Emittance measurements for low charge operation with short-pulse injector laser at FLASH

M. Rehders

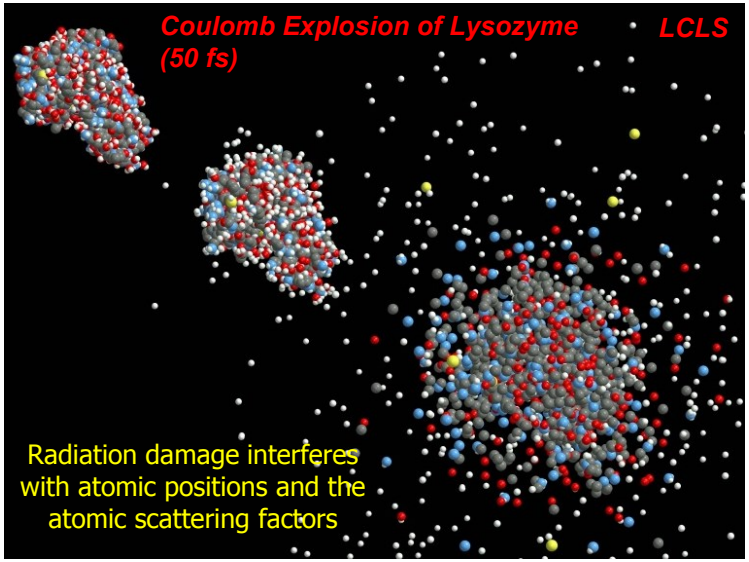
Motivation

Time resolved experiments: time resolution is limited by the pulse length of the radiation pulse

Pulse can be used as a pump and/or probe pulse

Shorter pulses → shorter time scales can be studied

Imaging experiments: short pulses prevent structural damage while the image is taken

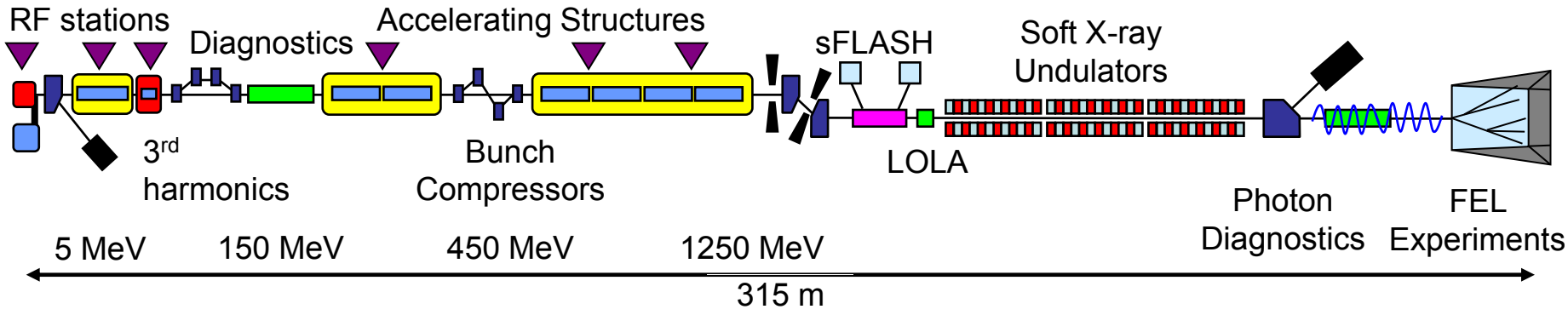


(Neutze, R., Wouts, R., van der Spoel, D., Weckert, E. Hajdu, J. (2000) *Nature* 406, 752-757)

outline

- Generation of extremely short SASE pulses at FLASH
  - Why do we need a short pulse injector laser (Laser3)?
- Influence of the injector laser pulse durations on electron bunch parameters for low charges
  - Simulation results
- Emittance measurements for low charges at FLASH
  - Laser2
  - Laser3
    - solenoid scan
    - Challenges for low charges
  - Comparison for identical machine settings

Generation of femtosecond scale radiation pulses at FLASH

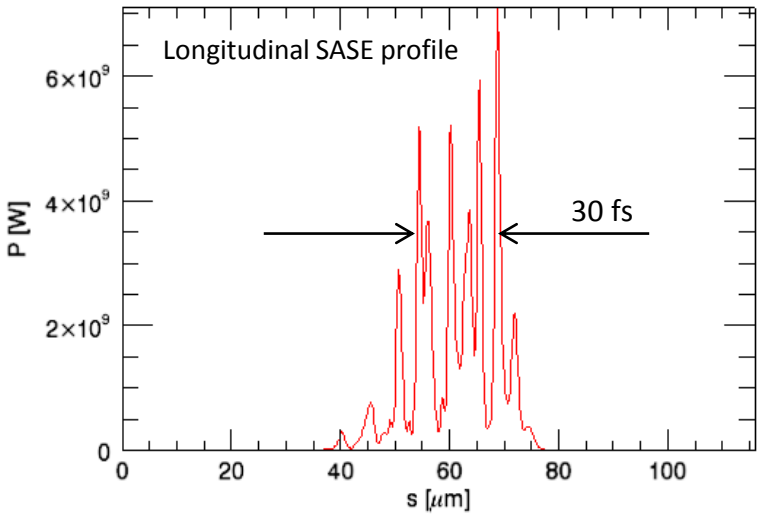


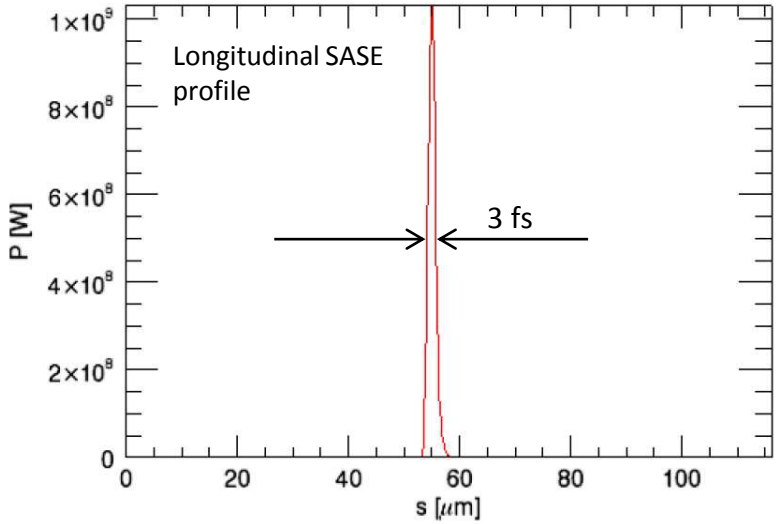
	Typical FLASH parameters
Injector laser pulse duration (FWHM)	15 ps
Bunch charge	0.08 – 1 nC
Compression factor	200 – 50
FEL pulse duration (FWHM)	30 – 200 fs

single spike limit

determined by slippage of photon pulse w.r.t. particles during 1 FEL gain length

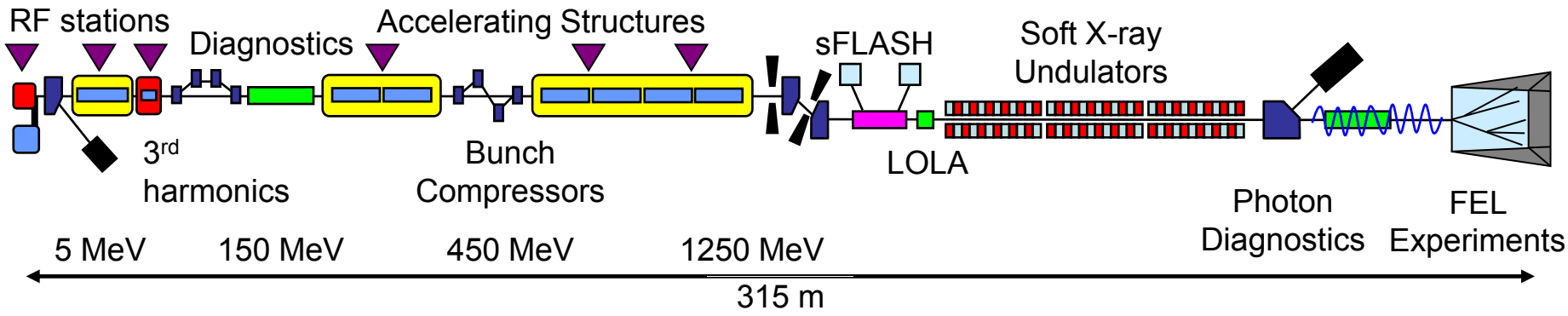
→ $\sigma_{z,ph.\,min} \approx 1\mu m$ (at FLASH)





