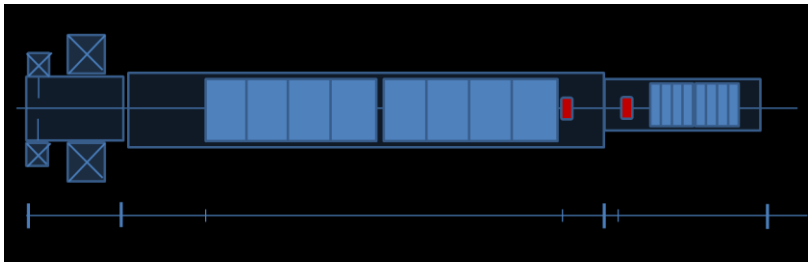
1. Working Points for Flat Top Laser Pulse Profile
2. Working Points for Gaussian Laser Pulse Profile
3. Combined Working Points for Flat Top, Single System
4. Combined WP for Flat Top with Two Lasers
5. Comparison FT vs Gauss for 1nC and S2E for Gaussian Case
6. Summary: Comparison Flat Top vs Gauss for 20pC Bunch Charge

Yauhen Kot

Summary for the S2E Meeting 12.08.2013

XFEL Photo Injector Setup for the BD Simulations

RF-Gun	Cathode Laser	Booster	ASTRA
Field Balance= 1.12	Temporal Profile: Flat Top 20/2ps Gauss 5.25-6.25ps rms (FWHM: 12.36-14.71ps)	ACC1: 8xTESLA cavities: 1st cavity centered at z=4.0401m → 1st iris at z=3.637m	200K particles
E_{cath}=60.00MV/m	Transverse: radial homogeneous	E_{peak}=34.42MV/m Phase=6.31 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)
- satisfy claimed design specifications → baseline UND
- matchable optics → β<60m, $|\alpha|$<4 @1st quadrupole
- 2 different bunch charges in the same bunch train
- etc…

1. Working Points for Flat Top Laser Pulse Profile

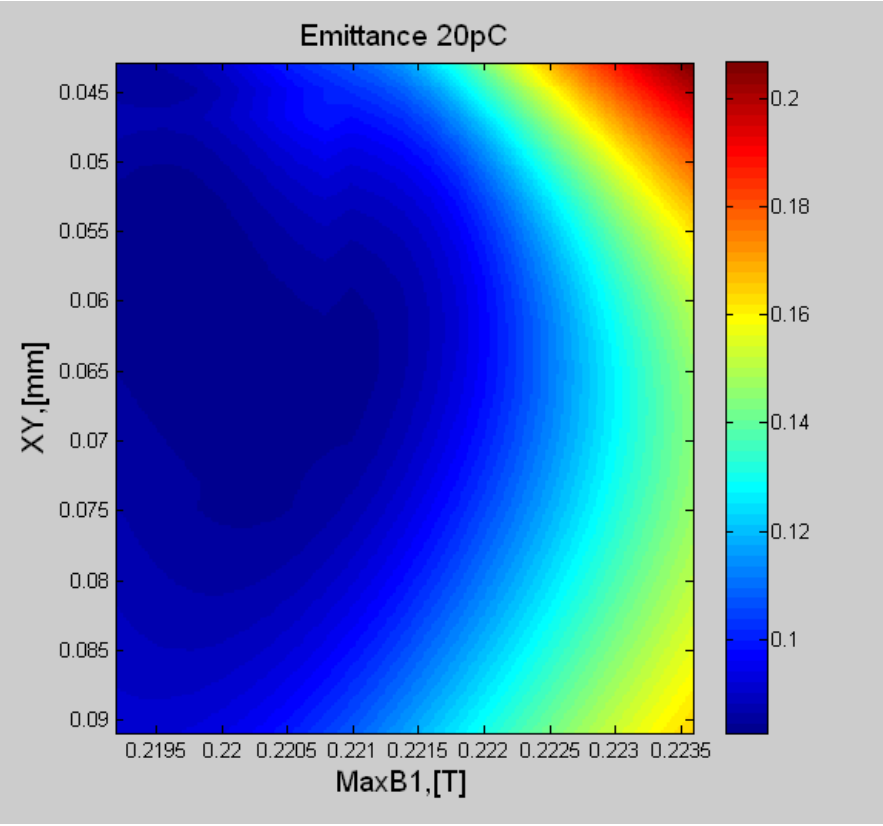
Working Points for the Operation with a Flat Top Laser pulse Profile (2/20\2ps) Summary at 1st Quadrupole

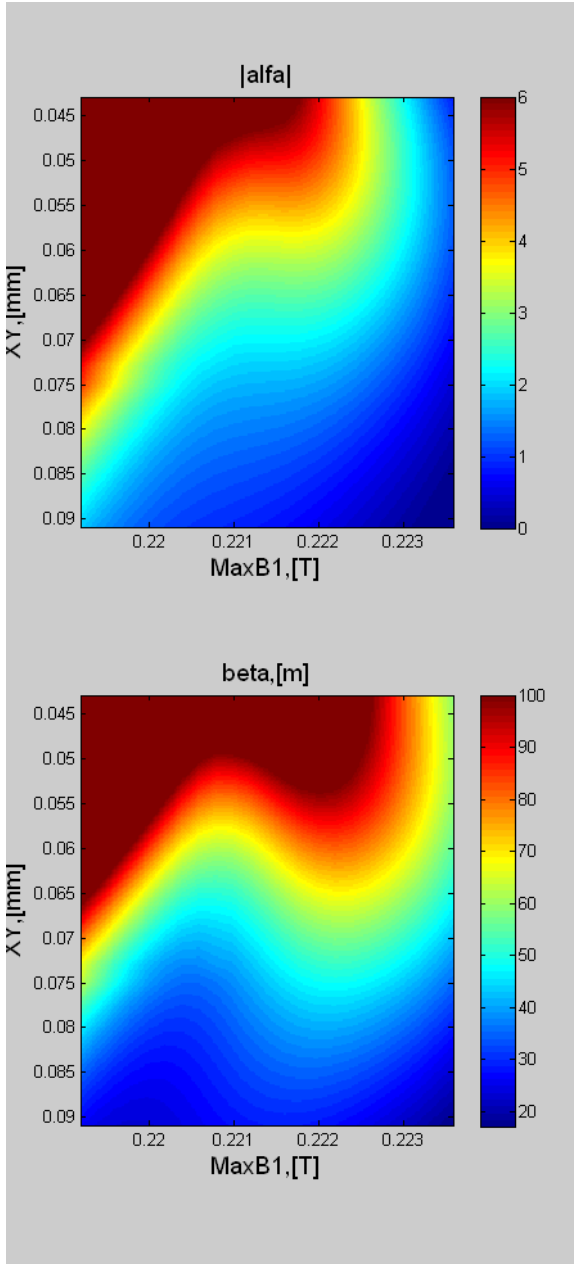
Q, [pC]	MaxB1, [T]	XYrms, [mm]	ε, [m^{-6}]	τ, [mm]	β, [m]	α
20	0.2196	0.057	0.0824	1.526	132.00	-9.483
100	0.2206	0.100	0.1925	1.818	161.10	-11.21
250	0.2220	0.180	0.2982	1.884	42.13	-2.305
500	0.2224	0.285	0.4391	1.944	19.81	-0.6045
1000	0.2226	0.440	0.7091	2.048	8.729	0.0299

Q, [pC]	$\varepsilon_{sl,av}$ [m^{-6}]	$\varepsilon_{sl,min}$ [m^{-6}]	$\varepsilon_{sl,max}$[m^{-6}]	$\delta E_{sl,av}$[keV]
20	0.057	0.055	0.059	0.30
100	0.13	0.12	0.15	0.38
250	0.23	0.18	0.27	0.58
500	0.40	0.27	0.43	0.70
1000	0.63	0.44	0.70	1.10

WP for 20pC, Flat Top 2/20\2ps

2D Scan vs MaxB1 and XY over [0.2194:0.2236]x[0.043:0.091], Step [0.0002:0.002]



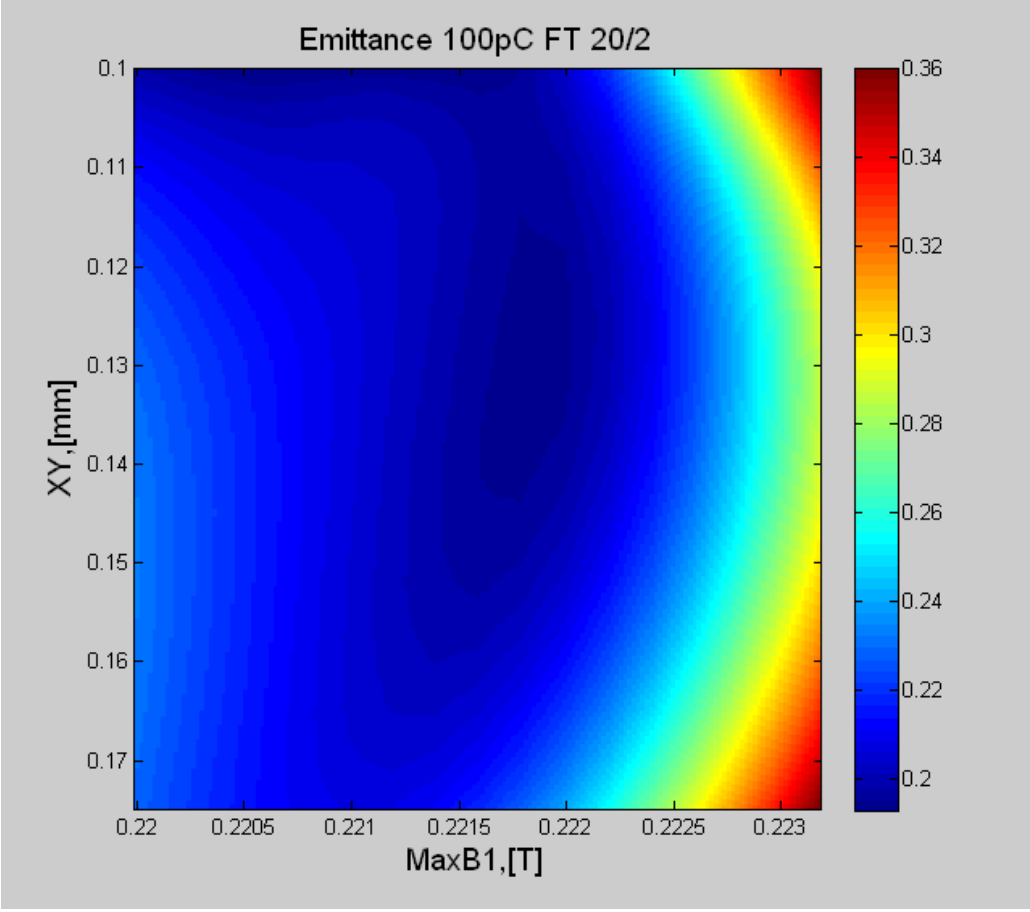


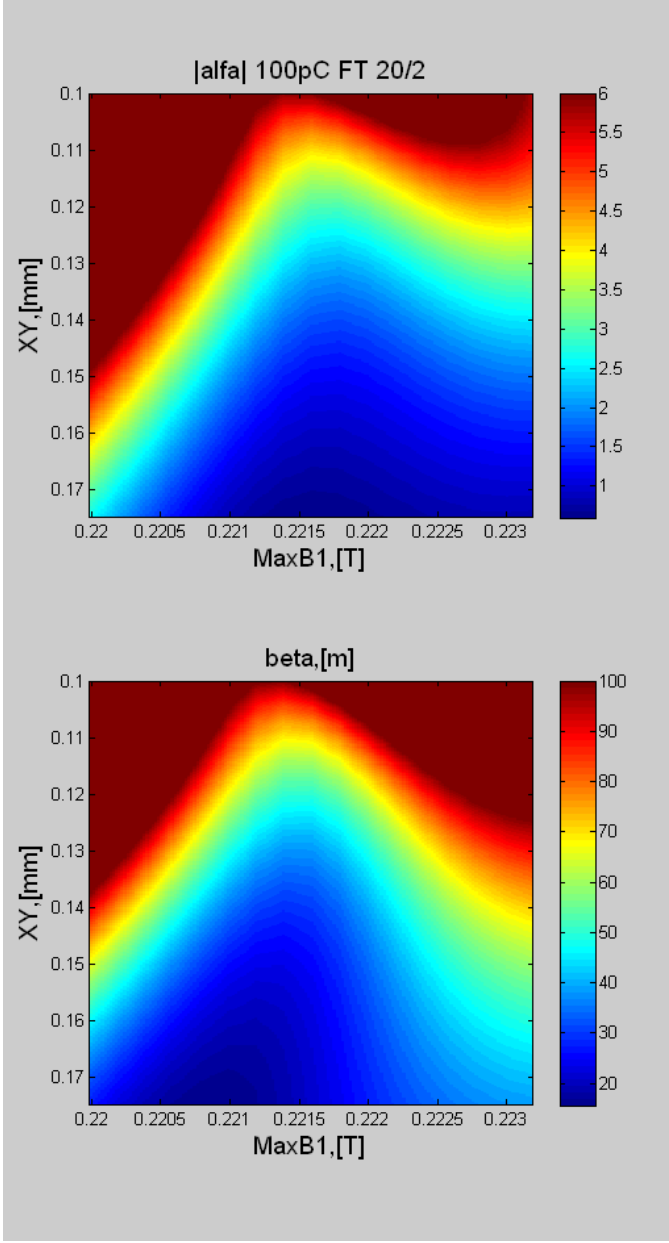
MaxB1, [T]	Xyrms, [mm]	ε, [m^{-6}]	τ, [mm]	β, [m]	α
0.2196	0.057	0.0824	1.526	132.00	-9.483

not matchable for the best emittance!

