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MEGHNAD – A multi element detector array for heavy ion collision studies

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Abstract. In the coming decade, the expanding field of experimental nuclear physics in our country is going to see a quantum leap in research and developmental activities with new accelerator facilities like the variable energy cyclotron with ECR heavy ion source, the upcoming K-500 superconducting cyclotron, both at VECC, Calcutta, and the superconducting linac boosters at both the Pelletron Accelerator Facilities at TIFR, Mumbai and NSC, New Delhi. When heavy ion beam available from such machines fall on a target and undergo collision, very rich and often pristine fields of research open up. In order to carry on such activities, we have taken up a project to build a multi element gamma, heavy ion and neutron array of detectors (MEGHNAD) to detect and study the properties of a wide variety of particles like neutrons, protons, light mass clusters, massive ejected fragments, and gamma rays with good solid angle coverage and efficiency. Design of the detector array, performance of the prototype detector and brief outline of the research programme to be undertaken with the detector array will be discussed.

Keywords. Nuclear detector array; gas filled counters; scintillation counters.

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1. Introduction

The last fifty years had seen a lot of research work into the study of nuclei excited by means of light ions. These investigations have led to a detailed picture of nuclei close to their ground state. With the availability of heavy ion beams during the last two decades, a wide range of research in heavy ion physics could be done by the encounter of two stable nuclei at various energies from the sub-Coulomb barrier energies right up to relativistic energies where the hadronic degrees of freedom come into play. When two such nuclei are brought into contact in heavy ion collision, a rich variety of phenomena take place which manifest the properties of the nuclear many-body system. At energies near the Coulomb barrier, when the two participating nuclei barely touch each other keeping their identity, one can study the interplay between the single particle and the collective degrees of freedom of the two nuclei. By appropriately selecting the targets, projectiles and bombarding energy, one may be able to specifically excite different degrees of freedom. On the other

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*For MEGHNAD Project.

hand, collisions where the nuclei come into more intimate contact lead to a combined nuclear matter system which at a later stage of the reaction may look like a normal nucleus that has been excited to a state of very high angular momentum and which is strongly deformed. Such a nucleus often becomes unstable, and sheds away the extra energy and angular momentum by emission of lighter particles and gamma rays. At even higher energies, heavy ion collision leads to formation of nuclear matter under extreme conditions of density and temperature, which then de-excites leading to multifragmentation. Detailed experimental investigation of this process is currently being undertaken at various laboratories to understand the basic properties of the equation of state of nuclear matter.

A complete and self-consistent experimental investigation of these interesting but mutually competing phenomena needs identification and energy measurements of almost all the reaction products, and event by event analysis of the nuclear reactions for a faithful event reconstruction. Such analysis should yield an accurate determination of mass and charge exchange between the products, total kinetic energy loss in the reaction, energy and multiplicities of the emitted light particles and identity of their sources, temperature of the hot composite system and/or the binary reaction products, etc. Therefore, a detection system with low energy threshold, good solid angle coverage and capable of detecting light and heavy particles will be ideally suited for these measurements.

Some of the studies mentioned above at near Coulomb barrier energies have been actively pursued at the two heavy ion accelerator centres (viz. the 14UD BARC–TIFR Pelletron at Tata Institute of Fundamental Research, Mumbai and the 16UD Pelletron at Nuclear Science Centre, New Delhi) in India during the last decade. With the commissioning of the ECR heavy ion source at variable energy cyclotron and also with the upcoming K-500 superconducting cyclotron, both at VECC, Calcutta, scope of extending such studies at higher energies will open up. However, a suitable detector array with the capabilities as mentioned above does not exist in the country.

