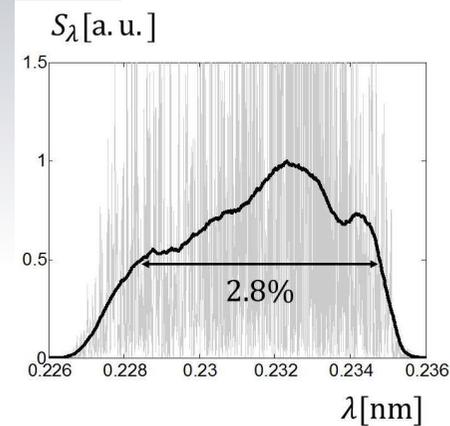
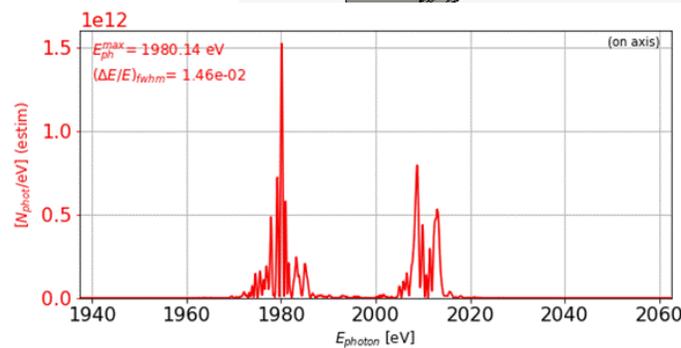
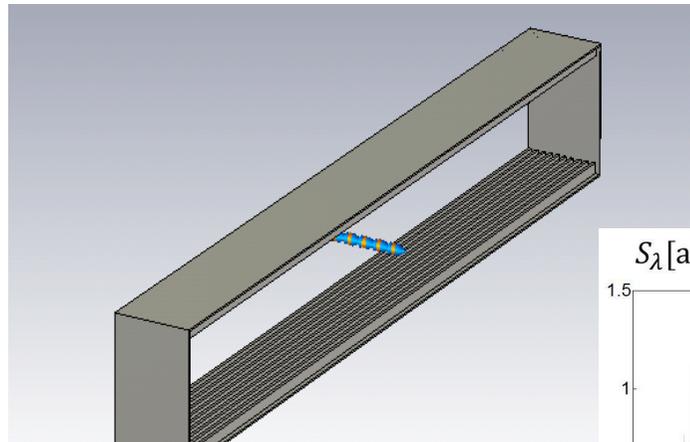


Beam Manipulation and Diagnostics with Wakefield Structure at the European XFEL

Igor Zagorodnov
DESY-TEMF-Meeting,
TU Darmstadt
June 8, 2017



HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES



Outline

- Motivation to use Wakefield Structure (WS)
- Technical design of WS
- WS as dechirper/chirper
- WS as kicker
 - two color/fresh-slice scheme
 - beam diagnostics
- Other applications
- Proposal



Motivation to use Wakefield Structure (WS)

- WS will allow the longitudinal and the transverse phase space manipulations of the electron beams
- The longitudinal wakefields introduce the correlated energy chirp along the bunch which can be used to increase or to decrease the radiation bandwidth of SASE
- The transverse wakefields introduce the correlated kick along the bunch which can be used for beam diagnostics or beam manipulations in the undulator section

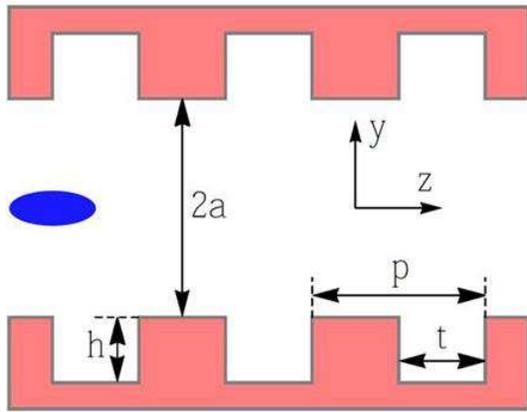
Technical design of WS

- Flat vs. round geometry
 - adjustment of strength
 - cancelation of quadrupole wake requires horizontal/vertical modules

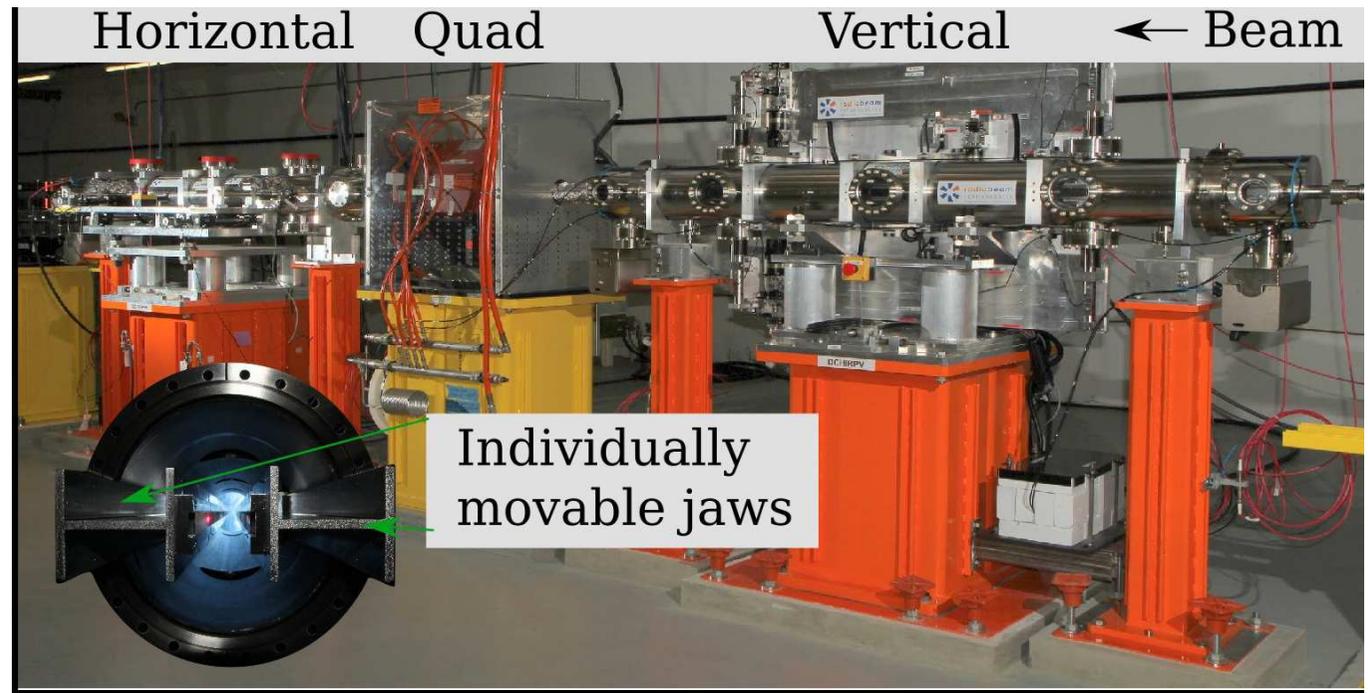
- Slowdown layer
 - Resistive beam pipe or periodic cavities do not work well as dechirpers, since the longitudinal short range wake drops quickly
 - Dielectric or corrugated aluminum could be used;
 - ▶ corrugated dechirpers have been build and tested at Pohang Accelerator Laboratory/SLAC
 - ▶ dielectric lined structures are tested at Brookhaven National Laboratory
 - Corrugated structures RadiaBeam/SLAC have been used at LCLS

- We choose flat geometry with corrugated plates used by SLAC. There are several publications where the choice of parameters for the structures is addressed. The European XFEL has the electron beam parameters which are close to those of LCLS and the same arguments hold.