WP for 100pC, Flat Top 2/20\2ps

2D Scan vs MaxB1 and XY over [0.2200:0.2232]x[0.100:0.175], Step [0.0002:0.0025]



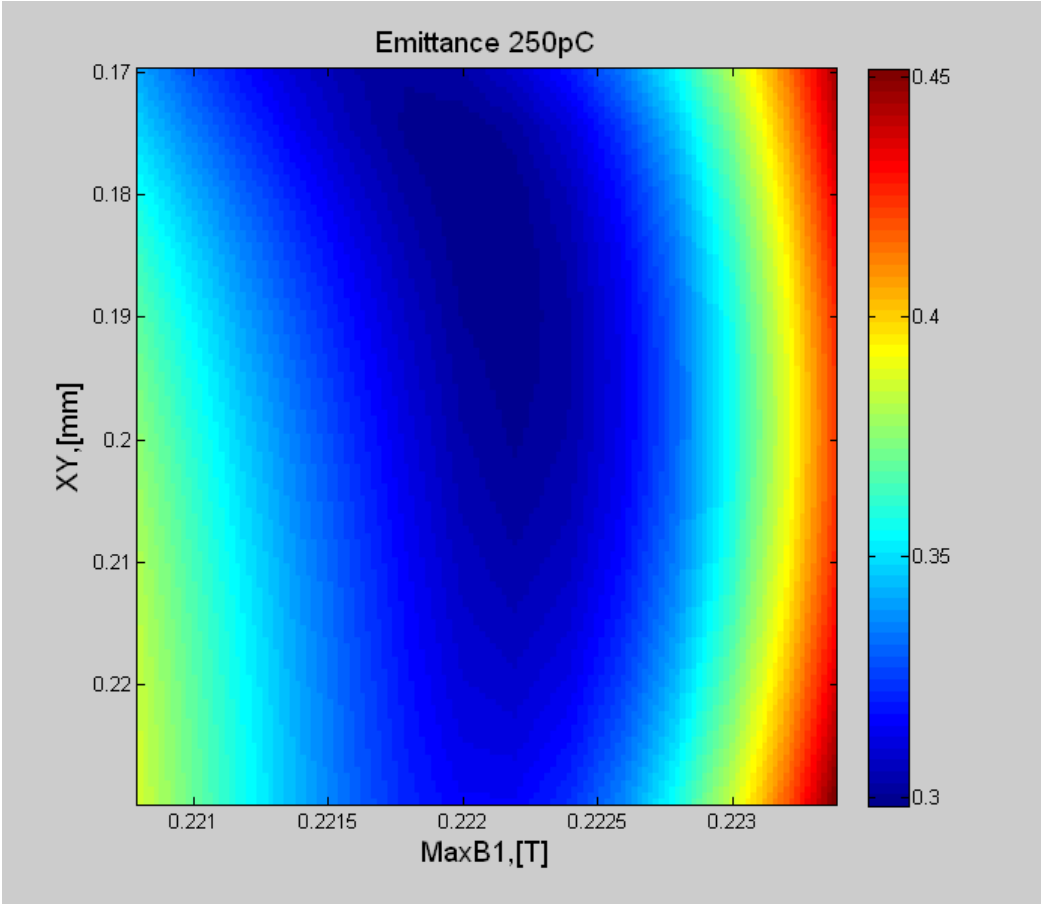


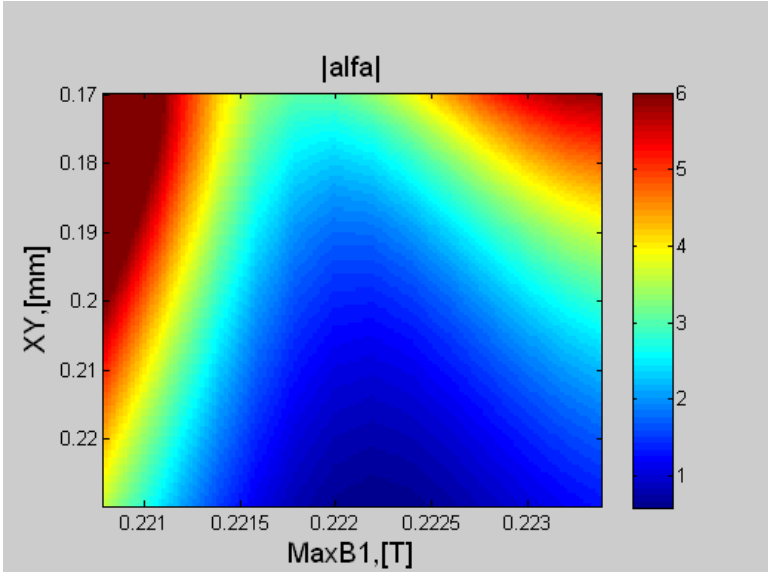
MaxB1, [T]	XYrms, [mm]	ε, [m^{-6}]	τ, [mm]	β, [m]	α
0.2206	0.100	0.1925	1.818	161.10	-11.21

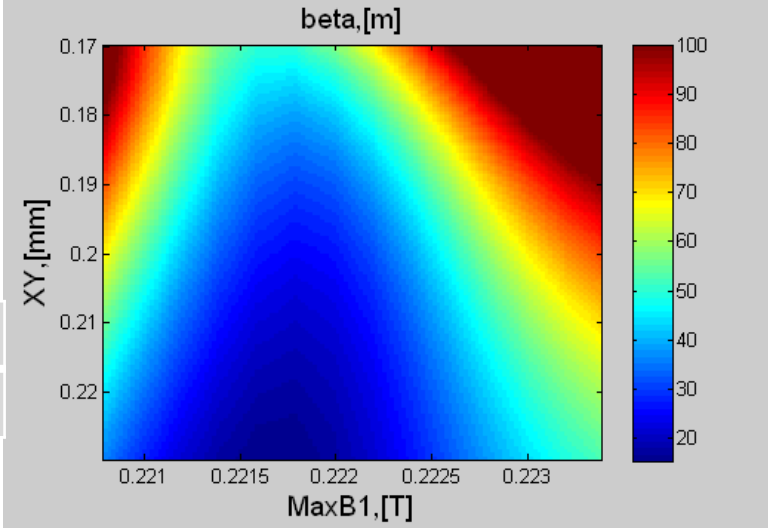
not matchable for the best emittance!

WP for 250pC, Flat Top 2/20\2ps

2D Scan vs MaxB1 and XY over [0.2208:0.2234]x[0.170:0.230], Step [0.0002:0.005]



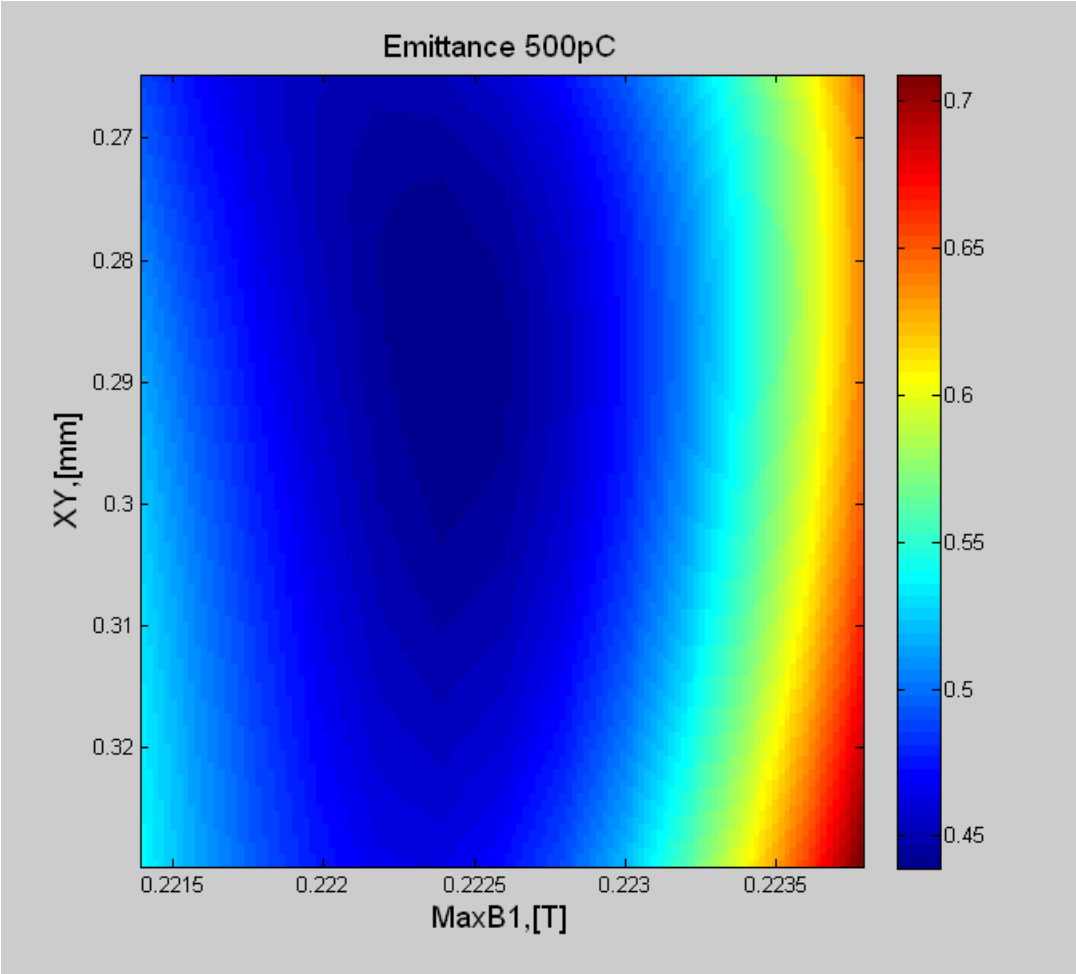


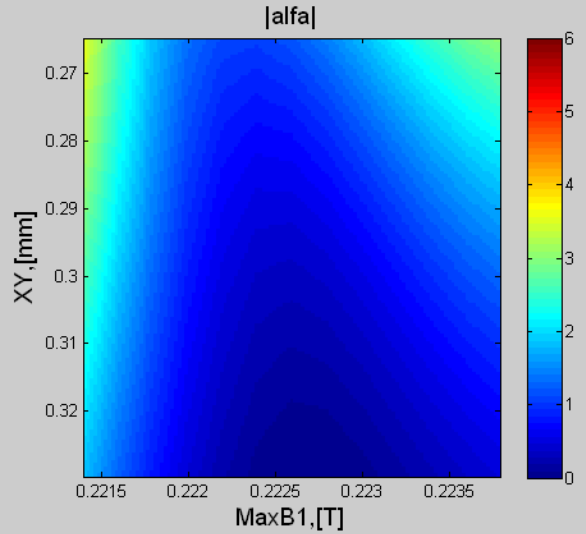


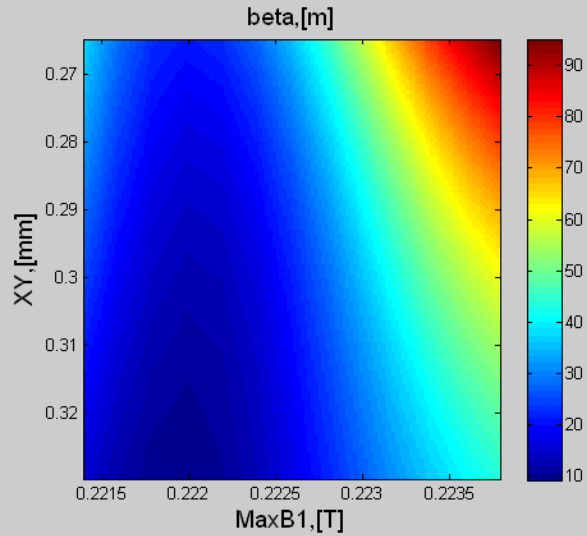
MaxB1, [T]	XYrms, [mm]	ε, [m^{-6}]	τ, [mm]	β, [m]	α
0.2220	0.180	0.2982	1.884	42.13	-2.305

WP for 500pC, Flat Top 2/20\2ps

2D Scan vs MaxB1 and XY over [0.2214:0.2238]x[0.265:0.330], Step [0.0002:0.005]



