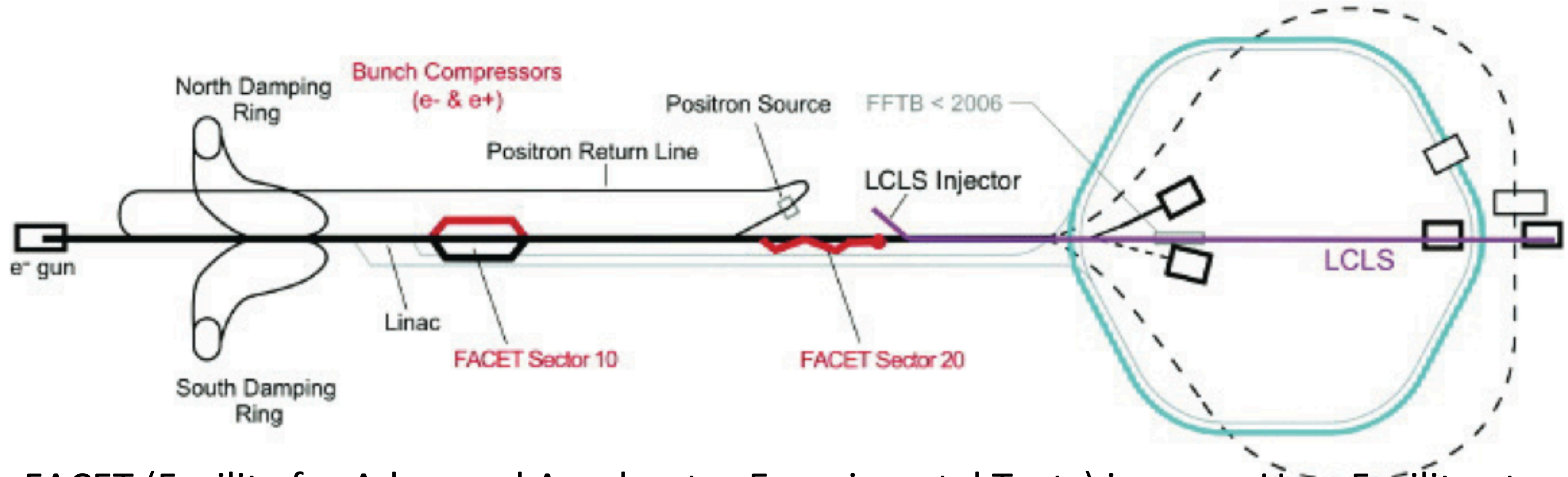
Tests of Dispersion-Free Steering at FACET (CERN-BBA)

A. Latina, J. Pfingstner, D. Schulte (CERN)
E. Adli (Univ. of Oslo/SLAC)

In collaboration with:
F.J. Decker and N. Lipkowitz (SLAC)

ECFA Workshop, May 27-31 2013 – DESY Hamburg

FACET



- FACET (Facility for Advanced Accelerator Experimental Tests) is a new User Facility at SLAC National Accelerator Laboratory. Experiments apply for beam time to a scientific committee.
- The first User Run started in spring 2012 with 20 GeV, 3 nC electron beams.
- The facility is designed to provide short (20 µm) bunches and small (20 µm wide) spot sizes.

FACET experiments:

- CLIC experiments
- Other experiments (not covered in this update) :
  - Plasma wake field acceleration, dielectric structure acceleration,
  - Smith-Purcell radiation, magnetic switching, teraherz generation …. and more

CLIC programme

- CLASSE: Measurement of long-range wakefields in the CLIC accelerating structures at FACET (G. De Michele, CERN) *(postponed)*

- Measurement of short-range wakefields in the collimators at End-Station B (ESTB) (J. Resta-Lopez, IFIC) *(pending)*

- Experimental Verification of System Identification algorithms and Beam-Based Alignment (BBA) Techniques at FACET (A. Latina, E. Adli, J. Pfingstner, D. Schulte) *(ongoing)*

CERN-BBA Motivation: Tests of BBA techniques

- Relevant beam parameters at injection

Symbol	Value
$\gamma\epsilon_x$	$3.0 \cdot 10^{-5}$ m $\cdot$ rad
$\gamma\epsilon_y$	$0.25 \cdot 10^{-5}$ m $\cdot$ rad
σ_z	1 mm
σ_E	1%
q	3.24 nC
E_0	1.19 GeV

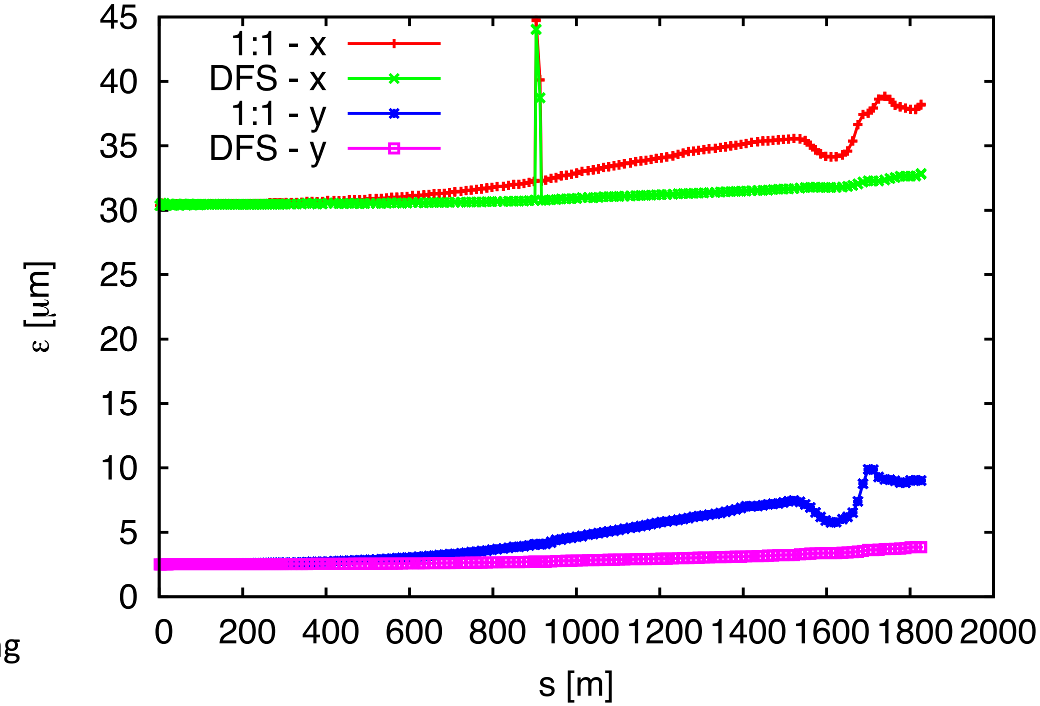
- Misalignment and BPM precision values

Symbol	Value, RMS
$\sigma_{\text{quadrupole offset}}$	100 μm
$\sigma_{\text{bpm offset}}$	100 μm
$\sigma_{\text{bpm precision}}$	5 μm

