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Observation of Coherent Cherenkov and Transition Radiation at the AREAL Accelerator

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International collaboration

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Outline

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III. Results of experiments

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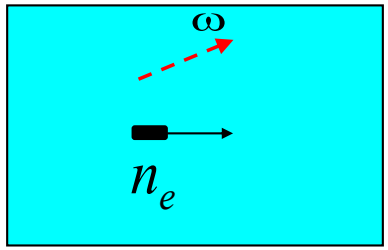
I. Introduction and motivation

Modern accelerators can generate beams of relativistic monoenergetic electrons

- with very small sizes and
- with very large number of electrons $n_e = 10^9$



Radiated energy

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

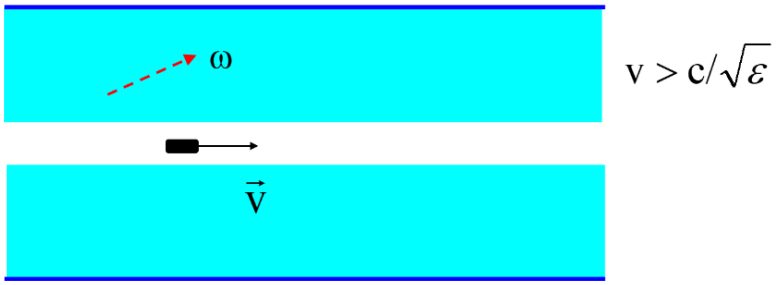
$$I_{Coh}(\omega) \approx n_e^2 I_1(\omega)$$ Quasi coherent radiation

Amplification coefficient

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

I. Introduction and motivation

- The works A.M. Cook et. al., Phys. Rev. Lett. **103** (2009) 095003, G. Andonian et. al., Appl.Phys.Lett. **98** (2011) 202901 reported the direct observation of narrow-band terahertz coherent CR radiated by a subpicosecond electron bunch (or train of bunches) traveling along the axis of a hollow cylindrical dielectric-lined waveguide

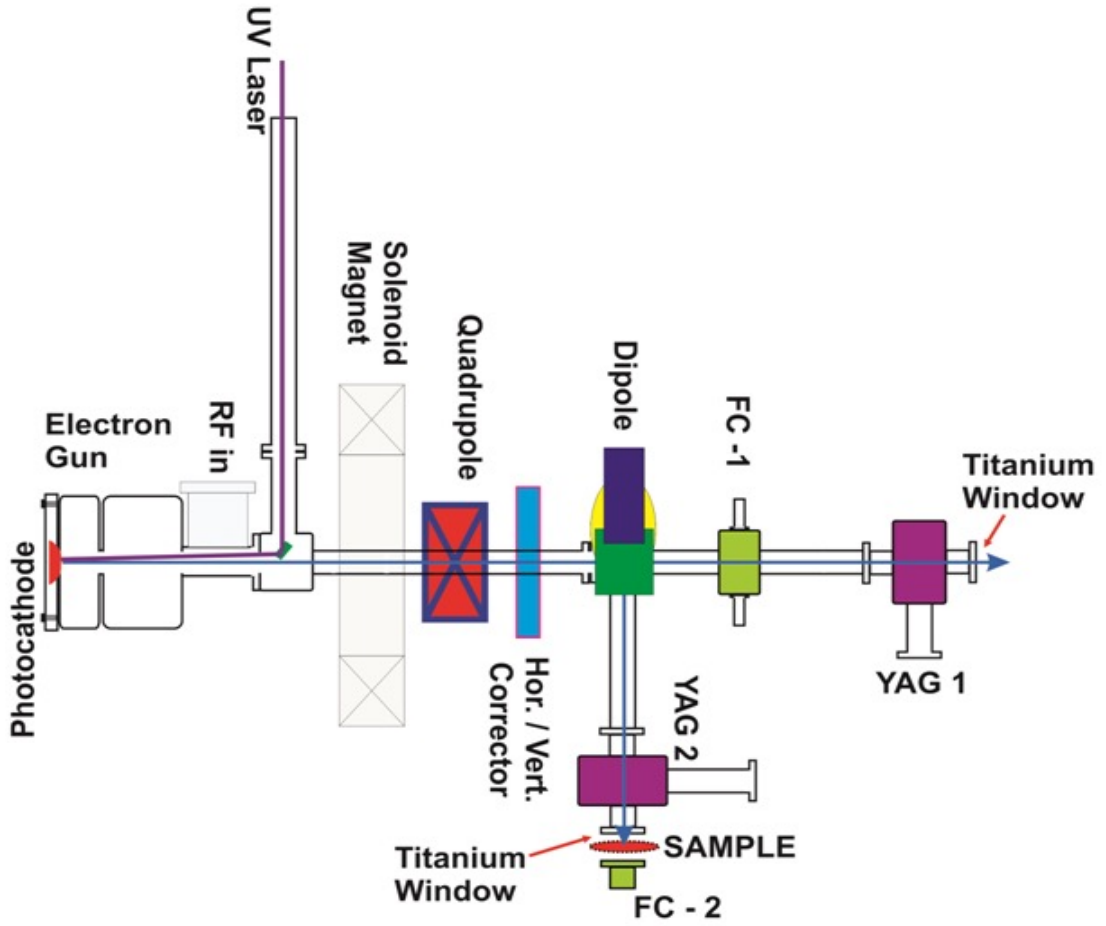


- The radiation was generated on a selected waveguide mode
- Our group has shown that train of electron bunches can generate coherent radiation simultaneously on several waveguide modes
- For the confirmation of that feature experiments have been done on the linear accelerator AREAL of CANDLE scientific centre in Yerevan.

