STATUS OF THE FAIR 70 MeV PROTON LINAC

L. Groening, W. Barth, R. Berezov, G. Clemente, P. Forck, A. Krämer, C. Mühle, R. Hollinger,
J. Pfister, W. Vinzenz, G. Schreiber, J. Trüller, C. Will,
GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany
B. Launé, J. Lesrel, IPNO, IN2P3, CNRS/Orsay, France
N. Chauvin, O. Delferrière, O. Tuske, C. Simon, IRFU, CEA/Saclay, France
B. Koubek, H. Podlech, U. Ratzinger, A. Schempp, R. Tiede, Goethe Univ., Frankfurt, Germany

Abstract

To provide the primary proton beam for the FAIR anti-proton research program, a 70 MeV, 70 mA linac is currently under design & construction at GSI. The nc machine comprises an ECR source, a 3 MeV RFQ, and a DTL based on CH-cavities. Up to 36 MeV pairs of rf-coupled cavities (CCH) are used. A prototype cavity has been built and is prepared for high power rf-testing. An overview of the status as well as on the perspectives of the project is given.

INTRODUCTION

The FAIR proton linac [1] has to provide the primary proton beam for the production of antiprotons. It will deliver a 70 MeV beam with a repetition rate of 4 Hz. Its conceptual layout is shown in Fig. 3 and its main beam parameters are listed in Tab. 1.

Table 1: FAIR Proton Linac Parameters

Final energy	70 MeV
Pulse current	70 mA
Protons per pulse	$7 \cdot 10^{12}$
Repetition rate	4 Hz
Trans. beam emittance	4.2 µm (tot. norm.)
Rf-frequency	325.224 MHz

DTL-CAVITIES

Acceleration from 3.0 to 70 MeV is accomplished with six H-mode cavities operated in the TE_{211}-mode [2]. Compared to conventional Alvarez cavities these Crossed-bar (CH) cavities feature higher shunt impedance at low energies as shown in Fig. 1. The first three cavities are pairs of two rf-coupled CH-cavities. Rf-coupling is accomplished by merging the first cavity’s exit half-drift tube with the second cavity’s entrance half-drift tube. This prolonged drift tube of the rf-coupled CHs (CCH) can house a quadrupole triplet. It also provides the rf-coupling cell in the TM_{010}-mode. Such CCHs allow for full exploitations of the available rf-power of up to 3 MW per rf-source. After the CCH-section acceleration from 36 to 70 MeV is done with three single CH-cavities. Tuning of the field flatness is done basically by properly choosing the gap lengths [3]. To this end initially the stems and drift tubes are produced from aluminium. Flatness optimization is done by iterative bead-pull measurements and re-fabrication of the drift tubes. Finally the stems & tubes are drilled from stainless and welded into the cavity. Post fine tuning can just be done by using mobile plungers. The CCH-cavity providing acceleration from 11.6 to 24 MeV (Fig. 2) has been produced and was successfully tuned w.r.t. field flatness. Copper plating is foreseen within this year.

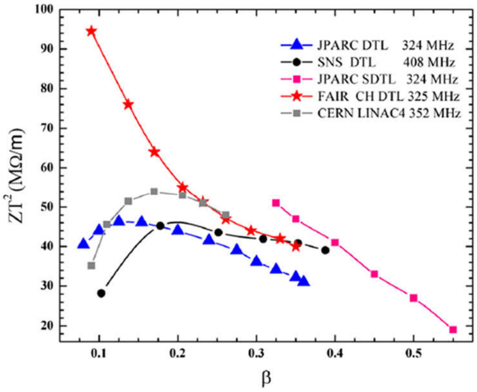

Figure 1: Shunt impedances of several cavity types.

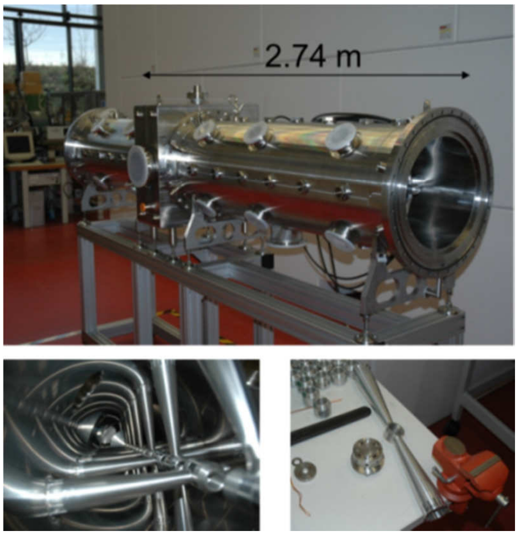

Figure 2: Prototype of CCH-cavity.

