PXR and DTR Radiations of 4.5 GeV Electrons in Diamond Crystals

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Resonance radiation

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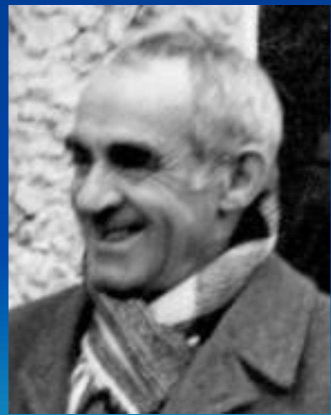
1923-2004

Quazi Cherenkov Radiation

G.M. Garibian

Parametric X-ray Radiation



V.G. Baryshevsky

The passage of charged particles through single crystals can be accompanied by X-ray radiation under relatively large angles due two mechanisms.

- The emission of the so-called X-ray parametric radiation (PXR) under certain angles can be interpreted, in particular, as Bragg diffraction of pseudophotons co-propagating the charge . The process of the production and absorption of PXR takes place along all the thickness of the crystal.

- The absorption length of the PXR photons with energies ~ 10 keV is about a few hundreds microns and it is not reasonable the use of crystals with thickness larger than a few absorption length. The primary extinction length X-ray diffraction is usually less than one micron.

•The relativistic charged particles entering into the crystal produce also X-ray photons of transition radiation (TR) under angles 1/γ in the first thin layer of the crystal corresponding to the formation zone of TR in medium, which is larger than extinction length, but less than the absorption length, usually less than a few of tens microns.

- A small part of TR photons with relatively large spectral distribution propagating further into the crystal can undergo Bragg diffraction on the crystallographic planes and be emitted as photons of diffracted TR (DTR) with energies and angles very close to ones of PXR.

For an ideal crystal the energy and thickness dependences of PXR and DTR have the following behavior:

For γ values lower than a certain critical $\gamma_{cr}=\omega/\omega_{pl}$, where ω is the PXR or DTR photon frequency, and ω_{pl} is the plasma frequency of the crystal, the PXR intensity increase with the increase of γ.

- **At $\gamma \approx \gamma_{cr}$ the intensities of PXR and DTR are approximately equal to each other, while at $\gamma > \gamma_{cr}$ the intensity of PXR is saturated, and the intensity of DTR increases logarithmically.**

For very thin crystal thicknesses of $L_{cryst} \leq L_{ext}$ where L_{ext} is the primary extinction length the PXR and DTR intensity increases with the increase of L_{cryst}, and for real crystals with thickness greater than a few microns intensity of DTR is saturated, while PXR increases up to thicknesses of the order of the absorption length of PXR or DTR photons.

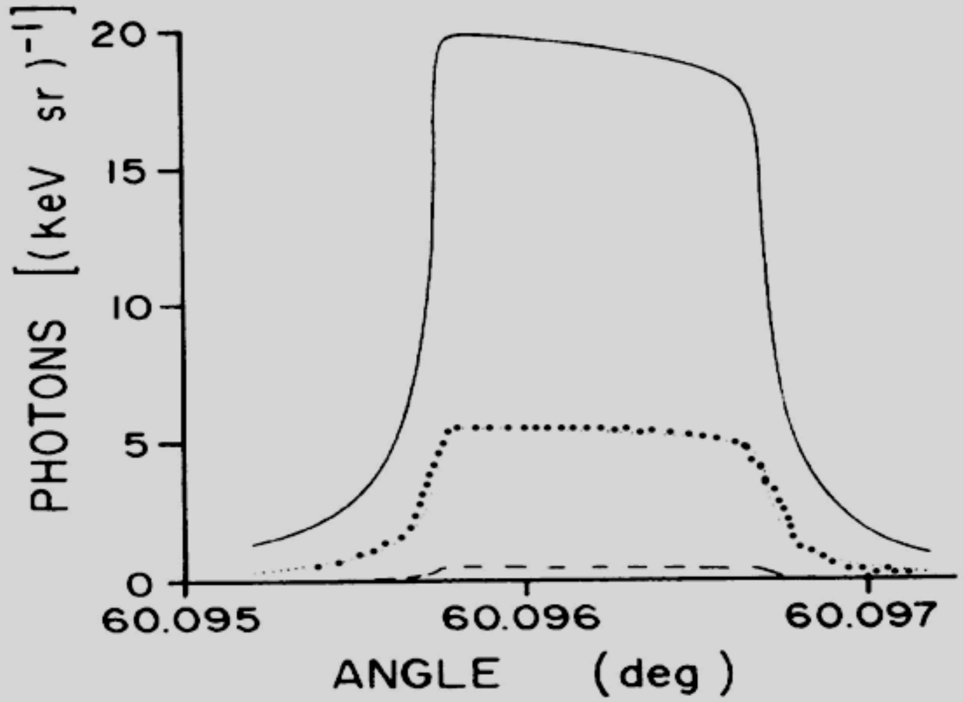
The above said is correct if one can neglect the influence of the multiple scattering.

