ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics B (Proc. Suppl.) 168 (2007) 169–172

NUCLEAR PHYSICS B
PROCEEDINGS
SUPPLEMENTS

www.elsevierphysics.com

CNGS neutrino beam: from CERN to Gran Sasso

A. Ferrari [a]* A. Guglielmi [b] P. R. Sala [c]

[a]CERN, 1211 Geneve 23, Switzerland.

[b]Istituto Nazionale di Fisica Nucleare and Dept. of Physics, via Marzolo 8, 35131 Padova, Italy.

[c]Istituto Nazionale di Fisica Nucleare, via Celoria 16, 20133 Milano, Italy.

Energy spectra, intensity and composition of the CERN to Gran Sasso CNGS neutrino beam for $\nu_\mu \rightarrow \nu_\tau$ search are presented with the first results of the beam commissioning and operations.

1. Introduction

The CERN neutrino to Gran Sasso (CNGS [1]) facility is addressed to study the $\nu_\mu \rightarrow \nu_\tau$ transitions as observed in atmospheric neutrinos. While K2K at KEK [2] and MINOS at FNAL [3] are looking for neutrino disappearance, the two experiments ICARUS and OPERA [4] will search for evidence of ν_τ interactions in the CNGS ν_μ beam, where the ν_τ component is initially absent. The CNGS beam design was accomplished on the basis of the previous WANF ν_μ beam experience at CERN [5] for CHORUS and NOMAD experiments [6] which allowed for a powerful study of conventional neutrino beams [7].

2. The CNGS neutrino beam

A schematic description of the CNGS beam line is shown in fig.1. Primary protons are extracted from the CERN SPS at 400 GeV/c of momentum in two spills of $2.4 \cdot 10^{13}$ protons every 6 s. The two spills lasts 10.5 μs each and are interleaved by 50 ms. The CNGS target consists of 13 graphite rods of 10 cm length, 5 (first two rods) and 4 mm diameter, spaced to reduce the meson reinteraction probability. Similarly to the previous WANF beam, a magnetic horn and a reflector, pulsed at $I = 150$ and 180 kA respectively, allow the focusing (defocusing) of positive (negative) charged secondaries produced in target into a 1 km long decay tunnel where neutrinos are produced. A large graphite and iron dump absorbs the residual hadrons at the end of the beam-line.

Table 1
Main parameters for CNGS neutrino beam.

	ν flux $[1/cm^2 pot]$	$< E_\nu >$ $[GeV]$	ν_i/ν_μ [%]	ν_i/ν_μ-CC [%]
ν_μ	$7.4 \cdot 10^{-13}$	17.9		
$\overline{\nu}_\mu$	$2.9 \cdot 10^{-14}$	21.8	3.9	0.89
ν_e	$4.7 \cdot 10^{-15}$	24.5	0.65	0.89
$\overline{\nu}_e$	$6.0 \cdot 10^{-16}$	24.4	0.08	0.06

A sound knowledge of meson production in the target as well as of the focusing system and reinteraction and decay processes of particles along the beam-line is required to predict energy spectra and composition of the ν beam.
A full detailed simulation of the CNGS beam line was performed with the FLUKA code [8]. The FLUKA code has been thoroughly validated against experimental hadroproduction data [9] relevant for neutrino beam production [10], and verified against the NOMAD data [7]. The simulation setup has recently been upgraded to match the final layout of the facility [11]. This Monte Carlo tool now allows to perform in the same framework all calculations of interest for the facility, namely energy deposition, activation, residual dose rate, response of beam monitors, and of course neutrino beam spectra and composition at

---

*On leave of absence from INFN Sez. di Milano.

