Flight Simulator (DFS & WFS) in the ATF LINAC and ATF2 EXT

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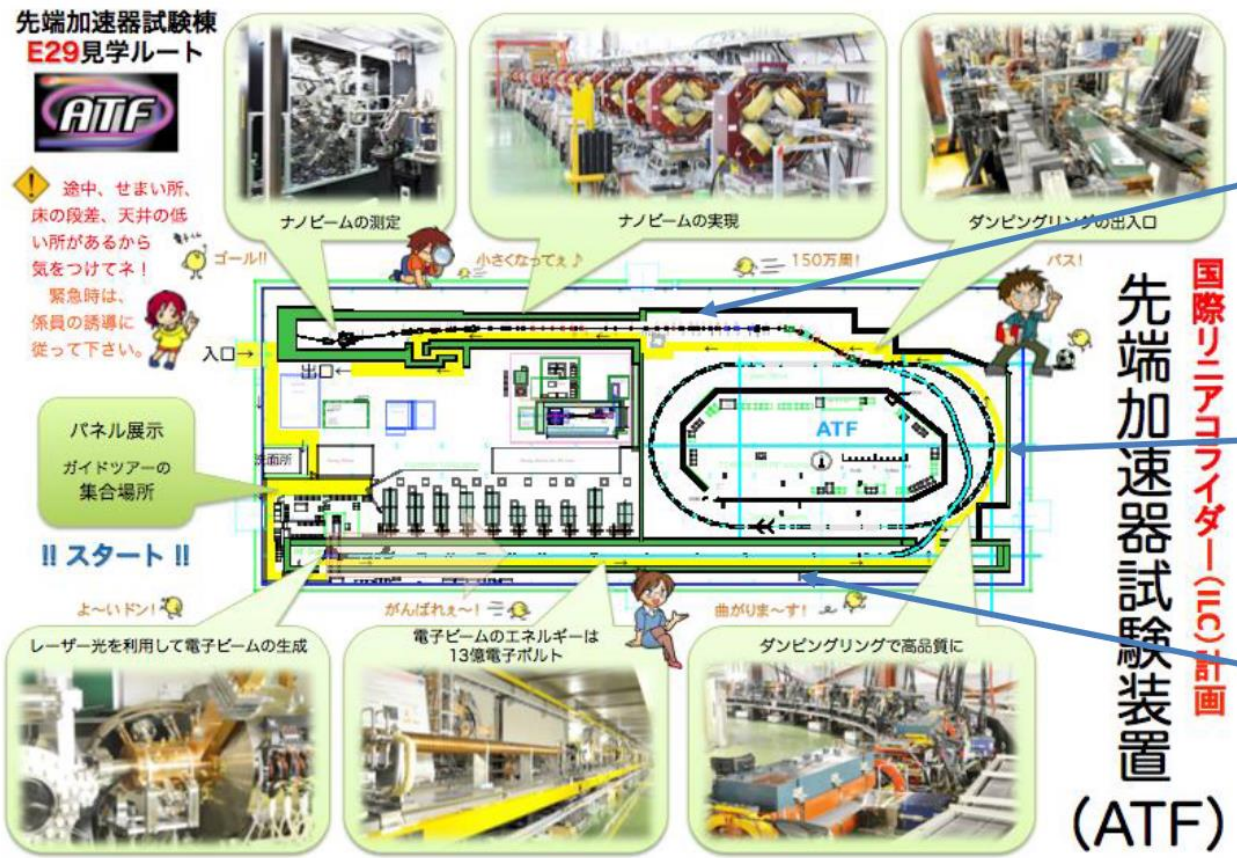
Outline

- ATF2 @ KEK: Motivation and Objectives
- ATF Matlab Flight Simulator
- DFS and WFS in the LINAC
- DFS and WFS in the EXT
- ATF2 Python Flight Simulator

The ATF2 at KEK

The Accelerator Test Facility 2 (ATF2)



Extraction Line
- Final Focus prototype for ILC and CLIC

Damping ring
- Nanometre vert. norm. emittance

Linac:
- 80m, S-band, 1.3 GeV

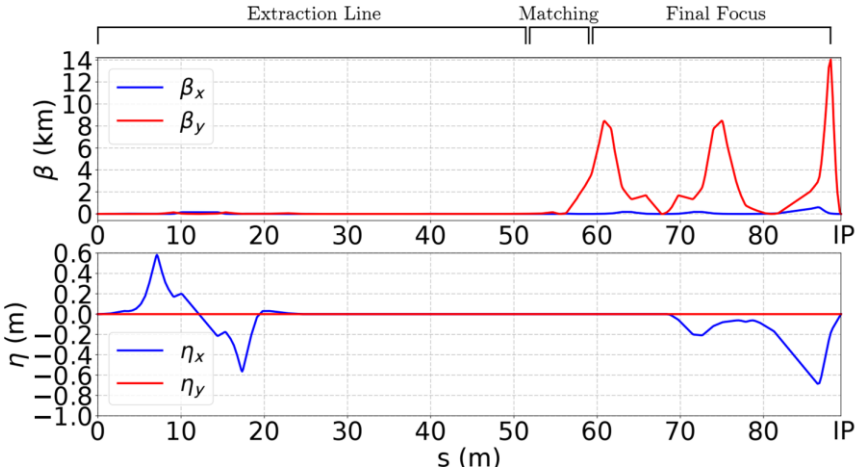
ATF2 studies

CLIC related studies in ATF2:

- Final Focus System (FFS) studies : local chromaticity correction scheme.
- Wakefields Mitigation Tools implementation.
- Beam Instrumentation tests (Cavity-BPMs, OTR/ODR beam profile monitors, etc).
- Automatic Beam-Based Alignment (BBA) and tuning procedures (DFS, WFS, etc) tests.
- R&D work on the extraction kicker from the DR.

Table : Beam and optics parameters for ATF2 beamline.

Parameter	Symbol	Value
Length of ATF2	L	90 m
Beam energy	E	1.28 GeV
Bunch population	N_e	1.0×10^{10}
Beta functions at IP	β_x^*/β_y^*	40 mm/0.10 mm
Beam sizes at IP	σ_x^*/σ_y^*	8.9 µm/37 nm
Bunch length	σ_z	7 mm



Automatic Beam-Based Alignment

DFS simultaneously corrects the orbit, x_i, and minimizes the difference between the nominal and a dispersive trajectory, $x_{\Delta E,i}$. This corresponds to minimizing:

$$\chi^2 = \sum_{\text{bpms}} x_i^2 + \omega^2 \sum_{\text{bpms}} \left(x_{\Delta E,i} - x_i\right)^2 + \beta^2 \sum_{\text{corrs}} \theta_j^2$$

which is equivalent to solving the system of equations:

$$\begin{pmatrix} \mathbf{x} \\ \omega(\mathbf{x}_{\Delta E} - \mathbf{x}) \\ \mathbf{0} \end{pmatrix} = \begin{pmatrix} \mathbf{R} \\ \omega\mathbf{D} \\ \beta\mathbf{I} \end{pmatrix} \begin{pmatrix} \theta_1 \\ \vdots \\ \theta_m \end{pmatrix}$$

with

$$R_{ij} = \frac{\partial y_i}{\partial \theta_j}$$

$$D_{ij} = R_{\Delta E,\,ij} - R_{ij}$$

$$\omega^2 = \frac{\sigma^2_{\text{bpm resolution}} + \sigma^2_{\text{bpm position}}}{2\sigma^2_{\text{bpm resolution}}}$$

It is a least-square problem that can be solved using an SVD.

R and **D** are the response matrices. The free parameter ω accounts for the relative weight of the orbit w.r.t. the dispersive term; β is a regularization parameter.

Results in the ATF2 extraction line (2019)

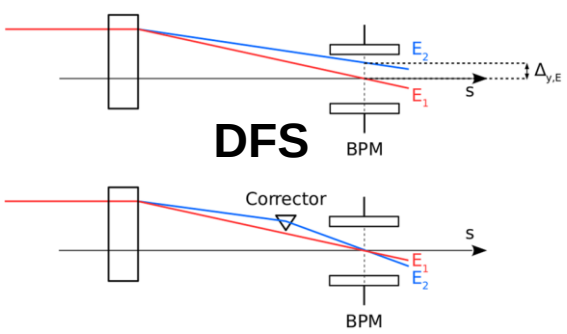


Figure: Schematic of the Dispersion Free Steering correction.

