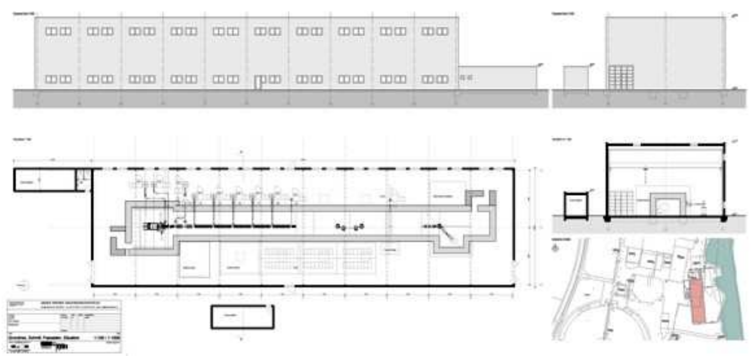

Simulation Results on a Backup Injector with CTF3 Gun Type V

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PSI XFEL-2008-06

Contents

- Short Introduction on CTF3 RF Gun Type V
- Possible Layout with CTF3 RF Gun Type V
- ASTRA Simulation Results with CTF3 RF Gun Type V
  - 0.2 nC, 100 MV/m - short bunch & larger transverse profile case
  - 0.2 nC, 100 MV/m - long bunch & smaller transverse profile case
- Impact of a Long Drift Space between Gun and Linac on Beam Parameters
- Performance Comparison with LCLS type Backup Injector
- Summary and Acknowledgement

Required Beam Parameters for PSI XFEL

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☐ Required Beam Parameters for 0.1 nm PSI XFEL Project

- beam energy = 5.8 GeV
- single bunch charge = 0.2 nC
- normalized slice emittance ≤ 0.2 μm
- rms slice energy spread = 0.6 MeV
- peak current = 1.5 kA
- saturation length ~ 32 m
- undulator period = 15 mm
- undulator strength *K* = 0.84 (rms)
- beta-function in undulator = 15 m

☐ For PSI XFEL Project, we assumed :

- gap voltage of pulser = 1 MV (now 400 kV, we are still fighting ...)
- gap size = 4 mm, gradient = 250 MV/m (now < 70 MV/m, we are still fighting ...)
- normalized slice emittance at gun exit ≤ 0.1 μm (now 0.2 μm, we are still fighting ...)
- peak current at gun exit = 5.5 A (now 1.5 A, it will be OK with new lasers)
- single bunch charge = 24 pC (it will be OK with new lasers)
- beam deceleration ~ 150 keV at the two-frequency two-cell cavity

Required Beam Parameters for PSI XFEL

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□ Required Beam Parameters for 0.1 nm PSI XFEL Project

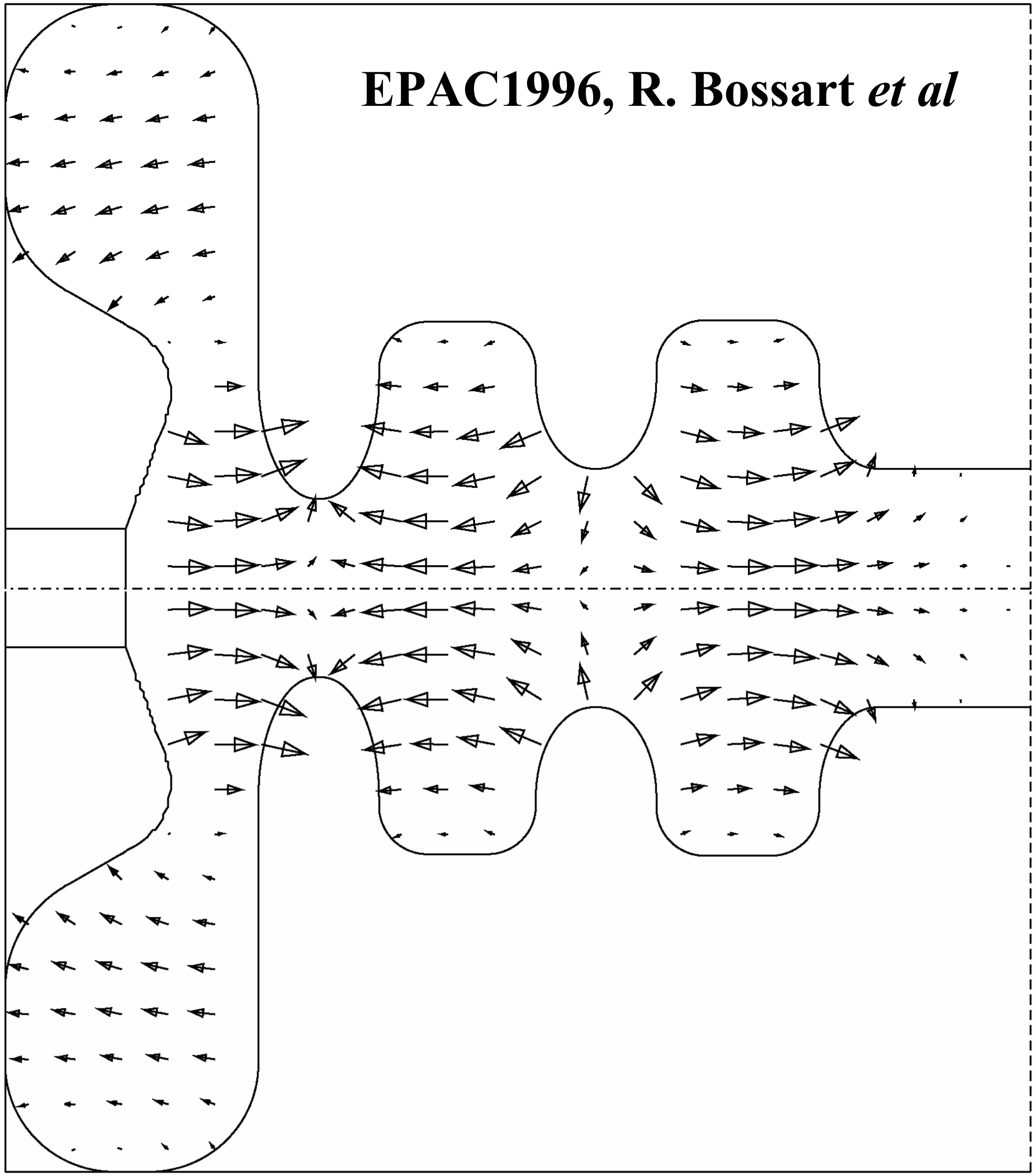
- beam energy = 5.8 GeV
- single bunch charge = 0.2 nC
- normalized slice emittance ≤ 0.2 μm
- rms slice energy spread = 0.6 MeV
- peak current = 1.5 kA
- saturation length ~ 32 m

After consideration current situation, we need a backup solution to keep our project ! Alternatively, we can choose low-emittance & high peak current instead of ultra-low emittance & low peak current !

□ For PSI XFEL Project, we assumed :

- gap voltage of pulser = 1 MV (now 400 kV, we are still fighting ...)
- gap size = 4 mm, gradient = 250 MV/m (now < 70 MV/m, we are still fighting ...)
- normalized slice emittance at gun exit ≤ 0.1 μm (now 0.2 μm, we are still fighting ...)
- peak current at gun exit = 5.5 A (now 0.3 A, it will be OK with new lasers)
- single bunch charge = 24 pC (it will be OK with new lasers)
- beam deceleration ~ 150 keV at the two-frequency two-cell cavity

CTF3 2.5 Cell S-band RF Gun Type V



From Micha & Rudi Bossart communication

RF tested @ 100 MV/m - two weeks operation
power for 100 MV/m = 22 MW with 4.5 μs RF pulse
power for 120 MV/m = 25 MW
RF frequency ~ 2998.5 MHz
cell = 2.5 cells (One TM02 + Two TM01)
Q_0 = 16300
number of bunch in a train = 48
cathode wall angle = 20 degree
total length ~ 0.25 m
full cell length ~ 50 mm
designed charge ~ 2.33 nC

CTF3 2.5 Cell S-band RF Gun Type V

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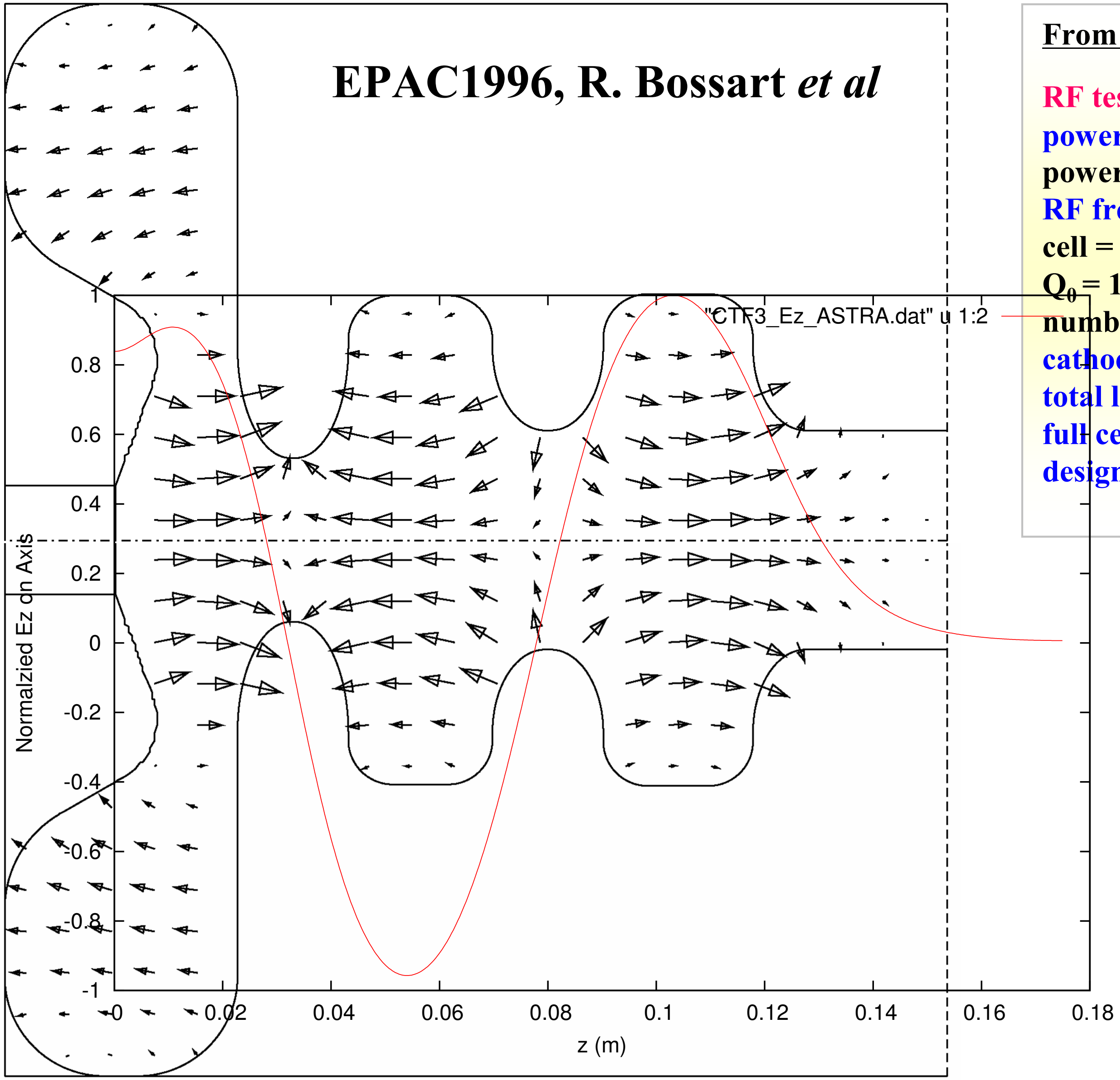

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cathode wall angle = 20 degree
total length ~ 0.25 m
full cell length ~ 50 mm
designed charge ~ 2.33 nC

Possible Layout with CTF3 RF Gun Type V

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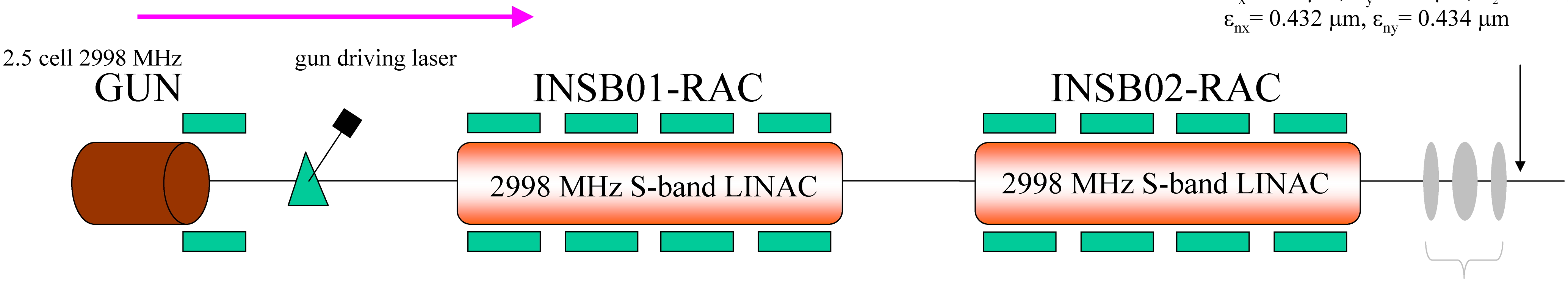
laser beam : $\sigma_{x,y}$ = 240 µm, ΔT = 9.9 ps (FWHM), rise & falling time = 0.7 ps
e-beams : $Q \sim 0.2$ nC, $\varepsilon_{thermal}$ = 0.173 µm

