Incomplete Overview over Emittance Measurements and Simulations at EXFEL

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PPS Meeting

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DESY

Outline

1. Injector Setup
2. Simulations Setup
3. Emittance Measurements in 2016
4. Simulations on WPs from 2016 and Comparison to Measurements
5. Emittance Measurements in 2017. Evaluation of the Statistics
6. Comparison of the Simulations to Emittance Measurements in 2017
7. Solenoid Current and Gun Phase Scan

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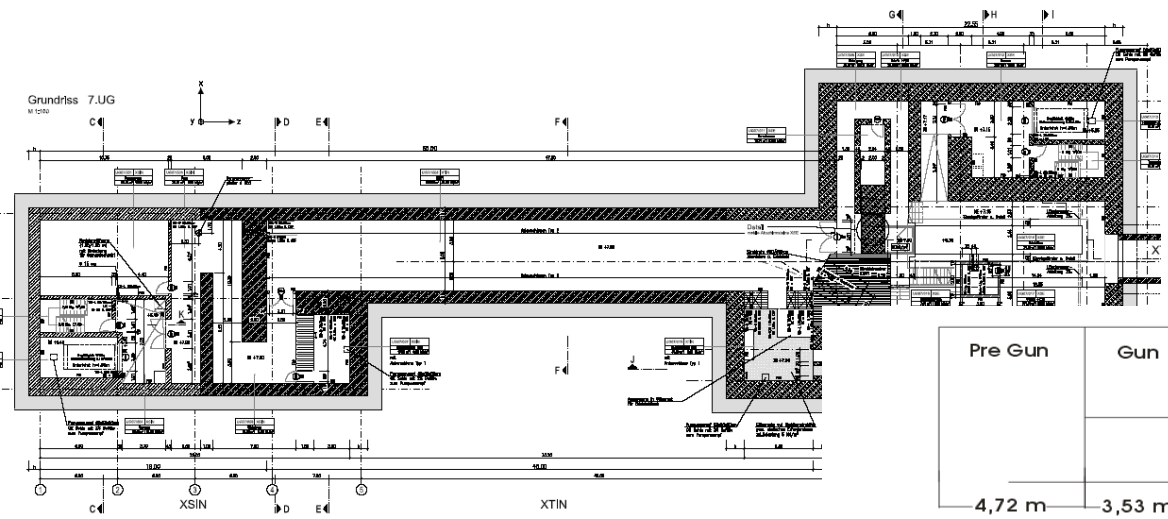
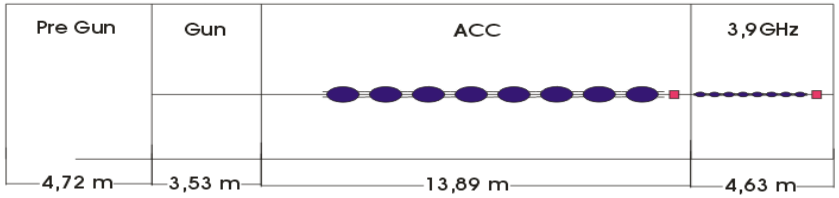
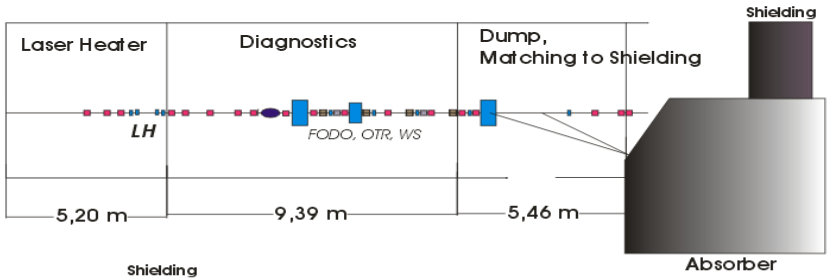
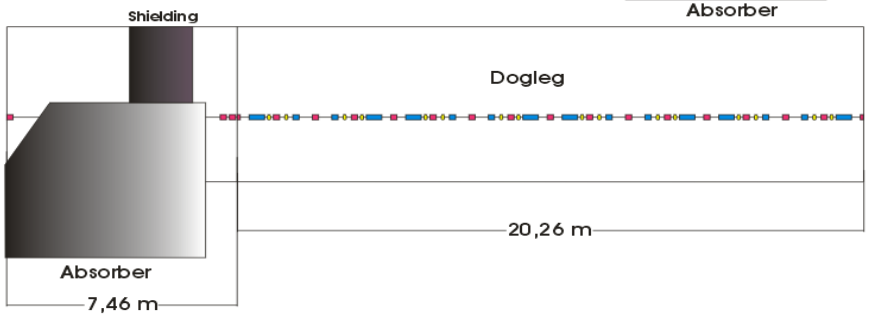
XFEL Injector Lattice Layout





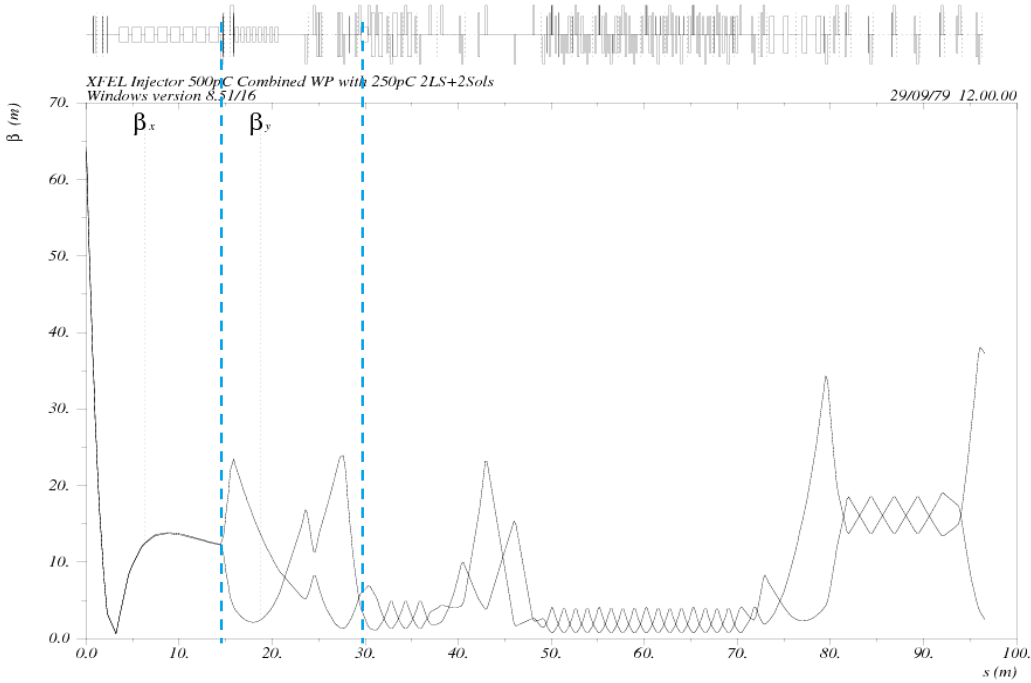


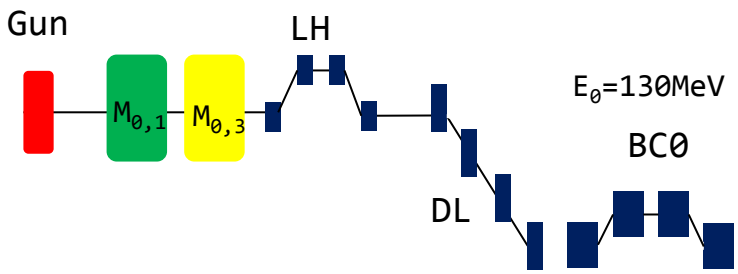


Gives place for:
- Photoinjector Gun
- ACC1 and ACC39
-Laser heater
- Diagnostics section
(1.5 76° FODO-cells with 4 OTR)
- TDS
- Spare place of about 3m for the dump exchange
- 6.5m long shielding
- 20m long Dogleg for the vertical Displacement of the beam (2.75m)

Beam Optical Functions in the Injector

Three regions of the injector divided by:
- end of the 1st accelerating module ACC1 at 14.448m
- begin of the diagnostics section at DIACORE at 29.559m





Depends on
- bunch charge
- solenoid field
- gun gradient
- RF focussing

Matching region
6 Quadrupoles

Fixed beam optical functions
→ to be used as reference optics

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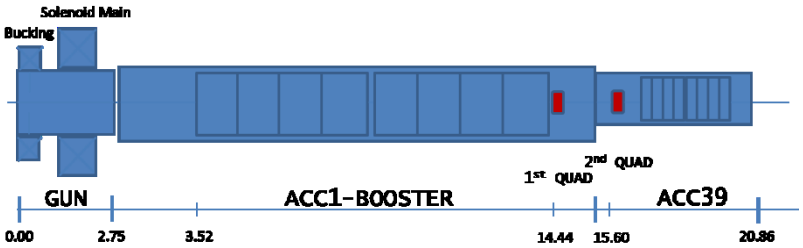
Simulations Setup

RF-Gun	Cathode Laser	Booster	ASTRA, XTrack
Field Balance= 1.04	Temporal Profile: Gauss 6.00ps rms (FWHM: 14.1ps)	ACC1: 8xTESLA cavities: 1st cavity centered at z=4.0401m → 1st iris at z=3.637m	200K particles - With wakes - With coupler kicks - With SCR
E_{cath}=50.00-53.00MV/m	Transverse: radial homogeneous	E_{peak}=34.42MV/m Phase=0.0 degree	Rotational symmetry Mesh: NradxNlong=40x100
Solenoid: main centered at z=0.276m Bucking coil at compensation			Tuned Parameters: - Main solenoid peak field - Laser rms spot size - Rms bunch length - Gun launch phase

Goals & Tasks: - minimized transverse emittance at the 1st quadrupole (z=14.44m)
- matchable optics → β<100m, $|\alpha|$<5 @1st quadrupole

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Summary of the Emittance Measurements in 2016*

Charge, [pC]	Horizontal, [mm mrad]	Vertical, [mm mrad]	Simulations
50	0.56±0.01	0.64±0.01	0.230
100	0.77±0.02	0.83±0.03	0.247
500	1.28±0.02	1.23±0.03	0.924
1000	2.95±0.02	2.81±0.03	1.903

Machine Parameters during Measurements	
Gun	50MV/m, -45 deg
Laser	Gauss, 6 ps rms
BSA	0.5-1.2-1.5 mm
Solenoid	Accordingly adjusted

