

Muon and Neutron Energy Analysis for Parameterized Depths

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Overview

- Muons have higher average energies at lower depths (Groom et. al)
- Question 1: Do muons have different overall energy spectra (shape/curvature, etc...)? Asked by Prisca
- Question 2: Can we characterize these differences? Asked by Anthony
- Question 3: Are these differences important to the experiment? Asked by all of us!

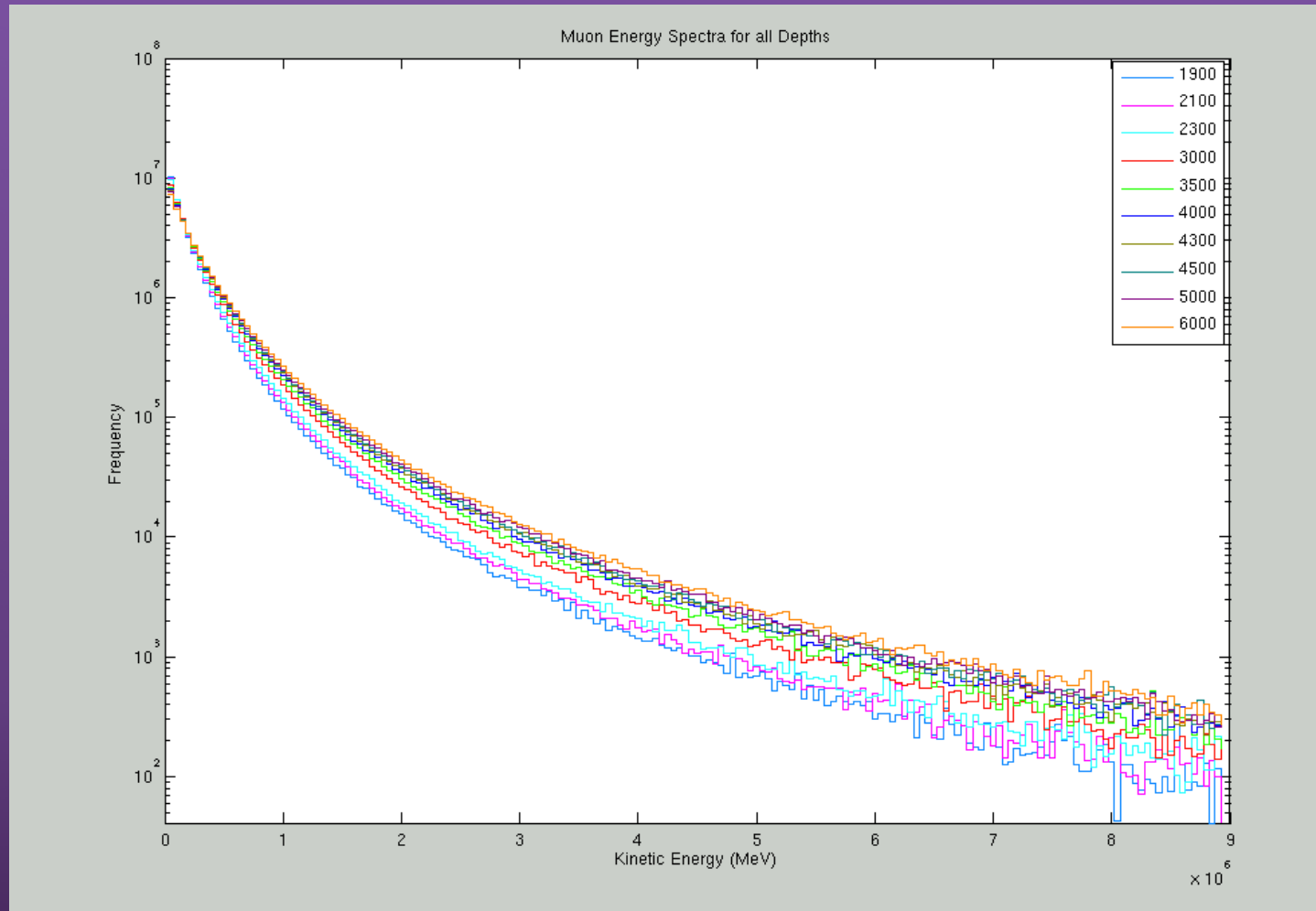
Overview

- geant4 simulations for GEODM geometry at different depths
 - 20 m x 20 m x 20 m cavern
 - 6 m radius water tank, 12 m height
 - 1 m radius detector volume, 2 m height

Overview

- Depths in Meters Water Equivalent (MWE)
 - 1900 (~Soudan)
 - 2100
 - 2300
 - 3000 (~Gran Sasso)
 - 3500
 - 4000
 - 4300 (~Homestake/DUSEL)
 - 4500
 - 5000
 - 6000 (~SnoLab)

Muon Energy Spectra (all depths*)



*Counts normalized by number of muons thrown

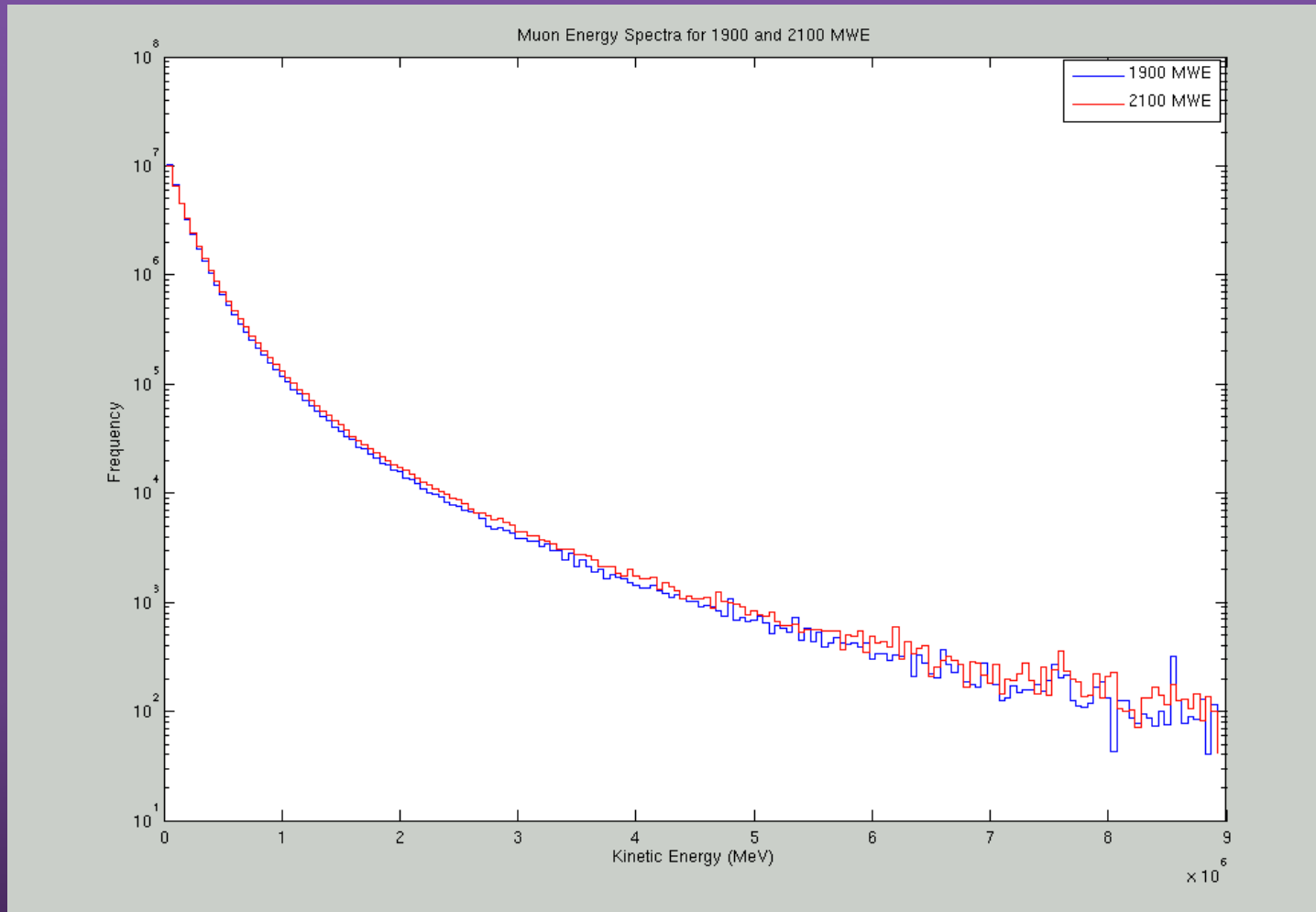
Muon Energy Spectra Statistical Comparisons

- The following table uses “Alexander” metrics and Kolmogorov-Smirnov tests to quantify and determine similarity between muon energy spectra at different depths.
 - {A1, A2, A3} similarity percentile followed by the KS result (True for same, False for different) for each pair of distributions
- Alexander metrics lie between 0 and 1; 0 are for identical spectra and 1 is for perfectly different spectra. Each metric is normally distributed and can be converted to a similarity percentile (See my paper on them if you are curious).

