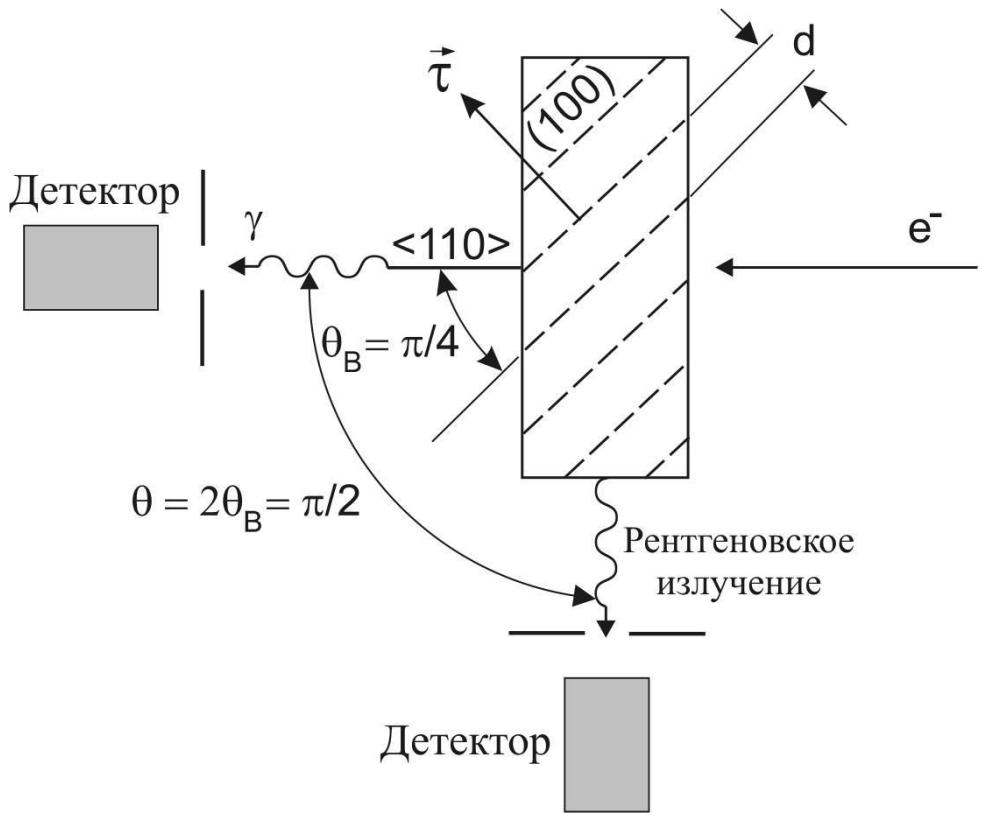
Development of the generators of the radiation in the wide spectrum range from mm, THz to optical and X-ray wavelengths on the basis of Volume Free Electron lasers for Fundamental and Applied Linear Accelerator Physics collaboration (FLAP, JINR)

