Charge particle detector development for the investigation of fusion & fusion-fission dynamics

*Akhil Jhingan[1], P. Sugathan[1]

[1]Inter University Accelerator Centre, P. O. Box 10502, New Delhi - 110067, INDIA

* email: akhil@iuac.res.in

Abstract : Inter University Accelerator Centre (IUAC), New Delhi provides facilities for accelerator based Nuclear Physics experiments, with 15MV tandem accelerator, which require particle detectors such as proportional counters, ionization chambers, Silicon detectors, etc. for investigating fusion & fusion-fission dynamics. In the scope of the upcoming experimental facilities such as NAND & HYRA with new superconducting LINAC at IUAC, new detector systems for particle identification are being planned and developed based on these detectors with the idea of improving the efficiency, timing, position and energy resolutions. The detector systems that are being used as well as being developed are position sensitive multi wire proportional counters for the detection of heavy ions such as fission fragments, evaporation residues, and transfer products (projectile like & target like). Detector telescopes have also been developed for energy measurement and nuclear charge identification of particles in transfer and fission experiments. The detectors are being routinely used in reaction experiments involving facilities of mass spectrometers & scattering chamber at IUAC. Detector system based on Silicon strip detectors are being developed for carrying out recoil alpha decay experiments with mass spectrometer, kinetic energy and time of flight measurements in fission & transfer experiments. A charge particle array based on CsI detectors is also being developed for the detection of light charge particles such as protons & alphas. This overall detector development carried out in the past and new development and testing of prototype detectors at the detector development laboratory of IUAC is presented here.

Introduction

The Nuclear Physics program at IUAC (formerly Nuclear Science Centre or NSC) [1,2], and many other labs in the world is focused at reactions around Coulomb barrier. To probe these reactions more deeply, nuclear physicist today demand charged particle detectors with higher detection efficiency, large solid angle coverage, good energy, position and timing resolutions with high count rates. At the same time detectors are required to detect different particles right from protons to heavy evaporation residues, heavy fission fragments etc. These particles have different energies ranging from few hundreds of keV/A to about 10 MeV/A depending upon the nature of reaction. Generally combination of various detectors with different operating parameters is required. The commonly used detectors for charged particle detection are Silicon detectors, gas detectors such as ionization chambers & proportional counters, hybrid telescopes (combination of gas & Silicon detector), and scintillation detectors such as Cesium Iodide coupled to photo-diode. Each of these detectors has its own unique characteristics.

The four reaction facilities at IUAC, namely GPSC & HIRA in beam hall I, and HYRA & NAND in beam hall II, are engaged in investigation of fusion & fusion-fission dynamics. The experiments being carried out are the measurement of fusion evaporation residue cross section measurements, fission mass & angular distributions, fission neutron multiplicity, transfer reactions and so on. It is also planned to carry out decay spectroscopy experiments utilizing HYRA-INGA combination or HYRA stand alone. These experiments are routinely performed using fast timing position sensitive proportional counters, ionization chambers & hybrid telescopes for particle identification, large area position sensitive silicon detectors etc. All these detectors are mostly used for the detection of heavy ions. Currently we are also working on the development of Cesium Iodide based charge particle array for the detection of light charged particles such as protons and Alphas. We describe some important developments in the area of detectors at IUAC in this article.

Multi Wire Proportional Counters

Position sensitive gaseous detectors based on Multi Wire Proportional Counters has been perhaps the most important detector used in reaction experiments at IUAC. This detector has been routinely used for the detection of evaporation residues & transfer products (target like) at the focal planes of the recoil spectrometers HIRA[3] & HYRA[4]. They are also being used for carrying out mass distribution experiments of fission fragments and their neutron multiplicity (in coincidence with neutron detectors) using GPSC[5] and upcoming NAND[6] facility. Recently we have also used them for carrying out transfer reactions above Coulomb barrier in GPSC. Currently there are ten MWPC operational in IUAC. The main advantage of these detectors is that they can be custom designed with areas and geometrical shape depending upon the experimental requirements.

