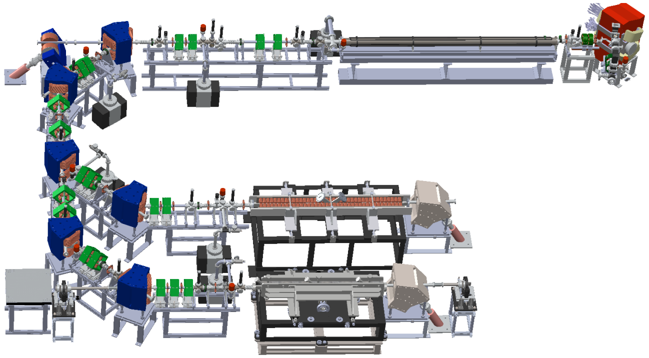
Development of Super-Radiant THz Source in Thailand



Plasma & Beam Physics Research Facility

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Outline

Introduction and motivation

- Terahertz (THz) radiation
- THz applications

Objective

PBP-CMU Electron Linac Laboratory (PCELL) accelerator

- Accelerator specifications

Undulator design

- Undulator simulation
- Radiation calculation

Results and conclusions

Current status of our accelerator

Introduction and motivation

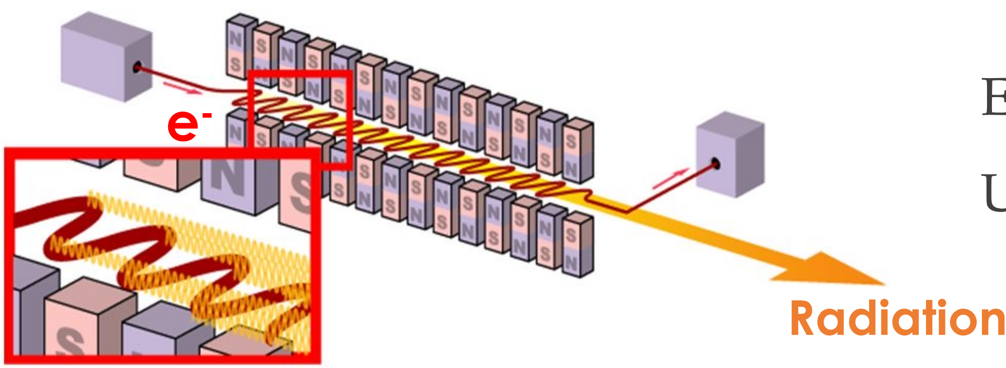
THz radiation source

Low output power radiation source **mW**

i.e. Black body radiation, solid state oscillator, quantum cascad oscillator.

High output power radiation source **MW**

THz **F**ree-**E**lectron **L**aser **(FEL)**



Electron accelerator

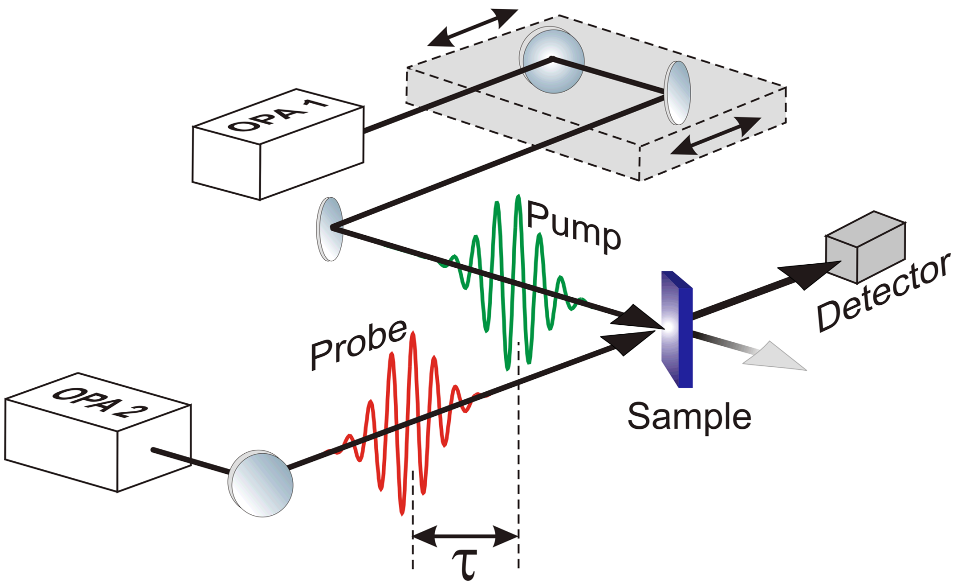
Undulator magnet

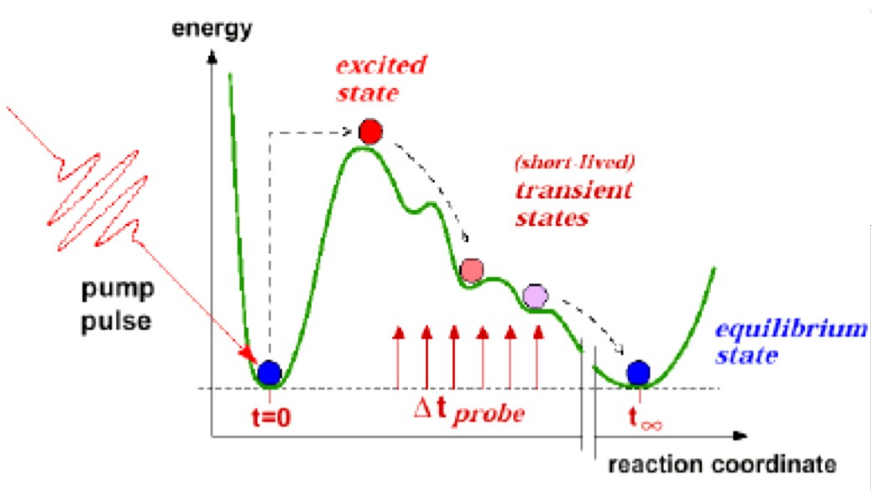
Properties:

Coherence, High power (MW), Tunable-frequency

Introduction and motivation

Applications Pump probe experiment





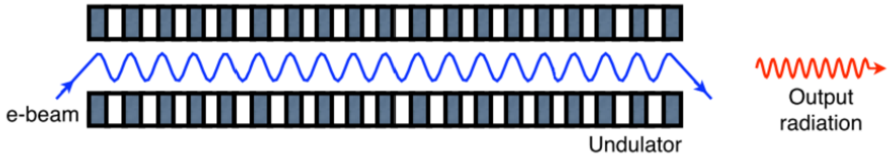
A pump pulse and a probe pulse, that interact with a sample material. The pump pulse initiates a sample response, and a probe pulse monitors the response.

