^2 = |(P_{\nu_{\mu}} - P_{\mu})^2| \tag{29}$$

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

$$Q^{2} = |(P_{\nu_{\mu,x}} - P_{\mu_{x}})^{2} + (P_{\nu_{\mu,y}} - P_{\mu_{y}})^{2} + (P_{\nu_{\mu,z}} - P_{\mu_{z}})^{2} + (P_{\nu_{\mu,E}} - P_{\mu_{E}})^{2}|$$
(30)

 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:

$$|t| = |(Q - P_{\pi})^{2}| = |(P_{\nu_{\mu}} - P_{\mu} - P_{\pi})^{2}|$$
(31)

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

$$|t| = |(P_{\nu_{\mu,x}} - P_{\mu_x} - P_{\pi_x})^2 + (P_{\nu_{\mu,y}} - P_{\mu_y} - P_{\pi_y})^2 + (P_{\nu_{\mu,z}} - P_{\mu_z} - P_{\pi_z})^2 + (P_{\nu_{\mu,E}} - P_{\mu_E} - P_{\pi_E})^2|$$
(32)

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

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).

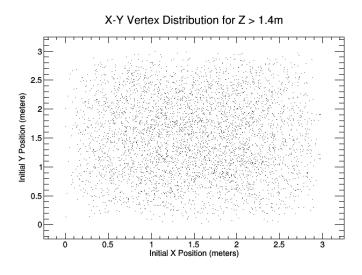


Figure 35: New $\bar{\nu}$ -Mode Rein-Sehgal X-Y vertex distributions for muons that made it to the MRD and penetrated at least to the third layer of steel.

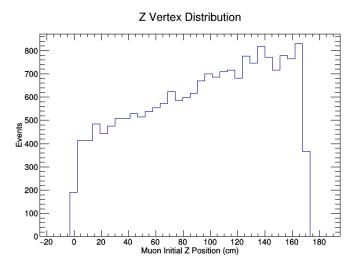


Figure 36: New $\bar{\nu}$ -Mode Rein-Sehgal Z vertex distributions for the interactions.

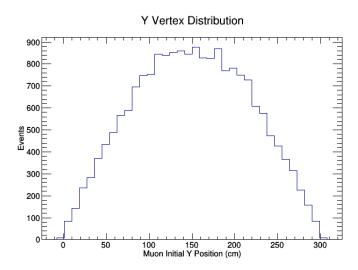


Figure 37: New $\bar{\nu}$ -Mode Rein-Sehgal Y vertex distributions for the interactions.

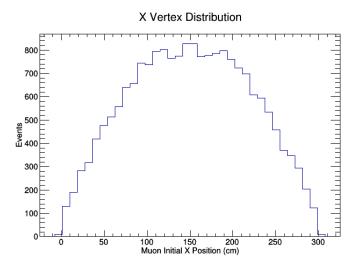


Figure 38: New $\bar{\nu}$ -Mode Rein-Sehgal X vertex distributions for the interactions.

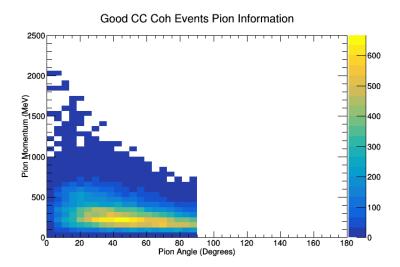


Figure 39: This is a 2D histogram for the momentum and angle of the pion in the CC Coh Pion events that met the qualification of being "good".

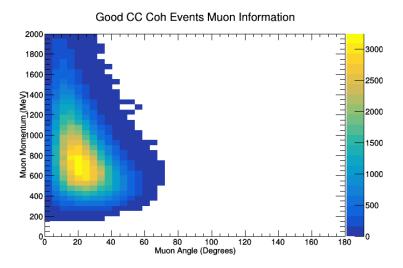


Figure 40: This is a 2D histogram for the momentum and angle of the muon in the CC Coh Pion events that met the qualification of being "good".

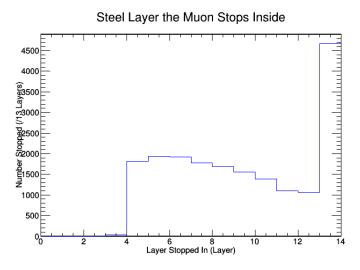


Figure 41: This histogram shows the amount of muons that embedded (or "Stopped") in a corresponding layer of steel in our simulation.

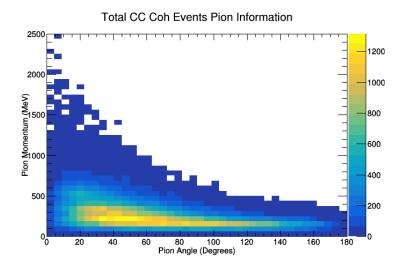


Figure 42: This is a 2D histogram for the momentum and angle of the pion in the total CC Coh Pion events.

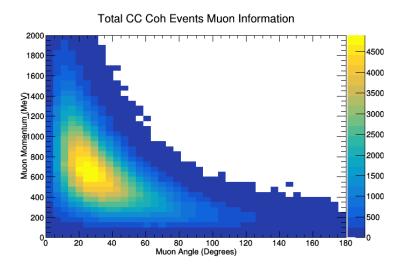


Figure 43: This is a 2D histogram for the momentum and angle of the muon in the total CC Coh Pion events.

The NewANMReinSehgal.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:

$$|\vec{p}_{\mu}| = \sqrt{P_{\mu_x}^2 + P_{\mu_y}^2 + P_{\mu_z}^2} \tag{33}$$

$$|\vec{p}_{\pi}| = \sqrt{P_{\pi_x}^2 + P_{\pi_y}^2 + P_{\pi_z}^2} \tag{34}$$

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:

$$\theta_{\mu} = tan^{-1}(\sqrt{P_{\mu_x}^2 + P_{\mu_y}^2}/P_{\mu_z}) \tag{35}$$

$$\theta_{\pi} = tan^{-1}(\sqrt{P_{\pi_x}^2 + P_{\pi_y}^2}/P_{\pi_z}) \tag{36}$$

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:

$$Q^2 = |(P_{\nu_{\mu}} - P_{\mu})^2| \tag{37}$$

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

$$Q^{2} = |(P_{\nu_{\mu,x}} - P_{\mu_{x}})^{2} + (P_{\nu_{\mu,y}} - P_{\mu_{y}})^{2} + (P_{\nu_{\mu,z}} - P_{\mu_{z}})^{2} + (P_{\nu_{\mu,E}} - P_{\mu_{E}})^{2}|$$
(38)

 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:

$$|t| = |(Q - P_{\pi})^{2}| = |(P_{\nu_{\mu}} - P_{\mu} - P_{\pi})^{2}| \tag{39}$$

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

$$|t| = |(P_{\nu_{\mu,x}} - P_{\mu_x} - P_{\pi_x})^2 + (P_{\nu_{\mu,y}} - P_{\mu_y} - P_{\pi_y})^2 + (P_{\nu_{\mu,z}} - P_{\mu_z} - P_{\pi_z})^2 + (P_{\nu_{\mu,E}} - P_{\mu_E} - P_{\pi_E})^2|$$
(40)

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

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).

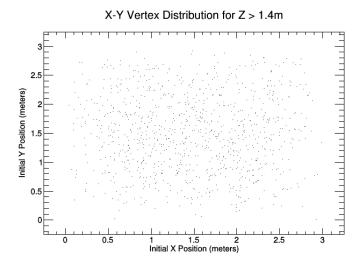


Figure 44: New $\bar{\nu}$ -Mode Berger-Sehgal X-Y vertex distributions for muons that made it to the MRD and penetrated at least to the third layer of steel.

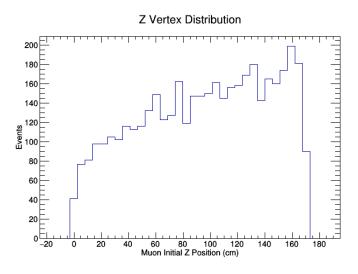


Figure 45: New $\bar{\nu}$ -Mode Berger-Sehgal Z vertex distributions for the interactions.

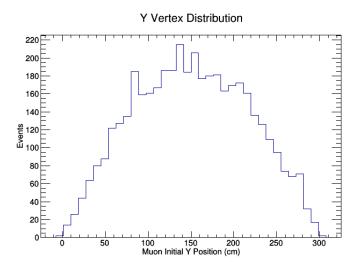


Figure 46: New $\bar{\nu}$ -Mode Berger-Sehgal Y vertex distributions for the interactions.

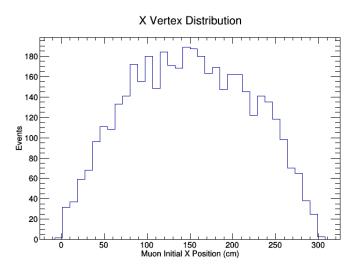


Figure 47: New $\bar{\nu}$ -Mode Berger-Sehgal X vertex distributions for the interactions.

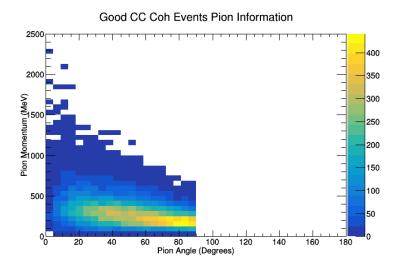


Figure 48: This is a 2D histogram for the momentum and angle of the pion in the CC Coh Pion events that met the qualification of being "good".

