CAPTURE AND TRANSPORT OF THE LASER ACCELERATED ION BEAMS FOR THE LIGHT PROJECT

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Abstract

An impressive advantage of Laser Ion Sources is an extremely high beam brilliance. The LIGHT project (**L**aser **I**on **G**eneration, **H**andling and **T**ransport) is dedicated to the production of protons (ions), accelerated up to 10 MeV by using the GSI PHELIX laser at GSI, and injected into a conventional accelerator. A successful experimental campaign stimulated further investigation of the focusing, transport and collimation of the high energy and high brilliance proton beam. In addition to the advanced codes, describing the very early expansion phase of the proton-electron cloud, the versatile multiparticle code DYNAMION was implemented to perform beam dynamics simulations for different possible transport lines. Potentially a transport line comprises magnetic quadrupole lenses and/or solenoids for transverse beam focusing. A bunch rotation rf cavity decreasing the energy spread of the protons was included into the simulations. The results of the beam dynamics simulations are presented, as well as benchmarking activities with other codes. Further developments of the experimental test stand and the different possibilities of its integration to the GSI accelerators chain are discussed.

INTRODUCTION

An acceleration of the ion beams with intense laser pulse, focused on a solid target, is recently under consideration at the leading scientific centers. Laser ion source can provide for 10^{12}-10^{13} particles per shot with small beam emittances due to the short pulse duration (< 1 ps) and a small beam spot of few tens of mkm.

The LIGHT collaboration [1] is dedicated to build up at Helmholtzzentrum GSI a test stand for an investigation of the proton beam, accelerated with laser PHELIX [2]. The installation (Fig. 1) is already integrated into a beam line of the GSI heavy ion high current linac UNILAC [3]. It provides for an unique possibility to tune the beam line and to calibrate diagnostics devices with an ion beams.

Generally the LIGHT Project combines together three different tasks:

- Development of the powerful laser and delivery of the laser beam to the target;
- Simulations of the very early expansion of the laser generated electron-ion cloud and an optimization of the target;
- Capture, collimation, focusing and rotation of the ion beam including its matching to the conventional accelerating-focusing structures.

This paper is dedicated mainly to the last topic.

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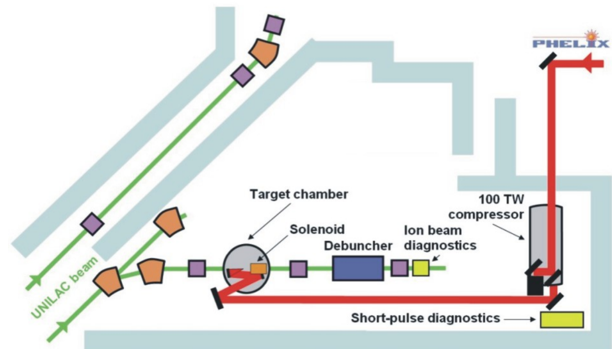

Figure 1: Integration of the LIGHT test stand into existing UNILAC beam line.

MULTIPARTICLE CODE DYNAMION

During the last years a set of beam dynamics simulations for the LIGHT project were done using versatile multiparticle code DYNAMION [4]. Since 1985 the code was used for the linac design and optimization at leading accelerator centers: ITEP (Moscow), GSI (Darmstadt), CERN (Geneva), MMF (Troitsk), LNL-INFN (Legnaro), ANL (Argonne) and others. Numerous benchmarking with other codes and comparison with experimental results confirm reliability and accuracy of the code DYNAMION.

General feature of the code is a solving of the full 3D-equation of particle motion. Therefore non-linear effects, as well as high order chromatic aberrations, are included into the simulations automatically. External electromagnetic fields are calculated inside the code or can be used as an externally modeled or measured 3D field mapping. Space charge effects are calculated using different solvers [5, 6].

INPUT BEAM PARAMETERS

The initial beam parameters (Tab. 1) for DYNAMION simulations are based on the experimental data and dedicated calculations of plasma expansion.

Table 1: Estimated Input Parameters of the Proton Beam

Energy	10 MeV
Energy spread	± 64%
Phase spread	± 0.75° (at 108 MHz)
Transverse emittance	< 5 mm*mrad
Transverse divergence	± 172 mrad
Transverse radius	± 0.03 mm

As already demonstrated, the influence by space charge forces behind a few millimeters away from the target is low [7]. Therefore space charge effects were neglected and simulated results can be treated as an optimum level for emittance growth and particle transmission.

Previously calculated typical trajectories of the particles with an energy spread of up to ±64%, focused by a solenoid, are illustrated on Fig. 2. As expected, an extremely strong dependence of the beam focusing and collimation on the beam energy spread was observed [8].

