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G. P. Murtas: COHERENT PHOTON EMISSION BY HIGH ENERGY ELECTRONS AND POSITRONS AND POSSIBLE USE OF A CRYSTAL AS DIRECTIONAL DETECTOR

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COHERENT PHOTON EMISSION BY HIGH ENERGY ELECTRONS AND POSITRONS AND POSSIBLE USE OF A CRYSTAL AS DIRECTIONAL DETECTOR

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There is a strong emission of photons when a high energy (40-100 GeV) electron or positron impinge a Si Crystal of few tenths of Rad. Length, parallel to the ⟨III⟩ Crystal axis within an angle $\theta < 8$ mrads.

This is the experimental result found by R. Del Fabbro (Pisa) and myself (Laboratori Nazionali di Frascati)[1] using the electron beam facility of FRAM NA1 Group at CERN.

About 15 photons with $K > 100$ MeV are emitted by a single 100 GeV electron when the crystal axis is aligned with respect to the electron direction in comparison to 1 photon with $K > 100$ MeV emitted when the crystal axis is not aligned, i. e. when the Si can be regarded as amorphous and the thickness is ~ 0.15 r. l. Before giving details I like to recall both old results[2,3] on coherent bremsstrahlung and the more recent results[4] on coherent bremsstrahlung by channeled electrons and positrons.

In this way we can understand better the results we obtain. In the last part of my talk I will give the details of the experiment.

It is well known that a particle of momentum p is coherently reflected from a set of planes with spacing a, when the recoil momentum transferred to the crystal is $\overline{q} = n\overline{g}$ where $\overline{g}$ is a vector in the reciprocal lattice of the crystal $g = 1/a$ and n is an integer number.

This relation can be demonstrated using Bragg's law (see Fig. 1).

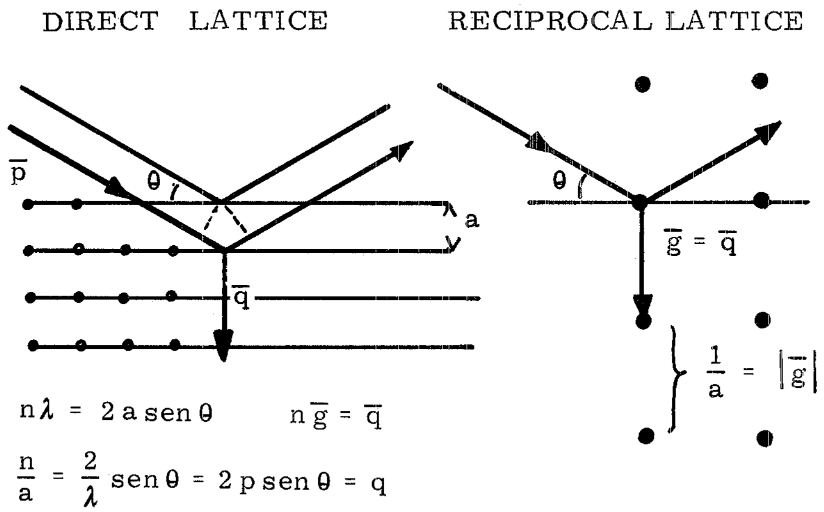

Fig. 1

The bremsstrahlung from electrons in crystals is coherently produced when the same condition is fulfilled. The feature of the coherent bremsstrahlung spectrum can be easily understood look ing to the recoil momentum distribution in a q space (i. e. in the reciprocal lattice space).

