# Simulations in CDMSII, SuperCDMS, and GEODM

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25 February 2011

# How CDMS uses simulations in general

- Electromagnetic backgrounds: estimate the contribution from contamination in materials surrounding the detectors using Geant4 and data.
- Radiogenic neutron backgrounds: use geant4 to simulate background contribution from contamination in materials around detectors. Input is results from counting, mainly limits. Also do a geant4 simulation of contribution from rock (very small).
- Cosmogenic neutron backgrounds: use geant4 to simulate cosmogenic neutron contribution.
- Surface event backgrounds/detector response sim: use in-house simulation to model phonon and charge propagation in the ZIP detectors. Helps with detector design and characterization. Use Geant4 to provide input to these simulations.

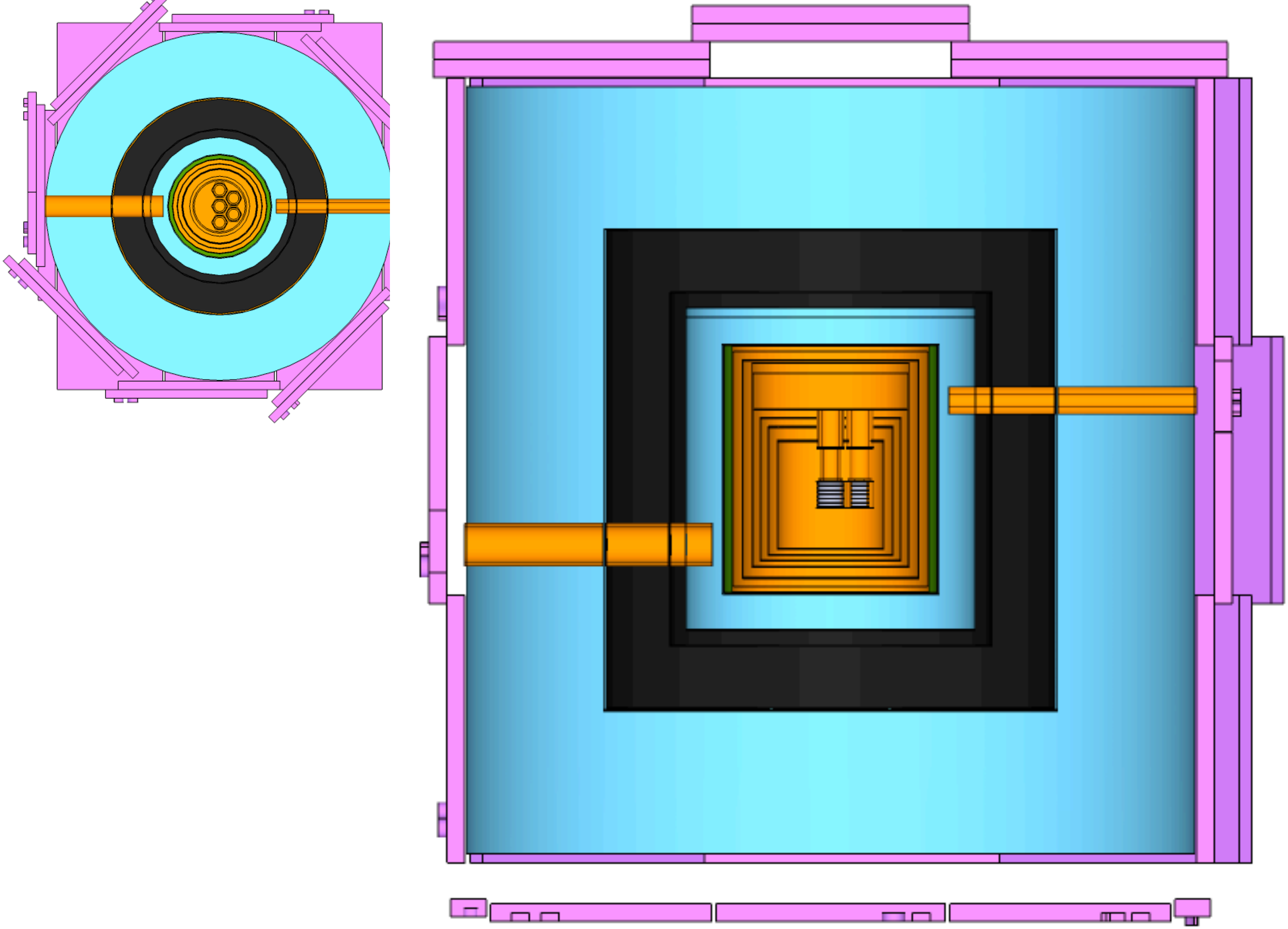
# A history of cosmogenic simulations in CDMS

