Chapter 2

Development of high resolution charged particle detector array

2.1 Introduction

The experimental study of nucleus-nucleus collision is essential to probe the properties of nuclei at extreme conditions of spin and temperature. Such study provides information about the reaction dynamics and the thermal properties of the nuclei under extreme condition, which includes the complete spectrum of mechanisms ranging from the compound nucleus formation, deep inelastic collision, projectile breakup to multi fragmentation of the colliding particles, depending on the collision energy. In order to disentangle these complex mechanisms or processes, simultaneous detection of all or as many as possible reaction products is very much essential. In the case of energetic heavy-ion collision, it is well known that multi detector arrays are very essential and important tools to investigate the dynamical properties of the reaction process. However, in the case of low energy (E ≤ 10 MeV/A) nucleus-nucleus collision, the interaction between the projectile and the target is dominated by mean field and the exit channel is mostly binary in nature. Therefore, one can extract the thermal or the
dynamical information of the reaction by detecting any one of the reaction product with the help of small number detectors. However, larger array of detectors is always desirable for more effective utilisation of beam time. At higher beam energy, i.e. for more energetic nuclear collisions (E \geq 30-40 \text{ MeV/A}), the reaction dynamics changes from mean field dominated regime to individual nucleon-nucleon collision. The transition is indicated by gradual change in observed reaction processes also; for example, mean field process like binary fission is gradually replaced by multi fragmentation; non-central, peripheral reactions like binary dissipative collisions change over to projectile fragmentation. In order to study these processes around the Fermi energy (\sim 37 \text{ MeV/nucleon}) domain, one needs powerful experimental equipments (detector arrays) for detecting as many of the reaction products as possible with best possible energy and spatial resolutions. The detector array should be designed in such a way that it should have large angular coverage with high granularity, capability of isotopic as well as mass identification of the fragments, and, as low as possible detection threshold.

The design consideration of the detector array in different energy regime is different and it also depends upon the physics motivation. For example, at low projectile energy, there is less kinematic focusing, array elements may be uniform in size and should cover a large solid angle in the laboratory. On the other hand, at high projectile energy, because of the strong kinematical focusing, it is required that the detector array should be high granular in forward hemisphere, as it covers the major part of the total (4\pi) solid angle sustained at the center of mass. Several such large detector arrays in different laboratory around the world are currently in operation [54]. For example, INDRA [55], is a 4\pi detector array which has been extensively used for multi-fragmentation study. It mostly consists of ionisation chamber plus Si- CsI(Tl) telescopes and covered 90 \% of 4\pi. The array CHIMERA [56], is also a large 4\pi charged particle detector array, made up of Si-CsI(Tl) telescopes with time of flight measurement. Large Area Silicon Strip Array (LASSA) [57] is another auxiliary detector array made up of nine high resolution telescopes, each telescope consisting of one 65 \mu m single sided Si-strip detector, one 500-1500 \mu m double sided Si-strip detec-
tor backed by four CsI(Tl) detectors of thickness 4-6 cm. The High Resolution Array (HiRA) [58], at National Superconducting Cyclotron Laboratory (NSCL), MSU, is a large solid-angle array of silicon strip-detectors that has been developed for the study of variety of nuclear structure, nuclear astrophysics and nuclear reaction experiments using heavy ion beam. It consists of 20 telescopes, each of which is constructed from a 65 µm Si-strip detector, 1.5 mm Si-strip detector and four CsI(Tl) detectors. The 65 µm Si-strip detector is single sided (32 strips on the junction (front) side only, while the 1.5 mm detector is segmented into 32 strips per side in front and back, mutually orthogonal to each other. Individual active surface areas of Si-strip detector is of 64 mm x 64 mm.

A 4π charged particle detector array (CPDA) facility is being developed at Variable Energy Cyclotron Centre (VECC), Kolkata, for nuclear physics experiment using the upcoming K500 superconducting cyclotron. Motivation behind the development of the array is to study the properties of the hot nuclei produced in energetic heavy ion collision at around Fermi energy domain. The K500 superconducting cyclotron at VECC will provide energetic ion beams (typically, 10 - 80 MeV/A for A_{proj} < 100 and 5 - 20 MeV/A for heaviest ions) for nuclear physics research. So the array being developed should be capable to detect all types of emitted charged particles ranging from light charged particles to fragments up to Z ≈ 40. Depending upon the kinematics, relative yield of different kinds of particles will vary at different angular region around the beam direction. So, the requirement of detectors are different in different angular range, which in turn depends upon the type and energy of the reaction products. Based on these considerations, it was decided that the 4π CPDA would consist of three different arrays, (i) forward array (angular coverage θ ~ 70 to 450), (ii) backward array (angular coverage θ ~ 450 to 1750) and (iii) extreme forward array (angular coverage θ ~ 30 to 70). A schematic view of the charged particle detector array being developed at VECC is displayed in Fig. 2.1. The backward array of CPDA will consists of only CsI(Tl) detectors of varying dimensions (thickness ~ 2 - 4 cm). This part of the array will be kept at 15 cm from the target in backward direction and has been designed in
Figure 2.1: Schematic view of the full $4\pi$ charged particle detector array.

such a fashion that the detectors after complete assembly will form a spherical surface of radius 15 cm. The extreme forward array will be made up of 32 plastic phoswich detectors (each will consist of a combination of one fast and one slow plastic scintillators). This part of the array will be kept at 40 cm from the target in forward direction and the face of the detector would form a wall. Development of the forward array, the high resolution Si(strip) - Si(strip) - CsI(Tl) charged particle detector array, contributes a part of the present thesis; therefore, the design and fabrication of forward part of the array has been described in details.

In the following sections the development of the high resolution forward array will be described. The design and simulation of the array as well as performance test of prototype elements will be described in section 2.2. The event identification and reconstruction techniques will be described in section 2.3 and in-beam performance test of the array elements will be given in section 2.4. Finally, the mechanical design and fabrication of whole mechanical structure of the array and the installation of detectors with complete electronics will be described in section 2.5.
2.2 Design and simulation of the high resolution charged particle detector array

Study of thermodynamical properties of nuclei requires precise information about the yields of charge as well as mass identified fragments emitted in the reaction. Due to wide variety of fragment type and energy, we need to build detectors that can simultaneously identify both heavy fragments as well as light charged particles and measure their energies over a wide angular range. To optimise the design of the high resolution array, detailed Monte Carlo simulation has been performed, which is described below. From the simulation study, it has been found that the emission of complex fragments is restricted to forward hemisphere only due to Lorentz boost. At these energies, 45° in the laboratory system typically covered > 90° in center of mass. Therefore, the forward array was designed to cover the angular range of 7° to 45°, as most of the intermediate mass fragments are likely to be emitted within this zone. It has also been observed that multiple hit probability are less at 20 cm from the target at this energy. It is needed to identify all these fragments in charge as well as mass (as far as possible). Therefore, the detector array should have good energy resolution, high granularity, low detection threshold and capability of good elemental as well as isotopic identification.

