Simulation of Undulator Radiation for the THz Source Project at PITZ

BE12.7

Considerations for the Design of the Undulator

Outline

> PITZ Facility

> THz source Project at PITZ

> Considerations for the Design of the Undulator

> Summary

> Outlook

Prach Boonpornprasert

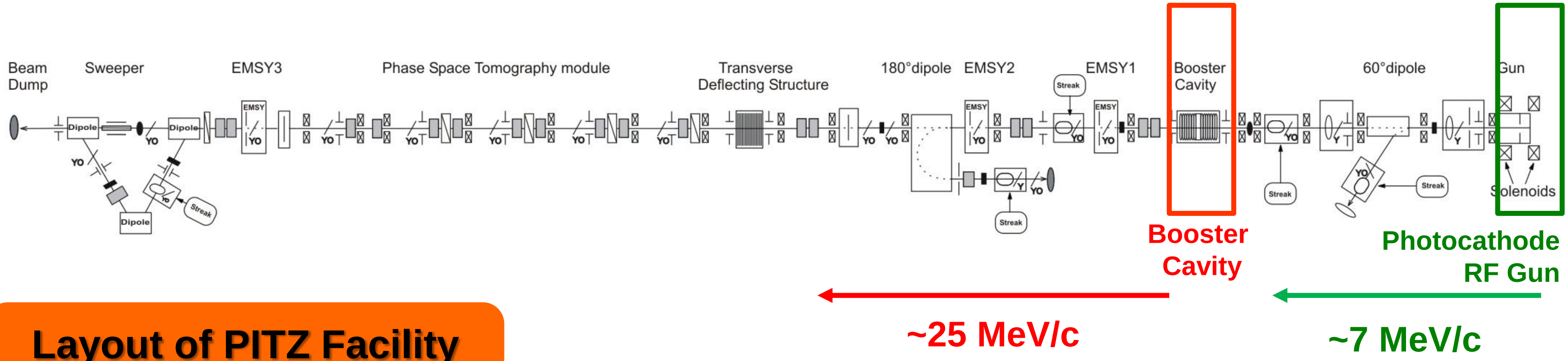
DPG Spring Meeting
Dresden
03.04.2014

HELMHOLTZ | ASSOCIATION

PITZ Photo Injector Test Facility Zeuthen

DESY

Photo Injector Test Facility at DESY, Location Zeuthen (PITZ)



Layout of PITZ Facility

Goal

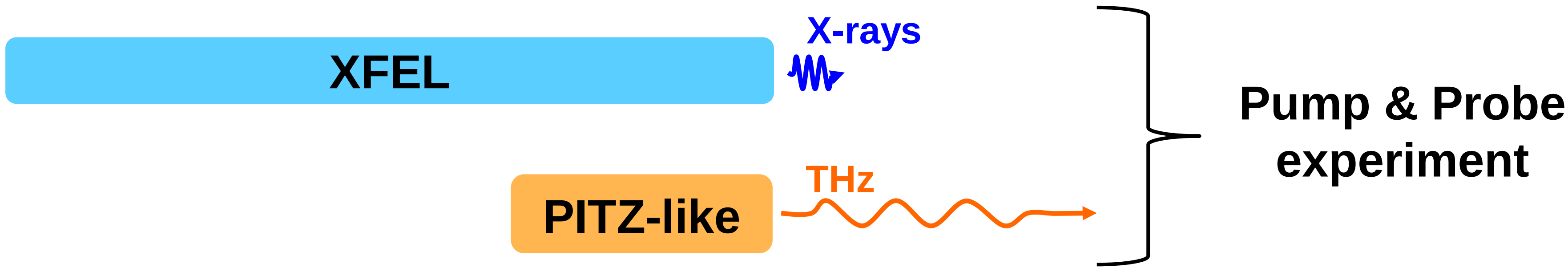
Development of a high brightness electron source for linac based FELs

Highlights in 2013 - 2014

- Preparation of RF guns for European XFEL
- Plasma wakefield acceleration experiment
- 3D-ellipsoidal cathode laser system

Parameter	Value
RF frequency	1.3 GHz
RF repetition rate	10 Hz
Laser → Flattop → FWHM	~20 ps
e- bunch charge	1 pC – 4 nC
Maximum peak current	~200 A

THz source Project at PITZ



The concept was presented in FEL2012 conference. (*E.A.Schneidmiller, et al., WEPD55*)

PITZ can be considered as a prototype THz source

Types of Radiation sources

- SASE FEL
- Coherent Transition Radiation

- The preliminary simulations for SASE FEL using GENESIS code were done.
- The results are comparable to the benchmark results obtained with FAST code.

Works in This Presentation

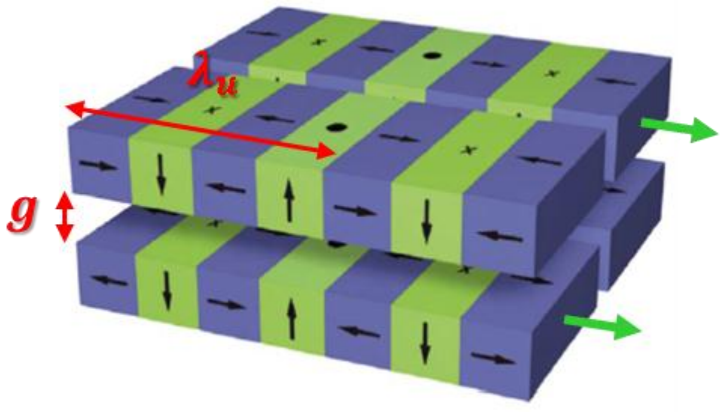
Considerations for the design of a undulator for goal radiation wavelengths:
5 µm, 20 µm and 100 µm

Design Consideration: Undulator Type

Condition : Variably Polarized Undulator

APPLE-II Type Undulator

- **A**dvanced **P**lanar **P**olarized **L**ight **E**mitter ➔ **APPLE**
- The undulator is made of pure permanent magnets which are arranged in 4 arrays.
- **The radiation** can be polarized vertically, horizontally, and circularly by moving two opposing magnet arrays.



