Simulating Modifications to the P42 Beamline for the KLEVER Experiment

Samantha Pagan

Advisors: Lau Gatignon and Alexander Gerbershagen

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New Physics Searches from Very Rare Kaon Decays

Studies of Very Rare Kaon Decays have the potential to search for new physics beyond the Standard Model by precision measurements. The branching ratio (BR) of $K \rightarrow \pi\nu\bar{\nu}$ is predicted precisely by the Standard Model. Measuring the BR of $K^+ \rightarrow \pi^+\nu\nu$ and $K_L \rightarrow \pi^0\nu\bar{\nu}$ could verify predictions by the Standard Model or help support new physics beyond the Standard Model theories. These measurements are particularly associated with predictions made by the CKM matrix, which describes quark mixing angles. The $K \rightarrow \pi\nu\bar{\nu}$ search is very sensitive. Currently, it is being studied by the NA62 experiment at CERN, and in the future could be studied by the KLEVER experiment [1].

NA62

The NA62 experiment is housed in the ECN3 underground cavern in CERN's North Area. The experiment is designed to measure the BR of $K^+ \rightarrow \pi^+\nu\nu$ using a K^+ beam. NA62 itself could be completed by the end of 2022 [2]. After this time, proposals to fill the ECN3 hall include NA62 Beam Dump mode, NA60++, KLEVER, and DIRAC++ [1]. KLEVER is the proposed project discussed in this report.

KLEVER Motivation

KLEVER is a proposed experiment to study the BR of $K_L \rightarrow \pi^0\nu\bar{\nu}$, which is predicted by the Standard Model to be $3.4 \pm .06 \times 10^{-11}$ [2]. This decay is complementary to the NA62 measurement of $K^+ \rightarrow \pi^+\nu\nu$. These results combined together could be used to study the CKM matrix [2]. A precise combined measurement of both branching ratios could lead to a verification of Standard Model predictions or to the support of new physics theories as shown in Figure 1.

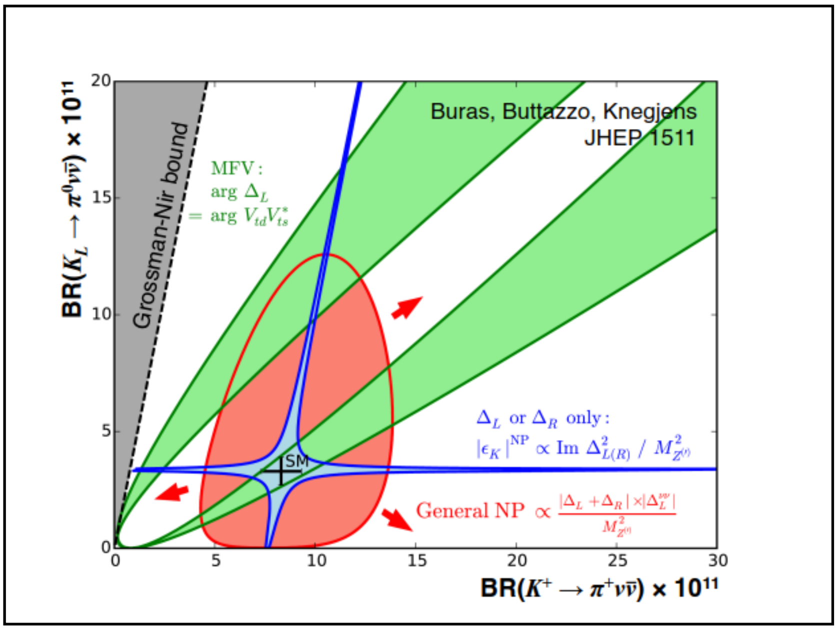

Figure 1: Diagram demonstrating how the branching ratios measured by NA62 and the proposed KLEVER experiment could support physics beyond the Standard Model. All areas outside of the Standard Model Region (SM) represent predictions of new physics theories [2].

KLEVER Experiment

KLEVER is a proposed experiment that would be housed in ECN3 after the completion of NA62. Modifications to the current beamline would have to be made to create a neutral Kaon beam for the KLEVER experiment. This experiment is proposed to begin in 2026 [2].

