October 28th, 2008, FELSI Meeting at PSI

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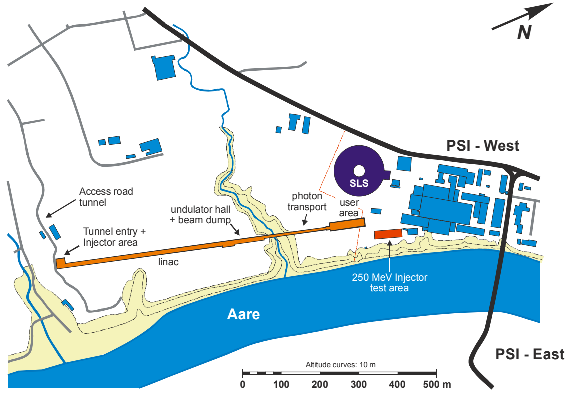

Tolerance Study Series - I

Performance & Tolerance of Solenoids in CTF3 RF GUN Based 250 MeV Injector

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Outline

- ☐ Why we need a New Gun Solenoid for CTF3 RF Gun ?
- ☐ Performance & Alignment Tolerance of New Longer Double Gun Solenoid
- ☐ Performance & Alignment Tolerance of New Longer Single Gun Solenoid
- ☐ Specification and Tolerance of Gun Bucking Solenoid
- ☐ Alignment Tolerance of Solenoids in S-band Accelerating Structure
- ☐ Summary and Acknowledgement

Futures Tolerance Study Series (alignment tolerance of QMs, BMs, and Linac Tubes, and RF amplitude and phase jitters)

Why we need a New Gun Solenoid ?

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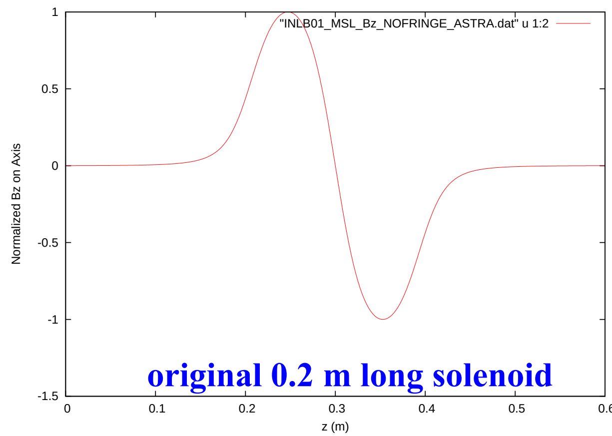
Originally Used GUN Solenoid (INLB-01-MSL10) for CTF3 GUN Optimization

- Length = 0.2 m
- Maximum Magnetic Field = 0.250 T
- Type = Double Solenoid



Needed Maximum Field for CTF3 GUN Operation

- 0.255 T for a gun Gradient of 100 MV/m
- 0.300 T for a gun Gradieent of 120 MV/m

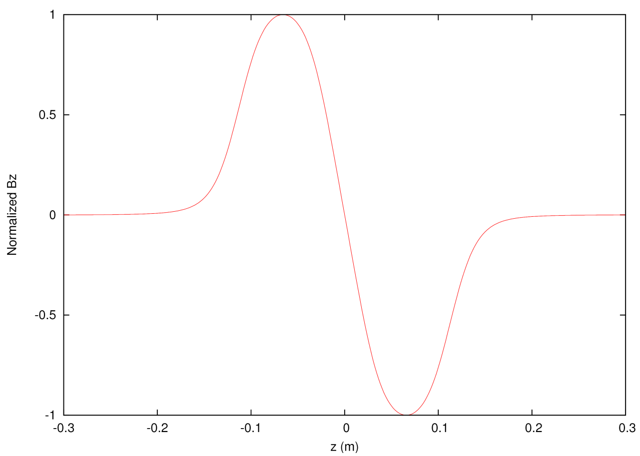
It seems that we need a new stronger gun solenoid for CTF3 RF Gun based Injector.

Recently, Marco Negrazus of magnet group have designed two new solenoids (single and double) for the CTF3 gun. Its length is about 0.26 m long and its maximum magnetic field is 0.35 T.

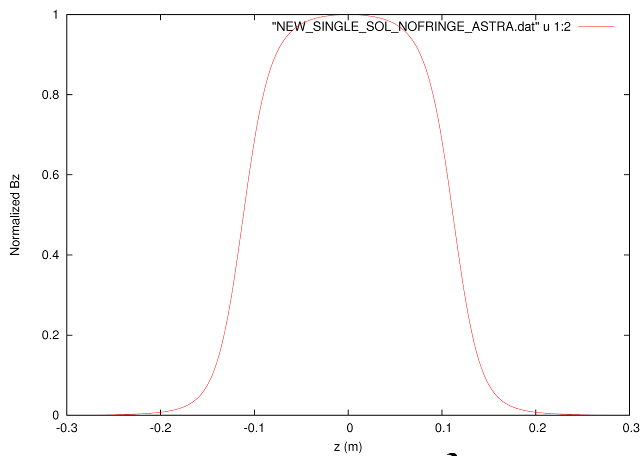
<u>New Single and Double Solenoids</u>:

maximum magnetic field = 0.35 T
maximum current = 220 A
inner diameter = 80 mm
outer diameter = 460 mm
mechanical length = 0.26 m
center position from the gun cathode = 0.3 m
starting point in tunnel = 5.37 m
ending point in tunnel = 5.63 m

new double solenoid



new single solenoid



Originally Used Field Maps for Optimization

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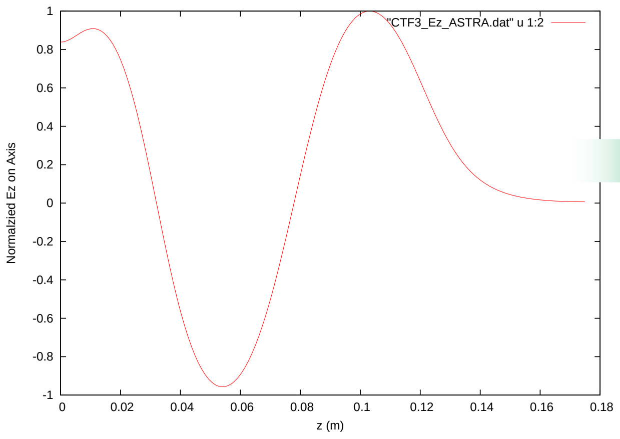
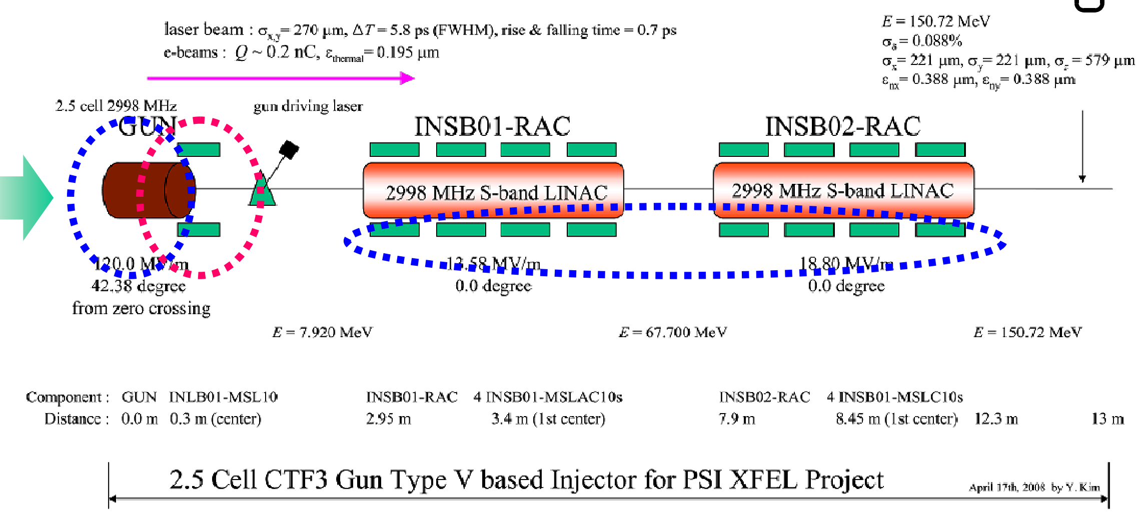
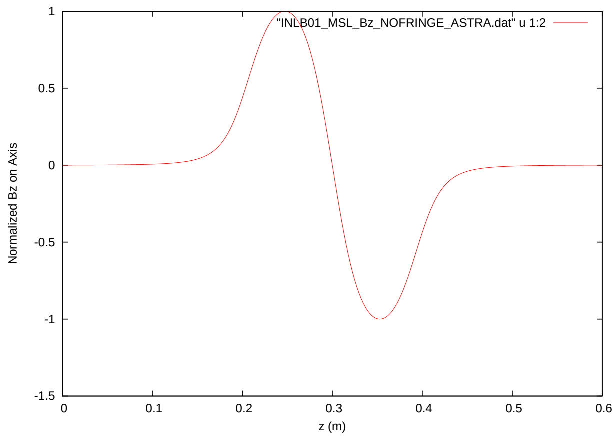
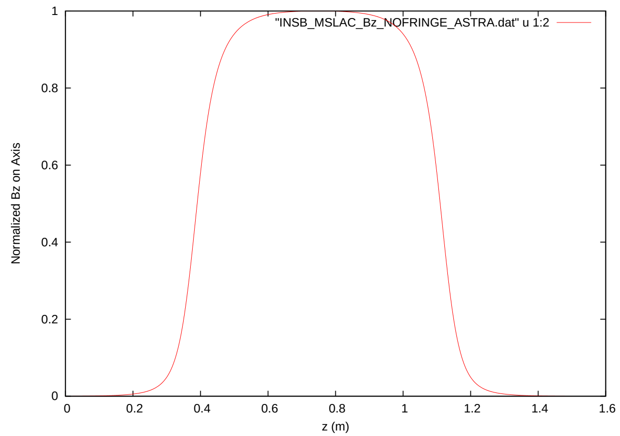
From Micha Dehler

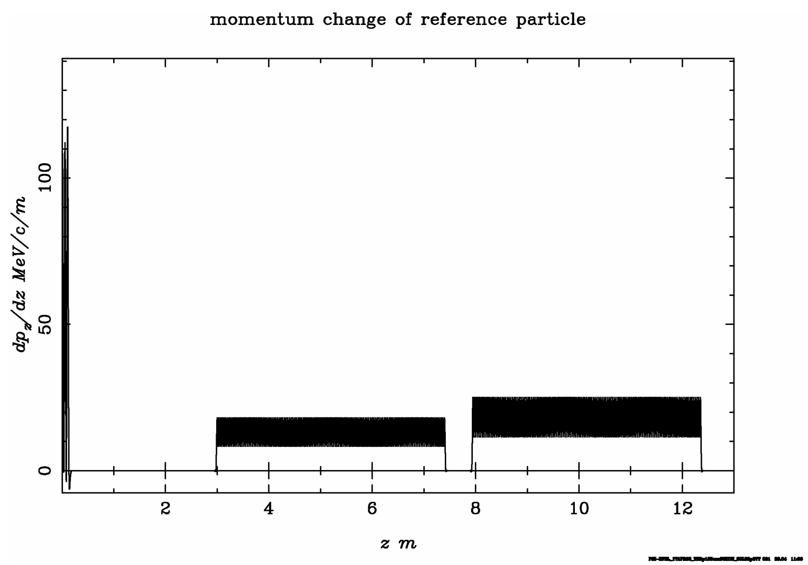




fieldmap of 0.2 m long double solenoid







Optimization with 120 MV/m & 0.2 m Solenoid

32 A - Good Projected Emittance & High Peak Current

laser $\sigma_{x,y}$ = 270 μm, INSB01 @ 2.95 m

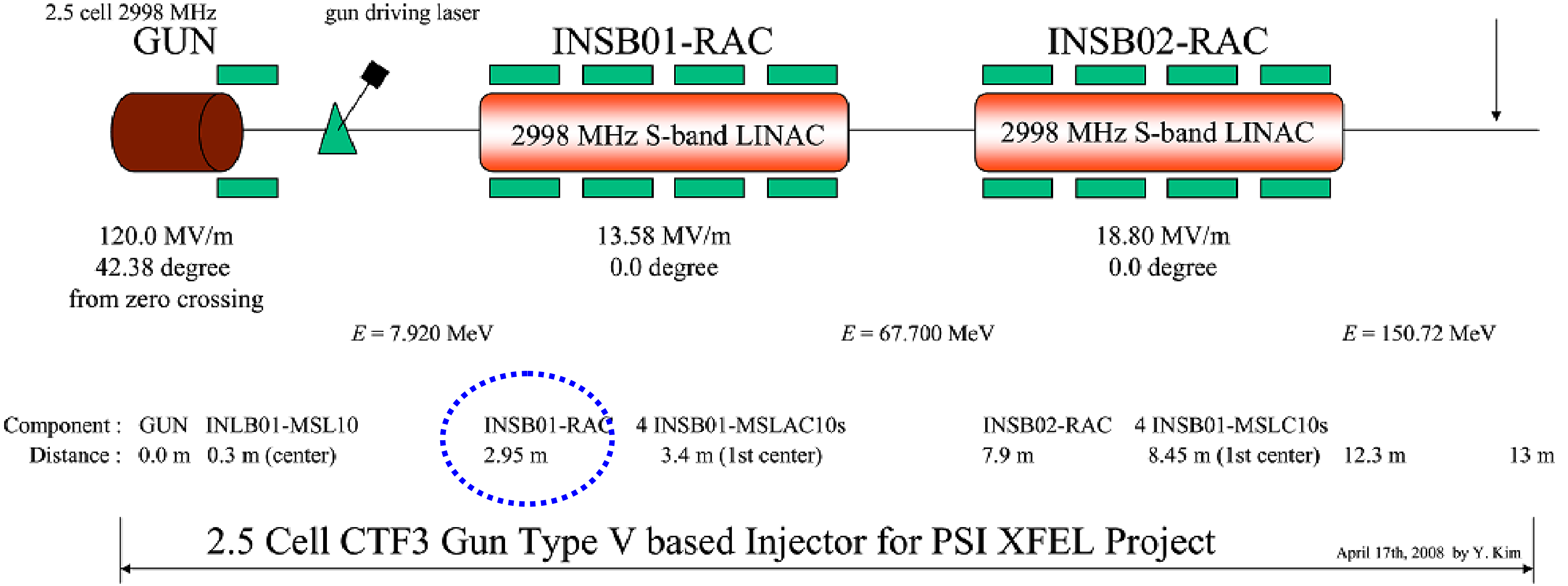
I_{peak} = 32 A

E = 150.72 MeV
σ_δ = 0.088%
σ_x = 221 μm, σ_y = 221 μm, σ_z = 579 μm
ε_{nx} = 0.388 μm, ε_{ny} = 0.388 μm

