Influence of lower frequency branch on the performance of a waveguided THz FEL

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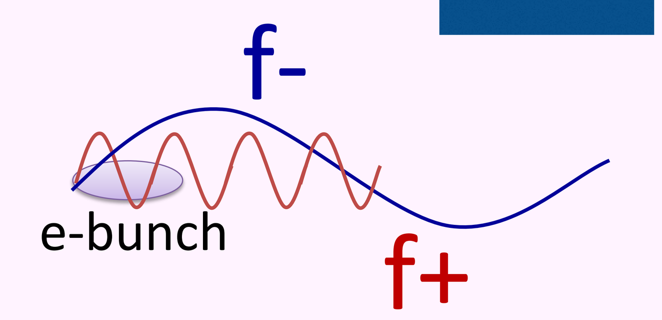

Introduction

THz FELs usually operate as oscillators and employ a waveguide to suppress diffraction losses. When a waveguide covers only a part of the optical cavity, substantial drops of the output power at certain wavelengths (spectral caps) are observed [1].

The THz FEL FLARE operating in the wavelength range of **0.1 - 1.5 mm (0.2 - 2.0 THz)** comprises a waveguide which covers the whole optical cavity length. Surprisingly, the scanning problem of FLARE is even more severe.

In this work we perform numerical simulations to get insight on the possible reasons of the observed spectral gaps. The simulation includes **lower frequency branch** established by the waveguide, as well as **interaction between neighboring electron bunches/optical pulses**.

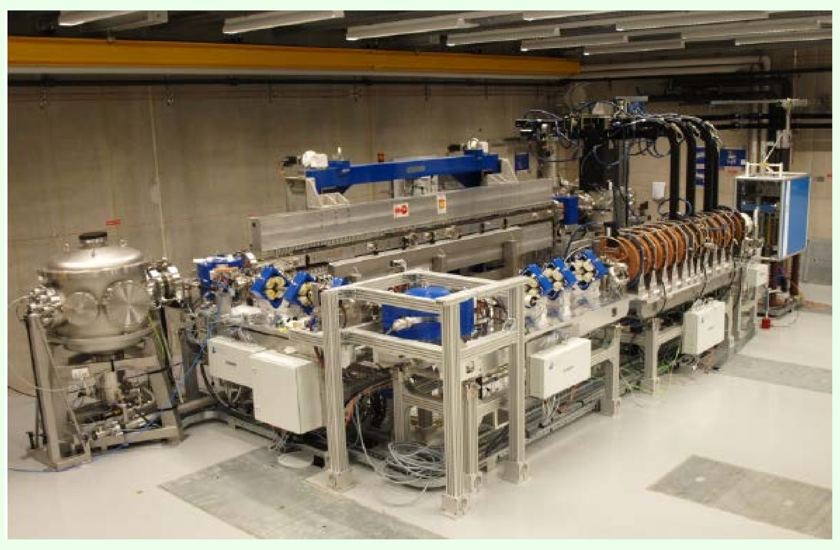

Fig. 1. Free-electron Laser for Advanced spectroscopy and high-Resolution Experiments (FLARE)

Methods

The FEL dynamics is simulated with a code based on a model similar to that reported in Refs. 2–3. Since this computational model does not employ any averaging over a ponderomotive or resonant wavelength, it enables simulation of the full FEL dynamics in the situation that the electron bunch length is comparable to the resonant wavelength, which is the case for FLARE.

The details of FLARE setup used for simulations are presented in Table 1. Previous study on mode dynamics [3] showed that mainly E^{π}_{01} Hermite-Gaussian mode is amplified in FLARE, so we use it for analysis to reduce the computational time. Also, the group velocity of lower frequency branch f- is lower then the velocity of electrons. We account this fact, as well as simultaneous propagation of 150 electron bunches by reducing the effective length of the cavity for f- branch. This approach is valid because long pulses of f- branch anyway overlap with subsequent electron bunches on the next cavity roundtrip.

