Monte Carlo Simulation of the muon-induced neutron experiment using LVD

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The main goal of LVD is searching for neutrino radiation from stellar core collapse. Neutrons generated by cosmic-ray muons underground is investigated as a background source in low-background experiments. To determine the efficiency of neutron detection and systematic measurement errors, it is necessary to fully simulate the experiment by the Monte Carlo method. We discuss about simulation errors, as well as sources of errors in the determination of physical quantities.

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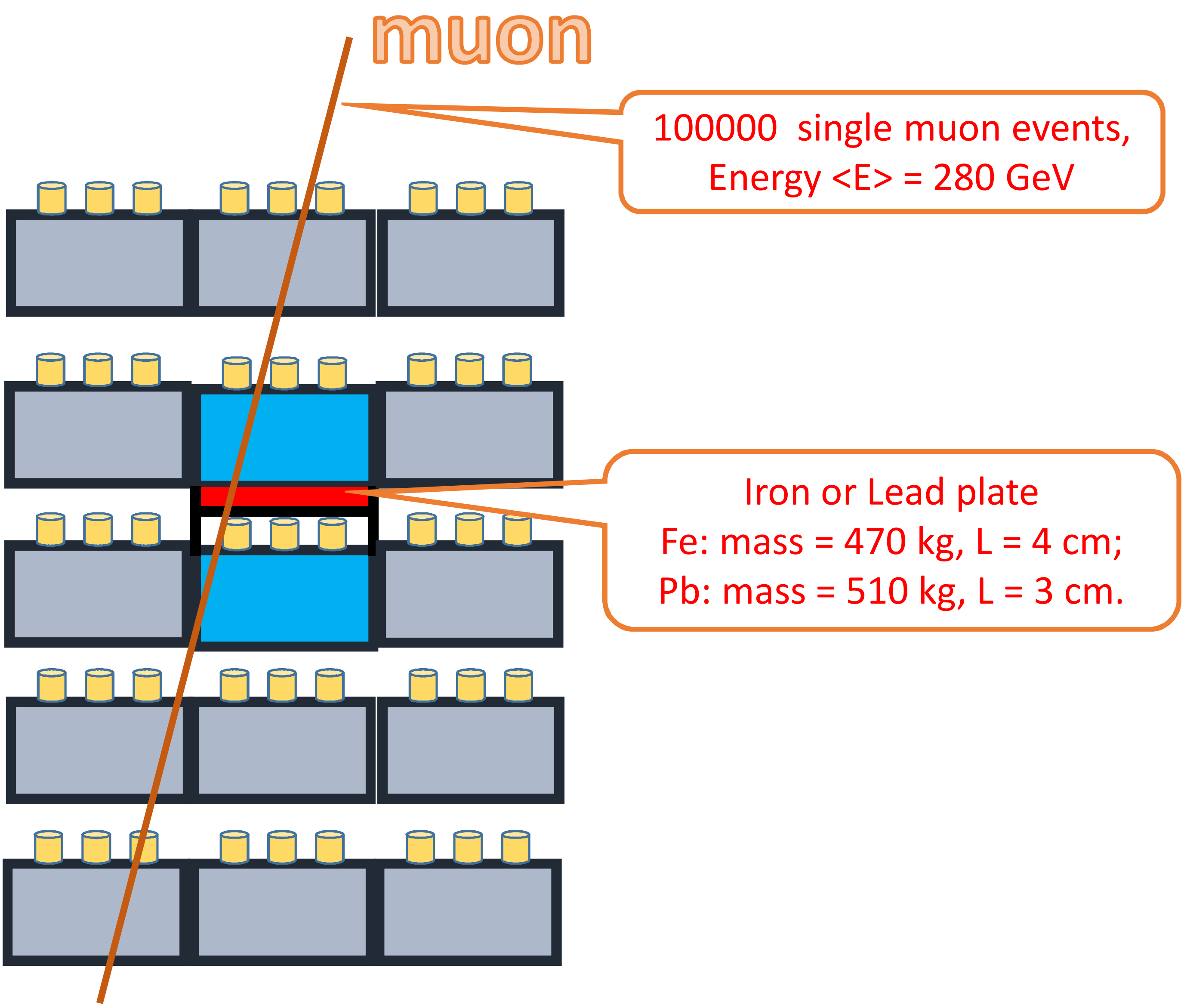
LVD – Large Volume Detector at LNGS, Italy, Gran Sasso

