MaGe Neutron Background Studies:

Muon-Induced Neutrons

Michael Marino
University of Washington
For the Majorana Simulation Group

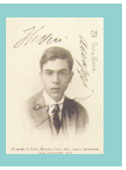
MaGe Meeting - München

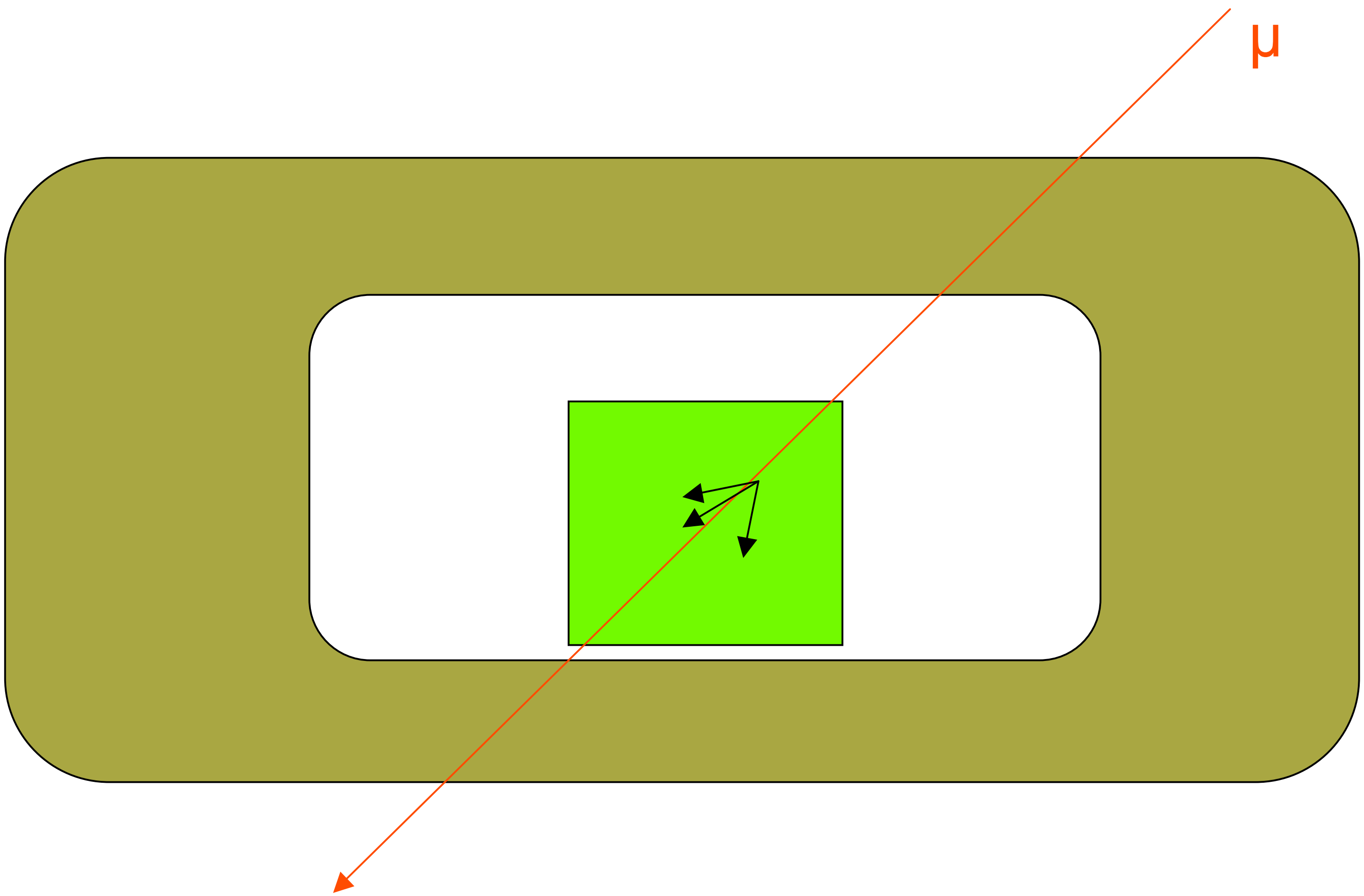
15 Feb 2007

Outline

- Introduction
- Validation
  - Neutron production from μ's
  - Neutron transport through material