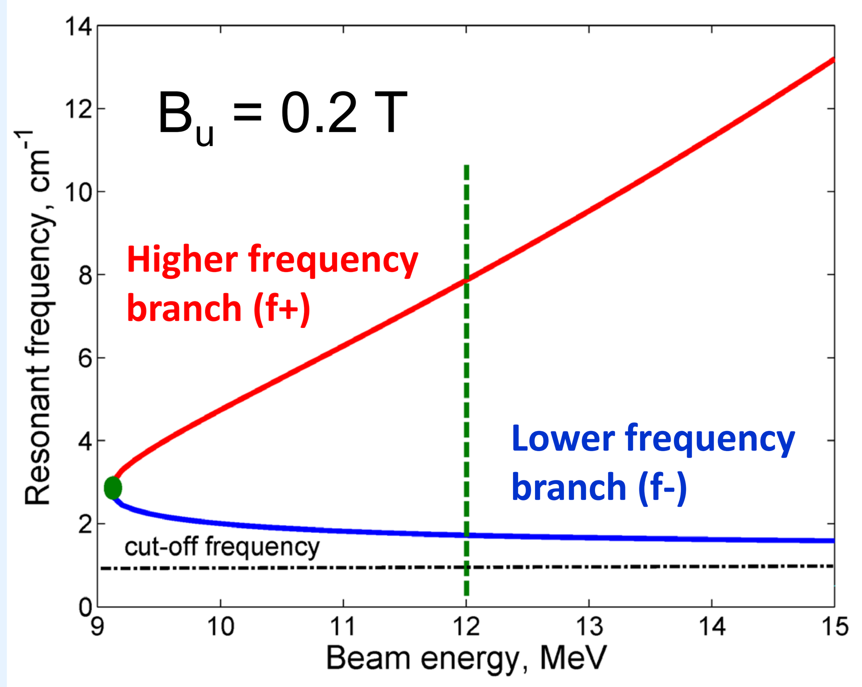

Fig. 2. Waveguide resonant wavelength versus electron beam energy

Optical wavelength range	**100–1600 μm**
RF linac frequency	**2.997 924 GHz**
Electron beam energy	**10–15 MeV**
Electron bunch duration	**3 ps (standard deviation)**
Electron bunch charge	**200 pC**
Undulator period	**110 mm**
Number of undulator periods	**40**
Undulator magnetic field	**0.1–0.47 T**
Optical cavity length	**7.5 m**
Waveguide gap	**10 mm**
Rayleigh distance	**2 m**

Table 1. FLARE parameters

Results of simulations

The radiation wavelength of FLARE is comparable with electron bunch length ($\sigma_z \sim$ 1.8 mm), which in combination with high 3 GHz repetition rate of RF linac leads to pronounced **spontaneous coherence** between short 3 ps electron bunches (see Fig 3).