- Beam-Based Alignment: Dispersion-Free Steering

$$\begin{pmatrix} y - y_0 \\ \omega(\eta - \eta_0) \\ 0 \end{pmatrix} = \begin{pmatrix} \mathbf{R} \\ \omega\mathbf{D} \\ \beta\mathbf{I} \end{pmatrix} \begin{pmatrix} \theta_1 \\ \vdots \\ \theta_m \end{pmatrix}$$

Emittance growth with static imperfections, after beam-based alignment. The result is the average of 100 random seeds.

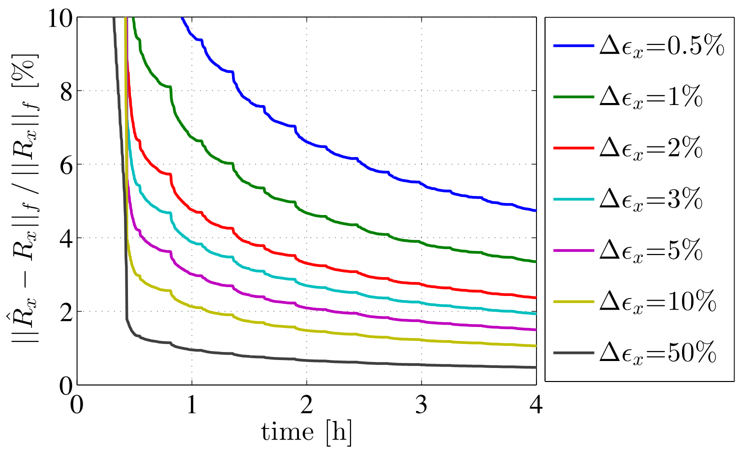


The challenge:
System Identification and BBA

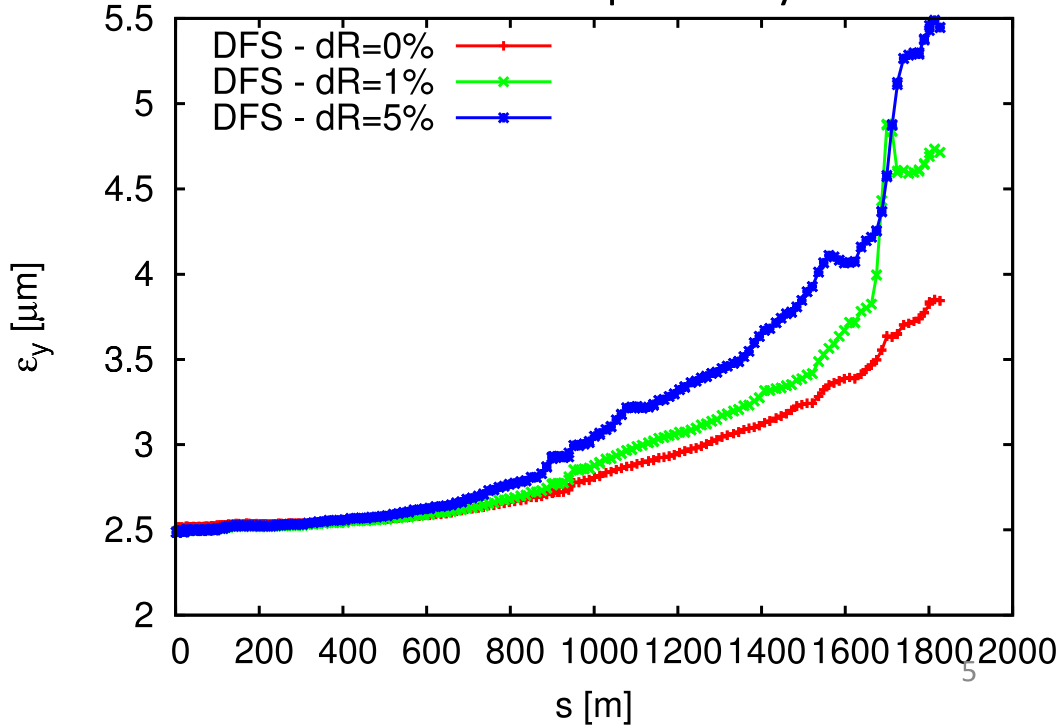
SYSID: inferring the *model* using an automatic **kick-measurement system identification algorithm** (for instance, Recursive Least-Square)

Challenge: the simulations utilise an ideal model which in reality we don't know.
The right-hand figure shows the emittance growth after dispersion-free steering, using an imperfect model. The result is the average of many seeds.

SysID convergence



Impact of SysID on BBA



Orbit correction principle

Linear response matrix from corrector j to BPM i:

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

The measured linear response includes all linear effects in the system:
- Quadrupole offsets (inducing dipole kicks)
- Dipole wake from beam offset in acc. Structures

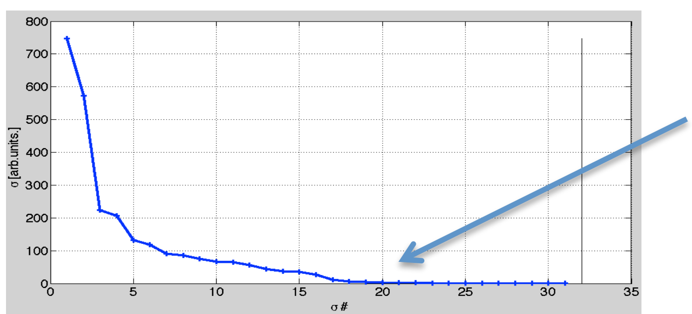
The response is found by difference measurements; is independent of absolute orbit.