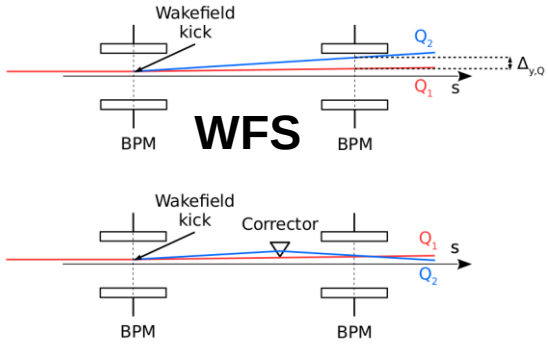
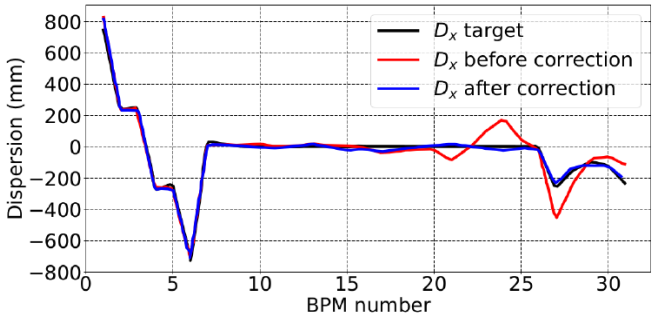
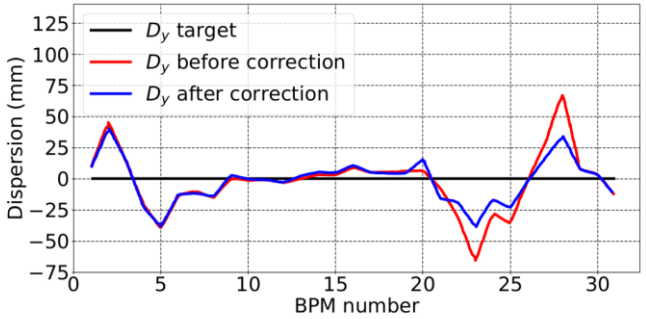


Figure: Schematic of the Wakefields Free Steering corrections.





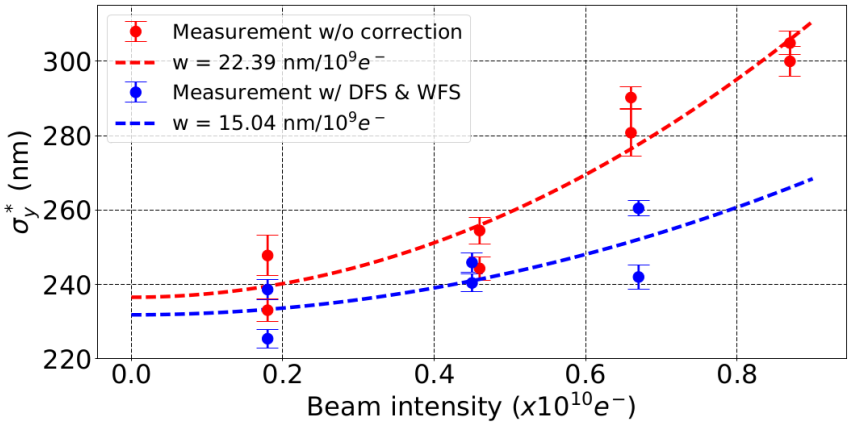
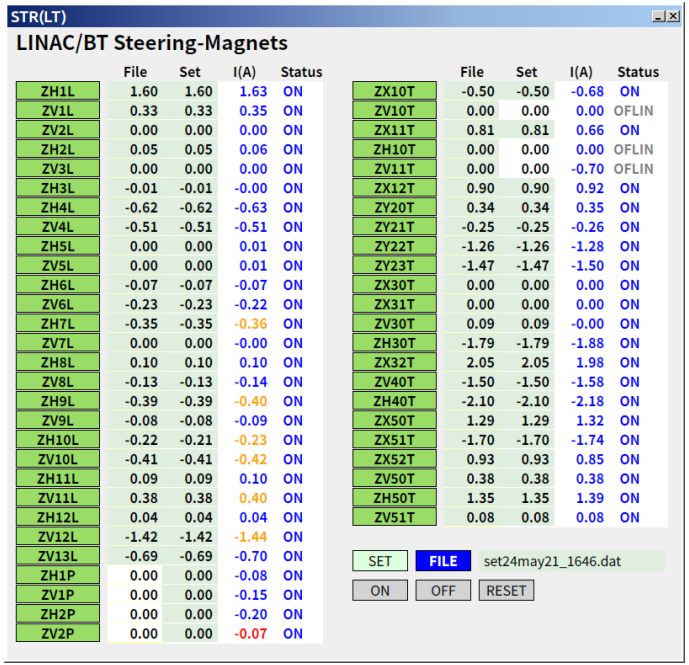


Figure: Measurement: impact of DFS and WFS on the vertical beam size at the IP.

ATF Matlab Tools:
Flight Simulator

ATF LINAC Matlab Flight Simulator

The Matlab Flight Simulator **SYSID** (System Identification) scripts were updated to work on the **ATF LINAC**.



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ZV2L	0.00	0.00	0.00	ON
ZH2L	0.05	0.05	0.06	ON
ZV3L	0.00	0.00	0.00	ON
ZH3L	-0.01	-0.01	-0.00	ON
ZH4L	-0.62	-0.62	-0.63	ON
ZV4L	-0.51	-0.51	-0.51	ON
ZH5L	0.00	0.00	0.01	ON
ZV5L	0.00	0.00	0.01	ON
ZH6L	-0.07	-0.07	-0.07	ON
ZV6L	-0.23	-0.23	-0.22	ON
ZH7L	-0.35	-0.35	-0.36	ON
ZV7L	0.00	0.00	-0.00	ON
ZH8L	0.10	0.10	0.10	ON
ZV8L	-0.13	-0.13	-0.14	ON
ZH9L	-0.39	-0.39	-0.40	ON
ZV9L	-0.08	-0.08	-0.09	ON
ZH10L	-0.22	-0.21	-0.23	ON
ZV10L	-0.41	-0.41	-0.42	ON
ZH11L	0.09	0.09	0.10	ON
ZV11L	0.38	0.38	0.40	ON
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ZV13L	-0.69	-0.69	-0.70	ON
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ZV11T	0.00	0.00	-0.70	OFLIN
ZX12T	0.90	0.90	0.92	ON
ZY20T	0.34	0.34	0.35	ON
ZY21T	-0.25	-0.25	-0.26	ON
ZY22T	-1.26	-1.26	-1.28	ON
ZY23T	-1.47	-1.47	-1.50	ON
ZX30T	0.00	0.00	0.00	ON
ZX31T	0.00	0.00	0.00	ON
ZV30T	0.09	0.09	-0.00	ON
ZH30T	-1.79	-1.79	-1.88	ON
ZX32T	2.05	2.05	1.98	ON
ZV40T	-1.50	-1.50	-1.58	ON
ZH40T	-2.10	-2.10	-2.18	ON
ZX50T	1.29	1.29	1.32	ON
ZX51T	-1.70	-1.70	-1.74	ON
ZX52T	0.93	0.93	0.85	ON
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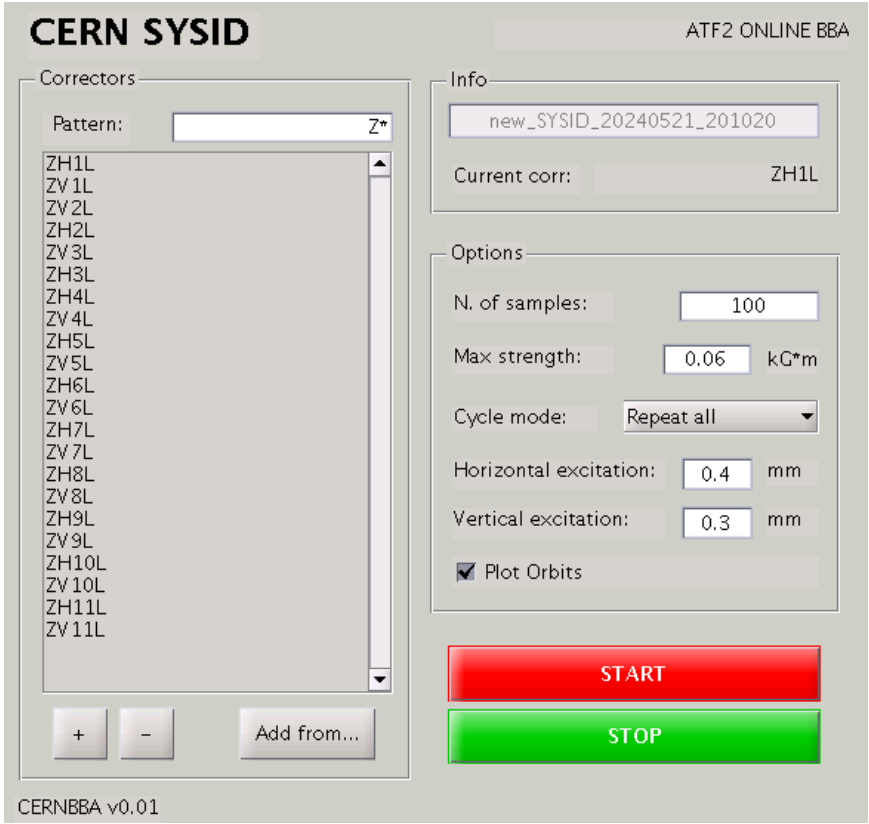
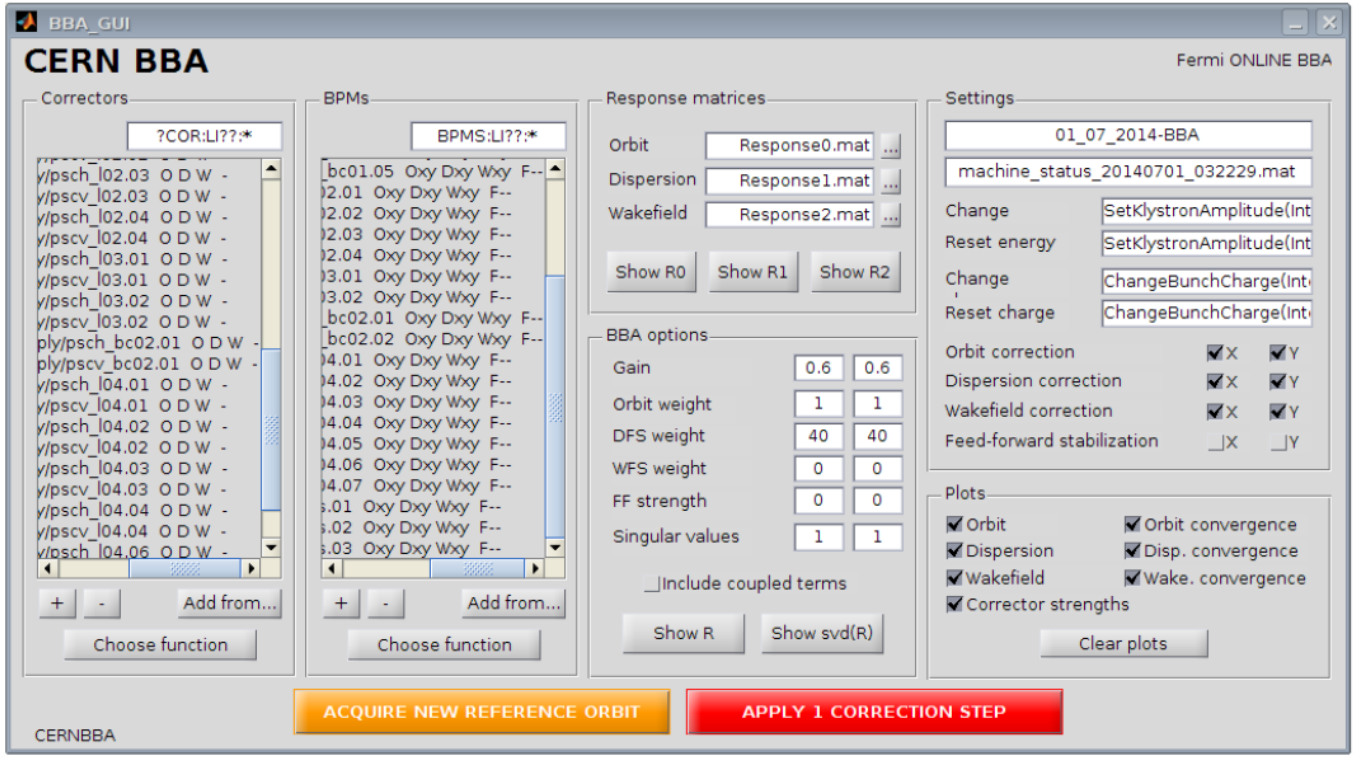
ZH50T	1.35	1.35	1.39	ON
ZV51T	0.08	0.08	0.08	ON