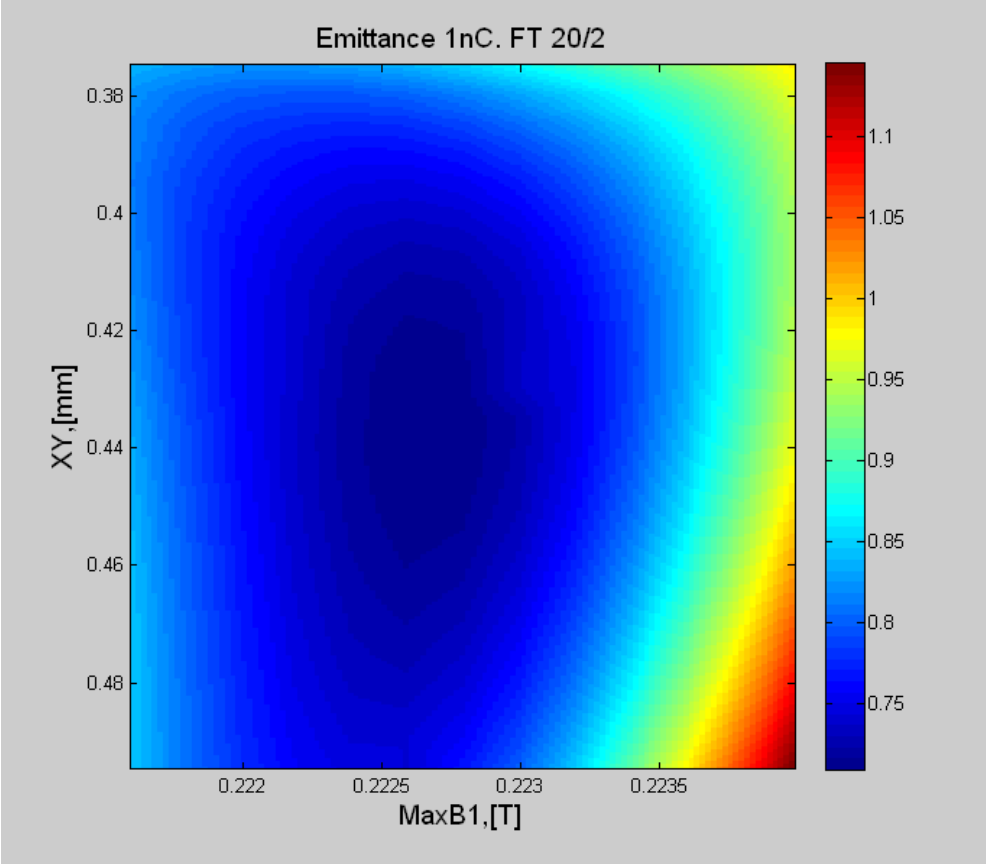


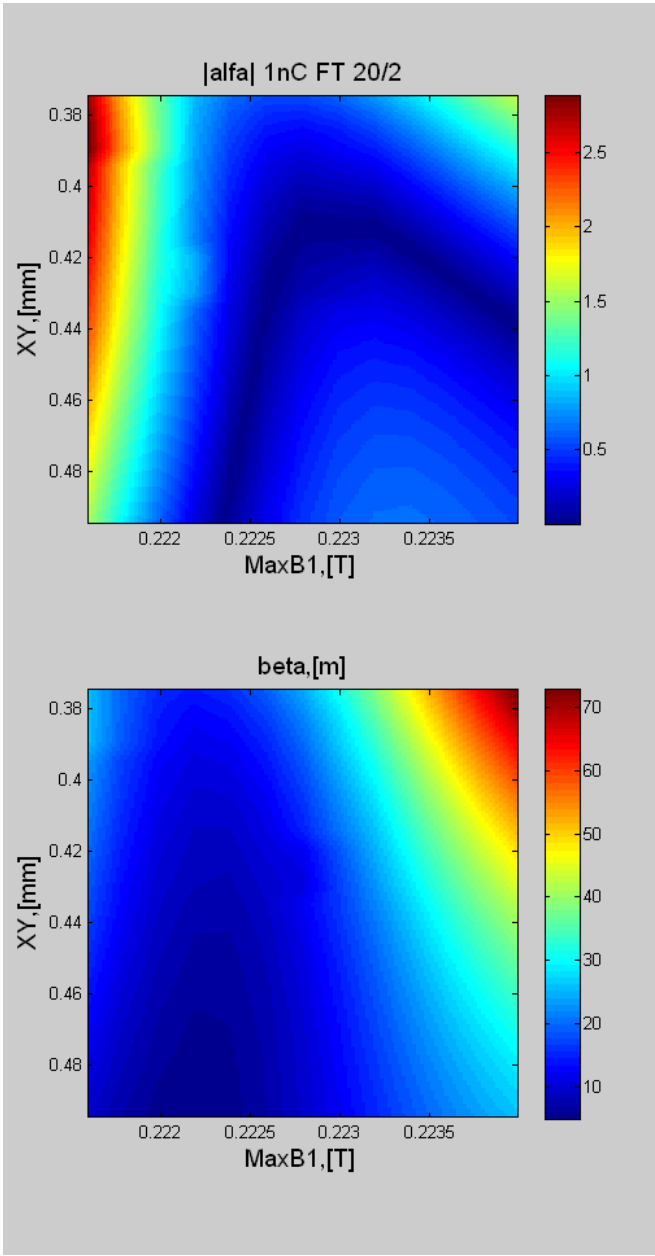


MaxB1, [T]	XYrms, [mm]	ε, [m^{-6}]	τ, [mm]	β, [m]	α
0.2224	0.285	0.4391	1.944	19.81	-0.6045

WP for 1nC, Flat Top 2/20\2ps

2D Scan vs MaxB1 and XY over [0.2216:0.2240]x[0.375:0.495], Step [0.0002:0.005]





MaxB1, [T]	XYrms, [mm]	ε, [m^{-6}]	τ, [mm]	β, [m]	α
0.2226	0.440	0.7091	2.048	8.729	0.0299

2. Working Points for Gaussian Laser Pulse Profile

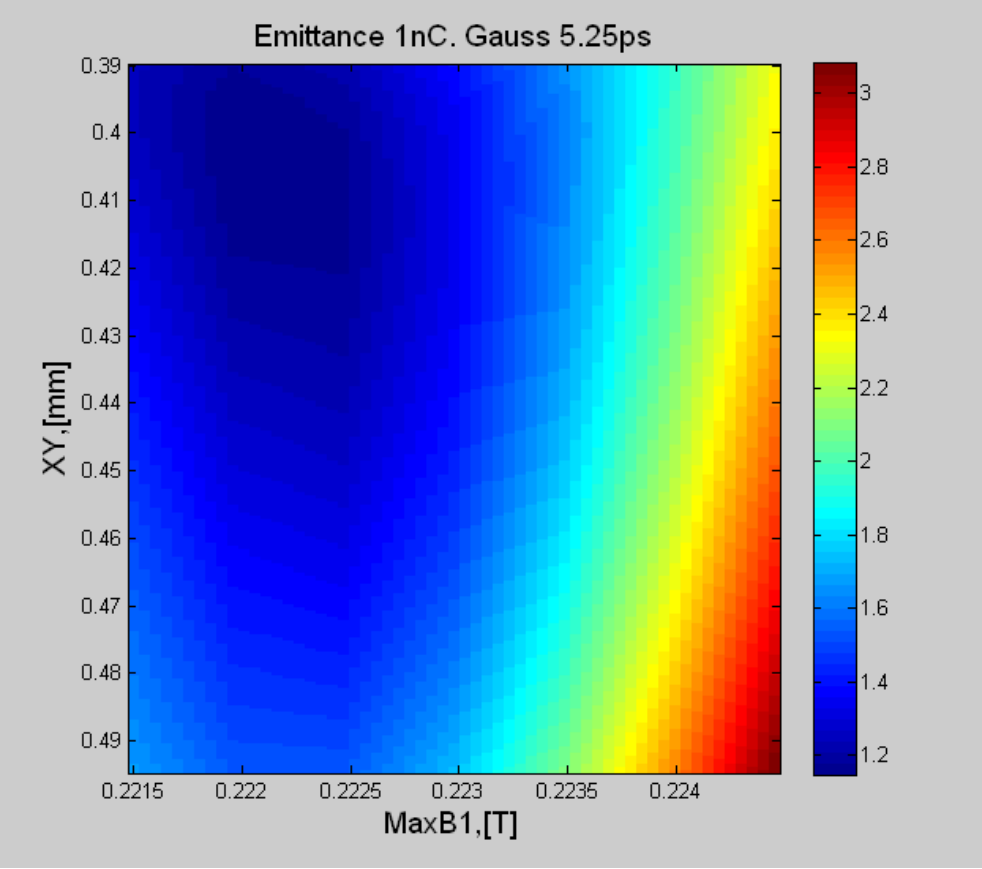
Working Points for the Operation with a Gaussian Laser Pulse Profile. Summary at 1st Quadrupole

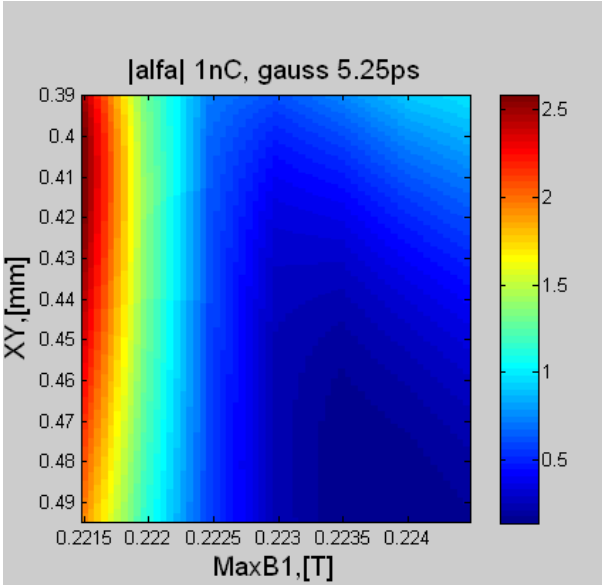
Q, [pC]	MaxB1, [T]	XYrms, [mm]	ε, [m^{-6}]	τ, [mm]	β, [m]	α
20			0.101	1.520		
100	0.2215	0.123	0.275	1.655	41.09	-2.573
250	0.2217	0.186	0.421	1.842	36.19	-2.355
500	0.2219	0.263	0.646	1.915	20.63	-1.447
1000	0.2221	0.404	1.107	2.103	13.22	-0.994

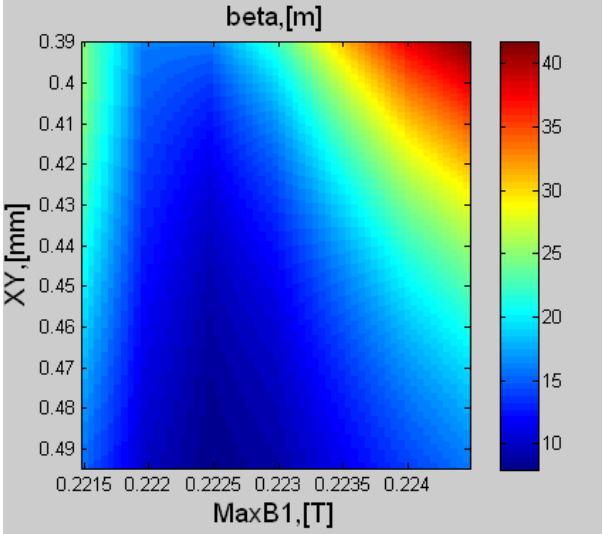
Q, [pC]	τ_{laser}[mm]	$\varepsilon_{sl,av}$ [m^{-6}]	$\varepsilon_{sl,min}$ [m^{-6}]	$\varepsilon_{sl,max}$[m^{-6}]	$\delta E_{sl,av}$[keV]
20	6.50	0.063	0.060	0.064	0.35
100	5.75	0.155	0.109	0.164	0.42
250	5.60	0.25	0.170	0.34	0.70
500	5.25	0.45	0.28	0.58	1.10
1000	5.25	0.75	0.45	0.98	2.0

WP for 1nC, Gauss 5.25ps rms

2D Scan vs MaxB1 and XY over [0.2215:0.2245]x[0.390:0.495], Step [0.0005:0.005]



