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### **Author**

Maier, M.R.

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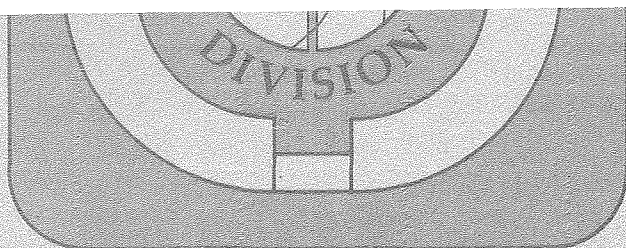
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THE PLASTIC BALL — A MULTI-DETECTOR, LARGE SOLID ANGLE SPECTROMETER  
WITH CHARGED PARTICLE IDENTIFICATION FOR THE BEVALAC

M. R. Maier,\* H. G. Ritter,\* and H. H. Gutbrod

Gesellschaft für Schwerionenforschung, Darmstadt, West Germany,  
and Lawrence Berkeley Laboratory, Berkeley, California

Summary

For the study of central relativistic nuclear heavy ion collisions, which are characterized by the emission of a large number of particles, one needs a detector which covers a large solid angle —  $4\pi$  if possible — and which is capable of identifying charged particles. The high multiplicity requires a large number of detectors, and the need for charged-particle identification requires a measurement of the energy loss, and the total energy for each particle detected.

The spectrometer consists of 815 detector modules, which cover 94% of  $4\pi$ . The geometry of these modules has been taken from the Stanford crystal ball detector for  $\gamma$ -rays — with minor modifications. This geometry is suited for the high multiplicities of particles emitted in relativistic heavy ion collisions. The dimension of the individual elements have been chosen to stop 240 MeV protons. Above this energy reaction losses start to dominate, so that the light output of a scintillator would no longer be a true indication of the energy. Out of 100 charged particles, 94 will hit the Plastic Ball, 87 will fire a detector element, and 80 will be identified uniquely.

For the individual detector modules we have used the "Phoswich" idea, by gluing a 4 mm thick  $\text{CaF}_2$  scintillator to a 35 cm thick plastic scintillator (NE114) with the shape of a truncated pyramid, which is viewed by one photomultiplier tube (PM2202B). The extremely different decay times of the  $\text{CaF}_2$  scintillator and the plastic allow us to separate their light output by integrating the signal from the phototube for the first 20 nsec (the "E signal") and then integrating the "delayed" signal for 2  $\mu\text{sec}$  (the " $\Delta E$  signal"). This constitutes a simple low cost detector telescope, which can identify the hydrogen and helium isotopes. We describe the electronic setup to separate the " $\Delta E$ " and "E" signals, and give some test results, which show the separation and identification, of protons, deuterons, tritons,  $^3\text{He}$ , and alpha particles.

Introduction

At the Bevalac a  $\text{CaF}_2$ -plastic scintillator spectrometer is under construction having nearly 98% of  $4\pi$  solid angle acceptance. The spectrometer consists of two systems: the Plastic Ball and the Plastic Wall (Fig. 1).

The Plastic Ball is a  $4\pi$  (96%) particle-identifying, multi-detector system (815  $\Delta E$ -E detector modules) with spherical shape. The Plastic Wall is a  $4\text{ m}^2$  multi-counter array (156  $\Delta E$  detectors) for accurate time-of-flight measurements in the most forward angular range.

The purpose of this  $4\pi$  spectrometer is to detect electronically central relativistic nuclear reactions, by employing appropriate trigger schemes and to analyze the data obtained in a reasonably short time. As can be seen in the streamer-chamber photograph (Fig. 2), a central nuclear collision at relativistic energies is

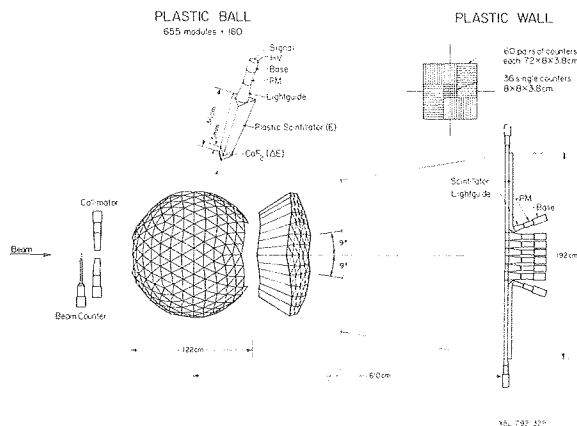


Fig. 1. Schematic drawing of the  $4\pi$  spectrometer, with sketch of one of the  $\text{CaF}_2$ -plastic scintillator modules.