The momentum distribution is well described by a pancake

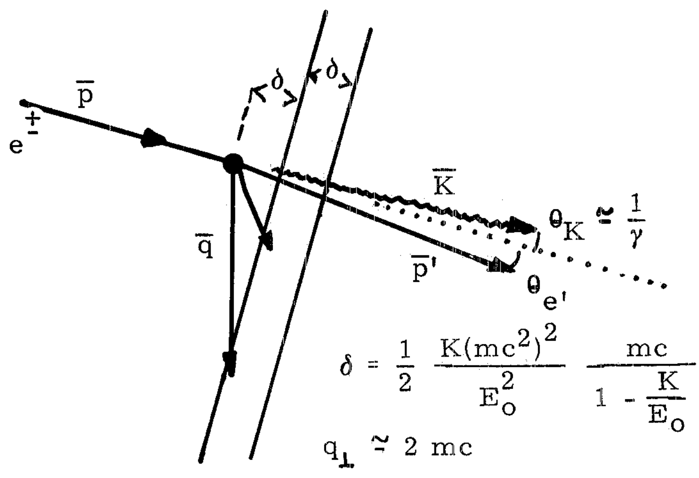

Fig. 2

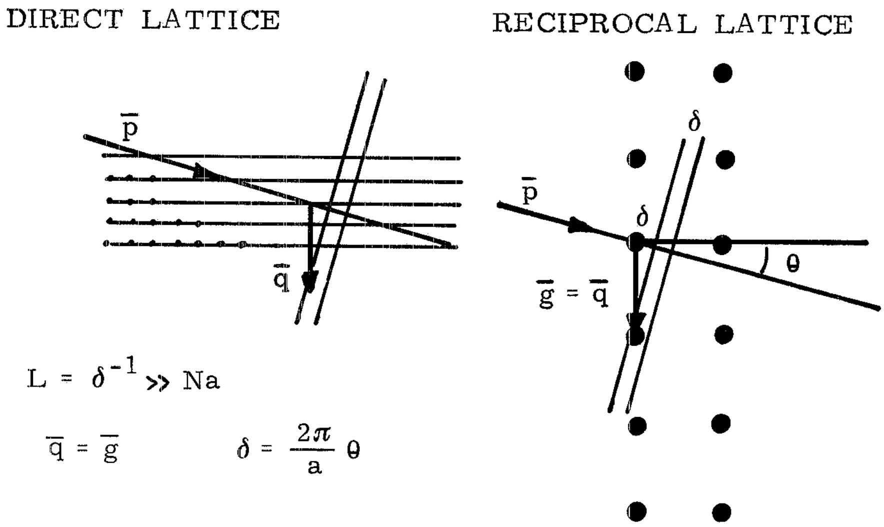

Fig. 3

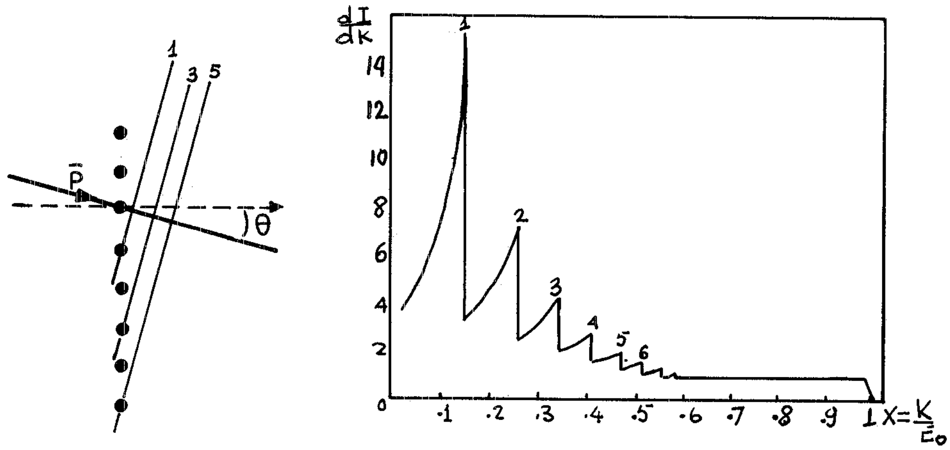

Fig. 4

shaped region, which for fixed energy K of the photon emitted is a thin disk perpendicular to p of thickness δ and distance δ from the origin (see Fig. 2). But in the crystal (see Fig. 3) the recoil momenta allowed are only $\bar{q} = n\bar{g}$, so if we rotate the crystal, every time a reciprocal lattice point enters (or leave) the momenta region, the intensity of bremsstrahlung of photons of energy K is enhanced (or suppressed).

Furthermore, for a fixed orientation of the crystal with increasing K the pancake thickness grows as does its distance from the origin, so that new q-values enter and others leave the allowed region.

The resulting bremsstrahlung spectrum is shown in Fig. 4.

The intensity $\left(\frac{dI}{dK}\right)_{K_d}$ of the coherent bremsstrahlung at the discontinuity $K = K_d$ is:

$$\left(\frac{dI}{dK}\right)_{K_d} = E_o f\left(\frac{K_d}{E_o}\right) \frac{(2\pi)^2}{a^3} |S|^2 e^{-Ag^2} F(g^2)$$

where:

$$f\left(\frac{K_d}{E_o}\right) = \left[1 + (1 - X_d)^2\right] \frac{(1 - X_d)}{X_d}, \quad X_d = \frac{K_d}{E_o},$$

$|S|^2$ = Structure factor of the crystal,

e^{-Ag^2} = Debey Waller factor, A : mean square thermal displacement of the atoms,

$F(g^2)$ = Atomic form factor.

It is evident that when $X = \frac{K}{E_o} << 1$, $\delta = \frac{1}{2} \frac{K_d}{E_o} = \frac{2\pi}{a} \theta$ and consequently the peak of intensity $\left(\frac{dI}{dK}\right)_{K_d} \propto \frac{I}{\delta}$ at $K_d = \frac{4\pi}{a} \theta E^2$.

