TESLA

S2E Simulations for TESLA XFEL Project with a New Bunch Compression Layout

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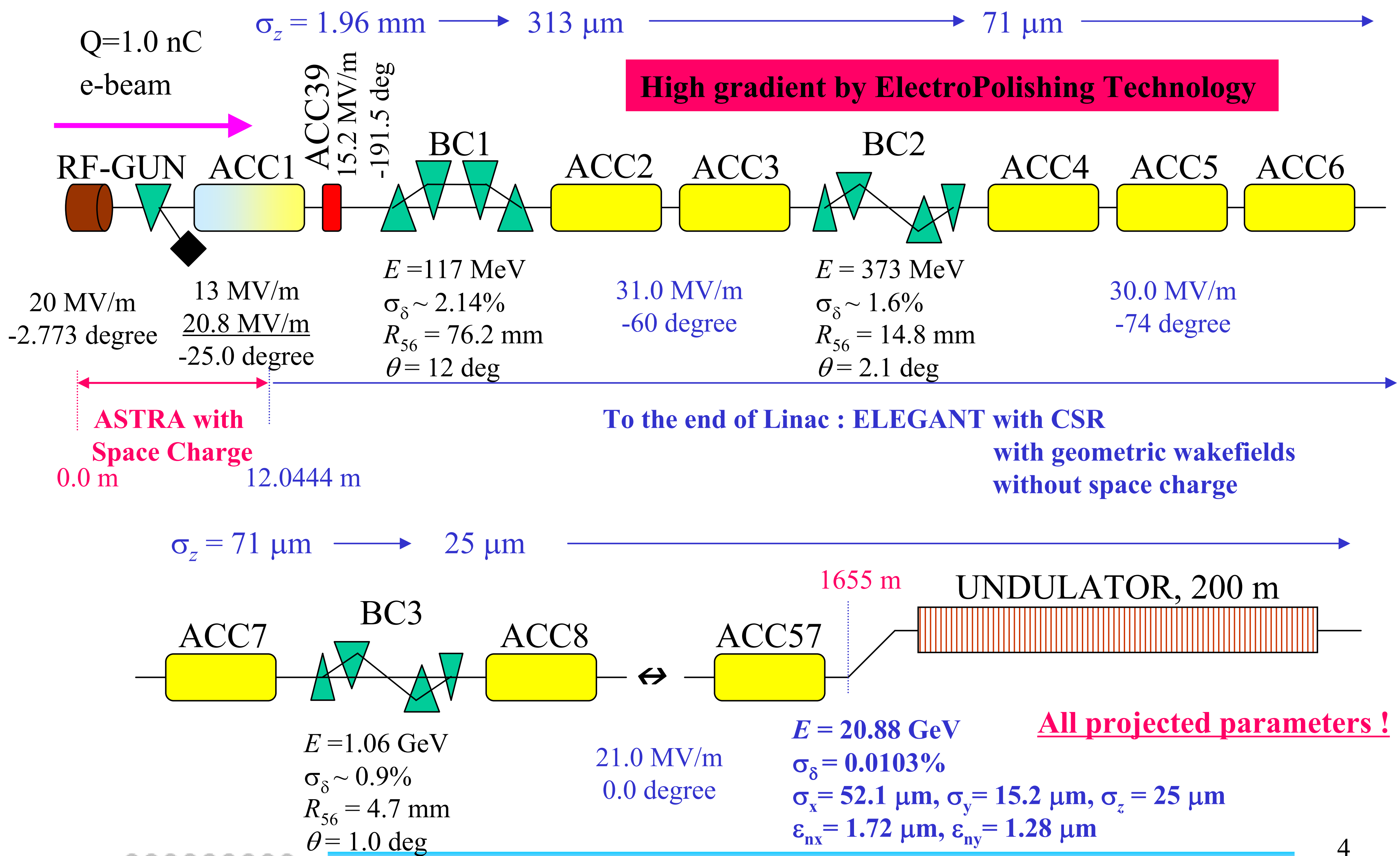
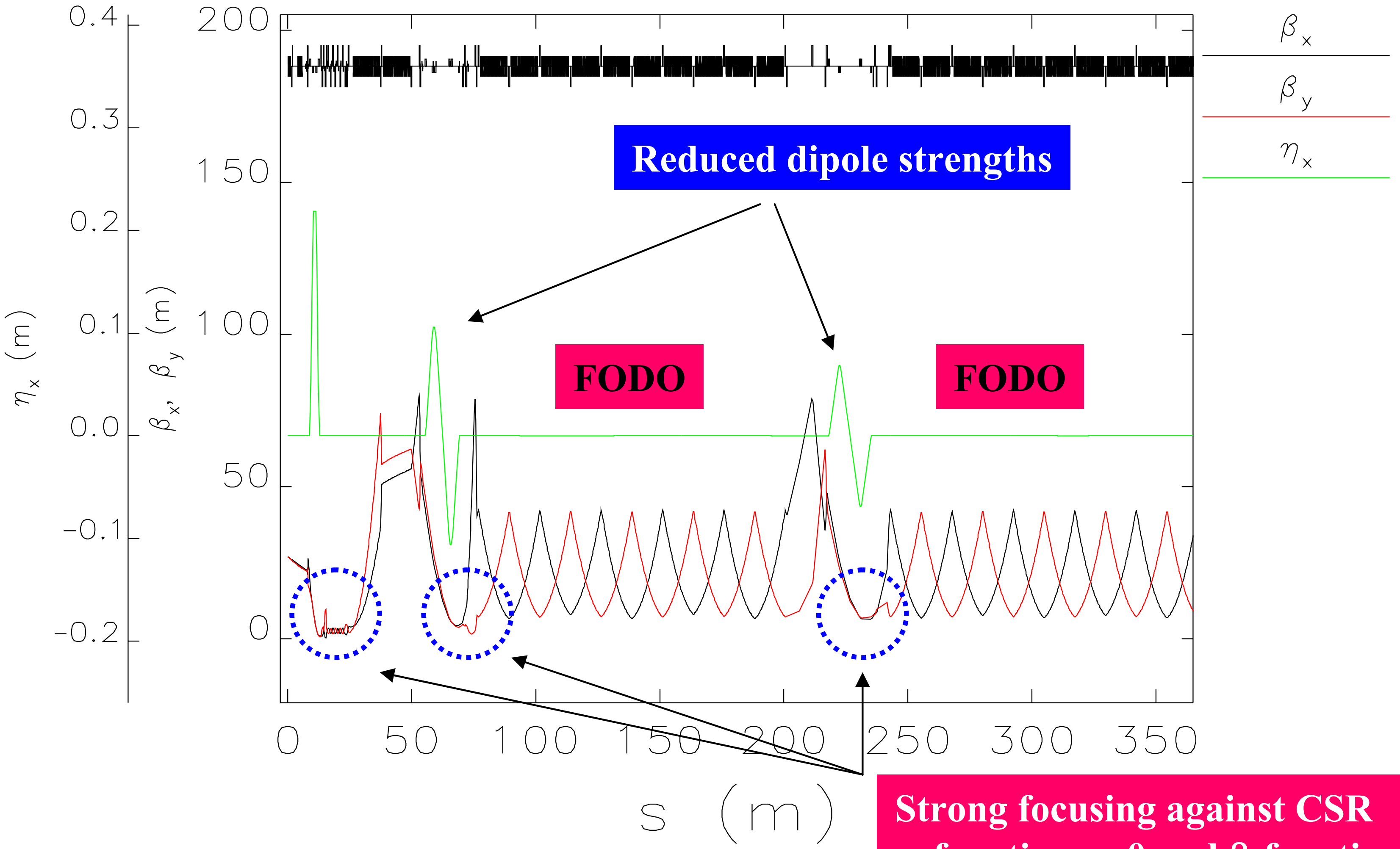
Requirements & Design Concepts of Old Lattice

Old Lattice for TESLA XFEL - 2nd Version



Old Lattice - Twiss Parameters

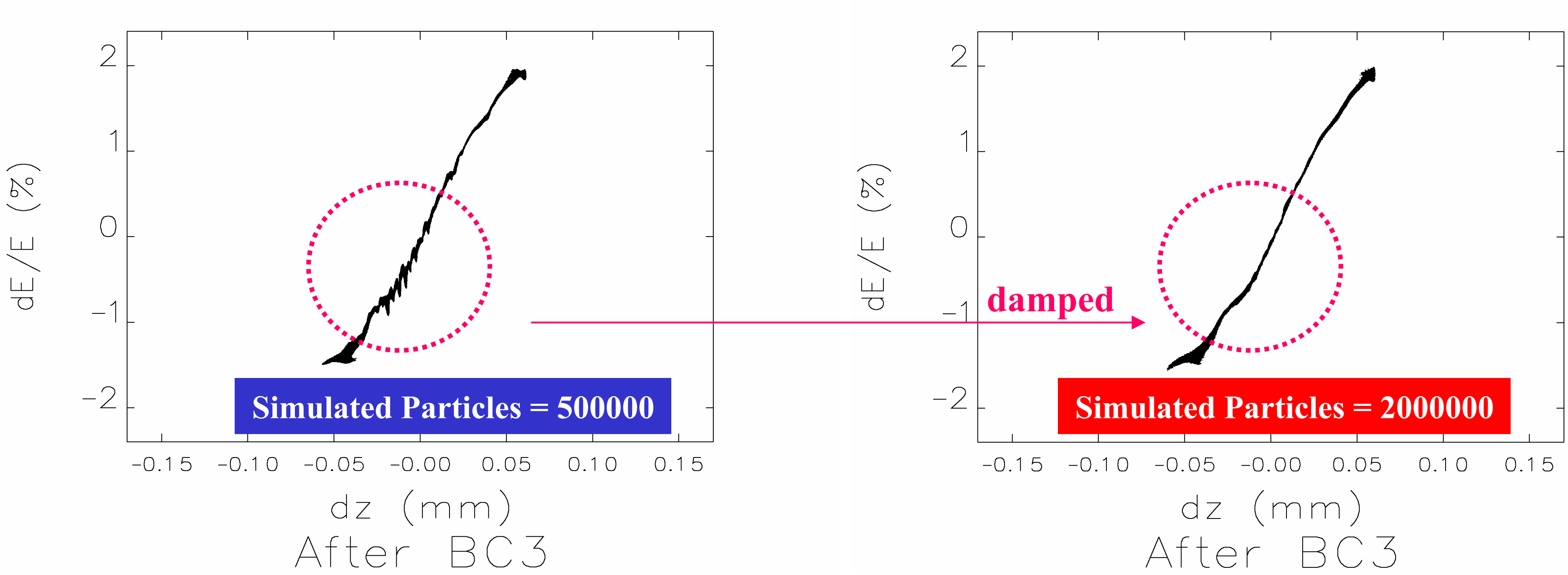
After adjusting gradient and phase of ACC39, and re-optimizing entire lattice.



Strong focusing against CSR
α-functions ~ 0 and β-functions ~ 1

Old Lattice - Before and After BC3

This artificial modulation is not a real one with only 500000 particles. This is damped when we increase the number of simulated particles in an initial ASTRA distribution up to a few million. However, from this fact, we can check the strong amplification action by S-type chicanes.

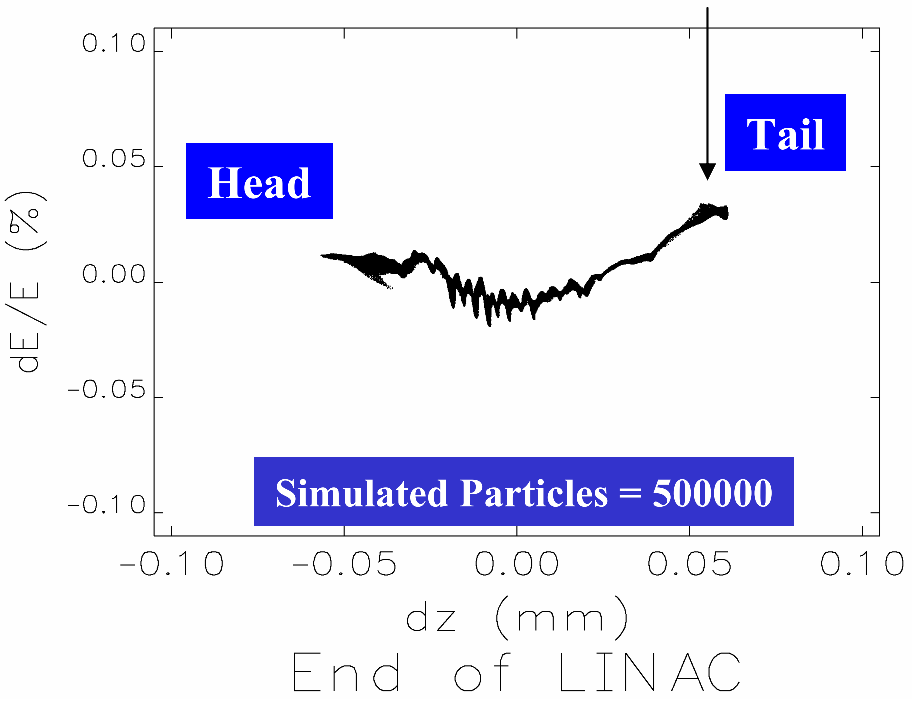


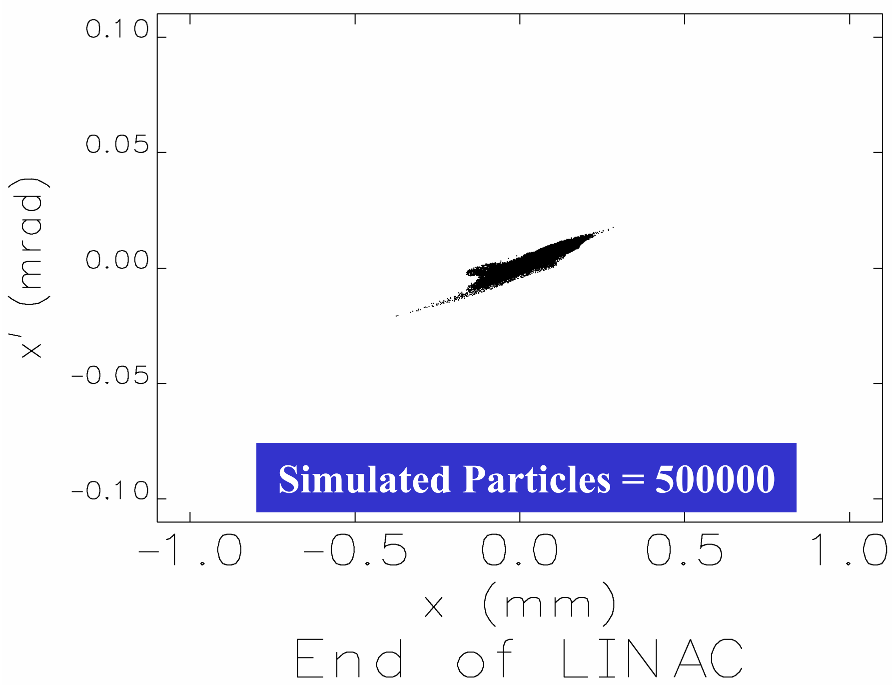
E = 1060 MeV
σ_δ = 0.891%
σ_x = 83.6 μm, σ_y = 77.3 μm, σ_z = 25.5 μm
ε_{nx} = 1.979 μm, ε_{ny} = 1.286 μm

E = 1060 MeV
σ_δ = 0.883%
σ_x = 84.2 μm, σ_y = 76.8 μm, σ_z = 25.4 μm
ε_{nx} = 1.987 μm, ε_{ny} = 1.280 μm

Old Lattice - At the end of Linac

After tracking a long TESLA XFEL linac, the short-range geometric longitudinal wakefield effectively damps the energy spread at the tail region.





Projected parameters at the end of Linac

E = 20.88 GeV

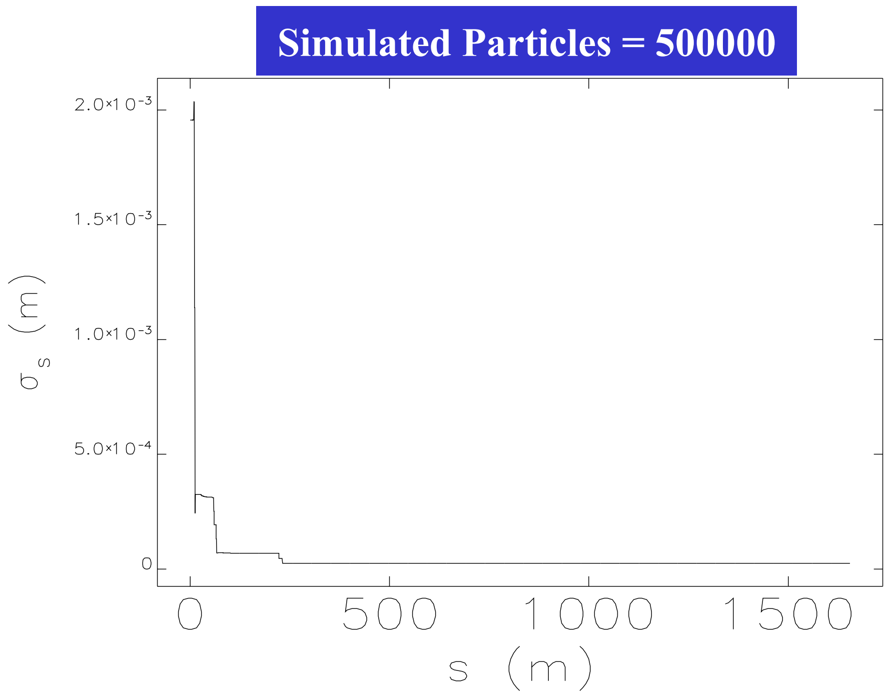
σ_δ = 0.0103%

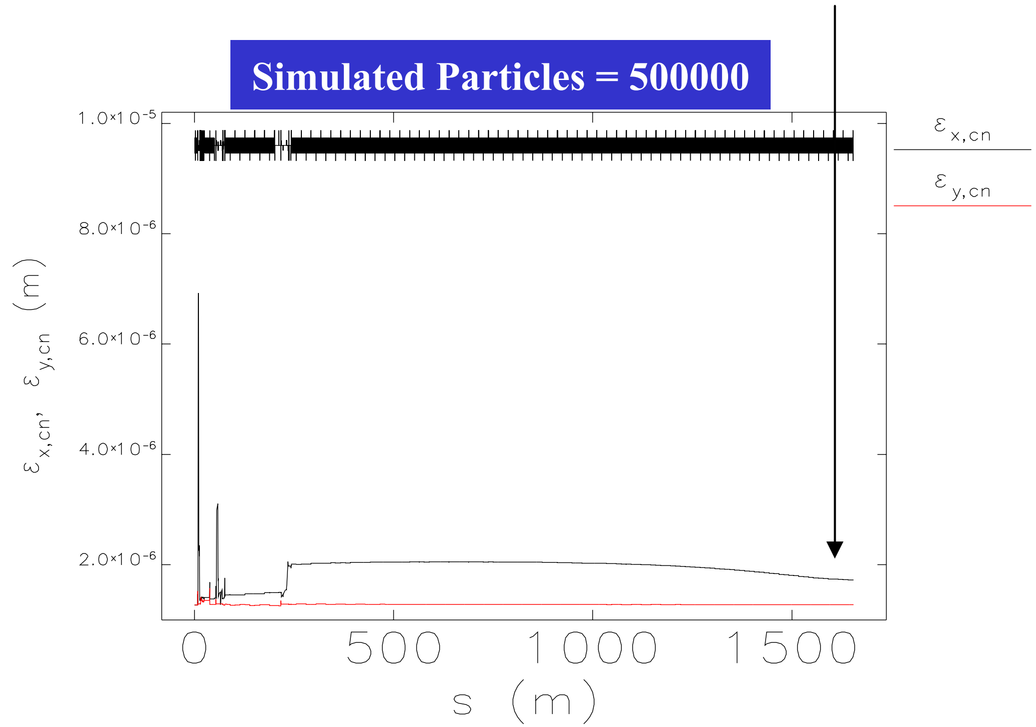
σ_x = 52.1 μm, σ_y = 15.2 μm, σ_z = 25 μm

