BEAM TRANSFER SYSTEMS FOR THE LAGUNA-LBNO LONG BASELINE NEUTRINO BEAM FROM THE CERN SPS*

B. Goddard, W. Bartmann, I. Efthymiopoulos, Y. Papaphilippou, A. Parfenova,
CERN, Geneva, Switzerland

Abstract

For the Long Baseline neutrino facility under study at CERN (LAGUNA-LBNO) it is initially planned to extract a 400 GeV beam from the second long straight section in the SPS into the existing transfer channel TT20 leading to the North Area experimental zone, to a new target aligned with a far detector at a distance of 2300 km [1]. In a second phase a new High-Power Proton Synchrotron (HP-PS) accelerator is proposed, to give a 2 MW beam at about 50 GeV on the same target. In this paper the required beam transfer systems are outlined, including the new sections of transfer line between the Superconducting Proton Linac (SPL), HP-PS and SPS, and from the SPS to the target, and also the injection and extraction systems in the long straight section of the HPPS. The feasibility of a 4 GeV H- injection system is discussed.

INTRODUCTION

A number of beam transfer systems are required for both phases of LAGUNA-LBNO [2], Fig. 1. With the 750 kW beam from the SPS, a new fast extraction from the SPS LSS2 is needed [3], with an upgrade of the TT20 transfer line, a switch working at 400 GeV and a new section of transfer line (so-called “TT27”) to bring the beam in the correct direction. In phase two, a High HP-PS [4] at the foreseen location close to SPL will require a 4 GeV H- transfer line, an H- injection system, a 50 GeV fast extraction and a new 50 GeV beamline which will be rather long, as this needs to join TT20 or the new TT27 beamline.

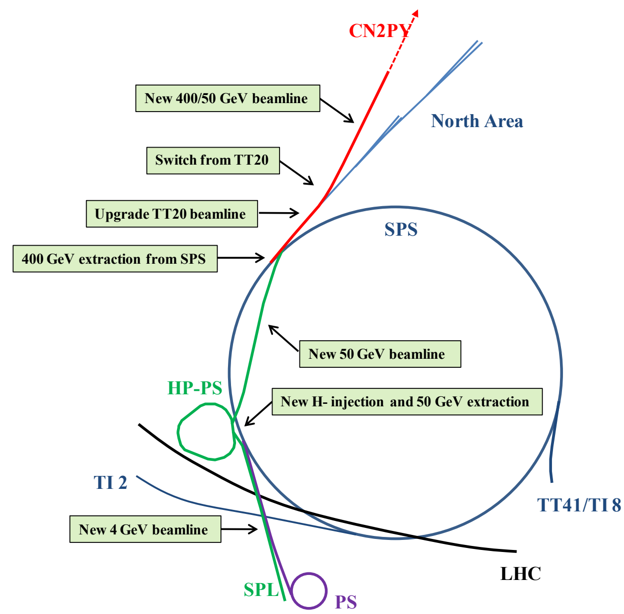

Figure 1: Beam transfer systems that need to be developed or upgraded for LAGUNA-LBNO phase 1 (red) and 2 (green).

PHASE 1 BEAM TRANSFER SUBSYSTEMS

400 GeV Fast Extraction from SPS LSS2

The fast extraction from SPS LSS2 has requirements similar to the present extraction [5] for CNGS. The lack of fast kickers in LSS2 and the difficulties of integrating such a system have led to the development of a non-local extraction where another kicker in the SPS is used to excite the beam, re-using the magnetic extraction septa in LSS2. A detailed study of this concept and successful SPS tests are given in [3]. The concept is feasible using a modified version of the present MKE kicker system and relatively inexpensive, although it requires particular attention on the interlocking and machine mode configuration since many machine parameters will affect the extraction trajectory and envelope.

Upgrade of TT20 and Switch to TT27

The present TT20 beamline needs to be equipped to accept high-intensity fast extracted beams. The powering scheme for the line will remain unchanged to the switch region, and all magnet supplies and apertures are compatible with 400 GeV beam with a new optics. A significant extension to the present beam instrumentation is needed, with the addition of Beam Position Monitors at about 12 existing quadrupoles, and a similar number of ionisation chamber Beam Loss Monitors. Screens will also need to be added or upgraded, especially in the extraction region of the SPS. Space has been identified in the lattice for all BPMs. The interlocking of the line also needs to be upgraded with the addition of a Beam Interlock (BIC) system.

Switching a 400 GeV beam from TT20 is problematic, as the obvious locations near the surface would entail major modifications to the existing layout, and potentially to the geometry of the downstream secondary beamlines. As a first approach in this initial study, a switch which does not affect the present beamline installation was studied, which can possibly be optimised at a later stage in the project, for example with changes to the present TT20 layout and geometry. The switch is based on existing SPS magnet type MBS, which is an open C-yoke

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dipole, with 56 mm vertical gap, already used for switching between 400-450 GeV beamlines. The layout of the switch is shown in Fig. 2.

