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CNGS - CERN NEUTRINOS TO GRAN SASSO

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Abstract

The CNGS project was approved by CERN Council in December 1999. This report gives a short description of the ν_μ beam to be built at CERN in the direction of the INFN Gran Sasso underground laboratory (LNGS). The first goal of this new facility is the production of sufficient ν_μ in an energy region optimised for the detection of an adequate number of ν_τ - produced by oscillation - at LNGS. The layout, cost, schedule and the expected beam performance of the CNGS facility is summarised.

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1 Introduction

The field of neutrino oscillation has received a considerable boost in recent years, to a large extent due to the exciting new observations on atmospheric neutrinos at the Superkamiokande detector in Japan [1]. A very likely interpretation of the lack of ν_μ events from below observed, is that a number of ν_μ disappear by oscillation into ν_τ. These observations have led to the proposal and construction of K2K in Japan, NumI/MINOS in the USA and more recently CNGS - a CERN neutrino beam to Gran Sasso - at CERN.

The CNGS facility will provide an intense beam of ν_μ with very small contamination of other neutrinos, in the direction of the existing Gran Sasso underground laboratory in Italy, at 732 km from CERN. The ν_μ produced will travel about 2.5 ms on this journey, long enough to allow some of them to oscillate - it is expected - into ν_τ. The detectors presently proposed, OPERA and ICANOE, are specially designed to detect the the ν_τ with a high rejection power of background events (for a description of these detectors, see the next contribution [2]). CNGS would therefore allow the first direct observation of the ν_μ-ν_τ oscillation.

2 The CNGS Project at CERN

2.1 Overview

The CNGS project is described in a design study [3] and its addendum [4]. The main ingredients of the CNGS facility are shown in Figs. 1 and 2. The CNGS facility is using the existing SPS accelerator and its injectors at CERN as a source of 400 GeV protons. These protons are extracted from the SPS by a system of kicker magnets into an 800 metre long beam transfer line. At the end of this beam line, the protons are travelling in the direction of Gran Sasso, shortly before hitting a graphite target. Secondary particles (most importantly, π^+ and K^+) produced in the target are focussed into a 1 kilometre long evacuated decay tunnel. Many of these mesons decay, thus producing an intense ν_μ beam. The remaining hadrons, together with the non-interacting protons, are stopped by a beam dump. Muons are measured in two locations, immediately after the dump and 67 metres downstream of the first detector plane. Observing the muons, which stem from the same parent particles as the ν_μ, allows to deduce the intensity, size and direction of the ν_μ neutrinos in the beam.

2.2 Design Criteria and Boundary Conditions

A number of important constraints had to be taken into account during the design phase of CNGS. First, the construction and operation of this new facility should in no way interfere with the LHC project. Second, there should be no additional surface building in the densely populated area around CERN.

For reasons of limited resources, the CNGS project was to take advantage as far as possible from existing installations (eg. the SPS accelerators and its injectors), from equipment becoming available

