Research and Development at the Institute of Applied Problems of Physics, NAS RA

Director of the institute
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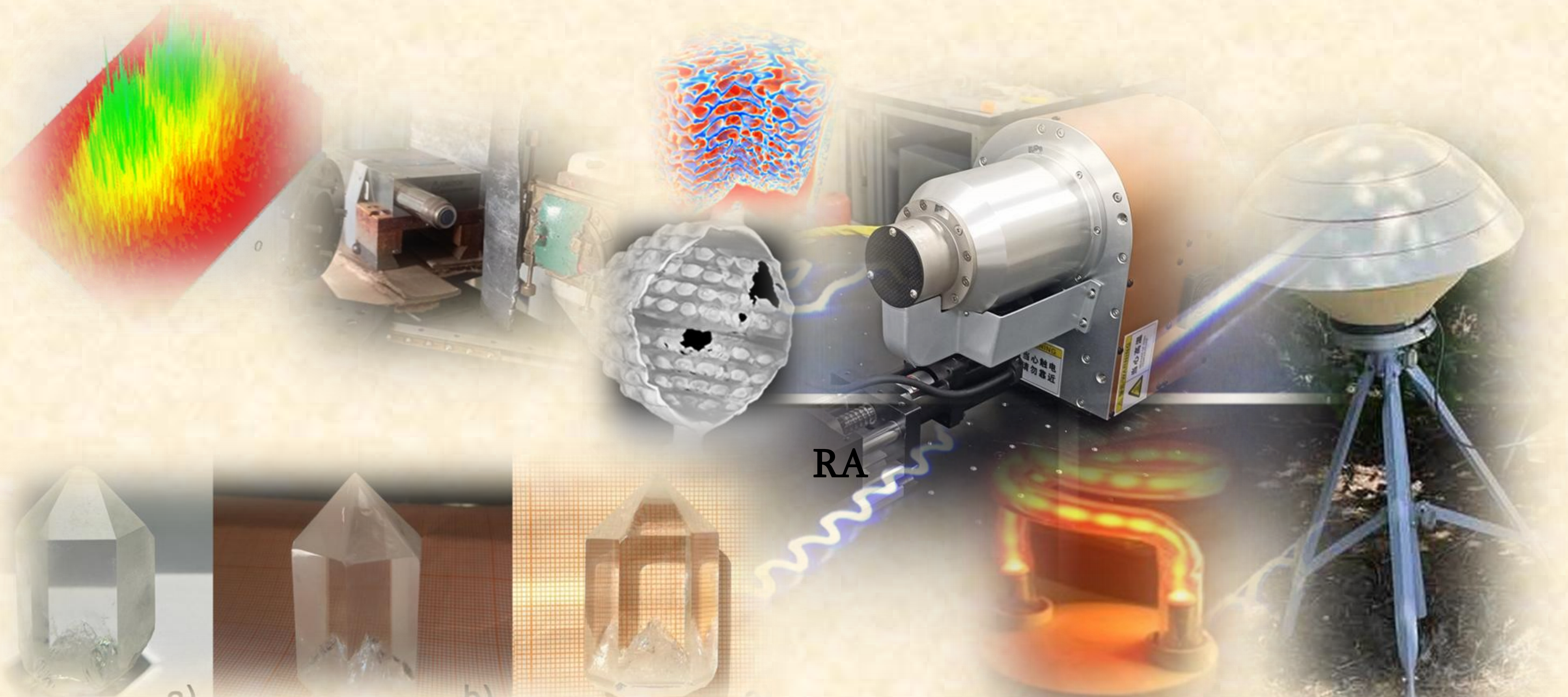
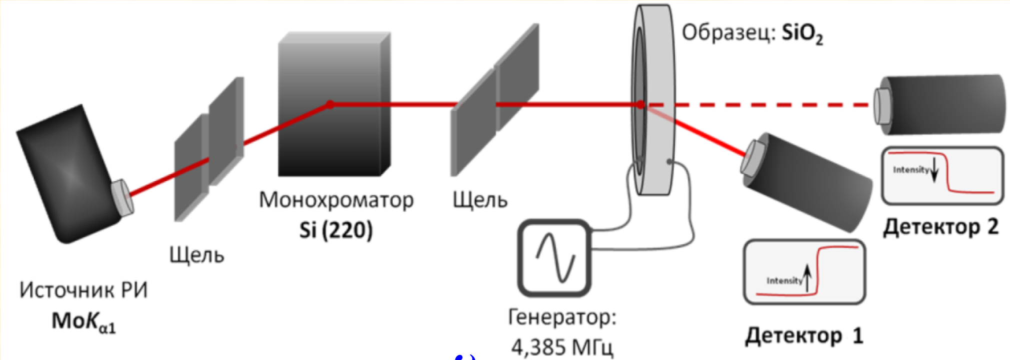
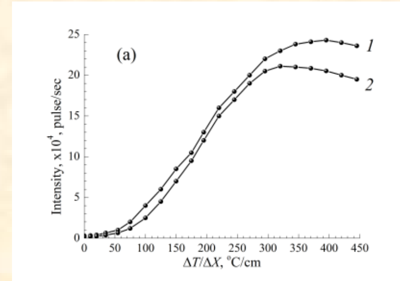
Institute of Applied Problems of Physics of NAS RA

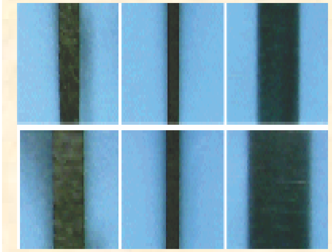


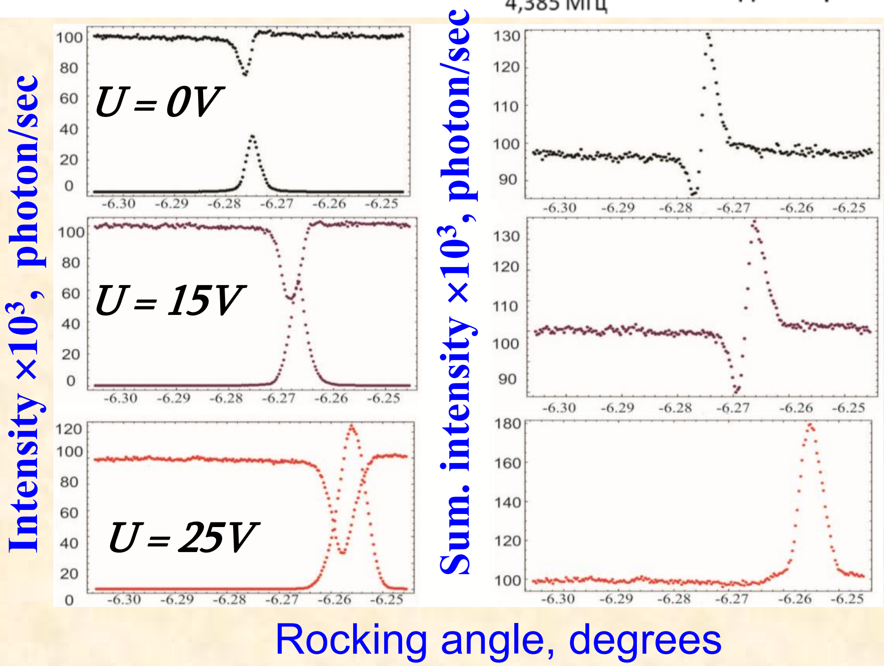
The activities of the IAPP of NAS RA are focused on the scientific research fields of condensed matter physics, materials science, acoustophysics, plasma physics, nano and meso systems physics, medical physics, alternative energy and scientific instrumentation.

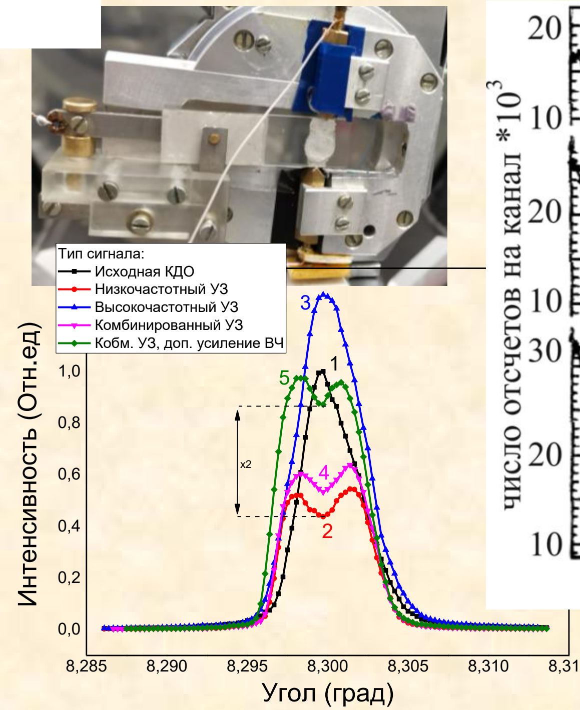
Lab 1. Interaction of radiation and elementary particles with matter

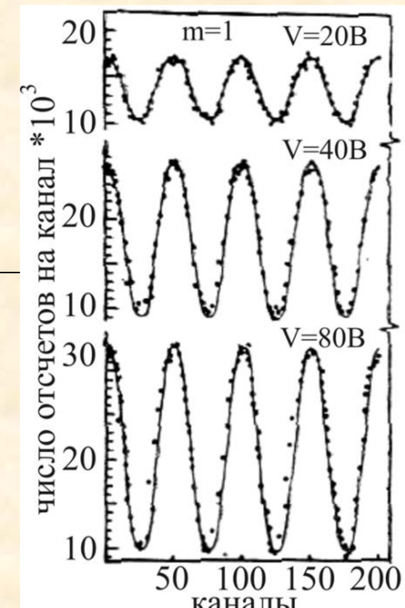






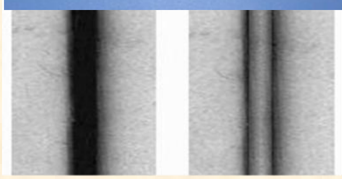


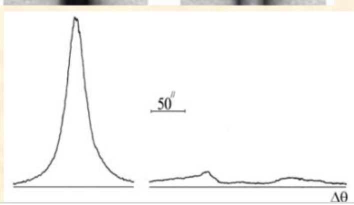


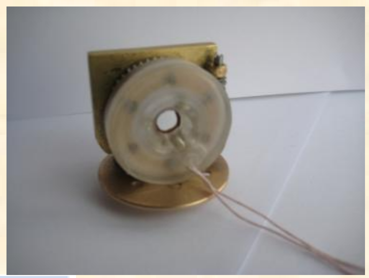


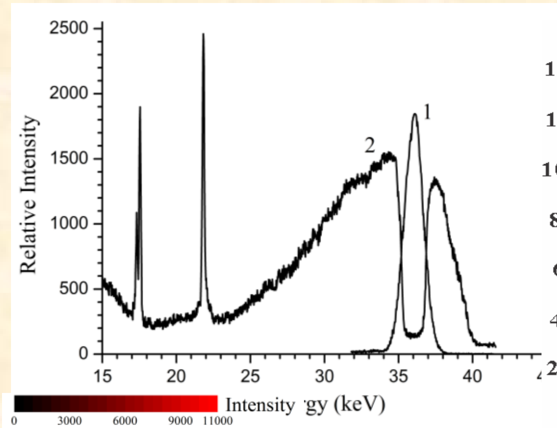
The laboratory conducts research on the features of X-ray diffraction phenomena in the presence of external acoustic waves, thermal, mechanical, and other influences in single crystals and materials with periodic micro-nanostructures:

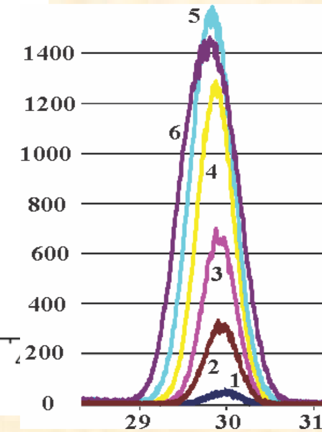
The laboratory develops acousto-optical elements for elementary particles and X-ray beams with controllable parameters, more sensitive and fast X-ray diffraction and local analysis methods for the study of materials composition, biological, archaeological, and other samples, as well as condensed media.

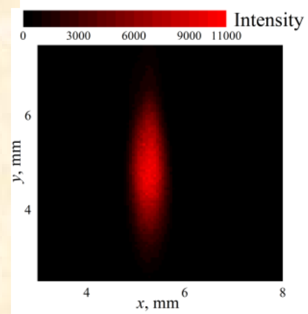


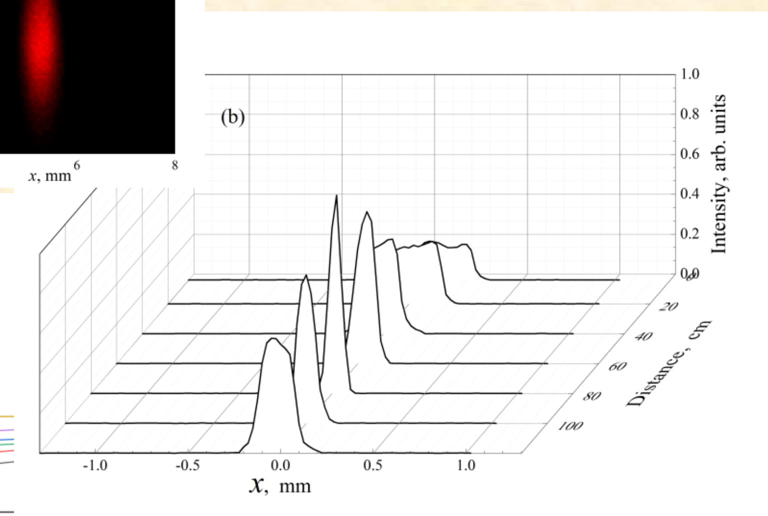


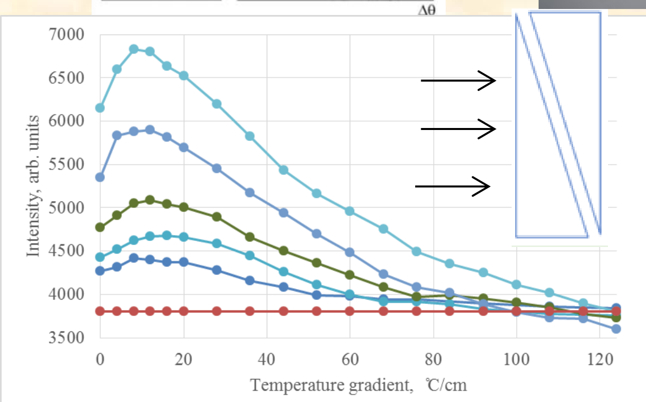


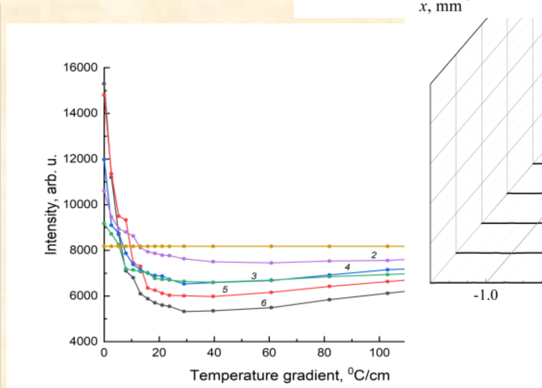






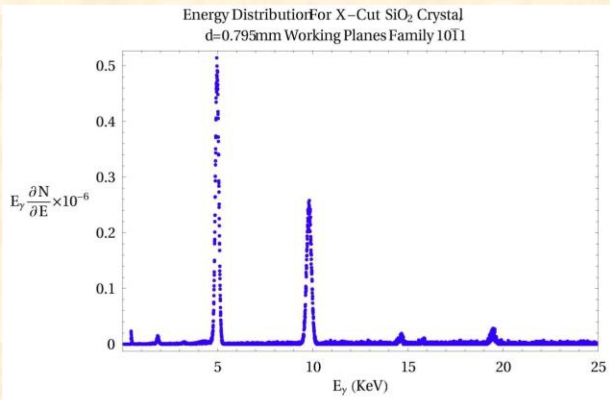


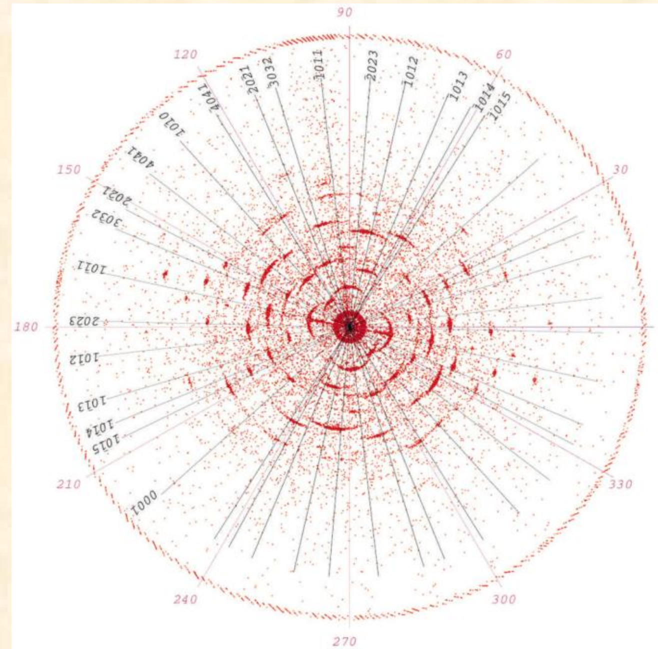


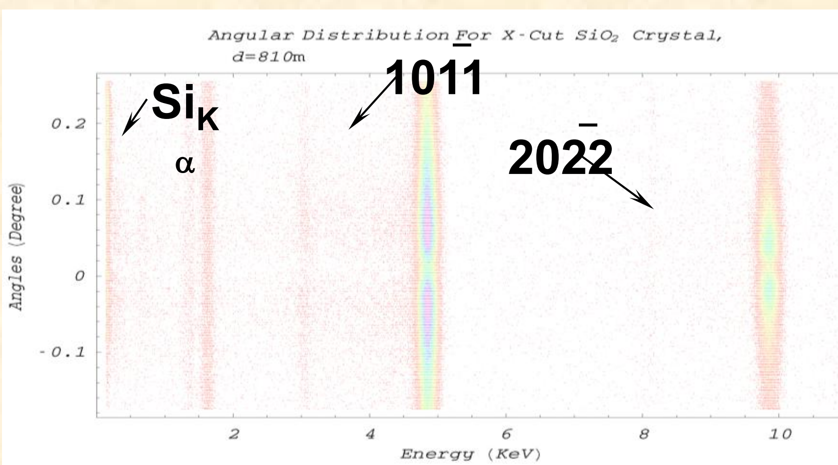


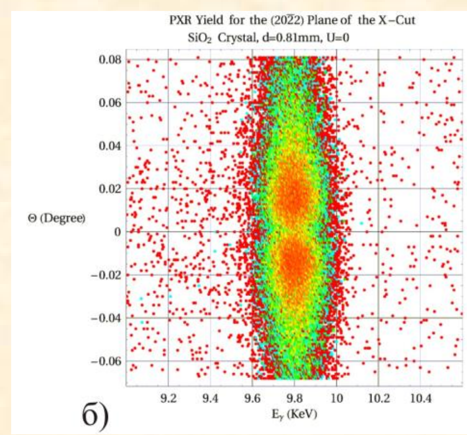
Research is being conducted on controlling the generation of parametric, transition, Cherenkov, diffraction, channeling, and coherent bremsstrahlung radiation produced by charged relativistic particles, ***with the aim of developing unique radiation sources.***

