High Charge Beam Dynamics Simulations for THz Radiation

Igor Zagorodnov

21.11.2011

DESY

THz pump/X-ray-probe experiment

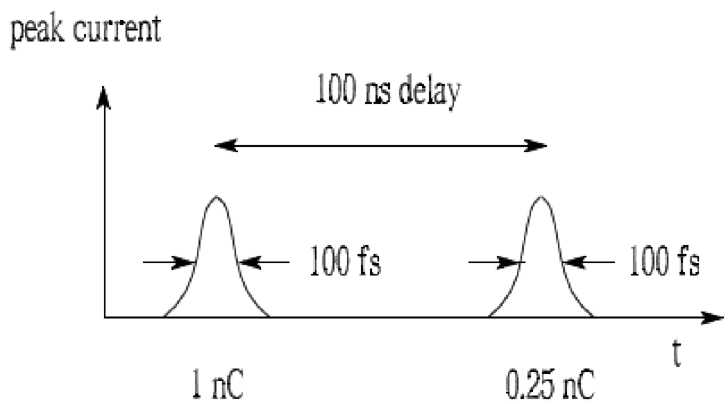


Fig. 26. Double electron bunch generation for THz pump/X-ray probe experiments at the LCLS. The THz radiation transport through the access maze introduces a path delay with respect to the X-ray path, which has to be compensated with the introduction of a delay between two bunches.

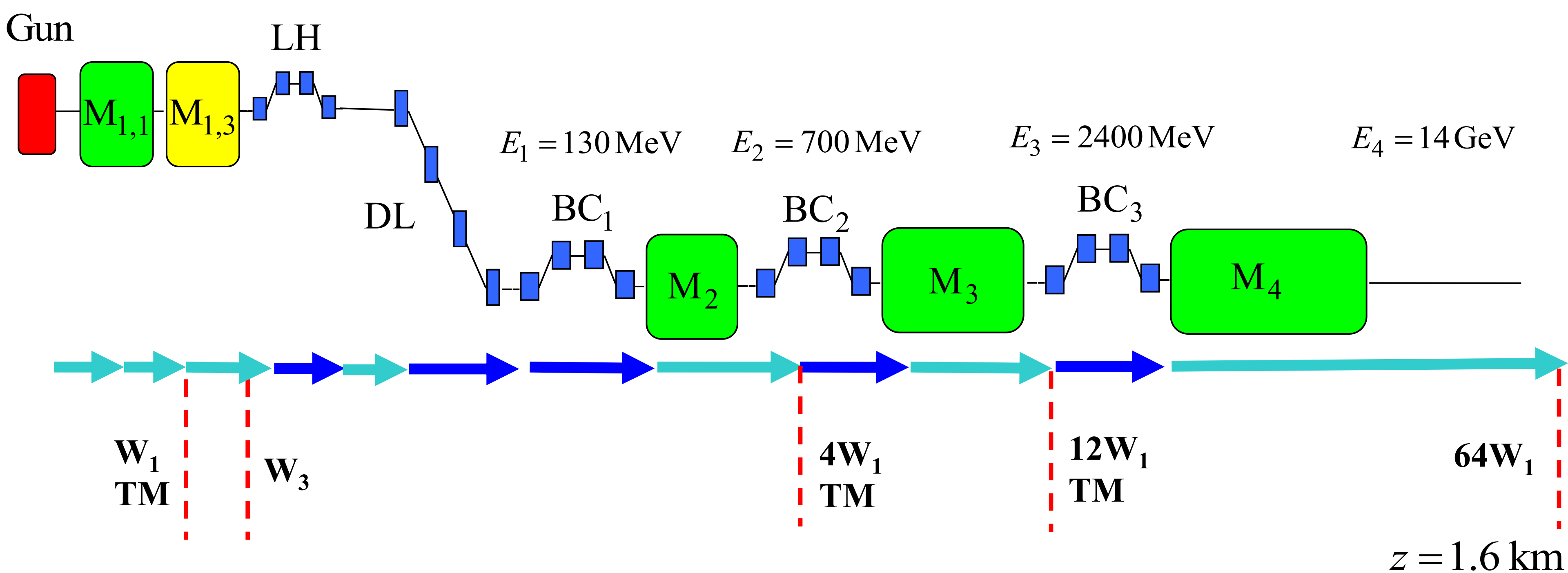
Scheme for generating and transporting THz radiation to the X-ray experimental floor at the LCLS baseline

Gianluca Geloni,
European XFEL GmbH, Hamburg

Vitali Kocharyan and Evgeni Saldin
Deutsches Elektronen-Synchrotron DESY, Hamburg

Beam dynamics simulations for the European XFEL

Full 3D simulation method (**200 CPU, ~ 5 hours**)



ASTRA (tracking with **3D space charge**, DESY, K. Flötmann)

CSRtrack (tracking through dipoles, DESY, M. Dohlus, T. Limberg)

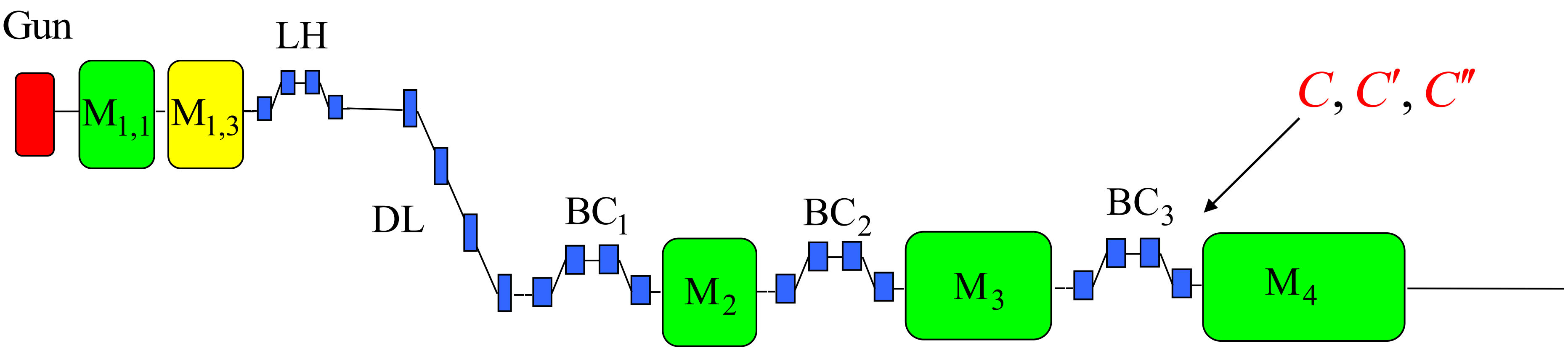
W1 -TESLA cryomodule wake (TESLA Report 2003-19, DESY, 2003)

W3 - ACC39 wake (TESLA Report 2004-01, DESY, 2004)

