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RESPONSE OF A PROTOTYPE MODULE OF A NEUTRON-MULTIPLICITY CALORIMETER

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Response of a Prototype Module of a Neutron-Multiplicity Calorimeter.

Abstract: The performance of a prototype module of a calorimeter for the measurement of the neutron multiplicity associated with reverse-kinematic heavy-ion reactions has been tested with 14 MeV neutrons. Its response was well reproduced by Monte Carlo (MC) calculations. Utilizing the experimental response, the detection of "groups" of monokinetic neutrons with known multiplicity has been simulated. These simulated results compare favourably with the MC calculations and show little sensitivity to the details of the response function at the lowest amplitudes, where possible noise could arise. A new neutron γ-ray discrimination technique has been successfully used to identify neutrons from 50 and 80 MeV/nucleon heavy-ion induced reactions at the Bevalac.

1. Introduction.

A prototype module of a calorimeter[1)] for the measurement of the neutron multiplicity associated with reverse-kinematic heavy-ion reactions, has been built with a NE110 plastic scintillator block with dimensions (50*25*60)cm^3 optically connected through the (50*25)cm^2 face to a EMI 9823B photomultiplier by means of a lucite light guide. Total internal reflection of the scintillation light was obtained by preserving a plastic-air separation surface optically isolated from the environment.

The anode pulse rise time and the mean pulse duration were measured to be 2.5 and 15 nsec respectively. No significant gain variations were observed at counting rates up to 3 * 10^5 s^{-1}. The background from thermal tube noise and activation in the experimental area was found to contribute appreciably to the singles counting rate below 0.3 MeVee (MeV electron equivalent). The study of the contribution of low amplitude pulses to the calorimetric response was one of the goals of this work. To this end, the detection efficiency and response function of the module were studied with 14 MeV neutrons. The good reproduction of the experimental results with Monte Carlo (MC) calculations will enable us to accurately calculate the detector response at different neutron energies and to rely on the multiplicity calibration derived.

Finally a new n-γ discrimination technique was tested and upper limits were set for the connected signal to noise ratio.

2. Experimental detection efficiency and response to 14 MeV neutrons.

The detection efficiency and response function of the prototype module have been measured for 14 MeV neutrons with the associated charged-particle technique[2)]. The neutrons were produced with the reaction $^3H(^2H,^4He)n$ induced by 200 keV deuterons, and impinged almost perpendicular to the (50*60)cm^2 face of the detector. Concurrent reactions, whose noise was confined at the percent level, were monitored with the methods described in ref.3.

For each trigger pulse from the associated-particle detector, the following parameters were recordered: the associated-particle amplitude pulse, the neutron-detector pulse in

coincidence and their time difference (TOF). The lower level timing discrimination on the neutron detector was set at 0.27 MeVee to eliminate the low energy background (this level is to be compared to the ~ 8 MeVee[4)] yielded by 14 MeV neutrons in NE110). The time resolution of the monokinetic peak of the associated particles was less than 6 nsec FWHM. The dominant contribution to this width is from the 5 nsec transit time of the neutrons across the 25 cm depth of the scintillator. Requiring a time gate of ~ 10 nsec on TOF peak would greatly reduce random coincidences. However, for in-beam measurements of the neutron multiplicity, it will not be possible to gate the calorimeter with so small a time gate, because of the technique employed to discriminate the neutrons from the prompt γ-flash coming from the same reaction[1)]. For these in-beam studies, time gates of about 200 nsec will be needed. Therefore, in the present measurements, the neutron amplitudes without any threshold have been recordered with 200 nsec time gates, to allow a higher random coincidence rate and to study its effect on the calorimetric multiplicity.

To determine the influence of the attenuation of the scintillation light on the shape and the overall amplitude extension of the neutron spectrum, the scintillator was irradiated by the correlated neutrons at different distances from the phototube, see Fig.1.

3. Results.

Only the central part (i.e. the one with the greatest signal-to-noise ratio) was selected for analysis, from the peak of the associated α particle. With such a gate, the systematic uncertainty was less than 2% and the statistical error was negligible. Taking into account all the other sources of error, the detection efficiency measurements with a small threshold have a 4-5 % uncertainty.

Fig.2 shows the module response functions to 14 MeV neutrons impinging: (a) on a small spot near the light guide (see Fig.1); (b) on the centre of the $(50*60)cm^2$ face and (c) far from the light guide. The mid-point amplitude of the spectra varies up to ±5% across the face of the detector. This difference in light attenuation is small enough to rule out any significant contribution to the uncertainty of the calorimetric multiplicity measurement. Furthermore, some compensation occurs between the light collection from near and far flashing events, so that enlarging the dimensions of the neutron irradiation zone (dashed

line in fig.3) shows only small differences with respect to the narrow central spot (solid curve in fig.3) and a mid-point amplitude within 1%.

The experimental response functions for the cases b) and d) are well reproduced by MC calculations[1)] adopting finite-resolution parameter values of 8 and 10 keVee, respectively. Fig. 4 shows the quality of the simulation for the second case. No treatment of light attenuation effects was incorporated since the test shows them to be negligible. In Table 1 are reported the measured and calculated detection efficiencies for the following cases: 1) a threshold of 0.27 MeVee and 2) no significant threshold. The good agreement with the 0.27 MeVee threshold deteriorates somewhat for the very low threshold because of random low amplitude coincidences. An extra 25% low amplitude events contribute to the overall response, whose role in the calorimetric response needs to be clarified.