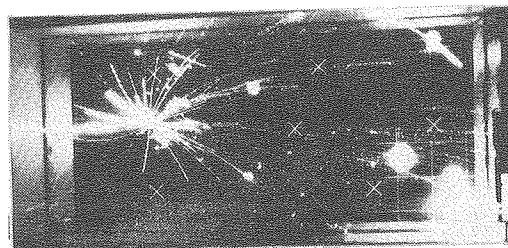


Fig. 2. An  $^{40}\text{Ar}$  nucleus of 1.86 GeV/n hits a Pb nucleus in a violent collision and the characteristic paths of the reaction products are made visible in the streamer chamber. (XBB 750-8445)

characterized by an extremely high multiplicity, where, at 1.8 GeV/n  $^{40}\text{Ar}$  on Pb, multiplicities of up to 120 charged particles have been observed. Thus a detector has to have the capability of detecting and identifying as many particles as possible in high multiplicity events. In the usual high-energy physics approach, this is done with many layers of multiwire proportional counters where multiparticle events are distinguished using the various combinations of wires fired.

The above procedure has been successfully used in combination with magnetic fields for multiplicities of 15 to 30. For the high multiplicities encountered at the Bevalac, this becomes extremely difficult. Therefore, the proposed detector consists of many individual  $\Delta E$ -E telescopes allowing fast analysis. The number of counters necessary to cover  $4\pi$  is related strongly to the multiplicities to be studied, since too few large counters would result in a high probability of multiple firing. Too many small counters for a given size of the  $4\pi$  detector volume, however, would cause a large percentage of the particles to scatter out of the detectors.

The Plastic Ball consists of 815  $\Delta E$ -E detector modules in which the  $\Delta E$  counter is a  $\text{CaF}_2$  crystal and the E counter is a plastic scintillator. Both are optically coupled and read out by one photomultiplier with subsequent separation of the signals by pulse-shape

\*From the University of Marburg, Marburg, W.Germany.

analysis. This design allows one to cover a solid angle of up to 96% of  $4\pi$  and provides particle identification of protons with energies of 30 to 210 MeV, deuterons of 45 to 330 MeV, tritons of 55-390 MeV,  $^3\text{He}$  of 124 to 880 MeV, and  $^4\text{He}$  of 135-980 MeV. Slower or faster particles are registered as such.

The most forward angles ( $0^\circ \pm 9^\circ$ ) are covered with a 150-element, time-of-flight (TOF) apparatus called the Plastic Wall. The inner part of the Wall, covering the angular region from  $0^\circ$  to  $2.5^\circ$ , consists of 36 plastic scintillators, whereas the outer part from  $2.5^\circ$  to approximately  $9^\circ$  consists of 60 double modules of position-sensitive plastic scintillation counters. This arrangement takes into account the higher fragment energies at forward angles. The Plastic Wall serves simultaneously as a trigger counter and specifically allows selecting events when *no beam* velocity particles are present in this forward cone. This kind of central event trigger has not yet been introduced in any of the Bevalac experiments. In addition, certain patterns in the Plastic Wall can be selected and used as a trigger for the Plastic Ball, enabling the study of other events - semi-peripheral collisions, for example.

#### The Plastic Ball Geometry

The geometry of the Plastic Ball was selected with specific consideration of realistic multiplicity distribution measurements made in Experiment 284H with the 80-scintillator multiplicity array. Since the  $4\pi$  detector will be used at various incident energies, its spatial resolution and thus the number and dimensions of individual counters must be suitable to resolve the strongly forward-peaked multiplicity distribution of the reaction particles. They also must be adequate to accommodate increases in multiplicity at larger angles as the projectile energy and/or the target mass are increased.

