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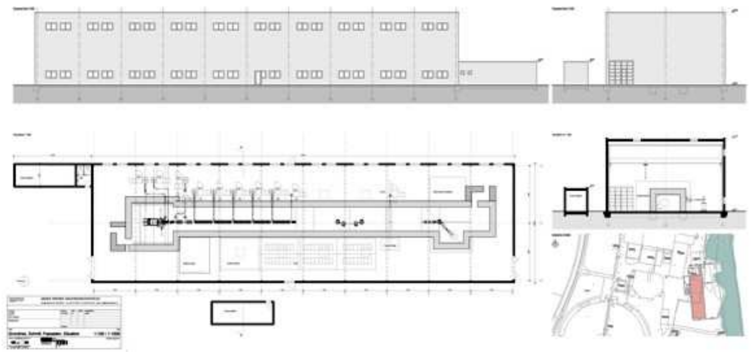

Two Injector Optimizations and Review of Diagnostic Section for 250 MeV Injector

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PSI XFEL-2008-11

Outline

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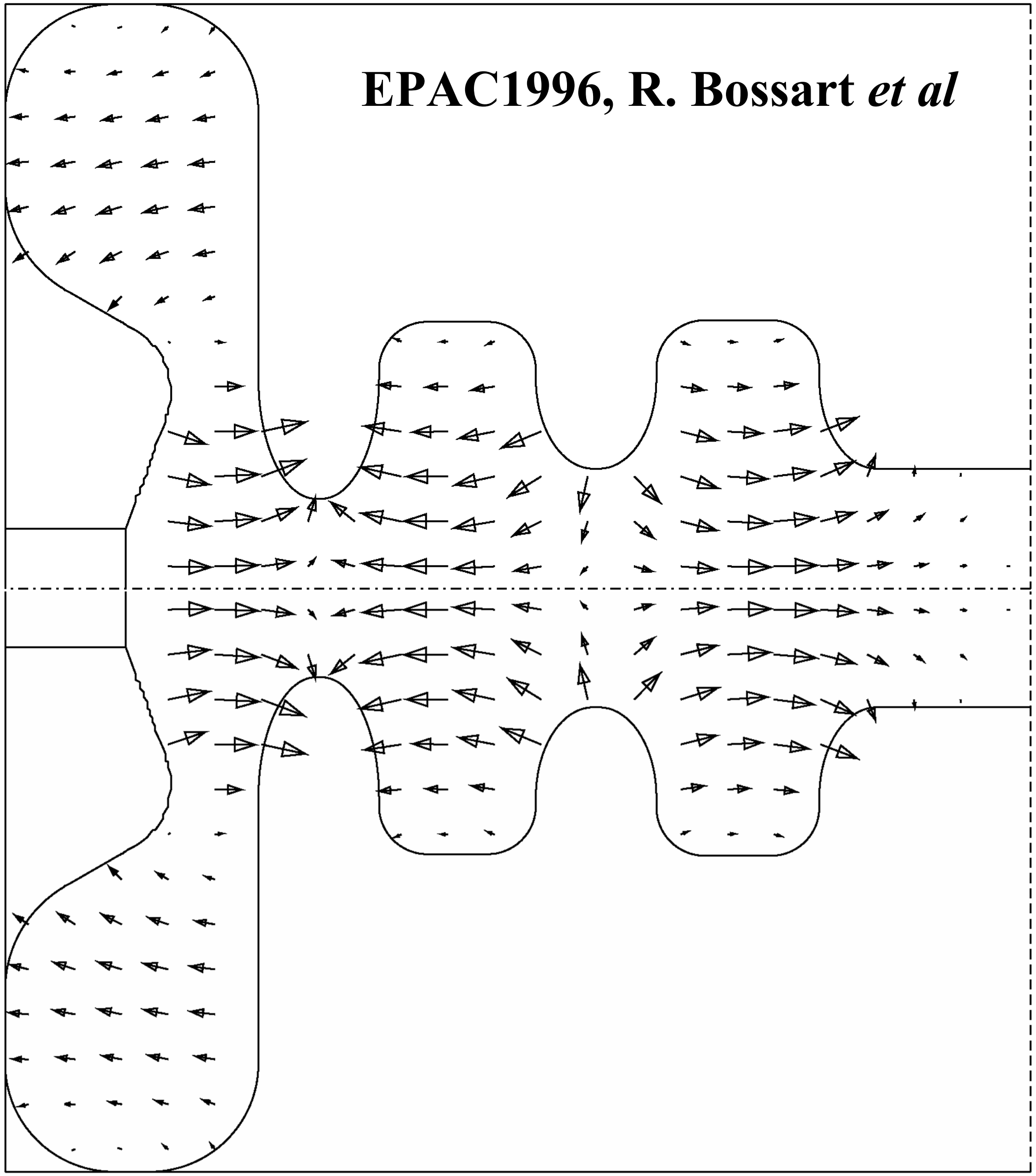
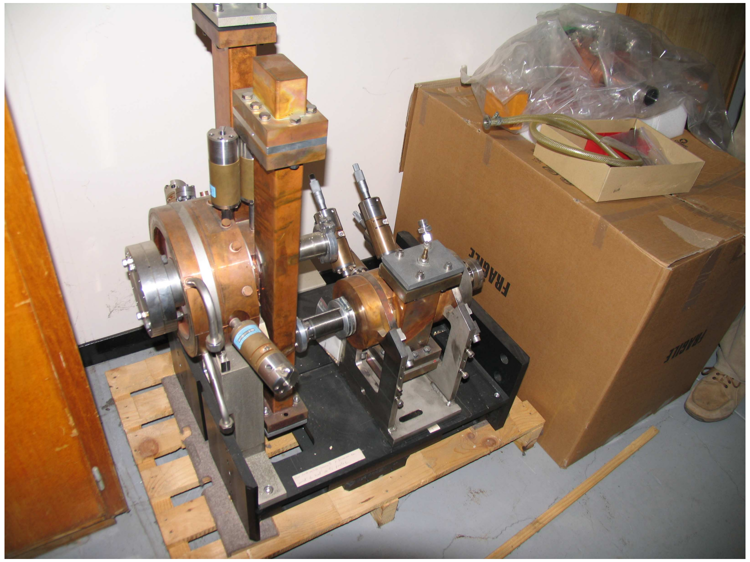
- Two Different Optimizations with CTF3 Gun Type V
  - Optimization with 120 MV/m for I_{peak} ~ 32 A, laser $\sigma_{x,y}$ = 270 μm, B_{sol} ~ 0.300 T
  - Optimization with 100 MV/m, I_{peak} ~ 22 A, laser $\sigma_{x,y}$ = 270 μm, B_{sol} ~ 0.255 T
- S2E Simulation for 250 MeV Injector with 100 MV/m and I_{peak} ~ 22 A
- Current Optics for Diagnostics with LOLA Cavity
  - Bunch Length Measurement - No problem with Current Optics
  - Longitudinal Phase Space Reconstruction - No problem with Current Optics
  - Slice Emittance Measurement with LOLA - Several Modified Optics are needed
- Optics for Diagnostic Section of European XFEL & a New Layout
- S2E Simulations with the newly suggested Layout, Problem, and Solutions
- Summary and Acknowledgement

Introduction to CTF3 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



Introduction to CTF3 Gun Type V

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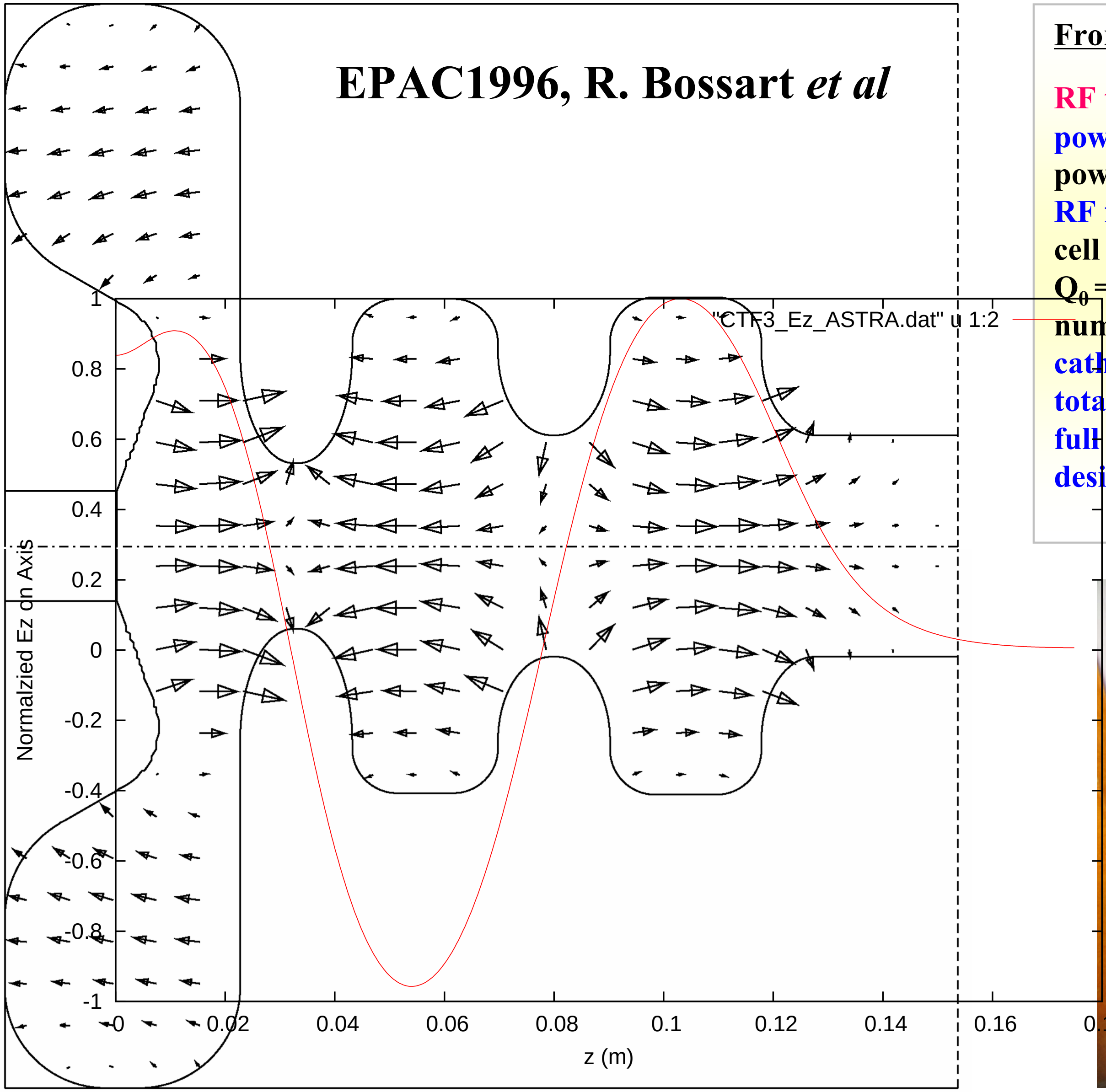

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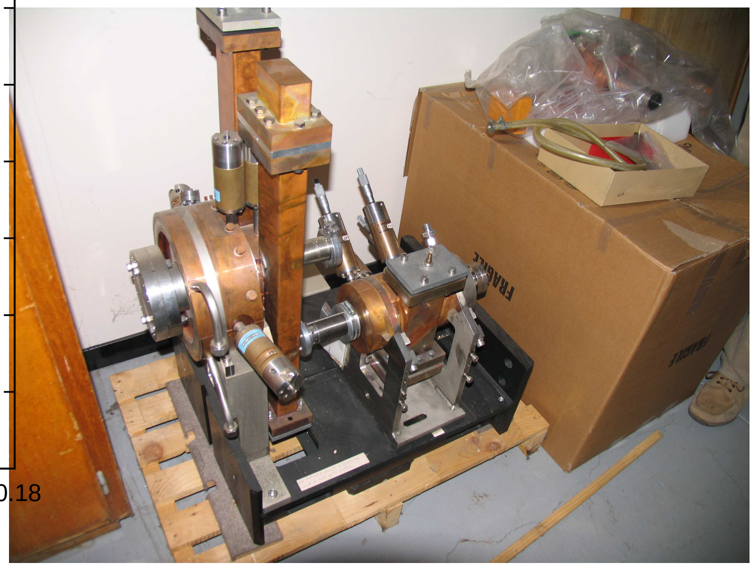

Optimization with 120 MV/m

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32 A - Good Projected Emittance & High Peak Current