doi:10.1016/j.nuclphysbps.2007.02.073

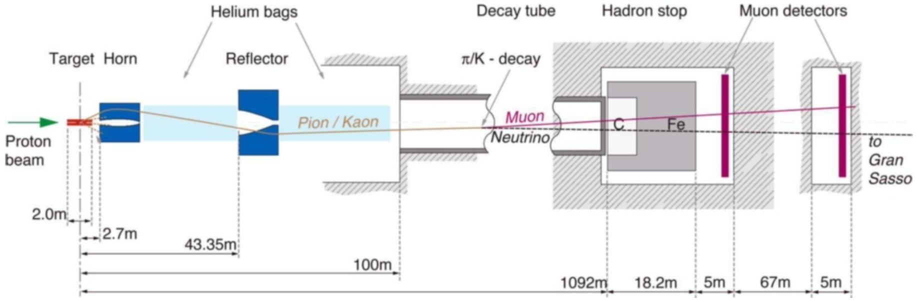

Figure 1. Schematic layout of the CNGS neutrino beam line.

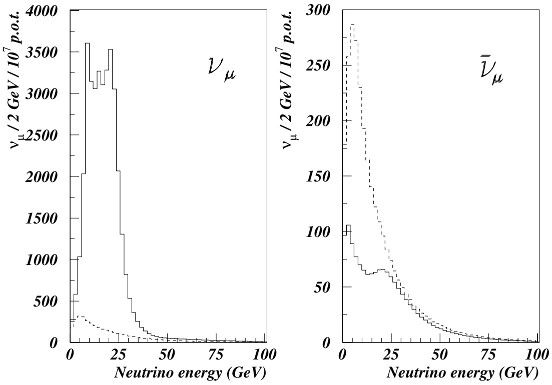

Figure 2. Comparison of ν_μ and $\overline{\nu}_\mu$ spectra at the Gran Sasso as obtained with the horn and the reflector switched on (full line) and off (dashed line).

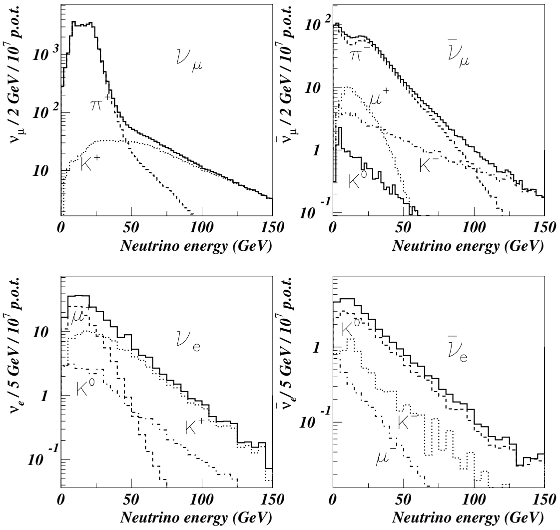

Figure 3. Neutrino spectra with last decay parents at the Gran Sasso site.

Gran Sasso. Tables of neutrino fluxes are available on the web[2].

At the nominal proton beam intensity ($4.5 \cdot 10^{19}$ pot/year) roughly 2800 ν-CC/kt/year are expected at the Gran Sasso site. The focusing of secondary particles increases the ν_μ flux at Gran Sasso by a factor 10 reducing at the same time the $\overline{\nu}_\mu$ contamination by a factor 2 (Fig. 2). The muon neutrino flux is characterized by an average energy of 17.9 GeV and $\sim$ 0.6 % ν_e to ν_μ contamination for $E_\nu < 40$ GeV (Fig. 3) while $\overline{\nu}_\mu$ and $\overline{\nu}_e$ components are below 4 % and 0.1 % respectively. The ν_τ intrinsic level in the beam is expected below 10^{-6}. Only 3 % of ν_μ originates from terziary meson decay following a reinteraction process downstream the target. Almost all ν_μ and $\overline{\nu}_\mu$ are generated in π^+ (97 %) and π^- (85 %) decay respectively, while ν_e comes from μ^+ ($\sim$ 47 %), K^+ ($\sim$ 39 %) and only $\sim$ 10 % from K^0, which however largely contributes (70 %) to the small $\overline{\nu}_e$ component.

Moreover a fluence of about 0.9 μ/m^2/day from neutrinos interacting in the rock at the Gran

---

[2] follow the links from the CNGS web page, http://www.cern.ch/cngs.