E = 149.100 MeV
σ_δ = 0.2%
σ_x = 351 µm, σ_y = 353 µm, σ_z = 924 µm
ε_{nx} = 0.432 µm, ε_{ny} = 0.434 µm



100.0 MV/m
37.9 degree
from zero crossing

13.58 MV/m
0.0 degree

18.80 MV/m
0.0 degree

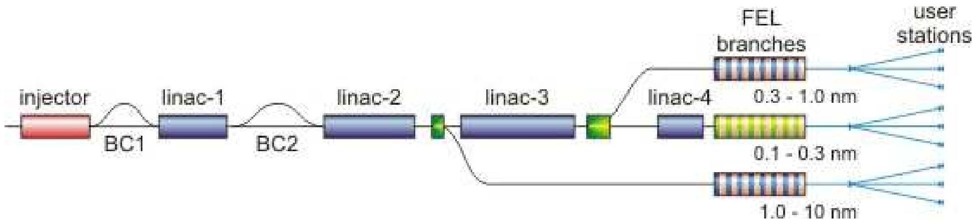
E = 6.594 MeV E = 66.374 MeV E = 149.100 MeV

Component :	GUN	INLB01-MSL10	INSB01-RAC	4 INSB01-MSLAC10s	INSB02-RAC	4 INSB01-MSLC10s		
Distance :	0.0 m	0.3 m (center)	3.15 m	3.6 m (1st center)	8.1 m	8.65 m (1st center)	12.5 m	14 m

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

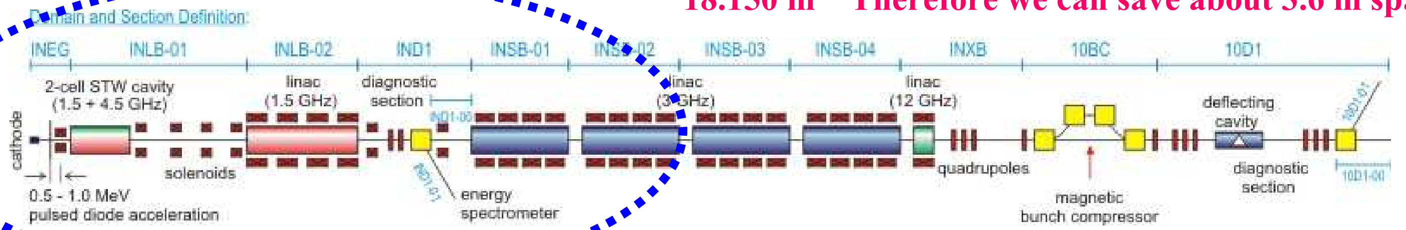
April 14th, 2008 by Y. Kim

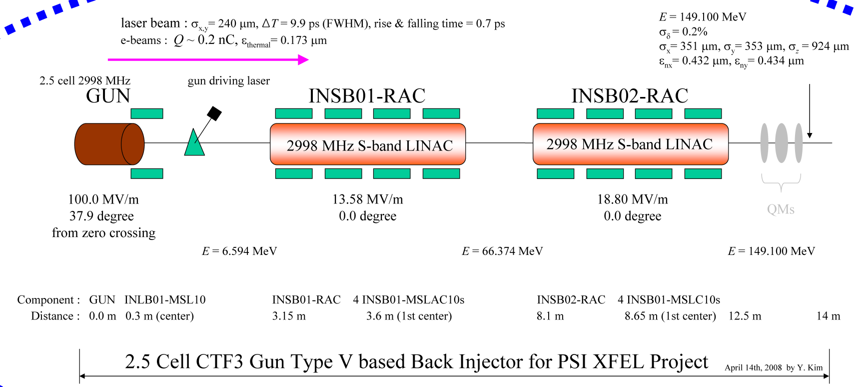
Backup Injector Layout with CTF3 Gun



With a backup layout, overall compression factor of 272 for I_{peak} = 1.5 kA can be reduced to about 100 for I_{peak} = 2.0 kA !!!

18.150 m Therefore we can save about 3.6 m space !





14 m

Fieldmap for ASTRA Simulations - 3.15 m

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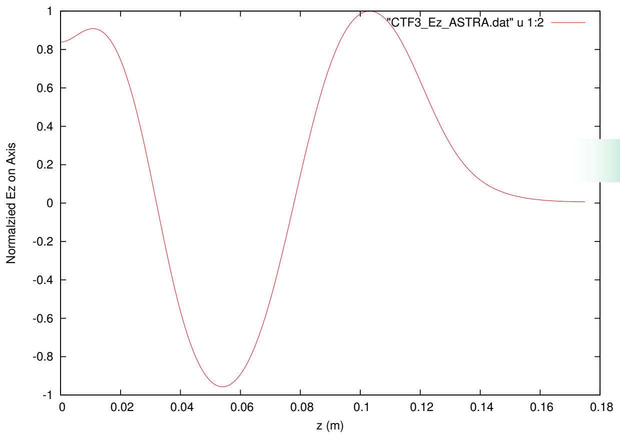
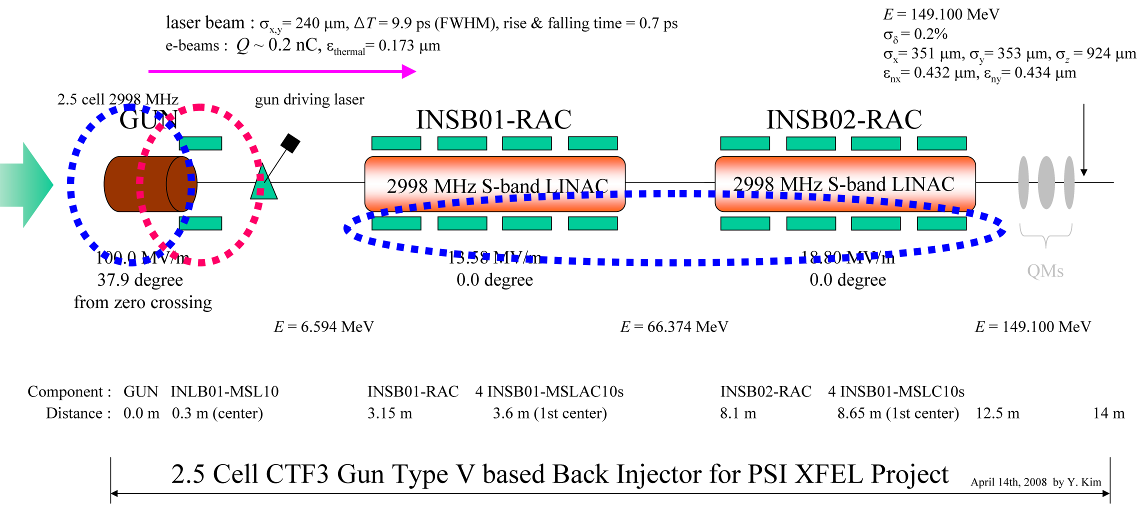
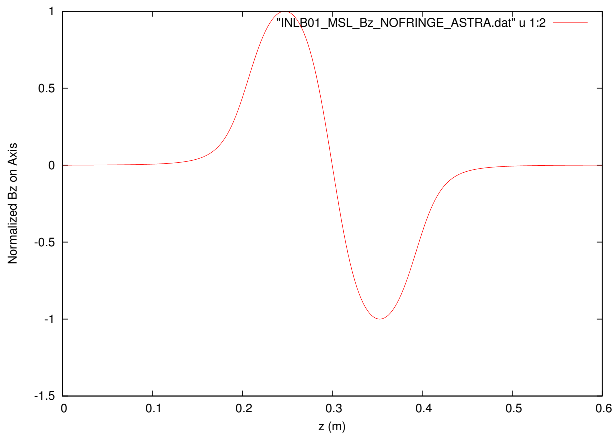
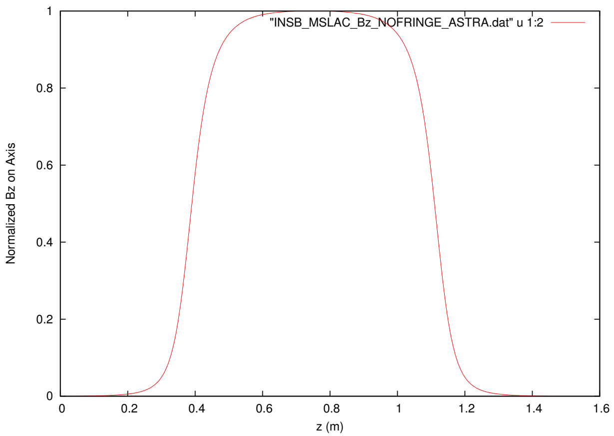
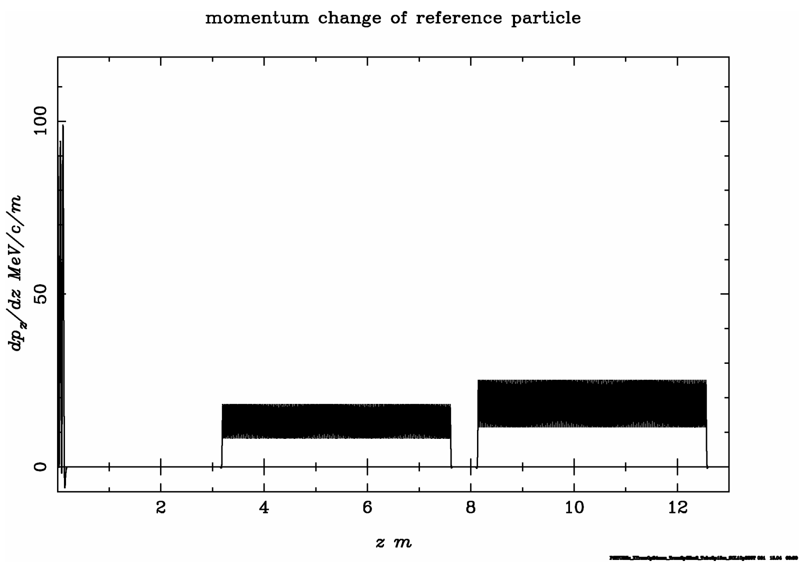
From Micha











Simulation Result with LCLS Type Injector

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- Note that thermal emittance is the most biggest contribution in slice emittance
- We can reduce slice emittance by reducing thermal emittance on the cathode !

$$\varepsilon_{th} \approx \sigma_{x,y}\sqrt{\frac{2K}{3m_e c^2}}, \quad \sigma_x = \sigma_y \ \text{ for a round beam}$$

Here we assumed $K = 0.4$ eV for Cu cathode

Optimization of LCLS Type RF Photoinjector with a gradient of 120 MV/m

Q	laser length (FWHM)	$I_{\text{peak, cathode}}$	laser $\sigma_{\text{x,or y}}$	$\varepsilon_{\text{thermal}}$	$\varepsilon_{\text{projected, exit}}$
0.4 nC	7.4 ps	54 A	0.44 mm	0.32 μm	~ 0.47 μm
0.2 nC	5.8 ps	34 A	0.35 mm	0.25 μm	~ 0.37 μm
0.1 nC	4.6 ps	22 A	0.28 mm	0.20 μm	~ 0.28 μm

Note that peak current is much higher than 5.5 A !

Simulation Result with CTF3 Gun Type V

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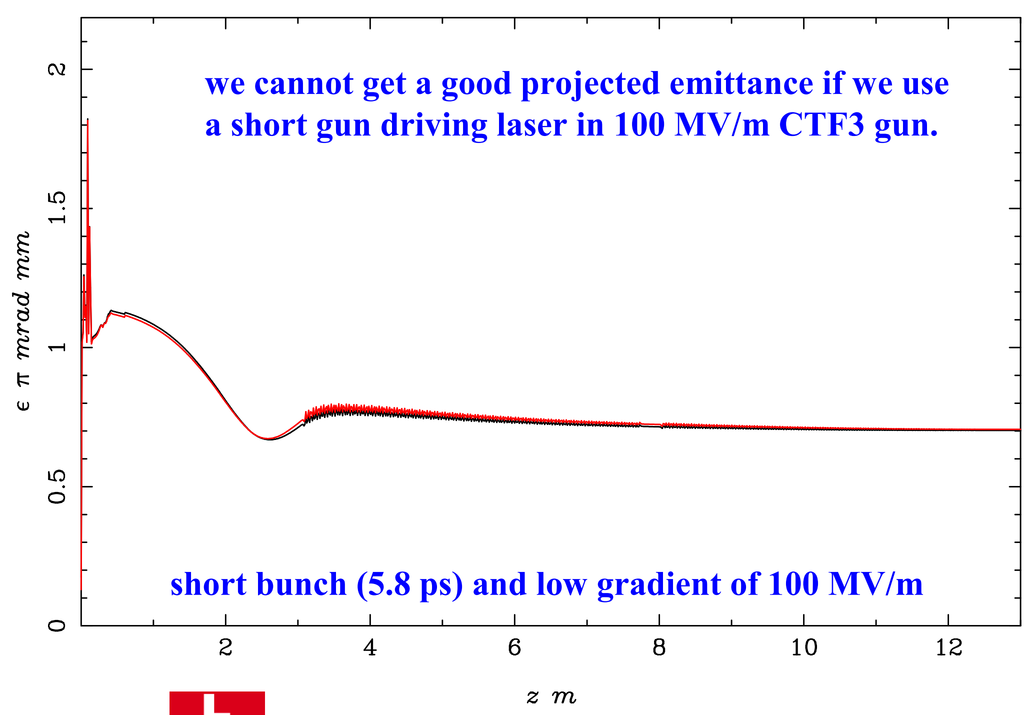
☐ But we can not use such a short laser due to a lower gradient of CTF3 Gun

