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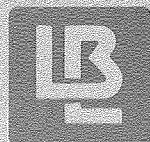
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Author

Maier, M.R.

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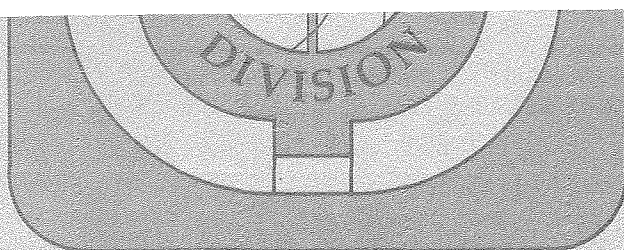
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THE PLASTIC BALL — A MULTI-DETECTOR, LARGE SOLID ANGLE SPECTROMETER
WITH CHARGED PARTICLE IDENTIFICATION FOR THE BEVALAC

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 — 4π 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 4π . The geometry of these modules has been taken from the Stanford crystal ball detector for γ -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 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 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 μsec (the " ΔE 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 " ΔE " and "E" signals, and give some test results, which show the separation and identification, of protons, deuterons, tritons, ^3He , and alpha particles.

Introduction

At the Bevalac a CaF_2 -plastic scintillator spectrometer is under construction having nearly 98% of 4π solid angle acceptance. The spectrometer consists of two systems: the Plastic Ball and the Plastic Wall (Fig. 1).

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

The purpose of this 4π 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

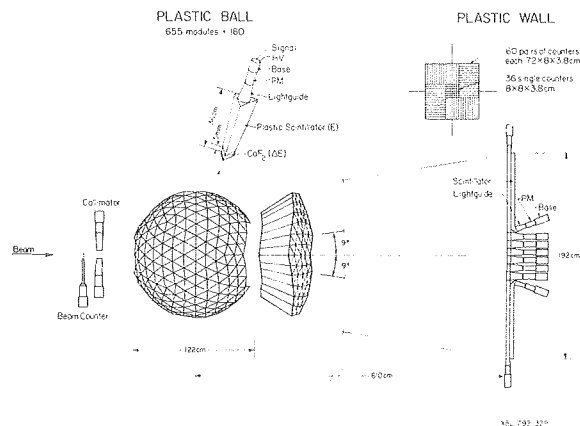


Fig. 1. Schematic drawing of the 4 spectrometer, with sketch of one of the CaF_2 -plastic scintillator modules.

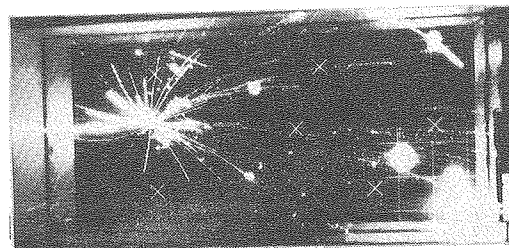


Fig. 2. An ^{40}Ar nucleus of 1.86 GeV/n hits a Pb nucleus in a violent collision and the characteristic paths of the reaction products are made visible in the streamer chamber. (XBB 750-8445)

characterized by an extremely high multiplicity, where, at 1.8 GeV/n ^{40}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 ΔE -E telescopes allowing fast analysis. The number of counters necessary to cover 4π 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 4π detector volume, however, would cause a large percentage of the particles to scatter out of the detectors.

The Plastic Ball consists of 815 ΔE -E detector modules in which the ΔE counter is a 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 4π and provides particle identification of protons with energies of 30 to 210 MeV, deuterons of 45 to 330 MeV, tritons of 55-390 MeV, ^3He of 124 to 880 MeV, and ^4He 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° to 2.5° , consists of 36 plastic scintillators, whereas the outer part from 2.5° to approximately 9° 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 4π 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° and 30° 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}Ar on U at 1.05 GeV/n (Fig. 3). The geometrical

