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TESTING THE MONOCHROMATIC PHOTON BEAM

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The use of positron annihilation to produce a monochromatic photon beam, and the major specifications of such a beam in SLAC end station B, have been described by Guiragossian.[1] We expect to use 10 Bev positrons annihilating in a hydrogen target and to take photons at angles between 5 and 10 milliradians to the positron beam into the SLAC Hydrogen Bubble Chamber, these limits being set by considerations of Bremsstrahlung background and intensity.

The annihilation process gives photons at angle θ with energy ω related (in small angle approximation) by:

$$\omega = \frac{E}{1 + \frac{\gamma\theta^2}{2}} \tag{1}$$

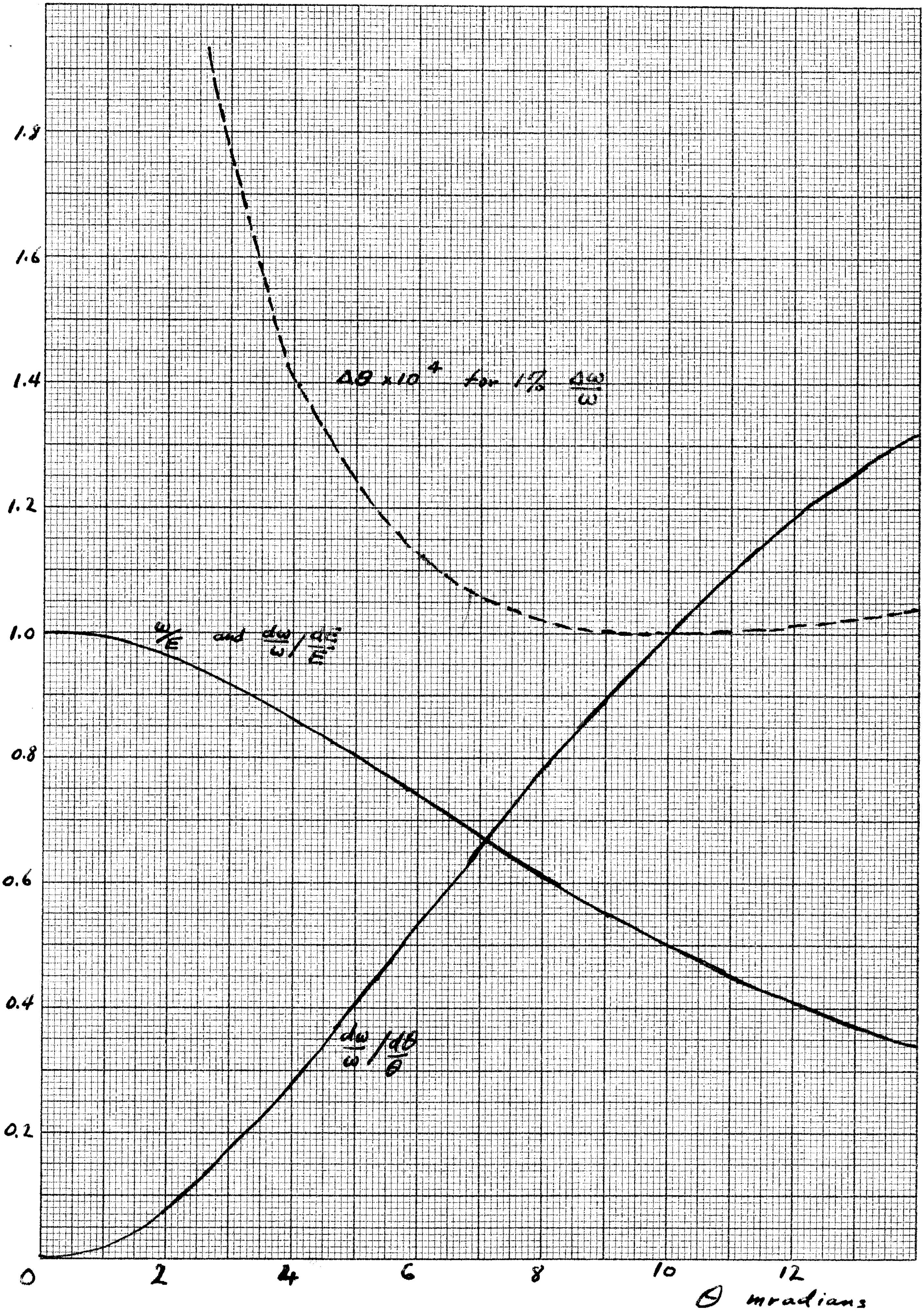
where E is the positron energy and $\gamma = \frac{E}{m_e}$.