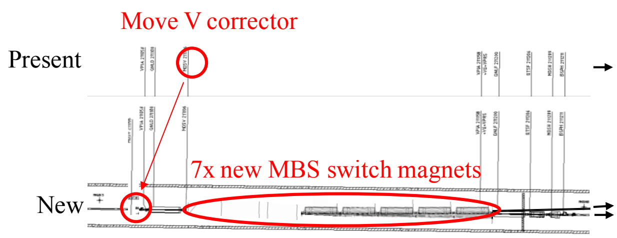

Figure 2: Switching beam at 400 GeV from the existing TT20 lattice, in half-cell 211.

New TT27 Transfer Line

The new transfer line to the neutrino target needs to work initially at 400 GeV, and for phase 2 at 50 GeV. Given the conflicting requirements of high field magnets for phase 1 and large apertures for phase 2, the line geometry and feasibility has been checked for 400 GeV using available magnet designs, while it is assumed that larger aperture, lower field magnets can be installed when phase 2 starts at 50 GeV.

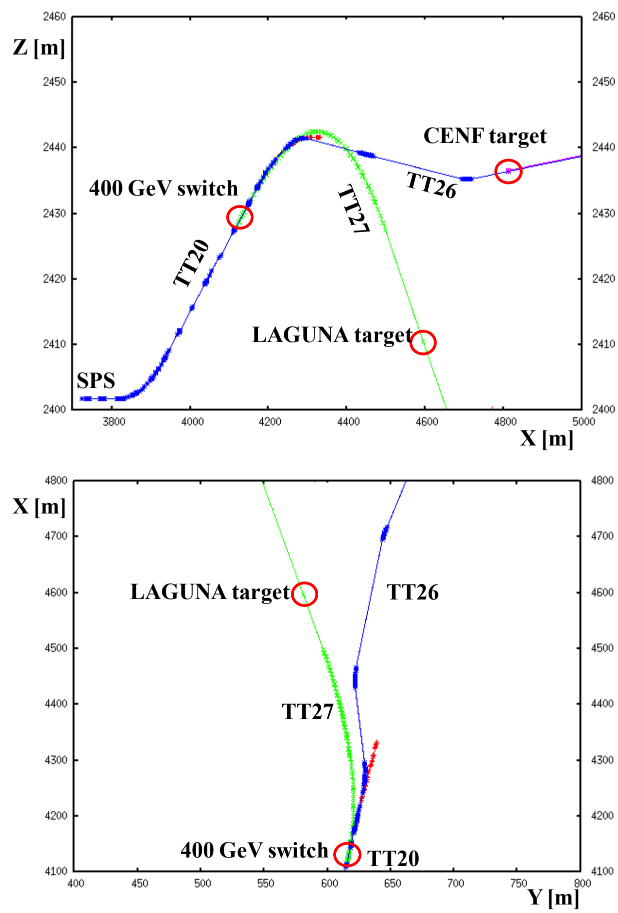

Figure 3: TT27 beamline geometry in vertical (top) and horizontal (bottom) planes. The beamline for the proposed CERN Neutrino Facility (CENF) is also shown [6].

The line geometry was designed using MBG magnets (SPS TT41 dipoles), which are 6.3 m long and have a peak field of 1.9 T and 9 mrad bending angle at 400 GeV. A free drift of 100 m has been left after the last dipole for the final focussing triplet, shielding and instrumentation before the target. The geometry is shown in Fig. 3. The final downward slope at the target is 18 % (10.4°), which is certain to pose some interesting engineering challenges for the magnet transport and handing. The depth of the target is approximately 40 m underground.

PHASE 2 BEAM TRANSFER SUBSYSTEMS

4 GeV H- SPL to HP-PS Transfer Line

A new 4 GeV H- transfer line will be needed to link SPL and HP-PS, similar to that already studied from SPL to PS2 [7]. To avoid excessive beam loss from Lorentz stripping, the maximum dipole field possible in the line will be about 0.1 T, which will determine the geometry. If the HP-PS is to be at or near the level of the SPS, to potentially exploit possible synergies in the proton physics program for a higher energy LHC and its injectors, then the height difference to overcome is about 21 m. The interferences with other tunnels mean that a slope of 8-9 % will be likely, depending on the exact location of HP-PS.

The line design itself should not present major issues – a FODO structure with achromat bending arrangement is foreseen to be re-used from the PS2 study as a starting point. Dipole magnets would be 6-7 m long with low field, similar to the LEP dipoles.

4 GeV H- Injection System

The 4 GeV H- injection system is designed around a 24 m long free drift in the centre of the injection/extraction straight section. The H- injection layout follows closely that designed for the PS2 4 GeV injection [8]. The doublet insertion has been matched into the HP-PS lattice, with the two 17 m long auxiliary straight sections (these lengths are determined by the matching requirements for the overall lattice). A schematic of the straight section is shown in Fig. 4, and the optics functions in Fig. 5.

