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High-Performance Detector System of TR4 Sit at HIRFL

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The update structure and specification of the high-performance detector system is described in this article. It consists of Si multiunit telescopes, IC+PSD+SPD+CsI(Tl) logarithmic density telescopes, projectilelike fragment TOF telescopes, 3×3 and 6×6 CsI(Tl) scintillator arrays, and Si+CsI(Tl) light particle telescopes. The $Z/\Delta Z \sim 50$, $\Delta E/E \sim 0.3\%$ for Si telescopes; $Z/\Delta Z \sim 44.5$, $\Delta x \sim 1.7$ mm for logarithmic density telescope; and $A/\Delta A \sim 86$, $Z/\Delta Z \sim 48$, $\Delta E/E \sim 0.78\%$, $\Delta t \sim 286$ ps for projectilelike fragment TOF telescope focusing with ellipsoidal surface mirror are obtained.

Key words: Si multiunit telescope, PSD telescope, TOF telescope, CsI(Tl) array, LP telescope.

1. INTRODUCTION

The experimental terminal with large-area position-sensitive ionization chambers (TR4) of the heavy ion accelerator in Lanzhou (HIRFL) is devoted mainly to the mechanism studies of intermediate-energy heavy ion reactions. Many experiments have been performed with the TR4 terminal since the inception of HIRFL, and some examples are given below. For the ^{12}C(46.7MeV/u)+^{58}Ni, ^{64}Ni, ^{115}In, and ^{197}Au systems, the studies of the projectile fragmentation processes, transfer reactions, emission of intermediate mass fragments (IMF) and light charged particles, and the correlation between light charged particles and small relative momentum have been carried out. In the peripheral collisions of ^{40}Ar(25MeV/u)+^{27}Al, ^{58}Ni, and ^{115}In systems, the particle-particle correlations, the production

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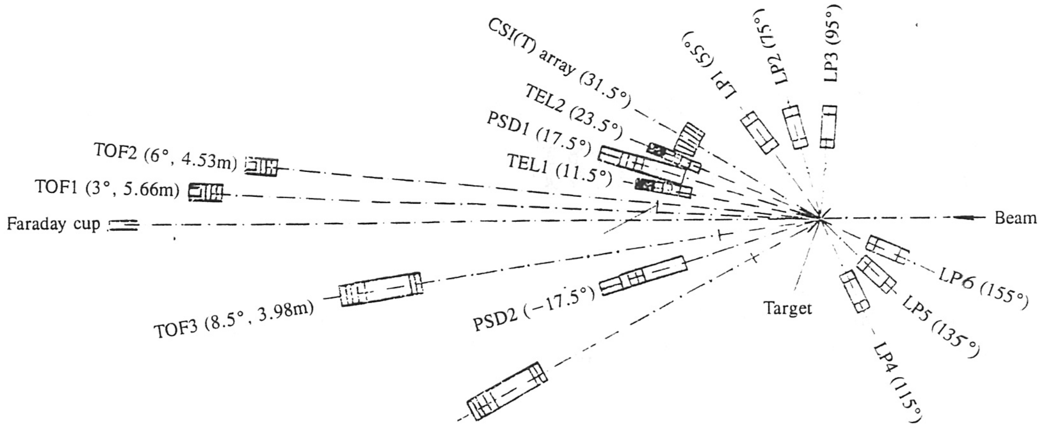

Fig. 1
The experimental setup for the reaction mechanism studies of ^{40}Ar(25MeV/u)+^{27}Al, ^{58}Ni, and ^{115}In systems.