* B. Beutner “European XFEL Injector Commissioning Results”

Summary of the Emittance Measurements in 2016

Measurements*			Simulations				
Charge, [pC]	Horizontal, [mm mrad]	Vertical, [mm mrad]	ASTRA at 14.45m	Xtrack at FODO	ε_{Slice} μm	δE_{peak}, [keV]	I_{max} [A]
50	0.56±0.01	0.64±0.01	0.230	0.236	0.159	0.26	3.44
100	0.77±0.02	0.83±0.03	0.247	0.285	0.183	0.42	5.88
500	1.28±0.02	1.23±0.03	0.924	1.086	0.661	1.24	24.3
1000	2.95±0.02	2.81±0.03	1.903	2.033	1.268	1.93	38.3

→ Best agreement for the 500pC case
→ Huge discrepancy between measured and simulated emittances for other charges due to:
- Most effort was set to establish performance with 500pC bunch charge
- Other charges got less priority
- Certain issues with screens for small beam spot size

→ Multi-quad scans with enlarged beta function needed for correct measurement of the emittances with small bunch charges

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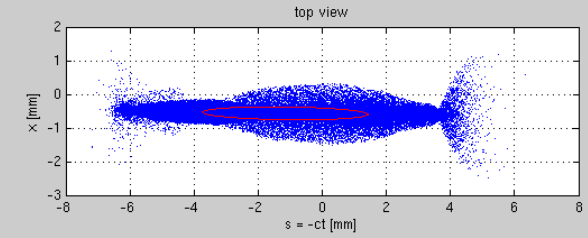
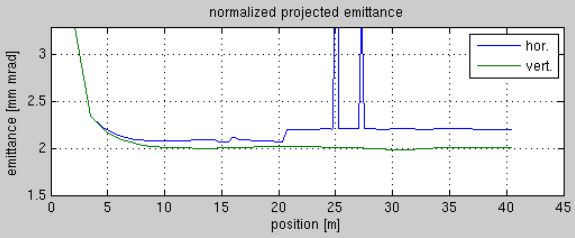
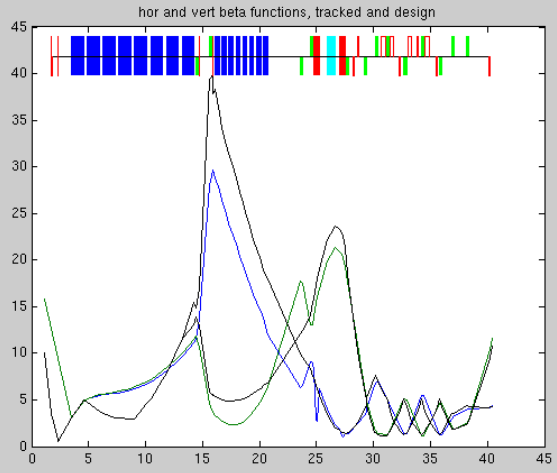
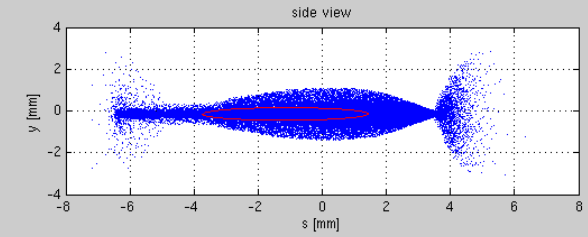
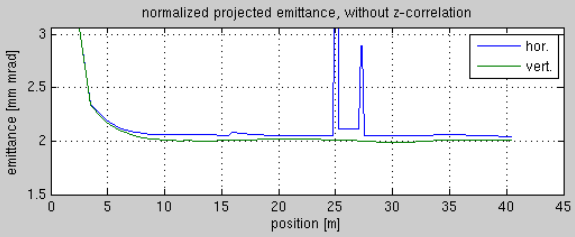
Simulations for 1nC Bunch Charge, GunV=50MV/m

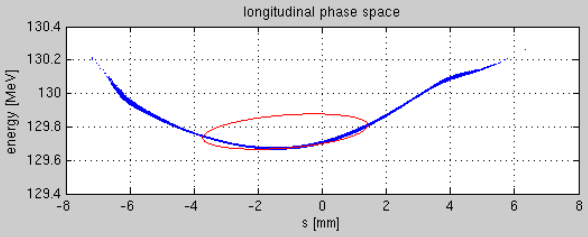


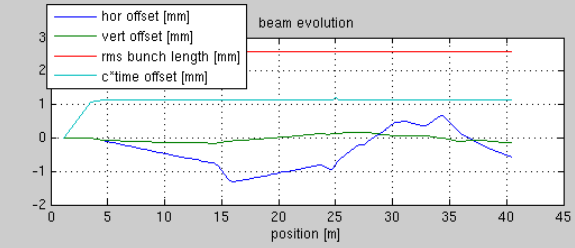


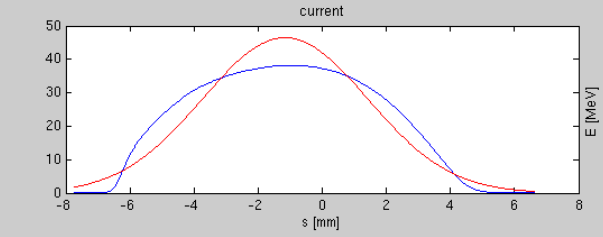


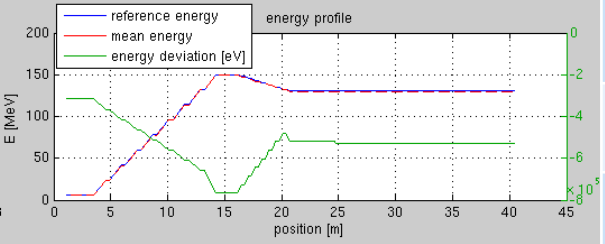






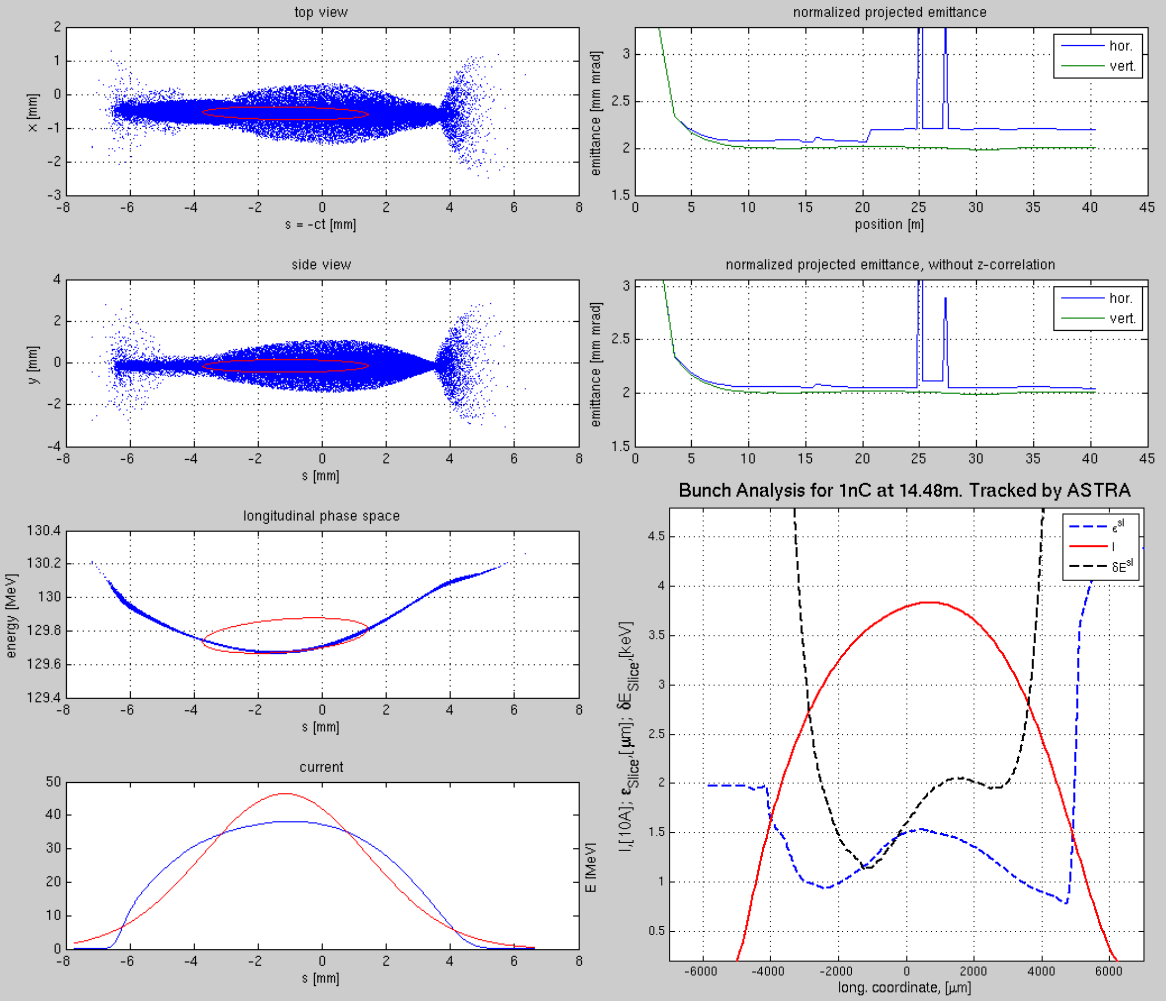






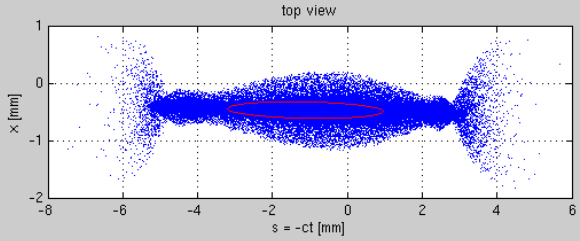
Working Point acc. to simulations	
Charge	1 nC
Gun	50MV/m; 0.0deg
Laser	Gauss, 6ps rms
BSA	1.5mm
Solenoid	318.0 A

