Backgrounds in underground laboratories

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Contributions from many others

Outline (and some notes)

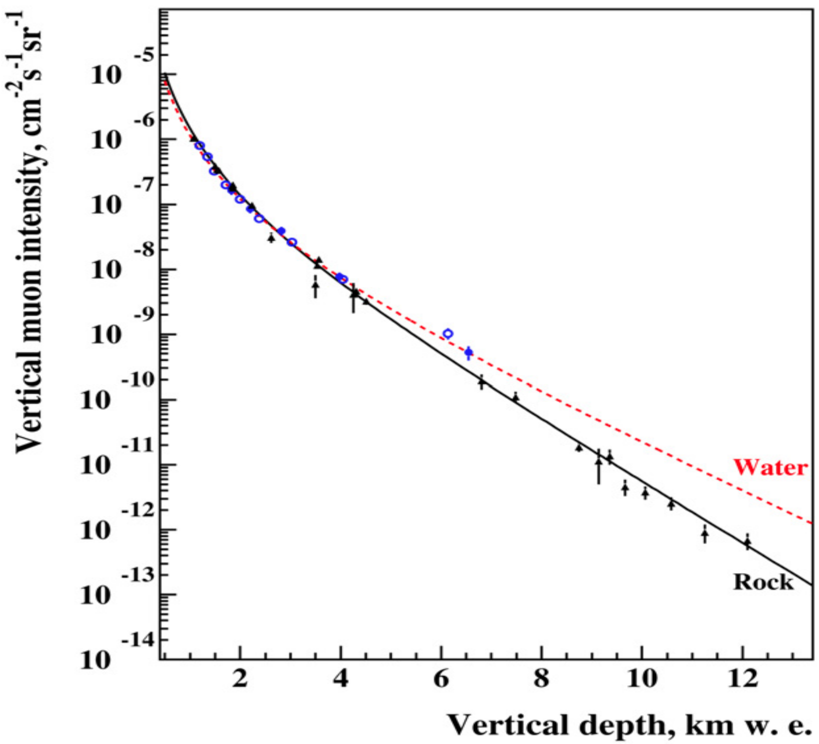
- Built on ILIAS work: background studies for underground experiments.
- This study is relevant mainly to ‘astroparticle physics’ programme (neutrino ‘astrophysics’ and proton decay).
- Background sources are important for all LAGUNA technologies (liquid argon, scintillator, water Cherenkov) but the end-point event signatures are different.
- Background effects depend on the underground lab location (mainly depth).

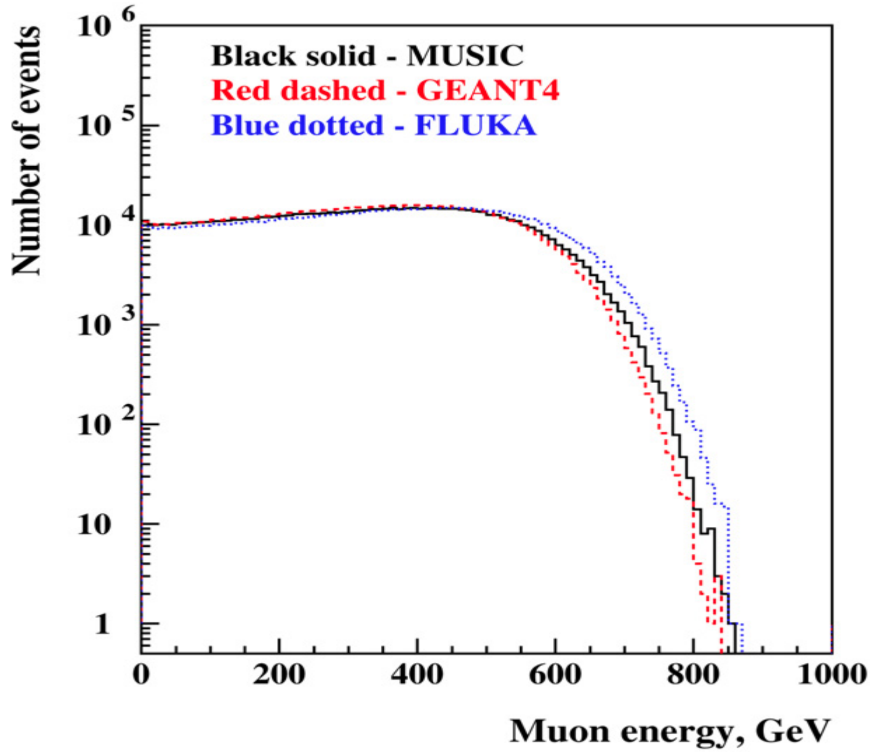
- Muon simulation codes: MUSIC and MUSUN.
- Muon-induced neutrons.
- Radioactivity.

MUSIC/MUSUN

- MUSIC is a MUon SImulation Code - code for muon transport (propagation) through matter - recent publication: Kudryavtsev. Comp. Phys. Commun. 180 (2009) 339; see also references therein.
- First version written in 1987. First 3D version written in 1997 (Antonioli et al. Astroparticle Physics (1997)).
- Features: 3D (or 1D) muon transport through matter; initial muon parameters (energy, coordinates, direction cosines) -> final muon parameters (…). A set of subroutines (in Fortran????!!!! ….). Other inputs: parameters for a (uniform) material: composition, density, radiation length (3D), density corrections.
- MUSUN is a code for MUon Simulations UNderground: uses the results of MUSIC written in the files.
- MUSUN aim: to generate muons according to the energy spectrum and angular distribution at an underground location; has to be written for any specific location (specific rock composition, slant depth distribution etc).
- Requires rock composition and slant depth distribution as inputs.
- MUSUN exists for standard rock and water (flat surface); also for LNGS, LSM, Boulby, Soudan, SNOLab.

