EMILIE Workshop

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Recycling of sediments from ECR chamber wall by the electron escape paths changing in the magnetic trap

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A well-known method of improving the operation of ECRIS with solid state materials is lining the plasma chamber to recover neutralized plasma material deposited on the walls. This method is used mainly in production of metallic ions by oven technique. The efficiency of this process can be improved by better understanding mechanisms of ECR plasma interactions with chamber wall materials. Different types of screens (liners) for the plasma chamber with various materials (Ta, Ti, Mo, W) and thickness have been tested. To increase magnitude of wall recycling effect the azimuthal position of hexapole magnetic trap has been rotated during ECR plasma burning. A rotary hexapole magnet system has been used to change the position of electron escape lines on the surface of the liner. Additionally different types of material deposited and recovered from the walls of the liner may affect the stability of the plasma. As an example, aluminum liner wall coating is able to reduce plasma potential which improves plasma stability and therefore can reduce ion recombination and sedimentation on the chamber wall. Electron density change in the plasma can be better estimated with controlled disordering of plasma burning process by modifying the arrangement of magnetic trap.

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A new electron beam ion source as charge breeder for rare isotope beams at TRIUMF

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Currently, the TRIUMF facility is upgraded with ARIEL (Advanced Rare IsotopE Laboratory), which will include a new EBIS (Electron Beam Ion Source) for charge breeding of rare isotopes. Heavy elements prepared into a high charge state are required to keep the mass-to-charge ratio A/Q low, which is essential for the two post-accelerators ISAC (Isotope Separator and ACcelerator) I and II. Because the isotopes of interest have short half-lives in the millisecond range and low production rates, the efficiency of the whole process of injection, charge breeding and extraction has to be very efficient. The repetition rate of 100 Hz requires fast high voltage control and switching. The goal is to achieve a charge breeding efficiency of at least 20 % to a single charge state. We describe the concept and development of the CANREB-EBIS which will be installed at ARIEL in the near future. Diagnostic techniques for the trapped ion species and preliminary simulation results for injection, charge breeding and extraction of the ions will be presented.

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Research of CB ECRIS plasma with the aid of injected 1+ beam

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An anomalous global efficiency of the extracted 1+ beam was discovered at the LPSC charge breeder. It was realized that a fraction of injected 1+ beam propagates through the charge breeder plasma without being captured and ionized. As a result of the further experiments and theoretical considerations it was realized and confirmed that 1+ beam injected into the charge breeder plasma can be used as a plasma diagnostics tool. Identification of the uncaptured fraction of the 1+ ions allow, for example, estimating the ion-ion collision mean free path of injected 1+ beam and plasma densities as a function of microwave power. The presentation will describe in more detail the injected 1+ beam as a diagnostic tool to reveal information about different plasma parameters. Further more, the prospects to use charge breeder ECRIS to study the effect of gas mixing on the ion confinement time will be discussed.

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The SPES-Charge Breeder and its beam line: technological aspects

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SPES is an INFN project supported by two Italian national laboratories, Laboratori Nazionali di Legnaro (LNL, Legnaro, Padova) and Laboratori Nazionali del Sud LNS, Catania), and is currently under way at LNL. Aim of this project is the production, ionization and post-acceleration of radioactive ions to perform forefront research in nuclear physics. To this scope, the project chose an ECR-based charge breeding technique: in particular, an upgraded version of the Phoenix booster, developed by LPSC of Grenoble in 2014 and successfully tested in March 2015. The SPES- Charge Breeder (SPES-CB) took advantage of the latest upgrades of this device, like the optimization of the axial position of the two iron rings surrounding the hexapole, carried out during the EMILIE Project. Other improvements derived from the experience on charge breeding made at INFN or from special needs of the SPES project. The SPES-CB will be equipped with a complete test bench, totally integrated with the SPES beam line, and a specially designed Medium Resolution Mass Spectrometer (MRMS), in order to limit beam contaminations induced by the breeding stage. This contribution will describe the main technological aspects of the SPES-CB and its beam line, together with the first results obtained during the acceptance tests. The presentation will show also the results of the work, carried out by the INFN in the framework of the EMILIE project, on the numerical simulation of the 1+ beam capture by the plasma of the charge breeder, evidencing the very good agreement between numerical and experimental results for both heavy and light ions.

