Coherent Smith-Purcell radiation and coherent grating transition radiation characteristics comparison

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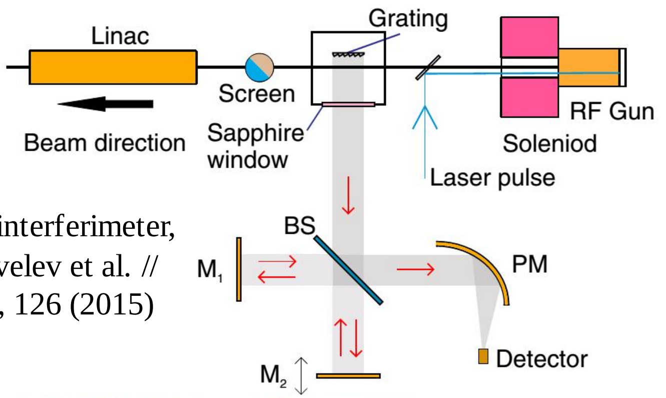
Introduction

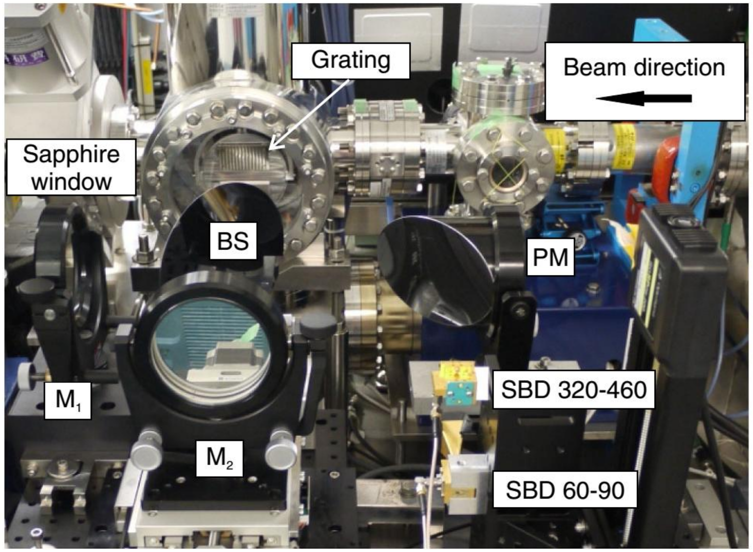
- Linac-based THz sources provide sub-ps ~μJ radiation pulses with continuous spectrum;
- To obtain narrow-band spectral line with a possibility of the frequency tuning one should use a monochromator;
- Other possibility is to use SPR source with spectral line adjustment changing emission angle;
- Source based on Grating Transition Radiation (GTR) can provide line adjustment for fixed emission angle.

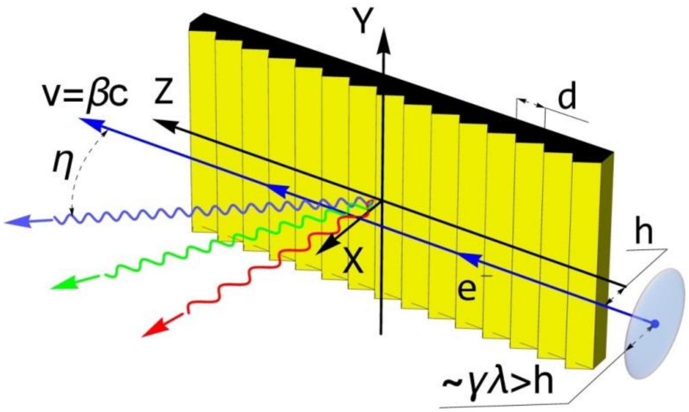
SPR investigations at LUCX (KEK, Japan)

A. Aryshev et al. // PR-AB 20, 024701 (2017)



Michelson interferimeter, see M. Shevelev et al. // NIM A 771, 126 (2015)





Top: experimental schematics
Bottom: photograph of the experimental station
Right: SPR target

Abbreviations: M1 — fixed interferometer mirror, M2 — movable interferometer mirror, BS — splitter, PM — off-axis parabolic mirror

Experimental set-up characteristics

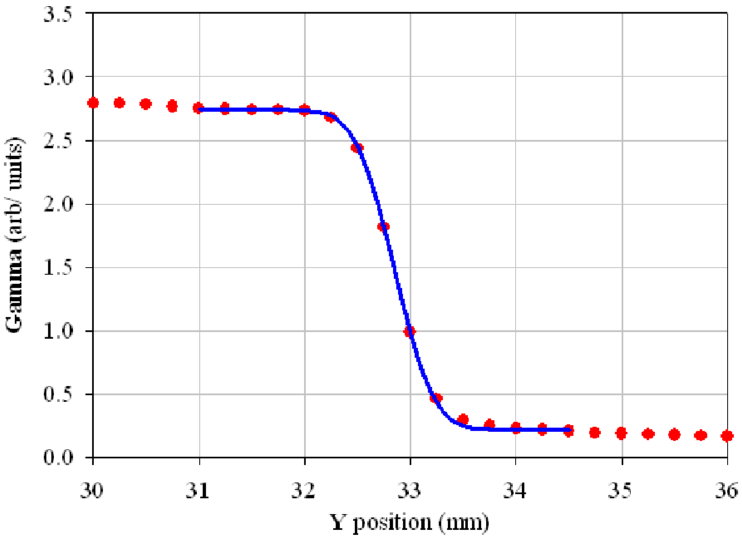
KEK: LUCX, beam parameters at the rf gun section.

Parameter	Value
Beam energy	8 MeV
Charge per bunch	25 pC
Bunch rms length	0.5 ps
Transverse rms size	$230 \times 230\ \mu m$
Repetition rate	3.13 bunch/s
Normalized emittance, typical	1.5×1.5 mm mrad

Detector parameters.

Parameter	SBD 60–90 GHz	SBD 320–460 GHz
Frequency range	60–90 GHz	320–460 GHz
Wavelength range	3.3–5.0 mm	0.94 – 0.65 mm
Response time	~250 ps	sub-ns
Antenna gain	24 dB	25 dB
Input aperture	30×23 mm	4×4 mm
Video sensitivity	20 V/W	1250 V/W

Coherent radiation for $\lambda \geq 0.3$ mm



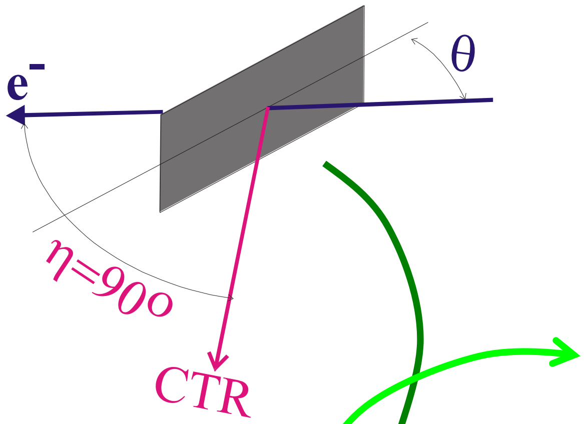
Bremsstrahlung produced by electrons in a target vs the impact parameter

