PROPERTIES OF SOME PHOTON DETECTORS

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(Notes by David Yount)

ABSTRACT

A table is presented of estimates of certain characteristics of different types of photon detectors, with emphasis on their relative merits.

The properties of various photon detectors are summarized in Table I. The table is intended to provide input and background information for other groups, particularly those concerned with neutral-particle experiments. References on shower theory, as well as on detectors, are provided, but most of the entries in the table are derived from a loose consensus of the study group listed above. The emphasis is on the relative merits of the devices listed, and not on the ultimate performance. In this spirit, we have tried to be realistic and consistent, applying the same performance criteria to all of the detectors.

In addition to the information in the table, the following notes may be useful.

(1) Notation:

MWPQ = multiwire proportional quantameter

PTC = proportional tube counter
PHA = pulse height analyzer
X_o = radiation length unit

x = thickness in radiation lengths

B = magnetic field in kG

L = path length in m

t = sampling thickness in radiation lengths

E_o = incident photon energy in GeV

$ = estimated price in dollars

(2) Notes on Categories:

(a) DETECTION EFFICIENCY is virtually 100% for all devices listed except the pair spectrometer for which the incident photon must convert in a target of thickness x in radiation lengths.

(b) THRESHOLD ENERGY is <u>loosely</u> defined as that energy at which at least 90% of the photons would be detected. A sampling thickness of 1 X_o is assumed for the first five detectors, but 0.1 X_o is taken for lead-liquid argon since it is a special advantage of this detector that the cost increases slowly with decreasing sampling thickness. The total absorption detectors (liquid scintillator, lead-glass, liquid proportional tube counter, NaI) have low thresholds, going well below 1 MeV for NaI. In practice, however, one would probably require a somewhat higher threshold, e.g., 10 MeV for NaI, to discriminate against background.

(c) ENERGY RESOLUTION is given as a standard deviation. Shower track sampling contributes about $\pm$ 10% $(t/E_o)^{1/2}$ in the case of the first six detectors. For the multiwire proportional quantameter and the proportional tube counter, the largest component of the energy resolution results from Landau straggling in the thin (in g/cm^2) gas gaps. Lead-lucite is typically somewhat poorer than lead-scintillator due to low light yields and statistical fluctuations in the number of photons collected. The total-absorption detectors are not sensitive to track sampling, lead glass and liquid scintillator being limited primarily by photon statistics, while the resolution of NaI is limited by several small effects, such as light-collection uniformity, photomultiplier gain and noise, background radiation, etc. In all cases except the pair spectrometer, the energy resolution and other parameters are applicable to detectors of thickness (e.g., 12 X_o) sufficient to contain a high percentage of the shower energy.

(d) SPATIAL RESOLUTION and $\$/X_o m^2$ are closely related, as the table illustrates. Here again we have tried to indicate typical ranges and not ultimate values.

(e) PHA TIME RESOLUTION refers to a typical PHA gate width required to collect a reproducible (usually high) fraction of the output signal. The timing resolution for triggering other devices is typically an order of magnitude smaller, except for the pair spectrometer, which does not require pulse-height analysis and can yield a trigger resolution of order 1 ns.

(f) BACKGROUND REJECTION is generally better for total absorption detectors than for sampling devices, and it improves with decreasing time resolution. Lead-lucite is listed as GOOD because it provides some discrimination against low-energy hadrons. NaI and the pair spectrometer are considered to be EXCELLENT in that they can distinguish particle types as well as discriminate against various low-energy backgrounds.

(g) Under EASE OF HANDLING, multiwire proportional quantameters are considered difficult because they involve many wires. Lead-liquid argon is difficult because cooling is required, and lead-liquid scintillator is more difficult than liquid scintillator because the liquid containers are more elaborate. Pair spectrometers could be considered easy or difficult depending upon how much of the necessary equipment (e.g., magnet, wire chambers, etc.) is already assumed to be present.