TM - transverse matching to the design optics

Beam dynamics simulations for the European XFEL

Working point (11 macro-parameters)



$E_1 = 130\,\mathrm{MeV}$

$r_{56,1} = ?$

$C_1 = ?$

$E_2 = 700\,\mathrm{MeV}$

$r_{56,2} = ?$

$C_2 = ?$

$E_3 = 2400\,\mathrm{MeV}$

$r_{56,3} = ?$

Chicane	Minimum R56 [mm]	Maximum R56 [mm]
BC0	0, 30	90
BC1	20	80
BC2	10	60

Table 1: R56 requirements for XFEL magnet compressor chicanes

Macroparameters for Q=0.25nC

Momentum compaction factor in BC_1 $R_{56,1}$, [mm]	Compr. in BC_1 C_1	Momentum compaction factor in BC_2 $R_{56,2}$, [mm]	Compr. in BC_2 C_2	Momentum compaction factor in BC_3 $R_{56,3}$, [mm]	Total compr. C	First inverse derivative Z', [m^{-1}]	Second inverse derivative Z'', [m^{-2}]	Current, I [kA]
-78	3.5	-43	8	-20	385	0	1000	5

RF settings in accelerating modules for all charges

$V_{1,1}$, [MV]	$\varphi_{1,1}$, [deg]	$V_{1,3}$, [MV]	$\varphi_{1,3}$, [deg]	V_2, [MV]	φ_2, [deg]	V_3, [MV]	φ_3, [deg]
157	17.6	26	186	689	33.7	1727	8.4

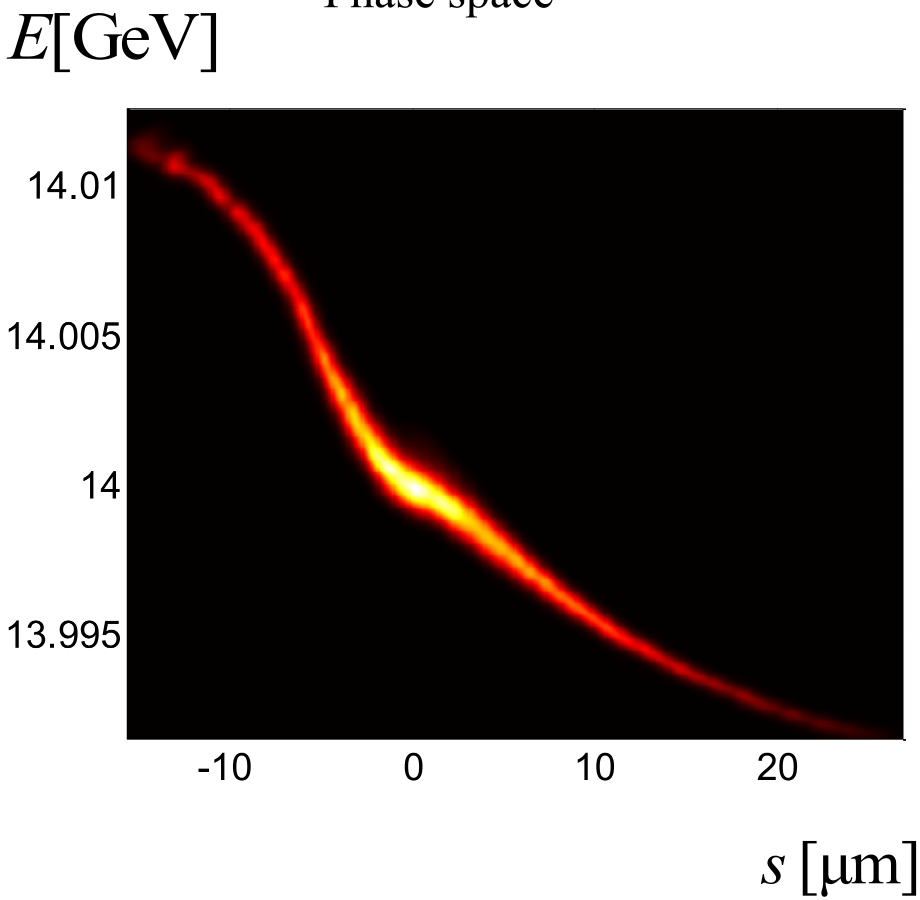
RF gun settings

Charge, [nC]	Laser spot size XY_{rms}, [mm]
0.25	0.23
0.5	0.29
1	0.4
2	0.65
3	0.9

Other gun settings are the same for all charges (optimal for 0.25pC).

