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Addendum to Letter of Intent

A High Sensitivity Short Baseline Experiment To Search For $\nu_\mu \rightarrow \nu_\tau$ Oscillation

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This addendum describes the possibility to perform a short baseline experiment in a new neutrino beam line towards the Gran Sasso laboratory.

1 Introduction

In Letter of Intent (SPSC/I213 [1]) we presented an experiment subsequently referred to as TOSCA, intended to search for $\nu_\mu - \nu_\tau$ oscillation. The aim is to improve the sensitivity of CHORUS and NOMAD towards both smaller mass differences and smaller mixing. The detector performance and sensitivity were calculated assuming the detector would be located in the West Area and exposed to the CERN West Area Neutrino Facility (WANF), the most intense neutrino beam presently available for experimentation.

However, continued running of the WANF seems incompatible with the present planning of the new Neutrino beam to Gran Sasso (NGS). Thus, during its discussion of SPSC/I213 the SPSC encouraged the TOSCA collaboration to study the technical feasibility and the performance of the TOSCA detector in this new beam [2]. In order to run in the NGS, TOSCA would have to cope with a much shorter spill, a different geometry of the decay tunnel and an experimental area located deep underground. This addendum addresses the impact of these points on the design and performance of TOSCA.

In the following, we will give some details on the beam performance, describe a possible location in the NGS beam line, address some of the key questions related to the detector design introduced by the short spill and predict the sensitivity to $\nu_\mu - \nu_\tau$ oscillation which can be obtained.

The conclusion of this study is that the experiment is feasible in the NGS beam, albeit with more technical restrictions on the detector technologies. The region of sensitivity is also slightly modified.

An experiment in the WANF would however be easier to perform and, in addition, it would reuse most of the existing infrastructure and would therefore be much less costly.

2 The Neutrino beam to Gran Sasso (NGS)

2.1 Overview of the New Facility

The NGS consists of a neutrino beam directed towards the INFN Gran Sasso Laboratory, an underground laboratory in central Italy, 732 km from CERN, and an underground experimental area for neutrino physics approximately 2 km from CERN at the boundary of the Geneva airport. The far site will allow the search for neutrino oscillations over a long baseline (LBL) while the experimental area near CERN will serve a short base line (SBL) experiment such as TOSCA. The main components of the NGS are shown in Figure 1.

The design of the NGS is deeply rooted in the WANF experience and many of the improvements proposed for the WANF in SPSC/I213 have been adopted in the NGS design. The experimental conditions are to a large extent similar. As the WANF, the NGS beam will be an essentially pure ν_μ beam with a similar average neutrino energy. We will emphasise here in some detail the main differences in the experimental conditions for TOSCA, that follow from differences in the two beams :

- The NGS will use a proton beam with a momentum up to 450 GeV/c extracted from the

CERN SPS in LSS4. The reference beam momentum is 400 GeV/c.

- The neutrino spill is foreseen to be almost 500 times shorter in the NGS, where a fast extraction (FE), over 10 μs, of the primary proton beam is planned. A slower 5 ms fast-slow resonant extraction (FS) is presently used in the WANF.
- The target station is designed to house a segmented graphite target, based on the successful design of the T9 target in the present WANF [3]. The change from a beryllium target in the WANF to a graphite target is suggested by the better thermo-mechanical properties of graphite and is expected to allow the change from fast-slow (5 ms) to fast (10 μs) proton beam extraction without danger to the target even at higher proton intensities. The secondary meson yield is expected to be similar.
- The decay tunnel of the NGS is foreseen to be about 1000 m long, more than three times longer than the WANF tunnel with a length of 289 m.
- The beam dump at the end of the decay tunnel starts with a graphite insert that provides a better distribution of the deposited heat.
- The distance of the TOSCA detector from the primary neutrino production target is foreseen to be about twice as long in the NGS compared to the WANF, 1858 m and 830 m, respectively.

A two-stage focusing system, horn and reflector will focus a range of chosen π and K momenta into a parallel beam, pointing towards the Gran Sasso Laboratory. The WANF experience is the origin of the choice for the focusing elements, horn and reflector, two coaxial lenses, similar in shape but different in size. Their characteristics are not very different from those used in the WANF [4]. The distances of horn and reflector from the target and the shape of the magnetic field provided by them are chosen such to provide a wide-band high-energy ν_μ beam.

Most of the pion and kaon decays produce a neutrino and a muon. A muon monitoring system will permit on-line monitoring, tuning and control of the beam and its alignment. Measuring the muon intensity and profile provides information on the intensity and profile of the neutrino beam.

The NGS is fully described in [5], the conceptual design report prepared by the NGS CERN-INFN Technical Committee.