ε_{nx} = 1.72 μm, ε_{ny} = 1.28 μm

Old Lattice - Parameters along Beamline

Damping in long linac with FODO cells





<u>**Projected parameters at the end of Linac**</u>

E = 20.88 GeV

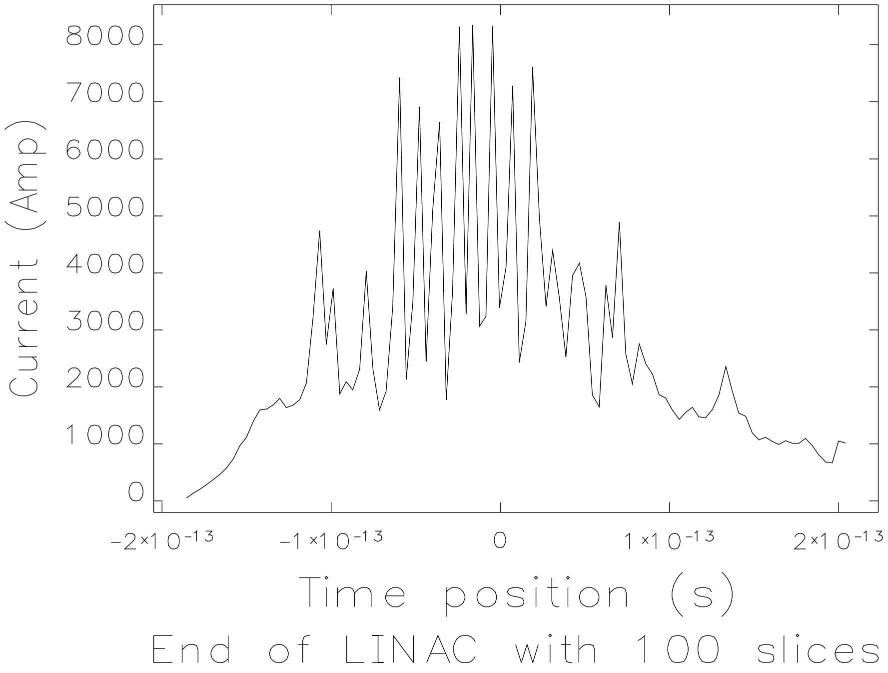
σ_δ = 0.0103%

σ_x = 52.1 μm, σ_y = 15.2 μm, σ_z = 25 μm

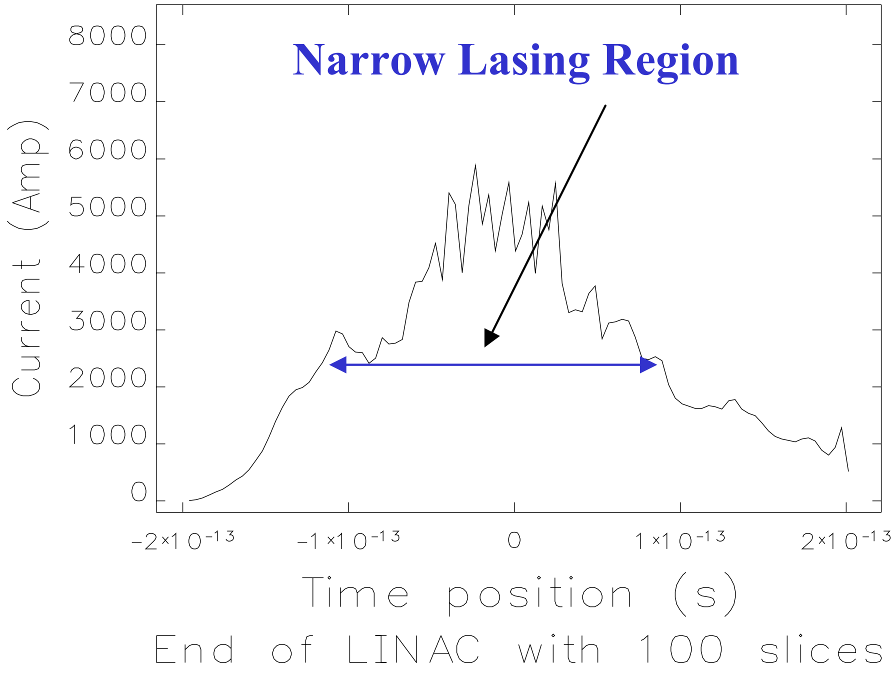
ε_{nx} = 1.72 μm, ε_{ny} = 1.28 μm

Old Lattice - Slice Parameters

Simulated Particles = 500000

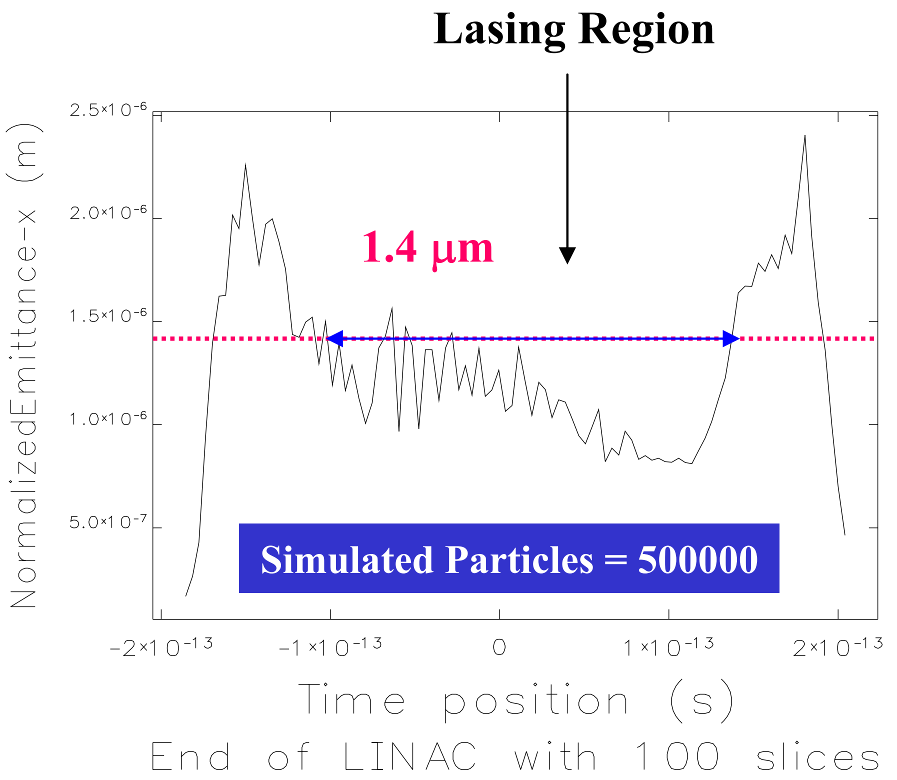


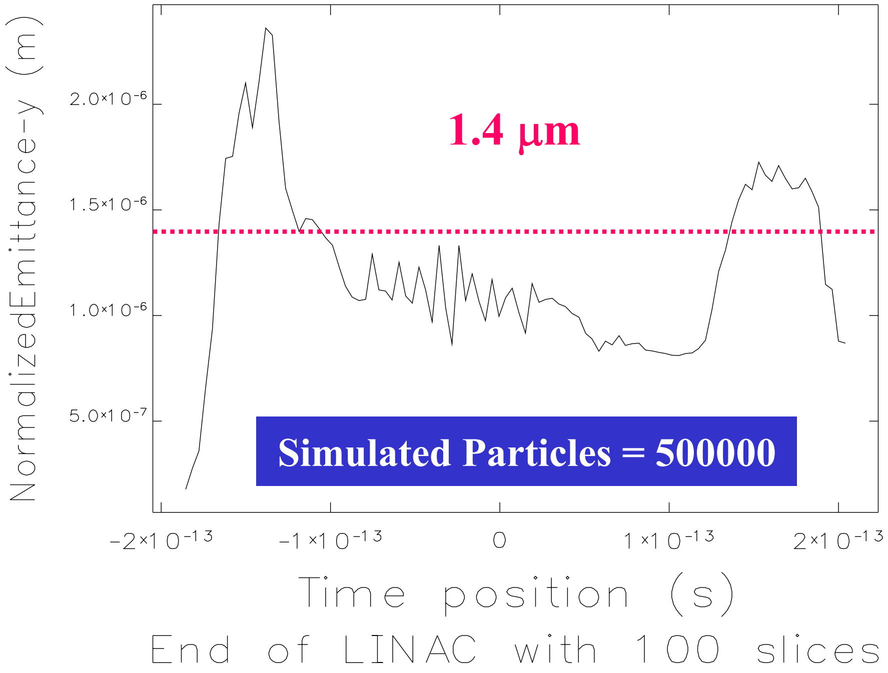
Simulated Particles = 2000000



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

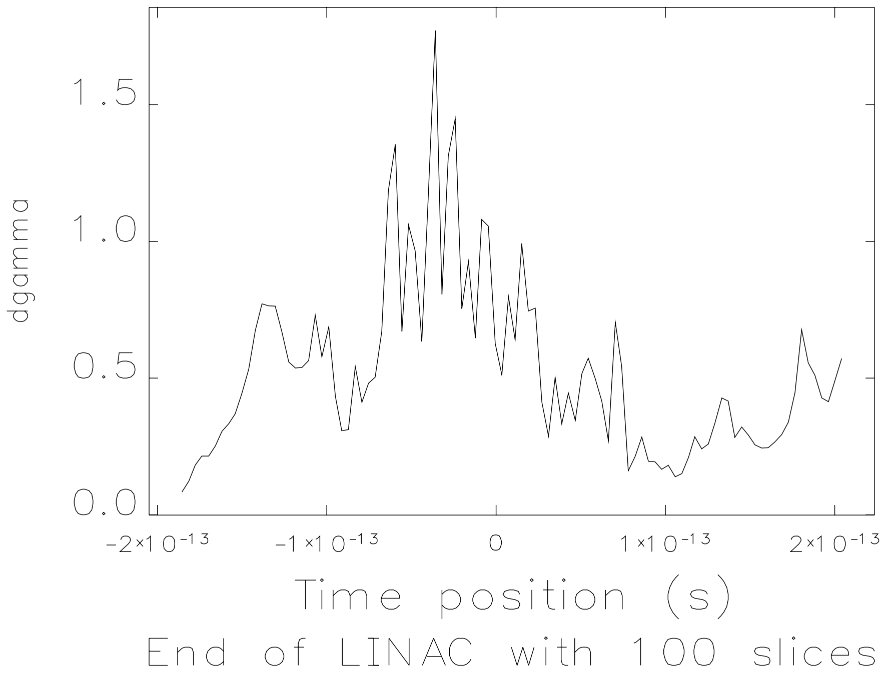




When the number of particles is 500000, there are many high spikes in the slice emittance due to the strong microbunching instability at S-type chicanes.

Old Lattice - Slice Parameters

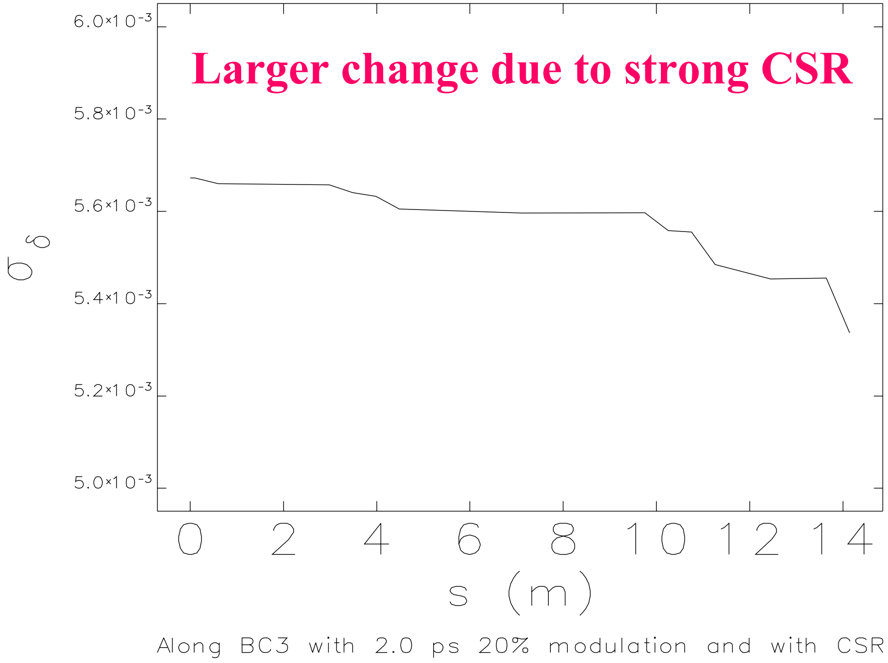
Simulated Particles = 500000

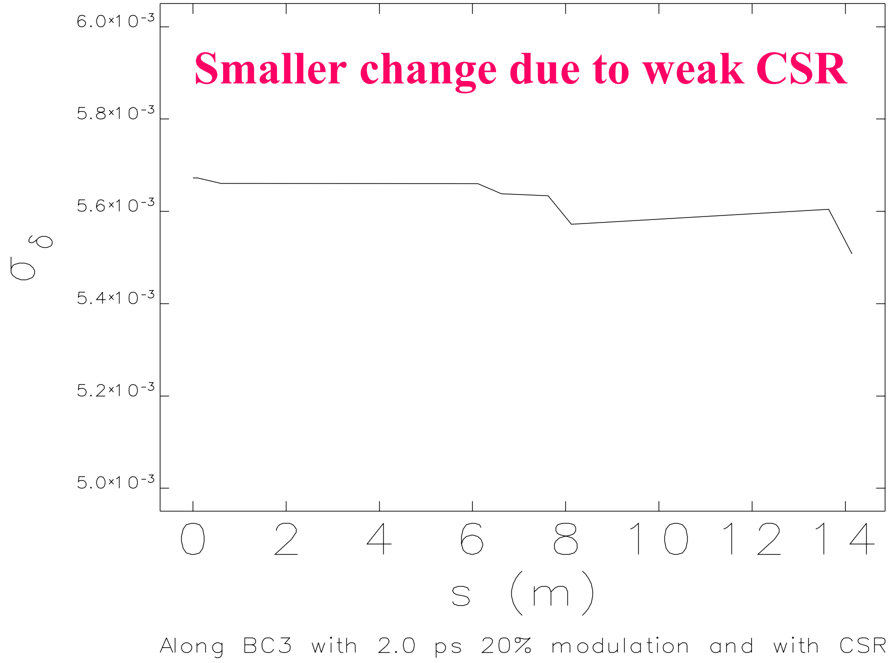


Maximum uncorrelated energy spread : 0.767 MeV @ 20.0 GeV ~ 0.0038% < 0.0125%
Please note that although the uncorrelated energy spread is not a hot issue at 20 GeV linac, the spread is highest at the center region, i.e., the main lasing region !

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)



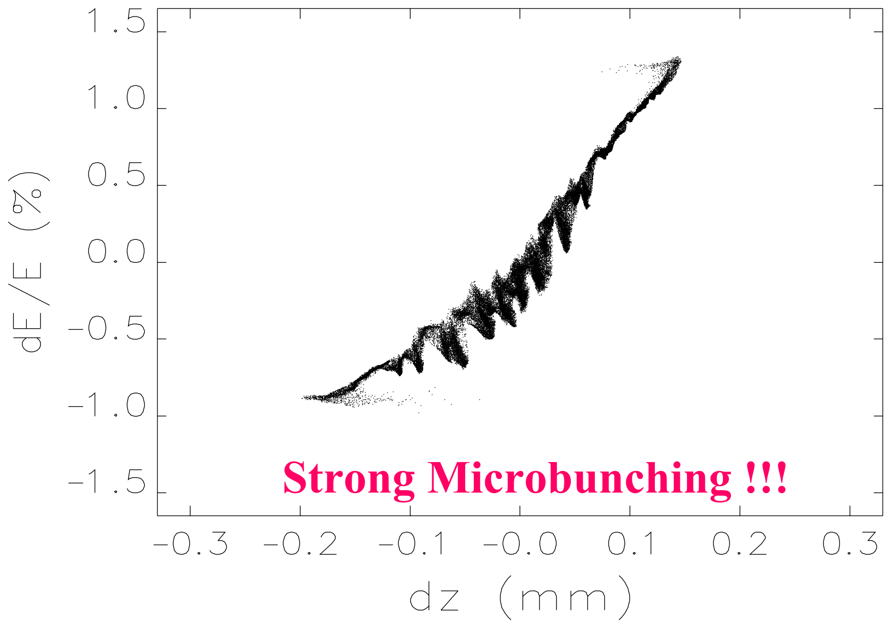


σ_{delta}= 0.567 ~ 0.53% for S-type chicane

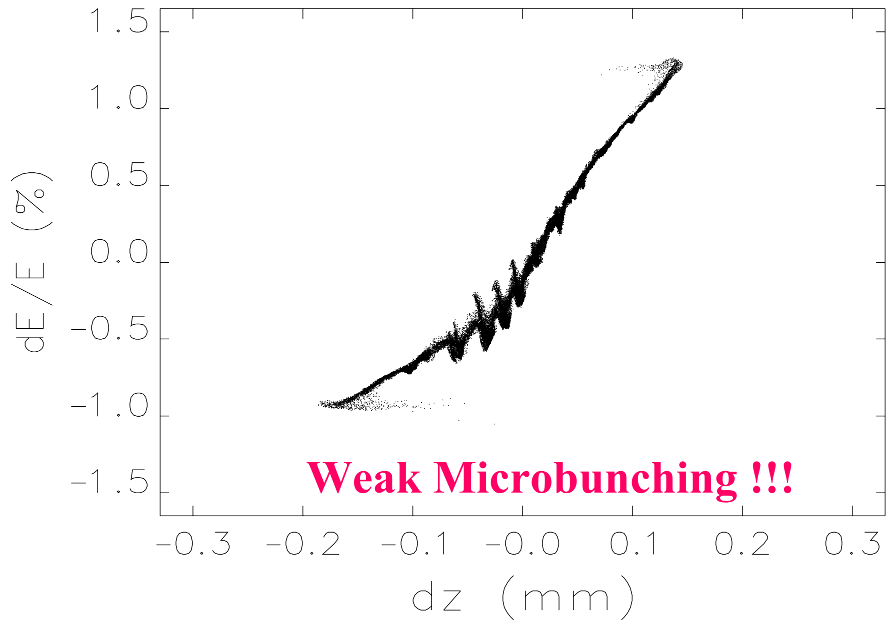
σ_{delta}= 0.567 ~ 0.55% for 4 bend chicane

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)



