Astra-3D Simulations and Low Slice Energy Spread study for FLASHII

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S2E Meeting, 28.10.2013

MPY, DESY

The plan for this month

1. Astra-3D simulations for FLASHII for different bunch charge cases (100%)

2. SASE FEL calculations for FLASHII (100%)

3. Low slice energy spread study for FLASHII HGHG option (60%)

4. SASE FEL calculations for EXFEL SASE1 for different bunch charge cases(100%)

5. The internal report for EXFEL simulations (95%)

Achieved progress

1. Low slice energy spread study for FLASHII **(70%)**

S2e simulation for Q=1.0nC

Parameters for the bunch compressors

Charge Q, nC	Curvature radius in BC_2 r1 [m]	Momentum compaction factor in BC_2, $R_{56,2}$ [mm]	compr. In BC2	Curvature radius in BC_3 r2 [m]	Momentum compaction factor in BC_3, $R_{56,3}$ [mm]	Total compr. C
1.0	**1.618**	**180.7**	**2.7**	**5.770**	**83.6**	**50**

E_1=145.5MeV, E_2=450MeV

Curvature radius in BCs# $1.4 \le \frac{r_1}{\mathrm{m}} \le 1.93$ $5.3 \le \frac{r_2}{\mathrm{m}} \le 16.8$

Exciting current* **I_{BC2}~70.93A I_{BC3} <62.00A**

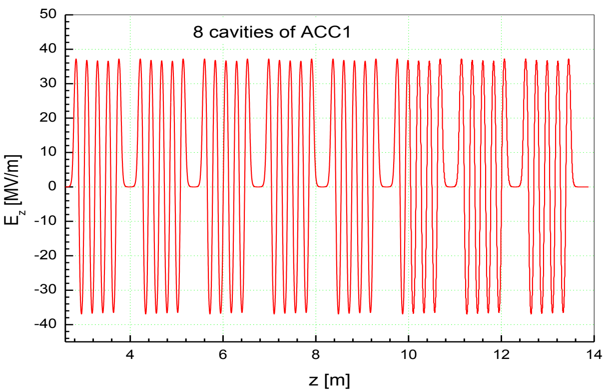
Low slice energy spread study for FLASHII

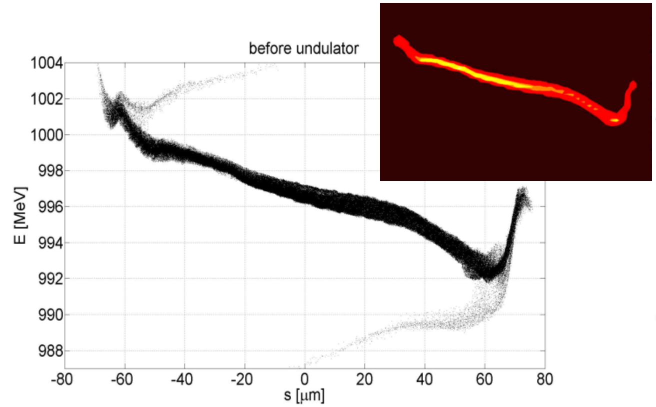
RF settings in accelerating modules for 1nC

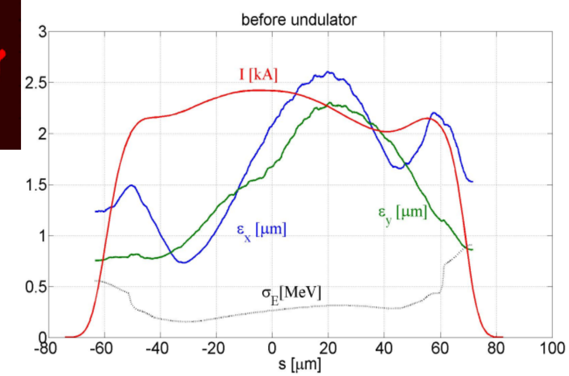
Charge nC	Vacc1* [MV]	φacc1 [deg]	Vacc39 [MV]	φacc39 [deg]	Vacc2,3 [MV]	Φacc2,3 [deg]	Vacc4,5,67 [MV]	Φacc4,5,6,7 [deg]
1.0	160.4	-3.2	21.9	153.4	337.3	25.0	550.0	0.0

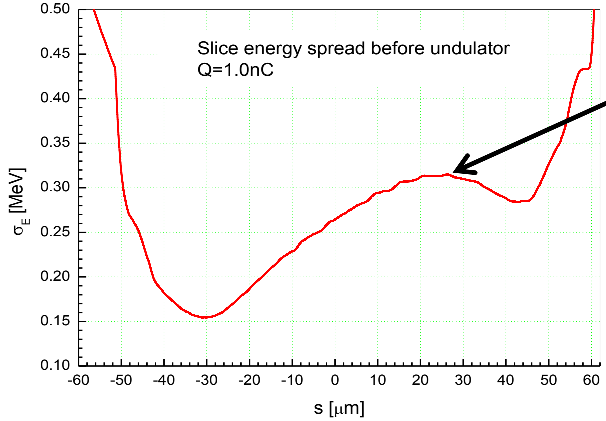
* Same voltage amplitude has been used for the first 4 cavities and the last 4 cavities of ACC1

$V_{1\text{-}4}=V_{5\text{-}8}$









σ_E >300keV

FLASH II HGHG option need beam bunch with low energy spread !!!