Monte Carlo simulation has been carried out to study the response of the high resolution array. Typical simulation using the phenomenological event generator HIPSE (heavy ion phase space exploration) [59] for the reactions \(^{40}\text{Ca} + ^{40}\text{Ca}\) and \(^{40}\text{Ca} + ^{197}\text{Au}\) (50 MeV/nucleon) have been studied (each reaction of 1 million events) [60, 61]. The events are macroscopic/microscopic representations of heavy ion collisions at energies around Fermi energy. The events span all possible impact parameters, maximum of touching radius of projectile and target, i.e., from central collision (higher multiplicity events) to elastic scattering (lower multiplicity events) events. The light charged particle (LCP) multiplicity events detected within the active geometrical acceptance of the high resolution array in percentage for different LCP multiplicities in the mother events of \(^{40}\text{Ca} + ^{40}\text{Ca}\) at 50 MeV/A are shown in Fig. 2.2. The inset of Fig. 2.2 shows mother
**Figure 2.2:** The detected LCP multiplicity events in percentage (mother event LCP multiplicities of 2, 8, 14, 20, 26, 32) for $^{40}$Ca + $^{40}$Ca reaction at 50 MeV/A. The solid lines are guides to the eyes while the dotted lines are reduced multiplicities. The inset shows distribution of 1 million HIPSE events with lines as guides to the eyes.

The event distribution for the reaction. The hollow circles/triangles imply multiplicities of LCP (1 ≤ Z ≤ 2)/fragments (Z ≥ 3) while the solid circles are multiplicities of all charged particles (Z ≥ 1). The fragment multiplicities are quite low and fall sharply while the majority are LCP. If the event LCP multiplicity is 26 (solid diamond), the most probable detected multiplicity is 13 and such events are about 18% of all LCP multiplicity 26 events. For $^{40}$Ca + $^{197}$Au the corresponding values are 4 and 22%. The dotted lines in Fig. 2.2 are reduced multiplicities due to multiple hits on same strips of the thin (ΔE) detector of the telescopes. The multiple hit probability in different detector elements of the telescope are shown in Fig. 2.3. The total charged particle multiplicity 26 events contain about 78% charged particles (Fig. 2.3a) and 22% neutrons (Fig. 2.3b) in an event. About 40% of the charged particles impinge on ΔE (Fig. 2.3c), most of which are LCP in this case. The charged particle multiple hit probability (for multiplicity 26 events) is about 0.7% at ΔE (Fig. 2.3d), 0.05% at ΔE/E (Fig. 2.3e).
Figure 2.3: The percentage of particles (a,b,c) and multiple hits (d,e,f) for $^{40}$Ca + $^{40}$Ca reaction at different detector elements of the telescope of array. The solid (open) circles correspond to multiplicity events for all (light) charged particles while open triangles are fragments other than LCP. The lines are the guides to the eyes. The inset in (f) shows the type of particles with atomic number Z at CsI(Tl) detectors of the array.

and 2% at CsI(Tl) (Fig. 2.3f) for $^{40}$Ca + $^{40}$Ca reaction and 0.04% at $\Delta E$, 0.002% at $\Delta E/E$ and 0.1% at CsI(Tl) for $^{40}$Ca + $^{197}$Au reaction.

The forward array has been designed and constructed to fulfill the above requirements. It consists of 24 identical telescopes. Each telescope consists of three elements [Si(strip) $\Delta E$, Si(strip) E/$\Delta E$, 4 CsI(Tl) detectors] and has an active area of 50 × 50 mm$^2$. The complete mechanical structure of this 24 telescope array is such that, after complete assembly, the detector faces will form a surface of a sphere of radius 20 cm. The schematic diagram for the arrangement of 24 telescopes is shown in Fig. 2.4. In the next section, the details of different elements of the telescope have been described.
**Figure 2.4:** The schematic design and arrangement of high resolution Si-strips-CsI(Tl) detector array.

**Figure 2.5:** The schematic view of different elements of a telescope.
2.2.1 Design of individual telescope

A schematic configuration of the telescope used in the forward array is shown in Fig. 2.5. In order to detect light charged particles as well as heavy fragments emitted in the reaction, each telescope is composed of a \((\Delta E)\) Single-sided Silicon Strip Detector (SSSD) of \(\sim 50 \mu m\) thickness, \((\Delta E/E)\) Double-sided Silicon Strip Detectors (DSSD) of \(\sim 500/1000 \mu m\) thickness and four \(\sim 6\) cm thickness CsI(Tl) detectors (E) (four crystal because to have fast response and to make the telescope more granular). First-second layers \((\sim 50 \mu m\) and \(\sim 500/1000 \mu m\) Si-strips) are for heavy fragments and second-third layers \((\sim 500/1000 \mu m\) Si-strip and CsI(Tl) detectors) are for light particles detection. The thicknesses were chosen to have good isotopic identification for the fragments with \((Z < 10)\) produced in low and intermediate energy heavy-ion reactions. In addition to good isotopic resolution, it will also provide a low energy threshold for particle identification. The detailed design and characteristics of each element are described in next few subsections.

2.2.2 Silicon Detectors

Silicon detector is very powerful device for detecting charged particles produced in energetic nucleus-nucleus collisions. Advantage of this detector is that it has a very good energy resolution with linear response over a wide range of energy. Because of the availability of large area silicon wafer, one can use single detector as a multi-detector by segmenting the contacts of the main detector volume into different section called strips. With this, one can achieve good position resolution and the corresponding detectors are referred as silicon strip detectors. Although silicon detectors are very good for charged particle detection, they have few drawbacks. These are very fragile (particularly the thinner ones) and are prone to radiation damage. The Silicon strip detectors (SSSD and DSSD) used in the present array are ion-implanted, passivated
devices obtained from M/s. Micron Semiconductors Ltd., UK [62] details of which will be described as below.

