Simulations and other stuff

Vitaly A. Kudryavtsev

University of Sheffield

Contributions from many others

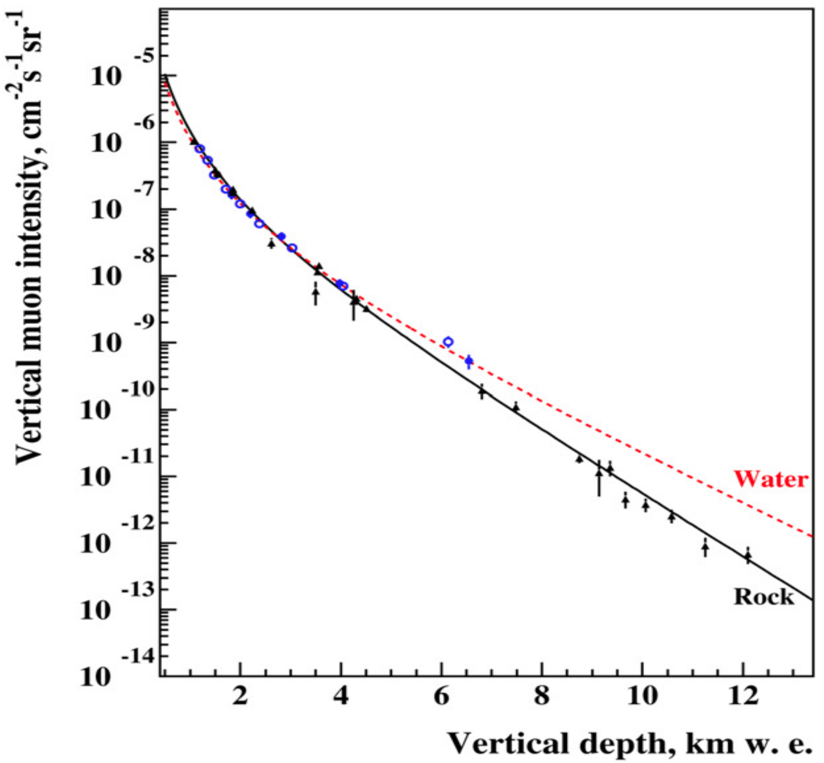
Outline

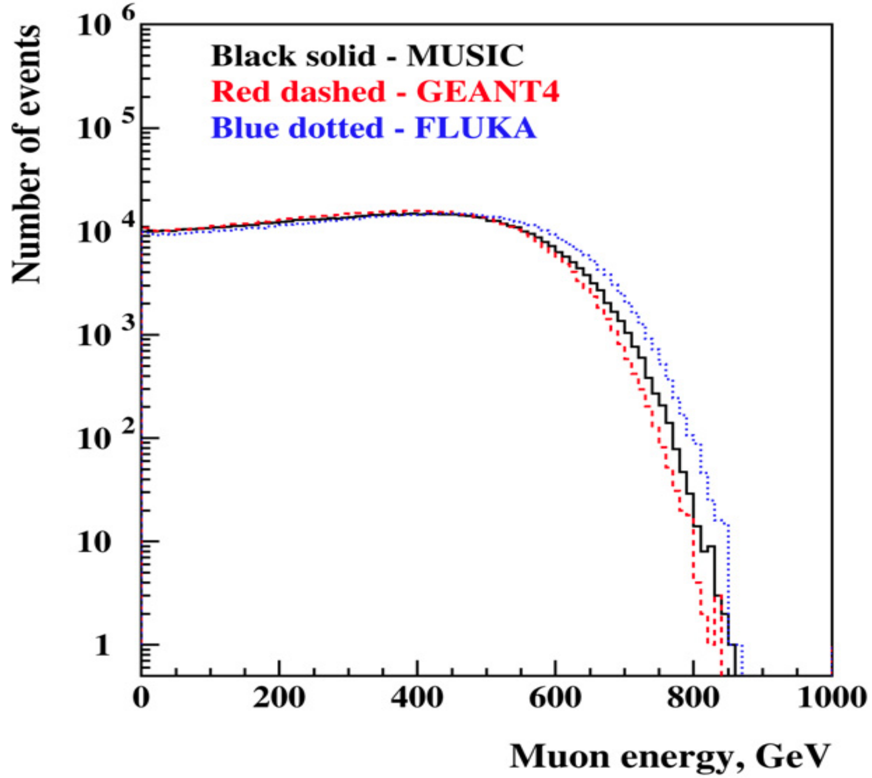
- Muon generators: MUSIC, MUSUN.
- Neutrons from muons.
- Neutrons from radioactivity.
- Some notes for simulators.
- European coordination.

MUSIC/MUSUN

- MUSIC is a MUon SImulation Code - code 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.