- Early work checking cross sections in geant4 and FLUKA.
- Geant4 and FLUKA/MCPNX, extensive comparison using Soudan experimental setup and parameterized muons, generating cosmogenic neutrons.
- Geant4 sim redone with new method for throwing muons (muon distribution based on data). Prediction for R125-128 backgrounds.
- Comparison with vetoed nuclear recoil data with R125.
- Currently working on updating physics, will redo Soudan simulation with both geant4 and FLUKA.

# Set-up for Soudan simulations

- 4mx8mx4m cavern surrounded by 10m of rock in each direction
- Detailed geometry off-center in geometry to get realistic albedo (0,2m,-.4m)
- Active volumes:  skin lining cavern (records everything), scintillating veto, inner-most layer of shielding (records everything), ZIP detectors
- Keep all shower particles thru to detector

Details for Geant4 code:  geant4.7, QGSP_BERT_HP (best cross sections in our materials) hadronic physics, low-energy EM package, MuNuclear processes turned on



# Conclusions from Geant4/FLUKA/MCNPX comparison

- Of nuclear recoil events, ~85% are vetoed by muons, but including the rest of the shower increases the veto rate to ~94%.
- The veto rate is much higher for events with NRs in more than one detector (multiples) than the rate for singles. Rates similar in 2 sims.
- Including EM fragments in simulation significantly reduces the rate of nuclear recoils (less than half of NRs are "identifiable", i.e. not drowned out by EM signals)
- Ratios of multiples:singles, and unvetoed:vetoed in each category were steady between softwares (geant/fluka), physics lists, muon-throwing schemes
- Depending on the category of NR event, FLUKA predicts a factor of 2 to 4 higher rate than Geant 4 does.

# Prediction for final run of CDMSII

- It is known that both the FLUKA and Geant4 (especially Geant4) prediction of rates of NR are too low.
- The ratios of singles:multiples and unvetoed:vetoed are trusted, and are used to predict overall rate.
- We DO see vetoed NR events in the data.  This serves as the normalization.  The ratios from sim are used to predict unvetoed rates.  There are many ways to do this.  Can get a systematics spread from doing calculation several different ways.

# Different event rate prediction for c58

**Method 1**
NR single event (passing timing): 1 * 2 / 36 **0.056 +0.136 / -0.056**
Based on data, MC only used for veto ratio
Poor statistics in data ➔ largest overall error
Systematics are less important, since this is more direct.

**Method 2**
NR+X hit (passing timing): 6 * 2 / 196 **0.061 +0.067 / -0.042**
Multiples in data have more statistics ➔ smaller error
Needs two MC ratios, veto and singles:multiples (S/M)

**Method 3**
NR single event all: 3 * 2 / 36 * .504 **0.084 +0.108 / -0.065**
Based on data, MC only used for veto ratio
Statistics increased by using data that doesn't pass timing cut, then correcting back using global timing efficiency. Assumes that all events are NR, so that the timing cut is just a neutron efficiency cut. Assumes that all detectors are the same efficiency. Will be skewed if there are many hits from endcap detectors.

**Method 5** (Variation on Method 3)
NR single event all: 3 * 2 / 36 * .374 **0.062 +0.227 / -0.049**
Use timing cut for each detector. The 3 evts are from T3Z2, T4Z6, T5Z5 = .374 for avg timing cut efficiency. Answer closer to Method 1, since it properly accounts for the endcap detector having a higher probability of losing its event to the timing cut.

**Method 4**
NR+X hit all: 11 * 2 / 196 * .504 **0.057 +0.056 / -0.036**
Highest statistics from the data since it uses multiples and no timing cut.
Requires MC correction for both veto and S/M, and corrected globally for the timing efficiency. Least direct, may have larger systematics.