### 2.2.2.1 Single-sided Silicon Strip Detector (SSSD)

The first element of the telescope has been chosen as $\sim 50 \mu m$ SSSD, so as to have low energy threshold for highly ionizing particles; the threshold for $\alpha \sim 2$ MeV/A, and that for $^{40}$Ca is $\sim 5.5$ MeV/A. It is made up of a single silicon wafer having an active surface area of $50 \times 50$ mm$^2$. It consists of 16 vertical strips in front side (each of dimension $50 \times 3$ mm and in between two consecutive strips $50 \times 0.13$ mm separation gap) which are read out individually and back side is grounded. This detector is used as transmission type ($\Delta E$) detector in telescopic mode. Typical full depletion voltage (FD) for these detectors ranges from 4 V to 8 V, and can be operated up to 2FD; total leakage current at 2FD is $\sim 20$ nA (typical) at $25^0C$ with max. leakage current 100 nA. The intrinsic resolution of the SSSD is $< 70$ keV (specified) for 5 MeV $\alpha$ - particle.

### 2.2.2.2 Double-sided Silicon Strip Detector (DSSD)

This detector is also made up of a single silicon wafer and has an active surface area of $50 \times 50$ mm$^2$. Each detector consists of 16 strips (each $50 \times 3$ mm) per side in mutually orthogonal directions (front side vertical and back side horizontal). Front and back strips together form $16 \times 16 = 256$ pixels, each of active area of $3 \times 3$ mm$^2$. The position of the detected particle is assigned to the middle point of the pixel, which basically leads to an uncertainty of 1.5 mm in each one of the two dimensions. Two different thicknesses of DSSD, one $\sim 500 \mu m$ and another $\sim 1000 \mu m$ have been used in two different angular zones. The 1000 $\mu m$ detector have been used in the more forward angles (inner nine telescopes), because fragments in this zone have more energy. The thickness of these detectors have been chosen to stop upto $\sim 42$ MeV/A $^{40}$Ca. Full depletion voltages (FD) for these detectors are typically 30 - 35 V for 500 $\mu m$ and 120
- 130 V for 1000 µm. The 500 µm DSSD can be operated up to 2FD; total leakage current at 2FD V is 300 nA (typical at 25 °C) with max. leakage current 1 µA. The 1000 µm DSSD can be operated up to FD + 30 V; total leakage current at FD + 30 V is ~ 600 nA (at 25°C) with max. leakage current is 3 µA. The intrinsic resolution of the DSSD, for 500 µm, it is < 30 keV (specified) and for 1000 µm, it is < 25 keV for 5 MeV α-particle.

2.2.2.3 Design of the detector frame

The frames and the readout cables with connectors have been specifically designed by optimizing physical strength and dead area. The design of all Si-strip detectors has been performed in close association with the manufacturer, M/s. Micron Semiconductors Ltd., UK [62]. As the silicon strip detectors are very fragile, the holding frame of the silicon wafer should be strong enough. On the other hand, the close-packed design of the telescopes in the array require the minimum dead area (frame size) surrounding each Si wafer. The commercially available detector frame did not allow close packing of the telescope. Hence, by optimizing fragility and compactness, a new frame (as shown in Fig. 2.6) has been designed for the present array. The frame is made from glass epoxy with total outer dimension 60 mm × 60 mm [Fig. 2.6(a), (c)]. There is a slot of width 1.75 mm and depth 2.25 mm in the inner (top) sides of the frame [Fig. 2.6(c)]. These were kept to glue the silicon wafer and also to protect the wafer from other detector when the detectors will be placed in the telescopic mode. The outer ridge has four through holes, one in each corner which may be used to align the frame by dowel pins. Two slots are there in side 4 [Fig. 2.6(a), (d)], one in the top side of depth 1.5 mm and other on the outer side of depth 1 mm to placed the front side kapton. Top side depth has been kept 1.5 mm to ensure that wire bonding of the front side strip will be safely positioned and the outer side slot is to pass the kapton of ∆E Si-strip detector through in between E detectors’s frame and housing wall. In side 3, a slot of depth 3.25 mm and width of 4 mm is there in rear and inner side to keep the
kapton connected to backside strip. Three holes (M2) are there in each side which may be used to fix the detector with the housing. The frame of the SSSD detector is exactly same as DSSD. Only difference is, no kapton is there in side 3 and the outer side depth (side 4) is 0.5 mm.

Signals from the strips are taken out by cables made of kapton, a flexible polyimide as shown in Fig. 2.7. At the detector end, the kapton is bent perpendicular to the detector frame which helps to put the detectors in compact shape when they are used as a telescope with other detector. At this end 18 soft gold pads are there with each electrical tracking to connect with the strips using wire bonding of 3 aluminium wires each of \(\sim 25 \mu m\) thickness. At the other end of the cable, there is female flat ribbon connector (FRC) (SAMTEC SSQ-22-G-D-RA) with \(2 \times 10\) connectors with spacing 2.54 mm (0.1") through a printed circuit board. Out of these 20 connectors, 16 in the middle are connected to 16 strips in each side. Two are connected to the guard ring (G/R). Rest two have no connections in DSSD and connected with the back side (grounded) in SSSD as shown in Fig. 2.7.

Both types of detectors are made of bulk n-type silicon with \(p^+\) implantation to form a junction near the front. A G/R is there in the front side only. Further, onto the strips a \(\sim 0.20 \mu m\) aluminium layer is evaporated for conducting the signal. Total dead layer in the DSSD detector is \(\sim 0.6 \mu m\) including the implantation depth of about \(\sim 0.40 \mu m\). It is very important to take this into account during the analysis, since different particle will loose different amount of energy in the dead layer.

### 2.2.2.4 Characterisation of silicon strip detectors

After physical checking, the strip detectors have been tested offline using \(\alpha\)-source. First, the detector characteristics were checked using a \(^{241}\)Am \(\alpha\)-source. Energy resolution of individual strip has been measured for both thin/thick Si-strip detectors and found to be \(< 70/40 \text{ keV}\) for 5.486 MeV \(\alpha\)-particles as shown in Fig. 2.8. Thickness variation along a strip of the detector, particularly in 50 \(\mu m\) SSSD’s, which are very
Figure 2.6: Design of the DSSD frame.
Figure 2.7: Strip detectors with kaptons.
Figure 2.8: The energy spectrum of α-particles emitted from $^{241}$Am source for a particular strip.

Figure 2.9: Non-uniformity in thickness along the strip in 16 different positions of all strips of 50 µm SSSD.

Prone to thickness non-uniformity, will result in poor isotopic identification. So, it is very crucial to measure the thickness non-uniformity, particularly for thin detectors. Typical thickness non-uniformity of a thin (50 µm SSSD) detector has been estimated using in-beam test and shown in Fig. 2.9. It has been found that the variation of thickness along a strip is within our acceptance limit (found to be < 3 %).