2.2 Operation of the SPS

A number of operation modes of the SPS have been investigated, where the number of protons on target per year has served as an important parameter in defining these schemes [5]. The proposed SPS cycle configuration is presented below, optimised for the NGS and for the users of the SPS requiring a flat top slow extraction (SE) spill structure.

The following assumptions have been used as input into the definition of a future SPS super-cycle :

- The current LEP cycles (2.4 s total duration) will no longer be required.
- The average SPS power dissipation over the duration of the super-cycle should respect the limit of 33 MW.

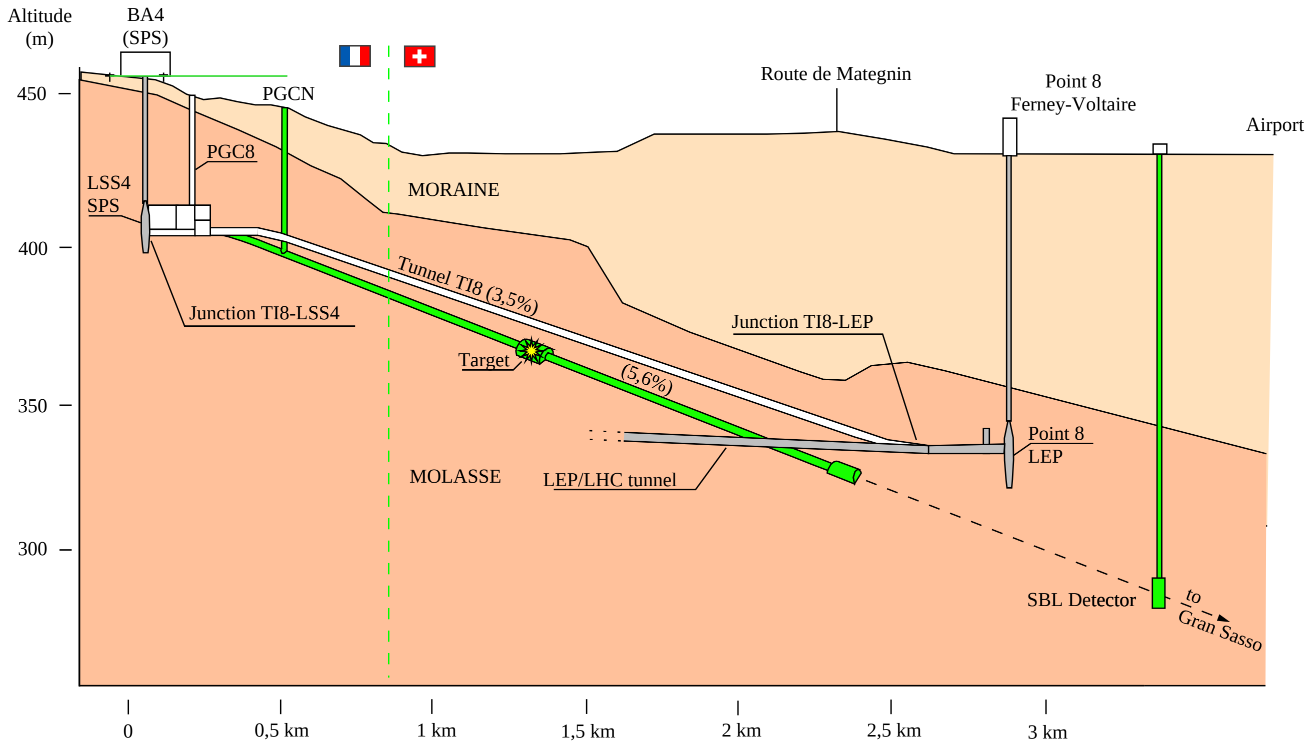

Figure 1: Vertical cut showing the SPS and the main components of the NGS.

- The SPS should be able to provide a SE at 450 GeV/c with a duty cycle around the present 16 %.
- The combination of a FE with a SE in one cycle seems to be very difficult, and no solution exists at present. It is instead possible to combine FS with SE in one cycle.

Figure 2 shows the proposed SPS super-cycle which could be used to provide protons for the shared mode of FE and SE physics. The super-cycle consists of separate cycles for the SE physics and for the FE neutrino programme, thus decoupling the parameters (*e.g.* incident proton momenta) requested by the two communities.

As a working hypothesis, the maximum number of protons per SPS cycle is assumed to be 4.5×10^{13}, a value which has been safely reached and even surpassed in 1997. Given the planned improvements in the SPS and PS complex for the LHC [6, 7], it is likely that the maximum achievable intensity will increase further so that 4.5×10^{13} protons could be safely assumed for normal SPS operation.

A graphite target is expected to sustain the thermal shock induced by the impinging protons [5]. For the two fast-extraction scheme proposed for the NGS, the graphite target limit at 400 GeV/c is 2.25×10^{13} protons per extraction, thus exploiting the full SPS intensity.

