TESLA

On Bunch Compressor Optimization against Microbunching Instability and CSR

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TESLA-S2E-19

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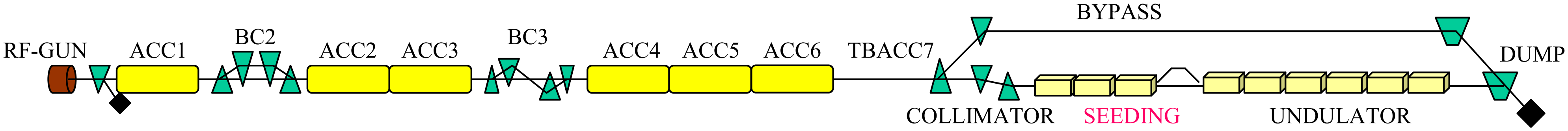
TESLA Test Phase-2 FEL (TTF-2 FEL)

Layout of TESLA Test Facility Phase-2 (TTF-2)



Beam energy : 1.0 GeV
Peak current : 2.5 kA
rms bunch length : 50 μm ~ 166 fs
Bunch separation : 111 ns
Number of bunch per train : 7200
Bunch train repetition rate : 10 Hz
Slice transverse normalized rms emittance : 2 μm
rms beam size : 68 μm
rms energy spread : 1 MeV @ 1.0 GeV
Undulator period : 27.3 mm
Undulator gap : 12 mm
K-parameter : 1.17
Undulator length : ~ 30 m
Peak magnetic field : 0.495 T
SASE source wavelength : 6.4 nm ~ 120 nm
Saturation length : 27 m
Peak power : 2.8 GW
Average power : 40 W
FEL pulse length (FWHM) : ca. 100 fs
Peak (average) spectral brightness : 2.4×10^{30} (3.5×10^{22}) photons/sec/mrad²/mm²/0.1%BW

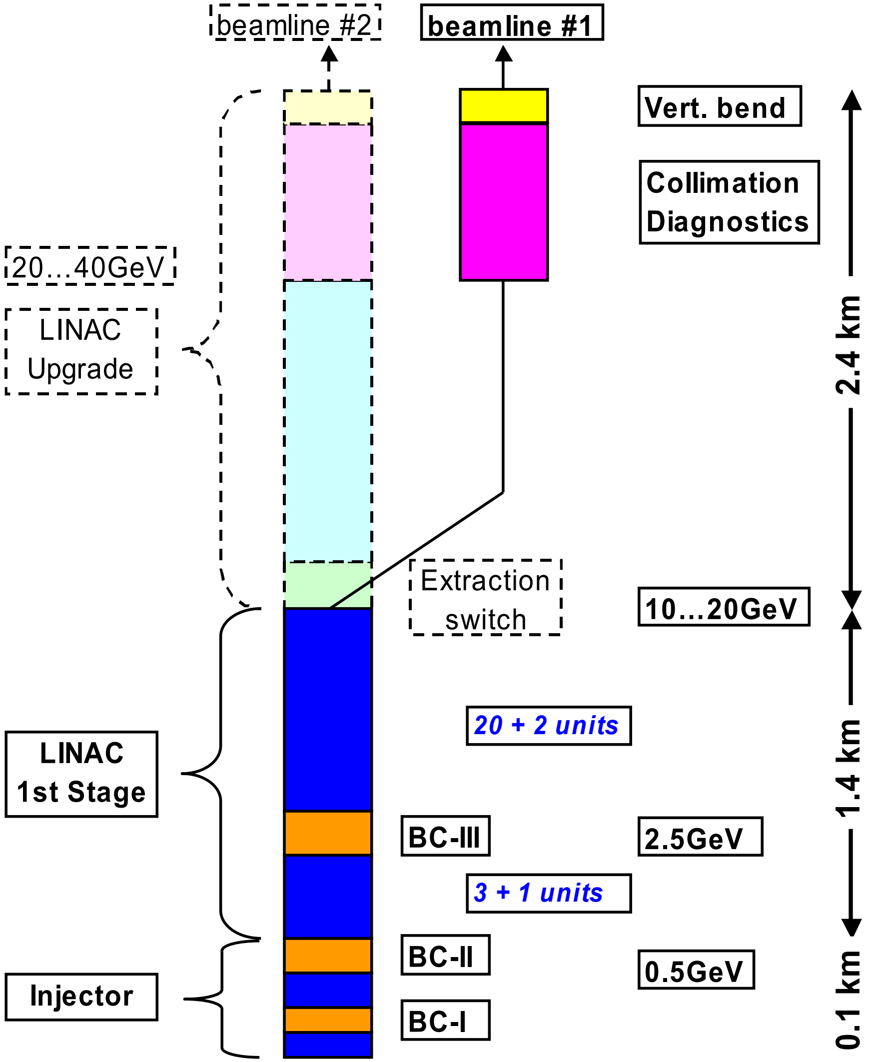
Under construction now !

courtesy of Prof. J. Rossbach

2003	Linac commissioning
	Injector installation
2004	Injector commissioning
	Complete vacuum installation
	Beam through undulator
	First Lasing @ 30 nm
2005	Saturation @30 nm
	First users @ 30 nm
	Tuning 30 – 120 nm
	Full beam current
2006	
	Installation of seeding and 3rd Harm. RF system
2007	
	6 nm
2008	

Short Introduction to TESLA XFEL Project

Layout of 20 GeV TESLA XFEL Project

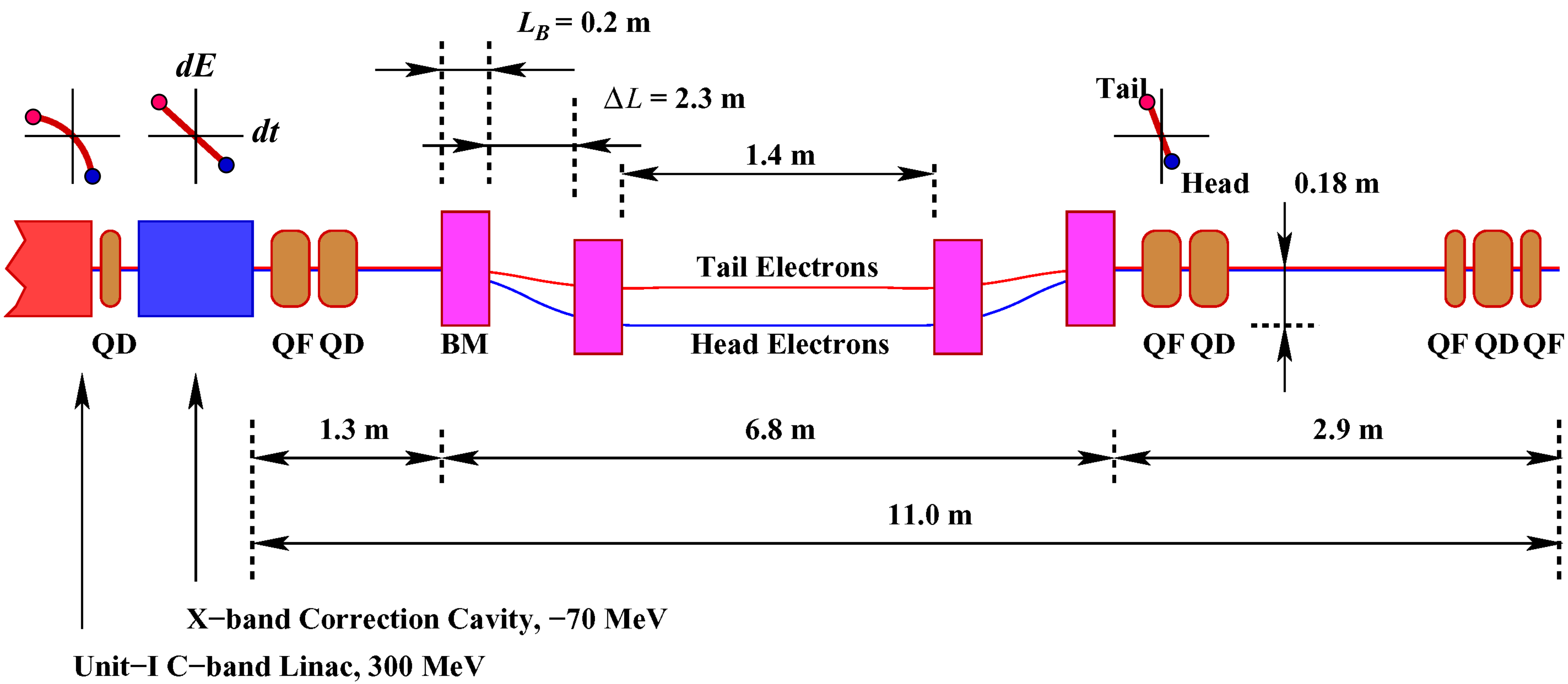


URL : http://XFEL.DESY.de

Already DESY got 50% of the total budget (684 Million Euro) for TESLA XFEL project from German government in February 2003.

Variable	Unit	Value		
electron energy range	GeV	10-20		
electron bunch length (rms)	fs	80		
electron bunch charge	nC	1		
normalized emittance	mrad mm	1.4		
uncorrelated energy spread (rms)	MeV	2.5		
photon pulse length (FWHM)	fs	100		
photon energy	keV	0.2	3.0	12.4
wavelength	nm	6.4	0.4	0.1
number of photons per bunch	$\times 10^{12}$	430	20	1.2
peak brilliance	$\times 10^{33}$	0.06	1.7	5.4
peak power	GW	135	100	24

Working Principle of Bunch Compressor

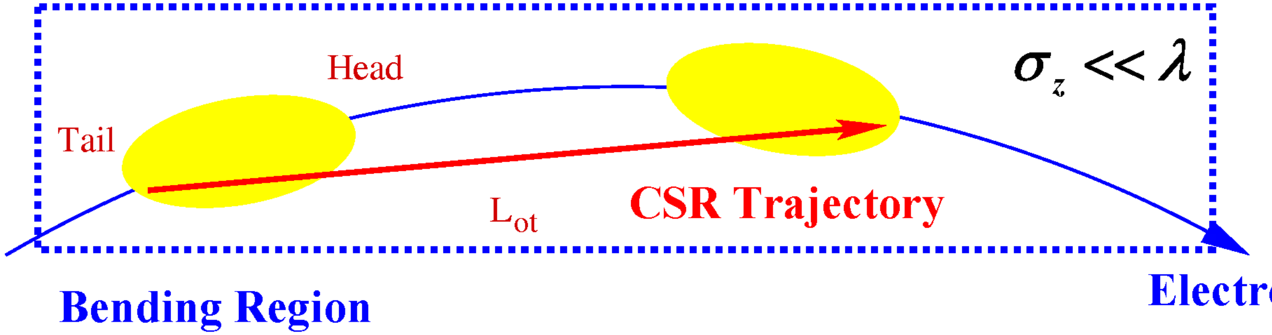


Introduction to CSR in BC

When the bunch length is smaller than the radiation wavelength, coherent synchrotron radiation (CSR) can be generated. CSR from the tail region can overtakes head electrons after the overtaking length. Generally, head electrons are accelerated by CSR, and tail electrons are decelerated due to their own CSR loss.

Since CSR generates correlated energy spread along bunch length, electrons are transversely kicked at the nonzero dispersion region or chicane. Hence, the projected normalized rms emittance is increased in the bunch compressor due to CSR.

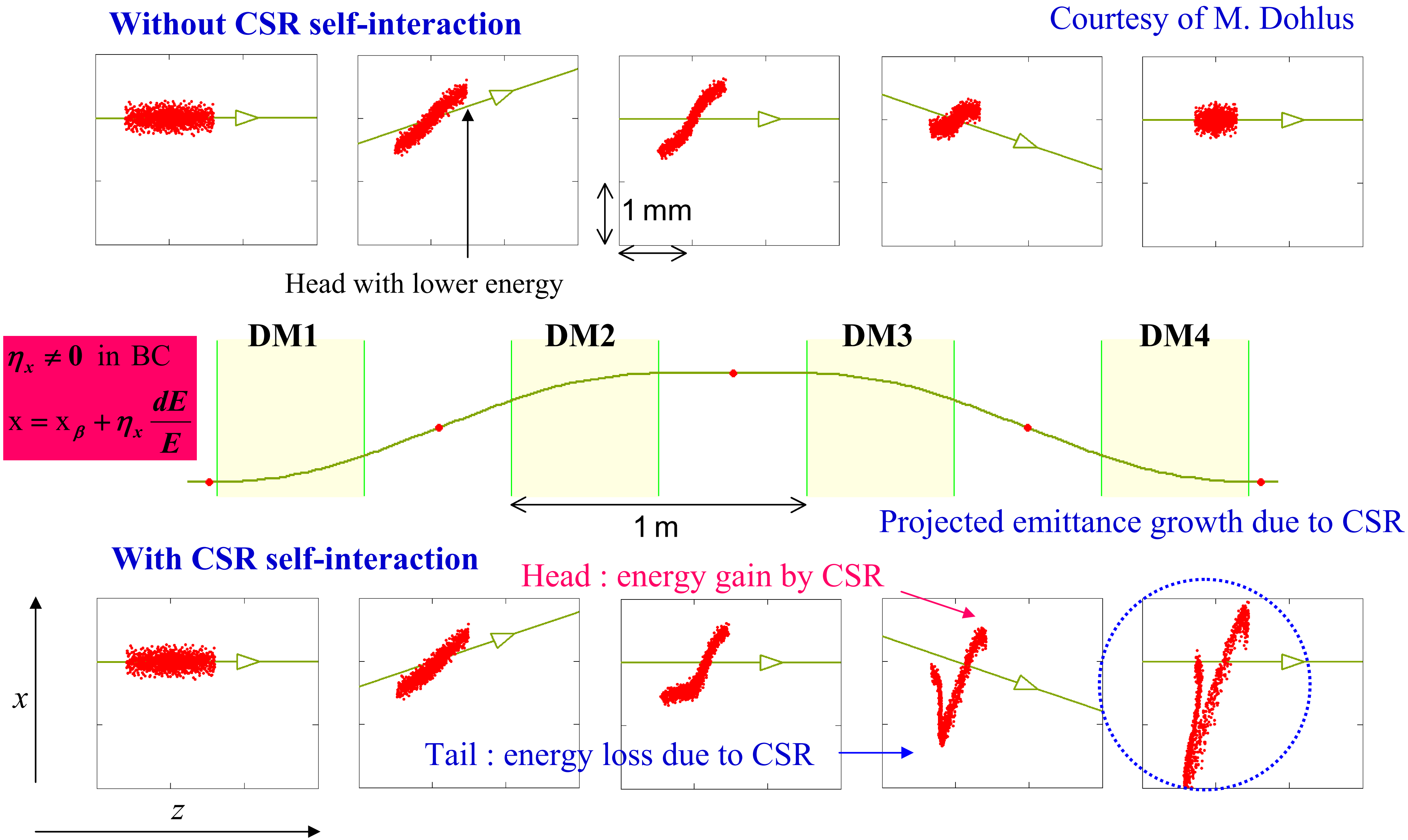
- **Projected emittance growth effects brightness of the SASE source.**
- **Slice emittance growth effects saturation length and brightness of SASE source.**



$$L_{ot} \approx \left(24\sigma_z R^2\right)^{1/3} \qquad \sigma_{\delta,1\,\mathrm{dipole}} \approx 0.22\,\frac{r_e N L_B}{R^{2/3}\sigma_z^{4/3}\gamma}$$

where σ_z is RMS bunch length, and R is bending radius.

Short Introduction to CSR in BC

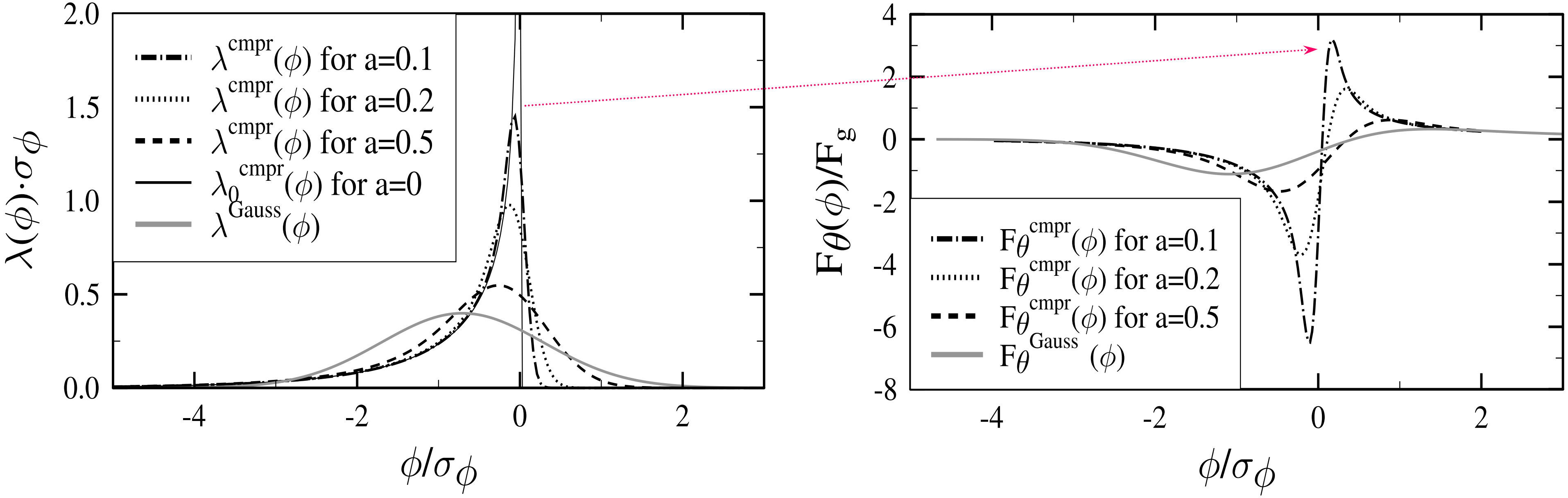


Short Introduction to CSR in BC

If there is a nonlinearity in current distribution, the local charge concentration or spike is generated during the bunch compression process. In this case, CSR is enhanced due to the local charge concentration. (R. Li, LINAC2000)

Courtesy of Dr. R. Li

a $\propto \delta_{un}$

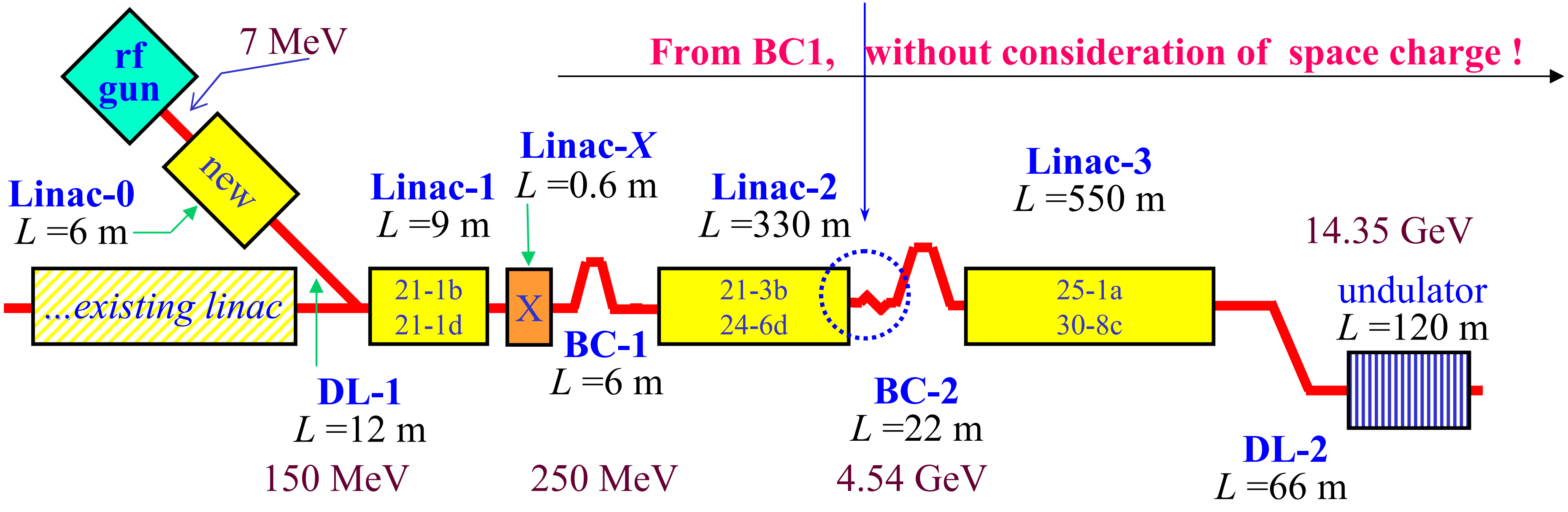


[Longitudinal Charge Distribution and CSR force for a compressed bunch]

Why does LCLS use SC-Wiggler before BC2 ?

Courtesy of Dr. P. Emma

σ_δ = 3E-5 with SC-wiggler before LCLS BC-2
σ_δ is increased by ISR in the wiggler, hence gain is reduced !



SLAC linac tunnel

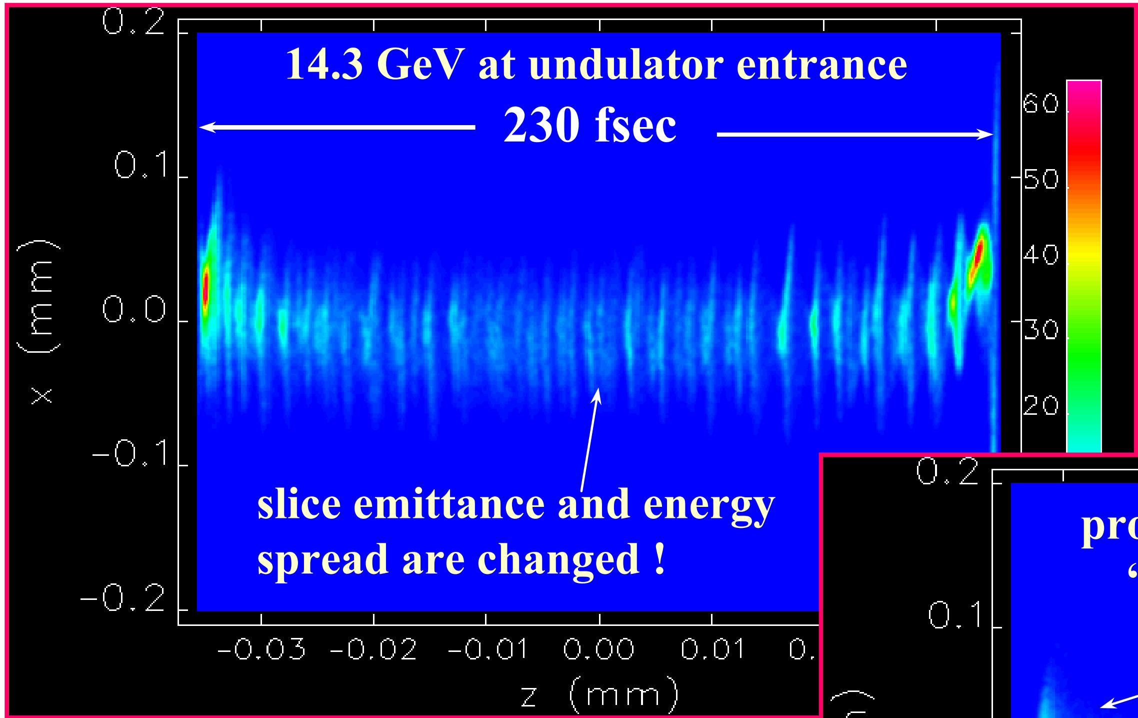
Limitations in ELEGANT Tracking

Linear & nonlinear space charge effects
Numerical error for small macro particles
1D CSR model

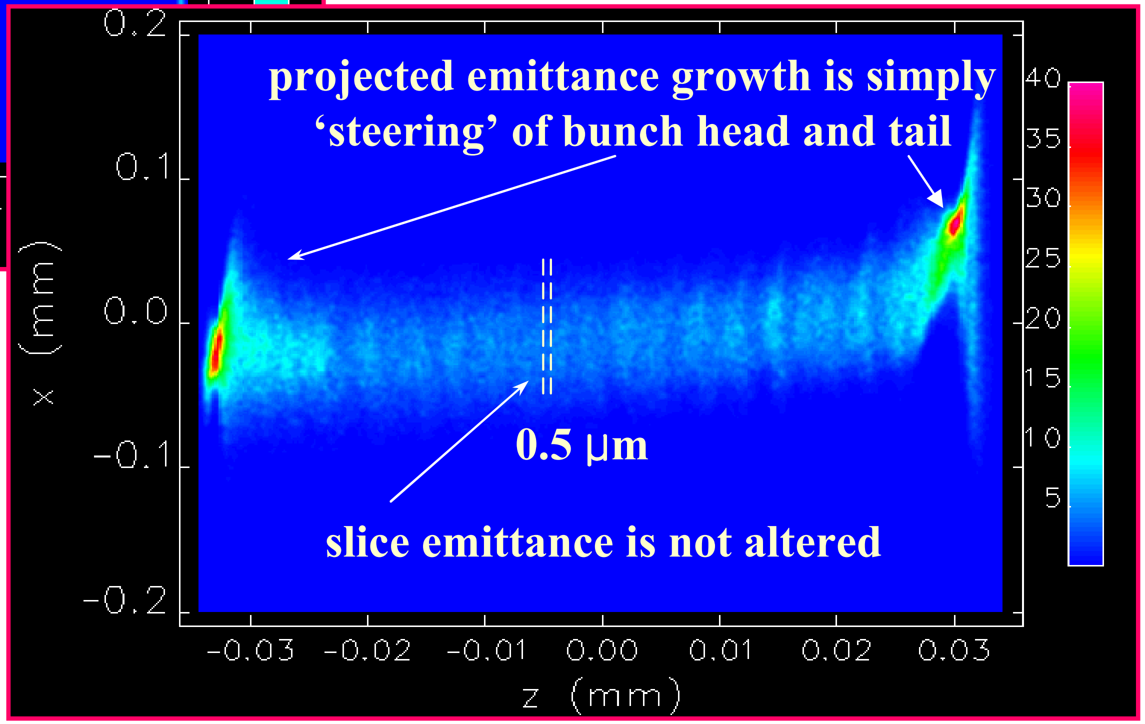
LCLS CSR Microbunching Instability

[x versus z without SC-wiggler]

Courtesy of Dr. M. Borland and P. Emma



[x versus z with SC-wiggler]



ELEGANT Tracking

without space charge force

CSR Microbunching Instability

- If initially, bunch has the density or energy modulation, CSR can be generated even for the wavelengths much shorter than the bunch length, and the initial modulation can be amplified in the bunch compressor by the CSR force (Microbunching Instability).

