S.M.Liuzzo, A.Franchi, D.Martin, G.Gatta, et al. , FCC Week, Paris June 2022

ESRF | The European Synchrotron

ESRF tuning algorithms

Outline

History of ESRF tuning

New tuning techniques tests

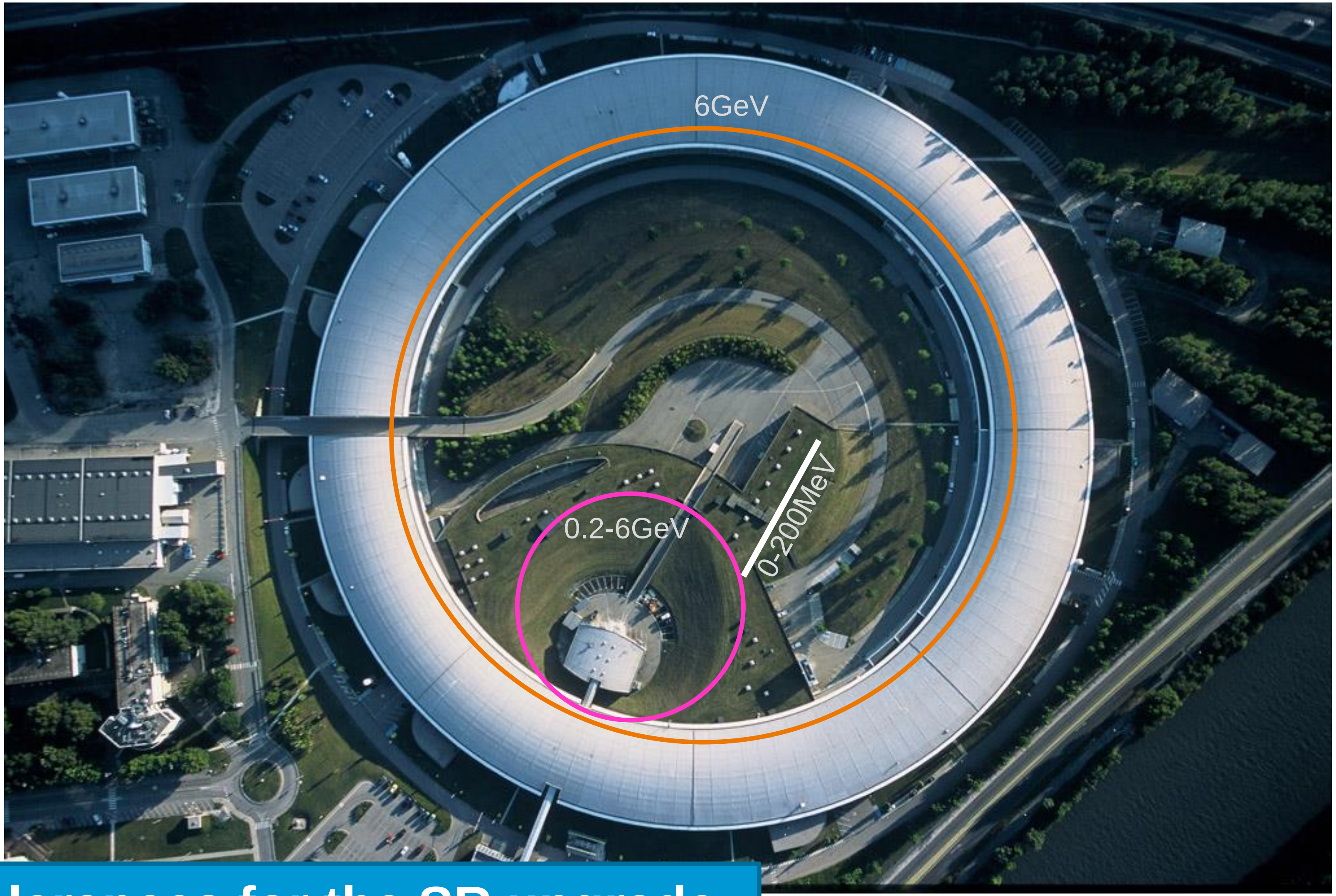
FCC-ee tuning simulations

Conclusions

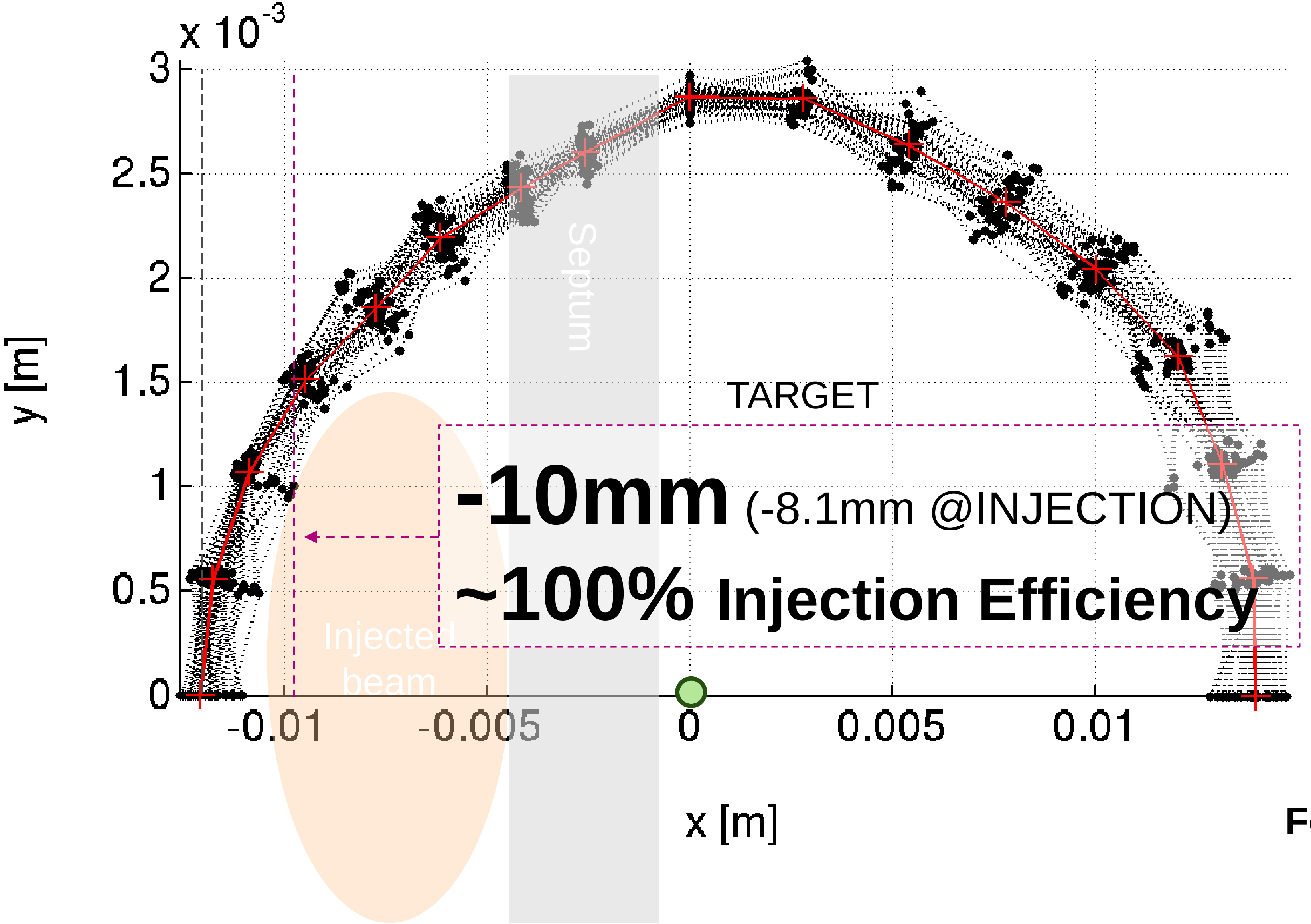
- → 60μm mag-mag tolerances,
- → simulated survey replace girder-to-girder
- → align on existing survey
- → NOECO (Non-linear optics from Off-Energy Closed Orbit
- → 10μm no IP , NOECO

ERSF
Storage ring
1994-2018 and 2019-??

C=844 m
E=6 GeV
τ= 5-26 h *
V_{RF}= 6 MV
ε_x=134 nm rad
ε_y= 10 pm rad
I = 40-200 mA *
(*) according to filling mode



Compute error tolerances for the SR upgrade



2 main parameters to achieve,
Absolute values depend on facility layout.

>10h
Touschek Lifetime
@ 200mA uniform, 5pm

Also :
Emittance variation < 2pm
Feasible correction strengths
Orbit < 100um rms
etc…

GUN, LINAC, Transfer Line to Booster

Booster Tr. Line Booster → SR

SR : **inject beam**

make first turn : lattice steerers, BPM, CT, beam losses ...

few turns -> RF on, beam accumulation (few mA)

orbit, tunes, BPM-QUAD offsets, chromaticity

Response matrix (optics/coupling)

Resonance knobs, sextupoles

specific optics adaptations

beam tuning for users

optimize injection efficiency / lifetime

Wait for vacuum, close collimators

Repeat:

Compute DA, lifetime, injection efficiency, etc…

days 1-30, 2 shifts/day

days 31-60, 2 shifts/day

WHAT IS SIMULATED IN COMMISSIONING-LIKE BEAM TUNING PROCEDURES

Most difficult and neglected

0 Assign lattice errors: magnetic centers + alignment survey

GUN, LINAC, Transfer Line to Booster

Booster Tr. Line Booster → SR

SR : inject beam

1 make first turn : lattice steerers, BPM, CT, beam losses...

2 few turns -> RF on, beam accumulation (few mA)

3 orbit, 4 tunes, BPM-QUAD offsets, 5 chromaticity

6 Response matrix (optics/coupling)

Resonance knobs, sextupoles

specific optics adaptations

beam tuning for users

optimize injection efficiency / lifetime

Wait for vacuum, close collimators

6 Repeat: 3 4 5 6 in an optimal order

7 Compute DA, lifetime, injection efficiency, etc…

Many days to simulate a fraction of the activity to be done in few days only!

Not included in commissioning-like simulations

dedicated simulations, not included in the loop

days 1-30, 2 shifts/day

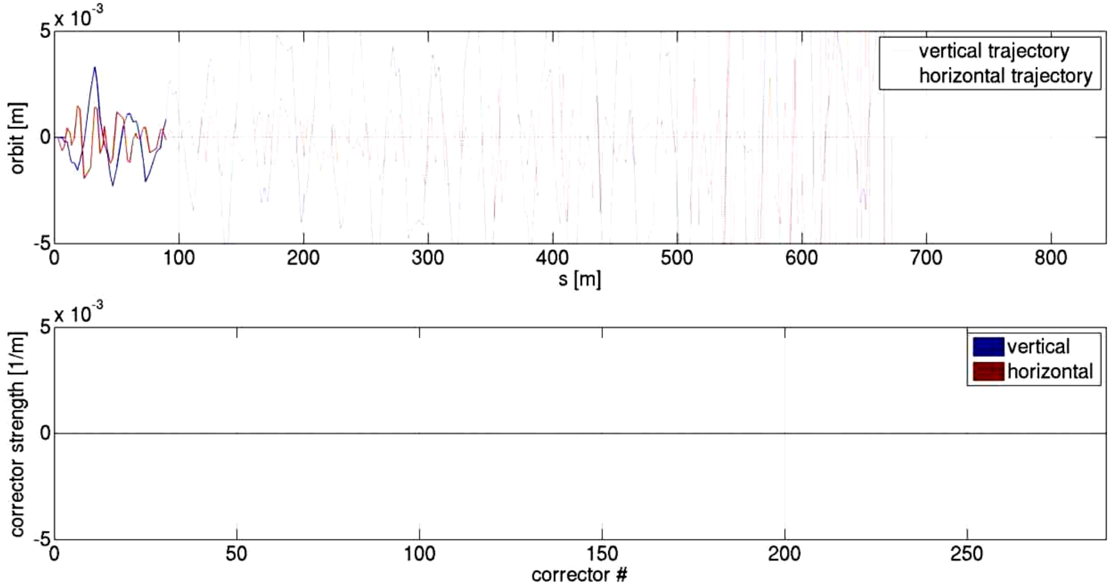
days 31-60, 2 shifts/day

From beam threading till accumulation

1) Injection on axis (static bump) or off axis (fit injected beam oscillation) available. Start from injection **off-axis**.
2) All magnets at their nominal working point
3) Power orbit steerers to achieve first turn (from simulations, beam survives about 3-4 cells without orbit steering, if magnets & alignment within tolerances).
4) Measure and correct tune based on few turns data (most relevant for off-axis injection)
5) Switch on RF, search for optimal frequency and phase
6) Beam accumulation

Not included in tuning simulations as it, but could be done. Usually before step 4, AT is able to provide a closed orbit and tunes.

Video: first turn correction simulations for beam injected on axis. Large BPM offsets (500µm) are included.



Measurements here: Preparation of the EBS beam commissioning
S M Liuzzo *et al* 2019 *J. Phys.: Conf. Ser.* **1350** 012022

Use in commissioning here: https://doi.org/10.1103/PhysRevAccelBeams.24.110701

PROCEDURE FOR OPTICS CORRECTION

```
%% RDT+DISPERSION CORRECTION from lattice error model

    % fit lattice errors model
    [rfit]=FitResponseMatrixAndDispersionEBSsimple(...
        rerr,...
        r0,...
        inCOD,...
        indBPM,...
        indHCor(1:9*2:end),... % 4 correctors, 1 every 8 cells
        indHCor(1:9*2:end),...  % 4 correctors, 1 every 8 cells
        [neigQuadFit,neigDipFit,neigSkewFit,neigDipFit],...
        4,...
        [speclab 'fitrm']);

    % get change of strength of correctors
    fq=atgetfieldvalues(rfit,indQuadCor,'PolynomB',{1,2});
    fs=atgetfieldvalues(rfit,indSkewQuadCor,'PolynomA',{1,2});

    % correct RDT and dispersion of fitted error model
    [~,inCOD,fcq,fcs]=atRDTdispersioncorrection(...
        rfit,... <<--- fitted error model! not lattice with errors!
        r0,...
        indBPM,...
        indQuadCor,...
        indSkewQuadCor,...
        inCOD,...
        [[floor(linspace(1,neigQuad,5)),neigQuad,neigQuad];...
        [floor(linspace(1,neigSkew,5)),neigSkew,neigSkew]]',...
        [true],...
        1.0,...
        [0.8 0.1 0.8],...
        ModelRM);

    %fcq=atgetfieldvalues(rfitcor,indQuadCor,'PolynomB',{1,2});
    %fcs=atgetfieldvalues(rfitcor,indSkewQuadCor,'PolynomA',{1,2});

    % store proposed correction
    dcq(1,:)=(fcq-fq);
    dcs(1,:)=(fcs-fs);
```

Commissioning-like sequence of corrections is implemented using matlab accelerator toolbox.

Fit of “measured” partial Orbit Response Matrix (slow)
→ **FITTED OPTICS MODEL**

Computation of normal and skew quadrupoles RDTs + dispersion and correction
→ **Normal and skew quadrupole correction strengths**

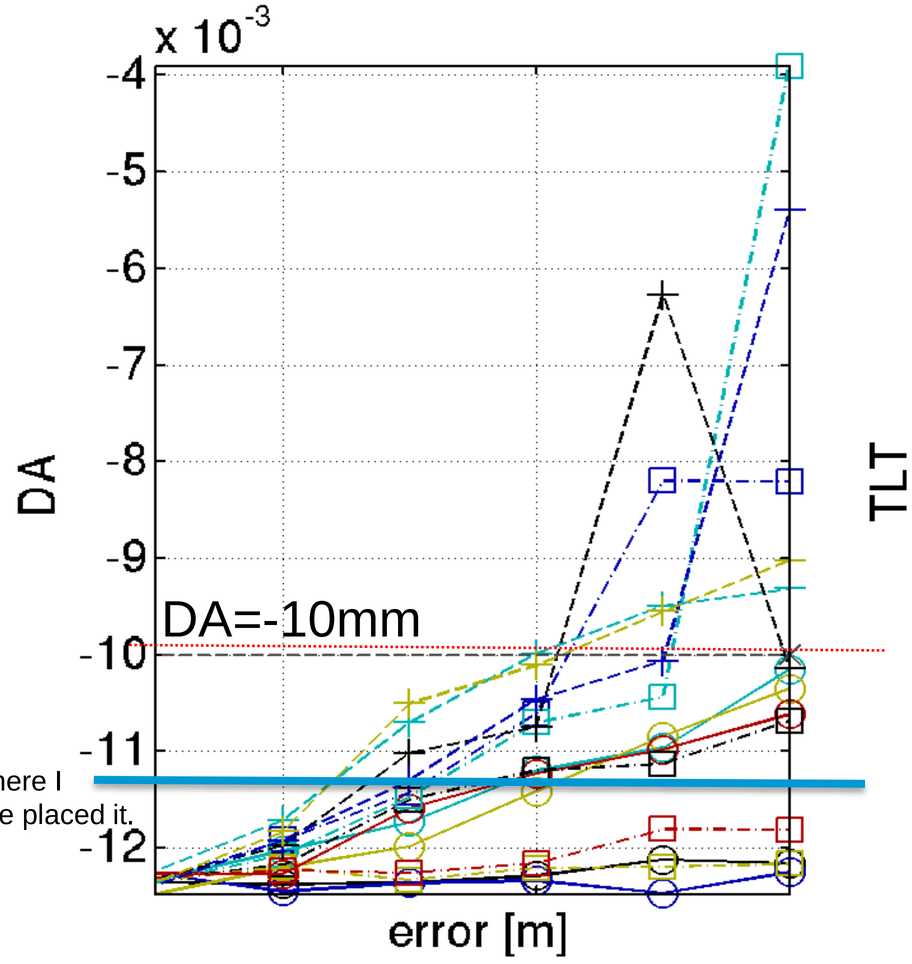
This is LOCO equivalent (+ RDTs)
Linear problem + generalize potentially different fit and correction locations

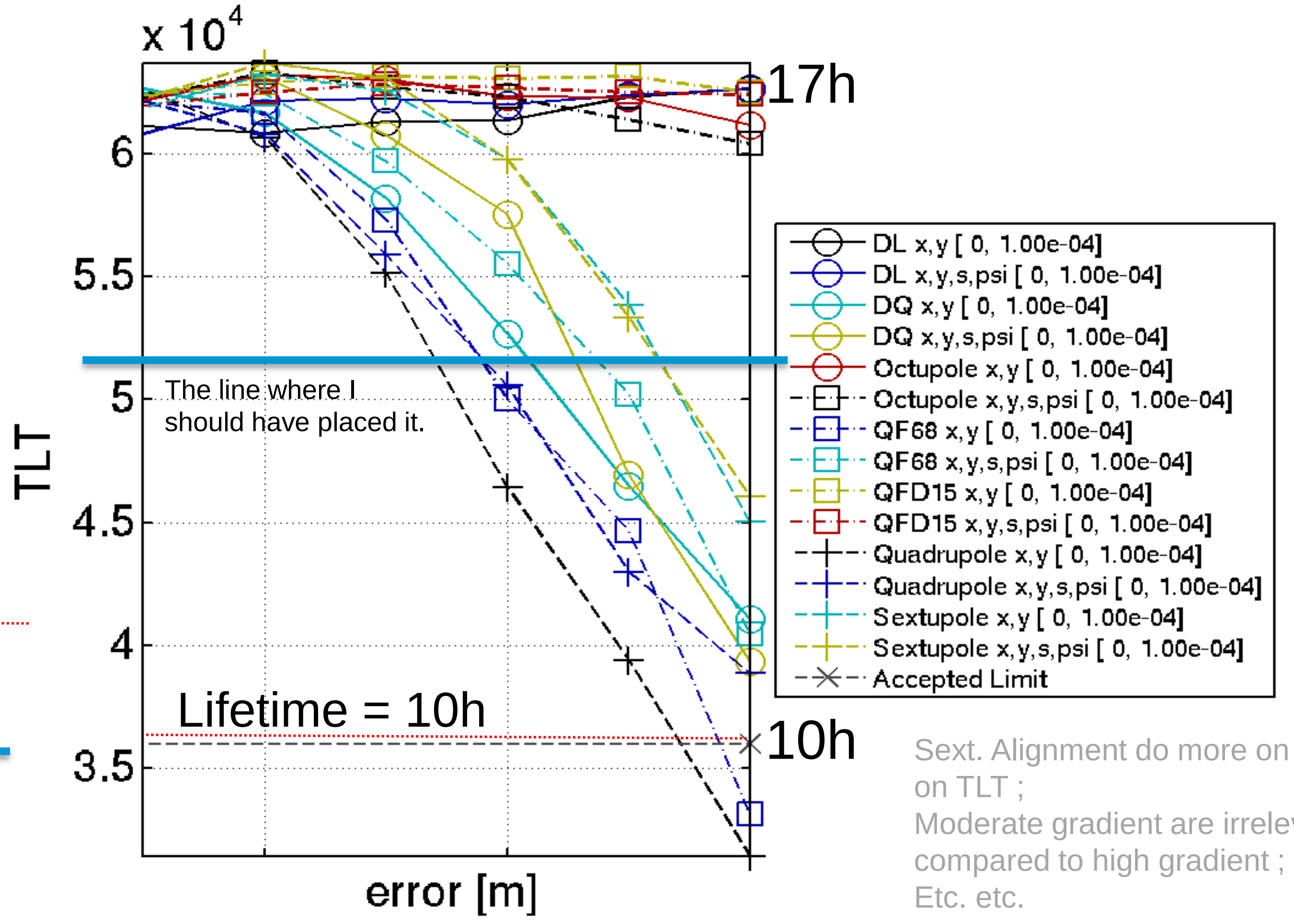
33. A. Franchi, L. Farvacque, J. Chavanne, F. Ewald, B. Nash, K. Scheidt, and R. Tomás, *Vertical emittance reduction and preservation in electron storage rings via resonance driving terms correction*, Phys. Rev. ST Accel. Beams **14**, 034002 (2011).

LIFETIME AND DYNAMIC APERTURES VS ERROR SOURCES

A CLUSTER is crucial for this analysis. Each error set to analyze requires 1CPUx4h

Each point is average of 5 seeds.





Sext. Alignment do more on DA than on TLT ;
Moderate gradient are irrelevant compared to high gradient ;
Etc. etc.

How to determine the "tolerance" ? ➔ DRAW A LINE (relative impact of each error), RESCALE globally.

Each error, on each magnet family, is studied individually looking at the dependence of DA, lifetime, emittances and all relevant parameters vs error amplitude.

This table represents only magnetic centers errors.

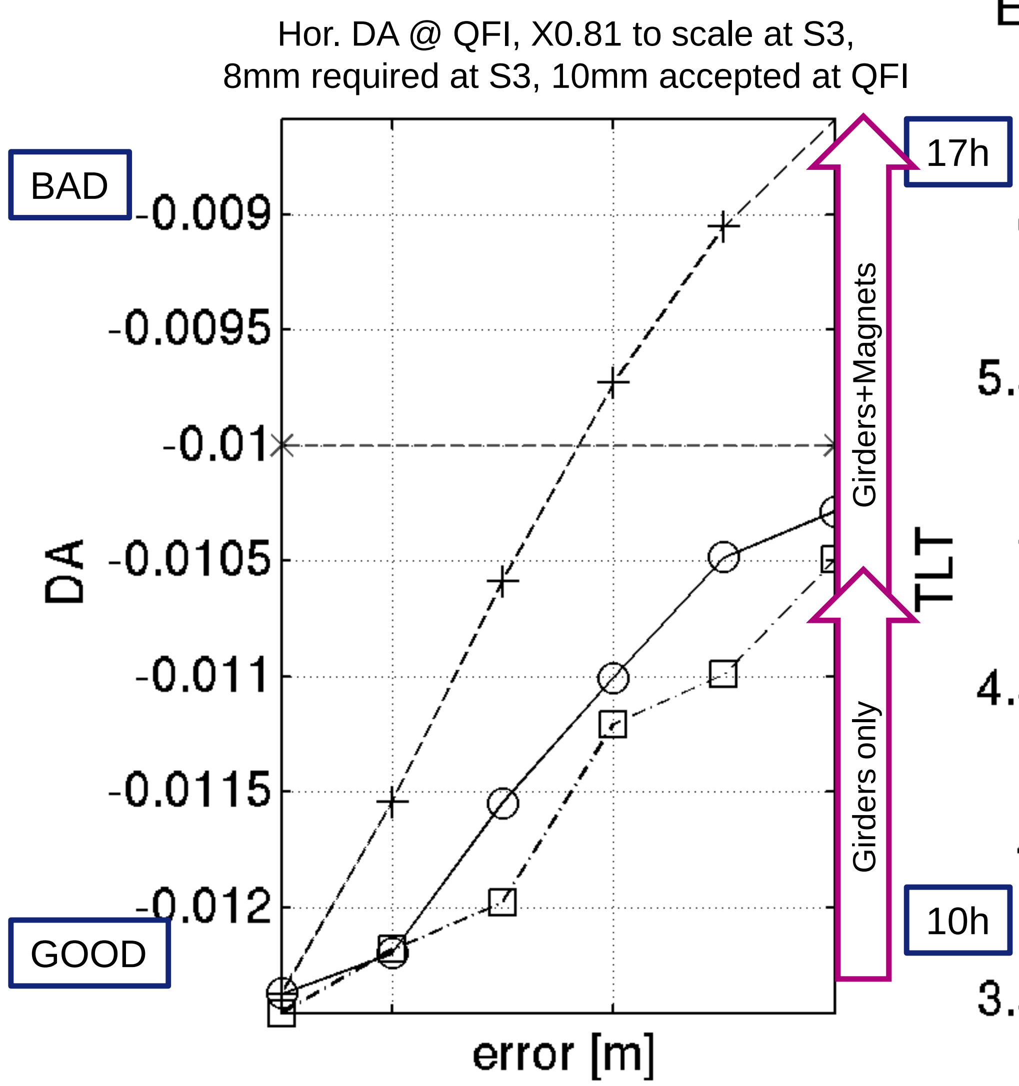
No alignment survey errors.