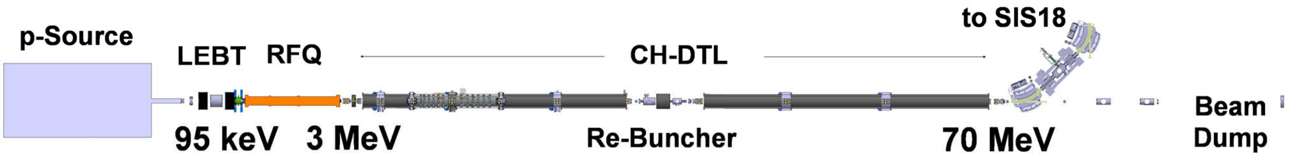

Figure 3: Layout of the FAIR proton linac.

RF-POWER SOURCES

The six DTL cavities and the RFQ will be powered by one klystron each. For the DTL the amount of beam load is up to 50% and the peak rf-power is designed not to exceed 2.2 MW. However, the klystrons are specified to deliver up to 2.7 MW in their linear range. The saturated power is 3.0 MW. Each klystron is fed by an individual modulator. Currently an rf-test stand is under construction at GSI. It will be used for extensive power testing of the prototype CCH-cavity as well as for the SAT procedure of the other cavities. A first TOSHIBA klystron has been delivered and its modulator is expected this year. Along the proton linac three bunchers are used. They require less than 50 kW of rf-power to be provided by solid state amplifiers. The RFQ will require about 800 kW of rf-power. CNRS/Orsay will provide for the procurement of the rf-chain of the proton linac. A considerable amount of equipment for the rf-test has been already delivered as llrf-components, waveguides, scopes etc.

FRONT-END

The proton source & LEBT has to provide a proton current of up to 100 mA within a normalized transverse rms emittance of 0.3 mm mrad. At CEA/Saclay the source & LEBT set-up is currently under construction. Its design is adopted from the IPHI deuteron injector. The beam line magnets are already produced and the terminal is under construction. Commissioning at CEA will start in 2013.

The RFQ is currently foreseen to be a 4-rod type of 3.2 m in length [4] although other types are still under study. Special care has been taken in damping of the dipole modes by extensive parameter scans w.r.t. to its rf-properties [5]. Individual tuning plates between the stems allow for individual tuning of each RFQ-cell thus providing a flat voltage distribution. To verify the simulations a dedicated few-cells copper model was built as shown in the upper part of Fig. 4. Good agreement between low-level rf-measurements and simulations has been obtained [6]. The RFQ beam dynamics layout is based on the New-Four-Section-Procedure which drops the constant-focussing scheme [4]. Figure 4 (lower part) displays the RFQ parameters as functions of the cell number.

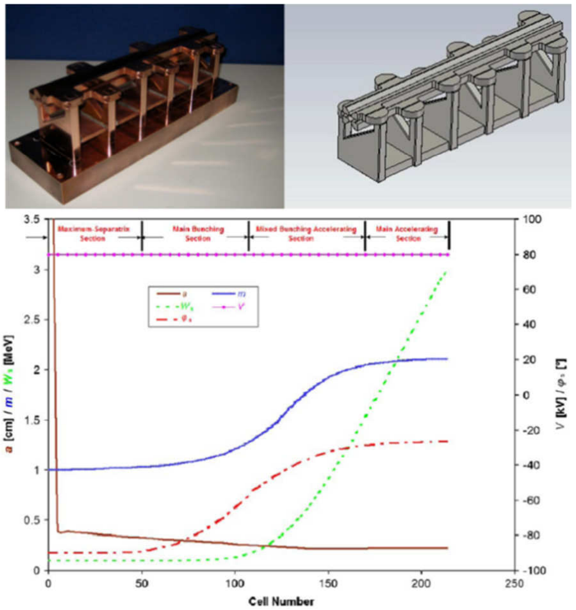

Figure 4: Model of 4-rod RFQ (upper) and beam dynamics parameters (lower).

BEAM DYNAMICS

The beam dynamics of the proton linac has been studied by end-to-end simulations. The linac was split into sections, i.e. source extract, LEBT, RFQ, DTL, and final transportation to the synchrotron. The output of one section served as the input of the following one. Special care was taken in the self-consistent simulation of the space & time dependence of the space charge compensation along the LEBT [7].

Table 2: Linac Sections and Codes for End-to-End Simulations

Section	Code	Features
Source Extract.	AXCEL-INP	2D-PIC, w/o space charge
LEBT	SOLMAX	3D-PIC, res.gas interact.
LEBT	TraceWin	3D-PIC
RFQ	DYNAMION	3D-part-part
DTL	LORASR	3D-PIC
To synchrotron	PARMILA	3D-SCHEFF

The longitudinal dynamic along the CH-DTL is of the KONUS type [8] as sketched in Fig. 5.

