Background radiation in dark matter experiments

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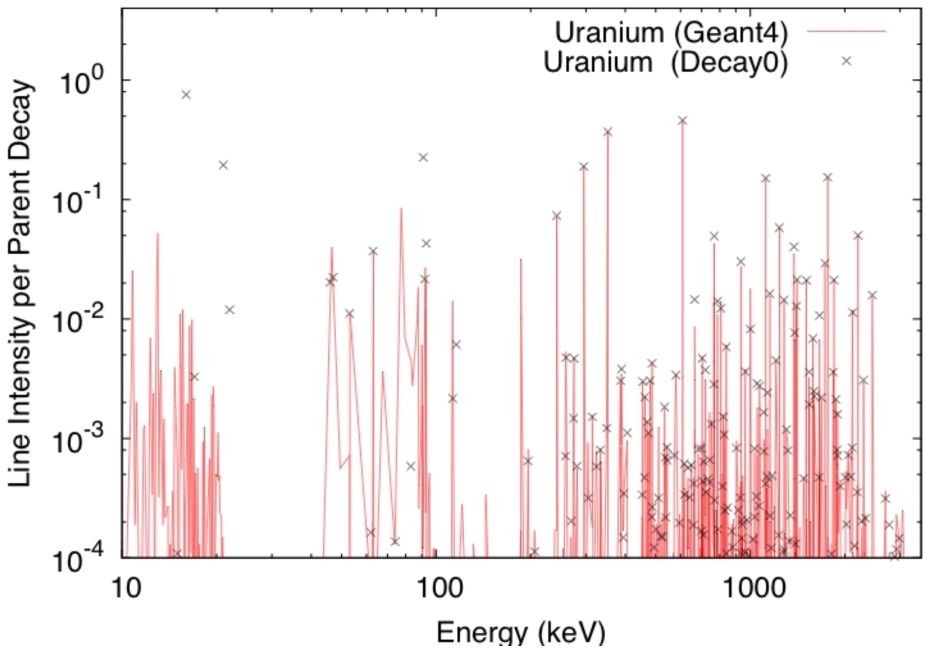
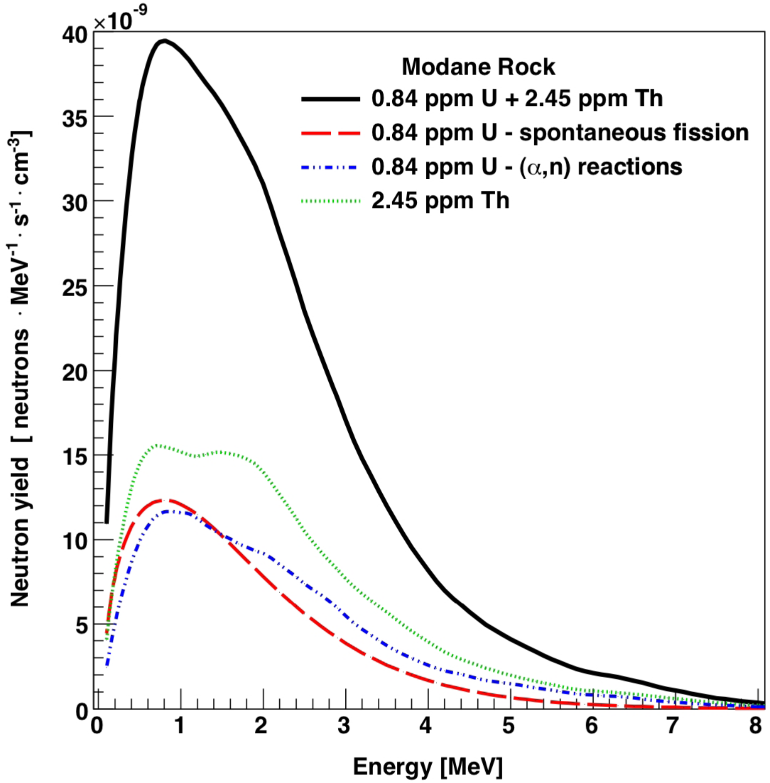
Contributions from many others

Outline

- Neutrons and gamma-rays from radioactivity.
  - Spectra of gamma-rays and neutrons at production and in the lab.
  - Gamma-ray and neutron transport through the shielding.
  - Water shielding against high-Z/low-Z combination.
  - ‘Submarine’ against ‘swimming pool’.
- Muon-induced neutrons.
  - Neutron production rate by muons in different materials.
  - MC for specific detectors: common features and specific predictions.
  - Water Cherenkov muon veto: how efficient will it be?
- Many thanks to ILIAS participants.

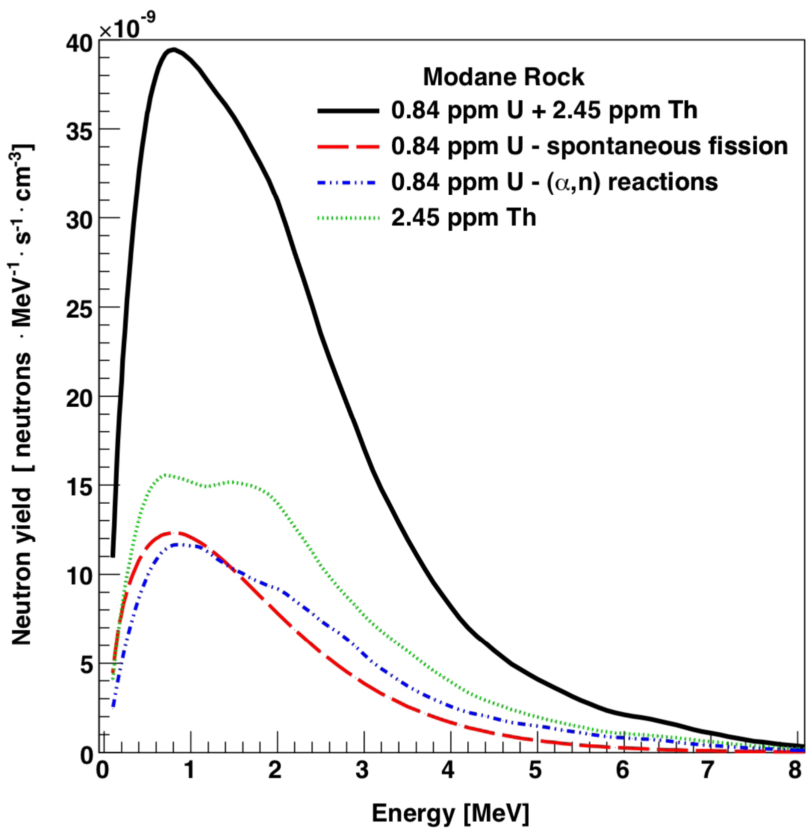
Gamma-ray and neutron production

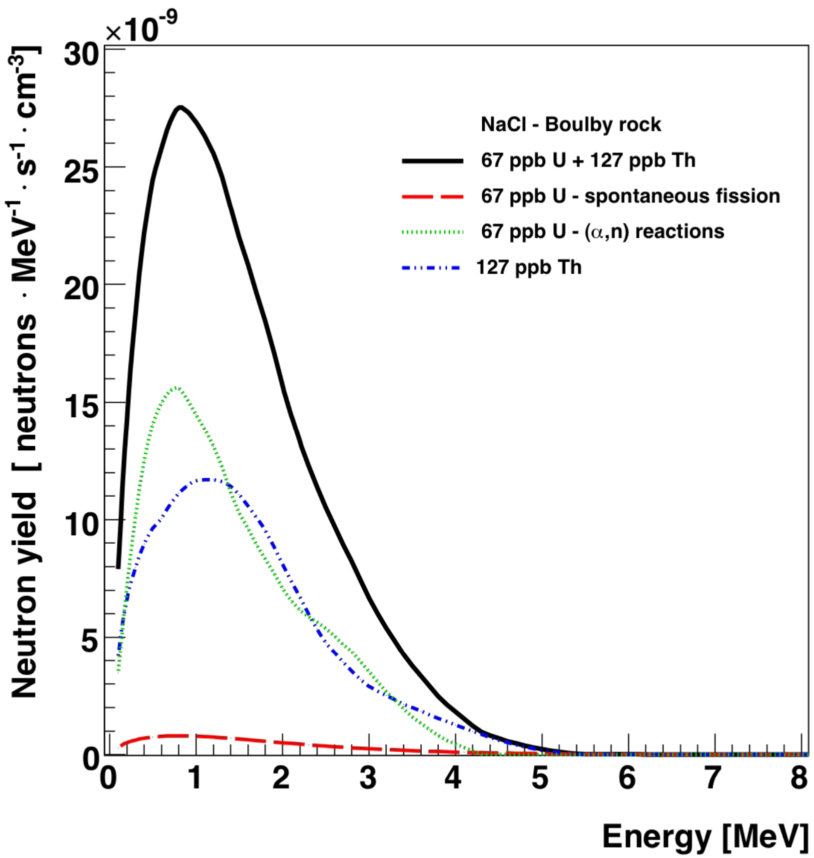




- Gamma-ray spectra from GEANT4 (L. Pandola). When using the whole decay chain be careful with timing precision.
- Neutron spectra from modified SOURCES4A (Wilson et al. Sources4A. Technical Report, LA-13639-MS (1999); Carson et al. Astropart. Phys. 21 (2004) 667).