Correction that finds the global solution, through the LS-inverse

$$\min_{\Delta\theta} = ||\mathbf{y} - \mathbf{R}\Delta\theta|| \quad \rightarrow \quad \Delta\theta = -R^{\dagger}\mathbf{y},$$

Need a way to take out correction directions due to noise in the measurement. We use a straight SVD-cut.

Sing.values of R :



Very little information in the low sing.val. directions -> huge corrector strength needed to make a small adjustment to correction -> ignore these directions.

Dispersion-Free Steering principle

Besides minimizing orbit, we minimize the difference between the nominal orbit and the dispersive orbit. We also need to constraint nominal orbit. Weighted solution; weight for difference orbit ~ BPM_{acc} / BPM_{res} .

$$\chi^2 = w_0^2 \Sigma y_{0,i}^2 + w_1^2 \Sigma (y_{1,i} - y_{0,i})^2.$$

Need to solve the following system of equations:

$$\begin{pmatrix} y - y_0 \\ \omega(\eta - \eta_0) \\ 0 \end{pmatrix} = \begin{pmatrix} \mathbf{R} \\ \omega \mathbf{D} \\ \beta \mathbf{I} \end{pmatrix} \begin{pmatrix} \theta_1 \\ \vdots \\ \theta_m \end{pmatrix}$$

This reduces to a LS-problem, analogous to the orbit correction.

Parameter ω accounts for the relative weight to give to orbit and dispersion correction, β is a regularization parameter to better condition the response matrices.

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

History of T-501 (E-211)

- Last year: T-501
  - We got ~12 hours of effective beam-time: we run SYSID, and managed to excite orbit bumps

- Last quarter of 2012
  - the SAREC committee (SLAC Accelerator Research Experimental Program Committee) accepted our proposal for continuing our tests at SLC-FACET
  - We've been promoted from T-501 to E-211 (i.e. from test-beam to *full featured* experiment)

- March 11 – 18, 2013
  - We got 32+ hours of beam-time

Lessons from year 2012

Last year we managed to control the orbit, but not the dispersion.

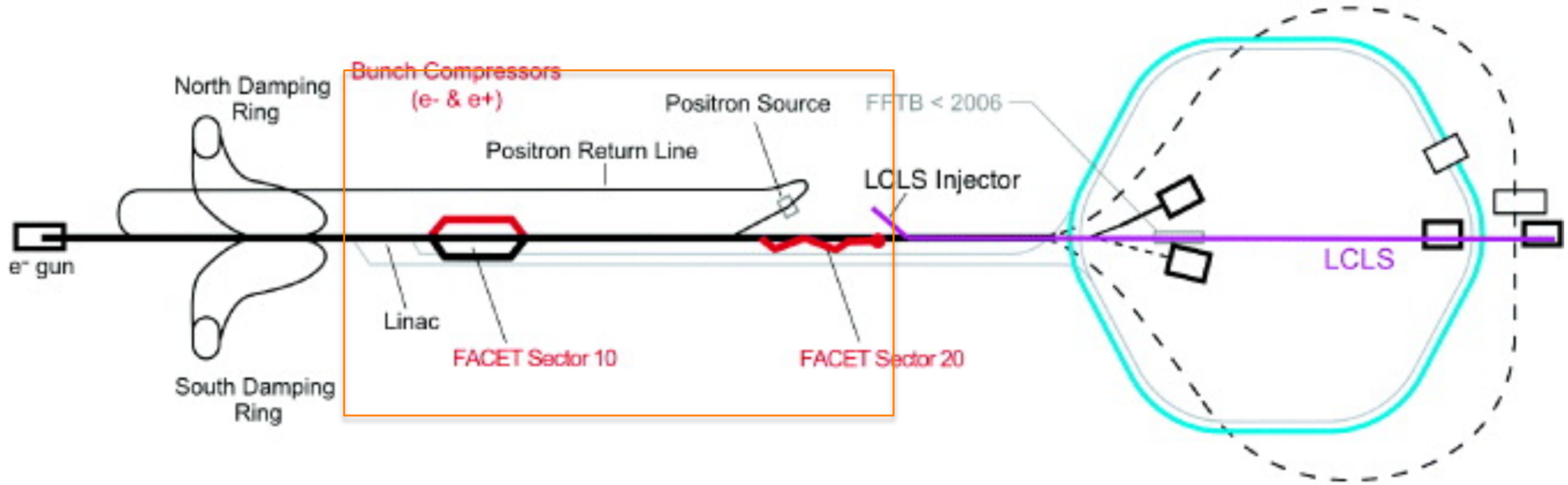
Lessons we learned:

- Try to avoid incoming dispersion
- Avoid to use N_bpms > N_correctors

Measures we took:

- ✓ We decided to focus on the first half of the linac
- ✓ N_bpms ~ N_correctors
- ✓ We picked the ‘best’ correctors in X/Y, matched by ‘best’ BPMS in X/Y (i.e. those located at large betas)
- ✓ We run extensive flight-simulations of realistic on-line conditions before the experiment

Experimental Setup



- We run with a 'pencil beam'
  - 1 nC charge

- Linac was in *no compression* mode
  - 1.5 mm bunch length

  (reduced wakes w.r.t. nominal charge 3nC, but still quite long bunches)

- We focused on sectors **LI04 thru LI08** (500 meters of Linac)
  - Dispersion was created off-phasing (by 90°) one klystron in sector LI02

Beam-time Schedule & Program

Beamtime:

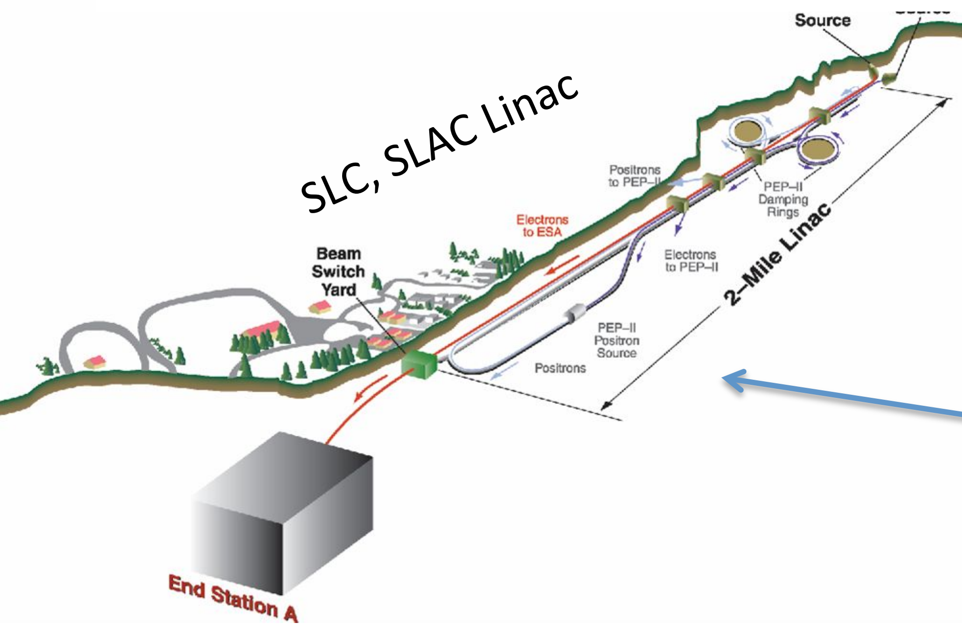
- March 11 (6pm-8am) 14 hours
- March 12 (12am-8am) 8 hours
- March 15 (12am-8am) 8 hours
- March 16 (12am-8am) 8 hours

Our program:

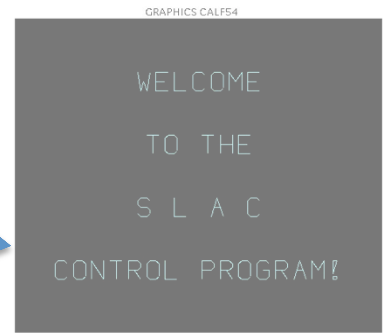
0) preparation
1) commissioning of our new software for the on-line; orbit response measurement (SYSID)
2) dispersion response measurement and orbit control excitation (SYSID+ 1:1 steering)
3) orbit correction and dispersion correction (take proof-of-principle plots) (BBA)
4) orbit correction and dispersion correction with emittance measurement (BBA +emittance measurement)

Preparation

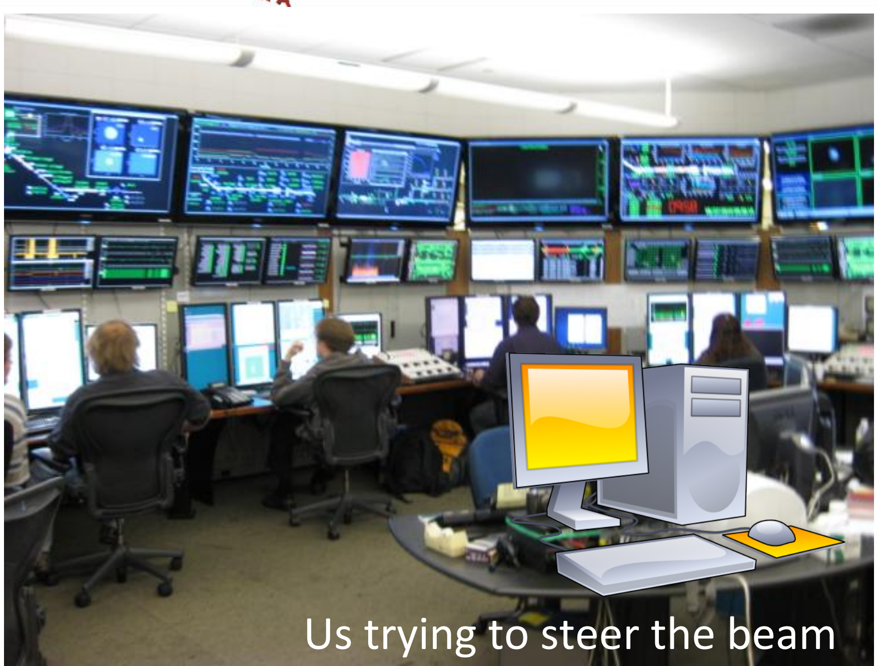
SLC, SLAC Linac



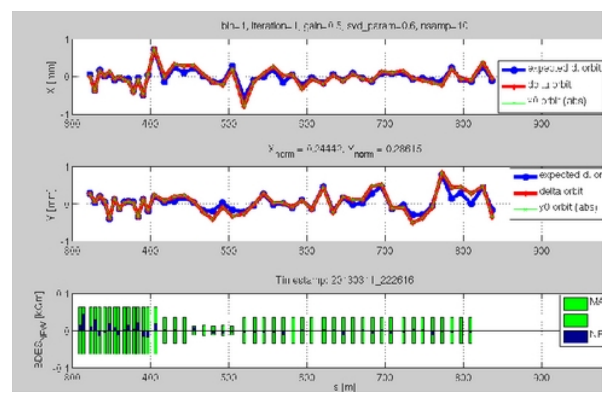
SCP, SLAC Control Program




```
facet_getMachine();
facet_setMachine();
```



Us trying to steer the beam



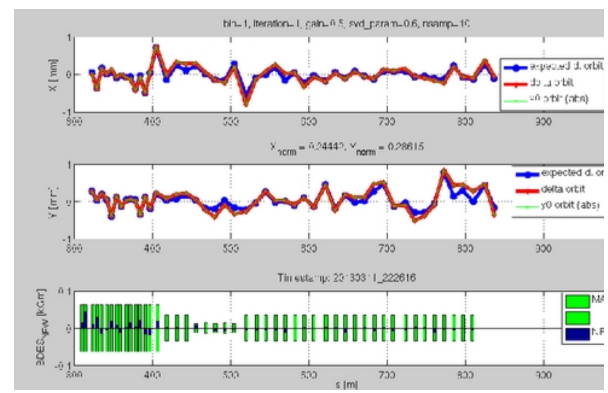
Our BBA routines (Matlab)