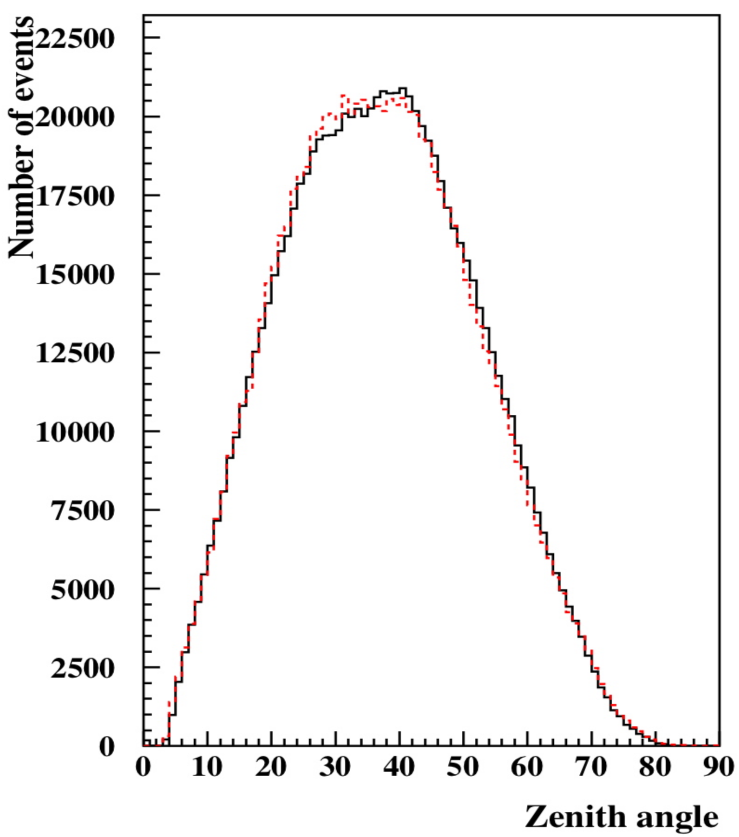
MUSIC results

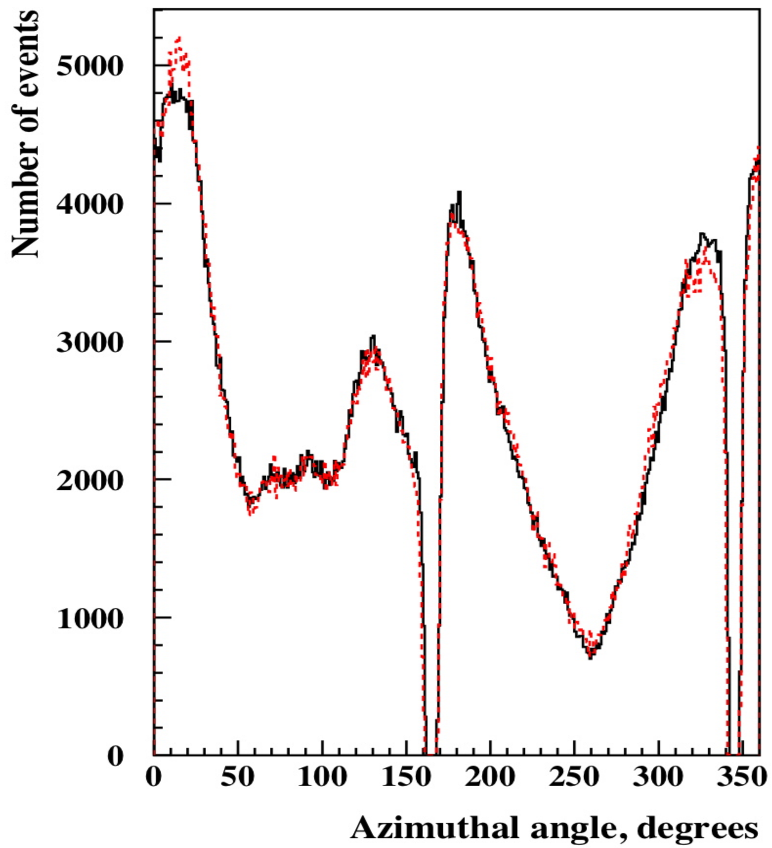




- **Left: Vertical muon intensity as a function of depth in standard rock and water in comparison with data (see also other references in CPC (2009)).**
- **Right: Energy distribution of muons with initial energy of 2 TeV transported through 3 km of water.**
- **See also Tang et al. Phys. Rev. D 74, 053007 (2006); A. Lindote et al. Astropart. Phys., 31 (2009) 366.**

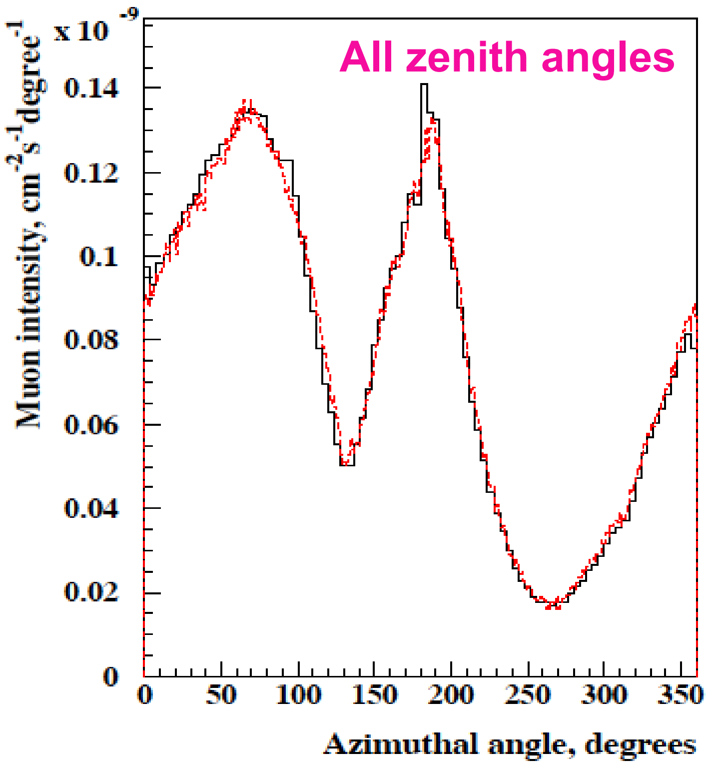
Muon generator - MUSUN (LSM)

