Center for the Advancement of Natural Discoveries using Light Emission

Middle Infrared and THz Sources at AREAL

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Ultrafast Beams and Applications
07 July 2017

Introduction

AREAL Project

	Phase 1 Gun section	Phase 2 Whole linac
Status:	Completed in 2014	In progress
Beam energy:	< 5 MeV	< 50 MeV

Experimental stations

1. **ALPHA** - Amplified Light Pulse for High-end Applications

   Goal: Coherent radiation source in Middle infrared and THz regions

   Physics, Materials science and engineering, Electrical engineering, Chemistry, Environmental science, Spectroscopy and imaging technology, Information science and technology, Biophysics and biochemistry, …

2. **BETA** - Booster for Emerging Technology Accelerators

   Goal: Test stand for advanced particle acceleration schemes and tailored beam formation for coherent radiation

THz radiation sources

Existing THz sources

	Frequency range	*Power*
✓ **Solid State Oscillators.**	100 GHz – 1 THz	0.1 – 1 mW
✓ **Gas and Quantum Cascade Laser.**	0.5 - 5 THz	~ 100 mW
✓ **Laser Driven THz Emitters.**	0.2 - 2 THz	~ 100 μW

Drawbacks

Low levels of generated power, Tunability

Accelerator- based sources of THz radiation

- ✓ **Synchrotron storage rings**
- ✓ **Dedicated user facilities (Linear accelerators)**
  - **IR/THz free electron lasers**
  - **Superradiant radiation**
  - ...

Advantages

- ✓ High brightness
- ✓ High power
- ✓ Pulse energy
- ✓ Tunability

THz radiation sources

Radiation production schemes

- Dipole radiation from a bending magnet.
- Transition radiation.
- Diffraction radiation.
- Edge radiation at bending magnets or undulators
- Cerenkov radiation
- Smith-Purcell radiation
- **Undulator radiation**

FELs can produce high power coherent radiation in the THz region

FELs

Advantages

- ✓ Tunability
- ✓ High peak power
- ✓ Time structure
- ✓ Coherence

Drawbacks

- *Large size*
- *High cost*
- *System complexity*

THz FELs

Radiation wavelength

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

λ_u – und. period

K – und. parameter

γ – beam energy

Requirements on e-beam parameters

Small energy spread → $\Delta E/E \sim 0.5\rho$

High peak current → $I_{peak} = \dfrac{Q}{\sqrt{2\pi}\,\dfrac{\sigma}{c}}$

Small emittance → $\varepsilon < \lambda_l / 4\pi$

THz FEL

↓

Less beam energy →

- ✓ Reduction in the cost and the size
- ✓ Not strong requirements on e-beam parameters
- ✓ Mitigation of problems with radiation shielding and safety

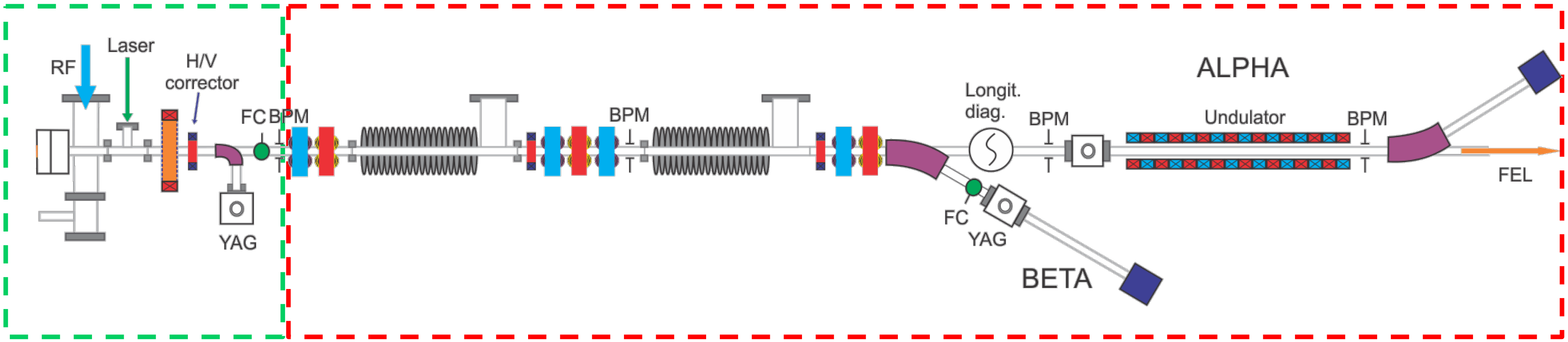
THz FELs*

	λ (μm)	σz (ps)	E(MeV)	I(A)	K(rms)
Nijmegen (FLARE)	100-1400	3	10-15	50	0.5-3.3
Osaka(ISIR,SASE) JAPAN	25-147	20-30	12.5-20.5	1000	1.5
Nijmegen (FELIX)	3-250	1	50	50	1.8
Novosibirsk (FEL2)	40-80	20	20	20	1.0
Orsay (CLIO)	3-150	1	12-50	100	1.8
UCLA-BNL(VISA) USA	0.8	0.5	64-72	250	1.2