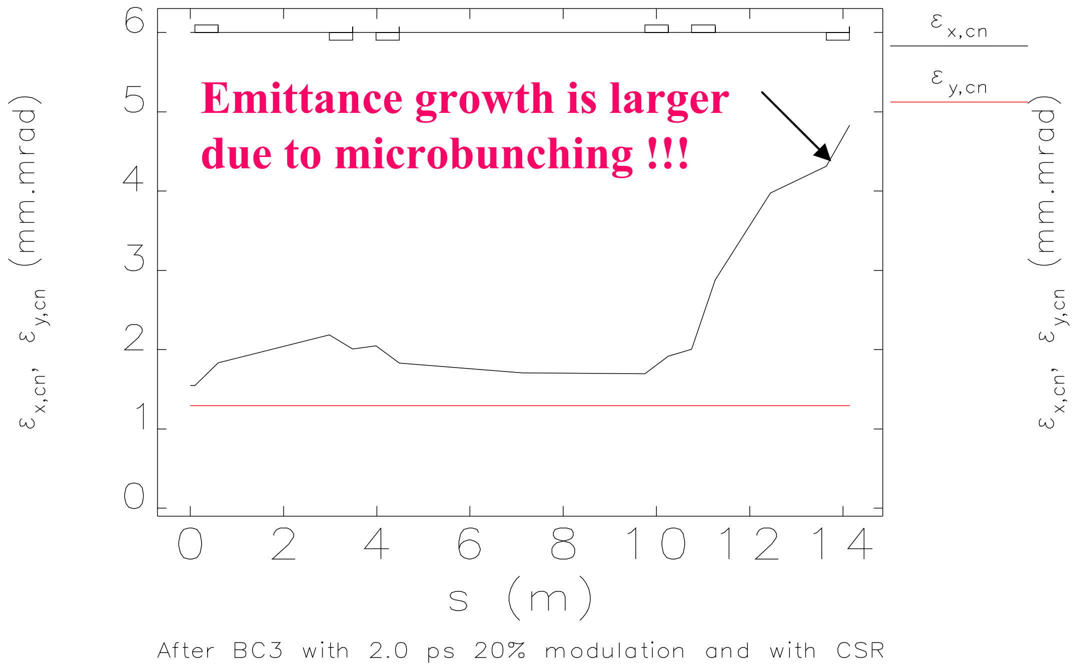
6-bends S-type chicane



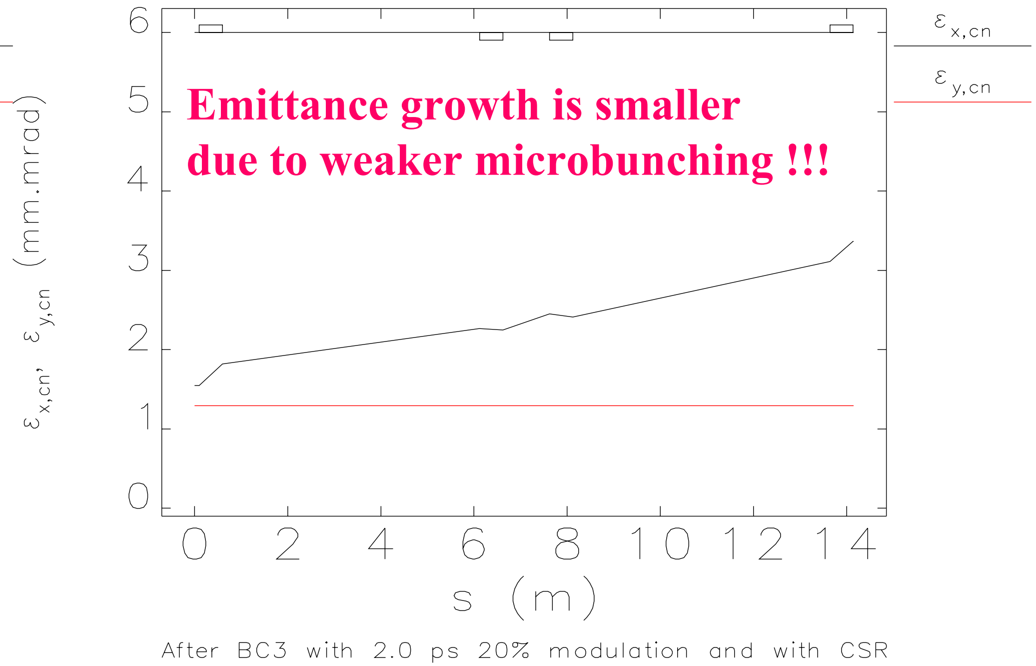
4-bends normal chicane

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

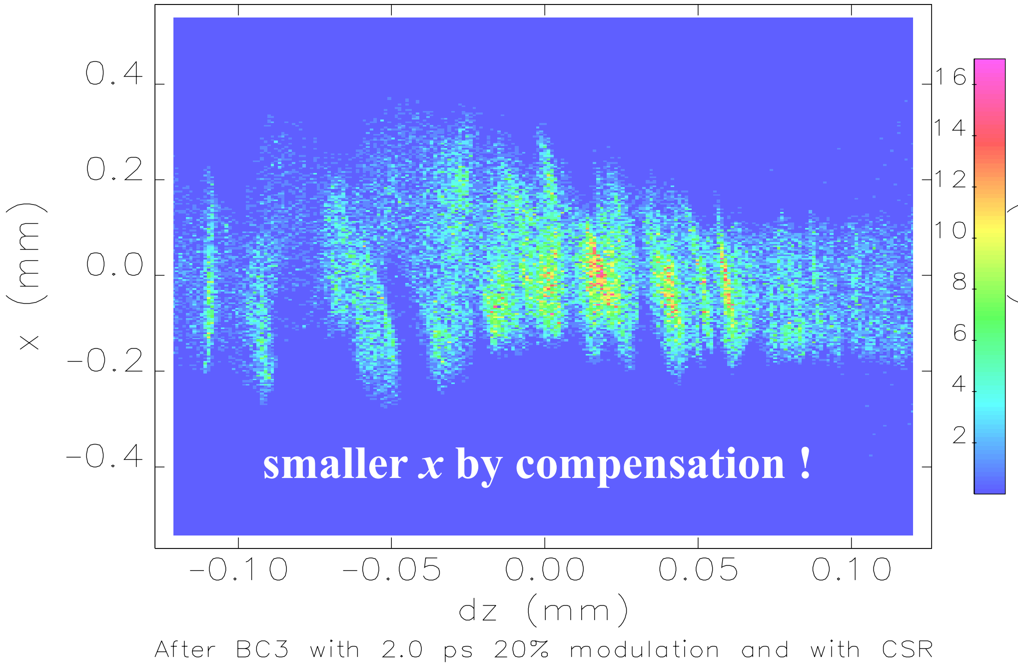
From the TTF-2 S2E Simulations on the microbunching instability, we found that S-type chicane is more dangerous against the microbunching instability due to two additional dipoles. When a 2.0 ps 20% current density modulation is applied at the cathode, we got following results at TTF-2 BC3. (Refer to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

6-bends S-type chicane

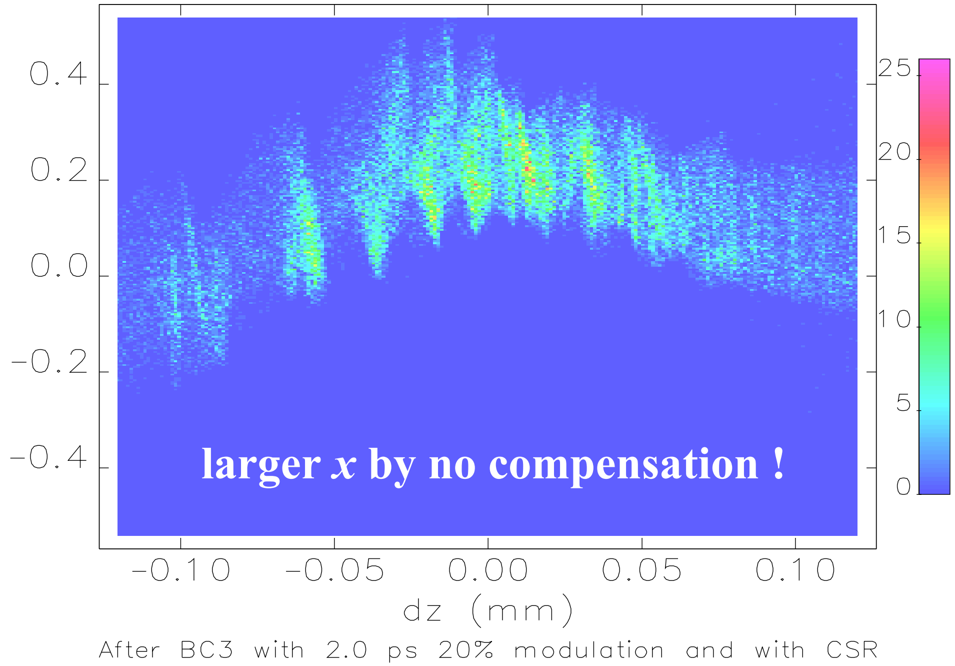
4-bends normal chicane

Chicane Comparison - 2D Histogram

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

Design Concepts of New Lattice

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
- 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

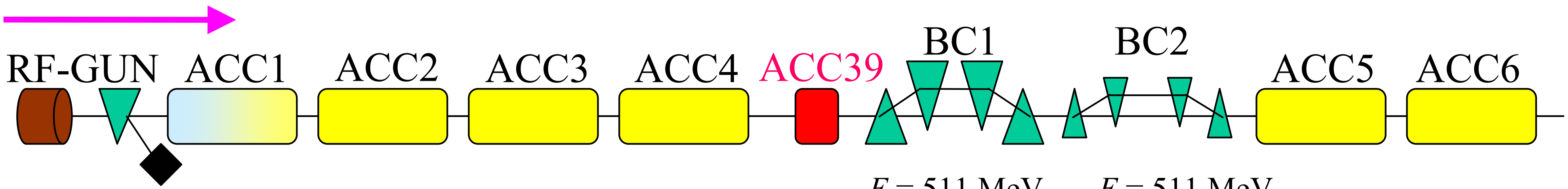
- Replace two 6-bends S-type chicanes into one 4-bends normal chicane
- Reducing three BC stages to one BC stage with a double chicane
- Smearing the microbunching instability at BC2 by keeping large uncorrelated energy spread at BC2 without any acceleration between BC1 and BC2

New Lattice for TESLA XFEL - 3rd Version

σ_z = 2.0 mm ⟶ 112 μm ⟶ 22 μm ⟶

Q=1.0 nC

e-beam



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

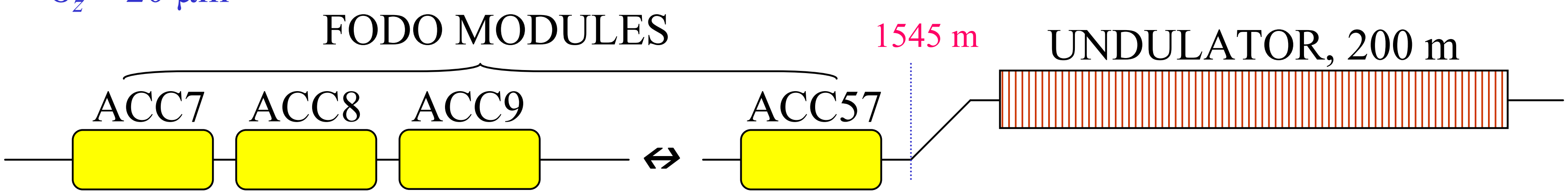
0.0 m — 12.0444 m

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

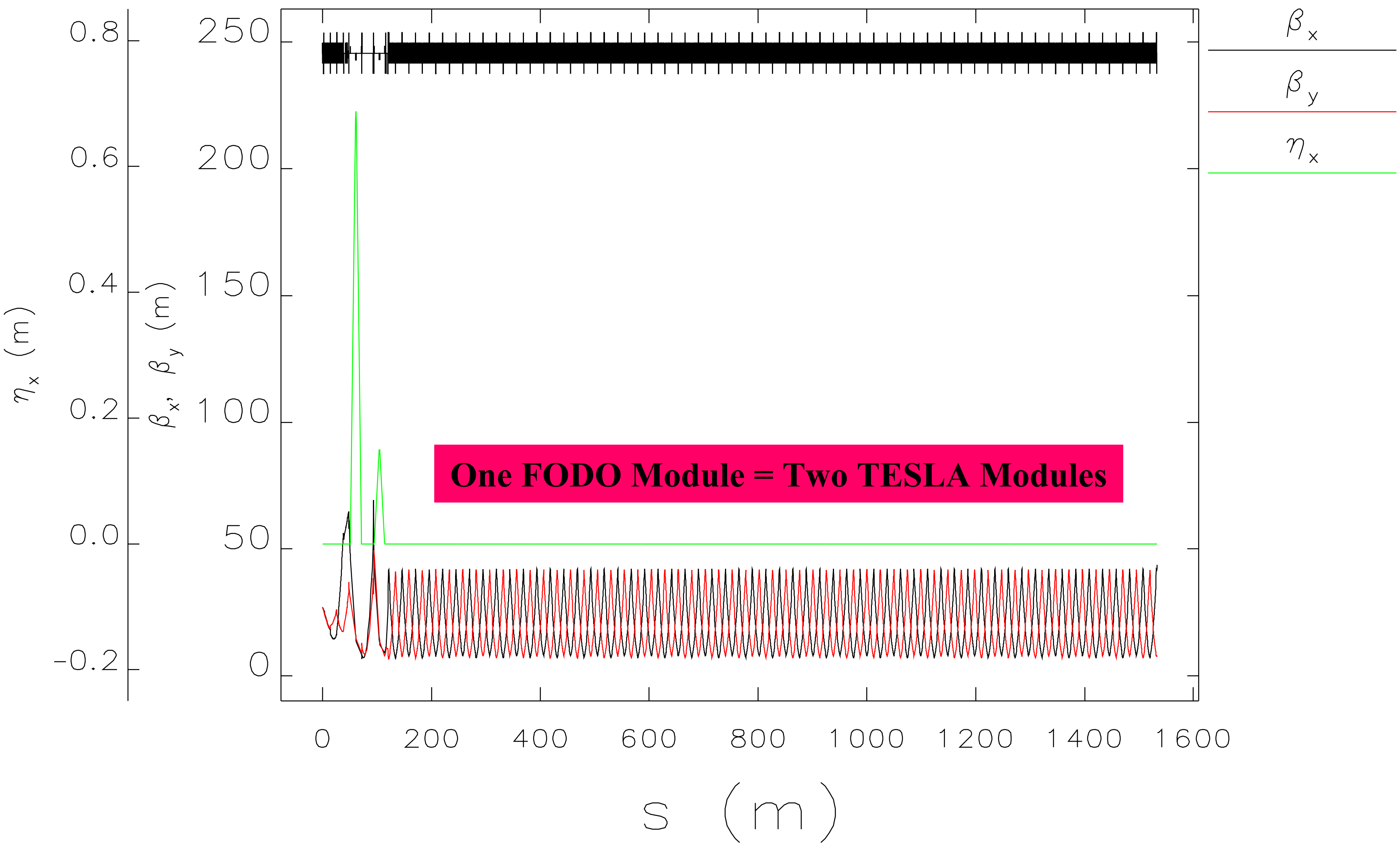
σ_δ = 0.0059%

σ_x = 41.7 μm, σ_y = 15.8 μm, σ_z = 20 μm

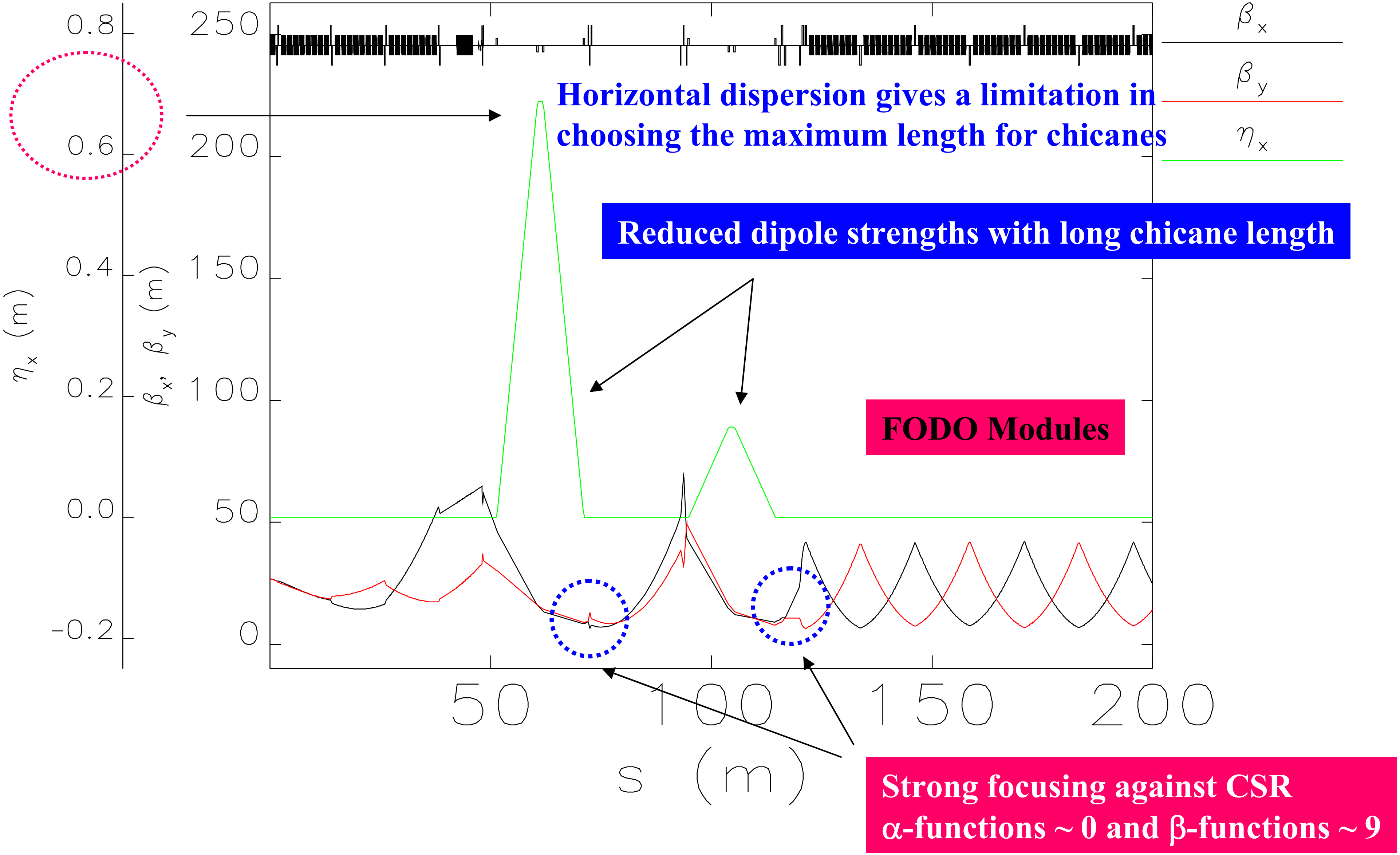
ε_{nx} = 1.525 μm, ε_{ny} = 1.295 μm

All projected parameters !