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LPSC contributions to the Emilie project

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In the frame of the Emilie project, in order to better understand the physics of the Charge Breeder process, the LPSC acted on several levers. First, the 1+N+ test bench was used to make experiments with 3 versions of the Phoenix Charge Breeder: LPSC, SPES and SPIRAL1. In parallel, two 1+ electron cyclotron resonance ion sources have been developed. The first is a hot (650°C) version of the 2.45 GHz COMIC source, which aims is to produce 1+ alkali ions and to study the atom ionization efficiency dependence with temperature (wall recycling). The second one is a new 5.8 GHz source able to produce stable low charge state ion beams. A roadmap for the future developments of the Charge Breeder has been defined at LPSC. First, an upgrade of the magnetic field configuration is considered in order to enhance the plasma confinement. This would possibly allow 18 GHz experiments. Second, the injection of several low charge state ions will be carried out to investigate further the ion capture process in the plasma, helped with new plasma diagnostics. The results of these experiments and developments will be presented together with the new development plan of the Charge Breeder.

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Simulations, design and commissioning of the debuncher prototype for the EMILIE project

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The goal of *WP2* of the *EMILIE* project was to simulate, design, build and commission a device which operates as a debuncher using high intensity *n+* bunched beams from *EBIS* charge breeders and which ejects continuous-wave (*CW*) ion beams.
The advantages of the *EBIS* breeding technique compared to the *ECR* method include formation of pure samples and very high charge states whereas the main disadvantage is related to lower intensities. In addition the *EBIS* is a pulsed device which provides all the statistics in relatively narrow time windows (typically in the order of several 10 μs and up to a few 100 μs in an extended extraction regime). The breeding time which is necessary for completion of the *EBIS* cycle can be as high as several 100 milliseconds. The ratio of the two characteristic times leads to the formation of very time-dense distributions which already at present intensities up to 10e+6 pps have started to be undesired due to large dead-times, pile-ups, and random coincidences at the experiments (e.g. beams from *REX-EBIS* at *ISOLDE*). With the planned increase of intensities in the future facilities this becomes a critical point for the utilization of EBIS breeders and need to be overcome.
The principle of operation of the debuncher is based on trapping of ion bunches using a linear radio frequency quadrupole (*RFQ*) structure and switching of *DC* potentials for radial and longitudinal confinement respectfully. The use of highly charged beams requires operation in very good vacuum conditions in order to avoid losses due to charge exchange processes which implies that only conservative forces are used in the debuncher operation, thus the beam emittance of the beam should be preserved. After the trapping of the beam bunches the ions are diffused

in longitudinal direction within the debuncher structure and by slow ramping of selected *DC* potentials *CW* beams are formed through the exit electrodes of the device achieving a very narrow energy distribution compared to the incoming ion bunches. The operation principles of the debuncher have been verified by extensive simulations at *GANIL* with *SIMION*. *RF* and *DC* potentials have been varied in order to determine the operational ranges for the device. The results from the simulations are promising – both high transmission (>85 % transmission for a 45 cm long debuncher and 50 microseconds incoming bunch length) and the desired flattened time structure have been achieved with many possibilities to improve both by increasing the length of the device and adjusting DC potentials/sequencing respectively.
The first results from the simulations allowed continuing with designing and building of the prototype debuncher in 2012 at *LPC Caen*. The required *RF* and *DC* electronics were built and tested soon after with the final step remaining the commissioning of the debuncher at a facility which could provide ion bunches with characteristics similar to the *EBIS* beams. The first tests of the debuncher operation were performed in 2015 at the *SHIRaC* test bench at *LPC Caen* where *1+* continuous stable ion beams were used. The results from these tests were sufficient for the qualitative confirmation of the operation principles but measurements of efficiencies of trapping and extraction were not achieved. The latter can be done eventually in a new set of measurements at an improved experimental setup which can allow for the formation of ion bunches at the input.

