



Simulation Study of the PSI XFEL with Updated Parameters

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CANDLE/YSU

CONTENT

Scope of work

The table of the new parameters

Major changes

Completed work and outline

work package L

Design work and Simulation of lasing and misalignment effect in XFEL undulator section.

L-1 Injection jitter impact to FEL performance.

L-2 Study of FEL performance sensitivity to beam main parameters.

L-3 Study of quadrupoles and BPM misalignments on FEL performance.

L-4 The FEL performance without external focusing.

In accordance with **L2** task the study of the SASE FEL main performance parameters: saturation length and saturation power sensitivity to beam parameters (emittance, energy spread and peak current) at the entrance of the undulator have to be evaluated for the 3 undulators (Athos, Porthos and Aramis).

L4 task implies performing simulations according to PSI-XFEL beam and undulator parameters' design values using SIMPLEX and GENESIS with switched-off quadrupole magnets.

The studies should be performed with beam and undulator updated parameters.

Beam updated parameters

Undulator	Athos	Porthos	Aramis	D'Artagnan
Energy [GeV]	2.1 - 3.4	2.1 – 3.4	5.8	2.1 – 3.4
Bunch charge [pC]	200/100 /10	200/100 /10	200/100 /10	200/100 /10
Projected emittance [mm-mrad]	0.46/0.4 /0.15	0.46/0.4 /0.15	0.46/0.4 /0.15	0.46/0.4 /0.15
Slice emittance [mm-mrad]	0.4/0.28 /0.1	0.4/0.28 /0.1	0.4/0.28 /0.1	0.4/0.28 /0.1
Energy spread [MeV]	0.3/0.23 /0.2	0.3/0.23 /0.2	0.3/0.23 /0.2	0.3/0.23 /0.2
Peak current [kA]	2.7/2/0. 7	2.7/2/0. 7	2.7/2/0. 7	2.7/2/0. 7
Beam size [micron]			15/?/7	

PSI XFEL electron beam parameters (Old)

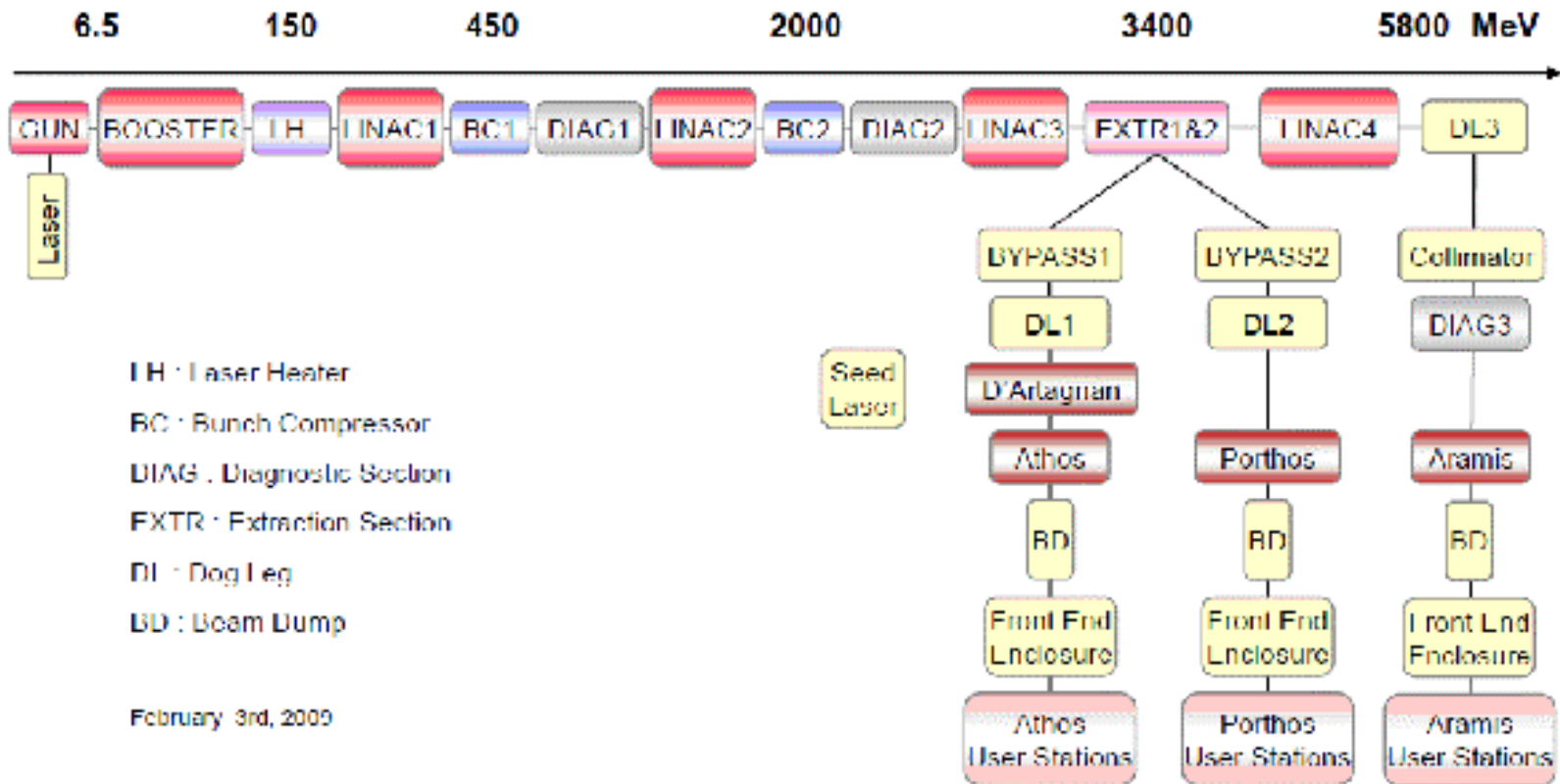
Beam energy [GeV]	5.8-3.4
Normalized emittance [mm mrad]	0.2
Energy spread [MeV]	0.5
Peak current [kA]	1.5
Bunch charge [nC]	0.2

