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A π^o SPECTROMETER FOR PHOTOPION PRODUCTION STUDIES

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One of the first experimental programs to be carried out with the BNL Gamma Ray Beam[1] will be a study of (γ,π^o). We present here a discussion of existing π^o spectrometers and two new designs which, for the π^o energy range of interest for this program, are superior to existing designs.

The π^o decays instantaneously ($\tau_{\pi^o}=0.84\text{x}10^{-16}$ sec) into 2 isotropic gammas which have a relative angle of 180° and equal energies in the rest frame of the π^o. The Lorentz transformations substantially modify the lab energies of the γ rays, even at very modest pion kinetic energies. The "forward" gamma (closest to the pion momentum $\vec{P}\pi$) carries most of the total pion energy,

$$E_\pi = T_\pi + 135 \text{ MeV},$$

while its partner carries very little of this energy. The photon energies are given by

$$E_\gamma = \frac{1}{2}E_\pi(1+\beta\cos\Theta),$$

and their laboratory angles by

$$\tan\theta = \frac{\frac{1}{\gamma}\sin\Theta}{\cos\Theta+\beta}$$

where βc is the pion velocity, $\gamma=(1-\beta^2)^{-\frac{1}{2}}$, and Θ,θ are the angles of the gamma ray in the pion rest frame and in the laboratory, respectively, measured relative to the π^o direction. The extreme values ($\Theta=0^o$ or 180^o) are listed for a few pion energies in Table II.

In the past, two different strategies have been used to detect the π^o decay gammas. The first, due to Baer looks at the decay gammas which are emitted at equal angles in the laboratory. The gamma energies are measured in Pb-glass calorimeters to a precision of ~30% (FWHM). The gamma directions are determined by wire chambers (MWPCs) which follow Pb-glass shower converters. The poor resolution energy measurement is used, in this strategy, only to ensure that the two photon energies are not very different, i.e.,

$$|X| = \frac{E_1 - E_2}{E_1 + E_2} < 0.1$$

The decay kinematics can be written in terms of the energy sharing, X, and the laboratory angle between the 2 gammas, η:

$$(E_{\pi^o})^2 = \frac{2(m_{\pi^o})^2}{(1-\cos\eta)(1-X^2)}$$

Thus this cut on X places all of the burden of the pion energy measurement on an accurate measurement of the opening angle, η. In Table I, some of the performance parameters expected for a Baer-type spectrometer are listed, for the case of R=50 cm, the distance to the front face of each detector arm. The effective solid angle is taken from the geometric acceptance of Fig. 9 in Ref. 2, reduced to account for converter and wire plane efficiencies following Eq. 24 of Ref. 2.

The second strategy is that of Bowles, et al.[3]. In this approach, the opening angle η is constrained to the vicinity of 180°, the forward gamma being detected by a Pb-glass calorimeter, and the backward gamma by a large NaI spectrometer. In this geometry, the partition of energy between the γ rays is roughly that in Table II and the pion energy resolution is given by

$$\frac{\Delta E_\pi}{E_\pi} = \frac{-\beta \Delta E_\gamma}{E_\gamma}$$

Thus, the pion energy resolution is determined by the fractional energy resolution of the NaI detector. The performance characteristics of such a spectrometer are given in the first columns of Table II, where a NaI spectrometer subtending a half angle of 10° ($\Delta\Omega_{eff}=\varepsilon\Delta\Omega=28.6$msr), and a Pb-glass detector subtending a half angle of 10° ($\Delta\Omega_{eff}=95$msr) have been assumed. The resolution of the NaI for the low energy γ ray was assumed to be 1.9%.

Several variations on these 2 strageties have been considered with the goal of retaining a good energy resolution with a greatly increased effective solid angle. Two promising alternatives are presented. The first utilizes the geometry of Baer[2], but the Pb-glass detectors are now replaced by NaI spectrometers. However, unlike the Baer-type spectrometer, the angle η is not measured to high precision. Rather, the pion energy is constructed from the sum of the gamma energies. This approach has the effect of increasing the effective solid angle dramatically with increasing energy, as shown in the second part of Table I. Comparison with the first part of the table shows that the energy resolution is only slightly worse with this geometry.

A second alternate geometry adapts that of Bowles, et al.[3]. Increasing the solid angle associated with fore-aft geometry results in degraded energy resolution due to the uncertainty in opening angle η. Here the forward (~0°) high-energy gamma ray is detected with a large NaI detector, subtending a half angle of 10°, with an effective solid angle of 28.6msr. The associated backward photon (~180°) detector is a thin plate of NaI (half-angle=45°) which measures position in a manner similar to that of an Anger camera[4]. This arrangement is shown schematically in Fig. 1. A correction would be applied to the high energy γ rays, based on the angle measurements from this low energy detector. The remaining uncertainty in angle is limited to the 10° acceptance of the forward detector. The performance of such a spectrometer is given in the righthand portion of Table II. (The energy resolution of the forward NaI detector is assumed to be 1.6%). Figure 2 shows measured energy resolution of the existing BNL NaI spectrometer.