B_{sol} ~ 0.300 T

laser beam : $\sigma_{x,y}$ = 270 μm, ΔT = 5.8 ps (FWHM), rise & falling time = 0.7 ps

e-beams : Q ~ 0.2 nC, $\varepsilon_{thermal}$ = 0.195 μm



Optimization with 100 MV/m & 0.2 m Solenoid

22 A - Good Slice & Projected Emittance & Low Peak Current

laser $\sigma_{x,y}$ = 270 μm, INSB01 @ 2.95 m

B_{sol} ~ 0.255 T

laser beam : $\sigma_{x,y}$ = 270 μm, ΔT = 9.9 ps (FWHM), rise & falling time = 0.7 ps

e-beams : Q ~ 0.2 nC, $\varepsilon_{thermal}$ = 0.195 μm

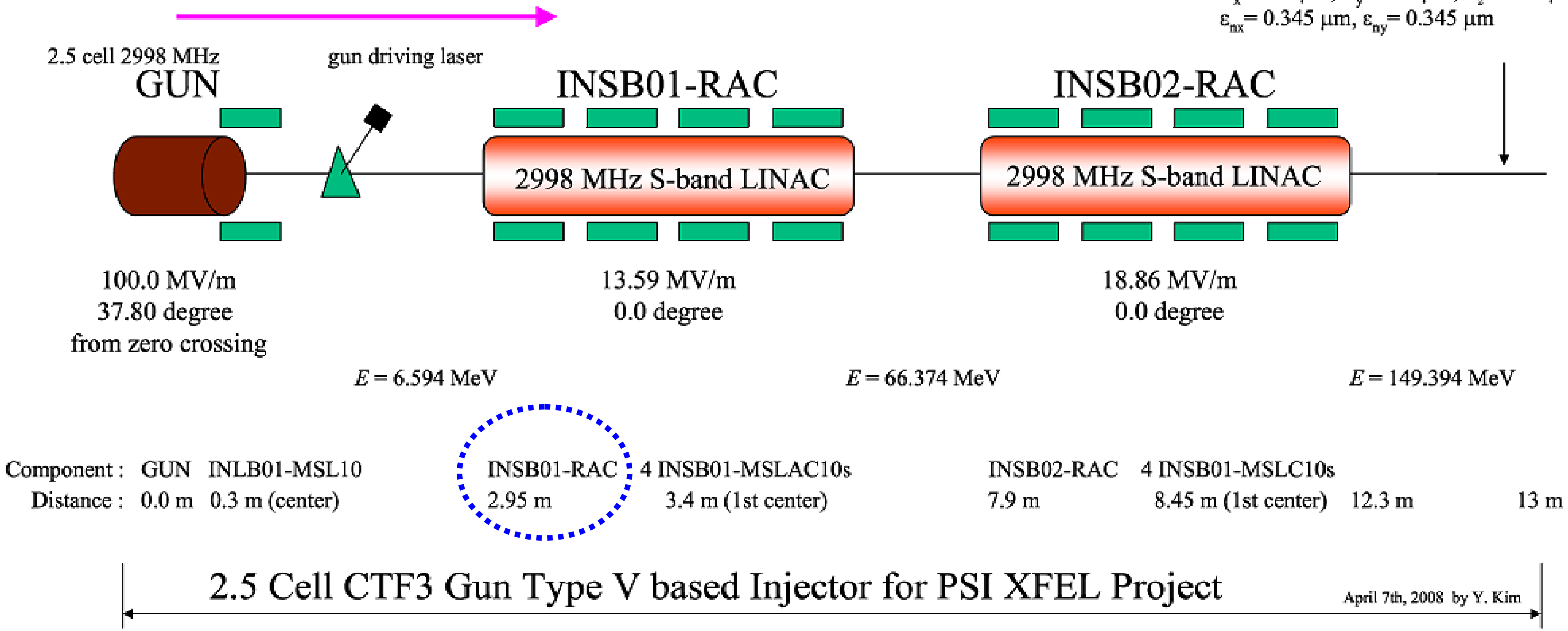
I_{peak} = 22 A

E = 149.394 MeV

σ_δ = 0.163%

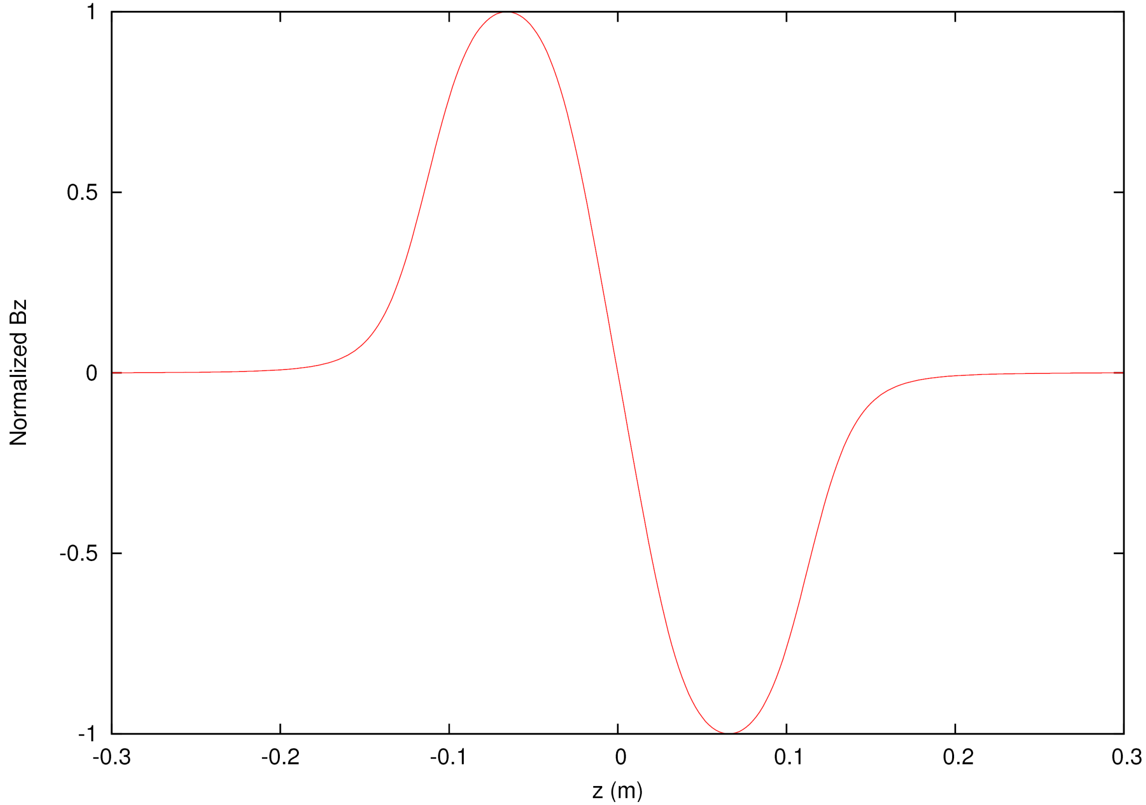
σ_x = 211 μm, σ_y = 211 μm, σ_z = 840 μm

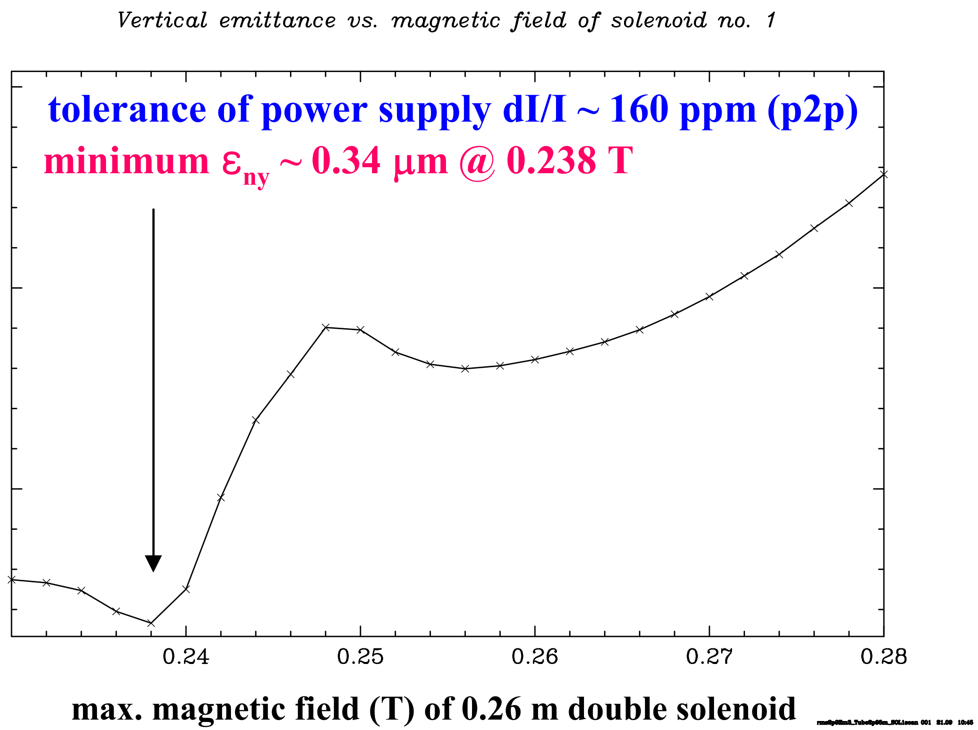
ε_{nx} = 0.345 μm, ε_{ny} = 0.345 μm



Re-optimization with 0.26 m double Solenoid

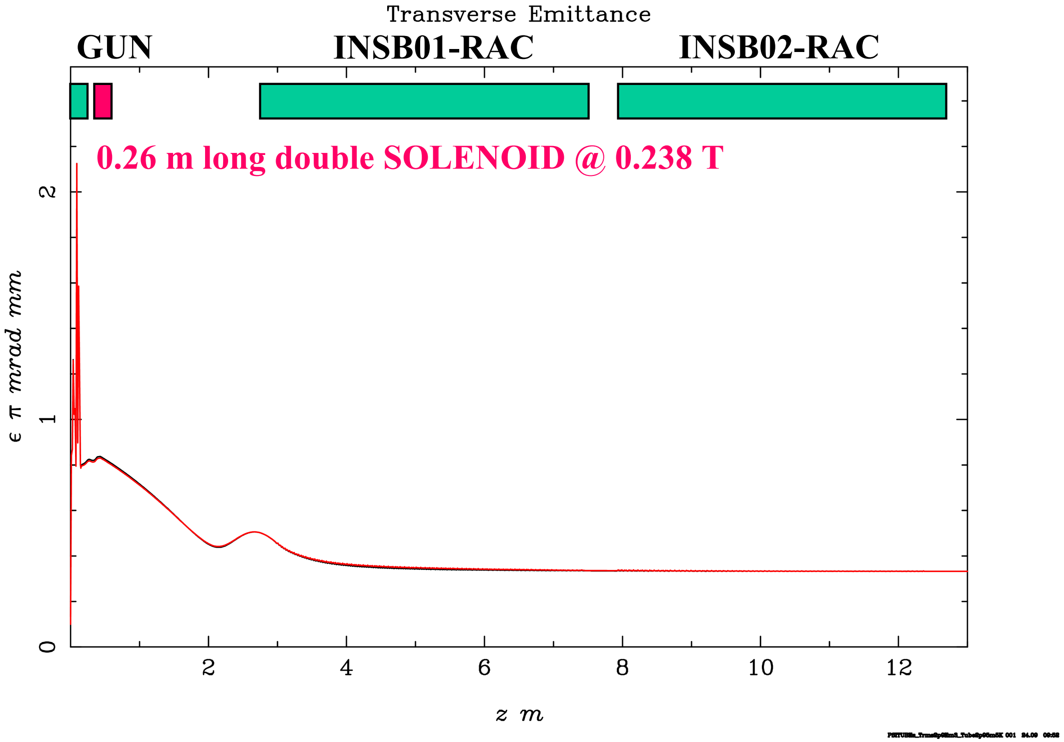
For 100 MV/m case, after swapping current 0.2 m long double solenoid with a new 0.26 m long double solenoid, we scanned its solenoid field strength to find a new optimized field giving the minimum emittance of about 0.34 μm at the end of SB02. The center position of the 0.26 m long double solenoid is 0.3 m downstream from the cathode, which is same as that of original one. All other parameters are same as those in page 6.