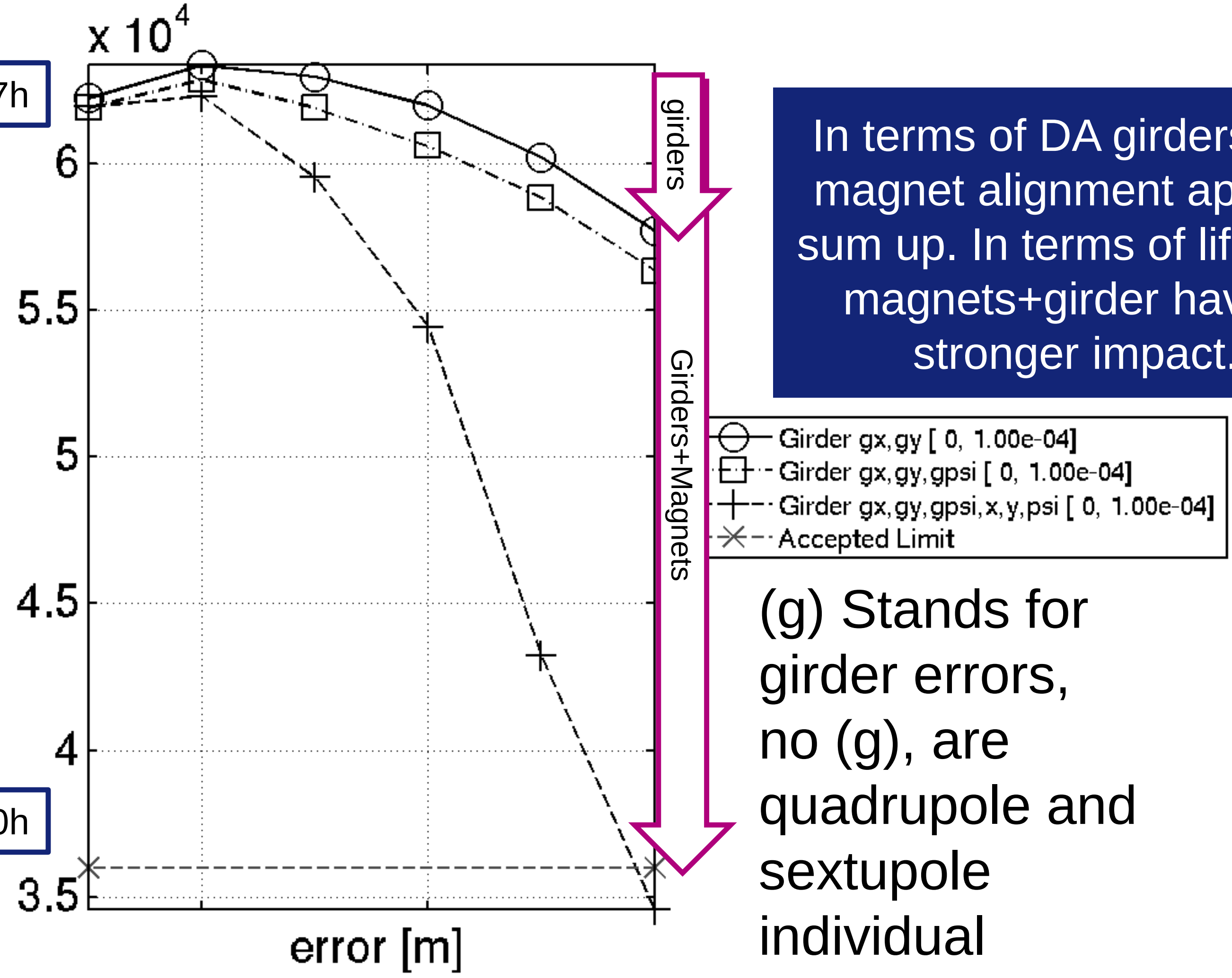
Required:	DX	DY	DS	DPSI	DK
	μm	μm	μm	μrad	10^-4
DL	>100	>100	1000	500	10
DQ, QF[68]	70	50	500	200	5
Q[DF][1-5]	100	85	500	500	5
SFD	70	50	500	1000	35
OF	100	100	500	1000	

Sextupoles and high gradient quadrupoles are the most relevant limitations, nevertheless, this alignment specifications are currently achievable. (DX=DY=60μm, 84 μm between two magnets).

ALIGNMENT SURVEY ERRORS, OPTION 1 (THE OLD SCHOOL): GIRDER ERRORS

Each point is average of 5 seeds.



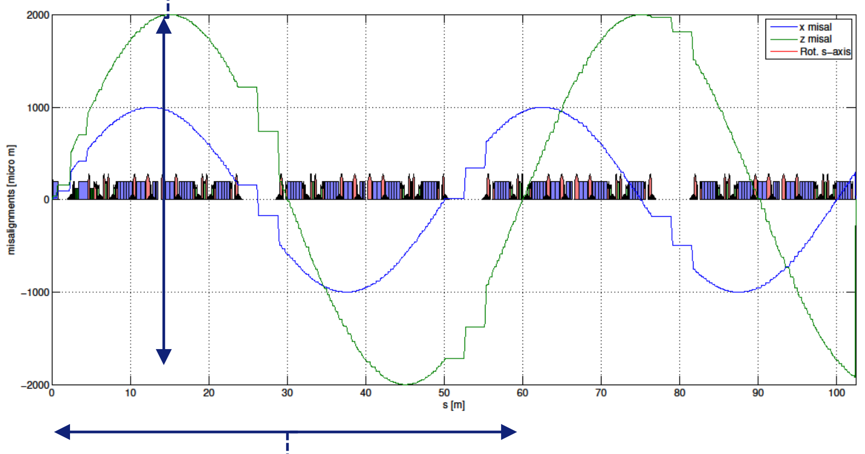


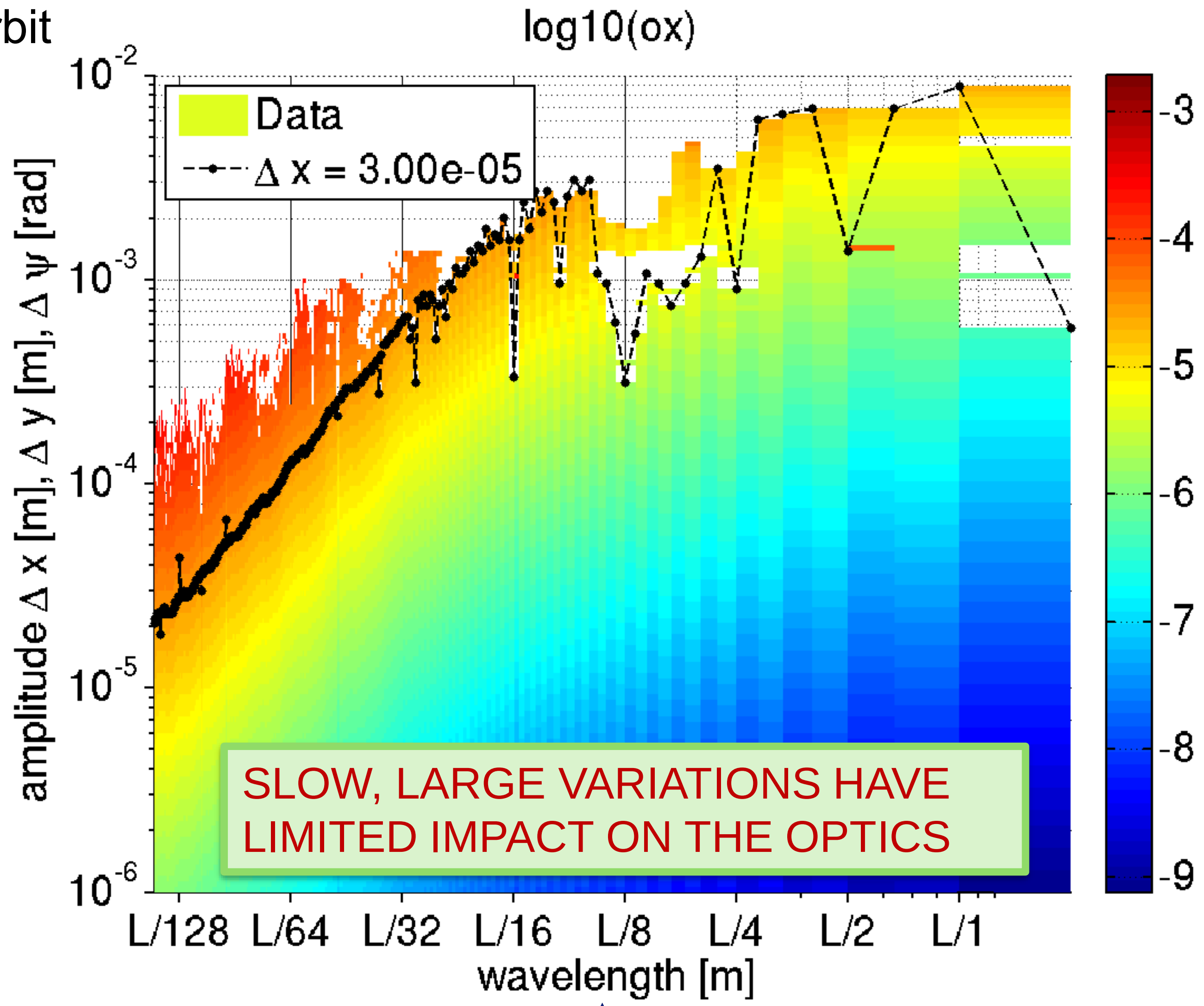
In terms of DA girders and magnet alignment approx. sum up. In terms of lifetime, magnets+girder have a stronger impact.

(g) Stands for girder errors, no (g), are quadrupole and sextupole individual misalignments

Impact of error “waves” on horizontal orbit

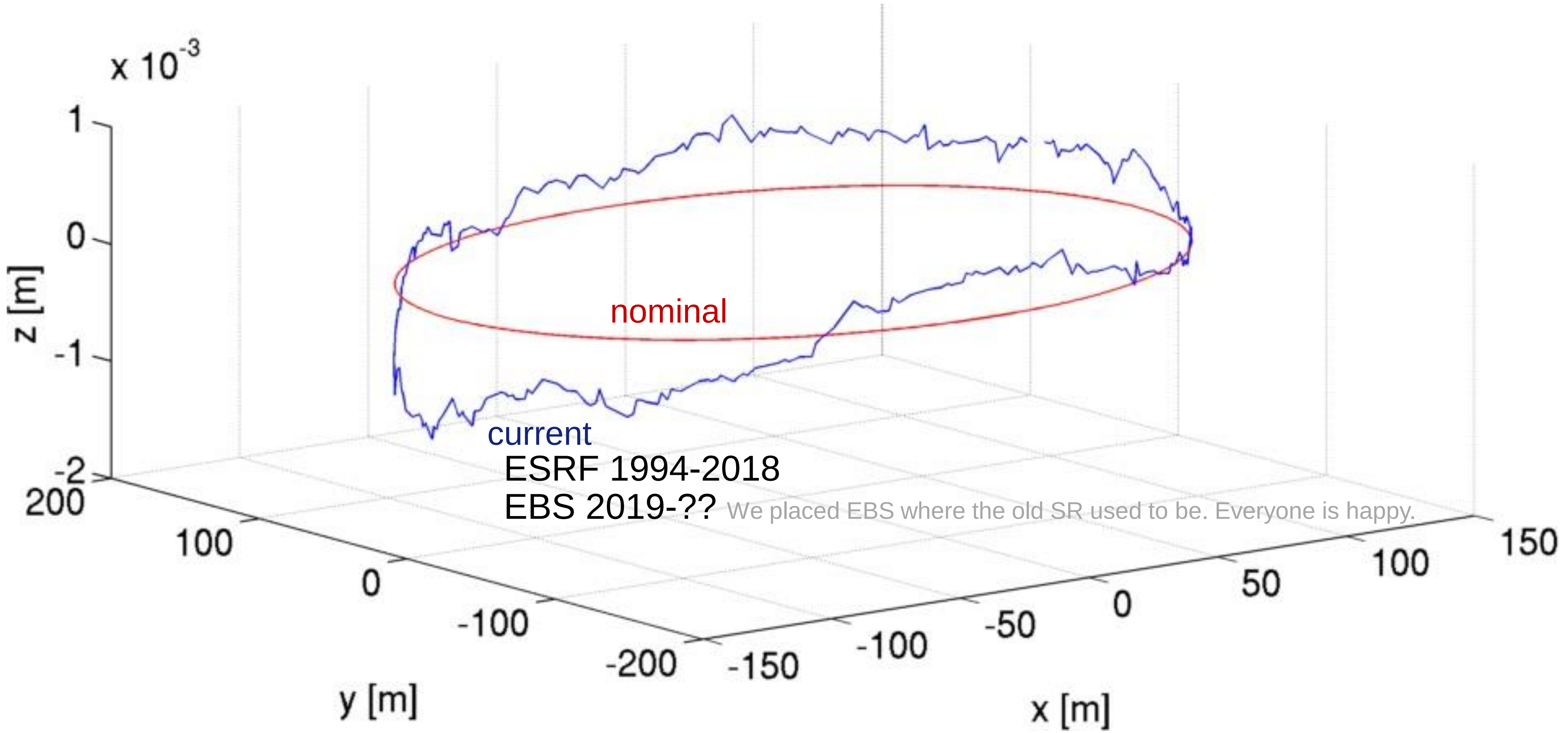
At a wavelength of L/128~6m
30um errors amplitude give
30 um residual orbit distortion.
At a wavelength of L/2~422m
7mm errors amplitude give
30 um residual orbit distortion.





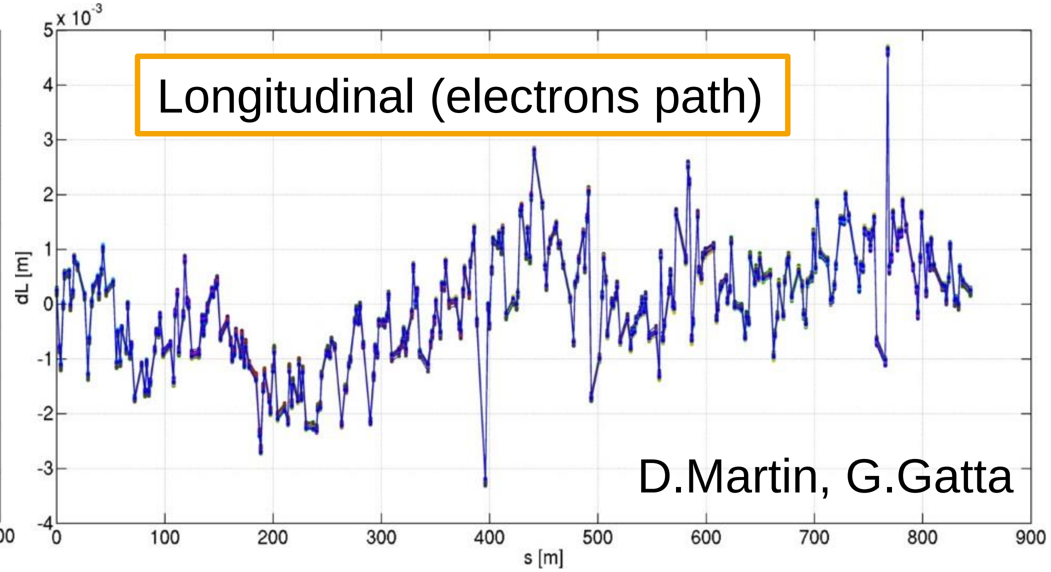
SLOW, LARGE VARIATIONS HAVE LIMITED IMPACT ON THE OPTICS

This is where the machine is. Let's use this information!

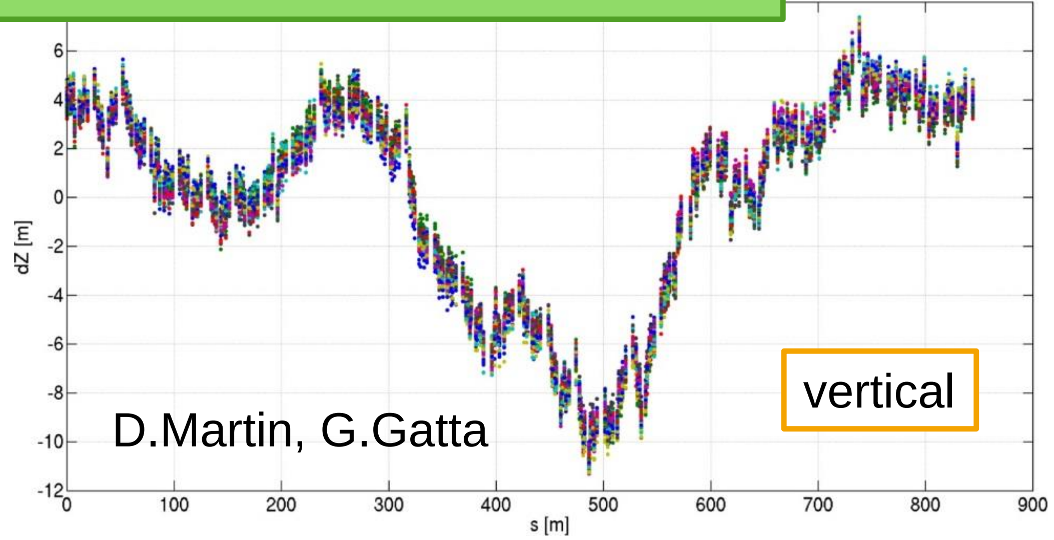


We placed EBS where the old SR used to be. Everyone is happy.

WHERE WILL THE SR BE
if we remove it and reinstall it?



DATA from ALIGNMENT GROUP



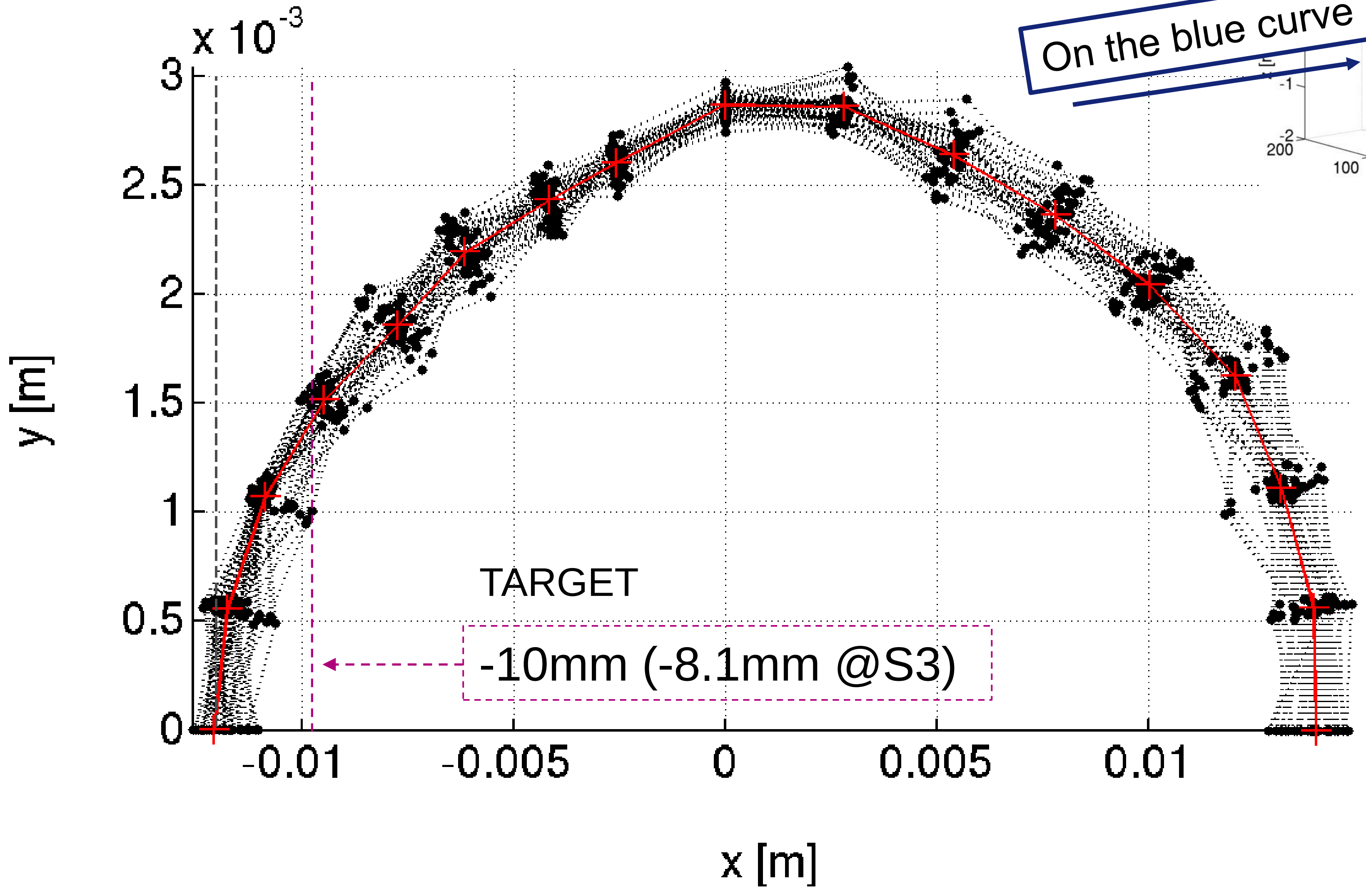
Simulated survey errors about the current position of the lattice.

Rotations are random, but for a 21urad systematic outward tilt.

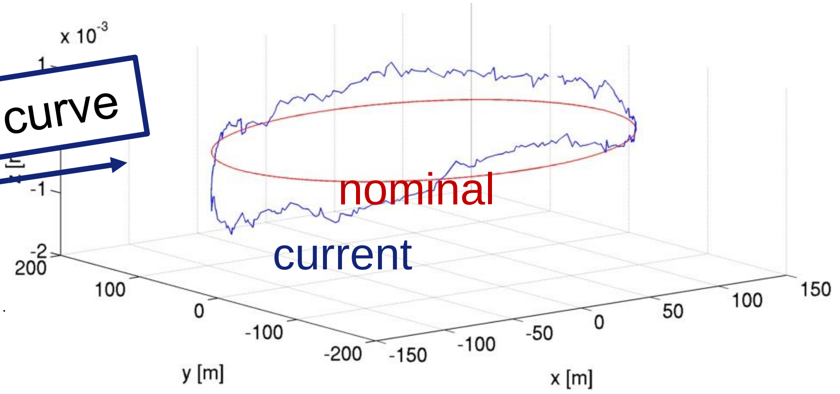
Data provided in 320 points for the current lattice.

Idea by P.Riamondi

The above curves are interpolated to set the errors in the S28A lattice.



On the blue curve

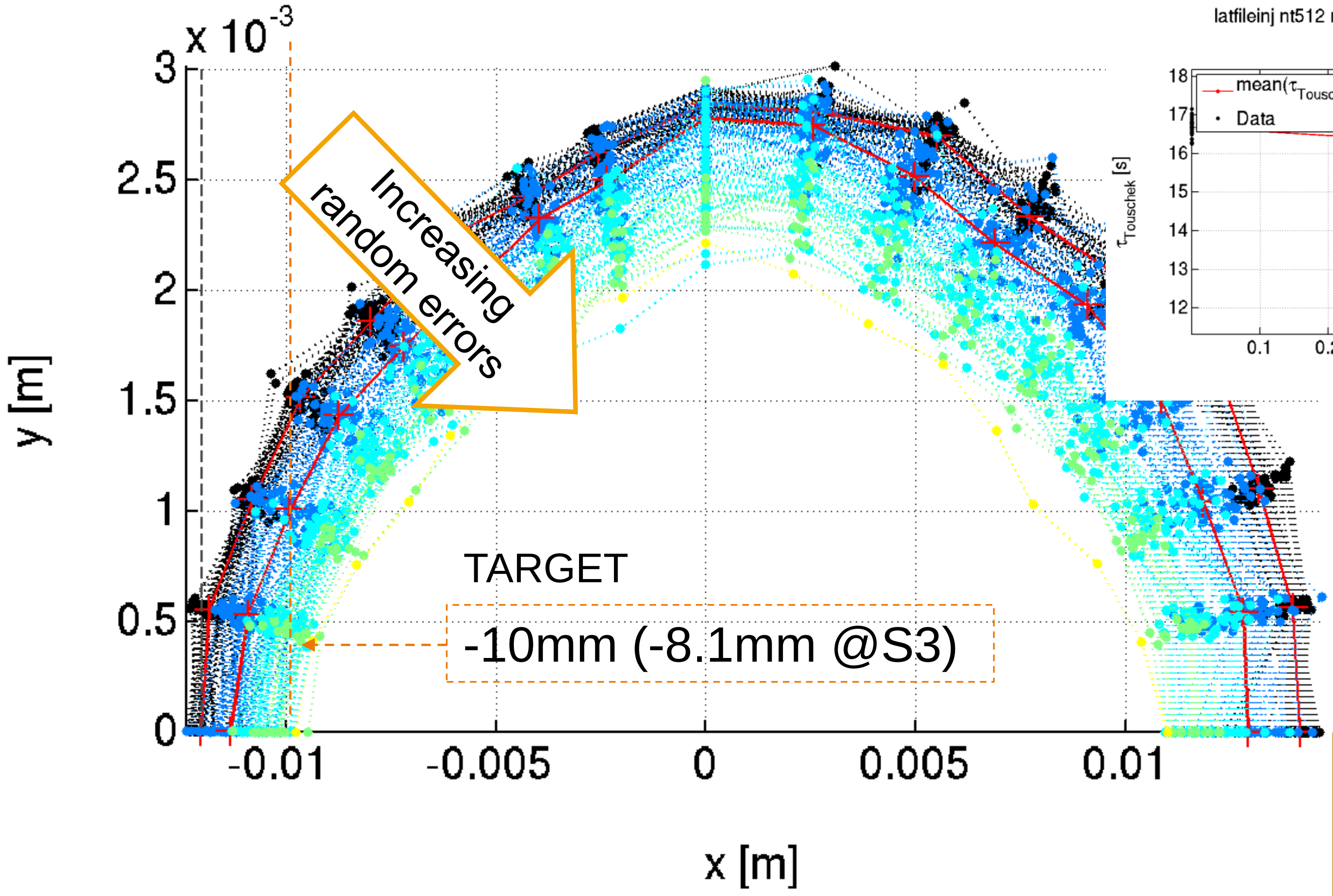


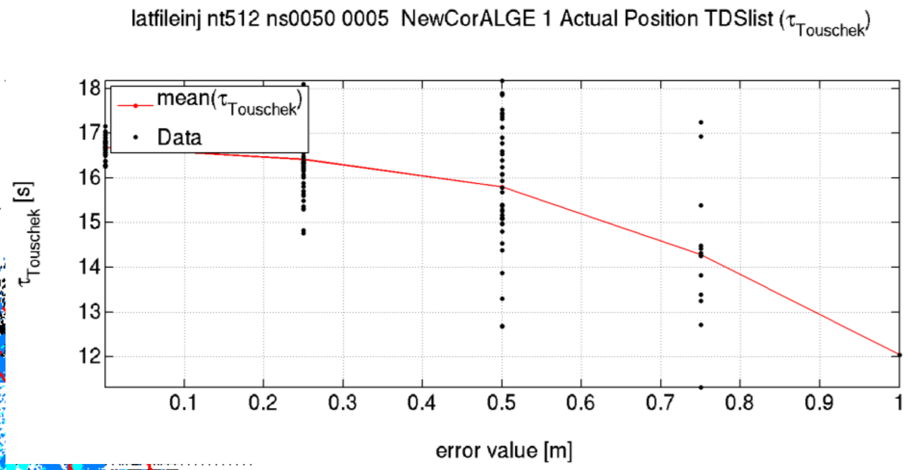
Lifetime: 16.6h
range:[16.4 17.1]

MEASURED SURVEY + simulated alignment errors SET IN THE LATTICE AND TESTED FOR DA/LIFETIME AFTER CORRECTION

ADDITIONAL RANDOM ERRORS

Additional random errors are still required to describe the error on the position of the **magnetic centers** of the magnets.