II. Experimental setup

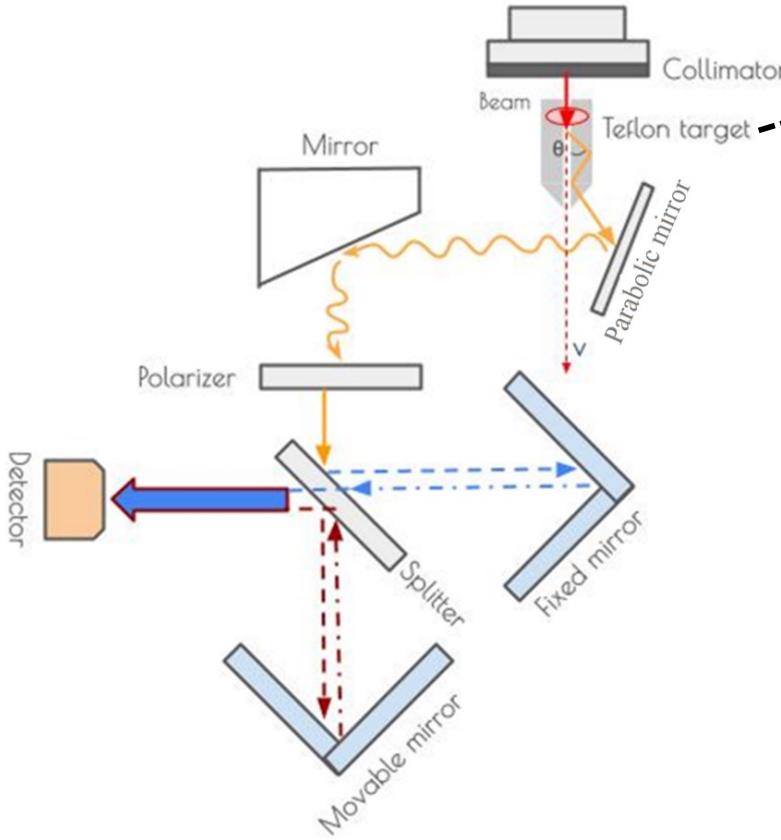
- AREAL-Advanced Research Electron Accelerator Laboratory is an electron linear accelerator facility based on photocathode RF gun.
- The facility is able to provide ultra-short electron bunches with about 0.5 ps bunch length with a particle charge up to 800 pC, and electron energies up to 5 MeV.

Schematic layout of AREAL accelerator facility



Experimental Scheme for CR

For the generation of CR radiation we have used hollow cylindrical target from Teflon



Detectors type ZBD-F for frequency range

1. **33.5 - 50 GHz**
2. **60-90 GHz**
3. **90-140 GHz**

were used.