Introduction and motivation

Types of FELs

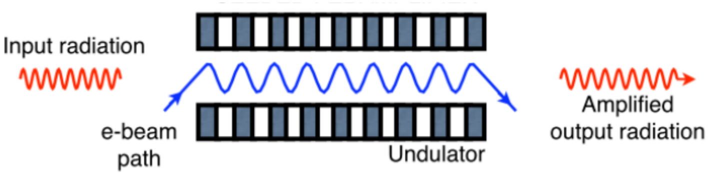
SASE FEL

Long undulator



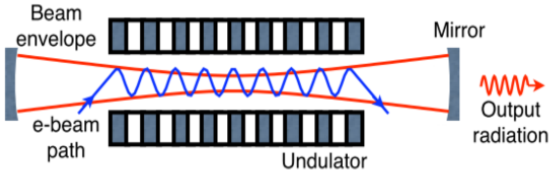
Seeded FEL

Input laser



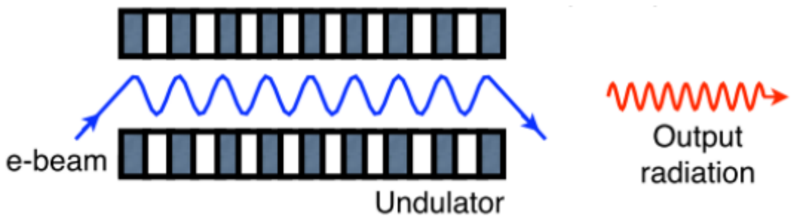
Oscillator FEL

Mirrors



Super-radiant FEL

Short electron bunch

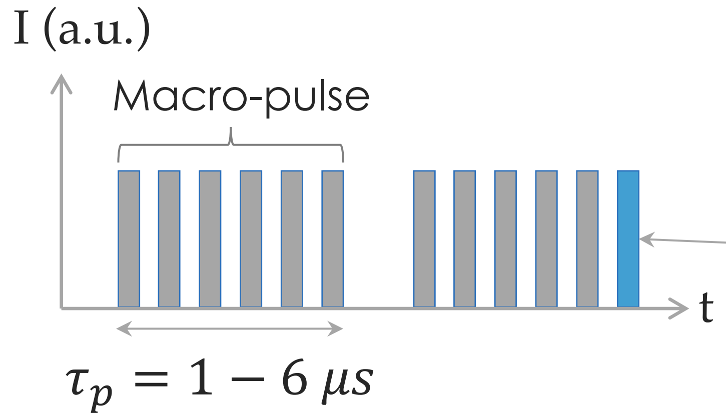


Undulator radiation

Coherent radiation source

Super radiant FEL

RF : 2.856 GHz



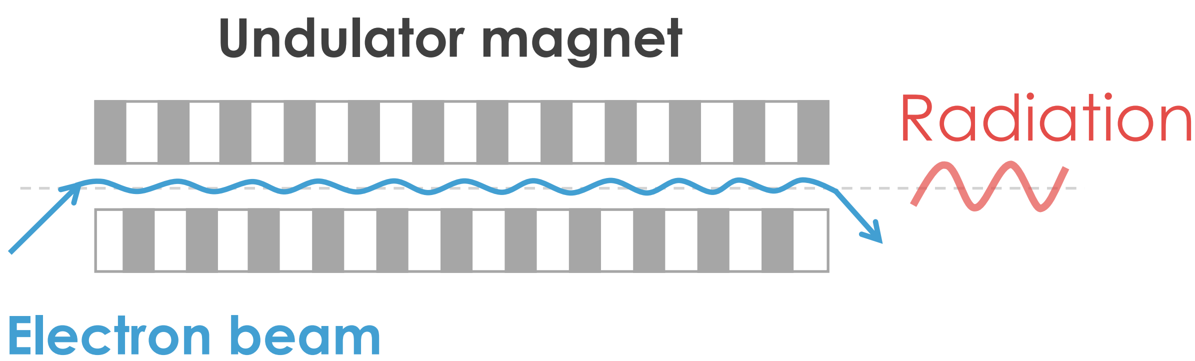
$10^8 - 10^{11}$ electrons

Micro-bunch

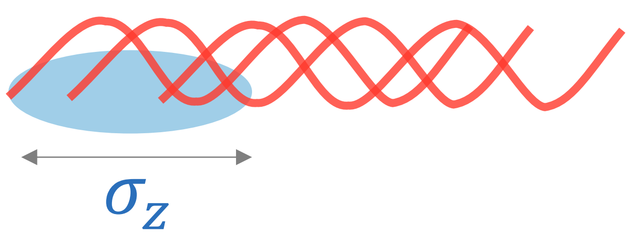
Electron bunch length < radiation wavelength

Undulator radiation

Superradiant radiation

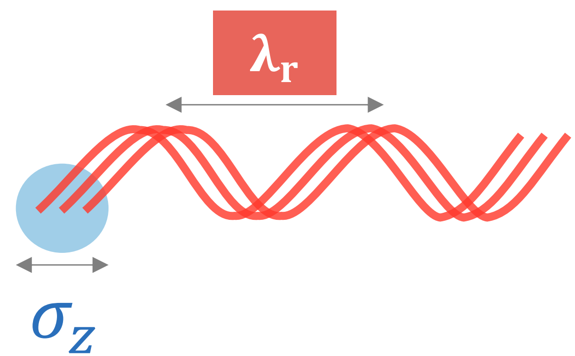


Incoherent radiation



Intensity $\propto N_e$

Coherent radiation



Intensity $\propto N_e^2$

Objective

"To design and develop the electromagnetic undulator for generation of super-radiant THz radiation at the Plasma and Beam Physics Research Facility in Thailand."