I>1kA

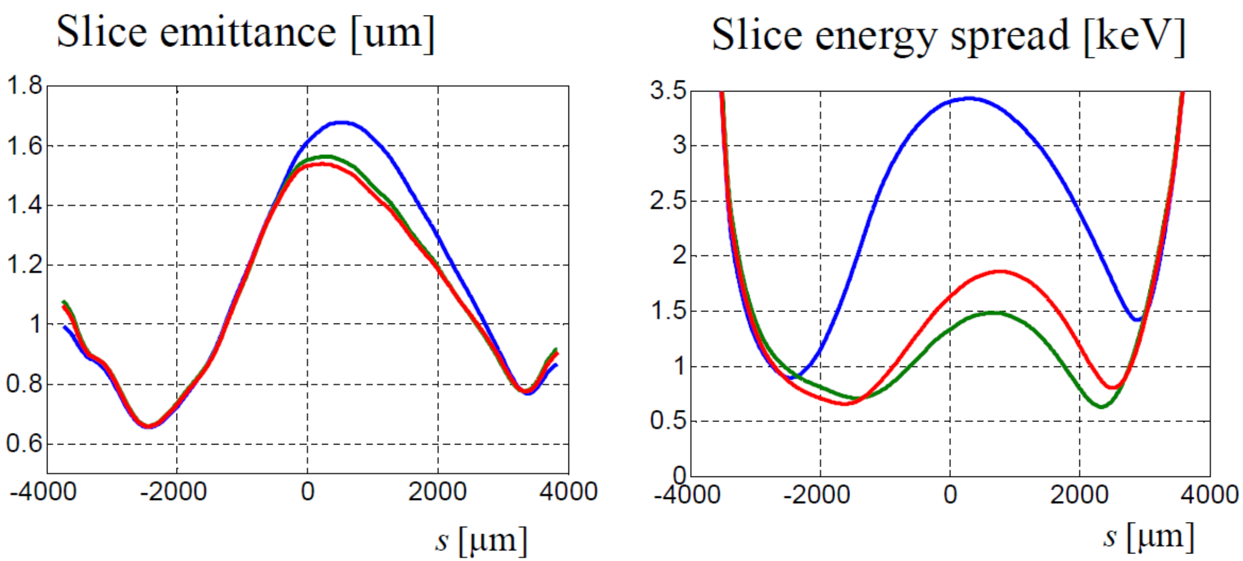
Energy spread < 120keV

Low Energy Spread for FLASH 2

E in BC 2 = 145 MeV, ACC1 (50%, 50 %)

E in BC 2 = 145 MeV, ACC1 (37.5%, 62.5 %)

E in BC 2 = 130 MeV, ACC1(40%, 60 %)



The voltage distribution in ACC1 will affect the slice energy spread of the bunch.

* Igor Zagorodnov, Beam Dynamics simulation at DESY, Collaboration meeting at PAL, 2013

Low slice energy spread study for FLASHII

New parameter settings are based on:

(1) After ACC39 E=130MeV
(2) In ACC1, $V_{1-4}:V_{5-8}=2:3$
} **Case2**

as a comparison of **case1:** E=145.5MeV, $V_{1-4}:V_{5-8}=1:1$

*** The parameters for bunch compressors have been fixed for both of the two cases.**

$$\begin{pmatrix} V_1 \\ \varphi_1 \\ V_{39} \\ \varphi_{39} \end{pmatrix} = M \begin{pmatrix} V(0) \\ V'(0) \\ V''(0) \\ V'''(0) \end{pmatrix}$$

V(0) → Beam energy
V′(0) → Compression ratio

Case1 → **Case2**

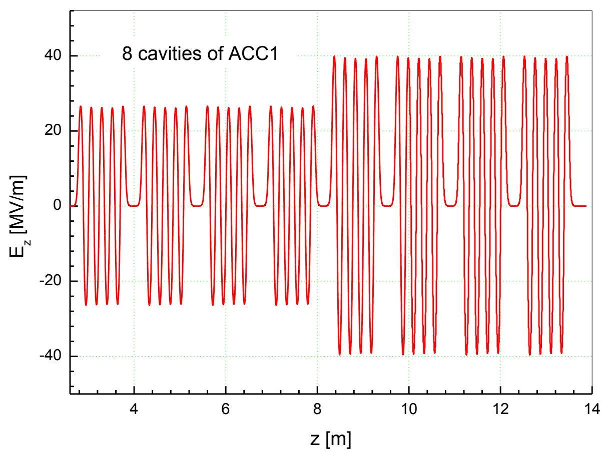
$$\begin{pmatrix} V_1 \\ \varphi_1 \\ V_{39} \\ \varphi_{39} \end{pmatrix} \Rightarrow \begin{pmatrix} V(0)/V(0) \\ V'(0)/V(0) \\ V''(0)/V(0) \\ V'''(0)/V(0) \end{pmatrix} \Rightarrow \begin{pmatrix} V_1 \\ \varphi_1 \\ V_{39} \\ \varphi_{39} \end{pmatrix}$$

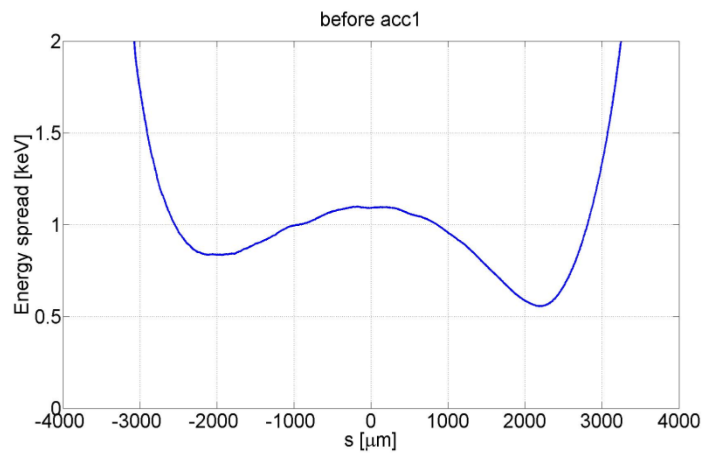
Low slice energy spread study for FLASHII

RF settings in accelerating modules for case2

Charge nC	V_{acc1}* [MV]	φ_{acc1} [deg]	V_{acc39} [MV]	φ_{acc39} [deg]	$V_{acc2,3}$ [MV]	$\Phi_{acc2,3}$ [deg]	$V_{acc4,5,67}$ [MV]	$\Phi_{acc4,5,6,7}$ [deg]
1.0	143.33	-5.1	20.63	149.4	337.3	25.0	550.0	0.0