Therefore, the number of protons on target per year, defined as a 200-day run with a global machine efficiency of 50%, for the proposed cycle at 400 GeV/c is calculated to be 3.0×10^{19} protons.

Finally, for comparison, Figure 3 shows the configuration of a dedicated neutrino cycle. At 400 GeV/c, the number of protons on to the neutrino target per year is estimated to be 5.4×10^{19}.

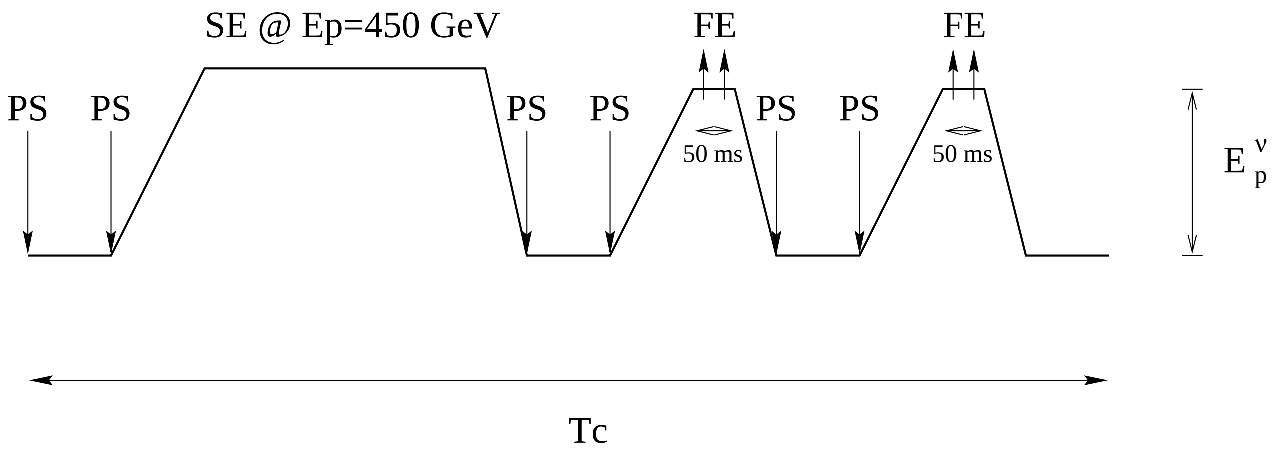

Figure 2: The proposed SPS super-cycle. The parameter E_p^ν is the incident proton momentum for the neutrino cycles and has been studied for various values between 350 and 450 GeV/c. For $E_p^\nu = 400$ GeV one obtains $T_c = 26.4$ sec.

Obviously, the gains for the NGS are substantial, but at the expense of the SE programme. However, given that such a neutrino mode of operation is relatively inexpensive in terms of electrical power, due to the absence of an extended flat-top, the neutrino beam could operate for periods extending beyond the normal SPS proton fixed target operation.

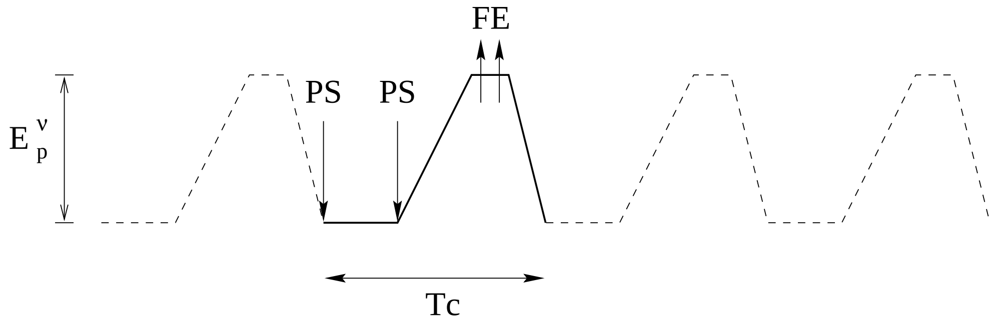

Figure 3: The dedicated neutrino operation mode of the SPS.

2.3 Beam Spectra and Event Rates

The expected performance of various neutrino beam configurations has been studied. The so-called 'reference beam', shown in Figure 4 and outlined in Appendix A of reference [5], has been investigated in detail and the results are discussed below. The 'reference beam' should be considered as a preliminary variant from which an optimised scheme to match the requirements for the LBL and SBL ν_τ appearance experiments will be developed.