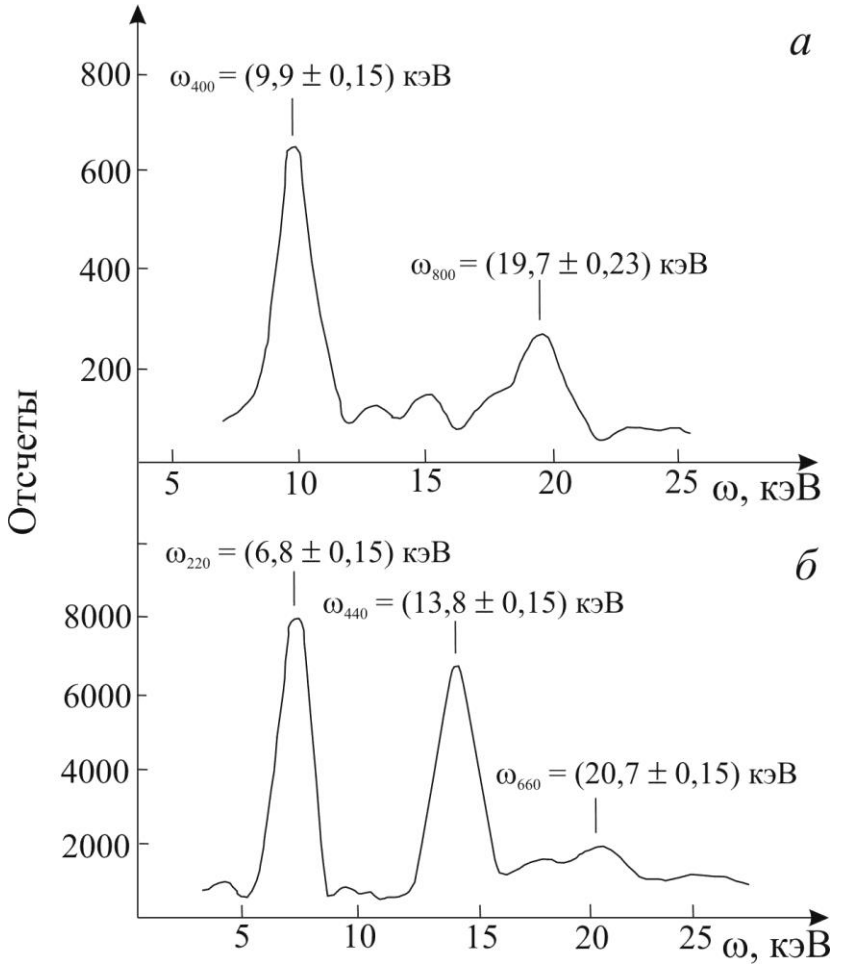
V.G. Baryshevsky

Institute for Nuclear Problems, Belarusian State University

Minsk 2023

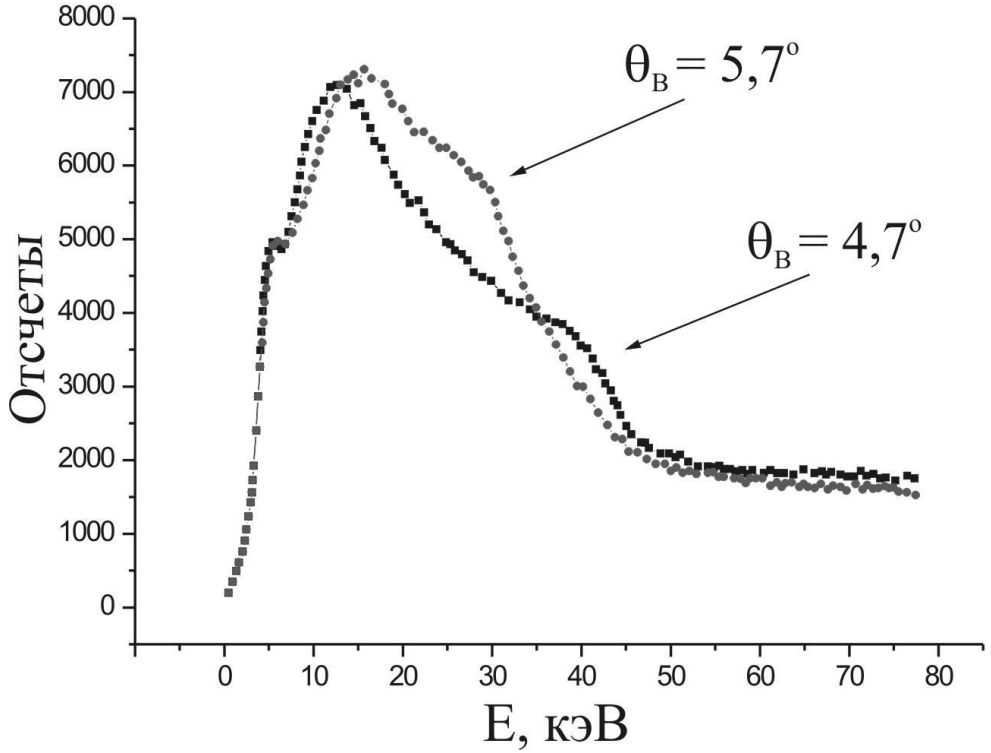
First experimental observations of PXR

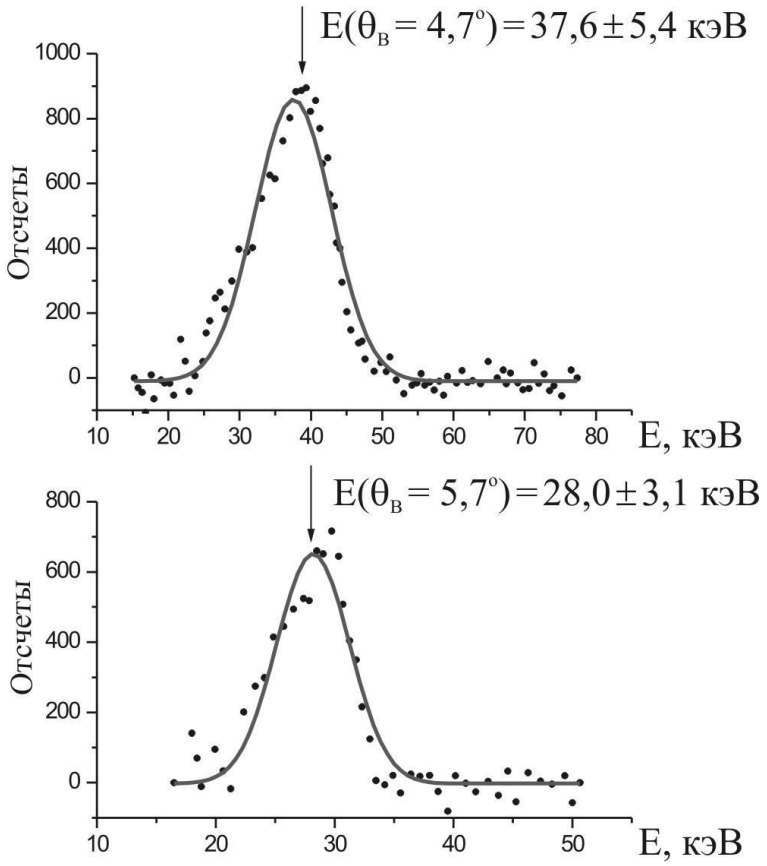




Yu.N. Adischev,V.G.Baryshevsky et al. // Sov. JETP. Lett. 41 (1985) 295;