Lifetime goes from 16.6h to about 12h with many lost seeds and increasing range.

AS ABOVE + RANDOM ERRORS SET IN THE LATTICE AND TESTED FOR DA/LIFETIME AFTER CORRECTION

IN PRACTICE

We have no specific beam dynamics interest in the girder-girder tolerance themselves.
Those are not precisely defined among different groups and may lead to lack of understanding.
From beam dynamics, we can say that: ***large, slow, smooth*****, variations of position are not detrimental.**

In order to model the lattice at the location where it will be installed, we included in all “predictive” (DA, LT, IE,etc) simulations the **Simulated Survey Position provided by the alignment group**.

From a beam dynamics point of view, as long as **magnet-magnet tolerances** (actually, single magnets rms position errors) are achieved **at every location in the machine**, including between magnets standing on neighboring girders, we will get the foreseen Dynamic Aperture and LIFETIME.

We let the alignment group decide how to achieve this requirement.

For ESRF-EBS It worked extremely well, largely exceeding expectations/simulations.

	Expected magnet-to-magnet	From steerers/orbit data Achieved magnet-to-magnet
rms DX DY alignment	60-70 μm	25-55 μm

TOLERABLE RANDOM ERRORS

What girder-girder tolerances did you use?

How far can be two magnets on opposite sides of the ring?

Required:	DX	DY	DS	DPSI	DK
	μm	μm	μm	μrad	10^-4
DL	>100	>100	1000	500	10
DQ, QF[68]	70	50	500	200	5
Q[DF][1-5]	100	85	[illegible]	[illegible]	[illegible]
SFD	70	50	500	1000	35
OF	100	100	500	1000	
GIRDERS	**SAME AS worst case MAGNET-MAGNET**				
Long range	**Simulated Survey**				

60

Many simulations for **1** number needed

All relative tolerance are as expectable from theory. Alignment will be based on a single value. Why running infinity of simulations? Just use a single number.

girder-girder error simulations are useless. Long range error simulations are useless.

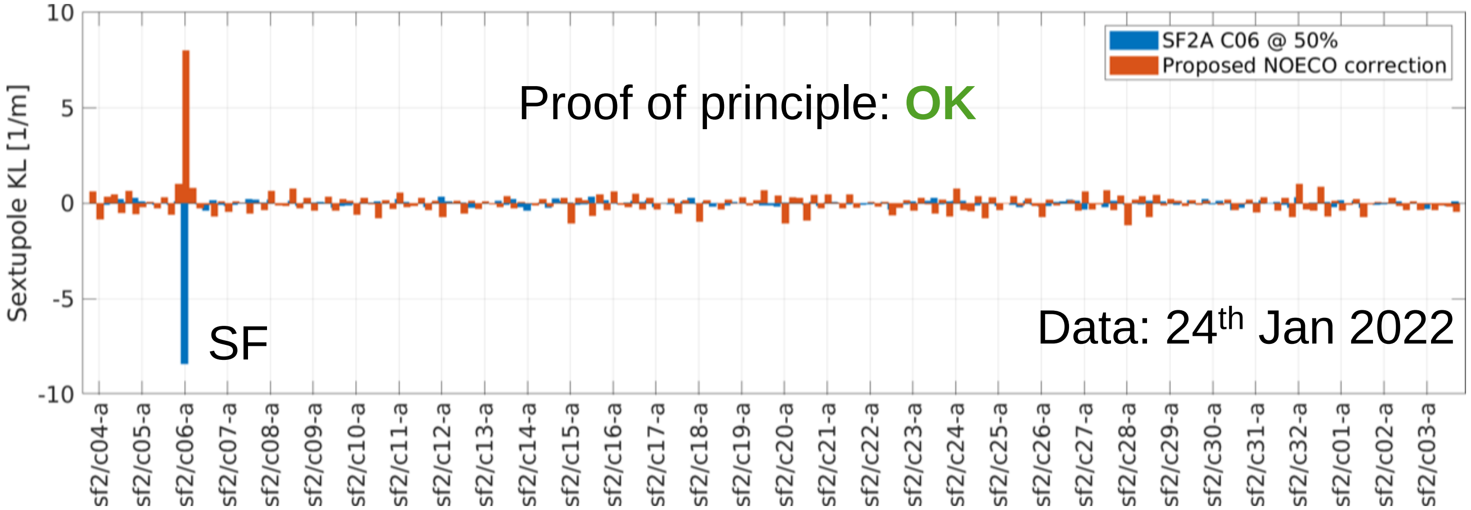
Sextupoles and high gradient quadrupoles are the most relevant limitations, nevertheless, this alignment specifications are currently achievable. (DX=DY=60μm, 84 μm between two magnets).

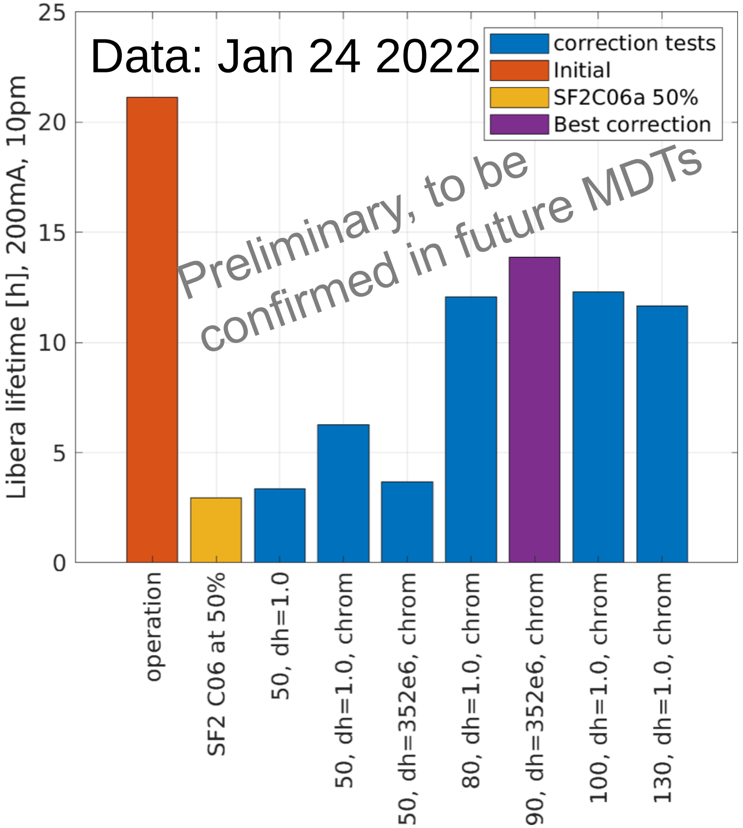
NOECO: SEXTUPOLES TUNING TO MAXIMIZE LIFETIME

After commissioning,

Improve measurement based tuning compared to the schemes used in commissioning-like simulations.

Compute SEXTUPOLE correction strengths based on off-energy Fast-RM and dispersion measurement





Function developed based on:

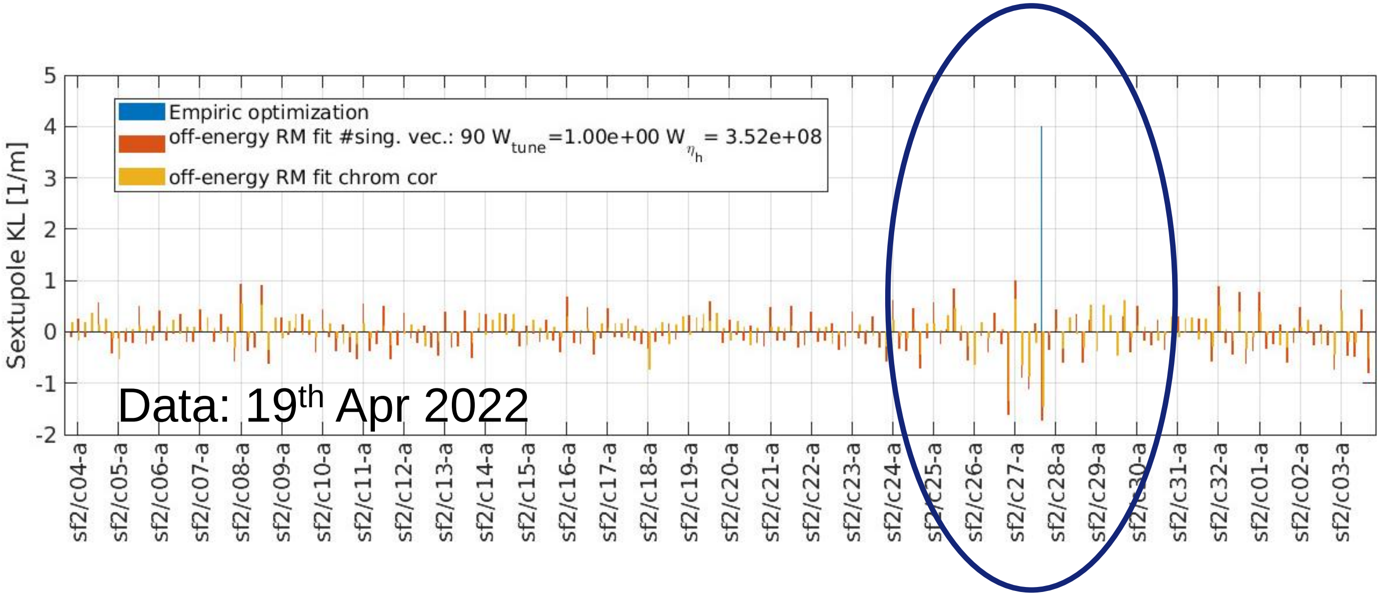
PHYSICAL REVIEW ACCELERATORS AND BEAMS **23**, 102803 (2020)

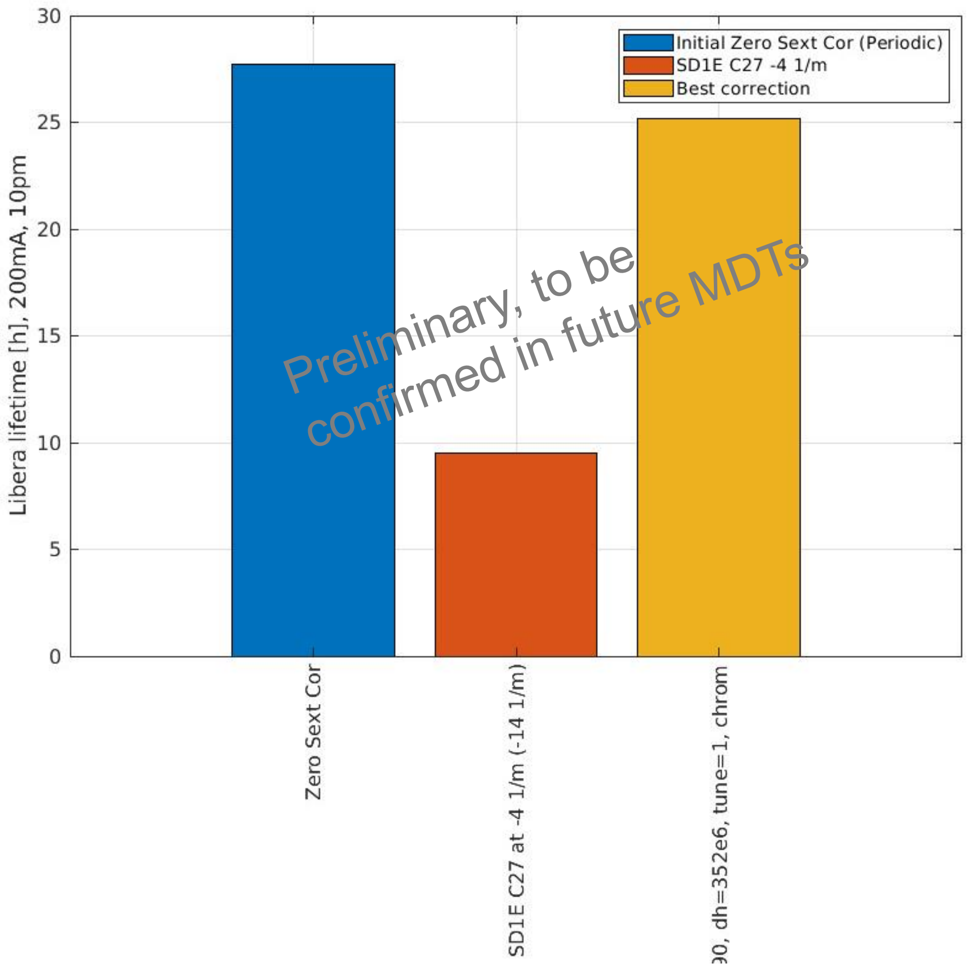
Nonlinear optics from off-energy closed orbits

David K. Olsson,* Åke Andersson, and Magnus Sjöström
MAX IV Laboratory, Lund University, SE-22100 Lund, Sweden

A.Franchi, N. Carmignani, Sextupole calibrations via measurements of off-energy orbit response matrix and high order dispersion, presented at the *25th European Synchrotron Light Source Workshop (ESLS'17), Dortmund, Germany, Nov. 2017*, https://indico.cern.ch/event/657829/contributions/2782617/attachments/1569843/2475779/ESLS17_Carmignani_SextCalibration.pdf.

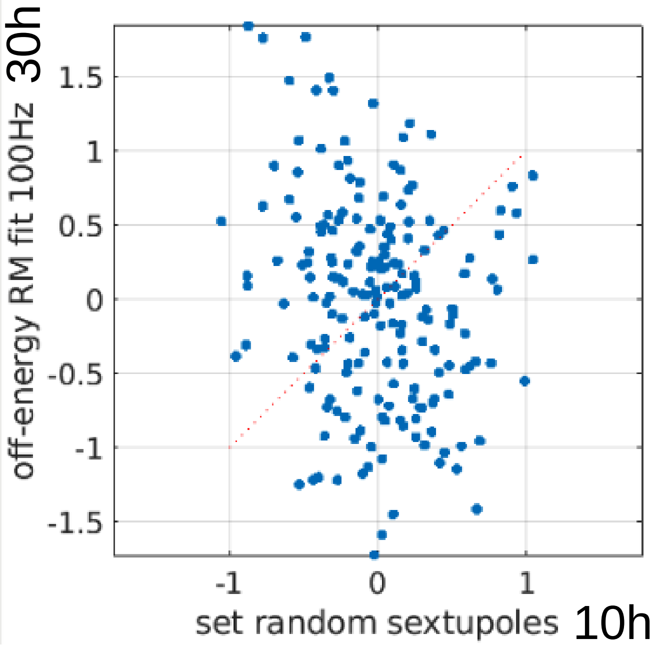
START FROM A BAD SD





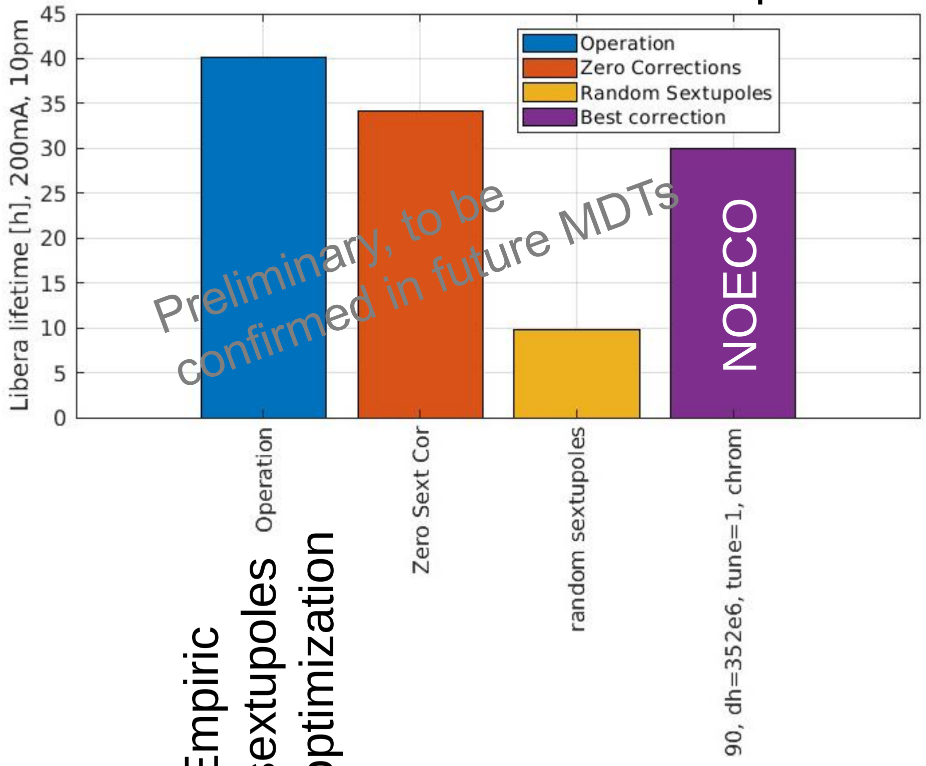
The specific SD sextupole corrector is NOT found.
Nevertheless, the correction applied recovers the lifetime.

RANDOM SEXTUPOLE CORRECTORS GIVING ~10H LIFETIME

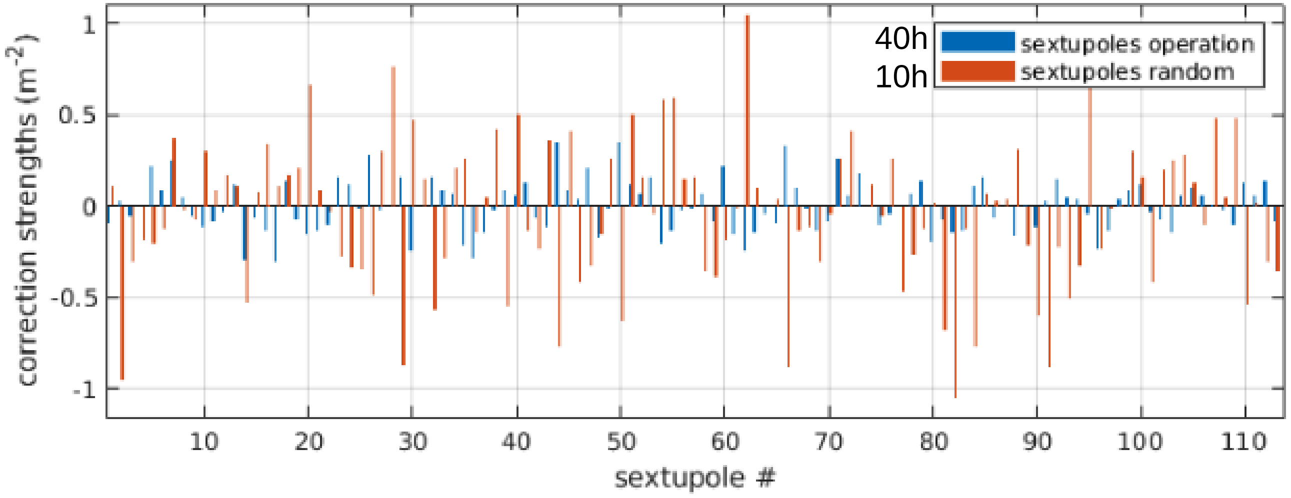


1) The specific random sextupole corrector pattern is NOT found.
2) Nevertheless, the correction applied recovers the lifetime.
3) Zero correction strengths are better then 1 iteration of NOECO correction

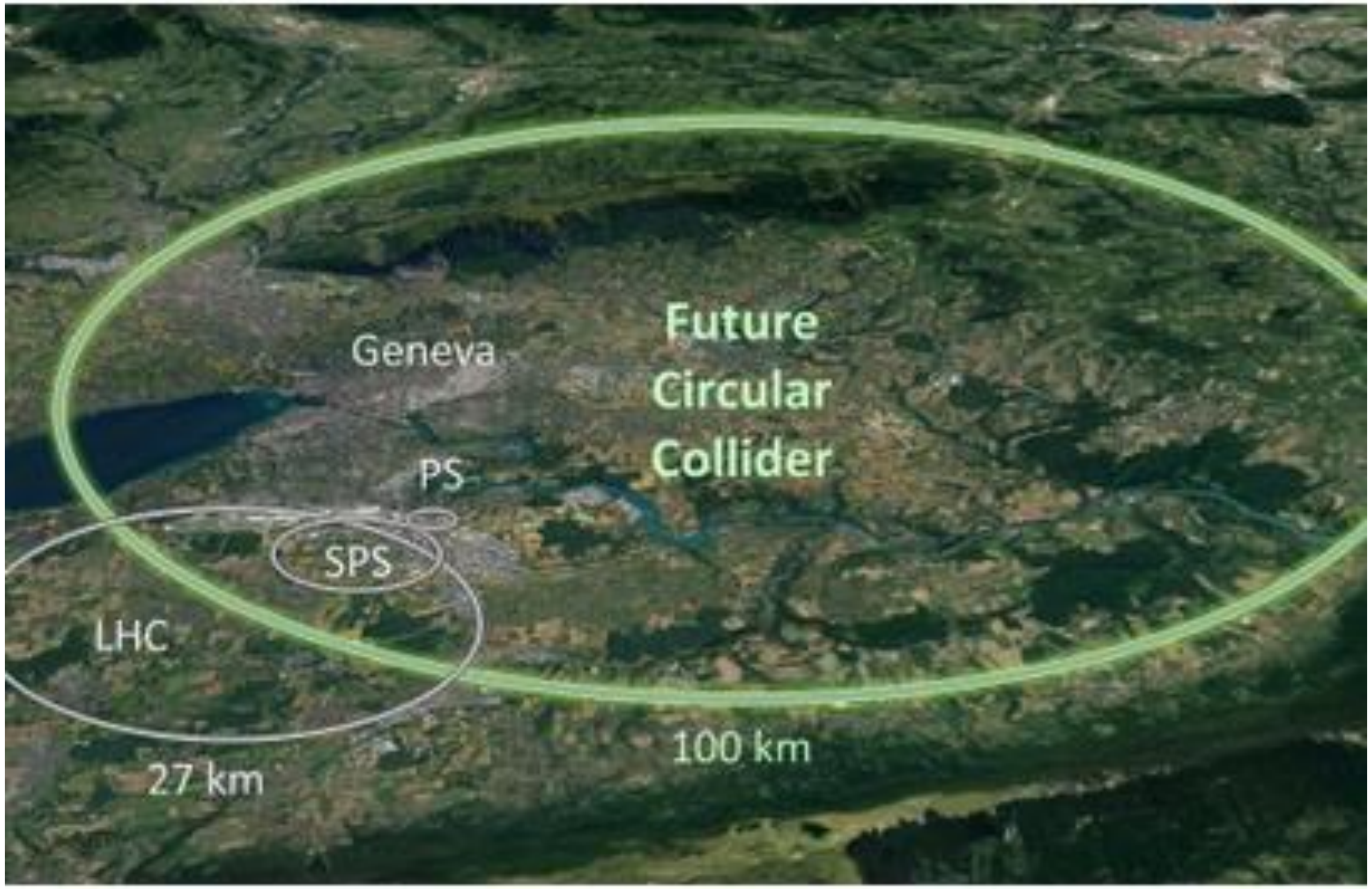
Data: 19th Apr 2022



Empiric sextupoles optimization



FCC-EE

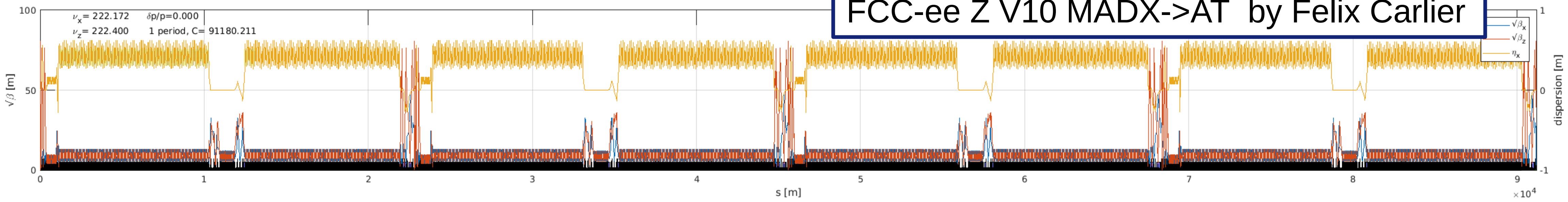


Apply the same tuning strategy for FCC-ee.

Not trivial!