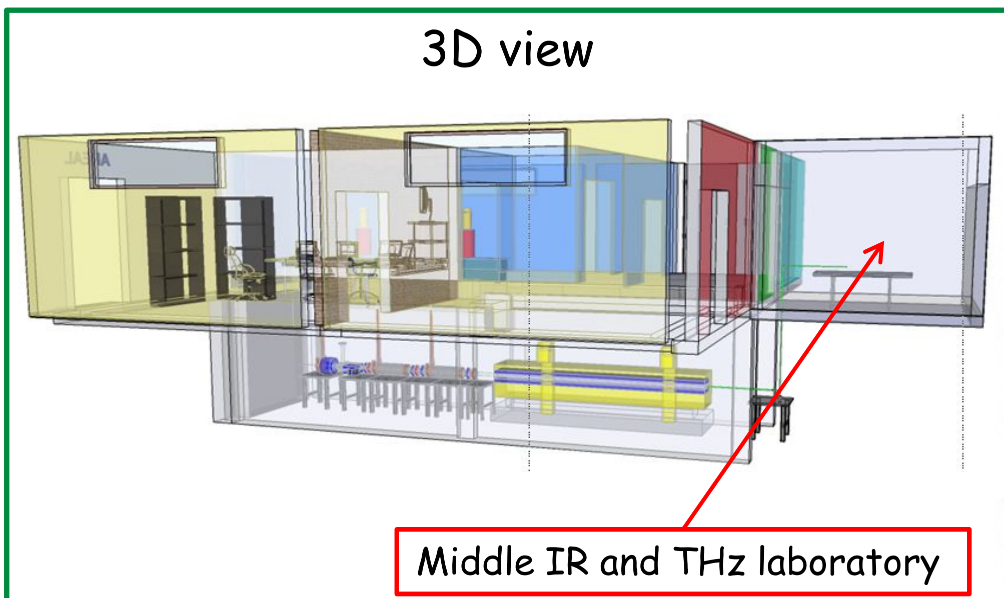
*J. Blau, et al., Free Electron Lasers in 2013, Proc. of FEL'13.

