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TARGET BYPASS BEAM OPTICS FOR FUTURE HIGH INTENSITY FIXED TARGET EXPERIMENTS IN THE CERN NORTH AREA

G. L. D'Alessandro*[1], D. Banerjee, J. Bernhard, M. Brugger, N. Doble[2], L. Gatignon[3],
A. Gerbershagen, B. Rae, F. M. Velotti, CERN, Meyrin, Switzerland
S. M. Gibson, JAI at Royal Holloway, University of London, Egham, UK
[1]also at JAI at Royal Holloway, University of London, Egham, UK
[2]also at Johannes Gutenberg Universitaet Mainz, Mainz, Germany
[3]also at Lancaster University, Lancaster, UK

Abstract

Several of the proposed experiments for operation at the K12 beam line would profit from significant beam intensity increase. Among those, there is the KLEVER experiment that would require an intensity of 2×10^{13} protons per 4.8 s long spill. The main goal of the experiment is to measure $BR(K_L \to \pi^0 \nu\overline{\nu})$ to test the Standard Model structure, by itself, and in combination with results from NA62 for $BR(K^+ \to \pi^+ \nu\overline{\nu})$. NA62 could also profit from higher intensities, and could be run in a new configuration called NA62-HI(gher intensity). In the current configuration the beam is transported from the SPS to the TT24 beamline. This beamline leads to the T4 target that attenuates the beam for P42. After T4 the beam is directed into the P42 beamline before impinging on the T10 target and creating the particles necessary for the experiment. Those are finally transported to the detector via K12. This paper presents the idea of partially bypassing T4 and changing the P42 beamline configuration in order to have a sufficiently small beam size at the T10 target for both KLEVER and NA62-HI. Optics studies are developed in MADX and the AppLE.py, software developed at CERN.

INTRODUCTION

Several fixed target experiments at CERN are located in the North Area. These in general use secondary beams produced by slowly-extracted 400 GeV/c primary protons from the SPS. One of these experiments is NA62 which uses a 75 GeV/c K^+ beam [1] transported by the K12 beamline. The goal of NA62 is to conduct precision tests of the Standard Model via rare decay studies, in particular, via the measurement of the rate of the ultra-rare decay mode $K^+ \to \pi^+ \nu\overline{\nu}$. The experiment recently published first results [2]. The KLEVER [3] experiment has been proposed to run after NA62 in order to perform physics searches that are complementary to those of NA62, performing studies on the rare decay $K_L \to \pi^0 \nu\overline{\nu}$. This rare decay could provide, by itself, and in combination with NA62, new information on the Standard Model (SM) structure [3]. The KLEVER experiment would require a higher intensity (2×10^{13} protons per 4.8 s spill) than NA62 that is approximately 3×10^{12} protons per 4.8 s spill. Alternatively NA62 would need only minor modifications to withstand a high proton flux, in a reconfiguration called NA62-HIgher intensity (NA62-HI or NA62×4). With the current settings of the beamlines serving the experiments these intensities cannot be achieved. This is mainly due to the fact that focusing a higher intensity proton beam on T4 would lead to significant attenuation of the primary beam and therefore require more protons on the target for the wanted rate on the downstream T10 target [4]. Therefore the beamlines need some optics adjustments that allow to have less interacting particles on target. This implementation, called target bypass, will be discussed in this paper. These studies were done using MADX [5] and AppLE.py [6], a software developed at CERN.

* gianluigi.dalessandro@cern.ch

TRANSPORT BEAMLINES

The beamlines involved in these studies are: TT24 and P42 [7]. These beamlines are mainly composed of dipole and quadrupole magnets and transport a 400 GeV/c proton beam extracted from the SPS. The P42 and TT24 are approximately 850 m and 900 m long respectively. TT24 is upstream of P42 and drives the protons on to a target (the T4 target) that works as an attenuator, see Fig. 1. The T4 target is 2 mm in vertical extent and is composed of several Be plates adjustable in series for a total length between 40-500 mm. This target is followed by the P42 beamline that steers the attenuated proton beam onto the T10 target which provides secondary particles that are selected by the K12 beamline (K^+ are required in the case of NA62).