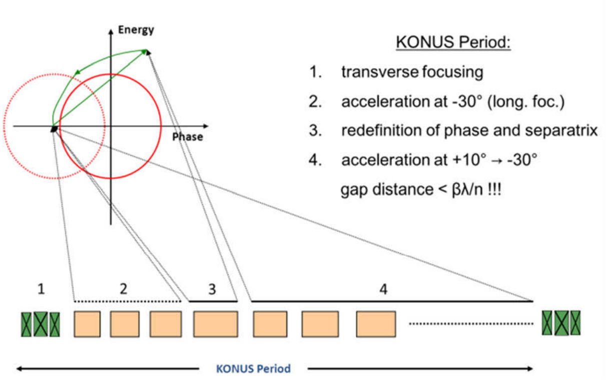

Figure 5: Principle of the KONUS beam dynamics.

Since the most CH-drift tubes do not include focussing quadrupoles, acceleration cannot be performed just at negative phases. The KONUS varies the design phase and even skips the identity of bunch center and synchronous particle. This allows partial acceleration on crest thus increasing the acceleration efficiency. The final distribution obtained at the entrance to the synchrotron [2] fits the requirements listed in Tab. 1. The DTL simulations were extended to error studies. Rf-amplitudes and phases were subject to Gaussian errors of 1° and 1% rms, respectively. As the main source of loss quadrupole translations of 0.1 mm (rms) was identified. However, roll, pitch, and yaw have been included as well. The results revealed loss hot spots (Fig. 6) that went into the layout of the shielding environment.

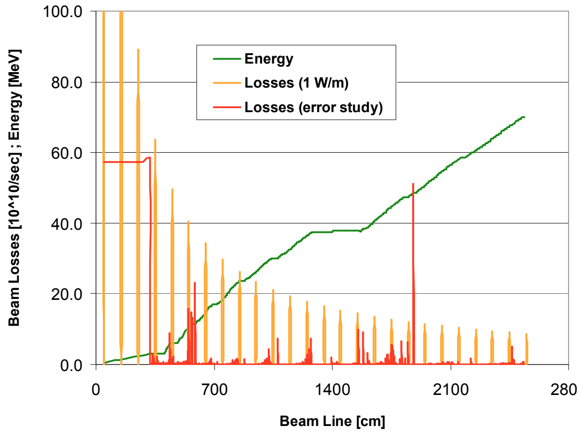

Figure 6: Beam loss profile from DTL error studies.

DIAGNOSTICS

The kind of beam diagnostics and the locations along the beam line are defined as shown in Fig. 7. The layout of the most devices is straight forward. However, the design, mechanical integration, and data acquisition of the phase probes & BPMs is challenging. These 4-bottom BPMs are partially to be integrated into the end drift tubes of the (C)CH-cavities. Special care must be taken for the suppression of primary rf sneeking into the drift tube that holds the BPM bottoms.

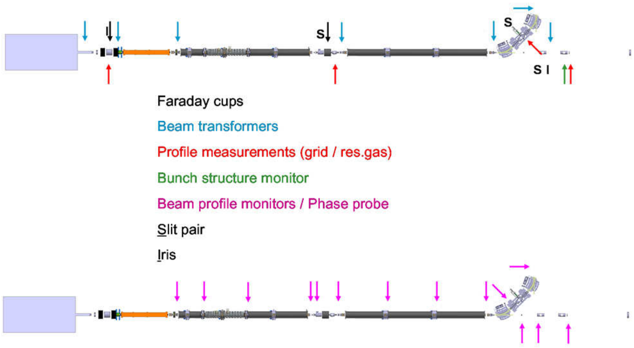

Figure 7: Beam diagnostic devices of the proton linac.

This shielding is accomplished by properly choosing the drift tube diameter being a compromise between reasonable beam tube diameter and sufficient rf cut off. The location of the BPMs represents the interface of many issues as beam dynamics, cavity design, magnets, and diagnostics itself. Extensive MWS-simulations w.r.t. to geometry parameter scans have been performed to this end. Data acquisition is based on evaluation of the second harmonic, i.e. 650.4 MHz. Spatial resolution of the beam center of less than 0.1 mm can be obtained. But there is still work on-going to achieve the required phase resolution of less than 1° for bunch shapes being different from Gaussian. The latter can be expected from the KONUS scheme featuring bunches with extended low energy tails.

SCHEDULE

The parameters of all devices are frozen and the technical specification including mechanical integration is in progress. Major efforts are currently made to finalize the civil construction planning, i.e. provision of load data, cabling lists, specification of rooms, etc. Recent planning assumes the building to be ready in summer of 2016. Commissioning of the linac will be section-wise up to the full design current of 70 mA. After each cavity a mobile diagnostic bench allowing for energy-, current-, and emittance measurement will be installed. We expect commissioning to full performance to last about two years.

REFERENCES

[1] Technical Report "Proton Linac", `https://edms.cern.ch/document/994418/1`
[2] G. Clemente et al., PRST-AB **14**, 110101 (2011).
[3] G. Clemente et al. these proceedings.
[4] C. Zhang, NIM a 609, p.95, (2009).
[5] B. Koubek et al., Proc. of PAC2011, (2011).
[6] B. Koubek et al., Proc. of IPAC2012, (2012).
[7] N. Chauvin et al., Proc. of LINAC2010, (2010).