DOE/ER/3072-29
November 13, 1985

PROPOSAL TO MEASURE THE SYNCHROTRON-ČERENKOV EFFECT

K.T. McDONALD

Joseph Henry Laboratories, Princeton University
Princeton, New Jersey 08544

Summary

I propose to measure the interference between the synchrotron radiation and Čerenkov radiation of 700 Mev electrons. The detector is a 5-m-long He-filled Čerenkov counter surrounded by Helmholtz coils which can produce up to 100 Gauss magnetic field. The signal is an oscillation in the radiation rate as a function of gas pressure in the vicinity of the Čerenkov threshold.

Requirements from the Bates Laboratory are:

- A parasitic electron beam of ~ 700 MeV;
- Beam intensity of $\sim 5 \times 10^4$ per second;
- Momentum spread as small as possible;
- Spot size $\sim 1 \times 1$ mm^2;
- About 20 feet of floor space along the beam;
- A magnet power supply of 0–500 amps capability;
- 48 hours of beam time.

If a charged particle moves with velocity $\beta = v/c$ through a gas of index of refraction n such that $n\beta > 1$ then Čerenkov radiation is emitted. If in addition a magnetic field exists along the path of the particle then synchrotron radiation will also be emitted. The usual perception of these two effects is that they are distinct, but this is not fundamentally so. In particular, if the frequency of the synchrotron radiation overlaps that of the Čerenkov radiation, and if the gas pressure is near the Čerenkov threshold so that both kinds of radiation are emitted very close to the forward direction, then substantial interference may be expected. As synchrotron radiation is primarily polarized in the plane of the orbit (perpendicular to the magnetic field) the interference effect is much more dramatic for this polarization.

The theory of the combined radiation effect has been worked out both classically[1,2] and quantum mechanically[3], and several suggestions have been made as to possible experiments to detect the interference effect[4-9]. However to date the effect has not been observed. This is probably because the interference effect is pronounced only in conditions in which less than one photon is emitted per charged particle in a laboratory-sized detector.

We propose to detect the interference effect by observing optical photons radiated by an electron beam which passes through a magnetized gas volume. If the applied magnetic field is to be large compared to the earth's field, and the radiation rates not too small, it turns out that the electron beam energy should be about 1 GeV, and the field about 100 Gauss. Thus the Bates Laboratory electron beam is very suitable.

Figure 1 shows a sketch of the very simple detector. An 8-in-diameter, 5-m-long pipe is filled with He gas below atmospheric pressure. Helmholtz coils wound above and below the pipe provide a field of 100 Gauss for about 1800 amp-turns current. The heat generated in the coils will be about 2.5 kW, so the coil will be water cooled. I would like to power the magnet with a supply provided by Bates Lab, if possible. This could be a quadrupole supply capable of 0–500 amps, and perhaps should have an actual quadrupole connected in series to provide the inductance needed to stabilize the supply. The length of the radiator is limited to 5 m so that the deflection of the electron beam is only 2″ for a 100 Gauss field. A flat mirror deflects the optical radiation onto a 5″ diameter phototube. A polarizing filter selects the desired orientation of the polarization of the light. The interference effect is more pronounced if the bandwidth of the light is limited. I plan to integrate over the range 300-500 nm. The 700 MeV electron beam is counted in a telescope of 3 small scintillators.

The expected counting rate as a function of He pressure is shown in Figure 2 for an applied magnetic field of 80 Gauss. The calculation is based on the formalism of Ref. 9, with the aid of a tabulation of certain Airy functions in Ref. 8. The Appendix summarizes the formalism.

The experiment consists of measuring the 'pressure curve' for several magnetic fields, including of course zero field. In the vicinity of the strongest rate oscillation, there will be only 1 detected photon per 100 incident electrons, taking into account the quantum efficiency of the phototube. To obtain 1% statistical accuracy at each data point, about 10^6 incident electrons will be required. Similarly it is desirable to know the pressure to 1%, and to have a beam energy spread of less than 1%. Less than 1% of a radiation length of material should precede the He gas volume.

I propose to count the incident electrons one by one in a scintillator telescope. Using $\sim$ 10 ns phototube pulses, it will be best to keep the instantaneous beam rate to $< 5 \times 10^6$ electrons/sec, so that the double pulse correction is reliable. Given the 1% duty factor of the Bates linac, the beam intensity should be $< 5 \times 10^4$ electrons/sec. Thus a typical datum point will require about 20 s of beam time. A pressure curve of 50 data points will require about 1000 s of beam time, and likely several times that during which the pressure is changed. I estimate that it should take no more than 4 hours per curve. The entire experiment would consist of 4 curves, at 0, 40, 80 and 120 Gauss field. Thus about 16 hours of beam time are required. I have requested 48 hours to allow for considerable beam tuning, and safety margin.

