Background radiation in direct dark matter experiments

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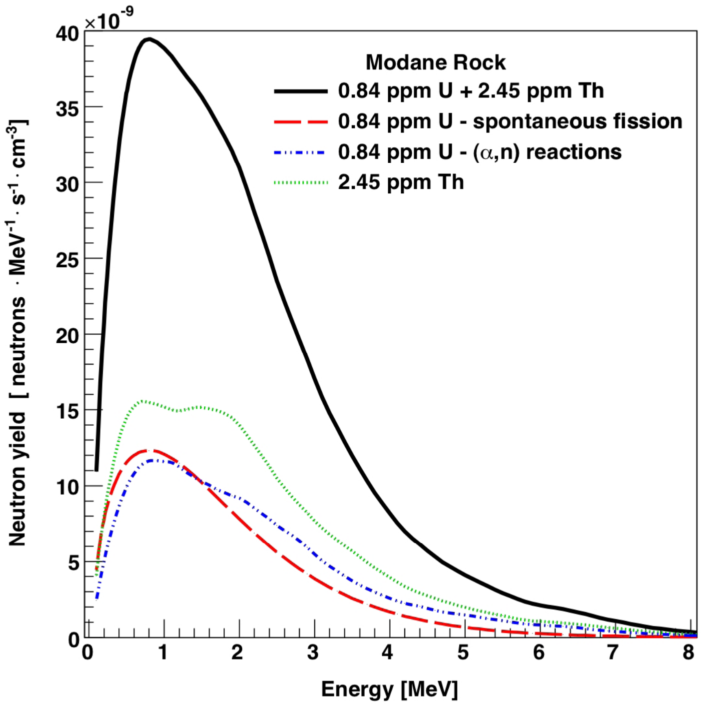
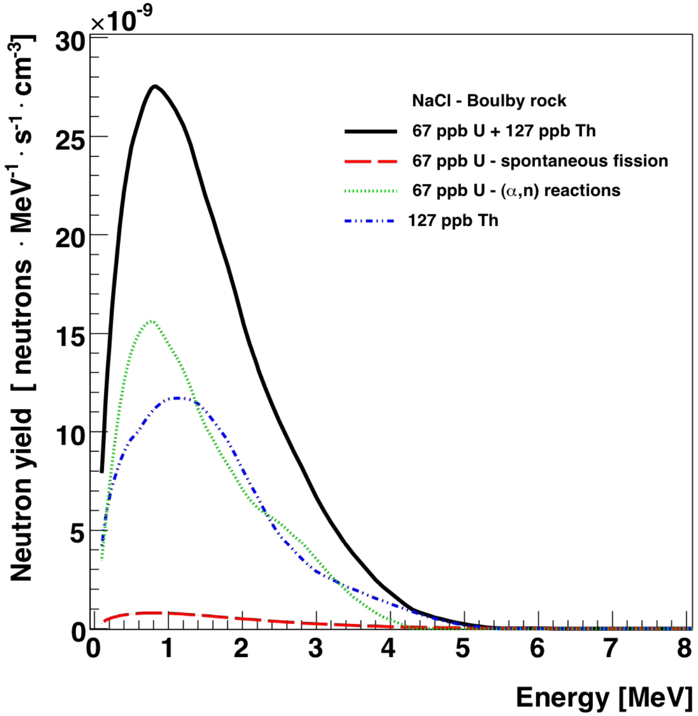
Contributions from many others

Outline

- This presentation is mainly about cryogenic DM experiments (EURECA) although many results are relevant to other experiments and techniques.
- Neutrons and gamma-rays from radioactivity.
  - Spectra of neutrons.
  - Gamma-ray and neutron transport through the shielding.
  - Event rate for different shielding configurations.
  - Background from detector components.
  - Intrinsic radio-purity.
- 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 can it be?

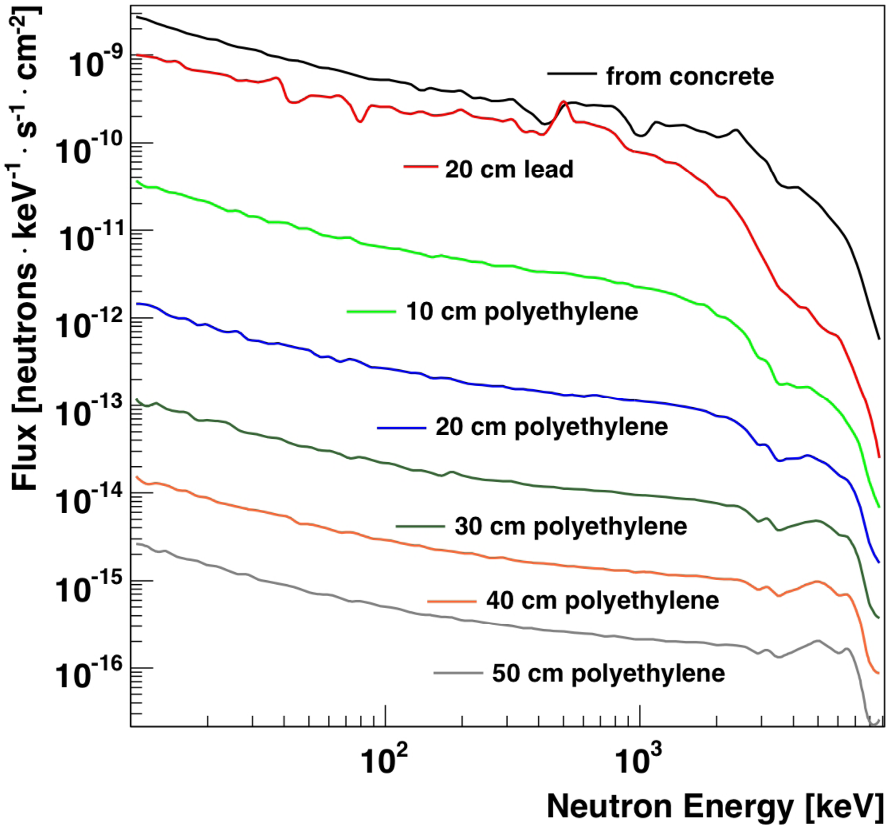
Neutron spectra in different rocks

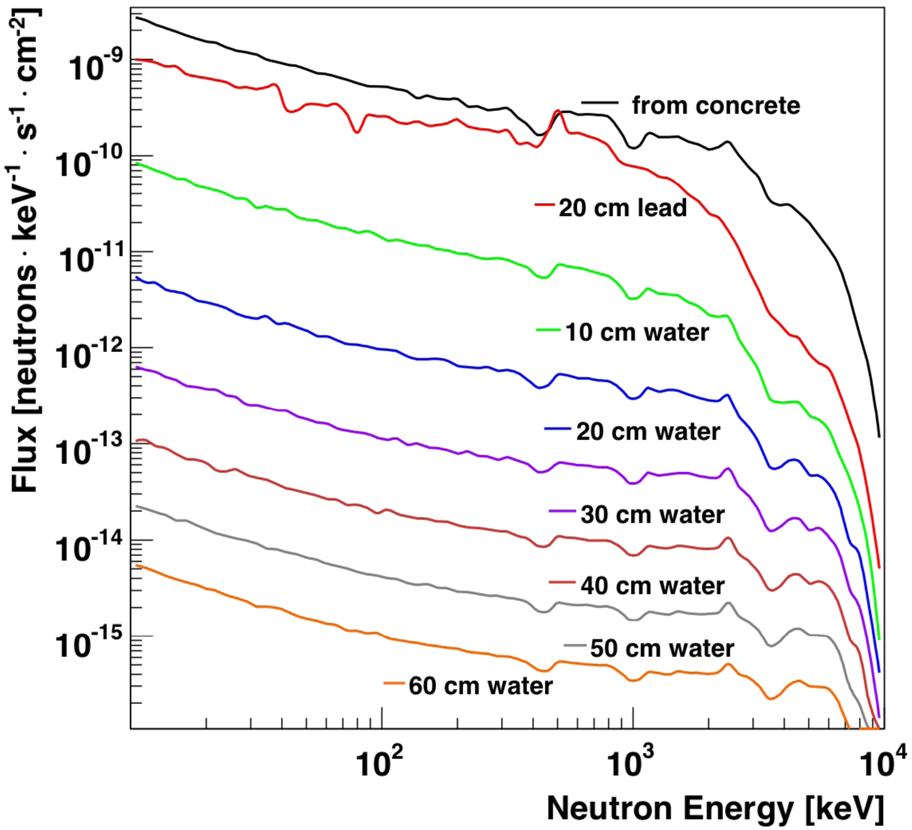




- Neutron spectra from modified SOURCES4A (Wilson et al. Sources4A. Technical Report, LA-13639-MS (1999); Carson et al. Astropart. Phys. 21 (2004) 667). Spectra and rates strongly depend on the material (composition).
- Plots taken from Tomasello et al. NIMA 595 (2008) 431; Astropart. Phys. (2010), in press; V. Tomasello, PhD Thesis, Univ. of Sheffield (2009).
- 1% of hydrogen reduces neutron flux on the rock face (after transport) by a factor 4.7 (1.8) above 100 keV (1 MeV).