Generation of radiation in matter: Parametric X-ray radiation

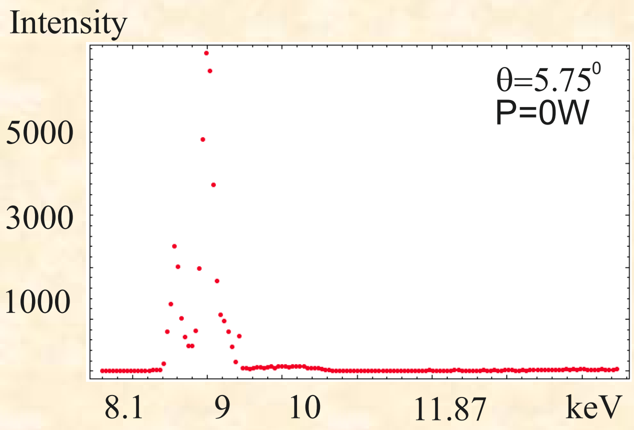


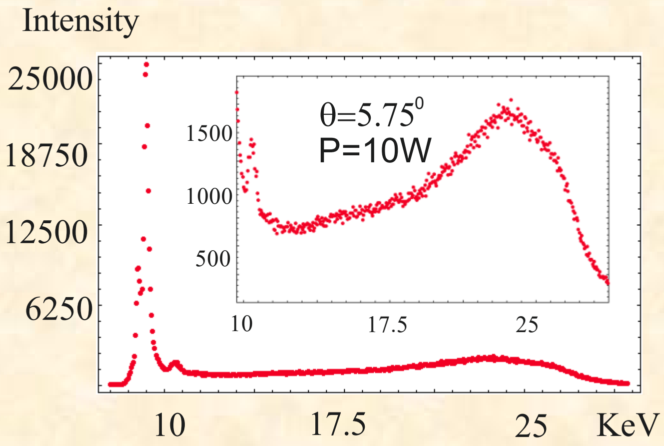


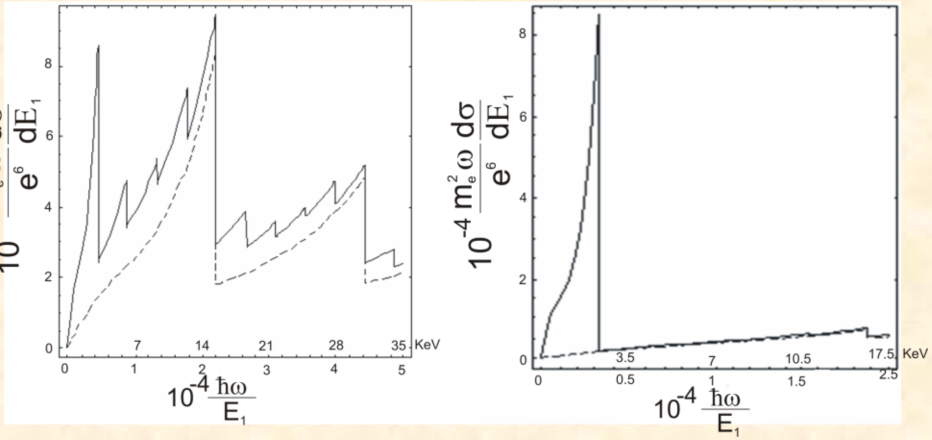


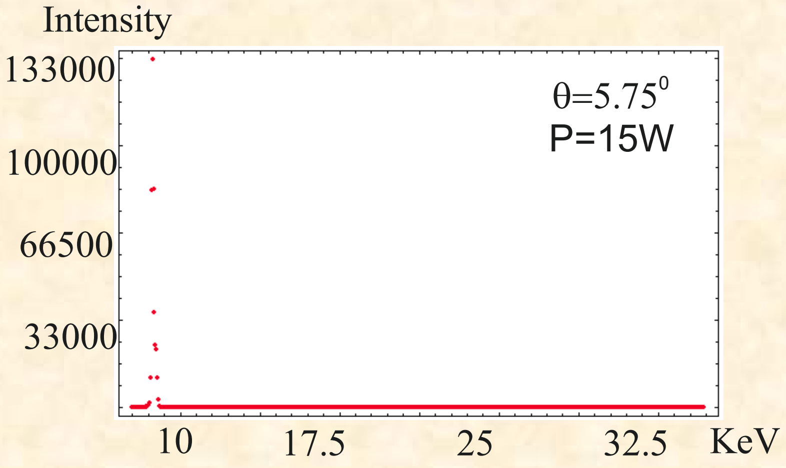


Generation of radiation in matter: Bremsstrahlung radiation



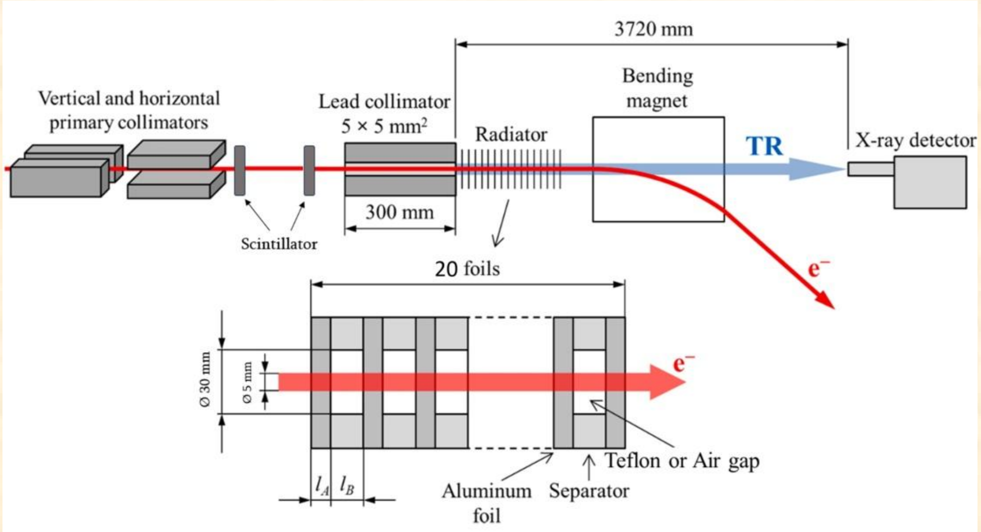


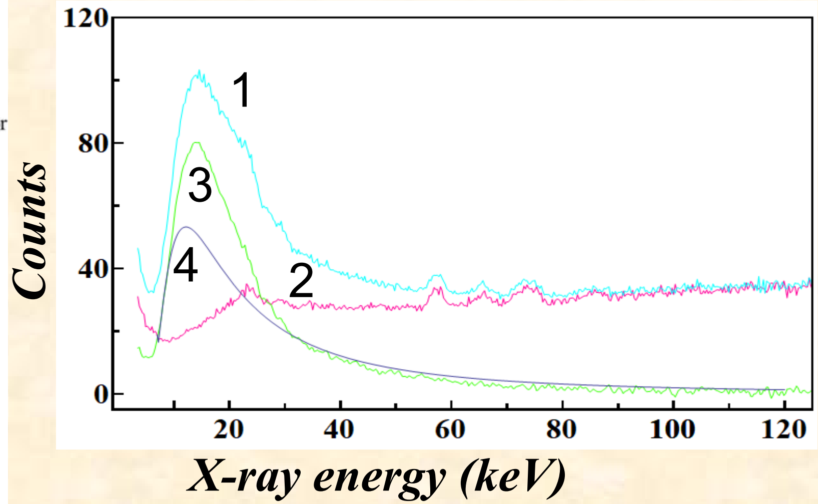


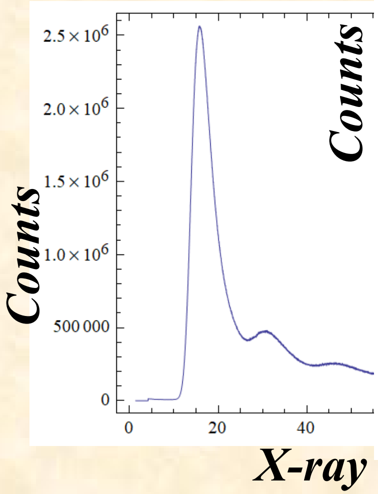


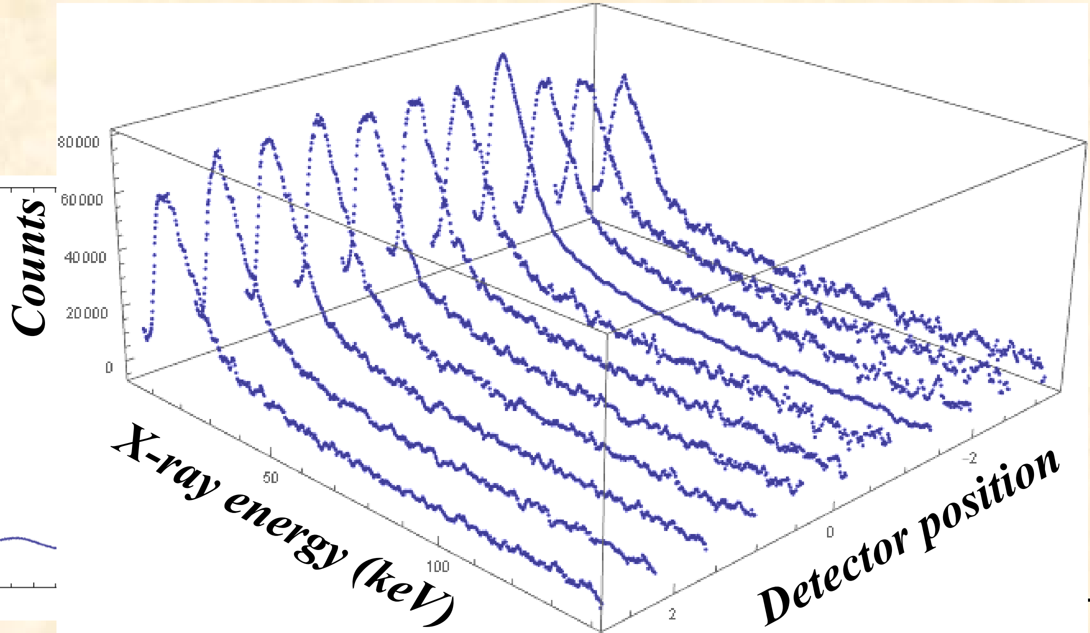
Generation of radiation in matter: Transition radiation

Experimental results obtained at DESY II Test Beam TB21



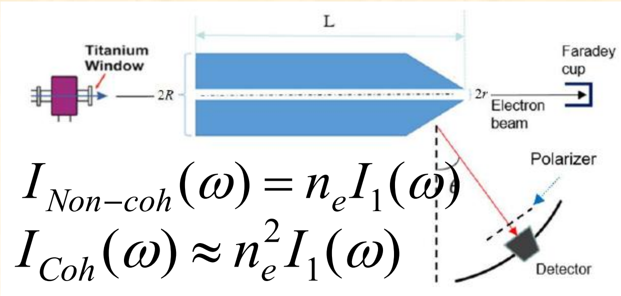






Generation of radiation in matter: Cherenkov radiation

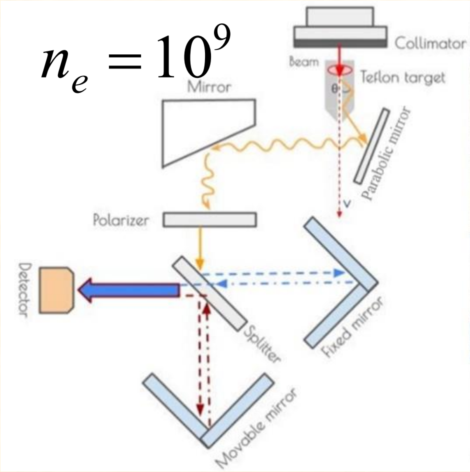
Experimental results obtained at CANDLE: Synchrotron Research Institute

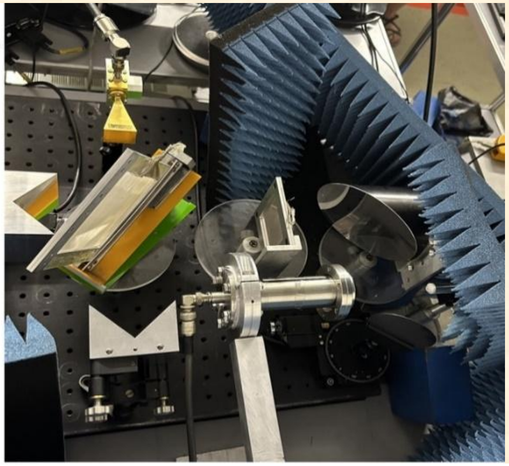


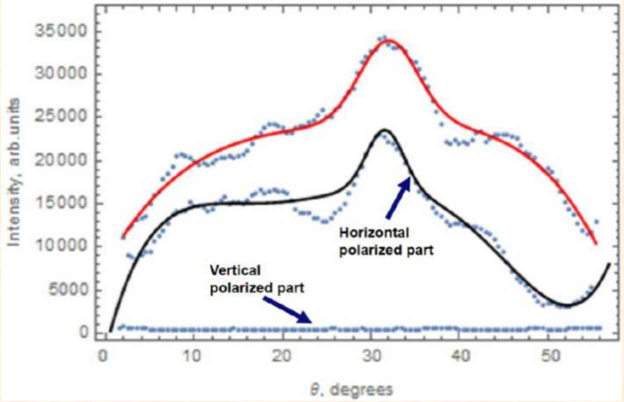
$$I_{Non-coh}(\omega) = n_e I_1(\omega)$$

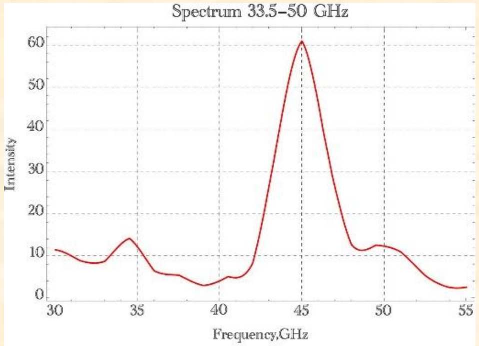
$$I_{Coh}(\omega) \approx n_e^2 I_1(\omega)$$

