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Concept of Tunable, High Power Source of Coherent THz Radiation

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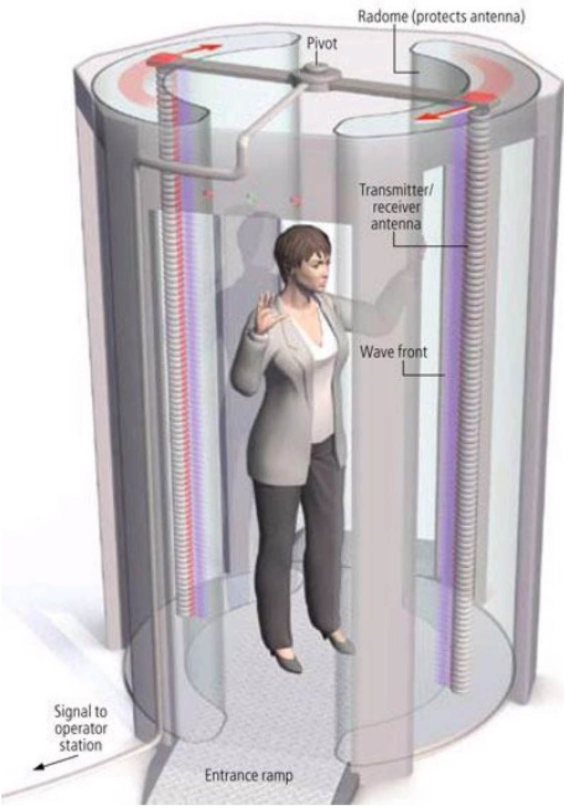
Overview

- Introduction
  - Requirements to THz sources
  - Available THz sources
    - Not RF LINAC driven
    - RF LINAC driven
    - Challenges to generate HP THz radiation
- HP THz Smith-Purcell tuneable oscillator experiments
  - ➢ Numerical simulations
  - ➢ Preliminary results
- Conclusion and Future work

Introduction

- ***Requirements to the radiation sources***
  - *Broadband (from 0.1THz to 10s of THz), short-pulse (fs), high-field intensity*
  - *Tuneable, single mode, single frequency*
  - *High Average Power for material studies and material quality control*
- ***Requirements to source***
  - *Compact*
  - *Energy efficient and easy to run*
  - *If not CW - capable of high-repetition rate*
- ***Environment requirement***
  - *Not sensitive to surrounding environment*
  - *No or low level of ionising radiation and material activation*
  - *Low DC Voltage*



Available THz sources (solid state, not LINAC based)

- **Solid State Oscillators** (High frequency Gunn, IMPATT and TUNNET diodes produce 100 mW@100GHz but falls as $1/f^2$ and at 400 GHz is typically in the range 0.1 to 1 mW)
- **Gas and Quantum Cascade Lasers** (typically up 100 mW operating in range from around 0.5THz to 5THz ,
  - low temperature, large magnetic fields are required for QCLs
  - CO_2 laser is required to pump the THz Gas laser
- **Laser Driven THz Emitters**

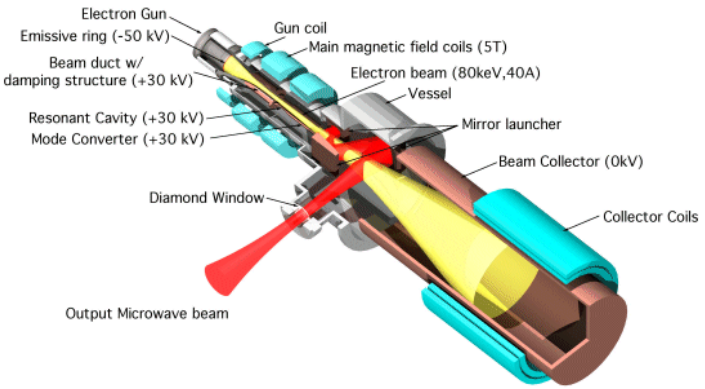
  (operating in 0.2THz to 2THz with average power from nano- to microwatts)

Available THz sources

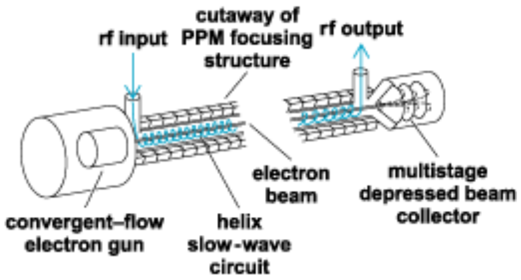
(vacuum tubes, not RF LINAC based)

Vacuum electronics:

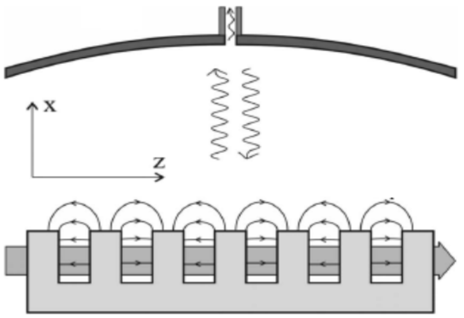
- Gyrotrons (not tuneable, high >10T magnetic fields is required)



- BWO (in frequency range from 30GHz till 1.2THz, power up to 100 mW@1.2THz)

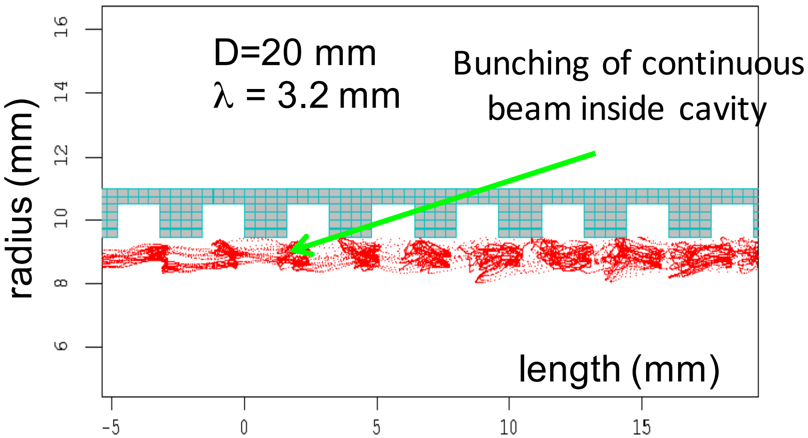


- Orotrons (Planar Smith-Purcell oscillators up to 1THz, power from 100mW@1THz to 1W@0.3THz)