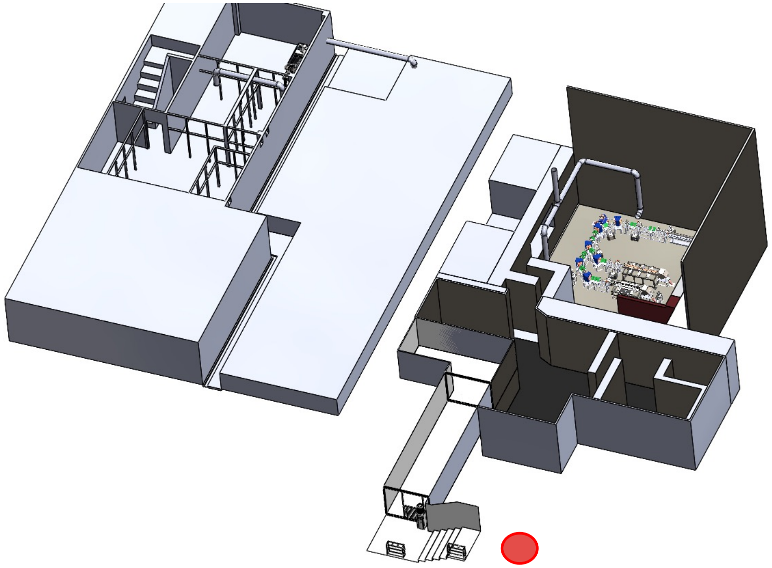
PCELL accelerator

PCELL accelerator

Chaing mai university

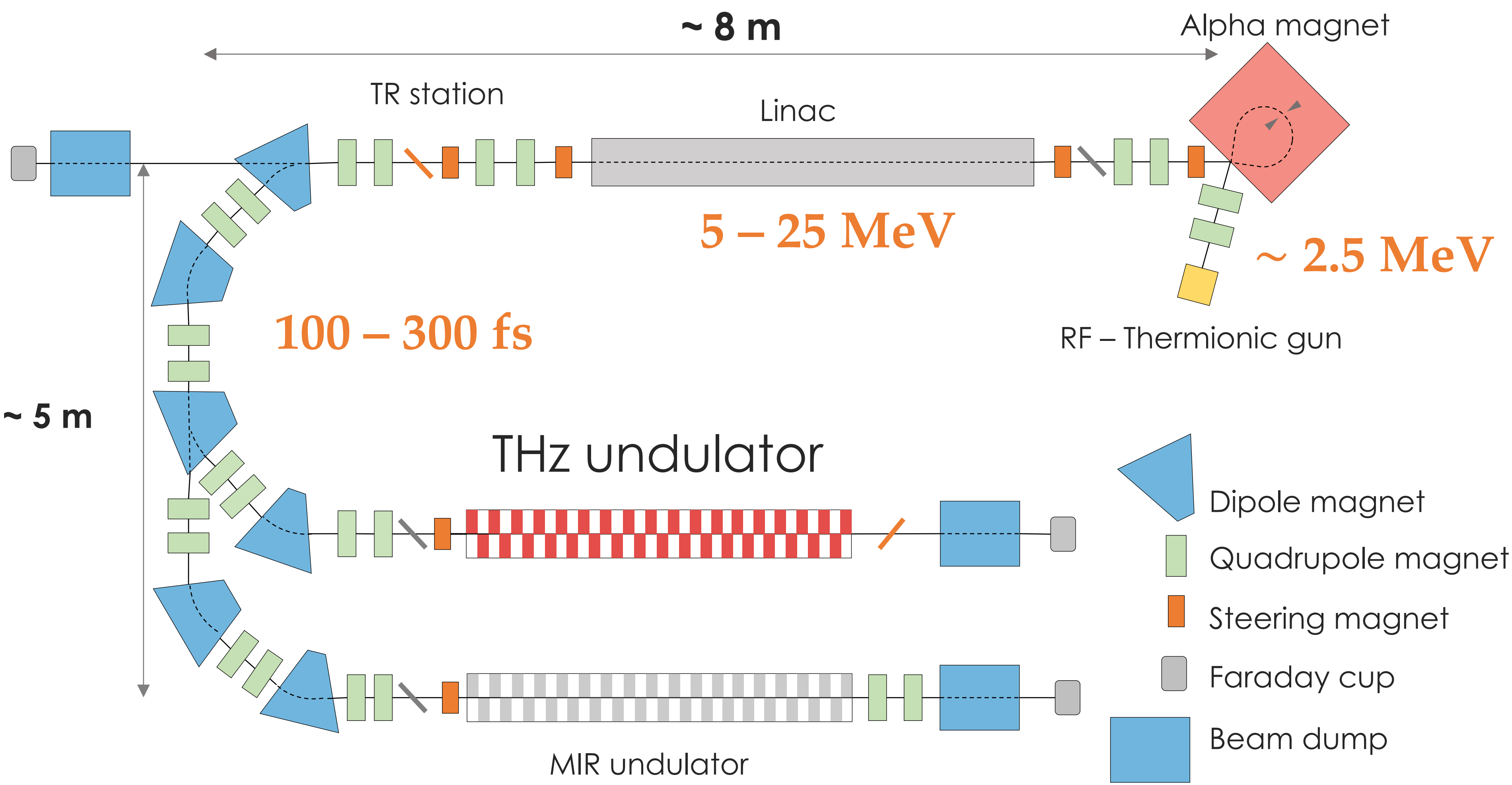
Faculty of science

PBP-CMU Electron Linac Laboratory (PCELL)



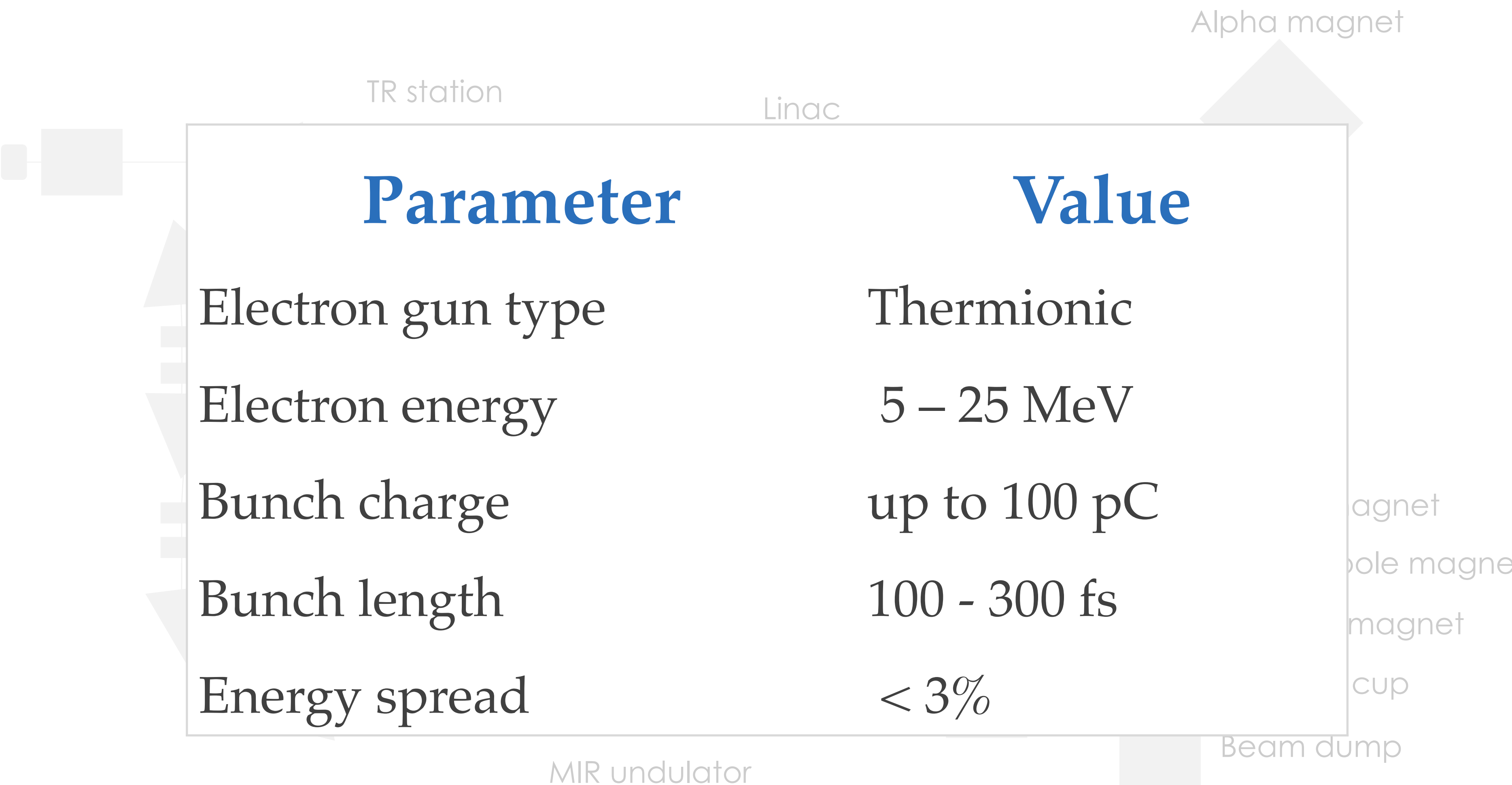
PCELL accelerator

PBP-CMU Electron Linac Laboratory (PCELL) Diagram



PCELL accelerator

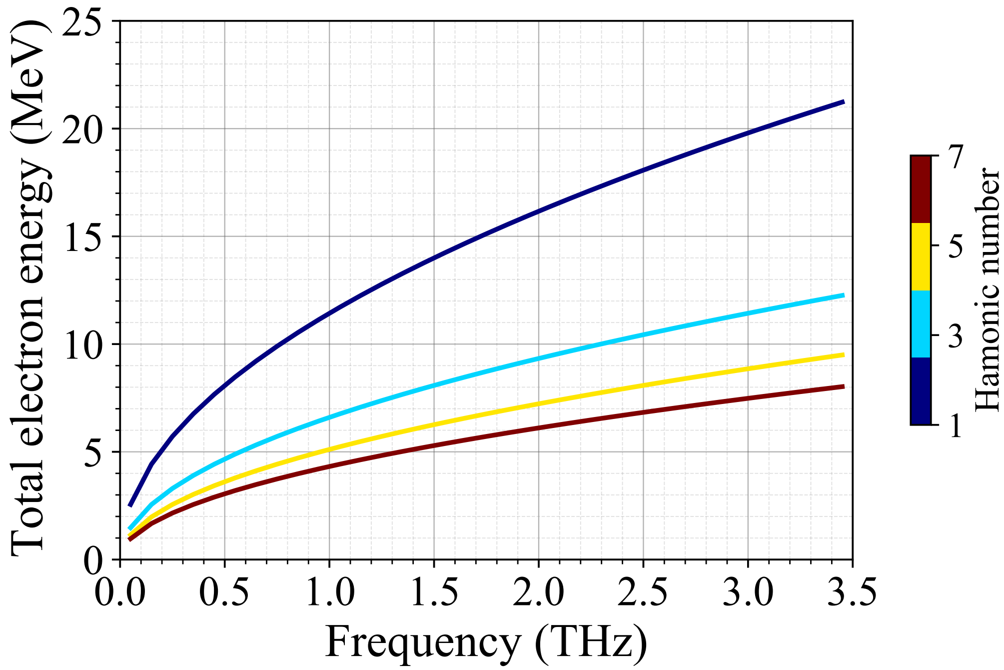
PCELL Accelerator Specifications



Parameter	Value
Electron gun type	Thermionic
Electron energy	5 – 25 MeV
Bunch charge	up to 100 pC
Bunch length	100 - 300 fs
Energy spread	$< 3\%$

