A FIRST LOOK AT A POLARIMETER FOR EPIC OR PEP

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Abstract

A derivation of the resolution function is given in terms of machine parameters and detector resolution. A preliminary design is outlined for a pair spectrometer to detect high energy backscattered laser photons. A more careful examination is needed of the asymmetry as a function of resolution, of laser geometry and rates, and of problems associated with installing and using the system at PEP.

1. Derivation of Resolution Function for Photons Emitted at 0°

In the machine, the beam vertical phase-space is defined by the ellipse

$$\gamma x^2 + 2\alpha x\dot{x} + \beta\dot{x}^2 = \Sigma$$

where

$$\beta\gamma = 1 + \alpha^2 \qquad \text{and } \Sigma \text{ is the emittance.}$$

The distribution is a double Gaussian. The projected distributions are also Gaussian with

$$\sigma_x = \sqrt{\Sigma\beta}$$
$$\sigma_y = \sqrt{\Sigma\gamma}$$

For a converging beam we have the situation shown in Fig. 1, where the intercepts are given by

$$I_x = \sqrt{\Sigma/\gamma}$$
$$I_{\dot{x}} = \sqrt{\Sigma/\beta}$$

Any scattering changes the angle, but not the position.

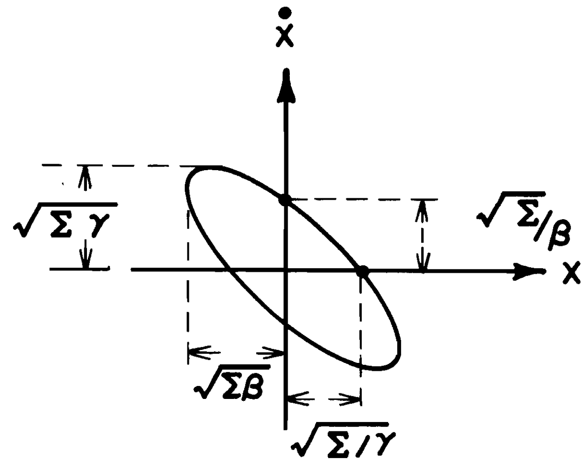

Figure 1

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Photons emitted at 0° to the beam direction will propagate with

$$x_1 = x + \ell\dot{x} \qquad \dot{x}_1 = \dot{x} \,,$$

So that the phase space of photons emitted at some point where $\ell = 0$ and α, β, γ are the machine parameters evolves according to:

$$\gamma x_1^2 + 2(\alpha - \ell\gamma)\, x_1\dot{x}_1 + (\beta - 2\alpha\ell + \gamma\ell^2)\dot{x}_1^2 = \Sigma$$

again with a double Gaussian distribution. If the photons are emitted with projected angle θ, $\dot{x}_1 \to \dot{x}_1 + \theta$ in this equation. The angles involved are $\sim m_e/E \sim 1/27.4$ milliradians at 14 GeV. This gives no hope of measuring γ-ray angles except by the lateral position of the conversion point at some large ℓ away from the emission point.

It is easy to show that the best resolution in angle occurs when

$$R = \frac{\theta\ell}{\sqrt{\Sigma(\beta - 2\alpha\ell + \gamma\ell^2}}$$

is a minimum. This occurs when

$$\ell = \ell_{OPT} = \beta/\alpha$$

giving (A)

$$R_{OPT} = \theta\sqrt{\beta/\Sigma}$$

This is for a detector with no measurement error. If we assume a detector with resolution Δ at some distance z from ℓ_{OPT} (i.e., $\ell = \ell_{OPT} + z$), then

$$R(z,\Delta) = R_{OPT}\left\{\frac{1 + z/\ell_{OPT}}{\left(1 + \frac{2z}{\ell_{OPT}} + (1+\alpha^2)\frac{z^2}{\ell_{OPT}^2} + \frac{\beta\Delta^2}{\Sigma\ell_{OPT}^2}\right)^{\frac{1}{2}}}\right\} \tag{B}$$

For $\alpha = 0$, this is not very useful; instead we use

$$R(\ell,\Delta(\alpha=0)) = \frac{\theta\ell}{\sqrt{\Sigma\beta(1 + \ell^2/\beta^2) + \Delta^2}} = \frac{R_{OPT}}{\sqrt{1 + \beta^2/\ell^2 + \Delta^2\beta/\Sigma\ell^2}} \tag{C}$$

(with $\ell \to \infty$, $R(\ell,\Delta(\alpha=0))_{\ell\to\infty} = \frac{\theta}{\sqrt{\Sigma\gamma}} = \theta\sqrt{\beta/\Sigma} = R_{OPT}$ as before.) Equations (A), (B), and (C) are sufficient to determine all one wants to know about resolution in projected angle. From the angular distribution of the laser backscattered photons, one can write the asymmetry as a function of the parameter R. It is obvious that we want $R \gtrsim 1$ for $\theta \sim m_e/E$ if at all possible. (Asymmetry peaks at this angle.)

