Comparison of the electron bunch quality achievable using a 3d ellipsoidal shaped laser with respect to the flat top one for the nominal working point at the European XFEL facility

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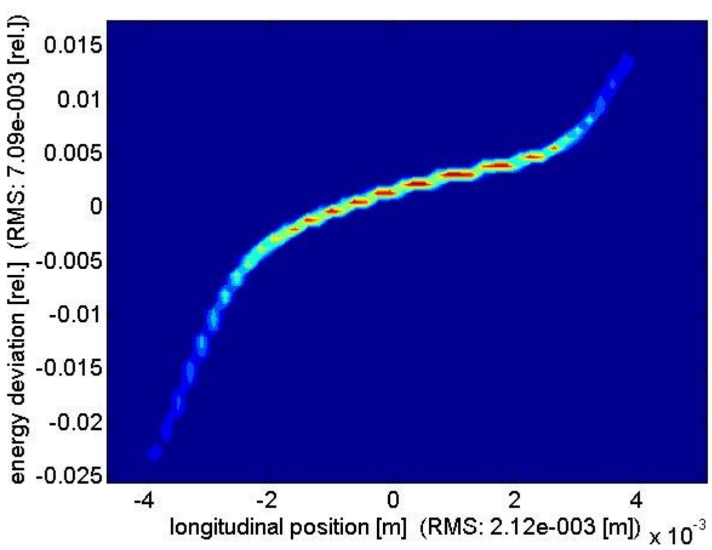
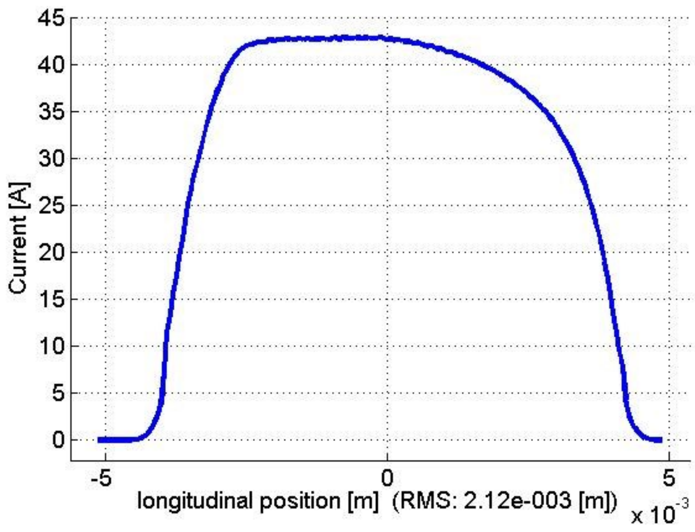
XFEL working point for 1 nC charged e-bunch

CASE A

Laser parameters:
Flat-top longitudinal laser distribution 20 ps FWHM and 2ps rise and fall times
Trms: 5.8442 ps
Gaussian spot-size XYrms = 0.4 mm

RF-gun setup:
Gradient: 60 MV/m
Phase: -0.9 deg w.r.t. MMMG phase
Solenoid field amplitude: 0.222 T





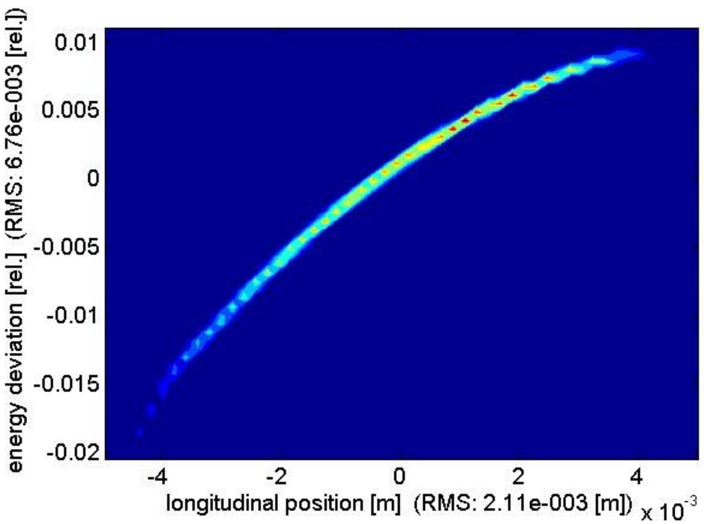
Equivalent working point using en ellipsoidal shaped bunch

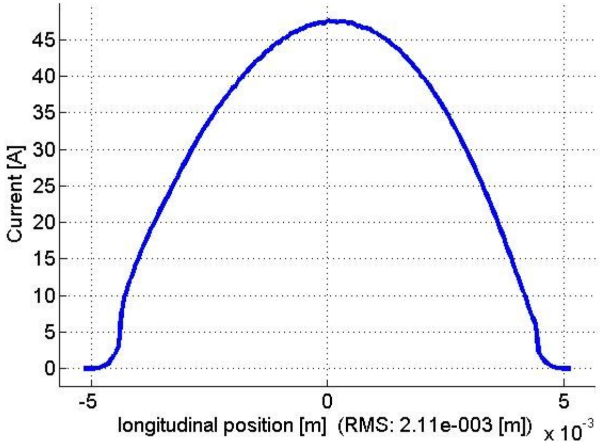
CASE B

Laser parameters:
3D ellipsoidal laser distribution
Trms: 5.765 ps
XYrms = 0.4 mm

RF-gun setup:
Gradient: 60 MV/m
Phase: -0.9 deg w.r.t. MMMG phase
Solenoid field amplitude: 0.22373 T

Obtained by M. Khojoyan by varying the solenoid field and Trms in order to fit the reference bunch length and spot-size at 3m from the cathode.





