Depth Working Group (Cosmogenic simulation working group for AARM) Status update

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21 March 2014

Projects

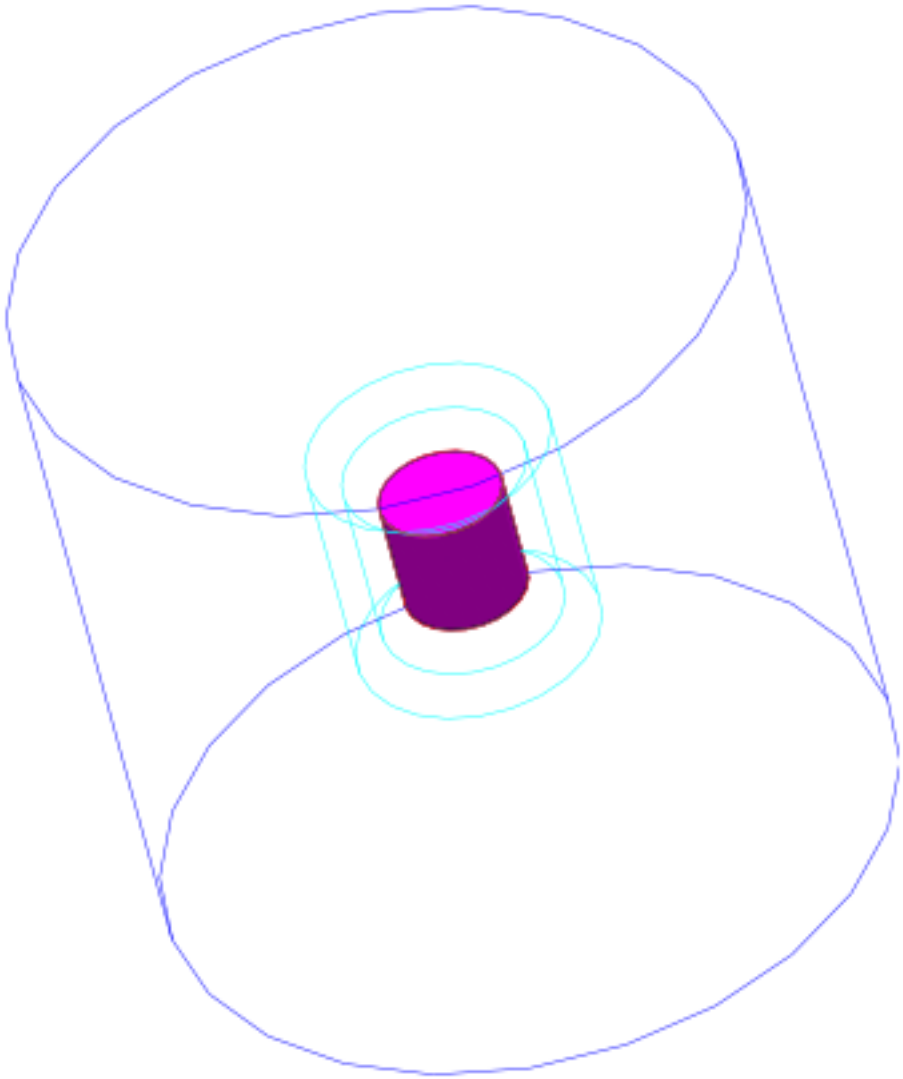
- Muon distributions: significant progress comparing Geant4 propagation, MUSUN
- Fortran compiler issues: rhel5 vs rhel6 give different mean muon energies for same MUSUN fortran code. Rhel6 appears to have been fixed.
- Study comparing muon and neutron distributions at different depths using Groom parametrization
- **Study comparing LXe, LAr, and Ge detector technologies (large scale) with same 5m water shield at 4850 depth using Sanford MUSUN muons**

LAr, LXe, and Ge comparison

- Simulations performed by Chao Zhang (Ar), Monica Pangilinan (Xe), and Angie Reisetter (Ge and low stats Xe) in geant4 (geant4.9.5.p01 + physics list patch with Shielding physics list)
- Using MUSUN muons with correct fortran compiler for Sanford lab
- Same geometries outside of detector volume for Xe/Ge (5m water shield centered in 20mx20mx20m cavern)