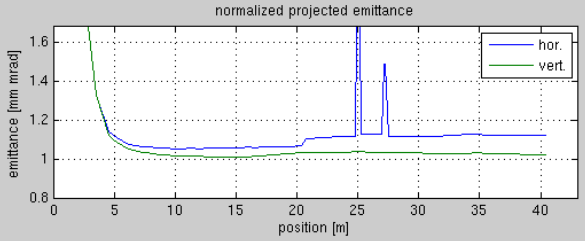
Simulations for 1nC Bunch Charge, GunV=50MV/m

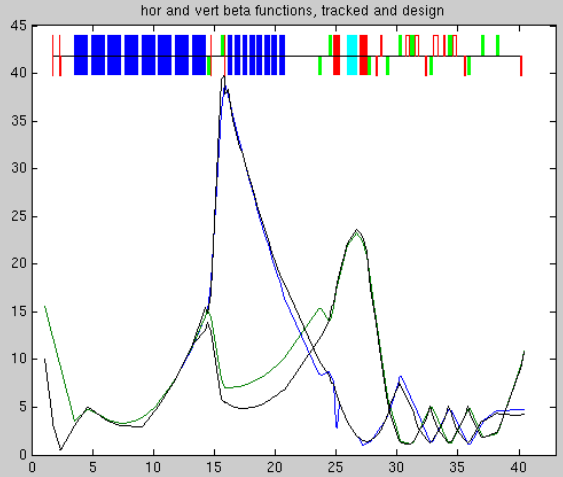


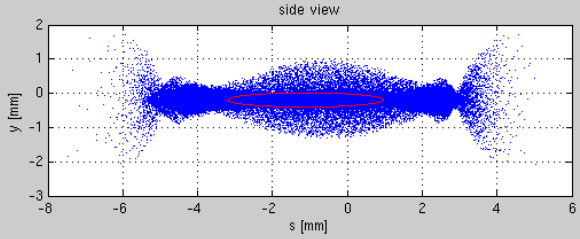
Bunch Parameters	
$\varepsilon_{x,y}$ proj. at 14.45m	1.923 μm
ε_x at FODO	2.188 μm
ε_y at FODO	2.018 μm
ε_{Slice} at 14.45m	1.268 μm
Twiss parameters at 14.48m	β=11.7m α=-0.604
Energy spread rms at peak (at 14.45m)	1.925 keV
I_{peak}	38.339 A
Working Point acc. to simulations	
BSA	1.5mm
Solenoid	318.0 A
Measured	
$\varepsilon_{x,y}$ proj	2.95 and 2.81

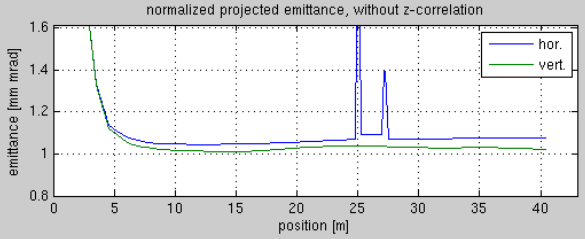
Simulations for 500pC Bunch Charge, GunV=50MV/m

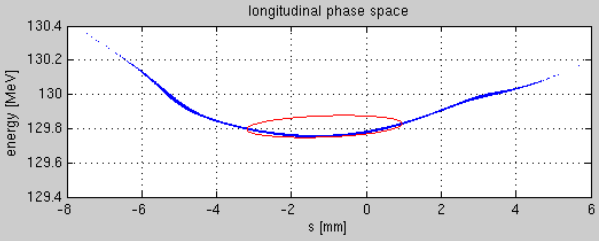


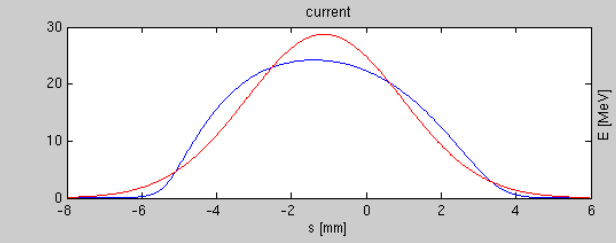


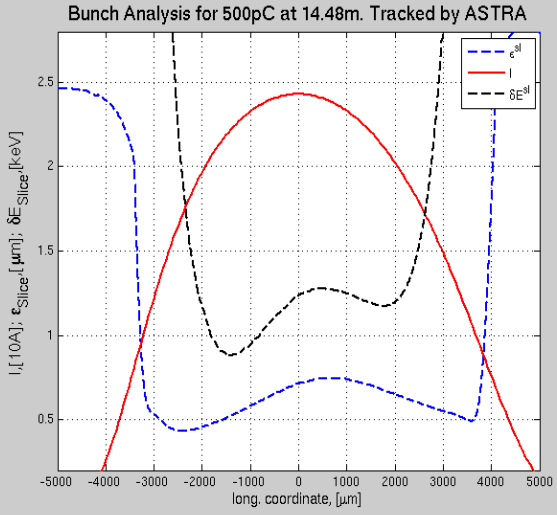






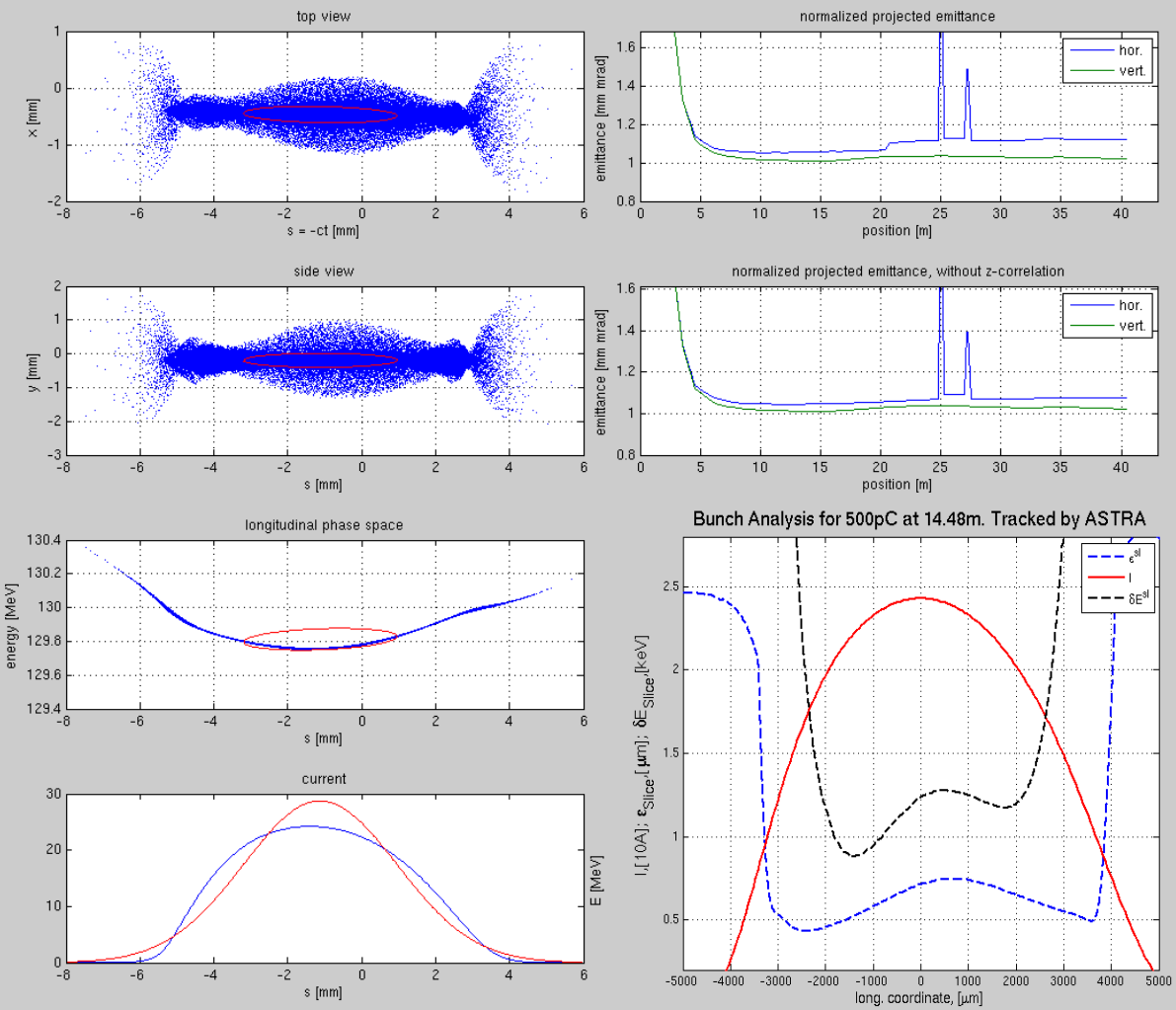






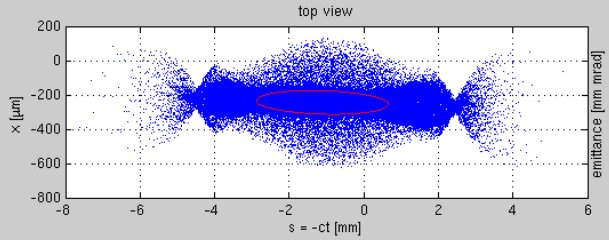
Working Point acc. to simulations	
Charge	500 pC
Gun	50MV/m; 0.0deg
Laser	Gauss, 6ps rms
BSA	1.2mm
Solenoid	317.2 A

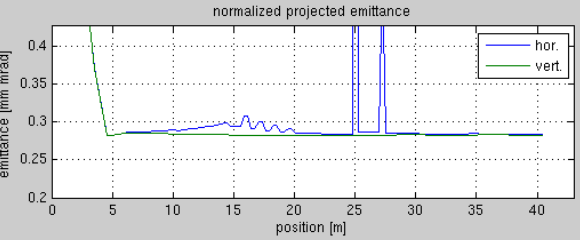
Simulations for 500pC Bunch Charge, GunV=50MV/m