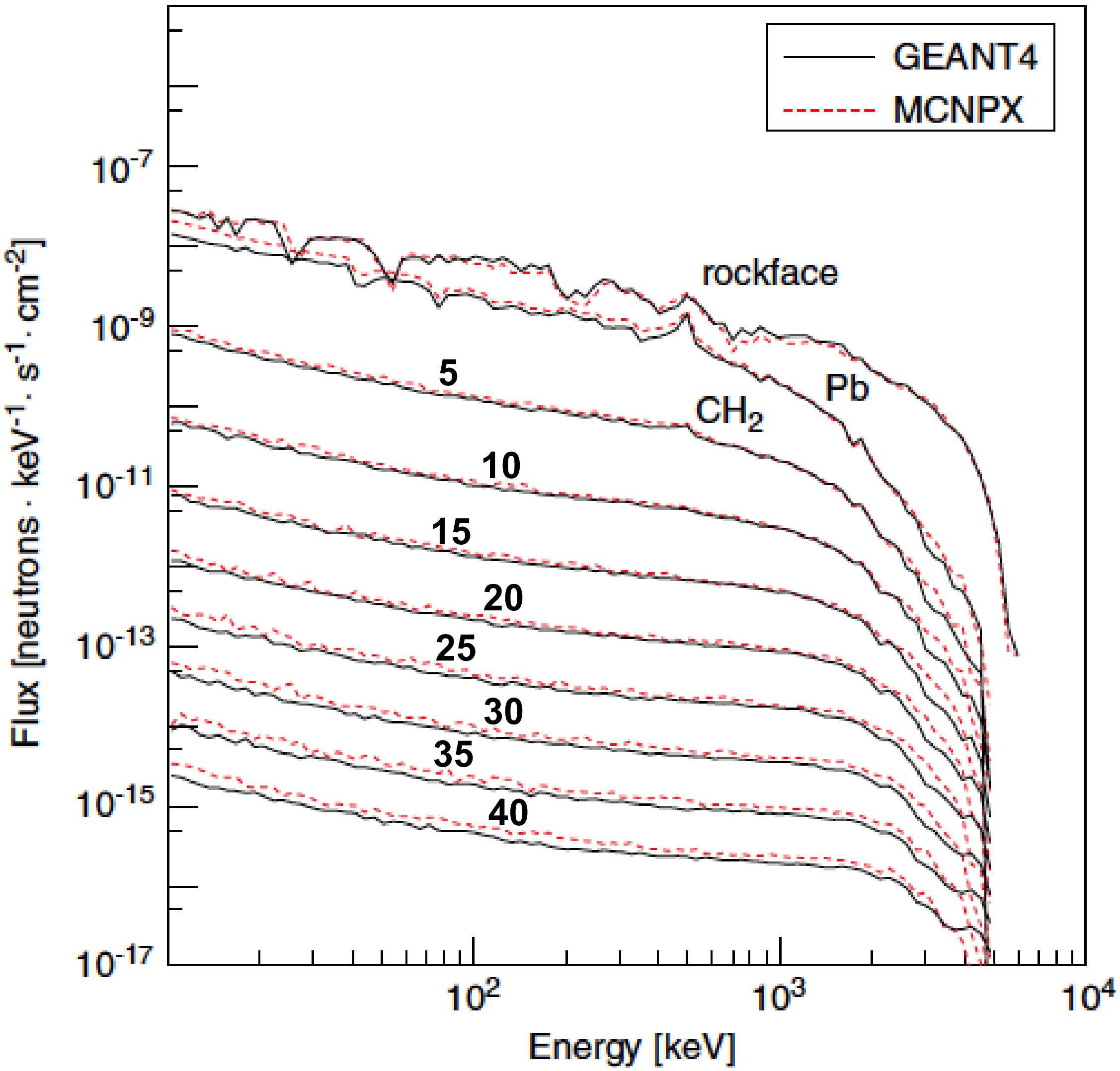
Neutrons in water and CH_2





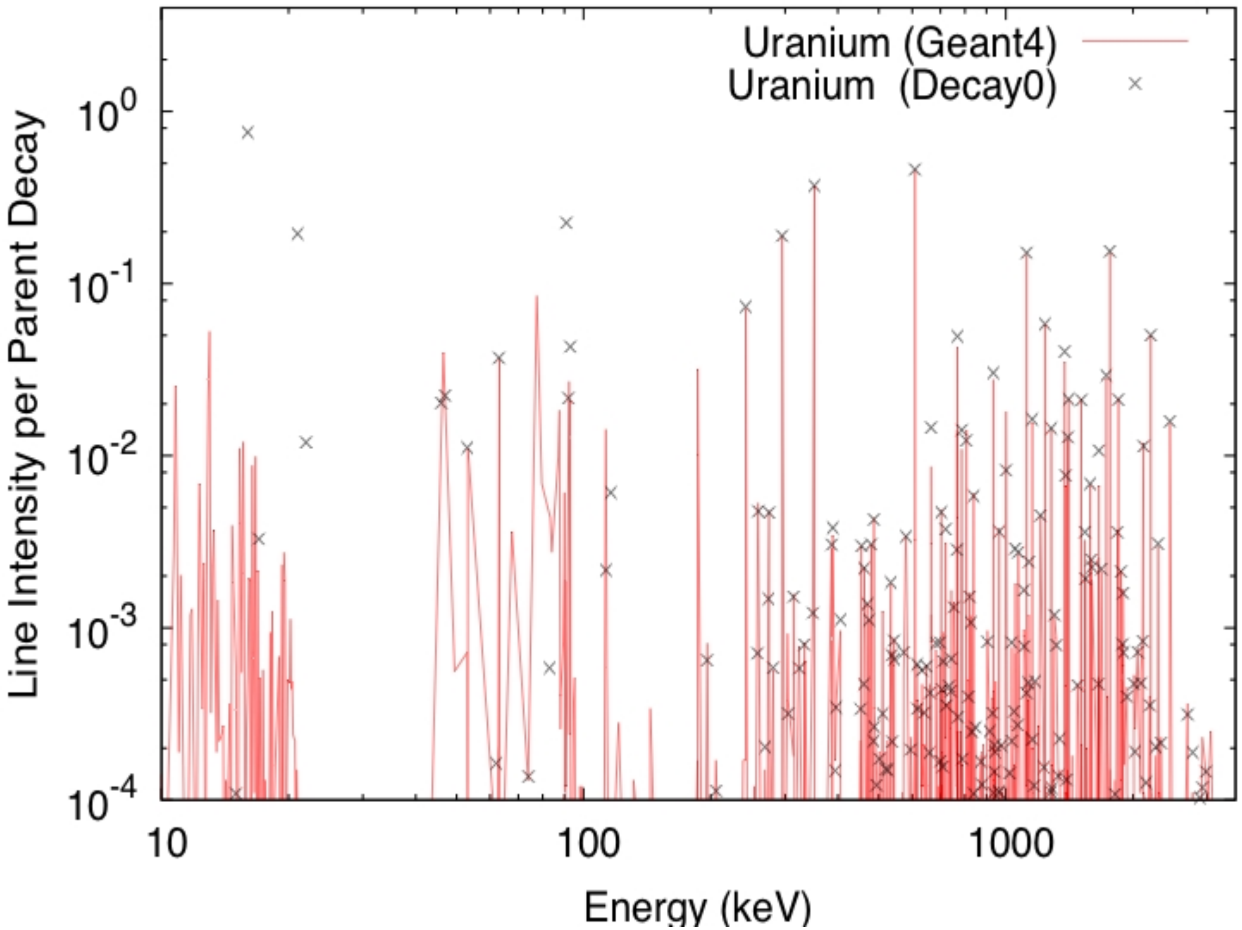
- **Neutron attenuation in water and CH_2 - V. Tomasello, PhD Thesis, Univ. of Sheffield (2009); Tomasello et al. Astropart. Phys. (2010), in press.**
- **Inelastic scattering in lead helps with neutron attenuation at E > 1 MeV.**