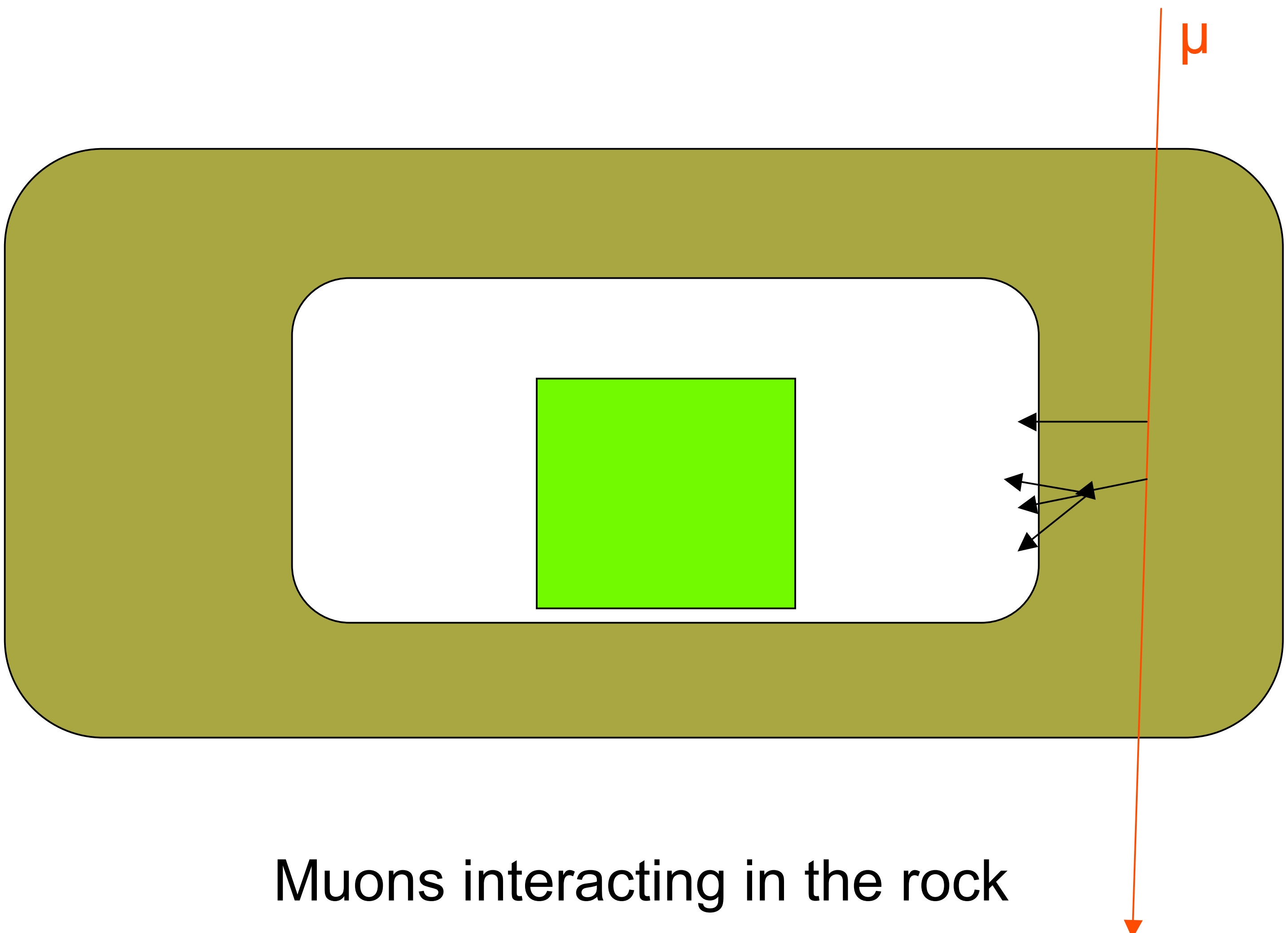
The problem





Muons interacting in the detector

The problem



Muons interacting in the rock

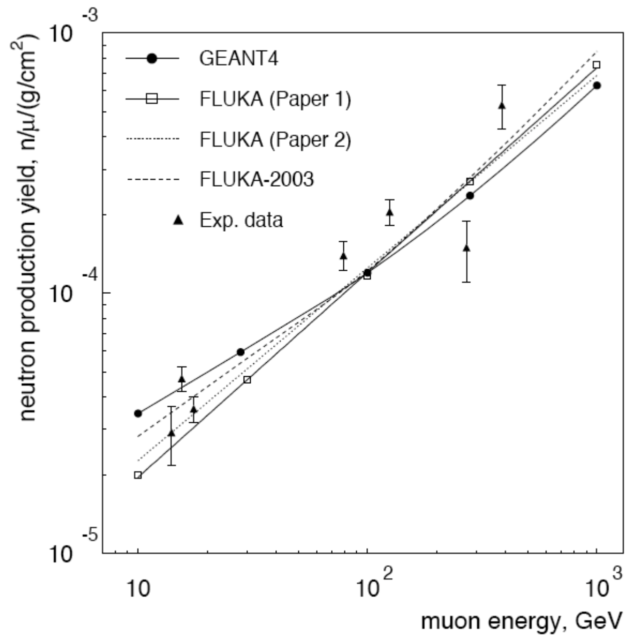
Tasks

- Verify the neutron production from muons within MaGe.
- Verify the transport of hard neutrons induced by muons.
- Must be done for variety of materials.
- Hadronic simulations are inexact: estimate errors.

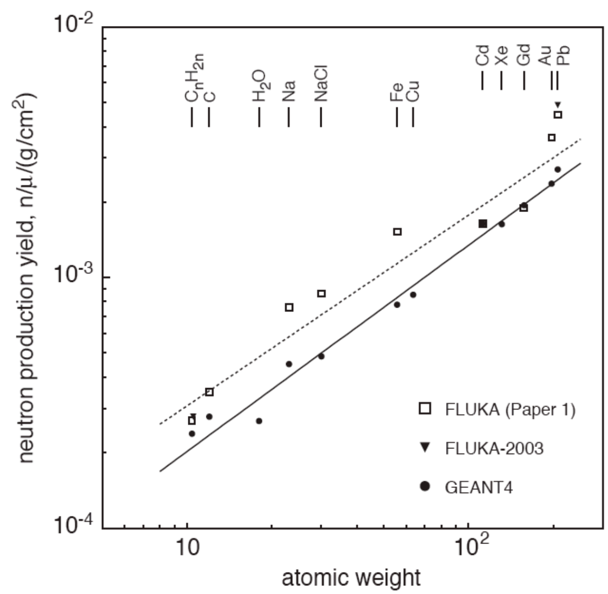
Muon-induced neutrons

- Previous work done has mainly involved thick low-Z, -A material (e.g. liquid scintillator)
- G4 and FLUKA agree within a factor of 2 and reasonably well with data.
- Power law fit to simulated data ~ $E^{0.75}$

