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New Evaluation Neutrino Fluxes at Reactor

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ABSTRACT

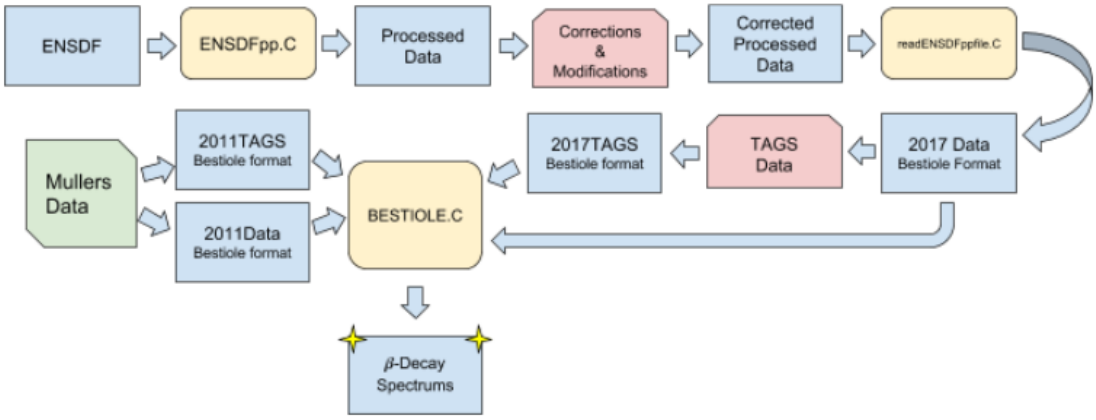
This is a detailed report of my internship at Commissariat à l'énergie Atomique et aux énergie renouvelable (CEA), with the New Evaluation Neutrino Fluxes at Reactor (NENuFAR) group. The goal of this internship, is to utilize recently released Evaluated Nuclear Structure Data Files (ENSDF) and compare the difference in the antineutrino β-decay spectrum from previous studies [1]. This included creating a comprehensive understanding of ENSDF, developing data formatting and assumption rules. As well as, bench marking present day data to previous data, which includes developing ab initio β-decay spectrum. The results from this report will show 92Rb, 96Y, 142Cs and 93Rb contribute significantly to the over all beta spectrum for all data sets, as well as, the 2017 ab initio spectrum tend closer to the Institute Laue-Langevin (ILL) experiment. The prospective for this work will hopefully bring a greater understanding to the antineutrino anomaly.

1 INTRODUCTION

The reactor antineutrino anomaly is the discrepancy between the β-decay spectrum's of experimental and theoretical data. Reevaluating the updated experimental might give insight into the underlying cause of the anomaly. The comparison between 2011 to 2017 data will act as a benchmark for how the data has changed over time. To take the updated data from ENSDF to β-decay spectrum requires several steps.

The steps to get from ENSDF into β-decay spectrum are shown in figure 1. The ENSDF files contains information regarding nuclear data, such as half-life, spin, parity, end point energy, isomeric state and lot more. Example figure 4. The ENSDF files come directly from the

Figure 1: Evolustion Of ENSDF to β-Decay Spectrums



National Nuclear Data Center. They are then ran through ENSDFpp.C. ENSDFpp.C extracts variables for β- and β+ decays like, endpoint energy, branching ratio, spin/parity and others which will generate our Processed data. There is an issue with ENSDFpp.C and the script is unable to differentiate between isomeric state one and two. This means the Processed data must be corrected. After the corrections, Processed data is sent through readENSDFppfile.C script. This script removes keywords and β+ branches, it formats the data to be BESTIOLE compatible and additionally applies assumptions for classification of β-decay. Applying Total Absorption Gamma-ray Spectrometer (TAGS) to 2017Data will create 2017TAGS. 2017TAGS is corrected for the pandemonium effect where 2017Data is not. These two data sets are sent through BESTIOLE.C. This script uses the ab initio (summation) approach to determine the total antineutrino spectrum. The β-spectrum's will then be compared to previous studies.

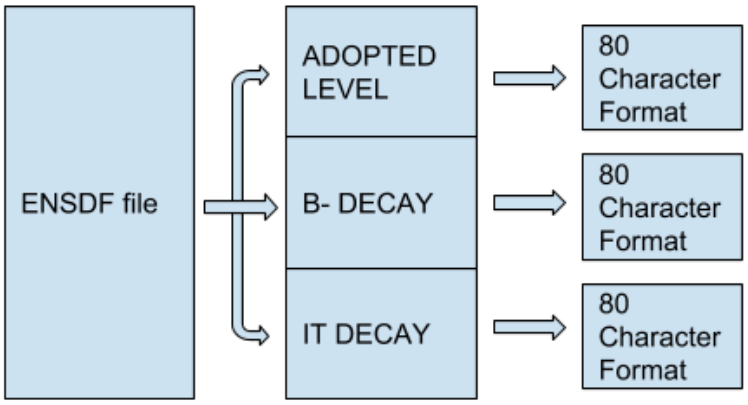
2 ENSDF

To arrive at 2017 data with and without TAGS corrections, the starting point I will use us the ENSDF manual [2]. Understanding the manual is important, to read ENSDF files which are very complicated.

The ENSDF files are structured like figure 2. There is the ENSDF file which is broken into several sections, which are called ADOPTED LEVEL, β- DECAY, IT DECAY... etc. These sections are then broken up further into an 80 character format. *Note: in this section I will refer to pages in the ENSDF manual.*

The 80 Character Format Records can be found on page 31 or Figure 2. follow along by opening an ENSDF file (found in the NENuFAR folder) or use the sample Figure 4 provided. The first two rows of Format Record (Figure 2) indicate the column or character number (the first two rows are not printed in the files). Each row is expressed with an abbreviation. IDENT is the abbreviation for The Identification Record found on page 10. IDENT is broken into fields, such as: The field Nuclide Identification, abbr NUCID. NUCID is found in columns 1-5. The

Figure 2: ENSDF General Layout of File.



next field is: Data Set Identification, abbr DSID. DSID is found in columns 10-39. The next field is: Reference to Main Supporting Publications and Analyses abbr DSREF. DSREF is found in columns 40-65. The different fields and rows express different information pertaining to that particular isotope. You can see that the Q-Value row has very different fields then the Level row.

Attention should be given to the ADOPTED LEVELS section, and the Level row (row underlined in Figure 4). This row is important because ENSDFpp.C can't differentiate between isomeric state one and two. This row will be used when corrections are made by hand, more in depth procedure will be outlined in section 3.

