Title
PERFORMANCE OF A PHOSWICH DETECTOR ARRAY FOR LIGHT PARTICLES AND HEAVY IONS

Author
Pouliot, J.

Publication Date
1987-12-01

LBL-24396 c.2
Preprint

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Submitted to Nuclear Instruments and Methods, A

Performance of a Phoswich Detector Array for Light Particles and Heavy Ions

J. Pouliot, Y. Chan, A. Dacal, A. Harmon,
R. Knop, M.E. Ortiz, E. Plagnol, and R.G. Stokstad

December 1987

NUCLEAR SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

DISCLAIMER

Performance of a Phoswich Detector Array for Light Particles and Heavy Ions[‡].

J.Pouliot, Y.Chan, A.Dacal[†], A.Harmon, R.Knop, M.E.Ortiz[†], E.Plagnol[*] and R.G.Stokstad.
Nuclear Science Division, Lawrence Berkeley Laboratory,
University of California, Berkeley, CA 94720

ABSTRACT

A phoswich array consisting of 48 ΔE-E elements with sufficient granularity ($\Delta\Theta = \pm 2.5^\circ$) to handle high multiplicity events has been built and used in several experiments. The full angular coverage is a 35° x 35° square cross section of the 4π sphere. Unit charge resolution for $Z \leq 10$ and mass resolution for Z=1 particles has been achieved with a ± 5% energy resolution. Experimental details and the performance of the array are presented and discussed.

‡ Work supported under DOE contracts DE-AC03-76SF00098 and DE-AM03-76SF000326.

† Permanent address: Instituto De Fisica, UNAM, México D.F. 01000, México.

* Permanent address: Institut de Physique Nucléaire, B.P. No 1, 91406 Orsay, France.

1. Introduction

It is well known that the average number of particles produced in a heavy ion collision increases rapidly with the bombarding energy in the intermediate energy region (20-100 MeV/A). A large particle multiplicity can result from multifragmentation of the projectile induced by a peripheral interaction with the target. In most cases, the energetic fragments are kinematically focused in the forward direction, making it possible to measure such quantities as the total longitudinal momentum and total charge of all the emitted fragments. The detector must therefore have good solid angle coverage and adequate segmentation for high multiplicity events, along with particle identification and good energy resolution. Although many arrays [1-3] and prototype elements of arrays have been used successfully in different experiments, those employing phoswich detectors are usually limited to the detection of light charged particles (Z=1 and 2).

In this report we describe a phoswich detector array with 48 elements for the detection of particles with $Z \leq 10$ that combines good geometric efficiency with sufficient granularity to handle high multiplicities. The array has already been used in two different experiments, to be reported later, with a 32.5 MeV/A ^{16}O beam from the 88-Inch Cyclotron at Lawrence Berkeley Laboratory.

2. Experimental Setup

2.1. Individual Phoswich Detector

Many different shapes [1-3] for the individual detector or module have been considered. For our particular applications, a square cross section shape was chosen. This shape provides a larger volume-to-surface ratio than the triangle, thus minimizing the amount of cross-talk between adjacent modules. The square shapes are also easy to machine, which reduces the cost. The detector has a tapered shape toward the front surface (fig. 1), i.e., a truncated pyramid geometry. This way, the effective solid angle is independent of the particle range. Each detector consists of two layers of plastic scintillator having different decay time constants to form a fast/slow phoswich. A fast scintillator (NE-102) of 1 mm thickness is used for the ΔE-element. The remainder of the detector is a slow scintillator plastic (NE-115) of 10.2 cm thickness and can stop protons up to 100 MeV. The front surface of each detector is 1.68x1.68 cm^2, with an angular resolution of $\Delta\Theta = \pm 2.5^\circ$. A 1.9 cm diameter Hamamatsu R1450 photo-tube is glued directly to the back of the slow plastic. An aluminized mylar sheet wrapped around the plastic components reduces light loss and keeps out ambient light.

2.2. The Array

The 48 detectors are configured in a 7 by 7 array (fig. 2). The center is left open to allow the beam to go through the array when placed at 0°. Although it is not possible to close pack regular squares on the surface of a sphere, the gaps left between the rows or columns of detector modules account for only 2% of the 35° by 35° square cross section spanned by the array.

