Transfer line to CNGS

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Abstract

The CERN Neutrino to Gran Sasso facility (CNGS) will provide a neutrino beam from the SPS to the Gran Sasso Laboratory in Italy, about 730 km away from CERN. The geometry and the layout of the CNGS primary proton line up to the target are described. The proton beam parameters are reviewed.

1 INTRODUCTION

The LEP results have confirmed the existence of three lepton families (e,μ,τ). To each of these families belongs a neutrino (ν_e,ν_μ,ν_τ). Neutrinos have no charge, and are weakly interacting with matter, which makes them very difficult to be detected. It is as yet unclear whether they have a mass. An answer to this question would allow to settle issues on the observed solar neutrino deficit, on the atmospheric neutrino anomaly and maybe also on the apparently missing mass in the universe. If the neutrinos have a mass, they would oscillate. In the first approximation the oscillation would occur between two neutrino flavours and is described by two parameters, the mixing parameter $\sin^2 2\theta$ and the mass squared difference Δm^2. The sensitivity of the experimental searches of these parameters depends on the neutrino energy (E) and on the distance between the neutrino source to the detector (L). The elapsed proper time is proportional to the ratio L/E and is a measure of the opportunity that a neutrino has to transform its state. For experiments at high energy accelerators, one usually refers to short (L$\sim$1km) or long baseline experiments (L$\sim$1000 km). With its 730 km length, the CNGS falls into the long baseline facilities. At CERN the focus is on the production of a ν_μ beam to measure ν_τ appearance at the Gran Sasso laboratory. In this presentation an overview of the project is given, the main part treats the transfer line itself, from the extraction in LSS4 in the SPS onto the target. The expected beam parameters are also presented.

2 PRINCIPLE

In Fig. 1, the principle of the CNGS facility is sketched. After some modifications to allow two fast extractions per cycle, the SPS fast extraction system foreseen for the LHC, will be used to extract the CNGS protons [1, 2]. The proton beam will then be transported through the TT40 line, which is used in common with the transfer to the LHC via TI 8. After 110 m, the line to the CNGS target, called TN4, branches off and heads to the target. Protons impinging the target will produce, among other particles, π and K mesons. A two stage focusing system, horn and reflector, will focus a range of chosen π and K momenta into a parallel beam,

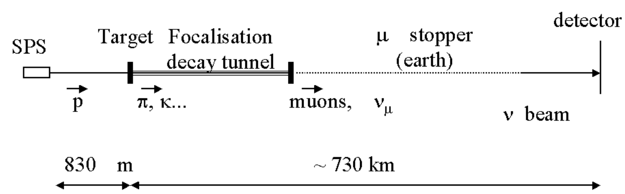

Figure 1: Principle of the CNGS facility.

pointing towards Gran Sasso. A 1000 m long decay tunnel, will allow a fraction of the π and K to decay in flight, producing a high-intensity ν_μ beam. A hadron stop will absorb the non-interacting primary protons as well as those secondary hadrons which have not decayed. A muon monitoring system will permit on-line monitoring, tuning, and control of the beam and its alignment. The natural shielding provided by a long stretch of earth (about 730 km) will absorb the muons.

3 CNGS LAYOUT AROUND CERN

In Fig. 2, the CNGS layout at and around CERN is shown. As there should be no additional permanent surface buildings, an 800 m long access gallery from point 4 of the SPS to the CNGS target cavern is needed for access to the target area with simultaneous LHC injection via TI 8. As the LHC project should not be hampered by the CNGS, a separate neutrino civil engineering shaft (PGCN) near point 4 of the SPS is required. This temporary shaft will be closed once the construction is completed. In order to protect equipment and to provide acceptable working conditions, a service gallery parallel to the target cavern, an enlargement of the cavern around the target, and a well-shielded radioactive storage area are foreseen.

4 TRANSFER LINE LAYOUT

In Fig. 3, the layout of TT40 is represented. Magnetic elements of TT40 and the first two quadrupoles in the TN4 line are used to match the optics parameters of the SPS to the FODO lattice proton line. At 110 m after the extraction point, a set of eight dipoles is used as a switch to separate TN4 from the line which continues as TI 8 to the LHC. These switch magnets, together with their power supply and vacuum chambers have been be recuperated from the WANF (West Area Neutrino Facility). The rest of the primary proton line essentially consists of a 580 m long arc to bend the beam into the direction of the Gran Sasso, followed by a 90 m long focusing section to obtain the desired beam size on target.