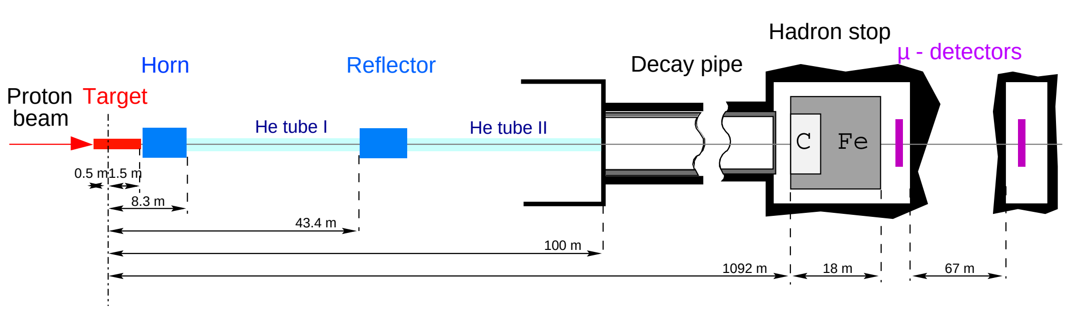

Figure 1: *Schematic view of the main ingredients of the CNGS beam.*

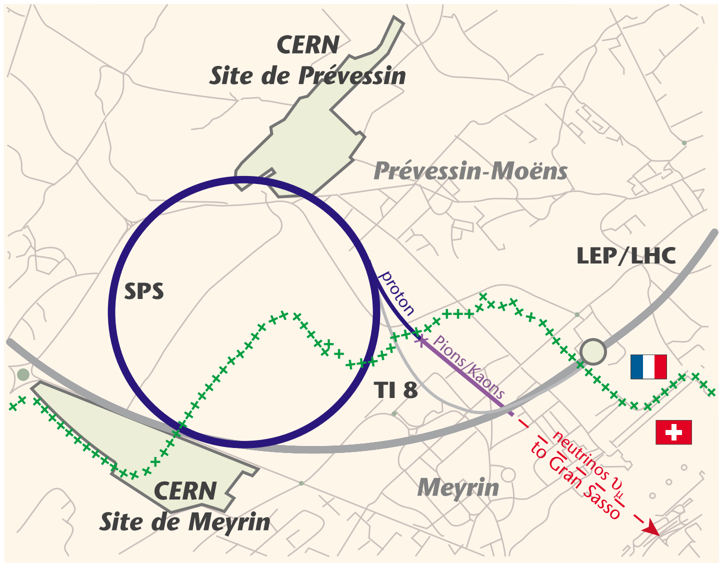

Figure 2: *Overview of the CNGS project at CERN: protons are extracted from the SPS towards a production target. Pions and kaons produced in this target are focussed towards Gran Sasso. Their decay in flight produces the* ν_μ *neutrinos.*

in connection with the LHC project (eg. the fast extraction system from SPS to LHC) as well as from other existing material (eg. magnets from the West Area Neutrino Facility or from LEP).

Finally, the design is based on the many years of experience in building neutrino beams at CERN, most recently the one for the CHORUS and NOMAD experiments. This is of particular value in the design and construction of the most delicate equipment, i.e. the target and the focusing devices, horn and reflector.

2.3 CNGS layout

The layout of the CNGS facility is shown in Fig. 3. Protons are extracted from the SPS using the extraction system to be built for the beam transfer via the TI8 line to the LHC. A switch magnet will direct the protons into the transfer line towards the CNGS target. Details of the underground works in the region of the extraction are shown in Fig. 4.

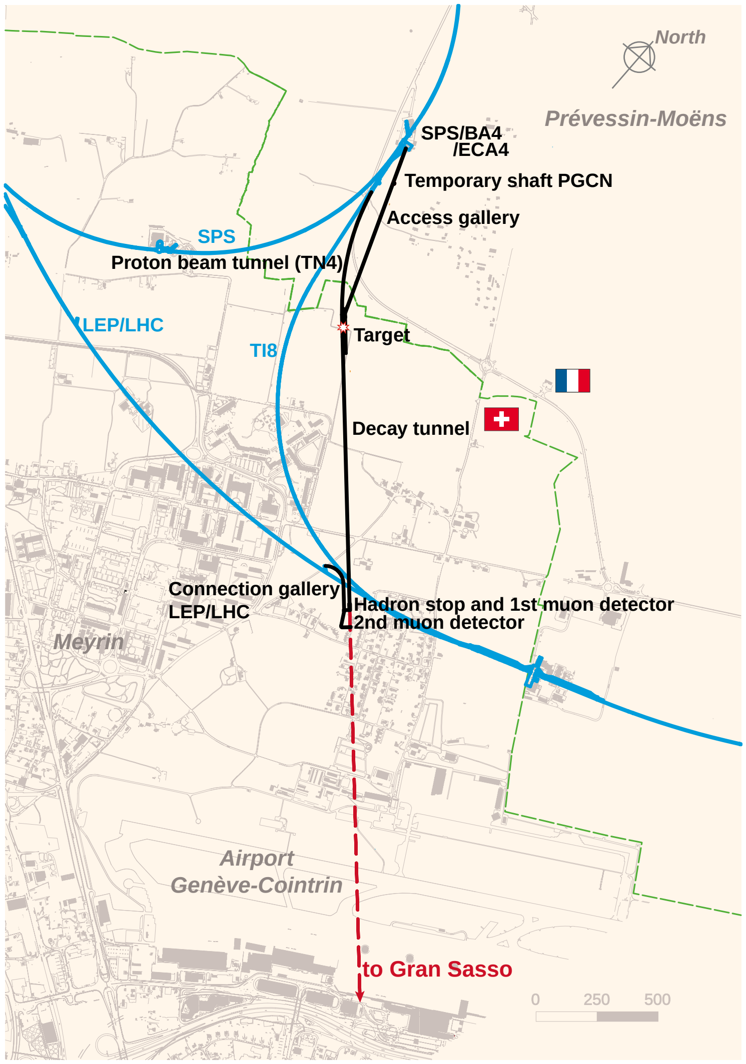

Figure 3: *The layout of the CNGS project at CERN, starting from the existing SPS accelerator at point 4. All the underground works will be conducted from the temporary shaft PGCN. No additional surface buildings will be needed for CNGS.*

The target cavern (cf. Fig. 5), which apart from the target houses also the focusing elements (horn and reflector), is connected to the point 4 of the SPS via an access gallery. The exit of the target cavern is also the entrance to the decay tunnel - a 2.45 cm diameter steel tube will be buried in concrete for reasons of stability and shielding of the surrounding rock.