There will be essentially no data analysis required (other than possible correction for temperature variation if this exceeds 1° K). The results will be submitted for publication in Physical Review Letters.

Appendix

The existing theory[2,3] of the synchrotron-Čerenkov effect does not calculate this as an interference phenomenon. Rather the radiation rate is calculated directly for the general case of a charged particle moving through a gas which is also in an external magnetic field. Then the usual expressions for synchrotron radiation and Čerenkov radiation emerge as the appropriate limiting cases.

The general radiation rate for the number of photons emitted by an electron per meter of flight path and per eV of optical bandwidth is[9]

$$\frac{d^2N}{d\omega dL}\left(\frac{\text{photons}}{\text{eV m}}\right) = 0.12\left(\frac{H(\text{kG})}{\omega(\text{eV})E(\text{GeV})}\right)^{2/3}[P_1(x)+P_2(x)],$$

where E is is electron energy, ω is the photon energy, H is the magnetic field,

$$x = 3.06\times 10^5\left(\frac{\omega(\text{eV})E(\text{GeV})}{H(\text{kG})}\right)^{2/3}\left[2\Delta n - \left(\frac{mc^2}{E}\right)^2\right],$$

Δn is the deviation of the index of refraction from 1, mc^2 is the electron rest energy, and the $P_j(x)$, $j = 1,2$ are defined in terms of Airy functions by

$$P_j(x) = (j - \tfrac{5}{2})Ai'(-x) + \frac{x}{6} + \frac{x}{2}\int_0^x dt\, Ai(-t).$$

Index 1 refers to polarization in the plane of the orbit (perpendicular to the magnetic field). Figure 3 shows the functions $P_j(x)$ in the interference region. A table of these functions, and their asymptotic expansions are found in Ref. 8.

References

1. T. Erber, Am. Math. Soc. Notices **22**, A422 (1975), Čerenkov-Magnetobremsstrahlung.
2. T. Erber, D. White and H.G. Latal, Acta Physica Austriaca **45**, 29 (1976), Inner Bremsstrahlung Processes II.
3. J. Schwinger, W.-Y. Tsai and T. Erber, Ann. Phys. **96**, 303 (1976), Classical and Quantum Theory of Synergic Synchrotron-Čerenkov Radiation.
4. T. Erber, D. White, W.-Y. Tsai and H.G. Latal, Ann. Phys. **102**, 405 (1976), Experimental Aspects of Synchrotron-Čerenkov Radiation.
5. T.M. Rynne, G.B. Baumgartner and T. Erber, J. Appl. Phys. **49**, 2233 (1978), The Angular Distribution of Synchrotron-Čerenkov Radiation.
6. T.M. Rynne, J. Appl. Phys. **50**, 5572 (1979), Synchrotron-Čerenkov Detectors for Electrons.
7. T.M. Rynne and T. Erber, Appl. Phys. Lett. **35**, 752 (1979), Optical Synchrotron-Čerenkov Radiation.
8. T.M Rynne, Ph.D. dissertation, Ill. Inst. of Tech, (1979), unpublished.
9. T.M. Rynne, J. Appl. Phys. **52**, 6471 (1981), Synchrotron-Čerenkov Radiation in the Vicinity of an Atomic Absorption Edge.