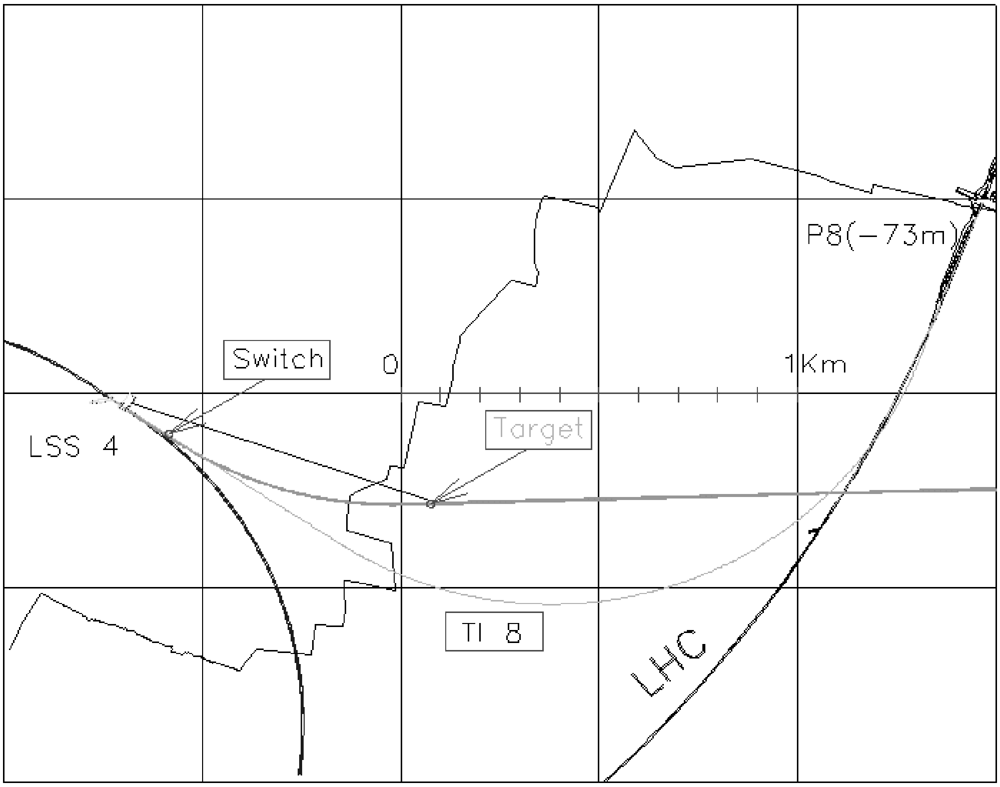

Figure 2: CNGS layout around CERN.

The arc must provide a horizontal deflection of 33^0 and a final vertical slope of 5.6 %. This is achieved by using 73 new long dipoles, each of them deflecting by 8 mrad. These magnets are enlarged versions (37 mm gap height) of the dipoles used in TI 2 and TI 8. The magnetic field of the main dipoles is 1.9 T at 450 GeV and 1.7 T at 400 GeV. A careful choice of the parameters of these magnets makes it possible to share the power supply with the TI 8 main bends. The required vertical direction is obtained by tilting 32 of the magnets along the beam axis by 12.8^0. The arc is made of seven FODO cells of 4 dipoles each, ending with five shortened cells to cancel the horizontal dispersion by means of individually powered quadrupoles. The half cell length is 31.3 m (Fig. 4). The shortened half-cell includes only three dipoles. The short straight section offers space for a monitor and a steering dipole.

Beam steering along the beam line still has to be studied. Using a scheme comparable to TI 8 would imply around 12 new steering dipoles. Four recuperated dipoles have to be added to allow orthogonal steering in both directions onto the target. The new steering dipoles will be powered with small (3.5 A) power supplies.

The quadrupoles are an enlarged version of the ones used in TI 2 and TI 8, their length is 2.2 m and the inscribed diameter is 45 mm. The nominal gradient of these quadrupoles, of which 21 will be used, is 40 T/m. The arc quadrupoles are powered by supplies recuperated from LEP.

