

OPAL-FEL meeting: Progress Updates on Photoinjector Optimization

Meng Cai
21.07.2025



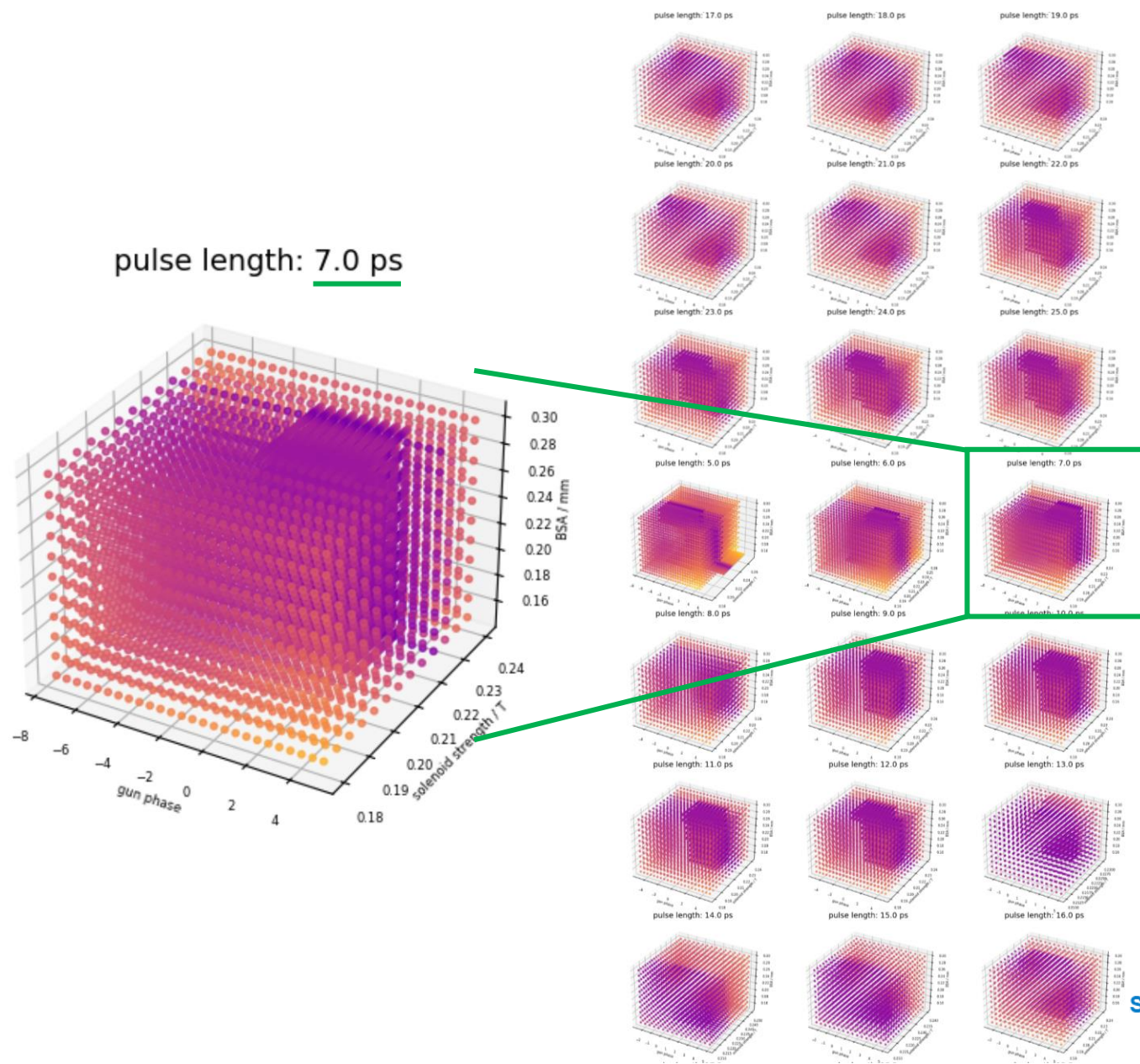
HELMHOLTZ

Simulation datasets of EuXFEL and PITZ for machine learning (Alex' model)

Variables	Range	Step
Laser temporal length	Flatop 5-25 ps	1 ps
Transverse spot size	0.15 - 0.3 mm	0.015 mm
Gun phase	-12.5 – 12.5 deg	2.5deg, 0.5deg
Solenoid	± 0.15 T – 0.3 T	0.05 T, 0.001 T
Electric field	59.5268 MV/m	/
Bunch charge	250 pC	/

Resolution	EuXFEL	PITZ
Particle numbers	20k	/
Nmin	200	/
Nrad	35	50
Nlong_in	70	100

- Total simulations: **199057** runs *2 facility
 - Average simulation time on Maxwell: 3 min 30 s
 - Only 24 stable nodes
- Overall time $\approx 58,058$ min $\approx$ **40.3** days



