Development of Coherent THz Radiation Source and MIR-FEL in Thailand

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Plasma and Beam Physics Research Facility (PBP)

Chiang Mai University, Thailand

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- Generation of femtosecond electron bunches
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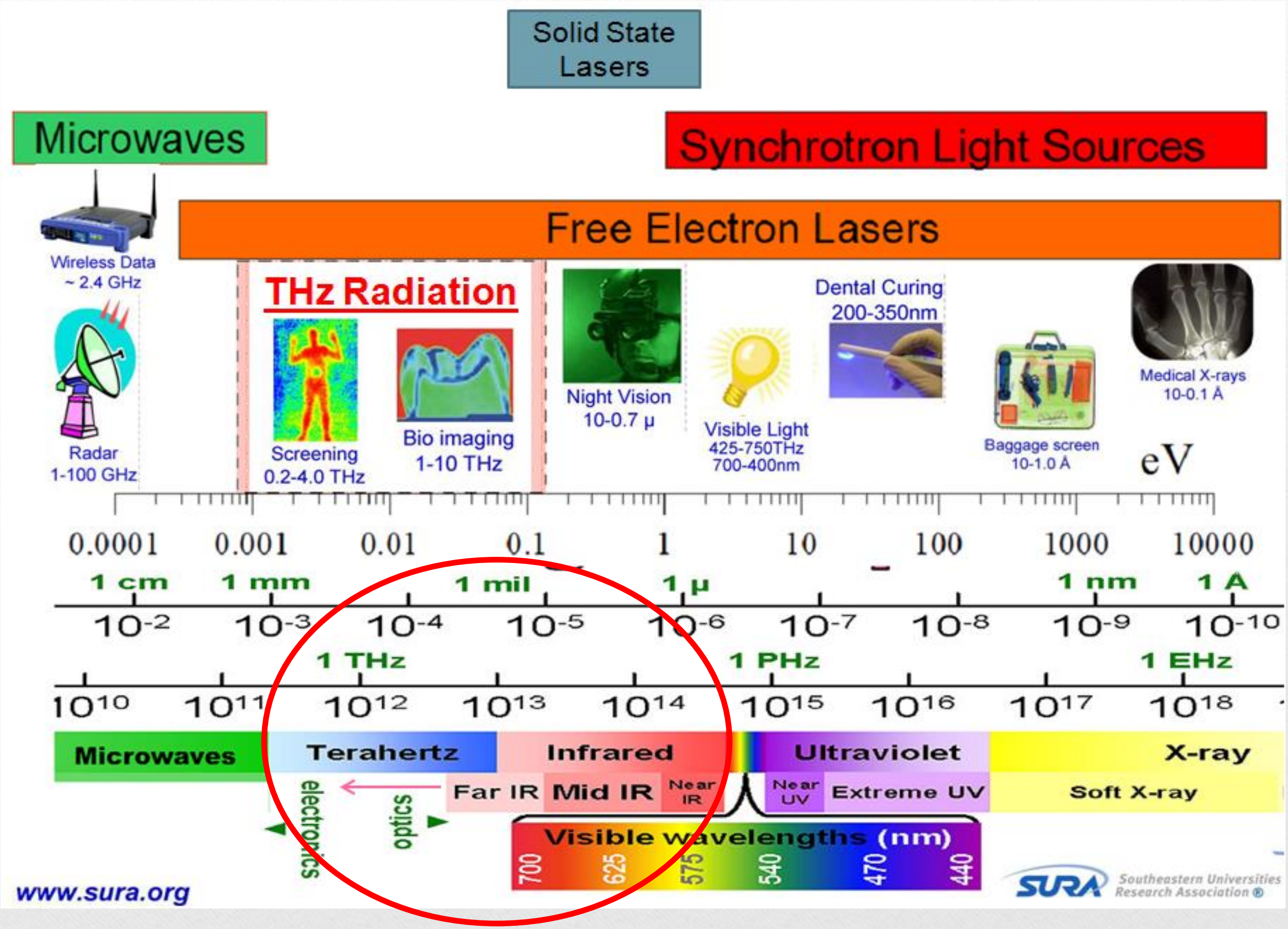
Motivation & Applications



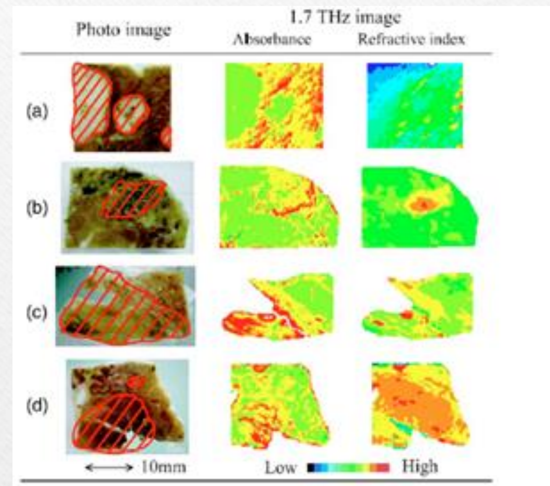
Applications of THz Radiation

THz imaging: quality inspection, security screening, medical applications etc.

- Penetrate non-conducting materials e.g. clothes, wood, plastic, ceramic, paper
- Blocked by metals
- Absorbed by water or liquid

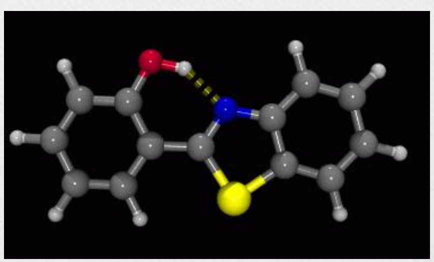
THz imaging diagnostic of cancer tissues

Nakagima et al. [APL **90** 041102(2007)]

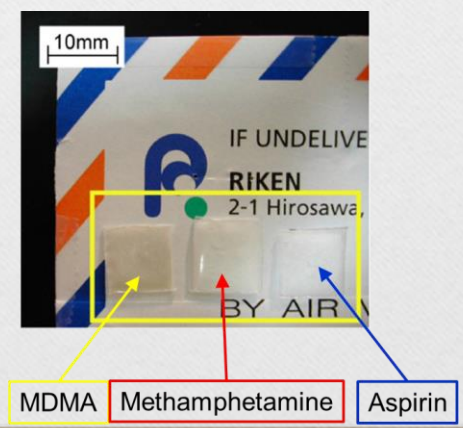


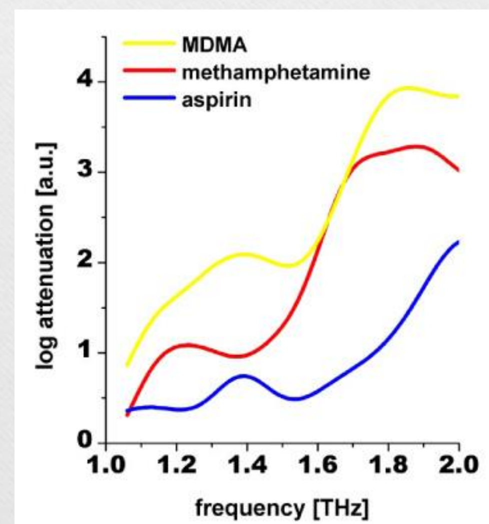
THz Spectroscopy

- Chemical sensitive:
  "finger print" absorption spectra
- Corresponds to intermolecular vibration and rotation



Weak hydrogen bond

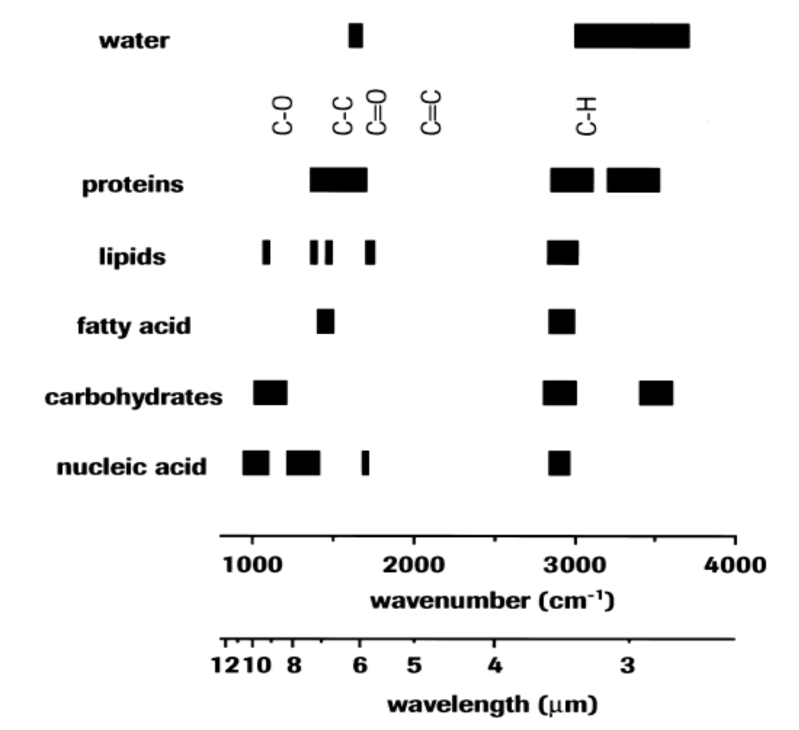


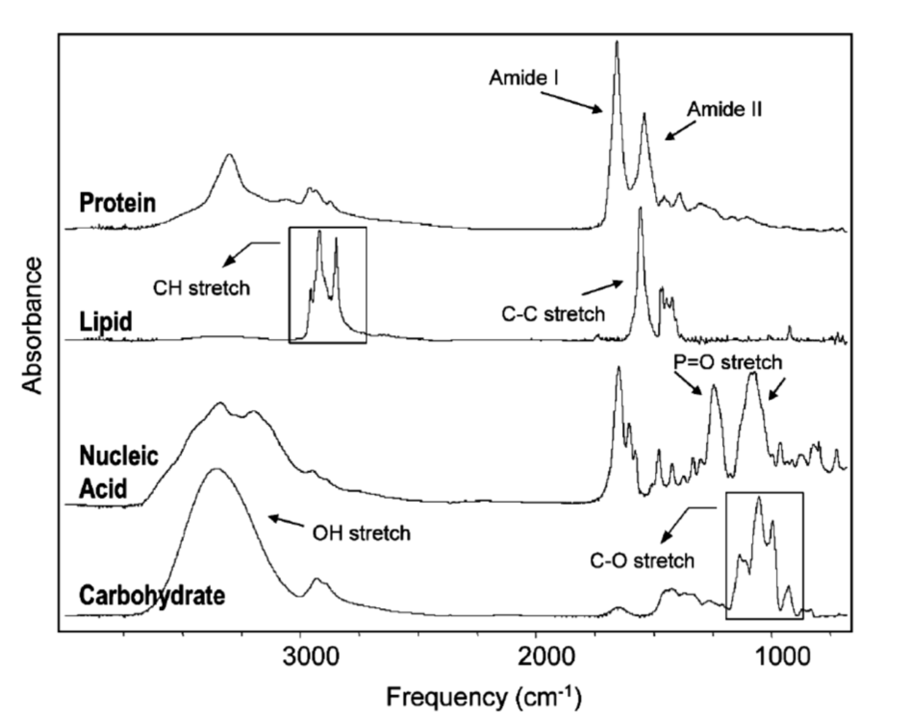


K.Kawase, Y. Ogawa, Y. Watanabe, Opt. Express 11 (2003) 2549.