From this formula we may deduce the differentials

$$\left.\frac{d\omega}{\omega}\right)_{\text{const } E} = -2\left(\frac{E-\omega}{E}\right) \frac{d\theta}{\theta} \tag{2}$$

$$\left.\frac{d\omega}{\omega}\right)_{\text{const } \theta} = \frac{\omega}{E}\ \frac{dE}{E} \tag{3}$$

Figure 1 shows these dependences and also indicates the angular resolution needed at each angle to achieve a full width resolution in


1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
2
4
6
8
10
12
θ mradians
Δθ × 10⁴ for 1% Δω/ω
ω/E and (dω/ω)/(dE/E)
(dω/ω)/(dθ/θ)

the beam of 1% using 10 Bev positrons. If the chamber is placed 60 meters from the target the required 10^{-4} radian slit will be 6 mm. wide.

Clearly, alignment problems are serious. Besides relying upon "brute accuracy" in surveying we should like to have a method for optimizing the beam properties. Such a method must give "on-line" answers to be most effective, thus ruling out a simple pair spectrometer which would require too great a time lapse for analysis, although a final calibration of the spectrum by this method is probably necessary. to determine the optimum hardening of the beam.

We propose to use a coincidence method, detecting both photons from the annihilation. Drickey[2] has discussed some aspects of the problem and suggested the correlation between photons be used to "tag" the photon energy.

Method

Consider detectors placed in a plane normal to the positron beam at a distance R from the target (Figure 2). If one annihilation photon is detected we should be able to predict the position of the second photon if we know the location in the plane at which the positron would have appeared if it hadn't annihilated. The relation (1) may be used recalling that it holds for either photon to give the relation

$$\theta_2 = \frac{2}{\gamma\theta_1} \tag{4}$$

and therefore the distance between photons should be

$$r = R\left(\theta_1 + \frac{2}{\gamma\theta_1}\right) \tag{5}$$

We may note that if $\theta_1 = \theta_2$ ($\omega_1 = \omega_2 = \frac{E}{2}$) r is nearly constant independent of θ_1. In this case only the energy spread of the incident positron beam should change r, while the angular and positional spread of the positrons will produce a vertical spread in the correlated positions.

The proposed testing method therefore is to detect pairs of photons using arrays of small counters in coincidence to determine the distance r in Figure 2, which will give a good measure of the angle of observation and therefore the energy. The spread CD of Figure 2 will provide a measure of the positional and angular uncertainty of the annihilating photon, while the spread of coincidence efficiency along r will give an idea of the positron energy spread. Clearly the number of coincidences will give a good measurement of the photon intensity, while a total absorption counter at A would give an immediate idea of Bremsstrahlung background.

Effect of "radiative corrections"

Since the two photon annihilation process must be considered as a limiting case of three photon annihilation where the third photon has zero energy (owing to the infra-red catastrophe) we must consider by how much the presence of a third photon will destroy the two body correlation. We estimate this effect by using the observation of Tsai [3] that in this "internal Bremsstrahlung" process the third photon is produced predominantly forward or backward in the e^+e^- center of mass