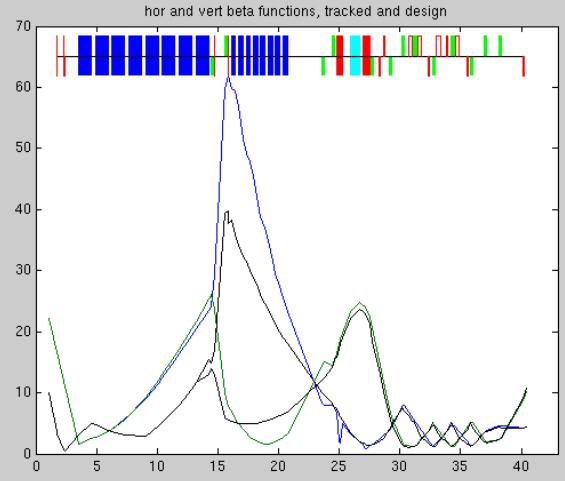


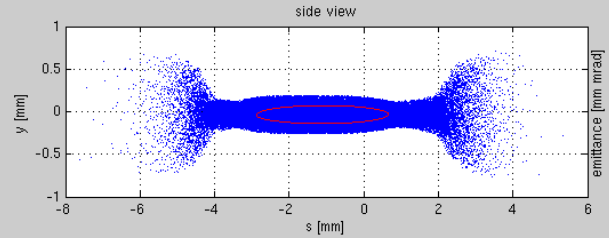
Bunch Parameters	
$\varepsilon_{x,y}$ proj. at 14.45m	0.9235 μm
ε_x at FODO	1.131 μm
ε_y at FODO	1.040 μm
ε_{Slice} at 14.45m	0.661 μm
Twiss parameters at 14.48m	β=12.9m α=-1.35
Energy spread rms at peak (at 14.45m)	1.241 keV
I_{peak}	24.293 A
Working Point acc. to simulations	
BSA	1.2mm
Solenoid	317.2 A
Measured	
$\varepsilon_{x,y}$ proj	1.28 and 1.23

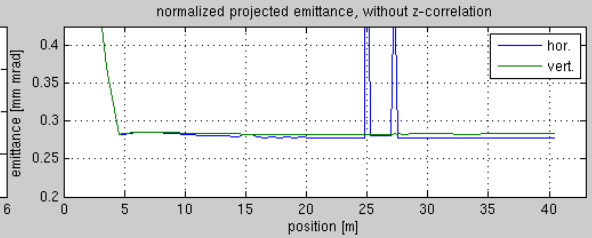
Simulations for 100pC Bunch Charge, GunV=50MV/m

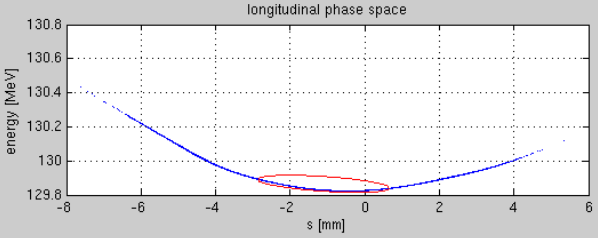


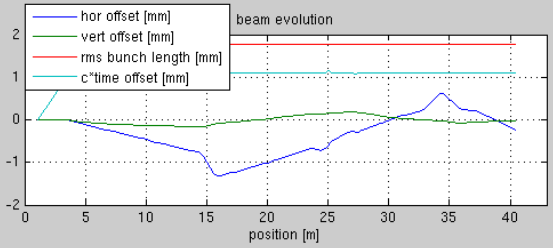


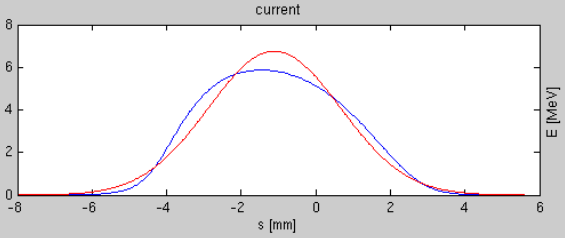


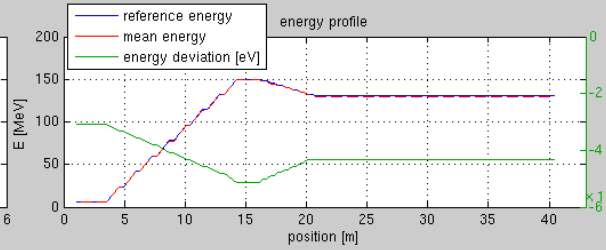








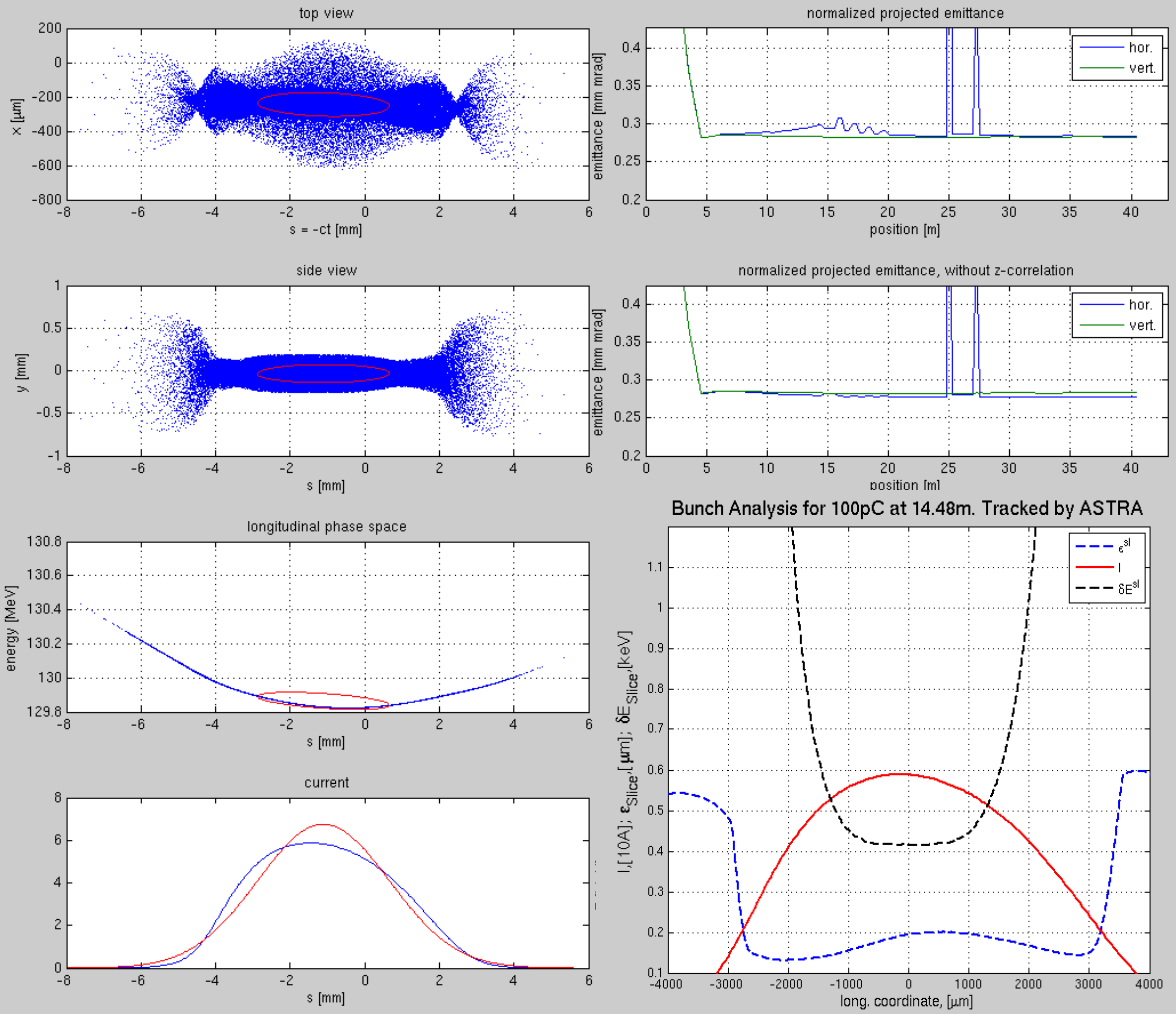




Working Point acc. to simulations

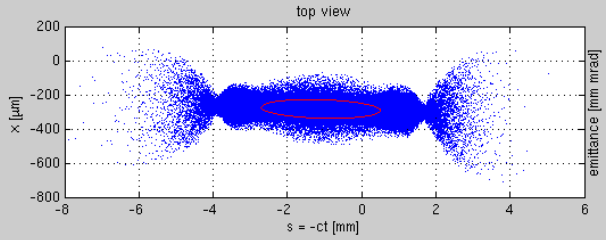
Charge	100 pC
Gun	50MV/m; 0.0deg
Laser	Gauss, 6ps rms
BSA	0.5 mm
Solenoid	316.2 A

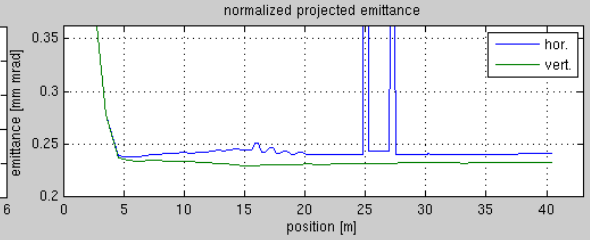
Simulations for 100pC Bunch Charge, GunV=50MV/m

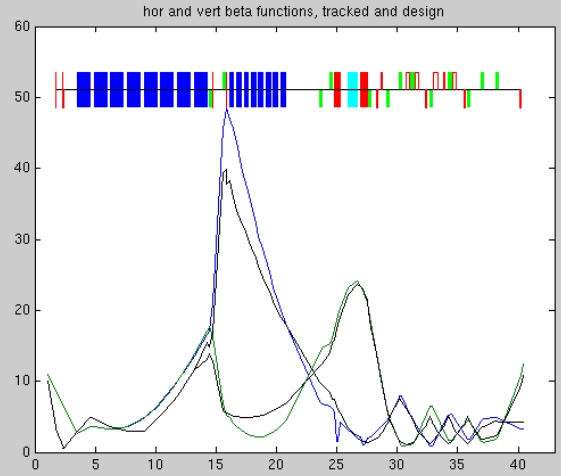


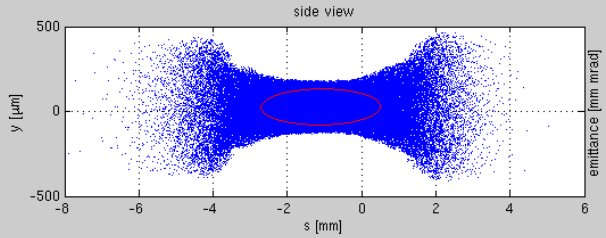
Bunch Parameters	
$\varepsilon_{x,y}$ proj. at 14.45m	0.247 µm
ε_x at FODO	0.288 µm
ε_y at FODO	0.284 µm
ε_{Slice} at 14.45m	0.183 µm
Twiss parameters at 14.48m	β=26.1m α=-1.85
Energy spread rms at peak (at 14.45m)	0.415 keV
I_{peak}	5.884 A
Working Point acc. to simulations	
BSA	0.5 mm
Solenoid	316.2 A
Measured	
$\varepsilon_{x,y}$ proj	0.77 and 0.83