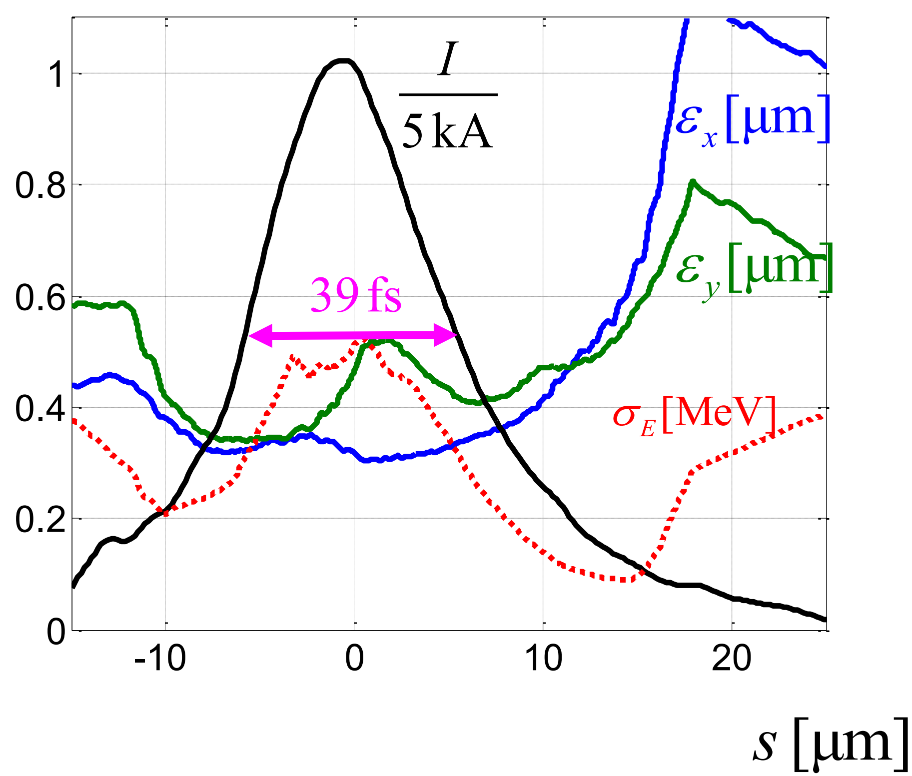
Q=0.25 nC

Phase space



bunch head

Current, emittance, energy spread



$$\varepsilon_x^{proj} = 0.5\,[\mu m]$$

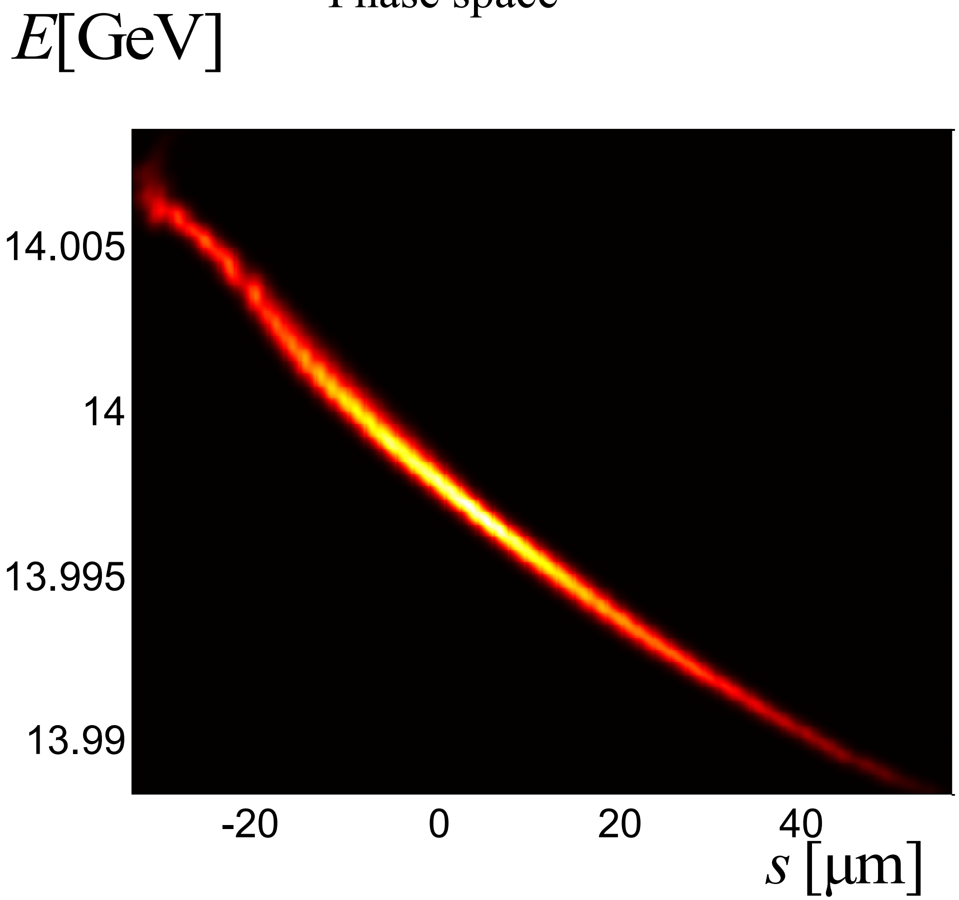
$$\varepsilon_y^{proj} = 2.1\,[\mu m]$$

We have removed 2% of bad particles in the analysis

(optimal for 0.25pC)

