LVD STATUS REPORT: UNDERGROUND MUON PHYSICS

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



The main goal of LVD is searching for neutrino radiation from stellar core collapse.

The coordinates of the LNGS: 13.5333E, 42.4275N.

Length ×Width ×Height	22.7×13.2×10
Iron mass	1020 +
11011111855	10201
Scintillator mass	1008 t
Amount of scintillation counters	840
Average depth	3650 m w.e.
minimal	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



Muon events reconstruction

$R_{\mu}(LVD) = 0.097 \pm 0.010 \text{ s}^{-1}$



300



M. Aglietta et al. (LVD Collaboration) Muon "depth-intensity" relation measured by the LVD underground experiment and cosmic-ray muon spectrum at sea level Phys. Rev. D **58**, 092005 – Published 1 October 1998



The charge ratio of vertical cosmic ray muons with energies > 1.3 TeV at sea level

LVD Collaboration «The μ^+/μ^- *Ratio at the Depth of 3000 m.w.e.» Proc. of 31st ICRC, 2009*

Muon group reconstruction



The track system consists of vertical and horizontal planes of **gas discharge tubes** operating in a limited streamer mode. **The accuracy** of determining the track coordinates of a charged particle is ± 3 cm. It is determined by the width of the strips of the planes of the track system (2 cm) and their spatial arrangement relative to each other.



Muon group multiplicity

нисло событий

A = 0.1480E+0.000

 $dN/dn = An^{-k}$

Experimental distributions obtained with MACRO, MINOS, SOUDAN, BUST and LVD setups. The data are normalized to the total number of muons.



Decoherent curve

Distribution of pair combinations by the distance between muons in a pair for all groups.



The dependence of the distance between muons in a group **gives** information about the transverse momenta. Together with the multiplicity of muons, information on the energy spectrum of hadrons can be obtained. Measurements of spectra and distance distributions of atmospheric muons make it possible to test models of a nuclear cascade in the atmosphere, i.e. parameters of primary cosmic radiation (energy spectrum and chemical composition) and interactions of particles at high energies.









Near-vertical muons

Near-horizontal muons



Epoch folder method

N. Agafonova et al. (LVD Collaboration) Physics of Atomic Nuclei. 2020. T. 83. № 1. C. 69-74.

 $Y_n(E_{II}) \propto E_{II}^{0.78}$

The energy of muons varies by 10 percent depending on the season,

due to the dependence of the neutron yield on the energy of muons to the power of 0.78.





LVD - OPERA IND horizontal muons

Relative position of the detectors LVD and OPERA in the Gran Sasso Laboratory Distance between LVD and OPERA is ~157 m E min ~ 70 GeV



Determination of the time shift between LVD and OPERA using horizontal muons passing through the detectors

Using a CERN - Gran Sasso neutrino beam, with short 3-ns wide bunches and an interval of 100 ns between them, the relative deviation of the neutrino velocity from the speed of light was measured using the LVD : - $3.3 \cdot 10^{-6} < (v_v - c)/c < 3.5 \cdot 10^{-6}$ (at 99% confidence level). *N.Yu. Agafonova et al. (LVD Collaboration), «Measurement of the Velocity of Neutrinos from the CNGS Beam with the Large Volume Detector». arXiv:1208.1392, Phys.Rev.Lett. 109, 070801 (2012)*

CNGS



The LVD, operating since 1992, detects cosmic ray muons at a depth of 3.6 km w.e. During 28 years of work, the characteristics of the **muon flux**, its dependence on depth and **seasonal variations** and, the **charge muon ratio**, the **multiplicity curve** of muon groups and the **decoherent curve** have been obtained.

Thank you.