- According to the published works the DTR has been considered by A.Caticha (Phys. Rev. A 40, 4322, 1989; Phys. Rev. B 45 9541, 1992).

The number of photons $d^2N/dh\omega d\Omega$, emitted by one electron per unit solid angle, per unit photon energy by a relativistic electron with $\gamma=500$ as a function of the angle θ between k, and H for various values of photon energies ($\varepsilon=3*10^{-3}$, $5*10^{-3}$, and 10^{-2}, $\hbar\omega=\hbar\omega_B(1+\varepsilon)$) was calculated.

- The dynamical diffraction reflectivity for X-rays of those energies are also presented. The most obvious feature is the existence two peaks. The TDR peak has a typical angular width of about 10^{-3} degree or a few seconds, is located exactly where the reflectivity for X-rays is large.

An important issue is the dependence of the emitted TDR with the energy of the incident electrons. The intensities for γ = 250, 500 and 1000 for a fixed ε are shown.



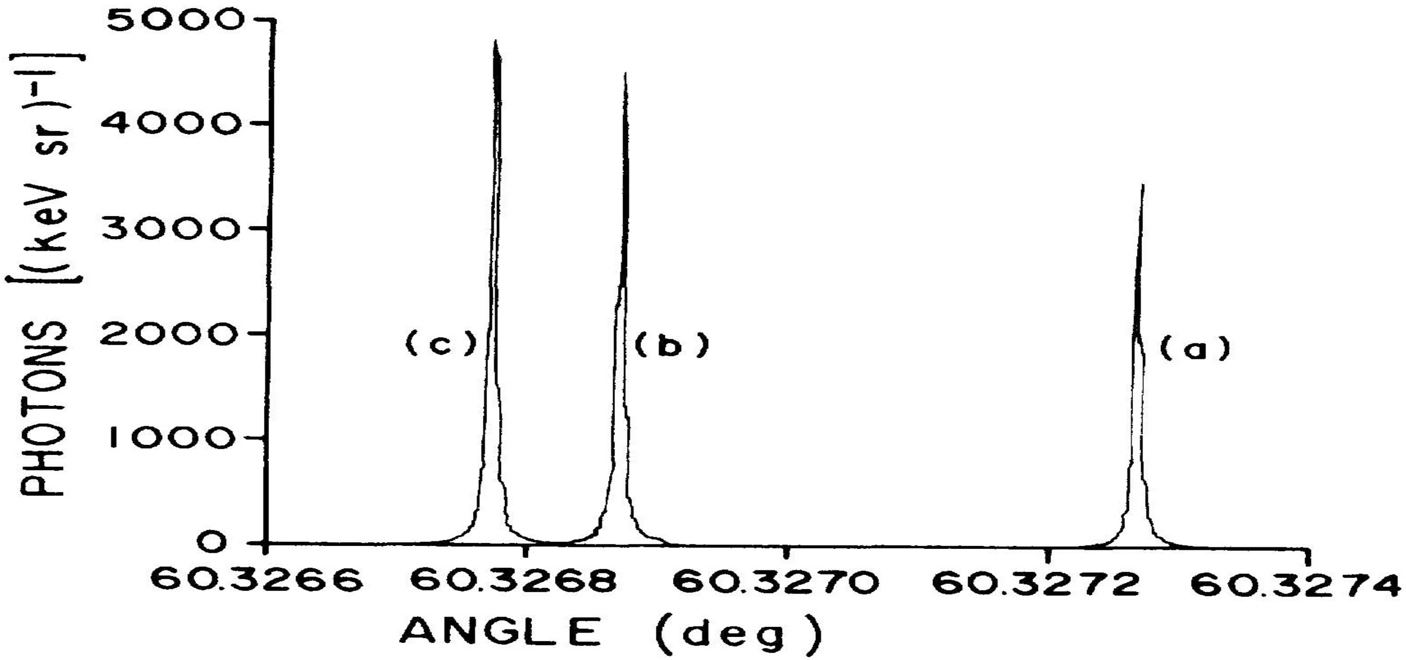
TDR at fixed $\varepsilon = 10^{-2}$, for various electron energies: $\gamma = 250$ (dashed), $\gamma = 500$ (dotted), and $\gamma = 1000$ (solid line).

It was found that peak in the angular distribution of TDR for given photon energy is not shifted as γ changed.

- The other one, the CR peak, is very narrow, much more intense, and is located at a place of negligible X-ray reflectivity.

γ-dependence of CR was considered. In fig. the CR peak for $\varepsilon=10^{-2}$ is shown for γ values of 250, 500, and 1000. We see, that as γ increase the location of the peak gradually shifts towards smaller angles.

In fact, for electron energies of a few GeV the intensities of both peaks will be comparable, and for higher energies the TDR peak will dominate.



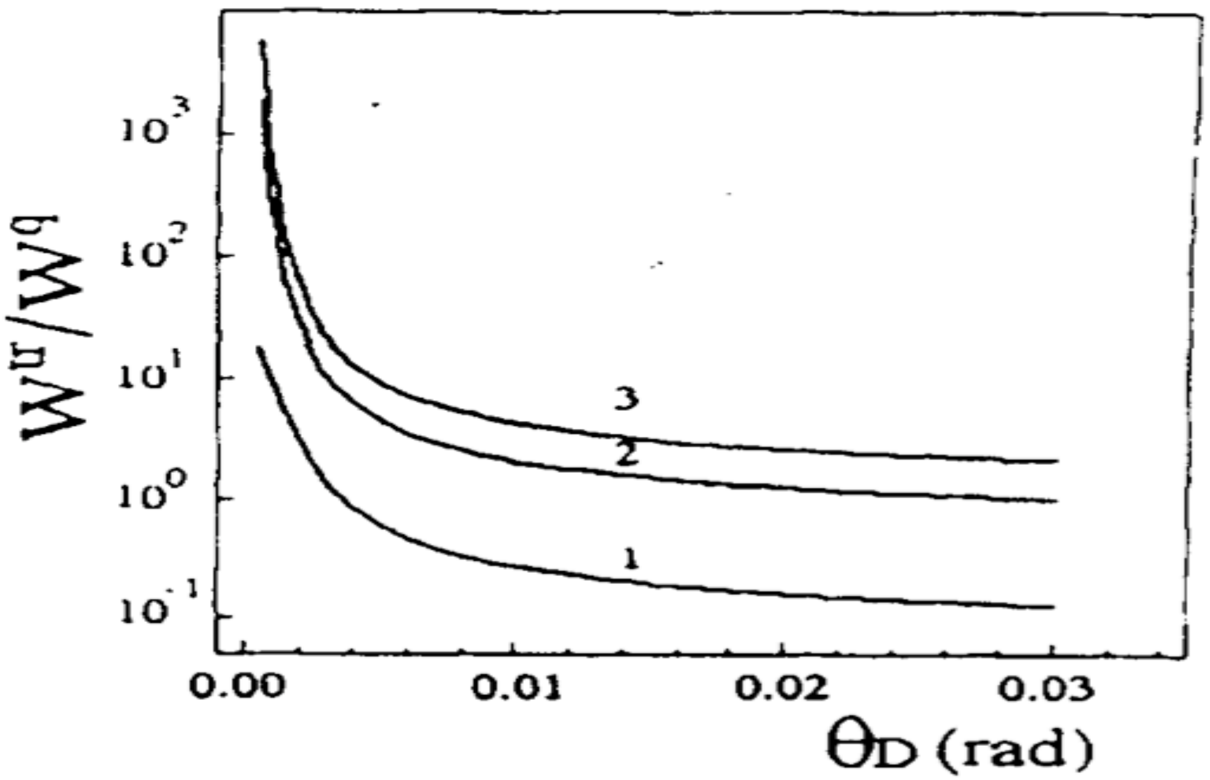
CR as a function of angle at fixed $\varepsilon = 10^{-2}$, for various electron energies: (*a*) $\gamma = 250$, (*b*) $\gamma = 500$, and (*c*) $\gamma = 1000$.

Second work A.Artru et al. (A. Artru, P. Rullhusen, Nucl. Instr. and Meth. B145, 1, 1998; Nucl. Instr. and Meth. B173, 16, 2001) using kinematical approach they found that the corresponding intensities have different angular distribution.

- The interference between PXR and DTR is most important and constructive for crystals thinner than the formation length, leading to an angular distribution similar to that of optical transition radiation.

DTR has the same energy threshold $\gamma \sim \omega/\omega_p$ as transition radiation. Above this threshold, its flux increases logarithmically with γ, whereas the PXR flux saturates at $\gamma \sim \omega/\omega_p$. The PXR intensity grows linearly with the crystal thickness whereas the DTR intensity saturates at the *TR formation length*

In the third one (A.P. Potylitsin, V.A. Verzilov, Physics Lett. 209, 380, 1995) to compare the PXR and the TDR was calculated the integrated energies W^q of the PXR and W^{tr} of the TDR following emitted into a solid angle with aperture θ_D, for the Bragg frequency ω_B = 14 keV. Given in figure are the dependence of W^{tr}/W^q on θ_D for several values of γ.

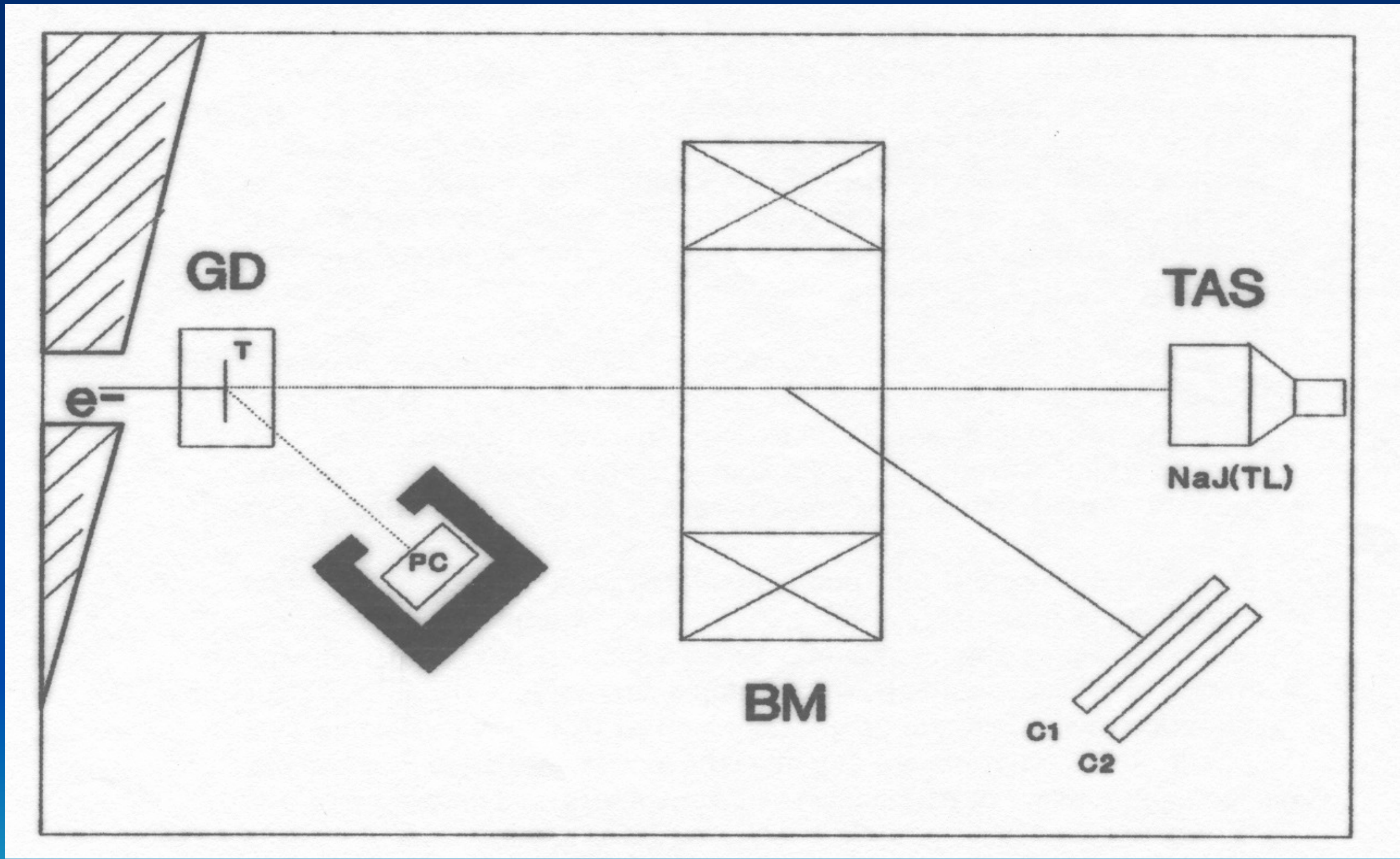


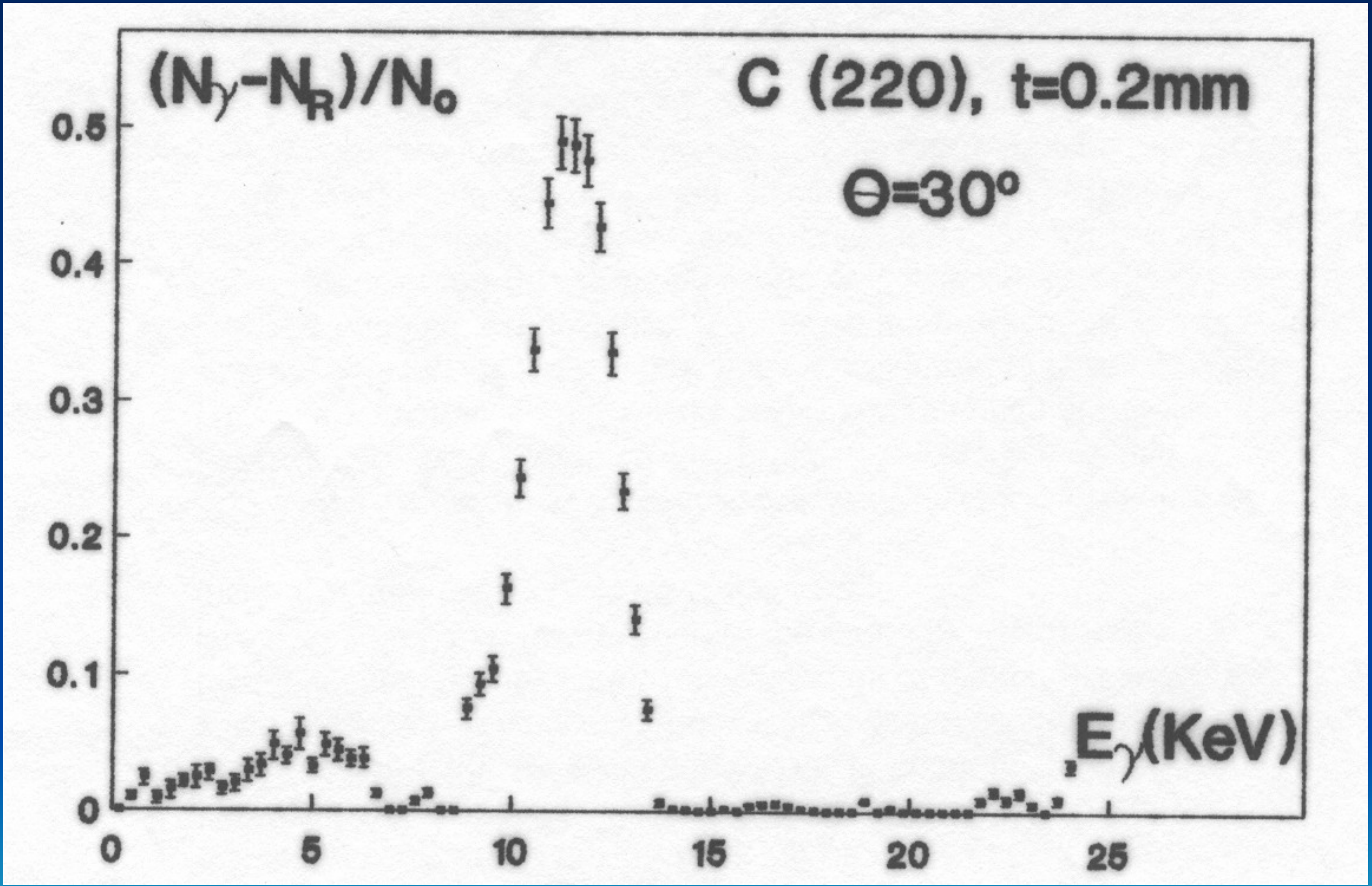
W^{Π}/W^{q}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
3
2
1
0.00
0.01
0.02
0.03
θ_D (rad)

It is evident from that figure that for $\theta_D \gamma \leq 1$ the emitted energy of the TDR for a single plate exceeds that of the PXR, while at $\theta_D \gamma >> 1$ its contribution to the total intensity decrease noticeably and is controlled by the particle energy .

- This is apparent because TDR is concentrated mainly within the range of angles $\sim\gamma^{-1}$ with respect to the center of the diffraction and, therefore, gives a higher spectral and angular density over those of the PXR, whose characteristic angle is determined by the value $(\gamma^{-2} + 1 - \varepsilon_0)^{1/2}$,
- $1 - \varepsilon_0 = \omega_p^2/\omega^2$.

PXR INVESTIGATIONS AT YERPHI



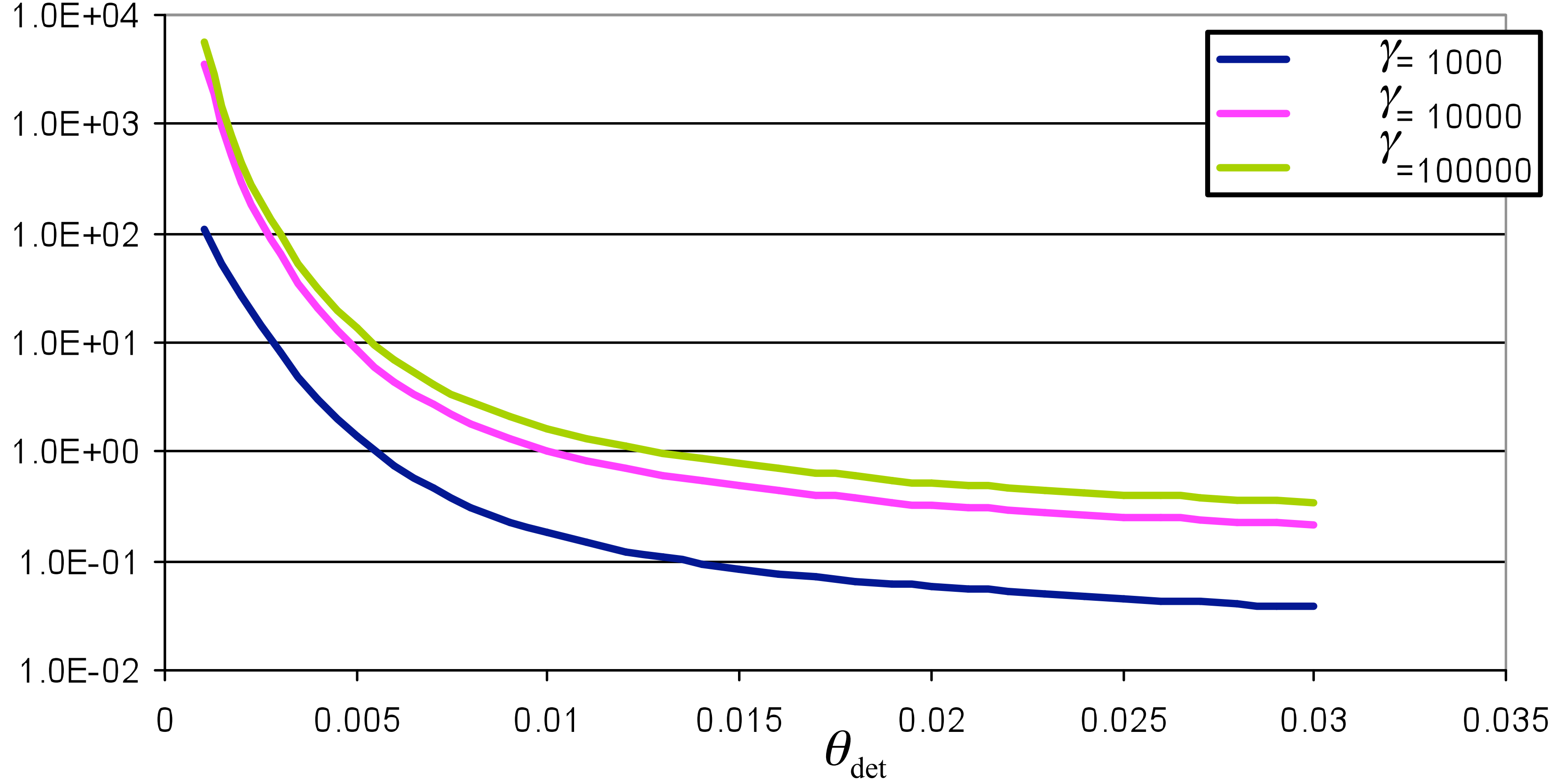


(Nγ-NR)/No
C (220), t=0.2mm
Θ=30°
0.5
0.4
0.3
0.2
0.1
0
Eγ(KeV)
0
5
10
15
20
25

θ_B	Target thick-ness, mm	E_{γ}, (keV)	Experiment
35^0	1.0	8.9 ± 1	$(1.1 \pm 0.1)\cdot 10^{-6}$
35^0	0.2	9.2 ± 1.1	$(6.61 \pm 0.8)\cdot 10^{-7}$
30^0	0.2	11.3 ± 1.3	$(1.0 \pm 0.17)\cdot 10^{-6}$

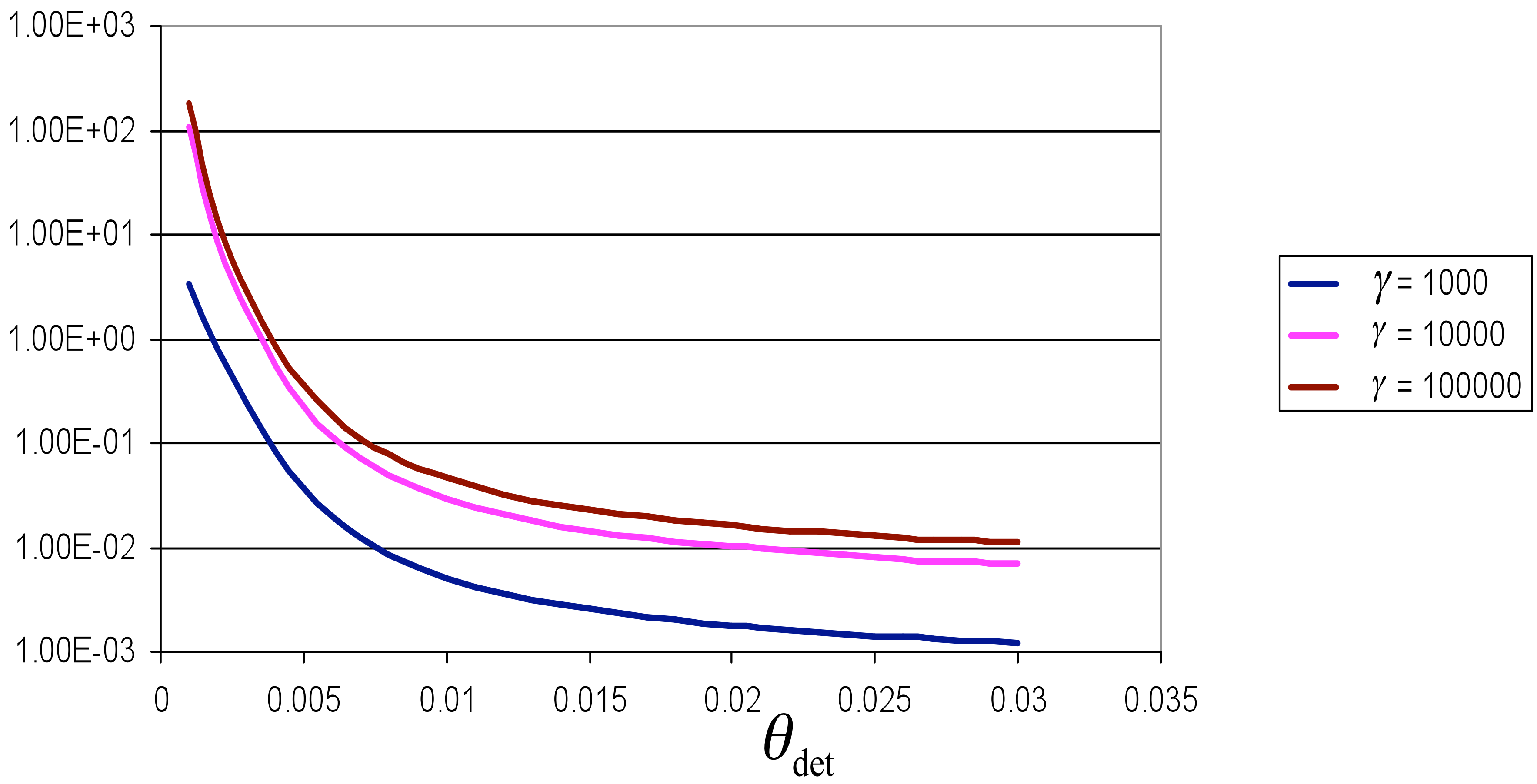
$\frac{DTR}{PXR}$ dependence from detector angle

a=0.02cm



$\frac{DTR}{PXR}$ dependence from detector angle

a=0.1cm



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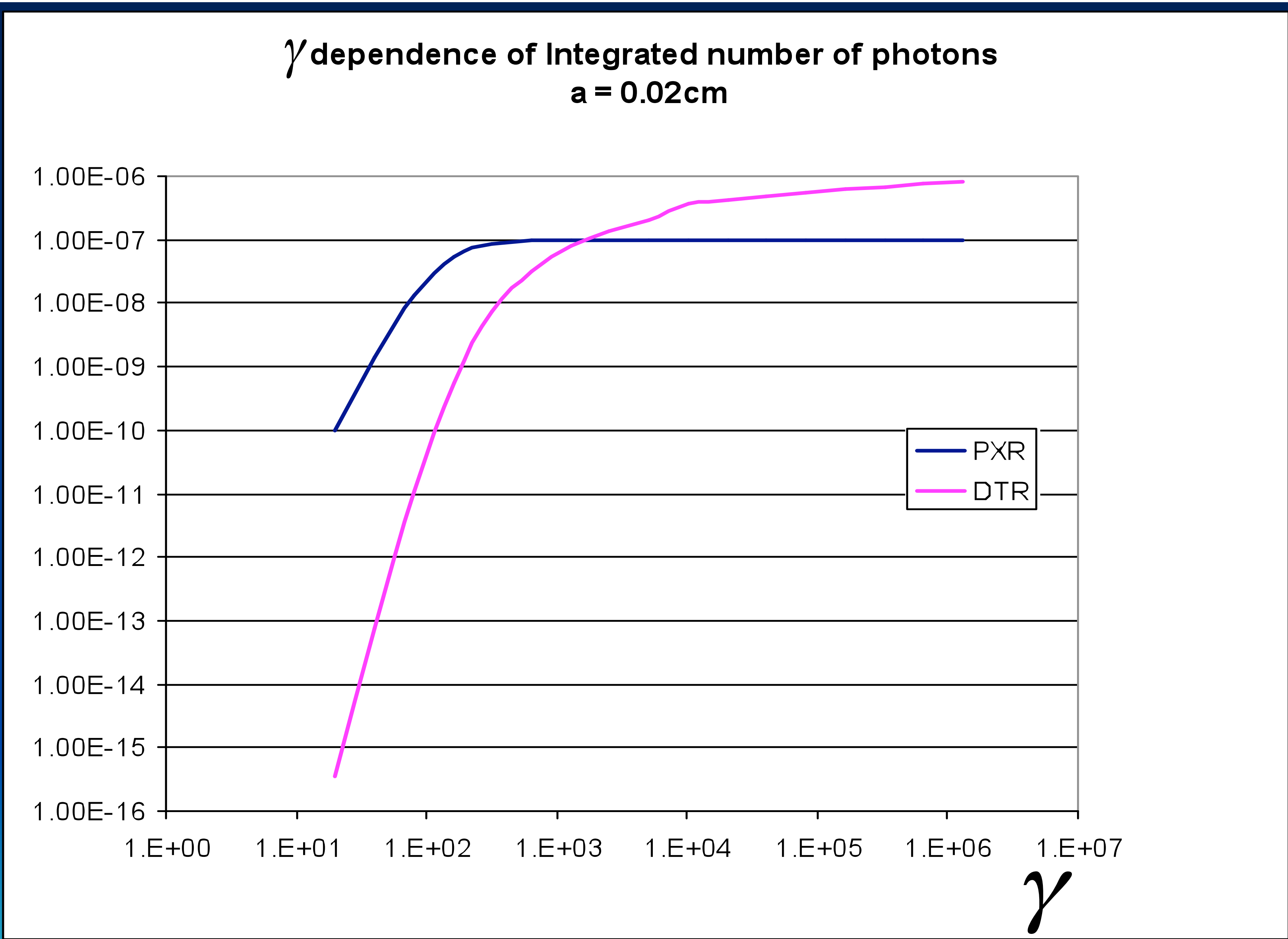
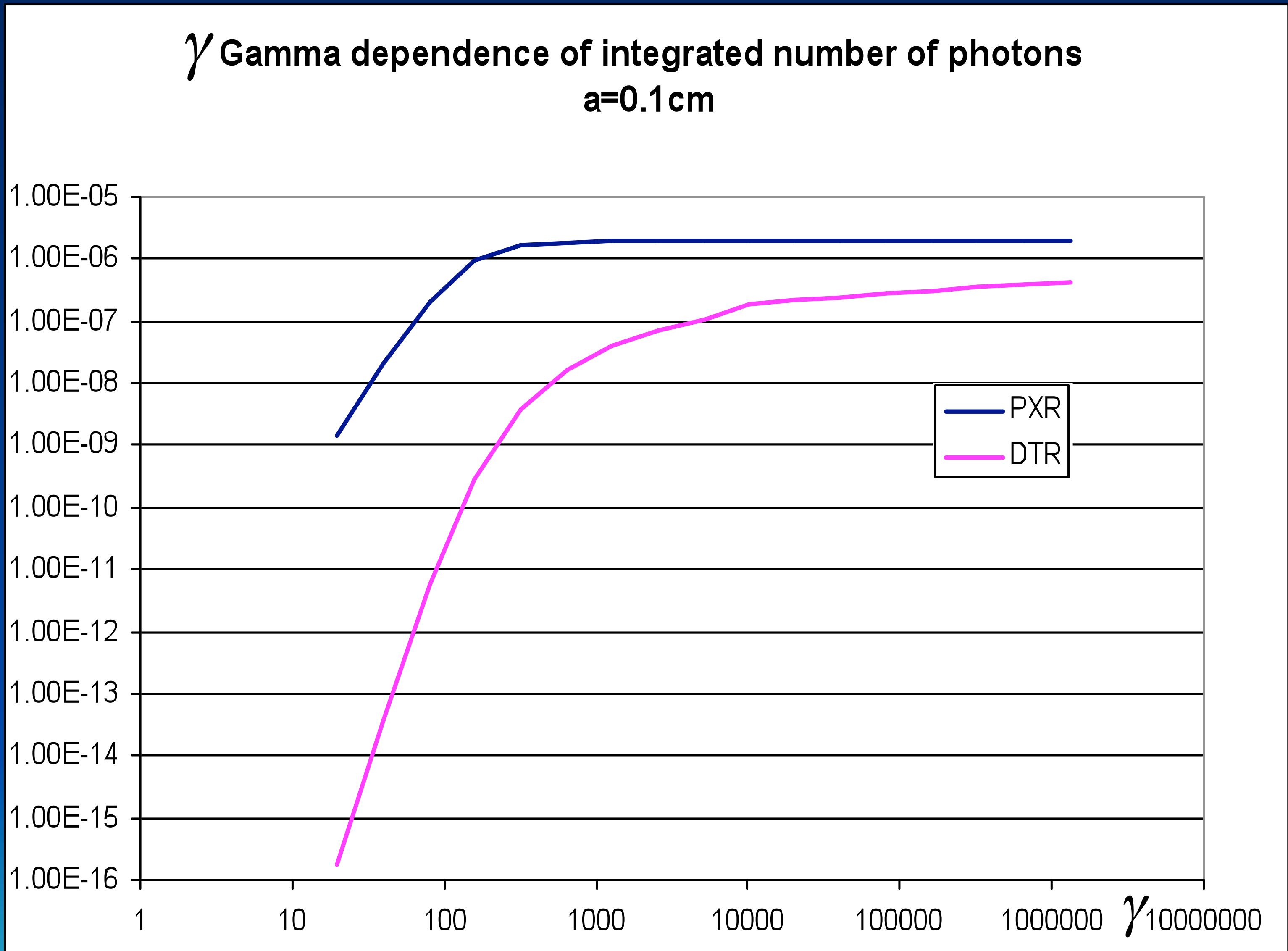


γ dependence of Integrated number of photons
a = 0.02cm
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
1.00E-15
1.00E-16
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
γ
PXR
DTR


γ Gamma dependence of integrated number of photons
a=0.1cm
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
1.00E-15
1.00E-16
1
10
100
1000
10000
100000
1000000
γ
10000000
PXR
DTR

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Conclusion:

1. On the base of calculation carried out by dynamical theory of Afanasev, Aginian (JETF, 1978) it was found that for electron energy 4.5 GeV for 0.02 cm thickness diamond crystal the DTR contribution on the radiation spectrum exceed the PXR intensity about 4 times.

- 2. The dependence of DTR/PXR ratio for the our detector angle θ_{det} for the diamond crystal of thickness 0.02 cm shows again that contribution of DTR is 8.62 times higher than PXR contribution. In the case of diamond crystal of thickness 0.1 cm the contribution of PXR is about 4 times higher than DTR contribution.