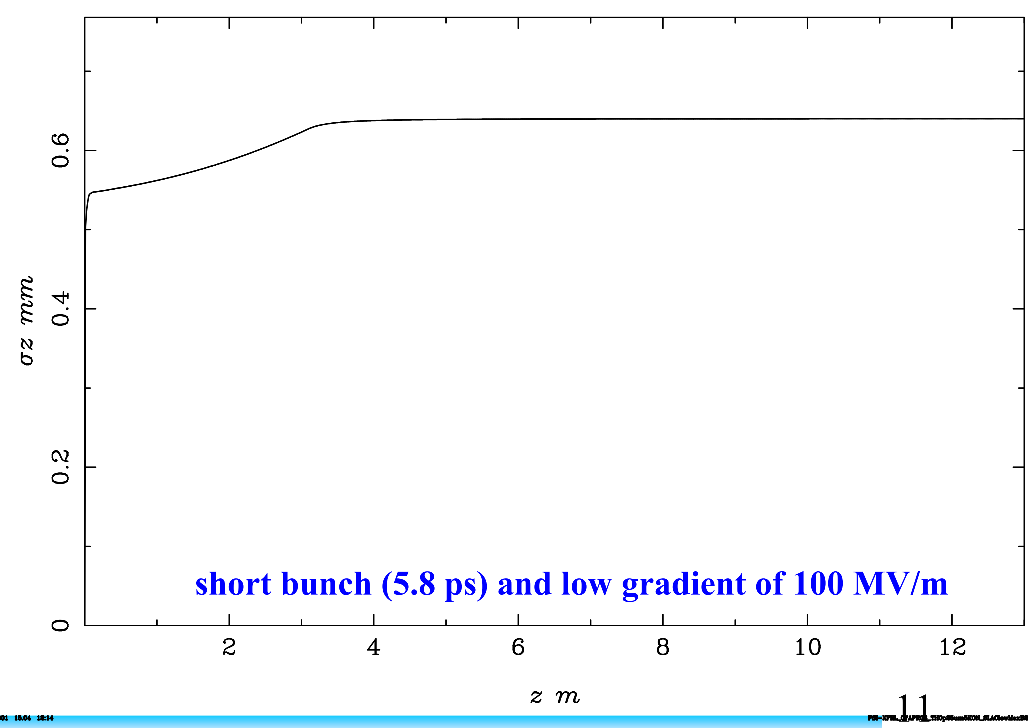
Q	laser length (FWHM)	$I_{peak, cathode}$	laser $\sigma_{x,or\ y}$	$\varepsilon_{thermal}$	$\varepsilon_{projected, exit}$
0.2 nC	5.8 ps	34 A	0.35 mm	0.25 μm	~ 0.702 μm
0.2 nC	9.9 ps	20 A	0.24 mm	0.17 μm	~ 0.396 μm

But we can get a good projected emittance by increasing length of gun laser. Note that its peak current is much lower than LCLS type backup injector !

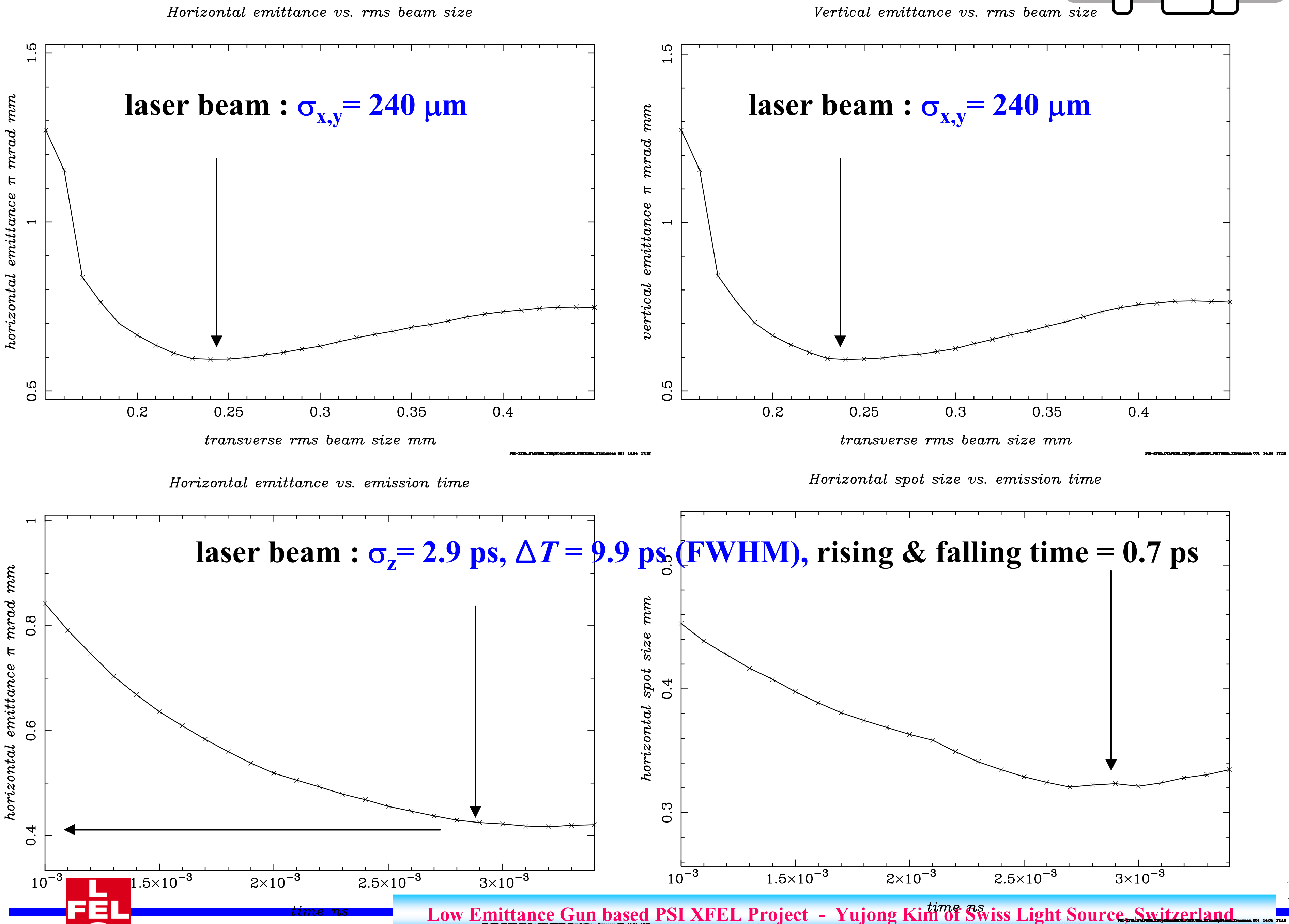
Transverse Emittance



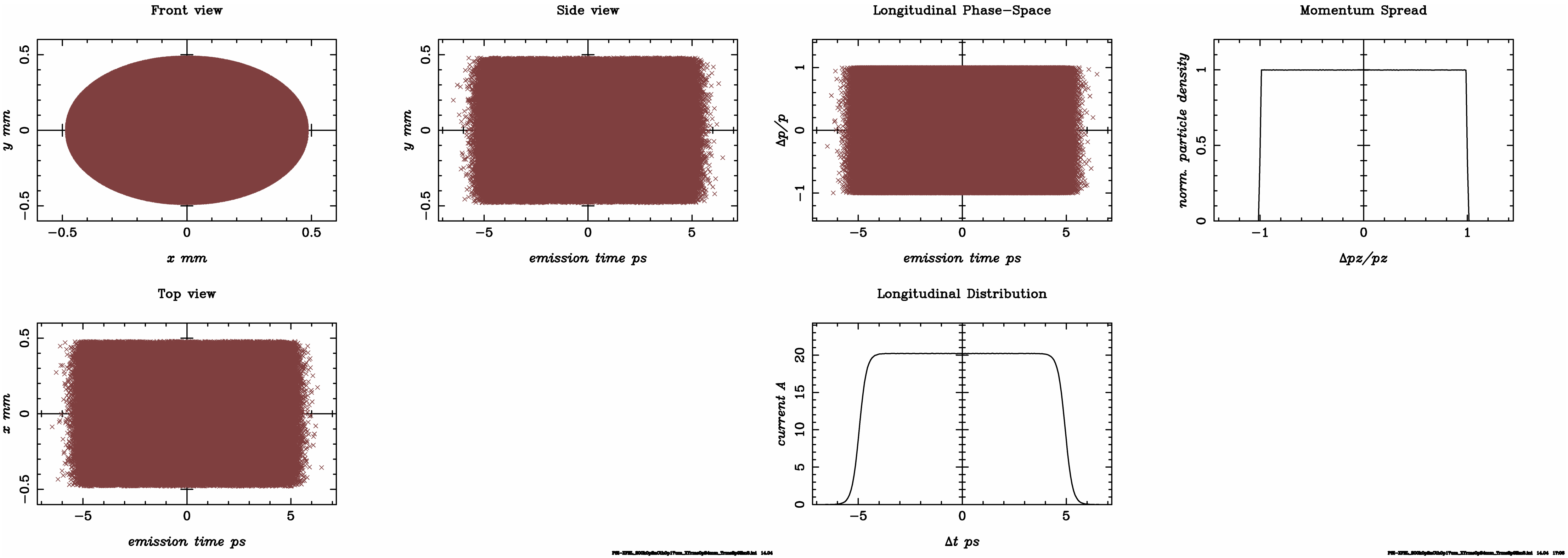
Bunch Length



Optimization of Gun Driving Laser Beam



Initial Gun Driving Laser for 0.2 nC



laser beam : $\sigma_{x,y}$ **= 240 μm,** ΔT **= 9.9 ps (FWHM), rising & falling time = 0.7 ps**

e-beams : Q ~ **0.2 nC,** I_{peak} **~ 20 A,** $\varepsilon_{thermal}$ **= 0.173 μm**

ASTRA Results - INSB01 @ 2.95 m

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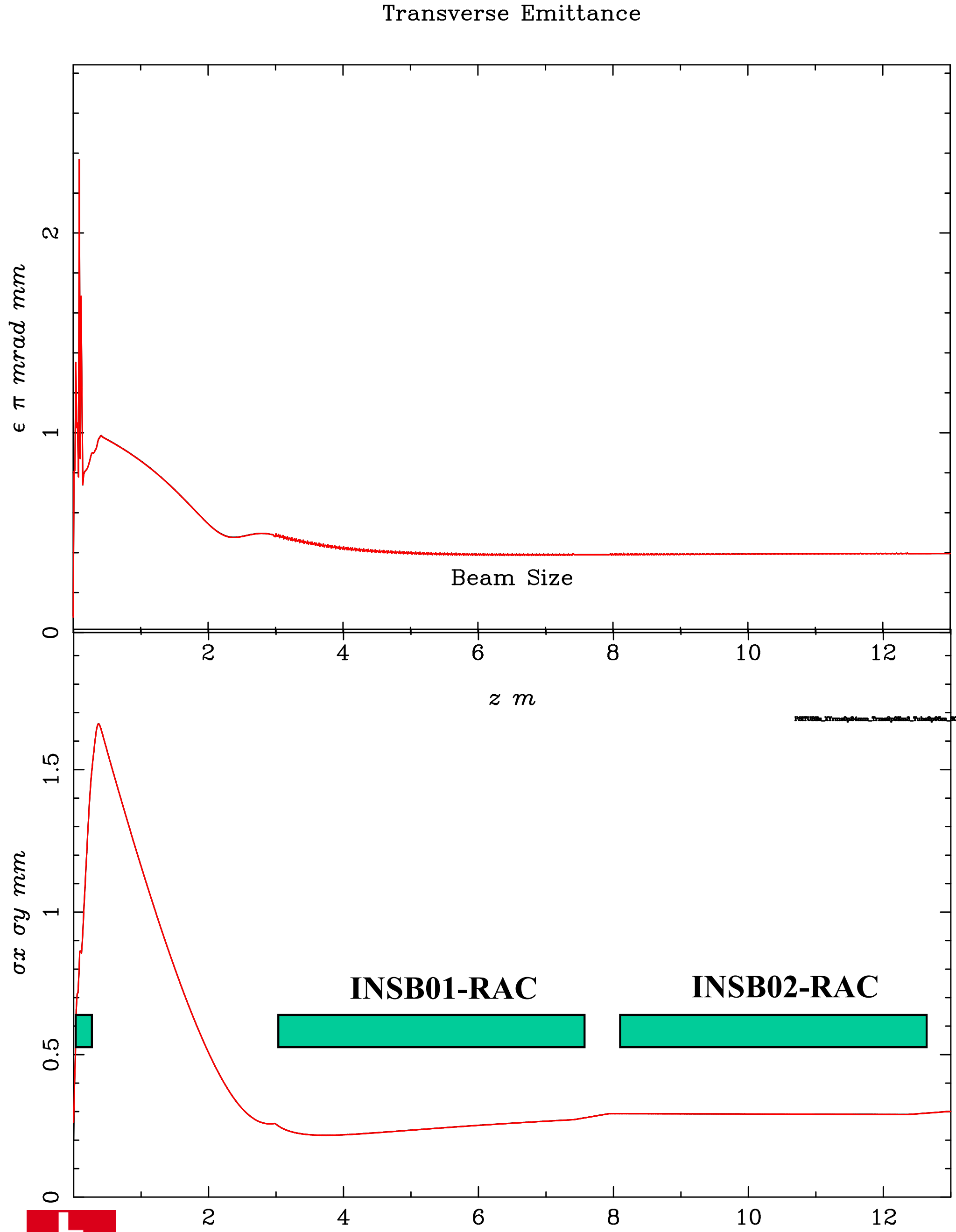


peak magnetic field @ 1st solenoid = 0.2550 T
length of the 1st solenoid = 0.2 m
peak magnetic field @ 2nd solenoid = 0.02 T
length of the 2nd solenoid = 0.75 m
peak magnetic field @ 3rd solenoid = 0.03 T
length of the 2nd solenoid = 0.75 m