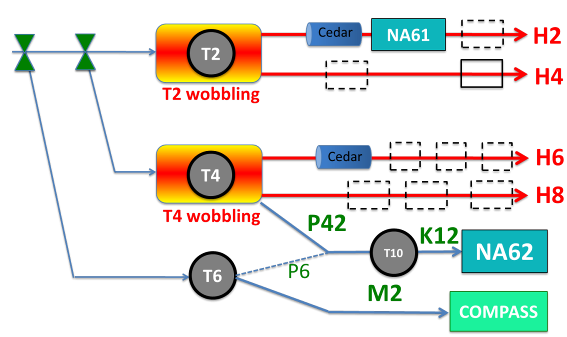

Figure 1: Scheme (not to scale) of the beamlines structure in the North Area. The T4 target is followed by the P42, H6 and H8 beamline. The P42 beamline drives protons on the T10 target where they interact and are selected in K12 before reaching the experiment detector.

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The secondary beam is afterwards directed to the detector of the experiment (NA62, NA62-HI or KLEVER). The centre of the T10 target is defined as the start of the K12 beamline.

In order to increase the intensity of KLEVER and NA62-HI, the idea is to partially bypass the T4 target [4]. For this purpose the beam size at TT24 can be increased to not entirely collide with the target and afterwards squeezed in order to fit into the magnets aperture of P42.

TT24 PARAMETERS

To reach a higher beam size such that only 10% of the beam interacts with the T4 target, while the remaining beam would bypass it vertically, see Fig. 2. The beam parameters can be calculated for the current configuration of TT24 and for the new configuration for a foreseen experiment (KLEVER or NA62-HI) to compare the difference.

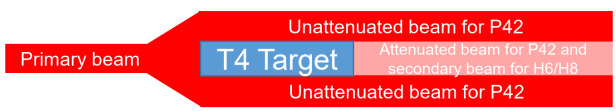

Figure 2: Schematic side view of proton beam being defocused before T4 target and partially interacting with it.

Table 1: Simulated Beam Parameters for the Standard (current) and New Configuration

Parameters	Standard Configuration	New Configuration
σ_x [mm]	0.5	0.5
σ_y [mm]	0.4	4
ϵ_x [mm× mrad]	2	2
ϵ_y [mm× mrad]	0.1	0.1
β_x [m]	58	58
β_y [m]	740	74000

The parameters obtained from TT24 can be afterwards used as input for the P42 beamline to check how these impact the beam parameters in this beamline. The values at the end of the TT24 beamline for the two configuration can be found in Table 1. These values refer to the beam size σ in x and y, the normalized emittance ϵ in x and y, and the β functions in x and y. These quantities are all related by Eq. (1) valid for a Gaussian beam

$$\sigma = \sqrt{\epsilon\beta}. \tag{1}$$

Assuming that the particle position and angle are uncorrelated at the location of the target the divergence of the beam can be calculated at various points using Eq. (2)

$$\epsilon = \sigma_x \sigma_{x'}. \tag{2}$$

BEAM SIZE OPTIMIZATION STUDIES IN P42

The beam size in P42 needs to be kept well within the magnet apertures to avoid damage via beam interactions or the generation of background for the experiment. The propagation through P42 has been studied for the current beam optics settings of TT24 and P42, in use for NA62. For this purpose a P42 model was created in MADX. The specification of the magnets currents and size specified in the CERN database. This analysis leads to the beam size in x and y shown in Fig. 3. It can be seen that in the current configuration the beam size is around a few millimetres.

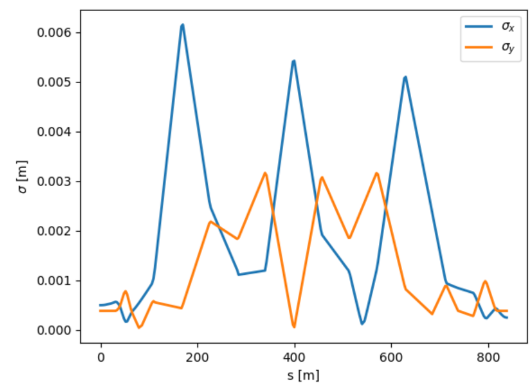

Figure 3: Beam size (one standard deviation) as a function of s along the P42 beamline in the current configuration of the TT24 beamline.

