

DESIGN STUDY FOR A CERN SHORT BASE-LINE NEUTRINO FACILITY

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Abstract

A design study has been initiated at CERN to the conception and construction of a short base-line neutrino facility, using a proton beam from the CERN Super Proton Synchrotron (SPS) that will be transferred to a new secondary beam production facility, which will provide a neutrino beam for the experiments and detector R&D. This paper resumes the general layout of the facility together with the main primary and secondary beam parameters and choices favoured for the neutrino beam production.

A NEW NEUTRINO FACILITY AT CERN

As detailed in [1], anomalies have been observed in different neutrino experiments; LSND where an excess of electron anti-neutrinos is observed in a pure muon anti-neutrino beam, but also the re-evaluation of the reactor anti-neutrino fluxes confirm an increase with respect to previous calculations. These observations could hint towards the possible existence of sterile neutrinos with $\Delta m^2_{\text{sterile}}$ in the order of 1 eV^2 .

Several letters of intent and proposals have been made to the CERN PS/SPS experimental committee (SPSC), either to discover or to exclude the existence of the sterile neutrinos [2][3].

A recent proposal from the ICARUS-NESSiE collaboration [4][5] together with an expression of interest by the LAGUNA-LBNO consortium [6], has led to the study of a new short base-line neutrino facility at CERN.

THE OPTIONS CONSIDERED

The most obvious option seems to re-use the existing CNGS facility [7] pointing toward Gran Sasso in Italy. However, the implementation of near and far detector facilities will be very difficult and expensive, as this facility is already at about 35 m underground and points down with a slope of 5.6%. In addition the detectors would need to be housed under non-CERN territory, making access extremely difficult.

For the earlier proposals, the revival of the PS Neutrino Facility (PSNF) was studied [8][9]. This facility, situated in the densely populated CERN Meyrin site, would not provide enough space for multiple experiments.

The revival of the West Area Neutrino Facility (WANF), stopped in 1999, was also studied. The amount of work to be done, impacting infrastructure inside, but also outside CERN, as well as the limited possibility to house the near and far detectors, let alone an additional detector for R&D, meant that this option was discarded too.

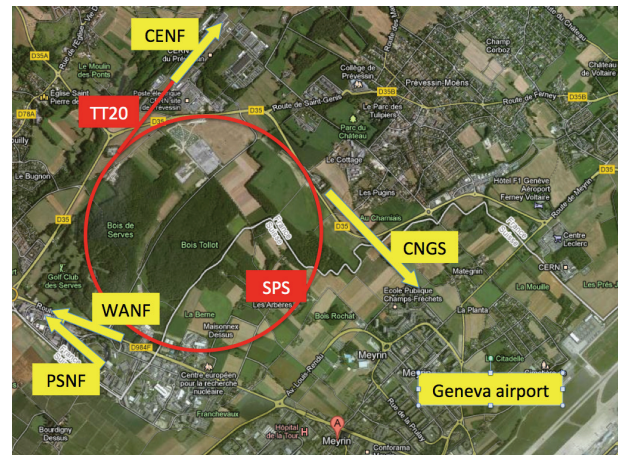


Figure 1: A bird's view of the different options considered at CERN.

The fourth option, constructing the short base-line facility on the Preveessin site, making use of the existing SPS, TT20 transfer line and the SPS North area experimental facilities (Fig. 2) has been retained [10]. The fast extracted beam will first be transported through a large part of the existing TT20 transfer line of which the beam instrumentation will be upgraded to be able to measure not only the de-bunched slow extracted beam, but also the fast extracted 200 MHz bunched beam.

A new branch-off region from TT20 will house the switching magnets to transfer the beam into the new TT26 transfer line that will then connect the beam to the target located in the secondary beam production facility. The front of the first detector in the near experimental facility will be situated at 456 m from the target, while the distance between target and the far detector amounts to 1.6 km. The layout has been conceived to have the top of the detectors at about ground level, resulting in a neutrino beam which points upwards with a slope of 1.58%.

PRIMARY PROTON BEAM

Production and Extraction

The SPS primary proton beam will be extracted from Long Straight Section 2 (LSS2), which is not equipped with a fast kicker and is presently only used to provide slow extracted hadron beams to the SPS North Area (NA). Successful studies and tests have been performed to use the injection kicker in LSS1, for 'non-local' extraction, to excite a 100 GeV beam and extract it using the magnetic extraction septum in LSS2 [11]. The transverse beam emittance and hence intensity may be limited by the extraction channel acceptance at this low energy.