Technical design of WS



Parameter	Value	Unit
Depth, h	0.5	mm
Gap, t	0.25	mm
Period, p	0.5	mm
Half aperture, a	0.7	mm
Half width, w	6	mm
Length, L	2	m



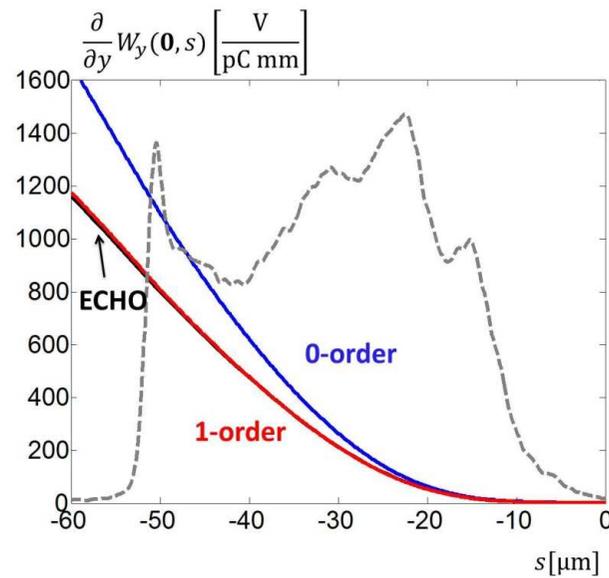
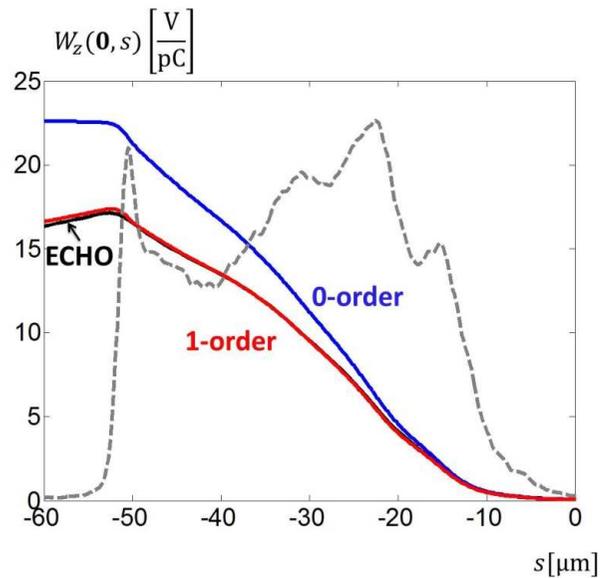
The two dechirper modules (RadiaBeam) installed at LCLS
 M. W. Guetg et al, SLAC-PUB-16834, 2016.

Technical design of WS

Wakefield estimation

Accurate analytical formulas are obtained and cross-checked with EM simulations

- ▶ K. Bane, G. Stupakov, I. Zagorodnov, *Analytical formulas for short bunch wakes in a flat dechirper*, Phys. Rev. Accel. Beams **19**, 084401 (2016)
- ▶ K. Bane, G. Stupakov, I. Zagorodnov, *Wakefields of a Beam near a Single Plate in a Flat Dechirper*, SLAC-PUB-16881, November 2016.

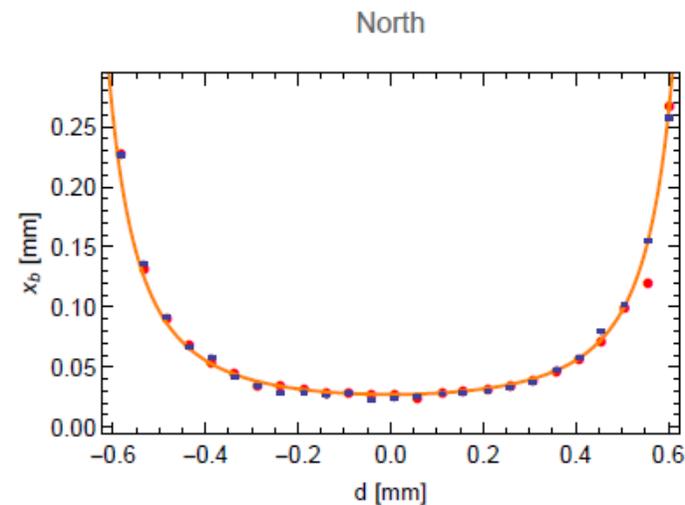
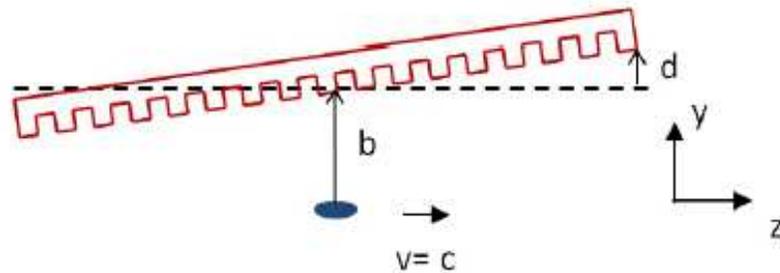


Technical design of WS

Wakefield estimation

The analytical (integral) wakes are cross-checked with measurements

- ▶ J. Zemella et al, *Measurement of wake-induced electron beam deflection in a dechirper at the Linac Coherent Light Source*, Phys. Rev. Accel. Beams **20**, 104403 (2017)
- ▶ K. Bane, M. Guetg, A. Lutman, *Wake measurements of a dechirper jaw with non-zero tilt angle*, SLAC-PUB-17209, January 2018



Calculated (solid line) vs
measurements (points)

Technical design of WS

Joule heating/cooling

K.Bane, G. Stupakov, E. Gjonaj, *Joule heating in a flat dechirper*, Phys. Rev. Acc. Beams **20**, 054403 (2017)

$$P = Q^2 k_{loss} f_{rep}$$

SLAC

$Q = 300\text{pC}$, $f_{rep} = 100\text{kHz}$, $l_z = 60\mu\text{m}$

	P_{total} [W/m]	$P_{heat,ana}$ [W/m]	$P_{heat,num}$ [W/m]
Two plates, a=0.7mm	170	5	21
Single plate, b=0.25 mm	435	14	24