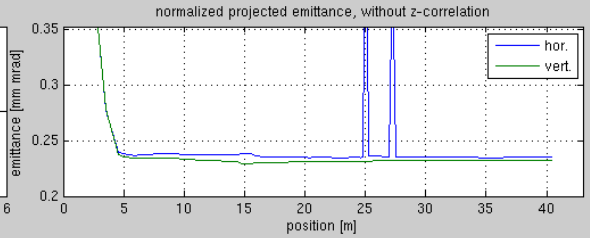
Simulations for 50pC Bunch Charge, GunV=50MV/m

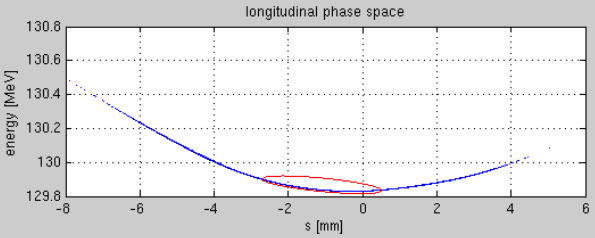


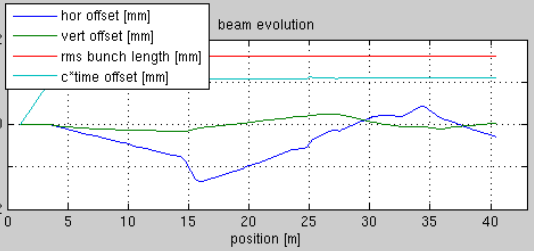


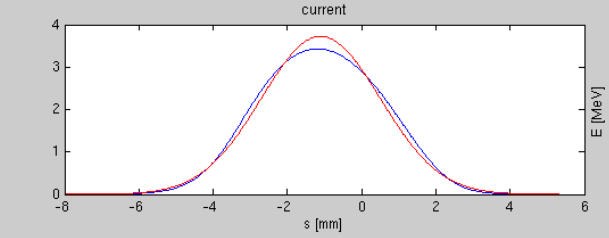


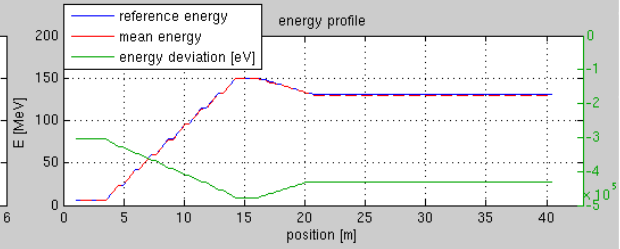






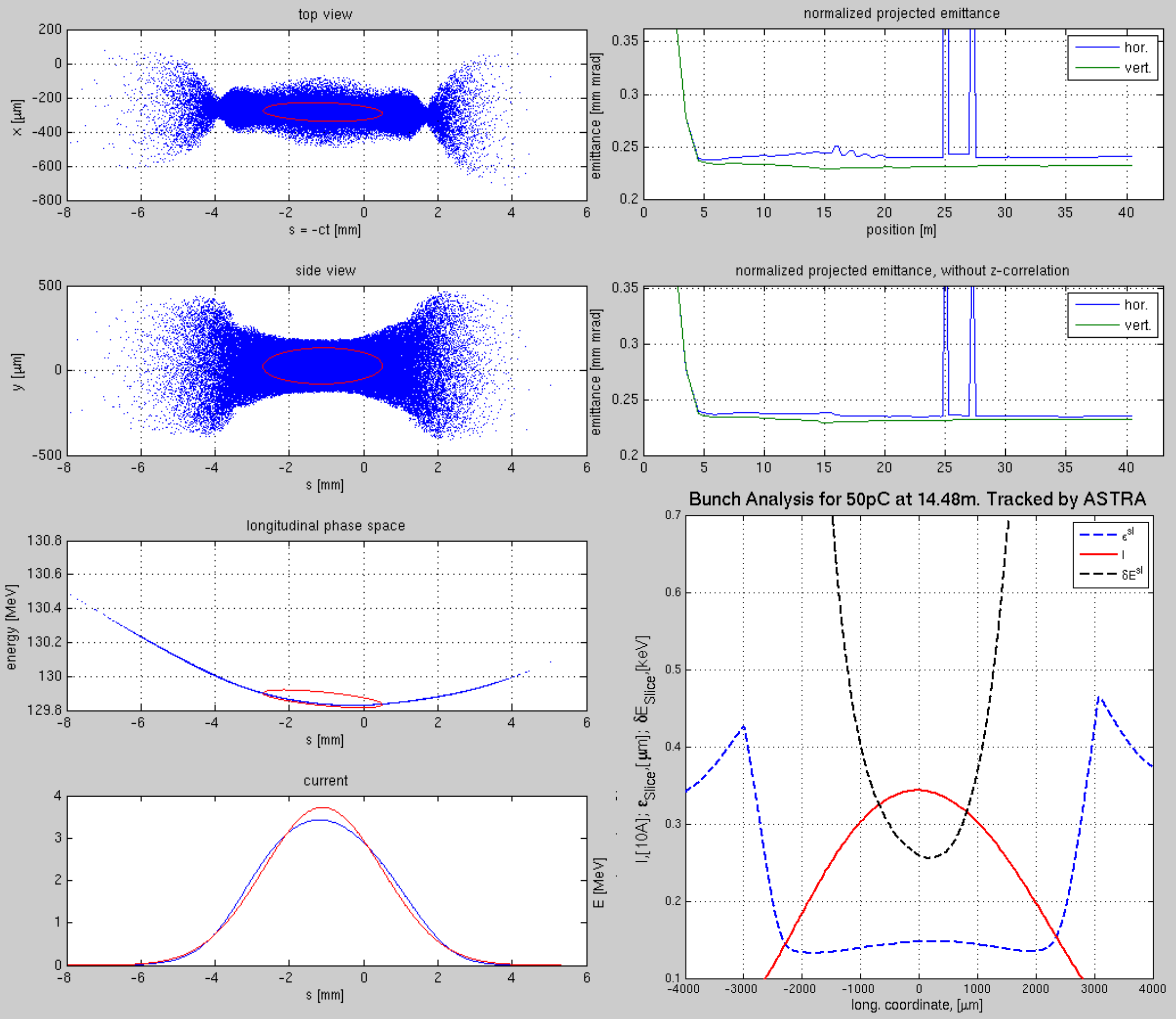






Working Point acc. to simulations	
Charge	50 pC
Gun	50MV/m; 0.0deg
Laser	Gauss, 6ps rms
BSA	0.5 mm
Solenoid	316.2 A

Simulations for 50pC Bunch Charge, GunV=50MV/m



Bunch Parameters	
$\varepsilon_{x,y}$ proj. at 14.45m	0.230 µm
ε_x at FODO	0.241 µm
ε_y at FODO	0.232 µm
ε_{Slice} at 14.45m	0.159 µm
Twiss parameters at 14.48m	β=25.8m α=-2.48
Energy spread rms at peak (at 14.45m)	0.263 keV
I_{peak}	3.438 A
Working Point acc. to simulations	
BSA	0.5 mm
Solenoid	316.2 A
Measured	
$\varepsilon_{x,y}$ proj	0.56 and 0.64

Outline

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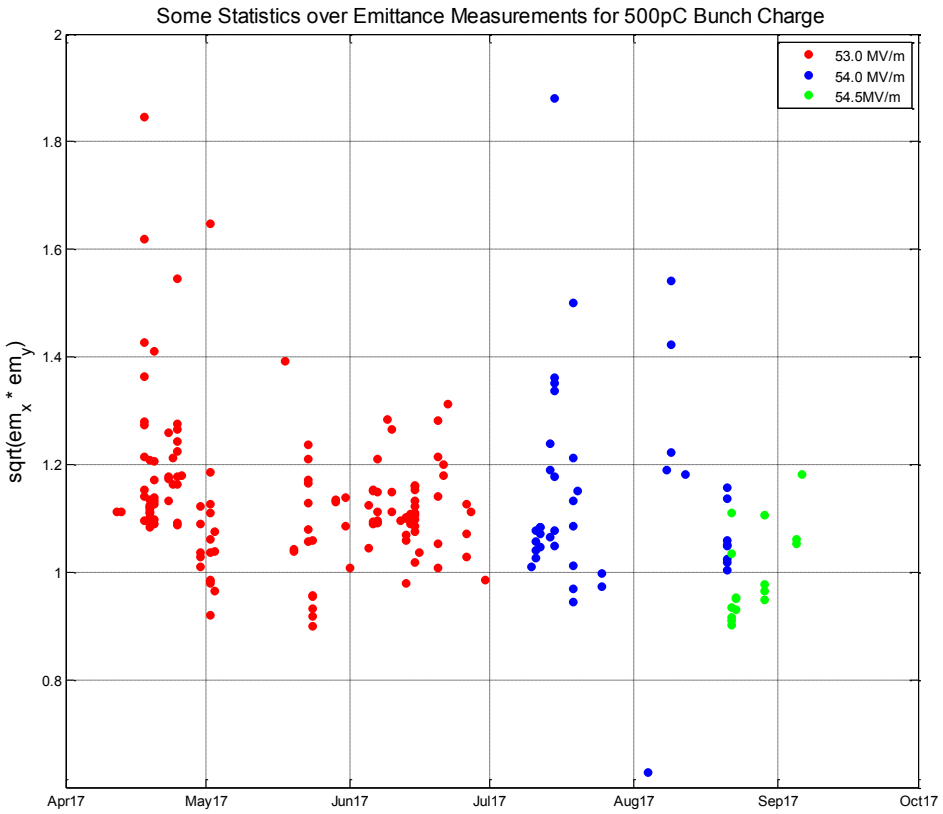
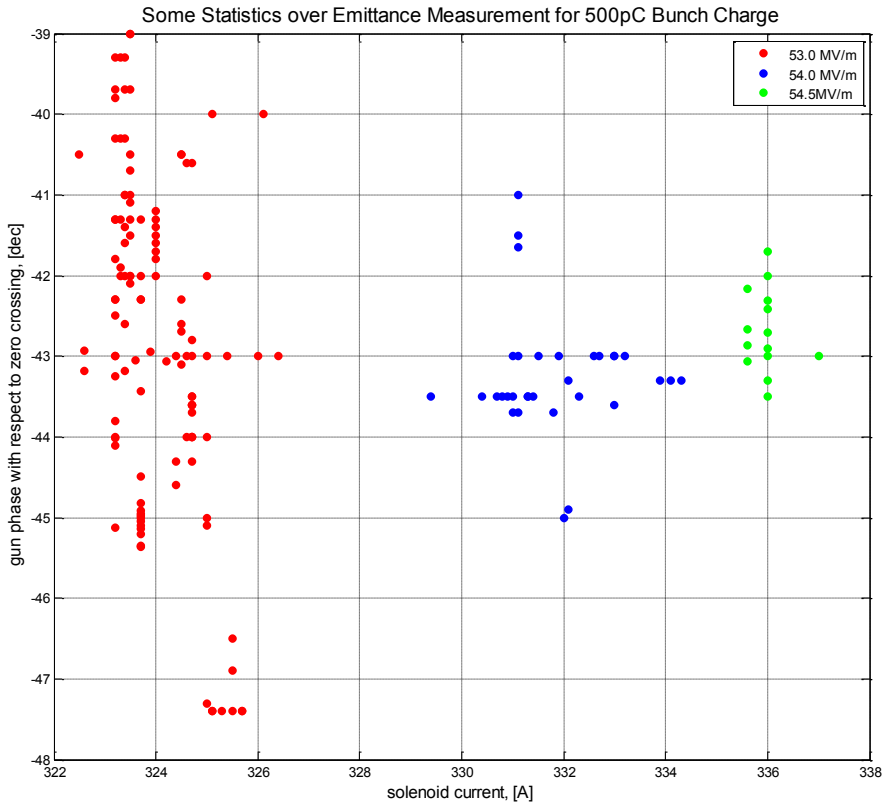
7. Solenoid Current and Gun Phase Scan