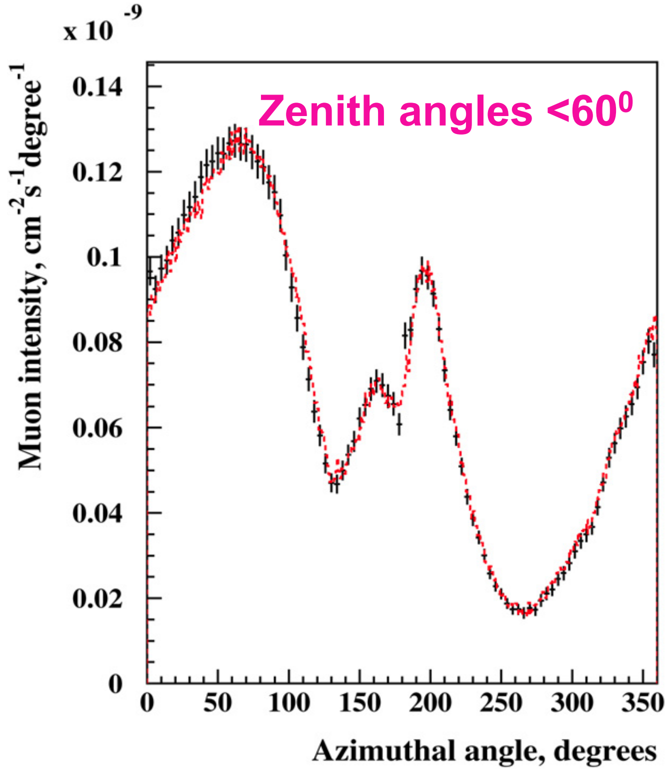




- **Zenith and azimuth angular distributions of muons from MUSUN (black) at LSM compared with data from the Frejus proton decay experiment (red).**
- **MUSIC and MUSUN, V. Kudryavtsev, Comp. Phys. Comm. 180 (2009) 339.**

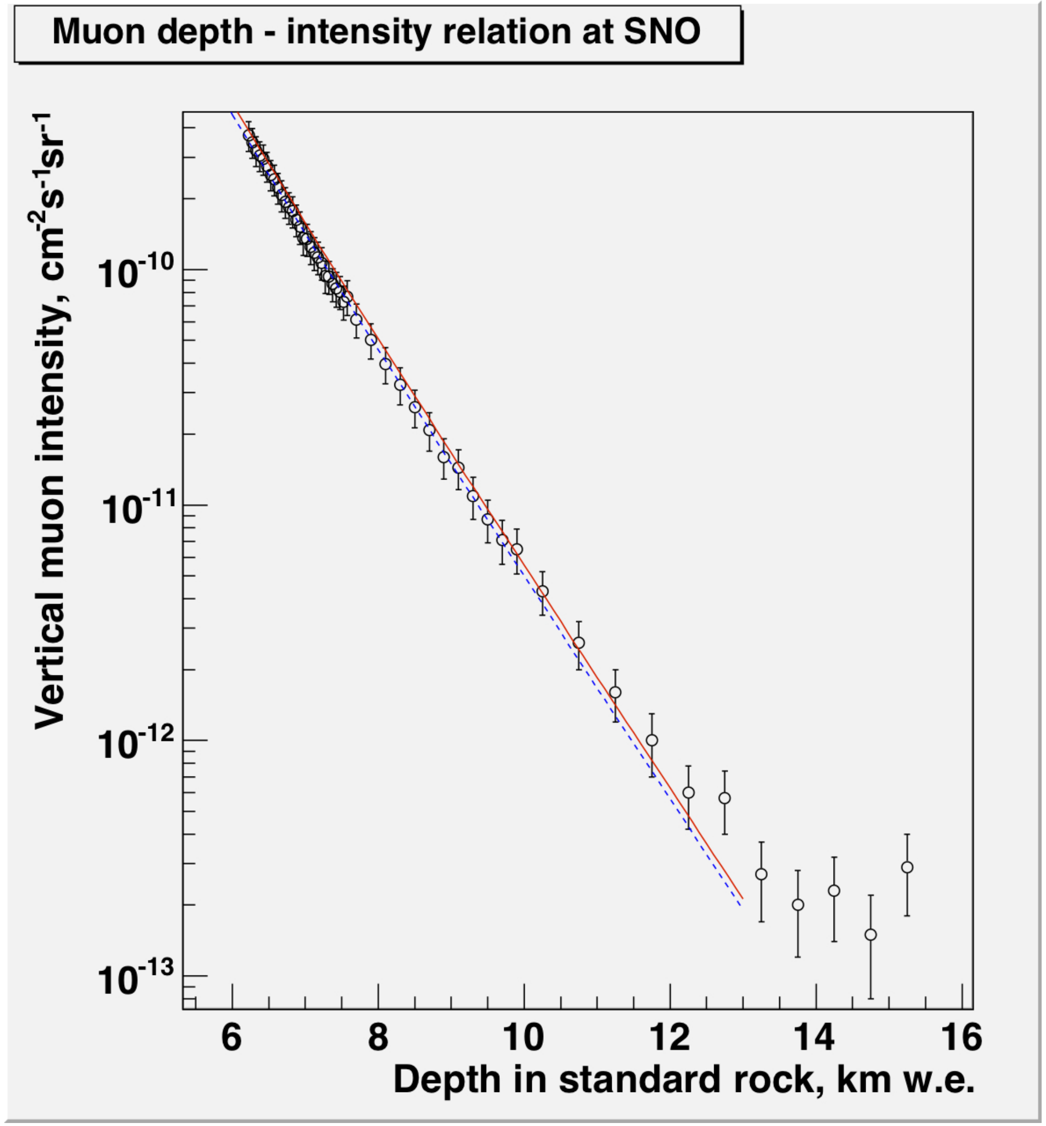
MUSIC/MUSUN for LNGS





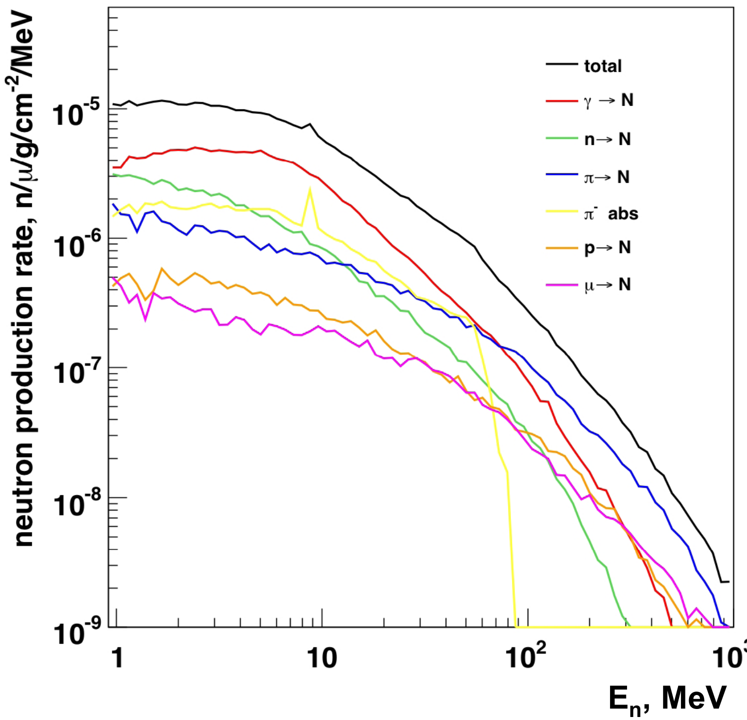
- Angular distribution of muons at LNGS as generated by MUSUN in comparison with the single muon data from LVD. From Kudryavtsev et al., Eur. Phys. J. A 36, 171 (2008); Comp. Phys. Commun. 180 (2009) 339.
- Normalisation: total muon flux 1.17 m^{-2} $hour^{-1}$ (sphere with 1 m^2 cross-sectional area).