2.2.3 CsI(Tl) detector

Thallium activated cesium iodide [CsI(Tl)] is used widely to detect energetic charged particles because of its high stopping power for charged particles and cost-effectiveness. The crystal is easily machinable to give required shape, less hygroscopic than NaI(Tl), have very good performance at room temperature, and produce light in a frequency range which is well detectable by the available photodiodes or photomultiplier tubes. CsI(Tl) is used as charged particle detector in two ways; (I) as a stop (E) detector in ΔE-E telescopic mode, or, (II) as a single detector using its particle discrimination property to detect light charged particles. In the present array of the telescopes, CsI(Tl) is used as a stop (E) detector for the energetic particles.
2.2.3.1 Design of CsI(Tl) detector

All the custom made CsI(Tl) detectors have been procured from M/s. Scionix Holland Bv, The Netherland [63], as a complete assembly of CsI(Tl) crystal and photodiode with an integrated low noise charge sensitive preamplifier. Final design of the detectors have been done in association with the manufacturer. As per design of the array of the telescopes, the front face of the first strip detector will form the part of a sphere of radius of \( \sim 20 \) cm. Accordingly, the shape of the CsI(Tl) crystal has been designed so as to ensure close pack geometry of the telescope; in addition, detectors have been slightly wedge shaped to ensure that the particle incident obliquely also get stopped in the crystal. The design of the typical detector is shown in Fig. 2.10(A); front and back faces are square shaped of dimension \( 2.5 \) cm \( \times \) \( 2.5 \) cm, and \( 3.5 \) cm \( \times \) \( 3.5 \) cm, respectively. The thickness of the detector is \( 6 \) cm, which can stop proton with energy upto \( \sim 140 \) MeV and \( ^{16} \)O with energy \( \sim 330 \) MeV/A. A stack of four such detectors has been used as final stopping detector in the third layer of the telescope. The segmentation helps in improving the multi-hit probability and better energy resolution of CsI(Tl) detector. Further reduction in size of the crystal for the CsI(Tl) detector of the telescope would certainly be best for granularity but the effective cost would also increase proportionally; so we have restricted it to four detectors. The assembly of four of such CsI(Tl) will form a truncated pyramid with base area of \( 7 \) cm \( \times \) \( 7 \)cm and front face will have same area as the active area \( (5 \) cm \( \times \) \( 5 \) cm) of the strip detectors as shown in Fig. 2.10(B). Each crystal is wrapped on all sides except the front face in a special reflecting material covered with aluminized mylar of thickness \( \sim 50 \) \( \mu \)m and the front face \( (2.5 \) cm \( \times \) \( 2.5 \) cm) is covered with a \( \sim 1 - 2 \) \( \mu \)m micron thick aluminized Mylar, which acts as entrance window. All these have been done to prevent scintillation light leaking through the crystal sides. Each crystal is coupled with a photodiode of active area \( 18 \) mm \( \times \) \( 18 \) mm (Hamamatsu S3204-08). The total dimension of the photo diode is \( 25.5 \) mm \( \times \) \( 25.5 \) mm with thickness \( 2.54 \pm 0.2 \) mm and it is coupled with crystal by special optical cement. The maximum reverse bias voltage that can be applied to photodiode is \( 100 \) V and the corresponding power dissipation is \( \sim 100 \) mW. It can be
operated in the temperature range -20\(^\circ\)C to 60\(^\circ\)C. The spectral response is 321 - 1100 nm whereas the photo peak of CsI(Tl) is 550 nm. A charge sensitive preamplifier with gain of \(\sim 5\) mV/MeV is directly coupled with the crystal. The power dissipation in the preamplifier is 50 mW and it can be operated in vacuum. Single detector with complete assembly (photo diode and charged sensitive preamplifier) is shown in Fig. 2.11 and stack of four such detector are shown in Fig. 2.12

### 2.2.3.2 Characterisation of CsI(Tl) detector

The detail characterisation of all CsI(Tl) detectors have been carried out using \(^{241}\)Am \(\alpha\)-source. Standard electronics have been used for testing purpose. The energy resolutions of all CsI(Tl) detectors are found to be less than 5 % at 5.486 MeV \(\alpha\) energy. Depending upon the uniformity of the thallium doping and the geometry of the detector, there may be some spatial non-uniformity in the light output of CsI(Tl) crystal. To measure the non-uniformity, a specially designed pin \(\alpha\)-source, \(^{241}\)Am
(5.486 MeV) has been put at different position of the front face of the detector. The source was collimated (diameter 1 mm & length 5 mm) and kept very close (2 mm) to the detector to irradiate the detector in a very small area (circle of diameter 1.4 mm) in a particular position. Fig. 2.13 represents the results of the spatial non uniformity of response test for the front face (area 25 mm × 25 mm) of a typical CsI(Tl) detector. The number in each segment is the peak positions of the α-spectra in terms of ADC channel number when the source has been kept within that segment during the test. With respect to the mean peak position (776), the variation is ∼ ± 0.49% which is less than the specified value (< 1 %). Total of 96 CsI(Tl) detectors for 24 telescopes have been procured. All detectors have been characterised in the same way as mentioned above.

2.3 Development of event reconstruction technique

In this section the general features of the data analysis tools that have been developed will be discussed. For the analysis, the standard analysis platform (ROOT) has been used. The whole analysis process for such an array involving multiple detector is quite complex and is generally executed in several steps; the major steps being
Figure 2.13: Non-uniformity in the light output. Numbers are the peak position of the α-spectrum in terms of channel number.

Figure 2.14: Spectrum of α-particle emitted from $^{241}$Am measured using a CsI(Tl) detector.

sampling/selection of events of interest, reconstruction of the selected events to extract complete information about the ejectiles, comparison with the simulation data, etc. The data reduction algorithm has been developed in ROOT platform to extract the details of the detected particle in each event [angular position $(\theta, \Phi)$, energy, types of particle, number of coincidence particles, etc.]. The main building blocks of the present analysis package are described in different sub-sections below.

2.3.1 Event selection

First step of the data reduction technique is to identify valid events. The programme identifies all valid events by selecting those events above a pre-set experimental threshold (depending upon the noise in the experiment) and then stores all these events with full information. In the second step, energy calibration of each channel of the telescope is done. The angular positions $(\theta, \Phi)$ of the emitted particles have been defined by the corresponding positions identified in the DSSD detector of the telescopes. The position identification technique in DSSD has been described below.
Figure 2.15: Schematic diagram for hit position generation using DSSD. Two particles are incident (as shown by two arrows) on the DSSD and their positions are defined by the corresponding front and back strips (shown in different colours).