A full Monte Carlo simulation of the 'reference beam', called NGSSIM and based on the CHORUS and NOMAD application, has been made using the hadronic production model FLUKA97 [8] specifically integrated into GEANT 3.21 for this simulation. The neutrino parents are tracked in detail to their point of decay and realistic values based on the reference beam parameters have been used for the definition of the geometry together with the material thicknesses, magnetic field strengths *etc.*

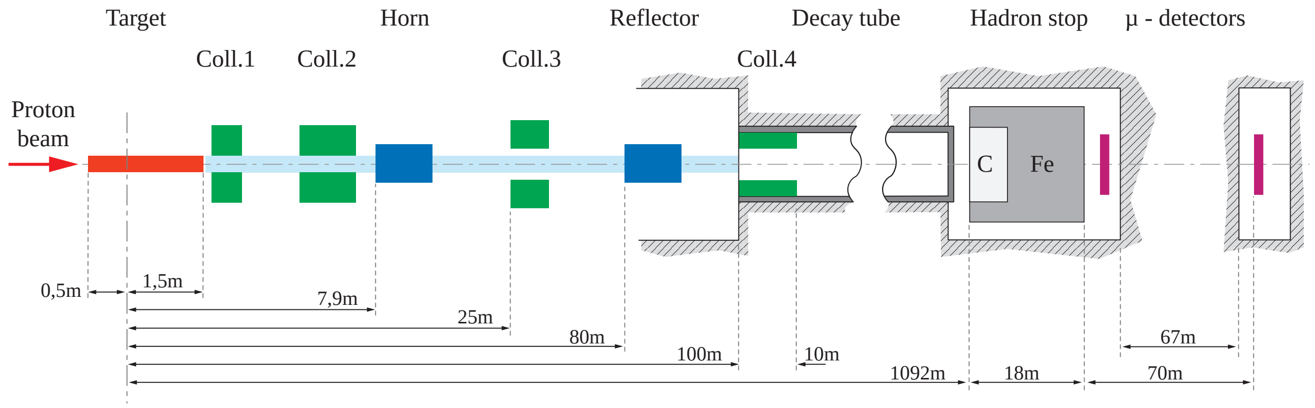

Figure 4: Components of the proposed neutrino beam.

Table 1: Predicted Performance of the NGS 'reference beam' at the Location of TOSCA.

	TOSCA
ν_μ [m^{-2}/pot]	1.55×10^{-3}
mean ν_μ energy [GeV]	25.0
ν_μ CC events/pot/ton	1.55×10^{-14}
ν_μ CC events/year/ton	4.65 10^5

Figure 5 shows the predicted ν_μ flux spectrum produced by the NGS 'reference beam' while Table 1 gives the average energies, contamination and expected number of events for TOSCA. The TOSCA fiducial mass and area are 2.4 t and 1.44 $\times$ 1.44 m^2, respectively.

It should be noted that NGSSIM predicts about a 40% higher flux than the FLUKA97 simulation detailed in reference [5]. The difference seems to be explainable by the different amount of material along the beamline assumed in the FLUKA97 simulation. A detailed comparison is presently in progress.

A number of different beam optics have already been tried and various beam configurations more favourable than the 'reference beam' for ν_τ appearance experiments have been identified. This optimisation work is presently in progress.

2.4 Prompt ν_τ Background

The ν_τ contamination in the beam, mostly due to the prompt tauonic decay of the D_s produced from proton interactions in the primary target and in the hadron stopper, is the ultimate irreducible background for a $\nu_\mu \to \nu_\tau$ oscillation search.

In the NGS, the prompt ν_τ problem appears less severe than in the WANF [9, 10]. Compared to the WANF, the NGS near detector site is about twice as far from both the primary target and the hadron dump. As the angular distribution of ν_τ 's is rather broad and approximately flat, a ν_τ yield lower by about a factor 4 is qualitatively expected just from the reduction of the solid angle.

Quantitative estimates of R in the NGS have also to take into account the different material,

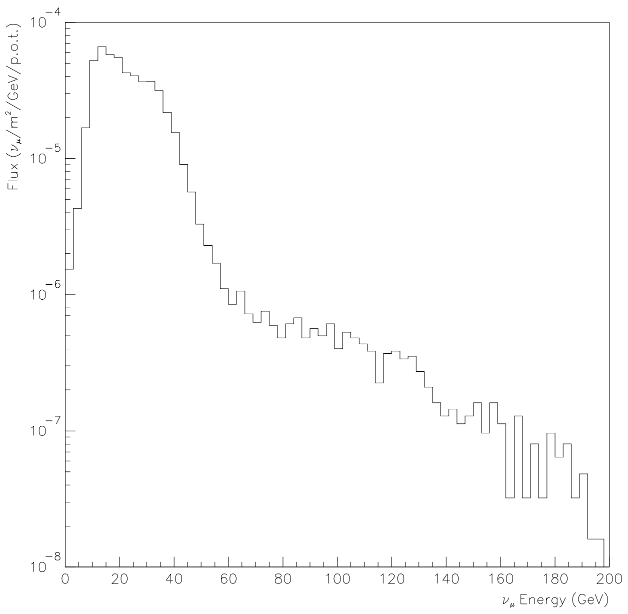

Figure 5: Energy distribution of the ν_μ flux at the TOSCA detector.