Parameters of target and electron bunch

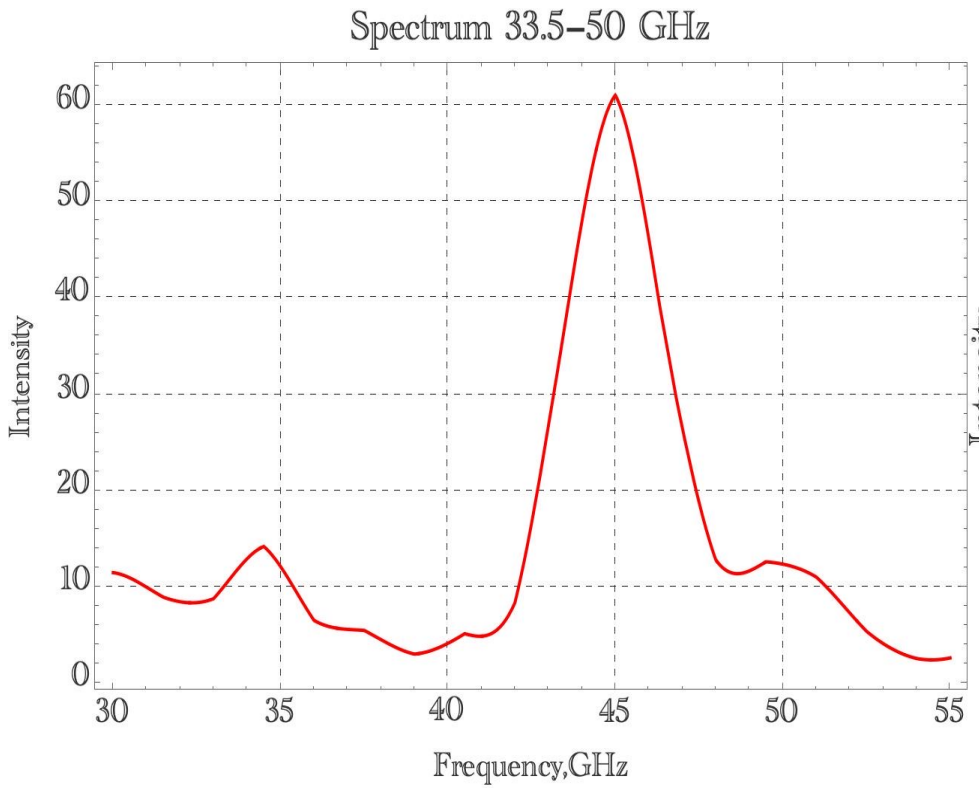
R – 7 mm
r – 2,5 mm;
L – 100 mm

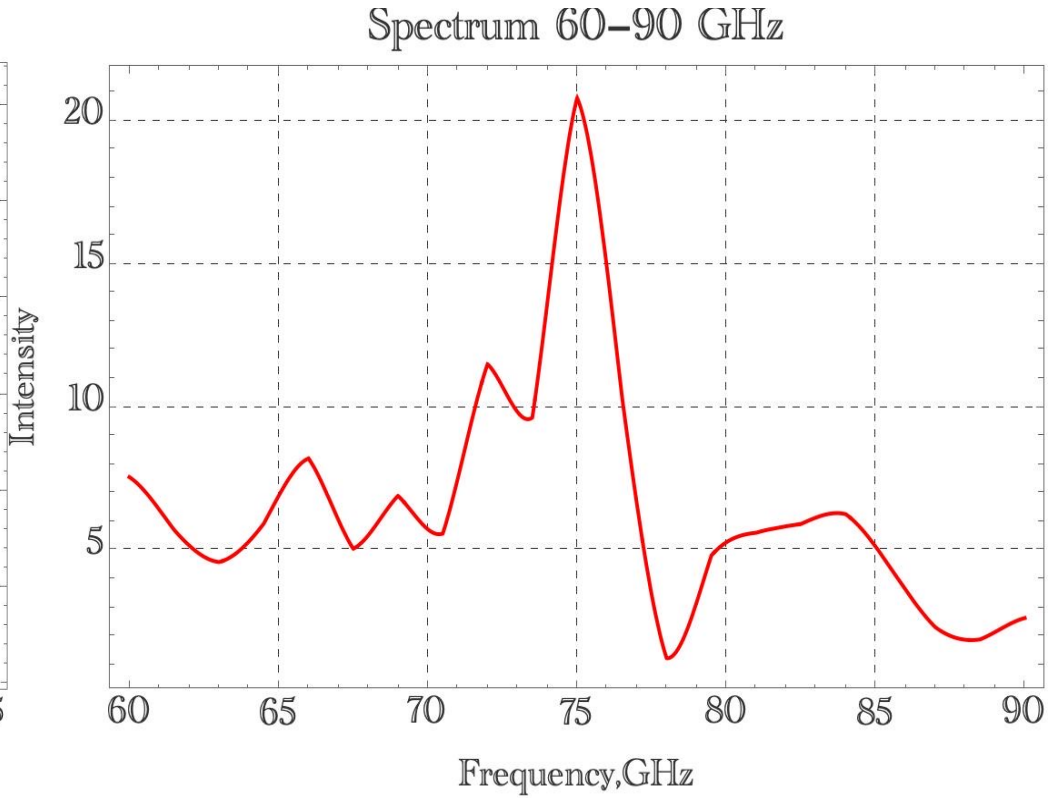
$$\varepsilon \cong 2 \cdot (1 + 10^{-4} i)$$