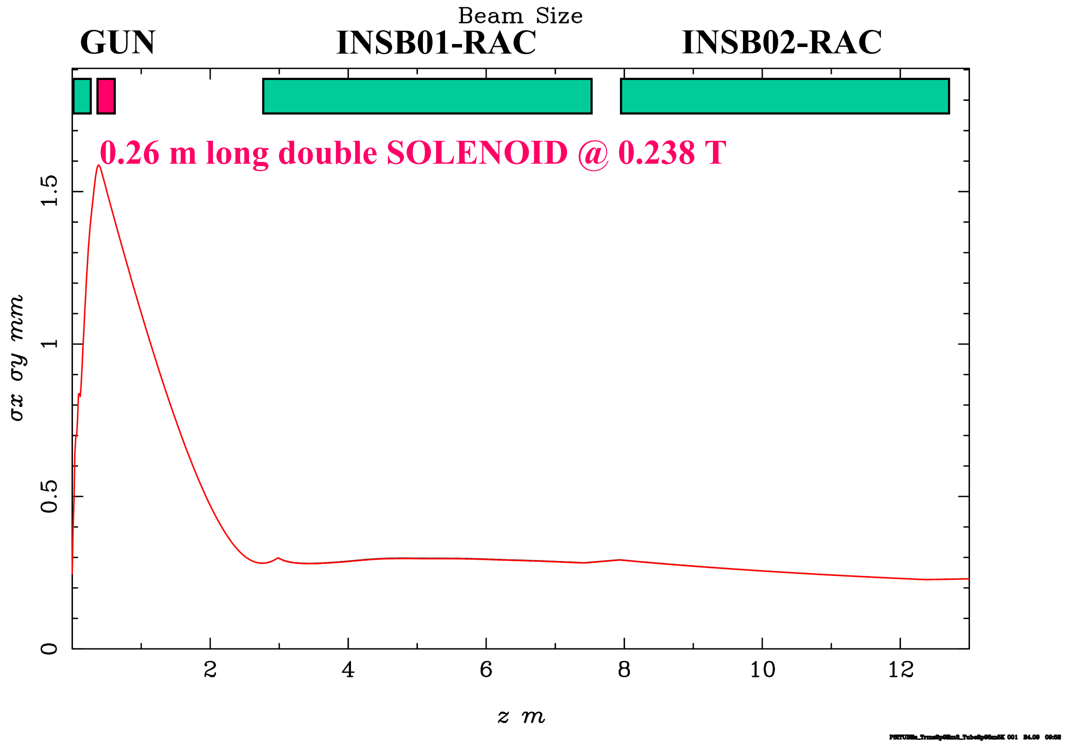




Re-optimization with 0.26 m double Solenoid

With a new 0.26 m long double solenoid, we could easily obtain the similar performance which we had obtained with 0.2 m long double solenoid. This is the first optimization step.





$E \sim 149.2$ MeV, $\sigma_\delta \sim 0.16\%$

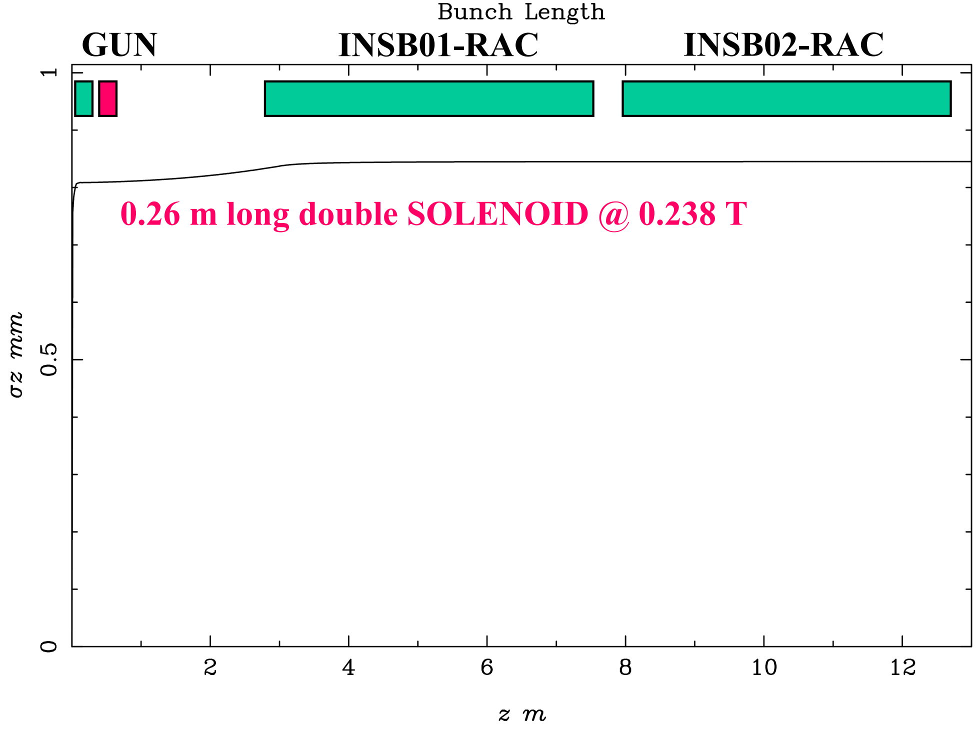
$\sigma_x \sim 230$ μm, $\sigma_y \sim 230$ μm, $\sigma_z \sim 842$ μm

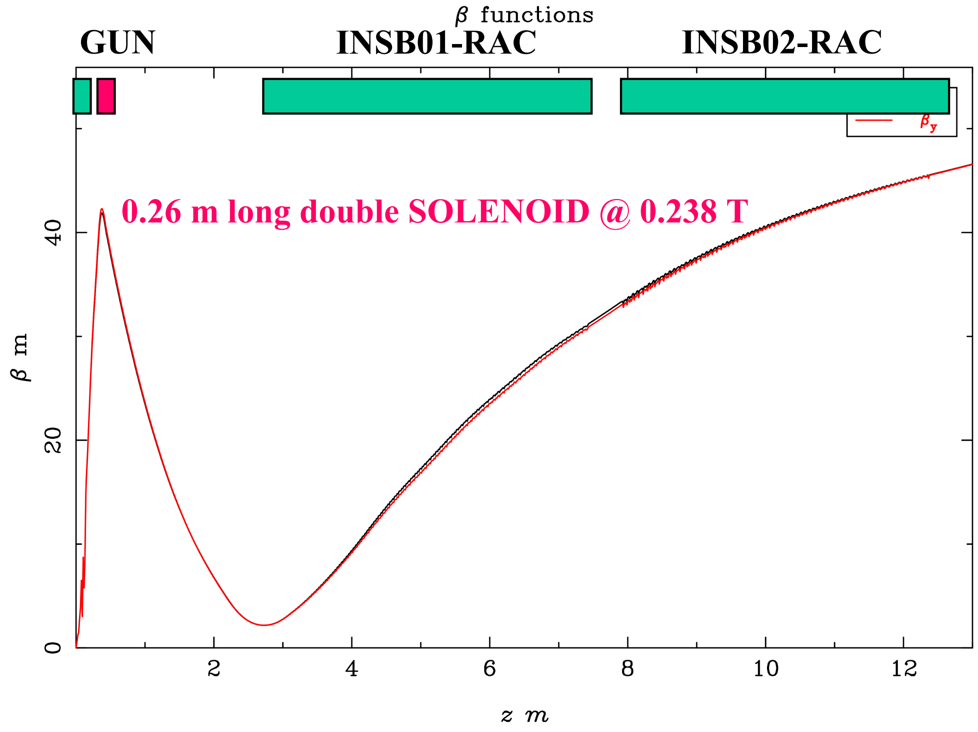
$\varepsilon_{nx} \sim 0.34$ μm, $\varepsilon_{ny} \sim 0.34$ μm

$Q = 0.2$ nC, $I_{peak} \sim 22$ A, $\varepsilon_{n,slice} \sim 0.32$ μm

Re-optimization with 0.26 m double Solenoid

With a new 0.26 m long double solenoid, we could easily obtain the similar performance which we had obtained with 0.2 m long double solenoid. This is the first optimization step.





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$Q = 0.2$ nC, $I_{peak} \sim 22$ A, $\varepsilon_{n,slice} \sim 0.32$ μm

Alignment Tolerance - 0.26 m double Solenoid

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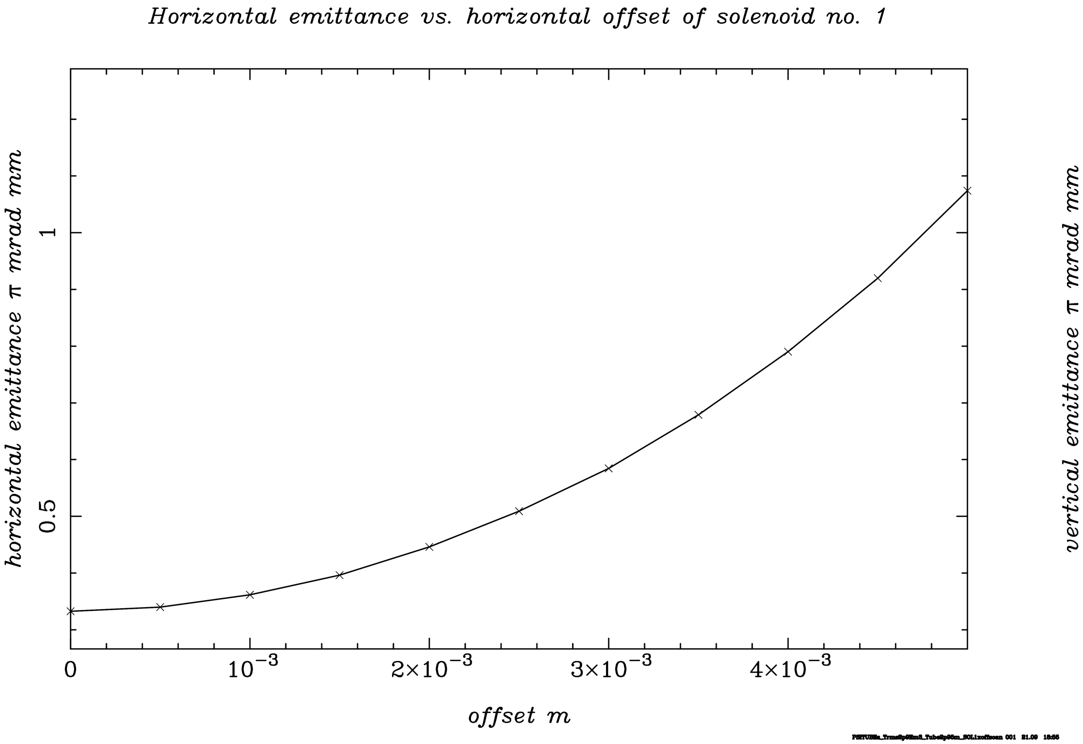
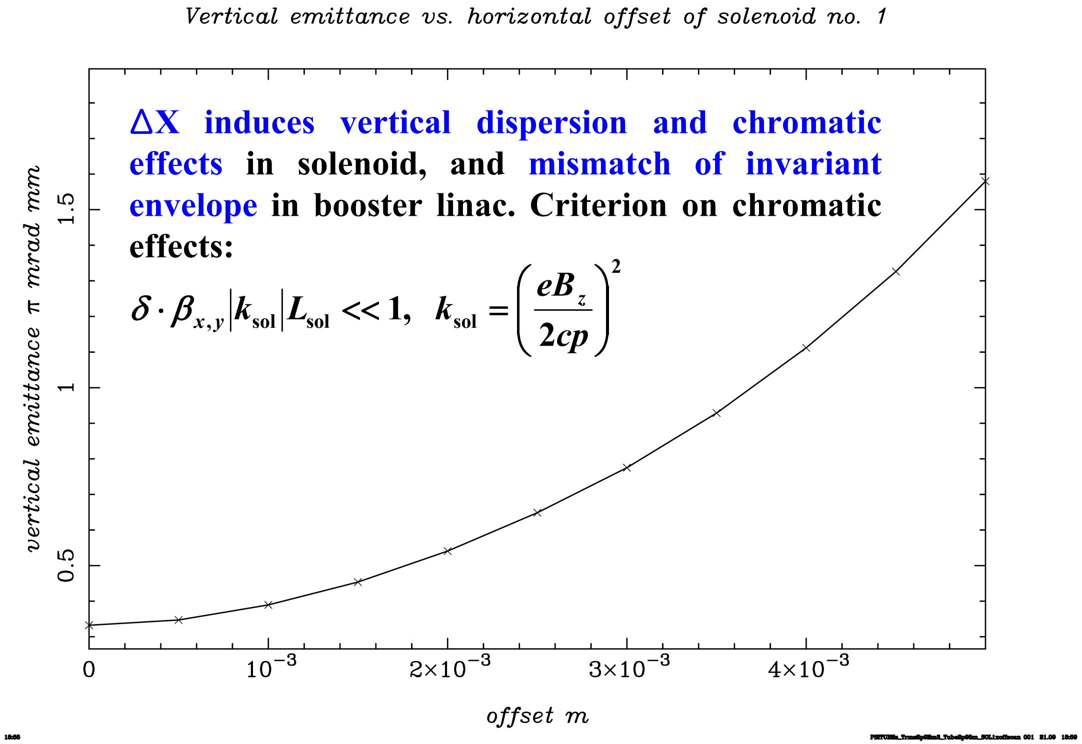
Tolerance of horizontal misalignment of the new 0.26 m long double solenoid is about 14 µm (p2p), giving 1% vertical emittance growth. It seems that we need the beam based alignment. The tolerance of a vertical misalignment is same range.