2.3.2 Position identification in DSSD

The position identification in DSSD detector is very complicated and very challenging for high multiplicity events as we will see for the present experiment in next chapter. For single particle incident on the detector, it is very simple to identify the position as only one front and one back strip will have the signal; hence their intersection defines the position of the particle. For more than one particle hits in one event, identification problem starts showing up, multiple (more than one) front and back strips are likely to fire, as shown in Fig. 2.15. The identification of the hit position requires matching the front strip signals with the corresponding back one. To identify X-Y positions (front and back strip number, respectively) for the particles incident on the strip detector, an algorithm has been developed in ROOT platform. The Program works in event-by-event mode. For each event, first it reads data for all elements of the detector; then for each case, it checks for valid hit (signal is above preset threshold as stated before) and then stores all valid hits in the form of a 2-dimensional (X-Y) array. In the next stage, by comparing the energy (or channel number) difference between each forward (X) - backward (Y) pair, the program identifies all genuine X-Y pairs corresponding to the particles that hit the detector. The result is illustrated in Fig. 2.16,
where EF, EB correspond to the energies registered in X and Y strips. Genuine event is defined by the condition EF-EB=0 (within experimental uncertainties). So from this program front and back strip numbers of each particle can be determined, which define the position of the particle. Though it looks simple, but in reality it is very difficult and more complex to extract positions for the coincident particles of nearly same energy. For multiple-hits, it has been observed that for a single particle there will be multiple positions within the experimental uncertainty (in EF-EB). So a minimization routine has been used to get the expected position of different particles. Using $^{229}$Th-$\alpha$-source at a certain distance from the DSSD, position has been determined using the position identification algorithm as shown in Fig. 2.17. After the position (X, Y) identification in DSSD, the corresponding position has been converted into the angular position ($\theta$, $\Phi$) using the perpendicular distance from the point of origin (0, 0) (experimental origin point is the target position) and each strip width (3 mm).
2.3.3 Particle Identification by $\Delta E - E$ method

After position identification in DSSD, event selection has been performed (multiparticle coincidence or single particle events). In the next step, particle identification in the telescope was done by $\Delta E - E$ method as described below.

The energy loss of charged particle passing through matter is given by Bethe Bloch formula \[64\]
\[
\frac{dE}{dx} = \frac{4\pi e^4 z^2}{m_0 v^2} NB \tag{2.1}
\]
where
\[
B = Z \left[ \ln \frac{2m_0 v^2}{I} - \ln \left(1 - \frac{v^2}{c^2}\right) - \frac{v^2}{c^2} \right] \tag{2.2}
\]
$E = \frac{1}{2} M v^2$, $v, z, M$ are the energy, velocity, charge and mass of the incident particle and $N, Z$ are the number density and atomic number of the absorber (here detector material) and $m_0, e$ are the mass, charge of electron, respectively. The parameter, $I$, represents the average excitation and ionization potential of the absorber and normally treated as an experimentally determined parameter for each element. For non-relativistic particle ($v \ll c$), the second and third terms of $B$ are negligibly small and
whole $B$ varies very slowly with the energy of the incident particle. So, the equation 2.1 reduces to

$$- \frac{dE}{dx} \propto \frac{M^2}{E}$$

(2.3)

In the case of a detector telescope which consists of one thin detector followed by a thick detector, the energy loss of the particle in this thin detector ($\Delta E$) is usually small compared to the total energy ($E$). Under such condition, equation 2.3 becomes

$$\Delta E \cdot E = f(A, z)$$

(2.4)

which is the equation of a rectangular hyperbola. From the equation, it has been seen that the particles of different mass or charge generate different rectangular hyperbola in the scatter plot of $\Delta E - E$. After the particle identification, the program will store, event wise, all the information needed for physics extraction.

Another program package, as a part of the event reconstruction technique, has been developed in ROOT platform to study the resonance particle spectroscopy of different particle unbound states using multi-particle in coincidence from this type of array. It uses many body kinematics for reconstruction of source excitation energy spectrum from the detected multi-particles in coincidence and identification the different particle unbound states of the corresponding source. The excitation energy, $E_x$, of source has been reconstructed from the detected multi-particles (n-particle) in coincidence using the equation given by

$$E_x = \sum_{i=1}^{n} E_i - \frac{(P_1 + P_2 + P_3 + ... + P_n)^2}{2M_{source}} + E_{th}$$

(2.5)

where, ‘n’ is the number of particle detected in coincidence, $E_i$ and $P_i$ for $i=1, 2, 3,...n$ are the energy and momentum of the n-particles in laboratory, respectively, $M_{source}$ is the mass of the source, and $E_{th}$ is the multi-particle breakup threshold. The use of the above event reconstruction technique will be discussed in the performance test of prototype telescope in next section.
2.4 In beam performance test of a prototype telescope

Main motivation behind the development of the array was to study the thermodynamical properties (*i.e.*, temperature, specific heat, etc.) of the hot nucleus produced in intermediate energy nuclear collisions. The measurement of temperature is crucial to characterise the equation of state of finite nuclear matter and to look for possible phase transition in the system. Since several methods such as slope thermometry, excited state thermometry and double-isotope thermometry, are being widely used to determine the temperature of the hot nucleus, it was decided that a prototype telescope should be developed first to measure the temperature in different ways using in-beam experiments. The in-beam test will also help in testing other characteristics of the prototype detectors and readout electronics, *i.e.*, energy resolution, noise, etc. At the same time, analysis software packages will also get tested in course of the data analysis.

The prototype telescope has been designed for testing before final procurement of all the telescope elements. It was developed from the standard Si-strip detectors as available in catalogue of M/s Micron semiconductor Pvt. Ltd., UK [62] and also the standard CsI(Tl) detectors from the manufacturer M/s Scionix Holland Bv, The Netherland [63]. The telescope consisted of a 65 µm ΔE single-sided silicon strip detector (SSSD), 300 µm E/ΔE double-sided silicon strip detector (DSSD) and backed by four CsI(Tl) crystals (thickness ∼ 4 cm and area 2 cm × 2 cm). In beam test of telescope has been performed as described below.