Genesis 1.3 simulations

Generation of femtosecond scale radiation pulses at FLASH

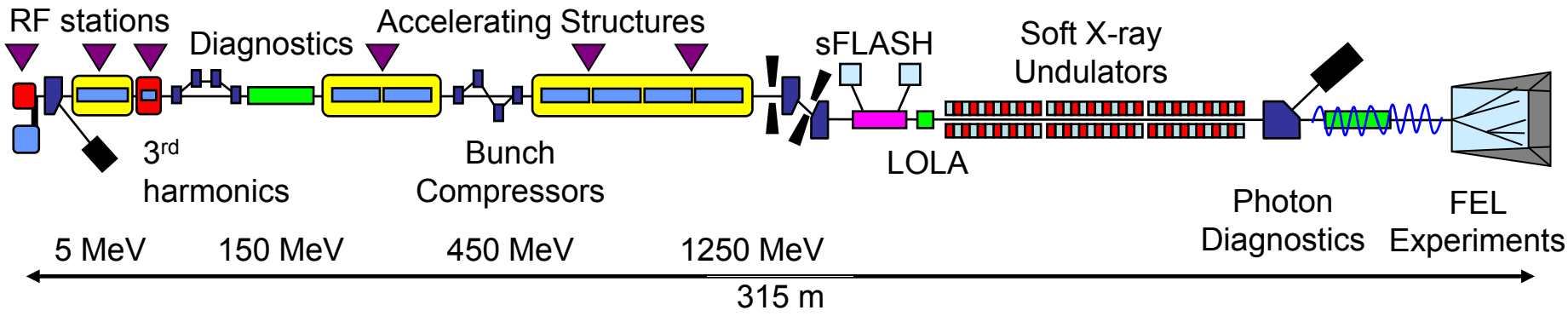


	Typical FLASH parameters	Very short pulses at FLASH
Injector laser pulse duration (FWHM)	15 ps	15 ps
Bunch charge	0.08 – 1 nC	20 pC
Compression factor	200 – 50	1600
FEL pulse duration (FWHM)	30 – 200 fs	~ 3 fs

A large compression factor requires large RF stability which is technically very challenging

➢ Requires further reduction of bunch lengths already at the injector

Generation of femtosecond scale radiation pulses at FLASH



	Typical FLASH parameters	Very short pulses at FLASH	
Injector laser pulse duration (FWHM)	15 ps	15 ps	1.7-3.7 ps
Bunch charge	0.08 – 1 nC	20 pC	
Compression factor	200 – 50	1600	350 – 700
FEL pulse duration (FWHM)	30 – 200 fs	~ 3 fs	

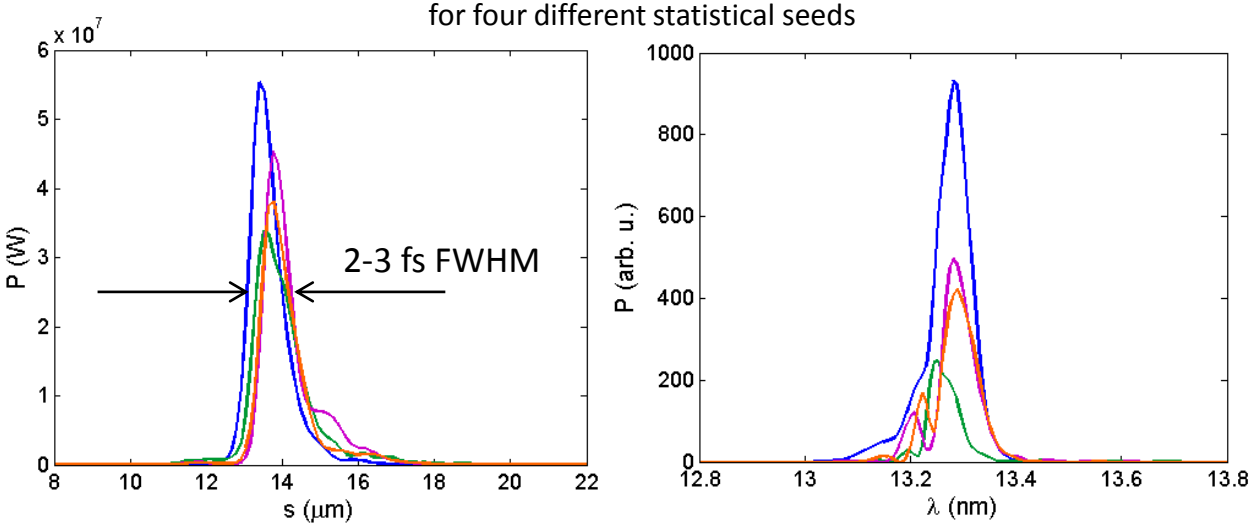
- New short pulse injector laser has been installed