mechanism of the IMFs, and the isotope distributions of projectilelike fragments have been studied. To perform these experiments, many different detector systems with good energy, mass, charge, and timing resolution have been developed, besides the two-dimensional position-sensitive ionization chambers of 80 cm and 140 cm in area. These detector systems include light particle telescopes, multiunit Si telescopes, two-dimensional position-sensitive logarithmic density telescopes for fragments, time of flight (TOF) telescopes for fragments, and 3×3 and 6×6 CsI(Tl) arrays for light charged particles. Figure 1 shows the experimental setup for the mechanism studies of ^{40}Ar(25MeV/u)+^{27}Al, ^{58}Ni, and ^{115}In systems, in which six telescopes for light particles in a large angle region, four multiunit Si telescopes, two position-sensitive logarithmic density telescopes, four TOF telescopes for fragments, and one each of 3×3 and 6×6 CsI(Tl) arrays for light charged particles are used to perform measurements of light particle–light particle, fragment–light particle, and fragment–fragment correlations. The experimental data have been recorded event by event on tapes for further off-line analysis.

2. STRUCTURE AND PERFORMANCE OF DETECTOR SYSTEM

2.1 Multiunit Si Telescope [1]

Each multiunit telescope consists of several totally depleted silicon detectors of different thicknesses. The thickness of the first piece is the thinnest; the following ones become thicker and thicker. The number of the Si pieces varies depending on the energy of the detected particles and the angle region it is placed. For the detection of light charged particles, the CsI(Tl) crystal is placed behind the Si detectors and is read out with the photodiode. The structure of the telescope is shown in Fig. 2(a), and the Al-plated Mylar foil and magnet in front of the telescope are used to shield and deflect the electrons so as to reduce the disturbance. Moreover, the telescope is cooled down to reduce the noise. The Z-distributions of the fragments in ^{12}C(46.7MeV/u)-induced reactions on ^{58}Ni, ^{64}Ni, ^{115}In, and ^{197}Au targets measured with this telescope are shown in Fig. 2(b); the energy resolution is $\Delta E/E\sim0.3\%$, the charge resolution is $Z/\Delta Z\sim50$. The isotopes of elements lighter than N can be separated clearly, and the good timing performance of the telescope makes it usable even in the small angle region ($\sim3°$).