Table 2: Predicted Prompt ν_τ Background at the Location of TOSCA.

Proton Momentum (GeV/c)	ν_τ CC (events/pot/ton)	ν_μ CC (events/pot/ton)	R $(= \frac{\nu_\tau \ \mathrm{CC}}{\nu_\mu \ \mathrm{CC}})$
400	1.05×10^{-20}	1.55×10^{-14}	0.7×10^{-6}

graphite, used here for both the target and the beam dump. This implies a 10% larger yield of D_s (and ν_τ) than that from the WANF beryllium target and a 40% lower yield than from the WANF iron beam dump.

Results from detailed estimates of R (the ratio of ν_τ -CC to ν_μ -CC events) in the NGS are given in Table 2. The background level appears, therefore, tolerable for the NGS reference proton beam momentum of 400 GeV/c. The value of R at 400 GeV/c proton momentum is lower than that expected for the operation of the WANF at 350 GeV/c (1.1×10^{-6})

2.5 Muon Flux at the TOSCA Experimental Area

The flux of muons at the SBL experimental site in the NGS beam line is the sum of two components:

1. Muons from hadron decay which punch through the shielding.
2. Muons from neutrino interactions in the shielding.

This second contribution cannot be eliminated. It can, however, be reliably estimated [11] from the predicted neutrino flux and the density of the molasse, taken to be 2.4 g/cm^3, that acts as shielding material. For a proton momentum of 450 GeV/c, the estimated background flux is 10 muons per 10^{13} protons over a 2×2 m^2 detector surface. About 95% of these muons come from the neutrino interactions in the last 40 m. of the shielding, just in front of the experimental site.

The first background is estimated to be much smaller than the second component. In the NGS design, the stopping power of the molasse is reinforced by the presence of the hadron stopper, made of graphite and iron. A detailed shielding calculation reported in Reference [5] indicates, for a 450 GeV/c proton beam, a flux from punch-through muons of 0.25 muons/m^2/10^{13} pot on an SBL detector. This is negligible with respect to the contribution from neutrino interactions, thus keeping the total muon flux per 10^{13} protons to about 2.5 muons/m^2.

This flux is substantially smaller than the one seen by the present neutrino detectors in the WANF. It will thus present no problem to the detector but, on the contrary, will be useful for troubleshooting, tuning and alignment of the detector.

3 The TOSCA Site at the CERN NGS

The planned location of the experiment is at 1858 m from the proton target. Due to the -5.6% slope of the beam, its underground depth is already 151 m at this location (see Figure 1). On the surface, the site corresponds to an unoccupied plot of land of around 3000 m^2 area, which belongs to the Geneva airport. According to our studies this plot is sufficiently large to house the necessary infrastructure for the TOSCA experiment.

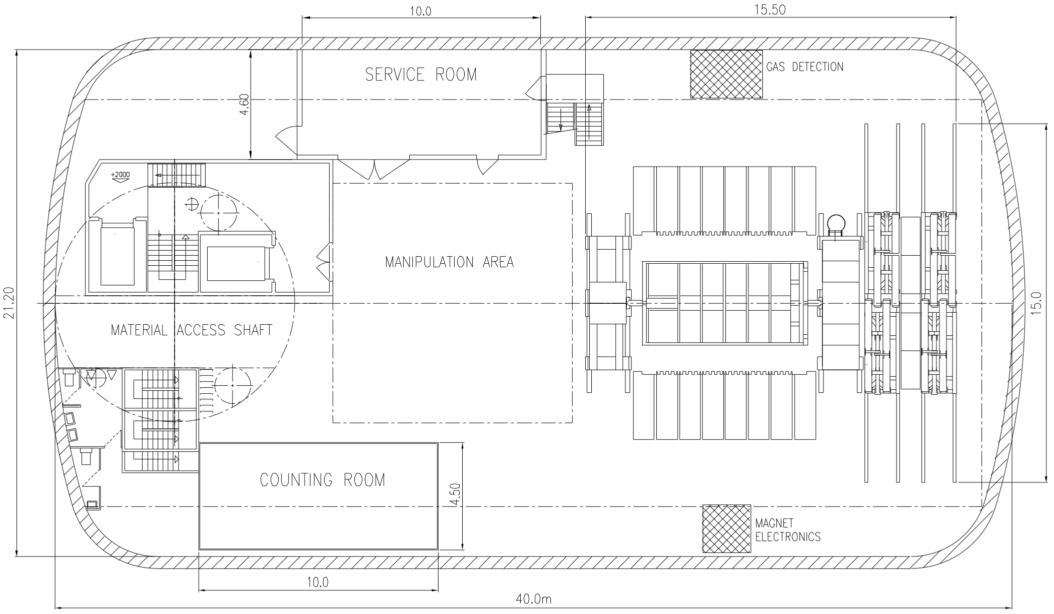

Figure 6: *The layout of the underground cavern (top view) with the access shaft on the left and the TOSCA experiment with open magnet on the right*

