Numerical Simulation of a Superradiant THz FEL Source at the PITZ Facility

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Outline of the Talk

1 Introduction

- Pump & probe experiments at the European XFEL and pump-probe experiments
- THz sources at PITZ
- Superradiant undulator radiation

2 Study process

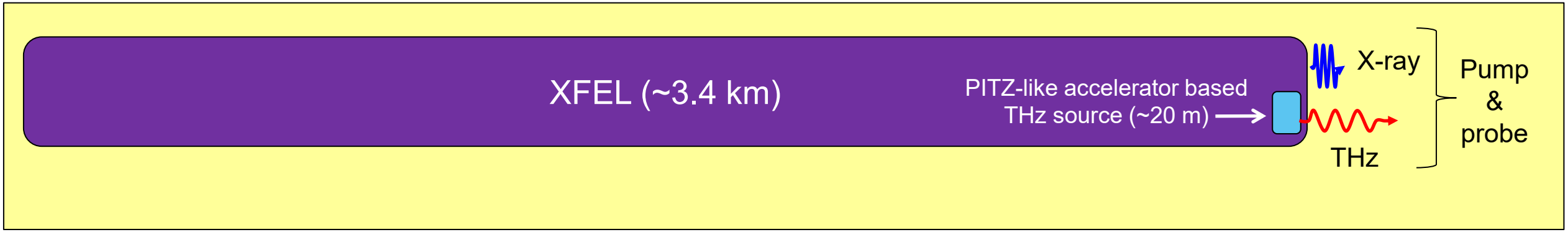
- Electron beam properties at PITZ
- Undulator specifications

3 Results and discussion

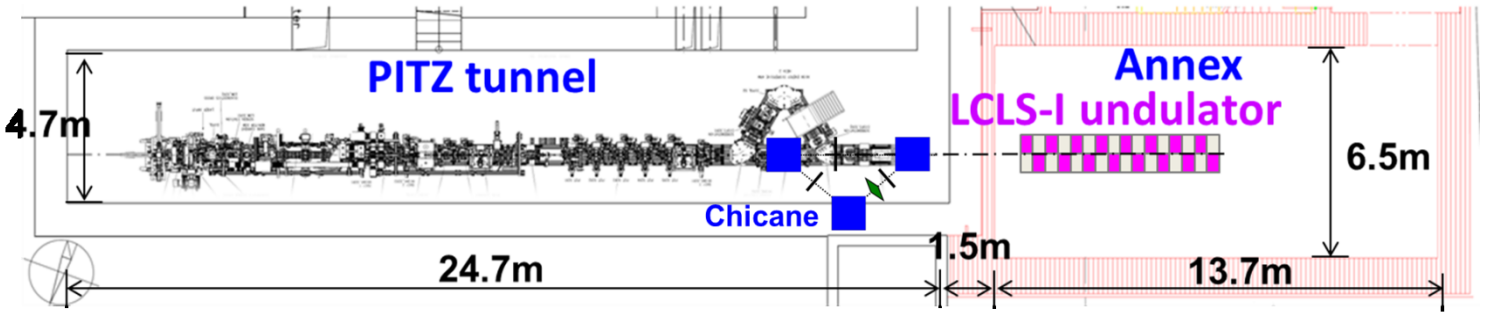
- Observed position
- Dependence of electron beam energy

4 Summary and outlook

Pump & Probe Experiments at the European XFEL



Parameter	Terahertz
Frequency	0.1 - 30 THz
Photon energy	0.4 meV - 0.1 eV
Wavelength	3 mm - 10 μm
Peak power	MW
Pulse energy	μJ - mJ
Application	• Ultrafast magnetism • Molecular vibration, rotations and alignment



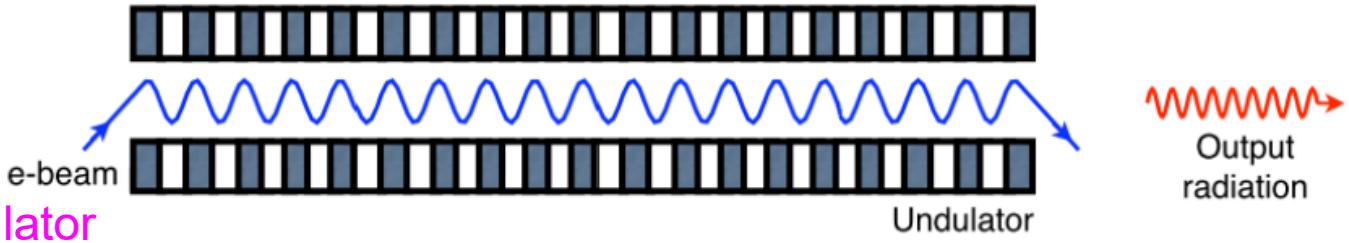
THz radiation produced from PITZ is synchronized with the x-ray pulses.