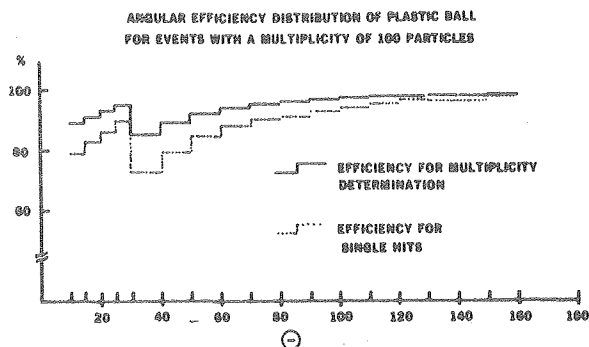


Fig. 3.

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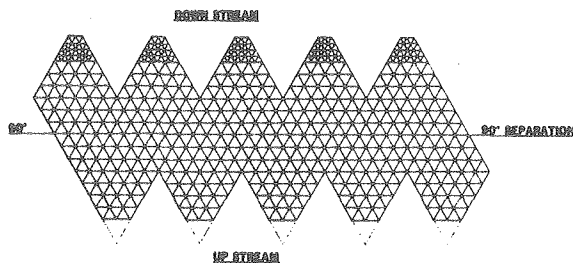


Fig. 4. Geometric arrangement of the Plastic Ball counters (unfolded into a plane).

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, ~ 94 particles will be emitted in the 96% solid angle of the Ball and ~ 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.

ΔE -E Particle Identification

Each detector module consists of a 4-mm thick CaF_2 crystal as a ΔE detector and a 36 cm long plastic scintillator as an E detector (Fig. 1). The calculated relation of energy loss in the CaF_2 (ΔE) to the energy deposited in the plastic scintillator (E) is shown in Fig. 5 for various particles: π^+ , p, d, t, ^3He , ^4He . A measurement of E and ΔE 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 CaF_2 crystal produces scintillation light with a decay time of 1 μsec . The efficiency of the light output compared to anthracene is 100%. The scintillator, in contrast, has a very short decay time of ~ 4 -5 nsec so that most of the E signal is given off within ~ 10 nsec,

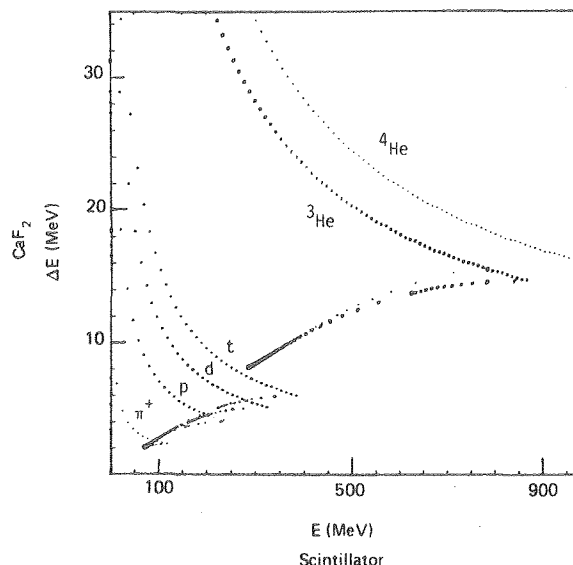


Fig. 5. Calculated ΔE -E response (particle separation) of charged particles in a Plastic Ball module.

(XBL 7910-12228)

that is, 100 times faster than from the ΔE 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 CaF_2 as the ΔE detector.

The readout of the ΔE -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 ΔE -E response has to be very small to ensure efficient data analysis.