AREAL 50 MeV Upgrade

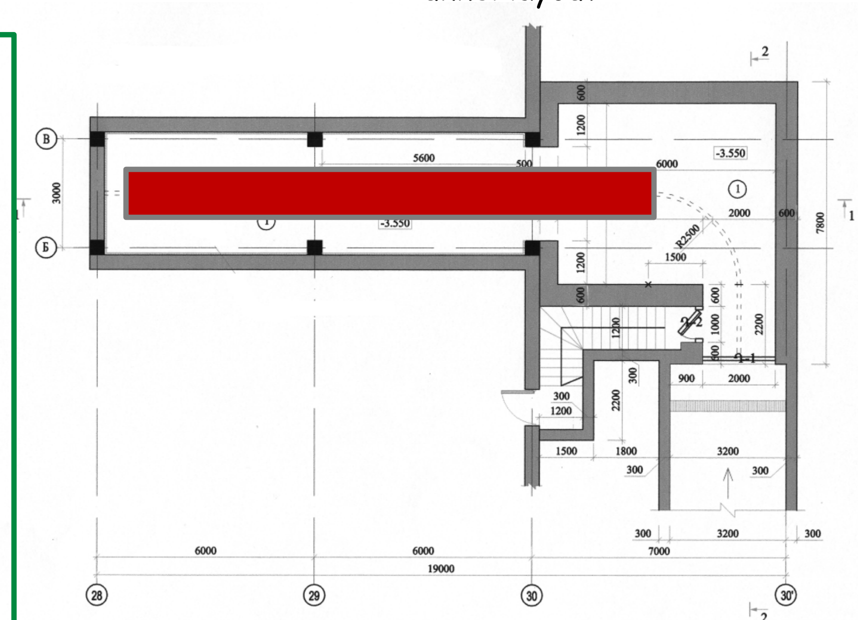
Schematic overview of AREAL



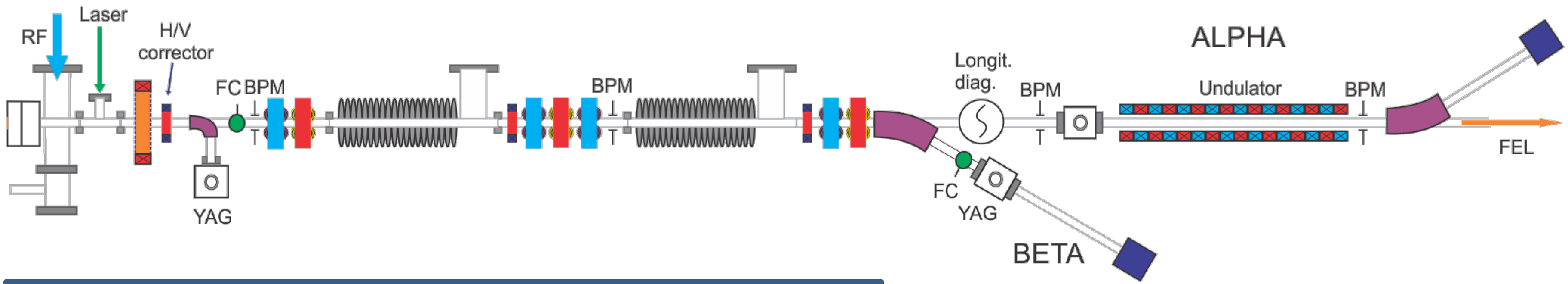
Current stage



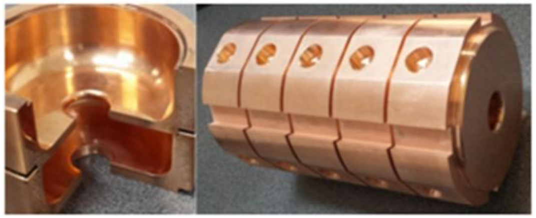
Tunnel layout



AREAL 50 MeV Upgrade



- **Two accelerating sections**
  - Travelling wave structure, L=1.5 m, E= 25 MV/m



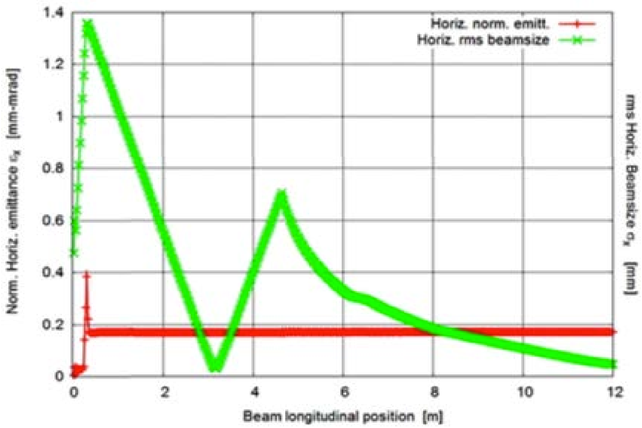
(A. Vardanyan)

- **Magnets**
  - Quadrupole magnets, Solenoid, Dipole, H/V correctors
- **Undulator**
- **Diagnostic system**
  - Energy/energy spread, Beam position, Emittance, Charge, current, Bunch length
- **Control system**
  - Change to MTCA technology

(G. Amatuni)

Beam main parameters

Energy [MeV]	<50
Charge [pC]	50-300
Emittance [mm-mrad]	<0.3
RMS bunch duration [ps]	0.5
Energy spread	0.2%



Beam size and normalized beam emittance evolution along the linac

Undulator

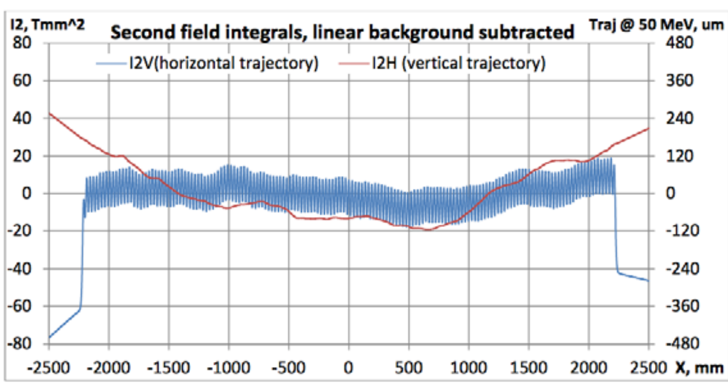
Undulator parameters

Period length [mm]	27.3
Gap [mm]	12
Peak Field [T]	0.468
K - Parameter	1.17
Length [mm]	4492.3