Matlab BBA Interface

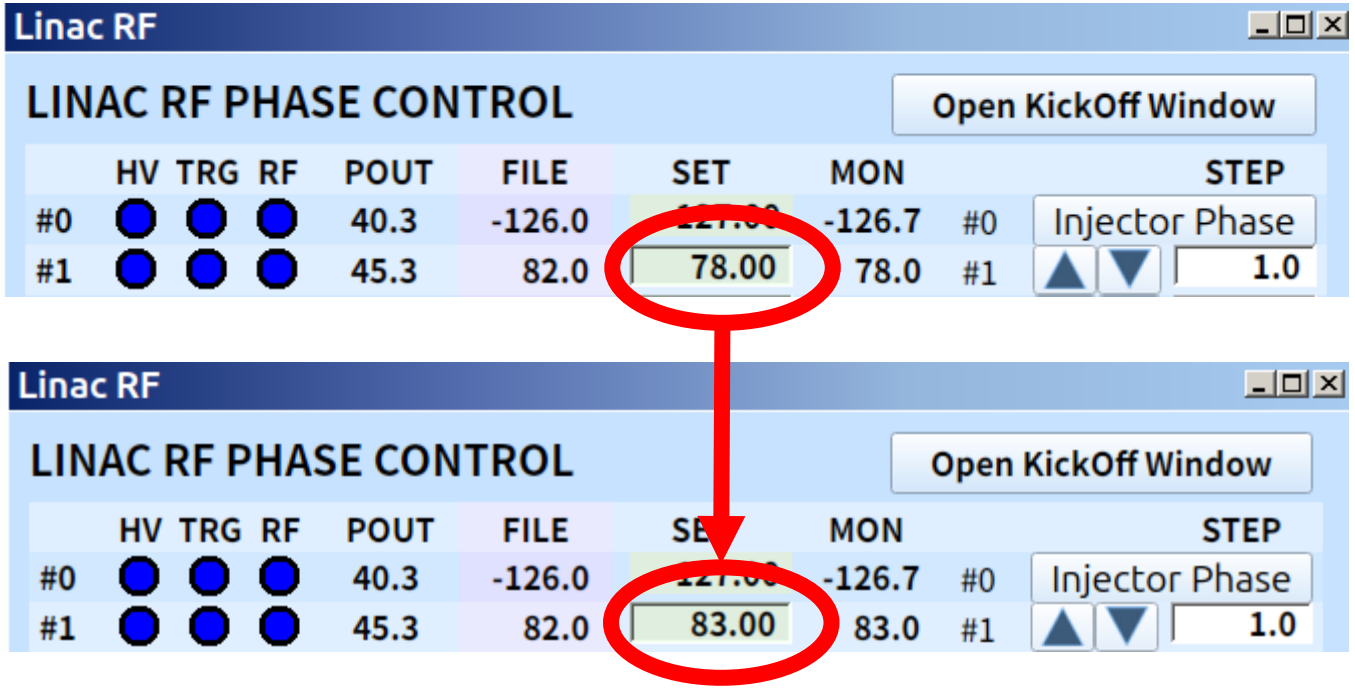
Beam-based Alignment Tool



DFS and WFS in the ATF LINAC

Change Energy in ATF LINAC

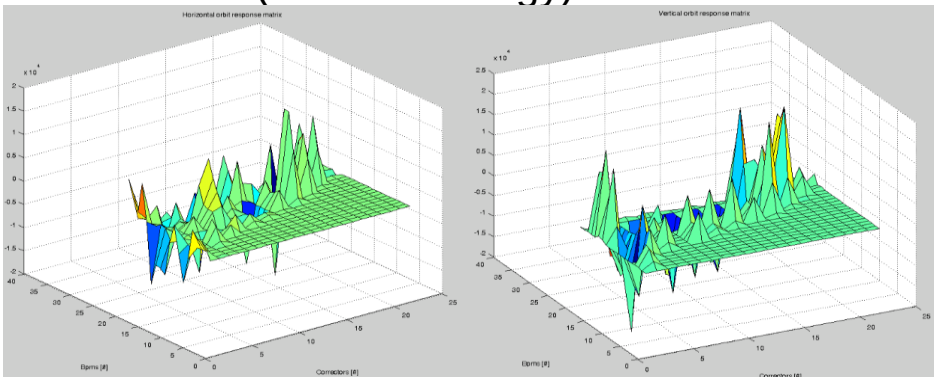
To change the **beam energy** in the LINAC, the **Phase** of the Klystron #1 was **increased by 5 degrees**:



