ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPME033

PARTICLE TRACKING STUDIES FOR THE LINCE SC LINAC*

Cristian Bontoiu†, Ismael Martel, Univ. of Huelva, Spain
Celia Gomez, IDOM, Bilbao, Spain
Antonio Falone, TTI, Aeropolis-Sevilla, Spain

Abstract

LINCE heavy-ion facility [1] makes use of a low-energy ion linac consisting of quarter-wave resonators (QWRs) designed for β = 0.045, 0.077 and 0.15 working at 72.75 MHz and 109.125 MHz, and solenoid magnets distributed along four different cryomodules. Particle tracking studies have been performed using realistic electric and magnetic field maps to reach the final energy of 8.5 MeV/u for A/Q = 7 ions.

OVERALL LAYOUT

The required intensities are of about 1 mA for protons and from 10 pμA to 100 pμA for heavy ions with A/Q = 7. The SC linac is designed to accelerate A/Q = 7 ions from 500 keV/u as delivered by a four-vane RFQ [2], to about 8.5 MeV/u, using 26 SC QWRs and 15 SC solenoids. The RF frequencies used for the resonators are harmonics of 18.19 MHz, the fundamental frequency for the LINCE Project. Beams from proton to Uranium with A/Q = 1 to 7 are produced by an ECR ion source [3] placed in a 250 kV platform. The energy for injection in the RFQ was defined as 40 keV/u. The main components of the beam line after the high voltage platform are:

1. Multi-Harmonic buncher;
2. Three electrostatic quadrupole triplets for transversal RFQ matching;
3. The RFQ;
4. One magnetic quadrupole triplet for transversal matching with the re-buncher and LINAC;
5. The re-buncher (room temperature) for longitudinal matching with the first cavity of the LINAC;
6. Four Cryomodules with SC resonators and SC solenoids.

The first linac cryomodule uses a 72.75 MHz QWR designed internally by our collaboration for β = 0.045 and 72.75 MHz. Details of the cryomodule including five cavities of this type and three solenoids can be found in [4]. The second and third cryomodules use a QWR designed by Argonne National Lab. (ANL) [5] for β = 0.077 and 72.75 MHz while the fourth cryomodule uses a β = 0.15 and 109.125 MHz design also produced at ANL [6]. Relevant parameters of the resonators are listed in Table 1.

* Work partially supported by the Spanish Government (MINECO-CDTI) under program FEDER INTERCONNECTA.
† cbontoiu@gmail.com

Table 1: Characteristics of the Quarter-Wave Resonators

Cryomodule	Frequency [MHz]	β	V_{acc} [MV]	No. of resonators
1	72.75	0.045	1.39	5
2	72.75	0.077	2.38	7
3	72.75	0.077	2.38	7
4	109.125	0.150	3.30	7

BEAM DYNAMICS WITH TRACK

Particle dynamics studies have been carried out in TRACK [7] using electric field maps for the QWRs generated by electromagnetic studies performed in both Comsol RF [9] and CST-MW [10] and solenoid magnetic field maps, generated in Comsol ACDC. The dynamics was studied for A/Q = 7, 6, 5, 4 and 3, without and with space charge effects. We found a very small effect for intensities above 200 μA, which can be overcome in changing the tuning of the quadrupoles and solenoids. However, for light ions (protons and alphas) and due to the intensities requirements up to 1 mA, space charge effects are more effective and modifications of the tuning are more effective. In particular, for these beams we included a second buncher (mono-harmonic) closer to the RFQ in addition to the one just after the high-voltage platform. In addition, the fundamental frequency should be changed to 36.375 MHz. The beam envelope of the beam for A/Q = 7 is shown in Fig. 1.