- Initial modulation can be converted in the bunch compressor
  - Energy modulation can be converted to density modulation via dispersion.
  - Density modulation can be converted to energy modulation via CSR.

- If the uncorrelated energy spread and transverse emittance are high enough, the amplification gain *G* can be reduced substantially, and the microbunching instability can be controlled by Landau damping.

Gain of CSR Microbunching Instability

Dr. Huang's PRST-AB Vol5, 074401, Gain of CSR Microbunching Instability G_f :

$$G_f = \left| b(k_f; f) / b(k_0; 0) \right|$$

$$\frac{b(k_f;f)}{b_0(k_0;0)} \approx \exp\left[-\frac{\bar\sigma_\delta^2}{2(1+\chi)^2}\right] + A\bar I_f\left[\frac{\sqrt{\pi}\mathrm{erf}(\bar\sigma_x)}{2\bar\sigma_x} \times \exp\left(-\frac{\bar\sigma_\delta^2}{2(1+\chi)^2}\right) + F_1(\chi,\bar\sigma_x,\alpha_0,\phi,\bar\sigma_\delta)\right] + A^2\bar I_f^2 F_0(\bar\sigma_x)F_2(\chi,\bar\sigma_x,\alpha_0,\phi,\bar\sigma_\delta). \quad (1)$$

Here $\chi = hR_{56}$, $\bar\sigma_\delta = k_0 R_{56}\sigma_\delta$, $A = 1.63i - 0.94$, $\bar I_f = I_f k_0^{4/3} R_{56} L_b/(\gamma I_A \rho_0^{2/3})$, I_f is the compressed beam current, $I_A \approx 17$ kA, $\bar\sigma_x = k_0 L_b\sqrt{\varepsilon_x\beta_0}/\rho_0$, $\phi = 2\Delta L/\beta_0$, the error function $\mathrm{erf}(x) = 2\pi^{-1/2}\int_0^x dt\,\exp(-t^2)$, and

$$F_0 = \frac{e^{-\bar\sigma_x^2} + \bar\sigma_x\sqrt{\pi}\mathrm{erf}(\bar\sigma_x) - 1}{2\bar\sigma_x^2},$$

$$F_1 = 2\int_0^1 dt \frac{(1-t)}{(1+\chi t)^{4/3}} H(t),$$

$$F_2 = 2\int_0^1 dt \frac{(1-t)t(1+\chi)}{(1+\chi t)^{7/3}} H(t),$$

$$H(t) = \exp\left[-\bar\sigma_x^2\frac{(1-2t+\alpha_0\phi t)^2 + \phi^2 t^2}{(1+\chi t)^2} - \frac{\bar\sigma_\delta^2}{2(1+\chi t)^2}\left(t^2 + \frac{(1-t)^2}{(1+\chi)^2}\right)\right]. \quad (2)$$

$$k_f = k_0/(1 + hR_{56})$$

$$k_0 = 2\pi/\lambda$$

Limitations of Formula

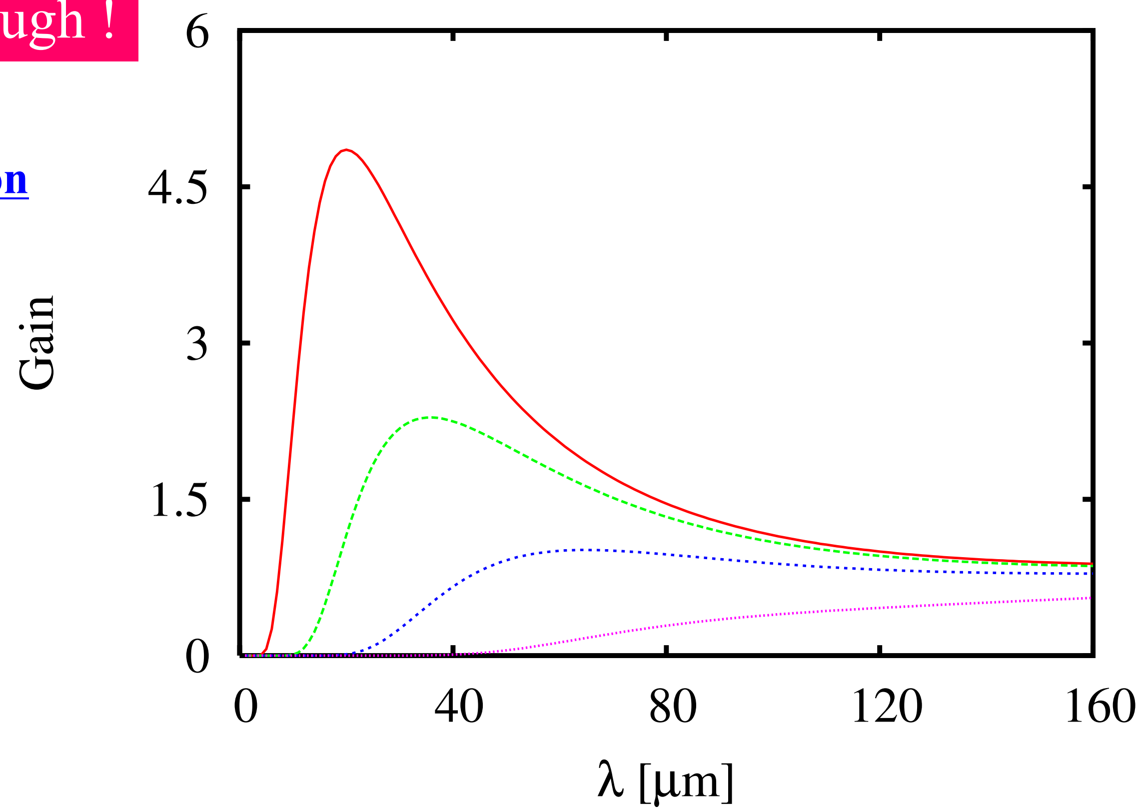
Uncorrelated energy spread growth in BC due to ISR, CSR, and LSC

Uncorrelated energy spread growth in LINAC due to LSC, and IBS (later added !)

***b*: bunching parameter, Fourier transform of the current modulation**

CSR Gain of Model Chicane

Gain of single chicane is small enough !



Common Parameters for Gain Calculation

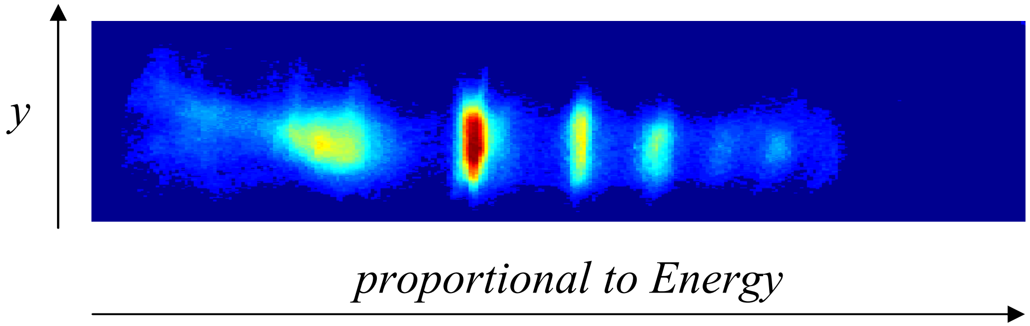
Dipole length L_b = 0.5 m
Drift length ΔL = 5.0 m
Middle drift length L_i = 1.0 m
Bending radius ρ_0 = 10.35 m
Bending angle = 2.77 degree
Final peak current I_f = 6000 A
Modulation amplitude ~ 5%
Initial beta function β_0 = 40 m
Initial alpha function α_0 = 2.6
Energy = 5.0 GeV
Total chicane length = 13.0 m

Parameters used for plotting

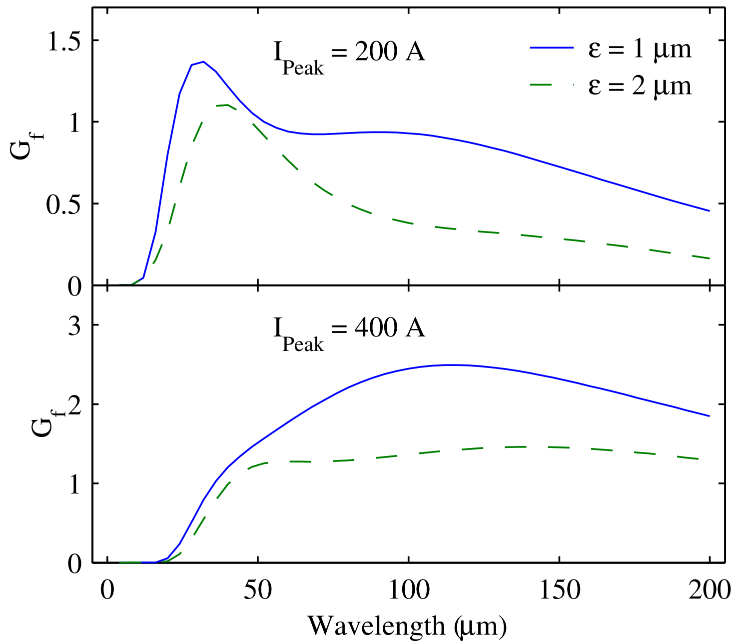
			IBS	TTF-2		FEL
Momentum compaction	R_{56}	[mm]	+25	+25	+25	+25
Chirping constant	h	[1/m]	- 36	- 36	- 36	- 36
Normalized rms emittance	ε_{nx}	[µm]	1.0	1.0	1.0	1.0
Uncorrelated energy spread	$\sigma_{\delta u}$	10^{-6}	9.5	25	50	100

Observation at SDL

We observed following thing similar to the microbunching instability at SDL !
For a while, we considered their observation as a CSR microbunching instability due to laser.
But gain of CSR microbunching instability for SDL chicane is small enough !
Then what is source of their observation ?
The most strong candidate is the Longitudinal Space Charge (LSC)



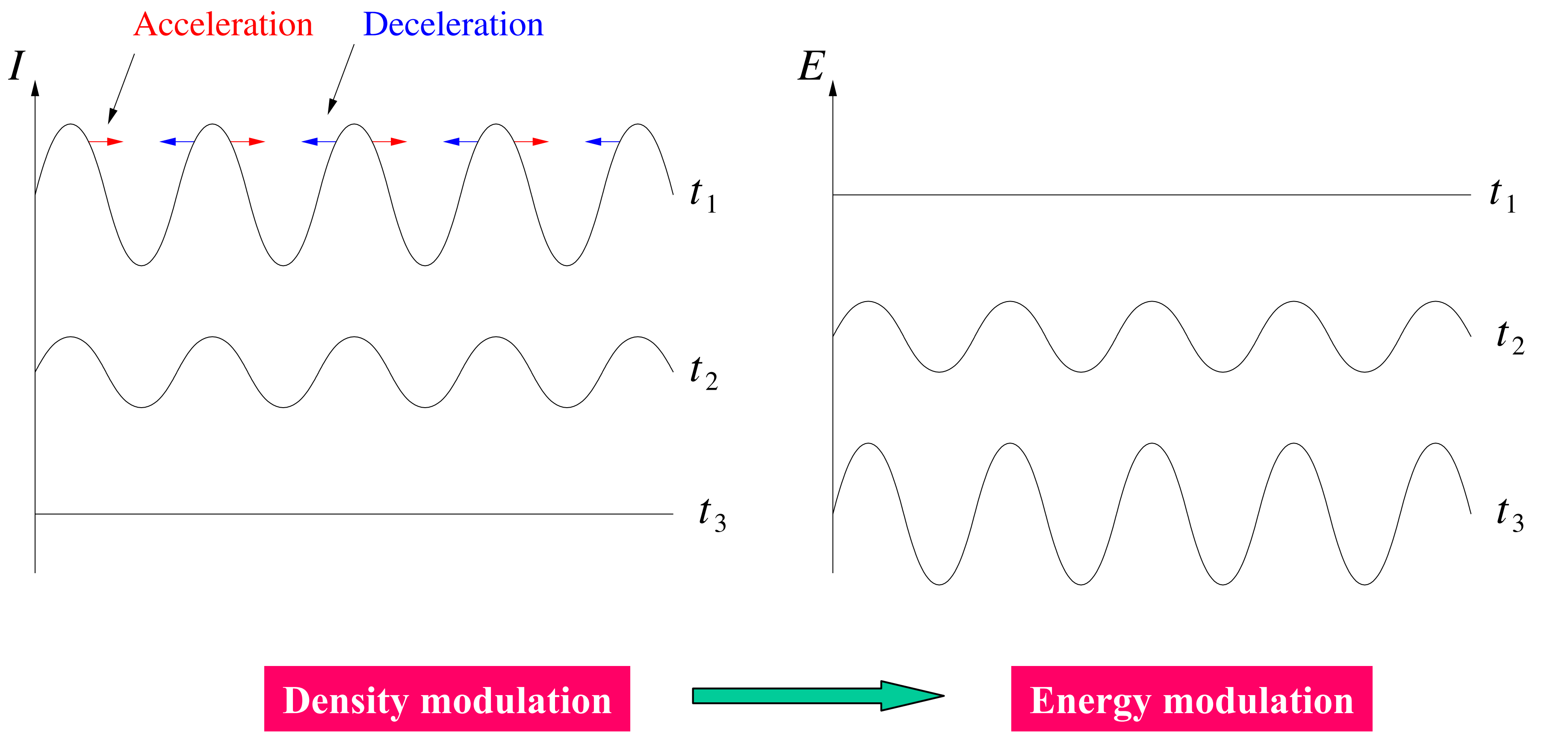
[After BC, energy profile at SDL]



[Gain of Micobunching Instability]

Action of Longitudinal Space Charge (LSC)

If there is a density modulation, space charge pushes particles from high density to low density, creating energy modulation in the process.



Energy modulation converts back to density modulation to complete space charge oscillation with Plasma oscillation frequency (Here Landau damping is ignored)

CSR & LSC Microbunching Instability

by longitudinal space charge force (LSC) in the drift & linac
by coherent synchrotron radiation (CSR) in the bunch compressor
by the geometric wakefields in Linac

Initial current density modulation → **Induced energy modulation**

$dz_f = dz_i + R_{56}(dE/E)_i$ in BC

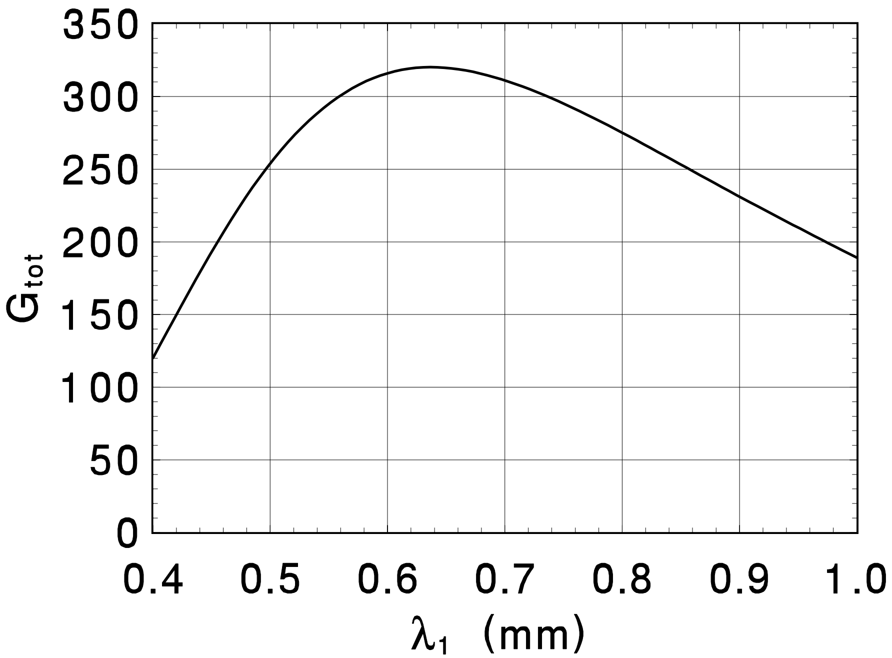
Amplified current density modulation

Slice emittance
Projected emittance
Slice energy spread
Growth !!!

$$Gain = \left|\frac{\text{Normalized amp. of current density}_2}{\text{Normalized amp. of current denisty}_1}\right|$$

Analytic Estimated Gain & Motivation

- **Motivation : Longitudinal Space Charge (LSC) driven Microbunching Instability TESLA-FEL-2003-02 by Dr. Schneidmiller *et al.***



Tu-P-49 at FEL2003

Maximum gain of the LSC driven microbunching instability in TTF-2 is about 320 for 2.0 ps initial density modulation.

Here they assumed that Plasma oscillation and Landau damping are ignorable. Therefore the initial modulation amplitude is constant and is not damped although beams go through the linac.

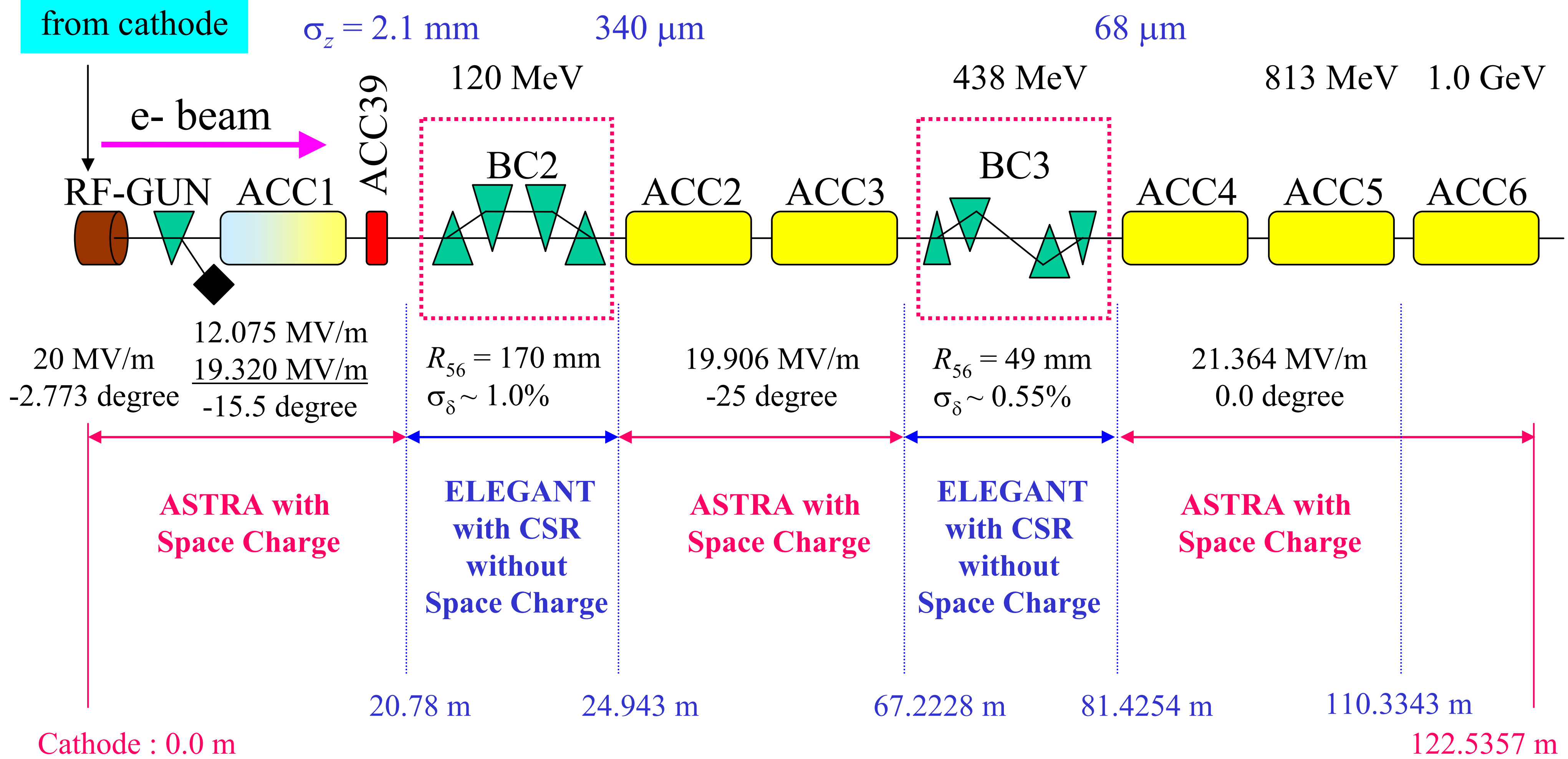
$$G = Ck|R_{56}|\frac{I_0}{\gamma_0 I_A}\frac{|Z(k)|}{Z_0}\exp\left(-\frac{1}{2}C^2k^2R_{56}^2\frac{\sigma_\gamma^2}{\gamma_0^2}\right)$$

- **A S2E simulation is needed to check whether the gain is really high or not.**

S2E on Microbunching Instability at TTF-2

1.0 nC beam starts from cathode

ELEGANT is used to consider CSR and vertical focusing in dipoles

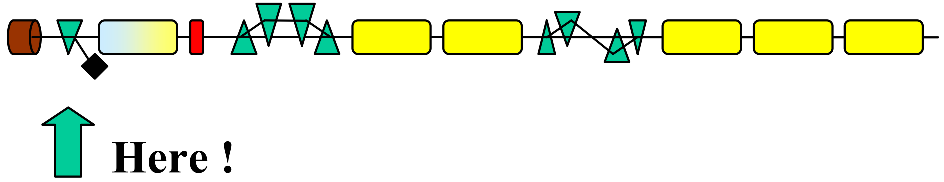


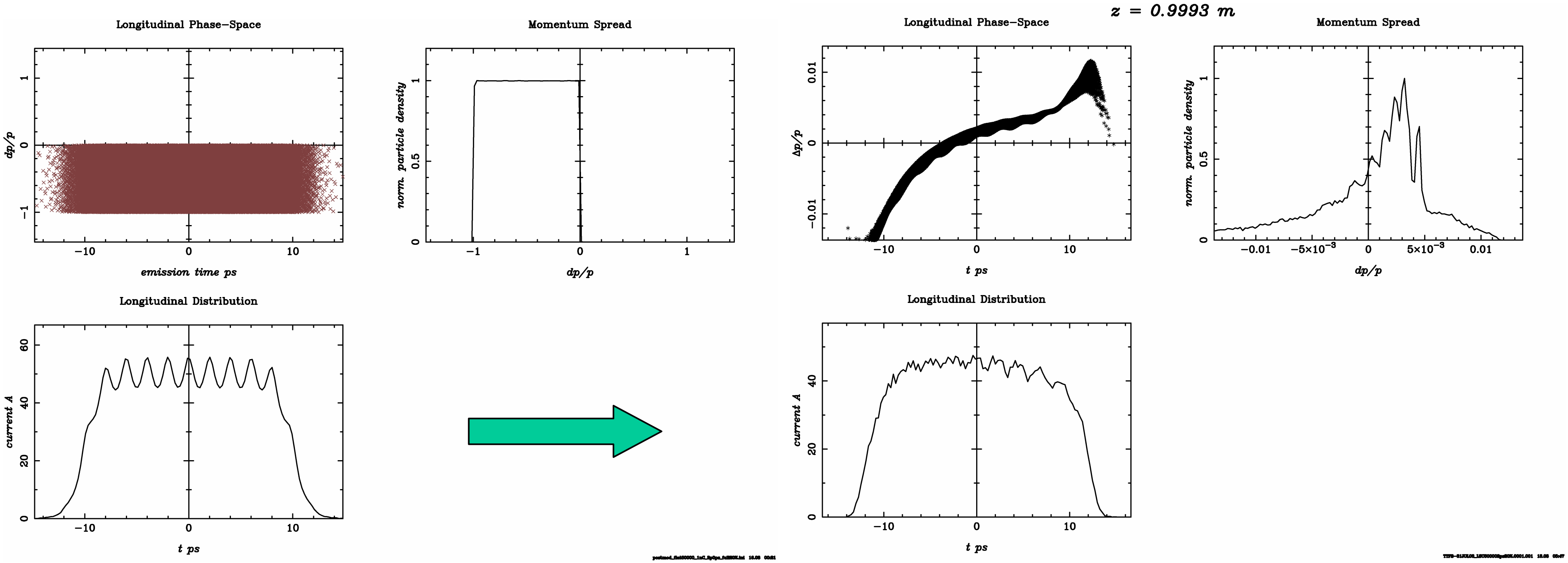
ELEGANT is called at all ends of module to apply geometric wakefields !!!