Araujo, et al. NIM A **545** (2005)



Simulation + Experiment



Simulation

Neutron production

- CERN NA55 experiment
  - Measured neutrons generated from 190-GeV muon beam incident on C, Cu, and Pb
- Lower-Z material simulations provide reasonable agreement with experimental results
- Geant4 reproduced simulated results of Araujo et al.

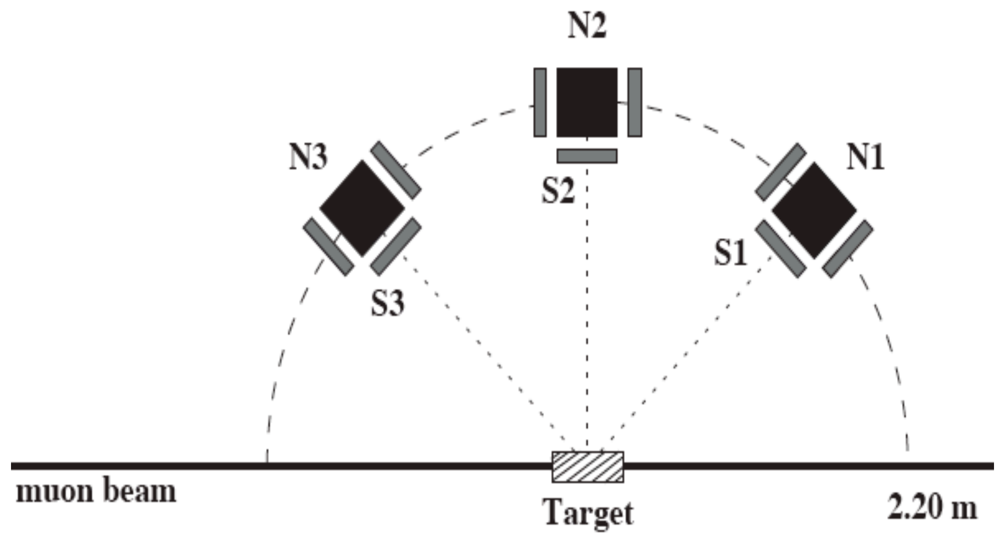
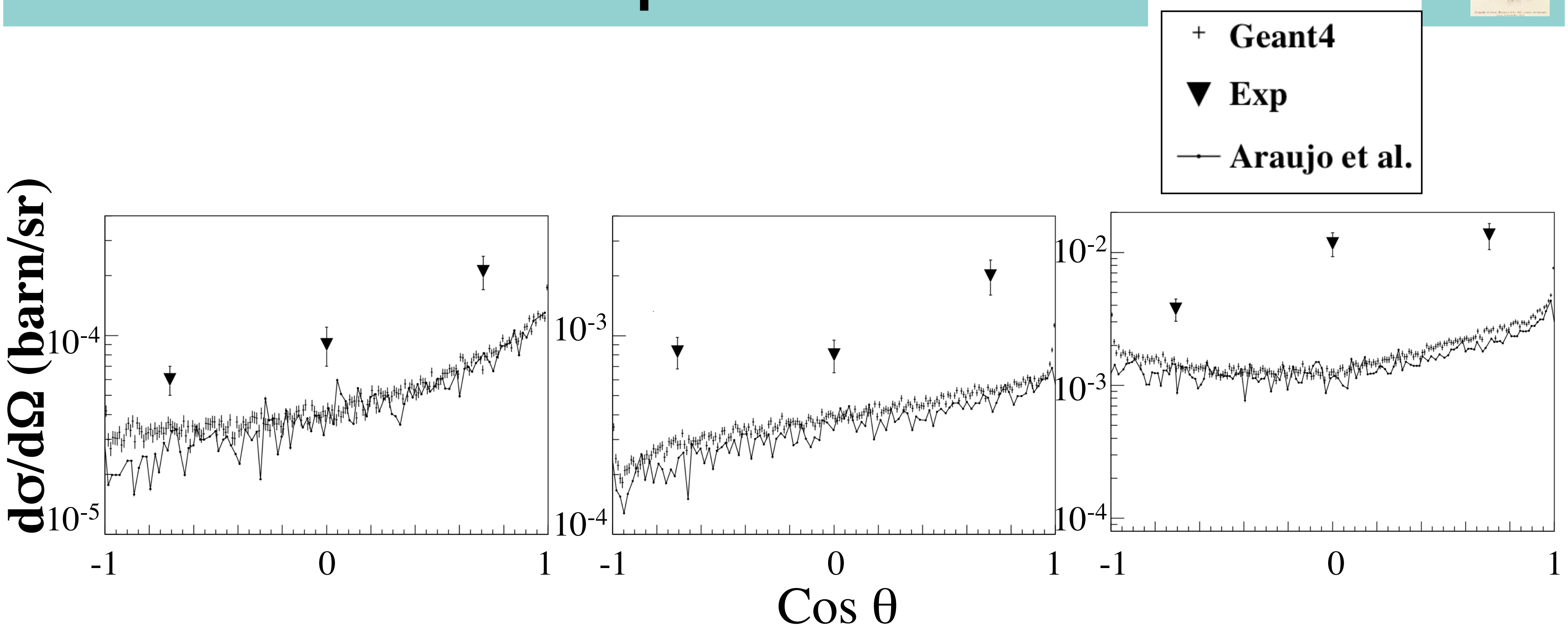