ΔX = ΔY ~ 14 µm (p2p) giving about 1% emittance growth.

Tilt Tolerance - 0.26 m double Solenoid

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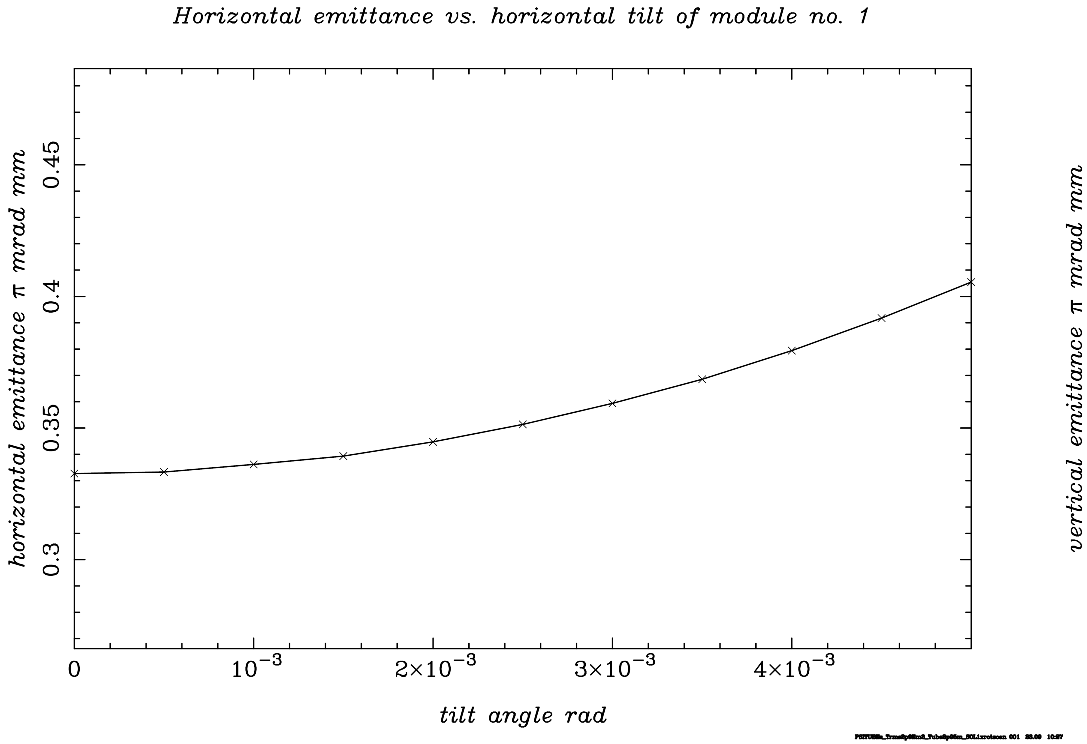
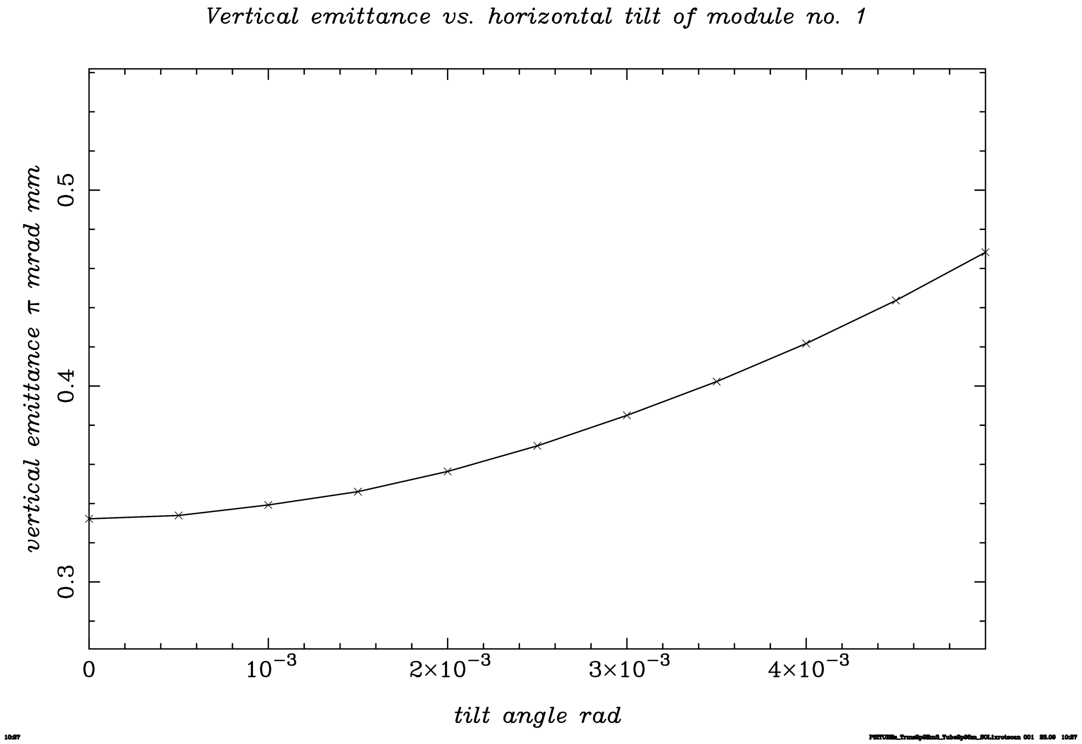
Tolerance of a rotation (or tilt) error around x-axis of the new 0.26 m long double solenoid is about 120 μrad (p2p), giving 1% vertical emittance growth. It seems that we need the beam based alignment. The tolerance of a rotation error around y-axis is same range.





$\Delta\phi_x = \Delta\phi_y \sim$ 120 μrad (p2p) giving about 1% emittance growth.

Re-optimization - 0.26 m single Solenoid

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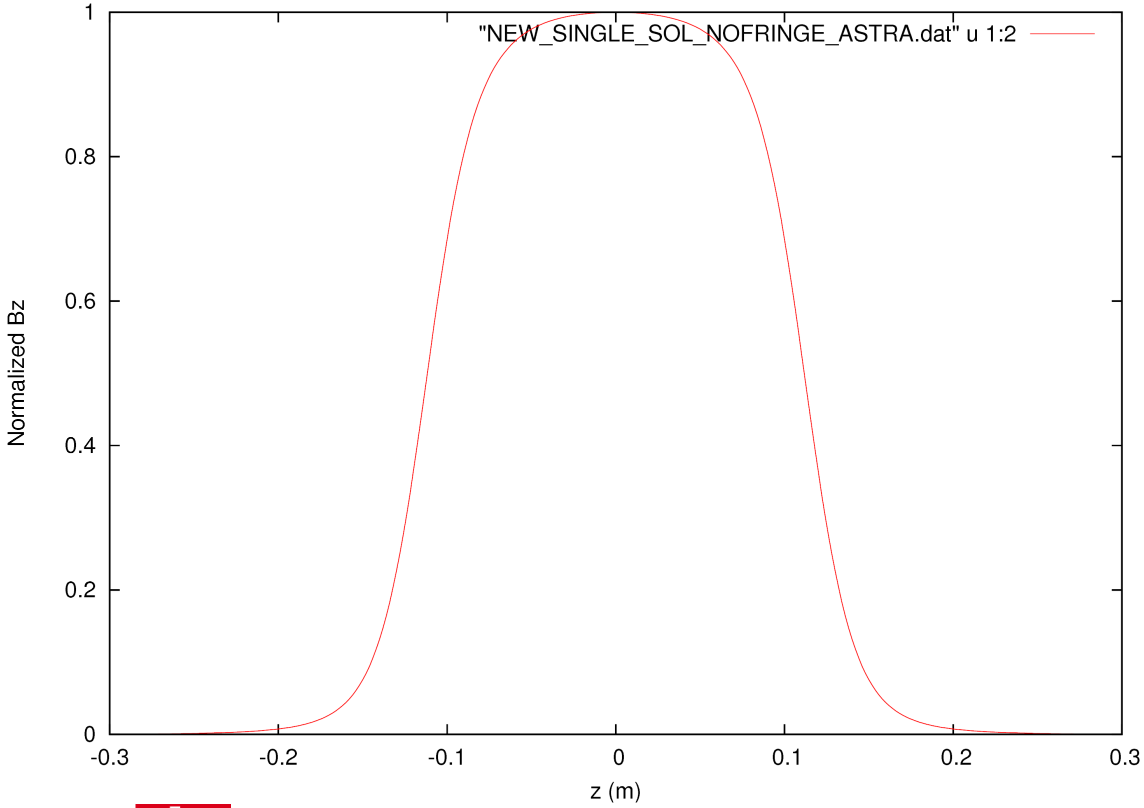
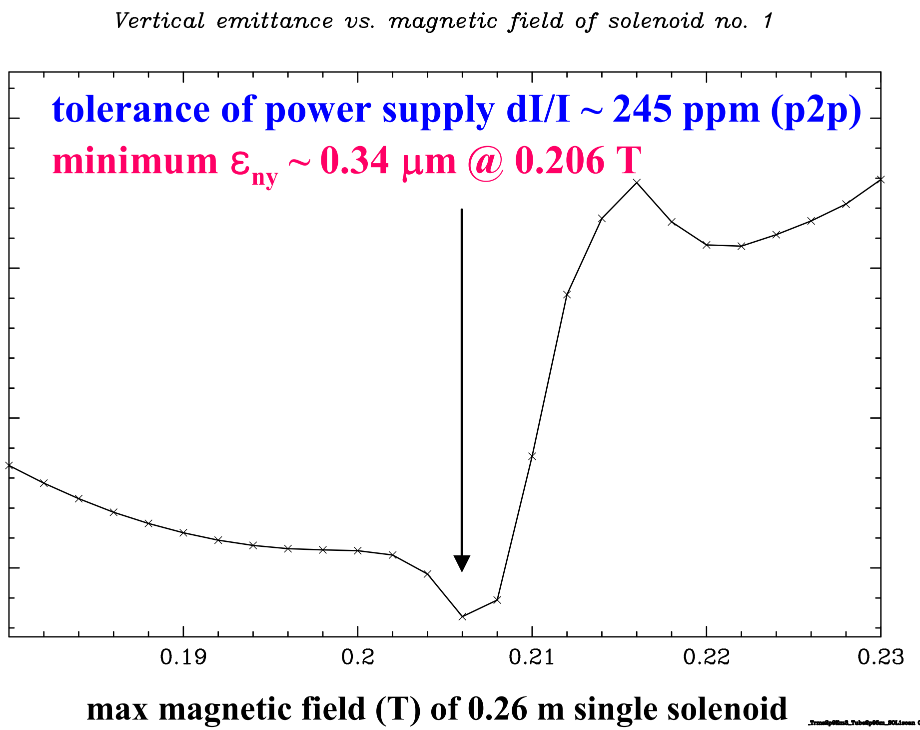
For 100 MV/m case, after swapping current 0.2 m long double solenoid with a new 0.26 m long single solenoid, we scanned its solenoid field strength to find a new optimized field giving the minimum emittance of about 0.34 μm at the end of SB02. The center position of the 0.26 m long single solenoid is 0.3 m downstream from the cathode, which is same as that of current one. All other parameters are same as those in page 6.