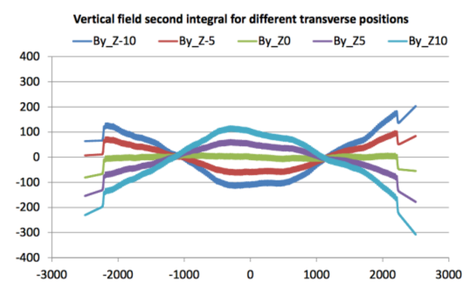
DESY

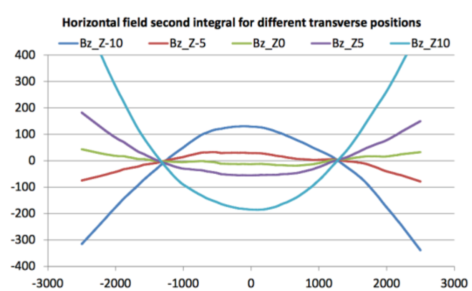
CANDLE

All measurements have been performed at DESY

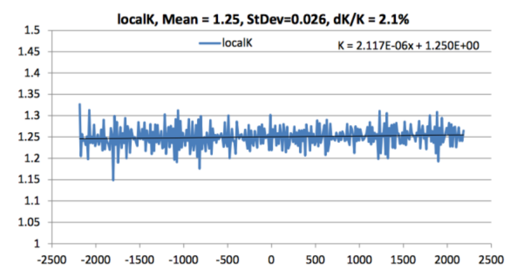


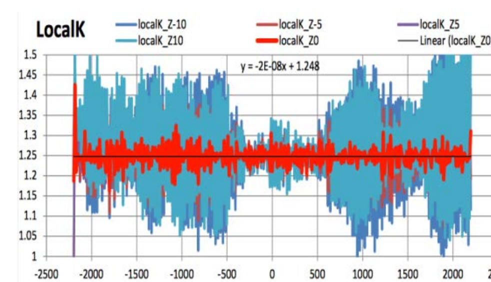
Field integrals





Correction of longitudinal taper





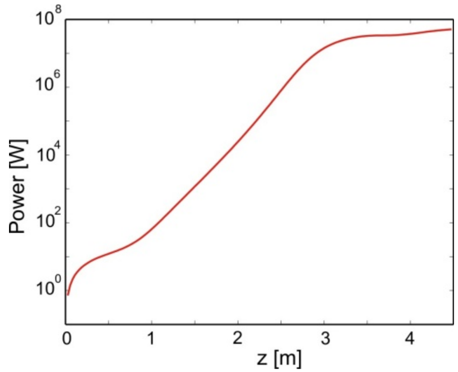
Simulation results

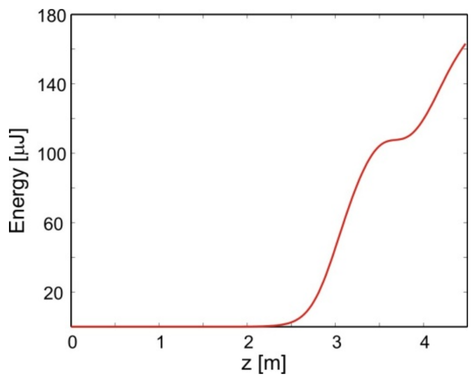
$$\lambda_l = \frac{\lambda_u}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$$

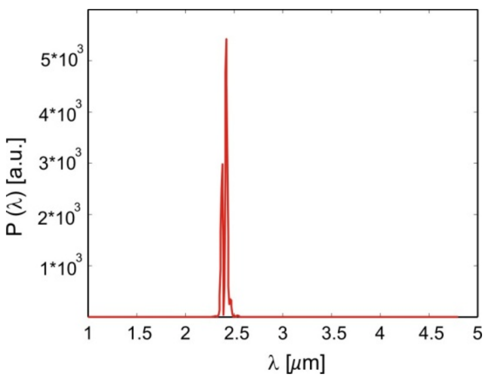
E = 30 -50 MeV → Rad. Wavelength 6.7-2.4 μm — Frequency 45-125 THz