The EXFEL

$Q = 500\text{pC}$, $f_{rep} = 27\text{kHz}$, $\sigma_z = 25\mu\text{m}$

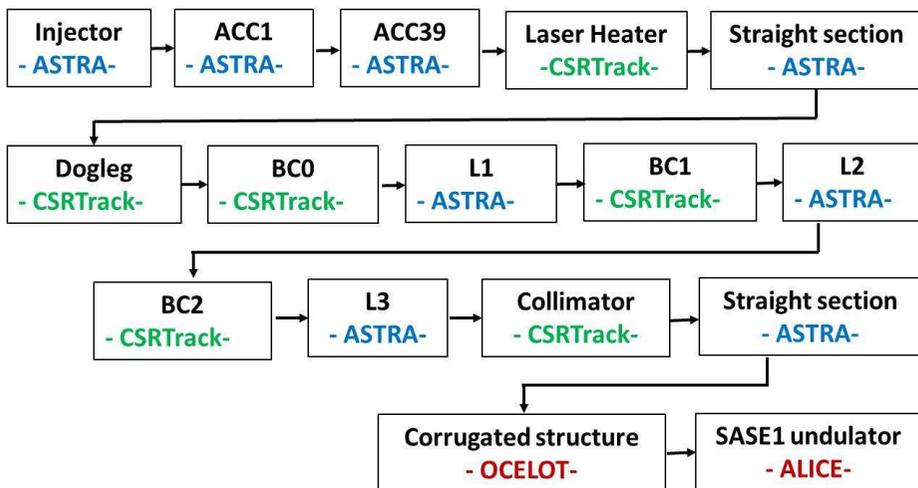
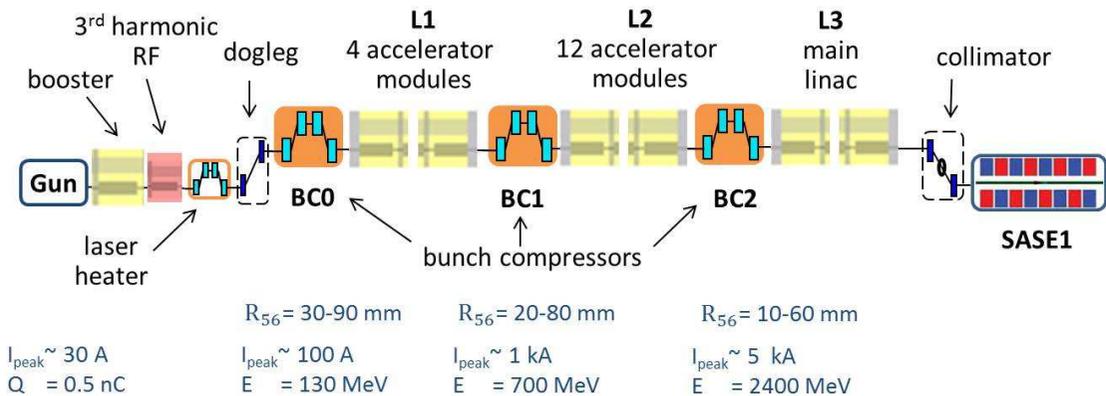
	P_{total} [W/m]	$P_{heat,ana}$ [W/m]	$P_{heat,num}$ [W/m]
Two plates, a=0.7mm	125	4	15
Single plate, b=0.25 mm	320	10	18

Heating studies should take into account the XFEL bunch structure (up to 4.5 MHz rep rate in a macro-pulse) and heat load on the corners of the grating

WS as dechirper/chirper

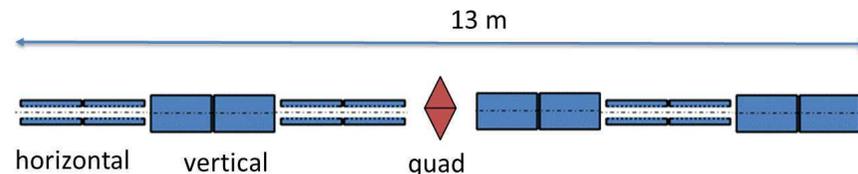
- The idea of using a corrugated structure as a dechirper was proposed at SLAC
 - K. Bane, G. Stupakov, *Corrugated pipe as a beam dechirper*, NIM A **690**, 2012
- The WS can be used as “dechirper” to reduce the radiation bandwidth at the nominal beam formation scenarios of the European XFEL
- The WS can be used as “chirper” to increase considerably the bandwidth of SASE radiation
 - A special scenario with the beam over-compression at the last bunch compressor can be used
 - There is a strong interest to obtain broad-bandwidth radiation at
 - ▶ reconstructing the structure of crystalline materials such as proteins
 - ▶ x-ray absorption spectroscopy
 - ▶ simulated Raman spectroscopy
 - ▶ multi-wavelength anomalous diffraction
 - S. Serkez et al, *Extension of SASE bandwidth up to 2% as a way to increase the efficiency of protein structure determination by x-ray nanocrystallography at the European XFEL*, DESY 13-109, 2013

WS as chirper (6 modules, SASE 1)

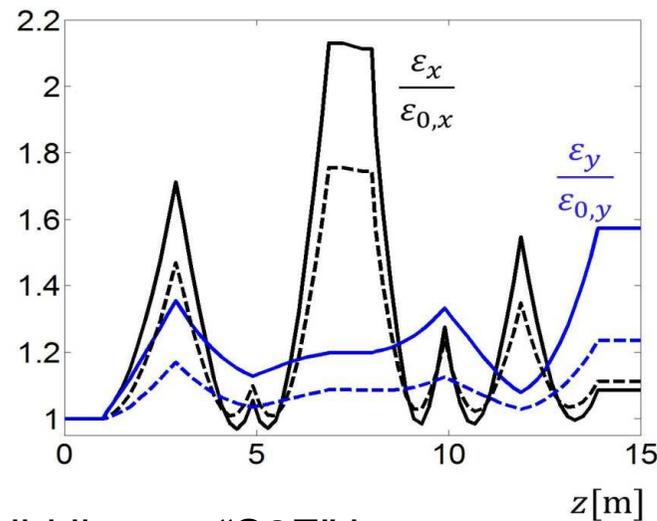


European XFEL

I. Zagorodnov, G. Feng, T. Limberg, *Corrugated structure insertion for extending the SASE bandwidth up to 3% at the European XFEL*, NIM A **837**, 69 (2016)



Projected emittance growth in the insertion

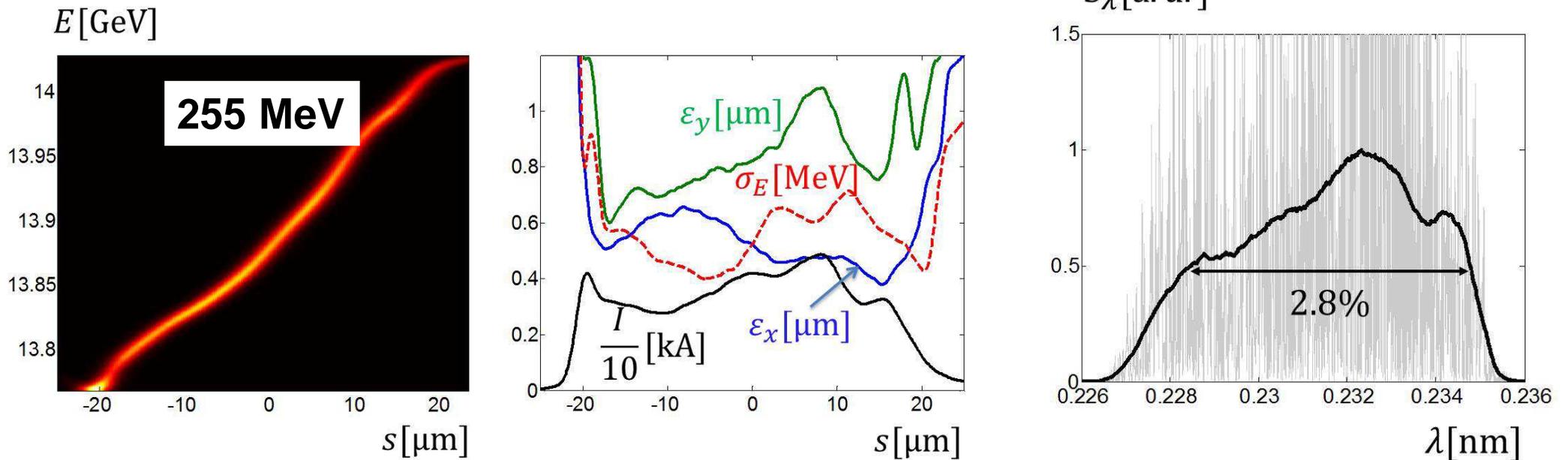


60%

solid lines – “S2E” beam
dashed lines – “ideal” beam



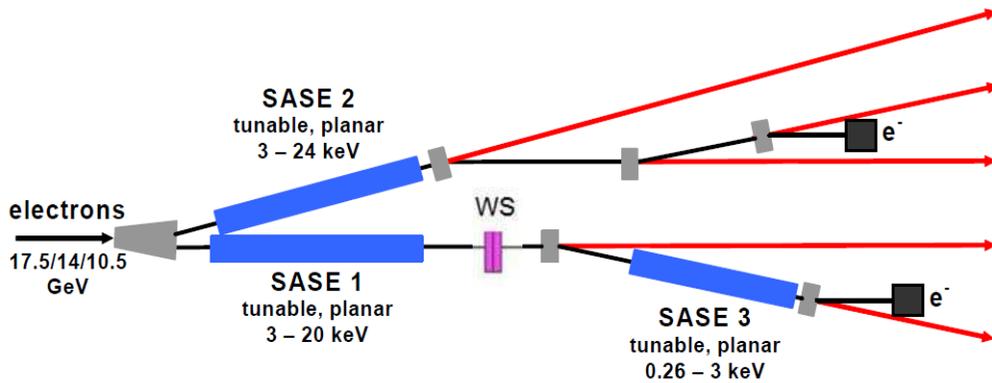
WS as chirper (6 modules, SASE 1)