GEANT4 vs MCNPX



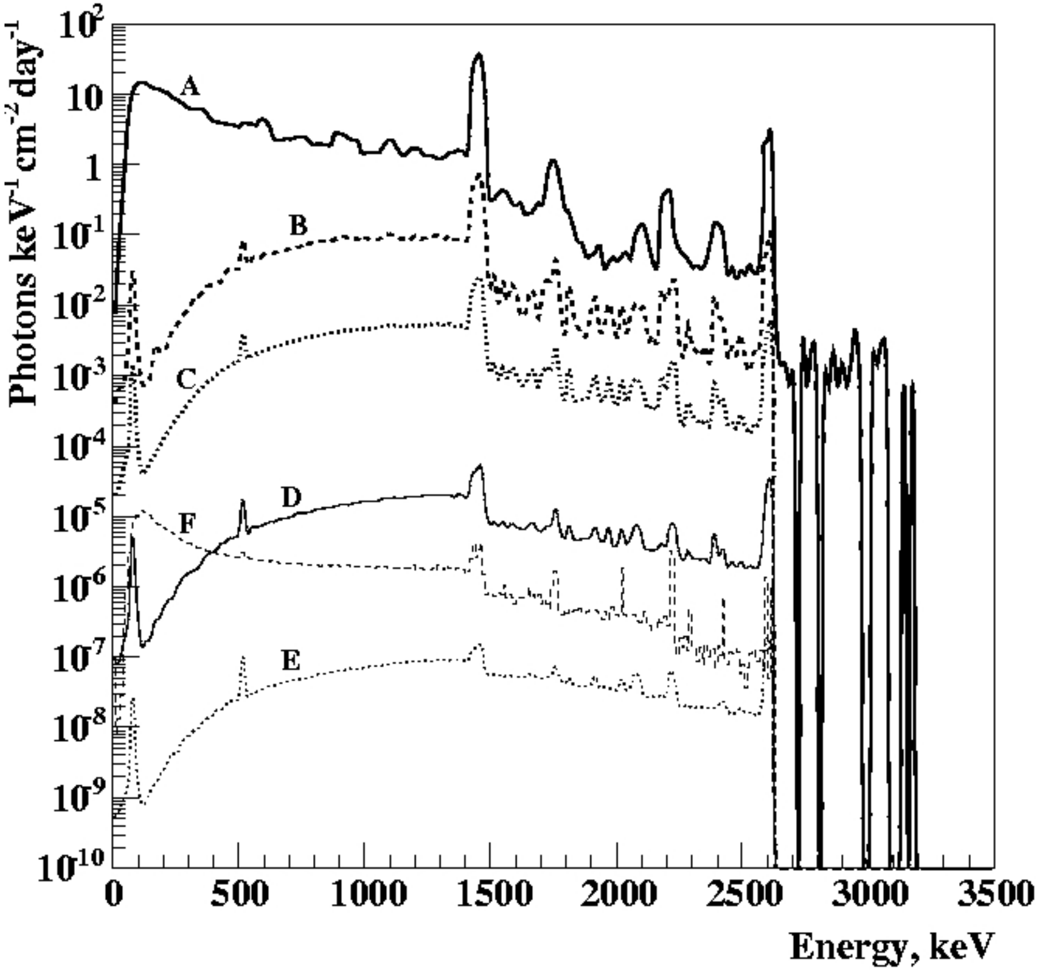
- **Neutron fluxes behind shielding.**
- **50% higher flux in MCNPX than in GEANT4 after 30 cm of lead and 40 g/cm^2 of CH_2.**
- **From R. Lemrani et al. Nucl. Instrum. and Meth. A 560 (2006) 454.**

Gamma-ray spectra



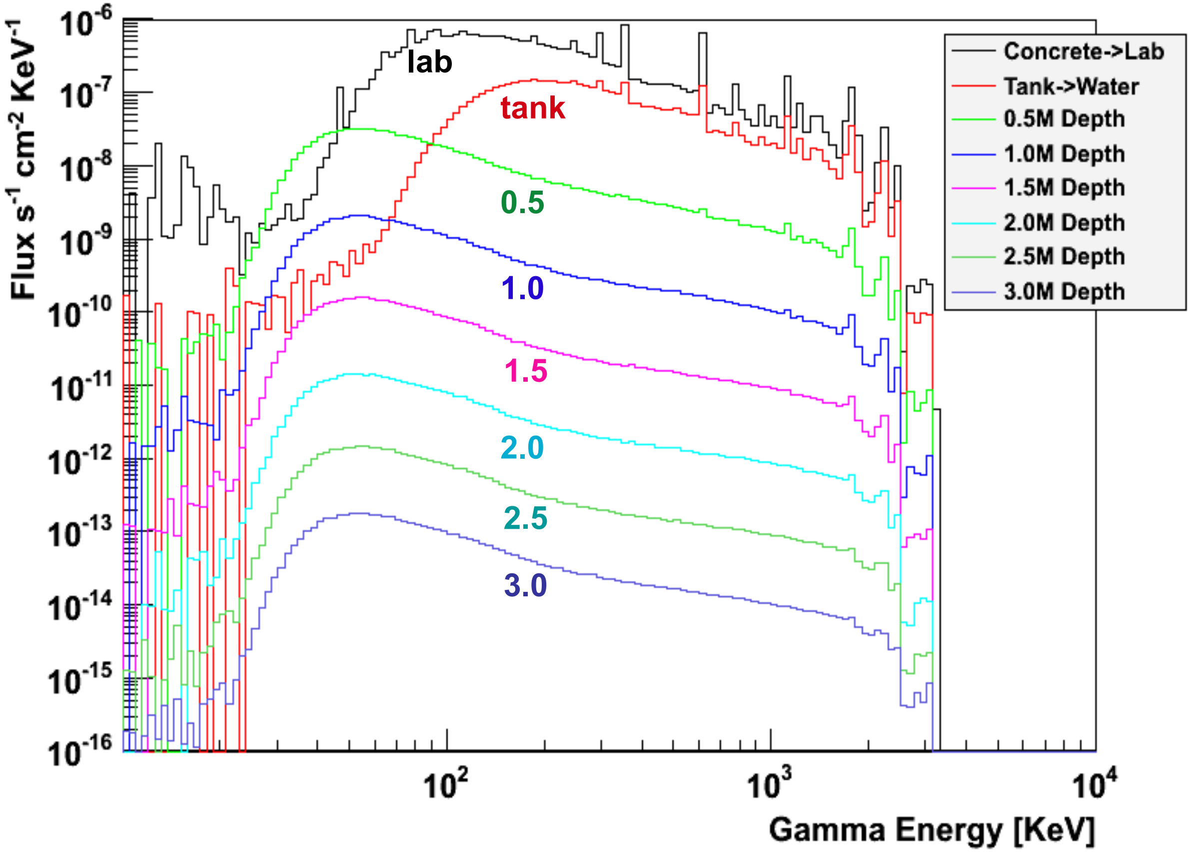
- Gamma-ray spectra from GEANT4 and DECAY0 (Tretyak, Kiev).
- Can start with photons (external source) or radioactive nuclei (internal source, the chain of decays can be simulated, but pay attention to the time of the decay).
- Assume secular equilibrium.

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.

