Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 5 (HE part 2), pages 1113–1116

30TH INTERNATIONAL COSMIC RAY CONFERENCE

First events of the CNGS beam detected by LVD

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Abstract: The Cern Neutrino to Gran Sasso (CNGS) project aims to produce a high energy, wide band ν_μ beam at Cern and send it towards the INFN Gran Sasso National Laboratory (LNGS), 732 km away. Its main goal is the observation of the ν_τ appearance, through neutrino flavour oscillation. The beam started its operation in August 2006 for about 12 days: a total amount of 7.6 10^{17} protons were delivered to the target. The LVD detector, installed in hall A of the LNGS and mainly dedicated to the study of supernova neutrinos, was fully operating during the whole CNGS running time. A total number of 569 events were detected in coincidence with the beam spill time. This is in good agreement with the expected number of events from Montecarlo simulations.

Introduction

The Cern Neutrinos to Gran Sasso (CNGS) project aims to produce a high energy, wide band ν_μ beam at Cern and send it towards the INFN Gran Sasso National Laboratory (LNGS). Its main goal is the observation of the ν_τ appearance, through neutrino flavour oscillation, by the Opera experiment.

The LVD detector, installed in the Hall A of the LNGS, is mainly dedicated to the observation of supernova neutrinos. As proven in [1], due to its large area and active mass, LVD can act as a very useful beam monitor, detecting the interaction of neutrinos inside the detector and the muons generated by the ν interaction in the rock upstream the detector.

The CNGS beam started its operation in August 2006, after three commissioning weeks. LVD was fully operative during the whole first run of the CNGS beam.

In this work we present the results of the events detected in coincidence with the beam spill time and show some comparisons with the Montecarlo simulation.

The CNGS beam

The information about the CNGS beam characteristics are taken by the LHCLOG_CNGS_OPERA database (hereafter DB) [2]. Two main quantities are relevant for each proton extraction: the UTC time of the spill (in ns) and the number of extracted protons on target (p.o.t.).

The CNGS beam started its first run of operation on 18^{th} August, 2006 (first spill at 11:31:54.072 UTC) and finished on 30^{th} August (last spill at

03:30:04.872 UTC). In the following we will refer to this first run as Run1. The total number of protons delivered against the graphite target is $7.59\ 10^{17}$. The beam intensity per each spill is shown in figure 1. The time structure of the CNGS beam is characterized by two extractions, $10.5\ \mu$s long, separated by 50 ms; this pattern is repeated each CNGS cycle, whose duration can change: during Run1 there were two main repetition cycles: 16.8 s and 22.8 s.

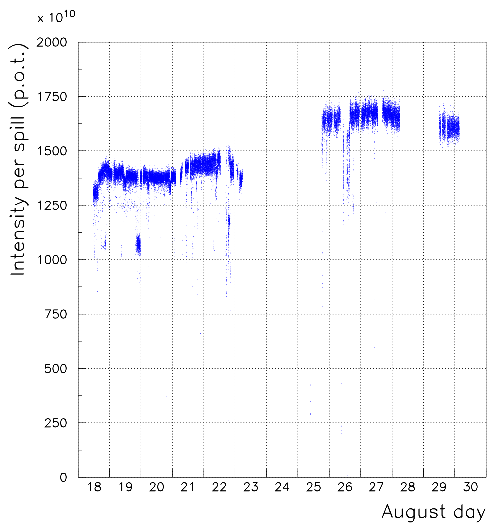

Figure 1: Beam intensity per spill during Run1.

The LVD detector

LVD is a large volume liquid scintillator detector dedicated to the study of core collapse supernova neutrinos. The active scintillator mass is about 1000 t, while the iron and stainless steel support structure is $\sim\ 900$ t. It has a modular structure, made of 840 identical scintillation counters. Each counter is viewed on the top by three photomultiplier tubes. The counters are grouped in three big modules, called "towers", with independent data acquisition. The energy calibration of the scintillation counters is done each month through the (known) energy released by cosmic muons. The highest detectable energy in each counter is between 200 and 400 MeV. The front area of the whole detector (orthogonal to the CNGS beam) is $\sim 12 \times 10$ m^2. A detailed description of the detector and its performances is in [3].

During Run1 LVD was fully operative with 100% of uptime (defined as the fraction of time where LVD is able to detect an event) and with an average active mass of 950 t.

MC simulation of the expected events

The CNGS events in LVD can be subdivided into two main categories:

- ν_μ charged current (CC) interactions in the rock upstream the LNGS; they produce a muon that can reach LVD and be detected,
- ν_μ CC and neutral current (NC) interactions in the material (liquid scintillator and iron of the support structure) of LVD.

We developed a full Montecarlo simulation that includes the generation of the neutrino interaction products, the propagation of the muon in the Gran Sasso rock and the response of the LVD detector. The details of the simulation were described in [1]; however, with respect to that paper, some modifications were done with up–to–date informations. In particular we now use the CNGS flux calculated in 2005 by the Fluka group [4] and the neutrino cross section NUX-FLUKA [5]. There are also some modifications in the detector: there are actually 7 active levels of scintillation counters instead of the 8 previously considered, and the energy threshold for the definition of a CNGS event is now 100 MeV instead of 200 MeV.

The resulting number of expected events, at the nominal intensity $4.5\ 10^{19}$ p.o.t./y is 32160/y, equivalent to $7.147\ 10^{-16}$ events per p.o.t. (considering 200 effective days per year, it corresponds to $\sim\ 160$ CNGS events per day): 78% are muons from the rock, 17% are CC interactions in the detector and 5% are NC.