Most of the MWPC at IUAC use the multi-step geometry using four or five electrode configuration. All of them use Iso-Butane gas. All the electrodes are made using wire frames having gold plated tungsten wires stretched on a custom designed commercial printed circuit boards. Advantage of multi-step design is that it has higher gains. The earlier MWPC[7] at IUAC at HIRA focal plane had a three electrode geometry with anode sandwiched between two position electrodes. Wire pitch is 1 mm with inter-electrode separation 3.2 mm. Wire diameter is 20μm. This design performed well with heavy ions such as ER, heavier projectiles (Silicon & above), target like particles etc. but gave very inferior signals for lighter particles such as Alphas, Lithium, Beryllium etc. With the development of Be^7 beam using the in-flight separation RIB facility of HIRA, it was required to develop MWPC with higher gains in order to detect lighter particles such as alphas, Lithium, Beryllium, etc. A new MWPC[8] with a five electrode configuration (fig.1) and active area 57mm x 57mm was developed.

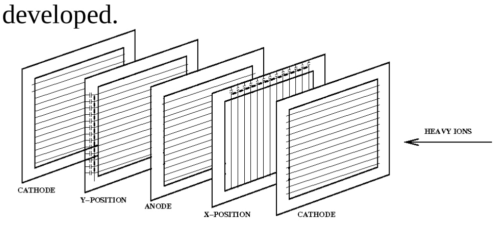

Fig.1: Schematic of MWPC

Fig.1 shows the schematic of the MWPC. The detector has two cathodes (one each at entrance & exit), one anode sandwiched between two position electrodes (x & y). The wires in x & y are oriented orthogonally to each other. The region between cathode and position electrodes are made to operate in drift region whereas that between positions & anode in avalanche region. Last electrode can be removed to provide a four electrode configuration. Positions are extracted using delay line technique. This design provided much higher gains as compared to the previous MWPC with three electrodes. The signal amplitude in anode was about 3 times at pressures half of that as compared to previous design. This detector was successfully used in RIB experiments using Be^7 beam. The detector was also used for ER detection in INGA-HIRA campaign and initial stages of HYRA gas filled separator focal plane.

An experimental program for investigating mass distribution[9,10] of fission fragments and mass gated/total neutron multiplicity [11] was initiated at IUAC. The experiments were/are carried out in GPSC facility. A new pair of MWPC[12] were developed for the same. The detectors were placed at coincident angle or folding angle on the rotating arms of GPSC to detect both the fission fragments in coincidence. Each detector has an active area of 20cm x 10 cm having the identical 5 electrode geometry as shown in fig.1. The wire pitch is 1.27 mm for all electrodes. The electrodes were housed in rectangular box milled from a solid Aluminum sheet (fig.2).

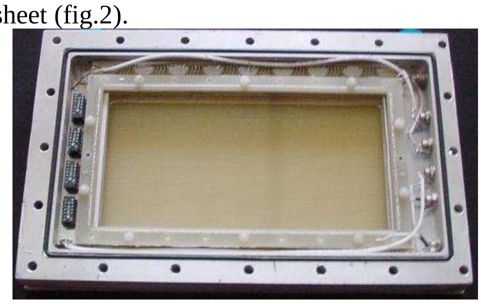

Fig.2 : Assembled MWPC

The detector was operated at 2 mbar Isobutane for fission fragments and 4 mbar for alphas from ^{241}Am source. The detector volume is isolated from the vacuum chamber by 1μm Mylar foil. Operating voltages at 2 mbar were +400V for anode and -180V for cathode. Position signals are extracted using Rhombus delay line chips TZB-125. Rise times of about 10ns are observed from central anode with pulse amplitudes as high as 1V for the fission fragments. An estimated time resolution of about 1 ns (fwhm) was observed for fission fragments. Position resolution of about 1 mm (fwhm) is observed. All timing signals are extracted using OrtecVT120A (for anode) and VT120B for positions. Cathode is read by a conventional charge sensitive preamplifier. Combination of cathode energy and timing (time of flight) from anode separates fission fragments from projectile & target like particles. Time of flight is generated w.r.t. RF signal from the beam pulsing system of IUAC tandem accelerator.