$$F(y) \sim \int_y^{\infty} \exp[-(y_1 - y_0)^2/2\sigma^2]dy$$

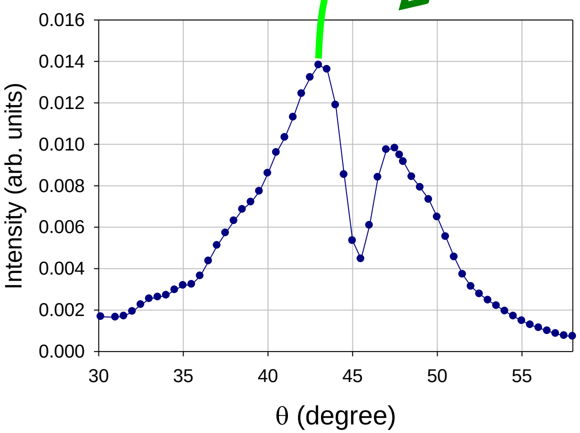
$y_0 = 33.15$ mm
$\sigma = 0.29$ mm

CTR spectral measurements

θ-scan measurement

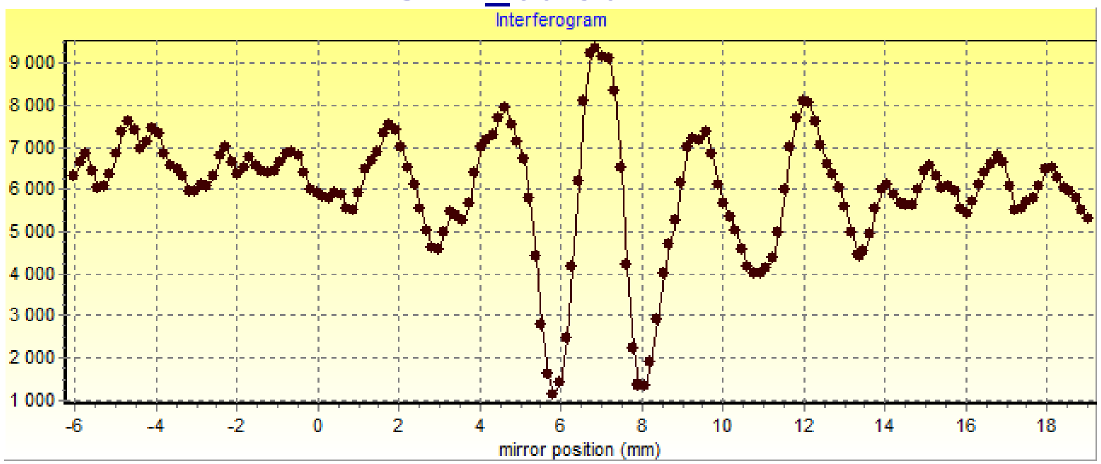


$$\eta = 93.5^o$$

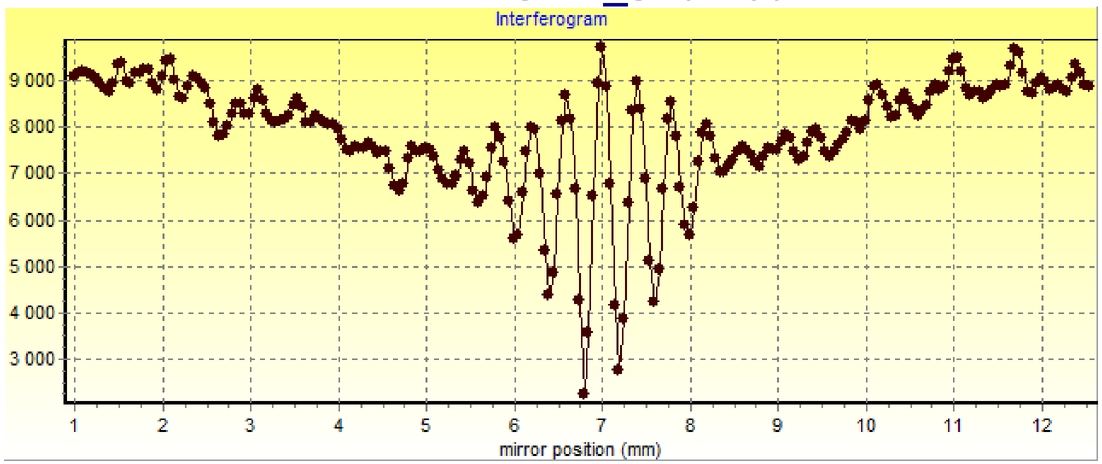


Interferograms

SBD_60-90



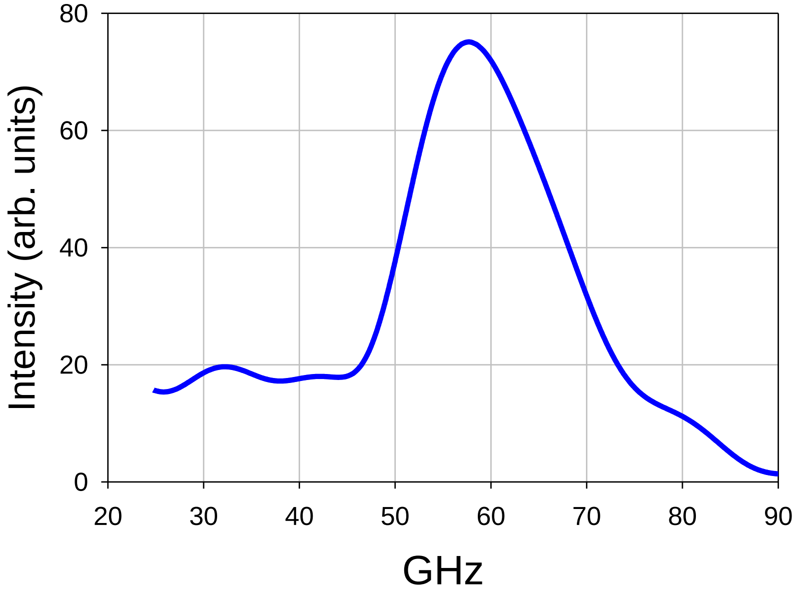
SBD_320-460



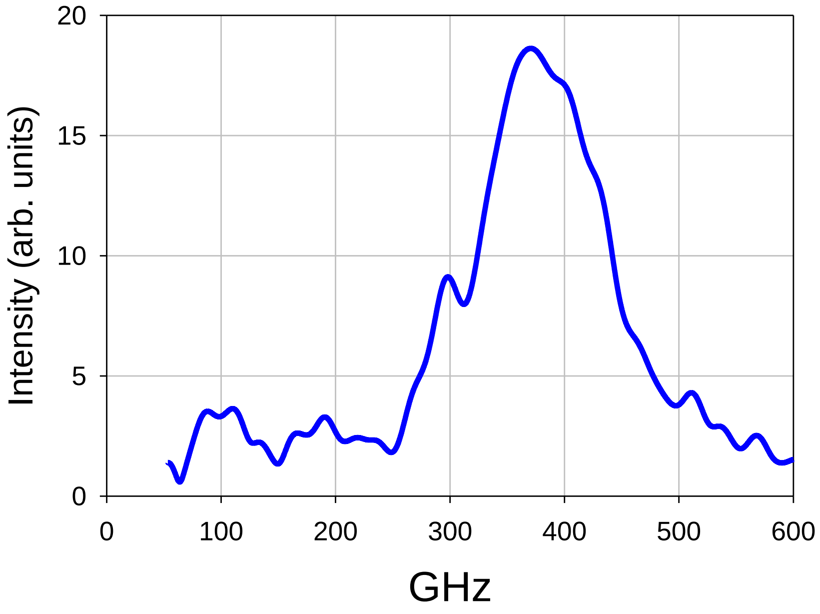
CTR spectra reconstruction

Reconstruction was performed using Fourier transform of interferograms with Gaussian apodization