<u>At the end of Injector (z ~ 13 m)</u>

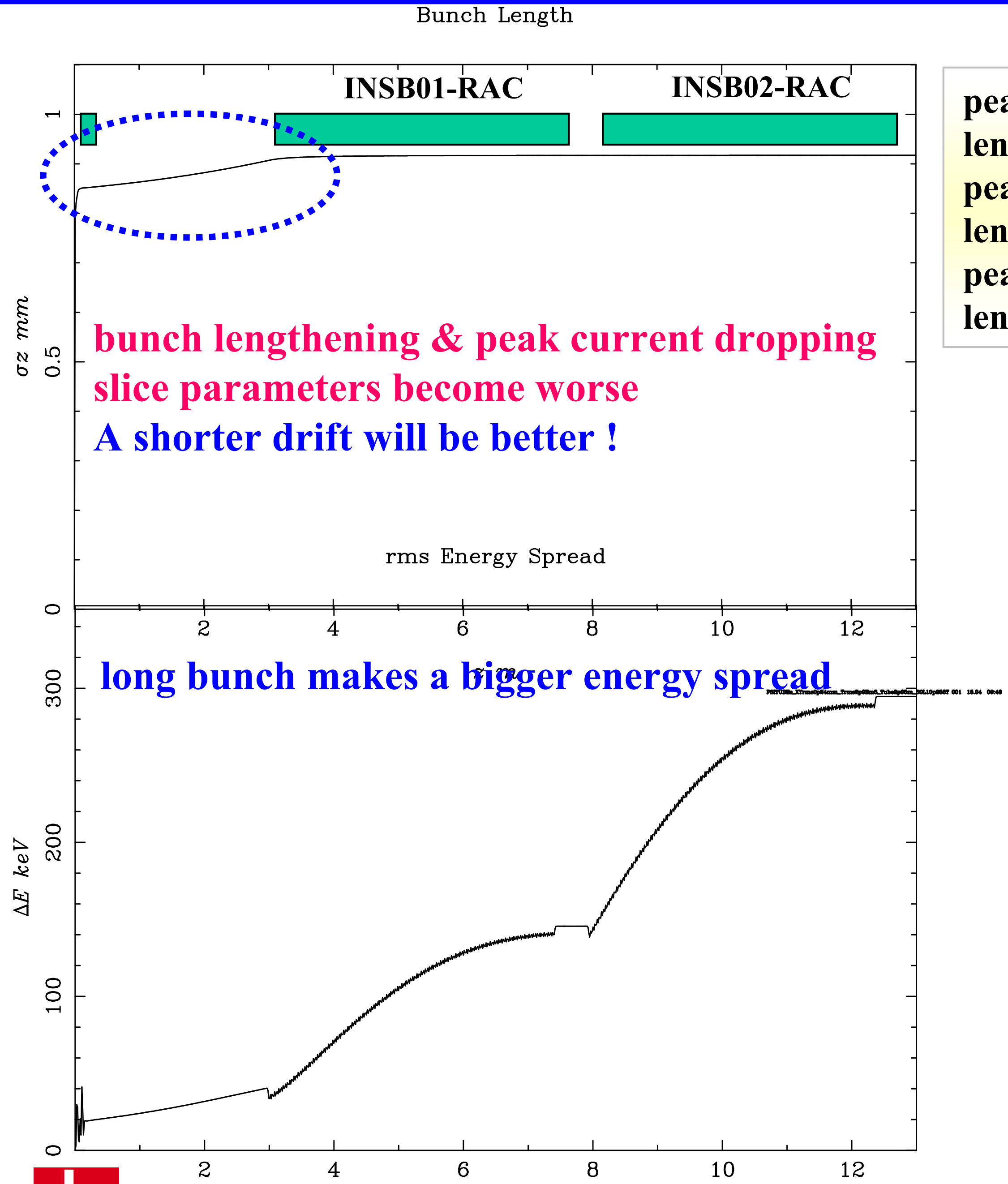
E = 149.100 MeV, σ_δ = 0.198%

σ_x = 301 μm, σ_y = 301 μm, σ_z = 917 μm

ε_{nx} = 0.396 μm, ε_{ny} = 0.396 μm

Q = 0.2 nC, I_{peak} ~ 20 A

ASTRA Results - INSB01 @ 2.95 m



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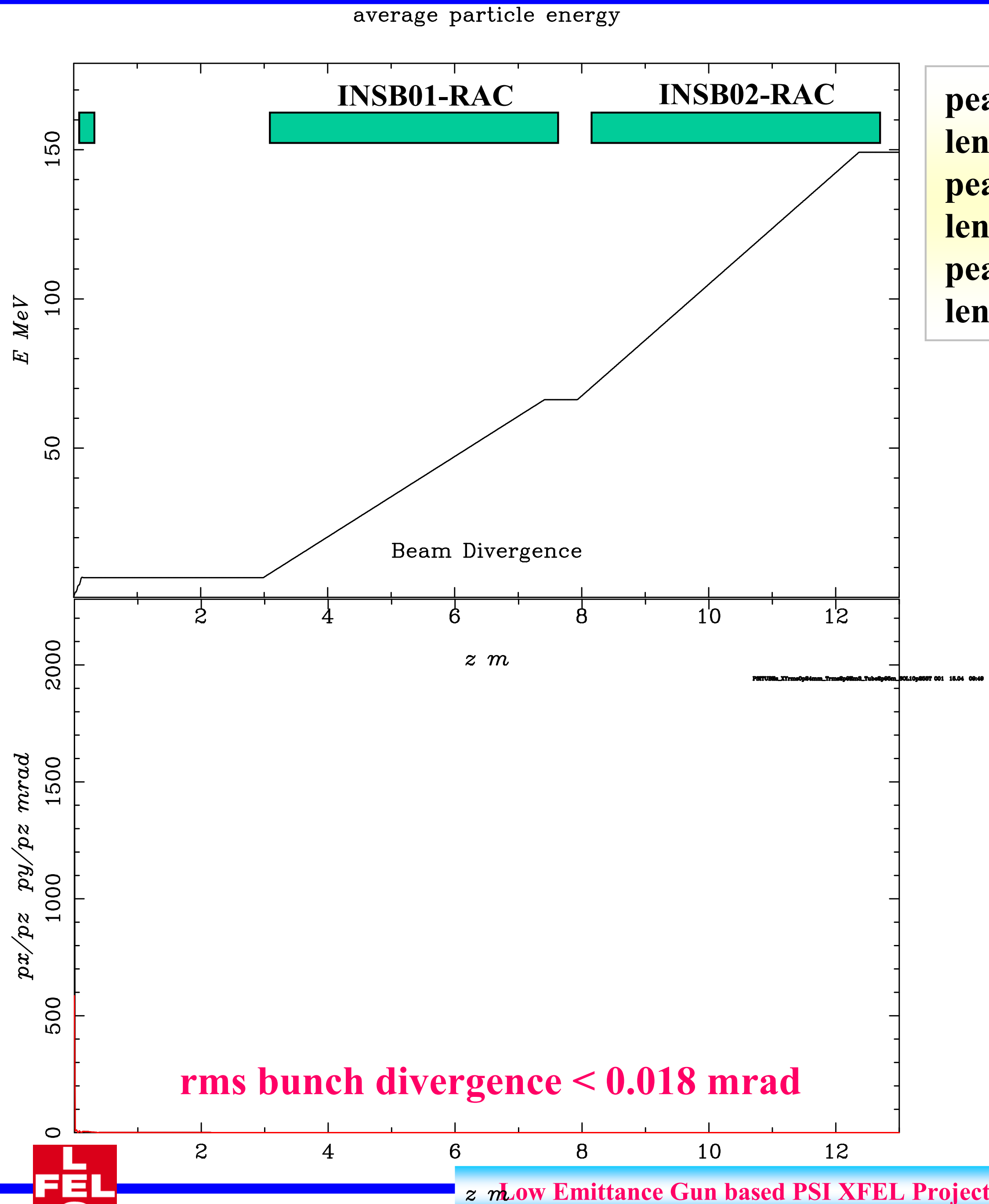
σ_x = 301 μm, σ_y = 301 μm, σ_z = 917 μm

ε_{nx} = 0.396 μm, ε_{ny} = 0.396 μm

Q = 0.2 nC, I_{peak} ~ 20 A

ASTRA Results - INSB01 @ 2.95 m



peak magnetic field @ 1st solenoid = 0.2550 T
length of the 1st solenoid = 0.2 m
peak magnetic field @ 2nd solenoid = 0.02 T
length of the 2nd solenoid = 0.75 m
peak magnetic field @ 3rd solenoid = 0.03 T
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At the end of Injector (z ~ 13 m)

E = 149.100 MeV, σ_δ = 0.198%

σ_x = 301 μm, σ_y = 301 μm, σ_z = 917 μm

ε_{nx} = 0.396 μm, ε_{ny} = 0.396 μm

Q = 0.2 nC, I_{peak} ~ 20 A

At the end of INSB02 - INSB01 @ 2.95 m

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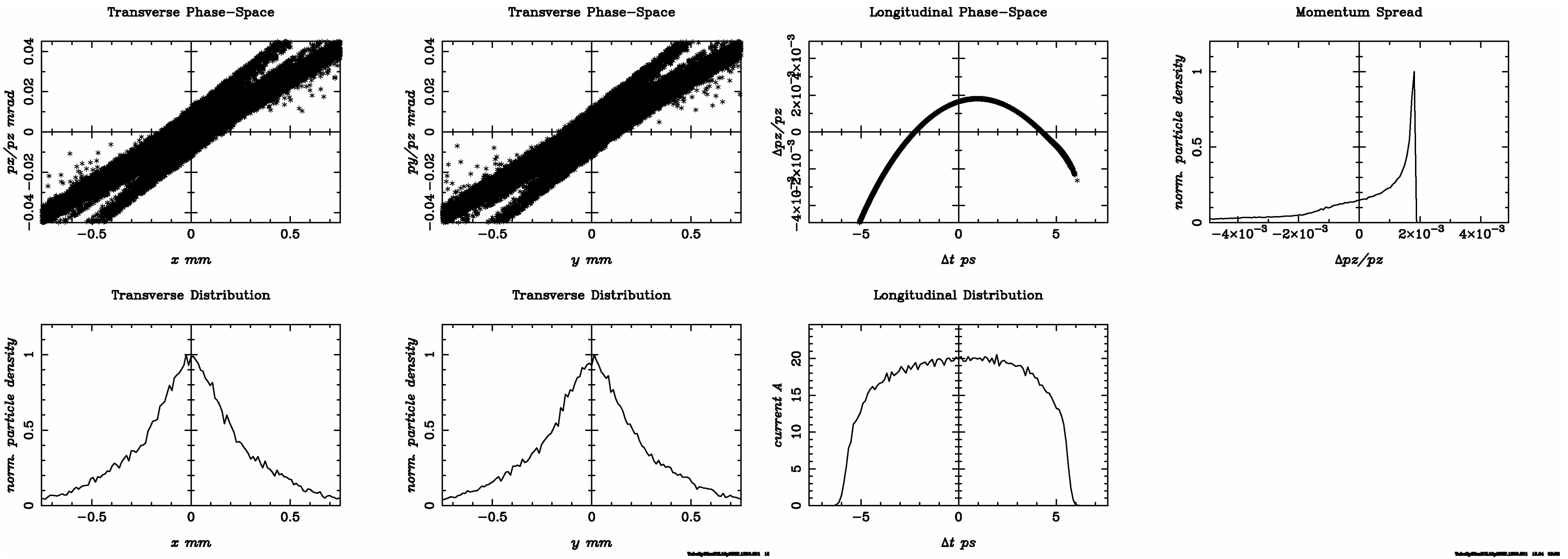