The energy resolution for this proposed spectrometer is equal to, or slightly better than, that of the design of Ref. 2. The solid angle is almost an order of magnitude larger than that of either Ref. 2 or Ref. 3. The solid angle for this design (Table II) complements the alternate symmetric angle geometry in that it is largest at low energies, while the solid angle of the spectrometer of Table I is larger for high pion energy.

At higher energies, the design of Ref. 2 is superior to the design presented here. But in view of the interest here in moderate energy pions, the second proposed design (Table II) is clearly the most suitable.

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1) A.M. Sandorfi, M.J. LeVine, C.E. Thorn, G. Giordano, and G. Matone, paper presented at this workshop.
2) H.W. Baer, et al., Nucl. Inst. Meth. 180, 445 (1981).
3) T.J. Bowles, et al., Phys. Rev. C23, 439 (1981).
4) H.O. Anger, in "Instrumentation in Nuclear Medicine", Vol. 1, 485 (ed. J. Hine), Academic Press, New York (1967).

Table I: Performance of two types of symmetric-angle spectrometers. NaI energy resolution was assumed to be 1.6% and the effective solid angles were taken to be 28.6msr.

T_{π^0} (MeV)	E_γ (MeV)	θ_1, θ_2	Baer-type spectrometer (Ref.2) for R = 50 cm			2 NaI detectors (this work)	
			$\Omega_g \cdot P_x$ (geom acc)	Ω_{eff}	ΔE_{π^0}	$\Delta\Omega_{total}$	ΔE_{π^0}
20	78	60°	2.5msr	0.55msr	1.4MeV	0.60msr	1.75
50	92	47°	2.4	0.53	1.5	0.92	2.08
100	118	35°	2.2	0.49	1.8	1.55	2.67
200	168	24°	2.2	0.49	3.3	3.06	3.80

Table II: Performance of two different fore-aft spectrometers, the design of Bowles (Ref. 3) and the design proposed here.

T_{π^0} (MeV)	$E_{\gamma 1}$(0°) (MeV)	$E_{\gamma 2}$(180°) (MeV)	Pb-glass(0°)-NaI(180°) (Ref. 3)		NaI(0°)-position meas.(180°)(this work)	
			$\Delta\Omega_{eff}$(msr)	ΔE_{π^0}(MeV)	$\Delta\Omega_{eff}$(msr)	ΔE_{π^0}(MeV)
20	116	39.4	0.59	1.90	3.84	1.26
50	156	29.2	0.22	2.57	1.90	2.04
100	214	21.3	0.092	3.72	1.25	3.09
200	321	14.2	0.036	5.85	0.48	4.92

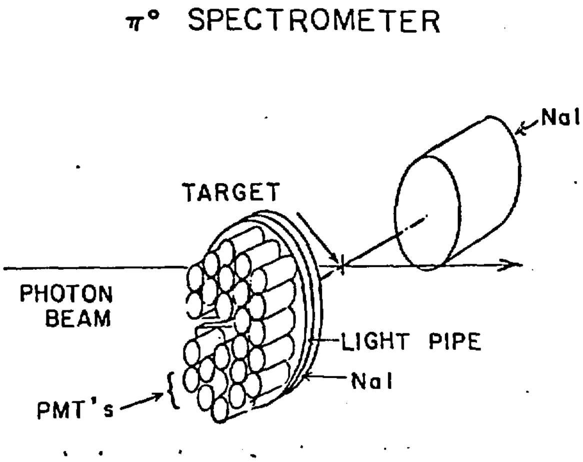

FIG. 1: A schematic representation of the π° spectrometer. The 24 cm x 36 cm NaI crystal is shown without its plastic anticoincidence annulus. The rear angle-measuring counter is comprised of a NaI plate, light pipe and an array of photomultipliers. The notch in the rear assembly allows measurements at extreme forward angles.

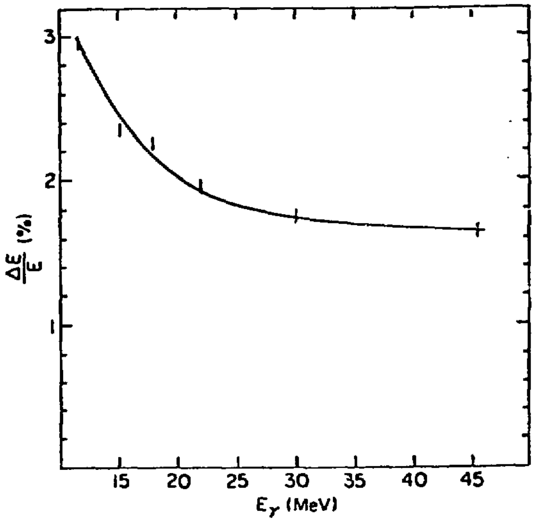

FIG. 2: Measured energy resolution for the BNL MarkIII NaI spectrometer.