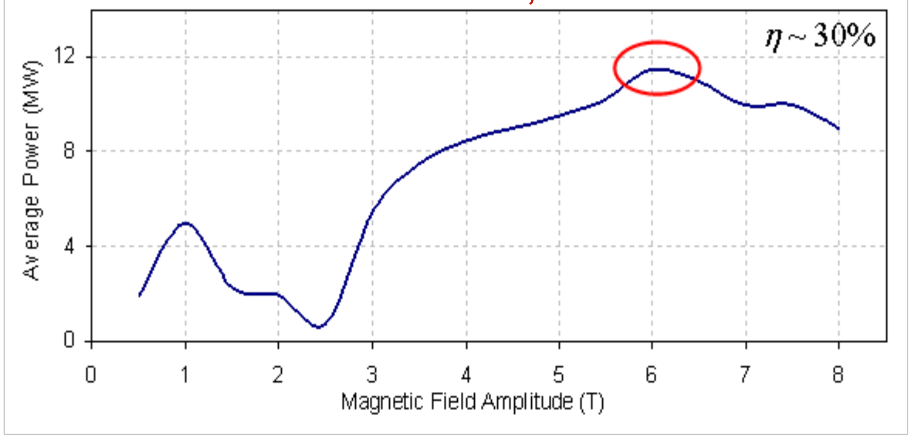


96GHz Maser based on 2D PSL

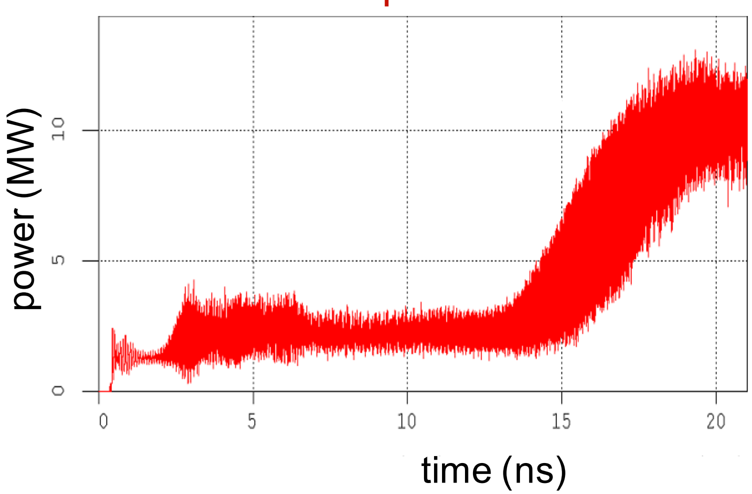
Electron bunch formation

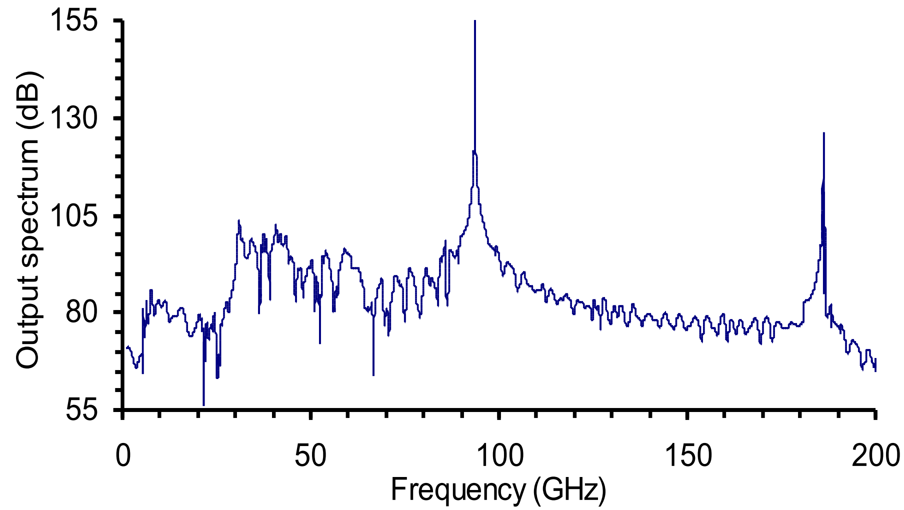


Electron Beam 300kV, 100A

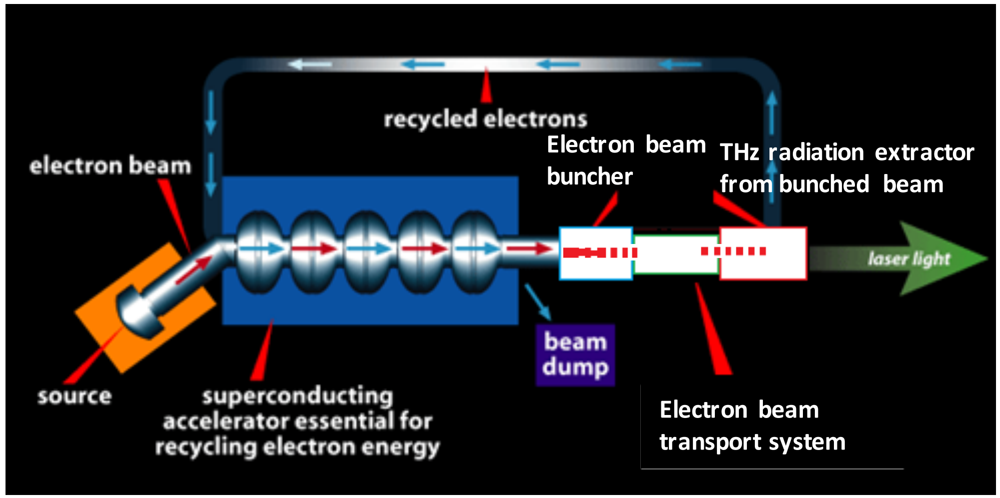


Output power from Cherenkov maser based on 2D periodic lattice





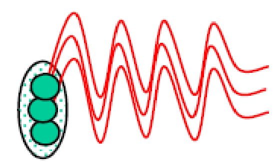
Below 10MeV LINAC THz sources



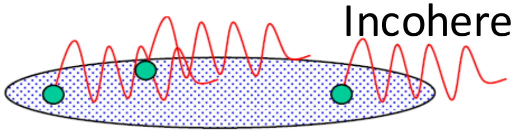
Coherence is insured by either installing a cavity or via pre-bunching electron beam making dimensions of the bunches smaller as compared with operating wavelength.

$$\left(\frac{dI}{d\Omega d\omega}\right)_{N_e} = \left(\frac{dI}{d\Omega d\omega}\right)_{sp} \cdot [N_e + N_e(N_e - 1)|F(\omega)|^2]$$

Coherent radiation

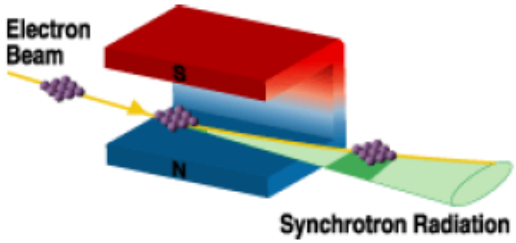


Incoherent radiation

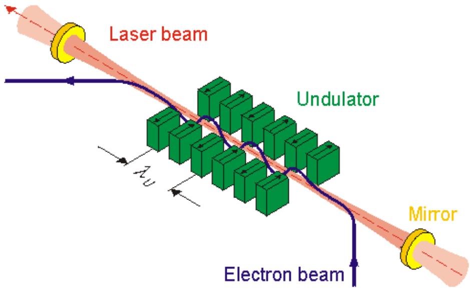


Available LINAC based sources

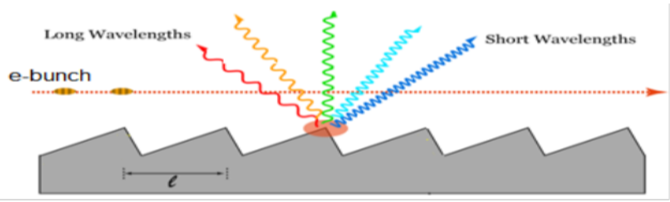
- Coherent Synchrotron radiation sources



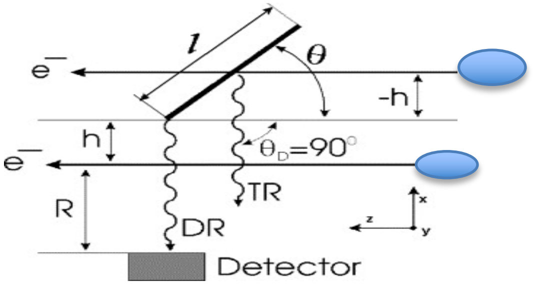
- Free Electron Lasers



- Coherent Smith-Purcell radiation (cSPr)