Table of Muon Energy Spectra Comparisons

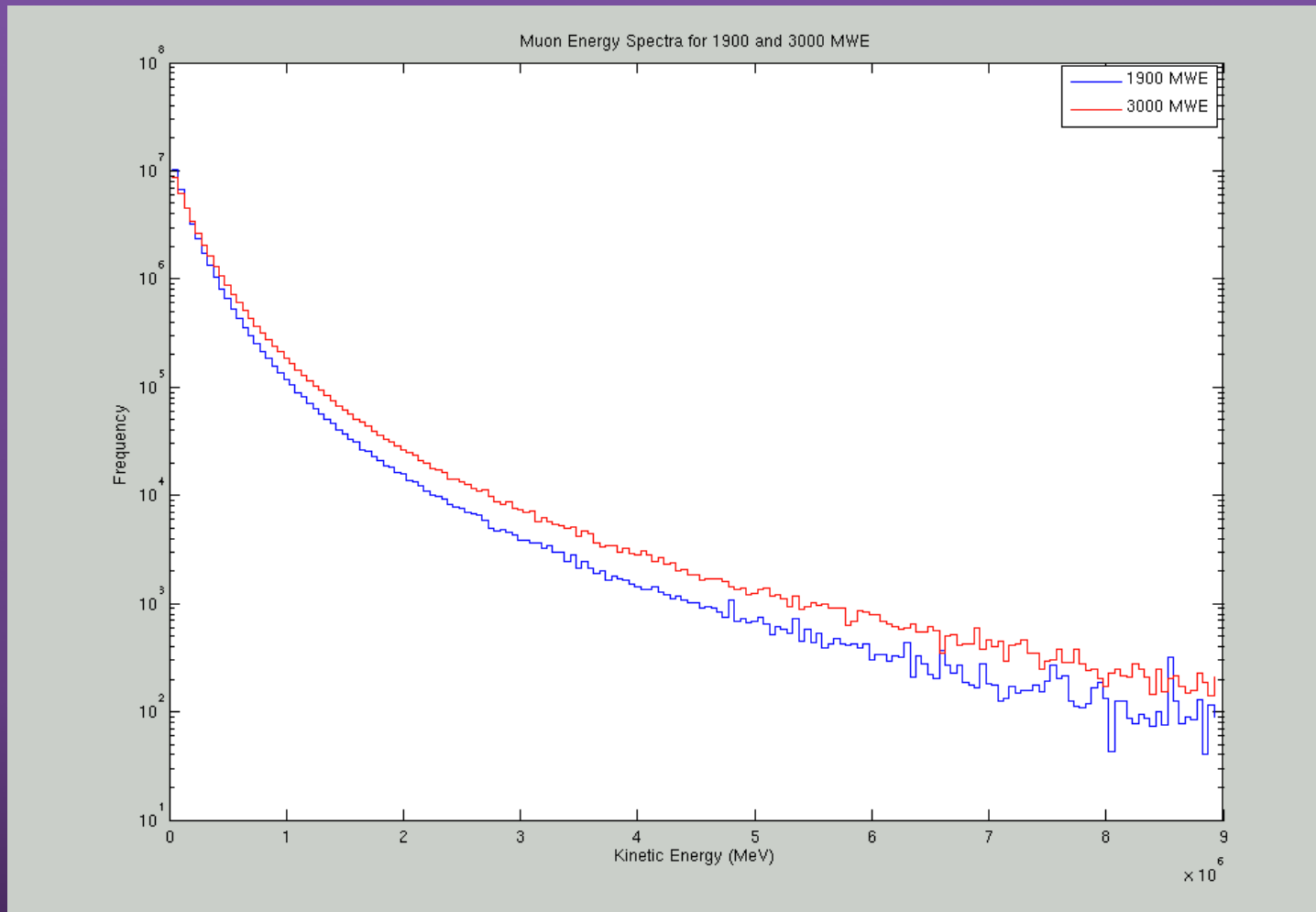
Cavern	Upper triangular are Muon Comparisons, Lower Triangular are Neutron Comparisons									
MWE	1900	2100	2300	3000	3500	4000	4300	4500	5000	6000
1900	100 100 100	100 100 100 F	100 100 100 F	100 99.9 52.6 F	92.2 4.0 0.0 F	1.2 0.0 0.0 F	0.0 0.0 0.0 F	0.0 0.0 0.0 F	0.0 0.0 0.0 F	0.0 0.0 0.0 F
2100		100 100 100	100 100 100 F	100 100 100 F	100 99.6 24.4 F	97.7 10.0 0.0 F	72.8 0.4 0.0 F	28.4 0.0 0.0 F	1.9 0.0 0.0 F	0.0 0.0 0.0 F
2300			100 100 100	100 100 100 F	100 100 99.9 F	100 99.8 33.15 F	99.9 89.8 1.19 F	99.9 52.3 0.0 F	96.6 6.7 0.0 F	9.7 0.0 0.0 F
3000				100 100 100	100 100 100 F	100 100 100 F	100 100 100 F	100 100 100 F	100 100 100 F	100 99.9 86.7 F
3500					100 100 100	100 100 100 F	100 100 100 F	100 100 100 F	100 100 100 F	100 100 100 F
4000						100 100 100	100 100 100 F	100 100 100 F	100 100 100 F	100 100 100 F
4300							100 100 100	100 100 100 F	100 100 100 F	100 100 100 F
4500								100 100 100	100 100 100 F	100 100 100 F
5000									100 100 100	100 100 100 F
6000										100 100 100

Muon Energy Spectra for 1900 and 2100* MWE



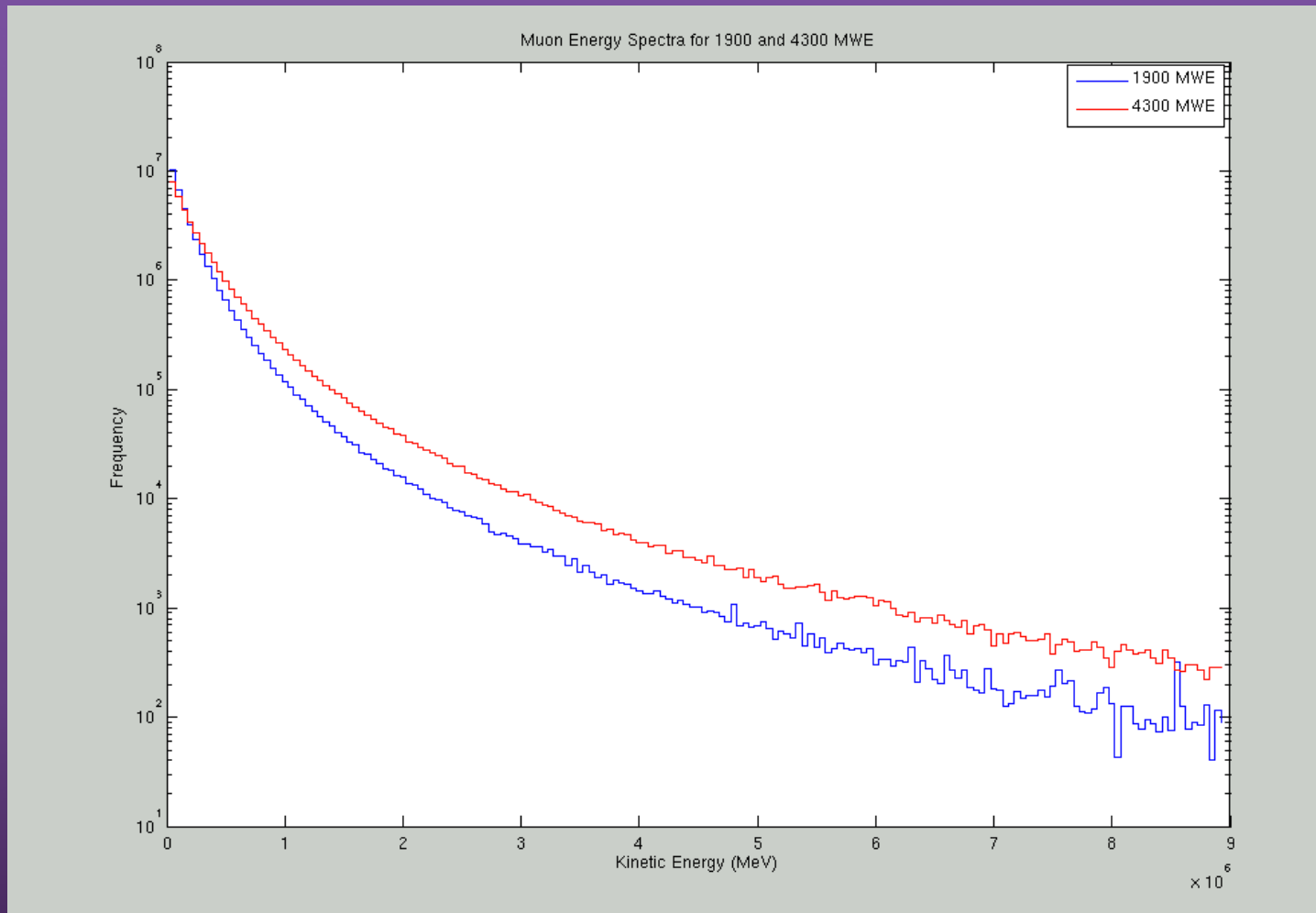
*Counts normalized by number of muons thrown

Muon Energy Spectra for 1900 and 3000* MWE



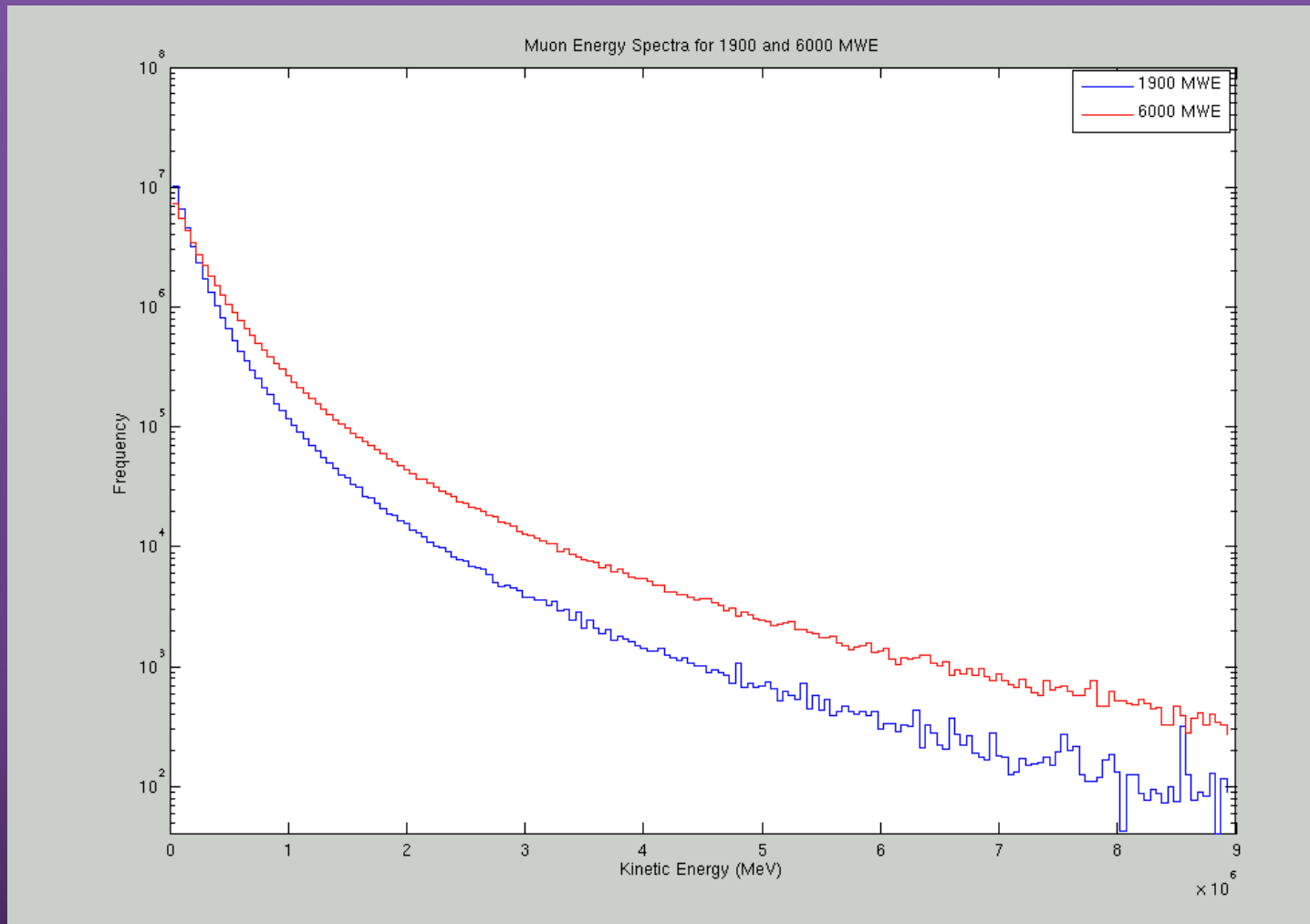
*Counts normalized by number of muons thrown