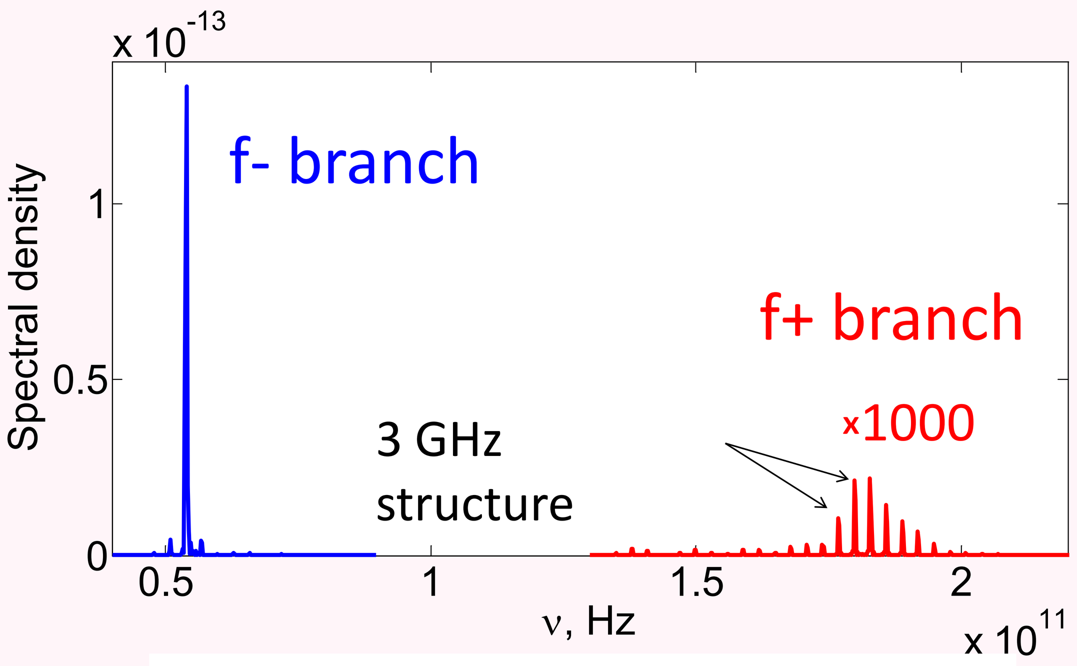

Fig. 3. Spectrum of spontaneous emission of FLARE (B_u = 0.44 T, E = 11.0 MeV)

The detuning curves presented in Fig. 5 show two cases:
- lower frequency branch is not taken into account (black curve)
- lower frequency branch is taken into account (**f-** shown in blue, **f+** in red).

Detuning curve of f- branch shows narrow peaks, which indicates that the main mechanism for radiation generation is coherent synchrotron radiation (stimulated superradiance regime). The power of f+ branch in the position of the f- peak is decreased, though the effect is rather small. However, some kind of competition on the first tens of cavity roundtrips is present, which can lead to problems with energy buildup and saturation of main branch (See Fig 3 and Fig 6).