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

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

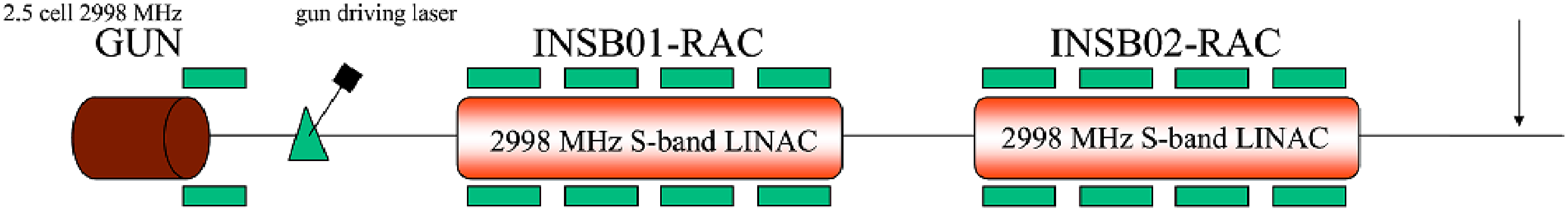
I_{peak} = 32 A

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



120.0 MV/m
42.38 degree
from zero crossing

13.58 MV/m
0.0 degree

18.80 MV/m
0.0 degree

E = 7.920 MeV　　E = 67.700 MeV　　E = 150.72 MeV

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 17th, 2008 by Y. Kim

Optimization with 120 MV/m @ 13 m

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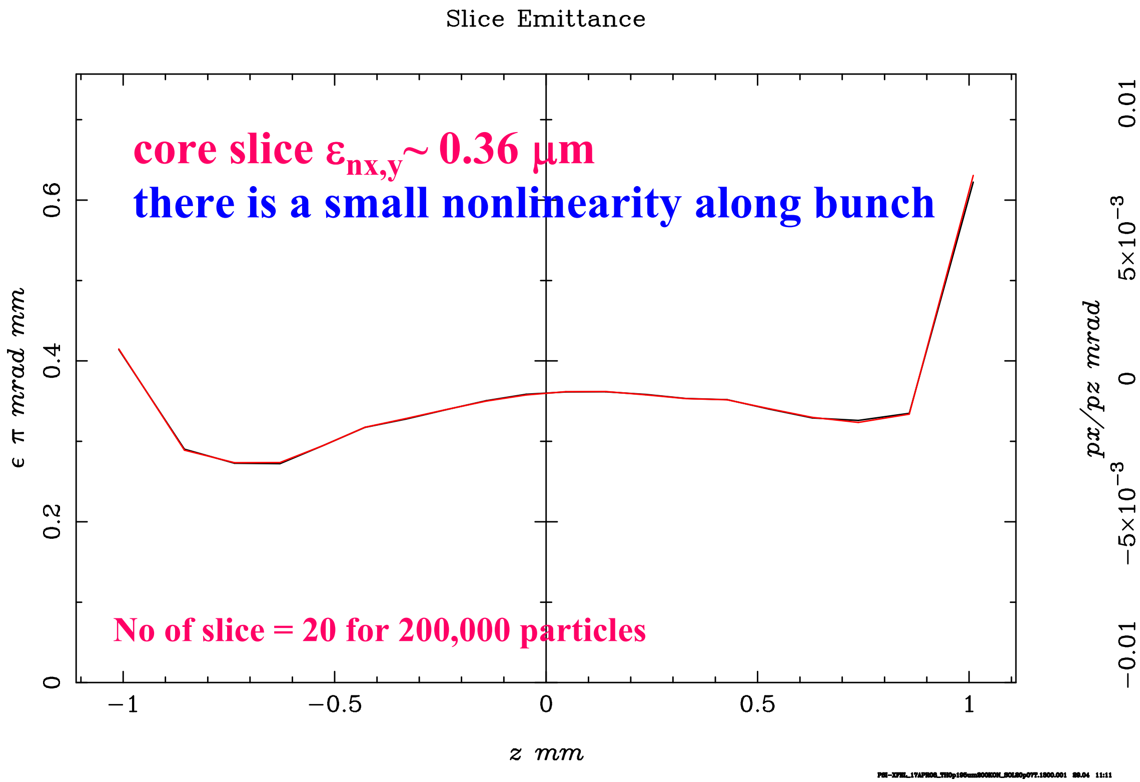
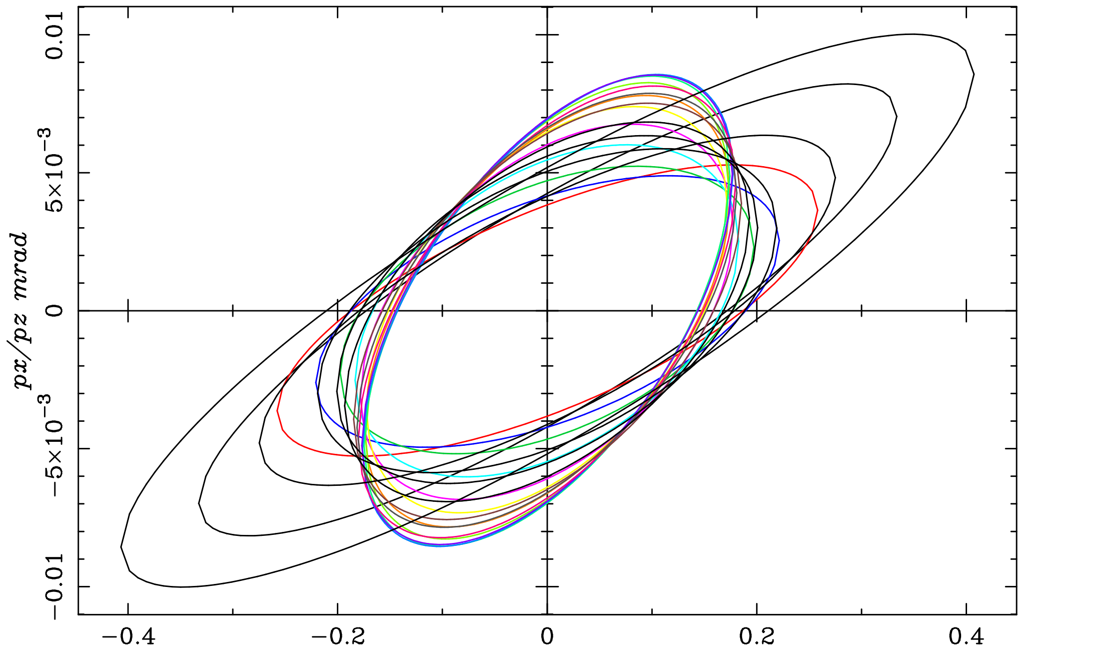
ASTRA Tracking results from the cathode to 150 MeV with 200,000 particles





difficulty due to a higher beam energy @ gun exit

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

Q = 0.2 nC, I_{peak} ~ 32 A

Optimization with 120 MV/m @ 13 m

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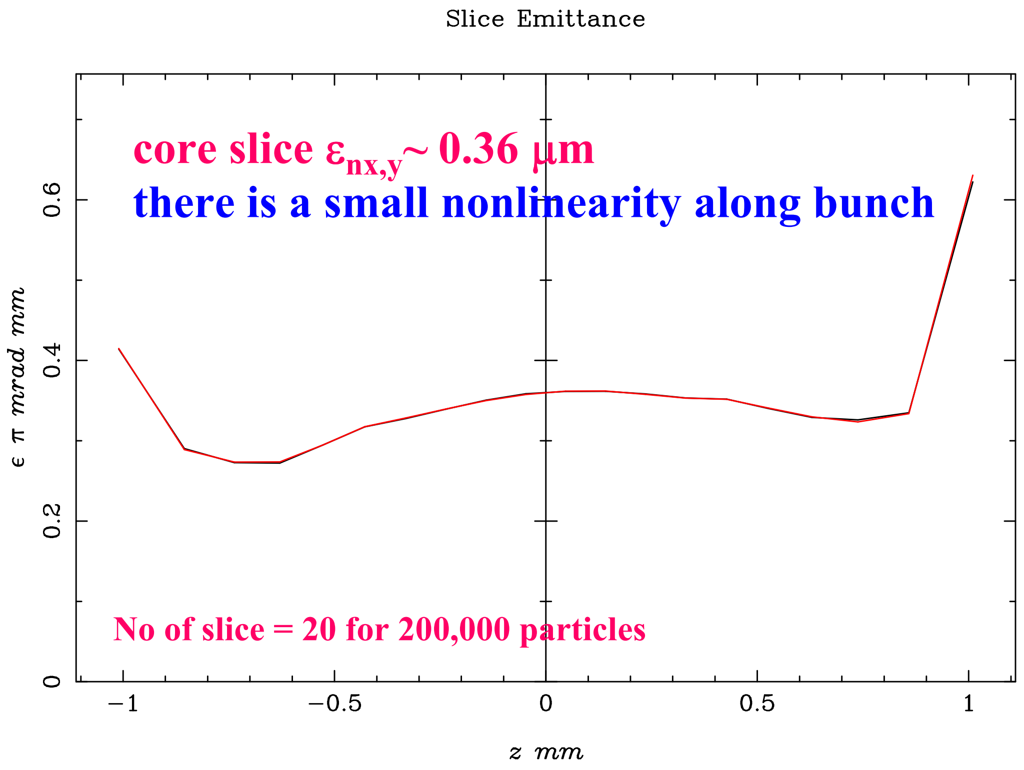
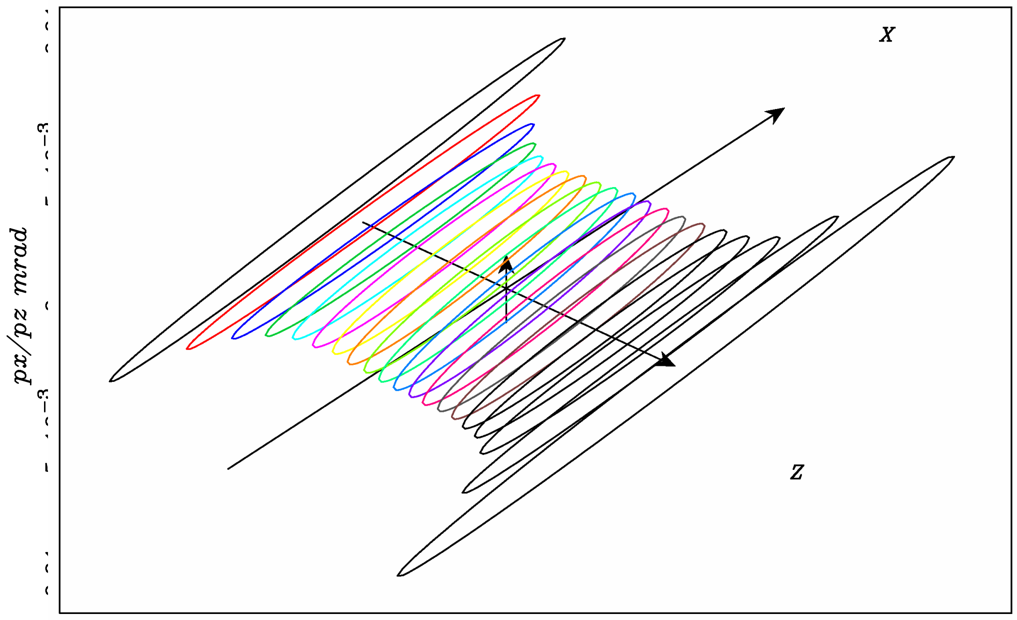
ASTRA Tracking results from the cathode to 150 MeV with 200,000 particles





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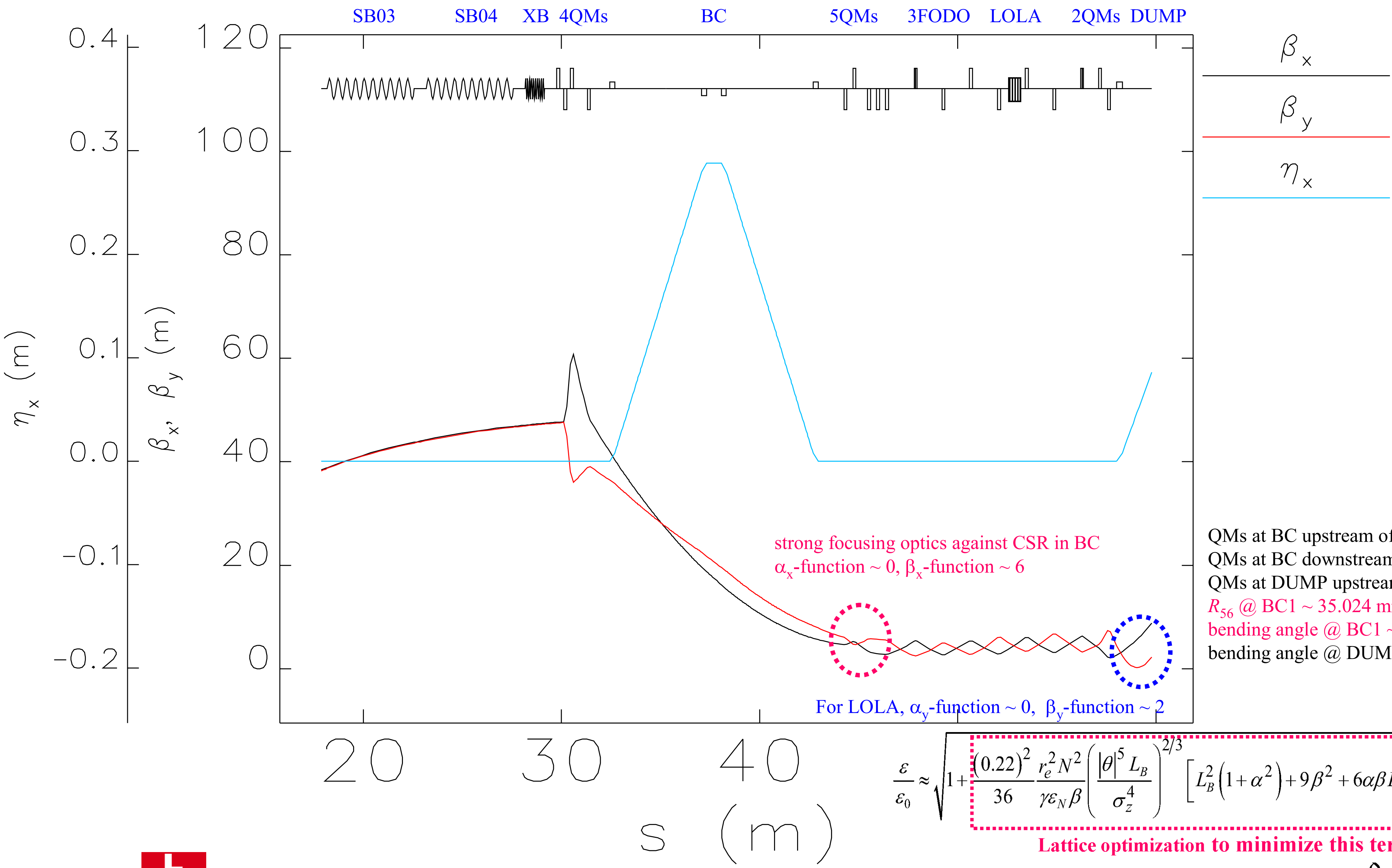
S2E Simulation with 120 MV/m

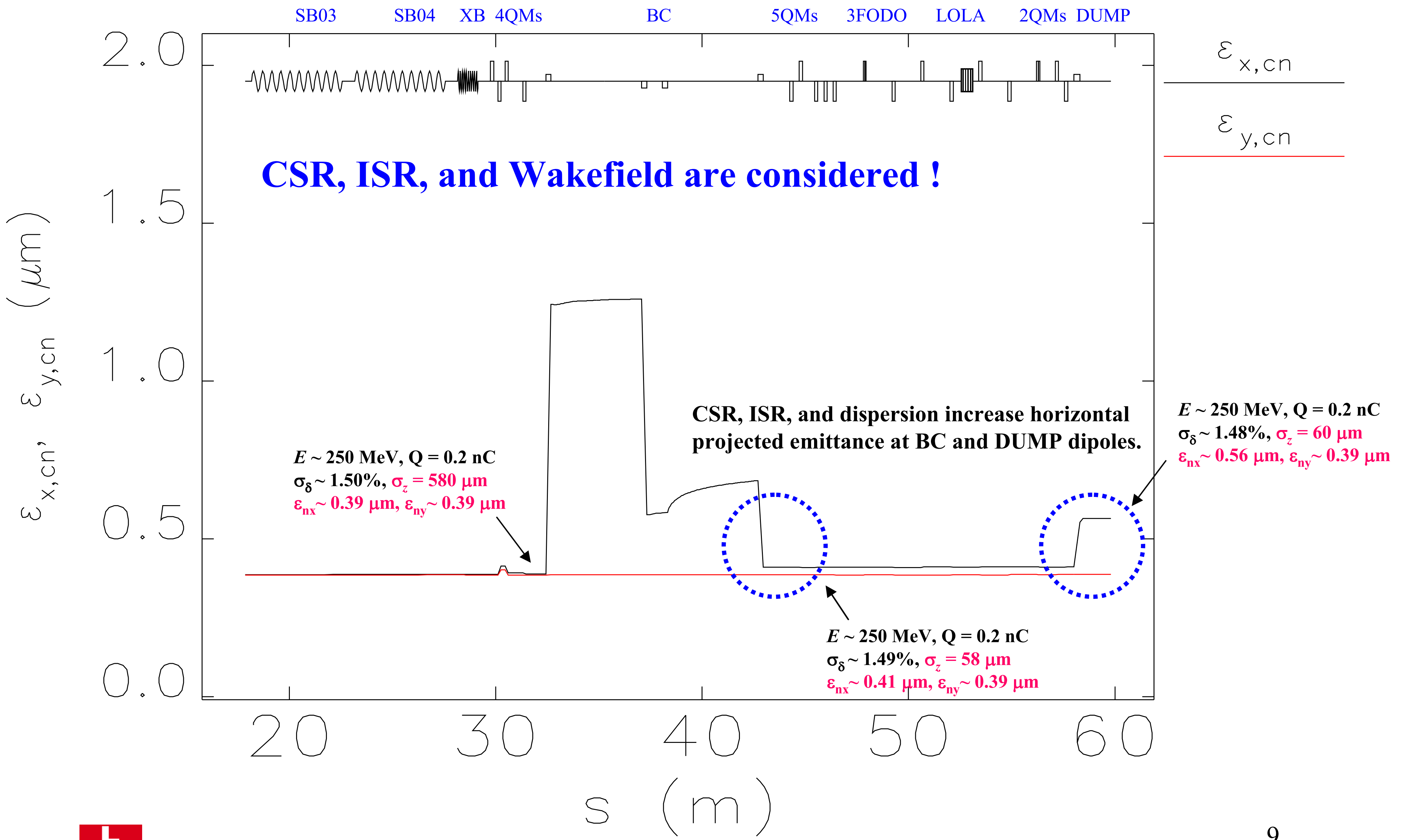


QMs at BC upstream of BC = 4
QMs at BC downstream = 5
QMs at DUMP upstream = 2
R_{56} @ BC1 ~ 35.024 mm
bending angle @ BC1 ~ 3.55 deg
bending angle @ DUMP ~ 3 deg