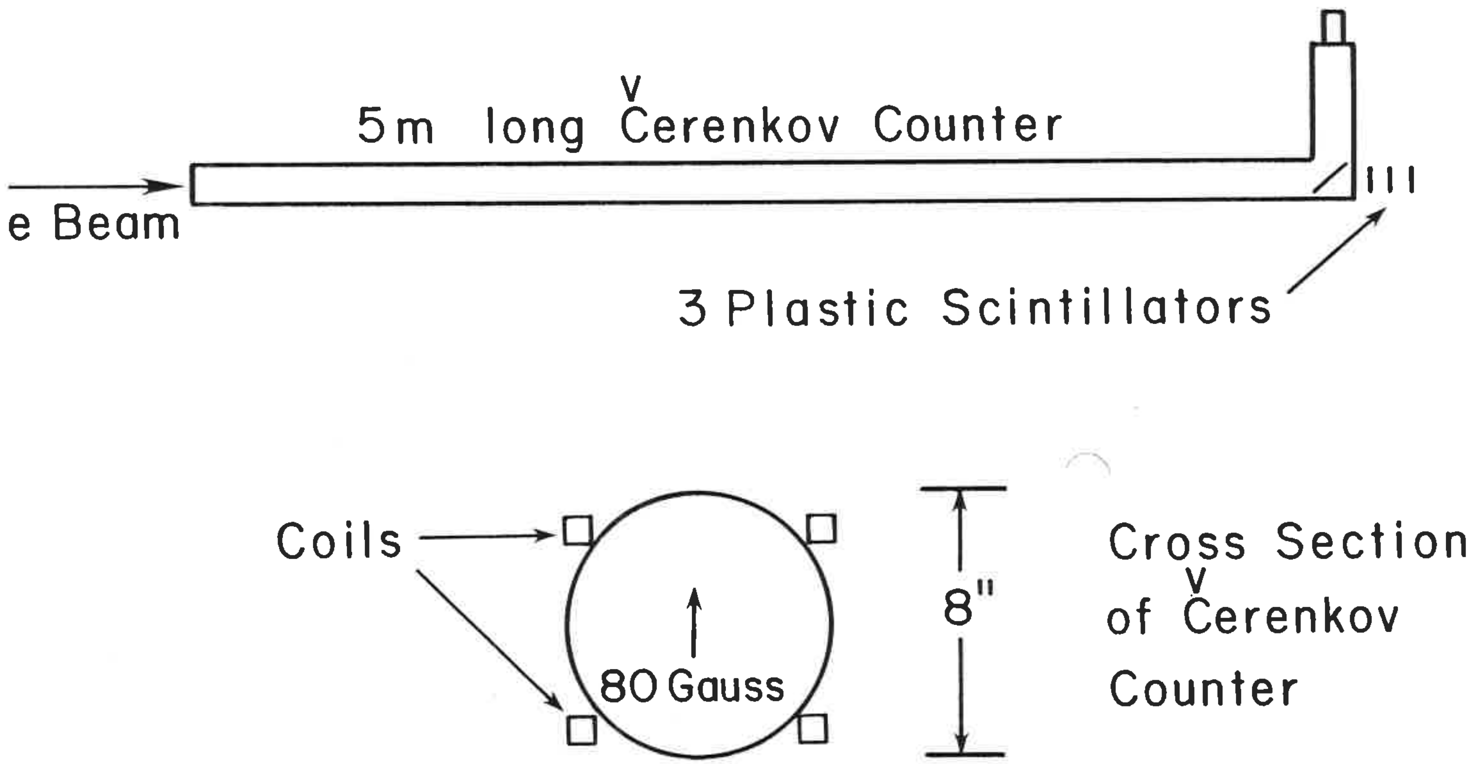

Fig. 1. Sketch of the proposed detector.