2.3. Data Acquisition

The light output of each photo-multiplier tube is sent to an Lecroy 612A amplifier. Two outputs are taken from the amplifier. One is delayed (200 ns) and then split into two signals that are individually attenuated before being sent to charge-sensitive analog to digital converters (Lecroy 2249A). The other output is used to generate short and long gates, for strobing the ADCs, generating event logic and other purposes. A STARBURST [4] system is used with the phoswich array and allows zero-suppressed CAMAC data acquisition to reduce the volume of data recorded on tape.

3. Performance

Several individual detectors were tested with a beam of 32.5 MeV/A ^{16}O from the 88-Inch Cyclotron at the Lawrence Berkeley Laboratory. An array of 34 detectors was used in an experiment to determine the multifragmentation of the projectiles (^{16}O,^{14}N,^{12}C). Following this, a larger array (41 phoswich detectors) was used in conjunction with two position sensitive multiwire proportional/parallel plate counters (for fission fragments) to investigate particle correlations as a function of momentum transfer for the ^{16}O+^{238}U reaction. The full array of 48 elements is now completed. If for a particular experiment, a larger angular coverage is needed, position-sensitive phoswich [5] detectors can be added on both sides of the array. Although these detectors do not have a multi-hit capability, they are still useful for covering the intermediate angular region, where the multiplicity is reasonably low for high-energy particles or projectile-like fragments.

3.1. Particle Identification

A typical particle identification spectrum (long gate vs short gate) obtained at Θ_{Lab}=6° for the ^{16}O+^{238}U reaction is shown in fig. 3. Charge separation up to Z=8 can be seen. Hydrogen isotopes are also resolved. The energy threshold along the vertical axis is due to the 1mm thick ΔE element. It is approximately 9.0 MeV/A for Z=1 and 2 and increases gradually to 19 MeV/A for Z=8.

3.2. Mapping

In order to obtain particle identification from all 48 phoswich detectors, free-form gates need to be drawn around each of the identified bands, as well as one for the threshold region or base line. If the gates are drawn individually, the number of gates becomes large, e.g., more than 500 in this case. To avoid this, one detector is chosen as a reference and the responses of the other phoswich detectors are then mapped onto that detector's response using a second order polynomial procedure. Fig. 4 shows the superimposed ΔE-E scatter plot of 34 detectors mapped together. It can be seen that good charge resolution is maintained. Therefore, only one set of gates, applied to the mapped outputs, is used for particle identification. Since some resolution is lost for the hydrogen isotopes, a separate mapping for the short gate is used in the p,d and t region of the spectrum to recover the separation of protons from the other hydrogen isotopes.

3.3. Energy Calibration

In the energy range of 10 MeV/A $< E <$ 50 MeV/A, the light output of a given Z from a scintillator can be expressed [5-6] as

$$E \propto F(Z) \times I^{\gamma} \tag{1}$$

where γ is close to unity and I is the light output obtained from the long gate. To investigate the Z response of those detectors, several different beams were scattered by a target. The ECR source at the 88 Inch Cyclotron was used with a gas mixture to obtain four beams (H_2^+,α,^{12}C,^{16}O) for calibration. Different energies were achieved by degrading the beam with appropriate foils.

A fairly simple expression for the Z dependence is used to fit the data:

$$F(Z) = C_1 Z^{C_2} - C_3 \tag{2}$$

where the C_i's are fitting coefficients. The values of C_i are similar from one detector to another. For instance, $C_2 = 0.73$ for most of the detectors with only small deviations for the others (σ=0.04).

The quality of the fit can be improved if γ is allowed to be weakly dependent on Z. From a global fit to all the detectors, we obtained $\gamma = 0.8 + 0.4/Z^{1.6}$. In this case, there are no adjustable parameters and the same expression is used for all the 48 detectors.