SASE simulation from start-to-end simulation for FLASH

Longitudinal SASE distribution

SASE spectrum

for four different statistical seeds

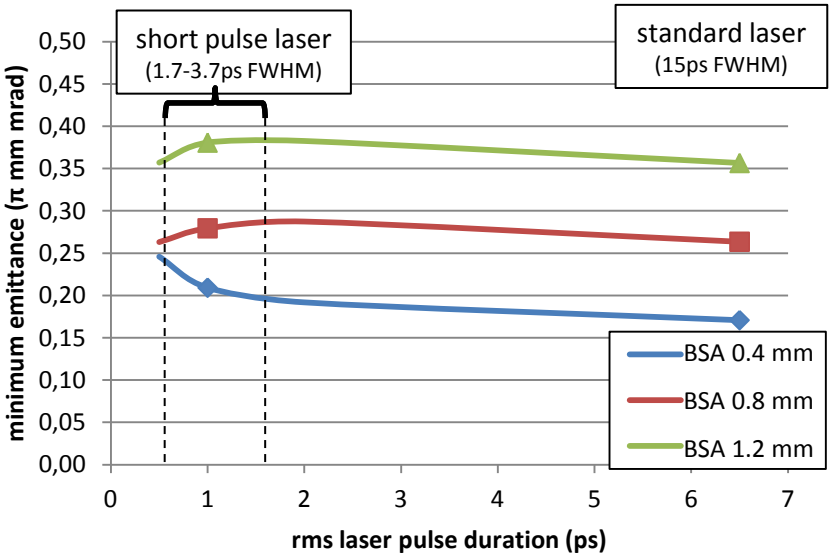


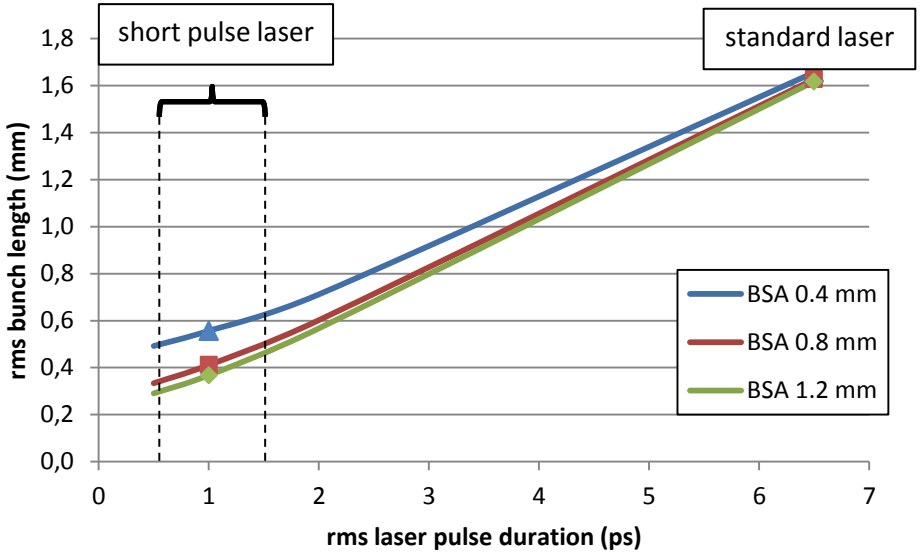
- Resulting from start-to-end simulation for FLASH
- Settings very close to real machine settings (optics) (not optimized)
- Longitudinal space charge forces and wakefields in the undulator are not included in the Genesis simulation

outline

- Generation of extremely short SASE pulses at FLASH
  - Why do we need a short pulse injector laser (Laser3)?
- Influence of the injector laser pulse durations on electron bunch parameters for low charges
  - Simulation results
- Emittance measurements for low charges at FLASH
  - Laser2
  - Laser3
    - solenoid scan
    - Challenges for low charges
  - Comparison for identical machine settings

influence of injector laser pulse duration at 20pC





ASTRA simulations for 20pC

From simulation: Reduction of bunch length by factor 3-5 doesn‘t increase the transverse emittance

- If this is the case, short pulse laser is well suited for low charge, short bunch operation

➢ Has to be verified by measurements!

Longitudinal Phase Space Distribution after the Gun

Laser2 (15ps FWHM)

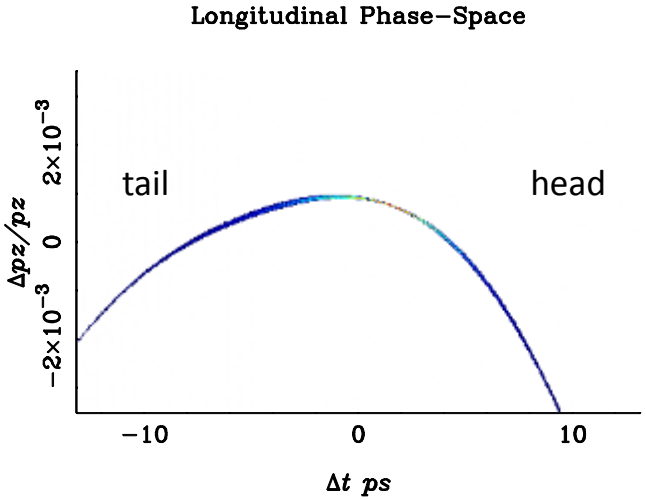
Charge: 20pC

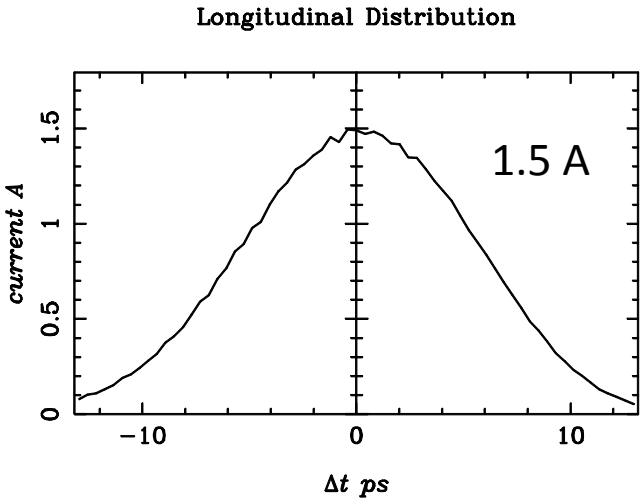
solenoid field: 192mT

BSA: 0.6 mm

gun phase: maximum energy gain (5MeV)

2 different laser pulse durations





Longitudinal Phase Space Distribution after the Gun

Charge: 20pC

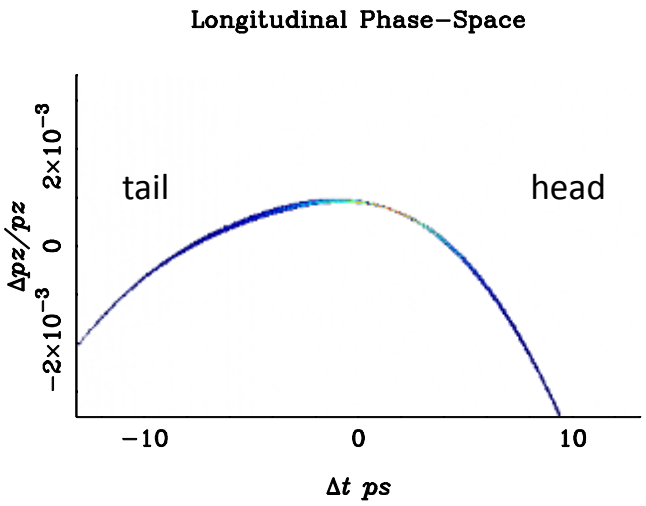
solenoid field: 192mT

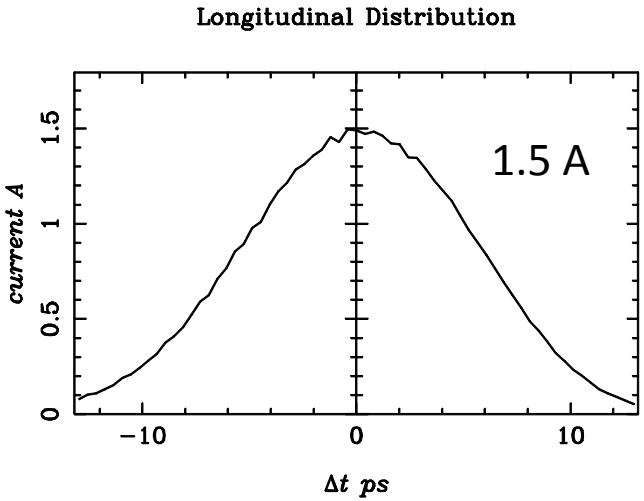
BSA: 0.6 mm

gun phase: maximum energy gain (5MeV)

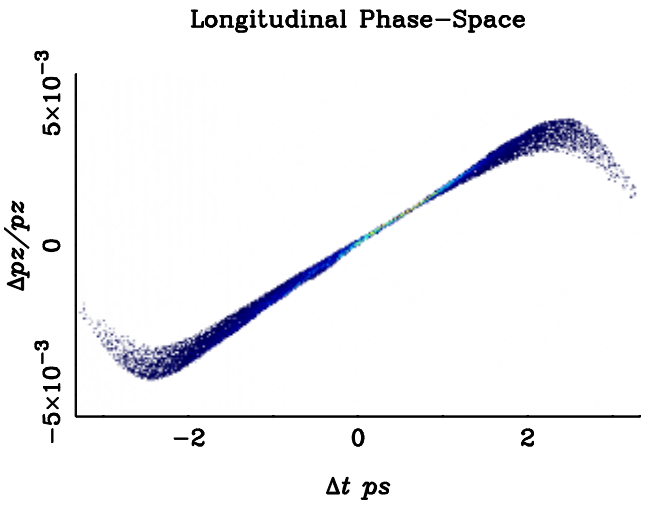
2 different laser pulse durations

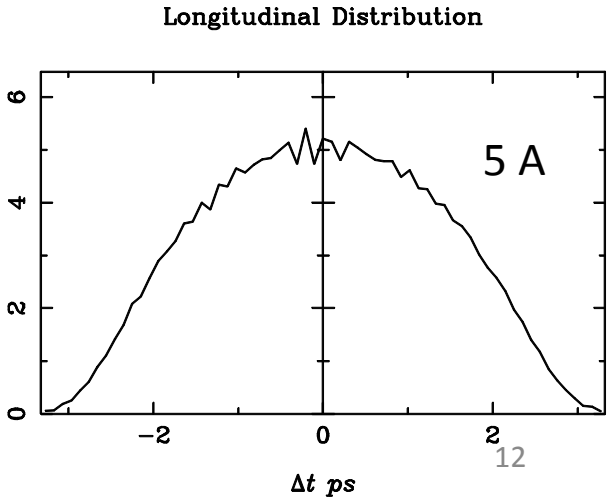
Laser2 (15ps FWHM)