Geometries: Ar

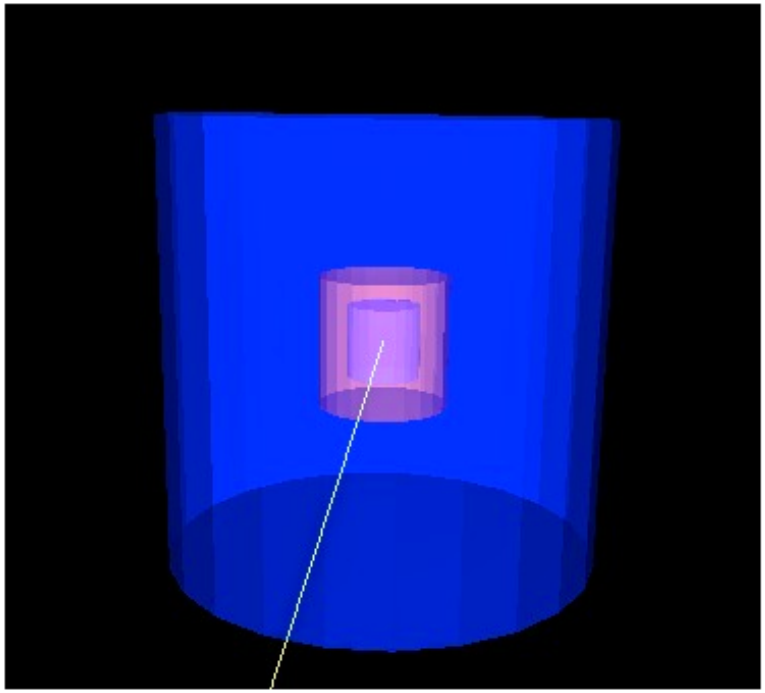
Dimension:
1 waterTank 12m*12m
2 OuterVessel 4m*4m, 2.5cm thick
3 Vacuum
4 InnerVessel 3m*3m, 2.5cm thick
5 Vacuum
6 PMTShell 0.5cm thick attach to Acrylic
7 Acrylic 1cm thick attach to LiquidAr
8 LiquidAr 2m*2m