(h) For the shower sampling devices, a sampling thickness of one radiation length has been used in calculating the price per radiation length per meter squared. The result, essentially, is the price per meter squared of detector plane. The total-absorption detectors, on the other hand, are most easily characterized by a price per unit volume, some examples being \$480 per liter for NaI, \$100 per liter for large pieces of lead glass, and \$30 per liter for pieces smaller than $15 \times 15 \times 15$ cm^3, and \$1 per liter for liquid scintillator. Tin-loaded liquid scintillator is \$40 per liter with a 25-cm radiation length. The figures given under $\$/X_o m^2$ in the table include the cost of electronic readout, e.g., amplifier, photomultiplier, ADC, etc.

(3) Notes on Detector Types:

(a) Liquid proportional tube counters have not yet been proven to be practical.

(b) Gas-filled proportional tube counters have been used thus far only to provide spatial resolution after the first several planes of a large shower detector.[2] The energy resolution and energy threshold are expected to be similar to those of the multiwire proportional quantameter.

(c) A radiation length in liquid scintillator is about 46 cm. Thus a total-absorption detector of this type would require a thickness of 5 meters or more to contain a 15-GeV electromagnetic shower.

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Ref.	Detector type	Detection efficiency	Energy threshold	Energy resolution	Spatial resolution	PHA-time resolution	Trigger functions	Background rejection	Ease of handling	$\$/X_o m^2$
1	MWPQ	100%	~150 MeV	$\pm 29\% (t/E_o)^{1/2}$	±3 mm	100 ns	POOR	POOR	DIFFICULT	5,000-10,000
2	PTC	100%	~150 MeV	$\pm 29\% (t/E_o)^{1/2}$	±1 cm	100 ns	POOR	POOR	MODERATE	3,000-6,000
3	Pb-lucite	100%	~150 MeV	$\pm 30\% (t/E_o)^{1/2}$	±3 mm	20 ns	GOOD	GOOD	EASY	5,000-10,000
4	Pb-lucite	100%	~150 MeV	$\pm 12.5\% (t/E_o)^{1/2}$	±5 cm	20 ns	GOOD	GOOD	EASY	700-1,500
3	Pb-plastic scintillator	100%	~150 MeV	$\pm 25\% (t/E_o)^{1/2}$	±3 mm	20 ns	GOOD	FAIR	EASY	5,000-10,000
4	Pb-plastic scintillator	100%	~150 MeV	$\pm 10\% (t/E_o)^{1/2}$	±5 cm	20 ns	GOOD	FAIR	EASY	1,000-2,000
5	Pb-liq. scint.	100%	~150 MeV	$\pm 10\% (t/E_o)^{1/2}$	±5 cm	20 ns	GOOD	FAIR	DIFFICULT	1,000-2,000
6	Pb-liq. argon	100%	~ 50 MeV	$\pm 11\% (t/E_o)^{1/2}$	±5 mm	0.3-1.0 μs	POOR	POOR	DIFFICULT	1,000-5,000
7	Liq. scint.	100%	< 10 MeV	$\pm 6\% / E_o^{1/2}$	±5 cm	20 ns	GOOD	GOOD	MODERATE	1,000-2,000
8	Pb-glass	100%	< 20 MeV	$\pm 6\% / E_o^{1/2}$	±3 cm	20 ns	GOOD	GOOD	EASY	5,000-10,000
8	Pb-glass	100%	< 20 MeV	$\pm 6\% / E_o^{1/2}$	±10 cm	20 ns	GOOD	GOOD	EASY	3,000-5,000
9	Liq. PTC	100%	< 10 MeV	similar to NaI?	±1 cm	500 ns	POOR	EXCELLENT?	MODERATE	3,000-5,000
10	NaI	100%	< 10 MeV	$\pm 1.0\% / E_o^{1/4}$	±3 cm	< 200 ns	GOOD	EXCELLENT	MODERATE	15,000-25,000
11	Pair-spectr.	x/X_o	0.015 BL	$x/4X_o$	±1 mm	--	GOOD	EXCELLENT	MODERATE	20,000-50,000 per m^2

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