Emittance Measurements for 500pC Bunch Charge from April 2017



- → Detailed measurements have been done for the peak electric field of the gun of 53.0MV/m
- → Peak electric field of the gun has been increased due to conditioning from 53.0MV/m in April 2017 to 54.5MV/m in September 2017

Emittance Measurements for 500pC Bunch Charge



→ Detailed measurements have been done for the peak electric field of the gun of 53.0MV/m

→ Tried the gun phase in the range of 9 degrees

→ Peak electric field of the gun has been increased due to conditioning from 53.0MV/m in April 2017 to 54.5MV/m in September 2017

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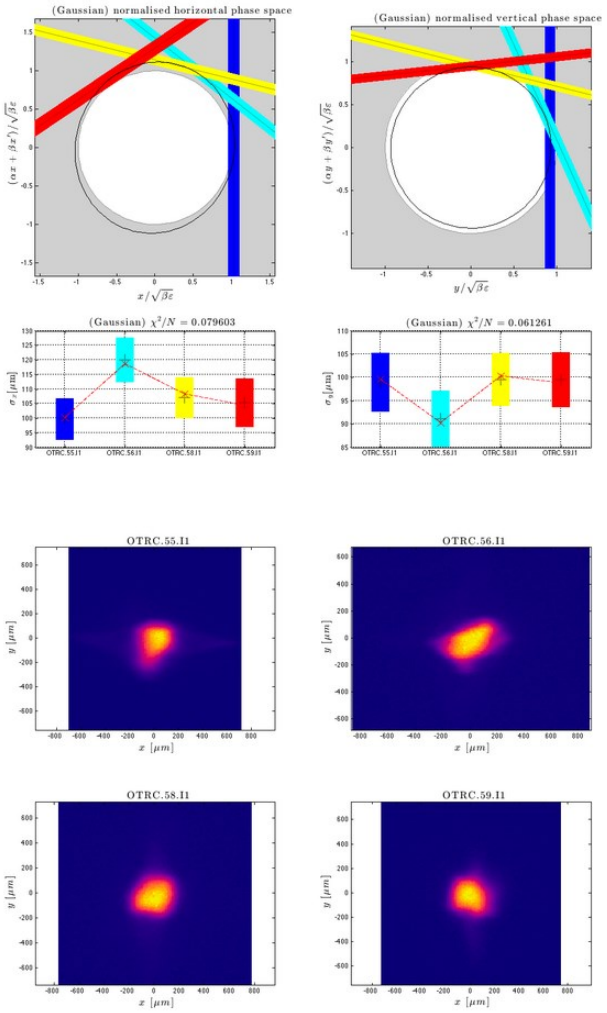
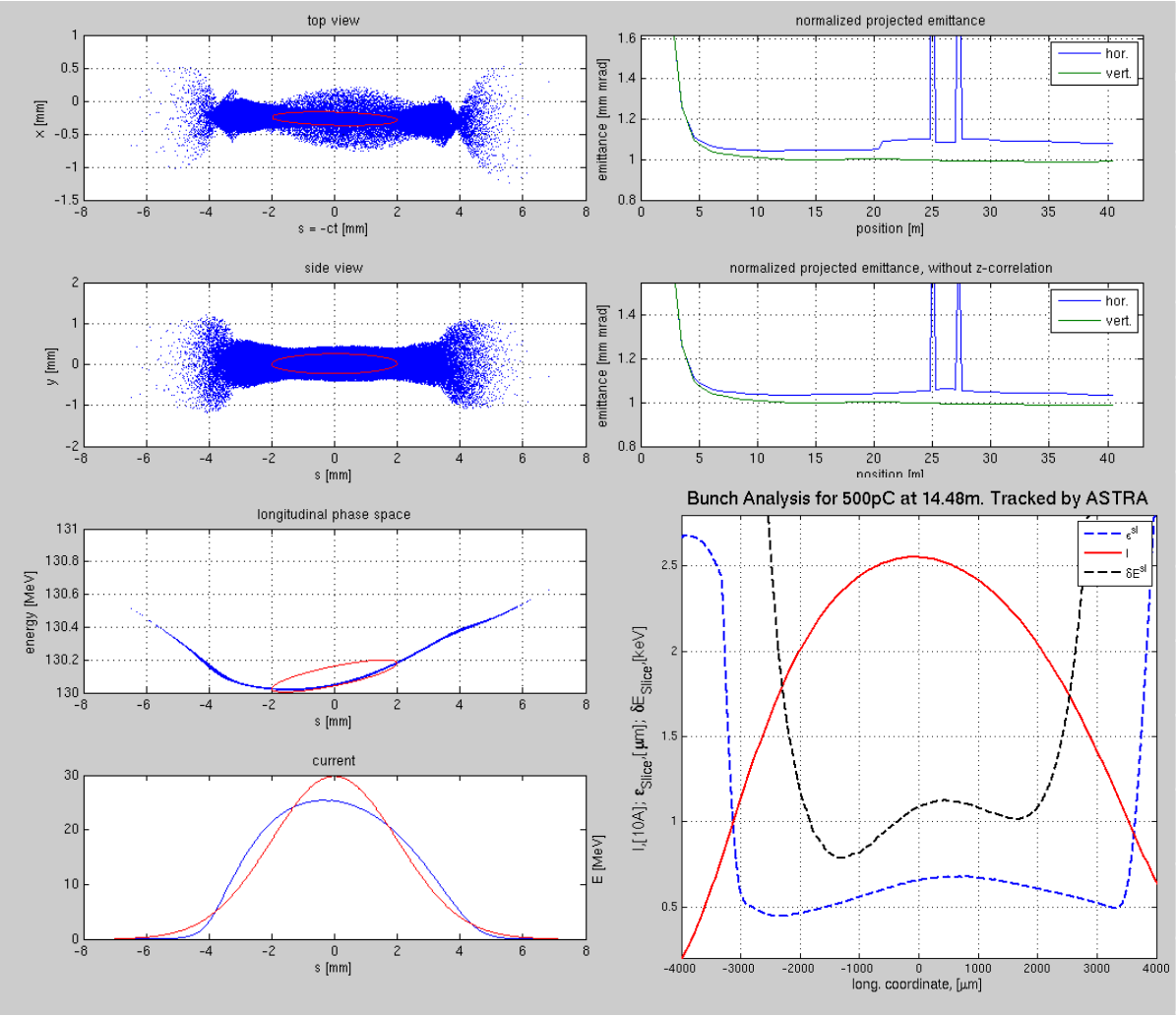
Representative Measurement for GunV=53.0MV/m



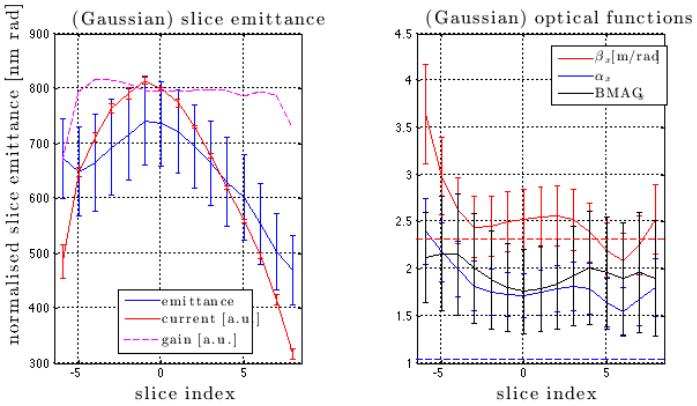
Measurement		Simulations WP	
Date	01.06.2017	at 14.45m	FODO
Charge, [pC]	500	500	
GunV, [MV/m]	52.9	53.0	
Isol, [A]	325.0 A	334.2	
Gun Phase, deg	- 44.0	0.0	
BSA, [mm]	1.2	1.2	
ε_x proj gauss	1.160±0.089	0.933	1.095
ε_y proj gauss	0.876±0.066	0.933	1.010
ε_x proj rms	1.52±0.10	0.933	1.095
ε_y proj rms	1.16±0.11	0.933	1.010
$Bmag_x$ gauss	1.088		
$Bmag_y$ gauss	1.01		
$Bmag_x$ rms	1.19		
$Bmag_y$ rms	1.24		