These factors and certain economic considerations led to adoption of the SLAC Crystal Ball design. This is based on the mathematics of an icosahedron: a 20-faced solid figure in which each face is an equilateral triangle of the same dimensions. In the Plastic Ball, each face is divided into 36 triangles, resulting in the division of the surface into 720 triangles, with only 11 different two-dimensional shapes. Modifications had to be made to details of the entrance and exit ports. A further modification was necessary for the region between  $10^\circ$  and  $30^\circ$  in order to guarantee a good particle identification despite the high multiplicities expected at forward angles. This region is subdivided into 160 modules, with  $1/4$  the solid angle at a radius of 30 inches. This final geometry was chosen from Monte Carlo calculations using a measured multiplicity distribution from the reaction  $^{40}\text{Ar}$  on U at 1.05 GeV/n (Fig. 3). The geometrical

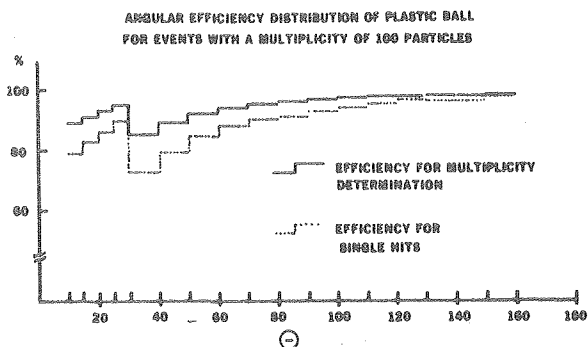


Fig. 3.

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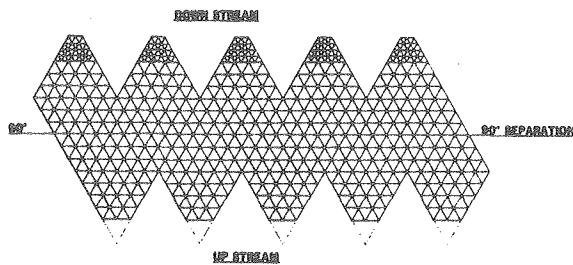


Fig. 4. Geometric arrangement of the Plastic Ball counters (unfolded into a plane).

relationship between the triangles in the Plastic Ball, unfolded into a plane is shown in Fig. 4.

The central spherical cavity of the ball has a 10-in radius; the outer radius is 24 in. The aforementioned surface-division scheme is applied to both the outer and inner surfaces. For assembly the ball is divided into two half spheres.

It was calculated that, for an event with a multiplicity of 100 charged particles,  $\sim 94$  particles will be emitted in the 96% solid angle of the Ball and  $\sim 87$  counters will fire. Eighty counters out of 87 fired counters will see only one particle. Such single firing is necessary for unique particle identification.

#### $\Delta E$ -E Particle Identification

Each detector module consists of a 4-mm thick  $\text{CaF}_2$  crystal as a  $\Delta E$  detector and a 36 cm long plastic scintillator as an E detector (Fig. 1). The calculated relation of energy loss in the  $\text{CaF}_2$  ( $\Delta E$ ) to the energy deposited in the plastic scintillator (E) is shown in Fig. 5 for various particles:  $\pi^+$ , p, d, t,  $^3\text{He}$ ,  $^4\text{He}$ . A measurement of E and  $\Delta E$  separately allows us therefore to identify these particles. The detector length is limited to a size where reaction loss and scattering out effects are still tolerable. The energy loss in the  $\text{CaF}_2$  crystal produces scintillation light with a decay time of 1  $\mu\text{sec}$ . The efficiency of the light output compared to anthracene is 100%. The scintillator, in contrast, has a very short decay time of  $\sim 4$ -5 nsec so that most of the E signal is given off within  $\sim 10$  nsec,