Figure and experimental data from Chazal et al., NIM A **490** (2002)

Previous simulation in Geant4/FLUKA by Araujo et al., NIM A 545 (2005)

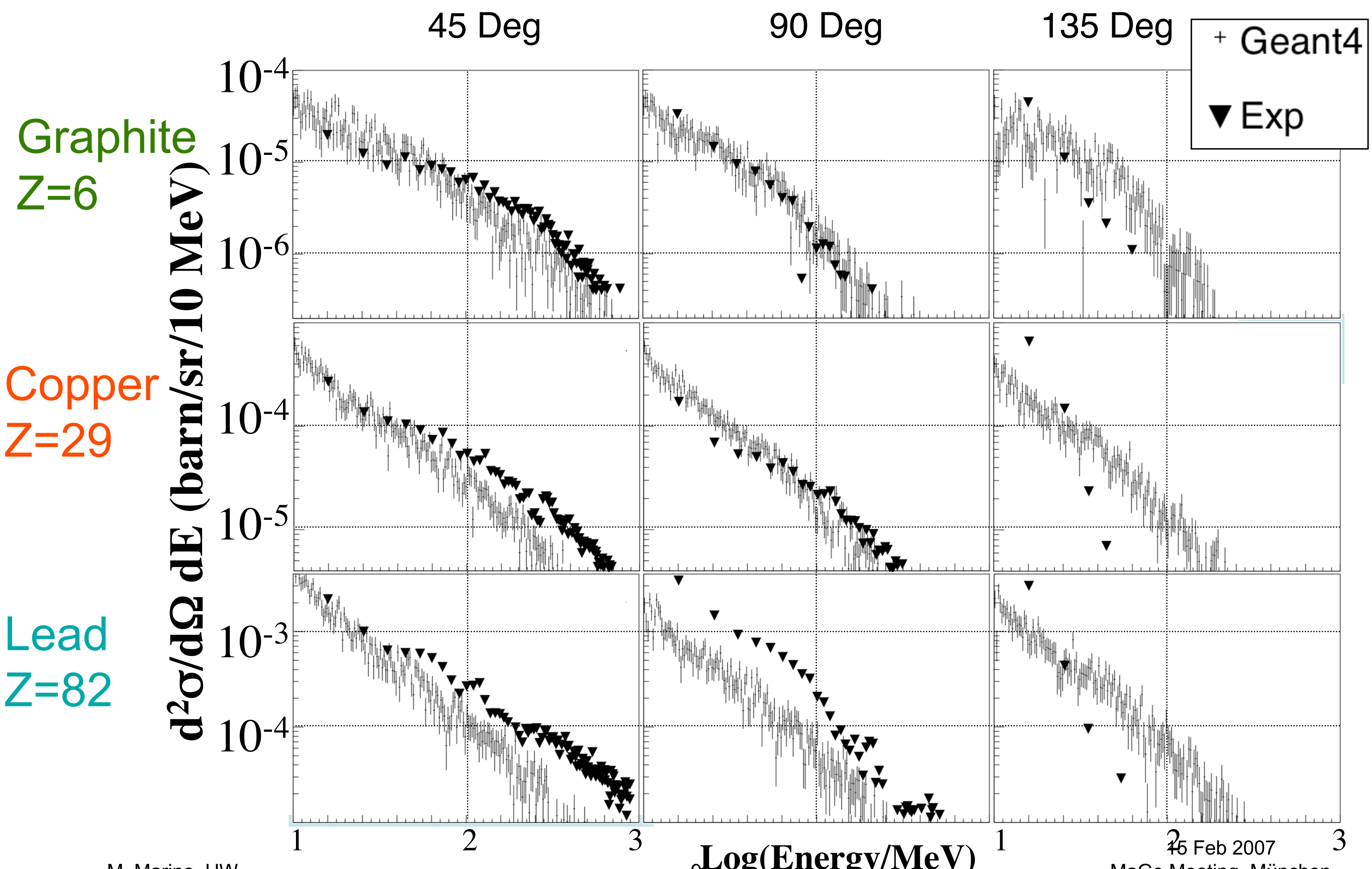
Neutron production



Graphite	Copper	Lead
Z=6	Z=29	Z=82

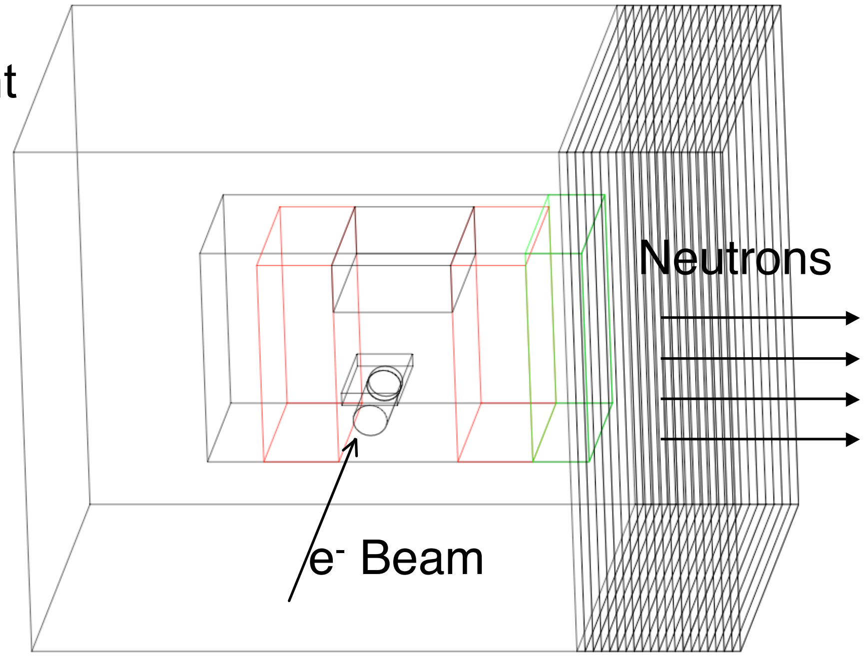
Material	Measured Fluence ($n/\mu/g/cm^2$)	Calculated Fluence	Ratio
Graphite	6.83E-05	3.28E-05	2.08
Copper	1.19E-04	4.82E-05	2.47
Lead	3.48E-04	5.87E-05	5.93

Neutron production



Neutron Transport

- SLAC electron-beam dump
  - 28.7-GeV electron beam incident on Al beam stop
  - Measured neutron flux through steel and concrete