In fig. 5 the light yield distributions are shown for both the MC[1)] and experimental events with neutron multiplicities of 10, 20 and 30. These distributions were constructed by summing the light yields for the same number of MC and experimental events (inefficient or random-coincidence events included). The mean and HWHM are summarized in Table 2, for two different size neutron irradiation areas (b and d) and two different thresholds. The unprimed (b and d) correspond to no threshold and the primed (b' and d') correspond to discarding events with amplitudes lower than 0.27 MeVee, (i.e. treating them as inefficient events contributing no yield). Good agreement is observed between the experiment and the calculation. The experimental results are relatively insensitive to the 0.27 MeVee threshold, which neglects the light yields corresponding to ~1/4 of the measured events. The good agreement between the calculated and experimental multiplicity is preserved since each discarded amplitude is very small. Therefore, the apparatus is weakly affected by the large number of hits with low light yields, whether these correspond to neutrons or to noise and background. This insensitivity may be very valuable when operating the device in "dirty" experimental environments.

It is worth remarking that the light yields of Table 2 can not be immediately compared with the ones from ref.1, which were obtained for a different sensitive depth and/or different impinging neutron energy.

In fig. 6 a spectrum of the light yields is shown for cosmic rays crossing the prototype module (vertical 60 cm dimension) and a small trigger scintillator placed on the centre of

the (50*60)cm^2 face. By extrapolating the light yield[4] of the measured 14 MeV neutrons, the mean amplitude value of the high yield peak in fig. 6 was determined to be 40.7 MeVee. It represents a high amplitude calibration point, easily available in all laboratories.

4. Neutron γ-ray discrimination.

The proposed[1] technique for the discrimination of neutrons against the prompt γ-ray flash has been applied utilizing a charge integrating 12 channel ADC with separate gates. The syncronizing ("start") pulse to this ADC was derived from a CFTD and the delays between the start and gate openings were obtained primarily by cables. Fine adjustments in the value of the individual delays were made by leading edge retriggering of the logical pulses at different discrimination levels. With a typical rate of change of 0.4 mV/psec in fast logical pulses, the possible few mV drifts in discrimination levels introduce time uncertainties of about 2.5 psec/mV, allowing very stable time intervals in the nanosecond range. Because we were not interested in recording low light yield contributions coming from very slow neutrons, all integration gates were closed 200 nsec after the start while their openings were adjusted to occur 8 nsec after each other from the beginning of the decay of the γ-ray flash. The difference between two successive integrals represents the charge integrated within a time interval of 8 nsec. This integration procedure minimizes the uncertainties related to the gating effectiveness of the leading and trailing edges of the gating pulse.

The digitization of the decay of the pulses due to cosmic rays (no delayed neutrons) is shown in fig.7 where the experimental points and errors represent the first and second moments of the distributions of the charge integrated within the 8 nsec bins, as normalized to the total charge. The curves in fig. 7 represent the fit of the appropriate time function[5] :

$$I(t)= -A\, e^{-\lambda t}\,(1- e^{-\tau t})$$

The evaluated rise time is 4.2 nsec, similar to the experimental one after the long cable delay required for data acquisition, while the fitted decay constant is close to the one of the scintillator: $\lambda= 0.3$ $nsec^{-1}$. The standard uncertainty (shadowed) represents ±5% of the

mean digitized charge.

Similar measurements have been undertaken triggering the prototype module, shielded with 3 mm lead, with the prompt γ-ray flash associated with reactions induced by 50 and 80 MeV/nucleon ^{197}Au beams on heavy targets from the Bevalac at the Lawrence Berkeley Laboratory, University of California. The maximum current amplitudes of the observed prompt γ-ray flashes were not greater than the ones due to cosmic rays (fig.6). With reference to the light calibration of the same spectrum reported at the end of Sect.3, the maximum background subtraction uncertainty in the multiple neutrons light yield is about ±2 MeVee.

In fig.8 the time evolution of large light yields from neutrons is shown for selected events featuring a high and a low prompt γ-ray background. Since only one module was used, any neutron event results from the detection of very few neutrons. The light yield which can be ascribed in fig. 8 to neutrons is 40 to 70 MeVee, while only 7 to 40 MeVee can be attributed to γ-rays. Comparing the shown neutron light yields to 39 [64] MeVee[4)] end-point response of 50 [80] MeV neutrons (expected from the reactions under investigation) it is evident that they represent the detection of only one or two neutrons in the module. This is very near the expected average neutron number per module in the whole calorimeter. Thus, similar signal to background ratios are expected in the future on-line multiplicity measurements.

As far as we are aware this is the first report on the time analysis of electronic pulses carrying a fast background and a delayed information content.

Conclusions.

We have demonstrated that the prototype module of the calorimeter performs adeguately to measure the neutron multiplicity associated with reverse kinematics heavy ion reactions[1)].

In particular, we have verified the insensitivity of the calorimetric response to several common sources of background, the ability of the MC calculation[1)] to reproduce the experimental 14 MeV neutron response and therefore to be used for calibration purposes, and the ability to subtract the prompt γ-ray flash as suggested in ref. 1. The results reported

for this n-γ discrimination measurements seem to be the first presented in the literature.

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Table 1.

	1		2	
	case b)	case d)	case b)	case d)
Exp.	69.9	67.0	94.9	93.1
MC	70.1	69.0	88.8	88.4

Table 2.

Multiplicity	**10**	**20**	**30**
case b) **Exp**	25.9±9.5	52.6±14.0	78.3±17.4
case b') **Exp**	25.6±9.5	52.0±14.3	77.7±17.9
case b) **MC**	26.7±9.7	53.4±14.0	79.5±17.9
case d) **Exp**	23.8±9.8	47.6±13.8	72.0±16.5
case d') **Exp**	23.4±9.9	46.4±14.0	69.8±16.7
case d) **MC**	26.6±9.8	53.2±14.1	79.7±18.0

Captions.