Fast start to end simulations for the XFEL

- ASTRA is used from the cathode up to the exit of the injector
- CSRtrack is used for the transport along the dogleg and the bunch compressors
- Linear matrix transport + analytical estimation of longitudinal space charge and RF wakefields for the transport through the main linacs (reference: I. Zagorodnov, M. Dohlus, Phys. Rev. ST Accel. Beams 14, 014403 (2011)).

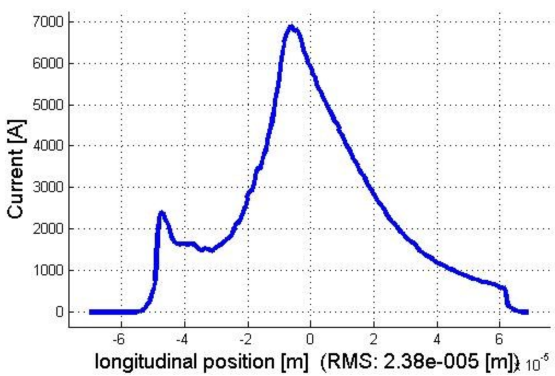
Bunch compression for CASE A

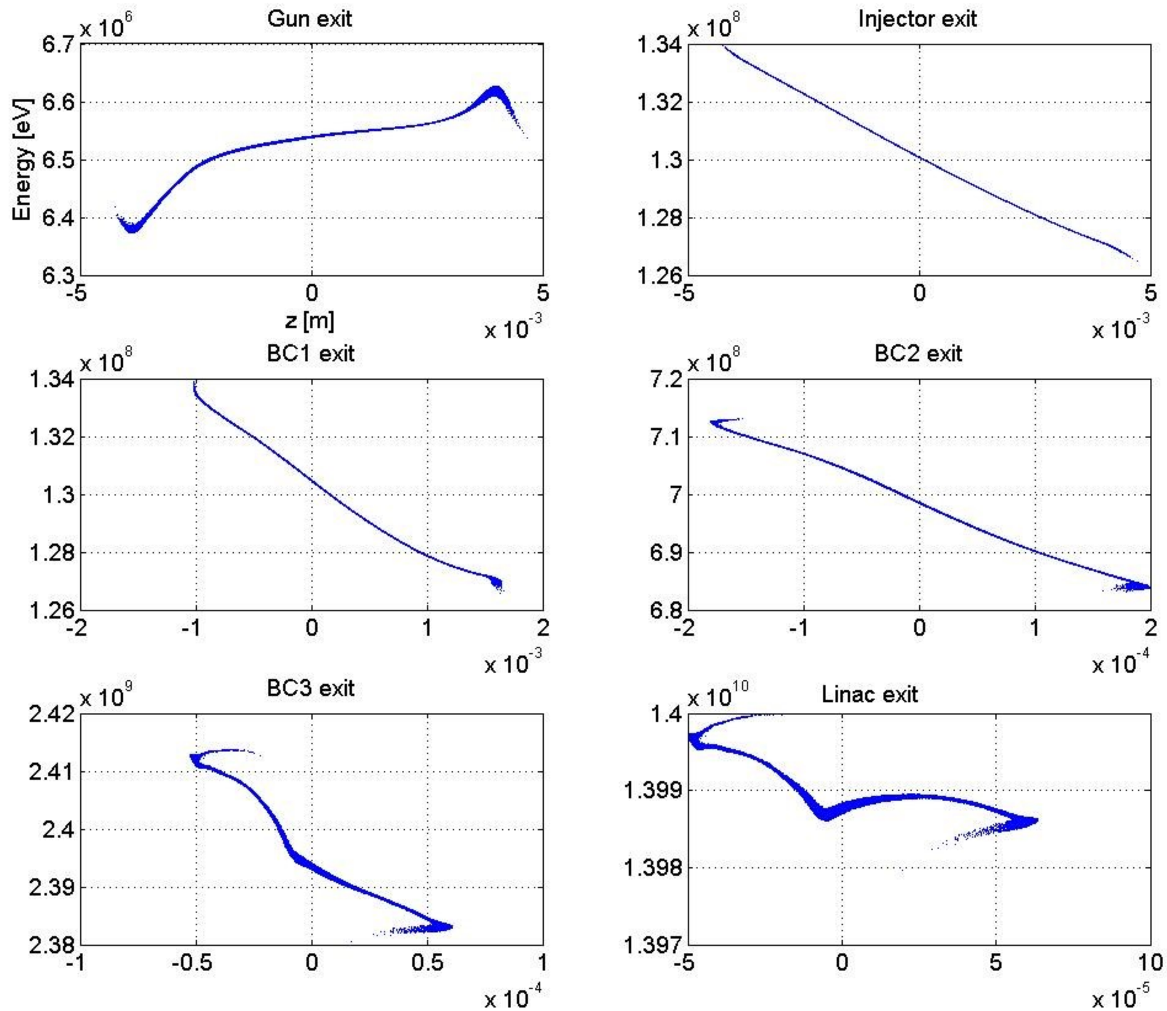
Normalized emittance x plane:1.04 mm*mrad

Normalized emittance y plane:3.19 mm*mrad

Bunch length (FWHM): 0.105 ps

Final current profile:





DESY

Compression for the ellipsoidal laser

- By using the same setup of the flattop case for the ellipsoidal one, the result at the exit of the main linac is completely different because the two initial longitudinal phase spaces are completely different.
- In order to be able to compare the two bunches, the compression of the ellipsoidal bunch must be as similar as possible to the flattop case. How can we achieve that? Our choice: the longitudinal phase space at the exit of the injector in the two cases must have the same shape and the magnetic compressors radius must be the same for the two cases.