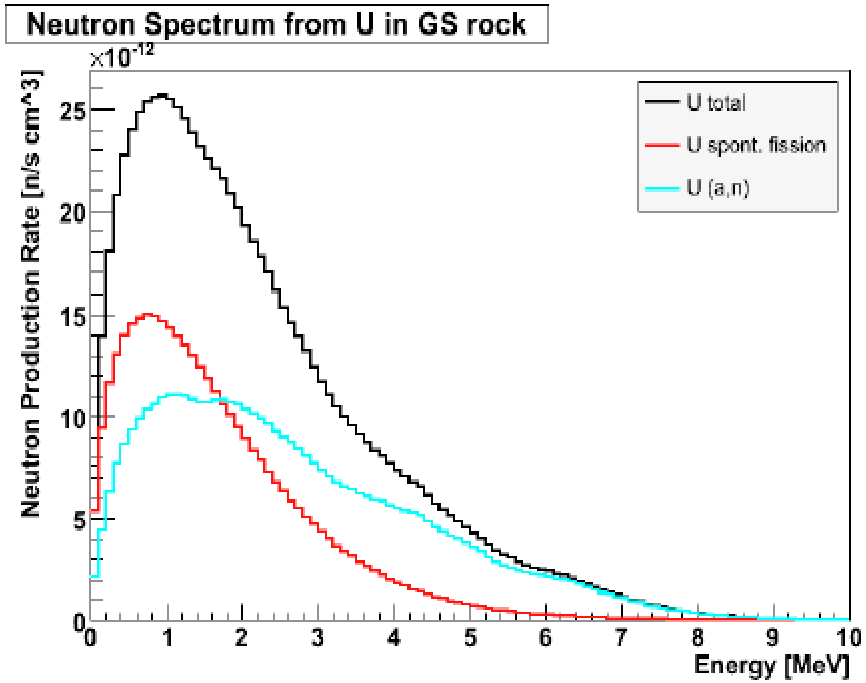
Neutron spectra in different rocks

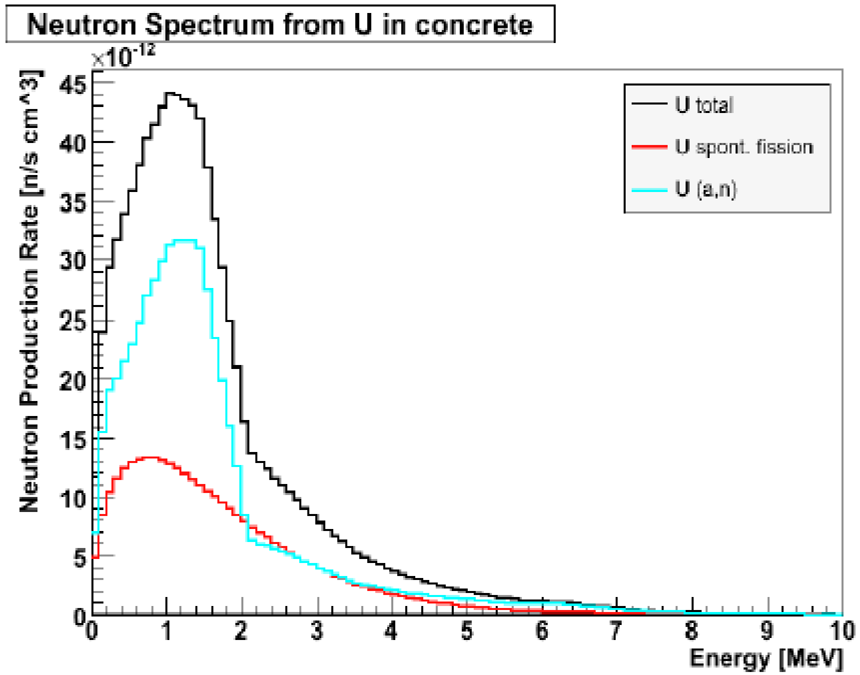




- **Spectra and rates strongly depend on the material (composition).**
- **Hydrogen reduces neutron flux on the rock face (after transport) by a factor 4.7 (1.8) above 100 keV (1 MeV).**

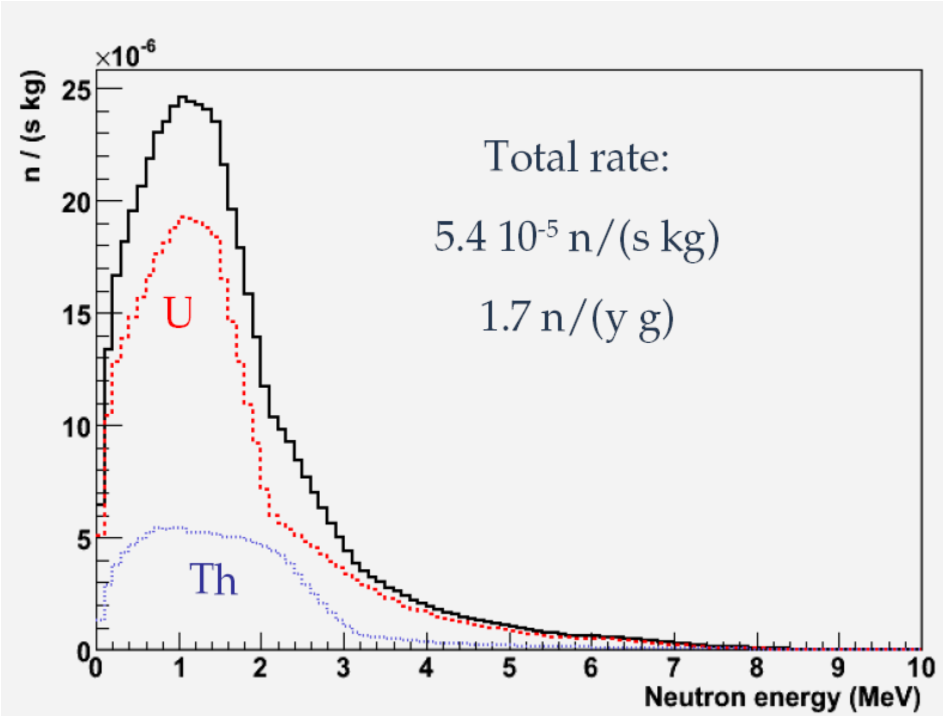
Neutron spectra for LNGS

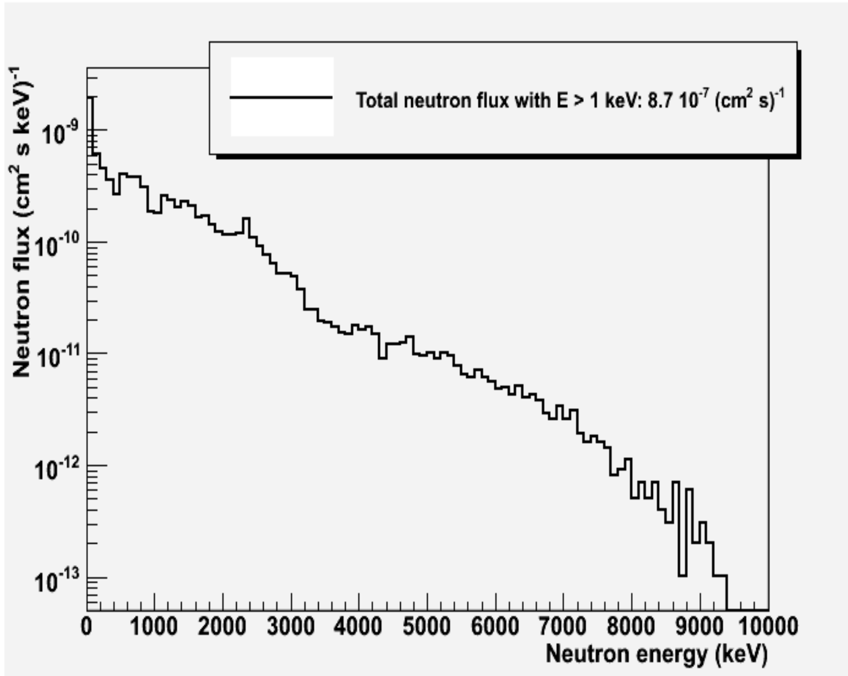




- **L. Baudis. Talk at IDM08 (Stockholm).**
- **Neutron production spectra from U normalised to 10 ppb.**

Neutron flux in the lab





- **Preliminary; M. Selvi, personal communication.**
- **The flux in the lab is in reasonable agreement with measurements.**

Measurements at LNGS

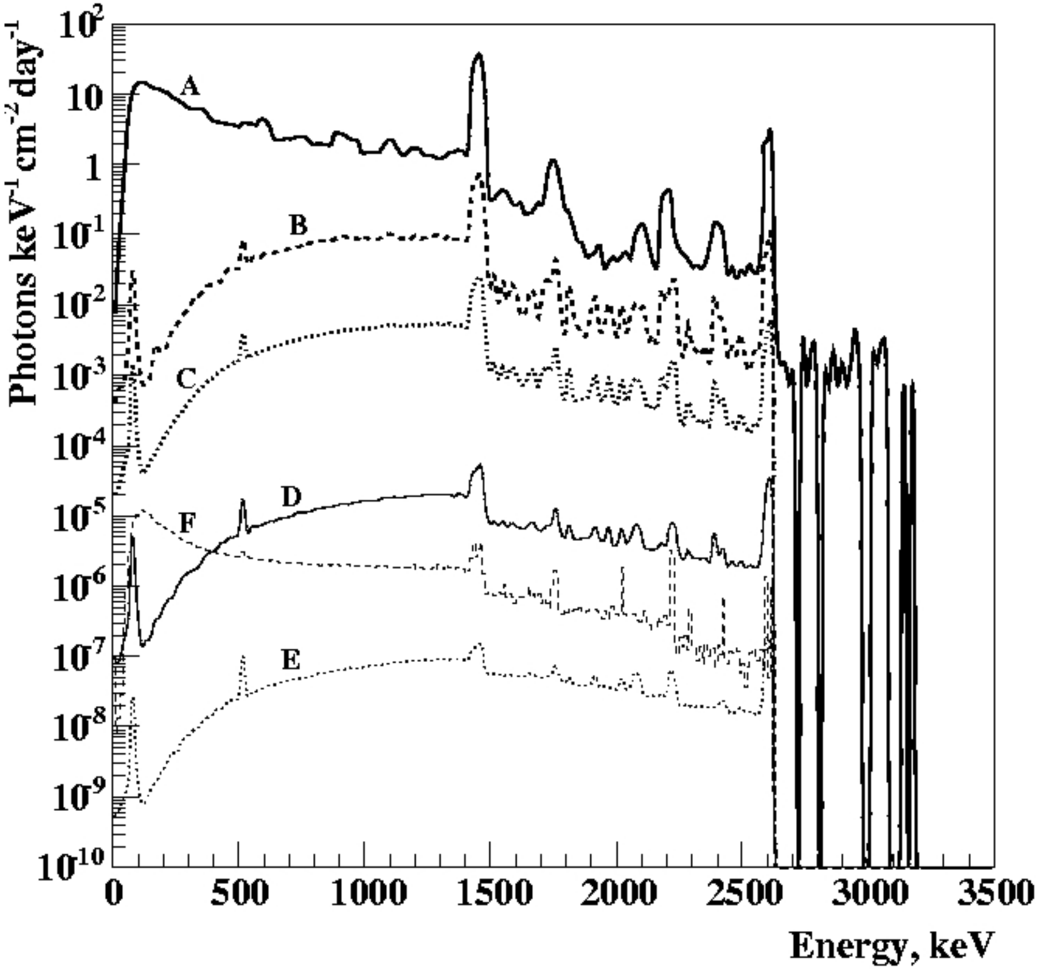
Table 1
Neutron flux measurements at the Gran Sasso laboratory reported by different authors

<table>
<tr><th>E interval</th><th colspan="6">Neutron Flux ($10^{-6}cm^{-2}s^{-1}$)</th></tr>
<tr><th>(MeV)</th><th>Ref. [1]</th><th>Ref. [2]</th><th>Ref. [3]</th><th>Ref. [4]</th><th>Ref. [5]</th><th>Ref. [6]</th></tr>
<tr><td>$10^{-3} - 0.5$</td><td rowspan="4"></td><td rowspan="2"></td><td rowspan="3">0.54±0.01
(0.53±0.08)</td><td rowspan="3"></td><td rowspan="3"></td><td></td></tr>
<tr><td>$0.5 - 1$</td><td rowspan="5">2.56±0.27</td></tr>
<tr><td>$1 - 2.5$</td><td>0.14±0.12</td></tr>
<tr><td>$2.5 - 3$</td><td rowspan="2">0.13±0.04</td><td rowspan="2">0.27±0.14
(0.18±0.04)</td><td rowspan="5">3.0±0.8</td><td rowspan="5">0.09±0.06</td></tr>
<tr><td>$3 - 5$</td><td rowspan="4">0.78±0.3</td></tr>
<tr><td>$5 - 10$</td><td>0.15±0.04</td><td>0.05±0.01
(0.04±0.01)</td></tr>
<tr><td>$10 - 15$</td><td>$(0.4 \pm 0.4) \cdot 10^{-3}$</td><td>$(0.6 \pm 0.2) \cdot 10^{-3}$
$((0.7 \pm 0.2) \cdot 10^{-3})$</td><td rowspan="2"></td></tr>
<tr><td>$15 - 25$</td><td></td><td>$(0.5 \pm 0.3) \cdot 10^{-6}$
$((0.1 \pm 0.3) \cdot 10^{-6})$</td></tr>
</table>

In analyzing their experimental data with Monte Carlo simulations, Belli et al. [3] have used two different hypothetical spectra: flat, and flat plus a Watt fission spectrum. This leads to the upper and lower data sets shown for Ref. [3] respectively.

