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BEAM TRANSPORT SIMULATIONS THROUGH FINAL FOCUS HIGH ENERGY TRANSPORT LINES WITH IMPLEMENTED GABOR LENSES

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Abstract

First investigations on Gabor Lens GL2000 at Goethe University have shown that it is possible to confine a 2m long stable Electron Plasma Column and to apply it as a hadron beam focusing device. With this knowledge theoretical implementations of GLs in final focus and transfer lines have started. The focusing with GLs is a weak but smooth focusing in radial direction. The GL is a suitable and inexpensive choice in addition to the existing focusing elements eg. magnetic quadrupoles. The device helps to improve beam quality and minimize losses over long distances. The investigation of relativistic hadron beams in GeV range using the example of the proposed NA61/SHINE VLE-beamline at CERN is carried out and will be presented. Thin-matrix simulations with a generated distribution as well as field map simulations with generated and realistic distributions (Geant4) at 1 - 6 GeV/c have been analysed and compared. In addition, the H4-beamline at North Area (CERN) is proposed to implement GLs for experimental tests.

VLE BEAMLINE DESIGN

Recent plans of the NA61/SHINE collaboration [1] about the conceptual design of a very low energy (VLE) beamline implemented into the H2 beamline in North Area of CERN have led to several studies to investigate possible spots for the placement of the GL and its effect on the beam properties as well as on the settings of surrounding focusing elements. The VLE beamline will guide hadrons, such as protons, pions and kaons, in a range of momenta from 1 up to 13 GeV/c from a primary target over a total distance of around 52 m to a secondary target where the NA61/SHINE experiments will take place. Along the path, the particles are first captured by an acceptance quadrupol duplet, before reaching a double bend achromat for horizontal momentum selection, followed by a final focus chain of four quadrupoles to hit the target in a matched spotsize. Due to its structure and length this beamline represents a perfect test bench to investigate the interaction of the GL as a weak radial focusing element in a HEBT line. Initial considerations included three scenarios (S1, S2, S3) in which the GL was simulated at different points on the beamline (see Fig. 1): S2 is discussed more thoroughly below, since at highly sensitive elements as an achromat the effects on the beam transport can be observed in most detail.

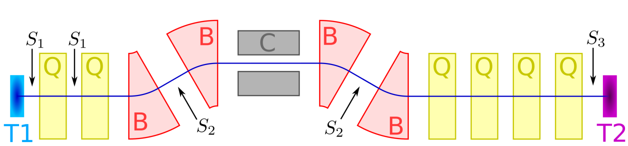

Figure 1: Conceptual design of the H2-VLE-beamline (CERN) from primary (T1) to secondary target (T2) including focusing and momentum selection devices and three possible positions for the implementation of Gabor Lenses.

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GABOR LENS

A Gabor lens (GL) [2] is a cylindrical device that can simply replace any drift section of a linear or circular accelerator, since it still allows plain drift when not operating (off) and radial weak focusing when fully operational (on). This is achieved by confining an electron column inside a cavity trough a superposition of electric and magnetic field along the logitudinal direction of beam propagation (see Fig. 2). For more details on GLs in general see [3]. As a result the positive space charge, which forces the beam to continously drift apart, is overcompensated by the electron density in the GL. Additionally the self electric field inside a homogenously distributed electron column is a linear radial field, so that positively charged beam particles are attracted and linearly focused towards the beam axis due to the Coulomb force.

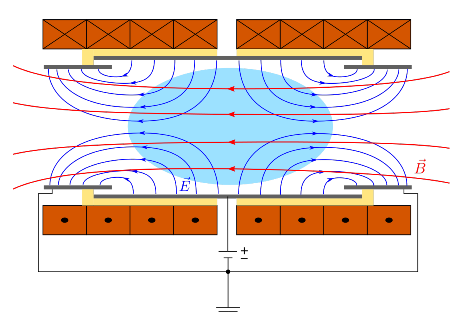

Figure 2: GL schematic setup taken from [4]: electric (blue) and magnetic field (red) confine electron cloud (light blue).