Geometries: Xe

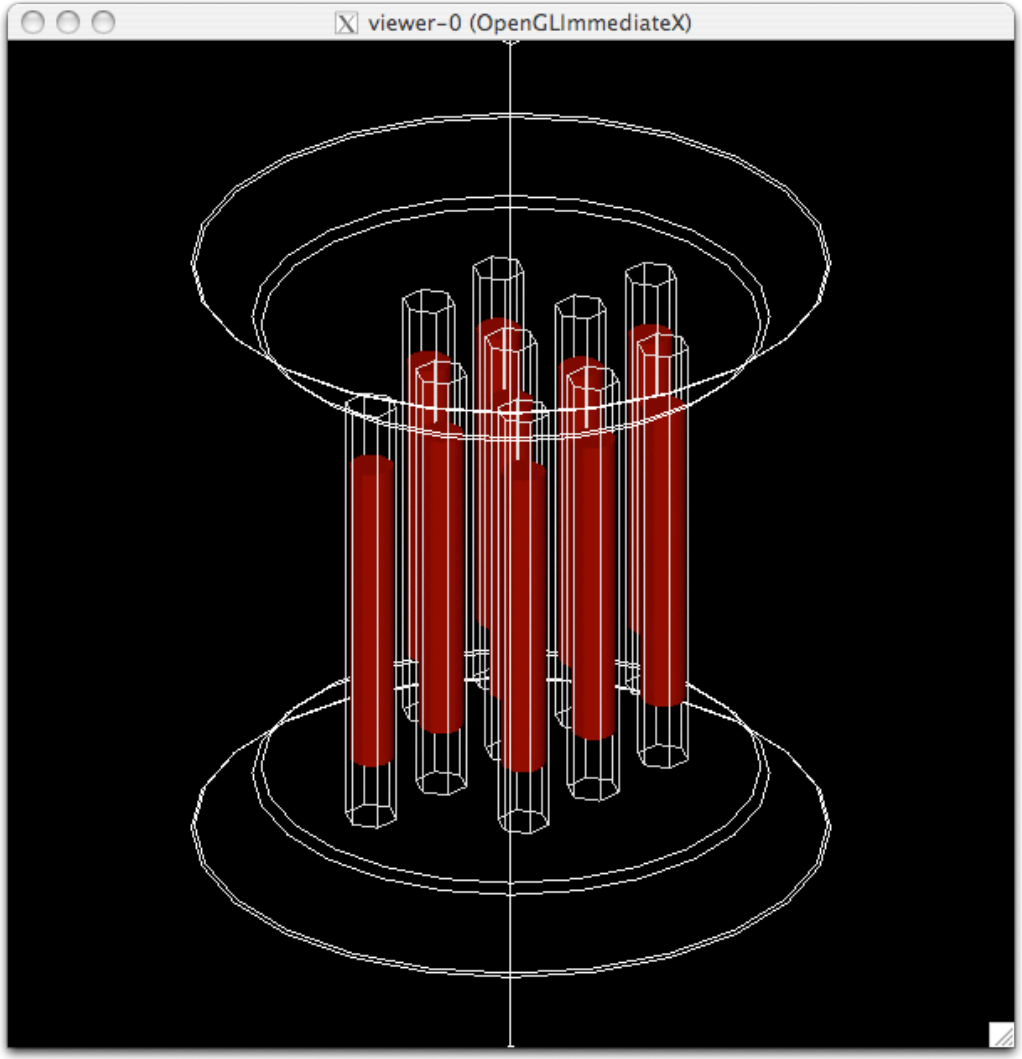
LZ20 Simple Geometry

- 17m x 17m x 17m Rock (7m thick rock)
- 10m x 10m x 10m cavern (vacuum)
- 6 m radius, 12 m high cylindrical water tank
- 1 m radius, 2 m high Liquid Xe cylinder
- 3 mm thick Ti shell surrounding the Liquid Xe
- 80 cm thick Scintillator surrounding the Ti



Geometries: Ge

- Water tank 6m radius, 4.9m thickness
- Steel 1.1m radius, 1cm thickness
- Poly (moderator) radius 1.09m thickness 20cm
- Copper Cryostat radius 0.89m, thickness 3 cm
- Each detector has 6 inch diameter, 2 inch thickness, Ge
- 300 detectors
- 10 towers of 30 detectors each



LiveTime

- Livetime calculated by normalizing muon flux through top of water tank to $6.46 \times 10^{-5}/s/m^2$
- Ar: 19.81 years
- Xe: 1.80 years (previously ~10 years with rhel5 muons)
- Ge: 12.4 years

Sim	Muon rate through all outer walls of water tank ($x10^{-5}$ /s/m^2)
Ar	2.11
Xe	1.76
Ge	1.76

Sim	Neutron rate through top of water tank ($x10^{-6}$ /s/m^2)
Ar	1.87
Xe	2.03
Ge	2.55

Sim	Neutron rate through all sides of water tank ($x10^{-6}$ /s/m^2)
Ar	1.83
Xe	1.83
Ge	2.26

Sim	Neutron rate entering detector volume ($x10^{-6}$ /s/m^2)
Ar	5.48
Xe	13.1
Ge	0.654

Sim	Events with at least one NR >5keV ($x10^{-5}$ /s)
Ar	1.25
Xe	12.3
Ge	0.501

Sim	Events with at least one NR in energy ROI ($x10^{-6}$ /s)
Ar	0.116
Xe	46.5
Ge	4.82

Sim	Single WIMP candidates with all cuts except veto & fiducial volume ($x10^{-8}$ /s)
Ar	1.60
Xe	<1.77
Ge	6.65

Comments on WIMP candidates with all cuts except fiducial and veto

Sim	Single WIMP candidates with all cuts except veto & fiducial volume ($x10^{-8}$ /s)
Ar	1.60
Xe	<1.77
Ge	6.65