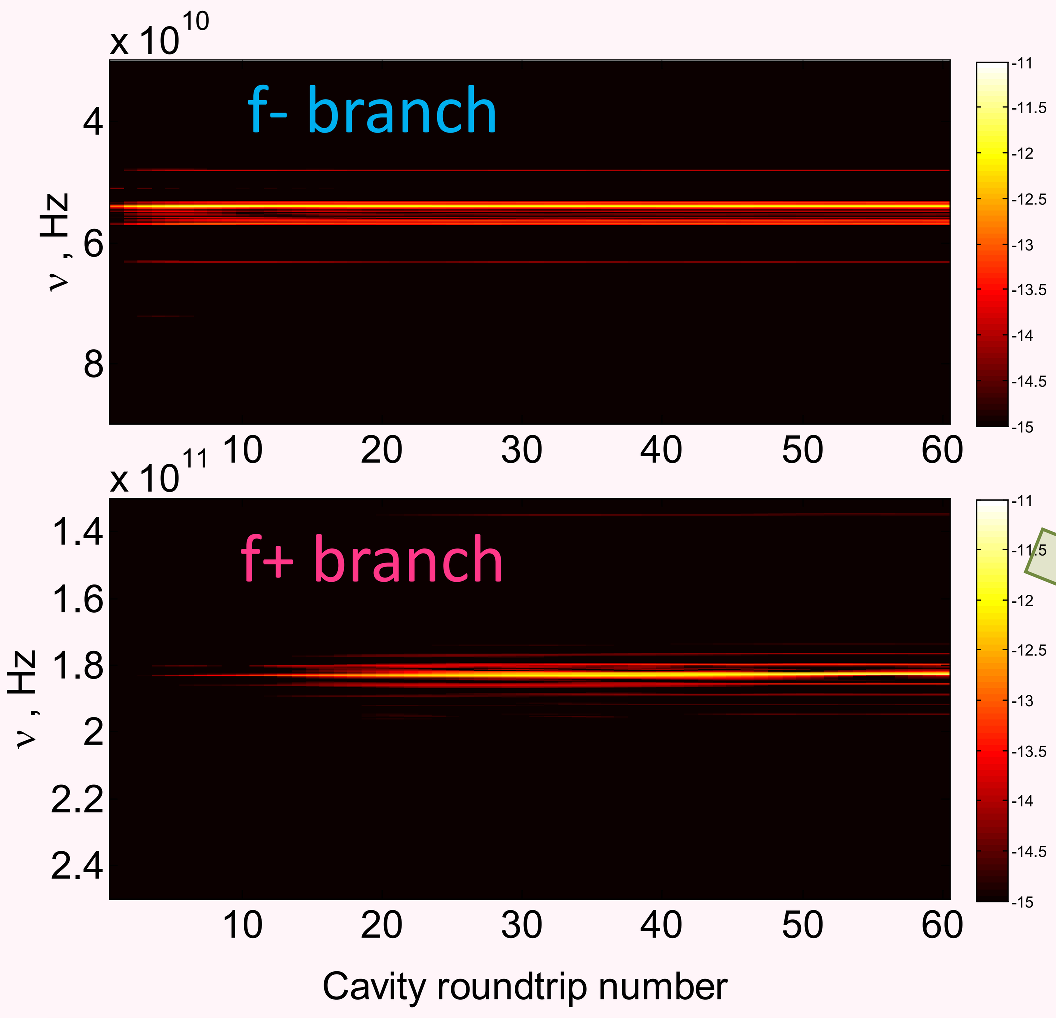

Fig. 4. Evolution of spectrum for f- and f+ frequency branches at relative detuning δL/λres = 21.6 (B_u = 0.44 T, E = 11.0 MeV, σ_z =1.8 mm)