KLEVER Beamline

The proposed KELVER beamline would begin with the 400 GeV P42 proton beam from the SPS. The P42 beamline is designed to hit a Beryllium target at T10. From there the new K12 beam passes through a series of collimators and sweeping magnets to create a neutral Kaon beamline. This beamline would be composed of neutral particles including K_L, K_S, Λ's, neutrons, and photons [1]. The main backgrounds of KLEVER include other K_L decays, Λ decays and neutrons [2]. After methods of vetoes, background must still be further suppressed [2]. A proposed solution is to have the primary proton beam of P42 hit the T10 target at 8mrad. This was shown in studies to significantly reduce the background of the experiment without significantly reducing the signal [1].

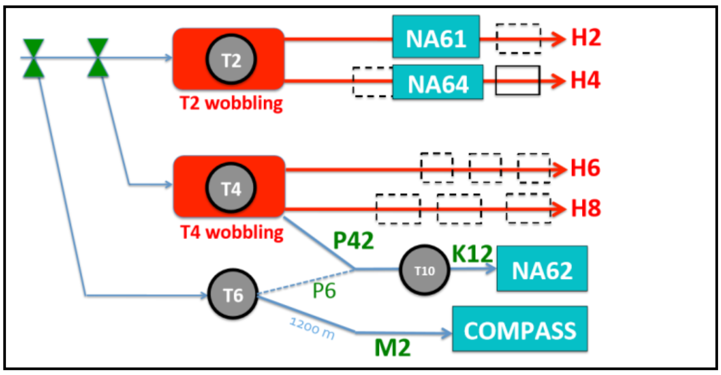

Figure 2: The beamlines of the North Area of CERN. KLEVER would be housed in the current location of the NA62 experiment [3].

Task

The purpose of this project was to simulate a modification for the P42 beamline that would result in the proposed 8 mrad production angle at T10 for the KLEVER beamline. The first stage of this project was modifying the design of the beamline to produce the desired downward vertical angle. The two designs simulated were modifications of the last three bending magnets and the strengths of magnets in the P42 beamline.

Methods

Simulations in this study were done using the programs BEATCH and TRANSPORT along with the beam optics drawing software BeamOpt. BEATCH is a beam geometry program that was used to modify the design so that the beamline would hit the T10 target at the desired angle. TRANSPORT is a beam optics program designed to track the trajectory of particles in “static-magnetic beam transport systems” [3] using matrix multiplication of beam elements. This program was used to fit the strength of all magnets in order to focus the beamline at the T10 target. The output files of TRANSPORT and BEATCH were used to create an optics drawing of the final design in BeamOpt.

Proposed Design

Two proposed modifications to the beamline are shown in Figure 3 and Figure 4. These designs modified the strength, location, and type of bending magnets used in the current P42 beamline configuration. The goal was to create a design where the beamline centroid hit the T10 target at a downward angle of 8mrad. The limits on the power of bending magnets due to current and field restrictions had to be carefully considered for this study. Normally an MTR magnet has a BL max of 7.5 Tm. The Beamline 2 design exceeded this limit, so a Beamline 1 option was also explored. However, for this MTR magnet, operation at 7.9 Tm is thought to be safe after further study and consideration of the magnet design.

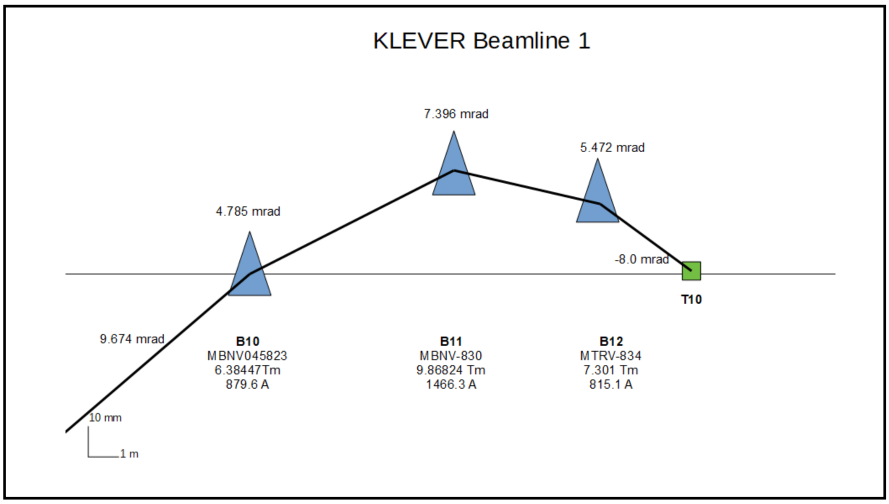

Figure 3: A diagram for the first design of the end of the P42 beamline for KLEVER.