- Ar sim: 10 events in 19.81 years, but none pass the fiducial volume cut
- Xe sim does not have any events in 1.80 live years
  - (previous sim found ~1 in 10 years)
  - (7T Xe geometry gave 3 orders of magnitude reduction to this step, which is about where the current limit is… larger detector will likely give bigger reduction)
- Ge sim: 26 events in 12.4 years (all pass the fiducial volume cut, which is high efficiency in Ge)

WIMP candidates in Ge

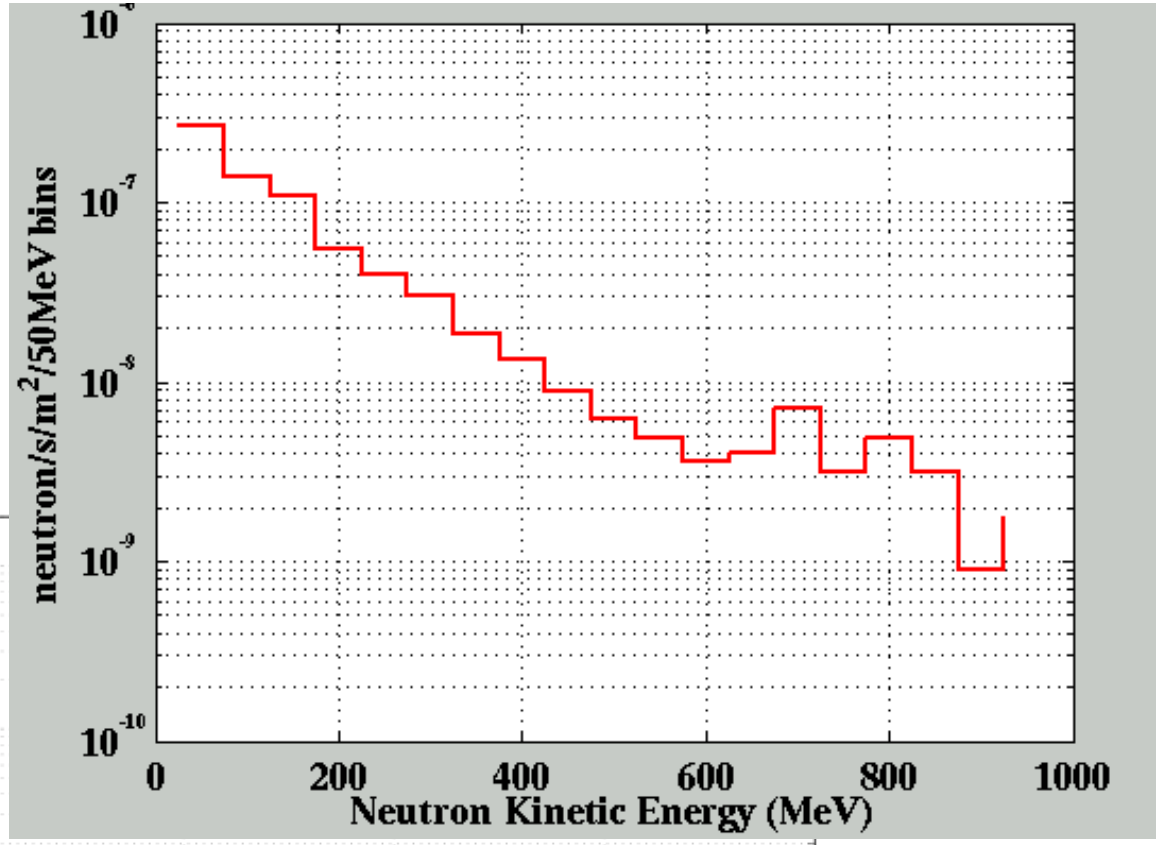
- Of the 26 WIMP candidates, only 13 are vetoed by a muon entering the water tank
- Singles veto: unvetoed rate 1:1 (13:13)
- Multiples veto:unvetoed rate 690:2