Applications of MIR/THz Radiation

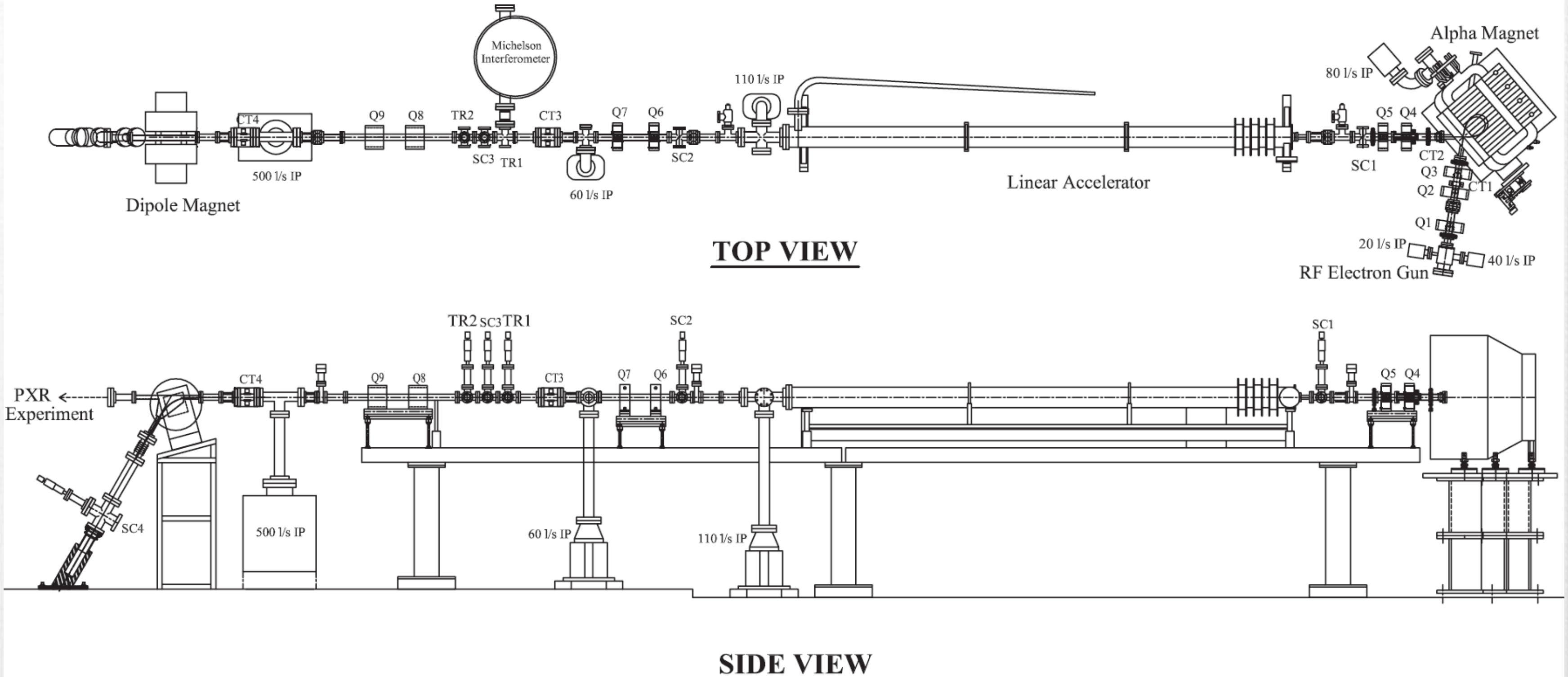
Respond and fingerprint spectra of biomolecules in MIR and FIR/THz frequency regime.





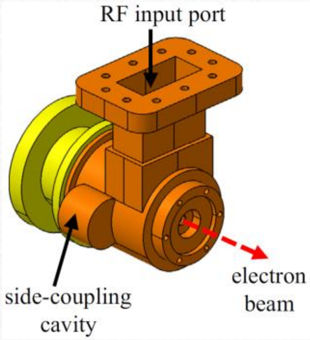
W. Petrich, Appl. Spectrosc. Rev. 36:2-3 (2001) & L.M. Miller, G.D. Smith, G.L. Carr, J. Biol. Phys. 29: 2-3 (2003) 219.

Linac-based THz Radiation Source @ CMU (2005 – 2016)

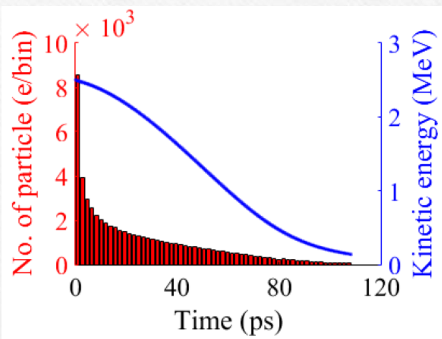


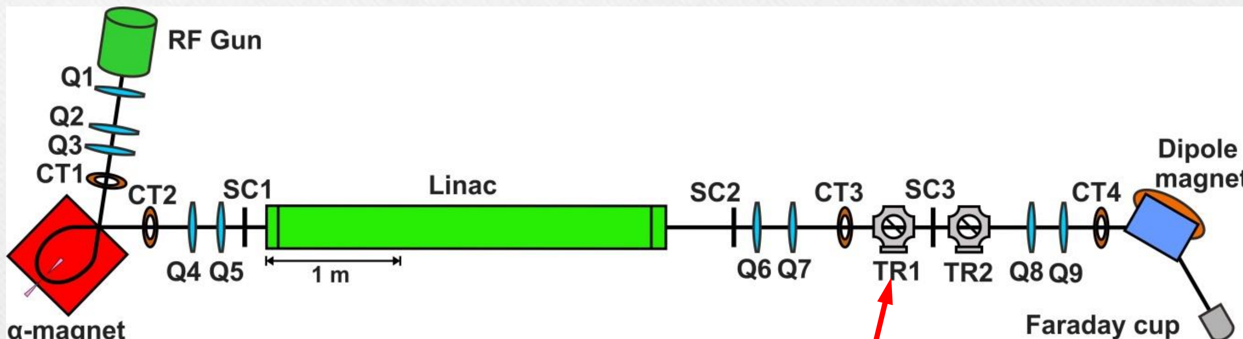
C. Thongbai et al., NIMA 587 (2008) 130 – 135.

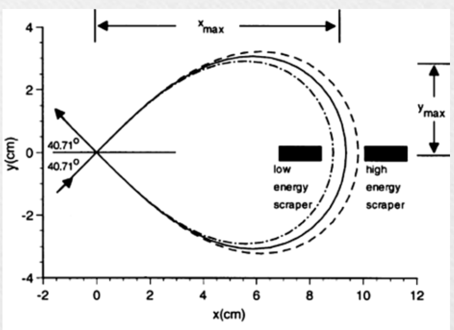
Generation of Femtosecond Electron Bunches



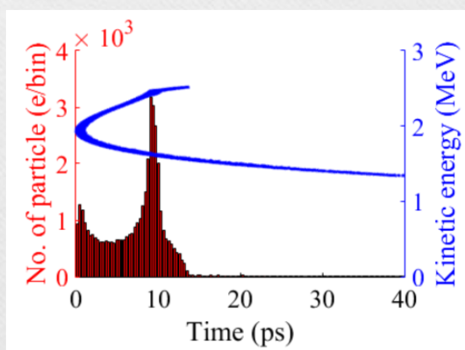
Parameters	RF-gun	Linac
Maximum beam energy (MeV)	2.5–3	10–12
Macropulse peak current (mA)	700–1000	50–150
RF-pulse length (μs)	2.8	8
Repetition rate (Hz)	10	10
Beam-pulse length (μs)	~2	~0.8
Number of microbunches per macropulse	5700	2300
Number of electrons per microbunch	1.4×10^9	$(1–6) \times 10^8$

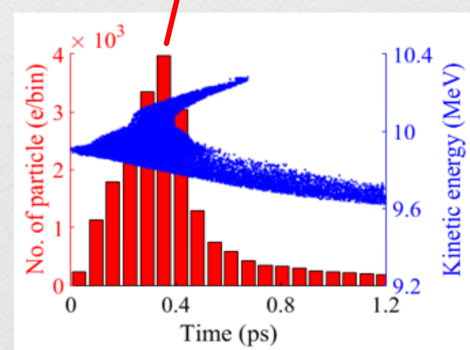






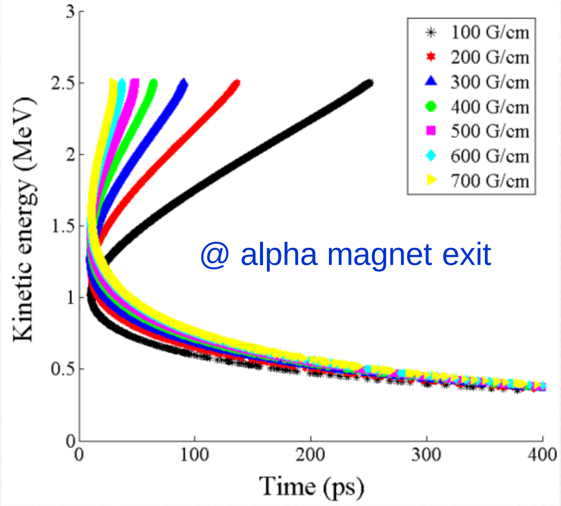
$$x_{max} = 75.05\sqrt{\frac{cp}{mc^2 g}}$$

