The 8th International Conference
Channeling 2018
Charged & Neutral Particles Channeling Phenomena

Specular asymmetry of unipolar radiation

Coherent Unipolar Cherenkov and Diffraction Radiation Generated by Relativistic Electrons

G. Naumenko*, M. Shevelev, K. Popov

Tomsk Polytechnic University, Russia

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About problem

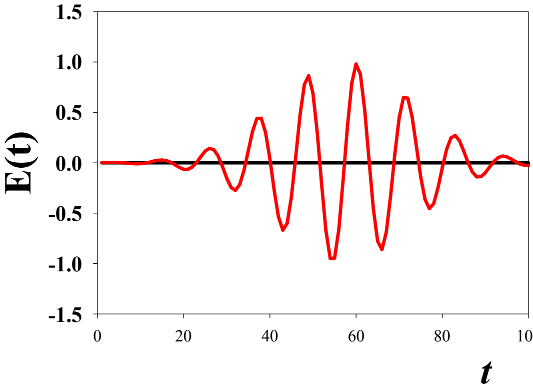
E.G. Bessonov

On a class of electromagnetic waves

P.N. Lebedev Physics Institute, Academy of Sciences of the USSR

Zh.Eksp. Teor. Fiz. **80** (1981) 852-858

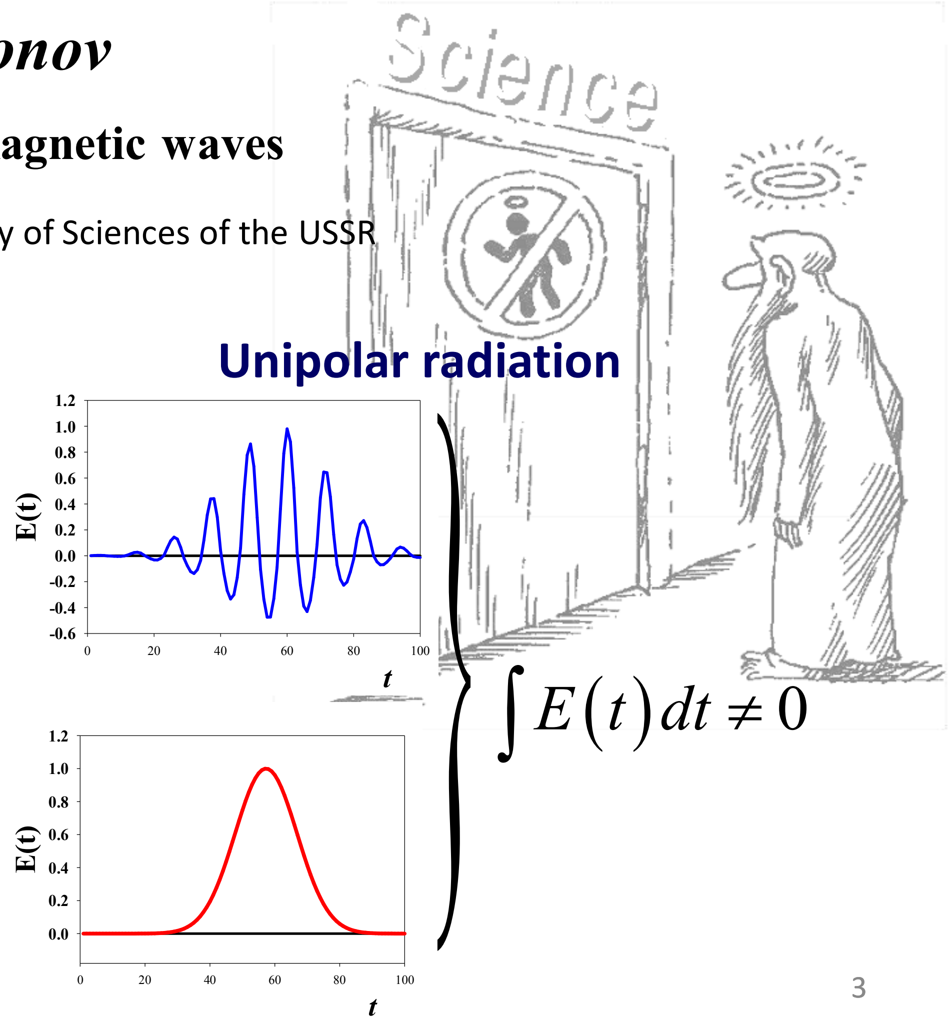
Bipolar radiation



Electric strength

$$\int E(t)\,dt = 0$$

Unipolar radiation



$$\int E(t)\,dt \neq 0$$

Propagation of unipolar radiation

May be propagating an unipolar radiation in free space?

Maxwell equation for free space:

$$\begin{cases} \Delta\ \vec{E} - \dfrac{\partial^2 \vec{E}}{\partial t^2} = 0 \\ div\ \vec{E} = 0 \end{cases}$$ - wave equation (1)

Here we assume that C=1

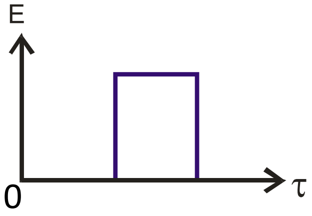
For example

$$\begin{cases} E_x = F_x(z-t) \\ E_y = F_y(z-t), \\ E_z = 0 \end{cases}$$

where $\left(F_x(\tau),\quad F_y(\tau)\right.$ are any arbitrary function of $\left.\tau = z - t\right)$

***satisfies equation* (1)**

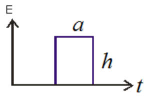
For example $F_x(\tau) =$



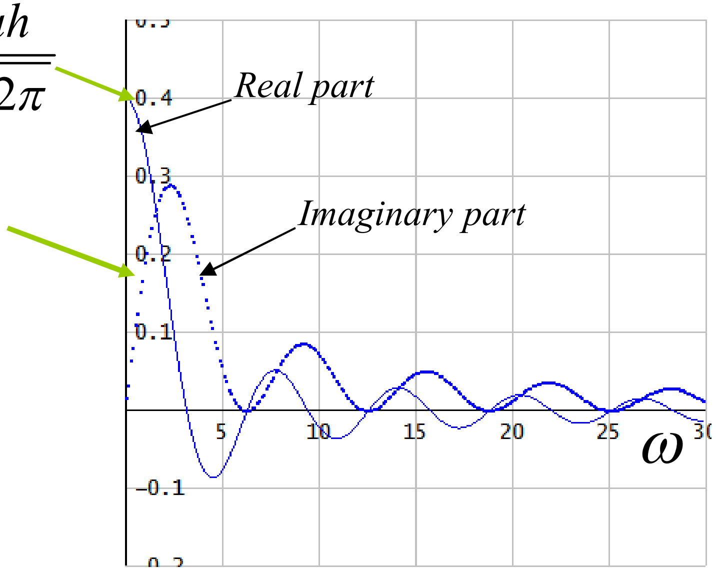
I.e. this profile propagate along the axis Z with the light velocity

Criterion of unipolarity:

$$E_\omega = \int e^{i\omega t}\,($$



$$)\,dt = \frac{ih}{\sqrt{2\pi\omega}}\left(1-e^{i\omega a}\right)$$



In the common case

$$E_\omega = \int e^{i\omega t} E(t)\,dt$$

It may be shown that

$$if \quad \int E(t)\,dt = 0 \quad \textbf{than} \quad E_{\omega\to 0} = 0$$

and vice versa

So $$\frac{E_{\omega\to 0}}{\int \left|E(t)\right| dt}$$ **Is the theoretical characteristic of the unipolarity of radiation**

(in experiment we can not measure $E_{\omega\to 0}$)

This factor is of fundamental importance

Generation of unipolar radiation by charged particles

a) V.L. Bratman, D.A. Jaroszynski, S.V. Samsonov, … NIM A 475 (2001) **(Theory)**

The possibility of emission of unipolar synchrotron radiation in magnetic field has been theoretically considered

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 475 (2001) 436–440

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.com/locate/nima

Generation of ultra-short quasi-unipolar electromagnetic pulses from quasi-planar electron bunches

V.L. Bratman[a], D.A. Jaroszynski[b], S.V. Samsonov[a], A.V. Savilov[a,*]

$$E_e = 3.2\ MeV$$

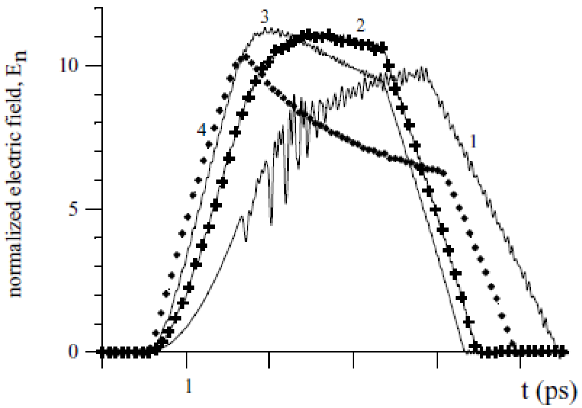


Fig. 4. Synchrotron radiation of TOPS electron bunch during its motion through a uniform bending field. Electronic efficiency and radiated electric field versus time in the cases of values of the bending field, B_b, 0.2 kGs (1), 0.5 kGs (2), 1.0 kGs (3), and 3.0 kGs (4). The normalized field, E_n, is connected with the radiated power by the formula $P = 2\,\text{MW}\ E_n^2$.

b) **Markus Schwarz,* Philipp Basler, Matthias v. Borstel, and Anke-Susanne Müller.**
Analytic calculation of the electric field of a coherent THz pulse. Phys. Rev. ST AB 17, 050701 (2014)

(Theory)

Theoretical consideration of coherent synchrotron radiation from 100 fs bunches

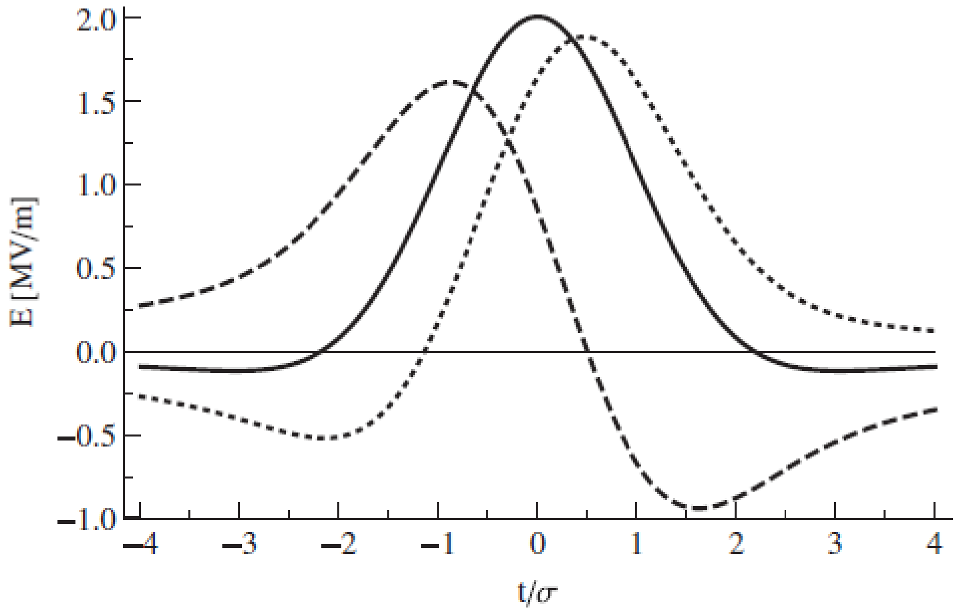


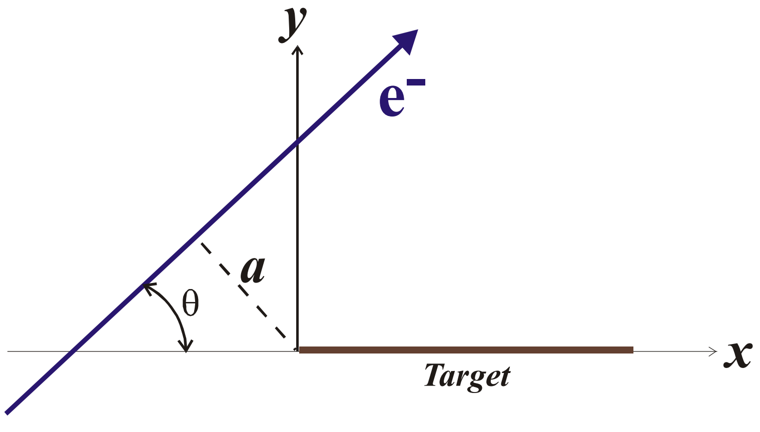
FIG. 1. Time dependence of the electric field E, coherently emitted by a Gaussian bunch with length σ according to Eq. (9). The parameters are $Q = 100$ pC, $R = 1$ m, $\rho = 1.1$ m, and $\sigma_b = 50$ fs. For $\phi = 0$ (continuous) we get a symmetric so-called half-cycle pulse whereas $\phi = 65°$ (dashed) and $\phi = 325°$ (dotted) yield single-cycle pulses with minima at $t > 0$ and $t < 0$, respectively.

c) Unipolarity of backward diffraction radiation

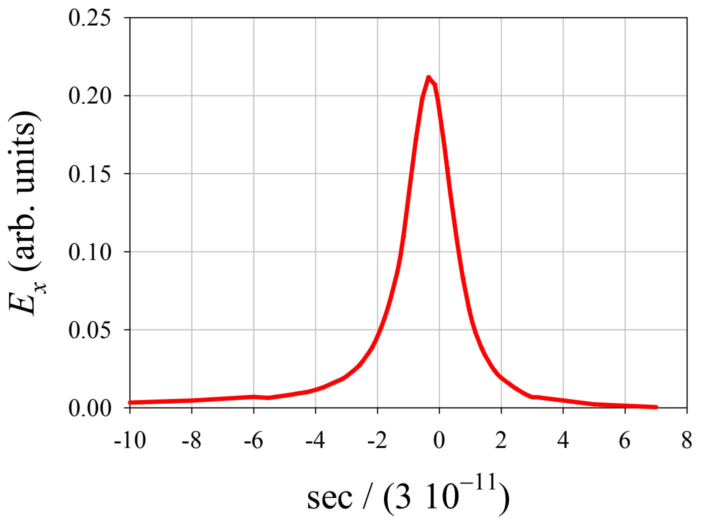
A.P. Kazantsev, G.I. Surdutovich, *Radiation from a charged particle flying near a metal screen,* Dokl. Akad. Nauk SSSR, 1962, Volume 147, Number 1, 74– 77

$$A_x(R) = \frac{2\pi e^{i\omega R}}{R} j_x(k_0, q_0)$$

$$E_x(t) = \int e^{i\omega t} \omega \cdot A_x(R) d\omega$$



Geometry of interaction



The time dependence of the *x*-polarization component of the BDR electric field strength

d) Proposal of experiment on unipolar transition rfdiation

J. Xu, B. Shen, X. Zhang,... Terawatt-scale optical half-cycle attosecond pulses.
Scientific Reports (**2018**) 8:2669

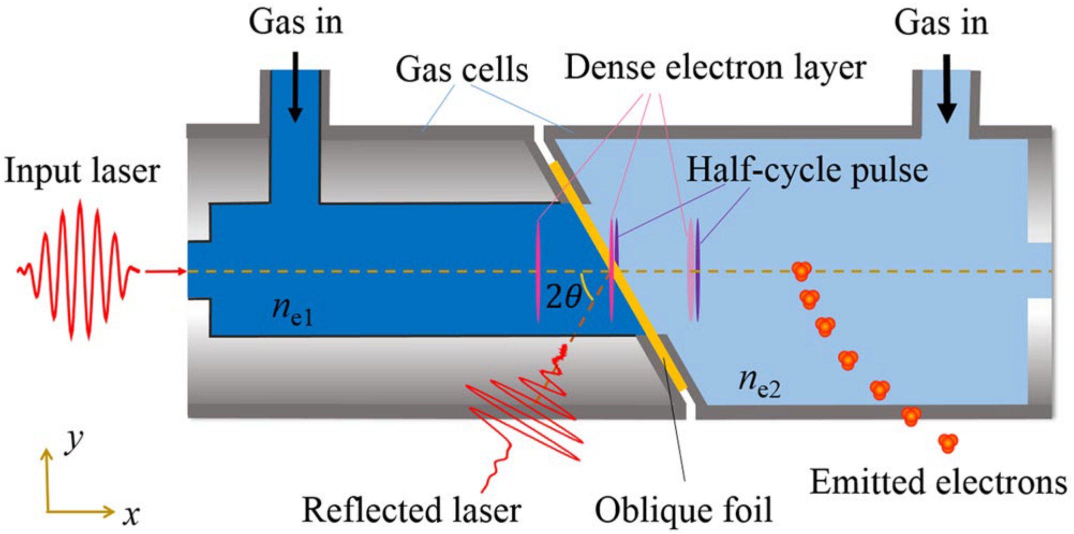
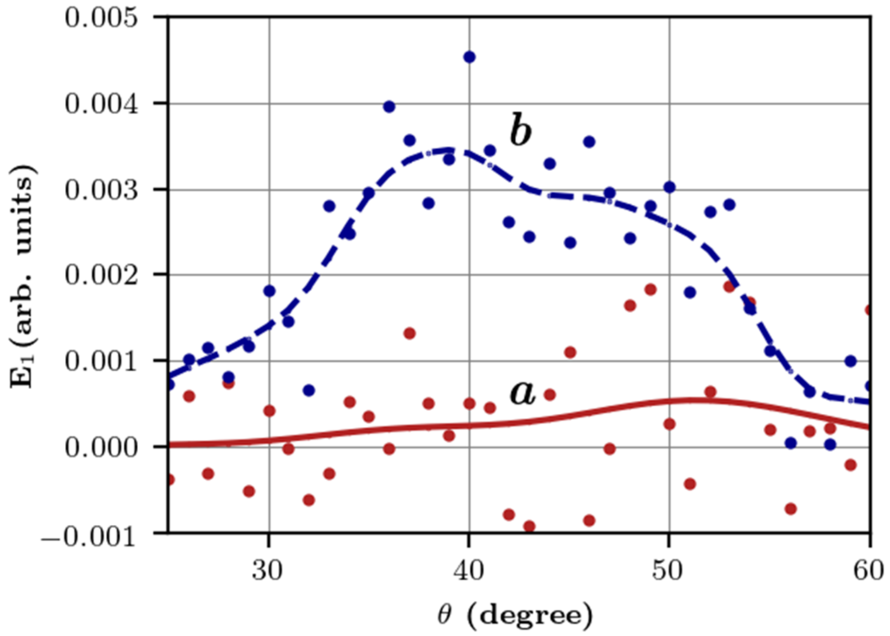


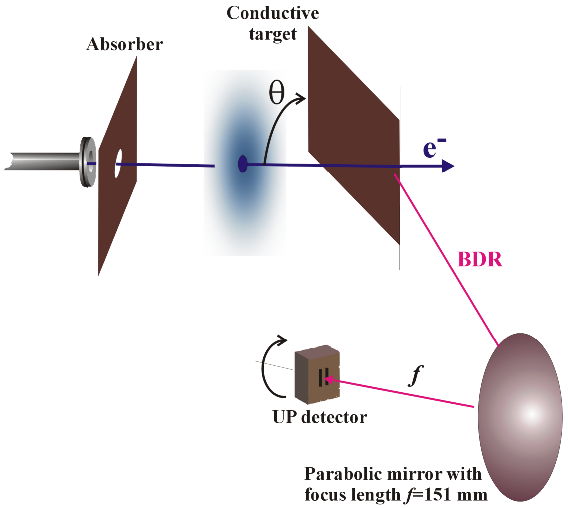
Figure 1. Physical scheme of half-cycle attosecond pulse emission and detection.

However, no experiments on investigations of radiation unipolarity has been carried out.

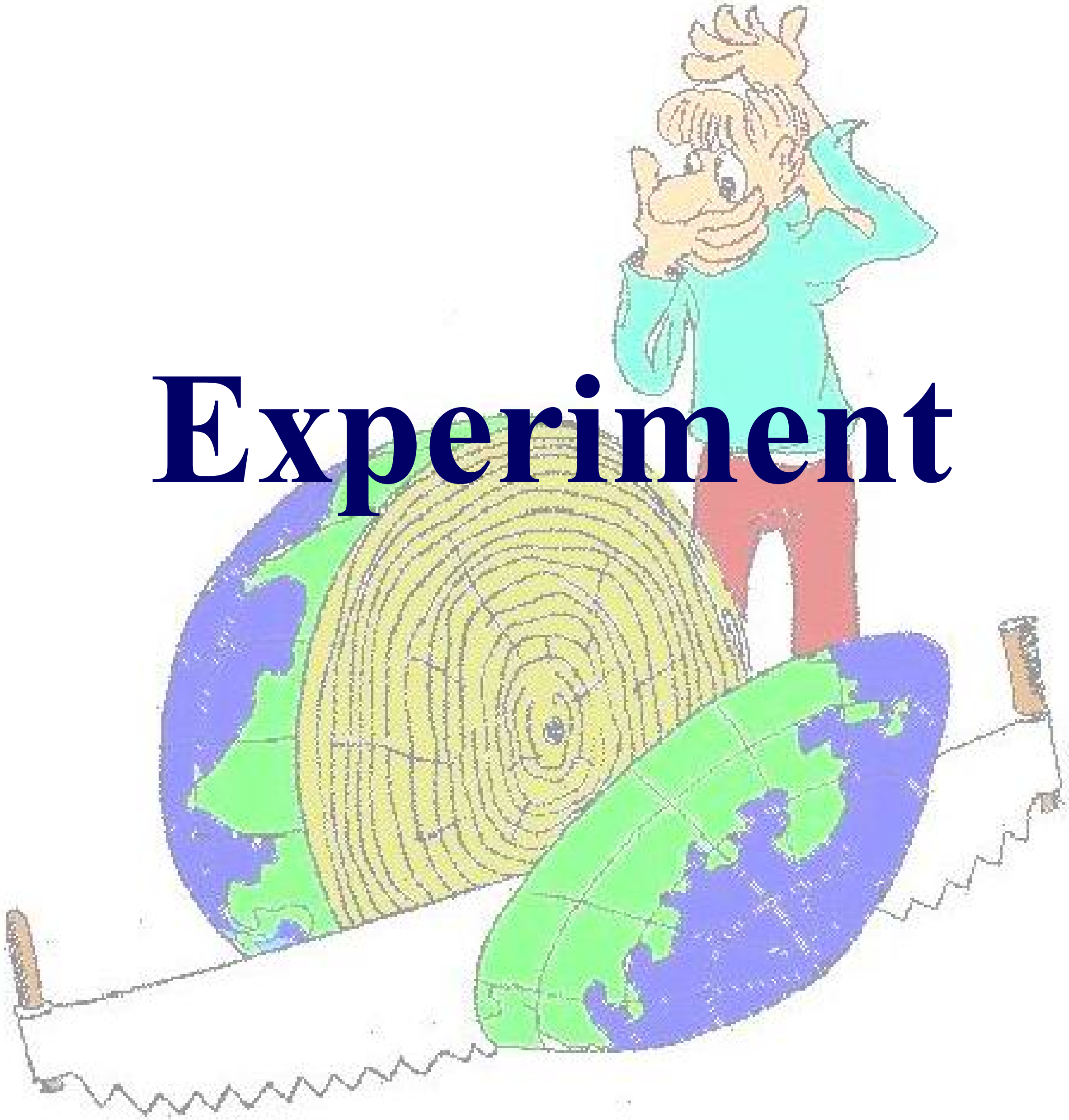
e) First indication of unipolar Diffraction Radiation

G. Naumenko and M. Shevelev. Journal of Instrumentation, Volume 13, May **2018**





Experiment



Electron beam

Tomsk microtron

Beam parameters:

Electron energy	**6.1 MeV** ($\gamma = 12$)
Macro-pulse (train) duration	**4** μs
Bunch length	$\sigma_z = 3 \pm 1\ mm$
Bunch population	10^8
Bunches in train	10^4
Distance between bunches	$\Lambda = 114\ mm$
Extracted beam size	$4 \times 2\ mm$

Train resonance's in radiation: $\nu_k = k \bullet 300 / \Lambda \left(GHz \right), \quad k = 1, 2, \ldots$

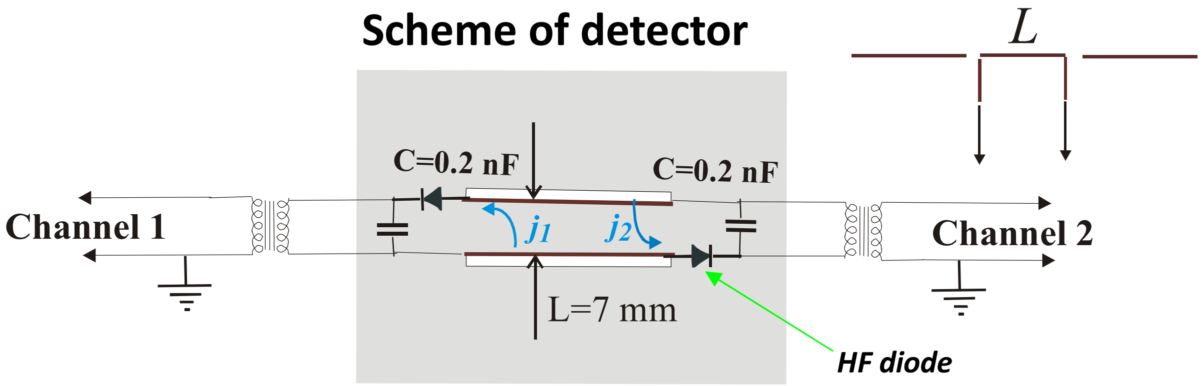
Unipolar detector

Based on the method of induced surface current measurement using strip-line sensor

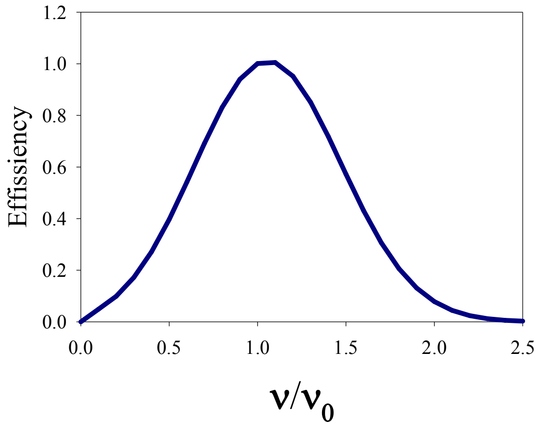
(Sargsyan V. Comparison of Stripline and Cavity Beam Position Monitors, (2004) *TESLA Report* 03)

Matching of the detector elements hav been performed.

Scheme of detector



Spectral efficiency

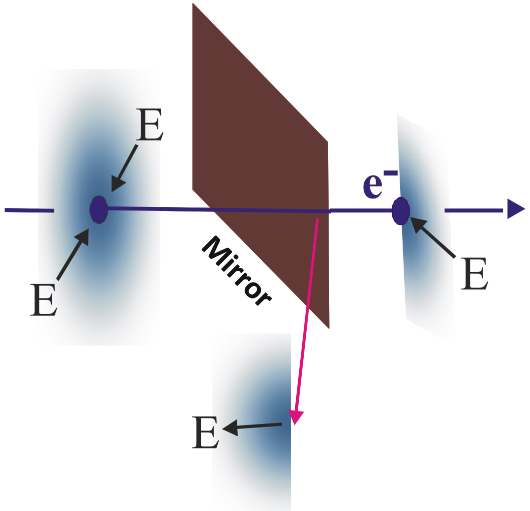


$$\nu_0 = \frac{C}{4L} = 10.7\ GHz$$

$$\Delta\nu_{FWHM} = 10\ GHz$$

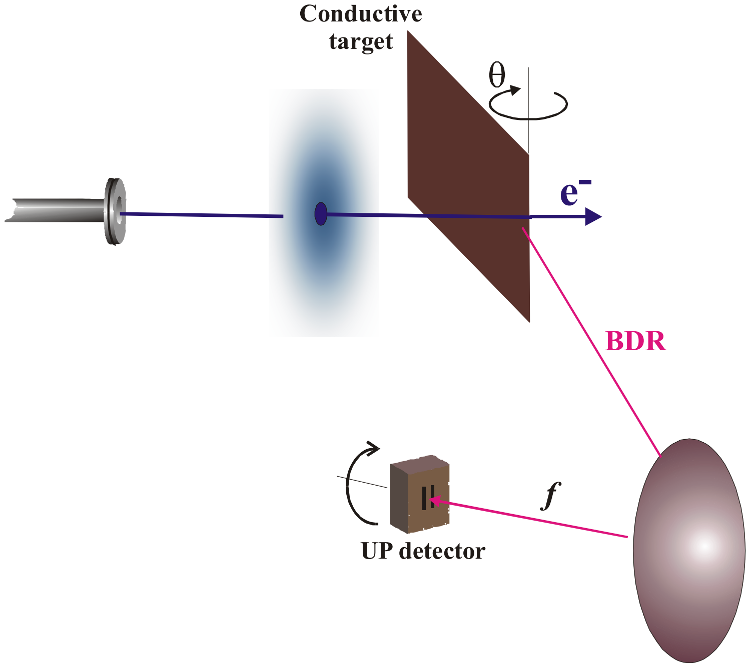
Unipolar diffraction radiation

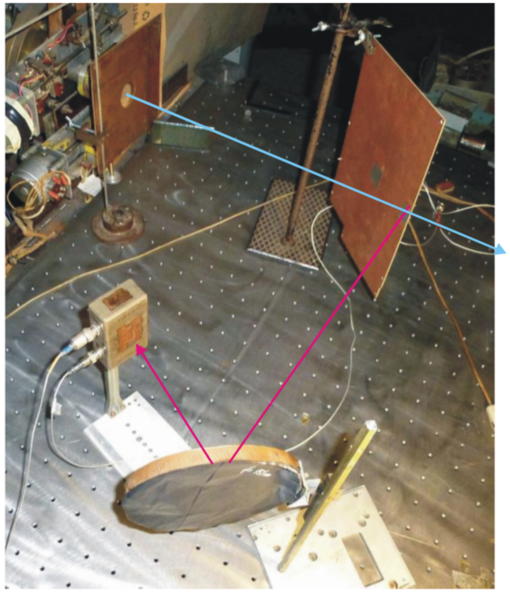
Why we can expect the unipolarity of backward DR (BDR)?



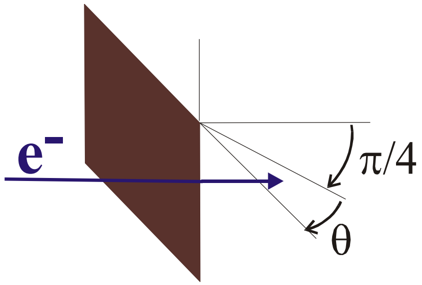
According to the pseudo-photon view-point a BDR is the reflection of bunch field from a mirror.

Scheme of experiment

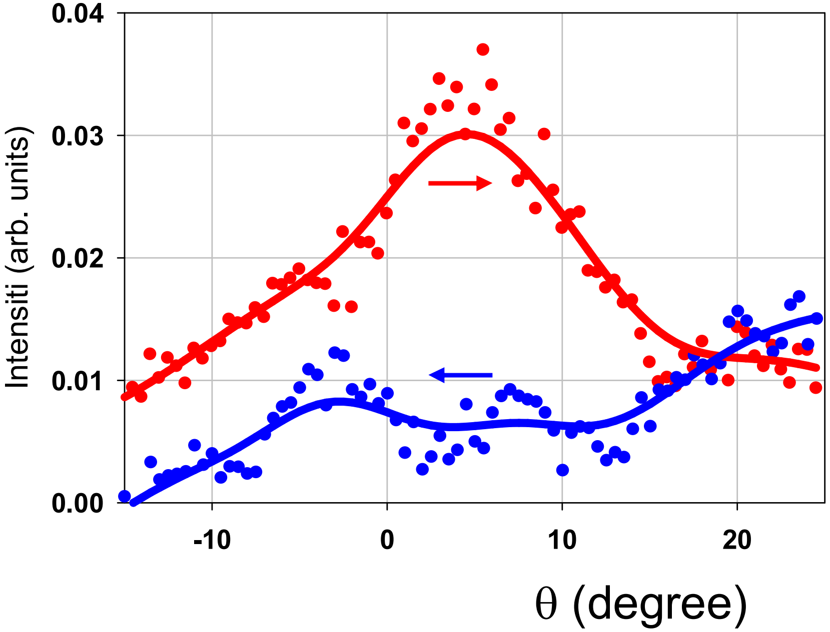




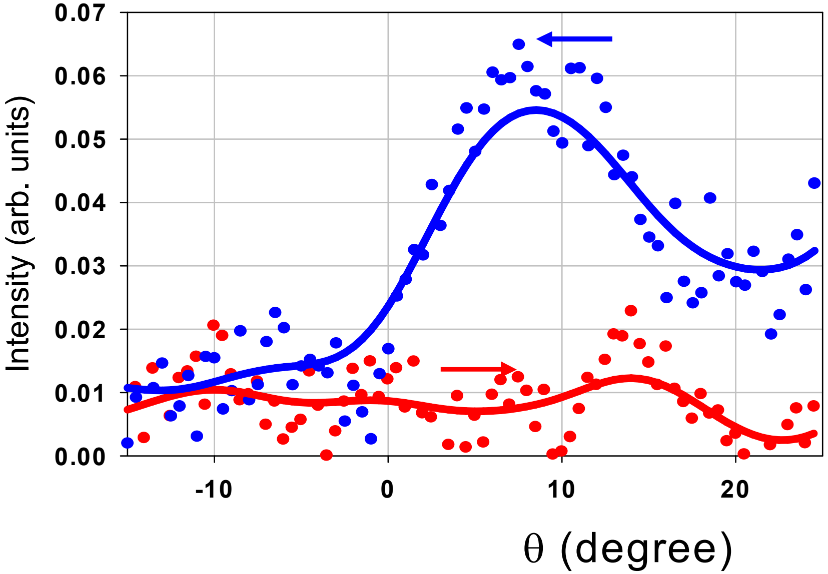
Experimental results



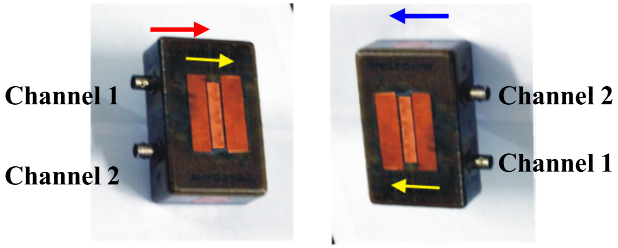
Channel 1



Channel 2



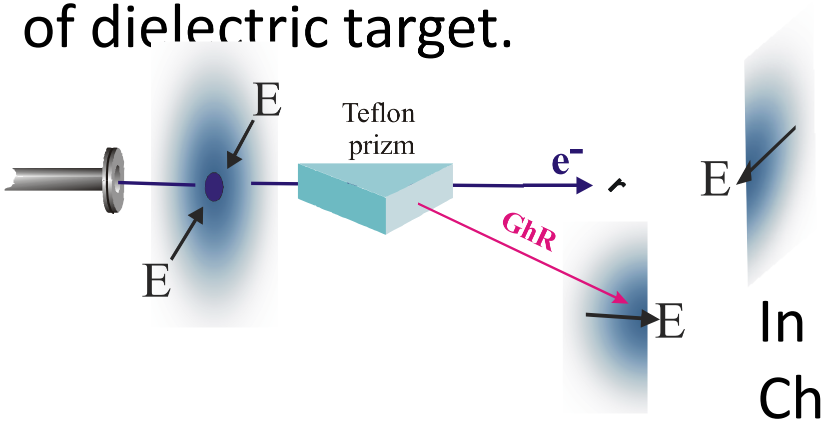
Detector rotation



Solid lines are the smoothed experimental data

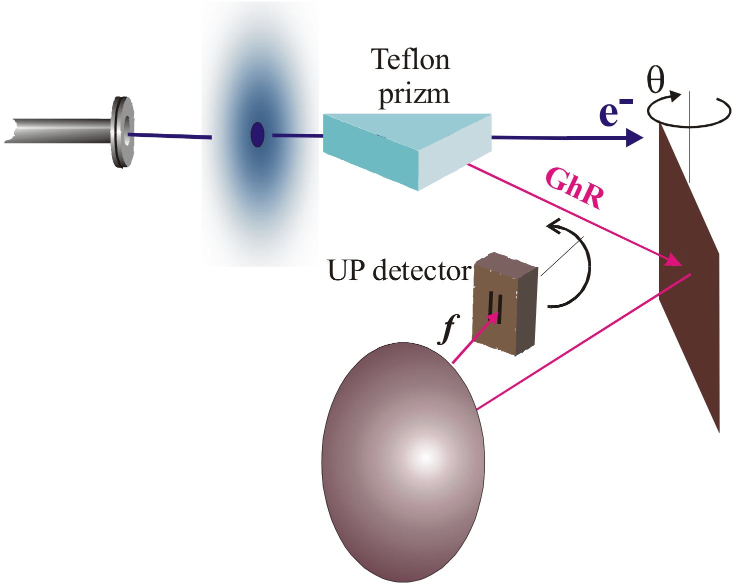
Unipolar Cherenkov radiation

In approximation of pseudo-photon model the Cherenkov radiation is the refraction of the electron field in the matter of dielectric target.



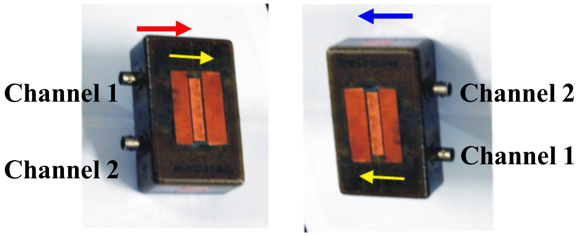
In this approach we may expect the Cherenkov radiation is unipolar

Experiment

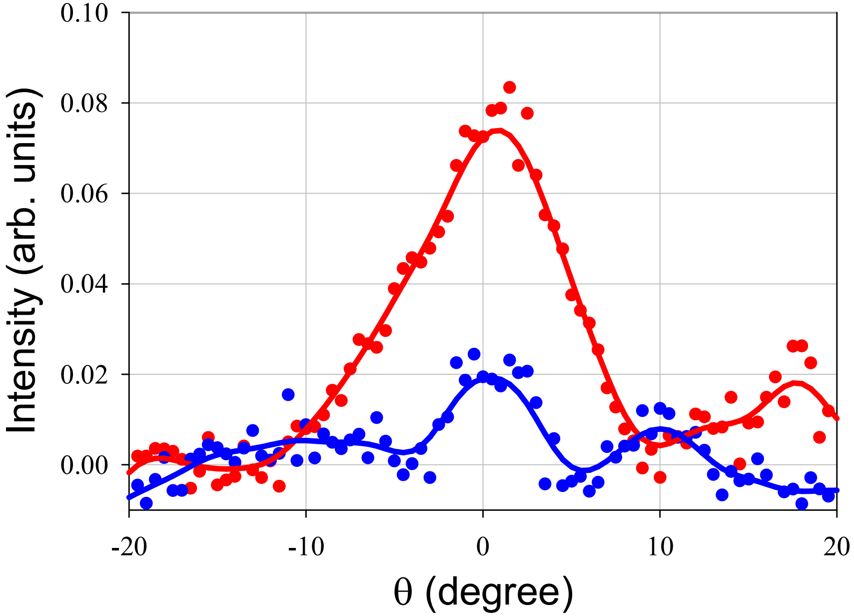


Angular distribution of unipolar radiation

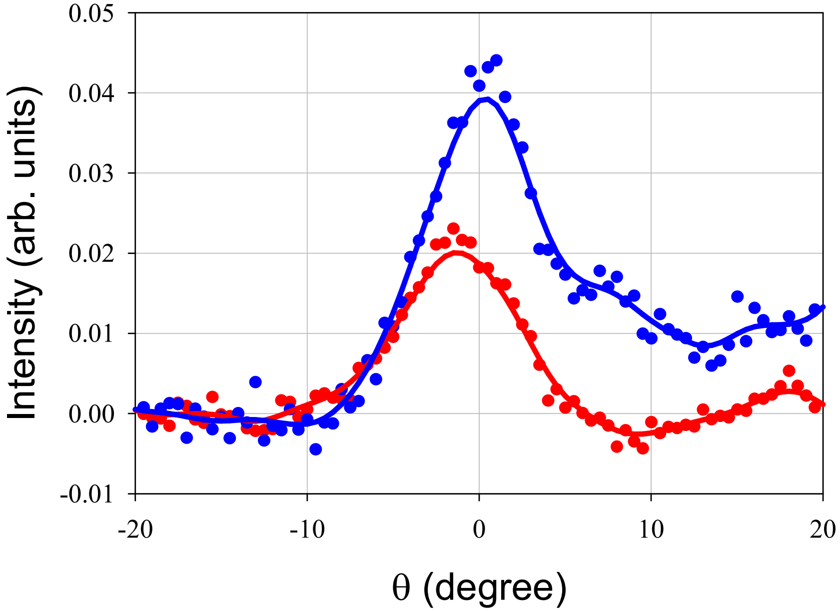
Detector rotation



Channel 2



Channel 1

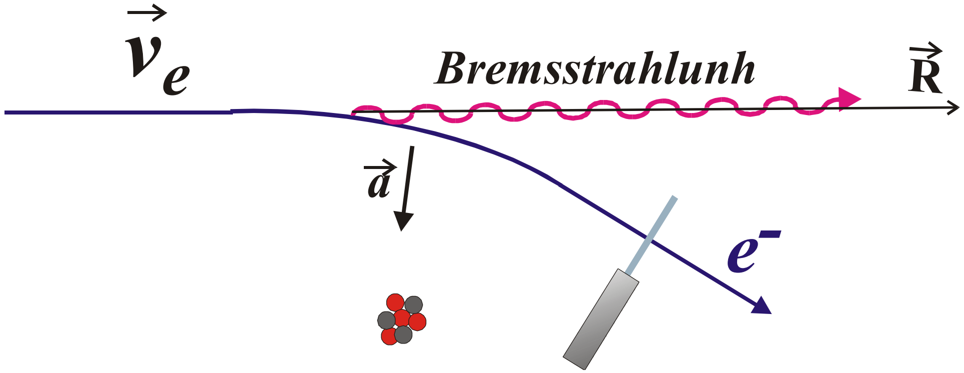


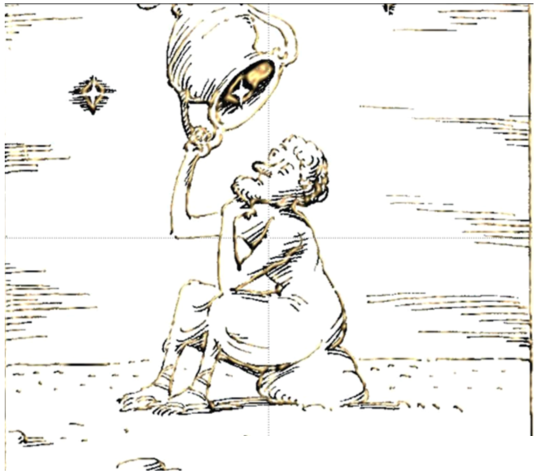
The Cherenkov radiation has been registered as not a fully unipolar radiation in millimeter wavelength region.

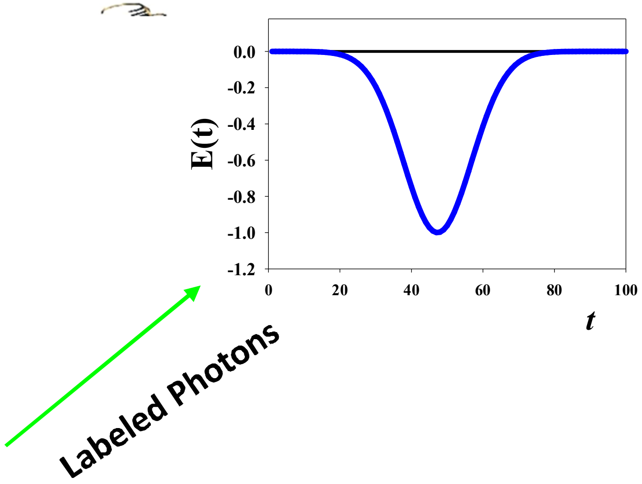
Resume

1. **The diffraction radiation has been registered as the almost fully unipolar radiation in millimeter wavelength region.**
2. **The Cherenkov radiation has been registered as the partly unipolar radiation. This result is to be analised more detail.**
3. **The unipolar radiation may affect some problems in interactions with matter, if a target is sensitive to the direction of the electric field of radiation.**