V.G. Baryshevsky et al. // Phys. Lett. A 110 (1985) 477

PXR from 70 GeV protons

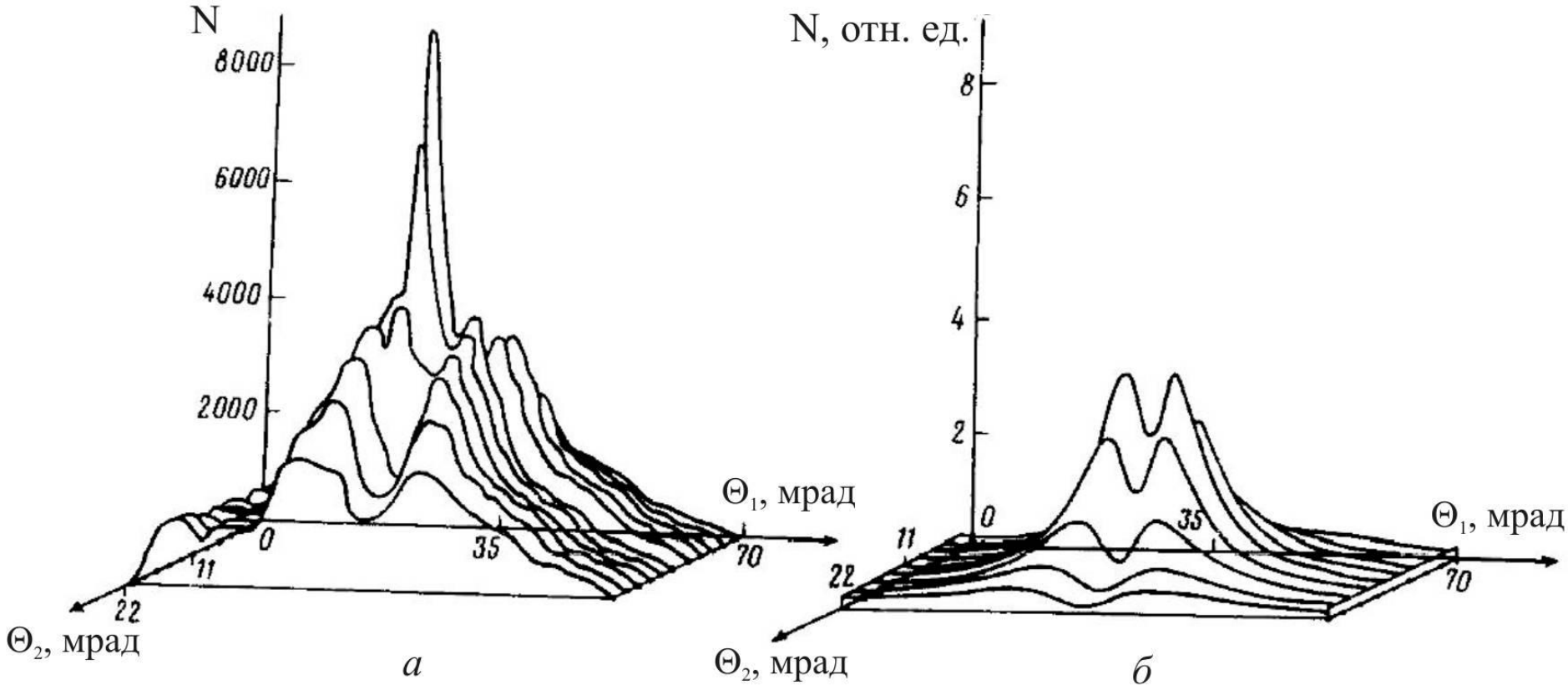




Sov. JETP Lett. 54 (1991) 493–495; Phys. Lett. A. 170 (1992) 315–318.

Recent experiment: Yu.N. Adischev et al // NIM B 252 (2006) 111–117.