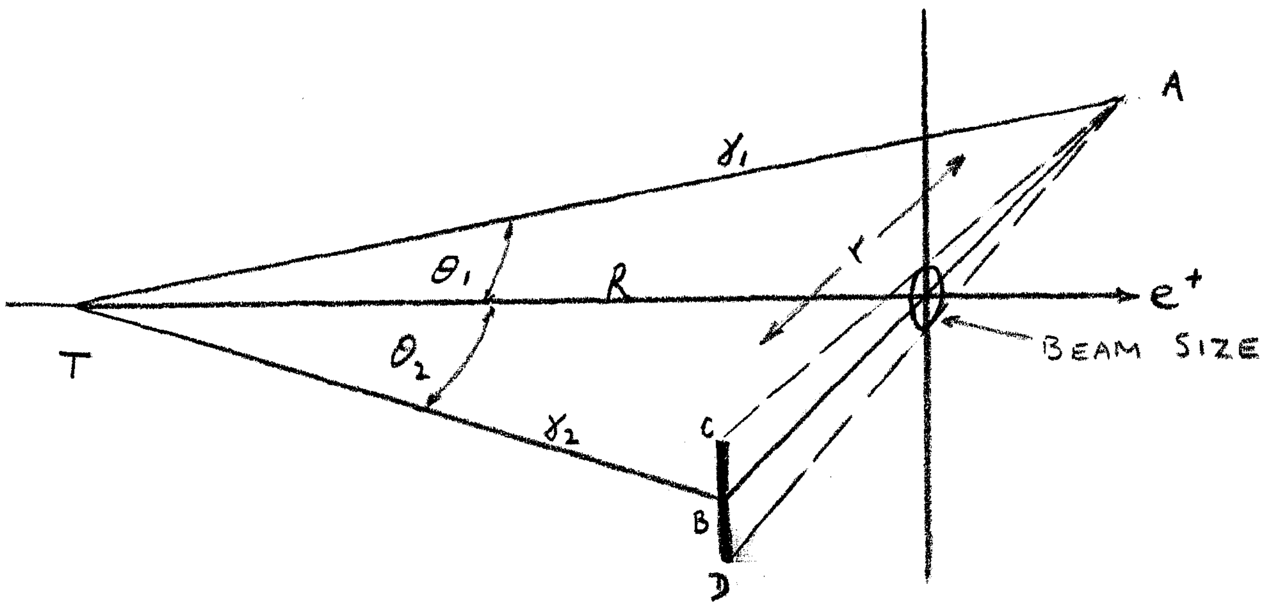

A
γ_1
r
θ_1
R
e^+
T
θ_2
BEAM SIZE
γ_2
C
B
D

FIG. 2.