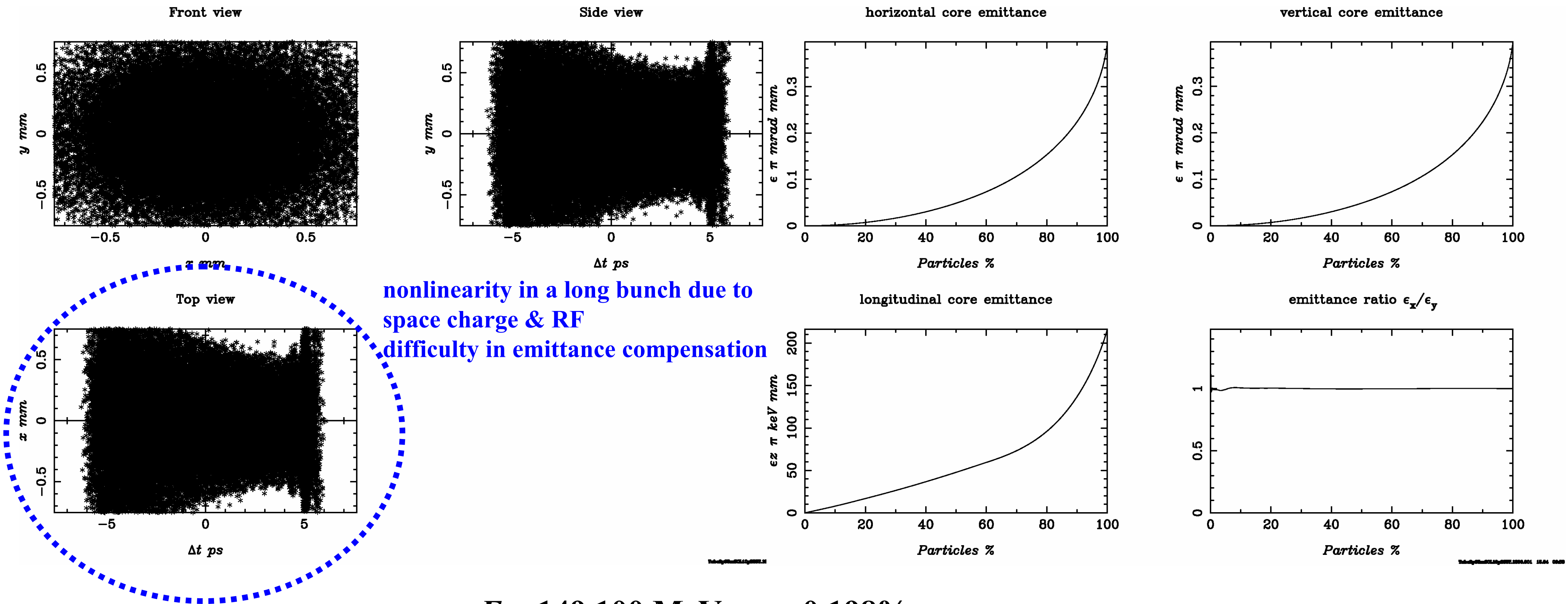
E = 149.100 MeV, σ_δ = 0.198%

σ_x= 301 μm, σ_y= 301 μm, σ_z = 917 μm

ε_{nx}= 0.396 μm, ε_{ny}= 0.396 μm

Q = 0.2 nC, I_{peak} ~ 20 A

At the end of INSB02 - INSB01 @ 2.95 m



nonlinearity in a long bunch due to
space charge & RF
difficulty in emittance compensation

E = 149.100 MeV, σ_δ = 0.198%

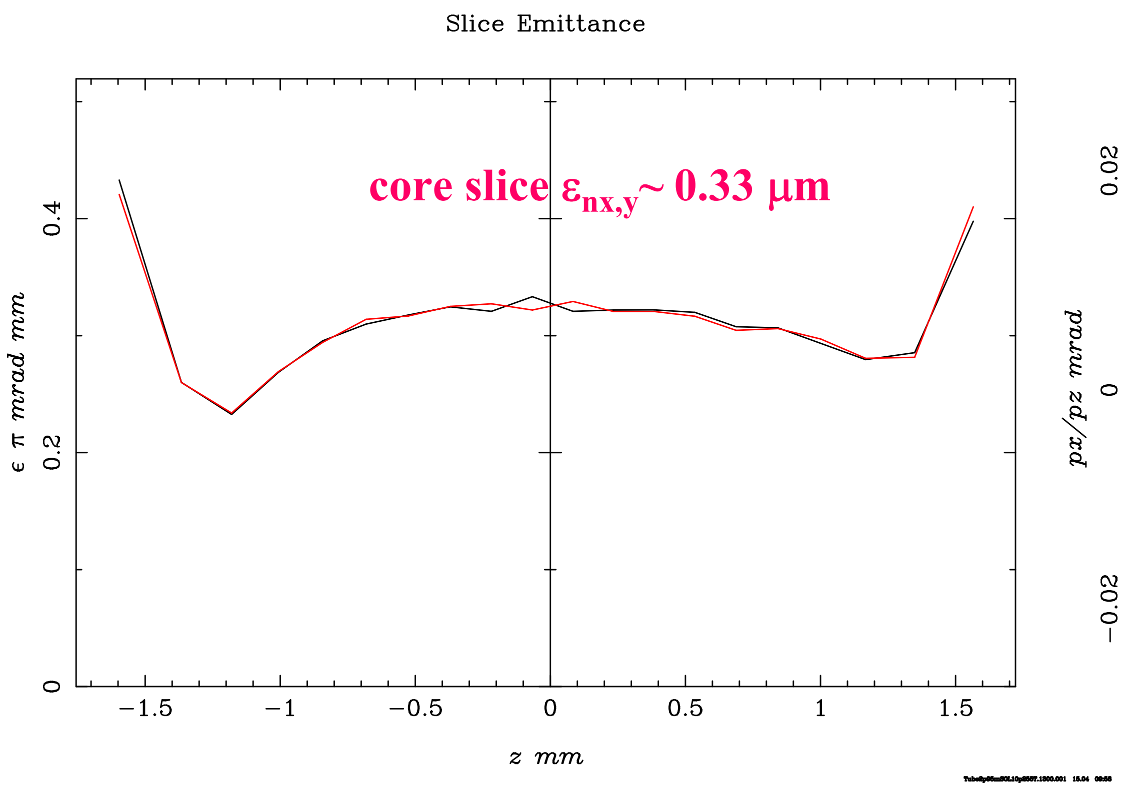
σ_x= 301 μm, σ_y= 301 μm, σ_z = 917 μm

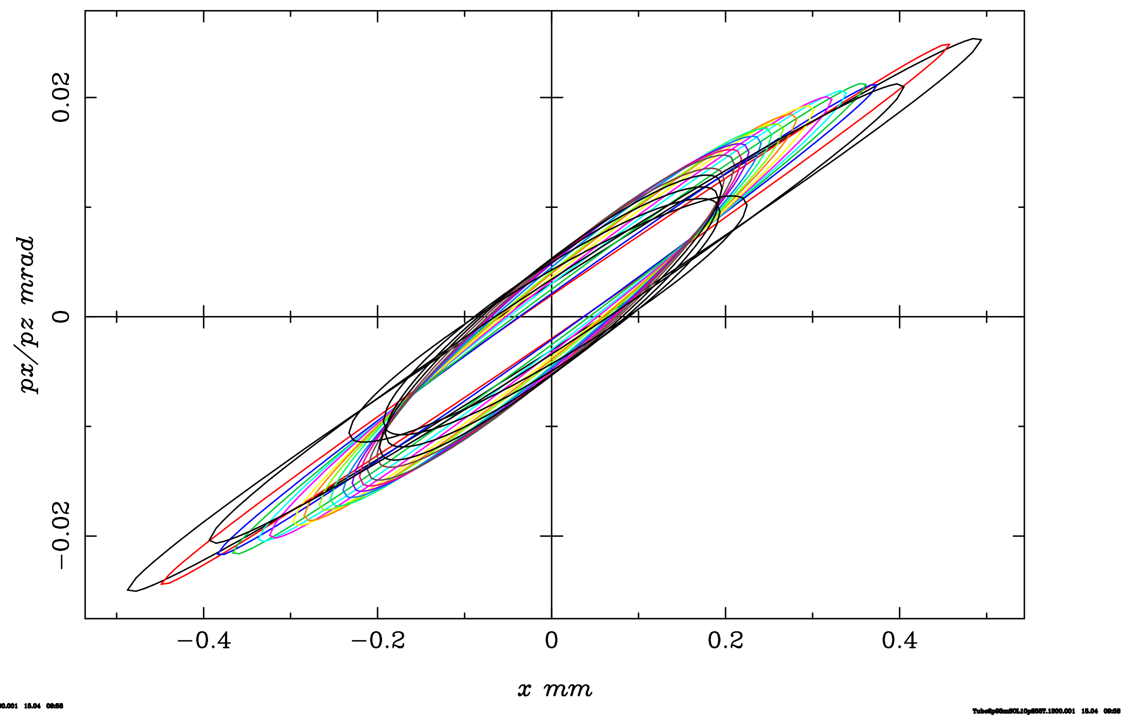
ε_{nx}= 0.396 μm, ε_{ny}= 0.396 μm

Q = 0.2 nC, I_{peak} ~ 20 A

Slice Parameters - INSB01 @ 2.95 m

At the end of INSB02





a long bunch induces nonlinearities along beam (beam energy due to RF, focusing at solenoid and focusing at gun and linac, and space charge force). they induces difficulty in emittance compensation along bunch.
big different slice emittance at head and tail region

Slice Parameters - INSB01 @ 2.95 m

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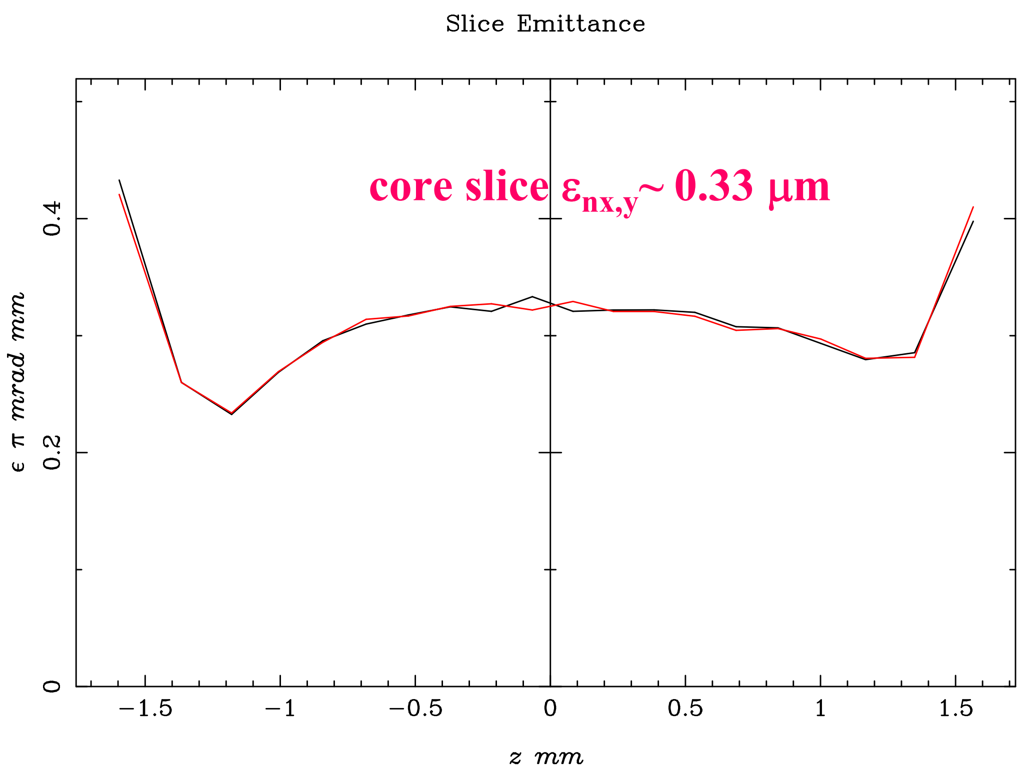
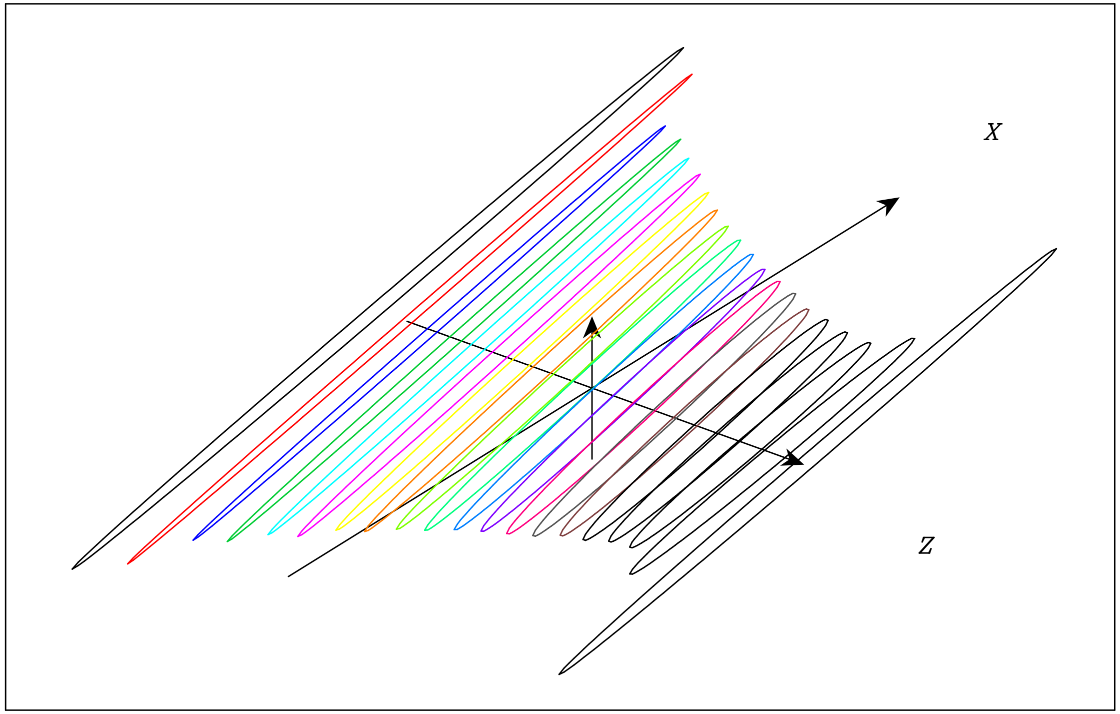
At the end of INSB02