Undulator design

Possible harmonic number at PCELL



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

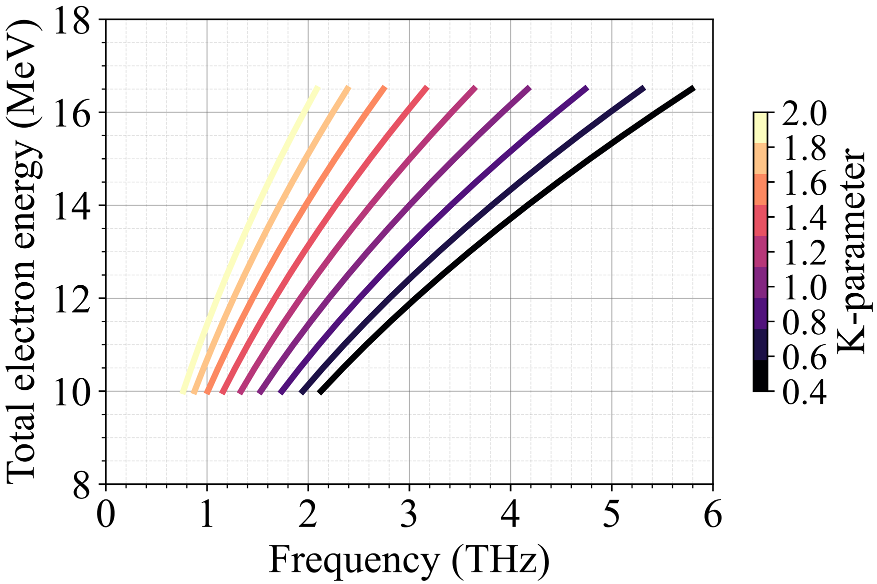
Harmonic number : 1, 3, 5, 7

1st harmonic : 0.5 – 3.5 THz

Undulator period length : 100 mm

Undulator design

PCELL Accelerator Specifications



Parameter	Value
Electron energy	10 – 16 MeV
Bunch charge	up to 100 pC
Bunch length	100 - 300 fs
Energy spread	$< 3\%$
Radiation frequency	0.5 – 3 THz
Radiation wavelength	300 – 100 μm
Period length	100 mm

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

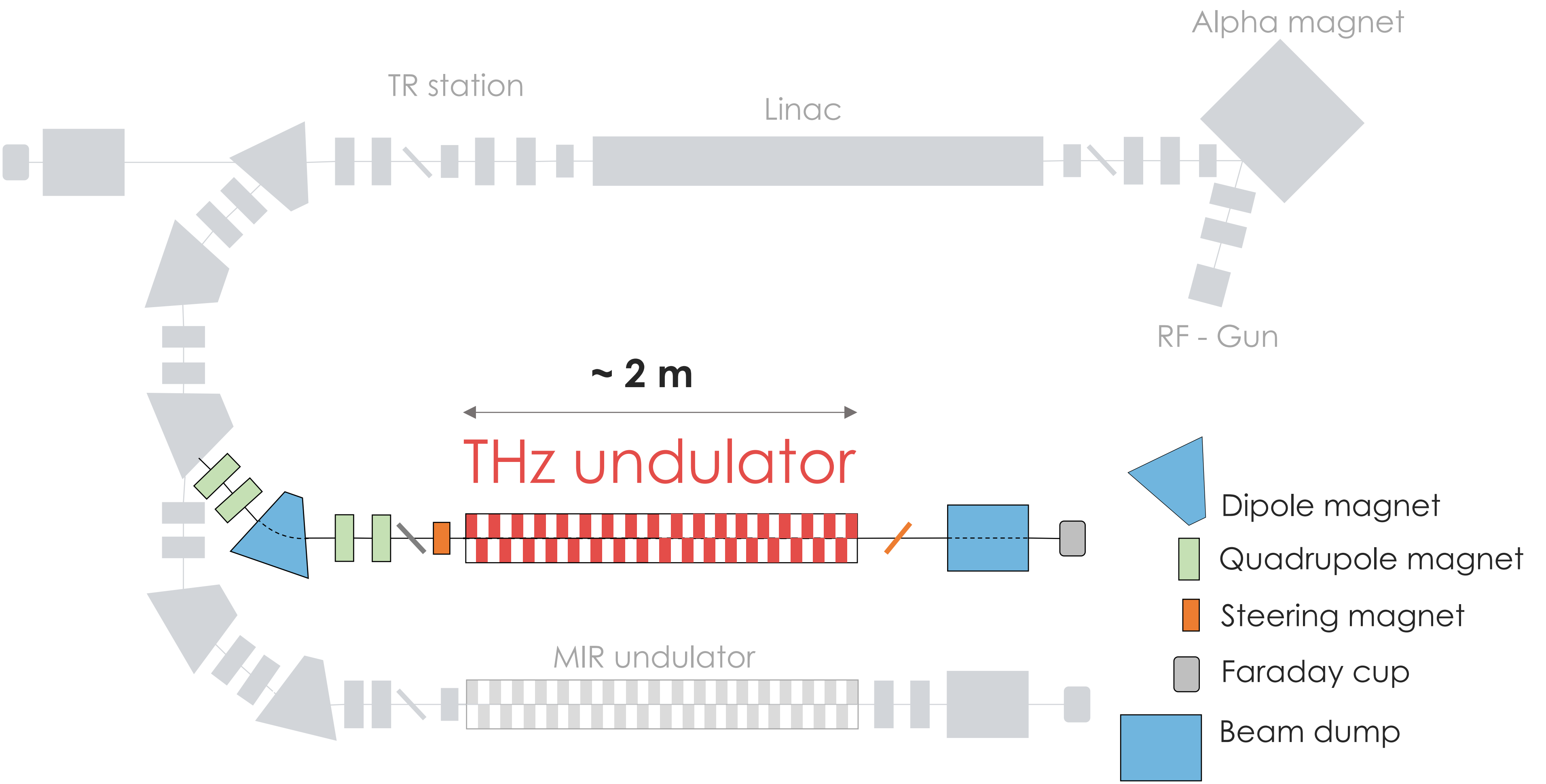
$K = 0.934 B[T] \lambda_u [cm]$

Pump-probe experiment

100 – 400 µm (3 – 0.75 THz)