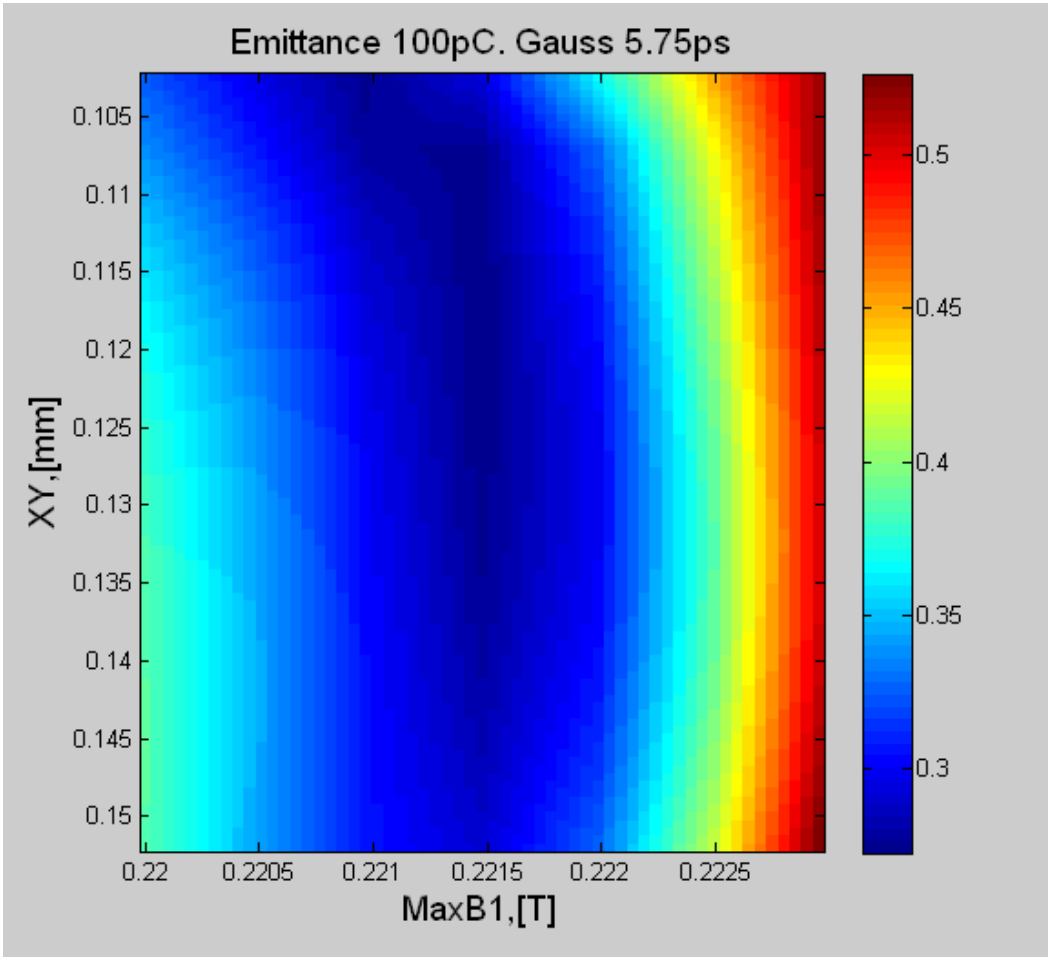


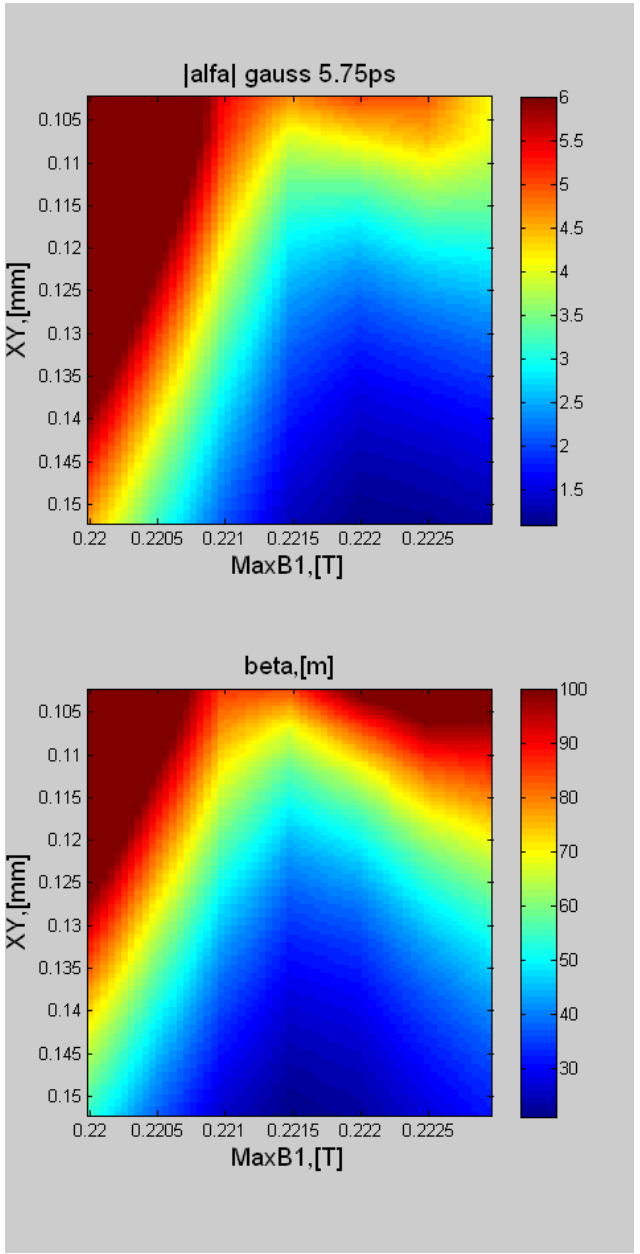


MaxB1, [T]	XYrms, [mm]	ε, [m^{-6}]	τ, [mm]	β, [m]	α
0.2220	0.400	1.148	2.127	15.29	-1.379

WP for 100pC, Gauss 5.75ps rms

2D Scan vs MaxB1 and XY over [0.2200:0.2230]x[0.1025:0.1525], Step [0.0005:0.005]

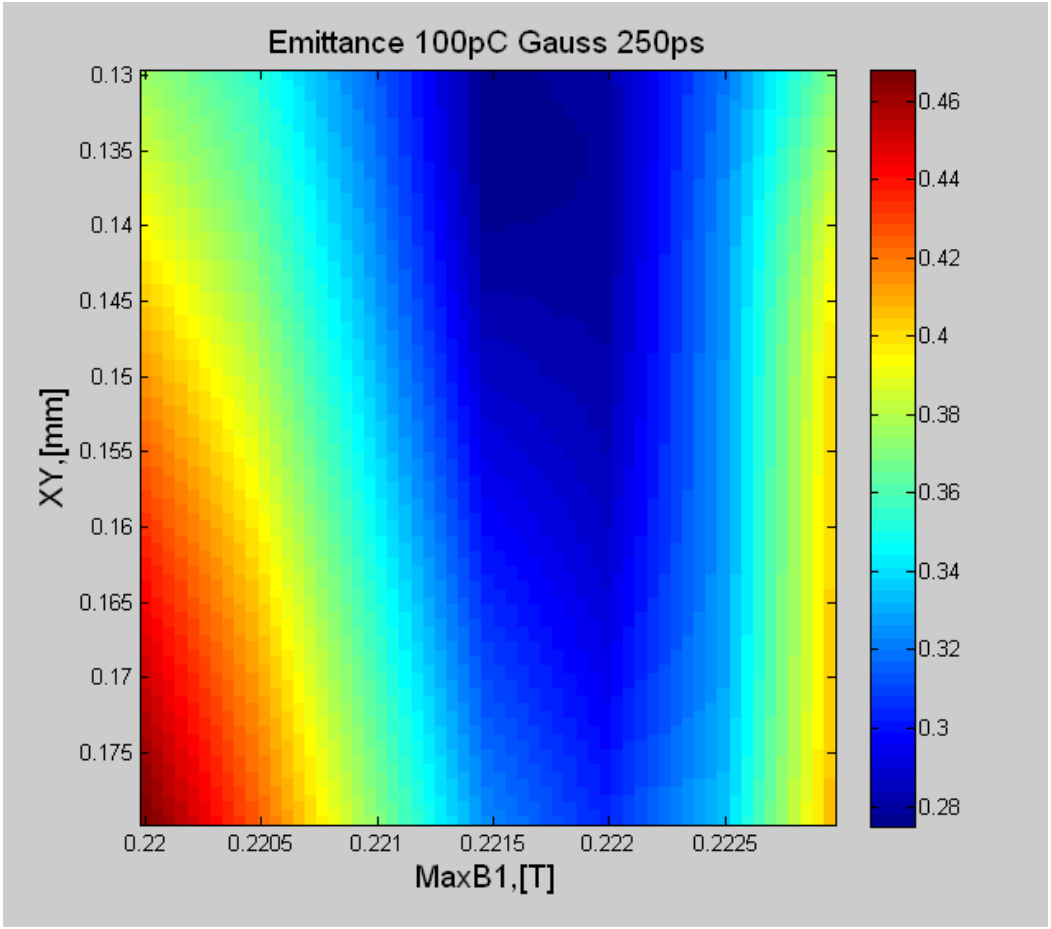


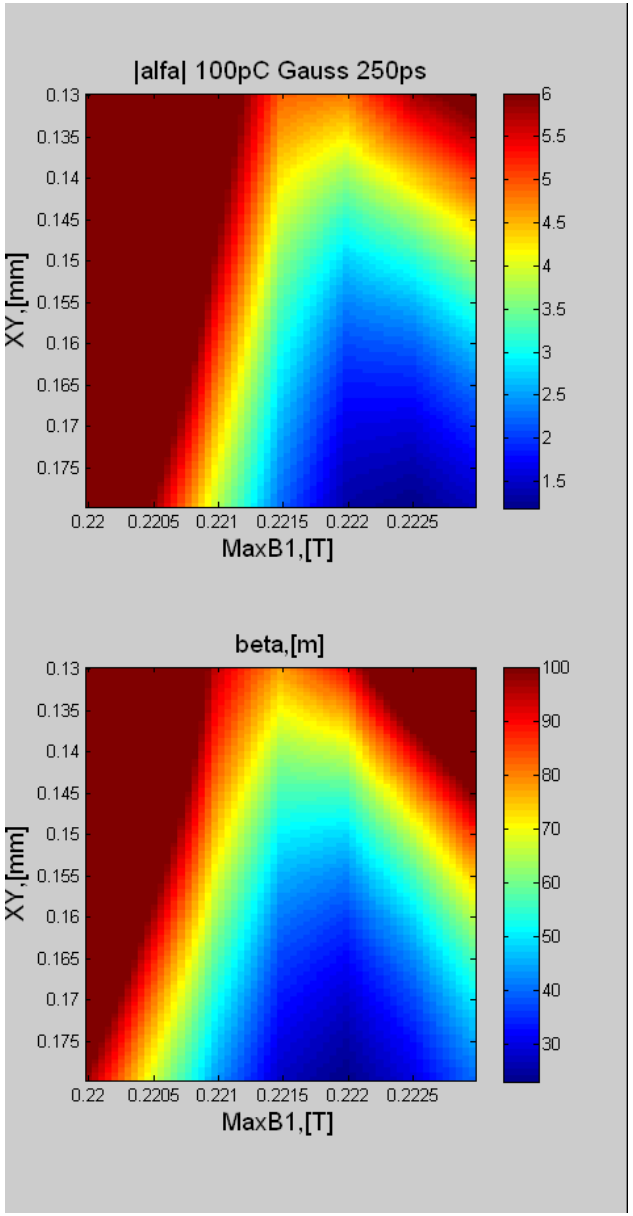


MaxB1, [T]	XYrms, [mm]	ε, [m^{-6}]	τ, [mm]	β, [m]	α
0.2215	0.1175	0.2723	1.685	48.27	-3.01

WP for 100pC, Gauss 2.50ps rms

2D Scan vs MaxB1 and XY over [0.2200:0.2230]x[0.1025:0.1525], Step [0.0005:0.005]

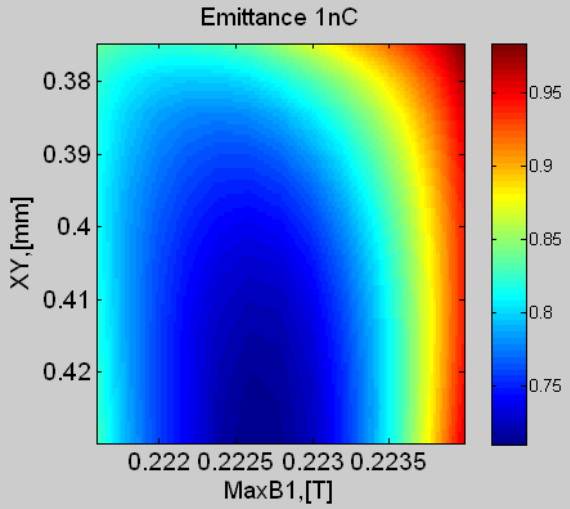


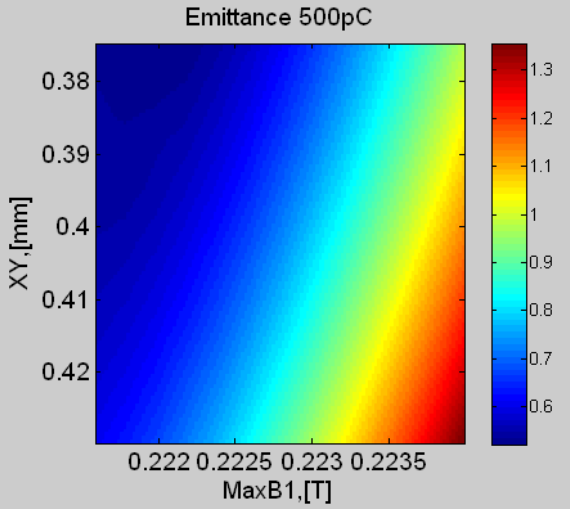


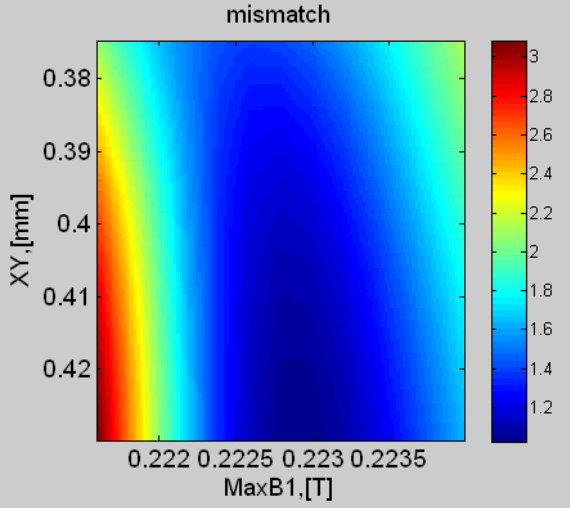
MaxB1, [T]	XYrms, [mm]	ε, [m^{-6}]	τ, [mm]	β, [m]	α
0.2215	0.135	0.2750	1.123	70.78	-4.621