Sasso site is expected in the detectors which will help to monitor also the beam intensity and measure the neutrino flux with $E_\nu > 40$ GeV.

A 5 % of systematic uncertainty of neutrino flux at Gran Sasso has been evaluated from the WANF experience. The ν_e/ν_μ ratio is expected to be known with $\sim$ 3.1 % normalization error and $3 \div 4$ % energy dependent error [12].

3. CNGS commissioning and first beam to Gran Sasso

The CNGS neutrino beam commissioning operation started July 10 2006 with the aim to align and monitor the beam-line components by horizontal, vertical and angular scans of proton beam on the target. The proton beam intensity was gradually increased up to 10^{13} proton per spill.

Simulations of the secondary beam monitors response in nominal and "faulty" conditions were performed in order to provide reference values and hints to troubleshooting.

The primary proton beam optics and stability has been checked with beam position monitors all along the trajectory.

Beam-target alignment was controlled by measuring the charged particle multiplicity at the TBID downstream the target as a function of the beam position on the monitor immediately upstream the target.

Further checks were performed by monitoring the muon flux in the two muon pits that are located after the hadron stop. These pits are equipped with 38 Beam Loss Monitor (BLMs) N_2 filled ionization counters which are held by a cross-shaped frame, allowing for the measurement of muon horizontal and vertical profiles, as well as of the μ flux intensity.

The angular alignment of the proton beam could be checked by a low intensity runs without target and without current in the magnetic lenses. As predicted by simulations, the muons produced in the beam dump by the undisturbed primary proton beam provide a signal sufficient to be detected in the muon pits. Thanks to the long decay tunnel, even a small angular misalignment produces a visible displacement of the muon flux: 1mrad misalignment at the target translates in 1m displacement at the beam dump, and then at the muon pits. Runs with the beam in the nominal position and with ±0.2 mrad steering allowed to verify the beam alignment.

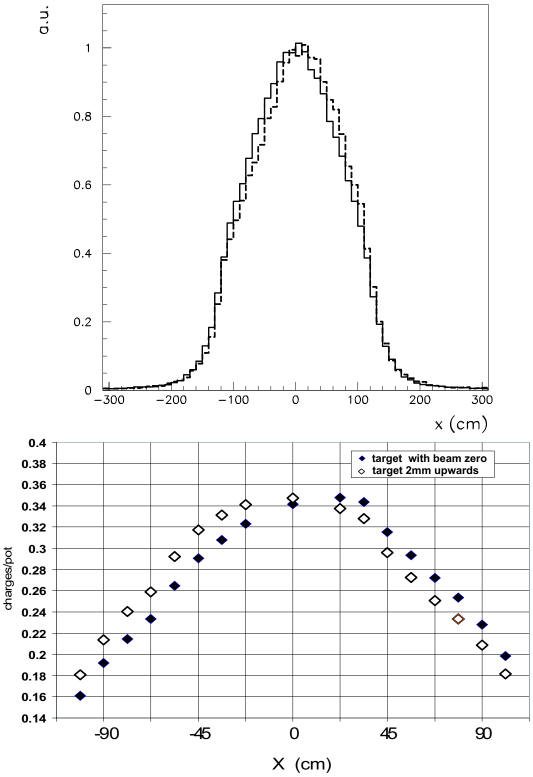

Figure 4. Top: simulated μ fluxes in the first muon pit, in the reference case (full line) and for a 2 mm horn misalignment (dashed line). Bottom: corresponding measured profiles with the nominal alignment (filled) and with a 2 mm upward displacement of target and proton beam (empty).

The relative target/horn alignment has been adjusted after inspection of the vertical muon profiles in the first pit, that showed a distortion compatible with a 2 mm horn displacement (Fig.4).

The focusing capability of the horn and the reflector is also visible in the muon pits. The comparison of muon fluence in the first pit with the horn and the reflector switched off showed a factor 10 difference with respect to the standard one, in agreement with simulations (Fig. 5).

