BASELINE DESIGN OF THE ESS BILBAO LINAC

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Abstract

The present document deals with the need of rethinking the baseline design of the ESS-Bilbao (ESS-B) linear accelerator. Such a need is dictated by the substantial lapse of time that has elapsed since the ESS baseline came to fruition, which now comes close to a decade. Also a number of concurrent activities have taken place since then within the Magnetic Fusion (IFMIF), Waste Transmutation (EURISOL, EUROTRANS), High-Energy Accelerators (LINAC4 at CERN) and Heavy Ion Research (FAIR, SPIRAL2) domains. Such efforts have lead to significantly shorter accelerators incorporating state-of-the-art technology which mainly replaces decades-old copper (normal-conducting, NC) drift-tubes by superconducting cavities (SC) of a wholly new kind.

There are a number of advantages in employing SC elements instead of NC structures. These have to do with the far more efficient use of the radio-frequency (RF) power delivered to the accelerator which translates into using less input power amplifiers and also significantly less electricity consumption. Other operational advantages include larger mechanical apertures, less sensitivity to the effects of wake fields and other collective effects, and a high operational stability due to operation at constant cryogenic temperature.

In the paragraphs that follow we are proposing to carry out a complete conceptual design study of a last generation high intensity proton linear accelerator to be done in close collaboration with colleagues at CIEMAT who have already taken responsibilities within IFMIF, SPIRAL2 and FAIR projects.

The design of such a new accelerator layout will be critically dependent upon the development of low β↓ superconducting cavities adequate for pulsed operation and high duty cycle↓.

THE ESS BILBAO CONCEPT

The current ESS-Bilbao proposal complies with the basic machine specifications contained in the ESFRI fiche published within the ESFRI 2006 Roadmap on Research Infrastructures [1]. This comprises a phased approach starting with the construction of a linear accelerator providing 2 millisecond pulses of 1.334 GeV protons which impinge on a liquid metal target with an average beam power of 5.1 MW, 16.67 times per second. A maximum of 20 instruments could possibly be accommodated all around the equatorial plane of this target station. The latter is by design optimized for the production of long-wavelength neutrons which will largely benefit studies on most areas of the Condensed Matter Sciences to address problems requiring low energy-transfers under relatively high signal/noise ratios. A second target station, able to feed some other 20 beamlines will have to be built during a second construction phase. As initially planned it will consist on a liquid metal target fed by 2 x 0.6 microsecond pulses at a frequency of 50 times a second and similar beam energy and power.

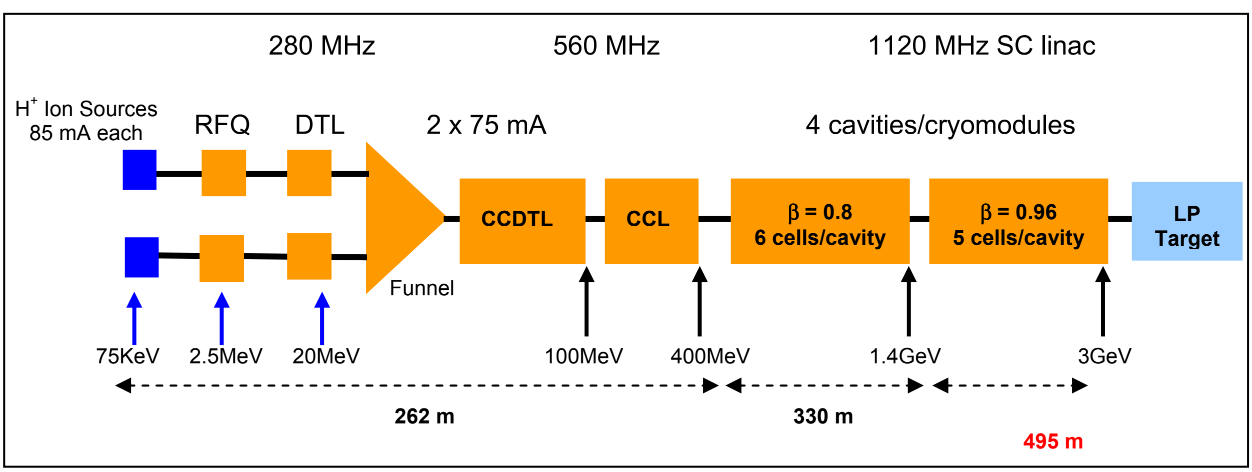

Figure 1: Alternative design layout for LP [11].