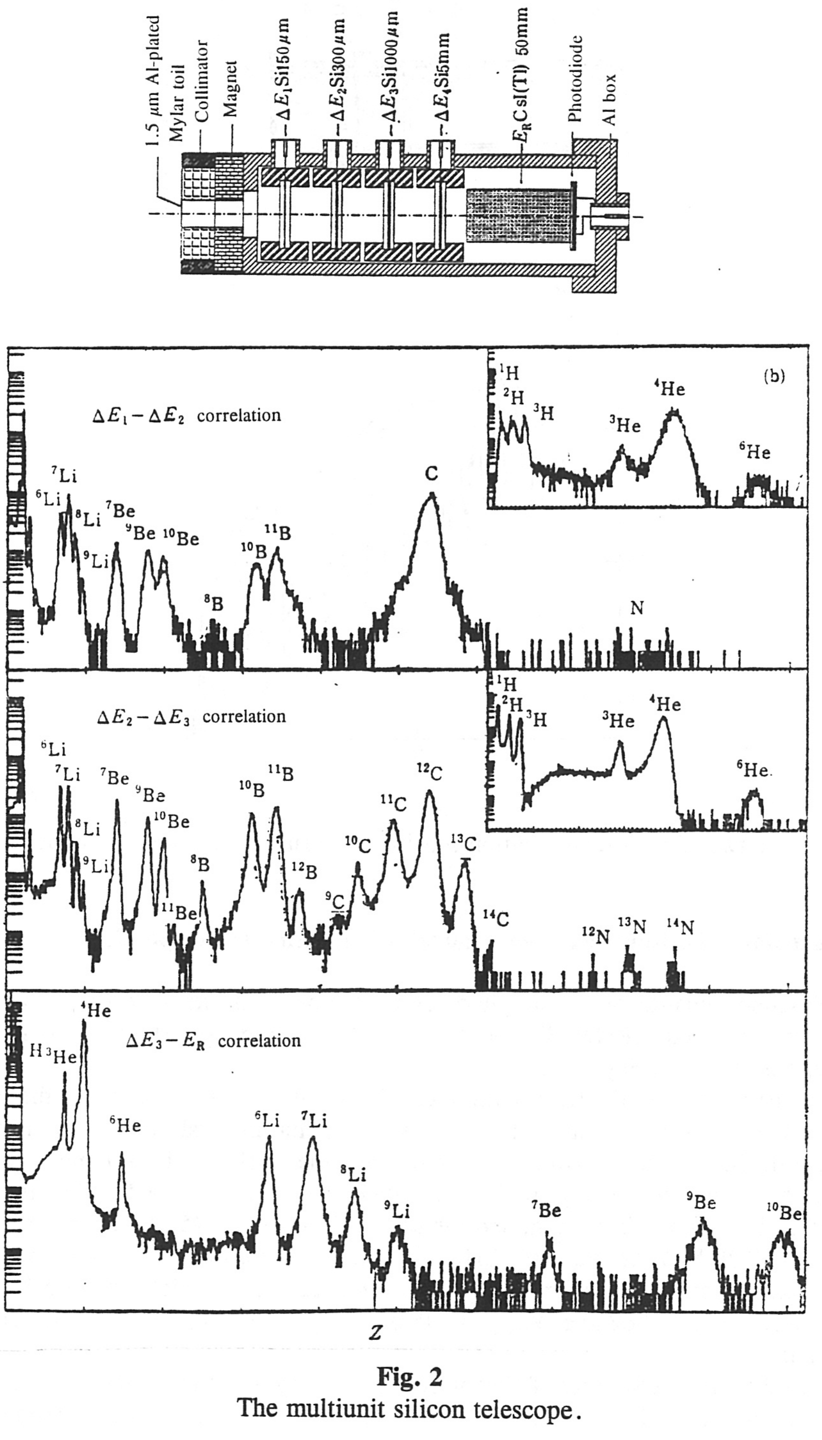

Fig. 2
The multiunit silicon telescope.

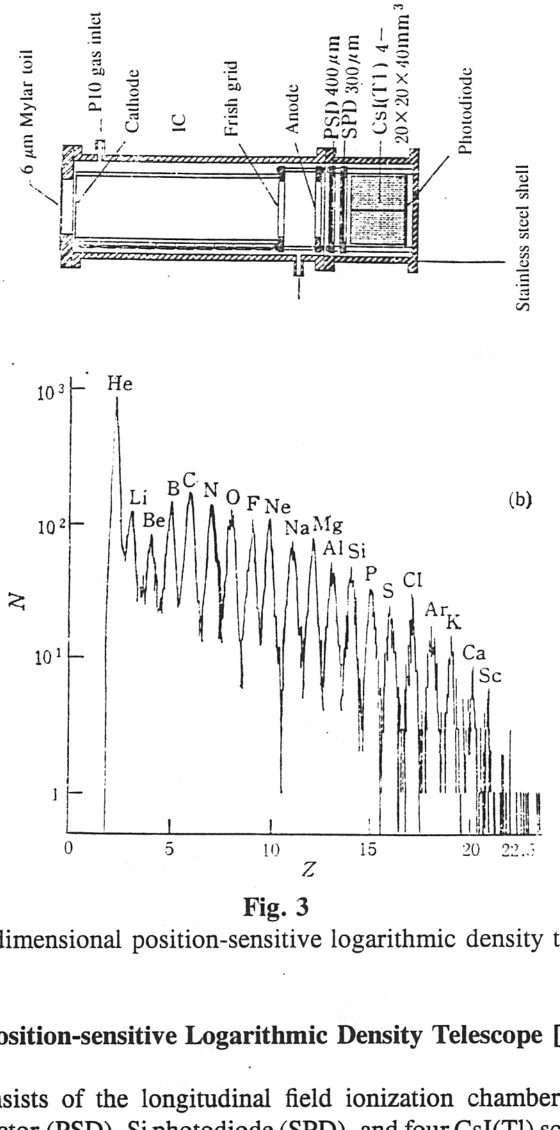

Fig. 3
The two-dimensional position-sensitive logarithmic density telescope.