↓

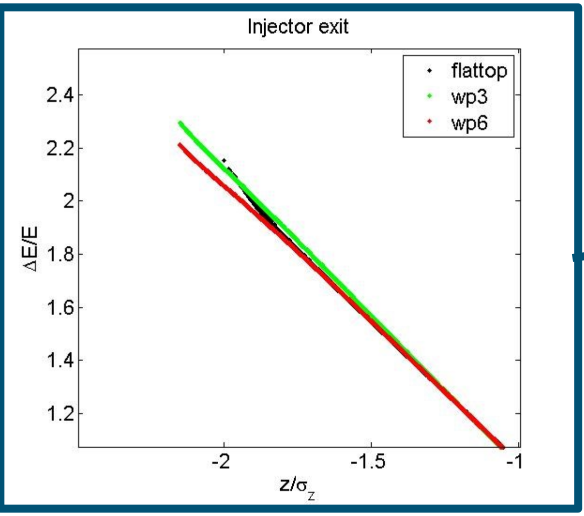
We need to find the injector setup (V1, phi1, V39, phi39) that delivers the same longitudinal phase space distribution of the flattop beam at the exit of ACC39.

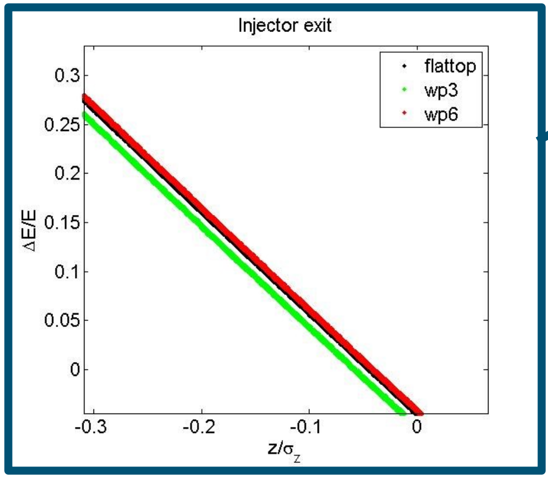
Transport adjustment for the ellipsoidal laser: how to find the injector settings to use in ASTRA

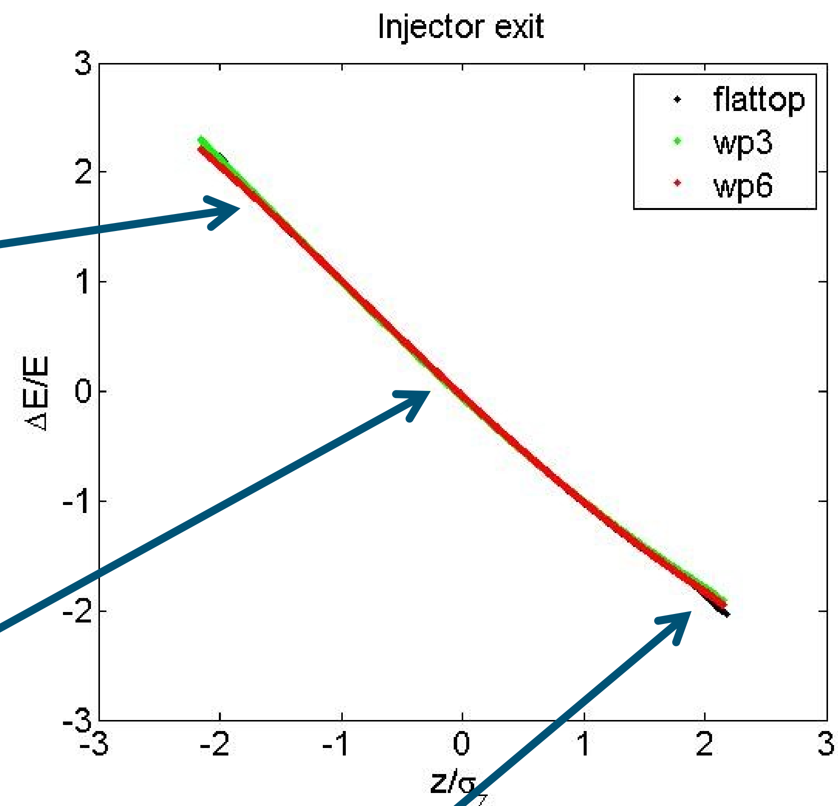
- Input: fit parameters representing the desired longitudinal phase space at the exit of the 3rd harmonic cavity + ellipsoidal beam at the gun exit
- STEP 1: Analytical calculation of the setup of the injector (wakes not included) to get the desired beam at the injector exit
- STEP 2: Iterative 1d track (loop) **including wakes** to obtain both the final RF parameters and the 2 reference phase spaces (one at the exit of the 1st accelerating cavity and the second at the exit of the third harmonic cavity) that will be used later
- STEP 3: S2E simulation using ASTRA and CSRtrack, including wakes and using the RF-correction routine written by Igor (this routine uses the 2 reference phase spaces calculated before).

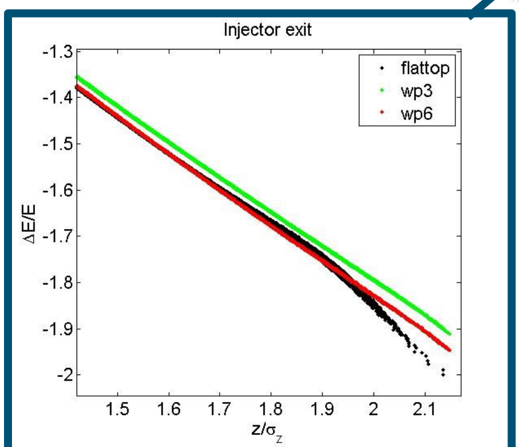
I will not go in the details of this procedure, I just show the final result...