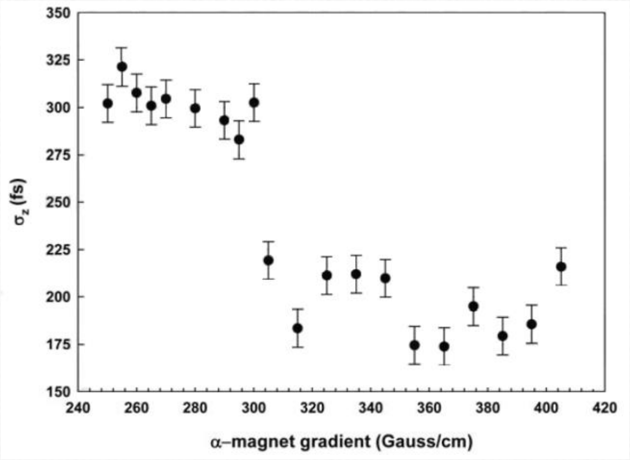




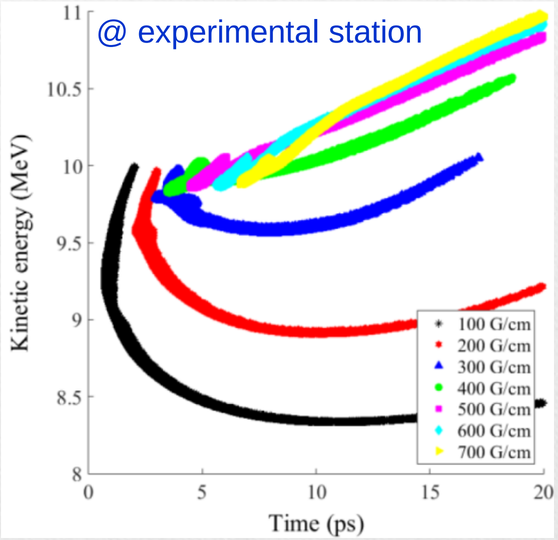
S. Rimjaem et al., NIMA 533 (2004) 258 – 269 & NIMA 736 (2014) 10–21 & C. Thongbai et al., NIMA 587 (2008) 130 – 135.

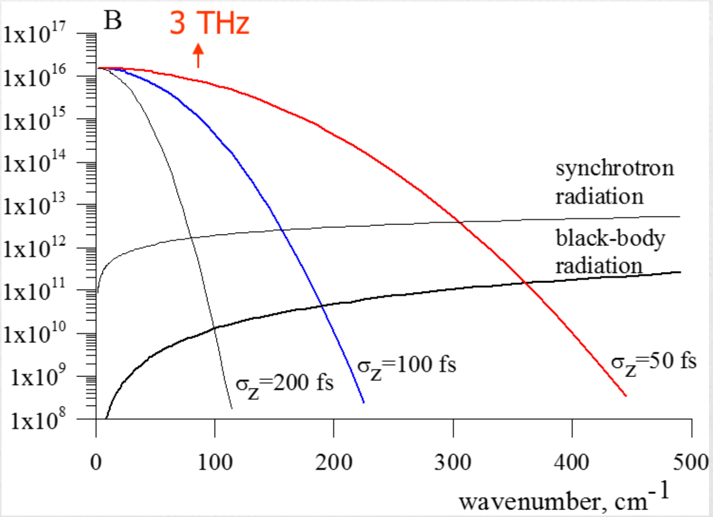
Electron beam @ Experimental Station





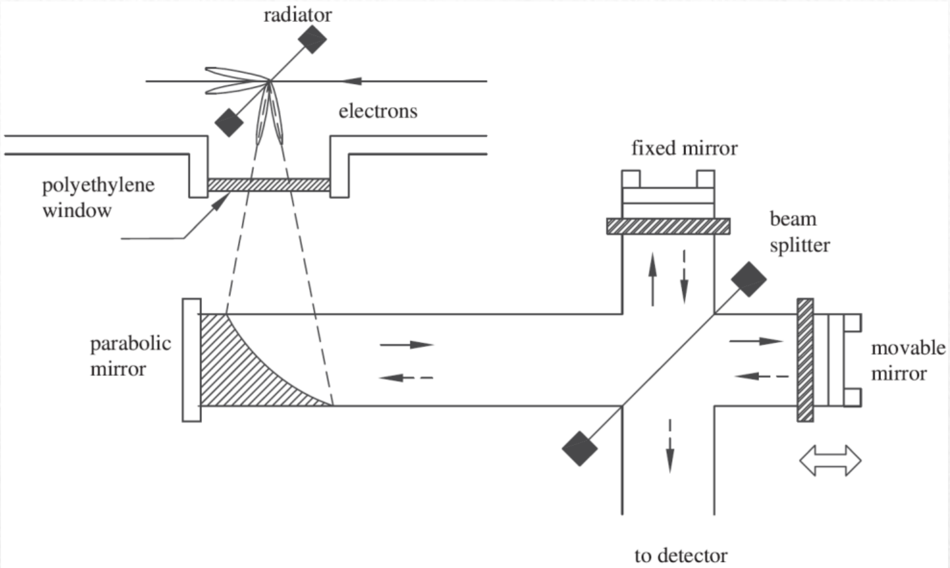
Measured electron bunch length vs. alpha magnet gradient.

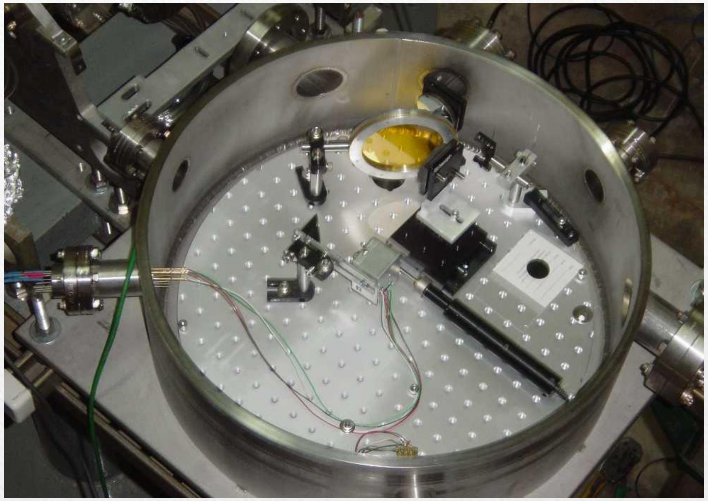




Radiation brightness B(ph/s/mm^2/100%BW) vs. wave number for CTR, SR and black body radiation.

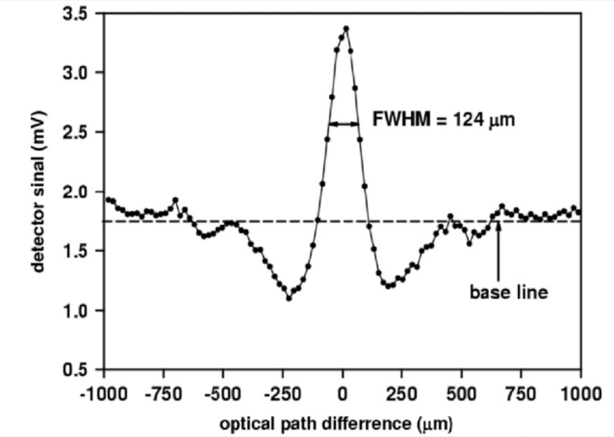
Generation & Measurement of CTR





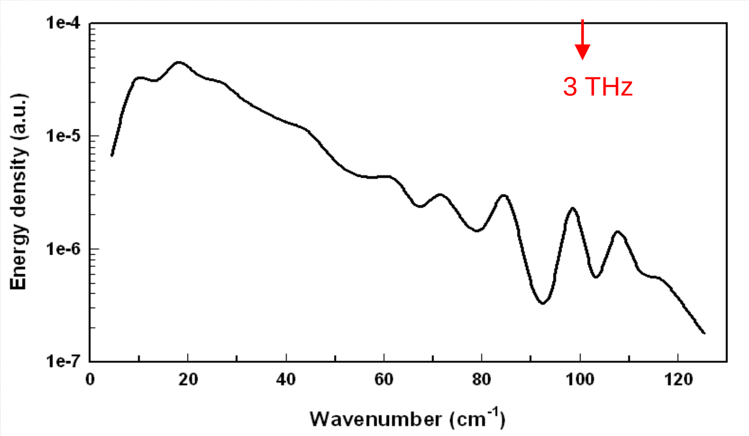
Michelson Interferometer
(Autocorrelation technique)

Measured electron bunch 124 μm (~200 fs).