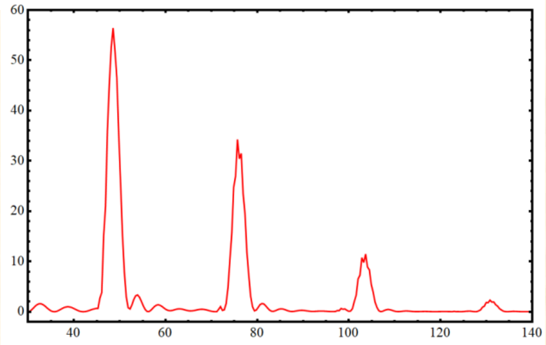
$$n_e = 10^9$$

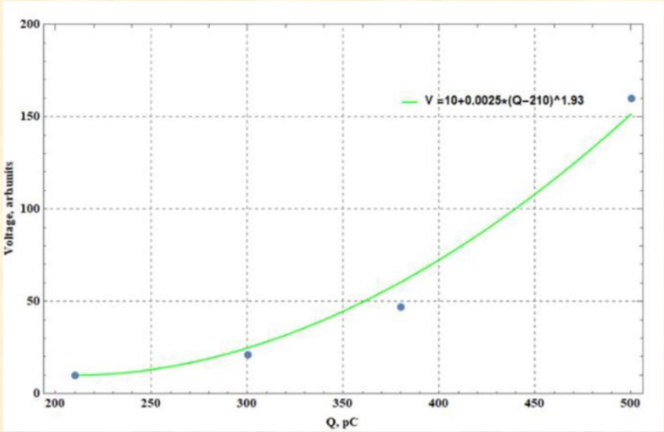


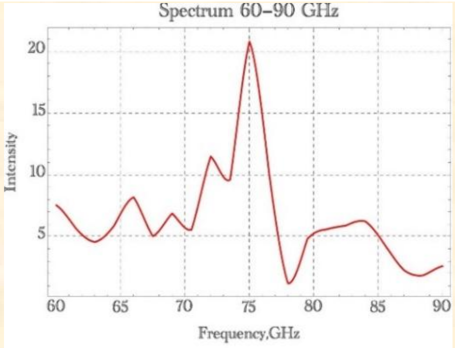


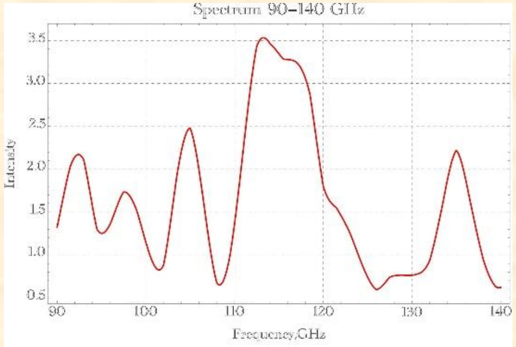






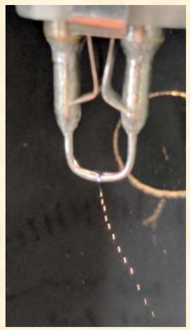
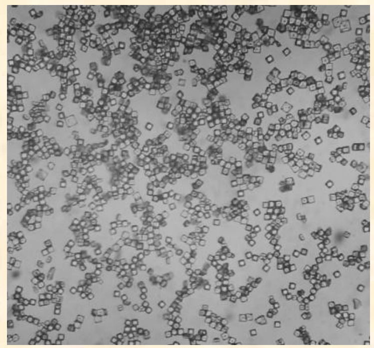
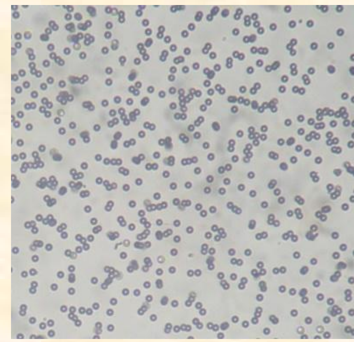


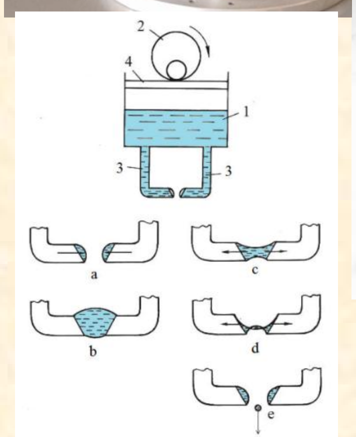


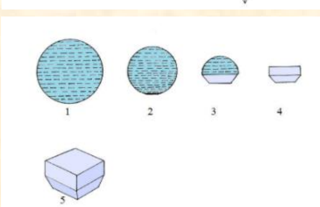


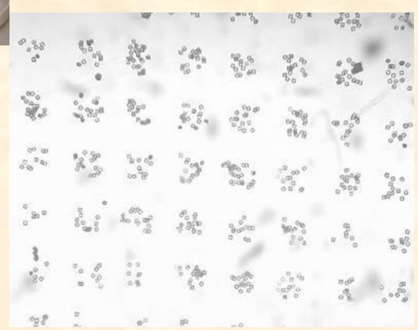
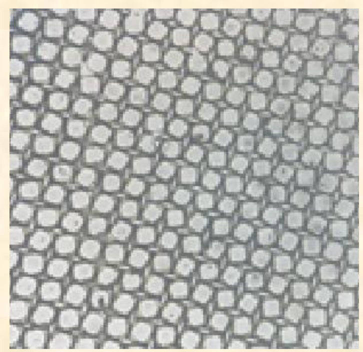
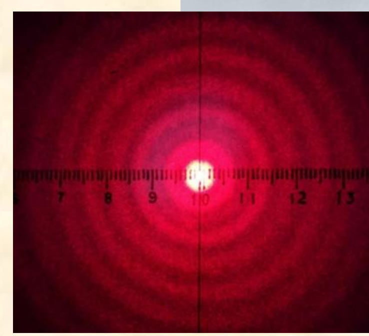
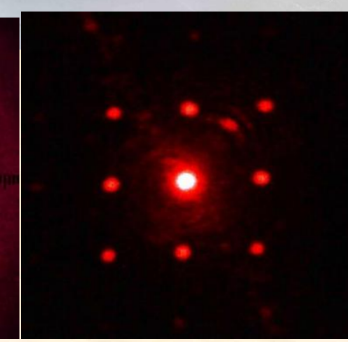
Lab 2. Spectroscopy and modulation phenomena

The work carried out in the laboratory is related to the production of micro- and nanoparticles, periodic structures, features, and applications of light scattering from these media.

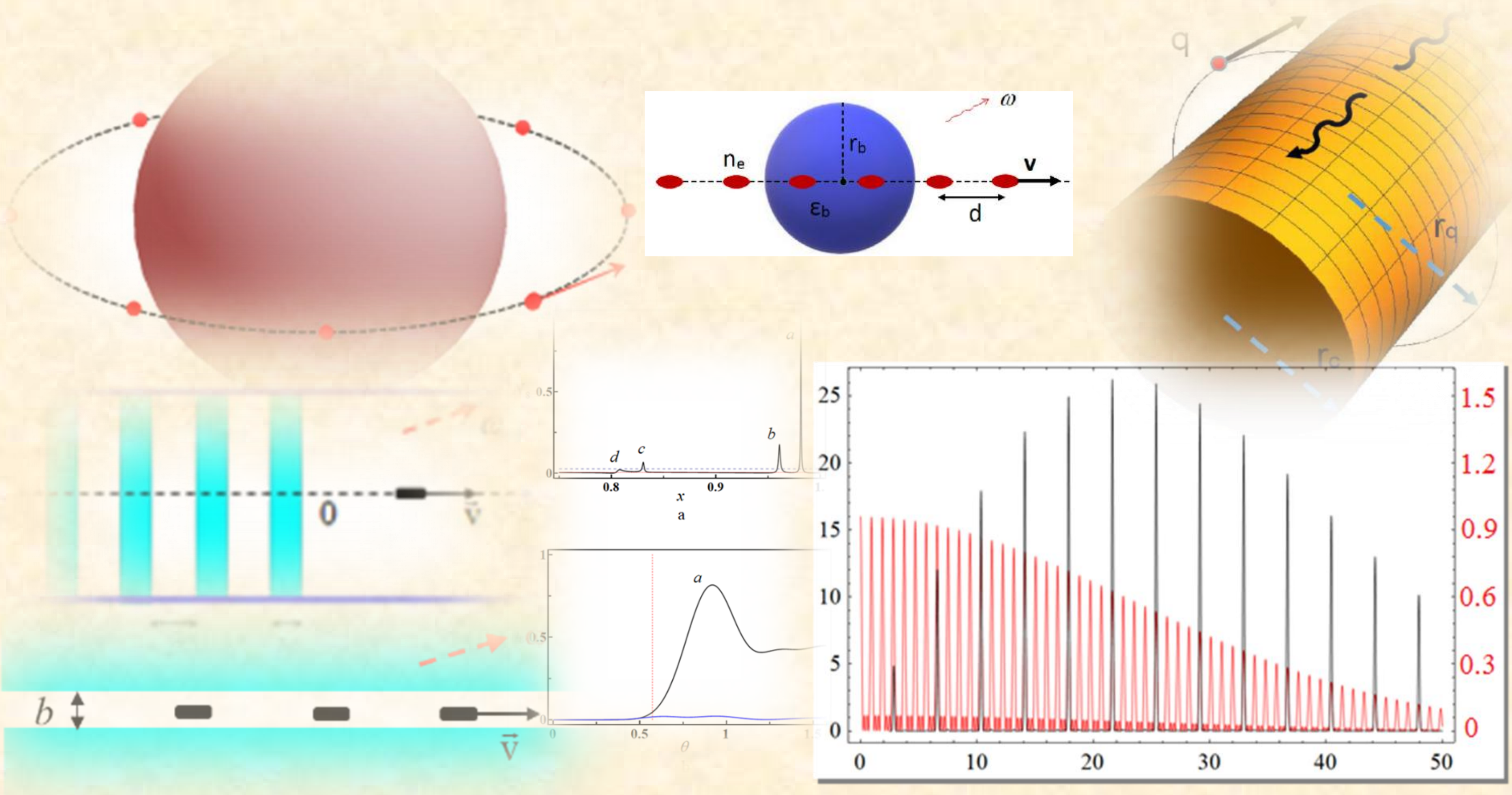




The lab is also engaged in calculations of medical radioisotope yields, target enrichment through proton and electron beam irradiation, and study of the expediency of their application.

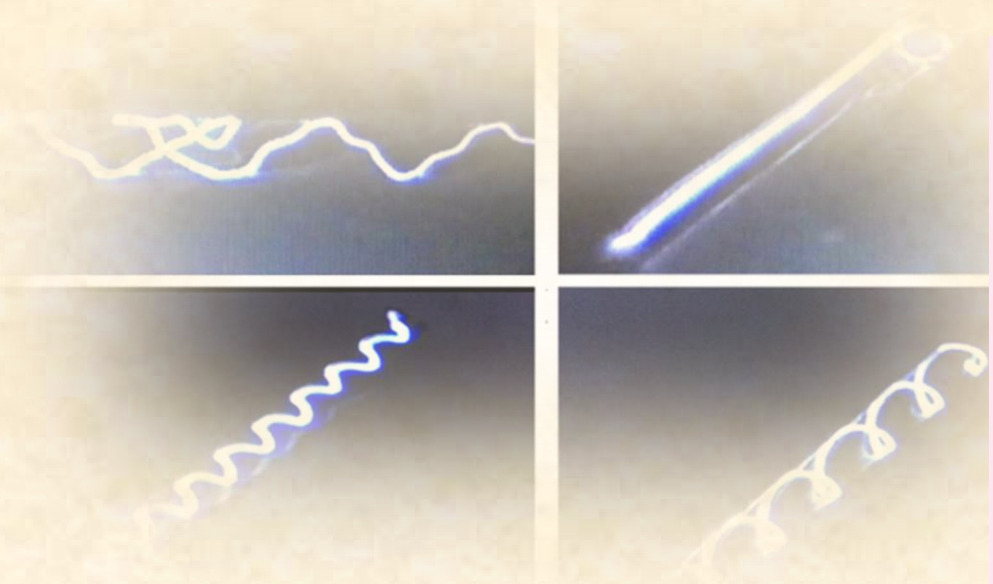
Lab 3. INDUCTION OF RADIATION IN MATTER



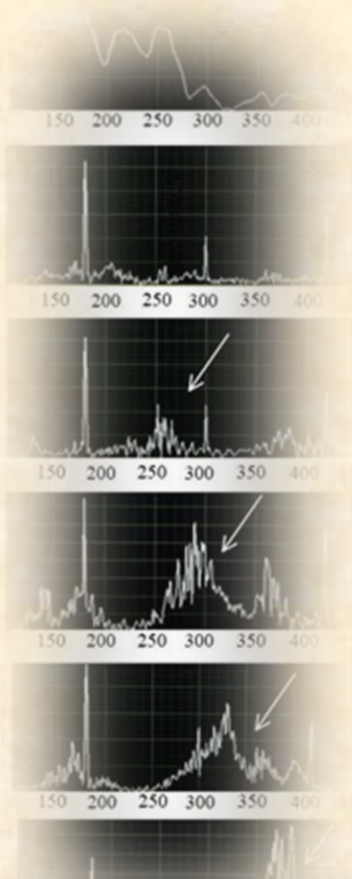
In the laboratory, mainly theoretical research is carried out, devoted to the study of the characteristics of the induced electromagnetic field of relativistic particles moving in media with different symmetry: Cherenkov, transition, parametric and other radiations.

Lab. 4 ACOUSTAPHYSICS

The laboratory conducts research on the interaction of acoustic waves with plasma; the creation of new light sources; development of magnetrons, etc.

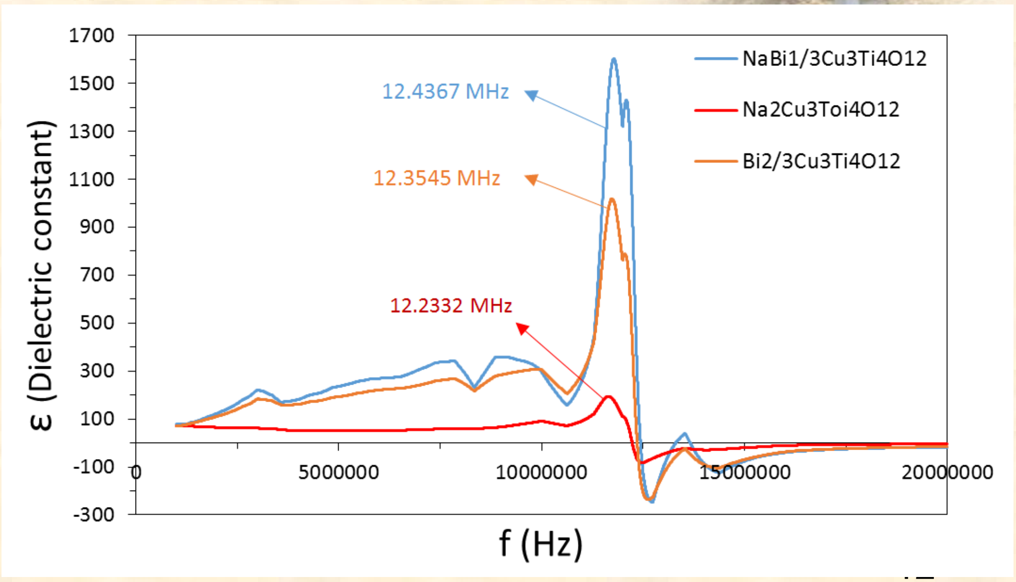


Lab. 5

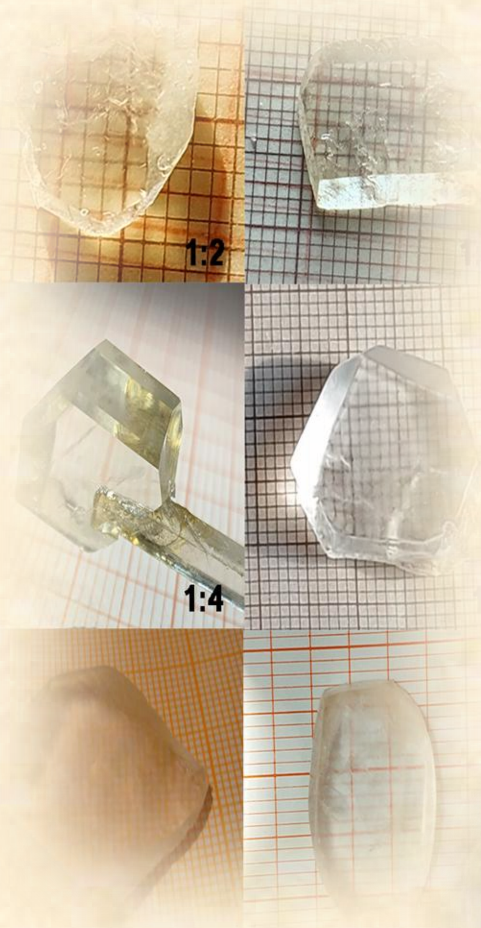


In the laboratory, studies are carried out dedicated to the characteristics of shock waves propagating in the atmosphere, methods of determining the speeds of supersonic moving bodies,

In the laboratory, synthesis of ceramic materials with high dielectric permeability, and study of their physical properties.



Lab 6 REGULATED AND NONREGULATED ENVIRONMENTS

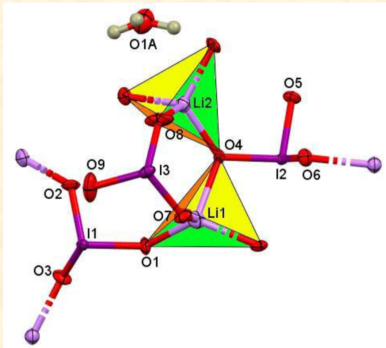


Pure and mixed single crystals of **$LiIO_3$** are grown, including lamellar crystals;

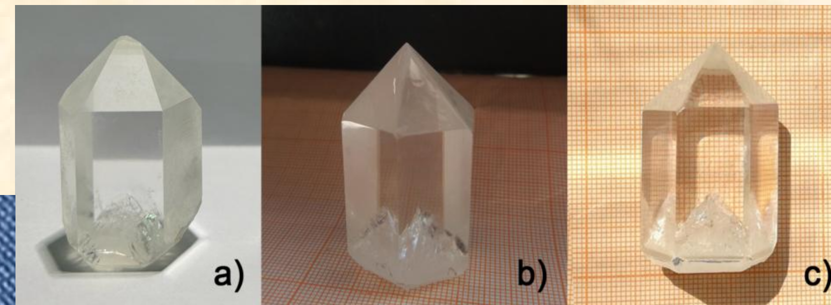
Single crystals of various salts of amino acids **Arg.2HBr.2H2O, L-Arg.H2SO4** are also synthesized and grown.