ASTRA Tracking with Laser Beam Modulation

From Cathode to Before ACC1- 1.0 m

Modulation period = 2.0 ps
Modulation Amplitude = ±10%
Postpro BIN number = 125
Simulation particles = 50,000
ASTRA Grids for space charge calculation = 10 rings × 50 cells





ASTRA Tracking with Laser Beam Modulation

From end of ACC1 to Upstream of BC2

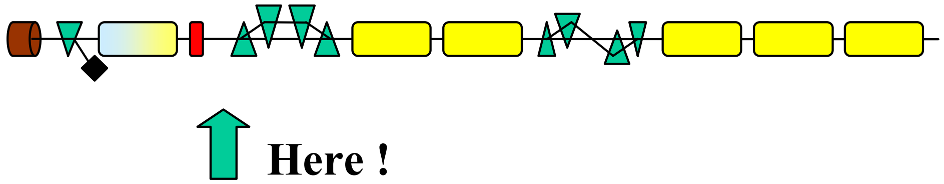
Modulation period = 2.0 ps

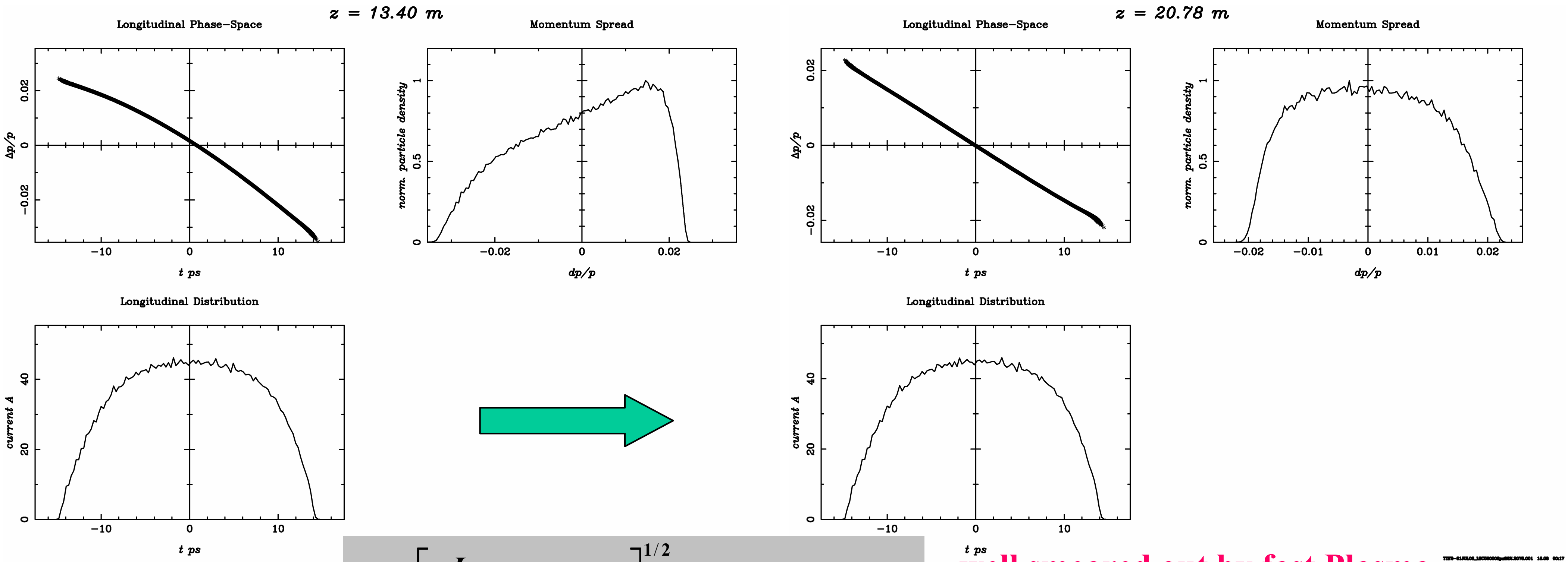
Modulation Amplitude = ±10%

Postpro BIN number = 125

Simulation particles = 50,000

ASTRA Grids for space charge calculation = 10 rings × 50 cells





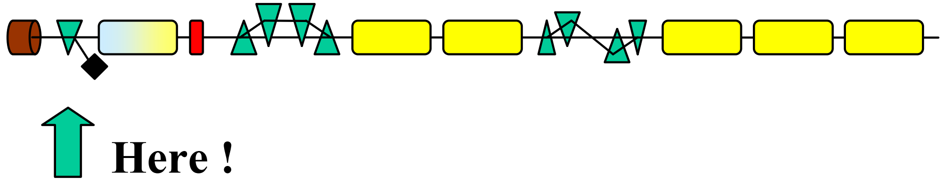
$$\omega = c\left[\frac{I_0}{\gamma^3 I_A} k\left|Z_{LSC}(k)\right|\right]^{1/2}, \text{ if } k \to \infty,\ \omega \to \omega_p$$

well smeared out by fast Plasma oscillation & strong Landau damping

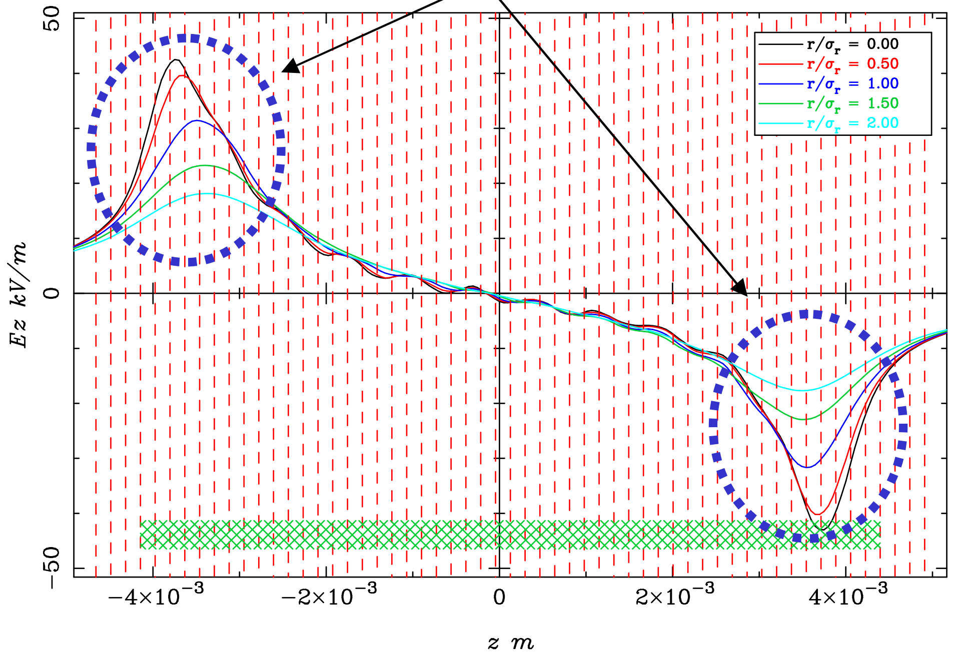
What happened in injector ?

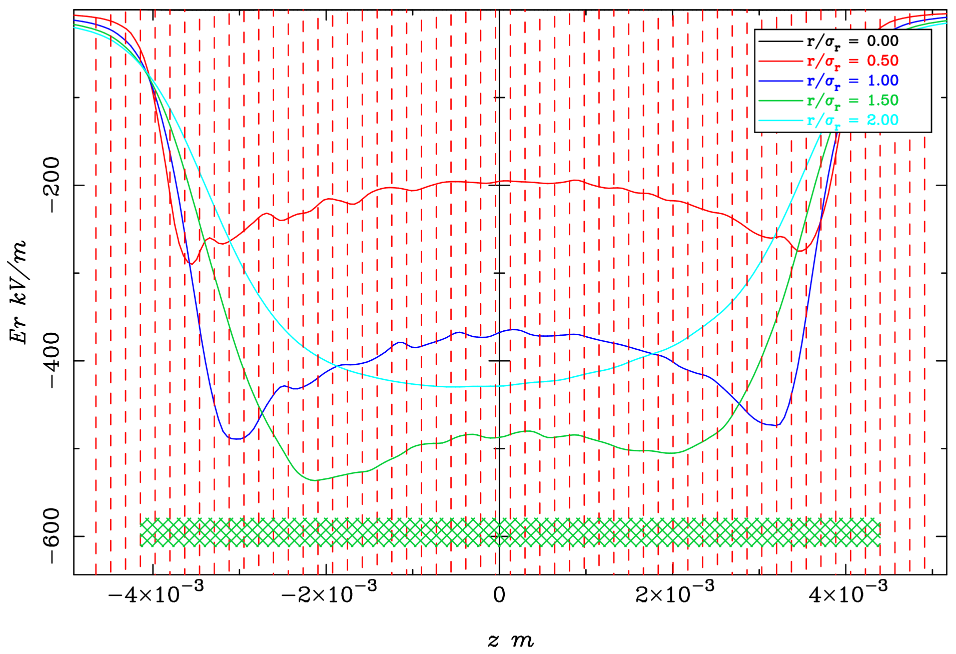
E-fields due to Space Charge at 1.0 m, *E*=4.2 MeV

Modulation period = 2.0 ps
Modulation Amplitude = ±10%
Postpro BIN number = 125
Simulation particles = 50,000
ASTRA Grids for space charge calculation = 10 rings × 50 cells



2D space charge force increases the local energy spread at the head & tail regions and helps in smearing of the initial density modulation

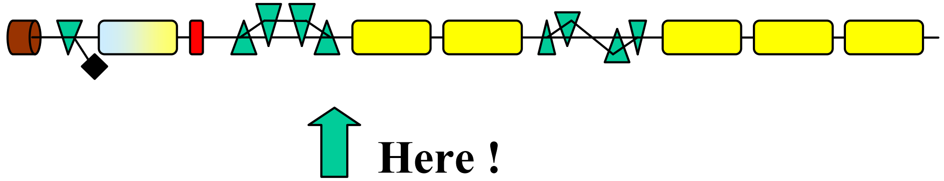




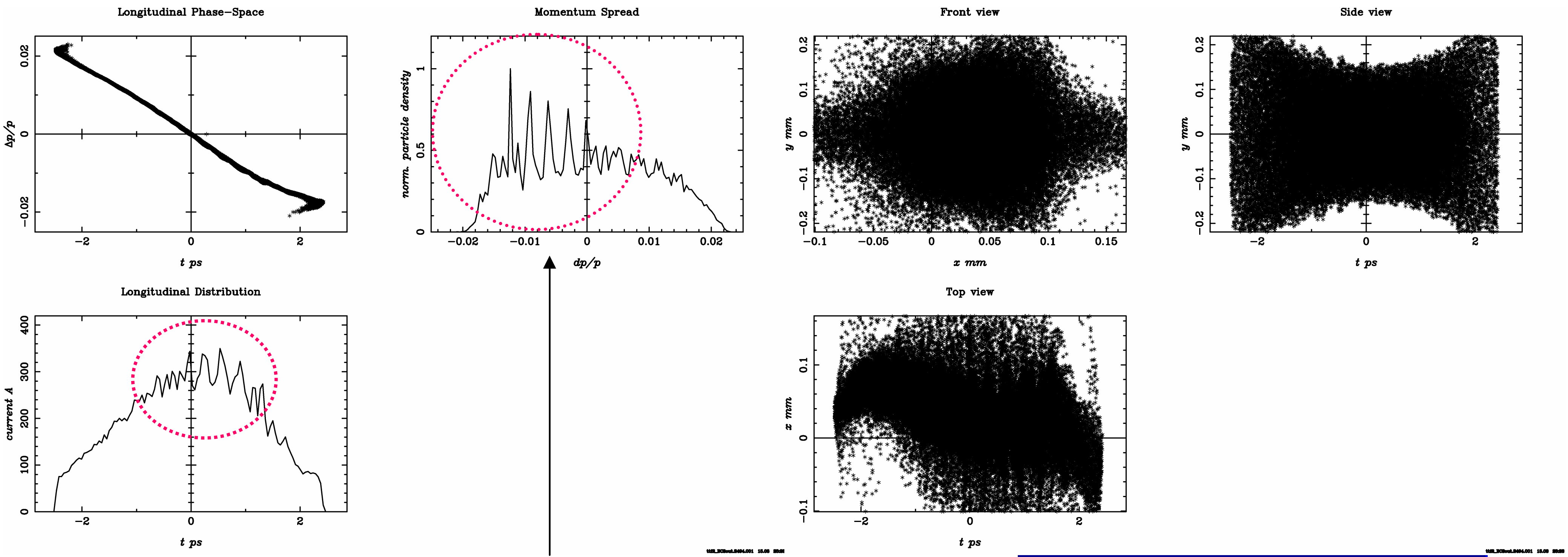
ASTRA Tracking with Laser Beam Modulation

At the end of BC2 with CSR

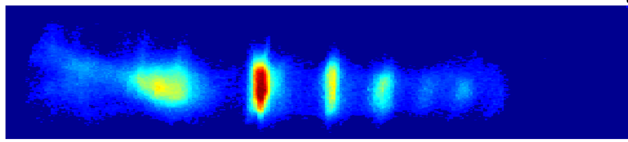
Modulation period = 2.0 ps
Modulation Amplitude = ±10%
Postpro BIN number = 125
Simulation particles = 50,000
ASTRA Grids for space charge calculation = 10 rings × 50 cells



Here !



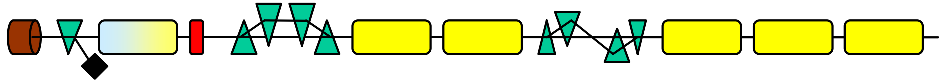
This energy modulation may be observed at SDL
We do not meet a strong density modulation yet !

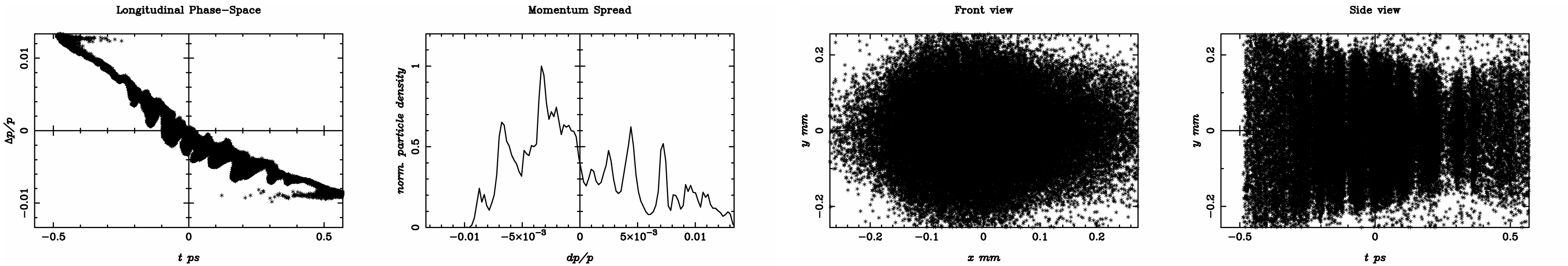


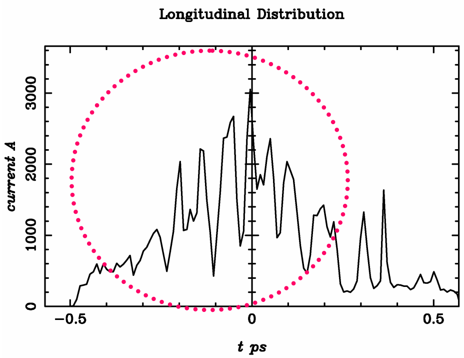
ASTRA Tracking with Laser Beam Modulation

At the end of BC3

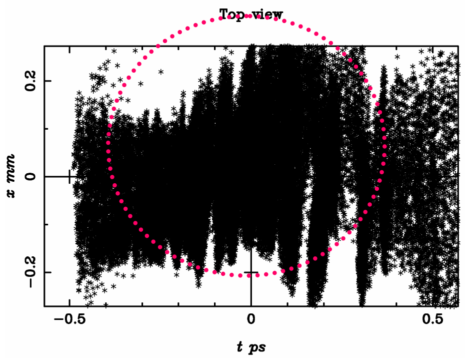
Modulation period = 2.0 ps
Modulation Amplitude = ±10%
Postpro BIN number = 125
Simulation particles = 50,000
ASTRA Grids for space charge calculation = 10 rings × 50 cells







±50% density modulation !
Total gain from cathode ~ 5

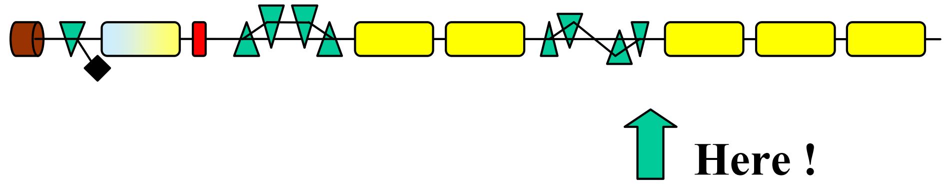


Unfortunately, we meet a density modulation !

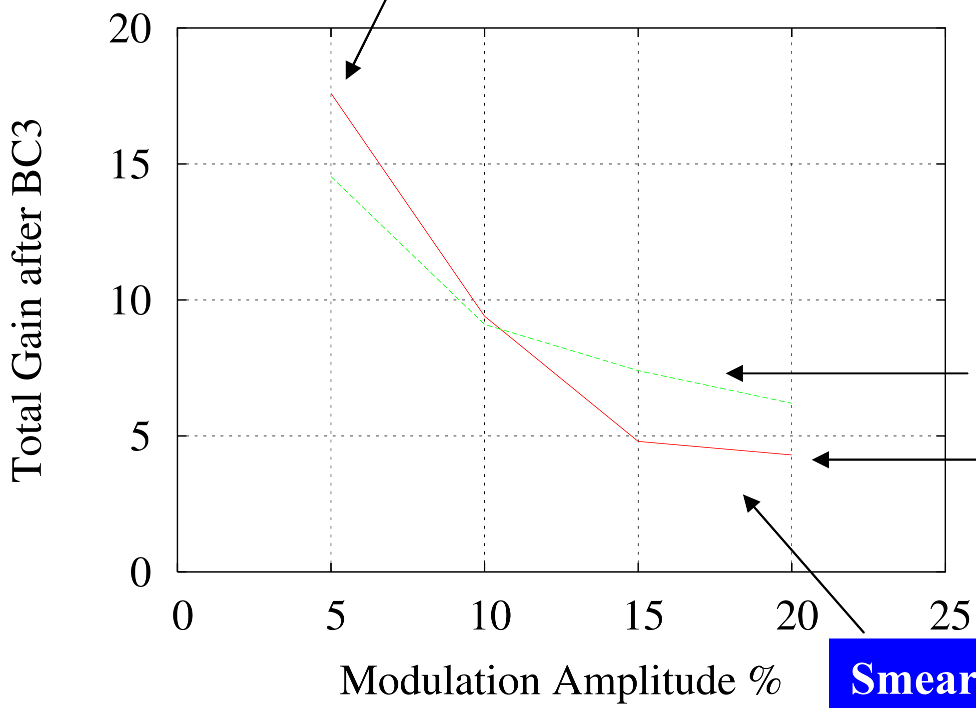
Gain after BC3

At the end of BC3

Modulation period = 2.0 ps
Modulation Amplitude = 5%, 10%, 15%, 20%
Postpro BIN number = 125
Simulation particles = 50,000
ASTRA Grids for space charge calculation = 10 rings × 50 cells



Gain is overestimated at small amplitude due to numerical noise



CSR effects becomes strong due to the increased non-uniformity in the current density profile when the modulation amplitude is increased.

Gain ~ 7 without CSR at BC3

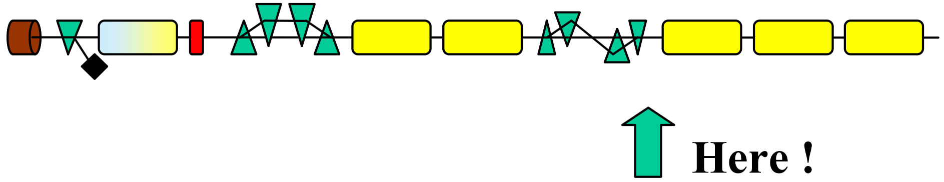
Gain ~ 5 with CSR at BC3

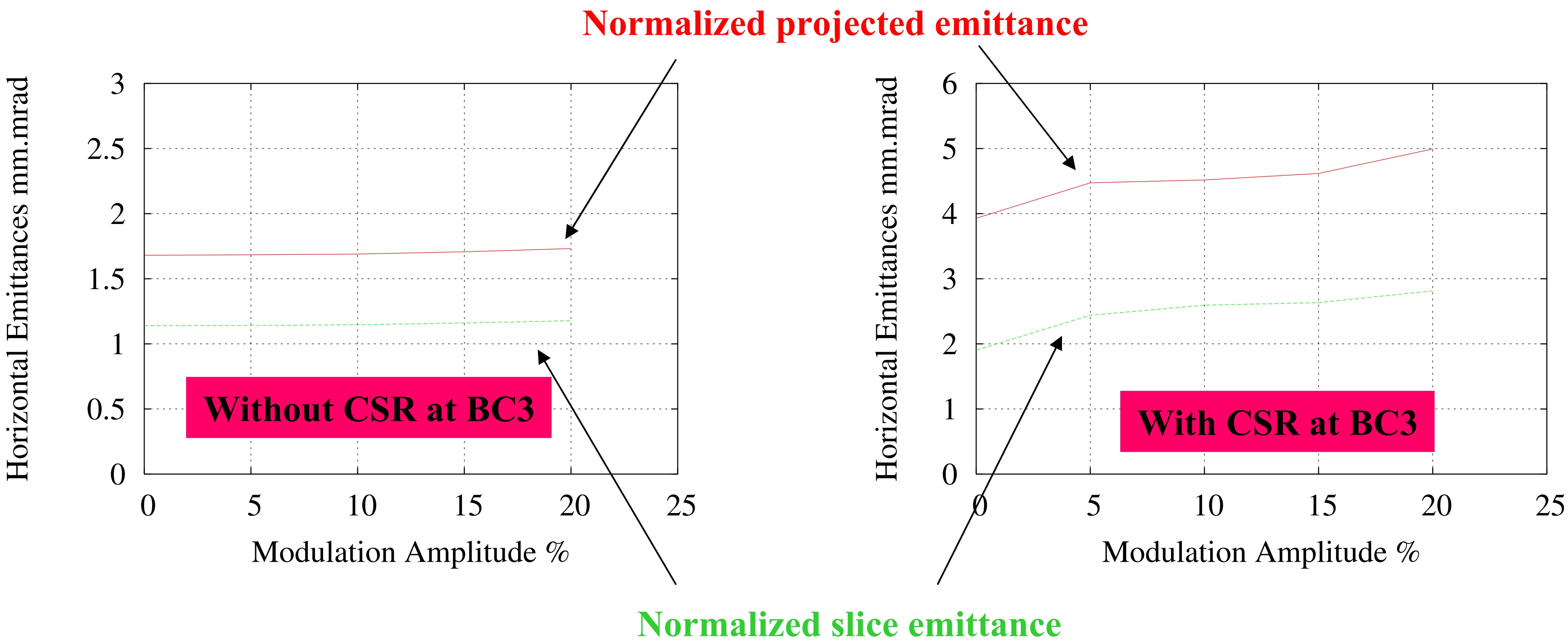
Smeared by the increased local energy spread due to CSR wakefield