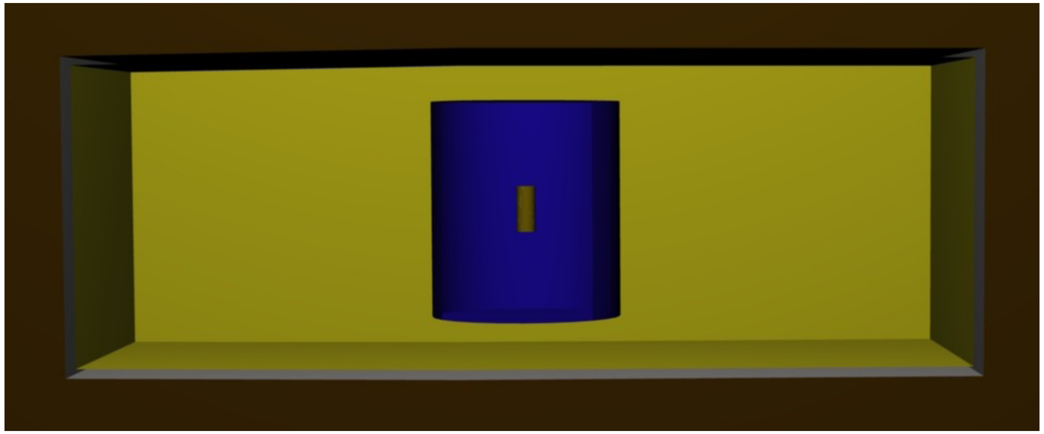
Attenuation in water



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

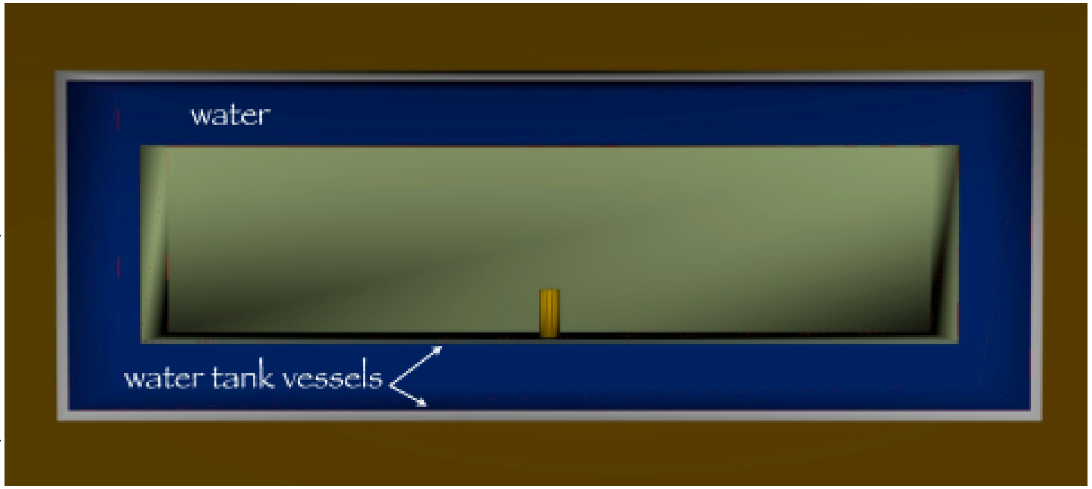
- With a large thickness of concrete (>10 cm) the background from concrete may dominate over that from rock.
- With 30 cm of concrete only <5% of radiation comes from rock.
- Required suppression of gamma-rays for a tonne-scale experiment is achieved with 3 m of water (discrimination $<10^{-4}$.
- Holes (pipes, readout) may be important.

Submarine vs swimming pool



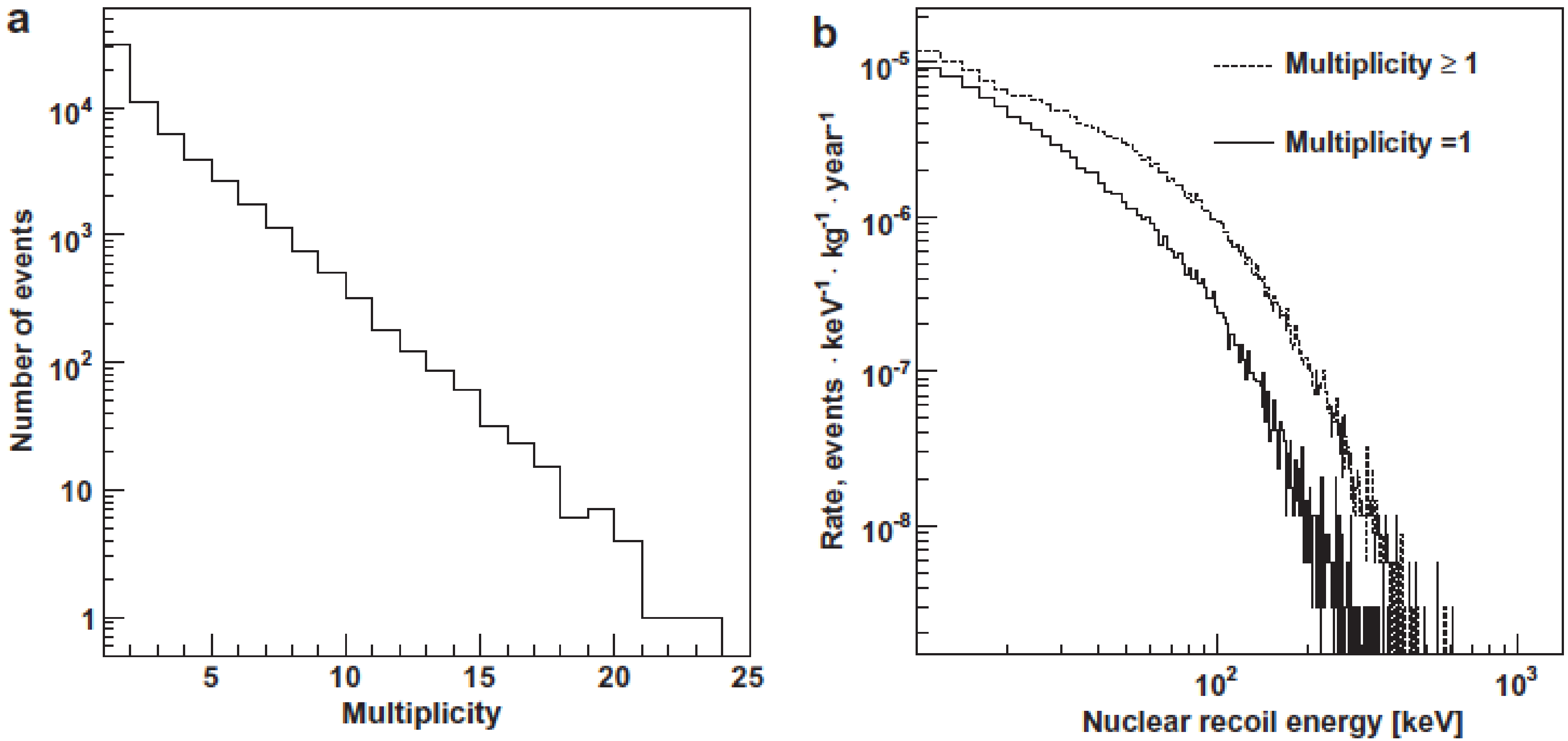
Swimming pool

Submarine



- Assume 1 ppb U/Th in steel in equilibrium.
- 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.