Power	Energy	Spectrum

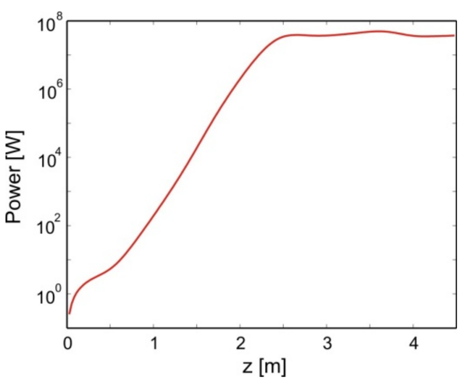
E=50 MeV

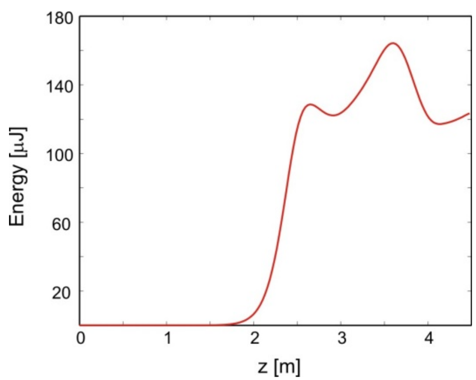


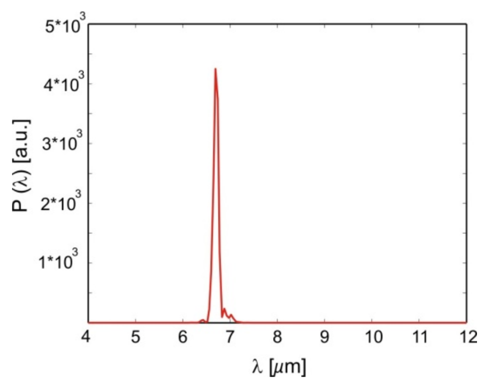




E=30 MeV







Saturation length= 2.1 - 3.2 m, Pulse energy= 60 - 100 μJ, Power= 40 - 60 MW

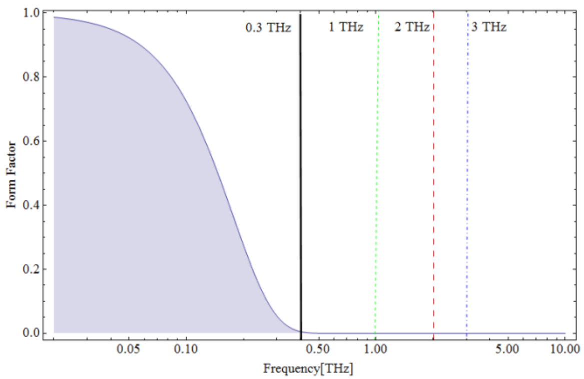
THz undulator

Total energy $$W_{N_e electrons} = W_{1electron}\left[N_e + N_e(N_e - 1) f(\upsilon)^2\right]$$

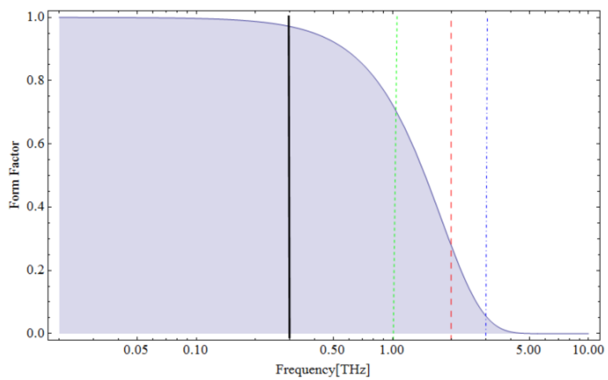
Coherent part $$W_{coh} \approx W_{1electron} N_e^2 f(\upsilon)^2$$

$$W_{1electron} = 2\frac{\pi q_e^2 N_P}{3\varepsilon_0 \lambda_u} K^2 \gamma^2$$

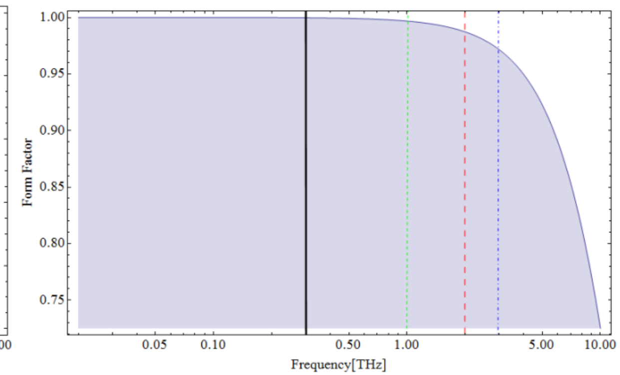
$$f(\upsilon) = \exp\left[-2(\pi\upsilon)^2\left(\frac{\tau}{2.35}\right)^2\right]$$