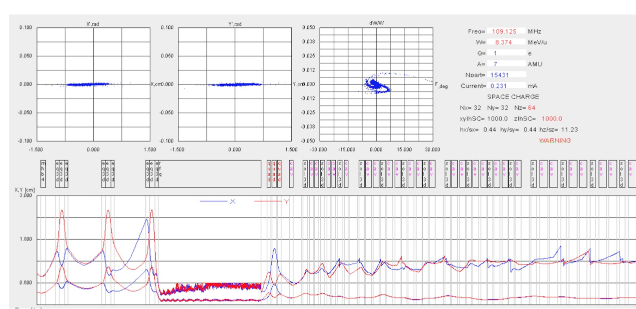

Figure 1: Beam Envelope for A/Q = 7 Ions as Obtained in TRACK.

The beam energy and longitudinal emittance reached for A/Q = 7 at the exit of each cryomodule are shown in Fig. 2. The synchronous phase adopted in the first cryomodule of the linac is −25 deg, whilst in the other cryomodules this value was changed to −20 deg. The results show the transport of 20000 initial particles. The overall beam transport efficiency for LINCE is 77 % while the linac transmission is larger than 95 % and beam characteristics in the exit of the linac are

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPME033

compatible with the final requirements of the facility. The topology of the cryomodules includes a lattice, which always start with a solenoid. The structure is SRRSRRSRRSR for the cryomodule with 7 resonators and SRRSRRSR for the cryomodule with 5 resonators, where S and R correspond to solenoid and resonator. This topology corresponds to the recently tested cryomodules for the ATLAS accelerator at ANL [5]. The lattice including solenoids has the advantage to exactly counteract the radial defocussing from the resonators [8]. Moreover, the last missing resonator in the cryomodule topology allows having a smooth and quasi-periodic lattice, where one resonator is replaced by a spacing transition between cryomodules.

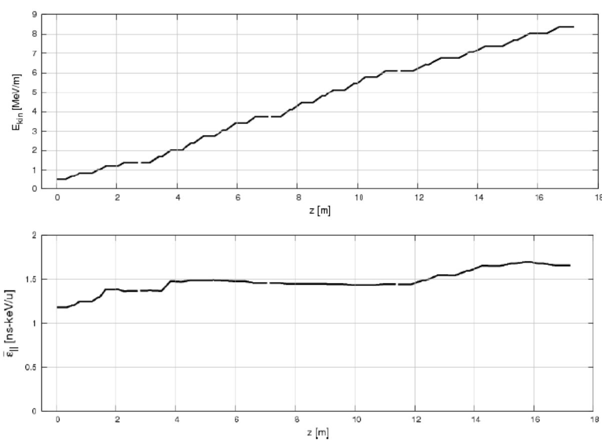

Figure 2: Beam energy (top) and longitudinal emittance (bottom) for A/Q = 7 ions as obtained in TRACK.

TRACKING WITH MADX AND GPT

In this section we present a complementary study performed on the LINCE linac layout, using the MADX [11] and GPT [12] codes. The linac lattice is defined by three types of solenoids (length) as described in Table 2.

Table 2: Characteristics of the Solenoids Along the Linac

Cryomodule	Length [cm]	Periodicity [m]	B_{max} [T]	No. of solenoids
1	21.9	1.0558	5.00	3
2	26.6	1.0660	4.57	4
3	26.6	1.0660	4.57	4
4	27.5	1.4830	5.02	4

Matching between the four solenoid lattices has been achieved using the MADX with a constant momentum beam. As a first stage, the periodic beta function has been found for each cryomodule, setting the magnetic field values shown in Table 2. Next, with the complete linac lattice in place, the transitions have been optimized by tuning the strength of solenoids at the beginning and end of each cryomodule. Front-to-end beta function is shown in Fig. 3 along with the peak magnetic field of each solenoid.

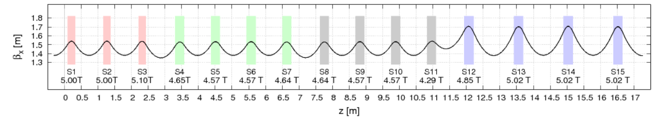
Figure 3: Horizontal beta function.

Particle tracking studies have been performed using GPT. From an arbitrary large transverse beam phase space at injection, each cryomodule transmits an area specific to its lattice periodicity, solenoid length and strength. Reverse particle mapping from the end of each cryomodule to the injection point shows that the fourth lattice has the lowest transverse acceptance.