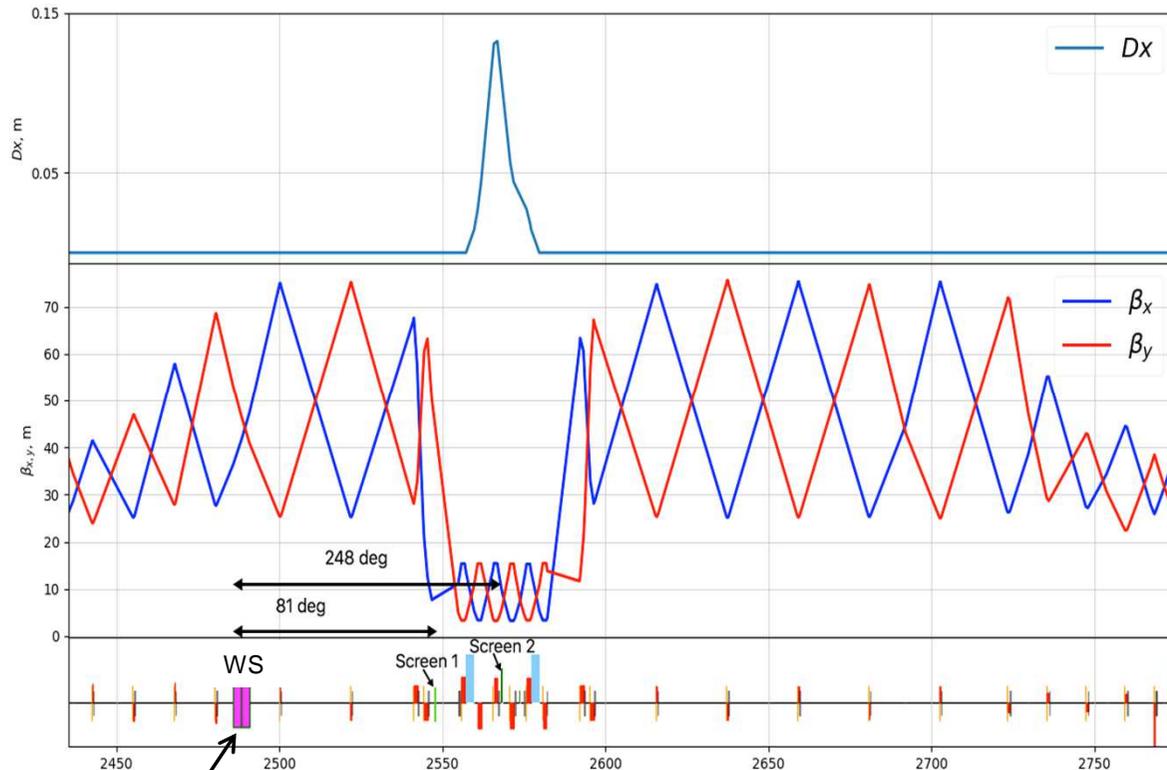
With 6 corrugated modules we can obtain 3% radiation bandwidth at 14 GeV (0.23 nm radiation wavelength)

Parameter	Value	Units
Bunch charge	500	pC
Radiation wavelength	0.23	nm
Pulse energy	~4	mJ
Bandwidth	~3	%

WS as dechirper/chirper (2 modules, SASE 3)



T4 beamline between SASE1 and SASE3



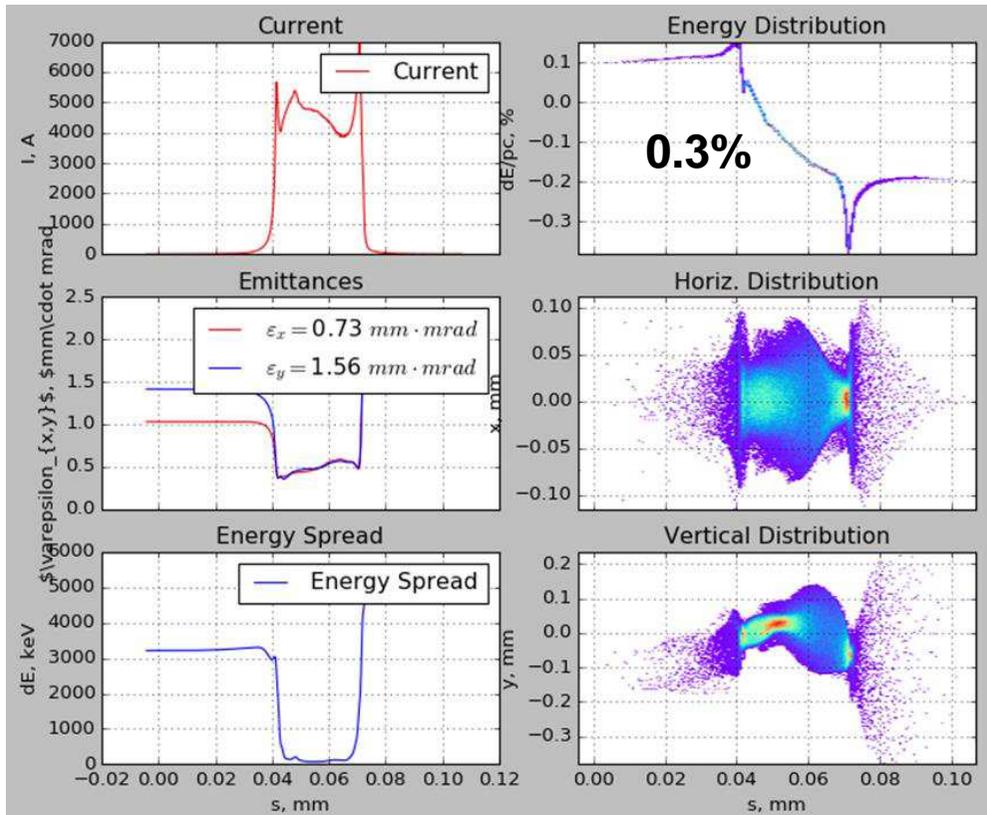
Only 2 corrugated modules are considered