Muon Energy Spectra for 1900 and 4300* MWE



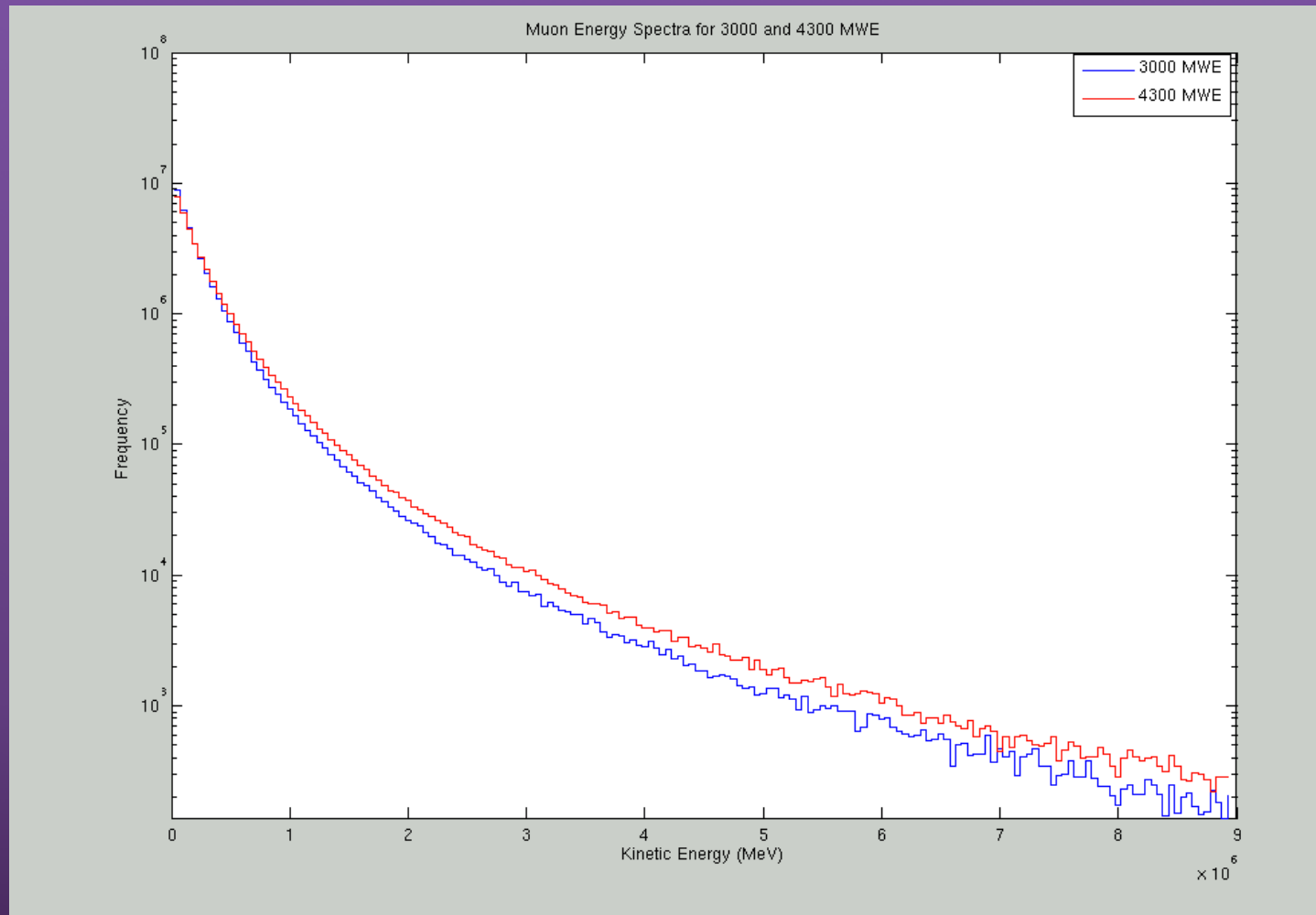
*Counts normalized by number of muons thrown

Muon Energy Spectra for 1900 and 6000* MWE



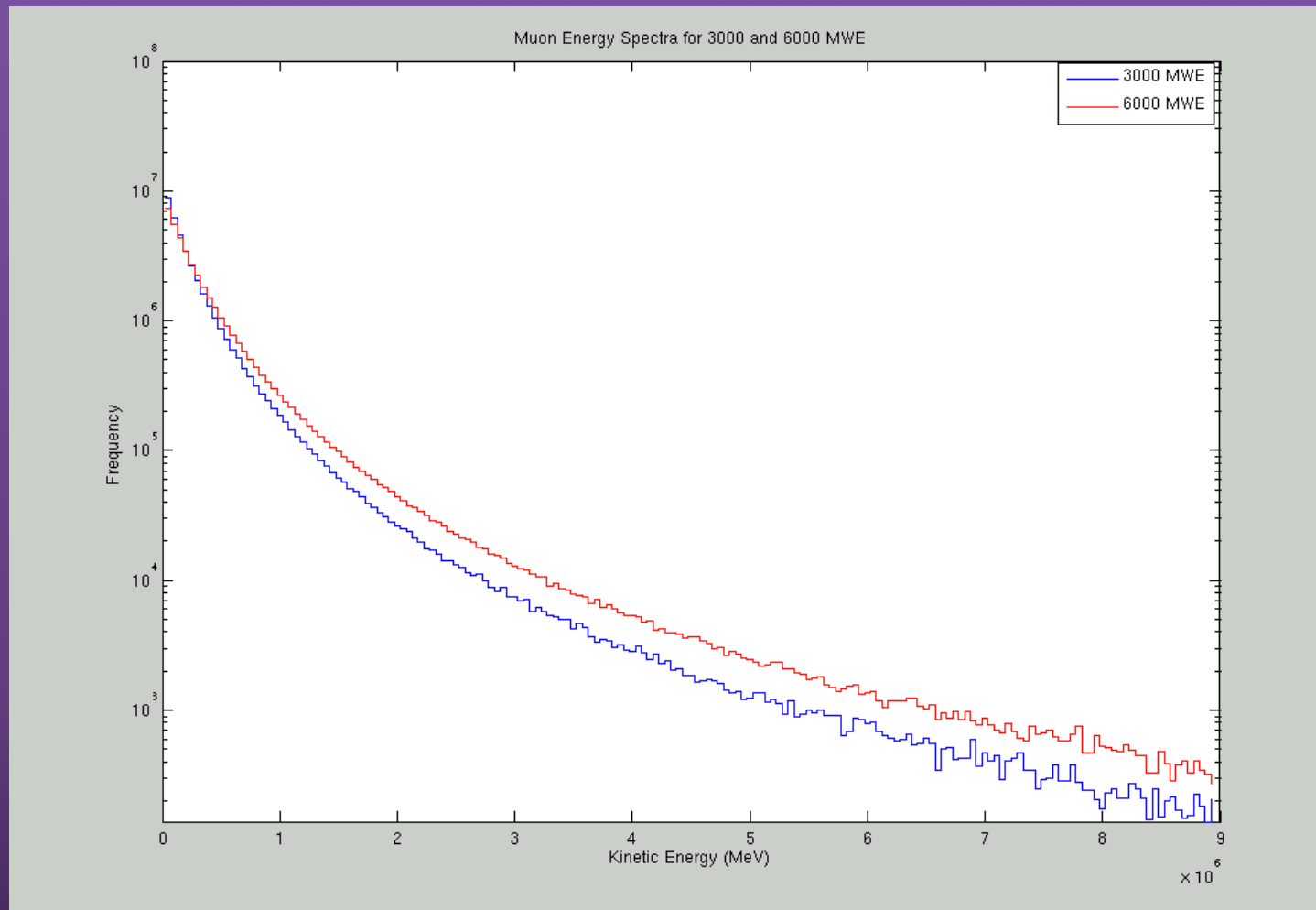
*Counts normalized by number of muons thrown

Muon Energy Spectra for 3000 and 4300* MWE



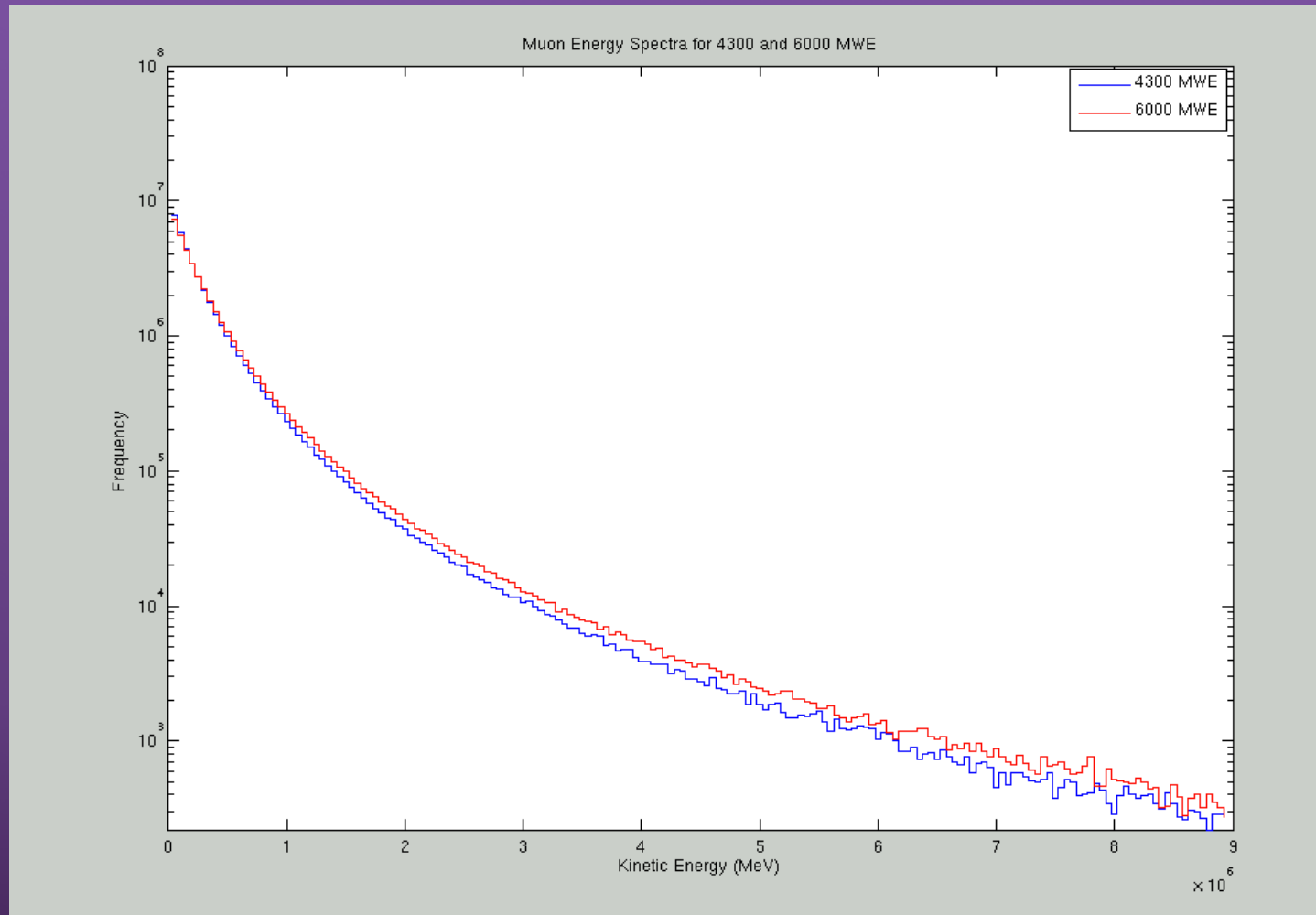
*Counts normalized by number of muons thrown