- Coherent Diffraction and Transition radiation



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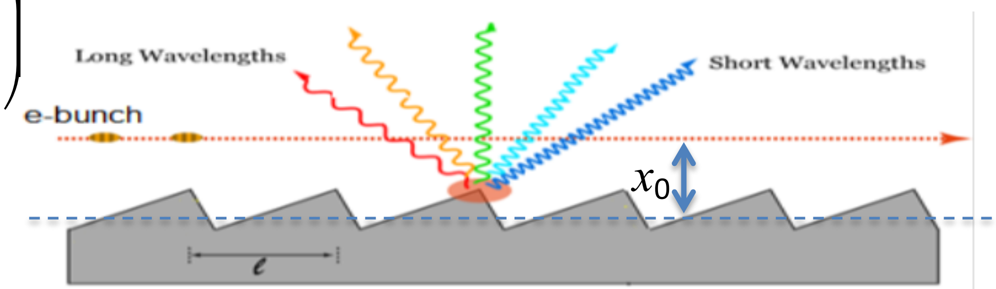
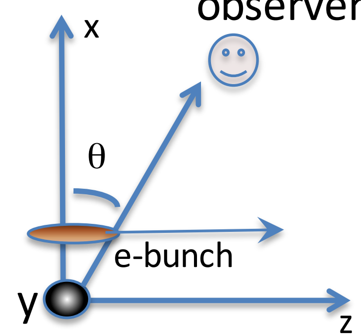
Smith-Purcell radiation

Dispersion relation links radiated wavelength and observation angle θ

$$\lambda = \frac{\ell}{m}\left(\frac{1}{\beta} - \cos\theta\right)$$





$$\left(\frac{dI}{d\Omega}\right)_{sp} = F \exp\left(-\frac{2x_0}{\lambda_e}\right)$$

$$\lambda_e = \frac{\lambda}{2\pi} \frac{\beta\gamma}{\sqrt{1 + \beta^2\gamma^2 \sin^2\theta \sin^2\phi}}$$

1/ x_0 is the distance between beam and the periodic structure

2/ λ_e is the electron beam - EM wave coupling parameter

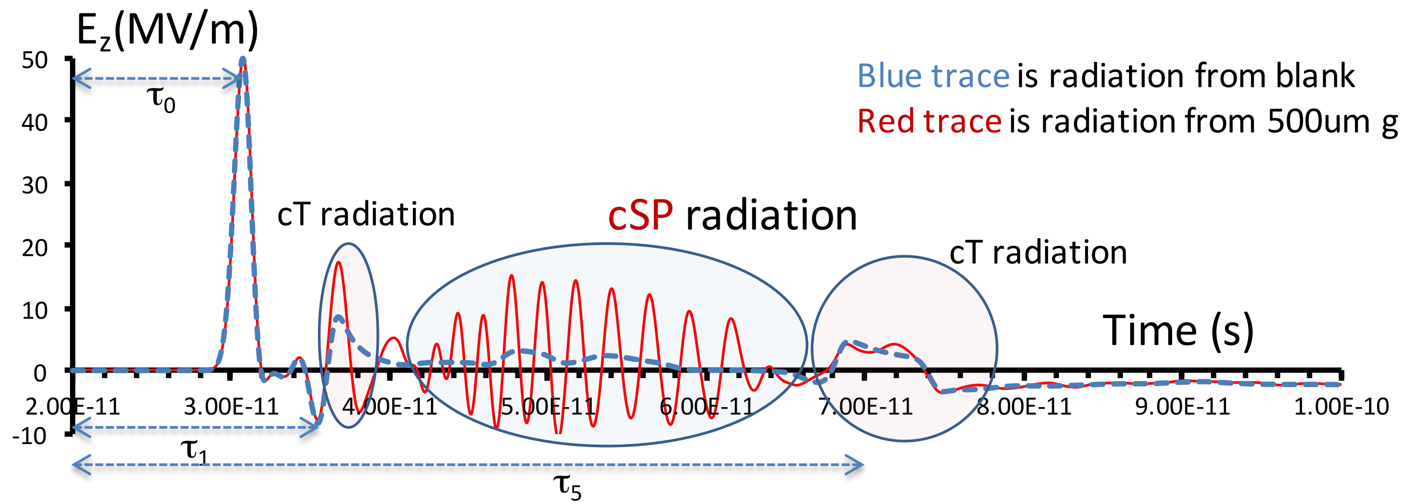
3/ larger x_0 smaller energy transfer to EM wave

For small θ and φ such that $(\theta\phi) << 1/\gamma$

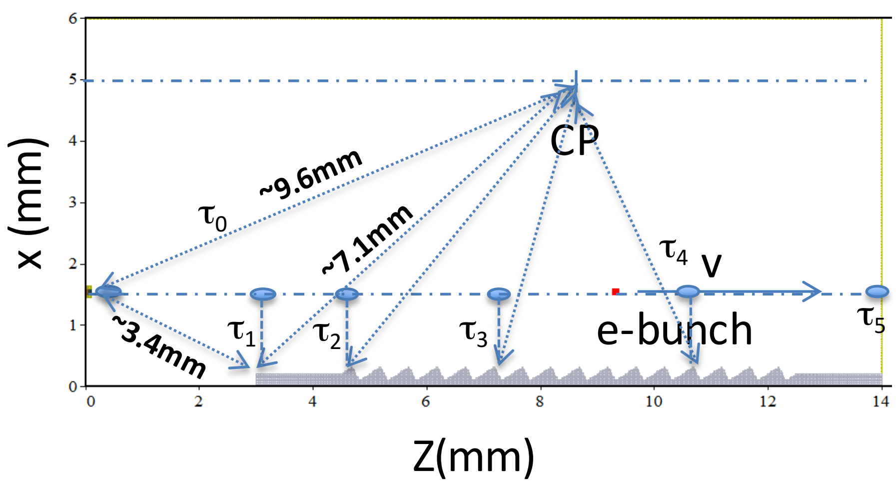
$$\lambda_e = \frac{\lambda\gamma\beta}{2\pi}$$