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

Lattice optimization to minimize this term

S2E Simulation with 120 MV/m



Optimization with 100 MV/m 2nd Version

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

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

$B_{sol} \sim 0.255$ T

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

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

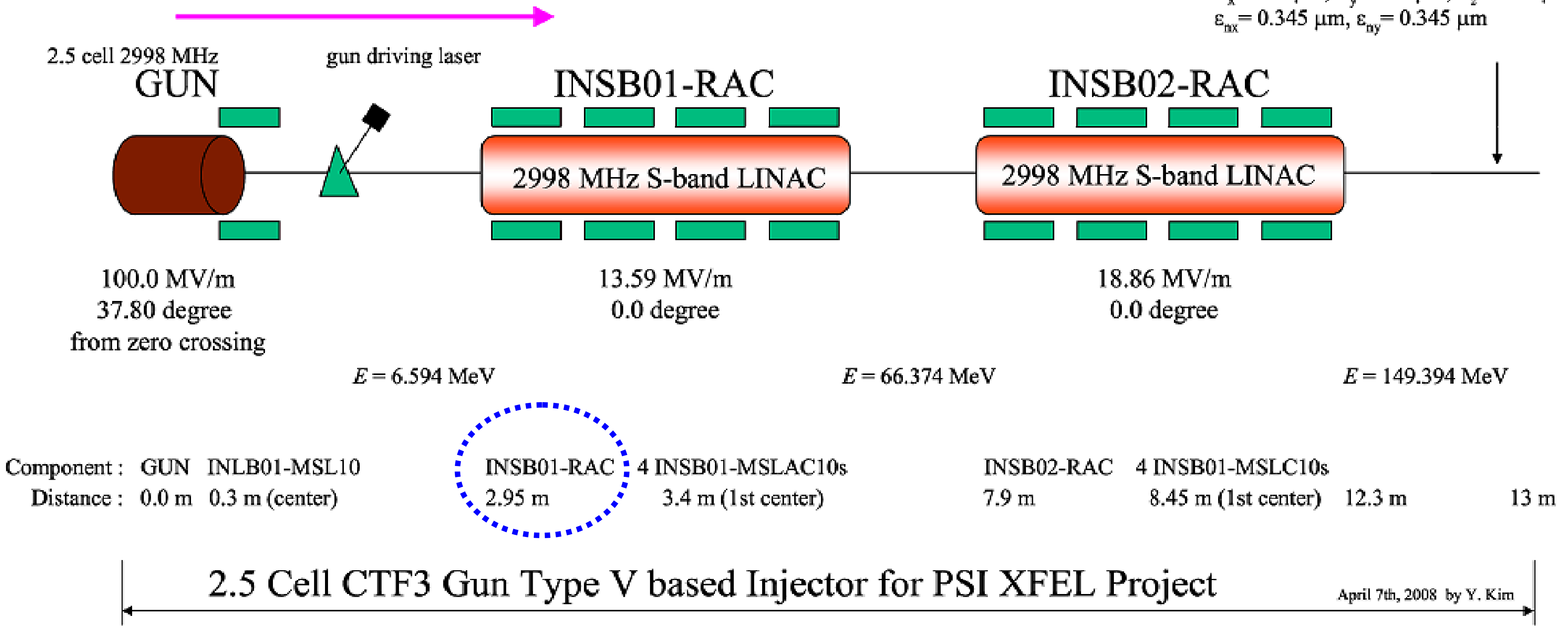
I_{peak} = 22 A

E = 149.394 MeV

σ_δ = 0.163%

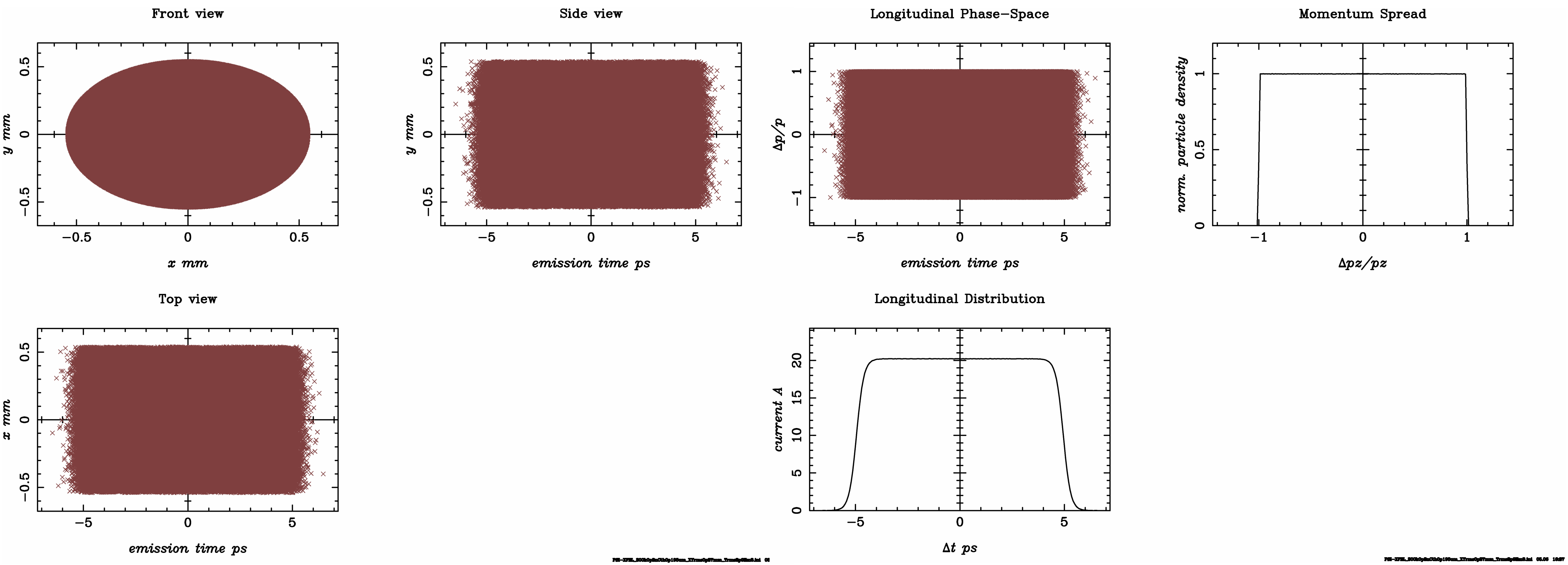
σ_x = 211 μm, σ_y = 211 μm, σ_z = 840 μm

ε_{nx} = 0.345 μm, ε_{ny} = 0.345 μm



Gun Driving Laser for 100 MV/m 2nd Version

22 A - Low Project Emittance & Somewhat Low Slice Emittance
INSB01 @ 2.95 m



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

e-beams : Q **~ 0.2 nC,** I_{peak} **~ 22 A,** $\varepsilon_{thermal}$ **= 0.195 μm**

Optimization with 100 MV/m 2nd Version

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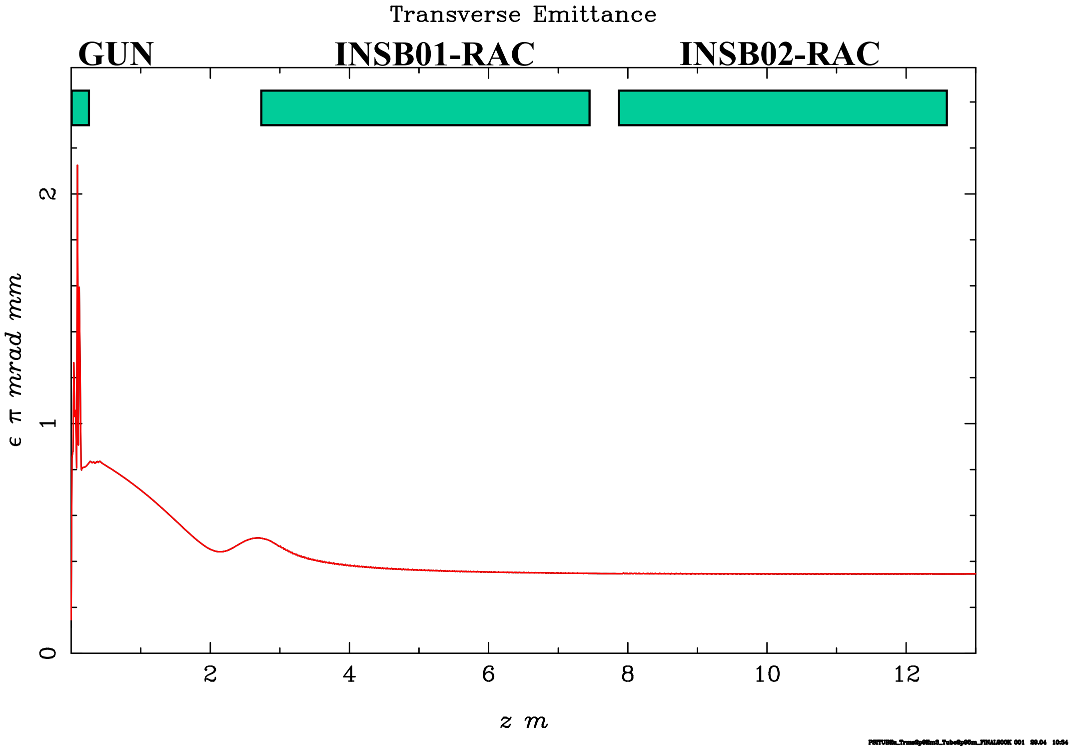
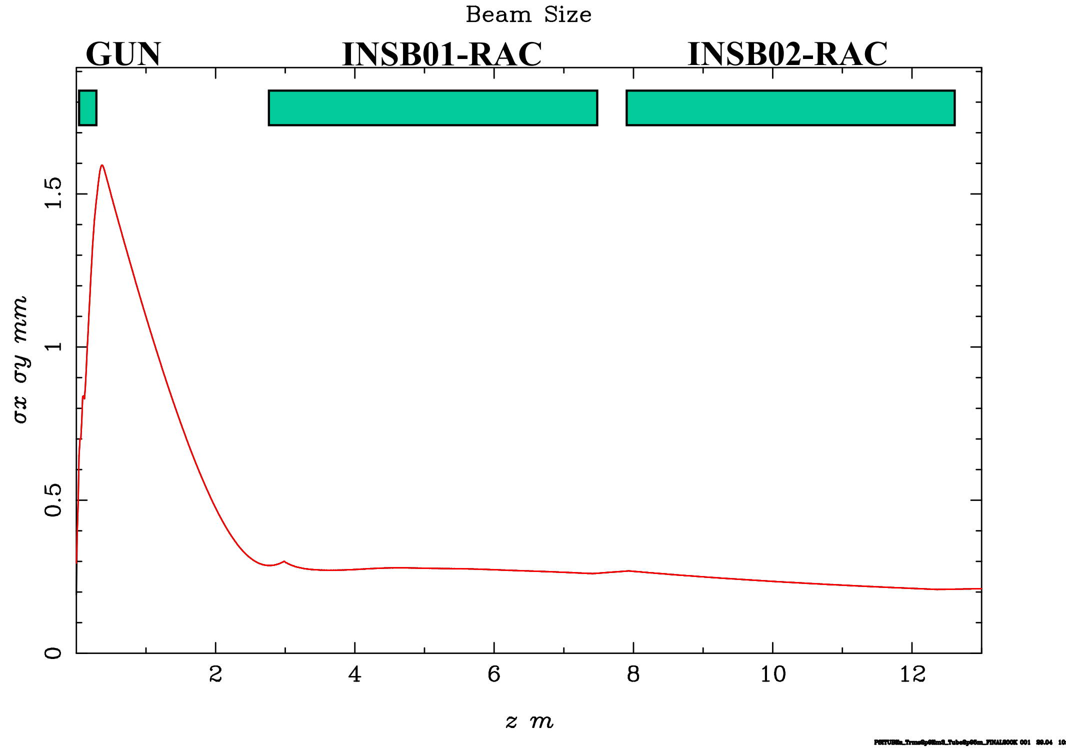
22 A - Low Project Emittance & Somewhat Low Slice Emittance
INSB01 @ 2.95 m





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

Q = 0.2 nC, I_{peak} ~ 22 A

Optimization with 100 MV/m 2nd Version

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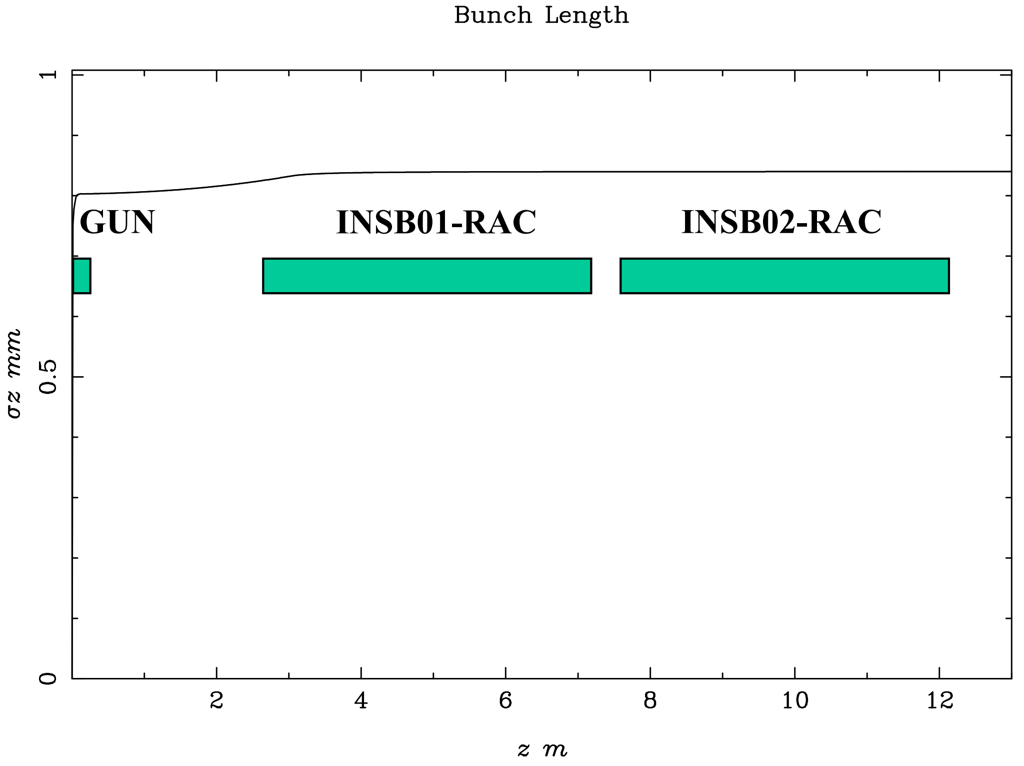
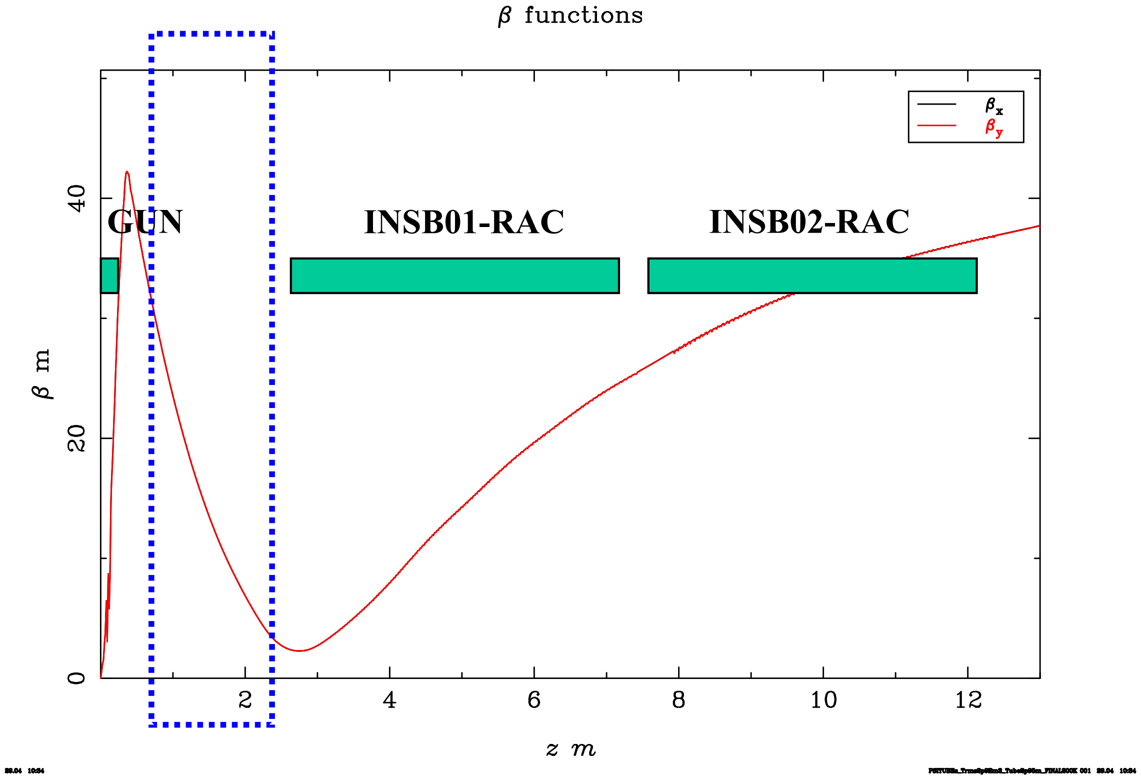
22 A - Low Project Emittance & Somewhat Low Slice Emittance
INSB01 @ 2.95 m