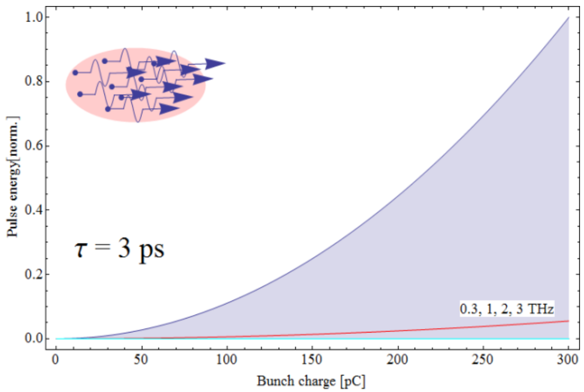
τ = 3 ps

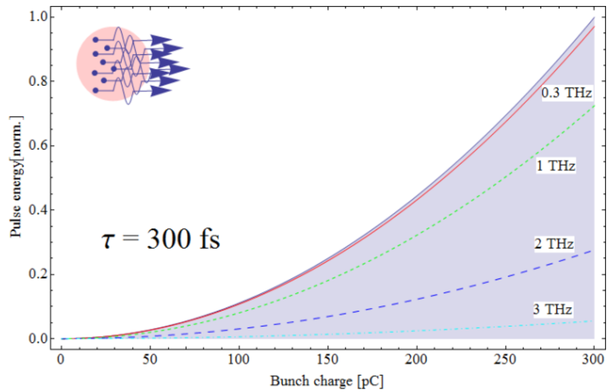


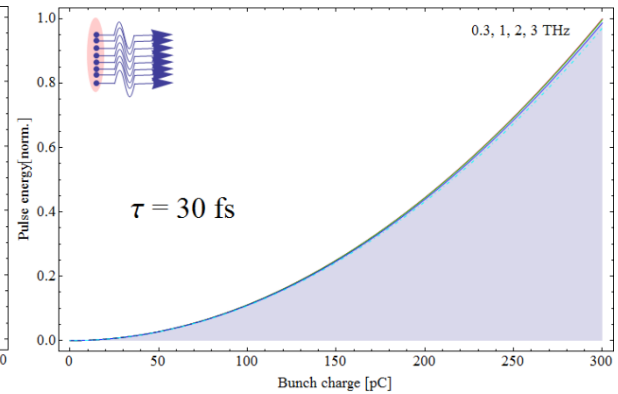
τ = 300 fs



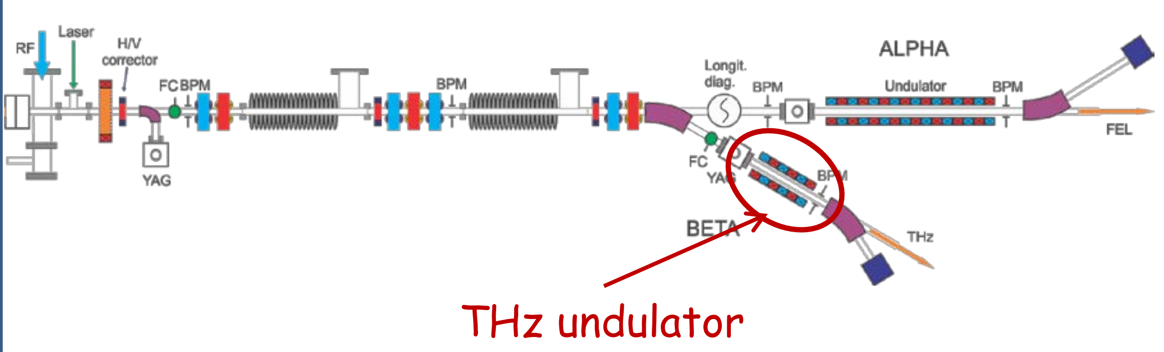
τ = 30 fs

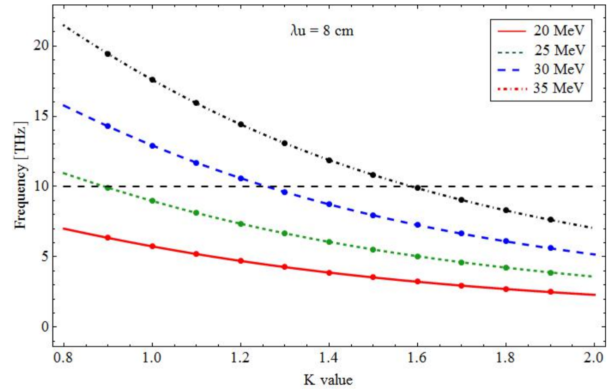


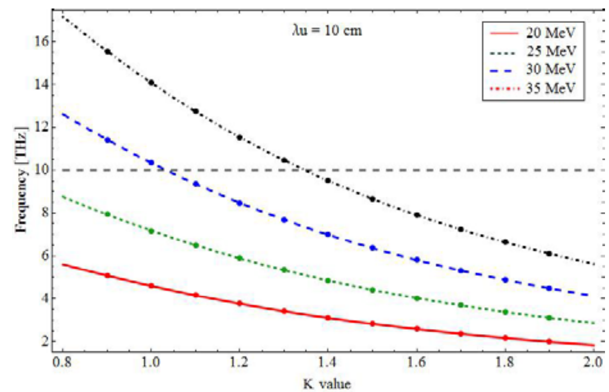


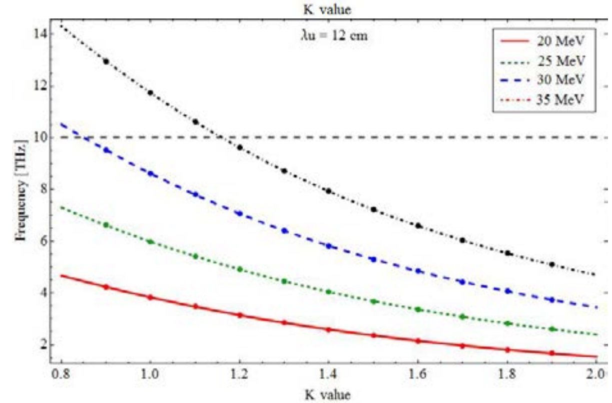


THz undulator









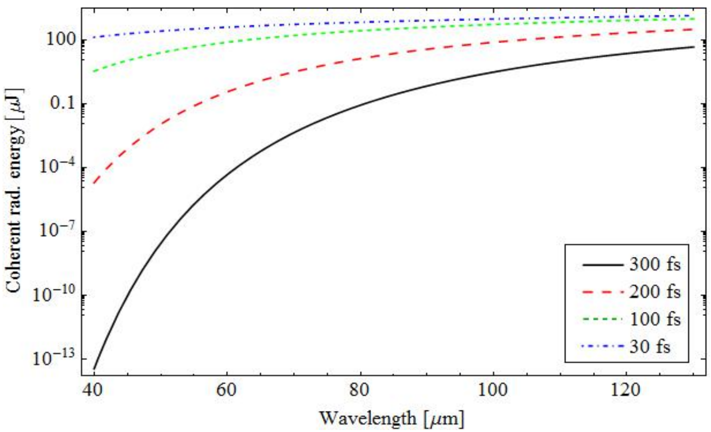
Undulator specifications

