Low Radioactivity Techniques Workshop V

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Seattle, WA

FLUKA

Predictive Power for Cosmogenic Backgrounds

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March 20, 2015

Atmospheric neutrino detection

Kolar Gold Fields India, 1965

M.G.K. Menon, S. Miyake etal.

East Rand gold mine South Africa, 1965

F. Reines, M.F. Crouch etal.

Solar neutrino detection

Homestake gold mine South Dakota, (suggested 1964) 1968

R. Davis, N. Bahcall

Cosmogenic background prediction

G.T. Zatsepin

Electron-nuclear showers of cosmic rays and cascade process
JETPh, 1949, p.827-850

Depth-intensity curve of nuclear events induced by muons
Proc. Int. Cosmic Rays Conf. (9^{th} ICRC) 1965

paper available online SAO/NASA Astrophysics Data System (ADS)
http://adsabs.harvard.edu/cgi-bin/nph-data_query?bibcode=1965ICRC....2..987R&db_key=AST&link_type=ABSTRACT&high=54d24f1f6d03610

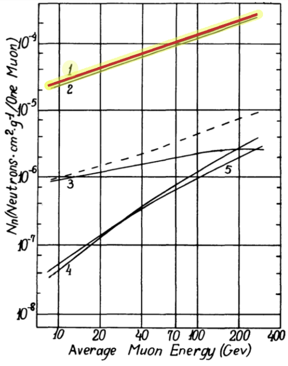


Fig. 1.

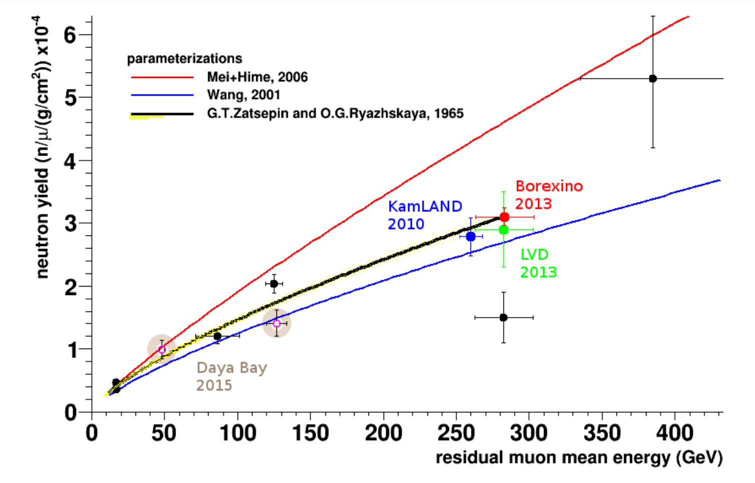
"In particular, our calculations give the generation of ***neutrons*** *underground. Apparently these may be detected by the* ***most simple methods****."*

"Such calculations give the dependence on $\overline{E_\mu}$ to good accuracy, but absolute values are accurate only in the order of magnitude."

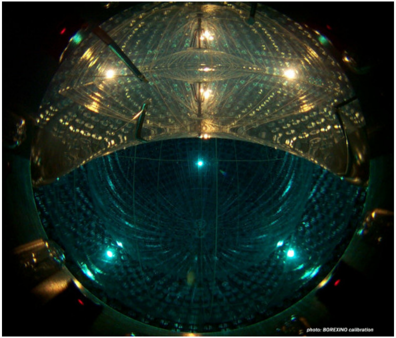
"All calculations in this work were made for $Z/A \approx 0.482$ and $Z^2/A \approx 6.27$"

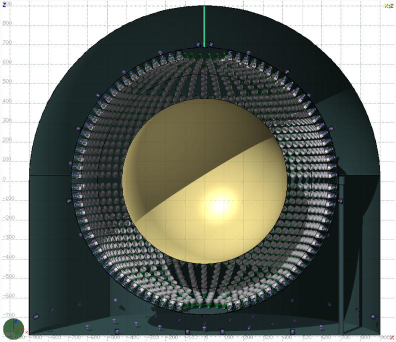
"... it is possible to find ... that at a depth of 1500 mwe the effect of the generation of ^{37}Ar by cosmic rays should be equal to the effect of the production of ^{37}Ar in the reaction $^{37}Cl(\nu, e^-)^{37}Ar$."