Yet not comparable to existing studies
(see T. Charles presentation)

FCC-ee Z V10 MADX->AT by Felix Carlier



Parameters table

```
Energy:                          45.60000 [GeV]
Circumference:                   91180.21106 [m]
Revolution time:                 304144.44603 [ns] (0.00329 [MHz])
Betatron tune H:          222.   0.17213 (0.56596 [kHz])
              V:          222.   0.39982 (1.31457 [kHz])
Momentum Compaction Factor:      0.00716
Chromaticity H:                  -0.12971
             V:                  +0.34827
Synchrotron Integral 1:          652.63347 [m]
                     2:          0.00064 [m^-1]
                     3:          0.00000 [m^-2]
                     4:          0.00001 [m^-1]
                     5:          0.00000 [m^-1]
Damping Partition H:             0.99030
                  V:             1.00000
                  E:             2.00970
Radiation Loss:                  39067.51652 [keV]
Natural Energy Spread:           3.90805e-04
Natural Emittance:               6.98281e-01 [nm]
Radiation Damping H:             716.95826 [ms]
                  V:             710.00094 [ms]
                  E:             353.28634 [ms]
Slip factor :             -0.00716

Assuming cavities Voltage: 120000.00000 [kV]
                Frequency: 399.99744 [MHz]
          Harmonic Number: 121657
Synchronous Phase:  2.80999 [rad] (161.00033 [deg])
Linear Energy Acceptance:  0.10212 %
Synchrotron Tune:   0.58723 (1.93075 kHz or 1.70 turns)
Bunch Length:       69.12622 [mm], 230.58023 [ps]
```

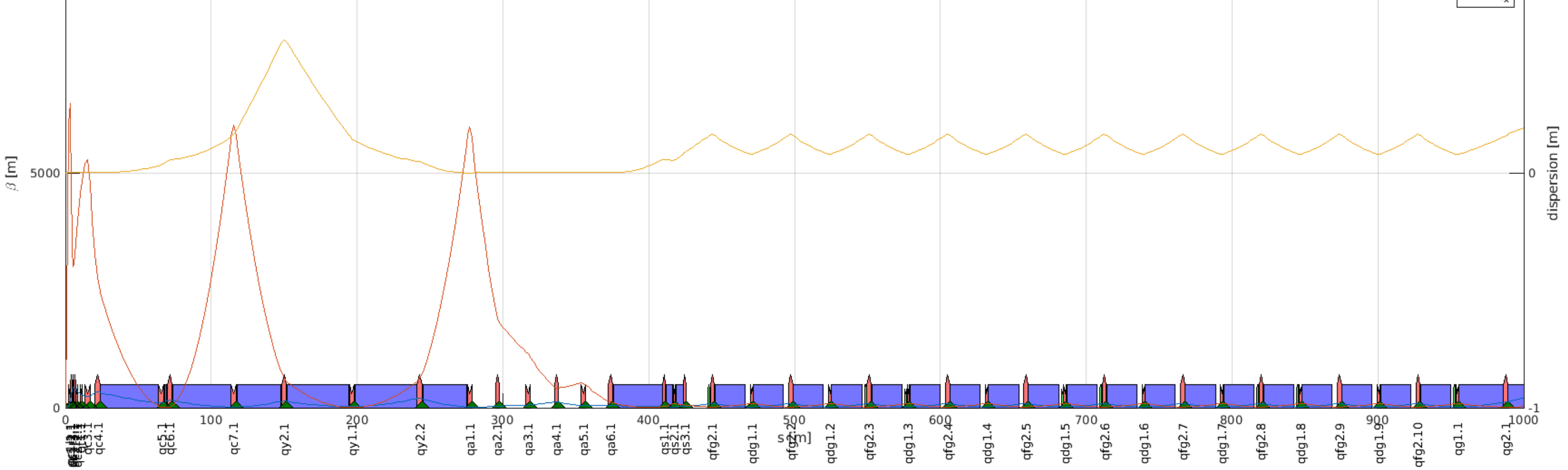
Add

1 BPM at each quadrupole

1892 BPMs

Consider

Each quadrupoles is an H/V steerer and a skew quad. (1862 correctors)



Grouped trying to follow family naming

Errors: *No multipole errors*

```
errset= 0.3 * [...H, V, rot, field
    [ 100e-6,  100e-6, 100e-6,   5e-4, 0, 0];... B*
    [ 100e-6,  100e-6, 100e-6,   5e-4, 0, 0];... BG*
    [ 100e-6,  100e-6, 100e-6,   5e-4, 0, 0];... Q[FD]#*
    [ 100e-6,  100e-6, 100e-6,   5e-4, 0, 0];... Q[FD][CG]*
    [ 100e-6,  100e-6, 100e-6,  35e-4, 0, 0];... S*
    [ 100e-6,  100e-6, 100e-6,   5e-4, 0, 0];... Q![FD]
    [ 100e-6,  100e-6, 100e-6,   0, 0, 0];... BPM (offset,
    [ 100e-6,  100e-6, 100e-6,   5e-4, 0, 0];... PQ*
    ]; %
```

SOME MAGNETS ARE described with "**slices**":
MUST MOVE TOGETHER For now, do not move

Correction matrices

```
  OrbHCor: {[1892×600 double]
  OrbVCor: {[1892×600 double]
  OrbHDPP: [1×1892 double]
  OrbVDPP: [1×1892 double]
 TrajHCor: {[1892×600 double]
 TrajVCor: {[1892×600 double]
 TrajHDPP: [1×1892 double]
 TrajVDPP: [1×1892 double]
     kval: 1.0000e-04
    delta: 1.0000e-03
```

+ matrices for RDT correction

Derivatives for optics fit, on computing cluster

fitrmNorm.mat | 176.... | 11/05/2... | MAT-file

fitrmNorm.mat (MAT-file)

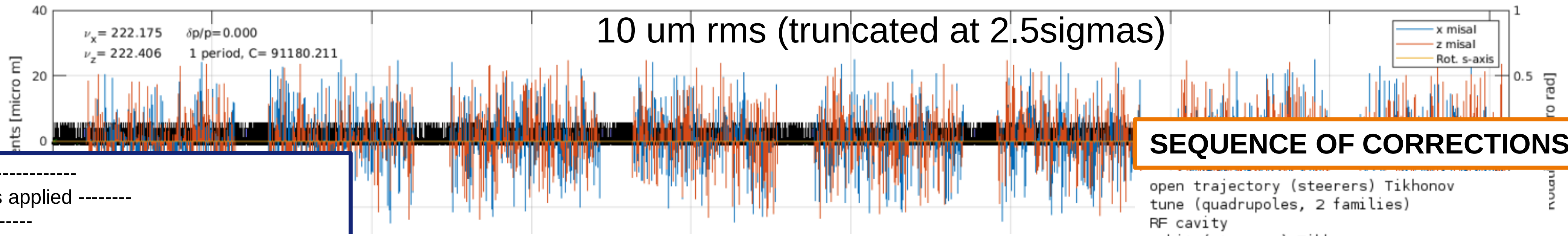
Name	Value
indBPM	1x1892 double
indHCor	1x34 double
indVCor	1x34 double
rmcalcfun	function_handle
dresp	130550x210 double
PertArray	1x210 struct

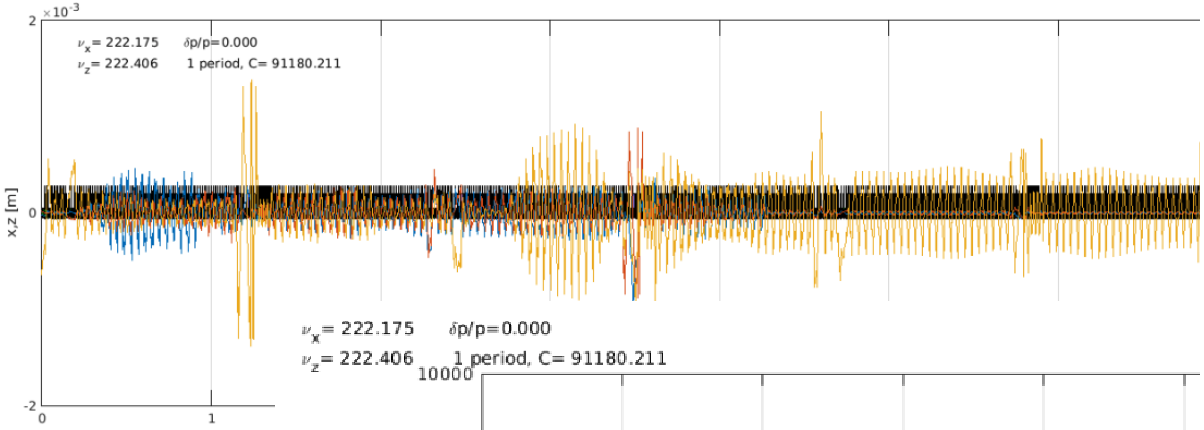
```
waiting for 50/50 processes to finish.
waiting for 50/50 processes to finish.
waiting for 50/50 processes to finish.
waiting for 50/50 processes to finish.
waiting for 50/50 processes to finish.
waiting for 48/50 processes to finish.
waiting for 47/50 processes to finish.
waiting for 16/50 processes to finish.
waiting for 11/50 processes to finish.
waiting for 10/50 processes to finish.
waiting for 10/50 processes to finish.
waiting for 10/50 processes to finish.
waiting for 10/50 processes to finish.
```

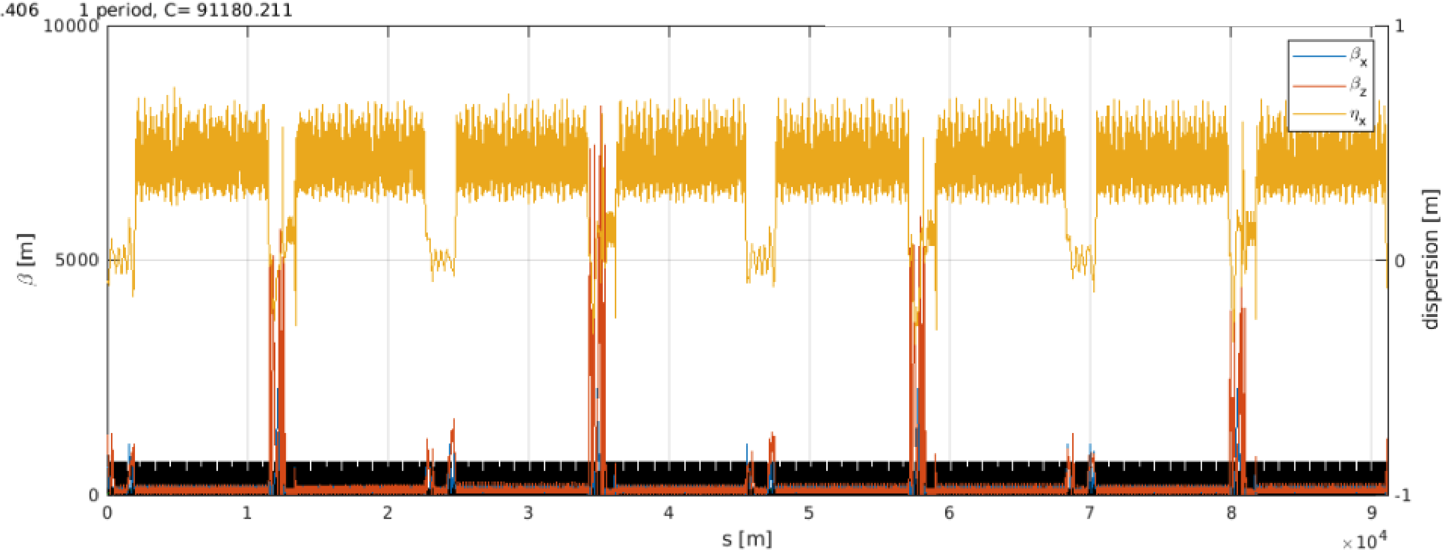
Correction strategy:

```
open trajectory (steerers) Tikhonov
tune (quadrupoles, 2 families)
RF cavity
orbit (steerers) Tikhonov
tune (quadrupoles, 2 families)
chromaticity (sextupoles, 2 families)
orbit (steerers) Tikhonov
tune (quadrupoles, 2 families)
chromaticity (sextupoles, 2 families)
Fit Quad+Dip Errors
Correct RDT and Dispersion of fitted model
orbit (steerers) Tikhonov
tune (quadrupoles, 2 families)
chromaticity (sextupoles, 2 families)
Fit Quad+Dip Errors
Correct RDT and Dispersion of fitted model
RF cavity
tune (quadrupoles, 2 families)
```

COMMISSIONING LIKE CORRECTION SEQUENCE COMPLETED FOR 3 SEEDS WITH LIMITED ERRORS.





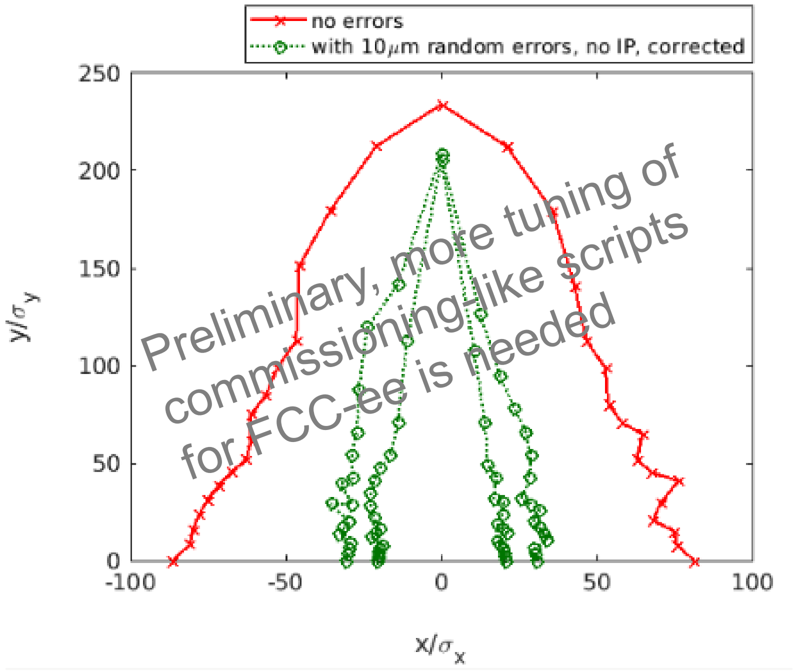



```
---------------------------------------------------
------ total std corrector values applied --------
------                                   --------
      HK (1892) [1/m]: 0.00e+00 -> 9.67e-08
      VK (1892) [1/m]: 0.00e+00 -> 6.64e-08
      SK (1892) [1/m2]: 0.00e+00 -> 1.11e-06
      QK (1892) [1/m2]: 4.17e-07 -> 5.14e-06
------                                   --------
------    residual orbit and dispersion   --------
------                                   --------
      OH (13363) [m]: 4.29e-04 -> 1.99e-05
      OV (13363) [m]: 2.23e-04 -> 1.60e-05
      DH (13363) [m]: 9.43e-02 -> 1.25e-01
      DV (13363) [m]:7.39e-02 -> 5.36e-03
      BBH (13363) %: 2.9 -> 1.6
      BBV (13363) %: 116.7 -> 2.4
      PhH (13363) : 2.28e-02 -> 1.22e-02
      PhV (13363) : 8.48e-02 -> 3.30e-02
------                                   --------
------        tune and emittance         --------
------                                   --------
      Qx [222.172]: 222.176 -> 222.175
      Qy [222.400]: 222.387 -> 222.402
      Cx [-0.070]: -0.354 -> -0.065
      Cy [-0.123]: -13.748 -> -1.718
      EX [705.313 pm]: -183082.420 -> 787.625
      EY [0.000pm]: -3340463.956 -> 0.105
------                                   --------
---------------------------------------------------
```

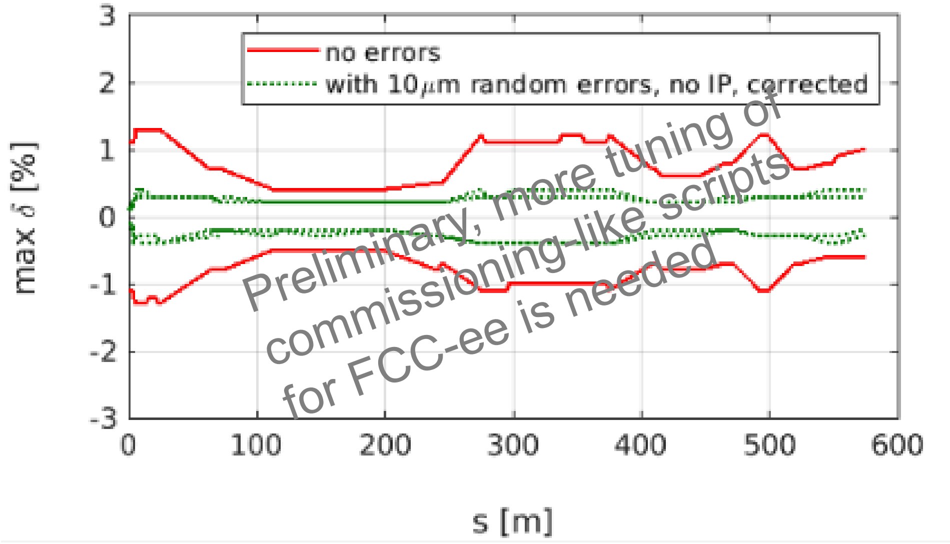
SEQUENCE OF CORRECTIONS

```
open trajectory (steerers) Tikhonov
tune (quadrupoles, 2 families)
RF cavity
orbit (steerers) Tikhonov
tune (quadrupoles, 2 families)
chromaticity (sextupoles, 2 families)
orbit (steerers) Tikhonov
tune (quadrupoles, 2 families)
chromaticity (sextupoles, 2 families)
Fit Quad+Dip Errors
Correct RDT and Dispersion of fitted model
orbit (steerers) Tikhonov
tune (quadrupoles, 2 families)
chromaticity (sextupoles, 2 families)
Fit Quad+Dip Errors
Correct RDT and Dispersion of fitted model
RF cavity
tune (quadrupoles, 2 families)
```

DYNAMIC APERTURE AND MOMENTUM ACCEPTANCE WITH ERRORS



1/3 seeds failed completing the loop.



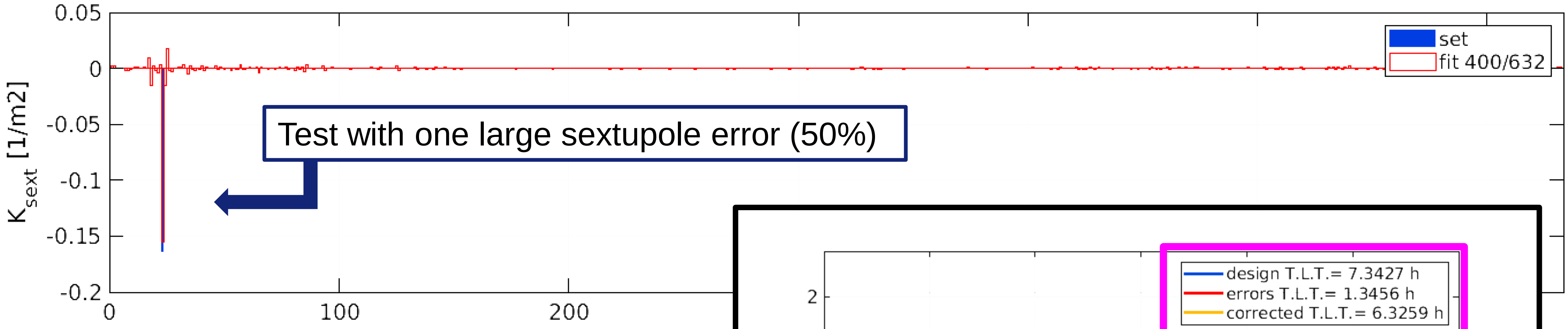
This is only a preliminary plot, only showing that we can compute DA and MA for FCC-ee with errors and correction.

We need to work more time on it!

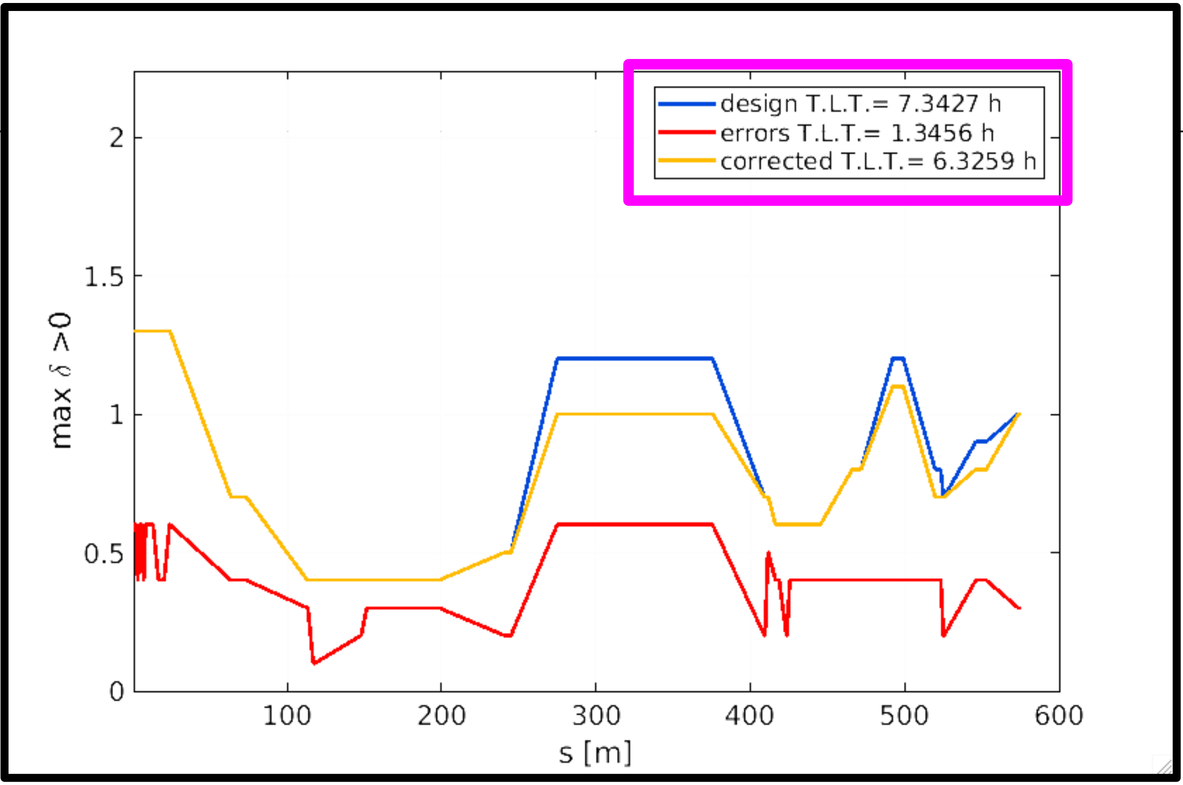
Assume the recent updates in AT
Tune the correction parameters (singular values cuts)
Tune the correction loop steps (tune, orbit, etc)
Start with COMMISSIONING OPTICS

The correction loop is unstable above 20-30 um (no IP errors). In most cases a closed orbit is found but tunes are NaN. May be fixed including an estimate of tunes from few turns, not presently available in the matlab AT toolkit.

NOECO SIMULATIONS (FIT & CORRECTION) FOR FCC-EE



Test with one large sextupole error (50%)



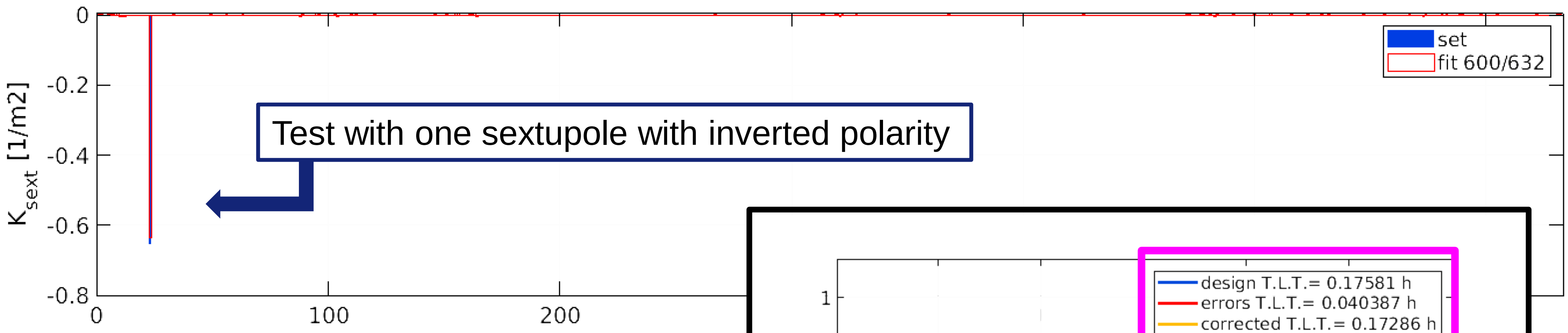
FCC-ee **ideal lattice**

only ± 25 Hz RF freq. shift possible w/o making optics unstable

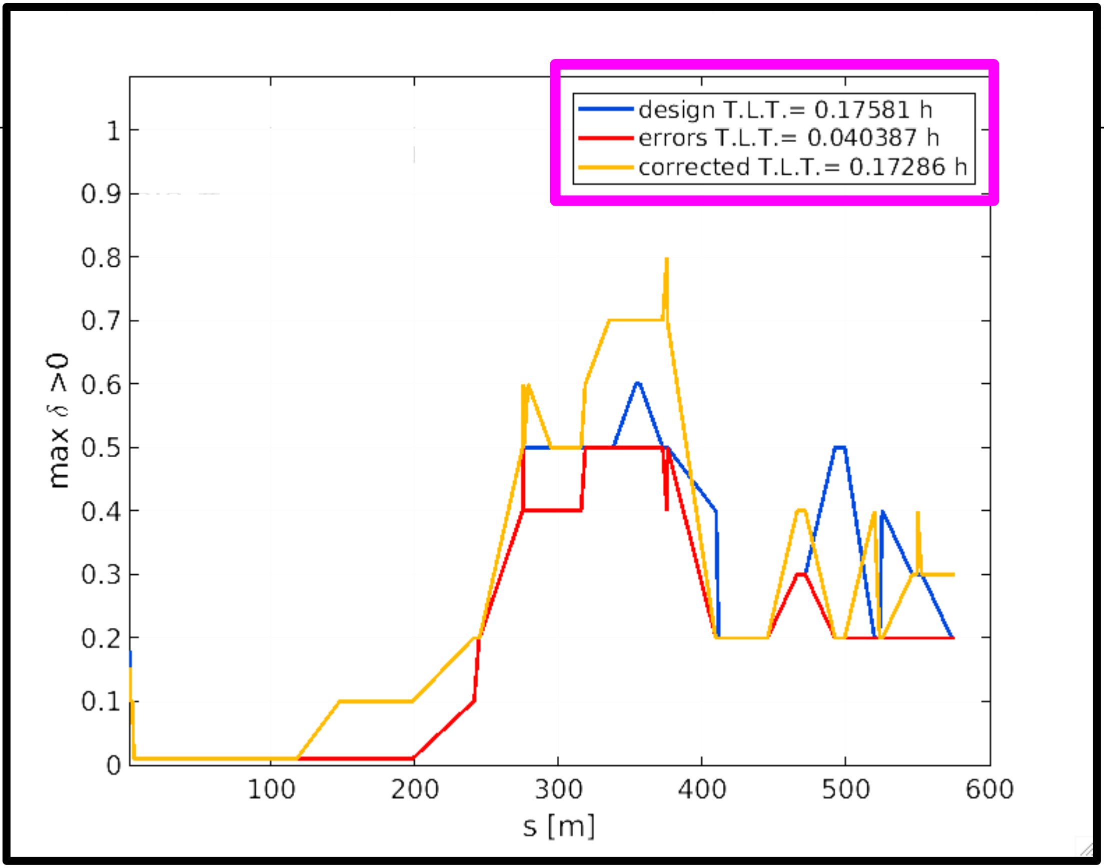
Top: Retrieve (large) sextupole error.