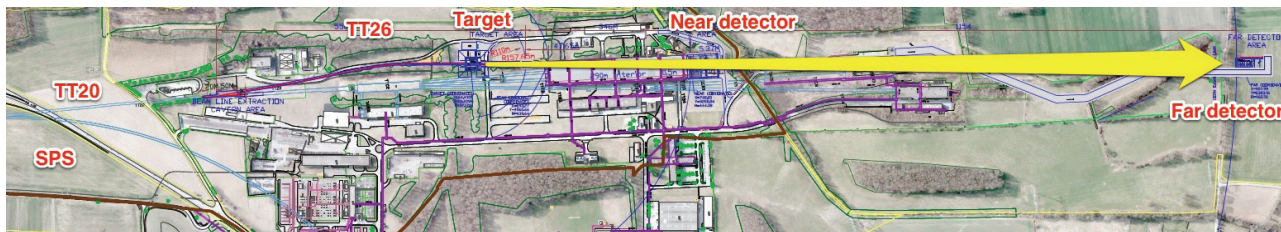


Figure 2: Base line layout for the CERN Neutrino Facility (CENF) on the CERN Prevezsin site.

The 100 GeV proton beam will be extracted in two batches separated by 50 ms, each 10.5 μ s long containing from 1.75×10^{13} to maximum 2.25×10^{13} protons. The nominal repetition rate is planned at 6 s, but can be reduced to 3.6 s, resulting in a primary proton beam power ranging from 100 to 200 kW. A summary of the primary beam characteristics is given in table 1.

Table 1: Primary Proton Beam Characteristics

	Value	Unit
Beam momentum (p)	100	[GeV/c]
SPS cycle length	3.6	[s]
Nominal / Maximum repetition rate	6/3.6	[s]
Max.hor. emittance (ϵ_h at 1σ)	8	[μ m rad]
Max. ver. emittance (ϵ_v at 1σ)	5	[μ m rad]
Number of extractions per cycle	2	-
Interval between extractions	50	[ms]
Duration per extraction	10.5	[μ s]
Number of bunches per extraction	2100	-
Nom./Max. intensity per extr.	1.75/2.25	[$\times 10^{13}$]
Bunch length (4σ)	2	[ns]
Bunch spacing	5	[ns]
Momentum spread (dp/p at 1σ)	2	[$\times 10^{-4}$]
Nom./Max. beam power	100/200	[kW]

Beam Transfer

The primary proton beam will be transferred, using part of the existing TT20 transfer line that connects the SPS with the existing NA experimental facilities. Presently three options for a new beam line, connecting the TT20 line with the secondary beam production facility are being or have been worked out. (Fig 3. and Fig. 4).

Option 1, the initial design, has been fully worked out requiring the construction of a new primary beam line of about 600 m, using existing magnets [12]. Unfortunately, this place, where the TT20 transfer lines levels at about 10 m underground, is densely populated with magnets, allowing, after a minor rearrangement, to insert a branch-off for a 100 GeV beam, but excluding a future 400 GeV option for the transfer of beam to the LAGUNA-LBNO secondary beam production facility using existing magnets. For this reason two additional options are being studied. Option 2 is much more upstream of TT20, requiring considerably more civil engineering at a deeper level and a longer transfer line. Option 3, is more down stream, close to the target facility. The length of the

transfer line will be approximately 120 m, requiring high field superconducting magnets that are presently not readily available at CERN.

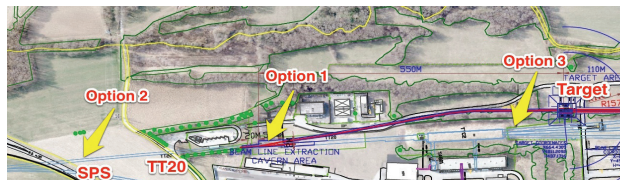


Figure 3: Bird's view of option 1 together with indications where options 2 and 3 would branch-off.

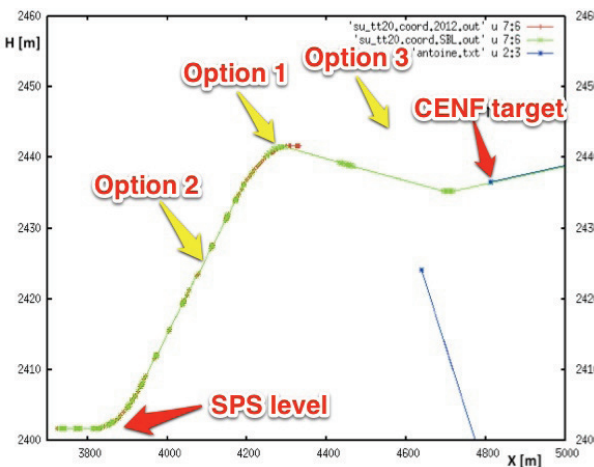


Figure 4: Side view of option 1 together with indications where options 2 and 3 would branch-off. The SPS is situated at about 35 m underground.