Some beams cannot be bunched thus are not available as pulsed beam. In such cases TOF information can be generated by time difference method or by placing a start detector close to target. The former gives inferior timing resolutions. Later one can give absolute timing with proper calibration. One such fast timing detector[13] with an active area of about 4cm x 4cm was developed. To avoid straggling, we used wire frames (4 electrode) instead of Aluminized Mylar foils. To improve upon the timing, wire pitch was reduced to 0.63 mm (from 1.27 mm) and inter-electrode separation to 1.6 mm. Rise times of about 3.5 ns were observed from the anode. Intrinsic time resolution is estimated to be about 250ps for fission fragments. The detector system has been used in GPSC for fission experiment, and also off-line data was recorded in coincidence with BC501 liquid scintillator using ^{252}Cf source. Fig.3 shows the TOF setup in GPSC with start-stop detector system on one arm and second large area MWPC on other arm at folding angle. We plan to have independent start-stop detector combination for both arms in coming days.

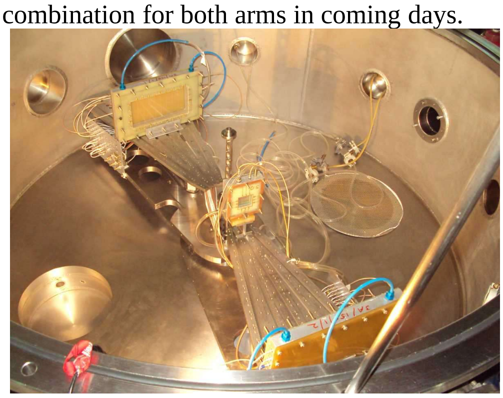

Fig.3 : TOF setup in GPSC

For mass identification at focal plane of spectrometer with higher detection efficiency/solid angle, the small MWPC[8] was replaced by a larger area MWPC[14] with active area 150 mm x 50 mm. The detector has five electrode configuration. The detector has been used for the detection of ER & target like transfer products [15,16]. Fig. 4 shows the position against TOF spectrum for ^{28}Si + ^{90,94}Zr transfer reaction (below barrier) with resolved mass peaks.

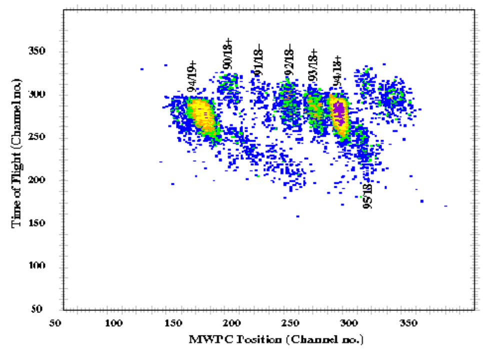

Fig.4 : TOF against X at HIRA focal plane

To carry out transfer reactions above barrier at grazing angles along with their angular distributions a new detector setup[17] was designed and fabricated. The system was designed to identify both M,Z of the reaction products. For mass identification two new MWPC, with active area 50 mm x 50 mm were fabricated with four electrode configuration.

To achieve a good timing resolution, all electrodes were fabricated with reduced wire pitch of 0.63 mm as against 1.27mm with 1.6 mm inter-electrode separation. Anode is made using 10µm diameter wire. Thinner wires provide higher gains and faster decay times thus providing better timing resolution required for mass identification. A position resolution of ~ 0.45 mm was observed along with a timing resolution of about 500 ps.

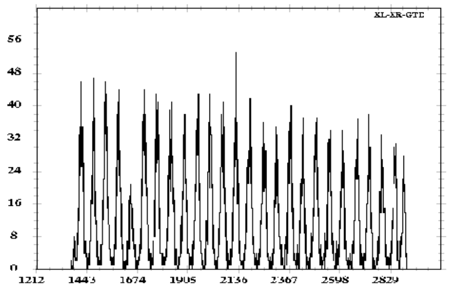

Fig.5 : Masked position spectrum

Fig.5 shows the masked position spectrum observed with ^{241}Am alphas. Fig.6 shows the setup in GSPC used for the ^{28}Si + ^{90,94}Zr system.

