THE CERN NEUTRINO BEAM TO GRAN SASSO (NGS)

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Abstract

After a short description of the NGS facility and its possible construction schedule, the presentation discusses how the huge demand for protons from the SPS can be met. This includes questions of peak and average number of protons accelerated, modes of extraction and the choice of machine cycles and supercycles to meet also the requirements of the other clients.

1 INTRODUCTION

There is a fair amount of circumstantial evidence for the existence of neutrino-oscillations and consequently of non-zero neutrino masses (solar deficit, atmospheric anomaly, excess of e^+ in the LSND experiment), but no proof. In order to clarify this fundamental question a new generation of powerful experiments is needed. Most promising are experiments with well defined accelerator born long baseline muon-neutrino beams to either observe the appearance of tau-neutrinos or to investigate the disappearance of a fraction of the source beam. There are two approved experiments:

(1) The K2K experiment in Japan, with a neutrino beam generated at the 12 GeV proton synchrotron at KEK ($1.7*10^{12}$ protons on target per s) and the Super-kamiokande detector at a distance of 250 km. Since the energy of the source beam is too low for the detection of tau-neutrinos, only disappearance can be measured.

(2) The MINOS experiment in the US, with a neutrino beam generated at the 120 GeV Main Injector at Fermilab ($3.6*10^{20}$ protons on target per year) and a detector at a distance of 730 km. Since the detector, as approved at present, is not capable of observing tau-neutrinos, again only disappearance will be measured.

In Europe a great effort is underway to determine and agree on a program, for which the NGS will be a key component. The NGS is generated at the SPS and directed toward the Gran Sasso Laboratory in Italy, 732 km away from CERN, where huge caverns exist to house large detectors like ICARUS (already approved for construction) or others, like OPERA, using complementary technologies. The detectors are conceived and the characteristics of the NGS are optimized to observe the appearance of tau-neutrinos.

2 SHORT DESCRIPTION OF THE NGS

The NGS facility has been studied over the past years by a Technical Committee, mandated by INFN and CERN, and a CERN internal working group, and the results are published in a conceptual design report [1]. The main components of this facility are shown schematically in Fig. 1. The layout at CERN in plan view is given in Fig. 2 and a vertical cut in Fig. 3. The fast extracted primary proton beam branches off from the existing LHC injection transfer line TI 8 and is brought onto an axis towards Gran Sasso and focused onto the target through a 550 m long transfer line, made with conventional warm magnets. Coaxial magnetic lenses focus pions and kaons in the desired energy range before they decay in an evacuated 1 km long and 2.45 m diameter tube, thus providing the muon-neutrino beam. Hadrons reaching the end of the decay tube are absorbed by a massive array of graphite followed by iron blocks. Monitoring stations are foreseen downstream of the hadron stop. Hadron stop and monitoring stations are accessible via the LEP/LHC tunnel.

The civil engineering design is finalized and a construction planning, compatible with the LHC work in this region, has been prepared. Commissioning of the beam can be in early 2005 if a positive decision is taken by the end of 1999.

3 SPS PERFORMANCE FOR NGS

In order to be sensitive to the expected very small mass differences of the neutrino flavours, the experiments, besides large mass detectors, require high fluxes of the source beam and therefore as many protons on target (p.o.t.) as possible. It is expected, that at least $4*10^{19}$ p.o.t. per year are delivered, which is 2.6 times more than the average over the past 4 years given to the CHORUS/NOMAD experiments. How this can be achieved is shown in the following.

Present Best Performance of the SPS

The SPS had its best performance during 1997 with a peak number of protons accelerated per cycle of $4.8*10^{13}$ and an average number of p.o.t. per scheduled cycle for physics of $2.64*10^{13}$, corresponding to an overall efficiency of 0.55 [2]. This efficiency includes downtimes as well as beam losses and the fact that not all cycles run at peak intensity. It is assumed that the performance of 1997 can be reproduced in the future.