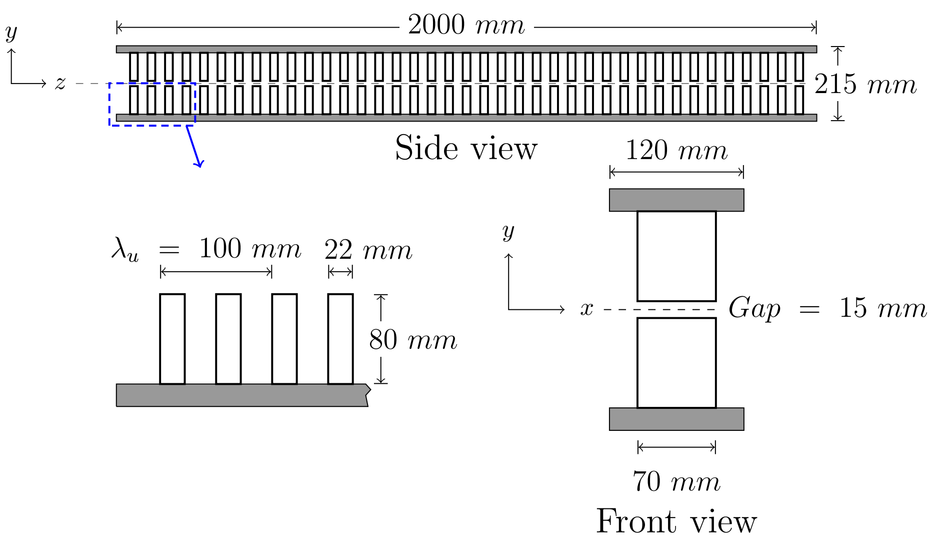
Undulator design

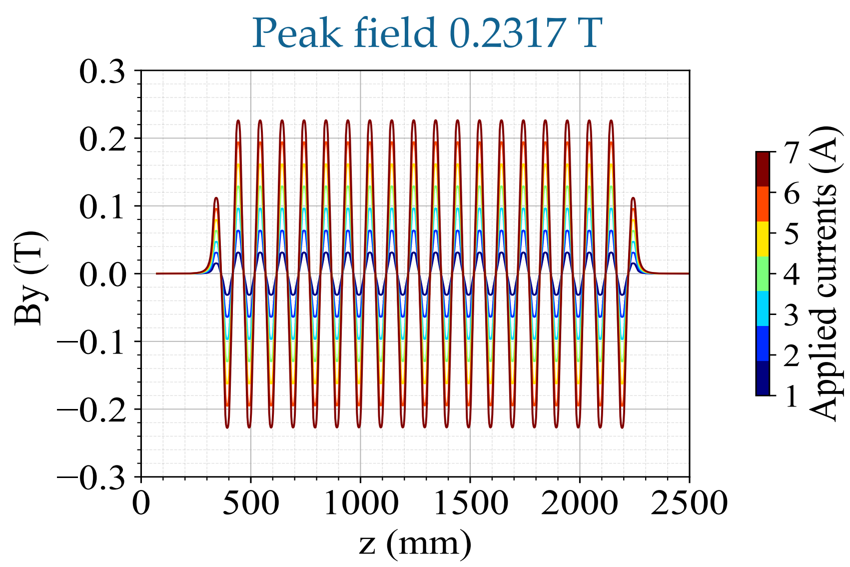
THz beamline



Undulator design

Undulator Simulation

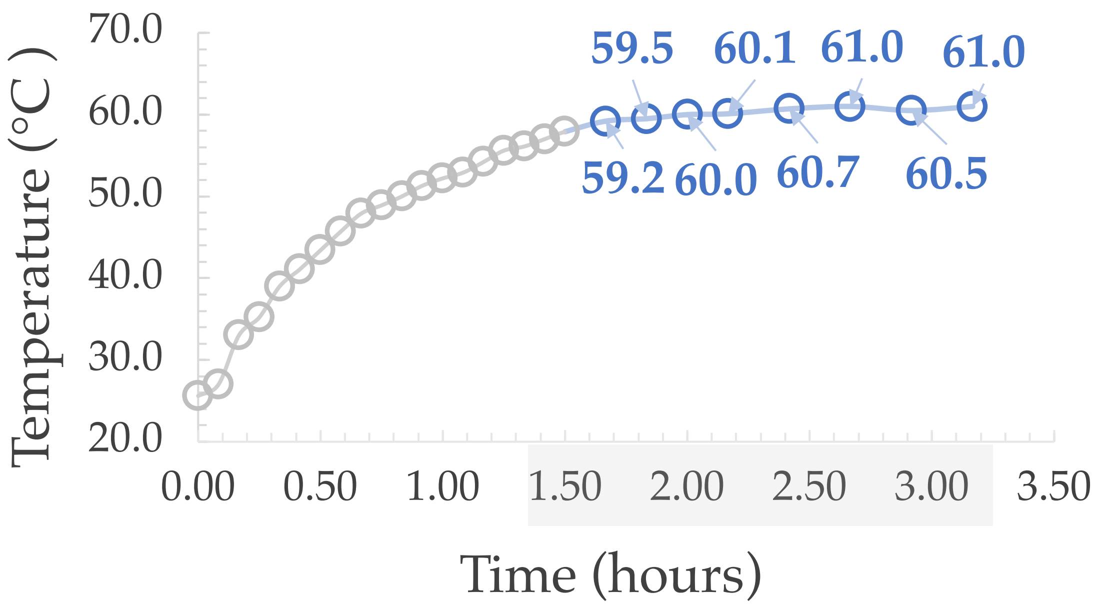




Parameter	Value
Number of periods	19.5
Period length (λ_u)	**100 mm**
Gap (g)	15 mm
K	0.1 – 2.164

Undulator design

Copper coil without cooling



Parameter	Value
Peak field	0.2317 T
Maximum applied current	7 A
Number of turns per pole	249
Coil diameter	1.829 mm (SWG No 15)

Undulator radiation

Superradiant radiation

Radiation energy of an electron bunch

Coherence Incoherence

$$W_{pulse} = W_{1e}[f(\omega, \sigma_t)N_e^2 - N_e(1 - f(\omega, \sigma_t))]$$

Gaussian bunch form factor

$$f(\omega, \sigma_t) = \exp(-\omega^2\sigma_t^2)$$

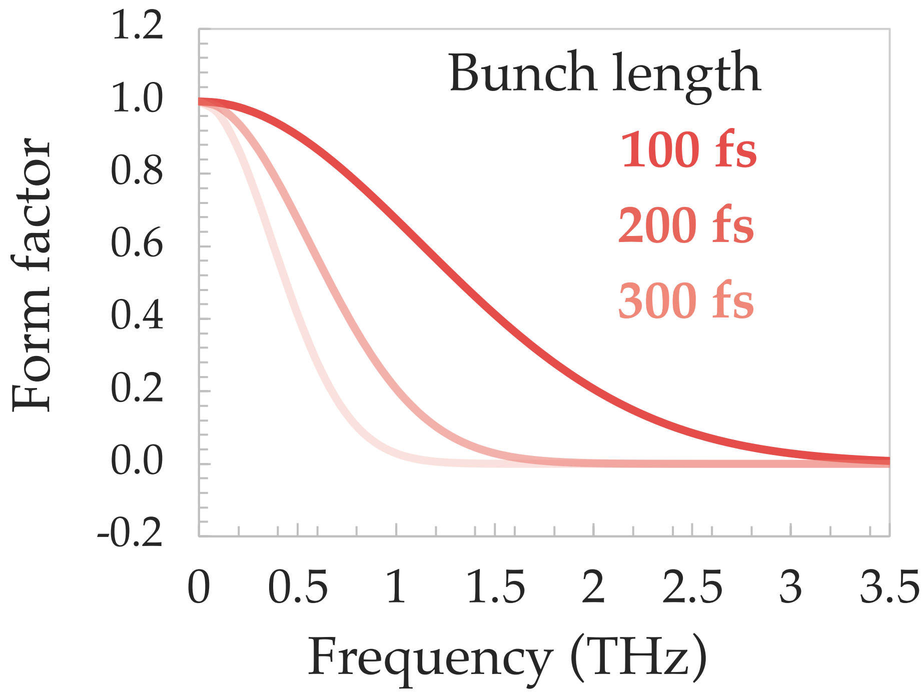
Radiation energy of a single electron

$$W_{1e} = \frac{d^2W}{d\Omega d\omega}\Delta\Omega\Delta\omega;$$

$$\Delta\Omega = \frac{2\pi}{\gamma^2}\frac{1+K^2/2}{2nN_u}, \frac{\Delta\omega}{\omega} = \frac{1}{nN_u}$$