2. Location of the Polarimeter

At 14 GeV, m_e/E is $1/27.4 \times 10^{-3}$ radians

$$\Sigma = 1/16 \times 10^{-6} \quad \text{meter-radians}$$

$$\text{put} \quad \theta = m_e/E, \quad \text{and} \quad R_{OPT} = \sqrt{\beta}/6.85$$

Since the polarization asymmetry peaks close to m_e/E, we want R_{OPT} large, i.e.,

$$\beta > 47. \ (\text{EPIC}) \quad (> 54. \ \text{PEP})$$

It is obvious that the distance to the detector should also be large, $\gtrsim$ 27.4 meters for EPIC (> 29.4 for PEP) to avoid the need for sub-sub millimeter resolution.

As can be seen from Table 1, there are very few places around the machine lattice where large β and large ℓ_{OPT} both occur. A third constraint is finding a place for a detector to intercept the scattered photons. In the present EPIC lattice, the most favorable solution is to scatter the laser photons from the

Table 1: Parameters from EPIC (Vertical Phase-Space)

Distance from Interaction Point (meters)	Location	β	α	R_{OPT}	ℓ_{OPT} (meters)	$\ell_{OPT} \frac{m_e}{E}$ (mm) E=14 GeV
0	Interaction point	.1244	0	0.051	∞	∞
8.5	Quad entrance high β	578.7	-68.1	3.59	-8.5	0.31
9.9	Quad exit	540.0	+92.0	3.39	+5.9	0.215
10.95	Quad entrance high β	364.1	+75.54	2.78	+27.2	0.99
12.75	Quad exit	236.9	+4.26	2.25	+55.5	2.02
60.24	Quad entrance matching	14.52	+0.419	0.555	+34.7	1.265
61.64	Quad exit	12.49	+0.99	0.516	+12.61	0.46
63.44	Quad entrance matching	9.43	+0.708	0.448	+13.3	0.485
64.84	Quad exit	8.616	-0.1086	0.428	-80.7	2.95
66.54	BM entrance θ = .02618	9.32	-.308	0.445	-30.2	1.10
71.04	BM exit	14.48	-.836	0.555	-17.3	0.631
82.0	Possible location for polarimeter					
83.44	Quad entrance	53.28	-2.29	1.067	-23.3	0.85
84.44	Quad exit	53.35	+2.23	1.068	+24.0	0.875
86.84	BM entrance	43.3	1.959	0.96	+22.1	0.806
91.34	BM exit	27.93	1.456	0.77	+19.15	0.70

beam somewhere in the region between the high-β and the matching quads, and to collect the scattered photons at a point about 70 meters downstream, 11.5 meters from the exit of the first bending magnet. Note that a detector resolution of the amount shown in the last column of Table 1 will reduce R by a factor of $1/\sqrt{2}$ from R_{OPT}.

3. Pair Spectrometer Polarimeter

In the position we have chosen, a detector resolution of approximately 1 - 2 mm is needed. This can be seen by working out $R(z,\Delta)$. Using (B), with varying Δ we find

		R	Δ (detector resolution)
Position 1	Scatter at 12.75 m from interaction point	1.70	0
		1.61	0.5 mm
		1.38	1.0 mm
	Detect at 82.5 m	1.01	2.0 mm
		0.74	3.0 mm
	z = 14.25 m		
Position 2	Scatter at 60.24 m from interaction point	0.54	0
		0.51	0.5
		0.45	1.0
	Detect at 82.5 m	0.31	2.0
		0.24	3.0
	z = -12.4 m		

Note that the detector will be exposed to synchrotron radiation from the bending magnet, which would likely cause problems at the front end of shower detectors. A substantial number of photons with energies > 100 keV are to be expected.

We will assume here that the synchrotron radiation problems plus the good lateral resolution needed make shower detectors unpleasant. Instead we will design a pair spectrometer. This has the advantage that it measured the full angular distribution, and by using unpolarized laser light pulses interspersed with ± 1 helicities, we can directly measure the resolution function given by the beam and detector errors. We can also determine where 0° is.

A possible detector configuration is shown in Fig. 2.