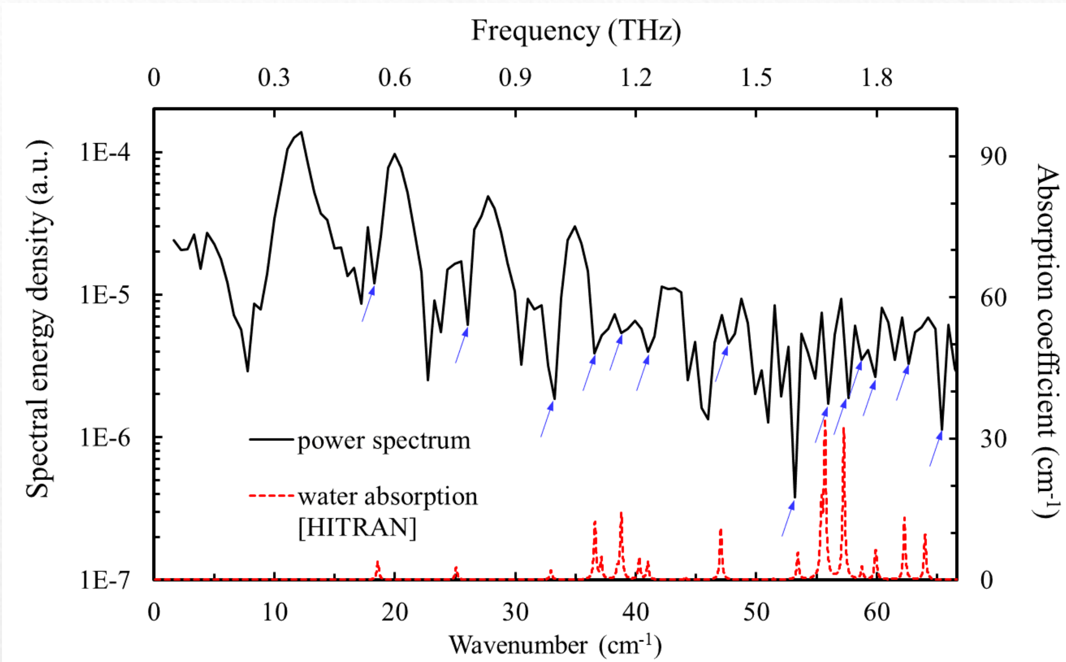


Fourier Transform

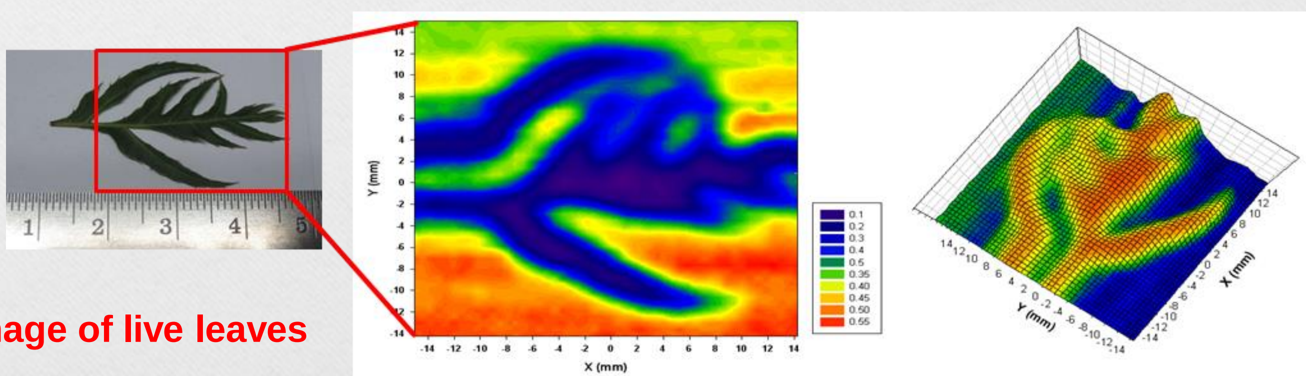
Measured THz radiation (frequency range of 0.3 – 2.4 THz).