Slice & Projected Emittances after BC3

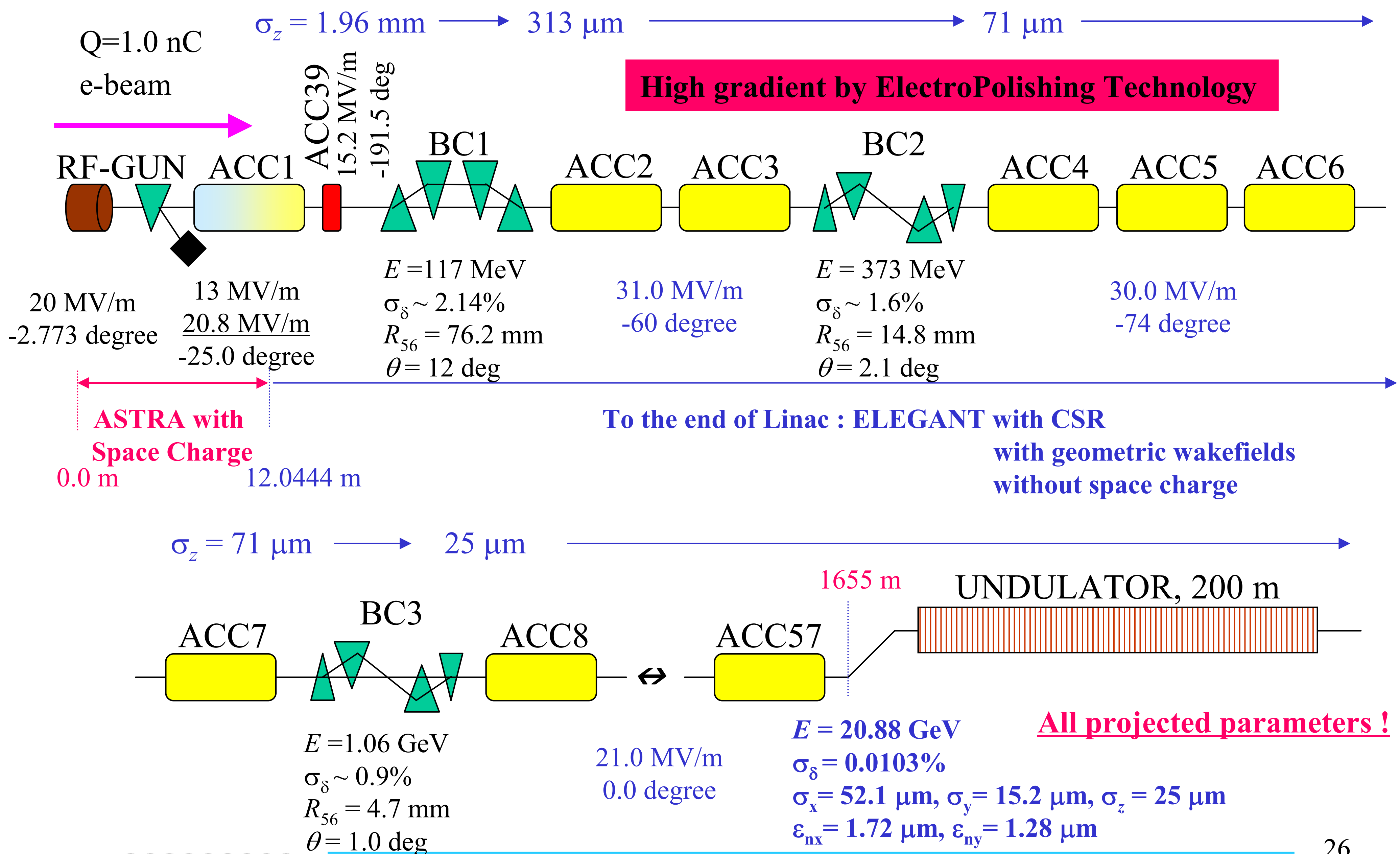
At the end of BC3

Modulation period = 2.0 ps
Modulation Amplitude = 5%, 10%, 15%, 20%
Postpro BIN number = 125
Simulation particles = 50,000
ASTRA Grids for space charge calculation = 10 rings × 50 cells

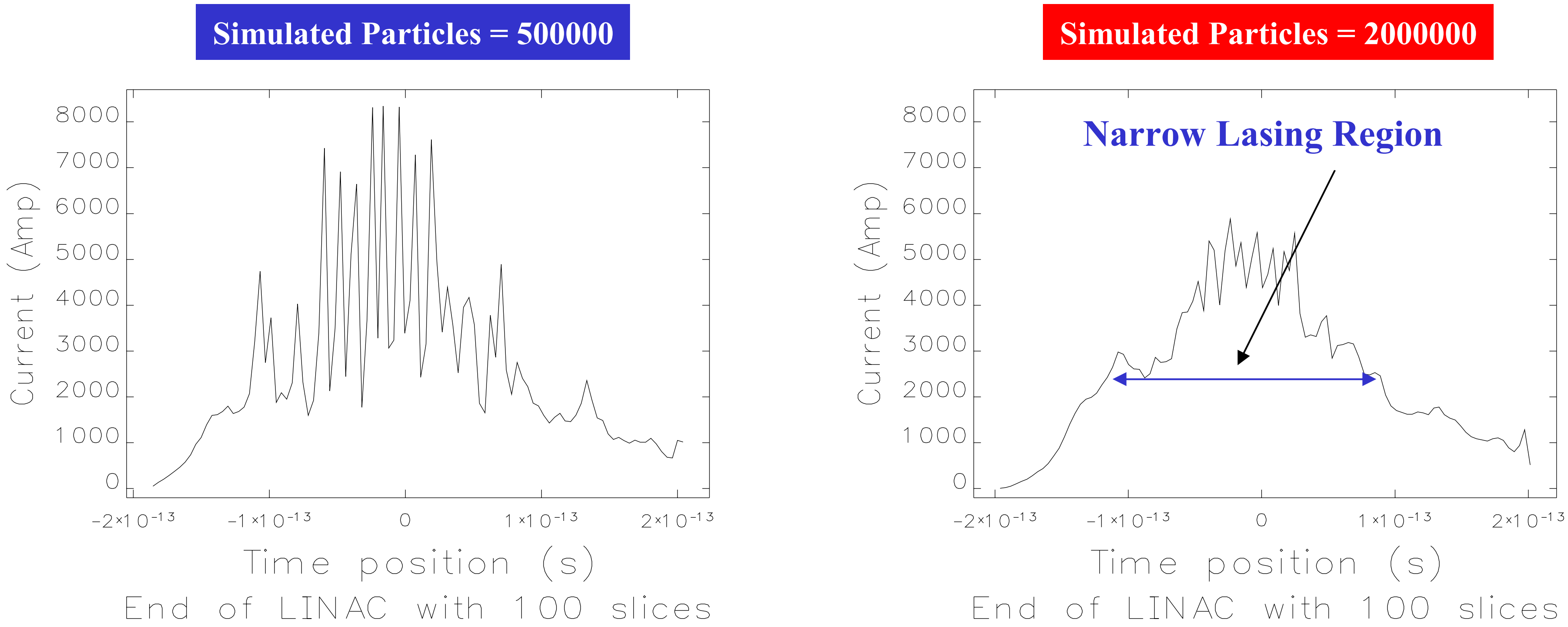




Old Lattice for TESLA XFEL - 2nd Version

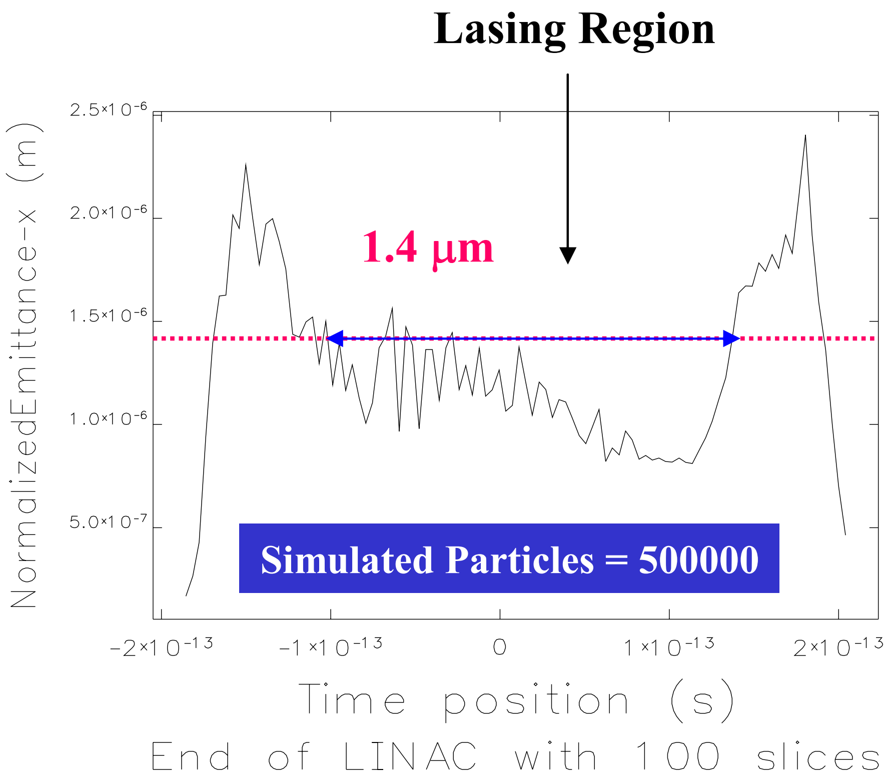


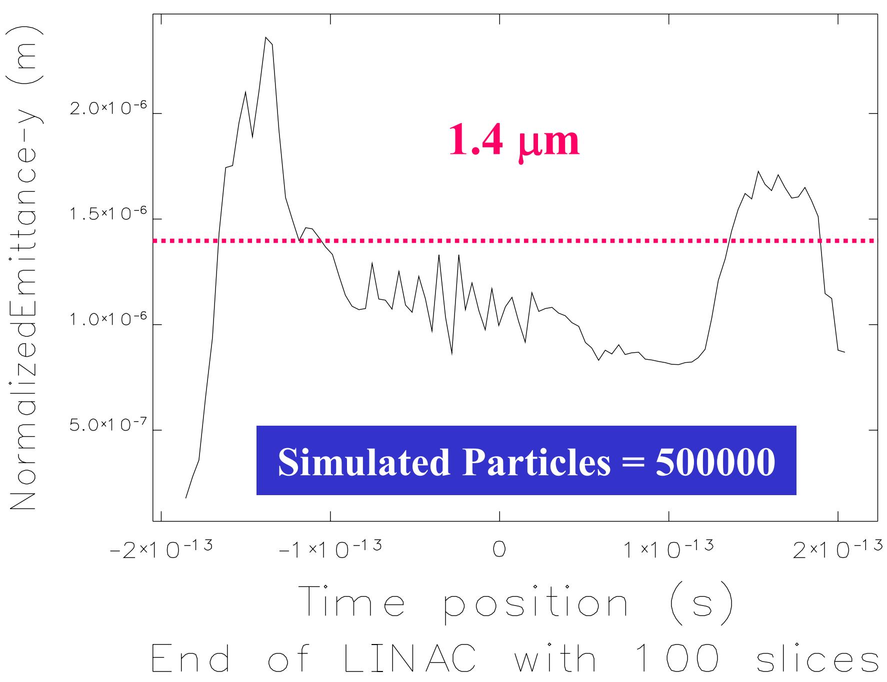
Old Lattice - Slice Parameters



When the number of particles is 500000, there are many high spikes in the current due to the strong microbunching instability at S-type chicanes. But those spikes are somewhat damped when we use 2000000 particles !

Old Lattice - Slice Parameters

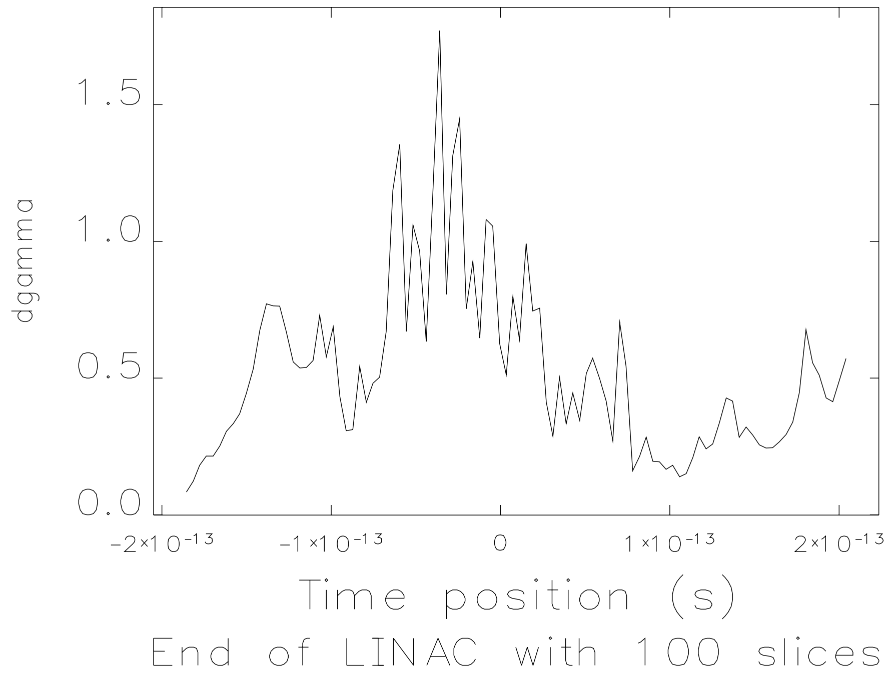




When the number of particles is 500000, there are many high spikes in the slice emittance due to the strong microbunching instability at S-type chicanes.

Old Lattice - Slice Parameters

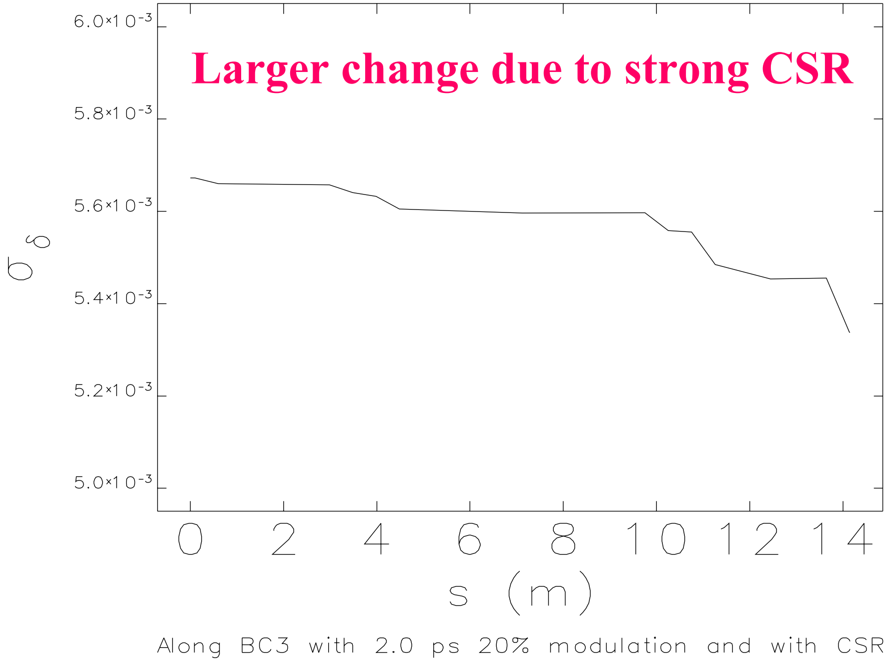
Simulated Particles = 500000



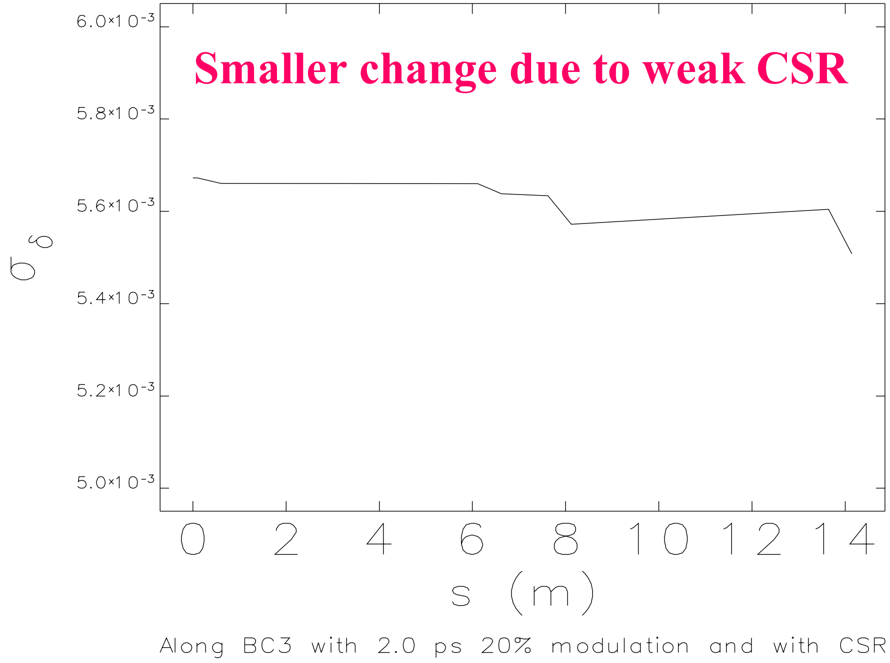
Maximum uncorrelated energy spread : 0.767 MeV @ 20.0 GeV ~ 0.0038% < 0.0125%
Please note that although the uncorrelated energy spread is not a hot issue at 20 GeV linac, the spread is highest at the center region, i.e., the main lasing region !

Chicane Comparison - Energy Spread Change

From the TTF-2 S2E Simulations on the microbunching instability, we found that S-type chicane is more dangerous against the microbunching instability due to two additional dipoles. When a 2.0 ps 20% current density modulation is applied at the cathode, we got following results at TTF-2 BC3. (Refer to Yujong's TESLA-S2E-2003-08 & TESLA-S2E-2003-10)



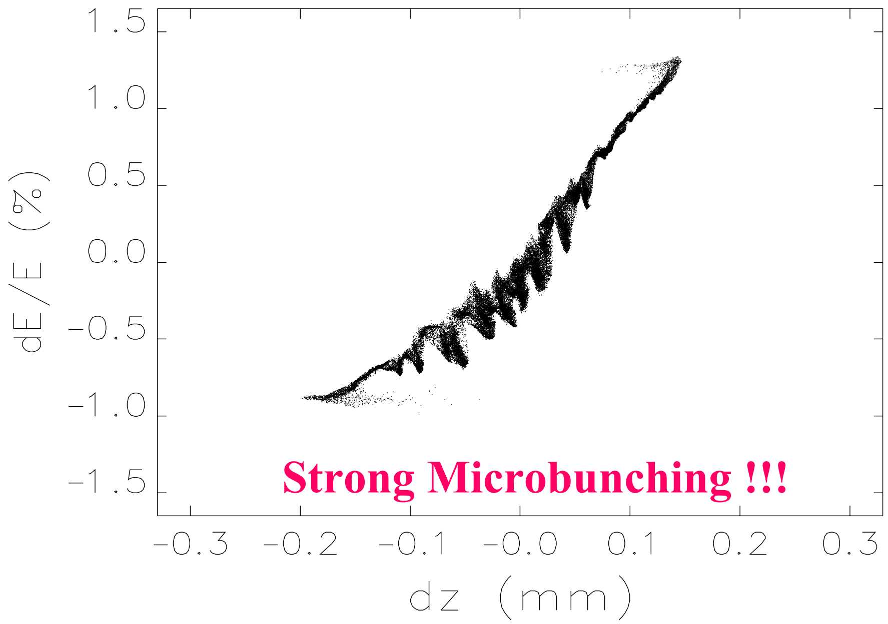
σ_{delta}= 0.567 ~ 0.53% for S-type chicane



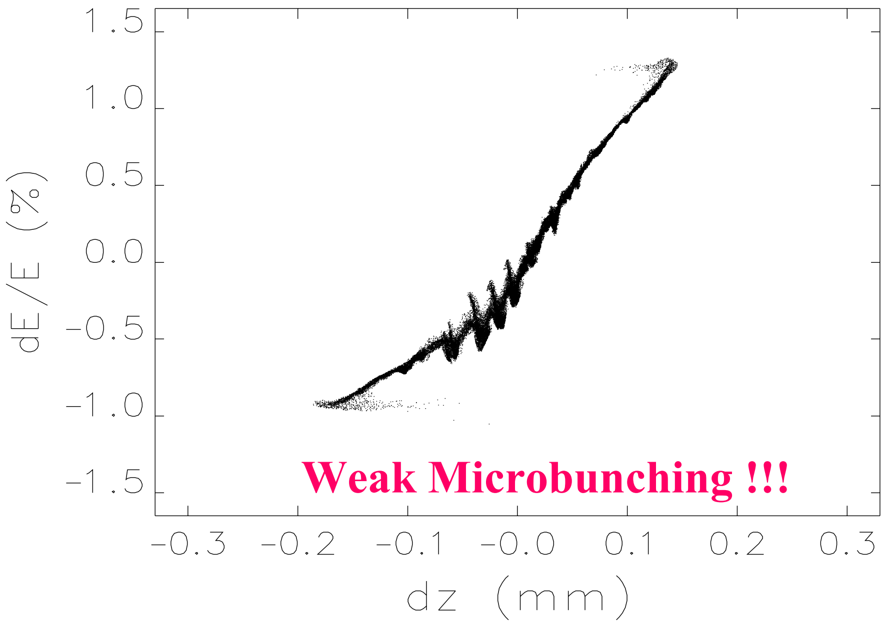
σ_{delta}= 0.567 ~ 0.55% for 4 bend chicane

Chicane Comparison - Longitudinal Space

From the TTF-2 S2E Simulations on the microbunching instability, we found that S-type chicane is more dangerous against the microbunching instability due to two additional dipoles. When a 2.0 ps 20% current density modulation is applied at the cathode, we got following results at TTF-2 BC3. (Refer to Yujong's TESLA-S2E-2003-08 & TESLA-S2E-2003-10)



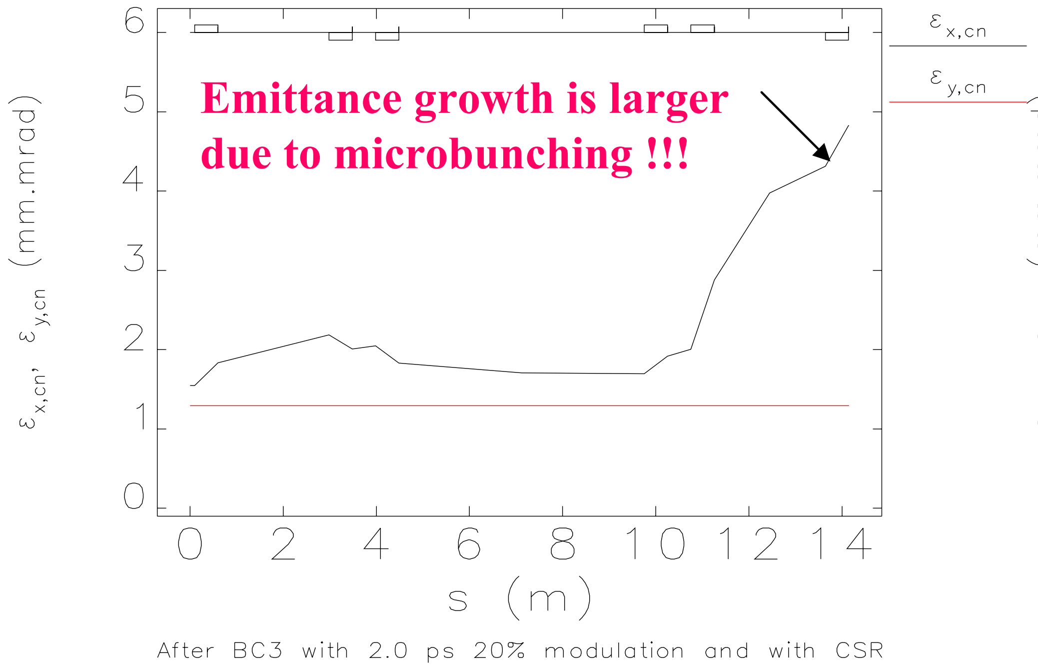
6-bends S-type chicane



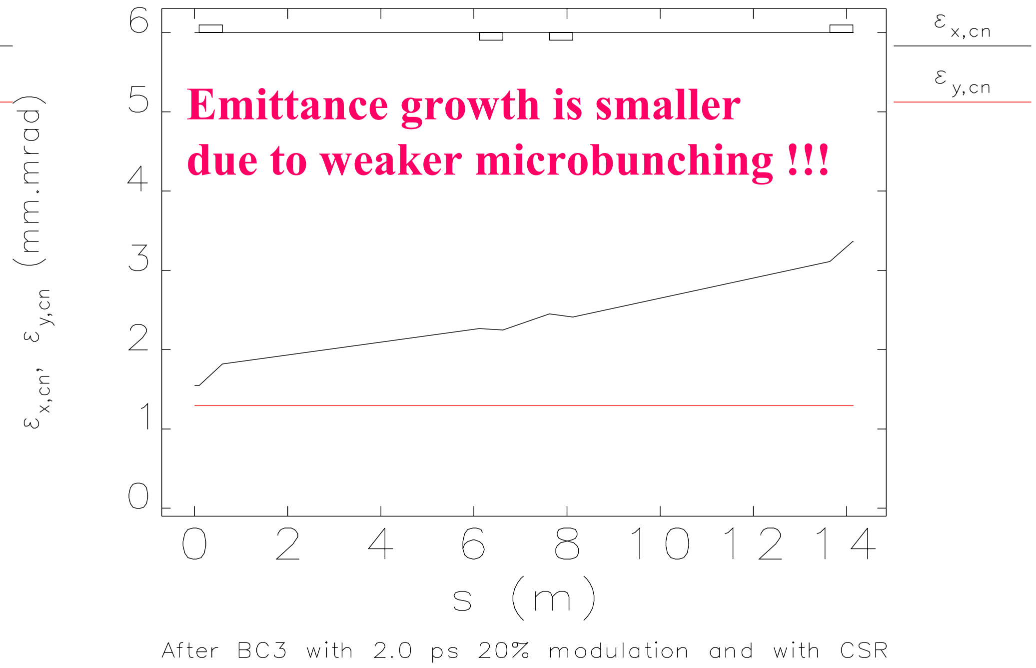
4-bends normal chicane

Chicane Comparison - Project emittance

From the TTF-2 S2E Simulations on the microbunching instability, we found that S-type chicane is more dangerous against the microbunching instability due to two additional dipoles. When a 2.0 ps 20% current density modulation is applied at the cathode, we got following results at TTF-2 BC3. (Refer to Yujong's TESLA-S2E-2003-08 & TESLA-S2E-2003-10)



ε_{nx}= 4.82 μm for S-type chicane



ε_{nx}= 3.36 μm for 4 bend chicane

Chicane Comparison - Slice emittance

From the TTF-2 S2E Simulations on the microbunching instability, we found that S-type chicane is more dangerous against the microbunching instability due to two additional dipoles. When a 2.0 ps 20% current density modulation is applied at the cathode, we got following results at TTF-2 BC3. (Refer to Yujong's TESLA-S2E-2003-08 & TESLA-S2E-2003-10)

6-bends S-type chicane

4-bends normal chicane

New Lattice Design Concepts

Generally the compensation of S-type chicane helps in reducing the projected emittance growth due to CSR. However the projected emittance growth in the 4-bend chicane can be small enough if we well-optimize the normal chicane.