Preparation: Flight Simulator

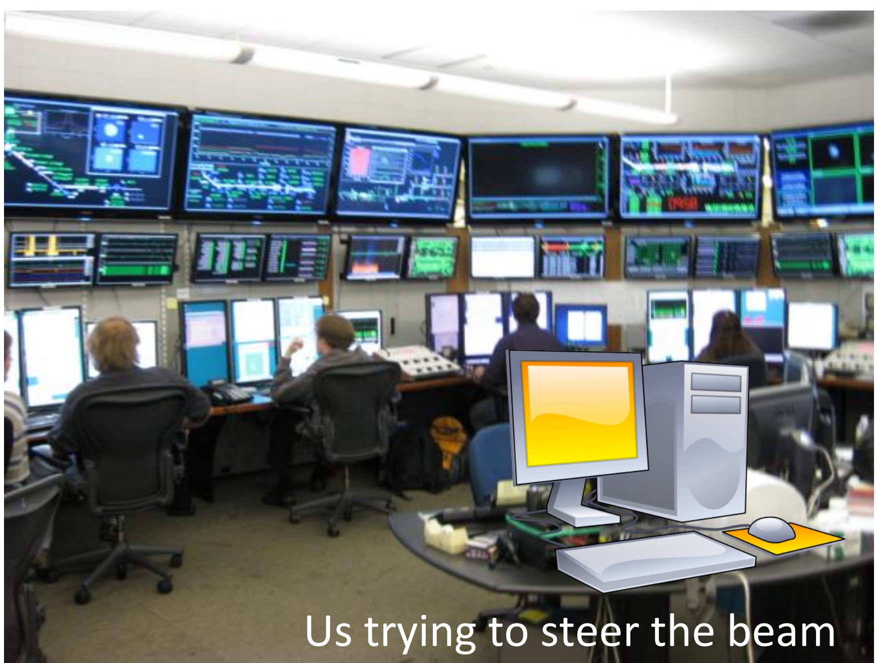
SCP, SLAC Control Program

PLACET

```
placet_getMachine();
placet_setMachine();
```

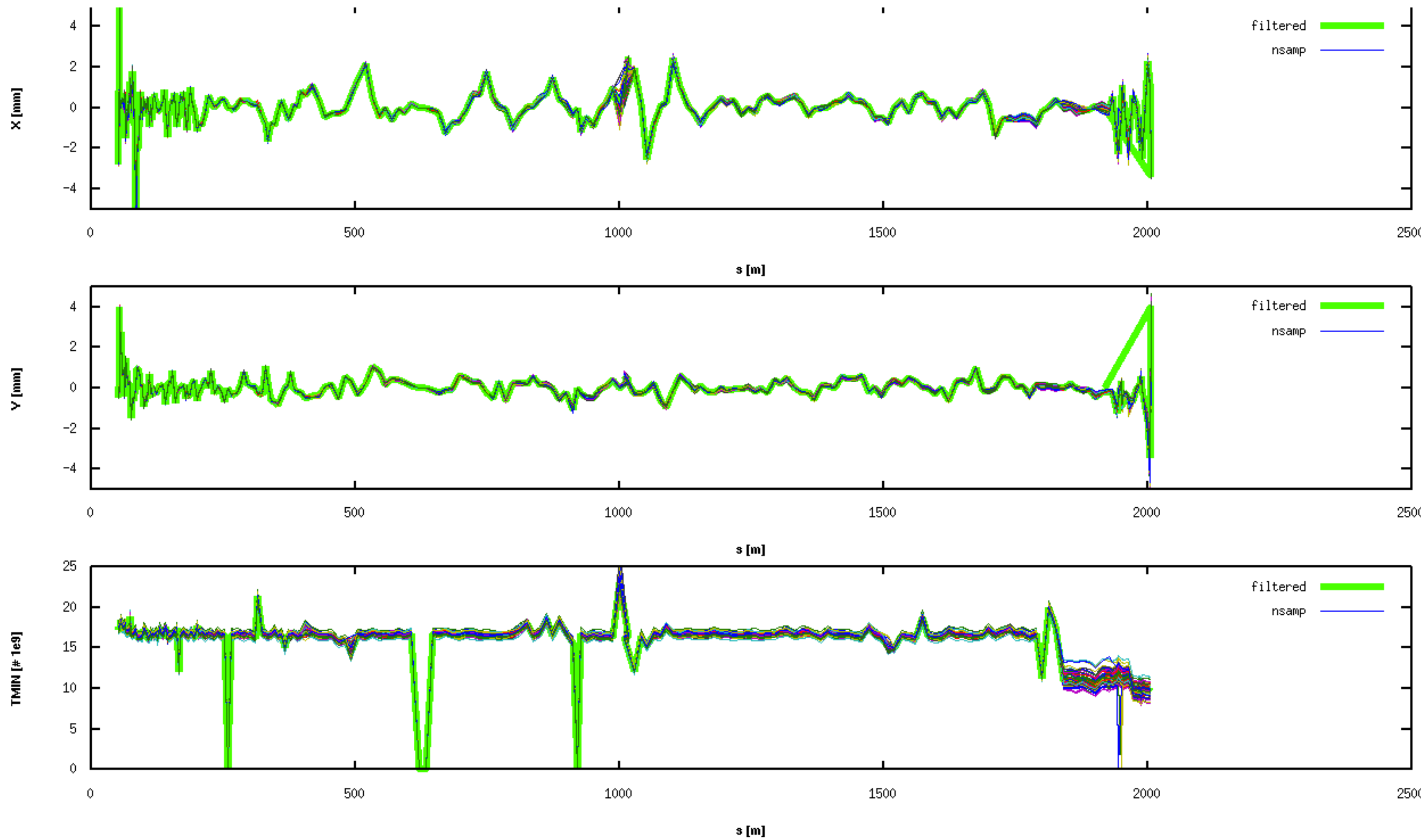


Our BBA routines (Matlab)