KEYWORDS IN ENSDF DATA

Inside the ENSDF data as well as Processed data, there are keywords associated with the spin/parity for most β- branch. In Table 1 the keywords are shown and there definitions are given. There are many more keywords, however, these are the only keywords I worked with. Some of these keywords made it hard to code for, so some are modified by hand. Table 5 indicated the modified β- branch but section 3 will go into more detail.

CONTACT PERSONNEL FOR ENSDF DATA

If there is any confusion or if anything else is not clear with the ENSDF manual please feel free to contact me KOT, Paul paurukot@gmail.com. If you need more assistance with the ENSDF manual contact JOHNSON, Timothy johnsont@bnl.gov I think he works at the National Nuclear Data. Or contact MOUGEOT, Xavier xavier.mougeot@cea.fr he is at CEA-Saclay.

ENSDFPP.C

Running ENSDFpp.C you must input your own boundary conditions for the data that you want outputted. Table 2 indicates the settings used to obtain the 2017 data. The minimum branch strength was chosen based on Mueller *et al.*[1] data's.

Figure 3: ENSDF 80 Character Format Records.

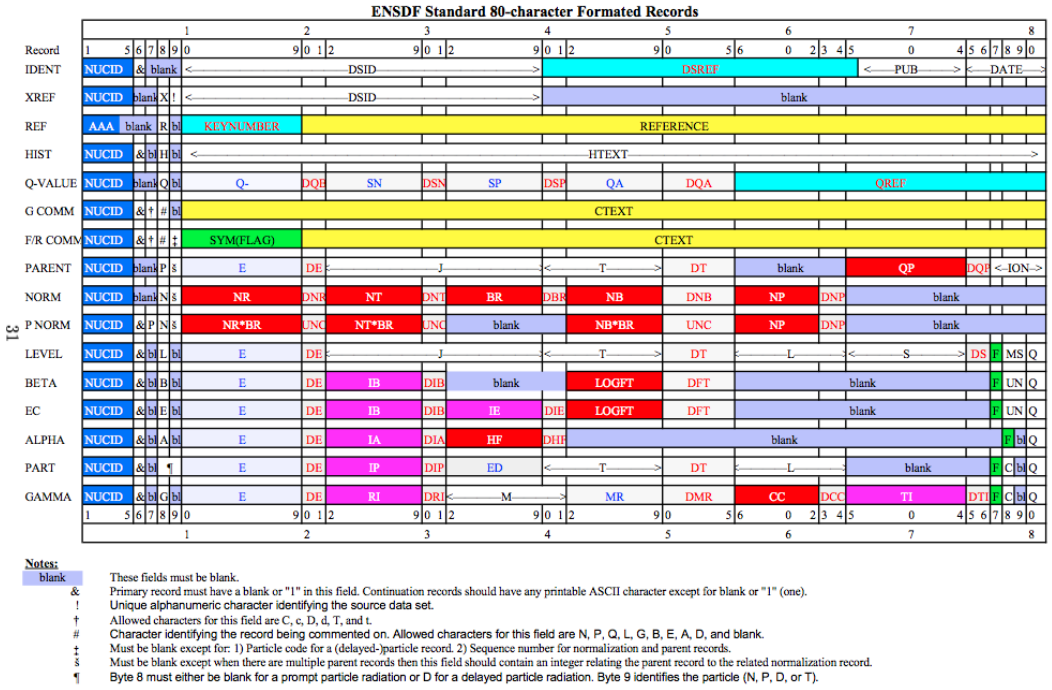


Table 1: Variables found in Raw Data and Processed Data

Character	Description (**Pages Numbers refer to ENSDF manual**)
"( )"	When you have parenthesis around a Spin and/or Parity, this means there is not a strong argument(s) and there is uncertainty associated with this. (**pg. 104**)
"[ ]"	When you have square brackets around a Spin and/or Parity, this means that it is assumed. Should these Spin/Parity be considered, I do not know, but it should be noted.(**pg. 104**)
"|>"	this means greater than or equal to. (**pg. 75**)
","	Commas are interpreted as an OR. (**pg. 46**)
"AND" "&"	AND and & are to be interpreted AND. I would think this is would mean both arguments/experiments give equally "good" arguments/results for the respective Spin/Parity analysis(**pg. 104**)
"GE" "GT" "LE"	these mean greater than or equal to, greater than, and less then or equal to, respectively. (**pg. 46**)
"TO" ":"	":" (colon) or "TO" is used to indicate a range of spins. (**pg. 46**)

Figure 4: ENSDF data file

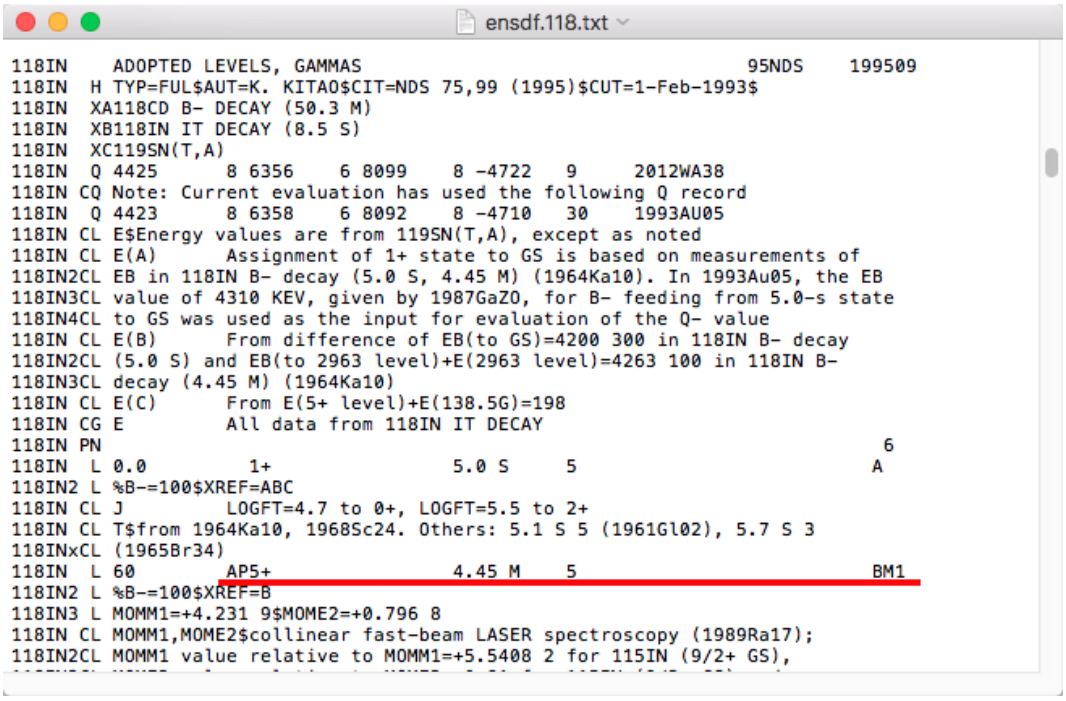


Table 2: ENSDFpp.C Settings to Extract 2017 Data.