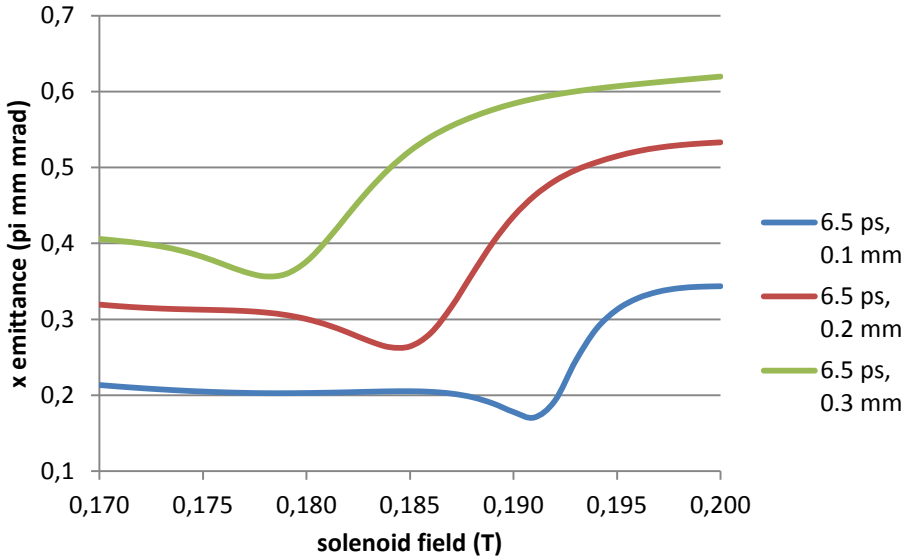
Laser3, 2.4ps FWHM



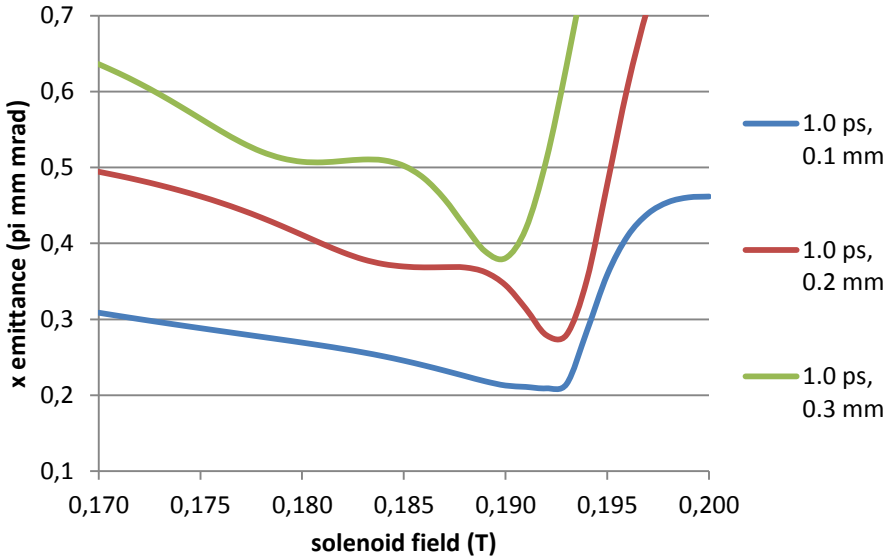


simulation of solenoid scan

10 ps (FWHM)



2.4 ps (FWHM)



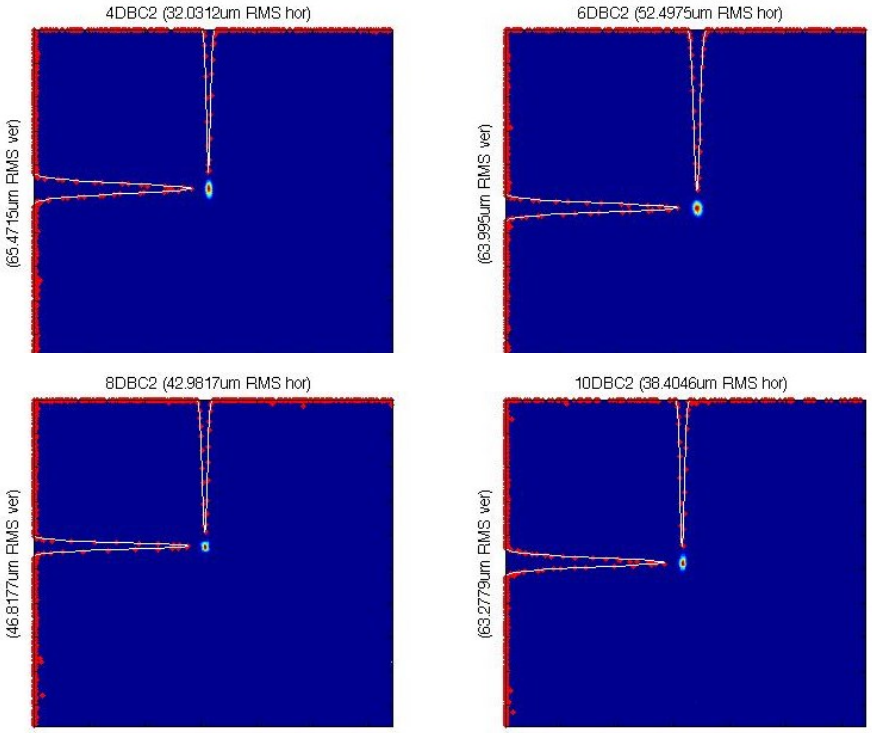
ASTRA simulations for 20pC

outline

- Generation of extremely short SASE pulses at FLASH
  - Why do we need a short pulse injector laser (Laser3)?
- Influence of the injector laser pulse durations on electron bunch parameters for low charges
  - Simulation results
- Emittance measurements for low charges at FLASH
  - Laser2
  - Laser3
    - solenoid scan
    - Challenges for low charges
  - Comparison for identical machine settings

Emittance measurement laser2

Measurement 2012/11/14



	Emittance	alpha	beta	BMAG
horizontal	$0.20\ ^{+0.13}_{-0.07}$	-1.41	2.10	1.59
vertical	$0.43\ ^{+0.14}_{-0.08}$	1.63	3.42	1.34