Running the SPS

To estimate the number of p.o.t. per year for the NGS one has to take into account that there are other users of the SPS. LEP will have come to an end but, as from 2005 onwards, the LHC will receive beam and there will also

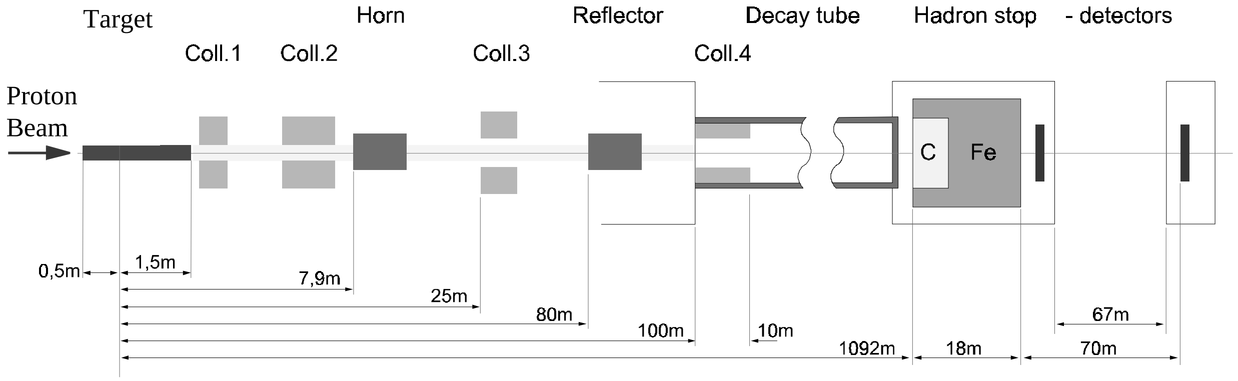

Figure 1: Components of the NGS as described in [1].

