



Collaboration Workshop

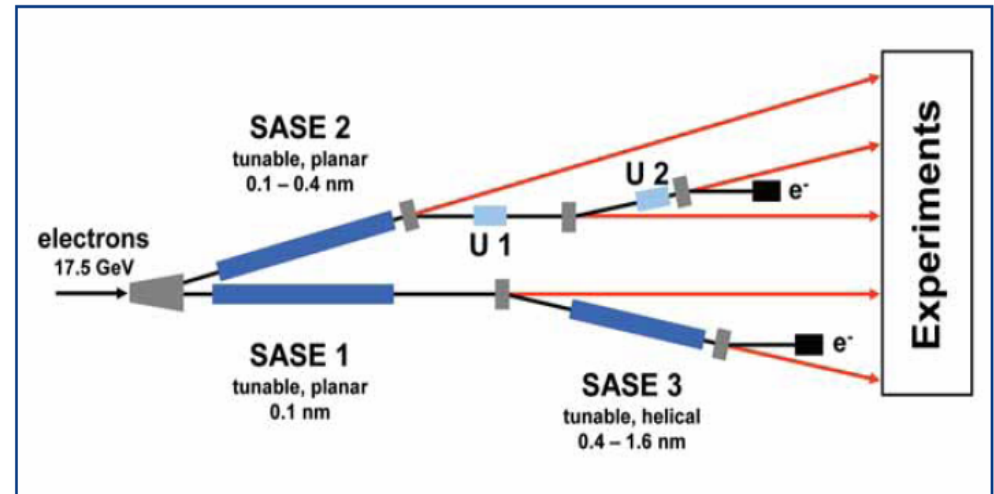
Advanced Topics of Brilliant Light Facilities

Time Dependent Simulations for European XFEL in Low Charge Regime

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Electron beam parameters at the entrance of the undulators

Electron Energy [GeV]	17.5
Bunch Charge [nC]	1
Peak current [kA]	5
Bunch length (rms) [μm]	25
Norm. emittance [mm-mrad]	1.4
Energy spread [MeV]	1.5



SASE1 undulator parameters

Resonant radiation wavelength [nm]	0.1
K value	3.3
Period length [cm]	3.56
Segment length [m]	5
Segment interval [m]	6.1
Total length [m]	201.3

The scaling function for the gain length is given by

$$L_G = \frac{\lambda_u}{4\pi\sqrt{3}\rho} (1 + \eta)$$

The saturation power P_{sat} is given by the total electron beam power P_{beam} as [K.-J. Kim, M. Xie, NIM. A331 (93), 359]:

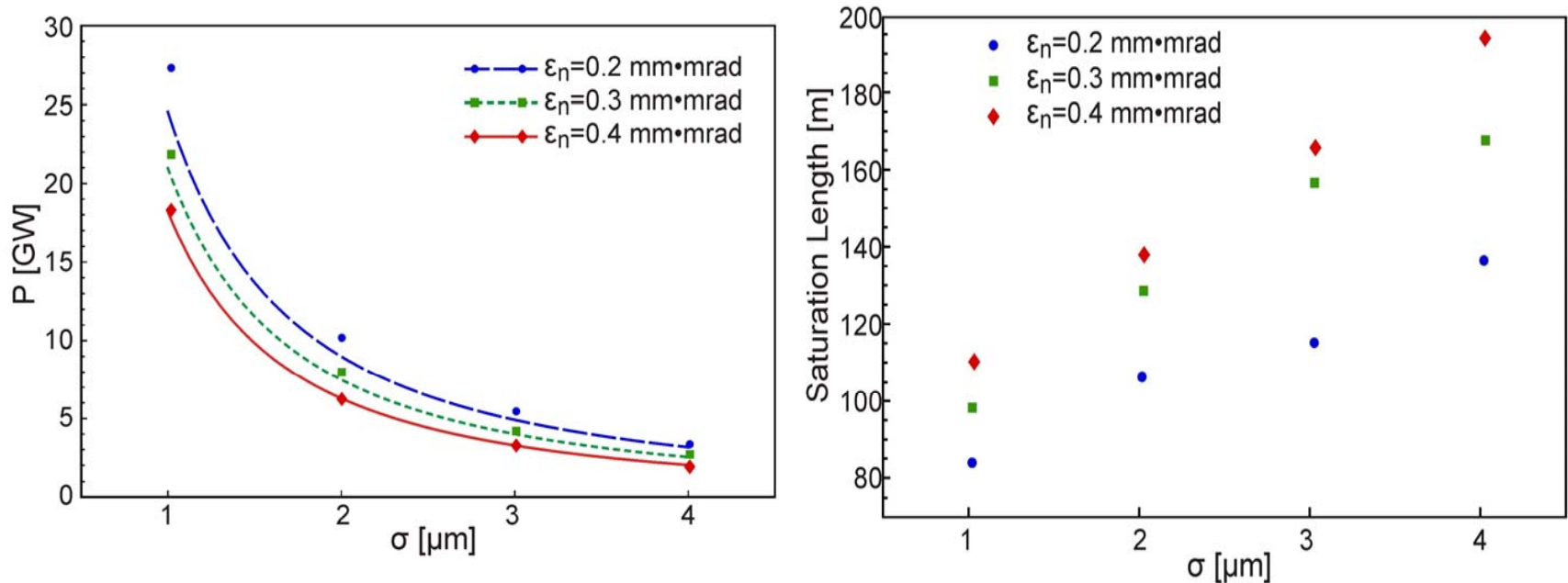
$$P_{sat} \approx \frac{1.6}{(1 + \eta)^2} \rho P_{beam}$$