2.2 Two-dimensional Position-sensitive Logarithmic Density Telescope [2,3]

This telescope consists of the longitudinal field ionization chamber (IC), two-dimensional position-sensitive Si detector (PSD), Si photodiode (SPD), and four CsI(Tl) scintillators. The structure of the telescope is shown in Fig. 3(a).

The entrance window of the IC is 6 μm thick Mylar foil, and the cathode and the Frish grid are Au-plated tungsten wires of ϕ75 μm and ϕ25 μm with a 1 mm interval. The anode uses 1.5 μm Al-plated Mylar foil. The distance between the cathode and the Frish grid is 100 mm, and 11 rings are set in between for field homogeneity, with the resistance being 11 $\times$ 10 MΩ. The distance between the Frish grid and the anode is 10 mm, and the sensitive volume is 45 $\times$ 45 mm^2 $\times$ 110 mm. The operating gas is P10 (90% Ar and 10% CH_4), and the gas pressure is controlled by an automatic pressure stabilizing system. The energy resolution obtained for α particles from a ^{241}Am source is ~3%, at the condition P = 362 torr, $V_{cathode}$ = 1000 V, V_{anode} = 350 V, with the Frish grid connected with the ground.

The PSD detector is a Si sheet of Hamamatsu 3S0364 type with the effective area being 45 $\times$ 45 mm^2 and the thickness being 400 μm. It provides one energy signal and four position signals from which both x and y positions of incident particles can be deduced. With the α particles from a mixed source (^{241}Am-^{210}Po-^{232}Th), the position resolution is measured to be ~1.7 mm, the position nonlinearity is ~0.61%, and the energy resolution is ~2.6%. Furthermore, the position resolution for fragments at 17.5° in ^{40}Ar(25MeV/u)+^{115}In reaction is measured to be better than 1 mm. The SPD detector is a large-area photodiode of Hamamatsu 4S1467 type on which the bias voltage of 100 V is supplied. It functions as a totally depleted transmission-type detector for light particles and as a stopping detector for heavy fragments.

The size of the CsI(Tl) crystal is 20 × 20 mm^2 × 40 mm, and both front and rear surfaces of the CsI(Tl) have been polished. The front end is covered with 1.5 μm Al-plated Mylar foil, the side surfaces are wrapped with 0.1 mm Teflon tape, and the rear end is coupled to a photodiode with the optical cement.

Figure 3(b) shows the Z distribution of fragments in ^{40}Ar(25MeV/u)+^{115}In reaction measured with the PSD telescope at θ_{lab} = 17.5°, and the charge resolution of $Z/\Delta Z$~44.5 is obtained from the peak of the Ar element.

The IC is chosen as the ΔE detector because its thickness is homogeneous and variable, and the energy threshold can therefore be rather low. The PSD telescope with an IC is an ideal detector for IMFs in the intermediate-ener gy heavy ion reactions.

2.3 TOF Telescopes for Projectilelike Fragments [4-6]

The TOF telescope consists of three parts: the starting timing counter, the stopping timing counter, and the detector for particle identification (PID). The PID detector may be either an Si telescope or a mixed-type telescope with an IC as the ΔE detector. Figure 4(a) shows the structure of one such telescope.

