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EXPLOITING THE POTENTIAL OF ISOLDE AT CERN (THE EPIC PROJECT)

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Abstract

The ISOLDE Facility at CERN is the world's leading facility for the production of radioactive ion beams (RIBs) using the ISOL (Isotope Separation On-Line) method, providing RIBs at energies from 30 keV to 10 MeV/u for a wide variety of experiments. To improve on its capacity to deliver RIBs further from stability, the EPIC project takes full advantage of recent investments by CERN to upgrade the LHC injectors. In particular, the higher proton-beam intensity and energy from the new Linac4 and the PS-Booster upgrade would inevitably produce higher radioactive ion beam intensities further from stability. Sharing the proton-beam between two target stations that simultaneously feed the low-energy and high-energy beamlines will more than double the annual available beam time for experiments.

To take further advantage of enhanced beam time, ISOLDE also aims to install a storage ring behind the HIE-ISOLDE post-accelerator to allow the storage of cooled exotic ion beams and thus opening up new possibilities in the fields of astrophysics, fundamental symmetry studies, atomic physics and nuclear physics. This paper outlines the EPIC proposal covering the essential requests for a complete upgrade of the ISOLDE Facility.

INTRODUCTION

The ISOLDE Facility at CERN [1] is the world's leading facility for the production of radioactive ion beams (RIBs) using the ISOL (isotope separation on-line) method, providing RIBs at energies ranging from 30 keV up to 10 MeV/u for a wide variety of experiments in nuclear physics, astrophysics, fundamental physics, biophysics and materials research. The facility is yearly serving over 500 active users (and nearly 1000 occasional users) that essentially make up the European 'low-energy' nuclear physics community. Within the next 5 years, this community can expect to benefit from future new European ISOL-facilities such as SPES at LNL, Italy [2] and Spiral 2 at GANIL, France [3] as well as from the Canadian facility ARIEL at TRIUMF [4] and RISP, IBS in South Korea [5]. However, ISOLDE is unique in that RIBs are produced by the interaction of high-energy protons (1.4 GeV) on fixed targets, providing a much wider range of RIBs. Yet much can be gained in terms of efficiency and availability of nuclei produced at ISOLDE by taking full advantage of recent upgrades at CERN, driven by the LHC Injectors Upgrade (LIU)[6].

To achieve this, the EPIC project proposes five key areas of development:

- An increase in driver beam energy and intensity
- Two new target stations with a high resolution mass spectrometer
- An upgrade of the HIE-ISOLDE post-accelerator
- The installation of a storage ring beyond the 10MeV/u post-accelerator
- A new experimental hall

The implementation of these five upgrades will ensure that ISOLDE remains at the forefront of nuclear physics, and remains unique in its production and manipulation of radioactive ion beams while providing at least a two-fold increase in the availability of RIB for an expanding user community.

DRIVER BEAM INTENSITY AND ENERGY INCREASE

In 2019, CERN entered its second long shutdown period where major upgrades in the accelerator complex are foreseen. This includes the connection of Linac 4, the new injection accelerator, to the PS-Booster and an upgrade of the latter to increase the proton-beam energy from 1.4 to 2GeV. Linac 4 will have a new ion source that will ultimately be able to double the present p-beam intensity to ISOLDE. The production rate of radio nuclei is linearly proportional to the proton-beam intensity therefore; any increase in intensity will have a direct improvement on production rates at ISOLDE.

Recent simulations of the production process from a 2 GeV proton beam have demonstrated that in some areas, notably for proton rich nuclei from the spallation process, a gain of up to 40 in production rates may be achieved. Simulations have also revealed higher yields in the fission and fragmentation regions.

Although these gains will benefit experiments requesting radio nuclei far from stability, not all experiments require maximum proton-beam power. Sharing the proton-beam between multiple target stations would allow different experiments to operate simultaneously.