Sketch of APPLE- II Undulator*

***Source: Conceptual Design Report ST/F-TN-07/12, Fermi@Elettra, 2007**

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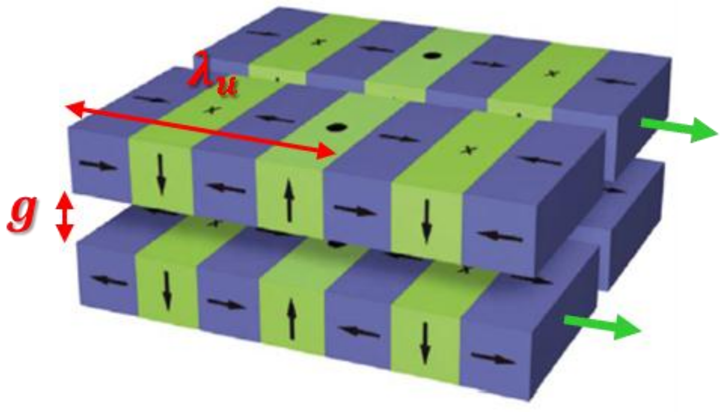

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Decision: APPLE-II Type Undulator

Design Consideration: Undulator Type

Condition : Variably Polarized Undulator

Important Equations

The Peak magnetic field (B_{max}) :

$$B_{max}[T] = a_1 \times \exp\left[a_2 \frac{g}{\lambda_u} + a_3 \left(\frac{g}{\lambda_u}\right)^2\right] ,$$

where $a_1, a_2,$ and a_3 are coefficients and $0.1 < \frac{g}{\lambda_u} < 1$.

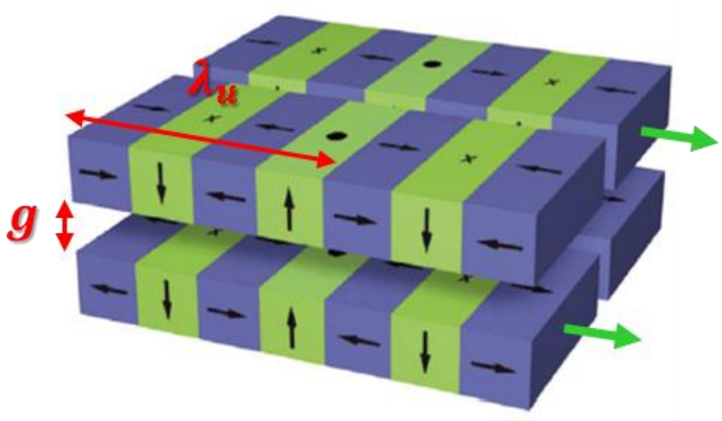
Undulator Parameter (K)

$$K = 0.934 \cdot B_{max}[T] \cdot \lambda_u[cm]$$

Radiation Wavelength (λ_{rad})

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

where γ is Lorentz factor.



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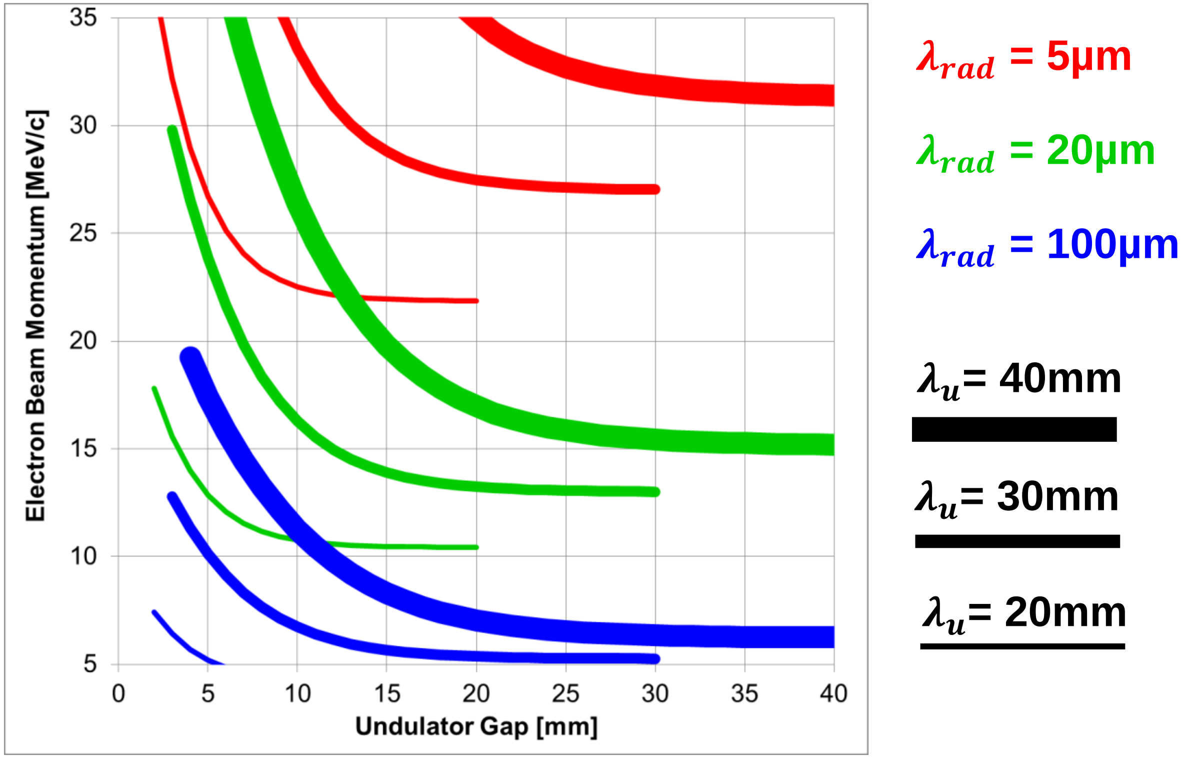
Decision: APPLE-II Type Undulator

Design Consideration: Undulator Period Length

Conditions : in-air undulator, range of e-beam momentum is 15 -25 MeV/c

- λ_u= 20mm, 30mm and 40mm were considered.
- λ_{rad} = 5µm, 20µm and 100µm were considered.
- Typical range of gap variation (in-air APPLE-II undulator): **6.5mm to 25mm**.