E – 3,6 MeV
Q ~ 250 pC
Bunch lenght ~ 0.1 mm

Experimental scheme for measurement of radiation frequency dependence

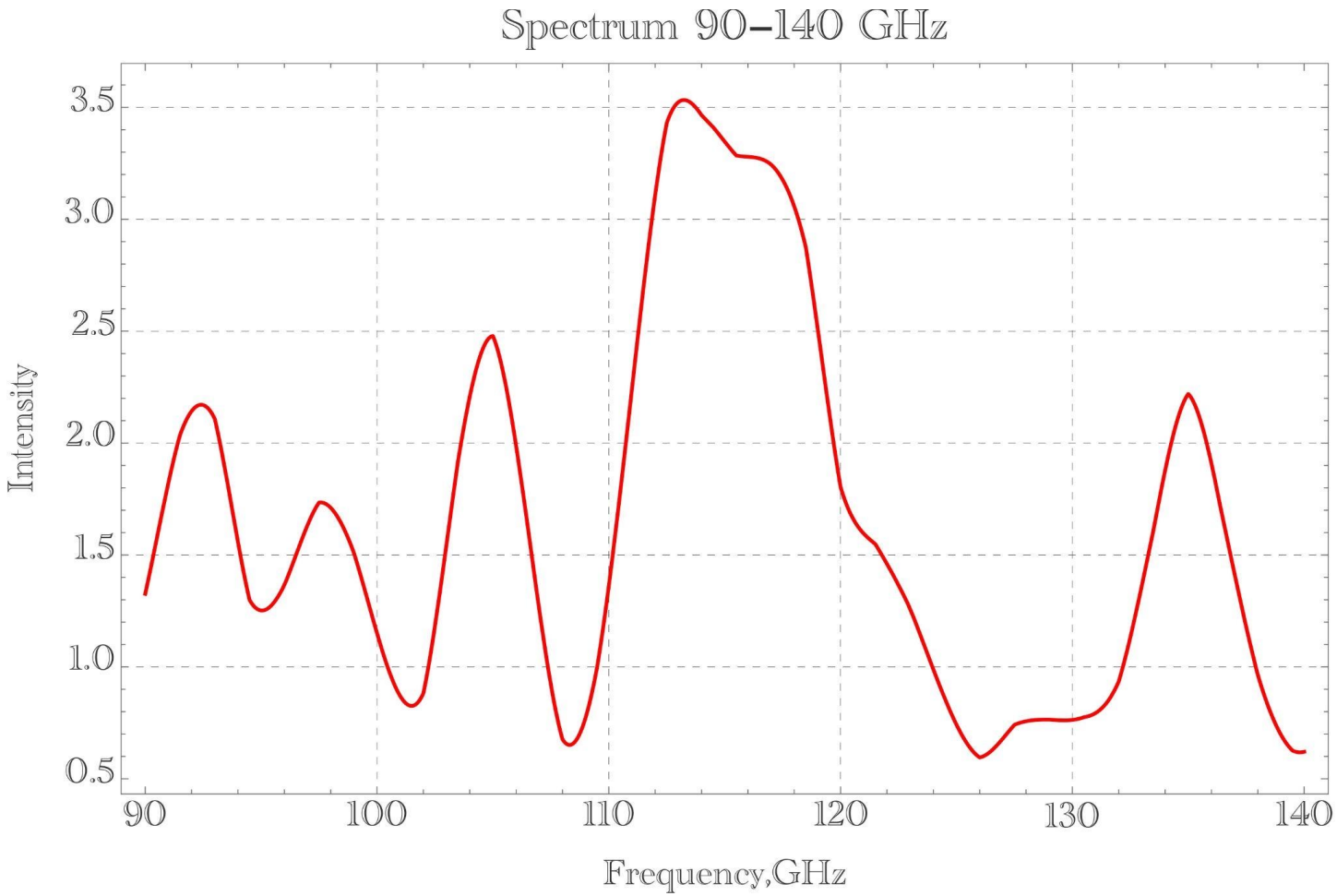
III. Results of experiments





Spectral distribution of the radiation

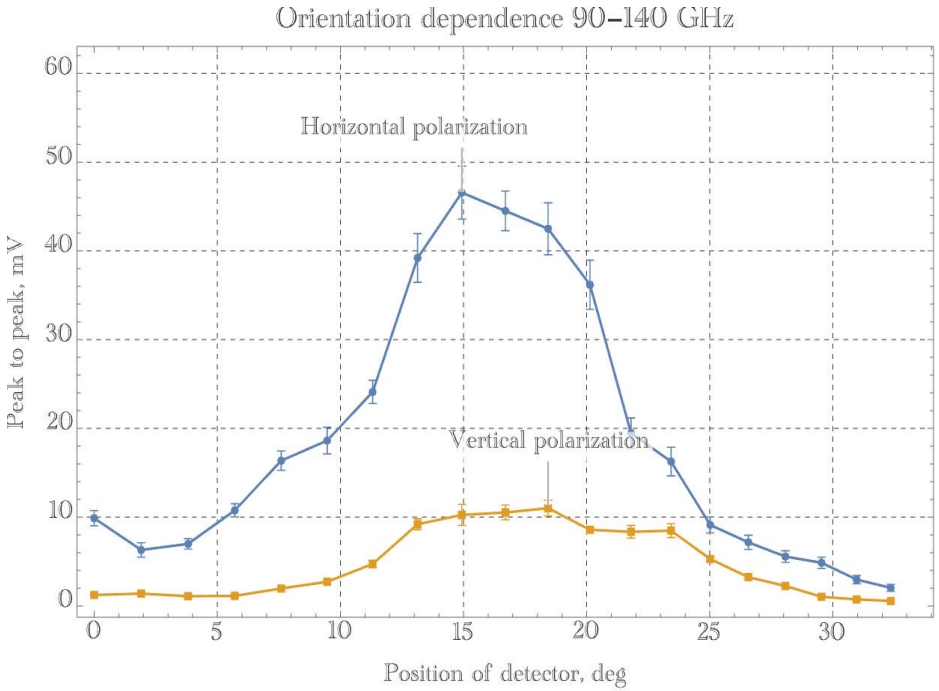
III. Results of experiments

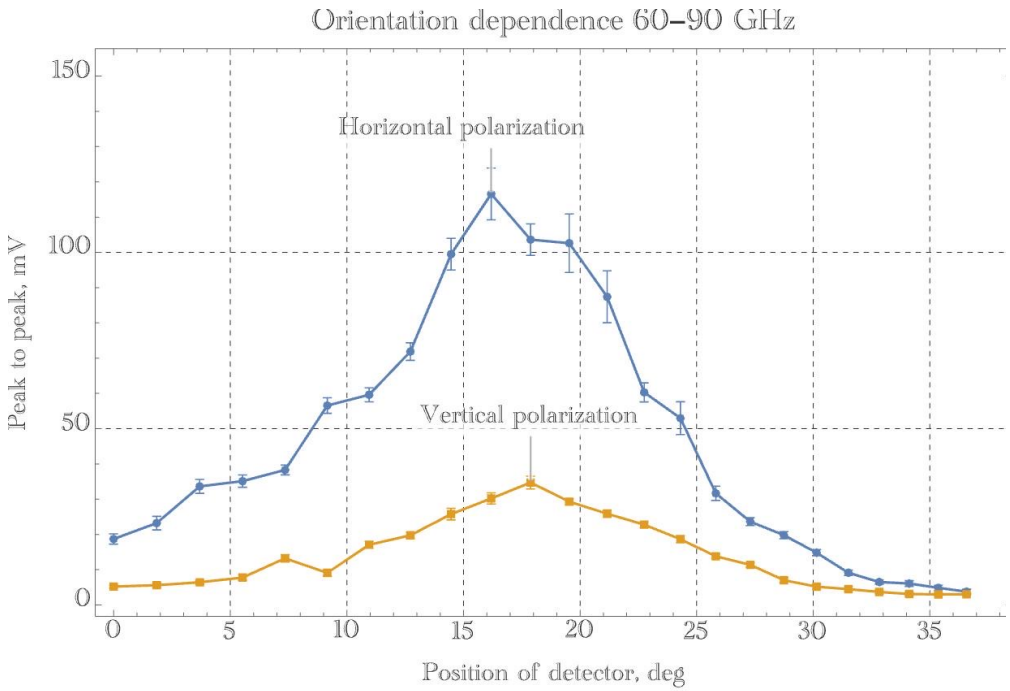


Spectral distribution of the radiation

III. Results of experiments

Polarization of the radiation





III. Results of experiments

Summary of the results of the experiment

- We have registered coherent CR of a picosecond electron bunch at the AREAL accelerator (in the frequency ranges on 30 - 140 GHz) and measured its spectral distribution.

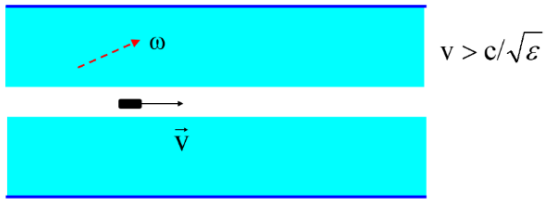
- The obtained results show that there are quasi-periodic picks in the spectral distribution of radiation.

- Polarization measurements confirmed observation of coherent CR with horizontal polarization.