2. Details of the detector array

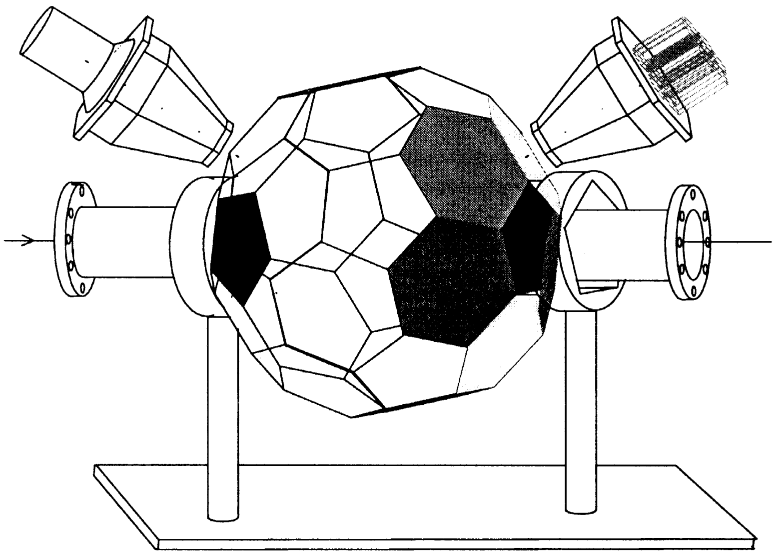
In this prespective, the MEGHNAD project was initiated as part of the IXth Five Year Plan to build multi element gamma, heavy ion and neutron arrays of detectors to detect and study the properties of a wide variety of particles like neutrons, protons, light mass clusters, massive ejected fragments, and gamma rays with good solid angle coverage and efficiency. The project essentially consists of three mutually independent detector arrays: (a) gamma detector array, (b) charged particle detector array, and (c) neutron detector array. The arrays will be used for experiments primarily at the variable energy cyclotron in Calcutta, and also at BARC–TIFR Pelletron, Mumbai and NSC Pelletron, New Delhi.

The gamma detector array consists of four numbers of Clover detectors, a few high efficiency HPGe detectors along with gamma multiplicity filters. Details of the gamma detector array can be found elsewhere [1].

3. Charged particle detector array

A schematic view of the charged particle detector array is shown in figure 1.

The array consists of thirty (30) numbers of multielement detectors (20 numbers with hexagonal and 10 numbers with pentagonal cross section areas) close packed to form a



Number of detectors = 30
Hexagons = 20 Pentagons = 10
Solid angles: Hexagonal detector = 0.31 sr
Pentagonal detector = 0.21 sr
Coverage = 66% of 4π

Distance of detectors from target = 18 cm
Height of beam line axis = 1.4 - 1.8 metre
Angular span (θ) of the hexagonal detectors = 30°

Figure 1. Schematic view of MEGHNAD charged particle detector array. Location of the detector modules in the front and the back hemispheres are shown.

soccerball-like structure. The solid angle coverage of the array is estimated to be about 65–70% of 4π and it should be able to detect charged particles over a wide range in mass and energy with good granularity. Table 1 shows the relevant characteristics of the array.

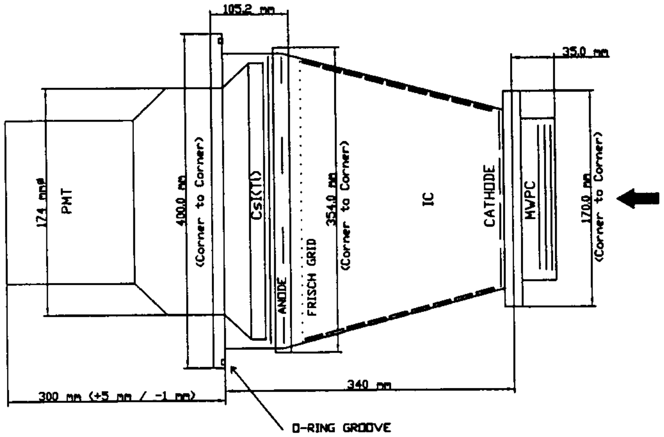
A schematic view of each of the detector elements is shown in figure 2 and photograph of the first prototype detector module is shown in the figure 3. Each detector module, enclosed in a trapezoidal chamber, consists of a two-dimensional position sensitive multiwire proportional counter (MWPC) with angular resolution of 0.2–0.5°, an axial ionization chamber (IC) for measurement of energy and charge of the heavy ions stopping within the active gas volume of the detector, followed by a CsI(Tl) scintillation detector to identify the lighter ions. The last detector element is capable of stopping up to 40 MeV protons, which should be adequate for experiments at the upcoming supeconducting cyclotron energies. The details of the elements of a detector module are given below.

