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G. Bologna, F. Celani, B. D'Ettorre Piazzoli, G. Mannocchi and P. Picchi: COHERENT BREMSSTRAHLUNG AS A POSSIBLE TOOL FOR ELECTROMAGNETIC BACKGROUND REJECTION IN A HIGH ENERGY PHOTOPRODUCTION EXPERIMENT.

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COHERENT BREMSSTRAHLUNG AS A POSSIBLE TOOL FOR ELECTROMAGNETIC BACKGROUND REJECTION IN A HIGH ENERGY PHOTOPRODUCTION EXPERIMENT.

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1. - MOTIVATION.

We present some considerations which could help in removing background at the trigger level in some high energy physics experiments.

We have in mind a specific case: the NA1 experiment (see ref. (1)), which has been running at CERN Super Proton Synchrotron. The method we propose could eventually be implemented at next run time, which is foreseen after the machine shut-down.

Fig. 1 is a sketch of the NA1 apparatus, designed for the photoproduction of vector and scalar bosons. Here the unwanted background is due mainly to the photoproduction of e^+e^- pairs ($\sim 10^5$ to 1 good event).

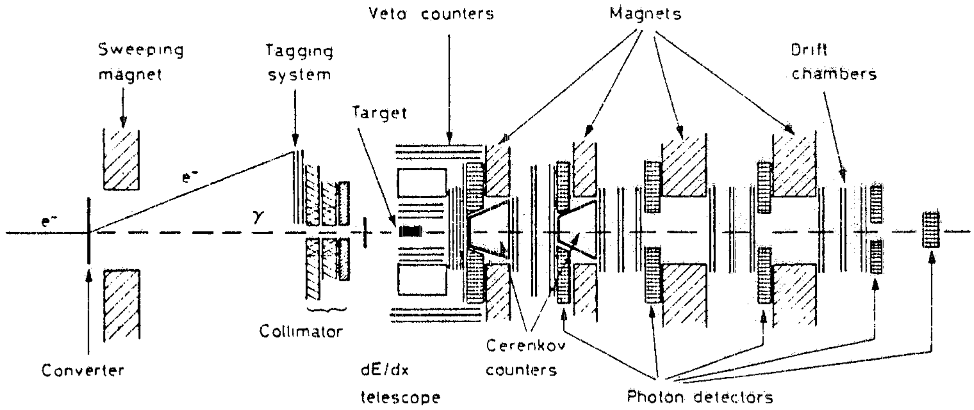

FIG. 1 - NA1 experiment general lay-out (top view).

At the energies we are concerned with (40-150 GeV), the separation of electrons and positrons from more massive particles (i.e. : pions and kaons) cannot be made by velocity - sensitive devices, like Cerenkov counters. Thus one has to rely on effects which depend on the energy of the particle (and do not essentially perturb the state of the particles being studied).

Specifically, detectors which exploit the transition radiation generated at the interface between two different repetitive media are by now reliable and have been used in some instances. However the radiators in these detectors are rather cumbersome (for instance, ref. (2) describes a radiator whose length is some 40 cm). As a matter of fact there is no sufficient free space close to the target for the radiator plus detector assembly in the mentioned experiment (Fig. 1).

We want to show that the signature of a high energy electron or positron could be made unambiguous by replacing transition radiation with coherent bremsstrahlung in a thin single crystal. The total thickness of the γ-radiation production plus detection system should be less than the total thickness of the boson-producing structured target system (12 mm silicon thickness).

2. - THE PROCESS OF COHERENT BREMSSTRAHLUNG.

We will simply recall the essential features of coherent bremsstrahlung without giving many details. See the review papers of ref. (3) and ref. (4) for a full discussion.

Let us define :

p_o	primary electron momentum ;
E_o	primary electron energy ;
k	photon energy ;
x	$= k/E_o$ fractional photon energy ;
mc^2	electron rest energy ;
δ	$= (mc^2/E_o)/(2x(1-x))$ minimum recoil momentum of the crystal in mc units ;
a	direct lattice spacing ($\lambda\!\!\!^{-}_c = \hbar/mc$ Compton units) ;
b_1, b_2, b_3	reciprocal lattice axes ;
g	reciprocal lattice vector ;
θ	$= \sphericalangle (b_1, p_o)$;
α	$= \sphericalangle (b_1, p_o)(b_1, b_2)$.