IV. Theoretical estimates

To explain the obtained experimental data, we theoretically examined two simplified cases

The radiation of an electronic bunch traveling along the axis of hollow channel in the infinitely long waveguide filled with a transparent dielectric



Under the condition $v > c/\sqrt{\varepsilon\mu}$ the bunch generated CR at discrete frequencies $\omega_s = 2\pi\upsilon_s$ determined from the following dispersion equation (***B.M. Bolotovskii, Sov. Phys. Usp.* 4, *1962, 781)***

$$k\varepsilon\varphi_0 I_0(kb) = \chi\varphi_1 I_1(kb)$$

where $I_n(x)$ is the modified Bessel function of the first kind of order n, and

$$k = \frac{\omega_s}{v}\sqrt{1 - v^2/c^2},\ \chi = \frac{\omega_s}{v}\sqrt{\varepsilon\mu v^2/c^2 - 1}$$

$$\varphi_0 = J_1(\chi b)N_0(\chi a) - J_0(\chi a)N_1(\chi b),\ \varphi_1 = J_0(\chi b)N_0(\chi a) - J_0(\chi a)N_0(\chi b)$$

$J_n(x)$ and $N_n(x)$ being the Bessel functions of the first and second kind of order n.

IV. Theoretical estimates

The energy of CR emitted per unit time is determined by the sum

$$\sum_{s=1}^{\infty} P(s) = \sum_{s=1}^{\infty} P_1(s)\, F(s)$$

where

$$P_1(s) = 2\frac{q^2\omega_s}{\mathrm{v}}\left(1-\frac{\mathrm{v}^2}{c^2}\right)\frac{\chi\varphi_1 K_1(kb)+k\varepsilon\varphi_0 K_0(kb)}{\mathrm{d}[\chi\varphi_1 I_1(kb)-k\varepsilon\varphi_0 I_0(kb)]/\mathrm{d}\omega_s}$$

is the radiation power from a single electron at the s-th waveguide mode.

$K_n(x)$ is the modified Bessel function of the second kind of the order n.

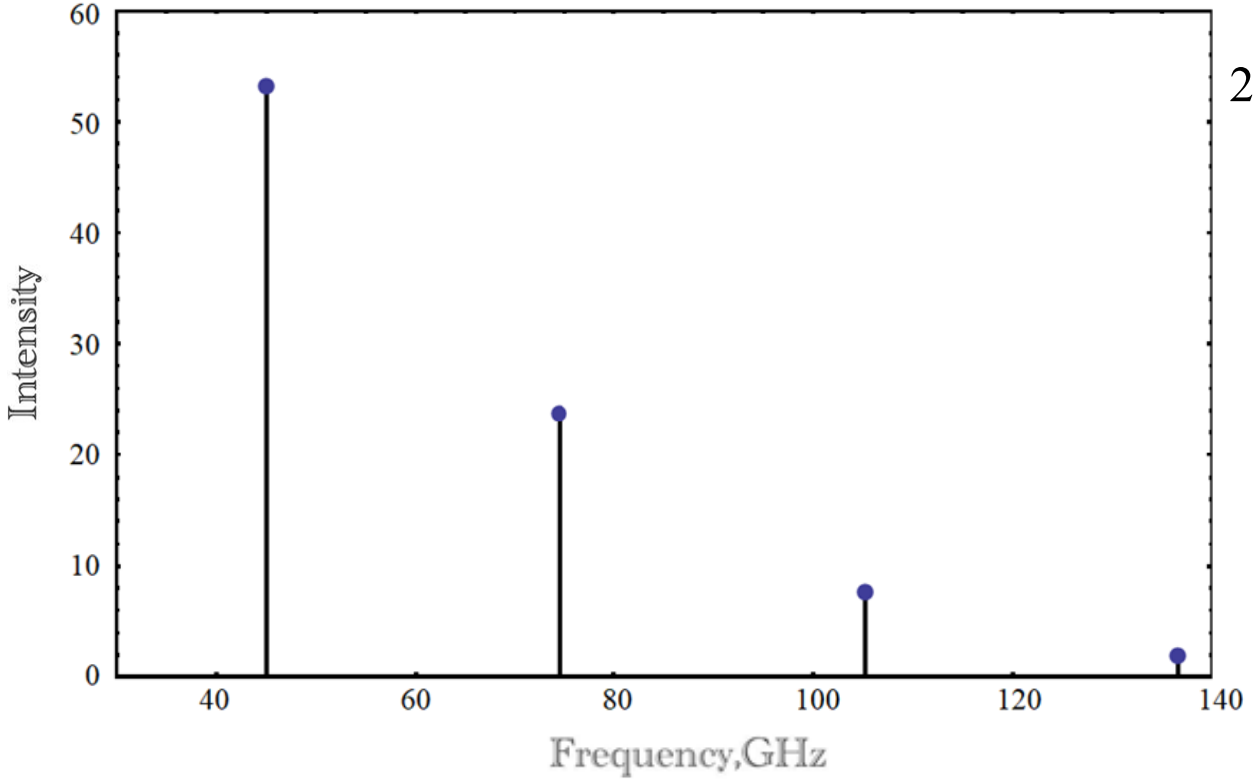
$F(s)$ is the structure factor of the bunch and is given by

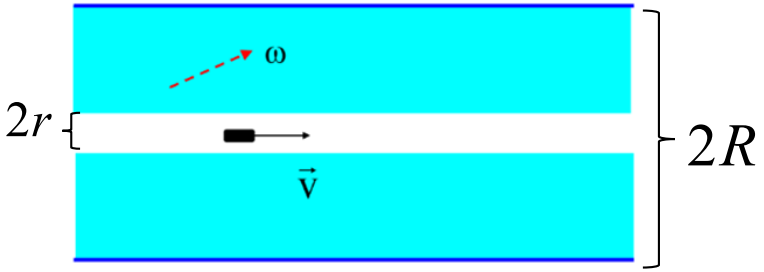
$$F(s) = n_q\left(1-\exp(-\omega_s^2\sigma^2/\mathrm{v}^2)\right) + n_q^2\exp(-\omega_s^2\sigma^2/\mathrm{v}^2)$$

for the Gaussian distribution with standard deviation σ.

