PSI XFEL Branch 3 SASE FEL Simulations with SIMPLEX

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Table 1. PSI XFEL specifications

(R.J. Bakker, FEL-BR06-014-2)

Undulator	Branch 1	Branch 2	Branch 3
Wavelength [nm]	0.1 - 0.3	0.3 - 1.0	1.0 – 10
Wavelength tuning method	beam energy	energy and gap	Undulator gap
Polarization	variable	variable	planar

Three brunches of the PSI XFEL undulators with tunable wavelength cover the wavelength wide range from 0.1 nm to 10 nm. Branch 3 undulator will produce radiation of wavelength ranging from the 1 to 10 nm utilizing 3.7 GeV beam. The corresponding radiation photons energy scope is 0.13 – 1.2 keV.

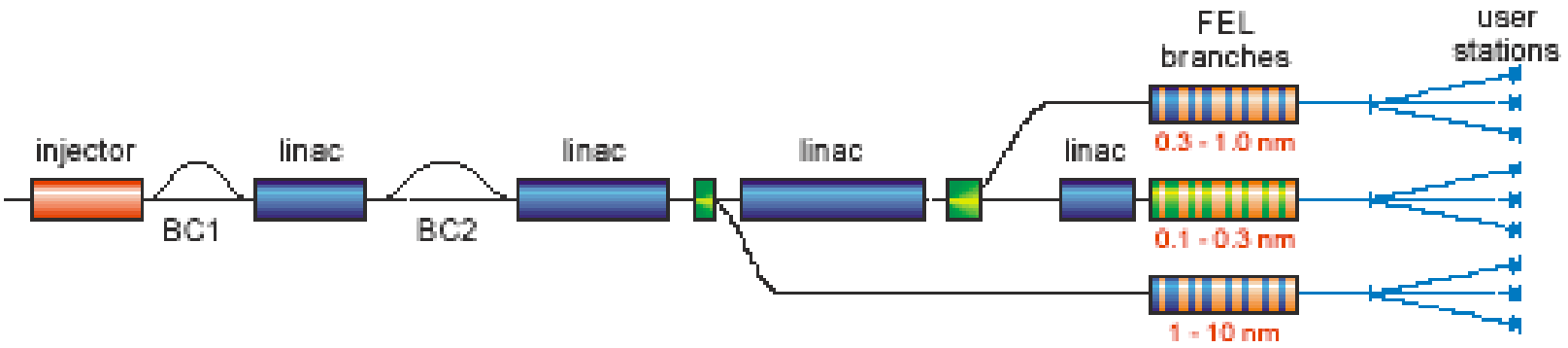
Performance Goals

(R.J. Bakker, FEL-BR06-014-2)

	Branch1	Branch2	Branch3	
Saturation length[3]	31.4	40.5	35.4	m
Power gain length	1.8	2.3	1.9	m
Peak power	2 – 6	10 – 20	10 – 20	GW
Peak brilliance	$10^{32} – 10^{33}$	$10^{32} – 10^{33}$	$10^{31} – 10^{32}$	ph/s/mm^2/mrad^2/0.1 % bw
Flux	$2\ 10^{11}$	$1\ 10^{12}$	$5\ 10^{12}$	ph/pulse/0.1 % bw
Pulse Energy	0.3 – 0.4	0.6 – 1.4	0.8 – 1.8	mJ
Spectral width (rms)	0.05	0.10	0.2 – 0.4	%
Beam-size (rms)	10	10	15	μm
Pulse duration (rms)	30	30	30	fs
Repetition rate	10 – 100	10 – 100	10 – 100	Hz