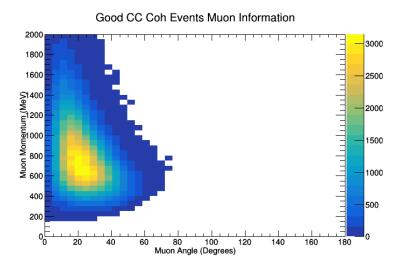


Figure 49: This is a 2D histogram for the momentum and angle of the muon in the CC Coh Pion events that met the qualification of being "good".

Steel Layer the Muon Stops Inside

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

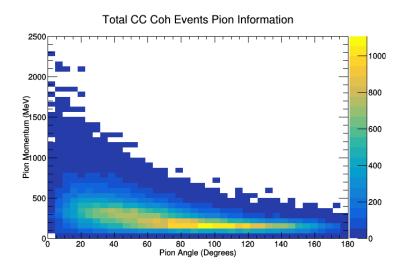


Figure 51: This is a 2D histogram for the momentum and angle of the pion in the total CC Coh Pion events.

Total CC Coh Events Muon Information Total CC Coh Events Muon Information 5000 1800 1600 1600 10

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

The NewANMBergerSehgal.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:

$$|\vec{p}_{\mu}| = \sqrt{P_{\mu_x}^2 + P_{\mu_y}^2 + P_{\mu_z}^2} \tag{41}$$

$$|\vec{p}_{\pi}| = \sqrt{P_{\pi_x}^2 + P_{\pi_y}^2 + P_{\pi_z}^2} \tag{42}$$

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:

$$\theta_{\mu} = tan^{-1}(\sqrt{P_{\mu_x}^2 + P_{\mu_y}^2}/P_{\mu_z}) \tag{43}$$

$$\theta_{\pi} = tan^{-1}(\sqrt{P_{\pi_x}^2 + P_{\pi_y}^2}/P_{\pi_z}) \tag{44}$$

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:

$$Q^2 = |(P_{\nu_{\mu}} - P_{\mu})^2| \tag{45}$$

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

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

$$(46)$$

 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:

$$|t| = |(Q - P_{\pi})^{2}| = |(P_{\nu_{\mu}} - P_{\mu} - P_{\pi})^{2}| \tag{47}$$

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

$$|t| = |(P_{\nu_{\mu,x}} - P_{\mu_x} - P_{\pi_x})^2 + (P_{\nu_{\mu,y}} - P_{\mu_y} - P_{\pi_y})^2 + (P_{\nu_{\mu,z}} - P_{\mu_z} - P_{\pi_z})^2 + (P_{\nu_{\mu,E}} - P_{\mu_E} - P_{\pi_E})^2|$$
(48)