SBD_60-90

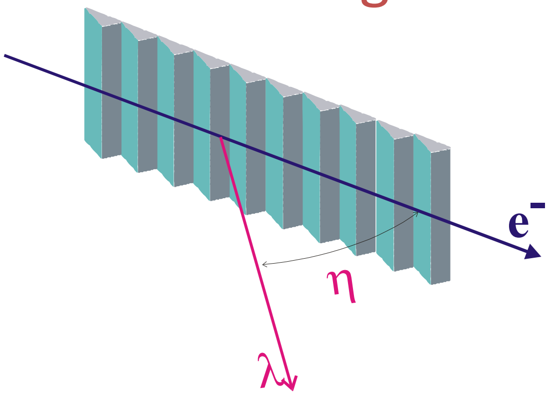


SBD_320-460



Smith-Purcell radiation

Smith Purcell geometry:

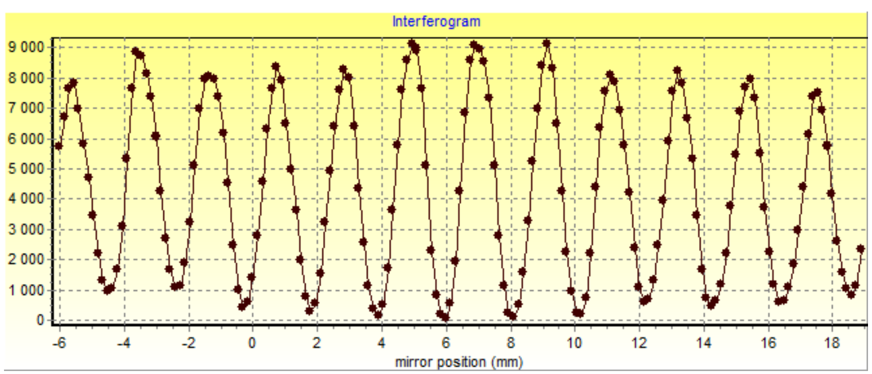


d = 4 mm

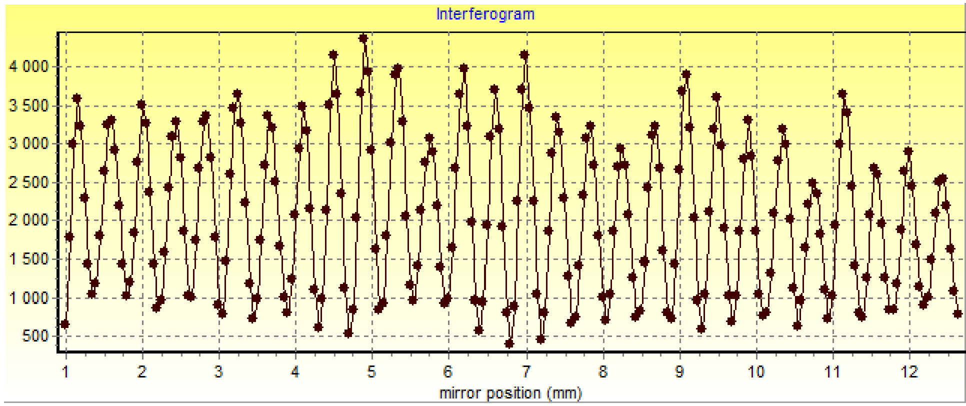
Dispersion relation: $$\frac{1}{\beta} - \cos(\eta) = k\frac{\lambda}{d}$$

Interferograms

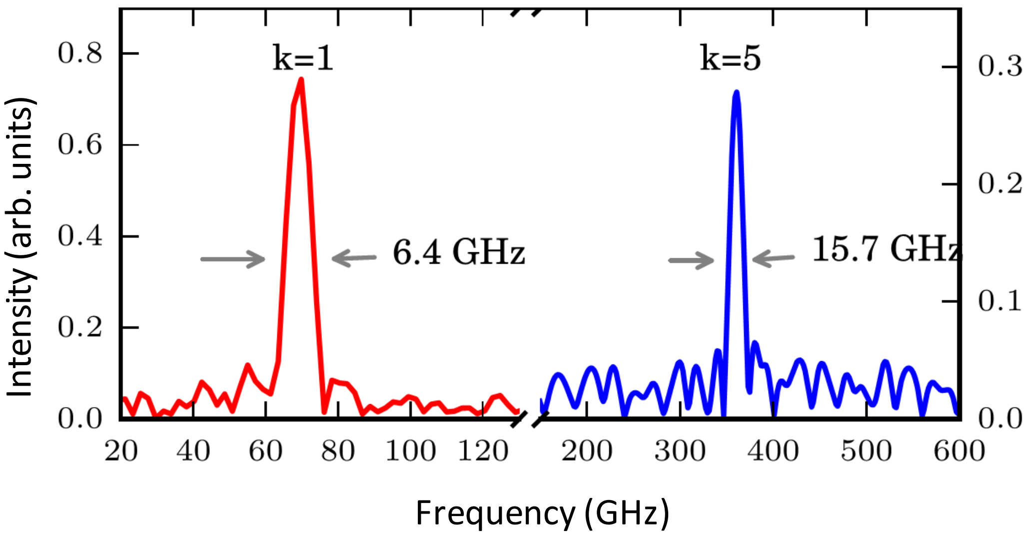
SBD_60-90



SBD_320-460



Coherent SPR spectral lines



SPR spectral measurements results

$$\frac{\Delta\nu_1}{\nu_1} \approx 9\% \qquad \frac{\Delta\nu_5}{\nu_5} \approx 4\%$$