Table 1.- Values (%) of the detection efficiencies for 14 MeV neutrons, measured (Exp) and calculated (MC) with a lower discrimination level of 0.27 MeVee (1) and without any significant threshold (2). Cases b) and d) refer to the ones shown in Fig.1.

Table 2.- Light yields and HWHM uncertainties (MeVee) of events with multiplicity 10, 20 and 30 built from the experimental (Exp) and calculated (MC) response of the calorimeter module. Cases b) and d) refer to the ones shown in Fig.1. Cases b') and d') refer to the same, but discard the light yield of all the experimental events with amplitudes lower than 0.27 MeVee.

Fig.1 - Sketch of the dimensions of the correlated 14 MeV neutron beam impinging on the prototype module. Impact direction is normal to the shaded area. Each one of the four cases (a, b, c ,d) shown refer to the conditions of a specific measurement.

Fig.2 - Experimental response functions of the prototype module to 14 MeV neutrons impinging at different distances from the light guide: (a) close, (b) central and (c) far from light guide, see fig.1.

Fig.3 - Experimental response functions of the prototype module to 14 MeV neutrons for the cases of central small (b) or large (d) irradiation area, see fig.1.

Fig.4 - Experimental and MC simulated response functions of the prototype module to 14 MeV neutrons for the case of central large impact area (d), see fig.1.The finite resolution parameter used in the MC calculation is 10 keVee.

Fig.5 - Light yields distributions for neutron multiplicities of 10, 20 and 30, obtained by summing the yields of as many individual events from the experimental and MC simulated response function of the prototype module to 14 MeV neutrons (impact case b, see fig.1).

Fig. 6 - Spectrum of the cosmic rays crossing the prototype module in coincidence with a small paddle scintillator attached to the centre of a vertical face (50 cm * 60 cm).

Fig. 7 - Time dependence of the pulses due to cosmic rays as digitized by the technique referred in section 4 and fitted by the appropriate time function. The standard uncertainty of the fitted curve is shaded.

Fig. 8 - Time evolution (points) of selected neutron events induced by 50 and 80 MeV/nucleon ^{197}Au beams on heavy targets. The full line curves show the prompt γ-ray flash contribution which must be subtracted from the overall light yield.