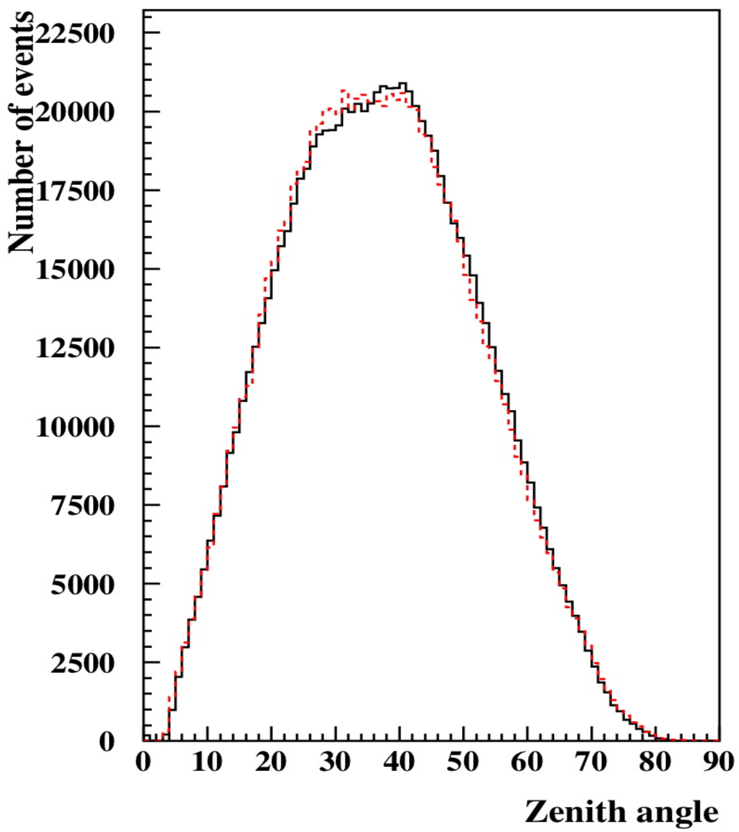
MUSIC results

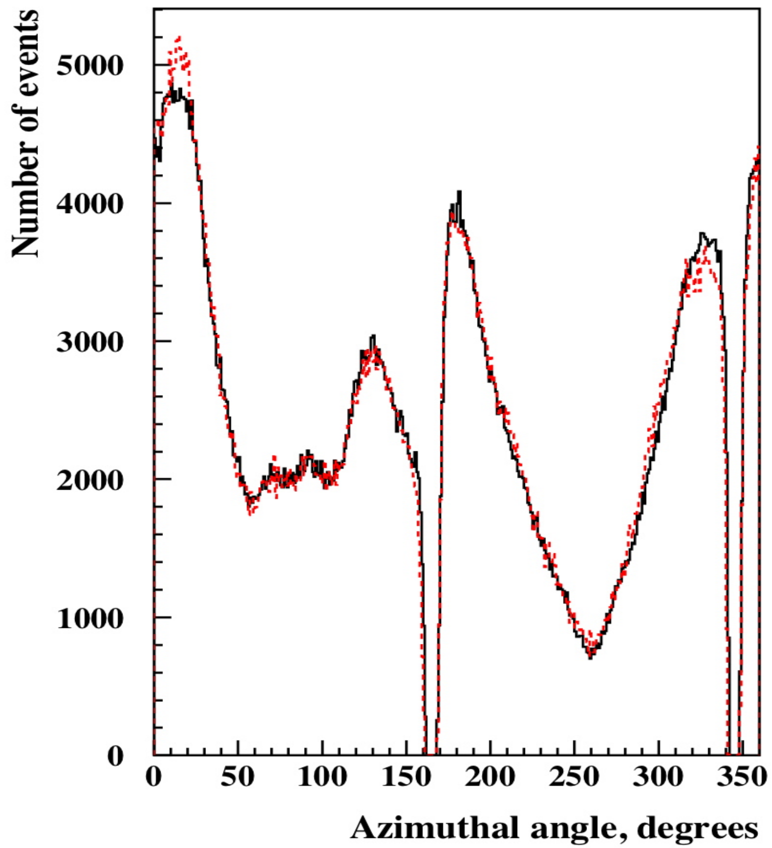




- **Left: Vertical muon intensity as a function of depth in standard rock and water in comparison with data (see also other references in CPC (2009)).**
- **Right: Energy distribution of muons with initial energy of 2 TeV transported through 3 km of water.**
- **See also Tang et al. Phys. Rev. D 74,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

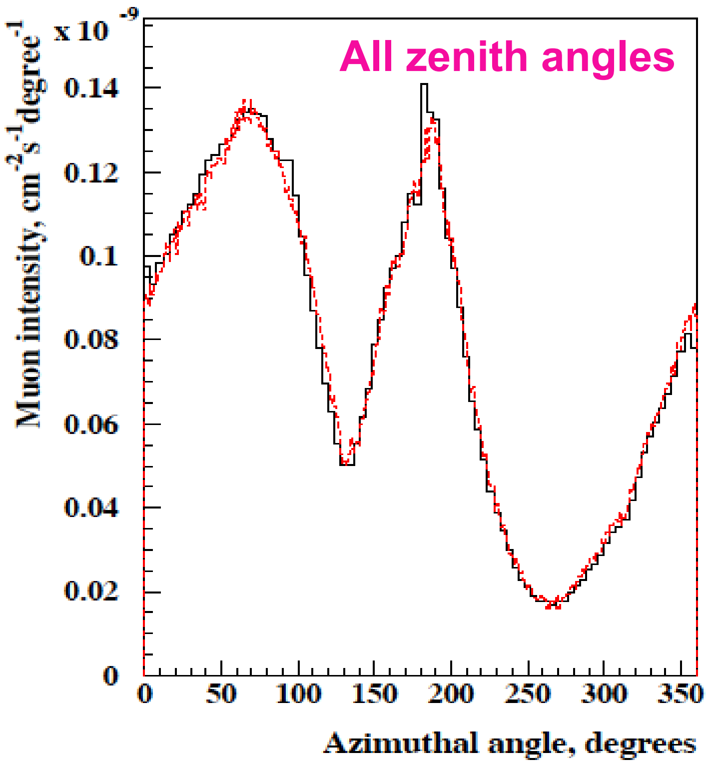
Muon generator - MUSIC/MUSUN (LSM)