Angular distribution for (400) reflex



a – experimental multi-wave distribution
b – theoretical two-wave distribution

Sov. JETP. Lett. 51 (1990) 213–215; Proc. SPIE 5974 (2005) R1–R8

New law of beam instability

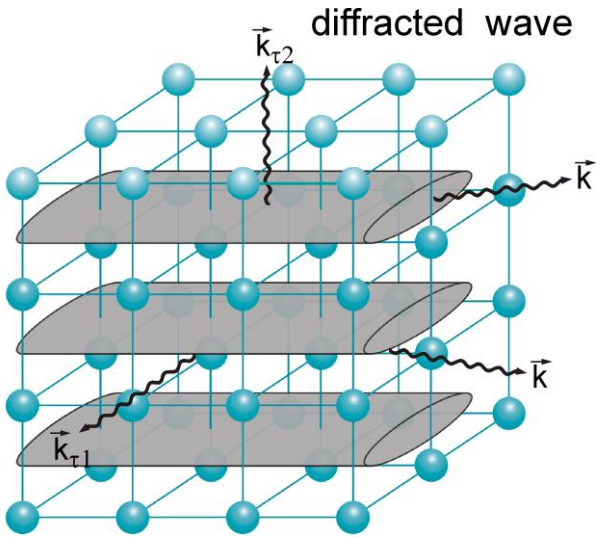
Dynamical Bragg diffraction in a periodic medium (crystal) evokes the peculiar conditions, that result in a new law of an electron beam instability:

$\sqrt[3+s]{\rho}$ (compare with $\sqrt[3]{\rho}$ for conventional systems)

here s is the number of surplus waves appearing due to diffraction (for example, in case of two-wave diffraction s=1, for three-wave diffraction s=2, etc).

Within these peculiar conditions the electron beam interacts with the electromagnetic wave more effectively yielding to drastic reduction of generation threshold :

$j_{thr} \sim L^{-(3+2s)}$ (for conventional systems $j_{thr} \sim L^{-3}$)



V.G.Baryshevsky, I.D.Feranchuk, Phys. Lett. 102 A, 141 (1984)

High Power Microwave Systems :3rd class

Volume Free Electron Laser (VFEL)

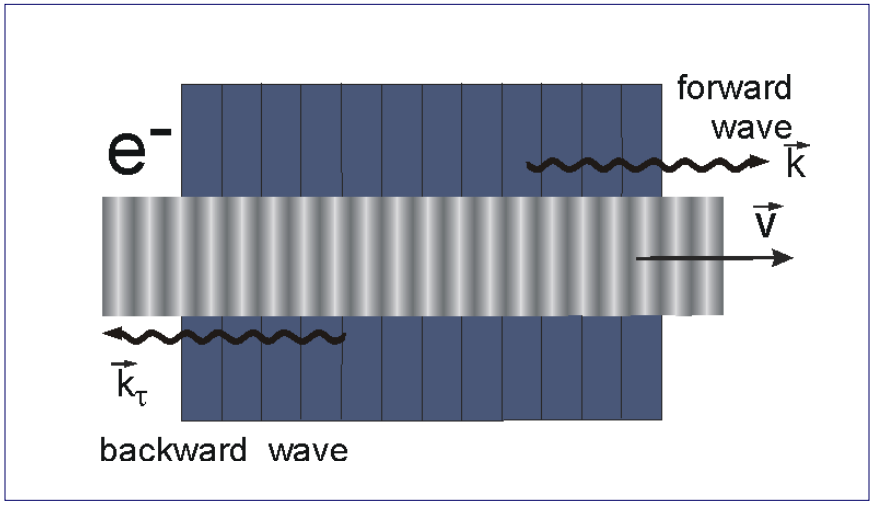
The law was demonstrated to be valid not only for parametric radiation but for any type of spontaneous radiation (magnetic bremsstrahlung in undulator, radiation in laser wave, Smith-Purcell, diffraction or Cherenkov radiation and so on) from a charged particle moving either in a periodic medium or close to its surface.

V.G.Baryshevsky, Doklady Akademy of Science USSR 299 (1988) 6.
V.G.Baryshevsky, NIM 445A (2000), II-281.
V.G.Baryshevsky, Spontaneous and induced radiation by electrons/positrons in natural and photonic crystals. Volume free electron lasers (VFELs): From microwave and optical to X-ray range. Nuclear Instruments and Methods in Physics Research B 355 (2015) 17–23