Question Asked by ENSDFpp Script	variables
Minimum time for beta decay (s):	0
maximum time for beta decay (s):	1e12
Minimum beta Branch Strength (%):	0.0001
Minimum Gamma branch strength (%):	0
Generate Gamma List {[Y/N]}?	n
Do you want to run another query? {[Y/N]}	n

3 PROCESSED DATA

After using ENSDFpp.C you will obtain the Processed data file, this file will have all the keywords discussed in Table 1. There is an error with ENSDFpp.C and determining isomeric states, and possibly an error with the ENSDF files.

CORRECTING FOR ENSDFPP.C ERROR

The error that comes from ENSDFpp.C, is β- branches that are isomeric state two are being outputted as isomeric state one. This error is in the script and could not be found, therefore, this error still exists and must be corrected by hand. The second possible error comes from ENSDF files, occasionally isomeric state one are output as ground state. The corrected errors

in the Processed data are listed in Table 3, 4 (ignore Weight, this is planned to be modified later by the Postdoc). The table lists the corrected ZAI's and the reason for the correction.

The script developed to locate the ZAI's with error is called _checkForDouble.C. The output is ZAI's with errors, which ENSDF file they come from and which NUCID they are.

To locate the ENSDF files follow this path: NENuFAR > NDBReader > ENSDFpp > data > ENSDF_db. Inside ENSDF_db folder locate the ensdf.xxx file (xxx = mass number). Again _checkForDouble.C outputs this ensdf.xxx file for you. Locate the NUCID the script outputs. Look at the ADOPTED LEVELS section in the ENSDF file. Locate the LEVEL row and look at column 78-79 and you should find an "MX", X indicates the isomeric state 1, 2, 3. Refer to Figure 4 the line indicates the initial spin, half life, and on the far right the isomeric state.

MODIFICATION

Some keywords in the spin/parity column were difficult to program for, they were modified by hand. In Table 5 the ZAI is given and the spin/parity before and after is indicated.

4 CORRECTED PROCESSED DATA

Here the Processed data is corrected, this data will be put through a script called readENSDF-ppfile.C which will output the Bestiole format. This chapter will review the assumptions made by this script. Additional, files formats will also be discussed.

READENSDFPPFILE.C SCRIPT

The script called readENSDFppfile.C extracts the variables of interest, such as, ZAI, Branching ratio, Branching Ratio Error, Endpoint Energy... etc. The main goal of the program is to look specifically for β- decays branches, and to output the lowest possible forbiddenness achievable for each branch. The forbiddenness is determined by using the Classification of Beta-Decay found in LANDOLT - BÖRNSTEIN [3]. Table 6 indicates the classification method found in readENSDFppfile.C.

To make a more accurate comparison between present and past data sets, there is a second scripted called _muellerENSDFppFile.C. This script will output the data with Mueller's classification of β- decay. The rules are indicated in Table 7.

BESTIOLE FORMAT AND FUTURE FORMAT

There are three different formats that can be output by readENSDFppfile.C indicated in Table 8. When readENSDFppfile.C is launched it will ask which of the formats you want outputted. The first selection being Bestiole format, this is the format that currently works with present day BESTIOLE.C. BESTIOLE.C is a very powerful script, however, BESTIOLE.C will be modified to be more robust. To accommodate this robustness two extra format are proposed, Bestiole+ and Bestiole++. Bestiole+ simply adds more information available for BESTIOLE.C, such as initial spin, final spin etc. Bestiole++ will output all possible forbiddenness combinations for a

Table 3: β branches with errors.

ZAI		Weight		Source file, NUCID, Reason for correction.
Before	After	235U	239Pu	
190460	No change			File: ends.046 NUCID: 46K ENSDF file inconclusive. might be duplicated data.
290701	290702			File: ensdf.070 NUCID: 70Cu Branches with 1+ initial spin are isomeric state 2
300711	No change			File: ensdf.071 NUCID: 71Zn Two isotopes with the same ZAI. inconclusive to determine error.
390971	390972			File: ensdf.097 NUCID: 97Y Branches with (27/2-) initial spin are isomeric state 2
451100	451101			File: ensdf.110 NUCID: 110Rh -Change branches with (6+) initial spin to isomeric state 1. ***** poor reasoning look into further ***** - Branches with 1+ initial spin are ground state 0.0, however, indicated as isomeric state 1. - Branches with (6+) initial spin are ground state 0.0Y, however, indicated as isomeric state 2.
451120	451121			File: ensdf.112 NUCID: 112Rh -Change branches with (6+) initial spin isomeric state 1. ***** poor reasoning look into further ***** - Branches with 1+ initial spin are ground state 0.0, however, indicated as isomeric state 1. - Branches with (6+) initial spin are ground state 0.0Y, however, indicated as isomeric state 2.
471161	471162			File: ensdf.116 NUCID: 116Ag Branches with (6+) initial spin are isomeric state 2

Table 4: β branches with errors Con't.

ZAI		Weight		Source file, NUCID, Reason for correction.
Before	After	235U	239Pu	
491181	491182			File: ends.118 NUCID: 118In Branches with 8- initial spin are isomeric state 2
491201	491202			File: ensdf.120 NUCID: 120In Branches with (5)+ initial spin are isomeric state 2
491221	491222			File: ensdf.122 NUCID: 122In branches with (8-) initial spin are isomeric state 2
491271	491272			File: ensdf.127 NUCID: 127In -Change branches with (21/2-) initial spin to isomeric state 2. ***** Poor reasoning look into further ***** - Potential error in ENSDF file - Branches with (1/2-) initial spin are indicated as an isomeric state but not indicted as 1 or 2 - Branches with (21/2-) initial spin are indicated as isomeric state 1, but there is something wrong.
491291	491292			File: ensdf.129 NUCID: 129In Branches with (23/2-) initial spin are isomeric state 2
491301	491302			File: ensdf.130 NUCID: 130In Branches with (3+) initial spin are isomeric state 2
491311	491312			File: ensdf.131 NUCID: 131In Branches with (23/2+) initial spin are isomeric state 2
531370	No change			File: ensdf.137 NUCID: 137I ENSDF file inconclusive Might be duplicated data.