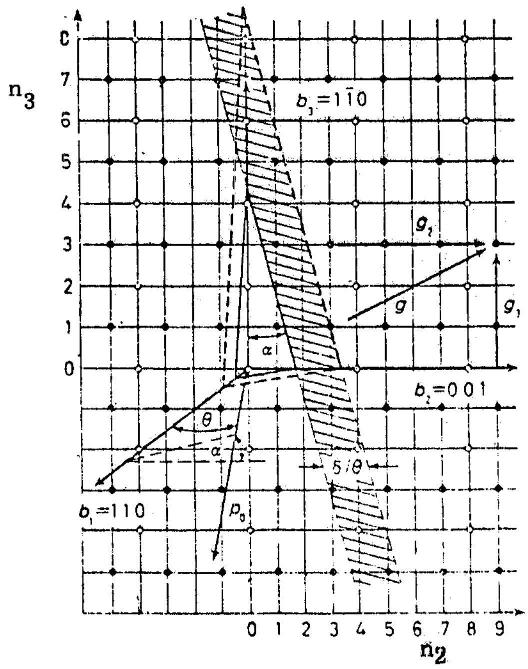

FIG. 2 - Reciprocal lattice space for a diamond crystal.

Fig. 2 shows the reciprocal lattice of a diamond crystal. The momentum p_o makes the angle θ with the axis b_1, while α is the angle of the planes (b_1, p_o) and (b_1, b_2). The kinematically allowed region for the recoil momentum of the crystal has the shape of a pancake orthogonal to p_o, having a sharp distance δ from the origin of the reciprocal lattice space, a smooth thickness δ and a smooth radius equal to 1. In Fig. 2 the intersections of the pancake surfaces with the reference lattice planes are drawn. The shaded area represents the intersection of the pancake with the plane (b_2, b_3).

Laue condition holds for coherent bremsstrahlung. This imposes a further restriction on the recoil momenta: only those are allowed which coincide with a reciprocal lattice vector. Furthermore, the contribution to the cross section is essentially different from zero only for those reciprocal lattice points which lie in the plane (b_2, b_3) through the origin.

By changing θ and/or k and/or E_0 the pancake sweeps the points of the lattice. Correspondingly the shaded area of Fig. 2 moves across the points of the plane (b_2, b_3). Every time it includes or escludes a point on the left side, a sharp discontinuity is produced in the cross section.

In Fig. 3 (taken from ref. (5)), the bremsstrahlung intensity for a diamond single crystal,

$$I(x) = k dN/dk ,$$

is represented, in arbitrary units, versus x; dN is the number of photons in the range dk at k. Other parameters are: $E_0 = 4.8$ GeV, $\theta = 3.44$ mrad, $\alpha = 0$.

The dashed curve was obtained for an ideal situation in which the primary electron beam enters the crystal without any divergence and suffers no multiple scattering. The discontinuous behaviour of this curve confirms the qualitative picture given above. Now the shaded area in Fig. 2 is vertical and an entire row of points escapes the pancake at a time, giving discontinuities at x = 0.3, etc.

The continuous curve has been obtained by making allowance for these effects (1 mrad electron natural spread, and 1 mm thickness multiple scattering). It is in remarkable agreement with the experimental results, represented by the dots.

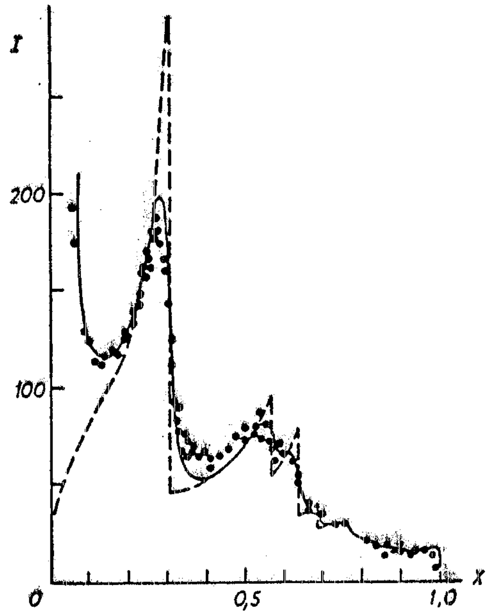

FIG. 3 - Bremsstrahlung intensity versus x (arbitrary units) $E_0 = 4.8$ GeV, $\theta = 3.44$ mrad, $\alpha = 0$.