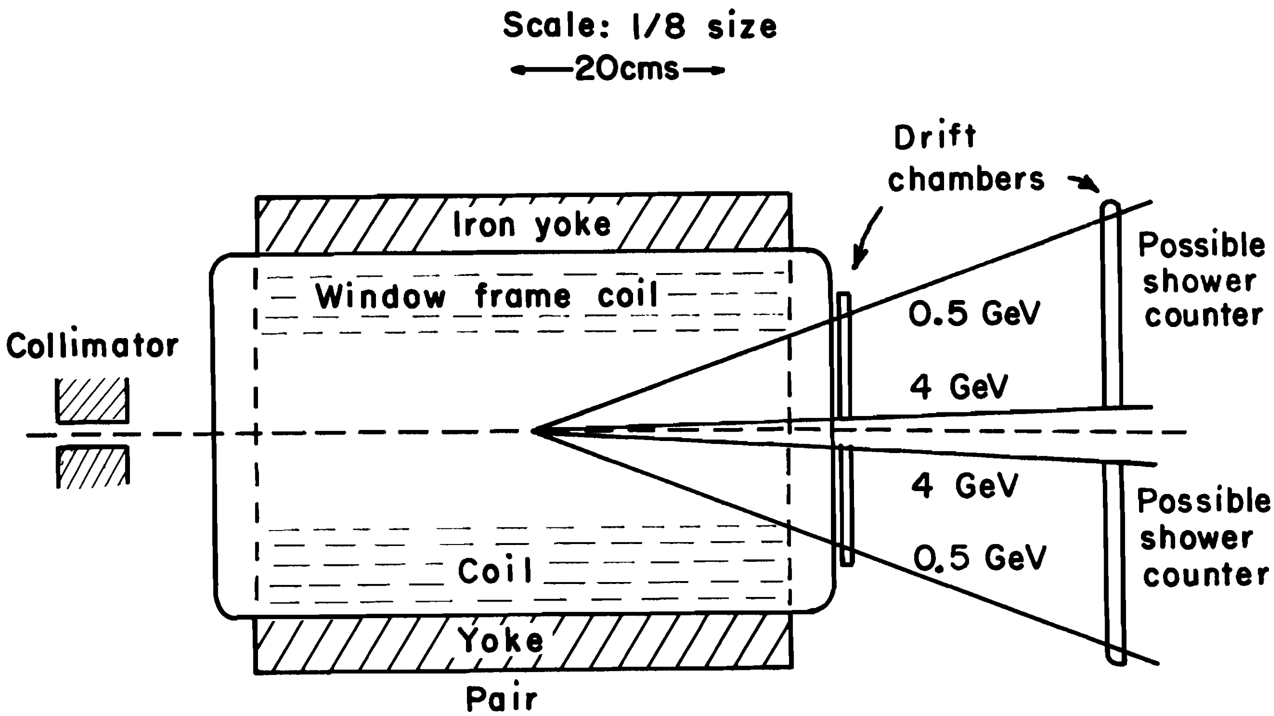

Figure 2

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Characteristics of the Pair Spectrometer are as follows:

1. The conversion efficiency of the .33 x_0 converter is $\sim$ 25%
2. The efficiency for the energy window shown is $\sim$ 50% at 2 GeV photon energy to 78% at 4.5 GeV. Thus, the overall efficiency is 12.5% to 20%, roughly.
3. The pair opening angle due to Coulomb scattering is $.014/p_e \sqrt{1/6} \sim 6$ mR for a typical case. Hence the vertical aperture of this magnet can be quite small.
4. The drift chambers are assumed to have 0.1 mm intrinsic resolution, giving $\Delta_m \sim 0.7$ mm in the geometry shown. Coulomb scattering gives $\Delta_c \sim 0.35$ mm for a chamber thickness of $\sim$ 1/400 of a radiation length.

The overall resolution $\Delta \approx 0.8$ mm, which should be sufficiently good.

5. A first look at the horizontal plane geometry shows that the laser photons are spread over $\sim$ 1 cm width; at the position shown the radiator will collect $\sim$ 80 watts of synchrotron light and must be cooled.
6. A collimator upstream of the magnet shields the drift chambers.
7. The magnet is 70 cm long, 54 cm wide and weighs about 0.7 metric tons.

This design is very crude and needs more work. For example, (a) the magnet needs to have $\sim$ 5.6 kGauss meters field integral to spread the high energy electrons far enough apart to let the synchrotron γ's through a hole in the drift chambers, and there may not be enough room for copper, and (b) the magnet comes uncomfortably close to the beam pipe and probably doesn't quite fit in the chosen position.