Table 5: Key Words Modified in Spin/Parity Column of Processed Data

ZAI	Initial Or Final S/P	Original	Changed
220550	Initial	(GE 1/2-)	(1/2-,3/2,5/2,7/2)
290730	Final	(LE 5/2)	(3/2,5/2)
320770	Final	(LE 7/2)	(7/2)
360910	Final	LE7/2(-); (LE7/2-)	5/2,7/2(-); (5/2,7/2-)
380920	Final	(LE3)	(0,1,2,3)
390920	Final	(LE2)	(2)
411000	Final	(LE 4)	(1,2,3,4)
431130	Initial	(GT 5/2)	(5/2,7/2)
431141	Final	(GE 3)	(3,4)
491190	Final	GE 7/2	7/2,9/2
591500	Final	LE 2	1,2
611510	Final	(LE 7/2)	(5/2,7/2)
651660	Final	(LE3-)	(2,3-)
671701	Final	LE 4	1,2,3,4
711830	Final	(LE9/2)	(7/2,9/2)
721830	Final	(LE5/2)	(3/2,5/2)
832121	Initial	GT16	17,18
190480	Final	(2+)&1-	2+&1-
360910	Final	3/2,5/25,7/2(-)	3/2,5/2,7/2(-)
781990	Final	(3/2,5/2,7/2)(+)	(3/2+,5/2+,7/2+)
832151	Initial	(25/2:29/2)(-)	(25/2:29/2)-

single branch. Error indicators are also included in Bestiole+ and Bestiole++ to define what is missing from initial and final spins. Error indicators are shown in Table 9 and 10.

5 2017 DATA

Following the output of the readENSDFppfile.C script there is one last correction that must be made. This is to add TAGS data which will correct for the pandemonium effect.

TOTAL ABSORPTION GAMMA-RAY SPECTROMETER DATA

The Pandemonium effect is corrected by using Total Absorption Gamma-ray Spectrometer data. The TAGS data used, is taken directly from Mueller's[1] 2011 data. Mueller's TAGS data was created using virtual branches, they are supposed to replicate the proposed TAGS beta-spectrum's. In Mueller's paper they used two papers for TAGS data, Greenwood *et al* [4], and Tangblad *et al* [5] with priority given to Tangblad. Mueller's paper found 111 measured electron

Table 6: Classification of Beta-Decay. Used in readENSDFppfile.C

Spin Δ	Parity Δ	Forbiddenness
ΔL = 0,1	$\pi_i \times \pi_f = +1$	0
	$\pi_i \times \pi_f = -1$	-1
	$\pi_i = n/a$ and/or $\pi_f = n/a$	0
Δ L = 2	$\pi_i \times \pi_f = +1$	-2
	$\pi_i \times \pi_f = -1$	1
	$\pi_i = n/a$ and/or $\pi_f = n/a$	1
Δ L = 3	$\pi_i \times \pi_f = +1$	2
	$\pi_i \times \pi_f = -1$	-3
	$\pi_i = n/a$ and/or $\pi_f = n/a$	2
Δ L = 4	$\pi_i \times \pi_f = +1$	-4
	$\pi_i \times \pi_f = -1$	3
	$\pi_i = n/a$ and/or $\pi_f = n/a$	3
Δ L = 5	$\pi_i \times \pi_f = +1$	4
	$\pi_i \times \pi_f = -1$	-5
	$\pi_i = n/a$ and/or $\pi_f = n/a$	4
Δ L = 6	$\pi_i \times \pi_f = +1$	-6
	$\pi_i \times \pi_f = -1$	5
	$\pi_i = n/a$ and/or $\pi_f = n/a$	5
$Spin_i$ = n/a and/or $Spin_f$ = n/a	$\pi_i = n/a$ and/or $\pi_f = n/a$	If Spin information missing will always assume: 0

Table 7: Mueller's Classification of β-Decay

Δ Spin and Δ Parity Exists		
Δ Spin	Δ Parity	Forbiddenness
ΔL = 0,1	π_i * π_f = +1	0
	π_i * π_f = -1	-1
ΔL = 2	π_i * π_f = +1	-2
	π_i * π_f = -1	1
ΔL = 3	π_i * π_f = +1	2
	π_i * π_f = -1	-3
ΔL >3	π_i * π_f = +1 π_i * π_f = -1	3
Δ Spin and LogFT Exists. Δ Parity Non-Existant		
LogFT	Δ Spin	Forbiddenness
LogFT <8	ΔL <2	0
	ΔL >2	1
LogFT <14	ΔL <2	0
	ΔL = 2	1
	ΔL >2	2
LogFT <18.5	ΔL <3	1
	ΔL = 3	2
	ΔL >3	3
LogFT >= 18.5	ΔL = 1,2,3...n	3
Δ Spin Only. No LogFT. No π_i and/or π_f		
Δ Spin	Forbid Rule	Forbiddenness
ΔL <=4	ΔL - 1 = forbid	0, 1, 2, 3
ΔL >4	ΔL = 3	3

spectra, 44 isotopes in perfect agreement with the ENSDF data, and 67 isotopes which were replaced.

In Table 11 there are 67 Isotopes. These are the replaced isotopes in Mueller's data. In turn I use this same TAGS data and implement it into my 2017 data. Table 11 shows the ZAI's which are changed by TAGS data, and I indicate if they are changed or added to the 2017 data. After implementing the TAGS data there are two data sets 2017Data and 2017TAGS data. From Muller there is 2011Data and 2011TAGS. These four data sets will be analyzed with 2011 data used at a benchmark.

BESTIOLE

Creating the β decay spectrum is very straights forward, run Bestiole formatted data through BESTIOLE.C. The 2017 data that has been created has the following correction: QED, weak magnetism and coulomb finite size correction.

Table 8: Format of Output data file for readENSDFppfile.C

Format	Column Number	Column Header	Description
Bestiole	1	ZAI	Z = Mass number, A = Atomic number, I = Isomeric state. Combination of ZAI = Z0AAI, ZZ0AAI, ZZAAAI.
	2	BR	Branching ratio
	3	erBR	Error in branching ratio
	4	E0	Endpoint energy MeV
	5	erE0	error in endpoint energy MeV
	6	qB	Q-Beta energy in MeV
	7	<E>	Energy average, this is automatically set to 0.000. This was done in Mueller's data.
	8	For	Forbiddenness. Refer to Table 6 for rules
	9	App	Approximation Code: always 10
Bestiole+	10	Log	LogFT
	11	iS	Initial Spin
	12	fS	Final Spin
	13	eriS	Error in initial spin. Refer to Table 9 and 10
	14	erfS	Error in final spin. Refer to Table 9 and 10
	15	1/N	Weight of branch
Bestiole++	16	Count	Will give all branches possible

Table 9: Bestiole+(+) Column 13-14 Error Indicators, for Initial Spin.