~ 2 m space for low energy diagnostic section





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

ε_{nx}= 0.345 µm, ε_{ny}= 0.345 µm

Q = 0.2 nC, I_{peak} ~ 22 A

Optimization with 100 MV/m @ 13 m

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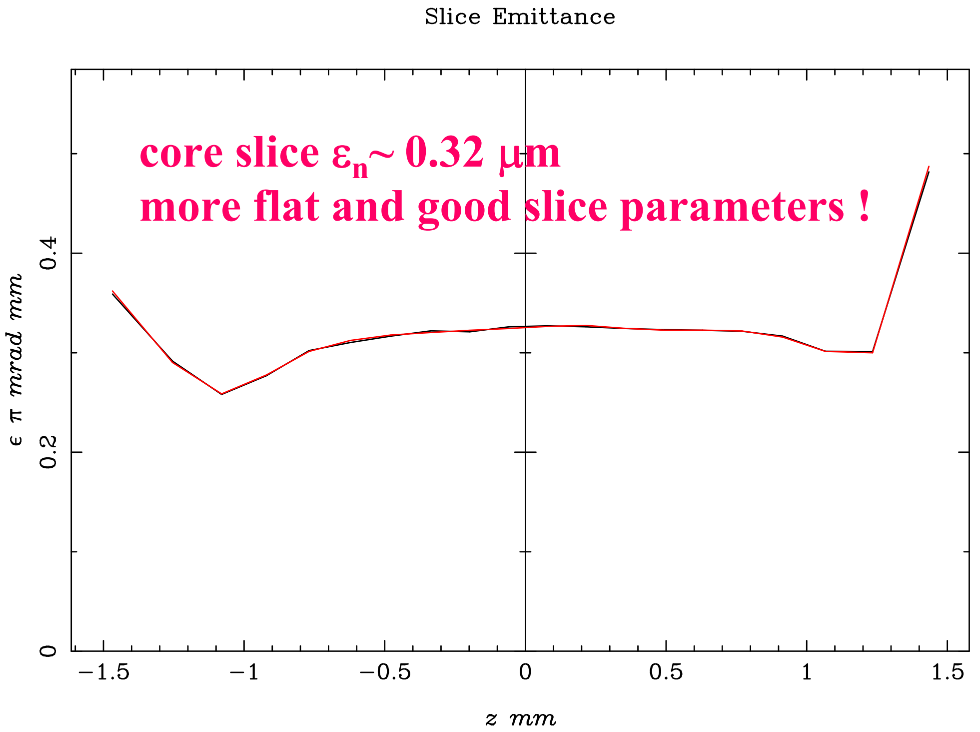
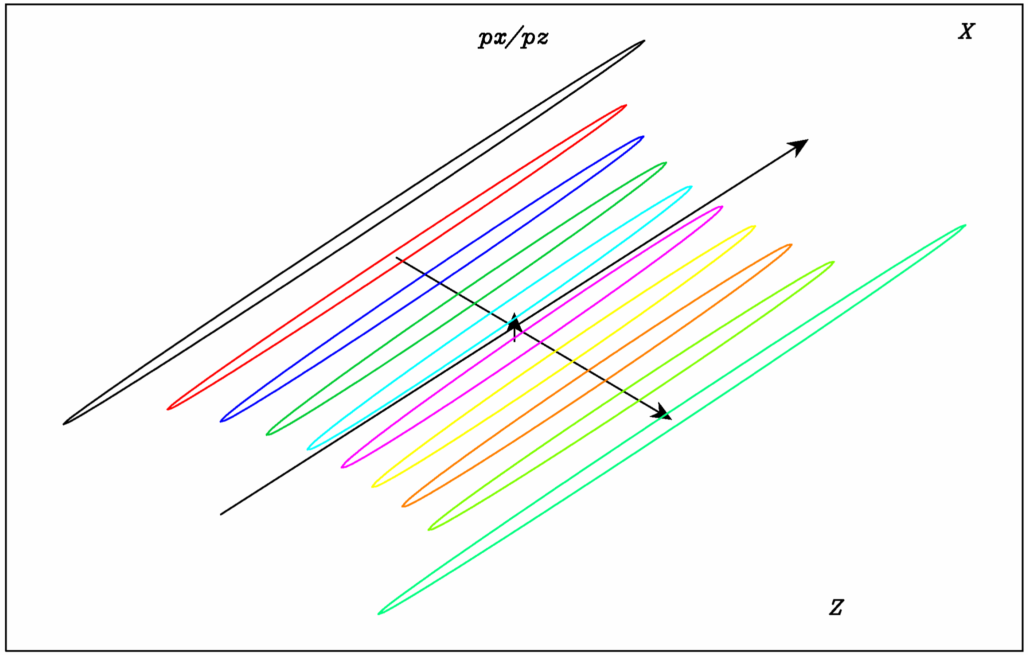
22 A - Low Project Emittance & Somewhat Low Slice Emittance
INSB01 @ 2.95 m





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

Q = 0.2 nC, I_{peak} ~ 22 A

Slice Twiss Parameter Mismatching @ 13 m

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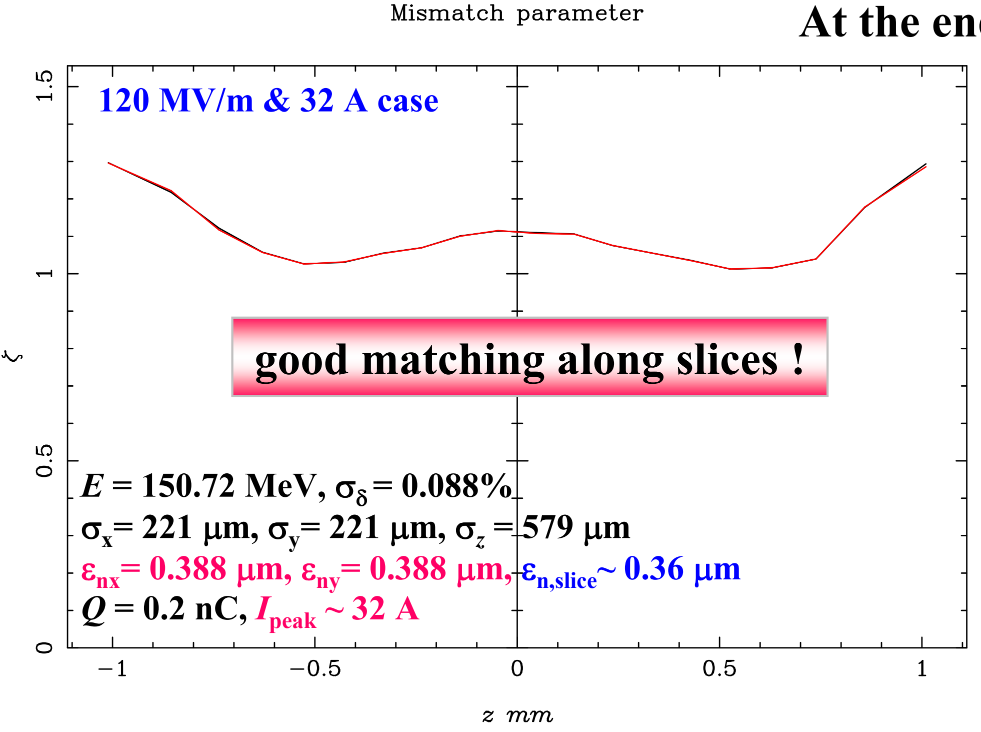
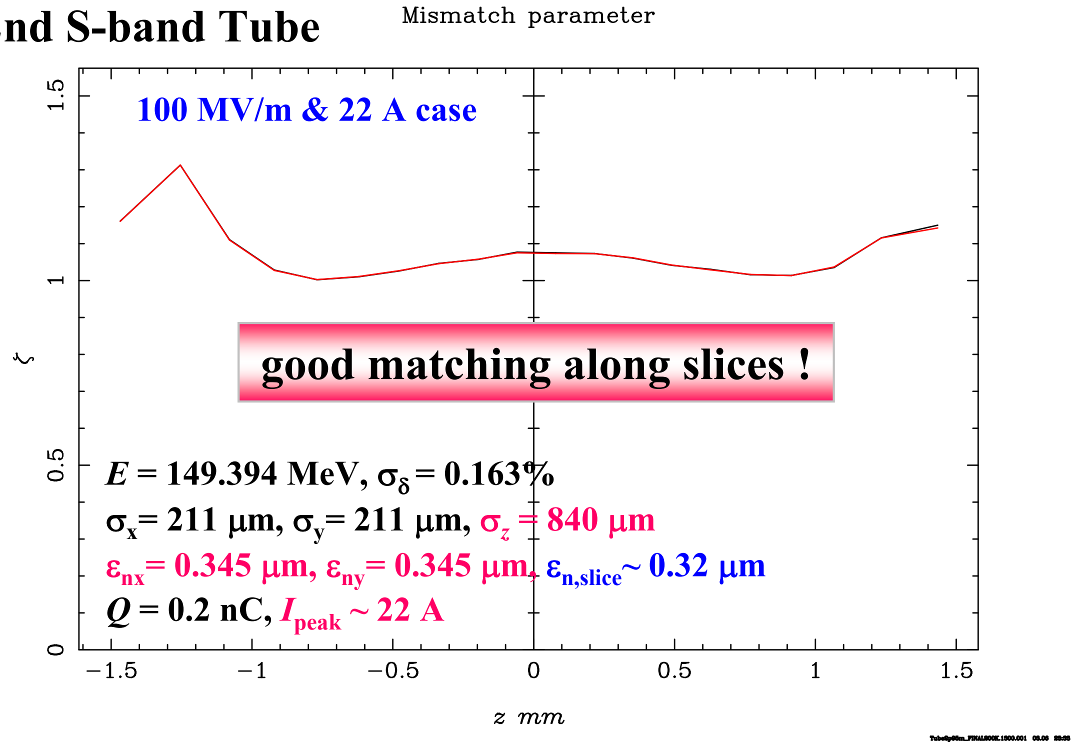
32 A - Project Emittance ~ Slice Emittance
laser $\sigma_{x,y}$ = 270 μm, ΔT = 5.8 ps (FWHM), INSB01@ 2.95 m

22 A - Project Emittance ~ Slice Emittance
laser $\sigma_{x,y}$ = 270 μm, ΔT = 9.9 ps (FWHM), INSB01@ 2.95 m

At the end of 2nd S-band Tube



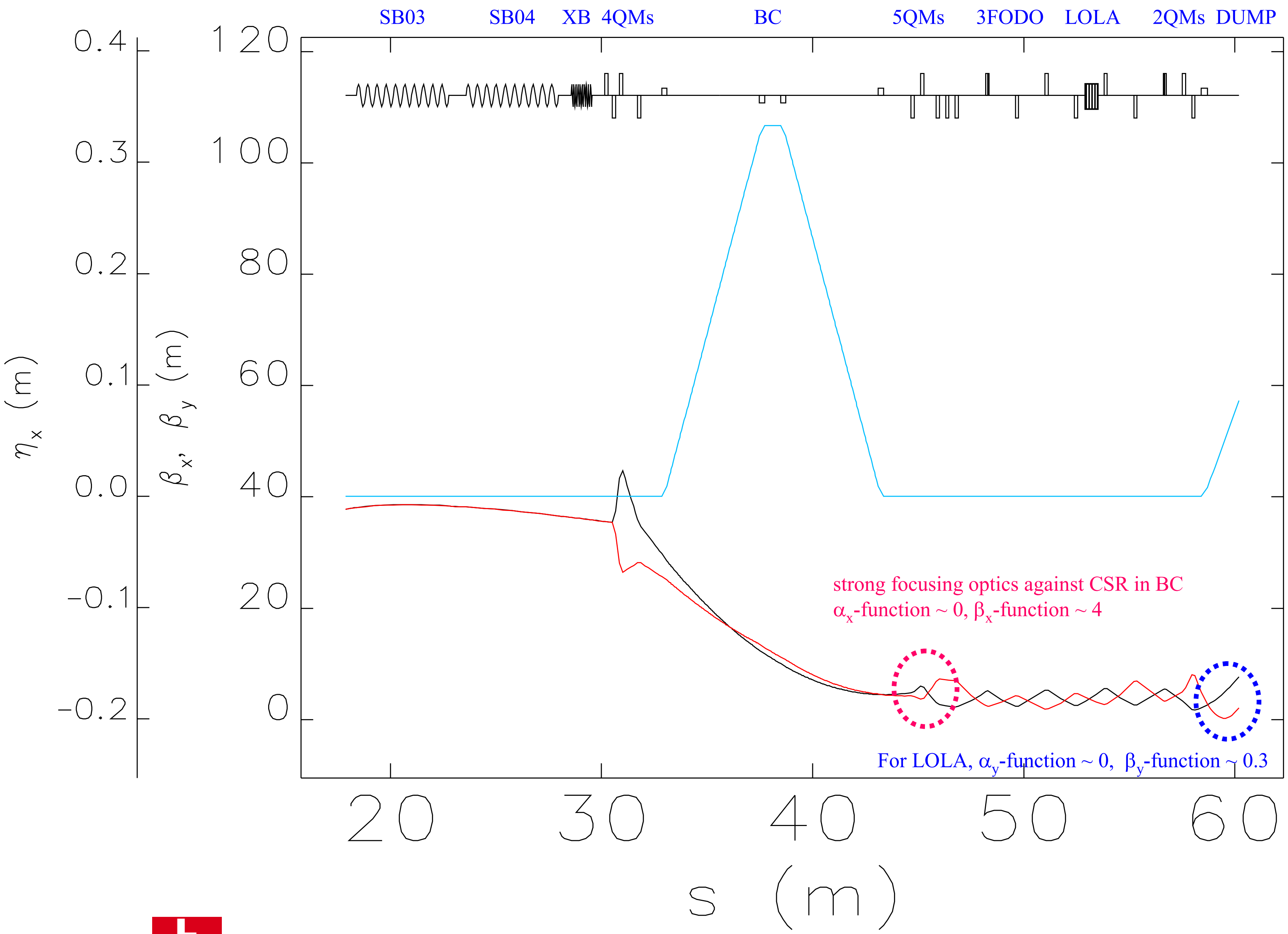


$$\varsigma = \frac{1}{2}(\beta_0\gamma - 2\alpha_0\alpha + \gamma_0\beta) \approx 1.0$$