IV. Theoretical estimates

In figure below we present the spectral distributions of CR intensity (in arbitrary units) from an electron bunch.





$\varepsilon = 2.06$

$E_e = 3.6 MeV$

$R = 7$ mm

$r = 2.5$ mm

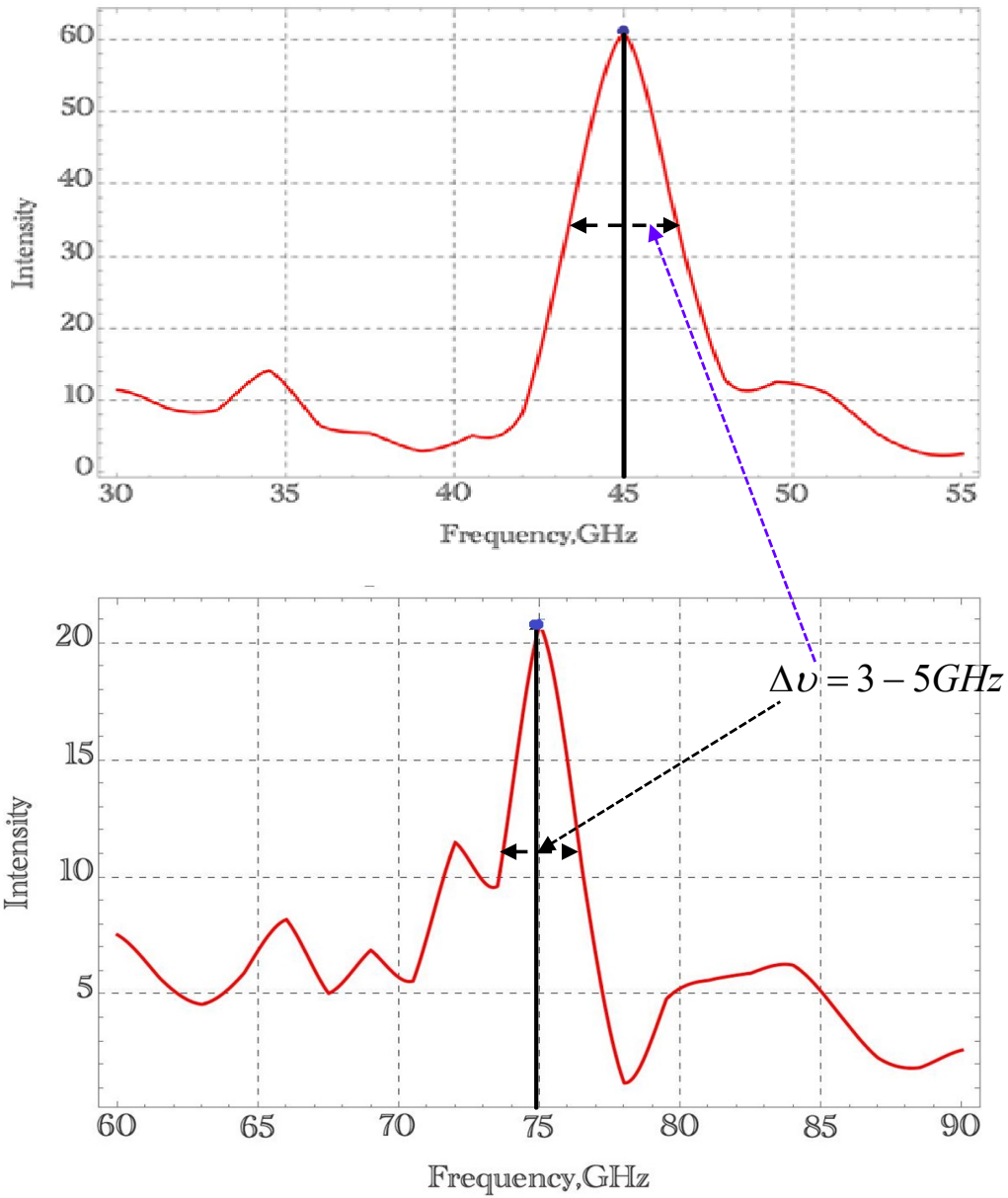
Q =250 pC

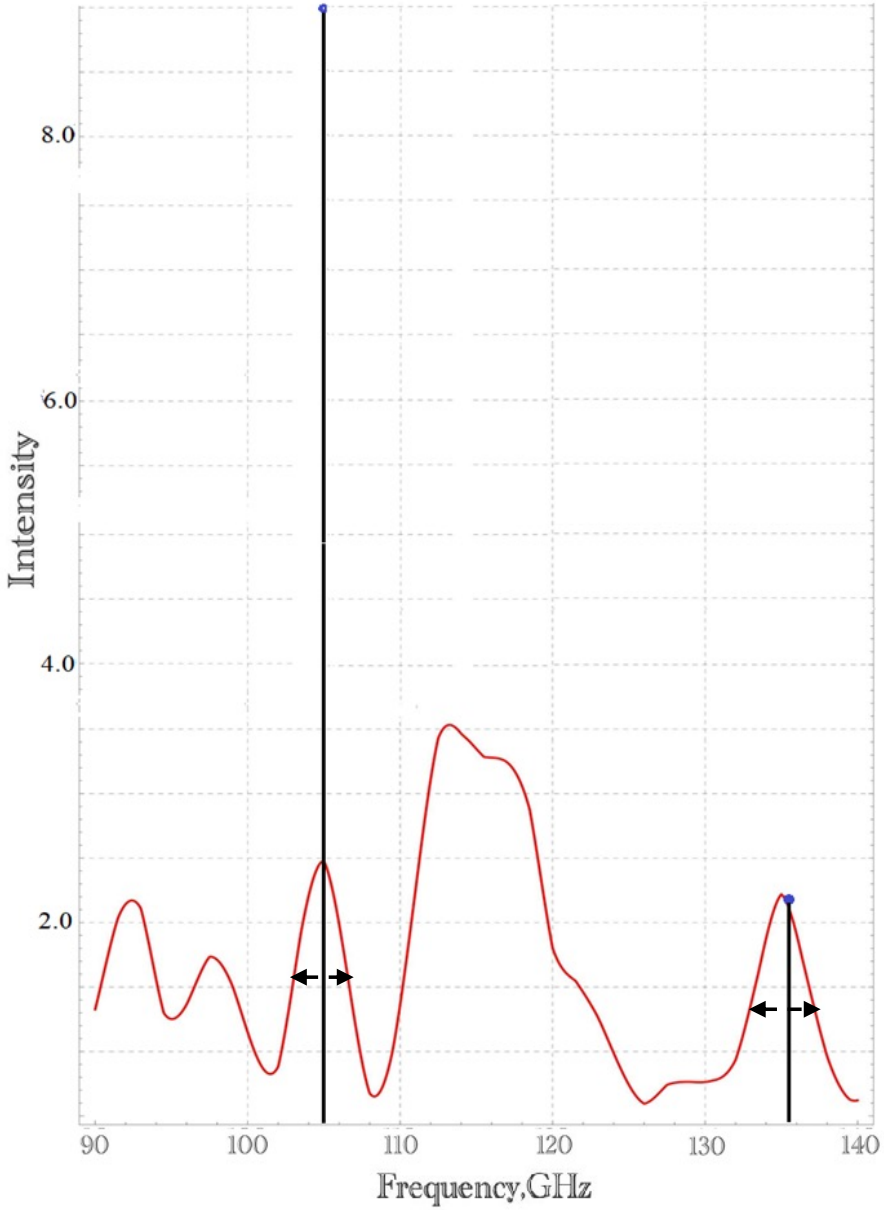
$\sigma = 0.5 mm$

Radiation energy from an electron bunch crossing a dielectric plate in waveguide

Comparison of experimental and theoretical results

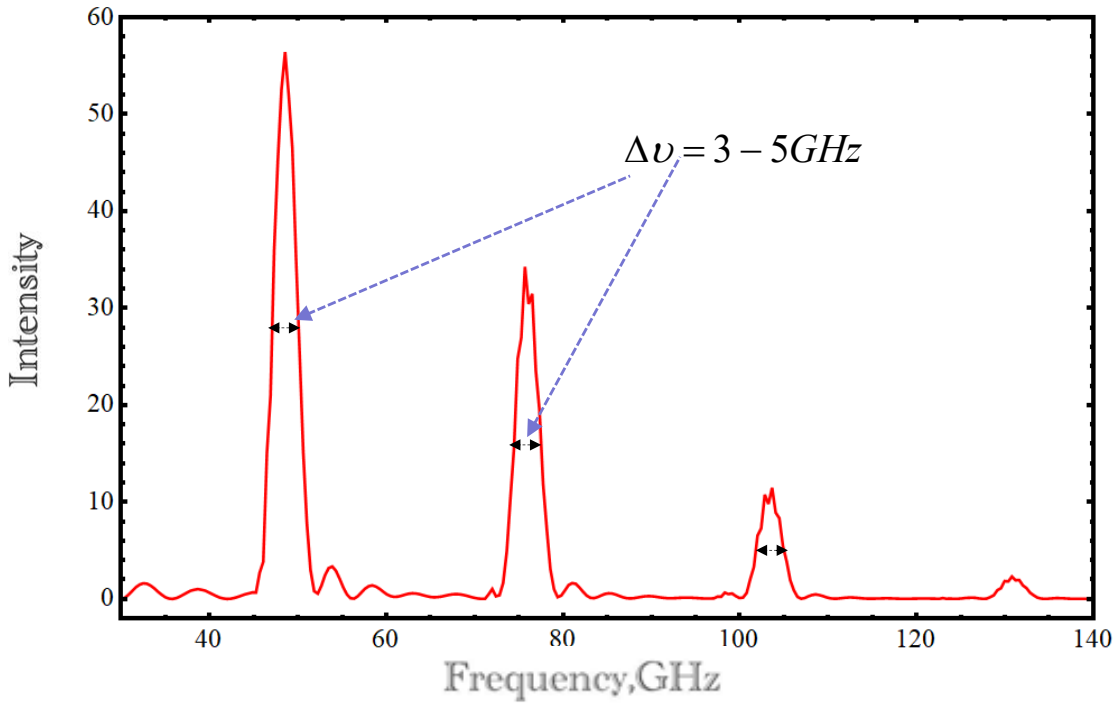
Experimentally obtained picks with high precision corresponds to II, III, IV and V waveguide modes

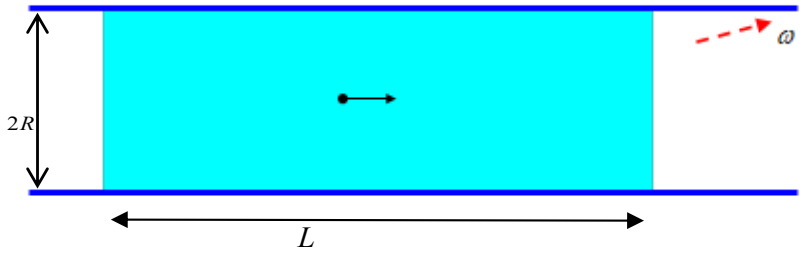




IV. Theoretical estimates

Figure below presents the results of theoretical investigation of spectral distribution of radiation energy of an electron bunch 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*)





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

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

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

Radiation energy from electron crossing a dielectric plate in waveguide

VI. Conclusions and future plans

1) The results of experimental observation of spectral distribution of coherent CR from picosecond electron bunches traveling along the axis of a hollow cylindrical target are presented.