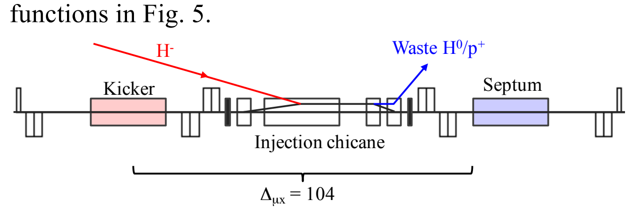

Figure 4: Schematic of injection/extraction straight section. Total length is 73.5 m.

A longitudinal space of 1 m has been left to accommodate a possible laser stripping insertion [9]. This is kinematically feasible for 4 GeV H- for the n=2 or n=3 principle quantum states, since the Doppler frequency enhancement factor at $\beta\gamma$ of 5.17 is around a factor 10. The n=3 state would require an intersection angle of 8.4°, which would pose some integration issues, but although n=2 only needs a 45° intersection angle, the difficulty in Lorentz stripping from this deep-lying state will lead to major issues of emittance growth, of up to 100 mm.mrad depending on the exact shape of the fringe field of the stripping dipole. A possible solution could be a resonant excitation inside a strong magnetic field, where the linewidth would be broadened by the Stark effect, and immediate field-stripping of the excited H^0 state would take place [10]. A large horizontal dispersion angle DPx will be needed at the laser stripping point, which may be an issue for the ring optics.

The strong chicane dipoles will perturb the optics, with a beta-beat of around 25%. This can be corrected to first-order by individual powering of the quadrupoles in the injection straight, although such a compensation will need to follow the fast switch-off of the chicane.

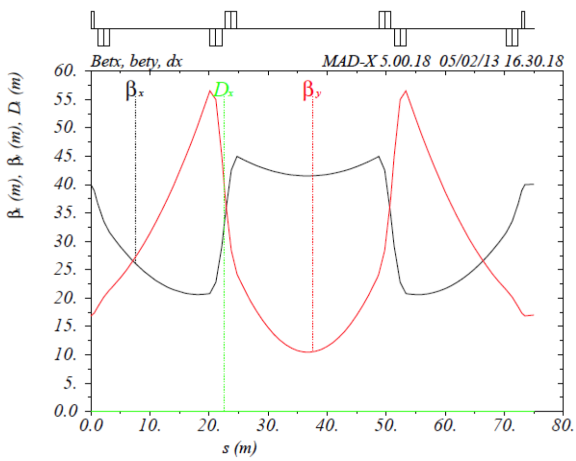

Figure 5: Optics functions in the HP-PS injection/ extraction straight, in absence of perturbations from the injection chicane dipoles.

50 GeV Fast Extraction

The 50 GeV fast extraction should naturally take place in the same straight section as the injection, to take advantage of the fact that the SPL is already pointing in the general direction of the LAGUNA target. The extraction is based on a fast kicker and pulsed in-vacuum septum. The optics provides a phase advance of about 104° between kicker centre and septum entrance, which means 97% effective kick strength. The beta function is about 22 m at the septum and 27 m at the kicker.

The kicker rise time which can be provided is about 250 ns, for a system of about 8 separate magnets, each 1.2 m long. The septum would have a thickness of 5 mm, be pulsed with a few ms duration and a peak field of about 1.2 T, corresponding to a current of 27 kA.

The main kicker and septa parameters are given in Table 1, for a 5 σ clearance for the circulating injected and the extracted beam.

Increasing the extraction energy to 70-75 GeV would increase the installed lengths of the kicker and septa by 40-50%, in a first approximation – the septum current might be reduced by a few percent with the gap height.

Table 1: Kicker and Septa for 50 GeV Fast Extraction

Parameter	Unit	Value
Kicker strength	mrad	2.1
Opening at septum	mm	50
Kicker impedance	Ω	12.5
Kicker rise time	ns	238
Kicker vertical gap	mm	90
Kicker vertical aperture (with screen)	mm	70
Kicker field	mT	33
Kicker magnetic/total length	m	10.4/13.3
Kicker total length	m	13.3
Kicker voltage	kV	50
Septum width	mm	5.0
Septum deflection	mrad	52
Septum field	T	1.0
Septum gap height	mm	34
Septum current	kA	27
Septum magnetic/total length	m	8.8/11.2

50 GeV HP-PS to Target Transfer Line

The 50 GeV transfer line from HP-PS to the LAGUNA target is likely to be a cost driver for the beam transfer systems, since the length in the present concept is at least 1 km and possibly more, depending on where the junction with TT20 or TT27 can be made. Apart from this, the line design in terms of optics and magnets is not likely to present any specific issues. A regular FODO lattice with approximately 35-40 quadrupoles will be used.

CONCLUSION

First studies on the beam transfer systems for LAGUNA-LBNO are based heavily on the work done for PS2. The proposed location of the HP-PS near the SPS is feasible for the 4 GeV H- injection line, although it means a very long 50 GeV transfer line to join the target. The injection and extraction systems in the same straight section should be feasible, with space for a laser stripping insertion for the injection. Kicker and septa parameters for 50 GeV look feasible although for 70-75 GeV the available straight sections become rather full and the systems will be 40-50% larger.

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