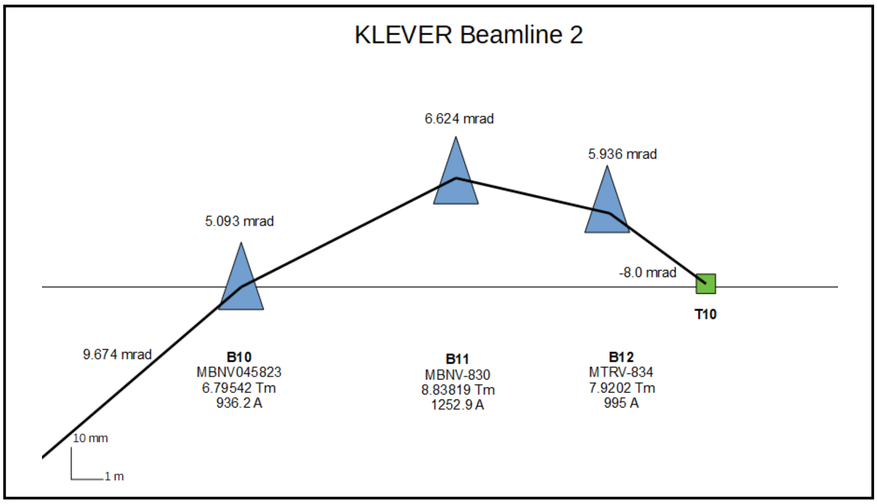

Figure 4: A diagram for the second design of the end of the P42 beamline for KLEVER.

Results: Achieving an 8 mrad Angle

After simulations in BEATCH and TRANSPORT designs using two MBNV magnets and an MTRV magnet at the end of the beamline were modified and focused to hit the T10 target. The power needed for quadrupoles and bending magnets in this design fit within their physical constraints. The beam optics drawing of the KELVER design is shown in Figure 5.