LASER-2, BSA=0.5mm, 20pC, Isol=-317.0A

12 bunches

Expected from simulation: 0.20 mm mrad

Measurements with 20pC: No signal at BPMs
→ very time consuming

→ more recent measurements have been performed with higher charge

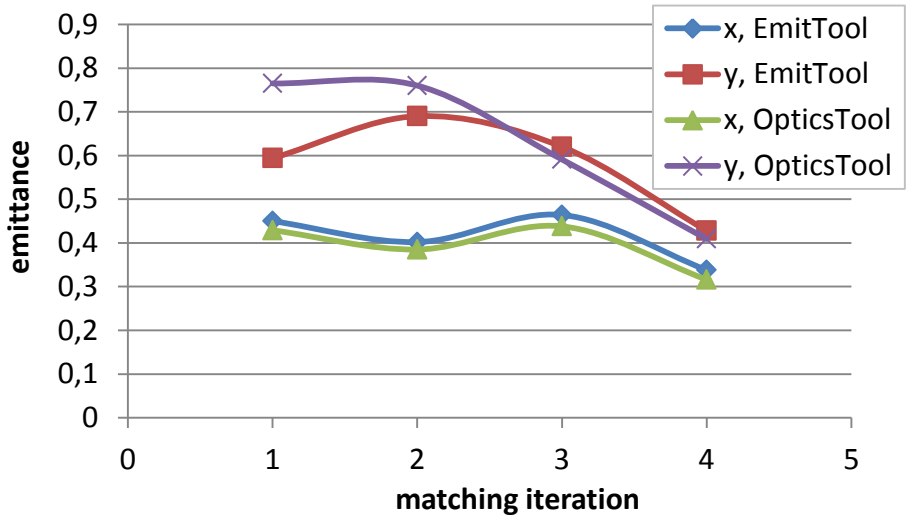
outline

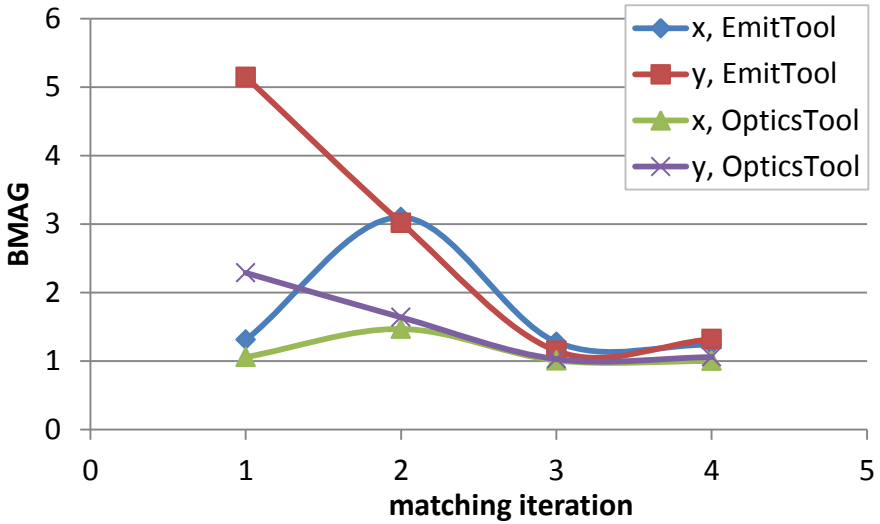
- Generation of extremely short SASE pulses at FLASH
  - Why do we need a short pulse injector laser (Laser3)?
- Influence of the injector laser pulse durations on electron bunch parameters for low charges
  - Simulation results
- Emittance measurements for low charges at FLASH
  - Laser2
  - Laser3
    - solenoid scan
    - Challenges for low charges
  - Comparison for identical machine settings

Matching

Measurement 2013/12/22

Matching with Optics Tool by W. Decking





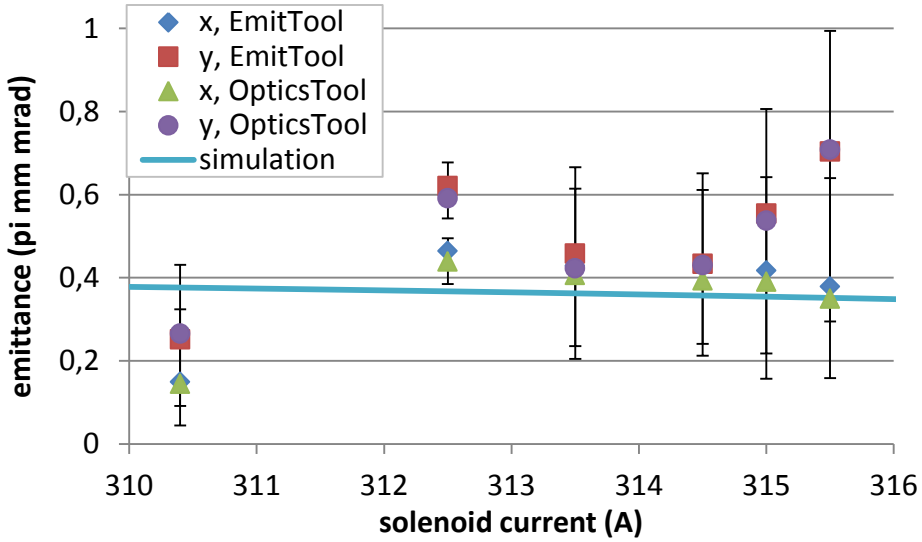
Matching works only in a narrow window between 310 -315 A

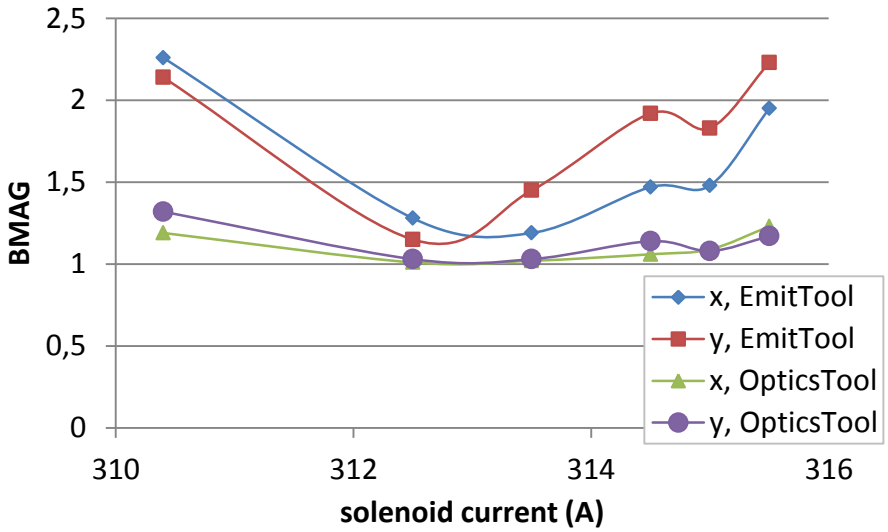
→ It was not possible to perform the planned solenoid scan to the expected minimum