Undulator	Athos	Porthos	Aramis	D'Artagnan
Undulator type	APPLE II	APPLE II	Planar/invac.	Planar
Magnetic material	SmCb/NdFeB	SmCb/NdFeB	NdFeB	
Operation mode	SASE	SASE	SASE	Seeded with 12nm
# Modules	14	14	14	
Undulator period length [cm]	4	4	1.5	6
Undulator periods	100	100	265	65
Active undulator length	4 m	4 m	3.975 m	
Effective drift length	70 cm	70 cm	72.5 cm	
Gap [mm]	6.5 - 50	6.5 - 50	4.2 – 20	
K value for vertical	3.5	3.5	1.2 (peak)	2.4 – 4.5 (peak)
K value for horizontal	3	3		
K value for helical	$3 < 3.5$	$3 < 3.5$		
Quadrupole max gradient	50 T/m	50 T/m	50 T/m	
Quadrupole nominal gradient	35 T/m	35 T/m	35 T/m	
Quadrupole length (effective length)	75 mm	75 mm	75 mm	7

PSI XFEL main design parameters(Old)

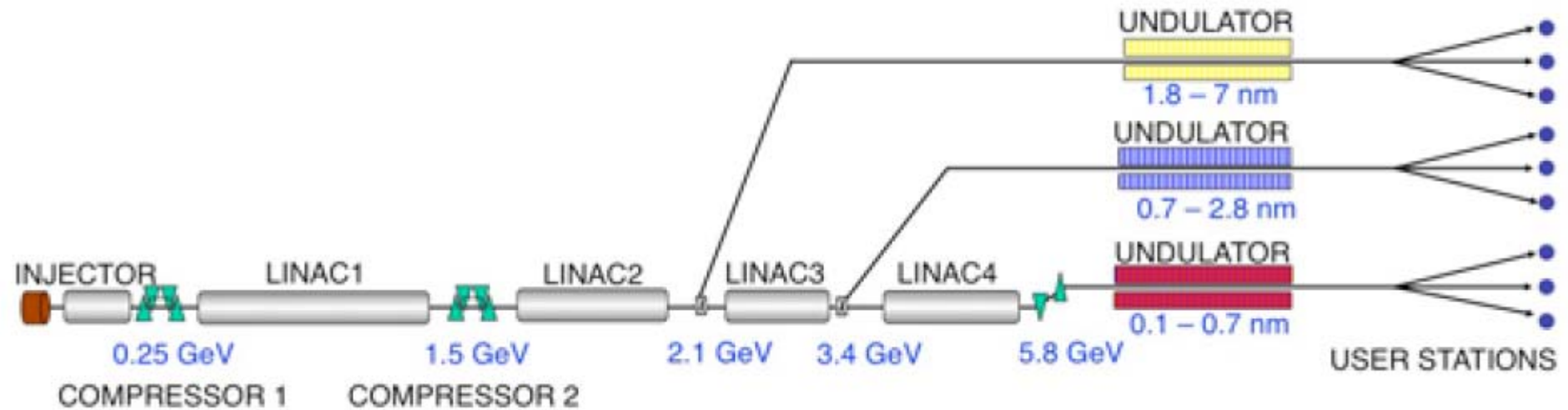
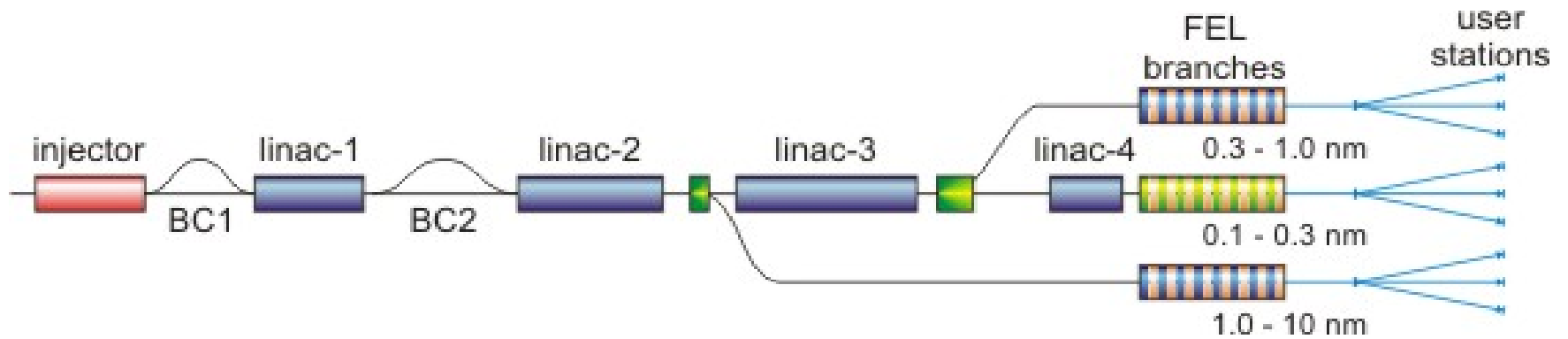
FEL	Branch 1	Branch 2	Branch 3
Wavelength [nm]	0.1– 0.3	0.3 – 1.0	1.0 – 10
Wavelength tuning	energy	energy and gap	Gap
Type	Planar	APPLE	APPLE
Period [mm]	15.0	36.6	52.0
Section length [m]	4.50	4.39	4.16
FODO period [m]	10.5	10.3	9.8
Beta function [m]	15	15	15
Saturation length [m]	31.4	40.5	35.4
Peak power [GW]	2 – 6	10 – 20	10 – 20