*** In ACC1, $V_{1-4}:V_{5-8}=2:3$**

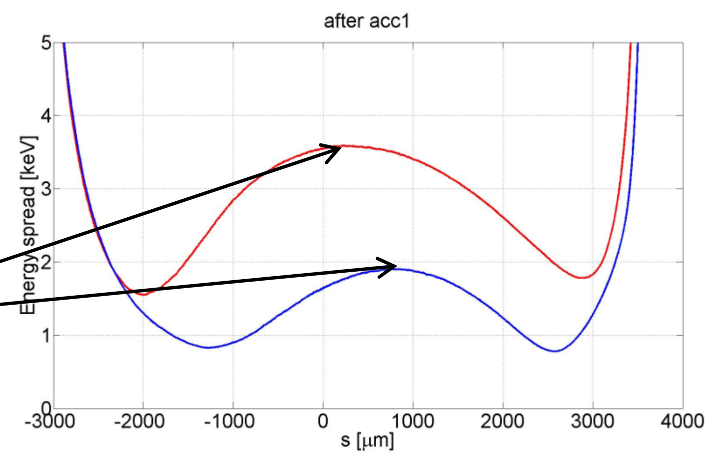




case1 (145.5MeV)

case2 (130.0MeV)

Significant difference can be found in ACC1



Transfer matrix of standing wave cavity

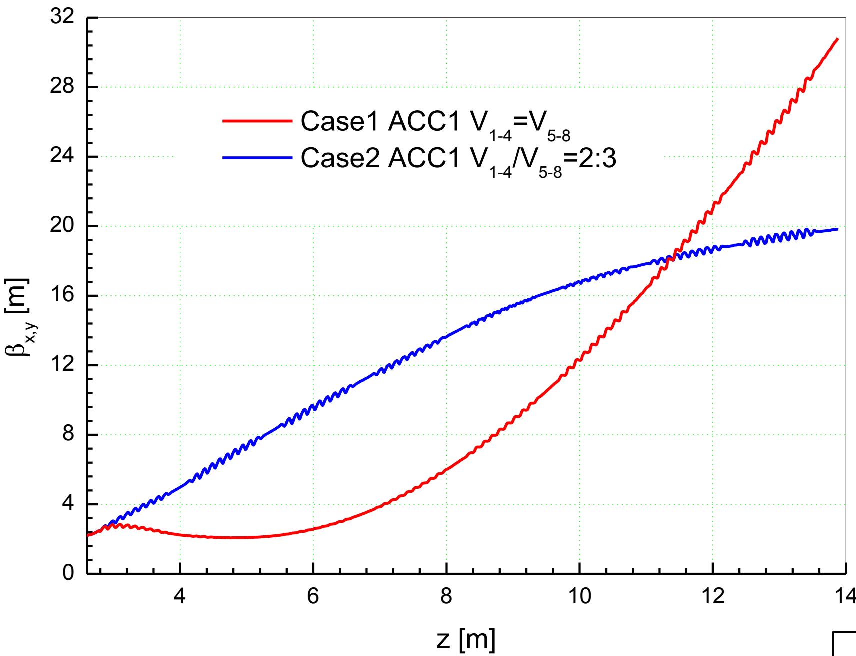
$$\mathrm{M}_{\mathrm{cavity}} = \begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix}$$

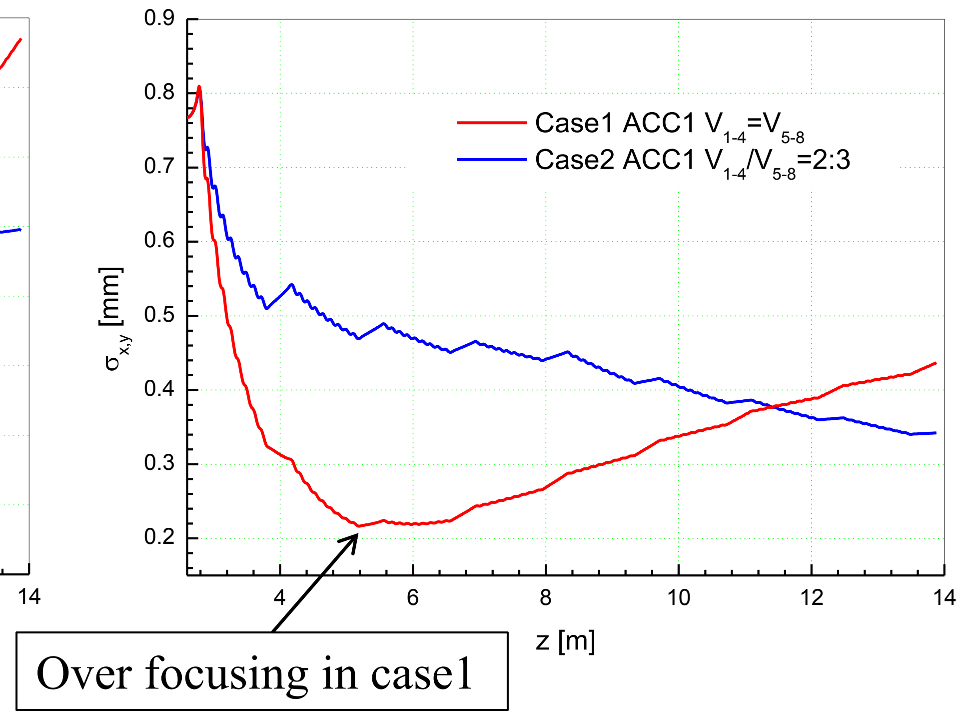
$$= \begin{pmatrix} \mathrm{Cos}(\alpha) - \sqrt{2}\,\mathrm{Cos}(\Delta\emptyset)\mathrm{Sin}(\alpha) & \sqrt{8}\,\frac{\gamma_i}{\gamma'}\,\mathrm{Cos}(\Delta\emptyset)\mathrm{Sin}(\alpha) \\ -\frac{\gamma'}{\gamma_f}\left[\frac{\mathrm{Cos}(\Delta\emptyset)}{\sqrt{2}} + \frac{1}{\sqrt{8}\mathrm{Cos}(\Delta\emptyset)}\right]\mathrm{Sin}(\alpha) & \frac{\gamma_i}{\gamma_f}\left[\mathrm{Cos}(\alpha) + \sqrt{2}\mathrm{Cos}(\Delta\emptyset)\mathrm{Sin}(\alpha)\right] \end{pmatrix}$$