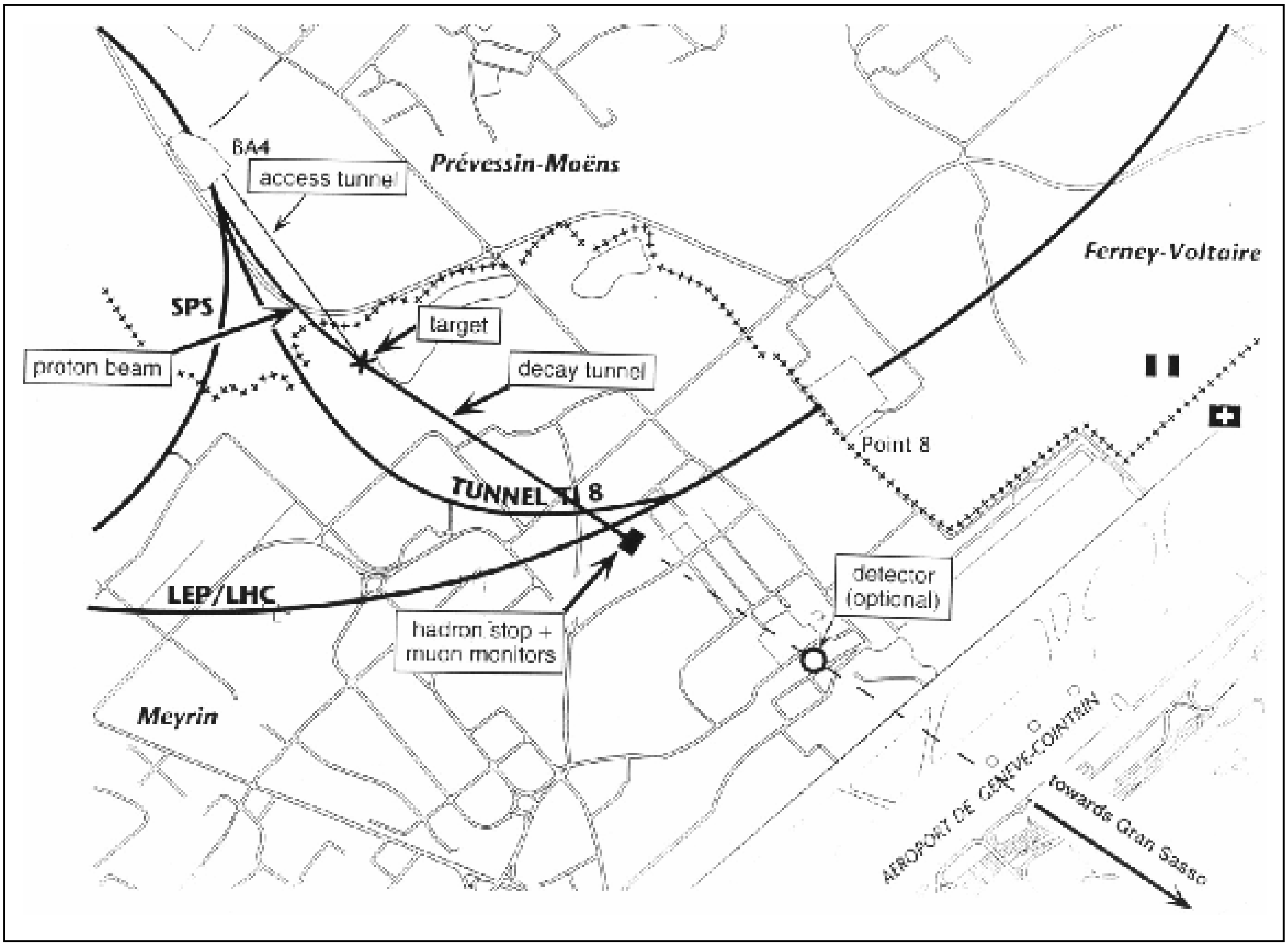

Figure 2: Layout of the proposed NGS Facility at CERN.