There are two main obstacles to overcome these new p-beam parameters at ISOLDE; one is the necessity to replace the existing beam dumps originally designed for 1.4 GeV protons and 2 µA to cope with the factor of four increase in proton beam power. The other is the modification of the bending magnets in the transfer line from the PS-Booster to ISOLDE in order to accommodate a p-beam energy of 2 GeV. Both upgrades are technically feasible but require at least 18 months for their installation.

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TWO NEW TARGET STATIONS AND A HIGH RESOLUTION MASS SEPARATOR (HRMS)

The backlog of beam time requests at ISOLDE (up to 1000 x 8 hour shifts) is partly due to the availability of only two target stations and one common beam line feeding the experimental hall. The EPIC project encompasses the ISOLDE V project [7] that proposes the installation of two extra target stations and two beam lines to the existing experimental hall. A third new beam line would serve the new experimental hall, which will allow for installation of several new low-energy experimental set-ups. Each new target station will deliver beam to one of two experimental halls either directly from its mass separator or through a common high-resolution mass separator. A combination of novel beam-manipulation techniques including switchyards, multiple beam lines and a bunching and cooling device will assure the beam transport.

A resolving power of 4000 is attainable with the existing High Resolution Mass Separator (HRMS), but many experiments would benefit from a resolving power of up to 20000 to reduce isobaric contamination on a particular mass. Modifying the existing HRMS is difficult due to space constraints and access, therefore, a new HRMS could be installed serving the two new target stations.

Figure 1 below shows a proposed layout of the target area with a HRMS and beam lines to the experimental hall. The operational possibilities are numerous and range from routine running with multiple simultaneous beams, flexible switching between cooled and un-cooled beams, stable beam from a dedicated ion source (thus liberating target stations for physics only) and irradiation facilities for material studies and off-line operation. Combined with higher primary beam power, these options should allow for more than a two-fold increase in physics beam time.

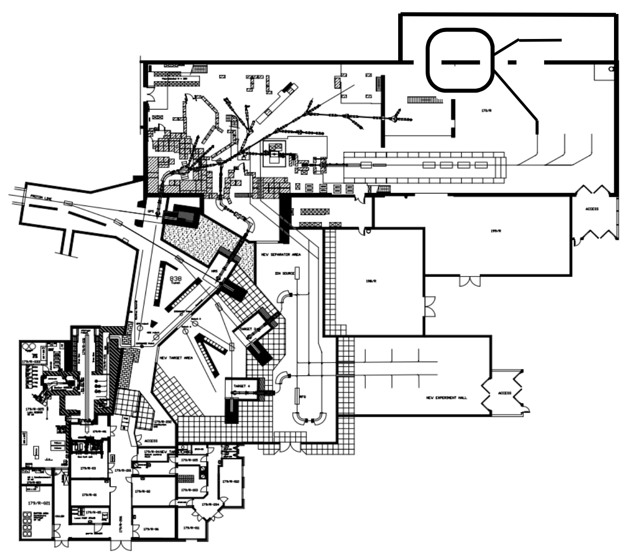

Figure 1: Preliminary layout of the ISOLDE target area with beam lines to the experimental hall and the implantation of the ISR.

UPGRADE OF HIE-ISOLDE POST ACCELERATOR

Since 2001, ISOLDE was the first facility to produce post-accelerated RIBs using the REX-ISOLDE accelerator, providing beams with an energy up to 2.8MeV/u. This opened the research portfolio of ISOLDE to a large new user community; those who use reactions with RIBs for studies of exotic nuclear structures and for nuclear astrophysics research.

In 2018, phase 2 of the HIE-ISOLDE project was completed providing post-accelerated RIB up to 9.4 MeV/u and new opportunities for transfer reaction studies [8].