Us trying to steer the beam

Golden Orbit and BPM resolution



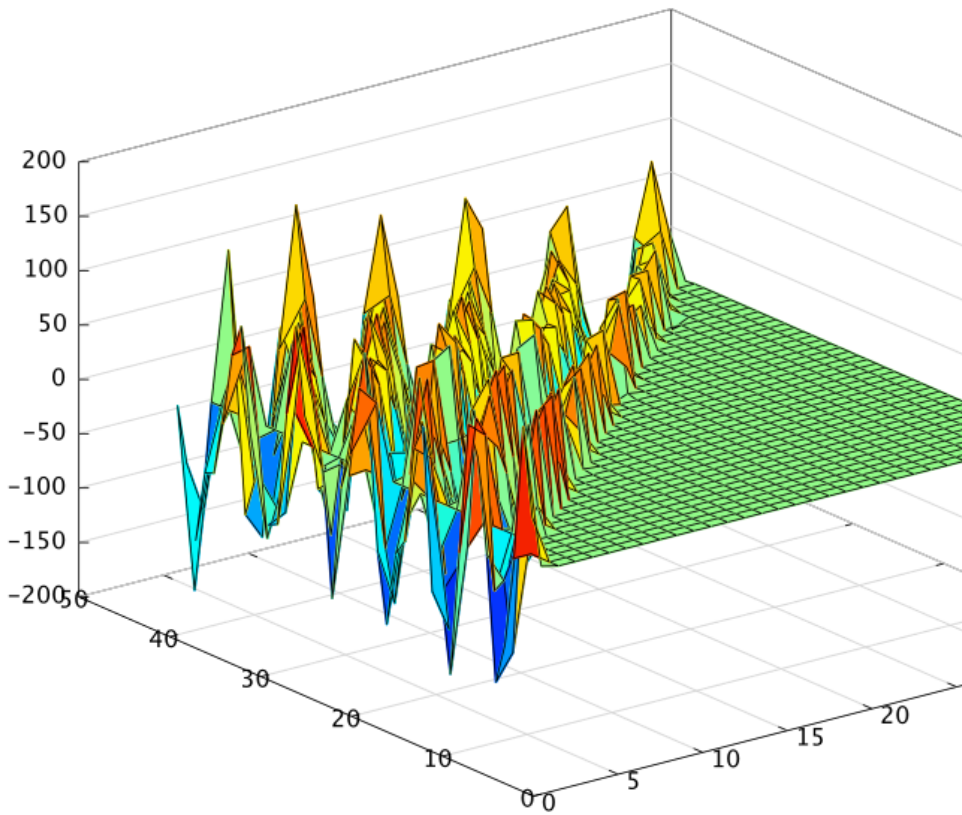
Effectively, BPM resolution is about 20-30 um (including beam-jitter). We averaged the BPM readings over 100 pulses, reaching an equivalent BPM resolution of:

Sx = 3.3 microm

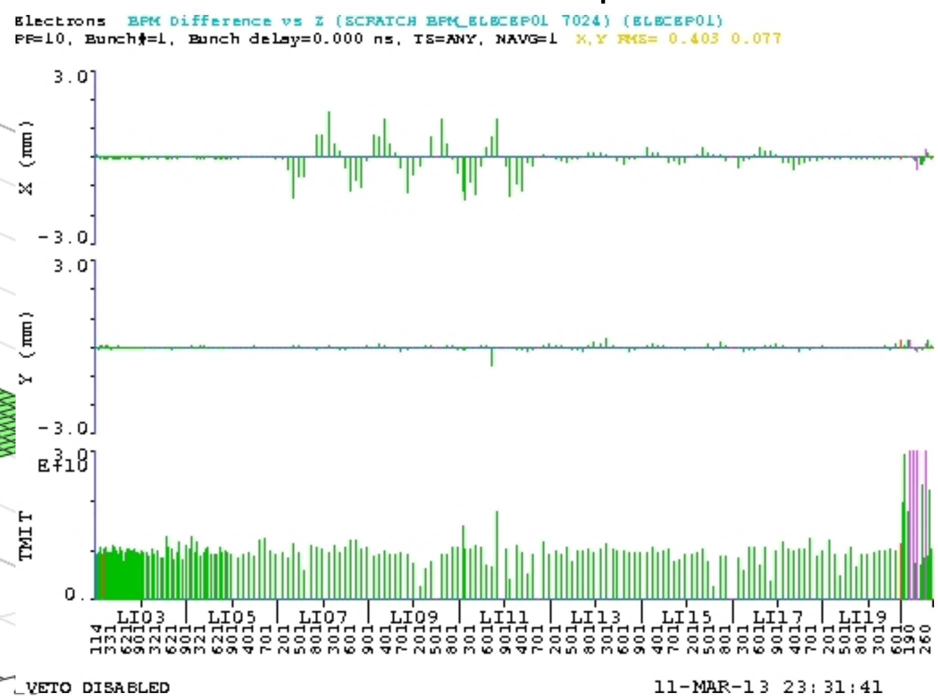
Sy = 2.5 microm

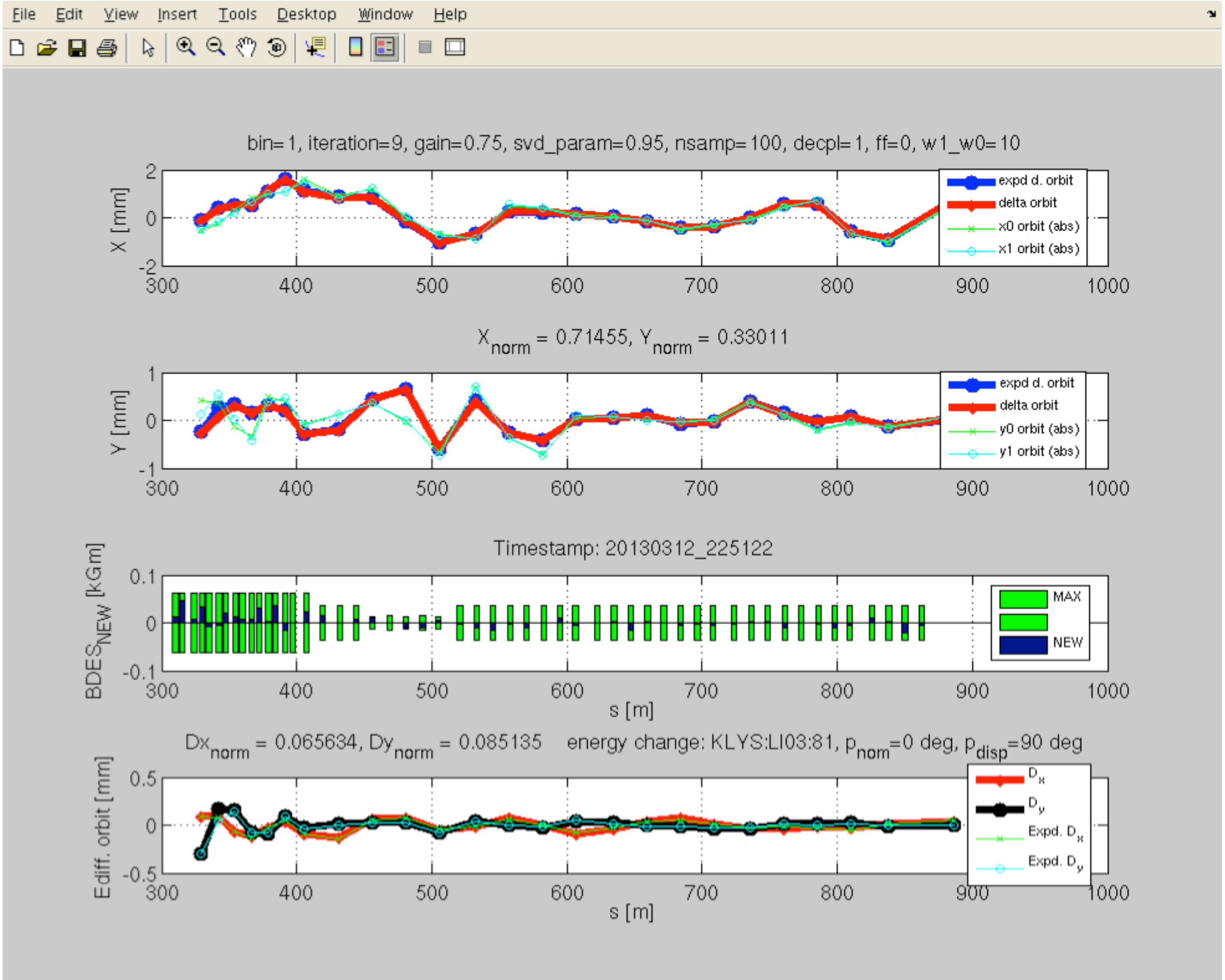
Results: SysID + orbit control

- Focused on Sectors 04 through 08 (500 m of linac!)
- Used 52 correctors in total (1h15 acquisition time)
- Measured orbit and dispersion (2h30 in total)
- Applied Orbit and DFS



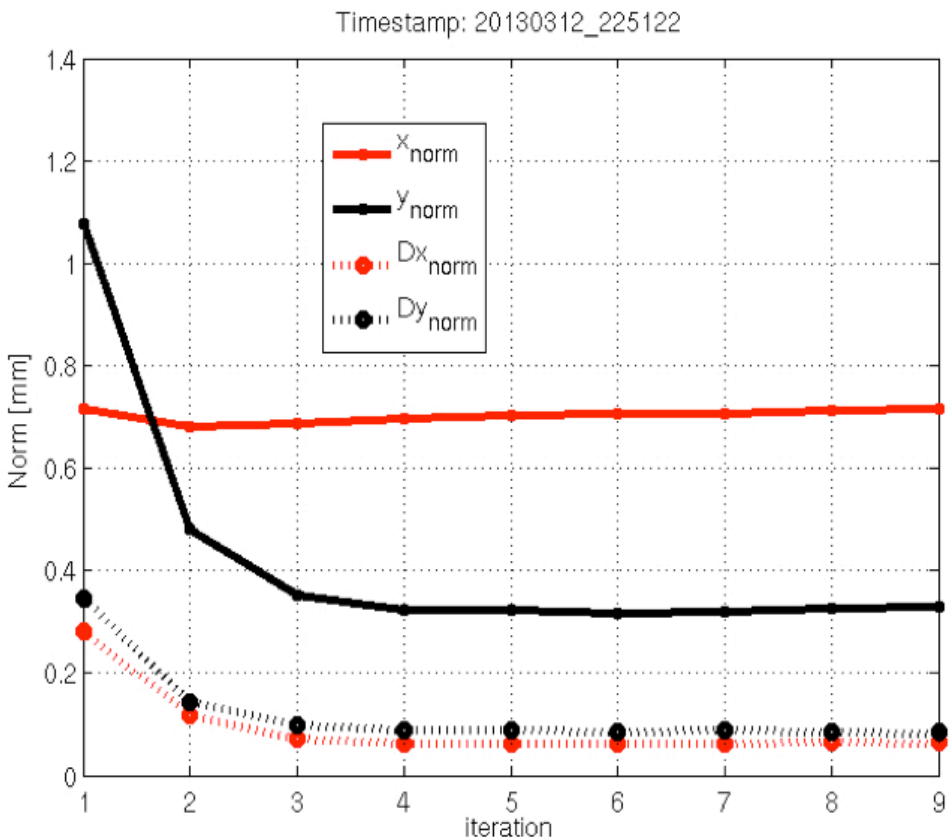
We excited a bump in X




File Edit View Insert Tools Desktop Window Help
bin=1, iteration=9, gain=0.75, svd_param=0.95, nsamp=100, decpl=1, ff=0, w1_w0=10
X [mm]
expd d. orbit
delta orbit
x0 orbit (abs)
x1 orbit (abs)
X_norm = 0.71455, Y_norm = 0.33011
Y [mm]
expd d. orbit
delta orbit
y0 orbit (abs)
y1 orbit (abs)
Timestamp: 20130312_225122
BDES_NEW [kGm]
MAX
NEW
s [m]
Dx_norm = 0.065634, Dy_norm = 0.085135 energy change: KLYS:LI03:81, p_nom=0 deg, p_disp=90 deg
Ediff. orbit [mm]
D_x
D_y
Expd. D_x
Expd. D_y
s [m]

Dispersion-Free Steering

We spoiled the orbit using correctors in sector 3 (ahead of our region)
We iterated DFS