1st Re-optimization - 0.26 m single Solenoid

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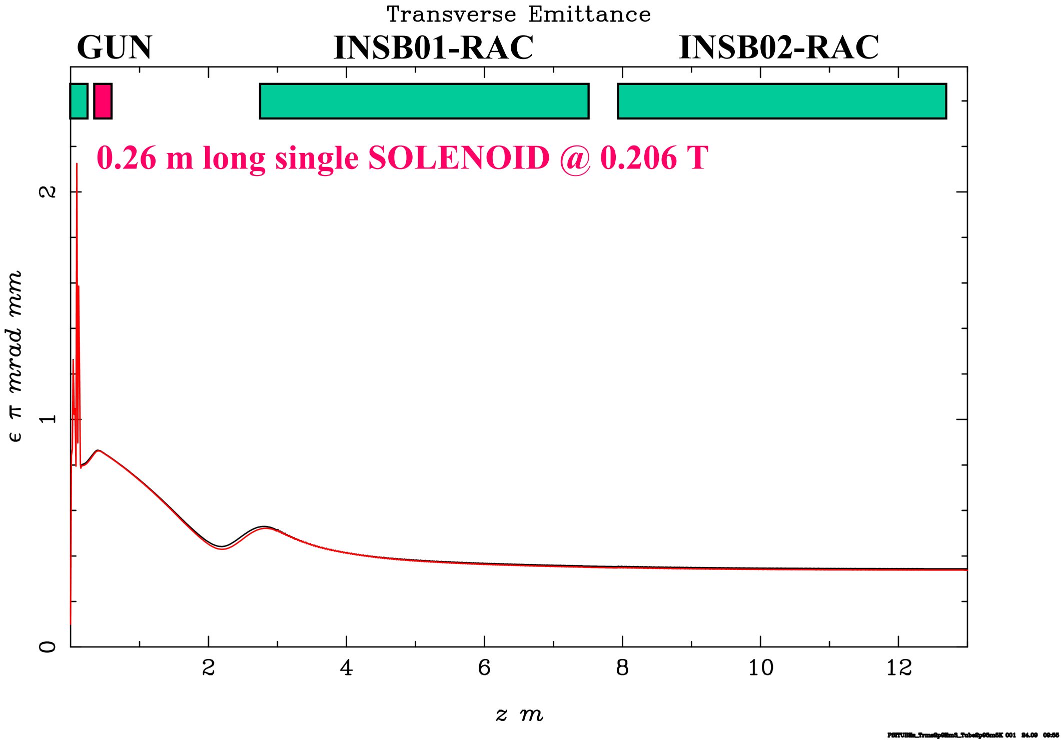
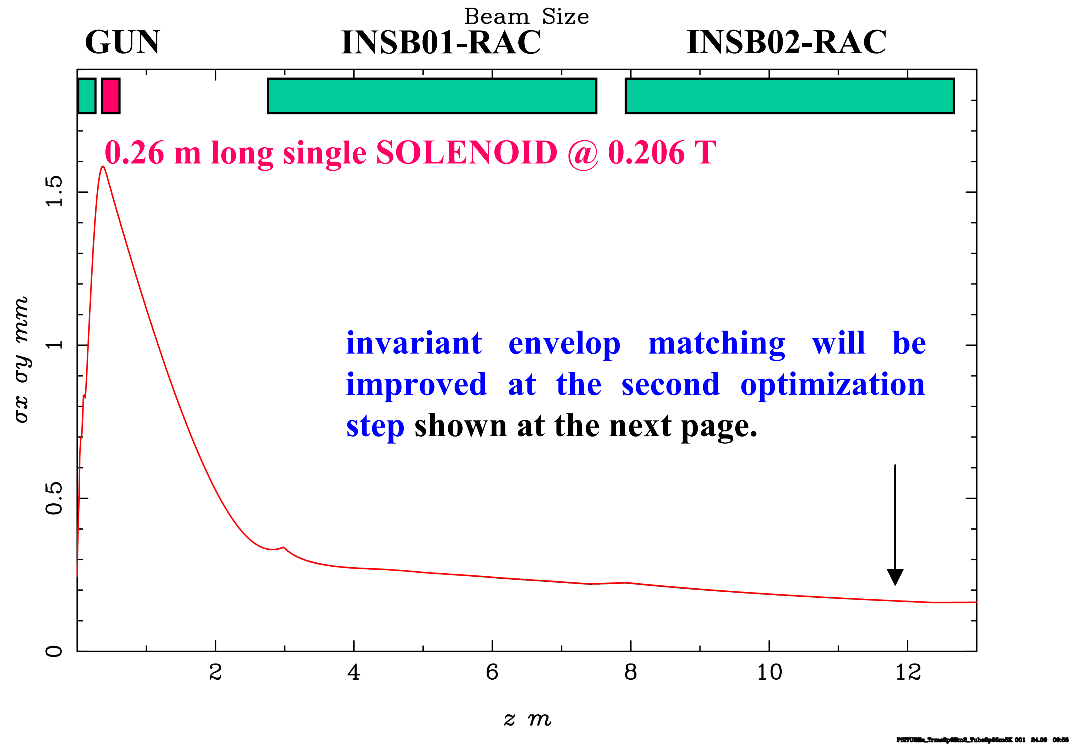
With a new 0.26 m long single solenoid, we could obtain the similar performance which we had obtained with 0.2 m long double solenoid. This is the first optimization step.





$E \sim 149.2$ MeV, $\sigma_\delta \sim 0.16\%$

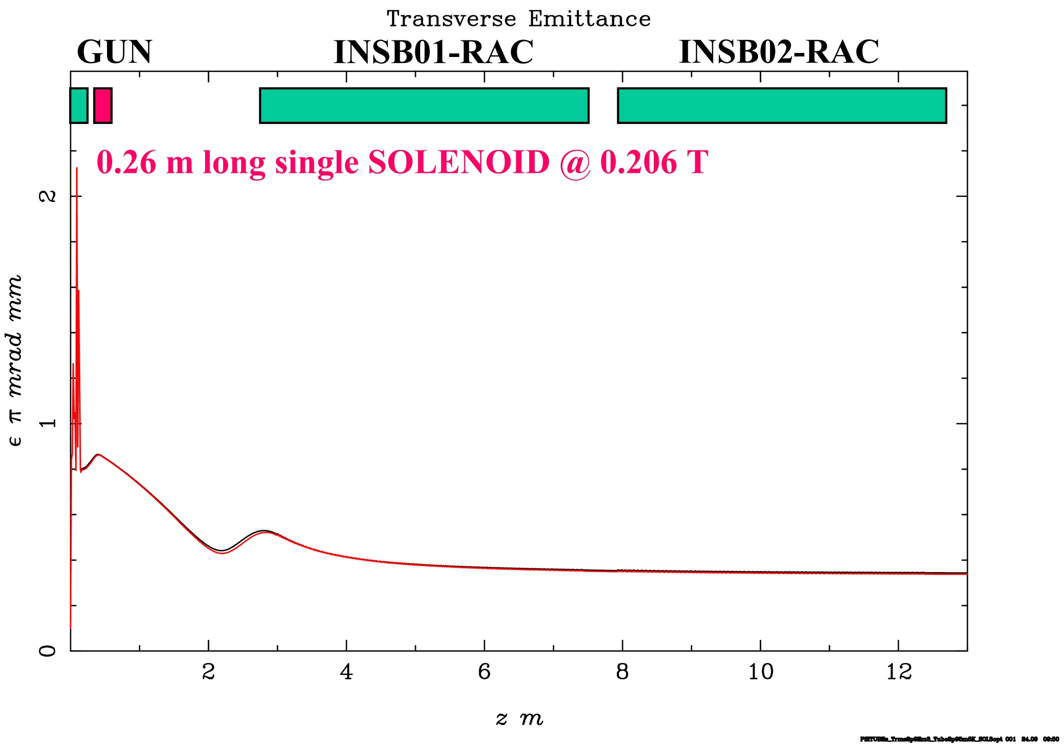
$\sigma_x \sim 160$ μm, $\sigma_y \sim 160$ μm, $\sigma_z \sim 842$ μm

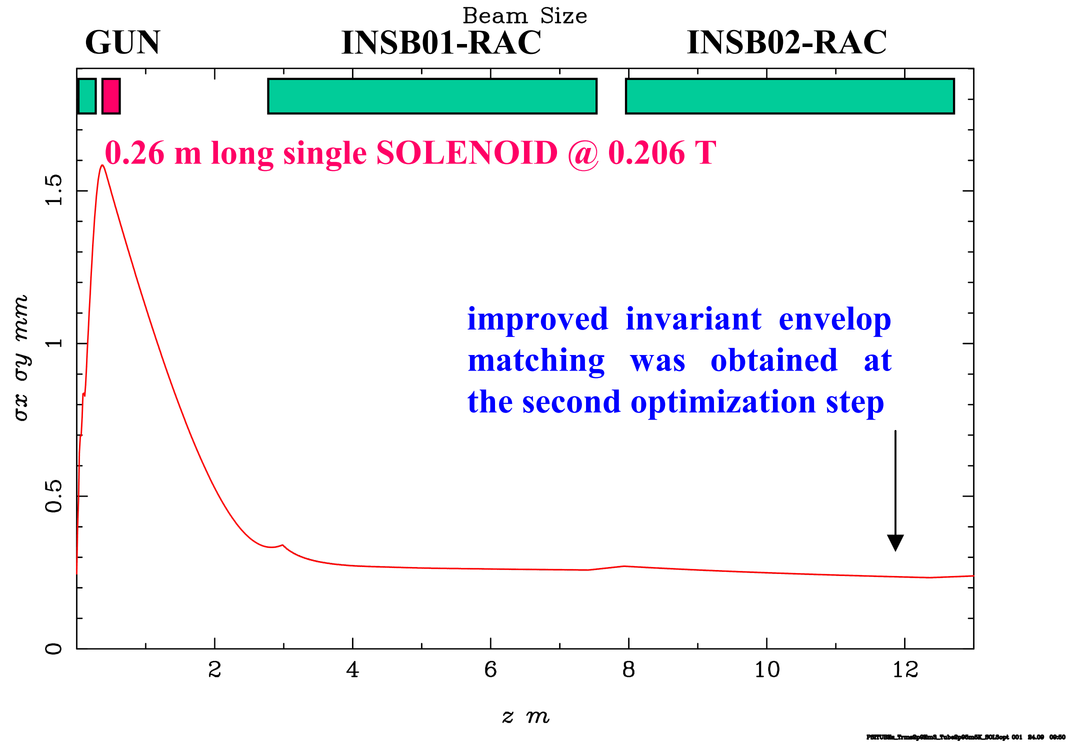
$\varepsilon_{nx} \sim 0.34$ μm, $\varepsilon_{ny} \sim 0.34$ μm

$Q = 0.2$ nC, $I_{peak} \sim 22$ A, $\varepsilon_{n,slice} \sim 0.30$ μm better slice emittance !

2nd Re-optimization - 0.26 m single Solenoid

With a new 0.26 m long single solenoid, we could obtain the similar performance which we had obtained with 0.2 m long double solenoid. This is the second optimization step.





$E \sim 149.2$ MeV, $\sigma_\delta \sim 0.16\%$

$\sigma_x \sim 240$ μm, $\sigma_y \sim 240$ μm, $\sigma_z \sim 842$ μm

$\varepsilon_{nx} \sim 0.34$ μm, $\varepsilon_{ny} \sim 0.34$ μm

$Q = 0.2$ nC, $I_{peak} \sim 22$ A, $\varepsilon_{n,slice} \sim 0.30$ μm better slice emittance !

2nd Re-optimization - 0.26 m single Solenoid

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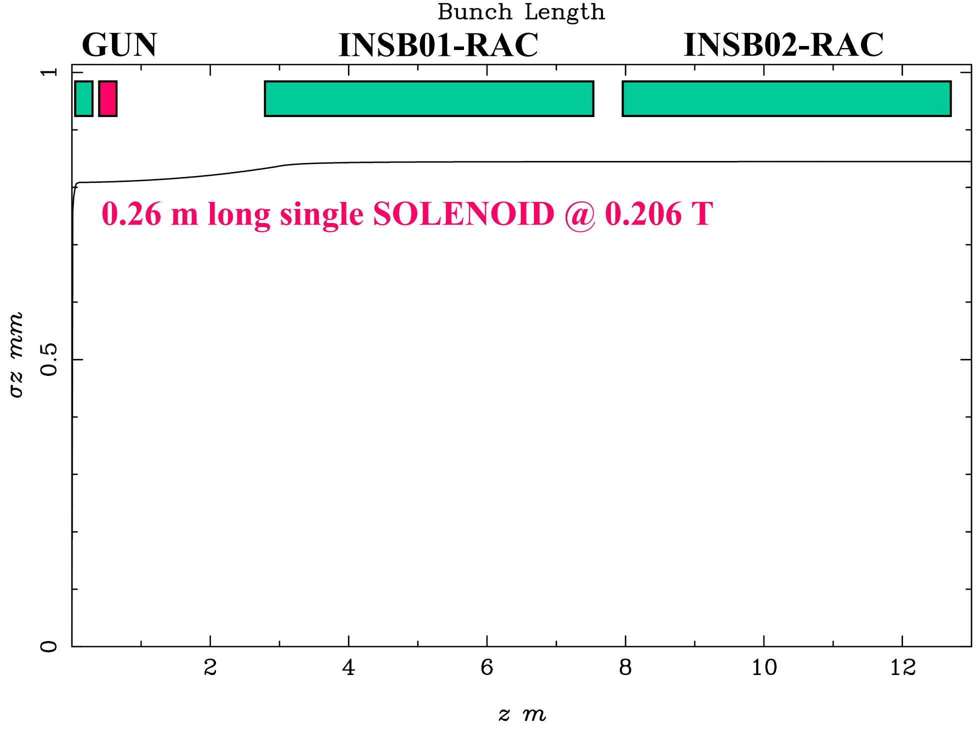
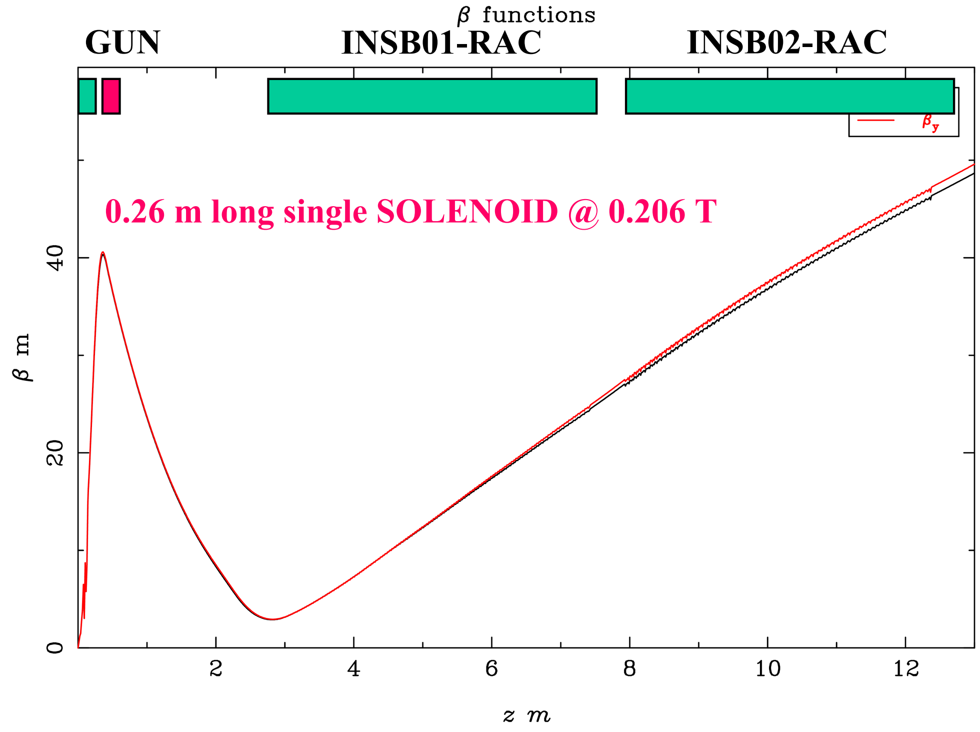
With a new 0.26 m long single solenoid, we could obtain the similar performance which we had obtained with 0.2 m long double solenoid. This is the second optimization step.