The calculated intensity[5] is in agreement with the experimental one up to $\theta \rightarrow \theta_{ch} = (2 Z e^2/E_o a)^{1/2}$. In this last case the particles are channeled.

In this condition the radiation is different for electrons and positrons, in agreement with the experimental results[4].

The number of photons emitted by channeled positrons is given in Table I together with θ_{ch} the critical angle of channeling and the value of $K_{ch} = \frac{4\pi}{a} \theta_{ch} E^2$ (the same value of K_{ch} is found considering the channeled positron as an armonic oscillator).

In conclusion an oriented crystal (i. e. $\theta \rightarrow 0$) with θ of the order of some milliradians is a beautiful tool to obtain a great number of photons from an high energy radiating electron or positron, while the bremsstrahlung cross section from a muon or pion is $\frac{m_\mu^2}{M_\mu^2}$ times the bremsstrahlung from an electron.

Table I

E_0 GeV	θ_{ch} mrad	K^+_{ch} GeV	$\frac{N(K)}{cm}$	Dechan length cm
1	0.27	0.005	3.5	0.1
5	0.12	0.05	8	0.5
10	0.08	0.137	12	1
40	0.04	1.1	24	4
80	0.03	2.9	33	8
100	0.025	4.3	38	10

So a counter made by a oriented single crystal followed by a photon detector must have directional properties as high energy electron detector and at the same time good performance in separating $e^{\pm}$ from μ, π, etc.

The preliminary test performed on such counter confirms this foresight. The photon detector was made by the same single crystal used as pair converter followed by a plastic scintillator E, 2 cm thick, in which the pulse height analysis was performed each time the crystal was hitted by an electron of momentum p. In the following Fig. 5 the pulse height distribution of the scintillator E is shown for electrons of different momenta aligned, i.e. $\theta = 0$ (Fig. 5a). and not aligned, i.e., $\theta > 8$ mrad (Fig. 5b)

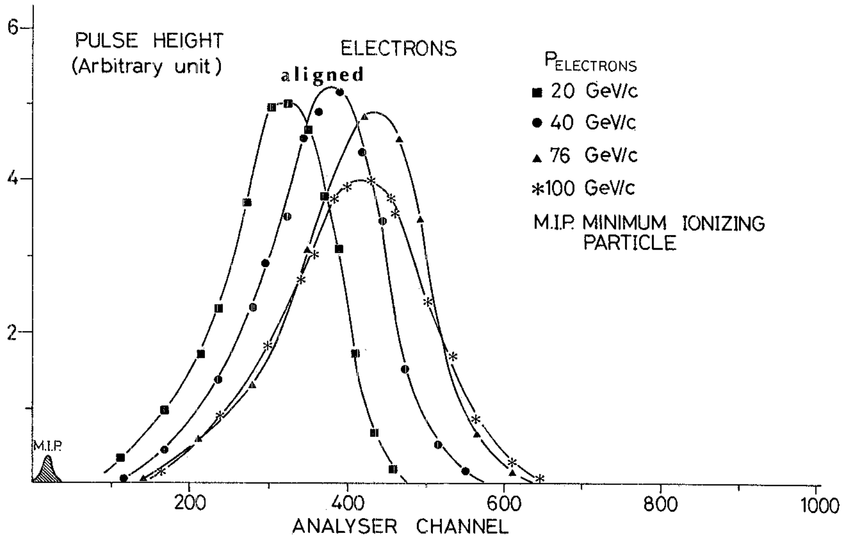

Fig. 5a

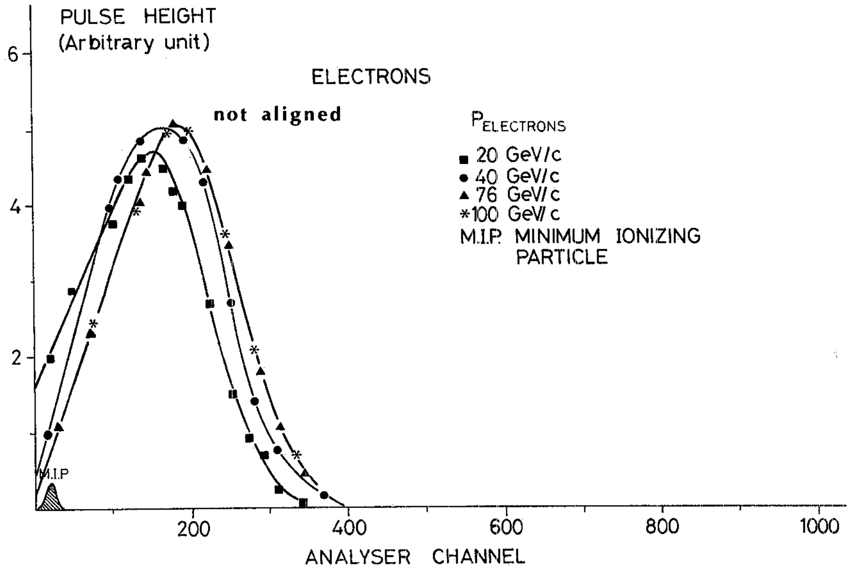

Fig. 5b

The directional effect of the coherent bremsstrahlung from 100 GeV/c positrons is evident for $\theta < 8$ mrad in Fig. 6 where the peak position of the pulse height distribution is plotted versus θ. For $\theta > 8$ mrad the shower development in the crystal is like