3.1 *Multiwire proportional counter* (*MWPC*)

Details of the MWPC and photographs of the first prototype are given in figure 4. The detector consists of multiple grids made from gold plated tungsten wires of diameters ranging from 20 to 50 μm. The cathodes and the position grids are made of wires of diameter 40 μm. The anode is made of wires of diameter 20 μm. Resistive chain readout

Table 1. Some relevant characteristics of the heavy ion detector array.

No. of detector modules	30
Distance of detector entry window from the target	18 cm
Solid angle subtended by each detector	0.2–0.4 sr(approx.)
Effective geometric efficiency of the array	$\sim$ 65–70%
Detector gas to be used	P-10, C_4H_{10}, CF_4
Typical gas pressure inside the IC	20–200 Torr
Length of the IC	25 cm
Minimum Z and corresponding maximum energy of the ions that will stop inside the IC (@ 300 Torr of CF_4)	$Z = 18$ E_{max}= 12 MeV/u
Typical Z resolution of the IC	$< 2\%$
Forward angular region over which segmented CsI(Tl) detectors will be placed	17°–60°



Parameters of the IC:
Cathode grid:
Length of each side = 68 mm   Diameter of the wire = 40 μm

Spacing between wires = 1 mm
Frisch Grid:
Length of each side = 145 mm   Diameter of the wire = 125 μm
Spacing between wires = 1 mm   Anode - Frisch Grid distance = 15 mm
Screening inefficiency = 1%
Anode:
Material = 1.5 μm thick aluminised mylar foil

Active length of the IC = 250 mm
Gas Pressure = 10 - 200 Torr
Gas to be used = P10, Isobutane, Freon
Reduced Field = 0.2 - 1.5 Volt / cm.Torr

Figure 2. Schematic view of one of the charged particle detector module of the array.

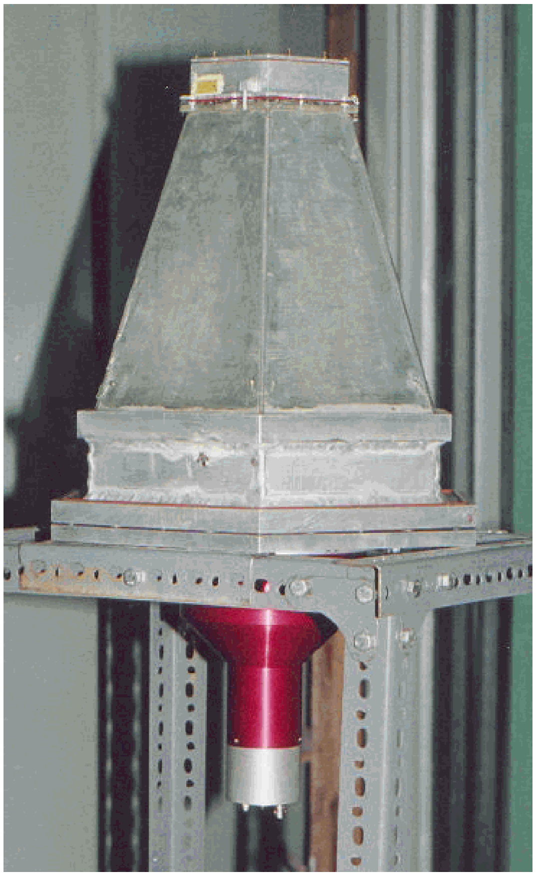


Figure 3. Photograph of the first prototype charged particle detector module.

using arrays of miniature surface mount resistors 470 Ω 1%, 0805 format metal film chip resistors) is incorporated. The grids are housed inside an aluminium chamber designed to maximize the exposed active area of the detector. Extremely thin (1 micron) polypropylene windows with stainless steel supporting mesh are placed at the entry and the exit to the detector to contain P-10 or isobutane gas (both of 99.9% purity) at low pressure (~ 3 to 20 Torr). The two-dimensional position spectrum taken through exposure by a spontaneous fission source with a mask written MEGHNAD on it is shown in figure 5. The position resolution, measured with the help of a mask, is found to be about 1 mm (FWHM) for fission fragments with almost 100% detection efficiency.