Twiss Parameters of New Lattice

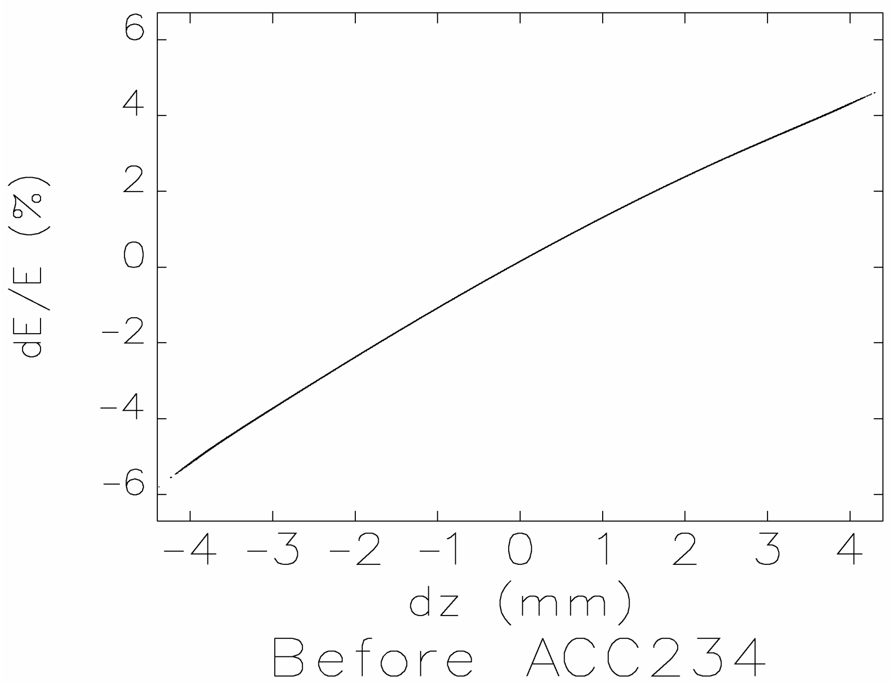


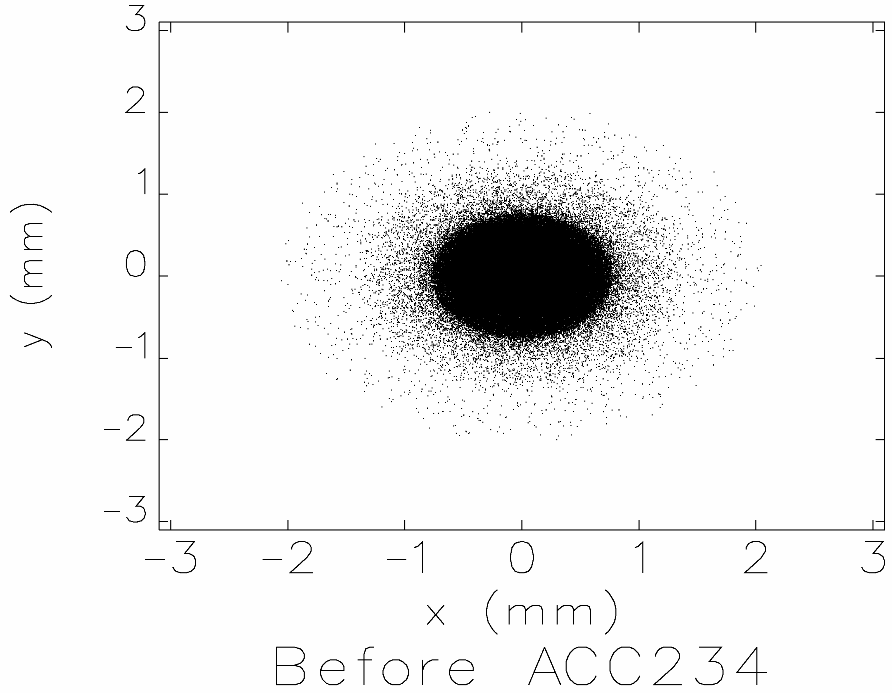
Twiss Parameters of New Lattice around BCs



New Lattice - Before ACC2

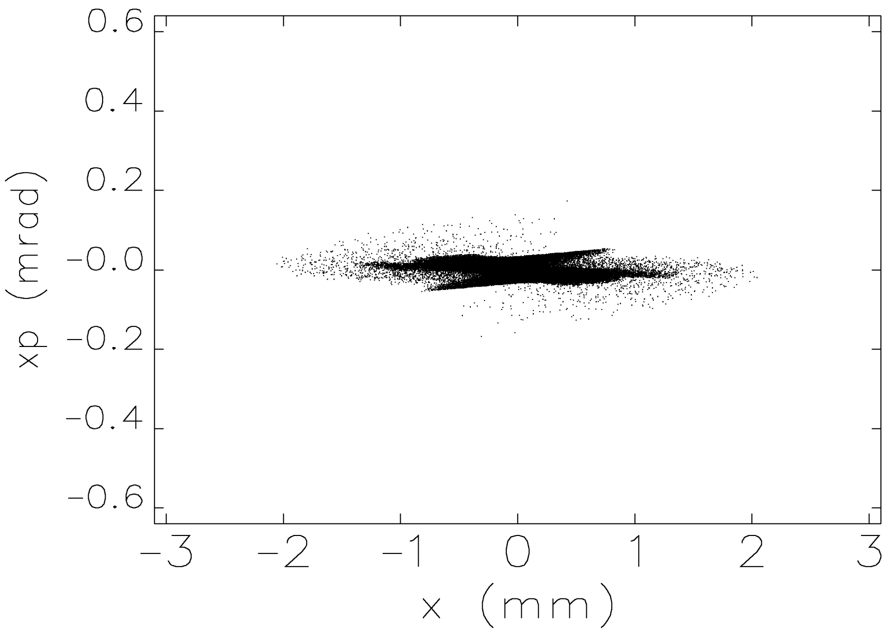
Simulated Particles = 200000



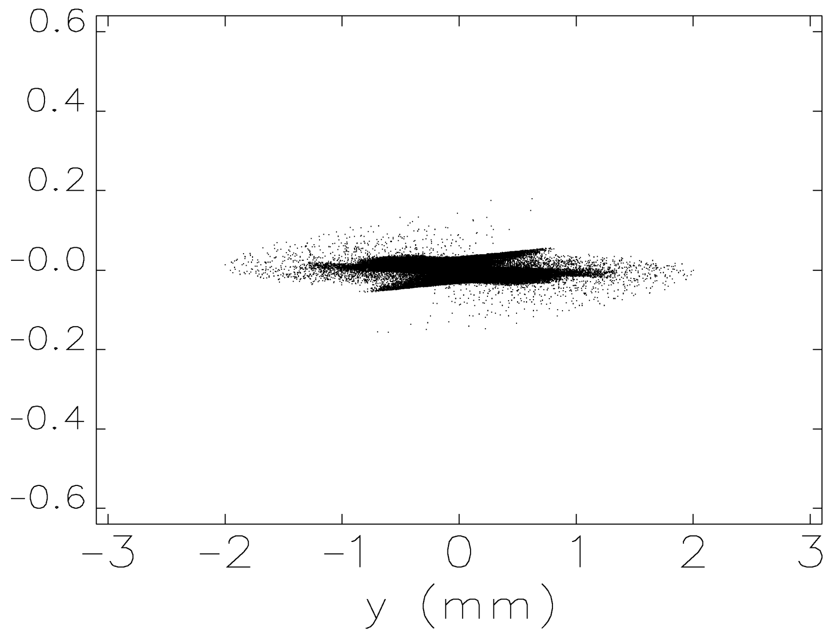


New Lattice - Before ACC2

Simulated Particles = 200000



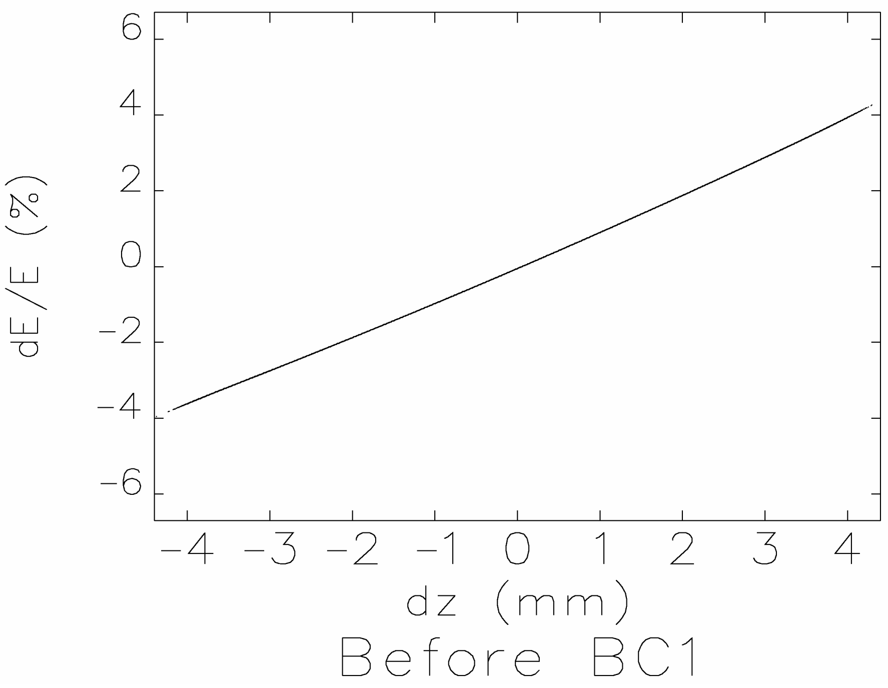
Before ACC234

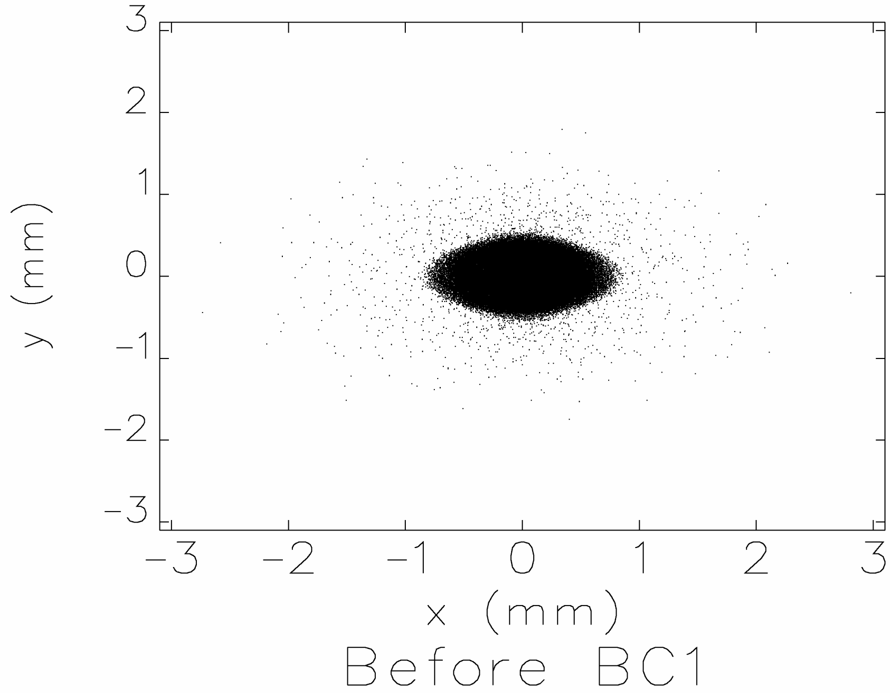


Before ACC234

New Lattice - Before BC1

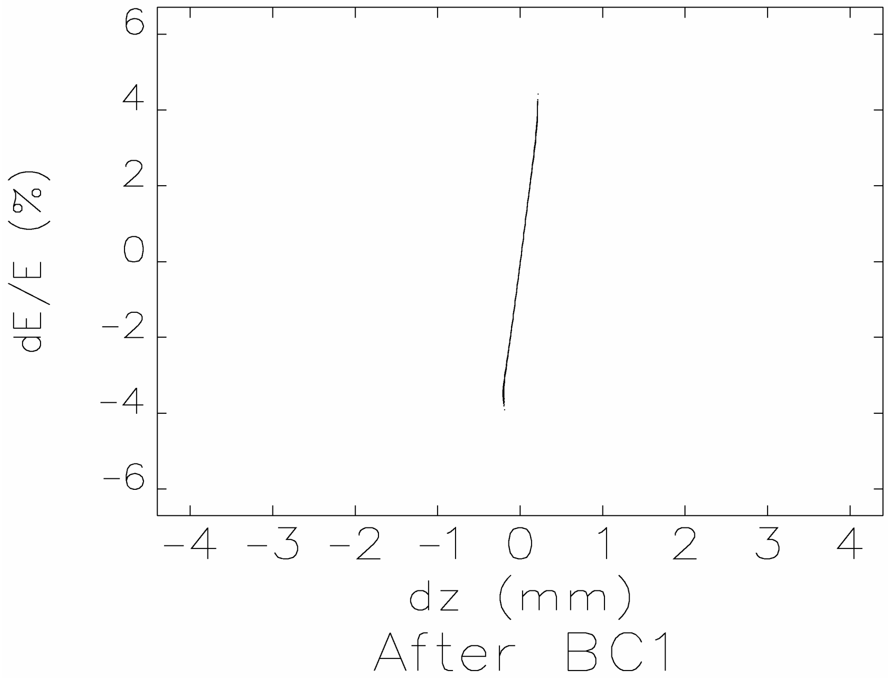
Simulated Particles = 200000

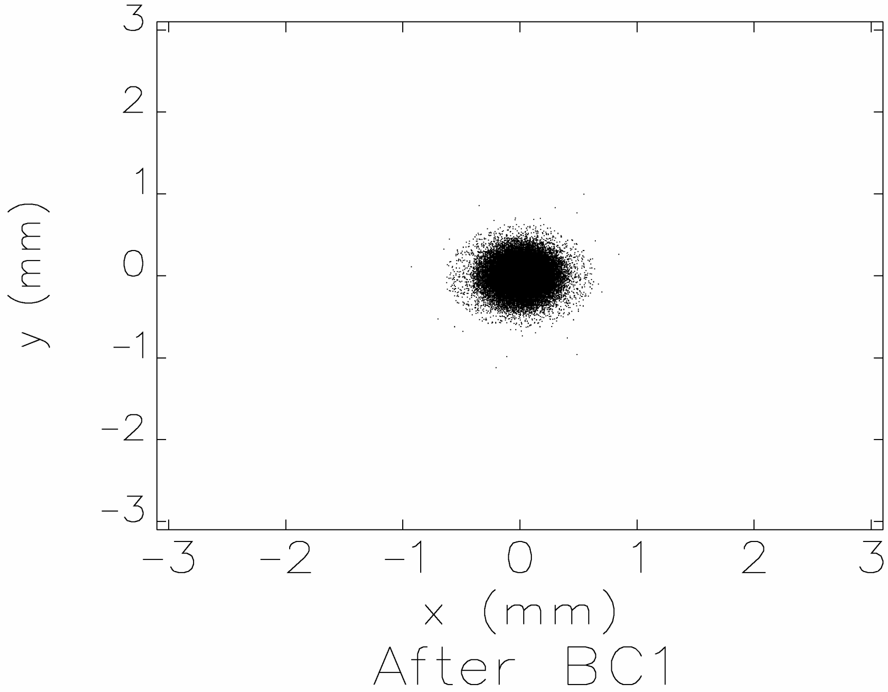




New Lattice - After BC1

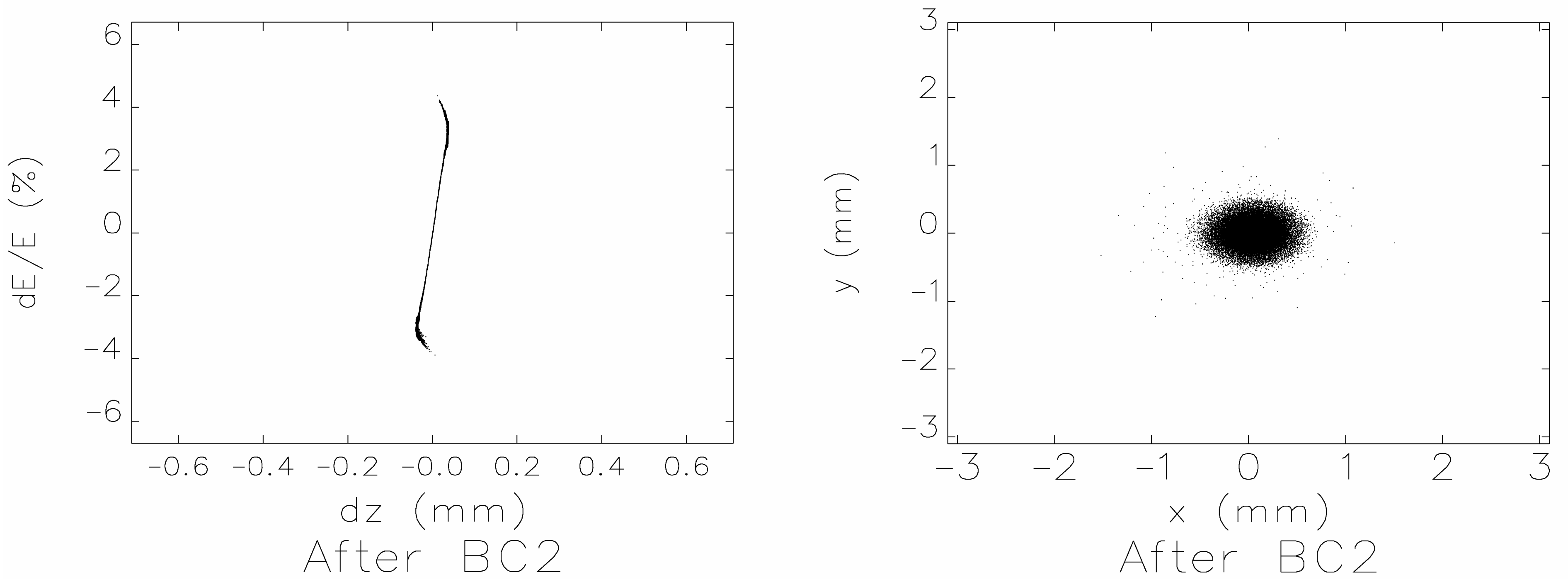
Simulated Particles = 200000





New Lattice - After BC2

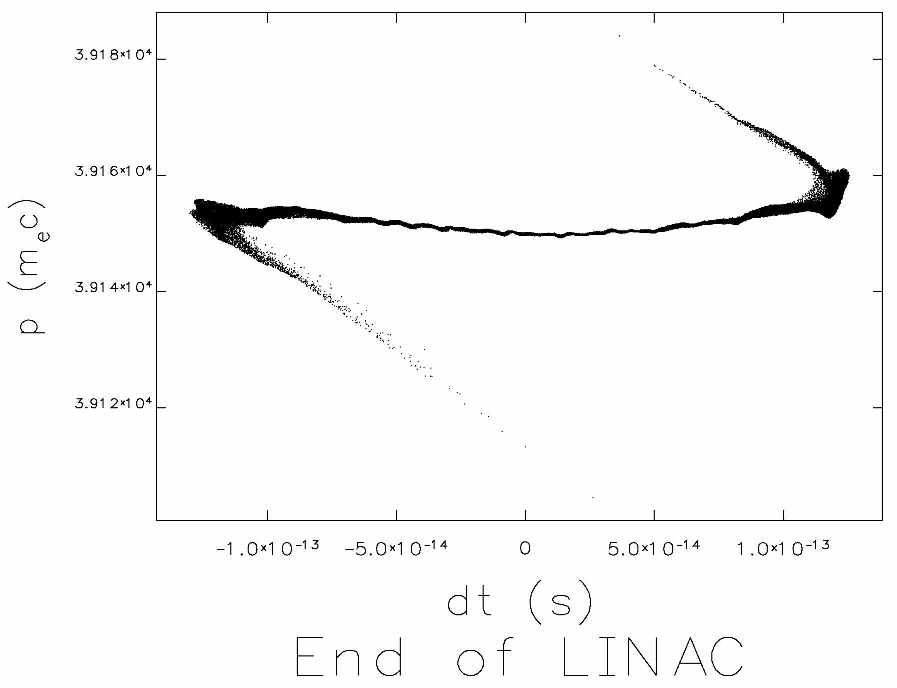
Simulated Particles = 200000

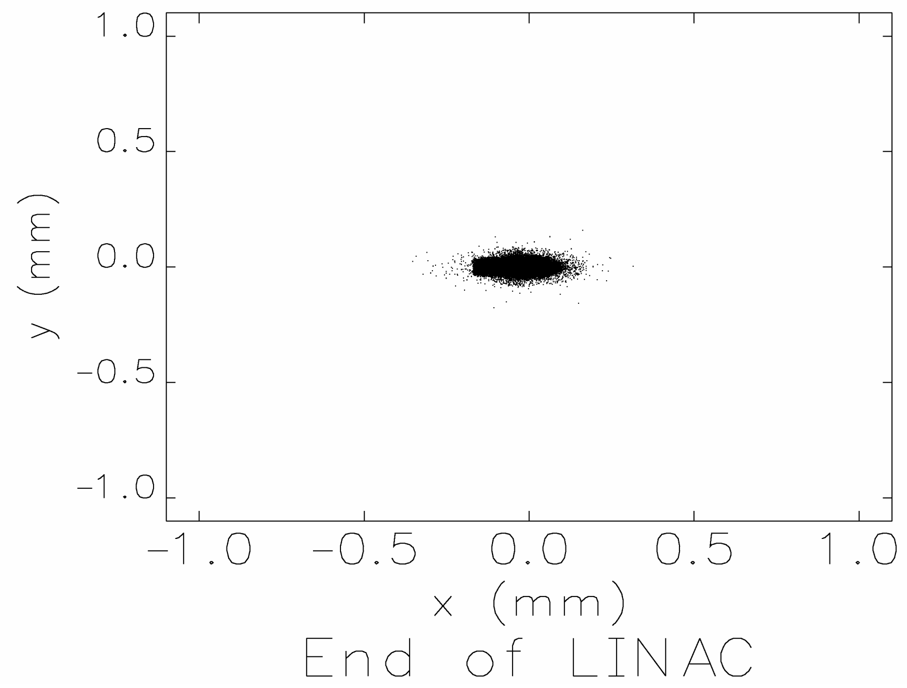


Although we use only 200000 particles, we did not meet any strong artificial modulation after BC2. This means that the amplification action of our new lattice is much weaker than that of our old lattice.