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Modelling of Electron Cyclotron Resonance Ion Sources plasmas: a 3D full-wave plus kinetic approach to Charge Breeding

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Numerical simulations are powerful tools for optimizing the wave-to-plasma interaction process in Electron Cyclotron Resonance Ion Sources. Several alternative methods of plasma heating like Frequency Tuning Effect (FTE) or Two Frequency Heating (TFH) can be exploited by a proper matching of the incoming RF power with the plasma electrons. This supports the increase of beam currents and charge states also in case of ECRIS-based Charge Breeders. The presentation will show an overview of the work on ECRIS modelling, carried out in the framework of the EMILIE Project by the INFN team. The impact of the resonator nature of the plasma chamber, the interplay between electrons and ion dynamics, and the overall impact on the beam properties will be discussed in details according to a step-by-step modelling of increasing complexity. The contribution will describe the several steps needed to achieve quasi-self-consistent results concerning the wave-to-plasma electrons coupling (made by matching a full-wave 3D approach to a collisional 3D kinetic code), based on a “cold plasma” approximation. A particular attention will be payed to modelling benchmarks coming from beam production or charge breeding experiments, and directly from plasma diagnostics tools.

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Performances of the SPIRAL1 charge breeder

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In the framework of the SPIRAL1 upgrade under progress at the GANIL lab, the charge breeder based on a LPSC Phoenix ECRIS, first tested at ISOLDE [1] has been modified as to benefit of the last enhancements of this device from the 1+ / n+ community [2].

Prior to its installation in the midst of the low energy beam line of the SPIRAL1 facility, it has been tested at the 1+/n+ LPSC test bench to evaluate its performances and investigate the future operational modes.
This contribution shall sum up the results obtained at LPSC concerning the 1+ to n+ conversion efficiencies for noble gazes as well as for alkali elements and the corresponding transformation times.
[1] P. Delahaye et al, Review of Scientific Instruments. 77, 03B105 (2006) [2] R. Vondrasek et al, Review of Scientific Instruments 83 113303 (2012)

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Ion and atoms traps developments at Laboratoire de Physique Corpusculaire de Caen.

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The talk will review the 20 years effort from LPC Caen to provide experiments with ion and atoms traps. The physics made with these traps are precision measurements to tests the standard model, high intensity radioactive ion, ion atoms collisions….Several news technological solution have been developed in order to reach the required users specifications.

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Charge Breeding Experiences with an ECR and an EBIS for CARIBU

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The efficient and rapid production of a high-quality, pure beam of highly charged ions is at the heart of any radioactive ion beam facility. An ECR charge breeder, as part of the Californium Rare Ion Breeder Upgrade (CARIBU) program at Argonne National Laboratory, was developed to fulfill this role. The charge breeding efficiency and high charge state production of the source were at the forefront of ECR charge breeders, but its overall performance as part of the accelerator system was limited by a pervasive stable ion background and relatively long breeding times. Steps were taken to reduce the level of background contamination but met with limited success. As such, an EBIS charge breeder was developed and tested in an off-line configuration. The EBIS demonstrated good breeding efficiencies, shorter residence times, and reduced background. The ECR charge breeder was decommissioned in late 2015 and the installation of the EBIS has been proceeding. The experiences with these breeders, possible paths forward, and the current status of the EBIS installation will be discussed. This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357 and used resources of ANL's ATLAS facility, an Office of Science User Facility

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The EMILIE project

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The EMILIE project aims at improving the charge breeding techniques with both Electron Cyclotron Resonance Ion Sources (ECRIS) and Electron Beam Ion Sources (EBIS) for European

Radioactive Ion Beam (RIB) facilities. This talk will review the objectives of the EMILIE project which motivated the different developments which will be discussed along the workshop.

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Introduction

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Injection and Ion Extraction Techniques at the Brookhaven High Current EBIS

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EMILIE: Perspectives

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The contribution of INFN to the EMILIE project

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