The position spectra along the two dimensions are obtained by charge division method across the resistive chain. Our choice of resistive read-out over delay line type readout is guided by the fact that the size of the commercially available lumped delay lines is quite large to fit inside the chamber. However, possibilities of designing an on-board distributed delay line within the limited space are being explored. We have also explored the

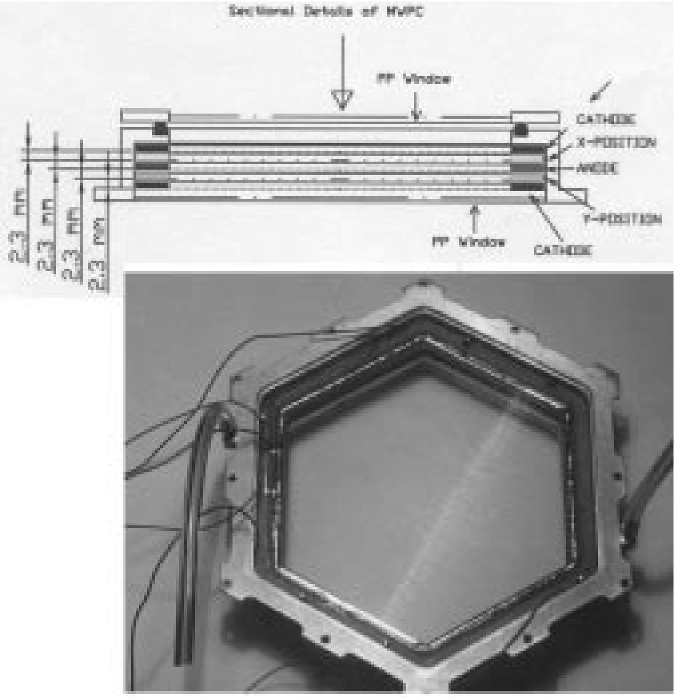


Figure 4. Sectional view of the multiwire proportional counter. Photograph of the first MWPC module is also shown.

possibilities of incorporating new and more efficient designs like MSGC and GEM [2], which can give better position resolution ($\sim$ 30–100 μm). Unfortunately, such techniques could not be incorporated in this transmission type MWPC which demands minimum absorber thickness in the path of the charged particles as required for the complete detection of ions at lower energies (e.g. at $E \leq 15$ MeV/u). However, these modifications can easily be incorporated when the beam from the superconducting cyclotron becomes available.

3.2 *Axial ionization chamber* (*IC*)

The charged particles passing through the MWPC, enters the axial ionization chamber. The chamber is made out of 3.2 mm thick copper clad FR-4 grade glass epoxy laminate boards. Details of this detector is shown in figure 2. The detector is operated with P-10, isobutane or freon (CF_4) gas at a pressure of $\sim$ 20–200 Torr. The operating pressure is set depending on the specific energy loss of the ions to be detected in the experiment. Another polypropylene window ($\sim$ 1 μm thick) separates the MWPC from the IC gas volume. In order to transmit the ions which do not stop inside the IC, the anode is made of aluminized mylar foil. High voltage is applied at the cathode grid, and the anode is kept at the ground potential. Potential rings on the walls of the detector volume are utilized to create a radial