SECONDARY BEAM PRODUCTION

The secondary beam production target will be located at about 15 m below ground level (Fig. 5.). Due to its shallow depth and in order to avoid activating large volumes of air, the design is inspired on the NUMI facility at FNAL [13] and the T2K facility at J-PARC [14], both using the ‘chase’ design. The secondary beam production elements together with the decay pipe volume will be contained in a vessel filled with helium at atmospheric pressure, in order to drastically reduce the production of radioactive isotopes with respect to a similar configuration filled with air. The removable shielding is designed to allow for relatively easy access to the beam line components, but also to allow access in the

target building during beam operation when the shielding is in place.

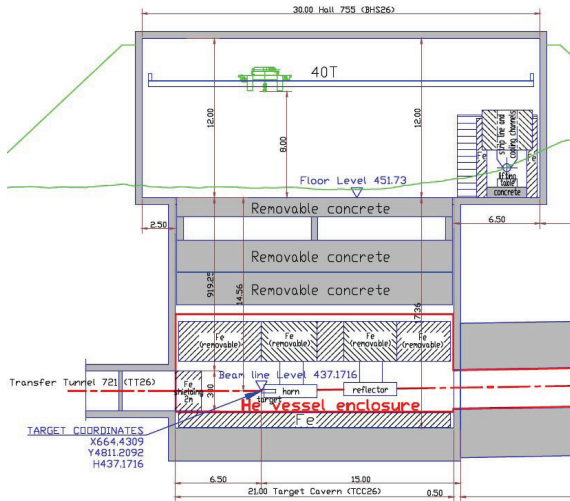


Figure 5: The CENF target cavern and target hall.

The target is fully inserted in the first focusing horn, pulsing at 250 kA, followed by a second horn, operating at 180 kA. This configuration is aimed at focussing the mesons in the energy range of 3 GeV, which are produced at large angles with respect to the proton beam. The mesons will decay in the 110 m long decay tube, which has an inner diameter of 3 m, to produce a neutrino beam (ν_{μ}) with an energy spectrum that peaks around 1.5 GeV (Fig. 6.), using the FLUKA Monte Carlo code [15][16].

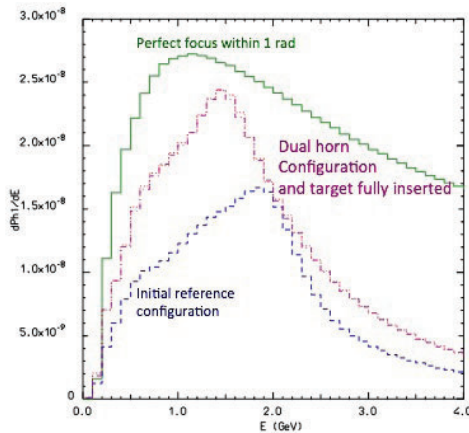


Figure 6: FLUKA Monte Carlo simulation results for different target and horn focusing system configurations.

The hadron absorber will be interleaved with a set of muon detectors that together with a second set of muon detectors, further down stream, will allow for neutrino beam steering, beam profile and stability measurements.

THE EXPERIMENTAL FACILITIES

The near experimental facility will house three detectors of which the first is the 150 t Liquid Argon Time Projection Chamber (LAR-TPC), which is a scaled down version of the ICARUS T600, presently located in the

Gran Sasso laboratory in Italy. This will be followed by the NESSiE spectrometer, consisting of resistive plate chambers (RPC), to provide charge identification and momentum reconstruction of the muons produced in neutrino interactions. An air core magnet will measure the low momentum muons, while the iron core magnet will measure the higher momenta. The third detector is a proto-type of the double phase LAGUNA-LBNO LAR-TPC that will also use low energy charge particle beams for calibration purposes in addition to the neutrino beam.

At 1.6 km from the target, the far experimental facility will house the ICARUS T600 LAR-TPC, which will be moved from Italy to CERN, together with a larger version of the NESSiE detector.

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