During Run1 the total number of p.o.t. was $7.59\ 10^{17}$, thus 542 events are expected in LVD.

CNGS detected events

The LVD events are filtered using a very loose selection cut: we require to have at least one scintillation counter with an energy release larger that 100 MeV. The resulting rate is quite stable, with an average value of 0.37 Hz.

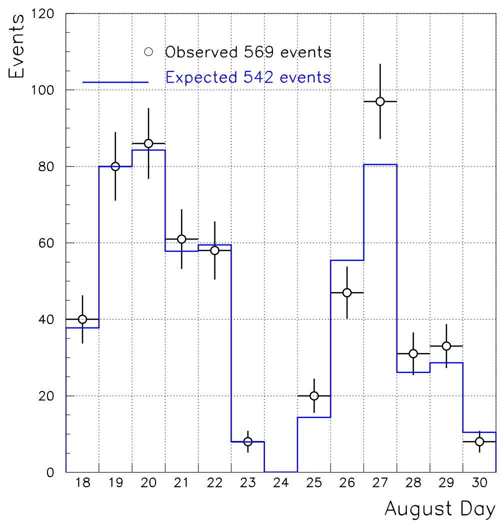

Figure 2: Number of CNGS events per day: observed (black circles) and expected (blue line).

Among this sample the selection criteria is based on the coincidence of the LVD event time with the beam spill time written in the DB. Two main corrections have been done: the neutrino time of flight from Cern to the LNGS (2.440 ms) and the propagation of the GPS time signal from the outside laboratories to slave clocks in the underground hall (about 42 μs).

After applying all these corrections, we search for the CNGS events in the interval $[-15, +25]$ μs around the start time of the beam spill. In this way 569 events are selected.

In figure 2 we show the comparison between the expected and detected event rate per each day of data acquisition; given the presently limited statistics, the agreement is good.

Two examples of typical CNGS events in LVD are shown in figure 3: a muon from the rock (left) and a neutrino interaction inside the detector (right).

Comparison with the MC simulation

We performed some comparisons between the CNGS detected events and the results of our MC simulation; a more detailed analysis can be found in [6]. The distribution of the number of scintillation counters hit per each event, and the total amount of energy detected by the scintillation counters present a quite good agreement, given the available statistics of 569 events.

In order to select the events generated in the rock, producing a penetrating muon inside the detector, we performed the muon track reconstruction with a linear fit to the centers of the hit scintillation counters. Requiring at least 3 hit counters and a good χ^2 (probability larger than 1% in both the *TOP* and *SIDE* projections) we select 319 events. From the MC simulation we estimate that, using this selection cut, the efficiency to detect "muons from the rock" is about 80% and the contamination of "internal events" is low (less than 5%). For this selected sample of events we can reconstruct the muon direction and compare it with the expectation from the reconstruction of MC events. The results are shown for the angle between the muon and the main axis of the hall A: its projection in the *SIDE* view of the detector is shown in figure 4.

The events are almost horizontal and the main part of them are reconstructed exactely at $0°$ because of the discreteness of the scintillation counters (cross section 1×1 m^2). In the *TOP* view the beam is parallel to the hall A axis, while in the *SIDE* view the beam "comes out" from the floor with an angle of $3.2°$, as seen in figure 4. The agreement of the data and the MC simulation is very good in both the projections.

Background

The background is estimated considering the rate of events among which the CNGS events are searched for, with an average value of 0.37 Hz. We remind that the time window where we search for the events around the beam spill time is 40 μs wide, and the number of useful spills in the DB is 51581. Thus the number of events due to the background during Run1 is $N_{bkg} = 0.76$, practically negligible.

Conclusions

We presented the results of the first events detected by the LVD detector in coincidence with the CNGS beam. The first run of the CNGS beam was started in August 2006, with an overall number of $7.6\ 10^{17}$ protons delivered on the target. The LVD detector was fully operative during the whole run, with an average active mass of 950 t. The expected number of events, as predicted by our Montecarlo simulation, is 542. We searched for the CNGS events by

Figure 3: Event displays: (left) a charged current interaction in the rock upstream LVD, producing a penetrating muon; (right) neutrino interaction inside the LVD detector. The colours represent the amount of energy released in the counters; the black straight line is the result of a linear fit to the hit counters.

looking at the time coincidence with the beam spill time; the number of detected events is 569. There is a good agreement, between the detected events and the MC simulation, in the distribution of the number of hit counters, the total energy released in the apparatus and the direction of the reconstructed muons. We estimate that the number of events due to the background is lower than one in the whole Run1 time.

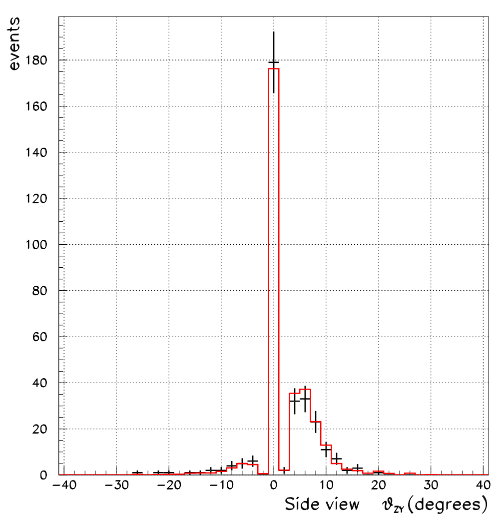

Figure 4: Distribution of the "side" projection of the angle between the μ track and the main axis of the LNGS: data (black +) and MC (red line).

Thus, this first run of the CNGS beam confirmed that, as it was proposed in [1], LVD can act as a very useful CNGS beam monitor.

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