PSI-XFEL LAYOUT



LH : Laser Heater
 BC : Bunch Compressor
 DIAG : Diagnostic Section
 FXTR : Extraction Section
 DL : Dog Leg
 BE : Beam Dump

February 3rd, 2009



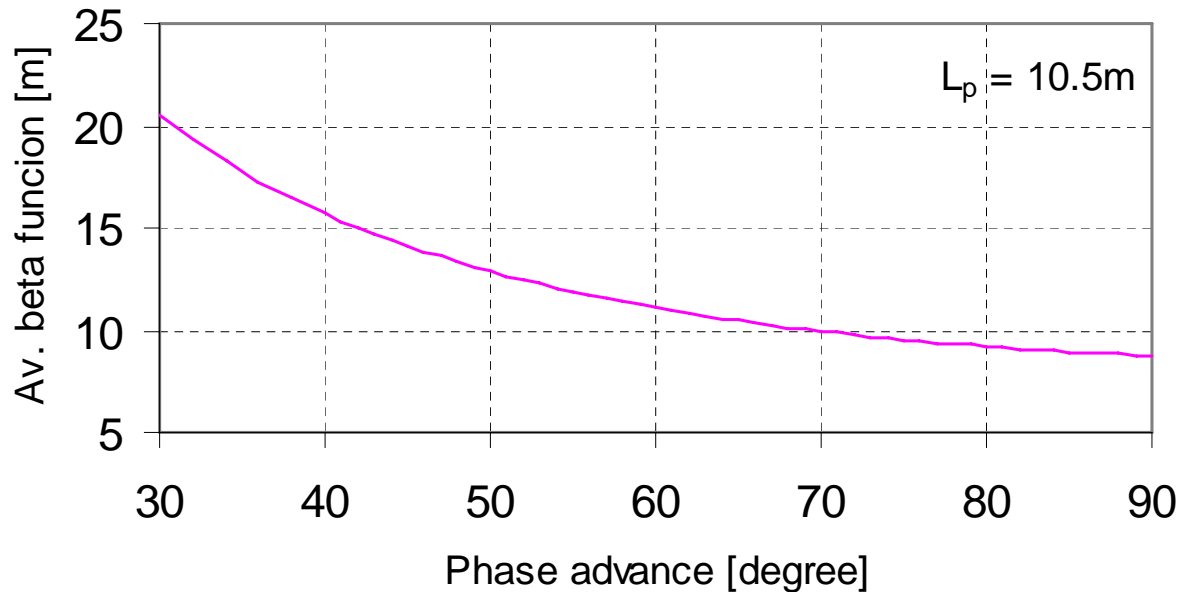
Completed work and outline

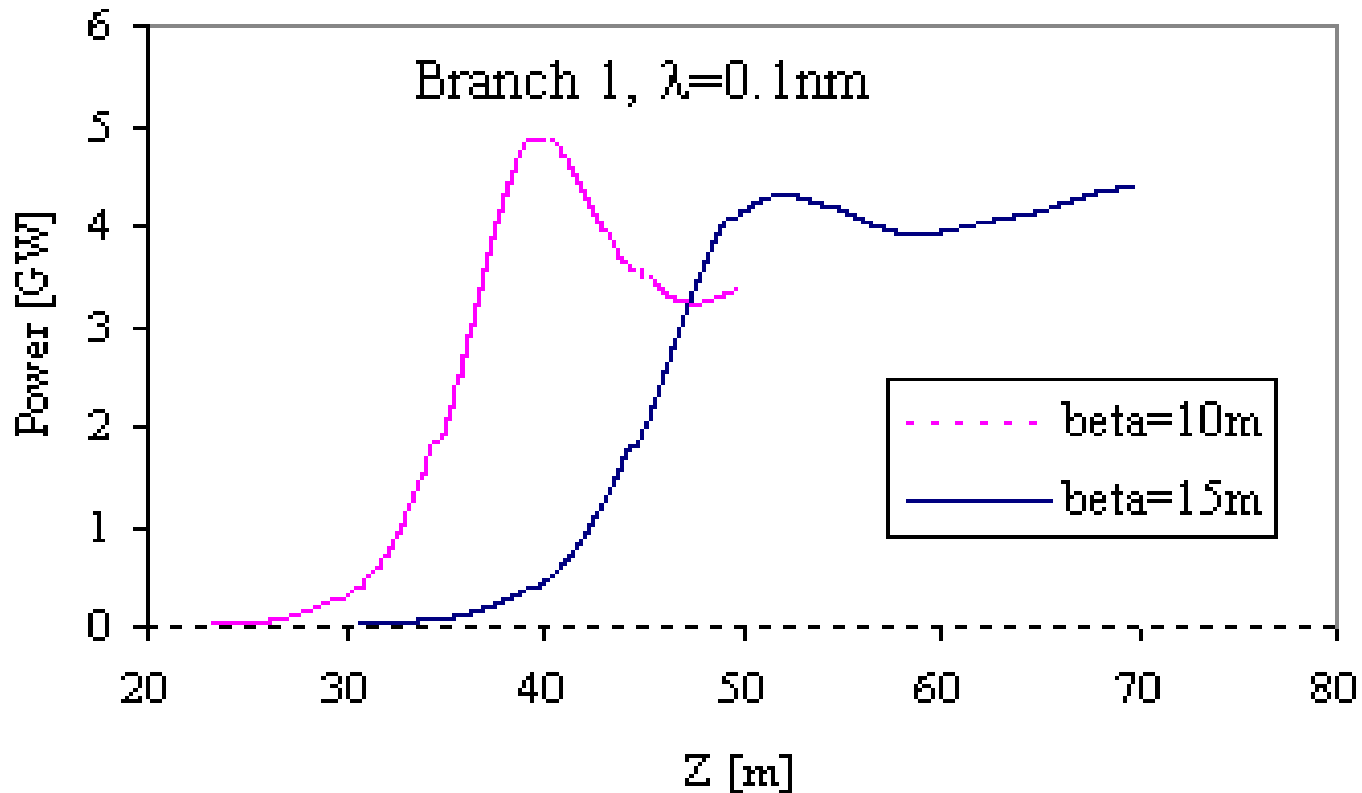
Saturation length and saturation power dependence on beam parameters (emittance, energy spread and peak current) at the entrance of the undulator have been evaluated for the Aramis undulator.