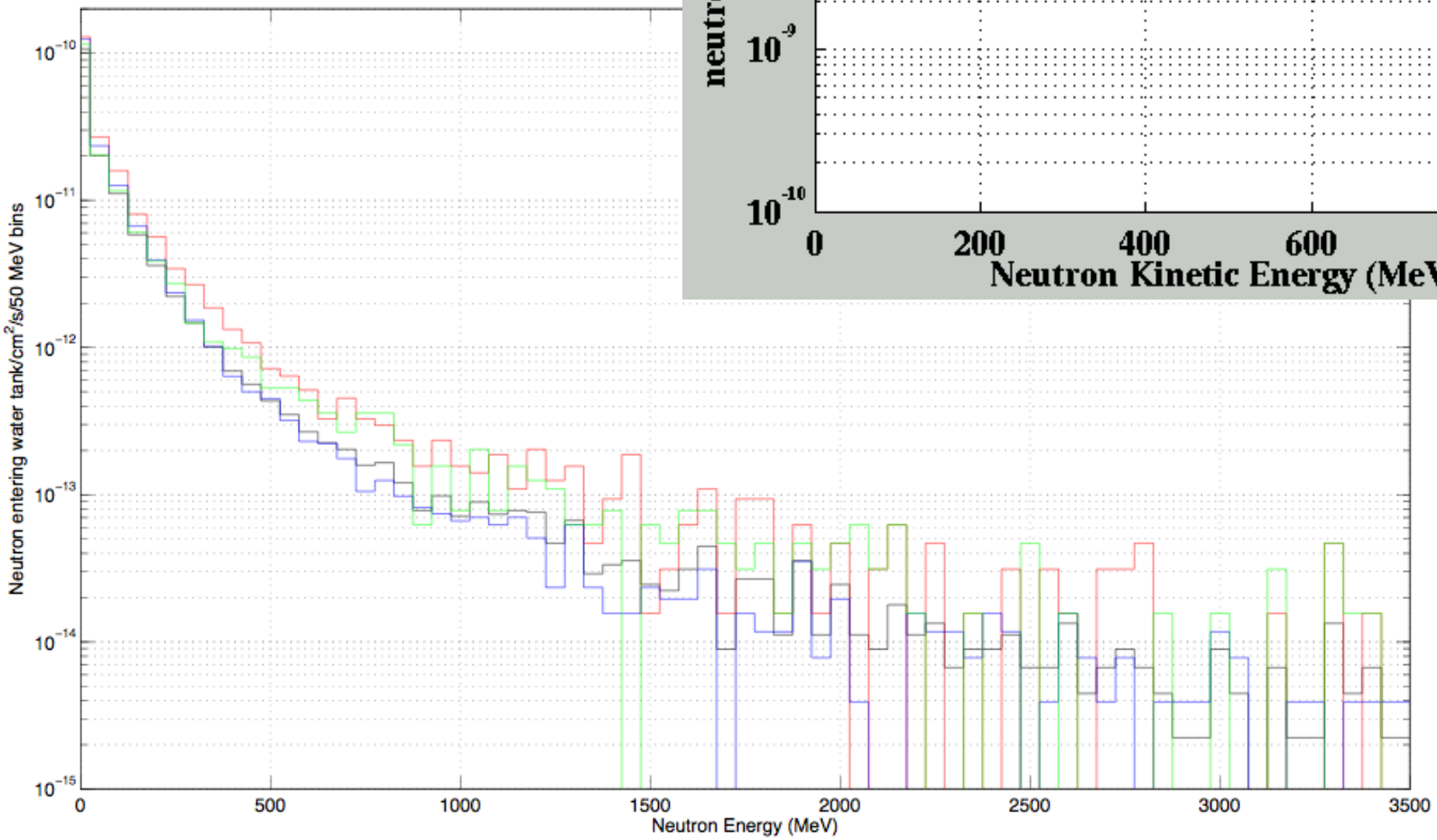
- Vetoed single:multiple ratio 1:53
- Unvetoed single:multiple ratio 6.5:1