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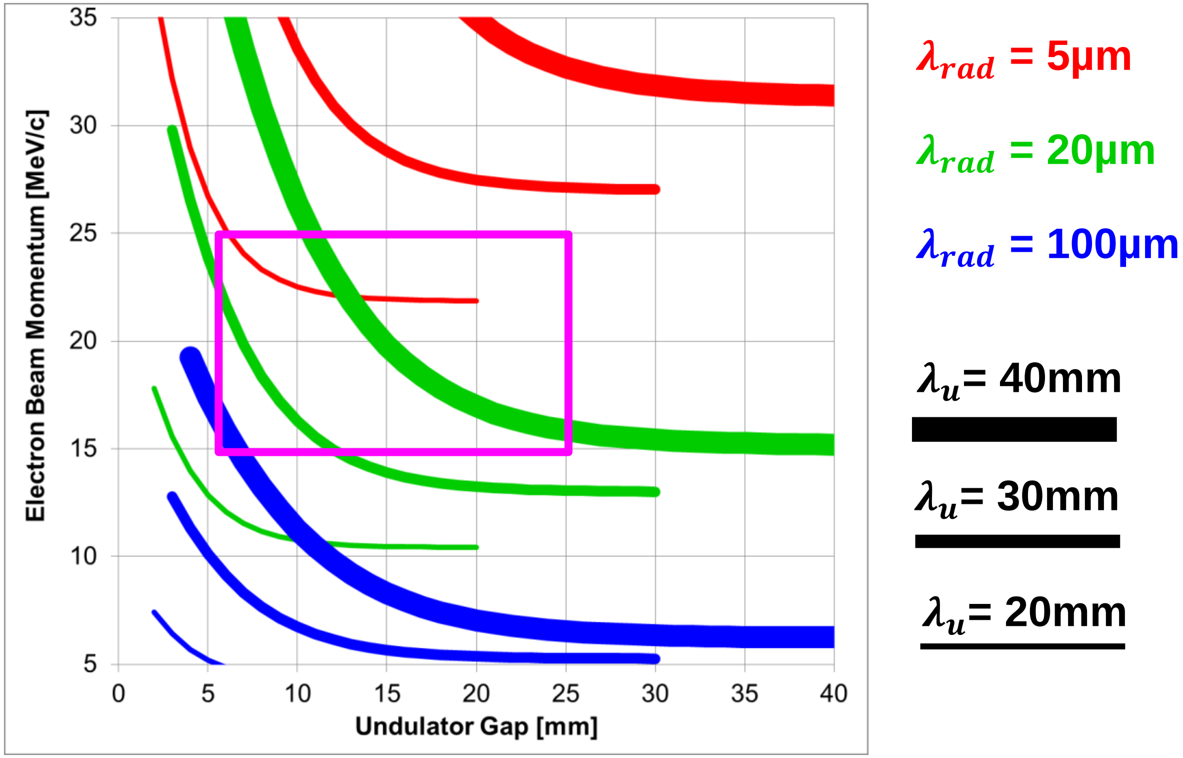

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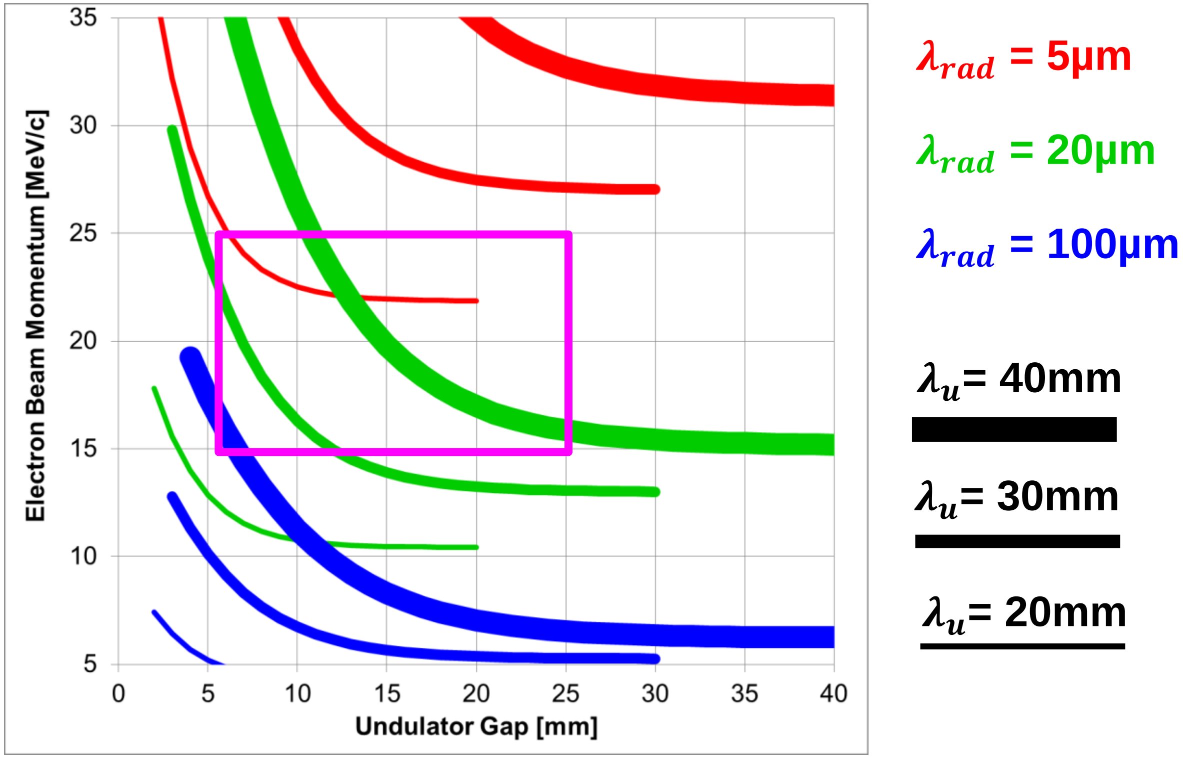


Decision: λ_u = 20 mm for λ_{rad} = 5 µm
λ_u = 40 mm for λ_{rad} = 20 µm and 100 µm

Design Consideration: Undulator Length

Conditions : maximum undulator length of 5 m,
radiation bandwidth ~5%, peak power in MW level

- GENESIS1.3 code was used for SASE FEL simulation.
- The space charge calculation is **excluded** in the simulation.
- In this presentation, only **20 µm** and **100 µm** cases were studied.
- The model Gaussian electron beam was used.
- From preliminary beam dynamics simulations, the possible range of $\varepsilon_{tr,rms}$ is **3 to 7 mm.mrad**.