Electron beam and undulator line parameters for 20 pC bunch charge regime

Electron Energy [GeV]	14
Bunch Charge [pC]	20
Peak current [kA]	2
Bunch length (rms) [μm]	1.2
Norm. emittance [mm-mrad]	0.4
Energy spread [MeV]	1.4

Resonant radiation wavelength [nm]	0.1
K value	2.6
Period length [cm]	3.56
Segment length [m]	5
Segment interval [m]	6.1
Total length [m]	201.3

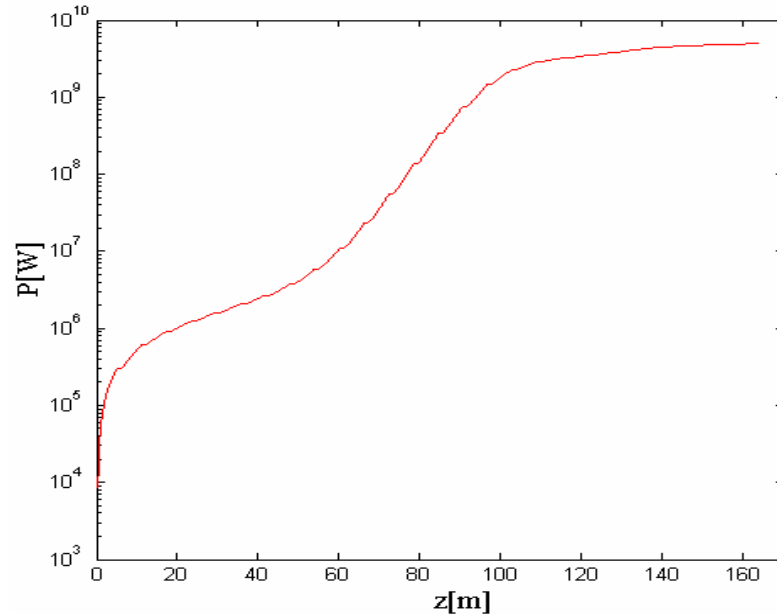
By means of GENESIS steady-state simulations the behaviour of the saturation length and saturation power for the beam normalized emittance 0.2, 0.3 and 0.4 mm-mrad have been investigated. For each case the bunch rms length varies from 1 to 4 μm .



Dependence of saturation power and saturation length on beam rms length at three values of beam normalized emittance