10MeV beam should be 0.1mm away to generate radiation at 10THz

Numerical studies of grating (500μm) and blank

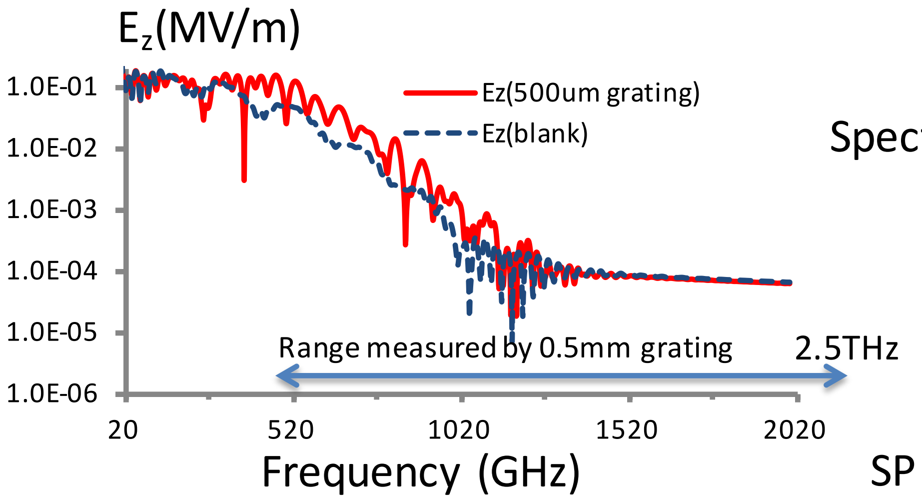


Blue trace is radiation from blank
Red trace is radiation from 500um grating



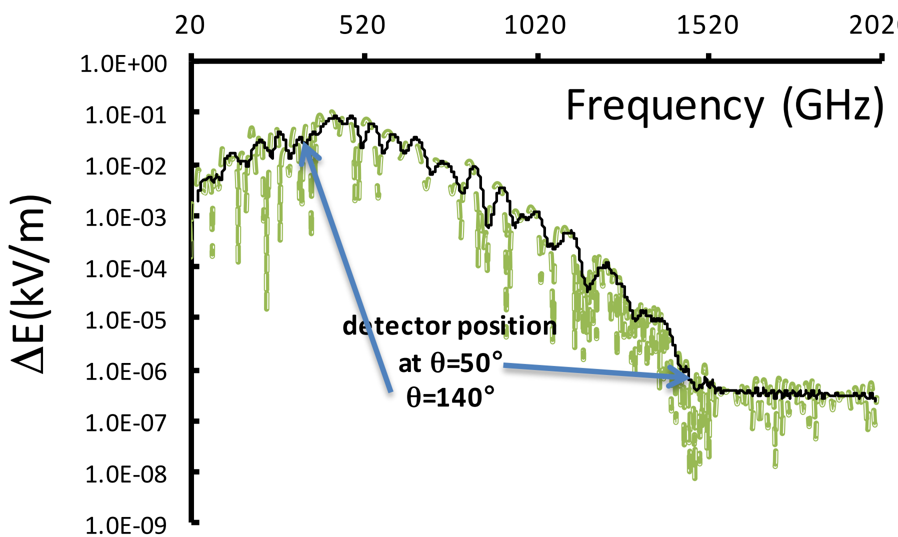
Comparison of electric fields time dependence at observation point (CP) locate above the centre of the grating observed from blank (dashed blue line) and 500um grating (solid red line). Two models are identical except for the corrugation. The differences between red and blue line can be attributed to the corrugation.

Numerical studies of grating (500μm) and blank



Spectra from blank (blue dashed line) and 500um grating (solid red line)

SP signal used for profile reconstruction

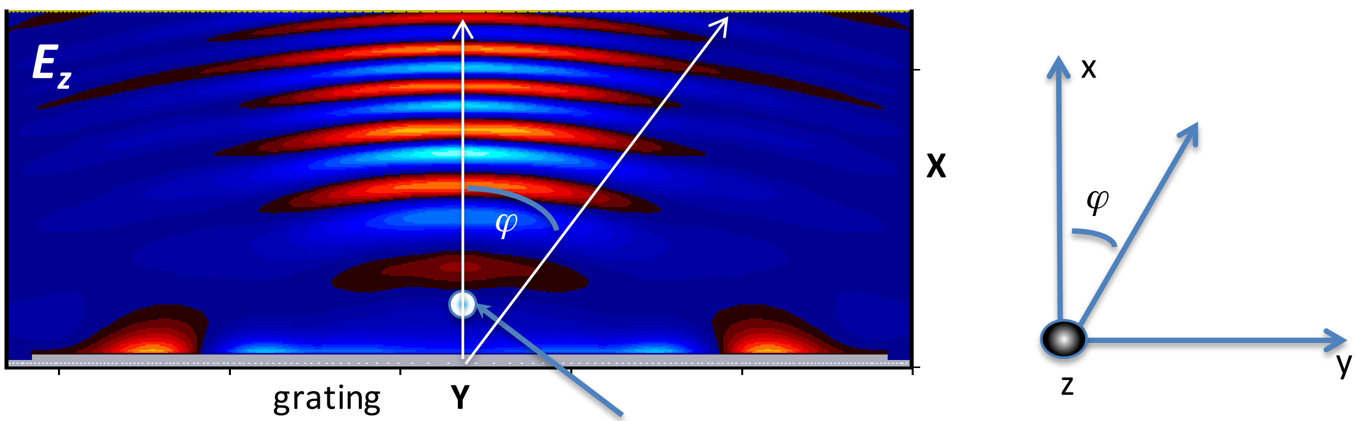


Black line over green shows a 20 points average which is similar to finite acceptance angle

Numerical studies of cSPr

PiC modelling of cSPr radiation from 500um planar grating

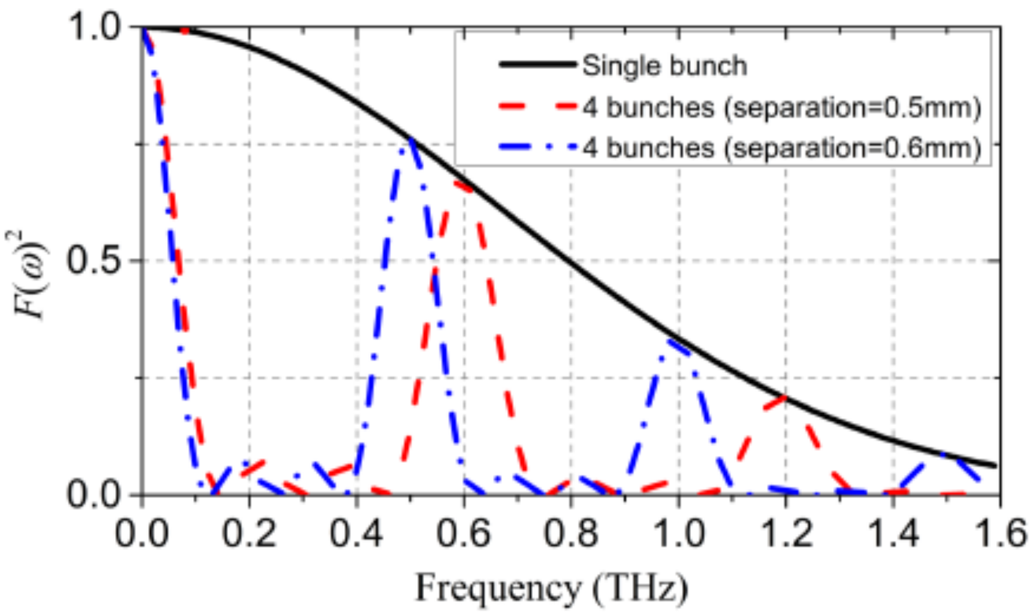
E_z is parallel to electron beam trajectory and located in *x-z* plane



Schematic position of the bunch moving toward us

The divergence angle 2φ (approx. 6°) of the cSPr from planar 1D grating of 500um period. Future gratings can be designed to minimise the divergence i.e. simplify the optics required to collect the signal.

Spectrum of coherent Smith-Purcell radiation



Spectrum of coherent Smith-Purcell radiation from single bunch (black line) and trains of 4 micro-bunches having bunch-bunch separation 0.5mm (0.6THz) and 0.6mm (0.5THz) while all 3 have the same total charge.

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Spectrum of coherent Smith-Purcell radiation

Single bunch: the same longitudinal dimension as a micro-bunch and total charge of the whole train

Problems:

1/ Focusing; 2/ Transportation; 3/ Beam halo; 4/ Bringing close to the grating

Advantages:

1/ Broad spectrum; 2/ No need for tuning

Train of micro-bunches

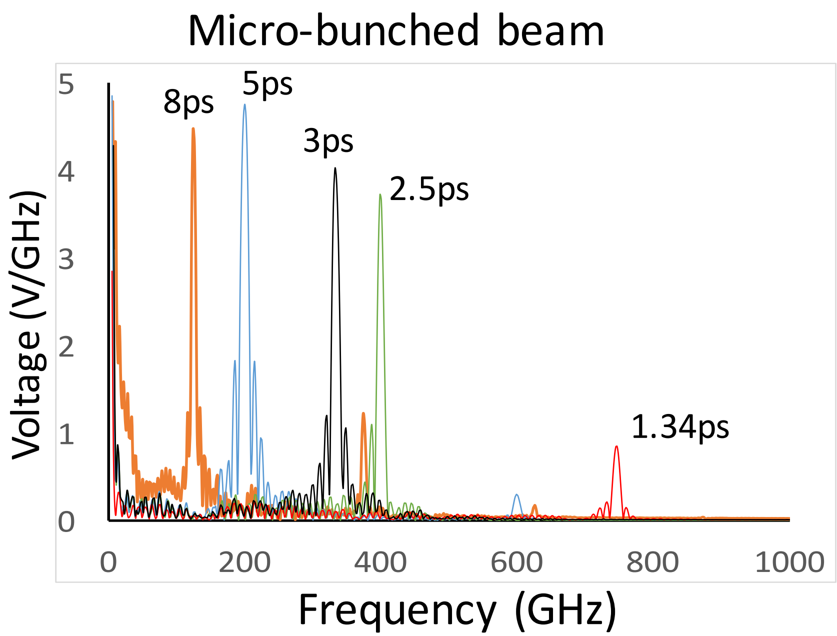
Problems:

