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A SIMPLE PAIR SPECTROMETER TO STUDY THE ANNIHILATION BEAM QUALITY

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Introduction

The annihilation beam will be in place and operative before the bubble chamber is ready to use it. After initial alignments have been made* we would like to investigate the true energy resolution of the monochromatic beam and the effects of the lithium hydride beam hardener in order to evaluate possible improvements such as the use of a liquid hydrogen hardener. For these purposes a simple pair spectrometer is proposed, to use a standard 18D72 bending magnet and scintillation coincidence counters. This report is a study of the problems involved.

Design Considerations

Since the photon beam will be well collimated and at the energies of interest the angle between pairs negligible, the lateral position at which the pairs are detected in coincidence after bending in a magnetic field gives the photon energy. If the electron and positron have equal energies (symmetric pairs) the distance that the point of origin is off axis gives only a second order effect, so that if the resolution required is 1% the radiator may be up to ten times the counter width. We, therefore, consider only a symmetric configuration.

* SLAC TN-65-50

If we can easily measure the magnetic field along the particle orbit the scintillators may be located outside the magnet gap with no loss of accuracy, making the placement of counters rather simple. We consider this case, where

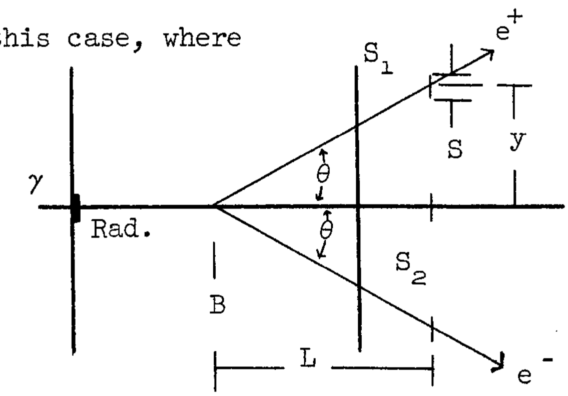

Figure 1

$$\theta \sim \frac{y}{L} \sim \frac{0.3\int B d\ell}{p}$$

$$\frac{d\theta}{\theta} \sim \frac{s}{y} \sim \frac{dp}{p} = \text{resolution}$$

The counting rate of scintillators S_1 and S_2 in coincidence if a monochromatic photon converts in the radiator forms a triangle when plotted against the magnetic field, or photon energy E_o for which the spectrometer is set. Scintillator S_1 records a "bite" of the positron spectrum from a monochromatic photon conversion, centered at $E_o/2$ with total width $E_o s/2y$ and these particles all have an electron of energy centered at $E - E_o/2$ which only records in coincidence if the two bands overlap. It will be useful to define a function $g(E,E_o)$ with these properties (Fig. 3).

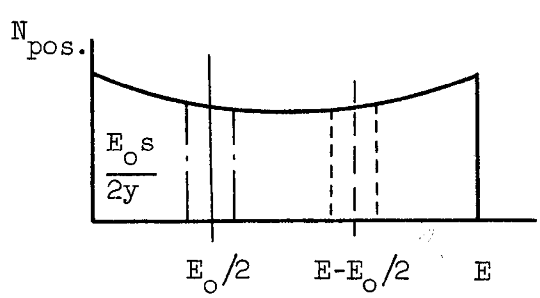

Figure 2

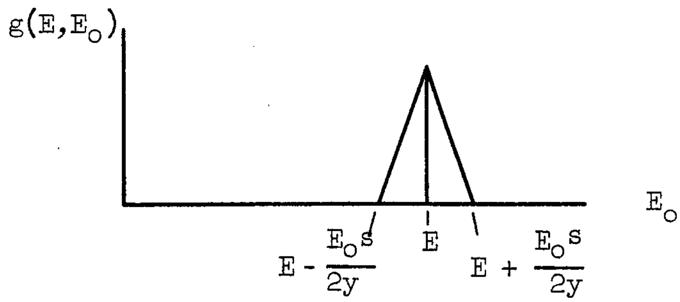

Figure 3

If a spectrum of form N(E) is incident upon the radiator which has a conversion efficiency c(E) we can make rough estimates of the "singles" and "doubles" rates to be expected in S_1 and S_2. If we assume the spectrum of pair leptons is flat with energy (to a factor 2), the fraction of singles counts in, say, S_1 from conversion of a photon of energy E will be $\frac{E_o s}{2y} \cdot \frac{1}{E}$ if $E > E_o/2$, zero otherwise (see Figure 2). Therefore, the singles rate from all energies is