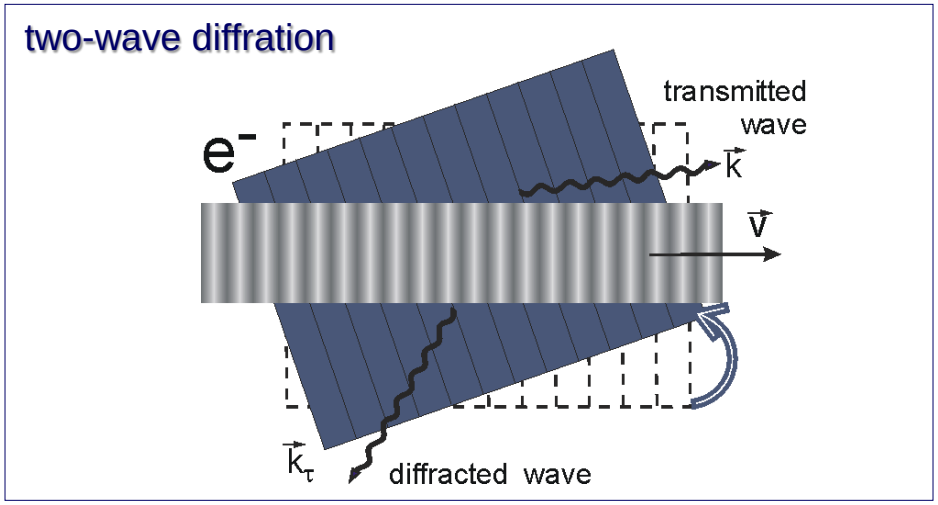
Surface and volume distributed feedback

Volume (non-one-dimensional) multi-wave distributed feedback is the distinctive feature of Volume Free Electron Laser (VFEL)