Single vs multiple hit events

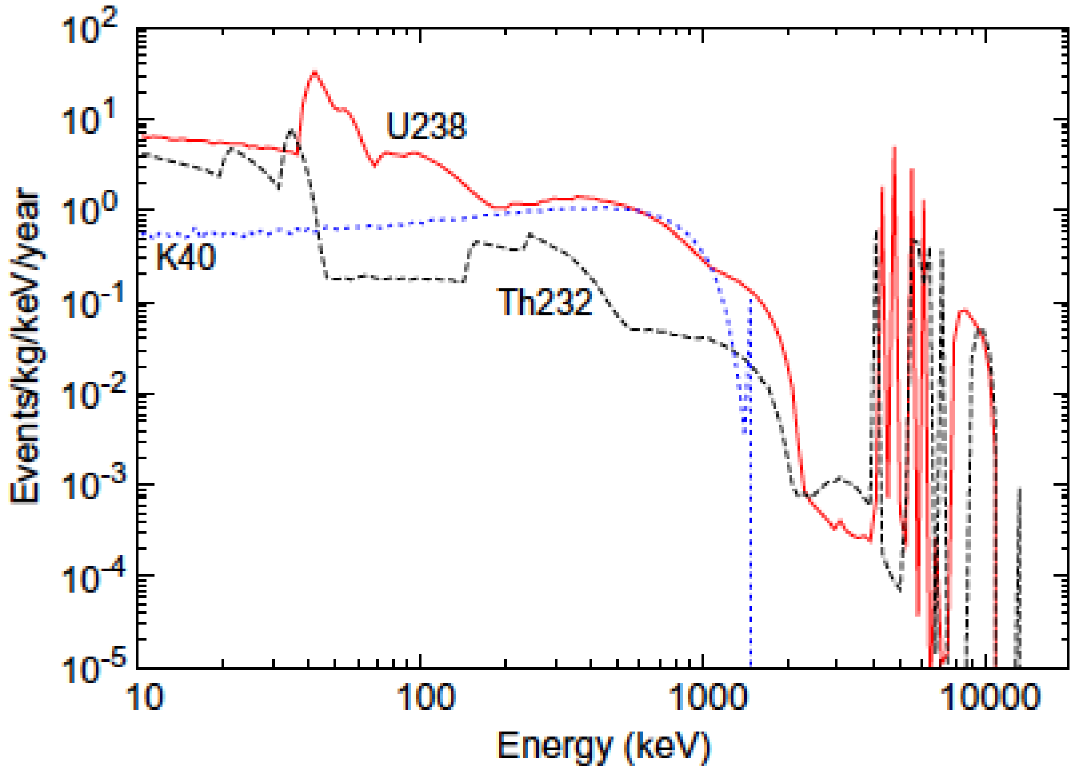


- Nuclear recoils from copper of the cryostat in 100 kg Ge; E > 10 keV.
- 30-40% of events can be rejected as multiple hits depending on geometry.
- Similar fraction of gamma-ray induced events can be rejected.

Detector components

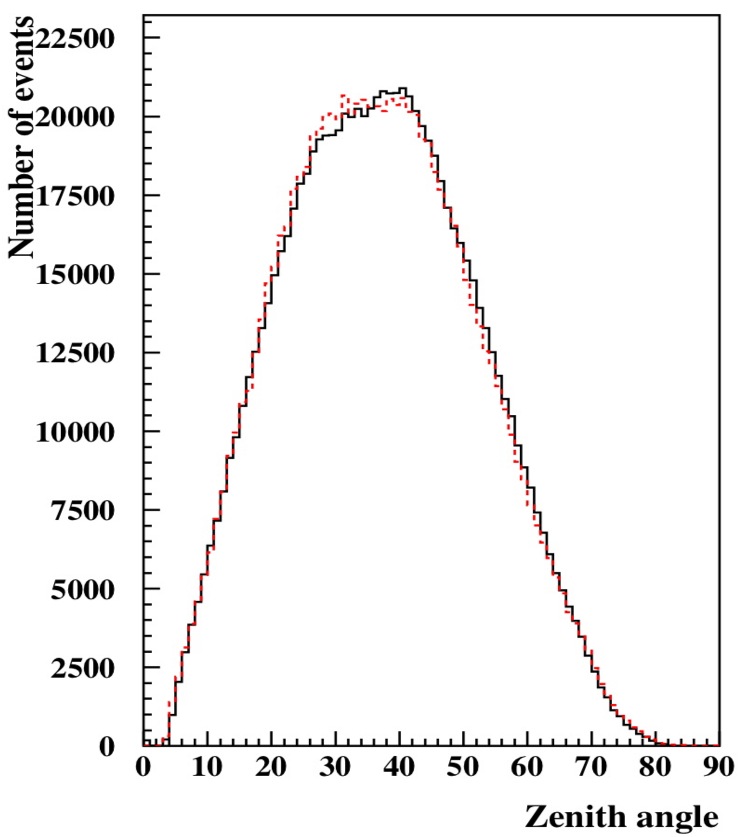
- **Source: 1.6 ppt U, 5.7 ppt Th, 0.01 mBq/kg ^{60}Co in ~3 tonnes of Cu (upper limits from G. Heusser, Talk at LRT 2004; M. Laubenstein et al., Appl. Radiat. Isot. 53 (2004) 167). Event rate per tonne of target (Ge/$CaWO_4$) per year at 10-50 keV: < 10^5 electron recoils, < 1 nuclear recoil.**
- **Source: 1 ppb U/Th in 100 kg of stainless steel close to the target. Event rate per tonne of target per year at 10-50 keV: ~4×10^5 electron recoils, ~3 nuclear recoils.**
- **No more than 20-30 kg of materials with ~1 ppb concentrations of U/Th.**

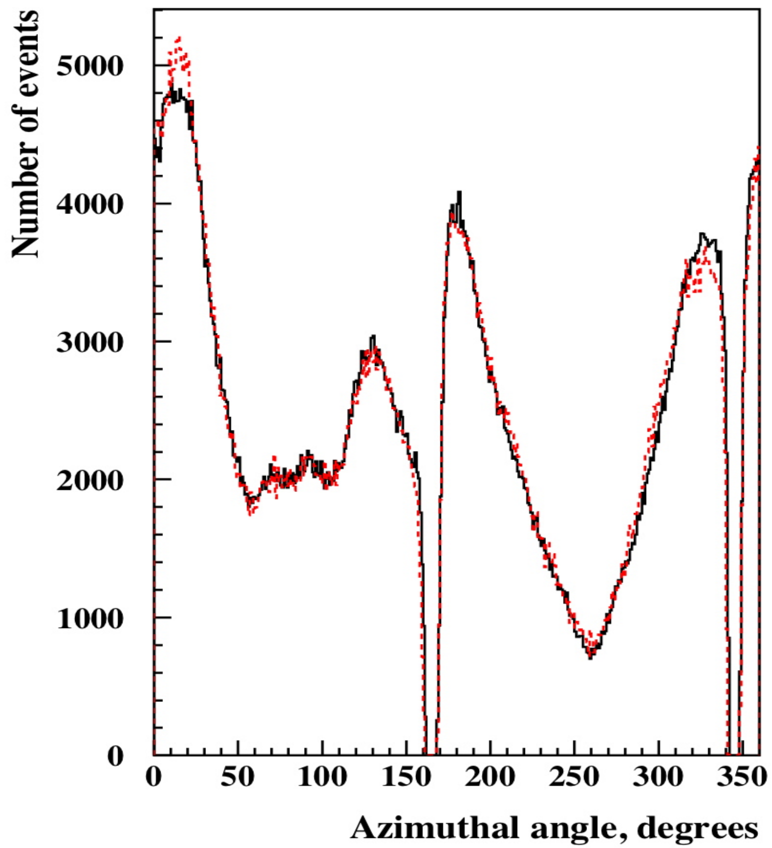
Intrinsic contamination



- **1 ppt U/Th in equilibrium, 1 ppb K; single hits.**
- **With 1 tonne target and 10^{-5} discrimination factor, the concentrations of < 0.1 ppt U/Th and < 1 ppb K are required.**