2.4.1 Experimental details

The experiment has been performed at the Variable Energy Cyclotron Centre, Kolkata, India, using 145 MeV \(^{20}\)Ne beam on a \(^{12}\)C target (self supported, thickness ∼550 µg/cm\(^2\)). Different fragments have been detected using the prototype 3-element telescope. The telescope was placed at a distance 20 cm from the target. The angular range in the laboratory covered by the telescope was from 27° to 40°. Typical angular
resolution of each Strip is ± 0.4°. All Strips and the CsI(Tl) detectors were read out individually using standard readout electronics. A VME-based online data acquisition system, indigenously developed at VECC, was used for collection of data on event-by-event basis. The silicon detectors were calibrated using elastically-scattered \(^{20}\)Ne ion from \(^{197}\)Au target, a precision pulser and a \(^{229}\)Th \(\alpha\)-source. Energy calibrations of the CsI(Tl) detectors were done using the two-dimensional spectra between the 300 \(\mu\)m Si-Strip and the CsI(Tl) detectors [57]. Event reconstruction from the hit patterns in orthogonal directions of the DSSD provided two-dimensional position information of the detected particle. Typical two dimensional spectra obtained in this experiment have been shown in Fig. 2.18 and Fig. 2.19. Good isotopic distribution have been obtained for \(Z = 1\) and \(Z = 2\) particles as shown in Fig. 2.19. In this case \(\Delta E\) detector has a poor resolution (\(> 2\% (110\) keV) in 5 MeV \(\alpha\)), hence isotopic identification of different fragments could not be obtained as shown in Fig. 2.18.
**2.4.2 Performance Testing of event reconstruction technique**

Event reconstruction technique code has been tested in this experiment to obtain information about the particle unstable state by identifying the coincidence events. Different two particle coincidences ($\alpha-\alpha$ and $d-\alpha$) have been measured and the reconstructed particle-particle correlation spectra from the relative momentum distribution for different particle unstable states as described below. The two particle angle-averaged correlation function $[65, 66]$, $1 + R(q)$, is defined experimentally by the following equation:

$$\sum Y_{12}(p_1, p_2) = C_{12}[1 + R(q)] \sum Y_1(p_1)Y_2(p_2) \quad (2.6)$$

where $p_1, p_2$ are the laboratory momenta of the coincident pair of particles with masses $m_1$ and $m_2$, $q = \mu(|\frac{p_2}{m_2} - \frac{p_1}{m_1}|)$ is the relative momentum of the correlated pair and $C_{12}$ is a normalization constant which is determined by the requirement that $R(q) = 0$ for large $q$. The sum on both sides of equation 2.6 are taken over all detectors and particle energy combinations satisfying a specific gating condition. $Y_1$ and $Y_2$ are the single-particle

**Figure 2.19:** Two dimensional spectrum between 300 $\mu$m strip versus CsI(Tl) detector. Light charged particles emitted in the reaction 145MeV $^{20}$Ne on $^{12}$C obtained by the prototype telescope.
yields for particle 1 and 2 respectively and $Y_{12}(p_1, p_2)$ is the two-particle coincidence yield.

Experimentally, the product of single particle yields $Y_1(p_1)Y_2(p_2)$ has been approximated as ‘uncorrelated’ two particle yields, $Y_{12}^{unc}(p_1, p_2)$, and was constructed by the ‘event-mixing technique’ [67, 68]. The two-particle correlation functions have been calculated as

$$\sum Y_{12}(p_1, p_2) = C_{12}[1 + R(q)] \sum Y_{12}^{unc}(p_1, p_2)$$  \hspace{1cm} (2.7)$$

The $\alpha-\alpha$ correlation function obtained in the reaction $^{20}\text{Ne} + ^{12}\text{C}$ is shown in Fig. 2.20(a). The background from the total coincidence yield which does not proceed through the decay of particle-unstable nuclei is shown in dotted line in the Fig. 2.20(a) [69]. The peaks at $q = 20 \text{ MeV}/c$ and $100 \text{ MeV}/c$ correspond to decays of the particle-unstable ground state of $^8\text{Be}$ ($J^P = 0^+$) with decay width of 6.8 eV and the 3.04 MeV
excited state of $^8$Be ($J^π = 2^+$) with decay width of 1.5 MeV, respectively. Both of these states decay only by $α$ particle emission. In addition, the peak at $q = 50$ MeV/c is due to the decay of the 2.43 MeV state in $^9$Be.

The d-$α$ correlation function obtained in this experiment is shown in Fig. 2.20(b). The measured correlation function exhibits two maxima corresponding to the $J^π = 3^+$ unstable excited state of $^6$Li at 2.186 MeV with decay width of 24 keV and the $J^π = 2^+$ at 4.31 MeV excited state of $^6$Li with decay width 1.3 MeV, respectively. A third peak, corresponding to 5.65 MeV excited state of $^6$Li with decay width of 1.9 MeV is also observed in the correlation function, which is in close proximity with the second peak.

2.4.3 Physics extraction from the prototype telescope testing

Using the above particle unstable state formations and isotopic identification of light particles, nuclear temperature have been estimated by using three different thermometric techniques (Slope thermometry, excited state thermometry and double isotope thermometry) at this moderate excitation energy. Temperature of excited composite $^{32}$S* formed in the nuclear reaction $^{20}$Ne + $^{12}$C have been estimated using these thermometric techniques [70].

Temperature from slope thermometry: This method is based on the concept of a canonical ensemble. The particles evaporated from the hot system are taken to be Maxwellian in shape [71, 72] and the value of the temperature can be extracted from the slopes of the kinetic energy spectra of light charged particles [73, 74, 75, 76, 77]. Experimentally obtained proton and $α$-particle spectra in the center of mass are shown in Fig. 2.21 and Fig. 2.22, respectively.

In order to extract temperature using the slope thermometer, the spectra have been fitted with a function $\sim f(E_{c.m})exp(-E_{c.m}/T)$, shown by the solid line in the Figs. 2.21
**Figure 2.21:** Typical energy spectrum of protons in the c.m. for the reaction $^{20}$Ne + $^{12}$C. Filled circles are the experimental data and the solid line represents the fitted curve to extract the slope.

**Figure 2.22:** Same as Fig. 2.21 for α particles.
The temperatures extracted from the slopes of proton and α spectra are $T = 2.6 \pm 0.3$ MeV and $T = 2.9 \pm 0.5$ MeV, respectively.

**Temperature from excited-state thermometry:** By knowing the phase space of the decay configuration, the “emission temperature” can be determined from the relative abundances of different particle species, or more directly from the relative populations of states in a given nucleus [78, 79, 80, 81]. The ratio, $R_p$, of the populations of two states (if no feeding by particle decay takes place) is related to the temperature ($T$) through the relation:

$$R_p = \frac{(2j_u + 1)}{(2j_l + 1)} \exp\left(-\frac{E_{\text{diff}}}{T}\right)$$

(2.8)

where, $j_u$ and $j_l$ are the spins of the upper and lower states respectively and $E_{\text{diff}}$ is the energy difference between these two states.