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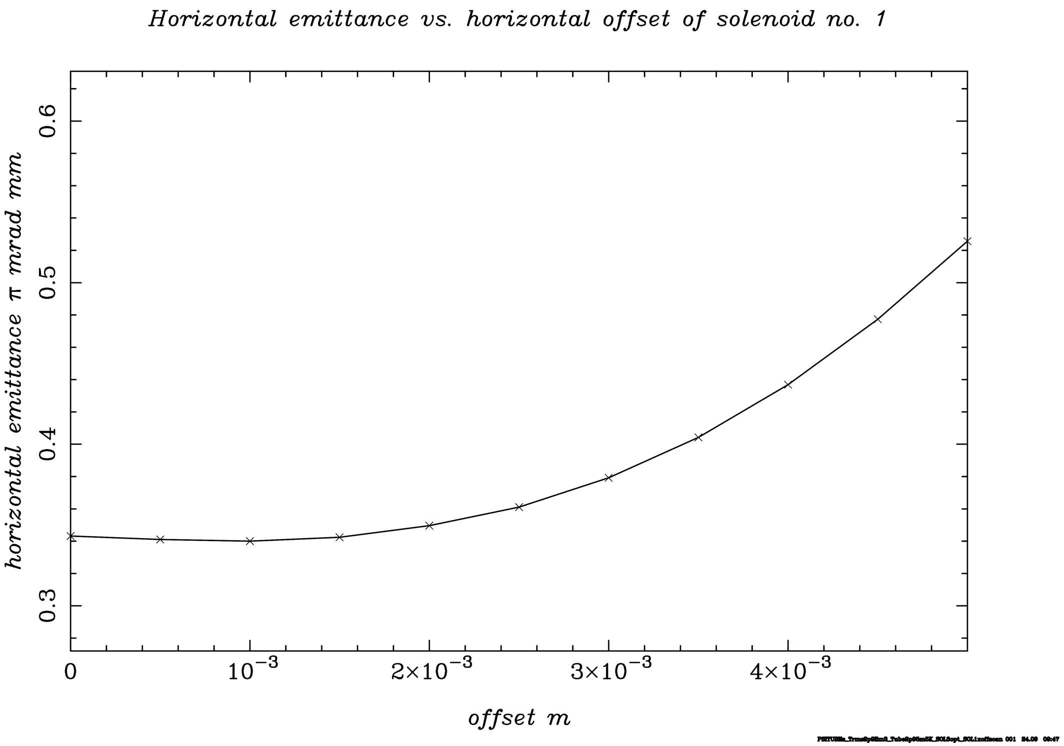
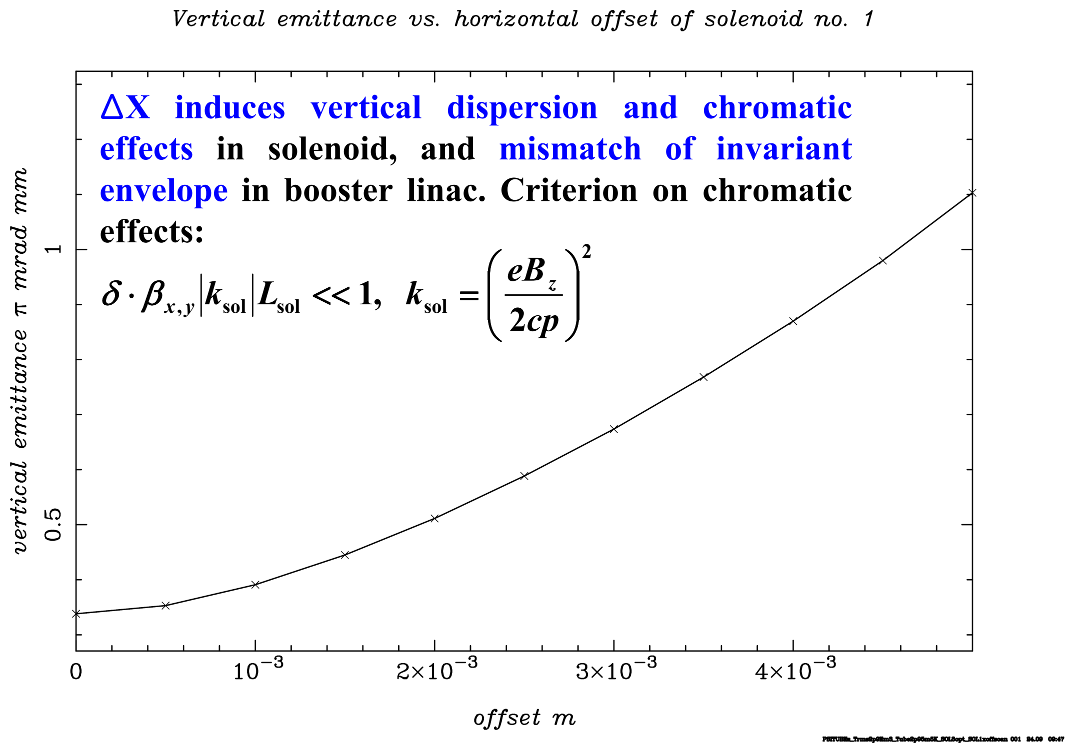
$Q = 0.2$ nC, $I_{peak} \sim 22$ A, $\varepsilon_{n,slice} \sim 0.30$ μm better slice emittance !

Alignment Tolerance - 0.26 m single Solenoid

With the second optimization, tolerance of horizontal misalignment of the new 0.26 m long single solenoid is about 22 μm (p2p), giving 1% vertical emittance growth. It seems that we need the beam based alignment. The tolerance of a vertical misalignment is same range.

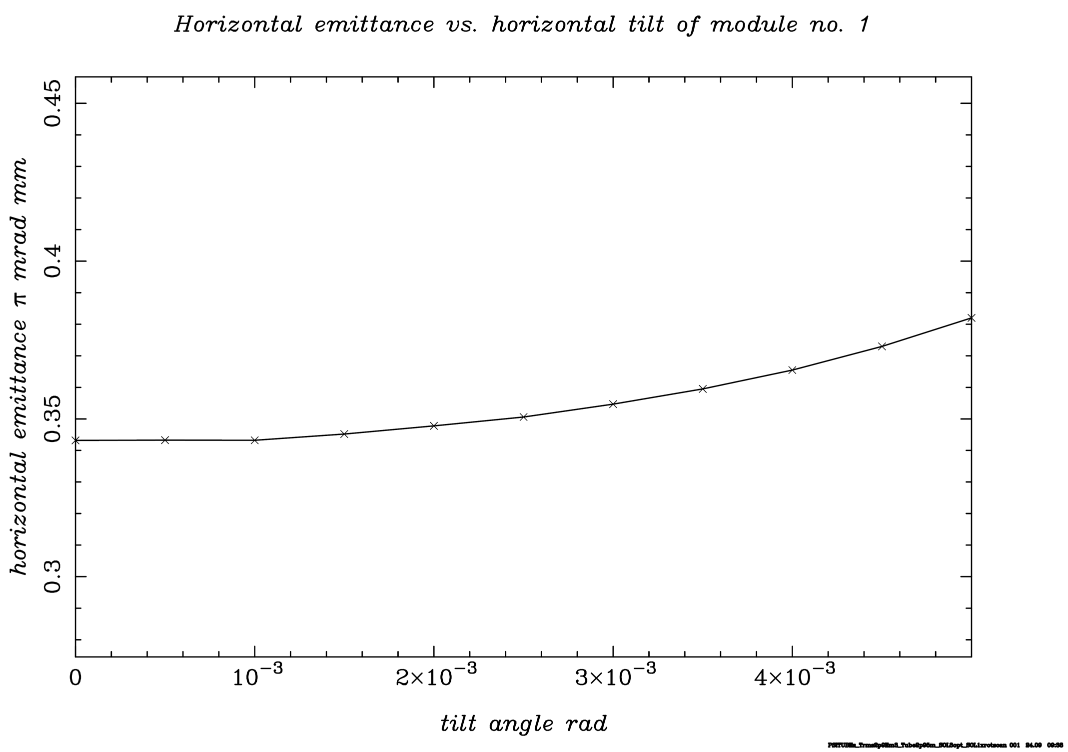


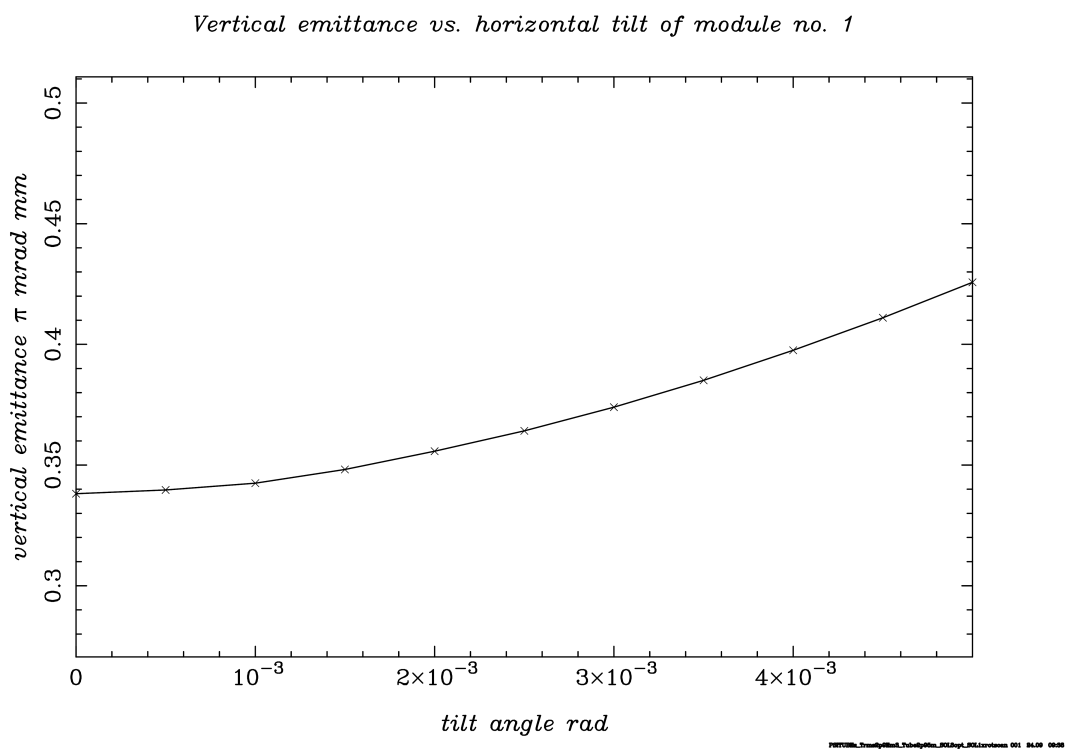


ΔX = ΔY ~ 22 μm (p2p) giving about 1% emittance growth.

Tilt Tolerance - 0.26 m single Solenoid

With the second optimization, tolerance of a rotation (or tilt) error around x-axis of the new 0.26 m long single solenoid is about 195 μrad (p2p), giving 1% vertical emittance growth. It seems that we need the beam based alignment. The tolerance of a rotation error around y-axis is same range.





$\Delta\phi_x = \Delta\phi_y \sim 195$ μrad (p2p) giving about 1% emittance growth.