The FEL performance with switched off quadrupoles has been studied for the 3 undulators.

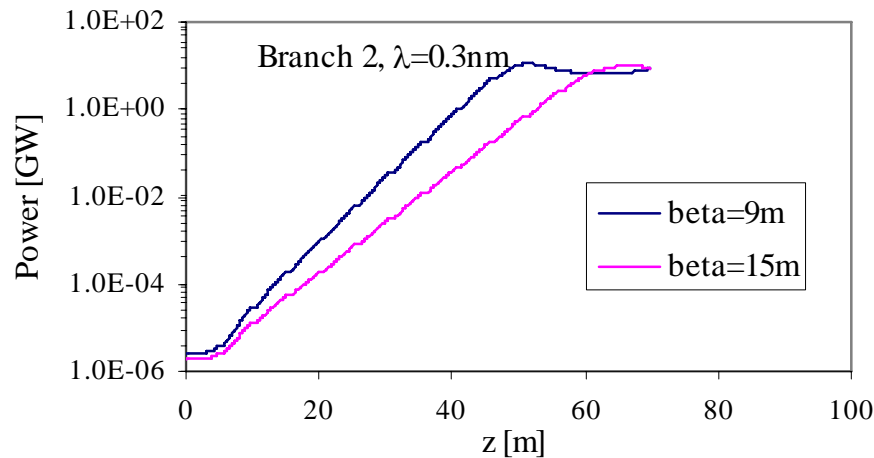
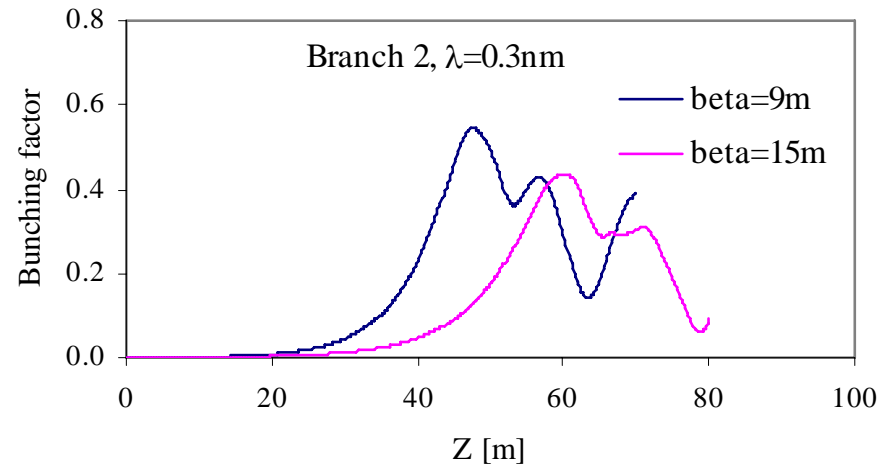
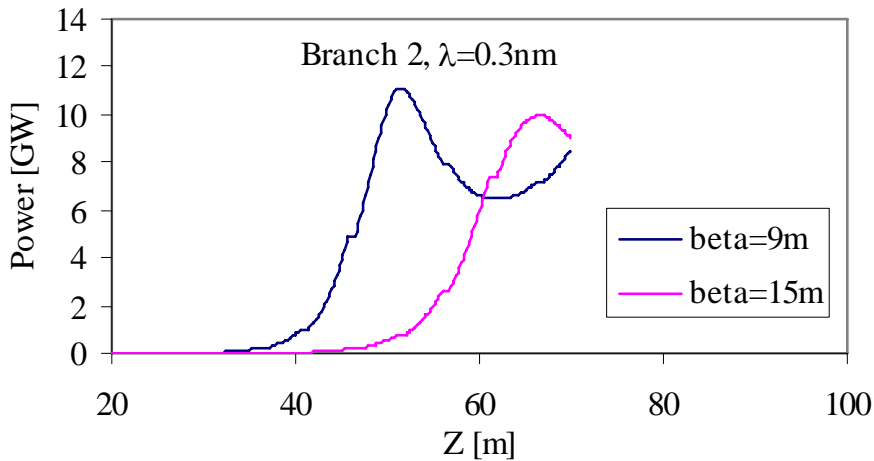
The minimal possible values for the average beta function are those corresponding to 90 degrees of phase advance per cell namely 8.8m, 8.4m, 8.2m for the branch 1, branch2 and branch3 FELs respectively.