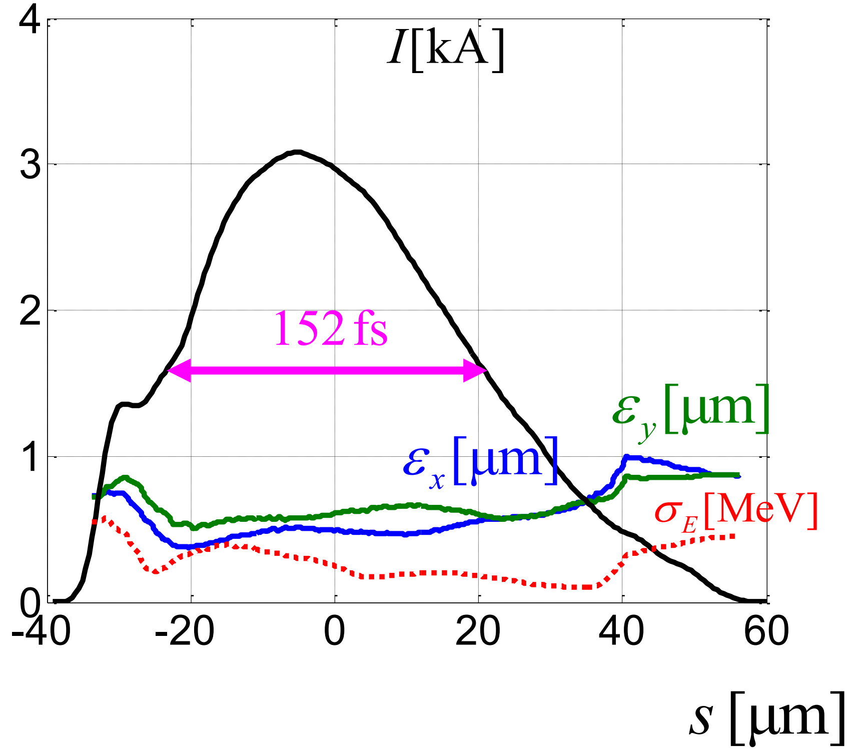
Q=0.5 nC

Phase space



bunch head

Current, emittance, energy spread



$$\varepsilon_x^{proj} = 0.6\,[\mu m]$$

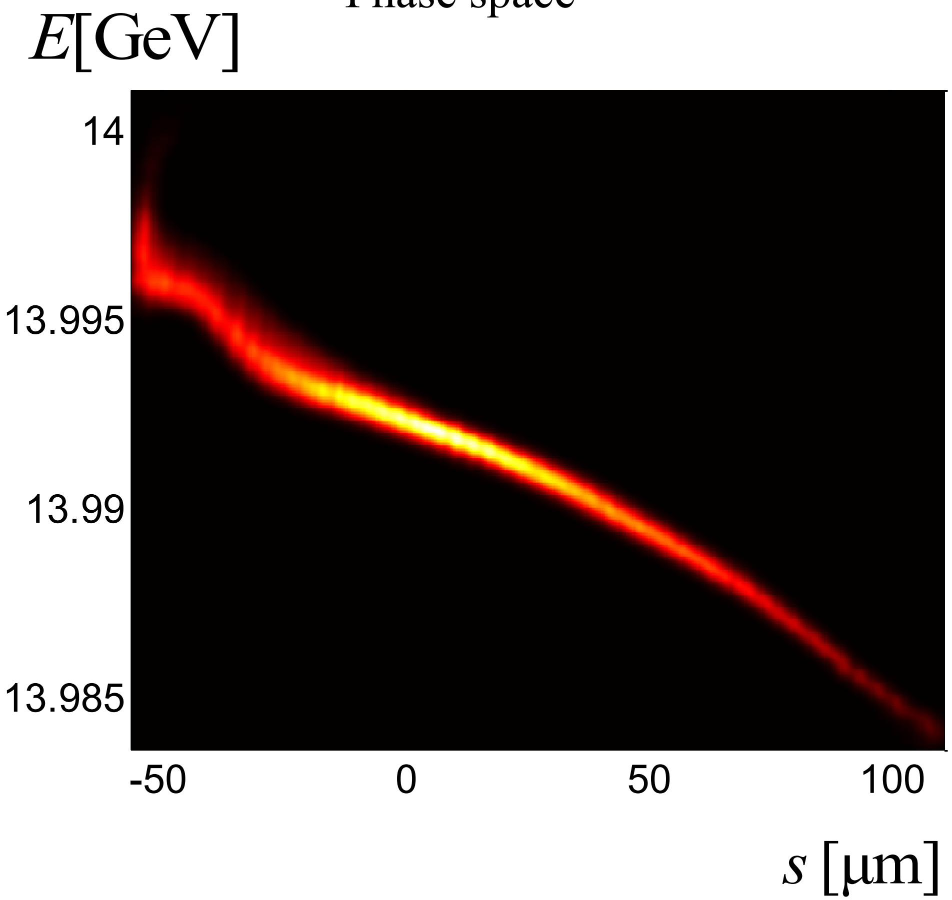
$$\varepsilon_y^{proj} = 1.8\,[\mu m]$$

We have removed 2% of bad particles in the analysis

(optimal for 0.25pC)

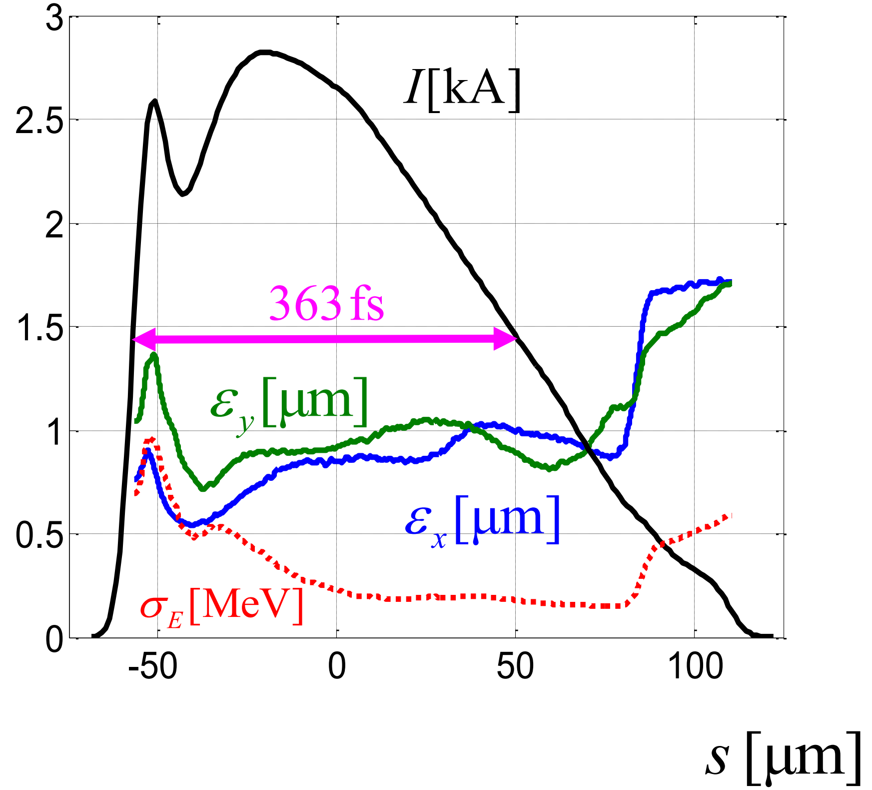
Q=1 nC

Phase space



bunch head

Current, emittance, energy spread



$$\varepsilon_x^{proj} = 1\,[\mu\text{m}]$$

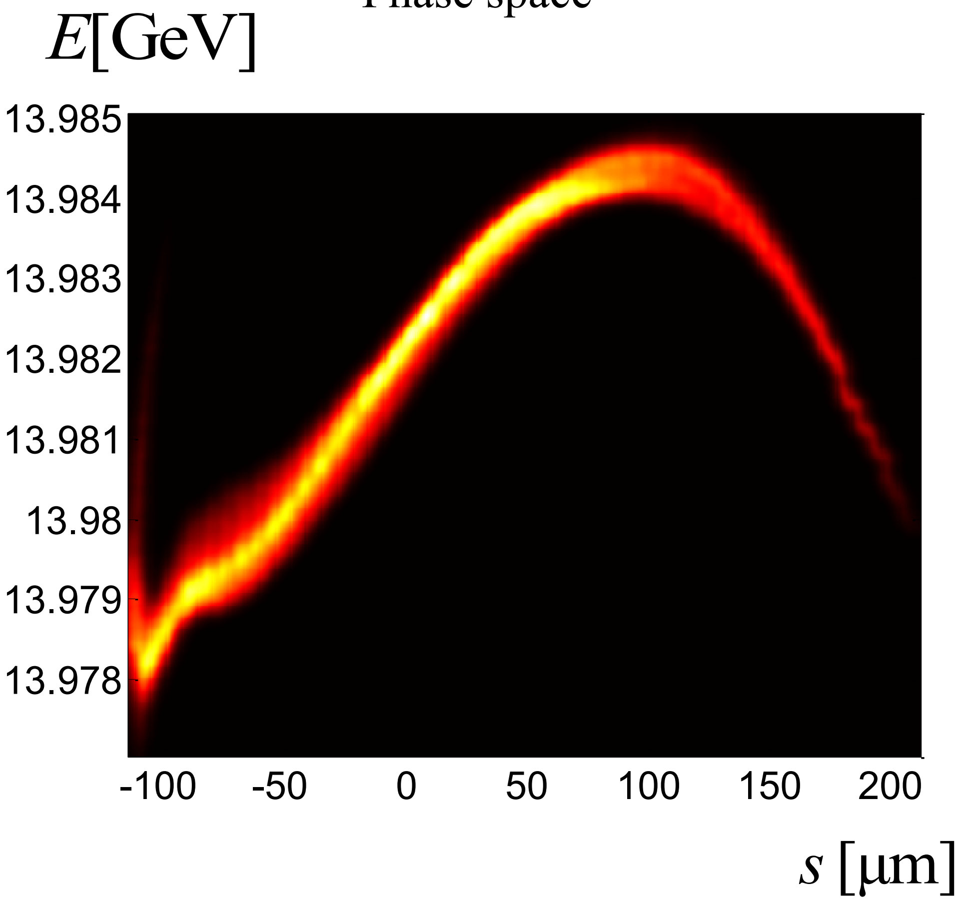
$$\varepsilon_y^{proj} = 2.8\,[\mu\text{m}]$$