The basic elements of the site infrastructure are:

- An underground cavern housing the experiment, its electronic counting house, a manipulation area for detector equipment and a service room for ventilation, cooling and electrical supplies (see Figures 6 and 7)

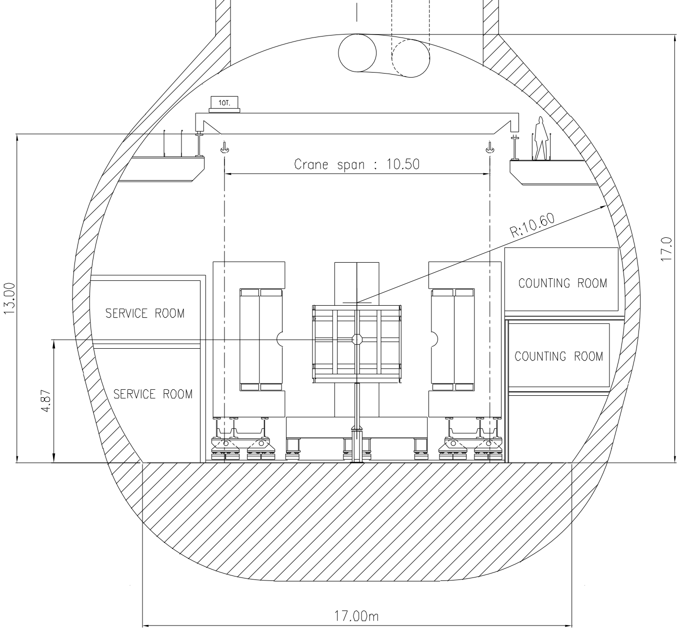

Figure 7: *The cross section of the underground cavern. The MEP50 magnet in open position is depicted at the centre.*

- A 140 m deep shaft of 10 m diameter comprising a 9x3 m^2 material shaft, cables trays and conducts as well as a pressurised personnel access zone with 2 elevators and a staircase.
- Several surface buildings: a hall for material access and manipulation, a building for cooling and ventilation equipment, 2 buildings for electrical power conversion and supplies, an office building housing the control room of the experiment and a building for detector gas supplies (see Figure 8).

The outer dimensions of the TOSCA experiment are essentially defined by the spectrometer magnet MEP50 and by the muon detection system. The MEP50 magnet is a classical magnet, presently in use by the NOMAD experiment and previously used by the UA1 experiment. Table 3 summarises the main characteristics of the spectrometer magnet. The magnet will be operated at maximum field. It requires sizeable cooling and electricity infrastructures. The proximity of existing buildings near the site and a tight construction height limit due to the proximity of the airport runway exclude the installation of cooling towers or power pylons in the area. Therefore the cooling water for the magnet as well as the electrical power will be transported from the LEP-PA8 site in a surface trench of about 1.2 km length. After the termination of LEP running sufficient cooling power and electrical power will be available at LEP-PA8 and the NGS time planning does not interfere with the LHC planning in this respect.

More detailed information on the design, cost and planning of the site are being written in a forthcoming report [12]. Concerning the time planning for the construction of the site, approximately 3 years starting from the approval date are necessary. The complete cost estimate of the TOSCA site amounts to approximately 41 MCHF. It includes: civil engineering, surface buildings, the trench to LEP-PA8, cooling, ventilation, electricity, cranes, lifts, access control, fire detection, gas detection and supplies for detector gas.