# Cosmogenic background estimate

From observed data:
**vetoed neutron rate**
(Ge ZIPs, no ZIP-coincidence)

$$\frac{3\ \text{events}}{844\ \text{kg} \bullet \text{days}} = 1.3\ /\ (\text{kg} \bullet \text{year})$$

From MC data:
**unvetoed/vetoed ratio**
(Ge ZIPs, no ZIP-coincidence)

$$\frac{35\ \text{events}}{606\ \text{events}} = 0.058 = \frac{1}{17}$$

**Unvetoed neutron rate**
(Ge ZIPs, no ZIP-coincidence)

$$0.075\ /\ (\text{kg} \bullet \text{year})$$

WIMP exposure for Runs 125-8: 194.1 kg•days

Background estimate: $0.04^{+0.04}_{-0.02}(\text{stat})$

# Current work

- Working on geant4 physics to do Soudan predictions for SuperCDMS, help with R&D for SNOlab.
- 4850m level GEODM (Homestake) simple monte carlo helps us examine effects of new cross sections, physics, and make some predictions for backgrounds.
- Working on simple comparisons of FLUKA (flugg) and geant physics with same geometries, benchmarking with data

# 4850m Sim Details and Livetime calculation

Cavern size 16mx16mx16m

Water tank size: cylinder r=5m, h=10m

Hole in center of water tank: cylinder r=2m, h=4m

100kg Ge detector at center of geometry

Muons thrown from horizontal 34mx34m plane

M&H Homestake muon rate: 4.4e-9 mu/cm$^2$/s

=**24.2 years total** for geant4.9.3 version sim w/QGSP_BIC_HP physics list

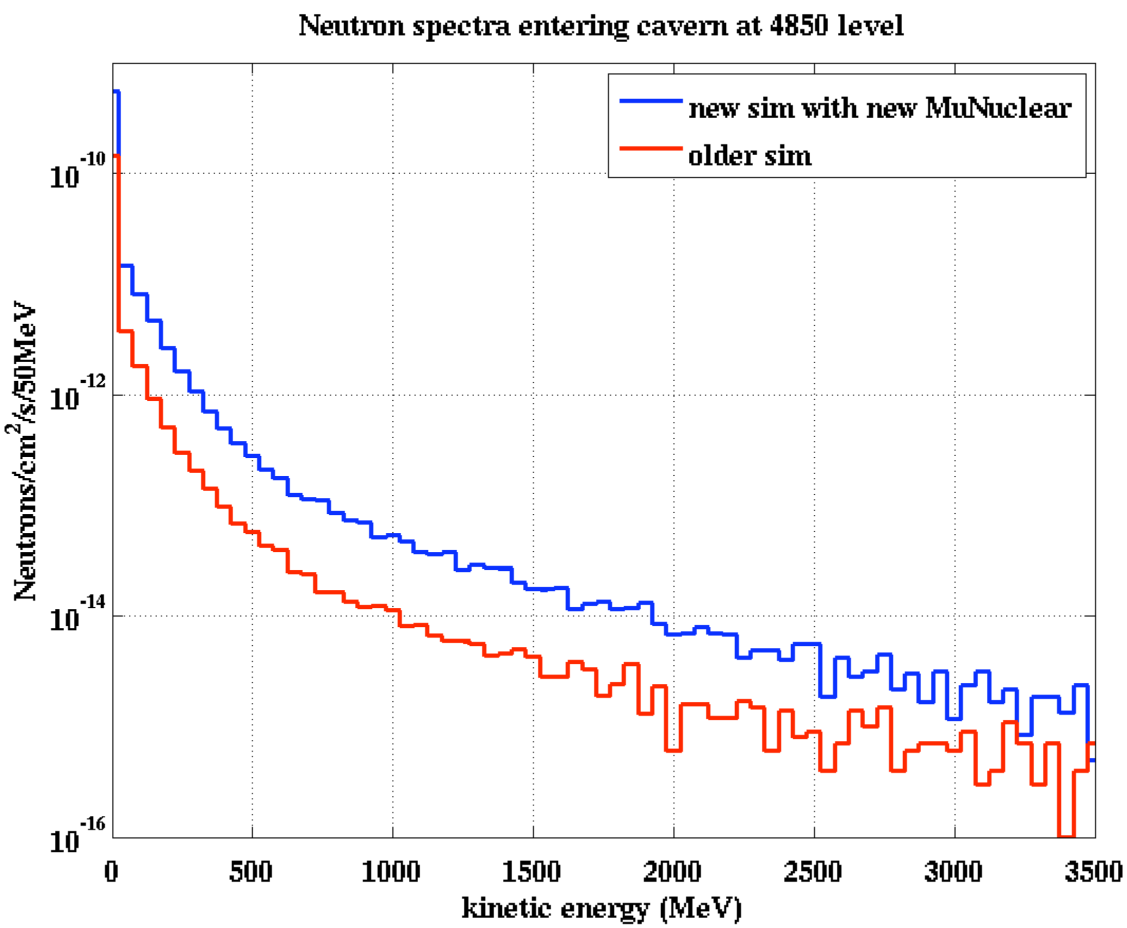
**=12.5 years total** for geant4.9.3.p02 version w/Shielding cross sections (from geant4.9.4) and updated MuNuclear process, as well as additional 3cm-thick copper box around Ge detector