Table 2. Branch 3 FEL parameters

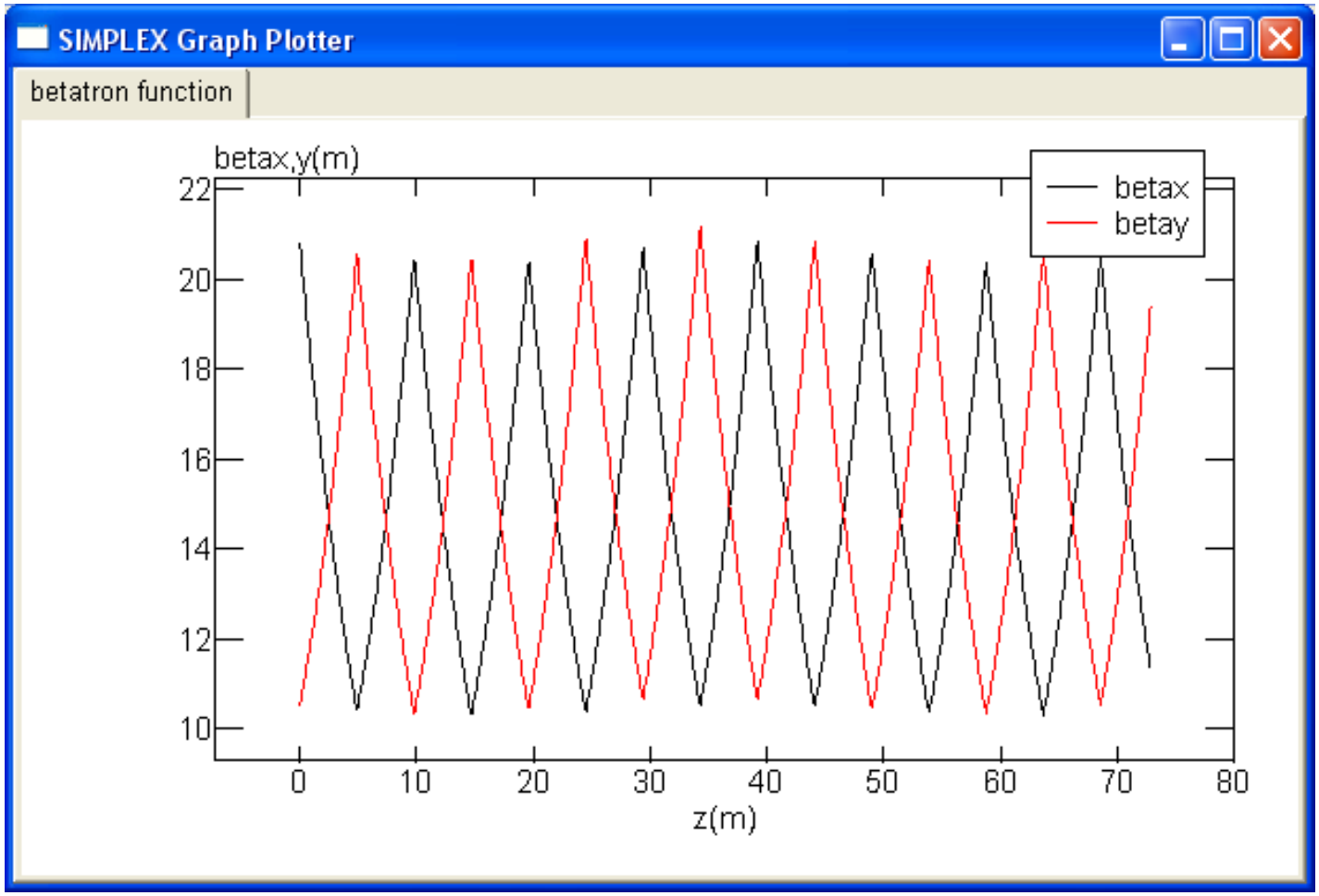
Wavelength [nm]	1.0	10
Undulator strength K	1.43	6.19
Pierce parameter	1.24×10^{-3}	2.92×10^{-3}
Saturation power [GW]	5.49	10.5
Saturation length [m]	62.7	36.8
Period [cm]	5.2	5.2
Max. field on axis [T]	1.24	0.2945
Gap [mm]	6	25.23
Section length [m]	4.16	4.16
Space between sections [m]	0.75	0.75
FODO period length [m]	9.8	9.8
Av. beta function [m]	15	15



(R.J. Bakker, FEL-BR06-014-2)

Table 3. Electron beam parameters at the entrance of the branch 3 undulator (R.J. Bakker, FEL-BR06-014-2)

Energy [GeV]	3.7
Peak current [kA]	1.5
Bunch charge [pC]	0.2
Normalized emittance [mm-mrad]	0.2
Energy spread [MeV]	0.5



Horizontal and vertical beta functions corresponding to branch 3 undulator design focusing lattice. Average beta is 15m. FODO period length is 9.8m. Quadrupoles integrated gradient is ~1.68 T.