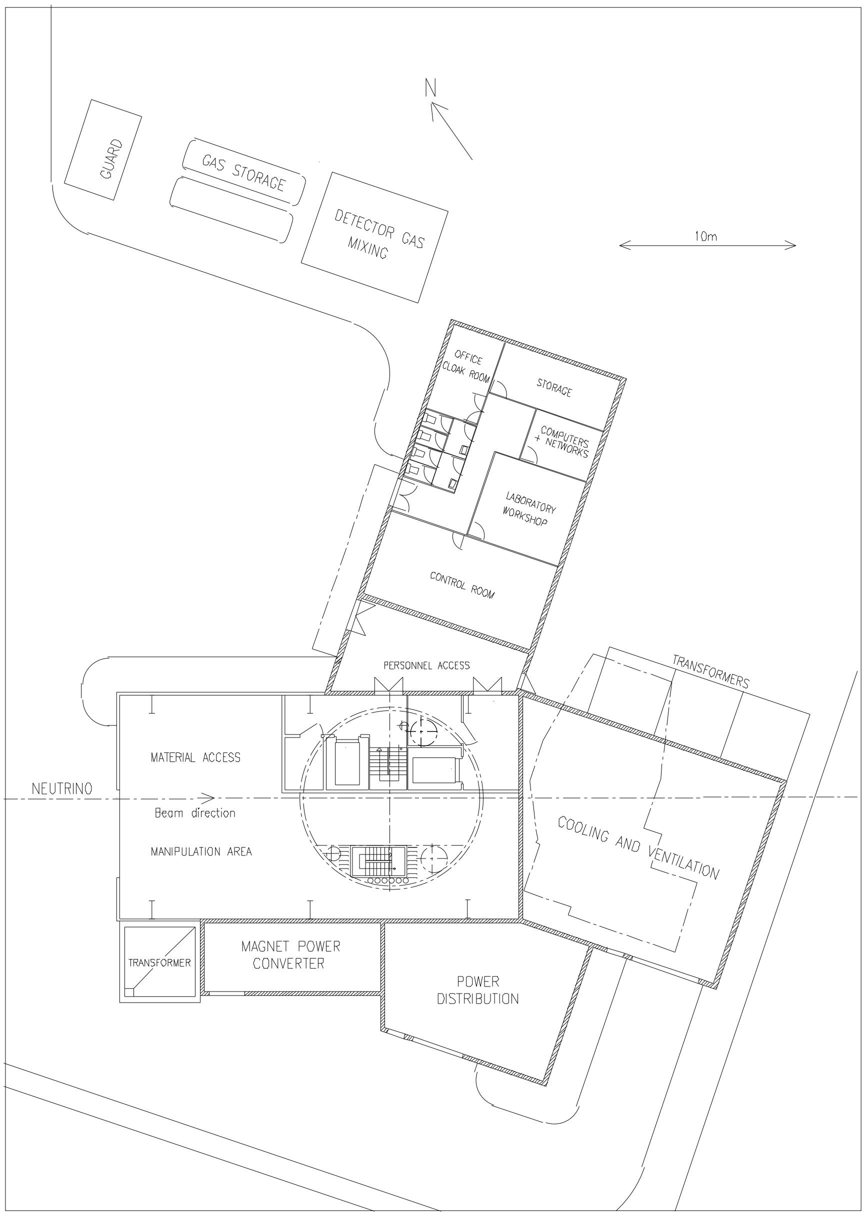

Figure 8: *The layout of the surface site showing the central hall for material access with the access shaft, surrounded by various infrastructure buildings.*

Table 3: *Characteristics of the MEP50 magnet*

Maximum field	0.7 T
Magnetic volume	3.5x3.5x7 m^3
Maximum current	10000 A
Power consumption at max. field	5.55 MWatt
Cooling water flow	180 m^3/hr
Cooling water pressure drop	17 bar
Temperature of water inlet	26^{o}C
Temperature of water outlet	52^{o}C
Total weight	1400 tons

4 Operation in Fast Extraction

4.1 Event Overlay

Neutrino events from up to $2.25 \cdot 10^{13}$ protons on target will be overlaid in the detector and have to be disentangled by the pattern recognition software.

The main contributions to the hit density in the tracking system come from events in the emulsion target (2.4 t) and events in the upstream part of the magnet coil (9 t). About 0.9 emulsion events and 3 coil events are expected per double extraction. A detailed simulation of the shower development of these events in the TOSCA setup has been done, taking into account the emulsion targets, silicon trackers and a (light-weight) tracking system. Bursts could be lost for analysis if the hit density becomes too high.

The average number of charged tracks, crossing a $3 \times 3m^2$ plane perpendicular to the beam, was found to be smaller than 50 per burst. 99% of all bursts can be analysed if the readout as well as the pattern recognition is able to handle up to 100 hits per plane per burst. Various options for tracking systems are currently under study but all of them can safely handle such hit densities. A study of high multiplicity events in NOMAD confirms this calculation.

For pattern recognition performance, the rate of double hits per detector element is another important parameter. Its increase due to the overlay of events in a burst is negligible.

4.2 Silicon Readout Chip

The design of the TOSCA experiment contains a silicon micro-strip tracker. The prototype system used in NOMAD [14, 15] uses the VA1 read-out chip[1], which is fully read out after each trigger. To allow the readout of many triggers within the 10 μsec spill, the VA1 chip design has to be modified.

The VA1 consists of 128 charge sensitive low-noise preamplifiers followed by CR-RC shapers, track-and-hold circuitry, output multiplexing and a multiplexed calibration input. After an external trigger, the sequential readout is performed by activating the output shift registers, using a clock operating at a frequency of 1 MHz.

The modification of the VA1 chip addresses the following requirements:

- Channel by channel multi-buffering capability.
- Optimisation of the signal-to-noise performance for the current detector design [16].