Phase space at the exit of acc39 (tracked using ASTRA + RF wakes)









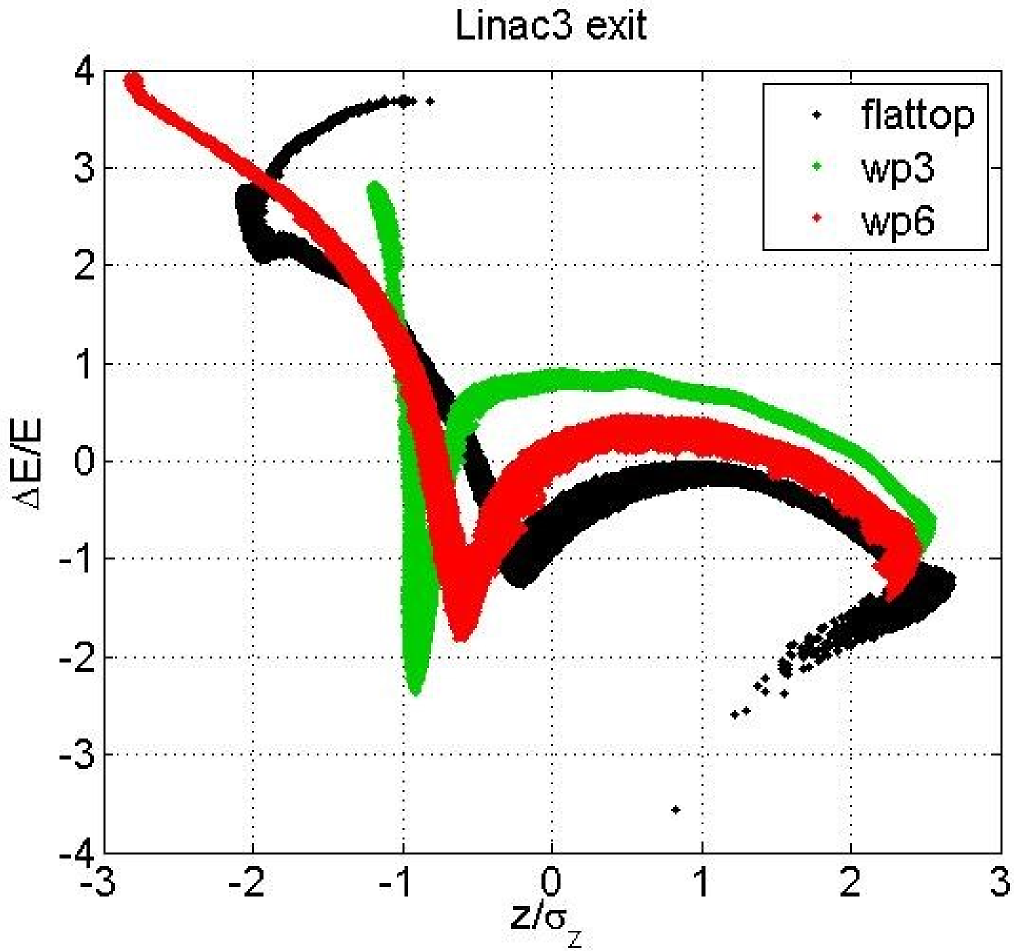
For the working point wp3-> the injector's parameters to use in ASTRA have been calculated analytically without including wakes

For the working point wp6->the injector's parameters to use in ASTRA have been calculated with the new iterative routine which includes the RF wakes

wp6 is more similar to the flattop

Final phase space distributions (exit of the main linac)

Small differences in the longitudinal phase space at the exit of the injector corresponds to big differences at the exit of the linac!



These distributions have been obtained using the same magnetic compressors curvature radius

There is still some discrepancy between the flattop and the wp6 distributions due to the remnant discrepancy between their corresponding distributions at the exit of the injector.

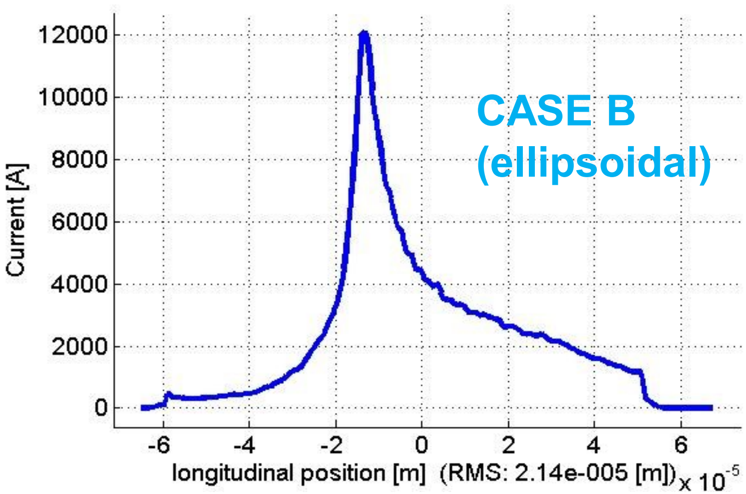
Comparison between flattop and wp6

Normalized emittance x plane:2.01 mm*mrad

Normalized emittance y plane:0.455 mm*mrad

Bunch length (FWHM): 0.036 ps

Final current profile:

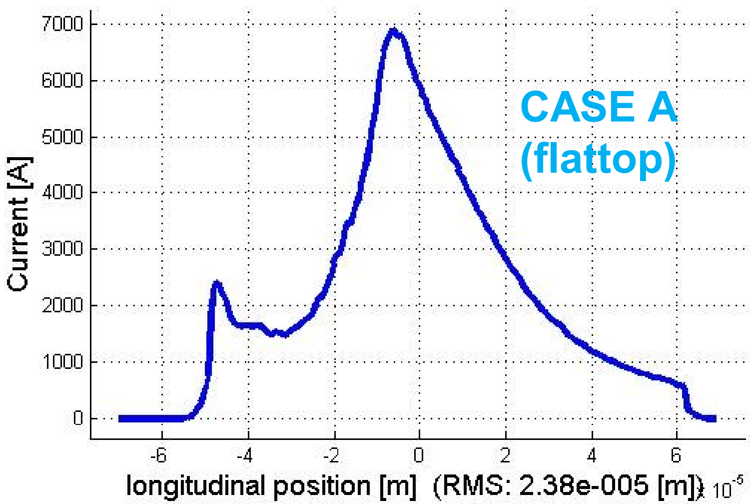


Normalized emittance x plane:1.04 mm*mrad

Normalized emittance y plane:3.19 mm*mrad

Bunch length (FWHM): 0.105 ps

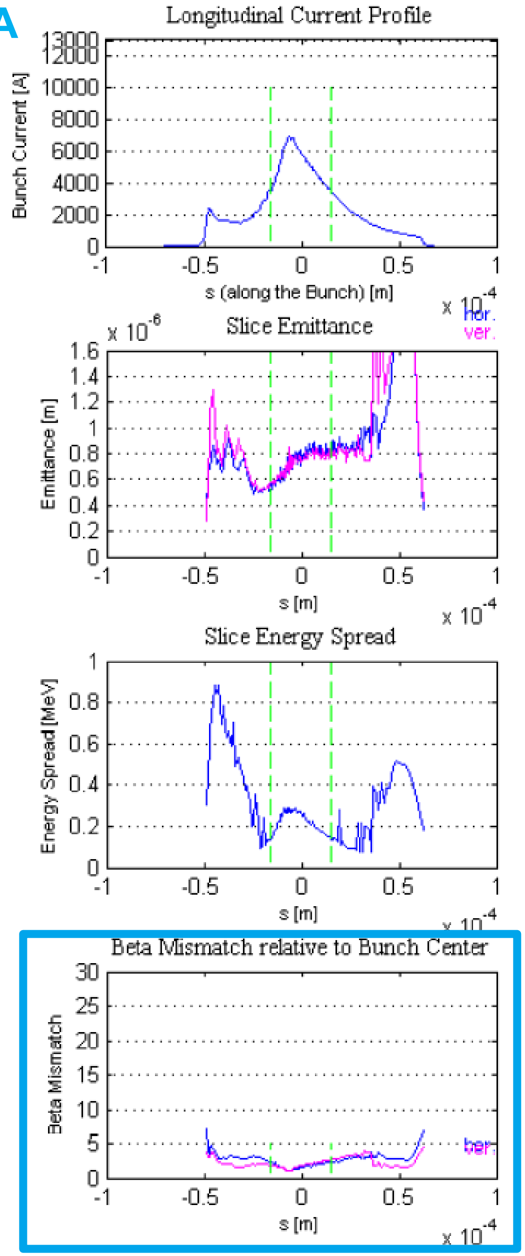
Final current profile:



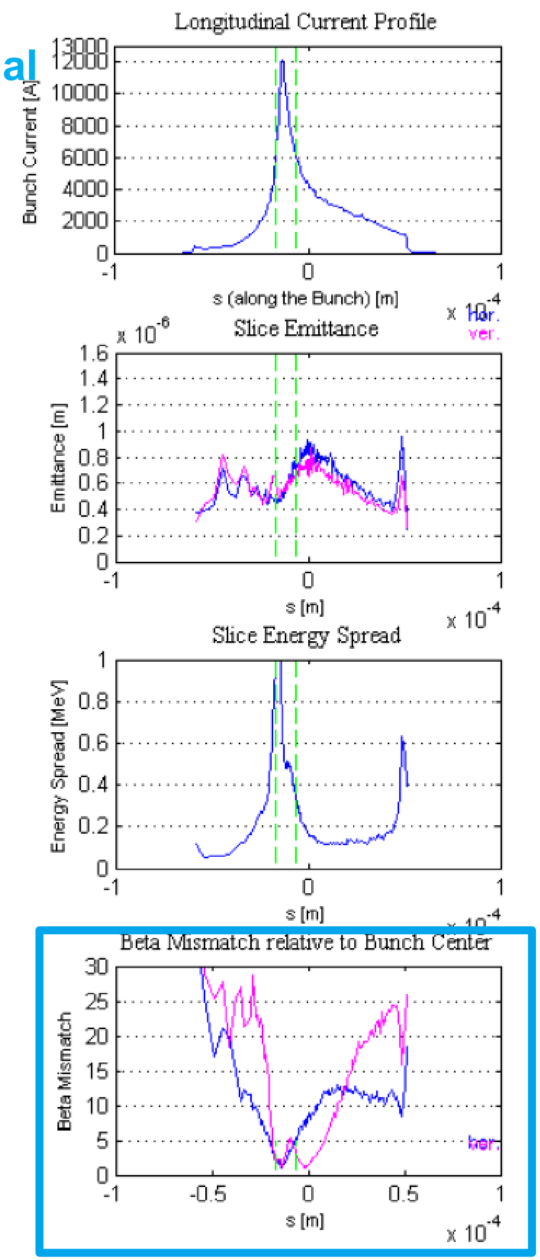
<u>The comparison is still not fare</u> since, due to the small discrepancies mentioned before, <u>the ellipsoidal beam is compressed more than the flattop one</u>.