New Lattice - At the end of LINAC

Simulated Particles = 200000





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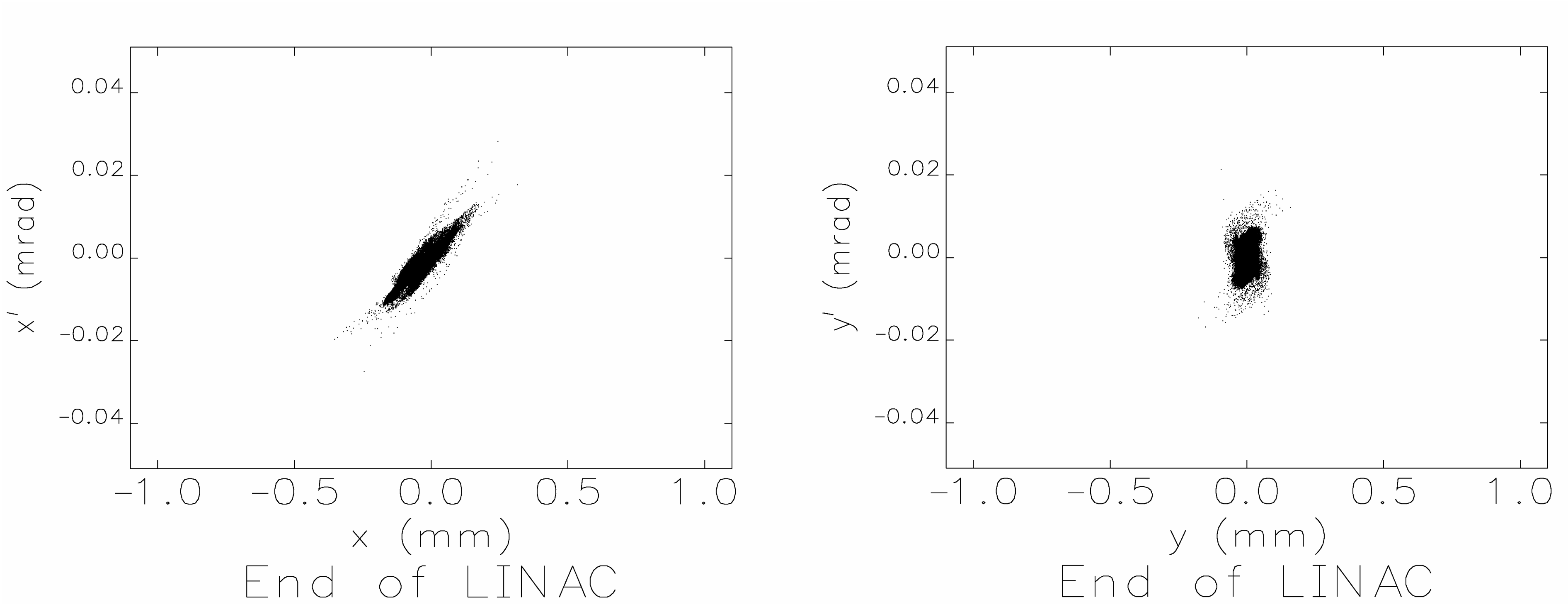
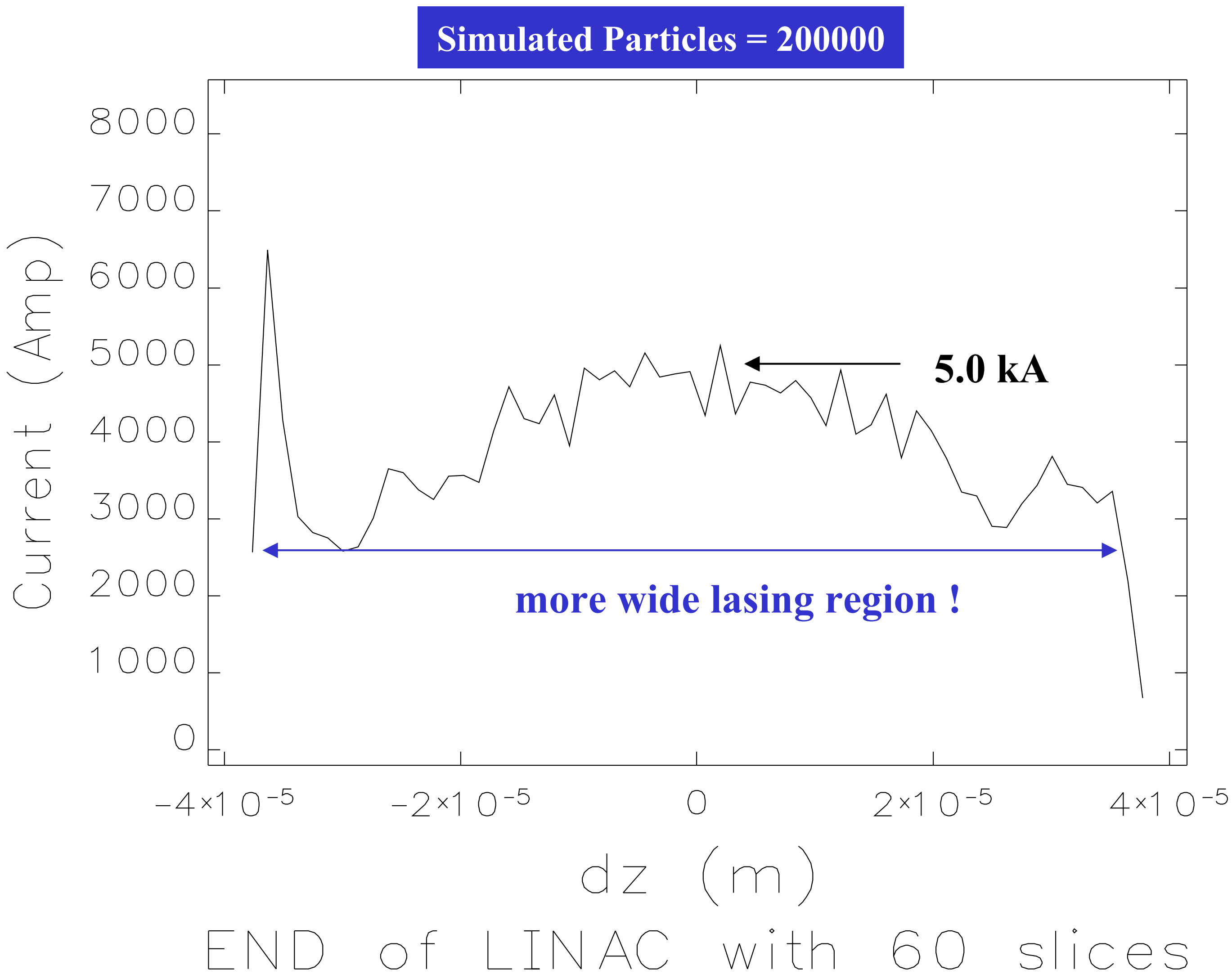
New Lattice - At the end of LINAC

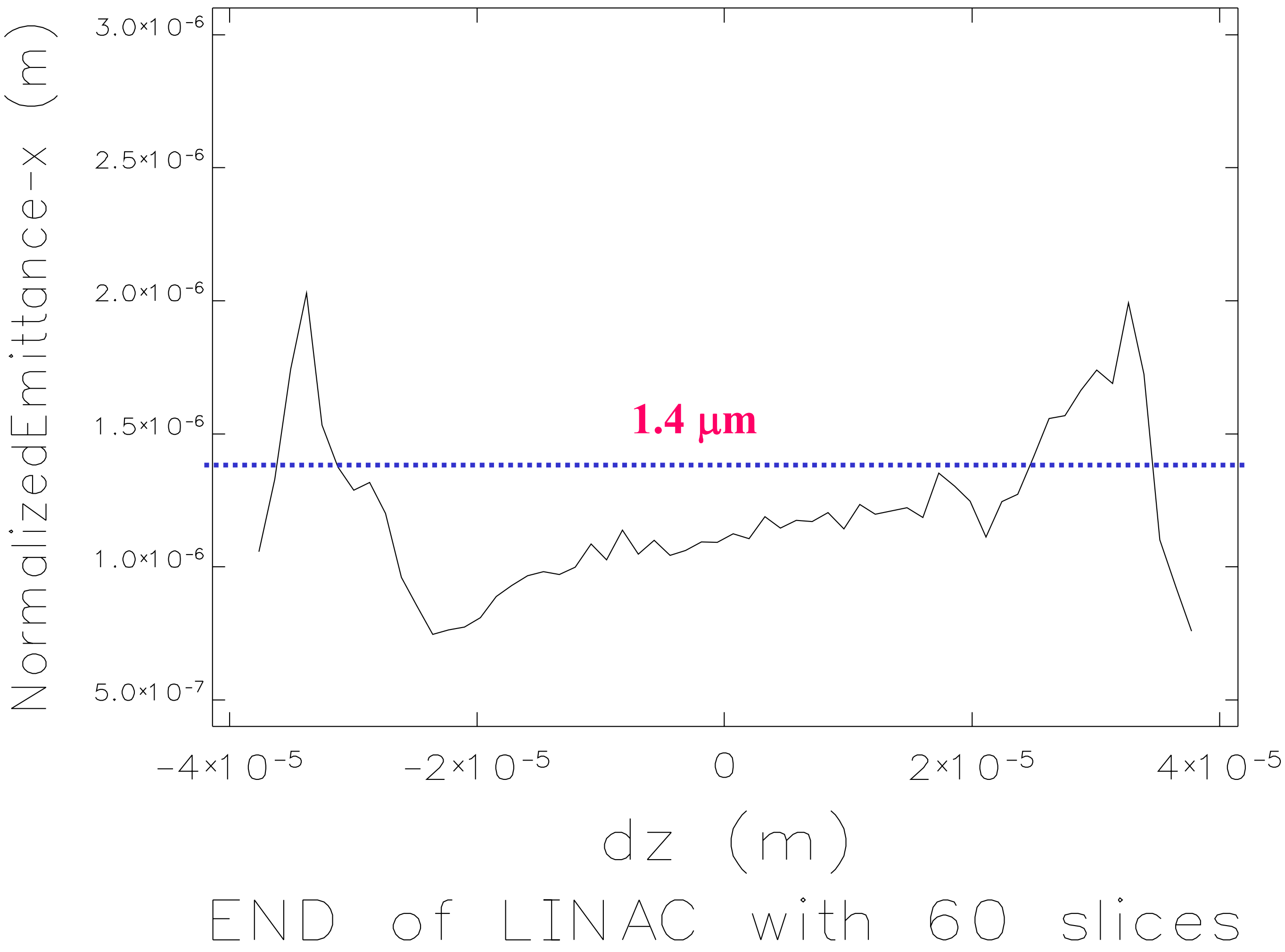


At the end of LINAC - Slice Parameters

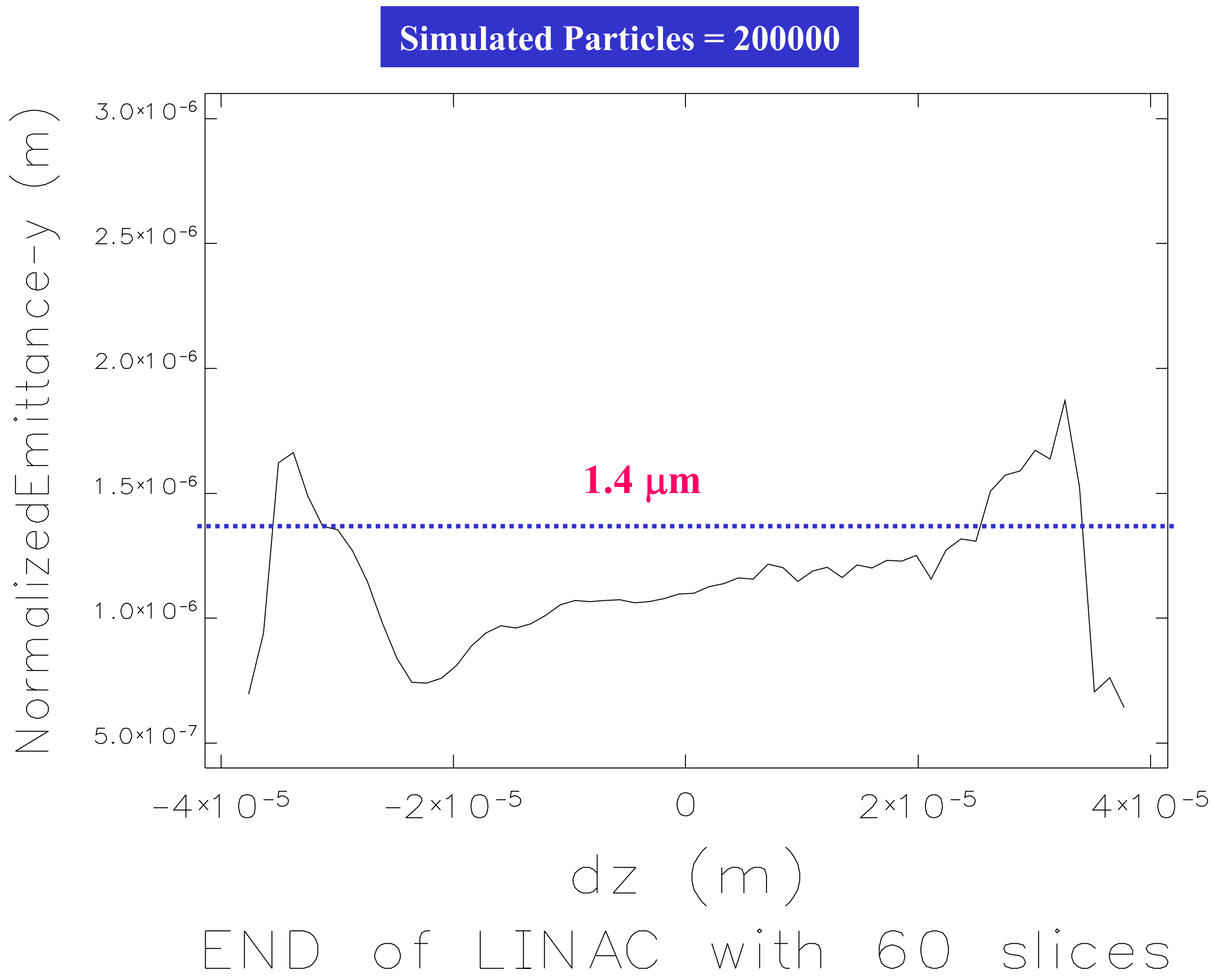


At the end of LINAC - Slice Parameters

Simulated Particles = 200000

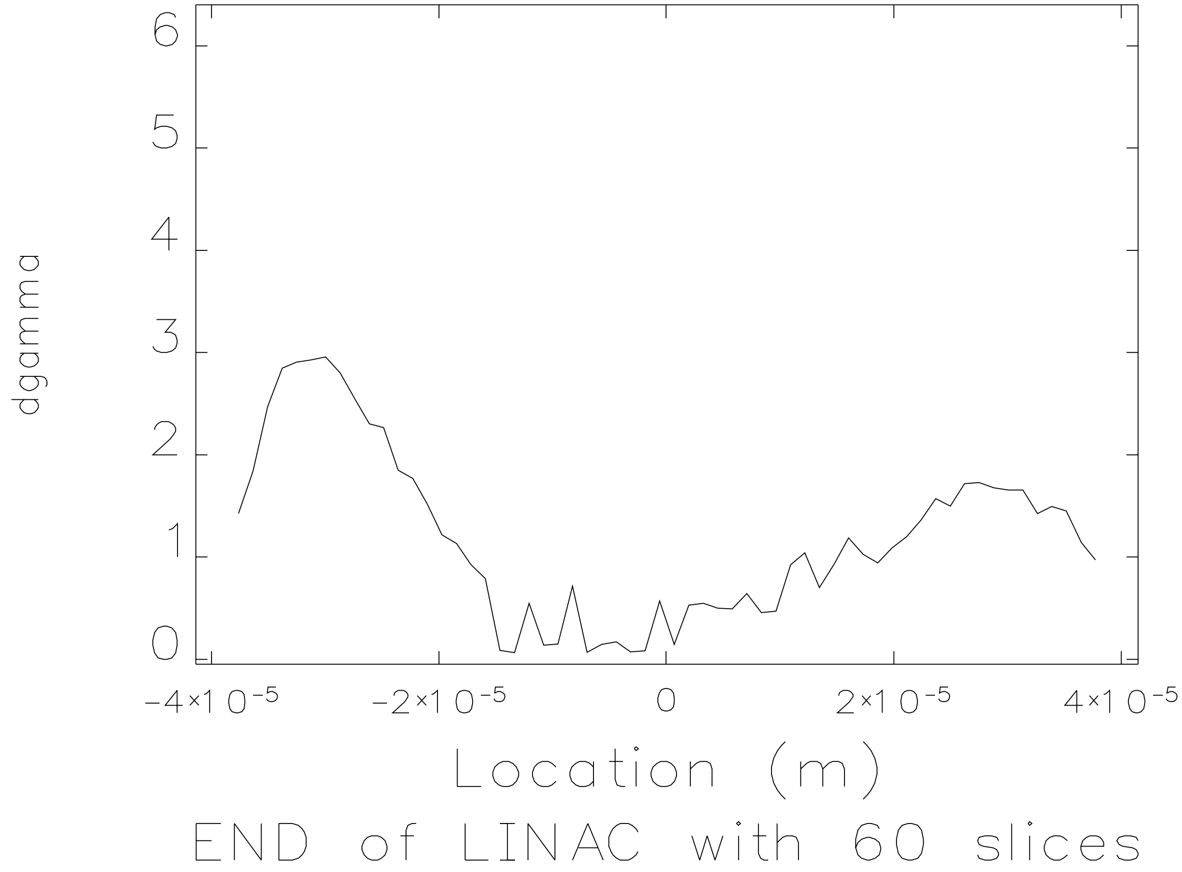


At the end of LINAC - Slice Parameters



At the end of LINAC - Slice Parameters

Simulated Particles = 200000

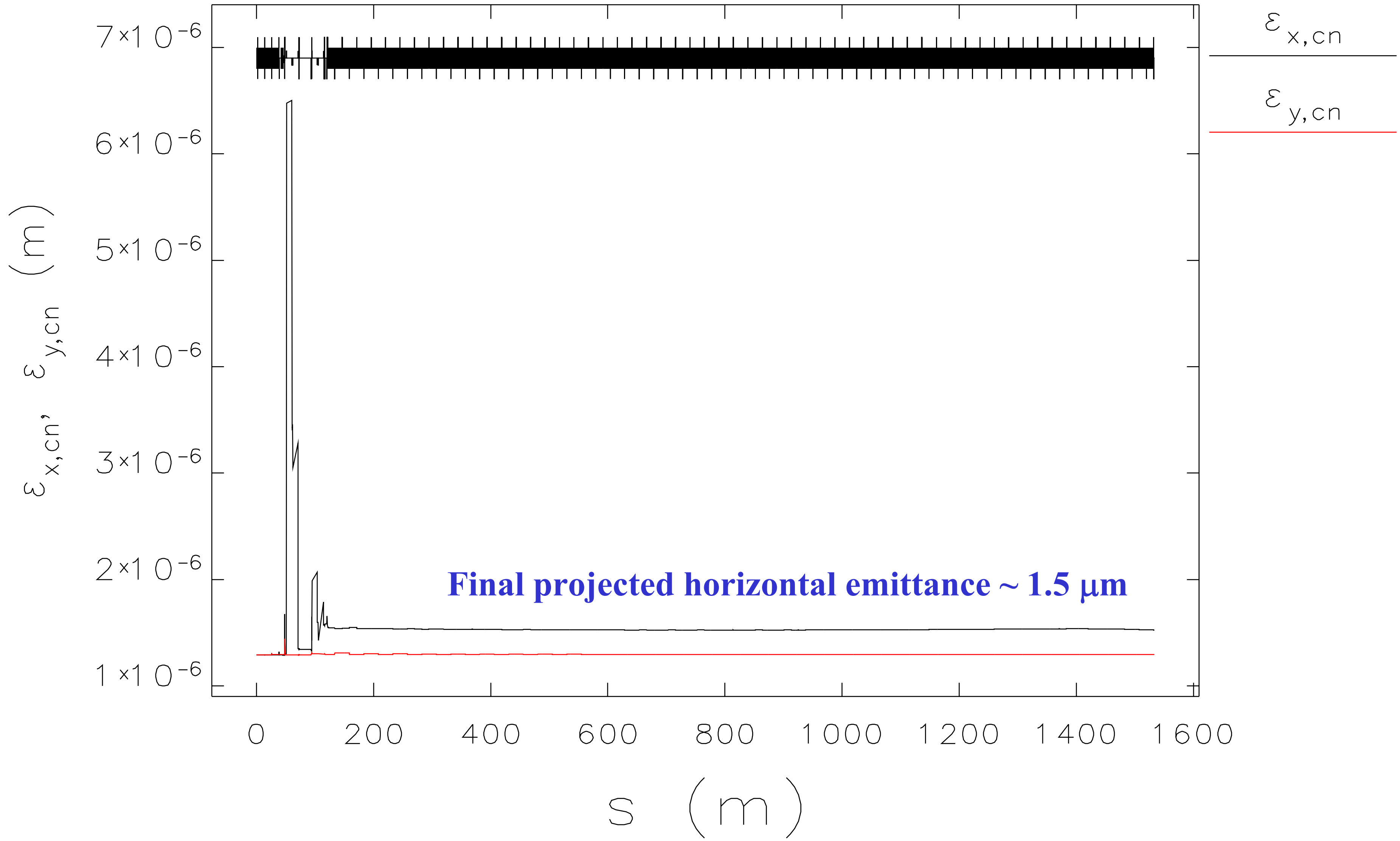


Maximum uncorrelated energy spread : 1.533 MeV @ 20.0 GeV ~ 0.0077% < 0.0125%

Fortunately, the uncorrelated energy spread in the center region is around 0.0013%