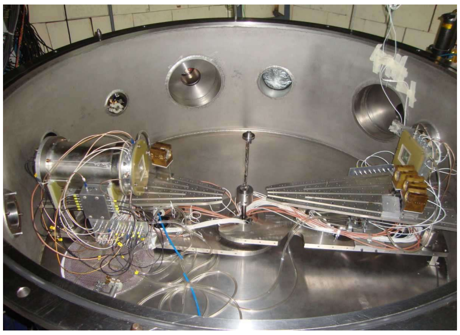

Fig.6 : Setup for transfer reaction in GPSC

The availability of beams from the superconducting LINAC with narrow bunch width ~ 200ps demanded detectors with timing resolutions of that order so as to exploit the timing for mass measurements using TOF method. Two new MWPC[18] were developed for the NAND facility in beam hall II. To achieve a better timing resolution (~ 200ps), we adopted the conventional three electrode geometry having a central cathode, made from mylar foil Aluminized on both sides, sandwiched between two position electrodes. To achieve better timing, the x-position wire frame was made from 10μm gold plated tungsten wire at 0.63 mm pitch. This provided faster rise times (~ 3ns) with higher gains at lower pressures. The detectors had active area of 125 mm x 75 mm. The Y position frame was made from PCB having tracks etched on it. A time resolution of 400 ps was observed for the elastics w.r.t. RF pulse from beam. For fission fragments we expect a timing resolution close to 100ps owing to higher amplitude signals and better signal to noise ratio. The detector has been used with 24 BC501 scintillators of NAND for measuring fission gated total neutron multiplicity[19].

HYRA gas filled separator is routinely being used for ER cross section measurements. The ER produced in very asymmetric reactions have energies below 10 MeV in mass A≥200 region. This requires MWPC to be operated at lower pressures (~ 1 Torr) as the MWPC is followed by Silicon strip detector for ER implantation and their subsequent decay. To have higher gains at lower pressures, a new MWPC with active area of 150 mm x 50 mm was developed[20]. The detector has a four electrode (all wire frames) configuration. Central anode & cathode have a wire pitch of 0.63 mm with anode having 10μm diameter wire and cathode 20μm wire. Position (x & y) electrodes are made with 20μm wire at 1.27 mm pitch. As described earlier, use of 10μm wire at reduced pitch of 0.63 mm provides higher gains at lower pressures. The geometrical transmission efficiency is 92 % for this design. Focal plane chamber is isolated from HYRA with 0.5 μm mylar foil. It is being used for ER cross-section measurements [21].

Gas Ionization Chambers (IC)

Gas ionization chamber have been used for nuclear charge (Z) identification of the reaction products. The detector can be operated only as a gas detector or as hybrid detector in combination with a Silicon detector. Currently we have six different type of these gas ionization chambers operational which have been custom designed and fabricated as per the experimental requirements. Some of them are operated in transverse field geometry mode and others in axial field geometry mode (same as MWPC).

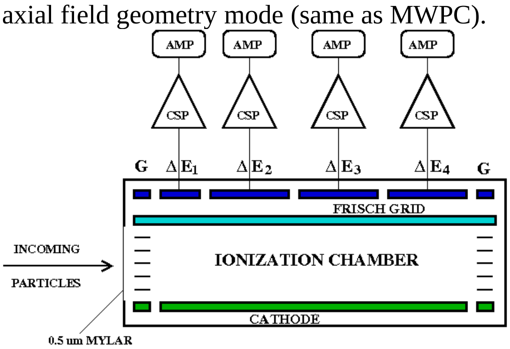

Fig. 7 : Schematic of IC

Fig.7 shows the schematic of an IC operated in transverse field geometry mode. It has an anode which is segmented to provide differential energy loss (ΔE) information. This energy loss is proportional to square of Z of the incident particle. The other two electrodes are cathode and Frisch grid. Guard electrodes with field shaping gradient are provided for optimum signal collection at the edges as shown in the figure. One such detector[14] is placed behind the MWPC at HIRA focal plane. It is used for Z identification of transfer products (beam/projectile like). It is a replica of IC designed at Daresbury in eighties. Anode is segmented in to three parts with length 3cm, 6cm & 19cm respectively. Active width is 7.5cm. A similar IC[17] was developed for GPSC for investigating transfer reactions. As shown in fig.6 the IC is placed behind one of the MWPC and the gas pressure was optimized for Z identification of projectile like products in the reaction $^{28}Si + ^{90,94}Zr$ (fig. 8). IC volume is isolated from MWPC with 0.5 µm Mylar. The anode signals are extracted using in-house developed charge sensitive preamplifier[31] with charge sensitivity 90mV/MeV (Si equivalent). The preamplifier were placed in vacuum close to detector to avoid degradation in signals. More details about the setup and experiment can be found in reference[17,22].