SIMULATION MODELS

Thin Lens

For the presented beam dynamics investigation the GL is a set of thin lens slices consisting of symmetrical drift-thin lens matrix-drift-combinations to approximate the focusing strength of the GL, which can be obtained geometrically:

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$$\frac{1}{f} = \frac{\eta_e L q}{2\epsilon_0 \gamma \beta^2 m_0 c^2} = \frac{\eta_e q}{2\epsilon_0 \beta c}\frac{L}{p}$$

where η_e states the electron density and L the length of GL. In the case of a 1 GeV/c proton beam, this corresponds to a focal length of about 20 m for a density $\eta_e = 10^{15}\,\mathrm{m}^{-3}$ and a length $L = 4$ m. Clearly the focal strength grows linearly by reducing momentum and also by increasing the length of the GL. Therefore first studies consider $p = 1$ GeV/c.

Fieldmap

In order to verify the thin lens approximation, the GL is also implemented as a field m ap. Therefore the cylinder-symmetric self electric field o f a s tatic homogeneously charged electron column is assumed for the calculation of the beam dynamics.

SIMULATIONS

Gabor Lens in Achromat

For the first simulation the thin lens implementation is used. A set of two 2 m long GLs is placed inbetween of the first double-bend to see how it affects the filtering at the collimator. In the case of gaussian distributed monoenergetic protons at $p = 1$ GeV/c, $dp/p = 0$ and neglecting non-linear effects, such as space charge, the normalized density of the beam in both transverse directions is compared for non- and operational GL (see Fig. 3). The weak radial focusing is visible by a smaller beam waist in y-direction and also by a lower rate of particle losses at the collimator in x-direction (ca. 1.4% instead of 2.8%). As can be seen, some particles are lost after the collimator due to collisions with the apertures of the quadrupoles. These particles can be symmetrically captured with an additional GL after the collimator.

Dispersion

A proton beam with a longitudinal momentum deviation in the range of −10% to +10% around the central momentum at $p = 1$ GeV/c is studied. An example for the density in y-direction is shown in Fig. 4. Since in x-direction the center line of such beam moves inside the achromat, the transmission right after the last quadrupole (t_1) and at the target for a given spotsize (20 × 30 mm) (t_2) is measured with the GL operating and non-operating (see Fig. 5). As the scan through the momentum deviation shows (Fig. 6), turning on the GL leads to a higher amount of particles passing the collimator not only in the adjusted momentum range, but also above, as the GL captures additional particles

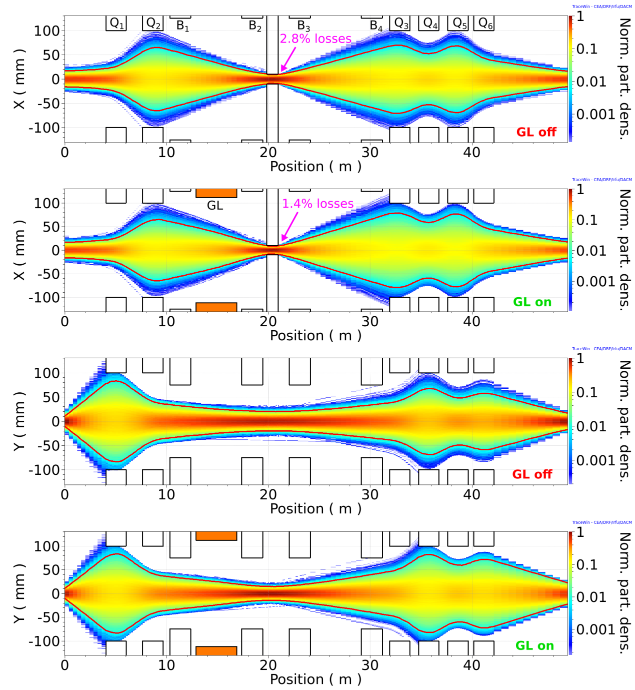

Figure 3: Normalized x- and y-density plot along beamline without (above) and with (below) GL and quadrupole adjustments. Note: The density distribution is normalized by the respective maximum density and therefore the color code between plots is not directly comparable.