THz Pump & X-ray Probe Experiment

Options of THz source

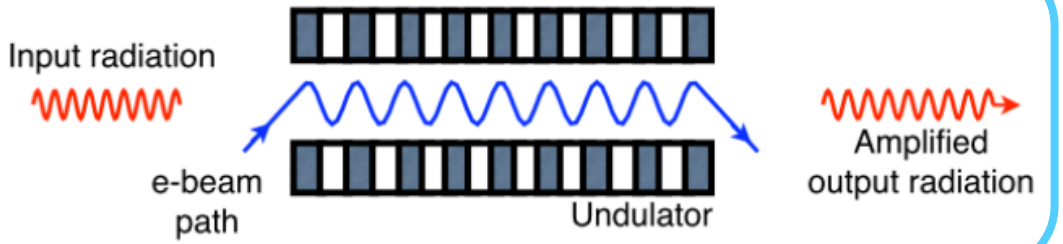
SASE FEL

Requires a long undulator



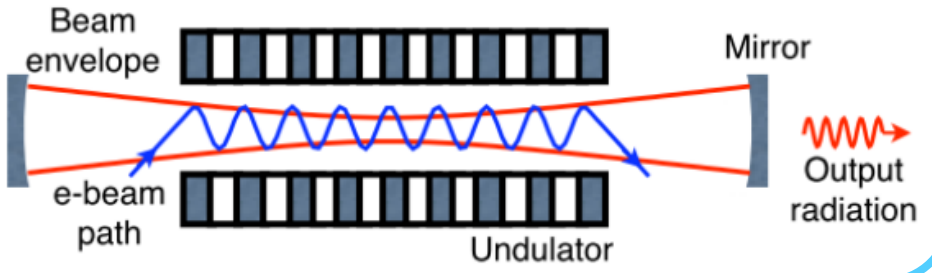
Seeded FEL

Requires input laser



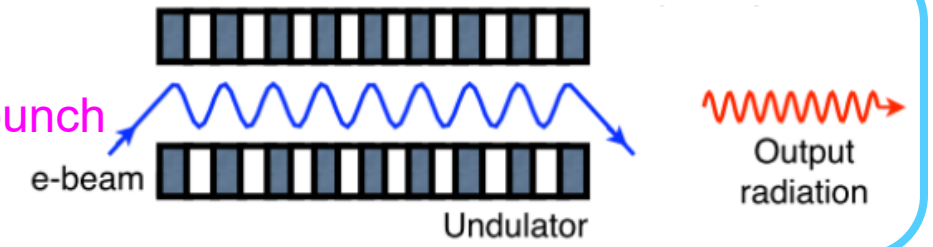
Oscillator FEL

Requires mirrors



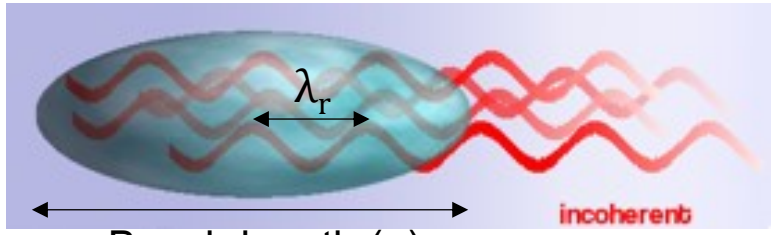
Pre-bunch FEL

Requires short electron bunch

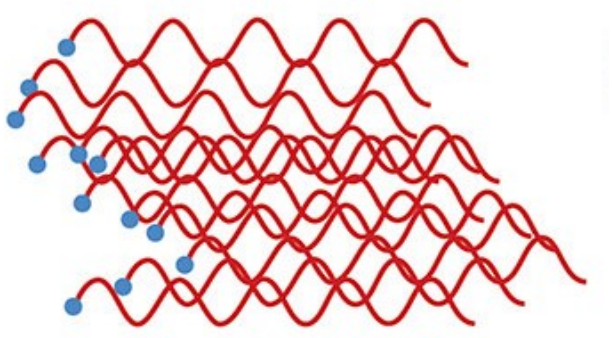


Superradiant undulator radiation

Incoherent radiation



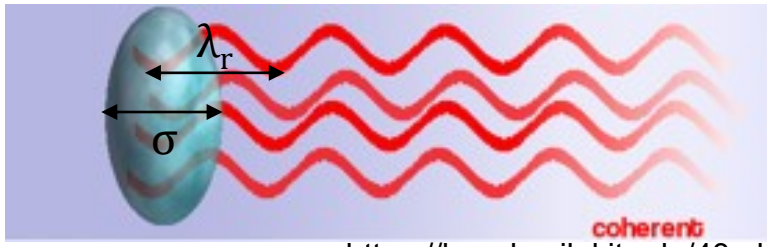
Bunch length (σ)



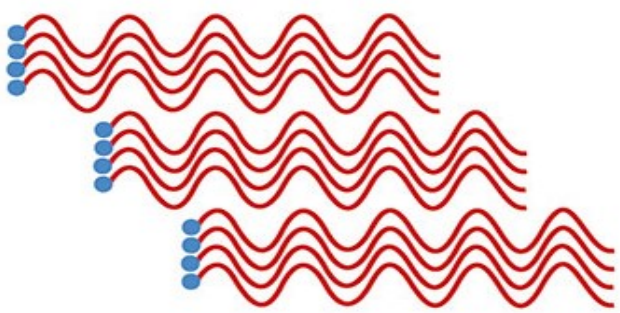
The intensity of the incoherent radiation is proportional to the electron number.