Time dependence simulations

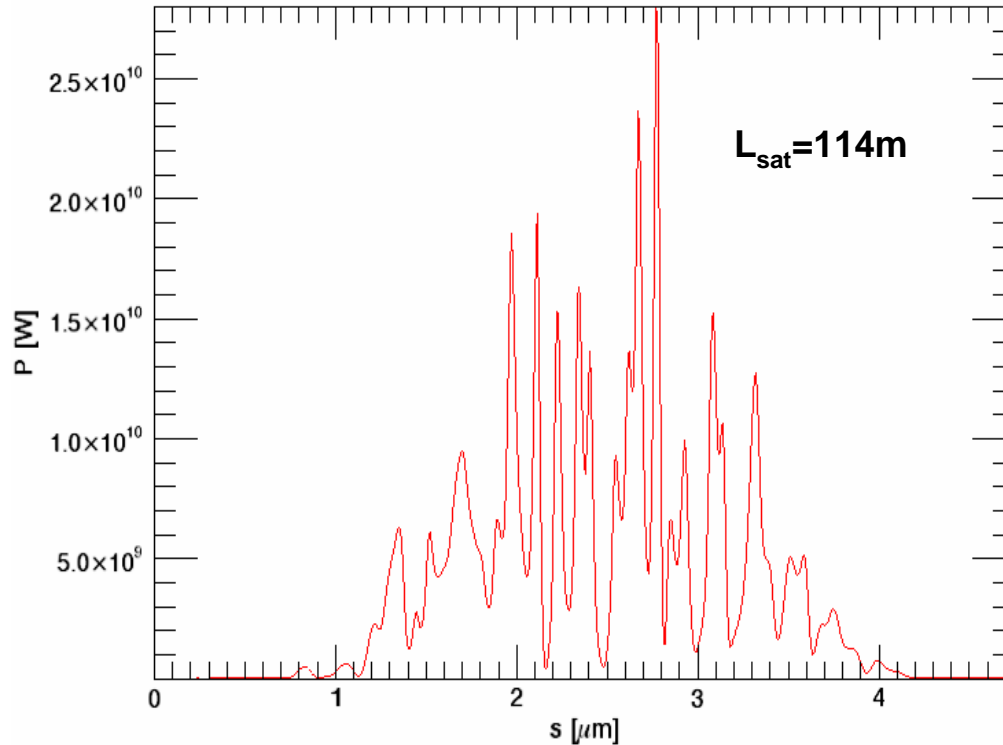
Time dependence simulations have been performed for the case when the beam normalized emittance is 0.4 mm-mrad. The bunch longitudinal shape is assumed to be Gaussian with rms length $\sigma = 1.2 \mu\text{m}$.



Average FEL power along the undulator

Saturation length 114m

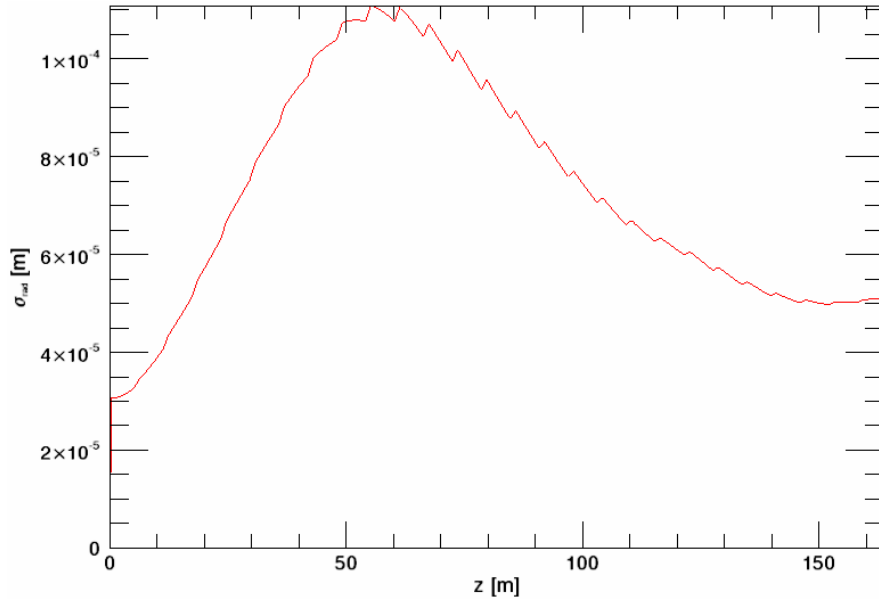
Power distribution along the bunch at saturation point ($L_{\text{sat}} = 114\text{m}$) for SASE1 undulator tuned to wavelength 0.1nm .



Only $\pm 2\sigma$ bunch length around the bunch centre is included into simulation.