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

A.12 NMCombinedPlots.C

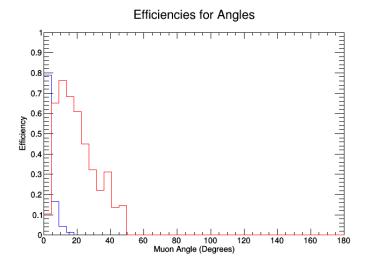


Figure 53

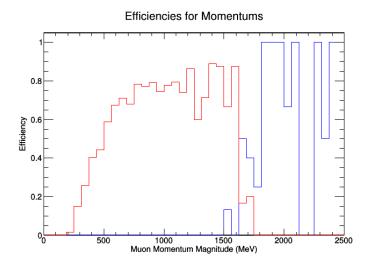


Figure 54

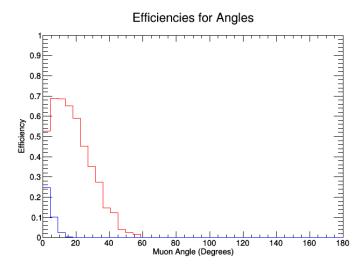


Figure 55

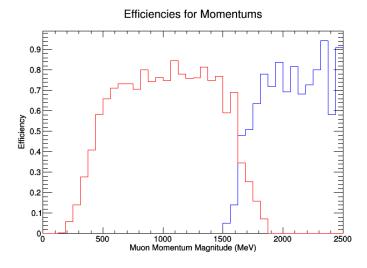


Figure 56

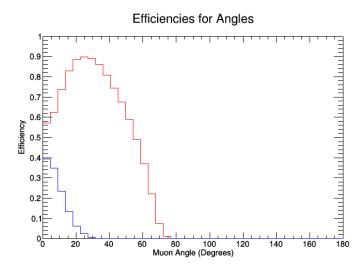


Figure 57

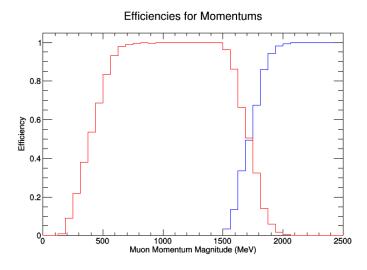


Figure 58

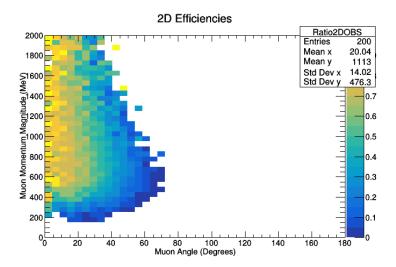


Figure 59

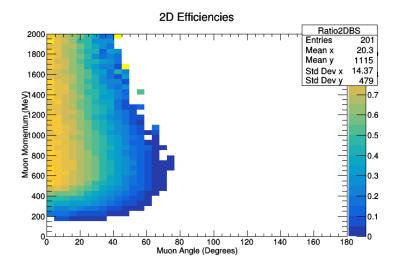


Figure 60

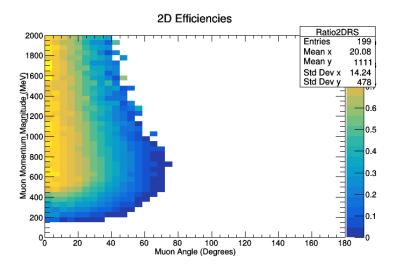


Figure 61

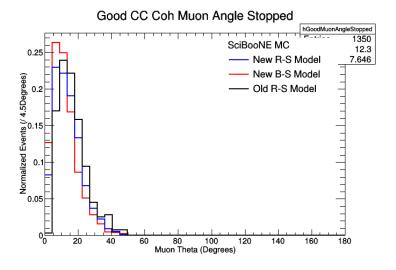


Figure 62

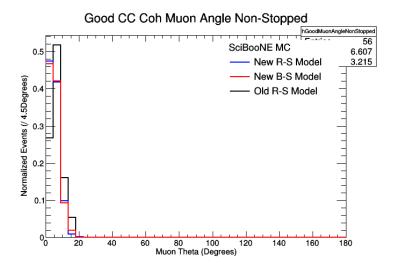


Figure 63

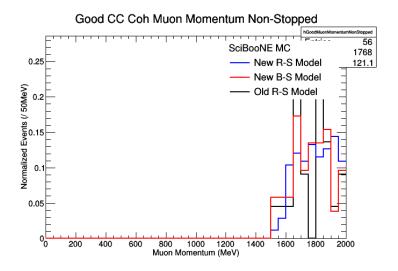


Figure 64

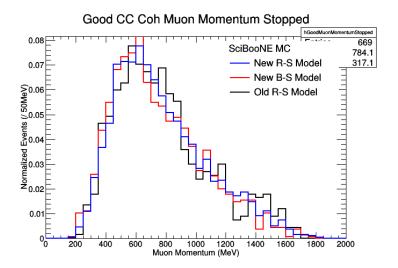


Figure 65

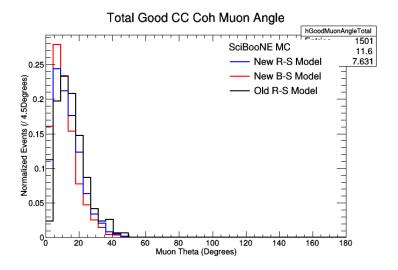


Figure 66

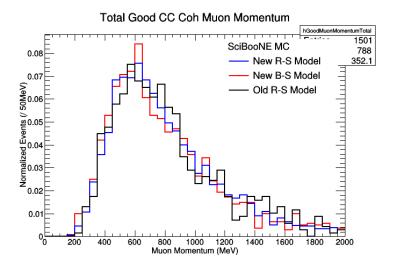


Figure 67

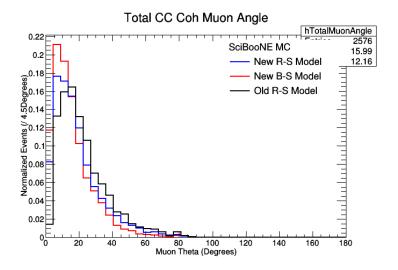


Figure 68

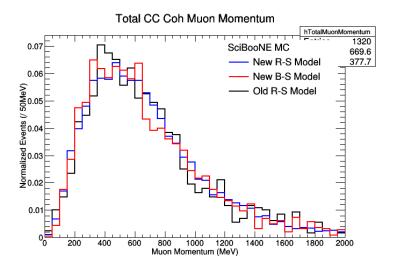


Figure 69

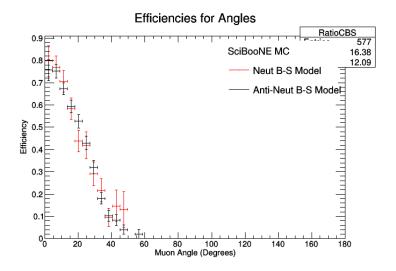


Figure 70

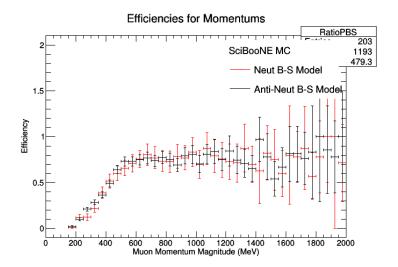


Figure 71

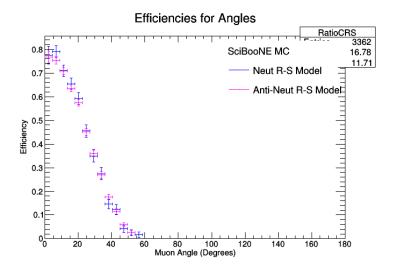


Figure 72

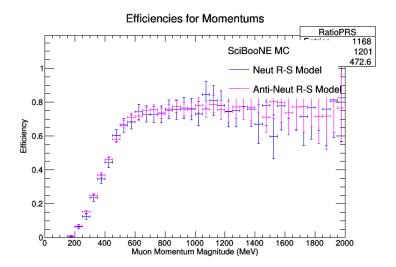


Figure 73

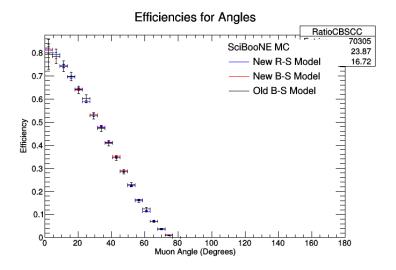


Figure 74

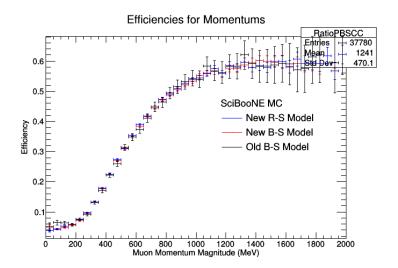


Figure 75

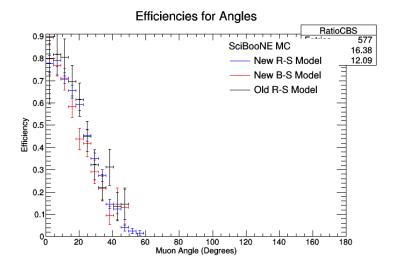


Figure 76

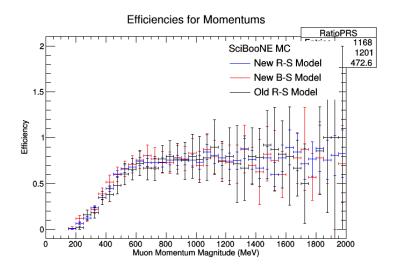


Figure 77

A.13 NMPionPlotting.C

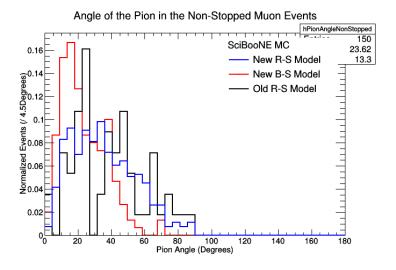


Figure 78

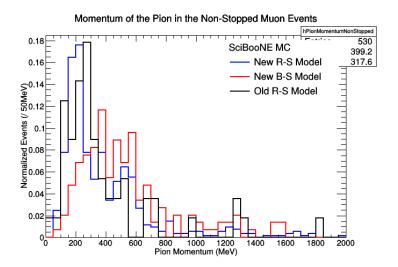


Figure 79

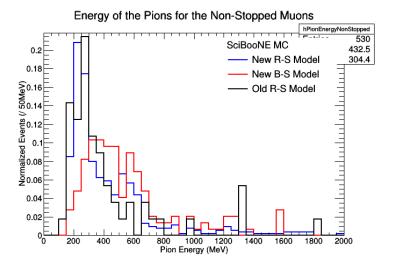


Figure 80

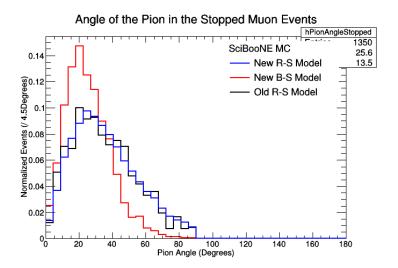


Figure 81

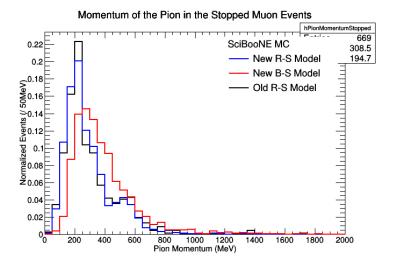


Figure 82

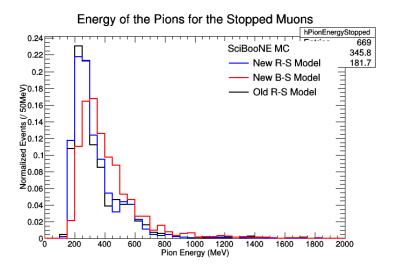


Figure 83

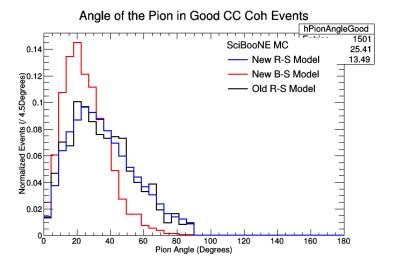


Figure 84

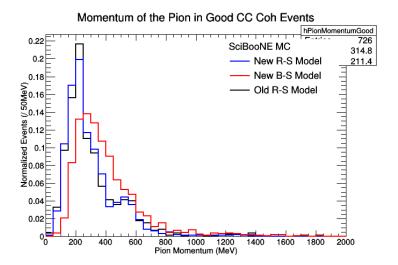


Figure 85

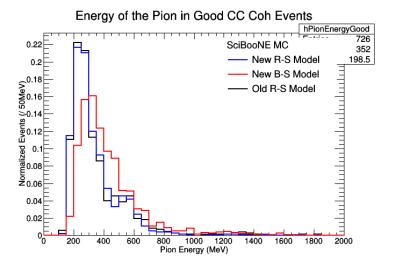


Figure 86

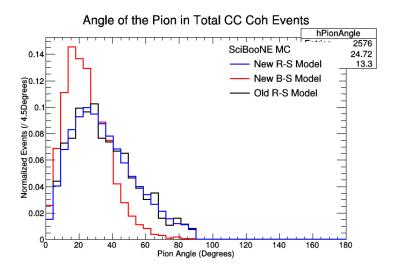


Figure 87

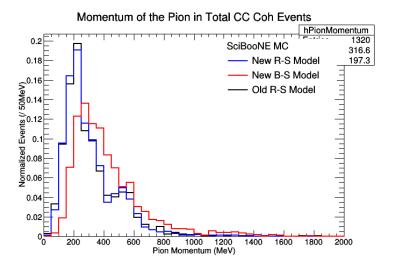


Figure 88

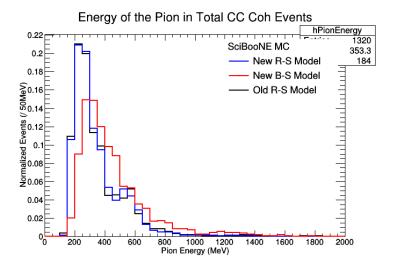


Figure 89

A.14 NMFourSquaredPlotting.C

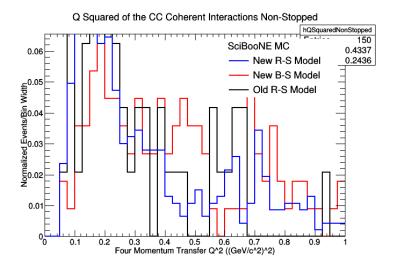


Figure 90

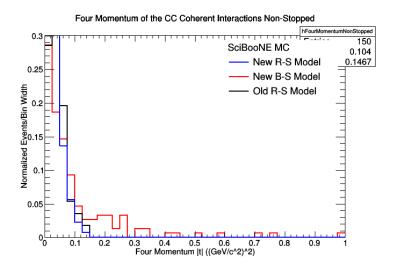


Figure 91

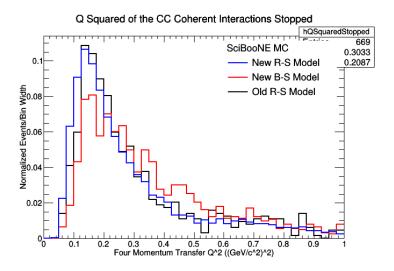


Figure 92

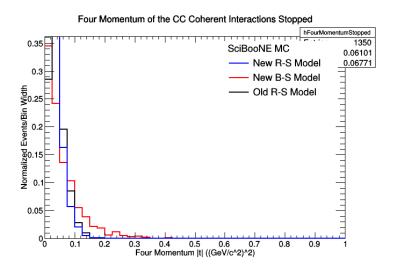


Figure 93

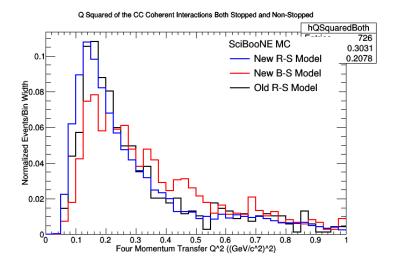


Figure 94

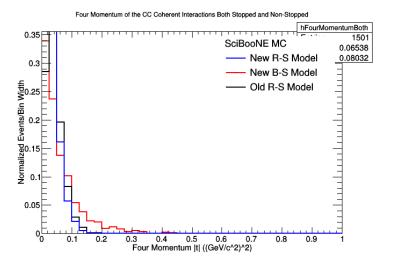


Figure 95

A.15 ANMCombinedPlots.C

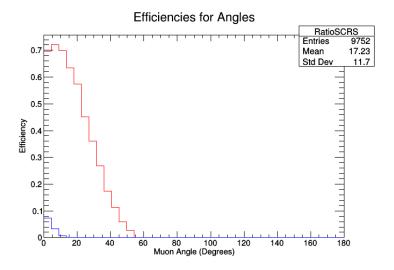


Figure 96

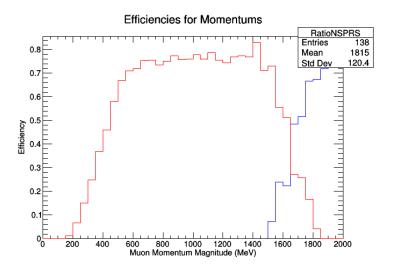


Figure 97

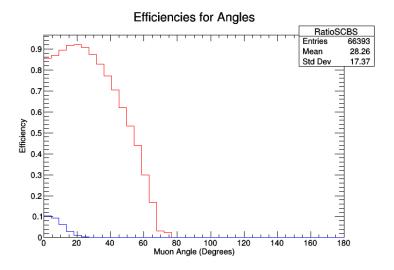


Figure 98

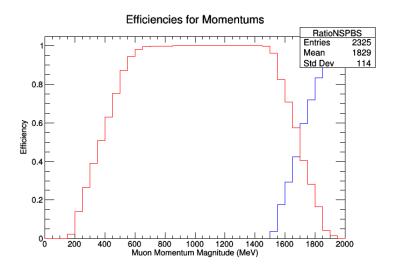


Figure 99

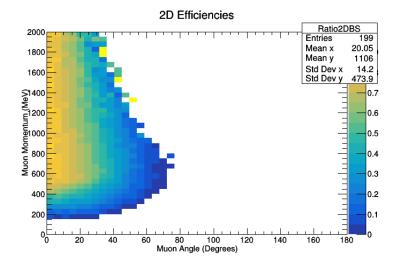


Figure 100

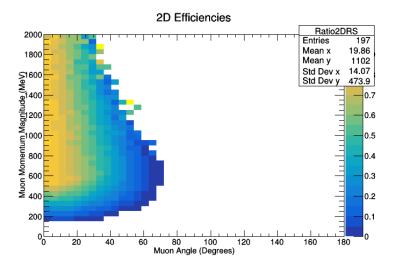


Figure 101

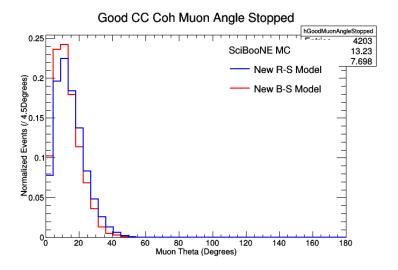


Figure 102

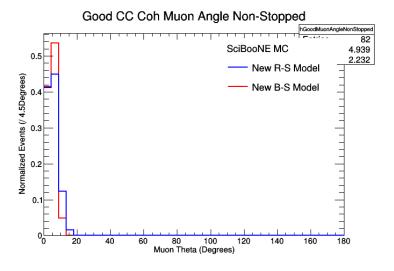


Figure 103

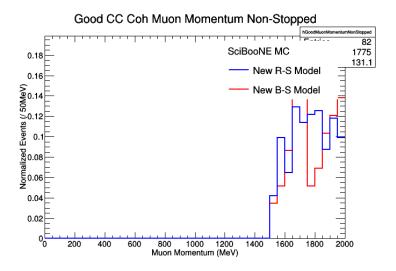


Figure 104

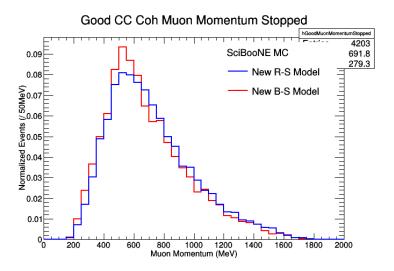


Figure 105

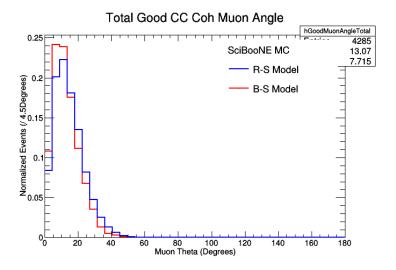


Figure 106

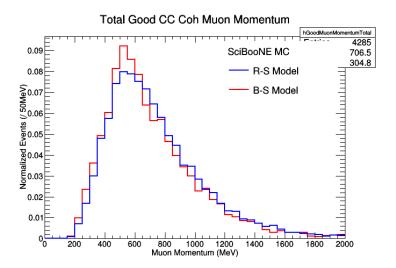


Figure 107

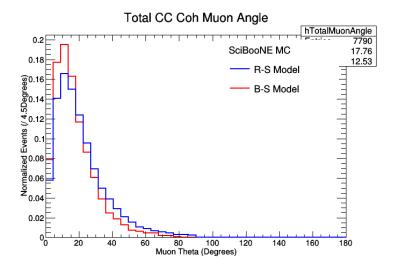