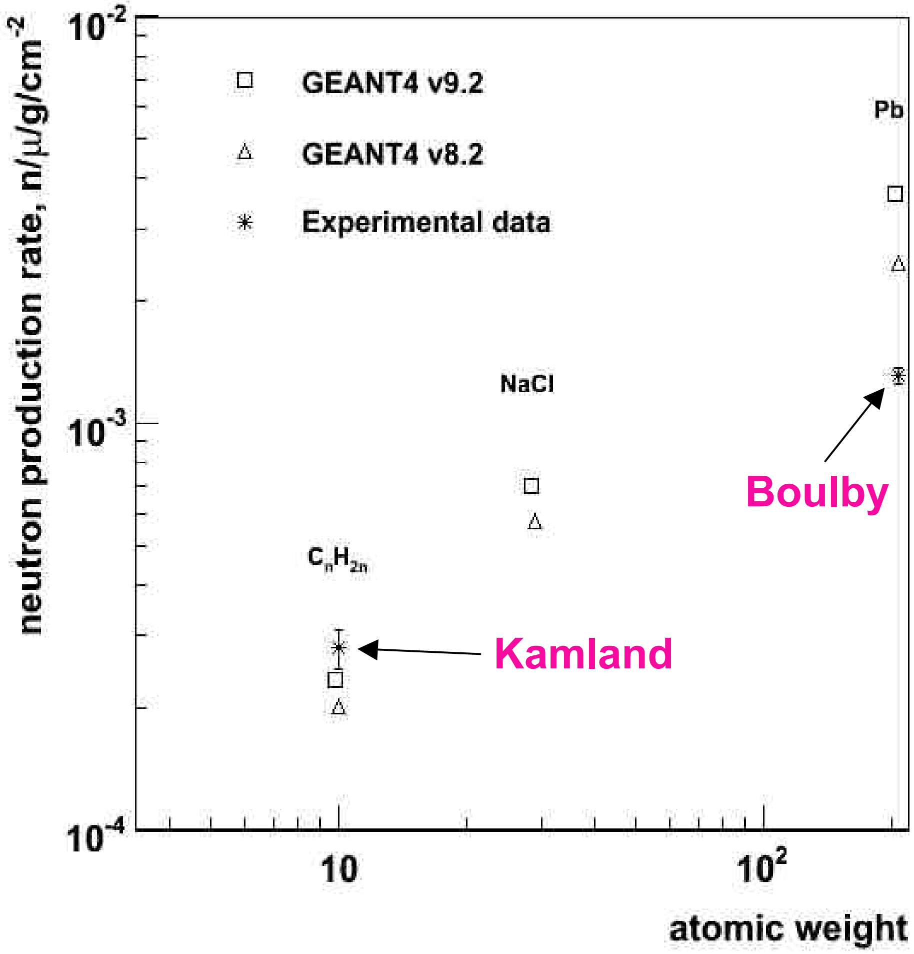
Muon generator - MUSUN





- **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.**

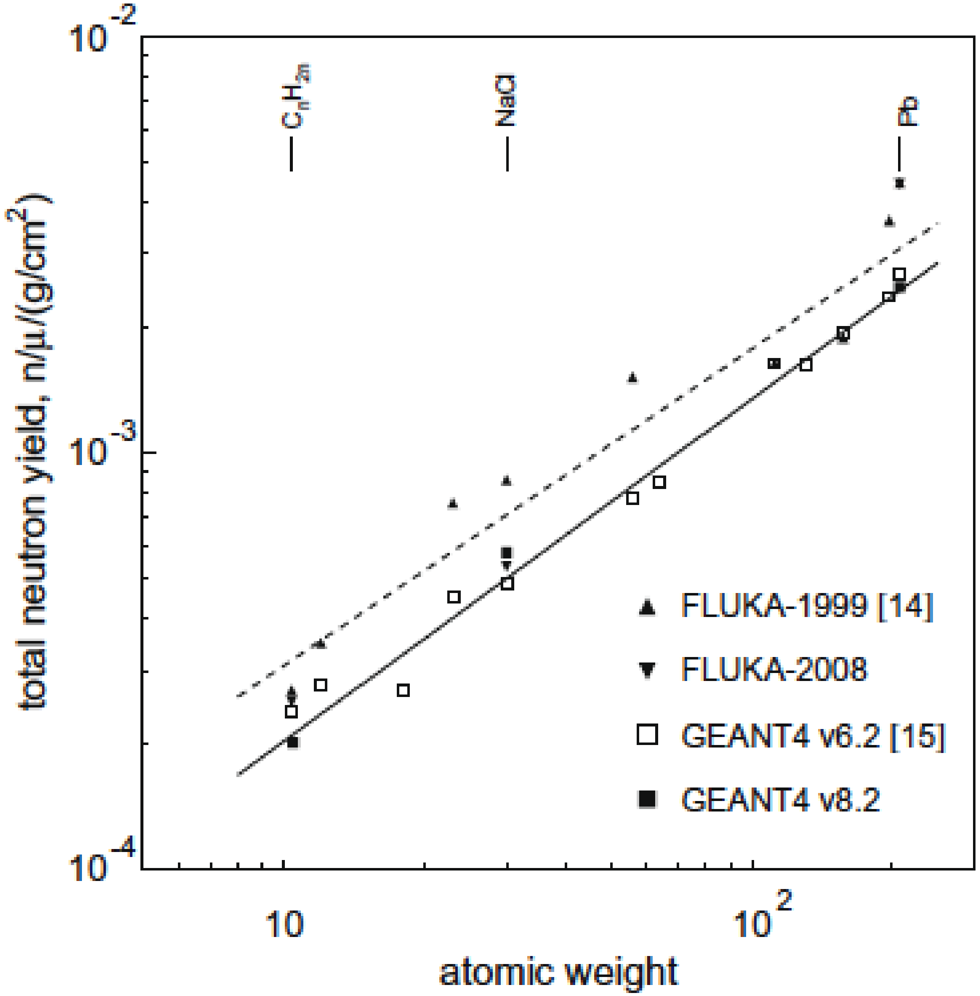
Neutron yield in different materials



Tomasello, PhD Thesis, Univ. of Sheffield (2009).

- Only two recent measurements with fully modelled setups are shown (~280 GeV muons). Slightly higher rate in CH_2 and lower rate in Pb were observed compared to simulations.
- Neutron capture rate is converted into the neutron yield - requires certain assumptions about neutron spectra, transport etc, taken from MC. Direct comparison between data and MC is crucial.
- Different versions and different models give different results. Various models were checked by M. Bauer (talk at IDM04) and others: <30% difference.

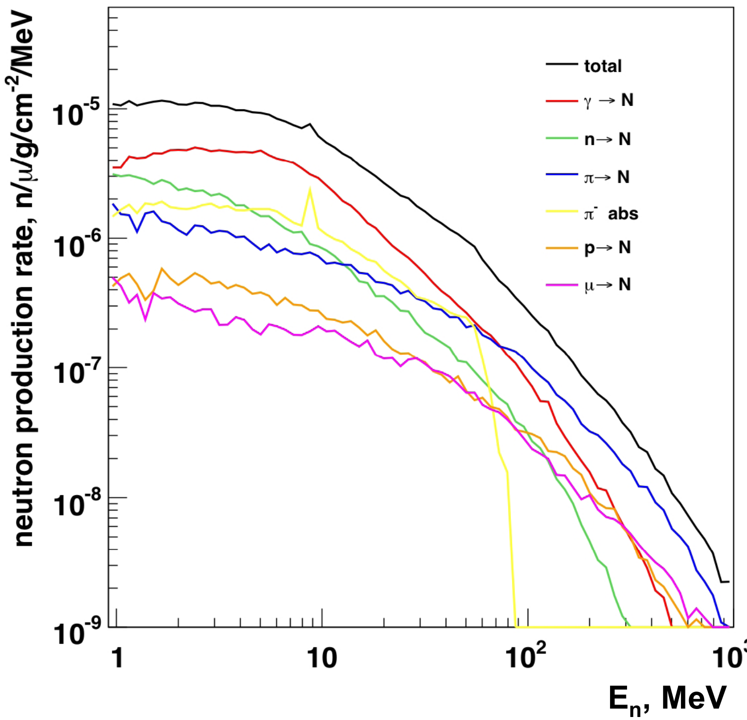
Neutron yield in different materials

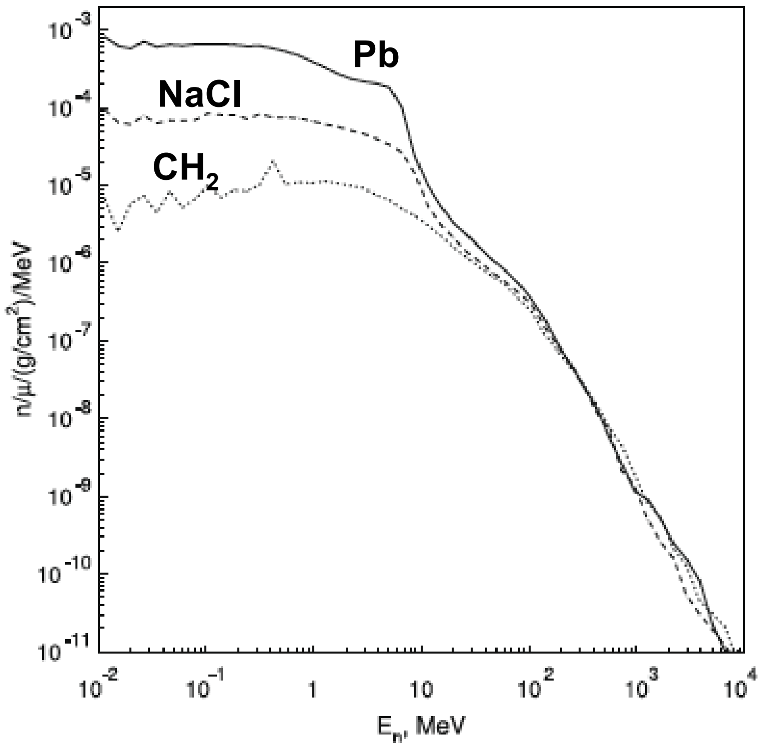


A. Lindote et al. Astropart. Phys., 31 (2009) 366.

- 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.

