First CNGS events detected by LVD

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Abstract. The CERN Neutrino to G ran Sasso (CNGS) project aims to produce a high energy, wide band beam at CERN and send it toward the INFN G ran Sasso National Laboratory (LNGS), 732 km away. Its main goal is the observation of the appearance, through neutrino avour oscillation. The beam started its operation in August 2006 for about 12 days: a total am ount of 7:6 10¹⁷ 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 num ber of 569 events were detected in coincidence with the beam spill time. This is in good agreement with the expected num ber of events from M ontecarlo simulations.

PACS. 14.60 Pq Neutrino mass and mixing { 29.27 Fh Beam characteristics { 29.40 M c Scintillation detectors { 95.55 N j Neutrino, muon, pion, and other elementary particle detectors; cosm ic ray detectors

1 Introduction

The CERN Neutrinos to G ran Sasso (CNGS) project aim s to produce a high energy, wide band beam at CERN and send it toward the INFN G ran Sasso National Laboratory (LNGS). Its main goal is the observation of the

appearance, through neutrino avour oscillation, by the 0 pera experiment.

The LVD detector, installed in the H allA 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 interaction in the rock upstream the detector.

The CNGS beam started its operation in August 2006, after three comm issioning weeks. LVD was fully operative during the whole $\$ rst 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 som e comparisons with the M ontecarlo simulation.

2 The CNGS beam

The informations about the CNGS beam characteristics are taken by the LHCLOG_CNGS_OPERA database (here-after DB) [2]. Two main quantities are relevant for each proton extraction:

- { the UTC time of the spill (in ns),
- { the num ber of extracted protons on target (p.o.t.) 1 .

The CNGS beam started its rst run of operation on 18^{th} August, 2006 (rst spill at 11:31:54.072 UTC) and nished on 30^{th} August (last spill at 03:30:04.872 UTC). In the following we will refer to this rst run as Run1. The totalnum ber of protons delivered against the graphite target is $7:59 \ 10^{17}$. The beam intensity per each spill is shown in gure1. It started with an average intensity of $1:38 \ 10^{13}$ p.o.t. per spill until 23^{rd} August; then there was a prede ned stop called \M achine D evelopm ent" (M D).

¹ Due to some known problems (see [3]) it happened that for some extraction there was only the UTC time or only the number of p.o.t. In the following we will consider only those extraction where both the informations were present.

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O n 25^{th} August the run restarted with a slightly higher intensity of 1.64 10^{13} p.o.t. per spill, on average.

The time structure of the CNGS beam is characterized by two extractions, 10:5 s long, separated by 50 m s; this pattern is repeated each CNGS cycle, whose duration can change: during R un1 there were two m ain repetition cycles: 16:8 s and 22:8 s.



F ig.1.Beam intensity (in protons on target) per each spill of R un1.

3 The LVD detector

LVD is a large volum e 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 900 t. It has a modular structure, made of 840 identical scintillation counters. Each counter is viewed on the top by three photom ultiplier 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 cosm ic muons. The highest detectable energy in each counter is between 200 and 400 M eV.

The front area of the whole detector (orthogonal to the CNGS beam) is $12 \quad 10 \text{ m}^2$, see gure2. A detailed description of the detector and its perform ances is in [7].

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



Fig. 2. Front view of the LVD detector.

4 M C simulation of the expected events

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

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

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

The resulting number of expected events, at the nom – inal intensity 4:5 10^{19} p.o.t./y is 32160/y, equivalent to 7:147 10¹⁶ events per p.o.t. (considering 200 e ective days per year, it corresponds to 160 CNGS events per day): 78% are muons from the rock, 17% are CC interactions in the detector and 5% are NC.

D uring R un1 the total num ber of p.o.t. was $7:59\ 10^{17}$, thus 542 events are expected in LVD.

5 CNGS detected events

The LVD events are ltered using a very bose selection cut: we require to have at least one scintillation counter with an energy release larger that 100 M eV. The resulting rate is quite stable, with an average value of 0:37 H z, see qure3.



F ig. 3. Background rate of events during R unl. These events present at least one scintillation counter with an energy release larger than 100 MeV.

A m ong this sam ple the rst selection criteria is based on the coincidence of the LVD event time with the beam spill time written in the DB. Two m ain corrections have been done: the neutrino time of ght from Cern to the LNGS (2:440 m s) and the propagation of the GPS time signal from the outside laboratories to slave clocks in the underground hall (42116, 42064 and 42041 ns respectively for tower 1, 2 and 3), measured in July, 2006 together with the other experiments at LNGS [6].

During Run1 there were some additional time shifts between the LNGS time and the UTC time written in the DB: from the beginning until 18^{th} 16:00 it was + 100 s, then + 10 s until 22^{nd} 9:00 and 2 m s until 23^{rd} 5:30. After the MD there was no additional bias.