We have removed 2% of bad particles in the analysis

(optimal for 0.25pC)

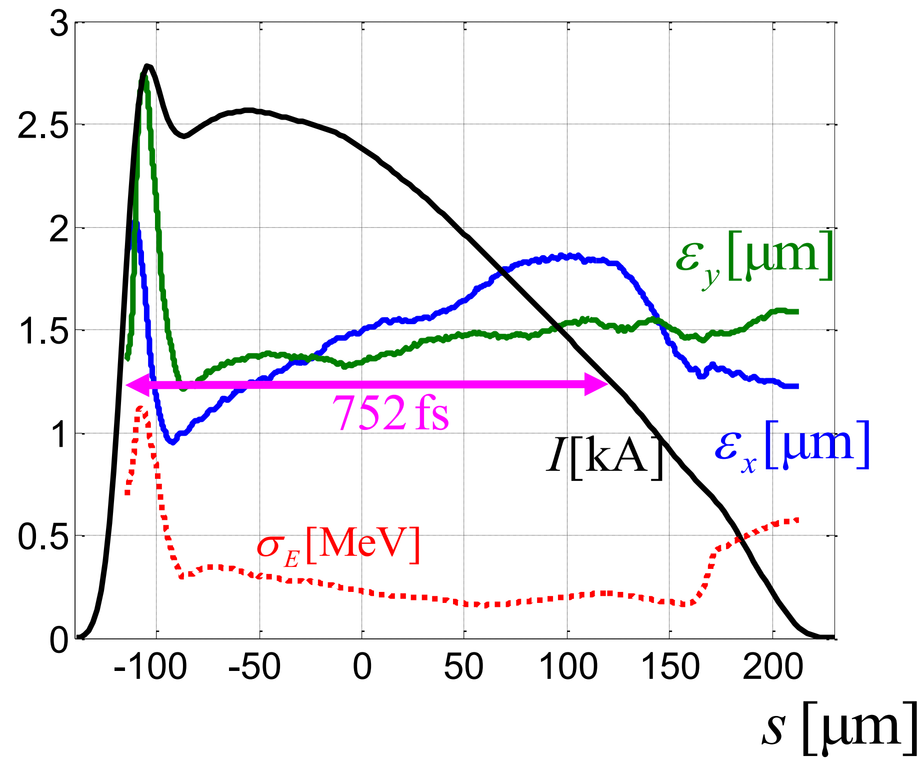
Q=2 nC

Phase space



bunch head

Current, emittance, energy spread



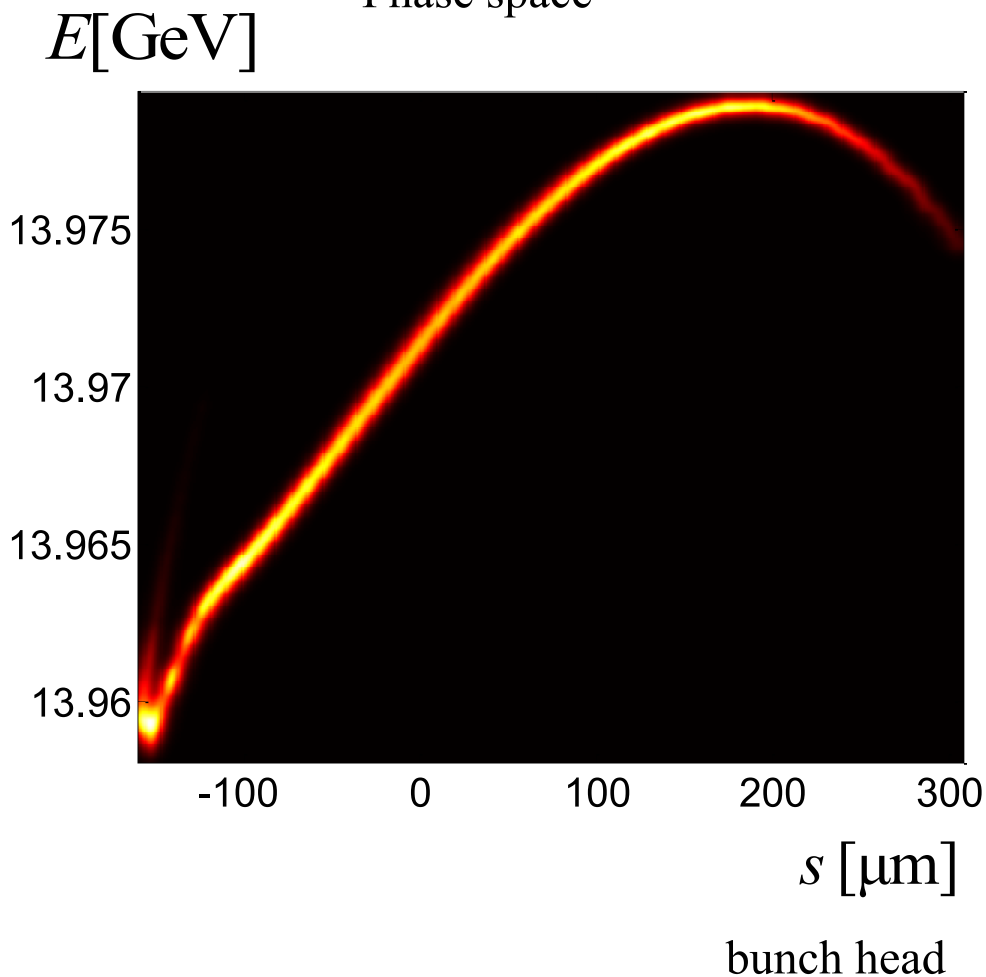
$\varepsilon_x^{proj} = 1.7$ [μm]