Performance Comparison of New Solenoids

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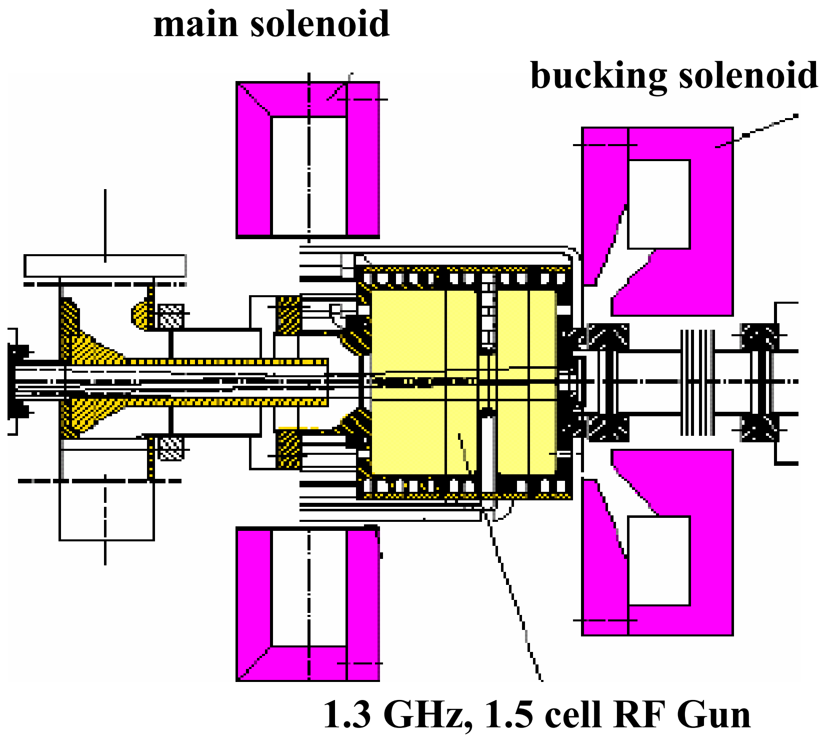
Parameters	unit	New Double Solenoid	New Single Solenoid
min. projected emittance at the exit of booster	μm	0.34	0.34
min core slice emittance at the exit of bootser	μm	0.32	0.30
max solenoid field B_z for 100 MV/m operation	T	0.238	0.206
length of solenoid	m	0.26	0.26
current tolerance of power supply	ppm (p2p)	160	245
transverse alignment tolerance	μm (p2p)	14	22
tilt alignment tolerance	μrad (p2p)	120	195
chromatic effect w.r.t original 0.2 m solenoid*	%	113	85
max beta-function at the end of booster	m	~ 45	~ 45

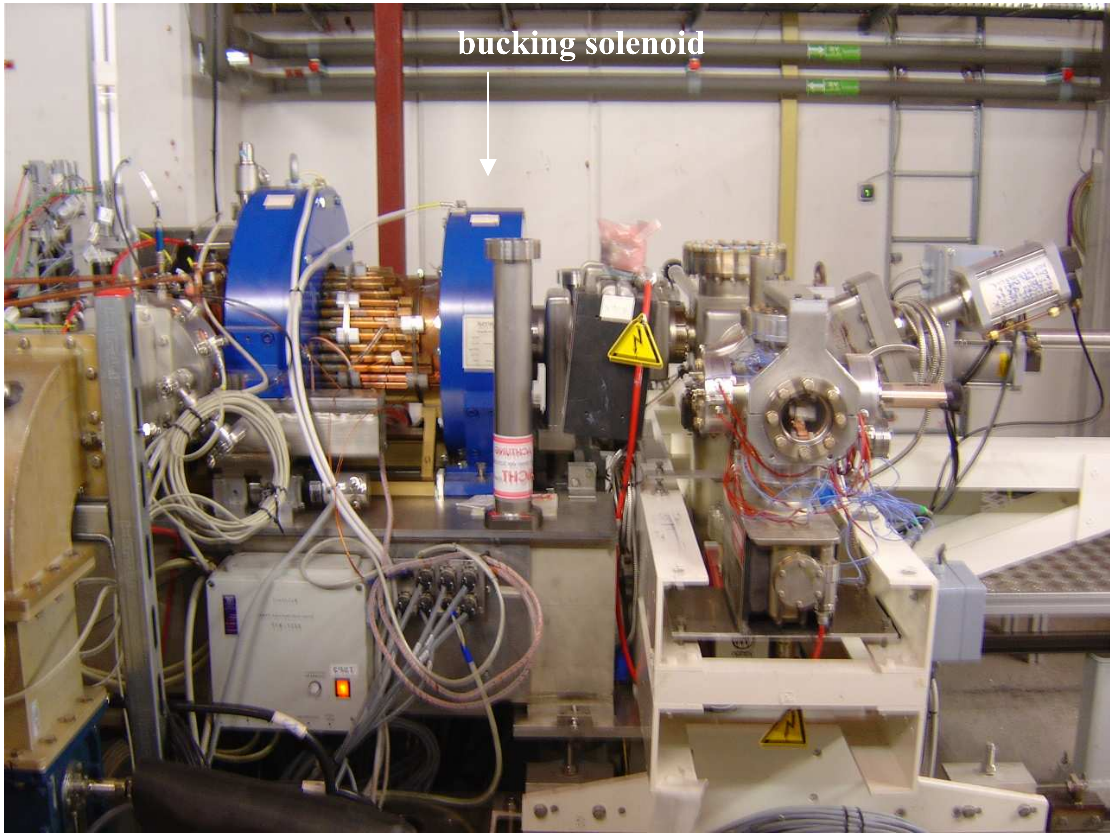
* chromatic effect in solenoid is proportional to $B_z^2 L_{sol}$ at gun exit.

It seems that all performances of a new 0.26 m long single solenoid are much better than those of 0.26 m long double solenoid. Therefore, from now on, we will use the 0.26 m long single solenoid for CTF3 RF gun based injector.

Gun Bucking Solenoid - FLASH Type

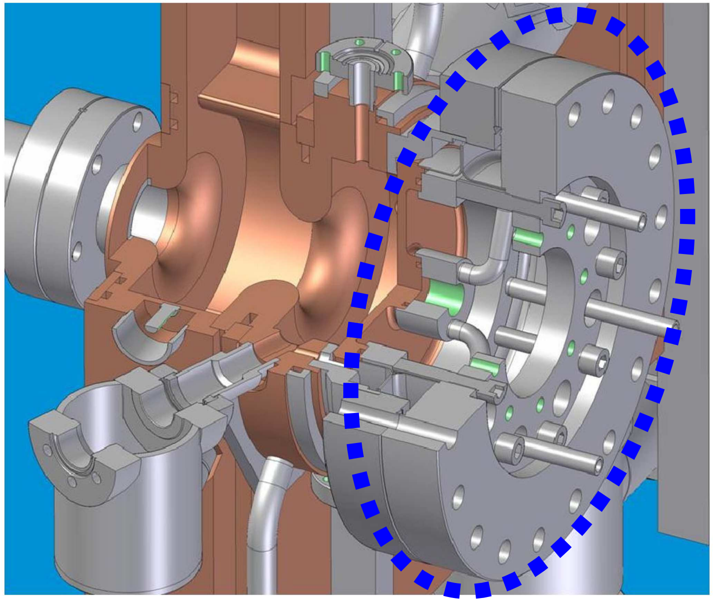
Generally, the magnetic field of the main gun solenoid is not zero on the cathode surface even though it is about 0.3 m away from the cathode. To compensate the residual magnetic field on the cathode, a bucking solenoid will be used for the CTF3 RF gun. Power supply should be connected to satisfy a condition that B_z direction of the bucking solenoid is opposite to that of the main gun solenoid.



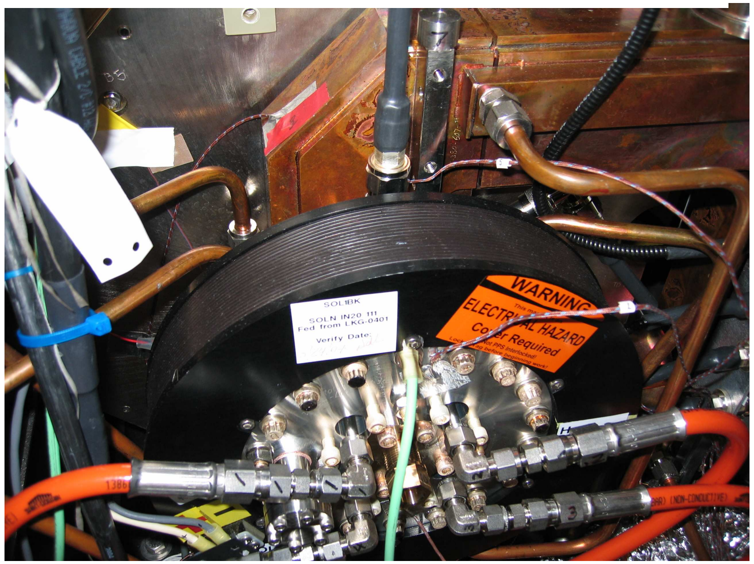


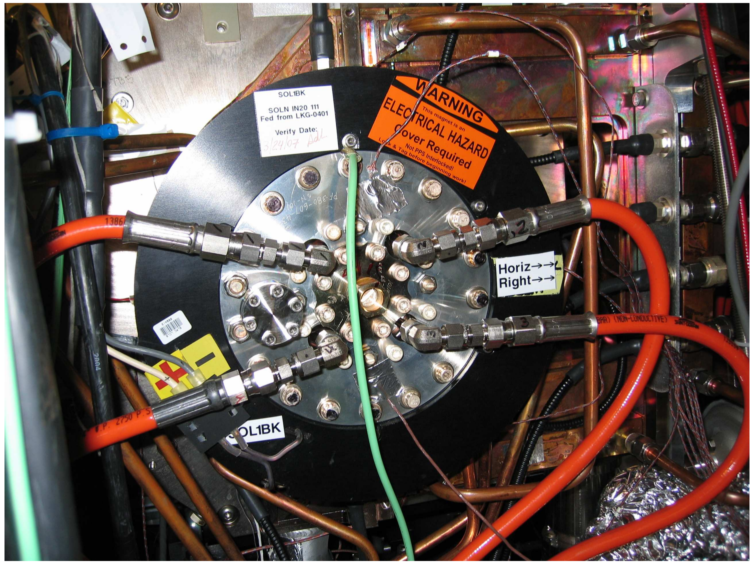
DESY FLASH RF Gun type Bucking Solenoid

Gun Bucking Solenoid - LCLS Type



LCLS installed a small bucking coil on a cathode flange.



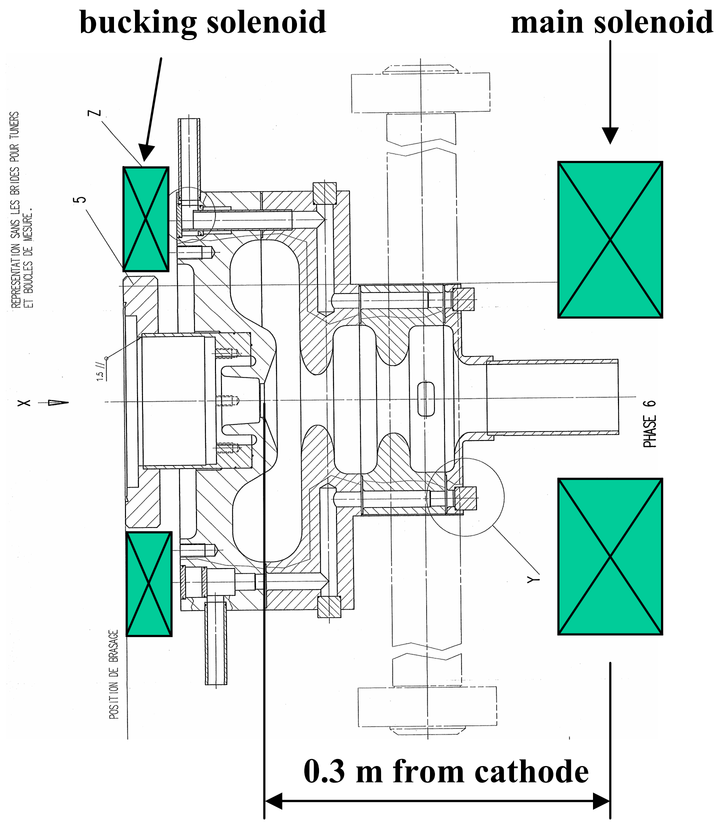


SLAC LCLS RF Gun type Bucking Solenoid

Gun Bucking Solenoid

To make easily, our bucking coil can be similar to that of LCLS as shown below. Followings are its specification and tolerances.