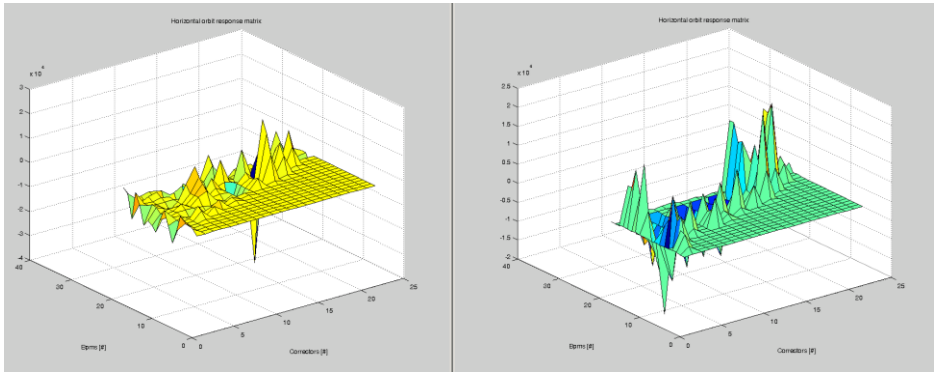
ATF LINAC Response Matrices (DFS)

Response Matrices in the ATF LINAC:

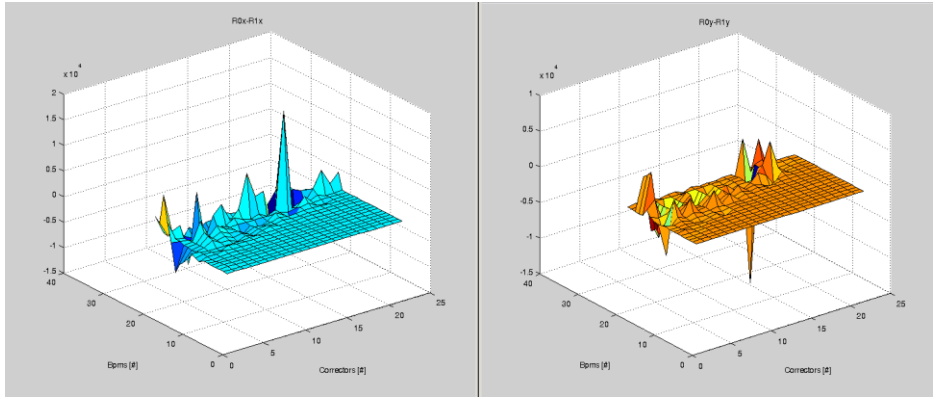
R0 (nominal energy)



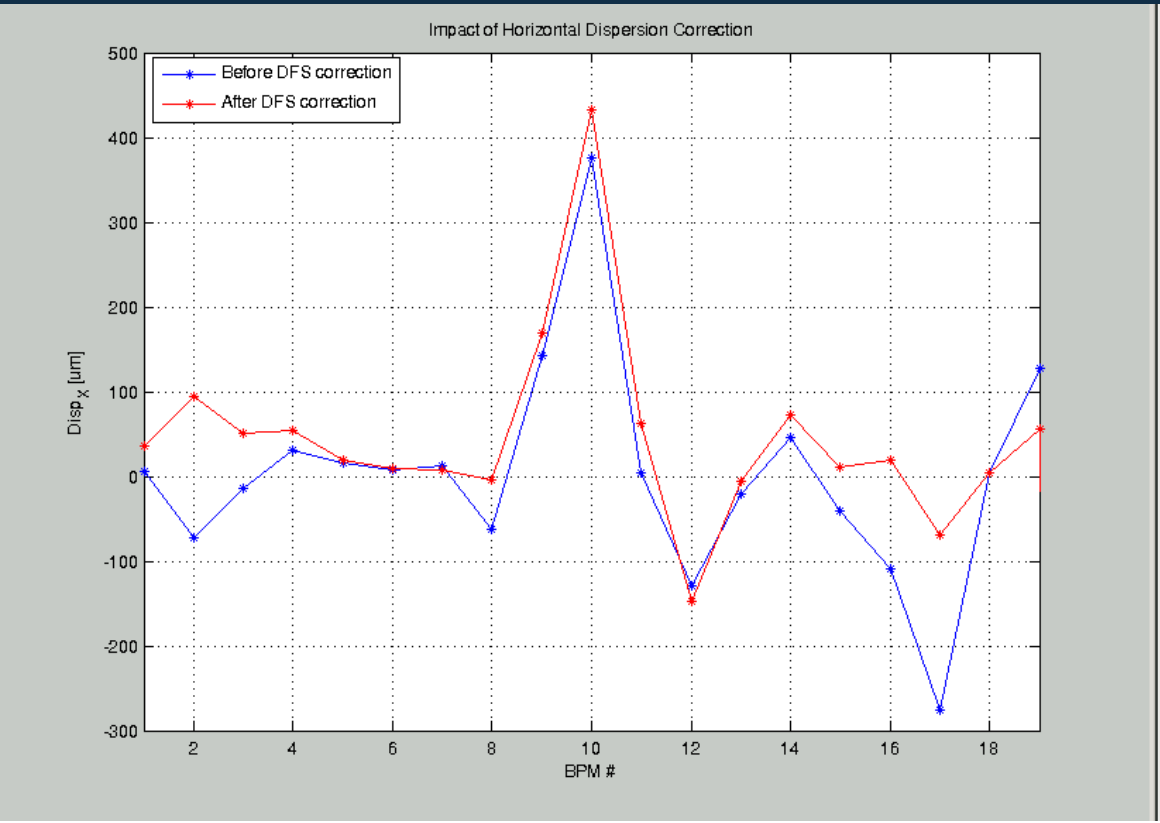
R1 (lower energy)