A fter applying all these corrections, we search for the CNGS events in the interval [15;+25] s around the start time of the beam spill. In this way 569 events are selected; their distribution in the time window is shown in gure4.

The four events with time di erence between 13 and 8 soccured on 19^{th} August when there was a failure in the LNGS master clock. The second master was switched on and a time shift of about 10 swas present. Thus those events are considered in the analysis.



F ig. 4. D istribution of the detection time of the 569 CNGS events, with respect to the initial time of the beam spill.

In gure5 (left) we show the comparison between the expected and detected event rate per each day of data acquisition; in gure5 (right) the comparison of the integral number of events, hour by hour, is show n.G iven the presently limited statistics, the agreement is rather good.

Two examples of typical CNGS events in LVD are shown in gure6 (muon from the rock) and 7 (neutrino interaction inside the detector).

5.1 Com parison with the M C simulation

In the following we show the comparison between the CNGS detected events and the results of our MC simulation, normalized to the same number of events. In gure 8 we show the distribution of the number of scintillation counters hit per each event, with an energy threshold of 10 M eV, normalized to the total sample of 569 detected events; given the available statistics the agreem ent is good.

In order to select the events generated in the rock, producing a penetrating m uon inside the detector, we perform the m uon track reconstruction with a linear to the centers of the hit scintillation counters. Requiring at least 3 hit counters and a good 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 e ciency to detect \m uons from the rock" is about 80% and the contam ination of \internal events" is low (less than 5%).

In gure9 the total am ount of energy detected by the scintillation counters in m uonic" events is displayed.

For this selected sam ple of events we can reconstruct the muon direction and compare it with the expectation



Fig. 5. Com parison between the expected and detected number of events during Run1. In the left panel there is the number of events per day: observed (black circles) and expected (blue line). In the right one the integrated num ber of events: observed (black solid line) and expected (blue dashed line).

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 projections in the SIDE and TOP view of the detector are in qure10 and 11 respectively.

The events are alm ost 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 \com es out" from the oor with an angle of 3:2, as seen in gure10. The agreem ent of the data and the M C simulation is very good in both the projections.

5.2 Background

The background is estimated considering the rate of events shown in gure3 am ong which the CNGS events are searched and the direction of the reconstructed m uons. for, with an average value of 0:37 Hz.W erem ind that the time window where we search for the events around the beam spill time is 40 swide, and the num ber of useful spills in the DB is 51581. Thus the num ber of events due to the background, during R un1, is

$$N_{bkg} = 0.37 H z$$
 40 s 51581 = 0.764

practically negligible.

6 Conclusions

W e presented the results of the st events detected by the LVD detector in coincidence with the CNGS beam. The

rst run of the CNGS beam was started in August 2006, with an overall number of 7:6 10¹⁷ protons delivered to the target. The LVD detector was fully operative during the whole run, with an average active m ass of 950 t.

LVD can detect the CNGS neutrinos through the observation of penetrating muons originated by CC interactions in the rock upstream the LNGS and through internalCC and NC neutrino interactions.

The expected number of events, as predicted by our M ontecarlo simulation, is 542.W e searched for the CNGS events by looking at the time coincidence with the beam spill time; the number of detected events is 569.

There is a good agreem ent, between the detected events and the M C simulation, in the distribution of the number of hit counters, the total energy released in the apparatus

We estimate that the number of events due to the background is lower than one in the whole R un1 time.

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

A lso the O pera collaboration reported about theirm easurem ents [8]: they detect 319 events against a prediction of 300, obtaining results very sim ilar to ours. A detailed discussion about the comparison of expected and detect events in LVD is postponed to the next CNGS runs (scheduled in fall 2007), when a large number of events will be available and the beam characteristics will be better under control.



Fig. 6. D isplay of a CNGS events: typical charged current interaction in the rock upstream LVD, producing a muon that goes through the detector. The colours represent the amount of energy released in the scintillation counters, sum med along each projected view; the legenda is expressed in GeV. The black straight line is the result of a linear to the hit counters.

7 A cknow ledgem ents

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F ig. 7. D isplay of a CNGS events: neutrino interaction inside the LVD detector. The colours represent the amount of energy released in the scintillation counters, sum m ed along each projected view; the legenda is the same as in gure 6.



F ig. 9. Distribution of the total energy detected in the apparatus per each CNGS event where a muon is reconstructed: comparison between the data (black crosses) and MC simulation (red line).



F ig. 8. Distribution of the number of scintillation counters hit per each CNGS event: com parison between the data (black crosses) and MC simulation (red line).



F ig. 10. D istribution of the \side" projection of the angle between the reconstructed muon track and the main axis of the LNGS hall: comparison between the data (black crosses) and MC simulation (red line). In the right picture there is a description of the considered angle $_{zy}$.



F ig. 11.D istribution of the \top" projection of the angle between the reconstructed m uon track and the main axis of the LNGS hall: com parison between the data (black crosses) and MC simulation (red line). In the right picture there is a description of the considered angle xy.