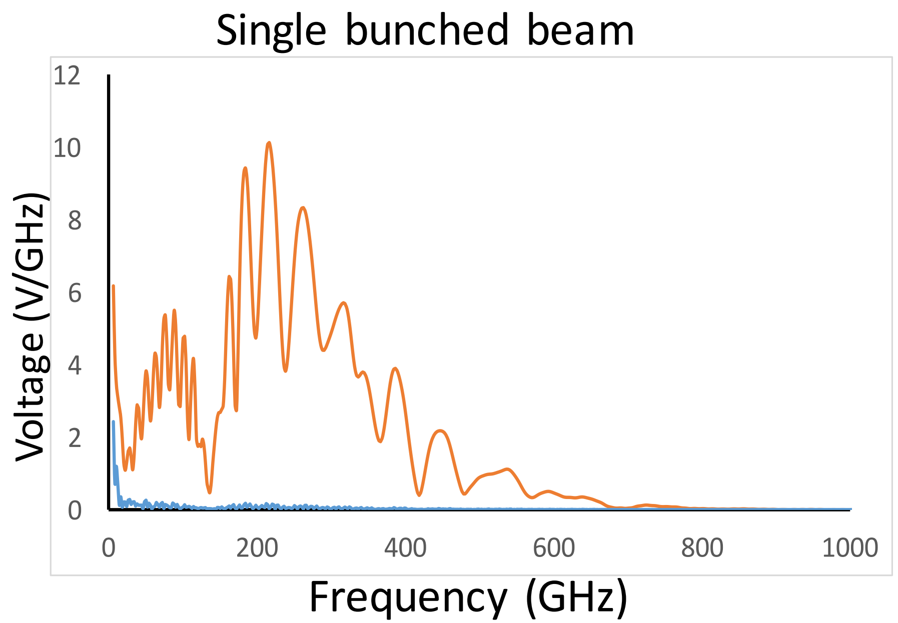
1/ Generation; 2/ Control and tuning; 3/ Narrow spectrum $\Delta\omega \sim 1/N$

Advantages:

1/ Space charge problem solved; 2/ No limitation of average power associated with the space charge; 3/ Tunability

Numerical studies of cSPr





Micro-bunched beam 10nC, 8MeV
Modulation: 1.34ps, 2.5ps, 3ps, 5ps, 8ps

Single bunch 10nC, 8MeV: 300ps, 1.5ps

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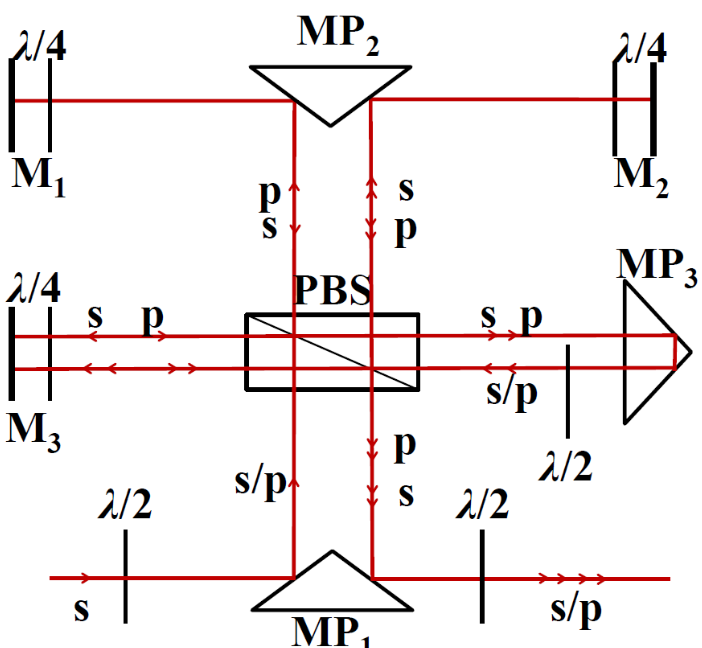
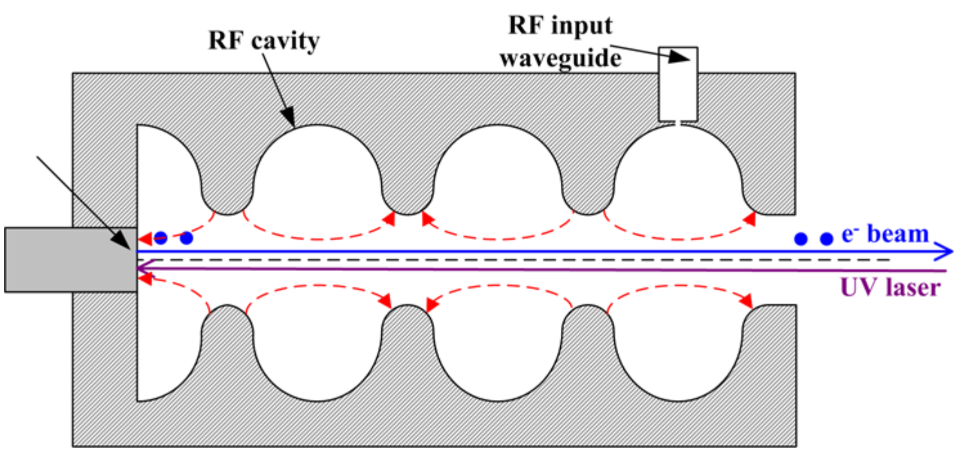
Experimental studies of cSPr at LUCX