The region of the dump (hadron stop) and muon detectors is shown in Fig. 6. The last section of the decay tunnel crosses some 8 metres under the LHC tunnel. A short and steep access tunnel from the region of the LHC cavern RE88 to the muon detector positions is foreseen.

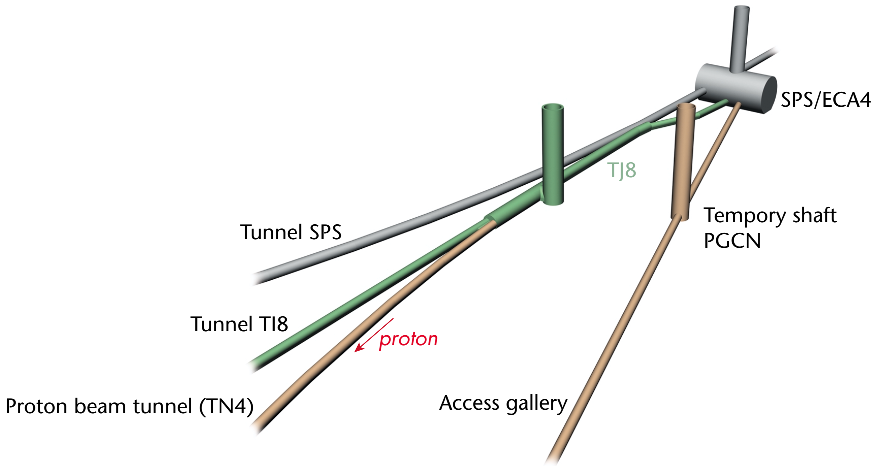

Figure 4: *The region around point 4 of the SPS: TI8 is the transfer tunnel from SPS to LHC, now under construction. The proton beam tunnel TN4 and the access gallery to the target chamber will be added for the CNGS project.*

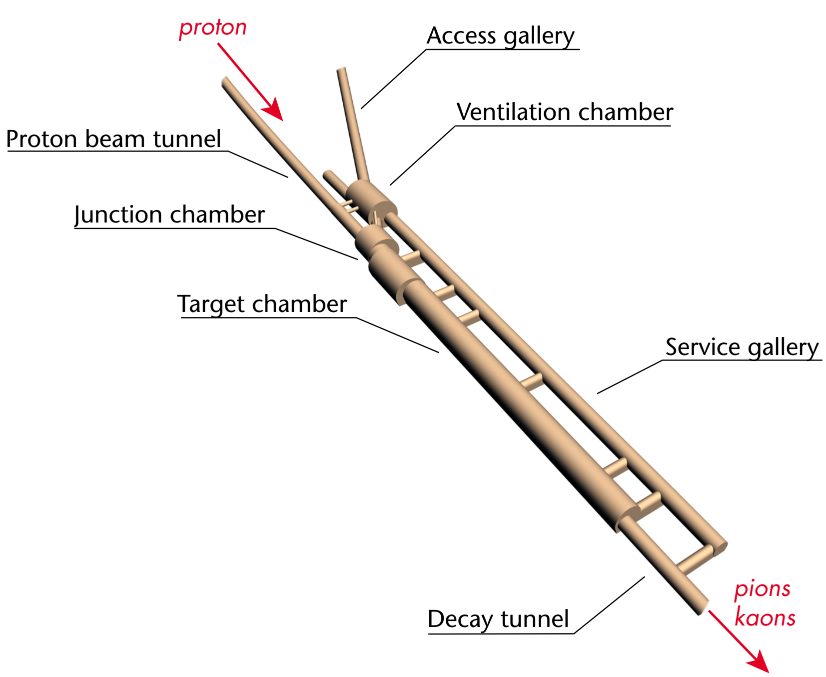

Figure 5: *The target chamber and its adjacent caverns and galleries: The service gallery will house power supplies, pumps and other equipment that must not be exposed to the high levels of radiation in the target region.*