Line broadening is due to finite aperture

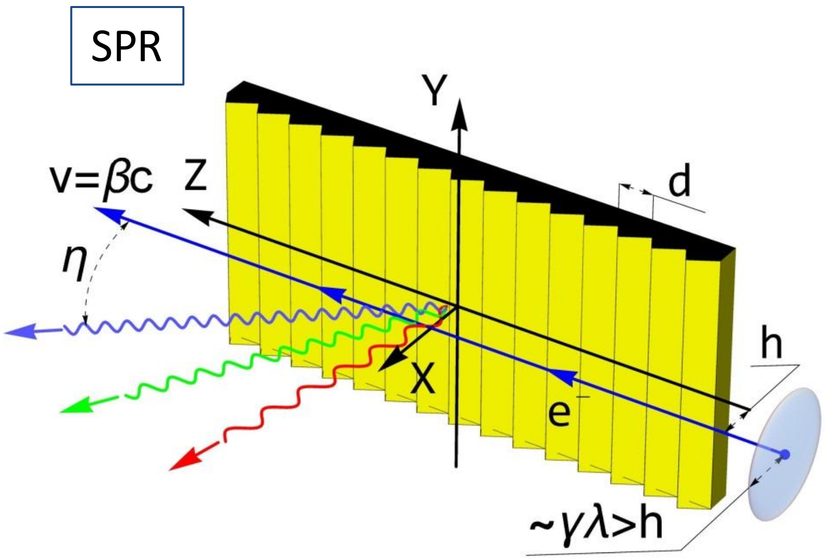
$$\Delta\nu_k / \nu_k \sim 1 / kN_0$$

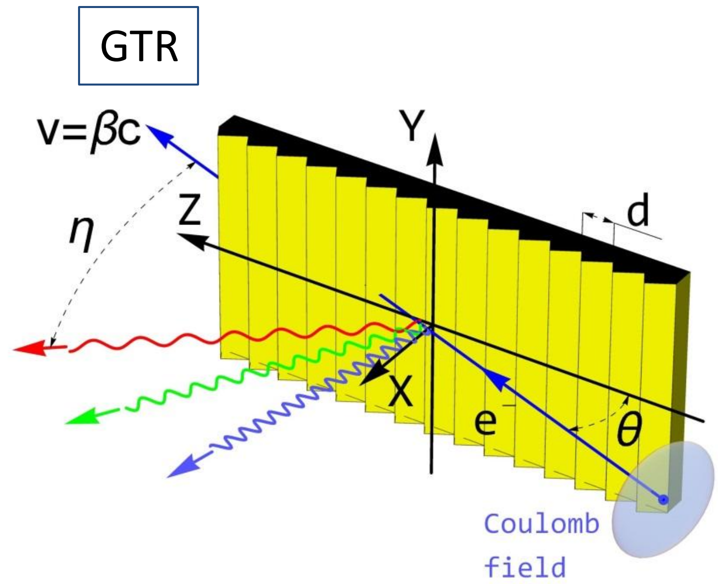
N_0 – number of periods

Frequency resolution of Michelson interferometer:

$$\Delta\nu_{int} \sim \frac{c}{2L_{int}} \sim 5\ GHz$$

Grating Transition Radiation





Dispersion relation: $$k\frac{\lambda}{d} = \cos(\eta - \theta) - \frac{\cos\theta}{\beta}$$

see, A.P. Potylitsyn et al. // Phys. Rev. E 61, 7039 (2000)

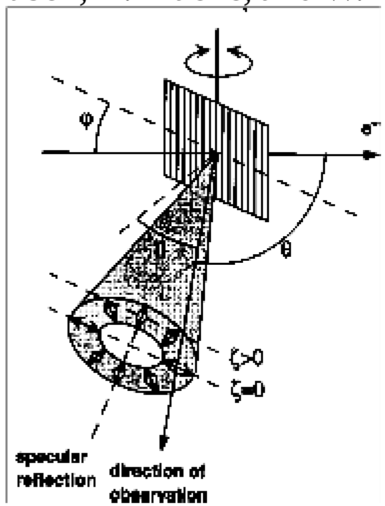
GTR monochromaticity is defined by overlapping of the Coulomb field and the grating

$\frac{\Delta\lambda}{\lambda} \sim \frac{1}{N_{eff}} \approx \frac{d \cdot sin\theta}{\gamma\lambda}$, if $N_{eff} \gg 1$

GTR in optical region

P. Henri, O. Haeberle, P. Rullhusen, N. Maene, and W. Mondelaers. Phys. Rev. E 60 (1999) 6214

$$\sin \eta_{n+1} - \sin \eta_n = \frac{\lambda}{D}$$



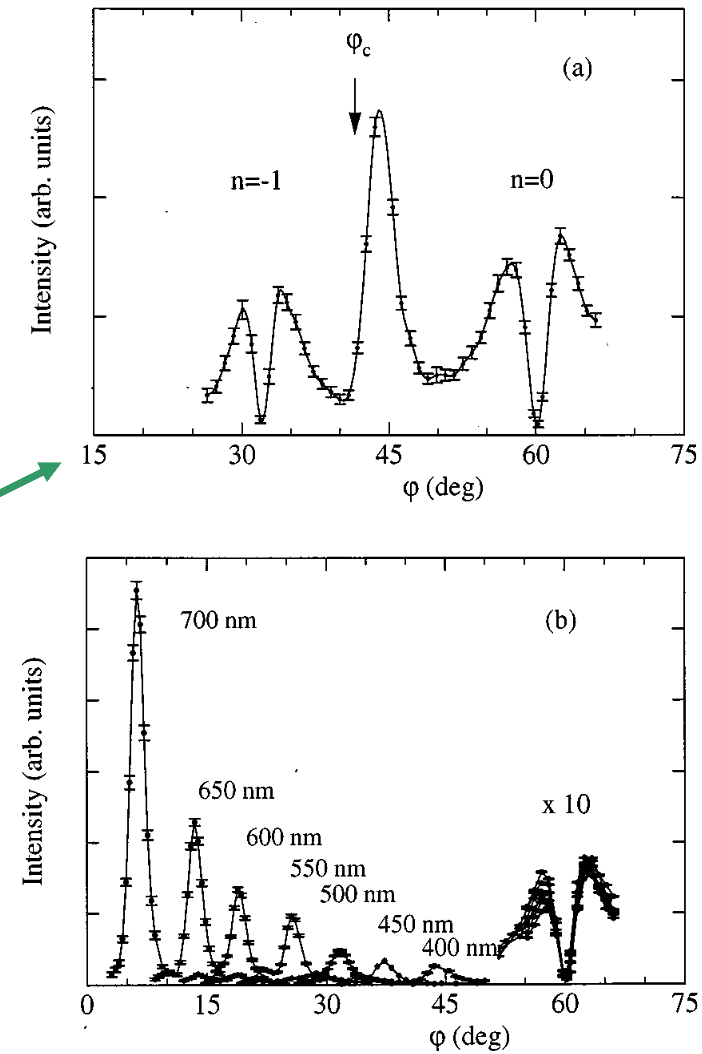
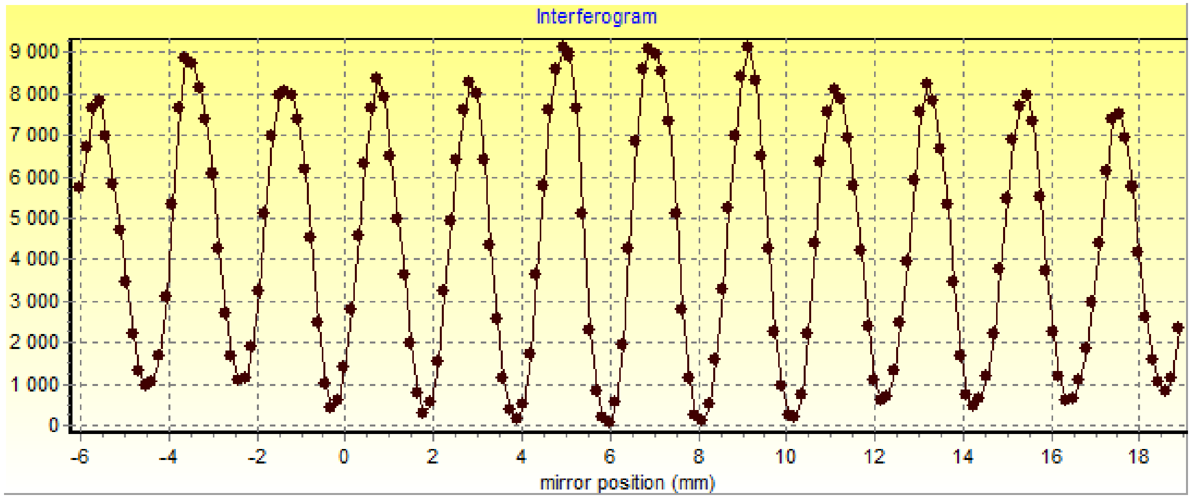


FIG. 3. Intensity observed at a fixed angle $\theta=120°$ (i.e., $\eta=\varphi-30°$). The electron energy is 5 MeV and the grating period 500 nm. (a) $\lambda=400$ nm. (b) Measurements with filters of different wavelengths superimposed. The lines are guides to the eye. The zero-order contributions in (b) have been increased by a factor of 10.