λ=1 nm

FEL Output

ρ	1.2431e-03
L_{g1D}(m)	1.92193
L_{g3D}(m)	2.46604
L_{sat}(m)	45.8167
P_{sat}(GW)	3.56394
Energy/Bunch (J)	8.9397e-04

Radiation Characteristics

ε1st(eV)	1236.17
λ1st(nm)	1.00297
Δλ/λ	2.7226e-03
Peak Flux	6.20972e+24
Brilliance	2.4692e+31
Degeneracy	1.03875e+10
Peak Photons	1.55762e+12
Total Photons	4.51419e+12

λ=10 nm

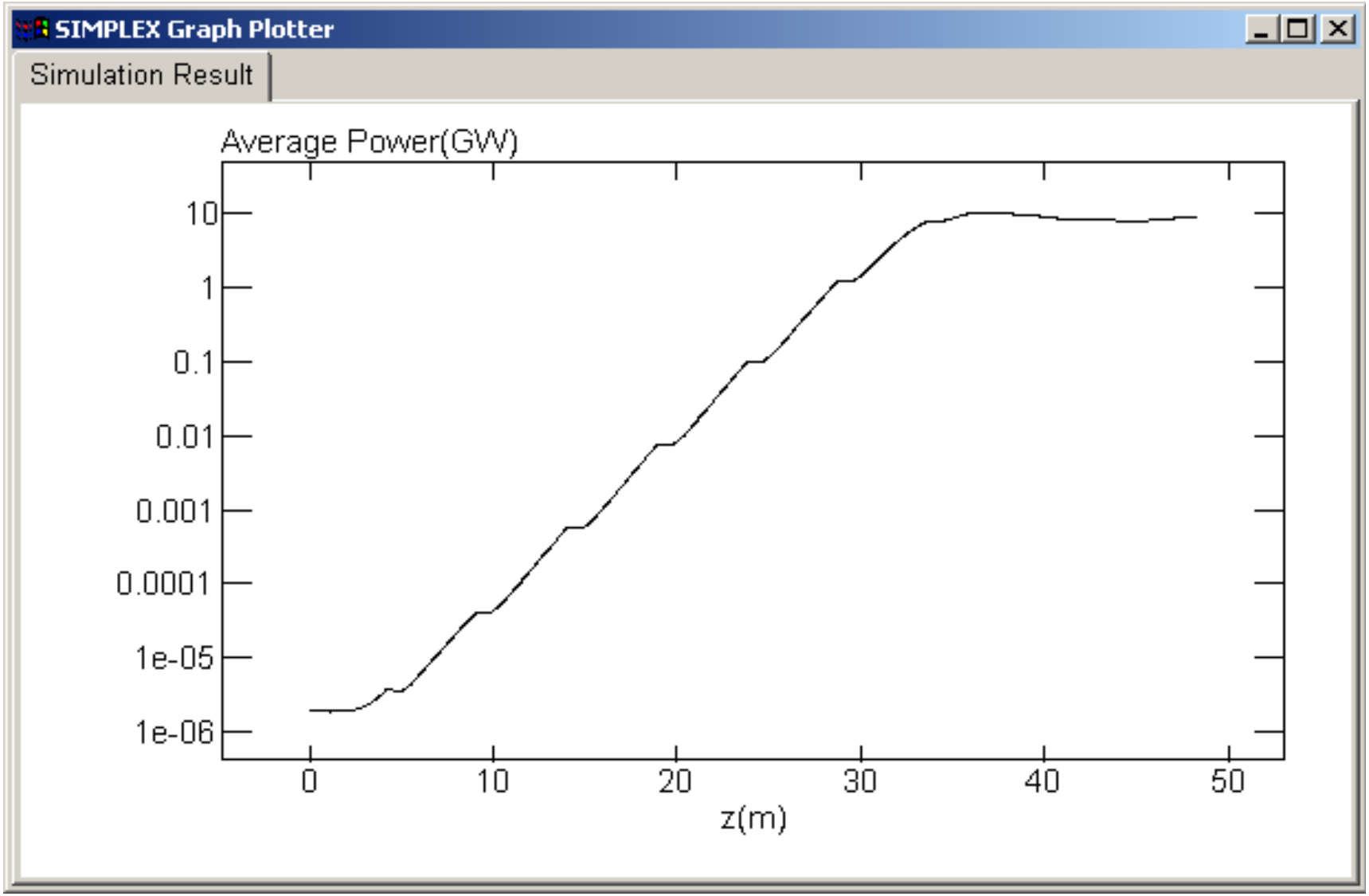
FEL Output

ρ	2.9199e-03
L_{g1D}(m)	0.818215
L_{g3D}(m)	1.29818
L_{sat}(m)	25.4441
P_{sat}(GW)	5.47509
Energy/Bunch (J)	1.3734e-03