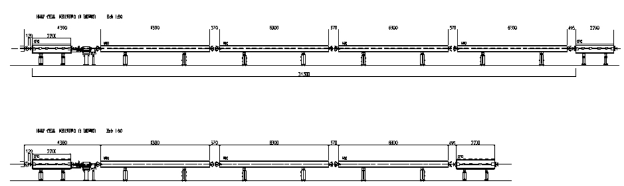

Figure 4: Half cell.

The final focus consists of three quadrupolar lenses. The first one is a single magnet which increases the horizontal dimension of the beam. Then follows a doublet which focuses the beam onto the target to achieve a final spot size of 2 mm in both directions (at 400 GeV, $\sigma \approx 0.3$mm). The first lens of the doublet is made of three quadrupoles powered in series and the last one of two such magnets. Both, the magnets and the power supplies for this section will be salvaged from other CERN facilities (WANF and LEP).

The optical functions for the beam line are shown in Fig. 5 and Fig. 6.

5 BEAM PARAMETERS

The beam parameters are summarised in Tab.1. The beam clearance in the line has been derived at 400 GeV/c, based

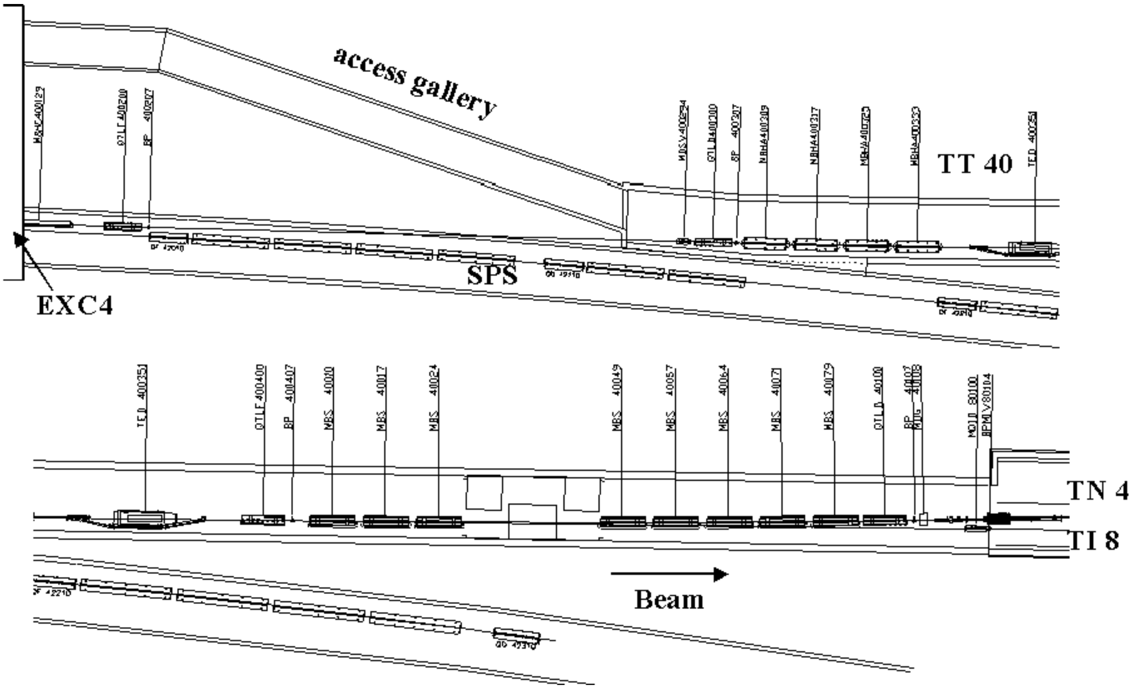

Figure 3: Layout of TT40 line.

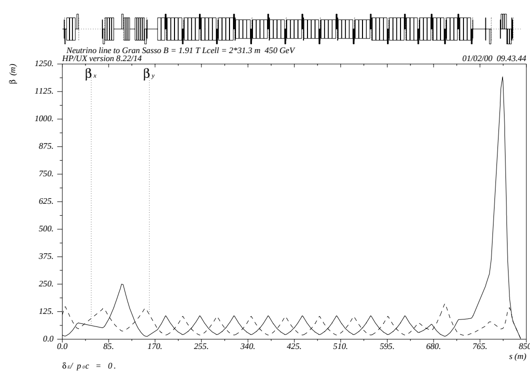

Figure 5: Beta functions along the beam line, plain line horizontal, dashed line vertical.