# Mei & Hime table V comparison using neutrons entering 16mx16m cavern units: n x$10^{-9}$/$cm^2$/s

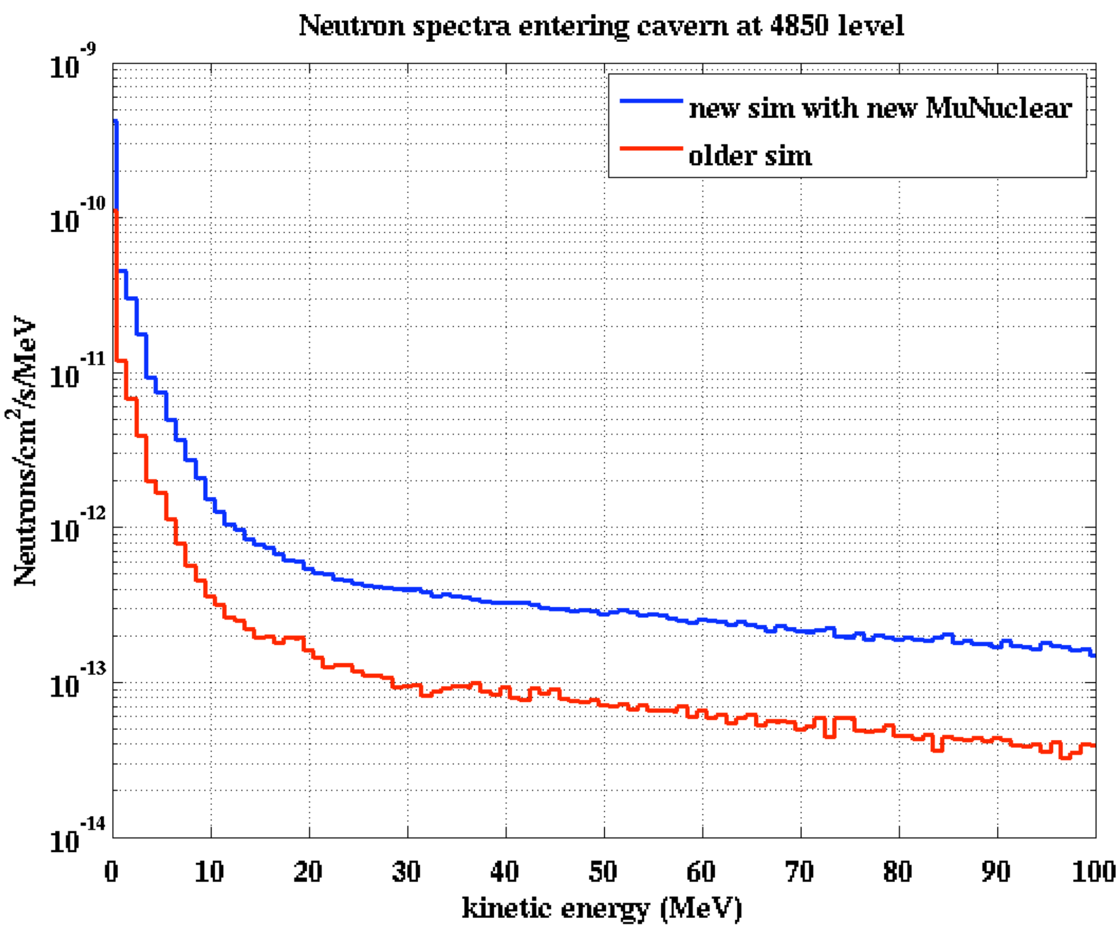
| | Total | >1MeV | >10MeV | >100MeV |
|---|---|---|---|---|
| M&H Gran Sasso rates | 2.72 | 0.81 | 0.73 | 0.201 |
| M&H GS rates scaled to Homestake using muon rates (.44/2.58) | 0.46 | 0.138 | 0.125 | 0.0343 |
| New 4850 sim rate | 0.587 | 0.140 | 0.0467 | 0.0168 |
| Old 4850 sim rates | 0.50 | 0.094 | 0.020 | 0.0027 |
| M&H Sudbury | 0.05 | 0.02 | 0.018 | 0.005 |