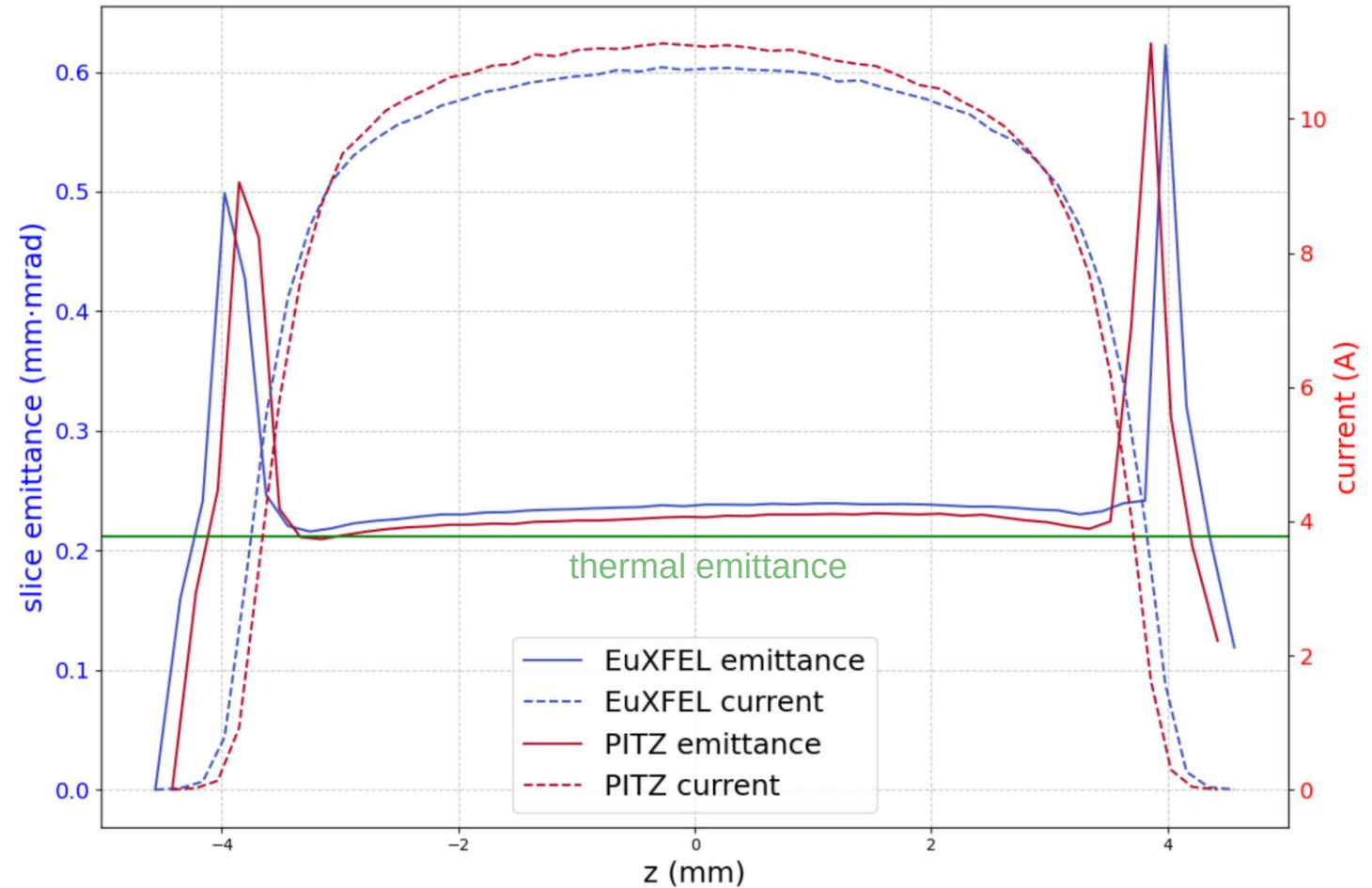
Selected best emittance cases from the database

rerun using 200k macroparticles

XFEL beam: downstream the first accelerating module A1

PITZ beam: downstream the CDS booster

BSA=1.0mm for 25 ps flattop, 250 pC
 (varied ϕ_{gun} & $B_{z_{\text{solenoid}}}$)
 → very similar best slice emittance
 → close to the thermal emittance level