    - <A> ~24, <Z> ~12



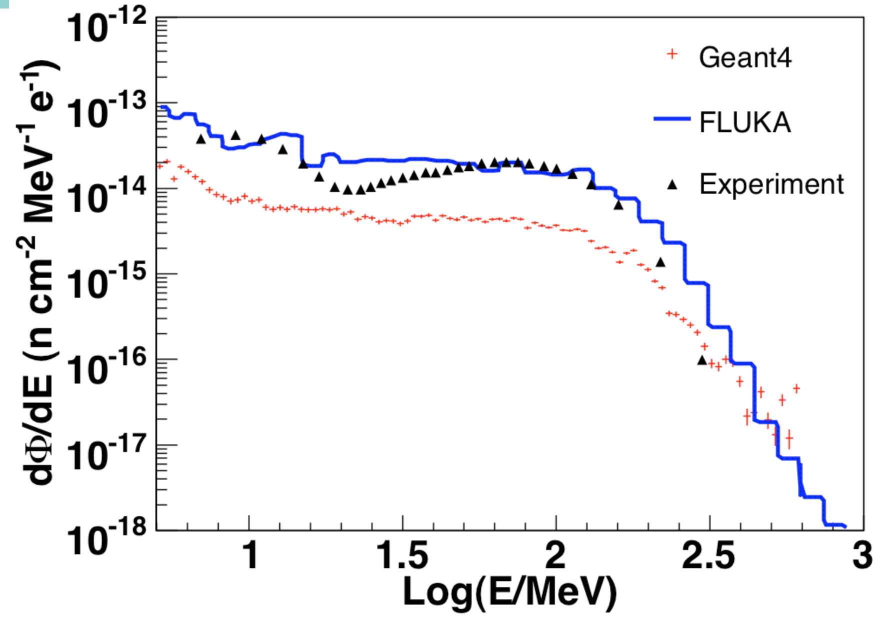
FLUKA simulation by
Roeslera et al. NIM A **503** (2003)

Experimental data from
Taniguchi et al., NIM A **503** (2003)

Site	$\langle A \rangle$	$\langle Z \rangle$	$\langle Z \rangle / \langle A \rangle$	g/cm^3
WIPP	30.0	14.64	0.488	2.3
Soudan	24.47	12.15	0.497	2.8
Kamioka	22.0	11.0	0.5	2.65
Boulby	23.6	11.7	0.496	2.7
Gran Sasso	22.87	11.41	0.499	2.71
Sudbury	24.77	12.15	0.491	2.894
SLAC Concrete	24.13	12.0	0.497	2.35

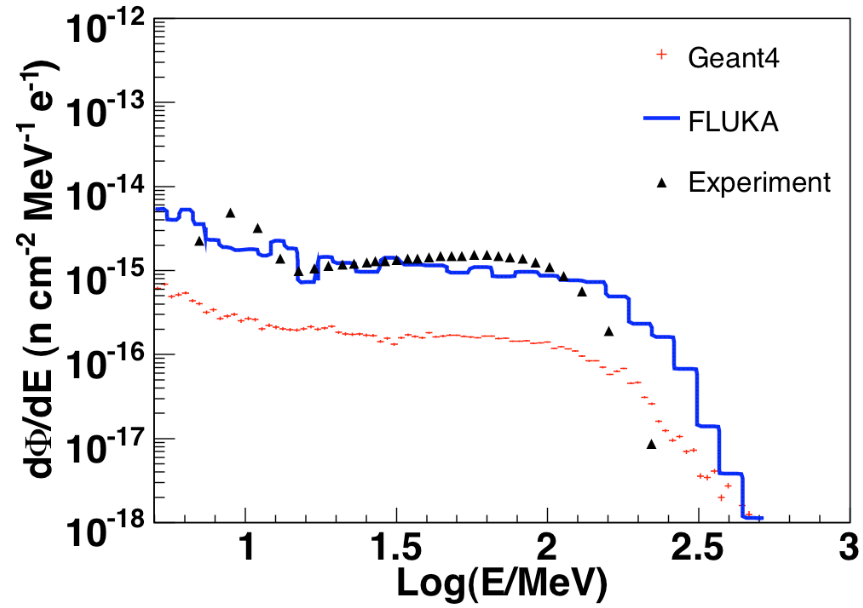
Table data from
D.-M. Mei and A. Hime,
Phys. Rev. D **73**, (2006).

