CNGS Beam Monitor with the LVD Detector

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Abstract

The importance of an adequate CNGS beam monitor at the Gran Sasso Laboratory has been stressed in many papers. Since the number of internal ν_μ CC and NC interactions in the various detectors will not allow to collect statistics rapidly, one should also be able to detect the ν_μ CC interactions in the upstream rock.
In this study we have investigated the performances of the LVD detector as a monitor for the CNGS neutrino beam.
Thanks to its wide area (13×11 m^2 orthogonal to the beam direction) LVD can detect about 120 muons per day originated by ν_μ CC interactions in the rock.
The LVD total mass is ~ 2 kt. This allows to get 30 more CNGS events per day as internal $(NC + CC)$ ν_μ interactions, for a total of ~ 150 events per day. A 3% statistical error can be reached in 7 days. Taking into account the time characteristics of the CNGS beam, the cosmic muon background can be reduced to a negligible level, of the order of 1.5 events per day.

1. Introduction

The CNGS beam from CERN to the Gran Sasso Laboratory (LNGS) is a wide-band high-energy ν_μ beam ($< E > \sim 23\, GeV$) optimized for τ appearance. It provides ~ 2600 $CC/kt/y$ and ~ 800 $NC/kt/y$ at Gran Sasso [3], that is, assuming 200 days of beam-time per year, a total number of ~ 17 $(CC + NC)/kt/day$.

In order to provide an adequate monitoring of the beam performance it has been estimated [4] that one should be able to collect an event sample affected by a statistical error of the order of 3% in a few days time.

Even considering an overall mass of the various experiments which will be active in GS at the beam start up as large as 5 kt, the number of CC and NC interaction per day, internal to the detectors, will be only $\sim$ 80 and therefore more than 14 days will be needed to collect a sample with the statistical significance mentioned above.

The number of events observed per day can be increased considering the muons produced by the ν_μ CC interactions in the upstream rock, emerging into the

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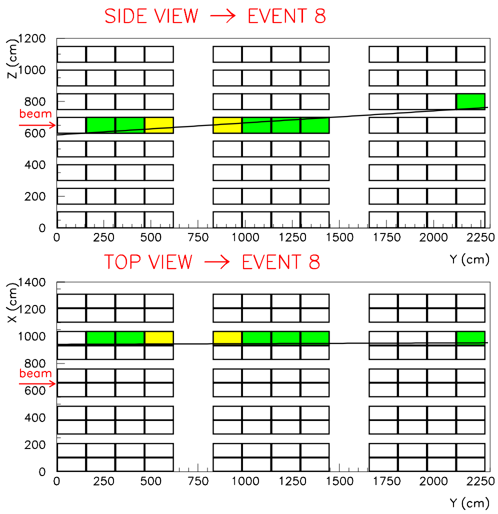

Fig. 1. Event display of a *CNGS* μ crossing 8 scintillation counters.

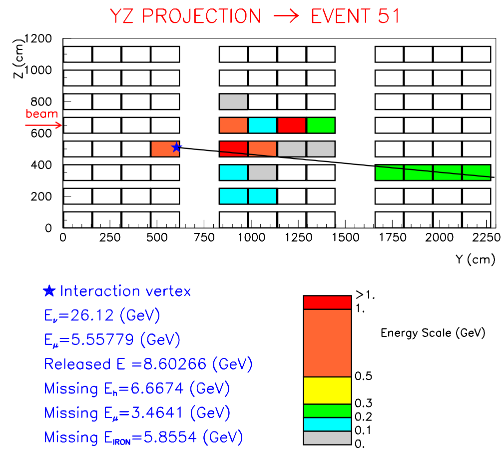

Fig. 2. Event display of CNGS ν_μ charged current internal interaction.

experimental halls and detected either by a simple wide area dedicated monitor or by the running experiments.

We have investigated the beam monitor capabilities of the LVD detector [1], whose beam orthogonal surface is 13×11 m^2, larger than the other foreseen CNGS experiments. A detailed MonteCarlo simulation to estimate both the muon flux inside LVD and the number of detectable CC and NC internal interactions has been developed.

2. MonteCarlo simulation description

The interactions, both in the rock and in the LVD detector, of the CNGS beam neutrinos have been simulated using the Lipari generator [7] and the neutrino energy from the reference CNGS beam spectrum [3]. To estimate the number of events we assumed 5.85×10^{-17} $CC/pot/kt$ and 4.5×10^{19} $pot/year$ (1 year $\equiv$ 200 days).