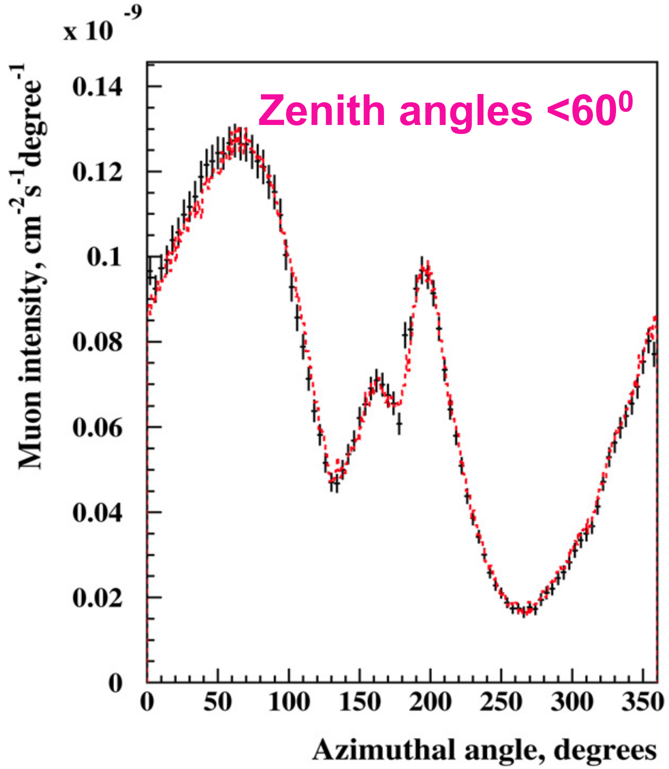




- Zenith and azimuth angular distributions of muons from MUSUN (black) at LSM compared with data from the Frejus proton decay experiment (red).
- MUSIC and MUSUN, V. Kudryavtsev, Comp. Phys. Comm. 180 (2009) 339.

