Summary: Theme meeting on Nuclear Lifetimes, Transitions and Moments (NLTM2022)

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Preamble

The theme meeting on Nuclear Lifetimes, Transitions and Moments (NLTM2022) was organized by Variable Energy Cyclotron Center, Kolkata, in online platform during 1-3 February 2022 to discuss on the past, present and future of nuclear structure studies with measurement of nuclear level lifetimes, transition moments and beta decay. The motivation behind this meeting was to,

1. Discuss physics of nuclear structure achieved with the measurement of nuclear lifetimes, transition moments and beta decay.

2. To have an overview of different facilities developed around the globe and the experiments performed on nuclear level lifetimes, transition moments and beta decay.

3. To discuss the physics goals and developmental aspects of VENTURE (VECC array for Nuclear fast Timing and angUlar CorRElation studies) and VEBGYOR (VECC array for Beta-Gamma spectroscopY of Radio-nuclei) facilities at VECC, Kolkata, India.

Several frontier developments on nuclear Lifetimes, Transition moments and Beta Decay were discussed in the meeting. The presentations included the contemporary Physics Research that are being carried out with different national and international laboratories/facilities like TRIUMF, Canada; GRETINA, FRIB, USA; HiCARI, Japan; ROSPHERE, Romania; FATIMA, GSI, Germany; ILL, Grenoble, France; ISOLDE, CERN; TIFR, Mumbai and VECC, Kolkata involving researchers from all the relevant institutes and most of the renowned national laboratories.

The future perspectives of nuclear structure research with measurements of nuclear level lifetimes, transitions and moments in India and at VECC were discussed in a session of the meeting, dedicated with a panel discussion having the panelists Prof. Sukalyan Chattopadhyay, SINP (who co-ordinated the discussion), Prof. Indranil Mazumdar, TIFR, Dr. Tumpa Bhattacharjee, VECC and Dr. Rajarshi Raut, UGC-DAE-CSR, Kolkata. The discussion was open to all the participants including young researchers and students. Representatives from the Pioneer groups in the world who are carrying out nuclear level lifetime measurements with electronic gamma-gamma fast timing technique were also present and actively participated in the discussion.

It has been felt necessary to make the summary document of the theme meeting that may provide a roadmap for the future research activities on nuclear structure studies with nuclear level lifetimes, transition moments and beta decay measurements in the country. Such a document was generated with contribution of all the authors based on their expertise and the authors acknowledge Dr. Rajarshi Raut for writing the Section 2a and 2b (iii) of the document.

The possibility of a gamma-gamma fast timing campaign at VECC, Kolkata has been explored. It is observed that a gamma-gamma fast timing campaign can be planned with VENTURE using the available detectors at VECC and other institutes who are interested to join the campaign.

A compilation has been made for the existing facilities in different laboratories in India with few relevant details. This is aimed to benefit especially the younger community and the research students who may plan state of the art world class experiments for their thesis.

Formation of a scientific committee including the active senior members in the community is felt to be important. Discussions on various developments and research will help to gather information and to execute/handle the difficulties faced in the implementation of the said R&D projects. Scientific sanctions from such a group of experts will help acquiring financial grants for facility developments for nuclear structure research in the country.

1. Introduction:

The progress in science is always motivated by the desire to solve problems. This takes place with the stimulation of additional research in a field or discipline, research of inter-disciplinary types and research on previously under researched questions. Science also develops when it attracts new facility developments and new people to work for an important research problem.

The discussions in NLTM2022 also started with the note to look for the future possibilities, keeping in mind the facilities that are in disposal and the ones that can be developed within a reasonable time. Such efforts must be capable of going beyond the present reach of nuclear structure research in the country and open up new horizon for the next generations to be involved in this field.

Nuclear lifetime measurement was considered as one of the key aspects that can unfold important information about the nucleus as was also highlighted by many eminent speakers in the meeting. The other avenues that were also discussed are the developments in fronts of nuclear transition moments and beta decays. It was emphasized that those developments are to be prioritized that can bring out important physics outcome and the developments must be made keeping in mind the physics goals that can be addressed with such facilities.

Focus on interdisciplinary collaborations and nuclear theory was also discussed and emphasized to be of great matter of importance for the future progress of nuclear structure studies in India.

The food for thoughts were driven by the recent initiation and progress that has already been made by different individual groups in different laboratories of the country in the direction of nuclear levels lifetimes, transition moments and beta decay measurements. The same was inspired by the research results that were displayed and discussed by the eminent speakers from the national and international laboratories.

2. Nuclear level lifetime measurement:

Nuclear level lifetimes provide unique information on the nuclear structure as it helps probing directly into the nuclear interaction matrix elements. The nuclear excited states may have a wide range of lifetime ($\sim10^{-15}$ sec to 10^{+15} sec) and most of them lie in the sub-nanosecond (ns) region. So, measurement of nuclear level lifetimes requires a very precise clock that could be developed for probing the nuclear decay at various conditions and in turn collecting the information on the radioactive decay time.

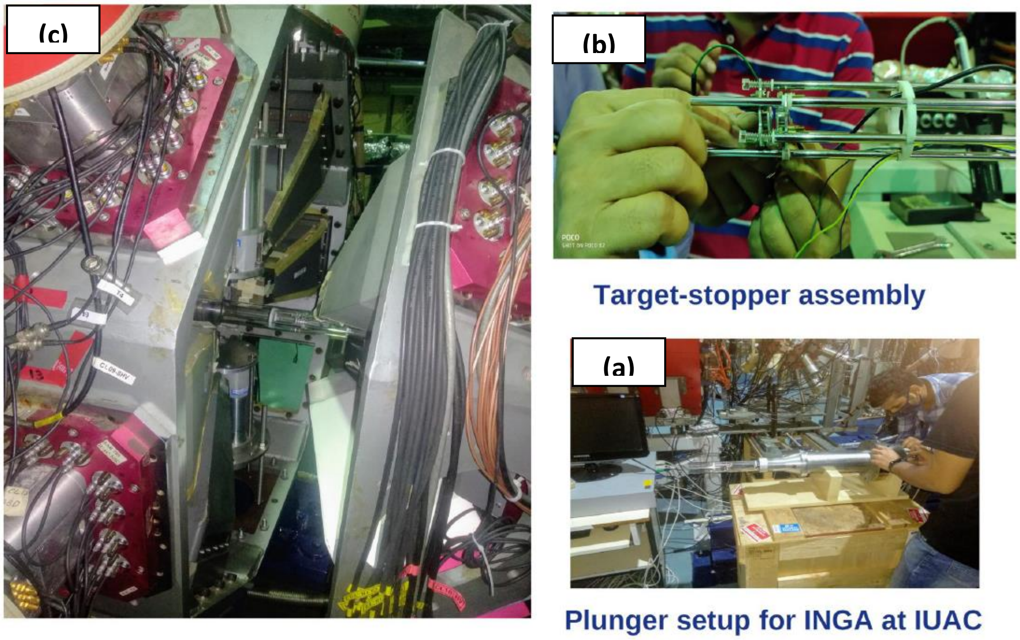
There are plenty of direct or indirect techniques that are used for measurement of nuclear level lifetimes and these techniques range from particle resonance spectroscopy to electronic techniques. Among these, two of the most widely used lifetime measurement techniques were the topics of discussion of the theme meeting. The first one is the Doppler technique that utilizes the Doppler shift in the energy of a de-excited gamma radiation due to its emission from a moving nucleus. The Doppler shift techniques can in principle access lifetimes down to 100s of femtoseconds to 100s of picoseconds and the latter range is possible with state of the art plunger devices. The lifetimes in the range of a few picoseconds to several microseconds can be measured with electronic timing techniques that can be applied in almost all experimental conditions. However, until very recently, the lower limit to which the electronic techniques were capable of measuring lifetimes was about few nanoseconds.

