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Editorial

Precision nuclear physics experiments and theory

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Abstract The advances in technology mainly concerning ion traps, storage rings, lasers, high-precision frequency measurements, detectors, and particle beams as well as advances in atom and ion manipulation have allowed for a considerable progress in the determination of fundamental parameters and quantities of radionuclides such as masses, electromagnetic moments, lifetimes and beta decay correlations. The main subjects covered by this topical collection are: high-precision mass measurements both with Penning traps and storage rings for neutrino physics, nuclear structure, astrophysics, and decay studies. Laser spectroscopy is applied for the determination of other ground state properties like spins, moments, and nuclear charge radii. Furthermore, results from decay studies of highly charged ions and reactions in storage rings are presented.

1 Introduction

Nuclear physics experiments for the determination of ground- and excited-state properties of radioactive isotopes provide, e.g., accurate lifetimes, masses, binding energies, cross sections, charge radii, spins, and electromagnetic moments. Most of these quantities have reached in recent years an amazing precision and sensitivity. Many topics in nuclear physics benefit from these highly accurate numbers, which allow among others to test state-of-the-art theory predictions. In combination with other results they give insight into details of the nuclear structure for a better understanding of the underlying effective interactions. They also provide important input for studies of fundamental symmetries in physics, and help to understand the nucleosynthesis processes that are responsible for the observed chemical abundances in the Universe. Numerous technical developments both in theory and experimental devices have led to major breakthroughs, which are highlighted in this Topical collection on *Precision Nuclear Physics Experiments and Theory*. The contributions to this issue articulate around four research pillars: (i) Nuclear Astrophysics, (ii) Nuclear Structure, (iii) Test of the Standard Model, and (iv) Weak Interaction.

The papers dedicated to astrophysics include a contribution on low-energy nuclear reactions with stored ions; entitled *A New Era of Astrophysical Experiments at Heavy Ion Storage Rings*, by Glorius and Bruno [1]. This paper describes the recent developments in ring physics. The idea is to study pure, exotic beams of rare nuclei that impinge on pure ultra-thin targets allowing the study of long-standing nuclear astrophysical questions. Pioneering work done at ESR in GSI is described as well as future plans at the same site with both ESR and CRYRING. The need for nuclear data for astrophysics applications challenges experimental techniques as well as the robustness and predictive power of present nuclear models. In the contribution entitled *Nuclear properties for nuclear astrophysics studies* Goriely [2] discusses the reliability and accuracy of recent nuclear theories for most of the relevant quantities needed to estimate reaction cross sections and beta rates, namely nuclear masses, nuclear level densities, gamma-ray strength, fission properties and beta-strength functions. In nuclear astrophysics the energy output and the produced elements depend on the masses of the involved nuclides. In *Precision mass measurements of radioactive nuclides for astrophysics* Clark et al. [3] argue that the masses of rare nuclides have to be known with a precision of 50 $\mathrm{keV}/\mathrm{c}^2$ or better to adequately discriminate models that explain the observables. Recently, thanks to the advent of new facilities and mass-measurement techniques, there is a wealth of precise and accurate mass data. These data combined with novel models and codes have greatly enhanced our understanding of astrophysical processes in the Universe although many challenges still remain and new questions appear. Violent stellar environment are character-

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ized by high temperature and densities that lead to high charged ions. At the laboratory we mainly measured properties of neutral atoms that are heavily altered when most of the inner electrons are removed. The study of the radioactive decay of highly charged ions has only become possible thanks to the existence of heavy-ion storage rings coupled to radioactive ion beam facilities. A concise review of the relevant experimental techniques and experiments is presented in the contribution of Litvinov and Chen [4] entitled *Radioactive Decays of Stored Highly Charged Ions*.