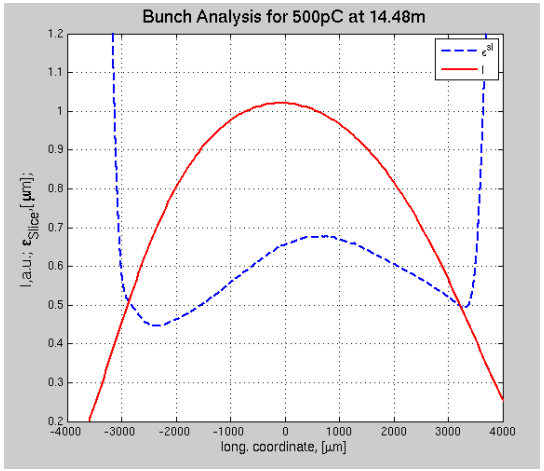
Simulations on 500pC Bunch Charge for GunV=53.0MV/m

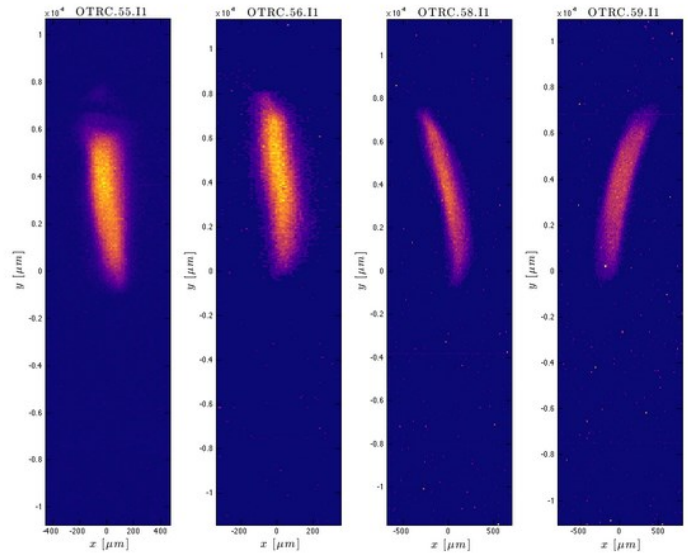


Bunch Parameters	
$\varepsilon_{x,y}$ proj. at 14.45m	0.933 μm
ε_x at FODO	1.095 μm
ε_y at FODO	1.010 μm
ε_{Slice} at 14.45m	0.655 μm
Twiss parameters at 14.48m	β=10.8m α=-0.911
Energy spread rms at peak (at 14.45m)	0.263 keV
I_{peak}	25.561 A
Working Point acc. to simulations	
BSA	1.2 mm
Solenoid	334.2 A
Measured	
$\varepsilon_{x,y}$ proj gauss	1.16 and 0.867
$\varepsilon_{x,y}$ proj rms	1.52 and 1.16

Representative Slice Emittance Measurement







Measurement		Simulations WP	
Date	20.04.2017	at 14.45m	FODO
Charge, [pC]	500	500	
GunV, [MV/m]	53.0	53.0	
Isol, [A]	323.2 A	334.2	
Gun Phase, deg	- 44.0	0.0	
BSA, [mm]	1.2	1.2	
ε_x slice average	0.60-0.70	0.64	
ε_y slice at I_{peak}	0.73	0.65	

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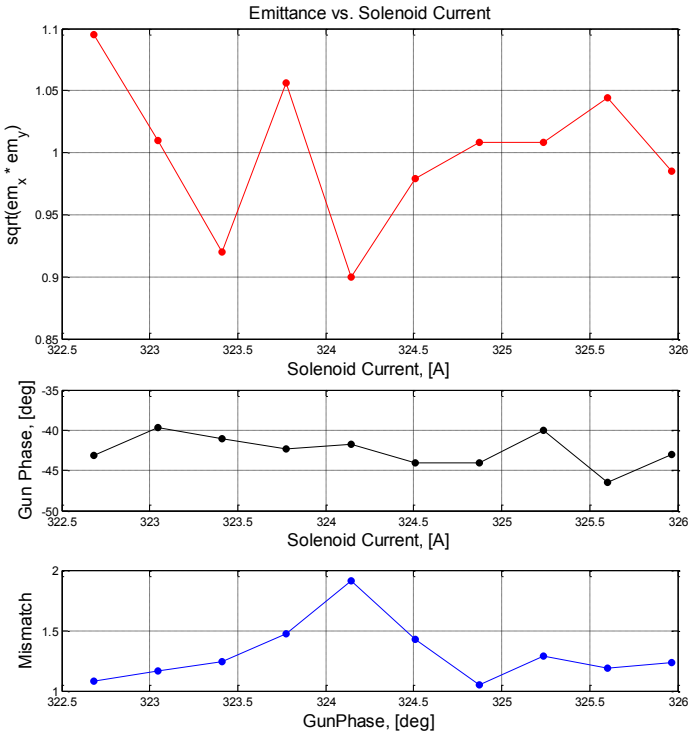
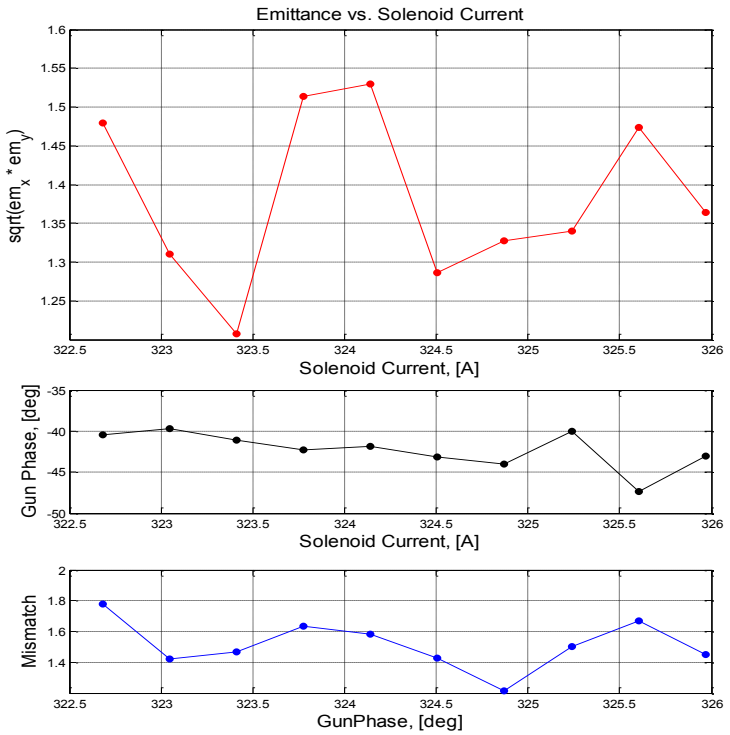
Evaluation of the Statistics: Solenoid Current Scan

Gaussian fit



rms fit



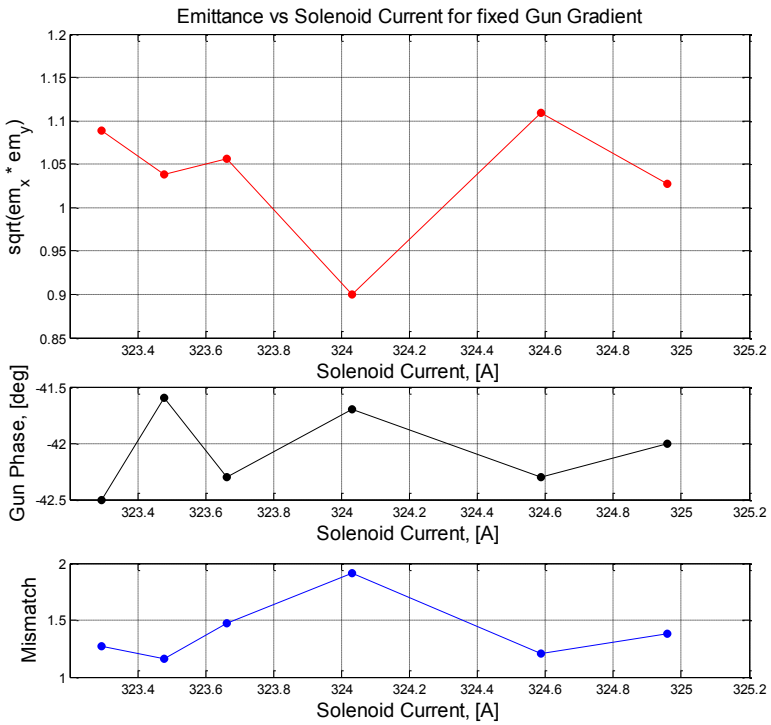
→ Tried the solenoid current in the range of 3.5A
→ Gun phase was not intendedly adjusted
→ Slope in the gun phase
→ Best emittance achieved for the solenoid current of 324.3A

Parameters:

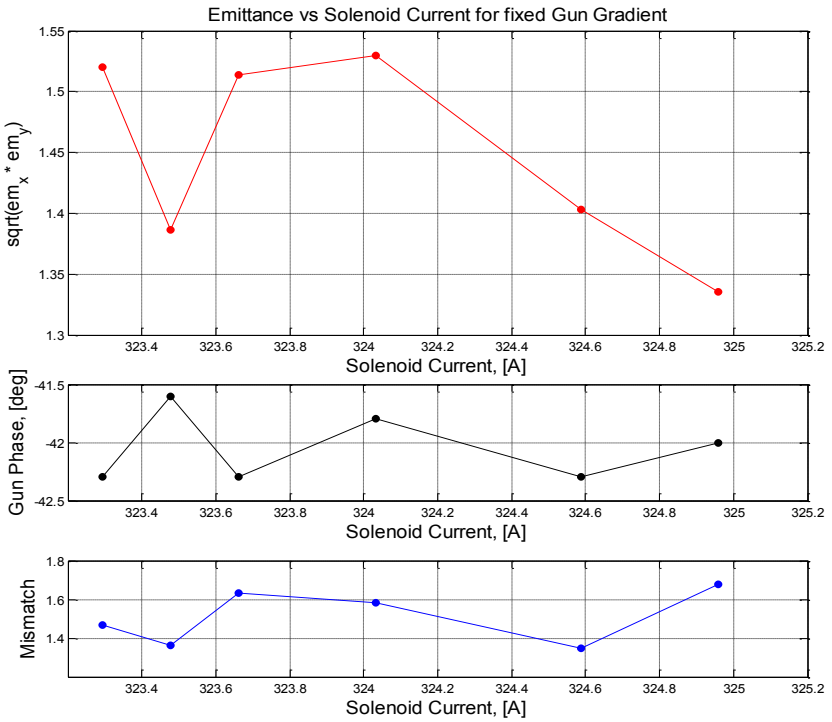
- GunV=53.0 MV/m
- Laser: Gauss, 6ps rms
- BSA=1.2mm,
- Q=500pC