Perspective







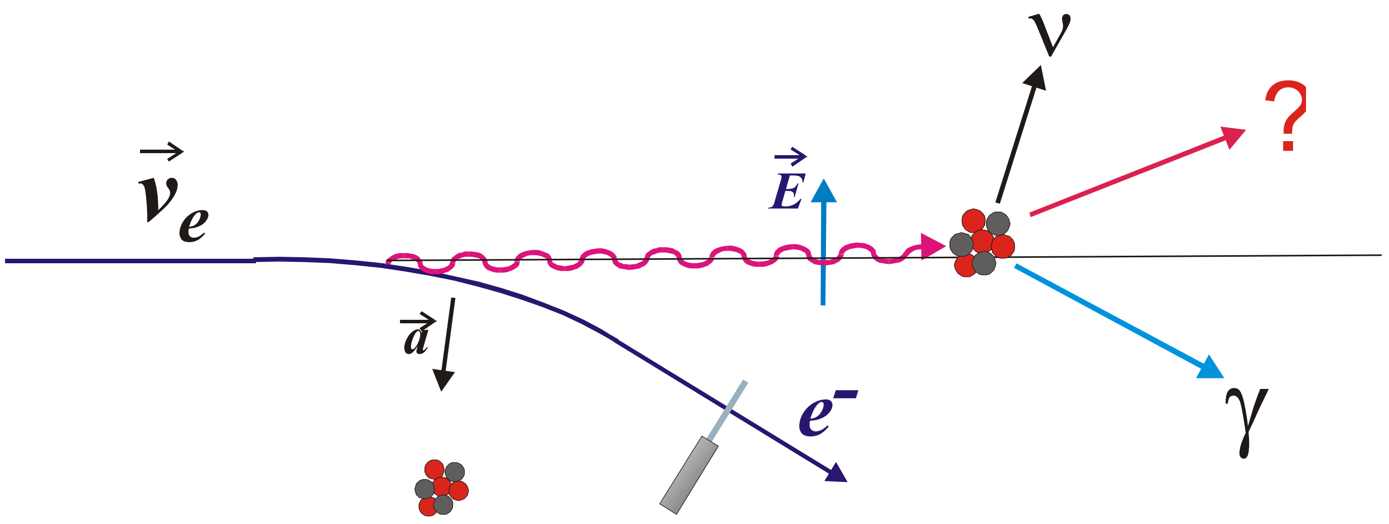
In approach of small frequency (L.D. Landau) we can use the Lenar-Vikhert potencials

$$\vec{E} = \frac{e}{c^2}\frac{1}{\left(R - \frac{\vec{v}\vec{R}}{c}\right)^3}\vec{R}\times\left(\left(\vec{R} - \frac{\vec{v}R}{c}\right)\times\vec{a}\right) \overset{\gamma >> 1}{\approx} -\frac{e\gamma^4}{Rc^2}\vec{a}$$

So if we use labeled photons, we can obtain the unipolar bremsstrahlung.

Possible effects of unipolarity

If we consider some labeled photons interaction, which is **sensitive to the direction of electric field**,



we may expect an **asymmetry** of results of this interaction **caused by unipolarity of radiation**.

So we can say that unipolarity (direction of electric field of radiation) is the additional degree of freedom of electromagnetic field.

Thank you
for
your attention