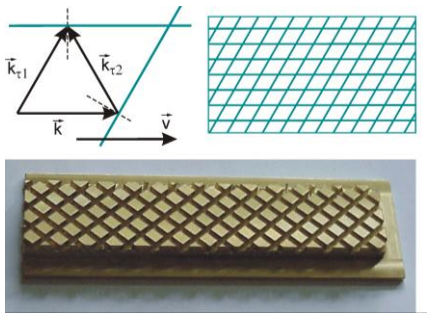
one-dimensional distributed feedback



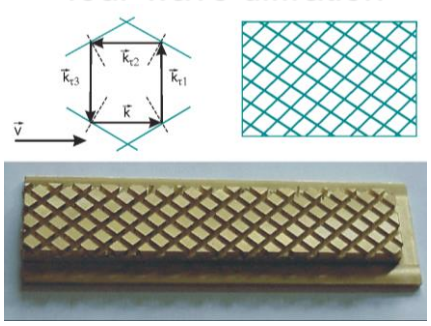
two-dimensional distributed feedback



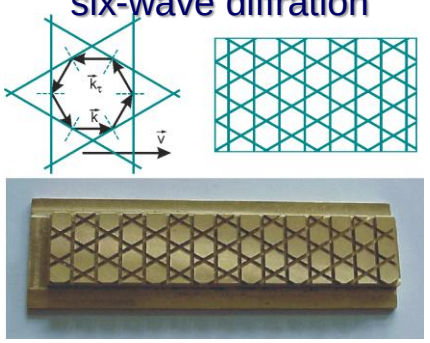
three-wave diffration



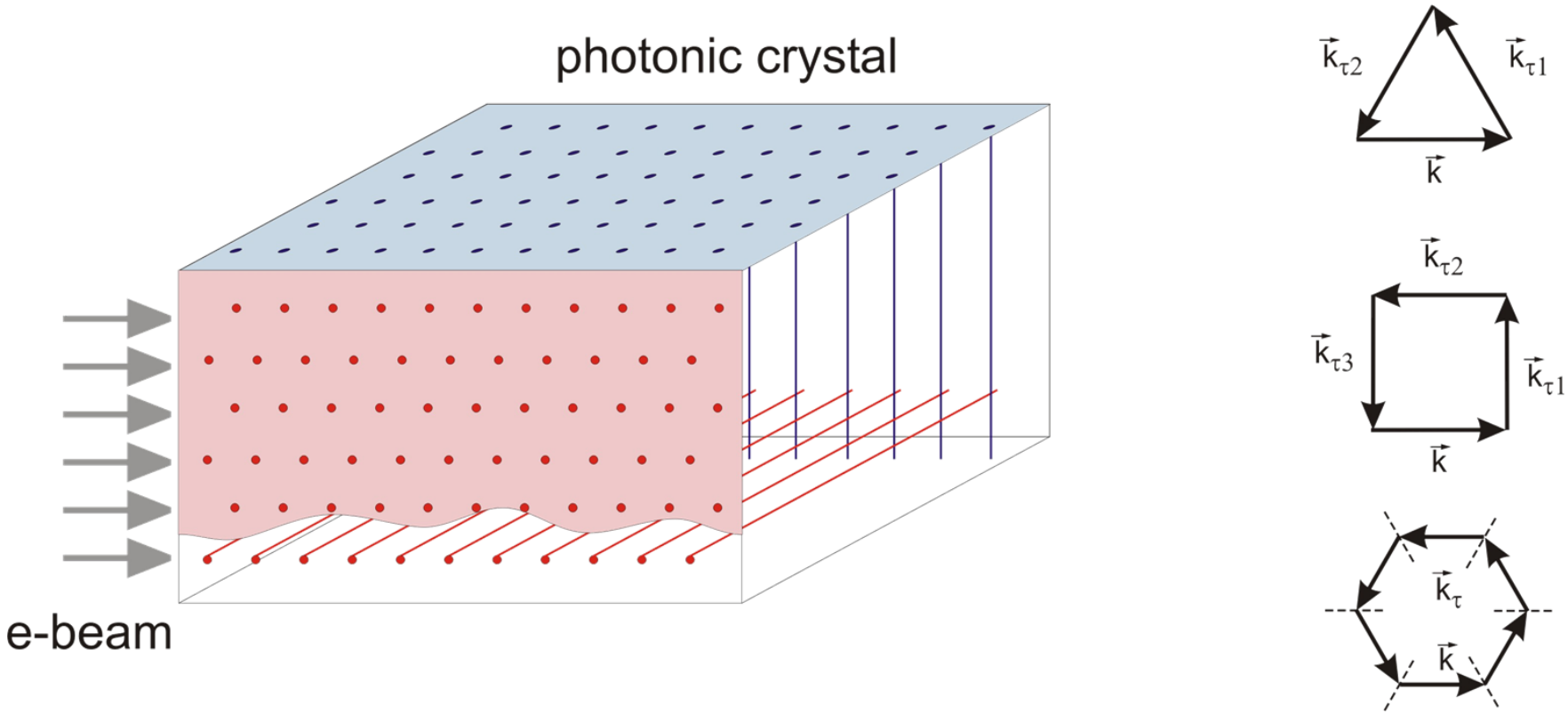
four-wave diffration



six-wave diffration



Photonic crystal providing multi-wave distributed feedback

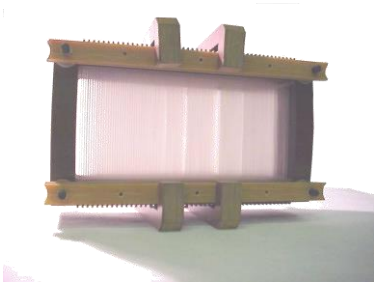


Threads are arranged to couple several waves (three, four, six …), which appear due to diffraction in such a structure, in both vertical and horizontal planes. The electron beam takes the whole volume of photonic crystal.

VFEL experimental history

1996

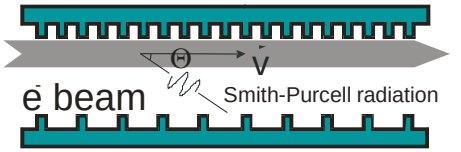
Experimental modeling of electrodynamic processes in the volume diffraction grating (photonic crystal) made from dielectric threads (Q-factor ~ 10^5)



V.G.Baryshevsky, K.G.Batrakov, I.Ya. Dubovskaya, V.A.Karpovich, V.M.Rodionova, *NIM 393A (1997) II-75*

2001

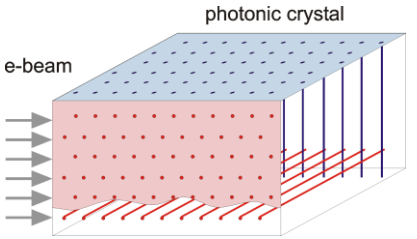
First lasing of volume free electron laser in mm-wavelength range. Demonstration of validity of VFEL principles and possibility for frequency tuning at constant electron energy