Indicator	Description
ijπ+	No error, it's a column holder. Initial spin and positive parity are present
ijπ-	No error, it's a column holder. Initial spin and negative parity are present
ij	ERROR. initial spin is present. Parity NOT present
iπ+	ERROR. initial spin NOT present. Parity = positive
iπ-	ERROR. Initial spin NOT present. Parity = negative
iDne	ERROR. Initial spin NOT present. Parity NOT present

Table 10: Bestiole+(+) Column 13-14 Error Indicators, for Final Spin.

Indicator	Description
fjπ+	No error, it's a column holder. Final spin and positive parity are present
fjπ-	No error, it's a column holder. Final spin and negative parity are present
fj	ERROR. Final spin is present. Parity NOT present
fπ+	ERROR. Final spin NOT present. Parity = positive
fπ-	ERROR. Final spin NOT present. Parity = negative
fDne	ERROR. Final spin NOT present. Parity NOT present

Table 11: ZAI Replaced or Added by TAGS Data.

ZAI	Change	ZAI	Change	ZAI	Change	ZAI	Change
310800	replaced	350900	replaced	390990	replaced	531390	replaced
310810	replaced	360870	replaced	410990	replaced	531400	replaced
310820	added	360890	replaced	501300	replaced	541370	replaced
320830	added	370890	replaced	501301	replaced	551400	replaced
330790	replaced	370900	replaced	501310	added	551410	replaced
330810	replaced	370901	replaced	501330	replaced	551430	replaced
330820	replaced	370910	replaced	511310	replaced	551440	added
330830	added	370920	replaced	511330	replaced	551460	replaced
330850	replaced	370930	replaced	511340	replaced	561410	replaced
330860	replaced	370940	replaced	511350	replaced	561430	replaced
340830	replaced	370950	replaced	511360	replaced	561460	replaced
340831	replaced	370960	replaced	511370	added	571430	replaced
350840	replaced	380930	replaced	521360	replaced	571450	replaced
350860	replaced	380950	replaced	521370	added	571460	replaced
350870	replaced	380970	replaced	531350	replaced	581450	replaced
350880	replaced	390971	replaced	531360	replaced		
350890	replaced	390980	replaced	531380	replaced		

6 ANALYSIS

The analysis focuses on how has the data changed from 2011 to 2017, ultimately showing how the β spectra have changed with time. The following scripts will give a greater understanding to the differences in the data.

6.1 COMPARING FORBIDDENNESS FOR 2017 AND 2011 DATA

The script _ForbiddennessDistribution.C extracts the forbiddenness of each branch, and will plot it in a histogram. Data generated for Figure 5 comes from _muellerENSDFppFile.C forbiddenness classification are the same for both data sets. Figure 5 and Table 12 shows the forbiddenness and how they change from 2011 to 2017 with and without TAGS data being applied. 2017 data has an additional 835 branches.

WEIGHTED SPECTRUM

Running the script called TBSgraph.C requires BESTIOLE.C root output files. This script will compute the contribution of each isotope to the total $\beta(\bar{\nu})$ spectra for any given fissile nucleus. Both the weighted spectrum and the percent contribution plots are generated on the same code. In the the TBSgraph.C script in the TBS() function, you need select which Root file you want to use and which Fission Yield you want to use. You will also need to comment out either BuildTBS (generates weighted spectrum's) or BuildNormilizedCont (generates percent contribution).

Figure 5: Distribution of Forbiddenness

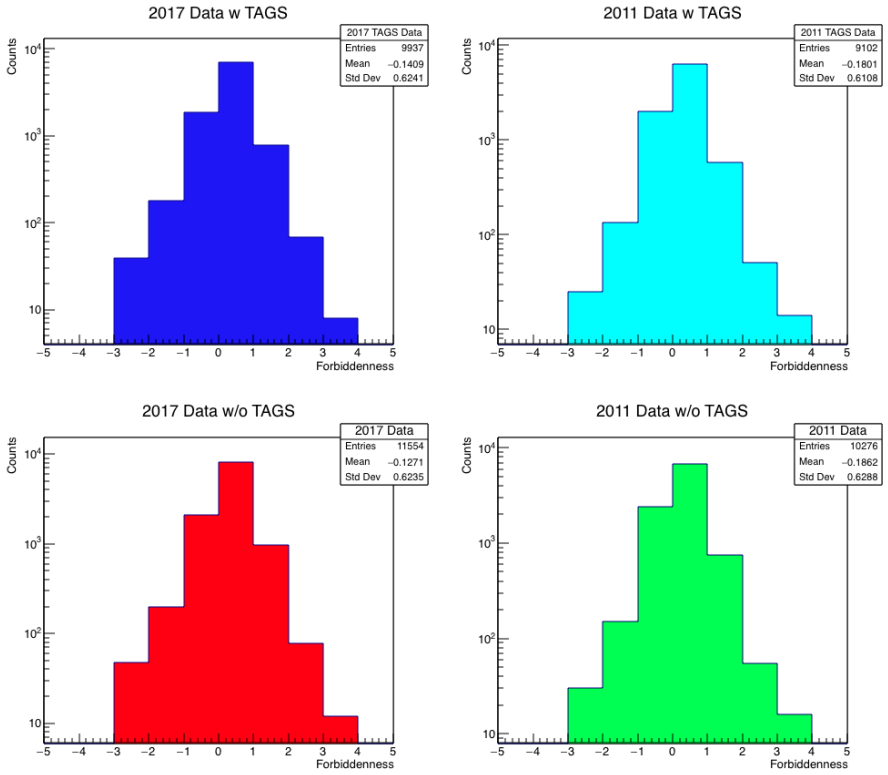


Table 12: Difference Between 2017 data and 2011 Data. Both Mueller β-Decay Classification

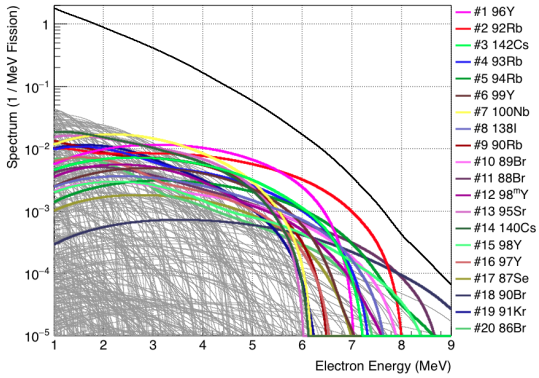
Data Set	Total Branches	Allowed	First	Second	Third	First	Second	Third
		Unique				Non-Unique		
2011 TAGS	9102	6278	580	51	14	2020	134	25
2017 TAGS	9937	6983	7897	68	8	1874	199	39
2011 Data	10276	6840	752	55	16	2433	150	30
2017 Data	11554	8179	959	78	12	2080	199	47
Analysis								
Data Set	Δ % 2011	Δ % 2017	Δ % 2011	Δ % 2017				
	Tags Reference		Non Tags					
2011 TAGS	n/a	8.40	11.4	21.2				
2017 TAGS	9.17	n/a	3.30	14.0				
2011 Data	12.9	3.41	n/a	11.1				
2017 Data	26.9	16.3	12.4	n/a				