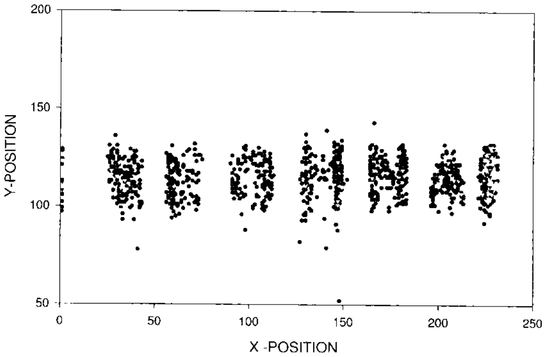


Figure 5. Two dimensional position spectrum from the MWPC when exposed with a mask containing the word MEGHNAD. The letters at the two ends were partially out of view.

electric field inside. The electrical signal from the anode was taken out through a load resistance of 500 kΩ, and processed through a charge sensitive preamplifier. Identification of the ions stopping within the IC volume are done using the BCS method [3] with the short and the long shaping times of the amplifiers set to $0.25\,\mu$s and 6 μs. Identification of the ions which do not stop within the IC gas volume, were done using the IC as a ΔE and the following CsI(Tl) scintillation detector as the E detector.

The off-line test of the detector has been done using a ^{252}Cf fission fragment source and an alpha source. A typical energy spectrum of fission fragment is shown in figure 6. Clear separation between the light and heavy fragments can be seen. The energy resolution of the IC, measured with the alpha source is 90 keV FWHM. Modification in the pulse processing electronics of the IC pulse is currently under way to improve the energy resolution. Performance study of different charge sensitive preamplifier chips (e.g. Models PR-8 and PR-16 from M/s. Eurorad, France and A422 from M/s. CAEN, Italy) for optimized processing of the IC pulse is currently under way.

3.3 *CsI*(*Tl*) *scintillation detector*

The energetic and lighter charged particles, which do not stop within the IC gas volume, pass through the anode foil and get detected by the CsI(Tl) scintillation detector. The scintillator crystal is 12.5 mm thick and 250 mm in dia. with a thin (50 μm) plastic placed in front of it to form a phoswich. The crystal, with thalium doping level optimized for charged particle detection, is coupled to a 125 mm ϕ dia. photomultiplier through a light guide. The scintillator is coupled to the light guide with optical cement. The front face of the scintillator is covered with a detachable 1.5 μm thick aluminized mylar foil. The side faces of the scintillator and the light guide are covered with reflecting paint designed for enhanced light collection efficiency ($\sim$ 85%). Vacuum sealing of the detector is done at the edge of the light guide for operation of the scintillator inside the gas volume of the IC but the photomultiplier remains outside in air. Signal from the photomultiplier is sent through

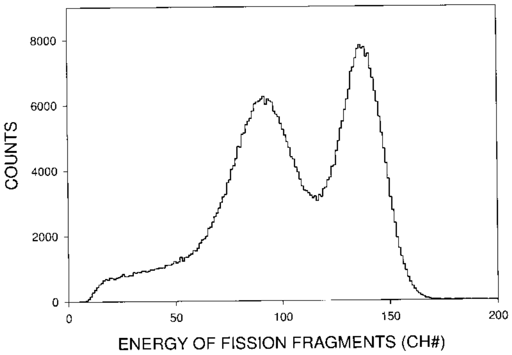


Figure 6. A typical energy spectrum obtained from the IC when exposed with a fission fragment source.

a fast buffer and processed by charge sensitive ADC, with short and long gates, optimized for pulse shape discrimination.

Because of the large size of the scintillator, the energy resolution is expected to be poor. The energy resolution of the detector, measured for the 511 keV gamma ray from a ^{22}Na source is found to be $\sim$ 12% with noise level equivalent to $\leq$ 30 keV of gamma ray energy. The energy resolution measured for 5.5 MeV alpha particles is found to be $\sim$ 28%. This is expected to be worse since the 5.5 MeV alpha particles stop within the 50 μm thick plastic scintillator. The resolution for higher energy alpha particles will definitely improve as the fraction of energy deposited to the CsI(Tl) increase with the energy.