Still, very small emittance values have been measured

Solenoid scan

Measurement 2013/12/22



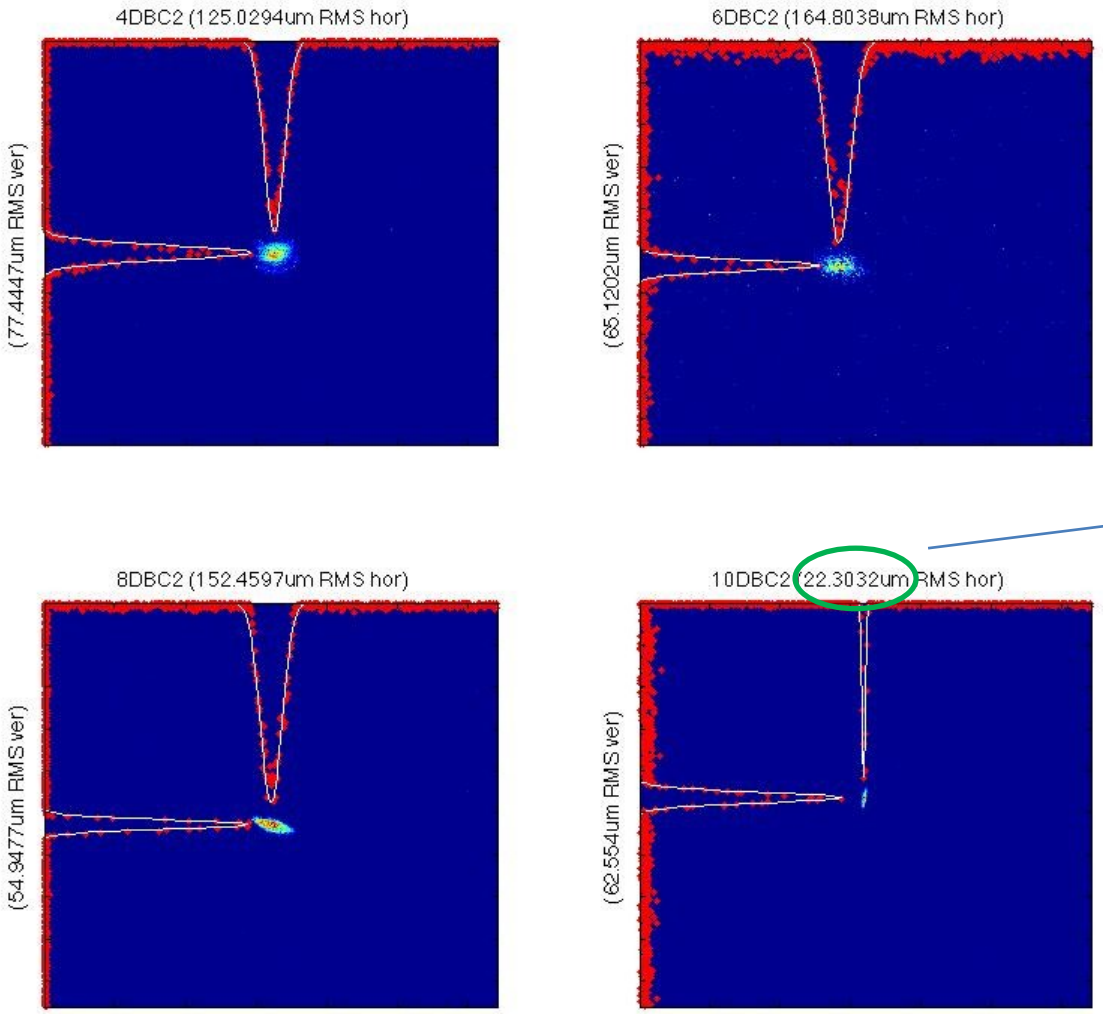


LASER-3: 2ps (FWHM)
Bunch charge: 30pC
BSA: 0.4mm

Expected emittance from the simulation: Approx. 0.36 mm mrad for 30 pC

Tiny spot sizes

Measurement 2013/12/22



Camera resolution is 11µm (rms, Gaussian)

→ we‘re getting close to the limit!

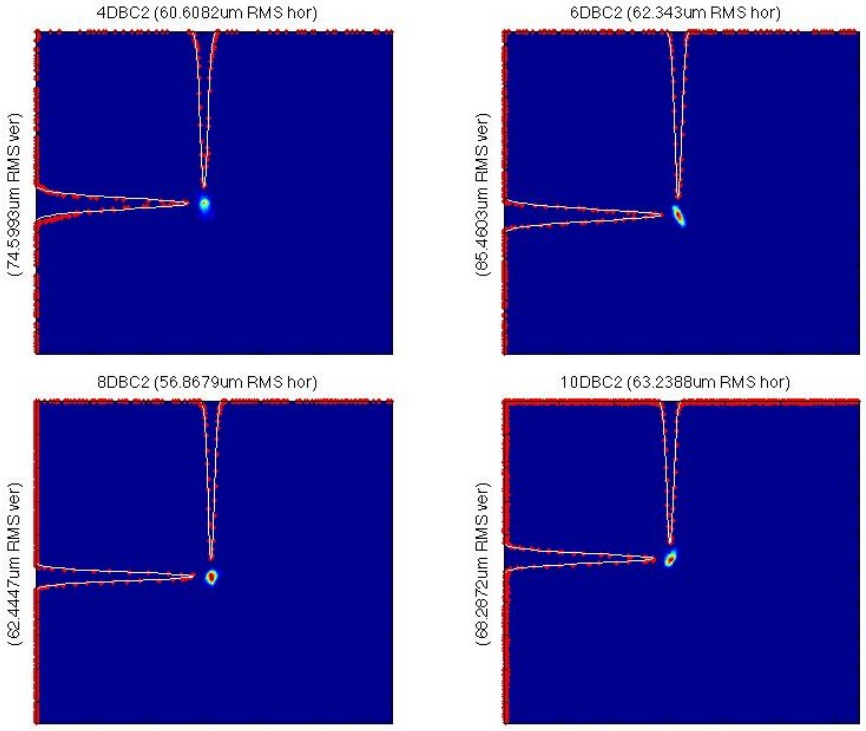
Influence of the number of bunches used for the measurement

Measurement 2013/12/22

LASER-3, 2ps FWHM, BSA=0.4, 30pC, Isol=312.5A

10 bunches

Expected from simulation: 0.37 mm mrad



	emittance	alpha	beta	BMAG
horizontal	$0.46\ ^{+0.06}_{-0.05}$	-1.32	2.41	1.28
vertical	$0.62\ ^{+0.09}_{-0.08}$	1.14	2.76	1.15

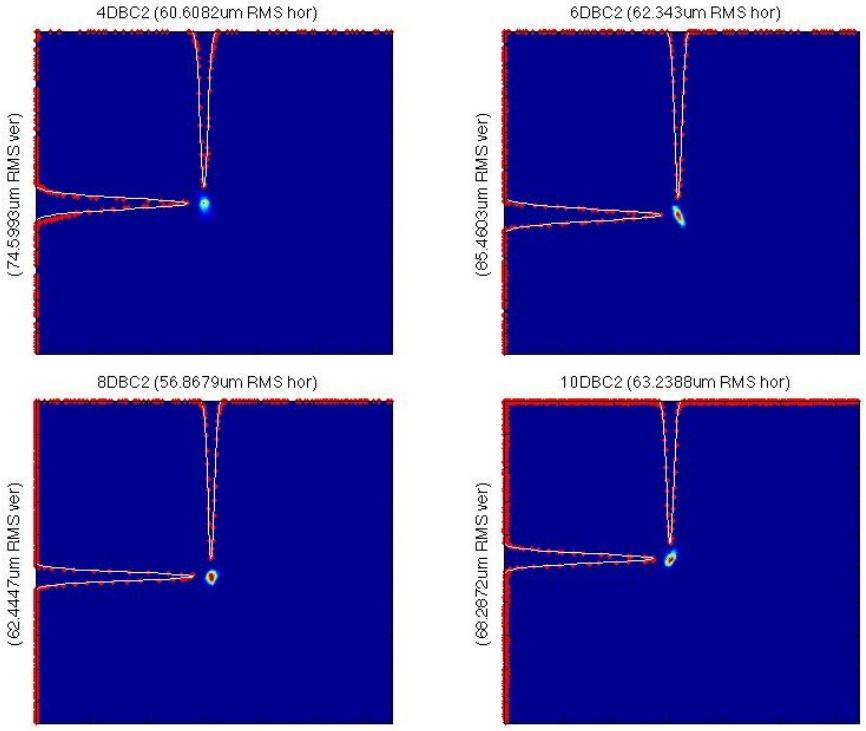
Influence of the number of bunches used for the measurement