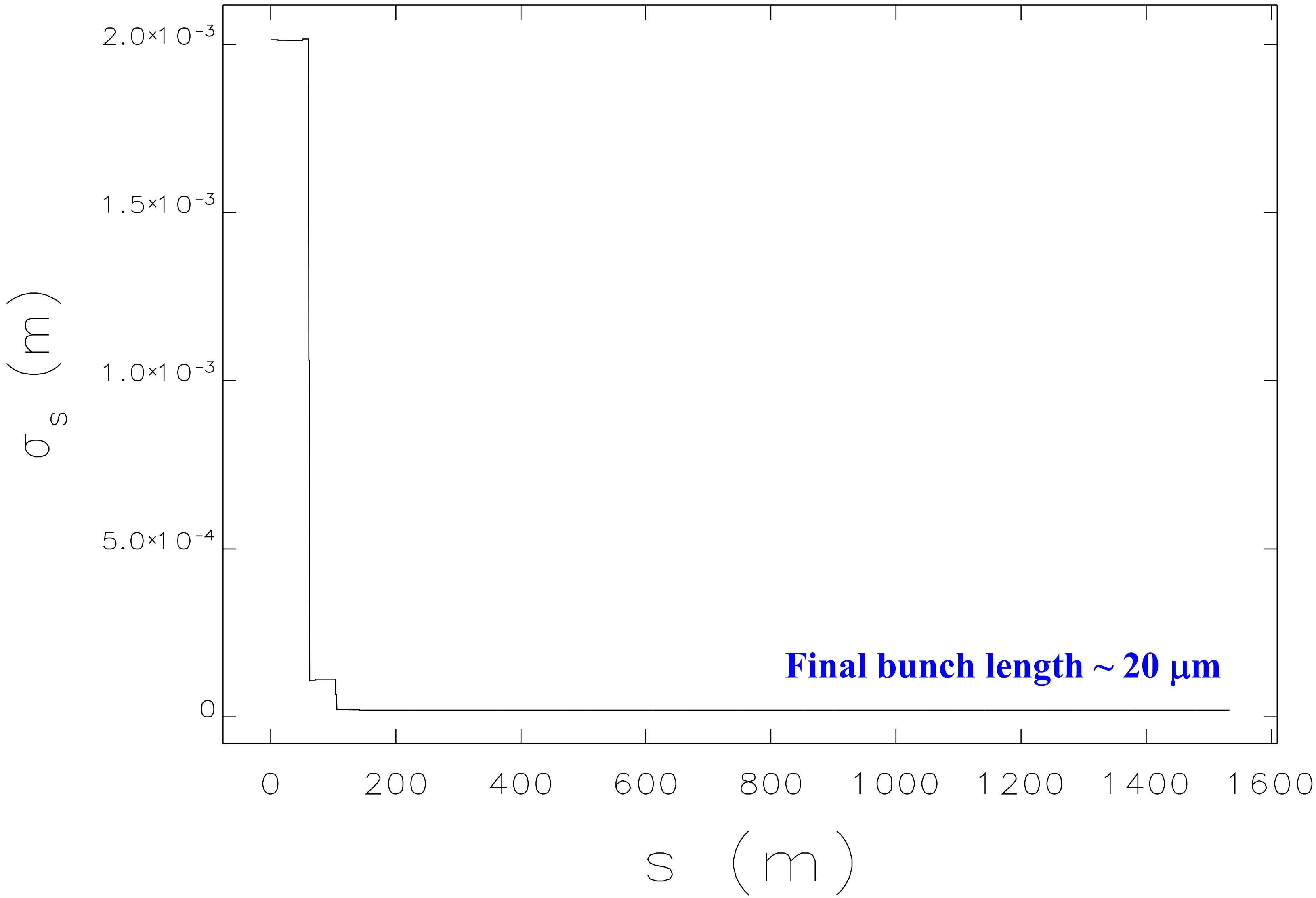
Projected Parameters Along Beamline

Simulated Particles = 200000



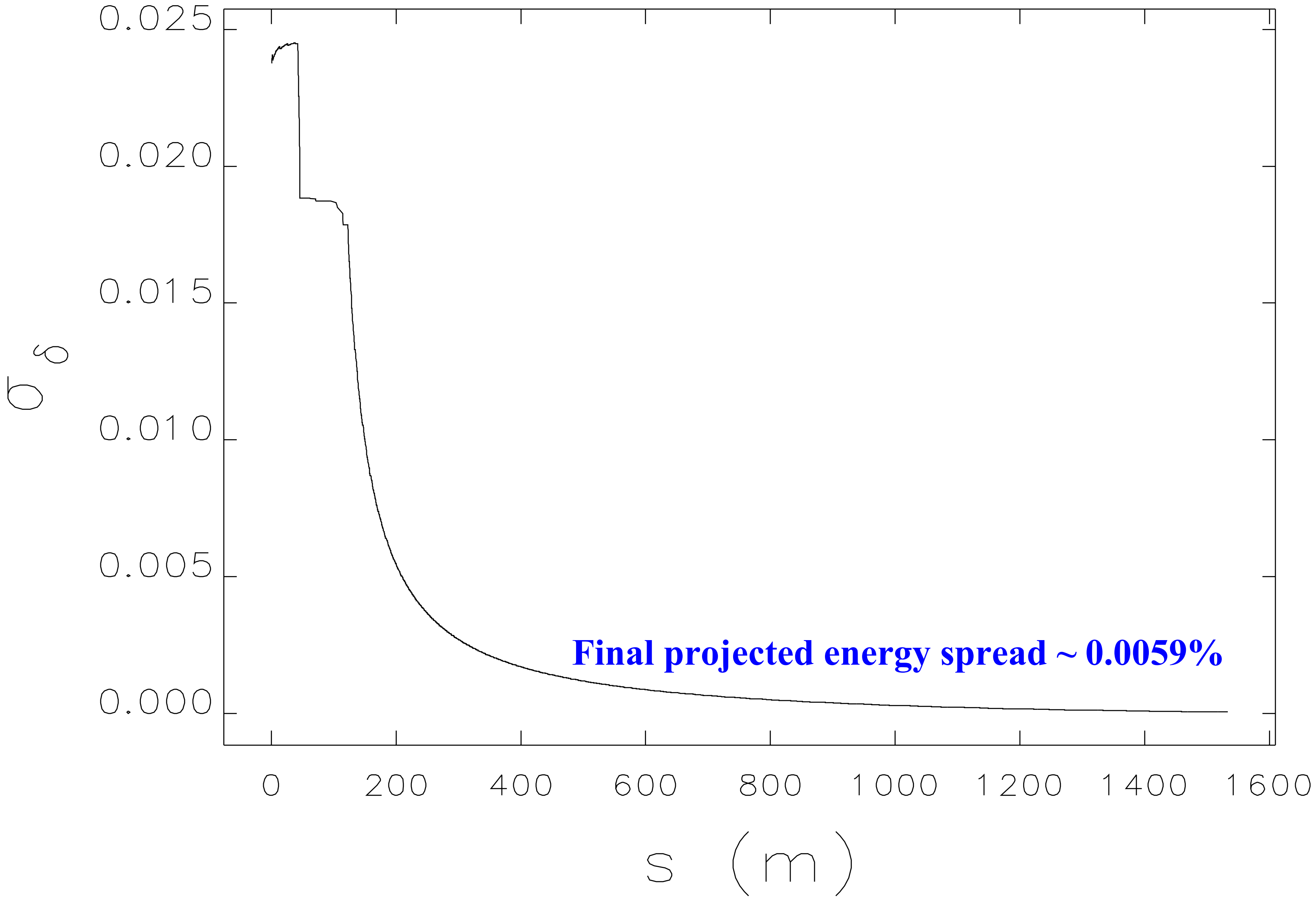
Projected Parameters Along Beamline

Simulated Particles = 200000



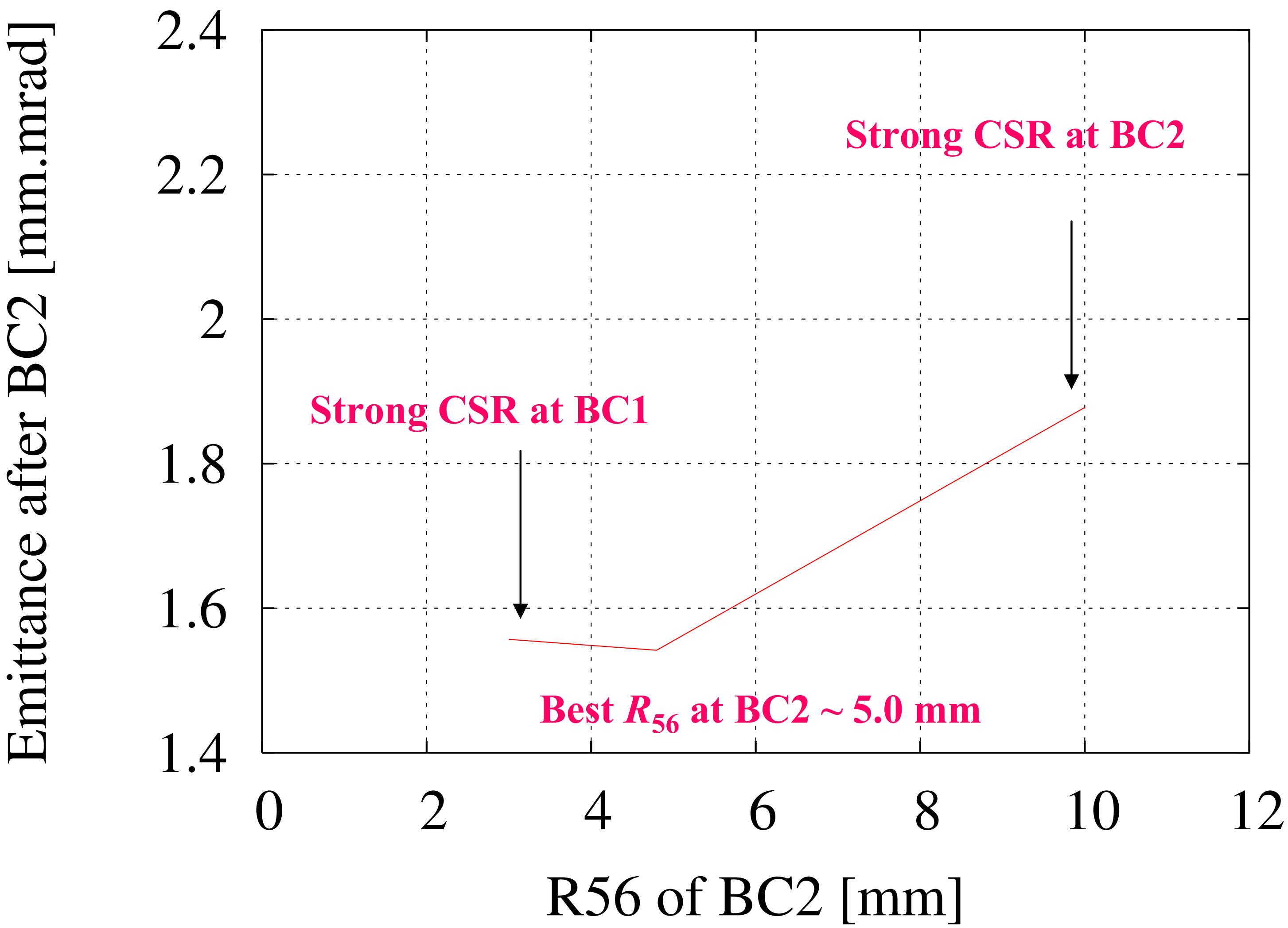
Projected Parameters Along Beamline

Simulated Particles = 200000

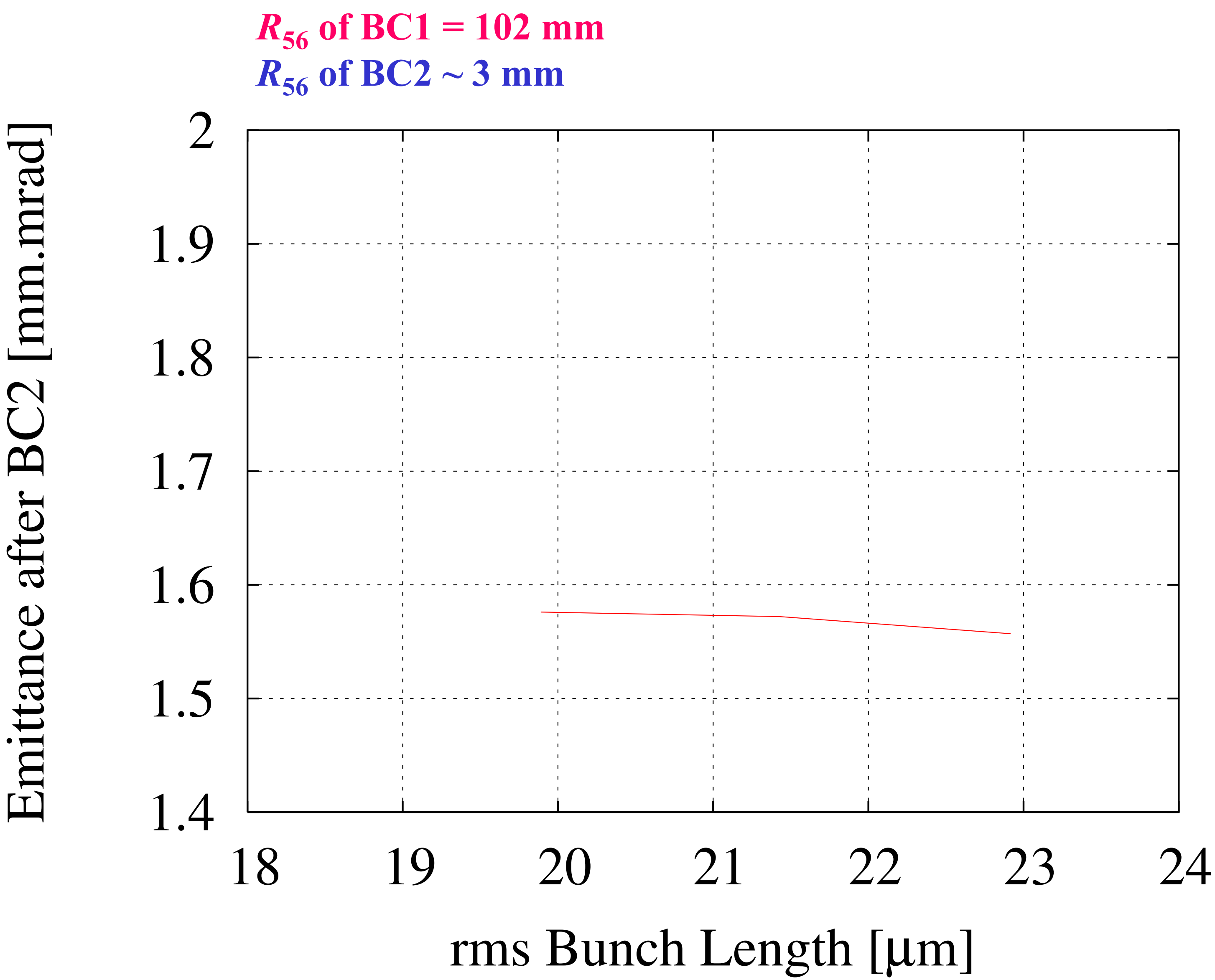


Different R_{56} Combinations at BC1 & BC2

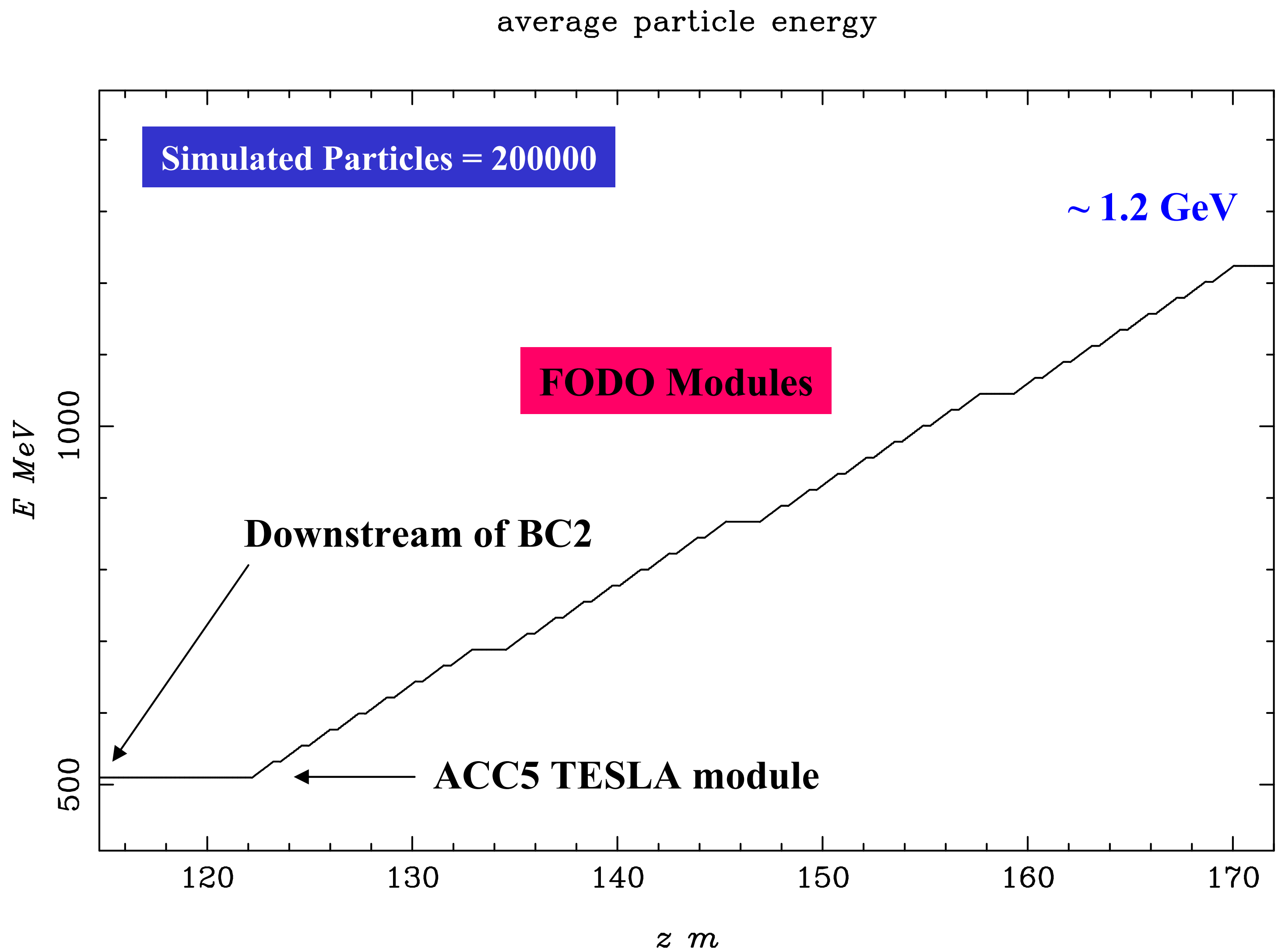
Always keep total R_{56} of BC1 + BC2 = 105 mm for $\sigma_z \sim 22$ μm