Significant Progress has been made in both the Doppler technique and Electronic technique so that the region within few picoseconds to a nanosecond can be accessed. The improvements in Doppler techniques have made it possible to increase the upper limit whereas the improvement in the electronic technique strived for lowering the lower limit accessible in such measurements. These methods were in the focus of the discussion of the present theme meeting and were considered as the emerging fields deciding the future facility developments in the country in the direction of nuclear level lifetime measurements. The following sections are dedicated to discuss the past, present and future of the nuclear level lifetime measurements in the country.

a. Nuclear level lifetime measurements through Doppler techniques: Present scenario and the future developments:

Lifetime measurements using the Doppler Shift Attenuation Method (DSAM) is being pursued by several groups in the country, for determining lifetimes in the range of few tens of femto-seconds to few pico-seconds. Developments [1] have been made to extend the applicability of the method beyond the conventional practices of using thin-target-on-thick-elemental-backing and producing the nuclei of interest through fusion-evaporation reactions. The new methodology has been applied by users (11 citations recorded under SCOPUS, at present), in and outside the country, for varied experimental conditions. The lifetime results, obtained thus, have been of facility towards conclusive identification of different excitation phenomena in the nuclei being investigated. In addition to the continued use of these developments by a larger community of users, the application of the (DSAM) technique can further evolve through use of particle detection in order to constrain the population of nuclei in the excited state being probed (for lifetime) and thus eliminate, or at least restrict, the uncertainties incurred by the modeled feeding. Use of particle detectors along with gamma-ray detector arrays, such as the Indian National Gamma Array (INGA), is a possible pathway towards accomplishing this improvement.

The Recoil Distance Method (RDM), for level lifetime measurements typically in the range of tens to hundreds of pico-seconds, is being practiced in the country currently using the plunger setup at IUAC, New Delhi. The device has been used with the Gamma Detector Array (GDA) [2] and a NEW plunger device (shown in Fig. 1) has recently been tested [3] with the INGA setup at IUAC. A campaign of experiments, aimed at lifetime measurements using the RDM, may be eventually planned at the facility. It may be deliberated if the fast timing technique using scintillator detectors, that is now being pursued in several facilities across the globe, will replace the RDM technique altogether for lifetime measurements; the range of lifetimes addressed by the two techniques are in overlap, at least partially. It may be put forth that the applicability of the methods would depend on specific experimental situations.



Target-stopper assembly

Plunger setup for INGA at IUAC

Fig. 1: (a) The new plunger device at IUAC, New Delhi, (b) target-stopper assembly, (c) coupled to INGA setup

b. Electronic gamma-gamma fast timing technique: present scenario and future possibilities:

The electronic gamma – gamma fast timing technique involves the measurement of nuclear level lifetimes through the measurement of time difference distribution between the detection of two gamma rays in cascade or the same with respect to an external prompt reference like accelerator RF. Typically, the deduction of level lifetime can be made (1) by simply studying the exponential decay of a particular nuclear level, through the slope technique (longer lifetimes) or de-convolution technique (shorter lifetimes) and (2) by measuring the centroid position of the time difference distribution with respect to a calibrated prompt. The lowest lifetimes that could be measured with these techniques were limited to about 1 ns and the limitation was mainly posed by the available fast timing detectors and the technique that were employed in the measurements.

The electronic gamma – gamma fast timing technique took a new dimension with the proposition of the concept for utilizing the Mirror Symmetry of the time difference distribution of a gamma-gamma cascade [4]. The Mirror symmetric centroid difference method utilized the availability of state-of-the-art scintillator detectors like $LaBr_3$ or $CeBr_3$ that has a reasonable energy resolution and the excellent time resolution for very precisely calibrating the energy dependent time walk for a two detector time clock setup. The MSCD technique was the foundation behind the development of large gamma-gamma fast timing arrays where the N detector gamma-gamma coincidence setup was used. The Generalized Centroid Difference (GCD) method [5] was thus introduced in which the N detector coincidence setup could be reduced to a two detector setup of gamma-gamma time difference measurement. The GCD method has been improved with rigorous research on nuclear instrumentation and analysis methodology. One of the important aspects has been the improvisation on the Compton background effects that is observed underlying the photo-peaks of interest in the fast scintillator detectors. The background correction formulization has been evolved with time and presently, the GCD method is proven as the unique method to measure nuclear level lifetimes in the ranges between 10’s of picoseconds to 100’s of picoseconds.

The basic principles and methodologies on gamma-gamma fast timing measurements; and the effect of Compton background in such measurements have been discussed in the meeting in great details. The fast timing measurement efforts at ILL, Grenoble, France and five other major facilities around the globe, as some of them are shown in Fig. 2, were discussed in the meeting which focused on lifetime measurements in nuclear excited levels using gamma-gamma fast timing techniques.

(1) Fast TIMing Array (FATIMA) [6] that consists of 36 1.5” dia x 2” thick $LaBr_3$ detectors, suitable to be placed at around the decay spectroscopy station at FAIR and was coupled to required numbers of Clover HPGe detectors in its different campaign around the globe in campaigns like EXILL-FATIMA, Gammasphere-FATIMA.

(2) ROSPHERE array [7] at INFN-HH which has flexibilities to be used as a high efficiency gamma array with 25 HPGe detectors without any $LaBr_3$ and as a fast timing array with addition of different sizes of $LaBr_3$ detectors and reducing the number of HPGe detectors in the structure to the required numbers (15).

(3) Indian National Gamma Array at TIFR that otherwise consisted of a large numbers of Clovers, where 2” x 2” $LaBr_3$ detectors are placed as per the space availability in the INGA support structure. The array with 11 Clover HPGe and 14 $LaBr_3$ detectors was used to measure

lifetimes with slope technique in the range of 250 ps in La isotope [8]. This measurement has addressed a very important phenomenon of octupole collectivity in ^{137}La nucleus.

(4) DURGA facility at BARC [9], Mumbai that is dedicated to neutron induced gamma spectroscopy measurements and is having few Clovers along with $LaBr_3$ detectors. The facility was successfully installed overcoming all the difficulties posed by the very different environment in neutron beam experiments in contrast to the ion beam reactions. The array, consisting of $LaBr_3$ detectors, has been utilized to address few topics of contemporary interest in nuclear structure research.

(5) VENTURE array at VECC [10], the first $CeBr_3$ based fast timing array in the world, and the first gamma-gamma fast timing array in India, is dedicated for both lifetime and quadrupole moment measurements. The array could be used in standalone mode as well as in coupled mode with the required numbers of Clover HPGe detectors for high resolution gamma gating and inspection in both off-beam and in-beam fast timing experiments. The $CeBr_3$ detectors bring an economic solution to replace the widely used $LaBr_3$ scintillators that has another limitation from their internal activities.