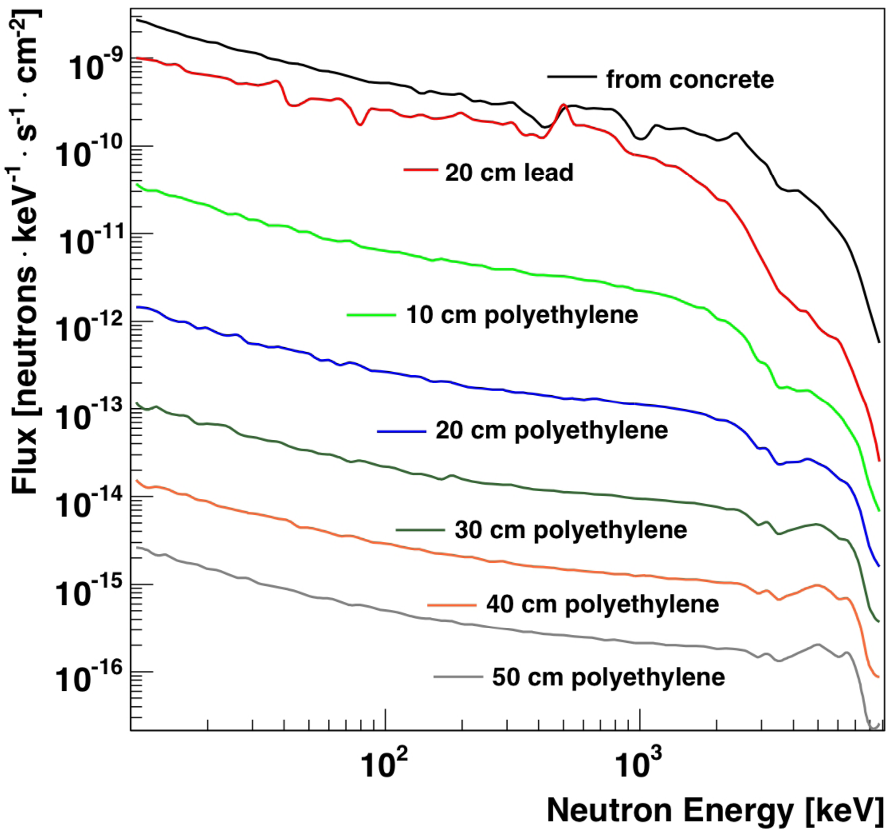
- **Compilation of various measurements from Wulandari et al. Astroparticle Phys. 22 (2004) 313.**
- **Results are different by up to a factor of 3.**
- **Measured parameters are not neutron spectra at production but either neutron capture rate or proton recoil spectra. Hence accurate MC is needed to interpret the data.**
- **It would be good to have more measurements supported by accurate MC of the setups.**
- **However, these neutrons will be attenuated anyway.**

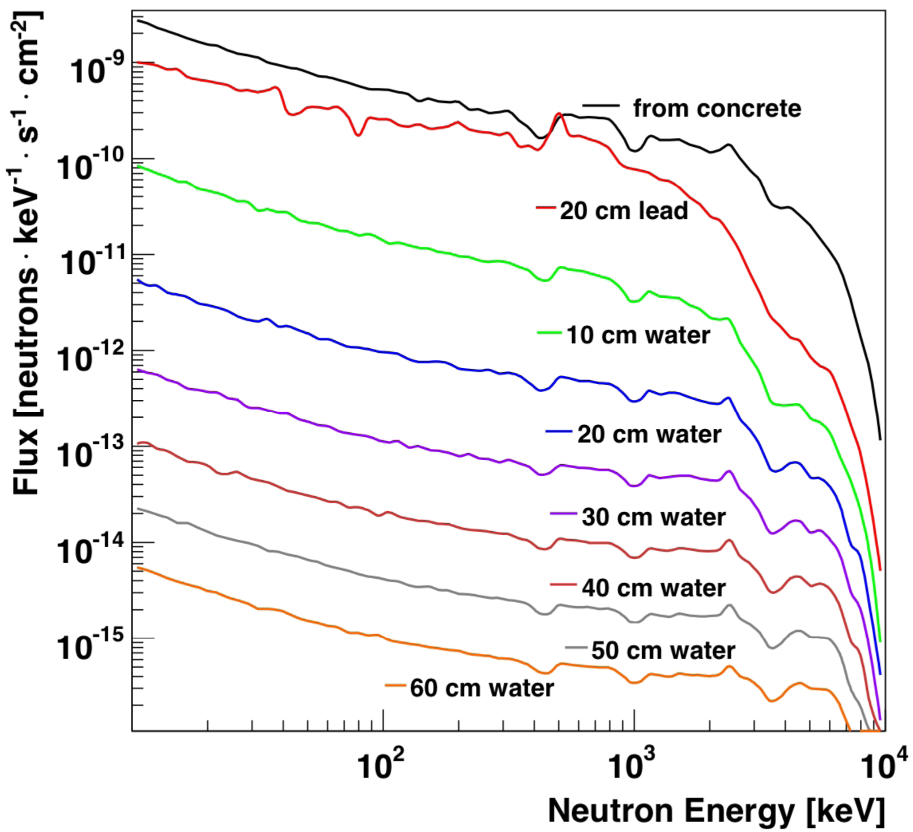
Gamma-ray attenuation in lead



- **A - spectrum at Boulby (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.**

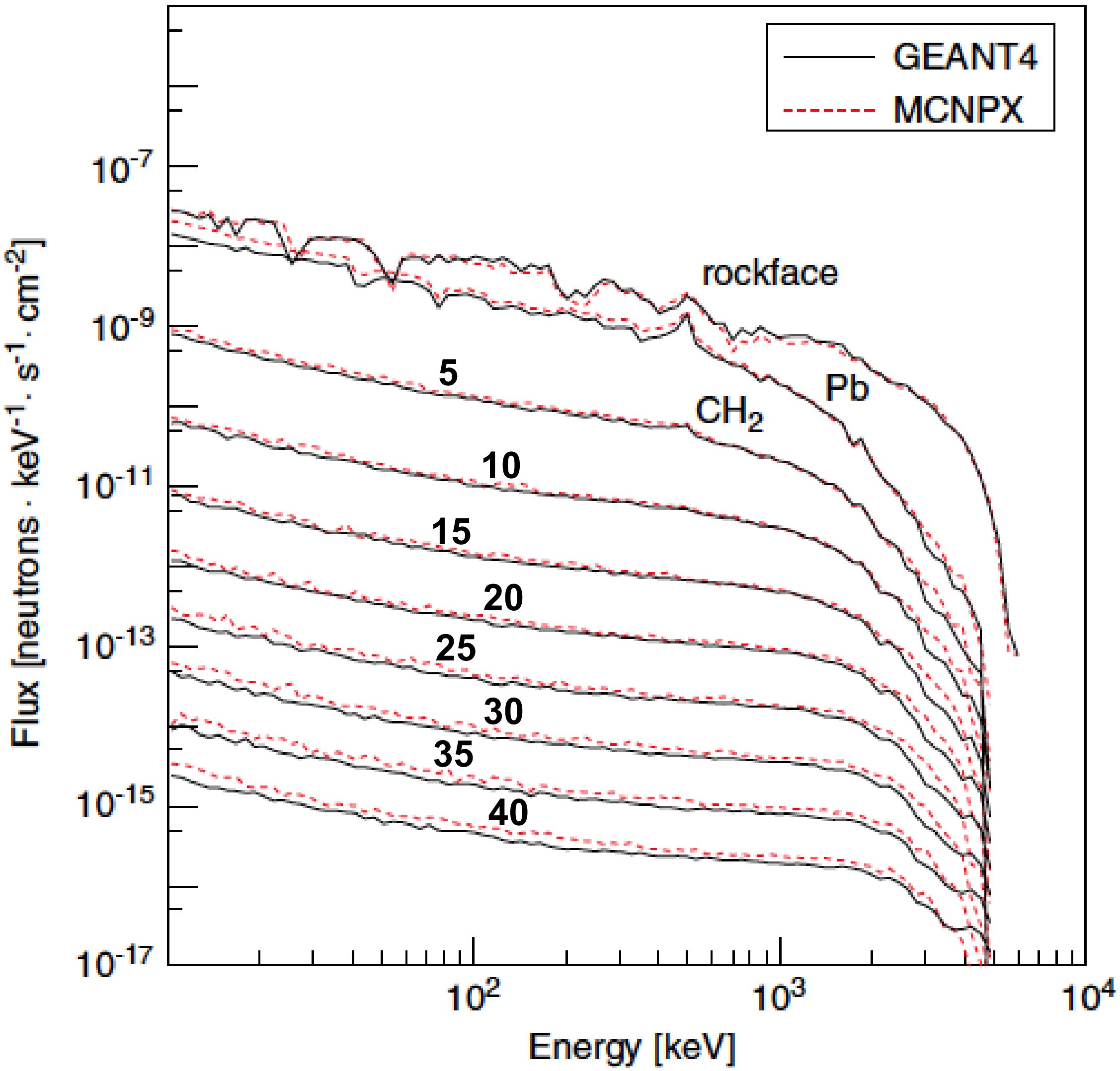
Neutrons in water and CH_2





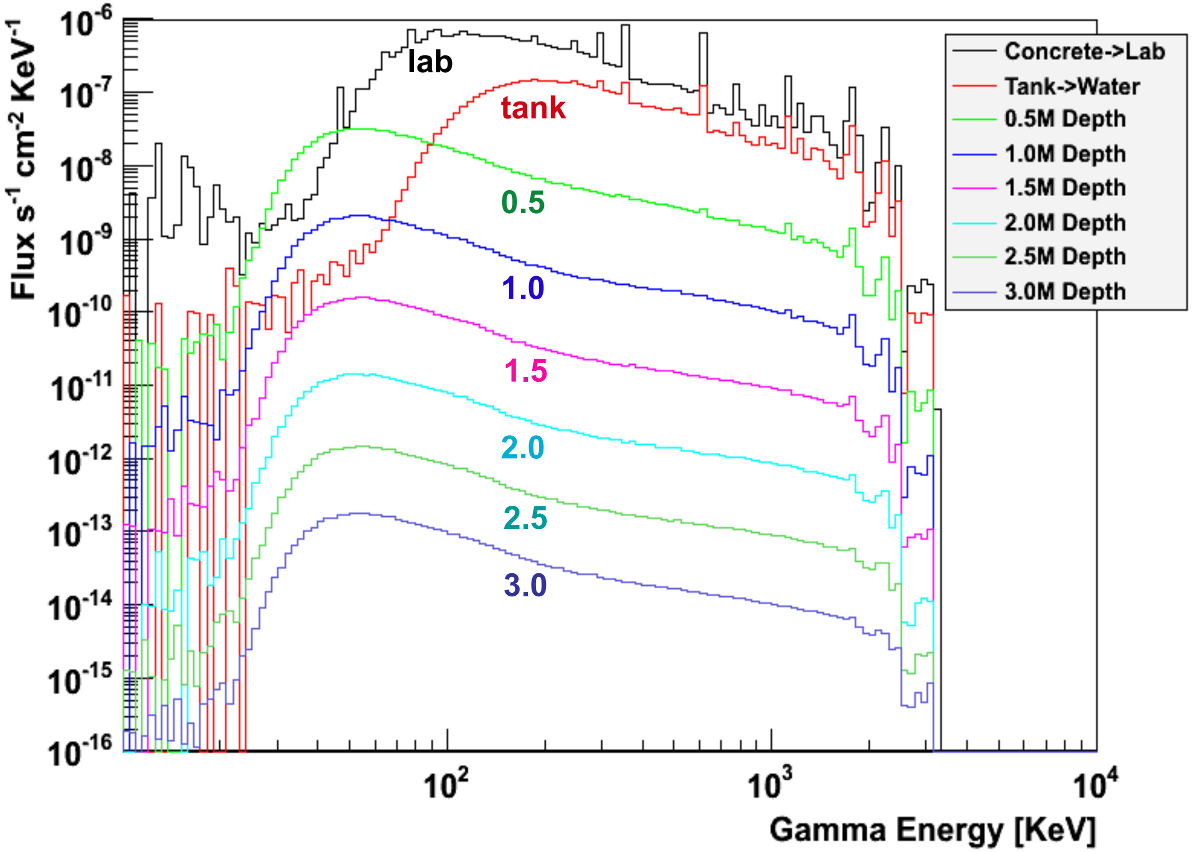
- Neutron attenuation in water and CH_2 - V. Tomasello, PhD Thesis, Univ. of Sheffield (2009).
- Inelastic scattering in lead helps with neutron attenuation at E > 1 MeV.