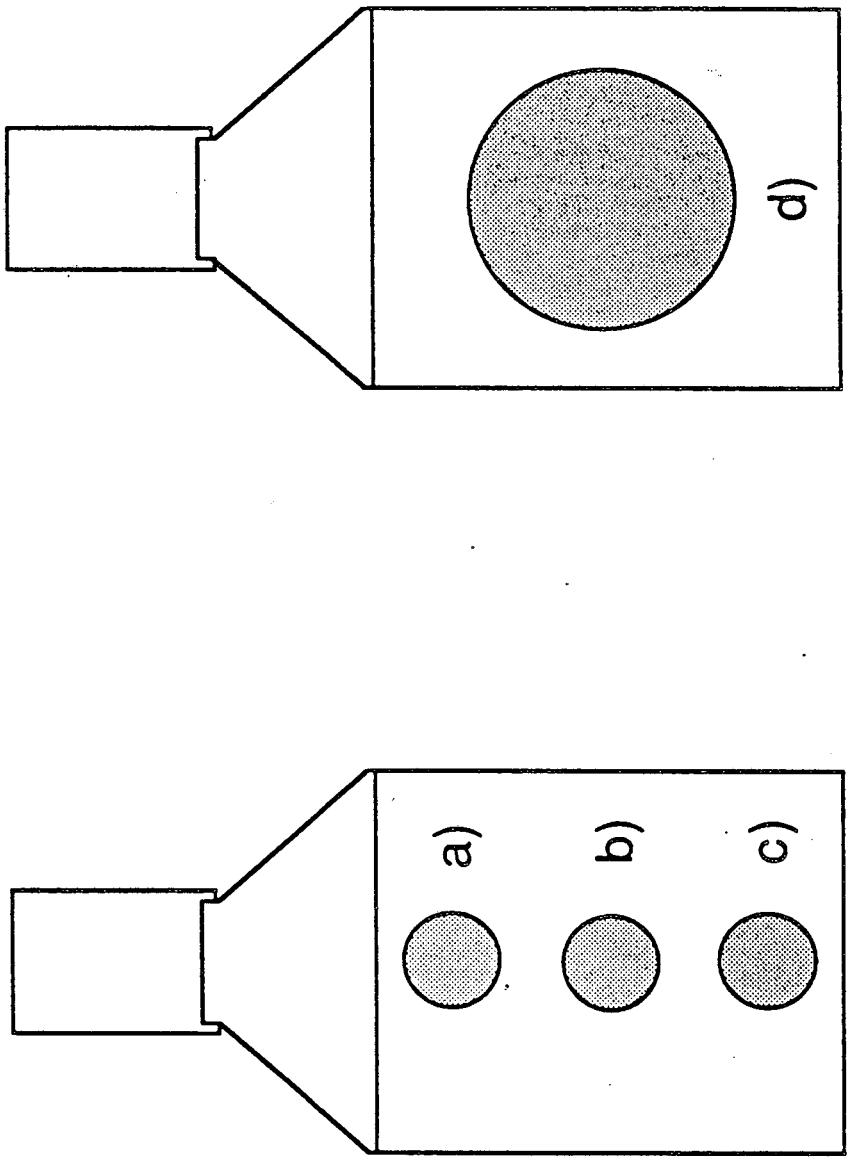

Figure 1

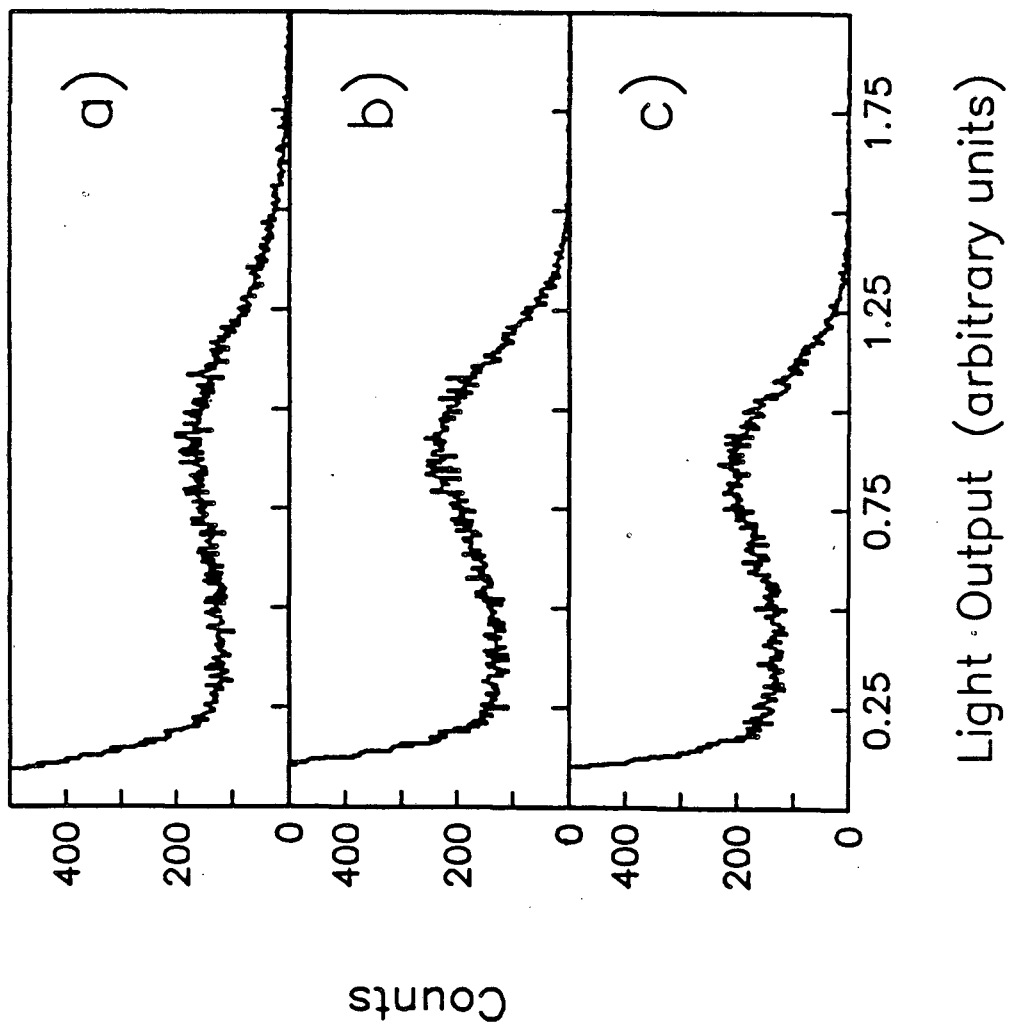
a)
b)
c)
400
200
0
400
200
0
400
200
0
0.25
0.75
1.25
1.75
Counts
Light Output (arbitrary units)