Considering the smallest aperture of the quadrupoles in the beam (QNL with 8 cm diameter) the beam is small enough to pass without interaction. With the new configuration at T4, the first five quadrupoles need to be adjusted to keep the beam size well within the aperture limits all along the P42 beam line and sufficiently small at the 2 mm diameter T10 target. This can be done for example by changing some of the initial quadrupole settings in P42. The new values of these parameters are obtained in MADX putting restrictions based on the maximum achievable gradient of the quadrupoles and forcing the beam size to be in the range of the standard configuration. The parameters can be extracted by implementing a fitting routine in MADX. The old and new values, resulting from the optimization procedure, for the focusing strength of the first five quadrupoles can be seen in Table 2.

Table 2: Parameters of the Quadrupoles in P42 Before and After the Fitting in MADX. Quadrupoles Are Numbered According to Their Appearance Order in the P42 Beamline and k Is the Focusing Strength in m^{-2}.

Parameters	Standard Configuration	Standard Configuration
Q1-k[m^{-2}]	0.009482	-0.005511
Q2-k[m^{-2}]	0.014060	0.0117363
Q3-k[m^{-2}]	-0.015110	-0.009590
Q3A-k[m^{-2}]	-0.015110	-0.009590
Q4-k[m^{-2}]	0.014060	0.011736

After implementing this new configuration, the values for the beam size can be seen in Fig. 4. These new values are acceptable and prove that a beam size in the order of mm

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can be achieved with the inversion of the polarity of the first quadrupole of P42 and some minor modification of the other magnets. These first results prove the feasibility of the T4 bypass in terms of beam size tolerance. Studies are also being conducted on the possibility of inserting a longer T4 target which would improve the electron rate and purity of electron beams in H6 and H8.

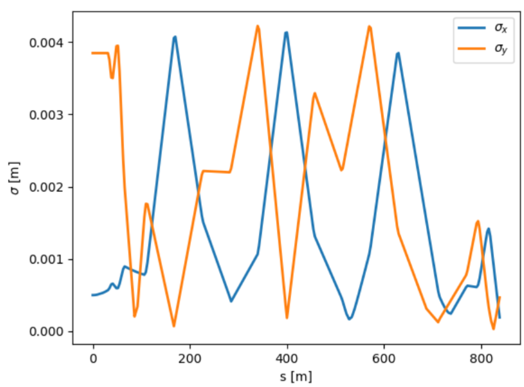

Figure 4: Beam size (one standard deviation) as a function of s along the P42 beamline in a possible new configuration with the TT24 beamline adapted to KLEVER and NA62-HI.

BEAM TRACKING IN P42

The configuration proposed for P42 furthermore are examined with tracking studies. These studies have been performed using the python-based software AppLE.py. This software uses MADX internally to process tracking but gives the possibility of using an interactive graphical user interface (GUI). In this GUI the various parameters can be modified and studies can be iterated faster instead of re-running MADX each time for different configurations. Using the parameters obtained from Table 1 and assuming $\frac{dp}{p} = 0.001$, the tracking shows that all the particles will fit in the apertures as shown in Fig. 5.

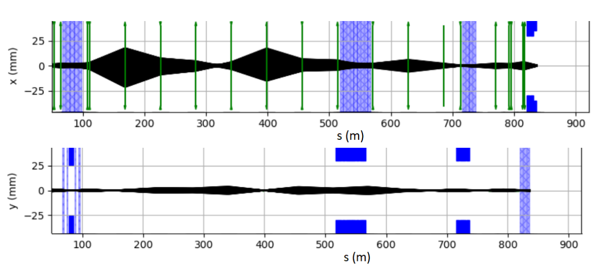

Figure 5: Tracking of particles along the P42 beamline. Particles tracks are represented with black lines. Dipoles are represented in dark blue and their apertures are in light blue. Quadrupoles are represented as green arrows that extend through their apertures.

CONCLUSION

It was shown that a limited beam size (below 0.5 mm) in both horizontal and vertical dimensions can by achieved by the proposed optics configuration for both KLEVER and NA62-HI. This was proven using the MADX and AppLE.py software that allow to use a fitting routine and a simple tracking method. The beam size values found for KLEVER and NA62-HI are similar to the ones that are currently in use for NA62. These studies represent a first proof of feasibility of the T4 bypass and a test of the proposed beam optics is envisaged for the upcoming operational period (LHC Run 3). This test would measure some beam parameters (beam-size and divergence) and transmission of old optics settings compared to the new one. It would also be possible to quantify the attenuation using different target thicknesses and the impact on H6 and H8 beam performance.

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