Examples of THz Spectroscopy & Imaging @ CMU

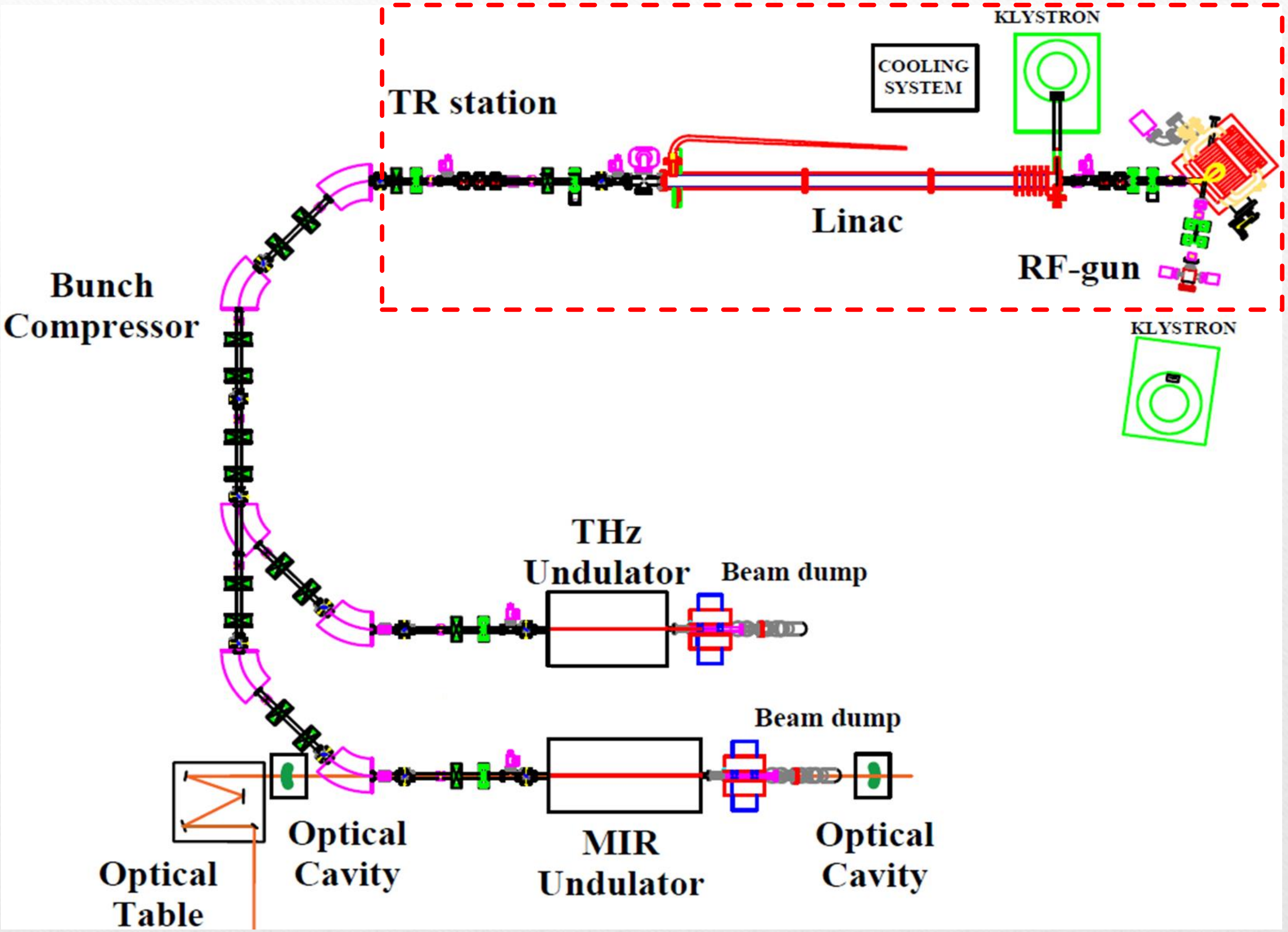


Water vapor spectrum & absorption lines

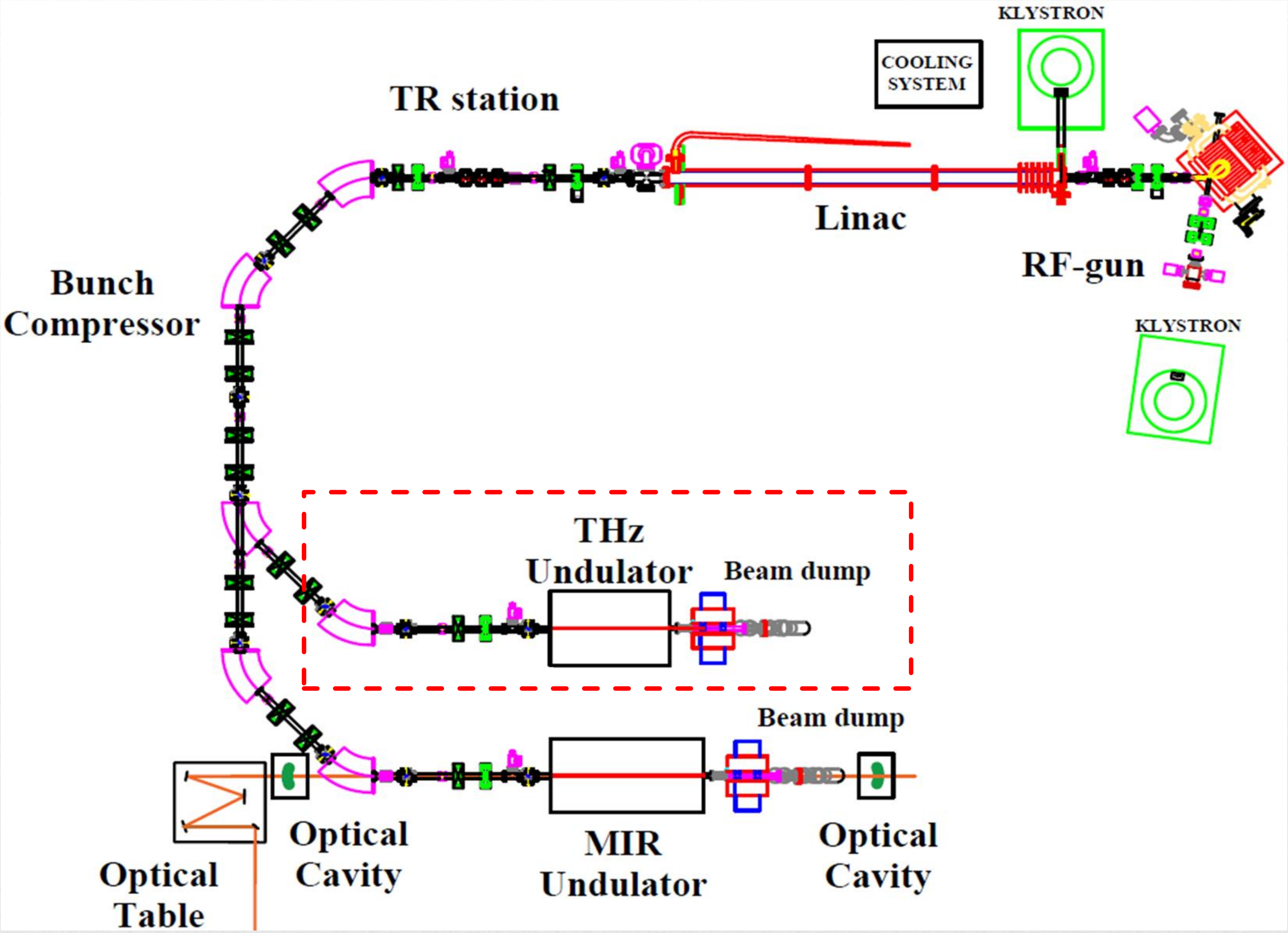


THz image of live leaves

PBP-CMU Linac System → Injector System

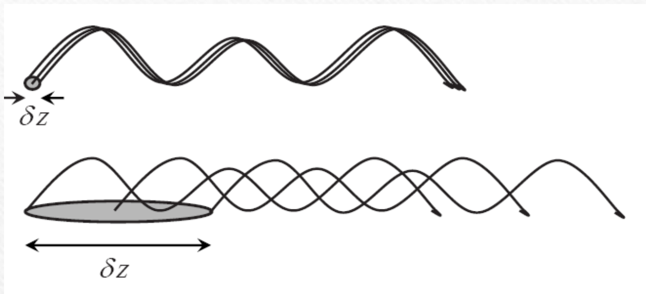


Coherent THz Undulator Radiation



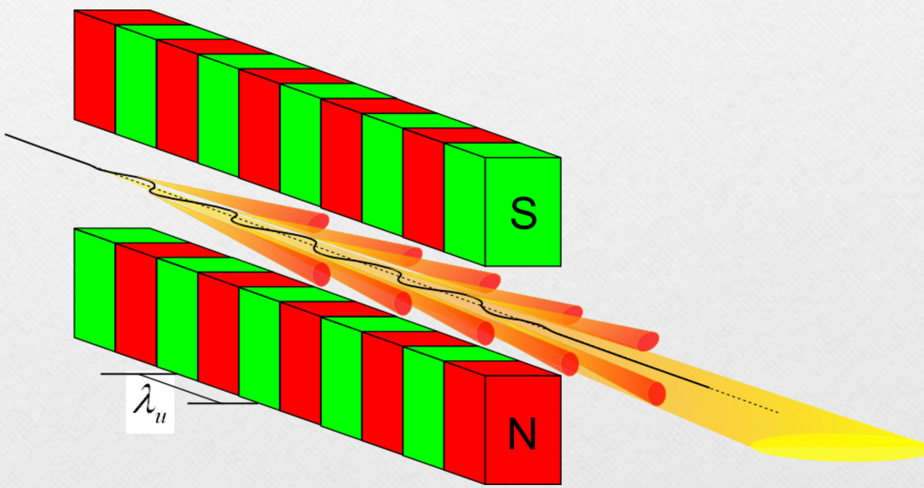
THz Undulator Radiation

Coherent THz Radiation from short electron bunches



ISR CSR

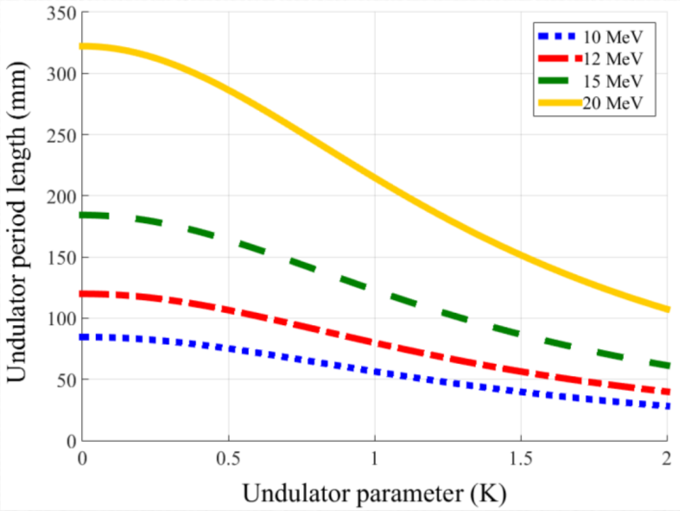
$$\frac{d^2 I}{d\omega\, d\Omega} = [N[1 - f(\omega)] + N^2 f(\omega)]$$



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

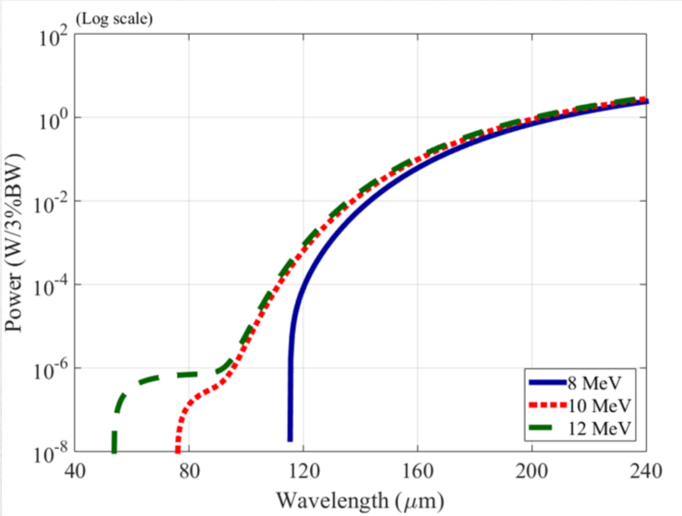
$$K = \frac{eB_0\lambda_u}{2\pi m_0 c} = 0.934 B_0 \lambda_u$$

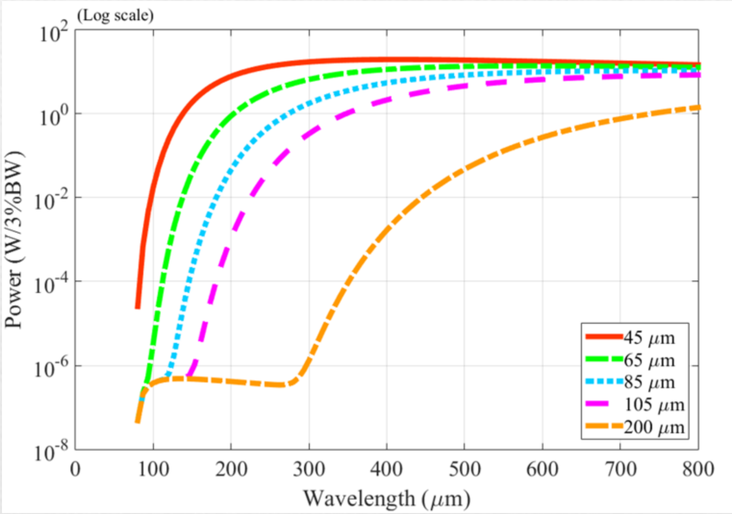
Generation of THz Undulator Radiation



Simulated beam parameter	Value
Beam size x / y (mm)	2.54 / 1.48
Divergence x / y (mrad)	1.32 / 4.04
Emittance x / y (mm.mrad)	0.81 / 0.65
Average energy (MeV)	9.82
Maximum energy (MeV)	10.28
Minimum energy (MeV)	9.34
Energy spread (MeV)	0.21
Bunch length (fs)	130
Bunch charge (pC)	104.4

Undularator period length = 64 mm, K = 1.0

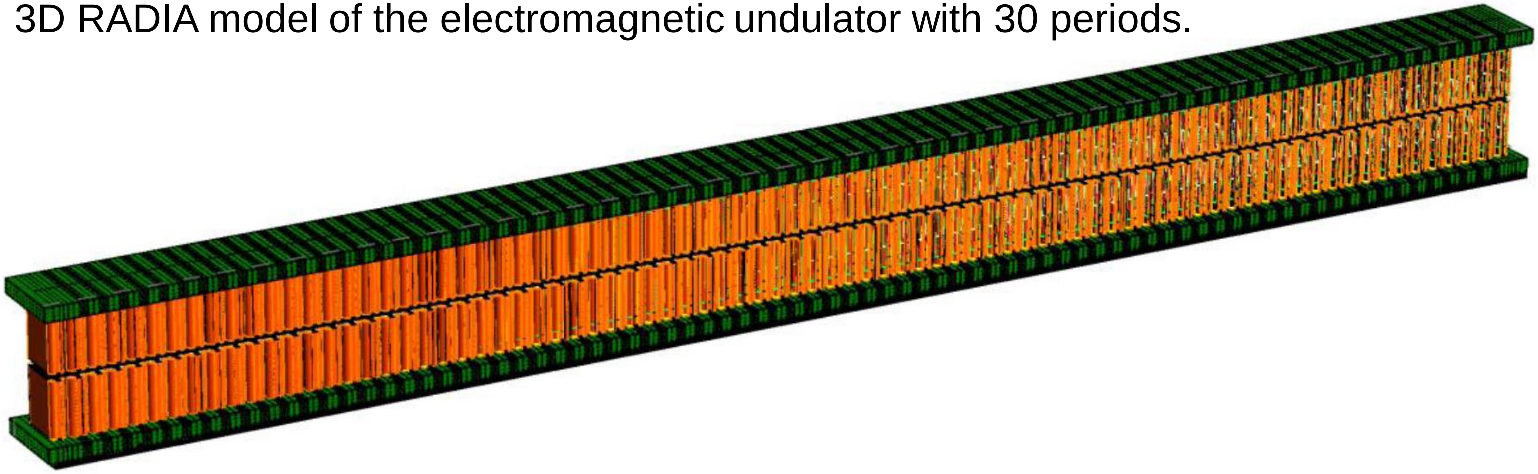




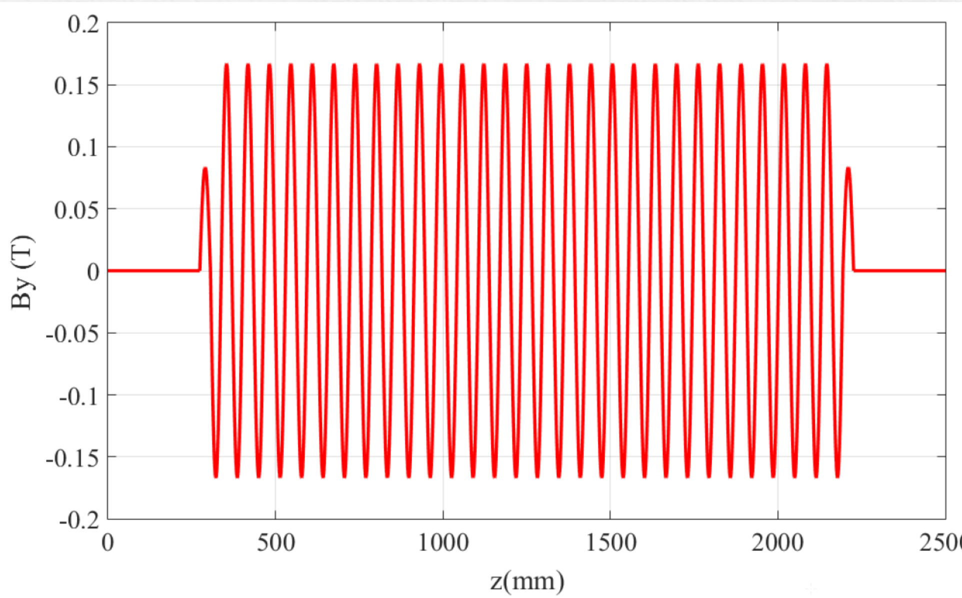
Undulator radiation power vs. radiation wavelength for different electron energies and bunch charges.

Development of THz Undulator Electromagnet

3D RADIA model of the electromagnetic undulator with 30 periods.