❑ Reducing projected emittance growth due to CSR & Chromatic Effects

- Keeping somewhat large energy spread at BCs by putting BCs at a lower energy
- Reducing QM length around BCs to reduce chromatic effect
- Removing emittance measuring FODO after BC1 to reduce chromatic effect
- Using weaker strength chicanes with a longer chicane length of ~ 20 m
- Using a longer drift space between 1st and 2nd dipoles in BCs ~ 8.9 m
- Optimizing Twiss parameters around BCs
- Selecting much smaller compression factor at BC2 against CSR there
- Reducing dipole length from 0.5 m to 0.3 m against CSR

❑ Reducing Slice Parameter Growths due to the Microbunching Instability

- Replace two 6-bends S-type chicanes into one 4-bends normal chicane
- Reducing three BC stages to one BC stage with a double chicane
- Smearing the microbunching instability at BC2 by keeping large uncorrelated energy spread at BC2 without any acceleration between BC1 and BC2

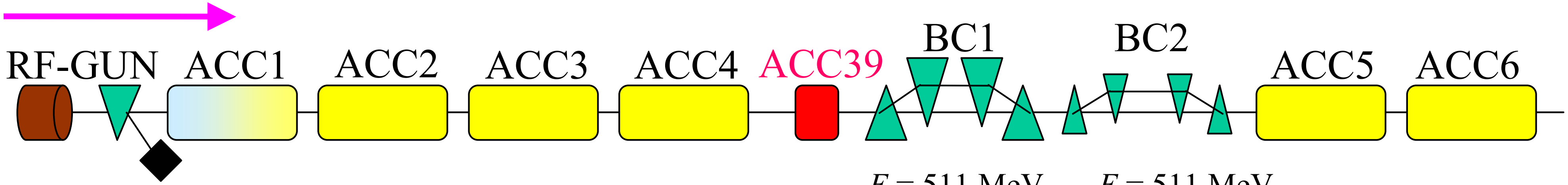
New Lattice for TESLA XFEL - 3rd Version

With TTF2 Injector, ε_n = 1.3 μm

Q=1.0 nC

e-beam

σ_z = 2.0 mm → 112 μm → 22 μm →



20 MV/m
-2.773 deg

13.65 MV/m
22.22 MV/m
-25.0 deg

20.22 MV/m
-24.3 deg

32.5 MV/m
160.6 deg

BC1: E = 511 MeV
$\sigma_\delta \sim$ 1.88%
R_{56} = 100.7 mm
θ = 4.25 deg

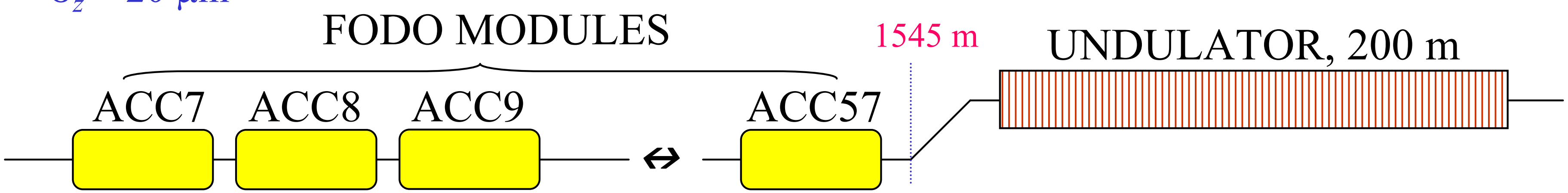
BC2: E = 511 MeV
$\sigma_\delta \sim$ 1.87%
R_{56} = 4.8 mm
θ = 0.93 deg

21.65 MV/m
0.0 deg

ASTRA with Space Charge
0.0 m — 12.0444 m

To the end of Linac : ELEGANT with CSR
with geometric wakefields
without space charge

σ_z = 20 μm →



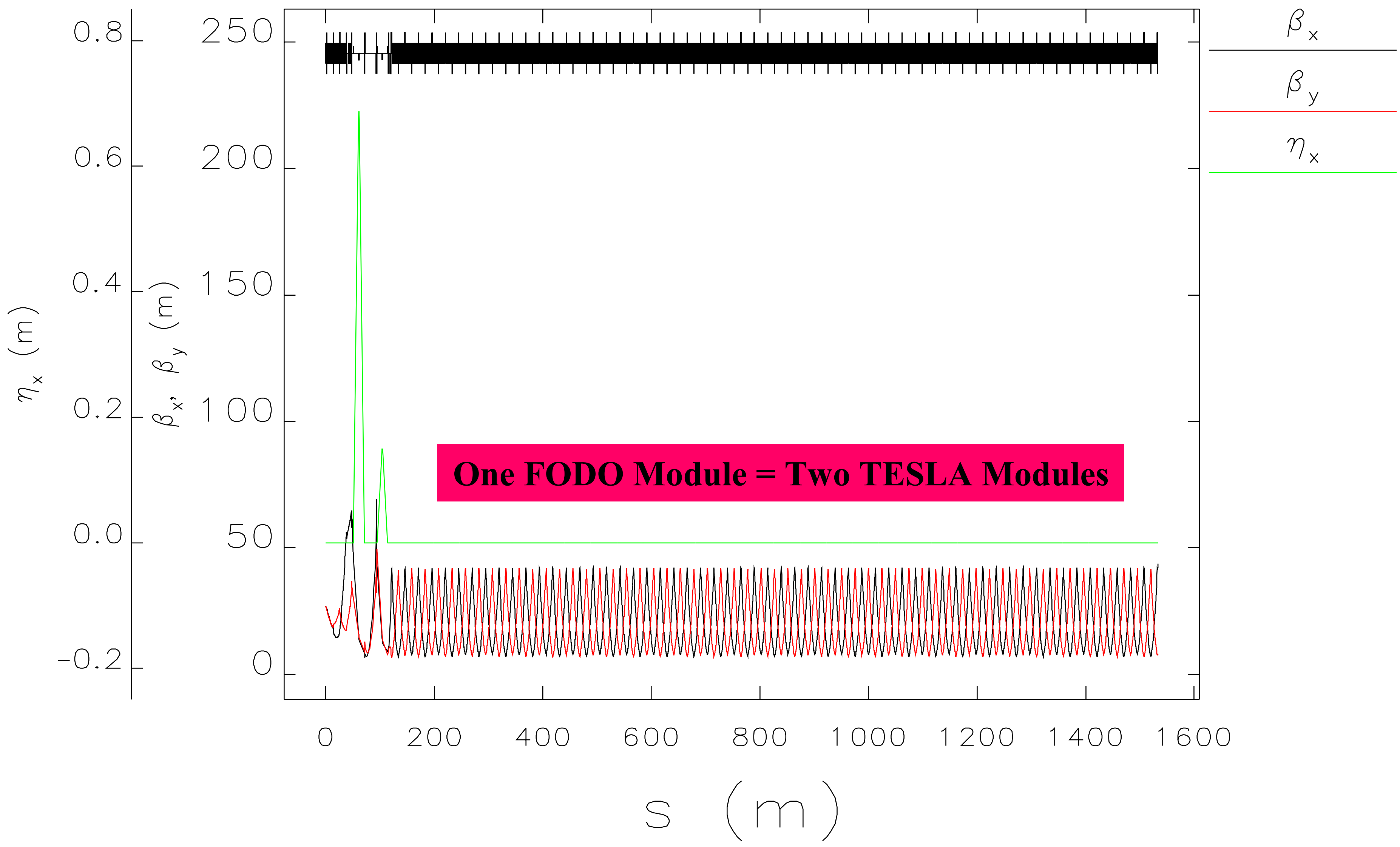
21.65 MV/m
0.0 deg

E = 20.0 GeV
σ_δ = 0.0059%
σ_x = 41.7 μm, σ_y = 15.8 μm, σ_z = 20 μm
ε_{nx} = 1.525 μm, ε_{ny} = 1.295 μm

All projected parameters !

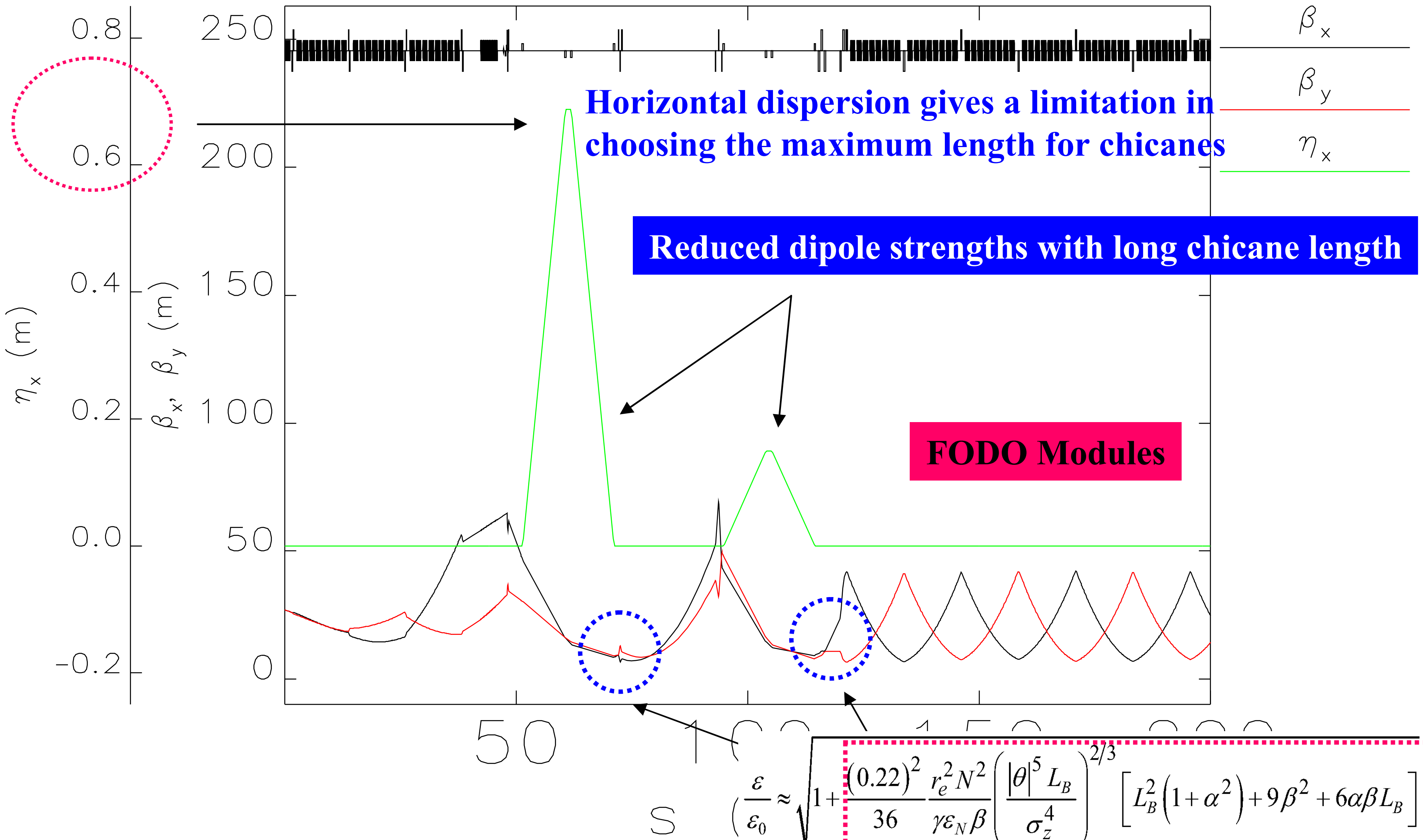
Twiss Parameters of New Lattice

With TTF2 Injector, ε_n= 1.3 μm



Twiss Parameters of New Lattice around BCs

With TTF2 Injector, $\varepsilon_n = 1.3\ \mu m$



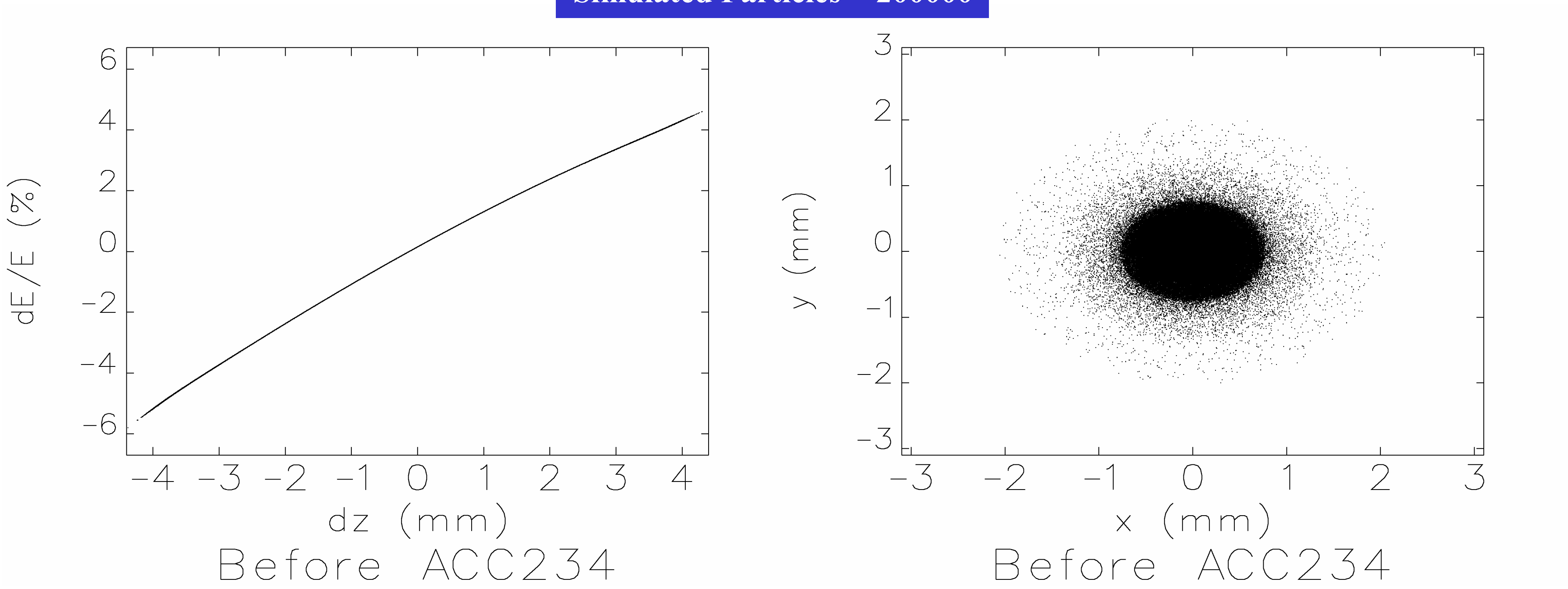
$$\frac{\varepsilon}{\varepsilon_0} \approx \sqrt{1 + \frac{(0.22)^2}{36}\frac{r_e^2 N^2}{\gamma \varepsilon_N \beta}\left(\frac{|\theta|^5 L_B}{\sigma_z^4}\right)^{2/3}\left[L_B^2\left(1+\alpha^2\right) + 9\beta^2 + 6\alpha\beta L_B\right]}$$

Lattice optimization to minimize this term

New Lattice - Before ACC2

With TTF2 Injector, ε_n= 1.3 μm

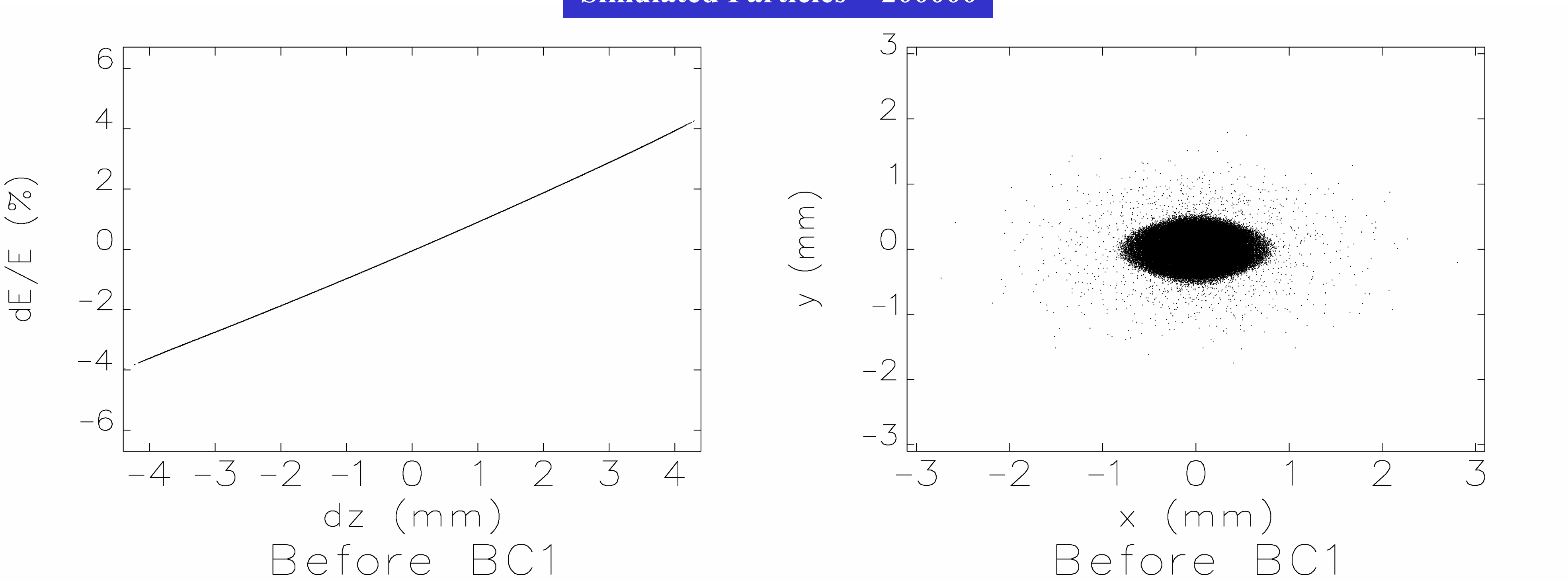
Simulated Particles = 200000



New Lattice - Before BC1

With TTF2 Injector, $\varepsilon_n = 1.3\ \mu m$

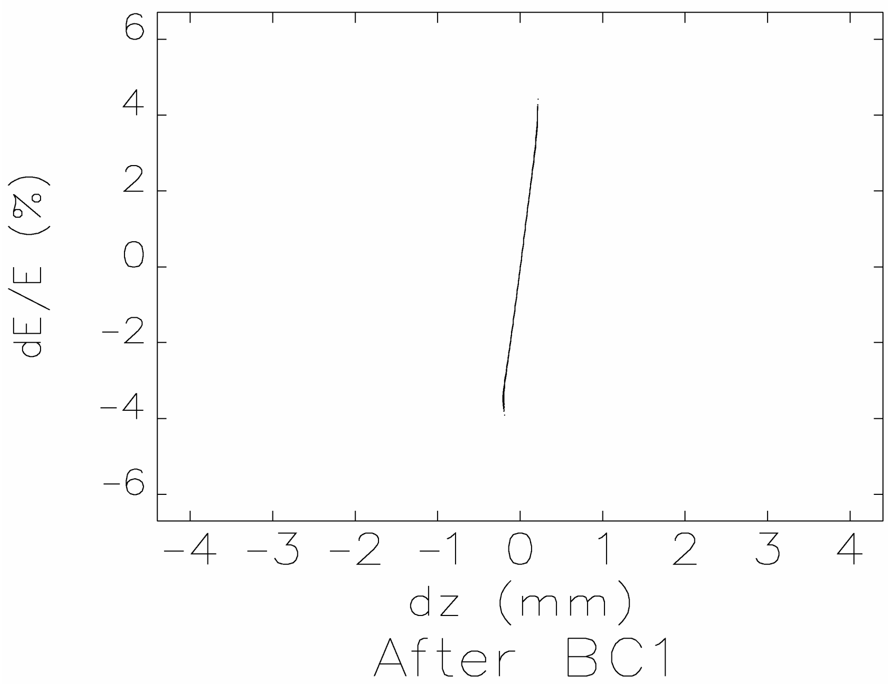
Simulated Particles = 200000

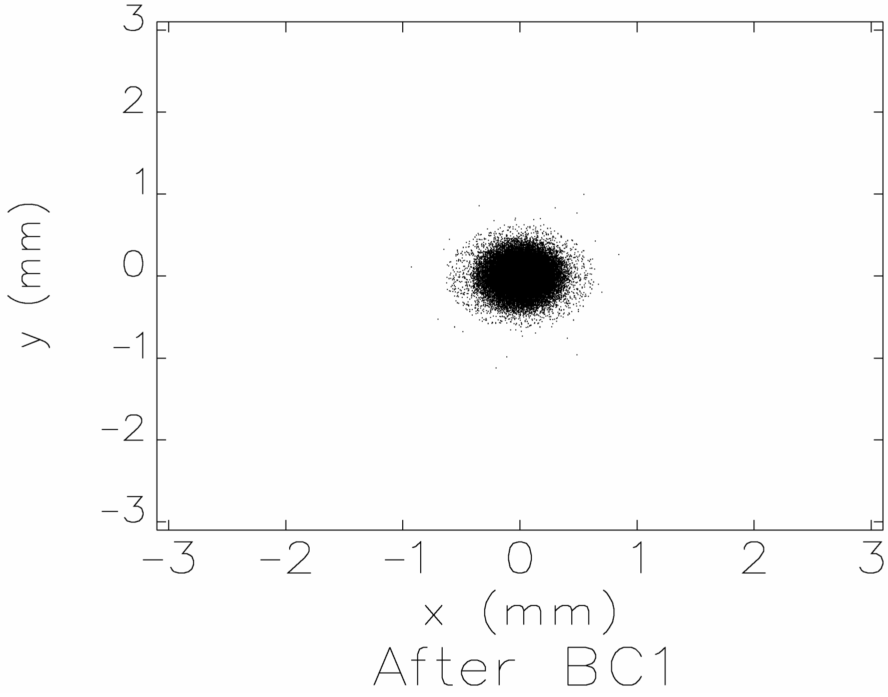


New Lattice - After BC1

With TTF2 Injector, $\varepsilon_n = 1.3\ \mu m$

Simulated Particles = 200000

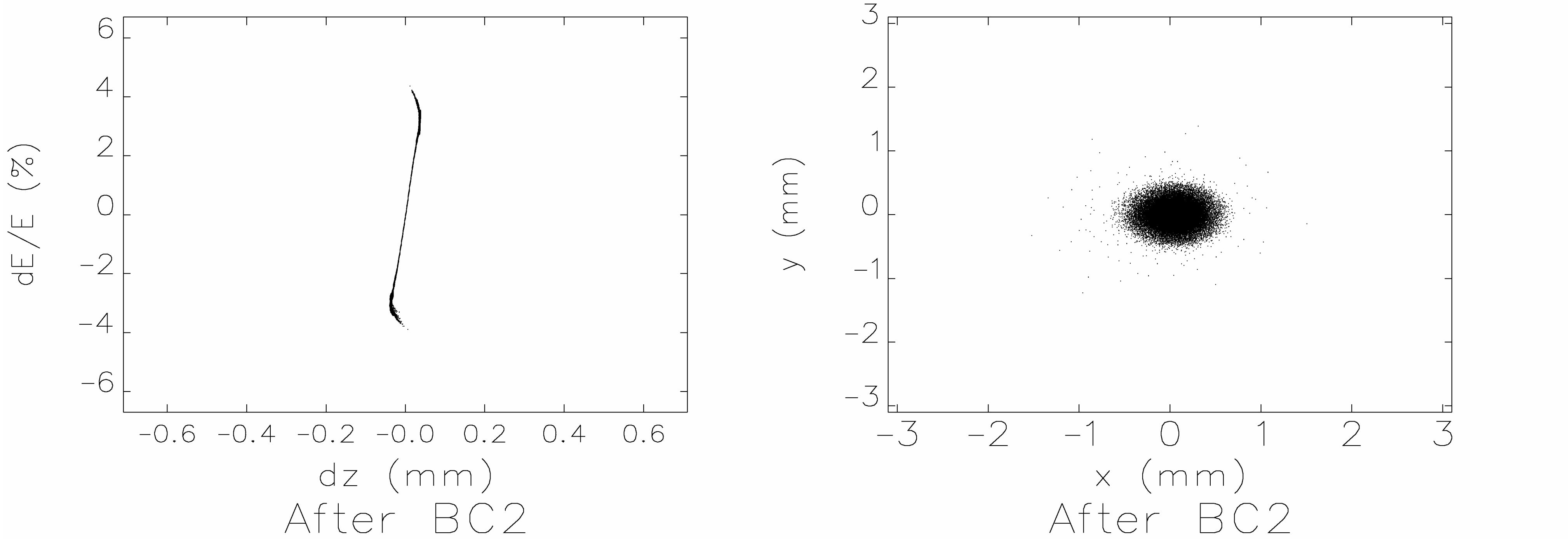




New Lattice - After BC2

With TTF2 Injector, ε_n= 1.3 μm

Simulated Particles = 200000

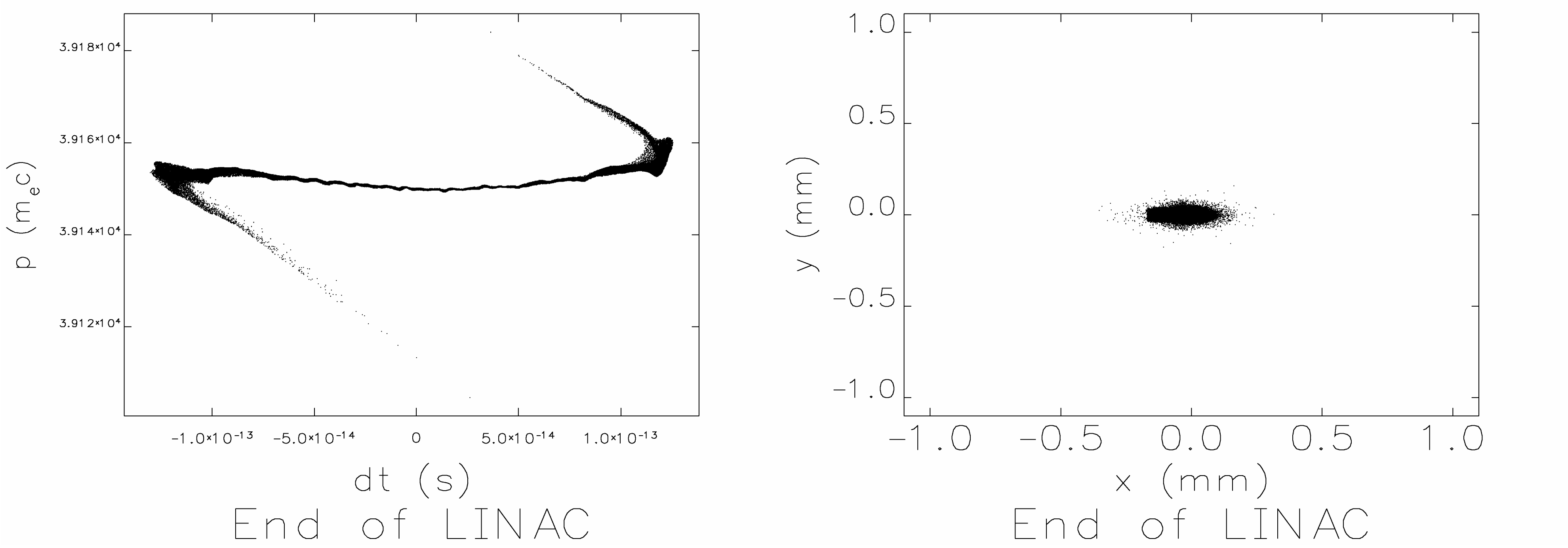


Although we use only 200000 particles, we did not meet any strong artificial modulation after BC2. This means that the amplification action of our new lattice is much weaker than that of our old lattice.