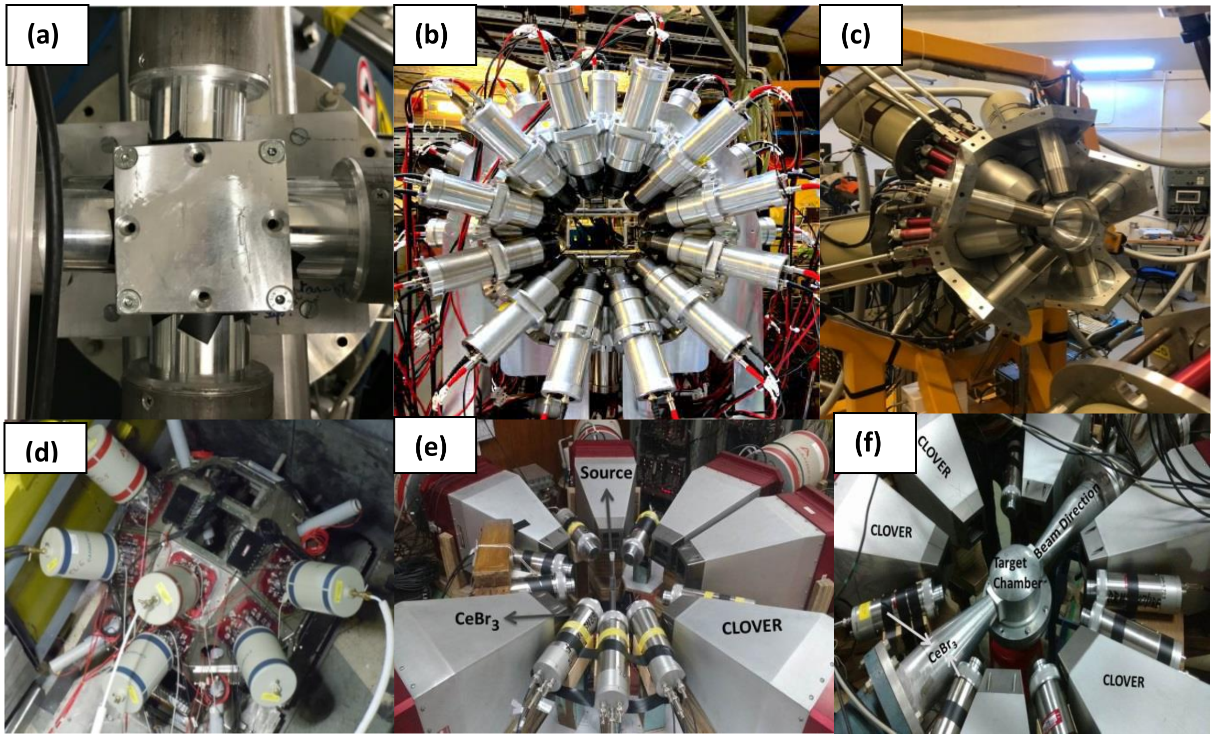


Fig. 2: The fast timing facilities discussed in the meeting, (a) Timing setup at ILL, Grenoble, France, (b) FATIMA at FAIR, GSI, Germany, (c) ROSPHERE array, INFN-HH, Romania, (d) DURGA facility at BARC, Mumbai, India and (e,f) VENTURE array at VECC, Kolkata (off-beam and in-bean set ups).

It was understood that in order to widen the nuclear lifetime measurement capabilities in the country, one needs to implement the use of Generalized Centroid Difference Technique utilizing an appropriate gamma-gamma fast timing setup. The development of VENTURE at VECC and its successful use demonstrated the 'proof of concept' for the possibility of lifetime measurement using GCD technique in India [10]. VENTURE, in its very tiny form of its first phase, could bring out publication of articles in the international journals of repute that addressed contemporary physics issues like shape coexistence in nuclei around N = 90 [11] and nuclear structure around doubly closed ^{132}Sn [12], obtained with lifetime measurements using GCD method. So, the confidence for success on the future development of a state-of-the-art gamma-gamma fast timing setup must be undoubted and could be considered as promising. Accordingly, the final form of VENTURE will include fast timing detectors of different sizes, as required for achieving the best time precision of the array and taking care of all other important factors required for lifetime measurement with gamma-gamma fast timing technique.

Following some of the above successes in addressing the physics of nuclear structure with gamma-gamma fast timing measurements [8,11,12], many users in the country were also found to be getting interested in these measurements and supported the requirement for future developments of a dedicated gamma-gamma fast timing array like VENTURE. Very recently, more interests in $CeBr_3$ detectors are observed and results on testing, characterizations and use of different shapes and sizes of these detectors are coming up from different institutions in India [13,14]. The following subsection discusses the details of next phase of VENTURE array development at VECC, Kolkata.

(i) Design of gamma-gamma fast timing array (VENTURE) at VECC, Kolkata:

The 2nd phase of VENTURE array has been discussed in the meeting and will have several numbers of $CeBr_3$ detectors covering most of 4π solid angle. The size of the detectors of VENTURE array will be decided based on the maximum time precision that can be obtained with the planned setup. Suggestions were received regarding the benefits of different sizes of detectors for the gamma-gamma fast timing array VENTURE at VECC. One of the experts and pioneers in the field of gamma-gamma fast timing suggested that the right way is to carry out the Monte Carlo simulation to study the detector efficiency, inter detector Compton scattering and the time responses of the detectors in the VENTURE array and to decide on the final size of the detectors based on the time precision that decides the output efficiency. The Monte Carlo simulation with GEANT4 and FLUKA packages has already been started by the VENTURE collaboration to understand these parameters and to finalize the detector size to be used in the array.

A test experiment has also been planned since 2019 to measure some of these parameters with different geometry of VENTURE array with all available sizes of the detectors with different types of PM Tubes. Several variations in the type of fast timing detectors were found with different sizes and coupled to different PM tubes. Along with comparison, the test experiment is aimed at studying the performance with a combination of fast timing detectors in the array.

The design of VENTURE array has been made following one of the very successful campaigns on gamma-gamma fast timing viz., EXILL-FATIMA [15] that was dedicated for nuclear structure studies through lifetime measurements. The VENTURE array will have six Clover HPGe detectors in its median plane that will suffice the triple gamma gating (Clover-CeBr-CeBr) with high resolution gamma gate in the Clover HPGe detectors. The horizontal ring of Clover Ge detectors will also act as a shield between the upper and lower rings of $CeBr_3$ detectors that will help reducing the inter-detector Compton scattering. Use of 0.5mm Pb shield will also be worked out during simulation to study the Compton shielding effects. Placement of fast detectors in the non-zero phi angles and in two sides of the Clover detectors are motivated towards providing a dedicated setup for gamma-gamma fast timing measurements with required output efficiency and for specific measurements on nuclear transition moments at VECC, Kolkata. The fast timing detectors have been placed at the closest possible distance from target and with this exercise, the number of detectors with 2 inch PMTs could be maximized. Detectors with thicknesses up to 2 inch can be placed in this setup and the final combination will be fixed to obtain the highest timing precision with lowest inter-detector Compton scattering. The fast timing detectors in its present design will also provide required combinations of inter-detector angles of 90^o and 180^o that can be utilized in some TDPAC/TDPAD measurements.