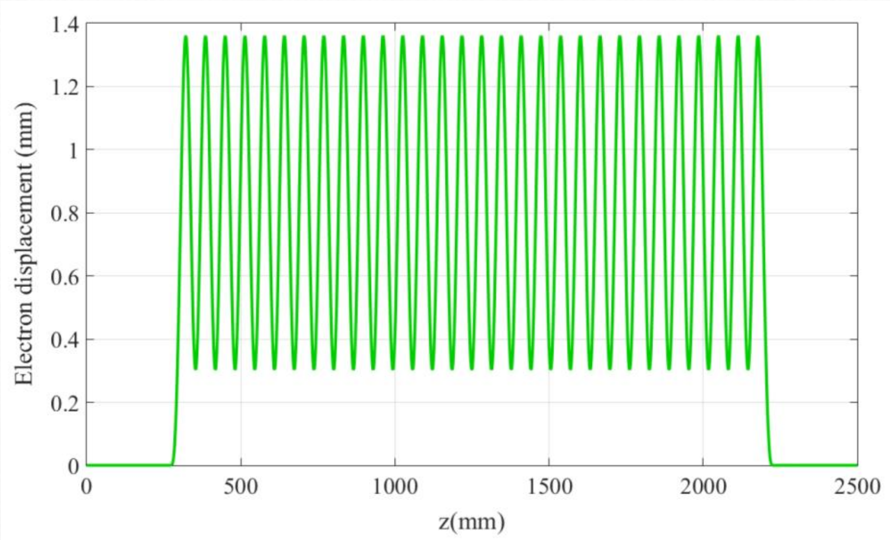


Parameter	Value
Type	planar
Period length	64 mm
Number of periods	30
Total length	1.92 m
Magnetic gap	10.5 mm
Peak magnetic field	50 - 167 mT
Undulator parameter (K)	0.3 - 1.0



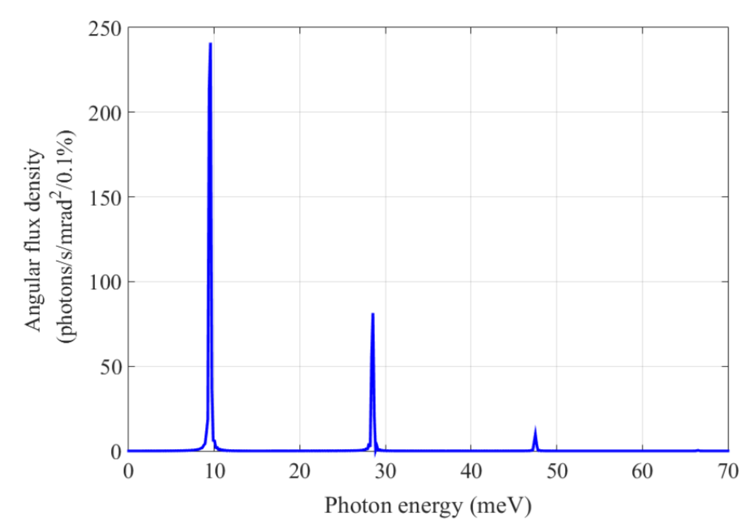
THz Undulator Radiation

Simulated trajectory of 10 MeV electron beam while traveling through an ideal magnetic field of 30 period undulator.

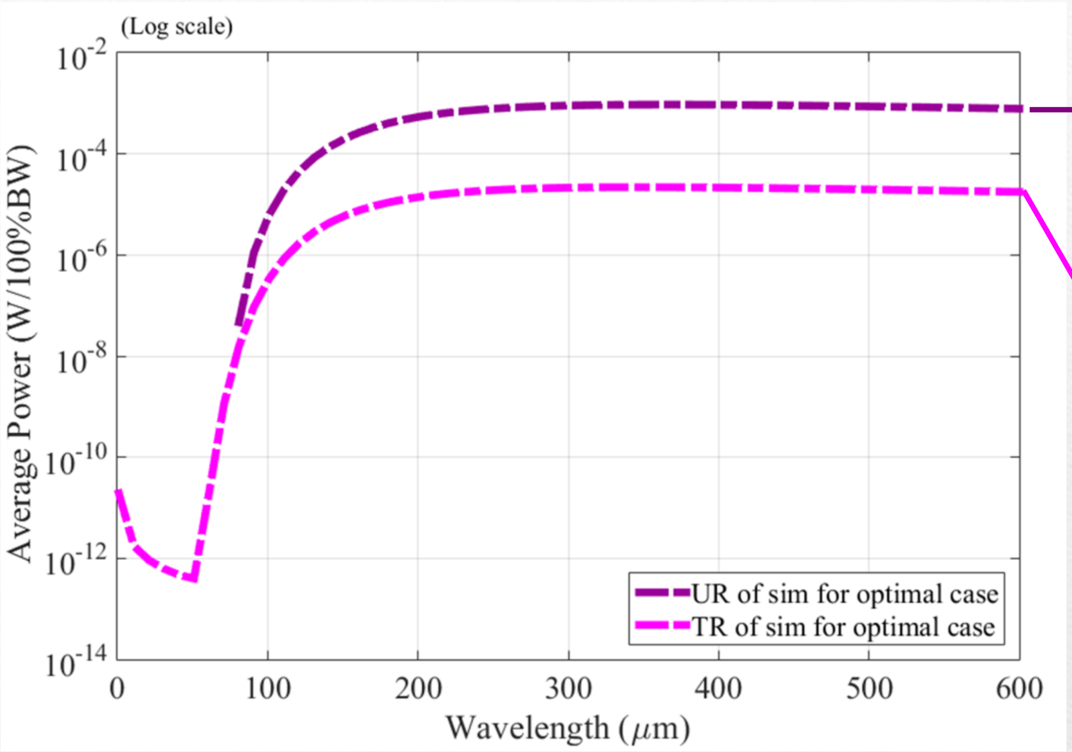


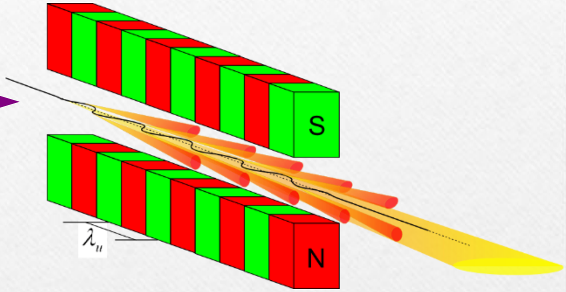
Calculated angular flux density as a function of photon energy with electron energy of 10 MeV for ideal magnetic field of 30 period undulator and a peak undulator field of 167 mT.

→ Fundamental harmonic is dominated at the photon energy of around 10 meV.



CUR vs. CTR


(Log scale)
Average Power (W/100%BW)
10^-2
10^-4
10^-6
10^-8
10^-10
10^-12
10^-14
0
100
200
300
400
500
600
Wavelength (μm)
UR of sim for optimal case
TR of sim for optimal case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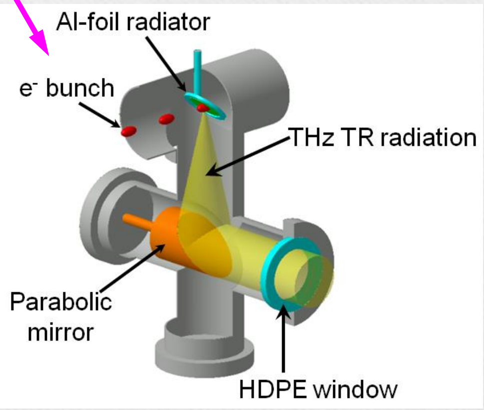
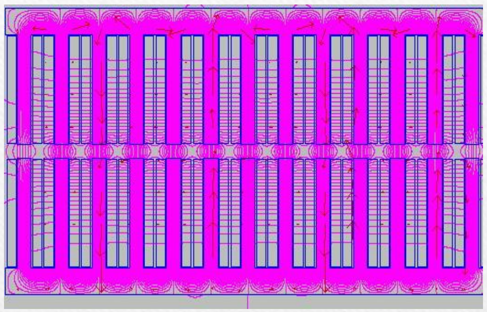

Al-foil radiator
e- bunch
THz TR radiation
Parabolic mirror
HDPE window

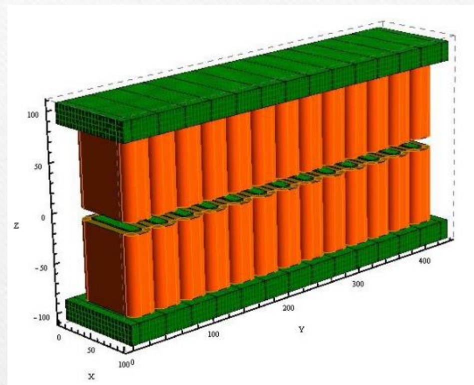
Prototype of THz Electromagnet Undulator

- 10 MeV electron beam produces THz radiation: 87 μm @ K = 0.3 and 125 μm @ K = 1.0