V.G.Baryshevsky et. al, *NIM 483A (2002) 21*

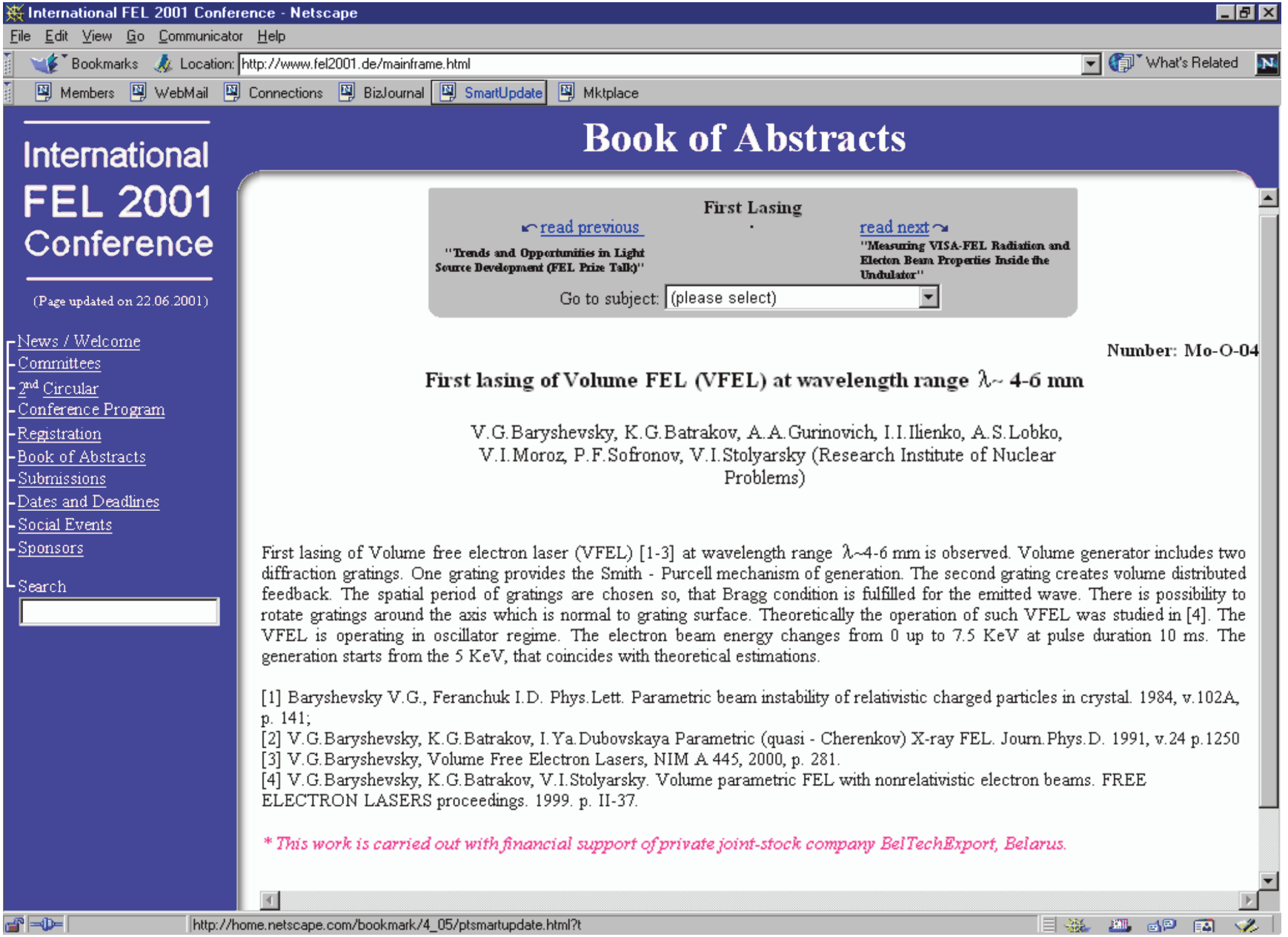
2004

VFEL prototype with volume photonic crystal made from metallic threads



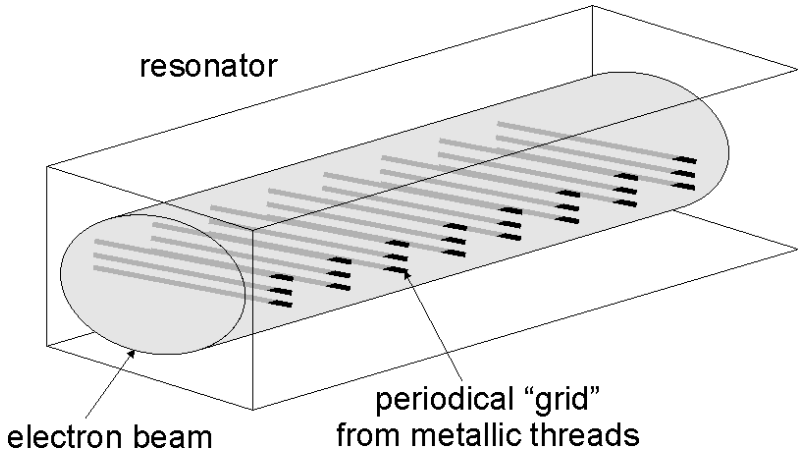
V.G.Baryshevsky, A.A.Gurinovich, *NIM 252B (2006) 91*
V.G.Baryshevsky, *Proc. of the 28th Intern. Free Electron Laser Conference FEL2006 (2006) 331*

International FEL Conference 2001 (Germany)



Electrodynamical properties of a "grid" photonic crystal *

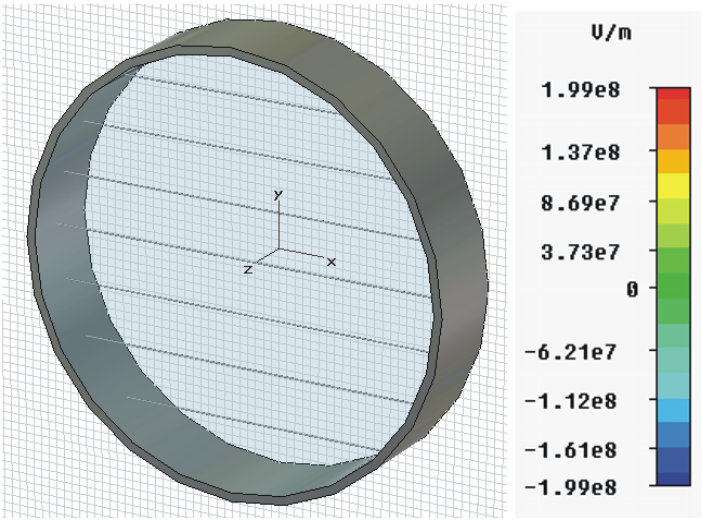
Theoretical analysis* showed that periodic metal grid does not absorb electromagnetic radiation and the "grid" photonic crystal, made of metal threads, is almost transparent for the electro-magnetic waves in the frequency range from GHz to THz.