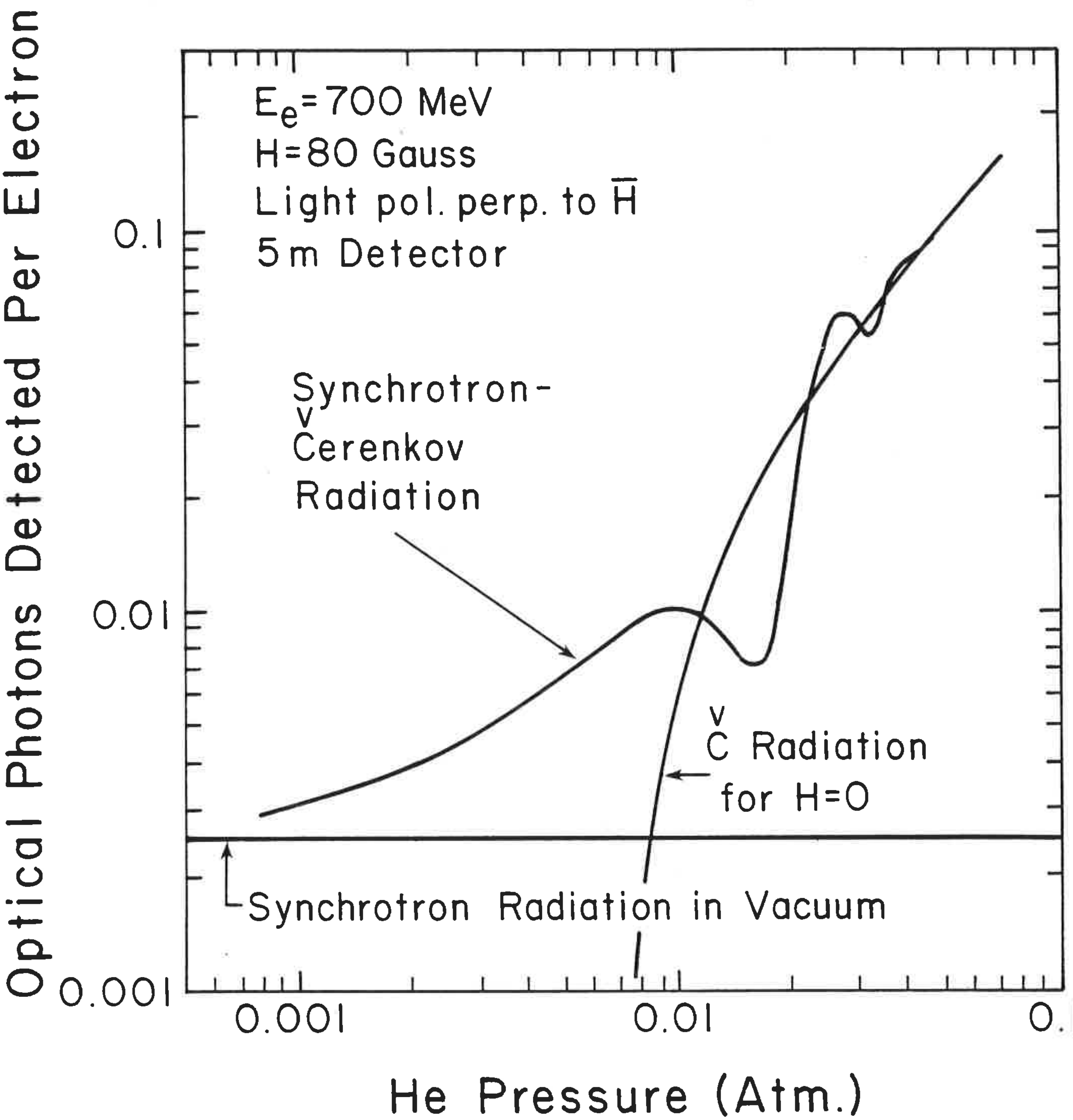

Fig. 2. Calculated rates for the synchrotron-Čerenkov radiation in the proposed experimental configuration, including phototube efficiency.

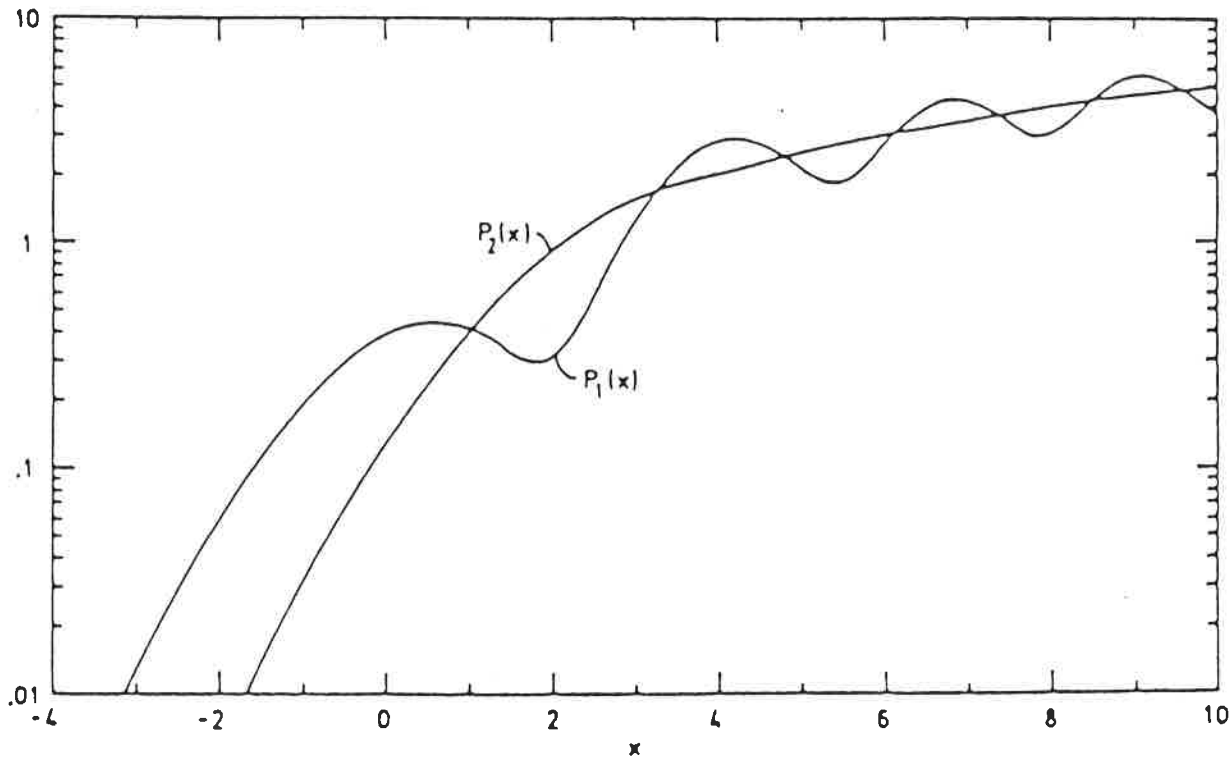

Fig. 3. The synchrotron-Čerenkov functions $P_1(x)$ and $P_2(x)$.