$$\bar{\beta} = L_P \left(\frac{1}{\sin(\mu)} - \frac{1}{6} \text{tg}(\mu/2) \right) \approx \frac{L_P}{\sin(\mu)}$$

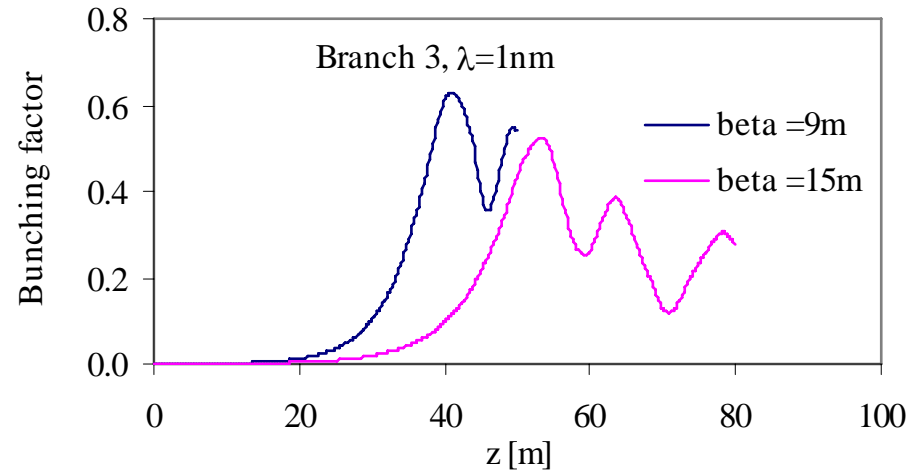
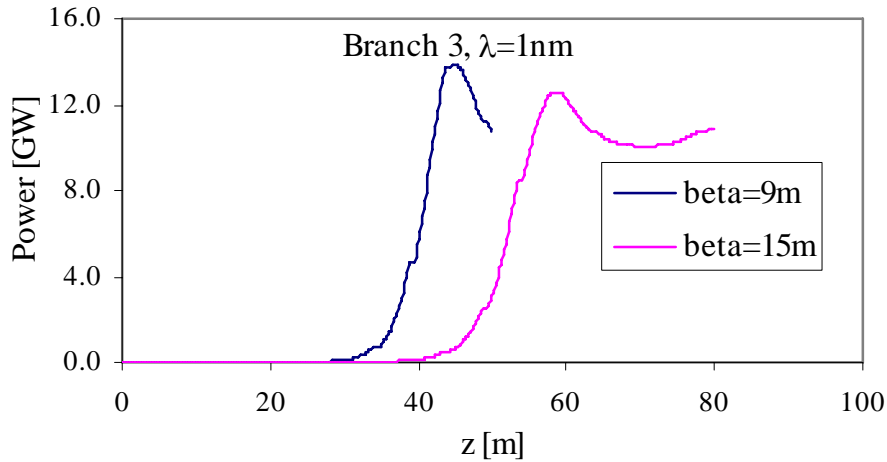




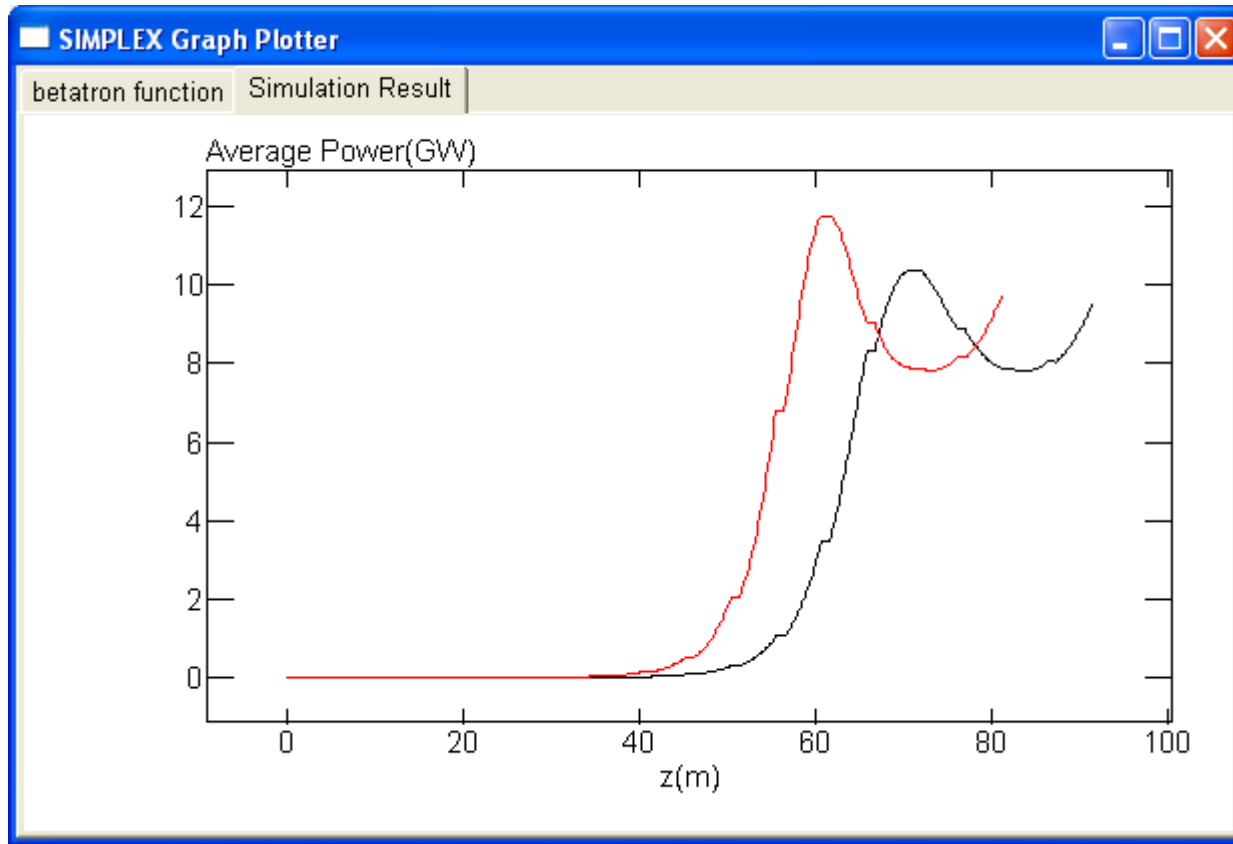
Power growth curves for branch 1 undulator when average value of the beta function is 10m (left curve) and 15m (right curve); (GENESIS simulation).