Hydroxynium Lithium Triiodate

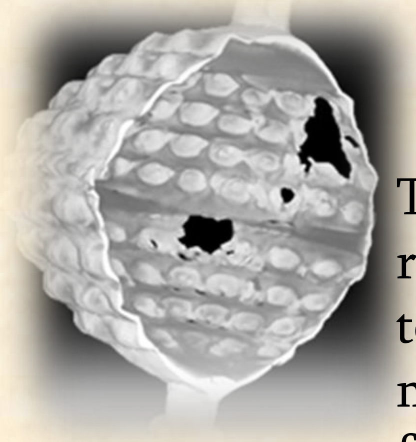
$(H_3O)Li_2(IO_3)_3$

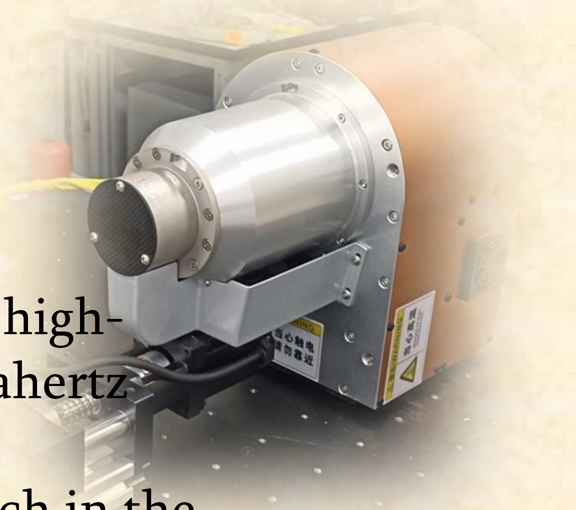


Single crystals of **$LiIO_3$** grown in pure form and using mixtures of amino acids

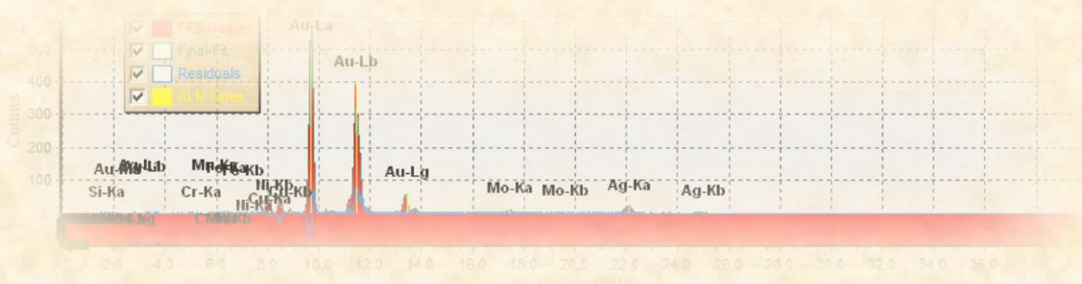


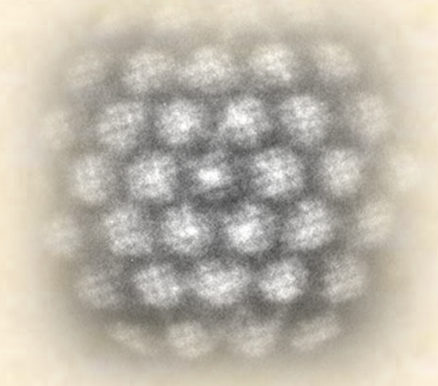
Lab 7. X-RAY AND GIGA-TERAHERTZ TOMOGRAPHY AND SPECTROSCOPY



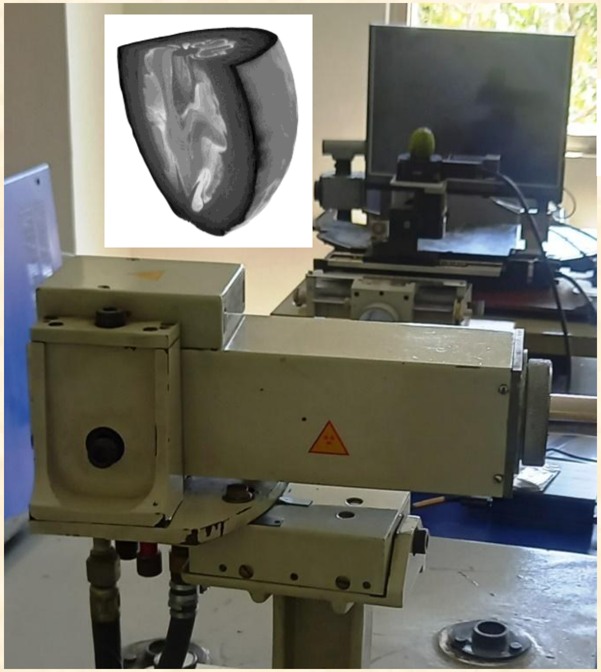


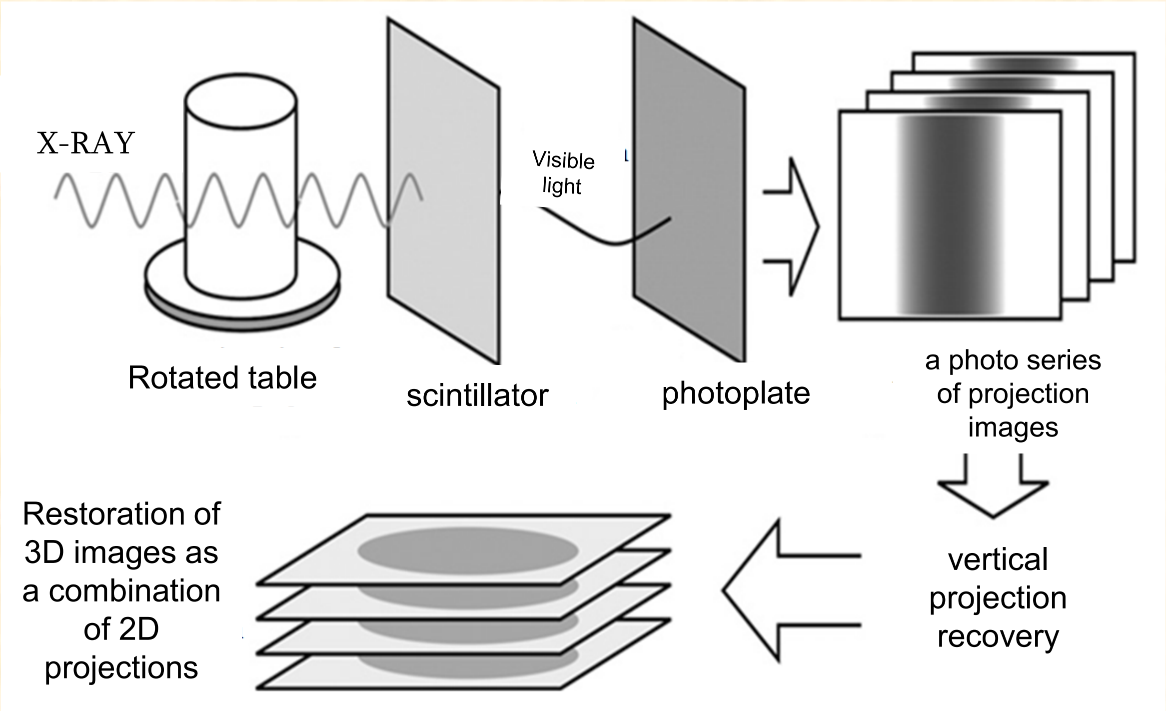
The aim of laboratory is to develop new high-resolution, high-speed X-ray and subterahertz tomographic and spectrometric methods for conducting scientific research in the field of physics of condensed media, as well as research on biological, geological, archaeological, and other materials.





X-RAY MICROTOMOGRAPH

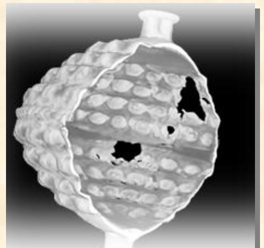




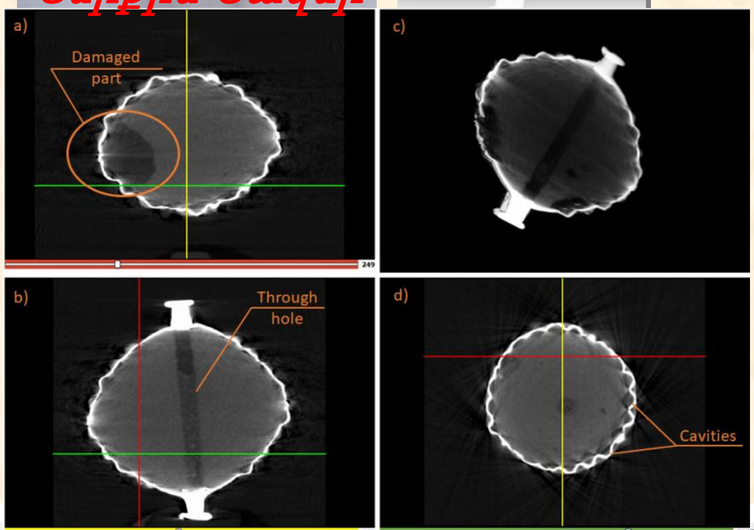
An X-ray microtomograph with a corresponding software package was developed and built, which enables 3D scanning of a sample up to 30 cm in diameter and 22 cm in height with a resolution of about 60 μm, and of a sample up to 1 cm with a resolution of about 4-5 μm.

A laboratory prototype of a 2D X-ray spectrometric mapping device for local analysis of material composition also developed

X-RAY MICROTOMOGRAPHY and SPECTROSCOPY

Ներքին Նավեր



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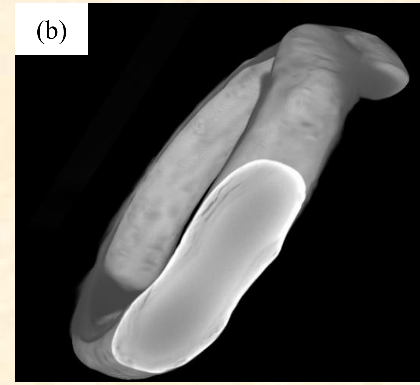
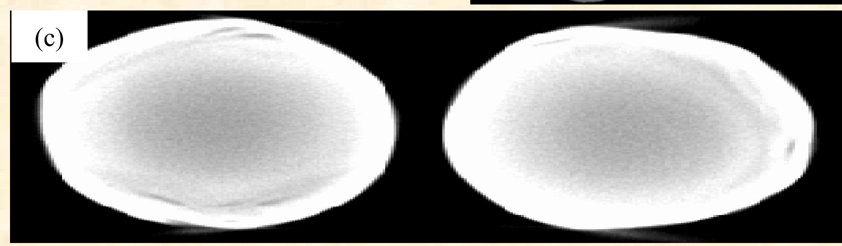
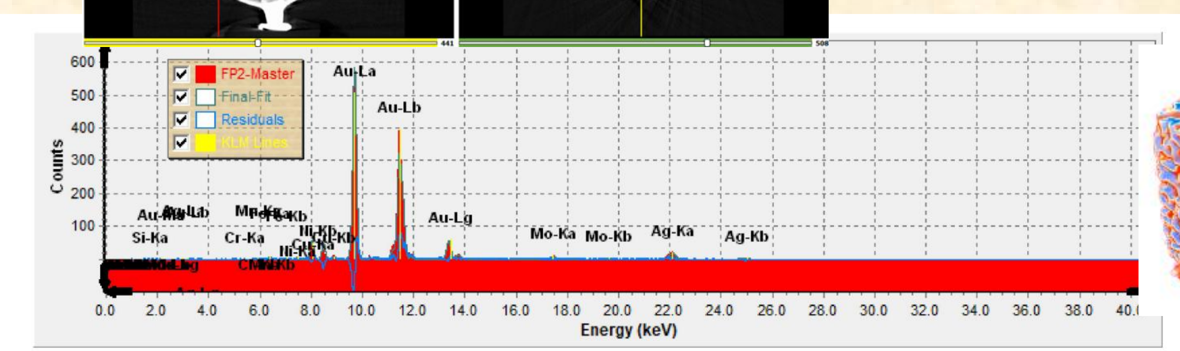
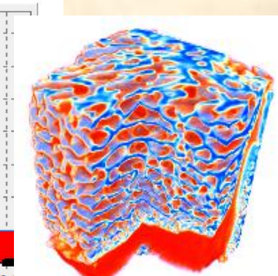
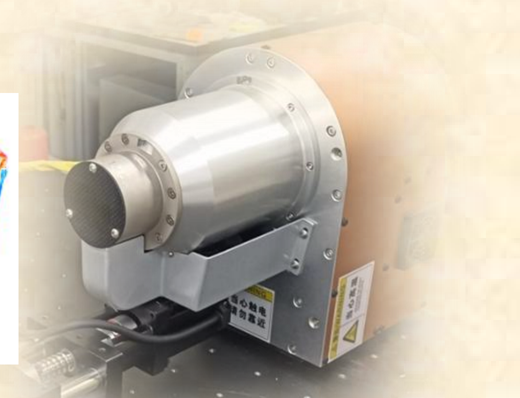


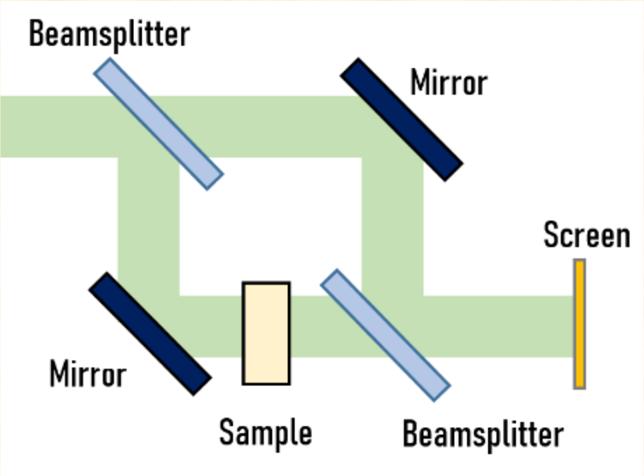


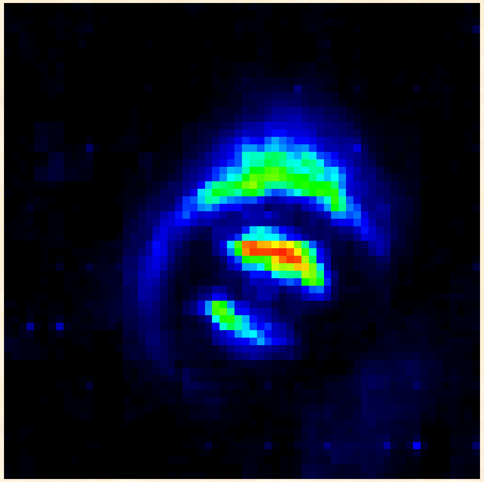


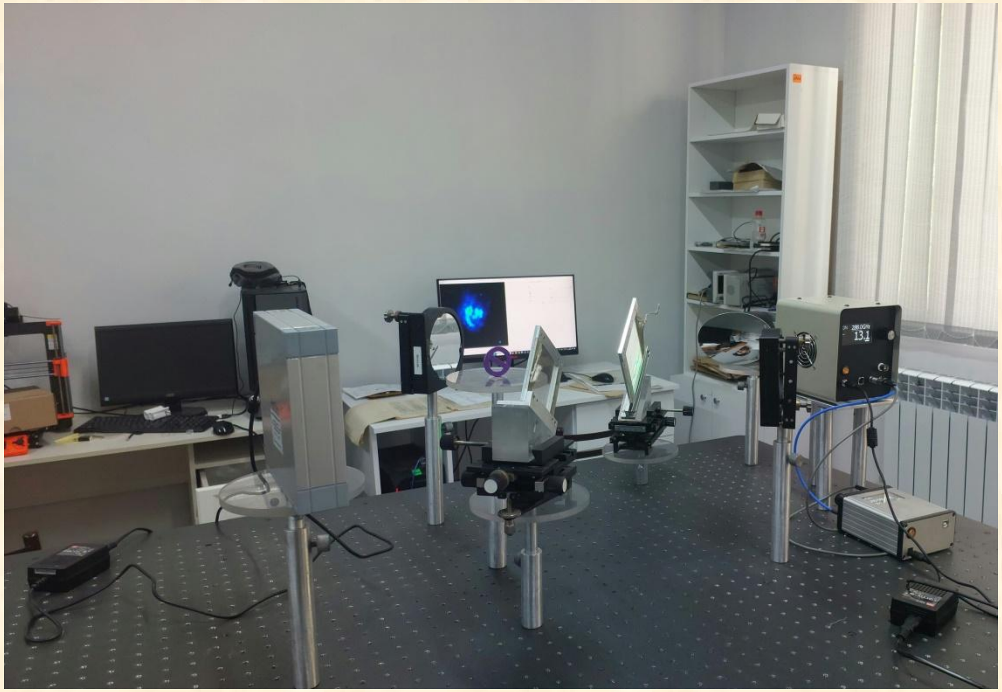



A microtomograph with 3-5 μm resolution is being developed.