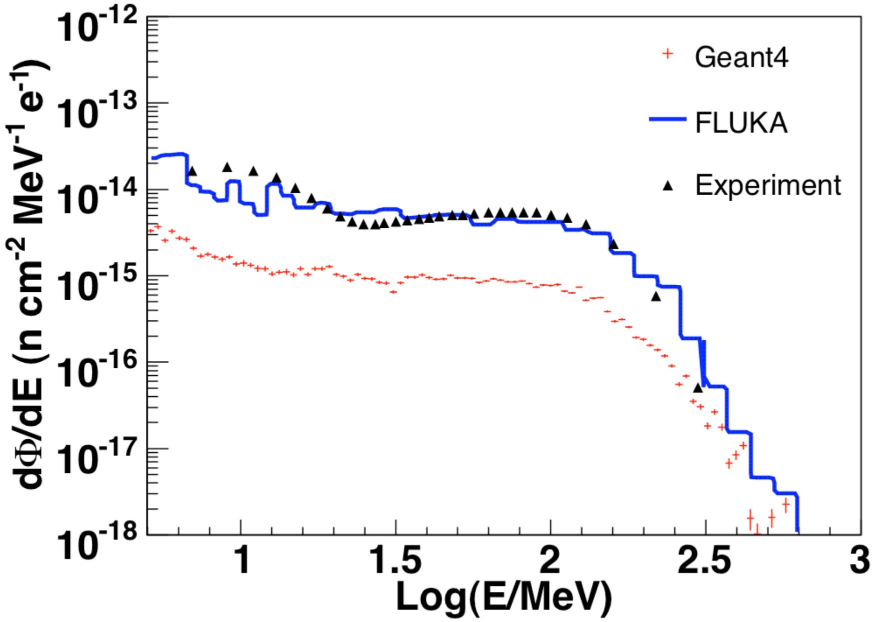
Neutron Transport - SLAC Results



9 ft.

13 ft.



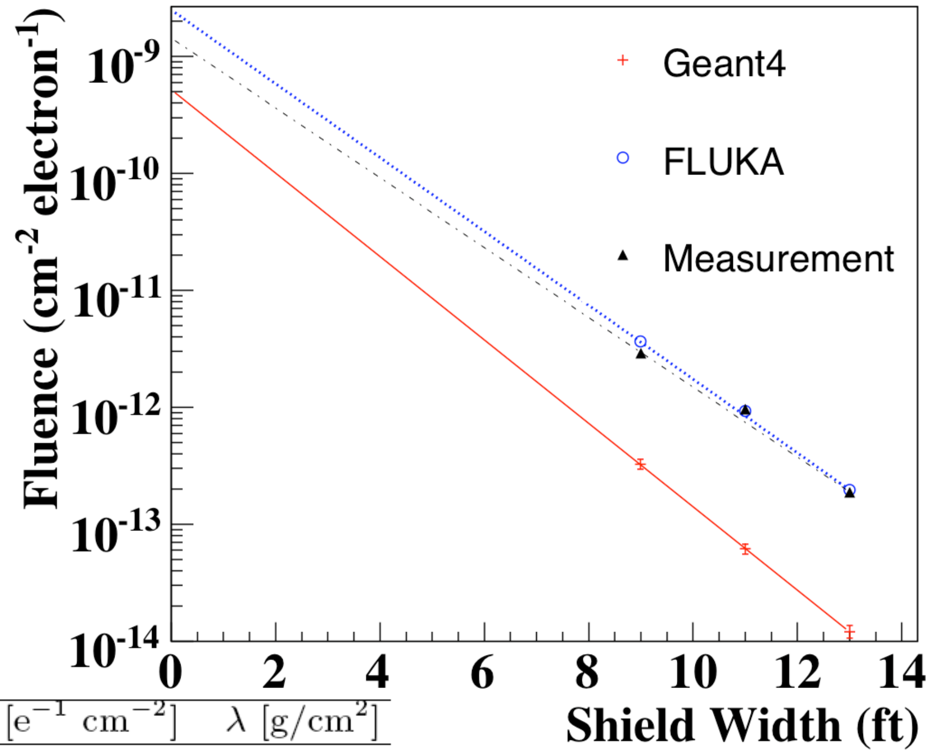


11 ft.

