ARE POLARIZED PHOTON BEAMS FEASIBLE AT NAL?

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ABSTRACT

It is shown that the technique of coherent bremsstrahlung from crystals will not give polarized beams of useful intensities for counter and spark-chamber work.

The exploitation of the projected 25% duty cycle at NAL for producing excellent tagged photon beams has been described in SS-72 (1969). The question was raised whether the radiator could be replaced by a diamond crystal (mounted on a very sensitive goniometer) to give a useful polarized beam.

The technique at lower energies is thoroughly discussed in the review article by Diambrini,[1] and all the relevant references are listed there. Some very useful design parameters and calculations are given by Bologna.[2]

The physics of the technique can be summarized as follows:

The polarization comes about because the crystal structure forces the nucleus to recoil only along preferred directions--normal to the crystalline planes--and effectively gives the quantum condition

$$\vec{q} = 2\pi\hbar\vec{g}, \tag{1}$$

where $\vec{q}$ = momentum transfer to the nucleus

$\vec{g} = n_1 \frac{1}{a_1} \hat{u}_1 + n_2 \frac{1}{a_2} \hat{u}_2 + n_3 \frac{1}{a_3} \hat{u}_3$

n_1, n_2, n_3 are integers,

a_1, a_2, a_3 are the lattice spacings,

$\hat{u}_1, \hat{u}_2, \hat{u}_3$ is an orthogonal triad in the lattice planes.

(This is a generalization of Bragg's Law.)

The coherence in the bremsstrahlung off a crystal (manifest by sharp intensity peaks superposed on a continuum) arises from the following considerations: The longitudinal and transverse momentum transfers for bremsstrahlung off a sufficiently heavy atom are limited by

$$0 < q_\perp < 2\,mc$$
$$\delta < q_2 < 2\delta. \tag{2}$$

δ is the minimum longitudinal momentum transfer and is given by

$$\delta = \frac{1}{2} \, mc \, \frac{mc^2}{\epsilon_0} \left(\frac{x}{1-x}\right), \quad (3)$$

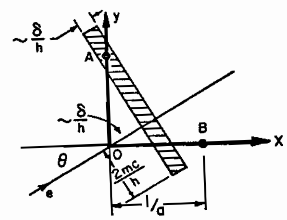
where m = electron mass

ϵ_0 = electron primary energy

ck = photon energy, and

$x = ck/\epsilon_0$.

These relations can be displayed graphically. The axes are scaled to the inverse lattice constants. For an electron interacting with an atom at 0, the permitted momentum transfers are the vector OA and others in the yz plane. The crucial point



is that at high energies and reasonable x,

$$\frac{\delta}{h} << \frac{1}{a}. \quad (4)$$

For a fixed x, one can choose an appropriate angle θ such that the "q pancake" intercepts a few inverse lattice points (of course, the smaller the number intercepted, the greater the polarization). Conversely, for a fixed θ, as one scans x, there will be intensity peaks wherever the pancake, as it moves and expands, intercepts inverse lattice points.

Experimentally, the crucial point is that because of incident electron-beam divergence and multiple scattering in the crystal, one has to collimate the photon beam to

$$\delta\theta_\gamma \approx \frac{\left(\frac{\delta}{h}\right)}{\left(\frac{1}{a}\right)}, \quad (5)$$

when the electrons are incident at small angles to the xy plane. Then, the variations in the angle with respect to the xy plane are sensitive to whether the peak will disintegrate and the polarization wash out.

Substituting

$$\delta\theta_\gamma \approx \frac{1}{2} \left(\frac{x}{1-x}\right) \frac{a}{\lambda_c} \left(\frac{mc^2}{\epsilon_0}\right).$$

For diamond

$$a = 3.6 \times 10^{-8}$$
$$\lambda_c = 0.024 \times 10^{-8}$$

Taking x = 0.3, we get

$$\delta\theta_\gamma \approx 30\left(\frac{mc^2}{\epsilon_0}\right).$$

Of course, mc^2/ϵ_0 is the natural opening angle of the bremsstrahlung cone.

Now we consider a practical example:

Example: $\epsilon_0 = 100$ GeV
$x = 0.3$
$\delta\theta_\gamma \approx 0.15$ mrad.

By looking at experimental results at lower energies, approximately 20% of the spectrum energy is in the first peak. We assume 1.0 mrad as a reasonable divergence for the tertiary electron beam. We take 0.05 radiation lengths for the crystal thickness. This corresponds to 0.9 mrad for the multiple-scattering angle.

$$\therefore \text{ (No. of equivalent Q in peak)} \approx \text{Ne} \times (0.05) \times \frac{0.15}{2.0} \times \left(\frac{20}{100}\right)$$
$$\approx \text{Ne } (0.75) \times 10^{-3}.$$

$$\therefore \text{ (No. of photons in the peak)} \approx 2.25 \times 10^{-3} \times \text{Ne}.$$

For an incident flux of 3×10^6 electrons per burst, we have 7,000 photons per burst at 30 GeV. Since most of the really interesting counter experiments with polarized photons are of the nondiffractive type, the cross sections will be in the nanobarn region. The flux available above is insufficient by a few orders of magnitude.

REFERENCES

[1] G. Diambrini Pallazzi, Rev. Mod. Phys. 40, 611 (1968).
[2] G. Bologna, Nuovo Cimento 49A, 756 (1967).