"Curve 1 is the number of neutrons produced in all the processes. The number of neutrons produced by one fast muon per gcm^{-2} of the ground increases with $\overline{E_\mu}$ approximately as $\overline{E_\mu}^{0.7}$."



Symbols show the experimental muon-induced neutron yield as originally published.
References for data points are given in JCAP 08 (2014) 064 - arXiv:1406.6081
except for Daya Bay data points; University of Houston thesis at this point in time



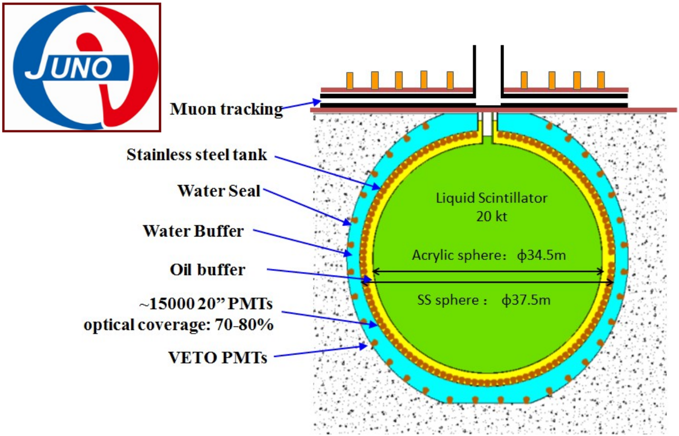


The Borexino inner detector as it was filling up with liquid scintillator and the experiment as it was implemented in FLUKA. Borexino contains approximately **300 t** of liquid scintillator in a **8.5 m** diameter inner nylon vessel.

Over 80% of the generated cosmogenic neutrons are recorded.

"Cosmogenic Backgrounds in Borexino at 3800 m water-equivalent depth", **JCAP 1308 (2013) 049** - arXiv:1304.7381

FLUKA visualization with **FLAIR**



As one Example: JUNO - Jiangmen Underground Neutrino Observatory

The detector will contain order **20000 t** of liquid scintillator in a **34.5 m** diameter stainless steel sphere. Groundbreaking ceremony was in Jan 2015 and first data taking is predicted for 2020.

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Contributing authors: G. Battistoni, F. Cerutti, M. Chin, A. Empl, M.V. Garzelli, M. Lantz, A. Mairani, V. Patera, S. Roesler, G. Smirnov, F. Sommerer and V. Vlachoudis

FLUKA is a general purpose tool for calculations of particle transport and interactions with matter, covering an extended range of applications:

Proton and electron accelerator shielding, Target design, Calorimetry, Dosimetry, **Activation**, Detector design, Accelerator Driven Systems, **neutrino physics**, **Cosmic rays**, radiotherapy, ...

Developed and maintained under an **INFN-CERN** agreement

official FLUKA website: **www.fluka.org**

FLUKA

latest public release version **Fluka 2011.2c.0** (October 2014)

Robust predictions

Design and development of FLUKA is based on the implementation of verified **microscopic models** of physical processes. FLUKA uses these models in a way which maintains consistency among all the reaction steps and types. This results in a consistent approach to all energy/target/projectile combinations with a minimal overall set of free parameters.

As a consequence, predictions for complex simulation problems are **robust** and arise naturally from underlying physical models.

The user is presented with an overall optimized configuration of models which cannot be user adjusted.