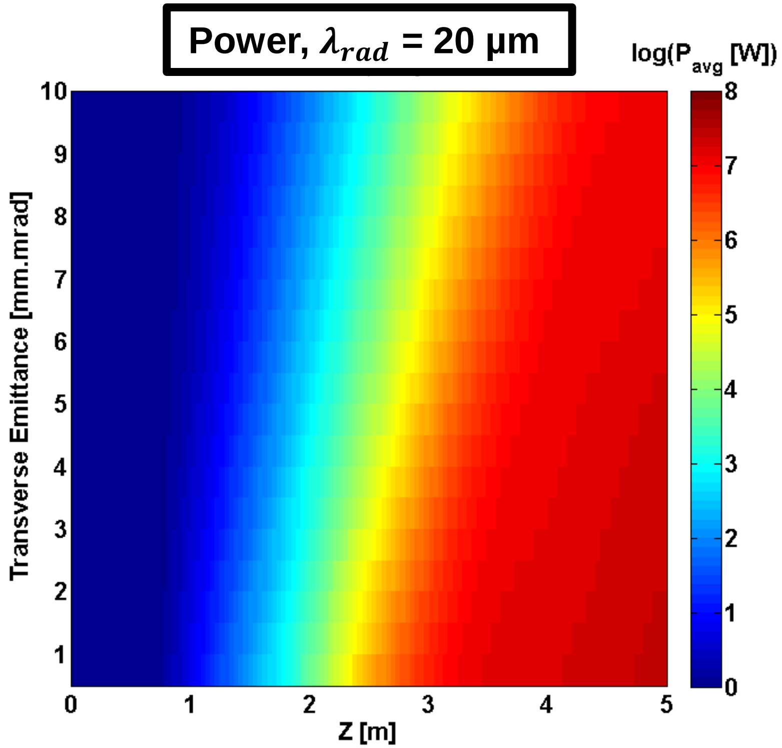
Procedure

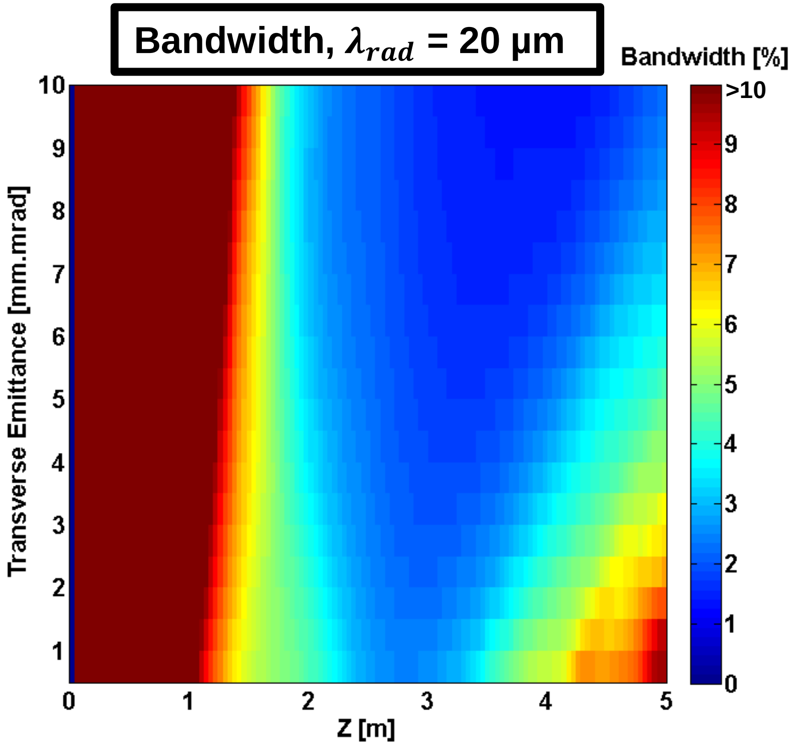
- scan transverse emittance in the simulations
- Find the compromised undulator length for the expected peak power and bandwidth

Parameter	Detail	
undulator type	Helical	
undulator period length (λ_u)	40 mm	
number of period	125	
radiation wavelength (λ_{rad})	20 µm	100 µm
undulator gap (g)	14 mm	6.5 mm
$K / \sqrt{2}$	0.90	1.99
$\langle P_z \rangle$	21 MeV/c	15 MeV/c
$P_{z,rms}/\langle P_z \rangle$	0.1%	
bunch charge	4 nC	
rms bunch length	2.4 mm	
peak current	200 A	
σ_x, σ_y	~0.2 mm	

Design Consideration: Undulator Length for λ_{rad} = 20 µm

Conditions : maximum undulator length of 5 m,
radiation bandwidth ~5%, peak power in MW level