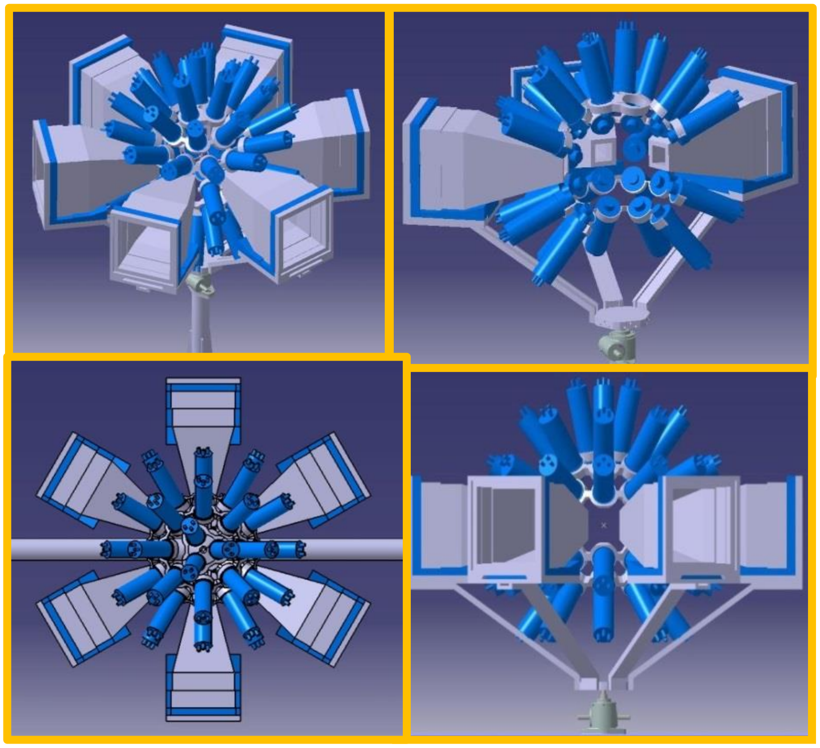


Fig. 3: Design of VENTURE array at VECC

Unlike EXILL-FATIMA, the Clover detectors are kept in the horizontal plane instead of vertical plane. This was adopted considering the fact that the beam line height of K-130 cyclotron do not allow to place Clover detectors comfortably under the beam line. Clovers are to provide reasonable efficiency of high resolution detectors in the fast timing array so that adequate Ge-CeBr-CeBr coincidences are obtained. The present positions of Clover detectors in the VENTURE array will also allow the interested users to take data for measuring DCO ratios and Polarization asymmetry, if required, in addition to gamma-gamma fast timing data. The mechanical structure of VENTURE is shown in Fig. 3 which is discussed in NLTM2022 and the fabrication will be started by VENTURE collaboration very soon.

With all its features, particularly the substantial number of fast timing detectors, VENTURE is a complementary setup to the INGA array at VECC, in terms of the measurements of lifetimes in the tens of picoseconds to a few nanoseconds. Also, in its full form, the sum energy measurements with this array would be useful, either on their own, or to enhance the selectivity. The development of VENTURE as a standalone facility can thus be taken up to access several new dimensions of gamma spectroscopic measurements.

(ii) Role of analog electronics and nuclear instrumentation in the success of fast timing experiments: Future requirements

During Panel discussion in NLTM2022, it was emphasized that efforts must be put towards the development of nuclear electronics in order to cope up with multi parameter signal processing from a huge numbers of detectors in the gamma arrays dedicated for fast timing, transition moments and beta decay measurements.

One of the very important components in the gamma-gamma fast timing measurement is the Constant Factor Discriminators with the lowest possible amplitude walk. Developmental efforts have already been triggered at VECC to develop in house CFD modules utilizing CMOS technology or discrete components. If successful, these modules will be very much helpful to run the gamma-gamma fast timing campaigns in near future. In addition, efforts must be made to develop in-house electronic modules for signal processing as per the requirement, viz., the CLOVER modules were developed at IUAC, New Delhi for running Clover detector setups (INGA).

VENTURE collaboration has developed a VME setup with high resolution Mesytec ADCs and high resolution TDCs. The LAMPS data acquisition software was upgraded with Mesytec TDCs by the respective development group at BARC (www.tifr.res.in/pell/~lamps.html) and with initiation and requirement from VENTURE collaboration. Both Mesytec ADCs and TDCs are having 32 channels (each module) and so can presently handle the big number of detectors, thereby reducing the required numbers of Time to Amplitude converters in the pulse processing circuit. The setup is being explored and could be used in the future campaigns on gamma-gamma fast timing measurements at VECC, Kolkata. In addition, the use of QDC is also being explored. The full VENTURE setup is available for experiments to the community, the setup being maintained and improved by the collaboration [16].

The GCD measurement, in particular, is very sensitive to the choice of electronics that is used for processing the fast timing pulses from the fast scintillator detectors. Till date, except very few, the GCD measurements have been performed either by full analog electronics or by mixed analog and digital electronics. However, for large setups it is necessary to go for digital DAQ that hugely reduces the size of pulse processing electronics. Efforts towards full digital electronics has been initiated at various laboratories around the world and full digital pulse processing for fast timing measurements through GCD technique at AFRODITE array [17] could go down to only 26ps precision compared to 3ps in analog or mixed setups.

Till date, GCD measurements in India have been done with NIM and VME electronics only [10,11,12,16,18]. So, it is of extreme importance that research and development in the use of digital DAQ facilities are made so that (1) the hardware as well as the algorithms are suitable for the lifetime measurements with fast timing techniques and (2) it is feasible to use GCD technique to its fullest capacity. So, it is warranted that a fast timing setup with available detectors is made using analog electronics and is comparatively tested with digital electronics to find out the capabilities of the setups of large fast timing arrays and its use in nuclear structure studies.

(iii) Role of Digital DAQ in multi-detector experiments on gamma-gamma fast timing and future requirements:

The digitizer based pulse processing and data acquisition (DAQ) systems are being used [19, 20] with large gamma-ray detector arrays in the country, such as the Indian National Gamma Array (INGA), for more than a decade now. The merits of fast processing and high throughput together with compact dimensions that characterize the digital DAQ systems have been of facility in their use to sustain experimental programme at INGA. The application of the digital DAQ has been successfully extended [8] to hybrid (gamma-ray detector) arrays of HPGe clovers and $LaBr_3$(Ce) for fast timing measurements. It is noteworthy that two-crate synchronization in the digital DAQ system was successfully implemented for the hybrid array setup at TIFR. One of the crates housed 100 MHz digitizers while the other had 250 MHz ones.

There have been efforts in the country, to test and optimize detector setups of $CeBr_3$ scintillators [10, 13] and $LaBr_3$ scintillators [8, 9] for lifetime measurements based on fast timing techniques. The $CeBr_3$ presumably provides a more economic alternative, while largely preserving the fast timing merits, and may facilitate assembly of larger arrays. The aforementioned tests with $CeBr_3$ detectors have reported use of different dimensions of the crystal as well as type of the PMTs and have been carried out using NIM based pulse processing electronics. The subsequent step would be to use the detectors with the digital system and optimize the relevant parameters towards accomplishing the best possible detector-detector timing resolution. Efforts have already been commenced in this direction, using the (1.5" x 1.5") $CeBr_3$ detectors available at VECC [13] and digital DAQ of UGC-DAE CSR, Kolkata Centre [19]. Measurements had also been undertaken during the recent campaign of digital Gamma Array at VECC wherein 2-3 large volume $LaBr_3$ detectors were used for a limited period in order to detect high energy gamma rays and the setup helped to probe the different aspects of integrating such detectors with INGA in a digital DAQ framework. More comprehensive tests, offline and in-beam, are warranted while pooling the maximum number of available ($CeBr_3$) detectors for the purpose. The above exercise will aid in optimizing the choice of $CeBr_3$ detectors that can be subsequently integrated with INGA for an experimental programme that spans gamma-ray spectroscopy as well as fast timing measurements and thus capacitate a wider variety of nuclear structure studies.