In general, the mass (A) dependence is not well known and could not be determined from these four different beams (fig. 5) because, in most cases, Z = 2A, and hence Z and A are not independent. Results reported in the literature [6, fig. 3] were fitted to extract an empirical expression for the A dependence. A good fit was obtained using the following form:

$$G(A) = 1 + \frac{A - A_0}{6A^{0.7}} \tag{3}$$

The function G(A) multiplies the whole expression and can be considered as a correction to the light output when $A \neq A_0$, where A_0 is the most abundant A for a given Z. Although this expression is needed in our case only for hydrogen isotopes, it gives a good result for isotopes up to Z=8. The complete expression for the energy response for our detectors is therefore

$$E(\mathrm{MeV}) = (1 + \frac{A - A_0}{6A^{0.7}})\,(C_1 Z^{C_2} - C_3)\, I^{\gamma}. \tag{4}$$

The light output response from one of the detectors for different particle types is presented in fig. 5. The dashed line corresponds to the thresholds due to the 1mm fast plastic component of the phoswich. The full lines have been calculated using Eq. (4). The energy calibration is valid for all particles with $Z \leq 8$ and within the energy range of 10-40 MeV/A. The energy resolution is ±5%.

During a long run spread over many days, slight gain shifts were observed. They seem to be related to the beam intensity and not, for example, to small changes in temperature of the array with time. Reference values were obtained throughout the runs to evaluate the magnitude of these shifts. The deviations are well within 5% for light particles (Z=1-3) but can reach 10% for the heaviest ions detected in the array (Z=8-10). A light pulser is under construction to monitor and eventually to stabilize on-line the gain of each phoswich detector.

3.4. Multiplicity

Fig. 6 displays the charged particle multiplicity distributions of fragments observed in this array (34 detectors) for two different systems, $^{16}O + ^{12}C$ and $^{14}N + ^{9}Be$ at 32.5 MeV/A. For comparison purposes, both distributions have been normalized at multiplicity one. The contributions due to neutrons and also to charged particles that were not detected by the array either because the deviation angle was to large or its energy was below the threshold of the detectors are excluded.

4. Conclusion

We have built a phoswich array to detect protons, deuterons and tritons and particles with $Z \leq 10$ and with good energy resolution. The array provides a large solid angle and a granularity for handling high multiplicity events. Furthermore, the close-packed geometry covers a wide range of angles and relative momenta between correlated particles. The array has been used both by itself and in conjunction with other types of detectors to perform a variety of experiments with heavy ions at intermediate energies.

Figure Captions

Fig. 1. Side view of a single detector. A schematic layout of the truncated pyramid phoswich detector is shown. The fast scintillator (NE-102) is used for the 1 mm thick ΔE and the slow component (NE-115) is 10.2 cm long. Each detector faces the target at a distance of 19 cm. The frontal area of the detector is 1.68 x 1.68 cm^2, ($\Delta\Theta=\pm 2.5°$). The energy thresholds, due to the thin plastic, range from 9.0 MeV for protons to 19.0 MeV/A for ^{16}O.

Fig. 2. Perspective view of the array.

Fig. 3. Sample phoswich detector spectrum. Identification of the elements up to Neon was obtained with a 32.5 MeV/A ^{16}O beam on a Uranium target at $\Theta_{lab}=6°$. In addition to Z resolution, protons, deuterons and tritons are also resolved.

Fig. 4. Mapped ΔE-E Spectrum. This spectrum is the superposition of all the phoswich detectors after each one has been mapped to the axes of a reference detector. Separate maps are used for the light Z=1 region and for the heavy ion region ($Z\geq 2$). Only one set of gates needs to be applied for the particle identification of any detector. The spectrum is for the $^{16}O + ^{12}C$ reaction.

Fig. 5. Energy Calibration. Light output response of the phoswich detector for different particles in the energy domain of 10-40 MeV/A .

Fig. 6. Multiplicity. The relative yield vs multiplicity of identified charged particles detected in the 34 detector array is shown for two different systems with 32.5 MeV/A beams. The distributions have been normalized for multiplicity one.

References

[1] A.Baden, H.H.Gutbrod, H.Lohner, M.R.Maier, A.M.Poskanzer T.Renner, H.Riedesel, H.G.Ritter, H.Spieler, A.Warwick, F.Weik and H.Wieman. Nucl. Inst. and Meth. A203 (1982) 189-211.