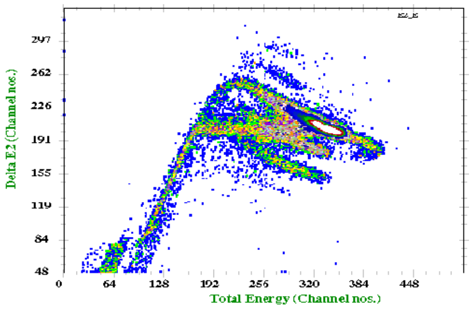

Fig. 8 : Plot between ΔE & total energy

Transverse field geometry IC require a longer active length/depth so as to operate the detector at reasonable pressures and to stop the particle completely. This generally also puts a limitation on solid angles in some cases. Certain experimental setups require a compact setup due to lack of space or due to experimental requirements. In such a case it is desirable to use a hybrid telescope. The active gas length/depth of IC can be reduced which is than followed by a Silicon detector acting as a stopping detector. IC can be transverse field type or axial type[23]. For light particles transverse field can provide better energy resolution because of more depth and thus energy loss. For heavier particles axial field is a better choice. Both versions were developed at IUAC. In the former case, a position sensitive Silicon detector (5cm x 5cm)[8] with readout from four corners was used as stopping detector. In the later case, we have used large area (active diameter 10 cm) annular position sensitive silicon detector[22] & the square (5cm x 5cm)[24] position sensitive silicon detector as stopping detectors. These setup were successfully used in RIB experiments[25,26] with Be^7. For fission angular distribution studies we used small (100 mm^2) PIPS detector from Canberra as stopping detectors after the axial field IC. Three such telescopes[27] were placed on one of the arms of GPSC. In all these detectors, axial field IC was fabricated using three electrode configuration of anode sandwiched between two cathodes at 10 mm inter-electrode separation. These electrodes are fabricated using stretched 20 µm diameter Gold plated Tungsten wires at 1 mm pitch. Active area is made identical to the area of the stopping detectors.

Silicon strip detectors (SSD)

Developmental activities have been initiated for having a Silicon strip detector[20] setup at the focal plane of HYRA gas filled separator. SSD is placed after MWPC where ER will be implanted following detection in MWPC. Subsequently ER are likely to decay within SSD by emission of protons or alphas. By correlation in time, position and energy of these alphas with ER detection in MWPC & SSD, one can uniquely identify the given reaction channel. This information can be further tagged with other detectors such as Germaniums. Variety of detectors are available commercially. Currently a double sided Silicon strip detector (design W) from Micron Semiconductors UK is installed. The detector has 16 strips each on both front and back side and has an active area of 5 x 5 cm^2. The front end electronics of strip detector is a 32 channel preamplifier MPR-32 followed by Shaping Amplifier cum discriminator (STM 16+) from Mesytec (Germany). The energy signals are fed to Phillips ADC 7164. The discriminator outputs (ECL logic) are fed to Phillips TDC 7186H. The timing signals will generate bit pattern for the identifications of the strips firing at a given instant. Each identified event will be time stamped using the in-house developed Global Event identifier Module (GEM). This will help in identifying the implanted recoils and their subsequent decays using the coincidence & anti-coincidence with MWPC signal.