$\alpha_0, \beta_0, \gamma_0$ = Twiss parameters of an integrated bunch

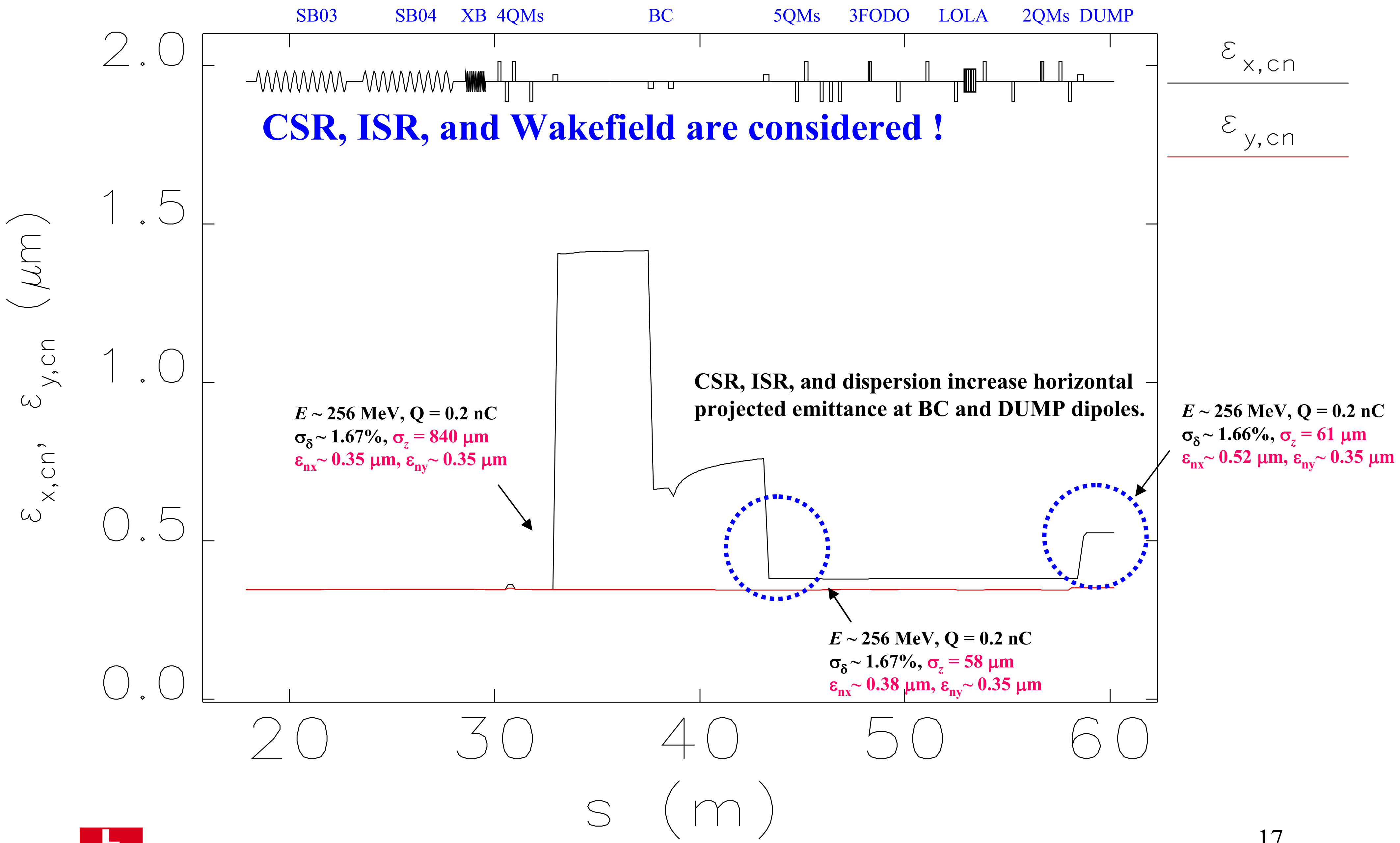
α, β, γ = Twiss parameters of each slice

S2E Simulation with 100 MV/m 2nd Version



QMs at BC upstream of BC = 4
QMs at BC downstream = 5
QMs at DUMP upstream = 2
R_{56} @ BC1 ~ 46.8 mm
bending angle @ BC1 ~ 4.1 deg
bending angle @ DUMP ~ 3 deg

S2E Simulation with 100 MV/m 2nd Version



S2E Simulation with 100 MV/m 2nd Version

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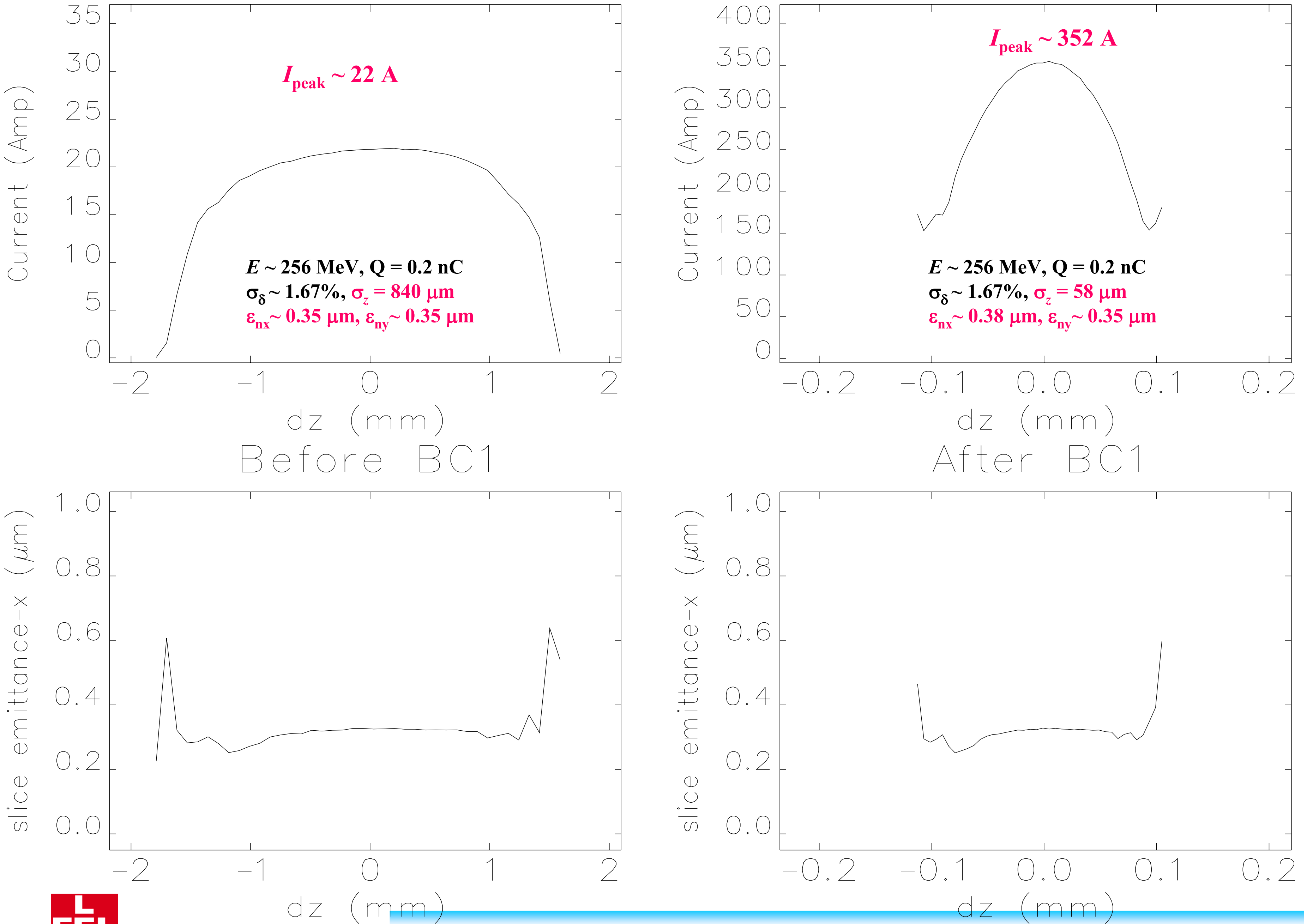

S2E Simulation with 100 MV/m 2nd Version

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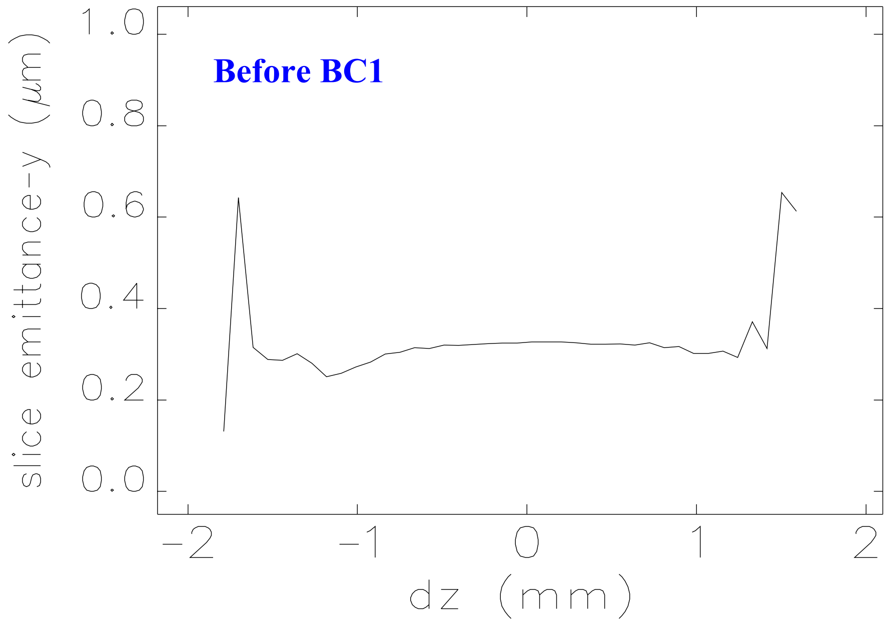
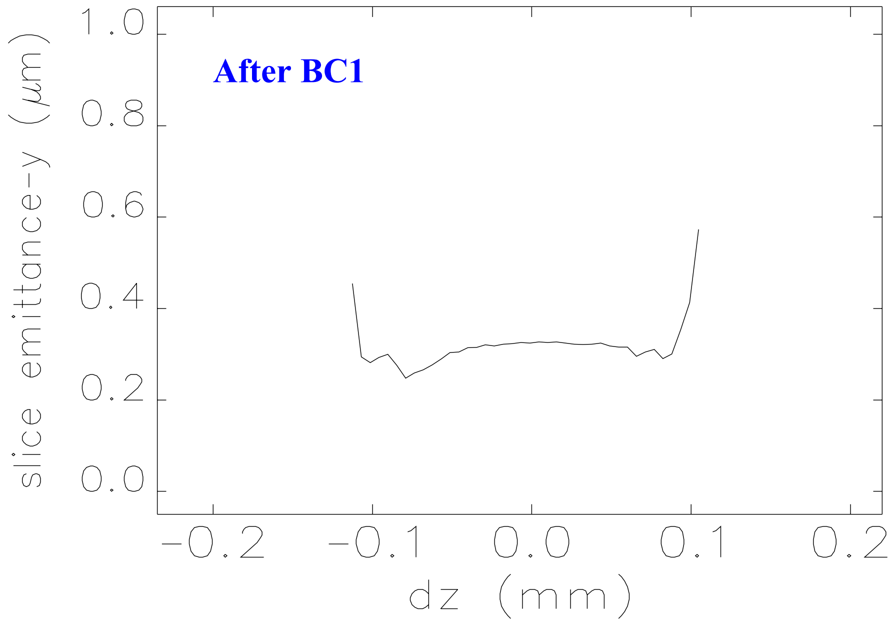
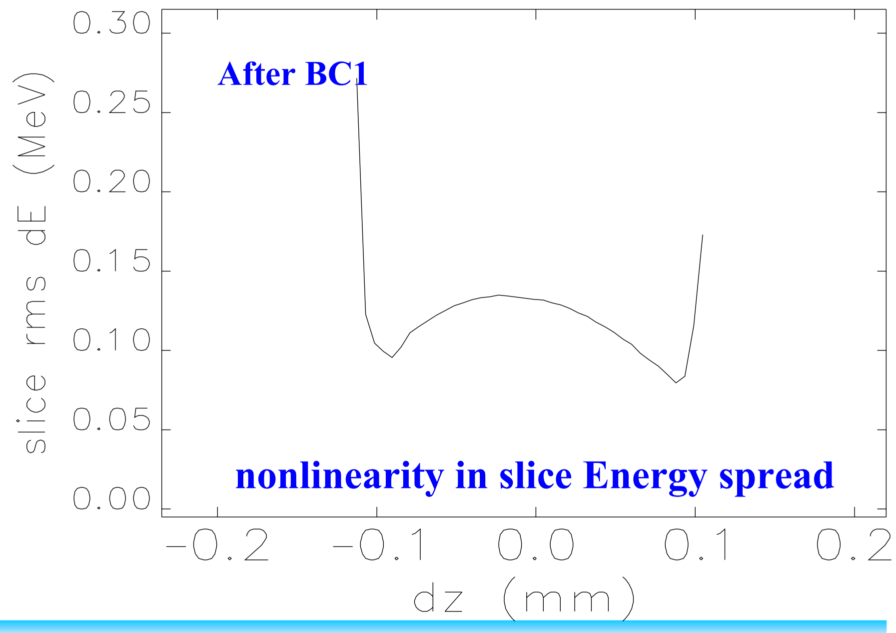




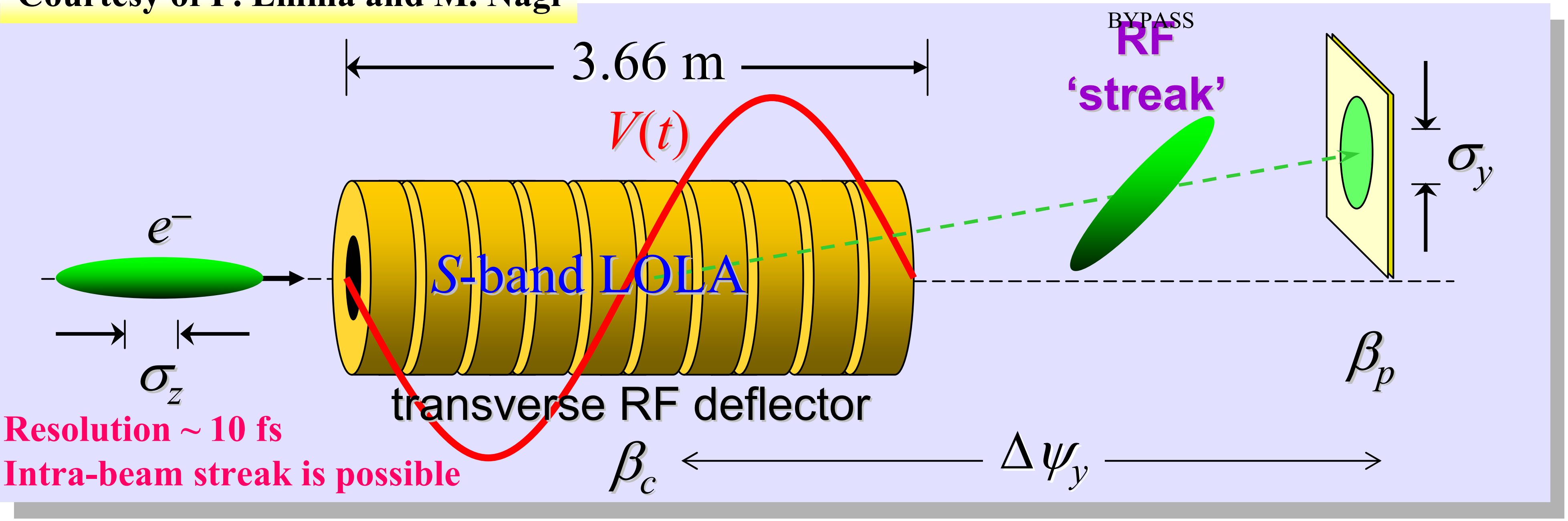
$$\frac{\varepsilon}{\varepsilon_0} \approx \sqrt{1+\frac{(0.22)^2}{36}\frac{r_e^2 N^2}{\gamma \varepsilon_N \beta}\left(\frac{|\theta|^5 L_B}{\sigma_z^4}\right)^{2/3}\left[L_B^2\left(1+\alpha^2\right)+9\beta^2+6\alpha\beta L_B\right]}$$