Table 13: Isotopes Contribution to 235U β Spectra. Cumulative Fission Yield JEFF 3.1

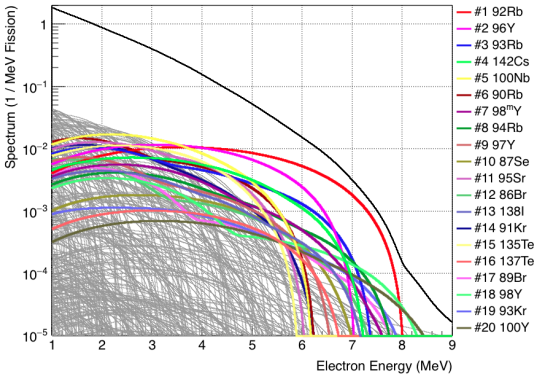
Rank	2011 Data		2011 TAGS		2017 Data		2017 TAGS	
	Isotope	Percent	Isotope	Percent	Isotope	Percent	Isotope	Percent
1	96 Y	13.8	92 Rb	24.4	92 Rb	19.2	92 Rb	23.2
2	92 Rb	13.7	96 Y	15.6	96 Y	12.7	96 Y	14.8
3	142 Cs	6.15	93 Rb	7.02	142 Cs	5.82	142 Cs	6.80
4	93 Rb	5.31	142 Cs	6.95	93 Rb	5.18	93 Rb	6.68
5	94 Rb	4.75	100 Nb	3.77	100 Nb	4.10	100 Nb	4.80
6	99 Y	4.15	90 Rb	3.61	99 Y	3.64	90 Rb	3.43
7	100 Nb	3.33	$98^{m}Y$	2.92	138 I	3.03	$98^{m}Y$	2.78
8	138 I	3.28	94 Rb	2.81	90 Rb	3.00	94 Rb	2.67
9	90 Rb	3.24	97 Y	2.06	94 Rb	2.84	91 Kr	2.52
10	89 Br	2.85	87 Se	1.91	89 Br	2.75	87 Se	2.05
11	88 Br	2.81	95 Sr	1.88	88 Br	2.47	97 Y	1.98
12	$98^{m}Y$	2.59	86 Br	1.74	$98^{m}Y$	2.38	95 Sr	1.80
13	95 Se	2.44	138 I	1.74	95 Sr	2.25	86 Br	1.66
14	140 Cs	2.26	91 Kr	1.54	91 Kr	2.16	138 I	1.65
15	98 Y	1.90	135 Te	1.40	140 Cs	2.06	$100^{m}Y$	1.29
16	97 Y	1.83	137 Te	1.20	98 Y	1.83	137 Te	1.14
17	87 Se	1.69	89 Br	1.19	87 Se	1.76	89 Br	1.13
18	90 Br	1.57	98 Y	1.17	97 Y	1.70	98 Y	1.11
19	91 Kr	1.37	93 Kr	1.14	86 Br	1.19	93 Kr	1.05
20	86 Br	1.34	100 Y	1.13	$100^{m}Y$	1.11	135 Te	0.99

Figure 6: Isotopes Contribution to 235U β Spectra. Cumulative Fission Yield JEFF 3.1

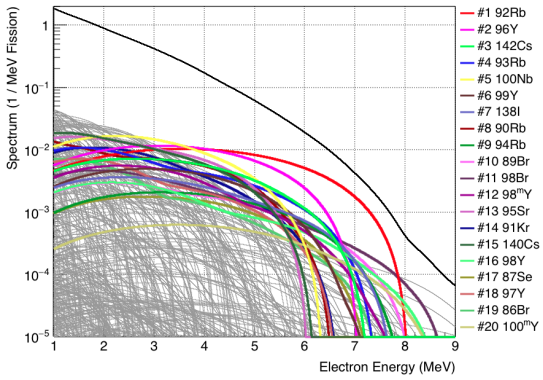
(a) 2011 Data



(b) 2011 TAGS data



(c) 2017 Data



(d) 2017 TAGS data

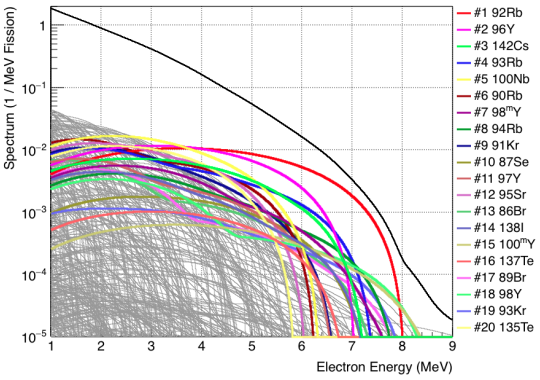
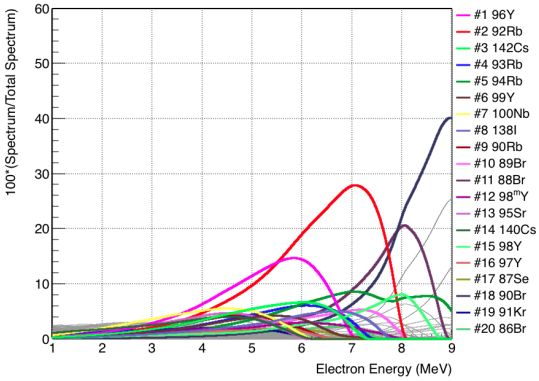
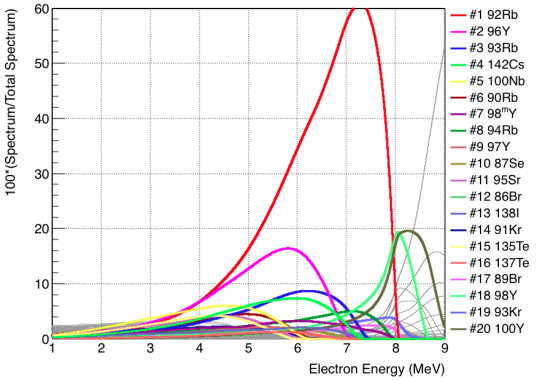


