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# FEASIBILITY STUDIES FOR 100 GEV BEAM TRANSFER LINES FOR A CERN NEUTRINO FACILITY

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*Abstract*

For a potential future CERN neutrino facility it is considered to extract a 100 GeV proton beam from the second long straight section in the SPS into the existing TT20 transfer line leading to the North Area. Two transfer line design options were developed simultaneously: early-branching from TT20 using existing, recuperated 'experimental area' DC dipoles and alternatively late-branching close to the target area, which requires superconducting magnets. This paper describes the feasibility of the two concepts in addition to the detailed study of the early-branching option. Optics and line geometry optimization are discussed and orbit correction is presented.

## INTRODUCTION

The CENF (CERN Neutrino Facility) experiment requires delivery of the 100 GeV proton beam to the target area with the characteristics shown in Table 1.

Table 1: Beam Characteristics

| Parameter | Unit | Value |
|---|---|---|
| Extraction momentum | GeV/c | 100 |
| Maximum momentum spread $\delta p/p$ (1 $\sigma$ rms) | | $2 \cdot 10^{-4}$ |
| Maximum intensity per extraction | p+ | $2.4 \cdot 10^{13}$ |
| Normalised horizontal/vertical emittance (1 $\sigma$ rms) | $\pi$.mm.mrad | 8/5 |

It is considered to extract by non-local fast extraction [1] the beam from the second long straight section (LSS2) of the SPS into the existing TT20 tunnel, which is connecting the SPS with the North Area. Two solutions were taken under consideration: re-use of the 500 m of existing TT20 tunnel for early-branching or design of a new switch using superconducting magnets for late-branching from H2 line.

Selection of the branching-off point from the TT20 line for the 100 GeV beam is strongly constrained by the geometry, local infrastructure and radioprotection. It is advised that the junction cavern is placed sufficiently far from the highly activated TT20 splitters to keep radiation levels low. Additionally, the switch layout should allow branching 100 GeV/c and 400 GeV/c beams for the future proposed long baseline LAGUNA-LBNO facility. Furthermore it is suggested that the new design will not influence significantly the performance of the existing TT20 line also in order to avoid a dedicated long shutdown of the North Area.

## EARLY-BRANCHING FROM TT20

The MBB.211356 bending magnet was chosen to serve as switch between the existing TT20 line and the future TT26 line. The extracted beam is planned to be transferred through the initial part of TT20, branched off around 500 m downstream at an MBB-type magnet and be passed through the 600 m long TT26 line.

TT26 has been entirely designed with recuperated magnets from the SPS experimental areas involving 20 quadrupoles type QNL arranged into 71.4 m long FODO cells and one triplet for final focusing on the target and 16 MBN bending magnets grouped in 4 different power converter families forming the line into an S-shape in both planes. The current geometry is mostly defined by the initial TT26 part containing: two horizontal bends type MBB, one vertical bend type MBE and 4 combined horizontal/vertical bend type MBN located in a junction cavern. The rest of the bending magnets were accommodated over the next 500m of the line leaving around 65m after the final bend for final steering and focusing.

For the 100 GeV/c p+ beam, the available aperture corresponds to 5 sigma due to optics rematching. Two aperture bottlenecks, one in the horizontal - and another one in the vertical plane, are located at the beginning of TT26, at the position of first bend built from MBN magnets. Their replacement by dipoles with a larger aperture (600mm) should be considered.

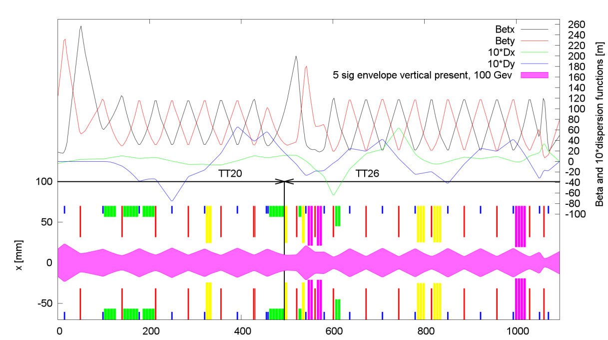


Figure 1: Optics and the vertical 5 sigma beam size.