"At large angles with respect to this direction and for low angles of incidence of the electrons on the grating surface, we observed the emission of quasimonochromatic radiation. This grating transition radiation may offer an alternative method for production of quasimonochromatic radiation in the far-infrared to mm wavelength range."

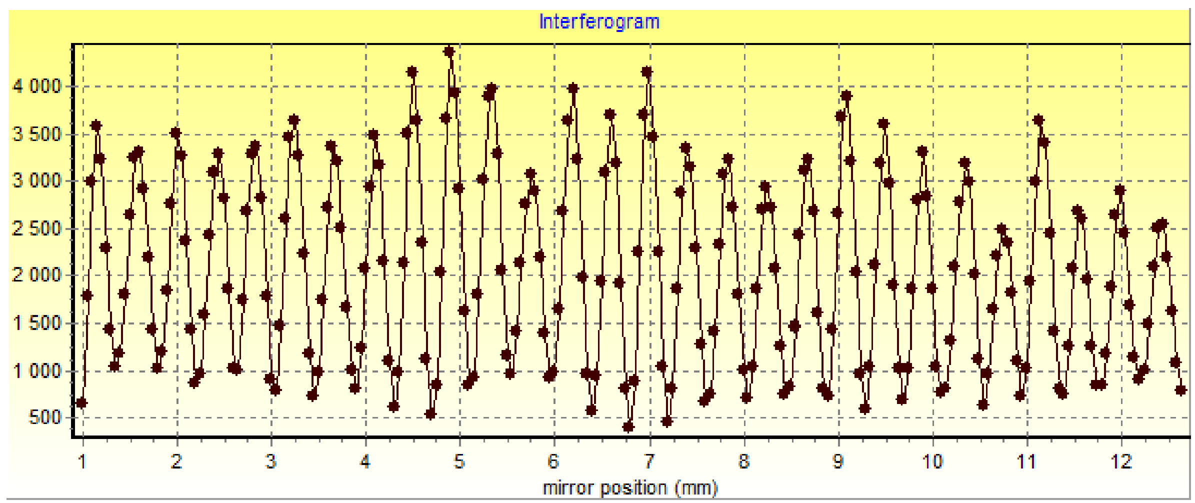
Coherent GTR spectral measurements

Sample of interferograms

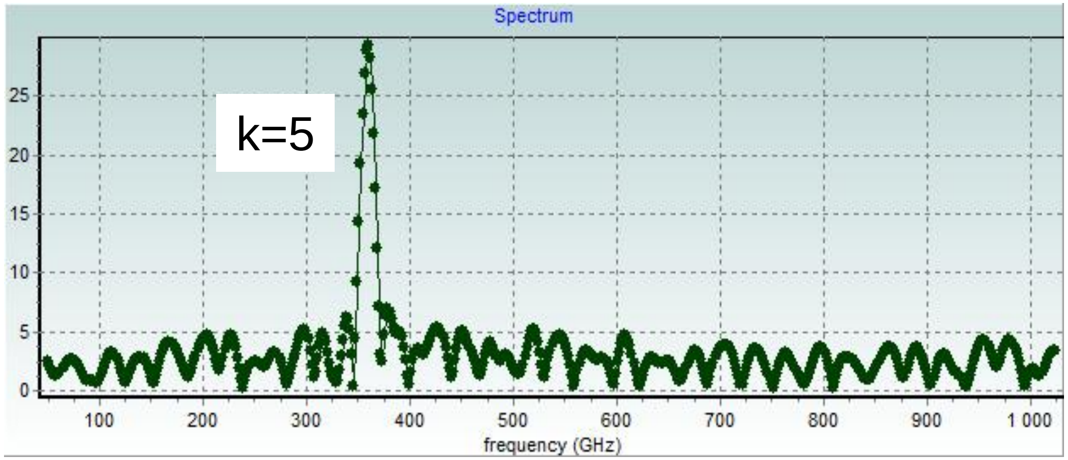


SBD_60-90

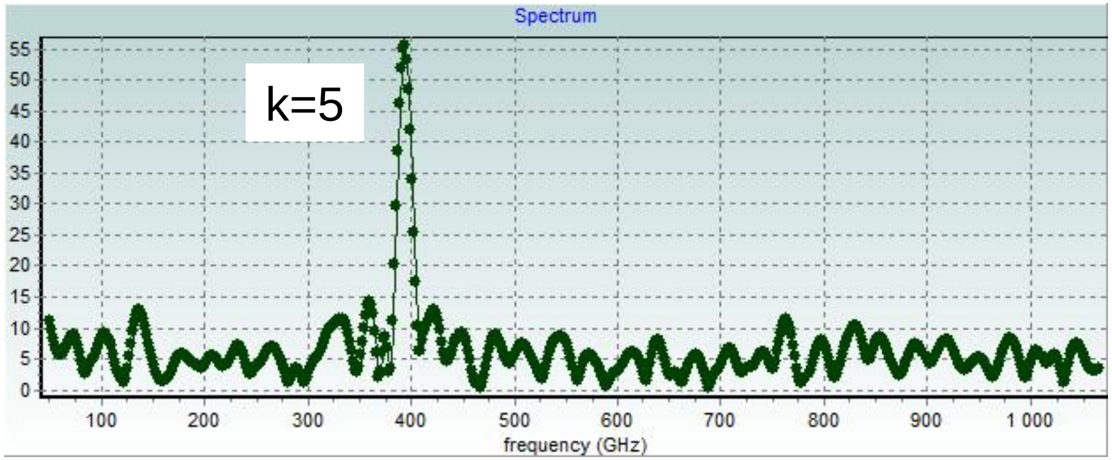
SBD_320-460



Spectra reconstruction (SBD 320-460)