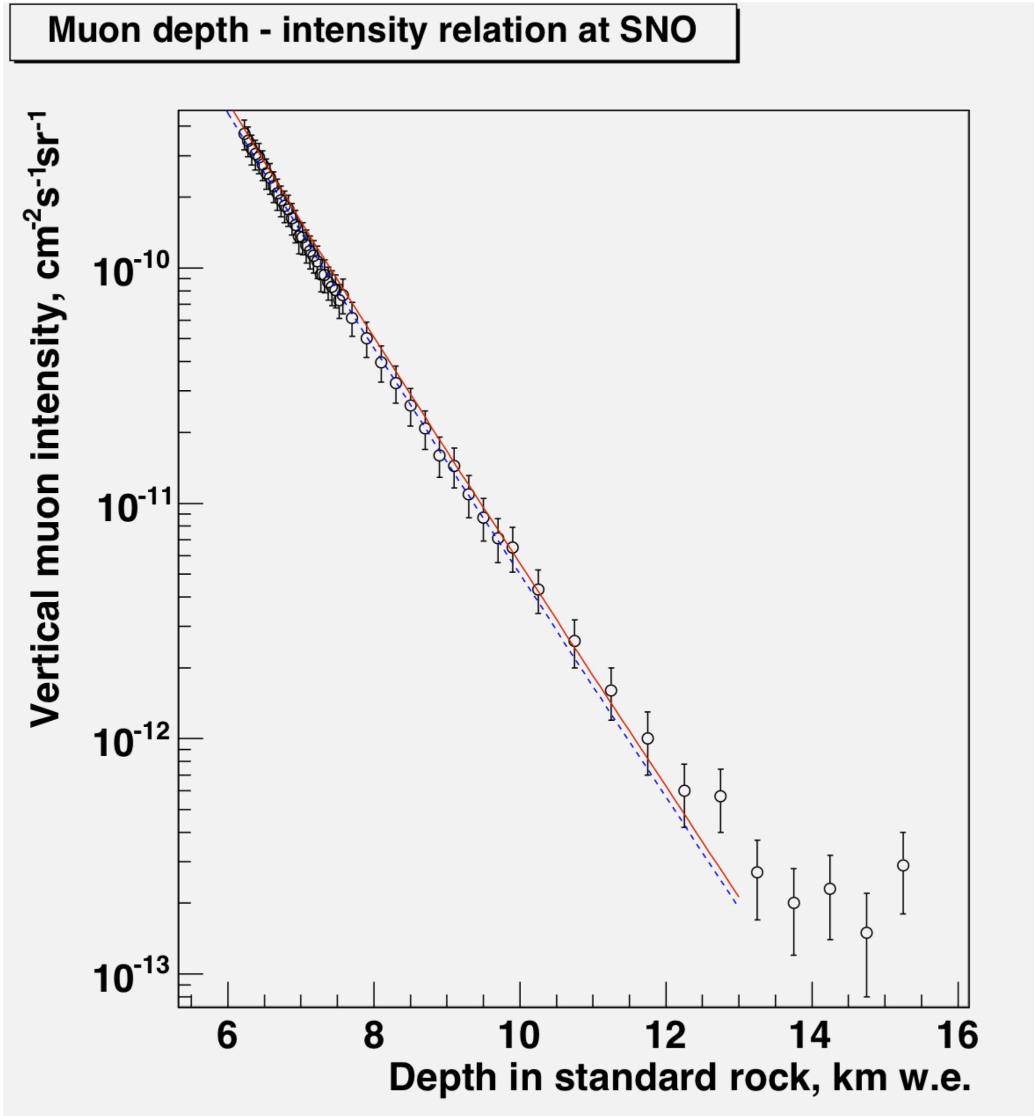
MUSIC/MUSUN for LNGS





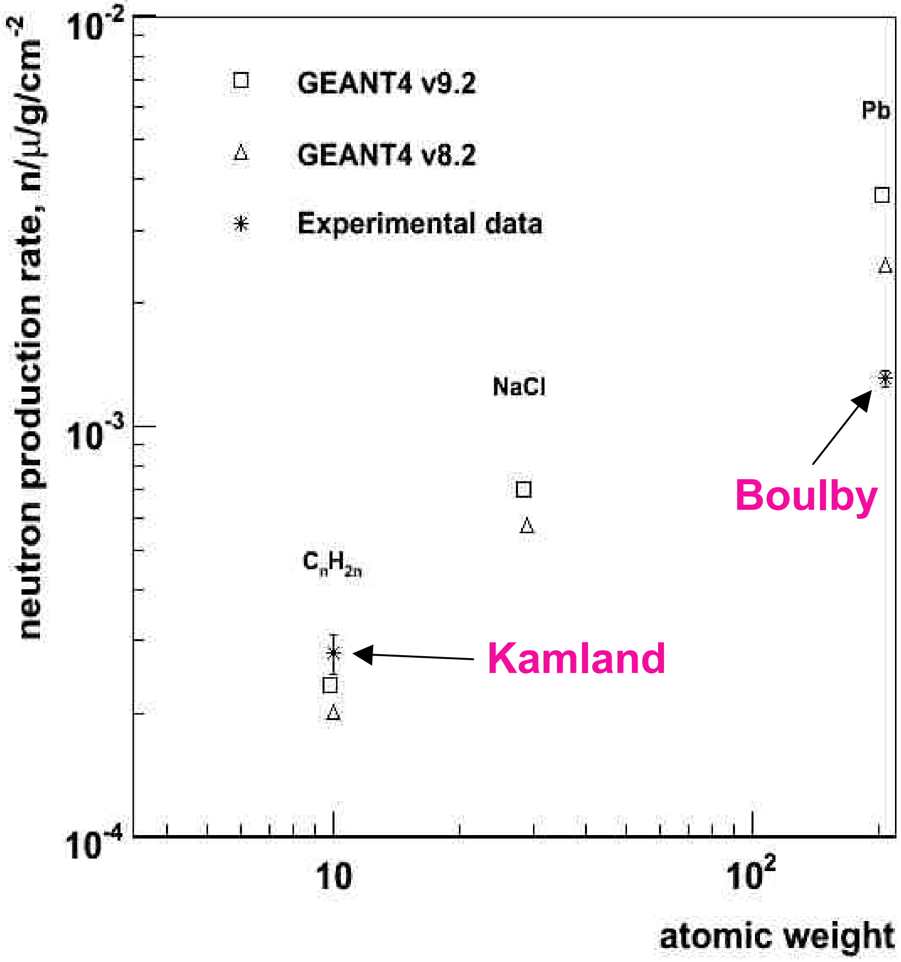
- Angular distribution of muons at LNGS as generated by MUSUN in comparison with the single muon data from LVD. From Kudryavtsev et al., Eur. Phys. J. A 36, 171 (2008); Comp. Phys. Commun. 180 (2009) 339.
- Normalisation: total muon flux 1.17 m^{-2} $hour^{-1}$ (sphere with 1 m^2) - slightly higher than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

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.

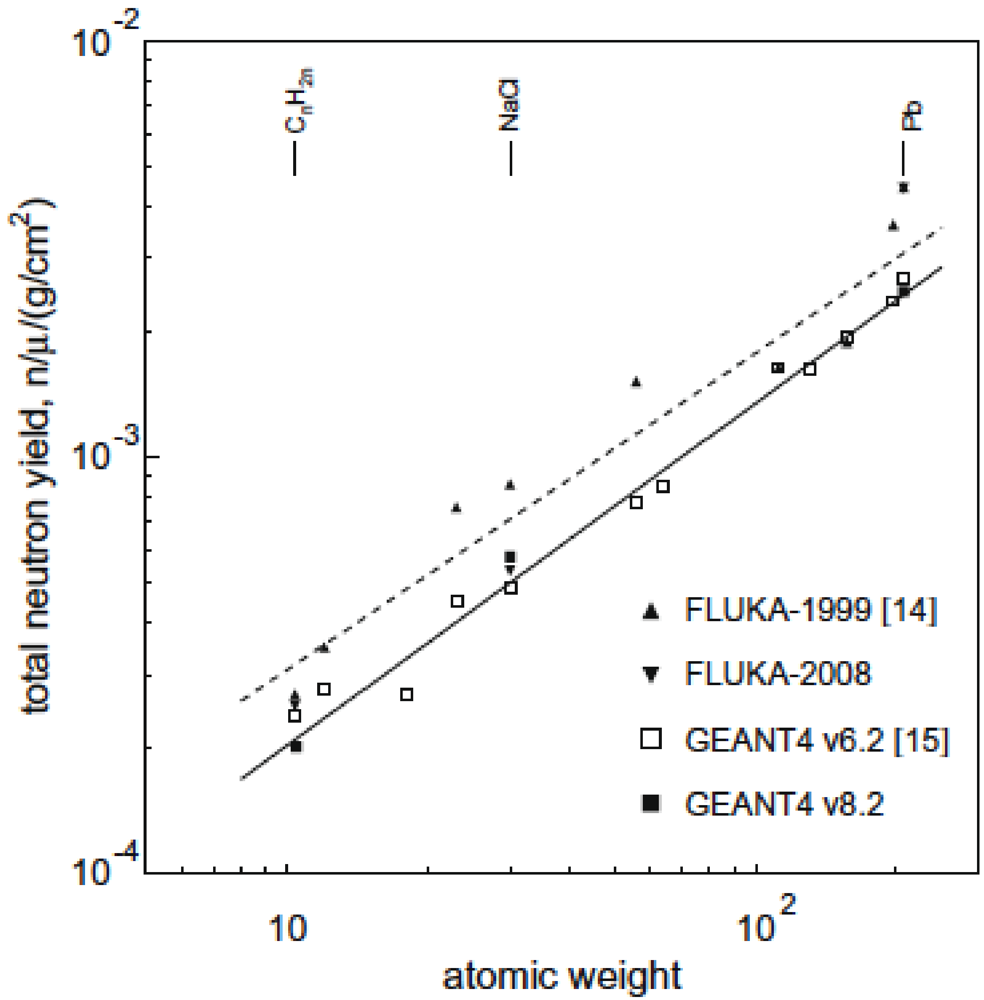
Neutron yield in different materials



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, v6.2), Lindote et al. Astropart. Phys., 31 (2009) 366 (v6.2, 8.2), 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, sometimes 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.