The present silicon detector has a disadvantage of having smaller active area and thick dead layer at the entrance (0.5 µm). This will not detect low energy heavy recoils efficiently. Remedy lies in using detectors with thinner entrance window (0.1 µm). Examples of such detectors are Design X from Micron Semiconductors, PF-RT series PAD detectors from Canberra. The detectors have strips which are resistive thus generating position information in the coordinate orthogonal to the orientation of the strip. Design X was tested off-line with source. Fig. 9 shows the position spectrum with a mask. A position resolution of 1 mm fwhm was observed. Energy is obtained by adding the signal from both ends of the resistive chain. Position gated energy resolution of 60 keV fwhm was observed. This is inferior as compared to design W which gives about 40 keV resolution. This is due to impedance differences in the connections at either end of the strips. A software correction or ballistic deficit correction has to be applied to improve the resolutions.

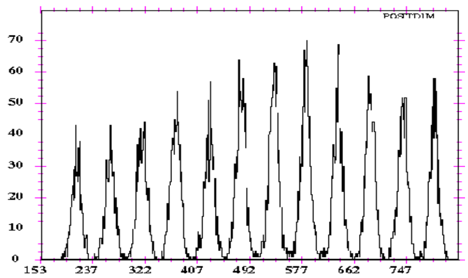

Fig.9: Position spectrum from strip

Other option is to use the resistive anode detectors [8] from Eurysis/Canberra having readouts from the four corners. All these detectors can be stacked together to have larger active area. Fig. 4 shows three such detectors stacked together to give an active area of 15 cm x 5 cm thus covering the entire focal plane. The detectors belong to the CATE[28] setup of RISING campaign at GSI. In off-line tests, an energy resolution of ~ 80 keV for 5.48 MeV alphas. This system will be used for experiments not demanding very high energy resolutions but requiring larger active area, low count rates and thin entrance window for low energy heavy ions.

The detectors has been tested off-line with ^{241}Am source and used in experiments with IUAC Tandem-Superconducting LINAC combination. In future we plan to install Canberra PAD detector [29] with an active area of 12 x 4 cm^2 having 12 resistive strips. The detector is intended for decay spectroscopy experiments.

CsI scintillation detectors

For investigating charge particle multiplicities, we have initiated development of a CsI-photodiode[30] based array for the detection of light charge particles such as protons & alphas in coincidence with heavy ions such as fission fragments. This array can be a useful tool for studying pre- or near scission charge particle multiplicities. One of the main characteristics of CsI(TI) detectors is its intrinsic ability to discriminate between different light charged particles such as protons, alphas, electrons (gamma photons) etc. according to their stopping power. This gives rise to different decay time constants in the light output (fast component) for different particles. Thus instrumentation for this array needs to be competent to exploit these features. The photo-diodes coupled to CsI(TI) detectors are read by conventional charge sensitive pre-amplifiers (CSP)[31]. Since the charge generated in photo-diodes is extremely low, it is desirable for the CSP to have a high gain, good timing features (ability to distinguish between different decay times from CsI), and low power consumption so that it can be placed next to photo-diode in vacuum to avoid degradation of signal. For large number of detectors in small volume, power dissipation needs to be small for each preamp. A preamp has been developed in-house with the above requirements in mind. It has a low power consumption < 50 mW, a gain of 2 V/pC (Si equivalent) and exhibits good timing characteristics for particle identification. The preamp has been realized in the form of a 8 pin SIL hybrid with a dimension of 1" x 1" The preamp has been tested thoroughly with Silicon and CsI detector in vacuum.

Ballistic deficit (BD) and zero-cross (ZC) timing are the two widely used techniques for particle identification in CsI. Sometimes both are used simultaneously as the combination of two improves discrimination. The first one uses two shaping amplifiers : one with shorter shaping time (0.5 μs) and other with larger shaping time (3 μs – gives total energy)). The second one uses the ZC time of a doubly differentiated bipolar pulse with respect to a constant fraction trigger generated on the rising edge of the signal. The CSP output from a CsI detector has large rise times varying from 100 ns to 2 μs. For such large rise times, it is impractical to use a large cable delay or delay chip (as done in a conventional CFD) for generating CF trigger. Thus a non-delay CF trigger needs to be generated which was realized by mixing two bipolar pulses of 0.5 μs and 1 μs time constant. The resulting tri-polar pulse (two ZC times) was fed to two ZC discriminator. The first ZC time provides CF trigger and the second ZC time gives the identity of the particle. For our preliminary tests we used ORTEC amplifiers and TAC, and CANBERRA discriminators. High density electronics (analog as well as digital) is currently under development.