(iv)Role of state-of-the-art data analysis software for gamma-gamma fast timing measurements:

The data analysis software packages play a key role in the success of experiments with multi-detector arrays. Radware [21] is such analysis software for high resolution gamma spectroscopic measurements. In India, the package like INGASORT [22] has been widely used for the first generation of GDA and INGA campaigns. LAMPS [23] and CANDLE [24] softwares played an important role in all gamma spectroscopic measurements till date. The MARCOS software [19] has been used since the first Digital INGA campaigns at TIFR. The INGA at VECC has been successful with the development of Pixisort software [20]. The good part of most of the codes developed within the country is that they have been made available by the developer to all the users for their understanding, learning and use. However, all these packages deal with only high resolution Ge detectors till date.

Lifetime measurements with fast timing detectors focus on gamma-gamma fast timing information with coincidence logics like Ge-CeBr-CeBr. So, it is important to develop new softwares or improvements of existing software that incorporate the analysis of energy and time information for a huge number of timing detectors in the array. One of such software, being used by laboratories in Europe, is Soco2 [25]. One of the major features would be to correct the gain drift in the scintillators that may arise not only from amplifiers but also from PMTs when handled with high rates. The online generation of gain matched delayed and anti-delayed time distributions and background corrections for GCD would be of extreme importance.

(v) Improvements in Calibration of Prompt Time Response Distribution (PRD) for GCD measurements:

The Prompt Response Distribution (PRD) curve is the central interest for the lifetime measurements with GCD technique. The issue was raised during the meeting to choose an appropriate source with gamma cascades for calibration of PRD curves for a wide dynamic range that is beyond that can be accessed with ^{152}Eu source that provide PRD from 40 keV to 1.5 MeV. Such efforts are already in place through preparing sources from nuclear reactions over and above the uses of standard sources like ^{152}Eu, ^{60}Co and ^{106}Ru. A major variety is found from the neutron induced reactions that makes the measurements successful at low energy range [26]. Efforts have been initiated by VENTURE collaboration to search for the appropriate reactions to access low energy ranges below 244 keV and high energy ranges above 1.4 MeV [27]. In this context, procurement of dedicated radioactive sources like ^{152}Eu and ^{182}Ta is of extreme importance and are being hereby proposed.

(vi) Proposal for a gamma-gamma fast timing campaign at VECC, Kolkata

The possibility of an in-beam gamma-gamma fast timing campaign at VECC, Kolkata was explored, following the discussions in panel of NLTM2022, with the existing facilities and infrastructures in different institutions around VECC and at other institutes who have expressed interest to join the campaign as well as the VENTURE collaboration. As per the available information from the discussion during NLTM2022 and from other resources in public domain, the detectors, electronics and other resources were explored. Also, the expression of interest was collected through NLTM website which shows that a reasonable number of proposals are expected for the campaign.

In view of the above resources and interest to perform gamma-gamma fast timing with VENTURE, it has been visualized that the campaign on gamma-gamma fast timing measurements with VENTURE can be planned considering the collection of resources from different institutes as per the convenience. The campaign can be initiated and continued as per the requirement, subjected to the administrative approval from the competent authorities at VECC, Kolkata and the beam time availability.

It is important that the campaign concentrates majorly on the recent techniques on gamma-gamma fast timing through GCD measurement and the pulse processing is first carried out with full analog electronics and then the standard data is compared with that obtained from using digital electronics.

3. Role of large volume $LaBr_3$ detectors and future possibilities in nuclear structure studies:

It was also emphasized that gamma array setups like INGA must consider the use of large volume $LaBr_3$ detectors for the detection of high energy gamma rays. Such measurements can be used in GDR tagged gamma ray spectroscopy and may help to study continuum excitations above particle emission thresholds. The latest gamma array campaign at VECC, Kolkata in collaboration with SINP, Kolkata and UGC-DAE-CSR, Kolkata, was held by augmenting the support structure fabricated by SINP, Kolkata in order to increase the capability of placing maximum twelve Clover HPGe detectors and four large volume $LaBr_3$ detectors. Such capabilities may also be extended in future developments of different gamma array structures in the country, considering the possibilities in case by case basis [28].

4. Nuclear Transition moments and Future Perspectives:

Measurement of nuclear transition moments was one of the key areas of discussion in the meeting after the nuclear level lifetime measurements. Renowned speakers talked on the benefits of nuclear transition moments and how such measurements improve the understanding on nuclear excitations and microscopic structure of the nuclear levels. One of the areas of focus was in A ~130 mass region and around the neutron rich Sn nuclei. Other regions were also discussed.

The transition moment measurements through various experimental techniques were discussed in the meeting that include Time Differential Perturbed Angular Distribution/Correlation (TDPAD/TDPAC) measurements, Recoils in vacuum (RIV) measurements and Transient Field measurements. One of the important aspects was the measurement of transition moments through TDPAC in free molecules which is a new path for the accurate quadrupole moment measurements. It was also understood that a high field magnet is an important component to make the TDPAD facility compatible for g-factor measurements. The pulsed beam facility with a varied beam-off period is also necessary to widen the possibility of transition moment measurements in nuclear levels with wide range of half-lives.

TDPAC/TDPAD measurements are already being carried out by different groups in VECC [29], Kolkata, IUAC, New Delhi [30] and TIFR, Mumbai [31]. Considering the users’ interest and expertise available in the country, it may be beneficial to have collaborative experiments and improve transition moment measurements using TDPAC/TDPAD in different region of the nuclear chart. The research and development in this field must be continued to address exciting phenomena with the nuclear deformation and single particle excitations in nuclei of interest.

5. Nuclear Beta Decay experiments: Future Perspectives:

Probing on nuclear beta decay allow us to explore very unique levels in nuclear many body system which are otherwise not populated through nuclear reactions. So, the spectroscopy of beta delayed gamma rays provides the scope to study the non yrast nuclear levels that are difficult to be accessed through nuclear reaction. Presentations were made on beta decay of neutron rich isotopes in A ~ 100 region that was utilized in the exploration of triaxial shapes in nuclei and the beta delayed neutron spectroscopy to explore nuclear structure in nuclei around ^{132}Sn.

The application of the beta decay end point energy measurement was also discussed in the meeting. It was shown that the beta decay end point energy measurements with LEPS detectors [32] can help in identifying and measuring the excitation energies of the long lived isomers in nuclei [33] with a wide range of beta decay Q values. It was understood that an efficient setup of thin window segmented LEPS and Clover HPGe detector will be required. Such a facility named VEBGYOR (**VE**CC array for **B**eta-**G**amma spectroscop**Y** of **R**adio-nuclei) has been planned at VECC, Kolkata.

6. Ancillary detector arrays in gamma-ray spectroscopy:

Ancillary detectors play an important role to perform unique measurements that are not possible with only conventional high resolution gamma arrays involving Clover HPGe detectors. One of the ancillary devices that play an important role is the charged particle multiplicity filter that helps tagging on the evaporated light charged particles in a fusion evaporation reaction. This in turn makes it possible to study the structures of residues that are produced through light charged particle evaporation and with very low cross section. One of the presentations in the theme meeting also elaborately discussed the use of CsI(Tl) detectors arrays and photodiodes in tagging of charged particles and heavy ions in gamma rays spectroscopy experiments for lifetime measurements with Doppler techniques. So, it was understood that a facility for light charged particle tagged gamma ray spectroscopy would be of extreme importance to add to the high resolution Clover detector arrays.

Development of a CsI(Tl) multiplicity filter array was taken up earlier at VECC, Kolkata [34] and it is observed that TIFR, Mumbai in collaboration with IUAC, New Delhi is presently developing a CsI(Tl) charged particle based multiplicity filter array [35]. At VECC, the Granular charged particle Multiplicity filter Detector Array (GMDA) is under development that will use an ASIC based CSA for having the low noise and low output power solution. The first prototype

ASIC based CSA has been tested for its performance [36]. Further development with the CSA is required to complete the facility development.