GEANT4 vs MCNPX



- **Neutron fluxes behind shielding.**
- **50% higher flux in MCNPX than in GEANT4 after 30 cm of lead and 40 g/cm^2 of CH_2.**
- **From R. Lemrani et al. Nucl. Instrum. and Meth. A 560 (2006) 454.**

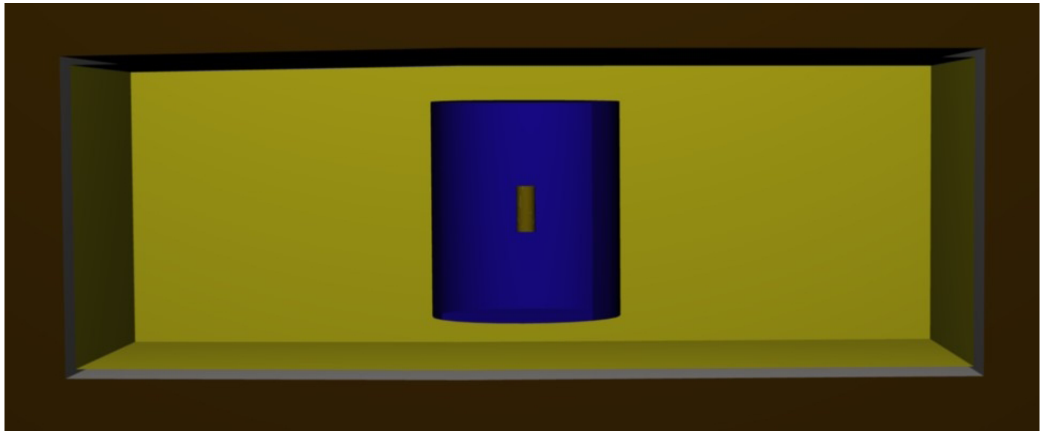
Attenuation in water



Spectra of gamma-rays from U in concrete. On average ×10 suppression per 0.5 m of H_2O.

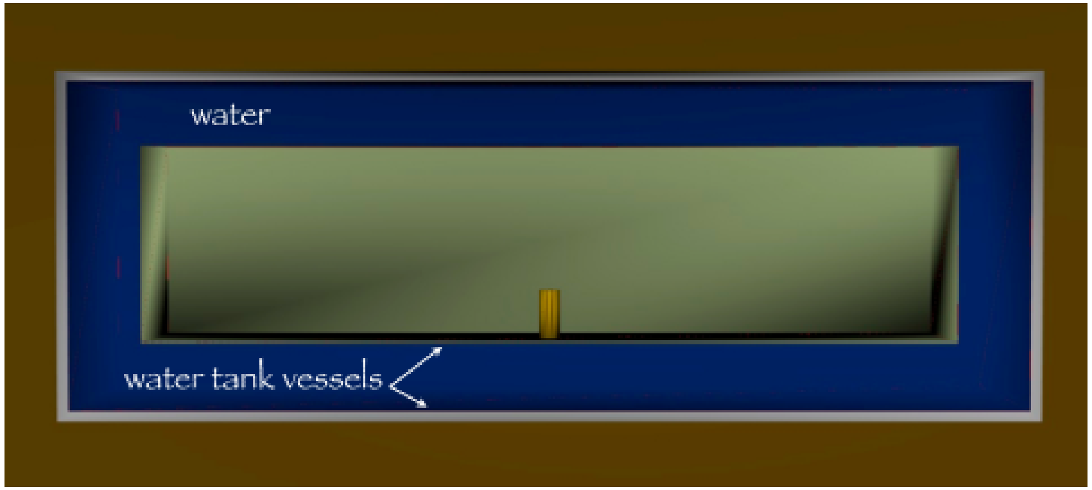
- **With a large thickness of concrete (>10 cm) the background from concrete may dominate over that from rock.**
- **With 30 cm of concrete only <5% of radiation comes from rock.**
- **Required suppression of gamma-rays for a tonne-scale experiment is achieved with 3 metres of water.**
- **Holes (pipes, readout) may be important.**

Submarine vs swimming pool



Swimming pool

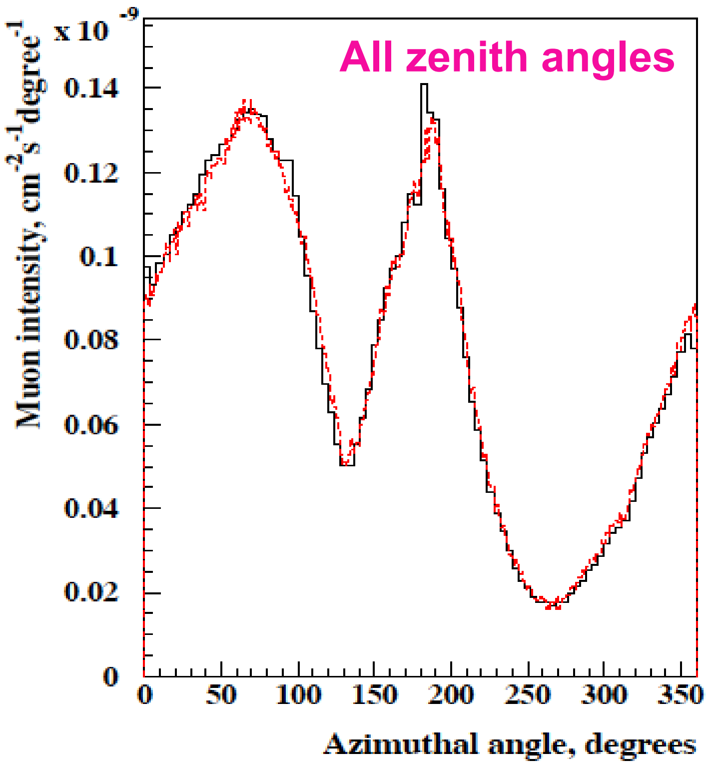
Submarine

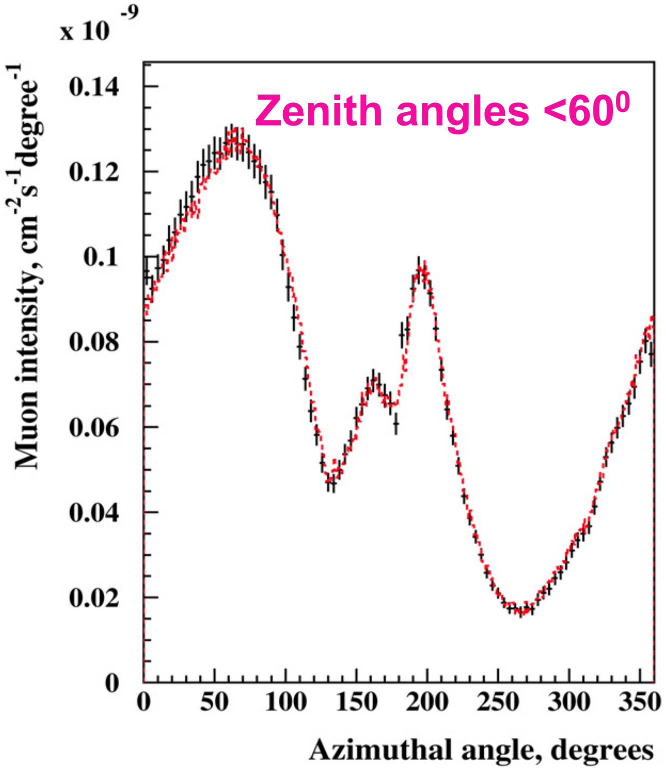


- About 17 nuclear recoils per year at 10-50 keV in 100 kg of Ge from the water tank stainless steel vessel (2 cm thick) along the walls.

- About 10^6 electron recoils per year at 10-50 keV in 100 kg of Ge from the water tank stainless steel vessel (2 cm thick) along the walls.