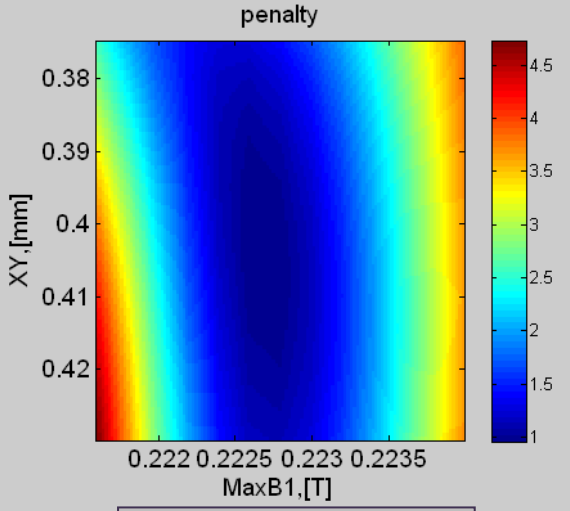
3. Combined Working Points for Flat Top, Single System

Combined Working Point for 1nC with 500pC, Flat Top Laser Pulse 20/2ps









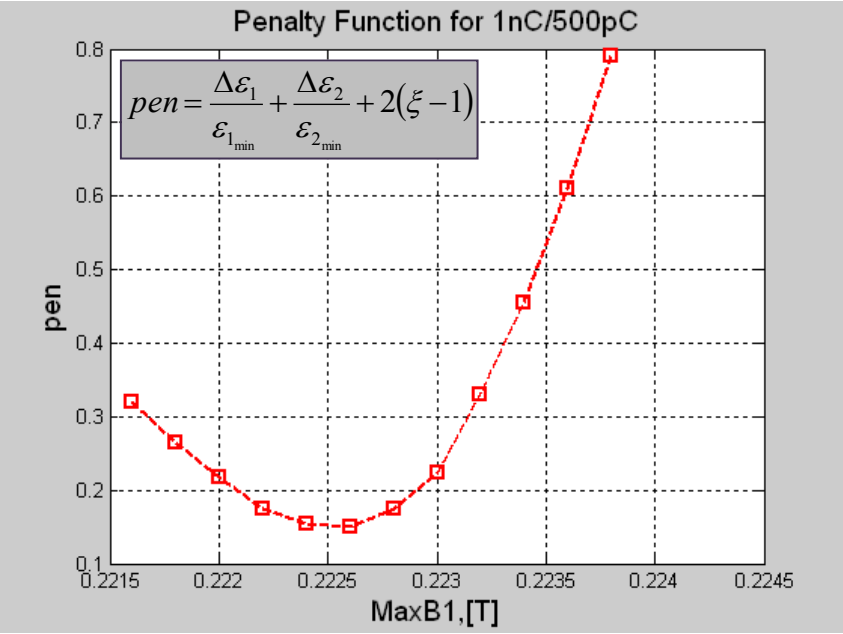
$$pen = \frac{\Delta\varepsilon_1}{\varepsilon_{1_{min}}} + \frac{\Delta\varepsilon_2}{\varepsilon_{2_{min}}} + 2(\xi - 1)$$

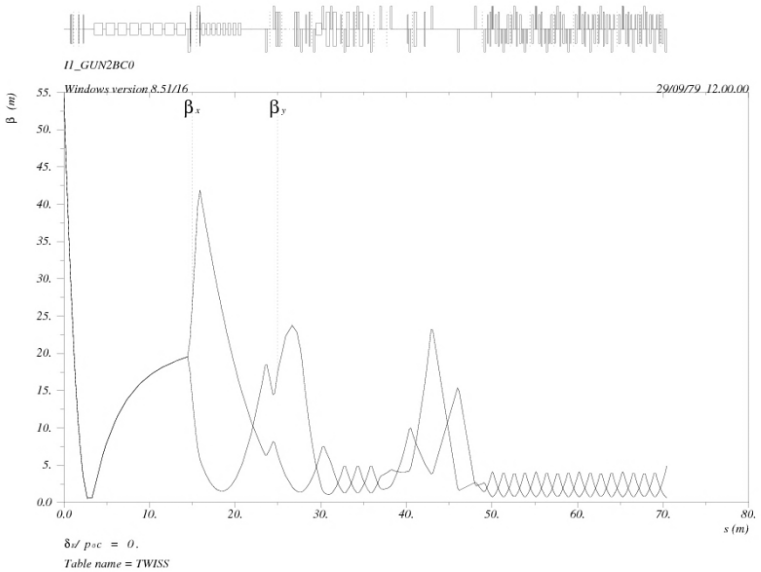
Parameter	Value
MaxB1, [T]	0.2226
XYrms, [mm]	0.400
ε_{1nC}	0.7384
$\Delta\varepsilon_{1nC,\,[\%]}$	4.13
ε_{500pC}	0.6661
$\Delta\varepsilon_{500pC,\,[\%]}$	51.7
Mismatch ξ	1.194
Penalty	0.9569

Optics at CWP

β_{1nC}, [m]	13.14
α_{1nC}	-0.2244
β_{500pC}, [m]	14.32
α_{500pC}	0.4002

Operation with Two Lasers on Cathode: 1nC/500pC

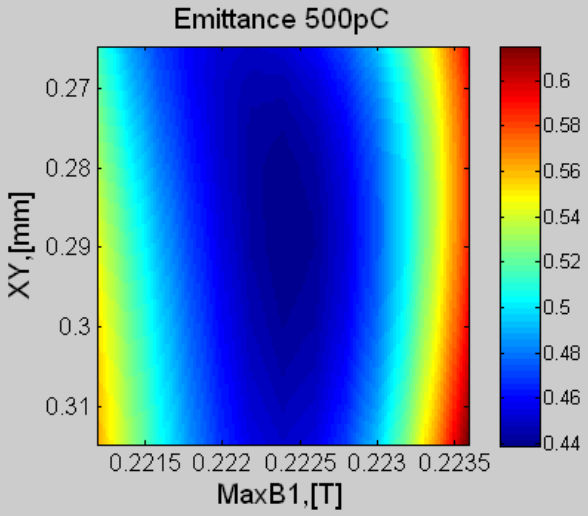


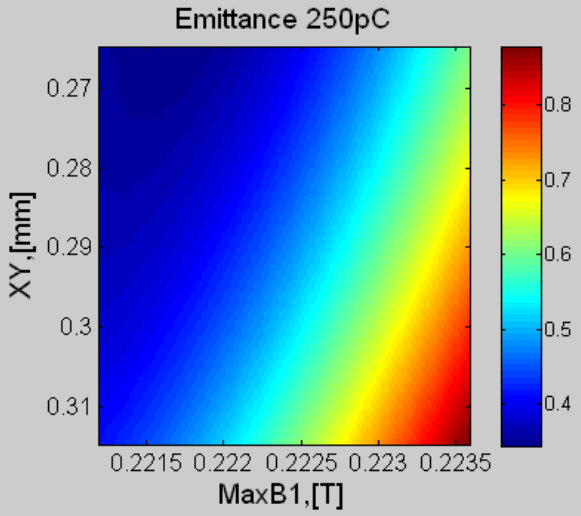


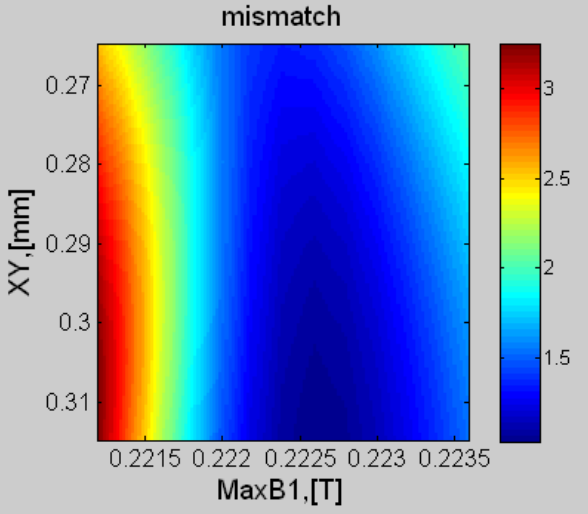
	Cathode Parameters			Beam Parameters @ 1st Quadrupole					
	MaxB1,[T]	XY_1,[mm]	XY_2,[mm]	ε_1,[μm]	ε_2,[μm]	β, [m]	α	ξ	pen
2 bunches	0.2226	0.395	0.310	0.7492	0.4506	19.55	-0.1938	1.0675	0.1502
1 bunch	0.2226/0.2224	0.440	0.285	0.7091	0.4391	8.73/19.81	0.03/-0.605	1.194	0.9569

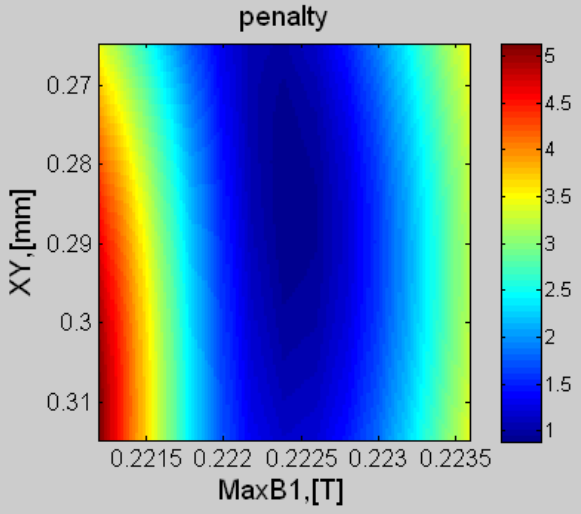
→ **pen reduces to 0.1502 compared to 0.9569 for the case of a single laser**

Combined Working Point for 500pC with 250pC, Flat Top Laser Pulse 20/2ps









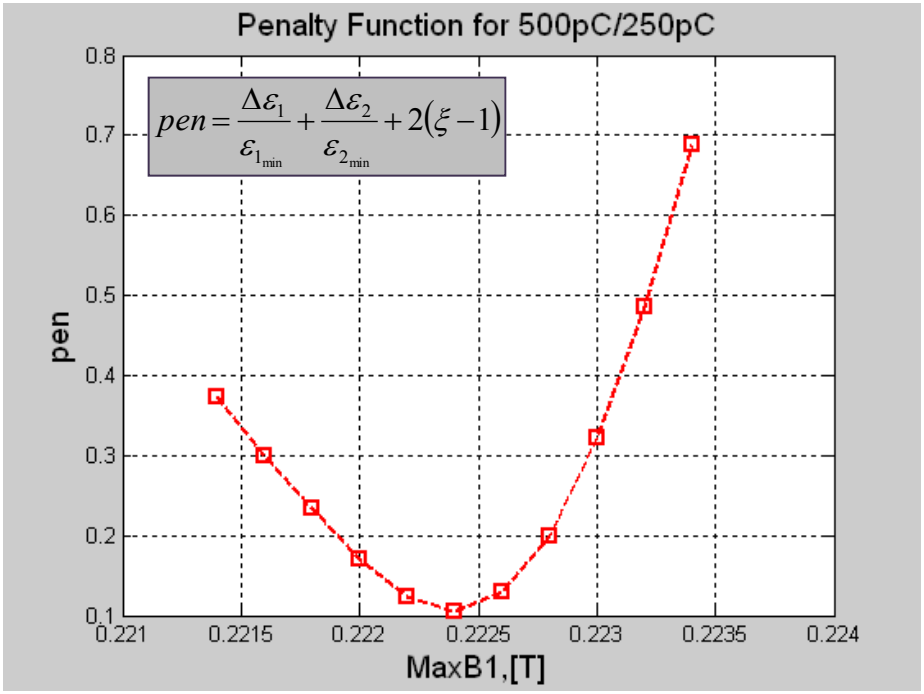
$$pen = \frac{\Delta\varepsilon_1}{\varepsilon_{1_{min}}} + \frac{\Delta\varepsilon_2}{\varepsilon_{2_{min}}} + 2(\xi - 1)$$

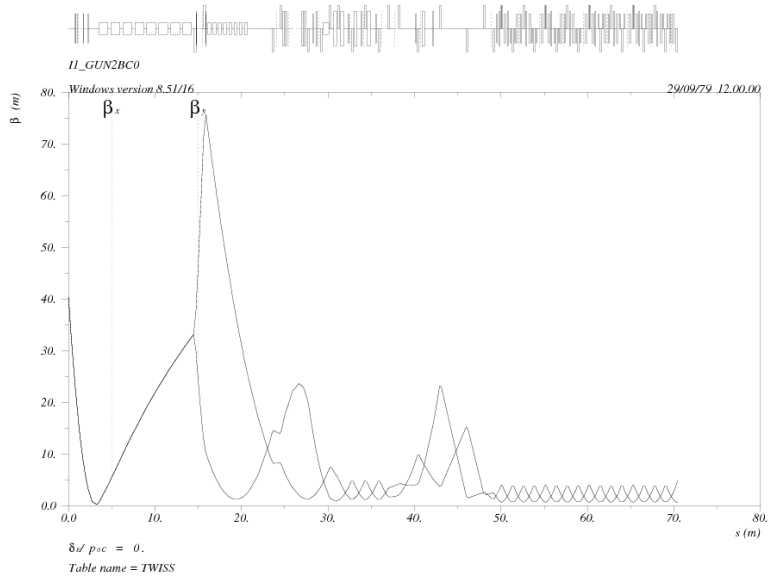
Parameter	Value
MaxB1, [T]	0.2224
XYrms, [mm]	0.2850
ε_{500pC}	0.4391
$\Delta\varepsilon_{500pC,[\%]}$	0.0
ε_{250pC}	0.4501
$\Delta\varepsilon_{250pC,[\%]}$	50.1
Mismatch ξ	1.192
Penalty	0.8869