… Nevertheless we have a look at the slice parameters:

CASE A
flattop



CASE B
ellipsoidal



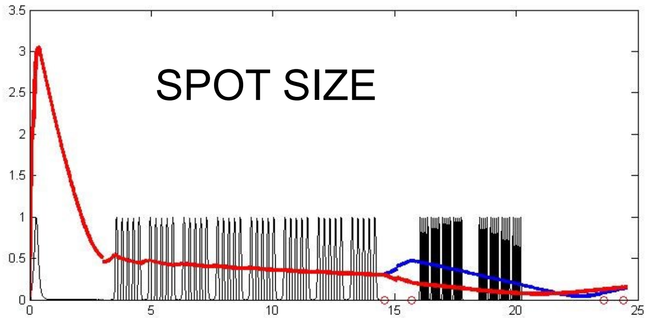
The green lines marks the FWHM area

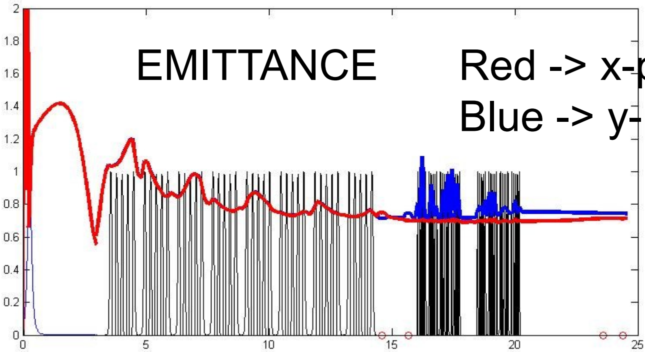
The ellipsoidal beam has mostly a lower slice emittance than the flattop (as expected)

The differences in the slice energy spread are difficult to interpret since CASE B has a higher compression

The ellipsoidal beam is completely mismatched outside its FWHM area! (not acceptable, must be corrected)

Fast investigation about the cause for the beta-mismatch…



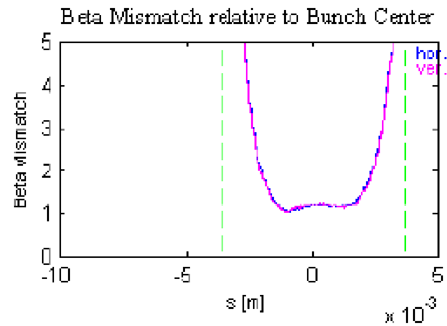


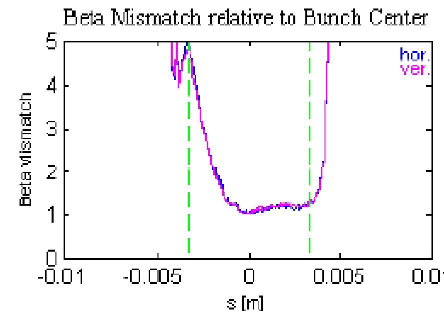
Red -> x-plane
Blue -> y-plane

FLAT-TOP

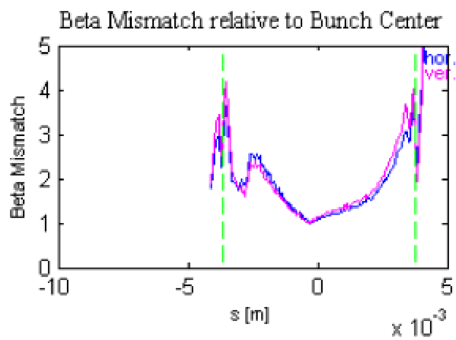
ELLIPSOIDAL

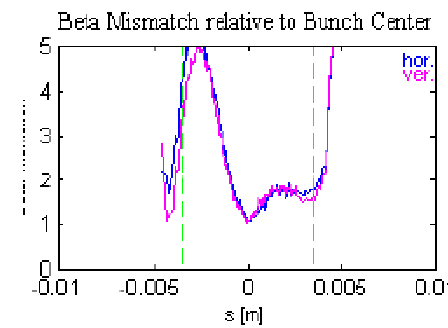
Gun exit (3 m)





Injector exit (25 m)