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.

Angular dependence

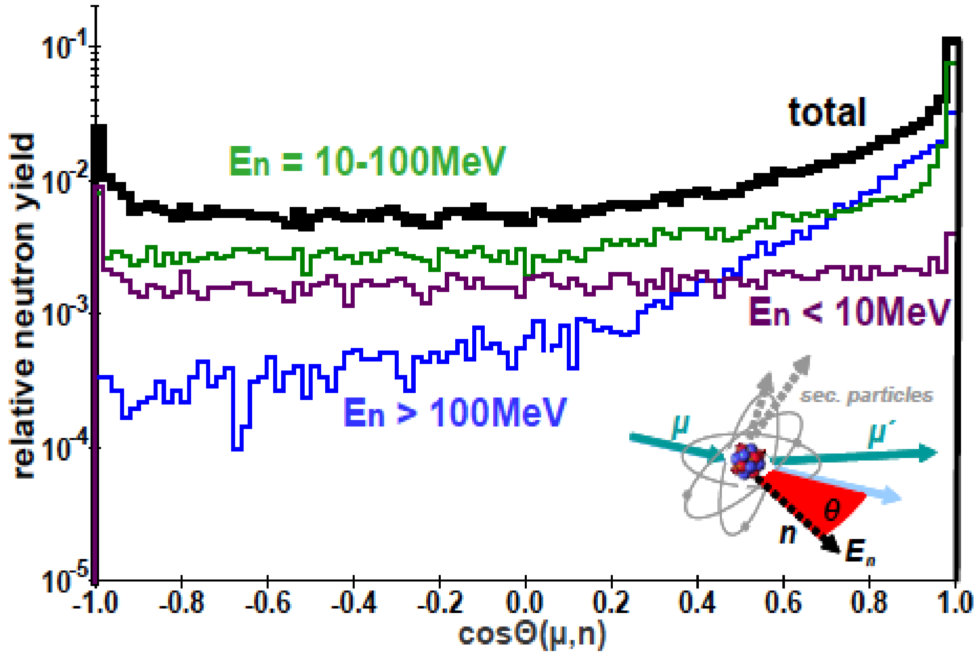


Figure 3.9: Angular distribution relative to the total neutron yield of neutrons produced in muon nuclear reactions with *Geant4* `8.2.p01`. For all neutron kinetic energies (black) or the respective kinetic energy ranges, $E_n > 100\ MeV$ (blue), $10\ MeV < E_n < 100\ MeV$ (green) and $E_n < 10\ MeV$ (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: LXe (2005)

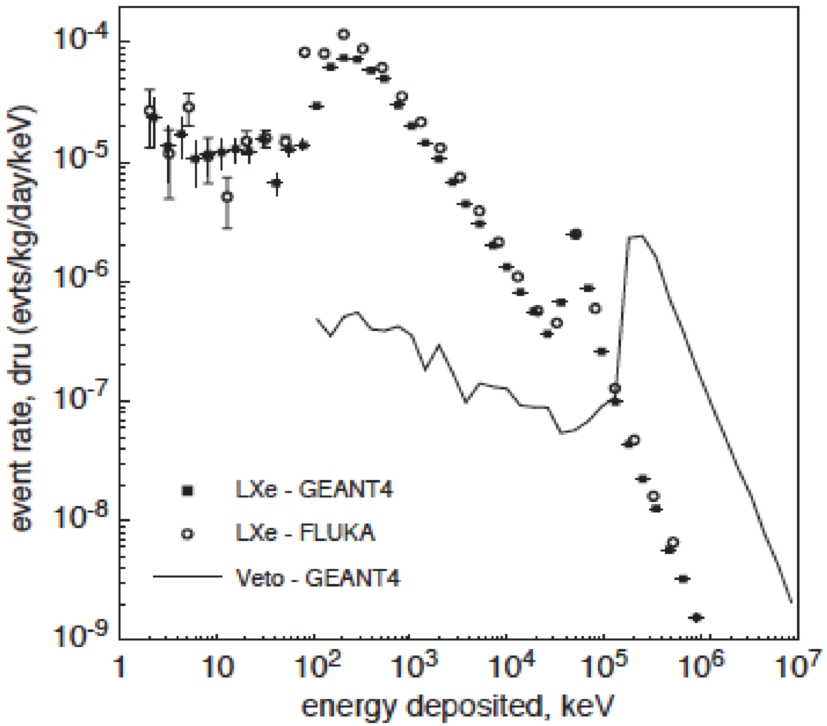


Fig. 11. Differential spectra of the total energy deposited in the liquid xenon (LXe) target as predicted by GEANT4 and FLUKA and in the veto scintillator according to GEANT4 (the latter is scaled down by a factor of 5×10^4).

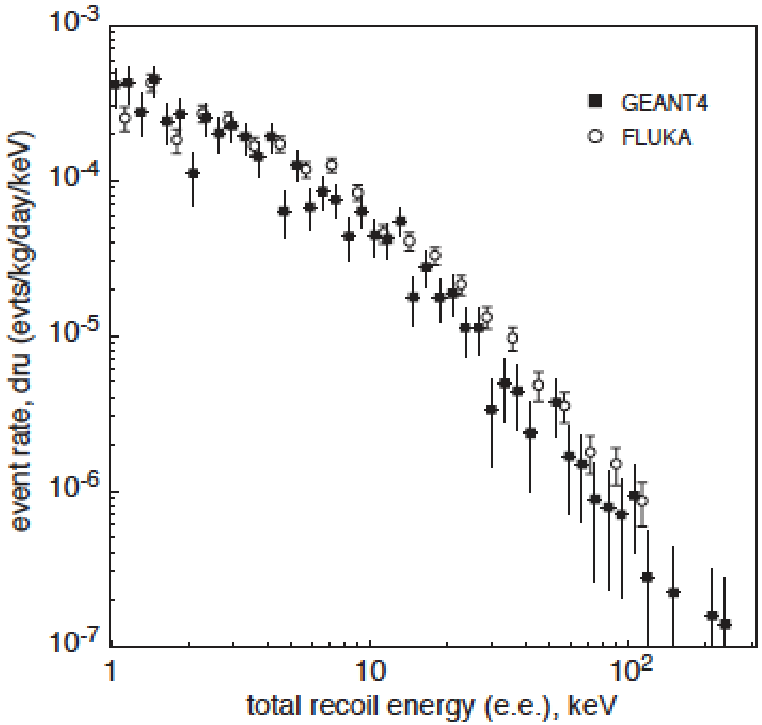
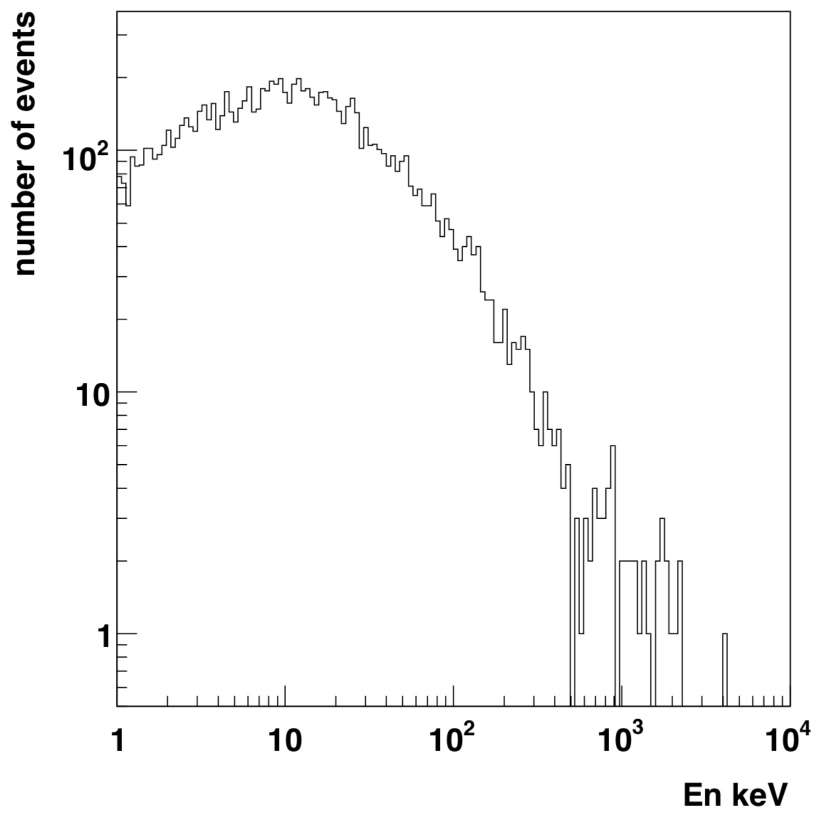