Undulator design

Longitudinal bunch **Form factor**

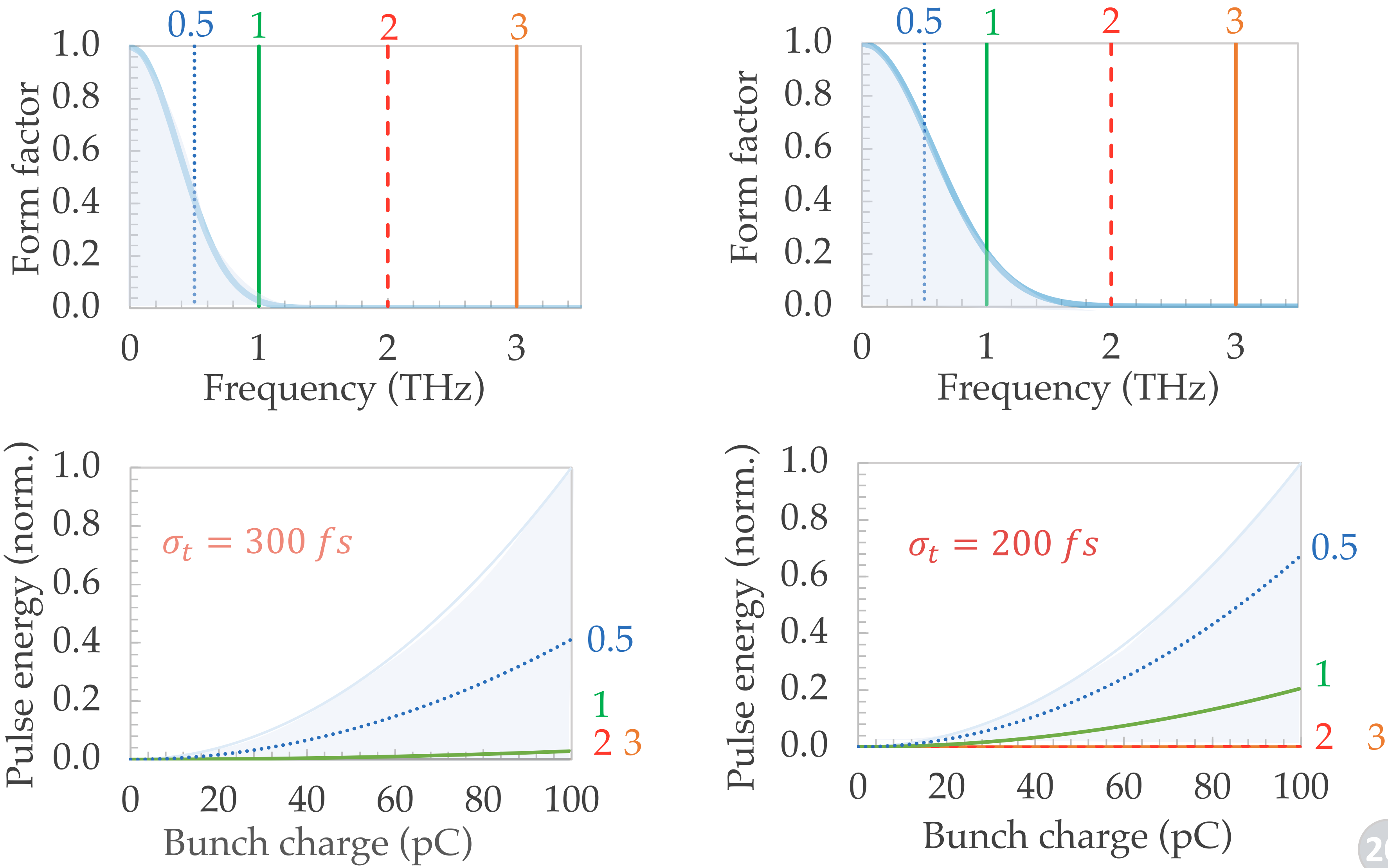


Longitudinal gaussian distribution

$$f(\omega, \sigma_t) = \exp(-\omega^2 \sigma_t^2)$$

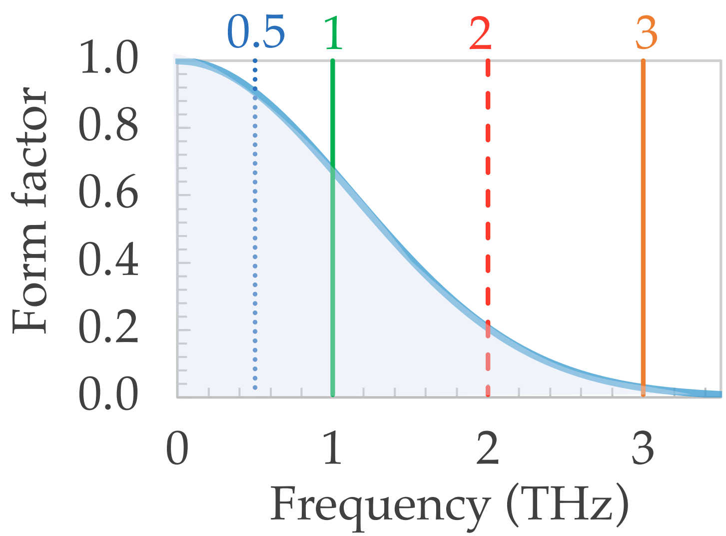
Undulator design

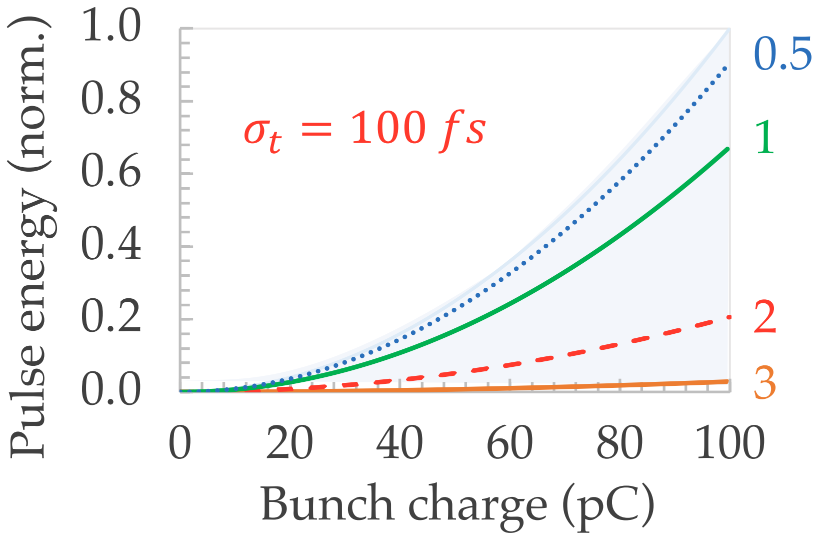
Superradiant THz FEL



Undulator design

Superradiant THz FEL





Pulse energy :