Figure 108

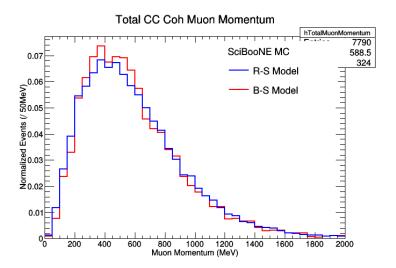


Figure 109

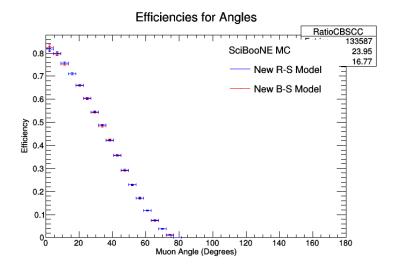


Figure 110

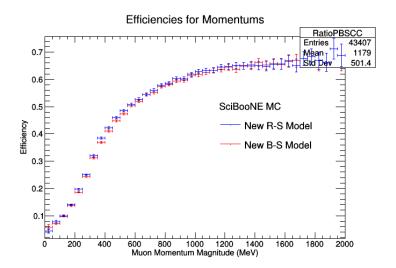


Figure 111

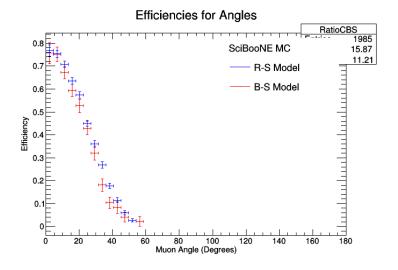


Figure 112

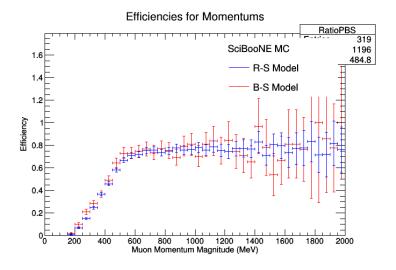


Figure 113

A.16 ANMPionPlotting.C

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

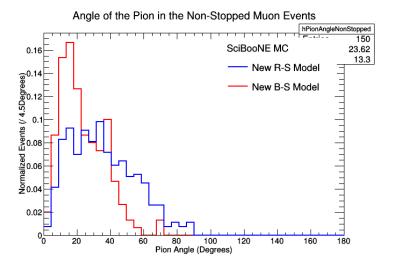


Figure 114

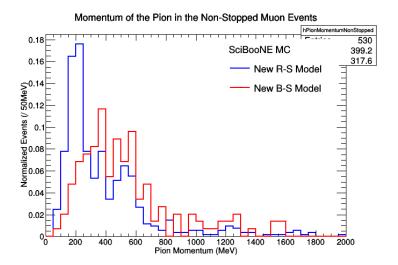


Figure 115

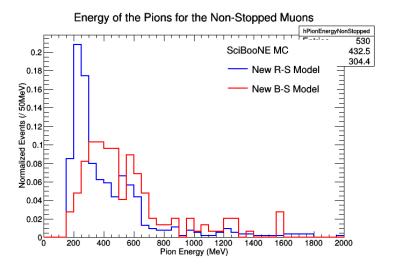


Figure 116

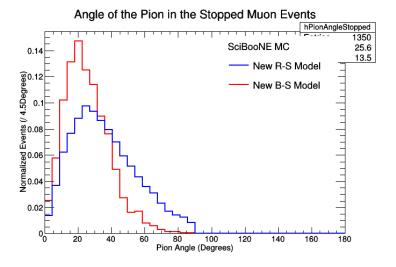


Figure 117

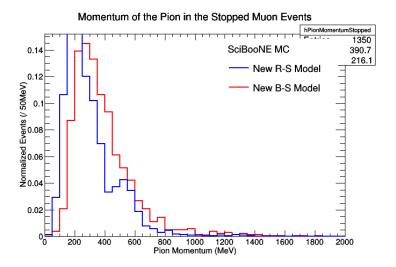


Figure 118

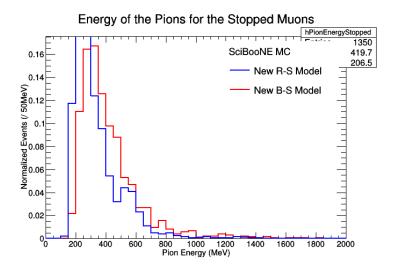


Figure 119

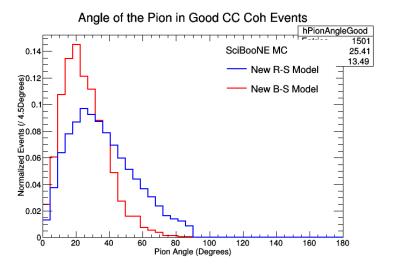


Figure 120

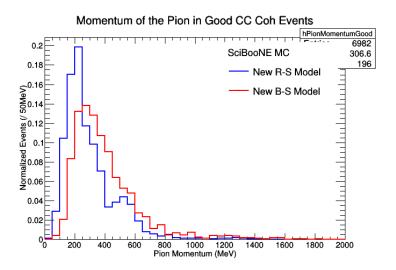


Figure 121

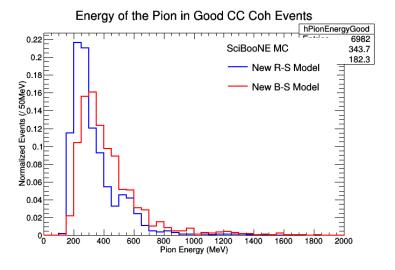


Figure 122

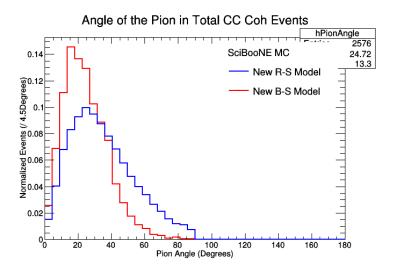


Figure 123

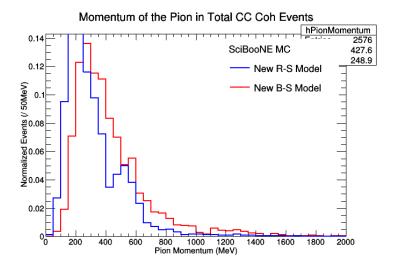


Figure 124

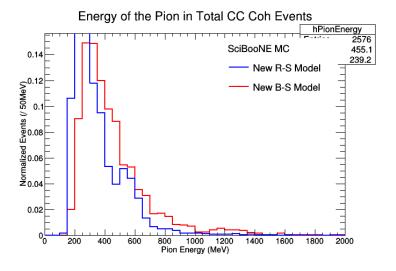


Figure 125

A.17 ANMFourSquaredPlotting.C

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

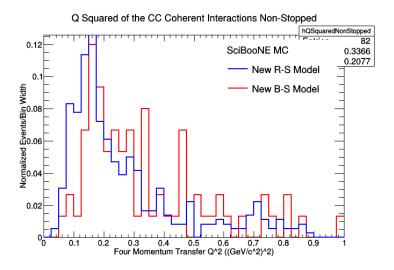


Figure 126

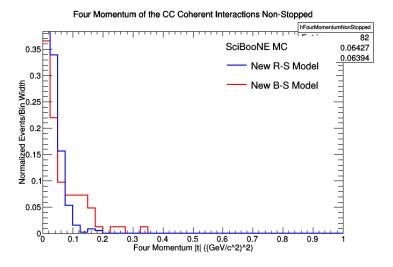


Figure 127

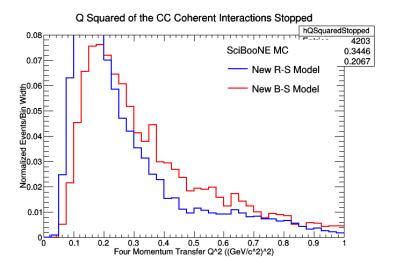


Figure 128

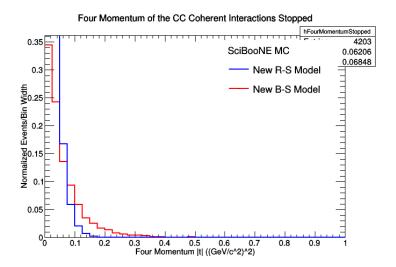


Figure 129

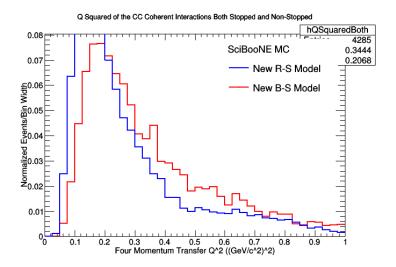


Figure 130

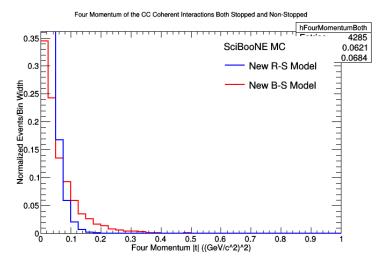


Figure 131

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 Closing Remarks and Cautions

These are just a few cautionary suggestions for potential issues that might be encountered while trying to use this code. This will also be where and further closing remarks can be made.

D Acknowledgements

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

E Figures and Tables

E.1 List of Figures

There will eventually be a huge list of figures here.

E.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

PWNMERS BEIMEV'C		= :	-	-	=	0		_	-			=		-	-	-	-	-	-	в	-	=		103 5 108 Deg 0	108-1125 Deg 0	12 5 117 Dag 0	17-1215 Deg 0	121 5-126 Deg 0	-	1315-135 Deg 0	135 139 5 Deg 0	129 5 1 44 Day 8	441485 Day 0	1.8 5.133 Day 0	133-1575 Dag B	157.5.162 Day 0	_	1855-171 Day 0	17-17-5 Dag 8
1																																							
20 100 I		- 1			_		-	_	-					-	-	-	-	-					-	_	_	_	_	_	_	_	-	-	-	-	_	_	_	_	_
130 130 130	20	-	*	*	ě	6	10.5	70	-	-				-	-	-	-	-	-		8					-	-	-	-	-	-	-			-			-	-
-	100375 02	_	-	-	-	_	_	OU 75581300		0							0		0					0	0												0	0	0
	_	= :	9,000	-	=	=	0.0832575 0.1	0.047749 0.1	_	-																									0				
	_	218182	10	- 1	_	20088	146399 0.2	1383fB 0.2	-					-																			0		8				
DF-000 000-00	1317173 0.45		234420	- 1	=	_	240517 0.32	215553 0.26	-	-	-				-	-			0					0	0												0		
1		_	1980	-	=	=	1328982 038	1260465 0.32	_	_	2100010	-		0.0165622 0.04		-			0					0	0												0		
	ш с	2	1207		_	_	381593 0.46	1322889 0.37					. 8		42	=					0											0	0	0					В
			_		_	212468	Ē	Ť	335716 0.35	_		_	106166 0.10	_	_	E		0		0	0		0			0	0	0	0	0	0	0	0	0		0			
2	0.816092 0.82	i i	17.0	-1900e	Depth II.A.	20021 0.61		-	0.5527 0.39					-																									