When x approaches zero (and so does δ), there are no points of the lattice within the pancake; thus the coherent cross section is vanishing in the "ideal" situation (however, the dashed curve does not reach zero at x = 0, due to the presence of an incoherent thermal background of the Bethe-Heitler type).

In the effective experimental conditions, the direction of p_0 has a range of values within a cone. Thus also α has a range of values and the pancake intersection in Fig. 2 includes the point $n_3 = 2$ on the axis b_3, for which the contribution to the cross section is largest. Correspondingly, the continuous curve has a steep rise. This effect could be exploited to obtain a sizeable number of photons.

To have an idea of the strength of this point, let us have a look to Fig. 4 (taken from ref. (6)), for which E_0 = 6 GeV, θ = 50 mrad, α = 23 mrad : the leading discontinuity at k = 1.44 GeV (x = 0.30) of Fig. 3 is pushed to x = 0.9 (k≅5.4 GeV) and its amplitude is decreased. Simultaneously, the points of the axis b_3 enter the pancake : the leading discontinuity (k = 2 GeV) is just due to the already mentioned point. No other point can enter the pancake after this. Accordingly, in Fig. 4 there is no rise at low x as in Fig. 3.

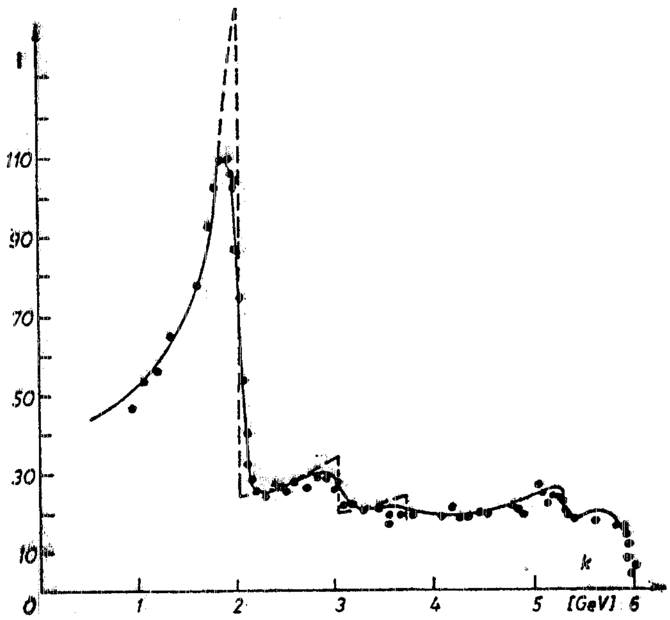

FIG. 4 - Same as Fig. 3, but with E_0 = 6 GeV, θ = 50 mrad, α = 20 mrad.

In Fig. 5 (taken from ref. (4)) the coherent contribution from a single reciprocal lattice point is presented (shaded area). The dashed curve represents how the peak value of the bremsstrahlung intensity changes by varying the x_d value of the discontinuity. The value of the function $\chi(x_d)$ is approximately proportional to

$$1/\delta_d = (2E_0/mc^2)(1 - x_d)/x_d ,$$

while the value of θ is proportional to δ_d. We now know which type of behaviour is to be expected when θ is decreased in order to increase the number of soft photons.

Before proceeding any further, a remark on the validity of this behaviour is in order. For a sufficiently high E_0 and/or sufficiently low θ, there will be some value of δ for which the bremsstrahlung cross section will be higher than the geometrical cross section of the atom, and this is manifestly absurd. The failure to predict the exact value of the cross section is connected with the non validity of the Born approximation in certain conditions. A careful analysis of this problem has been done in a series of papers by Akhiezer and collaborators (see ref. (7) and references cited therein). The results of this analysis are the following.