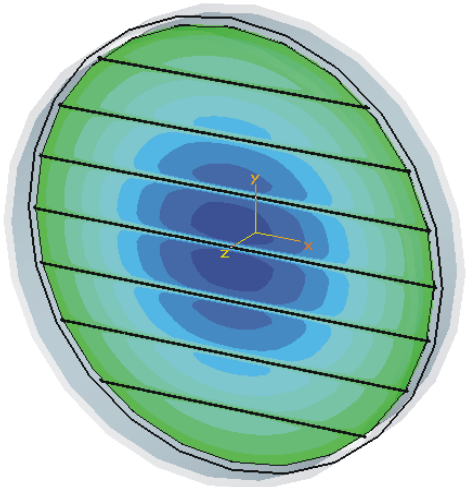


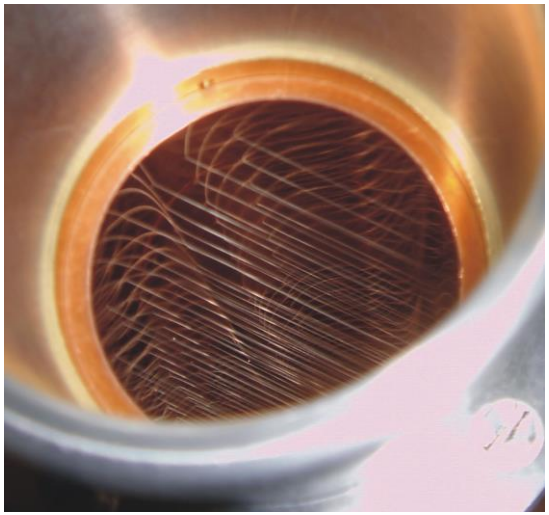
* Baryshevsky V.G., Gurinovich A.A. Spontaneous and induced parametric and Smith–Purcell radiation from electrons moving in a photonic crystal built from the metallic threads // Nucl. Instr. Meth. B. Vol.252. (2006) P. 92-101, physics/0409107

Photonic crystal made from tungsten threads

- a layer of 7 tungsten threads of 100 μm diameter distant 6.25mm
- two crystals with the periods d_1=12.5mm and d_2=10.5mm
- a circular waveguide with the inner diameter 50 mm
- up to 15 periods in the photonic crystal in different experiments



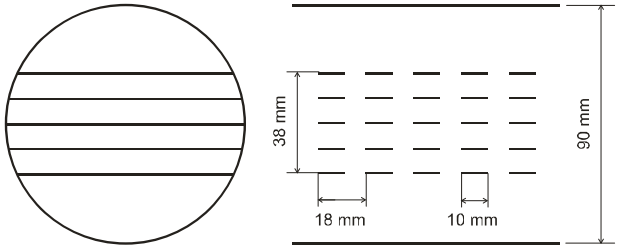


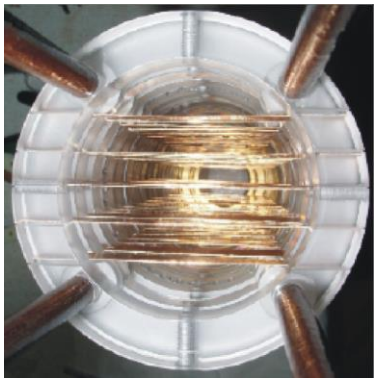


V. G. Baryshevsky et. al., Proceedings of 35th International Conference on Infrared, Milimeter and Terahertz waves (2010) IRMMW-THz2010

Foil photonic crystal

electron energy, keV	100	150	200	250
lasing frequency, GHz	1.68	1.68	1.68	1.68
	1.73	1.73	1.73	1.73
	1.92	1.93	1.94	1.94
	4.99	5.00	5.00	5.03
	5.13	5.13	5.13	5.13
	5.61	5.57	5.57	5.57
	6.12	6.66	7.03	7.29
	6.70	7.24	7.60	7.83
	6.99	7.55	7.90	8.11







- brass foils of 100 μm thickness and 10 mm width
- 5-foils layers with 18 mm period inside the drift tunnel

- the pencil-like electron beam has diameter about 40 mm

V. G. Baryshevsky, et al. Proc. of the 32st Intern. Free Electron Laser Conference FEL2010, THPB18.

“Grid” VFEL with variable period: experiment

V. G. Baryshevsky et. al., Proc. of the 31st Intern. Free Electron Laser Conference FEL2009 (2009) MOPC49

V. G. Baryshevsky et. al., Proceedings of 35th International Conference on Infrared, Milimeter and Terahertz waves IRMMW-THz2010