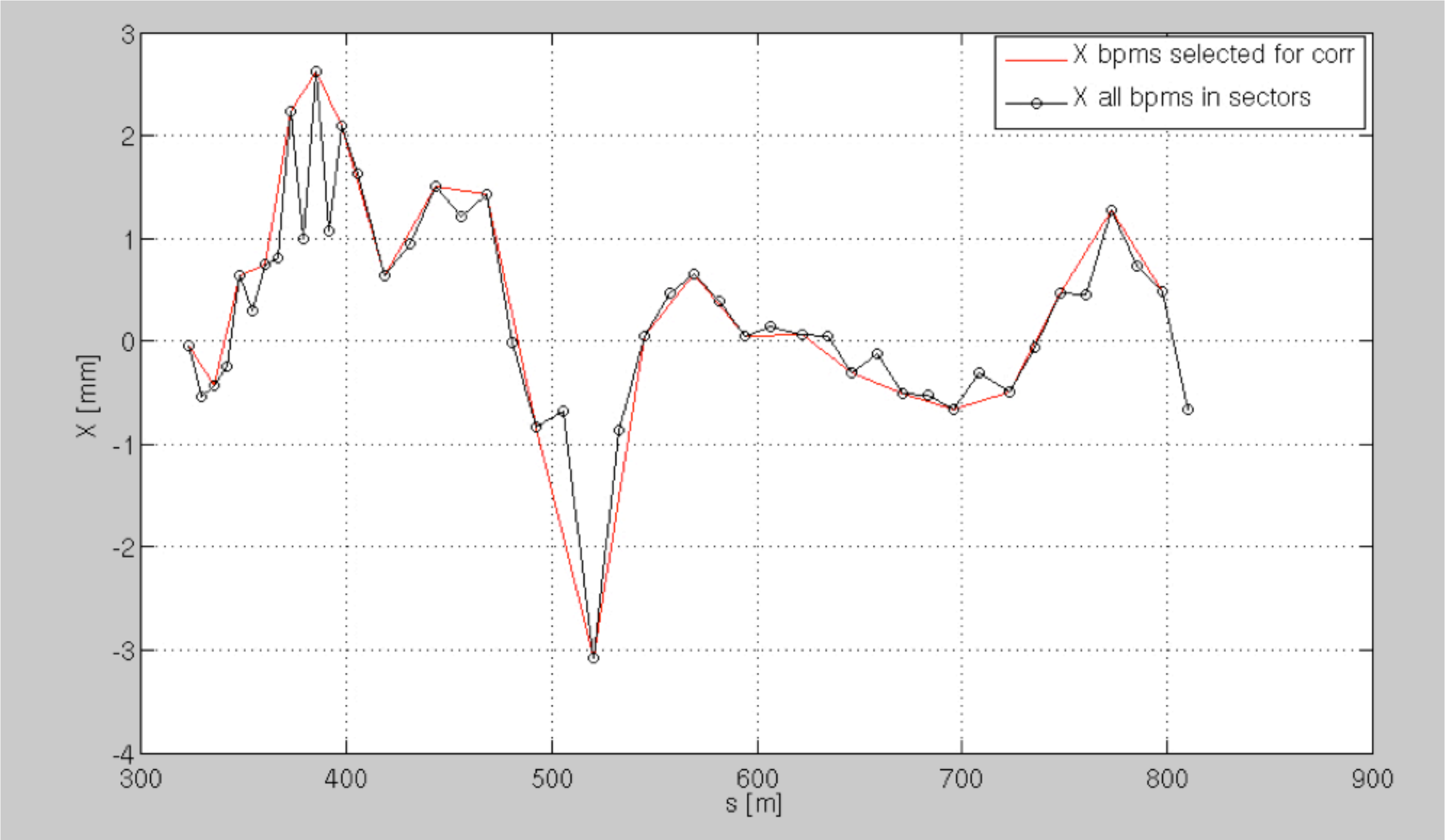


Bunch profile at S18 **before** correction

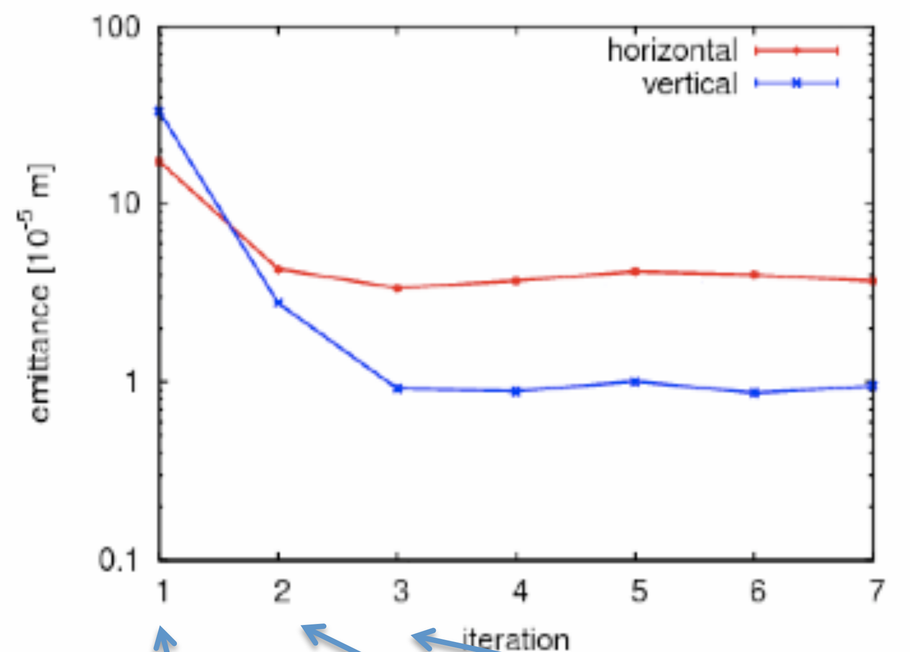
Bunch profile at S18 **after** correction

Dispersion-Free Steering

Tried some other BPM configurations; selecting every 2nd for correction, versus every BPM, did not result in large difference in correction results.



Emittance Growth and Dispersion-Free Steering



Incoming oscillation/dispersion is taken out and flattened; emittance in LI11 and emittance growth significantly reduced.

Emittance at LI11 (iteraton 1)
X: 43.2 um
Y: 27.82 um

Emittance at LI11 (iteration 4)
X: 3.71 um
Y: 0.89 um

S19 phos, PR185 :

Before correction

After 1 iteration

After 3 iterations

Conclusions and Future Steps

- We succeeded in proving the effectiveness of DFS to correct the emittance, and in showing the goodness of the SysID algorithms. Completed proof of principle case.
- The responses after one day are still effective -> (no need to re-measure the model); verified by applying same DFS after 1 day -> no significant change in the resulting machine
- Tried various BPM configurations: did not result in large difference in correction results
- Varied parameters w1_w0 and SVD cut, but ended up going back to best parameters we found in simulation (w1_w0 = 10, svd_cut = 0.95)
- Explore new beam-based algorithms to further improve the results

Flattening LI11-18

- On the spur of our success : We have been asked to correct the second part of the linac: LI11-18 (900m)

- We managed to flatten orbit and dispersion (gaining a factor 3 in both axes)

- But, the emittance did not show significant improvement
  - The reason might be that with such a long bunch, the wakefield-induced emittance growth is larger than the dispersive one
  - more studies / simulations are needed

- Wake-Free Steering?

Wake-Free Steering (WFS)

- Measure the system response to a change in the bunch charge, and use the correctors to minimize it
- Preliminary simulation result: