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FUTURE PLANS AT ISOLDE

Mats Lindroos

Abstract

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CERN has recently decided on a consolidation project for the facility to assure that the required number of shifts can be delivered in the future. An overview will be given of the on-going consolidation and development programme and its implications on the physics programme, in particular the REX-ISOLDE post accelerator experiment.
An important parameter for a better yield of very exotic elements is the primary proton beam intensity, beam energy and time structure. The possible short-term improvements of, in particular, beam intensity will be discussed in some detail.
While the main effort at CERN today goes towards the completion of the LHC, some resources have been found for accelerator R&D. A possible project is a new high intensity proton source at CERN, the Superconducting Proton Linac (SPL), which could open the door to the construction of a next-generation radioactive beam facility. The possible primary beam characteristics and some design considerations and their implications for such a facility will be discussed. Some ideas for the facility itself, such as the use of antiprotons and muons as new probes, production of a neutrino beam from stored radioactive ions and a preliminary design for a low energy storage ring, will be presented.

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FUTURE PLANS AT ISOLDE

Mats Lindroos on behalf of the CERN ISOLDE team, the ISOLDE Collaboration and the REX-ISOLDE Collaboration, CERN, Geneva, Switzerland

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Corresponding author: Mats Lindroos, PS division, CERN, CH-1211 Geneva 23, Switzerland, E-mail: Mats.Lindroos@cern.ch, FAX: +41 22 767 9145, Telephone: +41 22 767 3859

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Introduction

The ISOL technique for production of intense radioactive beams has been in use for over 50 years [1]. The focus in this paper will be on the application of this technique at the CERN ISOLDE facility now and in the future. An overview of the technique itself can be found elsewhere e.g. in [2].

ISOLDE has formed part of the CERN physics programme for more than 30 years [3]. ISOLDE has over the years produced impressive results and it continues to do so. Behind this success lies a well-organized user community and an important technical development of targets, ion sources and separators.

ISOLDE started at the CERN 600 MeV synchrocyclotron (SC) in the 60s [3] as a simple experiment using a single separator magnet. It soon developed into an experiment with two separators (ISOLDE-2 and ISOLDE-3) with a user community grouped within the ISOLDE Collaboration. In the early 90s the experiment was moved from the SC to the PS booster and it also became a CERN facility with its own scientific committee. The average proton beam intensity available for ISOLDE at the PS Booster is close to the average 2 that was available at the SC. However, the energy and time structure of the beam are dramatically different. The energy has increased from 600 MeV to 1.4 GeV (initially 1 GeV) and the beam structure has gone from a close to DC beam to a pulsed beam with up to $3x10^{13}$ protons per pulse. The increase of energy is a clear advantage for elements produced in deep spallation and for light fragments from heavy targets in multi-fragmentation and hot fission. However, the pulsed beam is a "mixed blessing" as, on the positive side, it provides a well defined beam in time for elements with a short release time while, on the negative side, it dramatically increases the target ageing [4]. In some rare cases, the intense proton pulse (the peak current reaches 2.6 A with a peak power of 4 MW/cm^3) enhances the diffusion efficiency of the element leading to an overall higher secondary beam yield [5]. The recent tests with a shorter PS Booster acceleration cycle [6] could give ISOLDE another boost, as it should increase the driver beam intensity by at least a factor of two.

Target and ion source development

ISOLDE has right from the beginning had a very active and innovative target and ion source R&D programme. The CERN team has recently been reinforced by a network within the European Union's fifth frame-work programme within the EURISOL study [7,8]. Furthermore, a new network (TARGISOL) has just been started with the aim to improve the understanding of (and to simulate) the complex processes involved in radioactive ion production, release, transport and ionization in a typical ISOL target-ion source unit [9,10]. An example of recent developments is the construction of so called neutron converter targets [11,12]. Such targets permit indirect production of radioactive ions through the neutrons emitted by a metallic rod fitted in parallel to the target container and irradiated by the driver proton beam. An important suppression of spallation and fragmentation products can be achieved with only a small loss in the production of fission products. The ageing of the actual target is much reduced, as very little of the primary proton beam impinges directly on the target container. However, the deterioration of the primary neutron converter rod has in the first test units proved to be important. Work is in progress to increase the fraction of the produced neutrons that hit the target and to slow the deterioration of the neutron converter itself.

The REX project

One of the key experiments at ISOLDE today is the post accelerator experiment REX-ISOLDE [13,14]. It consists of a cooler, buncher and charge breeder system combined with a typical low energy linac accelerating structure. The linac structure is made up of a RFQ, an IH-structure and seven-gap resonators for beam energy tuning up to a maximum of 2.2 MeV/u. The low energy part has a very innovative character with a Penning trap used for bunching and beam cooling [15,16,17] and an Electron Beam Ion Source (EBIS) [18,19,20] used for charge breeding. The EBIS operates at a very good vacuum as it does not depend on the formation of a gas-plasma, and can consequently deliver very pure beams of the bred isotopes, see figure 1. The main contaminants come from the buffer gas in the trap (typically a noble gas like He, Ne or Ar) and from residual gases originating in the mass separator sector. Furthermore, this system can be used for any isotope that can be produced at ISOLDE. Both these properties, beam purity and general applicability, are of great importance for experiments with radioactive beams. An energy upgrade to 3.1 MeV/u is planned for the coming year with further upgrades in view [21]. A detailed overview of the REX project can be found in [10].

The ISOLDE consolidation project

The objectives for this project [22] are twofold: i) to bring the level of radiation safety to a level compatible with European legislation and ii) to consolidate the facility so that the required number of shifts per year is assured. In addition, a number of research and development activities have been grouped within the project. The first point will require that two radioactive laboratory areas be created at ISOLDE. The first will be of the highest safety grading and should group all work on contaminated and/or activated parts of the target/ion source region. The second will be of a lower safety grading and will consist of the experimental hall itself. This part will be completed in 2002. Furthermore, the target handling system has been renovated and the two industrial standard robots used for this purpose at ISOLDE are now fitted with individual and improved control units. The off-line testing and target manufacturing facilities are being modernized and the control system has been given a thorough refurbishment. Beam instrumentation and power supplies are being renovated and upgraded to CERN standards to simplify the operation and maintenance. The beam optics used in the experimental hall is being reviewed with the purpose of reducing losses and to simplify the setting-up for the experiments. The elements linking the target and ion source units to the separators are the front-ends (see figure 2); these have been replaced, and a new generation is being developed. The aim is to increase the lifetime of these units and to enable some maintenance.

The R&D part of the project is largely financed by the ISOLDE Collaboration and concerns the Resonant Ionization Laser Ion Source (RILIS) [23], the high-resolution separator (HRS) [24] and a new development of a Radio Frequency Quadrupole (RFQ) cooler and buncher [25]. The latter will be used to improve the transverse and longitudinal emittance of the beam delivered to the experiments. Furthermore, it permits bunching of the beam, which is of great importance for e.g. half-life measurements. It will also open new possibilities for the REX-ISOLDE experiments and should yield an intensity increase.

An important recent acquisition is an emittance meter suitable for emittance characterization of ISOLDE target units. Measurements of the beam emittance at ISOLDE have been made earlier but only for some specific types of ion sources. This new campaign [26] aims to characterize all types of ISOLDE ion source and target units and to make comparisons of emittances off-line, on-line and at different stages in the beam transport system. This work should eventually yield an overall improvement of the beam quality for the experiments.

The SPL and a next generation RNB facility

While the main effort at CERN is to the complete the LHC project, some limited R&D is underway for the post LHC era. A study is underway of, the SPL [27,28], which could be built on the CERN site and could feed ISOLDE from existing tunnels. The choice to pursue this particular study is born out of the conviction that it will act as a generator for new physics at CERN and that it would be an important element in a later upgrade of the LHC. The new physics could, among other options, involve a neutrino source or a next generation radioactive beam facility.

The SPL consists of a low-energy room-temperature linac structure injecting into a super conducting section, which to some extent can be built with recuperated material from the LEP project. The room temperature section goes to 120 MeV, while the total linac will accelerate negative hydrogen ions (H^-) to 2.2 GeV. In a possible staged approach towards the full machine, the room temperature part with a high performance H^- ion source could replace the present 50 MeV proton linac in the PS Complex. This would permit an important increase (up to a factor of 2) of the PS booster intensity.

The ISOLDE facility would evidently benefit from both stages of such a development. In a first stage the present facility could, together with a faster cycling of the PS Booster, have a 10 A driver beam at its disposal. This is the maximum driver beam intensity that this facility could handle, and a further intensity upgrade from stage two would require the construction of a new target area. Plans for such a next generation facility are being drawn up [29] and would probably include a post-accelerator for up to 100 MeV/u radioactive ions, storage rings and large multi-segmented detectors including recoil mass separators (RMS).

New probes for nuclear physics

The proximity of ISOLDE to the antiproton decelerator and a possible high intensity muon source at CERN suggests search for possible synergies with nuclear physics. Two workshops have recently taken place, at CERN and at the European Centre for Theoretical nuclear physics (ECT*), with this objective, and there is indeed evidence that such synergies exist. For example: the formation of antiprotonic atoms and the subsequent annihilation process can yield important information on the mass radius and the proton-neutron composition of the nuclear surface [31]; the muonic equivalent opens possibilities to populate inaccessible nuclear states and to produce more exotic atoms [30].

The experimental techniques are still to be developed, but both storage rings and ion traps could be applied. A scenario with two intersecting storage rings merging antiprotons and radioactive ions has been developed [32] in collaboration between the Max Plank Institute in Heidelberg and CERN, see figure 3. It should be noted that this scenario could be realized at the present ISOLDE and Antiproton Decelerator (AD) facilities as a pioneering experiment for new probes in nuclear physics.

Radioactive nuclei as a source for neutrinos

It is possible to produce a collimated neutrino or antineutrino beam by accelerating, to a high Lorenz gamma value, radioactive ions that decay through a beta process (a so-called beta beam) [33]. Such a neutrino beam has three distinctive and novel features: i) a single neutrino flavor, ii) well-known energy spectrum and intensity, and iii) low energy combined with strong collimation resulting from the low neutrino energy in the centre-of-mass system and the large Lorenz boost of the parent ion. The time dilation at high energy will prolong the lifetime of the radioactive ion in the lab system and must be sufficiently short to yield a good decay rate. Suitable candidates are ^{6}He for an antineutrino beam, and ^{18}Ne for a neutrino beam. The production of these two elements has been studied at ISOLDE [34]. The ^{6}He beam could be produced in sufficient intensities with the SPL as driver, and a neutron converter target. The subsequent acceleration and storage with an important re-use of the existing CERN infrastructure (see figure 4) has been considered, and some possible scenarios have been presented [35]. The synergies with a next-generation radioactive ion beam facility of ISOL type are obvious and it is unlikely that a beta beam facility would be constructed without such a facility at CERN.

Conclusions

Important investments are being made at the ISOLDE facility for the future, and a very active R&D programme aimed at improving the facility is producing results that have the potential of generating new physics. In particular the REX-ISOLDE experiment is of great importance and will form the basis for a development of new physics with radioactive beams. Possible synergies at CERN, such as the use of antiprotons as probes and the production of collimated neutrinos by accelerated radioactive ions, are under study. Finally, the SPL study, and eventually the construction of this facility, is an essential ingredient for a next generation ISOL facility to be built at CERN.

References

[1] O. Kofoed-Hansen and K.O. Nielsen, “Measurements on Shortlived Radioactive Krypton Isotopes from Fission after Isotopic Separation”, Mat. Fys. Medd. Dan. Vid. Selsk. 26 (1951), 1.

[2] U. Köster, “Intense radioactive ion beams produced with the ISOL method”, in Proc. of the 3rd International Conf. on Exotic Nuclei and Atomic Masses, Hämeenlinna, Finland, 2001, The European Physics Journal A, in press

[3] A. Kjellberg and G. Rudstam, eds., “The ISOLDE isotope separator facility at CERN”, CERN 70-3, 1970

[4] J. Lettry et al., “Release from ISOLDE molten metal targets under pulsed proton beam conditions”, Nucl. Instr. Meth. B 126 (1997), 170.

[5] J. Lettry et al.,”Effects of thermal shocks on the release of radioisotopes and on molten metal target vessels”, in these proceedings

[6] M. Benedikt et al.,” Results of the tests for PS Booster 600 ms cycling”, PS Performance Committee Meeting on 20 April 2001, http://psdoc.web.cern.ch/PSdoc/ppc/ppc010420/ppc010420.html

[7] http://www.ganil.fr/eurisol or J. Vervier et al., “Status of the EURISOL programme”, in these proceedings

[8] EU RTD project EURISOL, HPRI-CT-2001-500001

[9] http://www.targisol.csic.es or O.Tengblad et al., “A WWW-database of diffusion and effusion data for ISOL-target production”, in these proceedings

[10] EU RTD project TARGISOL, HPRI-CT-2001-50033

[11] R. Catherall et al., “Radioactive ion beams produced by neutron-induced fission at ISOLDE”, in these proceedings

[12] J.A. Nolan et al., “An advanced ISOL facility based on ATLAS”, in Proc. of HIAT’98, ed. K.W. Shepard, AIP Conf. Proc. 473 (1998)

[13] D. Habs et al., “The REX-ISOLDE project”, Hyperfine Interaction 129, (2000) 43

[14] O. Kester et al, “Accelerated radioactive beams from REX-ISOLDE”, in these proceedings

[15] F. Ames et al., “REXTRAP, an ion buncher for REX-ISOLDE”, Proc. Of the Conf. on Exotic Nuclei and Atomic Masses, Bellaire, USA, 1998, AIP Conf. Proc. 455 (1998) 132

[16] P. Schmidt et al., “Bunching and cooling of radioactive ions with REXTRAP”, Nucl Phys A701 (2002) 550c-556c

[17] F. Ames et al., “Space charge effects in a gas filled penning trap”, Hyperfine Interactions 132 (2001) 469

[18] F. Wenander, B. Jonson, L. Liljeby, G. Nyman and the REX-ISOLDE
collaboration, “REXEBIS the electron beam ion source for the REX-ISOLDE project”, CERN-OPEN-2000-320

[19] F. Wenander, J. Axelsson, M. Björkhage, P. Carlé, L. Liljeby, K.

Rensfelt, B. Jonson and G. Nyman, “REXEBIS - a charge state breeder for the REX-ISOLDE post accelerator” , in Proc. of the 6th European Particle Accelerator Conference, Stockholm, Sweden, IOP Bristol (1999) p.1412-1414.
[20] B. Wolf, F. Wenander et al., “First radioactive ions charge bred in REXEBIS at the REXISOLDE accelerator”, in these proceedings
[21] D. Habs et al, “An Energy Upgrade of REX-ISOLDE to 3.1 MeV/u an Acceleration of Heavier Masses up to A = 150”, CERN-INTC-2002-009, Proposal to INTC, CERN, May 2002
[22] M. Lindroos, “The ISOLDE consolidation project”, CERN PS/OP/Note 2000-016
[23] V. Fedosseev et al., “Atomic Spectroscopy Studies of Short-Lived Isotopes and Nuclear Isomer Separation with the ISOLDE RILIS “, in these proceedings
[24] T. Giles et al., “The High Resolution Spectrometer at ISOLDE”, in these proceedings
[25] A. Jokinen et al., “A RFQ Cooler for Low-Energy Radioactive Ions at ISOLDE”, in these proceedings
[26] F. Wenander et al.,” Transverse Emittance Investigation of the Isolde Target Ion Sources”, in these proceedings
[27] M. Vretenar ed., “Conceptual design of the SPL, a high-power superconducting H- linac at CERN”, CERN yellow report, CERN 2000-012
[28] http://cern.web.cern.ch/CERN/Divisions/PS/Projects/SPL.html
[29] J. Äystö, D. Forkel-Wirth, M. Lindroos and H. Ravn, “A second-generation radioactive nuclear beam facility for CERN”, CERN-PS-2000-075-OP or CERN-EP-2000-149
[30] http://www.ect.it/html/projects/past/2001/RAMA/
[31] A. Trzcinska, J. Jastrzebski, P. Lubinski, F.J. Hartmann, R. Schmidt, T. von Egidy, and B. Klos, “Neutron Density Distributions Deduced from Antiprotonic Atoms” Phys. Rev. Lett. 87, 2001
[32] http://www.ganil.fr/eurisol/TOWN_MEETING_ABANO/MatsLindroos.pdf
[33] P. Zucchelli, “A novel concept for a antineutrino/neutrino factory: the beta beam”, Phys. Lett. B, in press
[34] http://www.ganil.fr/eurisol/TOWN_MEETING_ABANO, presentation by U. Köster, CERN
[35] M. Lindroos et al.,”The beta beam acceleration”, in neutrino factory Yellow report, CERN, 2002, to be published

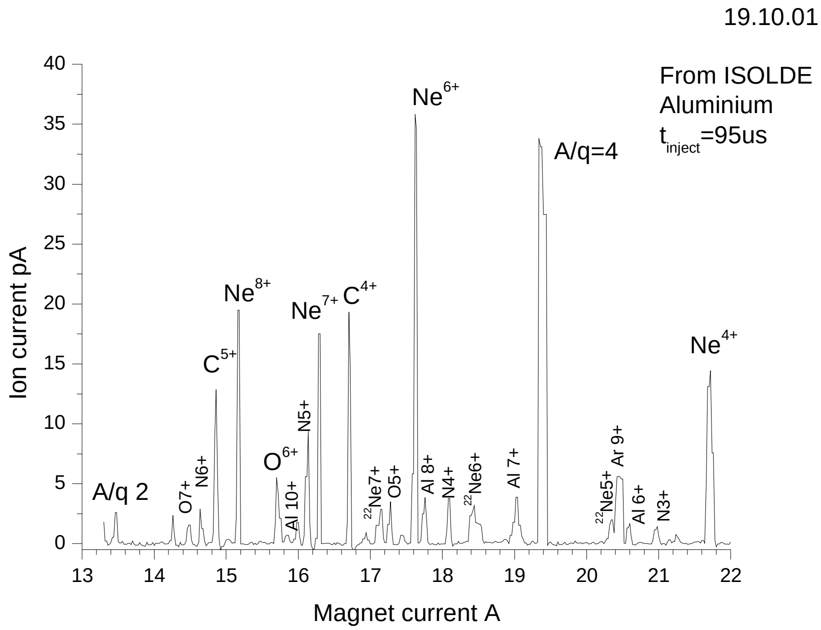

Figure 1: The EBIS source forms part of the REX-ISOLDE experiment. The positive ions are trapped in the potential of an intense electron beam, which is squeezed to a high density by a solenoid field. The electron beam increases the charge state of the ions through Coulomb interaction. The figure shows the extracted spectrum of aluminium ions with the majority of ions in the 7^+ and 8^+ charge states. A DC potential barrier traps the ions longitudinally and permits ejection of the ions in a short pulse.

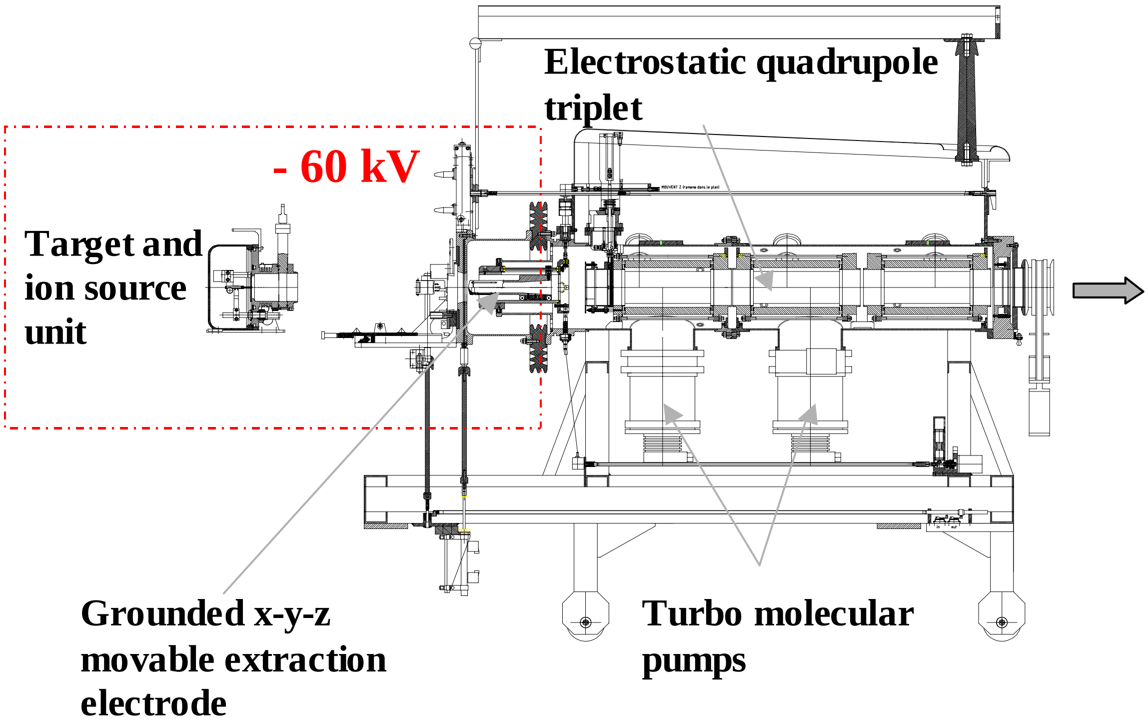

Figure 2: The unit linking the separator with the target and ion source is called a front end at ISOLDE. The front ends get highly contaminated during normal operation and it is therefore very difficult to perform any maintenance or repair work on these units. Consequently, they have to be replaced at regular intervals to assure the running of the facility. The figure shows the latest front-end at ISOLDE. A project has been started to develop a new generation of front ends. The present design dates from the 1980s and new technical developments should permit the construction of more reliable units. It is possible that they will also be modular to permit parts (rather than the full unit) to be replaced in case of failure.