Figure 2

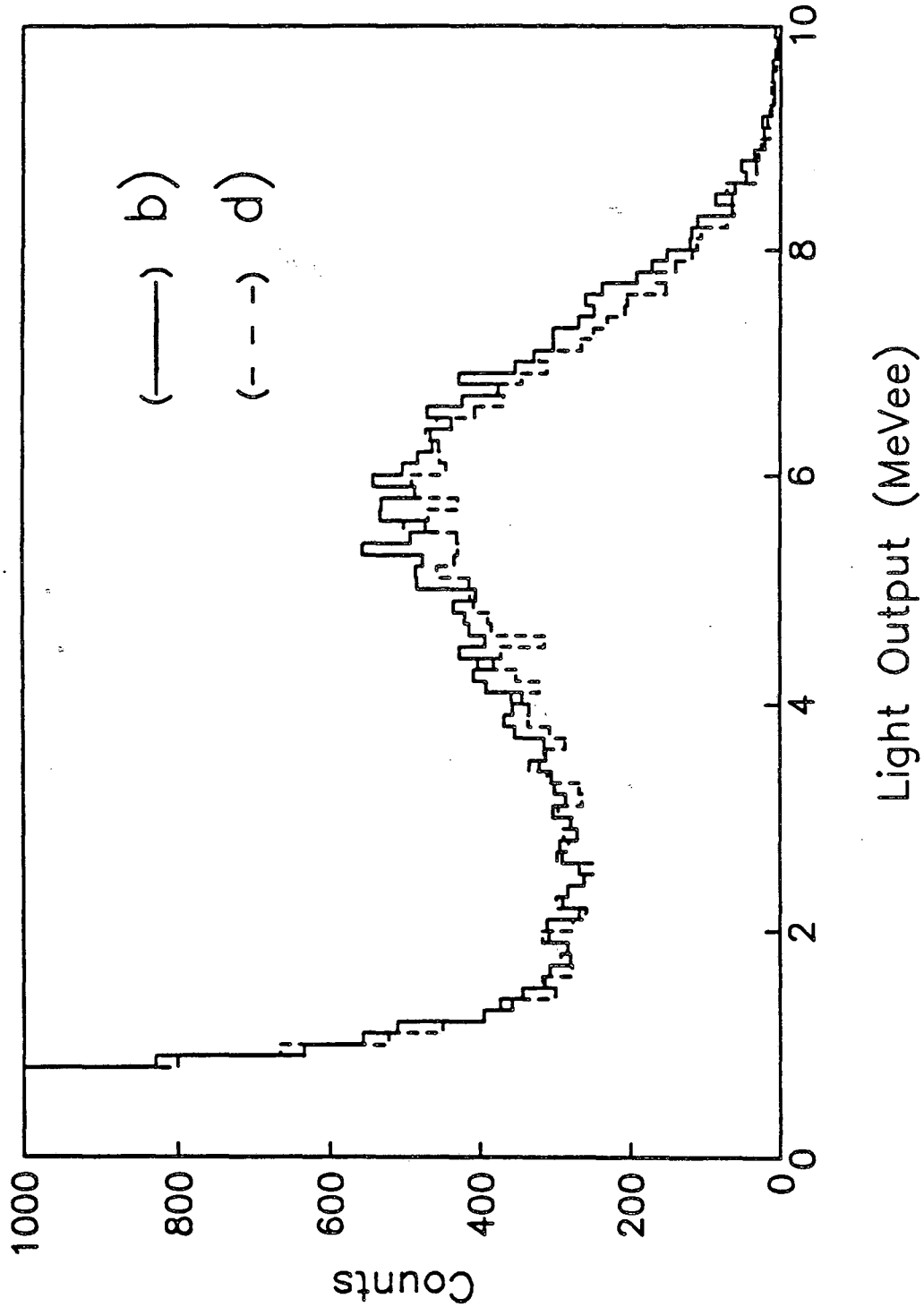

Figure 3

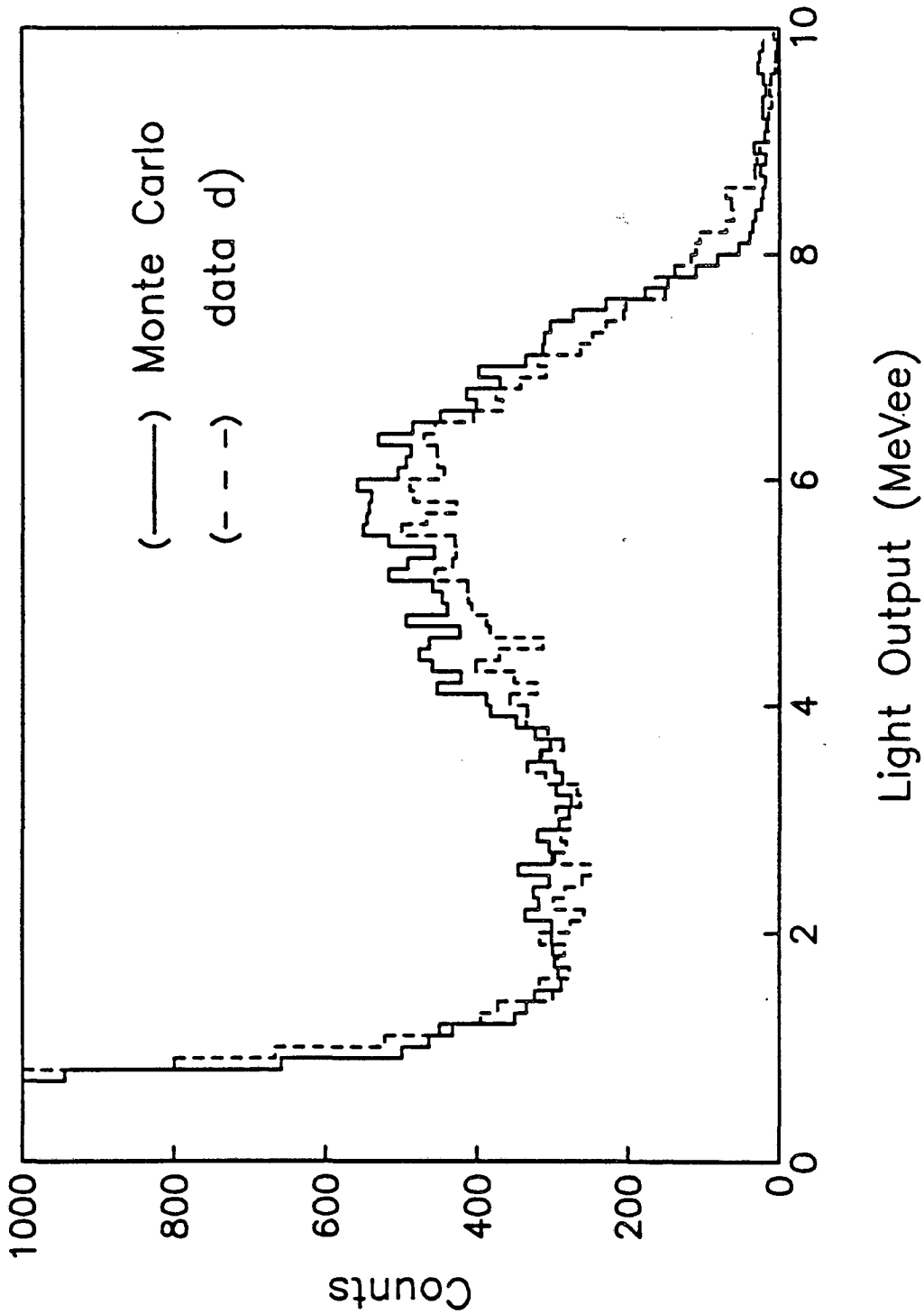
(——) Monte Carlo
(- - -) data d)
Counts
1000
800
600
400
200
0
0
2
4
6
8
10
Light Output (MeVee)