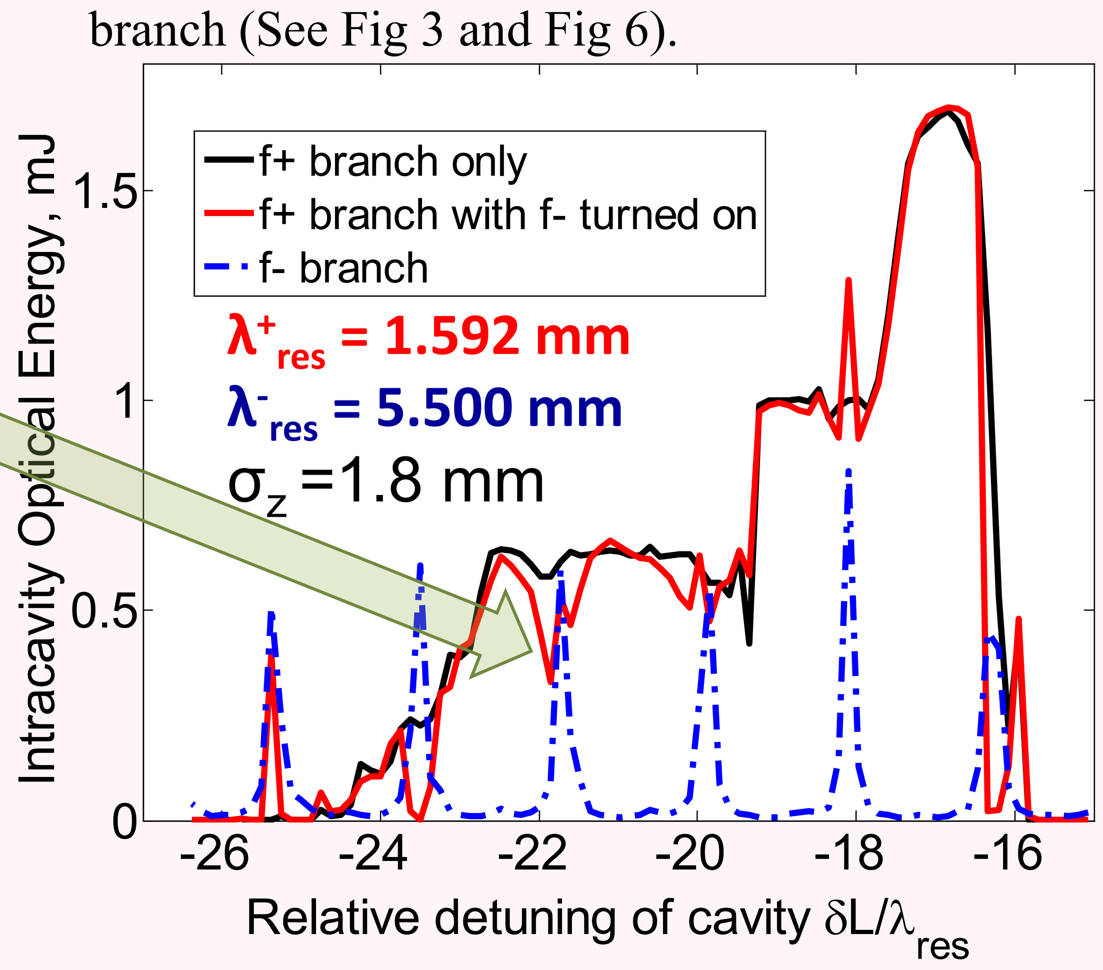

Fig. 5. Detuning curves for two cases: without f- branch taken into account (black) and with (red for f+, blue for f -). Parameters of simulation: B_u = 0.44 T; E = 11.0 MeV; σ_z =1.8 mm

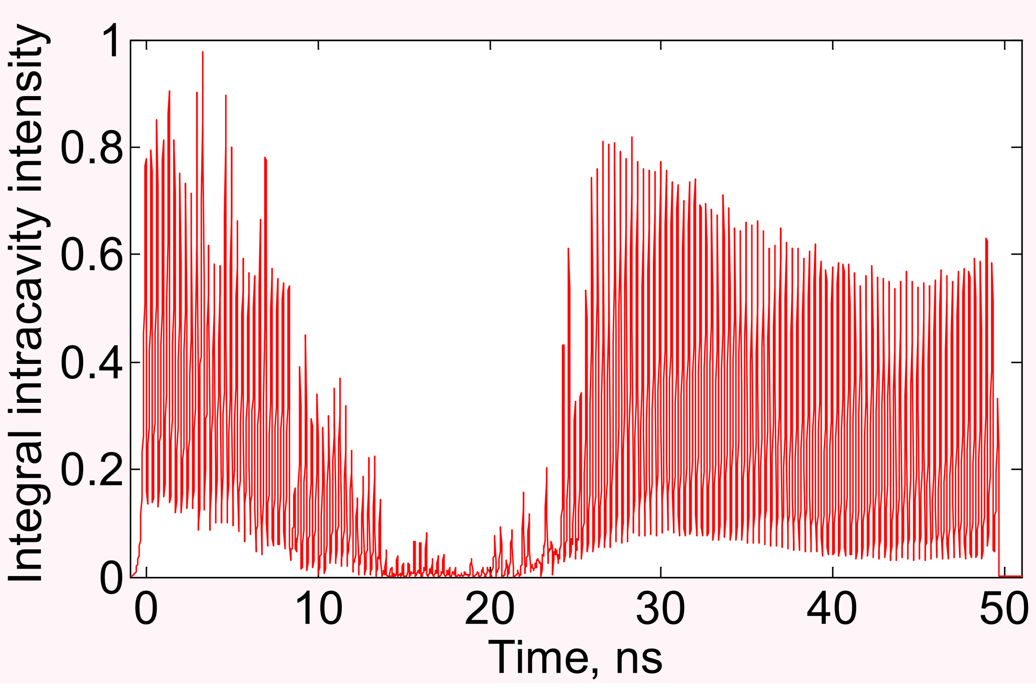

Fig. 6. Intensity of 150 optical pulses for f+ branch versus time after cavity roundtrip #50. Cavity detuning is preferable for f- energy buildup. Parameters same to Fig. 5.