The peak power at saturation is 26 GW

Beam size

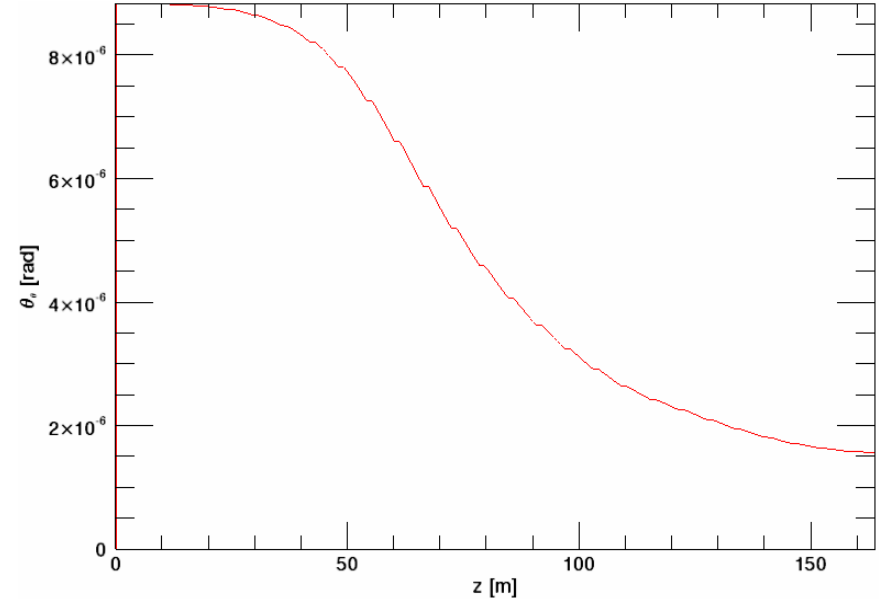


At the saturation point $\sigma_r = 68 \mu\text{m}$ $\sigma_\theta = 2.7 \mu\text{rad}$

FEL peak brilliance in the units of
(Photons/sec/ mm²/mrad²/0.1%bw)
is calculated as:

$$B = \frac{P_{\text{max}} / E_{ph}}{(2\pi)^2 \sigma_r^2 \sigma_\theta^2 0.1\%bw} \approx 2.4 \cdot 10^{33}$$

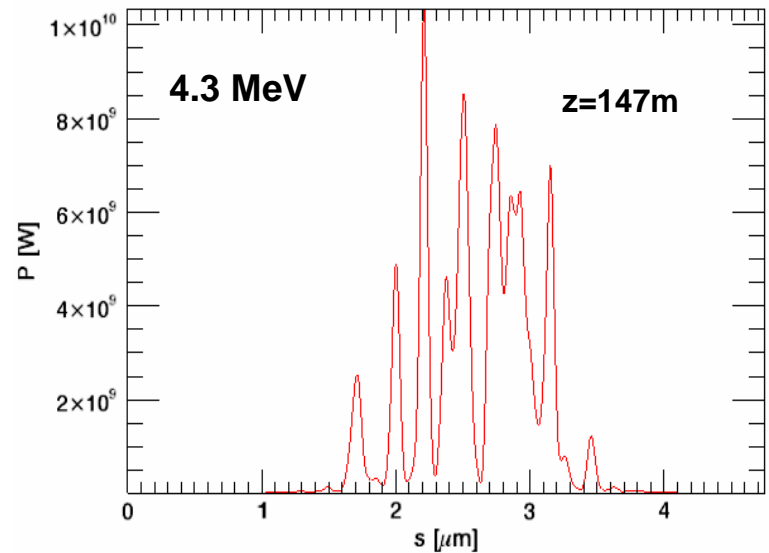
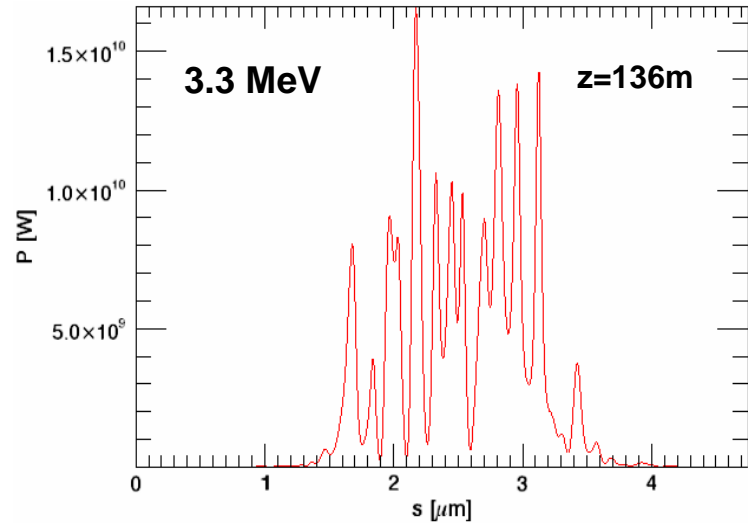
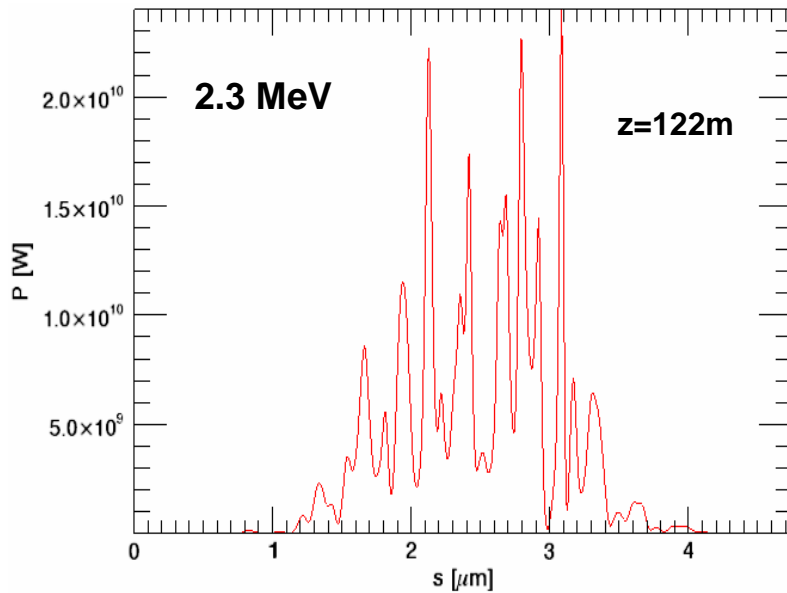
Divergence Angle