Right: computed momentum acceptance (over 600 m only) & Touschek lifetime

NOECO SIMULATIONS (FIT & CORRECTION) FOR FCC-EE



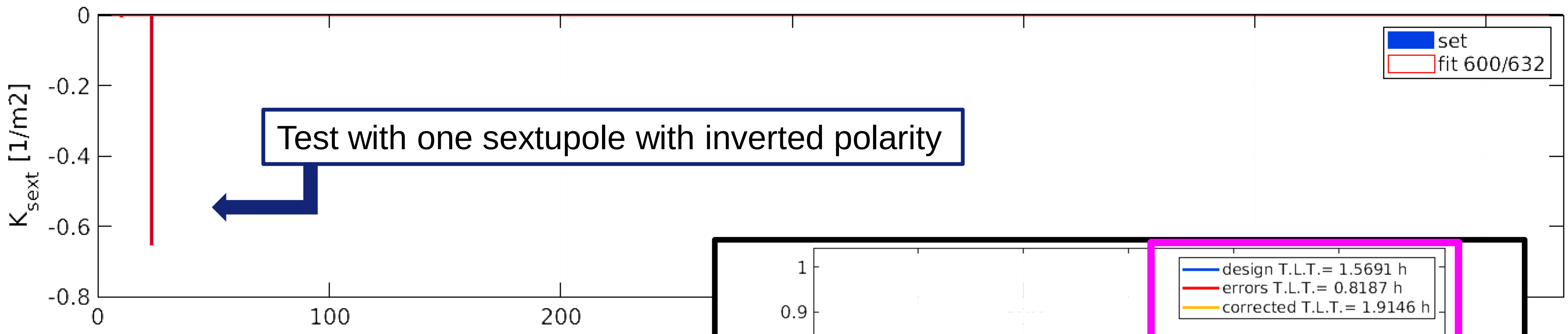
FCC-ee **uncorrected lattice with random quad. & sext. misalignments (RMS 0.1 μm)**



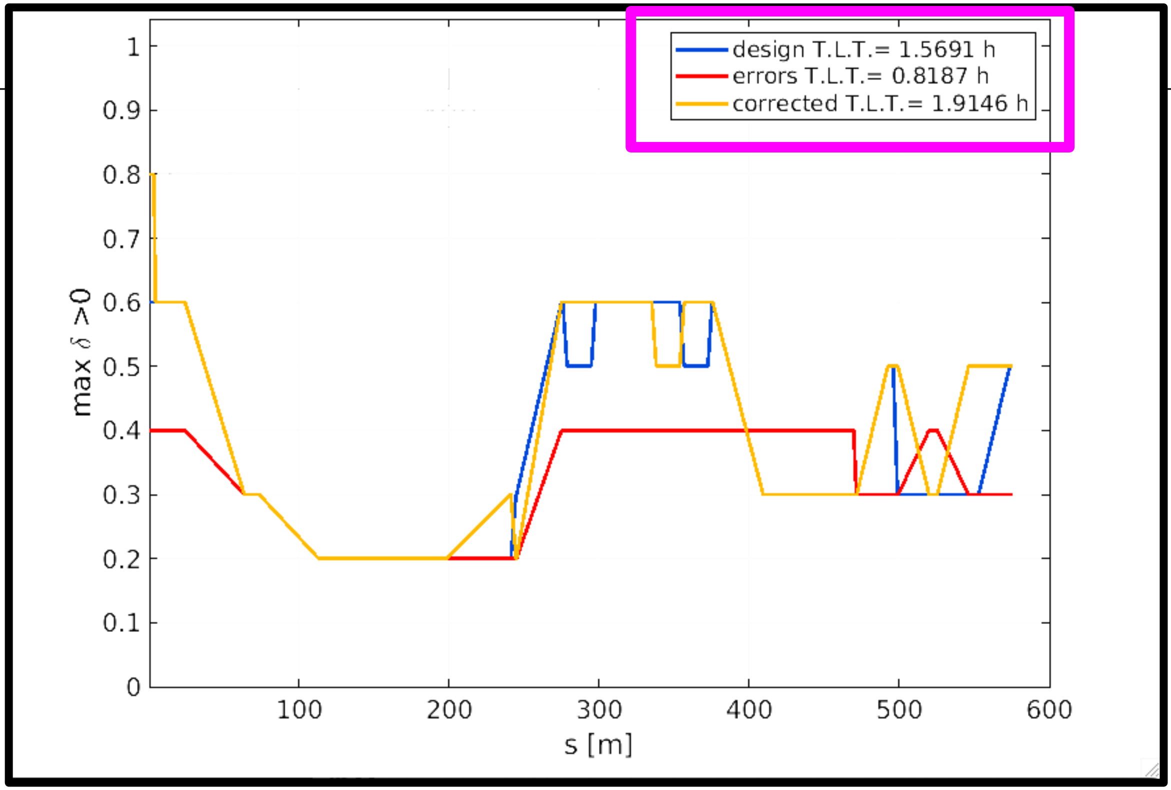
Top: Retrieve (large) sextupole error.

Right: computed momentum acceptance (over 600 m only) & Touschek lifetime

NOECO SIMULATIONS (FIT & CORRECTION) FOR FCC-EE



FCC-ee **uncorrected lattice with random quad. gradient errors (RMS 3x10^{-5} m^{-2})**



Top: Retrieve (large) sextupole error.

Right: computed momentum acceptance (over 600 m only) & Touschek lifetime

CONCLUSIONS

Commissioning-like simulations do not include many of the steps that are actually done during commissioning. Space for future developments.

For EBS tuning was not the real issue. It was rather to set the most correct and realistic errors.

Only one number is necessary for magnetic centers tolerances (for EBS 60 um). All other values are useful only if locally this value may not be achieved.

Use simulated survey rather than girder-to-girder tolerances: more information, more realistic, easier to simulate.

NOECO has been tested in MDT and shows good potential, even if it does not improve compared to our best optimized settings for operation.

Contrary to EBS, FCC-ee optics tuning with errors is not trivial at all. Even without radiation!

The matlab AT tuning procedure used for EBS is being adapted to FCC. Seen the amount of changes needed till now and the speed at which AT is developing, it is likely that the work will start over using pyAT. This activity is synergic with several other laboratories working on python AT commissioning like simulations.

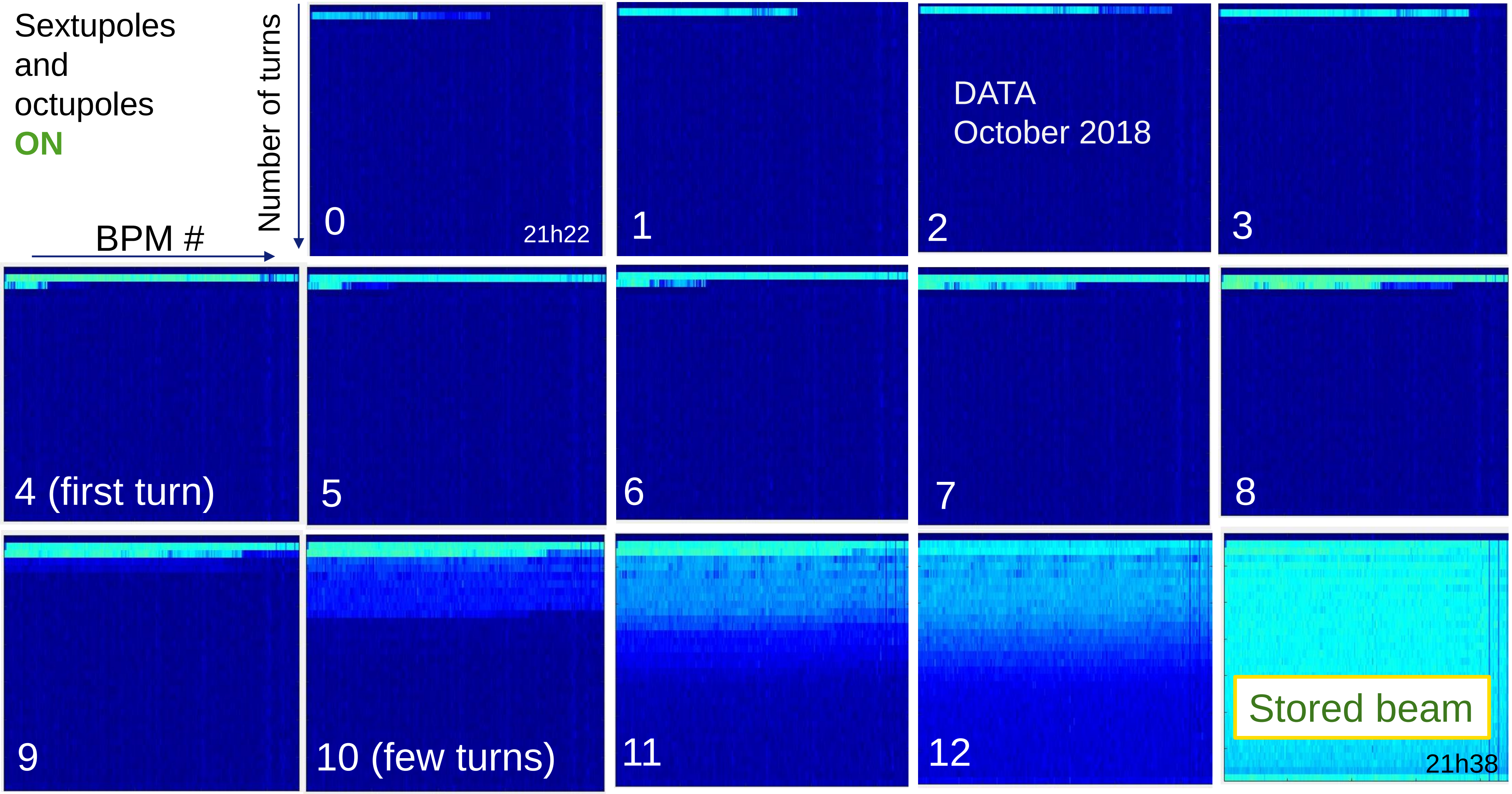
NOECO has been used in simulations also for the FCCee lattice, recovering the local momentum acceptance also in presence of errors.

Commissioning optics are being prepared and translated to AT. Dipoles will be sliced prior to the correction.

BACKUP

FIRST-TURNS TRAJECTORY CORRECTION PROGRESS ON TBT BPMS

Sextupoles and octupoles **ON**



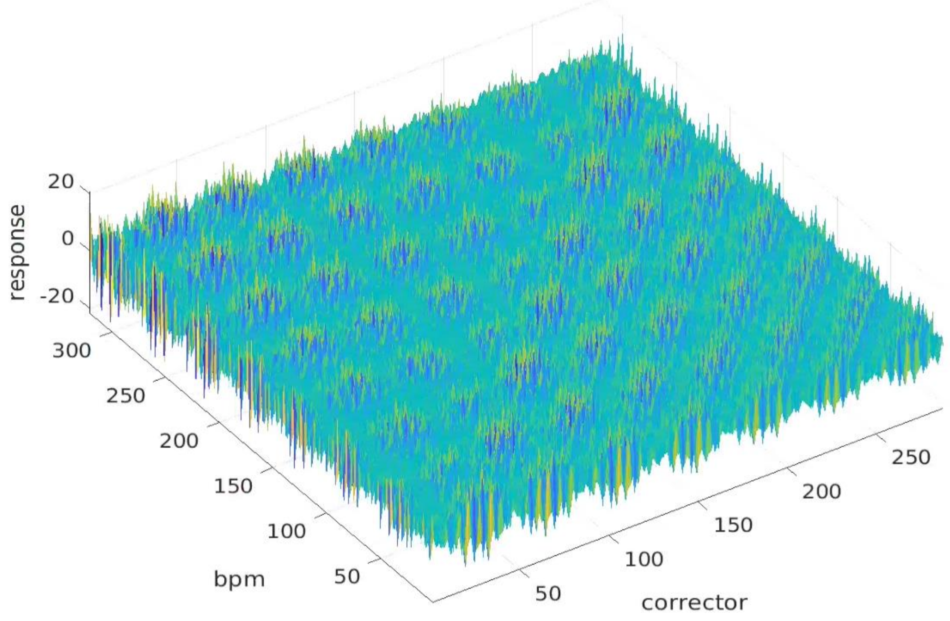
Preparation of the EBS beam commissioning
S M Liuzzo *et al* 2019 *J. Phys.: Conf. Ser.* **1350** 012022

Optics tuning/correction

- response matrix
- beam-based alignment
- tune working point
- emittances
- chromaticity
- dynamic apertures
- specific optics tuning (ex: phase advance between sextupoles)

Separated simulations for BBA, DA and special tunings.

For BBA in the tuning loop we assume it is possible by reducing BPM offsets from 500 to 50 um. (not as trivial as it sounds, as changing the offset the orbit has to be re-corrected)



Response matrix (ORM) measurements is used for:

- Precise orbit control (full, not compulsory)
- Optics and coupling tuning (partial)
- Check magnet calibrations

It is possible to use AC steerers for a fast partial response measurement. At ESRF this was only possible after the initial SLOW measurements, for calibration.

COMPARABLE TOLERANCE TABLE

How tolerances were defined

In **RED** The worst crossing of the “line” for each performance parameter

$\sqrt{\langle()^2\rangle}$	x	$(\eta_x - \eta_x^0)$	$\frac{\Delta\beta_x}{\beta_x^0}$	ϵ_x	y	η_y	$\frac{\Delta\beta_y}{\beta_y^0}$	ϵ_y	DA	$\tau_{Touschek}$
error	μm	μm	%	$pm\,rad$	μm	μm	%	$pm\,rad$	mm	s
thresholds:	5.0e-05	5.0e-04	1.0e-02	4.0e-12	5.0e-05	5.0e-04	1.0e-02	4.0e-12	-1.0e-02	3.6e+04
DL x,y [0, 1.00e-04]	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04
DL x,y,s,psi [0, 1.00e-04]	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04
DQ x,y [0, 1.00e-04]	7.2e-05	6.9e-05	1.0e-04	1.0e-04	8.6e-05	6.4e-05	1.0e-04	1.0e-04	1.0e-04	1.0e-04
DQ x,y,s,psi [0, 1.00e-04]	7.3e-05	6.9e-05	1.0e-04	1.0e-04	8.1e-05	6.6e-05	1.0e-04	1.0e-04	1.0e-04	1.0e-04
Octupole x,y [0, 1.00e-04]	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04
Octupole x,y,s,psi [0, 1.00e-04]	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04
QF68 x,y [0, 1.00e-04]	2.8e-05	3.1e-05	1.0e-04	1.0e-04	8.7e-05	1.0e-04	7.1e-05	1.0e-04	7.0e-05	9.5e-05
QF68 x,y,s,psi [0, 1.00e-04]	2.6e-05	2.9e-05	1.0e-04	1.0e-04	8.3e-05	1.0e-04	6.5e-05	2.2e-05	8.2e-05	1.0e-04
QFD15 x,y [0, 1.00e-04]	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04
QFD15 x,y,s,psi [0, 1.00e-04]	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04
Quadrupole x,y [0, 1.00e-04]	2.8e-05	2.5e-05	1.0e-04	1.0e-04	8.3e-05	1.0e-04	6.9e-05	7.1e-05	9.9e-05	8.9e-05
Quadrupole x,y,s,psi [0, 1.00e-04]	2.6e-05	2.9e-05	1.0e-04	1.0e-04	8.3e-05	1.0e-04	6.3e-05	1.0e-04	8.0e-05	1.0e-04
Sextupole x,y [0, 1.00e-04]	1.0e-04	5.8e-05	8.9e-05	1.0e-04	1.0e-04	1.0e-04	6.8e-05	5.4e-05	6.0e-05	1.0e-04
Sextupole x,y,s,psi [0, 1.00e-04]	1.0e-04	5.0e-05	8.3e-05	1.0e-04	1.0e-04	1.0e-04	7.5e-05	9.1e-05	6.4e-05	1.0e-04

- DQ (combined function dipoles) behave as quadrupoles concerning errors. Evident the impact on vertical dispersion compared to the other quadrupoles (defocussing quadrupoles).
- Quadrupoles have large impact on orbit and horizontal dispersion, also in this case, lifetime and DA are strongly affected. QF6 and QF8 are dominant.
- Sextupoles have the largest impact on DA, they are also the strongest source of beta-beating and emittance as expected.
- Octupoles influence is limited compared to quadrupole and sextupoles, nevertheless they do have an impact on DA. Their effect on lifetime is very small.
- Rotations up to 100urad have impact on the various parameters but limited.

CORRECTION OF REALISTIC ERRORS (100UM) , NO RADIATION

Last simulations with errors only in arcs and of 30um rms.

Now 100 um rms errors in all the elements, a part IP magnets (50um)

```
errset= 1.0 * [...H, V, rot, field
    [ 100e-6,  100e-6, 100e-6,   1e-4, 0, 0];... B*
    [ 100e-6,  100e-6, 100e-6,   1e-4, 0, 0];... BG*
    [ 100e-6,  100e-6, 100e-6,   1e-4, 0, 0];... Q[FD]#*
    [ 100e-6,  100e-6, 100e-6,   1e-4, 0, 0];... Q[FD][CG]*
    [ 100e-6,  100e-6, 100e-6,   1e-4, 0, 0];... S*
    0.5*[ 100e-6,  100e-6, 100e-6,   1e-4, 0, 0];... Q![FD]
    [ 100e-6,  100e-6, 100e-6,      0, 0, 0];... BPM (offset, rotation, reading, gain h gainv)
    0.5*[ 100e-6,  100e-6, 100e-6,   1e-4, 0, 0];... PQ*
    ]; %

radon = 0;
```

MATRICES FOR CORRECTION STEPS

```
   OrbHCor: {[1892×1892 double]  [1892×1892 double]  [1892×1892 double]  [1892×1892 double]}
   OrbVCor: {[1892×1892 double]  [1892×1892 double]  [1892×1892 double]  [1892×1892 double]}
   OrbHDPP: [1×1892 double]
   OrbVDPP: [1×1892 double]
  TrajHCor: {[1892×1892 double]  [1892×1892 double]  [1892×1892 double]  [1892×1892 double]}
  TrajVCor: {[1892×1892 double]  [1892×1892 double]  [1892×1892 double]  [1892×1892 double]}
  TrajHDPP: [1×1892 double]
  TrajVDPP: [1×1892 double]
  DispHCor: {[1892×1892 double]  [1892×1892 double]  [1892×1892 double]  [1892×1892 double]}
  DispVCor: {[1892×1892 double]  [1892×1892 double]  [1892×1892 double]  [1892×1892 double]}
  DispHDPP: [1×1892 double]
  DispVDPP: [1×1892 double]
  DispQCor: {[1892×1892 double]  [1892×1892 double]  [1892×1892 double]  [1892×1892 double]}
  DispSCor: {[1892×1892 double]  [1892×1892 double]  [1892×1892 double]  [1892×1892 double]}
  TuneQCor: {[1×1892 double]  [1×1892 double]  [1×1892 double]  [1×1892 double]}
```

orbit

Trajectory (Threading)

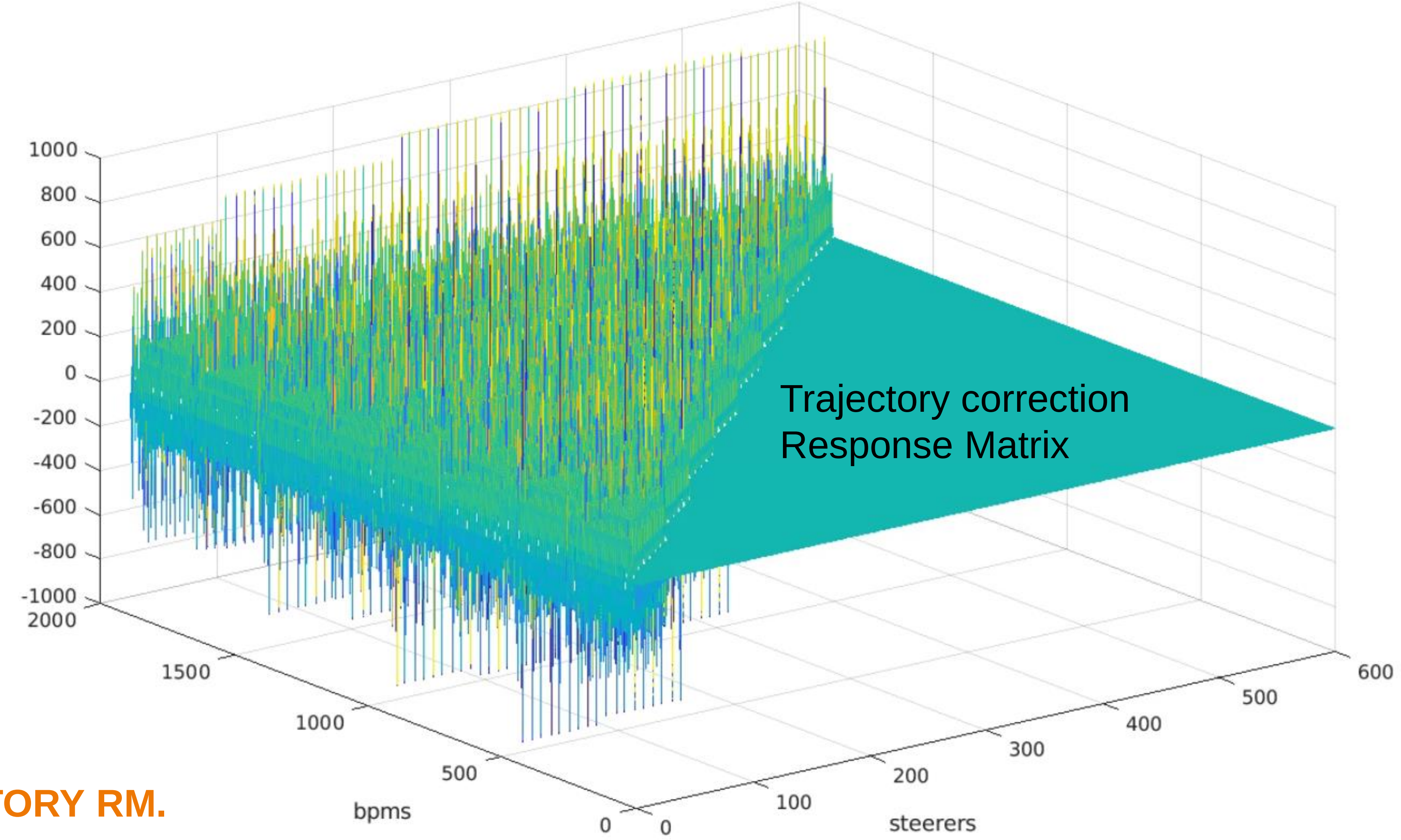
Optics correction

Long quads, small kicks (not integrated 1/m)!

TRAJECTORY CORRECTION, FAILS DUE TO MISSING CORRECTORS AT THE BEGINNING OF THE LATTICE.

Solution:

add more correctors : NOT OK. The corrector indexes look correct, first corrector before first BPM. Nevertheless the first block of the Trajectory response is ZEROS, thus the trajectory correction never starts.



RECOMPUTE TRAJECTORY RM.

BEAM THREADING IS RUNNING OK

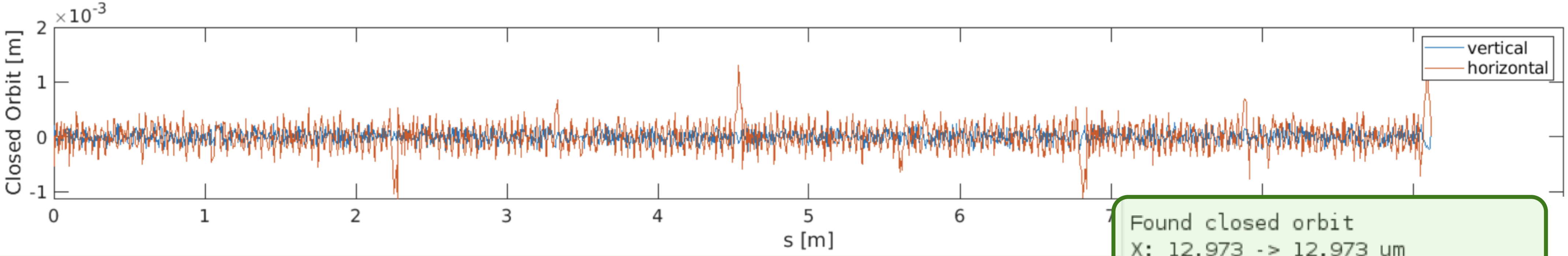
All magnets ON at their nominal strengths.

Steerers powered as soon as there is beam on the next BPMs

Steering till one turn and closure of the orbit with the last 2 steerers.