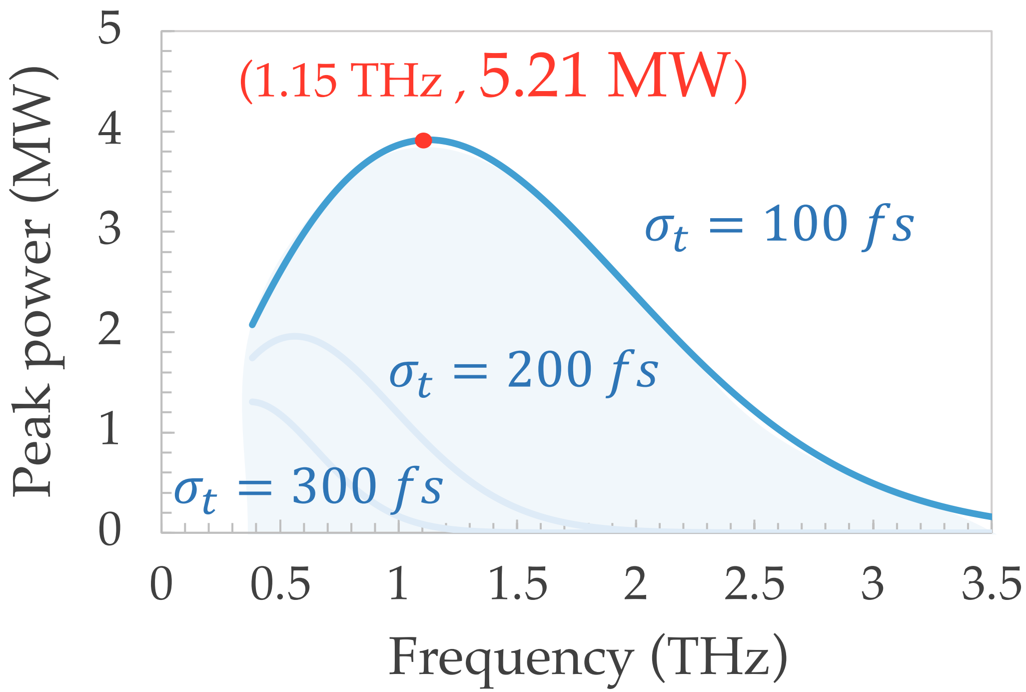
Bunch charge : 100 pC

Bunch length : 100 fs

W_{pulse} = 2.63 μJ at 1.15 THz

Undulator design

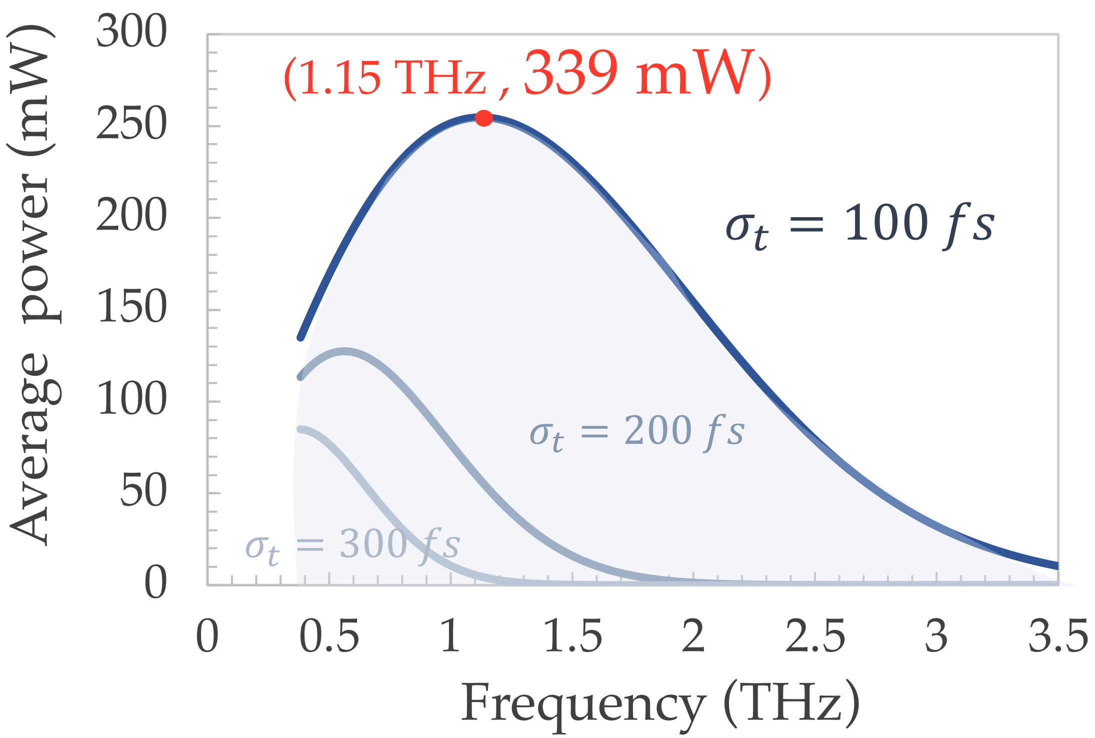
Superradiant THz FEL



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

Undulator design

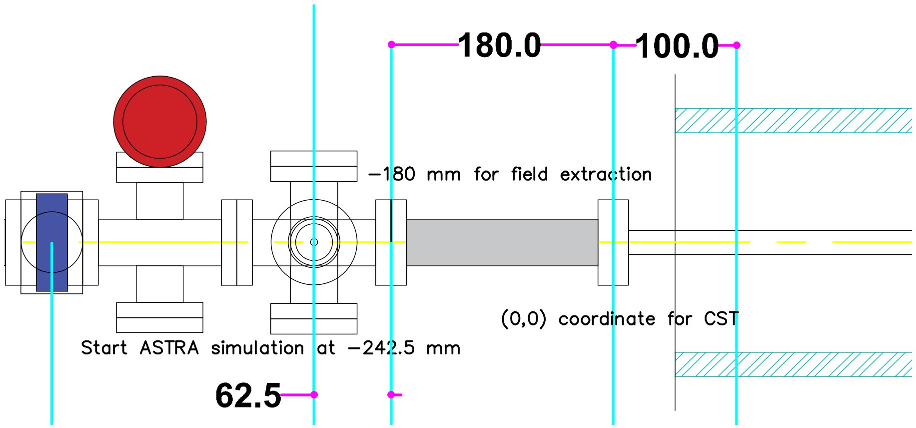
Superradiant THz FEL



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

Beam optimization at PCELL

Studied by N. Chaisueb



High bunch charge

High space charge forces

High energy spread

↓

Difficult to compress

Main parameters	10 MeV	16 MeV
RMS bunch length (fs)	304.3	203.4
Bunch charge (pC)	50	50
Peak current (A)	165.7	245.7
Energy spread	0.23%	0.16%
Horizontal emittance (mm.mrad)	0.42	0.34
Vertical emittance (mm.mrad)	0.29	0.35

Results

PCELL facility

Parameter	Design Value	Final Value
Electron energy (Kinetic)	10 – 16 MeV	**16 MeV**
Bunch charge	100 pC	**50 pC**
Bunch length	100 fs	**203.4 fs**
Energy spread	< 3%	**< 0.16%**
Radiation frequency	0.5 – 3 THz	**0.5 – 3 THz**
Radiation wavelength	300 – 100 μm	**300 – 100 μm**
Bunch energy	2.63 μJ	**0.904 μJ**
Radiation peak power	5.21 MW at 1.15 THz	**0.645 MW at 1.15 THz**
Average radiation power	339 mW at 1.15 THz	**44 mW at 1.15 THz**

Results

Superradiant THz FELs

Facility	THz-FEL source		Electron beam			Undulator	
	f (THz)	W_{pulse} (μJ)	E (MeV)	Q (pC)	σ_t (fs)	λ_u (mm)	N
NSRRC	0.67 – 2.3	0.5 – 2.7	18.3 – 33.5	100	90 - 223	100	18
ELBE	0.1 - 3	1.3	15 - 35	100	> 30	300	8
EU - XFEL	< 3 THz	8 - 279	(8.5 – 17.5) x 10^3	100 - 500	23 - 100	1000	10
Kyoto	0.16 – 0.65	< 1.3	4.6	< 200	200 - 1500	70	10
PCELL	0.5 - 3	< 0.9	5 – 20 (16)	< 100 (50)	100 – 300 (203.4)	100	19.5