Generation of pre-bunched beam for THz radiation generation at LUCX



Laser system



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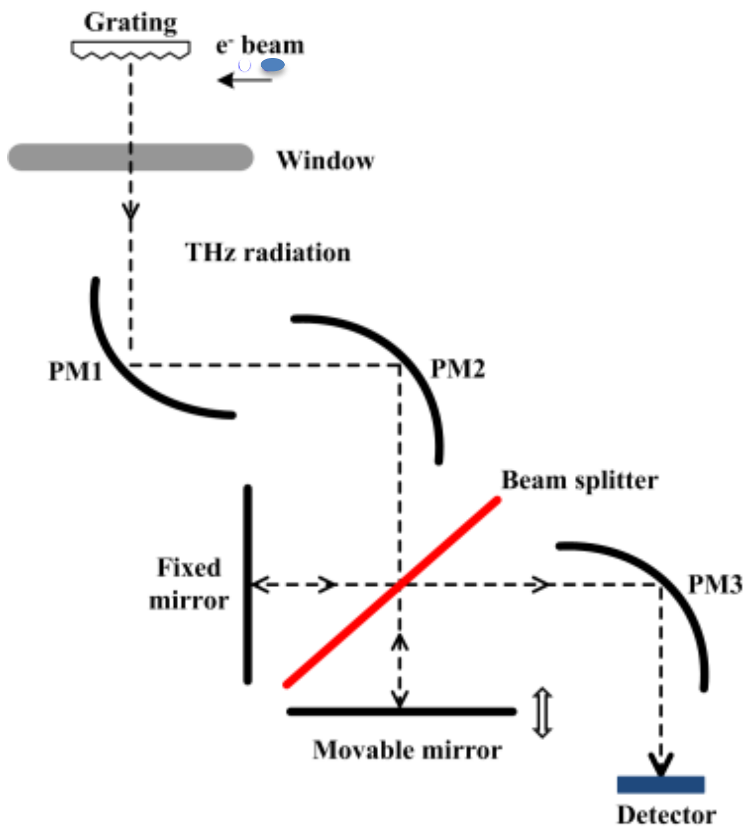
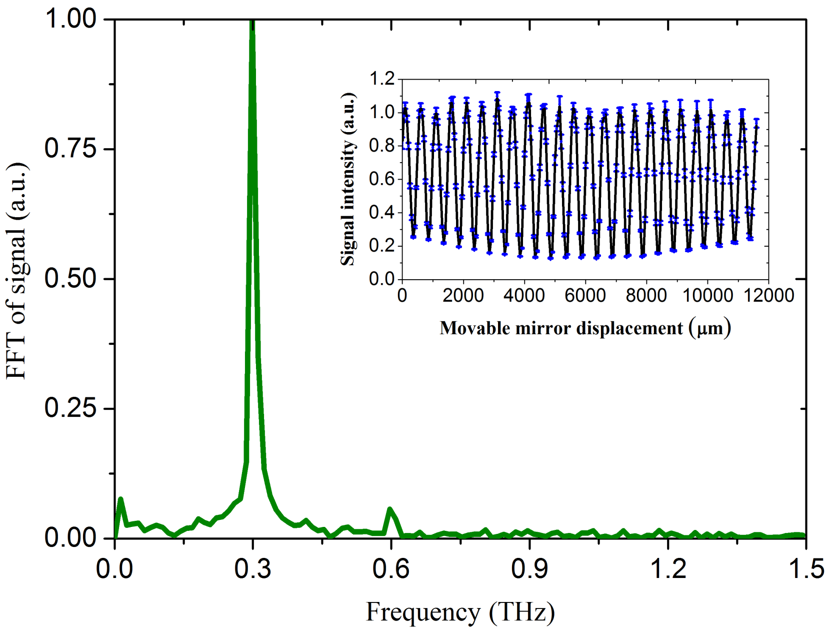
Spectrum of coherent Smith-Purcell radiation

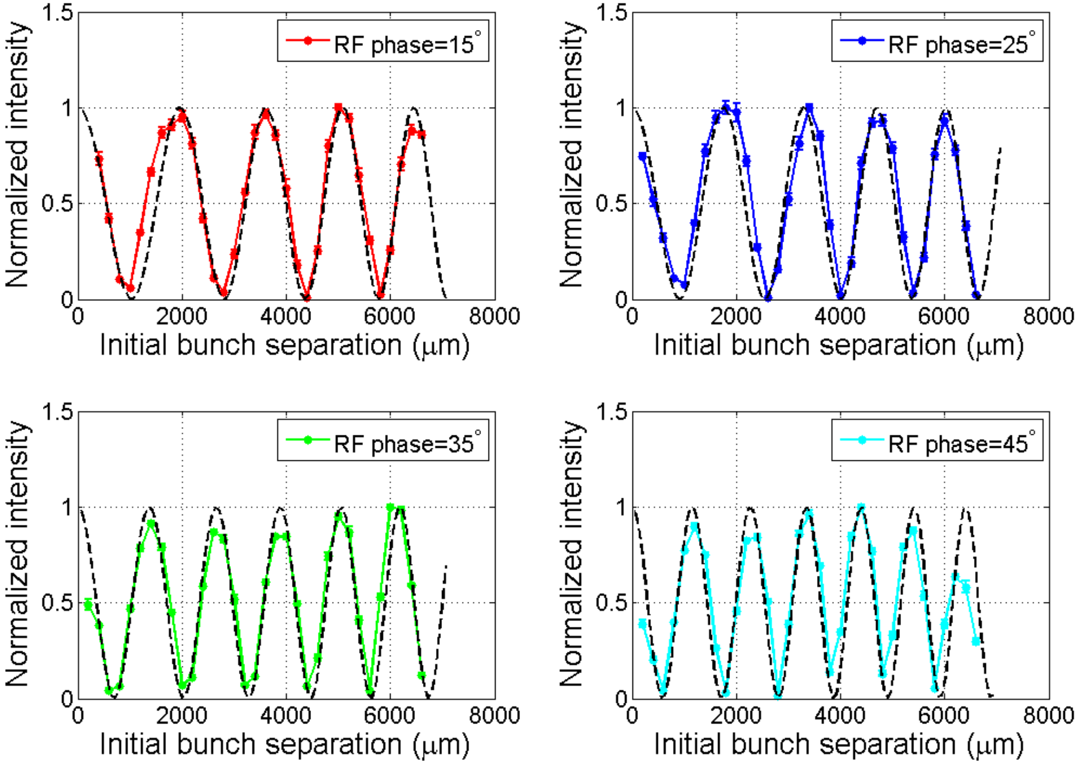


Interferometer installed at LUCX



Spectrum of radiation measured at θ= 90° detector position

Two-bunch interferogram of coherent Smith-Purcell radiation



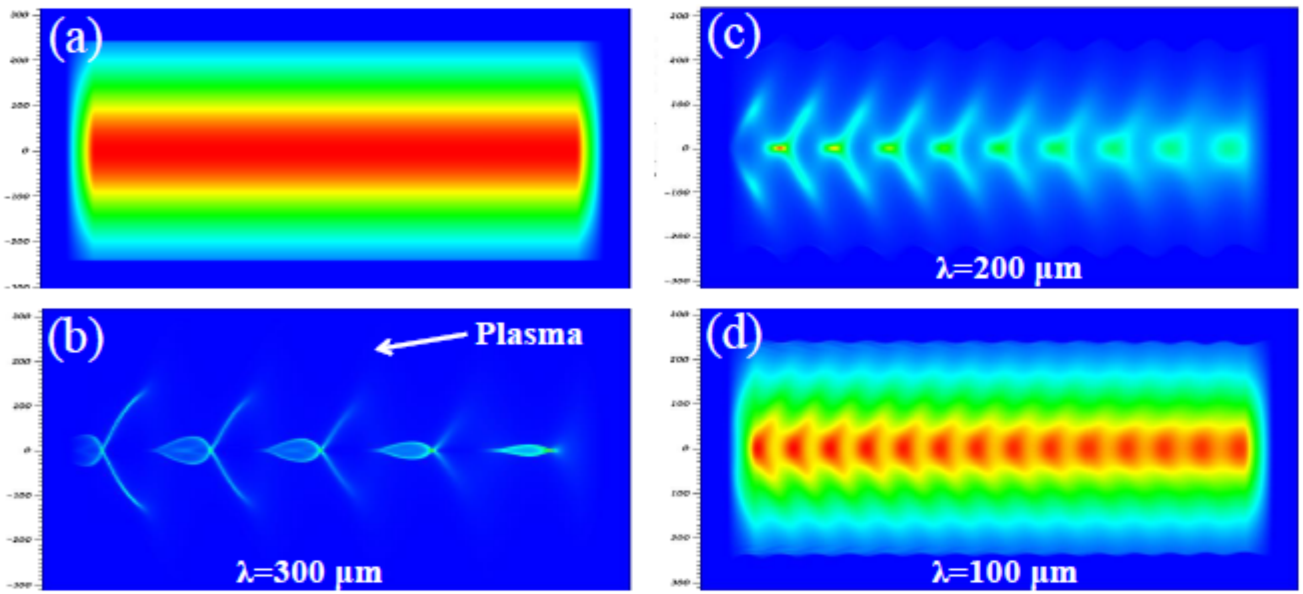
Study of two-bunch interferogram: each bunch generates coherent radiation which interfere creating typical interference patterns

Conclusion

- Brief overview of THz radiation sources
- Steps toward coherent THz radiation source
- Concept of new THz source of coherent radiation based on cSPr