The muon energy loss and the angular scatterings in the rock between the production point and the detector are taken into account with MUSIC [2], a three dimensional code for the muon propagation through the rock, that includes ionization, bremsstrahlung, pair production, nuclear interactions and multiple coulomb scattering.

Finally, the detector geometry and the particles' interactions inside the detector have been described with a GEANT simulation of LVD. A typical events of a muon emerging from the rock and entering LVD is shown in figure 1., while a CC neutrino interaction inside the detector is shown in figure 2..

3. Results

The number of μ hitting the GEANT reference volume enclosing the LVD apparatus in one "200-days year" is $\sim$ 33600, that is $\sim$ 170 per day. 79% of them go through a sensitive part of the detector (scintillator) and 92% of this latter sample release more than 200 MeV at least in one scintillation counter. Choosing it as the muon selection criteria, the number of detected muons in LVD is 24200 per year, that is $\sim$ 120 per day. Moreover, $\sim$ 30 events per day are expected due to ν_μ CC and NC inside the whole apparatus, for a total number of $\sim$ 150 CNGS events per day. The results are summarized in tables 1. and 2.. It is, therefore, possible to get a 3% statistical error in 7 days of running. These results fulfill the requirements made by CNGS beam experts [4]. The main background source is due to cosmic muons. The rate in the whole LVD detector is about 9300 muons/day (about 6.5 per minute), considering the events with at least one scintillation counter fired by the muon. The requirement of at least one counter with an energy loss greater than 200 MeV rejects 20% of them, leaving about 7500 muons per day. Considering the 10^4 reduction factor due to the CNGS beam timing characteristics (10.5 μs of spill length and 50 ms inter-spill gap [6]), the actual number of background μ per day is $\sim$ 1.5, practically negligible.

The expected number of events in an ideal monitor at LNGS depends mainly on the orthogonal area. We estimate, using the same software chain for the event generation and the muon propagation in rock, 146 muons/day in a 100% efficiency, $13m \times 13m$ wide detector.

Rock cylinder Volume	726493 m^3
Rock cylinder Mass	1969 kt
Nominal CNGS beam intensity	$4.5 \times 10^{19} pot/year$
CC Interaction Probability	5.85×10^{-17} $CC/pot/kt$
ν_μ CC interactions in the rock	5.18×10^6 *per year*
μ survival probability at LNGS	6.8%
Nb. of μ at the LNGS entrance wall	351600 *per year*
Probability to hit LVD "mother volume"	9.6%
Nb. of μ hitting LVD "mother volume"	33600 *per year*
Geometrical efficiency	79%
Nb. of μ hitting LVD sensitive volume	26200 *per year*
Selection cut efficiency	92%
Nb. of detected μ	24200 *per year*

Table 1. Number of *CNGS muons* detected in LVD.

	Volume	**Mass**
Scintillator	1340 m^3	1044 t
Stainless Steel	98.5 m^3	770 t
Total Target		$\sim$ 1810 t
	CC	**NC**
ν_μ interactions in LVD	4770 *per year*	1460 *per year*
efficiency for the selection cut	97%	91%
Nb. of detected events	4630 *per year*	1330 *per year*
Total nb. of detected events	5960 *per year*	

Table 2. Number of internal CC and NC events in LVD.

4. Summary and conclusions

The importance of a CNGS beam monitor apparatus in the experimental halls of Gran Sasso Laboratory has been stressed in many papers [3] [4]. In this paper the performances of the LVD detector as a monitor for the CNGS neutrino beam are shown.

Thanks to its wide area (13×11 m^2 orthogonal to the beam direction) LVD can detect about 120 muons per day using a very simple selection cut (at least one counter with an energy loss greater than 200 MeV). With a $\sim$ 2 kt total mass, LVD could detect 30 more CNGS events per day as internal ($NC + CC$) ν_μ interactions, for a total of $\sim$ 150 events per day. A 3% statistical error can thus be reached in 7 days. The cosmic muons background can be reduced to a negligible level, of the order of about one event per day, by taking into account the CNGS beam spill.

These results compare well with the expected performances of a dedicated muon detector.

5. References

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