Figure 4

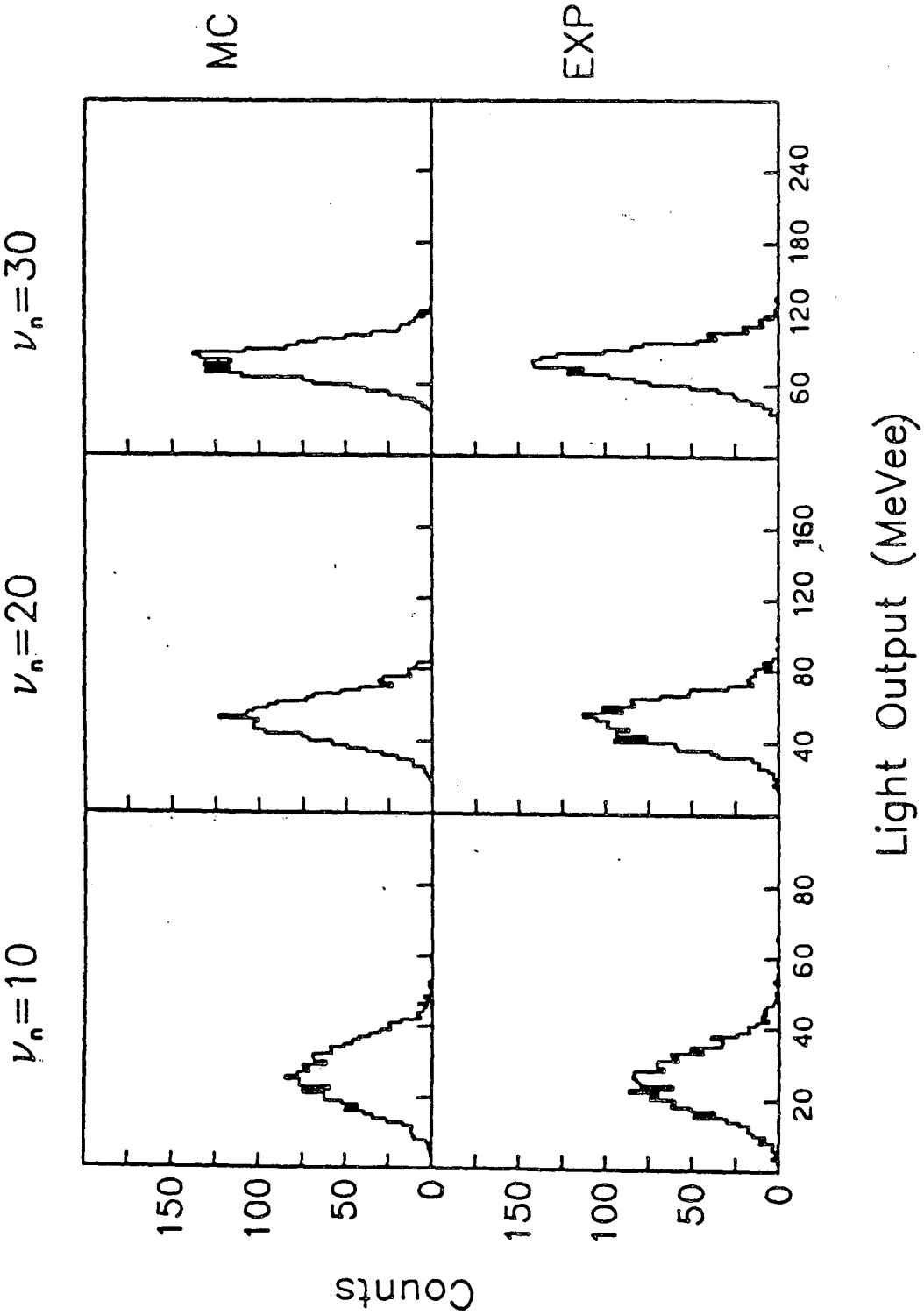
MC
EXP
ν_n=10
ν_n=20
ν_n=30
Counts
150
100
50
0
20
40
60
80
120
160
180
240
Light Output (MeVee)