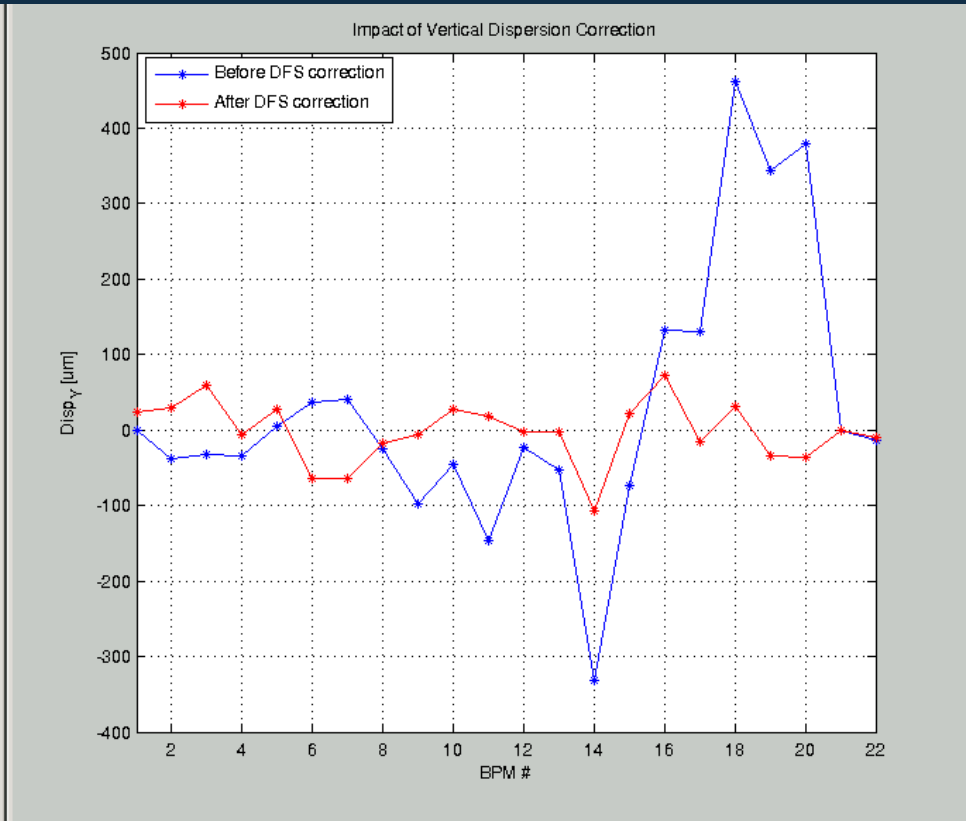


R1 – R0



DFS Correction in the ATF LINAC

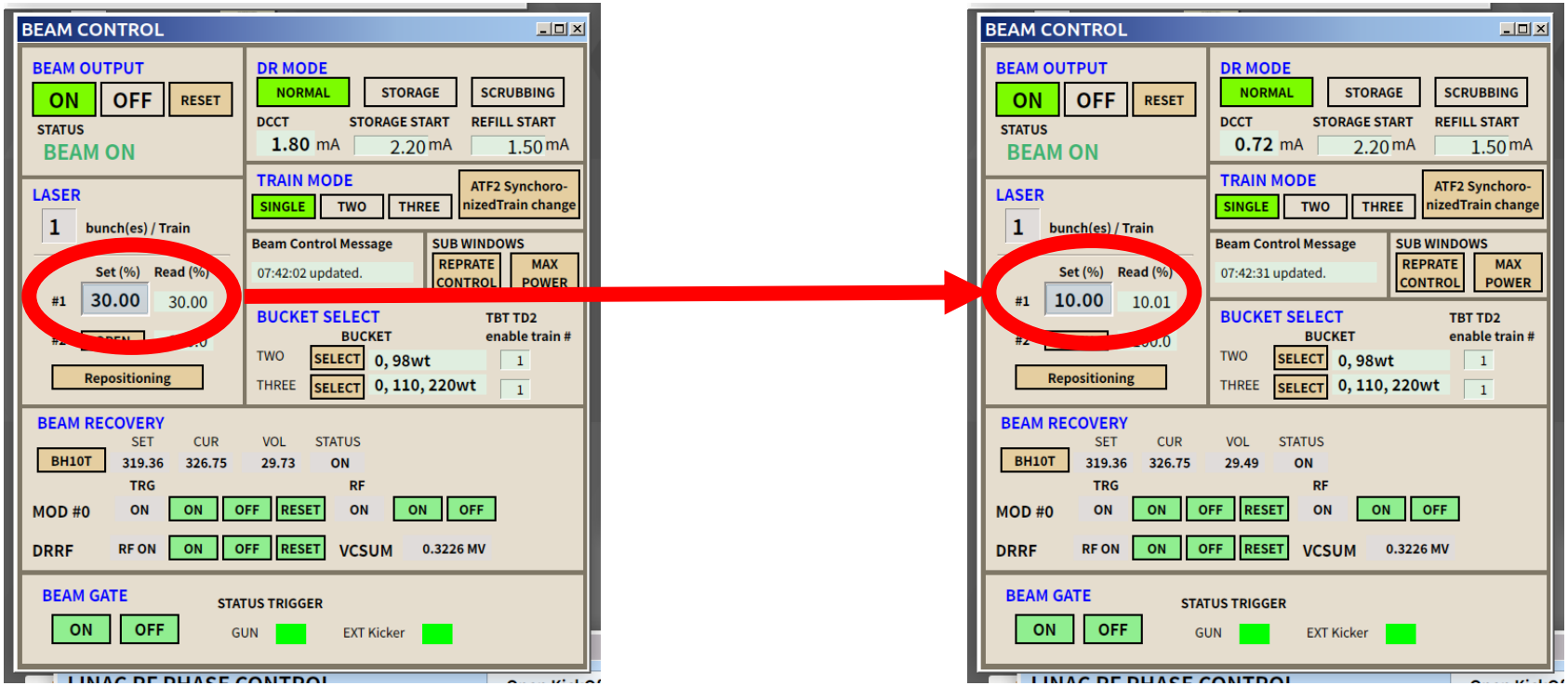




Good vertical dispersion correction

WFS in the ATF LINAC

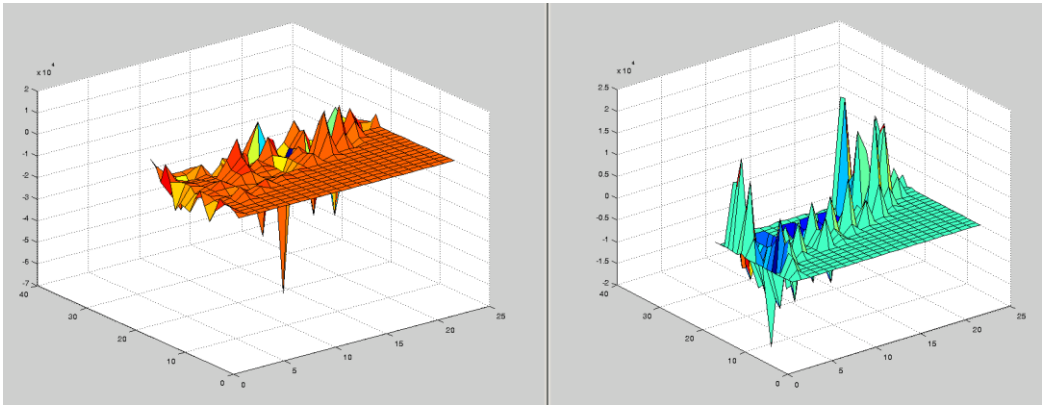
To change the **beam charge** in the LINAC, the **Laser** amplitude was decreased by 20%:



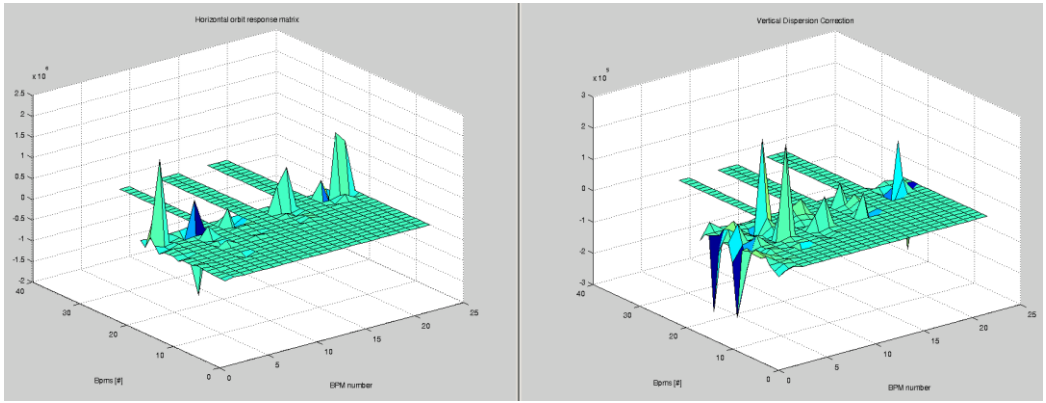
ATF LINAC Response Matrices (WFS)

Response Matrices in the ATF LINAC:

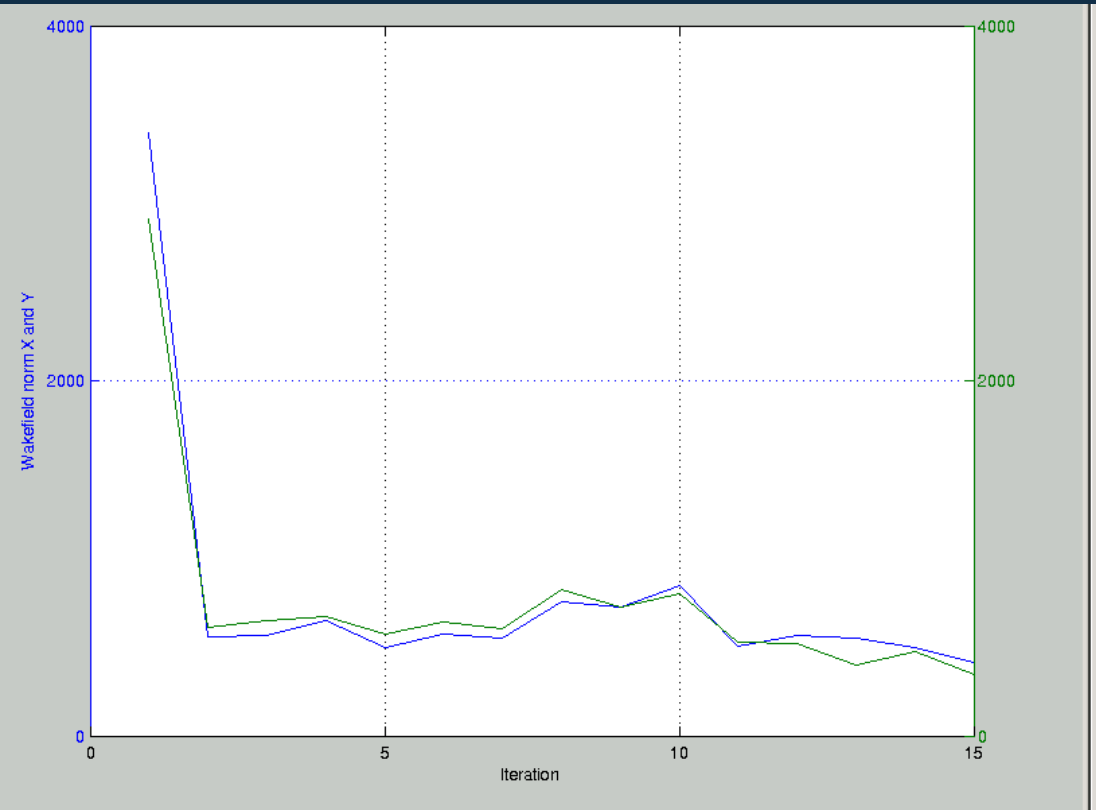
R0 (0.4E10 e-)

