Opportunities and challenges for studying rare events in nuclear physics using existing and future ion beam accelerators

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A new high intensity stable ion beam facility with energies at and above the Coulomb barrier, is considered to be one of the important issues of the nuclear physics community. The facility should be capable of accelerating ions from proton to uranium and deliver high intensity beam at target position. Selected physics problems to investigate the rare events in nuclear physics using modern high-resolution spectrometers and detectors will be highlighted. Advanced developmental center for detector technology and instrumentation will be essential for the proposed experiments.

Nuclei are highly complex quantum many-body systems. Understanding their properties is a cornerstone in our exploration of the deeper mysteries of the universe. These properties are determined by the nuclear forces between the protons and neutrons and they are still not fully understood up to now. Measurements of nuclear properties at the limits of existence provide important simplifications that can yield new insights and a deeper understanding of the fundamental mechanisms acting in the nucleus. Such experimental efforts aim for the investigations of very weak signals typical for the rare phenomena. This requires the development of extremely sensitive instruments as well as accelerator facilities capable of higher beam intensities and more variety of isotopes than those available today within India. These advances will provide the opportunity to see what was hidden to the well-established techniques. Such efforts are demanding in terms of resources and infrastructure to develop new facilities. Research with high-intensity beams of stable nuclei continues to produce high impact science. We also need to remember that discoveries at exotic beam facilities will raise new questions whose answers are accessible with stable beam facilities. One of the possible configurations will be a LINAC which can provide high-intensity beams from H to U with energy up to 10 – 20 MeV/u [1]. Some of the physics questions that can be uniquely addressed with a modern high-intensity stable beam facility are:

1) Structure and stability of superheavy nuclei
2) Exotic shapes and decay modes of rotating nuclei
3) Electromagnetic properties of ground state of exotic nuclei and isomers
4) Nuclear masses
5) Near barrier fusion and transfer reactions
6) Structure and reaction studies for nuclear astrophysics
7) Nuclear isomers in plasma
8) Ultra-cold nuclear matter

The combination of high-intensity stable ion beams and an ISOL or in-flight separator equipped with a gas catcher technique can provide intense and exotic beams of low-energy radioactive ions. A mass-separator of radioactive isotopes ionized by the laser resonance ionization method will be a powerful source for decay spectroscopy study of rare isotopes [2]. In addition, such a machine will be useful for boron-neutron capture therapy, high productivity isotope generation and material science. It is of prime importance to develop the detector instrumentation at this facility to support a broad and leading-edge research program. Here, we will highlight some of the instrumentation required for the detectors associated with nuclear structure studies at such facilities. Some of the other contributions in the special session of the current symposium will highlight the detectors for nuclear reaction studies. The proposed detectors can also be used in the existing accelerator facilities within India and abroad.

High-resolution gamma-ray spectroscopy is a versatile tool for the investigation of the complex nature of excited states. It continues to play a prominent role in the understanding of nuclear structure and dynamics [3,4]. Improved efficiency, resolution and sensitivity of the gamma spectrometers are mandatory to measure various observables with higher precision. This can refine and guide the theoretical models in the field. It is imperative to couple the high efficiency gamma array with electromagnetic spectrometers [3,4] as well as other ancillary detectors. Electromagnetic spectrometers coupled to gas cells and high precision mass spectrometers can give valuable inputs for the properties of ground state as well as isomers through mass measurements and laser spectroscopy [3,4].

The first phase of INGA became operational in 2001. The INGA grew, as it kept moving between the three accelerator centers at Delhi, Mumbai and Kolkata with more than 130 experiments performed. Some of the salient scientific achievements of INGA campaigns are exotic shapes and shape evolutions, nuclear isomers and reaction dynamics study.

To keep India in tune with the global developments in these fields, it is proposed to augment the INGA program by strengthening the gamma detection facility in 3 phases. In the first phase, it is proposed to augment the INGA program by strengthening the gamma detection facilities at each of the three accelerator centers [5]. Such a move will enable us to focus on landmark experiments with low cross-sections by using longer beam times. The need for the development of new ion beams like ^{2}H, ^{14}C and ^{40}Ca in the accelerator centers will be highlighted. In the second phase, we plan to develop a large array consisting of about 40 Compton suppressed clover detectors, which will move between the different accelerator centers for certain unique experiments. Design details of the new project will be presented. We will also plan to have the provision to add additional HPGe detectors through international collaboration. Such an array at a high current accelerator facility will be internationally competitive for nuclear structure studies. Some of the ancillary detectors required for the experiments include a large charged particle detector array, neutron detector array, gas detectors for binary reactions, and detectors for internal conversion electrons. For wide range timing spectroscopy the plunger and fast-timing array needs to be coupled to the clover array. Coupling this array with sophisticated spectrometers will improve the sensitivity of the measurements. At the same time, we need to develop a next generation gamma spectrometer for low energy nuclear physics, which will be the third phase. The next generation gamma rays are extremely sophisticated in terms of technology [5,6]. Looking at the global trend in the mega science projects, it seems joining the gamma tracking collaborations is a logical step forward. This will help to develop next generation of gamma spectrometer within the country. There is a strong requirement for an advance instrumentation center for development and upkeep of different detectors and readout systems discussed above. Such an initiative will attract early career researchers to pursue instrumentation for innovative research in basic and applied nuclear physics with the high current ion beam facility.

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