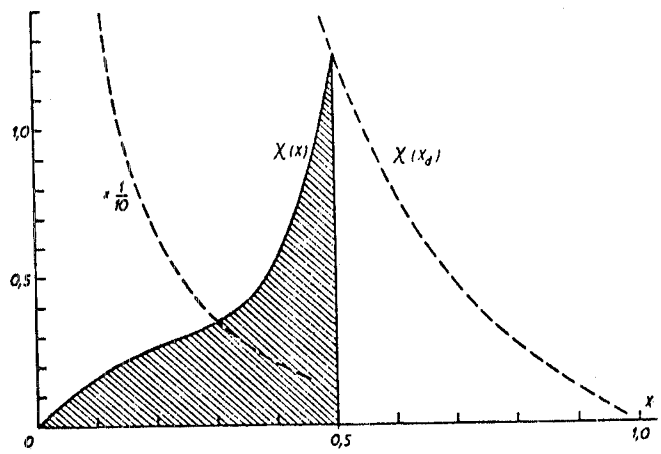

FIG. 5 - Coherent contribution to bremsstrahlung intensity from a single reciprocal lattice point (Arbitrary units).

The results of the calculations obtained by applying the first Born approximations are valid when

$$(Z/137)/(a\theta) \ll 1 \qquad (Z \text{ atomic number}) .$$

When this inequation is not satisfied, the coherent nature of the bremsstrahlung is lost, and the radiation is suppressed. This happens for diamond for

$$\theta \simeq 5 \times 10^{-5} \text{ rad.}$$

Furthermore the bremsstrahlung intensity depends on the sign of the charge of the particle (larger for electrons than for positrons). The critical parameter in this contex is

$$(Z/137)(mc^2/E_o)/(a\theta^2).$$

When this parameter is comparable to 1, a new phenomenon arise: the so called axial channeling (channeling effects are discussed in ref. (8)).

In a standard experimental situation the primary beam divergence will be of the order of 1 mrad. We can thus state that the suppression effect should be negligible. Equally, at very high energy, the influence of axial channeling can be hardly observed. For instance, for E_o = = 100 GeV the characteristic angle for axial channeling for diamond should be

$$\theta \simeq 2 \times 10^{-5} \text{ rad.}$$

The critical angle for planar channeling is even less than this (it is multiplied by β/a, where β is the screening radius of the atom).

In conclusion we can be confident that Born approximation calculations can be used at least for low Z and not too high particle energies, if the primary beam angular divergence is not too small. Also, the difference in bremsstrahlung between electron and positron should be negligible. For these reasons, all the results presented in this paper were calculated in first Born approximation.

3. - A TYPICAL EXAMPLE.

We have made some Born approximation calculations in the following conditions. A diamond crystal was chosen, because it has the best coherence properties for bremsstrahlung. Also a beryllium crystal could have been chosen, since it was recognized as the best crystal after diamond (see ref. (9)). Crystal thickness was assumed as 2 mm. An electron/positron beam of energy 100 GeV was considered with the central direction along the axis $\{110\}$ ($\theta = 0$). The beam angular distribution was considered gaussian with a 1/e width of $\pm$ 1 mrad. The influence of multiple scattering is negligible at these energies.

In such conditions each electron produces a number of soft photons which is estimated to be larger than 1, while the number of photons above 10 MeV is negligible. This result should be considered very preliminary. A refinement must be performed together with an extension to lower electron energies. However it can serve as a guideline for designing detectors. No experimental results exist in the stated conditions. We are planning to perform some experimental tests in future time.

4. - CONCLUSION.

By placing the crystal close to the target (see Fig. 1) and by detecting the soft γ-radiation, which is exclusive of the e^+, e^-, we hope to form a fast pretrigger signal which should allow the e^+, e^- to be rejected with reasonable efficiency.

Solid state detectors, microchannel plates and Xenon scintillation counters should be considered as candidates for the detection of the γ radiation in the range 20-100 keV. More difficult seem the task of detecting with good efficiency the radiation around 1 MeV, where the gamma absorption coefficients are small.

Three stringent conditions must be met in the NA1 experiment: small radiator + detector thickness (a fraction of 1 gr/cm^2), short length ($\sim$ 40 cm) to be allocated to the detector, and fast overall time response ($<$ 50 nsec), to be useful for the formation of the veto signal.

The test we have in mind to perform should give an answer also to these problems.

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