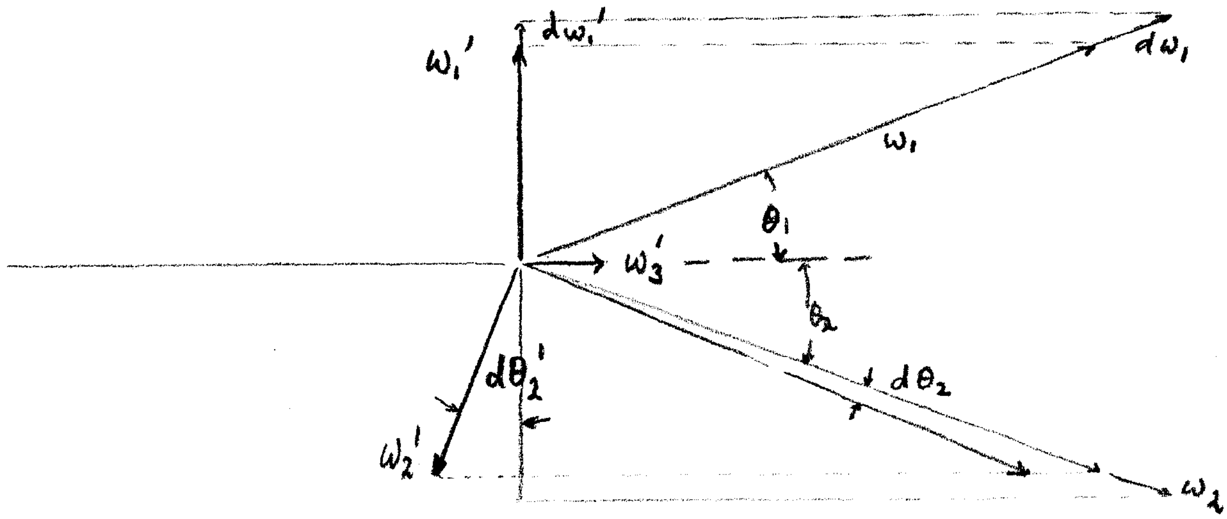

$d\omega_1'$
ω_1'
$d\omega_1$
ω_1
θ_1
ω_3'
θ_2
$d\theta_2'$
$d\theta_2$
ω_2'
ω_2

FIG. 3.

system. Using primed quantities to refer to the C.M.S. and unprimed for lab quantities, we consider the case of a photon emitted at 90° in the C.M.S. and a counter detecting it at the corresponding lab angle (see Figure 3). If the energy of this photon is $d\omega_1'$ less than for the two body case, it will still appear in the lab system with the same angle as in the two body case (by photon kinematics) but with energy diminished by

$$d\omega_1 = \gamma_L \, d\omega_1' \quad (\text{for } \theta_1' = 90^{\circ} \text{ only})$$

where γ_L is the Lorentz Transformation parameter. Since the second photon must balance momentum

$$\omega_2' \approx \omega_1'$$

so

$$\omega_3' \approx 2d\omega_1'$$

Therefore $d\theta_2'$ has possible values $\pm\, \omega_3'/\,\omega_2'$ and transformation into the lab system gives the formula:

$$\frac{d\theta_2}{\theta_2} \approx \pm\, 2\,\frac{d\omega_1}{\omega_1} \tag{6}$$

Thus the angular uncertainty reflects directly the energy uncertainty. The latter spectrum is given by Tsai [3] as proportioned to $(\Delta\omega)^{-1}$ and inserting numerical values we deduce that a counter of width w will detect about 4% coincidences when displaced a distance w from the "2 body" position independent of w. This is a property of the distribution: we may note however that for a counter of angular resolution $d\theta_2$, the number of photons found to miss the counter are as follows:

$d\theta_2$	% missing
1×10^{-5} rad	24%
5×10^{-5} rad	17%
10^{-4} rad	14%

The long tail of the distribution may provide a serious difficulty in "tagging" photons. However for our measurement we may consider the effective spread of the correlation to be due entirely to angular, positional, and energy uncertainty in the positron beam.

Details of the Method

A schematic counter lay-out is shown in Figure 4b, which represents the view as seen along the beam direction. Scintillators are mounted on boards with accurate horizontal and vertical traverse screws, and are made to be able to rotate into vertical (Figure 4a) or horizontal (Fibure 4b) positions for horizontal "r" or vertical "θ" scans. Each scintillator is placed in coincidence with its diametrically opposed twin. An array is used to provide an increased coincidence yield since singles counts are limited to < 10 per burst because of accelerator duty cycle. By plotting number of coincidences vs. position for one side fixed we obtain the angle of observation (maximum coincidences) and the width of the distribution can be related to positron phase space.

By detecting a shower initiated in one of the small counters in a total absorption counter we can, by requiring coincidences S to S', calibrate the counter, and by not requiring coincidence obtain the