New Lattice - At the end of LINAC

With TTF2 Injector, $\varepsilon_n = 1.3\ \mu m$

Simulated Particles = 200000

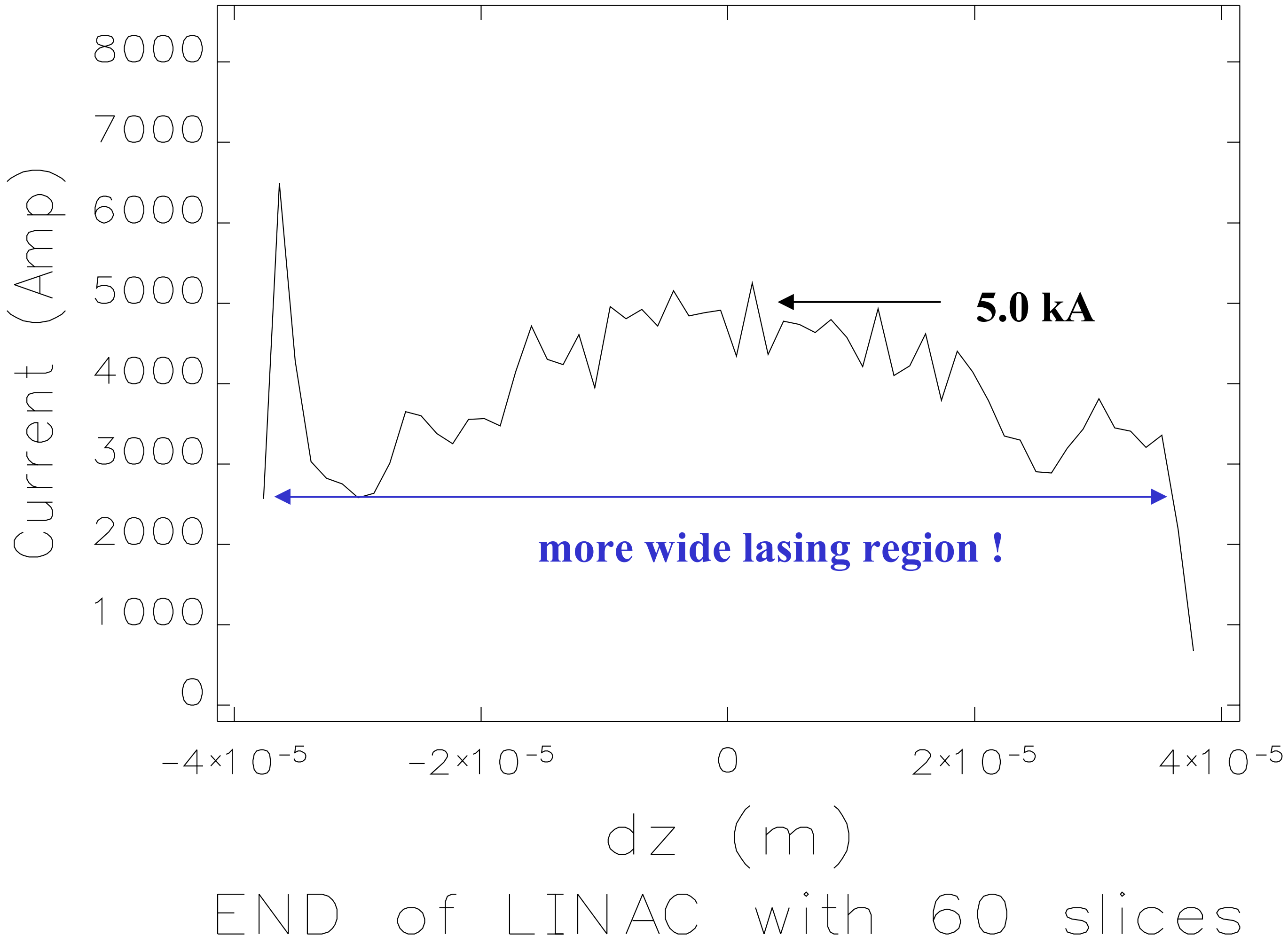


Although we use only 200000 particles, we did not meet any strong artificial modulation after BC2. This means that the amplification action of our new lattice is much weaker than that of our old lattice.

At the end of LINAC - Slice Parameters

With TTF2 Injector, ε_n= 1.3 μm

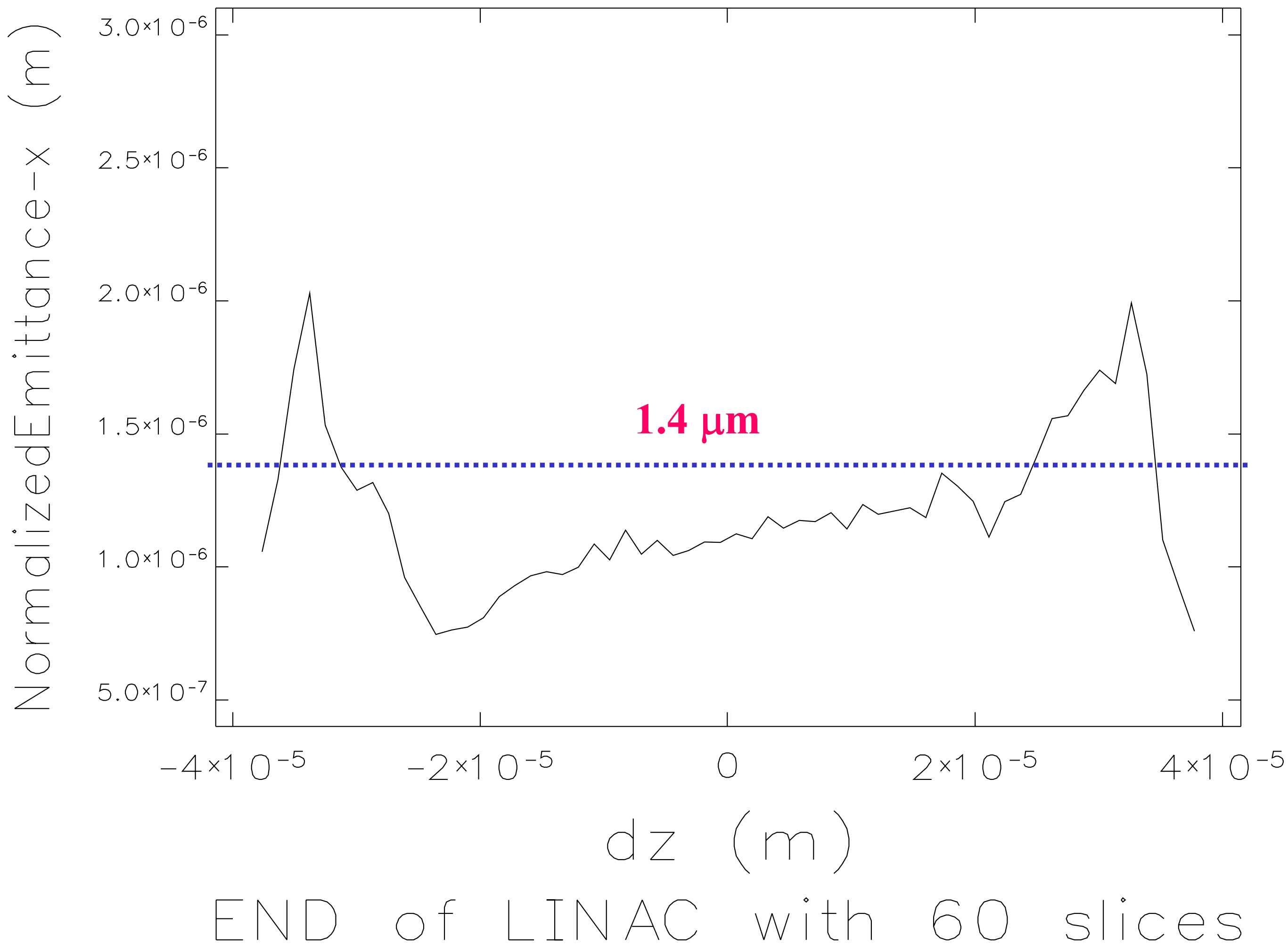
Simulated Particles = 200000



At the end of LINAC - Slice Parameters

With TTF2 Injector, ε_n= 1.3 µm

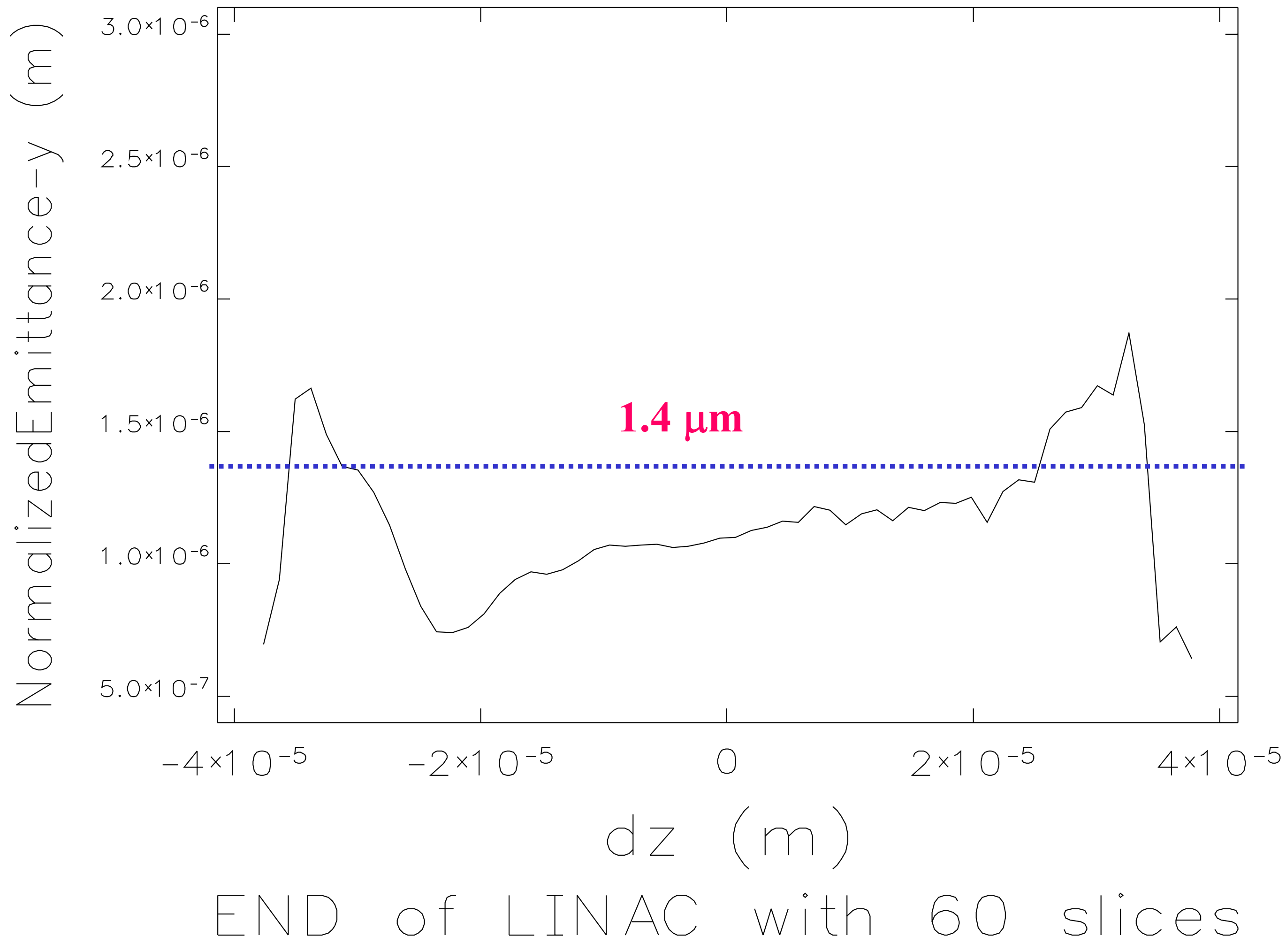
Simulated Particles = 200000



At the end of LINAC - Slice Parameters

With TTF2 Injector, ε_n= 1.3 µm

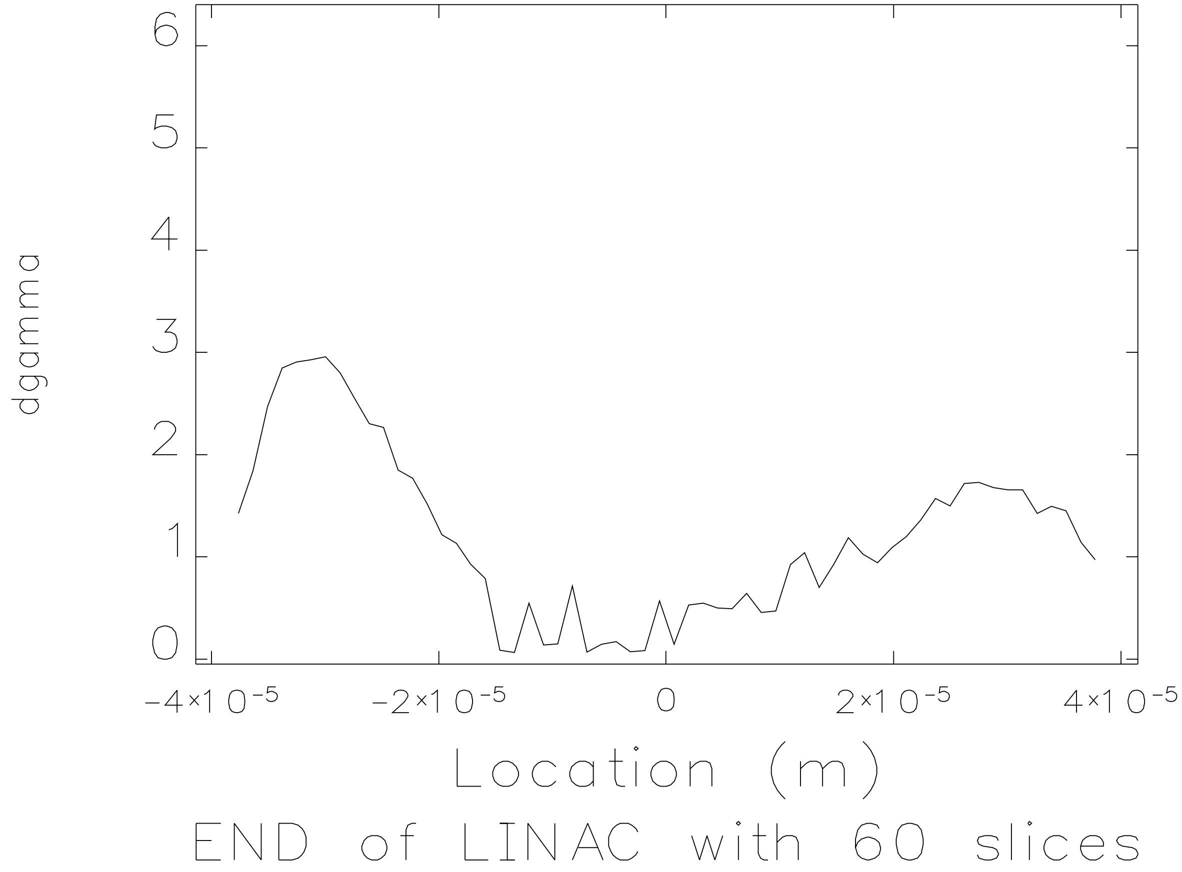
Simulated Particles = 200000



At the end of LINAC - Slice Parameters

With TTF2 Injector, ε_n= 1.3 μm

Simulated Particles = 200000

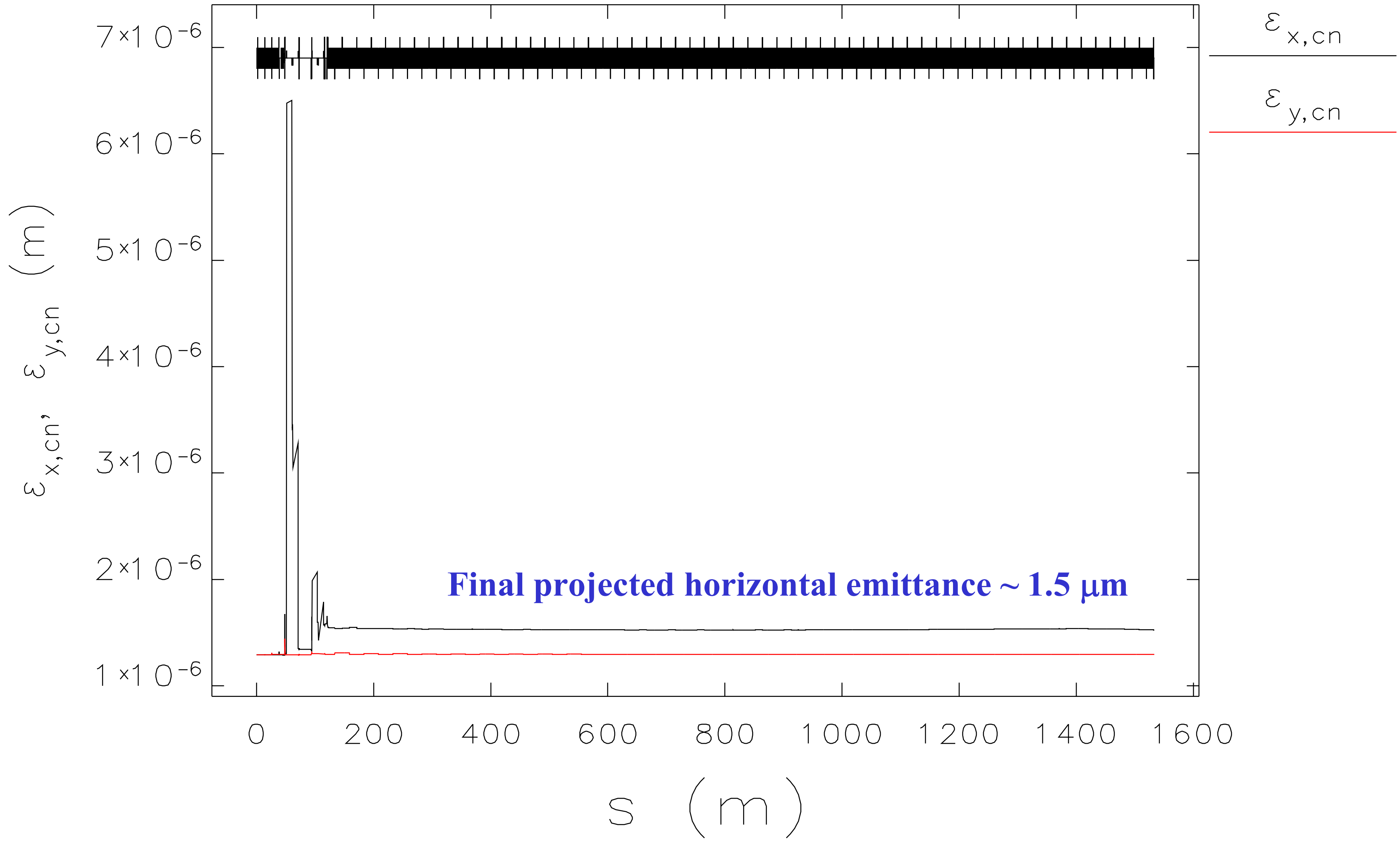


Maximum uncorrelated energy spread : 1.533 MeV @ 20.0 GeV ~ 0.0077% < 0.0125%
Fortunately, the uncorrelated energy spread in the center region is around 0.0013%