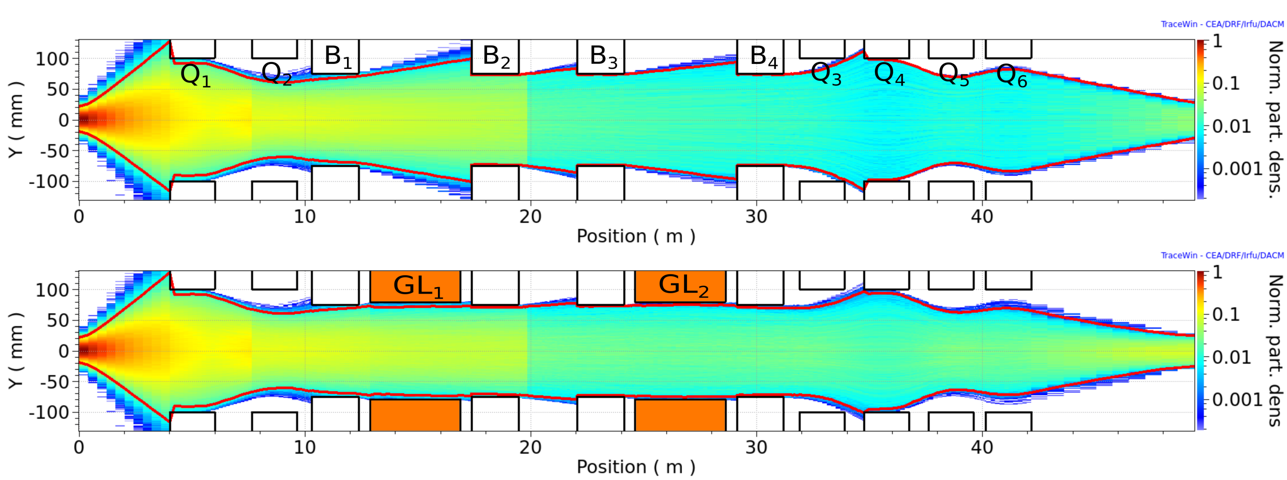

Figure 4: Normalized y-density of protons at $p = 1GeV/c$ and dp/p=+7% without (above) and with two GLs represented by thin lens matrix (below), which reduce particle losses at the apertures of the beam line elements.

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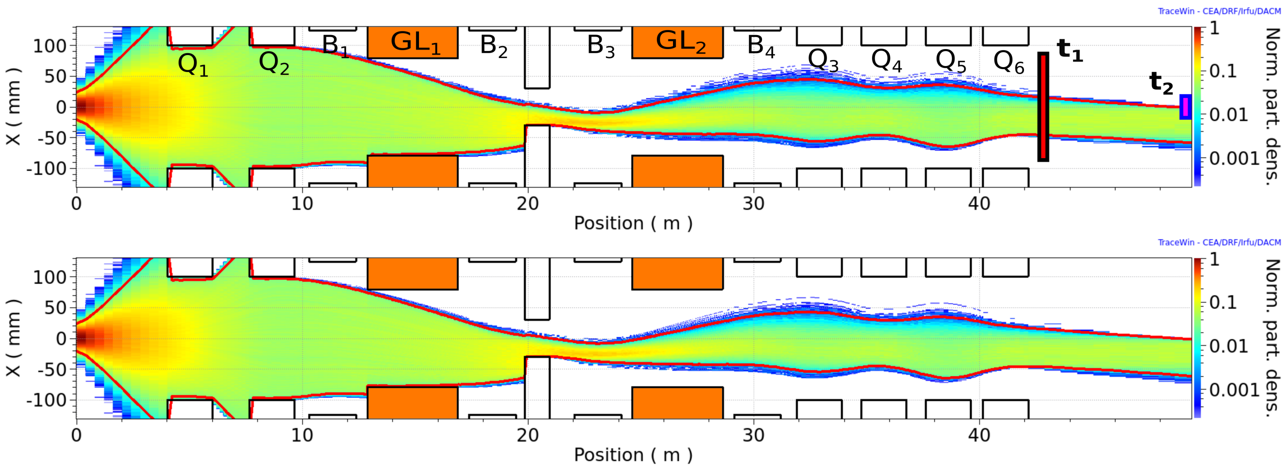

Figure 5: Beamline with dp/p=+7% with two GL represented by thin lens matrix (above) and fieldmap of static electric field of a homogenous electron column (below). Marked are the measured areas of transmission t_1 and t_2.