Muon Energy Spectra for 3000 and 6000* MWE



*Counts normalized by number of muons thrown

Muon Energy Spectra for 4300 and 6000* MWE



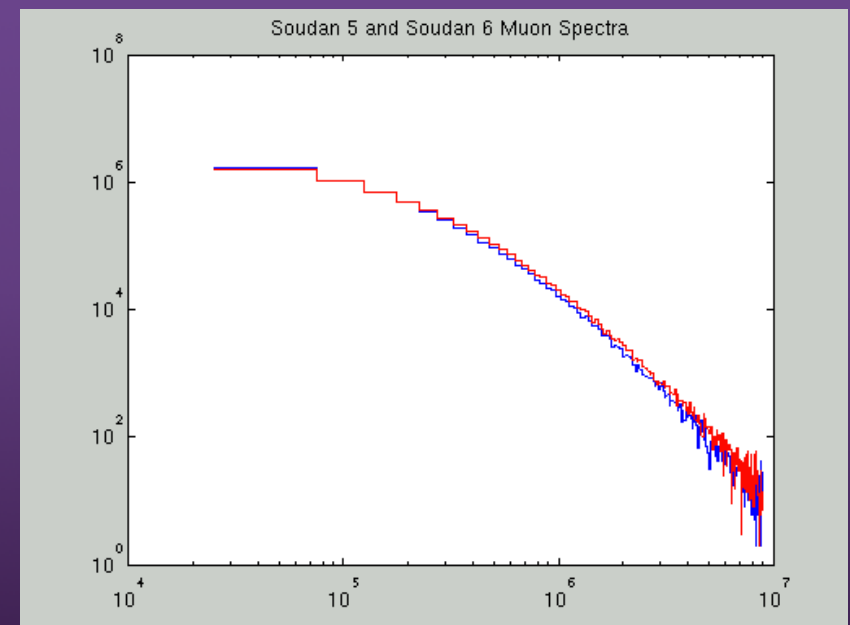
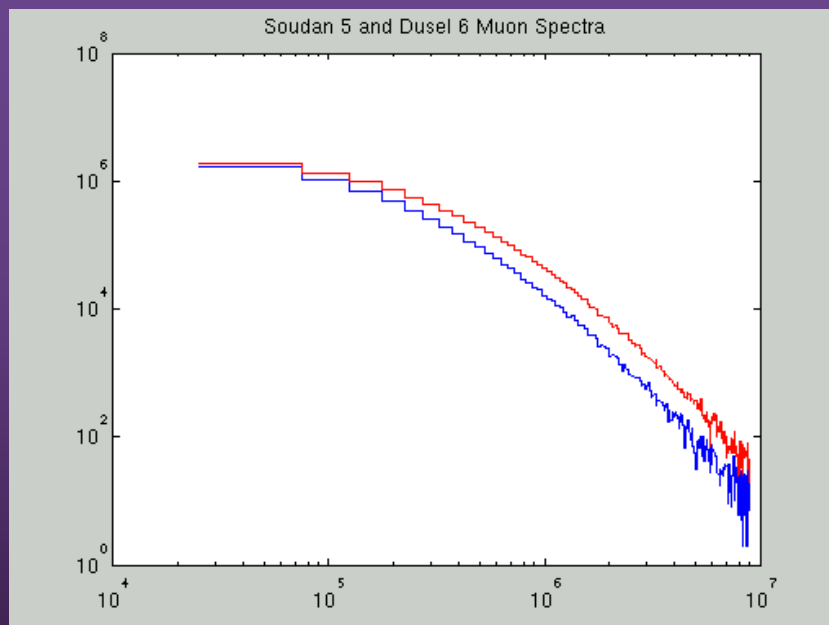
*Counts normalized by number of muons thrown

Analysis

- Good visual agreement between stats (especially A3 and KS) and plots.
- These differences make sense.
- KS tests give us a sense of when they are fundamentally different
- Alexander metrics give us a sense of how different they tend to be.
- If these differences are relevant depends upon how the neutron spectra look...

Comparison to Soudan/Dusel RHEL 5 /6 (muons into cavern)

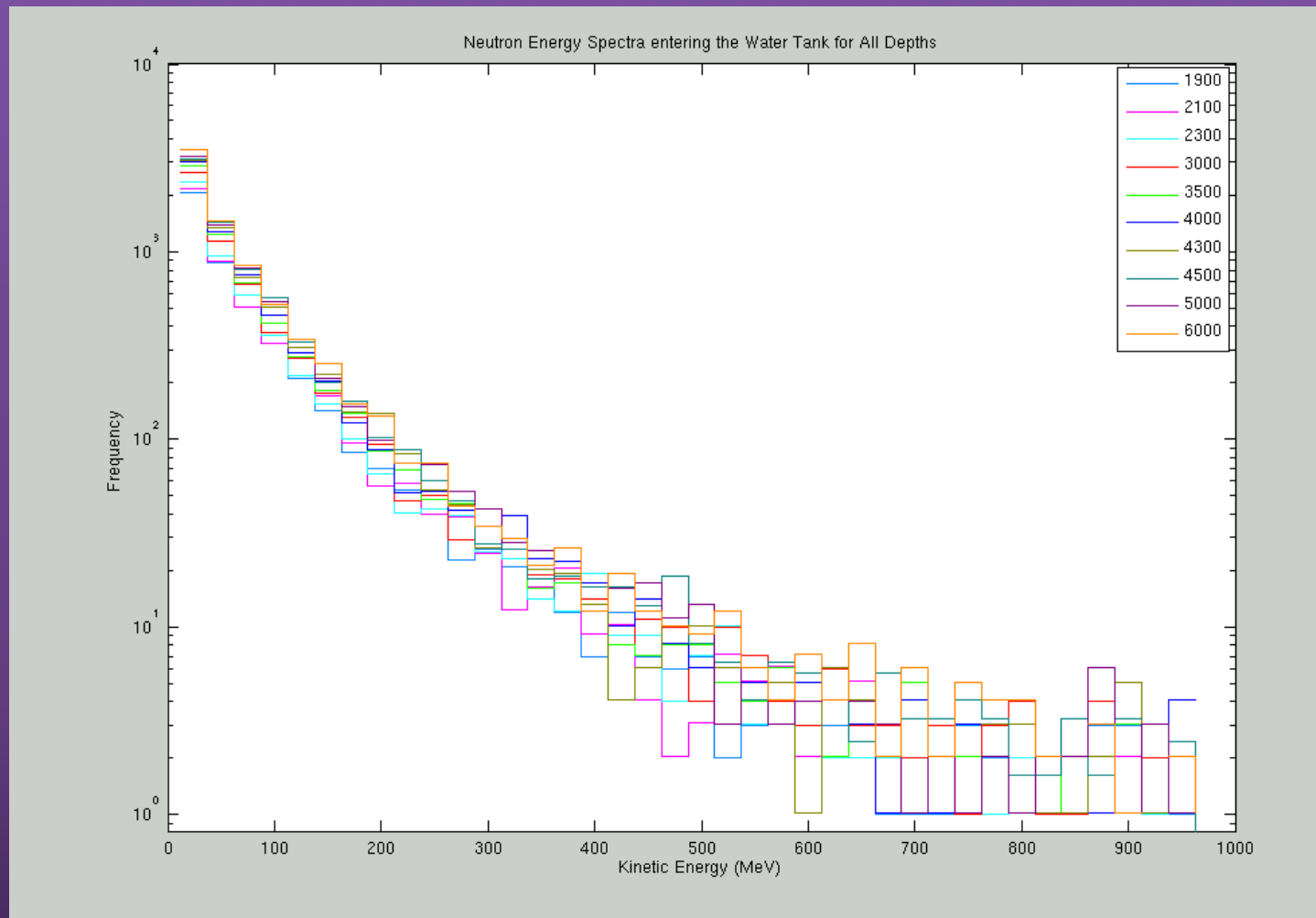
Comparison	A1	A2	A3
Soudan 5 - Dusel 6	0	0	0
Soudan 5 - Dusel 5	0.423	0	0
Soudan 5 - Soudan 6	100	100	100
Soudan 6 - Dusel 6	3.65	0	0.8
Soudan 6 - Dusel 5	99.99	92.57	9.94
Dusel 5 - Dusel 6	100	100	100



Overview

- Muons induce Neutrons (Mei and Hime, et. al)
- These neutrons can look like WIMPs in detectors
- We don't like neutrons; they aren't invited to the party.
- But they show up anyway, so we need to understand them better.
- Need to compare neutron energy spectra at different depths entering and exiting (entering detector volume) the water tank.

Neutron Energy Spectra (all depths*) entering Water Tank

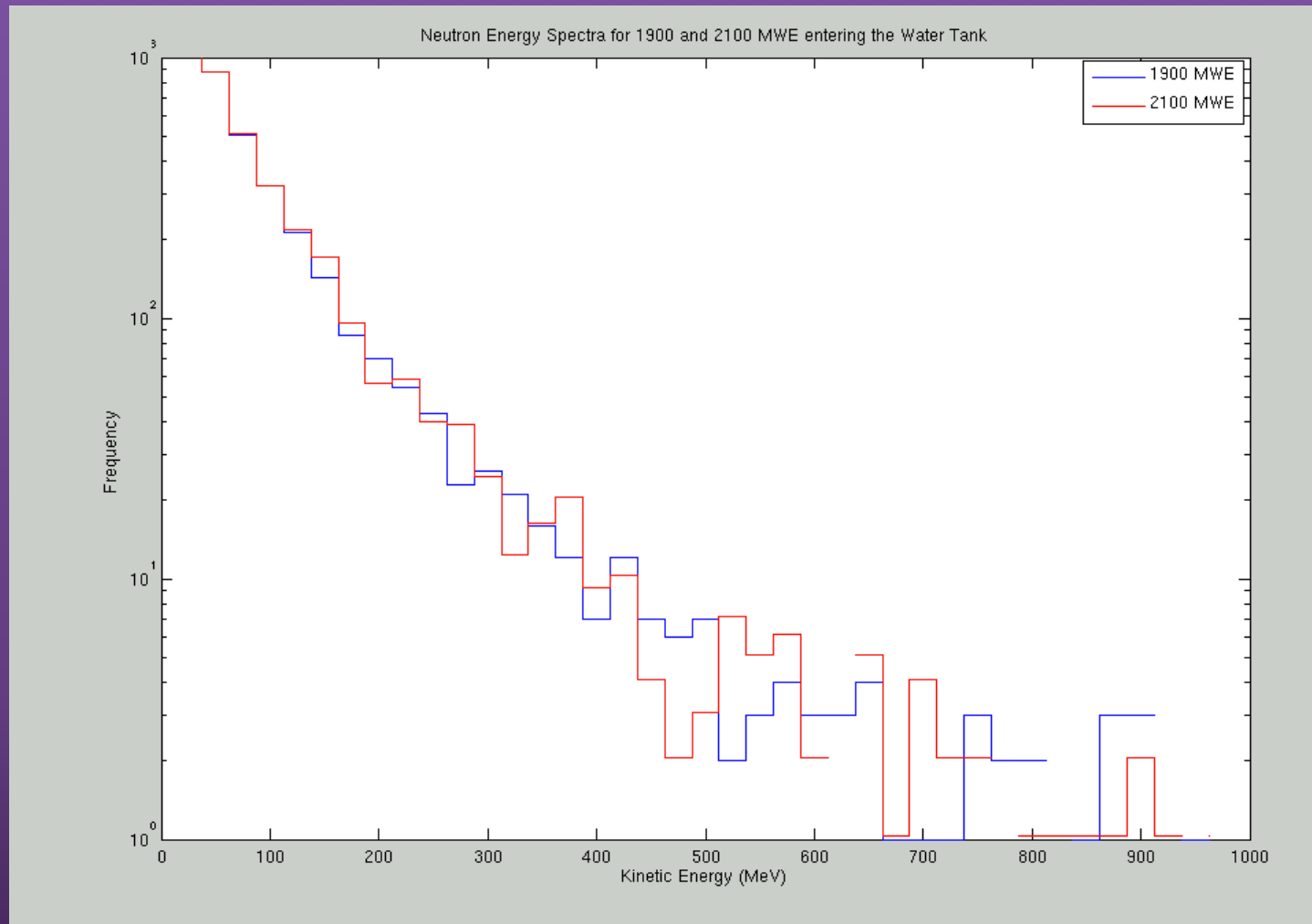


*Counts normalized by number of muons thrown

Table of Neutron Energy Spectra Comparisons (entering the water tank)