GEANT4 physics for muon-induced neutrons

```
// *** ELECTROMAGNETIC ***
// mu-    -> Nuclear capture process
// *** PHOTONUCLEAR ***
// muons    MuNuclear - 1 GeV < E
// gamma    CHIPS    -              E < 3.5 GeV
//          QGSC     -  3 GeV < E < 100 TeV
// e+/-     CHIPS    -              E < 10 TeV
// *** HADRONICS ***
//  : HP    for n at       0 keV < E < 19.9 MeV
//  : PreCo for n at  19.5 MeV < E < 70   MeV
//  : BiC   for n at     65 MeV < E < 6.1  GeV
//  : QGSP  for n at      6 GeV < E < 100  TeV
//
//  : PreCo for p at       0 keV < E < 70   MeV
//  : BiC   for p at     65 MeV < E < 6.1  GeV
//  : QGSP  for p at      6 GeV < E < 100  TeV
//
//  : BiC   for pi at      0 keV < E < 1.5  GeV
//  : LEP   for pi at    1.4 GeV < E < 6.1 GeV
//  : QGSP  for pi at      6 GeV < E < 100  TeV
//
// kaon     LEP      -              E < 25 GeV
//          QGSP     - 25 GeV < E < 100 TeV
//
// a,H2,H3  LEP      -              E < 100 MeV
//          BiC      - 80 MeV < E < 20 GeV
//
// GI,He3   BiC      -              E < 10 GeV
//
// others   LEP      -              E < 25 GeV
//          QGSP     - 25 GeV < E < 100 TeV
```

- **Left: physics for GEANT6.2 from Araujo et al. NIMA 545 (2005) 398.**
- **Right: physics for GEANT8.2 from Lindote et al. Astropart. Phys. 31 (2009) 366.**
- **3 models tested and compared to experimental data.**
- **Taken from Lindote et al. Talk at 12th GEANT4 Workshop.**

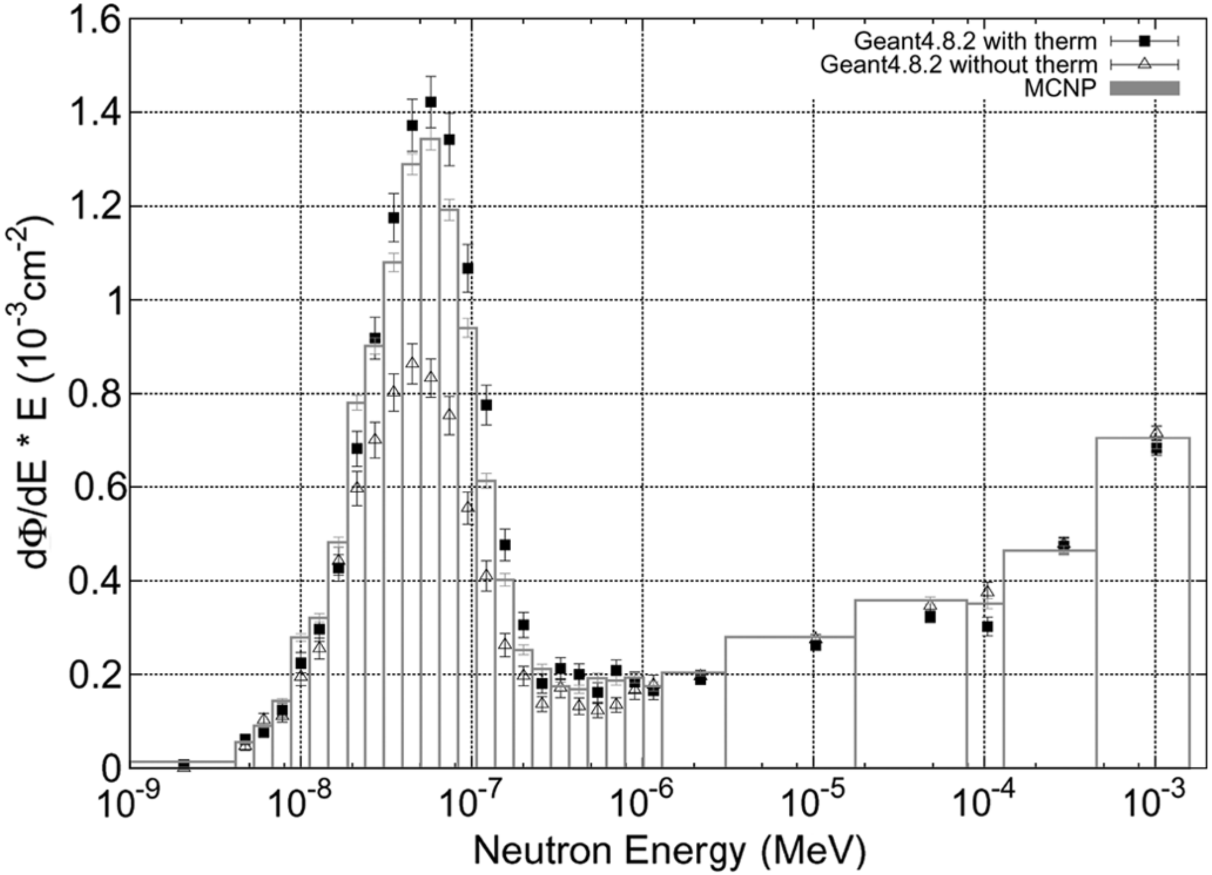
```
// *** ELECTROMAGNETIC ***
// mu-    -> G4QCaptureAtRest
// *** PHOTONUCLEAR ***
// muons    MuNuclear - (1 GeV)< E
// gamma    CHIPS    -              E < 3.5 GeV
//          QGSC     -  3 GeV < E < 100 TeV
// e+/-     CHIPS    -              E < 10 TeV
// *** HADRONICS ***
//  : HP    for n at     0 keV < E < 19.9 MeV
//  : BiC   for n at  19.5 MeV < E < 6.1  GeV
//  : LEP   for n at     6 GeV < E < 12.1 GeV
//  : QGSP  for n at    12 GeV < E < 100  TeV

//  : BiC   for p at     0 MeV < E < 6.1  GeV
//  : LEP   for p at     6 GeV < E < 12.1 GeV
//  : QGSP  for p at    12 GeV < E < 100  TeV

//  : BiC   for pi at    0 keV < E < 1.5  GeV
//  : LEP   for pi at 1.4 GeV < E < 12.1 GeV
//  : QGSP  for pi at   12 GeV < E < 100  TeV

// kaon     LEP      -              E < 25 GeV
//          QGSP     - 25 GeV < E < 100 TeV
//
// a,H2,H3  LEP      -              E < 100 MeV
//          BiC      - 80 MeV < E < 20 GeV
//
// GI,He3   BiC      -              E < 10 GeV
//
// others   LEP      -              E < 25 GeV
//          QGSP     - 25 GeV < E < 100 TeV
```