7. Indian National Gamma Array campaigns with ancillary detectors:

The Indian National Gamma Array has been setup and utilized till date, majorly with Clover HPGe detectors, except few occasions in recent times. Need for the use of particle tagging in gamma ray spectroscopy was greatly emphasized for the future campaigns of the setup. It is observed that different ancillary detectors are being explored at different institutes in the country for lifetime measurements using gamma-gamma fast timing methods and Recoil Distance Method. INGA campaigns with existing ancillary detectors are also proposed in the meeting.

8. Role of Nuclear Theory in nuclear structure studies:

(a) Lifetimes and Transition moments: Present scenario and Future Perspective

A reliable nuclear theory to study the nuclear structural properties is essential not only to extract the correct physics but also to predict the unknown spectroscopic numbers for future measurements. Such measurements are not very straight-forward and known to be an arduous task relying upon huge manpower and funds. The role of nuclear theory then becomes more crucial in view of predictions. Enormous efforts and advances have been made in recent years to establish the shell model in its most general form as the standard model of nuclear physics. However, the practical calculations for shell model in medium and heavy mass nuclei can only be carried out in highly truncated model spaces till date. Thus, it is more profitable to start from interpretations in terms of phenomenological models and subsequently, identifying appropriate truncated shell model spaces to gain a fully microscopic many-nucleon understanding of what is being observed in experiment. This vision led to the recent developments of the seniority and generalized seniority models as a tool for understanding the nuclear spectroscopic properties of nuclei, including medium and heavy-mass regions of the nuclear chart [37]. These phenomenological models use the quasi-spin schemes involving Lie algebra representation theory to map the nuclear states of these models into microscopic shell model interpretation and to seek an explanation of why their symmetries are preserved by realistic and fundamental nucleon interactions. Success of these models in explaining the decay probabilities of nuclear isomers [38] led to a new kind of seniority isomers decaying by electric-odd tensor transitions [39]. The decay rates of various isomers and other low-lying excitations in Sn and Pb isotopes, and N=82 isotones etc. has been explained reasonably well on the basis of generalized seniority [40-45]. This further motivated the development of Generalized Seniority Schmidt Model (GSSM) for calculating g-factors by using the generalized seniority suggested multi-j configurations [46]. It has been found that these generalized seniority symmetries persist and decipher both the decay probabilities (lifetimes) and moments (Q-moments and g-factors) for many nuclear excited states in Cd and Te isotopes (similar to the case of Sn isotopes) [47,48] and also in Hg and Po isotopes (similar to the case of Pb isotopes) [49]. This is due to the pairing symmetries of nuclear many-body Hamiltonian. Similar results are recently found for N=124, 126 and 128 isotones which are used to resolve the puzzle of finding a consistent configuration to explain both decay probabilities and moments of $9/2^-$, 8^+ and $21/2^-$ isomers [50]. Generalized seniority suggested configuration mixings and wave functions are also found to be in line with shell model results, wherever possible due to huge-dimensional Hamiltonian. Various predictions have also been made in these works for the gaps in measurements. As an example, no data for the Q-moments of $9/2^-$, 8^+ and $21/2^-$ isomers in N=128 chain are available. Also, the known Q-moments of 8^+ and $21/2^-$ isomers in N=124, 126 chains are not measured but estimated from the corresponding B(E2)s. Such issues require further investigation in view of current and modern experimental facilities. Possible future measurements on these predictions can also be used to test the theoretical models and constrain the necessary extrapolations into unknown territory.

(b) Nuclear beta decay: Present scenario and Future Perspective:

The study of β decay is a very important tool to determine the structure of atomic nuclei. Since beta-decay study is very sensitive to wave functions. Thus we should first correctly reproduce the electromagnetic properties of parent and daughter nuclei. In β decay, transitions are classified into two categories: allowed and forbidden, based on the value of orbital angular momentum (l) of the emitted leptons. Transitions with $l = 0$ correspond to allowed and those with $l > 0$ to forbidden transitions. With a nuclear shell model it is possible to calculate logft values, shape factors, electron spectra, and decomposition of the integrated shape factor are reported and compared with the available experimental data.

The nuclear β decay can be considered as a mutual interaction between the hadronic and leptonic current mediated by a massive W± vector bosons. These currents can be expressed as mixtures of the vector and axial-vector contributions. The values of the weak coupling constants enter the theory of β-decay when the hadronic current is renormalized at the nucleon level. The free-nucleon value of the vector coupling $g_V = 1.00$ and axial-vector coupling $g_A = 1.27$ derive from the conserved vector-current (CVC) hypothesis and the partially conserved axial-vector-current (PCAC) hypothesis, respectively. The value of g_A is affected inside nuclear matter by nuclear many-body, delta-nucleon and mesonic correlations. The effect of these corrections on the bare value of g_A can be represented as an effective value $geff_A = qg_A$, where q is a quenching factor. The effective value of g_A plays an important role when data on astrophysical processes, single beta decays and double beta decays are to be reproduced by nuclear many-body calculations. In the single β decays, the decay rate depends on the second power of g_A, while to the fourth power for ββ decays. Different methods have been used to extract information on the effective value of g_A. One possibility is the half-life method where the computed and experimental (partial) β-decay half-lives are matched by varying the value of g_A. This method has been used for the allowed, forbidden, and two-neutrino double β decays in the framework of the proton-neutron quasiparticle random-phase approximation (pnQRPA), the nuclear shell model (NSM), and the interacting boson model (IBM).

Studies of allowed and forbidden β decay using the nuclear shell model with phenomenological interactions are very successful to reproduce the experimental data. With the recent progress in the ab initio approaches for nuclear structure study, it is highly desirable to see how precisely these interactions are able to predict nuclear observables such as forbidden β decay.

9. The take home message from NLTM2022:

The take home message was very clearly delivered in the summary session of the meeting. It was indicated that the interest in nuclear structure studies has shifted to a different direction and one needs powerful state-of the art arrays for measurements like nuclear level, lifetimes, transition moments and beta decays through channel selection. National facilities must concentrate on identifying interesting physics problems that can be addressed with stable beams & targets and develop experimental facilities for available beams. The inverse kinematics with heavy ion beams at VECC and the beams from superconducting cyclotrons may open up new window for nuclear structure experiments.

One of the major observations that were delivered in the summary was that till date all the developments in the new directions were only personal initiatives at different institutes. So, it is required to come up collectively for such developments and bring new collaborations not only within the country but through the continents. It was suggested to put proposals in different facilities, viz., ISOLDE where India is an associate member state.

In this context, it may be appropriate to compile a list of facilities those exist in different laboratories in the country and may be useful to the whole community for performing experiments with the two Pelletrons, one Cyclotron and upcoming FRENA facility. This compilation is expected to benefit especially the young students who are entering in the field during their PhD program and working towards planning a quality experiment.

