Physics Highlights from Digital INGA and Future Developments

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Some of the important properties of nuclei can be inferred from the investigation of their excited states. The high resolution gamma ray spectroscopy using large array of High-Purity Germanium (HPGe) detectors at heavy-ion accelerator plays a pivotal role in the study of excited states of nuclei which unravel variety of nuclear structure phenomena related with novel shapes and modes of excitation. In this context, a 24 Clover HPGe detector array with a total photo-peak detection efficiency of $\sim 5\%$ named as Indian National Gamma Array (INGA) was conceived, designed and assembled within the country. This facility rotates between the three accelerator centers at TIFR (Mumbai), IUAC (New Delhi) and VECC (Kolkata). INGA is a powerful femtoscope for the study of structure of atomic nuclei at high spins. A long experimental campaign of INGA coupled to a digital data acquisition [1] system has been completed at BARC-TIFR Pelletron Linac Facility at TIFR, Mumbai. 45 experiments based on proposals from different groups within India and abroad have been accepted for this experimental campaign of INGA at TIFR. Some of the selected physics results from this experimental campaign are highlighted here.

The shape of the nucleus, which is governed by the spontaneously broken symmetries, determines the basic properties, for instance lifetime, binding energy and excitation modes [2]. Tilted axis cranking which breaks $R_z(\pi)$ symmetry gives rise to magnetic rotation (MR) due to shear structure of proton particles and neutron holes (or vice-versa). Antimagnetic rotation (AMR) resulting from the anti-alignment of two shears similar to the anti-ferromagnetic phenomenon in the condensed matter physics is a rare phenomenon compared to MR. Lifetime measurement in sub picosecond range for the excited states in ^{107}Cd has been carried out to establish the coexistence of MR and AMR modes in the same nucleus [3]. First observation of AMR bands in $A \sim 140$ region has been established recently [4]. The breaking of axial symmetry in the nuclear intrinsic state is uniquely related to two novel excitation modes, namely, chiral rotation and wobbling [5]. Experimental manifestation of the breaking of chiral symmetry is the observation of near-degenerate dipole bands with similar electromagnetic properties and moments of inertia. Spectroscopic studies of degenerate dipole bands in ^{106,108}Ag isotopes have been carried out to understand the role of triaxiality for these nuclei [6,7]. The two bands of ^{106}Ag have unique properties, similar B(M1), B(E2) values, but different moment of inertia [6]. More recently, evidence of multiple chiral bands has been reported in ^{195}Tl [8]. The polarization measurements with INGA at TIFR have generated important data on wobbling mode at low spin for the first time for N=76 isotones of Pr, La and Cs [9,10].

Another highlight of the present campaign is spectroscopic study of nuclei near ^{132}Sn region using fusion/transfer induced fission process. The prompt-delayed coincident data from INGA complements the fragment gated gamma spectroscopy data from EXOGAM-VAMOS++ and makes a firm assignment of the placement of various transitions in the level scheme of ^{132}Te which has long-lived isomers [11]. These measurements have been carried out to investigate the competition of neutron and proton pairs for the generation of high spin states in ^{132}Te. The experimental study provides new information on the nn, pp and pn interactions used in the shell model calculations to describe the level scheme of ^{132}Te. Similar study has been carried out for nuclei near ^{68}Ni using multi-nucleon transfer reaction [12]. New results on high spin structure of ^{89}Zr indicated rotation about the long axis [13].

To keep India in tune with the global developments in this field, it is required to improve the sensitivity of INGA by strengthening the gamma detection facilities and designing new ancillary detectors at each of the three accelerator centers. Such a move will enable us to focus on landmark experiments with low cross-sections to explore some of the major questions in nuclear structure associated with high spin physics. A fast timing array consisting of 16 $LaBr_3$(Ce) detectors and a 4π charged particle array with 84 CsI(Tl) detectors are being developed which will be coupled to Indian National Gamma Array(INGA). For coupling these ancillary detectors to INGA, we need to upgrade existing Digital Data Acquisition system. A root based multi-threaded software has been developed to control and acquire data from PIXIE-16 DGF from XIA for the hybrid configuration with 100 MHz, 250 MHz and 500 MHz cards for clovers coupled with different type of ancillary detectors with slow and fast signals. TIFR Digital Data Acquisition Software for Nuclear Structure Studies (TIDES) is designed and developed to control data acquisition(DAQ) system and acquire data for gamma-ray spectroscopy. The hardware is XIA based PIXIE 16 system. It permits acquisition at a very high count rate with digital pulse processing (DPP) on a field programmable gate array (FPGA) performing pulse height analysis (PHA), pulse shape discrimination (PSD) and pile-up rejection (PUR) algorithms. Test results from these ancillary detectors coupled to INGA will be presented. The conceptual design for a new array of HPGe detectors with a photo-peak efficiency up to 8% will be presented. This new array will have the provision to accommodate the existing clover detectors along with the new generation of HPGe detectors. This new array will enhance the physics capability of the existing and future accelerator facilities within India.

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