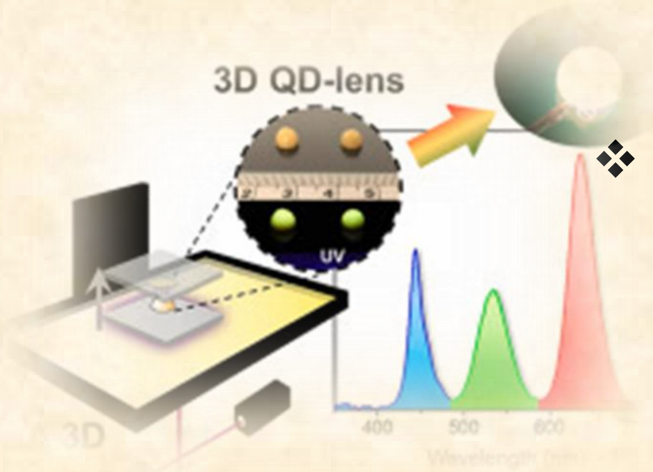
A system for imaging refractive index inhomogeneities from different samples based on absorption and phase contrast in the GHz-THZ radiation range is under development.







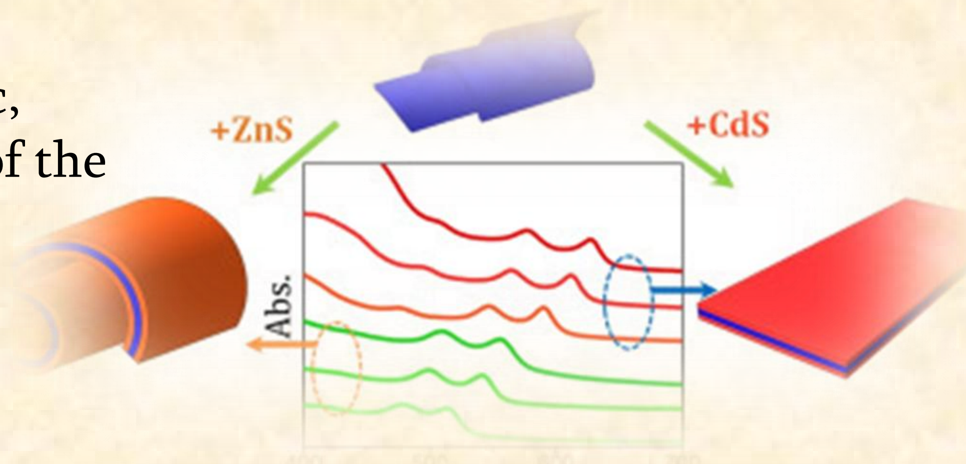
Lab. 8 PHYSICS OF NANO AND MESO SYSTEMS



The laboratory was established in 2024.

- ❖ The aim is to study the physical properties of low-dimensional systems: quantum dots, nanoplates, two-dimensional nanomaterials,

- ❖ In particular to investigate the electronic, optical, thermodynamic, spin, and coulomb characteristics of the mentioned systems.



Investigation of Spectral Parameters of Coherent Cherenkov Radiation Emitted by Pair Electron Bunches at the AREAL Accelerator

We studied how two electron bunches produce coherent Cherenkov radiation as they pass through a cylindrical Teflon resonator. The key focus was how the radiation changes with the time gap between the bunches, varied up to 12 picoseconds:

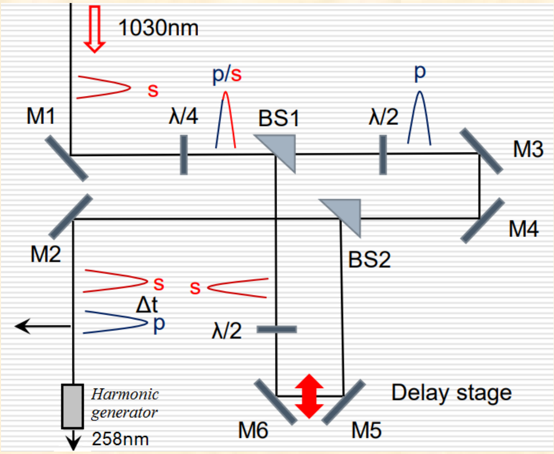
- ***Let us consider the Cherenkov radiation in the 33–55 GHz and 90–140 GHz ranges, generated by two electron bunches passing through a hollow cylindrical Teflon waveguide, using the beam at the CANDLE Synchrotron Radiation Institute (Yerevan, Armenia).***
- ***Theoretical calculations of the radiation emitted by two electron bunches propagating along the axis of a waveguide filled with a finite-length transparent dielectric stack.***

EXPERIMENTAL INSTALLATION

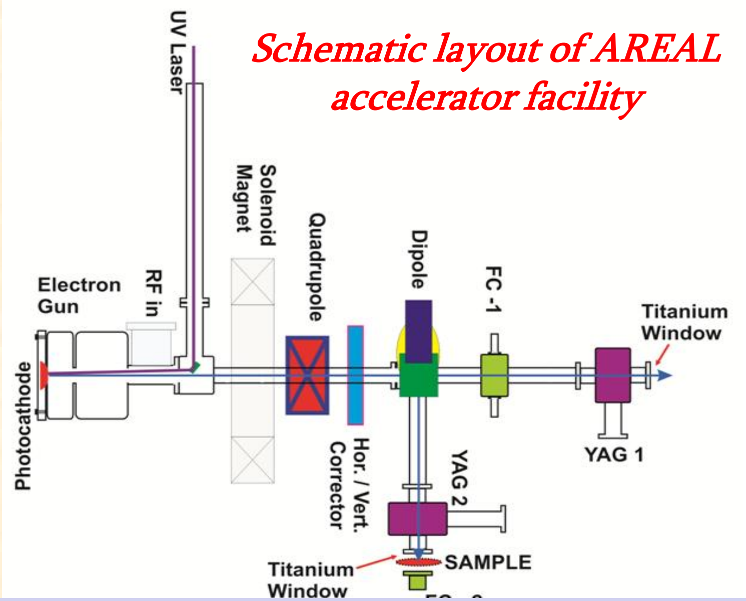
- ❖ The experiment was carried out at AREAL (Advanced Research Electron Accelerator Laboratory), an electron linear accelerator facility based on a photocathode RF gun, at the CANDLE Synchrotron Research Institute in Yerevan.
- ❖ The facility can deliver ultra-short electron bunches with lengths from 0.15 mm to 3mm (0.5 ps to 10 ps), charges up to 800 pC, and energies up to 5 MeV. It can also generate a few separate bunches with time intervals of up to several tens of picoseconds, controlled with high precision.

Laser system Delay-line setup

UV Laser



Schematic layout of AREAL accelerator facility

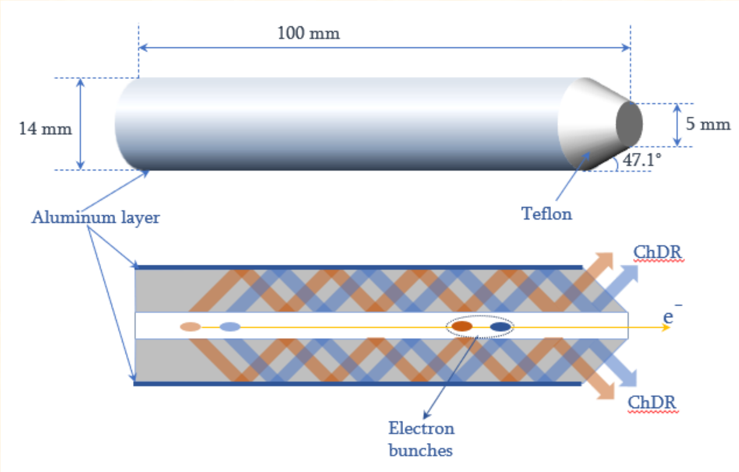


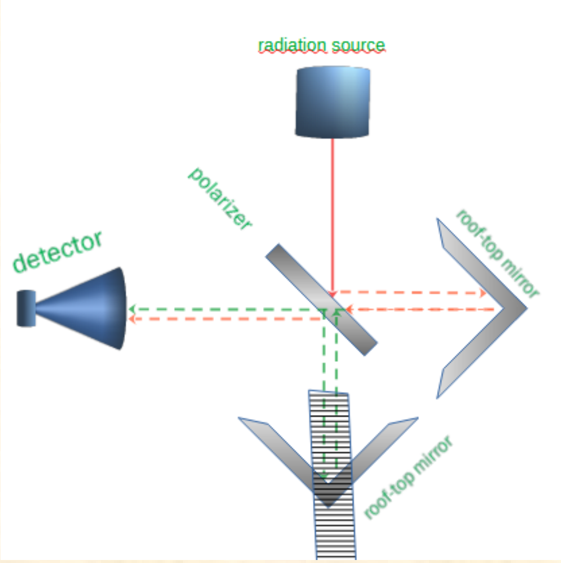
➢In our experiment, a photocathode RF gun was triggered by a 550-fs UV laser pulse that was split into two equal-intensity 550-fs pulses using a delay-line setup with a programmable inter-pulse delay. This configuration produced two electron bunches, separated on the picosecond scale, charges 50 pC, with an energy of 3.6 MeV at a repetition rate of 20 Hz. The beam was formed using a collimator with a 2 mm diameter hole.

EXPERIMENTAL INSTALLATION

The target from which Cherenkov radiation was generated when two electron bunches passed through it.

The experiments were carried out using the Martin-Puplett interferometer scheme in order to reconstruct the full radiation spectrum.





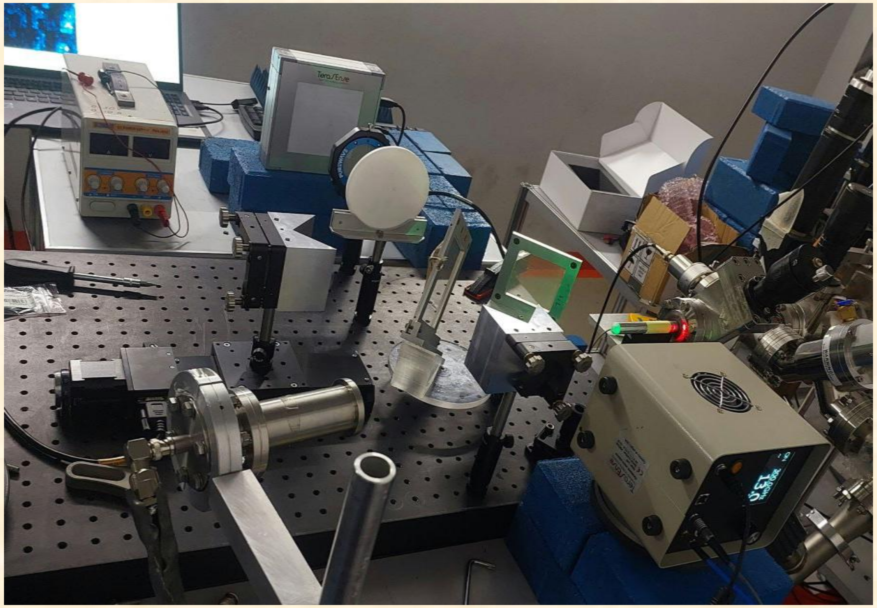
The Teflon radiator has the following geometric parameters:

- ***Length: 100 mm***
- ***Outer diameter: 14 mm,***
- ***inner diameter: 5 mm.***
- ***Conical output angle: 47.1°***

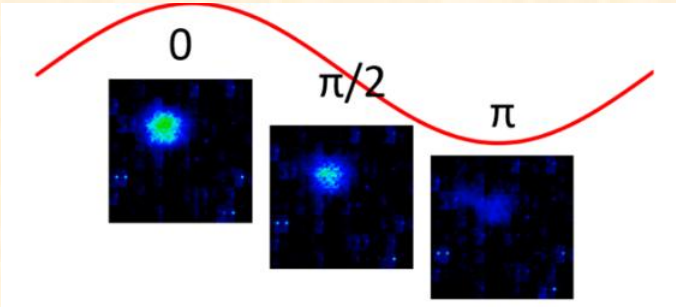
The **Martin-Puplett interferometer** splits an incoming polarized beam into two orthogonally polarized components using a wire-grid polarizer. These two beams travel along separate paths with variable length differences, reflected by rooftop mirrors that rotate their polarization. When recombined by another polarizer, the beams interfere, producing an intensity pattern (interferogram) that depends on the optical path difference. By scanning this path difference and recording the interferogram, the frequency spectrum of the radiation can be retrieved through a Fourier transform.

EXPERIMENTAL INSTALLATION

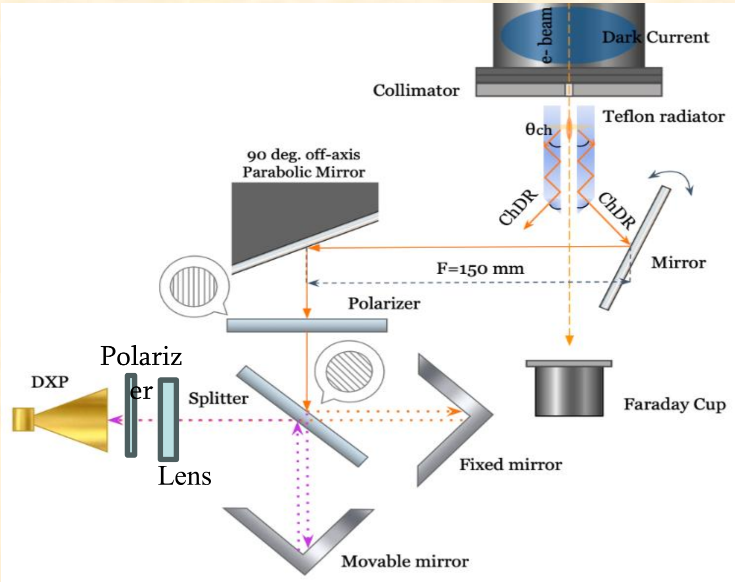
- The alignment of the Martin–Puplett interferometer was carried out using a 300 GHz emitter (TeraSense) and a position-sensitive detector (TeraSense 4096), with a polarizer–analyzer placed in front of the camera. By adjusting one mirror relative to the other, polarization variations were directly observed. The figure illustrates this alignment procedure and the corresponding beam pattern.



- When the optical path lengths of the two arms were equal or differed by integer multiples of 2π in phase, the detected intensity reached a maximum. Conversely, when the arms were exactly out of phase, the final polarizer blocked the radiation, resulting in a minimum intensity.



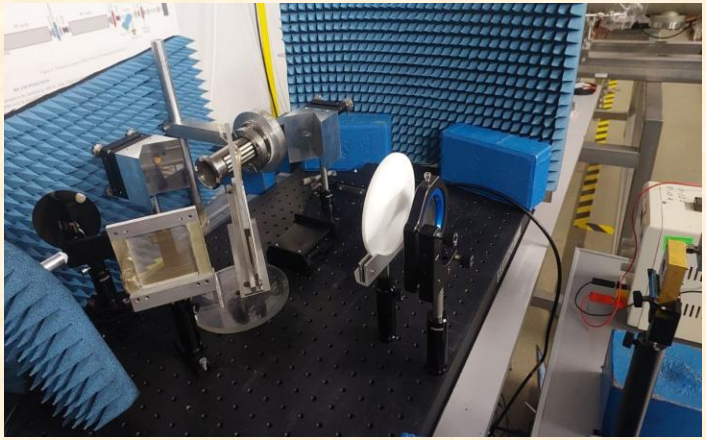
EXPERIMENTAL INSTALLATION



- Lens was used to focus the radiation into the detector, allowing it to collect the radiation more effectively. Then, a polarizer is used to filter and analyze the polarization of radiation.
- As sensors we used two Schottky Barrier Diodes detectors manufactured by Millitech Inc.