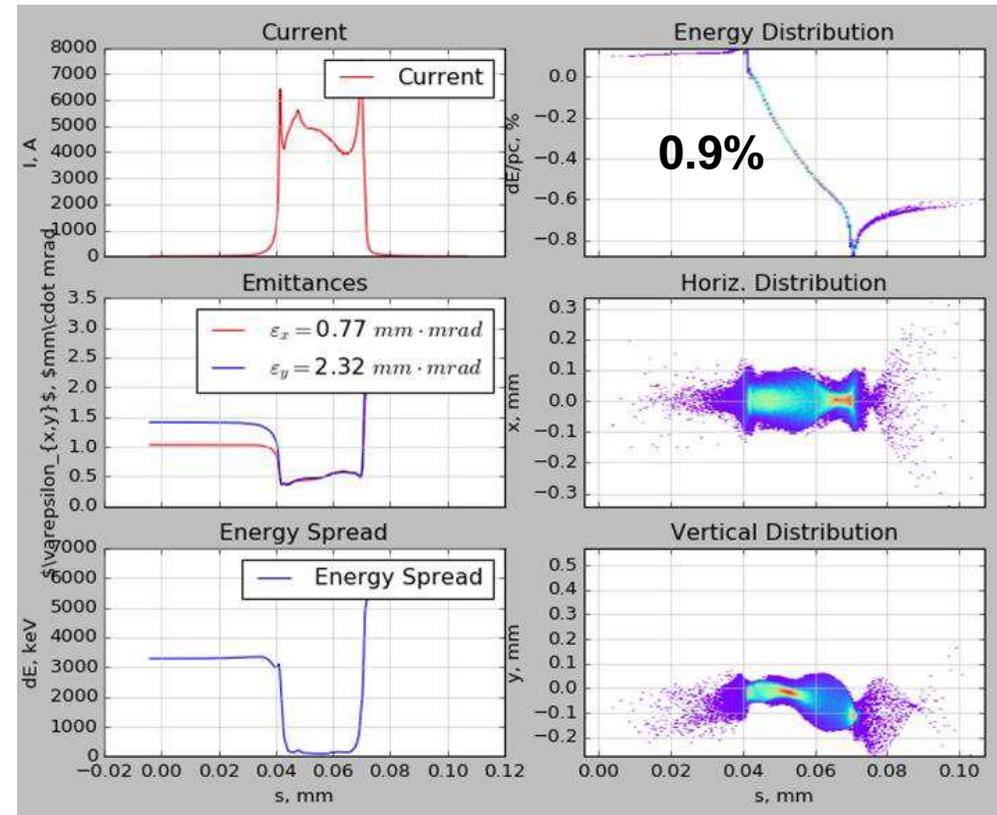
Parameter	SASE1 /SASE2	SASE3	Units
Undulator wavelength	40	68	mm
K-range	3.9-1.65	9.06-4.08	
Wavelength at 17.5 GeV	0.147-0.040	1.22-0.27	nm
Wavelength at 14.0 GeV	0.230-0.063	1.90-0.42	nm
Wavelength at 8.5 GeV	0.625-0.171	5.17-1.15	nm
Active undulator length	175	105	m

WS as chirper (2 modules, SASE 3)

Before T4 beamline

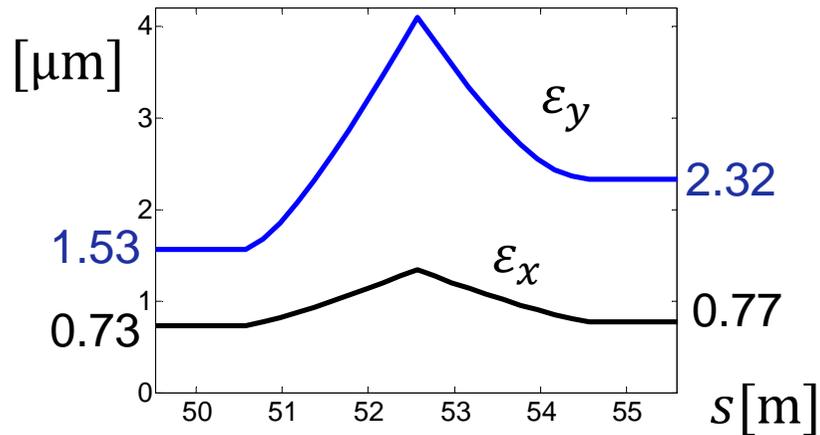


After T4 beamline

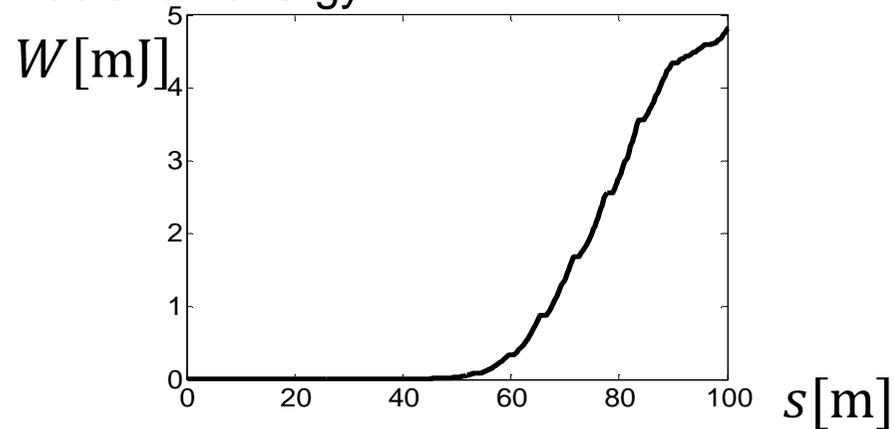


WS as chirper (2 modules, SASE 3)

Projected emittance in the insertion



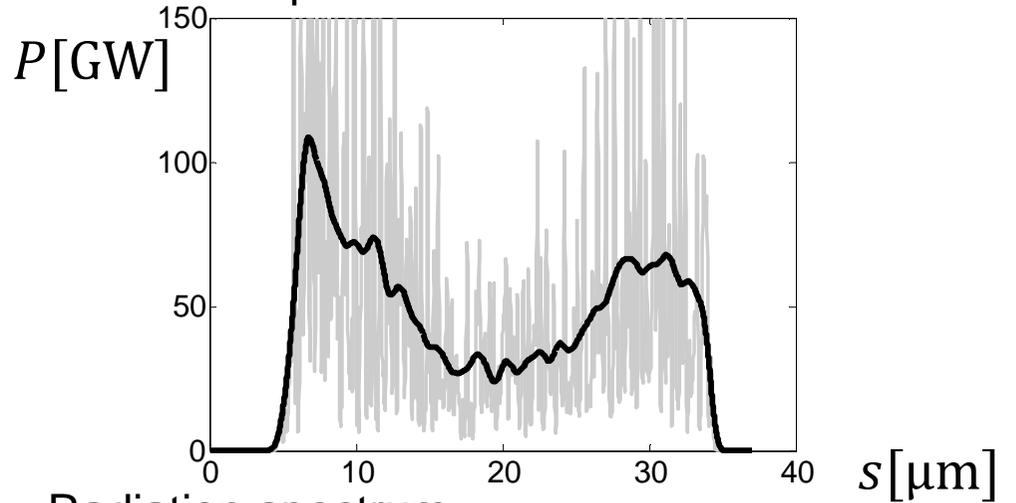
Radiation energy



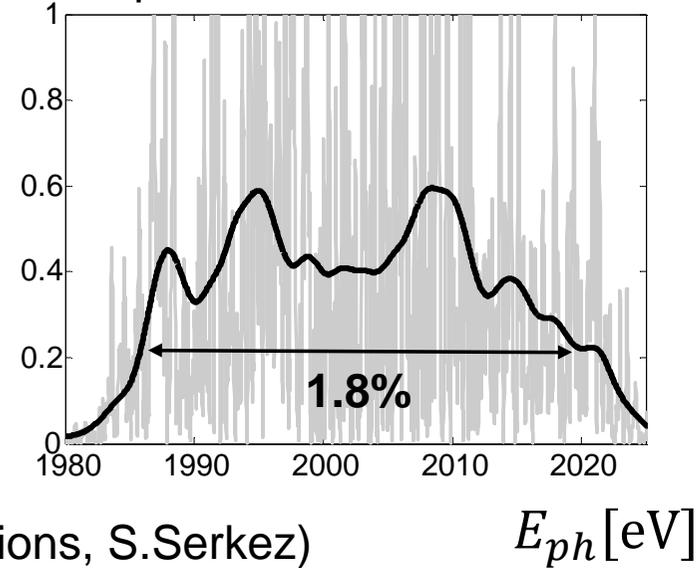
European XFEL

(Genesis simulations, S.Serkez)