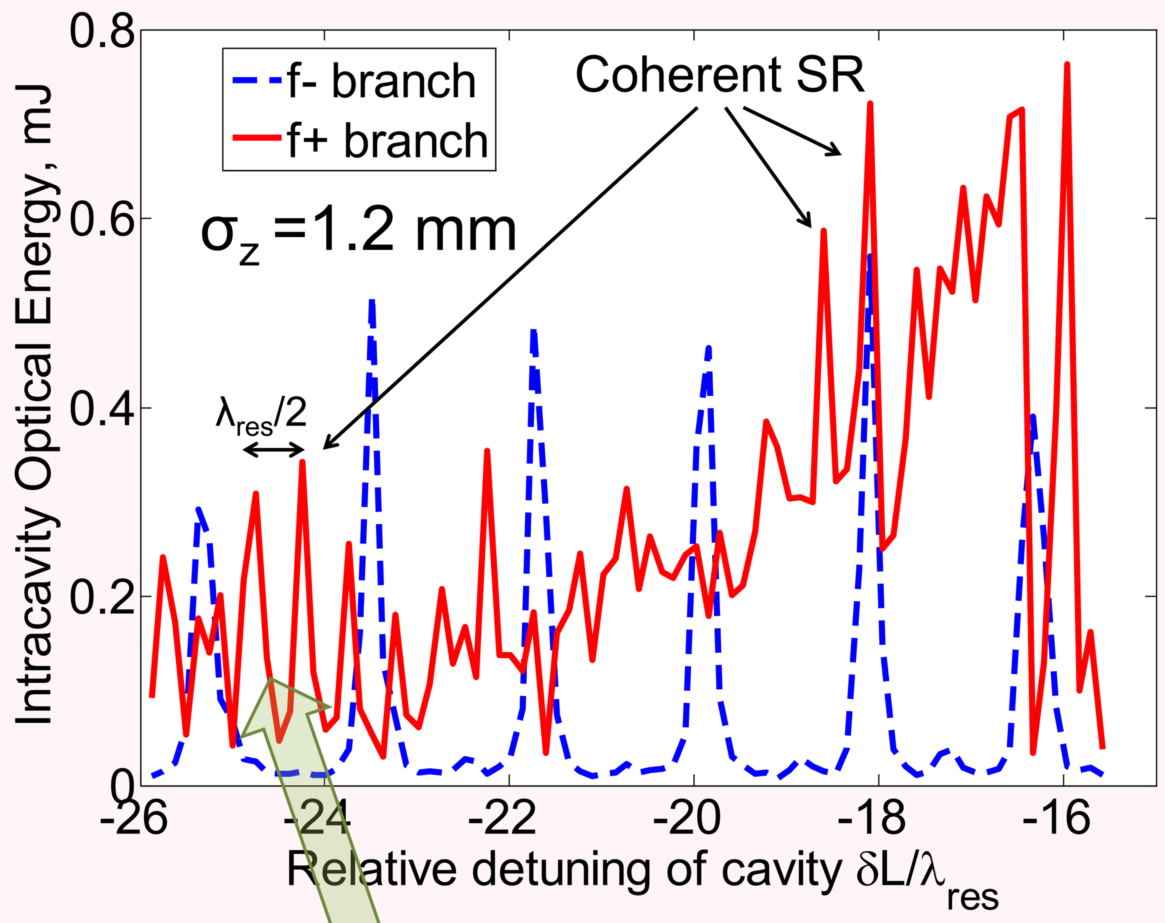

Fig. 7. Detuning curves for two branches of radiation in case the duration of electron pulse is **2.0 ps (σ_z =1.2 mm)**. Parameters same to Fig. 5.