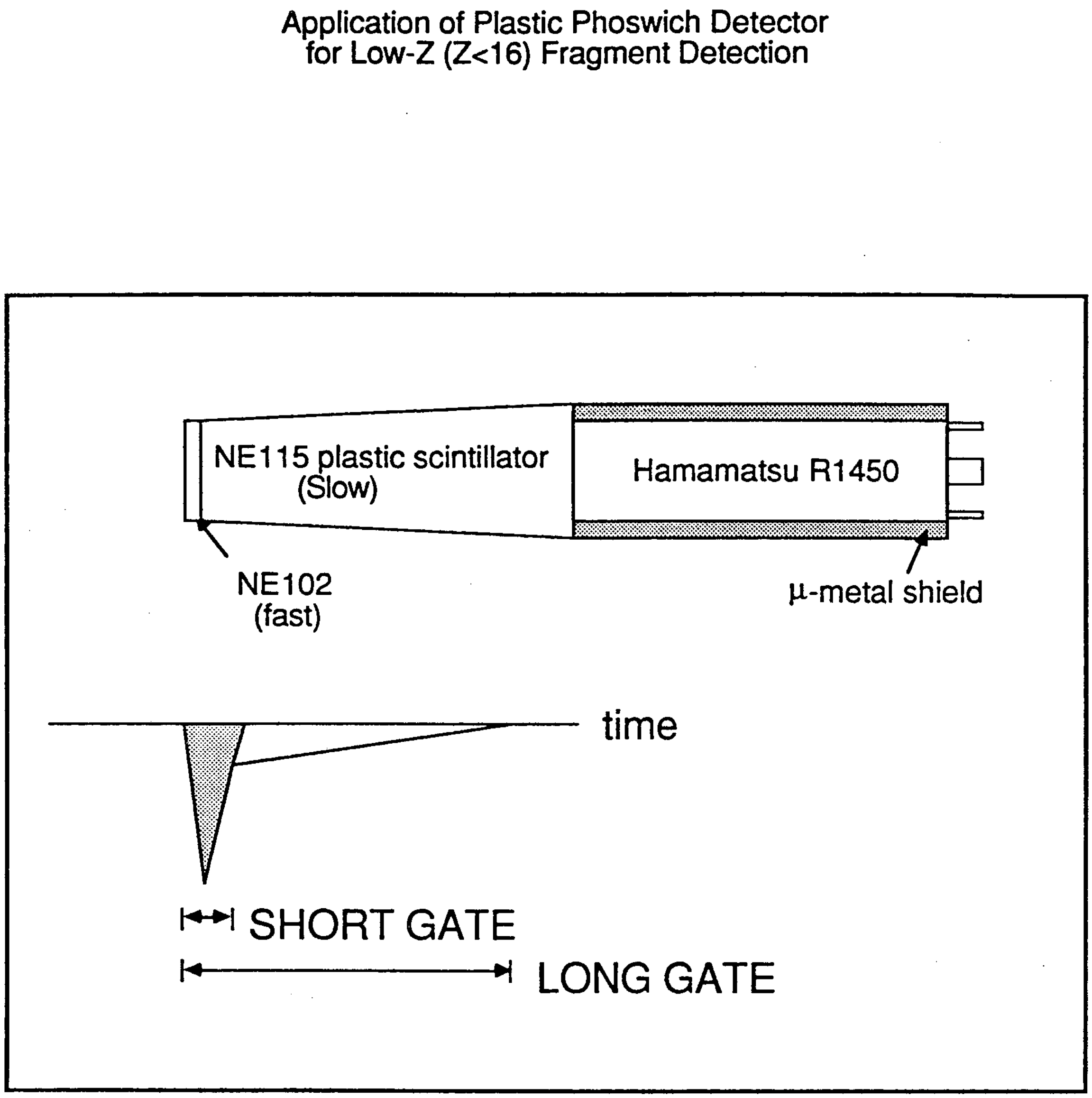
[2] R.Bougault, D.Horn, G.C.Ball, M.G.Steer and L.Potvin. Nucl. Inst. and Meth. A245 (1986) 455-466.

[3] G.D.Westfall, J.E.Yurkon, J.V.D.Plicht, Z.M.Koenig, B.V.Jacak, R.Fox, G.M.Crawley, M.R.Maier and B.E.Hasselquist. Nucl. Inst. and Meth. A238 (1985) 347-353.

[4] W.Rathbun, R.Leres and R.Belshe. Experiment with STARBURST, Proceedings of the Fifth Conference on Real Time Computer Applications in Nuclear Plasma and Particle Physics, NS232 (1987).