The EPIC project proposes to build on recently acquired technology, especially in the production of superconducting rf-cavities, to upgrade the older REX post-accelerator. This consists of the replacing the old 7-GAP and 9-GAP normal conducting rf-cavities of REX-ISOLDE by 2 low-beta cryomodules each containing 6 superconducting rf-cavities and 2 superconducting solenoids. It also includes the installation of a buncher/chopper which will provide the possibility of delivering micro-bunches with 100ns spacing (10MHz), instead of the natural 100 MHz frequency of the LINAC, while maintaining the beam intensity and the low background between bunches. This will allow time of flight measurements that are necessary for neutron energy measurements and will greatly enhance the particle identification capability of the detectors.

ISOLDE STORAGE RING

The idea of a storage ring dedicated to post-accelerated radioactive ion beams has been circulating for a few years [9]. Representatives from Max Planck Institute für Kernphysik (MPI-K), Heidelberg have proposed a new compact version that maintains all the functional specifications required for the physics program with HIE-ISOLDE beams (Fig. 2).

The addition of a storage ring for multi-charged low-energy ion beams would bring unique capabilities to ISOLDE. Matched to the existing HIE-ISOLDE post-accelerator, the ISOLDE Storage Ring (ISR) would be the first installation to store short-lived isotopes of high luminosity with half-lives below 100 ms.

The envisaged physics program is rich and varied, spanning from investigations of nuclear ground-state properties and reaction studies of astrophysical relevance to investigations with highly-charged and pure isomeric beams.

The storage ring will be employed for the removal of isobaric contaminants from stored ion beams and for systematic studies within the neutrino beam program. In addition to experiments performed with recirculating beams, cooled beams will be extracted for use in external spectrometers for high-precision measurements. The ring, with a circumference of 40m will be able to store highly charged ions with intensities up to 10^8 ions and energies between a few 100 keV/u and 10 MeV/u.

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A NEW EXPERIMENTAL HALL

The user community at ISOLDE has expanded from 400 users in 2004 to 1300 in 2019 and with the recent commissioning of HIE-ISOLDE, more experiments are expected at ISOLDE. Experiments already on the horizon include Pbar Unstable Matter Annihilation (PUMA) [10], the ISOLDE Superconducting Recoil Separator (ISRS) [11] and Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy (MIRACLS [12]), all of which require floor space alongside the existing permanent experiments.

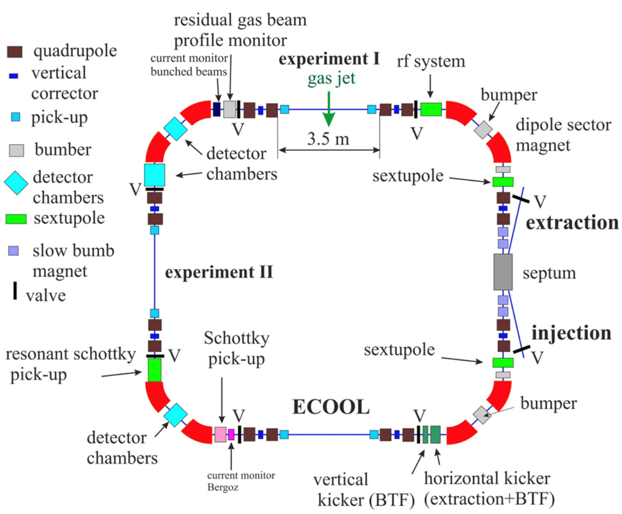

Figure 2: Layout for a new compact ISOLDE storage ring by M. Grieser, MPI-K Heidelberg

Space in the existing experimental hall is limited; therefore, the EPIC project proposes the construction of a new experimental hall as shown in Fig. 1.

CONCLUSION

The ISOLDE Facility has been providing radioactive ion beams to the nuclear physics community for over 50 years. The EPIC project proposal builds on this wealth of experience by benefitting from recent infrastructure upgrades at CERN and exploiting new possibilities in physics research. The EPIC project aims at providing significantly more beam time to an expanding user community, enhanced accessibility to exotic nuclei far from stability and beam manipulation techniques that will enhance existing research programs and open the door to new physics research.

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