Figure 5

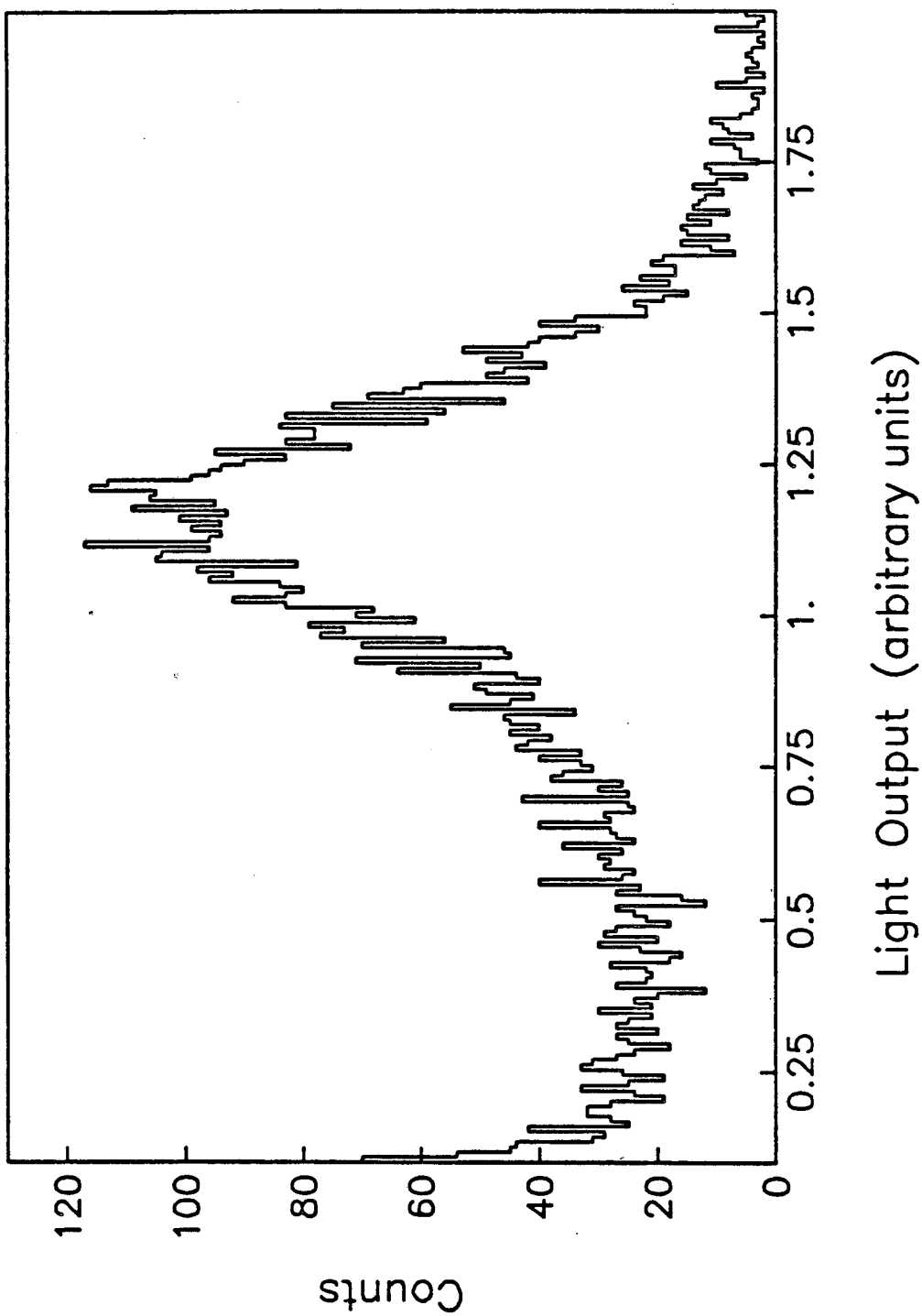
Counts
120
100
80
60
40
20
0
0.25
0.5
0.75
1.
1.25
1.5
1.75
Light Output (arbitrary units)