The choice of the MBB.211356 as a branching location requires changes in the TT20 instrumentation as well as

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the use of two quadrupoles from TT20 and six quadrupoles from TT26 to match the optics. The phase advance in the TT20 FODO cell part was reduced from a standard μ=π/2 to μ=2π/5 in order to suppress the incoming dispersion. The length of the FODO cell from TT20 (35.6 m) was fixed and kept constant for the whole line to allow optics repeatability. The FODO cell length in the matching section was modified and reduced to 20 m per half-cell, in favour of TWISS function rematching.

The incoming dispersion from TT20 part is the major issue while designing the sequence. Along the junction cavern, the vertical dispersion peak needs to be cancelled while the beam has to be deflected horizontally. The optimum solution is achieved by using tilted MBN bends. The positions of the magnets are optimized to suppress the incoming dispersion while matching the geometry constraints of the line.

The early-branching option is described in detail in [2].

## ORBIT CORRECTION

In order to simulate the future possible orbit perturbations, random field and misalignment errors, in experience-based range, were assigned to bending and focusing elements of the TT20 and TT26 lines. One pair of additional correctors type MDX and beam position monitors (BPM) per quadrupole was added to the line. The orbit correction was performed using the MICADO algorithm.

The observations of 1000 different orbits obtained with 1000 different seeds have been analyzed. The average RMS orbit distortion over 1000 seeds was calculated to be 2.7 mm and 2.8 mm in the horizontal and vertical plane, respectively, before the applied correction. With 16 correctors and 16 BPMs the trajectory excursions were reduced to 0.46 mm and 0.33 mm, respectively.

Figure 2 shows the results of the performed simulations for 1000 different error sets and illustrates the possible perturbed orbit before and after correction.

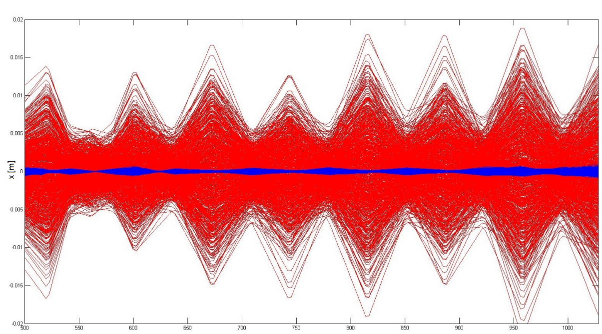

Figure 2: 1000 perturbed orbits before correction in red and after correction in blue (MATLAB), only TT26 part, horizontal plane.

## LATE-BRANCHING FROM H2

The switch for the late-branching option is located in the H2 beam line downstream of the QNL021099 quadrupole. It implies a much shorter length of the TT26 transfer line and imposes many constraints due to the new location. Furthermore, it will result in sending the beam through the existing splitters, collimator, target, instrumentation and secondary beam line zones. Due to its proximity to the target area the presented design will require mostly the use of magnets with dipolar fields well above 2.0 T.

The existing H2 lattice offers more than 30 m of free space to accommodate the switch components. The switch was suggested to be designed with 5 strong open C core dipoles (type MBS) of field B=1.7 T and length L=3m in order to create an offset of 500 mm from the H2 line with the initial bending angle equal to 0.0151 rad.

The proximity of the switch to the target area and beam angles on the target face makes the geometrical design complicated and unfeasible imposing the use of superconducting dipoles in order to reach the strong deflection needed. The maximum field provided is 6 T with the magnetic length of 3.88 m for the short and 7.75 m for the long version of SIS300.

Following assumptions on the superconducting magnets and instrumentation dimensions were made for the late branching design. The superconducting quadrupole magnetic length was set to 1 m. The distance of 0.5 m was left as the free drift upstream and downstream of each dipole and quadrupole. The length of 1m was foreseen to accommodate a pair of corrector and beam position monitor. The final focusing geometry was designed using 3 superconducting quadrupoles followed by a 5 m long drift.

Short SIS300 dipoles were selected in order to allow for adjustability of the line geometry. The distance from the branching point to the target area allows to accommodate 15 SIS300 dipoles, which was proved insufficient in terms of bending strength, to deliver the beam to the target location while respecting the horizontal and vertical angles. In the described design, the C-core MBS magnets in the switch area are replaced by 4 additional superconducting dipoles, ignoring the feasibility of the construction. In total 19 SIS300 were divided into 4 families, with independent tilt for each family. A drift of 27 m is left to accommodate the final focusing triplet and steering magnets.