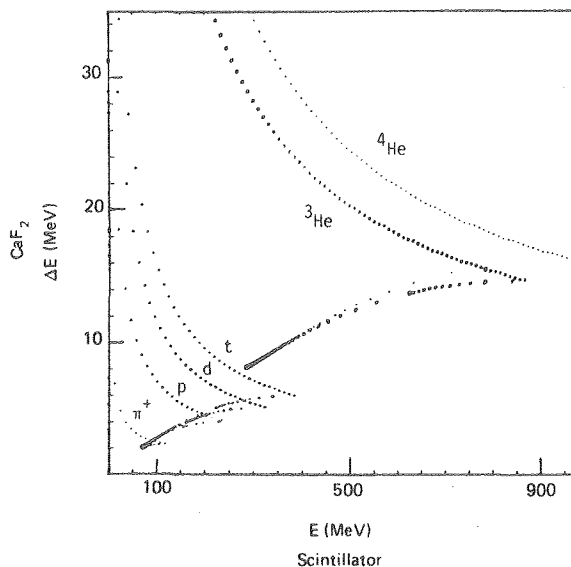


Fig. 5. Calculated  $\Delta E$ -E response (particle separation) of charged particles in a Plastic Ball module.

(XBL 7910-12228)

that is, 100 times faster than from the  $\Delta E$  counter. The plastic light output is 45% of anthracene. However, pulses from the plastic scintillation counters have very long decay-time components besides the main short components, so that after 120 nsec only a pulse-height ratio of 1000:1 can be achieved between fast decay and slow decay. This ratio determines the choice of  $\text{CaF}_2$  as the  $\Delta E$  detector.

The readout of the  $\Delta E$ -E module is done via a conically shaped lightguide (lucite) which couples to a 2-inch, 10-stage photomultiplier (PM-2202B). The phototube was selected for good gain and high linearity up to the high currents which are necessary for the subsequent pulse shape analysis. The gain of the phototube is controlled by a light pulse fed into the light guide via an optical fiber from a pulsed LED. Each module is optically isolated from its neighbors with a thin separator. The module-to-module variation in the  $\Delta E$ -E response has to be very small to ensure efficient data analysis.

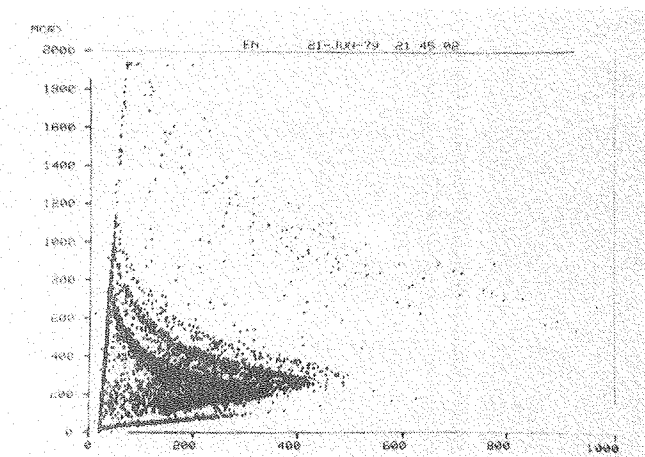


Fig. 6. The  $p$ - $d$ - $t$  separation via  $\Delta E$ -E, as obtained in a test run at the Bevalac with a prototype module. (XBB 790-13584)

Figure 6 shows the  $\Delta E$ -E contour plot (simple dot plot) measured with a prototype module using the reaction  $^{20}\text{Ne}$  on  $\text{Ag}$  at 2 GeV/n. The separation between  $p$ ,  $d$ , and  $t$  is clearly seen, whereas the statistics are not sufficient to show separation between the two He isotopes in this test. The delayed coincidence for the  $\pi^+$  identification has not been applied. The slightly inclined  $\Delta E$  and  $E$  axes are due to incomplete separation between  $\Delta E$  and  $E$  pulses.