Different Bunch Length for R_{56} of BC2 ~ 3 mm

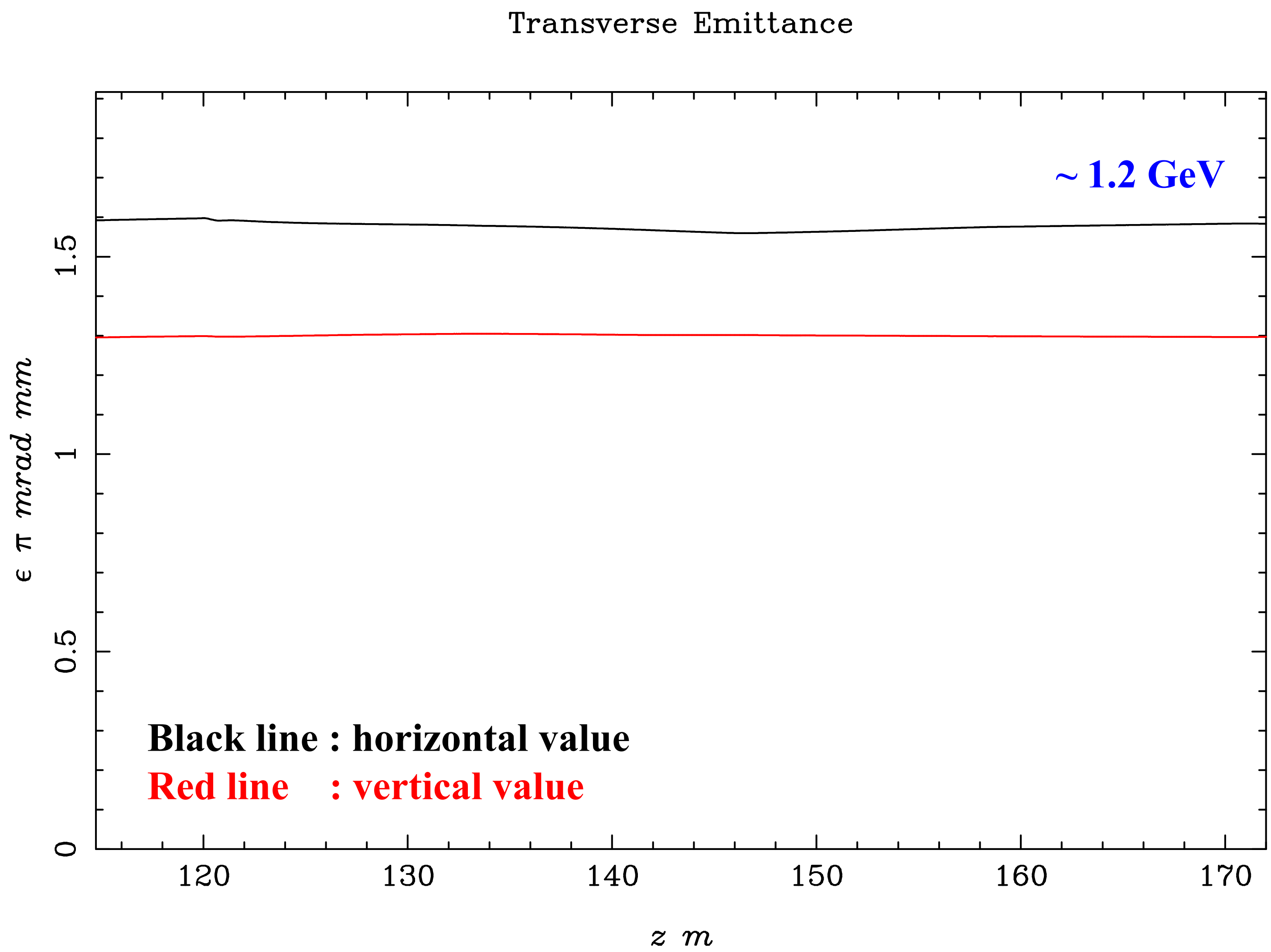


ASTRA Tracking after BC2 with Space Charge



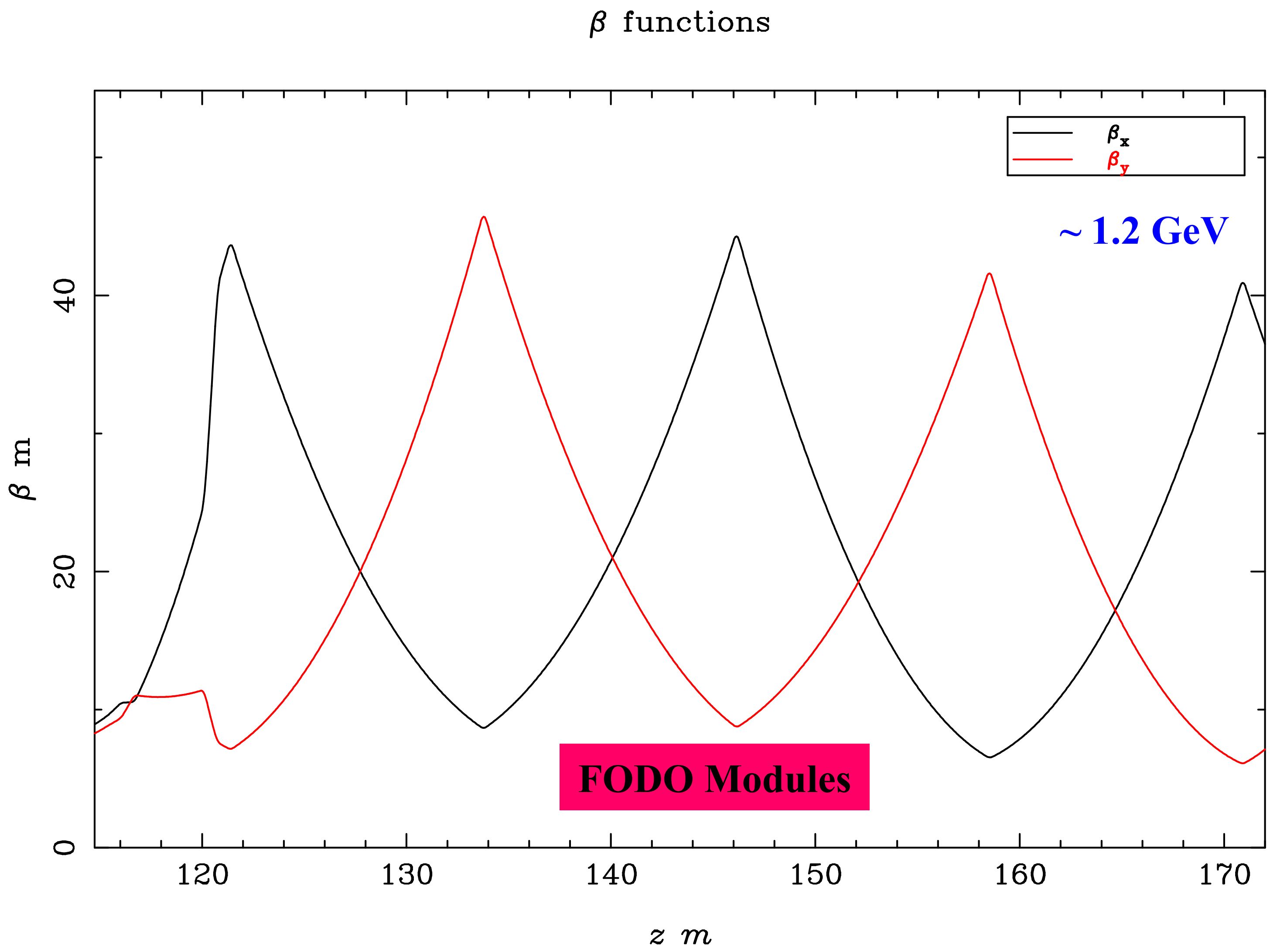
We have used ASTRA to investigate the space charge effect after BC2. Here ELEGANT output is directly converted as an input of ASTRA from the downstream of BC2.

ASTRA Tracking after BC2 with Space Charge



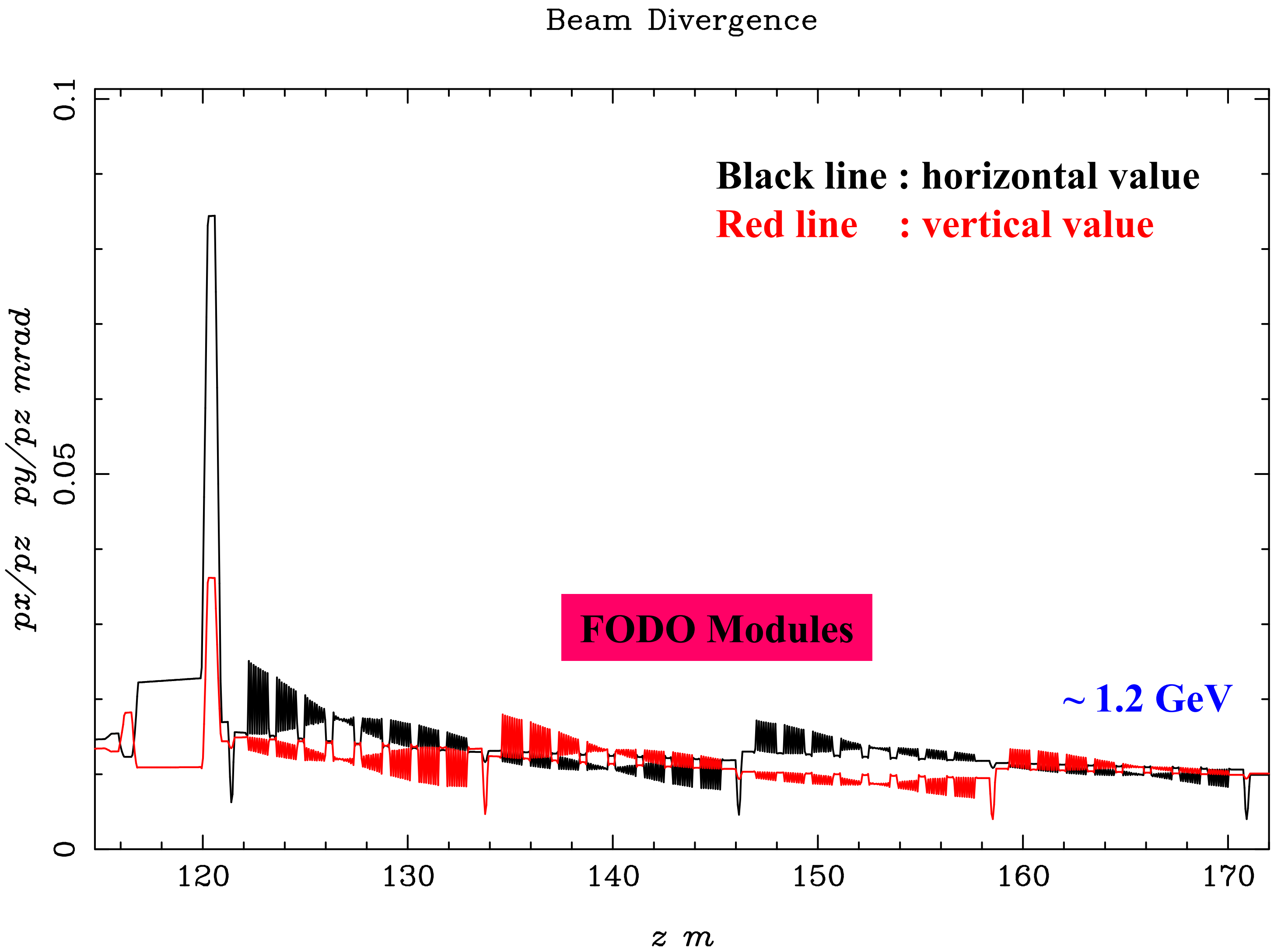
Projected transverse emittances are almost constant under space charge force !!!

ASTRA Tracking after BC2 with Space Charge



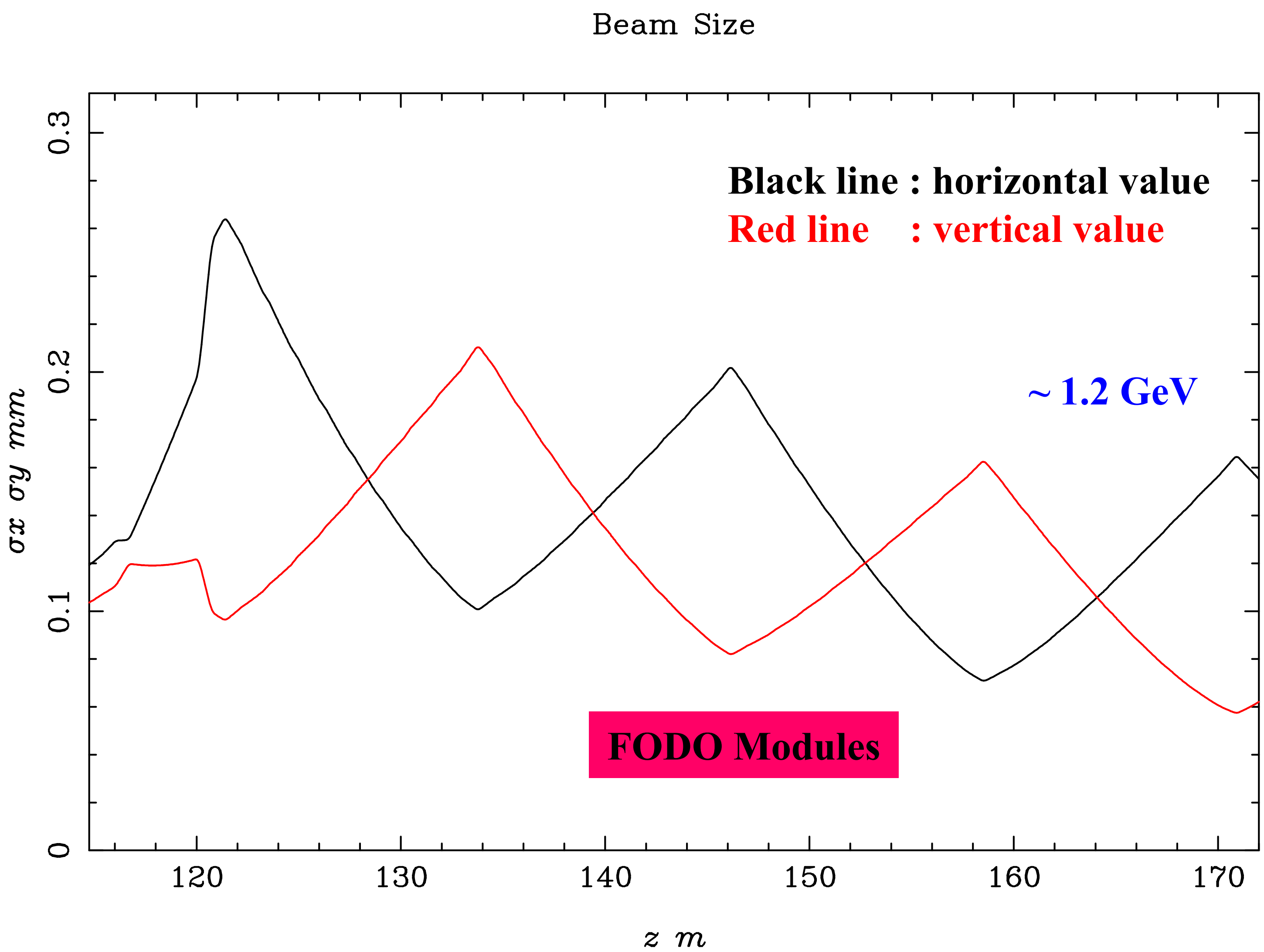
beta-functions are slightly changed due to space charge force.

ASTRA Tracking after BC2 with Space Charge



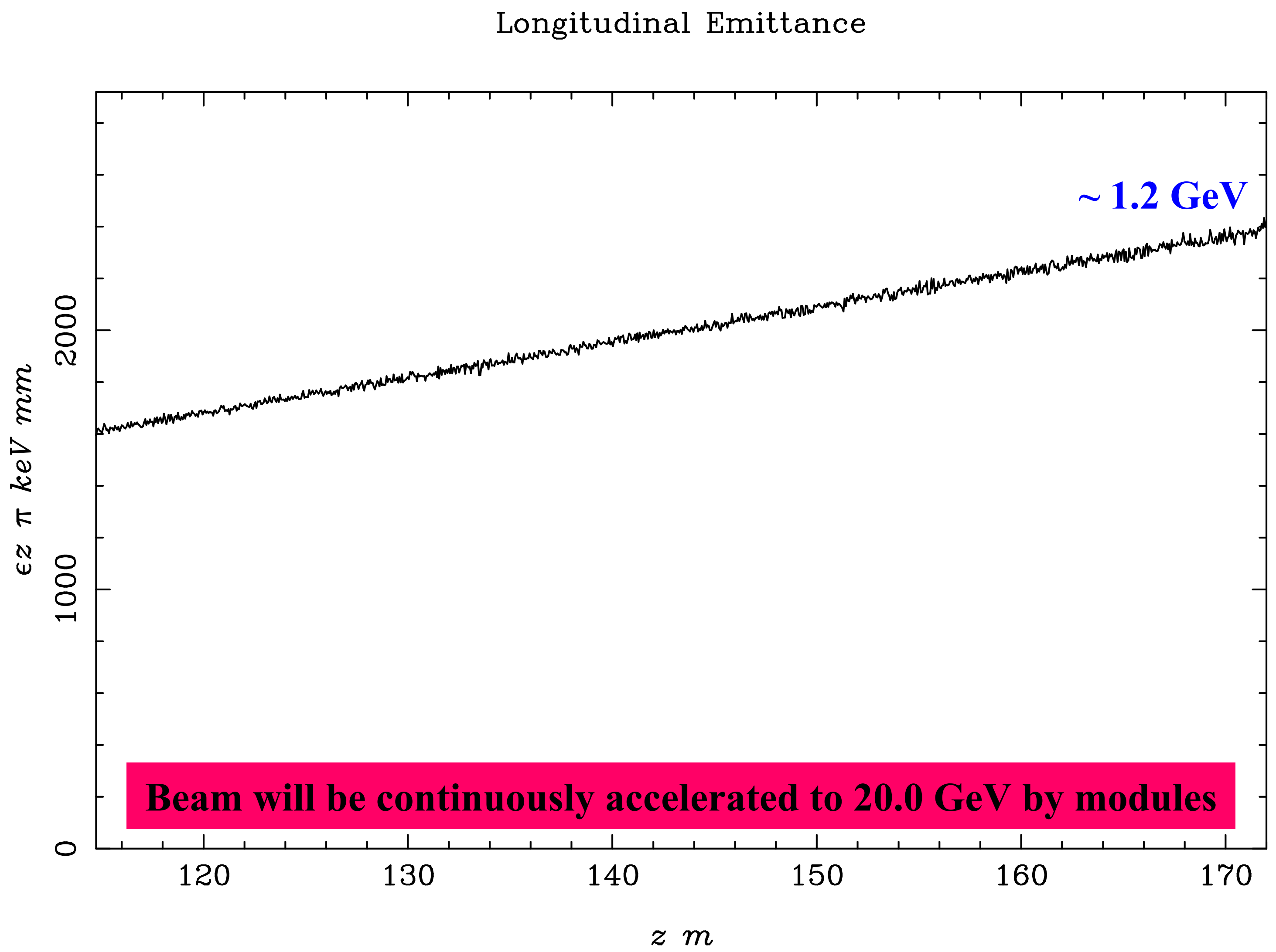
Transverse divergences are damped in FODO modules as beams are accelerated.