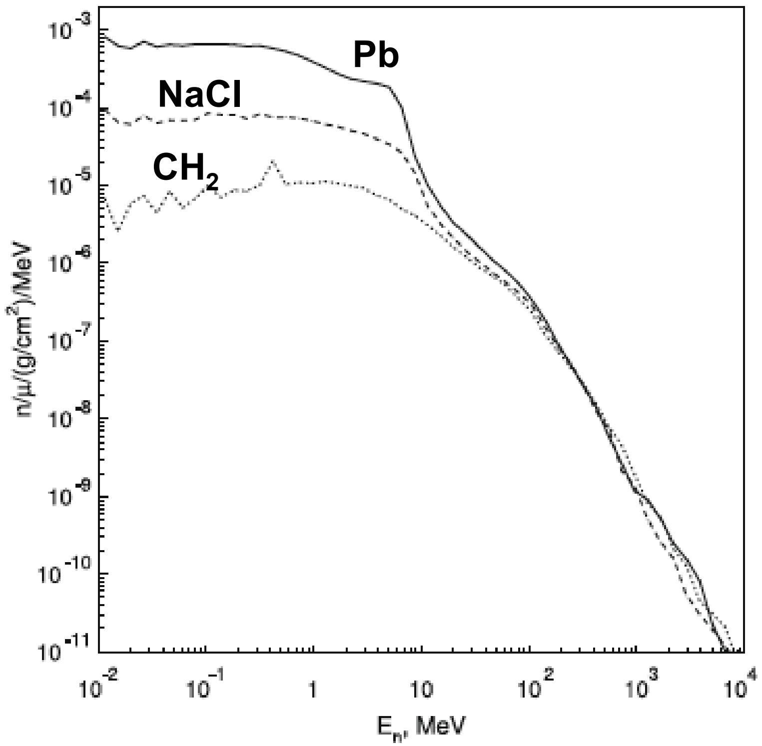
MUSIC/MUSUN for SNOLAB



- Data from SNO converted to standard rock: B.Aharmim et al. (SNO Collaboration), PRD 80 (2009) 012001.
- Simulations with MUSIC for standard rock: solid red - LVD best fit parameters from surface muon spectrum; dashed blue - intensity multiplied by 0.9.
- Total flux: measured - 3.31×10^{-10} cm^{-2} s^{-1}, simulated with LVD parameters - 3.50×10^{-10} cm^{-2} s^{-1}.
- Required normalisation for simulated flux: 0.95.

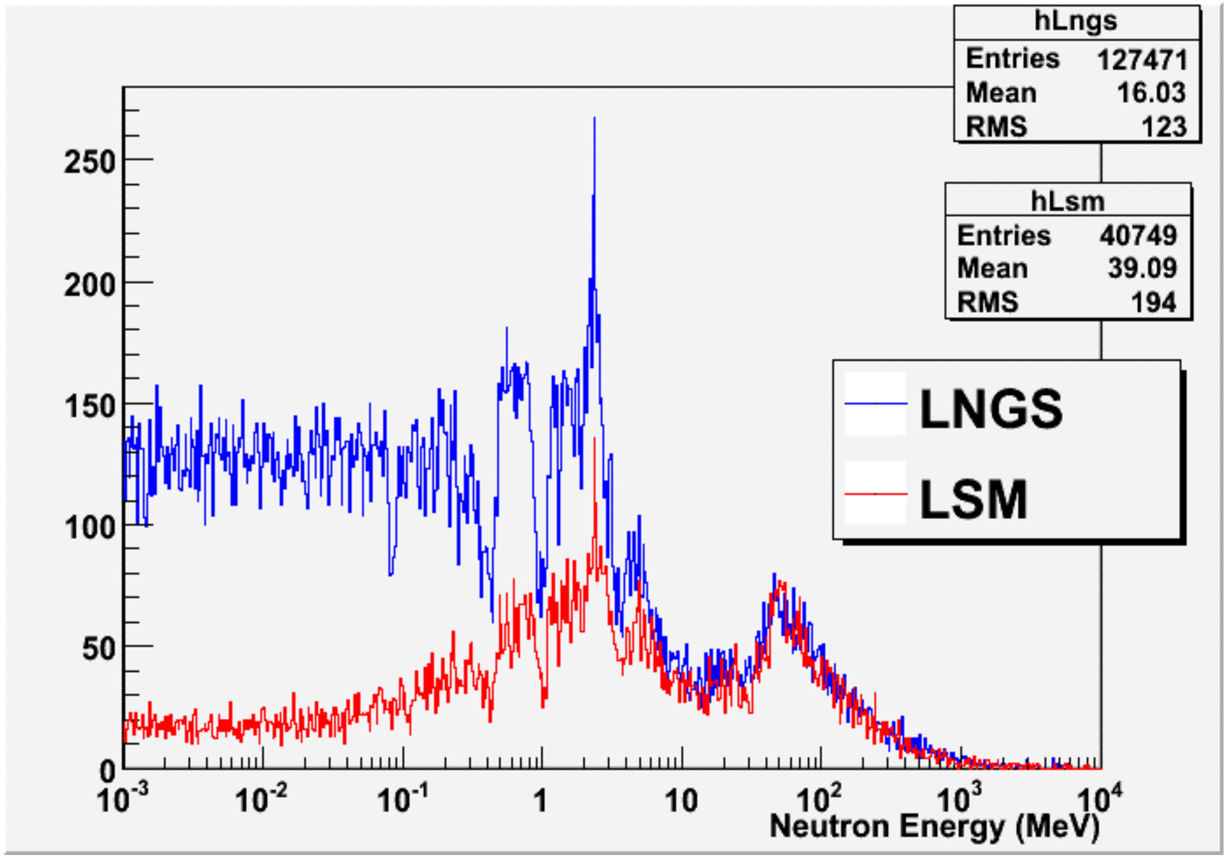
Neutron spectra at production





- Left: CH_2, 280 GeV muons, GEANT4 9.2 (V. Tomasello, 2009); also M. Horn, H. Araújo, M. Bauer, A. Lindote, R. Persiani and others with various versions of GEANT4.
- Right: spectra in CH_2, NaCl and lead; <E> = 65.3 MeV, 23.4 MeV and 8.8 MeV (A. Lindote et al. Astropart. Phys., 31 (2009) 366). Neutron spectrum strongly depends on the material.