Figure 8: Isotopes Contribution to 235U β Spectra. Cumulative Fission Yield JEFF 3.1

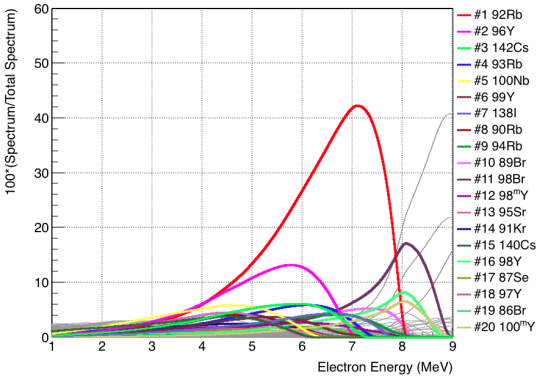
(a) 2011 Data



(b) 2011 TAGS data



(c) 2017 Data



(d) 2017 TAGS data

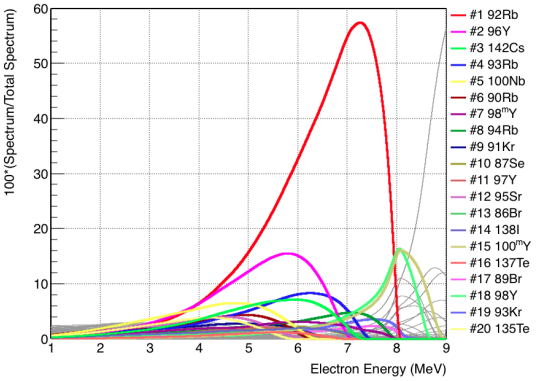
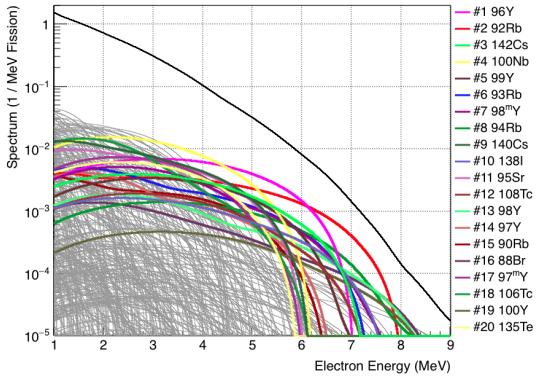


Table 14: Isotopes Contribution to 239Pu β Spectra. Cumulative Fission Yield JEFF 3.1

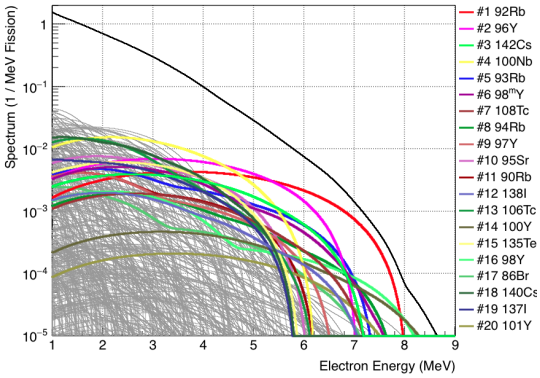
Rank	2011 Data		2011 TAGS		2017 Data		2017 TAGS	
	Isotope	Percent	Isotope	Percent	Isotope	Percent	Isotope	Percent
1	96 Y	16.0	92 Rb	19.2	92 Rb	15.1	92 Rb	18.0
2	92 Rb	10.9	96 Y	18.0	96 Y	14.5	96 Y	16.8
3	142 Cs	6.48	142 Cs	7.31	100 Nb	7.14	100 Nb	8.25
4	100 Nb	5.86	100 Nb	6.62	142 Cs	6.07	142 Cs	7.01
5	99 Y	5.57	93 Rb	6.30	99 Y	4.83	93 Rb	5.88
6	93 Rb	4.77	$98^{m}Y$	5.23	93 Y	4.61	$98^{m}Y$	4.87
7	$98^{m}Y$	4.63	108 Tc	2.81	$98^{m}Y$	4.22	108 Tc	2.62
8	94 Rb	4.20	94 Rb	2.48	140 Cs	2.85	94 Rb	2.31
9	140 Cs	3.16	97 Y	2.28	138 I	2.61	97 Y	2.14
10	138 I	2.87	95 Sr	2.17	95 Sr	2.58	95 Sr	2.03
11	95 Sr	2.82	90 Rb	1.97	94 Rb	2.48	90 Rb	1.84
12	108 Tc	2.49	138 I	1.52	108 Tc	2.27	$100^{m}Y$	1.69
13	98 Y	2.28	106 Tc	1.50	98 Y	2.17	138 I	1.41
14	97 Y	2.02	100 Y	1.48	97 Y	1.86	106 Tc	1.40
15	90 Rb	1.78	135 Te	1.47	90 Rb	1.62	98 Y	1.31
16	88 Br	1.47	98 Y	1.40	$100^{m}Y$	1.47	91 Kr	1.23
17	$97^{m}Y$	1.37	86 Br	1.19	88 Br	1.28	100 Y	1.21
18	106 Tc	1.33	140 Cs	1.14	106 Tc	1.21	102 Nb	1.12
19	100 Y	1.31	137 I	0.83	89 Br	1.17	86 Br	1.11
20	135 Te	1.30	101 Y	0.82	91 Kr	1.07	140 Cs	1.07

Figure 10: Isotopes Contribution to 239Pu β Spectra. Cumulative Fission Yield JEFF 3.1