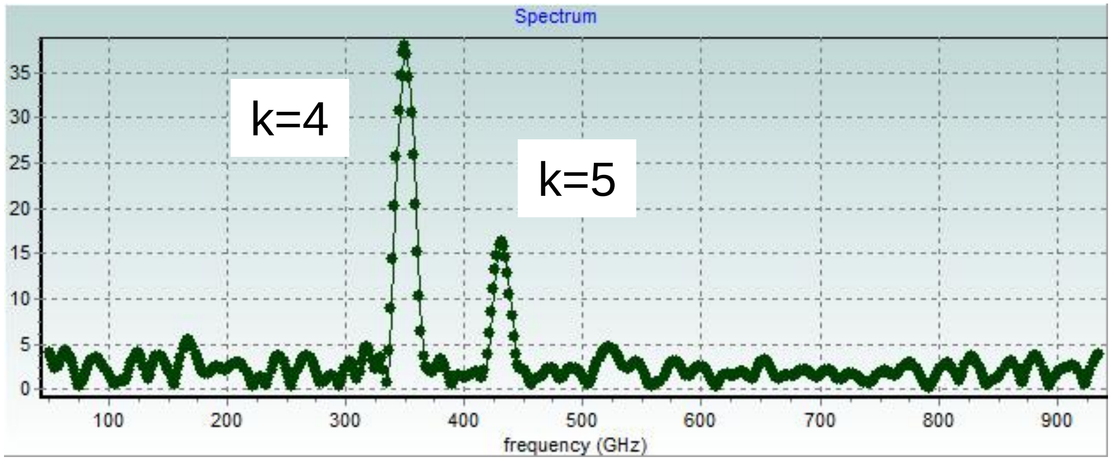


1 bunch
SBD 320-460
SBD att = 0 dB
$\theta = 0^0$
SPR geometry

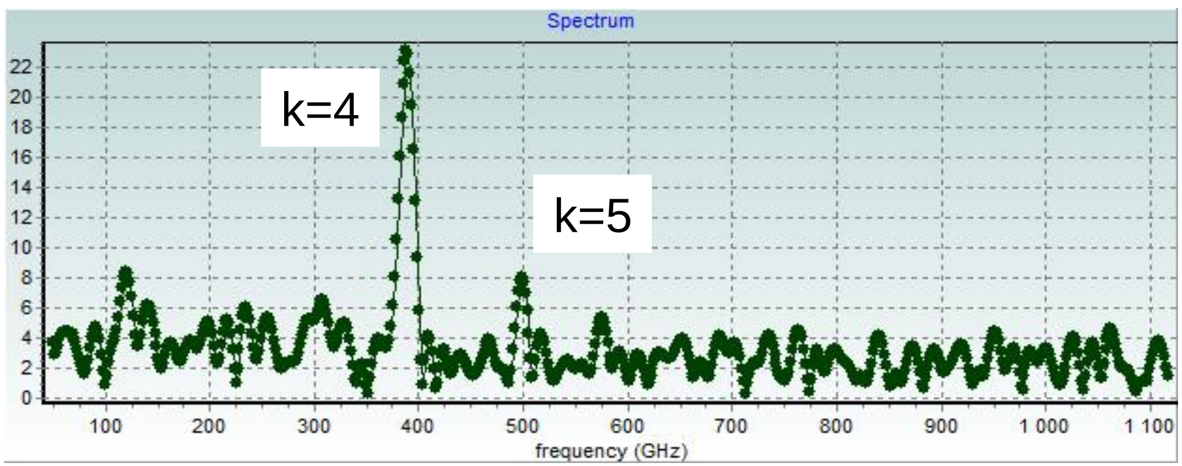


1 bunch
SBD 320-460
SBD att = 0 dB
$\theta = 5^0$

Spectra reconstruction (SBD 320-460)

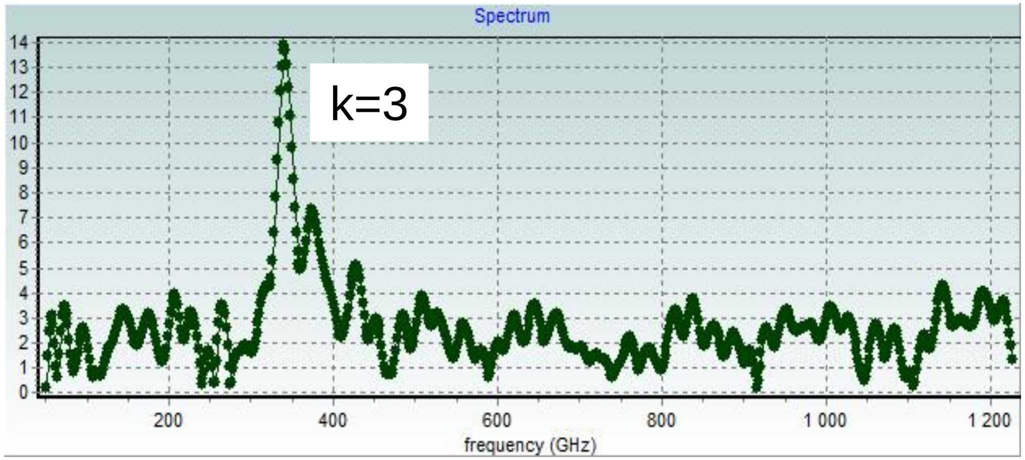


1 bunch
SBD 320-460
SBD att = 1 dB
$\theta = 10^0$



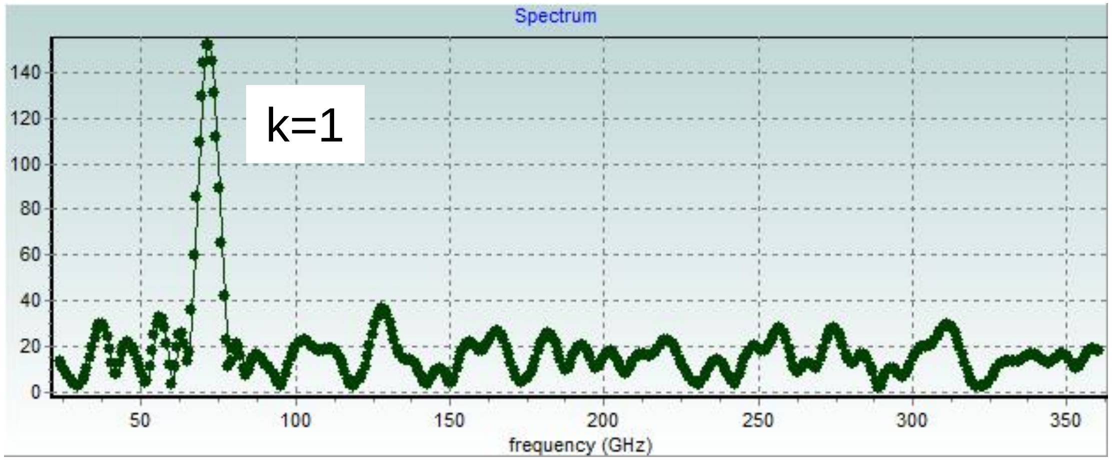
1 bunch
SBD 320-460
SBD att = 5 dB
$\theta = 15^0$

Spectra reconstruction (SBD 320-460)

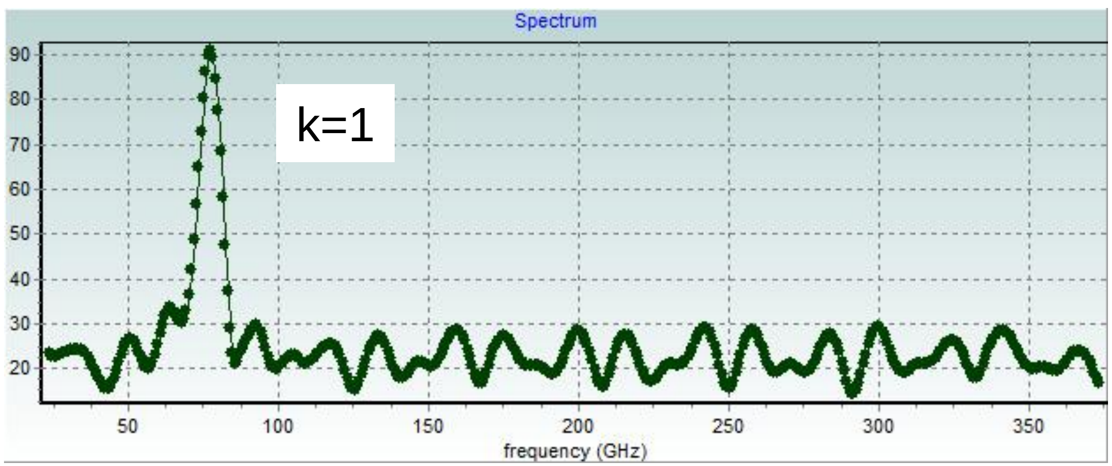


1 bunch
SBD 320-460
SBD att = 7 dB
θ = 20^0

Spectra reconstruction (SBD 60-90)