From 18 to 30 August 2006 the CNGS facility entered in the operation and sent to Gran Sasso detectors the first high intensity neutrino beam, 7.6×10^{17} pot with an almost constant extraction intensity of 1.7×10^{13} proton per spill.

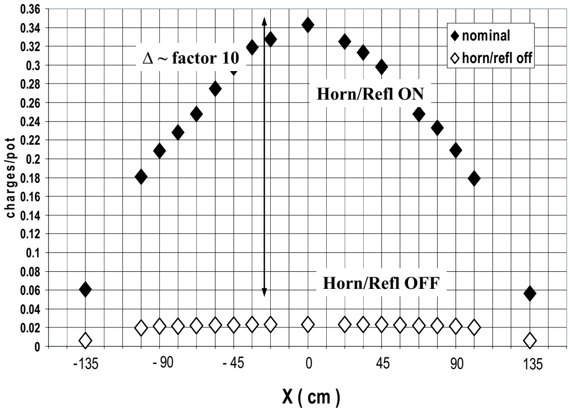

Figure 5. Comparison of the measured muon horizontal profiles in the first muon pit with the horn and the reflector switched off.

4. Conclusions

The CNGS neutrino beam from CERN to Gran Sasso is designed to $\nu_\mu \to \nu_\tau$ oscillation search looking for ν_τ appearance in a pure ν_μ beam as indicated by the experiments with atmospheric neutrinos. The project was approved on December 1999: civil engineering, equipment design and production and installation phases lasted six years and handed over to operation on 18 August 2006. The beam commissioning shows that both the proton beam and the secondary beam parameters are within the specifications. The CNGS neutrino beam facility is operational: now the neutrino has to be carefully measured and studied, the toughest and more interesting part is still ahead.

Acknowledgments

The authors would like to thank all the CNGS team, and in particular E. Geschwendter who provided commissioning data and plots.

REFERENCES

1. G. Acquistapace et al., CERN-98-02, INFN/AE-98/05 (1998); CERN-SL/99-034(DI), INFN/AE-99/05 Addendum.
2. M.H. Ahn et al.,Phys. Rev. Lett. 90 (2003) 021802; T. Kajita this Workshop; I. Kato, this Workshop.
3. The Fermilab NuMI Group, FNAL NuMI-346, 1998; E. Ables et al., FNAL P-875, 1995; Nucl. Instrum. and Meth. A503 (2001) 122. S. Kopp, this Workshop; B. Rebel, this Workshop.
4. The ICARUS Coll., Nucl. Instrum. and Meth. A461 (2001) 324; CERN-SPSC/2002-27, SPSC-P-323,(2002); The OPERA Coll., CERN-SPSC-P-318, LNGS-P25-00; M. Komatsu and al., hep-ph/0210043 (2002); Y. Declais this Workshop; M. Sioli, this Workshop.
5. L. Casagrande et al., CERN 96-06, 1996.
6. The CHORUS Coll., Phys. Lett. B 497 (2001) 8, and references therein; The NOMAD Coll., Nucl. Instr. and Meth. A 404 (1998) 96.
7. P. Astier *et al.*, Nucl. Instr. and Meth. A 515 (2003) 800; A. Guglielmi and G. Collazuol, INFN/AE-03/05 (2003).
8. A. Fassò, A. Ferrari, J. Ranft, P.R. Sala, Proc. of CHEP2003, eConf C0303241, arXiv:hep-ph/0306267 (2003); A. Ferrari, P.R. Sala, A. Fassò, J. Ranft, "FLUKA: a multi-particle transport code"(program version 2005) CERN-2005-010, INFN/TC_05/11 (2005).
9. H.W. Atherton et al., CERN-80-07, 1980; G. Ambrosini et al., Eur. Phys. J. C 10 (1999) 605.
10. G. Collazuol et al., Nucl. Instr. and Meth. A 449 (2000) 609.
11. A. Ferrari et al., CERN-AB-Note-2006-038, EDMS No 745389, August 29 2006.
12. A. Ferrari , A. Guglielmi and P.R. Sala, Nucl. Phys. B 145 (2005) 93.