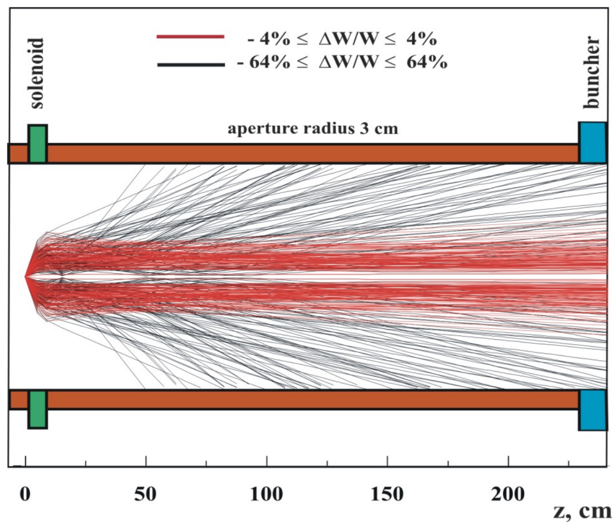

Figure 2: Typical particle trajectories along the beam line. Red lines show particle with input energy spread of ±4%.

RECENT BEAM LINE LAYOUT

Recent layout of the LIGHT beam line (Fig. 3) comprises the sc solenoid for collection and transverse focusing of the particles and the rf buncher for longitudinal beam rotation (decreasing of the beam energy spread) [9].

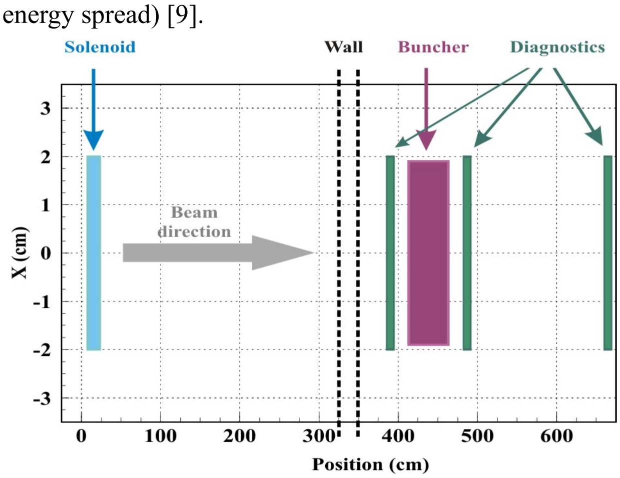

Figure 3: Scheme of the LIGHT beam line

Magnetic field of the already installed sc-solenoid was calculated by means of the CST-Studio package and included into the code as a 3D axisymmetric field mapping [9]. A use of the measured at GSI 3D magnetic field is foreseen for the further study.

TRANSVERSE BEAM FOCUSING

Assumed recently a beam energy spread up to ±50% leads to a significant beam loss: the particles with high energy and/or high transverse divergence angle are under focused, while the low energy particles are over focused (Fig. 2). Therefore the aperture of the beam line works as an energy and divergence filter.

Due to the technical limitations the focusing solenoid is positioned now at the distance of 80 mm from the laser target. Ideally the solenoid should focus the beam with defined energy at the center of the buncher. This allows to minimize an additional degradation of the beam quality in the buncher due to the nonlinear dependence of the buncher action from the transverse coordinate of particle.

An optimum field of the solenoid (7.50 Tesla), leading to a smallest beam size at buncher, was found by beam dynamics simulations using a monoenergetic proton beam (10 MeV) with low transverse divergence (±43 mrad). As shown on Fig.4, even a beam with such optimistic input parameters can not be focused close to the position of buncher. An increase of the beam divergence and of the energy spread up to realistic values leads (for recent layout of the line) to a dramatical beam loss of up to 95%.

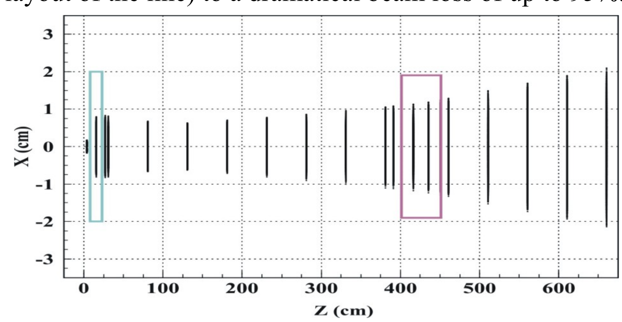

Figure 4: Beam envelopes of the monoenergetic beam with small initial transverse divergence of ±43 mrad along the recent transport line with solenoid (blue box) and buncher (magenta box).

BUNCH ROTATION

The beam rotation and focusing in the longitudinal phase plane is foreseen by means of the existing GSI 3-gap 108 MHz buncher. It is planned to be installed into the beam line in 2011. A 3D electrical field inside the buncher was calculated with the DYNAMION package solving Laplace equation for the measured topology of the gaps and tubes. A comparison of the calculated and measured electrical field [10] is shown on Fig. 5.

A buncher action on the longitudinal phase plane is illustrated on Fig. 6. An initial beam energy spread of ±5% after 4 meter drift leads to a bunch length of about ±90° (at 108 MHz). The total buncher voltage of 550 kV (max. 1.0 MV) is required for the minimization of the energy spread from ±5% to less than ±1%. As this buncher was designed for the beam energy of 11.4 Mev/u (design UNILAC energy), an optimization of the rf-phase during simulations was performed to preserve the proton energy of 10 MeV behind the buncher.