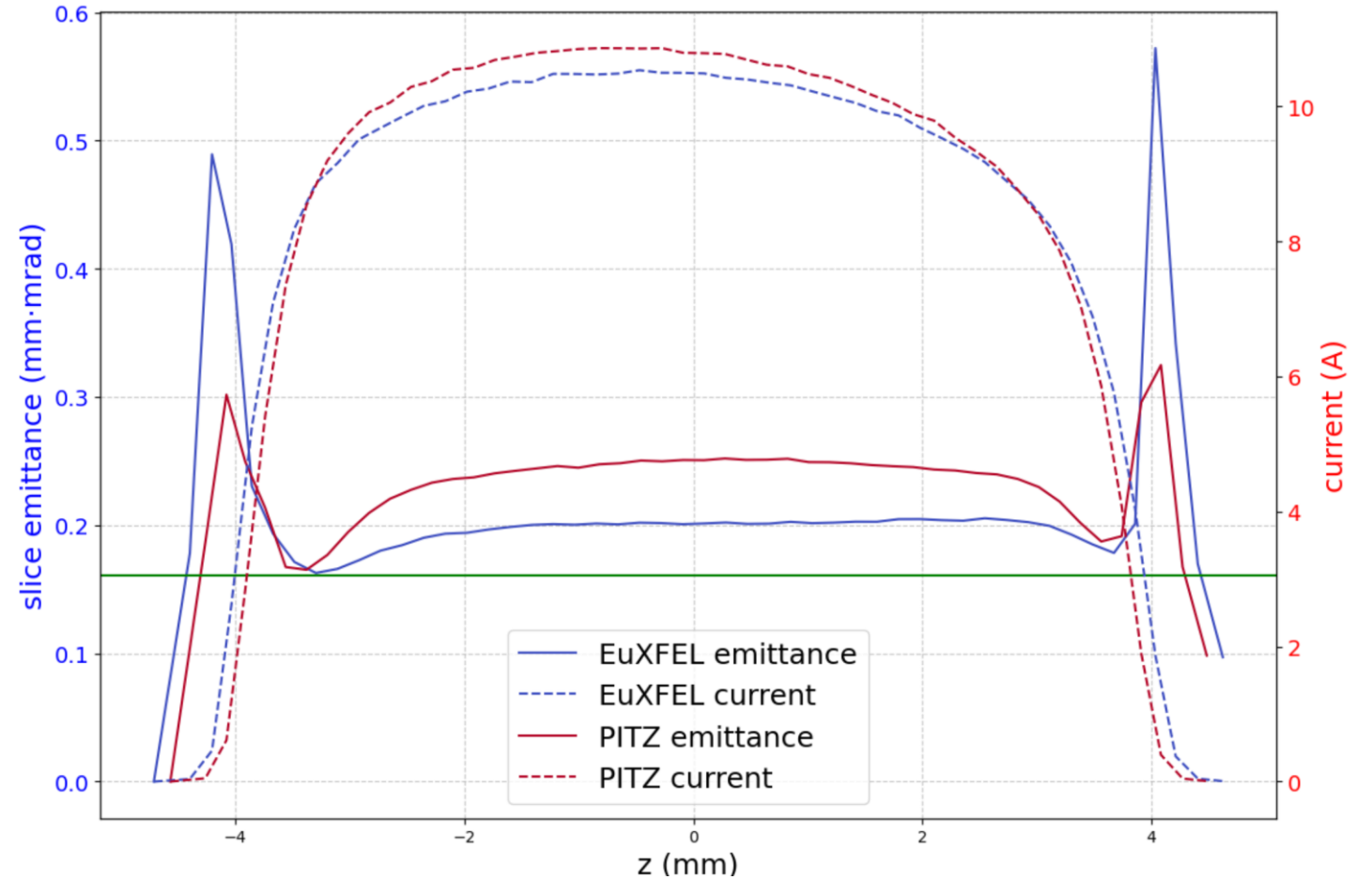
Selected other cases from the database

rerun using 200k macroparticles

XFEL beam: downstream the first accelerating module A1

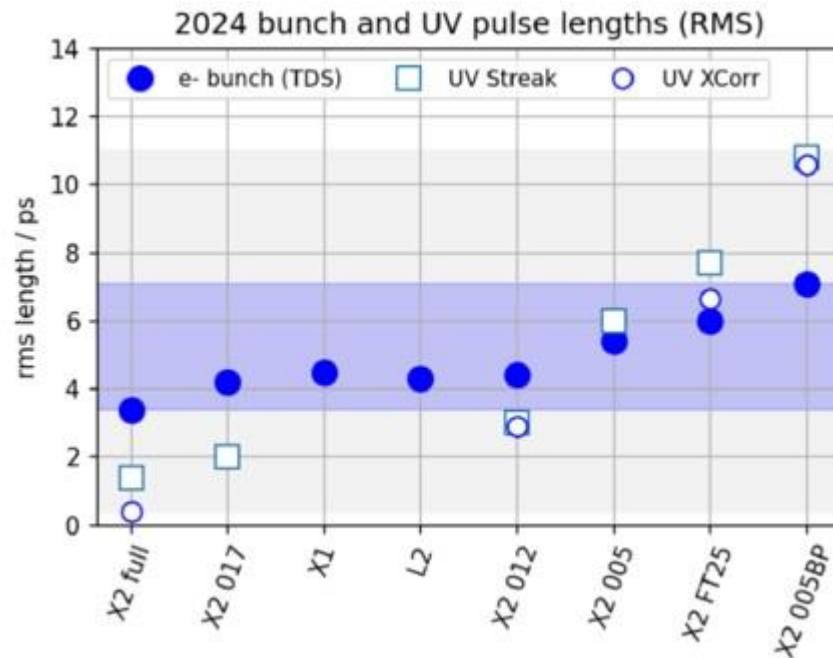
PITZ beam: downstream the CDS booster

BSA=0.76mm for 25 ps flattop, 250 pC
(varied ϕ_{gun} & $B_{z_solenoid}$)
→ Lower best slice emittance
for the XFEL case than BSA1.0