Intensity α N_e

Coherent radiation



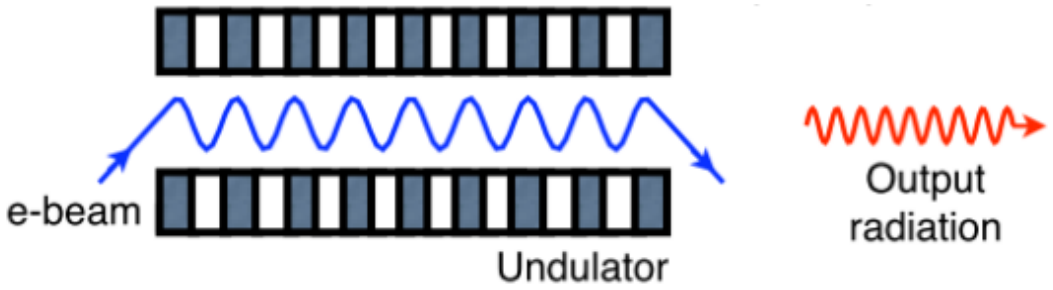
https://las.physik.kit.edu/43.php



The coherent radiation can be called **superradiant emission** or **a pre-bunched FEL**

Intensity α N_e^2

Superradiant undulator radiation



Radiation wavelength

$$\lambda_r = \frac{\lambda_u}{2n\gamma^2}\left(1 + \frac{K^2}{2} + \theta^2\gamma^2\right)$$

Undulator parameter

$$K = \frac{eB_0\lambda_u}{2\pi m_e c} = 0.934 B_0 \lambda_u$$

Total radiated energy

$$W_{tot} = W_{1e} N_e \left[1 + \left(N_e - 1\right) f(\omega)\right]$$

Spectral brightness

$$B_r = \frac{dN_{ph}/dt}{d\Omega dA\, d\omega/\omega} = \frac{\dot{N}_{ph}}{4\pi^2 \Sigma_x \Sigma_y \Sigma_{x'} \Sigma_{y'}}$$

Average power

$$P_{average}(\lambda_r) = \frac{\pi e^2}{2\varepsilon_0} \frac{N_u N_b \left(2n\gamma^2\lambda_r - \lambda_u\right)}{\tau_{rep}\gamma^2\lambda_r^2} N_e \left(1 + \left(N_e - 1\right) f(\omega)\right)\left(\frac{\Delta\omega}{\omega}\right) L_n F_n$$