In order to extract the information of the population of different particle-unstable states, we have measured the coincidence yield (sum of all coincident pair of hits between any two front side strips of DSSD) detected from the decay of particle-unstable nuclei and extracted the two-particle correlations function [65, 66], as described in previous subsection.

Nuclear temperatures have been extracted both from $^8$Be and $^6$Li decays using the α-α correlation (Fig. 2.20(a)) and d-α correlation spectra (Fig. 2.20(b)), respectively. The populations of the particle-unstable states were extracted by integrating the experimental yields over the range of $q$ dominated by the corresponding resonance. The temperature has been extracted using equation 2.8 from the ratio of yields of $^8Be_{g.s}/^8Be_{3.04}$ and is found to be $T = 2.2 \pm 0.5$ MeV. Similarly, the temperature has been extracted from the ratio of yields of $^6Li_{2.186}/^6Li_{4.31}$ and is found to be $T = 2.6 \pm 0.4$ MeV.

**Temperature from double-isotope thermometry:** This method evaluates the temperature of equilibrated nuclear regions from which light fragments are emitted using the yields of different light nuclides. In this scheme, originally proposed by Albergo et
al. [82] based on grand canonical ensemble, the isotope yield for a system in chemical and thermal equilibrium can be related to temperature $T_{iso}$ via the expression

$$T_{iso} = \frac{B}{\ln(aR)} \quad (2.9)$$

where ‘$R$’ is the ground state fragment yield ratio, ‘$B$’ is the binding energy parameter, and ‘$a$’ is the statistical weights of the ground state nuclear spins. Expression for $B$, $a$ and $R$ are

$$B = BE(A_i, Z_i) - BE(A_i + \Delta A, Z_i + \Delta Z) - BE(A_j, Z_j) + BE(A_j + \Delta A, Z_j + \Delta Z) \quad (2.10)$$

$$a = \frac{[2S(A_i, Z_i) + 1]/[2S(A_j, \Delta A, Z_j + \Delta Z) + 1]}{[2S(A_i, Z_i) + 1]/[2S(A_i + \Delta A, Z_i + \Delta Z) + 1]} \times \left( \frac{[A_j/(A_i + \Delta A)]}{[A_i/(A_i + \Delta A)]} \right)^\gamma \quad (2.11)$$

$$R = \frac{[Y(A_i, Z_i)/Y(A_i + \Delta A, Z_i + \Delta Z)]}{[Y(A_j, Z_j)/Y(A_j + \Delta A, Z_j + \Delta Z)]} \quad (2.12)$$

Here, BE($A_i,Z_i$), $S(A_i,Z_i)$ and $Y(A_i,Z_i)$ are the known binding energy, ground-state spin and the total yield of the fragment with mass $A_i$ and charge $Z_i$, respectively. The value of $\Delta A$ and $\Delta Z$ are chosen to be same for both $i^{th}$ and $j^{th}$ fragment pairs [82]. The value of the exponent $\gamma$ is 1 or 1.5 depending on the assumption of surface or volume emission, respectively. In order to remove the coulomb effects in determining the temperature using double-isotope thermometer, we have taken system with $\Delta Z=0$ and $\Delta A=1$, which is the most reliable thermometer [83]. The temperature has been calculated, assuming $\gamma$ to be 1 (surface emission), using equation 2.9 and from the isotopic yields of $p$, $d$, $t$, $^3$He and $\alpha$. The temperature of hot composite $^{32}S^*$ was estimated to be $2.6 \pm 0.2$ MeV from the double isotopic yields of $(p, d)$, $(^3$He, $\alpha)$ and $2.4 \pm 0.3$ MeV from the yields of $(d, t)$, $(^3$He, $\alpha)$, respectively.

Thus, temperatures of excited composite $^{32}S^*$ formed in the nuclear reaction $^{20}$Ne $+$ $^{12}$C have been estimated using different thermometric techniques. The experiment was performed in a single run to minimize the contributions of systematic errors. The
estimated temperatures are shown in Fig. 2.23 and their weighted average value (2.6 ± 0.1) is shown by solid line. From Fig. 2.23 it is evident that temperatures estimated by different techniques are consistent within the limits of experimental uncertainties for the present system [70].

2.4.4 Performance test of final telescopes

The experiment was performed at the BARC-TIFR 14UD Pelletron Accelerator Laboratory, Mumbai, using 77 MeV $^{12}$C ion and 75 MeV $^{13}$C beams on a $^{12}$C target (self supported, thickness $\sim$ 90 $\mu$g/cm$^2$). Different fragments have been detected using one final prototype of the final 3-element telescope. The telescope consisted of a $\sim$ 50 $\mu$m $\Delta$E single-sided silicon strip detector (16 channels), $\sim$ 500 $\mu$m $\Delta$E/ E double-sided silicon strip detector (16 X 16 channels) and backed by four CsI(Tl) detectors (thickness $\sim$ 6 cm). Angular coverage of telescope was from 18$^\circ$ to 32$^\circ$. Typical angular resolution of each strip was $\sim$ $\pm$ 0.45$^\circ$. All strips and the CsI(Tl) detectors were read out individually using standard readout electronics (procured from M/s Mesytec, GmbH). Particle identification spectra have been obtained in this experiment have been
shown in Fig. 2.24. It is clear from Fig. 2.24 that very good isotopic identification of the fragments have been obtained upto $Z=6$.

For the present study, event reconstruction technique has also been tested, all detected $2\alpha$ and $3\alpha$ events have been extracted from the inclusive event-by-event data to reconstruct the excitation energy spectra of the respective decays. The $2\alpha$ events originate mainly from (i) decay of particle unbound $^8$Be states and (ii) decay of particle unbound excited states of $^{12}$C ($^{13}$C)$\rightarrow 3\alpha (+n)$ emission, either directly or through the sequential process $^{12}$C ($^{13}$C)$\rightarrow ^8$Be ($^9$Be)$ + \alpha \rightarrow 3\alpha (+n)$. The decay of $^8$Be was identified by reconstructing the $^8$Be excitation energy spectrum for all events in which two alpha particles hit two separate strips within the detector. Fig. 2.25 shows the plot of reconstructed excitation energy spectra of all events of two coincident alpha particles in these two reactions (normalize cross sections along the Y-axis of Fig. 2.25). The peaks at excitation energy $(E_x)$ = 0 MeV correspond to decays of the particle-unstable ground state of $^8$Be $(J^p = 0^+)$ formed in both the reactions; it is seen that the yield is more in the case of $^{12}$C + $^{12}$C reaction. The pronounced bump at excitation energy 0.51
Figure 2.25: Excitation energy of \(^{8}\text{Be}\) reconstructed from 2\(\alpha\) coincidence in both \(^{12}\text{C} + ^{12}\text{C}\) (solid circle) and \(^{13}\text{C} + ^{12}\text{C}\) (solid triangle) reactions. Normalized cross sections along the Y-axis.