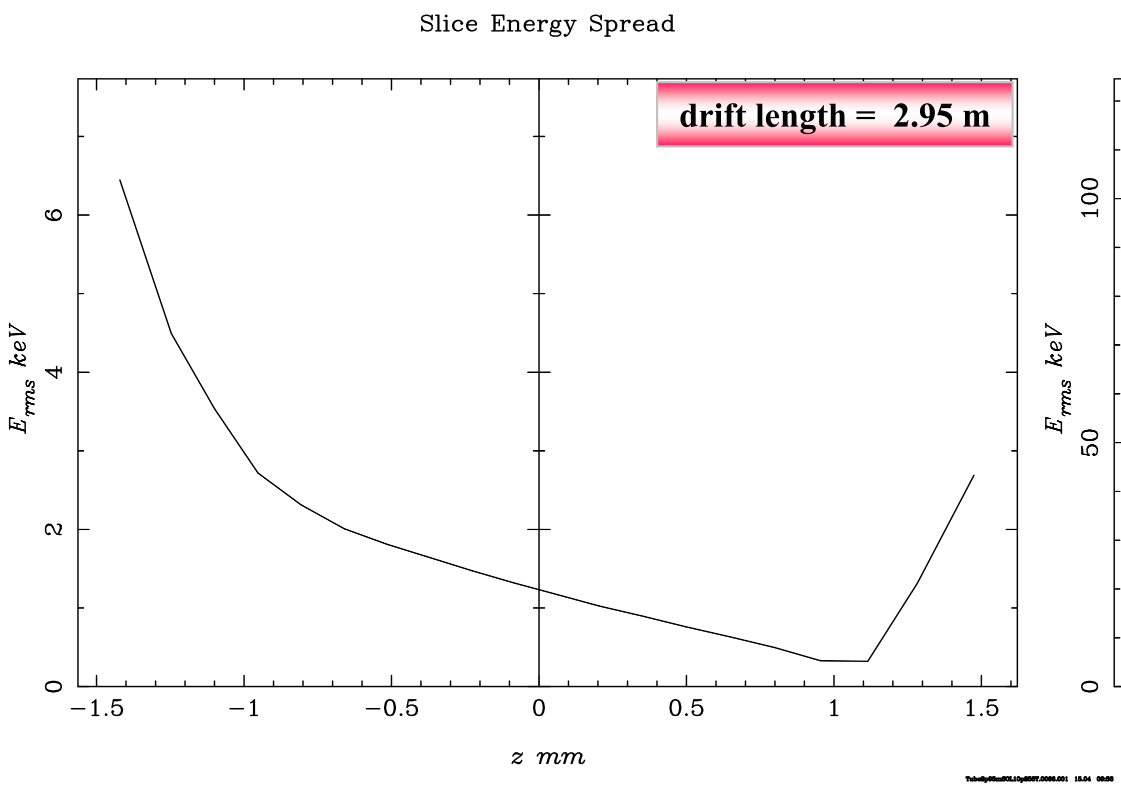




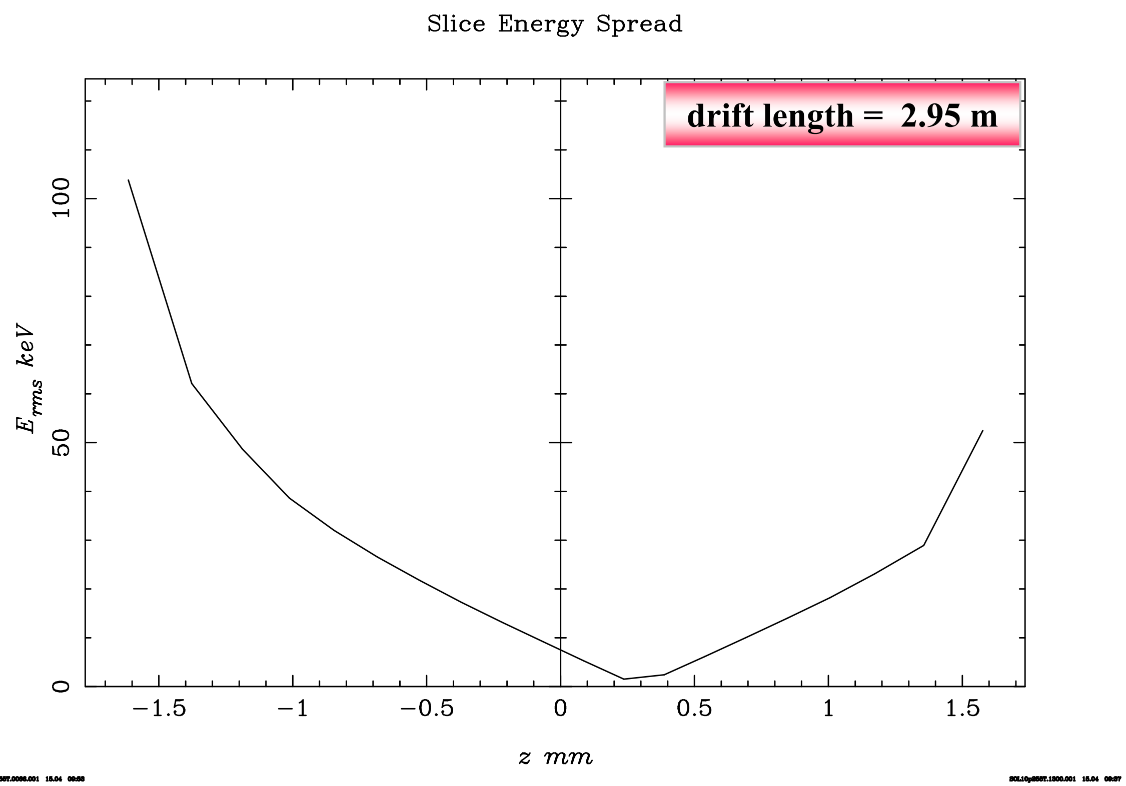
a long bunch induces nonlinearities along beam (beam energy due to RF, focusing at solenoid and focusing at gun and linac, and space charge force).
they induces difficulty in emittance compensation along bunch.
big different slice emittance at head and tail region

Slice Parameters - INSB01 @ 2.95 m

After GUN (~ 0.66 m)



At the end of INSB02



a long bunch induces nonlinearities along beam (beam energy due to RF, focusing at solenoid and focusing at gun and linac, and space charge force).
they induces difficulty in emittance compensation along bunch.
big different slice energy spread at head and tail region

Impact of a long Drift on Beam Quality

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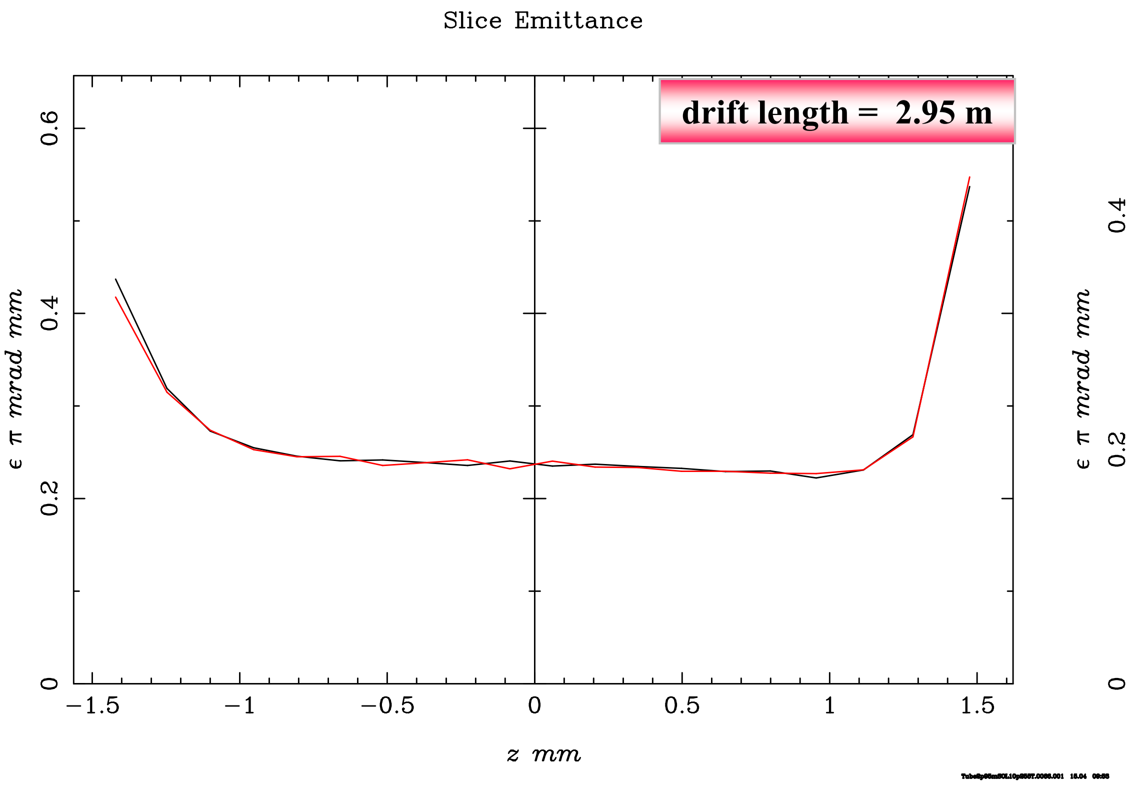
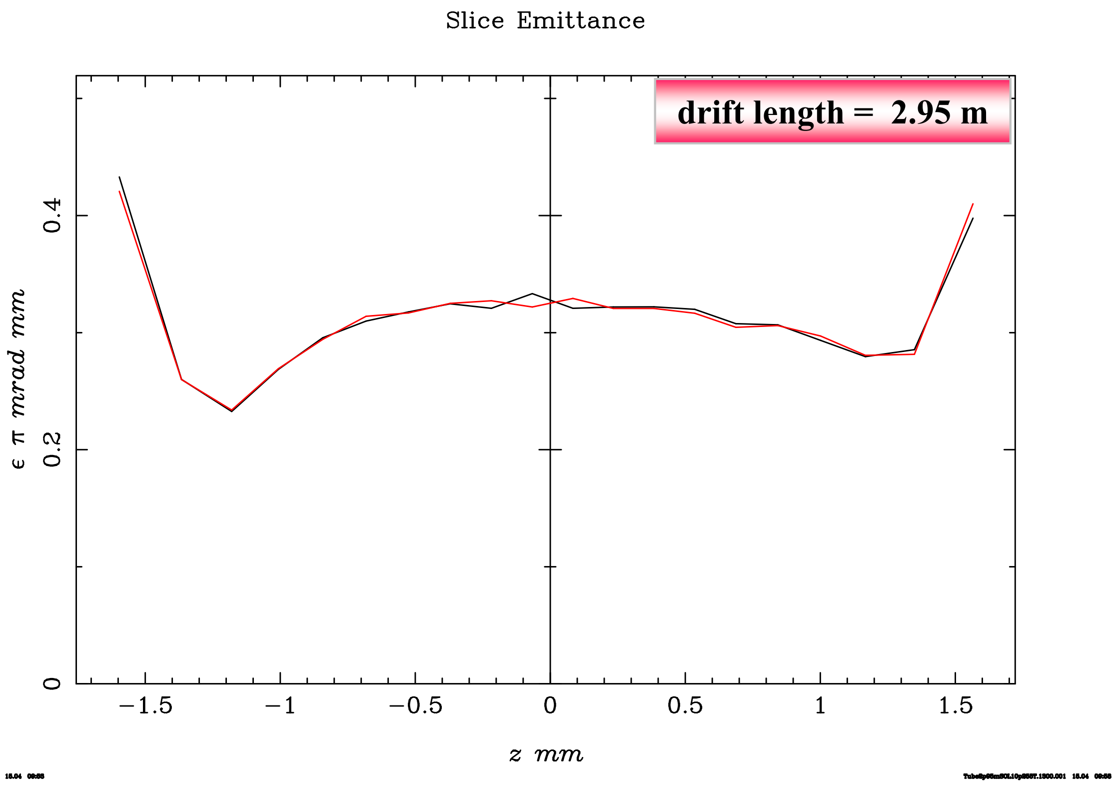
After GUN (~ 0.66 m)