Conclusions from comparison of technologies study

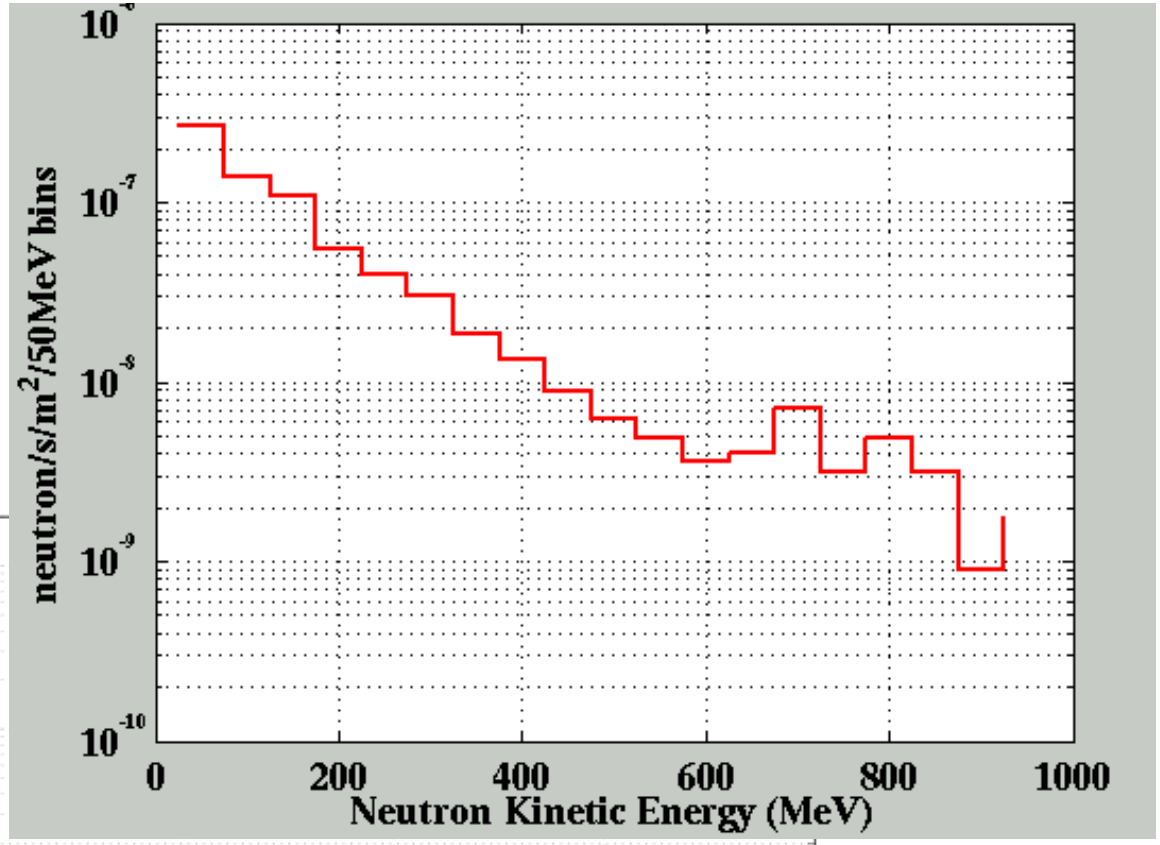
- Good agreement for Ge/Xe simulations where expected
- For rate of WIMP candidates in Xe, need more statistics, but it will likely be lower than current limit
- For Ge technology, rate of ~1 unvetoed single per year in ton-scale experiment is unacceptable: would need better veto and would not use water tank at this depth