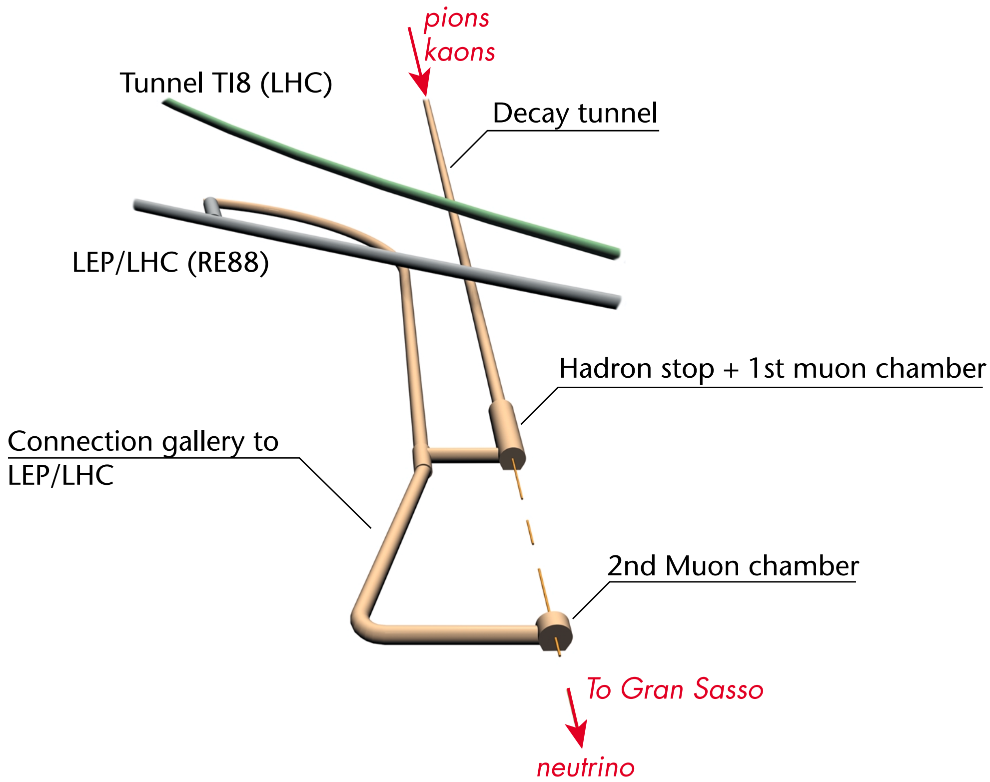

Figure 6: *The region of the CNGS beam dump (hadron stop): the exisiting LHC tunnel and the TI8 transfer line are passing above the CNGS decay tunnel. Access to the muon detectors is via the LHC tunnel.*

3 Expected CNGS Performance

The presently assumed performance of the CNGS facility is described in detail in [4]. A short summary is given here.

3.1 Proton beam and target

The intensity of the 400 GeV proton beam on the CNGS target has been carefully estimated, taking into account the different scenarios of SPS operation beyond the year 2005: other SPS fixed target experiments (slow extraction), LHC pilot beams, and LHC filling scenarios (both for proton and ion running of LHC). For the SPS performance per cycle, the numbers from the best year so far (1997) have been assumed. The result of these studies shows that 4.5×10^{19} protons on target per year can be expected in a run of 200 days. It should be pointed out, however, that significant improvements are expected for the coming years, mostly thanks to the efforts towards the SPS as an LHC injector.

Two fast proton beam extractions per cycle are foreseen (10 microsec per extraction, 50 millisec apart). In each extraction, 2.4×10^{13} protons will be delivered to the CNGS target. This is a considerable challenge for the design of the target, which is still under study. Presently, a row of thin graphite cylinders (diameter 4 mm, length 100 mm), cooled by helium gas, is envisaged.

3.2 Neutrino beam performance

Considerable effort was devoted to improve the neutrino beam with respect to the previous beams at CERN. For example, the focusing devices (horn and reflector) will be operated at 150 kA (rather than 100 kA), and the amount of material in the path of the secondary particles has been greatly reduced. The optics is tuned in such a way as to produce a ν_μ spectrum which is well adjusted to optimise the number of expected ν_τ at Gran Sasso (cf. Fig 7): the spectrum is placed near the maximum of the product of ν_μ-ν_τ oscillation probablity[1] times the ν_τ charged current cross section. Input from the proposed experiments lead to a design with a rather sharp cut-off at around 30 GeV: higher energy ν_μ might produce undesirable background (in particular charmed mesons) and obscure the signal expected from ν_τ interactions.