Projected Parameters Along Beamline

With TTF2 Injector, ε_n= 1.3 μm

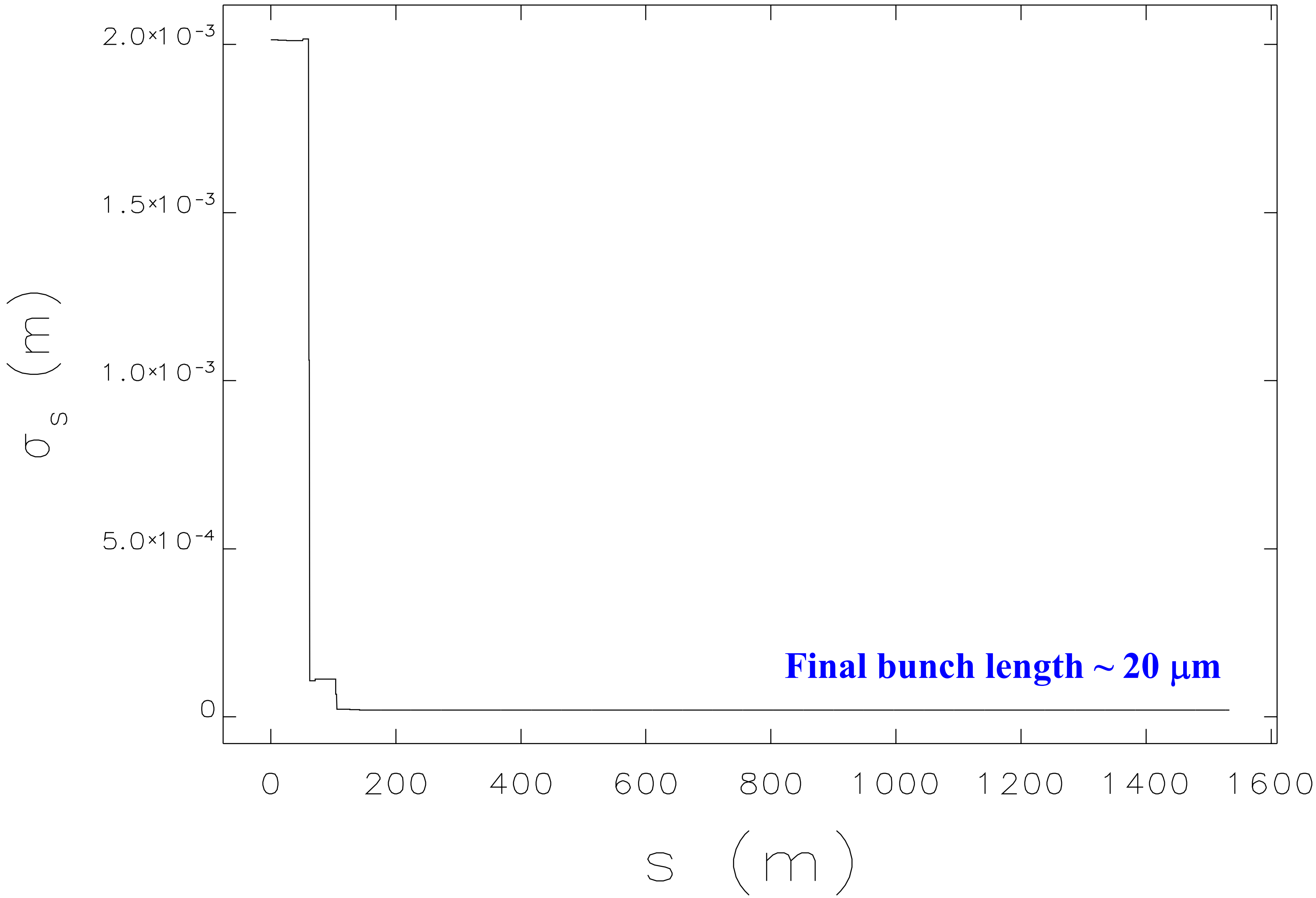
Simulated Particles = 200000



Projected Parameters Along Beamline

With TTF2 Injector, ε_n= 1.3 µm

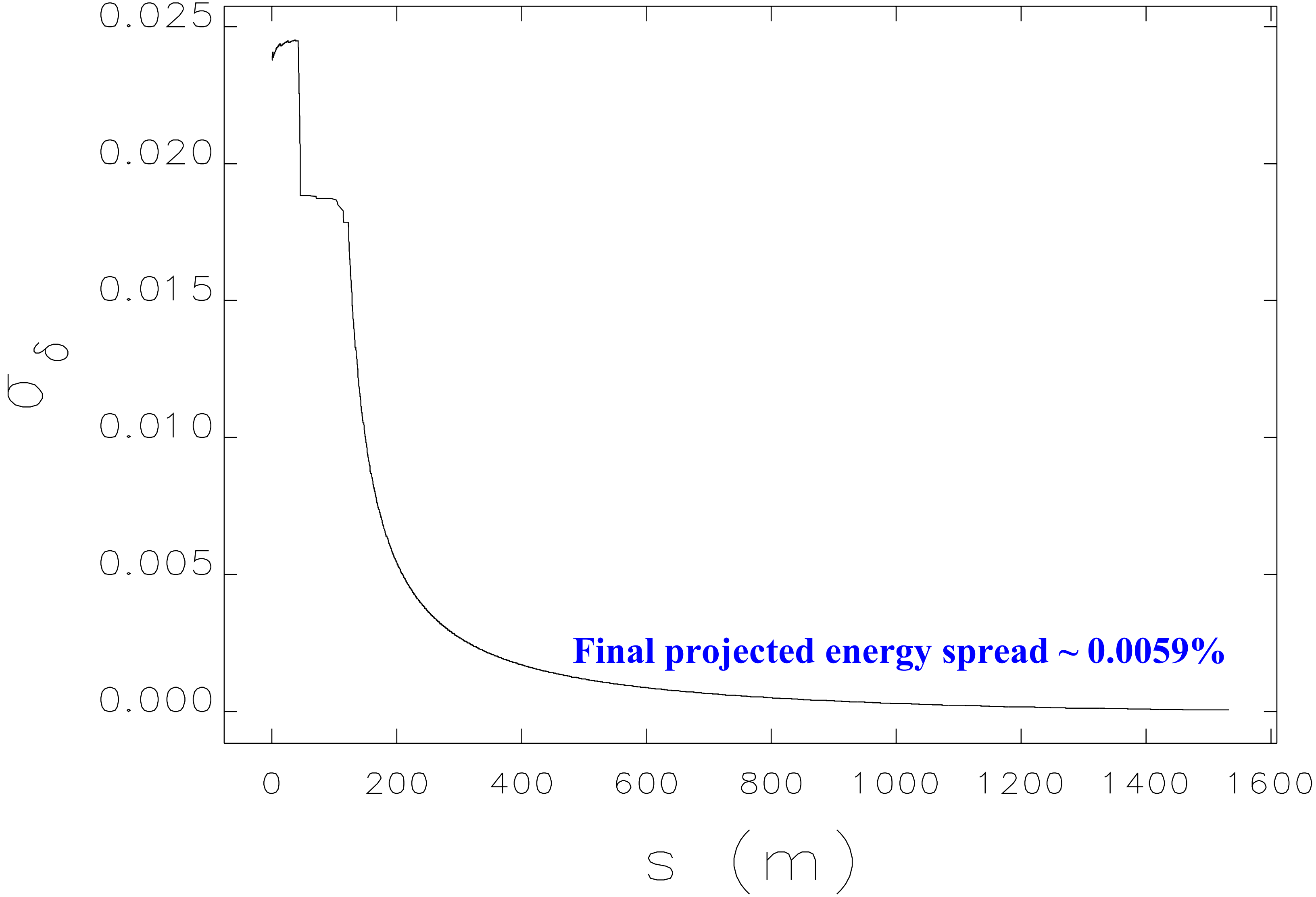
Simulated Particles = 200000



Projected Parameters Along Beamline

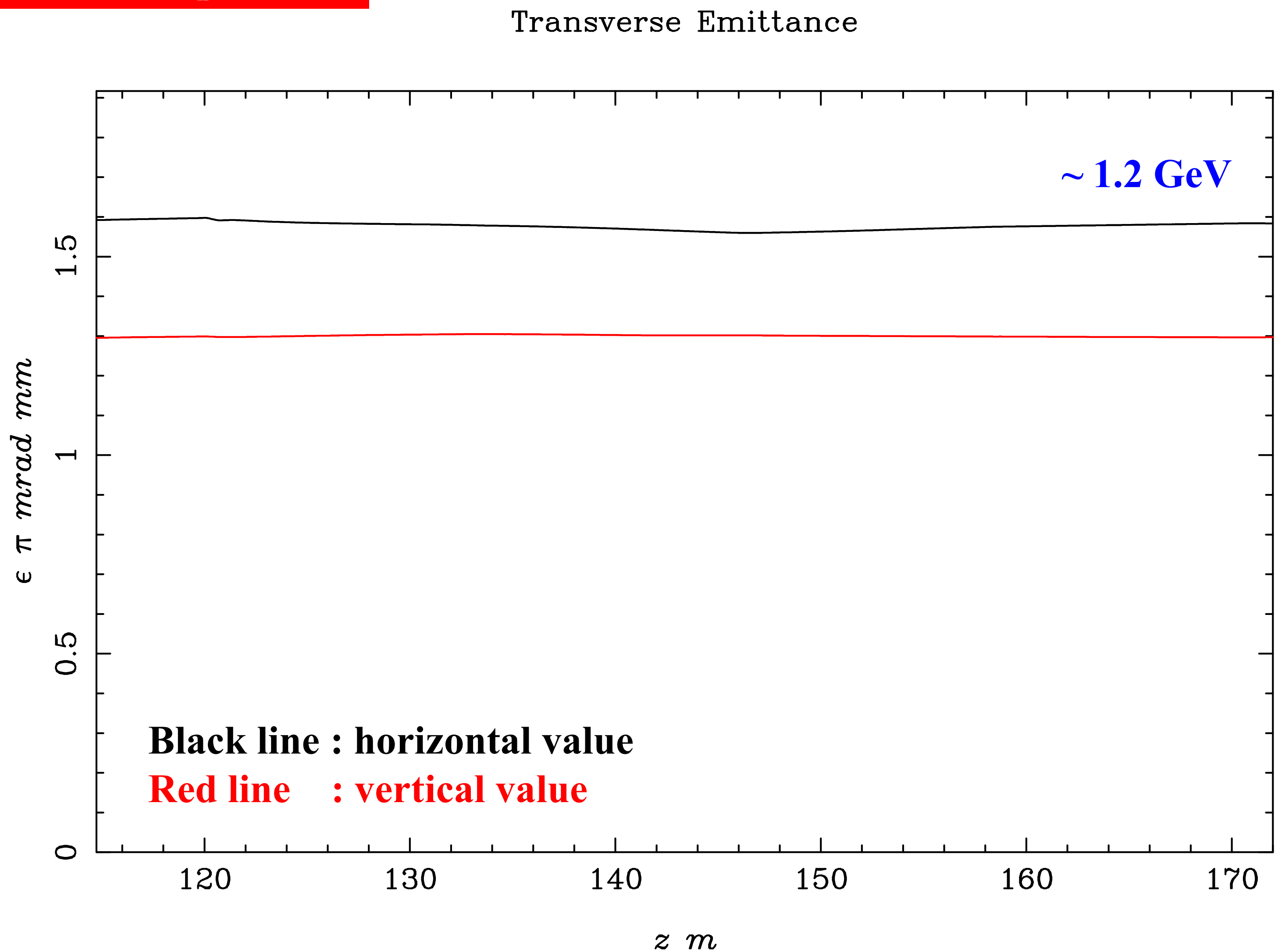
With TTF2 Injector, ε_n= 1.3 μm

Simulated Particles = 200000



ASTRA Tracking after BC2 with Space Charge

With TTF2 Injector, ε_n= 1.3 μm



Projected transverse emittances are almost constant under space charge force !!!

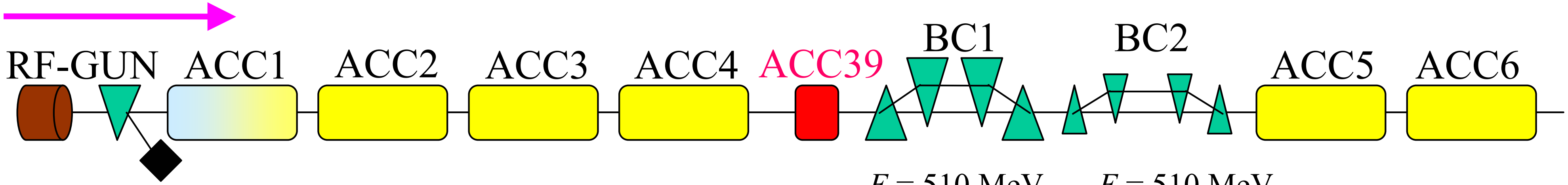
New Lattice for TESLA XFEL – 4th Version

With TESLA XFEL Injector, ε_n= 0.9 μm

Q=1.0 nC

e-beam

σ_z = 1.76 mm → 113 μm → 23 μm →



30 MV/m
-0.724 deg

11.5 MV/m
25.0 MV/m
-18.3 deg

20.5 MV/m
-29.6 deg

34.8 MV/m
160.6 deg

E = 510 MeV
$\sigma_\delta \sim$ 1.89%
R_{56} = 87 mm
θ= 3.95 deg

E = 510 MeV
$\sigma_\delta \sim$ 1.88%
R_{56} = 4.8 mm
θ= 0.93 deg

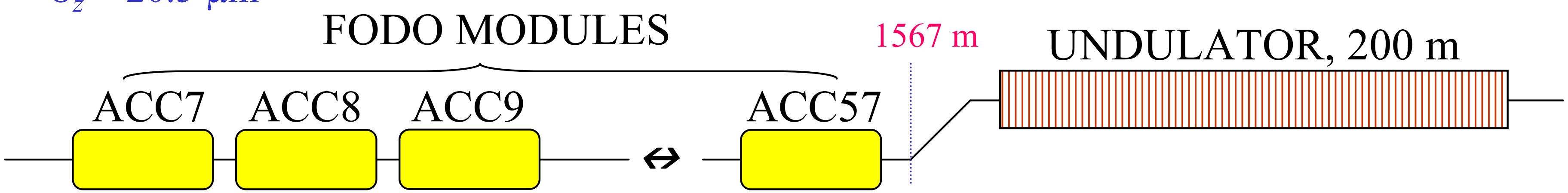
20.65 MV/m
0.0 deg

ASTRA with Space Charge

0.0 m — 12.0444 m

To the end of Linac : ELEGANT with CSR
with geometric wakefields
without space charge

σ_z = 20.5 μm →



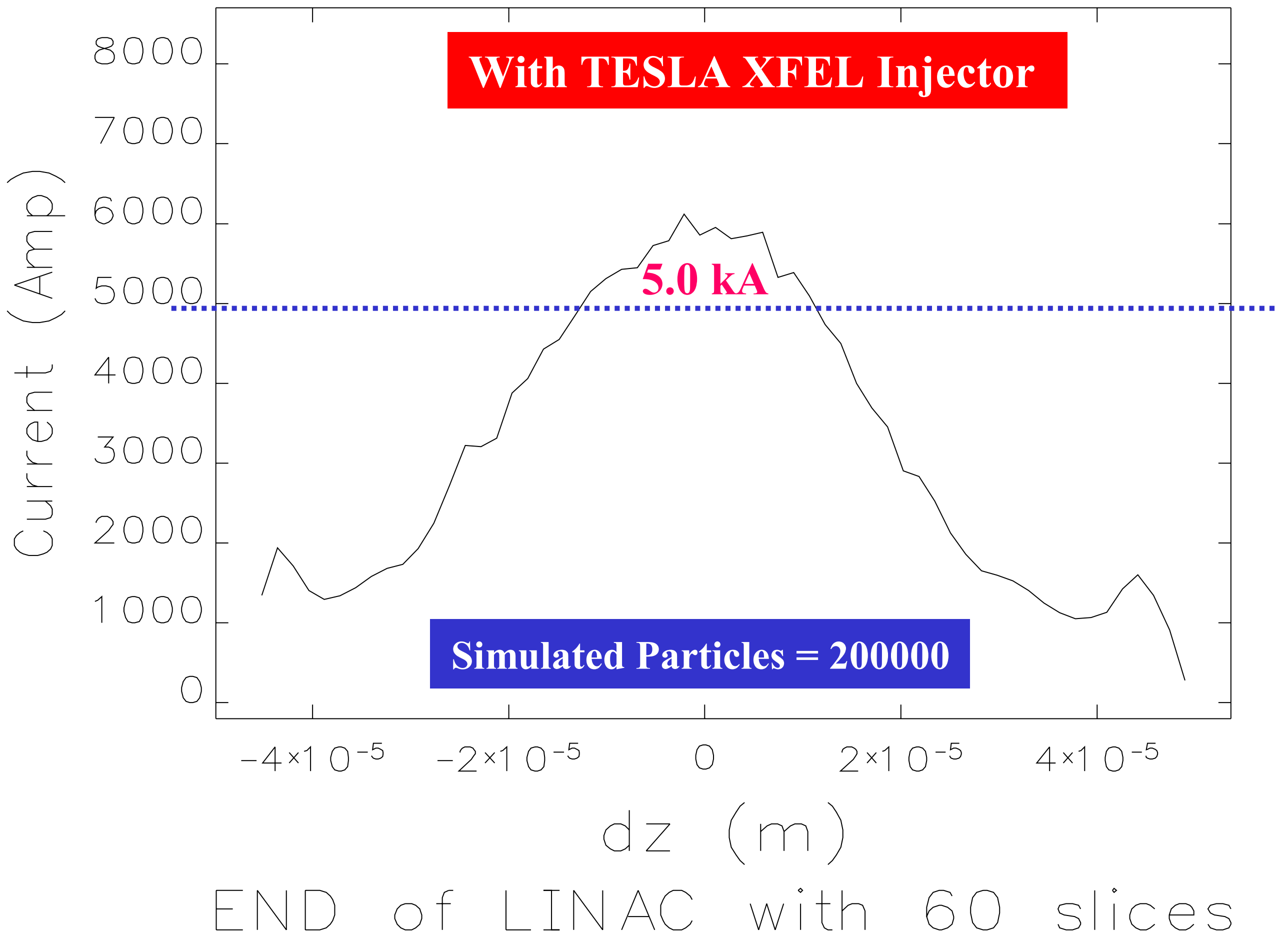
20.65 MV/m
0.0 deg

E = 20.0 GeV
σ_δ = 0.008%
σ_x= 37.3 μm, σ_y= 31.6 μm, σ_z = 20.5 μm
ε_{nx}= 1.5 μm, ε_{ny}= 0.94 μm

All projected parameters !

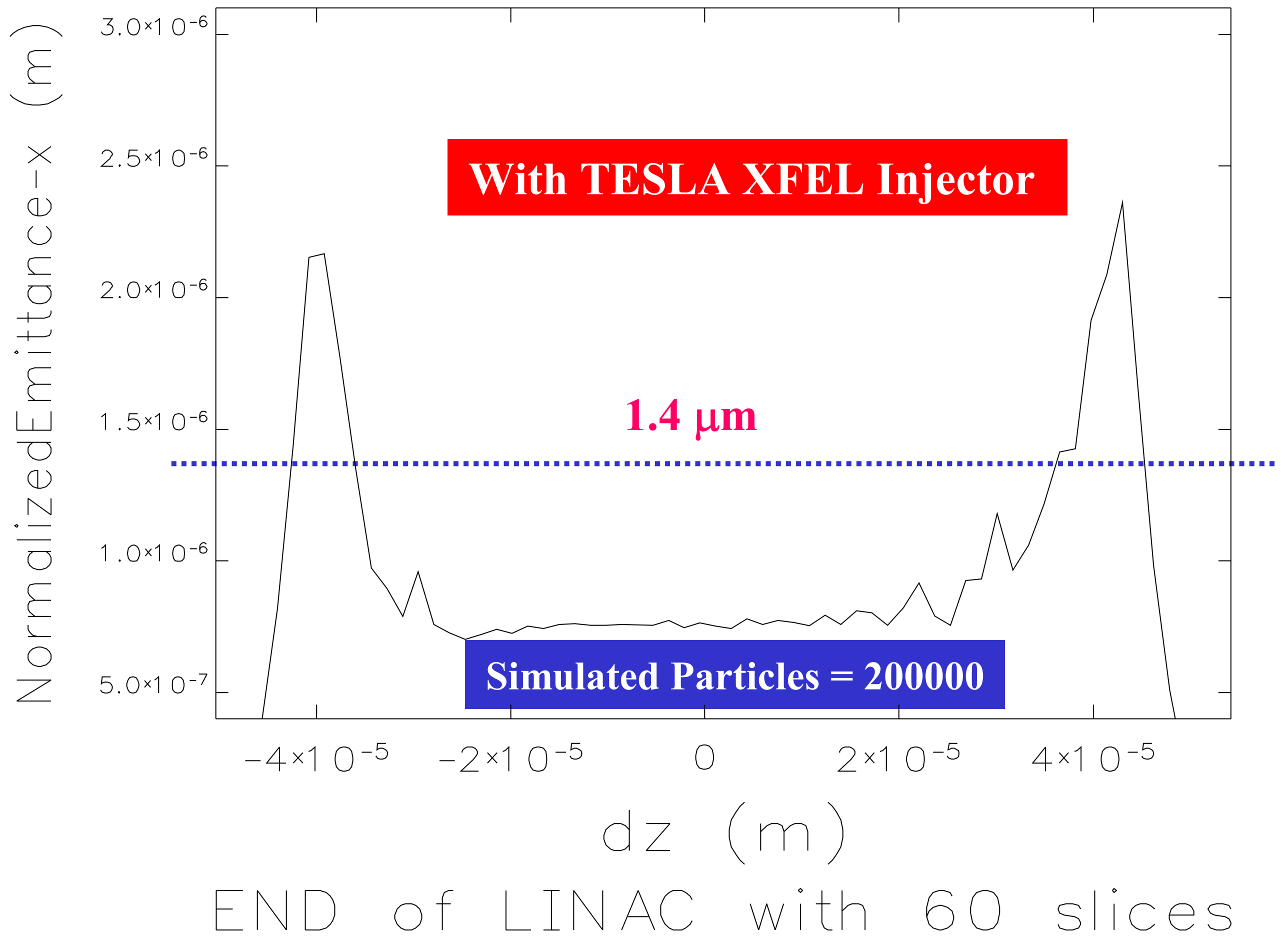
4th Lattice with TESLA XFEL Injector Layout

With TESLA XFEL Injector, ε_n= 0.9 μm



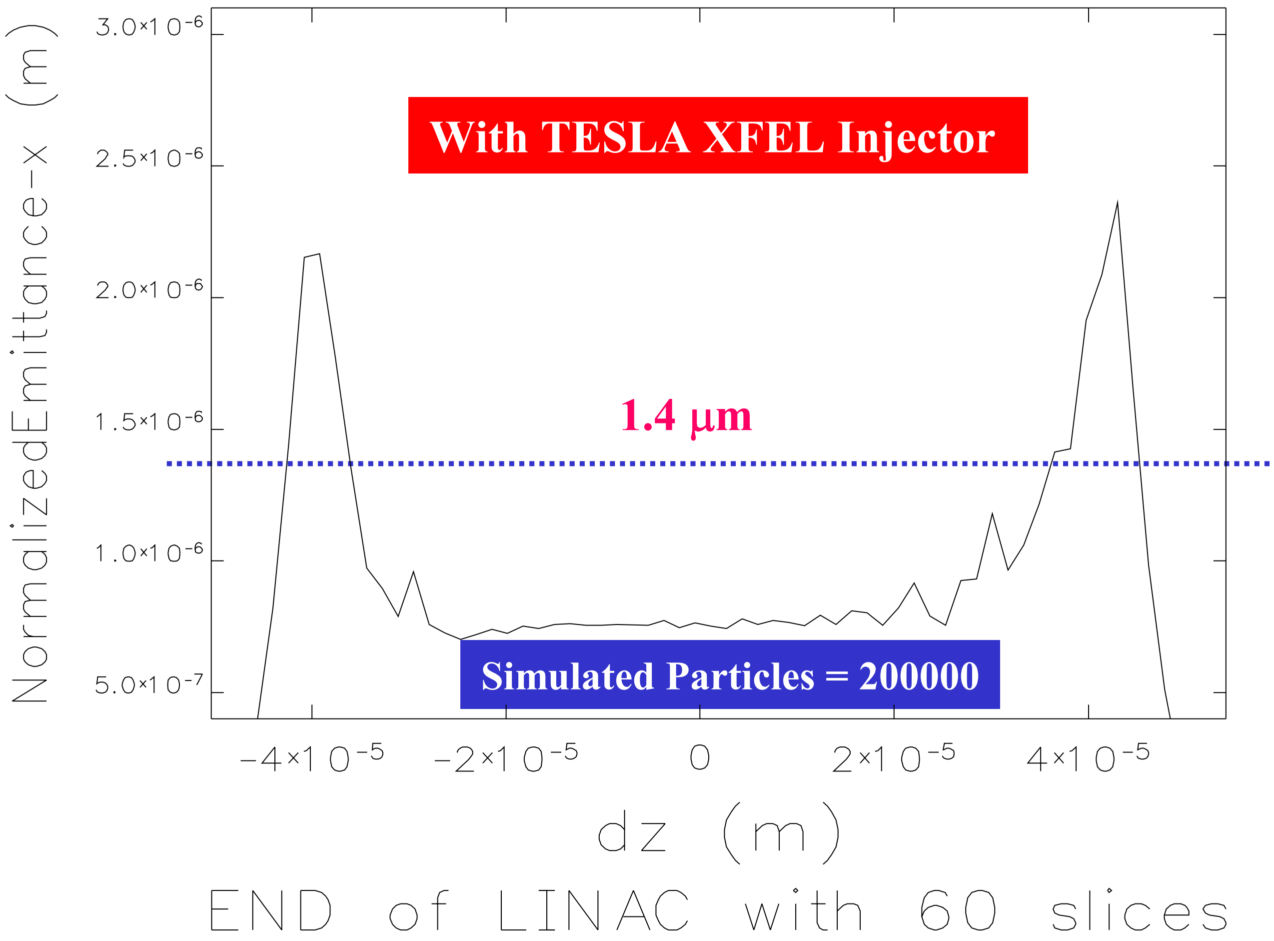
4th Lattice with TESLA XFEL Injector Layout