Electron Bunch Length (BL) Characterization

- Motivation: quantify how electron bunch length at injector exit depends on initial laser conditions and injector settings, considering strong collective beam effects.



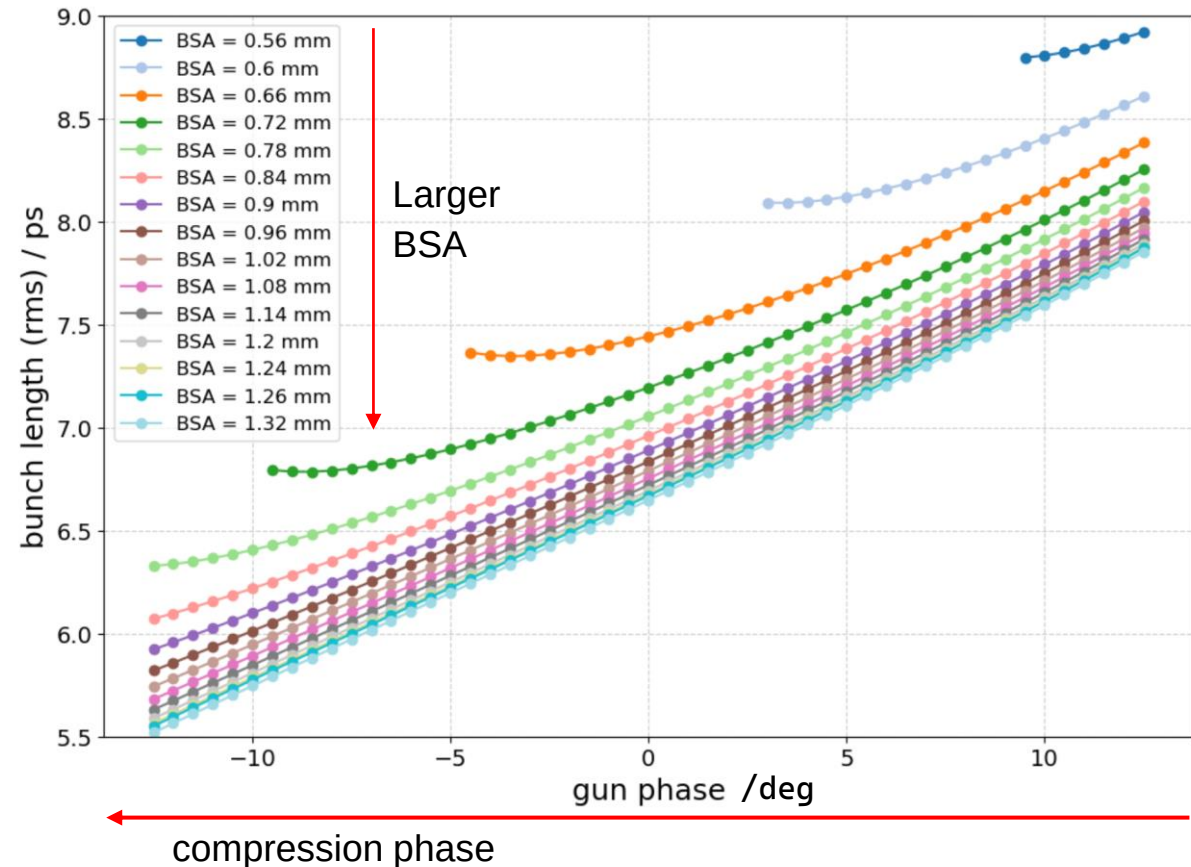
Electron BL depends on

- initial photon bunch length
- bunch charge
- gun phase
- laser spot size
- measurement uncertainty...