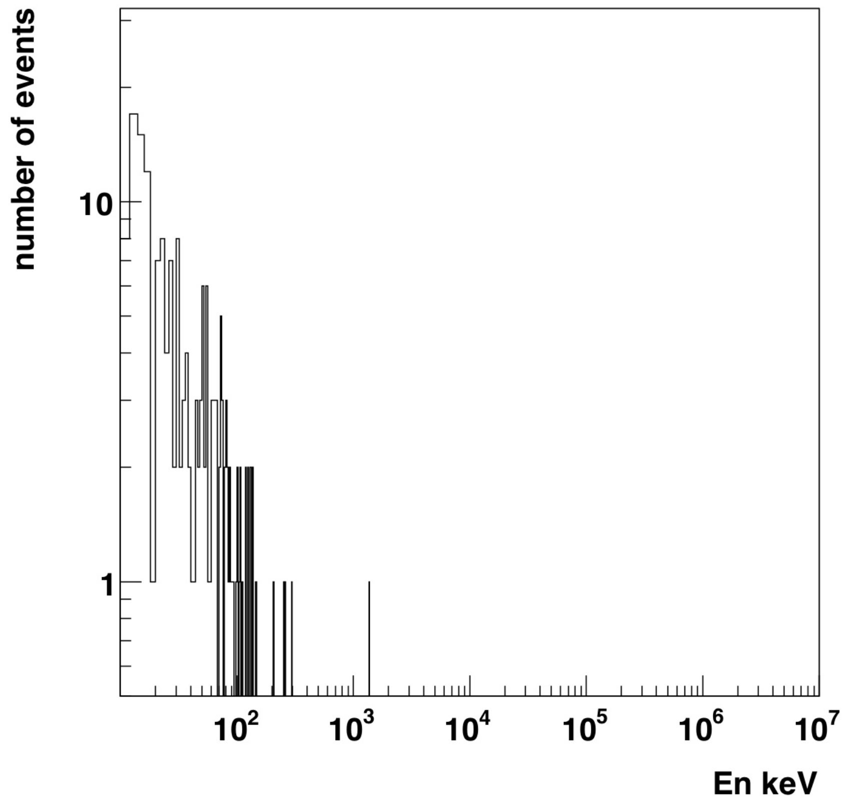
Fig. 12. NR energy spectrum in the liquid xenon detector as a function of the visible energy deposited by all nuclear recoils in each event. The spectra include 'mixed' events involving electromagnetic energy deposits, not just 'pure' nuclear recoils, but only the energy left by NRs was counted.

Araújo et al. NIMA 545 (2005) 398. Boulby lab, 250 kg of xenon, shielding - 30 cm Pb (ext), 40 g/cm^2 CH_2 (int); only 2-3 single recoils per year at 10-50 keVnr (w/o veto); < 1 per year with veto. (Nuclear recoil quenching = 0.2.)

Muon-induced neutrons: Ge target



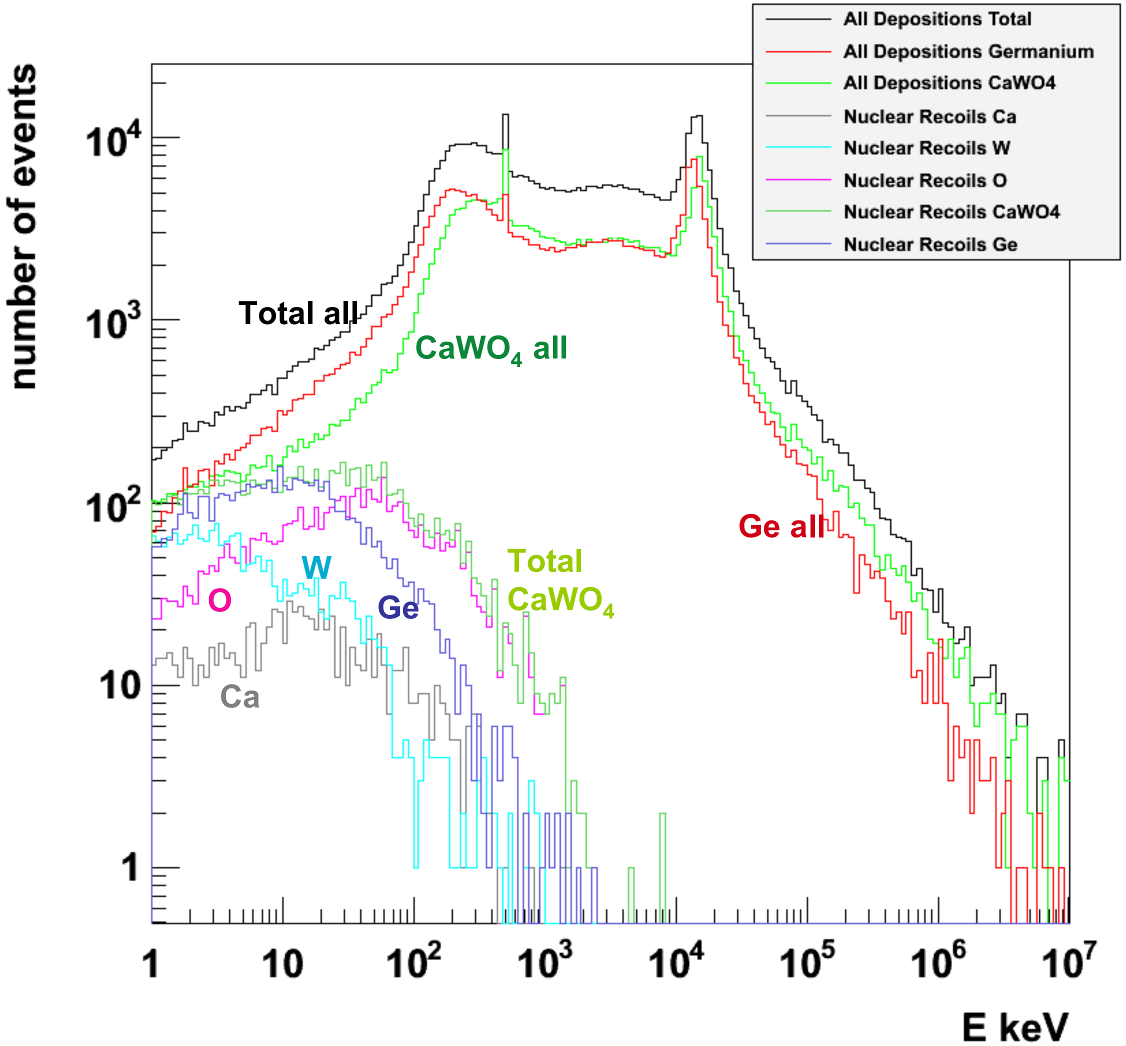
Spectrum of nuclear recoils in Ge - all multiplicities. Other energy depositions are assumed to be not seen. 3.7 years' statistics.



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

- **LSM - 3 m water shielding around the cryostats.**
- **Only single nuclear recoils (without any other energy deposition): 1.6±0.5 events/year at E > 10 keV keV in 1 t (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 (discrimination $\sim 10^{-5}$):
  - 20-25 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.
- Ultra-pure copper (< 10 ppt U/Th) is OK as a material for detector vessels/cryostats. Materials with concentrations ~ 1 ppb should not be present in large quantities (<20-30 kg).
- Still an uncertainty of $\times 2$ in measured and simulated neutron production rate by muons, 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.
- Optimistic results for muon-induced neutrons (with uncertainty about $\times 2$).
  - 1.6 ± 0.5 events/year/tonne - single recoils above 10 keV in EURECA at LSM. No event survives a veto cut (E > 0.2 GeV) in 11.1 years of simulated statistics.
  - Shielding configuration is important.