First Cavity of ACC1

Stronger focusing

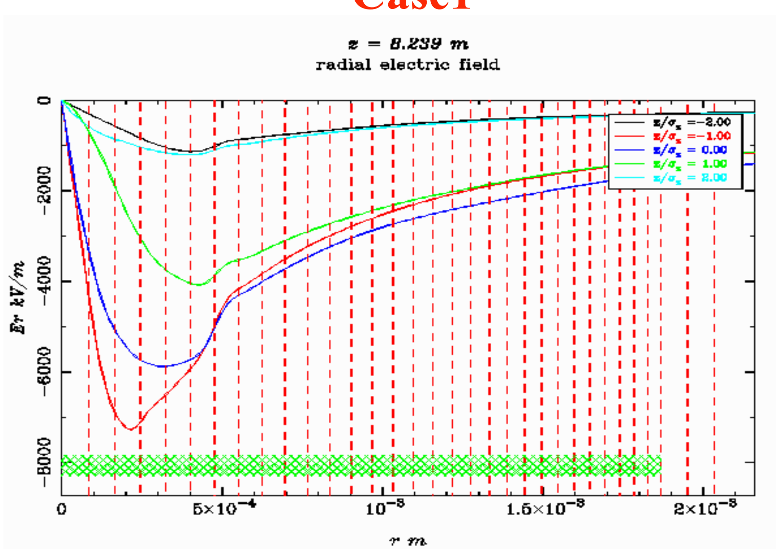
	L_{Cavity} [m]	$\Delta\emptyset$ [°]	γ_i	γ_f	γ' [1/m]	α	m_{21} [1/m]
Case1	1.3757	3.15797	9.80626	48.9927	28.4847	0.569609	-0.332407
Case2	1.3757	5.11289	9.80626	37.7417	20.3063	0.478403	-0.262368



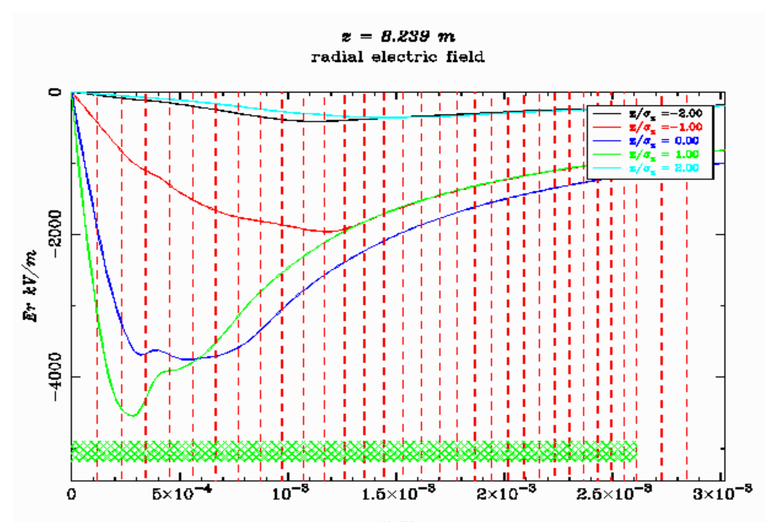


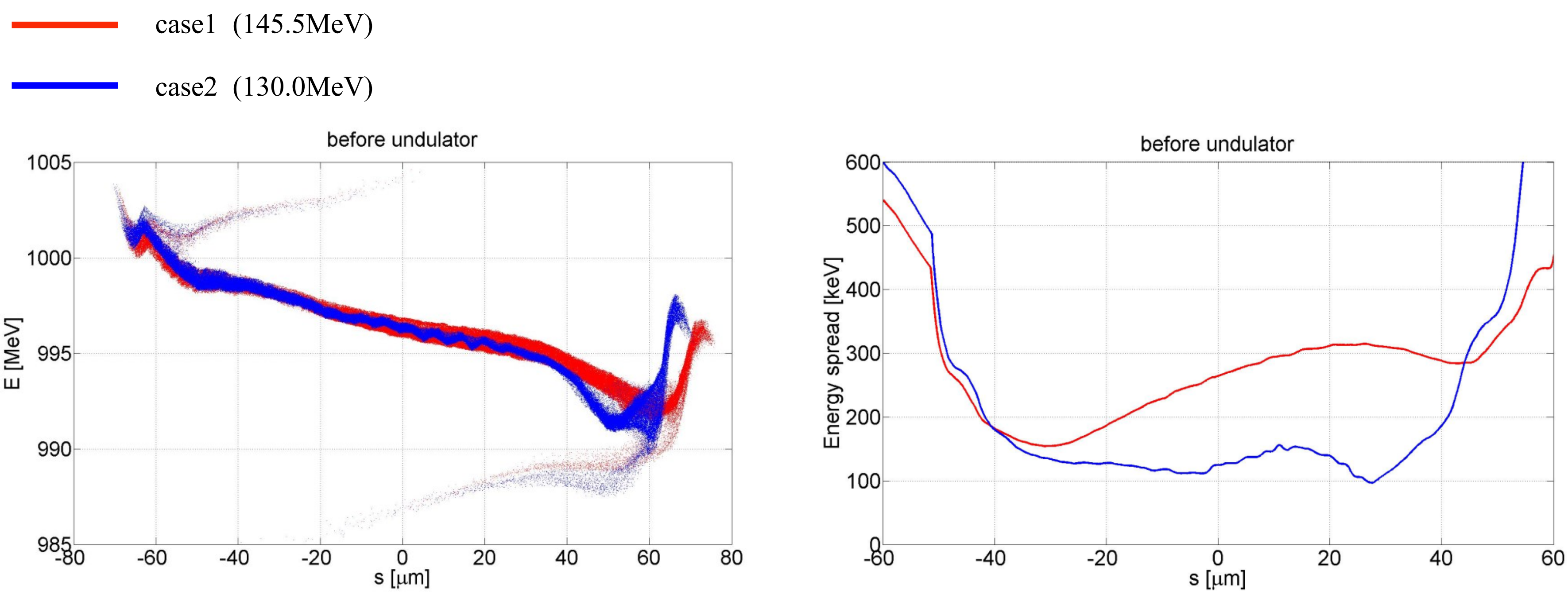
Space charge force after the first 4 cavities of ACC1