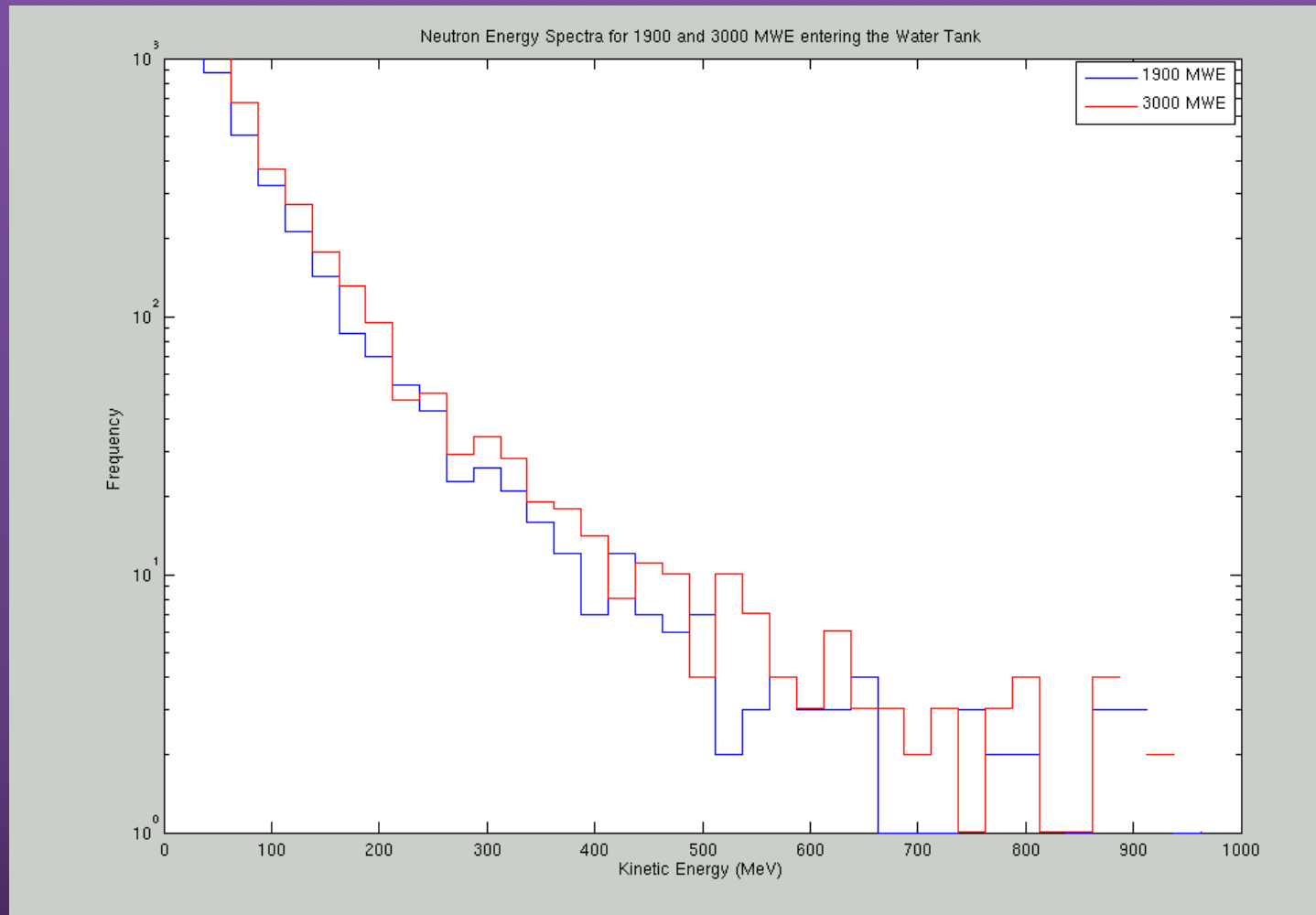
H ₂ O Tk.	Upper triangular are Muon Comparisons, Lower Triangular are Neutron Comparisons									
MWE	1900	2100	2300	3000	3500	4000	4300	4500	5000	6000
1900	100, 100, 100									
2100	99.6 99.9 100 T	100, 100, 100								
2300	98.7 99.9 100 F		100, 100, 100							
3000	99.5 99.7 99.8 T			100, 100, 100						
3500					100, 100, 100					
4000						100, 100, 100				
4300	99.7 99.4 98.7 F						100, 100, 100			
4500								100, 100, 100		
5000									100, 100, 100	
6000	97.1 91.1 76.5 T									100, 100, 100

Neutron Energy Spectra for 1900 and 2100* MWE



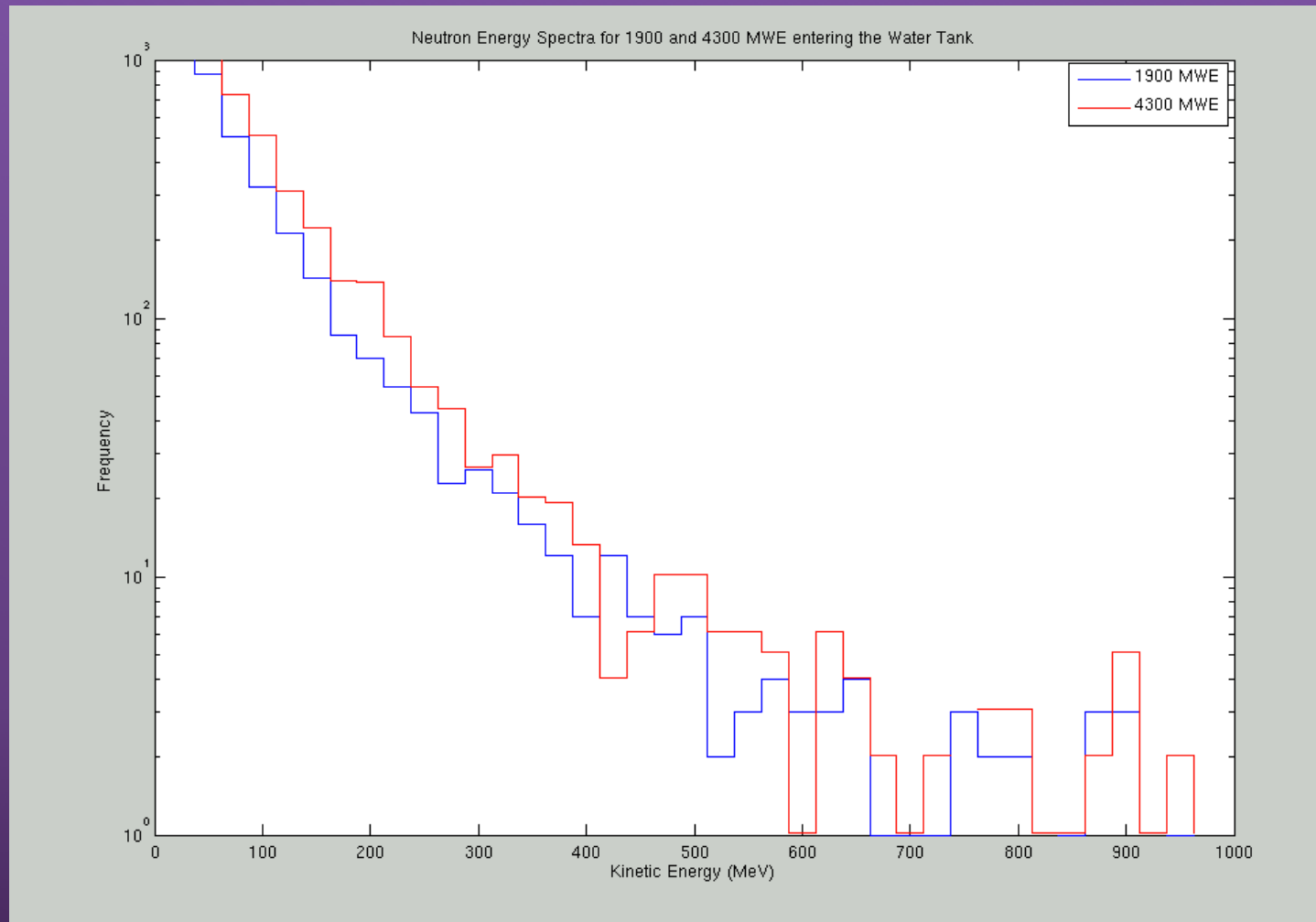
*Counts normalized by number of muons thrown

Neutron Energy Spectra for 1900 and 3000* MWE



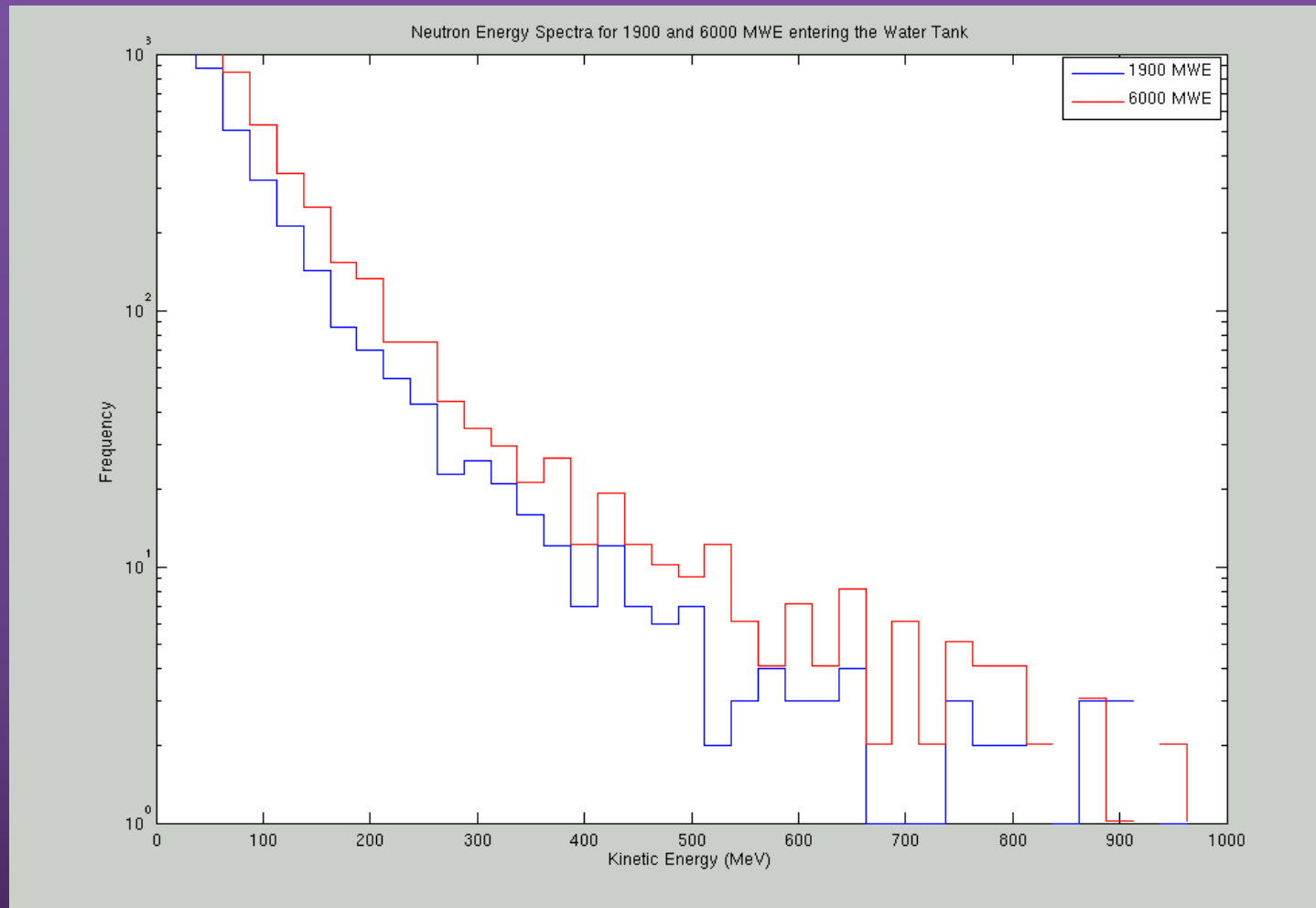
*Counts normalized by number of muons thrown