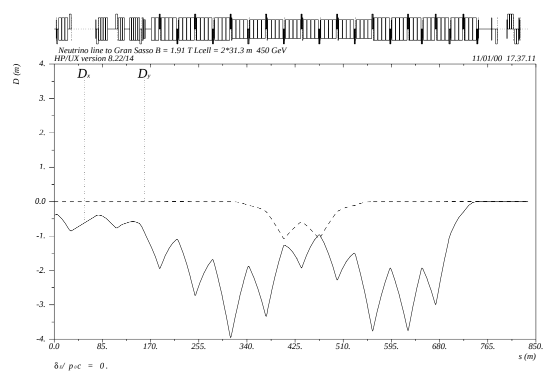

Figure 6: Dispersion functions along the beam line, plain line horizontal, dashed line vertical.

on a trajectory deviation of 4 mm and total tolerances adding up to 4.5 mm. The clearance is above 5 σ except towards the final focusing where the clearance is around 4 σ. However, with a better correction in this region, a trajectory deviation reduced to 2 mm provides 1 σ aperture increased of CNGS operation with 350 GeV.

The implications of 350 GeV CNGS extraction have been studied [3]. This work has been performed in the context of a study to eventually use the existing weak UNK dipoles, an idea which by now has been discarded. The formula used for the aperture calculation was :

$$A/2 = n[\beta\epsilon + (D\frac{\Delta p}{p})^2]^{1/2} + c.o.(\frac{\beta}{\beta_{max}})^{1/2} + Mec.Tol.$$

with β the betatron function, ϵ the emittance, D the dispersion, $\frac{\Delta p}{p}$ the momentum spread. A trajectory deviation (c.o) of 2 mm and mechanical tolerances (Mec.) of 1.4 mm have been assumed. For 350 GeV, the vertical and the horizontal aperture are below the calculated required value (Tab.2, Tab.3). The horizontal aperture could still be acceptable, using an increased kicker strength, and/or negative orbit bumps at injection. However, the vertical aperture is more difficult to increase (relaxing both the orbit and the mechanical tolerances would have the drawback of leaving less margin for problems). Also, increasing the vertical magnetic aperture would imply delays and significant extra cost.

In conclusion the operation at 350 GeV seems still feasi-

Parameters	
Maximum proton beam momentum	450 GeV/c
Proton beam momentum assumed for operation	400 GeV/c
Normalised emittance (1σ)	12 mm mrad
Emittance at 350 GeV	0.032 mm.mrad
Emittance at 400 GeV	0.028 mm.mrad
Emittance at 450 GeV	0.025 mm.mrad
Minimum β at the focus	2.5 m (h/v)
Minimum beam size	0.27 mm
Maximum divergence	.1 mrad
Momentum spread	0.12 %

Table 1: beam parameters)

	Ay_{extr} [mm]
CNGS 350 GeV	21.3
CNGS 400 GeV	20.3
CNGS 450 GeV	19.5
LHC 450 GeV	13.3
Available	20.0

Table 2: Vertical aperture requirements for CNGS and LHC beams (n=5σ).

ble with the presented planned design. However operation with high intensity beam as foreseen for CNGS will be difficult in many respects in critical regions like the extraction channels, where it seems desirable to maintain the sensible tolerances assumed in the design.

6 OUTLOOK

The civil engineering for the CNGS project will start in September 2000. The first beam is expected mid May 2005. In the meantime studies are on-going on the design of the magnets with the beam parameters presented (aperture and field), beam instrumentation, trajectory correction, target, final focus onto the target.

	$Ax_{circ}/2$ [mm]	$Ax_{extr}/2$ [mm]
CNGS 350 GeV	19.9	11.5
CNGS 400 GeV	18.9	11.0
CNGS 450 GeV	18.8	10.9
CLHC 450 GeV	11.1	7.1
Available	19.5	11.1

Table 3: Horizontal aperture requirements for CNGS and LHC beams (n=5σ injected, 10 σ circulating)

7 ACKNOWLEDGEMENTS

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8 REFERENCES

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[2] *The CERN Neutrino Beam to Gran Sasso, Addendum to report CERN 98-02, INFN/AE-98/05*, CERN-SL/99-034(DI) and INFN/AE-99/05.

[3] B. Goddard, private communication.