Lattice optimization to minimize this term



Lattice for LOLA Operation

Courtesy of P. Emma and M. Nagl



Resolution ~ 10 fs

Intra-beam streak is possible

$$\sigma_y = \sqrt{\sigma_{y0}^2 + \sigma_z^2 \beta_c \beta_p \left(\frac{2\pi e V_0}{\lambda E_0} \sin \Delta\psi_y \cos\varphi \right)^2}$$

$$\langle \Delta y \rangle = \frac{eV_0}{E_0} \sqrt{\beta_c \beta_p} \sin\Delta\psi_y \sin\varphi, \qquad V_0 \approx \left(1.6\ \text{MV/m/MW}^{1/2}\right) L \sqrt{P_0}$$

For resolution

β_y @ LOLA ~ 40 m

β_y @ OTR ~ 5 m

$\Delta\psi_y$ ~ 60 degree

$\sigma_z \approx 25\ \mu m$

$E_0 \approx 0.6$ GeV

$(\beta_c\beta_p)^{1/2} \approx 51$ m

$\gamma\varepsilon_y \approx 5\ \mu m$

$\Delta\psi_y \approx 15.8°$

$\varphi \approx 0°$

$\lambda \approx 105$ mm

$\sigma_{y0} \approx 317\ \mu m$

$L \approx 3.66$ m, $V_0 \approx 25$ MV,

$P_0 \approx 18$ MW

$\sigma_y \approx 925\ \mu m$

Current Optics for LOLA Operation

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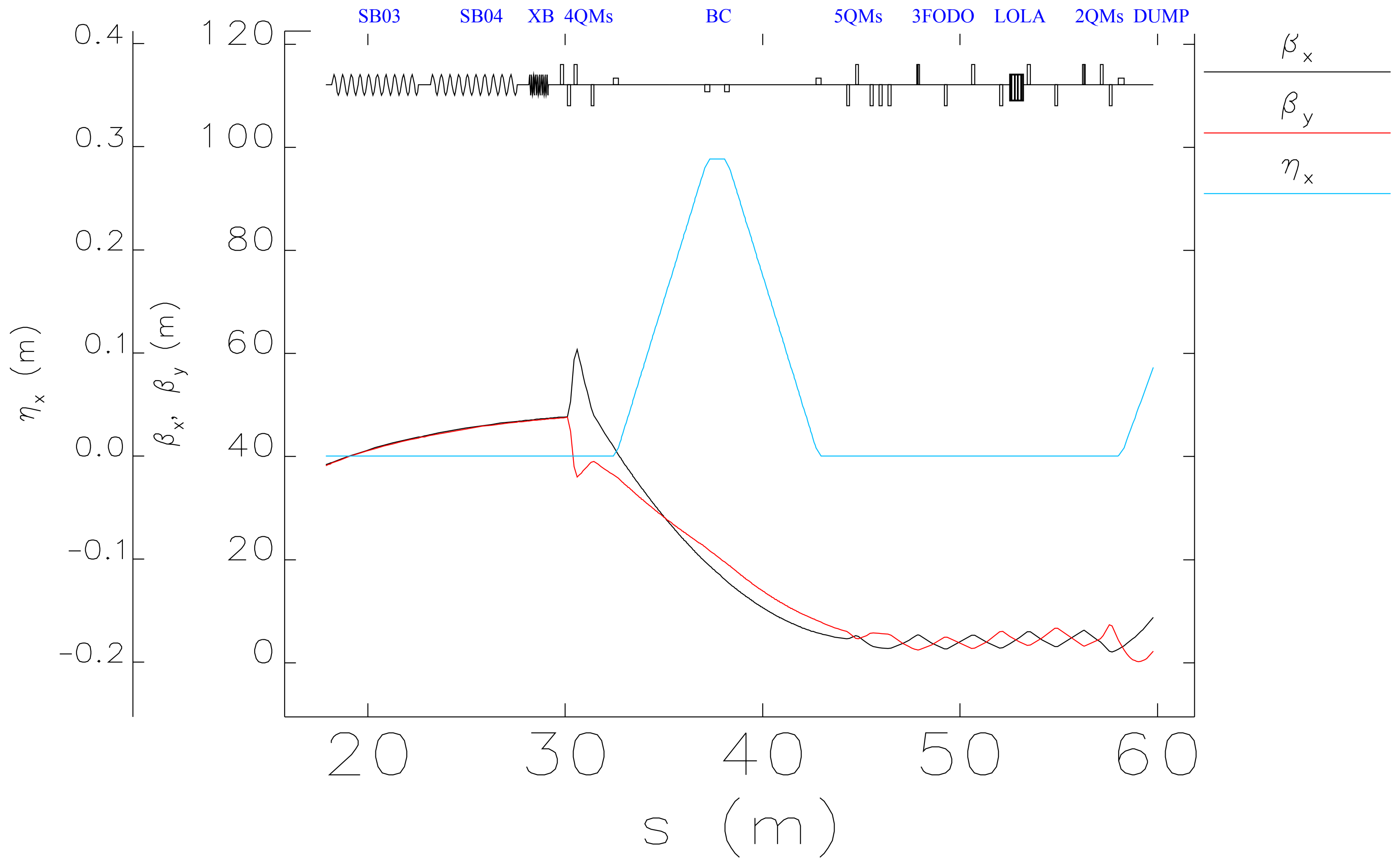

bunch Length = turn on LOLA & no optics change
bunch Length for a higher resolution = turn on LOLA & modified new optics
longitudinal phase space reconstruction = turn on LOLA & no change
slice emittance = severl modified optics to get sufficient horizontal phase advance

Current Optics for LOLA Operation

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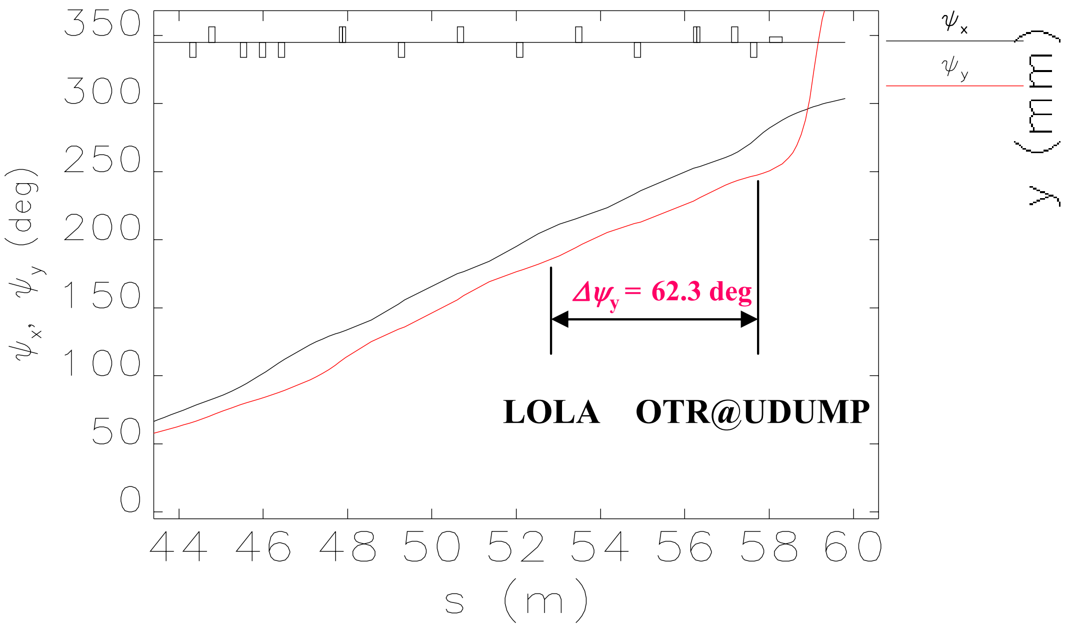
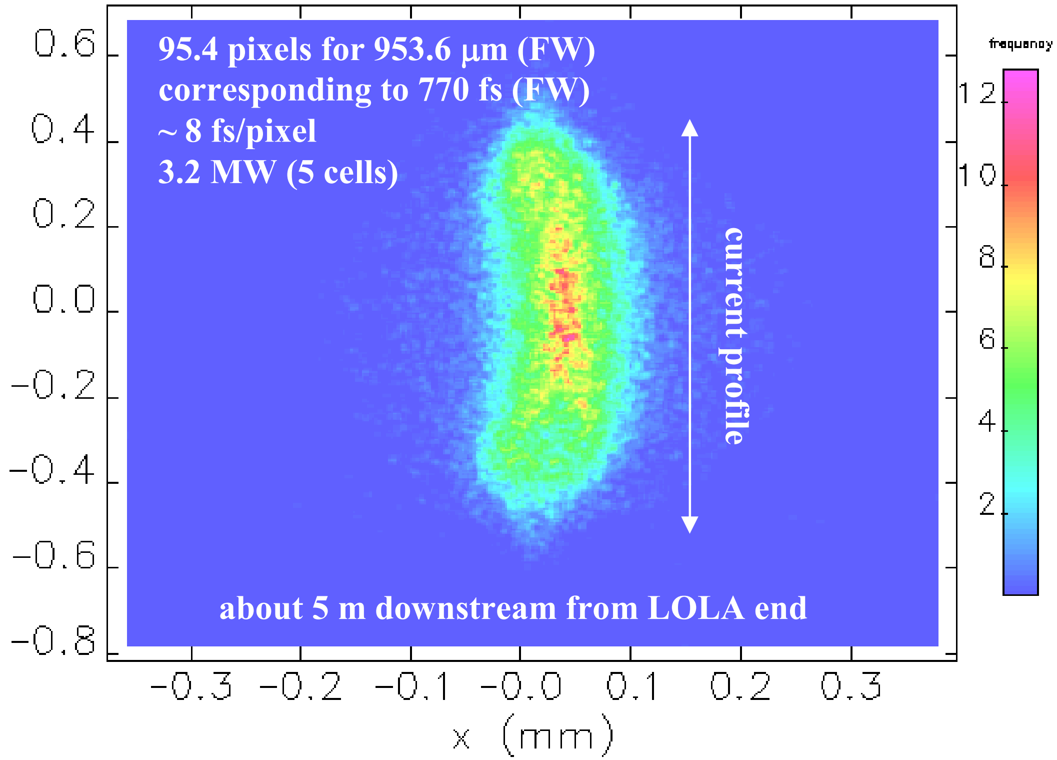
with 4 MV (5 cells) at OTR@UDUMP (just upstream of DUMP dipole)

σ_x= 59 μm @ LOLA
σ_y= 58 μm @ LOLA
σ_x= 47.3 μm @ UDUMP
σ_y= 238.4 μm @UDUMP
$\Delta\psi_y$ = 62.3 degree from center of LOLA
β_y @ LOLA ~ 4.0 m (~ 40 m with a changed optics)
β_y @ UDUMP ~ 4.5 m



Phase Advance for LOLA Operation

Bunch Length Measurement



OTR@UDUMP

$$P_{RF}[\mathrm{MW}] \sim \frac{V[\mathrm{MV}]^2}{n}, \quad E_{peak,surf}[\mathrm{MV/m}] \sim 90\sqrt{\frac{P_{RF}[\mathrm{MW}]}{n}}$$

Optics for Bunch Length - Better Resolution

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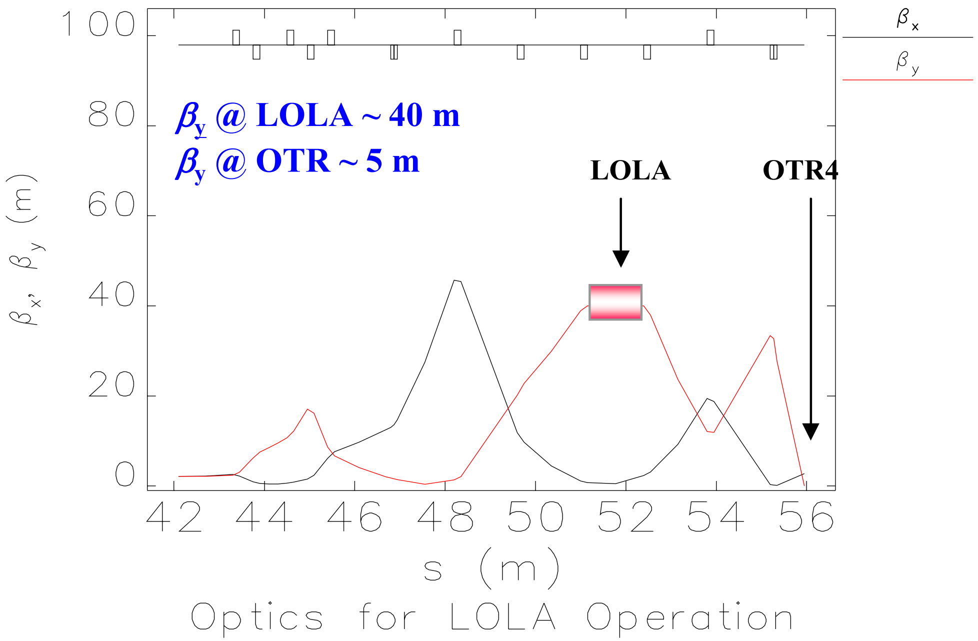