2) Polarization measurements confirmed observation of coherent CR with horizontal polarization.

3) The obtained results were compared with theoretical estimates.

4) We plan experimentally study the coherent radiation from a **train** of electron bunches simultaneously on several waveguide modes.

5) Obtained results can be used for development of intense sources of radiation in GHz-THz frequency ranges, as well as for particle beam diagnostics.

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[1] B.M. Bolotovskii, Theory of the Vavilov-Cherenkov effect (III), Sov. Phys. Usp. 4 (1962) 781.

[2] A.M. Cook, R. Tikhoplav, S.Y. Tochitsky, G. Travish, O.B. Williams, J.B. Rosenzweig, Phys. Rev. Lett. **103** (2009) 095003.

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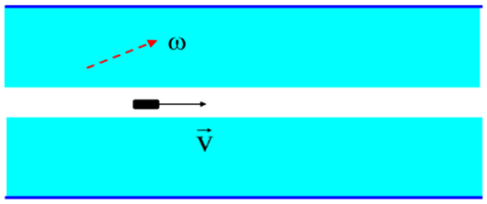
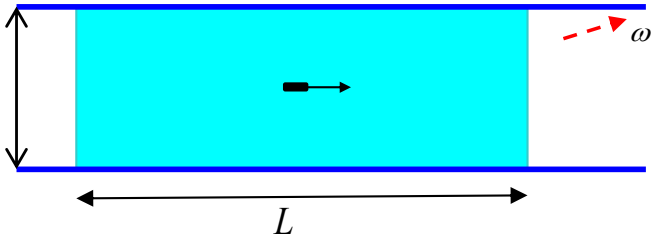
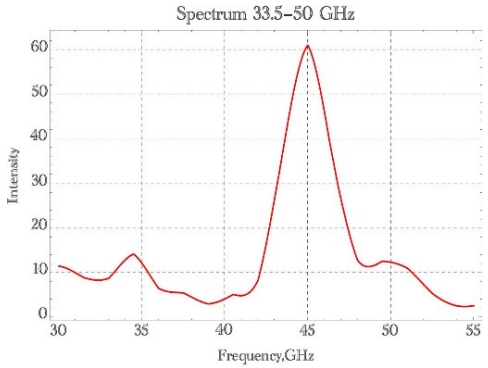
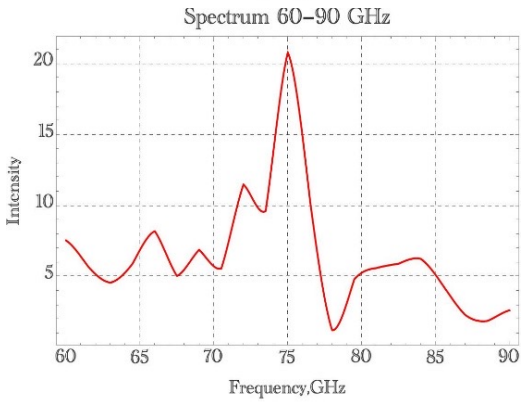
[5] L.Sh Grigoryan, A.R. Mkrtchyan, H.F. Khachatryan, S.R. Arzumanyan, W. Wagner, J. Phys.: Conf. Ser. **357** (2012) 012004.

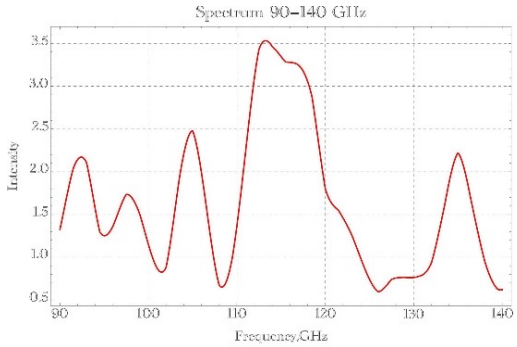
[6] A.R. Mkrtchyan, L.S. Grigoryan, A.A. Saharian, A.H. Mkrtchyan, H.F. Khachatryan, V.K. Kotanjyan, JINST **15** (2020) C06019.

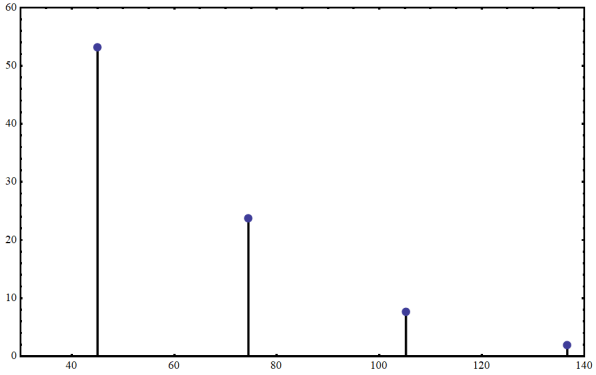


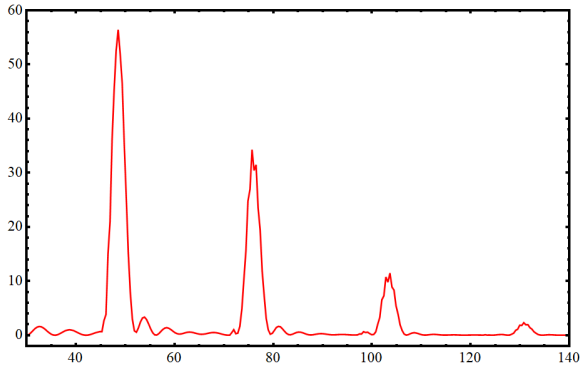












Thank you for attention

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Experimental Scheme and Photo