3.4 *Support stand and vacuum enclosure for the array*

The detector modules are designed for operation under vacuum. This requires a support stand of soccer ball like structure, with beam entry and exit ports through the two diametrically opposite pentagonal faces (see figure 1). Each of the 30 faces (20 hexagons and 10 pentagons) will be hollow flanges where the matched detector modules can be inserted to form the vacuum enclosure. Differential pumping through turbomolecular pumps will be provided for sustained in-vacuum operation of the detector array. Mounting of the target at the centre of the array, gas flow to the MWPC modules and the electrical connections will be taken out through the beam entry and exit ports. The detailed engineering design of the stand is currently under progress. Fabrication of the stand will be started soon.

3.5 *Performance of the detector*

The first hexagonal module of the detector was tested in-beam at the BARC–TIFR 14 UD Pelletron accelerator in Mumbai with ^{12}C, ^{16}O, ^{28}Si and ^{58}Ni beams at energies from 70 to 150 MeV on various targets. The detector module was placed with the grids in the vertical plane inside an adapter chamber placed at 90° with respect to the beam direction. The major diagonal of the hexagonal plane was kept in the reaction plane. In the test run, the

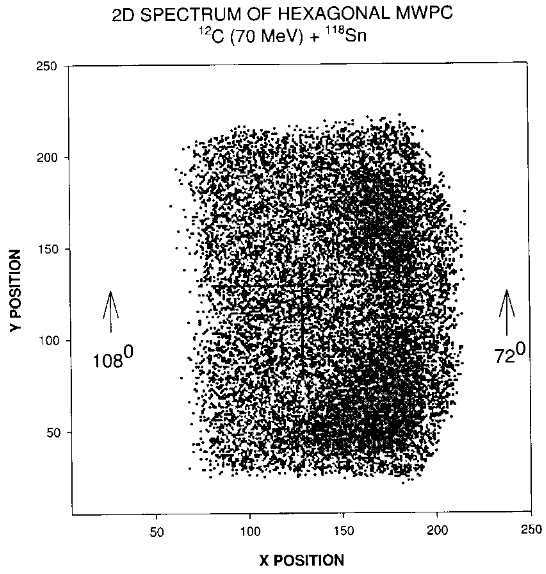


Figure 7. A typical two-dimensional position spectrum of the MWPC obtained during the experiment. Majority of the detected ions are ^{16}O with energies ranging from 40 to 80 MeV.

trigger was generated from the MWPC anode for all the detector elements of the module. A two-dimensional position spectrum of the MWPC obtained during the experiment is shown in the figure 7. The spectrum shows some non-uniformity of response which is found to be more pronounced along the azimuthal plane. This is due to the fact that the MWPC module had to be operated at a lower potential due to the occurrence of sparking at higher potential on the grids. Improvement in the performance of the MWPC is expected with modifications in the design (e.g. using anode wires of smaller diameter, using proper insulation of the connecting wires, etc.) which are being incorporated.

The two dimensional spectrum (height of the Bragg peak as function of energy) obtained from the IC is shown in figure 8. The Z-separation between the detected heavy ions can be clearly seen. Improvement in the Z resolution is necessary for clear identification of the ions. We hope to achieve that through modified design of the charge sensitive preamplifier and better shielding of it from RF noise and ground loop pick up. Further testing of the detector will be done at VECC after modification.

A typical two-dimensional ($\Delta E_{\rm IC}$ vs $E_{\rm CsI}$) spectrum, taken with ^{12}C beam is shown in figure 9. The energy deposited by the carbon ions in the CsI(Tl) phoswich is $\sim$ 20 MeV. These ions stop within the fast plastic which has a smaller but faster response as compared to the CsI(Tl). Because of the low energy of the ions detected by the CsI(Tl), and the intrinsic nonlinearity of the scintillator, energy calibration of the detector could not be carried out. The bands for ^{12}C and ^{16}O ions can be seen as somewhat smeared along the y-axis in the spectrum of figure 9. Improvement in the energy resolution of the IC will improve the particle discrimination capability of the detector. Detection and discrimination of the lighter particles (proton, deuteron, alpha etc.) were attempted by fast-slow gate method. Preliminary result shows distinct separation between gamma rays, protons and