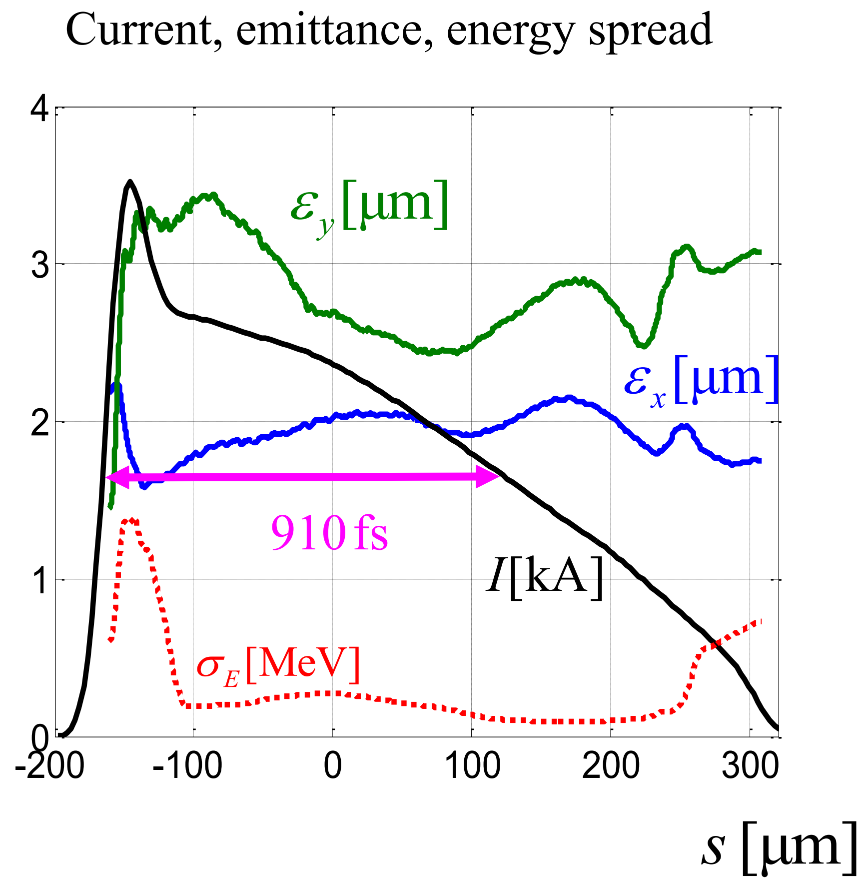
$\varepsilon_y^{proj} = 5.4$ [μm]

We have removed 2% of bad particles in the analysis

(optimal for 0.25pC)

Q=3 nC





$$\varepsilon_x^{proj} = 2.3\,[\mu m]$$

$$\varepsilon_y^{proj} = 10\,[\mu m]$$

We have removed 2% of bad particles in the analysis

Beam parameters from S2E simulations

Parameter	Unit					
Bunch charge	nC	3	2	1	0.5	0.25
Peak current (gun)	A	128	84	43	24	13.5
Bunch length (gun, FWHM)	ps	24	24	25	22	20
Slice emittance (gun)	µm	1.5	1.1	0.8	0.5	0.3
Projected emittance (gun)	µm	3.3	2.2	1	0.7	0.6
Compression		**18**	**29**	**65**	**125**	**363**
Current (in center)	kA	**2.3**	**2.4**	**2.8**	**3**	**5**
Bunch length (FWHM)	fs	910	752	363	152	39
Slice emittance	µm	**2.5**	**1.5**	**1**	**0.6**	**0.5**
Projected emittance	µm	10	5.4	2.8	1.8	1.5
Slice energy spread **(laser heater off)**	MeV	0.2	0.2	0.3	0.3	0.6

Choosing of machine parameters

Macro-parameters

$E_1 = 130\,\text{MeV}$ $E_2 = 700\,\text{MeV}$ $E_3 = 2400\,\text{MeV}$

Charge Q, nC	Momentum compaction factor in BC_1 $R_{56,1}$, [mm]	Compr. in BC_1 C_1	Momentum compaction factor in BC_2 $R_{56,2}$, [mm]	Compr. in BC_2 C_2	Momentum compaction factor in BC_3 $R_{56,3}$, [mm]	Total compr. C	First derivative Z', [m^{-1}]	Second derivative Z'', [m^{-2}]
0.25	-78	3.5	-43	8	-20	385	0	1000
1	-100	3.5	-54	8	-20	121	0	2000
1	**-86**	**3.5**	**-54**	**8**	**-20**	**242**	**0**	**1500**
2	-86	3	-49	3	-50	121	0	500
3						121		

Chicane	Minimum R56 [mm]	Maximum R56 [mm]
BC0	0, 30	90
BC1	20	80
BC2	10	60

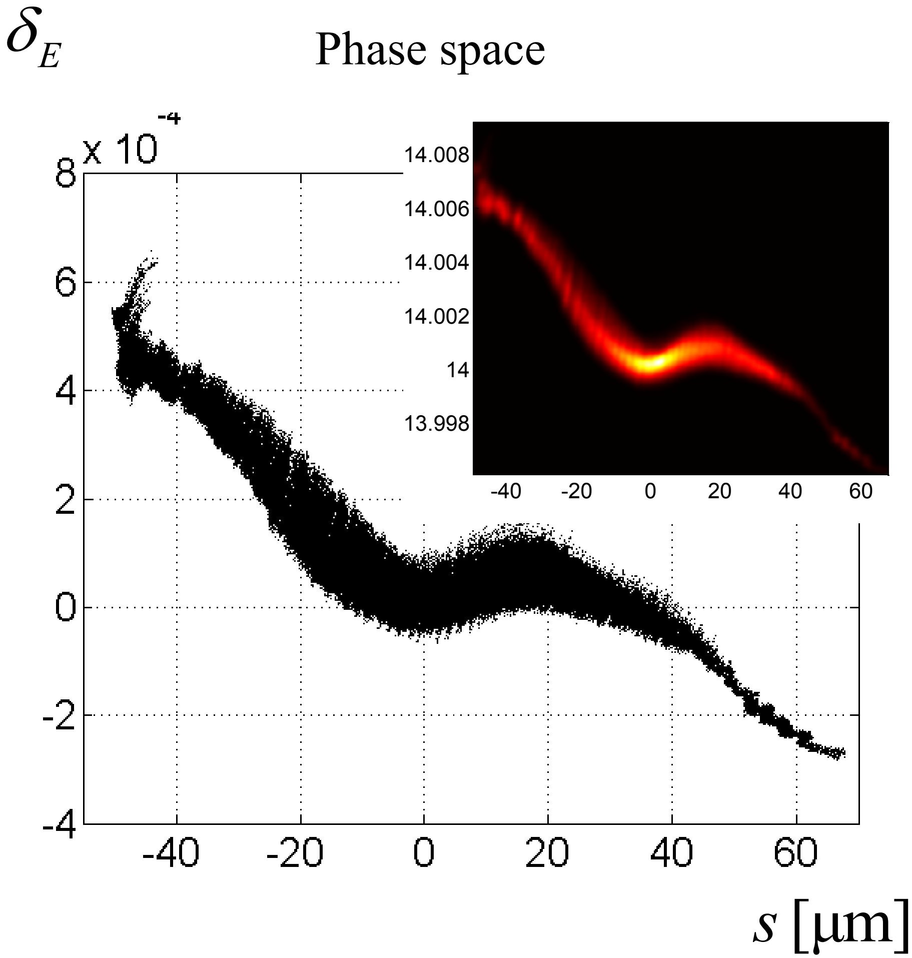
Table 1: R56 requirements for XFEL magnet compressor chicanes