10. List of Major facilities in the country (Existing & Planned)

Name of the Facility	Brief Description of the facility	Present Status	Available at	Relevant References
Indian National Gamma Array	-An array of high resolution Clover HPGe detectors (24 in numbers as per its approved plan) -The array can be setup is three accelerator centers of the country. INGA at TIFR, Mumbai and VECC, Kolkata are coupled to digital DAQ facility. The one at IUAC, New Delhi is based on VME data acquisition system. -At TIFR, INGA array has been augmented to add different ancillary detector setups as per requirement	Working; Setup for different campaigns	VECC, Kolkata; TIFR, Mumbai; IUAC, New Delhi	Proceedings of Fourth International Conference on Fission and Properties of Neutron-Rich Nuclei, World Scientific, 2007, p. 258; Pramana 57 (1) (2001) 21; Nuclear Instruments and Methods in Physics Research Section A 622 (2010) 281; Nuclear Instruments and Methods in Physics Research A 680 (2012) 90. DAE symp. On Nucl Phys. **61** (2018) 1156. Nucl. Instr. Meth. Phys. Res. A 680, 90(2012). Phys. Rev. C 104, L011301(2021)
VECC array for Nuclear fast Timing and angUlar corRElation Studies (VENTURE)	- The gamma-gamma fast timing array consisting of $CeBr_3$ detectors. - Can be used for in-beam and off-bean measurements in standalone mode or in coupled mode with high resolution Clover detectors of VENUS array.	First phase Working Second phase under development	VECC, Kolkata	Nucl. Instr. & Meth. **A 874** (2017) 103; Phys. Rev. **C 99** (2019) 014306. Phys. Rev. **C 104** (2021) 24320

	- Lifetime measurement using slope method and GCD method down to few picoseconds can be performed. -TDPAC measurements can be planned with additional setups			
VECC array for **NU**clear Spectroscopy **(VENUS)**	-High resolution Clover detectors array -Can be used for gamma-gamma coincidence measurement for level structure studies. -Can be used in both off-beam and in-beam experiments	Working	VECC, Kolkata	DAE Symp. Nucl. Phys. **61** (2016) 98. Nuclear Physics **A** **976** (2018) 1. Phys. Rev. **C** **98** (2018) 044311
Dhruva **U**tilization in **R**esearch using **G**amma **Ar**ray (DURGA)	-Array of six Compton-suppressed clover Germanium detectors and eleven LaBr3(Ce) fast scintillators coupled to a multi-frequency digitizers based data acquisition system. Fission spectroscopy of neutron-rich fragment nuclei will be carried out in this facility employing collimated thermal neutron beam and fissile targets. Planned to be used heavily in studying low-spin vibrational structure of atomic nuclei following Capture Gamma prompt and decay Spectroscopy (CGS). Additionally, the facility can also be utilized for Prompt Gamma Neutron Activation (PGNA) measurements.	Working	DHRUVA reactor facility, BARC, Mumbai	Proc. DAE-BRNS Symp. Nucl. Phys., Vol. **65**, 34 (2021). Proc. DAE-BRNS Symp. Nucl. Phys., Vol. **63**, 328 (2018). Proc. DAE-BRNS Symp. Nucl. Phys., Vol. **63**, 1188 (2018). Proc. DAE-BRNS Symp. Nucl. Phys., Vol. **61**, 1032 (2016).
CHAKRA (**Ch**arged particle detector **A**rray for **K**inematic **R**econstruction and **A**nalysis)	A large 4π array of charged particle detector array. High resolution charged particle reaction and spectroscopy studies can be performed with	Working	VECC, Kolkata	Nuclear Instruments and Methods in Physics Research A 943 (2019)

	heavy ion reactions at energy ~ 10–60 MeV/A. The forward part ($\theta \sim \pm 7^\circ$ - $\pm 45^\circ$) of the array consists of 24 highly granular, high resolution charged particle telescopes, each of which is made by three layers [single sided silicon strip (ΔE) + double sided silicon strip (E/ΔE) + CsI(Tl)(E)] of detectors. The backward part of the array consists of 112 CsI(Tl) detectors, which are capable of detecting primarily the light charged particles ($Z \leq 2$) emitted in the angular range of $\theta \sim \pm 45^\circ$ - $\pm 175^\circ$. The extreme forward part of the array ($\theta \sim \pm 3^\circ$ - $\pm 7^\circ$) is made up of 32 slow-fast plastic phoswich detectors that are capable of detecting light ($Z \leq 2$) and heavy charged particles ($3 \leq Z \lesssim 20$) as well as handling high count rates.			162411
TOF Neutron Detector Array	Based on cylindrical liquid scintillator-based neutron detectors (of 5-in. length and 5-in. diameter) Can be placed at different laboratory angles. The neutron energy is measured from TOF method taking the start trigger from gamma multiplicity filter array made of BaF2 detectors	Working	VECC, Kolkata	Nuclear Instruments and Methods in Physics Research A 608 (2009) 440-446 Phys. Rev. C 102, 061601(R) K. Banerjee, Study of nuclear dynamics using neutrons, Ph.D. thesis, HBNI, India, 2012.
4pi Neutron multiplicity	Measures neutron multiplicity, important for		VECC, Kolkata	K. Banerjee, Study of nuclear

Detector	determining the reaction mechanism, particularly in the Fermi energy domain. Consists of two stainless steel hemispheres of one metre diameter, filled with 500 litres of 0.5% Gd loaded liquid scintillator BC521. The hemispheres have been fabricated from a 8 mm thick stainless steel sheet machined to get a uniform thickness of 5 mm. The hemishpheres are mounted on a mild steel movable trolley with adjustable jack. For scintillator light output readout, each hemisphere is fitted with five photo multiplier tubes (PMT) (model: 9823B; Electron tube Ltd) each of 5" diameter, and, 10 mm thick pyrex glass windows are used at the interface of the scintillator and the PMT.			dynamics using neutrons, Ph.D. thesis, HBNI, India, 2012.
LAMBDA (**L**arge **A**rea **M**odular **B**aF_2 **D**etector **A**rray)	The detector array is composed of 162 square faced BaF_2 Crystals (3.5cm^2 x 35cm). Can be arranged in two 9 x 9, three 7 x 7 or six 5 x 5 matrix formations and can be placed at different angles with respect to the beam axis. For the measurement of high energy γ rays, GDR angular distribution studies and coincidence measurements.	Working	VECC, Kolkata	Nuclear Instruments and Methods in Physics Research A 582 (2007) 603–610
Gamma Multiplicity Filter array	50-element gamma multiplicity filter made of BaF_2 (3.5cm x 3.5cm x 5 cm), developed at the Variable Energy Cyclotron Centre,	Working	VECC, Kolkata	Nuclear Instruments and Methods in Physics Research A 624 (2010)

	Kolkata. Used for selection of angular momenta from hot nuclei.			148–152
90 cm general purpose scattering chamber	Installed at beam line 2 of K130 cyclotron	Working	VECC, Kolkata	
Penning Ion Trap	Penning Trap is a tool which confines subatomic particles under combined application of uniform magnetic field and weak quadrupolar static electric potential. Under the application of external fields, the confined ions oscillate with characteristic frequencies which can be measured very accurately with sensitive electronics. Since the characteristics frequencies depend on the mass of the confined ions, this device offers highest precision in mass measurement. Recent publications reveal that Penning trap currently offers relative mass uncertainties down to 10^{-9} for radionuclides and better than 10^{-12} for stable species. Penning trap operated at liquid helium temperature (4 K) offers sensitive detection where the thermal noise of the detection electronics is greatly reduced. Moreover, the reduced background collision enhances the trapping time which further help to achieve high precision in mass measurement of the stored ions.	Commissioned	VECC, Kolkata	Indian Journal of Cryogenics, **41 (1)**, 146-150, 2016 Review of Scientific Instruments, **88** (3), 034705, 2017 Rev. Sci. Instr. 91, 074707 (2020) Nucl. Inst. Meth. A 978, 164465 (2020). Review of Scientific Instruments 93, 014706 (2022).
SHARC (Large High Vacuum Reaction Chamber	A large, segmented, horizontal axis, reaction chamber and integrated with	Working	VECC, Kolkata	Journal of Physics: **390** (2012) 012075