Case1



Case2





Calculation for other cases (1nC)

Restrictions :

(1) Keeping $V_{1-4}=V_{5-8}$ for ACC1.

(2) RF parameters of ACC1 and ACC39 should be optimized at the same time to keep the linear energy distribution after ACC39.

(3) Same gun model has been used.

(4) Beam energy after ACC3: 450MeV.

(5) RF power restrictions for accelerating modules.

RF Parameter Settings for ACC1 and ACC39

$V_{1-4}=V_{5-8}$ for ACC1

	Beam energy after ACC39	V_{ACC1} [MV]	φ_{ACC1} [deg]	V_{ACC39} [MV]	φ_{ACC39} [deg]
Case1*	145 MeV	160.39	-3.161	22.00	153.34
Case2*	140 MeV	154.87	-3.911	21.59	151.77
Case3*	135 MeV	149.30	-4.342	21.04	150.92
Case4*	130 MeV	143.74	-4.806	20.49	150.01
Case5*	125 MeV	138.18	-5.306	19.94	149.07
Case6*	120 MeV	132.64	-5.847	19.40	148.06

First cavity of ACC1

V_{1-4}=V_{5-8} for ACC1

Transverse focusing

	Beam energy after ACC39	L_{Cavity} [m]	$\Delta\emptyset$ [°]	γ_i	γ_f	γ' [1/m]	α	m_{21} [1/m]
Case1*	145 MeV	1.3757	-3.161	9.80626	48.9971	28.4879	0.5696	**−0.33243**
Case2*	140 MeV	1.3757	-3.911	9.80626	47.6272	27.4921	0.5596	**−0.32476**
Case3*	135 MeV	1.3757	-4.342	9.80626	46.2329	26.4786	0.5491	**-0.316734**
Case4*	130 MeV	1.3757	-4.806	9.80626	44.863	25.4828	0.5384	**-0.308578**
Case5*	125 MeV	1.3757	-5.306	9.80626	43.4932	24.4871	0.5274	**-0.300142**
Case6*	120 MeV	1.3757	-5.847	9.80626	42.0988	23.4736	0.5159	**-0.291253**

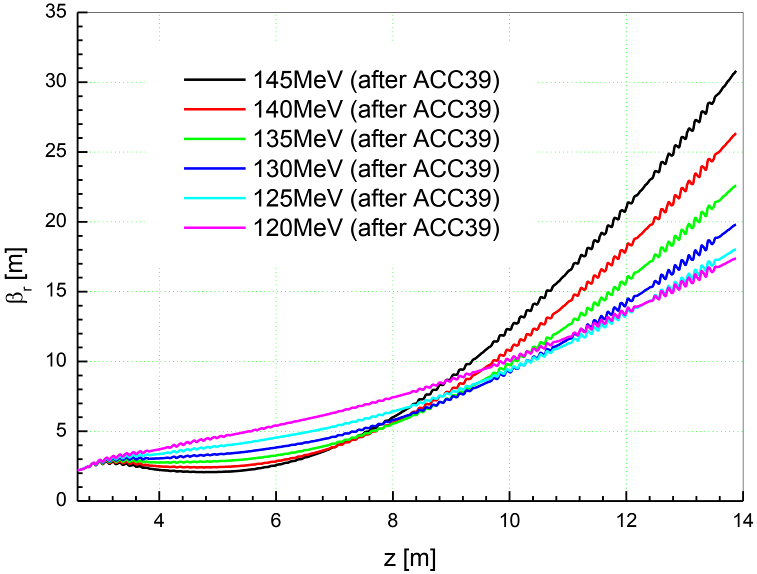
Comparing with Case2:

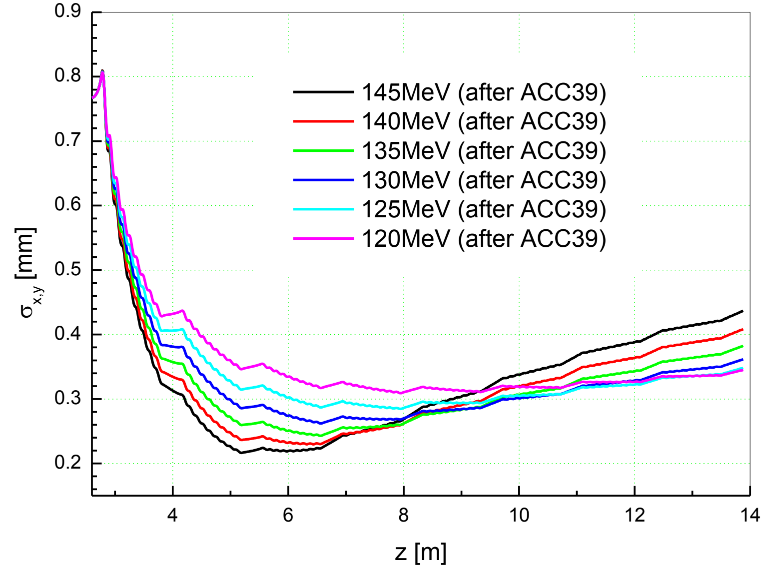
First cavity of ACC1

V_{1-4}:V_{5-8} =2:3 for ACC1

Beam energy after ACC39	L_{Cavity} [m]	$\Delta\emptyset$ [°]	γ_i	γ_f	γ' [1/m]	α	m_{21} [1/m]
130 MeV	1.3757	5.11289	9.80626	37.7417	20.3063	0.478403	$-\mathbf{0.262368}$