The present design studies show that the above requirements can be fulfilled, making it possible for the VA1 readout chip to operate under the conditions of the NGS.

The possible overlap of information between high multiplicity events and other neutrino events recorded during the same spill can be cured by the implementation of a fast clear driven by inhibiting the processing of these high multiplicity events through an external trigger.

[1] A commercial version of the VIKING chip [13] distributed by IDE AS, Norway.

5 Sensitivity to Oscillation

The different conditions in the Gran Sasso beam line compared to the WANF influence the sensitivity of TOSCA in terms of oscillation parameters. Table 4 shows all relevant parameters necessary for such a comparison.

Table 4: *Comparison of beam line parameters*

	Upgraded WANF	NGS
protons per year (50% eff.)	$3.6 \cdot 10^{19}$	$3.0 \cdot 10^{19}$
ν_μ CC events/pot/ton	1.91×10^{-14}	1.55×10^{-14}
ν_μ CC (2.4 t, 3 years)	$5.0 \cdot 10^{6}$	$3.3 \cdot 10^{6}$
background expected	1.1	0.6
events observed (assumed)	1	1
90% excluded signal	3.2	3.2
$< E_\nu >$	25 GeV	25 GeV
$< L >$	0.6 km	1.3 km

The numbers for the column "Upgraded WANF" have been derived from applying to the WANF the super-cycle shown in Figure 2, but with a FS replacing the FE. Therefore an additional $2.0 \cdot 10^{13}$ protons per super-cycle can be sent to the neutrino target during the same cycle as the SE. Moreover, table 4 assumes a global efficiency of 50% rather than the 75% quoted in [1].

The annual proton yield in the NGS will be smaller than the one in the upgraded WANF assuming the same efficiencies for both beams. The neutrino interaction rate per proton will be smaller as a consequence of the larger distance between proton target and detector. For a detector setup as described in SPSC/I213 and a data taking period of 3 years, one expects 67% of ν_μ charge current events in the NGS compared to the WANF[2]. Using the tau sensitivity and background estimation of SPSC/I213, a sensitivity in mixing angle for large Δm^2 of $2.7 \cdot 10^{-5}$ is expected (to be compared with $1.8 \cdot 10^{-5}$ for the upgraded WANF).

For small Δm^2 the sensitivity improves due to the two times larger average flight length of the neutrinos. The minimal reachable Δm^2 improves from 0.11 eV^2 to 0.06 eV^2.

The sensitivity ranges for TOSCA at the WANF and at NGS are illustrated in Figure 9. The present limits and the expected final results from CHORUS and NOMAD are shown as well.

6 Conclusion

Running TOSCA in the NGS appears to be feasible. The shorter spill and longer target-detector distance do not result in any insurmountable problems. The sensitivity in $\sin^2 2\Theta$ at high Δm^2 would be reduced marginally while at low Δm^2 it would be improved.

[2]The NGS interaction rate is calculated using the same Geant based beam simulation that provides the rates for the WANF (present and upgraded) and agrees to better than 15-20% with the rates detected by CHORUS and NOMAD. It is higher than in [5]. This difference is probably due to the different assumptions about the thicknesses of materials present in the beam. It is presently under investigation.

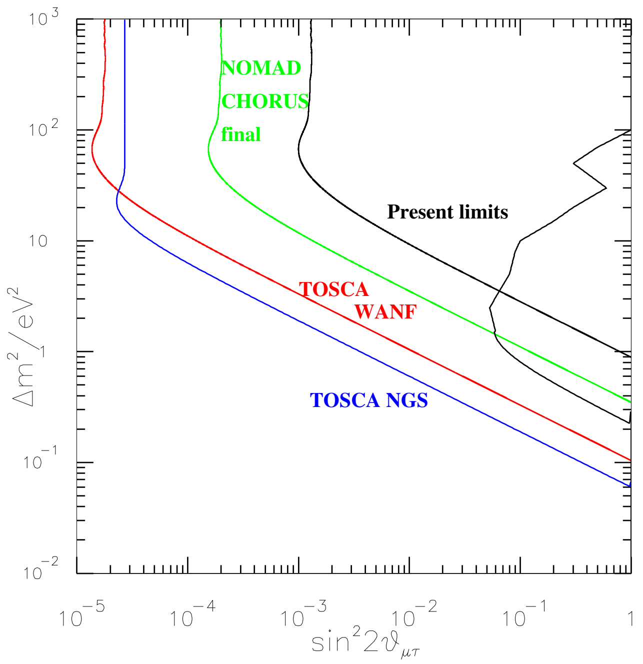

Figure 9: *TOSCA sensitivity for WANF and NGS*

However, while it is evident that running TOSCA in the WANF would cause no infrastructure, logistic or civil engineering problems, these points would become a major issue if the experiment were to run in the NGS.

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