Beam parameters from S2E simulations

Parameter	Unit		
Bunch charge	nC	1	
Peak current (gun)	A	43	
Bunch length (gun, FWHM)	ps	25	
Slice emittance (gun)	µm	0.8	
Projected emittance (gun)	µm	1	
Compression		116	**228**
Current (in center)	kA	**5**	**9.8**
Bunch length (FWHM)	fs	178	75
Slice emittance	µm	**1**	**1**
Projected emittance	µm	3.5	8
Slice energy spread **(laser heater off)**	MeV	0.45	1

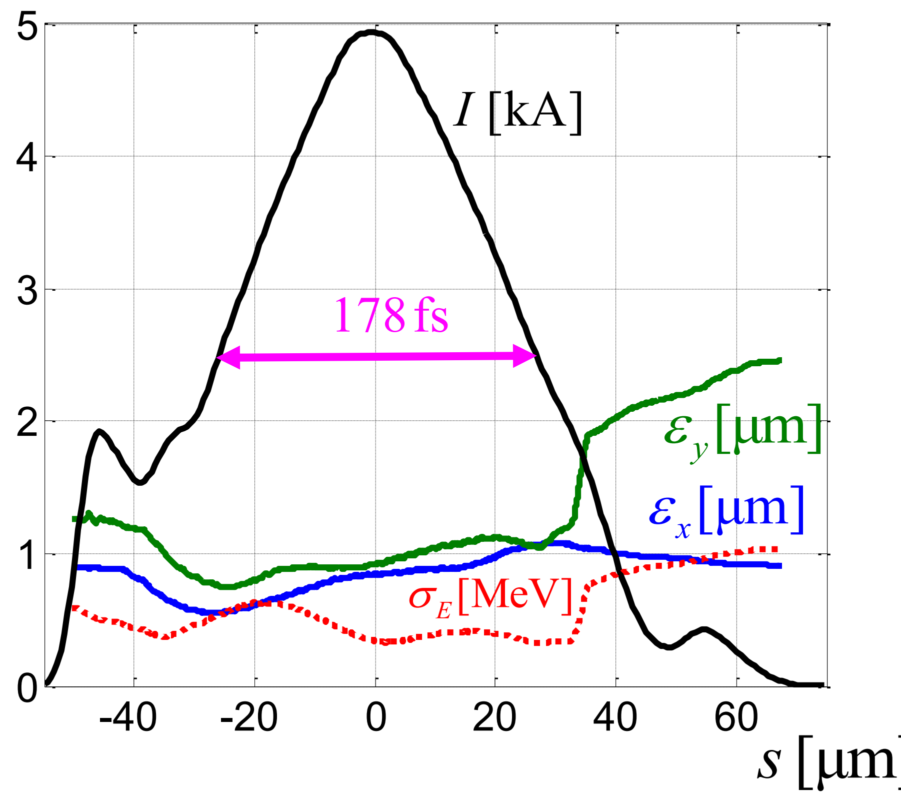
Q=1 nC, I=5 kA

Phase space



bunch head

Current, emittance, energy spread



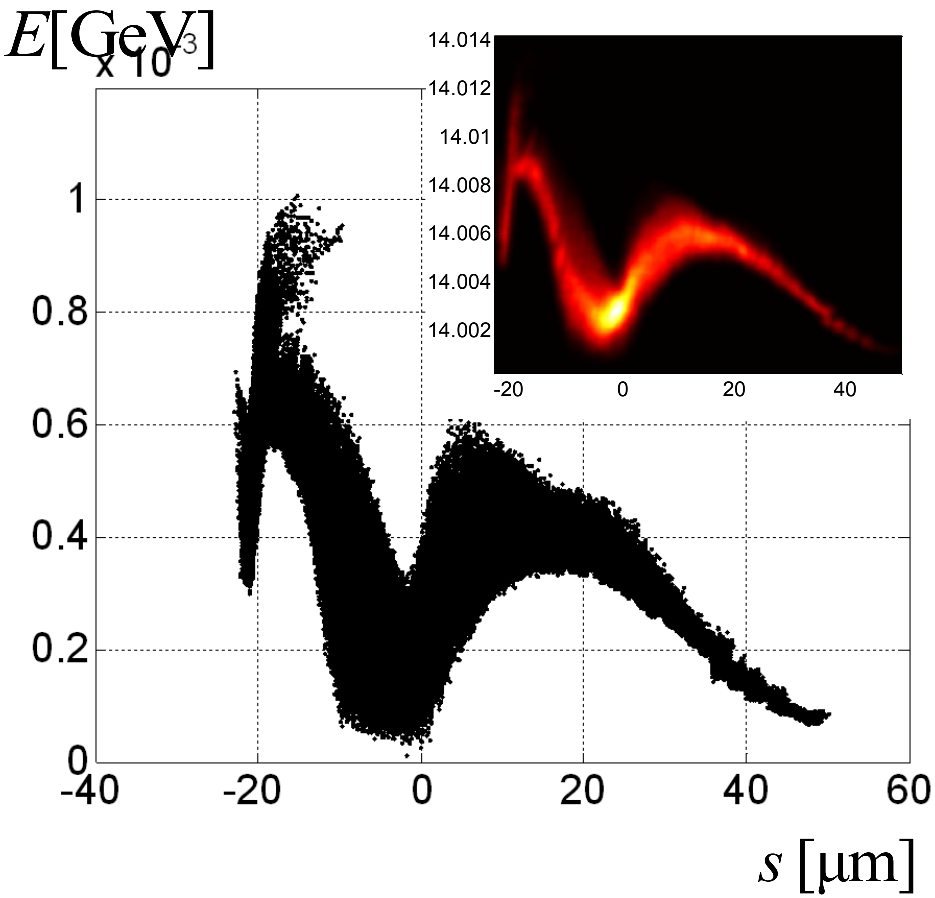
$$\varepsilon_x^{proj} = 0.9\,[\mu\mathrm{m}]$$