Radiation power



Radiation spectrum

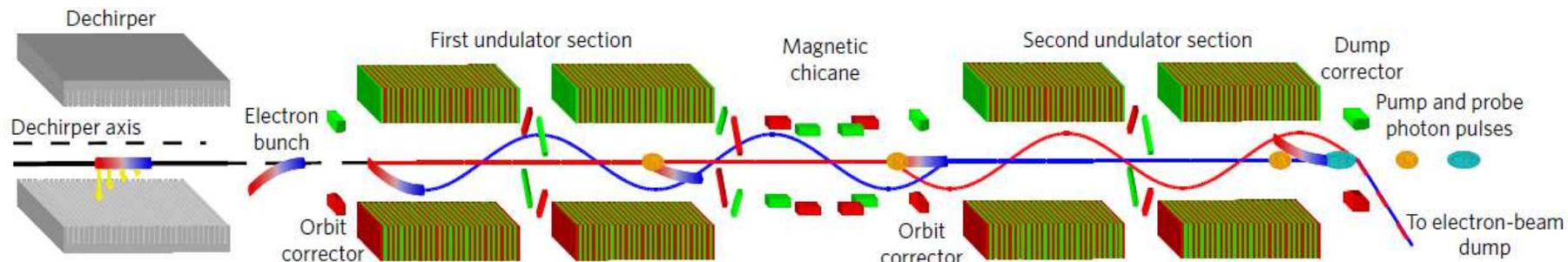


WS as kicker for two color/fresh slice scheme

■ The RadiaBeam/SLAC dechirper at the LCLS is being used as a fast kicker for fresh-slice two-color scheme of SASE generation

■ Theory

- ▶ R. Brinkmann, E.A. Schneidmiller, M.V. Yurkov, *Possible operation of the European XFEL with ultra-low emittance beams*, NIM A **616**, 81 (2010)
- ▶ S. Reiche, E. Prat, *Two-color operation of a free-electron laser with a tilted beam*, J. Synchrotron Radiation **23**, 869–873 (2016)
- ▶ A. Lutman et al, *Fresh-slice multi-colour x-ray free-electron lasers*, Nat. Photon. **10**, 745–750 (2016)

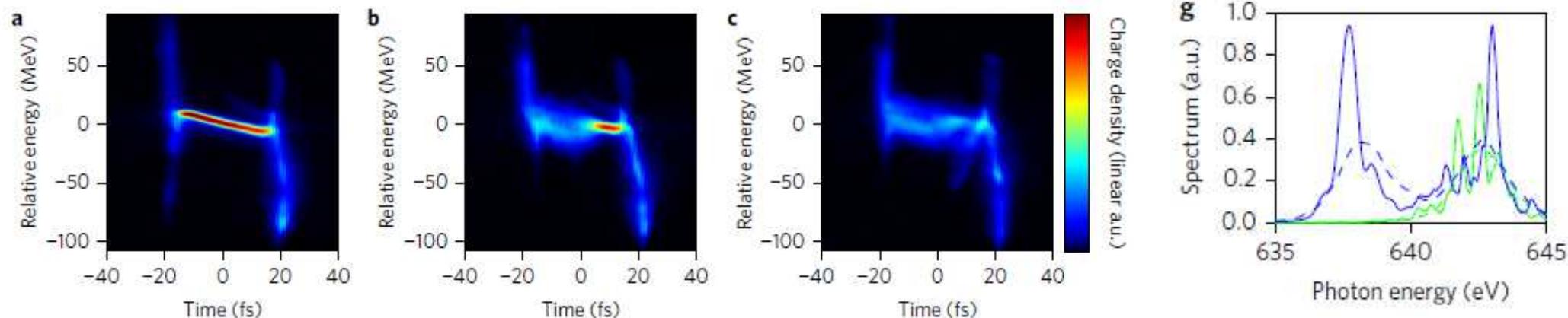


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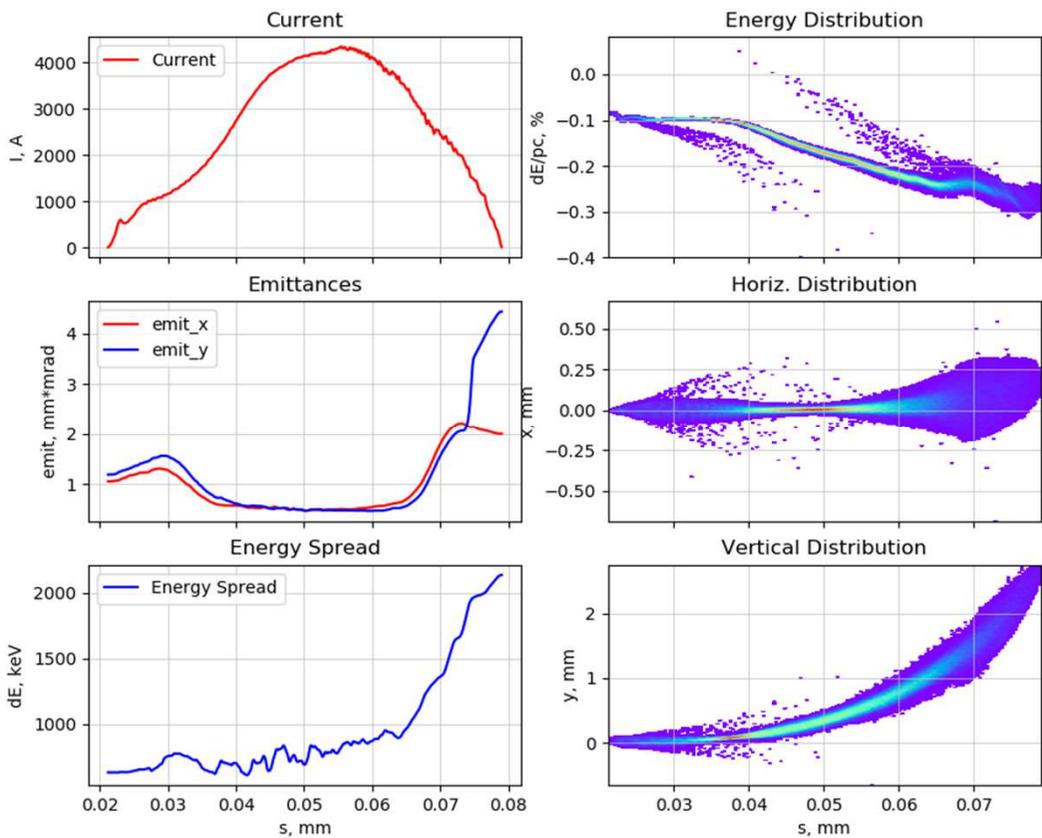
■ Experiment

- ▶ A. Lutman et al, *Fresh-slice multi-color x-ray free-electron lasers*, Nat. Photon. **10**, 745–750 (2016)
- ▶ C.Emma et al, *Experimental demonstration of fresh bunch self-seeding in an X-ray free electron laser*, App. Phys. Lett. **110**, 154101 (2017)