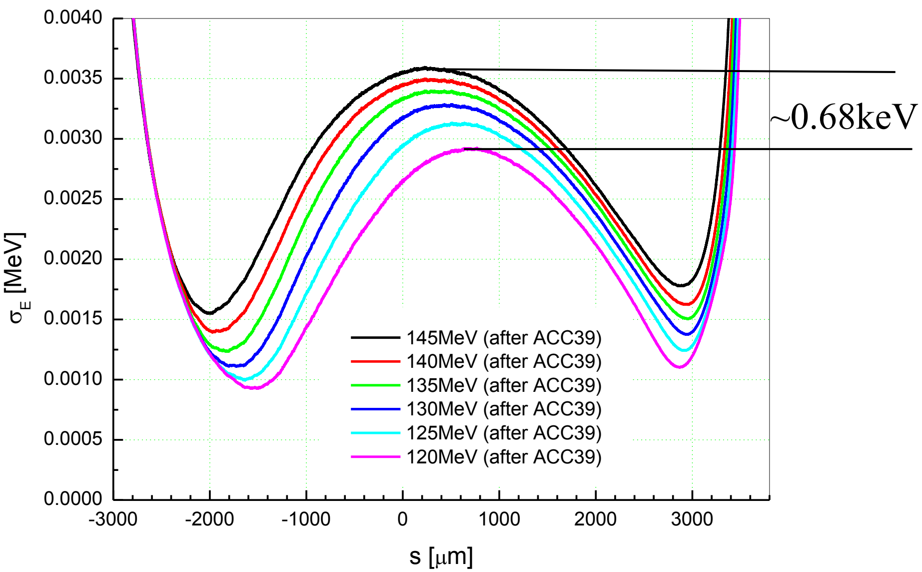
Parameters in ACC1 (Astra simulation including space charge effects)

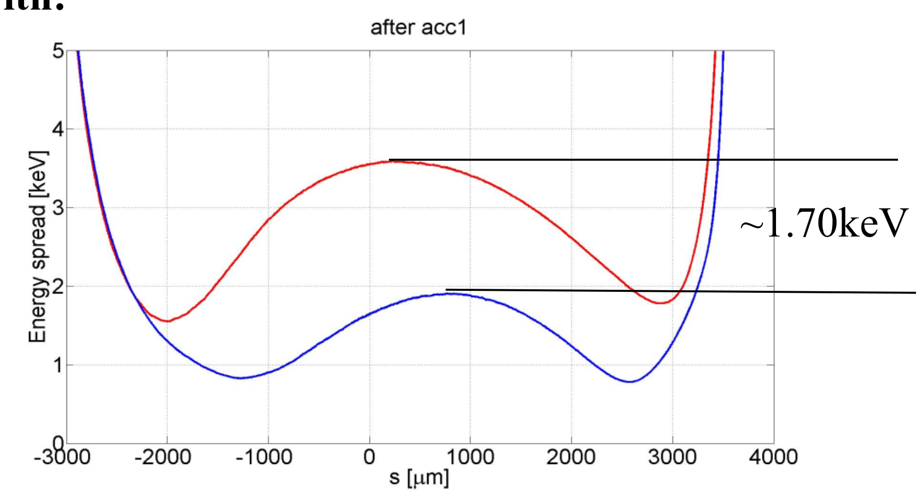




Comparing with:

After ACC1 (**$V_{1-4}=V_{5-8}$ for ACC1)**





case1 (145.5MeV, **$V_{1-4}=V_{5-8}$ for ACC1**)