[5] Y.D.Chan, E.Chavez, A.Dacal, S.Gazes, B.A.Harmon, E.Plagnol, J.Pouliot, M.E.Ortiz and R.G.Stokstad. Symposium for Nuclear Instrumentation, ACS Meeting, April 1987, Denver, Colorado.

[6] F.D. Bechetti, C.E.Thorn and M.J.Levine. Nucl. Inst. & Meth. A138 (1976) 93-10.



XBL 8711-4684

Fig. 1

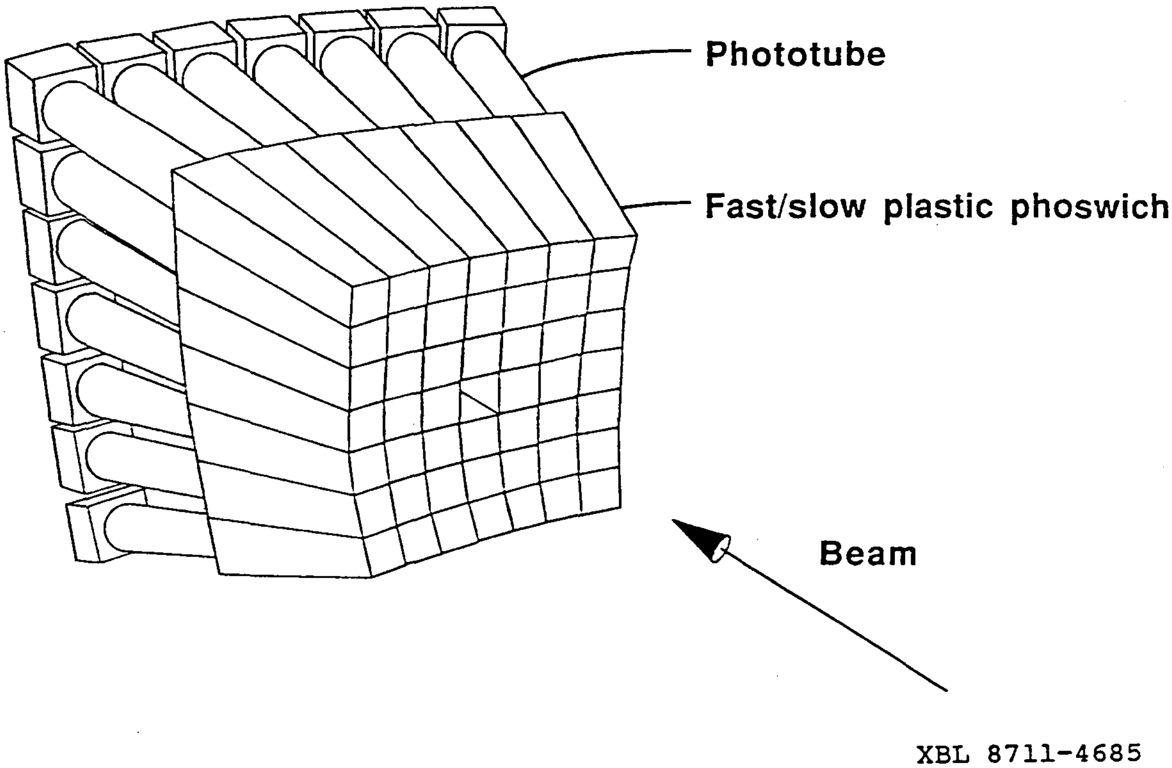
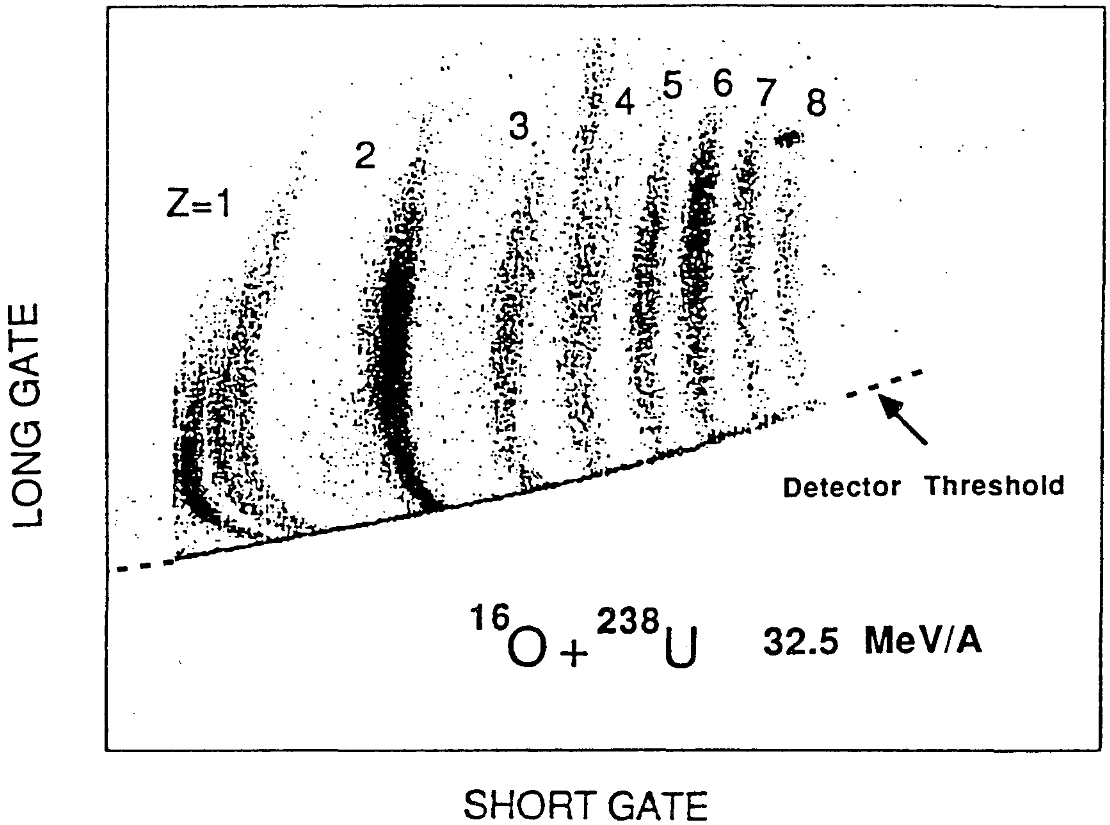
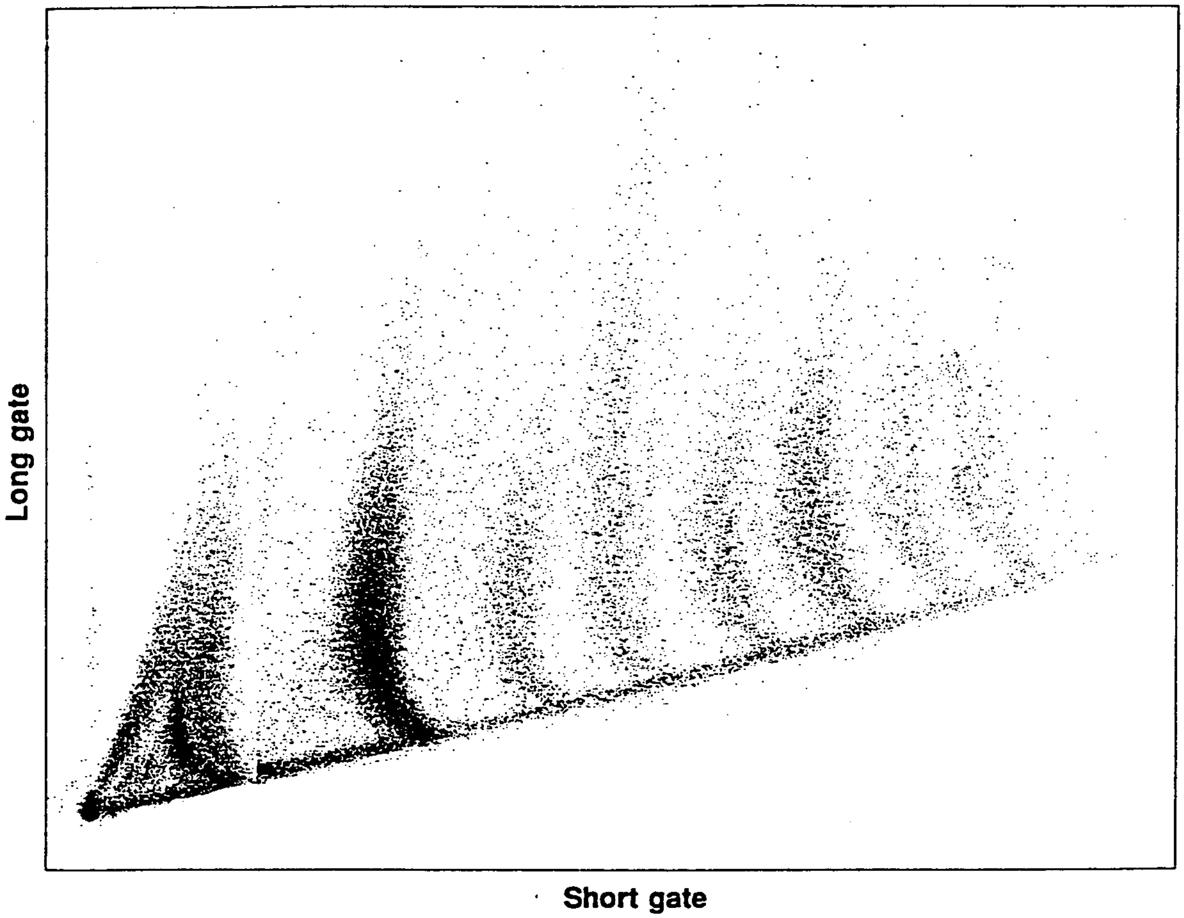