Evaluation of the Statistics: Solenoid Current Scan

Gaussian fit



rms fit

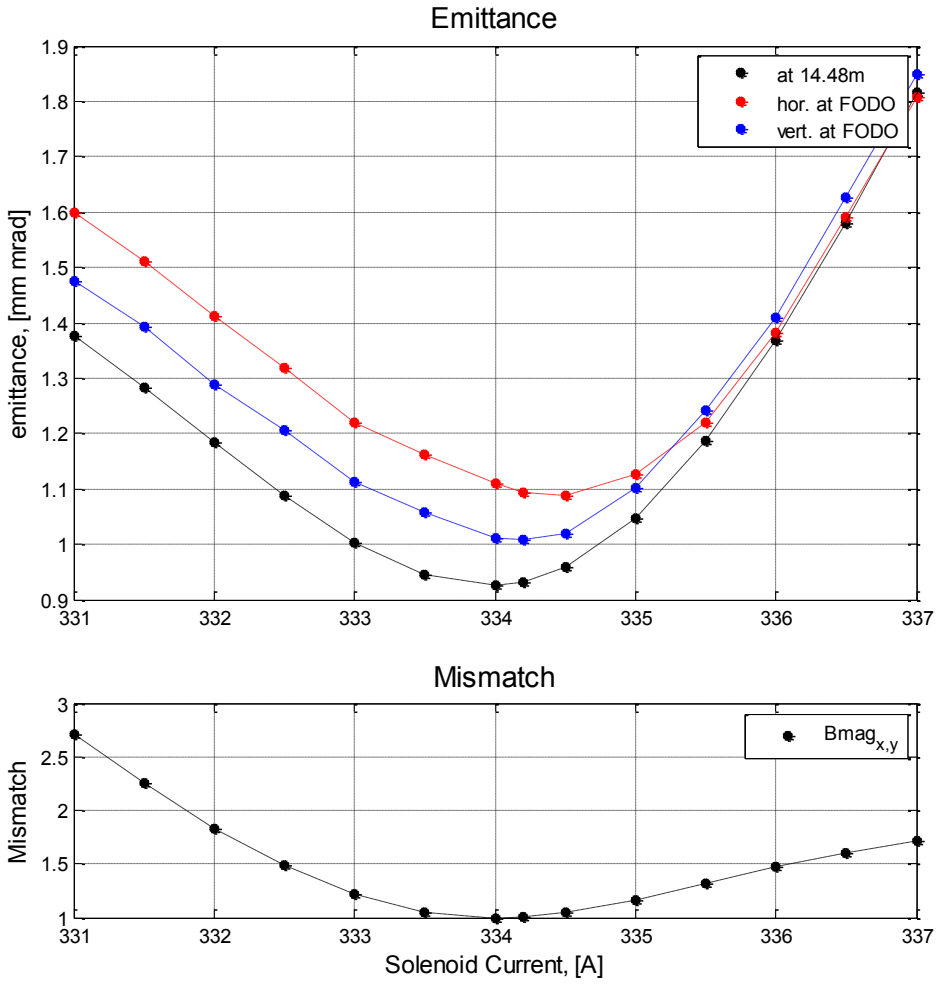


→ Tried the solenoid current in the range of 2.0A
→ Gun phase was fixed in the range of 1 deg
→ Best emittance achieved for the solenoid current of 324.3A

Parameters:

- GunV=53.0 MV/m
- Laser: Gauss, 6ps rms
- BSA=1.2mm,
- Q=500pC

Simulations: Solenoid Current Scan



- Simulations performed in 2 ways:

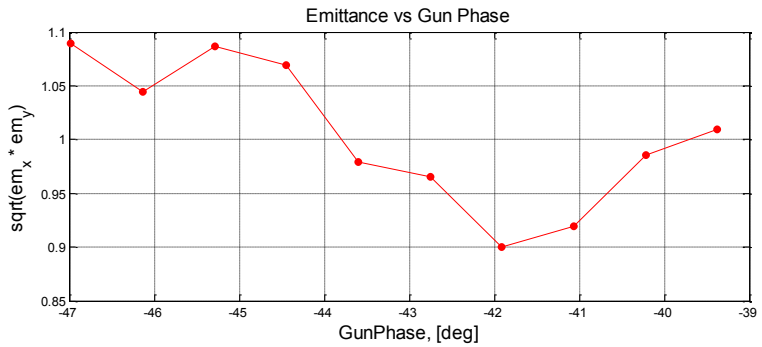
1. 2D-ASTRA till 14.48m
2. Xtrack from ASTRA file at 1.09m till 40m right after FODO section with taking into account wakes, coupler kick and SCR

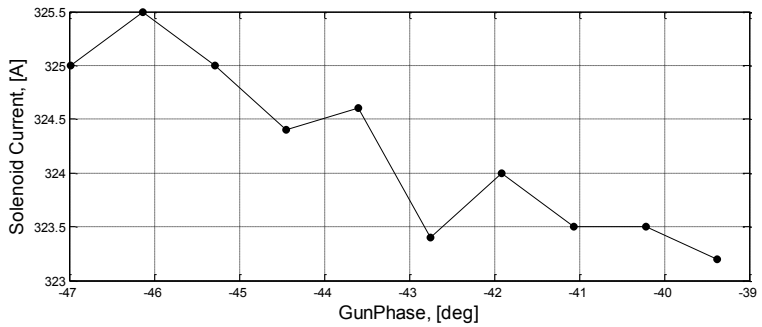
Parameters:

- GunV=53.0MV/m
- GunPhi=0.0, fixed
- Laser: Gauss, 6ps rms
- BSA=1.2mm,
- Q=500pC

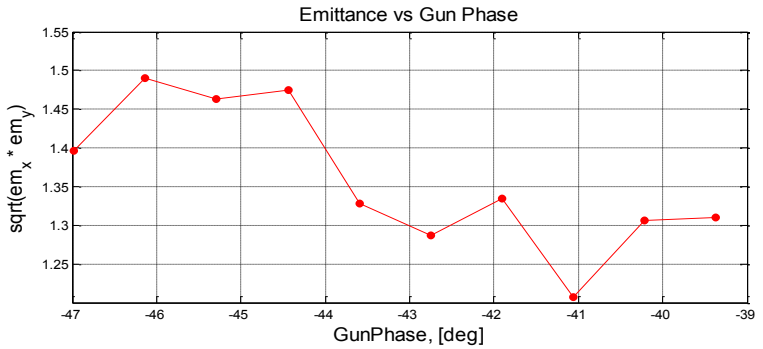
Evaluation of the Statistics: Gun Phase Scan

Gaussian fit





rms fit

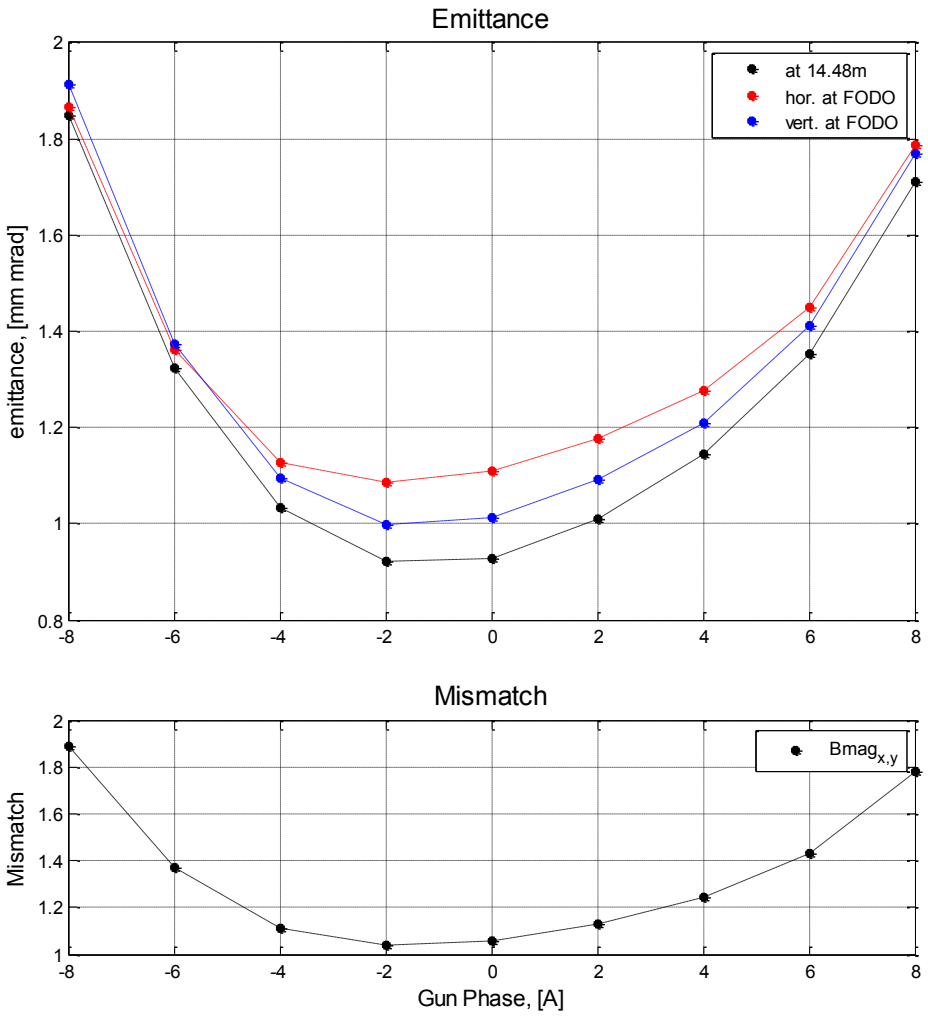


→ Tried the gun phase 9.0 deg
→ Solenoid current adjusted accordingly
→ Best emittance achieved for the gun phase around -41 deg with respect to the zero crossing

Parameters:

- GunV=53.0 MV/m
- Laser: Gauss, 6ps rms
- BSA=1.2mm,
- Q=500pC

Simulations: Gun Phase Scan



- Simulations performed in 2 ways:

1. 2D-ASTRA till 14.48m
2. Xtrack from ASTRA file at 1.09m till 40m right after FODO section with taking into account wakes, coupler kick and SCR

Parameters:

- GunV=53.0 MV/m
- Isol=334.2 A, fixed
- Laser: Gauss, 6ps rms
- BSA=1.2mm,
- Q=500pC