Allow for 0.5mm trajectory amplitude accepted. May be this has to be revisited.

```
correcting available V trajectory
V PLANE
correcting available V trajectory
X: 104.969 -> 52.523 um
Y: 43.905 -> 21.887 um
Search closed orbit
Trajectory correction: nbpms= 1875 ncor: 1875, 1875,
computing ORM for available trajectory
H PLANE
correcting available V trajectory
V PLANE
correcting available V trajectory
X: 53.389 -> 26.960 um
Y: 54.155 -> 27.303 um
Search closed orbit
Trajectory correction: nbpms= 1885 ncor: 1885, 1885,
computing ORM for available trajectory
H PLANE
correcting available V trajectory
V PLANE
correcting available V trajectory
X: 96.471 -> 48.678 um
Y: 81.014 -> 40.532 um
Search closed orbit
Trajectory correction: nbpms= 1891 ncor: 1891, 1891,
computing ORM for available trajectory
H PLANE
```




```
Found closed orbit
X: 12.973 -> 12.973 um
Y: 10.574 -> 10.574 um
Finished: Correction Step: 1/16
Elapsed time is 317.886735 seconds.
```

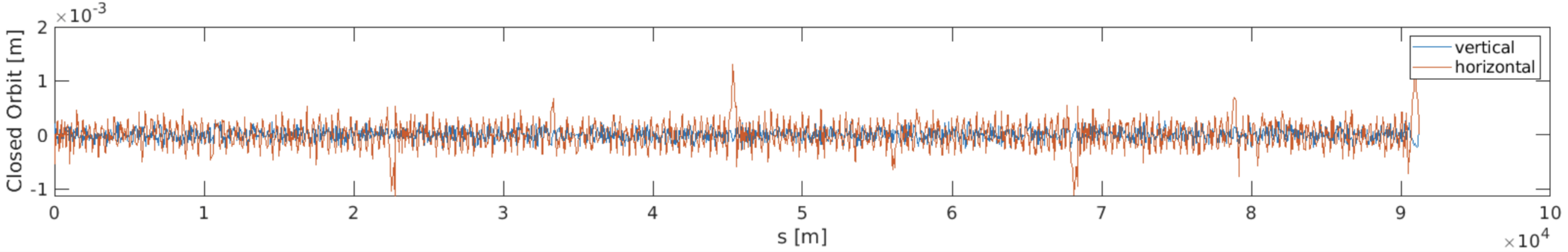
Once a closed orbit is found, correct it using all available H/V steerers.

No limits set to steerers for now.

Truncation of SVD to 500 singular vectors / >1800, to keep forces required to a minimum.

There is a closed orbit but tunes are several units different from nominal.

```
Tune Matching
Nominal tune: 222.17213, 222.39982,
Initial tune: 222.05755, 213.78119,
Going to tune: 222.17213, 222.39982,
Could not match Tune
```



CORRECTION LOOP CONTINUES WITH TUNE AND CHROMATICITY CORRECTION

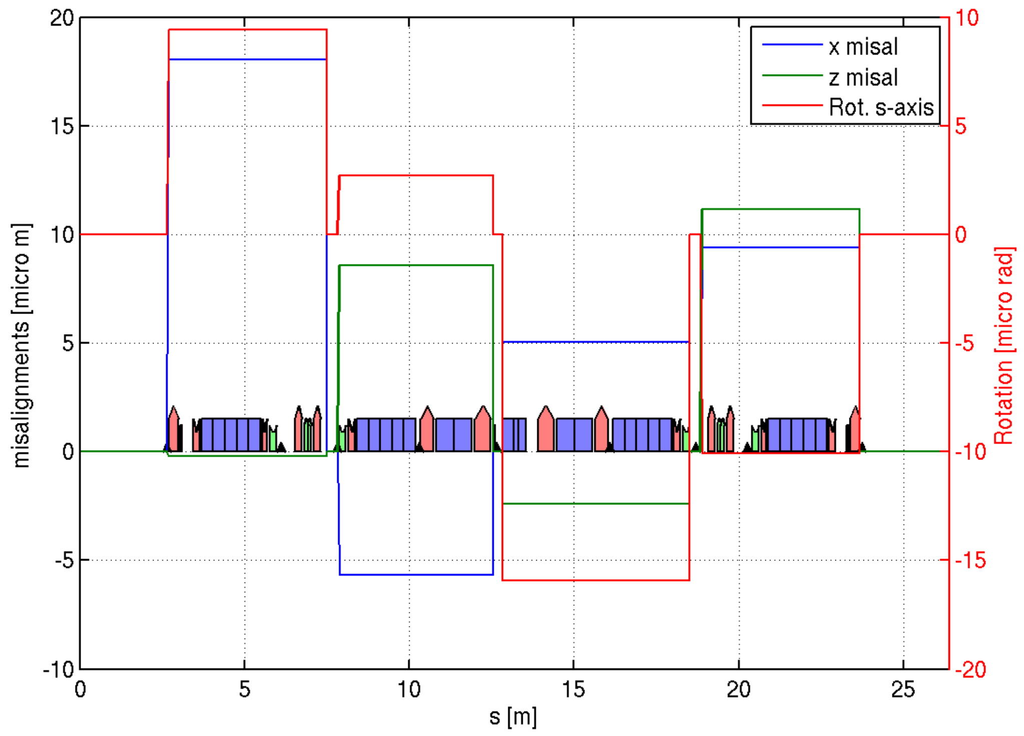
```
Found closed orbit
X: 23.076 -> 23.076 um
Y: 13.526 -> 13.526 um
Finished: Correction Step: 1/16
Elapsed time is 136.982589 seconds.
Correction Step: 2/16
Tune Matching
Nominal tune: 222.17213, 222.39982,
Initial tune: 222.18332, 222.30962,
Going to tune: 222.17213, 222.39982,
Single correction step
Could not match Tune
Finished: Correction Step: 2/16
Elapsed time is 6.000173 seconds.
Correction Step: 3/16
Set RF cavity. 120 MV, 121657 buckets, 0 radiation
Finished: Correction Step: 3/16
```

```
Finished: Correction Step: 4/16
Elapsed time is 11.936607 seconds.
Correction Step: 5/16
Tune Matching
Nominal tune: 222.17213, 222.39982,
Initial tune: 222.05755, 213.78119,
Going to tune: 222.17213, 222.39982,
Could not match Tune
Finished: Correction Step: 5/16
Elapsed time is 10.077279 seconds.
Correction Step: 6/16
 - - - -  chromaticty correction - - - - -
All SF and All SD moved by a constant value
Nominal chrom: -0.130,  0.348,
```

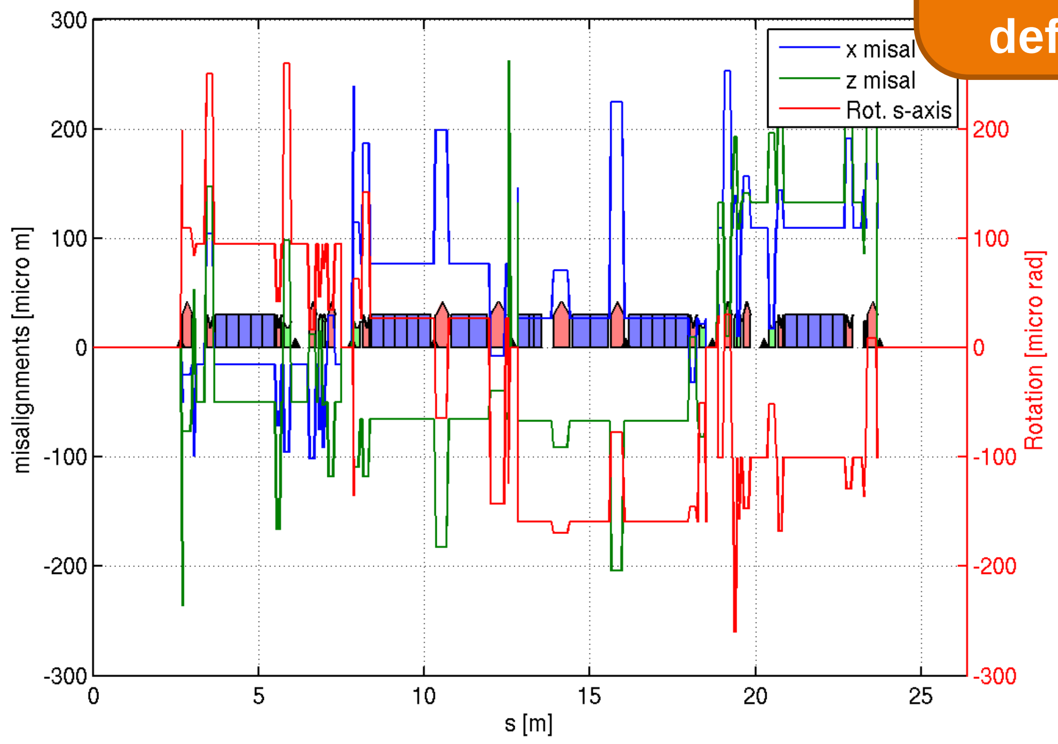
O: Add orbit in in all functions, it must be given to atlinopt, atfittune, atm

TRY REDUCED ERRORS AND SIMPLIFIED ORBIT CORRECTION (2 STEPS ONLY)

How GIRDER tolerances were defined



Girder displacements and rotations

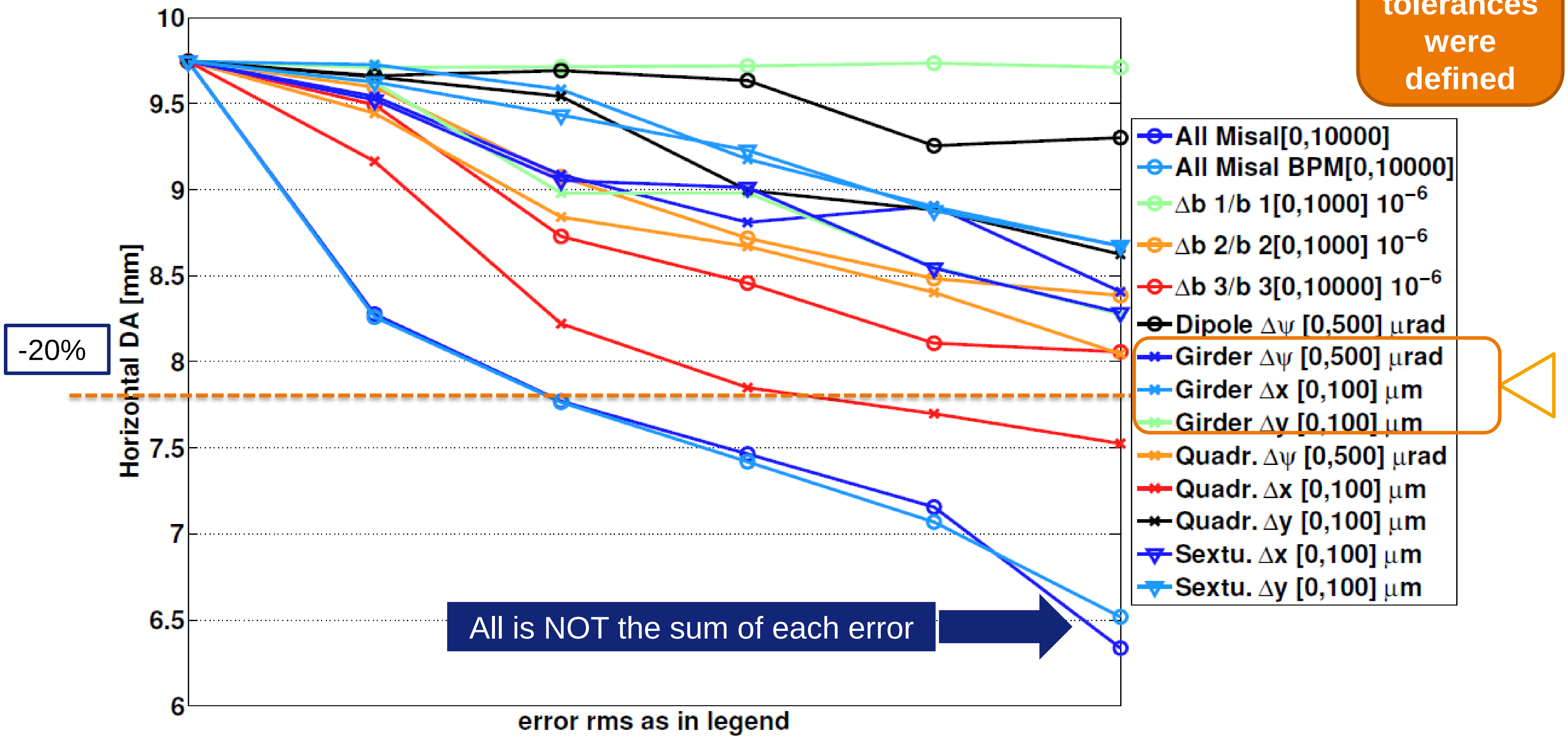


Girder displacements and rotations + random errors Quad. and Sext.

4 girders, BPMs are moved with the girder.

DYNAMIC APERTURE @S3 SEPTUM VS ERRORS FOR S28A + RDT CORRECTION

How GIRDER tolerances were defined



ERROR VALUES FOR A REDUCTION OF 20% OF HOR. DYNAMIC APERTURE @S3

How GIRDER tolerances were defined

	dynamic aperture					emittance		acceptance		
error	H	V	area	+2%	−2%	ϵ_x	ϵ_y	H	V	mi
AllMisal	39.0	35.8	27.2	f 25.2	27.4	100.0	100.0	31.5	36.1	25.2
AllMisalBPM	3869.3	3867.1	2585.4	f2517.6	2867.8	10000.0	10000.0	3312.4	3496.4	2517.6
$\Delta b_1/b_1$	1000.0	1000.0	f1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	$1000.0\ 10^{-6}$
$\Delta b_2/b_2$	1000.0	1000.0	f1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	$1000.0\ 10^{-6}$
$\Delta b_3/b_3$	10000.0	10000.0	f7427.8	7826.8	7841.3	10000.0	10000.0	10000.0	10000.0	$7427.8\ 10^{-6}$
$Dipole\Delta\psi$	500.0	500.0	f 500.0	500.0	500.0	500.0	500.0	500.0	500.0	$500.0\ \mu rad$
$Girder\Delta\psi$	500.0	500.0	f 500.0	500.0	500.0	500.0	500.0	500.0	500.0	$500.0\ \mu rad$
$Girder\Delta x$	100.0	100.0	f 100.0	100.0	100.0	100.0	100.0	100.0	100.0	$100.0\ \mu m$
$Girder\Delta y$	100.0	100.0	100.0	f 73.2	77.7	100.0	100.0	100.0	100.0	$73.2\ \mu m$
$Quadrupole\Delta\psi$	500.0	500.0	f 500.0	500.0	500.0	500.0	500.0	500.0	500.0	$500.0\ \mu rad$
$Quadrupole\Delta x$	66.9	100.0	59.0	f 46.4	50.1	100.0	100.0	59.7	100.0	$46.4\ \mu m$
$Quadrupole\Delta y$	100.0	100.0	f 100.0	100.0	100.0	100.0	100.0	100.0	100.0	$100.0\ \mu m$
$Sextupole\Delta x$	100.0	100.0	f 100.0	100.0	100.0	100.0	100.0	100.0	100.0	$100.0\ \mu m$
$Sextupole\Delta y$	100.0	100.0	f 100.0	100.0	100.0	100.0	100.0	100.0	100.0	$100.0\ \mu m$

Strong impact of quadrupole errors

No influence on emittances

RDT correction

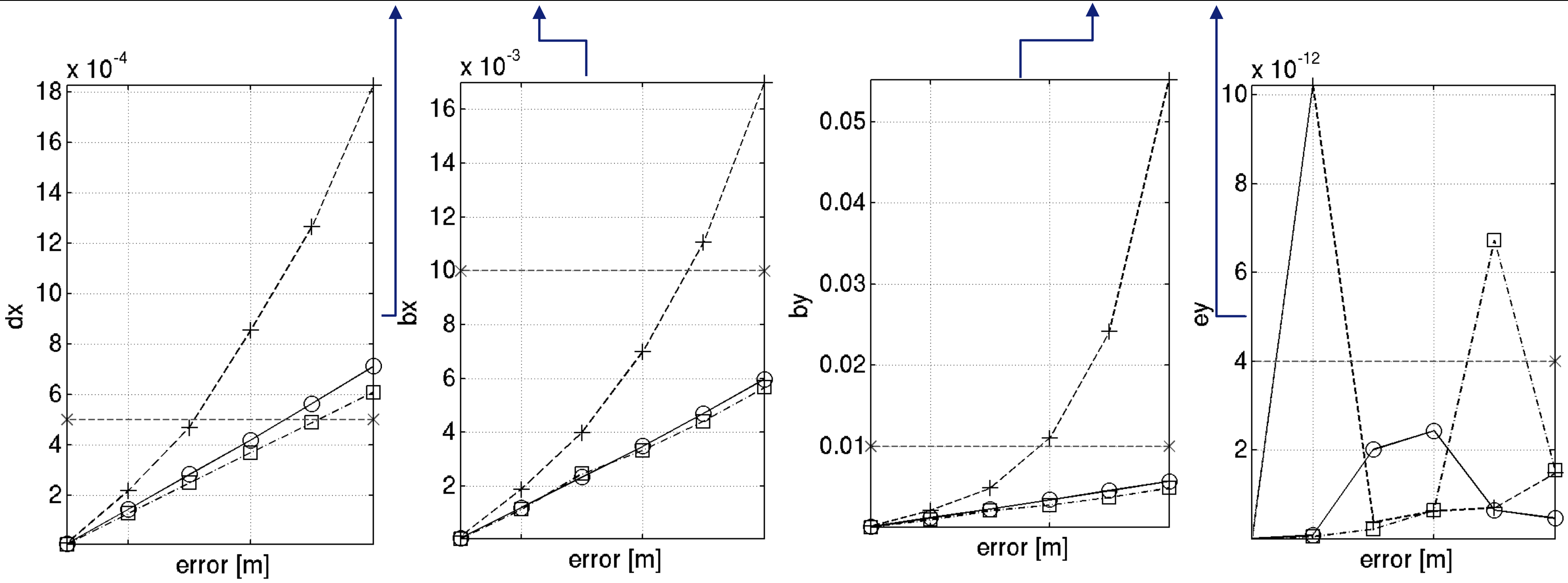
SUMMARY TABLE OF GIRDER ERRORS

Commissioning-like correction sequence to get these data
Cluster, Average over several (10) error seeds.

Computing cluster

$\sqrt{\langle()^2\rangle}$	x	$(\eta_x - \eta_x^0)$	$\frac{\Delta\beta_x}{\beta_x^0}$	ϵ_x	y	η_y	$\frac{\Delta\beta_y}{\beta_y^0}$	ϵ_y	DA	$\tau_{Touschek}$
error	μm	μm	%	$pm\,rad$	μm	μm	%	$pm\,rad$	mm	s
thresholds:	5.0e-05	5.0e-04	1.0e-02	4.0e-12	5.0e-05	5.0e-04	1.0e-02	4.0e-12	-1.0e-02	3.6e+04
Girder gx,gy [0, 1.00e-04]	8.5e-05	7.1e-05	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04
Girder gx,gy,gpsi [0, 1.00e-04]	1.0e-04	8.2e-05	1.0e-04	1.0e-04	1.0e-04	1.0e-04	1.0e-04	9.1e-05	1.0e-04	1.0e-04
Girder gx,gy,gpsi,x,y,psi [0, 1.00e-04]	1.0e-04	4.2e-05	7.5e-05	1.0e-04	1.0e-04	1.0e-04	5.7e-05	7.7e-05	5.4e-05	9.7e-05

(g) Stands for girder errors, no g, are quadrupole and sextupole individual misalignments

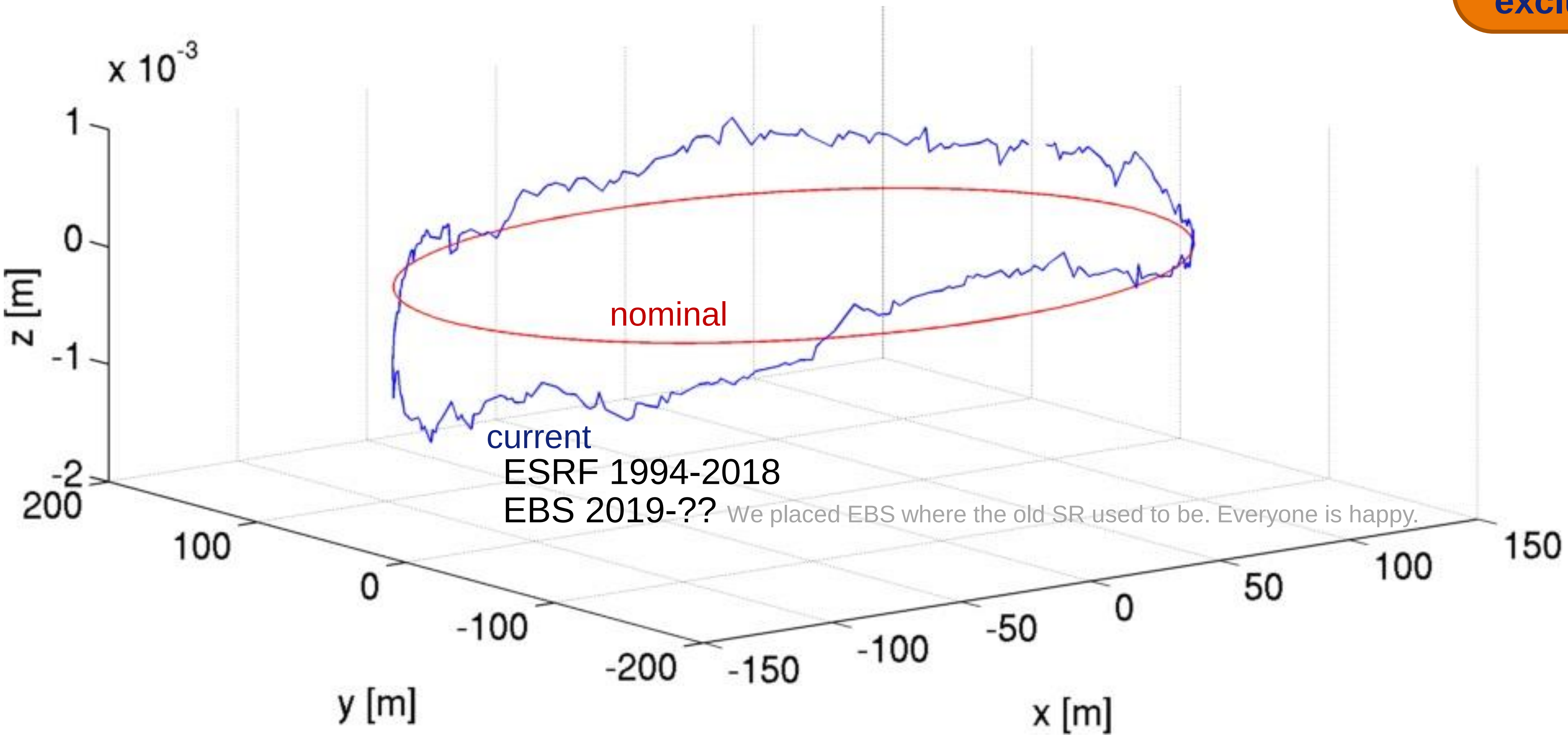


How GIRDER tolerances were defined

THE MEASURED POSITION OF THE LATTICE

How GIRDER tolerances were excluded

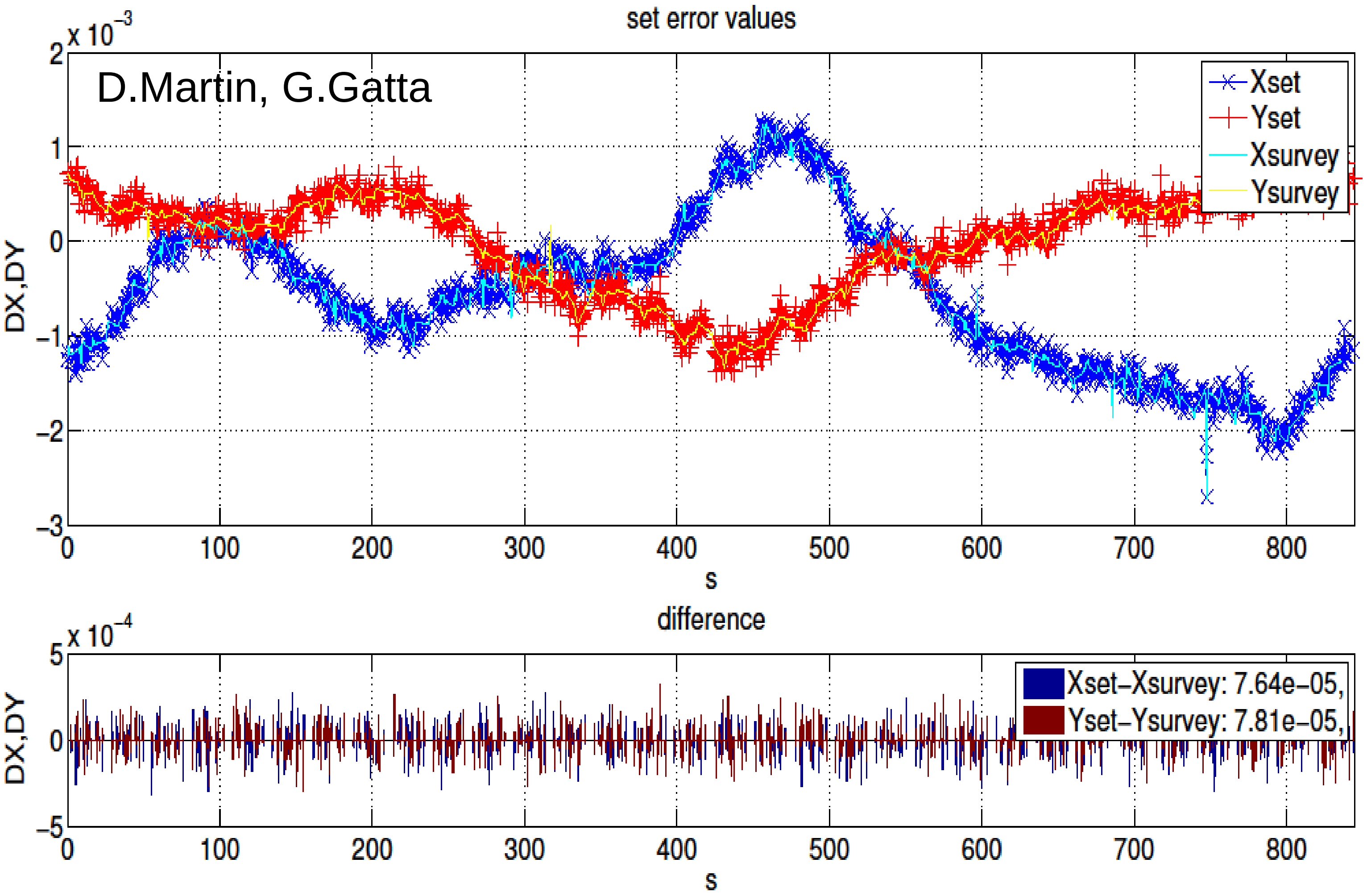
This is where the machine is. Let's use this information!