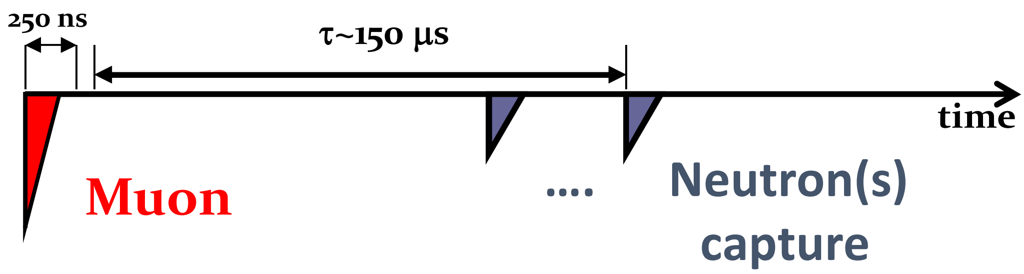
Length ×Width ×Height	22.7×13.2×10 m
Iron mass	1020 t
Scintillator mass	1008 t
Amount of scintillation counters	840
Average depth minimal	3620 m w.e. 3000 m w.e.
Mean muon energy	280 GeV
E_{μ} on see level (min.)	1.3 TeV
Muon rate (on 1 tower)	~ 120 h^{-1}
Threshold ε_{th}	5 MeV

Monte-Carlo simulation using Geant4



$$n + p \rightarrow D + \gamma, \quad E\gamma = 2.2 \text{ MeV}$$

$$n + Fe^{56} \rightarrow Fe^{57} + \gamma, \quad \Sigma E\gamma = 10.16 \text{MeV}$$



Experiment using LVD

Fe – 4 cm

Pb – 3 cm

Fe

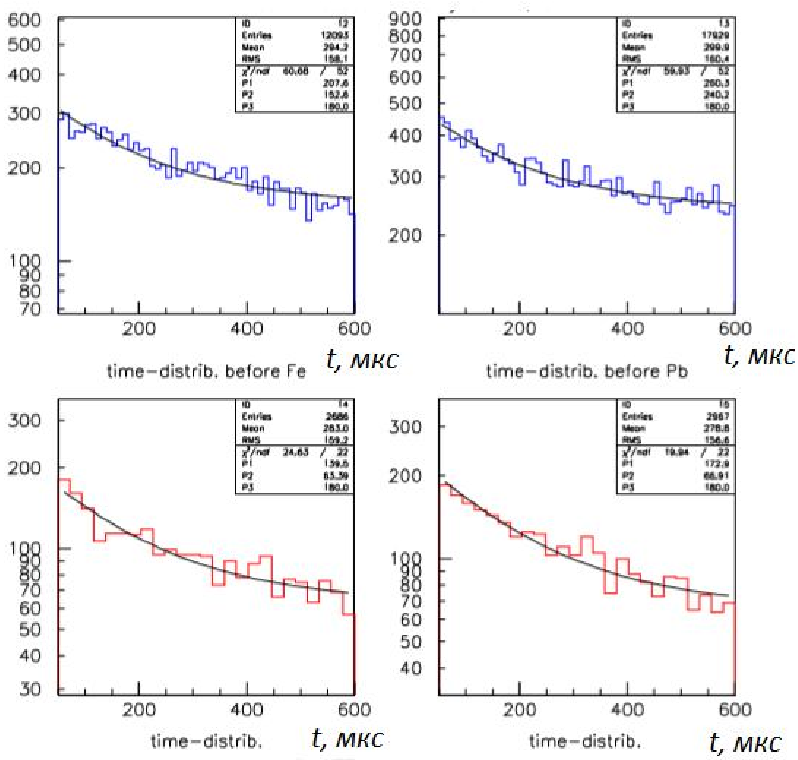
(ΔNn/Nm)/ρl/η

$(15.4 \pm 1.3) \times 10^{-4}$

Pb

(ΔNn/Nm)/ρl/η

$(54 \pm 10) \times 10^{-4}$



Experimental time distributions of neutron pulses before (blue) and after (red) the installation of plates of iron and lead.