At the end of INSB02



Impact of a long Drift on Beam Quality

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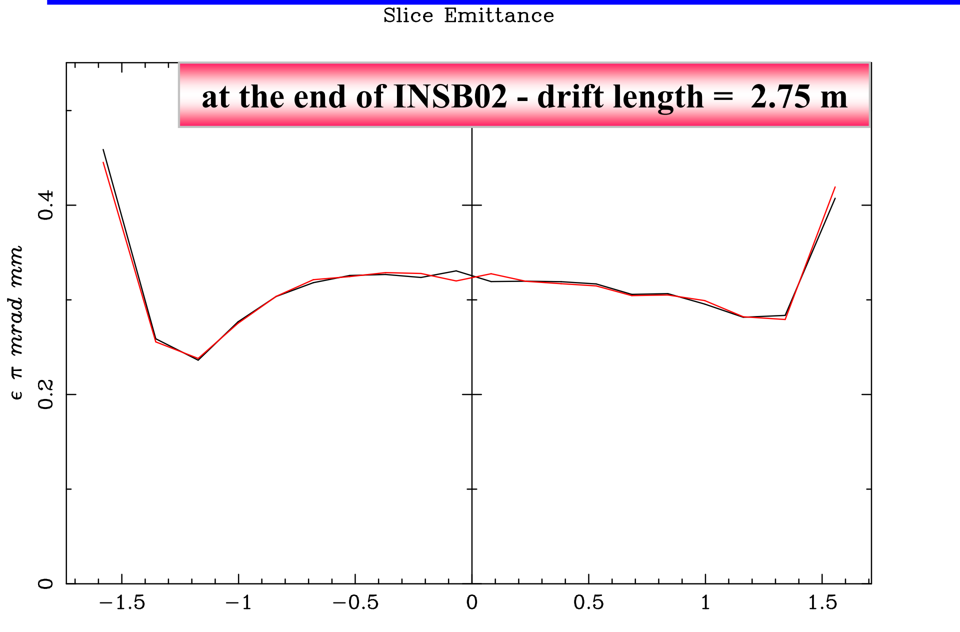
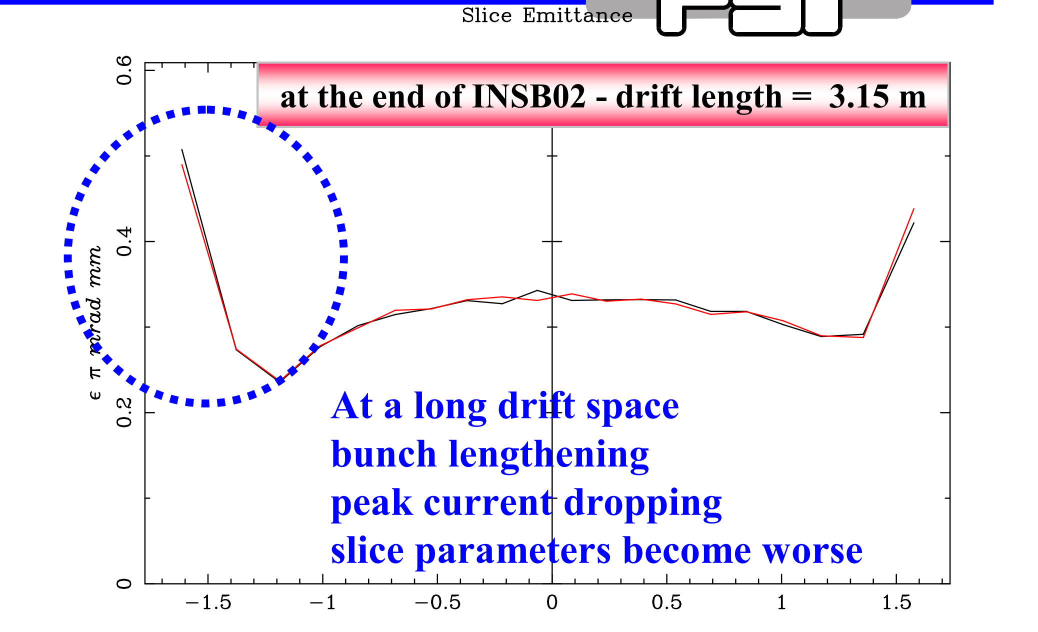
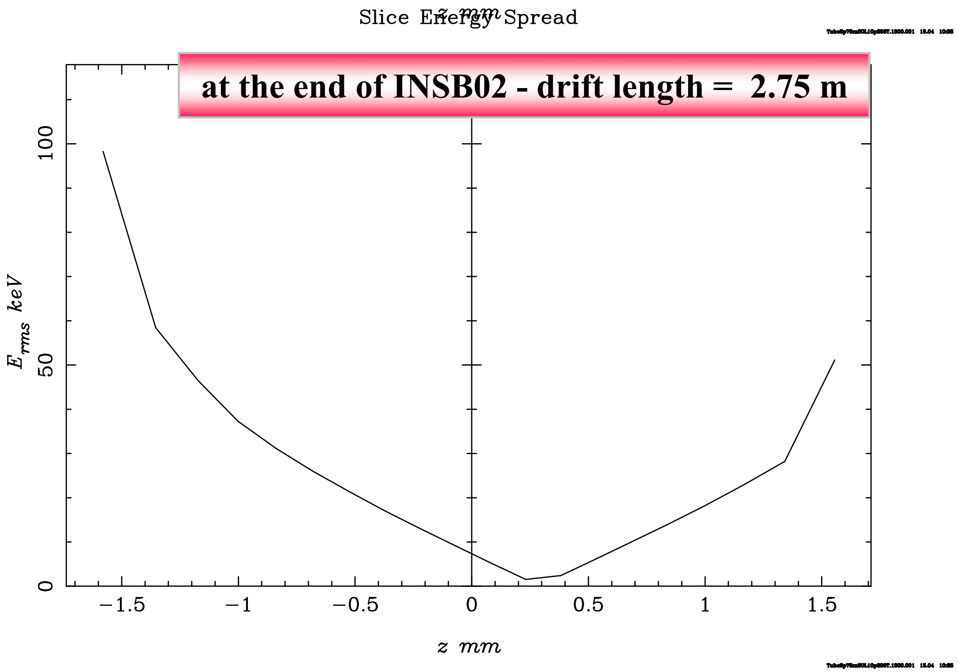
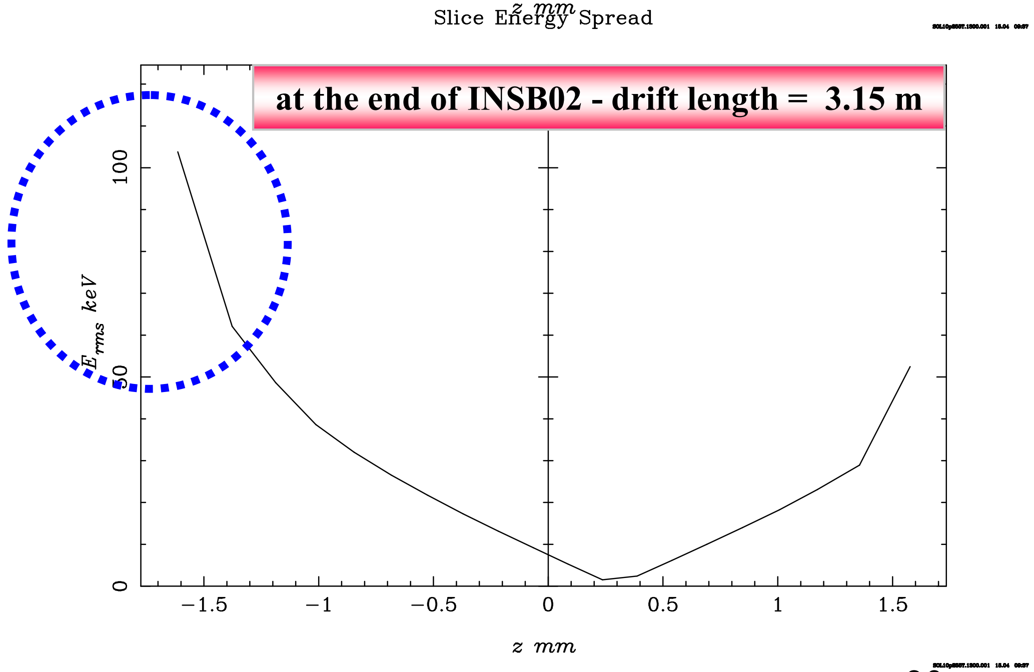