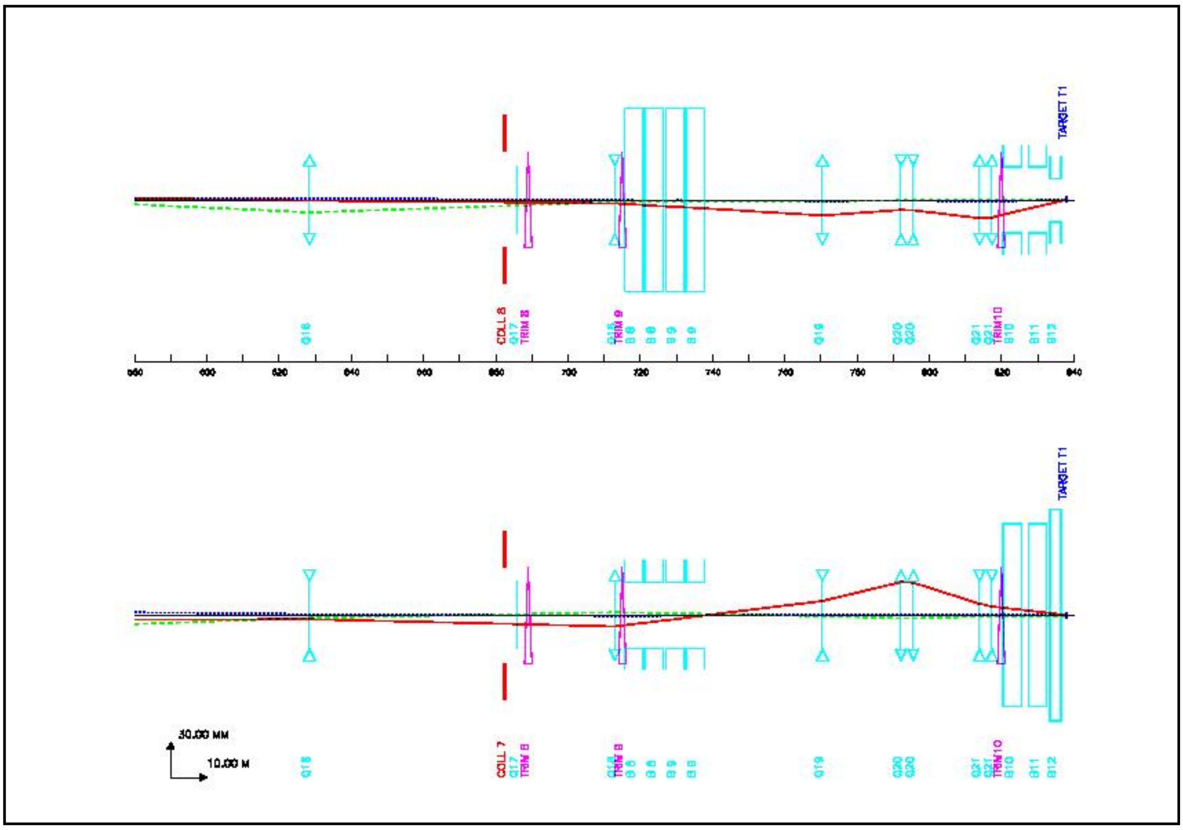

Figure 5: Beam optics drawing of the end of P42 for the KLEVER1 design.

The specifications of all modified magnets are given in Table 1 and Table 2 for the KLEVER1 and KLEVER2 design respectively.

Bend	**Deflection (mrad)**	**P_t-kick (GeV/c)**	**BL (T.m)**	**Magnet type**	**Current (Amps)**	**I for NA62 (Amps)**
BEND10	4.785	1.914	6.38447	MBN	879.6	1339.6
BEND11	7.396	2.9584	9.86824	MBN	1466.3	1117.4
BEND12	5.472	2.1888	7.30111	MTR	815.1	Was MCW

Table 1: The configuration of the bending magnets for the KLEVER 1 design.

Bend	**Deflection (mrad)**	**P_t-kick (GeV/c)**	**BL (T.m)**	**Magnet type**	**Current (Amps)**	**I for NA62 (Amps)**
BEND10	5.093	2.0372	6.79542	MBN	936.2	1339.6
BEND11	6.624	2.6496	8.83819	MBN	1252.9	1117.4
BEND12	5.936	2.3744	7.9202	MTR	995	BL_{max} 7.5?

Table 2: The configuration of the bending magnets for the KLEVER 2 design.

TRANSPORT and BEATCH output and input files were created for both designs and saved to the directory of the group as P42KLEVER and P42KLEVERb. The study of the new designs using BEATCH and TRANSPORT were compared to the same studies done in MAD-X. The two methods produced consistent results simulating both new designs.

Conclusion

The designs explored in this study were shown by two independent methods to create a vertical downward angle of 8mrad while having the beam hit and be focused on the T10 target. The KLEVER1 design had the final bending magnet operating at a lower current. After further study of dose and safety, these designs could be proposed and adopted by the collaboration. The present results will be integrated into the report of the PBC Conventional Beams working group to the Physics Beyond Colliders study that also serves as input to the European Strategy Group.

Previously, other designs were explored such as inserting an additional bending magnet before the final three bending elements to obtain the desired 8 mrad angle production angle. These were not analyzed in this report but could be further studied if problems in these designs arose.

Acknowledgements

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Works Cited

[1] EN-EA Group(the Experimental Areas group of the European Organization for Nuclear Research), Physics Beyond Colliders Conventional Beams report, 2018 (in preparation)

[2] M. Moulson, Laboratori Nazionali di Frascati. KLEVER, 2018. https://agenda.infn.it/conferenceDisplay.py?confId=15807

[3] Physics at the SPS. L. Gatignon (CERN). 2018. 7 pp. Published in Rev.Sci.Instrum. 89 (2018) no.5, 052501. DOI: 10.1063/1.5016162

[4 K. Brown, et al, *TRANSPORT: a computer program for designing charged-particle beam-transport systems.* CERN-80-04 (CERN, 1980).