We placed EBS where the old SR used to be. Everyone is happy.

SURVEY ERRORS PLUS RANDOM ERRORS

How GIRDER tolerances were excluded



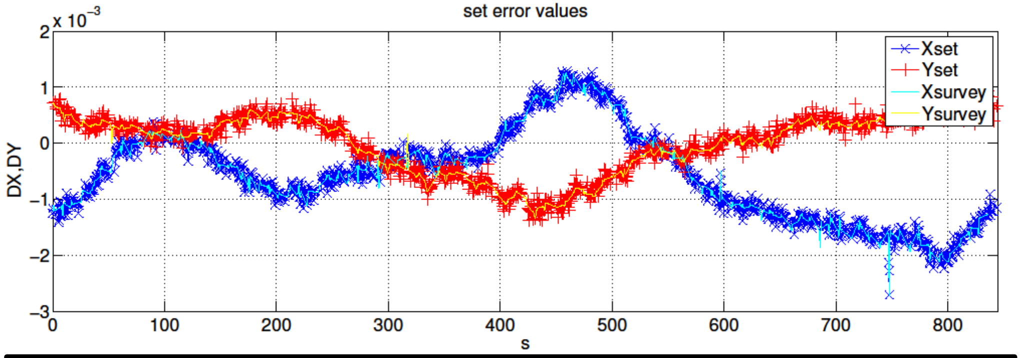
- The blue curve represents the current ESRF storage ring position.
- The x symbols are the interpolated positions on this curve for the S28A lattice.
- BPM are positioned on the same curve.
- DX and DZ and girder rotations are applied.
- ~~Errors are ramped in steps of 20% up to the nominal value.~~
- Added random errors to account for unknown magnetic center position

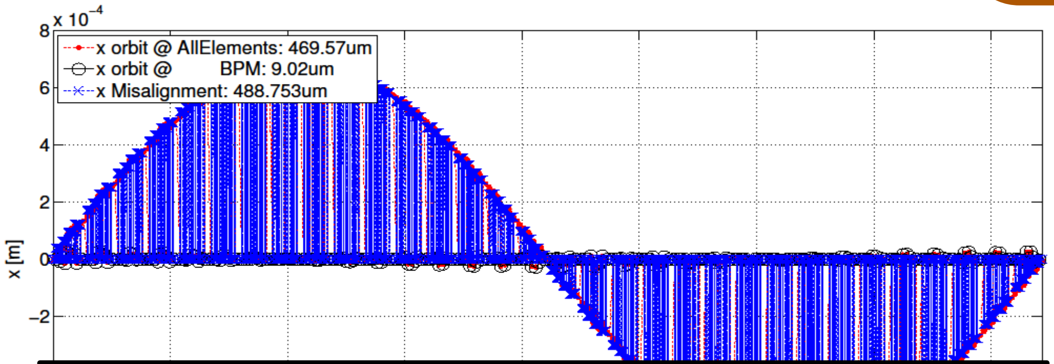
Random Gaussian DX DY in quadrupoles and sextupoles on top of the survey errors.

LONG RANGE ERRORS

How GIRDER tolerances were excluded

Error “waves” applied to the lattice: DX, DY, Rotations for quad and sext.





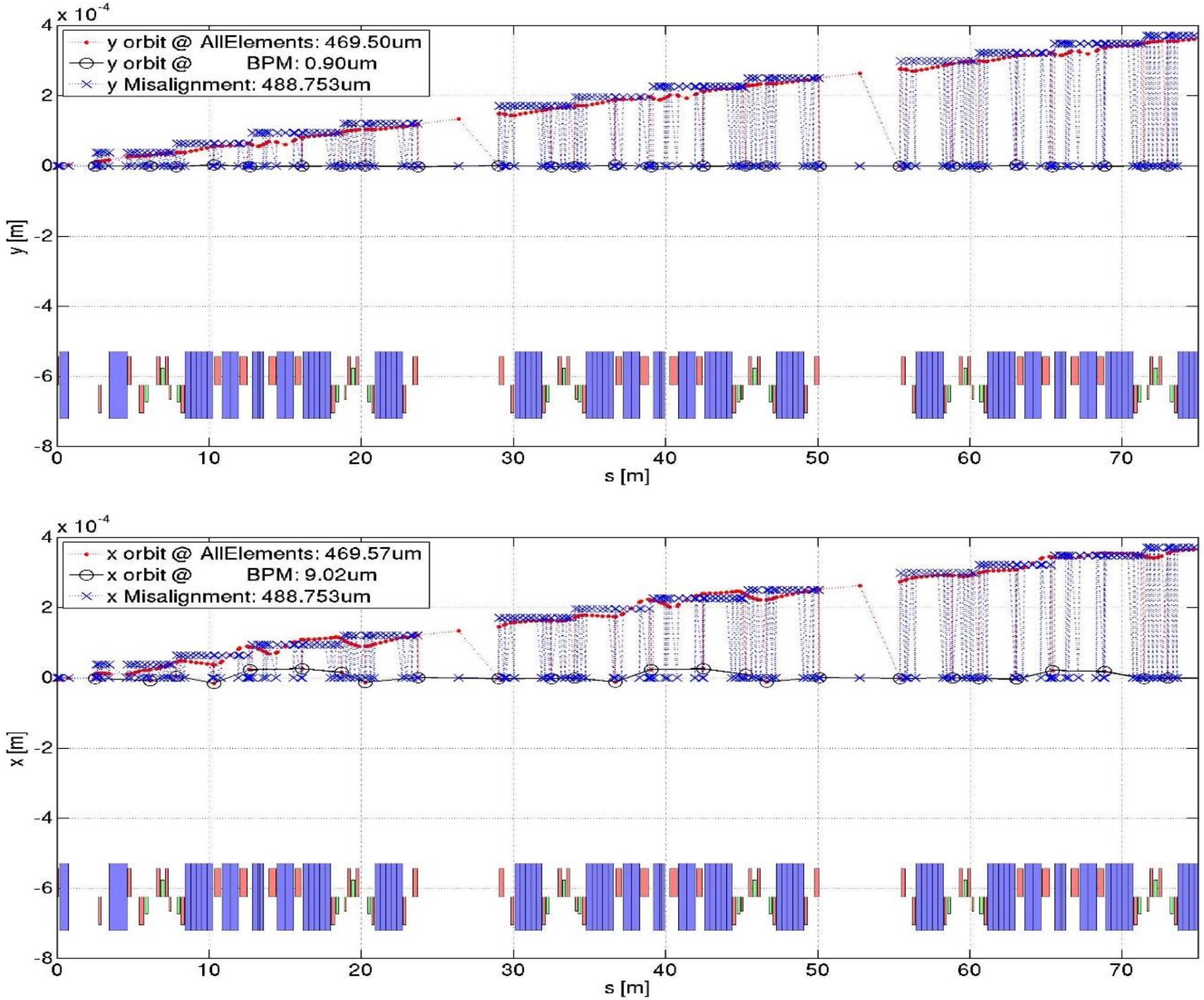
storage ring survey data → simulated 1st harmonic,

Correction performed for each frequency and amplitude set as:

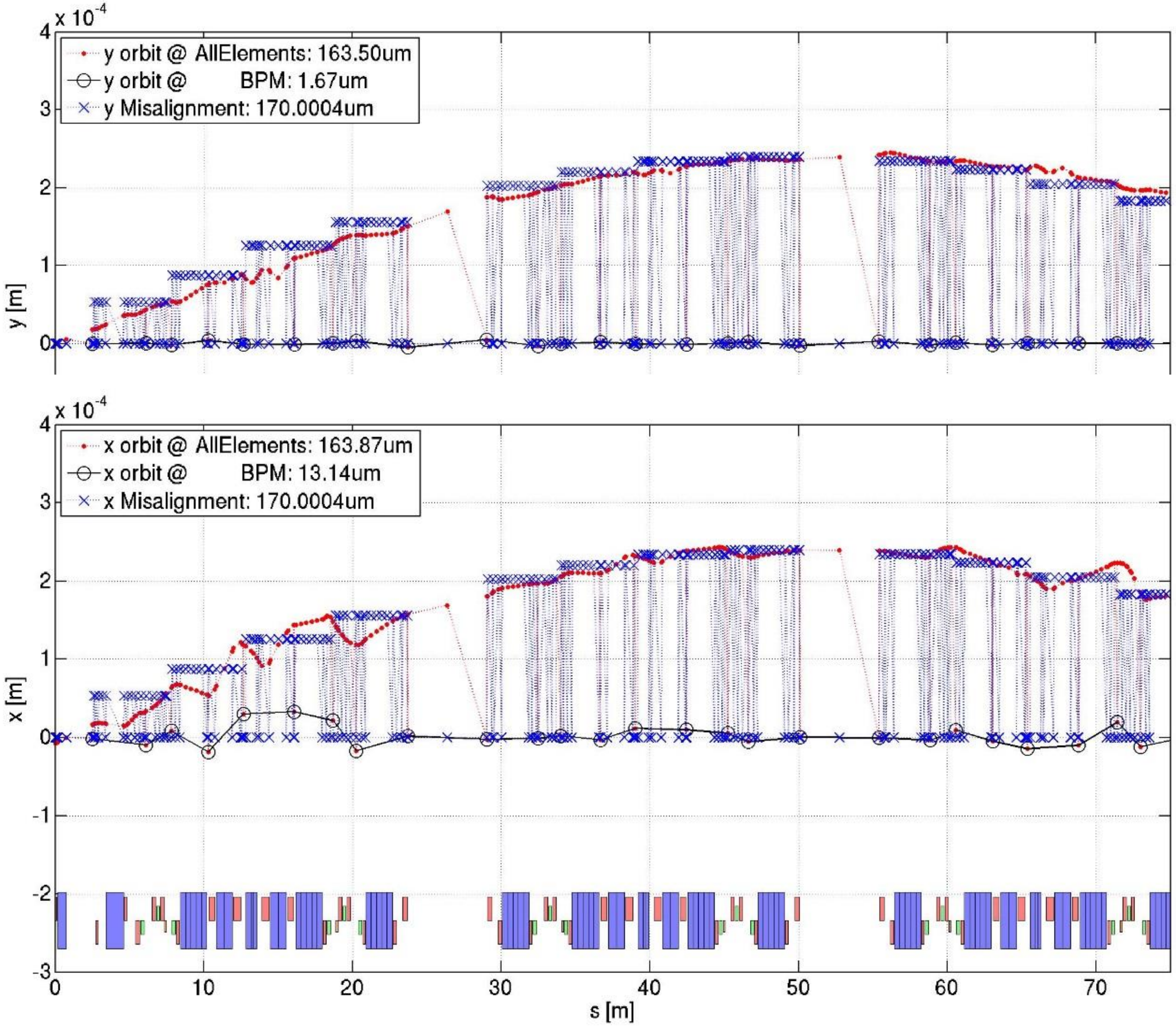
- Open trajectory correction
- Orbit correction
- RDT correction

Simulations performed on the OAR asd cluster, 8h-600cpu

DISPLACEMENTS AND GLOBAL TILT

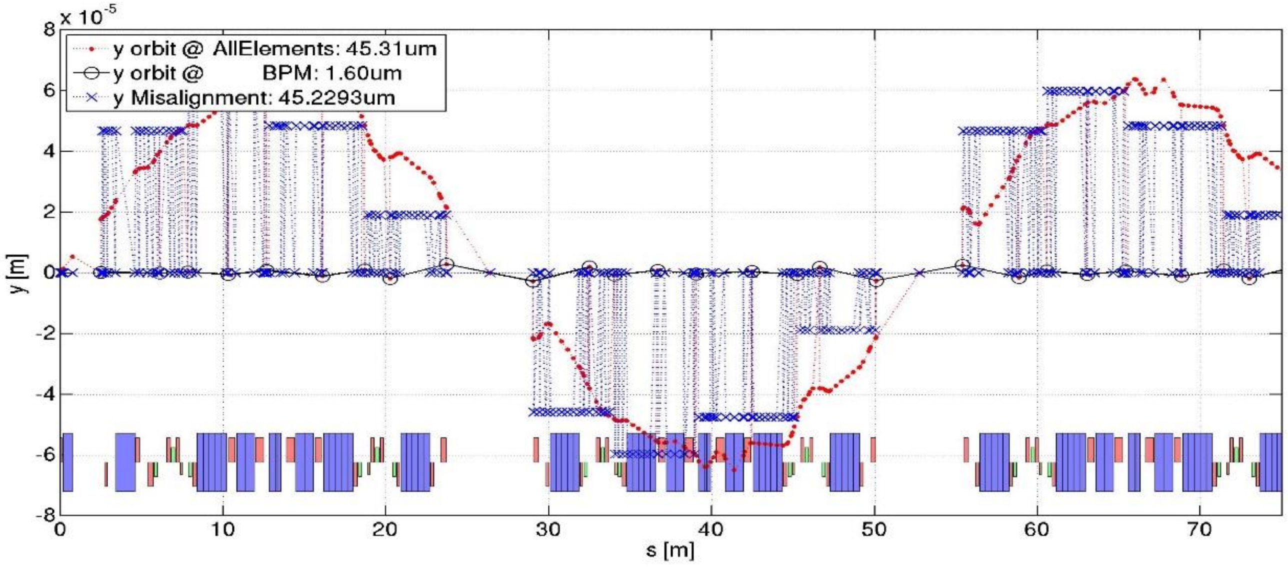


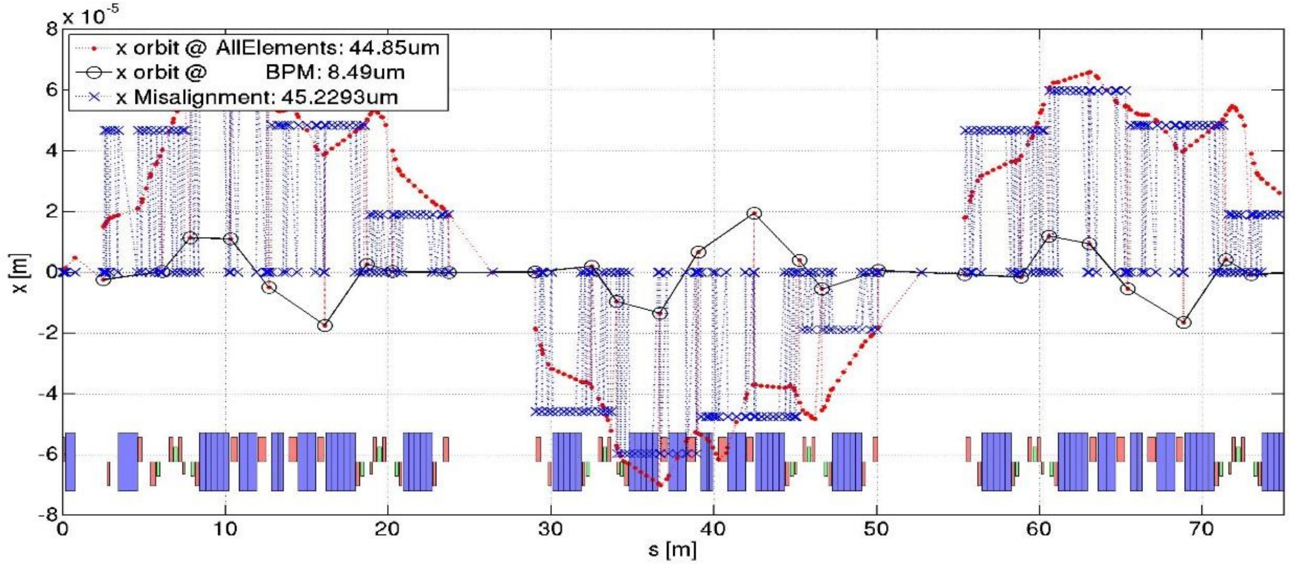

```
------------------------------------------------
------ total std corrector values applyed --------
------                              --------
      HK (288) [1/m]: 0.00e+00 -> 1.06e-04
      VK (288) [1/m]: 0.00e+00 -> 1.19e-04
      SK (288) [1/m2]: 0.00e+00 -> 0.00e+00
      QK (514) [1/m2]: 0.00e+00 -> 0.00e+00
      HKL (288) [rad]: 0.00e+00 -> 1.08e-05
      VKL (288) [rad]: 0.00e+00 -> 8.25e-06
      SKL (288) [T/m]: 0.00e+00 -> 0.00e+00
      QKL (514) [T/m]: 0.00e+00 -> 0.00e+00
------                              --------
------   residual orbit and dispersion   --------
------                              --------
      OH (288) [m]: 3.78e-05 -> 9.02e-06
      OV (288) [m]: 1.48e-04 -> 9.05e-07
      DH (288) [m]: 3.80e-04 -> 1.18e-04
      DV (288) [m]:1.38e-03 -> 3.33e-04
      BBH (288) %: 0.9 -> 0.3
      BBV (288) %: 0.6 -> 0.3
      PhH (288) : 2.09e-02 -> 1.75e-02
      PhV (288) : 1.70e-02 -> 1.07e-02
------                              --------
------      tune and emittance      --------
------                              --------
      Qx [0.580]: 0.580 -> 0.580
      Qy [0.620]: 0.619 -> 0.619
      EX [147.528 pm]: 147.506 -> 147.545
      EY [0.000pm]: 0.986 -> 0.049
------                              --------
------------------------------------------------
----- ----- -- -- -- -- ------ -----
initial   (ex, ey): 147.53,        0.00,
errors    (ex, ey): 147.51,        0.99,
corrected (ex, ey): 147.54,        0.05,

Freq 1, every 32
```




```
--------------------------------------------------
------ total std corrector values applyed --------
------                                    --------
       HK  (288)  [1/m]: 0.00e+00 -> 1.37e-04
       VK  (288)  [1/m]: 0.00e+00 -> 1.63e-04
       SK  (288)  [1/m2]: 0.00e+00 -> 0.00e+00
       QK  (514)  [1/m2]: 0.00e+00 -> 0.00e+00
       HKL  (288)  [rad]: 0.00e+00 -> 1.54e-05
       VKL  (288)  [rad]: 0.00e+00 -> 1.14e-05
       SKL  (288)  [T/m]: 0.00e+00 -> 0.00e+00
       QKL  (514)  [T/m]: 0.00e+00 -> 0.00e+00
------                                    --------
------    residual orbit and dispersion   --------
------                                    --------
       OH  (288)  [m]: 8.79e-05 -> 1.31e-05
       OV  (288)  [m]: 1.35e-03 -> 1.67e-06
       DH  (288)  [m]: 2.59e-03 -> 2.61e-04
       DV  (288)  [m]:1.02e-02 -> 3.12e-03
       BBH  (288) %: 3.9 -> 0.5
       BBV  (288) %: 2.2 -> 0.5
       PhH  (288)  : 2.95e-02 -> 6.91e-03
       PhV  (288)  : 2.13e-02 -> 5.69e-03
------                                    --------
------        tune and emittance          --------
------                                    --------
       Qx [0.580]: 0.574 -> 0.580
       Qy [0.620]: 0.612 -> 0.619
       EX [147.528 pm]: 147.077 -> 147.596
       EY [0.000pm]: 67.039 -> 4.014
------                                    --------
--------------------------------------------------
----- ----- -- -- -- -- ------ -----
initial   (ex, ey): 147.53,           0.00,
errors    (ex, ey): 147.08,          67.04,
corrected (ex, ey): 147.60,           4.01,

Freq 4, every 8 cells
```

MISALIGNMENT PATTERN, EVERY 2 CELLS





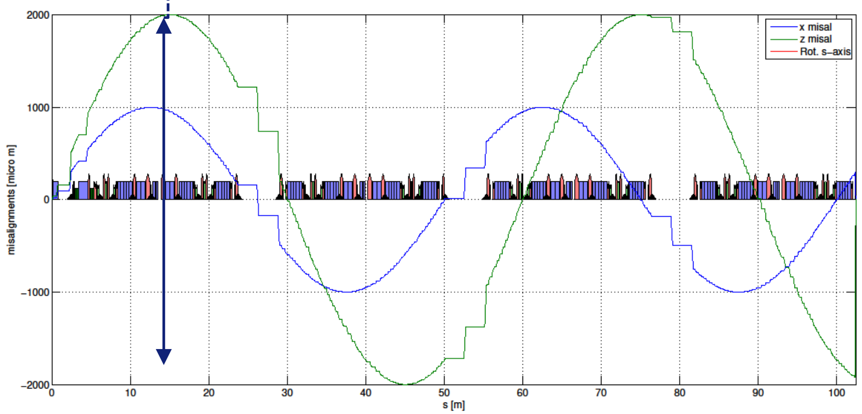

```
--------------------------------------------------
------ total std corrector values applyed --------
------                                    --------
       HK (288) [1/m]: 0.00e+00 -> 1.05e-04
       VK (288) [1/m]: 0.00e+00 -> 5.10e-05
       SK (288) [1/m2]: 0.00e+00 -> 0.00e+00
       QK (514) [1/m2]: 0.00e+00 -> 0.00e+00
       HKL (288) [rad]: 0.00e+00 -> 1.07e-05
       VKL (288) [rad]: 0.00e+00 -> 6.21e-06
       SKL (288) [T/m]: 0.00e+00 -> 0.00e+00
       QKL (514) [T/m]: 0.00e+00 -> 0.00e+00
------                                    --------
------    residual orbit and dispersion   --------
------                                    --------
       OH (288) [m]: 4.93e-05 -> 8.49e-06
       OV (288) [m]: 3.13e-05 -> 1.60e-06
       DH (288) [m]: 5.04e-04 -> 3.98e-04
       DV (288) [m]:3.92e-04 -> 1.69e-04
       BBH (288) %: 1.1 -> 0.6
       BBV (288) %: 0.8 -> 0.2
       PhH (288) : 7.76e-03 -> 2.97e-03
       PhV (288) : 9.02e-03 -> 3.40e-03
------                                    --------
------        tune and emittance          --------
------                                    --------
       Qx [0.580]: 0.582 -> 0.579
       Qy [0.620]: 0.616 -> 0.622
       EX [147.528 pm]: 147.483 -> 141.513
       EY [0.000pm]: 0.301 -> 13.404
------                                    --------
--------------------------------------------------
----- ----- -- -- -- -- ------ -----
initial   (ex, ey): 147.53,             0.00,
errors    (ex, ey): 147.48,             0.30,
corrected (ex, ey): 141.51,            13.40,

Freq 16, Every 2 cells
```

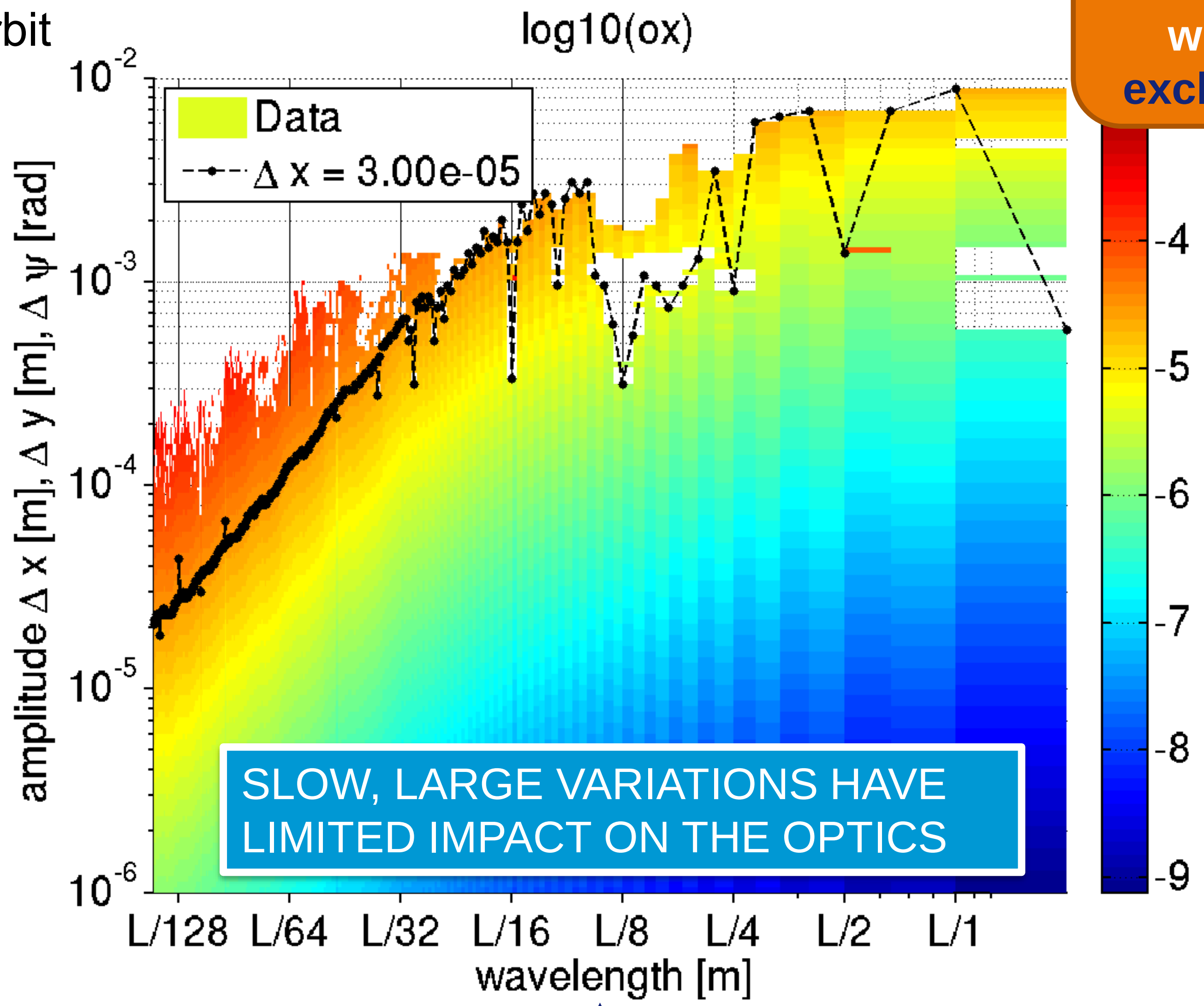
LONG RANGE ERRORS: ERROR ENVELOPE FUNCTION

How GIRDER tolerances were excluded

Impact of error “waves” on horizontal orbit

At a wavelength of L/128~6m
30um errors amplitude give
30 um residual orbit distortion.
At a wavelength of L/2~422m
7mm errors amplitude give
30 um residual orbit distortion.