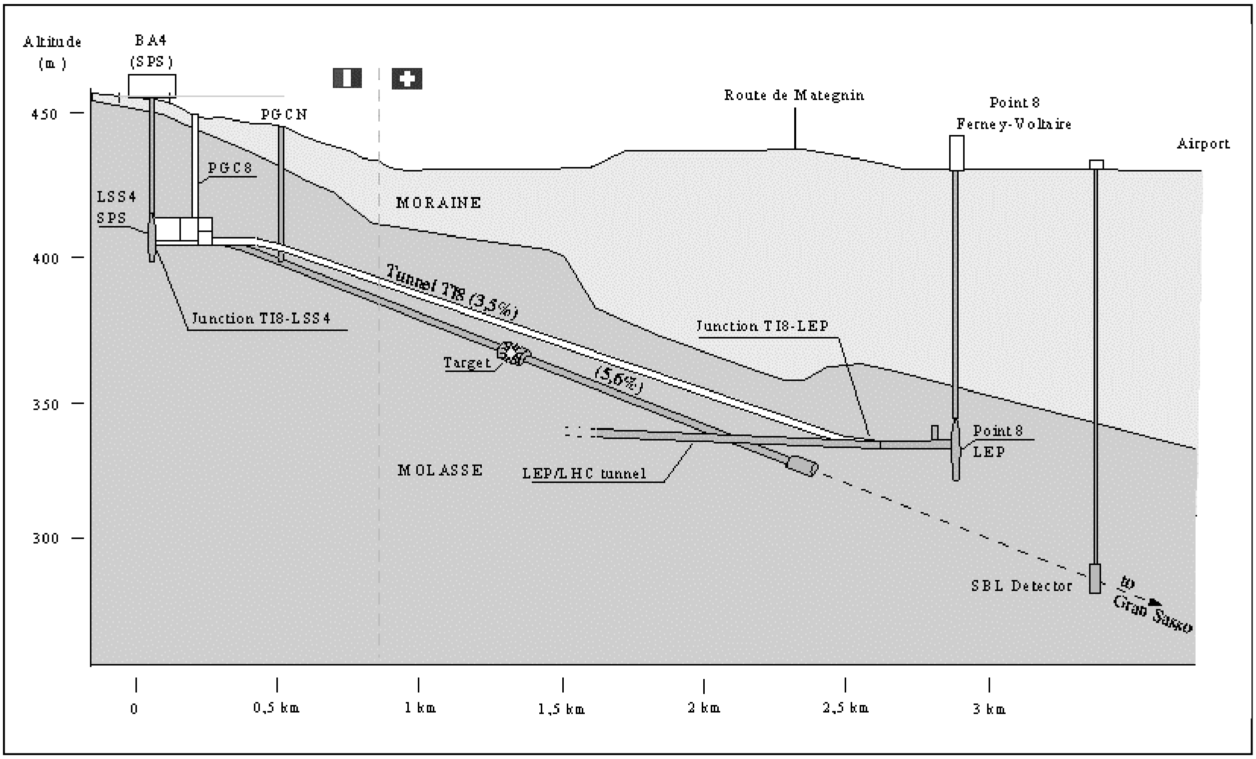

Figure 3:Vertical cut of the proposed NGS layout at CERN.

Nb FE cycles	T_{SC} [s]	T_{FT} [s]	Duty Factor	P_D [MW]	ΔT [°C]	p.o.t. NGS [10^{19}/ 200 d]	p.o.t. SE [10^{19}/ 200 d]
Type A: 1 SE-cycle at 450 GeV, followed by 2 FE-cycles at 400 GeV							
2	26.4	4.0	0.15	32.3	14.7	3.45	1.72
2	25.2	4.0	0.16	33.8	15.4	3.62	1.81
2	24.0	4.0	0.17	35.5	16.1	3.80	1.90
2	22.8	4.0	0.18	37.3	17.0	4.00	2.00
2	21.6	2.8	0.13	33.3	15.1	4.22	2.11
Type B: 1 SE-cycle at 450 GeV, followed by > 2 FE-cycles at 400 GeV							
3	28.8	4.0	0.14	33.4	15.2	4.75	1.58
3	30.0	5.2	0.17	36.4	16.3	4.56	1.52
4	34.8	4.0	0.12	30.8	14.0	5.24	1.31
4	36.0	5.2	0.14	33.4	15.2	5.06	1.26
Type C: 1 SE-cycle at 400 GeV, followed by ≥ 2 FE-cycles at 400 GeV							
2	21.6	3.5	0.16	28.1	< 15	4.22	2.11
2	22.8	4.7	0.21	30.7	< 15	4.00	2.00
3	27.6	3.5	0.13	26.1	< 15	4.96	1.65
3	28.8	4.7	0.16	28.2	< 15	4.75	1.58
4	33.6	3.5	0.10	24.7	< 15	5.43	1.36
4	34.8	4.7	0.14	26.5	< 15	5.24	1.31

Table 1: Examples of SPS supercycles for NGS running.

be an ongoing extended fixed target program in the West and North Experimental Areas [3]. There will be (relatively short) periods of dedicated running for filling the LHC and the time between will be shared between the NGS which gets a fast extracted beam (FE) from LSS4 and the other users who require slowly extracted beams (SE) from LSS2 and LSS6. Since FE after SE from the same flat top is not (yet) an operational technique and since most of the protons are to be delivered to the NGS, it is best to run the SPS with a supercycle, containing one cycle to satisfy all SE-users followed by two or more cycles at 400 GeV with FE, dedicated to NGS.

4 POSSIBLE SUPERCYCLES FOR NGS

The exercise is to maximize the p.o.t./y for NGS, while satisfying the SE-users not only what concerns their total required p.o.t. but also instantaneous rates and a duty factor (ratio of SE spill length and length of supercycle) about as at present.. In defining such supercycles one must respect constraints coming from the hardware, in particular from powering the SPS dipoles, which at present are assumed to be limited to a dissipation of 33 MW, corresponding to an average temperature increase of 15° [4]. It is interesting to understand better this limit and whether it can be shifted slightly. This constraint will not exist any more when, as foreseen in the future, the SE cycle runs at 400 GeV only.

In the following examples it is assumed that the accumulated periods of fixed target operation are 200 days per year. This is considered realistic, maybe somewhat optimistic during the commissioning phase of the LHC [5].

Examples of Supercycles

Type A: 1 SE-cycle at 450 GeV followed by 2 FE-cycles at 400 GeV

Such a supercycle is shown in Fig. 4. The elementary SE-cycle has a length of 10.8 s with a 4 s flat top and the FE-cycles have each a length of 6 s. The elementary cycle lengths include the 1.2 s extra time for injection of 2 PS batches.