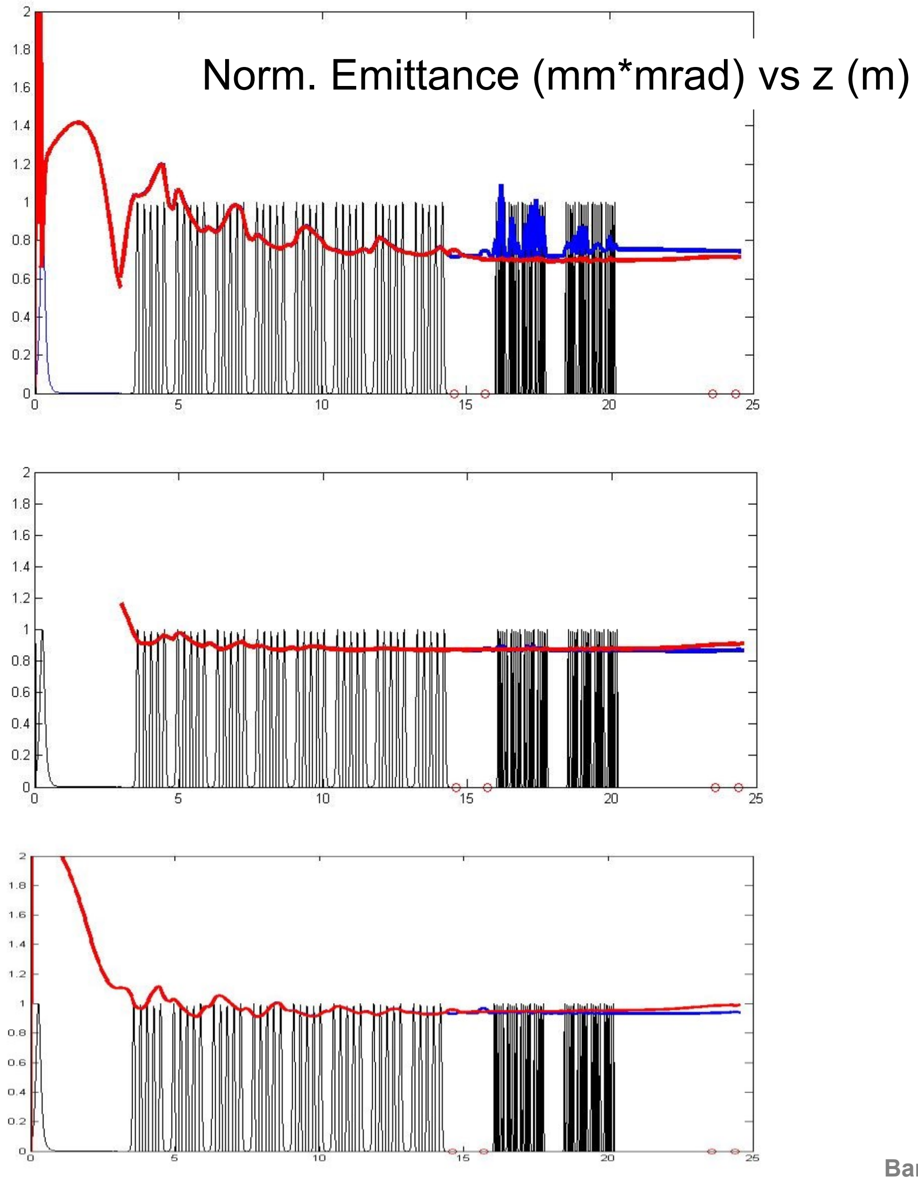


Fast investigation about the cause for the beta-mismatch…

Ellipsoidal

Flat-top using pitz solenoid curve

Flat-top using flash solenoid (Igor's files)



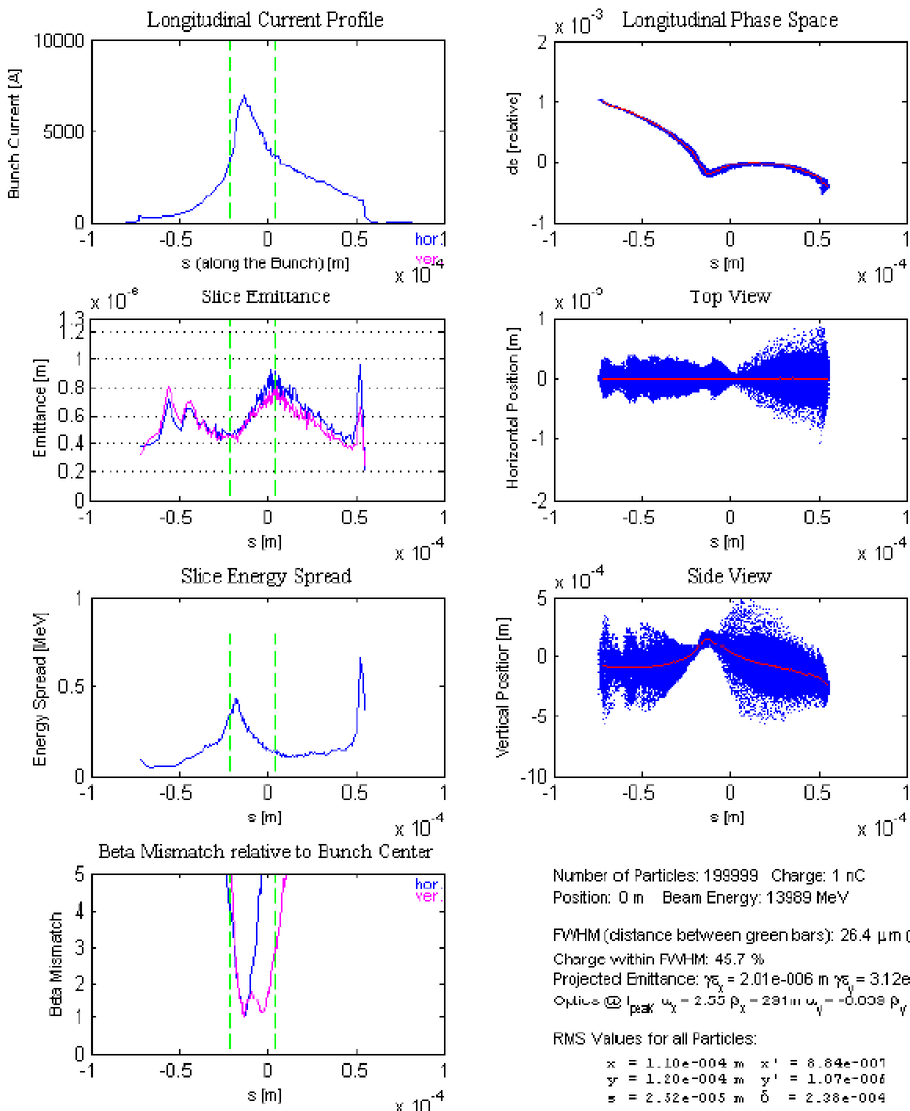
The matching with the accelerating cavity is completely different. None of them looks correct to minimize the total emittance (and the beta-mismatch along the bunch) at the injector exit.