The starting timing counter consists of an 8 μm foil of NE102A plastic scintillator, an ellipsoidal mirror, and an XP2020Q photomultiplier (PMT). The ellipsoidal mirror as the light reflector is made of aluminum and its surface is well polished. The NE102A foil is placed at one focal point of the ellipsoid, and the center of the photocathode surface of the PMT is positioned at the other focal point. The incoming particles pass through the hole and hit the scintillation foil, and the emitted light is focused on the center of the PMT's photocathode after the reflection on the ellipsoidal mirror. This leads to narrow distribution of the pulse height, high light collection efficiency, high detection efficiency, and low detection threshold. The optical path lengths for light emitted in different directions are the same, and hence the timing property is greatly improved. This kind of timing counter has advantages of low cost, low threshold, beautiful timing resolution (~144 ns), and high detection efficiency (~100%), and it can work well under a high counting rate. Furthermore, it is more suitable than the microchannel plate and avalanche counter in timing aspect. It has been successfully used as the timing counter in the particle identification of the radioactive products from the ^{40}Ar(25MeV/u)+^{27}Al(~67mg/cm^2) and ^{18}O(50MeV/u)+^{9}Be(~200mg/cm^2) reactions implemented on the radioactive ion beam line of HIRFL.

The stopping timing counter is a parallel plate avalanche counter (PPAC). Both the anode and the cathode are 1.5 μm Al-plated Mylar foils; the interval between them is 2 mm. It has cylindrical shape with a diameter of 75 mm. The gas used is n-hepton and the gas pressure is chosen as 10 mb. The voltage of the cathode is −575 V, and the anode is connected to the ground through low impedance. The stopping timing signal is extracted from the anode.

The ionization chamber (IC) and two Si detectors constitute the telescope for PID. The IC is cylindrical and has a diameter of 75 mm, and the electric field is longitudinal. Both the cathode and the anode are 1.5 μm Al-plated Mylar foils, and the Frish grid uses the Au-plated tungsten wires of 20 μm diameter. The distances between the cathode-grid and the grid-anode are 60 mm and 5 mm, respectively, and the entrance window is a 6 μm Mylar foil that is mechanically supported by a grid made of stainless steel wire. The working gas is P10, and the gas pressure is chosen to be 400 mb. The

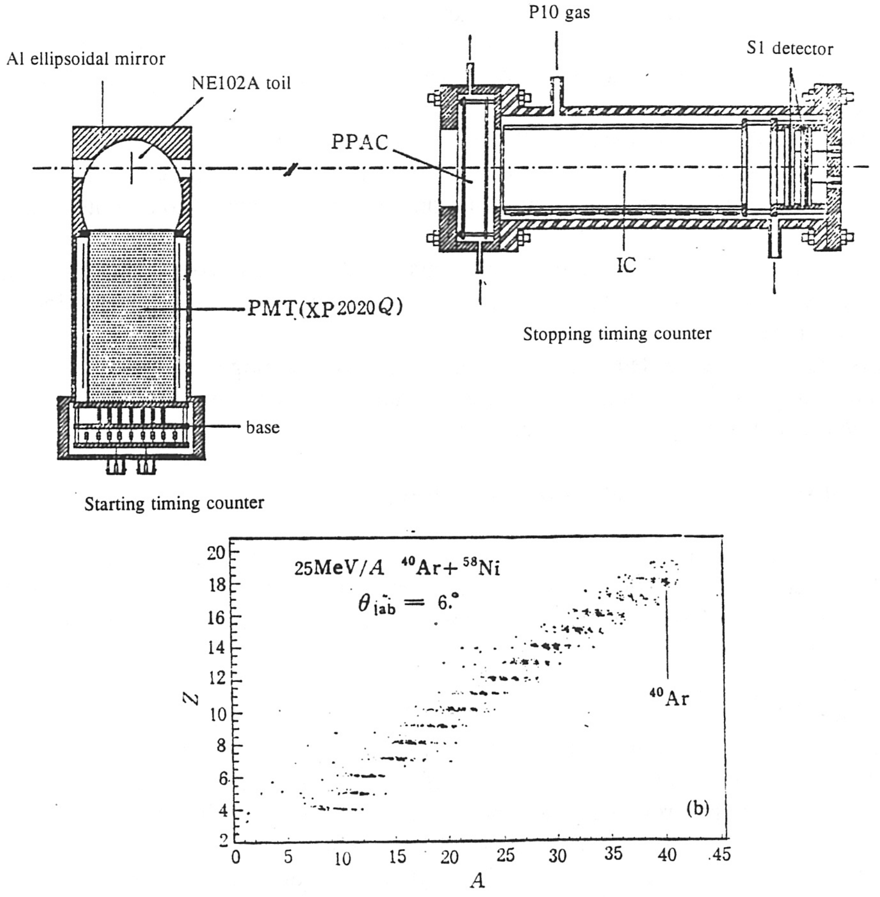

Fig. 4
The TOF telescope for projectilelike fragments.