Design Consideration: Undulator Length for λ_{rad} = 20 µm

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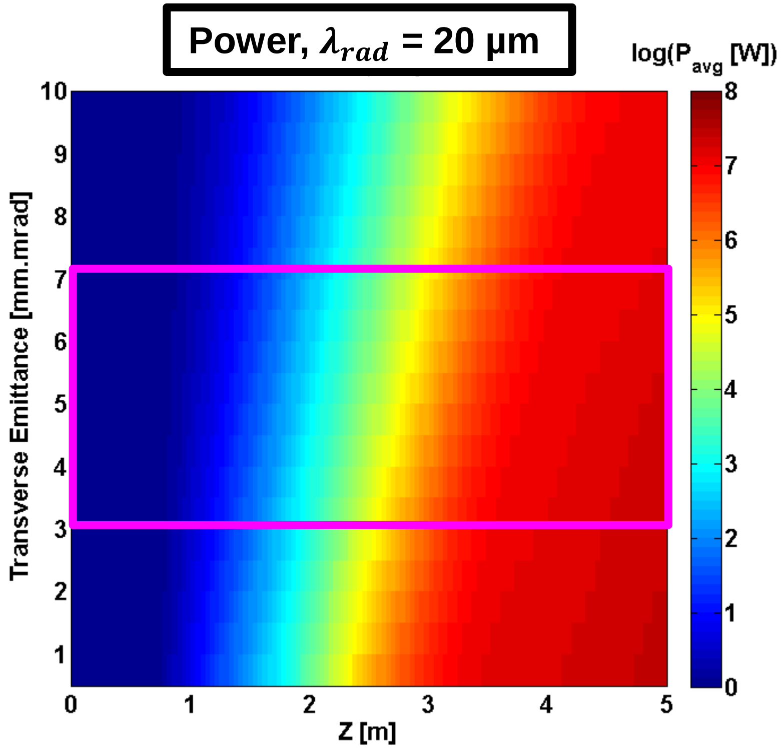
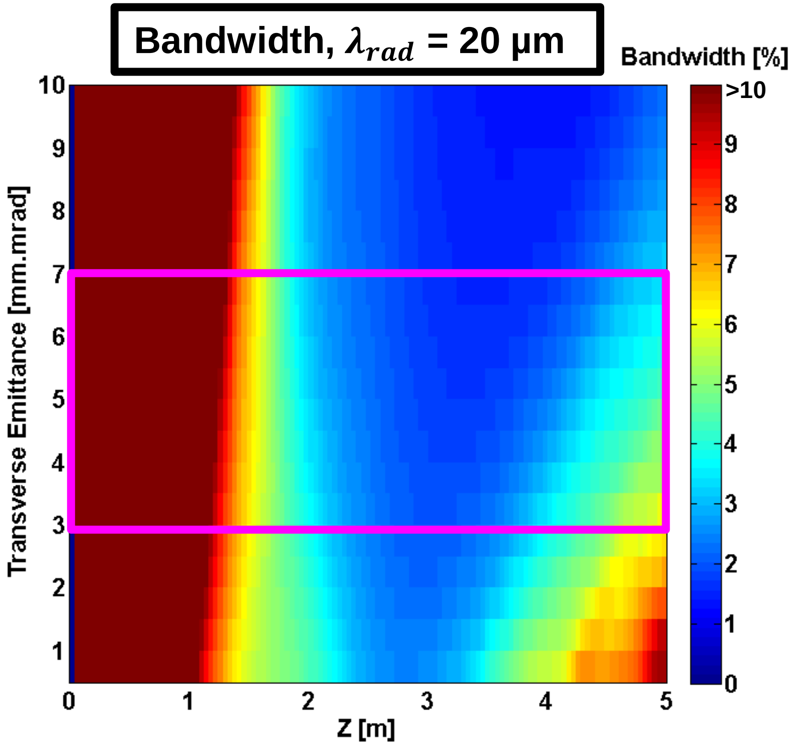
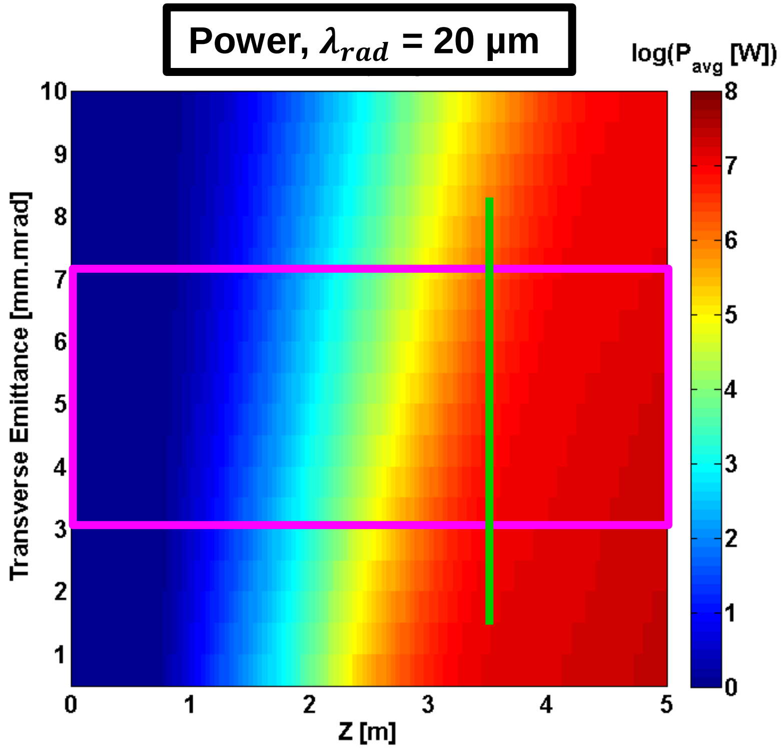
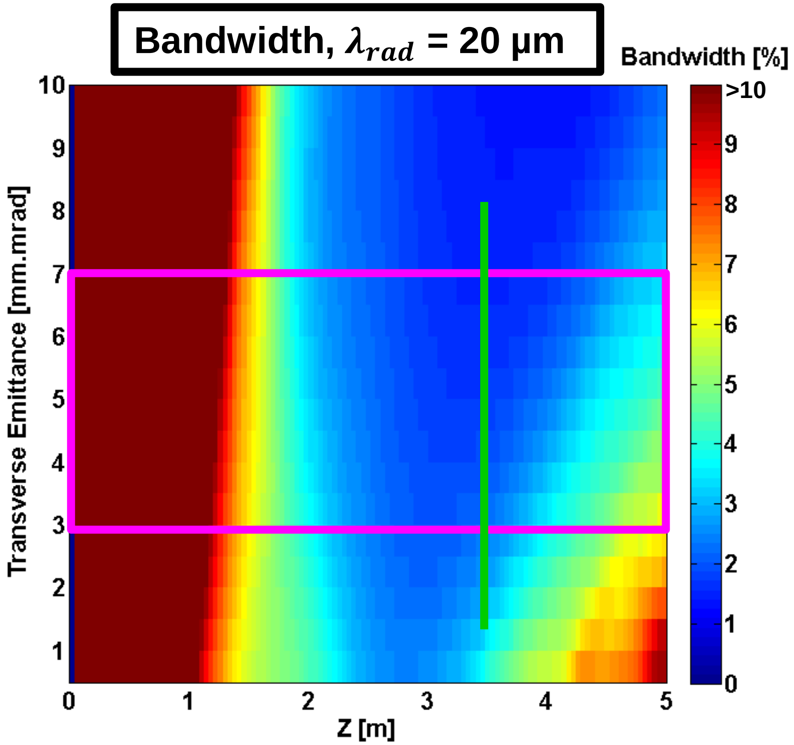




Design Consideration: Undulator Length for λ_{rad} = 20 µm

Conditions : maximum undulator length of 5 m,
radiation bandwidth ~5%, peak power in MW level