Measurement 2013/12/22

LASER-3, 2ps FWHM, BSA=0.4, 30pC, Isol=312.5A

10 bunches

Expected from simulation: 0.37 mm mrad

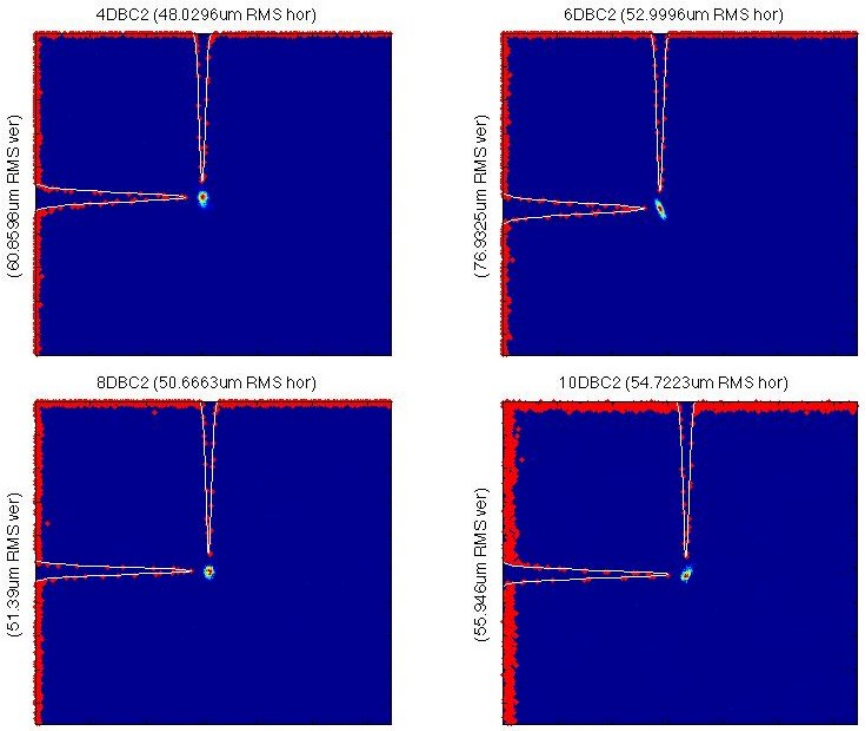


	emittance	alpha	beta	BMAG
horizontal	$0.46\ ^{+0.06}_{-0.05}$	-1.32	2.41	1.28
vertical	$0.62\ ^{+0.09}_{-0.08}$	1.14	2.76	1.15

LASER-3, 2ps FWHM, BSA=0.4, 30pC, Isol=312.5A

1-2 bunches

Expected from simulation: 0.37 mm mrad



	emittance	alpha	beta	BMAG
horizontal	$0.34\ ^{+0.06}_{-0.05}$	-1.15	2.19	1.24
vertical	$0.43\ ^{+0.09}_{-0.08}$	1.02	2.83	1.32

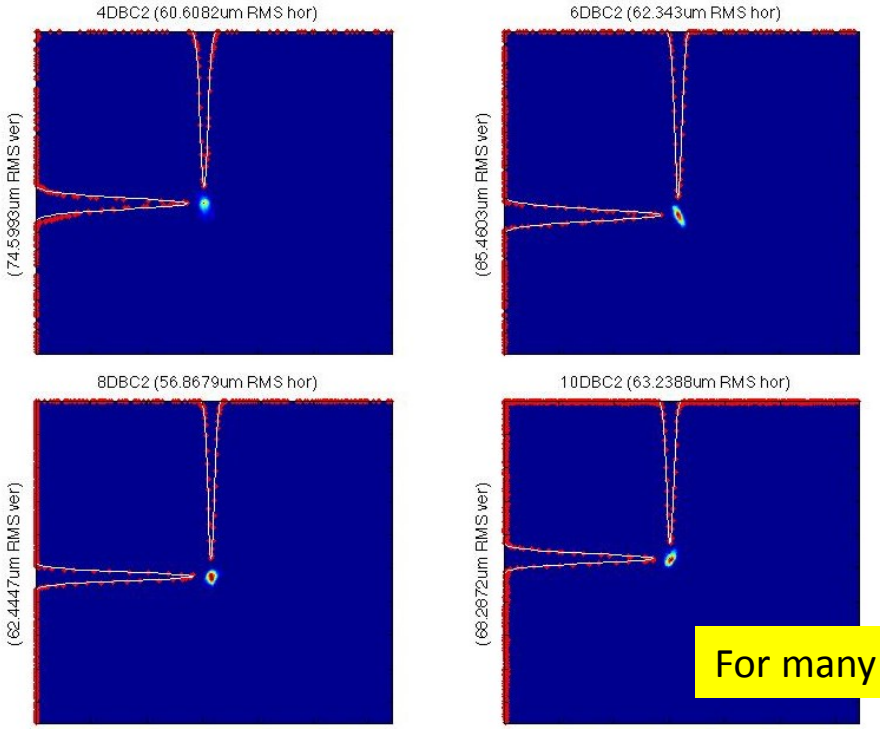
Influence of the number of bunches used for the measurement

Measurement 2013/12/22

LASER-3, 2ps FWHM, BSA=0.4, 30pC, Isol=312.5A

10 bunches

Expected from simulation: 0.37 mm mrad

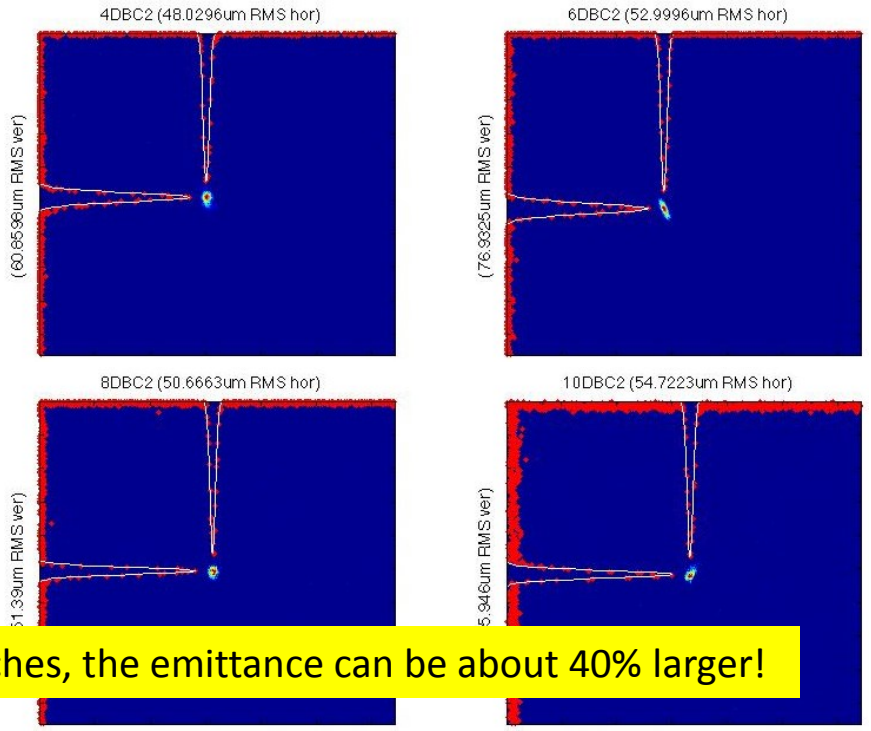


	emittance	alpha	beta	BMAG
horizontal	$0.46\ ^{+0.06}_{-0.05}$	-1.32	2.41	1.28
vertical	$0.62\ ^{+0.09}_{-0.08}$	1.14	2.76	1.15

LASER-3, 2ps FWHM, BSA=0.4, 30pC, Isol=312.5A

1-2 bunches

Expected from simulation: 0.37 mm mrad



For many bunches, the emittance can be about 40% larger!

	emittance	alpha	beta	BMAG
horizontal	$0.34\ ^{+0.06}_{-0.05}$	-1.15	2.19	1.24
vertical	$0.43\ ^{+0.09}_{-0.08}$	1.02	2.83	1.32