Study process

Electron beam properties at PITZ and Undulator specification

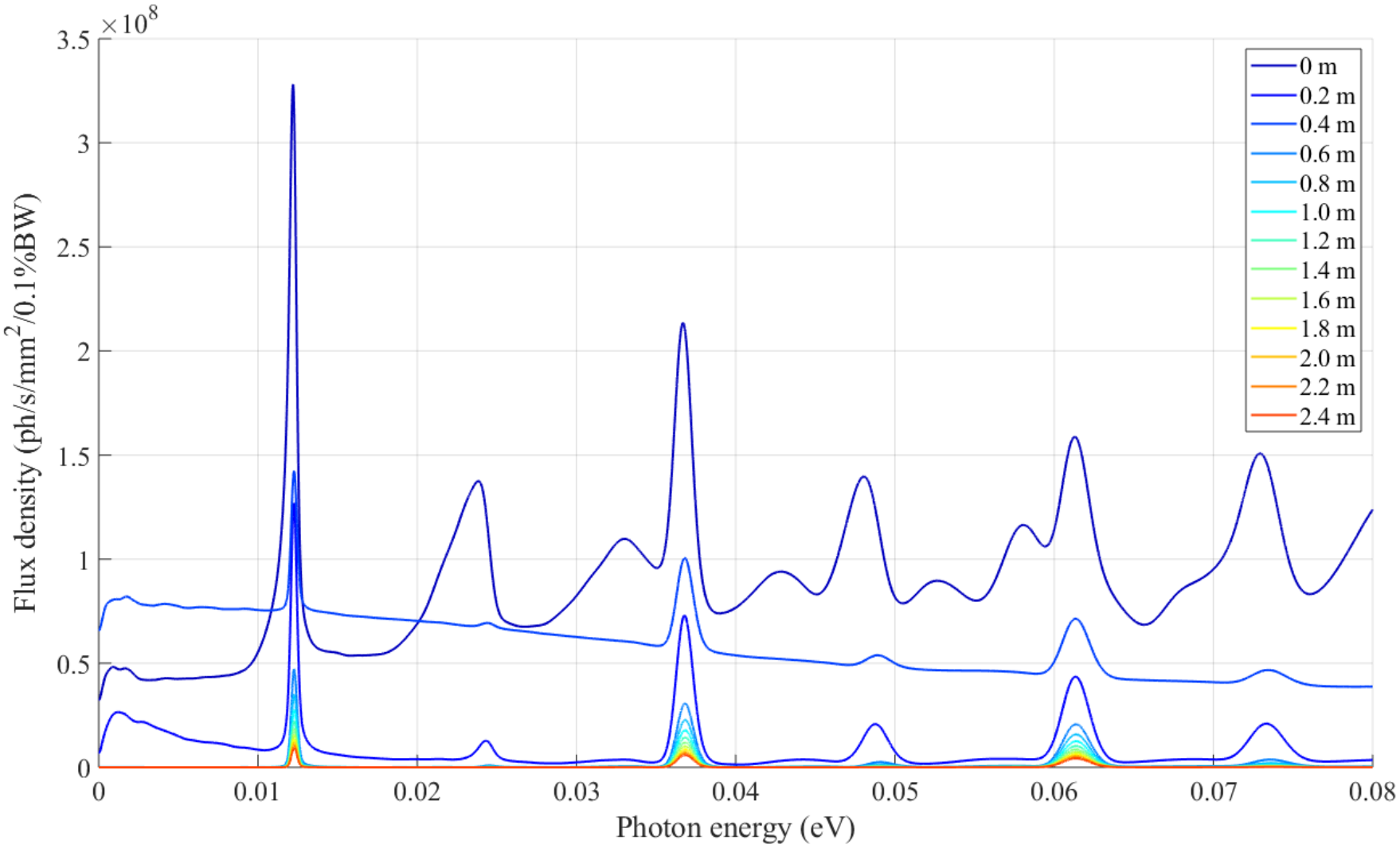
Properties	Electron beam
Bunch charge	**1 nC**
Energy	16.6 MeV
Energy spread	0.7%
FWHM Bunch length	391.8 µm
Emittance y	0.51 mm.mrad
Emittance x	0.07 mm.mrad

Properties	LCLS undulator
Type	planar
K-value	3.58
Undulator length	3.42 m
Vacuum chamber size	11 mm x 5 mm
Magnetic field	1.28 T
Period length	30 mm