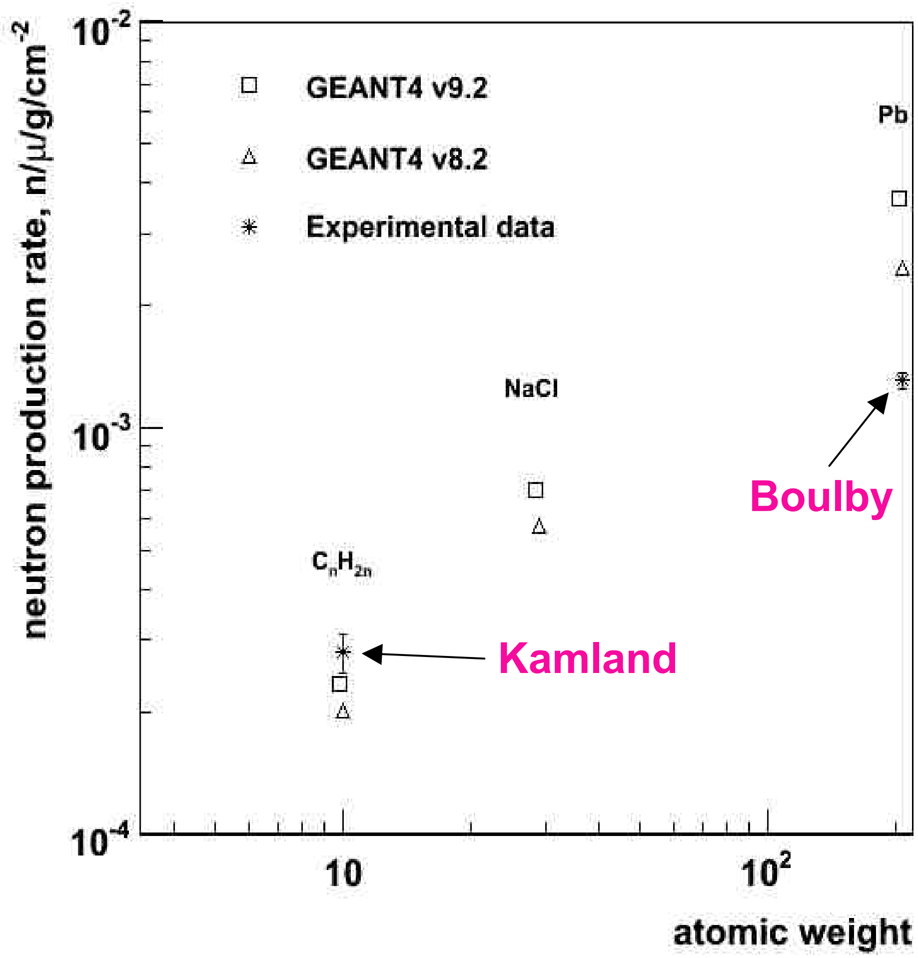
Muon generator: MUSUN





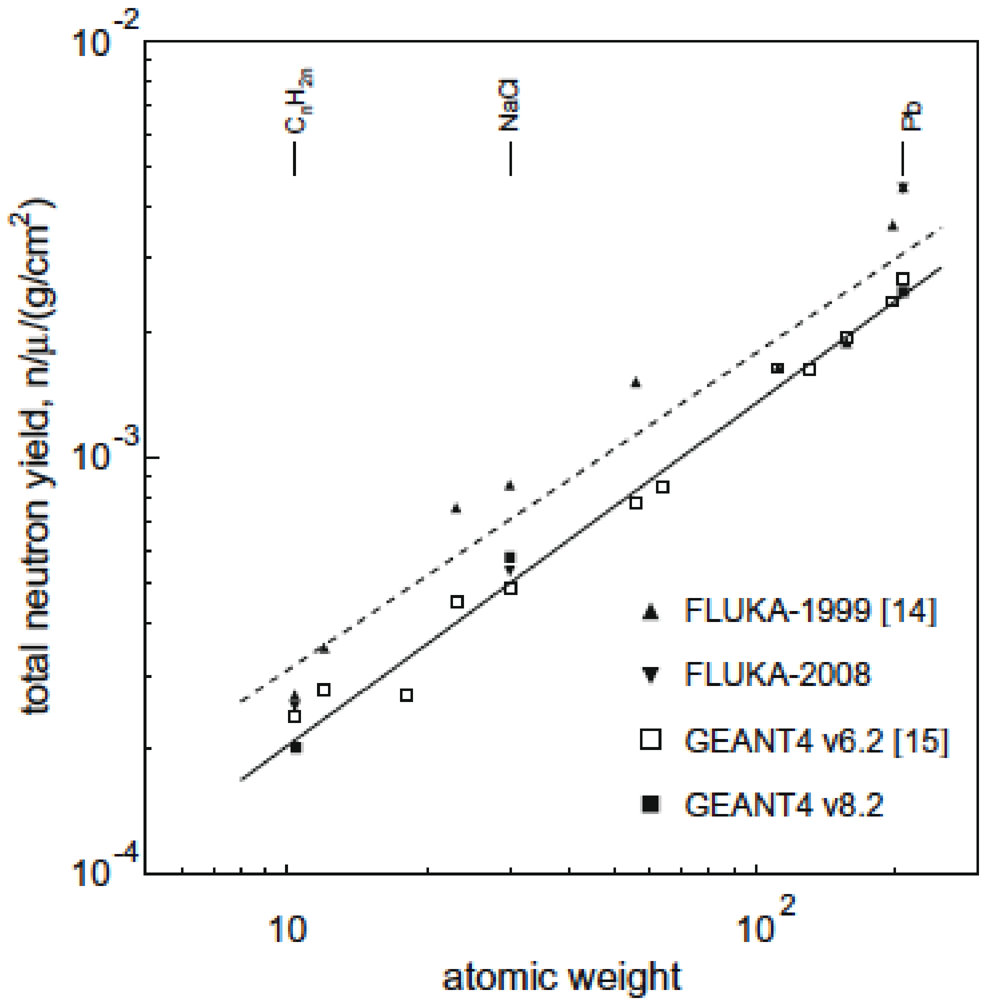
- **Angular distribution of muons at LNGS as generated by MUSUN in comparison with the single muon data from LVD. From Kudryavtsev et al., Eur. Phys. J. A 36, 171 (2008); Comp. Phys. Commun. 180 (2009) 339.**
- **Normalisation: total muon flux 1.17 m^{-2} hour^{-1} (sphere with 1 m^2) - slightly higher than MACRO value of ~1 m^{-2} hour^{-1}. Different location or something more requiring a revision?**

Neutron yield in different materials



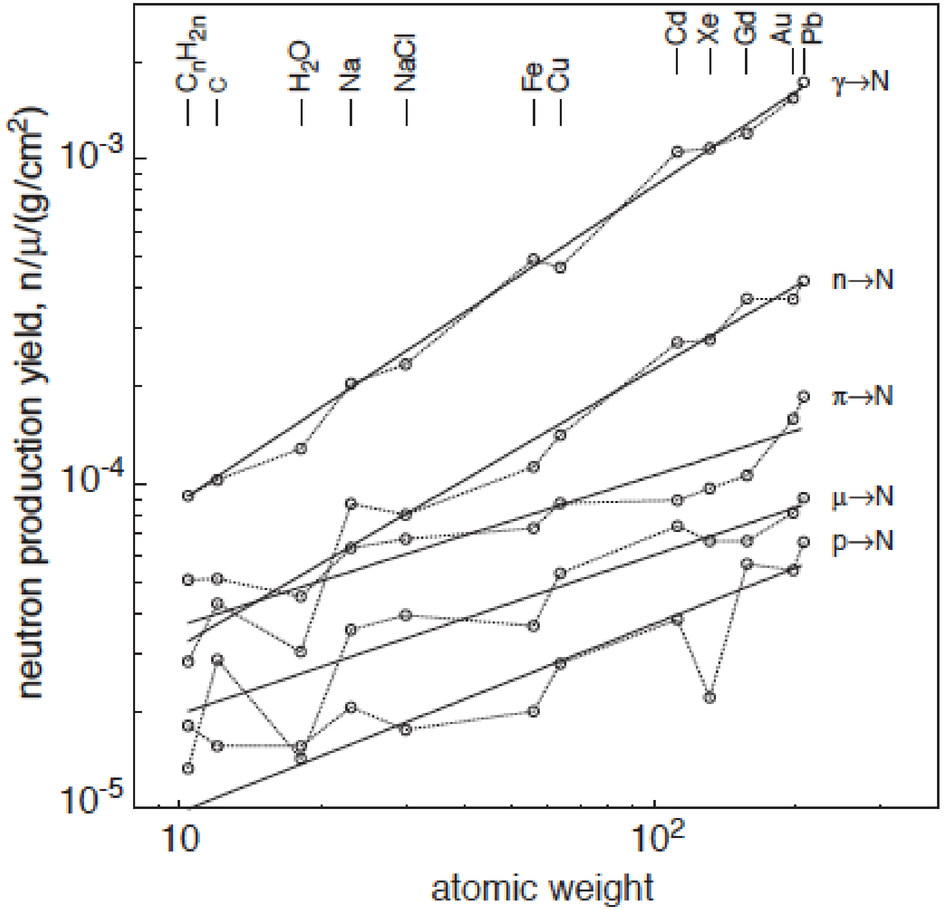
- Only two recent measurements with modelled setups are shown (~280 GeV muons). Slightly higher rate in CH_2 and lower rate in Pb.
- New results (data with full MC) is expected from LVD and other experiments.
- However, neutron capture rate is converted into the neutron yield - requires certain assumptions about neutron spectra, transport etc, taken from MC.
- Different versions and different models give different results. Various models were checked by M. Bauer (talk at IDM04): <30% difference.

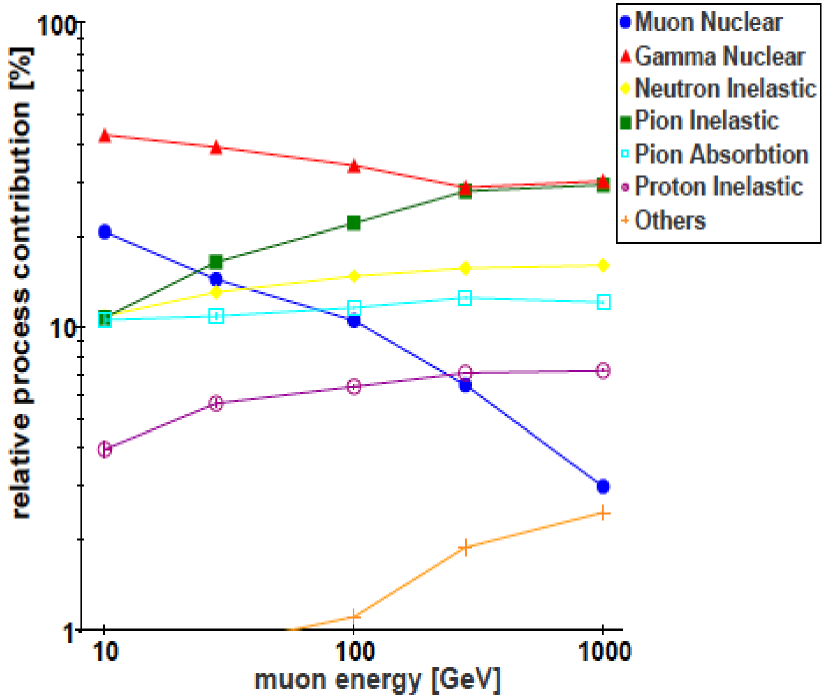
Neutron yield in different materials



- 280 GeV muons.
- The trend is shown by the dashed (FLUKA-1999) and solid (GEANT4 6.2) lines.
- Simulation results for different materials deviate significantly from the lines.
- It is not excluded that the model is more or less correct for some materials but does not give accurate predictions for another one.
- More measurements in different materials are needed supported by full MC.