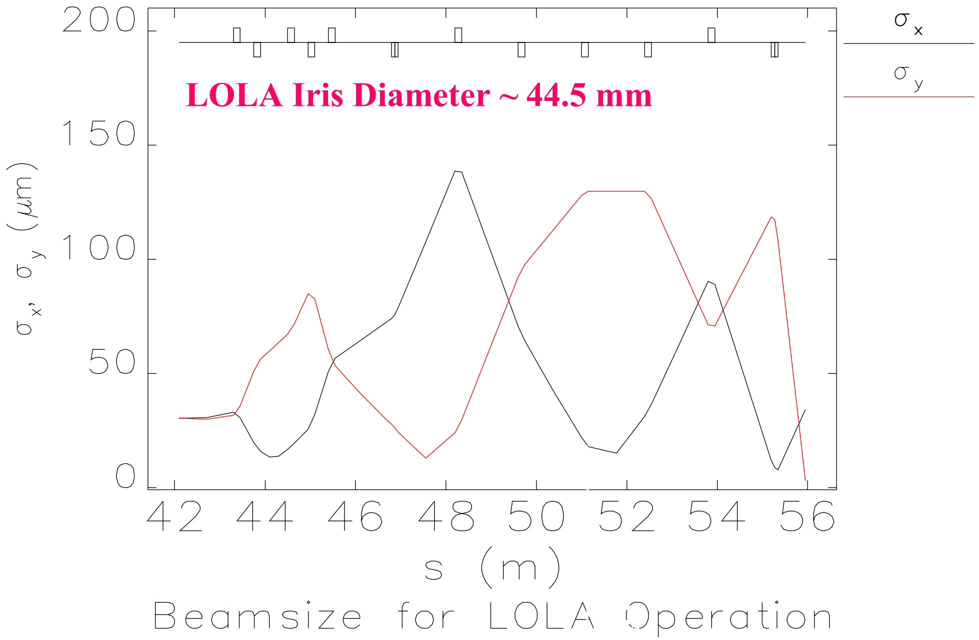

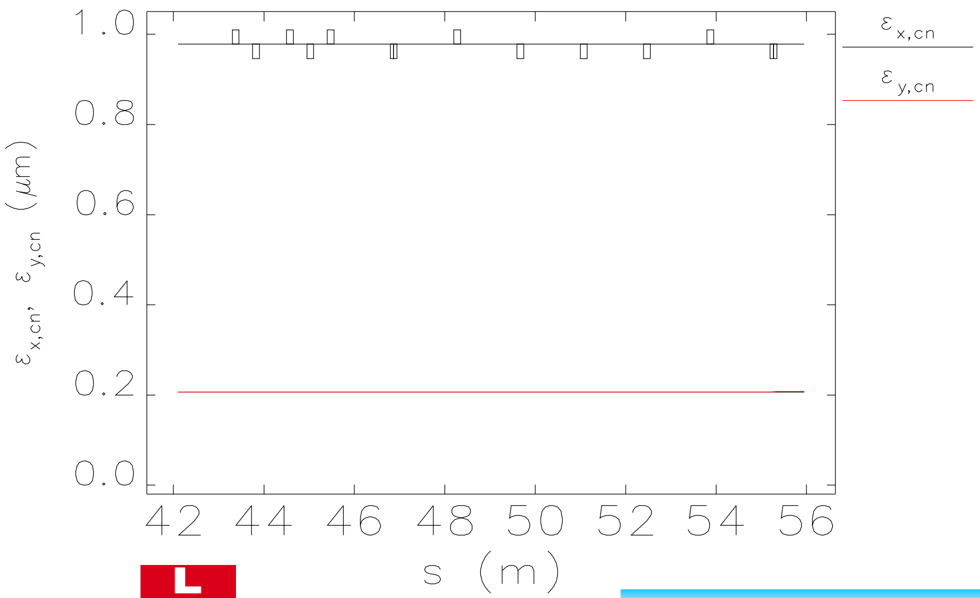

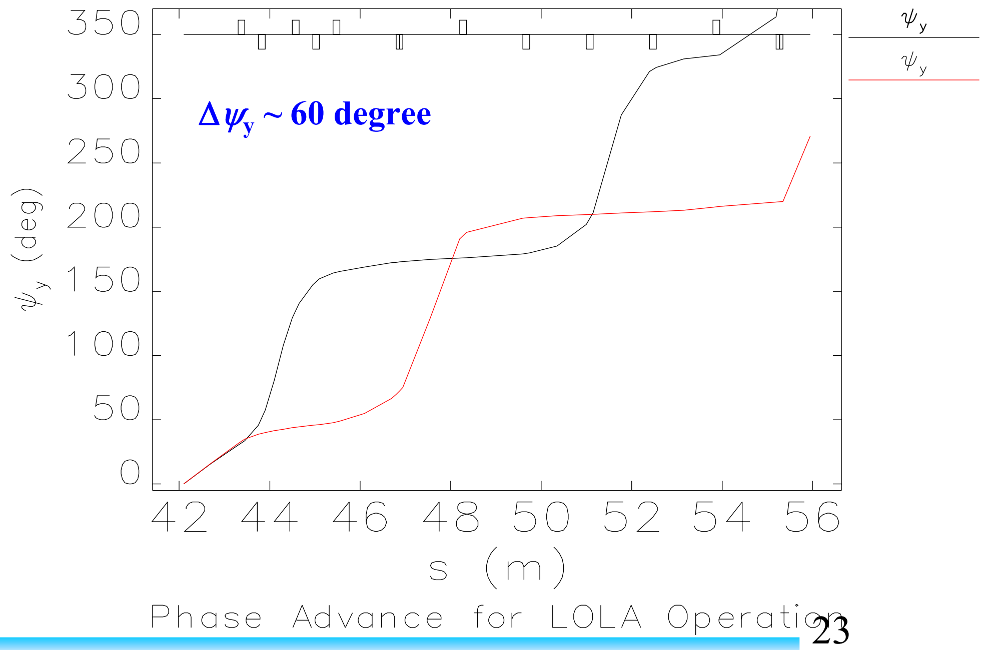

Longitudinal Phase Space Reconstruction

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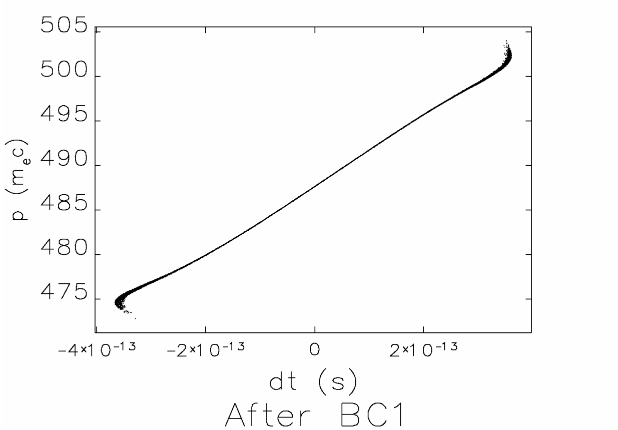
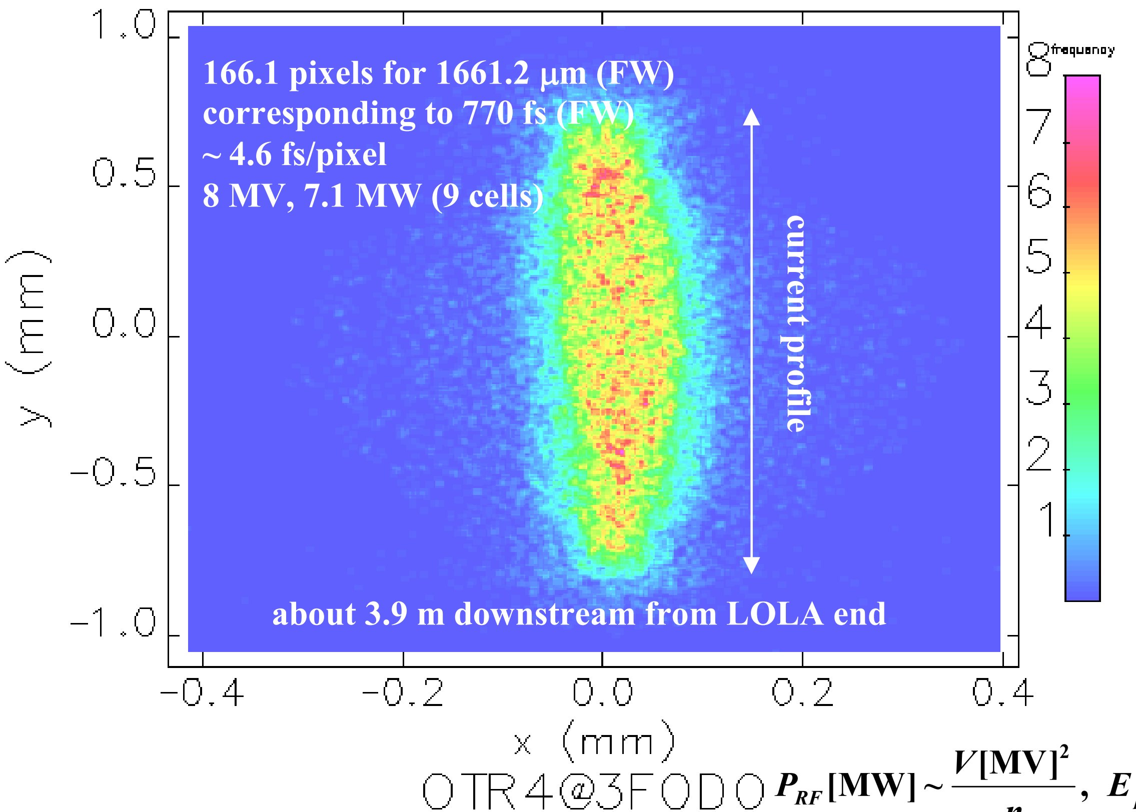
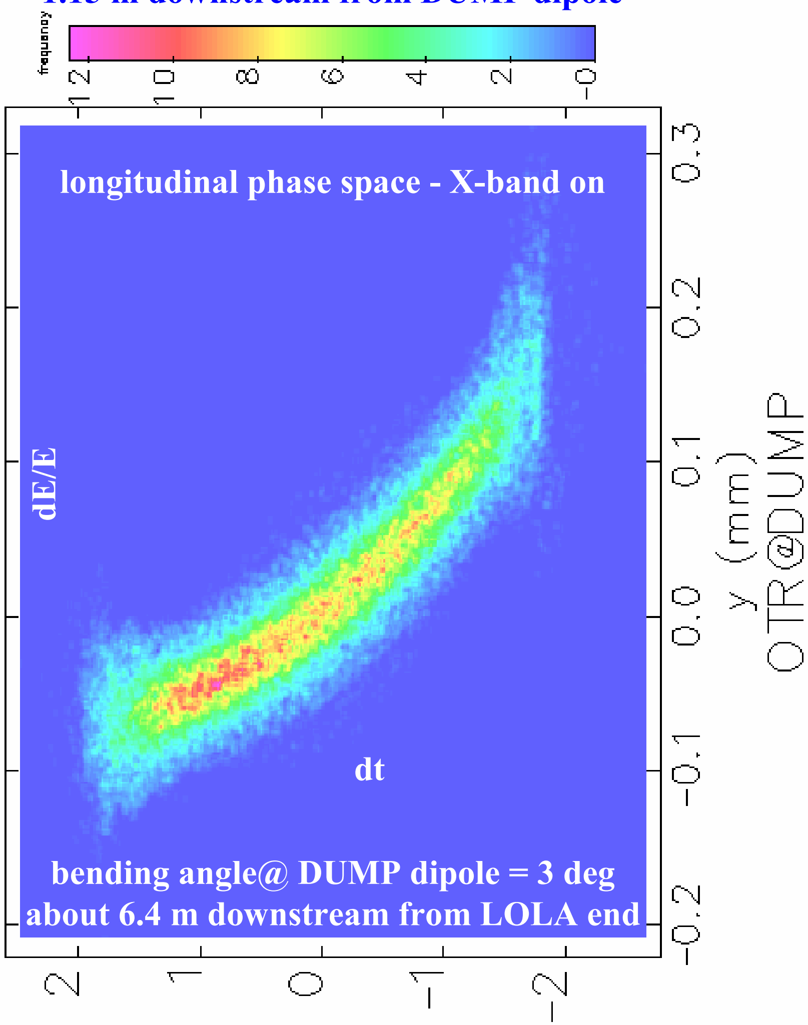


bunch length (rms) ~ 193 fs / 57.9 μm
bunch length (FWHM) ~ 455 fs
bunch length (FW) ~ 770 fs
σ_x = 60.2 μm @ OTR4
σ_y = 415.3 μm @ OTR4
σ_x = 1.014 mm @ DUMP
σ_y = 71.4 μm @ DUMP

DUMP Dipole = On

1.15 m downstream from DUMP dipole

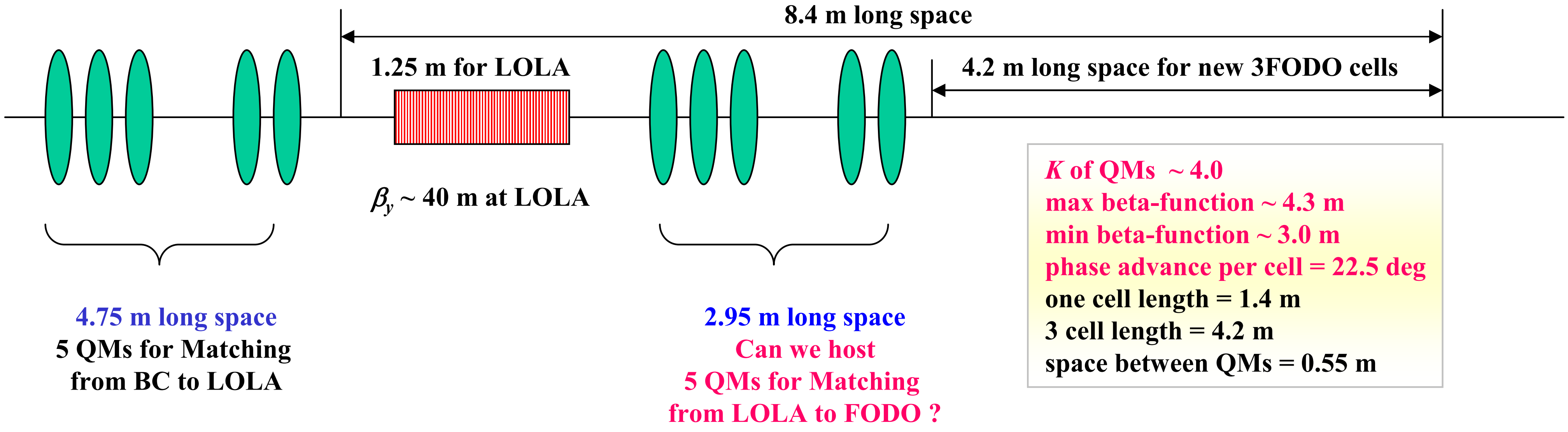




$$P_{RF}[\text{MW}] \sim \frac{V[\text{MV}]^2}{n}, \quad E_{peak,surf}[\text{MV/m}] \sim 90\sqrt{\frac{P_{RF}[\text{MW}]}{n}}$$

Possible LOLA Layout for Slice Emittance

1.4 m long FODO + 22.5 deg phase advance



K of QMs ~ 4.0
max beta-function ~ 4.3 m
min beta-function ~ 3.0 m
phase advance per cell = 22.5 deg
one cell length = 1.4 m
3 cell length = 4.2 m
space between QMs = 0.55 m

We have to check with simulations.
But at the moment, it seems that we need a longer space to choose this layout.