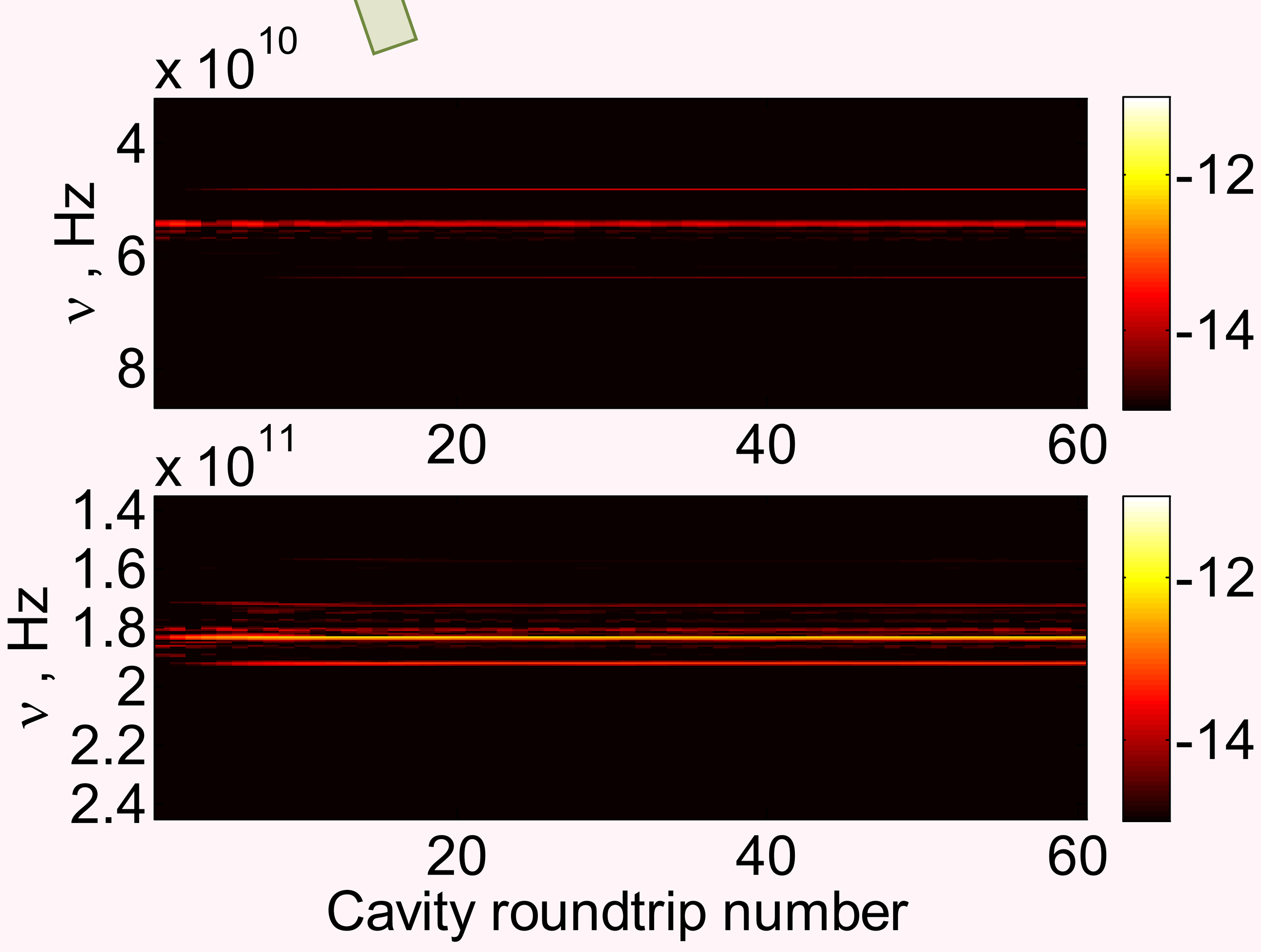

Fig. 8. Evolution of spectrum for f- and f+ frequency branches at relative detuning δL/λres = 25.6 (B_u = 0.44 T, E = 11.0 MeV, electron bunch duration **2.0 ps, σ_z =1.2 mm**)

Important result obtained during simulations is the preference of FLARE to coherent spontaneous (synchrotron) radiation in case when the length of the electron bunch is less or comparable to radiation wavelength. This gives rise to complicated detuning curves and spectrum (see Fig. 7-8), and can lead to nonlinear behavior of FEL. Thus, the study in this direction should be continued in order to resolve the tuning problem of FLARE.

Literature cited:
[1] R. Prazeres et al. Phys. Rev. ST Accel. Beams 12, 010701 (2009)
[2] Y. Pinhasi et al. Nucl. Instrum. Methods Phys. Res. A 475, 147 (2001)
[3] R. Chulkov et al. Phys. Rev. ST Accel. Beams 17, 050703 (2014)

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