Rock composition and neutron spectra



Simulated (not normalised) energy spectra of neutrons coming from the rock (preliminary, from R. Persiani and M. Selvi).

No H was included in LNGS rock but probably should be there.

- Some elements even with small concentrations can be important (hydrogen).

Angular dependence

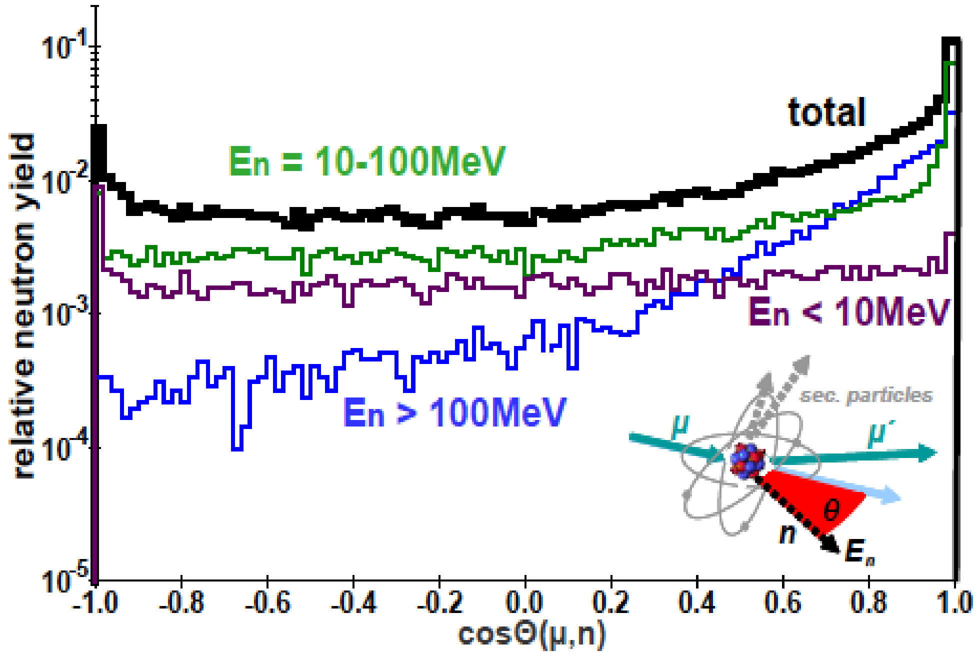
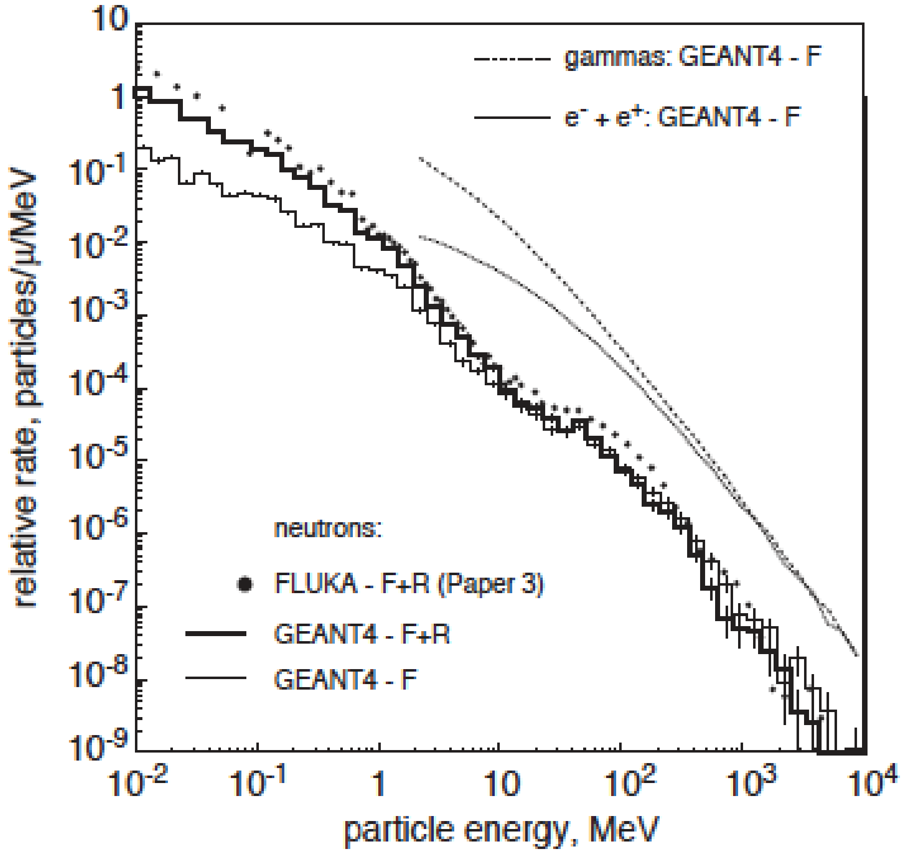