voltages are set as $V_{cathode}$ = −620 V and V_{anode} = 200 V, and the Frish grid is connected to the ground. The ΔE_1 signal is extracted from the anode.

Figure 4(b) shows the ΔE-TOF scatter plot measured at θ_{Lab} = 6° in the ^{40}Ar(25MeV/u)+^{58}Ni reaction. The flight path of TOF is 4.53 m. The PID detector is silicon telescope, and the stopping timing signal is given by the first piece of Si. The obtained specifications are $A/\Delta A \sim 86$, $Z/\Delta Z \sim 48$, and $\Delta E/E \sim 0.78\%$. The timing resolution for PPAC and for NE102A+PMT are $\Delta t_{ppac} \sim 310$ ps and $\Delta t_{NE102A} \sim 140$ ps, respectively, and the total timing resolution for the detector system is $\Delta t_{TOF} \sim 286$ ps. At θ_{Lab} = 8.5°, the PID telescope uses the IC, and the flight path is 3.98 m. With this kind of detectors, the obtained specifications are $A/\Delta A \sim 67$, $Z/\Delta Z \sim 46$, and $\Delta E/E \sim 0.8\%$. The total timing resolution for the detector system is $\Delta t_{TOF} \sim 344$ ps.

2.4 CsI(Tl) Detector Arrays [7-9]

The CsI(Tl) scintillator read out with a large area photodiode can be used to identify light charged particles and measure their energies with the time-of-crossing zero method. This method has