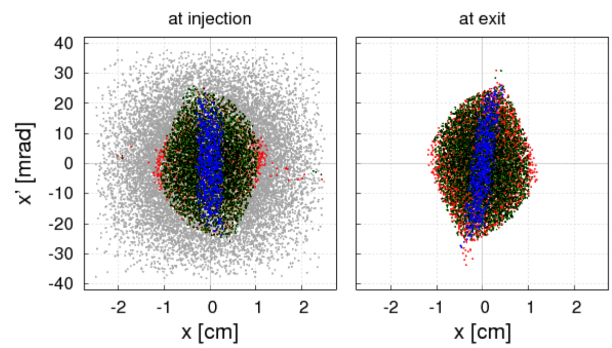

Figure 4: Transmitted particles for the 1st (red), 2nd (green), 3rd (black) and 4th (blue) cryomodule out of a test Gaussian distribution (grey).

With the maximum magnetic fields trajectories and rms beam size along the first cryomodule are shown in Fig. 5. Having the highest beta function values, the fourth cryomodule solenoids focus the beam to a smaller size and this reduces the transverse acceptance.

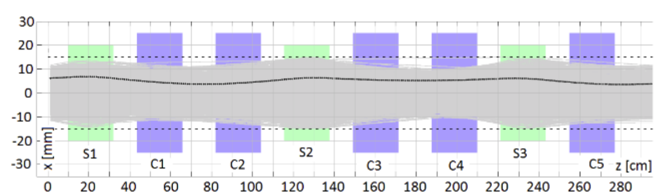

Figure 5: Particle trajectories (grey) and rms beam size (black), along the first cryomodule lattice.

There is no unique choice for the peak on-axis electric field $\hat{E}_{||}$ and phase Φ, as some combinations are more suitable for acceleration and other for bunching. Gradient-phase scans have been carried out for a test Gaussian bunch passing through the first cavity gaps, in order to understand the impact on the energy gain as shown in Fig. 6.

This scan allows a choice for the working point (phase-electric field gradient) such that a predetermined energy gain level can be obtained without compromising on the energy spread or time spread. For example working at −15 deg synchronous phase, the needed accelerating gradient to reach 150 keV/u is around 1 MV for the first cryomodule. Sim-

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPME033

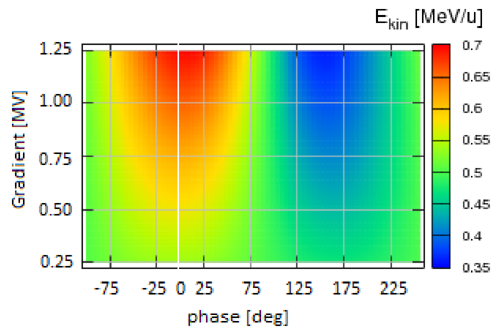

Figure 6: Gradient-phase scan for a test Gaussian bunch passing through the first cavity.

ilar studies have resulted in suitable choices for the second and third cryomodules with gradients of 2.76 MV/m to enable 350 keV/u energy gain per cavity and respectively 3.22 MV/m for the fourth cryomodule with the same energy gain per cavity. Snapshots of the longitudinal phase space during acceleration are shown in Fig. 7. The kinetic energy after passing through each of the 26 QWRs is shown in Fig. 8 proving smooth acceleration from 500 keV/u to 8.5 MeV/u for A/Q = 7 ions. The results are consistent with previous beam dynamics calculations using TRACK shown in Fig. 2.