Off-line test of CsI detector was carried out using radioactive sources Cs^{134}, Cs^{137}, Co^{60}, Am^{241} and Cf^{252}. Detectors of various sizes (crystal & photo-diode combination) were used to optimize electronics. Fig.10 & 11 are the 2-D plots of ZC PSD and ballistic deficit PSD taken with a 50 mm x 50 mm crystal (Scionix, Holland) coupled to 18 mm x 18 mm photo-diode exposed to Cf^{252} source. A pulser signal was also fed simultaneously. For such a large crystal also, three well separated bands, corresponding one each to alphas, γ from CsI, γ from photo-diode (along with pulser), are observed in both plots. Figure of merit (FOM) observed were 3 and 4 for BD and ZC respectively at alpha energy of 4 MeV. Combination of the two yields a FOM of 5. For BD , as observed from fig.11, the FOM improves with increase in energy whereas for ZC it remains constant. Energy resolution of 150 keV (for 5.48 MeV alpha) and 50 keV (662 keV gamma) were observed.

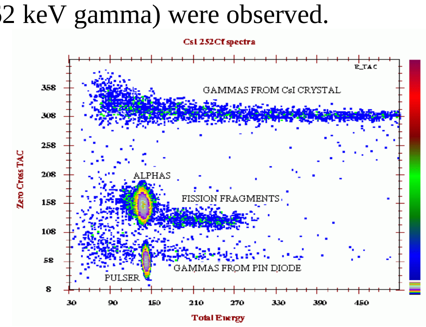

Fig.10: Zero cross PSD spectrum

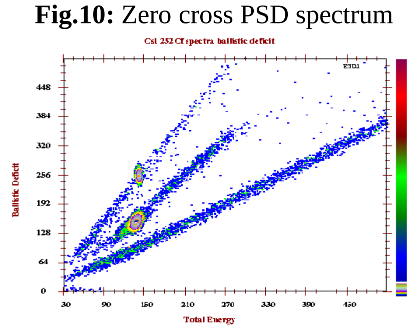

Fig.11: Ballistic deficit PSD spectrum

Future

We plan to have a new TOF system for our upcoming NAND facility comprising of fast MWPC with start-stop detector arrangement for generating absolute timing. The detectors are being designed to give angular resolutions better than 0.3 degrees and time of flight resolutions better than 500 ps. Such a system is expected to give a mass resolution of about 4 a.m.u. required for carrying out mass gated neutron multiplicity experiment in super-heavy region. Along with that we plan to have CsI detectors coupled to photo-diode for detecting light charged particles in co-incidence with fission fragments. In the backward angles (~ 170 degree) we plan to have hybrid telescopes for detecting backscattered projectiles for performing quasi-elastic scattering experiments. A new TOF system based on MWPC is also being planned at the focal plane of spectrometers. This will be followed by Silicon strip detectors for decay spectroscopy experiments. An efficient and high resolution charge particle detection will give a better insight to Nuclear reaction experiments to be performed in future.

Acknowledgements

We would like to acknowledge the support of our group members N. Madhavan, T. Varughese, S. Nath, K. S. Golda, J. Gehlot & R. P. Singh. We also acknowledge technical support from B. P. Ajith Kumar, E. T. Subramniam, S. Venkataramanan, R. Ahuja, K. Singh, P. Barua & Jimson Zacharias. We also acknowledge the encouragement and support from our Director Dr. A. Roy and our former group members J. J. Das, S. K. Datta & R. K. Bhowmik. We also acknowledge the encouragement provided by our former director Prof. G. K. Mehta during the initial stages of our detector development program. We acknowledge the support of Mechanical workshop IUAC in fabricating the detector fixtures. We thank the accelerator group namely Pelletron group and LINAC group for providing good quality beams for our experiments. We thank our collaborators Dr. B. R. Behera (Punjab Univ.), Dr. S. K. Mandal (Delhi Univ.), Dr. P. V. M. Rao (Andhra Univ.), Prof. R. Singh (Delhi Univ.), Dr. A. K. Sinha (UGC-DAE-CSIR, Kolkatta), Dr. R. G. Thomas (NPD-BARC), Dr. B. K. Nayak (NPD-BARC), Dr. A. Saxena (NPD-BARC) & Prof. H. J. Wollersheim (GSI). Last but not least we thank and acknowledge the hard work & support from our students S. Barua, Hardev Singh, S. Verma, K. Kalita, P. D. Shidling, S.