case2 (130.0MeV), **$V_{1-4}:V_{5-8}=2:3$**

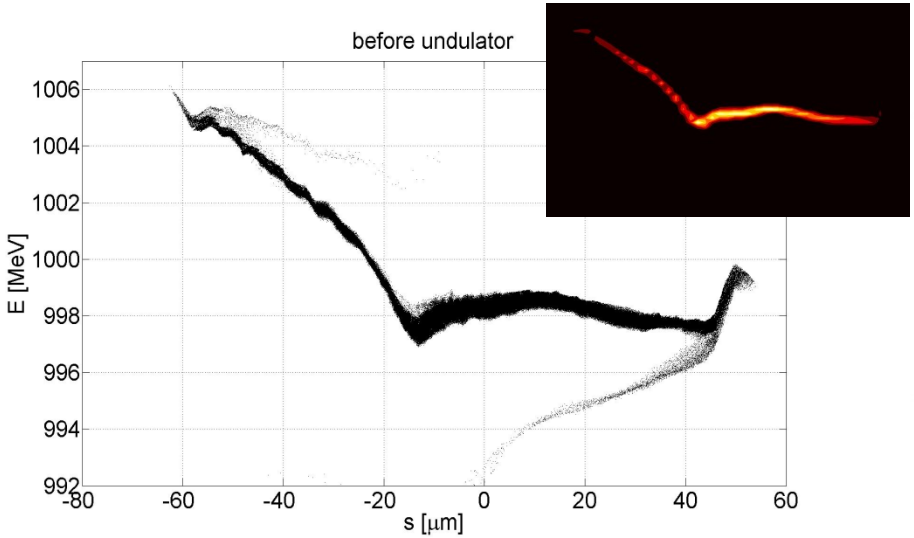
Achieved progress

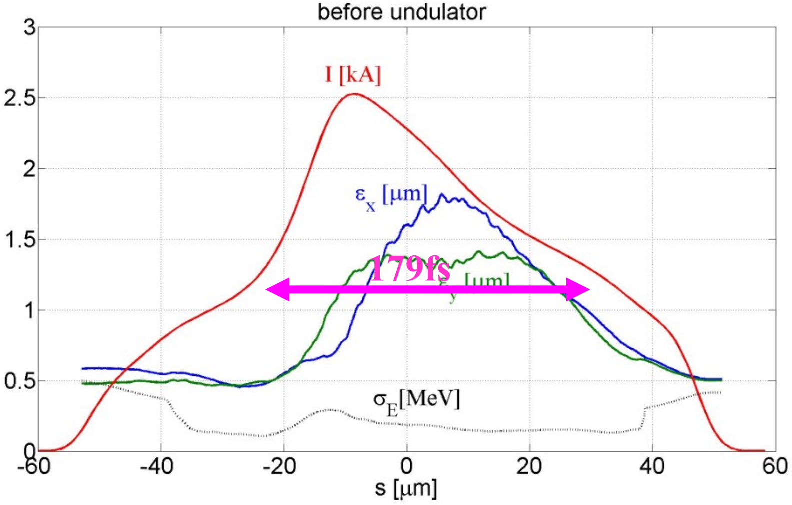
2. Astra-3D simulations for FLASHII for different bunch charge cases (100%)

Beam parameters from beam dynamics simulations

Parameter	Unit					
Bunch charge	nC	1	0.5	0.25	0.1	0.02
Peak current (gun)	A	50	26	15.5	7.8	2.05
Bunch length (gun, FWHM)	ps	21	20.2	16.7	13.1	9.38
Projected emittance (gun)	μm	2.6	1.3	0.93	0.59	0.29
Compression		49	96	160	333	1049
Peak current	kA	2.46	2.5	2.48	~2.6	2.15
Bunch length (FWHM)	fs	422	179	70.2	44	2.0
Projected emittance	μm	3.08	1.38	0.78	2.18	0.76

Astra-3D simulations for FLASHII



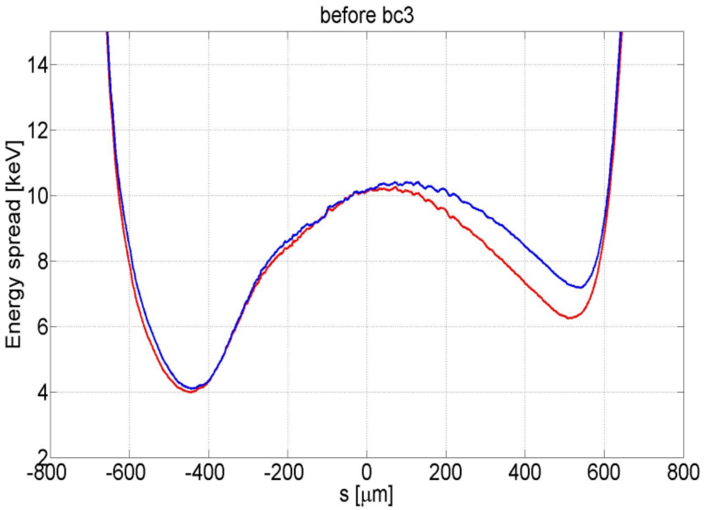


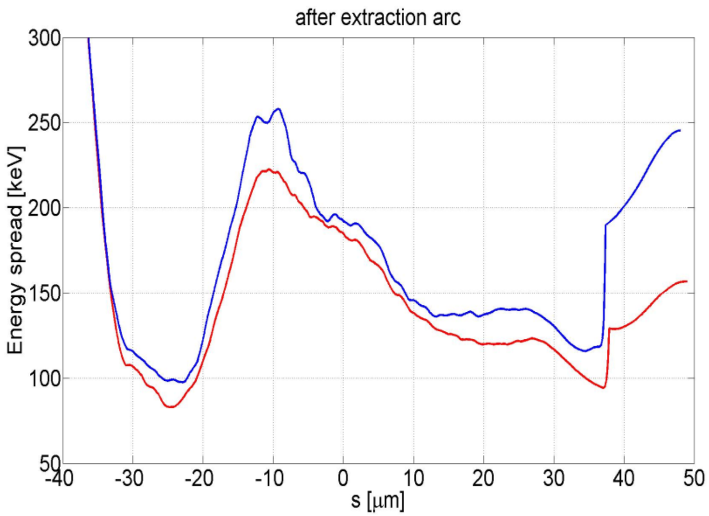
Q=0.5nC

$\varepsilon_x{}^{proj} = 1.38\mu m \cdot rad, \varepsilon_y{}^{proj} = 1.19\mu m \cdot rad$