New 4850 sim rate above 200keV impinging on water: 0.0964

New 4850 sim rate above 200keV entering det volume inside 3m water shield: 0.0812

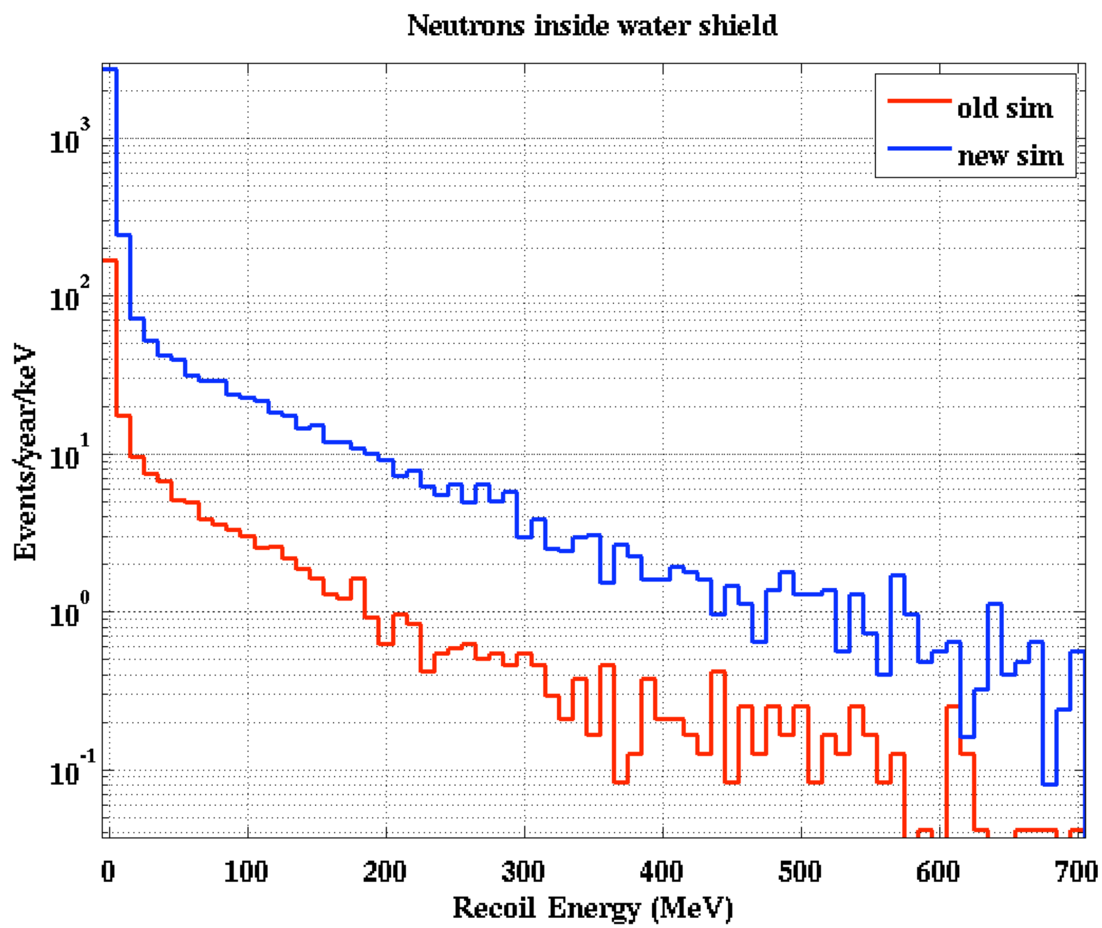


Neutron spectra entering cavern at 4850 level
new sim with new MuNuclear
older sim
Neutrons/cm$^2$/s/50MeV
$10^{-10}$
$10^{-12}$
$10^{-14}$
$10^{-16}$
0
500
1000
1500
2000
2500
3000
3500
kinetic energy (MeV)