000	- I	7890 / 1984	27-07	0.00	0.55 U.45 U.45 U.45 U.45 U.45 U.45 U.45 U	19898 0.65	53869 0.57	48985 0.50	39772 8.4	-	-			IN	-	-		0		0	0		0				0	0	0	0	0	0	0	0	0	0			
OND DES		-	0.00		181216 11994	3967 0.628	336 0536199	20	0.410602	331977 11347877	-	_	-	œ	-	-	_																					-	
2.00	-	- 1	- 1000 to 1000	_	_	628694 0.61255	3199 0537204	0.51273	-	2000 033025	-	-	-	-	_	-	=																					-	
CORPA	687	10807		-	la di di di	12 0.617	204 0.5-633	734 0.4852-02					0 0			-	0 179			0	0		0				0	0	0				0	0		0			
onne on	0.7867	(A 1816)		= 1	=	109 0.601285	332 0.5-252	2.42		-		-	188 0.12807	10	-	-																							
DOLLO IN	48 0.798611	14 (1828)	0.090.00	_	=	_	26 0532462	72 0.455387	_	_	-	_		-	-	-	_							0	0										0		0		
Shoroan	-	= 1	ON OTHER	-	_	12925	2 052-615	77 0.439182	_	_	-	-	-	_	_	_		0		0	0		0			0	0	0	0	0	0	0	0	0		0			
	4 0815549	31	= 1	-	=	1 0578595	0.503736	2 0.459893			-	-		_	=	-																						-	
4	9 0.83-632	1000000	0.0400	-	o uspillibili	92289	0.498278	8 0.82253			-	_	-	-	0.136364	-																							
TIVE CONT.	832174	1,838.0	0.700033	-	0.4527.73	0.56538	0.453636	0.403556	0.335748	_	-	_	-	-	-	-																							
440054430	0.8835	C SHIP C	10.00.0	0.000.000	1462881	828	0.481938	0.82373	0.352837	0.27.0.47	0.216867	0.145161	0.032581					_					_			_	_	_	_	_	_					_			
Tier Tree	0.782712 0.0000	18382£	1,123.43	100000	0.6279.00	0.533719	0.446392	111111111111111111111111111111111111111	0.316279	201010	15234	_	-											_	_												_	_	_
The allies	0.807592	17,697.0	0.0000	0.0000	0.4654488	. 0.55(B)62 L	0.463785 0	0.379548			-	_					9	-	-	-	-		1	1	1		1	1	1	1	-	-	-	9	1 0	1	1	_	-
1	0.802198	= :	0.740557	-	=	0.498274 0.	0.474016 0.	0.411483 0.	_	-	-	-	133333					-	-	-	9	-	-	-	-	-	-	-	-	-	-	-	-	-	9	-	-	-	-
1	-	= :	193724	- 1	=	Ξ.	1.65487 0.3	377868 0.3			-							_				_				_					_							_	_
1	00 0	Course II.	770 O	-	=	266828	389868 0.4	=	182422 11.28		-	_		-	-	-								0	0												0		
200.140	72386 0.77	(989)		1.	9250	20000	488953 0.38	361702 0.35	_	_	-			-	-	-			0		В	0		0	0										0		0		0
1001 HOLD	-	= :	257.0 0.6017	-	-	1928 031	384615 0.8-872	355101 0.29418	_		0.2020			-	-	-																			0				
1	-	= !	75760 0 00077	= 1	=	S11166 0.513616	875 0.300577	#18 0.29578			9			-	-	-				В	В		В	В	В												В		В
AUDI AUDIEAU	80 08	= 1			=	10.63674	27 0.0.463	13334	_	Ė	-			-	-	-																							
1	0.921569	= 1	22 0.7303.0	200 000	22 0 0 0 0	74 053909	34 0.34058	49 0.32857	73 0.238016		_			-	-	-				0	В		0				0	0	0	0			0	0		0			=
3	-	= 1	0.24(1)	0.000	l assibi	0.44761	0.242901	1 0.272727	_	7,66,637				-	-	-								0	0												0		-
1020-100	12.03	= :	-	- 1	-	Φ.	0.416667	0.34875	8.25		0.02			-	-	-					В					В													_
4	0.848485	0.935	707-070	1/000/1	197/09/	Ĕ	Ē	0.227273	0.071-288	2.0																													
1930-1901	1111980	912/30	0.730.29	0.00000	/gegge g	0.462963	0.33333	0.290323	0.25										В		В																		
4200*4330	789287	1,48387	0.655005	0.4500.452	0 addition	0.379162	0.25974	153	100	12										0	0		0		_					0			0	0		0			8
10.00	0.82352	1/8/1	0.73543	1000	Habba	0.455185	0.4038-46	0.381952	0.33333					-	-	-		_	_	_	_			_	_	_	_	_	_	_	_					_			