	Option 1	Option 2	Option 3
Type	Helical		
K	0.8 – 2		
Period length [cm]	8	10	12
Total length [m]	2.5		
(Beam energy 20 – 35 MeV)			
Radiation wavelength [μm]	30 – 130	30 – 163	28 – 195
Frequency [THz]	2.3 – 10	1.8 – 10	1.5 – 10

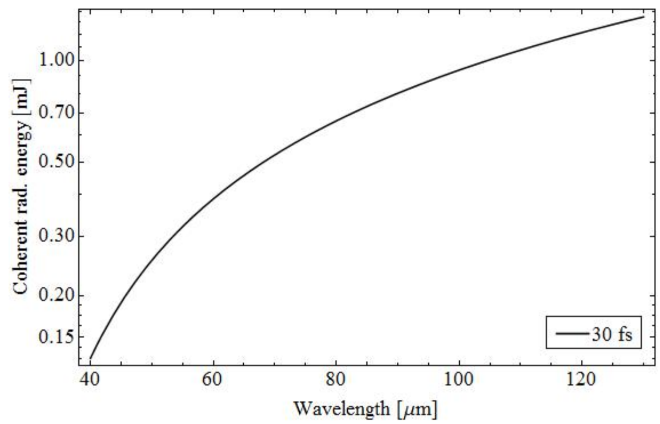
Radiation Energy

E = 20 – 35 MeV, τ = 30 – 300 fs, Q = 50 pC

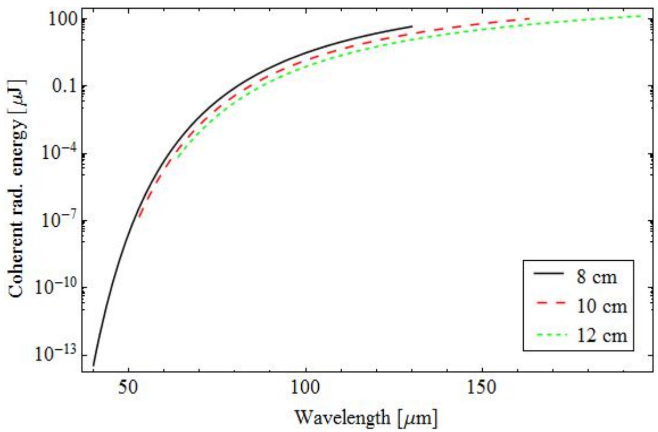
Coherent energy for different bunch durations (λ_u = 8cm)