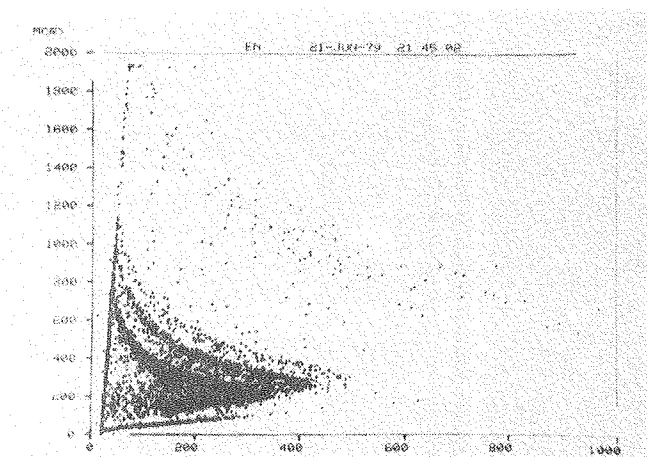


Fig. 6. The p - d - t separation via ΔE -E, as obtained in a test run at the Bevalac with a prototype module. (XBB 790-13584)

Figure 6 shows the ΔE -E contour plot (simple dot plot) measured with a prototype module using the reaction ^{20}Ne on 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 π^+ identification has not been applied. The slightly inclined ΔE and E axes are due to incomplete separation between ΔE and E pulses.

π^+ 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 π^+ 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 π^+ decays after a mean life of 26 nsec, into a 4.12 MeV μ^+ and a neutrino. Nearly all stopped pions have decayed into μ^+ within a 120 nsec time period. The ΔE signal is charge-integrated after 120 nsec for a duration of 2 μsec . During that time and later the μ^+ decays into $e^+ + \bar{\nu} + \nu$ with an E_{e^+} of up to 53 MeV, with a mean life of 2.2 μsec . The electronics thus looks for a second sharp signal from the plastic scintillator. If this second signal occurs during the 2 μsec integration of the ΔE signal, a gate closes its integration time for 50 nsec so as not to spoil the ΔE -E identification of the pion. The time of the delayed coincidence is recorded up to 8 μsec so that nearly 90% of all $\pi^+ \rightarrow \mu^+ \rightarrow e^+$ decays are recorded.

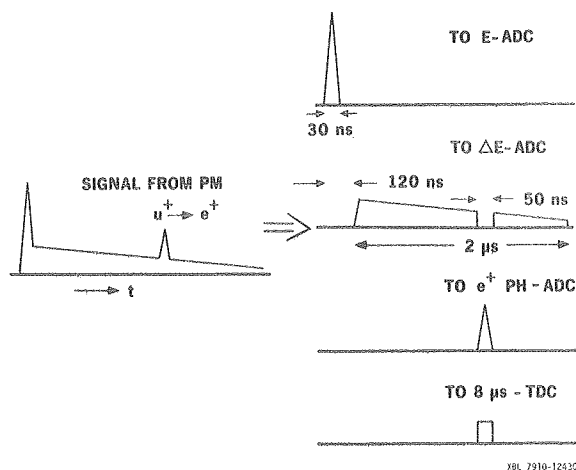


Fig. 7. General scheme of the pulse-shape analysis for the Plastic Ball detector modules.

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 4π 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 (21×158), 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 48×48 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.

Thus its signals are compared with those of the upstream beam counter (see Fig. 1). The fragments are identified by their time of flight and their pulse height in the scintillators. The trigger can thus be defined by selections on fragment velocity and/or on nuclear charge in the 36 counters. The count rate is limited by the upstream counter system which can handle some 5×10^6 part/sec. A fragmentation can lead to several fragments hitting the inner region so a subdivision into 36 individual detectors allows us to identify the degree of fragmentation. The central region is also used to provide information on the beam profile from pulse to pulse. Thus beam spills too far off-center can be eliminated via software.

The Outer Region

The purpose of the Wall's outer region is to detect the reaction products or projectile fragments at angles between 2° and 9° with sufficient angular resolution and sufficient multiparticle detection capability. It is made of 60 position-sensitive double modules, each consisting of two scintillator rods with dimensions of $72 \text{ cm} \times 8 \text{ cm} \times 4 \text{ cm}$ thick. Each scintillator of the double module is viewed by one photomultiplier at different ends (Fig. 8).