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

_	_	_			_	_	_	_	_	_	_	_	_	_	_	_	_	_		_			_	_	_	_	_	_	_	_	_	_	_	_		_	
1950-3101	883838	0.794521	0.083030	0.622711	E4500.0	3.55.5.0	0.306835	0.137931	0.181818	_																											
1900-1950	111116	Sugar.	_	_	969207	3,451538	-	-	0.285714																												
1850-1900 19	F	701905 0.	0 8228	0 299999	÷	÷	0.353535	_	.166667 0.	0		0	0	0	0	0	0	0		0	0	0	0	0	0	0	0					0		_	0 1		0.0
1800-1850 18	-	-	_		_	_	Ť	_	.33333 0.1	_	_	_	_	_	_	_	_	_		_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	-	= 1	
_	P	_	_	_	_		Ť	÷	Ť	27 0.25	-																								-	= :	
20 1720-1800	P	4 0.770053	_	8 0.62073	0.508002	1 0.482387	Ť	Ť	4 0.214286	7 0.105057	-	_	_	_	_	_	_	_		_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	- 1	= 1	
0.170.176	-	_	_	0.6-803	0.52568		÷	_	0.28574	5 0.16666	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	- 1	- 1	
1620-17	11845826	72067	0.747423	0.637168	0.554007	0.44777	0,323,333	0.246753	0214286	0.0788237	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_			
1600-1620	19962230	0,728648	0.664251	0.648629	0.538375	0.535354	0.3622-55	0.3086.22	0.181818	G-428571	173																										
1550,1600	176742	0.741784	0,71,7833	0,66548	0.587356	122	0.416667	0.2931G3	7:08I	0.0526316	0,333333																						_	_			
200123	873016	120000	0.2807	558863	590654	48-0-63	1433735	1277372	12321-8		0.0714286																										
1.56.150	0 262238	2003	2089	0 82979	2829	÷	÷	Ť	0.30.819	0.157855 0	0.25	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_			
1400 1450 1	F	75-5716 0.	753835 0.	52251 0.	9819 0.	0.0093 0.	0.451791 0.	381395 0.	348624 0.	1.22222 0.	0.136364 0.	_	_	_	_	_								_	_	_	_	_	_	_	_	_			0 1	-	
320 1400 140	F.	702094 0.7	9	0.0	612863 0.72	209404 0.4	.d55169 0.4	33354 0.3	_	231884 0.2	T10 250001	_	0.0	_	_	_	-	-	-	-	-	-	-	_	_	_	_	_	_	_	_	_	-	-	-	-	
E	P	_	_	_	502 0.61	_	_	_	525 0.328	Ť	_	_	_	_	_	_	_	_		_	_	-	_	_	_	_	_	_	_	_	_	_	_	_	-	= 1	
300 1300-135	F	_	0.70886	75 0.08321	0.207	_	6 0.431408	13 0.389207	0.366279	74 0.197368	32 0.083232	0 161	-	-	-	-	-	-					-	-	-	-	-	_	_	_	_	_	-		-	= 1	
50 12301300	-	0.774205		22.18970 2	0.5793	ei N	0.426-556	0.405963	1 0.38785	0.189-574	Ť	31 0.090909	0.11111				0	0	_	0	0													_	- :	-	
1200-125	28.81	0.784204	0.73B677	0.700-657	0,60516	0.53566	0.474730	0.406551	03006	0.233918	num.	0.075923	_															_	_	_	_	_	_				
1130-1300	11820258	0.814336	0.717308	0.683544	0.630074	0.528678	0.444332	0.397764	0.295117	0.214286	0.138879	0.097361	0.0202091	_	_	_	_	_		_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	-		
1100-1130	0.813725	16111081	0.733735	0.705101	0.6-0.326	0.557520	0.475651	0.437118	0.325.411	1272981	0.180723	0.0859365	0.0344828																				_				
1020-1100	870	0.82-40-45	0.770286	0.7086	0.633392	0.571780	0.490654	0.411755	0357923	0.264716	0212820	0.133838	0.0851054	_	0.166667									_	_	_	_	_	_	_	_	_	_				
0201-900	988//	227087	256738	703534	2522297	571275	227727	142383	(342320	152-521	23670	132184	10617284	0.0333333	0.0714286																						
20.000	F	722G7 R	70384 0.	683544 R	334515 R	100 T/S	518553 R	451835 0.	368859	313023 0.	202232	151292 R	108844 0	2	0.0-0.0567 0.0	-	_	_	-	_	_	-	-	-	_	_	_	_	_	_	_	_	_	_	-		-
500.930 95	=	0	0	702804 0.0	65554 0.0	0.0	517520 0.0	C461108 0.4	3650-22 0.3	312284 0.3	219613 0.3	0.142512 0.1	1117773 0.1	0.0428716 0	0.0227273 0.0	_	_	_	0	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	-	= 1	
Г	F	÷	2	=	661634 0.63	281746 0.5	6	Ť	4m812 n3	305206 0.3	_	120744 0.1	118863 0.1	JIG825 0.0	0.035 P. B 0.03	0.03125 0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
20 820-200	Ē.		0		0	0	_	19 0.42864	_	<u> </u>	0	0	_	=	-	0.03	_	_	0	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	- 1	= 1	
0 800.830	Ē	-	-	÷	÷	Ī	÷	÷	64 0396520	52 0323817	÷	58 (1)61473	11 0.105568	528 0.0780781	136 R0162162	_	0 201					-	-	-	_	_	_	_	_	_	_	_	-	-	-		
750.80	-	0.80021	0	0.732403	0.661647	0.622306	0.53257	0.494205	0.352764	0.331052	_	0.197558	0.118211	9 0.0845538	0.0.26135		51 0.0123457	_		_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	- 1	= :	
200,750	0.84337	0.814286	0.78270	0.75270	0.689.0	0.637363	0.551891	0.479320	0.40383	0.330302	0.358858	0.30450	0.125182	0.0060020	0.0363636	_	0.006.0351	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	- 1	- 1	
002-029	0.864865	0.801402	0.794269	0.749489	0.677215	0.615-445	0.054788	0.402462	0.425845	0.345987	0.359272	0.19-403	0.135583	0.0205091	0.039056	0.0166667	0.00280809	0		0	0							0	0	0	0	0					
029-000	(188) 433	0,805305	1877.080	0,730.172	1687027	896290	1264264	0.488325	0.419254	03-20579	0.261-186	0.20203	0.120520	00780856	0.0367232	0.0195072												_	_	_	_	_	_	_			
009 025	30702	601218	738274	736387	.02331	72252	254516	472959	387314	319185	244851	1187-24	803817	0.0700216	0.0436238	0.011-213																					
200.530	.895522	3,811448	28089	727545	202929	378365		36444	386159	30273	24054	169353	1,119633	0.0534228	8811920	73037	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_			
Ë	F	Ť		_	_	_	_	_	_	_	_	_	Ī	_	0.0242928 0.1	3000740-856 0.1	0	0	-	0	0	0	0	0	_	_	_	0	0	0	0	0	-	_	-		0.0
20.30	F	1 0.773279	_		3 0.582547	Ē	Ĭ.	Ť	2 0.327-0.0	3 0,272.452		4 0.1-18533	6220110 22	OF 0.0768421	_	80	-	-				-	-	-	-	-	-	-	-	-	-	-	-		-	= :	
400-50	0.61538	-	_	_	Ť	_	_	-	0.275212	0.22483		4 0.125334	3 0.0810065	7 0.0457306	0.00745573	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	- 1	= :	
320-400	0.596566	0.478261	0,4633-8	0,448833	0.415013	0.381265	0312166	0283494	0233583	0.192308	0.141328	0.0928814	0.05522683	0.0128637																				_	-		
300.350	0.42222	0.306694	0.352563	0.330233	0.318452	0.321879	0.25338	0.218271	0.170164	0.129657	0.0040285	0.0531873	0.0199523	0.0007-285			0	0		0	0							0	0	0	0	0					
256.310	325	235849	223229	1201736	228145	1197461	1172859	0.1.2232	0.0817963	0.0078972	0.0202038	0.0110121	0.000-555314																								
200 220	F	_	-	2	10573451 R	÷	=		0.032338 0.		n 701-15210.	2	2	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0		_	0 1		
L	F	_	_	_	-			0.0 7545700.	00	00	99						0	0		0	0							0	0	0	0	0		-	-		
100 150 150 200	0	0.0025	0.09375	0.03	0.03	0.03	0.00	0.00	0	0	_	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	- 1	= 1	
20.100	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	_	-		-
B 30 MeV/c 3	f	٥	۵	۵	۵	_	۵	_			_						٥	٥	_	٥	۵							٥	٥	٥	۵	۵		_	- 1	- 1	_ 0
	-		0 55	0 260	0 260	20	0 260	20	-	-	20	-	-	-	-	-	200	0 260	20	0 260	0 260	-	Dug D	1 Day	Dog 0	T Day	Dog 0	0 Day	O Day	O Day	O Day	1 Deg 0	O Deg O	Deg I	e i	a de la compania del compania de la compania del compania de la compania del compa	20
New NM B-S	Nac co-n	4.50 Drg	9-135 Dc	135-18 Dey	18-22.5 Day	225-27 Deg	27-31.5 Day	31.5-36 Deg	36-40.5 Dec	40.5-45 Dry	45 40 5 Dey	495-54 Dry	54 38.5 Deg	585.63 Deg	63 67.5 Day	675-72 Day	72.75.51	765-81 Day	81-85.5 Dag	85.5.90 Day	98-94.5 Day	945.99 Deg	99 103.5 Deg	103.5 108 Day	108-112.5 Day	112.5-117 Day	117.121.5 Day	121.5 126 Dag	125-130.5 Day	130,5-135 Day	135-130.5 Dag	120.5-144 Day	144-1-8.5 Dag	148.5 153 Dag	133-157-5 Dag	10/co.102 LPg	105 5 171 Day