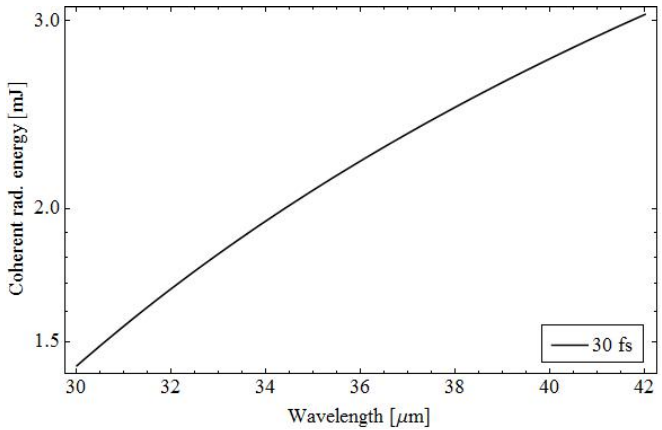
E = 20 MeV



Coherent *energy for different periods (20 MeV)*

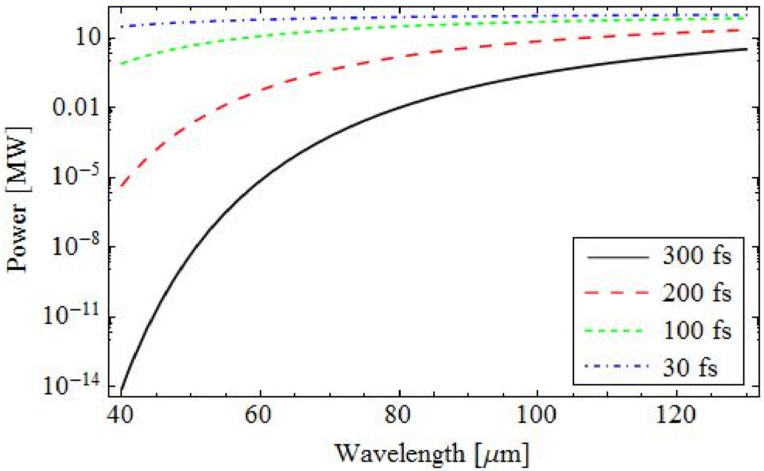


E = 35 MeV

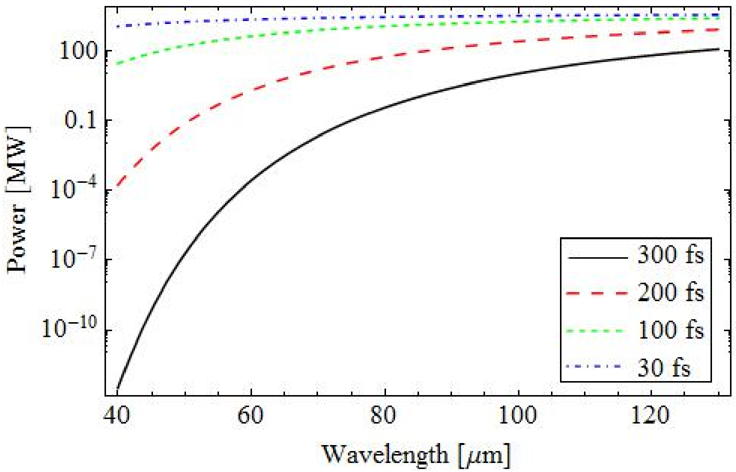


Radiation Power

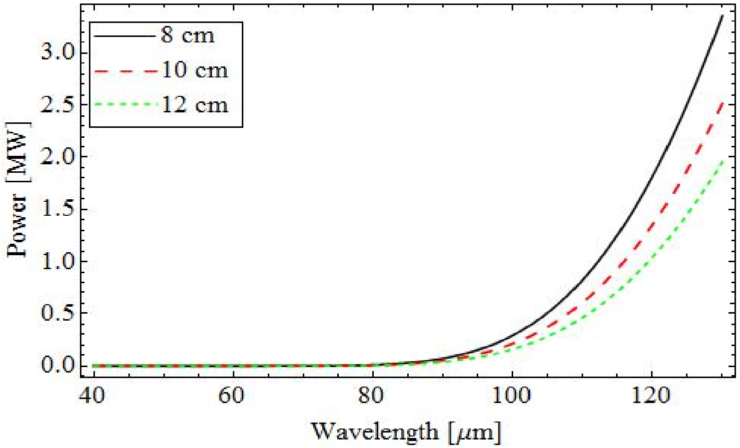
$\lambda_u = 8cm,\quad Q = 50\,pC,\quad E = 20MeV$



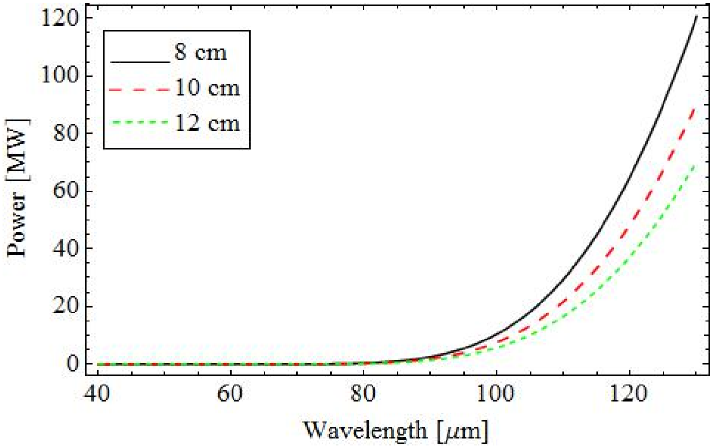
$\lambda_u = 8cm,\quad Q = 300\,pC,\quad E = 20MeV$



$Q = 50\,pC,\quad \tau = 300\,fs,\ E = 20MeV$



$Q = 300\,pC,\quad \tau = 30\,fs,\ E = 20MeV$



THANK YOU FOR ATTENTION