THE HIGH-ENERGY INVERSE BREMSSTRAHLUNG PROCESS
AND SELF-ACCELERATION OF HIGH-DENSITY ELECTRON BEAMS

CROSSING A TARGET

G. Diambrini-Palazzi*)
CERN, Geneva, Switzerland

Geneva - 12 May 1975

(Submitted to Physics Letters)

*) On leave of absence from the University of Genoa, Italy.

Subscription prices: Five dollars per annum in advance. Single copies, fifteen cents. Payment in advance. All communications should be addressed to the Editor, The Journal of the American Medical Association, 535 North Dearborn Street, Chicago, Ill.

Entered as Second-Class Matter, October 3, 1917, under Post Office No. 384, at Chicago, Ill., under special rate of postage provided for in Act of October 3, 1917. Accepted for mailing at special rate of postage provided for in Act of October 3, 1917. Postmaster: Pay no attention to any statement from anyone purporting to represent this publication.

I want to call attention to the existence of a process that has not attracted any attention so far. I am referring to a kind of high-energy inverse bremsstrahlung process shown by the diagrams in Fig. 1, which can be described as follows. In Fig. 1a a real electron e (momentum $\vec{p}_0$, energy E_0) absorbs a real photon γ (momentum $\vec{k}$, energy K). The virtual electron e' interacts with a nucleus N and the energy momentum conservation is restored. In the final state we have a real electron e with momentum $\vec{p}$, energy E , and recoiling nucleus with momentum $\vec{q}$ and energy ε . The amplitude and kinematics of the process look like those of the bremsstrahlung case.

Now let us assume in the initial state an electron and photon flying along directions making a small angle $\theta \sim mc^2/E$, which finally interact in the Coulomb field of a target nucleus. Then the dominant feature of the final state is given by an electron emerging from the target with energy $E \approx K + E_0$ and momentum $\vec{p} \approx \vec{k} + \vec{p}_0$, due to the negligible energy and small momentum taken out by the nucleus recoil. Furthermore, the longitudinal recoil momentum (i.e. parallel to $\vec{p}$) $q_{||}$ is vanishing for $E \rightarrow \infty$, and so coherent behaviour should be expected when the process happens in monocrystals as in direct bremsstrahlung and electron pair photoproduction processes.

Now we want to consider the feasibility of an experimental study of this new process. This would be very interesting for a number of reasons. Firstly, the study of such an electrodynamic interaction implies a new experimentation of three-body collisions never accomplished up to now. Secondly, one interesting consequence of the existence of this process is the possibility, in principle, of acceleration of electrons belonging to relativistic electron beams, by a mechanism which will be considered in some detail in the following.

In order to realize experimentally the inverse bremsstrahlung reaction, namely:

$$\gamma + e + N \rightarrow e + N, \quad (1)$$

we have to produce the three-body collision on the left-hand side of the above reaction. This could be made by a photon beam overlapping with an electron beam crossing a target. Then from the point of view of the incident photons actually there are two "targets": a material target and a flying electron distribution inside this target. In this situation, the order of magnitude of the number of events expected for the inverse bremsstrahlung process, N_{IB} , can be estimated as follows:

$$N_{IB} = N_{br} \frac{V_0}{V} \rho_Y \lambda_c^3. \quad (2)$$

Here N_{br} is the number of bremsstrahlung photons produced inside the target, V_0/V is the fraction of the overlapping volumes of the photon and electron beams (for example, ratio of smaller to larger beam cross-sections for completely overlapping cylindrical volumes), ρ_γ is the photon density (per volume unit) of the primary photon beam (not necessarily the bremsstrahlung beam) and λ_c is the Compton wavelength of the electron. But we have $N_{br} = \sigma_{br} n_0 N_e \approx t N_e$, where σ_{br} , n_0 , N_e are the bremsstrahlung cross-section, the number of atoms per cm^2 in the target, and the number of electrons in the primary beam, respectively, while $t = \ell/X_r$ is the target thickness in radiation lengths. Therefore Eq. (2) can be written as follows:

$$N_{IB} = \frac{V_0}{V} N_e \rho_\gamma \lambda_c^3 n_0 \sigma_{br} = t N_e \rho_\gamma \frac{V_0}{V} \lambda_c^3 .$$

This expression, which gives a rough order of magnitude, shows that the counting rate is depending in a crucial way on the product $N_e \rho_\gamma$ which must compete with the 10^{-29} cm^3 value of λ_c^3 . In fact N_{IB} is depending not only on N_e and n_0 , but also on the number of photons which are present in the typical interaction volume λ_c^3 , i.e. $\rho_\gamma \lambda_c^3$.