Table 2: The SC Dipoles Parameters for H2 Option

| Dipole family | Number of dipoles | Bending angle [rad] | Tilt [rad] |
|---|---|---|---|
| I | 4 | 0.0691261 | -0.3020 |
| II | 5 | 0.0691261 | -0.3274 |
| III | 5 | 0.0691261 | -0.2909 |
| IV | 5 | 0.0691261 | -0.2042 |

MAD-X simulations demonstrate the unfeasibility of matching both, the target and far detector positions even using all available space in the lattice to accommodate superconducting magnets. The minimum difference between the target and detector default coordinates and the matched coordinates within the strength of SIS300

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dipoles was calculated to be 3 m/3 m respectively in horizontal plane and 1 m/7 m in the vertical plane, which resulted in different beam angles on target and detectors. The deviation from the default path is shown in the Figure 3.

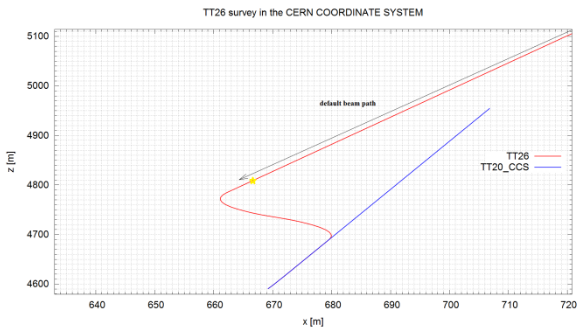


Figure 3: The geometry of the TT26 line (horizontal plane). The existing H2 line is marked in blue, TT26 is marked in red with a new target marked as an asterisk and the default beam path is marked with the black arrow indicating the target.

## PROPOSED SOLUTION

In order to liberate space for extra bends it was suggested to shift the target downstream while keeping both detectors at their original positions. The minimum distance was calculated to be equal to 25m. In the presented design the neutrino beam path remains unchanged and both angles (horizontal and vertical) are respected. The concept is presented in Figure 4.

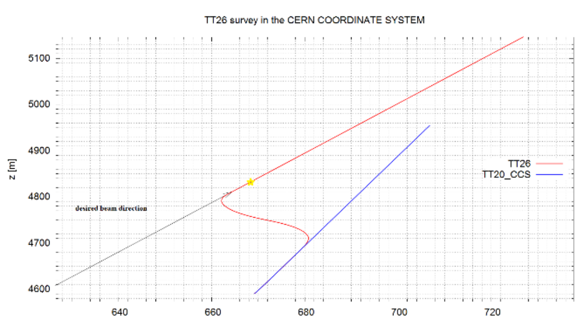


Figure 4: The geometry of the TT26 line (horizontal plane). The existing H2 line is marked in blue, TT26 is market in red with a new shifted by 25 m target marked as an asterisk and the default beam direction is marked with the black arrow pointing to the target.

The geometrical constraints can be met with 19 superconducting dipoles divided into 4 families with independent tilts, Table 3:

Table 3: The SC Dipole Parameters for the H2 Option with the Shifted Target

| Dipole family | Number of dipoles | Bending angle [rad] | Tilt [rad] |
|---|---|---|---|
| I | 5 | 0.0614931 | -0.4033 |
| II | 3 | 0.0689979 | -0.4157 |
| III | 6 | 0.0521916 | -0.2809 |
| IV | 5 | 0.0681318 | -0.2562 |

The distance of almost 17 m was left in order to accommodate the triplet and final steering magnets. The optics for both layouts was not investigated and is likely expected to be an issue due to dispersion control and strong edge focusing. In addition, the slopes of the tunnel were calculated to reach more than 10%, which may impose additional constraints on transport or cryogenics.

## CONCLUSIONS

This paper discusses two concepts of the primary beam line delivering the 100 GeV/c p+ beam to the CERN Neutrino Facility. It was proved that for the early-branching option the target and detector coordinates can be matched while fulfilling the optics and geometry, radiation protection, civil engineering and transport constraints. However the design is compatible only with a 100 GeV/c p+ beam and therefore cannot be used to deliver the 400 GeV/c beam for LAGUNA-LBNO facility. The aperture accommodates 5 sigma of the beam in both – the existing TT20 and the new TT26 line.

The late branching option was proved unfeasible due to physical limits of magnet construction. Placing the switch in the H2 line seems to be a reasonable solution only if the target can be shifted by 25 m downstream in order to match the geometrical constraints. The optics design for this option is expected to be an issue.

## REFERENCES

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