The peak brilliance for design case in units of
(Photons/sec/ mm²/mrad²/0.1%bw) is

$$B = 5 \cdot 10^{33}$$

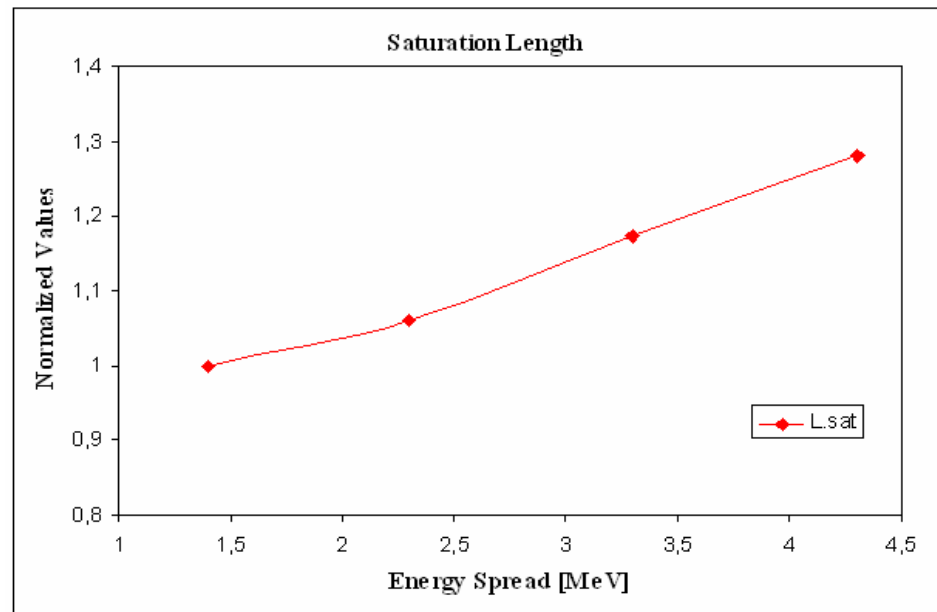
Power distribution along the bunch at saturation point for three different values of energy spread.



Energy Spread Scan

Saturation length and radiation parameters (peak power at saturation, radiation size, divergence and brilliance) dependence on the energy spread. All parameters are normalized those corresponding to the case when energy spread is 1.4 MeV.

Energy Spread [MeV]	L_{sat}	$P_{peak,sat}$	R.size	Div.	Brilliance
1.4	1	1	1	1	1
2.3	1.07	0.99	1.19	1.21	0.53
3.3	1.19	0.68	1.49	1.50	0.18
4.3	1.29	0.37	1.89	1.90	0.05



The numerical results for SASE1 undulator section at low bunch charge regime, based on GENESIS simulations have shown:

- Sensitivity of FEL saturation length is about 60-70 % for the beam normalized emittance and bunch rms length.
- By means of GENESIS time dependence simulations, saturation length increases by 33 % with the rise of energy spread from 1.4 to 4.3 MeV. For this variation range of energy spread the peak power at saturation will decrease by about 60%. The peak brilliance decreases by about 90 % of its maximum value. With the increasing of energy spread the pulse length decreases.