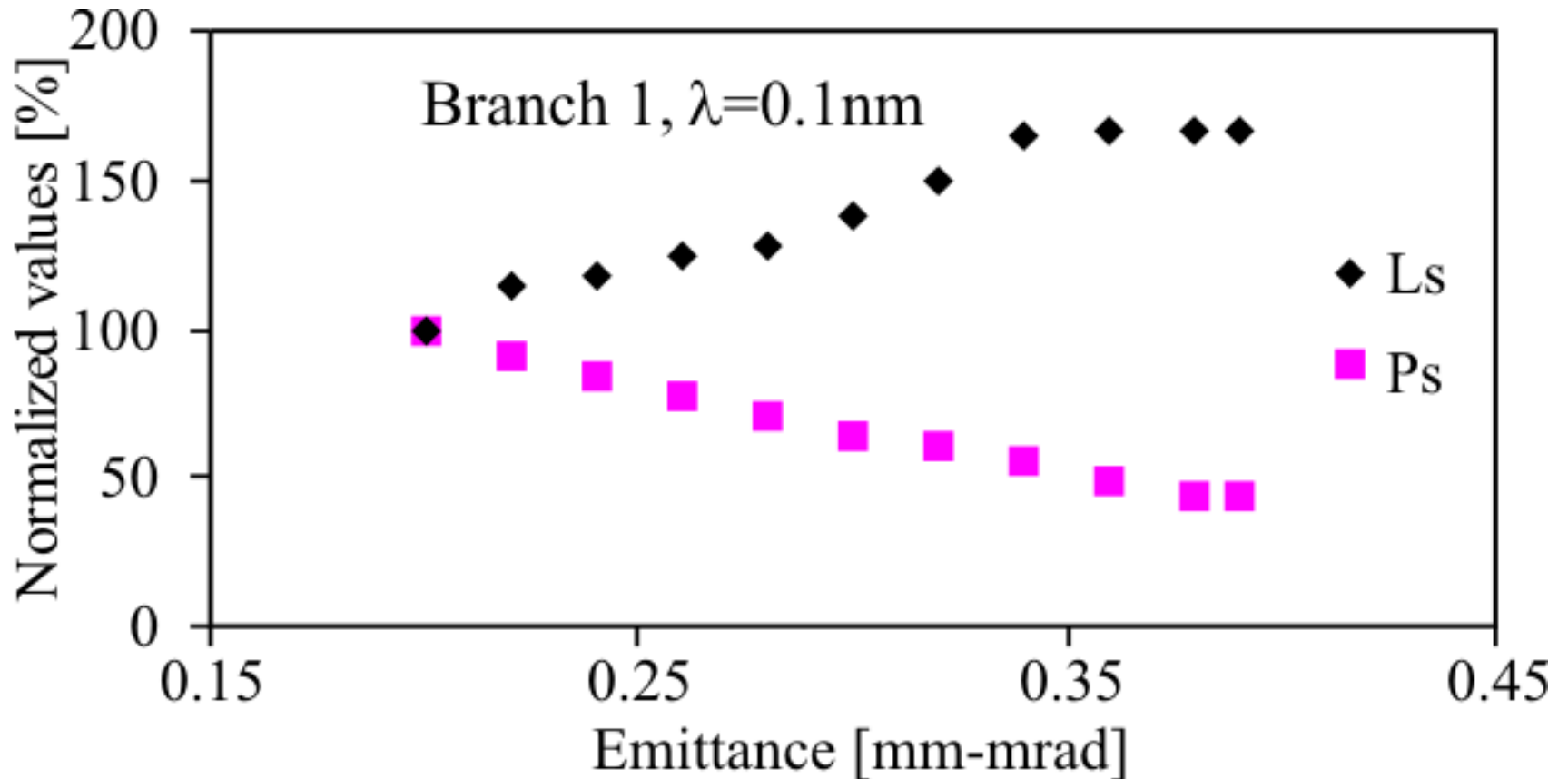
Power growth and bunching factor curves for branch 2 undulator when average value of the beta function is 9m (left curve and 15m (right curve). (GENESIS simulation).