#### $\pi^+$ Identification

Positive pions having an energy of 15 to 120 MeV can be identified as well with this type of detector. Figure 7 shows the general scheme for pulse-shape analysis. If a  $\pi^+$  is stopped, the energy loss in the plastic is quickly collected within 20 nsec due to the fast response of the plastic scintillator. The stopped  $\pi^+$  decays after a mean life of 26 nsec, into a 4.12 MeV  $\mu^+$  and a neutrino. Nearly all stopped pions have decayed into  $\mu^+$  within a 120 nsec time period. The  $\Delta E$  signal is charge-integrated after 120 nsec for a duration of 2  $\mu\text{sec}$ . During that time and later the  $\mu^+$  decays into  $e^+ + \bar{\nu} + \nu$  with an  $E_{e^+}$  of up to 53 MeV, with a mean life of 2.2  $\mu\text{sec}$ . The electronics thus looks for a second sharp signal from the plastic scintillator. If this second signal occurs during the 2  $\mu\text{sec}$  integration of the  $\Delta E$  signal, a gate closes its integration time for 50 nsec so as not to spoil the  $\Delta E$ -E identification of the pion. The time of the delayed coincidence is recorded up to 8  $\mu\text{sec}$  so that nearly 90% of all  $\pi^+ \rightarrow \mu^+ \rightarrow e^+$  decays are recorded.

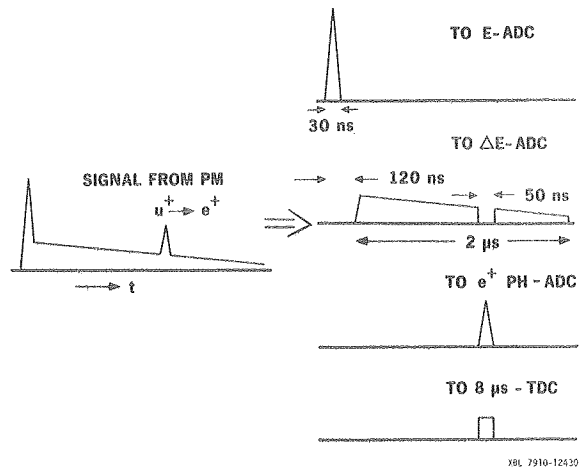


Fig. 7. General scheme of the pulse-shape analysis for the Plastic Ball detector modules.

Since there is a large probability of scattering out for pions, the pulse-shape analysis will be tedious and has to incorporate the investigation of neighboring detector modules. Fortunately, at low energies the pion multiplicity is low as is the charged particle multiplicity so that both products can be determined quite accurately since most detector modules will not have seen another reaction product. At higher energies the additional information of the delayed coincidence time recorded with adequate time resolution allows an immediate determination of the total multiplicity of all stopped positive pions in the  $4\pi$  detector.

#### Ball Processor

The Ball Processor (BOX) will contain those linear gates that will separate the different components (Fig. 7) of the anode signal from the Ball photomultiplier tubes. The time reference for the individual modules will be derived from the anode signals themselves to minimize errors from shifting triggering times from the general trigger. The design of the gate will be similar to the "fast linear gate" of LBL (21  $\times$  158), which has a very good dynamic range. "Energy" and timing signals will be distributed via "mass terminated" cables, as used for the LeCroy ADC's. One unit will contain 24 channels of electronics, to conform to the packaging of the LeCroy ADC's.

#### The Plastic Wall Geometry

The Plastic Wall covers an area of 192 cm by 192 cm and consists of scintillators arranged in two areas: the inner area and the outer area. The inner one is a square of 48  $\times$  48 cm consisting of 36 individual counters each 4 cm thick (see Fig. 1). At a distance of 600 cm from the target in the Plastic Ball this area covers an angular region of about 0° to 2.5°. The outer region extends to  $\sim 9^\circ$  and consists of 60 pairs of position-sensitive scintillation detectors. Provision has been made to move it on rails to a closer distance for accurate time calibration. Comparison of the time of flight at two different precisely known distances allows establishment of an absolute time calibration if the mass of the detected fragment, e.g., the beam particle, is known. The distance of 6 m corresponds to flight times varying from 24 nsec at 800 MeV/n to 65 nsec at 50 MeV/n. The width of the scintillators of 8 cm results in an angular resolution of 0.75°.

The purpose of the inner region of the Plastic Wall is to provide the information necessary to form an event trigger for both the Plastic Ball and the Wall.