M. Brugger, M. Calviani, F. Cerutti, A. Fedynitch, Alfredo Ferrari, L.Esposito, R.Esposito, R. GarciaAlia, P. GarciaOrtega, L. Lari, A. Lechner, M.Magistris, C. Mancini, A. Manousos, A.Mereghetti, E. Nowak, S. Roesler, P. Schoofs, L. Skordis, N. Shetty, G. Smirnov, C. Theis, T. Viana Miranda, Heinz Vincke, Helmut Vincke, V. Vlachoudis, J.Vollaire, C.Weiss
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C. Cuccagna TERA Foundation,
F. Fiorini CRUK and MRC Oxford Institute for Radiation Oncology

taken from A. Ferrari, collaboration meeting, December 2014, Pavia
https://indico.cern.ch/event/358091/

Main Physics developments (since 2011):

FLUKA:

- ElectroMagneticDissociation *(LHC ion beams)*
- ElectroNuclear interactions *(electron machines)*
- Virtual photon interactions by $\mu+/\mu-$ below ρ *(neutrons underground)*
- New hadronization: *(5-10 GeV beams, GLAST, ν interactions)*
- Spin/parity effects in nuclear de-excitation *(EMD, underground exps, RP)*
- Prompt photons in hA and AA nucl. int. *(hadrontherapy monitoring)*
- (p,d) and (p,α) "direct" reactions *(β+ emitters, light ion fragmentation)*
- β^+ emitter production by protons *(hadrontherapy monitoring and RP)*
- α's induced reactions *(At, Po, Isolde, RP)*
- Isomer production by neutrons below 20 MeV *(Activation, RP)*
- BME extended to mass 3 *(Light ion interactions)*
- Synchrotron radiation *(Tlep aka FCCee)*
- New mass, decay, level, radiation database *(almost everything)*
- ...

taken from A. Ferrari, collaboration meeting, December 2014, Pavia *(and adapted)*
https://indico.cern.ch/event/358091/

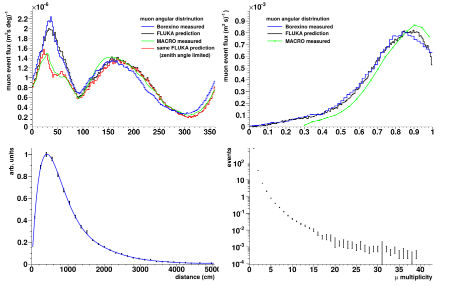
"A Fluka Study of Underground Cosmogenic Neutron Production"
JCAP 08 (2014) 064 - arXiv:1406.6081, August 2014

"A FLUKA Study of β-delayed Neutron Emission for the Ton-size DarkSide Dark Matter Detector"
arXiv:1407.6628, July 2014

We are currently working on updated benchmarking results making use of current version of FLUKA rather than FLUKA 2011. This work was supported in part by NSF awards 1004051 and 1242471.

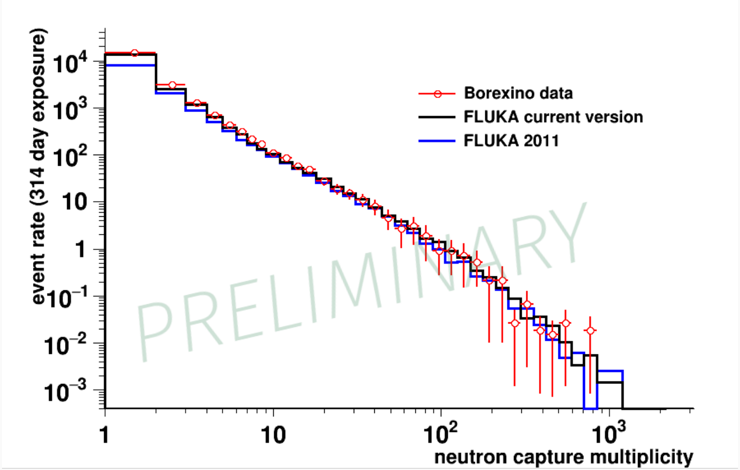
Given the current veto detector systems even a **ton-sized DarkSide experiment** is predicted to operate **free of cosmogenic background for more than 5 years**. The background rate from β-delayed (not prompt, ie not in coincidence with the muon) neutrons is predicted to be small, on the order of < 0.1 event/year.