Neutron Energy Spectra for 1900 and 4300* MWE



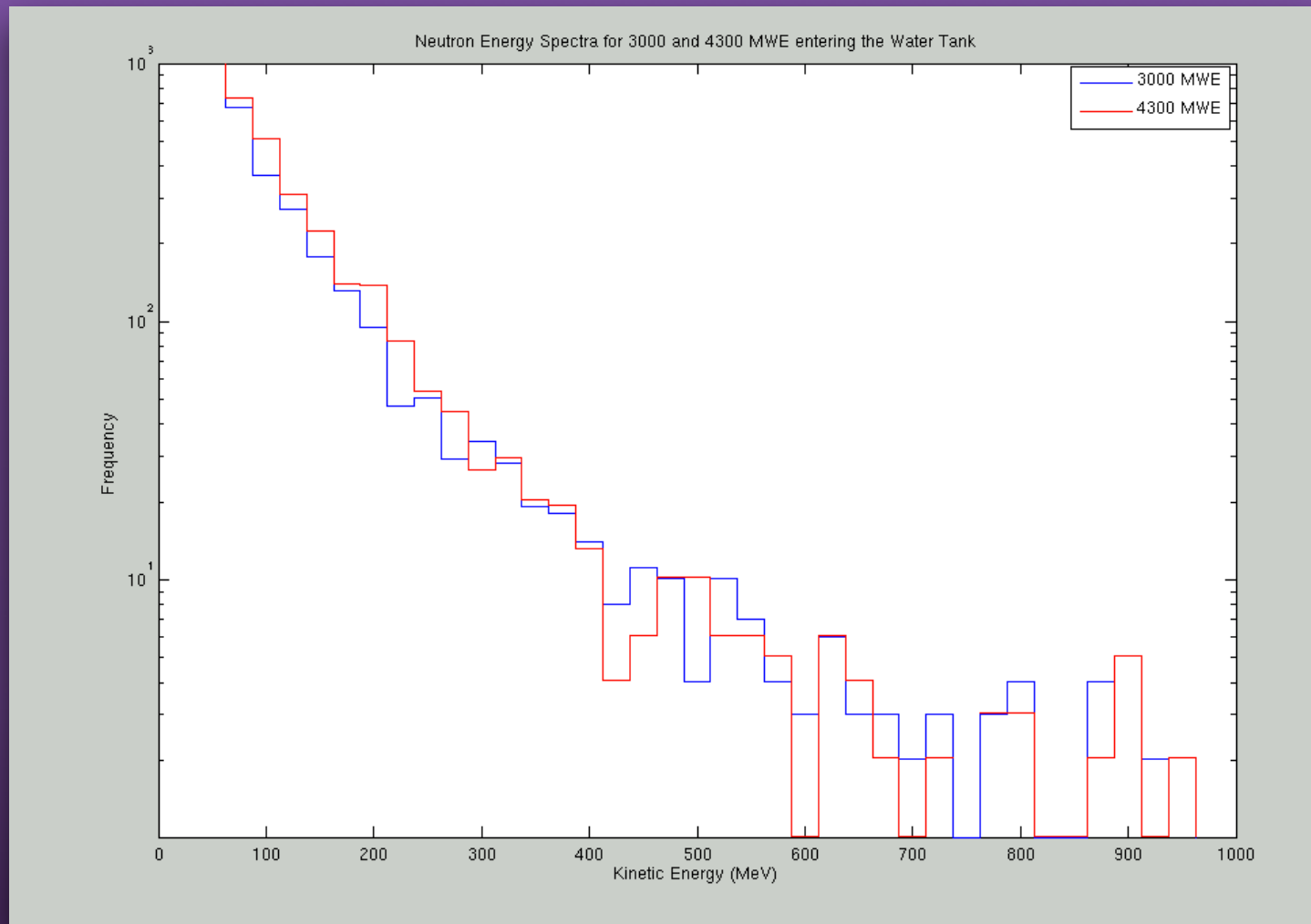
*Counts normalized by number of muons thrown

Neutron Energy Spectra for 1900 and 6000* MWE



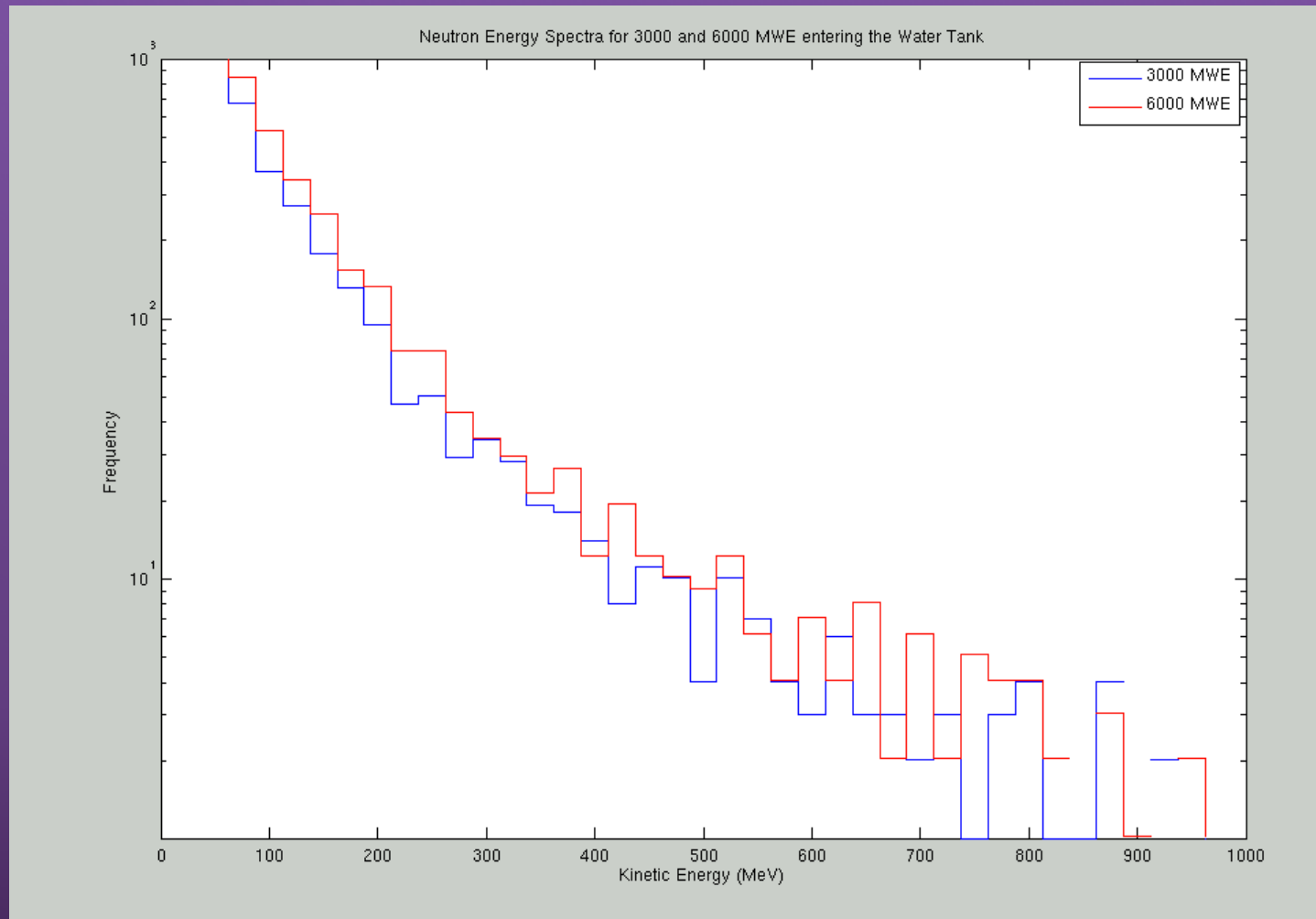
*Counts normalized by number of muons thrown

Neutron Energy Spectra for 3000 and 4300* MWE



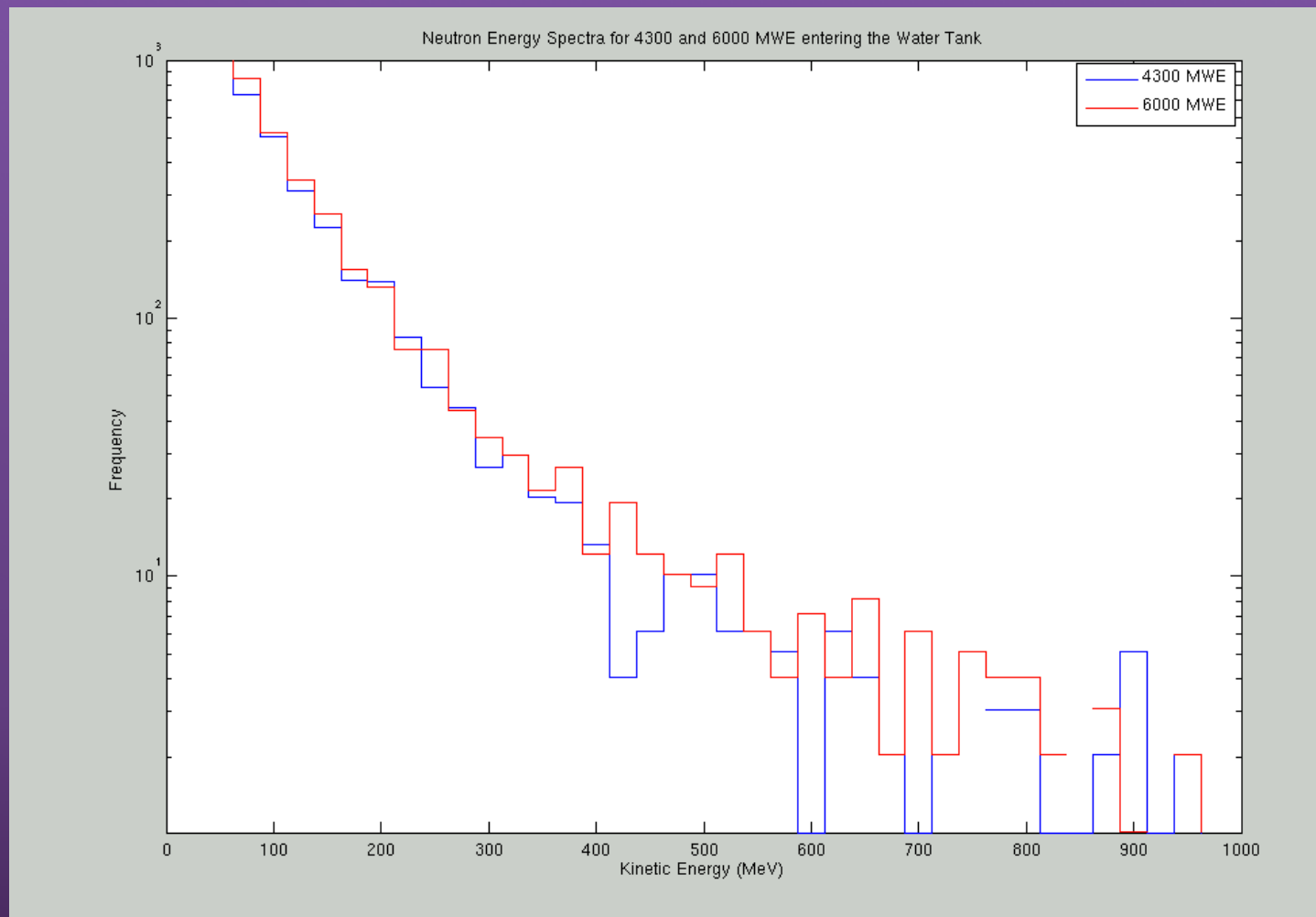
*Counts normalized by number of muons thrown