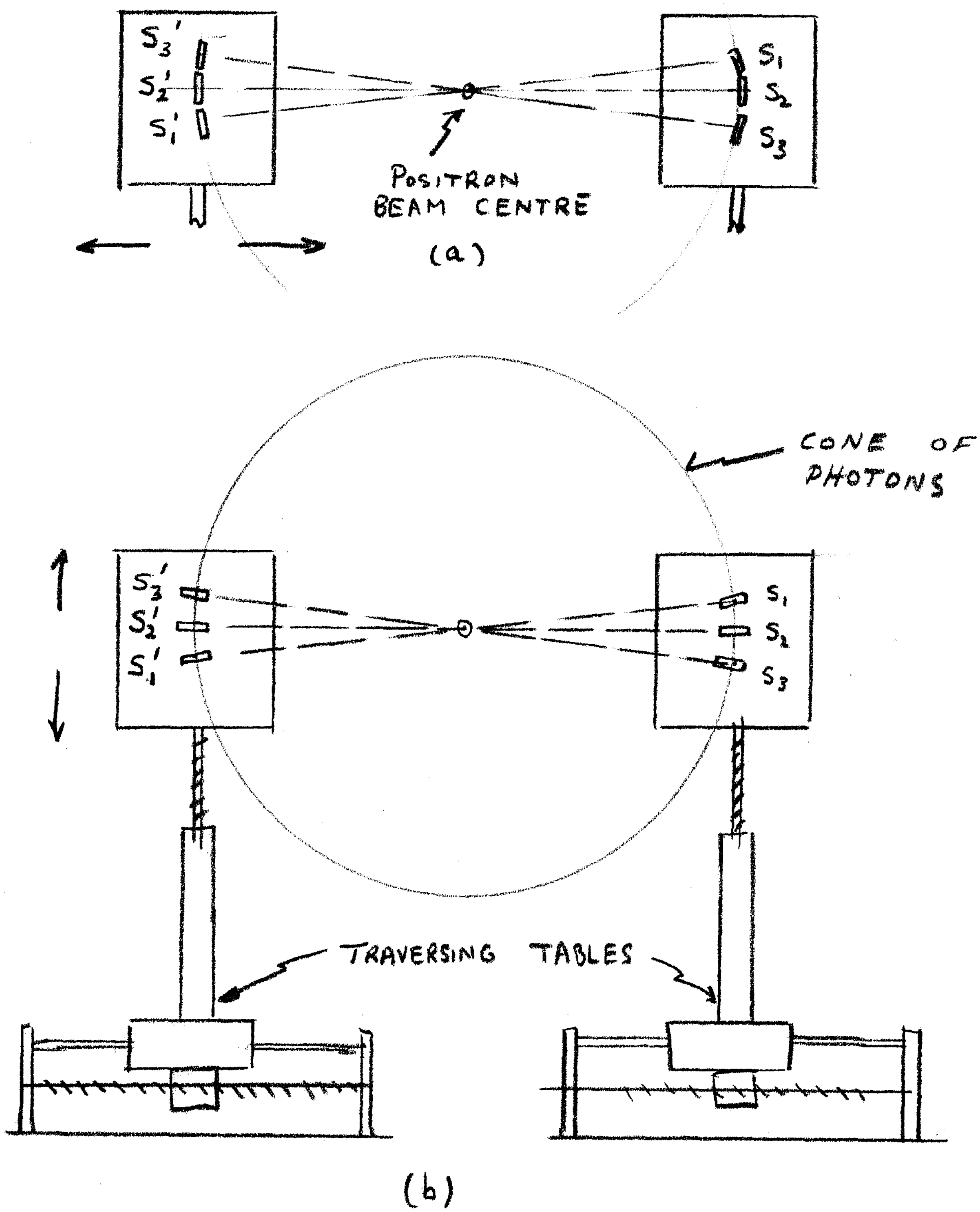

S_3'
S_2'
S_1'
S_1
S_2
S_3
POSITRON
BEAM CENTRE
(a)
CONE OF
PHOTONS
S_3'
S_2'
S_1'
S_1
S_2
S_3
TRAVERSING TABLES
(b)

FIG. 4.

background Bremsstrahlung intensity.

As mentioned earlier, we should prepare a precision pair spectrometer using a 72" bending magnet and thin spark chambers for final spectrum calibration.

REFERENCES

1. Z. Guiragossian, Almost Monochromatic Photon Beam, SLAC TN-63-104.

2. D. Drickey, Tagged Photons, SLAC TN-65-35.

3. Y. S. Tsai, Phys. Rev. 137, B730 (1965).