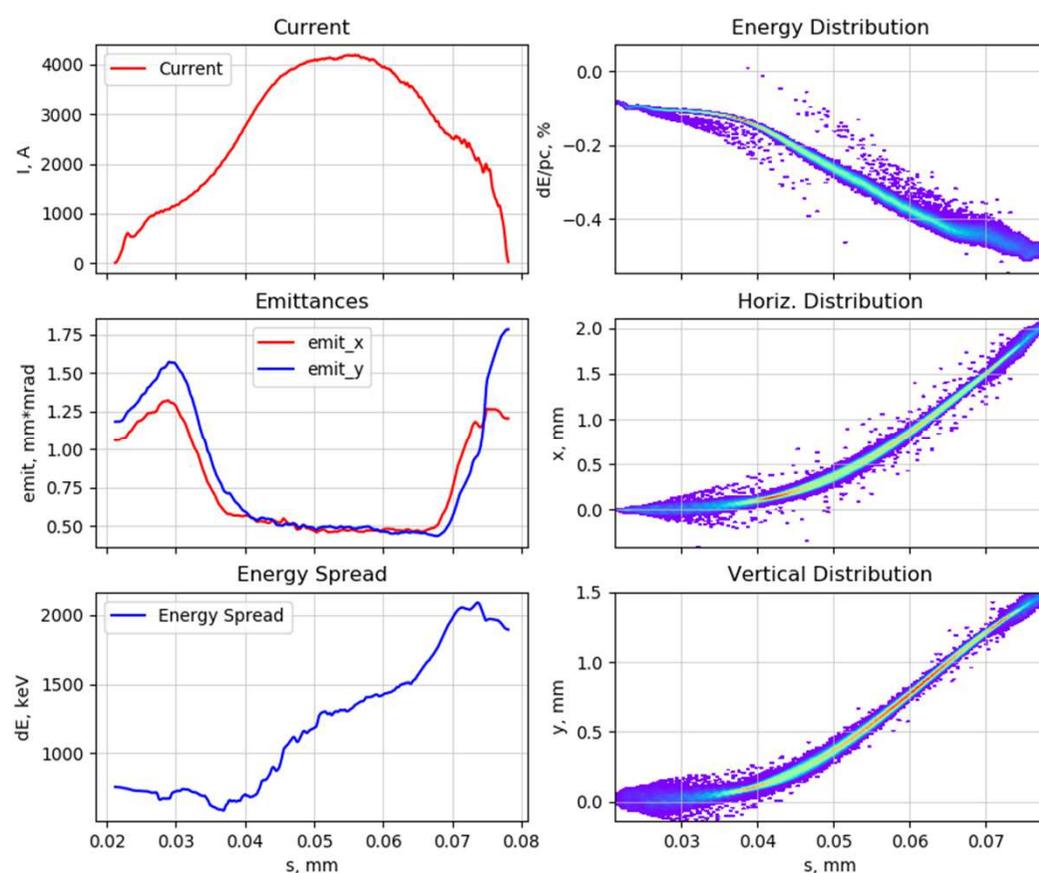


WS as kicker for two color/fresh slice scheme

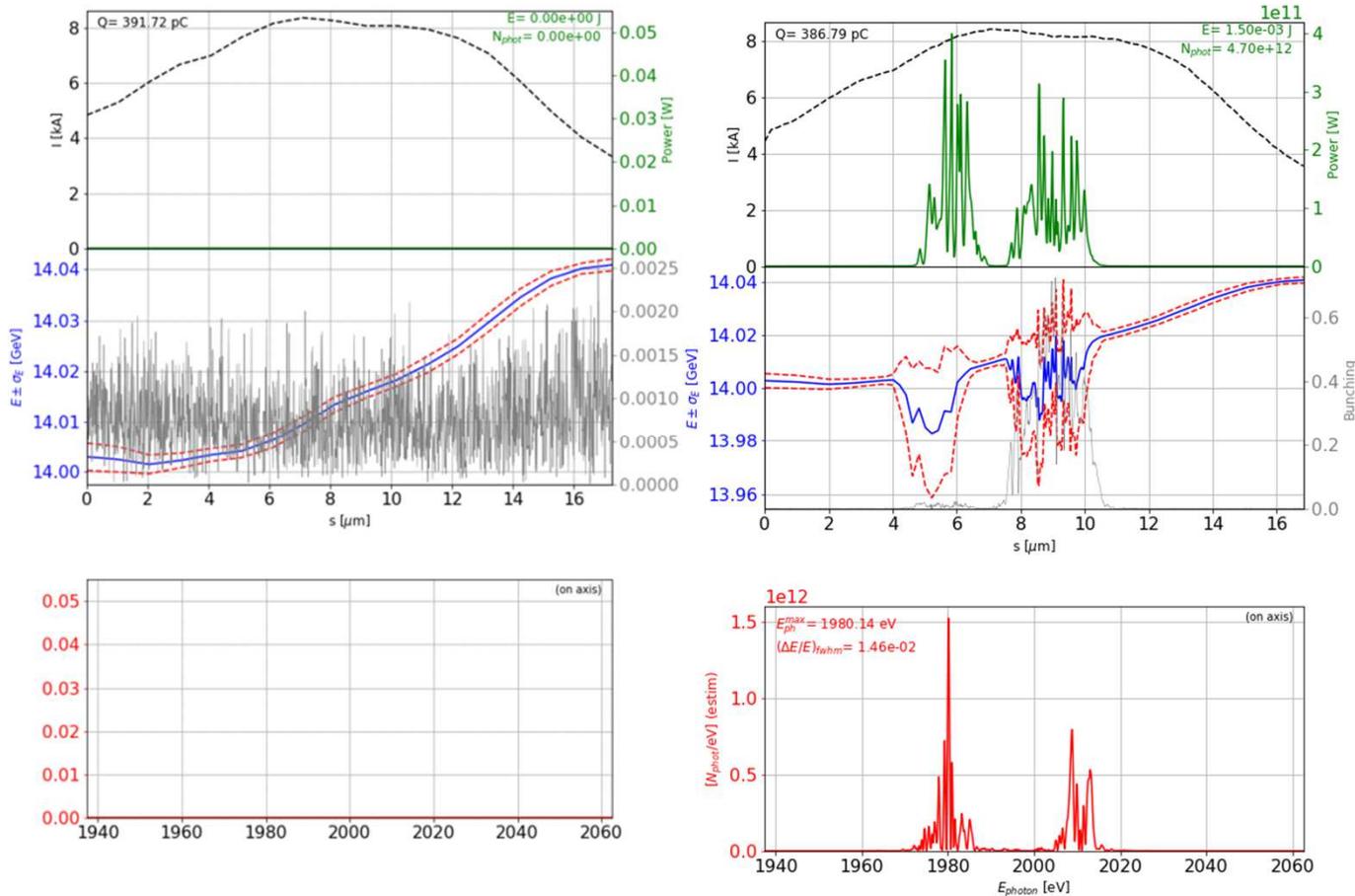
■ Kick from one horizontal plate



■ Kick from horizontal and vertical plates



WS as kicker for two color/fresh slice scheme



- Kick done with one plate, $b=0.5$ mm
- Two color pulses example (without chicane)
 - 750uJ each
 - 1.5% wave length difference (up to 15% is possible)
 - 10 fs separation
- a chicane should allow two-color separation from -10 fs to 1 ps

(Genesis simulations, S. Serkez)