Next steps

- Modify the routine for the calculation of the injector setup (suggestion by Mikhail) and see if it is possible to obtain a better overlap with the flattop distribution at the injector exit.
- Solenoid scan of the injector to see if the beta mismatch along the bunch can be compensated

What if we change the R56 to have the same bunch compression

flattop



Number of Particles: 199999 Charge: 1 nC
Position: 0 m Beam Energy: 13989 MeV

FWHM (distance between green bars): 26.4 µm (0.088 ps)
Charge within FWHM: 45.7 %
Projected Emittance: $\gamma\varepsilon_x$ = 2.01e-006 m $\gamma\varepsilon_y$ = 3.12e-006 m
Optics @ I_{peak} α_x = 2.55 β_x = 291 m α_y = -0.008 β_y = 50.5 m

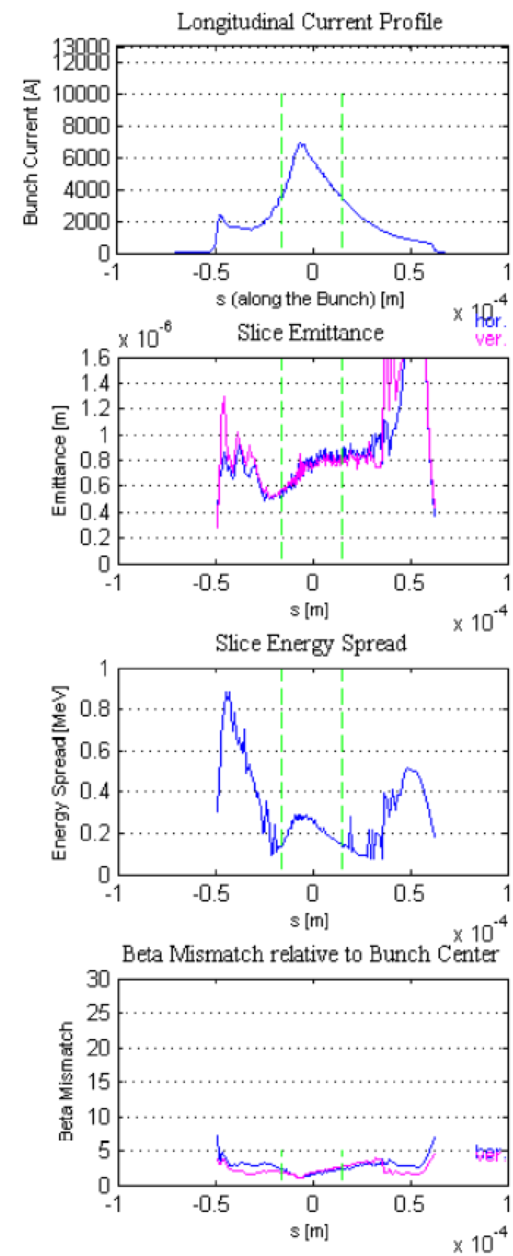
RMS Values for all Particles:

```
x  = 1.10e-004 m   x' = 8.84e-007
y  = 1.20e-004 m   y' = 1.07e-006
s  = 2.52e-005 m   δ  = 2.38e-004
```

RMS Values within FWHM:

```
x  = 7.06e-005 m   x' = 9.36e-007
y  = 6.27e-005 m   y' = 8.06e-007
s  = 7.02e-006 m   δ  = 7.85e-005
```

The curvature radius of BC0 has been set 3.065m instead of 3.03m as was for the previous simulations.



Barbara Marchet

Mismatch parameter

Beam in the normalized phase space

$$u = \beta^{-1/2} x, \qquad v = du/d\phi.$$

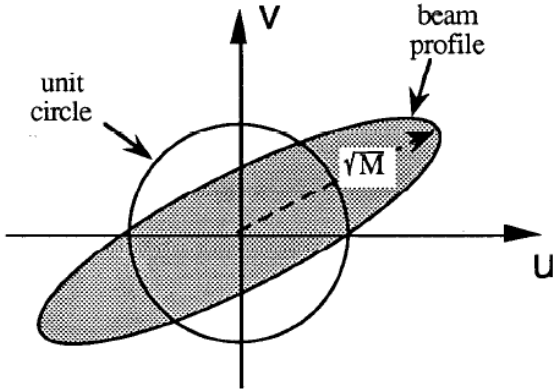


Fig. 6. The beta mismatch parameter M in relation to the beam ellipse in the rationalized phase plane (u,v) for a beam of unit emittance.

A BETA MISMATCH PARAMETER*

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(AP)

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mismatch of the beam. I choose to define the "beta mismatch parameter" M as the square of the semi-major axis of the (u,v) ellipse. See Fig.6. Other quantities could, of course, be used to characterize the ellipse, but this particular choice makes M directly related to the beat of the beta parameter as was shown in Fig.3. As defined, M would be equal to 1 everywhere for the design transport, but in any disturbed transport will always be a number greater than — or, at best, equal to — one.

If the beam is initially mismatched but the transport is ideal, the ellipse only rotates