The preformance of the presently designed CNGS neutrino beam is summarised in Table 1. If the hypothesis of ν_μ-ν_τ oscillations is correct, and for the case of $sin^2(2\theta) = 1$, the expected number of ν_τ events is shown in Table 2.

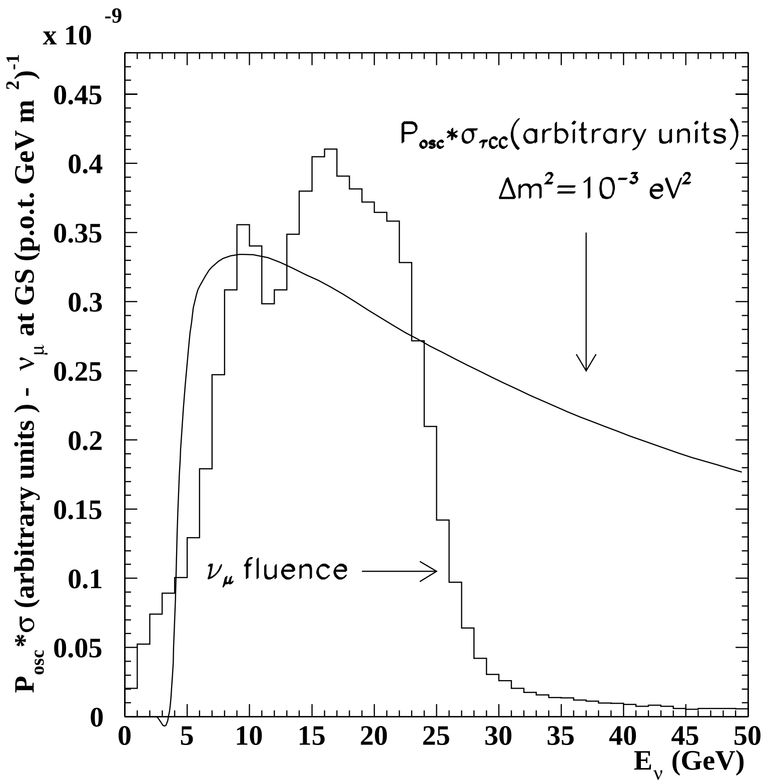

Figure 7: Expected ν_μ fluence spectrum at Gran Sasso, compared to the product of oscillation probability times ν_τ cross section.

4 Status of CNGS

4.1 Decision Process

The conceptual design of the CNGS facility was first presented in June 1998 [3]. The scientific committees of CERN and INFN/LNGS jointly recommended, in September 1998, to build this facility, with ν_τ appearance experiments as a first priority. Following this decision, the CNGS neutrino beam was further optimised, and the present design published in June 1999 [4]. The CERN Scientific Policy Committee unanimously recommended the CNGS facility in June 1999. Finally, CERN Council approved the construction of CNGS in December 1999.

[1] For two flavour mixing, the oscillation probability can be expressed as

$$P_{osc} = \sin^2(2\theta) \times \sin^2(1.27 \times \Delta m^2 \times L / E).$$

Table 1: *Predicted performance of the new CNGS reference beam. The statistical accuracy of the Monte-Carlo simulations is 1 % for the ν_μ component of the beam, somewhat larger for the other neutrino species.*

Energy region E_{ν_μ} [GeV]	1 - 30	1 - 100
ν_μ [m^{-2}/pot]	7.1×10^{-9}	7.45×10^{-9}
ν_μ CC events/pot/kt	4.70×10^{-17}	5.44×10^{-17}
$\langle E \rangle_{\nu_\mu\, fluence}$ [GeV]		17
fraction of other neutrino events:		
ν_e/ν_μ	0.8 %	
$\overline{\nu}_\mu/\nu_\mu$	2.0 %	
$\overline{\nu}_e/\nu_\mu$	0.05 %	

Table 2: *Expected number of ν_τ CC events at Gran Sasso per kt per year. Results of simulations for different values of Δm^2 and for $sin^2(2\theta)$ = 1 are given for 4.5 $\times$ 10^{19} pot/year. These event numbers do not take detector efficiencies into account.*