Now first we want to show the possibility, in principle, of self-acceleration of a relativistic electron beam; then we will make some remarks on the experimental study feasibility.

Suppose we have a beam of multi-GeV mono-energetic electrons and let it be crossing a target radiator of, say, $t = 0.1$ radiation length thickness. Then $\sim 10\%$ of the electrons will radiate a bremsstrahlung photon spectrum, while the other $\sim 90\%$ leave the target with about the initial energy E_0 .

If reaction (1) takes place, then a photon inside the target can give all of its energy to one electron with E_0 energy, so that it emerges from the target with an energy of $E = E_0 + K \leq 2E_0$, due to the range of the photon energy K in the bremsstrahlung spectrum. So it should be possible to detect electrons with energy higher than the energy of the accelerator generating the primary electron beam. In fact, the energy spectrum of electrons leaving the radiator will show, in the range $0 < E < E_0$, almost unchanged straggling distribution, while in the range $E_0 \leq E \leq 2E_0$ another tiny tail should be present whose distribution imitates the bremsstrahlung spectrum itself.

Now have a look at the feasibility of experimental detection of such energetic electrons. First of all, let us estimate the counting rate based on Eq. (2). We can write now

$$\dot{N}_{IB} = t \dot{N}_e \rho_\gamma \lambda_c^3 = \frac{t^2}{2} N_e \rho_e \lambda_c^3 .$$

Here we put $V_0/V = 1$, because a bunch of photons in the multi-GeV energy region has, inside the target, about the same cross-section area as the parent electron bunch, and the factor $\frac{1}{2}$ is an approximate average of the photon paths inside the target. In order to obtain 1 count per hour, we need to have electron intensity and density (the latter in single bunches) of the order of

$$\dot{N}_e \rho_e \sim \frac{2}{3600 t^2 \lambda_c^3} \approx 2 \times 10^{26} \text{ cm}^{-3} \text{ sec}^{-1},$$

where $t = 0.5$ radiation length has been used. For example, this value could be obtained by a beam of 2×10^{13} electrons/sec, structured in bunches of 10^{13} electrons per cm^3 . These conditions are not far from SLAC values¹⁾, and perhaps could be approached by choosing some special linac working conditions. High-density electron bunches are available in storage rings too, for example, the EPIC²⁾ project design expects circulating bunches of $\sim 2 \times 10^{14}$ electrons/ cm^3 density and a total number of 3.2×10^{12} circulating particles.

Concerning identification of accelerated electrons, this is made easier by the large value of their energies which can be up to a factor of 2 higher with respect to the accelerator energy! A suitable magnetic analysis of the electron momentum, together with direct measuring of total electron energy, must allow discrimination against background.

In conclusion, assuming Eq. (2) is giving the correct order of magnitude, it seems to us that experimental study of the inverse bremsstrahlung process is within the range of present-day technology. More accurate evaluations of the cross-section in amorphous and crystal targets are in progress.

We wish to thank R. Barbieri for discussions, especially concerning Eq. (2), and D. Amati and S. Fubini for encouragement and advice.

REFERENCES

- 1) Proc. VII Internat. Conf. on High-Energy Accelerators, Erevan, USSR, 1969
(Publishing House of the Academy of Sciences of the Armenian SSR, 1970),
p. 79; see also
The SLAC users handbook -- SLAC, Stanford, Calif. USA.
- 2) A proposal to build a 14 GeV electron-positron colliding beam facility --EPIC,
Rutherford Laboratory, Report RL 74-100, Sept. 1974.

Figure caption

Fig. 1 : Diagrams for the inverse bremsstrahlung process.

Fig. 1