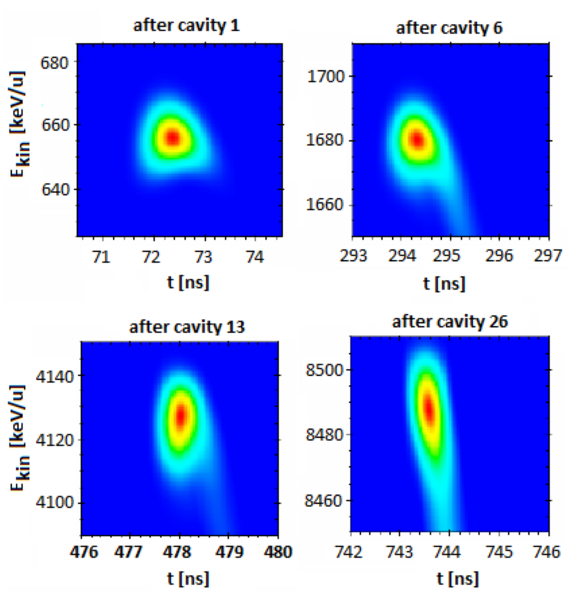

Figure 7: Snapshots of the longitudinal phase space at different locations along the linac.

CONCLUSIONS

The article reported beam dynamics studies for the LINCE SC linac made of four cryomodule lattices. The most important goal, to prove the viability of the lattice, has been reached, using complementary approaches based on TRACK, MADX and GPT codes. It was shown that 26 QWRs are sufficient for the acceleration of A/Q = 7 ions up to 8.5 MeV/m within 17 m. The beam dynamics study is fairly advanced and will be continued in the nearest future with iterative engineering of the QWRs and solenoids.

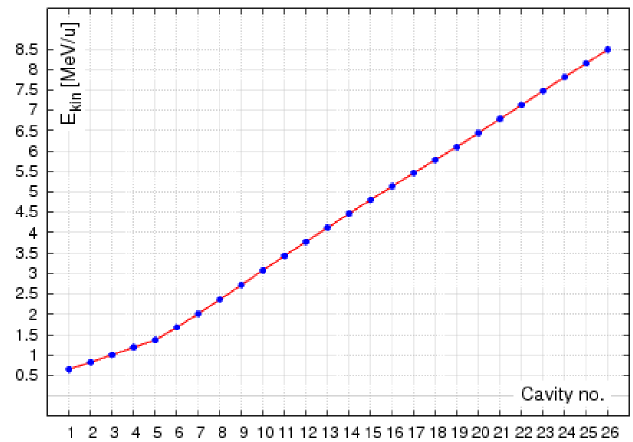

Figure 8: Kinetic energy after each cavity.

REFERENCES

[1] I. Martel, et al., “LINCE: A High Intensity Multi-ion Superconducting Linac for Nuclear Structure and Reactions”, THPME036 , IPAC 14, Dresden, Germany, (2014).
[2] A. Orduz, et al., “Development of a 72.75 MHz RFQ for the LINCE Accelerator Complex”, THPME037, IPAC’14, Dresden, Germany, (2014).
[3] I. Martel et al., “Development of a 14.5 – 18 GHz ECR Ion Source at University of Huelva”, MOPRI013, IPAC’14, Dresden, Germany, (2014).
[4] D. Gordo Yanez, et al., “High-performance accelerating cryomodule for the LINCE Project”, THPME035, IPAC’14, Dresden, Germany, (2014).
[5] Kelly M., et al., “Superconducting 72 MHz beta=0.077 quarter-wave cavity for ATLAS”, TUP046, PAC’11, New York, USA, (2011).
[6] Kelly M., et al., “SC quarter-wave resonators for the ATLAS energy upgrade”, THP025, LINAC’08, New York, USA, (2008).
[7] V. Aseev, et al.,“TRACK: The new beam dynamics code”, TPAT028, PAC’05, Knoxville, USA, (2005).
[8] A. Lunin, et al., “FINAL RESULTS ON RF AND WAKE KICKS CAUSED BY THE COUPLERS FOR THE ILC CAVITY“, WEPE034, IPAC 10, Kyoto, Japan, (2010).
[9] Comsol website: http://www.comsol.com/products/multiphysics/
[10] Computer Simulation Technology website: https://www.cst.com/Products/CSTMWS
[11] CERN MADX website: http://mad.web.cern.ch/mad/
[12] General Particle Tracer website: http://www.pulsar.nl/gpt