Parameters	unit	bucking solenoid
max solenoid field B_z	T	0.04
length of solenoid	m	0.03
inner diameter of solenoid	m	0.16
current tolerance of power supply	ppm (p2p)	200
transverse alignment tolerance	μm (p2p)	50
tilt alignment tolerance	μrad (p2p)	200



CTF3 RF Gun for PSI 250 MeV Injector

Tolerance of Solenoids in S-band Structures

22 A - Good Slice & Projected Emittance & Low Peak Current

laser $\sigma_{x,y}$ = 270 μm, INSB01 @ 2.95 m

B_{sol} ~ 0.255 T

laser beam : $\sigma_{x,y}$ = 270 μm, ΔT = 9.9 ps (FWHM), rise & falling time = 0.7 ps

e-beams : Q ~ 0.2 nC, $\varepsilon_{thermal}$ = 0.195 μm

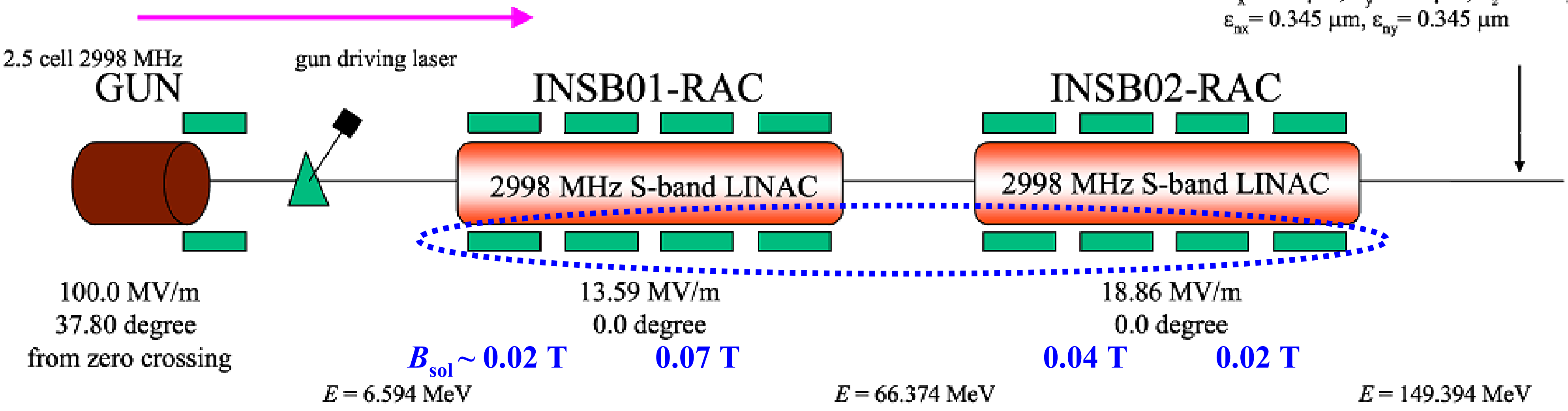
I_{peak} = 22 A

E = 149.394 MeV

σ_{δ} = 0.163%

σ_x = 211 μm, σ_y = 211 μm, σ_z = 840 μm

ε_{nx} = 0.345 μm, ε_{ny} = 0.345 μm



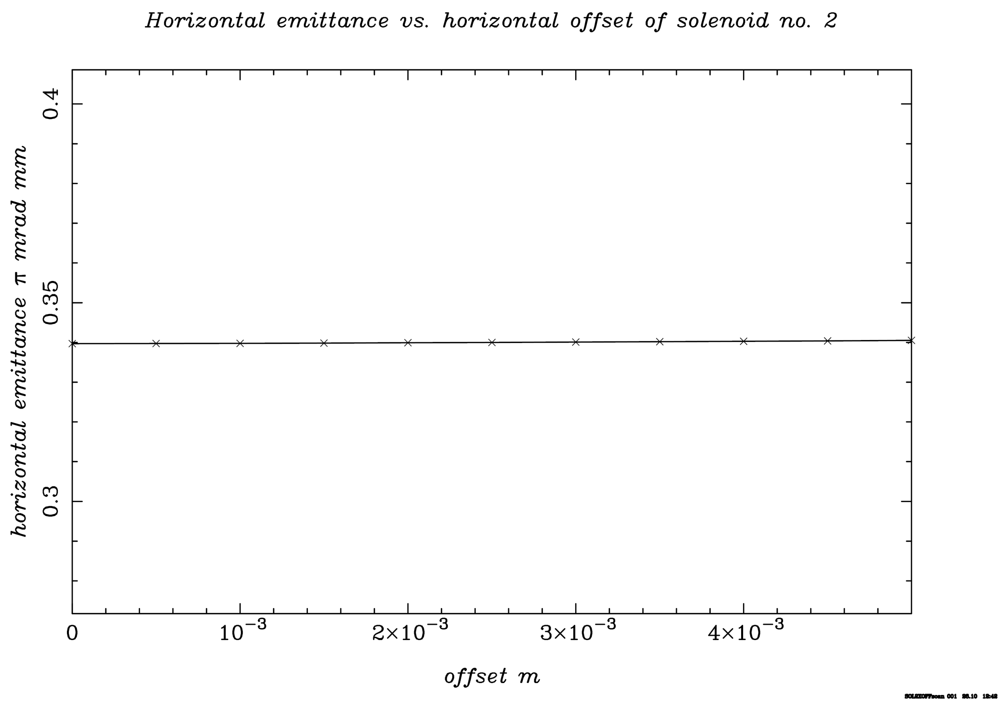
Component :	GUN	INLB01-MSL10	INSB01-RAC	4 INSB01-MSLAC10s	INSB02-RAC	4 INSB01-MSLC10s		
Distance :	0.0 m	0.3 m (center)	2.95 m	3.4 m (1st center)	7.9 m	8.45 m (1st center)	12.3 m	13 m

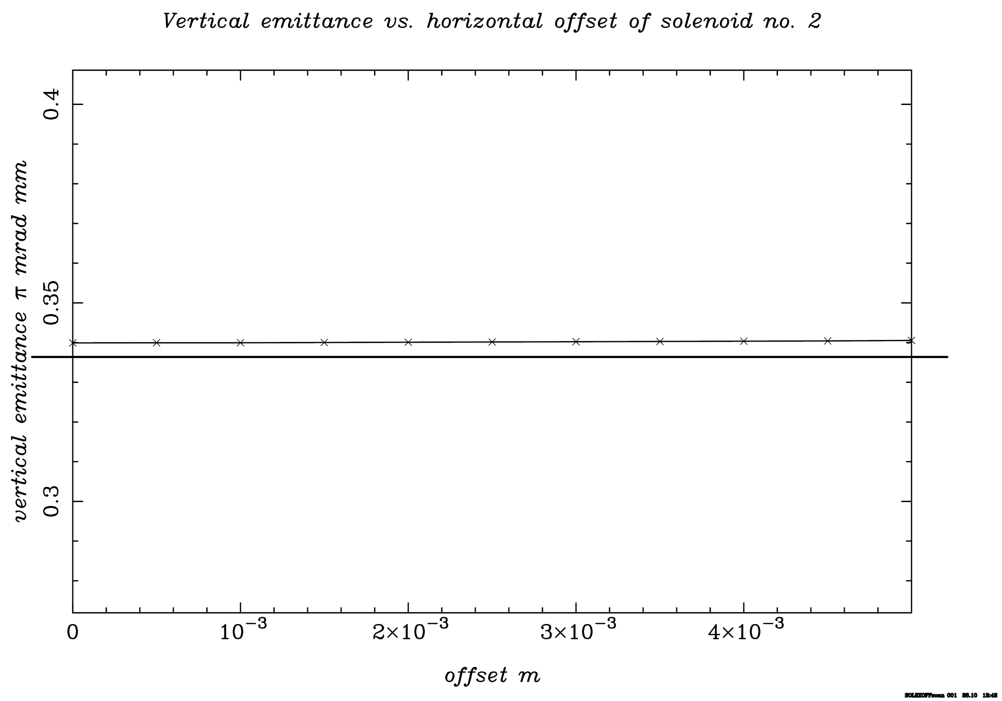
2.5 Cell CTF3 Gun Type V based Injector for PSI XFEL Project

April 7th, 2008 by Y. Kim

We expect that chromatic effect will be much lower for solenoids in S-band structures due to a higher energy & much lower B_z

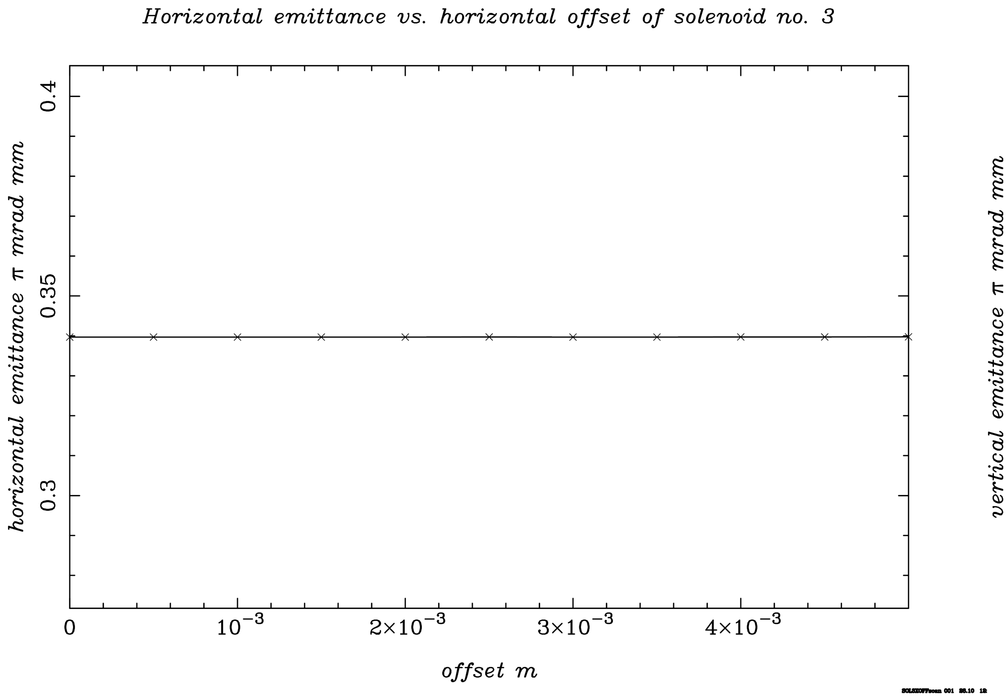
Tolerance of 1st Solenoid in 1st S-band Tube

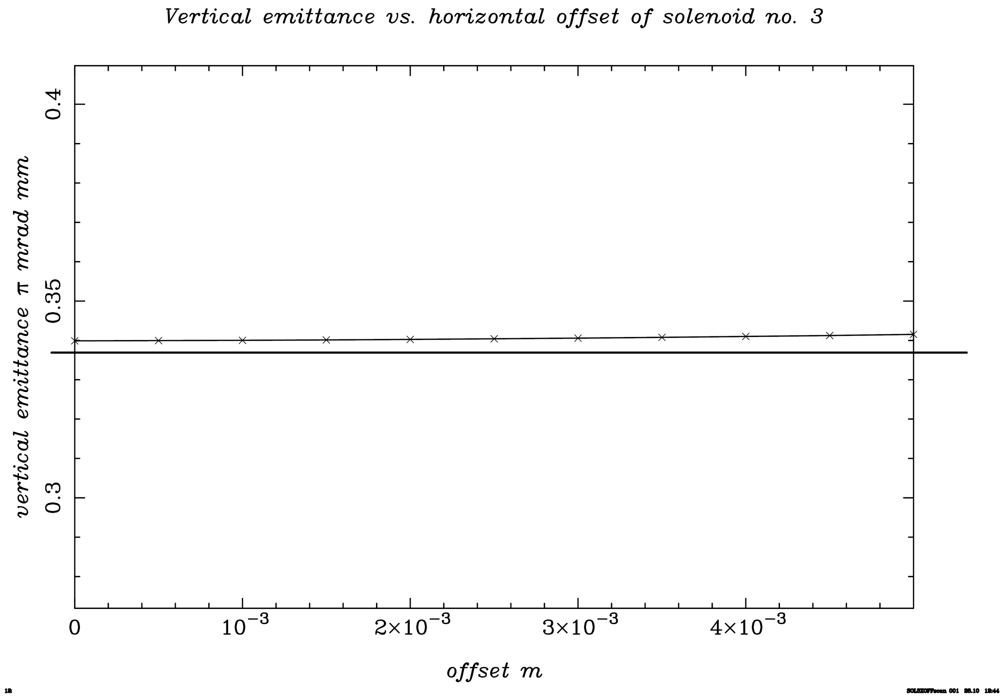




For the first solenoid in the S-band accelerating tube, we applied 5 mm horizontal misalignemt. But its emittance growth is ignorable due to a higher beam energy & a much lower B_z = 0.02 T.

Tolerance of 2nd Solenoid in 1st S-band Tube





For the second solenoid in the S-band accelerating tube, we applied 5 mm horizontal misalignemt. But its emittance growth is also ignorable due to a higher beam energy & a much lower B_z = 0.07 T.

Tolerance of Solenoids in S-band Structures

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Even though we do not need tight alignment tolerance, it will be safer for us to choose following tolerances:

Parameters	unit	all solenoid in S-band structures
max solenoid field B_z for 100 MV/m operation	T	<< 0.1
length of solenoid	m	0.75
current tolerance of power supply	ppm (p2p)	200
transverse alignment tolerance	μm (p2p)	150
tilt alignment tolerance	μrad (p2p)	200

Summary

Since current 0.2 m long double solenoid can not supply a required magnetic field of about 0.255 ~ 0.300 T for CTF3 gun based injector, recently, M. Negrazus of magnet group has designed 0.26 m long single and double solenoids, which can supply the higher maximum magnetic field of 0.4 T.

From quick re-optimizations, we found that the required magnetic field of the new double solenoid is about 0.238 T for 100 MV/m operation. However, we found that a lower field strength of 0.206 T is needed if we would like to use the new single solenoid.

With those new solenoids, we can obtain almost same beam quality (ε_n ~ 0.34 μm at the end of SB02), which we have obtained with current 0.2 m long double solenoid. But in case of the single solenoid, it can supply a slightly improved slice emittance of 0.3 μm, and its alignment tolerances and current jitter of power supply are much looser than those of the double solenoid.

Horizontal or vertical misalignment tolerance of the single solenoid is 22 μm (p2p) giving 1% emittance growth, and tolerance of tilt error around x-axis or y-axis of the single solenoid is about 195 μm (p2p). Therefore, we have to use the beam based alignment (BBA) to align the single solenoid properly.

Summary & Acknowledgement

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To loose alignment tolerances and to obtain an improved slice emittance, we have to choose the single solenoid instead of the double solenoid for the CTF3 RF gun based injector.

We will choose the LCLS type bucking coil to make easily.

All tolerances of solenoids in S-band structures are much looser than those of gun solenoid due to a much lower B_z and a much higher beam energy.

In the near future, performance and tolerance of double solenoids in the pulser based injector and LEG phase-II should be investigated.

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