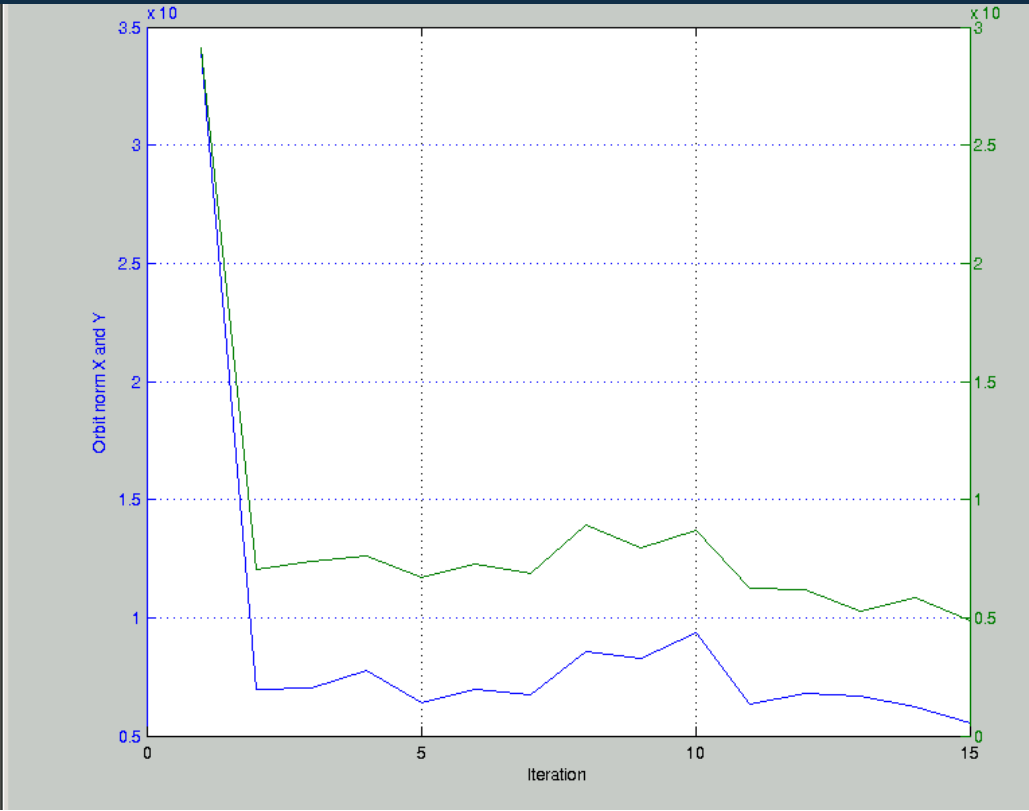


R1 (0.2E10 e-)



WFS Correction in the ATF LINAC



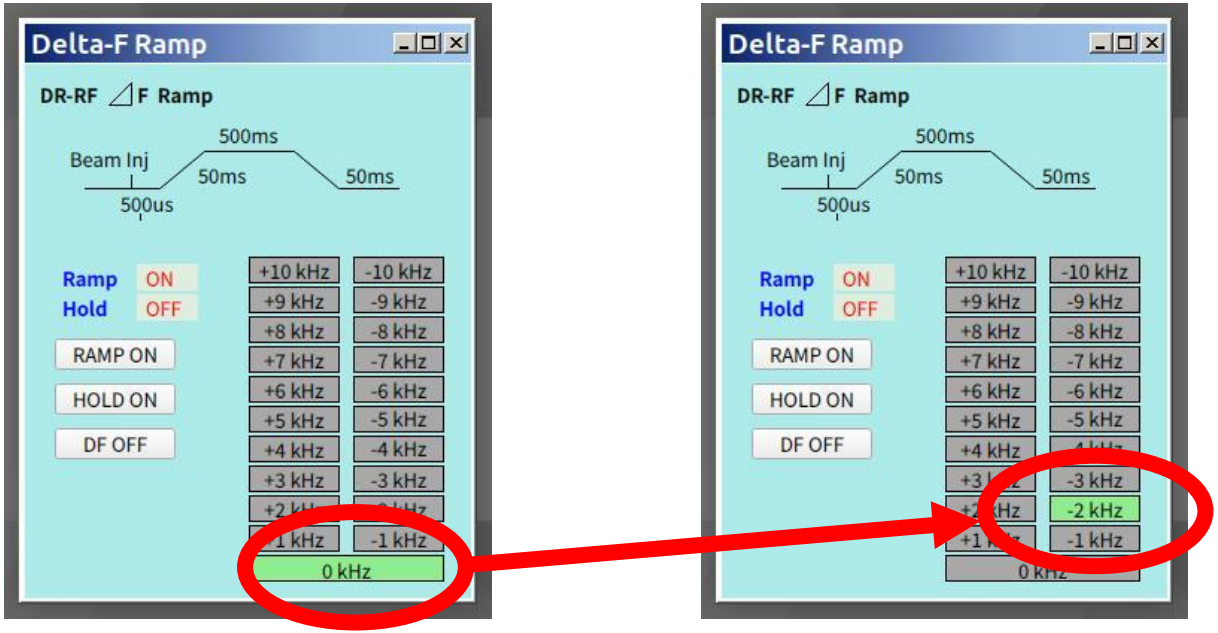


WFS correction convergences for both X and Y

DFS and WFS in the ATF2 EXT

Change Energy in ATF2 EXT

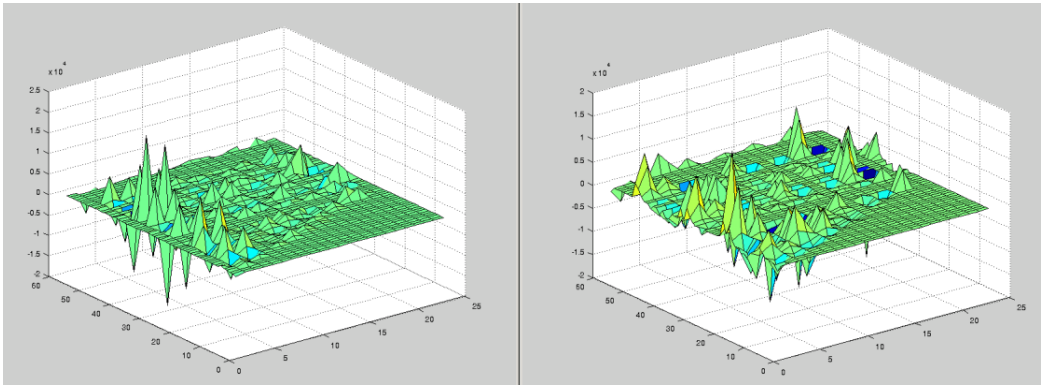
To change the **beam energy** in the EXT, the **DR Delta-F was decreased by 2 kHz:**



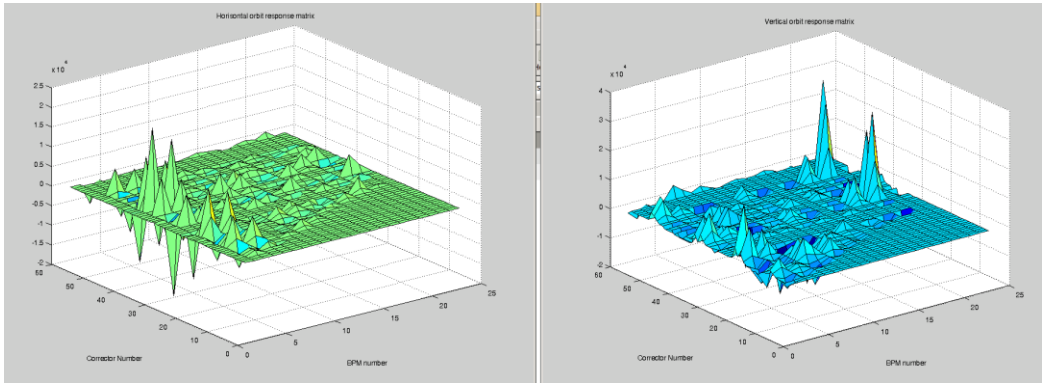
ATF2 EXT Response Matrices (DFS)

Response Matrices in the ATF2 EXT:

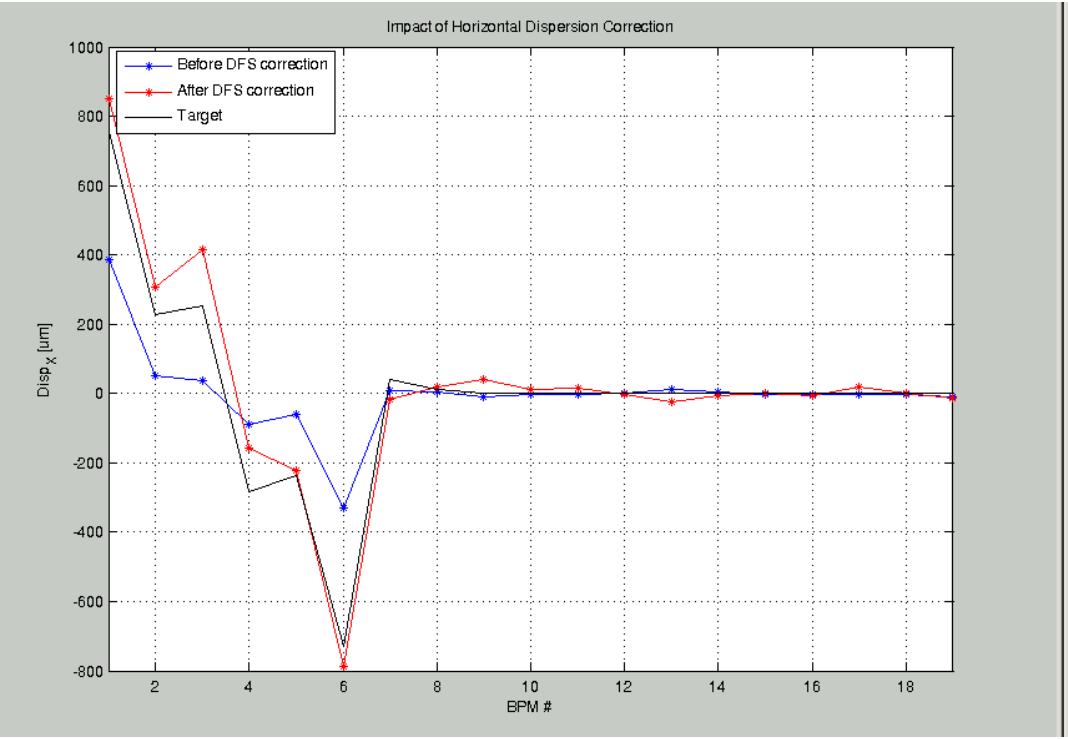
R0 (nominal energy)

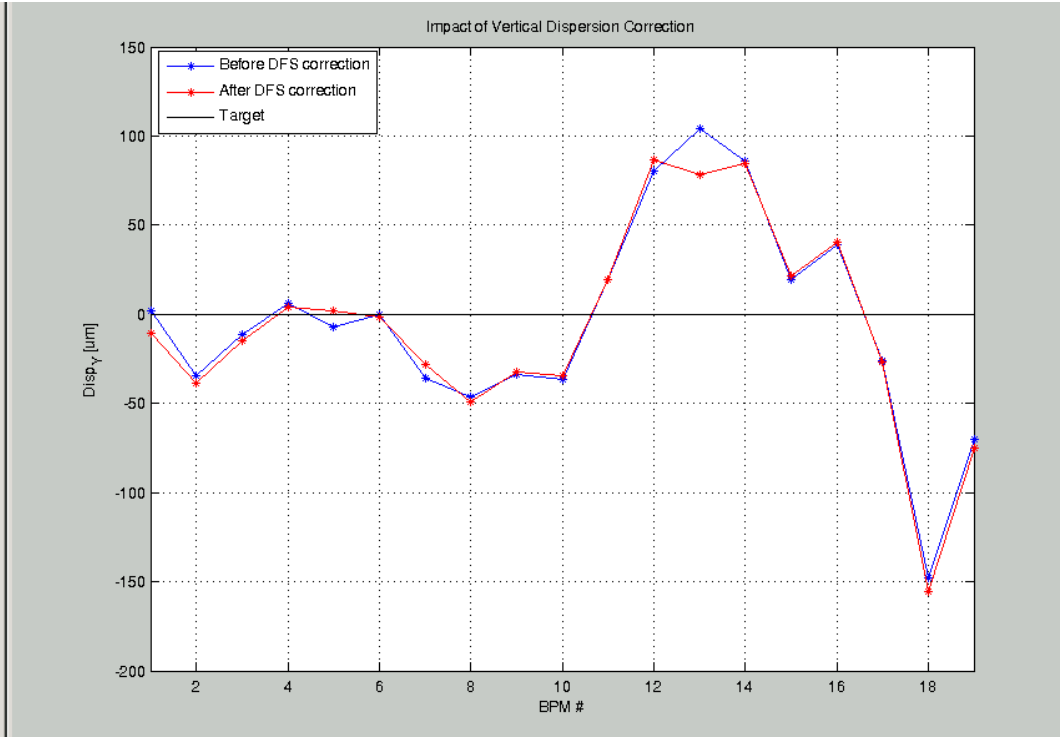


R1 (lower energy)



DFS Correction in ATF2 EXT



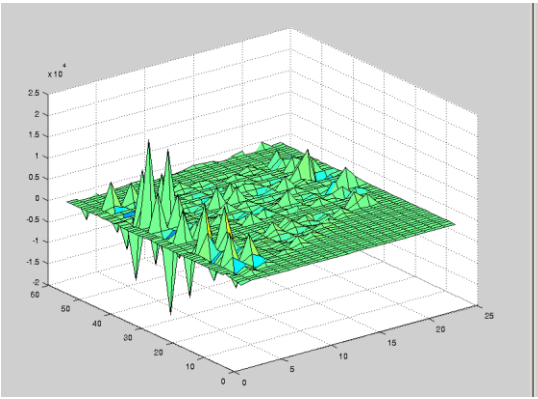


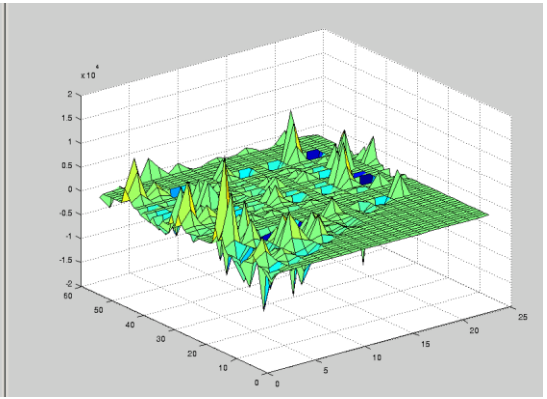
Good Horizontal dispersion correction

ATF2 EXT Response Matrices (WFS)

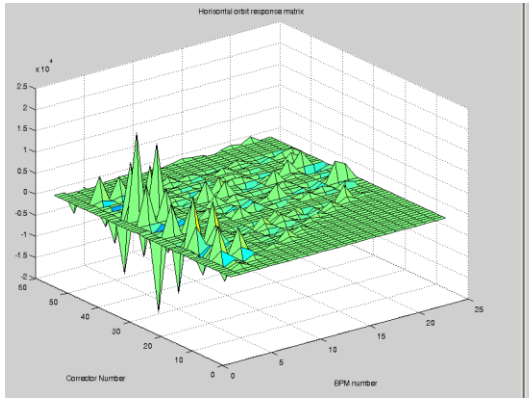
Response Matrices in the ATF2 EXT:

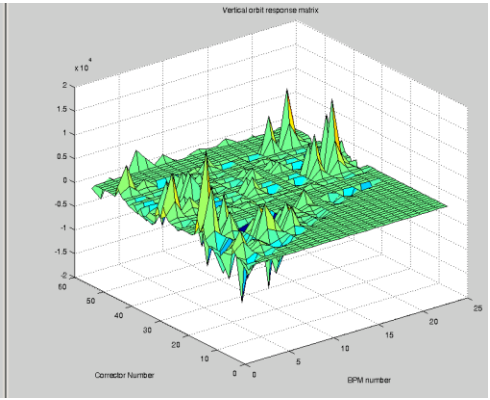
R0 (0.2E10 e-)



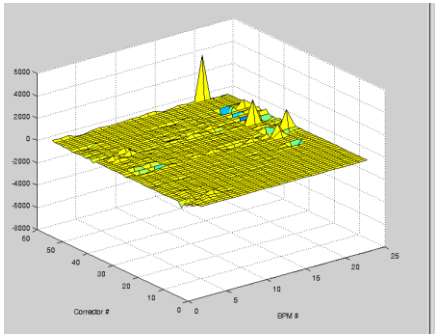


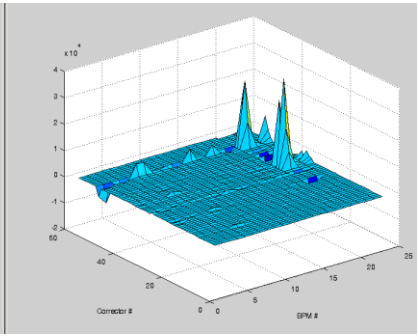
R1 (0.4E10 e-)





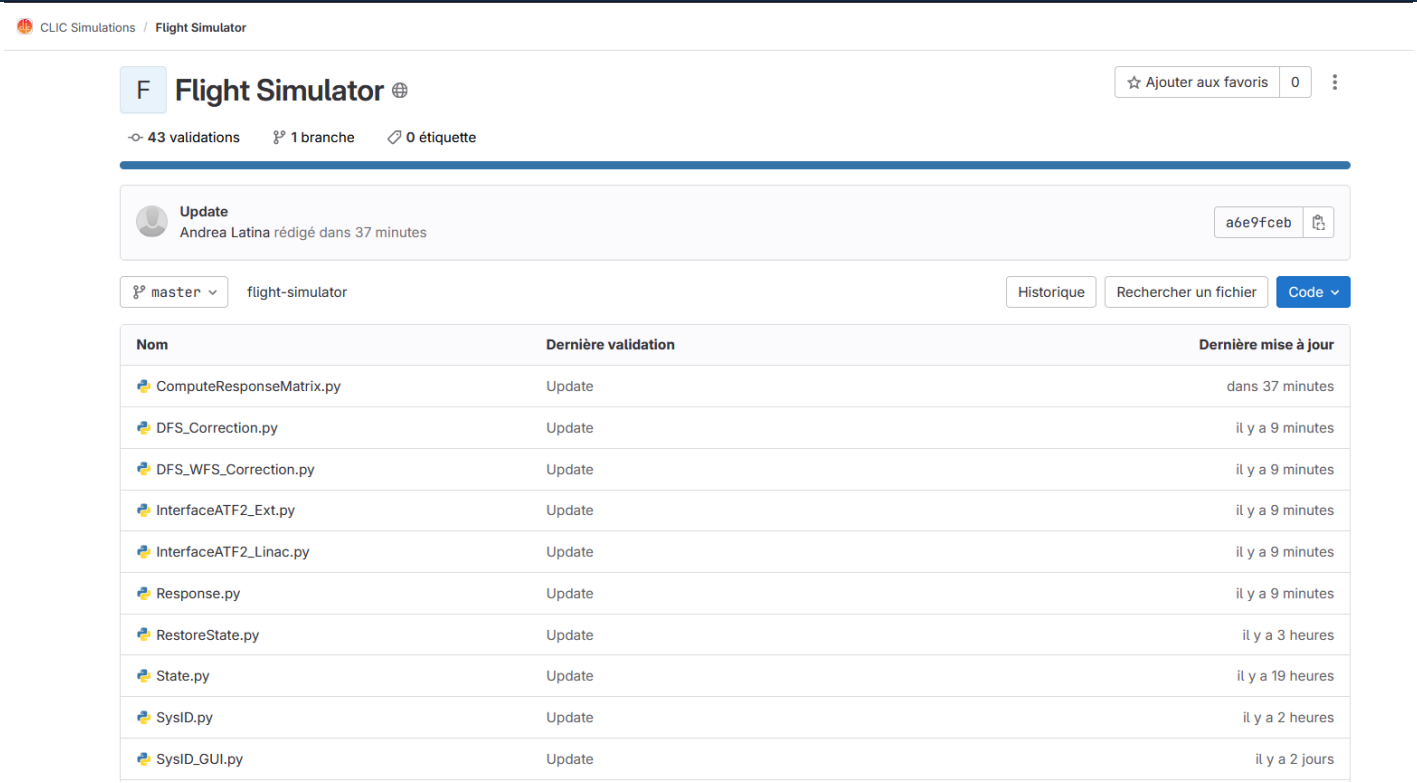
R1 – R0





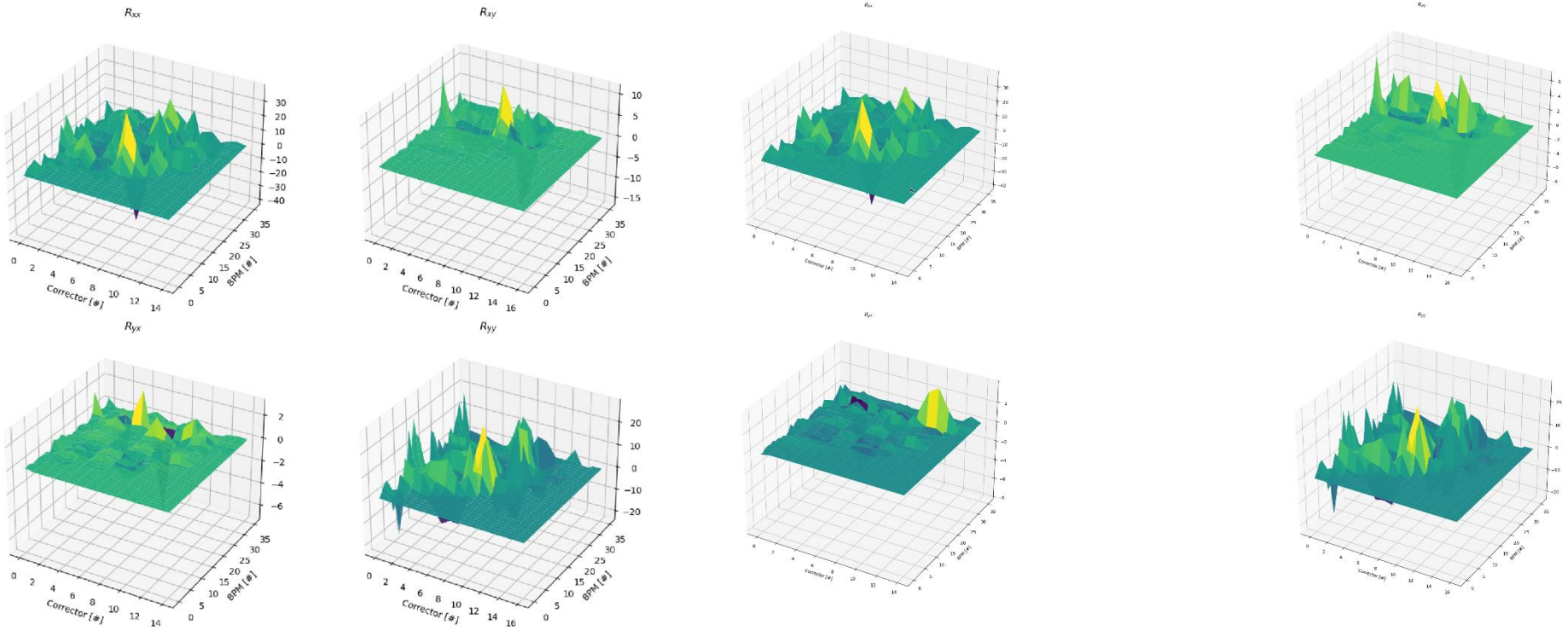
ATF Python Flight Simulator

Python Flight Simulator



https://gitlab.cern.ch/clic-simulations/flight-simulator

Python Response Matrices (DFS)

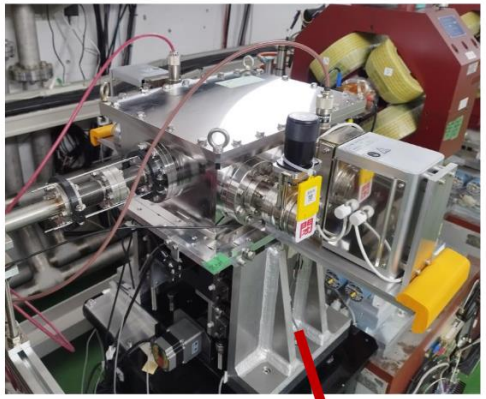


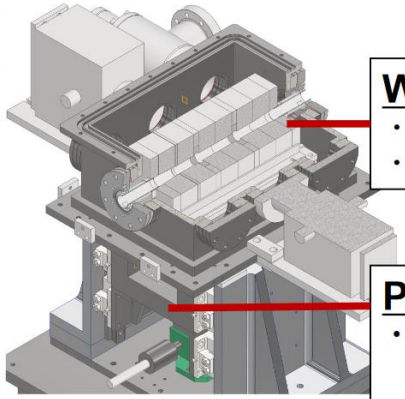
Movable Wakefield Source

Movable Wakefield Source

Installed a movable wakefield source to generate targeted wakefield kick

- **Evaluate the acted wakefield kick at the single wakefield source**
  - Measure the beam orbit change downstream from the wakefield source after the wakefield source is moved

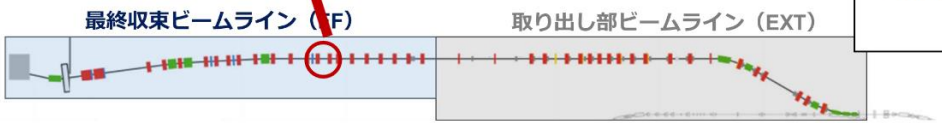




Wakefield study chamber
- **Produce the target wakefield source**
- Set on the block with arbitrary inside structure

Easy to compare with simulation results

Position adjustment mover
- **Control the wakefield kick strength** by adjusting the position of the wakefield source
- movable range：Ver. ±10 mm (1um step)
  Hor. ±6 mm (10um step)



8

Yuki Abe

Conclusions & Plans

- Matlab Flight Simulator (FS), DFS and WFS gave good results in LINAC and EXT.
- New Framework in Python being implemented (to replace Matlab).
- To do: Python FS GUI in PyQT6 and interface with simulation (RF-Track).
- To do: Apply BBA (DFS & WFS) in the DR.
- To do: Use, optimize and apply correction with the Movable Wakefield Source.

Thank you