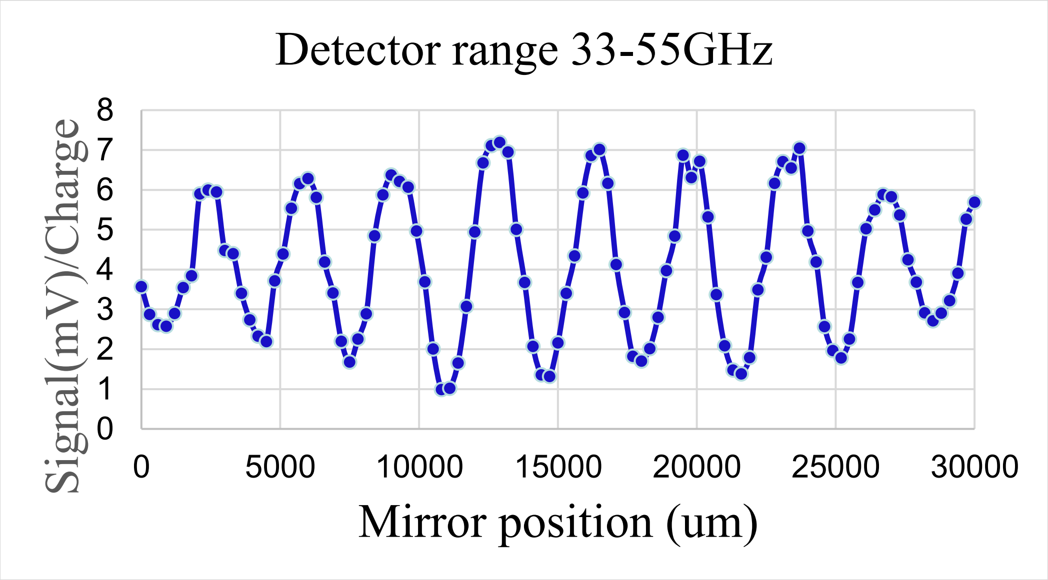
(33-55 GHz spectral response) and
(90-140 GHz spectral response),

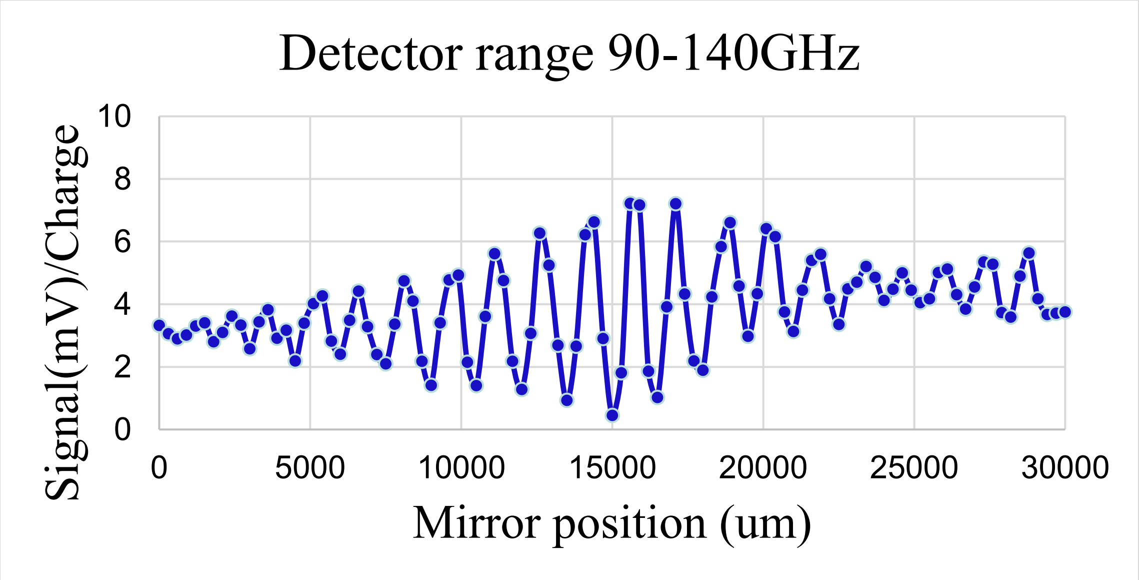
- The radiation emitted from electrons in the target, reflecting by semi-transparent mirror. Then it reflected from the polarizer and enters the interferometer. At the input of the interferometer, the beam is divided into two orthogonally polarized beams using a beam splitter. After reflecting from roof-top mirrors the interfered beams are recorded by a detector.
  - The beam propagated through the 5 mm hole in the Teflon radiator was terminated in the Faraday cup to measure the beam charge and its stability simultaneously with the ChDR signal.



EXPERIMENTAL RESULTS

These interferograms correspond to electron bunch delays of 4 ps and 7 ps, recorded with detectors operating in the 90–140 GHz and 33–55 GHz ranges, respectively.

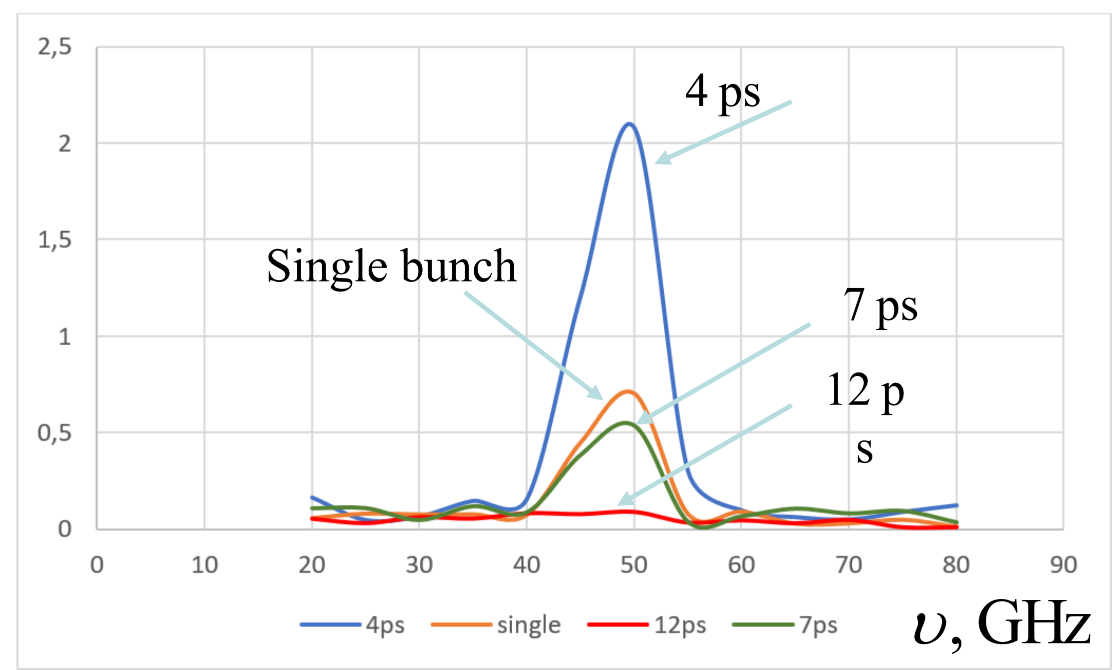




The change in the optical path between the two arms of the interferometer is carried out by scanning with a one mirror with a step of 120 μm.

EXPERIMENTAL RESULTS

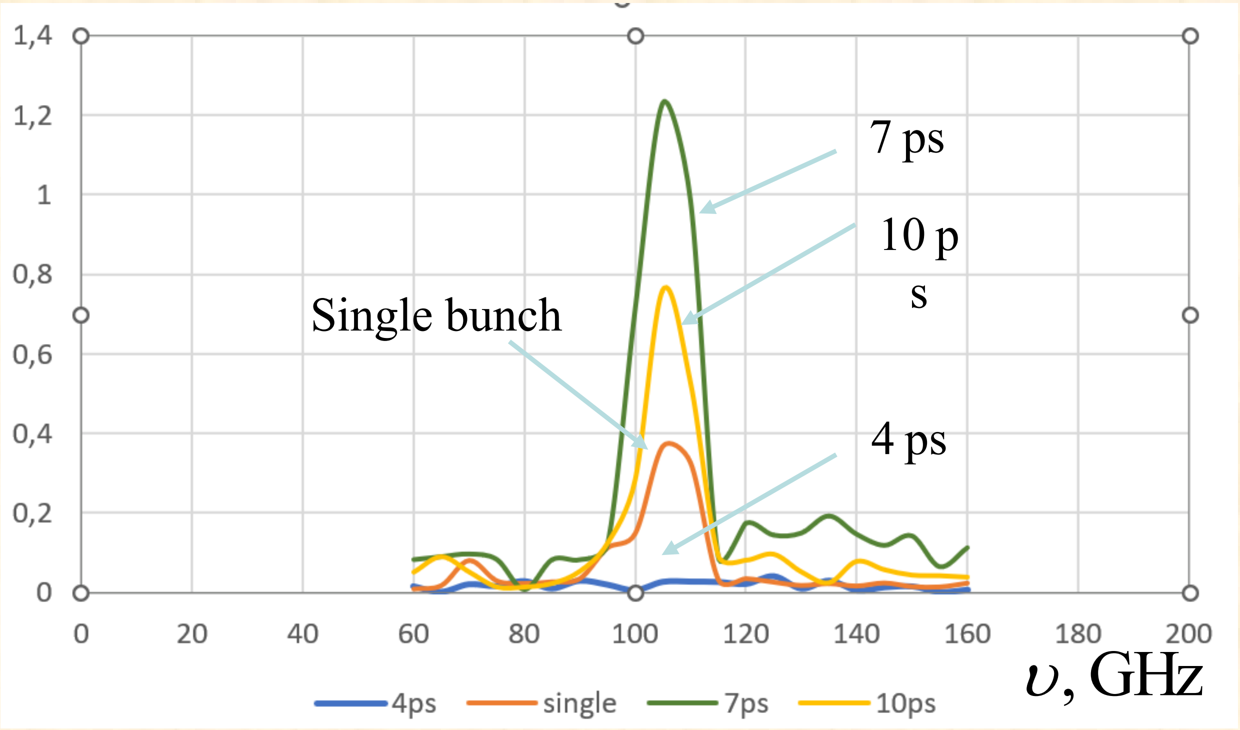
At a frequency of 45 GHz, we obtained the following curves. According to the results, the 4 ps delay (shown in blue) corresponds to a maximum, the 12 ps delay (shown in red) corresponds to a minimum, and the 7 ps delay yields an intermediate value. The curve corresponding to the single bunch is shown in orange.



As you can see in the spectrum, we have a peak, and its value changes (due to interference) when the time interval between the two bunches changes.

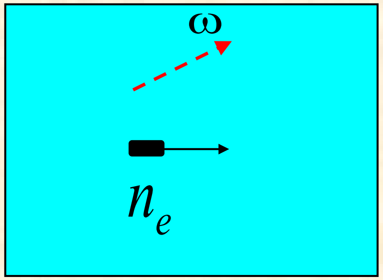
EXPERIMENTAL RESULTS

At a frequency of 105 GHz, we obtained the following curves. According to the results, the 7 ps delay (shown in green) corresponds to a maximum, the 4 ps delay (shown in blue) to a minimum, and the 10 ps delay yields an intermediate value. The curve corresponding to the single bunch is shown in red.



As you can see in the spectrum, we have a peak, and its value changes (due to interference) when the time interval between the two bunches changes.

Theoretical estimates



Modern accelerators generate:

- beams of relativistic monoenergetic electrons
  - with small sizes and
- with large number of electrons

$$n_e = 10^9$$

Radiated energy of single electron $I_1(\omega)$

Radiated energy

$$I_{Non-coh}(\omega) = n_e I_1(\omega)$$

Noncoherent radiation

$$I_{Coh}(\omega) \approx n_e^2 I_1(\omega)$$

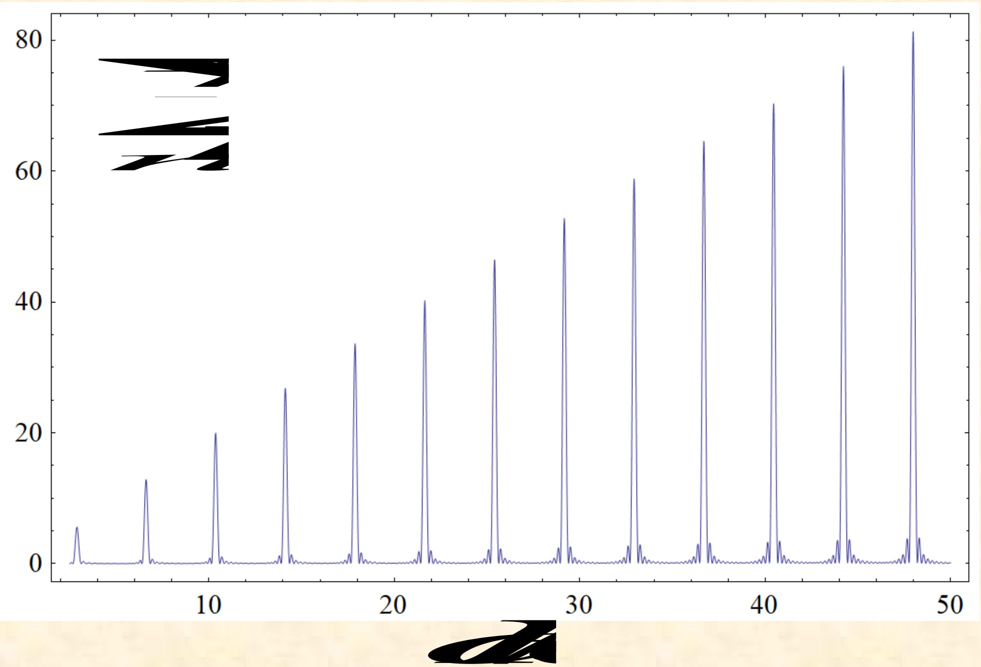
Quasi coherent radiation

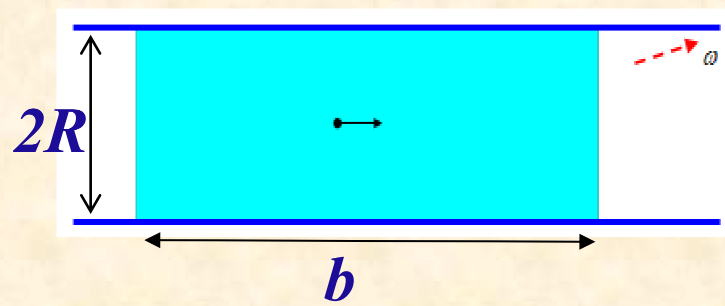
Amplification coefficient

$$I_{Coh}(\omega) / I_{Non-coh}(\omega) \approx n_e = 10^9$$

Figure below presents the results of theoretical investigation of spectral distribution of radiation energy of an electron passing through a dielectric plate in waveguide

(L.Sh. Grigoryan, et. al., IL Nuovo Cimento **34C** (2011) 317), L.Sh. Grigoryan, et. al., J. Phys.: Conf. Ser. **357** (2012) 012004, A.R. Mkrtchyan et. al., JINST **15** (2020) C06019)





$$\varepsilon_b(\omega) = 1.7(1 + 10^{-4} i),$$

$$E_e = 10\,MeV,\ R = 1\text{ cm}$$

$$b = 40\text{ cm} \qquad \mu_b(\omega) = 1$$

Radiation energy from electron crossing a dielectric plate in waveguide

Theoretical estimates

The radiation energy W emitted during the entire time of the bunches (chain) passing through the cross section of the waveguide at large distances:

$$W = \sum_n W_n = \sum_{n=1}^{\infty} \int_{\omega_n}^{\infty} F(\omega) I_n(\omega)\, d\omega$$

$W_n \Leftarrow$ radiation energy on the n-th mode of the waveguide.

$I_n \Leftarrow$ spectral density of the radiation energy of a single particle on the n-th mode

$\omega_n \Leftarrow$ boundary frequency of the n-th mode of the waveguide.