Thank you

Pre-bunched beam for THz radiation generation using beam plasma interaction



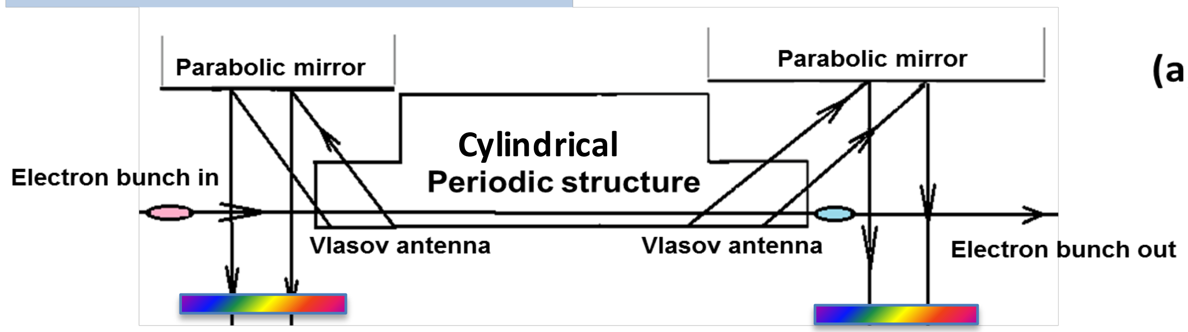
Beam density distribution. (a) Initial beam charge distribution (Energy=50MeV, total charge=0.5nC, length=1.5mm); (b)-(d) Beam density distribution after propagating 1.8cm through plasmas with different densities (λ is the plasma wavelength).

Source of coherent SP radiation

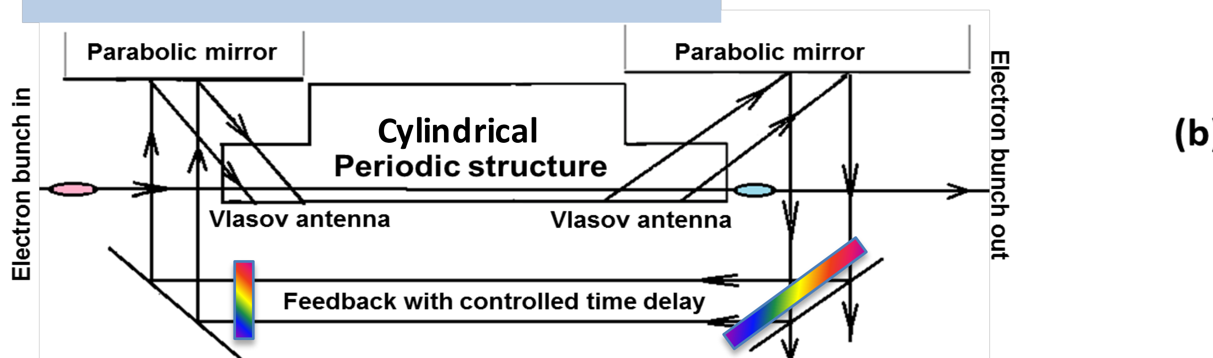
concept of experiment at LUCX (KEK, Japan)

The $2Q/\omega$ time (EM field decay time inside the cavity) is less as compared with distance between two neighbouring bunches

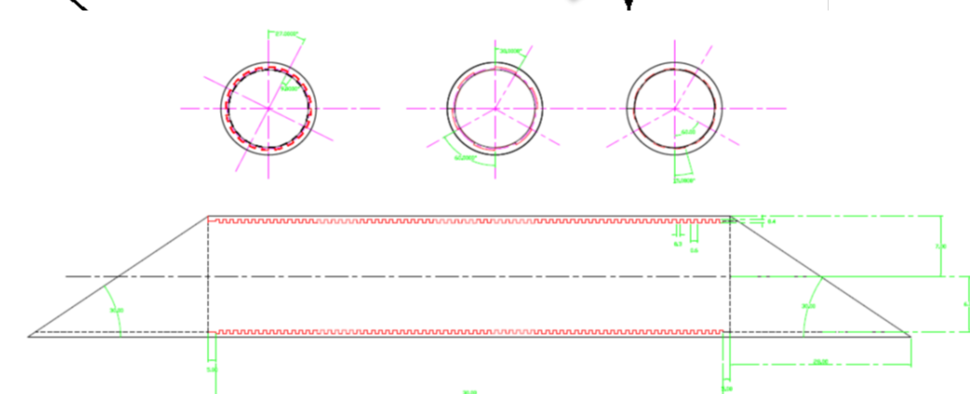
Broadband THz source of cSPr



Narrow band THz source of cSPr



1/ The $(2Q/\omega)$ time is controlled by additional feedback mirrors
2/ Timing between feedback loop and distance between bunches also can be controlled
3/ Tuning via frequency selection inside feedback loop



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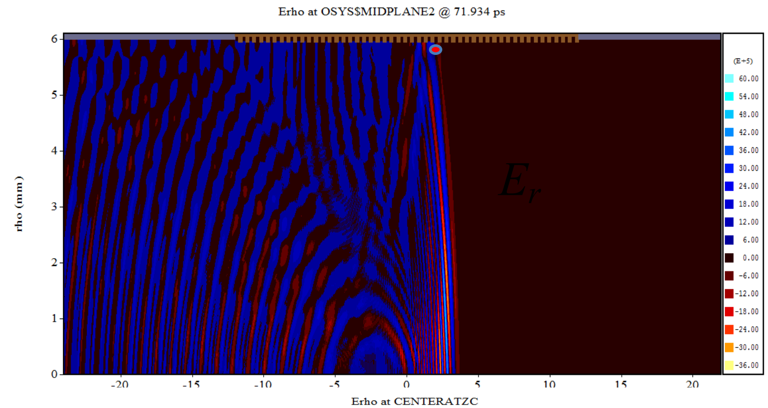
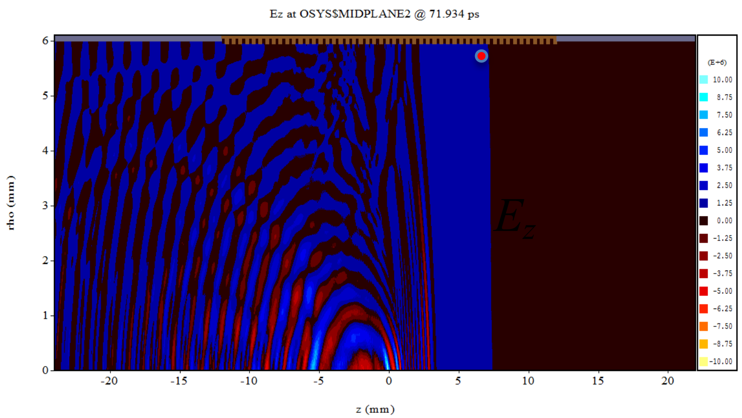
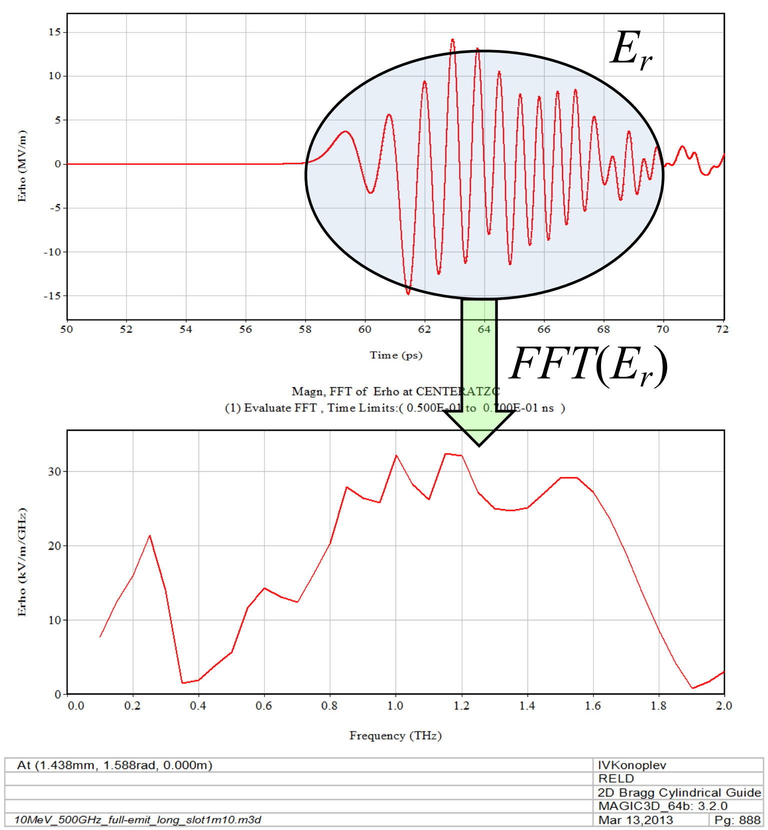
Source of coherent SP radiation