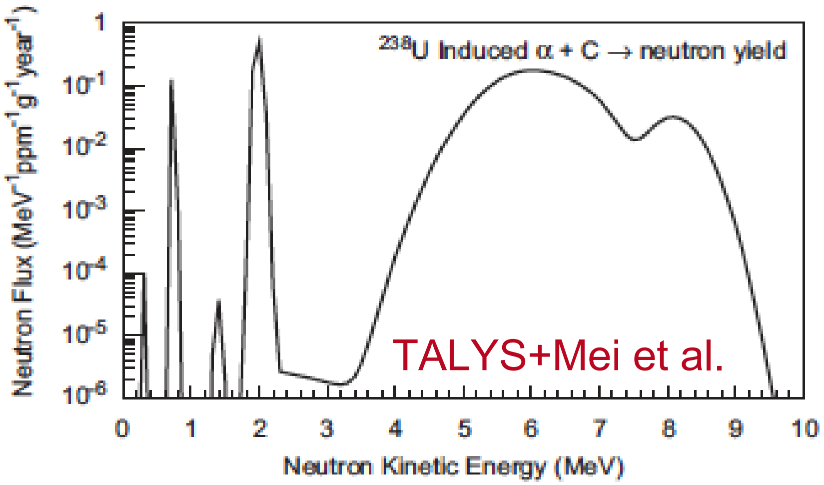
Some new (?) 'discoveries'

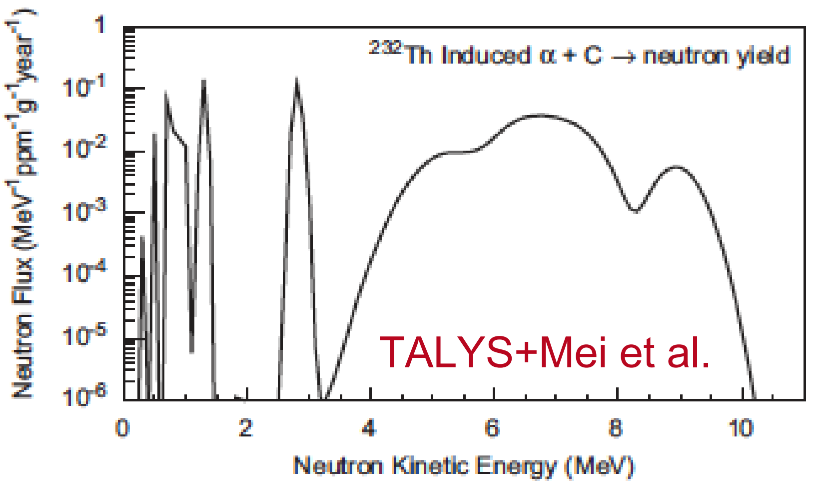


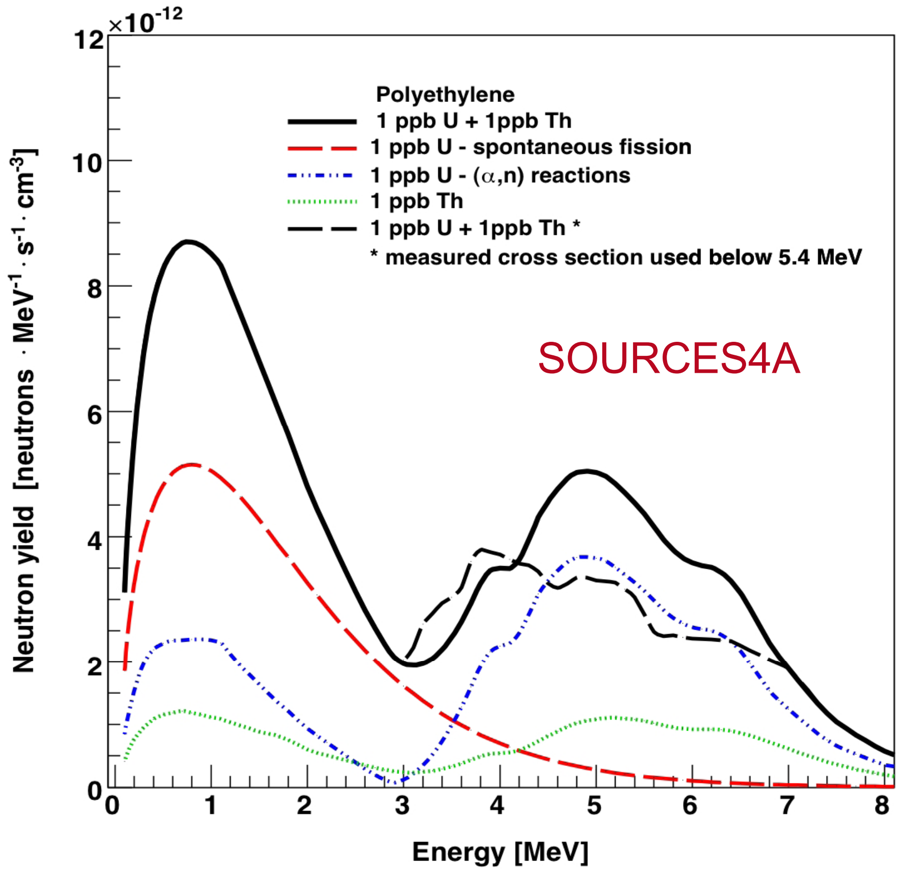
S. Garny et al. IEEE Transactions on Nuclear Science, 56 (2009) 2392; credits to S. Semikh (JINR, Dubna).