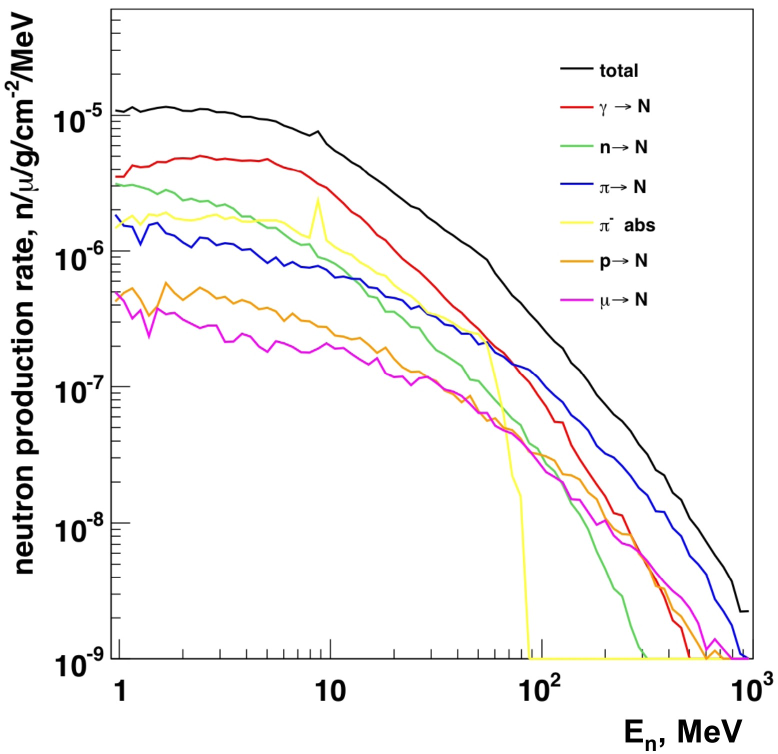
Processes

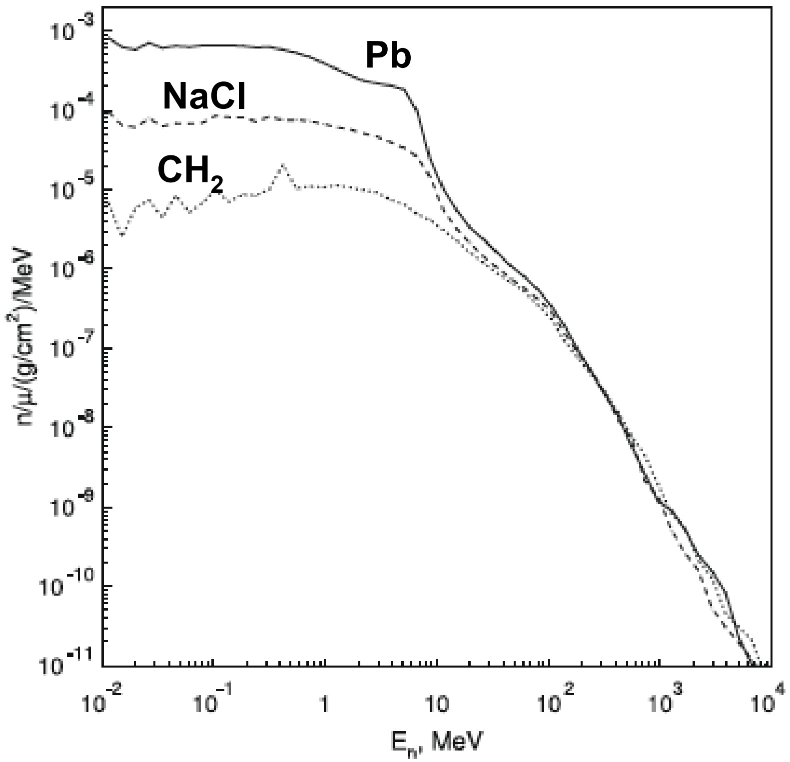




- M. Horn. Processes in CH_2, GEANT4 9.1.
- H. Araujo et al. Processes in different materials for 280 GeV muons, GEANT4 6.2.

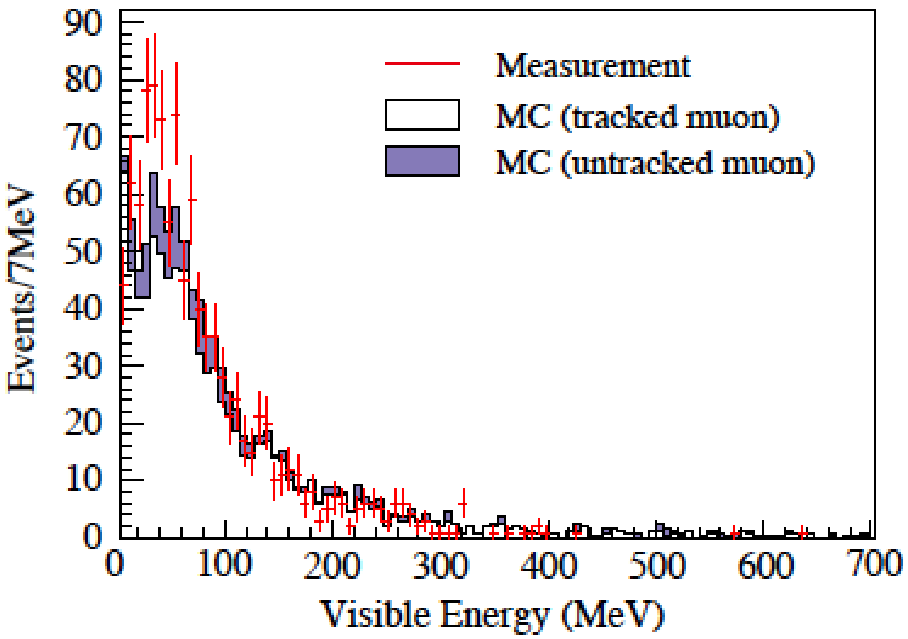
Neutron spectra at production

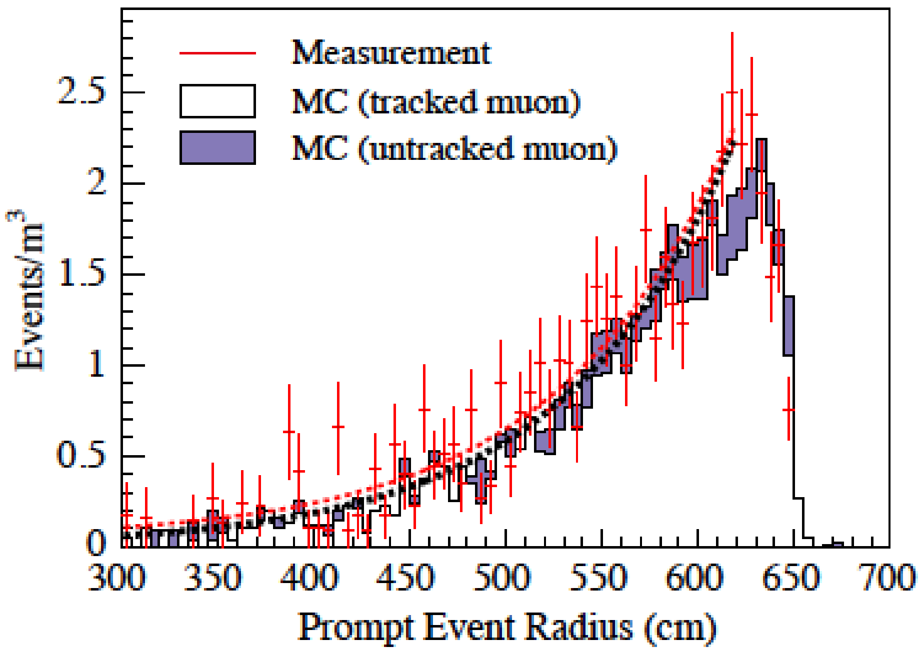




- **Left: CH_2, 280 GeV muons, GEANT4 9.2 (V. Tomasello, 2009); also M. Horn, H. Araujo, M. Bauer, A. Lindote, R. Persiani and others with various versions of GEANT4.**
- **Right: spectra in CH_2, NaCl and lead; $\langle E \rangle$ = 65.3 MeV, 23.4 MeV and 8.8 MeV (A. Lindote et al. Astropart. Phys., 31 (2009) 366). Different spectra in different materials.**

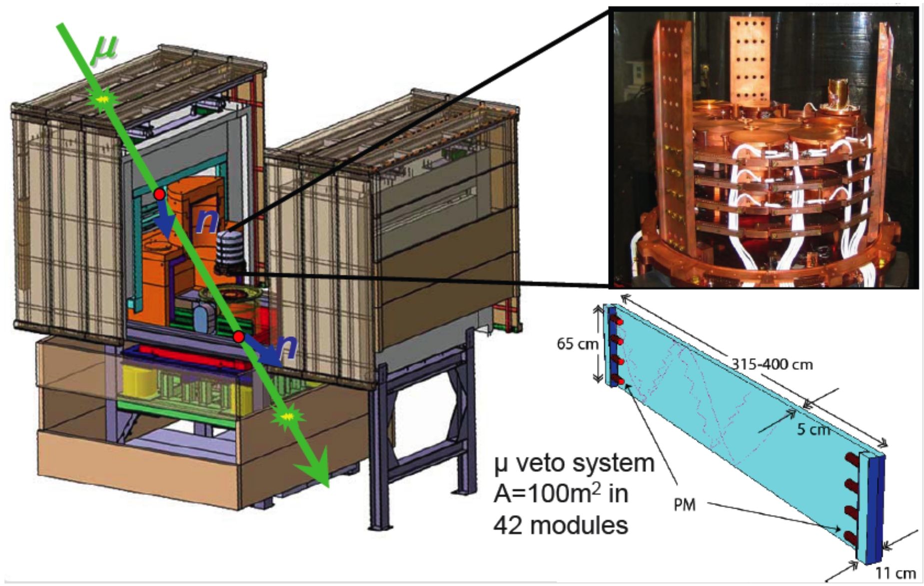
Neutron spectrum and radial distribution

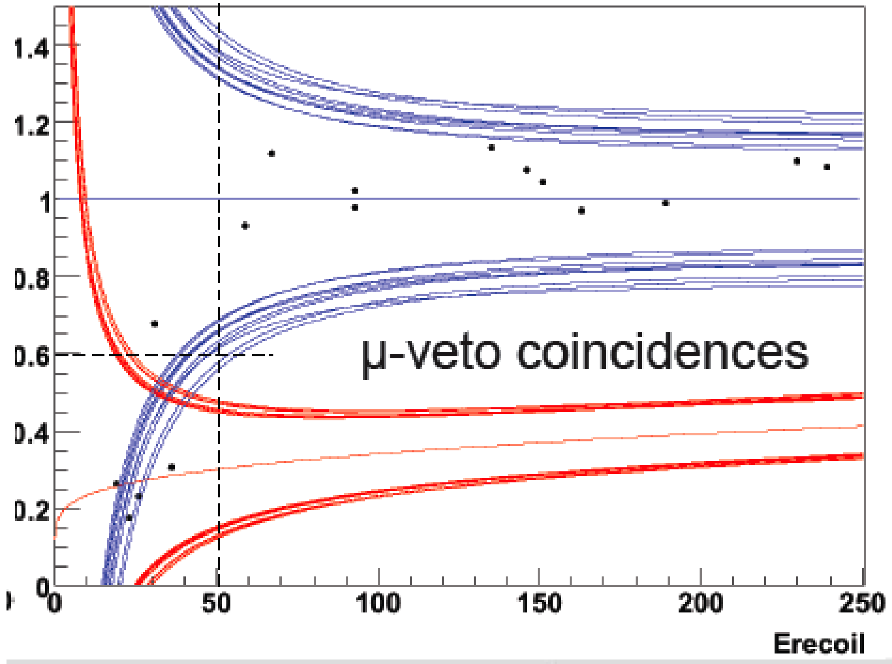




- Underground experiments need also neutrons spectra, lateral displacement distributions that have to be measured too.
- Kamland measurements: a small excess of data over simulations is also seen in the neutron spectrum and radial distribution.
- Is there a contamination of visible energy by the deposition of secondaries other than neutrons?