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

88 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6	
1.0.2.3.33.33 1.0.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1	
0.8522533 0.870 0.75 0.675 0.625 0.6	
0.85.70 4.8 0.95.80.33 0.95.80.33 0.97.70 9 0.97.70 9 0.	
2000-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-	
5 5 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	
2.52.53.53.53.53.54.54.54.54.54.54.54.54.54.54.54.54.54.	
2	
6.50 6.50 6.50 6.50 6.50 6.50 6.50 6.50	
1.519195	
8833333 775555 775555 775555 77778 7778	
8.57 8.67 8.68	
8353333 87 825 87 827 87 82	
2 (2) (2) (2) (2) (3) (3) (3) (3) (3) (3) (3) (3) (3) (3	
= La , La L	
7.57. 9.10.	
200 055 100	
77 10 10 10 10 10 10 10 10 10 10 10 10 10	
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	
13 19 19 19 19 19 19 19 19 19 19 19 19 19	
19645 18881	
777777 7777777 862777 7786 86277 7786 7786 86277 7786 86277 7786 8617 7786 8	
55. 57. 75. 75. 75. 75. 75. 75. 75. 75.	
8 27 27 27 27 27 27 27 27 27 27 27 27 27	
74777777777777777777777777777777777777	
8 4 7 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	
n nan-h- ana-8 n	
20 C S S S C C C C C C C C C C C C C C C	
74 0.28 (1998) 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1	
2 466674 2 46674 2 5 6 6 6 78 77 2 6 78 77 2 7 7 7 1.08 200 2 7 7 7 1.08 200 2 7 7 1.08	
2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2	
18.5 19.5 14.4 14.4 14.5 14.4 14.4 14.4 14.4 14	
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	
10.77 L256 10.77 A T T T T T T T T T T T T T T T T T T	

19.4.3 Dec. 19.4.4.2 Dec. 19.4.3 Dec. 19.4	162 166 5 Deg 166 5 171 Deg 171 175 5 Deg

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

_	_	_		_	_	_	_	_			_	_	_	_	_	_	_	_	_	_	_	_		_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_
1930-20E	0.715882	8812125	B688776	0.635714	218150	0321430	2	2	=	Φ		_						= 1	=													_	-	-	-			-	-		
1900-1950	0.884658	0.74335	0.719368	0.648275	0.635294	0.6.5759	10		=			_						= 1	=		В	В	В	В								_									
1858-1966	0.783784	0.55991	0.698052	0.615385	0.522523	0.300.44	8		-			_						= 1	=													_	-	-	-			-	-		
1800-1830	0.808989	H-73-4982	0.711469	8-86090	0.56923	0.497979	030200		9			_							=													_									
1730-1800	0.835356	0.786323	0.718579	1648734	152377	0.422233	0.55		_			_						-	_													_									
1308 1750	0.836538	863-670	191102	818189	0.03852	0.49.4382	55974		e.			_																				_									_
1658-1788	88	0.7331-6	12327	0.628592	19191191	0.515385	2,488.77		1033333	2									_																						
1600-1650	81315	0.732484	0.724876	18229	53882	38.000	346154		233333			_							_													_									_
1359-1600	0.802721	98168	219912	590237	182281	100000	29000	000000	26593	799991		_							_													_									_
1588-1538	2812842	0.7907.B	1672617.0	63144	59465	251370	E9185.0	1	1282831	142857	033333	_							_	_				_								_	_	_	_			_	_		_
450 1500	820896	15100	712513	8181891	597598	488,432		-	_	-	_										_	_	_	_	_	_	_	_	_	_	_									_	_
400-1-60	905-881	.793201	616122	860094	568153	201000	45.405		70672	192308	7	_	_						_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_		_	_	_	_
	÷	730123	229168	228999	582904	535011	12852	-	/09/25	1263625	127277								_	_	_	_	_	_																	
388-1330	Ť	92.627	_	0 62233	÷	52286	467102	_	_	-	unur 0	-			_	_	_															_	_	_	_		_	_	_		
258-1318 1	829352	819524	0 662927	882373 B	296406	5,4507	54714		=	Φ.	22222		_		2	_		21	_																						
200 1230 1	_	799636	7,45802 0.	700468	0 268191		~		=	_	203125 0.	1235294 0					2 1	21	-	_												-			_	-		_			
7	_	_	12642	=	÷	-	-	_	=	Ĕ	=	3000	-						_	_	8		8		0	0		-	-	-	-	_								-	
-	~	33486	-	68934 0.	_	-		-	=	Φ.	_	2	0 222230		0.0	0.0		= 1	=	0	0	В	0	0																	0
58-1100	_	780172	_	69735 0	6.49533 0	0 222	50302		=	Ť	0.287736 0	23-0-68	-	-	0.0	0.0			=	0	0	0	0	0	0	0	0	0	0	0	0									0	
B 1030	Ξ	=	_	718415 04	6463-65 0	283087		2 0	-	=	311653 02	2519 IB	-	2000	200	0.0		= 1	=	0	8	В	8	8	В	В	В	0	0	0	0									0	0
28-1000 10	21	79961	0	715178	1656827 0.3		0 0	3 0	=	366126	27393 0.5	218107 0.3		-					=		В	В	В	В	0	0	0	0	0	0	0	_								0	
00 930	9	816404	769928	699029 0	16-49262 11	-		-	-	374224	279793 0	214834	-		0.02.22.20.0	1105	7		_	_	_	_	_	_	_	_	_	_	_	_	_	_								_	_
28-9ED 9	Ť	22,928.5	78877	723165	0 102391		-	-	-	40734	329013	Sums.	-	_	-				_	_	_	_	_	_				-	-	-	_									_	_
E8 E8	83-821	15EE	618822	16224	116129	785767	98.25.85		1959	6988	30,7036	235294	125556	191076	_		-		_	_	_	_	_	_	_	_	_	_	_	_	_	Ī								_	_
T	280087	80314	7227	16987	57,000	2100	250,677	1	2,525	92538	343166	1.552766	18063	191564	10000	1000	7		_	_	_	_	_	_	_	_	_	_	_	_	_									_	_
00 Z0	846154	1228	380004	72938	675312	GIRGIN 2	-	-	9000	1528	333774	280552	185201	100100	-			0289820	_	_	_	_	_	_	_	_	_	_	_	_	_	_								_	_
20 400	81697	807565	7494	28165	28289	631820	2020		all sall sal	768151	133394	27338	2000	1300.00	200200	0.00000	1000	1007-170F		_	_	_	_	_				_	_	_	_			_					_	_	
Ť	_	_	_	246173 0.	Ξ	-	-	-	=	=	346117 02	254128 02	-		-	-		10 SZB4400	=			В			В	В	В	0	0	0	0	=								0	0
7	=	_	_	1254711 0.3	÷	-	1566528 07	-	=	=	=	1250172 0.5	-	3 0	1001000		_	101103103	=		В	0	В	В	0	0	0	0	0	0	0									0	_
-	81232 08	=	778963 0.5	=	Ŧ	-	202003	-	-		Ē	f	-	_	_	-	_	Hotolet III	=		8	0	8	8	0	0	0	0	0	0	0									0	_
170	-		_	542508 0.7	=		0 0	2 0	=	Φ.	268313 0.30	212046 0.22		0 0	9 0	0 0	9 1	2 1	=		В		В	В								=	-	-	-	-		-	-		
7	_	270 9161191	3528 0.65	529018 0.6	50 6120	200	38230		3	29-63	188	177444 0.23	_	_		-	_	= 1	=													=	-	-	-			-	-		
909	-	_	27 856.	71 052	98 050	597 0 788	138	100	124	302	825 0.2267	13	-		_	1		= 1	=		В	0	В	В	0	0	0	0	0	0	0	=				-	-			0	
330-4	_	406 0.52265	555 0.559.27	408 0.62	15 0.200	181	202 0 2181		17.00	67 0.222.	976 0.200.	JA9-64 0.3313	065882 0 103003	-		-		= 1	=		В		В	В								=	-	-	-			-	-		
300	2	9221406		10.372408	4 0.324	0 38.407	0 0		10.215	2 0.168	72 0.131	_		3 0				= 1	=													=									
250.388	=	7 0.254881	Φ.	2 0.264642	8 0.24095		0 0	_	_	=	G1 0.0757272	0.047888	0 01144	0 00025 4017	-			= 1	=						0	0	0					=	-	-	-			-	-		
200.256	_	2 0.179487	_	9 0.162912	3 0.135068		3 6	9 0	_	0.0358187	0.0164051	=			0.0	0.0		= 1	=													=									
2	0.037037	0.0538922	0.0881226	0.030295	0.0457253	0.075681	0.0135.247		0.0152636		0	_						= 1	=			0			0	0	0		0		0	_	=	=	=			=	=		
188 188 158					=				=	-		=					-	= 1	=			0			8							=	=	=	=			=	=		_
MeV/c 56-10		0	0	0	=				=	=		=			0.0	0.0		= 1	=	0	0		0	0								=	-	-	-			-	-		
0.50 N					18-22.5 Dev III				=	-	-	=							=	-	-	-	-	-	0 14	103-108 Day 0	10g	112.5-117 Deg 0	117-1215 Deg 0	102	126-130 5 Deg 0	1315-135 Dev 0	135-1395 Dev 0	135.14 Dec 0	141.485 Dev 0	148 S-153 Dec 0	133-1575 Day	157.5 182 Dev III	162-1665 Dev 0	165-17 Deg 0	0 Mag
ANNURS			9-13.5 Drg			225.27 Dec	27.31 5 Dec	1 00 00	÷	36-40.5 Deg	40.5-45 Deg	15-41.5 Dec	105.54 Dec	1 70 5 70	The Court of	CO CO CO	Ť,	Brank Ing	Cartio Ing	765-81 Deg	1.85.5 Deg	35.5 90 Deg	30 945 Deg	345.89 Deg	99-103.5 Deg	Η	IB-1125 Deg	8	8	9	8	9	. 8	8	Θ	5		- 0	9	Э	74755 Day