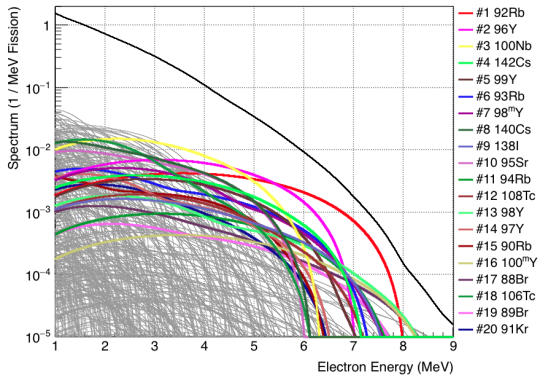
(a) 2011 Data



(b) 2011 TAGS data



(c) 2017 Data



(d) 2017 TAGS data

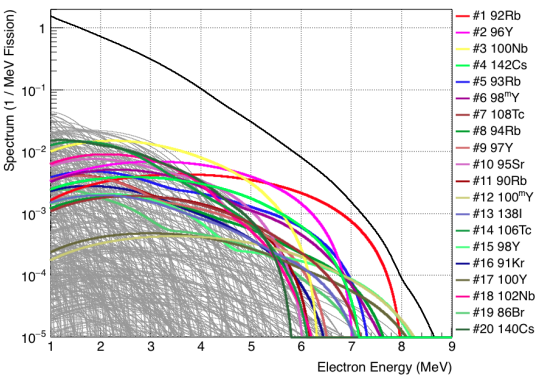
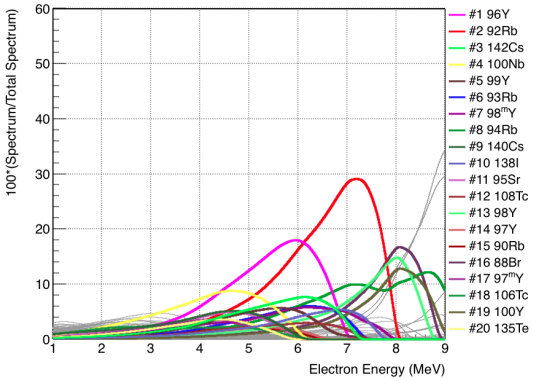
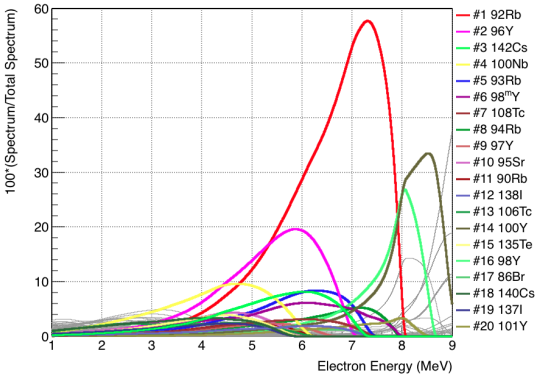


Figure 12: Isotopes Contribution to 239Pu β Spectra. Cumulative Fission Yield JEFF 3.1

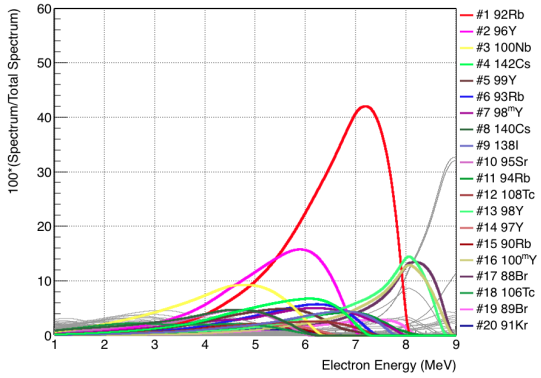
(a) 2011 Data



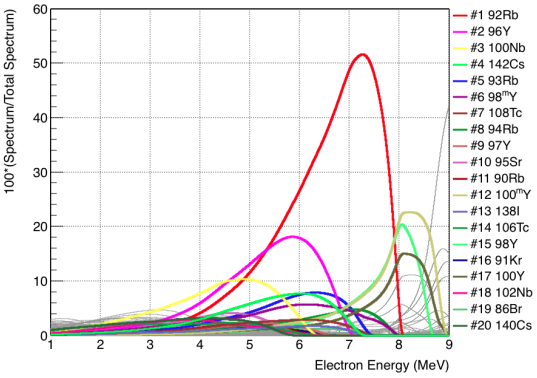
(b) 2011 TAGS data



(c) 2017 Data



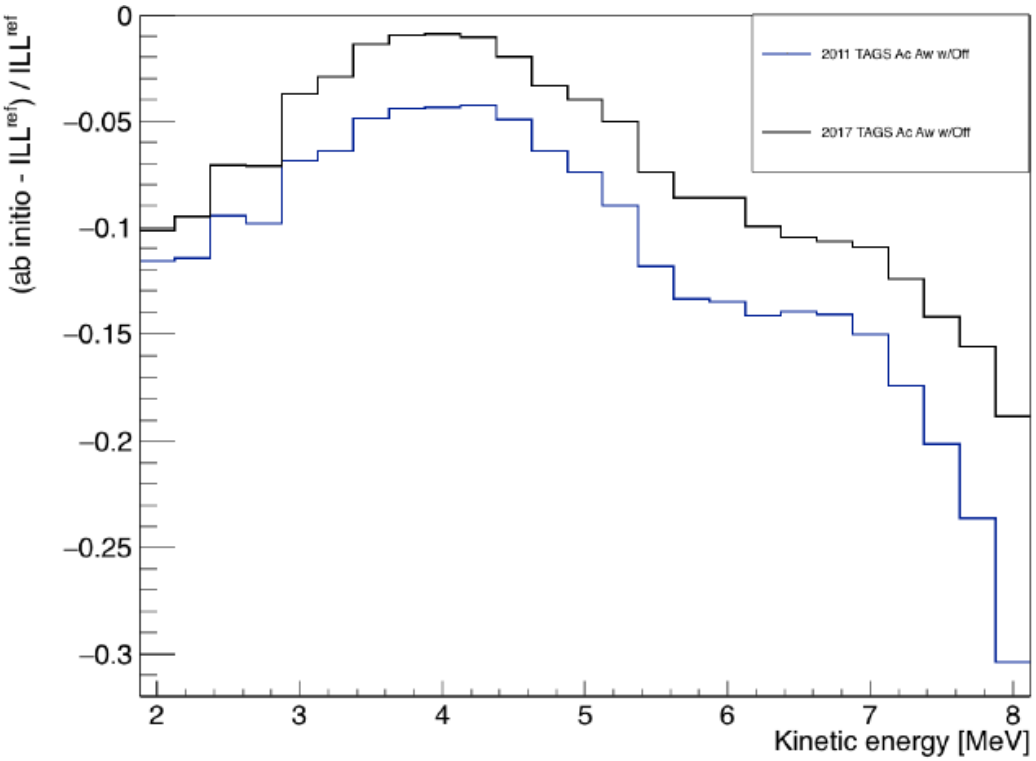
(d) 2017 TAGS data



AB INITIO

Lastly Figure 14 is the difference when comparing the ab initio spectrum's from 2011 and 2017 and comparing them with the ILL Reference Spectra. TBrowser was used with the generated root files from TBS.

Figure 14: 235U Ab Initio Spectrum with Respect to ILL with Off Equilibrium Correction



7 CONCLUSION

The difference between the 2011 and 2017 is present with the 2017 reference data trending closer to the ILL reference spectra. The significance that 92Rb, 96Y, 142Cs and 93Rb play in the nuclear reactor antineutrino anomaly is not clear in this report. However, the work done in this internship has build a solid base for further development and understanding of the reactor antineutrino anomaly.

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