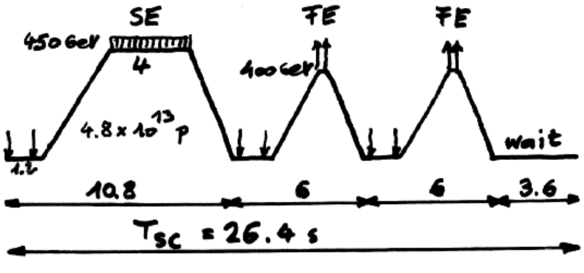

Figure 4: Example of supercycle type A.

If the dissipation in the SPS dipoles is to be limited to 33 MW a recovery time of 3.6 s is necessary, which then leads to an overall supercycle length (T_{SC}) of 26.4 s. In Table 1 the number of p.o.t./y for NGS are given for various T_{SC} reducing the recovery time in steps of 1.2 s and consequently increasing the dissipation (P_D) in the SPS dipoles. Also given are numbers for a supercycle, where the flat-top length (T_{FT}) of the SE-cycle is reduced from 4 s to 2.8 s, which is unfavourable for the duty factor but which brings the dissipation in the SPS dipoles again down to 33 MW. The shown examples provide 3.45 to $4.22*10^{19}$ p.o.t./y for NGS, while providing between 1.72 to $2.11*10^{19}$ p.o.t./y for the other users.

Type B: 1 SE-cycle at 450 Gev followed by > 2 FE-cycles at 400 GeV

Here, longer supercycles with 3 and 4 FE-cycles without recovery time are considered. The duty factor is improved by lengthening the flat top from 4 s to 5.2 s. As shown in Table 1 4.75 to $5.06*10^{19}$ p.o.t./y for NGS can be delivered, leaving between 1.26 to $1.58*10^{19}$ for the other users.

Type C: 1 SE-cycle at 400 GeV followed by ≥ 2 FE-cycles at 400 GeV

Here, supercycles with 2, 3 and 4 FE-cycles and a flat top length of the SE-cycle of 3.5 s and 4.7 s are considered. The dissipation in the dipoles stays always below 33 MW. As shown in Table 1 up to $5.43*10^{19}$ p.o.t./y can be obtained for NGS.

In the case that not all of the possible $4.8*10^{13}$ protons in the SE-cycle are needed, it would be desirable to give them also to the NGS. This requires that a technique becomes operational which preserves the beam gaps left from injection to the end of the flat top, for the rise of the FE kicker, while SE takes place as usual. This seems feasible by turning on during these gaps the existing 200 MHz or another dedicated RF-system at optimum frequency, thus creating a barrier and preventing the protons from penetrating into the gaps [6].

If the SPS would run entirely dedicated for NGS, which is unlikely unless for shorter periods, $2.64*10^{13}$ p.o.t. would be available every 6 s, which, normalized to 200 days, would amount to $7.6*10^{19}$ p.o.t.

5 INCREASING THE SPS INTENSITY

To deliver even more protons to the NGS it is necessary to increase significantly the intensity of the SPS. This is a difficult and complex problem although several of the present limitations will have to be removed to provide the nominal beams for the LHC. To really profit for the NGS one must keep in mind that the protons have to be brought safely onto the target and that an eventually necessary lengthening of the cycle, e.g. for 3 batch injection/extraction, must be compensated by even higher intensities.

6 CONCLUSIONS

The NGS, if built, will become a very demanding client for the SPS. It has been shown, that the expected

$4*10^{19}$ p.o.t./y can be provided at present potential running conditions and that under circumstances up to $5*10^{19}$ p.o.t./y are possible. In order to be well prepared an effort should be made to get (again) acquainted with fast extraction, to review the maximum tolerable dissipation in the SPS dipoles and to study a technique to do fast after slow extraction from the same flat top. Finally, thought should be given to increase the peak intensity of the SPS to beyond the present $4.8*10^{13}$.

ACKNOWLEDGEMENT

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