3D calculation

2D calculation





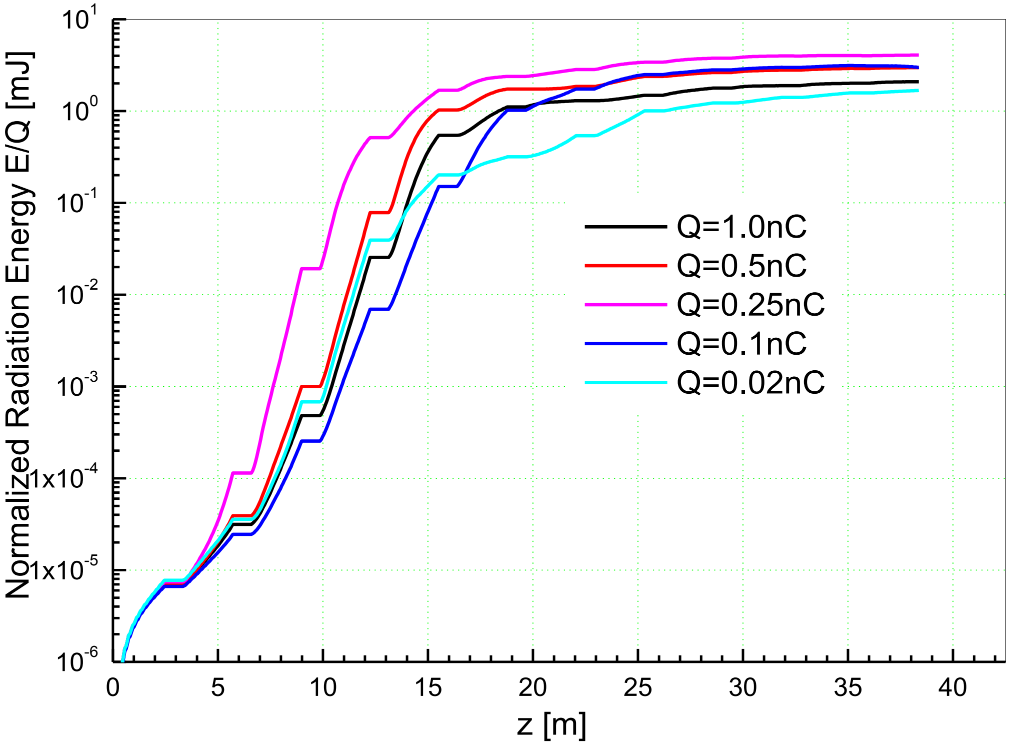
Achieved progress

3. SASE FEL calculations for FLASHII (100%)

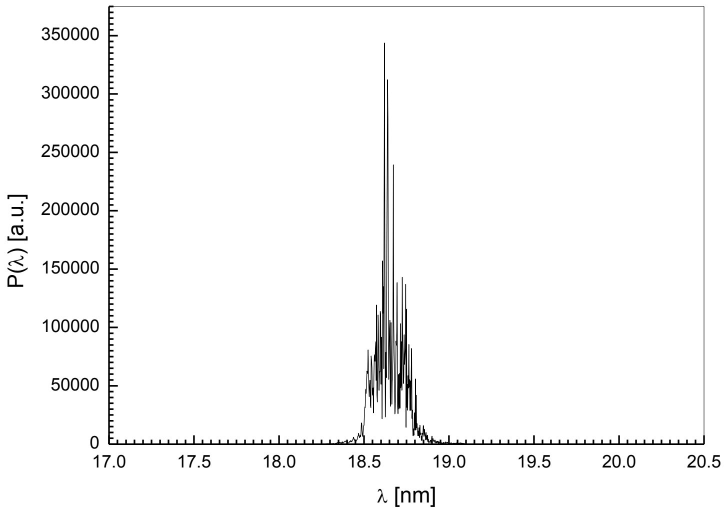
Slice parameters are extracted from s2e simulations for SASE simulation

$$\gamma \quad \Delta\gamma \quad \varepsilon_x \quad \varepsilon_y \quad \beta_x \quad \beta_y \quad \langle x \rangle \quad \langle y \rangle \quad \langle x' \rangle \quad \langle y' \rangle \quad \alpha_x \quad \alpha_y \quad I$$

λu=31.4mm, K=1.87



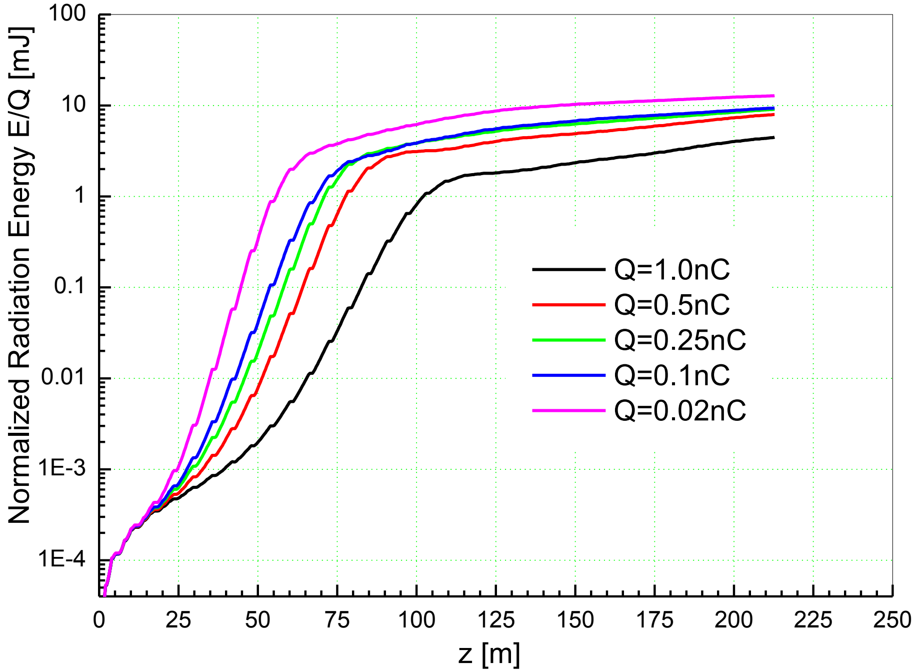
10 random seeds for each bunch charge case



* The magnet description file for the undulator system comes from Matthias Scholz.

Achieved progress

4. SASE FEL calculations for EXFEL SASE1 for different bunch charge cases(100%)



λu=40.0mm, K=2.13676

10 random seeds
for each bunch charge case

Bunch charge, nC	1.0	0.5	0.25	0.1	0.02
Wavelength, nm	~0.1nm				
Beam energy, GeV	~17.5				
Peak current, kA	~5.0				
Saturation length, m	110	88	80	75	62
Mean radiation energy in the pulse, mJ	4.5	3.98	2.27	0.94	0.26
Averaged peak power, GW	41.1	55.4	69.2	80.4	110.2

The plan for next month

1. The internal report for EXFEL simulations. (100%)
2. Optimization for FLASHII HGHG operation mode. (30%)
3. Preparing particle distributions of FLASH for Johann Zemella for special purpose of plasma study. (100%)