$$\varepsilon_y^{proj} = 3.5\,[\mu\mathrm{m}]$$

We have removed 6% of bad particles in the analysis

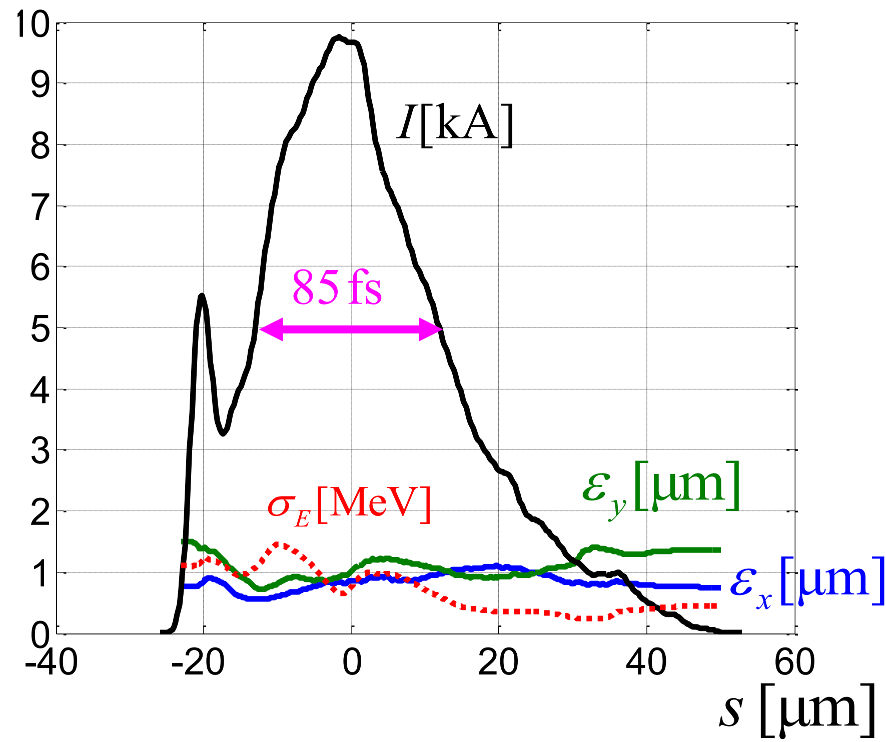
Q=1 nC, I=10kA

Phase space



bunch head

Current, emittance, energy spread



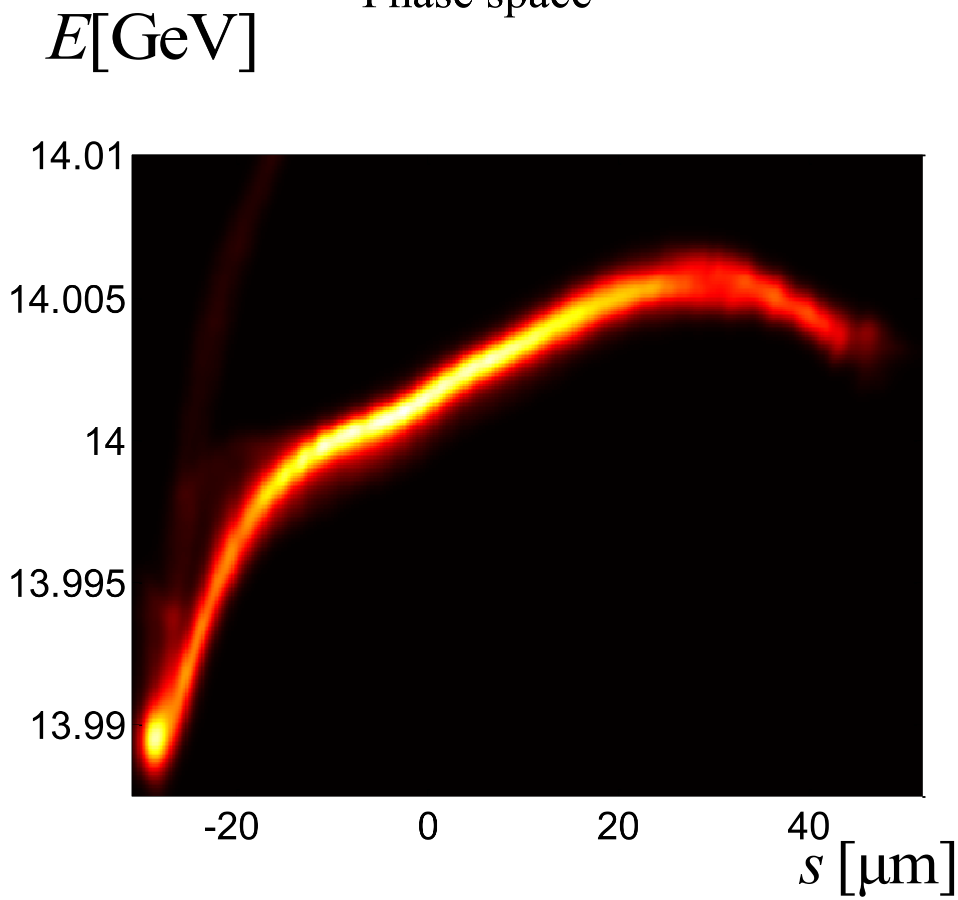
$$\varepsilon_x^{proj} = 0.9\ [\mu m]$$

$$\varepsilon_y^{proj} = 8\ [\mu m]$$

We have removed 2% of bad particles in the analysis

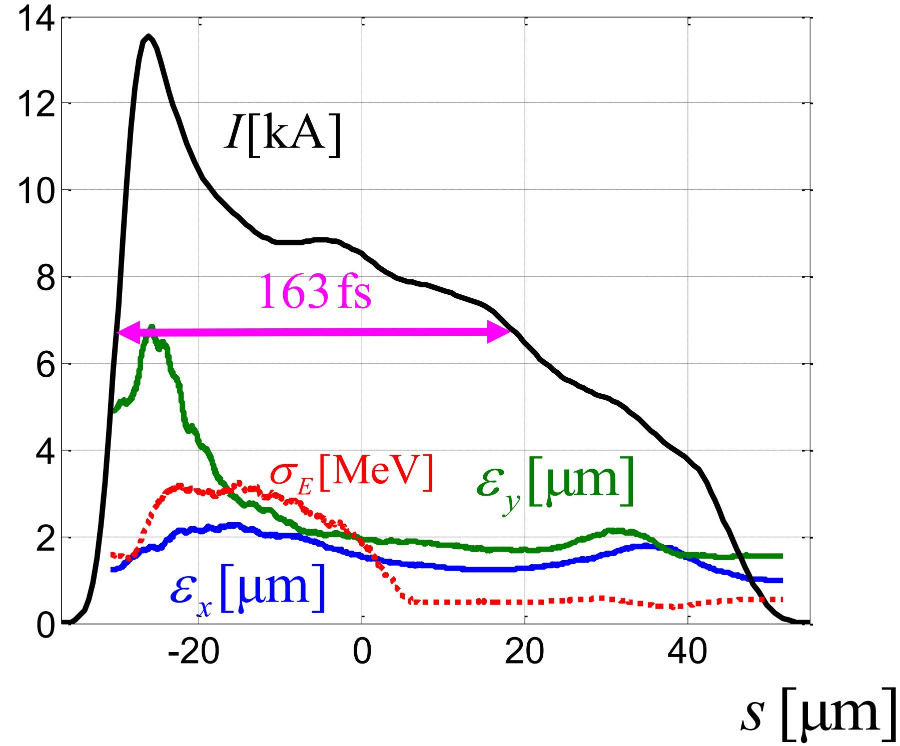
Q=2 nC

Phase space



bunch head

Current, emittance, energy spread



$$\varepsilon_x^{proj} = 1.9\ [\mu m]$$

$$\varepsilon_y^{proj} = 19\ [\mu m]$$

We have removed 2% of bad particles in the analysis