Energy region E_{ν_τ} [GeV]	1 - 30	1 - 100
$\Delta m^2 = 1 \times 10^{-3}$ eV^2	2.34	2.48
$\Delta m^2 = 3 \times 10^{-3}$ eV^2	20.7	21.4
$\Delta m^2 = 5 \times 10^{-3}$ eV^2	55.9	57.7
$\Delta m^2 = 1 \times 10^{-2}$ eV^2	195	202

4.2 Schedule

The construction schedule of CNGS is shown in Fig. 8. The first six months of 2000 are needed for the tendering process for the civil engineering contract, and to obtain the construction permits. Starting in August 2000, civil engineering will take about 32 months, until April 2003. In a second step, the hadron stop and the decay tunnel vacuum pipe have to be constructed, and the general services installed. The installation of beam equipment can start in July 2004. First neutrino beam towards Gran Sasso is expected in May 2005.

4.3 Cost

The existing equipments together with the investments for LHC represent an estimated value of 22 MCHF to CNGS. The marginal cost of CNGS is estimated to be 71 MCHF, of which 41.6 MCHF are for civil engineering, 19.6 MCHF for equipment (proton beam, secondary beam, hadron stop) and 7.3 MCHF for infrastructure (cooling, ventilation, electrical infrastructure, etc.). 2.5 MCHF have been set aside as contingency.

The project will be primarily financed by the voluntary in cash and/or in kind contributions of CERN Member States. Belgium, France, Germany, Italy and Spain have indicated their readiness to provide funding. Other Member States are invited to join this initiative. If needed, the remainder of the cost would be covered from the CERN budget.

5 Summary

Following its approval in December 1999, the CNGS facility is now well under way to join the effort towards a better understanding of the hints on neutrino-oscillation from the Superkamiokande results on

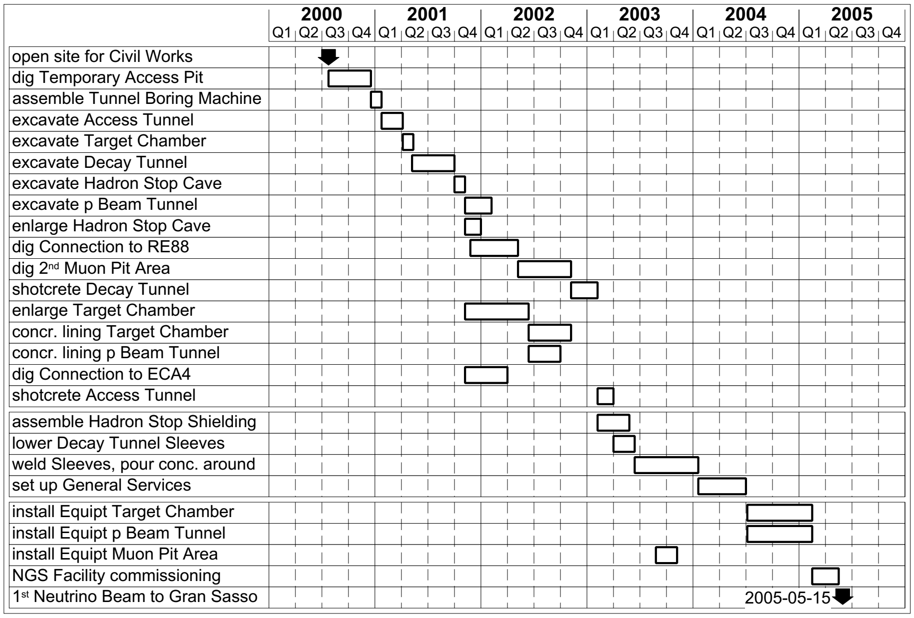

Figure 8: *Construction schedule of the CNGS project.*

atmospheric neutrinos. According to the schedule, in May 2005 an intense ν_μ beam from CERN will be sent 732 km to Gran Sasso, with the aim to detect ν_τ appearance in the experiments installed there.

6 Acknowledgements

This report is a summary of the CNGS project, as described in Refs. [3, 4]. The fruitful collaboration with and the invaluable contributions by all the authors of those reports, which has led to the CNGS project approval, is gratefully acknowledged. More recent illustrations of the CNGS layout and the underground works have been created by J.L. Caron for the general description of the project [5].

References

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[2] A. Bettini, these proceedings.

[3] G. Acquistapace et al., CERN 98-02 and INFN/AE-98/05.

[4] R. Bailey et al., CERN-SL/99-034(DI) and INFN/AE-99/05.

[5] M. Buhler-Broglin et al., CERN AC Note (2000-03) (in French).