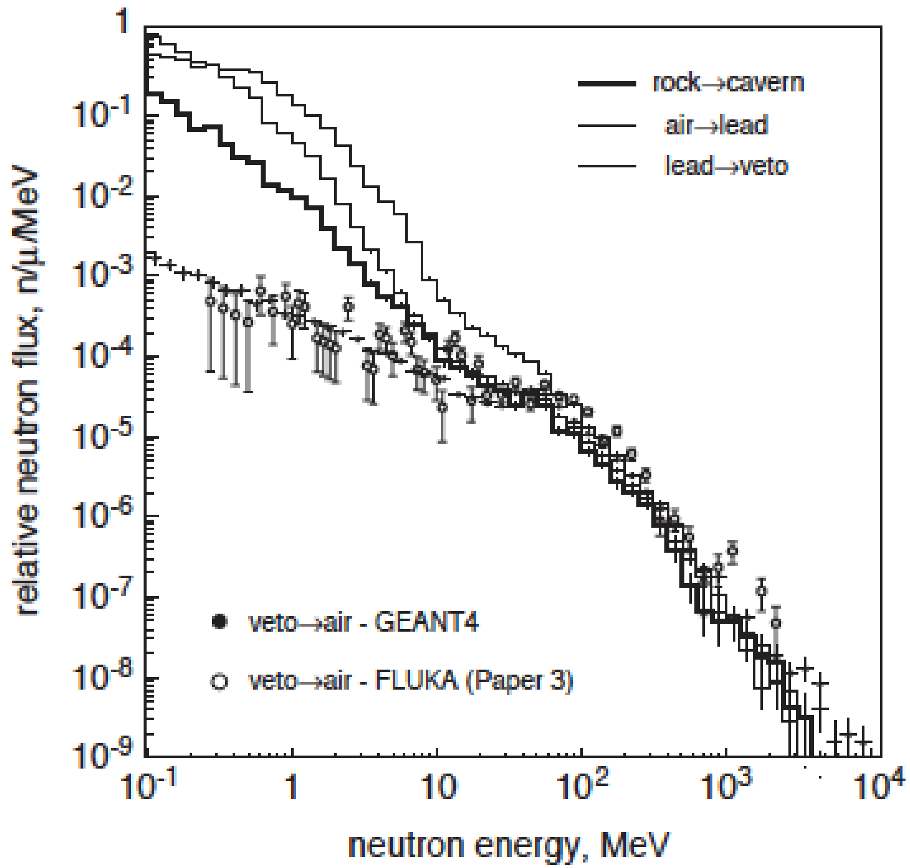
Figure 3.9: Angular distribution relative to the total neutron yield of neutrons produced in muon nuclear reactions with *Geant4* `8.2.p01`. For all neutron kinetic energies (black) or the respective kinetic energy ranges, $E_n > 100\ MeV$ (blue), $10\ MeV < E_n < 100\ MeV$ (green) and $E_n < 10\ MeV$ (purple). The inlet shows the definition of the angle θ with respect to the incident muon. See text for details.

M. Horn. PhD thesis. Univ. of Karlsruhe (2007).

- **Angular distribution of emitted neutrons.**
- **High-energy neutron emission is not isotropic but is correlated with the muon direction.**
- **Hence the signal from high-energy neutrons travelling long distance to the detector (from rock) may be accompanied by the energy deposition from a muon or muon-induced cascade.**
- **Production and transport of all particles in a cascade is important for correct evaluation of neutron-induced signal.**

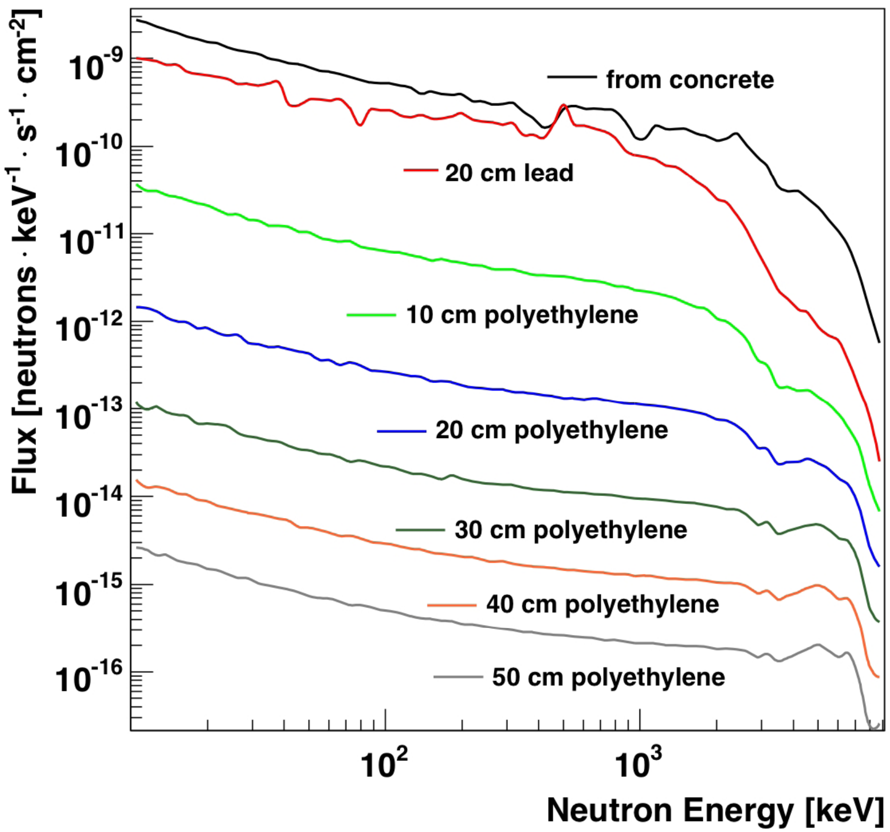
Neutron spectra after shielding

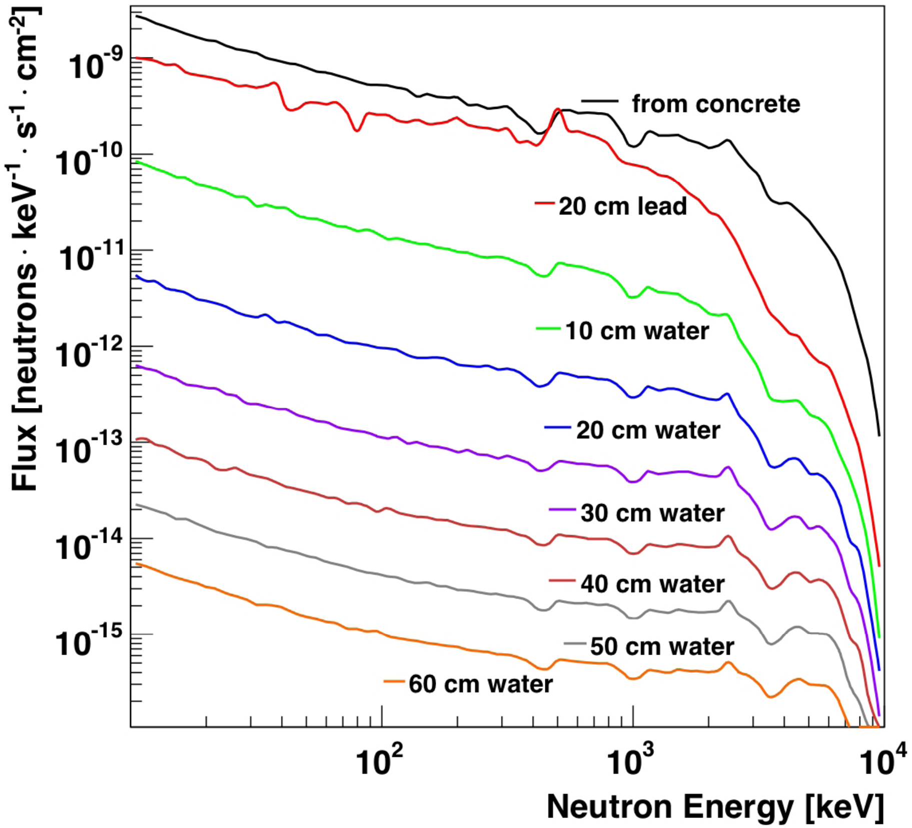




- **Neutron fluxes at various boundaries behind the shielding (lead + CH_2).**
- **Significant suppression of neutron flux below 10 MeV after 50 cm of polyethylene.**