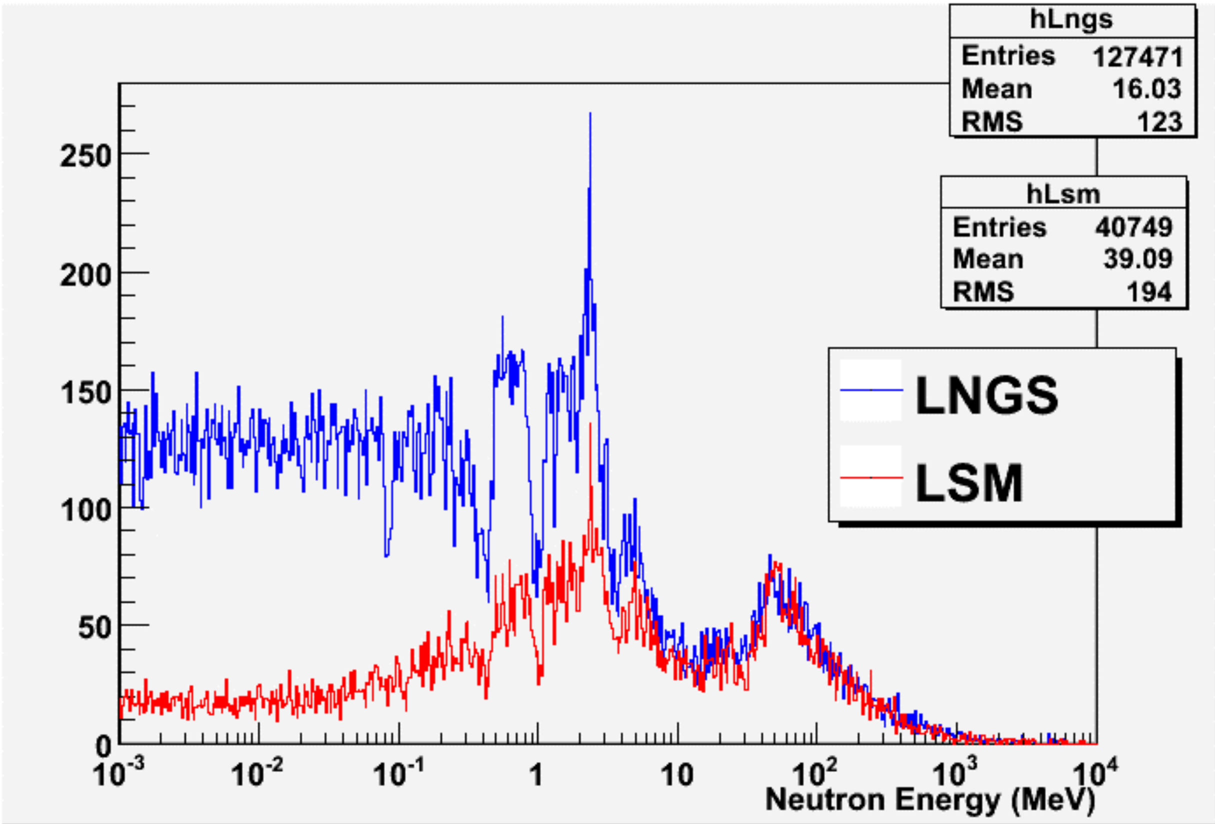
Coincidences with veto





- **Coincidences between EDELWEISS-II bolometers and active veto system.**
- **Preliminary: agreement between measured rate of neutron + gamma events, and simulations at low energies (V. Kozlov, K. Eitel, talks at IDM2008, TAUP2009).**
- **A large scintillator detector is also installed to measure coincident events.**

Dependence on rock composition



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. Neutron flux at LNGS above 1 MeV: 4.27×10^{-10} cm^{-2} s^{-1}, FLUKA, w/o back-scattering. (Wulandari et al., hep-ex/0401032), 3.8×10^{-10} cm^{-2} s^{-1} GEANT4 (Persiani and Selvi).

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

Angular dependence

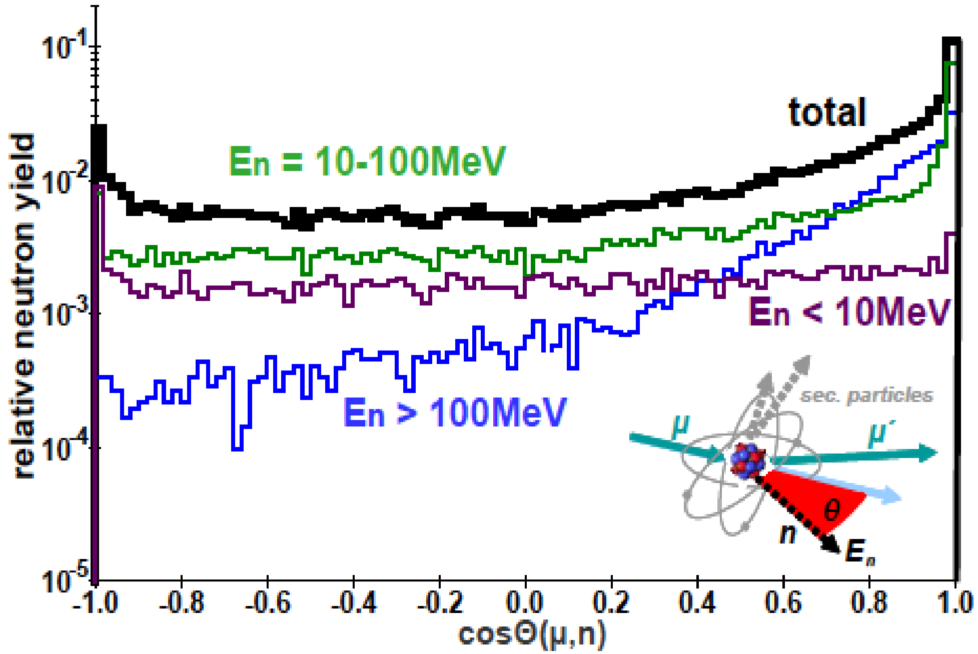


Figure 3.9: Angular distribution relative to the total neutron yield of neutrons produced in muon nuclear reactions with *Geant4* `8.2.p01`. For all neutron kinetic energies (black) or the respective kinetic energy ranges, $E_n > 100\ MeV$ (blue), $10\ MeV < E_n < 100\ MeV$ (green) and $E_n < 10\ MeV$ (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.**

Spectra in detectors

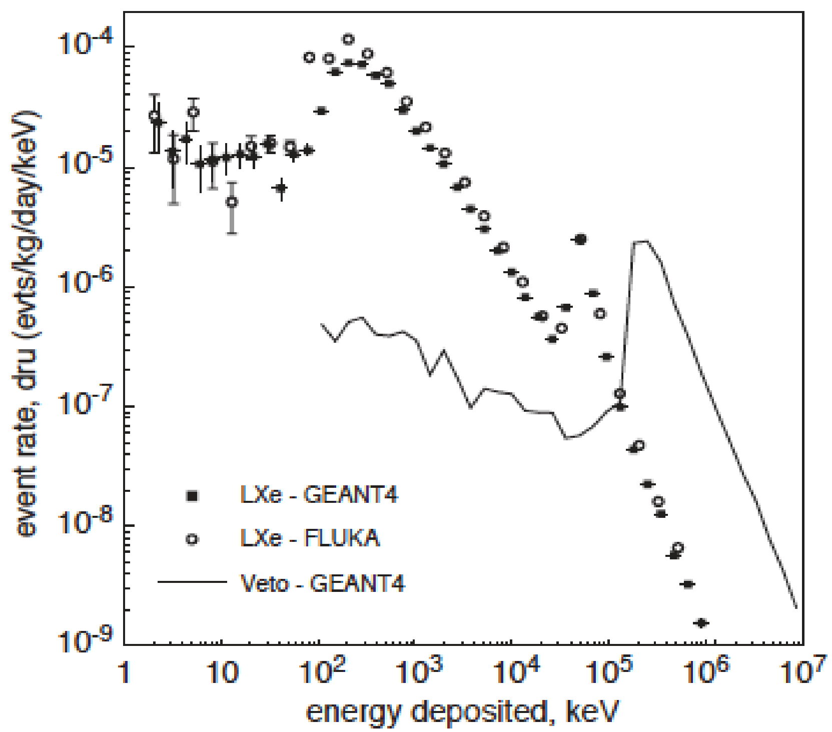


Fig. 11. Differential spectra of the total energy deposited in the liquid xenon (LXe) target as predicted by GEANT4 and FLUKA and in the veto scintillator according to GEANT4 (the latter is scaled down by a factor of 5×10^4).

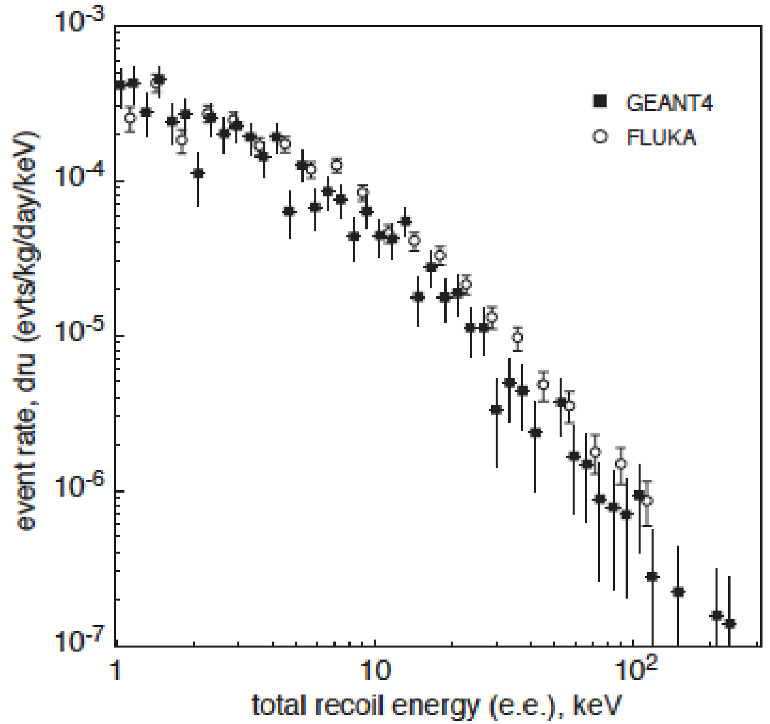
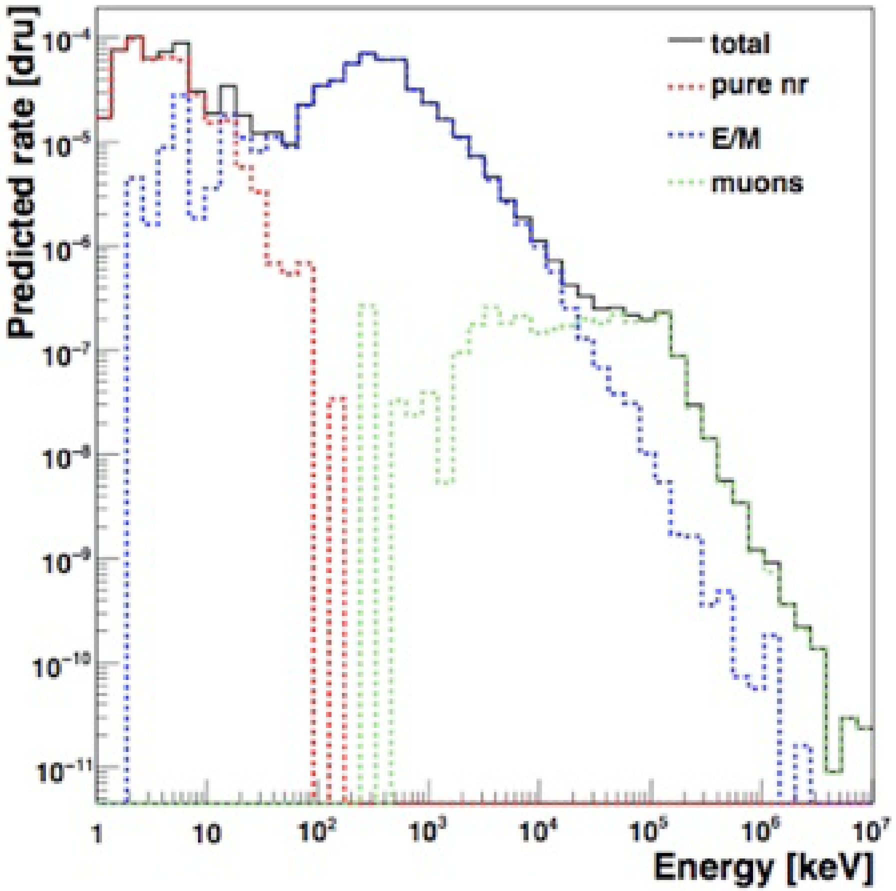


Fig. 12. NR energy spectrum in the liquid xenon detector as a function of the visible energy deposited by all nuclear recoils in each event. The spectra include 'mixed' events involving electromagnetic energy deposits, not just 'pure' nuclear recoils, but only the energy left by NRs was counted.