- Systematical studies on impacts of gun phase and laser spot size on BL at 2 bunch charges and 3 laser pulse lengths

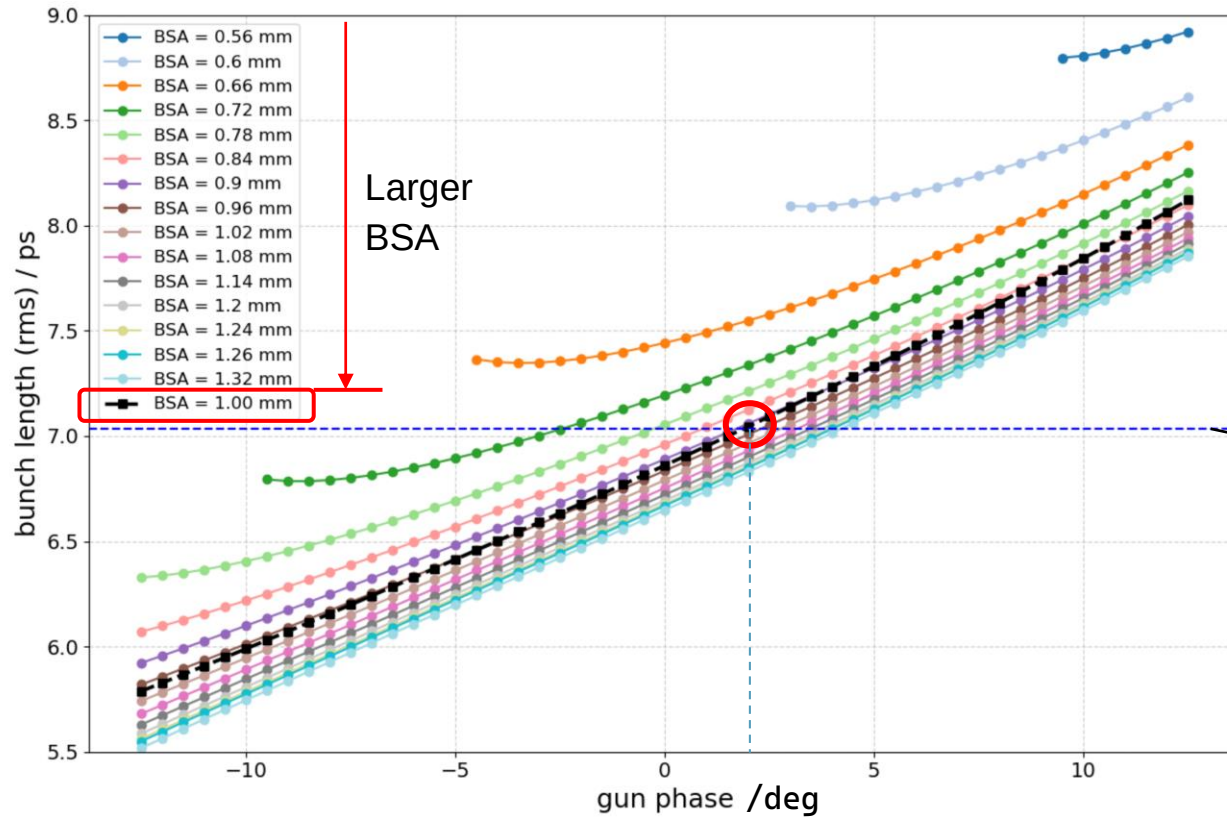
Variables	Range
Laser temporal length	Flatop 5, 9, 25 ps
Bunch charge	10, 250 pC
Transverse spot size	0.04 - 0.45 mm
Gun phase	-12.5 – 12.5 deg
Solenoid	0.225 T
Electric field	56 MV/m

Laser temporal length: 25 ps (rms=7.2736 ps)
Bunch charge: 250 pC



Identify simulation points consistent with measurements

Simulations data points:
25 ps (rms=7.2736 ps)
250 pC



Measurements data points:

25 ps 250 pC BSA=1.0 mm
Bunch length = 7.0341 ps in experiments

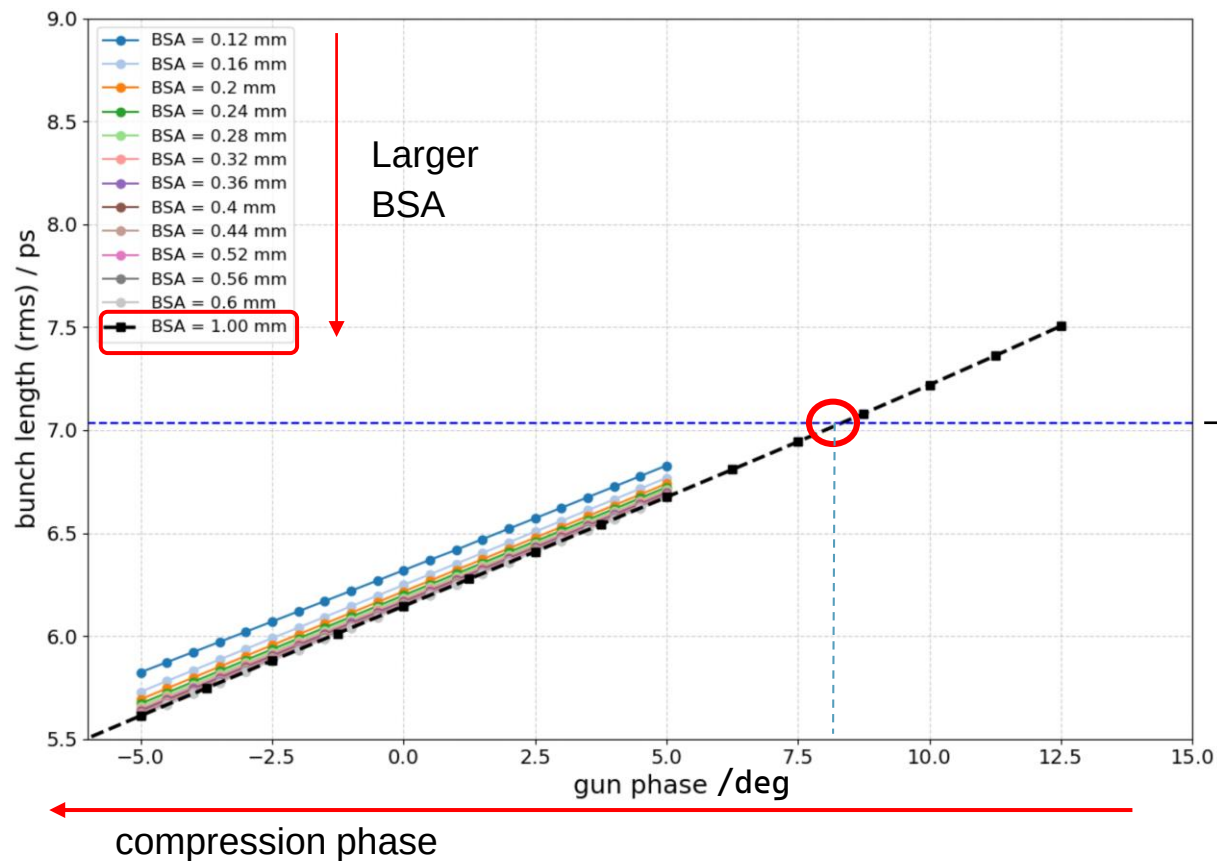


In simulations
At 25 ps 250 pC BSA=1.0 mm
gun phase ≈ 1.88 , BL = 7.0341 ps

Rerun with 200k macroparticles
At 25 ps 250 pC BSA=1.0 mm
gun phase ≈ 1.88 , BL = 6.93 ps

Lowering charge to 10 pC: finding simulation settings consistent with measured bunch length under reduced space charge

Simulations data points:
25 ps (rms=7.2736 ps)
10 pC



Measurements data points:

25 ps 250 pC BSA=1.0 mm
Bunch length = 7.0341 ps in experiments



In simulations
At 25 ps 10 pC BSA=1.0 mm
gun phase ≈ 8.33 , BL = 7.0341 ps

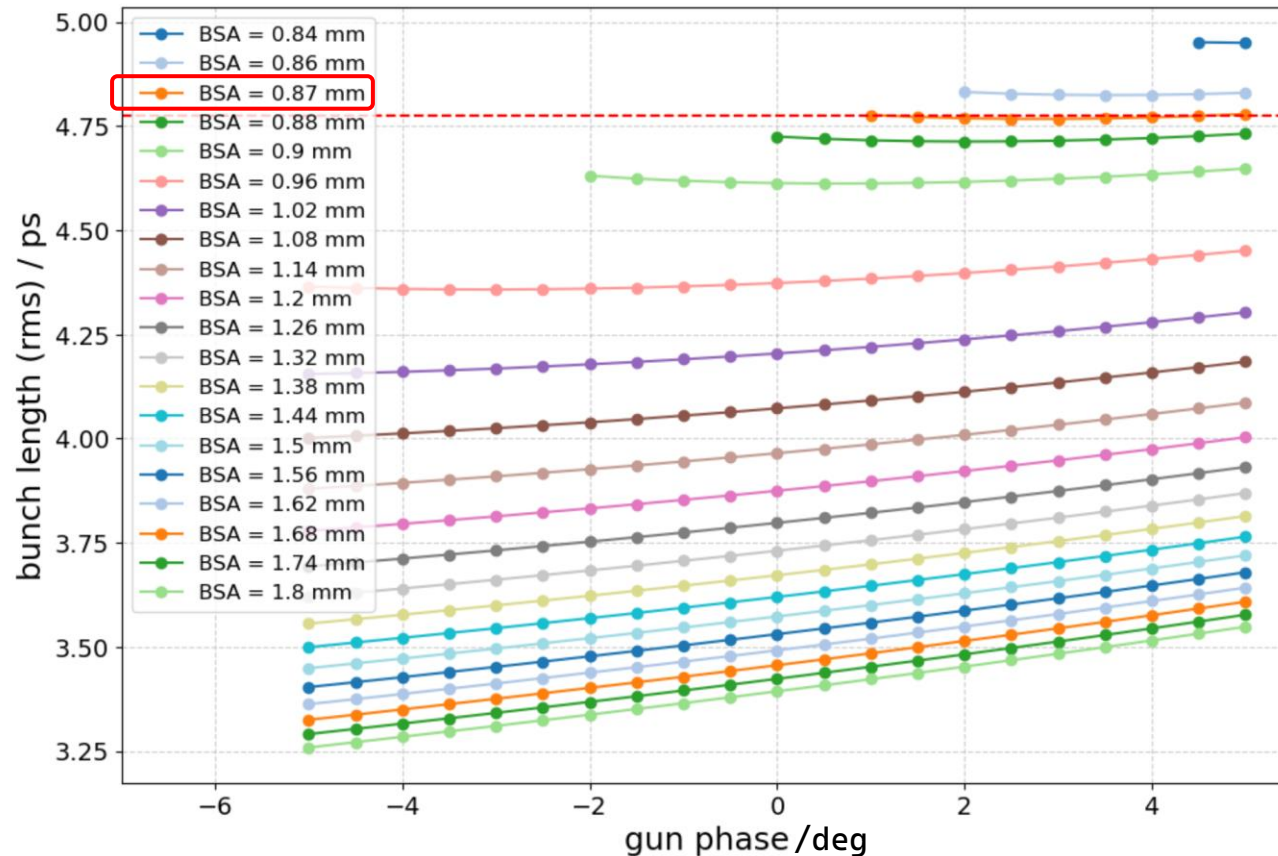
Rerun with 200k macroparticles
At 25 ps 10 pC BSA=1.0 mm
gun phase ≈ 8.33 , BL = 7.0315 ps