Optics at CWP

β_{500pC}, [m]	19.81
α_{500pC}	-0.6045
β_{250pC}, [m]	20.14
α_{250pC}	0.0102

Operation with Two Lasers on Cathode: 500pC/250pC

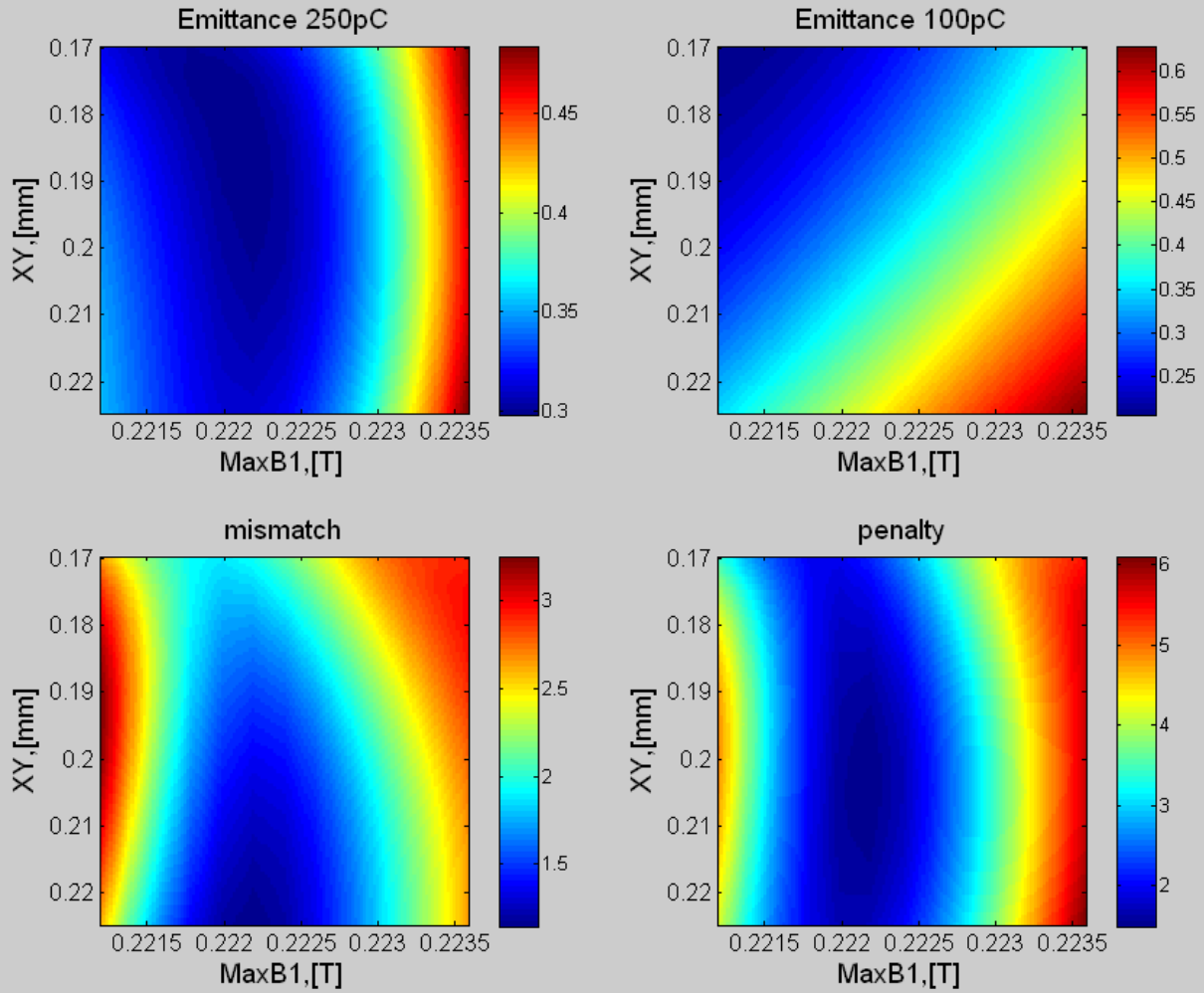




	Cathode Parameters			Beam Parameters @ 1st Quadrupole					
	MaxB1,[T]	XY_1,[mm]	XY_2,[mm]	ε_1,[μm]	ε_2,[μm]	β, [m]	α	ξ	pen
2 bunches	0.2224	0.265	0.210	0.4522	0.3069	33.18	-1.115	1.0264	0.1058
1 bunch	0.2224/0.2220	0.285	0.180	0.4392	0.2999	19.81/42.13	-0.605/-2.31	1.192	0.8869

→ **pen reduces to 0.1058 compared to 0.8869 for the case of a single laser**

Combined Working Point for 250pC with 100pC, Flat Top Laser Pulse 20/2ps



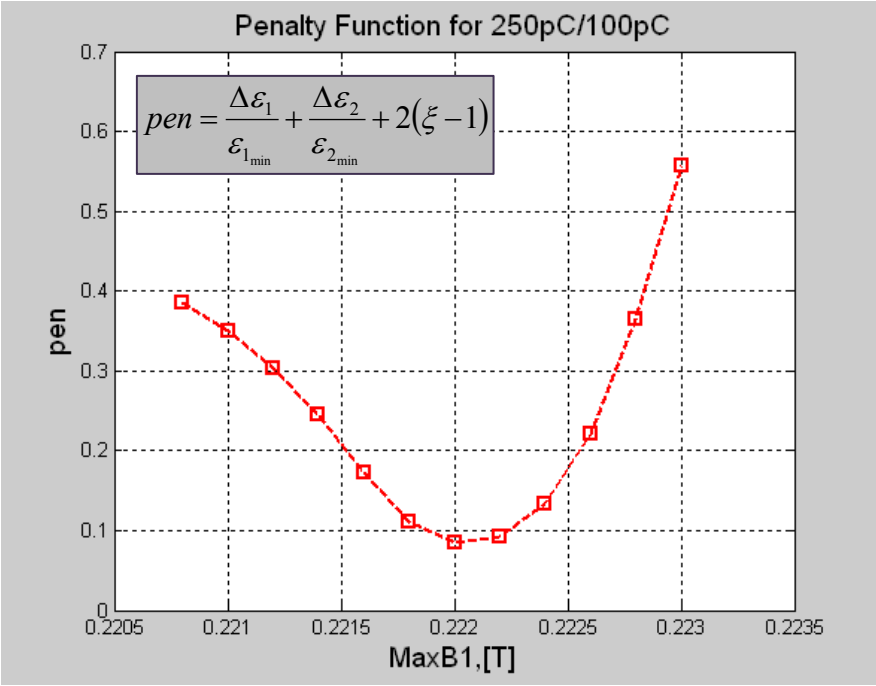
$$pen = \frac{\Delta\varepsilon_1}{\varepsilon_{1_{min}}} + \frac{\Delta\varepsilon_2}{\varepsilon_{2_{min}}} + 2(\xi - 1)$$

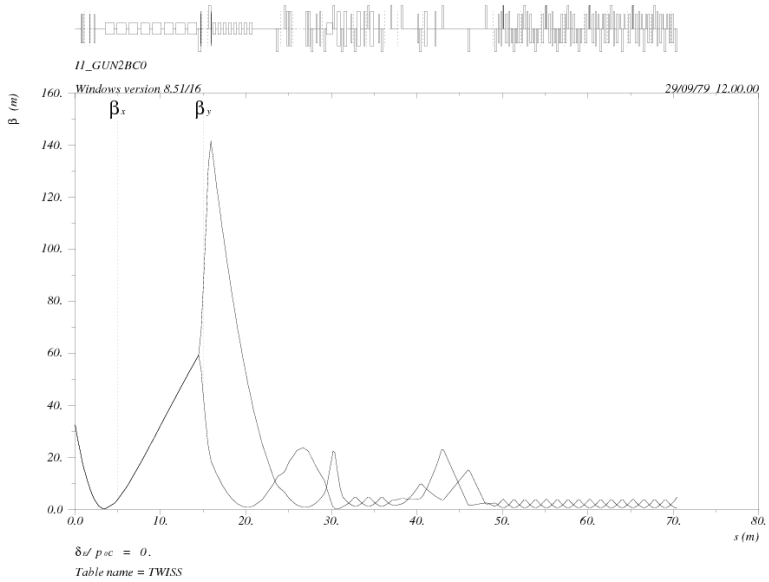
Parameter	Value
MaxB1, [T]	0.2222
XYrms, [mm]	0.2050
ε_{250pC}	0.3050
$\Delta\varepsilon_{250pC,[\%]}$	1.71
ε_{100pC}	0.3400
$\Delta\varepsilon_{250pC,[\%]}$	74.8
Mismatch ξ	1.4030
Penalty	1.4871

Optics at CWP

β_{250pC}, [m]	24.21
α_{250pC}	-1.223
β_{100pC}, [m]	22.28
α_{100pC}	-2.677

Operation with Two Lasers on Cathode: 250pC/100pC



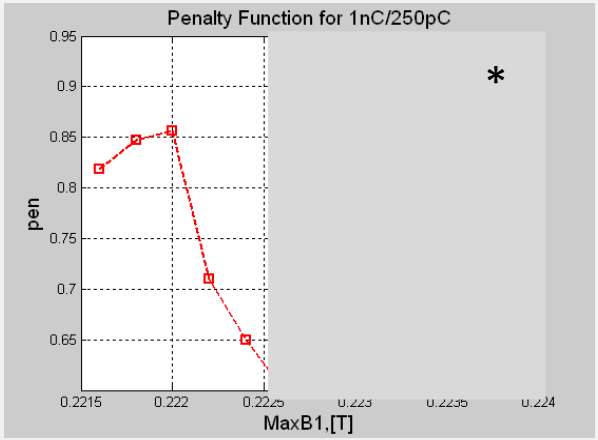


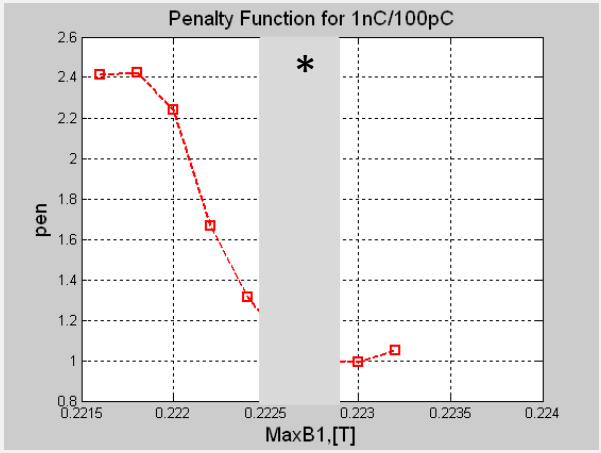
	Cathode Parameters			Beam Parameters @ 1st Quadrupole					
	MaxB1,[T]	XY_1,[mm]	XY_2,[mm]	ε_1,[μm]	ε_2,[μm]	β, [m]	α	ξ	pen
2 bunches	0.2220	0.170	0.1225	0.3031	0.1949	59.39	-2.931	1.0342	0.0842
1 bunch	0.2220/0.2218	0.180	0.135	0.2999	0.1939	42.13/37.36	-2.31/-1.87	1.4030	1.4871

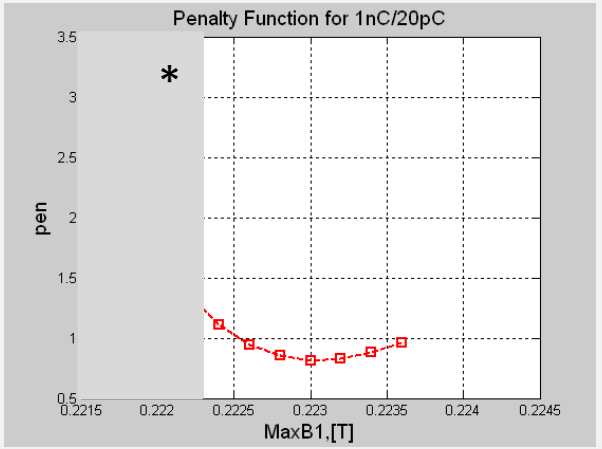
→ pen reduces to 0.0842 compared to 1.4871 for the case of a single laser

4. Combined WP for Flat Top with Two Lasers

Combined WP for 1nC with Low Charges and Two lasers







Parameter	CWP	Single WP
MaxB1, [T]	0.2226	0.2226/0.2220
XY, [mm]	0.375/0.230	0.440/0.180
ε_{1nC},[m^{-6}]	0.840	0.709
ε_{250pC},[m^{-6}]	0.337	0.298
ξ	1.1473	
pen	0.6027	

Parameter	CWP	Single WP
MaxB1, [T]	0.2230	0.2226/0.2206
XY, [mm]	0.375/0.168	0.440/0.100
ε_{1nC},[m^{-6}]	0.871	0.709
ε_{100pC},[m^{-6}]	0.317	0.193
ξ	1.0647	
pen	0.9916	