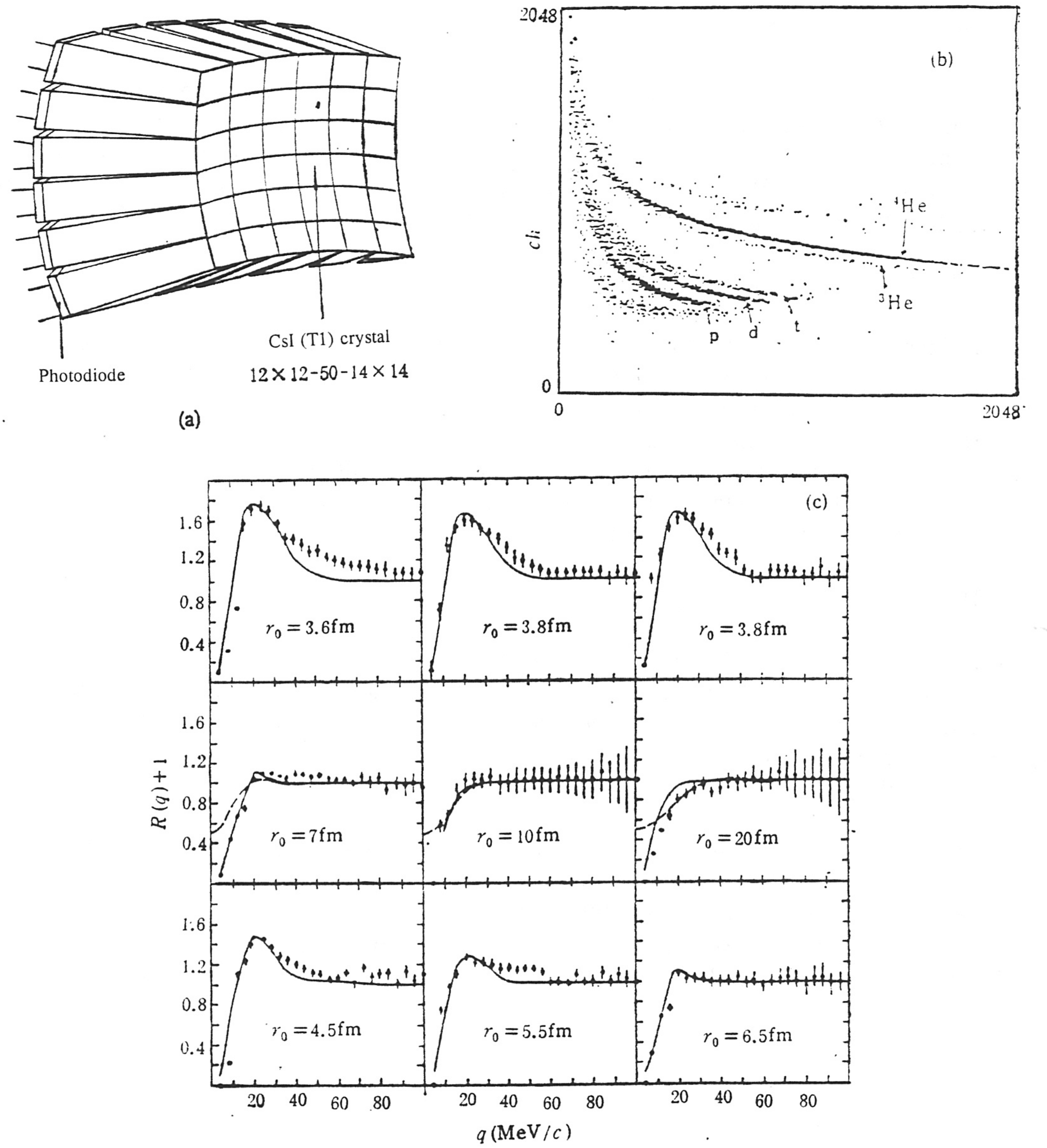

Fig. 5
The 6×6 CsI(Tl) detector array.

advantages in compactness, stability, and reliability. Furthermore, it has a very low energy threshold, which makes it an ideal detector for light charged particles. The 3×3 and 6×6 CsI(Tl) arrays have been used in correlation measurements of light charged particles in the intermediate-energy heavy ion reactions. Figure 5(a) shows the structure of the 6×6 CsI(Tl) array. The 6×6 array is placed in an aluminum box with a 10 mm thick Pb mask in front of it. The output of the photodiode is preamplified and then sent to the main amplifier and the constant fraction discriminator for further coincidence measurement. The scatter plot of light charged particle measured with the 3×3 array in the $^{12}C(46.7MeV/u)+^{58}Ni$ reaction is shown in Fig. 5(b), which gives clear separation of p, d, t, ^{3}He, and α; and Fig. 5(c) shows the obtained p-p correlation function.

2.5 Telescope for Light Particles [10]

The telescope for light particles is the simplified version of the multiunit silicon telescope. It uses a totally depleted Si as the ΔE detector, and a CsI(Tl) scintillator as the residual energy detector. The light isotopes up to He can be well identified using the ΔE-E method. Such kinds of telescopes have been applied in the ^{40}Ar(25MeV/u)- and ^{12}C(46.7MeV/u)-induced reactions to measure the inclusive light charged particles and the correlation between light charged particles and fragments.

3. CONCLUSION

The high-performance detector system has been developed according to the requirements of experiments and has been used successfully in many experimental measurements. The emphasis is put on the starting timing counter, which is better than MCP and PPAC. The coupling of the NE102A with fast light emission time ($\sim$2ns) and the XP2020Q with fast response time ($\sim$2ns) gives it the best timing property. It has been set in the radioactive ion beam facility of HIRFL. The 3×3 and 6×6 CsI(Tl) arrays are still in development and will be very helpful in the measurements of the azimuth distributions and the azimuth correlations.

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