LOLA Layout for European XFEL

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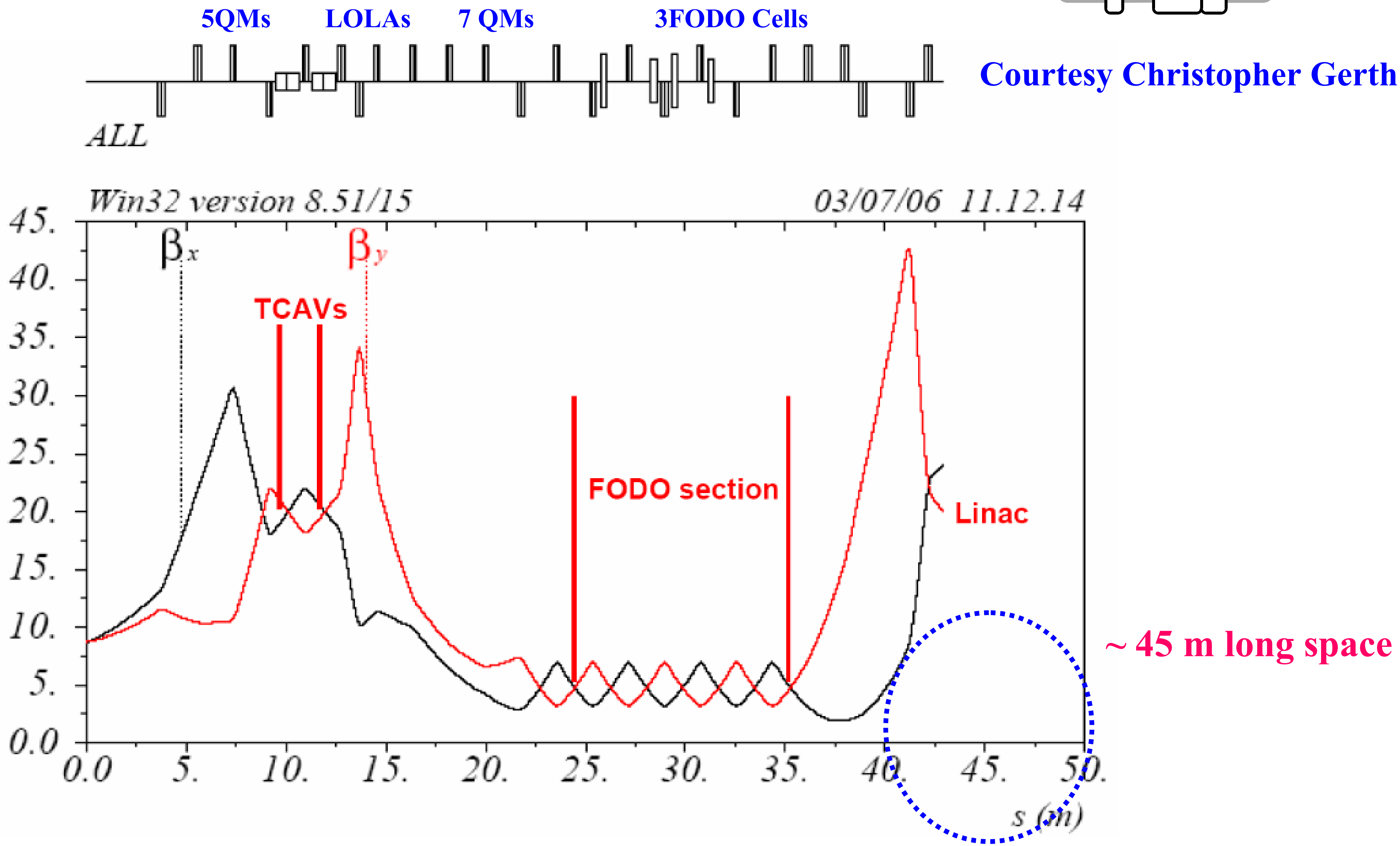
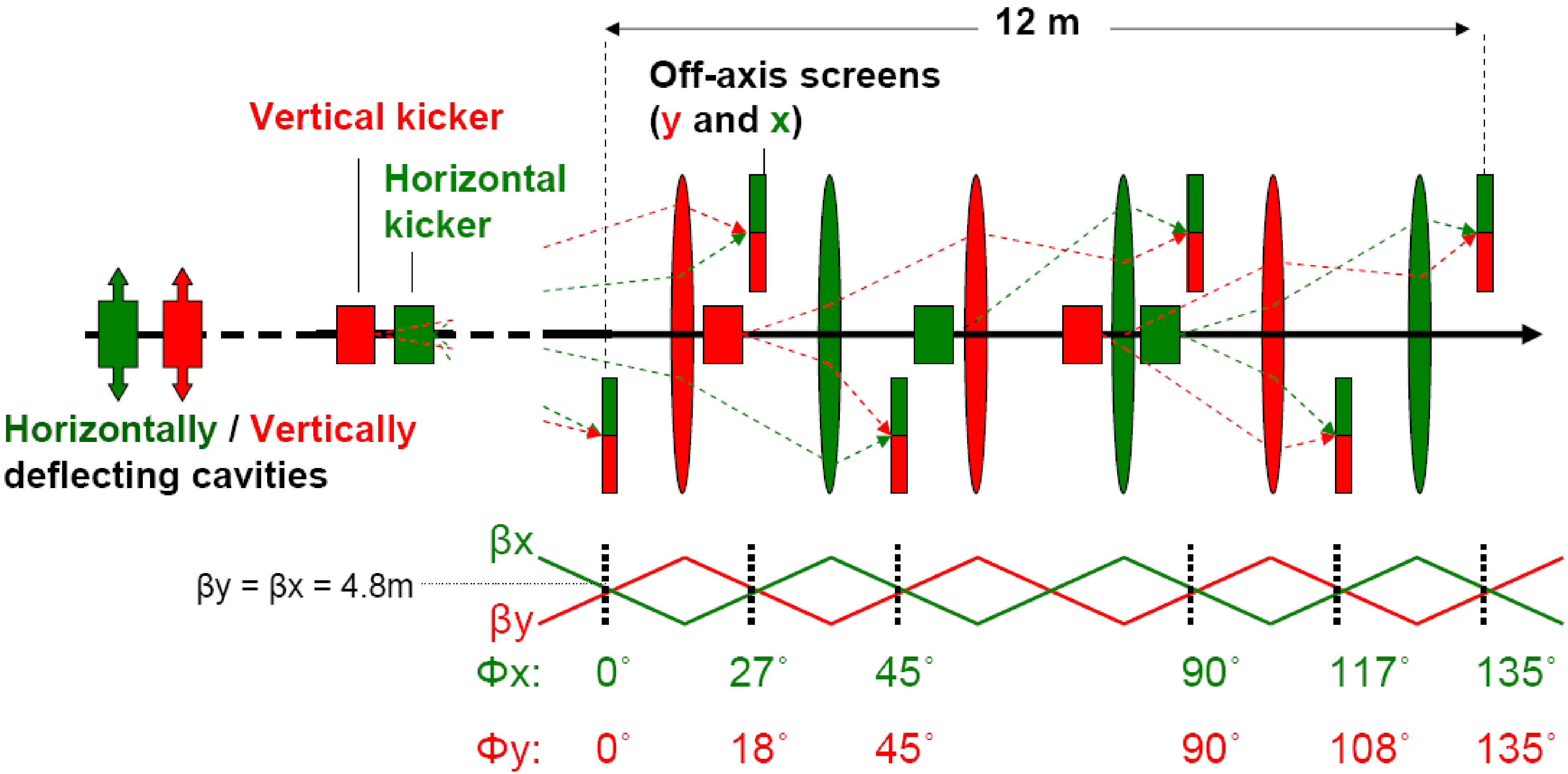


Courtesy Christopher Gerth

LOLA Layout for European XFEL

PAUL SCHERRER INSTITUT

Courtesy Michael Röhrs



New Layout - Rasmus, Christopher, Michael

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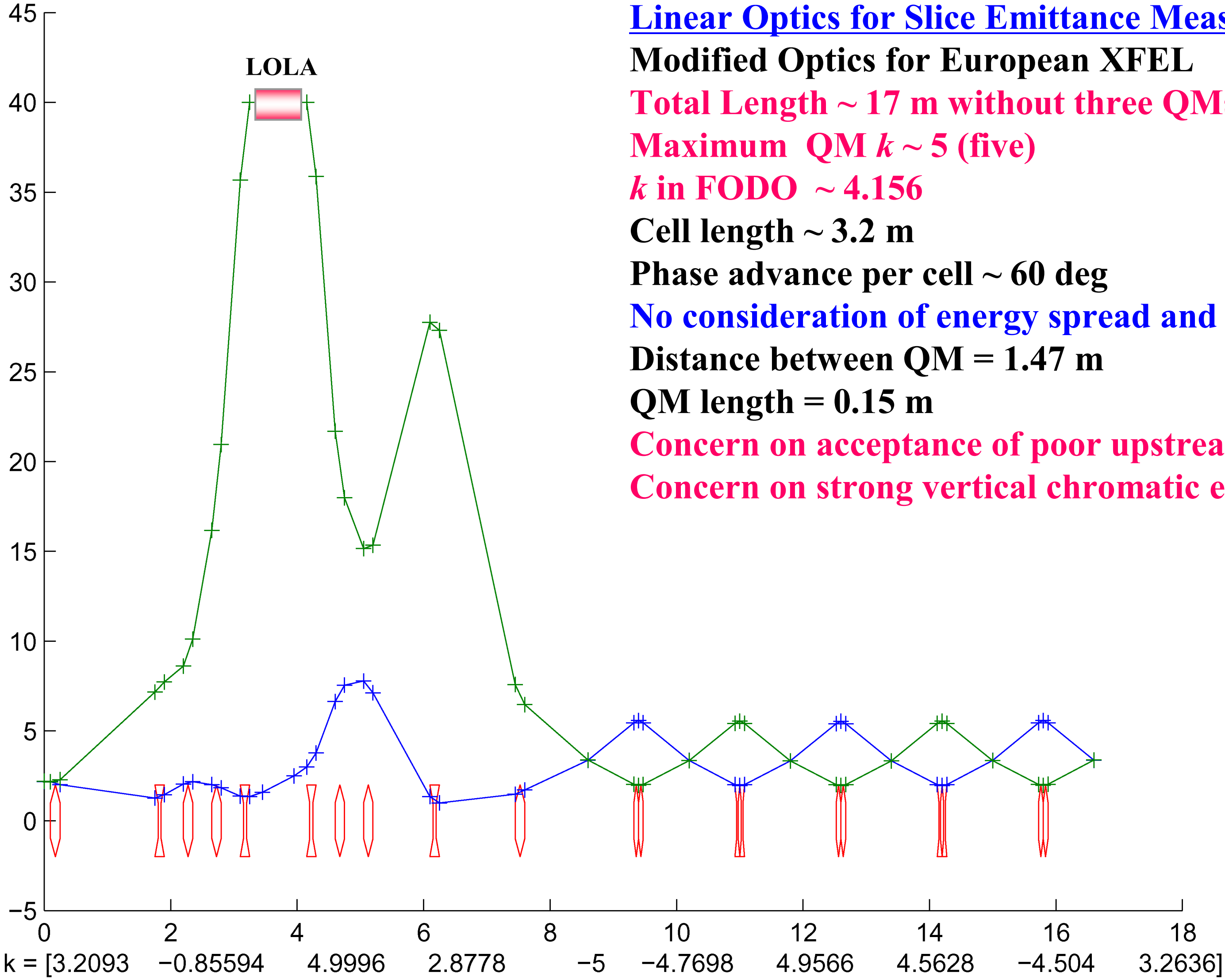


Linear Optics for Slice Emittance Measurement with LOLA

Modified Optics for European XFEL

Total Length ~ 17 m without three QMs & dump region

Maximum QM *k* ~ 5 (five)

***k* in FODO ~ 4.156**

Cell length ~ 3.2 m

Phase advance per cell ~ 60 deg

No consideration of energy spread and so on.

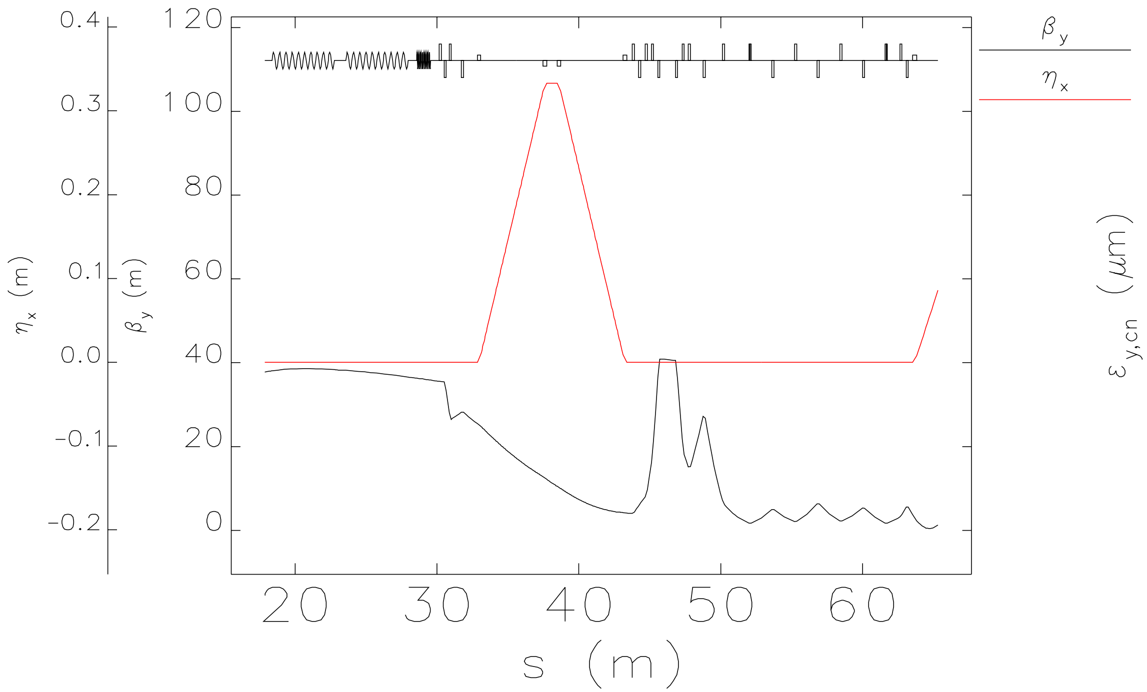
Distance between QM = 1.47 m

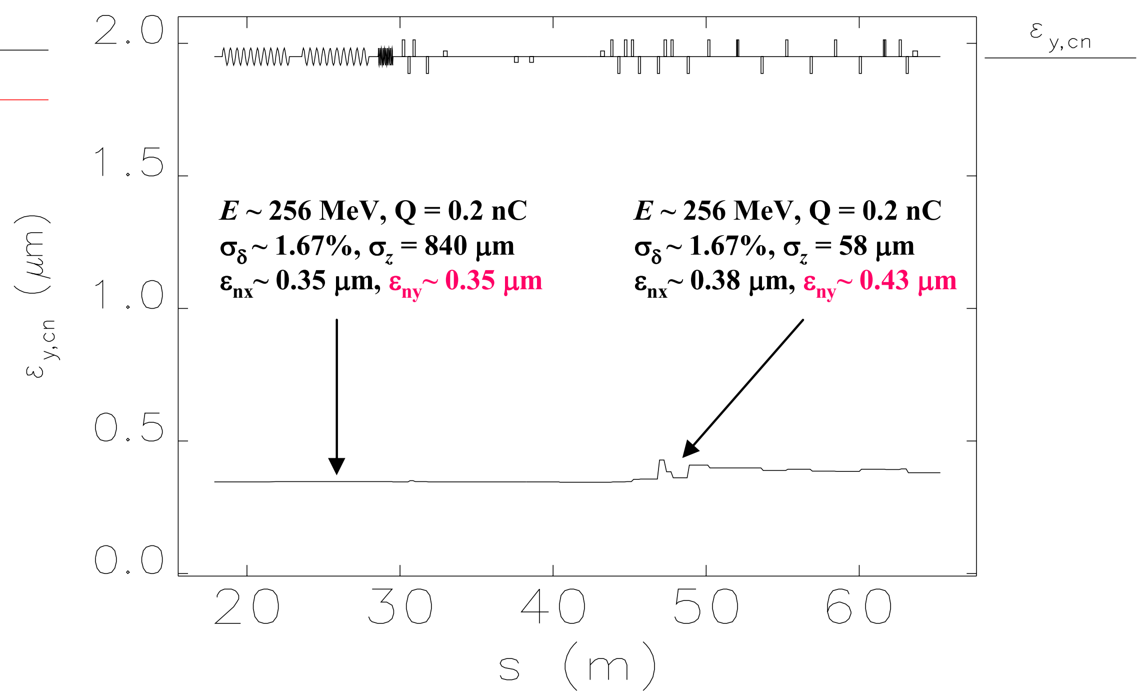
QM length = 0.15 m

Concern on acceptance of poor upstream optics

Concern on strong vertical chromatic effect

New Optimization is ongoing !





S2E Simulation with 100 MV/m & 22 A Optimization
Acceptance of poor upstream optics = poor
Vertical chromatic effect = very strong (24% emittance growth)

Solution
longer space
more QMs
lower beta function
smaller phase advance per cell
lower QM *k*
lower energy spread (impossible due to BC)

Summary

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For 250 MeV injector test facility, now we have two standard injector optimizations and optics from the cathode to dump. To optimize them, we used the same machine layout without change of any position of machine components. But we used different machine parameters such as different solenoid setting.

The one optimization with 120 MV/m gives a peak current of 32 A, while the other optimization with 100 MV/m gives a peak current of 22 A. It seems that the former optimization with 120 MV/m gives a higher peak current with a good projected emittance. While the latter optimization with 100 MV/m gives a low slice and projected emittance (projected emittance ~ 0.35 μm and slice emittance ~ 0.32 μm at the upstream of BC).

For both optimizations, growth of projected emittance in BC is within 10% even though peak current is increased to 350 A.

For both optimizations, slice mis-matching amplitude ζs are close to 1, which means that matching along slices is optimized properly.

Current optics does not have any problem to measure bunch length, to reconstruct the longitudinal phase space with LOLA. However, to measure the slice emittance, we have to modify current optics several times for various horizontal phase advance (0 ~ 180 degree). It is possible with current layout but it will be an inconvenient process.

Summary & Acknowledgement

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To avoid the inconvenient process to modify optics several times for one slice emittance measurement, in 2006, DESY friends suggested a new layout for European XFEL project where LOLA cavity is located at the upstream of 3FODO cells. Its total required space is about 45 m.

Newly suggested diagnostic optics for our 250 MeV injector is a modified version of the optics for European XFEL. But QM strength is much higher than that of European XFEL due to a much shorter allowed space, which induces a strong chromatic effect in the vertical plane at the downstream of BC. The vertical emittance was increased by 24% due to the strong vertical chromatic effect. Additionally, acceptance of mismatched upstream optics is problematic in the suggested optics.

Therefore we can not use the suggested layout due to the strong vertical chromatic effects and poor acceptance of mismatched upstream optics. But we are trying to use a longer space, more QMs, choosing a lower beta function, choosing a smaller phase advance per cell, optimizing with a lower QM strength to relax the strong vertical chromatic effects and poor acceptance of mismatched upstream optics.

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