Figure 6

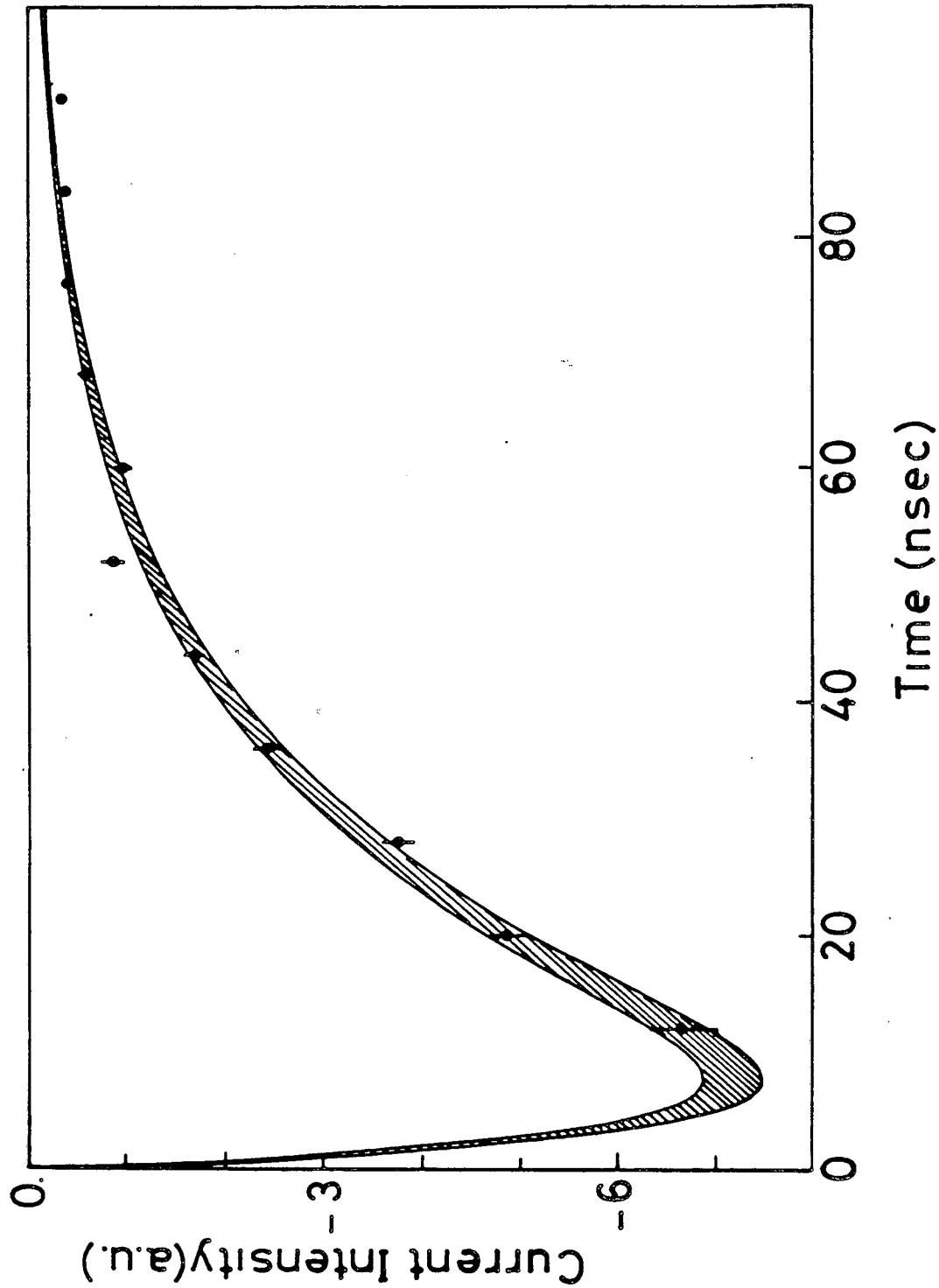

Figure 7

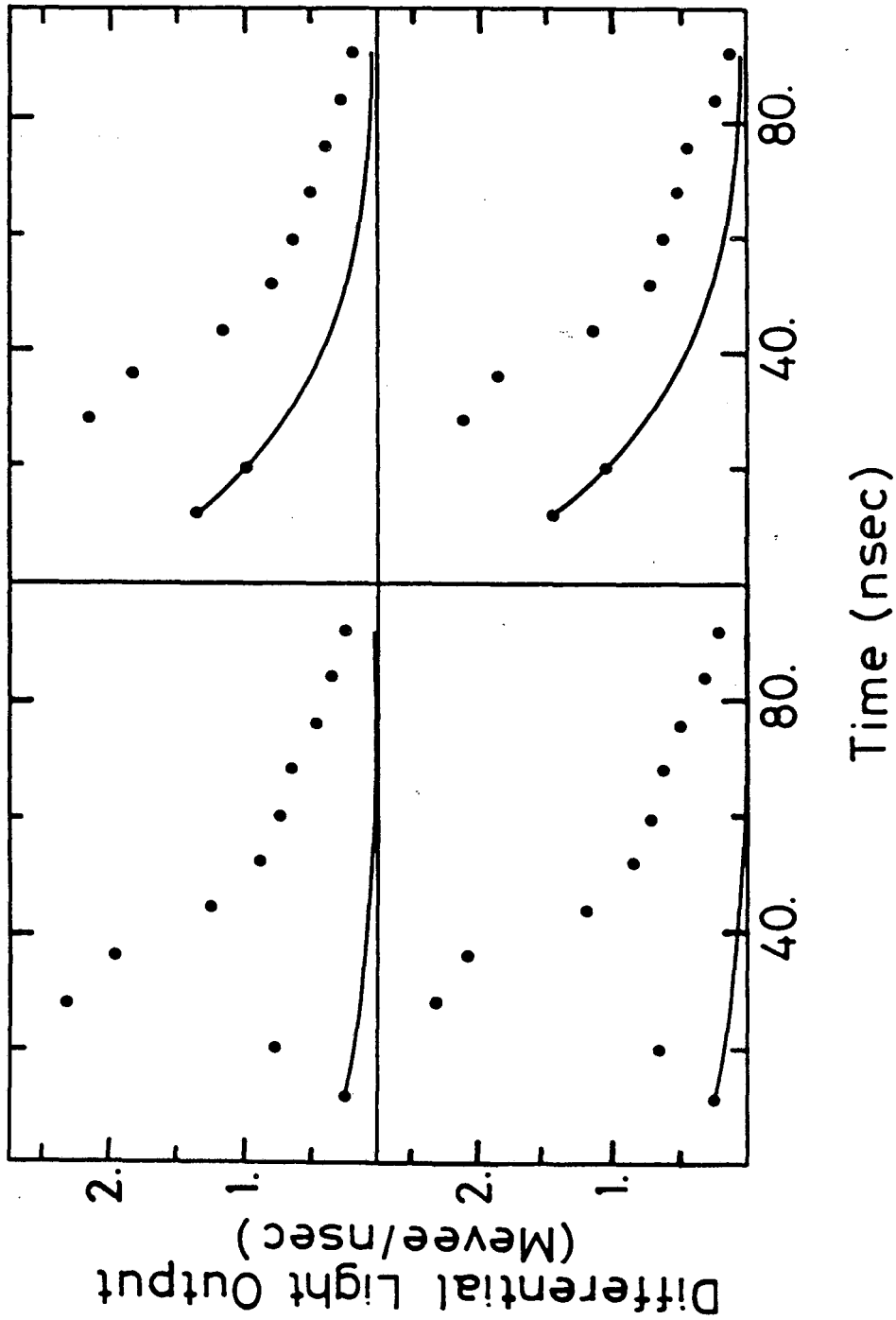
Differential Light Output
(Mevee/nsec)
2.
1.
2.
1.
40.
80.
40.
80.
Time (nsec)

Figure 8

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