Calculation of Superradiant THz undulator radiation by using SPECTRA

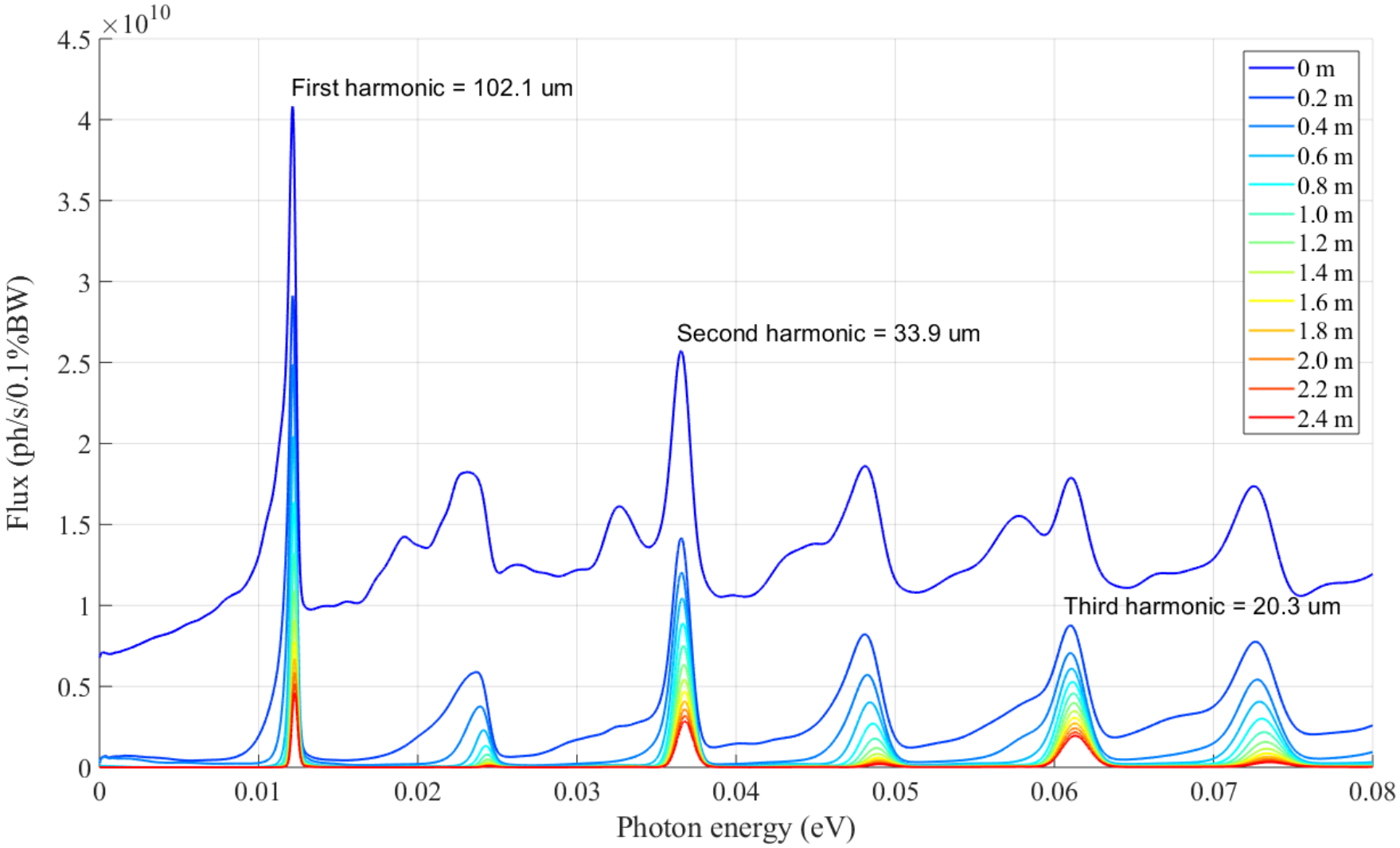
Results and discussion

Flux density on axis with different observed positions