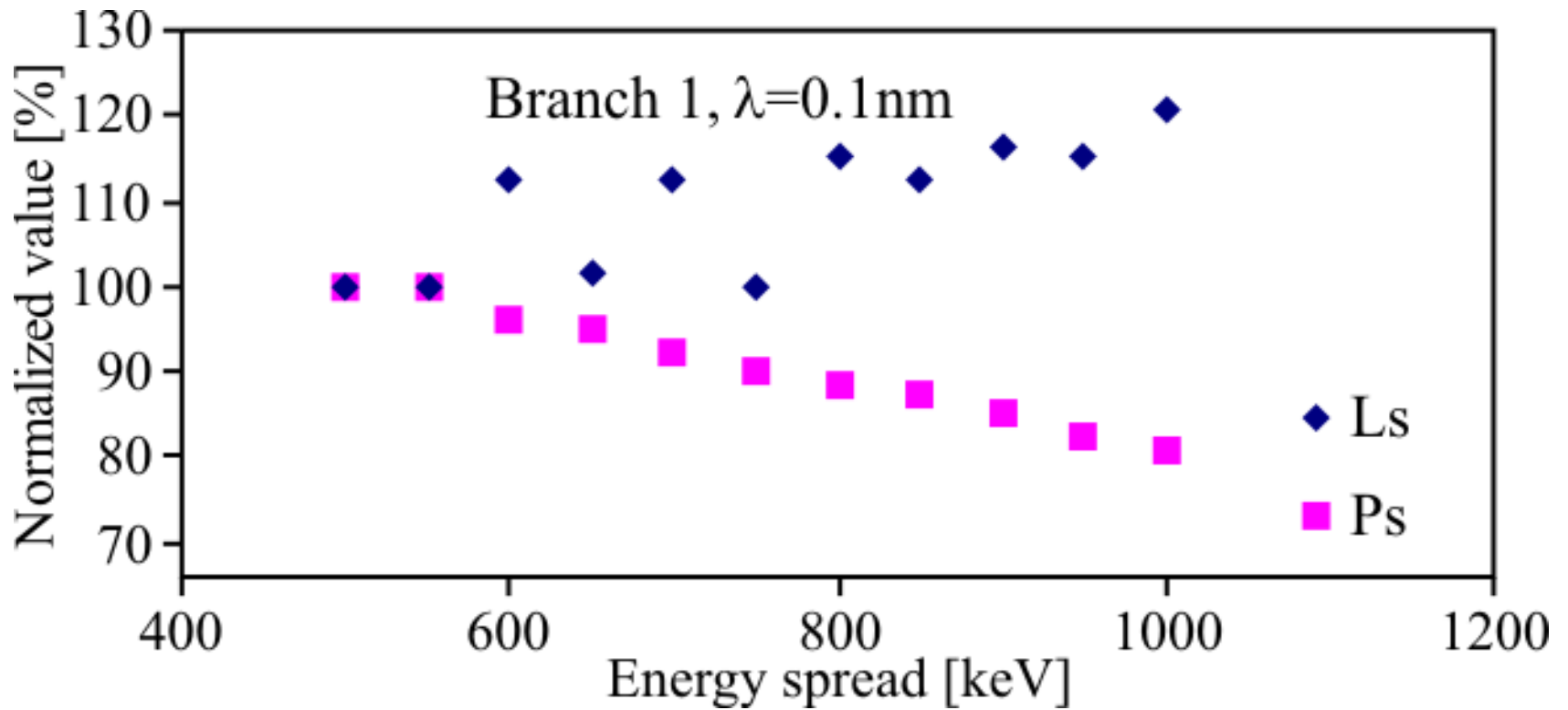
Power growth and bunching factor curves for branch 2 undulator when average value of the beta function is 9m (left curve) and 15m (right curve). (GENESIS simulation).



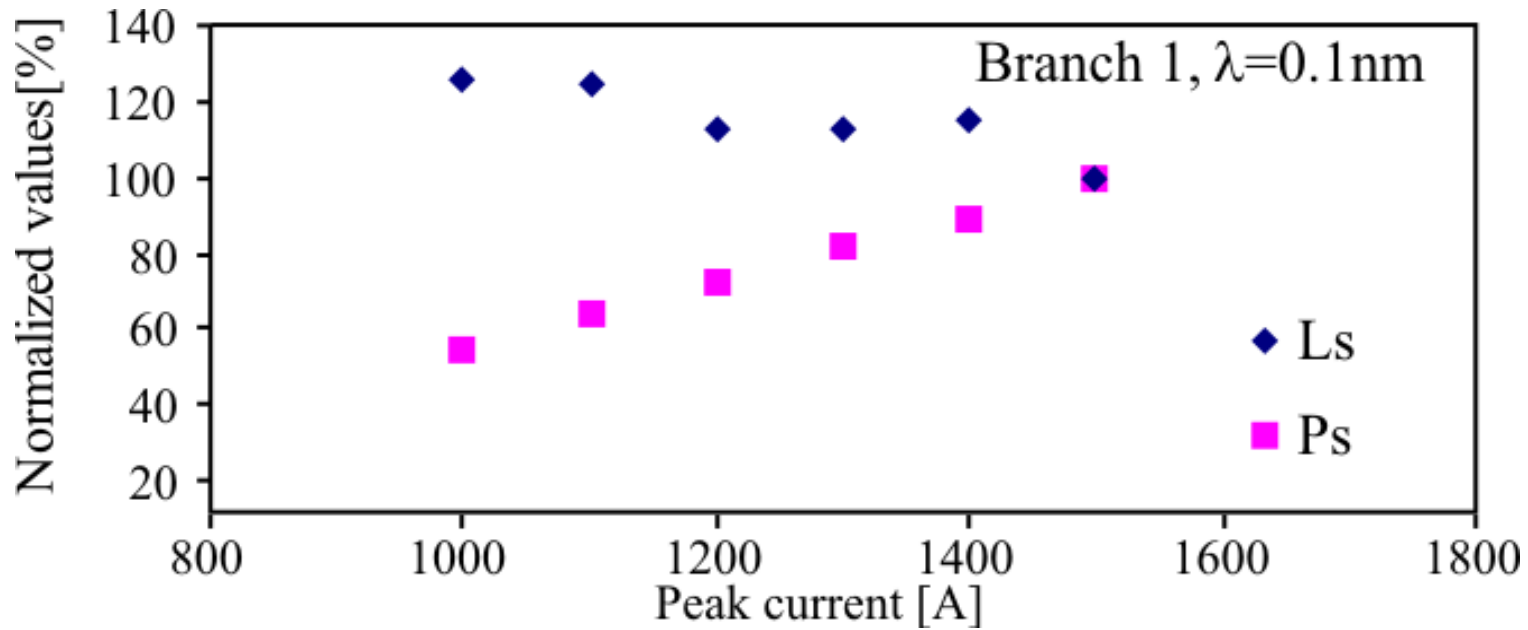
Power growth curves for branch 2 undulator when average value of the beta function is 9m (left curve) and 15m (right curve). (SIMPLEX simulation).