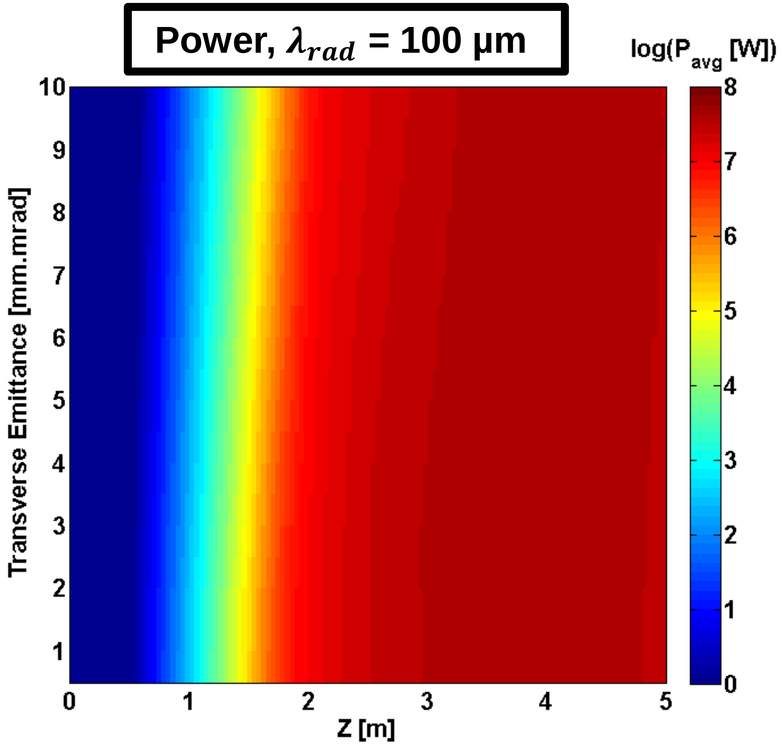


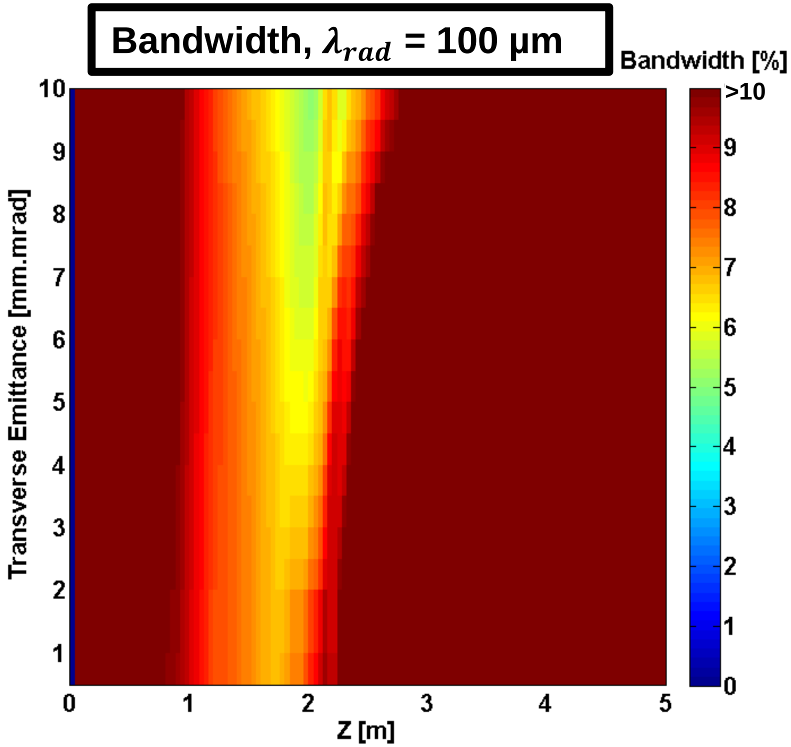


Undulator length of 3.5 m for λ_{rad} = 20 µm

Design Consideration: Undulator Length for λ_{rad} = 100 µm

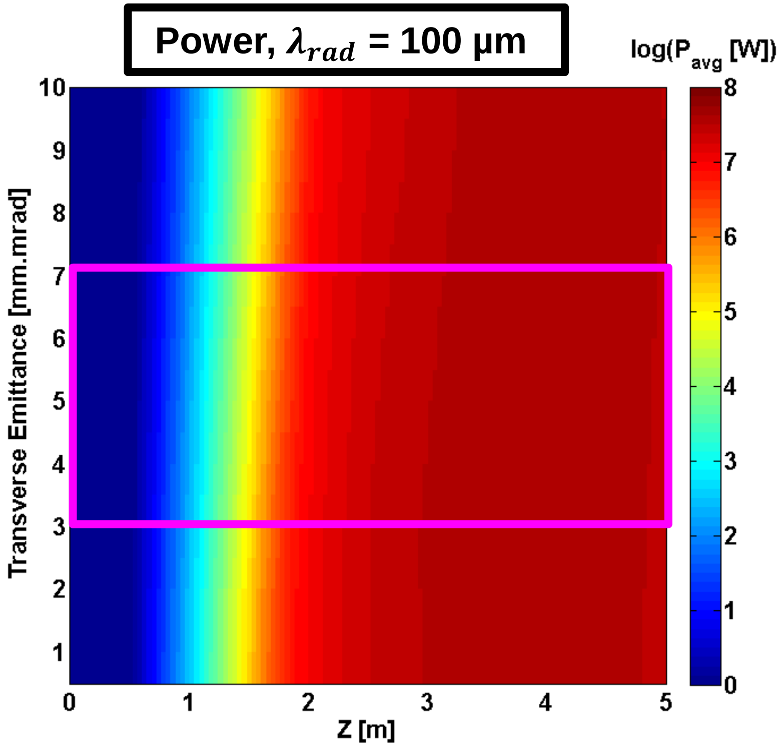
Conditions : maximum undulator length of 5 m,
radiation bandwidth ~5%, peak power in MW level