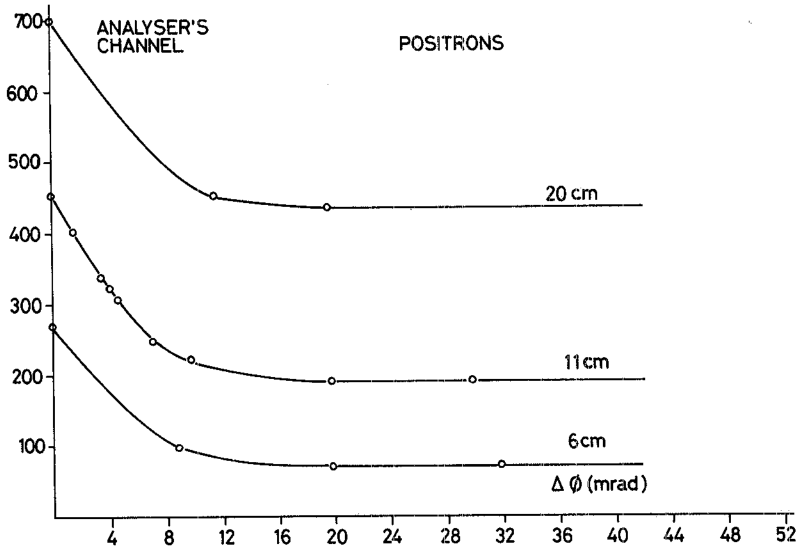

Fig. 6

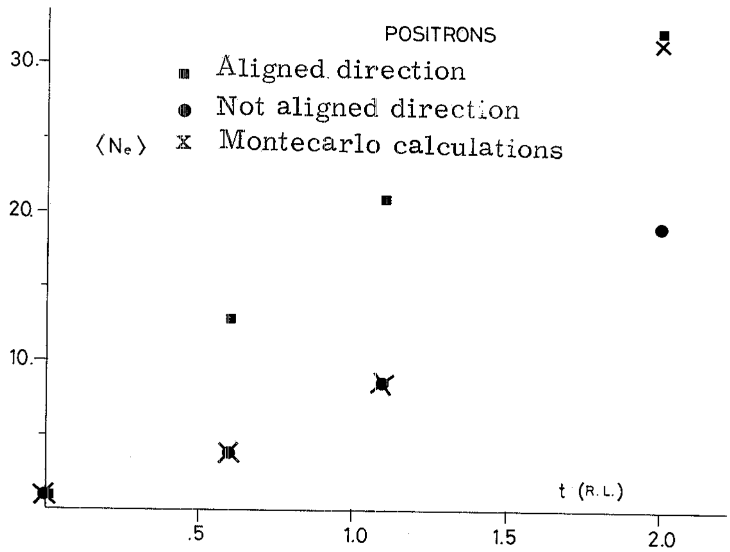

Fig. 7

as in an amorphous Si. Also, the coherent effect is quite indepen- dent from the thickness of the crystal. Really the coherent effect seems to happen in less than some tenths of radiation length.

The average number of electrons $\langle Ne \rangle$ going out the crys- tal is easily obtained from the pulse height analysis of the coun- ter E and it is shown in Fig. 7 together with the average number of electrons calculated by the Montecarlo method for an amorpho- us Si (i. e. not aligned crystal).

As consequence of such results the electrons coming out from the crystal seems to be produced from about 15 photons in the first tenths of radiation length of the crystal.

The results obtained for the crystal length of 20 cm is until now not fully understood.

Conclusions

Roughly speaking about 15 photons with $K > 100$ MeV are e- mitted by a single 100 GeV electron by coherent bremsstrahlung in an oriented crystal, comparing with 1 photon with $K > 100$ MeV emitted by bremsstrahlung in an amorphous medium of ~ 0.15 r.l.

These preliminary results obtained are incouraging and work is in progress to increase the sensitivity of the photon detector, to choose the optimal thickness of the single crystal, to test crystals with smaller lattice spacing a (remember $(\frac{dI}{dK})_{K_d} \propto \frac{|S|^2}{a^3}$!). In addition it is needed to look again to the calorimetry behind the single crystal radiator.

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