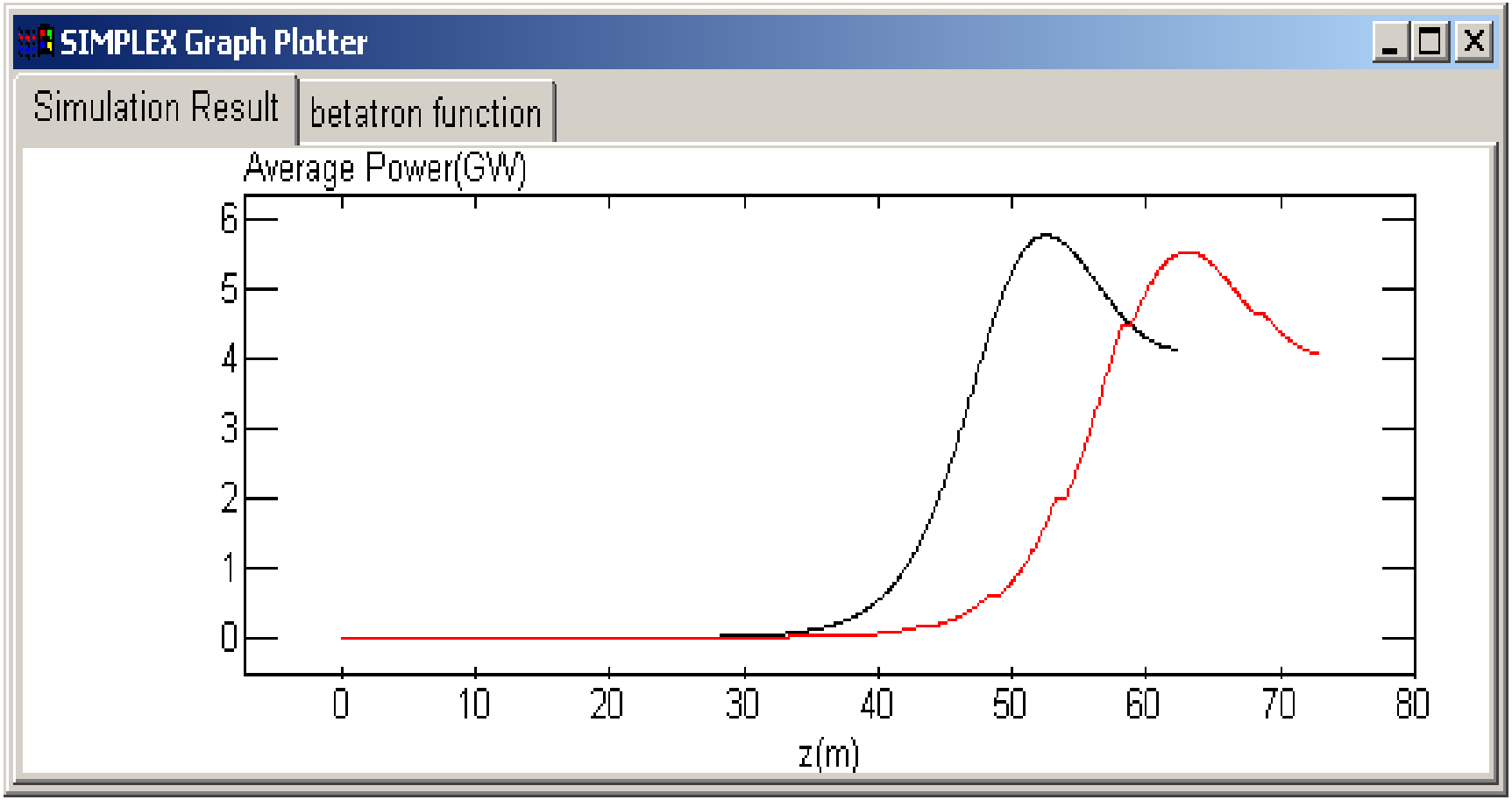
Radiation Characteristics

ε1st(eV)	124.025
λ1st(nm)	9.99675
Δλ/λ	6.2436e-03
Peak Flux	4.14623e+25
Brilliance	1.65957e+30
Degeneracy	6.91291e+11