Conclusions

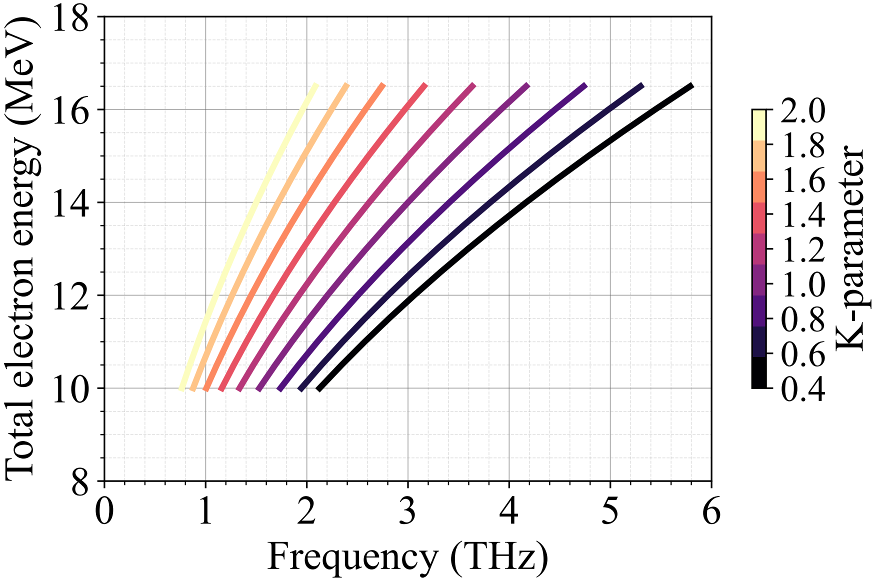
Electron energy : 16 MeV

Bunch charge : 50 pC

Bunch length : 203.4 fs

Undulator period length : 100 mm

Number of period : 19.5 periods



Bunch energy : 0.904 μJ

Radiation peak power : 0.645 MW at 1.15 THz

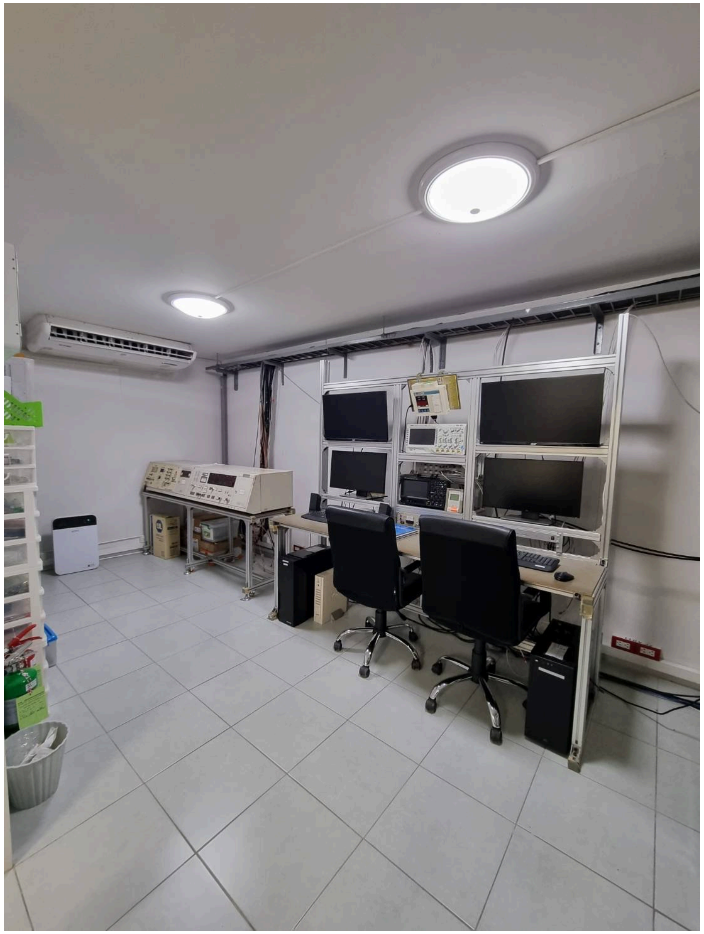
Average radiation power : 44 mW at 1.15 THz

Future works

1. Benchmark the results from my calculation with the SPECTRA calculation.
2. Using electron beam distribution to re-calculate all of essential parameters.
3. Using software to track electrons though undulator magnet and observe the energy of the radiation.
4. Design the radiation properties measurement station.
5. Design beam transportation to transport THz radiation to the experimental hall.

Current status

PCELL accelerator



Control room

Accelerator hall

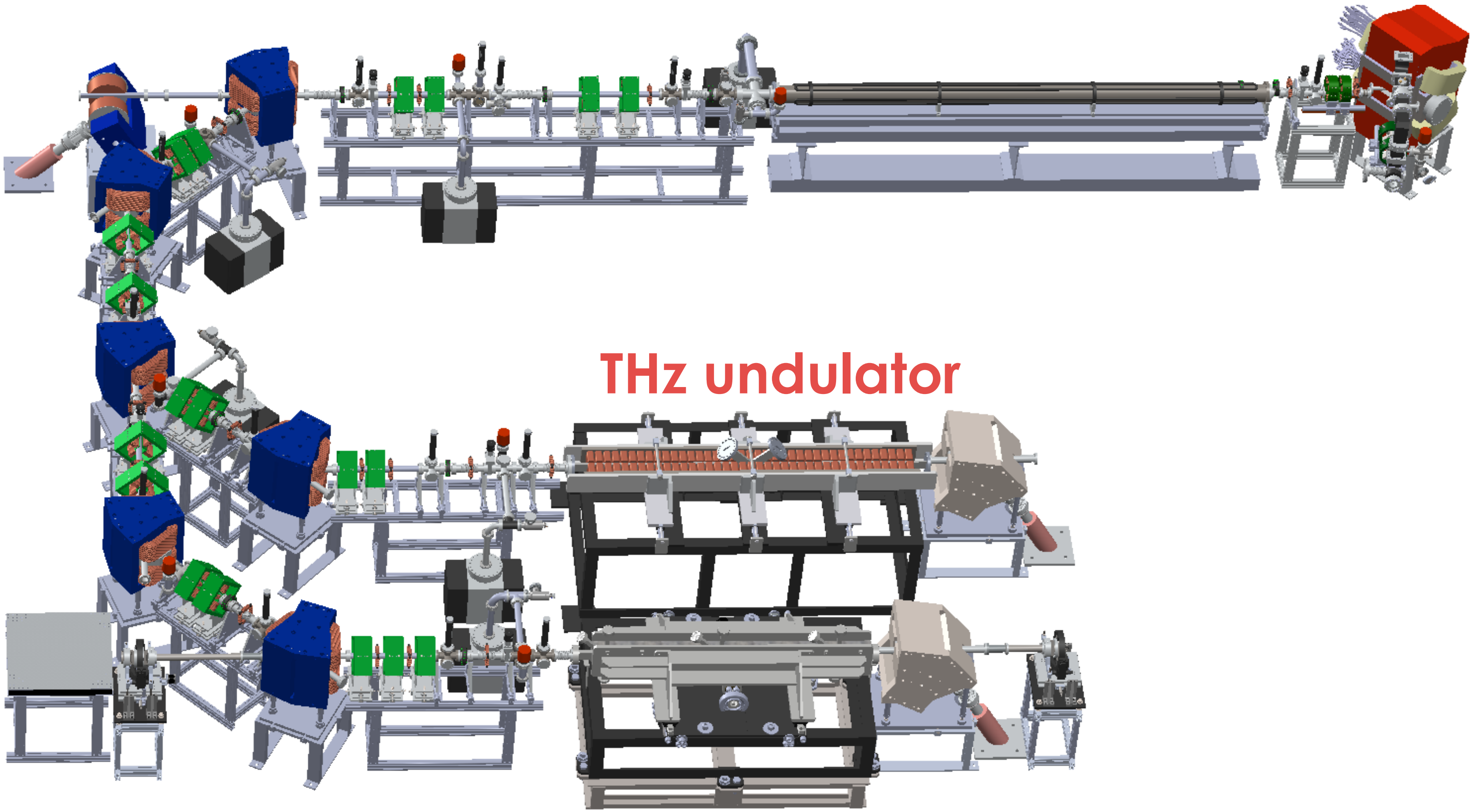
Current status

PCELL accelerator

Accelerator hall

Future plan

PCELL accelerator



Thank you for your attention