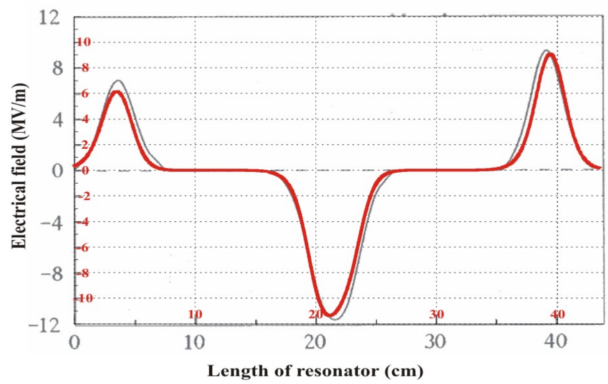

Figure 5: Measured (black) and calculated with DYNAMION (red) longitudinal electrical field on the axis along the 108 MHz GSI-LIGHT-buncher.

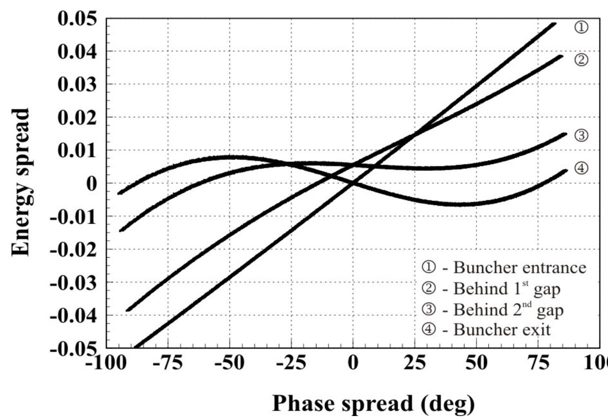

Figure 6: Bunch rotation with the 3-gap buncher. Input energy spread ±5%, input divergence ±43 mrad.

The beam dynamics simulations for the whole LIGHT transport line (total length of 7 m) including the solenoid, the buncher and the drift for the diagnostics were performed for a wide range of the initial beam-divergence (up to ±172 mrad) and -energy spread (up to ±50%). The solenoid and the buncher were optimized for the proton energy of 10 MeV. Downstream the buncher a fraction of protons with required energy spread of ±1% is only a few percent of the initial particle distribution with realistic characteristics. The total particle transmission at the position of the last diagnostics device is summarized in Table 2.

Table 2: Particle Transmission for the LIGHT Beam Line

	Energy spread (%)		
Divergence (mrad)	**0**	**5**	**50**
43	98%	44%	13%
86	97%	42%	12%
172	32%	12%	5%

The main reason for a beam loss is the energy spread of particles. Nevertheless one can observe a good energy resolution behind the buncher (Fig. 7). This result is promising for the planned experimental parameter study of the laser generated beam at the LIGHT test stand.

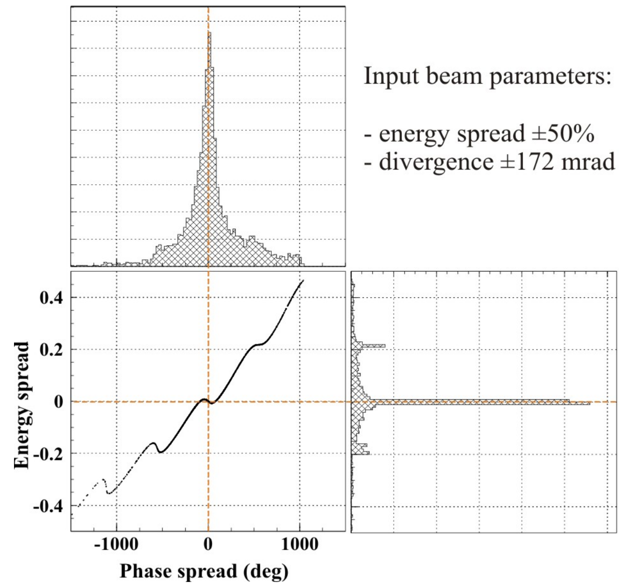

Figure 7: A longitudinal beam phase portrait at the end of the transport line.

CONCLUSION AND OUTLOOK

- An unique installation for the transport, collimation and rotation of the proton beam, generated by powerful laser PHELIX, is integrated into GSI UNILAC beam line.
- An ion beam with variable energy from routine UNILAC operation can be used for a tuning of the beam line settings and for a calibration of the diagnostics.
- Dedicated experiments were performed in 2010 and 2011 including laser generation of the proton beam and its focusing with the solenoid.
- Advanced beam dynamics simulations, done by means of multiparticle DYNAMION code, are used for the optimization of the beam line, as well as for the prediction of the experimental results.
- On the base of the recent simulation results the buncher will be installed closer to the solenoid to provide for the improved beam matching and higher transmission.
- Experiments with laser generated proton beam, focused by the solenoid and rotated with the buncher are already planned for 2012.

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