Peak Photons	1.04002e+13
Total Photons	6.91212e+13

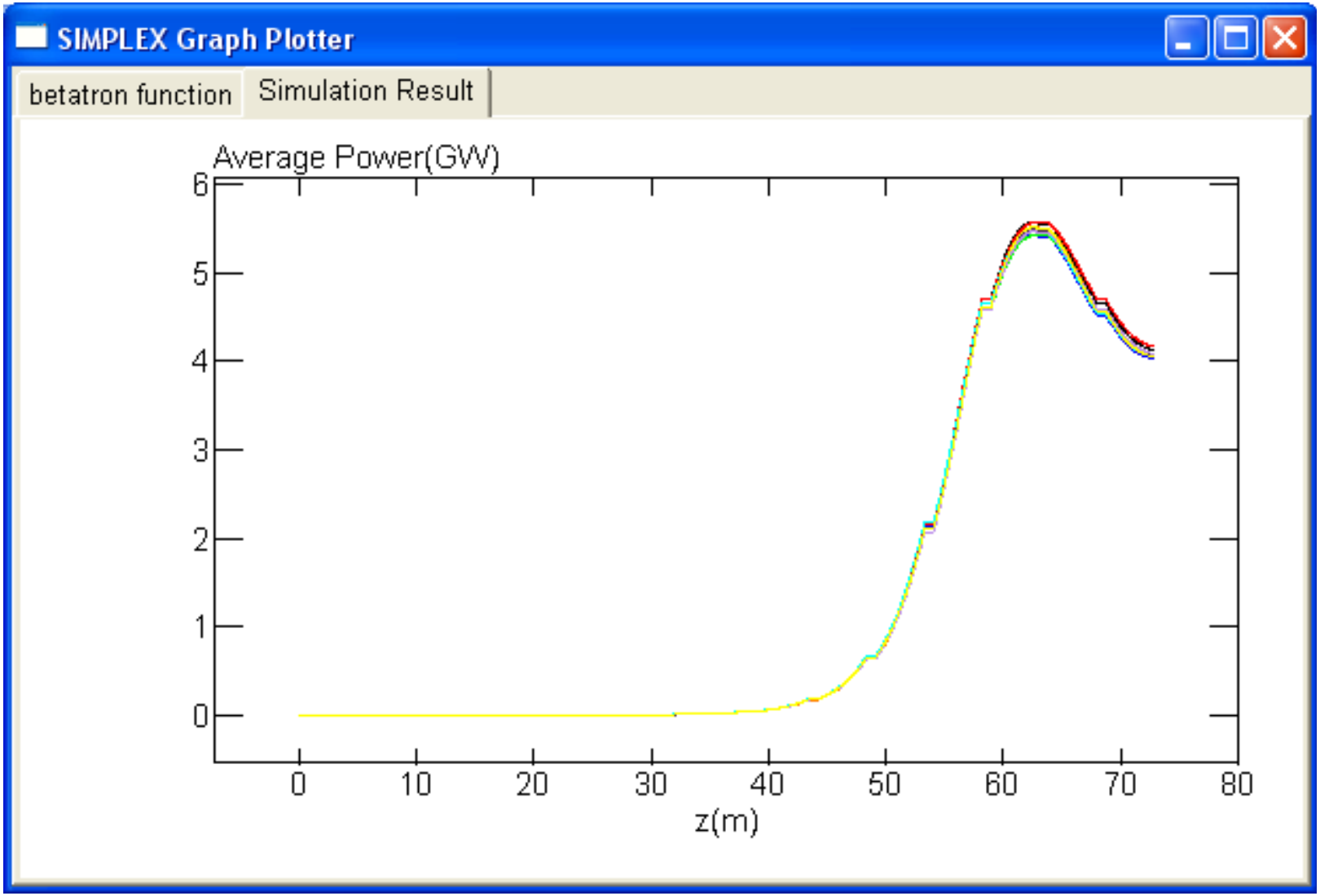
Branch 3 FEL output parameters predicted by SIMPLEX using analytical and phenomenological formulae.