Araujo et al. NIMA 545 (2005) 398. Boulby lab, 50% higher μ-flux compared to LNGS, 250 kg of xenon, shielding - 30 cm Pb (ext), 40 g/cm^2 CH_2 (int); only 2-3 events per year at 10-50 keVnr (w/o veto); < 1 per year with veto.

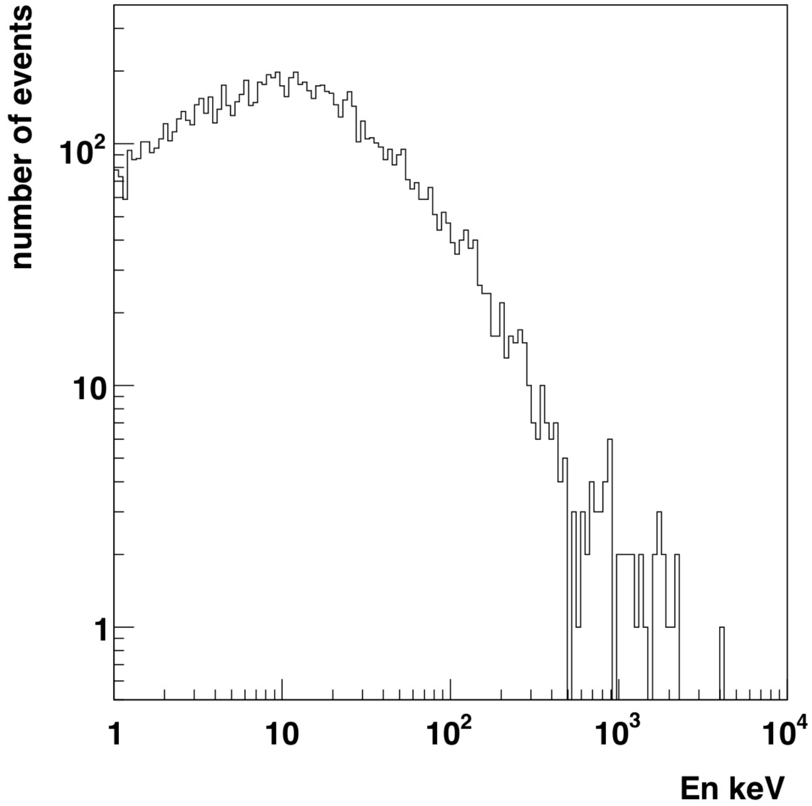
Spectra in detectors



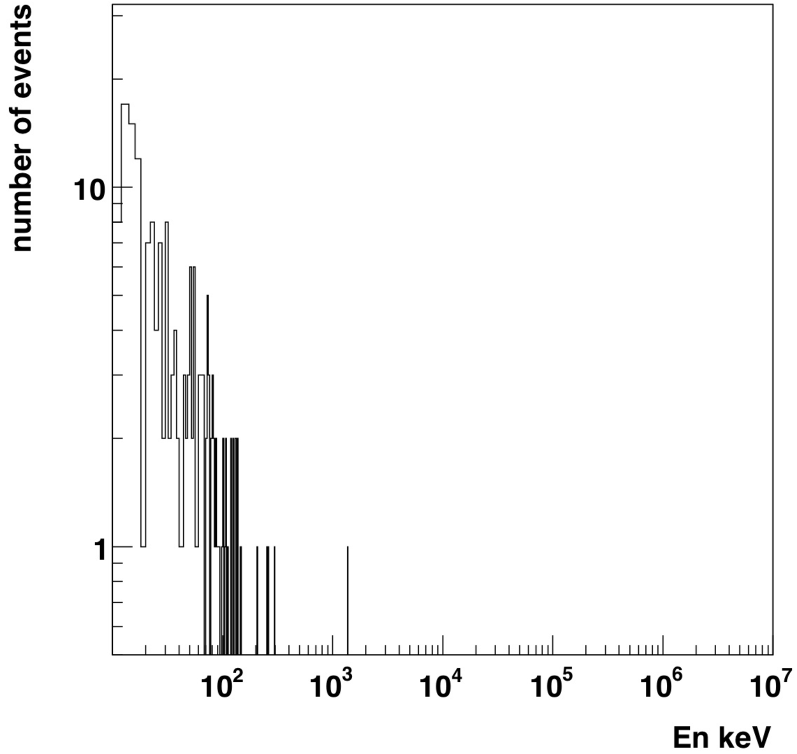
A. Kish, talks at GEANT4 Workshop (October 2009) and DM2010 (February 2010).

- Simulations for XENON-100 (LNGS).
- Shielding (starting from detector): copper (5 cm), PE (20 cm), lead (20 cm), PE (20 cm) - according to MC (supported by comparison with data) this combination should attenuate the flux from rock down to the level required for the projected detector sensitivity.
- Additional background suppression is achieved by the fiducial volume cut and active veto system.
- Other groups are doing similar MC.
- Cross-checks are required: total neutron flux above a certain threshold, energy spectrum.

Muon-induced neutrons: Ge target



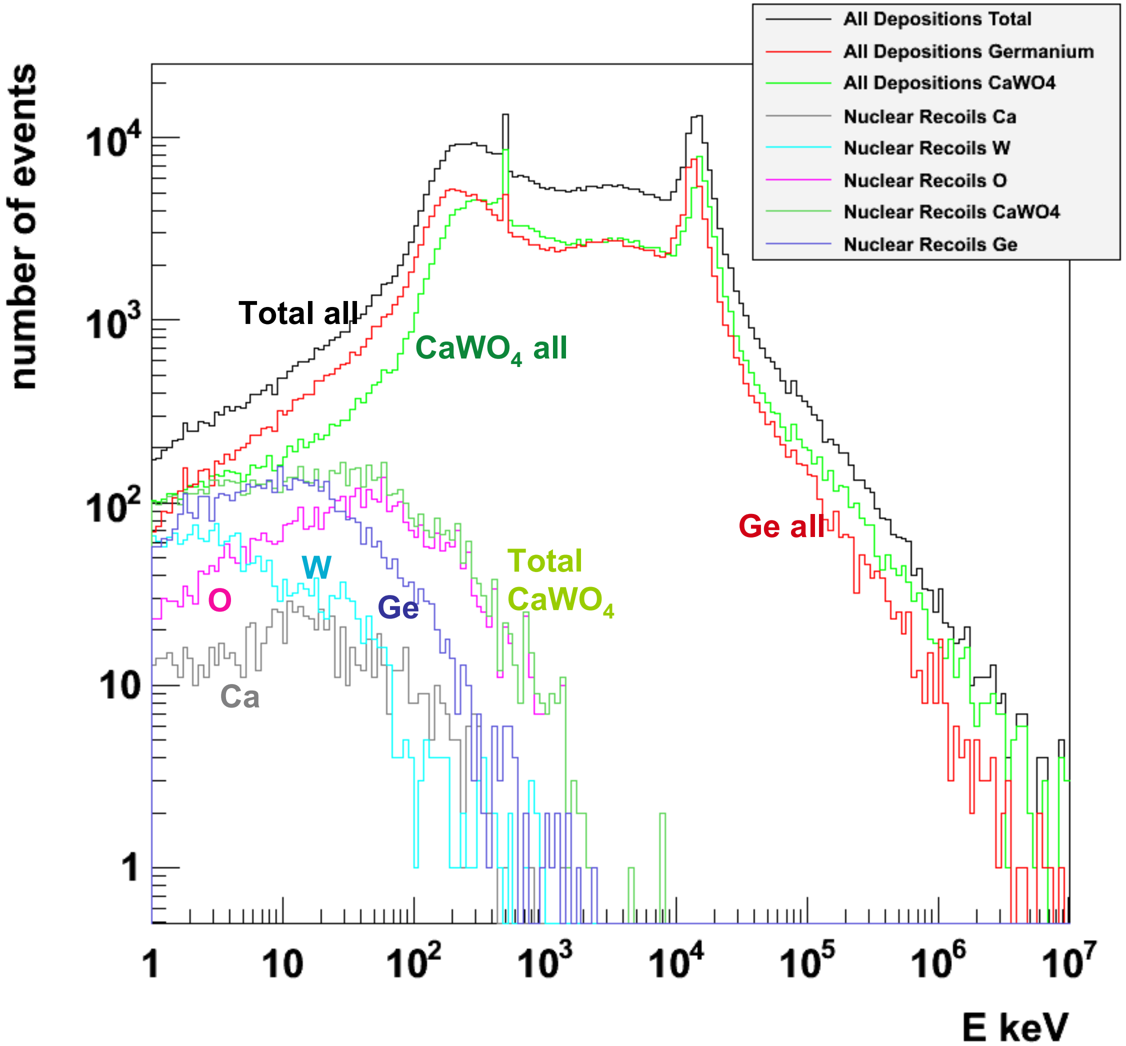
Spectrum of nuclear recoils in Ge - all multiplicities. Other energy depositions are assumed to be not seen.



Spectrum of single nuclear recoils. Other energy depositions are assumed to be not seen. The energy threshold was assumed to be 10 keV.

Muon-induced neutrons in EURECA

- 3 m thick water shielding around each cryostat.
- Only single nuclear recoils (without any other energy deposition): 1.6±0.5 ev/year at 10-50 keV (independently of the signal in veto - veto is not switched on).
- No events in anticoincidence with veto.
- One event with energy deposition in veto of only 0.278 GeV. Others - with E_{dep} > 1 GeV.
- In $CaWO_2$ most events are O recoils at high energies.



Conclusions

- **Shielding for one-tonne scale experiment:**
  - **20 cm of lead + 40-50 g/cm^2 of CH_2 or**
  - **3 m of water.**
- **Water shielding along the walls is not efficient: many background events from the water tank walls if no additional shielding in the lab is in place.**
- **Still an uncertainty of about a factor of 2 in measured and simulated neutron production rate, especially in high-Z targets. We need to simulate and compare with the measurements exactly what is measured - in most cases this is neutron capture rate, not the neutron production rate.**
- **More experiments (and simulations) are needed, also to measure neutron spectra, lateral displacement etc.**
- **Optimistic results for muon-induced neutrons even with existing uncertainty. LNGS is well suited for tonne-scale dark matter experiments:**
  - **results for XENON-100: expected rate <0.07 ev/year.**
  - **1.6 ± 0.5 ev/year/tonne - single Ge recoils at 10-50 keV at LSM (a factor of 5 lower high-energy neutron flux compared to LNGS). No event survives veto cut (E > 0.2 GeV) in 11.1 years of simulated statistics.**