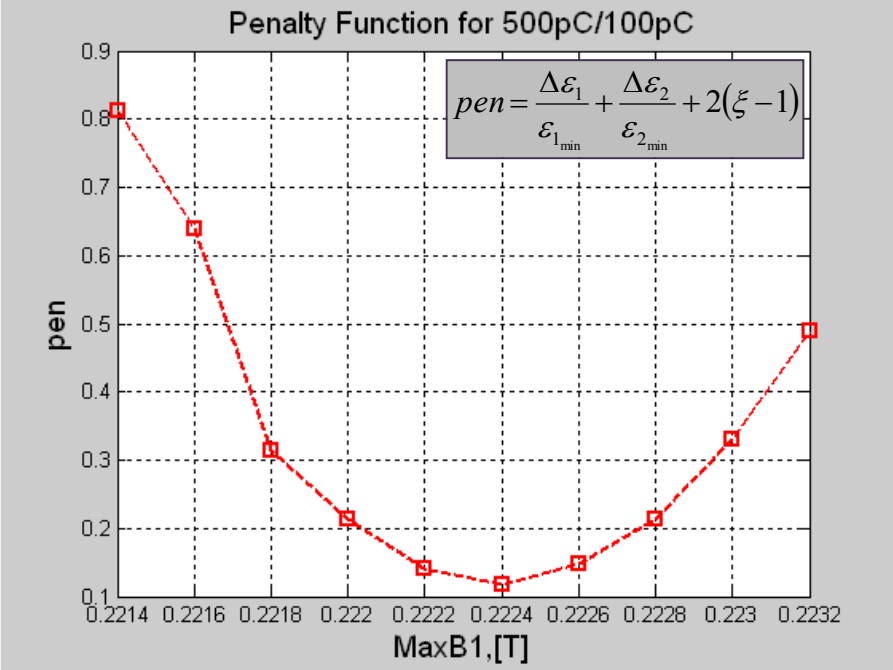
Parameter	CWP	Single WP
MaxB1, [T]	0.2230	0.2226/0.2196
XY, [mm]	0.390/0.081	0.440/0.057
ε_{1nC},[m^{-6}]	0.785	0.709
ε_{020pC},[m^{-6}]	0.138	0.0824
ξ	1.0448	
pen	0.8139	

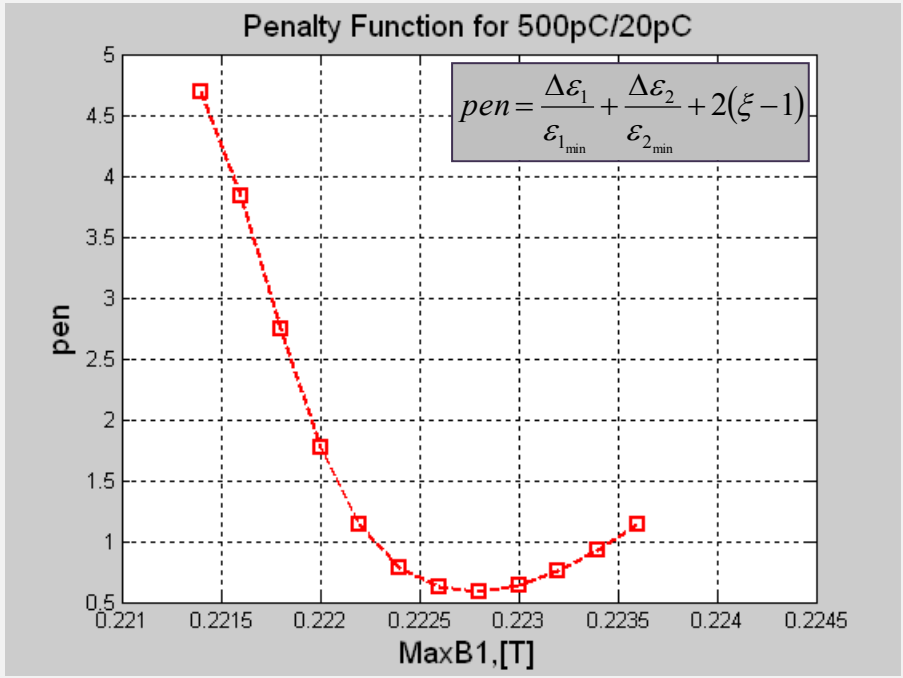
* “grey zone” – insufficient data

$$pen = \frac{\Delta\varepsilon_1}{\varepsilon_{1_{min}}} + \frac{\Delta\varepsilon_2}{\varepsilon_{2_{min}}} + 2(\xi - 1)$$

→ Additional laser system makes possible simultaneous operation with totally different bunch charges

Combined WP for 500pC with Low Charges and Two lasers





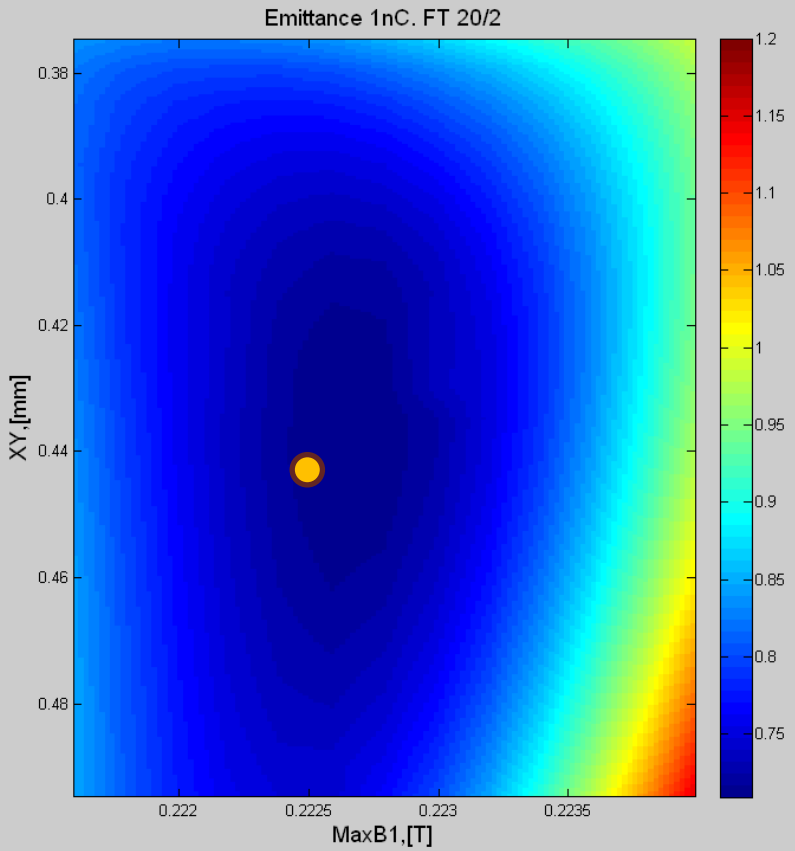
Parameter	CWP	Single WP
MaxB1, [T]	0.2224	0.2224/0.2206
XY, [mm]	0.265/0.145	0.285/0.100
ε_{500pC},[m^{-6}]	0.452	0.439
ε_{100pC},[m^{-6}]	0.203	0.193
ξ	1.0209	
pen	0.1168	

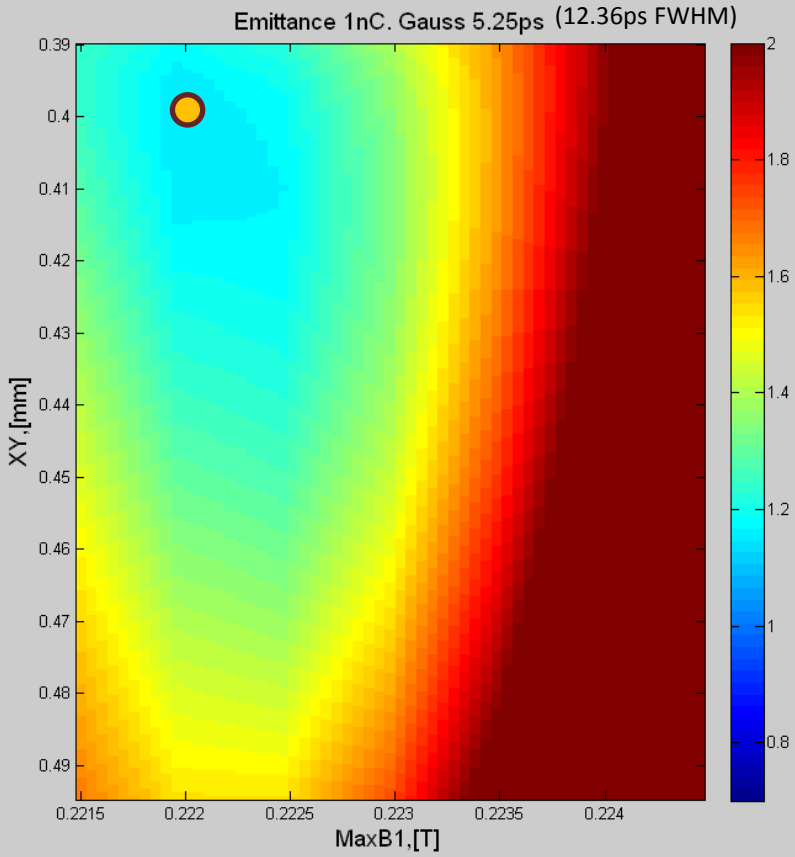
Parameter	CWP	Single WP
MaxB1, [T]	0.2228	0.2224/0.2196
XY, [mm]	0.270/0.071	0.285/0.057
ε_{500pC},[m^{-6}]	0.465	0.439
ε_{100pC},[m^{-6}]	0.123	0.0824
ξ	1.0270	
pen	0.5880	

5. Comparison FT vs Gauss for 1nC and S2E for Gaussian Case

2D Scan for 1nC Bunch vs MaxB and XYrms.

Comparison Flat Top Laser Pulse vs. Gaussian





working point for the best emittance

$\varepsilon^{pr}_{min}=0.704m^{-6}$

100% transmission at XY=0.370mm

$\varepsilon^{pr}_{min}=1.107m^{-6}$

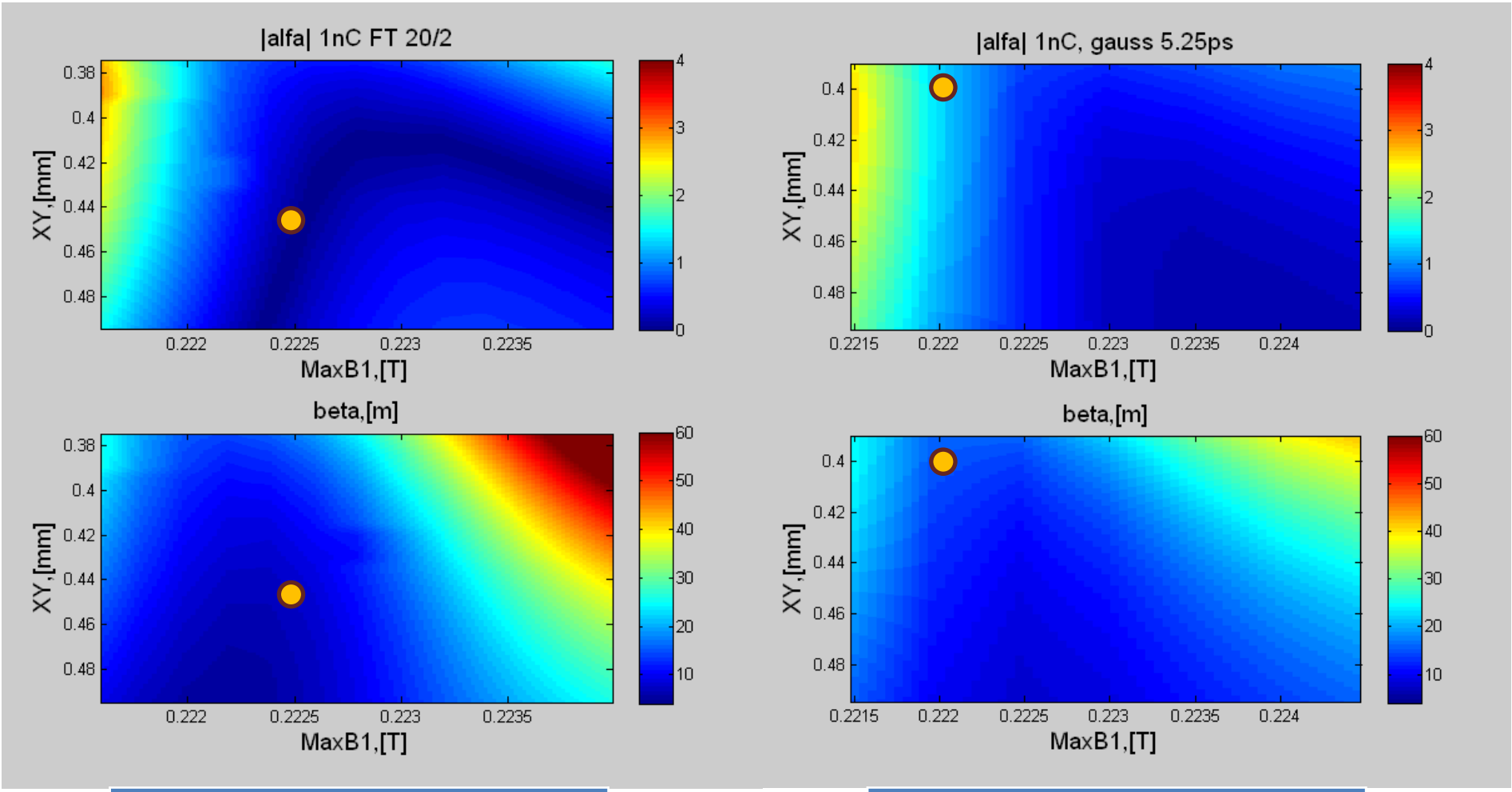
100% transmission at XY=0.380mm

Complete scan window acceptable for the operation

Length of the gaussian laser pulse is adjusted to get the same bunch length as in the case of Flat Top

2D Scan for 1nC Bunch vs MaxB and XYrms.