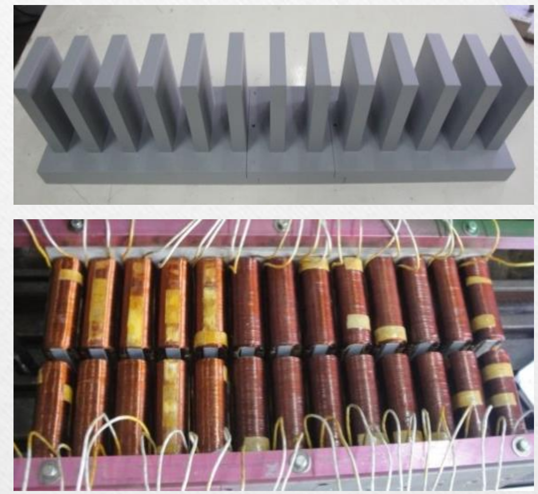
2D POISSON model

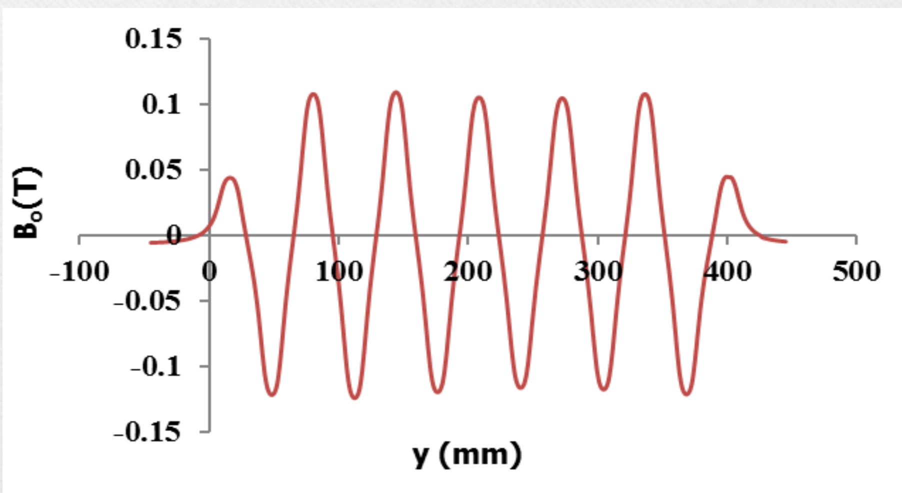


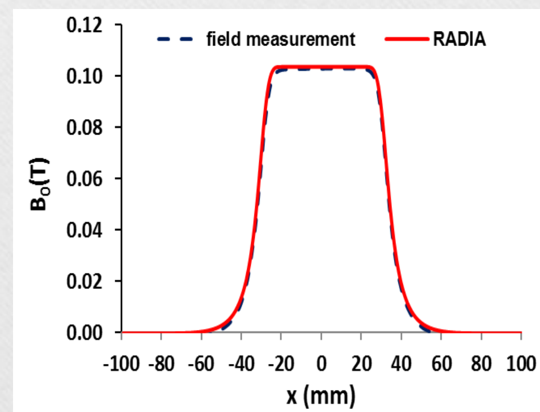
3D RADIA model



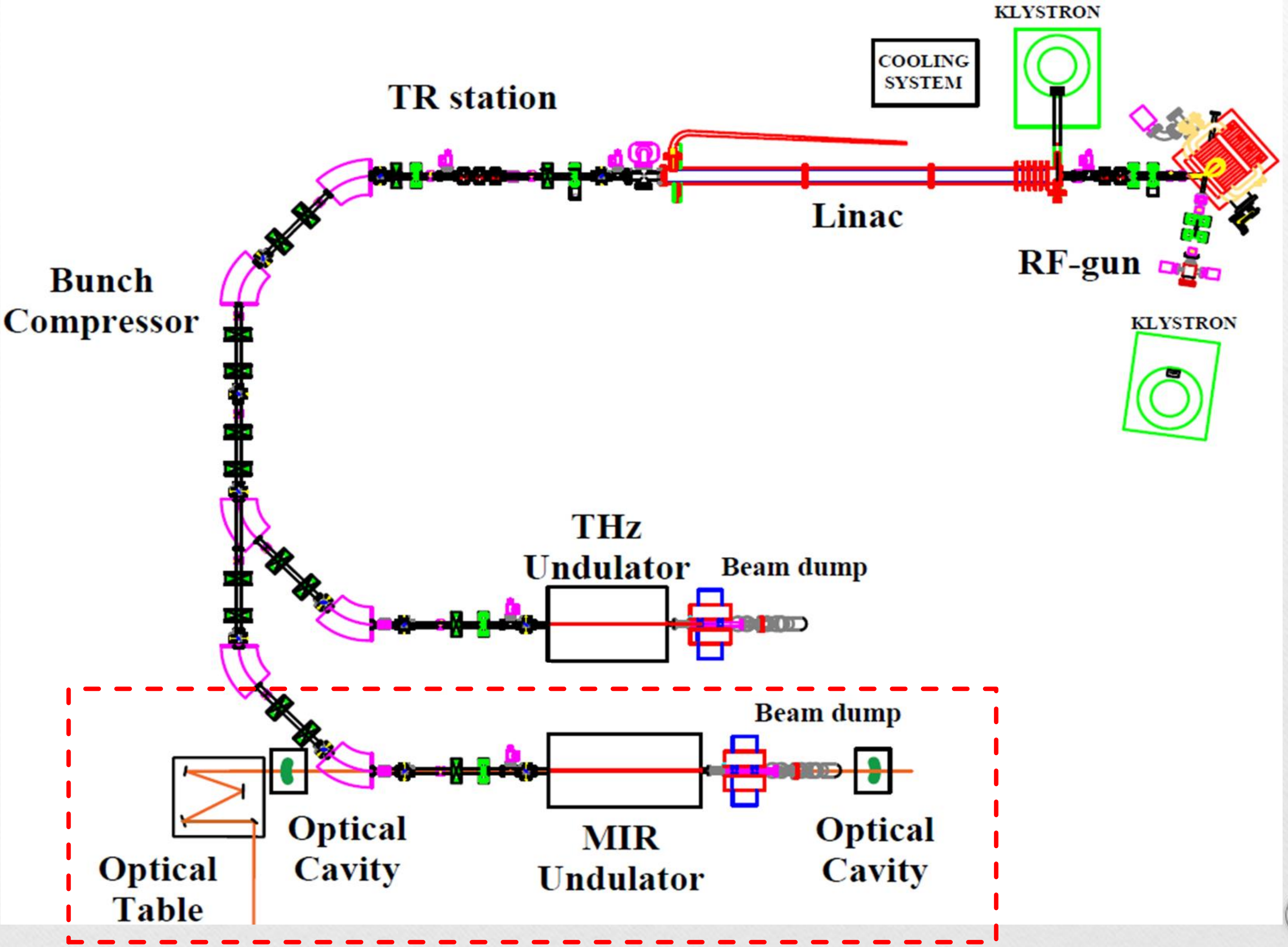
Actual undulator magnet



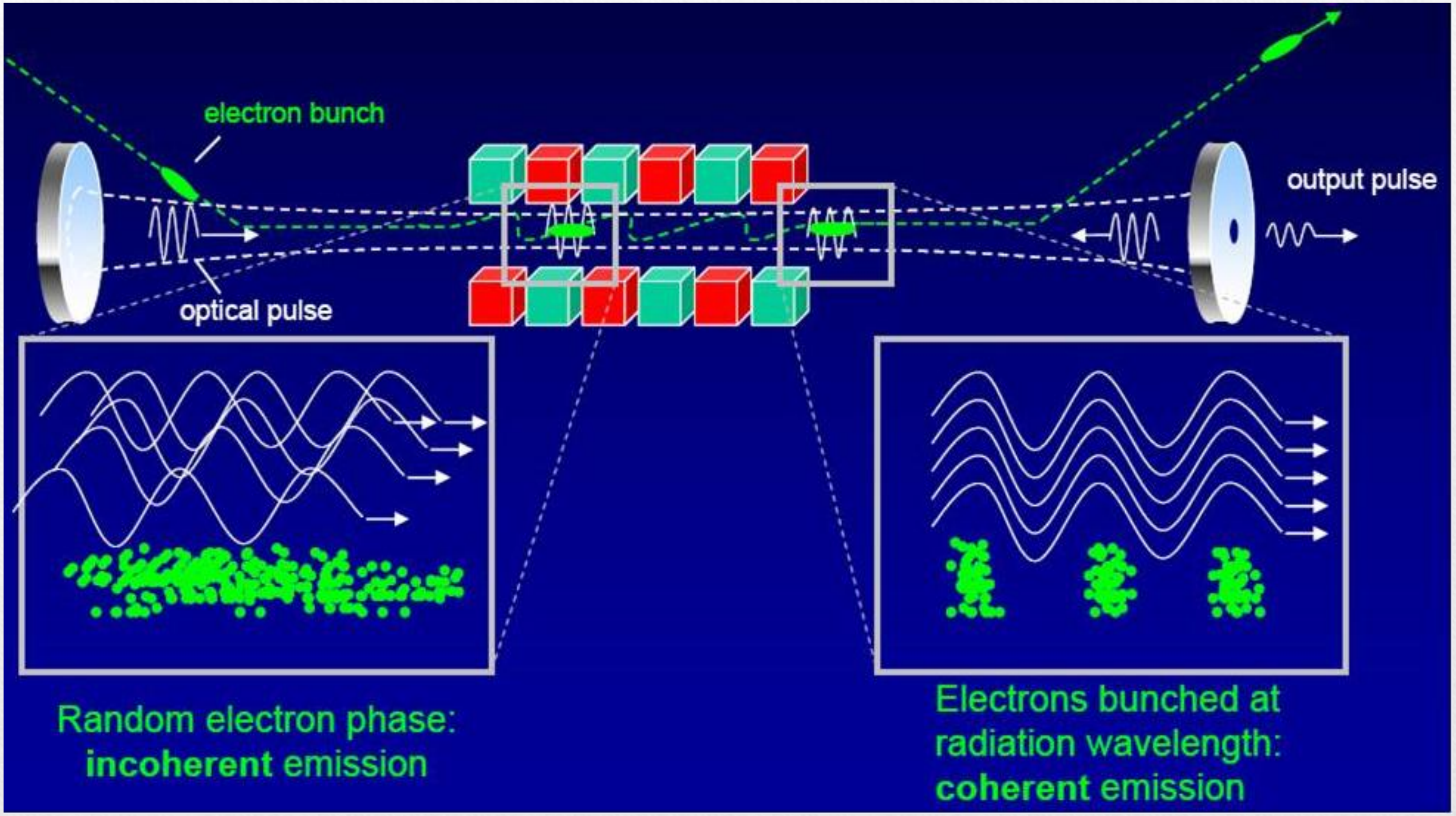




MIR Free-electron Lasers



MIR Free-Electron Lasers



Generation of MIR-FEL

Goal parameters of electron beam.

Goal parameter	Value
Beam energy	20 MeV
Energy spread	≤ 1%
Bunch charge	50 - 100 pC
Bunch length	1 - 3 ps
RMS emittance	≤ 3 mm-mrad

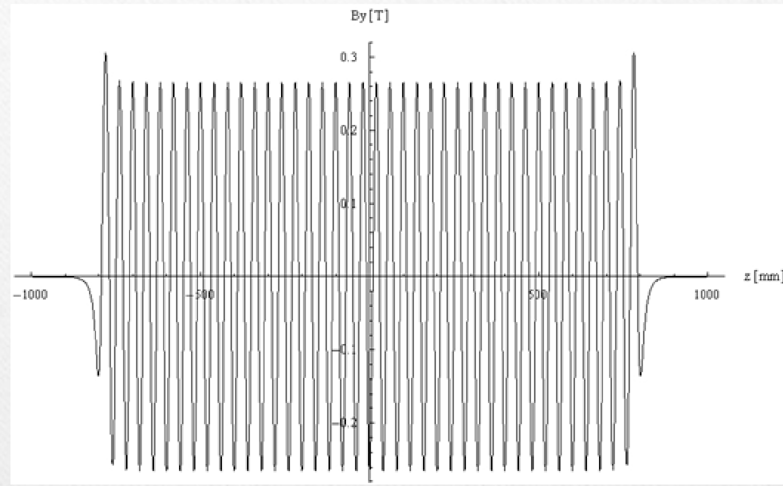
Undulator parameters & expected radiation wavelengths.