Fig. 2



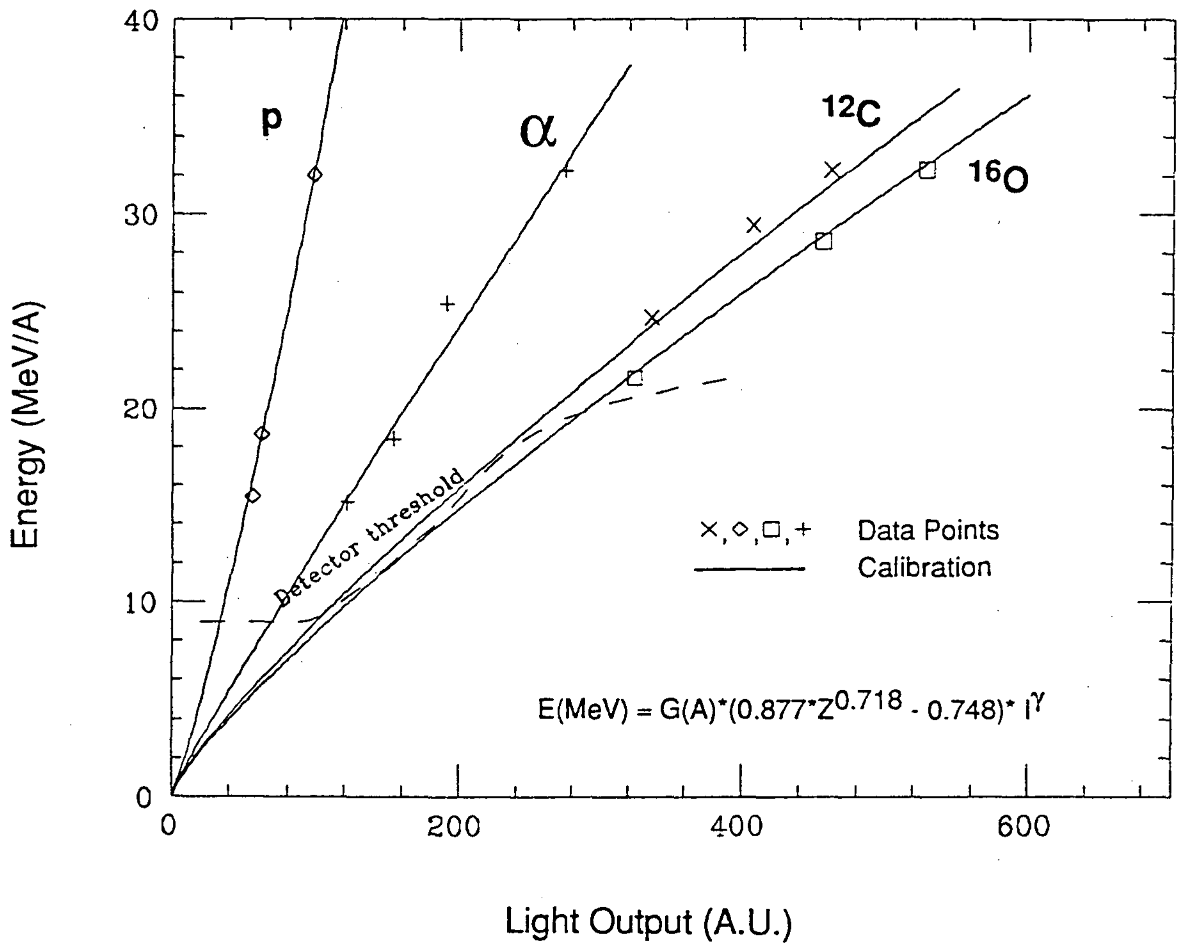
XBL 8711-4686

Fig. 3