Simulation results:

	Fe	
Amount of muons		100000
Length in Fe (ρl)		35.6
Neutron generated in Fe		3378
Captured neutron	in scintillator in iron in Fe-plate	1212 58 221
Gammas with E>1MeV in 2 counters		722
Efficiency (722/3378)		0.213
Neutron Yield in Fe		9.4×10^{-4}

	Pb	
Amount of muons		100000
Length in Fe (ρl)		38.7
Neutron generated in Pb		13714
Captured neutron	in scintillator in iron in Pb-plate	5114 281 59
Gammas with E>1MeV in 2 counters		2772
Efficiency (2772/13714)		0.202
Neutron Yield in Pb		35.4×10^{-4}

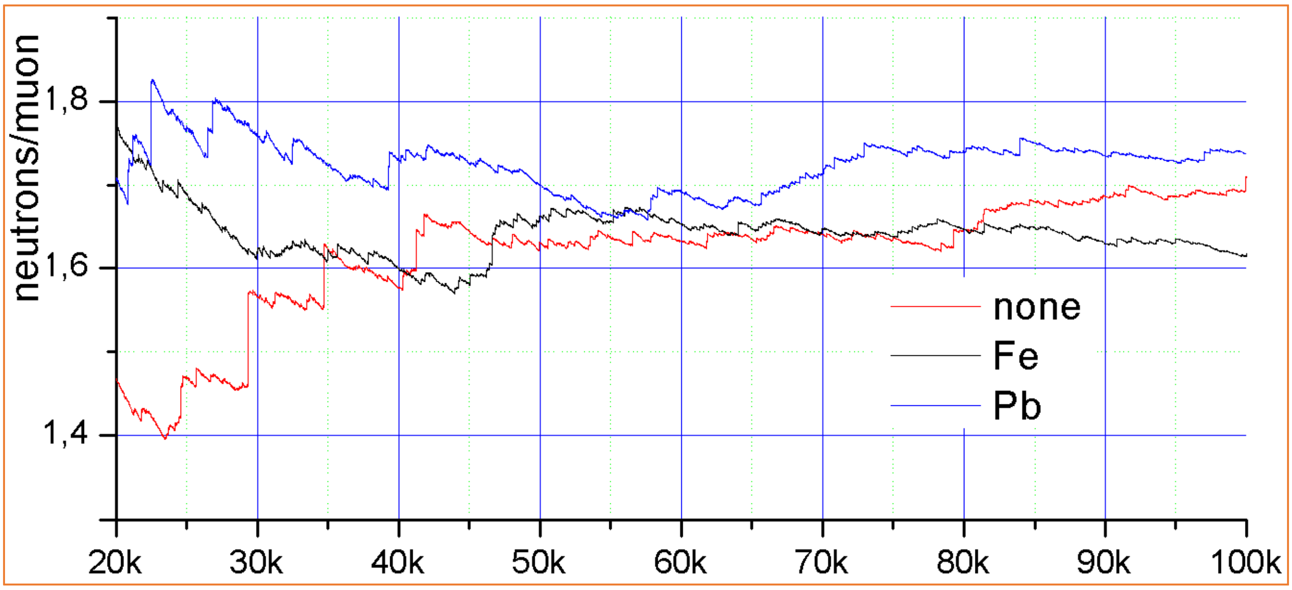
Problems:

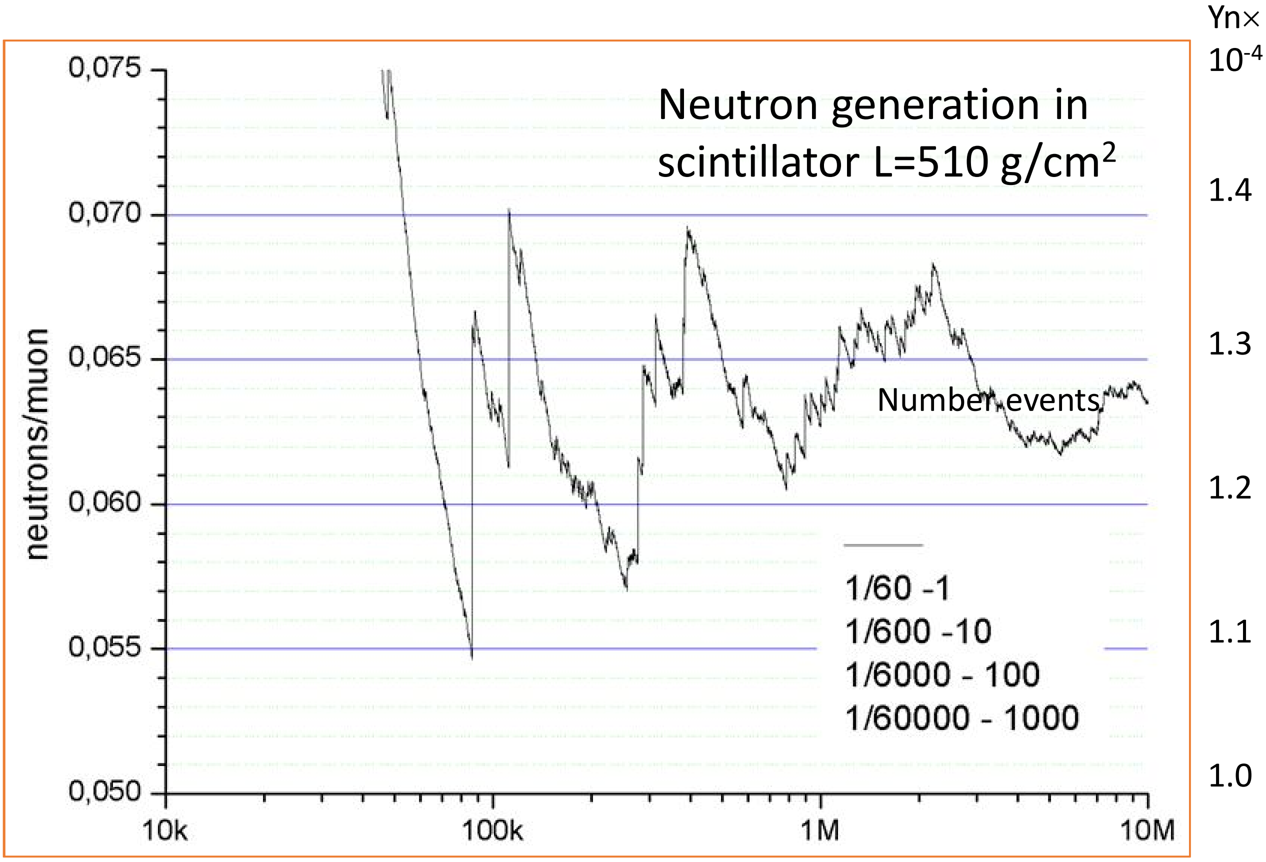
- Calculations are smaller than in experiment data;
  - due to simulation only single muons?
  - due to contribution nuclear and electromagnetic cascades?
  - due to average value of muon energy spectrum?
- Calculations get different values even with large statistics using the same code;

What is M-C Simulation for?

- To compare the experimental results with each other;
- To determine the detection efficiency;
- To take into account the geometric factor;
- For obtaining true dependencies.

Dependence on statistics





Simulation VS Experiment

Fe

Experiment, year	Eμ, GeV	Y_{Fe}, n/μ/(g/cm²)
LVD, LNGS, 2011	280	$(19 \pm 1) \times 10^{-4}$
LVD, LNGS, 2014	280	$(14.3 \pm 1.6) \times 10^{-4}$
LVD, LNGS, 2016	280	$(15.4 \pm 1.3) \times 10^{-4}$
Calculation: author, year	Eμ, GeV	Y_{Fe}, n/μ/(g/cm²)
Horn, 2008	280	15×10^{-4}
Mai, Haim,(PRD) 2006	280	16×10^{-4}
M., R., S., Yu., 2014	280	14.9×10^{-4}

Pb

Experiment, year	Eμ, GeV	Y_{Pb}, n/μ/(g/cm²)
Boulby UL,ZeplinIII, 2013	260	$(58 \pm 2) \times 10^{-4}$
M-Bl, Bergamasco, 1973	280	$(116 \pm 44) \times 10^{-4}$
LVD, LNGS, 2016	280	$(54 \pm 10) \times 10^{-4}$
Calculation: author, year	Eμ, GeV	Y_{Pb}, n/μ/(g/cm²)
Horn, 2008	280	60×10^{-4}
Mai, Haim,(PRD) 2006	280	47×10^{-4}
M., R., S., Yu., 2014	280	47.6×10^{-4}

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Моделирование эксперимента по изучению нейтронов на LVD