The ESS Bilbao linac

The baseline specification for the ESS-B accelerator adheres to suggestions made by ESS-I, and seeks to enter a design phase for a machine based upon a 150 mA $^{+}$H proton beam. Such intensity was to be delivered, as stated in the 2003 Technical Report [2], by a tandem of two proton ion sources of some 85 mA each funnelled after the two beams are accelerated up to about 20 MeV.

We keep as a reference the SC Linac, as sketched above, which has as working frequencies those already published [2]. Its design was based upon a sequence of drift tubes and coupled cavities operating at 560 MHz as well as a Super Conducting section comprised by a low beta (β=0.8) set of four cavities comprising six cells each operating at a frequency of 1120 MHz.

The main thrust towards seeking alternative and up to date design for the ESS-B accelerator is grounded upon current activities developed during the last few years within the CARE (Coordinated Accelerator Research in Europe) and EUROTRANS (TRANSmutation of High Level Nuclear Waste in an Accelerator Driven System) programmes which have resulted in very significant advances in both ion source and low-energy acceleration technologies which will surely have a relevant impact on the proposed accelerator design. Such advances which have taken place well after the ESS reference design was published have shown that:

a) Low β, superconducting cavities came forward as an alternative to classic Alvarez-type DTL tubes [3], and in fact, these are considered nowadays to be the technology of choice for a wide range $0.1 < \beta < 0.6$.
b) Superconducting TEM-class cavities have RF losses some 100 times less than conventional copper cavities and thus provide an economical and efficient use of RF power which is not offset by the expense incurred in cryogenic systems operation.
c) Funnel structures such as that appearing in the figure above constitute one of the most complicated parts of the accelerator. In fact, although the principles of the proposed funnel scheme were advanced a long time ago, there is no similar piece of equipment operating in the world today. Its performance results from compensation of several effects (space-charge, beam rigidity, etc.) and therefore the development of such a funnel concept will involve a substantial R&D effort which could be avoided if a single proton source providing the whole current were available.

Recent estimations for construction and operational costs for the superconducting option for IFMIF [4], show that up to 20% of the accelerator capital costs could be reduced if low β cavities of spoke or quarter-wave geometries are adopted instead of conventional normal-conducting DTL tubes. In addition, a cost reduction of 9% has been estimated for the operational period.

The arguments given above seem to us to be explicit enough so that a number or activities need to be started towards the exploration of a baseline design which incorporates up to date advances in superconducting technologies. In some more detail, our current tasks comprise the evaluation of:

a) The use of a single proton source capable to deliver proton currents of 150 mA or above. Prototypes for such proton injector, delivering some 5000 hours/year with low downtimes have been reported in the literature [5]. Proton sources such as SILHI at CEA have already produced currents of 130 mA at low duty factors [6]. The rationale behind such an effort stems from the possibility of avoiding the use of the funnel section which still constitutes one of the main showstoppers of the 2003 concept, and has not changed up to this very day.
b) The use of superconducting cavities (spokes, quarter-wave etc.) for medium energy (20 – 100 MeV) acceleration. The technology has already been developed, mostly geared towards applications within IFMIF and SPIRAL2 projects and could provide a cost effective substitute for the copper cavities both in terms of fabrication and operation, since as can be gauged by comparison of both schemes herein shown, the total length of the accelerator would be significantly reduced.

The behaviour of beams extracted from present day proton sources at medium and high energies. Present day ECR proton sources typically deliver beams with a proton fraction somewhat less than 0.9. Beam dynamics simulations using realistic conditions are now being planned in order to get a better understanding of the transport of the intense, multi-species beams.