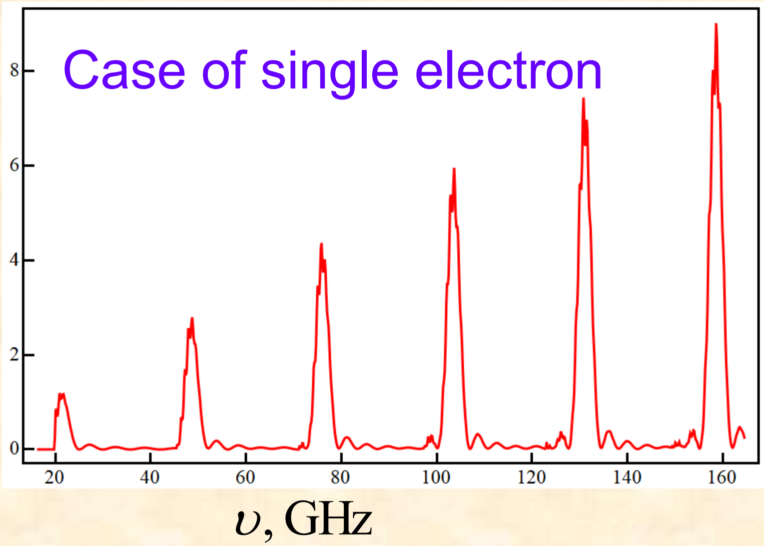
$F(\omega)$ - Structure factor of chain $F = n_q(1 - f_q f_{tr}) n_b + n_q^2 f_q n_b^2 f_{tr} \approx n_q^2 f_q n_b^2 f_{tr}$

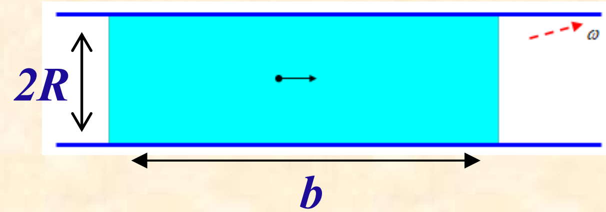
where $f_q = \exp(-\omega^2 \sigma^2 / \mathrm{v}^2)$ $\quad f_{tr} = \dfrac{\sin^2(\omega d\, n_b / 2\mathrm{v})}{n_b^2 \sin^2(\omega d / 2\mathrm{v})}$ $\quad d$ - ***distance between bunches***

Theoretical estimates

Fig. 8.

$$\sum_n \frac{I_n}{\hbar}$$





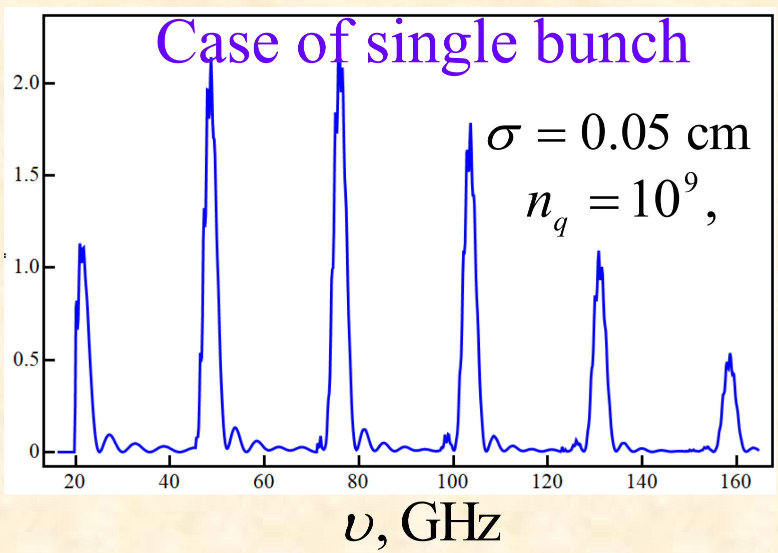
$$\varepsilon_b(\omega) = 1.9(1 + 10^{-4} i), \quad \mu_b(\omega) = 1$$

$$E_e = 3.6 MeV, \quad R = 0.58 \text{ cm}$$

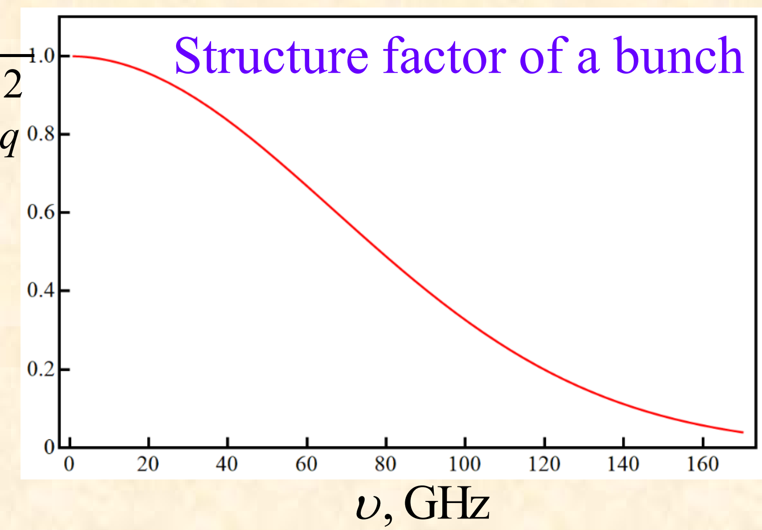
$$b = 10 \text{ cm}$$

Fig. 9.

$$\frac{F}{n_b^2 n_q^2} \sum_n \frac{I_n}{\hbar}$$

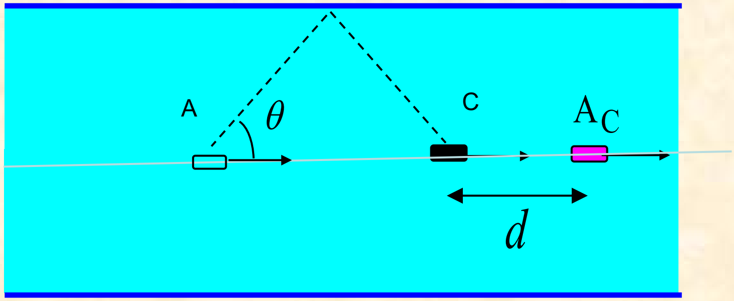


$$\frac{F}{n_b^2 n_q^2}$$



Radiation spectra from electrons crossing a dielectric plate in waveguide.

Visual explanation



$$d = CA_C$$

Consider the Cherenkov wave (dotted line) emitted by the first bunch at ***point A***. While propagating, at some time moment the wave will approach the bunch trajectory at ***point C***.

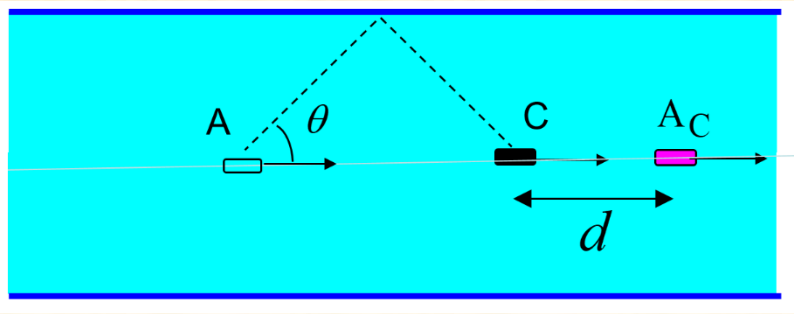
By this point in time, it will lag behind its source (the first bunch), which, moving at superluminal speed, will be at the ***point A_C***. In this case, the second bunch of the chain is to the left at a ***distance d*** from the first one, and if

$$d = 2R\sqrt{\varepsilon \mathrm{v}^2 / c^2 - 1}$$

then it will be in the vicinity of ***point C*** simultaneously with the wave.

Thus, in the areas directly adjacent to each of the bunches (with the exception of the first), two processes will simultaneously occur: ***emission and interference of waves.***

Visual explanation



The in-phase superposition ($d_0 = 4d$) of electromagnetic oscillations leads to an amplification of the field in the radiation formation zone. As a result, the force retarding the motion of bunches also increases, and an additional work performed by the external force constraining the uniform motion of bunches shall be used for formation of higher power resonant CR stimulated on the larger number of neighboring modes.

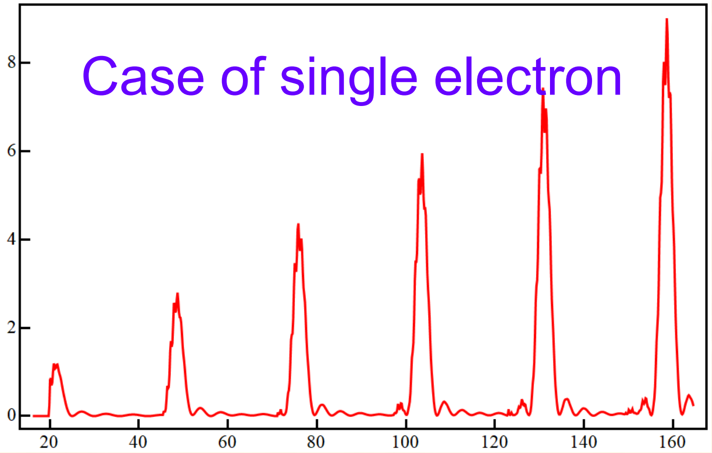
The condition of the resonant amplification (stimulation) of the quasi-coherent CR on a large number of waveguide modes.

$$d_0 = 4 \times d$$
$$= 4 \times 2R\sqrt{\varepsilon \mathrm{v}^2/c^2 - 1}$$

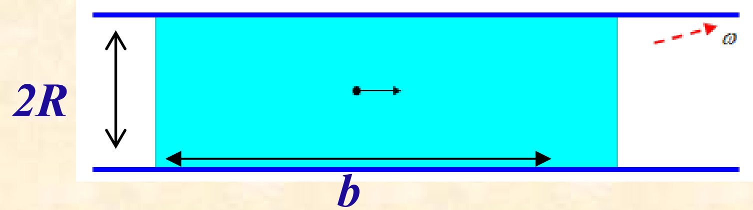
Theoretical estimates

$$\sum_n \frac{I_n}{\hbar}$$

Fig. 8.



υ, GHz



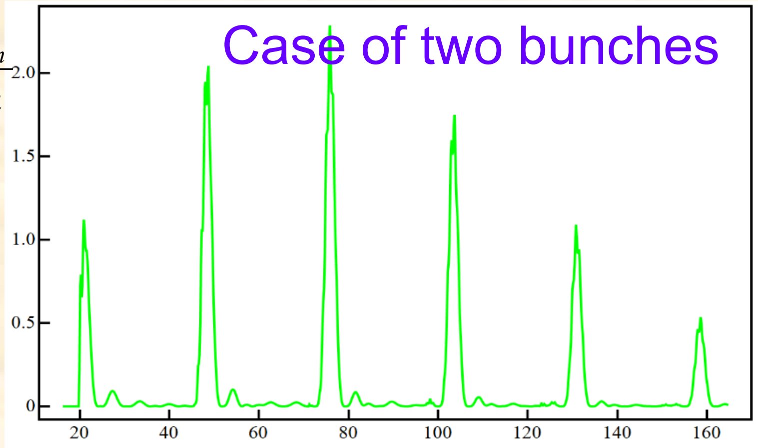
$$\varepsilon_b(\omega) = 1.9(1 + 10^{-4} i), \quad \mu_b(\omega) = 1$$

$$E_e = 3.6 MeV, \quad R = 0.58 \text{ cm}$$

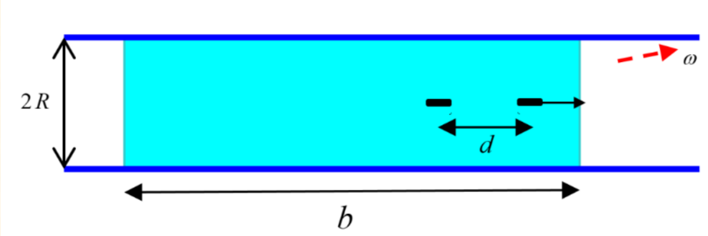
$$b = 10 \text{ cm}$$

Fig. 10.

$$\frac{F}{n_b^2 n_q^2} \sum_n \frac{I_n}{\hbar}$$



υ, GHz



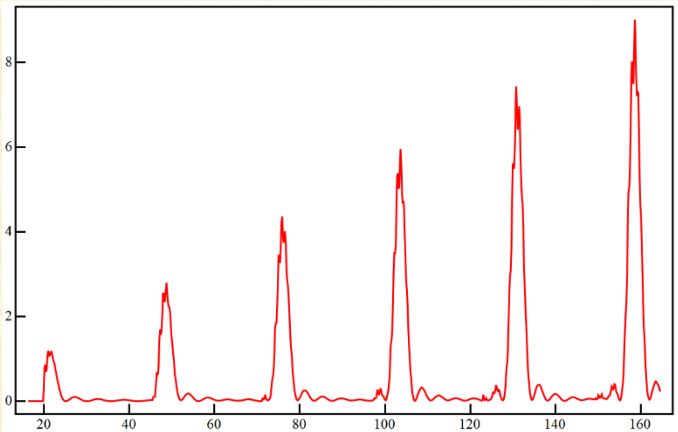
$$n_q = 10^9, \; n_b = 2, \; \sigma = 0.05 \text{ cm}$$

$$d = 8R\sqrt{\varepsilon \mathrm{v}^2 / c^2 - 1} = 4.31 \text{ cm}$$

Theoretical estimates

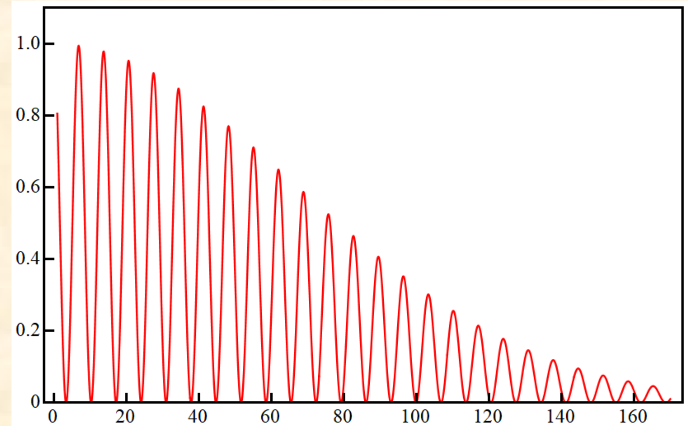
Case of single electron

$$\sum_n \frac{I_n}{\hbar}$$



υ, GHz

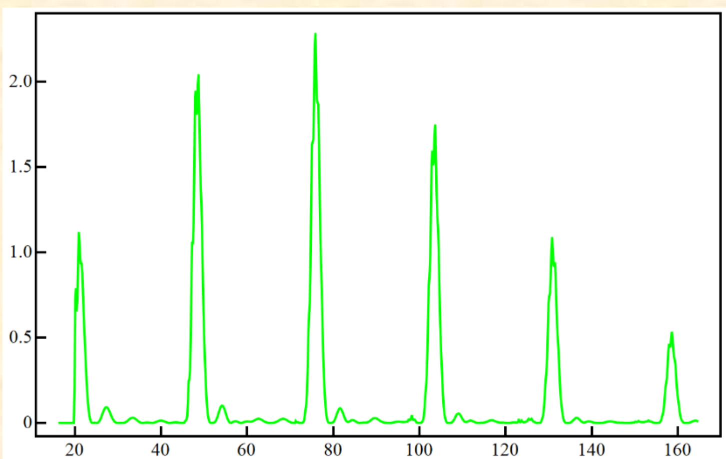
Structure factor

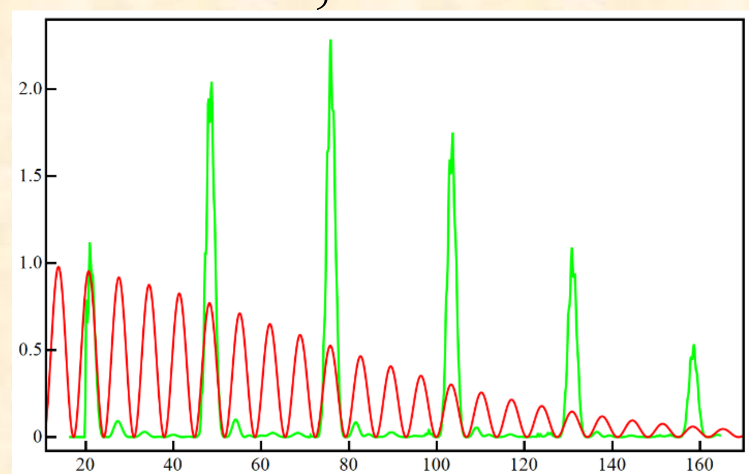


υ, GHz

Case of two bunches

$$\frac{F}{n_b^2 n_q^2} \sum_n \frac{I_n}{\hbar}$$





υ, GHz

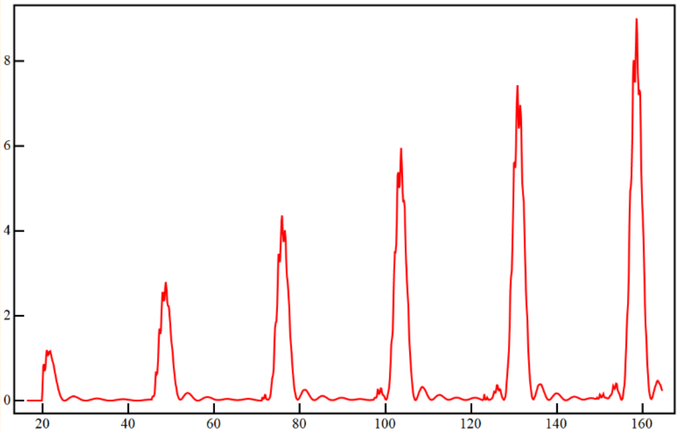
$$d = 8R\sqrt{\varepsilon \mathrm{v}^2/c^2 - 1}$$

Theoretical estimates

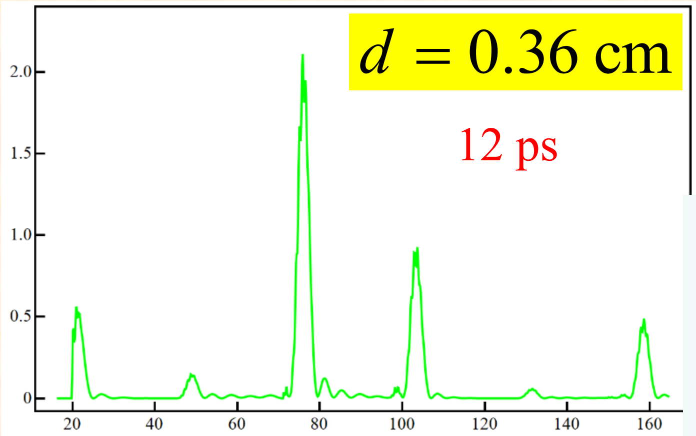
$\sum_n \frac{I_n}{\hbar}$ Case of single electron