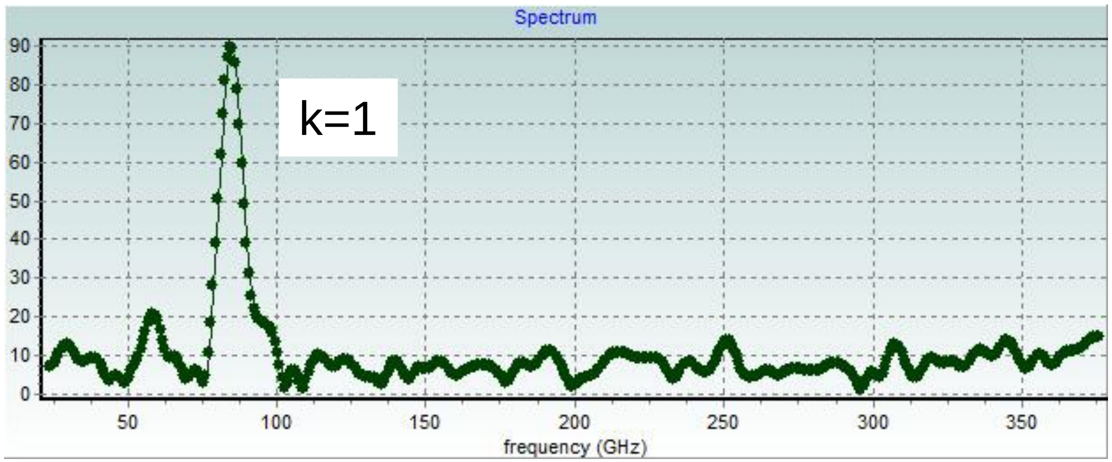


1 bunch
SBD 320-460
SBD att = 5 dB
$\theta = 0^0$
SPR geometry

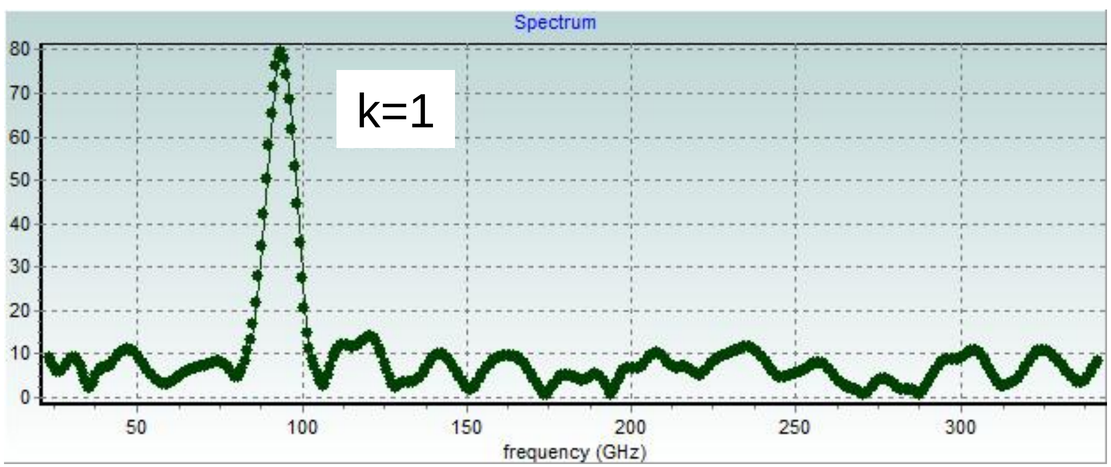


1 bunch
SBD 320-460
SBD att = 5 dB
$\theta = 5^0$

Spectra reconstruction (SBD 60-90)

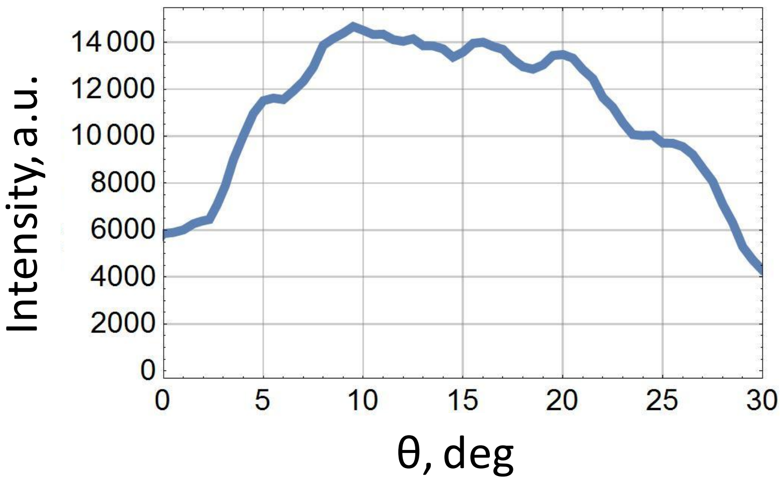


1 bunch
SBD 320-460
SBD att = 5 dB
θ = 10^0

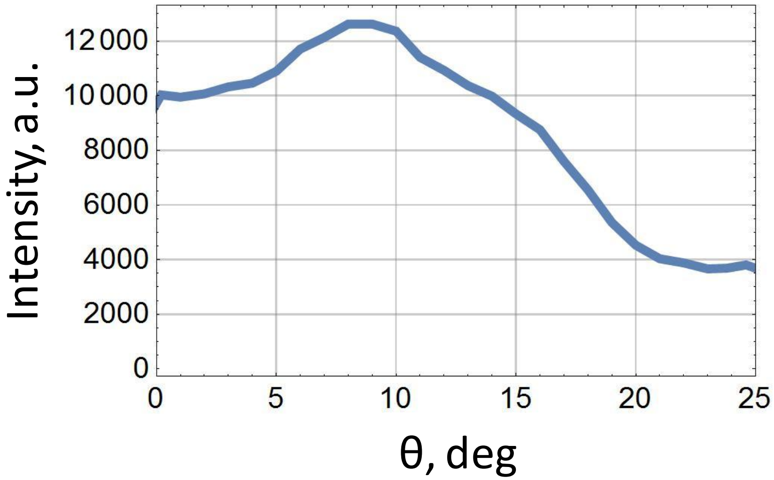


1 bunch
SBD 320-460
SBD att = 4 dB
θ = 15^0

Registered coherent radiation intensity vs. grating rotation angle (θ-scan)