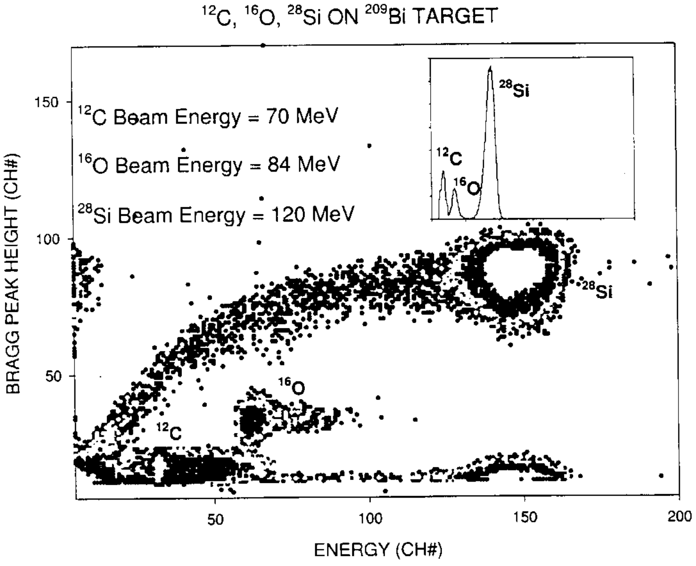


Figure 8. A typical two-dimensional spectrum (height of Bragg peak vs energy) of the IC obtained during the experiment. The bands corresponding to ^{28}Si, ^{16}O, and ^{12}C detected ions are clearly seen.

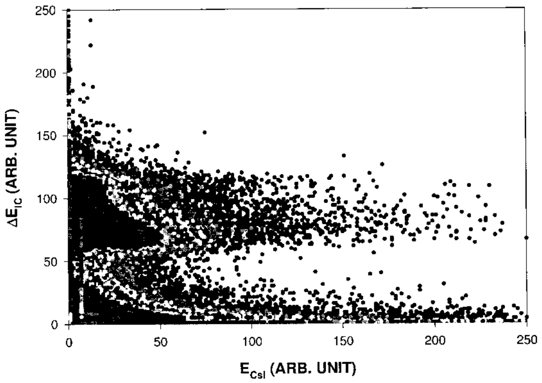


Figure 9. A typical two-dimensional spectrum ($\Delta E_{\rm IC}$ vs. $E_{\rm CsI}$) obtained during the ^{12}C + ^{118}Sn experiment.

alpha which were produced by fusion evaporation. Further testing of the detector module using reactions at higher beam energies ($\geq$ 20 MeV/u) will be necessary before we can conclude about the discrimination capability and also the energy threshold above which discrimination is possible with the detector.

4. Neutron detector array

The neutron detector array consists of 10 numbers of neutron detectors. Each detector consists of 125 mm ϕ dia. × 125 mm long liquid organic scintillator (Bicron BC-501A) viewed by 130 mm ϕ dia. photomultiplier tubes (Phillips XP4512B). Neutron–gamma discrimination can be done by either of the three methods: (1) time-of-flight (TOF), (2) pulse shape discrimination by the ratio of the fast component to the total, as prescribed by Toke *et al* [4], and (3) pulse shape discrimination by zero crossing detection [5,6]. The detectors will be placed at a distance of 40–70 cm from the target position for optimum performance of the detectors. Tha array can be used as a stand-alone system for heavy ion collision studies through measurement of neutron multiplicities, and for the study of exclusive neutron energy spectra. Provision to couple the array with the charged particle detector array have also been kept for inclusive measurements which will be important in many ways for the experiments. The array can also be used as a tagging device for gamma spectroscopic studies.

5. Summary and outlook

In summary, a charged particle detector array for heavy ion collision studies at low and intermediate energies is being designed and developed at SINP as part of the MEGHNAD project. Performance of the prototype charged particle detector was studied both in offline and online experiments and has been found to be satisfactory. More online tests and measurements will be done after the necessary modifications needed as described above. Provision to couple this detector array with a gamma detector array and also a neutron detector array will be made in the future. This will make the array a very versatile and powerful tool for heavy ion collision studies.

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