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

	_																																				
1930-2000	0.8(0524	0.821239	0.663507	0.613924	0.487173	0.482730	22222							_		_																					
	823328			14501888	1352632	0.405405	203300	,																													
39-19III	161221			÷	-	297297	-	7		_	_	_	_	_	_	_	_	_		_		_	_	_	_	_	_	_	_	_	_	_					
9-1850 18	15789 8.2	78723 0.7	0.698895 0.4	27737 04	_	0.442623 0.0	5 0				_	_		0		0	В	0	0		0	0	0	0	_	0	0			В	В	В					
180 18	252	1523 0.7	0.727488 0.498895 0.	2834 1689	-	4678 0.4	-	. =		-	-	_													_												
128					_						_	_													_										-		
			29 0.698795				0 10000					_							0		0				_				0						-		
20 1630-1	5 825248	ä	_	=	=	6 0.477273	5 0	_																													
_	E1280 .	_	_	_	_	0.69945			17			_													_												
1530-16	0.825397	=	_	=	=	0.469828		1.06667	17	в	_	_								в					_												
_	0.823129	_	0.736546	_	0.381722	0.201502	1000	1	-																												
1420-15E	2999880	0.785739	0.714434	0.667735	0.570149	0.493539	0.00000	15786			_	_													_												
1400-1-50	88	0.79651	69057.0	0.683562	0.003365	0.518738	700000	0.242424	0.285714		В	В								В					В												
330.140	1813084			664591	524873	504687	20000	410236	nini	1.7	_	_	_	_	_	_	_		_		_	_	_	_	_	_	_	_	_	_	_	_					
300-1350		791063	72022	689633	386435	548585	2000	28883	216526		_	_		_		_								_	_	_	_									_	
1 HE 12 HE	Ë	Ĕ	Ť	Ĕ	Ĕ	23848	_	_	-	13333	_	_	_	-	_	-	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_					
0.1250 12	-	_	_	_	-	99000	5 0		-	1285714 0.0	_	_	0		0			0		0					_			0						-			
	F	_	Ť	Ĕ	Ĕ	537256 0.5	_	_	-	11-2857 0.2		-							0		0				-				0				-				
H50 113	H	Ï	Ť	_	_			_	_	_	857 8	_													_												
1100	F	÷	-	=	=	187 0.543549	-		_	332 0.196429	_	9231	-				0		0		0	0	0	0	_	0	0		0	0	0	0					
150 1030-1	-	Ï	Ť	_	_	39 0.583187	20 0 20 0 20	_	-	39 0.195652	_	0.075													_												
1001		52 0.803085				96 0.369439				22 0.229299		-										0															
939-10		28 B.3549	12-12:0	E 17:10	E 0.6578	0.20786	0.000	98 134316	88 0.2943	68 0.22222	B 0.1489	54 B 2857																									
	⊢	=	_	_	-	2012 2012 2013 2013 2013 2013 2013 2013	0.0	_	-	_	_	0.1-9254	_												_												
	2202280 8	=	<u> </u>	Ξ.	=	5 0.502548	0 0			-	=	_	14 0.088889	_											_												
	H	-	0.75586	=	_	0.603815	0.0		-	Ť	-	-	-	3 0.0552381																							
-	-	-	0.781453	-	1673-84	0.009545		129820		_	-	_	0.0851064	0.003333		0.483333									_												
7E-220	706258.0	0.823651	0.773578	0.736466	0.686069	0.604635	0.00000	0.407023	0.337821	0.287346	0.176355	0.12-426	0.0846372	0.067847	0.013698										_												
658-700	20611-80	0.814583	0.785362	0.748866	0.689579	0.629526	1000000	0.4229-6	0.3-8088	191720	0.20357	0.1-0563	10019367	0.0387354	0.01652486	0.0366667																					
	1834184	182494	0.774114	174733	1219891	82828	120100	1,418747	337145	1232555	13864	11-8609	1088785	1.0-446927	8121648	_	_	_	_	В	_	_	_	_	_	_	_	_	_	_	_	_				_	
П	г	_	0.786837	_	1,701815	16-6331	9000	Am137	316985	123659	1194822	0.128324	0.0804312	0.0497512	10041-038							_	_	_	_	_	_										
					=	0.600138 0.0	-	9 6	_	0.229012 0.2	_	_	_	=	0.00373309 0.0				0		0				_								0.0				
Ī	Н	_	_	_	_				_	_	_	_	_	_	001829K3 000				0		0	0	0	0	-			-							-		
9899	21001210 1	Ť	Ť	1 0.638281		0.51675	0.000000	12225	1 0.272047	Ť	_	_	=	=	100																						
400 - 50	-	0.613402	_	_		28240	0.0000	128588	0.23526	_	-	-	_	0.00793003																							
330-400	86816178	15.4867	0.480322	0.414129	0.423721	0.38573	100	123452	0.172-68	7777218	961010 2		0.0150616												_				=								
300.350	8.21384	170	0.353012	0.336159	0.319925	0.312657	0.0000	16869	0.137308	_	71891510	0.021052													_												
230 300	0.283186	0.269231	780172.0	=	=	0.204236				_	0.0113568																										
200.230	2834418	163094	0.13(019	0.149742	0.137774	0.109134	0.00.00.00	0.044674	0.0210938	В																											
П	1.093(233	2999918	0.0700935	0401338	1877778	8196464	Elerena de la constante de la				_	_	_	_	_			_		_					_			_						_			
100-150	0 0	0		0	0		20			0	0	0					0	0		0		0	0	0	0	0	0			0	0	0					
20.40			_																	В																	
New ANM B S 0.50 MeV/c 50.100 100.150 150.200	0		0								0	0								0					0												
NAME OF	1 3ac	Jeg T	Dog	S Dog 1	5 Deg 1	225.27 Day	200	Dow	Dog.	2 Day	1 Dogs	5 Dog 1	3 Deg 1	5 Deg 1	2 Deg 1	5 Deg 1	1 Deg 1	5 Deg 1	1 Dog	5 Dog 1	4 Dogs	2 Day 1	UR Dog 1	25 Dag 1	UZ Dog 1	15 Dog 1	136 Dog 1	102 Day 1	120 Day	195 Dryg 1	144 Dog 1	85 Dryg 1	150 Day	2000	S Dow	166547 Deg 0	AS Doe
New A.	B-45 E	45.9 E	9-1351	135-18	18.22.5	225.27	215.95	36.40.5	40.5-45	45.48.5	495.54	25	585.63	63.67.5	675-72	P	765.81	81-85.5	855.96	98.945	945.99	99-103	16551	168-112	112.5-1	117.12.	121 5-1	126-13	1382	135-13:	1385	14414	14852		162.166	166.5-4	6