A schematic view of an accelerator which incorporates the above given features is shown above. Its concept is grounded on a basic design developed by colleagues at CEA-Saclay and there is still room for further improvement by extending the SC section down to 20 MeV or below.

The FETS Bilbao Project

Actual working experience in developing an accelerator front-end is being gained at present by the ESS-Bilbao project team, in close collaboration with colleagues at CIEMAT involved in developments geared towards IFMIF and SPIRAL2 installations. The effort which has recently been set into motion, was launched exploiting the synergies resulting from the collaboration established between the Spanish Ministry for Science & Innovation and the ISIS new Front-End-Test-Stand [7]. A collaborative research group is now being set up between the project team and the CEA/CNRS SUPRATech platform aiming to develop the baseline specifications for the ESS-Bilbao superconducting cavities.

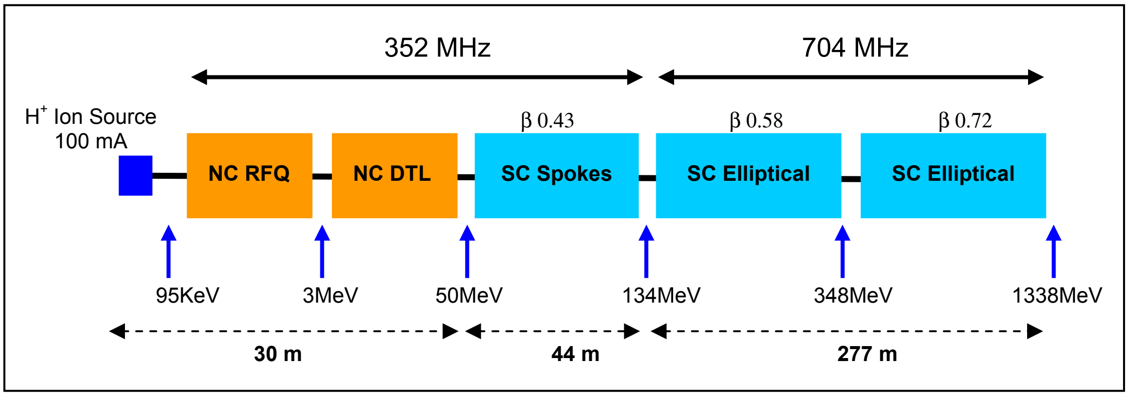

Figure 2: Possible new lay-out [11].

The most prominent activity dealing with technical issues carried out within the realm of ESS-Bilbao concerns R&D work on ion sources. As it is well known, the beam current required from the ion source and LEBT is strongly dependent upon the beam emittance, because the RFQ transmission decreases rapidly with increasing emittance and increasing beam current. In fact the requirement of a current of 150-mA at the beginning of the medium-energy beam transport requires an RFQ input current between 85 and 95 mA for a normalized rms emittance between 0.20 and 0.35 $\pi \cdot$mm$\cdot$mrad, which put into different words tells us that developing a low-emittance source is a must. In addition, as recognized by various ESS documents [2], improving the reliability of high power, high duty cycle $^{+}$H ion sources is also a pre-condition if the design specification of the ESS accelerator is to be met within a reasonable lapse of time. Our programme aims to develop the high-current, low-emittance ion sources and an LEBT that inflicts minimal emittance growth to meet the current requirement for producing 60-mA peak current in the MEBT section. The first phase of such a research programme which is financed through CDTI [8] is well underway and consists on a test stand able to compare the emittance characteristics of both ECR proton and H^- arc-discharge sources such as the Penning trap used at ISIS and RF driven sources such as the multicusp H^- source being at present in use at SNS [9] and a caesium-free multicusp source such as that developed by DESY [10].

Our strategic goal for the coming three years will consist on the construction of a complete accelerator Front-End Test-Stand able to diagnose ion beams with energy up to 3.5 MeV generated by the set of ion sources referred to above. The effort is conceived as a genuine R&D endeavour which will be financed by both Basque and Spanish Central Governments and, as a consequence, it will be carried out independent of the fate of the ESS-Bilbao bid.

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