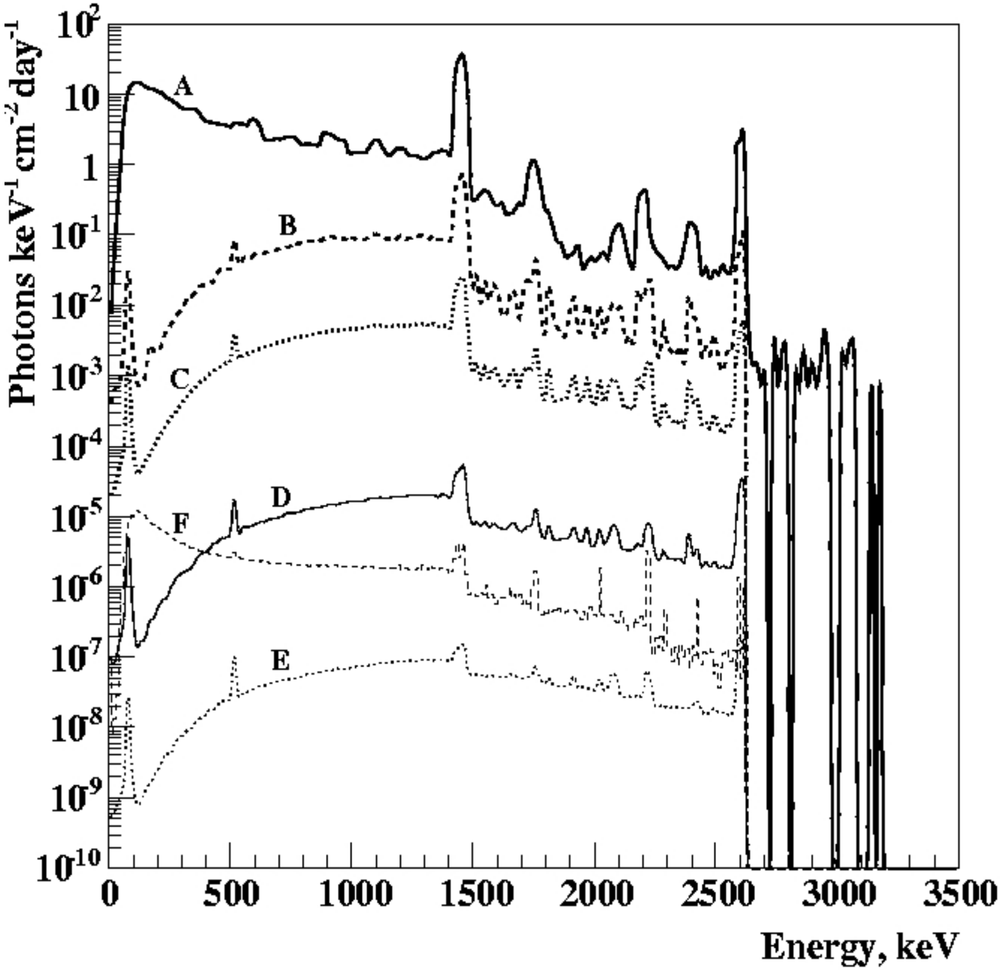
Neutrons in water and CH_2





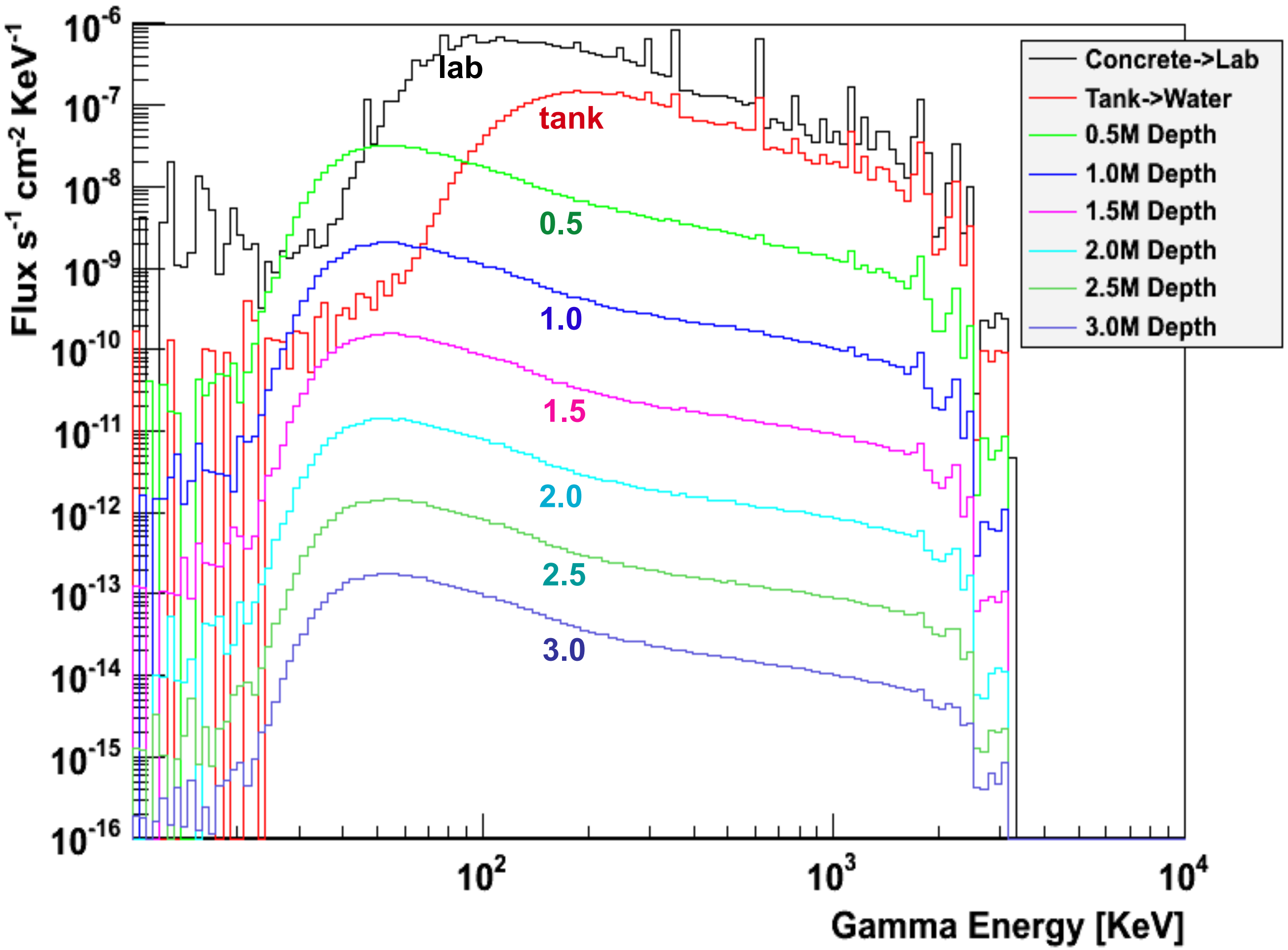
- Neutron attenuation in water and CH_2 - V. Tomasello, PhD Thesis, Univ. of Sheffield (2009); Tomasello et al. Astropart. Phys. 34 (2010), 70.