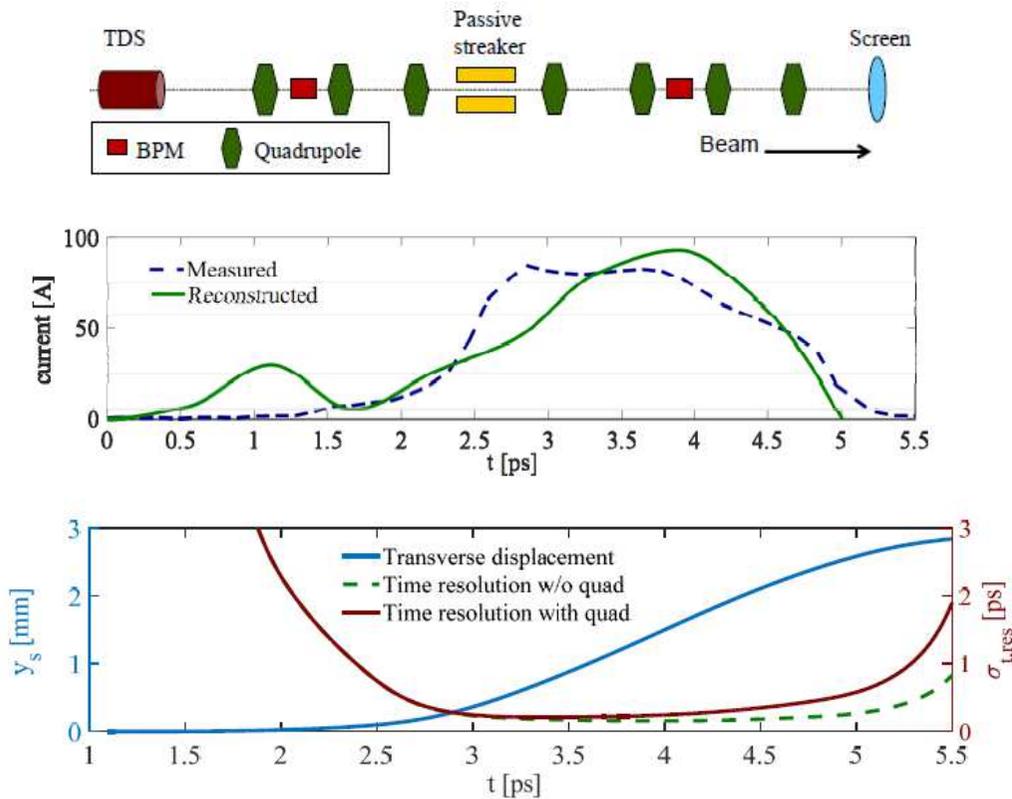


WS as kicker for beam diagnostics

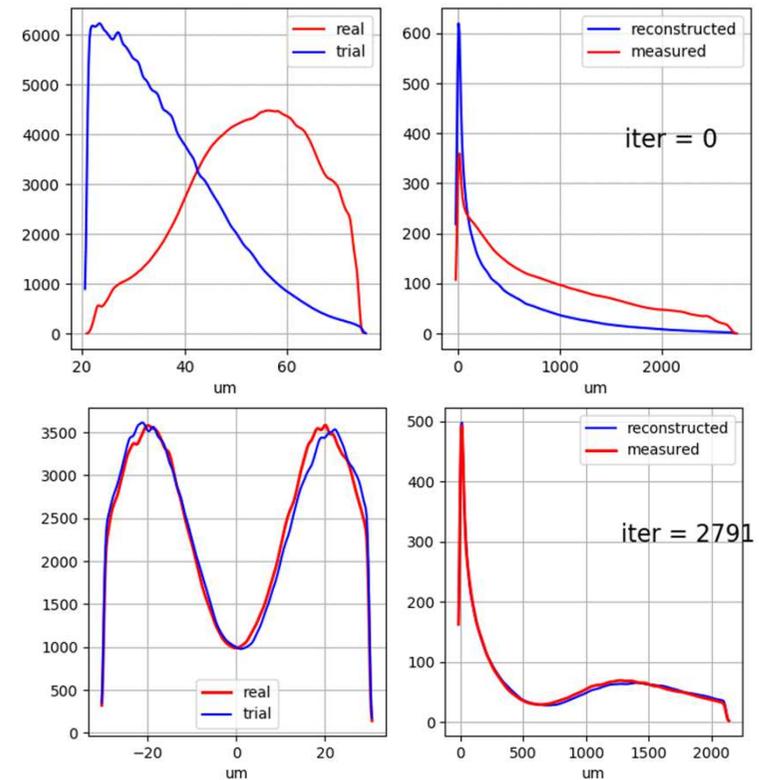
- The WS can be used as passive deflector for electron beam diagnostics at SASE1
 - The device does not need to be powered and its manufacture is simpler compared to radio-frequency transverse deflecting structure
 - The passive deflector does not require any synchronization: the kick is produced by the transverse wakefield when the electron bunch moves closer to one of the plates
 - Theory, simulations and experiment
 - ▶ A. Novokhatski, *Wakefield potentials of corrugated structures*, Phys. Rev. Accel. Beams **18**, 104402 (2015)
 - ▶ S. Bettoni et al, *Temporal profile measurements of relativistic electron bunch based on wakefield generation*, Phys. Rev. Accel. Beams **19**, 021304 (2016)
- The main drawback: the “geometrical” resolution is poor at the head of the beam (no streaking)
- The reconstruction requires more complicated computation

WS as kicker for beam diagnostics

Proof-of Principle experiment at SwissFEL Injector Test Facility (E=140MeV)



Current reconstruction for EXFEL (OCELOT simulations, S. Tomin)



Longitudinal phase space reconstruction to be studied



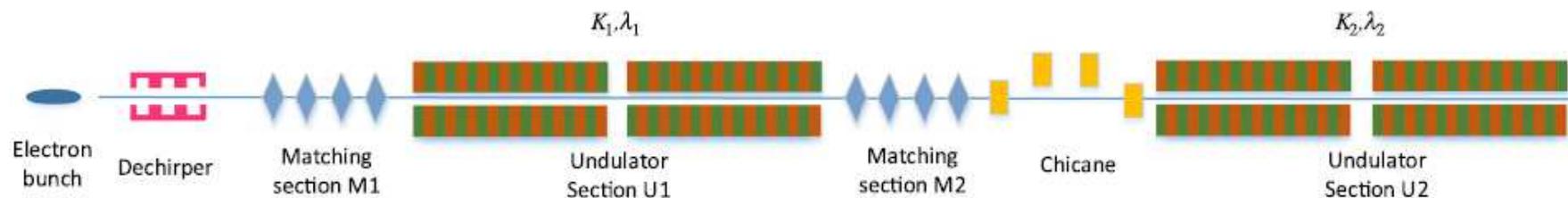
Other applications

- WS can be used as a source of THz-radiation

- K.Bane et al, *Measurements of terahertz radiation generated using a metallic, corrugated pipe*, NIM A **844**, 121 (2017)

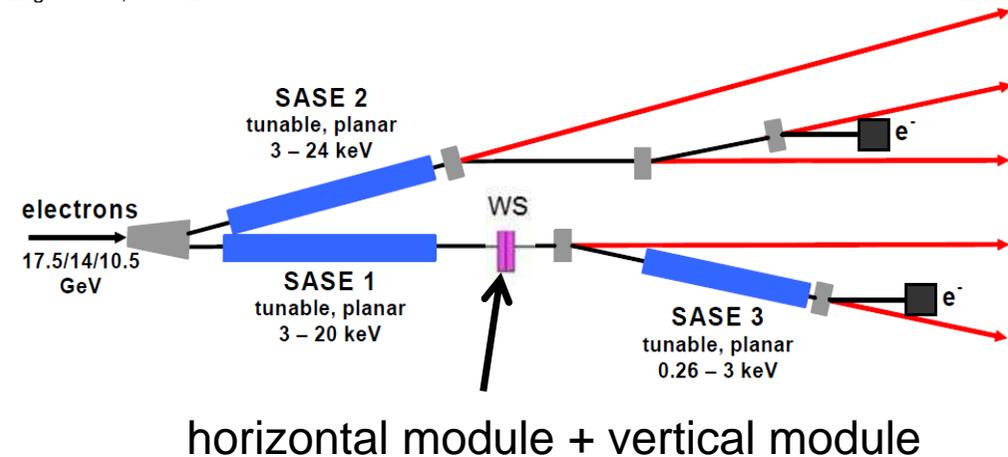
- WS can be used without quadrupole wake compensation to introduce a mismatch along the bunch for two-color scheme

- W. Qin et al, *Matching-based fresh-slice method for generating two-color x-ray free-electron lasers*, Phys. Rev. Accel. Beams **20**, 090701 (2017)



Proposal

- We suggest to install 2 corrugated structures (WS) between SASE1 and SASE 3
- WS will be used as kicker for **two-color scheme**
 - one plate of one module will be used
- WS will be used as kicker for **beam diagnostics**
 - one plate of each module will be used to suppress the quadrupole component
- WS will be used as **dechirper**
 - two modules will be used (the quadrupole component suppressed)
 - the gap could be larger than 1.4 mm
- WS will be used as **chirper**
 - two modules will be used (the quadrupole component suppressed)
 - a protection could be necessary for small gaps



Acknowledgements

- The wakefield studies are done together with K. Bane and G. Stupakov
- The beam dynamics and FEL simulations are done together with G. Feng, T. Limberg, S. Tomin, S. Serkez