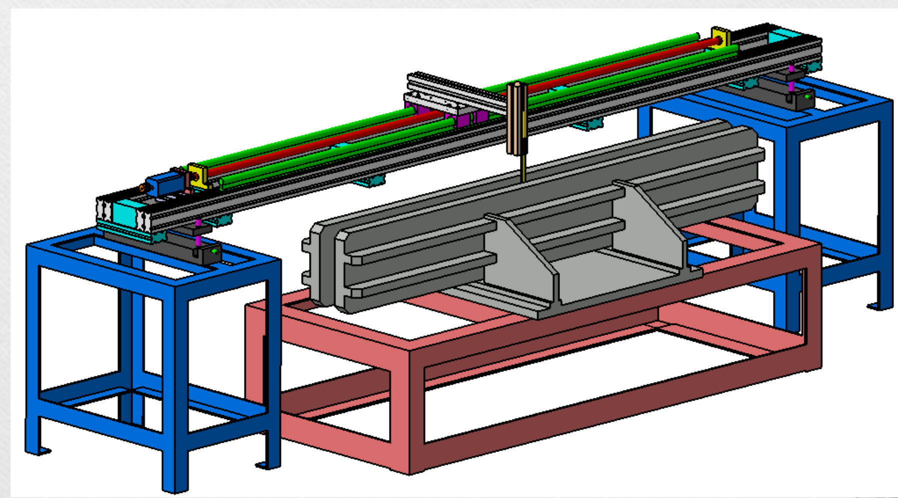
Parameter	MIR
Type	planar Halbach
Period length	40 mm
Number of periods	40
Total length	1.6 m
Magnetic gap	26 - 45 mm
Peak magnetic field	4.5 - 260 mT
Undulator parameter	0.17 - 0.95
Radiation wavelength	13 – 19 µm

MIR Permaenent Undulator Magnet

- 20 MeV electron beam produces MIR-FEL:13 μm @ K = 0.17 and 19 μm @ K = 0.95

Specification	MIR permanent undulator
Type	planar Halbach
Total length	1.6 m
Period length	40 mm
Number of periods	40
Magnetic gap	26 – 45 mm
Peak magnetic field	4.5 – 260 mT
Undulator parameter (K)	0.17 – 0.95

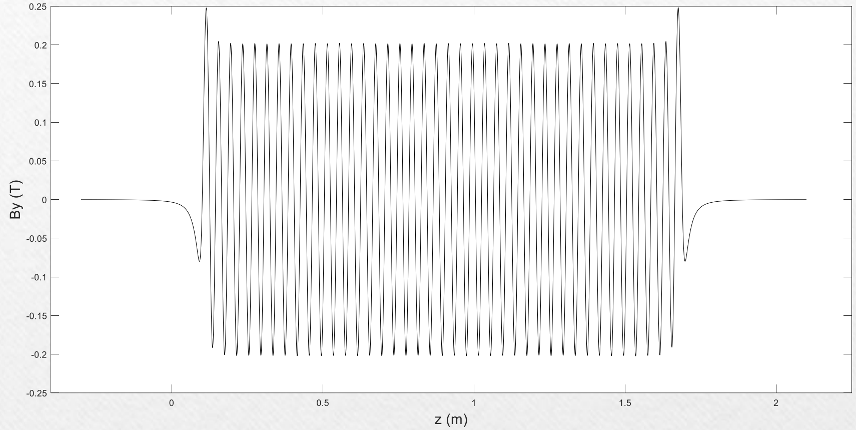




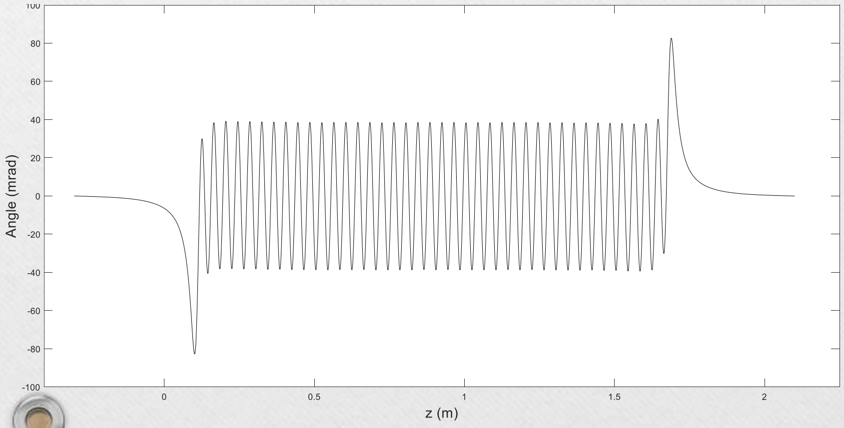
2D Simulation of MIR Undulator Magnet

- 2D simulation with program PANDIRA (3D simulation with program RADIA is underway).

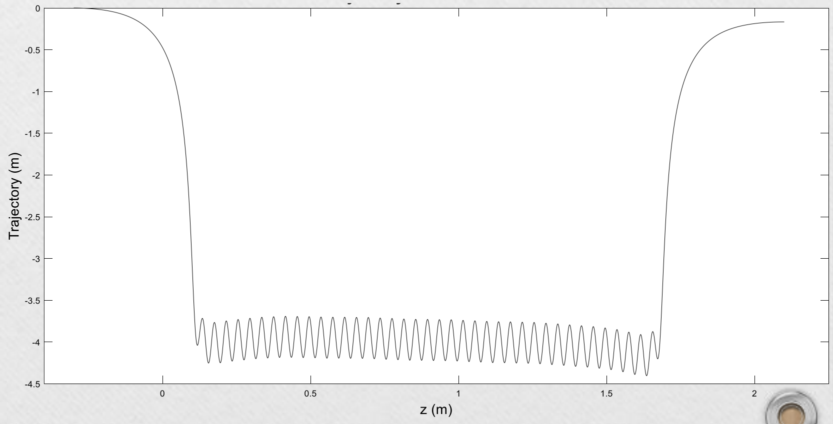
Simulated magnetic field along the undulator axis.



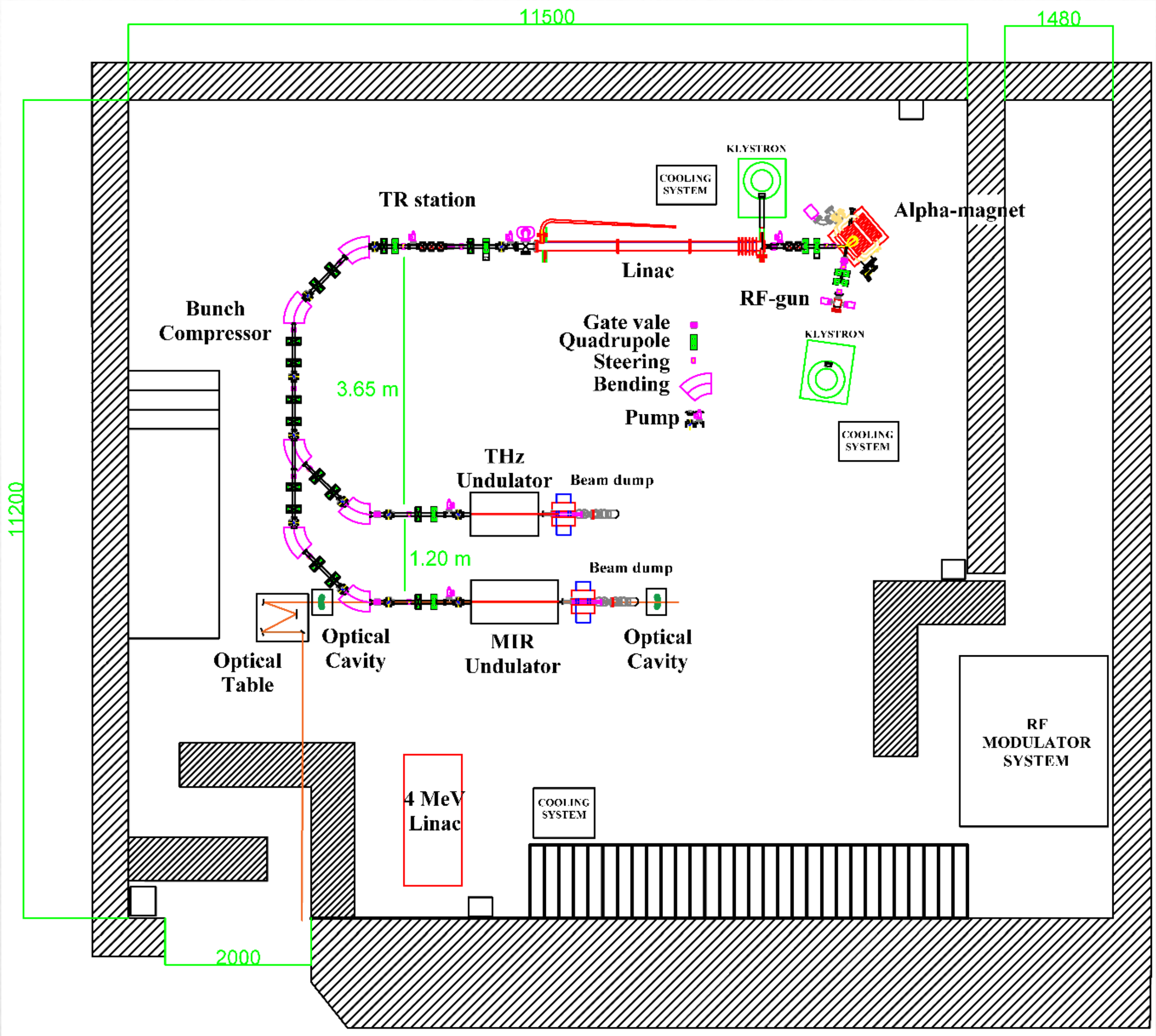
Simulated angular displacement of electron.



Simulated electron trajectory.



Plan of PBP-CMU Linac Laboratory



Conclusion

- Development of CUR and MIR-FEL is going on at the PBP-CMU Linac Laboratory.
- Existing accelerator system will be modified to be the injector system. New acromat magnetic bunch compressor is under designing.
- Development of THz electromagnet undulator magnet is underway.
- 2D and 3D modeling as well as magnetic field measurements of the permanent undulator magnet for MIR-FEL is in progress.
- Study on generation of MIR-FEL is ongoing.

Thank you for your attention!

Q & A