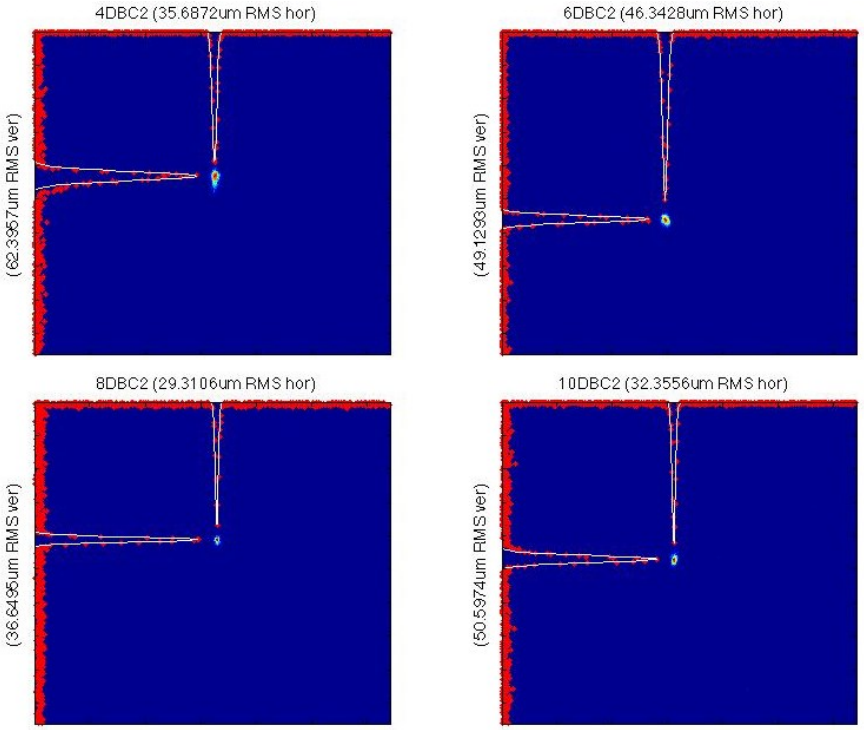
Comparison of Laser2 and Laser3 at identical machine settings

Measurement 2013/12/22

LASER-2: 15ps FWHM

BSA=0.4mm, 30pC, Isol=310.4A, 1-2 bunches

Expected from simulation: 0.25 mm mrad



	emittance	alpha	beta	BMAG
horizontal	$0.15\ ^{+0.18}_{-0.10}$	-2.13	2.87	2.19
vertical	$0.26\ ^{+0.31}_{-0.16}$	2.02	4.05	1.62

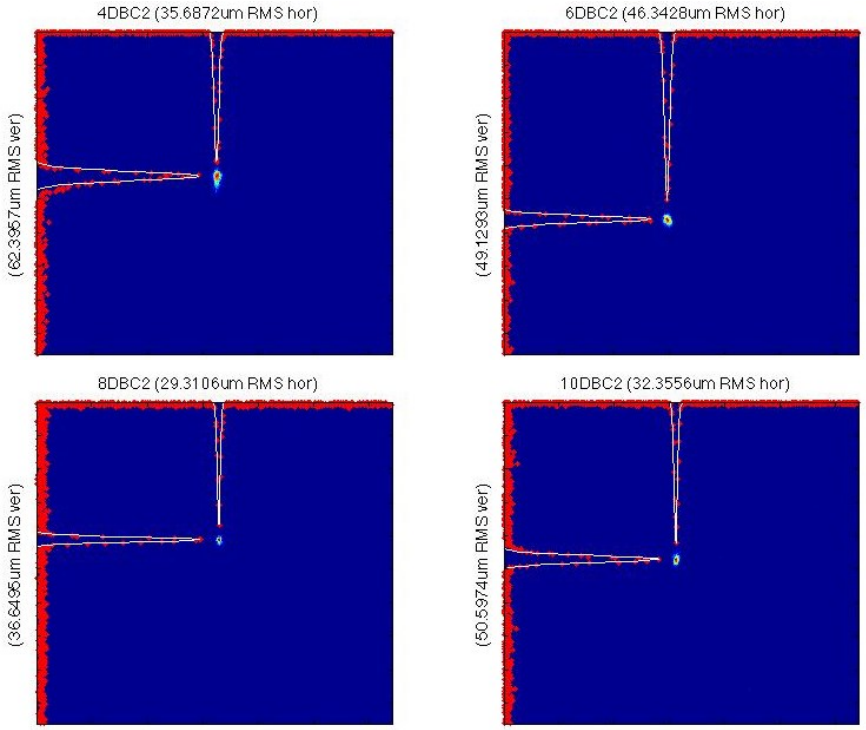
Comparison of Laser2 and Laser3 at identical machine settings

Measurement 2013/12/22

LASER-2: 15ps FWHM

BSA=0.4mm, 30pC, Isol=310.4A, 1-2 bunches

Expected from simulation: 0.25 mm mrad

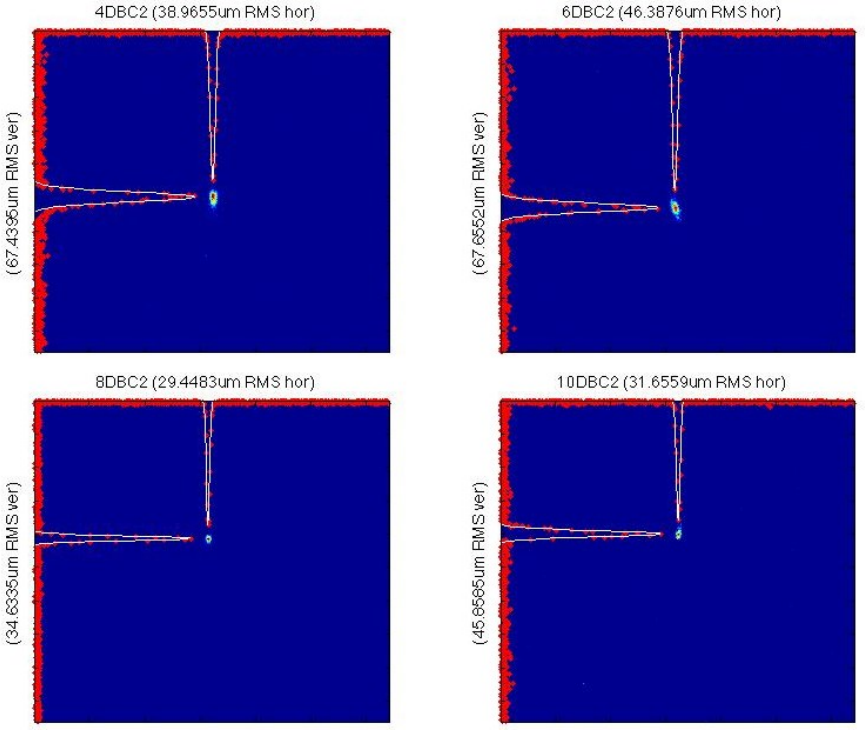


	emittance	alpha	beta	BMAG
horizontal	$0.15\ ^{+0.18}_{-0.10}$	-2.13	2.87	2.19
vertical	$0.26\ ^{+0.31}_{-0.16}$	2.02	4.05	1.62

LASER-3: 2ps FWHM

BSA=0.4mm, 30pC, Isol=310.4A, 1-2 bunches

Expected from simulation: 0.37 mm mrad



	emittance	alpha	beta	BMAG
horizontal	$0.15\ ^{+0.19}_{-0.10}$	-2.29	3.11	2.26
vertical	$0.25\ ^{+0.33}_{-0.16}$	1.83	5.06	2.14

conclusion

- Single spike SASE radiation at FLASH requires
  - low charges
  - short laser pulse duration at injector

- Very small emittance has been demonstrated for low charge
  - Comparable for long and short laser pulses (30pC)

  → supports simulation results
  - Error bars still large due to matching + sensitivity of screens

- Emittance measurement for low charges with screen method

  → requires a more sensitive screen/camera

outlook

- Systematic study of influence of number of bunches on emittance measurements
- Confirm the comparison between lasers 2 & 3 by more measurements (better BMAG, statistics)
- bunch length measurements in BC2

Thank you for your attention!