- 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 detection.
- Anything else we need to know?

Neutrons from radioactivity

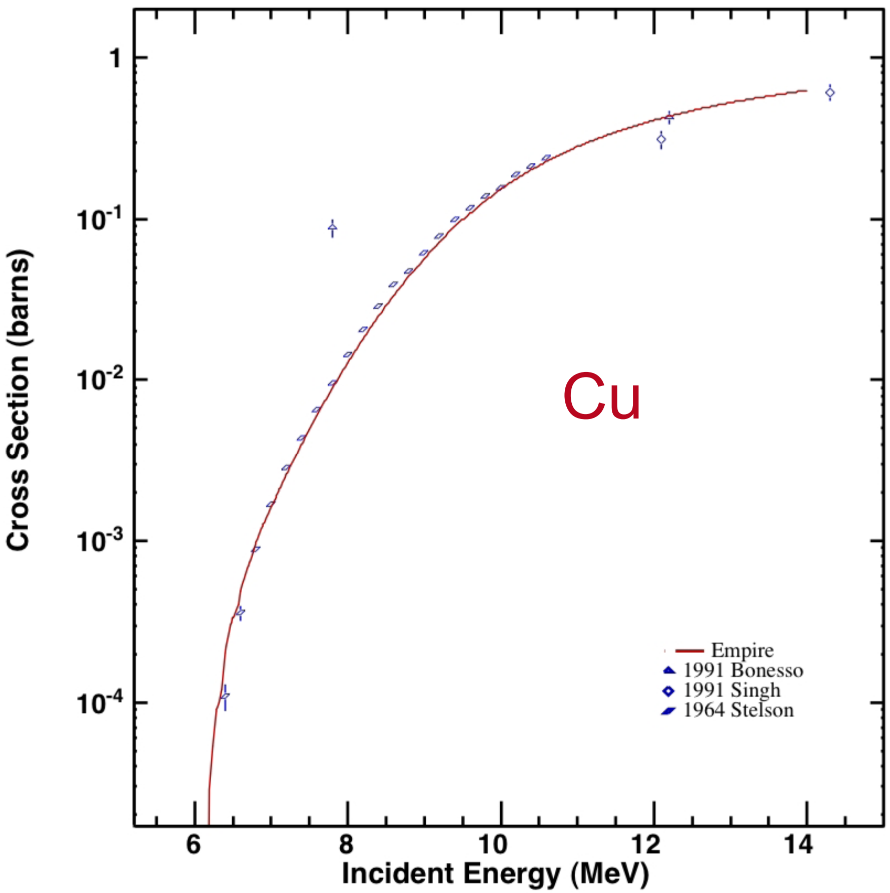


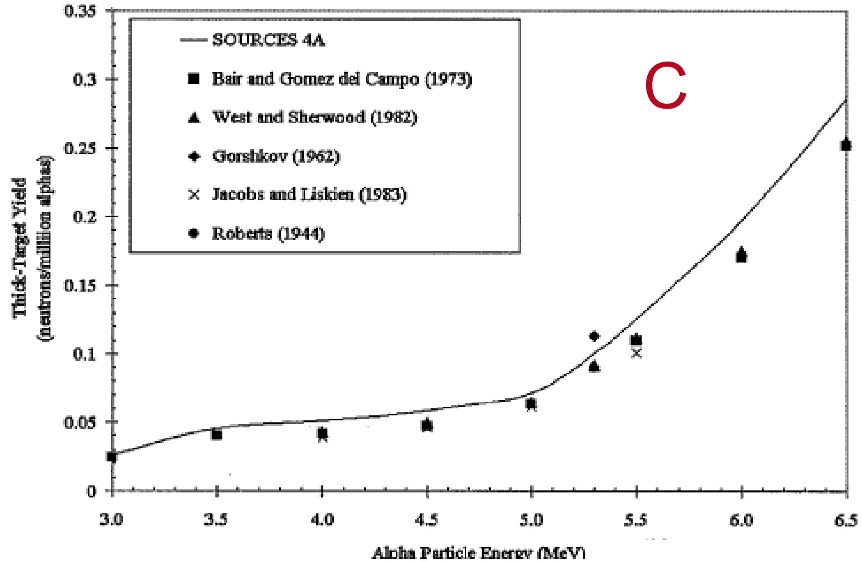


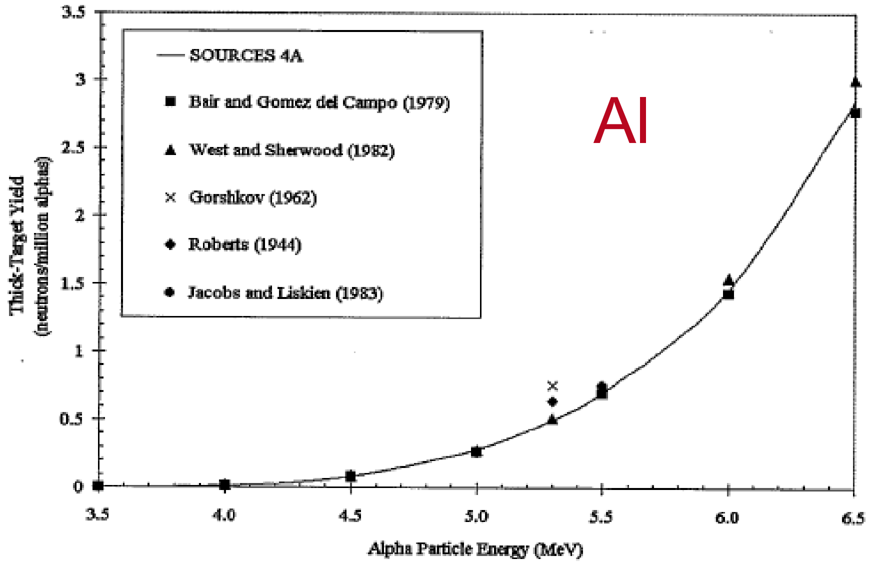


- **TALYS + Mei et al. NIMA 606 (2009), 651 : 9.7×10^{-12} (U), 2.8×10^{-12} (Th) cm^{-3} s^{-1} ppb^{-1} (polyethylene).**
- **EMPIRE-2.19 + modified SOURCES4A: 1.44×10^{-11} (U), 5.8×10^{-12} (Th) cm^{-3} s^{-1} ppb^{-1}.**

Validation of EMPIRE and SOURCES

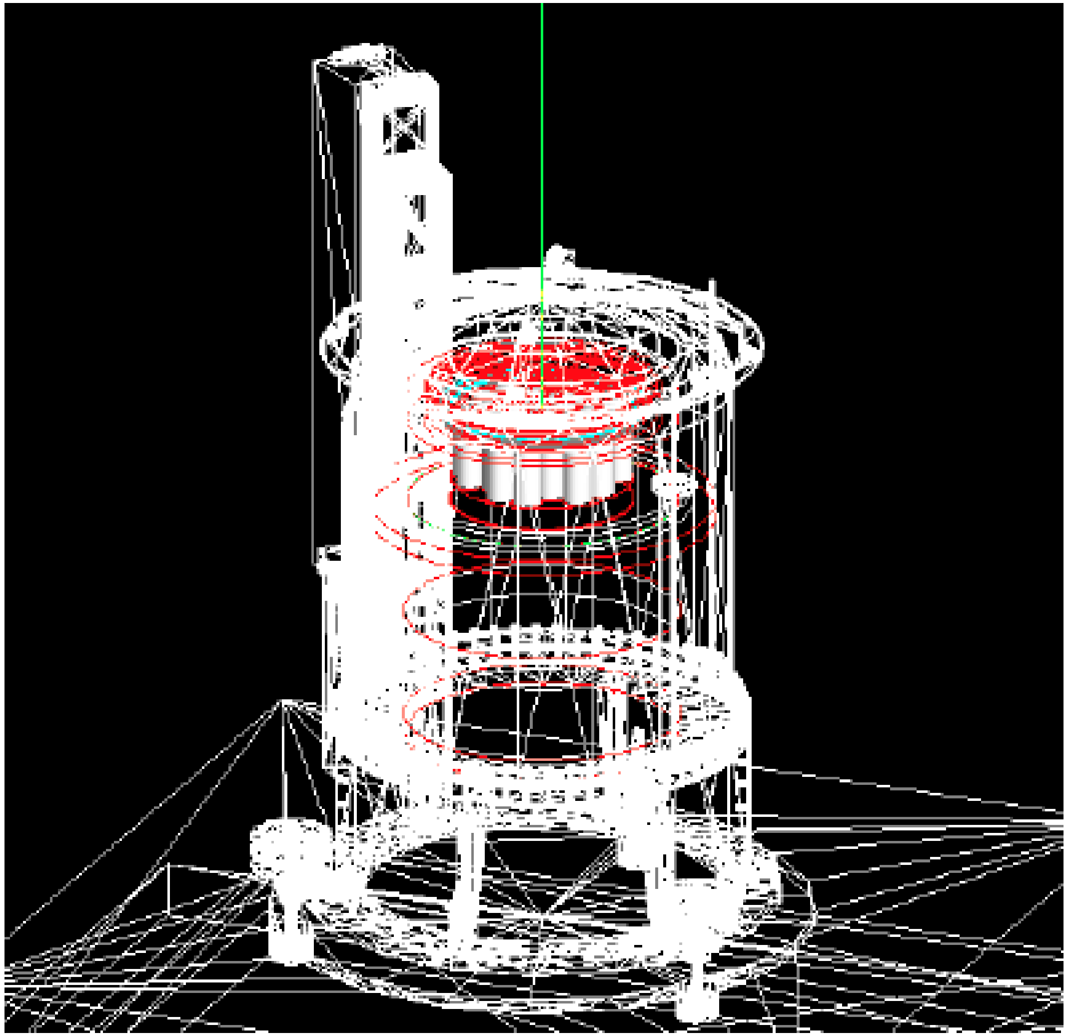






(α,n) cross-section on Cu and thick-target neutron yields in C and Al.

Geometry



- From the talk by H. Araujo at LRT2010.
- ZEPLIN-III model in GEANT4 converted from CAD using FASTRAD.
- Too many details -> severe penalty in CPU time (a factor of 2-5); overlapping volumes.
- Too big volume (cavern) -> big CPU time.

European coordination

- **Past: ILIAS - Integrated Large Infrastructures for Underground Science: 2004-2009.**
- **Joint working group for background measurements and simulations: http://www.unizar.es/ilias/JRA1/01.htm; the site at Tuebingen does not work anymore.**
- **ILIAS-Next: 2 proposals submitted to EC in 2008 and 2009, both passed initial thresholds, both were just below the threshold for funded projects and included in the list of projects for possible funding but, unfortunately neither was funded.**
- **Proposals included:**
  - **Database (web-site) for codes, code validation, measurements;**
  - **Web-based forum for people working on simulations in astroparticle physics.**
  - **Closer links with code developers: meetings, coordinated plans.**
- **Try to keep in touch without a formal structure (working group or similar): exchange information, code fragment, knowledge.**
- **Very difficult to do work without funding.**