With TESLA XFEL Injector, $\varepsilon_n = 0.9\ \mu m$



4th Lattice with TESLA XFEL Injector Layout

With TESLA XFEL Injector, ε_n= 0.9 µm

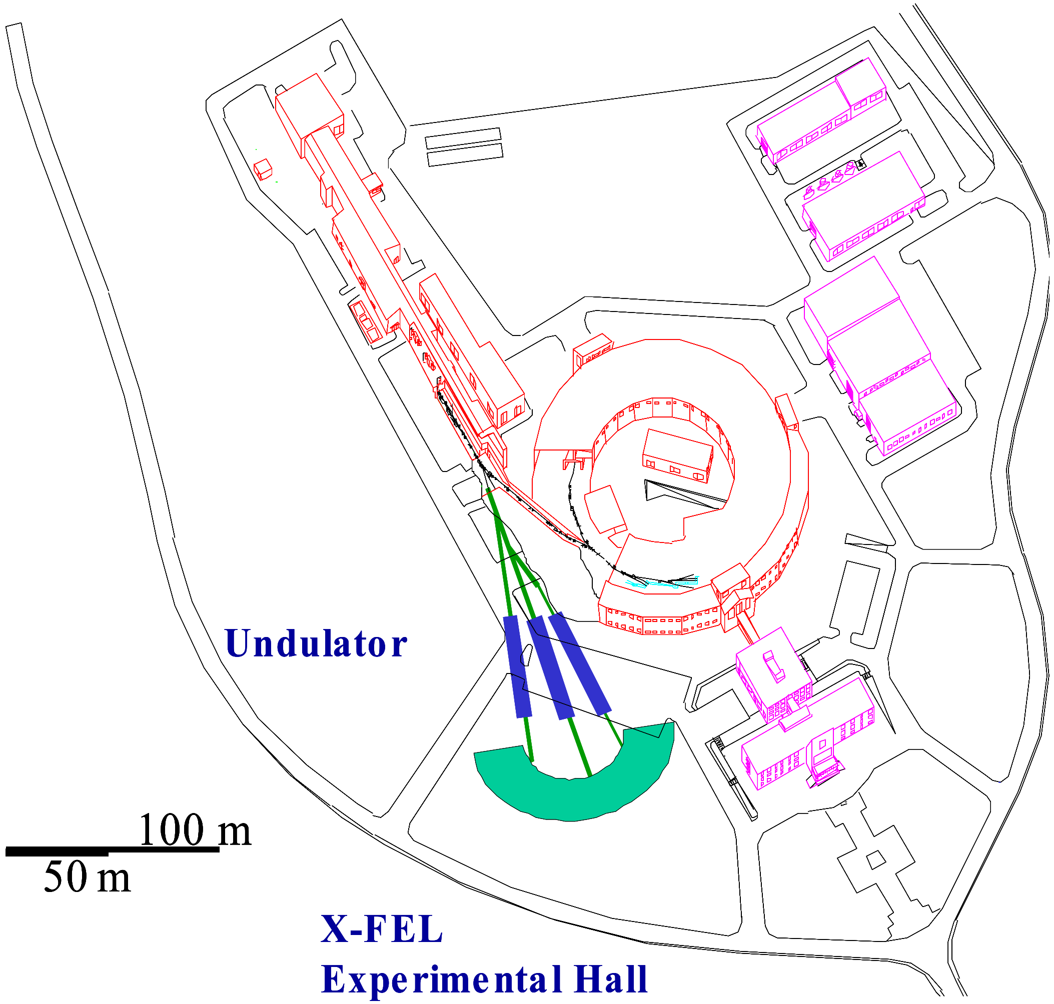


PAL XFEL Project

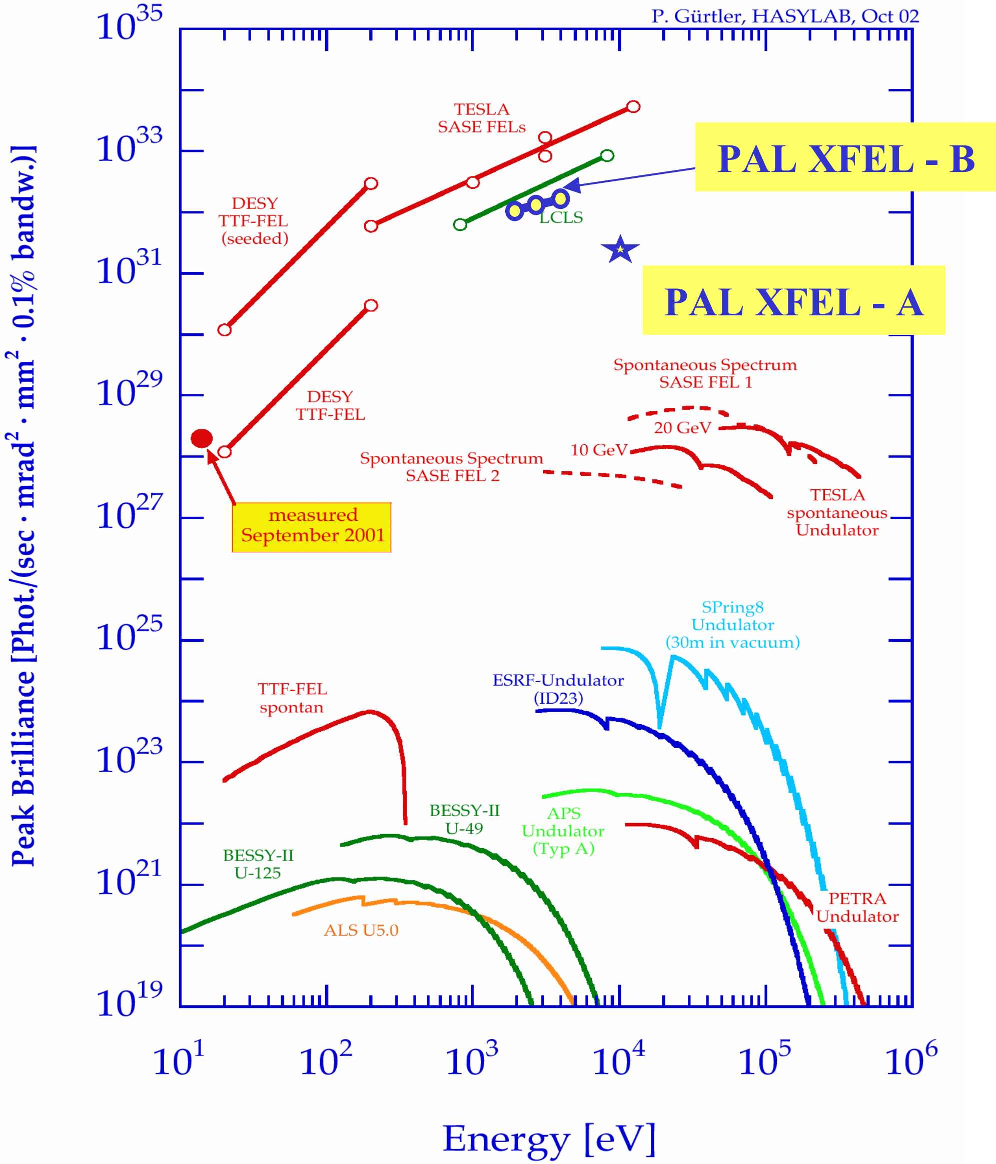
For 3.0 Å PAL XFEL Project:

Courtesy of J. S. Oh

Existing 2.5 GeV S-band PLS Linac
+ New S-band Photoinjector
+ New 0.5 GeV Linac
+ New Two Bunch Compressors
+ New ~ 60 m long Undulator



PAL XFEL Project

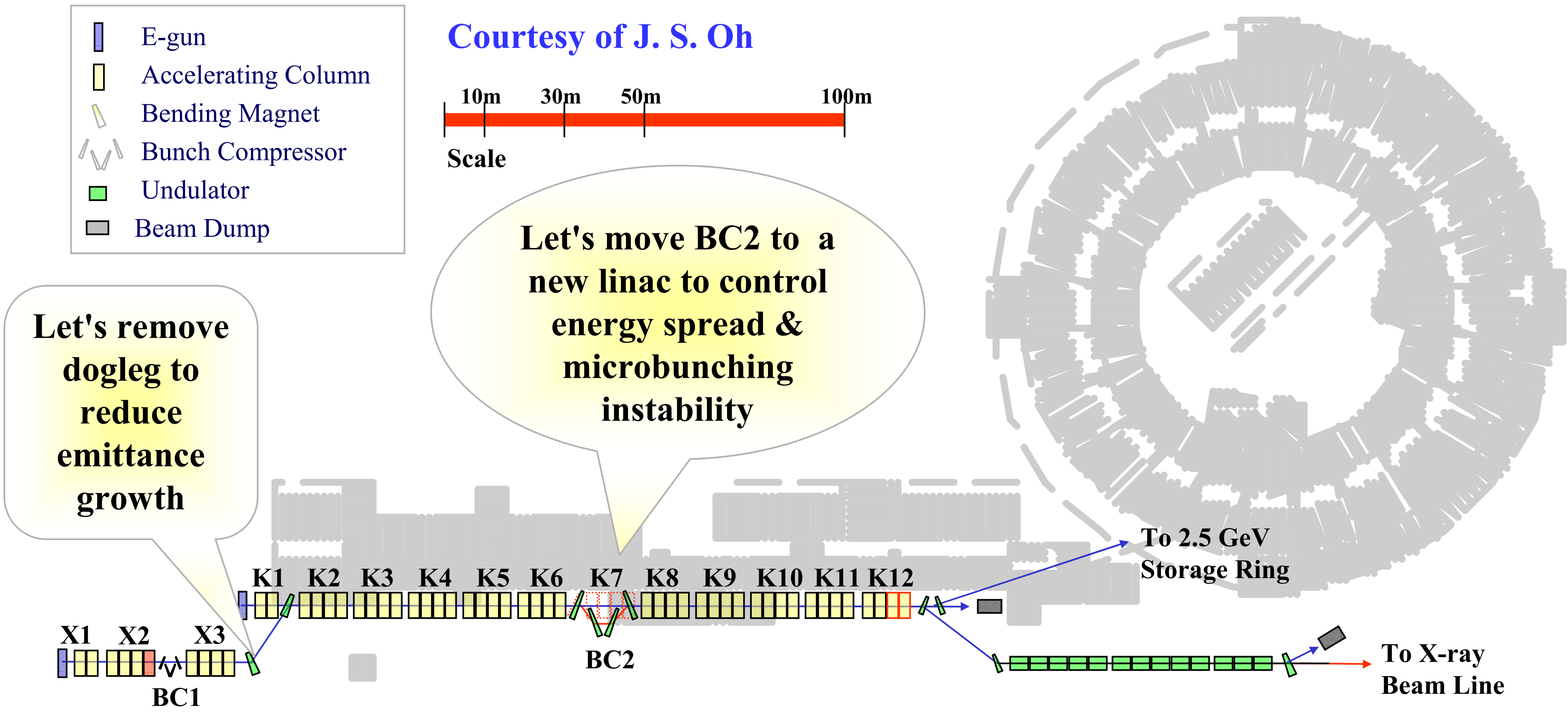


Courtesy of J. S. Oh

	A	B
λ_x (Å)	1.0	3.0
ε_n (μm)	1.0	1.5
τ (fs)	20	233
λ_u (mm)	6.5	12.5
gap (mm)	3.0	3.0
K	0.4	1.14
β(m)	30	15
L_u(m)	22.5 + 36	58.5
PB ($\times 10^{32}$)	0.4	1.4

A: HGHG layout with B undulator

Original Linac Layout for PAL XFEL Project



New 0.5 GeV Linac
X1=150 MeV
X2=100 MeV
X3=250 MeV

Existing 2.5 GeV PLS Linac
K1= 100 MeV Injector
K2~K6, K8~K12=250 MeV
BC2 @ K7 + 2 A/C @ K12

New Undulator (λ_x=0.3 nm)
E_o=3.0 GeV, ε_n=1.5um-rad
I_P=4.0 kA, σ_E=0.02%
λ_U=1.25 cm, g=3.0mm, L_U=58.5 m

New Layout for PAL XFEL - 05DEC03 Version

With S-band Photoinjector, ε_n= 0.9 μm

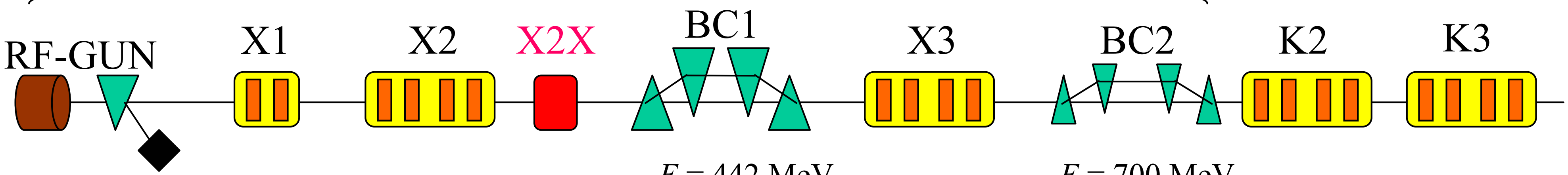
Q=1.0 nC

e-beam

σ_z = 829 μm → 114 μm → 26 μm →

New Linac & BCs

Existing PLS Linac



120 MV/m
-2.38 deg

12.02 MV/m
20.34 MV/m
5.5/-2.5 deg

30.0 MV/m
-27.5 deg

56.75 MV/m
180.0 deg

E = 442 MeV
σ_δ ~ 1.84%
R_{56} = 38.9 mm
θ = 3.5 deg

30.0 MV/m
-45.0 deg

E = 700 MeV
σ_δ ~ 1.31%
R_{56} = 6.7 mm
θ = 1.45 deg

20.0 MV/m
0.0 deg

ASTRA with Space Charge

0.0 m

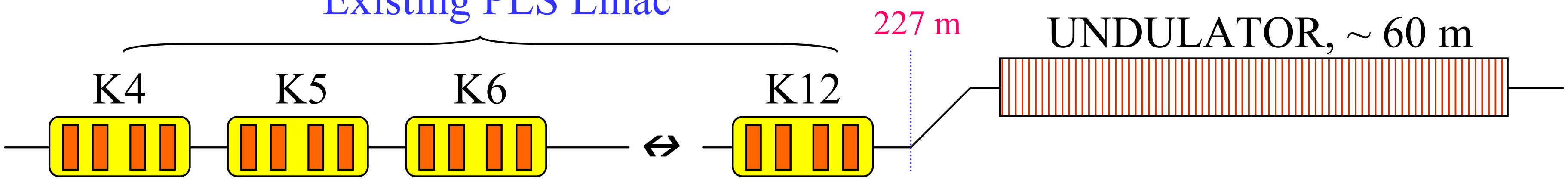
8.7 m

To the end of Linac : ELEGANT with CSR

with geometric wakefields
without space charge

σ_z = 26 μm →

Existing PLS Linac

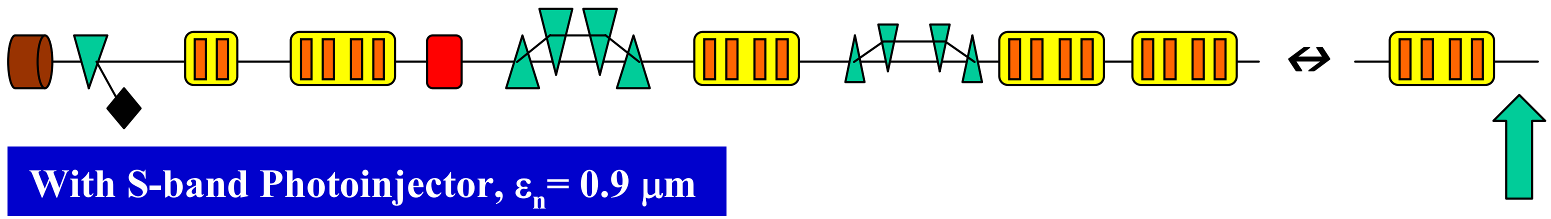


20.0 MV/m
0.0 deg

E = 3.389 GeV
σ_δ = 0.033%
σ_x = 68 μm, σ_y = 62 μm, σ_z = 26 μm
ε_{nx} = 1.116 μm, ε_{ny} = 1.004 μm

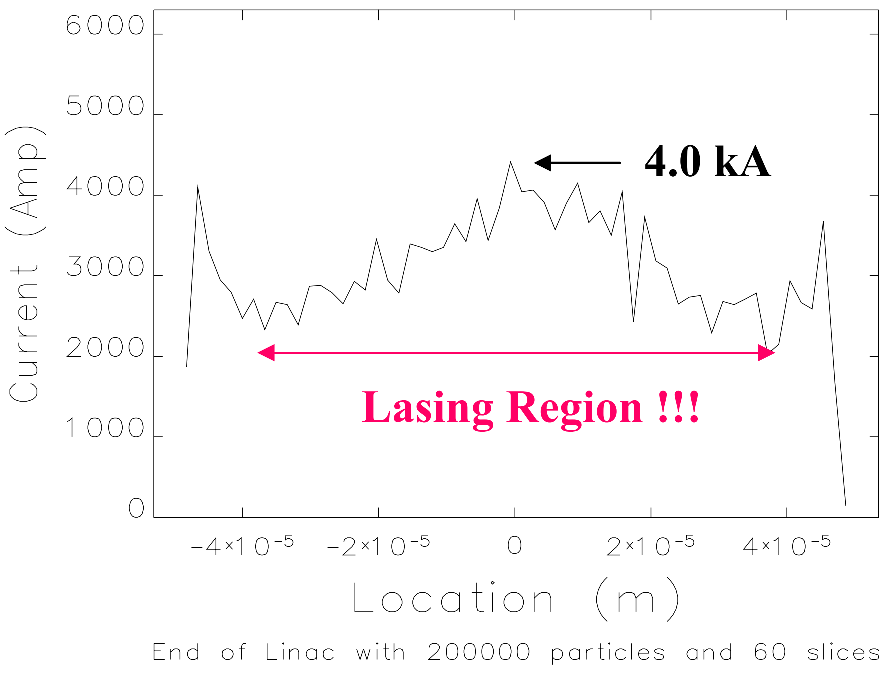
All projected parameters !

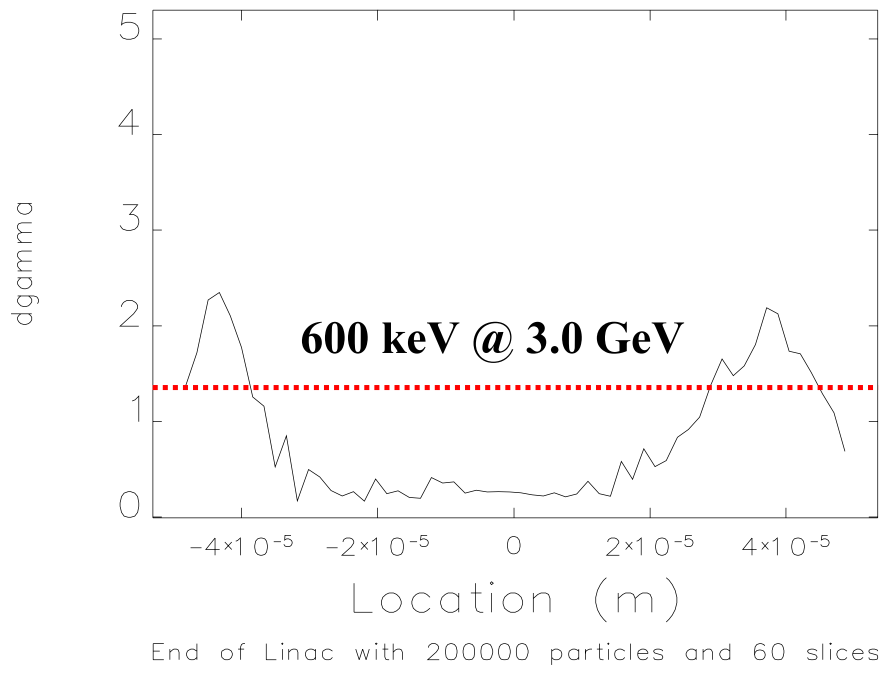
Current & Slice Energy Spread at End of Linac



With S-band Photoinjector, ε_n= 0.9 μm

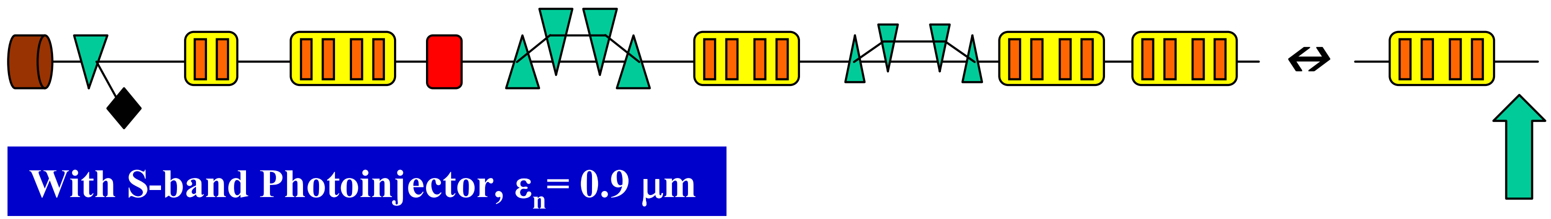
Simulated Particles = 200000





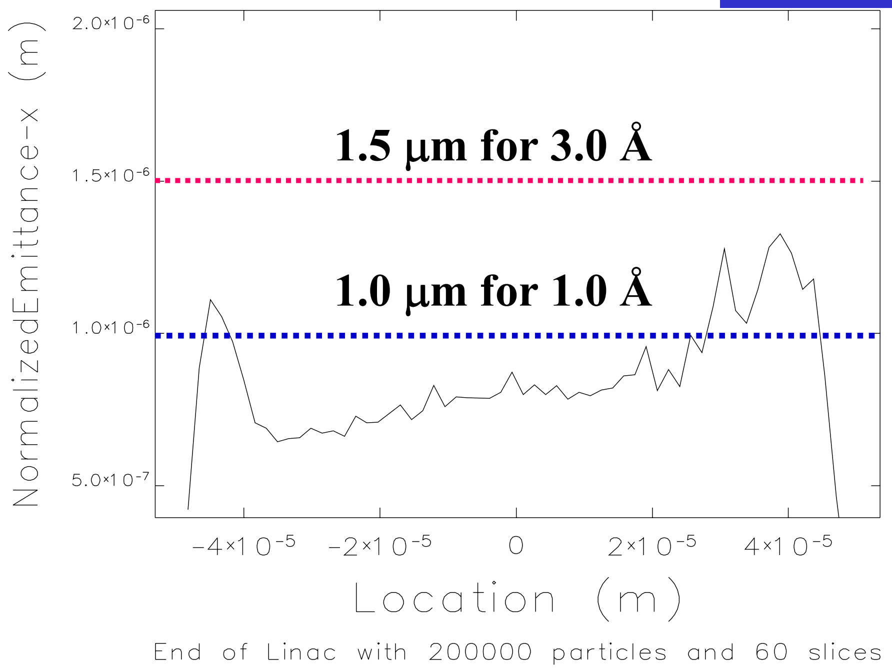
E = 3.389 GeV
σ_δ = 0.033%
σ_x= 68.1 μm, σ_y= 61.9 μm, σ_z = 26 μm
ε_{nx}= 1.116 μm, ε_{ny}= 1.004 μm

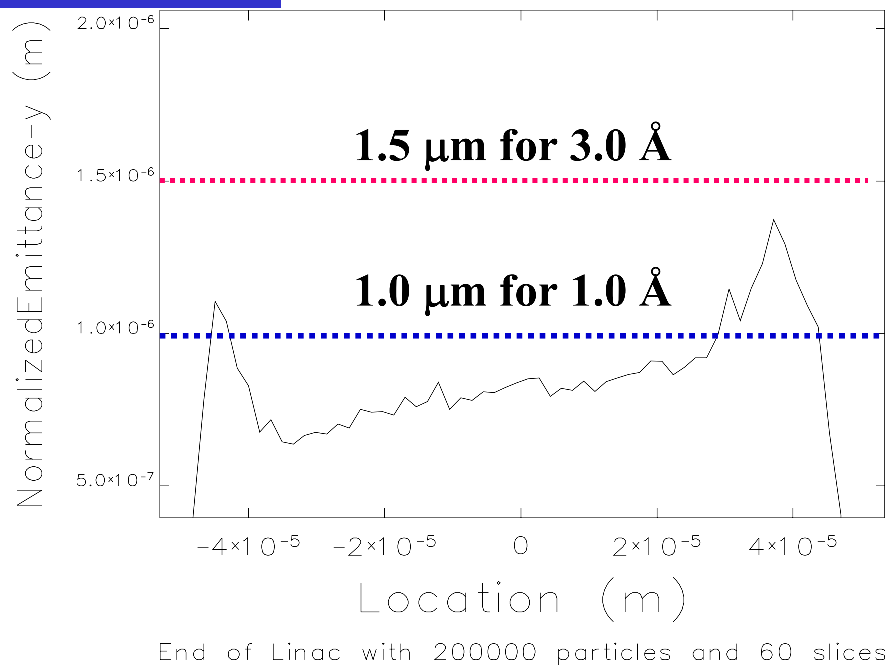
Slice Emittances at the End of PAL XFEL Linac



With S-band Photoinjector, ε_n= 0.9 µm

Simulated Particles = 200000





E = 3.389 GeV
σ_δ = 0.033%
σ_x= 68.1 µm, σ_y= 61.9 µm, σ_z = 26 µm
ε_{nx}= 1.116 µm, ε_{ny}= 1.004 µm

Summary

We have optimized a new lattice for TESLA XFEL and PAL XFEL projects to reduce the slice parameter growths due to the microbunching instability.

By removing two S-type chicanes and by using only one BC stage with double chicanes, the total number of dipoles in BCs is reduced from 16 to 8, which certainly helped in reducing the microbunching instability at TESLA XFEL.

Although we did not use any laser beam heater in the low energy region or any superconducting wiggler before BC2, we have achieved promising beam parameters for TESLA XFEL and PAL XFEL projects only by optimizing BC layout.

We do not worry about too much on the emittance growth in BCs any more if we optimize BC well with a large energy spread and a long space for BCs.

Acknowledgments

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