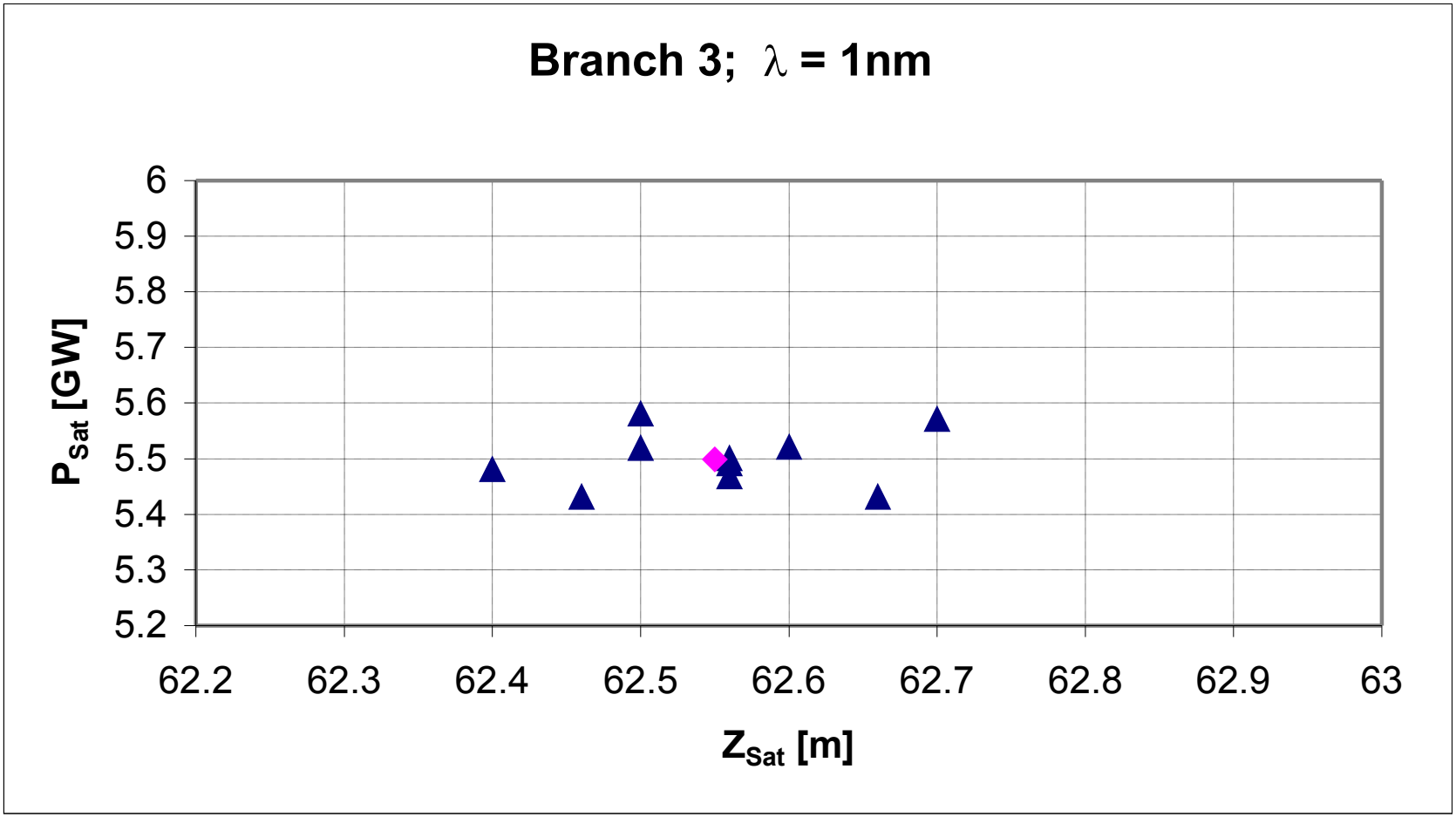
SASE FEL power growth curve for branch 3 undulator in λ =10 nm regime. Saturation occurs at 36.8 m . saturation power is 10.5 GW.