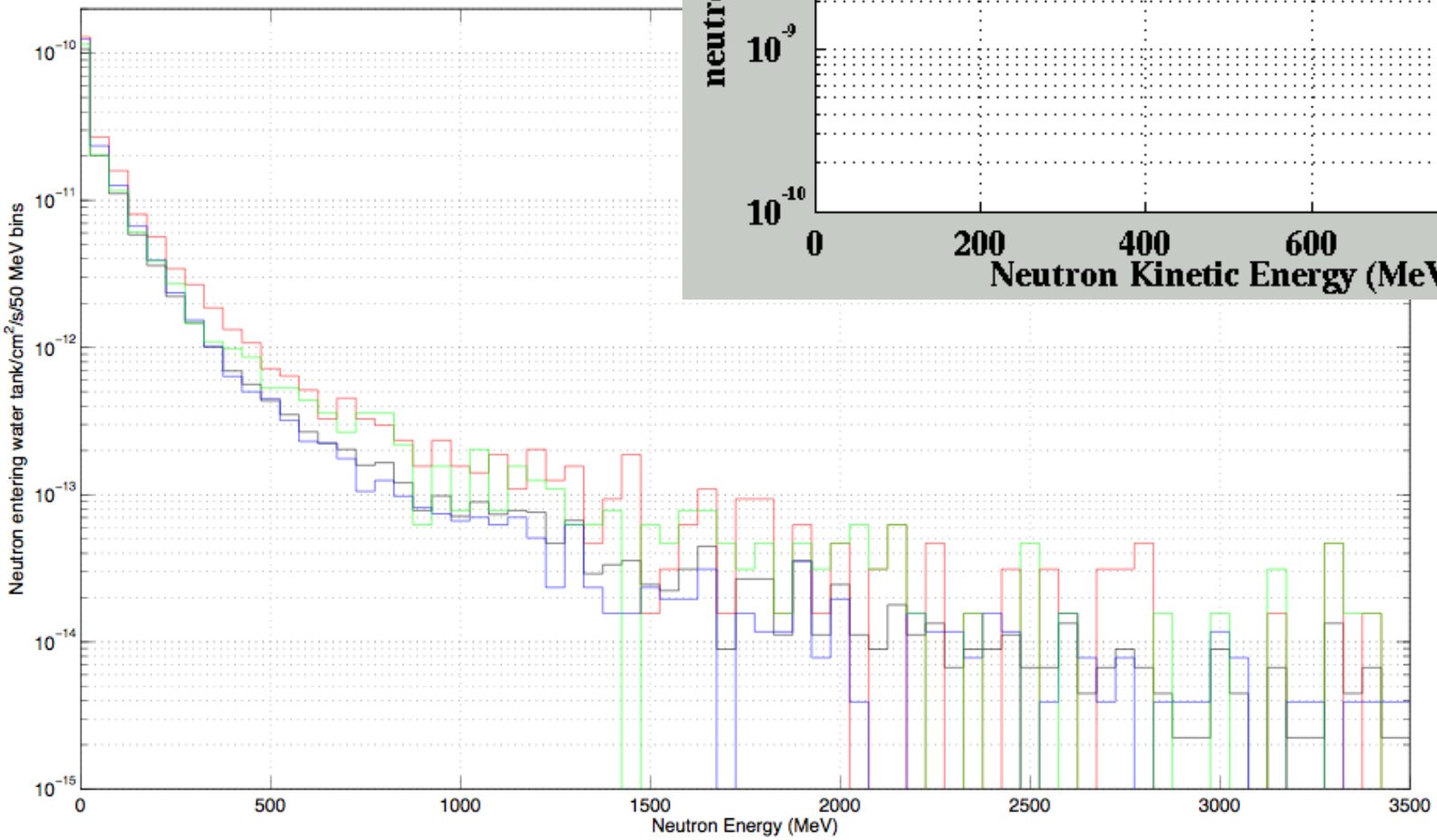
Neutrons entering
Water shield





Neutrons entering
Water shield





Conclusions from muon distribution studies

- Chao propagated muons from surface using geant4
- Good agreement with MUSUN muons for Soudan and Sanford lab
- Both differ significantly from parametrization (assumes flat overburden)

Conclusions from muon energy study vs depth

- Compiler error results in different average muon energy (195 GeV vs 218 GeV Soudan) (250GeV vs 280 GeV Sanford)
- Muon and neutron flux small differences outside water shield, indistinguishable inside water shield
- Study vs depth (1900mwe – 6000mwe: similar differences outside tank, small differences inside tank (ongoing)
- As depth increases, differences decrease

Neutrons Entering Cavern Summary Table

Run Type	Muon Average Energy	Neutron Average Energy	Percent Difference	Total Number of Neutrons	Percent Difference
Soudan RHEL 5	193.15 GeV	68.8605 MeV	-26.60%	9527	+14.49%
Soudan RHEL 6	216.03 GeV	50.5424 MeV		10907	
Dusel RHEL 5	252.79 GeV	50.6163 MeV	-2.53%	15706	+27.80%
Dusel RHEL 6	282.51 GeV	49.3369 MeV		20073	