Saturation length (Ls) and power (Ps) (normalized to 39.3m and 5.1GW) dependence on the beam (normalized) emittance.



Normalized saturation length (Ls) and power (Ps) dependence on the beam energy spread.



Normalized saturation length (Ls) and power (Ps) dependence on the beam peak current.

Wiggler parameter k:

$$k = 0.9337287 \cdot B_{max}[T] \cdot \lambda[cm];$$

resonance wavelength

$$\lambda = \frac{\lambda_u}{2\gamma^2} (1 + K_{rms}^2)$$

Field gain length:

$$L_g \approx \lambda_u / (4\pi\rho_{1D}), \quad L_{sat} \approx 10 \times L_g$$

$$\rho_{1D} = \frac{\lambda_u}{4\pi} \left[\frac{4\pi^2 j_o K_{rms}^2 A_{jj}^2}{I_A \lambda_u \gamma^3} \right]^{1/3}$$

On the undulator axis the field can be calculated with using the formula

$$B = a \cdot \exp\left(b \frac{g}{\lambda_u} + c \left(\frac{g}{\lambda_u}\right)^2\right)$$

The formula is valid if $0.1 < g / \lambda_u < 1.0$

1. For the NdFeB hybrid undulators

$$a = 3.694, b = -5.068, c = 1.52$$

[KHalbach, Nucl. Instrum. Methods Phys. Res., 187 \(1987\) 109.](#)

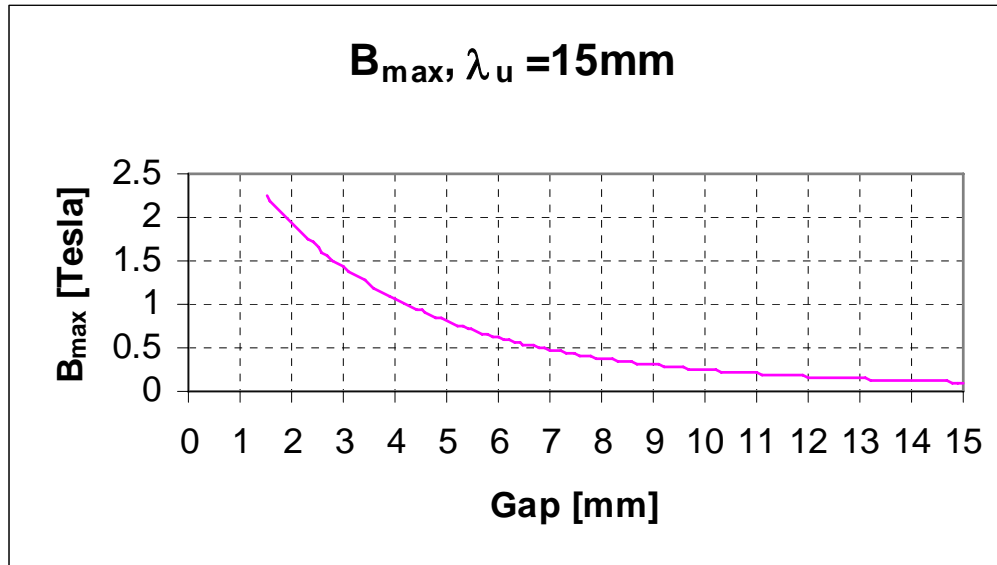
2. For the cryogenic permanent magnet

technology $a = 8.62703, b = -81857, c = 5.9718$

[T. Hara et al, Phys. Rev. ST 7 \(2004\) 050702](#)

Branch 1 undulator gap is 4.8mm for technology 1,

Branch 1 undulator gap is 6mm for technology 2,



$$B_{\max} = a \times \exp\left(b \frac{g}{\lambda_u} + c \left(\frac{g}{\lambda_u}\right)^2\right)$$

$$0.1 < g / \lambda_u < 1.0$$

$$a = 3.694, b = -5.068, c = 1.520$$

The field on the Branch 1 undulator axis vs. gap. NdFeB hybrid technology is assumed.