Input to the cosmogenic background simulation



Compared to different underground labs, the experimental information available about the muon radiation field at LNGS is exceptional. This includes information on **muon bundles**, the **muon energy spectrum** and **muon flux** and its variation throughout the year. The muon charge ratio has been reported by the OPERA experiment both for single and multi-muon events.

Borexino and DarkSide are located right next to each other in Hall C at LNGS.

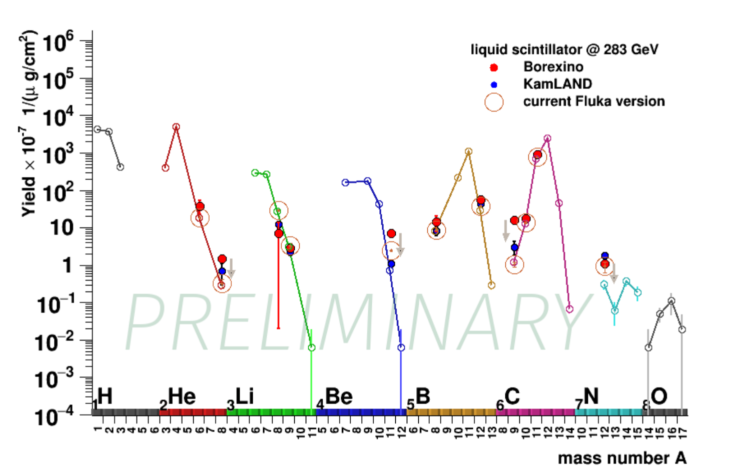


associated issue: neutron producing muon event rate

[events per day for inner inner detector vessel]

Borexino (67±1)

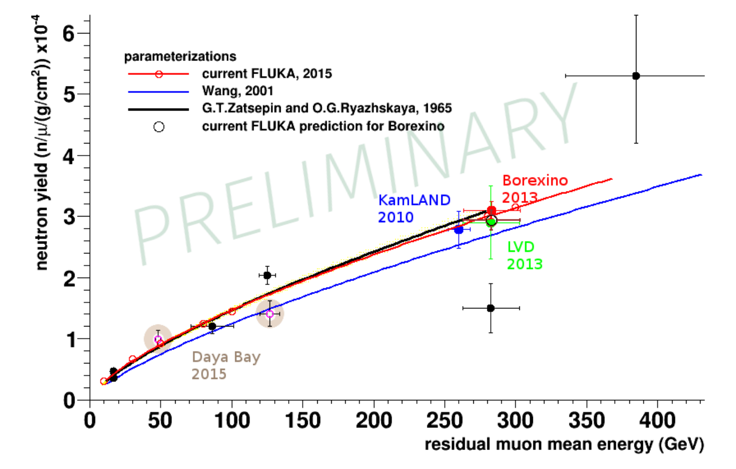
current FLUKA (62) preliminary - FLUKA 2011 (42)



^{11}C production yield $[10^{-7}(\mu\ g/cm^2)]$

Borexino (866 ± 115)

current FLUKA (767 ± 19) preliminary - FLUKA 2011 (467 ± 23)



neutron capture yield $[10^{-4}(\mu\ g/cm^2)]$

Borexino **(3.1 ± 0.11)**

current FLUKA **(2.93±0.16)** preliminary - FLUKA 2011 **(2.46±0.12)**

SUMMARY

- Overall agreement between experimental data and FLUKA predictions for muon-induced neutrons in liquid scintillator at the depth of LNGS is certainly at the 5% level now.
- We did not evaluate FLUKA predictions for other target materials yet. This issue is complicated by the fact that very little experimental data exists. There is a need to address common shielding/construction materials like iron and lead.
- The improved physics models in FLUKA will become publicly available with the next code release.
- There was quite some work carried out within the AARM project to compare FLUKA and Geant4 predictions. Please visit the AARM website for more information. http://www.hep.umn.aarm/