Case of two bunches

$$d = 8R\sqrt{\varepsilon v^2/c^2 - 1}$$

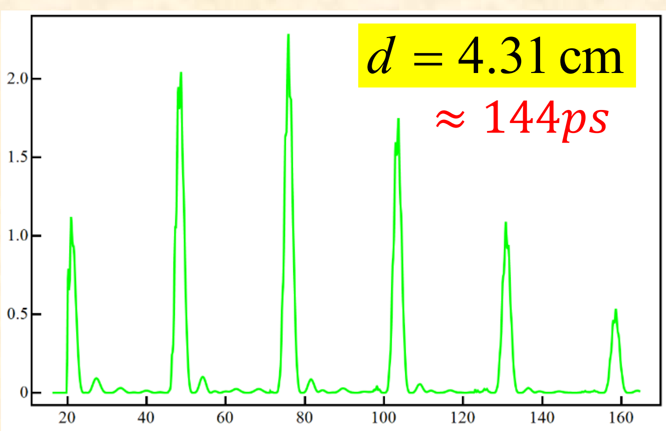


υ, GHz

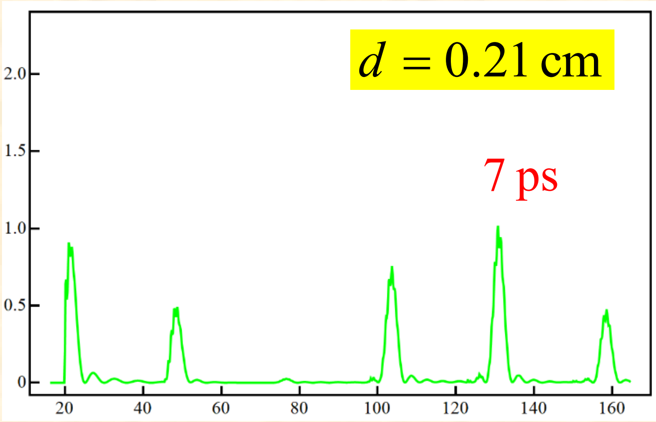


υ, GHz

$\frac{F}{n_b^2 n_q^2} \sum_n \frac{I_n}{\hbar}$ Case of two bunches



υ, GHz



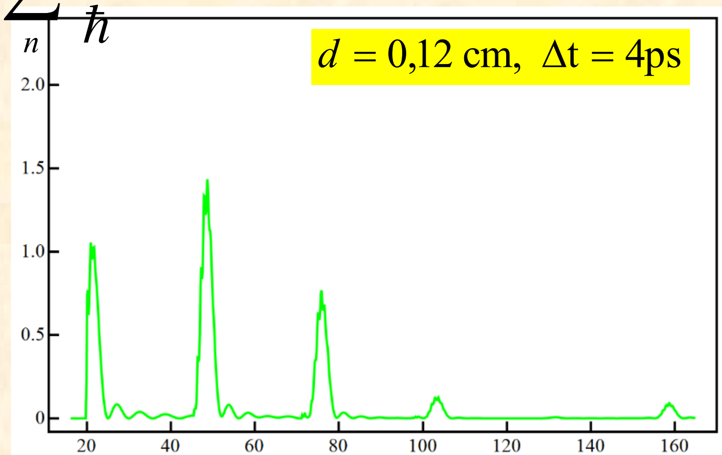
υ, GHz

Our beamline can't achieve this delay line under conditions of resonant amplification on a large number of waveguide modes simultaneously for two beams, but we can see radiation changes (due to interference) of individual modes with a change time interval between the beams.

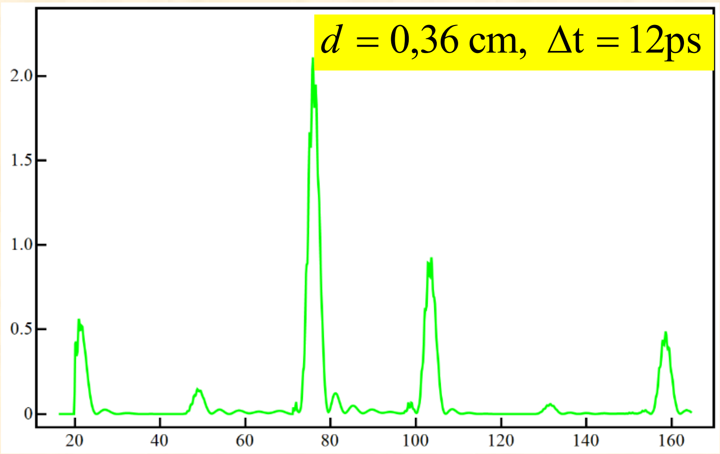
Theoretical estimates

Case of two bunches

$$\frac{F}{n_b^2 n_q^2}\sum_n \frac{I_n}{\hbar}$$

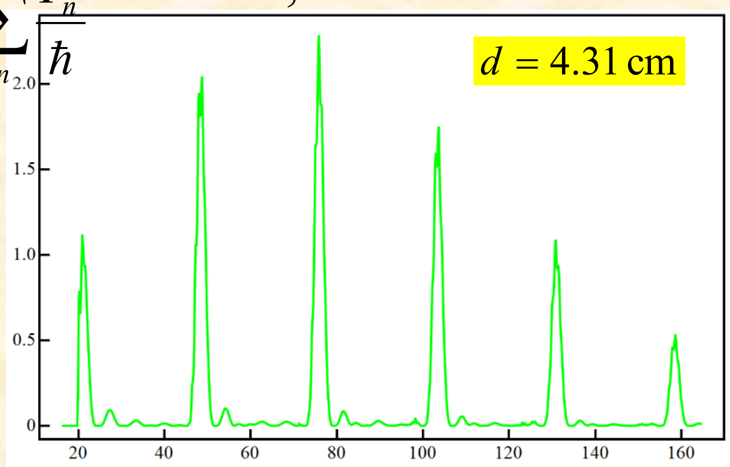


υ, GHz

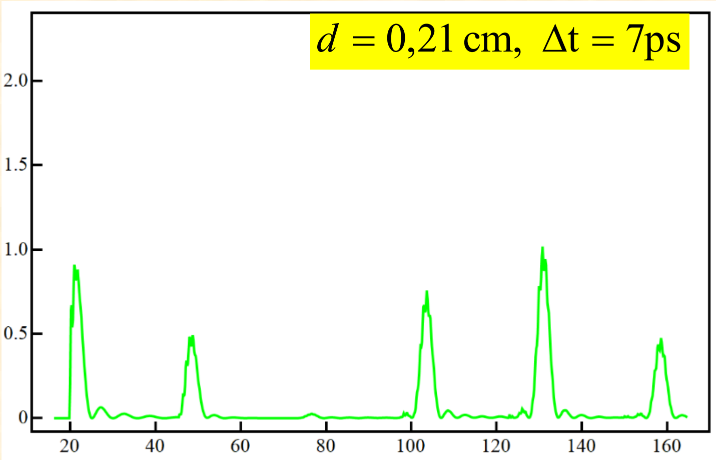


υ, GHz

$$\frac{F}{n_b^2 n_q^2}\sum_n \frac{I_n}{\hbar}$$



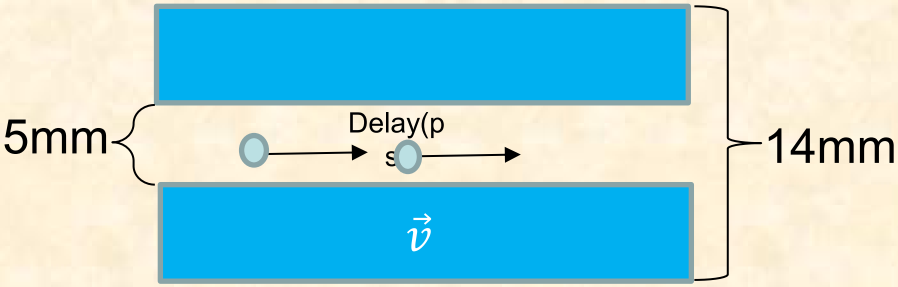
υ, GHz



υ, GHz

We can see radiation changes (due to interference) of individual modes with a change time interval between the beams.

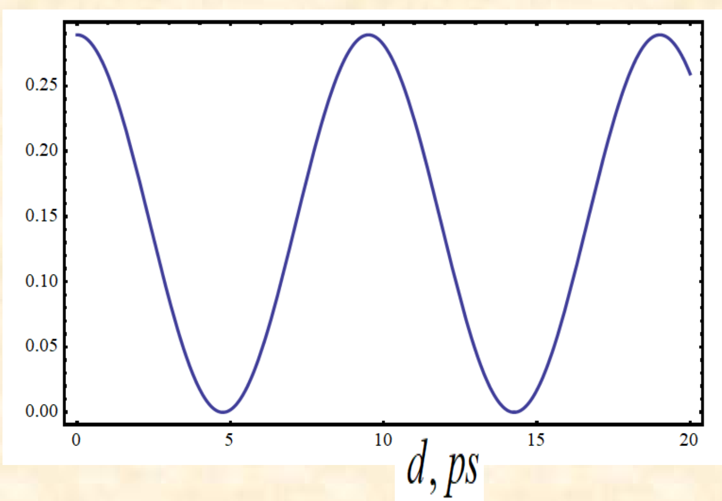
Theoretical estimates



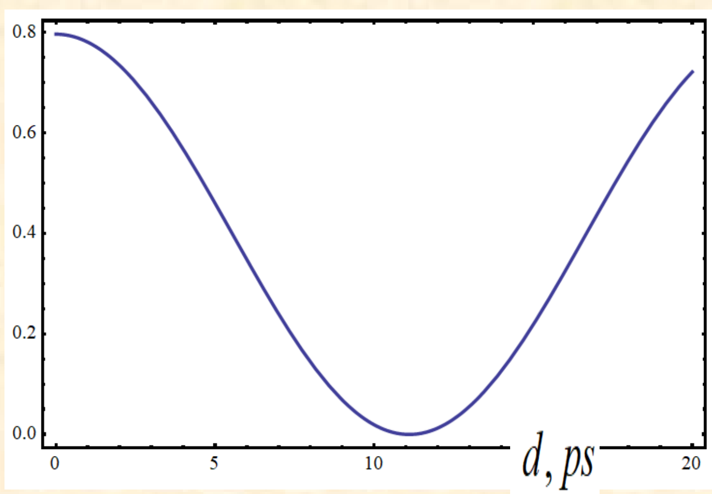
- Since the Areal accelerator allows obtaining two individual electron bunches, it seemed interesting to carry out theoretical calculations of the intensity of the obtained modes depending on the delay between bunches.

- These dependences of intensity on the distance between two bunches are obtained for two different modes.

Mode 4 $\upsilon_4 = 105\,GHz$

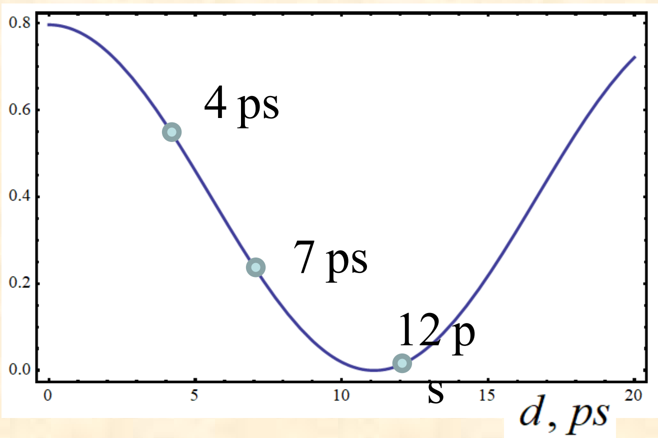


Mode 2 $\upsilon_2 = 45\,GHz$



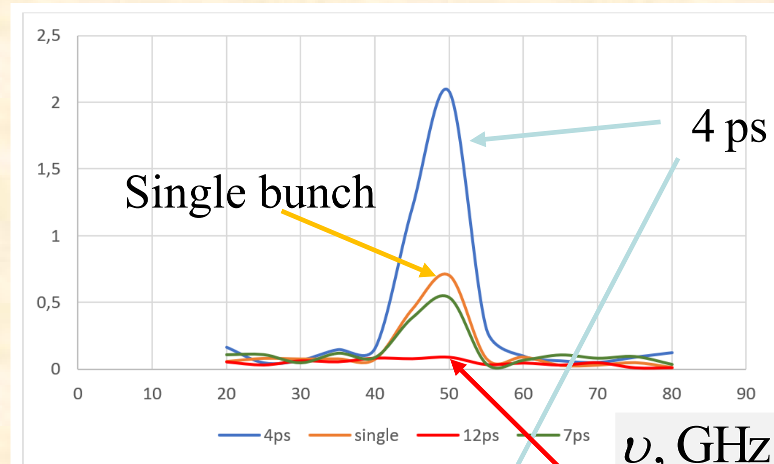
Comparison of theoretical and experimental results

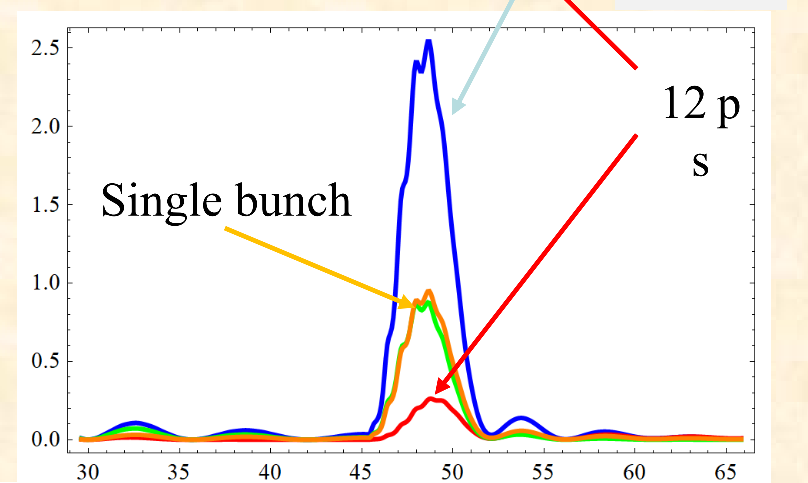
Mode $2\upsilon_2 = 45GHz$



The relative intensity of the mode depending on the distance between two bunches for the frequency of 45 GHz (mode 2).

We can see changes in the radiation intensity (due to interference) of the second mode with a change in the time interval between the beams and the results are in good agreement with theoretical predictions.



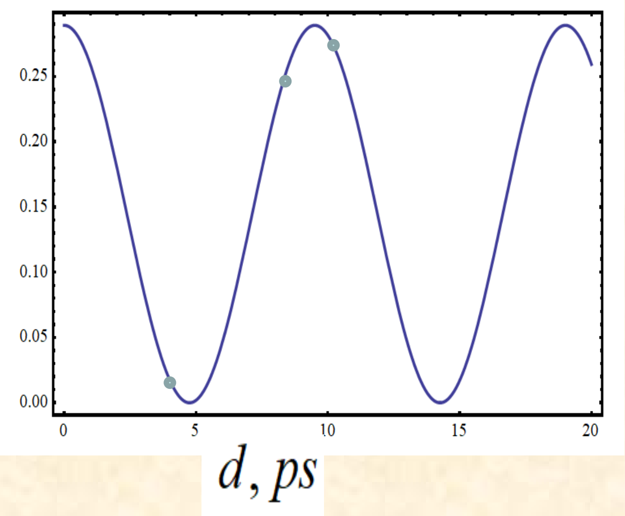


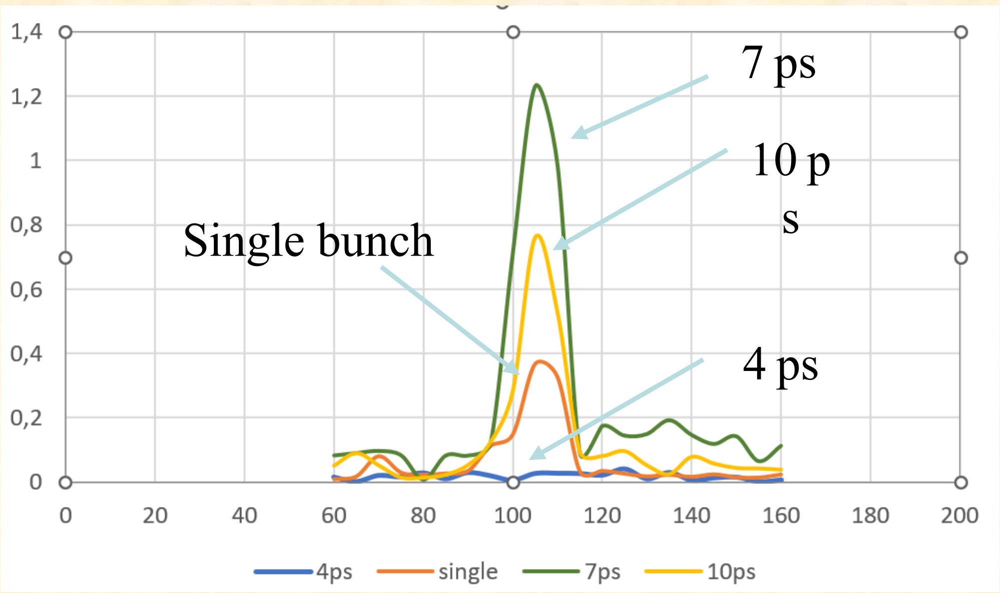
Theoretical calculations results.

Comparison of theoretical and experimental results

We can see changes in the radiation (due to interference) of the second mode with a change in the time interval between the beams.

Mode 4 $\upsilon_4 = 105GHz$





The relative intensity of the 4-th mode depending on the distance between two bunches for the frequency of 105 GHz.

CONCLUSION

We studied the generation of coherent Cherenkov radiation by two electron bunches passing through a cylindrical Teflon resonator, with time intervals up to 12 picoseconds. Our spectral intensity measurements show that, depending on the bunches spacing and the resonator size, quasi-coherent Cherenkov radiation can be produced in the sub-terahertz range. The results are in good agreement with theoretical predictions.

THANK YOU

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