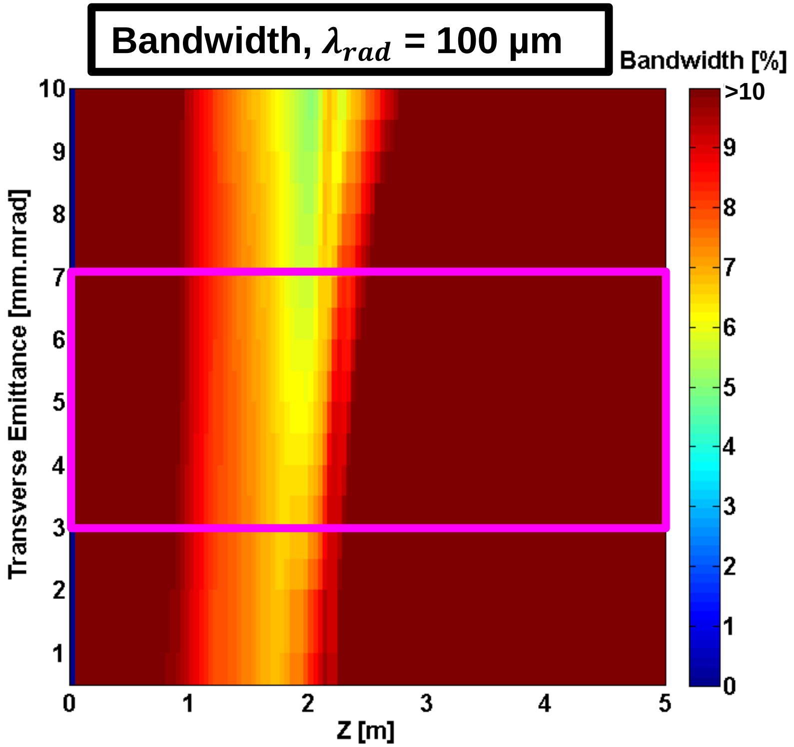




Design Consideration: Undulator Length for λ_{rad} = 100 µm

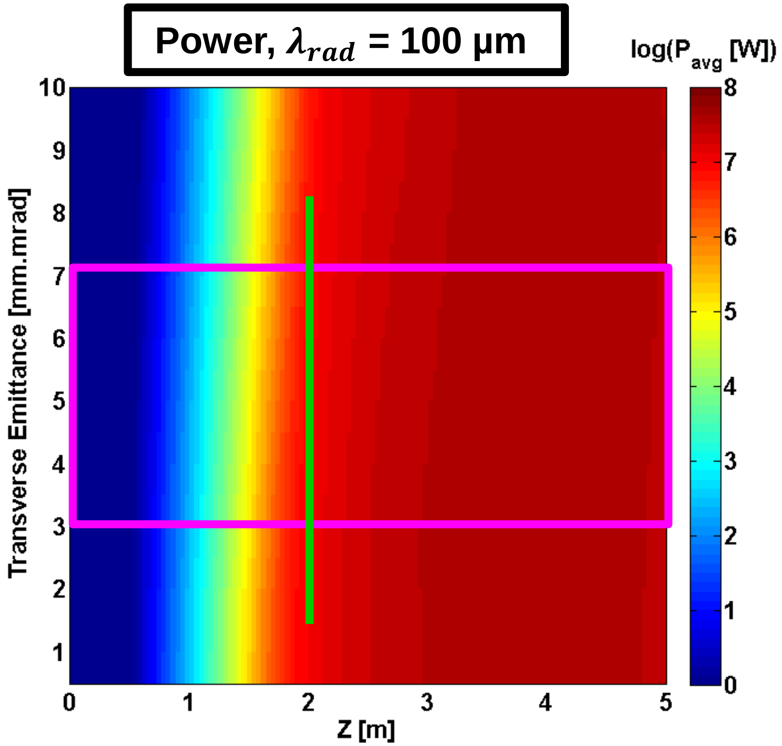
Conditions : maximum undulator length of 5 m,
radiation bandwidth ~5%, peak power in MW level

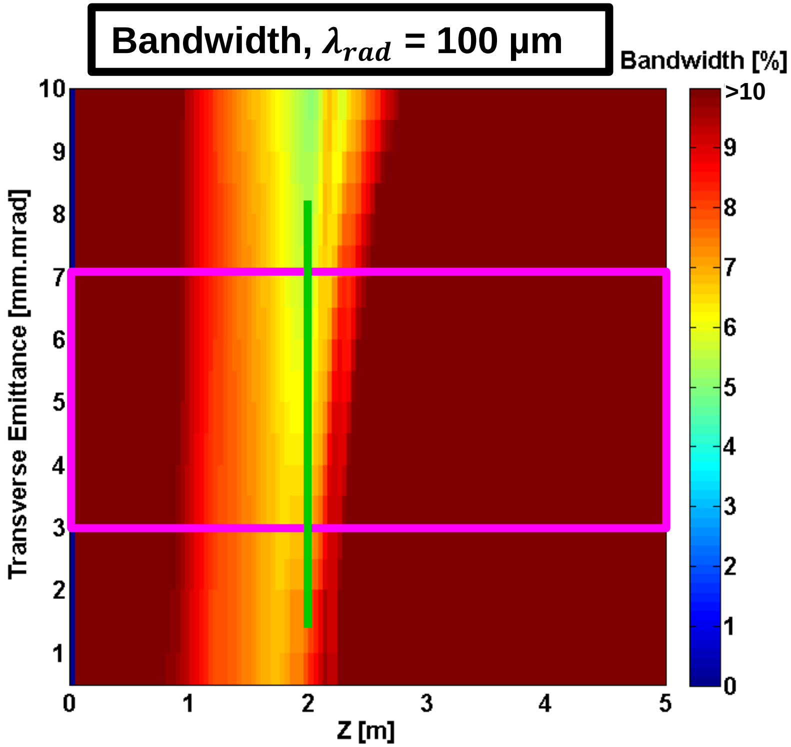




Design Consideration: Undulator Length for λ_{rad} = 100 µm

Conditions : maximum undulator length of 5 m,
radiation bandwidth ~5%, peak power in MW level





Undulator length of 2 m for λ_{rad} = 100 µm

Summary of Considerations for the Design of Undulator

Specification	Decision
Undulator Type	In-air, APPLE-II type undulator
Range of gap variation	6.5 mm to 25 mm (preliminary)
Period Length	λ_u = 20 mm for λ_{rad} = 5 µm (?) λ_u = 40 mm for λ_{rad} = 20 µm λ_u = 40 mm for λ_{rad} = 100 µm
Undulator length	under study…(between 2m to 5m)

Outlook

- Repeat the last part of the study including the space charge effect.
- Perform the same study for λ_{rad} = 5 µm.
- Start to End (S2E) simulation for SASE FEL.

- Simulation of the production of THz radiation using Coherent Transition Radiation.

Thanks for your attention !

Backup: more information of APPLE-II

APPLE-II Type Undulator*

$$B_{max}[T] = a_1 \times \exp\left[a_2 \frac{g}{\lambda_u} + a_3 \left(\frac{g}{\lambda_u}\right)^2\right] ,$$

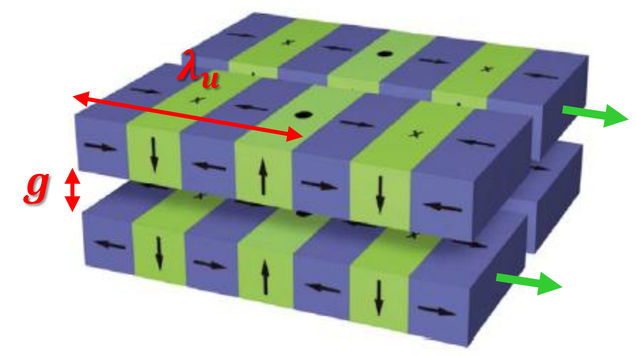
Polarization	a_1	a_2	a_3
Horizontal	1.76	-2.77	-0.37
Circular	1.54	-4.46	0.43
Vertical	2.22	-5.19	0.88

*Reference: Conceptual Design Report ST/F-TN-07/12, Fermi@Elettra, 2007

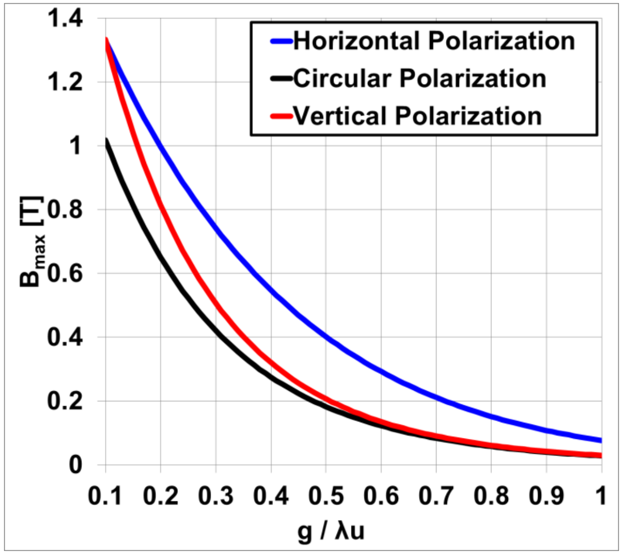
Example of APPLE-II Parameters

	UE40**
gap (magnetic)	6.5 – 25 mm
gap (vacuum)	5.0 mm
period length	40 mm
undulator length	4 m