Neutron Energy Spectra for 3000 and 6000* MWE



*Counts normalized by number of muons thrown

Neutron Energy Spectra for 4300 and 6000* MWE



*Counts normalized by number of muons thrown

Comparison to Soudan/ DUSEL RHEL 5/6 (water tank)

Comparison	A1	A2	A3
Soudan 5 - Dusel 6	0.66	2.38	6.3
Soudan 5 - Dusel 5	71.24	87.94	93.43
Soudan 5 - Soudan 6	100	100	100
Soudan 6 - Dusel 6	1.1	8.8	28.7
Soudan 6 - Dusel 5	79.2	95.9	99.1
Dusel 5 - Dusel 6	99.99	100	100

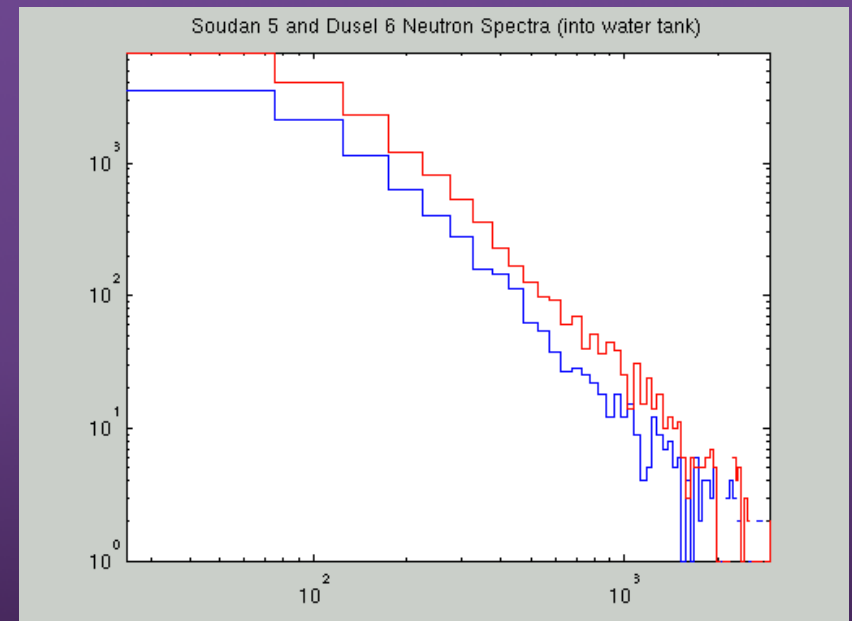
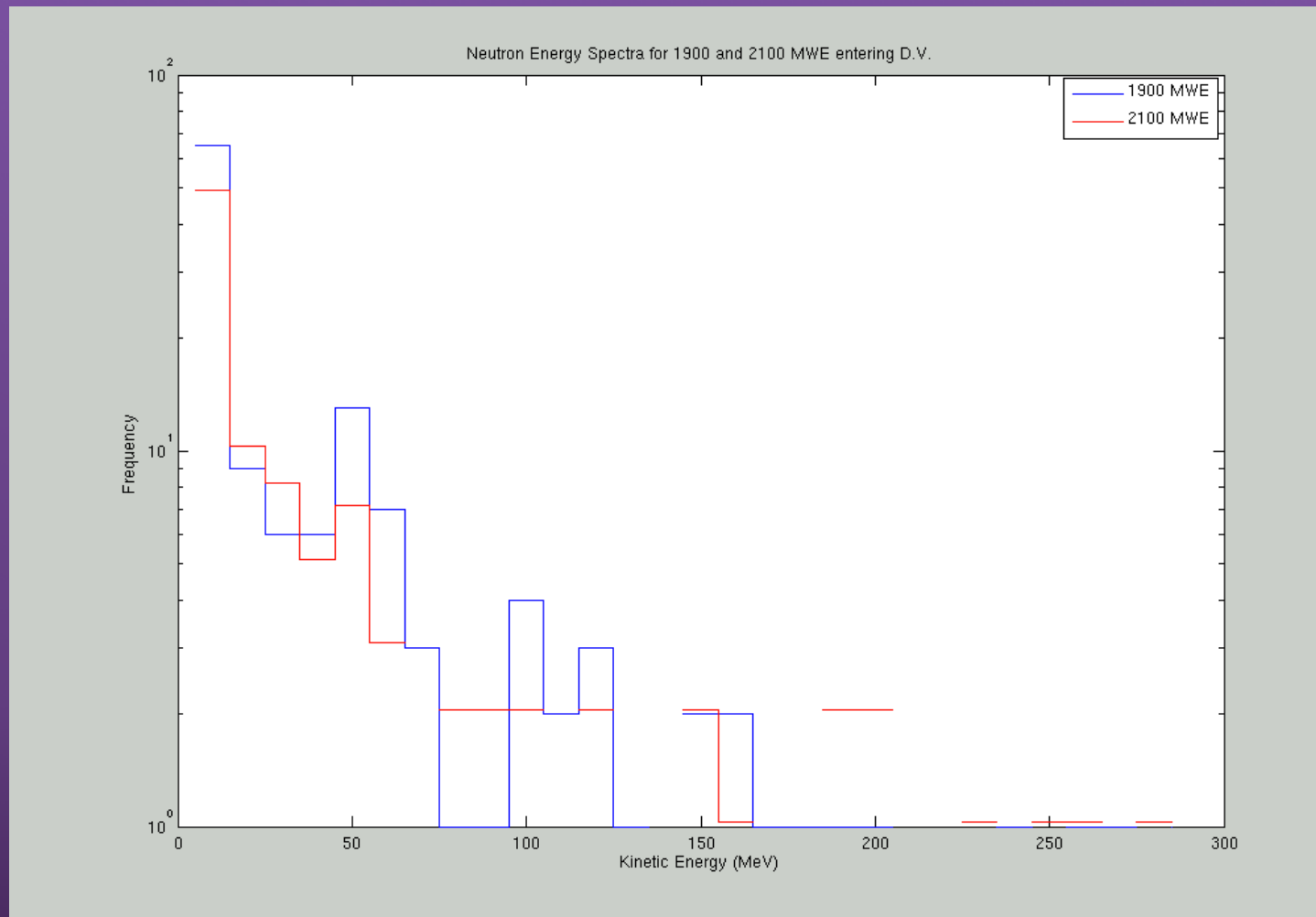


Table of Neutron Energy Spectra Comparisons (entering the detector volume)

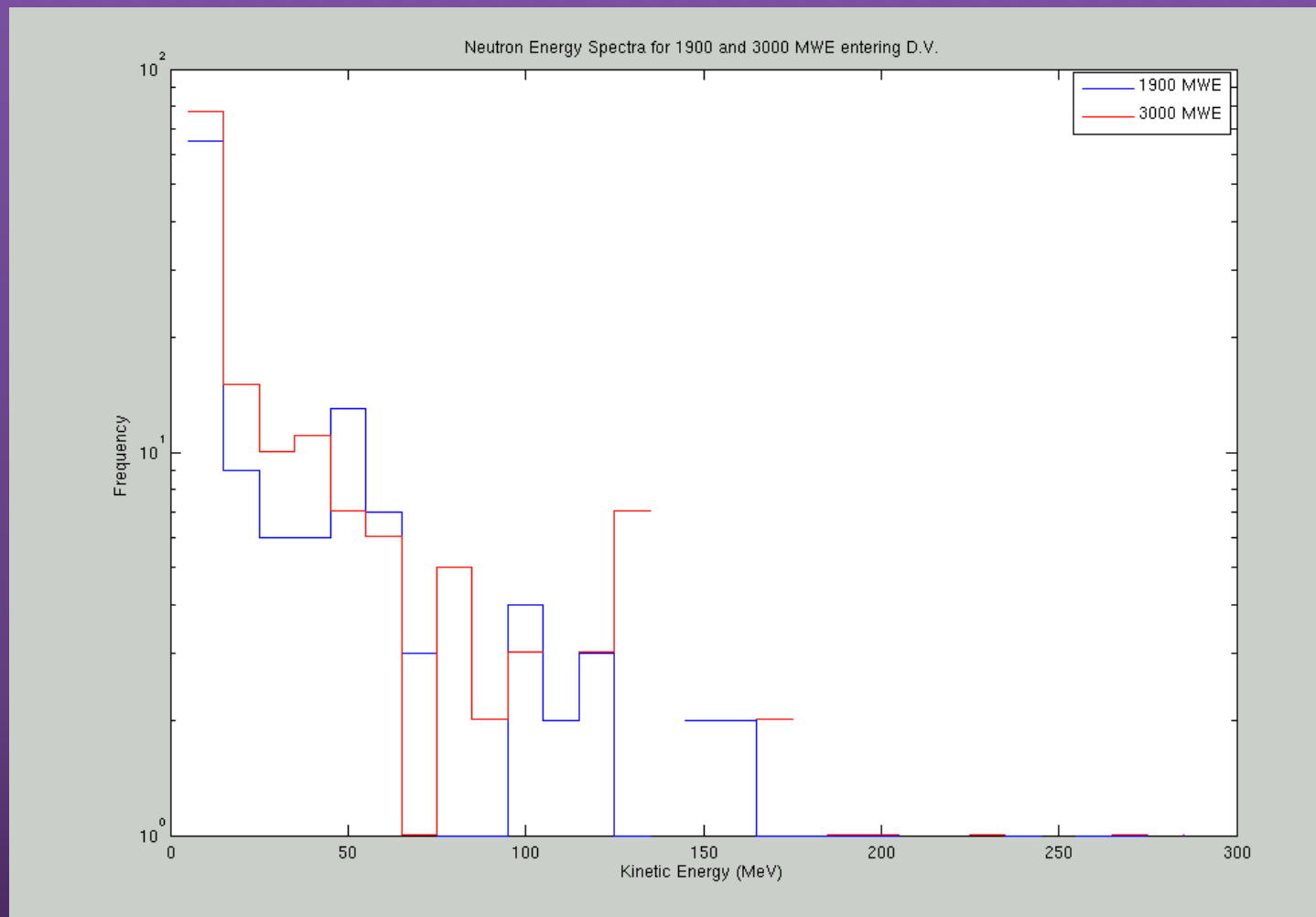
Det. Vol.	Upper triangular are Muon Comparisons, Lower Triangular are Neutron Comparisons									
MWE	1900	2100	2300	3000	3500	4000	4300	4500	5000	6000
1900	100, 100, 100									
2100	.3 18.4 80 F	100, 100, 100								
2300	1.1 20.7 71 T	1.1 50.2 97.7 T	100, 100, 100							
3000	50.2 99.6 99.9 T	12.6 93.1 99.9 F	0.0 12.3 88.7 F	100, 100, 100						
3500	8.3 76.4 99.4 T	0 2.7 64.5 T	97.6 99.9 100 T	0.7 41.8 96.7 F	100, 100, 100					
4000	23.1 88.8 99.8 T	0.6 15.4 69.0 T	32.1 91.6 99.8 T	0.9 40.2 95.7 F	75.7 99.9 100 T	100, 100, 100				
4300	99.6 99.9 100 T	0 0 0.4 T	0 3.1 36.1 T	15.0 85.3 99.7 F	13.6 51.1 80.0 T	79.4 97.4 99.6 T	100, 100, 100			
4500	65.1 93.4 99.4 T	0.1 3.3 32.1 T	2.6 12.1 41.9 T	0.0 6.7 66.7 T	5.1 40.8 90.4 T	96.0 99.0 99.8 T	4.7 11.2 29.9 T	100, 100, 100		
5000	22.7 70.6 94.3	0.2 11.9 66.5 F	1.5 29.5 81.9 F	0.7 32.8 91.8 T	21.6 89.0 99.7 T	90.3 99.3 99.9 T	98.9 99.9 99.9 T	32.0 64.6 90.0 T	100, 100, 100	
6000	29.0 85.7 99.0 T	2.3 63.5 99.0 T	68.4 99.8 99.9 F	0.0 1.9 46.2 F	87.0 99.9 100 T	35.2 89.5 99.5 T	0.2 6.0 43.0 T	99.9 99.9 100 T	10.0 84.7 99.8 T	100, 100, 100