SASE FEL saturation power vs. saturation length for Branch 3 undulator operating in 1.0 nm wavelength regime. Black curve is average power for the "filling factor"=100% (Lsat = 52.5m, Psat = 5.79GW). Red curve is power growth with 0.75 m inter-segments spaces considered (Lsat = 62.7m, Psat = 5.5GW).



Branch 3 undulator. 1.0 nm wavelength regime. SASE FEL power growth for 10 different random number generator seeds. The sequence of the random numbers is used for beam particle distribution modeling in phase space. Saturation occurs at 62.6 m and saturation power is 5.5 GW.



SASE FEL saturation power vs. saturation length for Branch 3.10 random seeds. Diamond indicates the point corresponding to mean values of the saturation length (~62.55m) and saturation power (~5.5 GW).

Summary

	Study results (1nm / 10 nm)	Preliminary design values (R.J. Bakker, FEL-BR06-014-2)
Peak power [GW]	5.49 / 10.5	10 - 20
Saturation length [m]	62.7 / 36.8	35.4 (@1nm)
Bandwidth [%] *	0.3 / 0.6	0.2 – 0.4
Peak brightness* [ph/s/mm^2/mrad^2/0.1%bw]	10^{31} / 10^{30}	10^{32} - 10^{31}

* Rough estimate

Summary & Conclusions

PSI XFEL Branch 3 FEL simulations with SIMPLEX code have been performed using initial design parameter.

Rough estimate of the FEL output parameters has been done by SIMPLEX using analytical and phenomenological formulae.

Simulations with 100% "filling factor" gave initial rough values of the performance parameters that are comparable with ones mentioned as performance goals.

Using SIMPLEX simulations in steady-state mode Branch 3 SASE FEL saturation length and saturation power obtained and the brightness is estimated.

Since Branch 3 FEL should produce radiation within the wavelength range 1 – 10 nm simulation studies have been done for both boundary values of wavelength.

Performance parameters values obtained by simulations taking into account spaces between the segments ("Filling factor" = 4.16/4.91*100% = 84.7%) provide more realistic estimate of the FEL performance.

Branch 3 FEL SIMPLEX steady-state simulations yield in higher values for saturation length (36.8 – 62.6 m) and lower values for saturation power (5.5-10.5 GW) than preliminary design values.

Recommended length of the Branch3 undulator is about 75m (with 20% contingency).