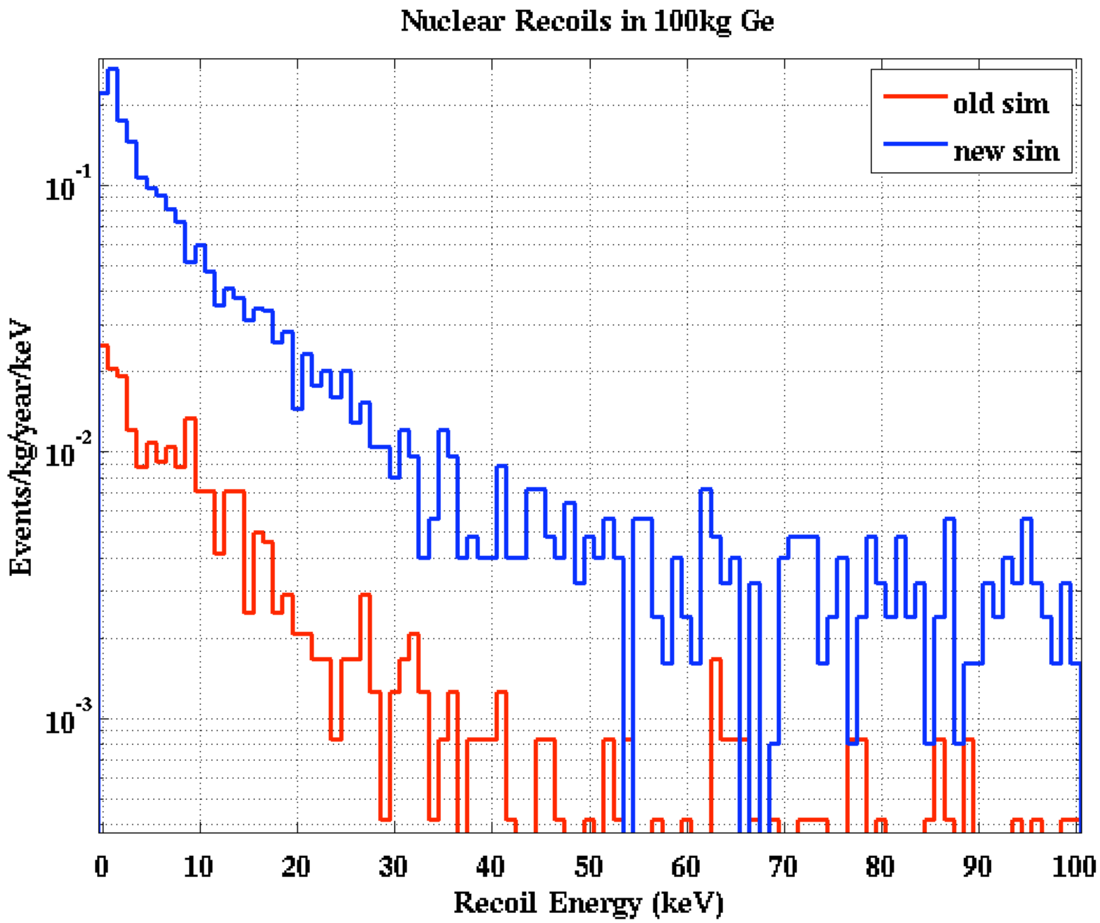


Neutron spectra entering cavern at 4850 level
new sim with new MuNuclear
older sim
Neutrons/cm$^2$/s/MeV
kinetic energy (MeV)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
0
10
20
30
40
50
60
70
80
90
100

Rate of events with neutrons entering detector volume (inside water shield) is 7x higher in new sim.



Rate of events with nuclear recoils 10-100keV in Ge detector is 12x higher in new sim.



# Conclusions

- CDMSII/SuperCDMS has used data to normalize ratios from sims to predict cosmogenic neutron rates. Absolute rates from sims are too low.
- The ratios from sims have been steady in comparisons between Geant4 and FLUKA/MCPNX.
- Current work is to improve Geant4 physics and compare directly to data and FLUGG physics.
- Most recent simulations indicate that numbers of NRs will increase by ~10x if new physics cross sections and processes are used. We will rerun this sim once we reach equilibrium on physics benchmarking.