ASTRA Tracking after BC2 with Space Charge



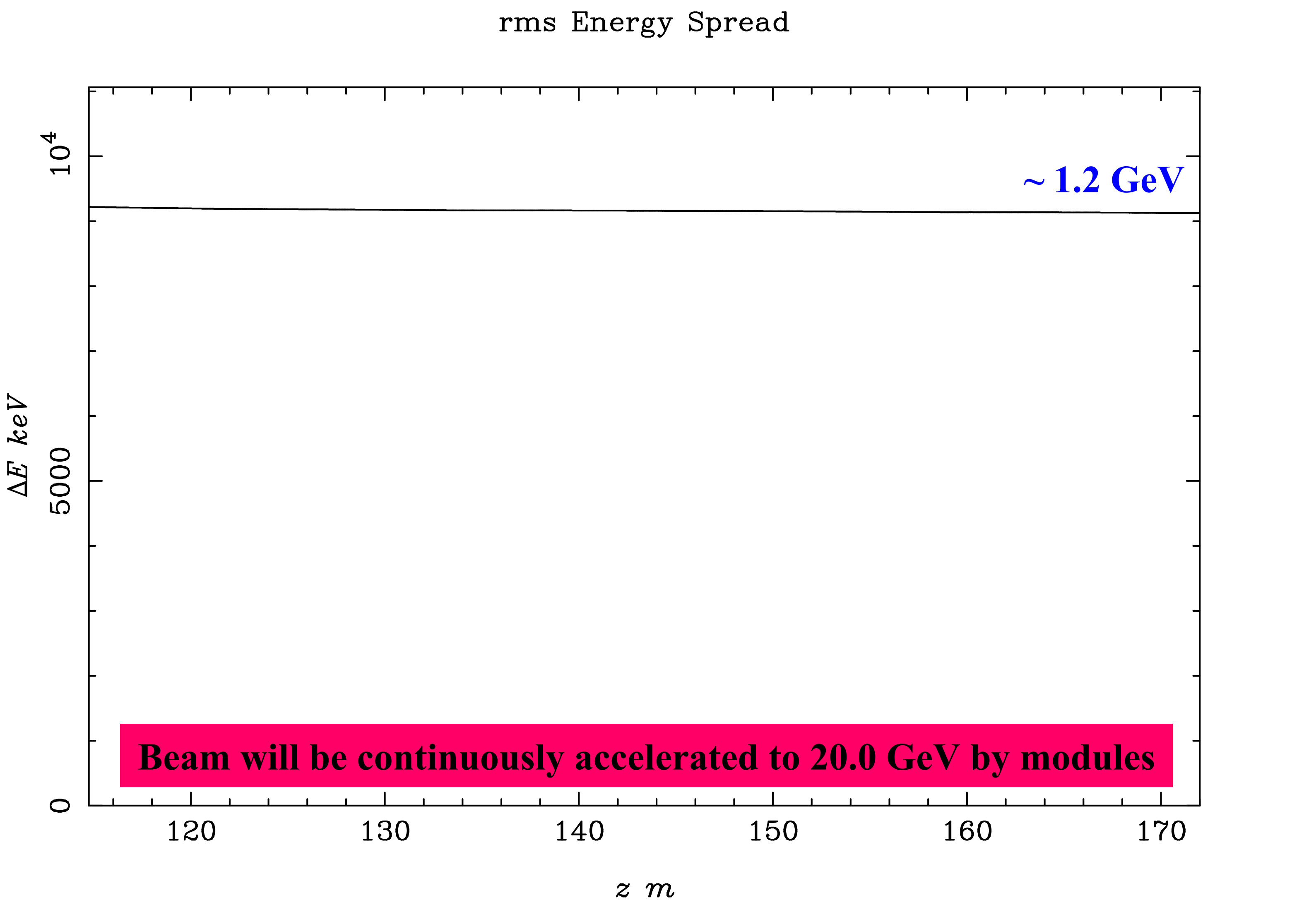
Beam sizes are also damped in FODO modules as beams are accelerated.

ASTRA Tracking after BC2 with Space Charge



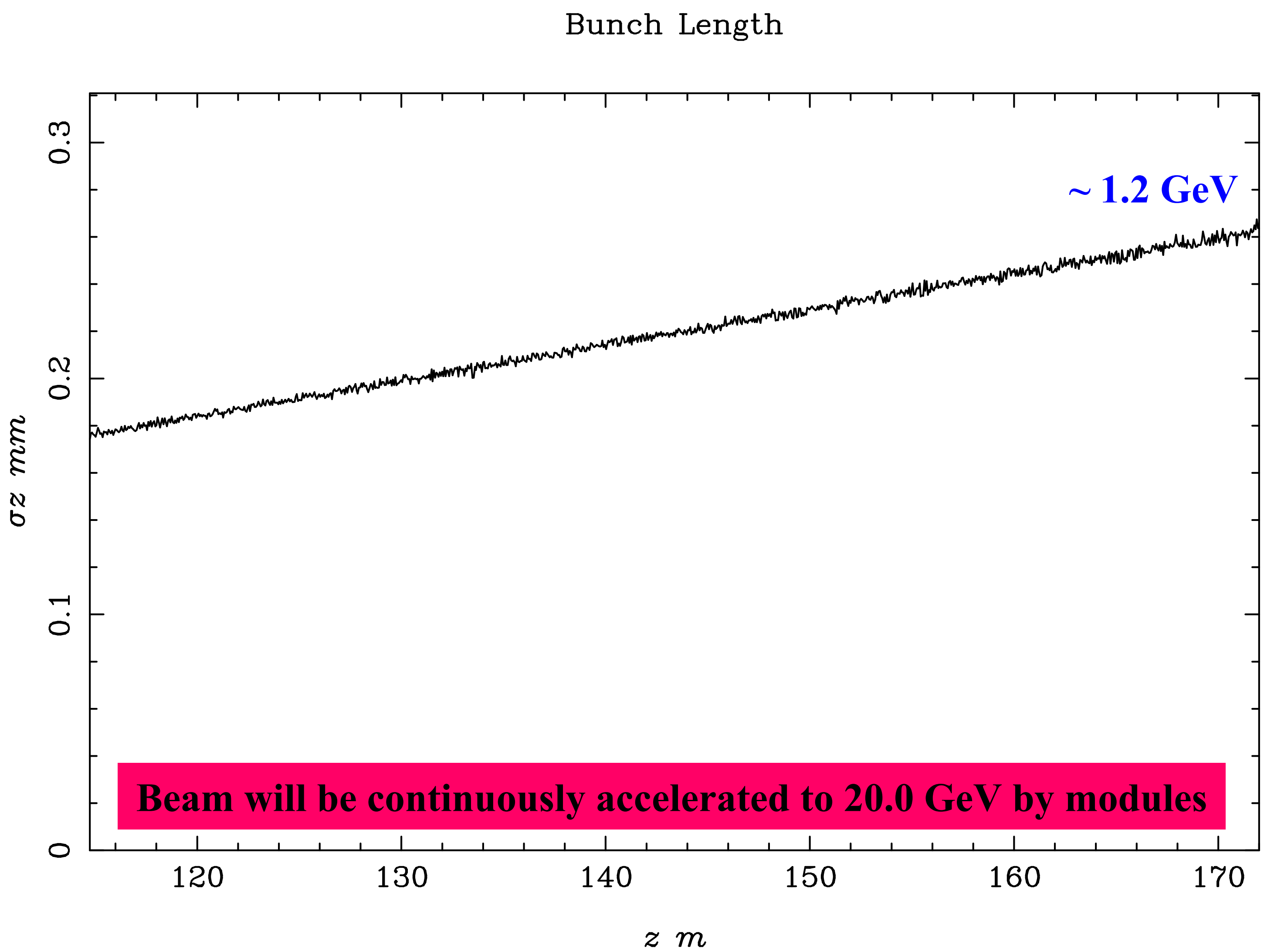
Though long. emittance is increased somewhat, this will be saturated as beams are accelerated.

ASTRA Tracking after BC2 with Space Charge



Energy spread is slightly reduced as beams are accelerated.

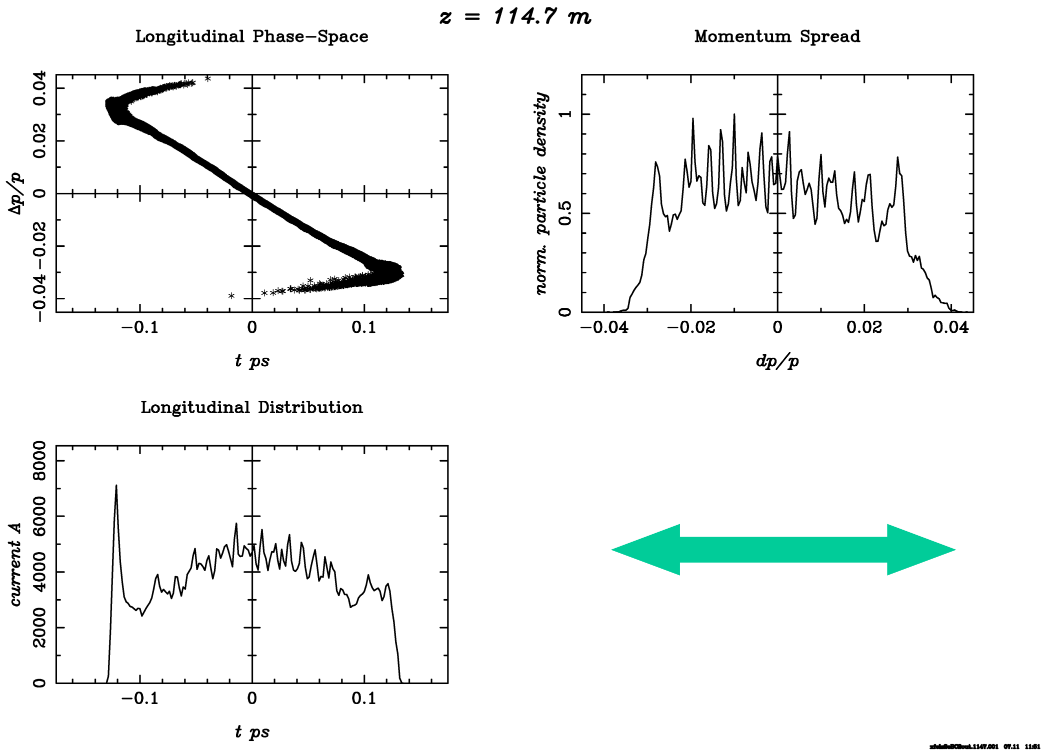
ASTRA Tracking after BC2 with Space Charge

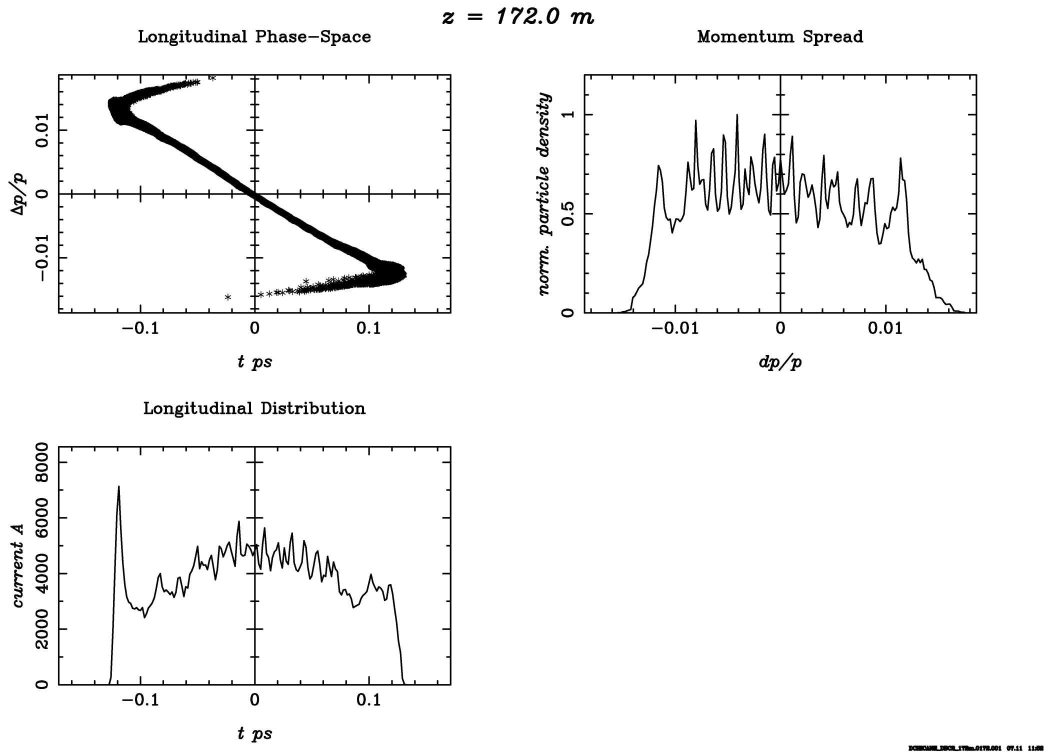


Though bunch length is slightly increased, this will be saturated as beams are accelerated more.

ASTRA Tracking after BC2 with Space Charge

Simulated Particles = 200000



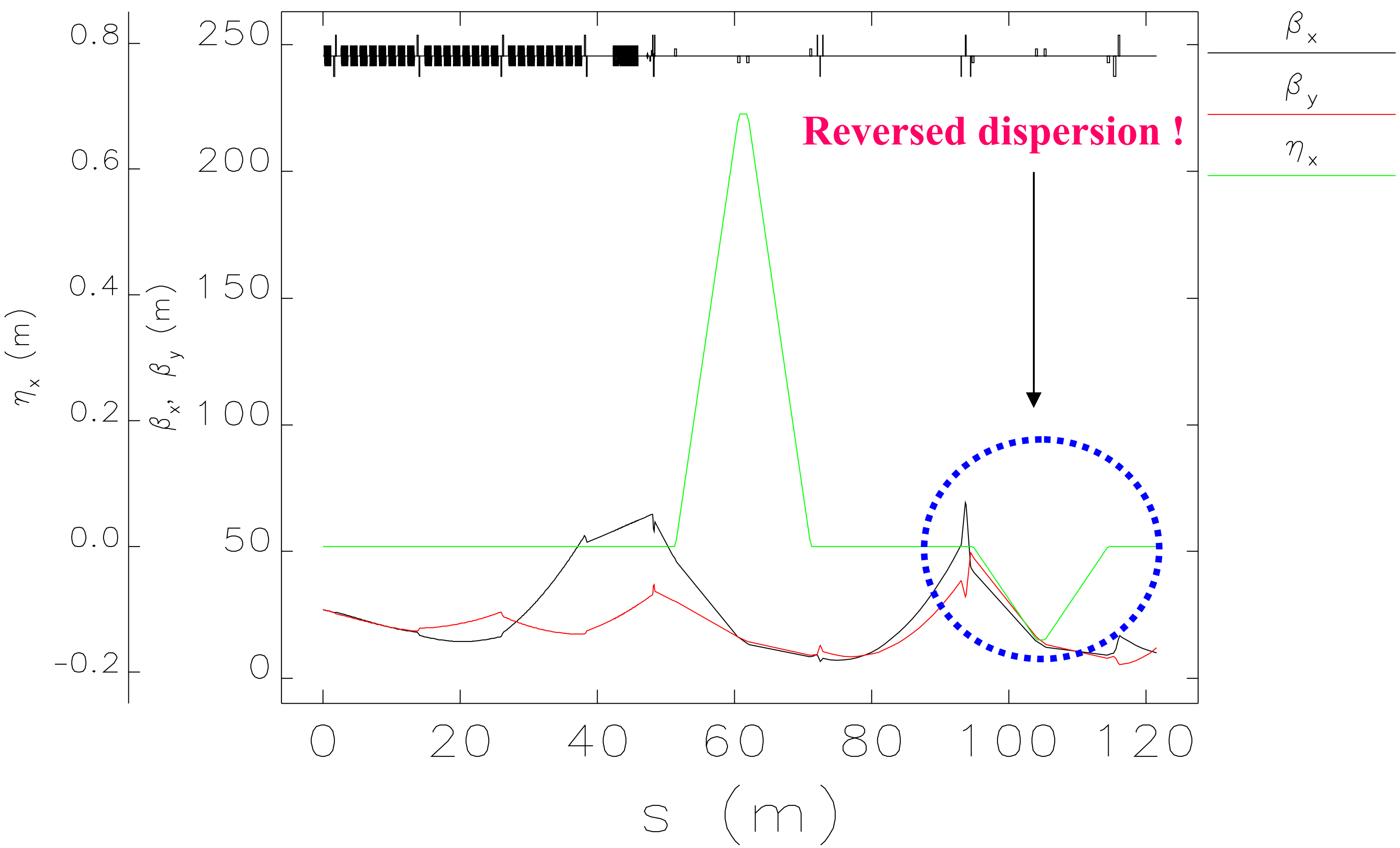


Downstream of BC : Energy ~ 510 MeV

In FODO modules : Energy ~ 1.2 GeV

Though bunch length is slightly increased, peak current & energy spread are almost constant.

Future Optional Layout for Compensation



To reduce the projected emittance growth further, a compensation layout can be considered by reversing bending angle at BC2, which is similar to the layout of S-type chicane. This double chicane based S-type BC layout will be optimized in the near future.

Summary

We have optimized a new lattice for TESLA XFEL project 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 chicane, the total number of dipoles in BCs is reduced from 16 to 8, which certainly helped in reducing the microbunching instability.

Although we did not use any laser beam heater in the low energy region or any superconducting wiggler before BC2, and though we used the injector layout for TTF-2 in these S2E simulations, we have achieved much promising beam parameters for TESLA XFEL project only by optimizing BC layout.

We will investigate the jitter budget of the new lattice, and the gain of the microbunching instability in the near future although we can easily expect that its gain is small enough.

Soon we will use the proper injector layout for TESLA XFEL project in S2E simulations, In that case, we expect that we can get much smaller emittances.

Summary & Acknowledgments

For the online emittance measurement, we can consider FODO channels at a higher energy region (~ a few GeV), where chromatic effect is ignorable.

In the near future, we will deeply investigate the beam energy at BCs against the space charge effect, Twiss parameters around BCs, different combinations of R_{56}, and the new double chicane based S-type BC layout for the compensation.

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