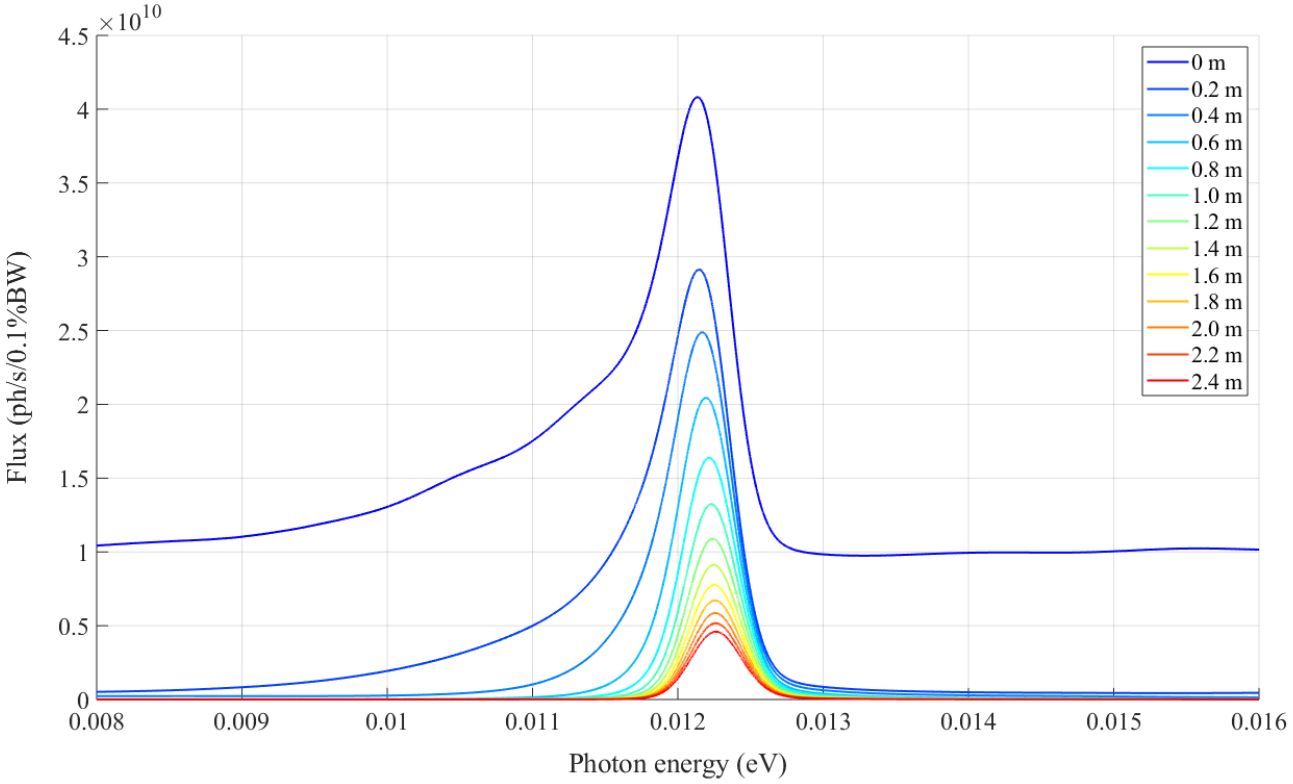
Results and discussion

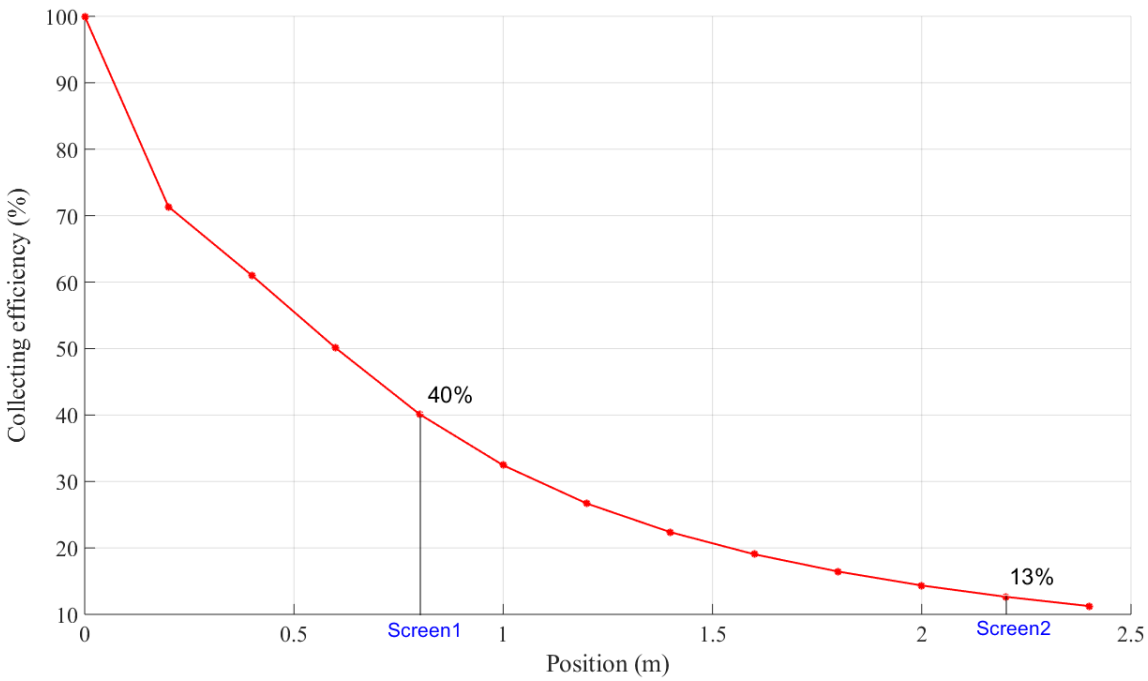
Flux passing through circular aperture with diameter of 1 inch