Neutron Energy Spectra for 1900 and 2100* MWE



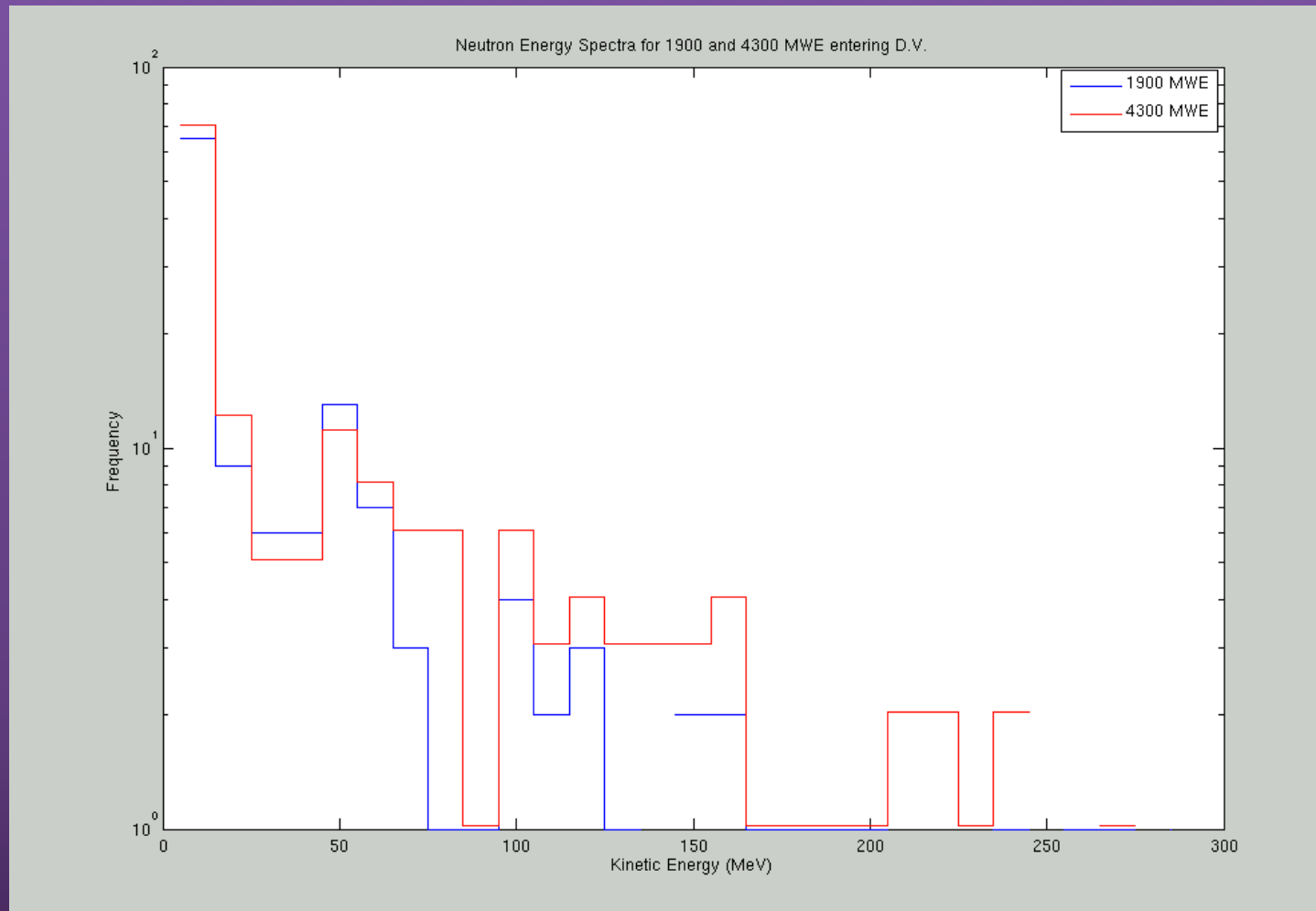
*Counts normalized by number of muons thrown

Neutron Energy Spectra for 1900 and 3000* MWE



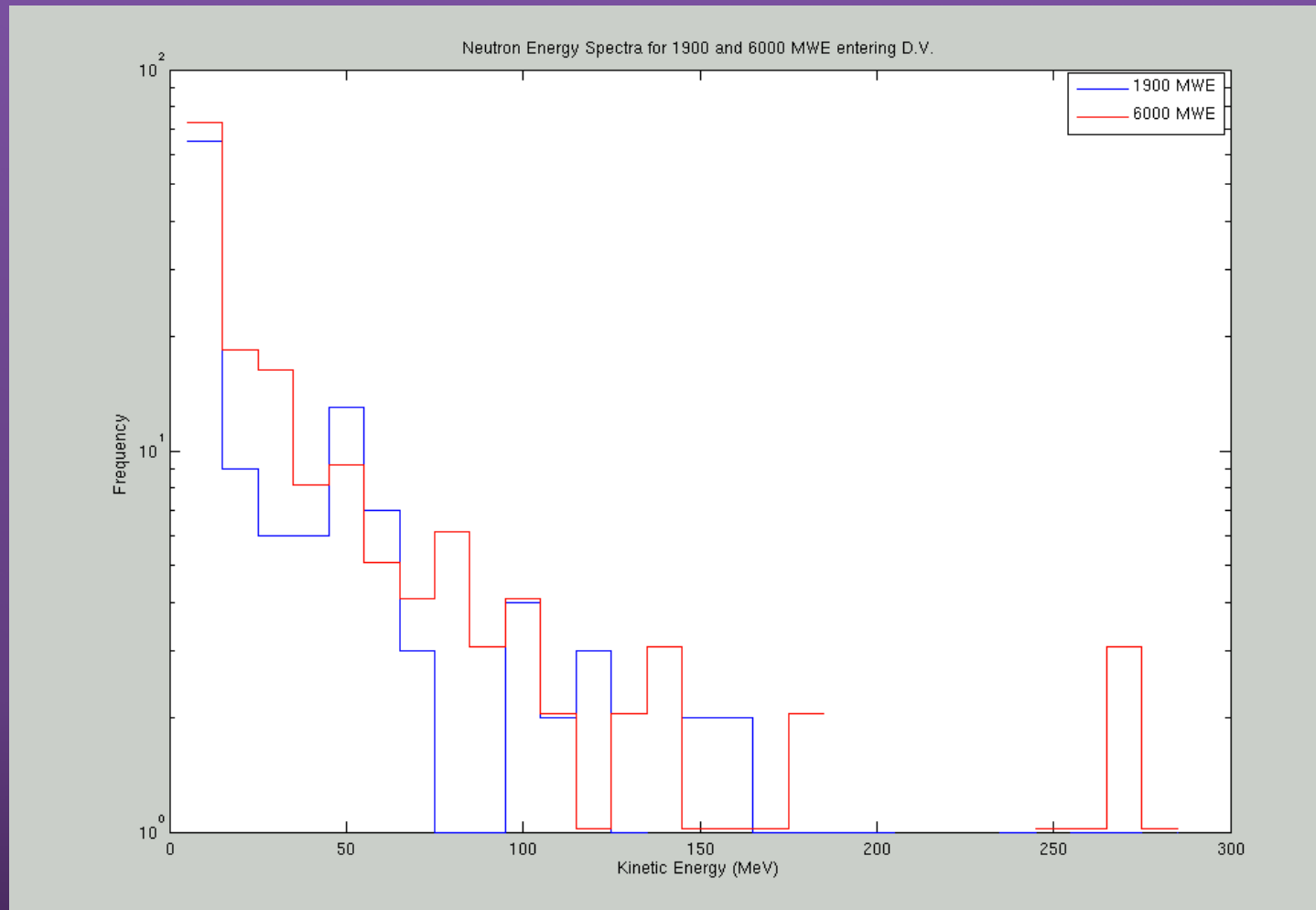
*Counts normalized by number of muons thrown

Neutron Energy Spectra for 1900 and 4300* MWE



*Counts normalized by number of muons thrown

Neutron Energy Spectra for 1900 and 6000* MWE



*Counts normalized by number of muons thrown

Comparison to Soudan/ DUSEL RHEL 5/6 (d.v.)

Comparison	A1	A2	A3
Soudan 5 - Dusel 6	100	100	100
Soudan 5 - Dusel 5	100	100	100
Soudan 5 - Soudan 6	100	100	100
Soudan 6 - Dusel 6	100	100	100
Soudan 6 - Dusel 5	100	100	100
Dusel 5 - Dusel 6	100	100	100

Comparison (tail only)	A1	A2	A3
Soudan 5 - Dusel 6	79.88	53.7	24.08
Soudan 5 - Dusel 5	99.81	99.53	99.28
Soudan 5 - Soudan 6	99.99	99.99	99.99
Soudan 6 - Dusel 6	96.22	85.44	62.99
Soudan 6 - Dusel 5	99.98	99.84	98.7
Dusel 5 - Dusel 6	100	100	99.99