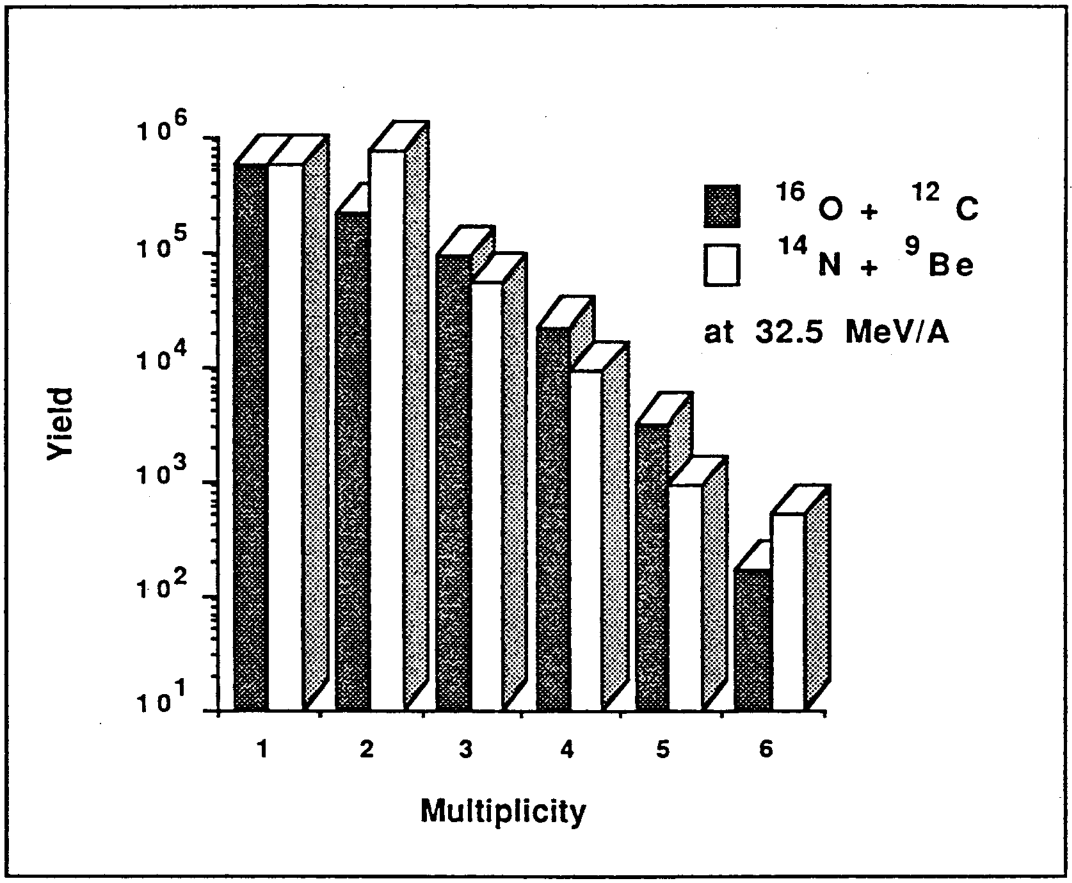
XBL 8711-4687

Fig. 4



XBL 8711-4688

Fig. 5



XBL 8711-4689

Fig. 6