Gamma-ray attenuation in lead



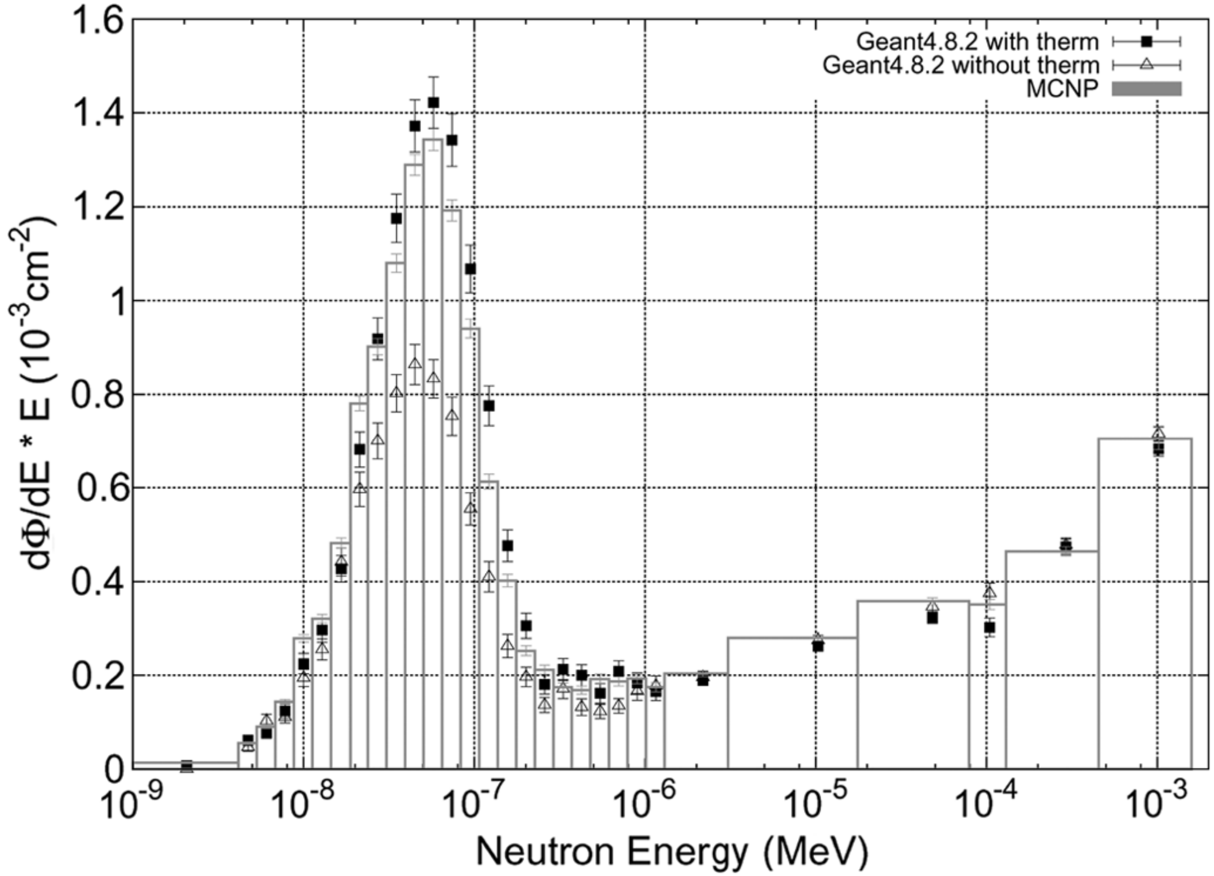
- A - spectrum from rock;
- B - behind 5 cm of lead;
- C - 10 cm of lead;
- D - 20 cm of lead;
- E - 30 cm of lead;
- F - 20 cm of lead and 40 g/cm^2 of CH_2.
- From M. J. Carson et al., Nucl. Instrum. and Meth. A 548 (2005) 418.

Attenuation in water



- Spectra of gamma-rays from U in concrete. On average ×10 suppression per 0.5 m of H_2O.
- Required suppression of gamma-rays for a 1 t experiment is achieved with 3 m of water (discrimination $<10^{-4}$).

Some new (?) 'discoveries'



S. Garny et al. IEEE Transactions on Nuclear Science, 56 (2009) 2392; credits to S. Semikh (JINR, Dubna).

- Importance of thermal neutron cross-sections.
- Does not affect high-energy neutron attenuation in the shielding but may affect the efficiency of neutron detectors based on thermal neutron capture neutron detection.
- Anything else we need to know?

Summary

- We have expertise in background radiation (simulations and measurements).
- So far applied to the background studies for dark matter experiments (low energy depositions < 100 keV).
- Muon codes are relevant to all labs, technologies etc.
- Muon-induced background is key to the success of many experiments (not only DM).
- Our simulations can be extended to neutrons at GeV energies (proton decay) and to MeV-neutrino background.