Neutron Transport

- For neutrons with energies greater than 6 MeV:
  - Geant4 has higher attenuation than FLUKA or experiment

FLUKA, Experiment data:
Taniguchi et al., Roeslera et al.
NIM A **503** (2003) p. 595



Source	Shield Width [cm]	Fluence [e^{-1} cm^{-2}]	λ [g/cm^2]
FLUKA	274	3.59×10^{-12}	
	335	9.30×10^{-13}	115 ± 5
	396	1.97×10^{-13}	
Measured	274	2.91×10^{-12}	
	335	9.62×10^{-13}	124 ± 4
	396	1.88×10^{-13}	
Geant4	274	$3.22 \pm 0.32 \times 10^{-13}$	
	335	$6.17 \pm 0.61 \times 10^{-14}$	98.9 ± 5.3
	396	$1.21 \pm 0.15 \times 10^{-14}$	

Correcting Neutron Transport

Correcting for over-attenuation hard to do by some overall multiplicative ("fudge") factor.

Need a method to correct "on the fly."

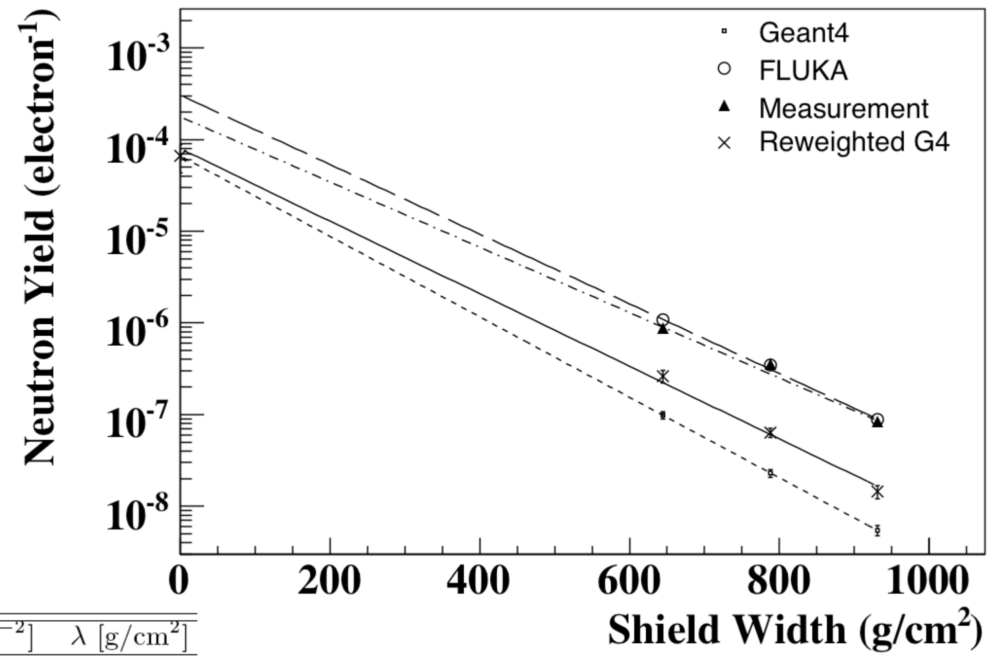
"Reweight" the neutrons on each step according to their step length.
Multiply by R:

$$R = \exp\left(x\left(1/\lambda_{Geant4} - 1/\lambda_{Exp}\right)\right)$$

Where x is the step length; lambdas, attenuation lengths

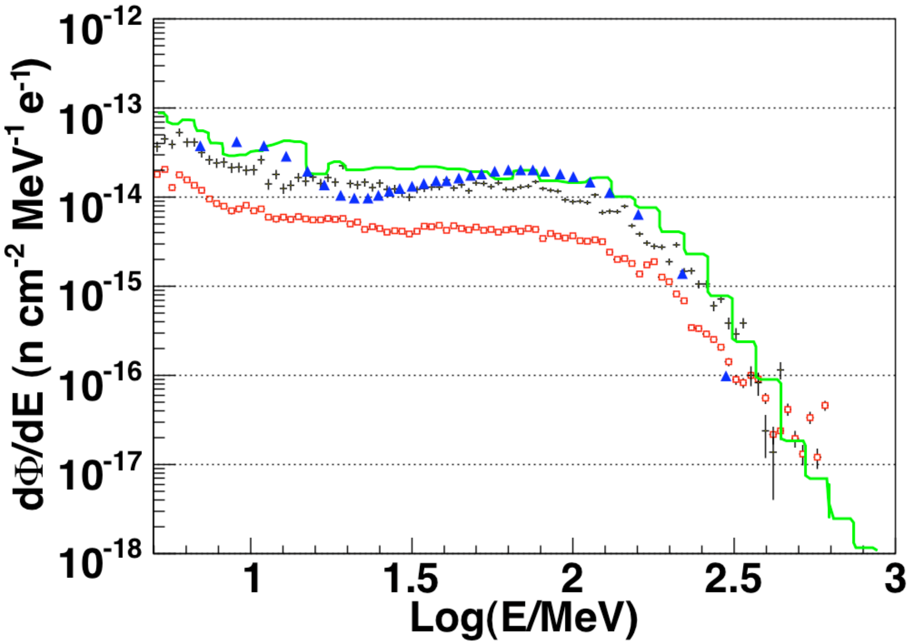
Neutron Transport

How well does this work?