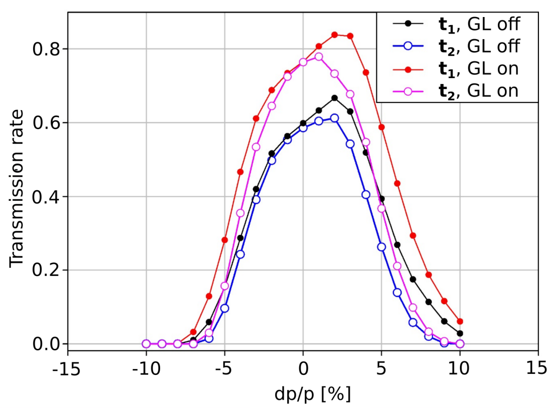

Figure 6: Transmission rate at t_1 and t_2 as a function of dp/p.

due to its radial focusing property. Especially in such long transport lines the advantage of weak but smooth focusing in both planes becomes clear by comparing the increase in transmission rate at the second target (t_2).

Further fieldmap simulations with increasing particle momentum also show higher transmission on t_2 when the GL is operational:

Table 1: Accumulated transmission of initial 5×10^5 protons over all momentum deviation of ±10% on t_2

p [GeV/c]	Particles, GL off	Increase, GL on
1	13938	+36%
2	13156	+15%
3	13421	+6%
4	11975	+4%

Fieldmap

For the last part, to check whether thin lens representation of the GL yields the same results as characterising the GL by a fieldmap, two GLs are implemented around the collimator and the transmission right before and after the collimator in both cases is compared. Here it is assumed that the aperture of the GL is $r = 0.08$ m and its lenght is $L = 2\times\,2$ m . Furthermore the beam particles have a momentum deviation of 7%. As one can easily see in Fig. 5 both representations lead to equal focusing effects on the beam. More precisely comparing the transmission right before and after the collimator results in the same loss rate.

CONCLUSION

First simulations of GLs implemented in an achromat of a HEBT line have been useful to test and analyse its weak radial focusing effect on the beam with different settings. Simulations show an increase in acceptance and beam transmission with GLs and therefore a higher number of particles reaching the target. Due to the additional focusing of GLs it is necessary to adjust the settings of surrounding quadrupoles. In several scenarios the applicability of the thin-lens approximation could be confirmed by field map simulations. Next steps considering space charge effects of the beam and the GL itself are planned to get a better picture of the behaviour of a GL in a high energy beam. Also experimental studies of the GL in HEBT lines are in preperation.

ACKNOWLEDGEMENTS

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REFERENCES

[1] C. A. Mussolini, N. Charitonidis, E. D. Zimmerman, Y. Nagai, and P. Burrows, "Design of a Very Low Energy Beamline for NA61/SHINE", presented at the IPAC'22, Bangkok, Thailand, Jun. 2022, paper WEPOST023, this conference.

ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-MOPOMS017

[2] K. Schulte, "Studies on the focusing performance of a Gabor lens depending on nonneutral plasma properties", PhD Thesis, Apr. 2014, urn:nbn:de:hebis:30:3-334310

[3] K. I. Thoma, M. Droba, and O. Meusel, "Investigation, Simulation and First Measurements of a 2m Long Electron Column Trapped in a Gabor Lens Device", presented at the IPAC'22, Bangkok, Thailand, Jun. 2022, paper WEPOTK002, this conference.

[4] J. Rausch, "Development, design and construction of a measuring station for momentum spectrometry of low-energy particle sources", p. 16., Goethe University Frankfurt, Dec. 2021.