Kalkal, R. Sandal, Varinderjit Singh, S. Appanababu, E. Prasad, G. Mohanto & Ranjeet.

References :

[1] G. K. Mehta et al NIMA268(1988)334
[2] D. Kanjilal et al NIMA328(1993)97
[3] "HIRA" A. K. Sinha et al NIMA339(1994)543
[4]"HYRA" N. Madhavan et al Vol. 75 (2010)Pramana J. Phys. Proceeding Int. Symp. Nucl. Physics 2009
[5]http://www.iuac.res.in/research/nuclear_physics/GPSC/GPSC_main.html
[6]K. S. Golda et al " National Array of Neutron Detectors (NAND) a versatile setup for studies on reaction dynamics" Proceedings of the DAE – BRNS symposium on Nuclear Physics Vol. 51 (2006)626
[7] D. O. Kataria et al NIMA372(1996)311
[8] A. Jhingan et al 'A new detector system for radioactive ion beam experiments at the focal plane of the recoil mass spectrometer HIRA at NSC' NIMA526(2004)376
[9]S. Appanababu et al PRC 83,034605(2011)
[10]E. Prasad et al PRC 81, 054608 (2010)
[11]H. Singh et al PRC 80 064615 (2009)
[12]A. Jhingan et al 'Compact multi wire proportional counters for the detection of fission fragments' Review of Scientific Instruments 80, 123502 (2009)
[13]A. Jhingan et al 'A time zero MWPC detector for fission TOF experiments' DAE-BRNS symposium on Nuclear Physics pg 672 Vol.55(2010)
[14] A. Jhingan et al 'New Focal Plane Detector system of recoil mass separator HIRA' DAE-BRNS symposium on Nuclear Physics pg 585 Vol.52(2007)
[15] S. Kalkal et al PRC 83, 044610 (2010)
[16] S. Kalkal et al PRC 83, 054607 (2011)
[17] A. Jhingan et al 'Detector sytem for transfer reaction studies in GPSC' DAE-BRNS symposium on Nuclear Physics pg 654 Vol.55(2010)
[18] A. Jhingan et al 'Fission Fragment Time Of Flight Spectrometer for NAND array at IUAC' DAE-BRNS symposium on Nuclear Physics pg 675 Vol.53(2008)
[19] V. Singh et al PRC 86, 014609 (2012)
[20] A. Jhingan et al 'Focal plane detector system for HYRA' DAE-BRNS symposium on Nuclear Physics pg 1096 Vol.56(2011)
[21] G. Mohanto et al NPA 890-891(2012)62
[22] S. Kalkal et al PRC 85, 034606 (2012)
[23] A. Jhingan et al 'Development of a high efficiency annular detector system for RIB experiments at NSC' NIM A 539,(2005)269
[24] K. Kalita, et al 'Development of a large area telescopic detector system for elastic and transfer reaction angular distribution measurements' *Indian Journal of Pure and Applied Physics* 43 (8), (2005), pp. 567-572
[25] J. J Das et al PRC 73, 015808 (2006)
[26] S. Barua et al PRC 72, 044602 (2005)
[27] A. Jhingan et al 'Hybrid Telescopes for Heavy ion detection' DAE-BRNS symposium on Nuclear Physics pg 1040 Vol.56(2011)
[28] "CATE" NIM A 562 (2006) 298-305
[29] Tsyganov et al NIM A 392 (1997) 197
[30] A. Jhingan et al 'Developmental activities in charge particle detector array at IUAC' DAE-BRNS symposium on Nuclear Physics pg 640 Vol.54(2009)
[31] A. Jhingan et al 'Development of a charge sensitive preamplifier to operate in vacuum' DAE-BRNS symposium on Nuclear Physics pg457 Vol.50(2005)