Identify simulation points consistent with measurements

Simulations data points:

9 ps (rms=2.752 ps)

250 pC



Measurements data points:

9 ps 250 pC BSA=1.0 mm

Bunch length = 4.7754 ps in experiments



In simulations

At 25 ps 10 pC BSA=0.87 mm

gun phase $\approx$ 1-5

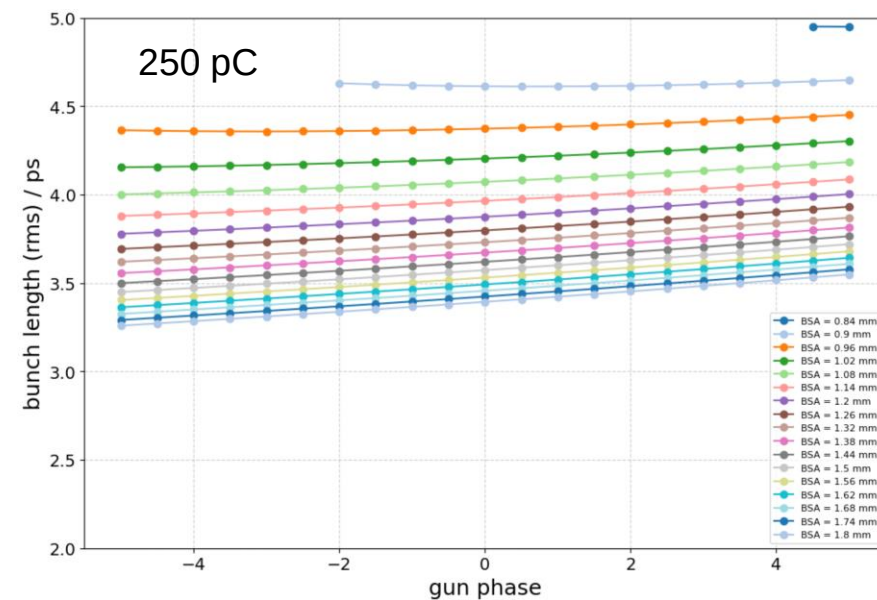
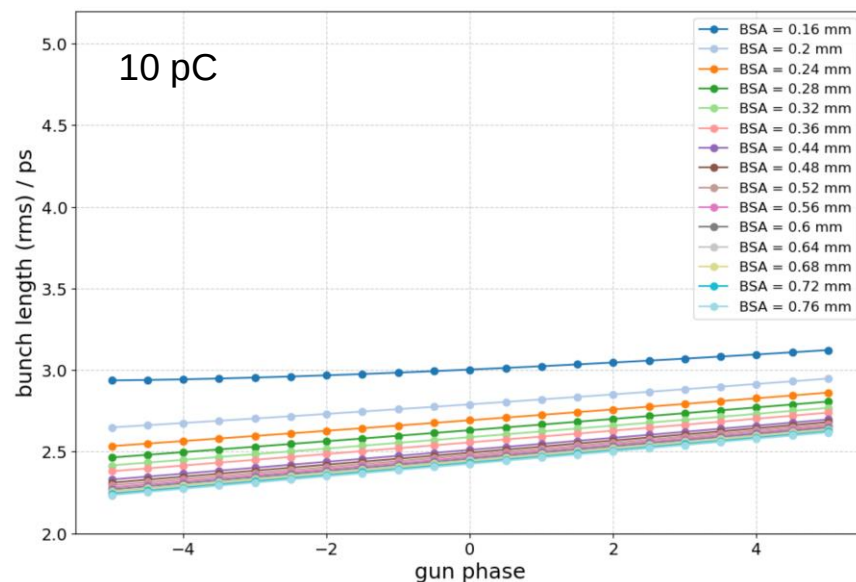
BL = 4.7754 ps