Results and discussion

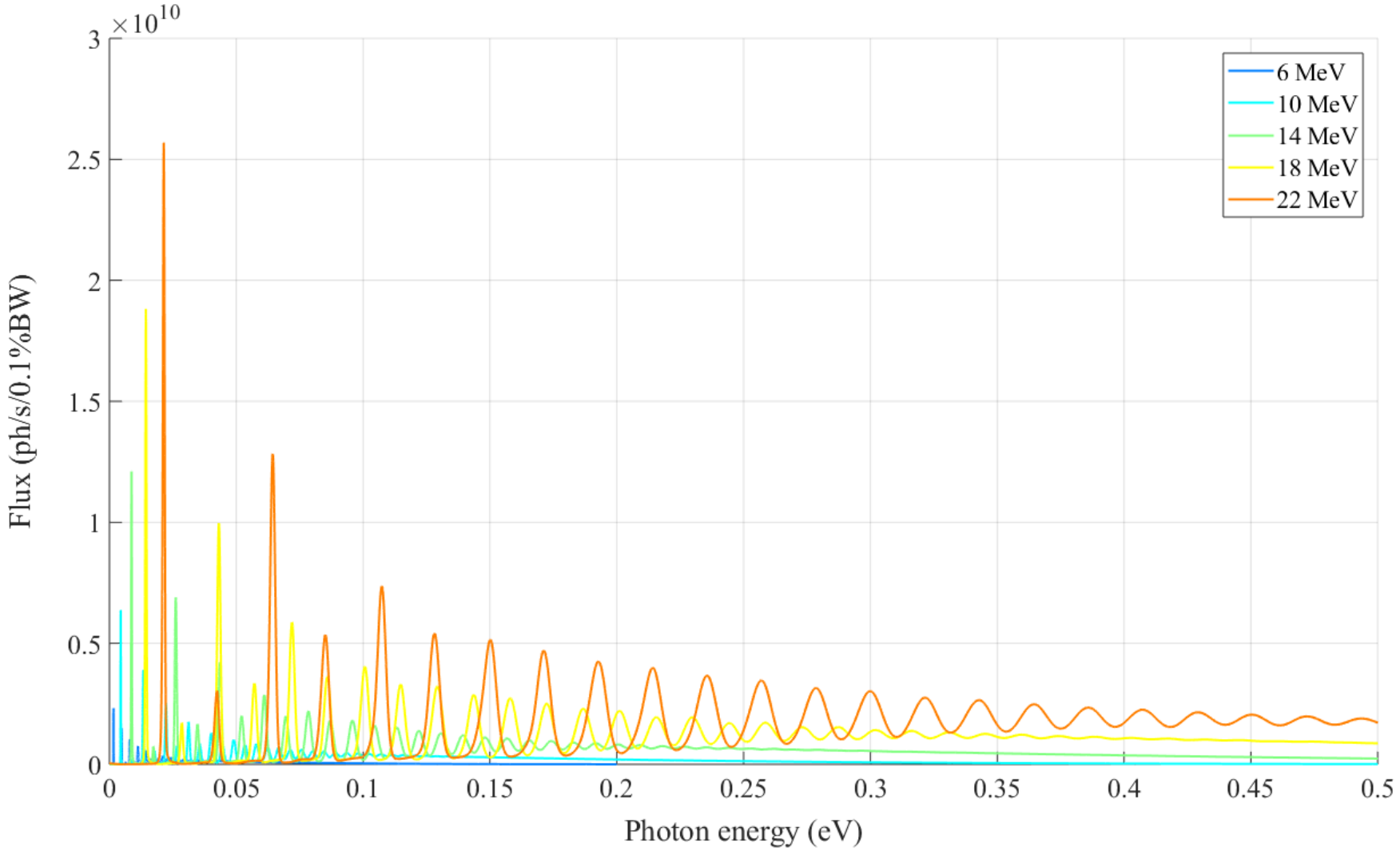
Flux at fundamental harmonic





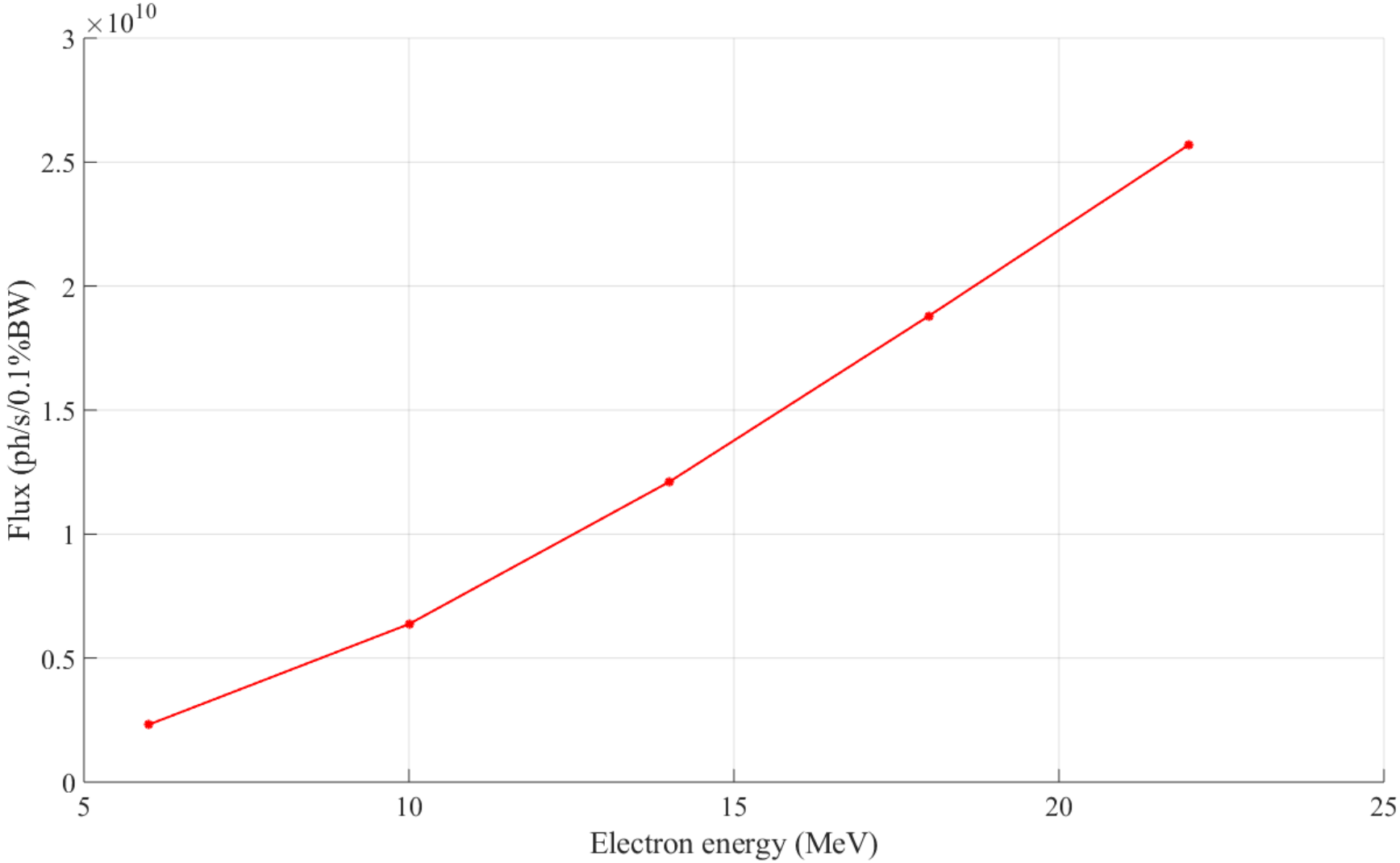
Results and discussion

Flux at screen1 with different beam energies



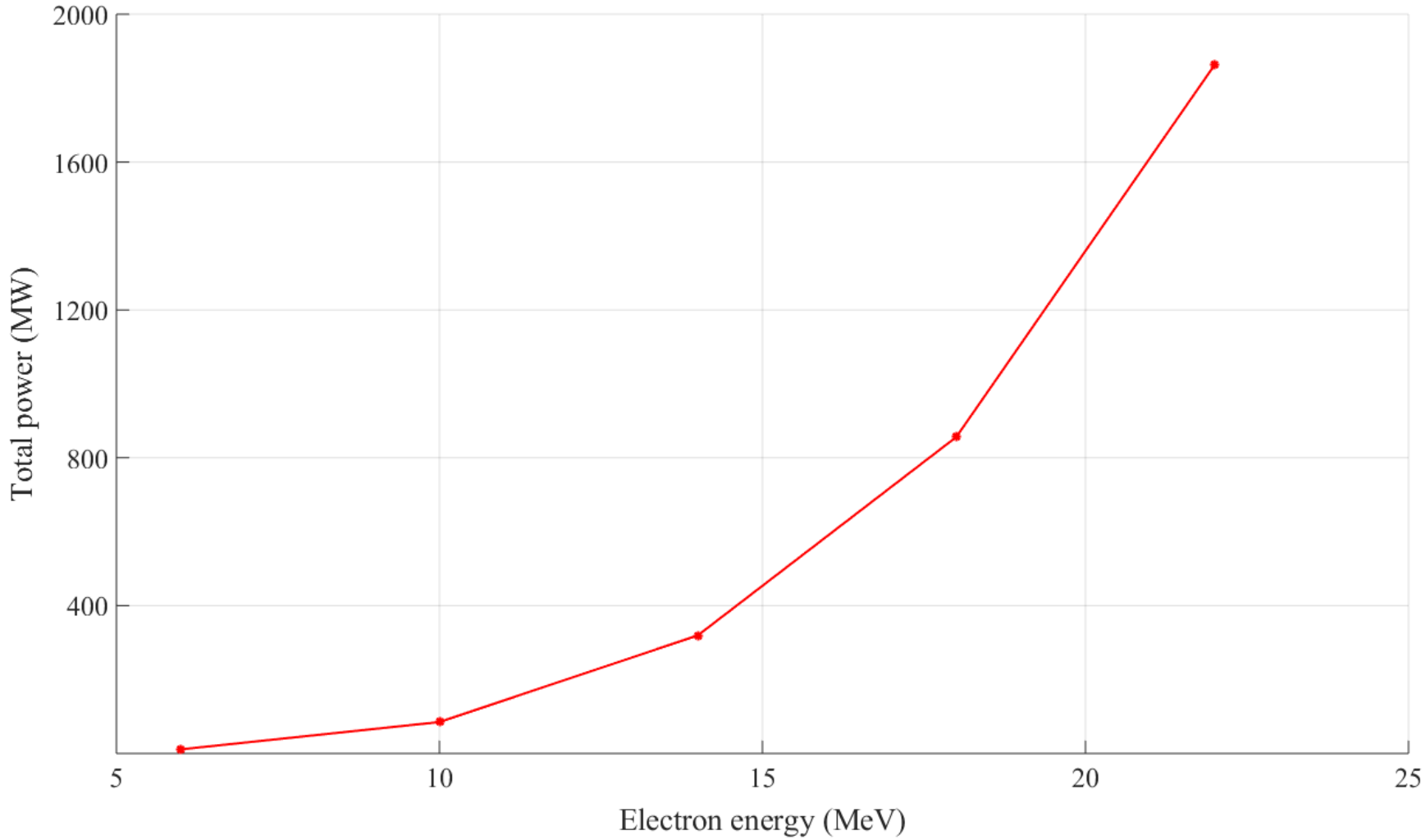
Results and discussion

Total power at screen1 for fundamental harmonic



Results and discussion

Total power at screen1 for fundamental harmonic



Summary and outlook

Summary

- The radiation wavelength of 57 – 772 μm with the total power of 11 – 1800 MW can be received for electron beam energy of 6 – 22 MeV at the fundamental harmonic.
- The total power changes 30% when the electron energy changes 10%.

Outlook

- Vary **bunch length, bunch charge, beam emittance, energy spread**
- Calculate **peak power and pulse energy**
- **3D bunch form factor** included both longitudinal and transverse electron beam properties
- Define **spectral bandwidth** of radiation (spectral filtering and angular filtering)
- **Time** domain analysis
- **Transverse** properties of radiation

Thank you