Comparison Flat Top Laser Pulse vs. Gaussian – Beam Optical Functions



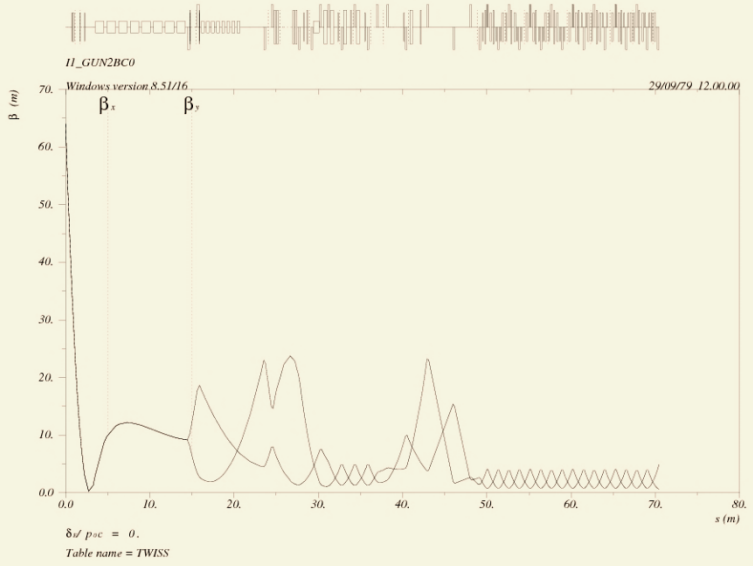
Twiss parameters at the working point	
beta	**alfa**
9.18	**0.100**

Twiss parameters at the working point	
beta	**alfa**
13.22	**-0.994**

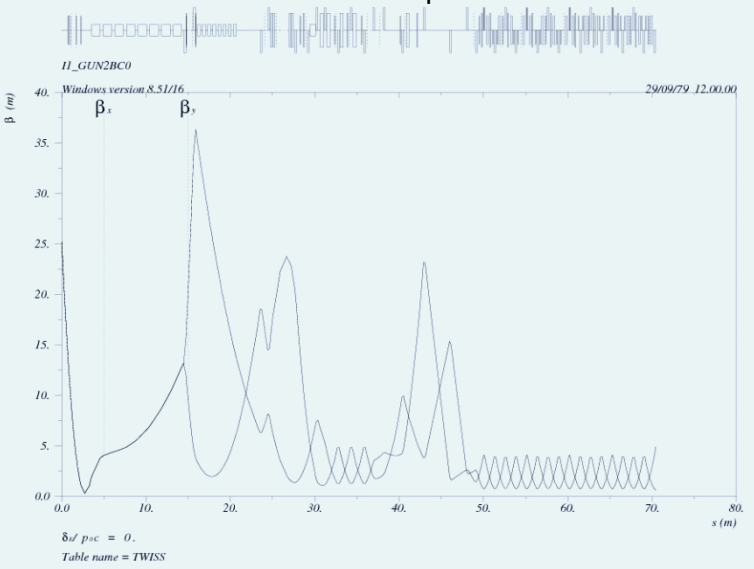
Beam Optical Functions are suitable for matching over the most part of the scan window

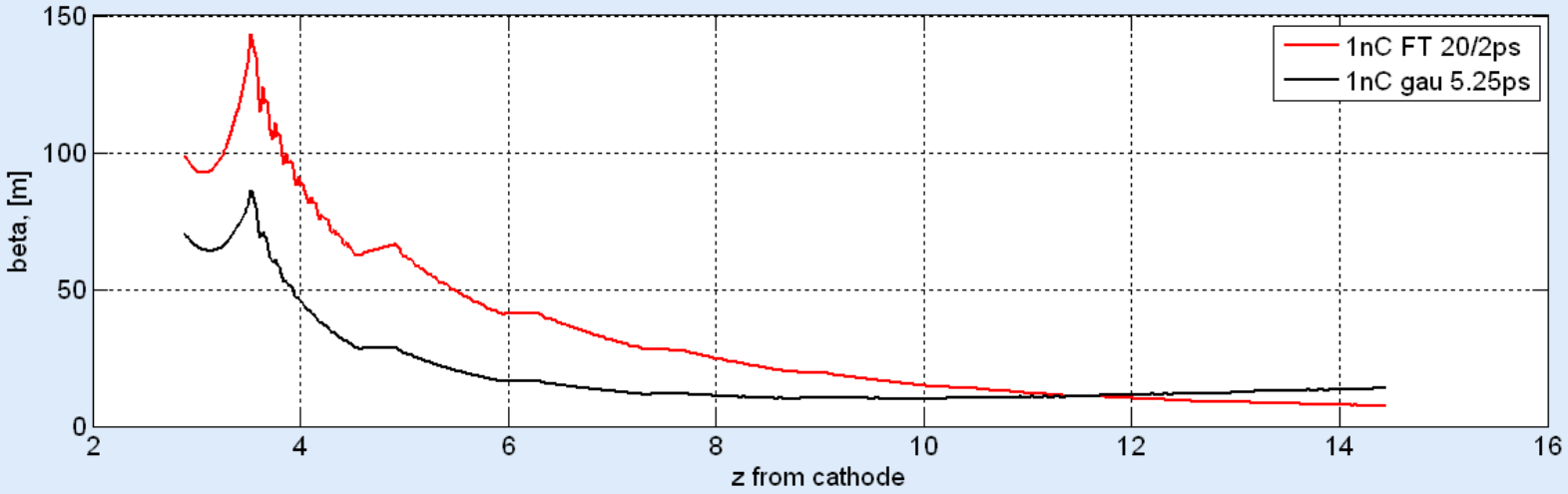
Beam Optics at the XFEL Injector for 1nC Working Points

Flat Top 20/2ps



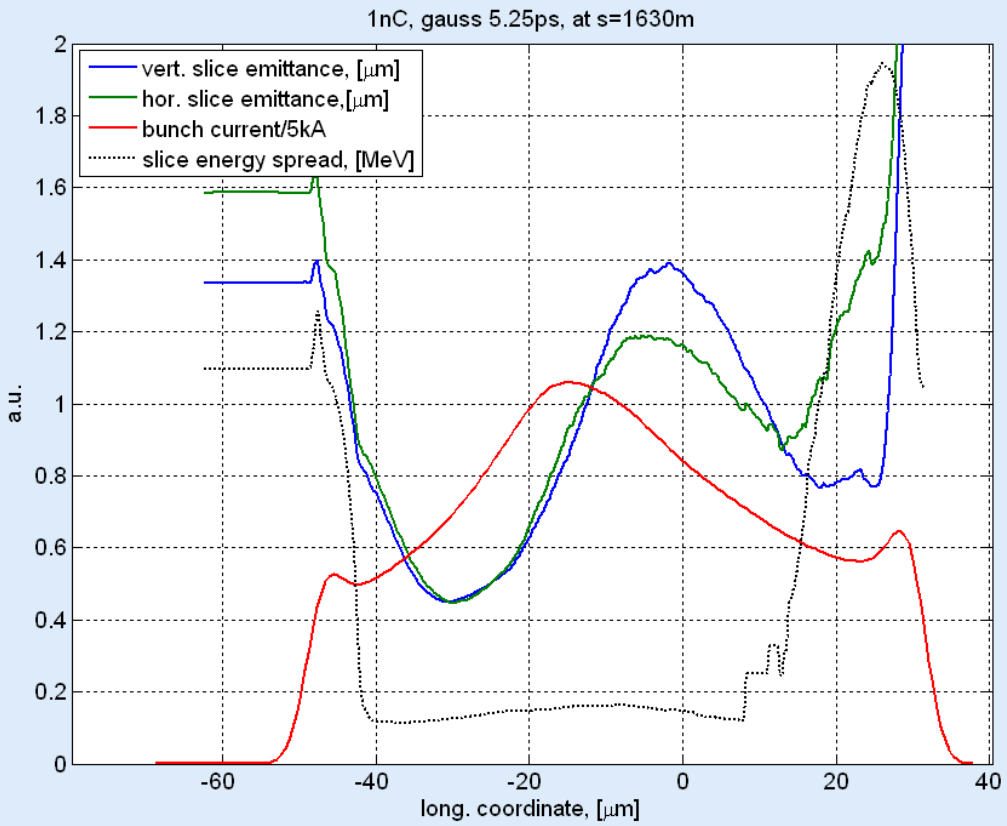
Gauss 5.25ps





→ Easily matchable optics in both cases

S2E Run with 1 nC
Summary for gauss 5.25ps rms. s=1630m



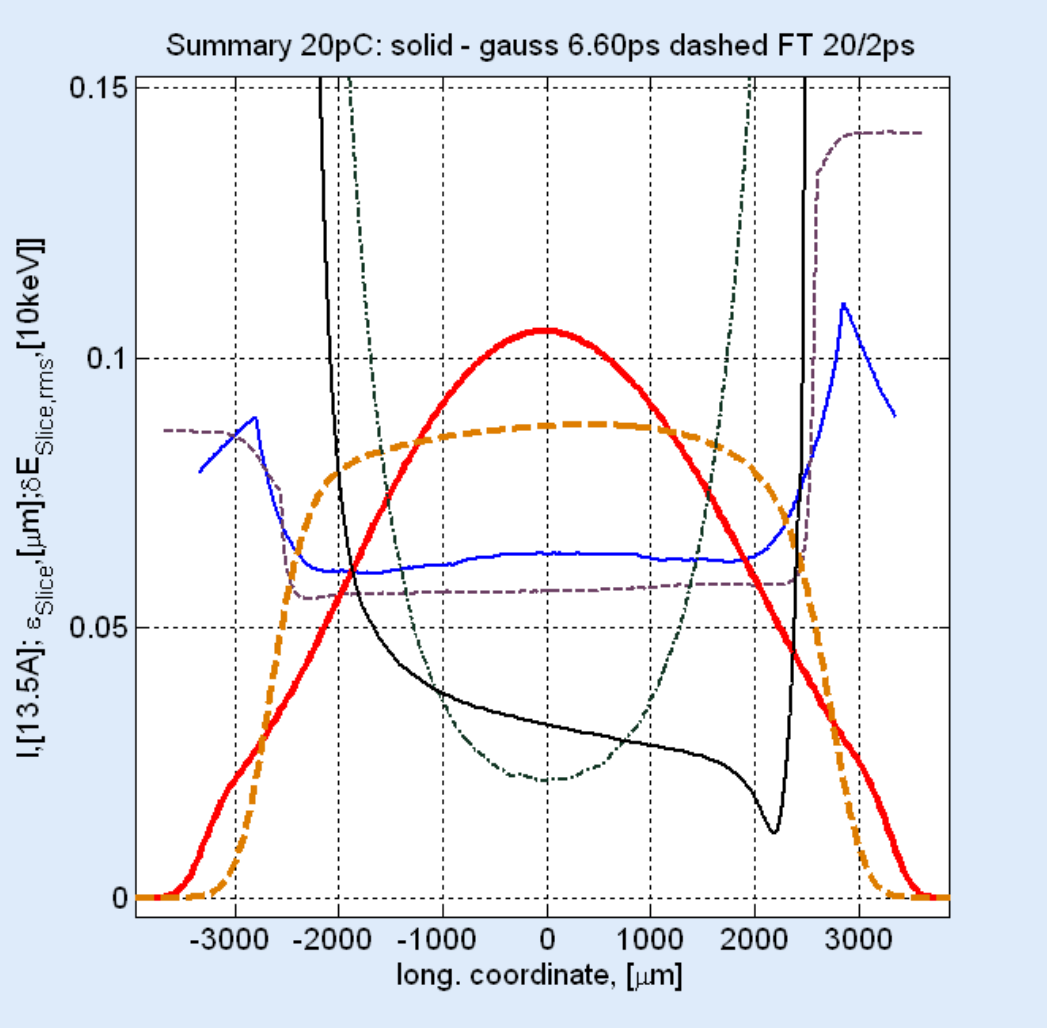
Charge	**1nC**	
Laser form	Gauss	Baseline
Laser rms, [ps]	5.25	
$\varepsilon^{pr}_{s=1630m}$, [mrad]	1.13/2.83	
$\varepsilon^{sl,av}_{s=1630m}$, [mrad]	0.90	0.92
$\varepsilon^{sl,min}_{s=1630m}$, [mrad]	0.45	0.75
$\varepsilon^{sl,max}_{s=1630m}$, [mrad]	1.40	1.09
$\delta E^{sl,av}$,rms [keV]	155	450
Ip, [A]	5000	5000
τ FWHM, [mm]	0.075	0.0766

→ Baseline specifications probably may be hold

→ Requires accurate tuning since only the best emittance can provide this

6. Summary: Comparison Flat Top vs Gauss for 20pC Bunch Charge

Summary: Comparison for 20pC Bunch at 14.44m
FT vs Gaussian Pulse



Charge	**100pC**	
Laser form	Flat Top	Gauss
Laser rms, [ps]	20/2	5.75
$\varepsilon^{pr}_{s=14.44m}$, [mrad]	0.085	0.101
$\varepsilon^{sl,av}_{s=14.44m}$, [mrad]	0.057	0.063
$\varepsilon^{sl,min}_{s=14.44m}$, [mrad]	0.055	0.060
$\varepsilon^{sl,max}_{s=14.44m}$, [mrad]	0.059	0.064
$\delta E^{sl,av}$,rms [keV]	0.30	0.35
Ip, [A]	1.181	1.404
τ rms, [mm]	1.521	