Summary

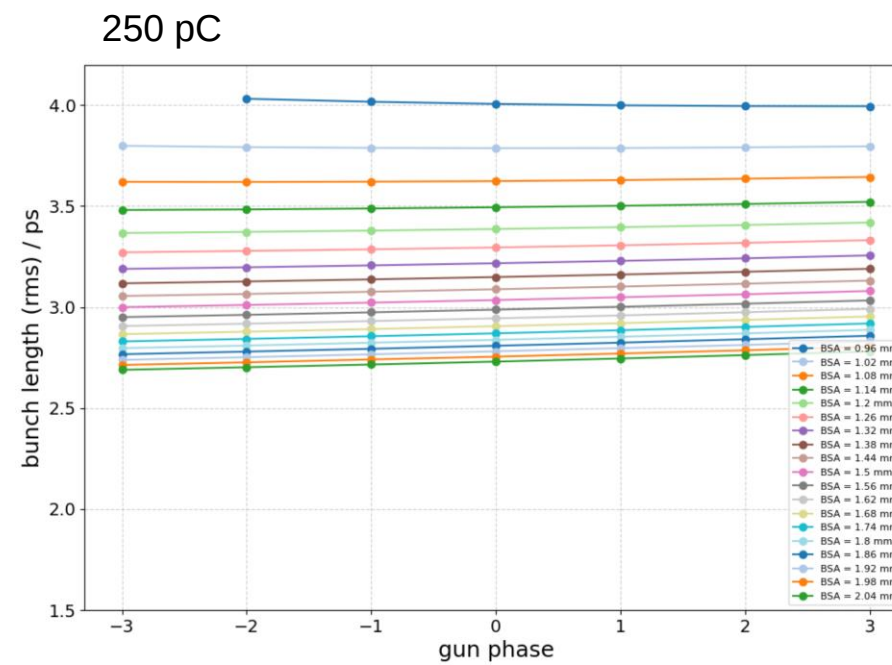
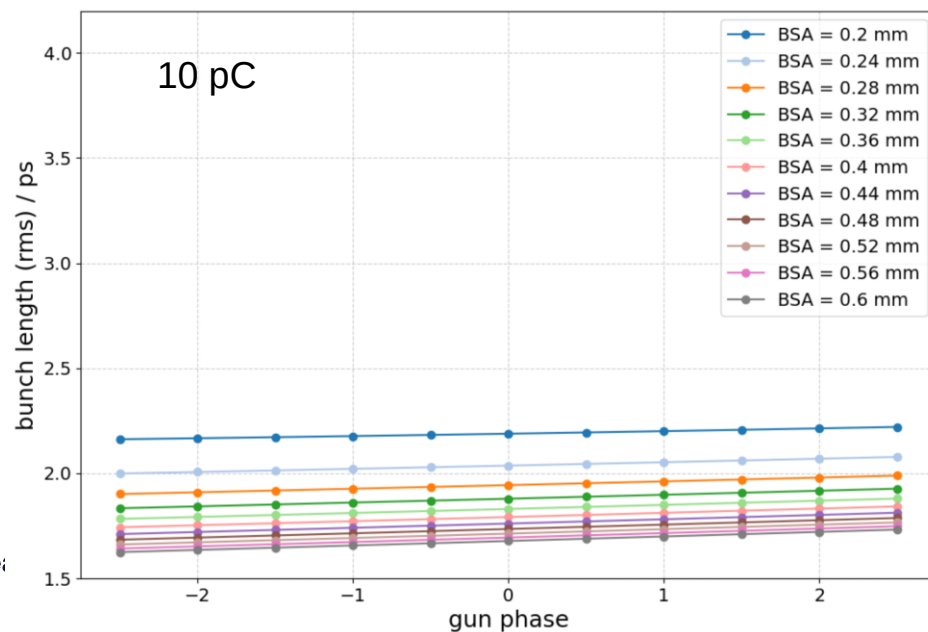
- Simulation Database of EuXFEL and PITZ Established for Machine Learning Applications
- Emittance Optimization and Performance Analysis for EuXFEL and PITZ
- Characterization and Validation of Bunch Length Dynamics

Backup slides

9 ps (rms=2.752 ps)



5 ps (rms=1.705 ps)



25 ps, bunch charge 10 pC vs. without space charge