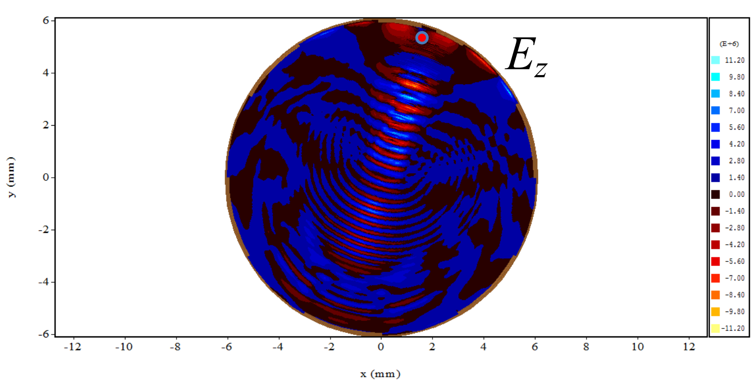
Electron bunch having the following parameters:

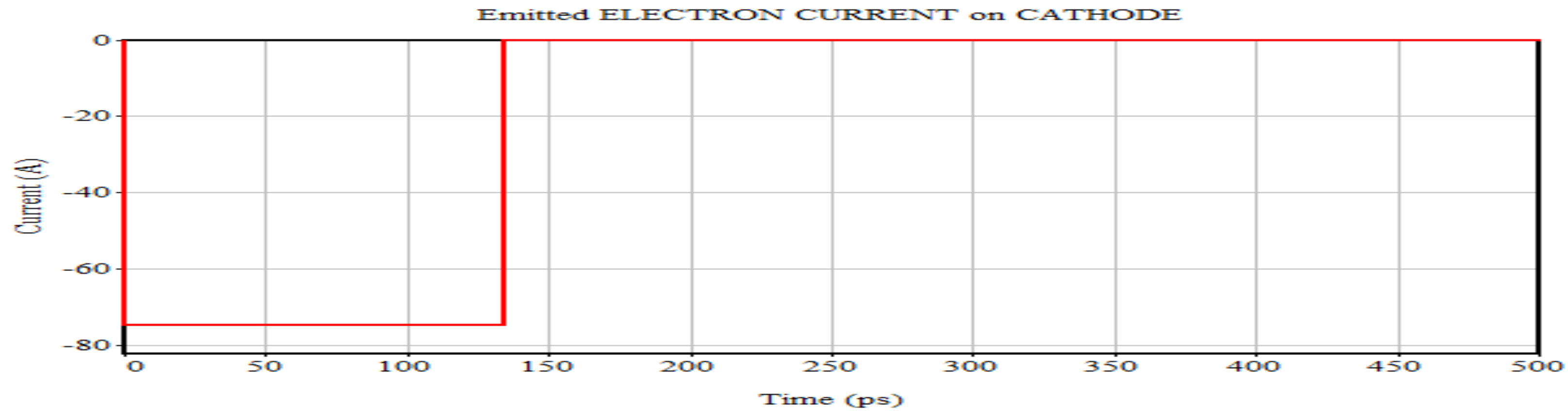
- 0.8nc
- Bunch length 800fs
- Electron energy 8MeV











on Conductor/Surface CATHODE	IVK	
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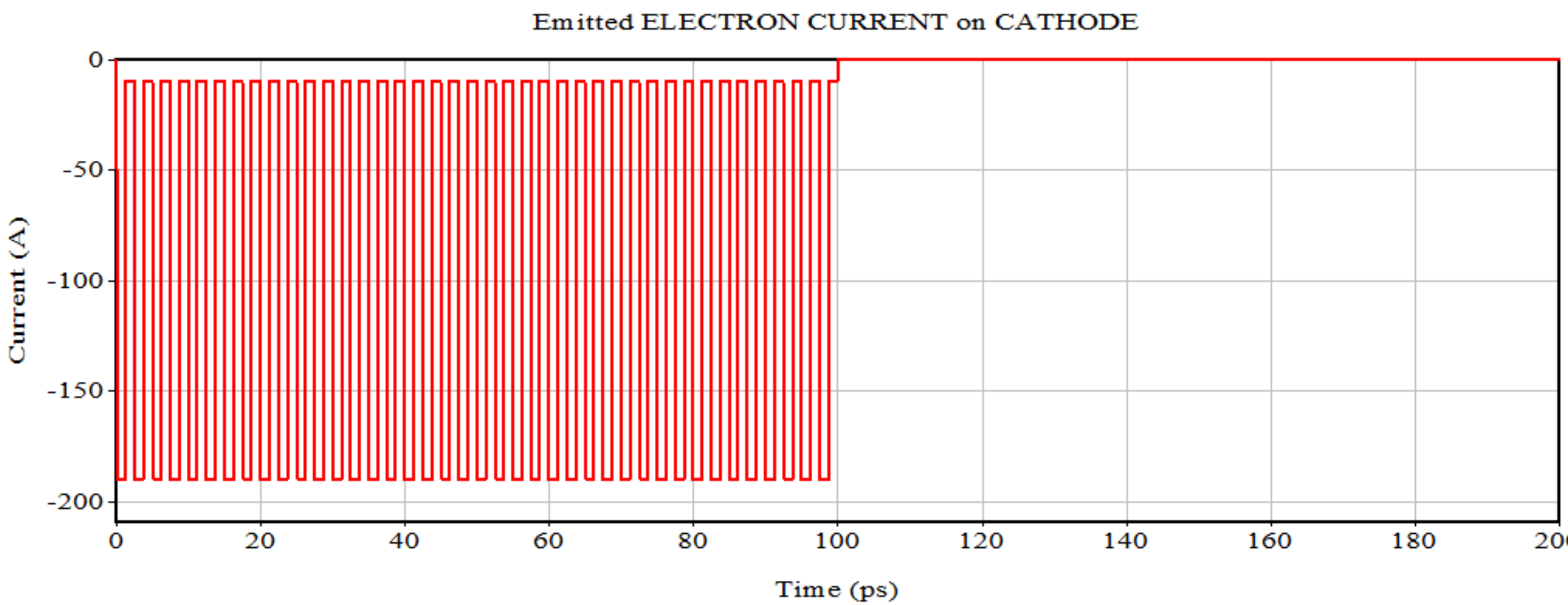
	c-Smith-Purcell-radiator	
	MAGIC3D_64b: 3.2.2	
SP test-1i0mm-full modulated-bunch-268ps-single-bunch.m3d	Sep 06,2016	Pg: 1



on Conductor/Surface CATHODE	IVK	
	JAI, University of OXFORD	
	c-Smith-Purcell-radiator	
	MAGIC3D_64b: 3.2.2	
SP test-1i0mm-full modulated-bunch-1i5ps.m3d	Sep 22,2016	Pg: 1428