for Nuclear Physics Research)	the beam line in the VECC superconducting cyclotron (SCC) experimental area. It is a cylindrical, three segment, stainless steel chamber of length 2.2 m, diameter 1 m. Two pairs of parallel rails have been provided internally for placement of the target assembly and detector systems within the chamber. The whole target assembly can be placed anywhere on the rail to facilitate optimum flight path.			
Plunger Setup	- Facilities for the measurement of nuclear lifetime measurement through RDM technique - Required to be coupled with an high resolution gamma array	Working	IUAC, New Delhi	Phys. Rev. C 100, 024325(2019).
HYbrid Recoil Mass Analyzer (HYRA)	HYbrid Recoil mass Analyzer (HYRA) is a dual mode, dual stage spectrometer / separator with its first stage capable of operating in gas-filled mode in normal kinematics (to access heavy nuclei surviving fission, around mass 200 amu and beyond) and both stages in vacuum mode in inverse kinematics (to access nuclei around N ~ Z up to 100 amu mass and to provide light, secondary beams produced in direct reactions).	Working	IUAC, New Delhi	Pramana- Journal of Physics, Vol. 75, No. 2 (2010) pp.. 317–331
4pi-Sum Spin Spectrometer	A 4pi-Sum Spin Spectrometer comprising 32 conical NaI(Tl) detectors has been designed and commissioned at TIFR, Mumbai. There are 20 pentagonal and 12 hexagonal	Working	TIFR, Mumbai	NIM-A 611 76 (2009), Acta Physica Polonica B 42 (2011) 643-652, Phys Rev. C 88 024312

	detectors. The full array covers almost hundred percent of the total solid angle. When used for in-beam measurements three crystals are removed for beam inlet, outlet and for the target ladder, leading to total solid angle coverage of nearly 86 percent. the array is built in soccer ball geometry and can be used as a stand alone spin-spectrometer or can be coupled with other detection systems. A spin spectrometer is of crucial importance to understand the dependence of angular momentum in nuclear structure and reaction studies. The response of the spin spectrometer to multiple gamma -rays have been thoroughly studied using detailed Monte Carlo simulations and gamma-ray sources. Since commissioning the spectrometer is heavily used for angular momentum gating for Giant Dipole Resonance (GDR) decay studies, measurement of spin distributions in heavy ion induced reactions etc. This spectrometer has been coupled to the Gas Filled Recoil Mass Analyser (HYRA) in IUAC- Delhi and a large number of experiments have been carried out with this system. To the best of our knowledge, this combined detection facility is possibly only of its kind in the world.			(2013), Phys Rev C 88 034606 (2013), Nucl. Phys. A 890 62 (2012), Jour. Phys. G 41 (2014), EPJ Web of Sc.(2011,2013), Phys. Rev. C 95 (2017) 024604, EPJ Web of Conf 86 (2015), EPJ Web of Conf. 63 (2013), Phys. Rev. C 96 (2017) 034613, Phys. Rev. C 99 (2019), Phys. Rev. C 101 (2020) 014616,

	The system provides very high quality spin distribution data when the low energy gamma rays are detected in coincidence with the Evaporation Residues (ERs) at the focal plane of the HYRA spectrometer.			
National Array of Neutron Detectors (NAND)	The large array of neutron detectors, named National Array of Neutron Detectors (NAND) is a DST-supported nuclear physics experimental facility set up at IUAC. The detector array consists of 100 liquid scintillators, each cell having 5"x5" cylindrical size and type BC501A (Saint Gobain) coupled to a 5" photomultiplier tube (Hamamatsu R4144). They are all mounted at a fixed flight distance of 175 cm from the target position. The detectors are mounted on a semi-spherical dome (geodesic) structure optimized for the present geometry.	Working	IUAC, New Delhi	Nucl. Instrum. Methods Physics Res. A: 763, (2014), 58-64
Gamma Detector Array (GDA)	The facility has twelve HPGe detectors placed coaxially in the 'anti-Compton shields' at 45^o, 99^o and 153^o with respect to the beam direction in two horizontal rings at ± 25^o to the horizontal plane. 14 BGO detectors, seven above and seven below the scattering chamber in the 'honey comb structure' arrangement, cover about 35% of total solid angle at the target. These are used as total energy and/or multiplicity filter.	Working	IUAC, New Delhi	

Heavy Ion Reaction Analyzer (HIRA)	HIRA is dedicated to the study of heavy ion induced nuclear reaction dynamics and can operate in the direction of primary beam. Efficient rejection of primary beam and transportation of reaction products to the focal plane with mass identification are the forte of HIRA. It is based on symmetric [electrostatic dipole]-[magnetic dipole]-[electrostatic dipole] (ED-MD-ED) configuration (first used in Rochester RMS design), with two quadrupole doublets placed before and after the first and last electrostatic dipoles. Space focus (in both dispersive and non-dispersive planes) and energy achromaticity are obtained at the focal plane with variable mass dispersion. The ion-optical parameters of ED-MD-ED combination of HIRA are unique and quite different from other existing recoil mass spectrometers.	Working	IUAC, New Delhi	Nucl. Instr. and Meth. A 339 (1994) 543
General Purpose Scattering Chamber (GPSC)	General Purpose Scattering Chamber is the 1.5 m diameter scattering chamber facility installed in Beam Hall I of IUAC. The chamber is equipped with two rotating arms and in-vacuum target transfer system. The stainless-steel chamber is of 1.5 m diameter, 0.6 m height and 1100 liter volume.	Working	IUAC, New Delhi	
CsI(Tl) charged particle array	Used in Gamma tagged particle spectroscopic measurement	Working	TIFR, Mumbai	Phys. Lett. B 806 (2020)135487

7 T Super-conducting magnet for g-factor measurement	g-factor measurements through TDPAD technique can be performed	Working	TIFR, Mumbai	Phys. Rev. C 101, 034315 (2020)
VEBGYOR (**VE**CC array for **B**eta-Gamma spectroscop**Y** of **R**adio-nuclei)	Array of thin window LEPS and Clover HPGe detectors for beta – gamma coincidence measurements	Methodology studied Facility under development	VECC, Kolkata	Nucl. Instr. & Meth. A, 767, 19 (2014). Eur Phys. Jour. 56, 189 (2020).
GMDA (**G**ranular charged particle **M**ultiplicity filter **D**etector **A**rray)	An array of CsI(Tl) detectors for channel tagging in gamma ray spectroscopy	Under Development	VECC, Kolkata	DAE symp. On Nucl. Phys. 65 (2021) 778

11. Formation of a National Scientific Committee:

Following several discrete suggestions during NLTM2002, it has been felt necessary that a national scientific committee is formed who can advise, suggest and work on successful implementation of the important facility developments in the country to add up new dimensions in experimental nuclear structure research, in addition to the conventional gamma spectroscopic measurements that was the focus of Indian National Gamma Array (INGA) since its beginning. The committee can meet on regular basis and review the progress happening around the globe and suggest for the initiation of new developments and related projects.

The committee formation may consider the individuals who are already working in the field of nuclear structure addressing new developments and opening up new dimensions of research along with senior faculty members to share their experience and provide advice for the benefit of the developments.

The committee may also include both experimentalist and theoreticians and it must have a wide spectrum with members who are experts in instrumentation and data acquisition.

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