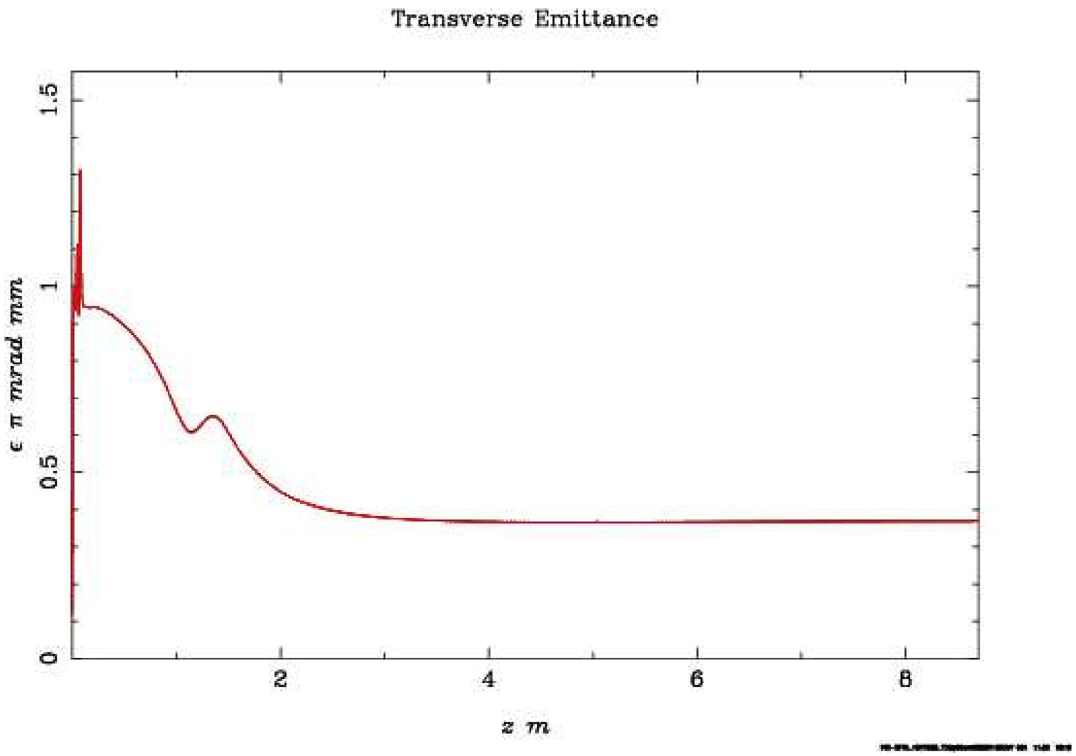


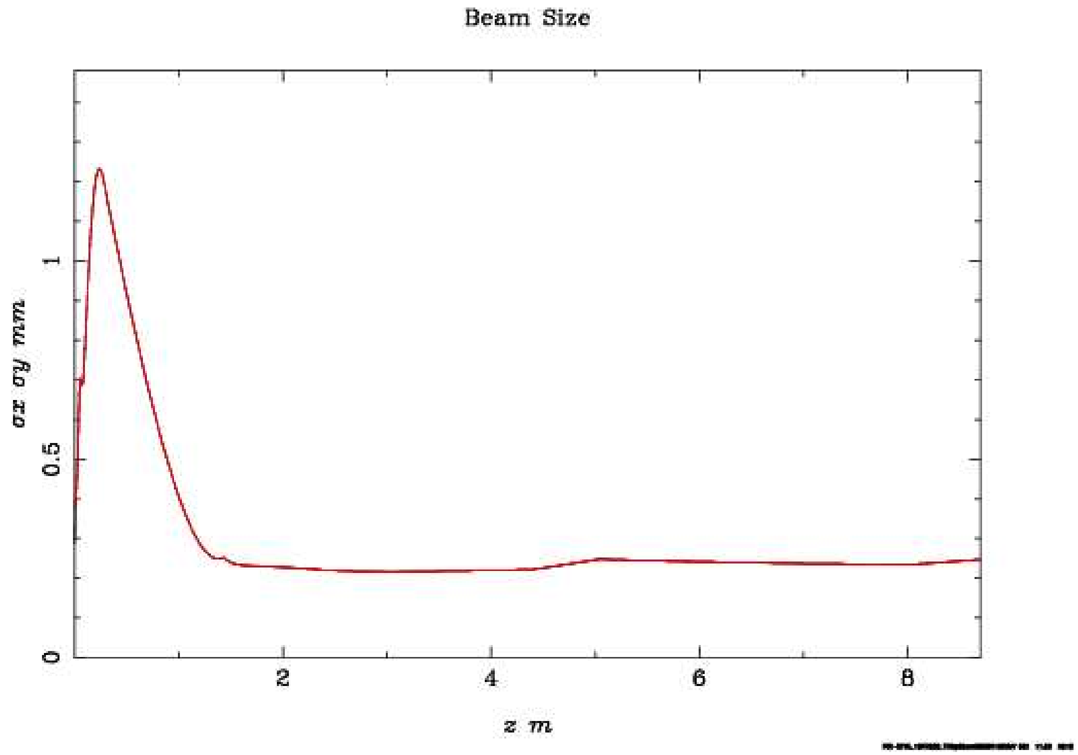




Performance Comparison - LCLS Type Gun

ASTRA Simulation Results along LCLS Type Backup Injector





E = 137.7 MeV, Q = 0.2 nC

σ_δ = 0.07%

σ_x= 247 μm, σ_y= 247 μm, σ_z = 510 μm

ε_{nx}= 0.369 μm, ε_{ny}= 0.369 μm

Performance Comparison - LCLS Type Gun

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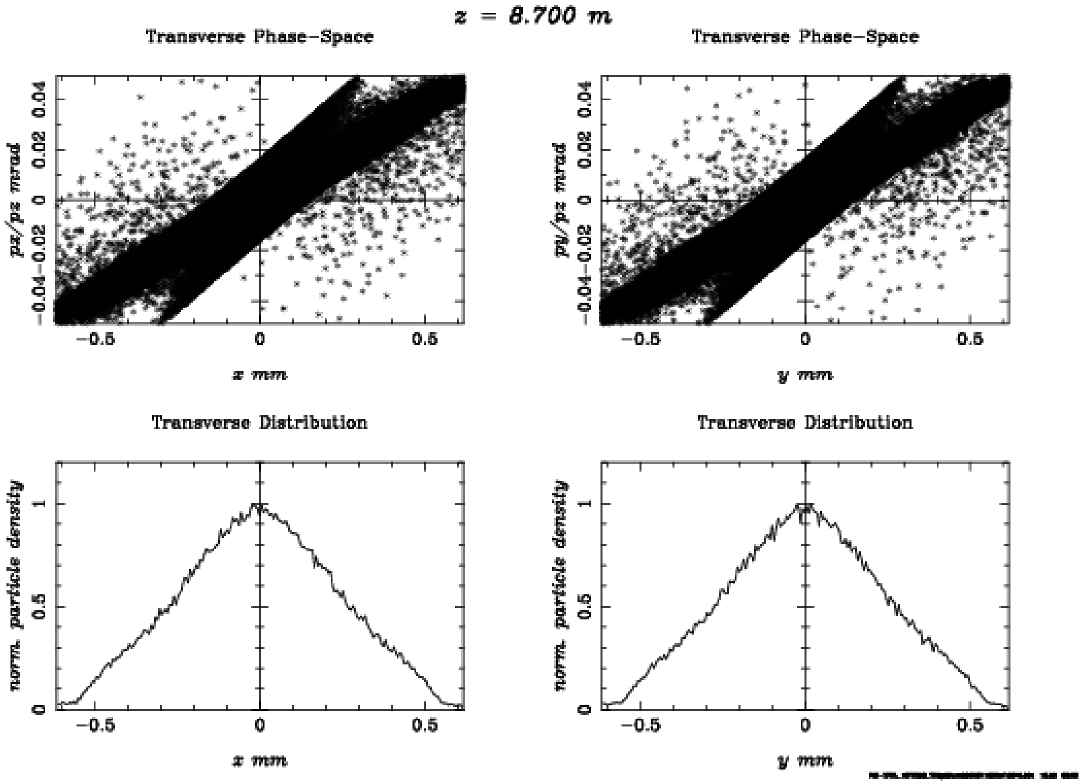
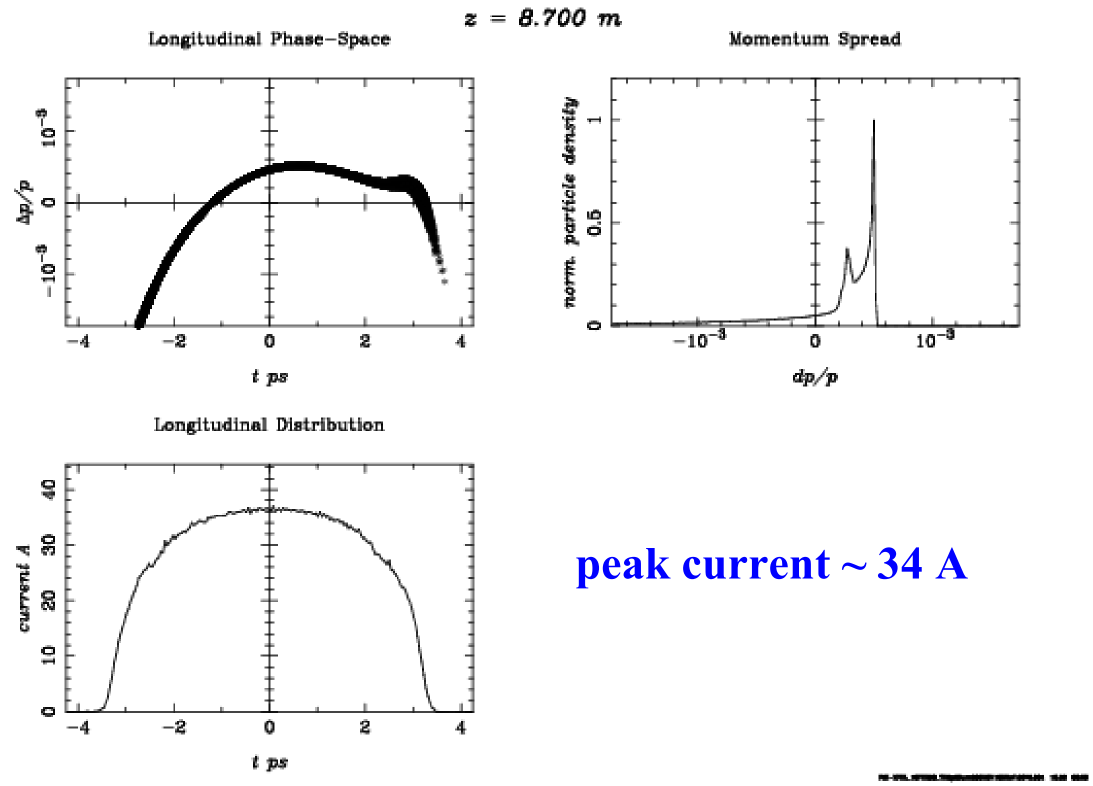
ASTRA Simulation Results at the end of LCLS Type Backup Injector





peak current ~ 34 A

E = 137.7 MeV, Q = 0.2 nC

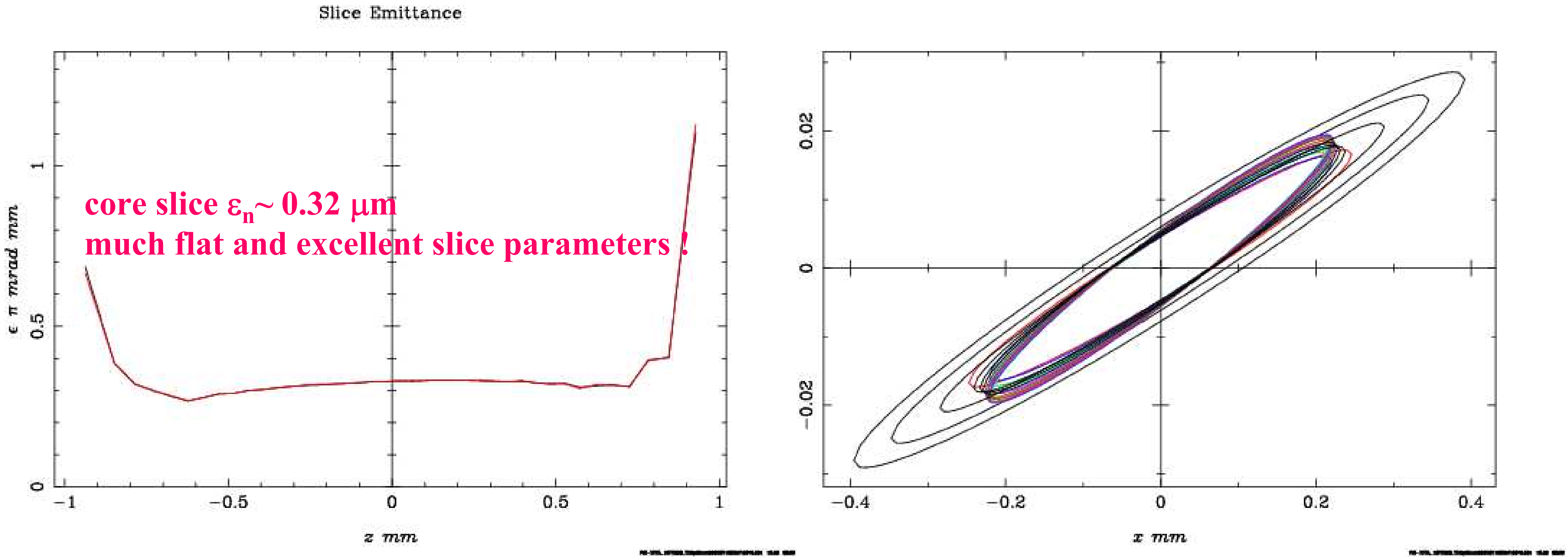
σ_δ = 0.07%

σ_x = 247 μm, σ_y = 247 μm, σ_z = 510 μm

ε_{nx} = 0.369 μm, ε_{ny} = 0.369 μm

Performance Comparison - LCLS Type Gun

ASTRA Simulation Results at the end of LCLS Type Backup Injector



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Performance Comparison - LCLS Type Gun

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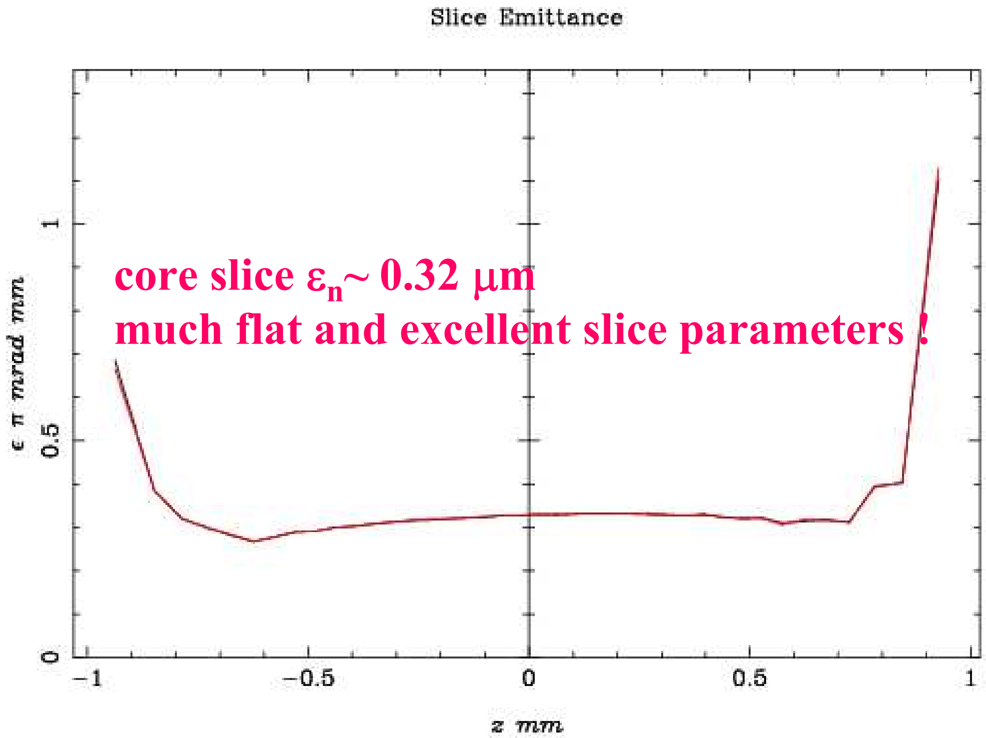
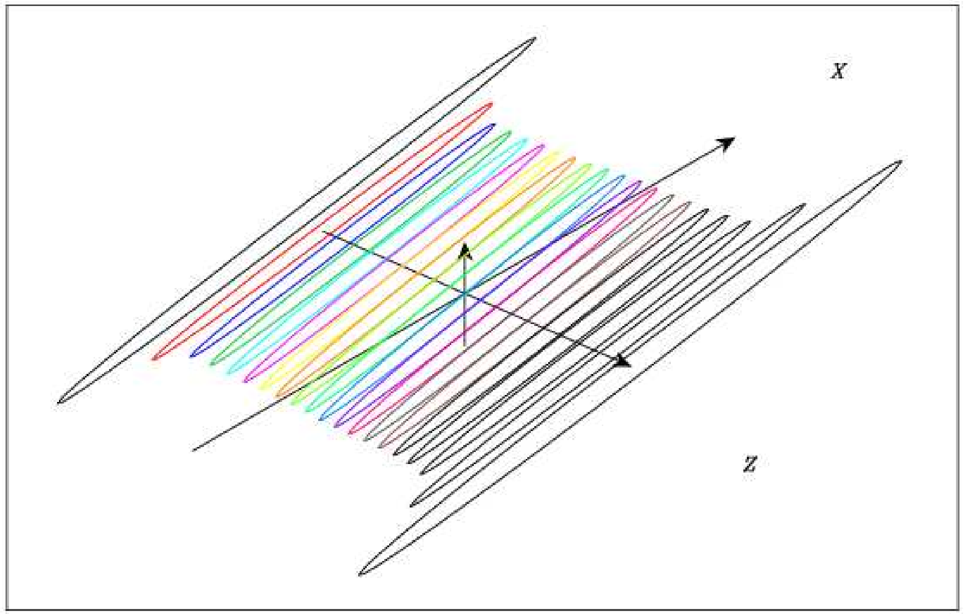
ASTRA Simulation Results at the end of LCLS Type Backup Injector





E = 137.7 MeV, Q = 0.2 nC

σ_δ = 0.07%

σ_x = 247 μm, σ_y = 247 μm, σ_z = 510 μm

ε_{nx} = 0.369 μm, ε_{ny} = 0.369 μm

Summary

We checked performance of CTF3 gun type V with a gradient of 100 MV/m. It seems that it can supply a good projected (slice) emittance of around 0.4 μm (0.33 μm), which is sufficient for our soft X-ray FEL beamline (FEL3). But we may need a much better injector for the hard X-ray FEL beamlines (FEL1 & FEL2).

In case of LCLS type backup injector, we can get a higher peak current of 34 A and flat slice parameters. But in case of CTF3 gun type V, we can not get good beam parameters with a short laser beam (5.8 ps) due to a stronger longitudinal space charge force at 100 MV/m.

To avoid the longitudinal space charge effect in the CTF3 gun type V based backup injector, we used a longer laser pulse of 9.9 ps, which gives a lower peak current of about 20 A and a good projected emittance of around 0.4 μm.

At the end of CTF3 gun type V, there is somewhat strong nonlinearities in slice parameters due to a longer bunch length and a longer drift between gun and linac.

We expect that we can get more better slice beam parameters if we can operate the CTF3 gun with a higher gradient (>= 110 MV/m) and with a shorter drift space between gun and linac.

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