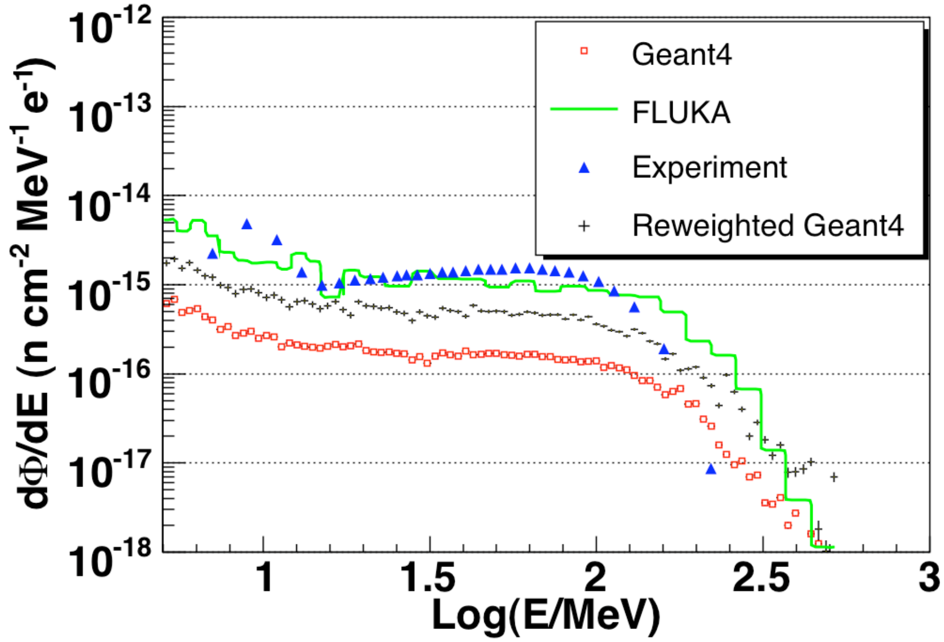
Source	Shield Width [cm]	Fluence [e^{-1} cm^{-2}]	λ [g/cm^2]
FLUKA	274	3.59×10^{-12}	
	335	9.30×10^{-13}	115 ± 5
	396	1.97×10^{-13}	
Measured	274	2.91×10^{-12}	
	335	9.62×10^{-13}	124 ± 4
	396	1.88×10^{-13}	
Geant4	274	$3.22 \pm 0.32 \times 10^{-13}$	
	335	$6.17 \pm 0.61 \times 10^{-14}$	98.9 ± 5.3
	396	$1.21 \pm 0.15 \times 10^{-14}$	
Reweighted Geant4	274	$8.68 \pm 1.37 \times 10^{-13}$	
	335	$1.70 \pm 0.19 \times 10^{-13}$	109 ± 3.8
	396	$3.20 \pm 0.51 \times 10^{-14}$	

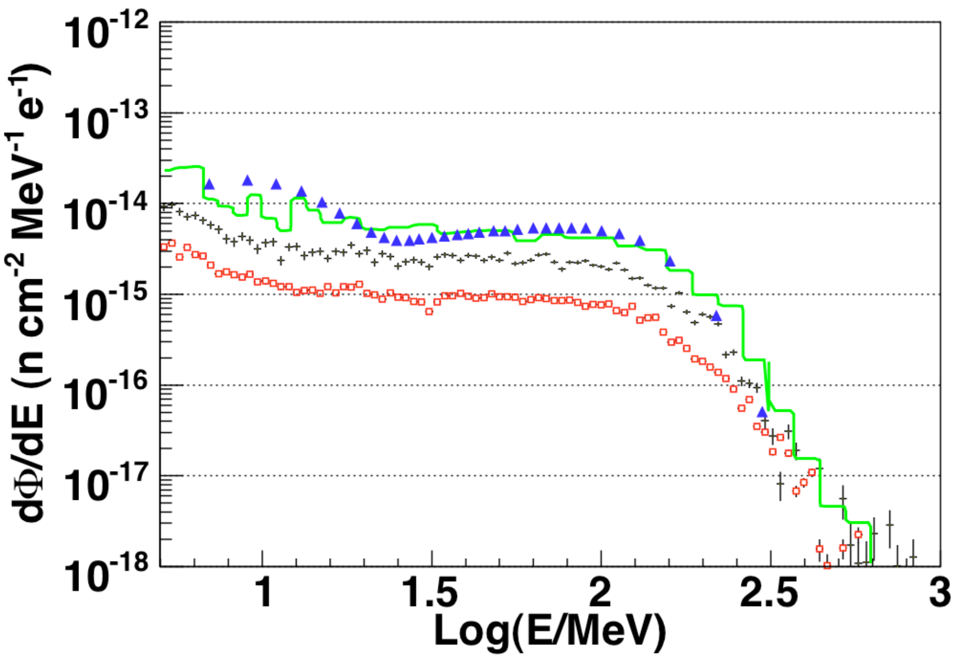
FLUKA, Experiment data:
Taniguchi et al., Roeslera et al.
NIM A **503** (2003) p. 595



9 ft.

13 ft.





11 ft.

Conclusions

- Validation for muon-induced neutron production
  - Low-Z: Conservative estimate, within a factor of 2-3.
  - High-Z: Estimate within a factor of 6; more conservative to say within a factor of 10.
- Validation for neutron transport
  - Dependent on path length through material.
  - Low-Z material (e.g. rock) well-verified.
  - High-Z material not specifically verified.
  - Reweighting reasonably successful.
- Work to do-
  - Full muon simulations with the Majorana Reference Design.