$$S\ (E_o) = \int_{E_o/2}^{E_{max}} c(E)N(E)\frac{dE}{E}\ \frac{E_o s}{2y}$$

and introducing the coincidence requirement, doubles rate is:

$$D(E_o) = \int_{E_o/2}^{E_{max}} c(E)N(E)\frac{dE}{E}\ \frac{E_o s}{2y}\ g(E,E_o) \quad .$$

If we are dealing with a Bremsstrahlung spectrum

$$N(E) = \frac{a}{E} \quad .$$

We may put c(E) constant and equal to the radiator thickness in radiation lengths. The resulting integrations yield

$$S_B(E_o) = c\frac{as}{y}\ (1 - \frac{E_o}{2E_{max}})$$

$$D_B\ (E_o) = ca(\frac{s}{2y})^2$$

so that doubles to singles rates are

$$\frac{D(E_o)}{S(E_o)} = \frac{s}{4y}\ (1 - \frac{E_o}{2E_{max}})$$

where $E_o/2E_{max} < \frac{1}{4}$.

For 1% resolution the doubles to singles rates will be ~ 1:400.

If a monochromatic line of strength Nm is superimposed upon the Bremsstrahlung, and since in our case we expect approximately equal numbers from this line and Bremsstrahlung above 1 Bev, we may put

$$Nm = \int_{1\text{ Bev}}^{10\text{ Bev}} \frac{a}{E}\, dE \sim 3a$$

and evaluate the integrals again for $E_o < 2E_{mono}$

$$D(E_o) = \frac{cs}{2y}\, Nm \left\{ \frac{s}{6y} + g\,(E_{mono}, E_o) \right\}$$

$$S(E_o) = \frac{cs}{y}\, Nm \left\{ \frac{1}{3} - \frac{E_o}{6E_{max}} + \frac{E_o}{E_{mono}} \right\} .$$

Thus

$$\frac{D}{S}\ (\text{mono peak}) \sim \frac{3}{8}$$

$$\frac{D}{S}\ (\text{off peak}) \sim \frac{s}{16y} \qquad \text{or} \qquad 1{:}1600$$

We, therefore, deduce that we may easily observe the monochromatic peak but will find it hard to measure the Bremsstrahlung spectrum at this resolution. We are led to consider introducing some larger scintillator pairs along with these fine ones in order to observe the Bremsstrahlung shape, which is of physics interest at the large angles we are using.

Radiator thickness and counting rates

The thickness of radiator we can tolerate is set by multiple scattering. If we set y = 200 mm, about the half width of the 18D72, the counter must have s = 2 mm. The mean projected scattering angle then can produce a deflection of 1 mm over 2m or $5 \cdot 10^{-4}$ radians. Since the pairs are produced uniformly through the radiator its effective thickness is one half its actual thickness, so that for 2 Bev pairs we find radiator thickness

$$c = 2 \left(\frac{2 \text{ Bev}}{.015 \text{ Bev}} \cdot 5 \times 10^{-4} \right)^2$$

$$= 0.009 \text{ rad lengths}.$$

Thus the coincidence efficiency for 4 Bev photons is

$$\frac{D}{Nm} = 4.5 \times 10^{-5} .$$

We have estimated that there will be 25 monochromatic photons per burst so that we will find 1 count per 1000 cycles or one every 3 seconds at full machine rep rate. The singles rate will be only 8/3 times this.

If counters set for worse resolution are present, the radiator thickness can be increased as the square; the coincidence counting rate increases as the fourth power of the resolution, singles as the third power. We, therefore, remain within the counting rate limitations of the scintillators.

Two meters of Helium gas would represent 0.0005 radiation lengths. Its contribution to the resolution would, therefore, be negligible and a vacuum tank is not necessary. A helium bag extending into one of the beam sweeping magnets would be most convenient, particularly for changing radiator thickness.