MeV observed in the reaction \(^{13}\text{C} + ^{12}\text{C}\) is due to the decay of the 2.43 MeV state in \(^{9}\text{Be}\), which is not at all visible for \(^{12}\text{C} + ^{12}\text{C}\) reaction. The broad peak observed at \(E_x = 1.41\) MeV, is due to the sequential breakup channel of \(^{12}\text{C}\) and is more pronounced for \(^{12}\text{C} + ^{12}\text{C}\) reaction.

The reconstructed excitation energy spectra of \(^{12}\text{C}\) obtained for observed 3\(\alpha\) events have been shown in Fig. 2.26 for the reactions \((^{12}\text{C} + ^{12}\text{C} \) and \(^{13}\text{C} + ^{12}\text{C}\)). The peak at \(E_x = 7.65\) MeV corresponds to second 0\(^+\) level in \(^{12}\text{C}\), known as the Hoyle state. The broad peak near \(E_x = 9.64\) MeV corresponds to 3\(^-\) level in \(^{12}\text{C}\). It is clear from Fig. 2.26 that the relative yields of both these states are more in case of \(^{12}\text{C} + ^{12}\text{C}\) reaction, which might be due to the fact that both target and projectile are alpha cluster nuclei [84].

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2.5 Design and development of mechanical structure of detector array

The mechanical structure of the array consists of two parts; (1) housing of individual telescope and (2) support structure which holds all the telescopes in a particular configuration as per specification. In this section, the details of mechanical design of each telescope as well as the support structure of the array have been discussed.

2.5.1 Single telescope housing

To encapsulate the detectors, in a telescopic mode, a special housing has been designed and fabricated as shown in Fig. 2.27. The fabrication of the mechanical housing of all telescopes were done using a special pure ultra high vacuum grade Aluminum (6061-T6) for smooth fitting of all the elements. The housing was designed and fabri-
cated so as to contribute as small as possible to the dead area of the detector telescope. The entire detector telescope assembly was housed in two separable aluminium boxes and can be reassembling with the help of screws. Two separate slot have been designed for the two Si-strip detectors as shown in Fig. 2.27 (left). The Si-strip detectors have been fixed rigidly in the housing with the help of three holes on the housing frame through which screws were inserted to the threaded hole on the strip frame. To keep the four CsI(Tl) detectors rigidly behind the strip detector (DSSD), the inner volume of the housing has been given a shape similar to the overall shape of four CsI(Tl) detector assembly, i.e., truncated pyramid. The assembly of 4 CsI(Tl) detectors has been held in proper position with the help of a back support plate connected to a long threaded rod as shown in Fig. 2.27 (left). By rotating the rod slowly, the detectors can be placed in proper position. In the inner sides of the housing there are slots of depth 0.8 mm and width 44 mm to take out the kapton of the strip detectors. The outer sides of the housings have been shaped in such a way that when all telescope would be fitted in the form of array, the front surface would form a part of a sphere of radius 20 cm. To attach all housings in the form of a array, a deep slot was kept in the outer side of the walls of the housings, as shown in the side of Fig. 2.27 (left). The complete assembly of a housing with all the detectors (top plate opened) is shown in Fig. 2.27 (right).

### 2.5.2 Support structure of detector array

To put the telescopes in a form of array, a support structure has been designed and fabricated. The telescopes have been put in 5 columns with five telescopes in each except in the middle column; one telescope has been removed from middle of this column for the exit of beam. Shapes of the housings are such that, all the front faces together will form the surface of an imaginary sphere of radius 20 cm. The whole array will be kept on two parallel rails inside a large reaction chamber SHARC [85]. To align the whole array with the beam line axis, arrangement has been kept to
move it vertically and horizontally. Complete assembly of all telescopes along with the detectors has been shown in Fig. 2.28.

2.5.3 Readout electronics and data acquisition system

In this subsection, a general description of the electronics and the data acquisition system will be described. A schematic diagram of the readout electronics for a single strip or channel is shown in Fig. 2.29 and for the typical full electronics for 24 telescopes as shown in Fig. 2.30. The electronic signals from the strip is fed to the pre-amplifier, the output of which is a fast rising differential signal of few millivolts with a long tail of the order of 50 µs or more. The pre-amplifier output is differential. Differential signal of preamplifier has been chosen in order to eliminate the interfering noise, which cancels out due to positive and negative signals of the same signal in differential mode, when the amplifier subtracts the differential reference from the normal signal. The output of the pre-amplifier is then fed to the amplifier for further
Figure 2.28: Complete high resolution charged particle detector array with support structure.

Figure 2.29: Block diagram of electronics used for individual channel.
amplification and shaping. The output of the amplifier is a Gaussian shaped pulse of height $\sim$ a few volts and a width of 1 $\mu$s, which is directly fed to the analog to digital converter (ADC) (maximum of 8 volts, range of ADC) and stored using the data acquisition system. The schematic given above is for a single channel electronics but each Si-strip detector has 16 channels per side, so we have used custom made 16 channels pre-amplifier (MPR-16, differential output) and 16 channels amplifier (MSCF-16, differential input) manufactured by M/s Mesytec Pvt. Ltd, Germany as per our specification. The MSCF 16 channel amplifier has in built TFA (Timing-Filter-Amplifier) - CFD (Constant Fraction Discriminator), for timing and threshold applications. In addition to the energy signal, these amplifiers also generate one OR-logic output of all 16 channels, which has been used for master trigger generation after some logic operation. Then these amplifier signals are fed to 32 channel ADC (Model CAEN V778) for further processing with the help of a Versa-Module Eurocard (VME) data acquisition system (DAQ) developed in-house. For the all CsI(Tl) detectors, we have used custom made 16 channel shaper with timing filter amplifier and constant fraction discriminator (MSCF-16, unipolar header input). Full electronics setup (all parameters of amplifier and the detector bias voltage) of the array as well as the VME-DAQ are remotely controllable via the ethernet.

2.5.4 Status of the high resolution array

Performance test of all elements of the detector array have been completed. The complete high resolution detector array with electronics is shown in Fig. 2.31. The complete detector array with all the elements as well as the electronics have been tested in offline with $\alpha$-source and also using a precision pulsar at 10K rates for continuously 72 hours. Now the array (full or part of it) is being used for physics experiment.
Figure 2.30: Block diagram of electronics for 24 telescopes.

Figure 2.31: Detector array with complete electronics and data acquisition system (DAQ).