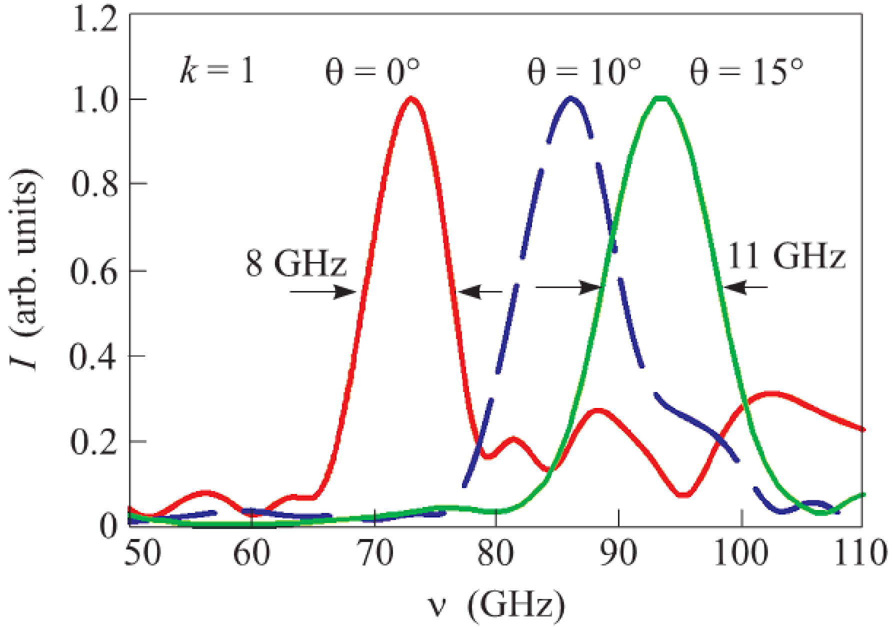


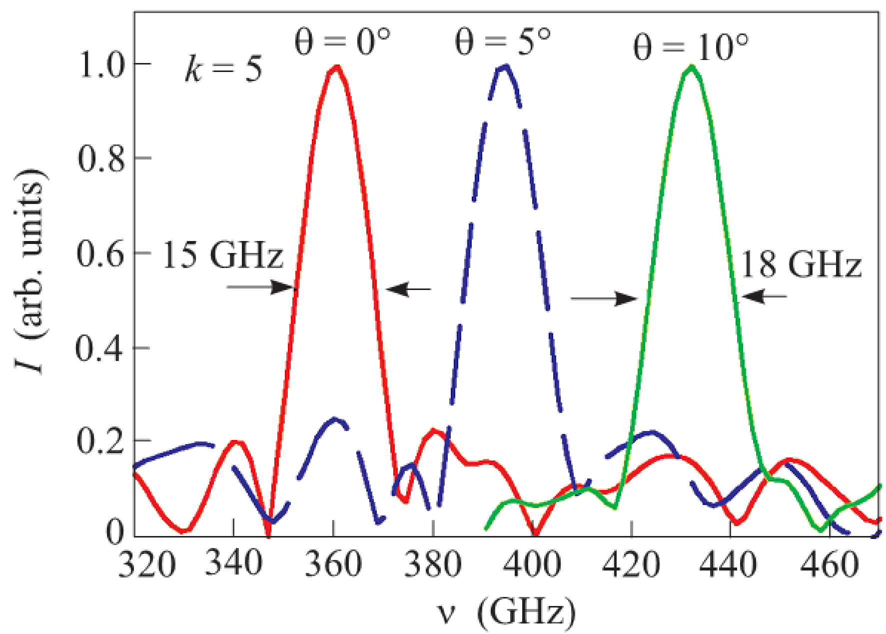
1 bunch
SBD 320-460
SBD att = 0 dB



1 bunch
SBD 60-90
SBD att = 5 dB

GTR monochromaticity



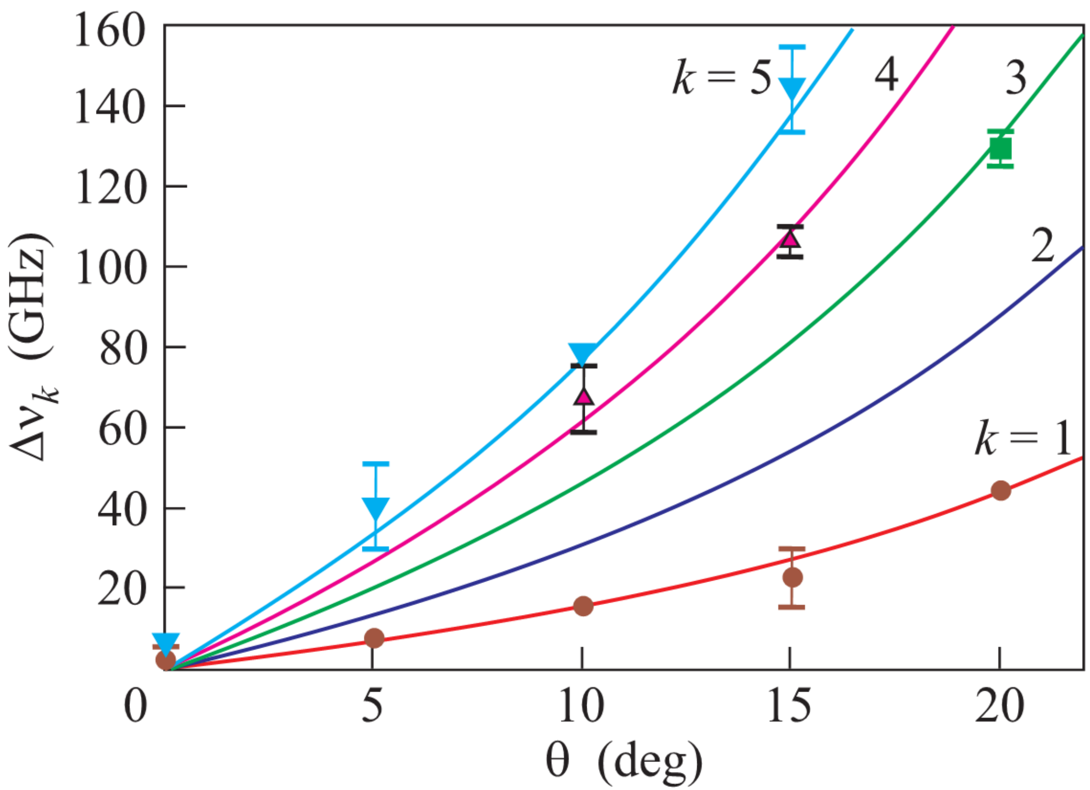


$$\frac{\Delta\nu_1}{\nu_1} \sim 11\%$$

$$\frac{\Delta\nu_5}{\nu_5} \sim 4\%$$

Experimental line spectra for the first order (left k = 1 and right k = 5) at various rotation angle θ of the targets with respect to the direction of the electron beam normalized to unity

Confirmation of the dispersion relation



$$\eta = 93.5^o$$

Frequency shift of GTR lines from the Smith–Purcell frequency in comparison with an estimate from the dispersion relation

Summary

- We have observed GTR in the sub-THz range and confirmed the dispersion relation depending on two angular variables (θ, η);
- Monochromaticity of GTR $\Delta\nu_k/\nu_k$ depends on the diffraction order *k* and coincides practically with the SPR monochromaticity;
- Intensity of GTR is comparable with intensity of SPR for the grating rotation angles $\theta = 0..20°$ and spectral line shift ~20..25%.

Thanks for attention!