**T.Schmidt, Undulators for SwissFEL, FEL2009, Liverpool



Sketch of APPLE- II Undulator

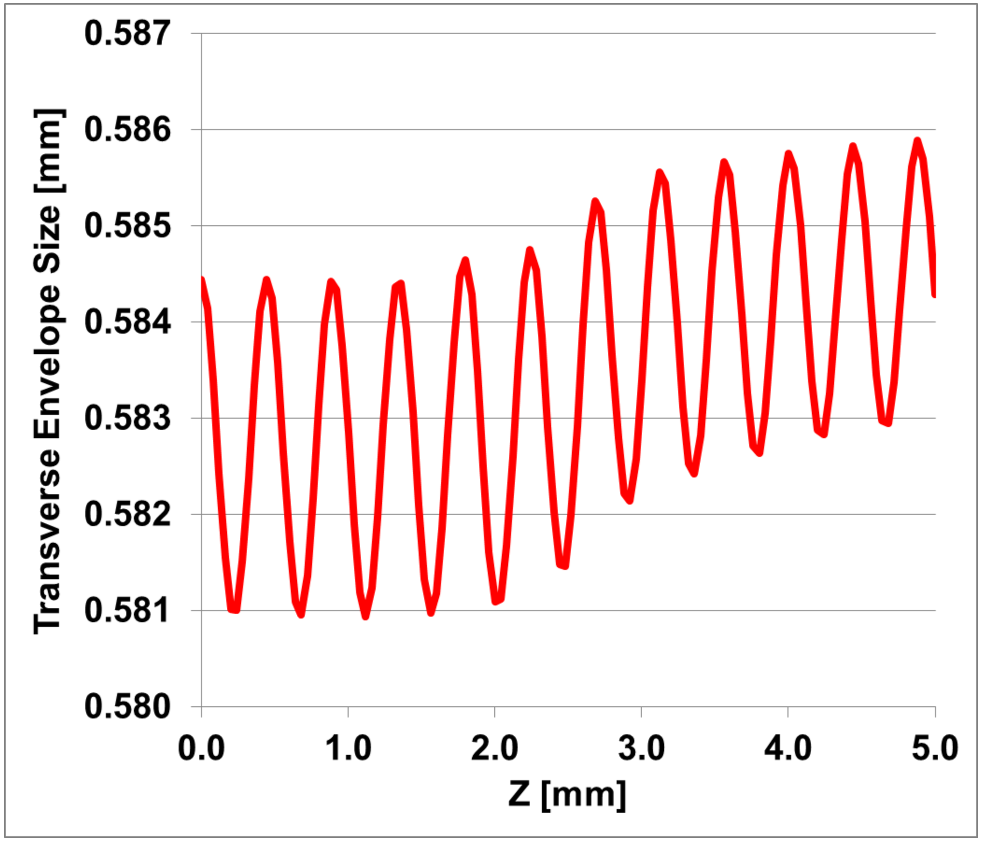


B_{max} from Various Polarization Mode

Backup: Preliminary results of beam dynamics along the undulator

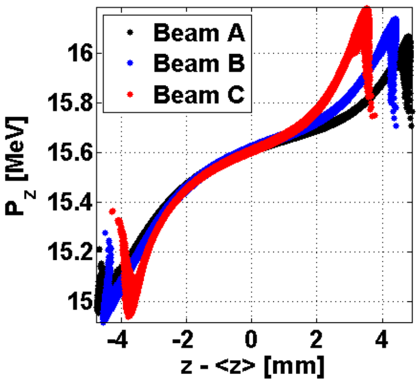
Parameter	Detail
undulator type	Helical
$K / \sqrt{2}$	1.9092
undulator period length (λ_u)	4 cm
number of period	125
radiation wavelength (λ_{rad})	100 µm
bunch charge	4 nC
rms current length	2.4 mm
peak current	200 A
e-beam energy	15 MeV
energy spread	20 keV
β_x, β_y	14.4 cm
ε_x, ε_y	10 mm.mrad
α_x, α_y	0

Transverse envelope size = $6*\sigma_{x,y}$

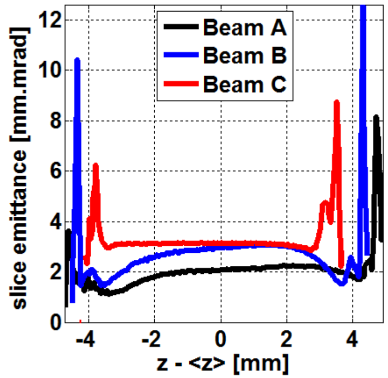


Backup: Preliminary Beam Dynamics simulations

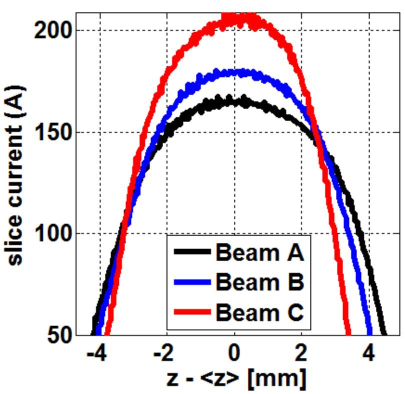
Long. Phase Space



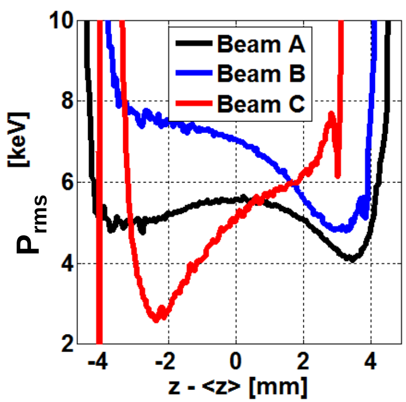
Slice Tr. Emittance



Beam Current



Slice momentum



ASTRA input parameters			
Parameter	Beam A	Beam B	Beam C
rms laser spot size (mm)	1.092	1.455	3.500
I_{main} (A)	378	380	340
Φ_{gun} (degree)	-1.404	-1.404	-1.404
$E_{max,booster}$ (MV/m)	10.2	10.2	10.2

Beam parameters after matching			
Parameter	Beam A	Beam B	Beam C
$\varepsilon_{tr,n}$ (mm.mrad)	2.66	4.99	7.01
$\langle\varepsilon_{slice}\rangle$ (mm.mrad)	2.06	2.74	3.33
$\langle P_{rms,slice}\rangle$ (keV)	7.35	9.23	9.60
I_{peak} (A)	160	170	205

Backup: Bandwidth (full scale)