Atomic masses represent key ingredients to understand the structure of atomic nuclei. They provide insights into the nuclear binding energy and, thus, into the combined forces that govern the stability of atomic nuclei. In the context of nuclear structure, the contribution of *$B\rho$-defined Isochronous Mass Spectrometry and Mass Measurements of ^{58}Ni Fragments*, by Zhang et al. [5] describes a novel isochronous mass spectrometry technique at the cooler-storage ring CSRe in Lanzhou. Two time-of-flight detectors allow for the simultaneous measurement of the velocity and revolution time of each stored short-lived ion. This technique is of special interest for very short-lived and low produced species for which an energy resolution of 5 keV is achieved. With this new method the masses of nuclei near ^{58}Ni have been remeasured and the validity of the isobaric multiplet mass equation tested to the heaviest isospin quartet with $A = 55$. Among the contributions to nuclear structure it is important to mention the mass measurements at RIKEN by Naimi et al. [6] entitled *Recent Achievements of The Rare-RI Ring, A Unique Mass Spectrometer at the RIBF/RIKEN*. This contribution describes the Rare-RI Ring based in Isochronous Mass Spectrometry that accept event-by-event nuclei allowing for high-precision mass determination. As example, the determination of the new mass of the palladium isotope fifteen neutrons away from stability emphasizes the importance of precision mass measurements in the r-process.

The current status of precision atomic mass measurements and the relevant techniques employed at TRIUMF's Ion Trap for Atomic and Nuclear science (TITAN) is reviewed in the contribution entitled *15 years of precision mass measurements at TITAN* by Kwiatkowski et al. [7]. An updated view on the phenomenon of mutually enhanced magicity based on the current experimental knowledge of atomic masses is presented in the contribution entitled *The empirical shell gap revisited in light of recent high precision mass spectrometry data* by Manea et al. [8]. They showed that the empirical shell-gap trend along neighboring isotonic chains differing by two nucleon numbers is anti-correlated to the one observed along the magic number chains. They perform theoretical calculations to understand the origin of this feature.

High-resolution laser spectroscopy can be used to precisely measure atomic hyperfine structures and isotope shifts in spectral lines. These nuclear perturbations of the atomic structure provide insight into the bulk properties of nuclei as well as the intricate details of the nucleon-nucleon interactions inside the atomic nucleus. Collinear laser spectroscopy in particular allows for the extraction of nuclear moments and changes in the mean-square charge radii with high precision. An overview of the manner in which collinear laser spectroscopy is currently implemented at radioactive ion beam facilities is given in the contribution entitled *Nuclear structure studies by collinear laser spectroscopy* by Koszorús et al. [9]. In this contribution they also illustrate how this method gives access to direct and nuclear model-independent evidence for changes in nuclear spins, electromagnetic moments and nuclear radii caused by structural changes in atomic nuclei.

The contributions related to tests of the standard model are *High-precision Penning-trap mass spectrometry for neutrino physics* by Eliseev and Novikov [10]. This contribution explains one of the applications of high-precision mass determination to neutrino physics, i.e. the determination of neutrino mass, search for sterile and relic neutrinos, etc. The role of superallowed transitions in determining the strength of the weak interaction and the search for new physics beyond the standard electroweak model is reviewed in the contribution entitled *Superallowed decays within and beyond the Standard Model* by Falkowski et al. [11].

The contributions in weak interactions include *Precise Q value determinations for forbidden and low energy β-decays using Penning trap mass spectrometry* by Redshaw [12]. Nuclear β-decay is a great laboratory to investigate weak decays occurring in the nuclear medium. It provides information on the underlying interaction and the properties of the particle involved. In particular Penning trap measurements provide through the measurement of the masses of the parent and daughter nucleus a very precise value of the energy available (Q-value). This contribution concentrates on the Q-value determination for some primordial nuclei and in particular for a subset of β-unstable nuclei that populate with very low β-energy an excited state in the daughter nucleus. These studies are of interest as test of systematics of beta detector used to determine the shape factor for forbidden transitions.

Beta decay between mirror nuclei is reviewed in the contribution entitled *Mirror beta decays* by Riisager [13]. It is well known that Fermi transitions of mirror nuclei are very similar, however Gamow-Teller transitions can differ by more than a factor of two. The different effects that contribute to the asymmetries are discussed.

These papers describe a number of cutting-edge nuclear physics studies that are all interesting by themselves; we hope that by uniting them in one volume, the reader will be offered a view of their relationships, which give us some of our best opportunities for testing the overall consistency of our fundamental theories and experimental methods. An overview is given by the following table of contents.

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