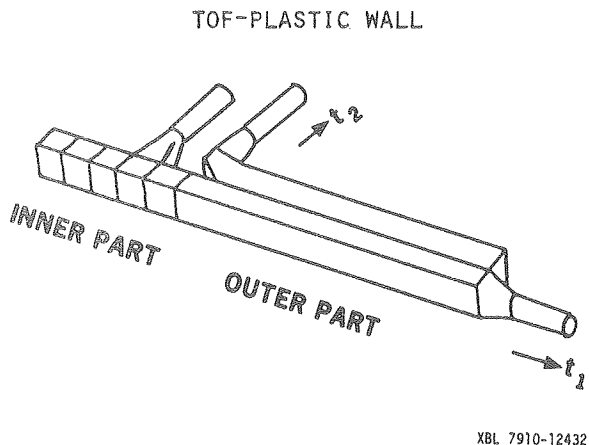


Fig. 8.

The time difference between the two photomultiplier signals gives the longitudinal position of the particle in the double module, the mean time gives the flight time from the upstream detector.

For high energy charged particles the dE/dx in one or both scintillators combined with time-of-flight will allow us to detect Z and E/A . For energies below 120 MeV/n, particles are stopped in the wall. Thus the velocity measurement and the E information determines the mass of the stopped particles. The double coincident dE/dx information for particles above 80 MeV/n, furthermore, allows one to discriminate against neutron and γ response in the scintillators, which is rather important since as many neutrons as protons are expected for light projectiles at forward angles. In tests with beam particles, a time resolution in a double module of 350 psec (FWHM) was obtained.

This work was prepared with the support of the U. S. Department of Energy under Contract W-7405-ENG-48.

Wall Processor

The Wall processor (WOX) will contain a constant fraction trigger to define an optimum timing signal from the anode pulse of the wall photomultiplier tubes. It will also generate an "energy" signal. (The constant fraction is similar to the LBL quad unit, 21×414 , which is very well accepted for its dynamic range — and low cost.) One unit will contain eight channels, and generate eight individual energy signals and a summed signal. It will also have two timing outputs per channel — one goes to the TDC's, the other to a "pattern trigger unit." It will also generate an OR of all timing signals for triggering purposes.

General Electronics Layout

The reference signal for all timing information will be derived from a fast upstream counter, which is surrounded by an active collimator. This signal in coincidence with specific time and/or amplitude conditions in the Wall will be used to generate an event trigger.

The following signals will be available from the Wall for triggering:

- 1) The OR'ed timing signals from all Wall detectors. These will be derived by constant fraction triggers from the anode signals. We measured the time resolution to be about 350 ps FWHM for the energies considered here.
- 2) The analog sum of all anode signals to give an indication about total energy loss in the Wall.

The following Event Triggers are possible:

- 1) Beam + specified pulse height in Wall.
 - 2) Beam + at least one beam velocity particle in Wall.
 - 3) Beam + no beam velocity particle in Wall.
 - 4) Beam + no signal in the Wall.
 - 5) Beam + specified hit pattern in Wall.
 - 6) Beam + specified pattern of beam velocity particles in Wall.
 - 7) Beam + no beam velocity particles + specified pulse height in Wall.
 - 8) Beam + only beam velocity particles in Wall.
 - 9) Beam + specified pattern of non-beam velocity particles in Wall.
- etc.

On receipt of a trigger signal, all "electronic boxes" for the Ball and the Wall will be enabled. Detectors which had a signal will generate the appropriate ΔE , E , and pion signals for the Ball elements, and the TOF and energy signal for the Wall elements. These will be digitized in commercial multi-ADC and TDC systems (LeCroy) and only non-zero information will be written on tape. There will be a total number of 2600 ADC's and 970 TDC's.

The initial experiment is scheduled for summer 1980. The new 4π detector will provide immediate digitized information and it is appropriate instrumentation for fine-step excitation function measurements. Since its detection scheme is based on stopping the particles, its main domain is the investigation of central collisions at low and intermediate Bevalac energies.