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ECOS-LINCE: A HIGH INTENSITY MULTI-ION SUPERCONDUCTING LINAC FOR NUCLEAR STRUCTURE AND REACTIONS

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Abstract

During the past years, ECOS working group strongly supported the construction of a dedicated high-intensity stable-ion-beam facility in Europe, with energies at and above the Coulomb barrier as part of the Long-Range Plan of the Nuclear-Physics community. LINCE will be a multi-user facility dedicated to ECOS science: fundamental physics, astrophysics, nuclear structure and reaction dynamics. Applied research is foreseen in the fields of medical physics, aerospace and material sciences with energetic heavy ions. The facility will produce a wide range of ions, from protons (45 MeV) up to Uranium (8.5 MeV/u) with 1mA maximum beam intensity. A very compact linac has been designed by using a HV platform with a double-frequency ECR ion source, multi-harmonic buncher, an innovative CW RFQ design ($1 \leq A/Q \leq 7$) and 26 accelerating cavities made of bulk niobium ($\beta = 0.045, 0.077$ and 0.15) working at 72.75 and 109.125 MHz.

INTRODUCTION

Present knowledge of subatomic degrees of freedom and nuclear structure has been exponentially growing during the last decades by the use of heavy ion facilities. A number of facilities are presently operating at the European Union delivering ion beams with intensities of up to a few 10^{12} particles/sec, being recognized as leading European research infrastructures. As the understanding of the atomic nucleus has increased, new physics domains have emerged that require the construction of a dedicated European facility for providing higher intensity stable heavy-ion beams. In the latest report of ECOS (European Collaboration on Stable Ion Beams, an expert working group of NuPECC [1, 2]), the construction of a high-intensity accelerator for stable beams with energies at and above the Coulomb barrier, is considered as one of the most important issues for the next long term plan of the nuclear physics community in Europe. This accelerator should be dedicated to fundamental research proposals requiring long beam times and high intensities, which will not be feasible at existing or new planned facilities at EU. The ECOS report identifies several nuclear physics topics

where investigations can be only addressed with high intensity stable beams:

- Synthesis and spectroscopy of super-heavy nuclei
- Nuclear structure studies at low, medium and high-spin
- Ground-state properties
- Near barrier transfer and fusion reactions
- Nuclear astrophysics
- Ion-ion collisions in plasma

Applied research should be also foreseen in the fields of medical physics, energy, aerospace and material sciences. In order to accomplish for a demanding program on fundamental and applied nuclear physics, we propose the construction of a high-intensity CW superconducting linac for light- and heavy-Ion beams: the ECOS-LINCE facility. The conceptual design should be based on a reliable design using well-established technologies, aiming to provide an effective beam time allocation of about 5000 h/y for fundamental physics and 2000 h/y for applications.

Table 1: Selected Beam Intensities and Energies

Ion	Q	A/q	E (MeV/u)	I (μA) / I ($\text{e}\mu\text{A}$)
H	1	1	45	1000 / 1000
^4He	2	2	10	500 / 1000
^{28}Si	9	3.1	12	10 / 90
^{48}Ca	8 or 10	6 or 5	7.5	10 / 80 or 100
^{184}W	27	6.8	2.5	1 / 27
^{238}U	34	7	8.5	0.5 / 17

A sample of selected ion beams and intensities are listed in Table 1. The development of this new facility should benefit from the state-of-the-art technologies and expertise recently acquired in the construction of high intensity linacs for SPIRAL2 (Caen, France), FAIR (Darmstadt, Germany), SPES (Legnaro, Italy), ATLAS (Chicago, USA) and FRIB (Michigan, USA).

with reasonable accelerator sizes and RF power levels. The critical performance is the accelerating gradient, which is obtained with present state-of-the-art technologies, in a reproducible way, between 5 - 10 MV/m. All these performances are the result of many recent technological developments, improving fabrication techniques and preparation of the surfaces. Three Heavy Ion Linacs have been recently designed with associated detailed studies and R&D programs: ATLAS upgrade phase (ANL, USA), Spiral 2 (GANIL, France), FRIB (Michigan, USA). Construction of LINCE resonators can take advantage of these best well-known performance cavities.

To provide the needed acceleration voltages the SC QWR resonators should be built using pure Nb bulk material, working at T=4.5 K. The different parts of each resonator are produced primarily by Nb sheet forming and precision machining while the resonator is to be assembled by using electron beam welding. Appropriate RF surface processing including buffer chemical polishing, electropolishing and high pressure water rinsing are required prior the installation of resonators into the cryomodule. The results obtained recently for the QWR structures at ATLAS and SPIRAL2 project [6, 7] confirm the possibility to obtain an accelerating total voltage for the cavity up to 4 MV, operating in a safe nominal point between 1.2 and 3.5 MV with Q₀ values > 10⁹.

Only 26 superconducting QWR cavities with three values of β = 0.045, 0.077, 0.15, working at 72.75 and 109.125 MHz, are required to reach the design energy goal and are summarized in Table 2. The SC cavities have been organized in four accelerating cryomodules, providing reasonable compactness, construction complexity and maintenance.

Table 2. Configuration Used for the Design Study

Cryo-module	Type	Freq. (MHz.)	Harmonic	Beta	V _{acc} (MV)	N ^o Resonators
C1	QWR	72,75	4	0,045	1,39	5
C2	QWR	72,75	4	0,077	2,38	7
C3	QWR	72,75	4	0,077	2,38	7
C4	QWR	109,125	6	0,15	3,30	7
C5	Rebuncher	109,125	6	0,15	3,30	1

Beam dynamics calculations have been performed with the code TRACK [3]. With the present structure of the accelerator, all ion beams with mass to charge ratio from 1 to 7 can be accelerated with maximum overall efficiencies. We continue optimization design of the linac to minimize beam losses below the acceptable level in the presence of machine errors.

The SC cavities operate within cryostats fed with Liquid Helium at 4.5 K. Dimensioning the installed

cryogenic power consists to add the static losses, the dynamic losses and the margin for possible operation with higher voltages (power is proportional to V²). The expected dynamic cryogenic load is below 10 W per cavity (total of 260 W). The static losses depend strongly on the cryostats design and the distribution of infrastructure installation, and a typical margin level installed in other similar linacs is about 30 %. Therefore the cryogenic system should be designed for a minimum 1kW at 4.5 K.

SUMMARY AND CONCLUSIONS

In this paper we present an overview of the ECOS-LINCE facility, a high-intensity facility for basic nuclear physics and applications. The design is based on a CW superconducting heavy-ion linac for q/A=1/7, working at the fundamental frequency of 18.1875 MHz and 26 superconducting quarter wave resonators, with three beta values β = 0.045, 0.077, 0.15. The choice of a double frequency superconducting ECR should allow to achieve beam intensities up to 1 mA for light ions and 10 puA for heavy-ions, with energies up to 45 MeV for protons and 8.5 MeV/u for ²³⁸U. The conceptual design is fairly advanced, and will continue in nearest future with extensive end-to-end beam dynamics simulations iterated with the engineering design of the various accelerator elements.

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