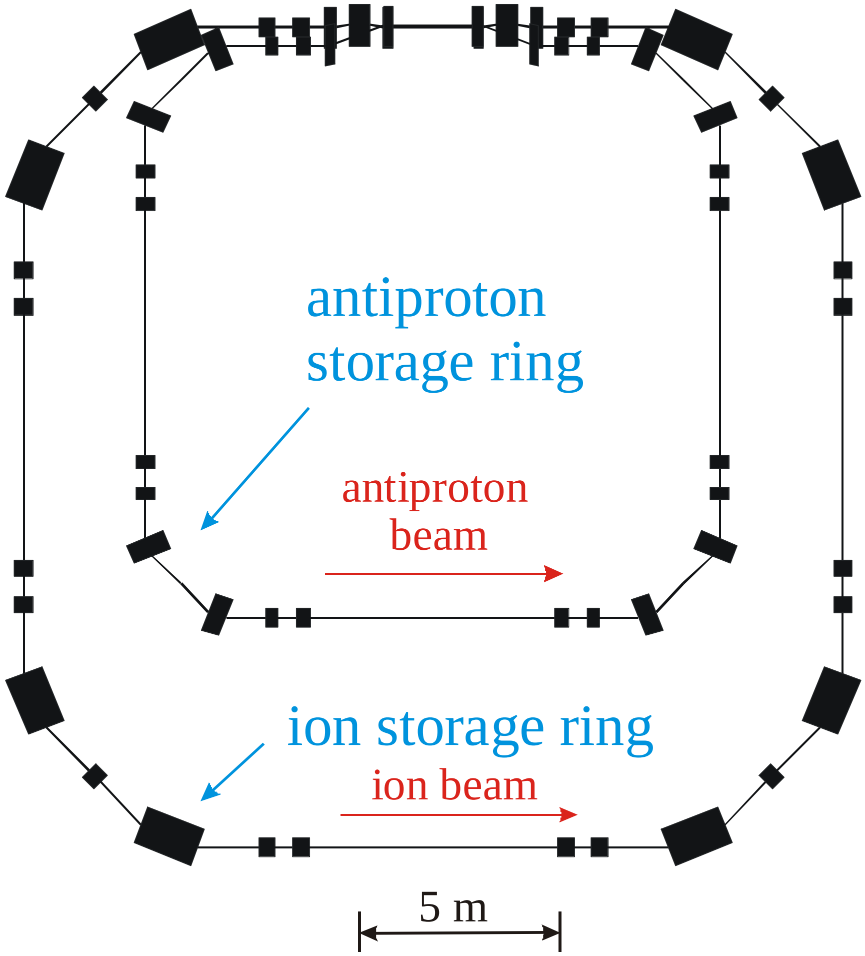

Figure 3: A design has been made for two intersecting storage rings, with antiprotons in one ring and radioactive ions in the other. The merging of the beams will lead to the formation of antiprotonic nuclei and the subsequent study of these could yield important information about the nuclear mass radius and the composition of the nuclear surface. The figure shows the two rings with an insertion in the upper straight section that will bring the ions to overlap with the anti protons that circulates in a parallel ring with a similar insertion. The ions will stay on the same orbit in the insertion independently of mass and charge state.

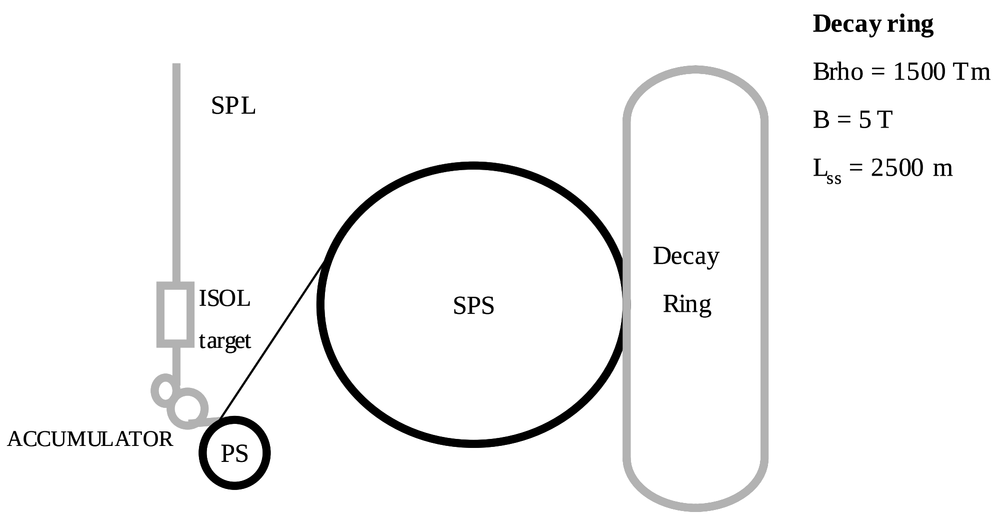

Figure 4: An intense and collimated electron neutrino or anti electron neutrino beam can be produced by accelerating an intense beam of radioactive ions and subsequently storing it in a decay ring with long straight sections. Such a beam is of great interest for neutrino physics as it will yield a beam of a single neutrino flavor. The possible implementation of such a facility at CERN has been studied and the figure shows a possible configuration with a maximum re-use of the existing CERN accelerator infrastructure. The grey machines and transfer lines will have to be built.