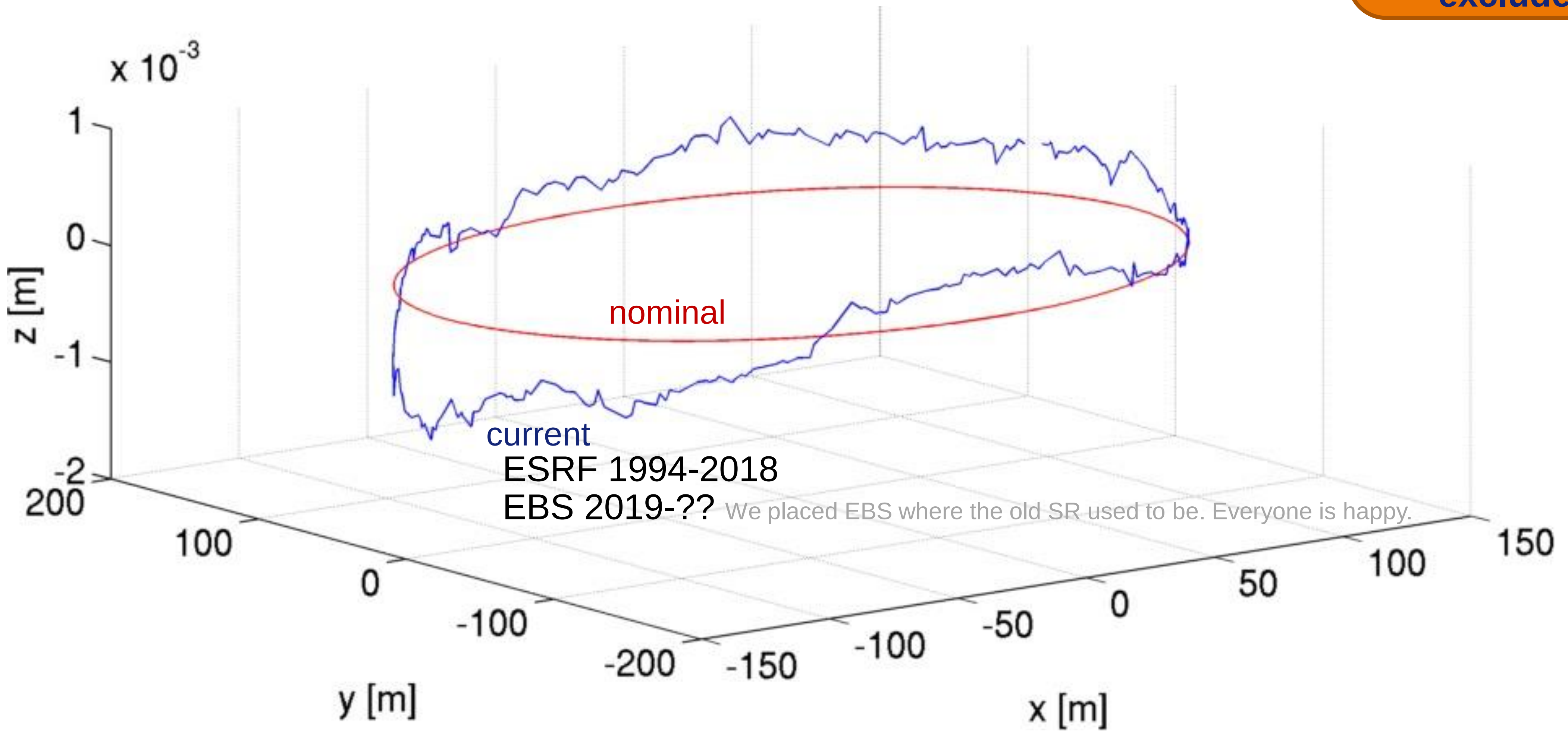




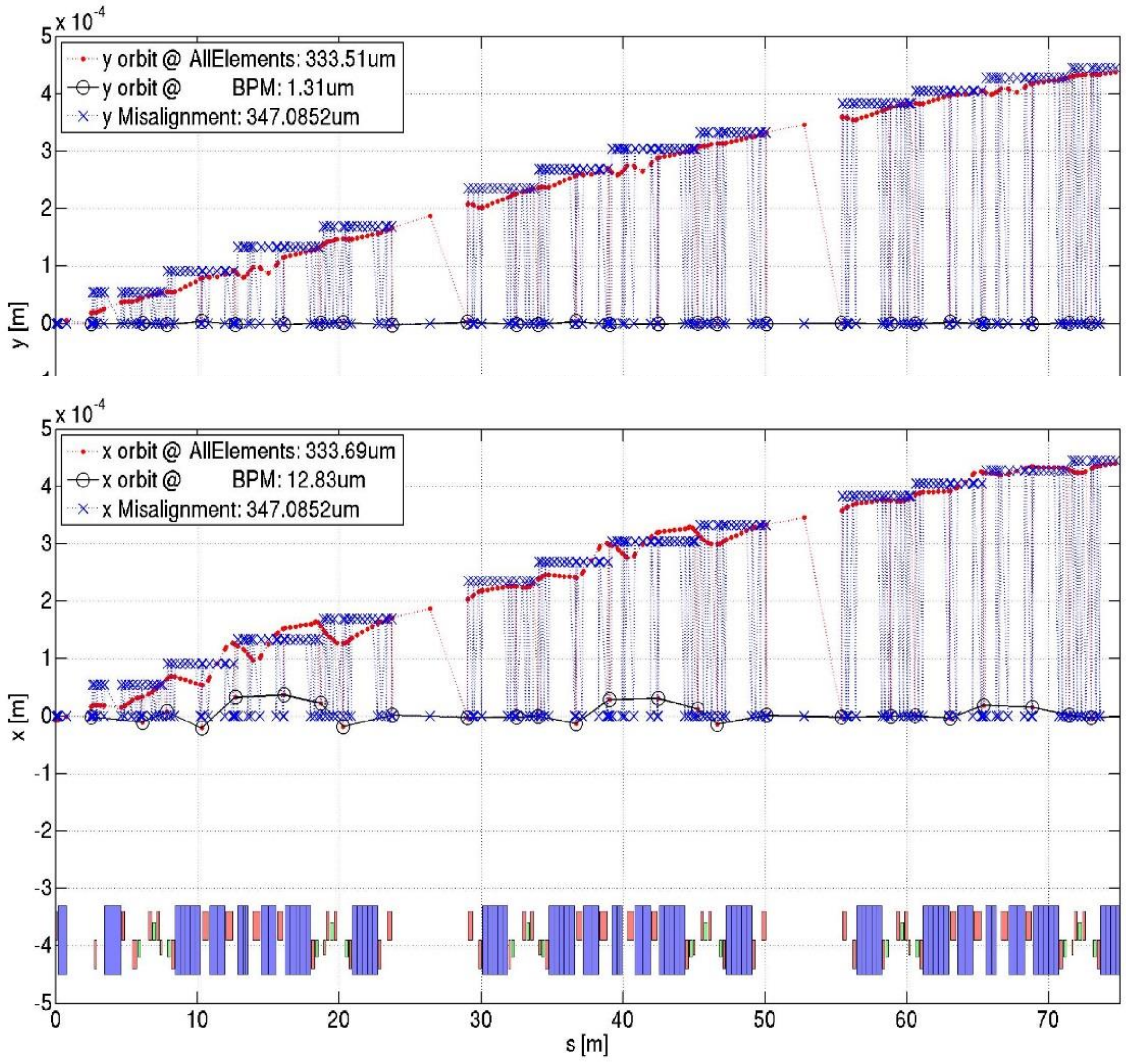
THE MEASURED POSITION OF THE LATTICE

How GIRDER and LONG RANGE tolerances were **excluded**

This is where the machine is. Let's use this information!

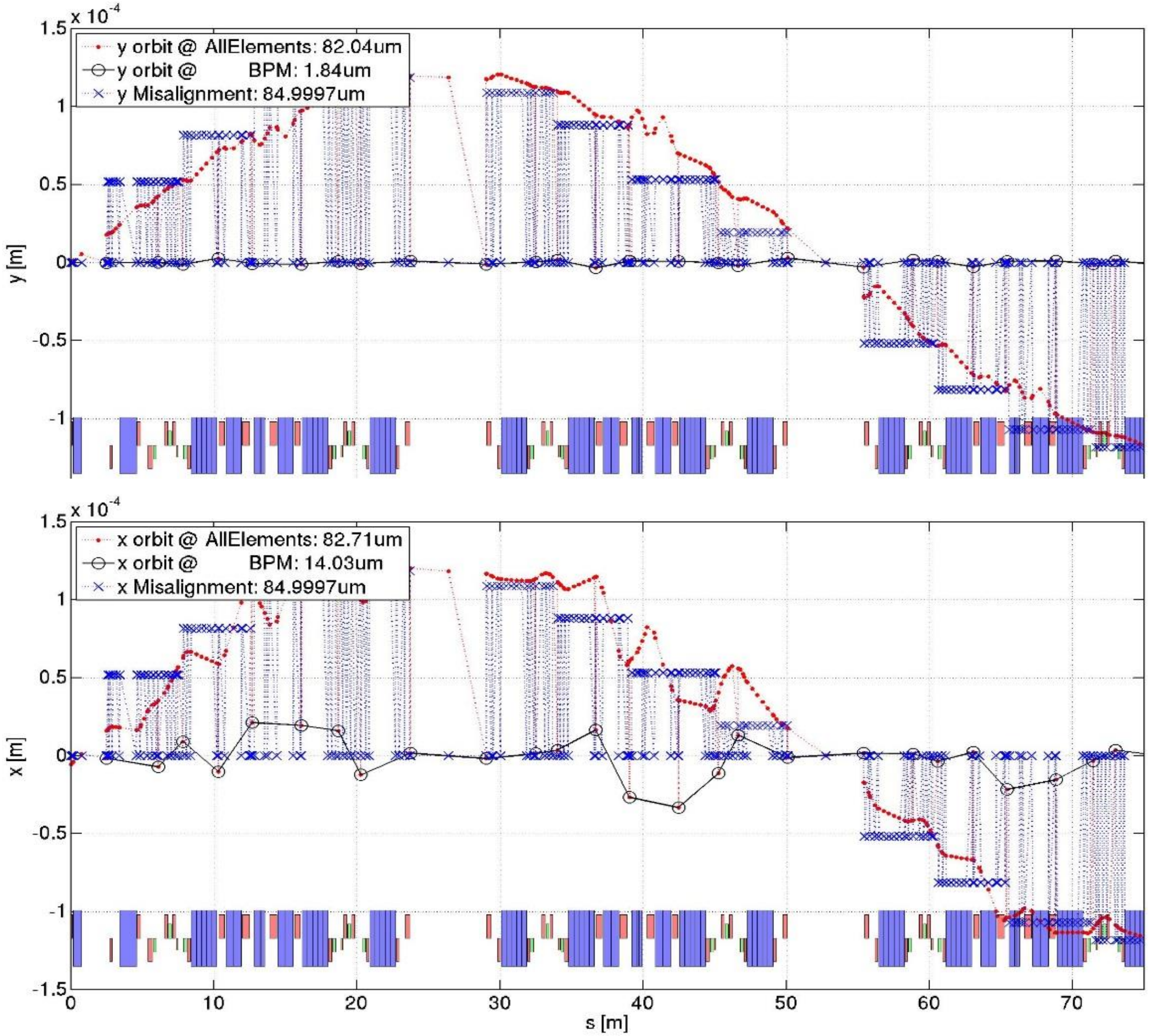


EVERY 16 CELLS




```
--------------------------------------------------
------ total std corrector values applyed --------
------                                    --------
       HK  (288)  [1/m]: 0.00e+00 -> 1.51e-04
       VK  (288)  [1/m]: 0.00e+00 -> 1.68e-04
       SK  (288)  [1/m2]: 0.00e+00 -> 0.00e+00
       QK  (514)  [1/m2]: 0.00e+00 -> 0.00e+00
       HKL  (288)  [rad]: 0.00e+00 -> 1.54e-05
       VKL  (288)  [rad]: 0.00e+00 -> 1.17e-05
       SKL  (288)  [T/m]: 0.00e+00 -> 0.00e+00
       QKL  (514)  [T/m]: 0.00e+00 -> 0.00e+00
------                                    --------
------    residual orbit and dispersion   --------
------                                    --------
       OH  (288)  [m]: 6.01e-05 -> 1.28e-05
       OV  (288)  [m]: 2.61e-04 -> 1.31e-06
       DH  (288)  [m]: 5.95e-04 -> 1.75e-04
       DV  (288)  [m]:2.41e-03 -> 5.84e-04
       BBH  (288)  %: 1.4 -> 0.5
       BBV  (288)  %: 0.9 -> 0.5
       PhH  (288)  : 1.77e-02 -> 1.28e-02
       PhV  (288)  : 1.42e-02 -> 8.11e-03
------                                    --------
------        tune and emittance          --------
------                                    --------
       Qx [0.580]: 0.579 -> 0.580
       Qy [0.620]: 0.618 -> 0.619
       EX [147.528 pm]: 147.487 -> 147.563
       EY [0.000pm]: 2.806 -> 0.137
------                                    --------
--------------------------------------------------
Freq 2, evry 16 cells
```

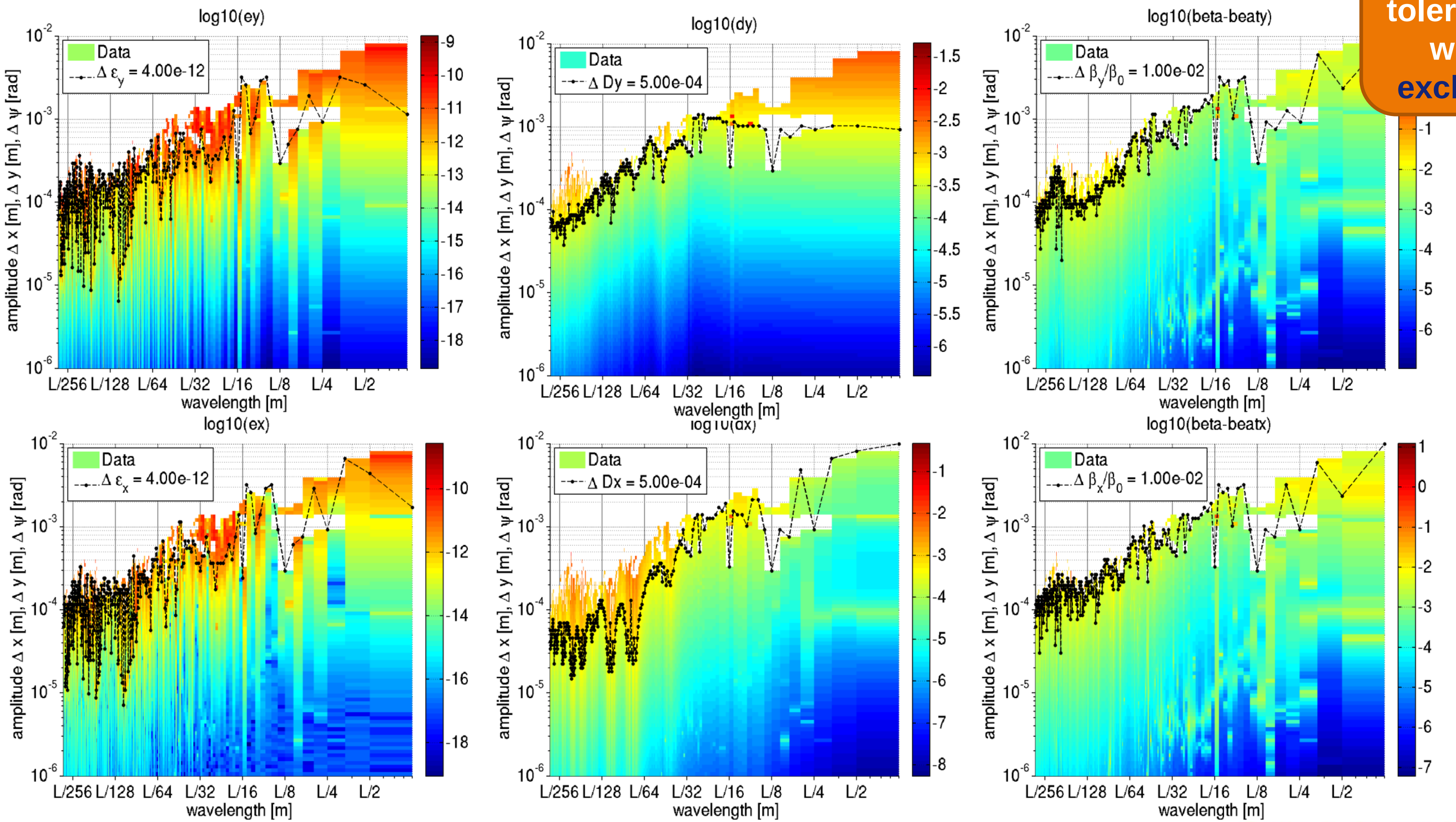
EVERY 4 CELLS



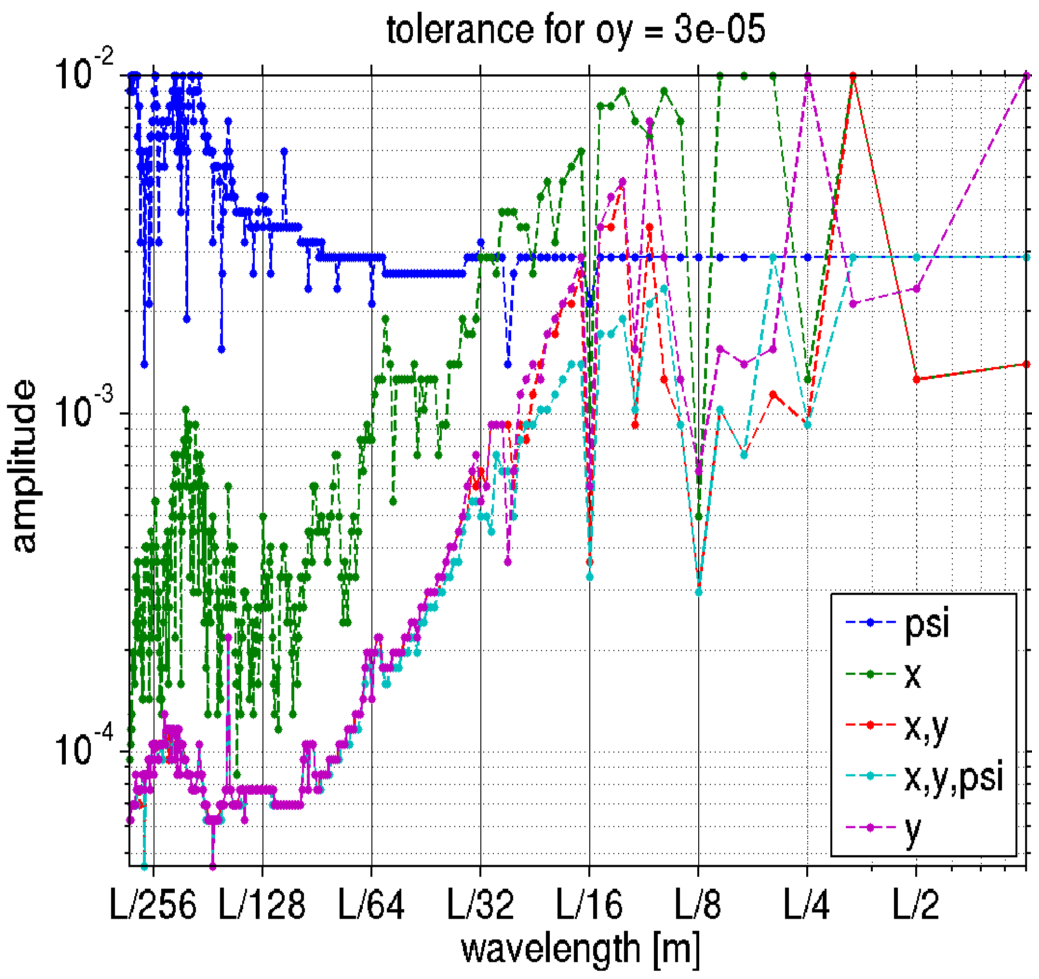

```
-----------------------------------------------------
------ total std corrector values applyed --------
------                                     --------
       HK (288) [1/m]: 0.00e+00 -> 1.24e-04
       VK (288) [1/m]: 0.00e+00 -> 1.63e-04
       SK (288) [1/m2]: 0.00e+00 -> 0.00e+00
       QK (514) [1/m2]: 0.00e+00 -> 0.00e+00
       HKL (288) [rad]: 0.00e+00 -> 1.59e-05
       VKL (288) [rad]: 0.00e+00 -> 1.14e-05
       SKL (288) [T/m]: 0.00e+00 -> 0.00e+00
       QKL (514) [T/m]: 0.00e+00 -> 0.00e+00
------                                     --------
------    residual orbit and dispersion    --------
------                                     --------
       OH (288) [m]: 6.11e-05 -> 1.40e-05
       OV (288) [m]: 1.37e-04 -> 1.84e-06
       DH (288) [m]: 7.00e-04 -> 2.83e-04
       DV (288) [m]:1.72e-03 -> 3.68e-04
       BBH (288) %: 3.8 -> 2.4
       BBV (288) %: 1.8 -> 2.5
       PhH (288) : 2.23e-02 -> 1.34e-02
       PhV (288) : 1.19e-02 -> 1.38e-02
------                                     --------
------        tune and emittance           --------
------                                     --------
       Qx [0.580]: 0.583 -> 0.580
       Qy [0.620]: 0.622 -> 0.620
       EX [147.528 pm]: 147.809 -> 147.692
       EY [0.000pm]: 1.477 -> 0.133
------                                     --------
-----------------------------------------------------
----- ----- -- -- -- -- ------ -----
initial   (ex, ey): 147.53,           0.00,
errors    (ex, ey): 147.81,           1.48,
corrected (ex, ey): 147.69,           0.13,

Freq 8, every 4 cells
```

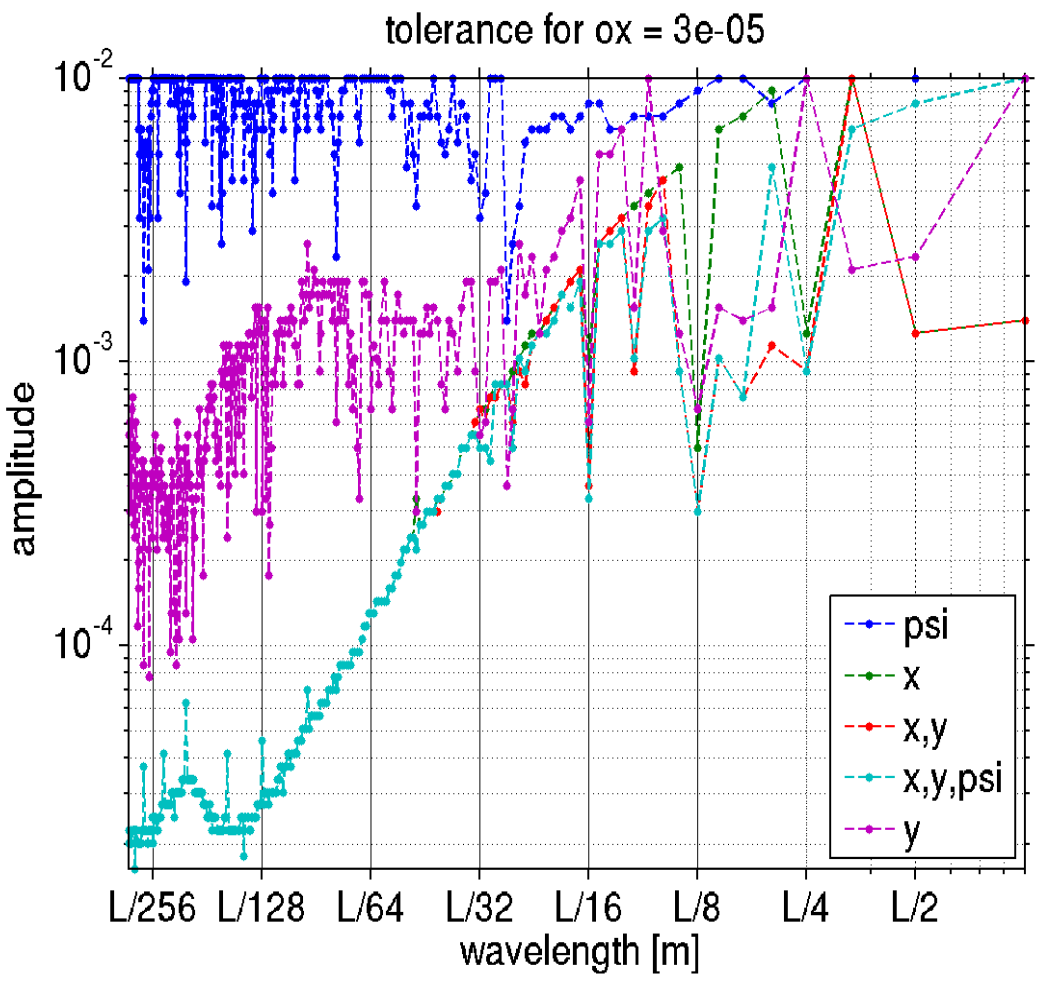
EMITTANCE, DISPERSION AND BETA-BEATING VS WAVELENGTH

How GIRDER tolerances were excluded

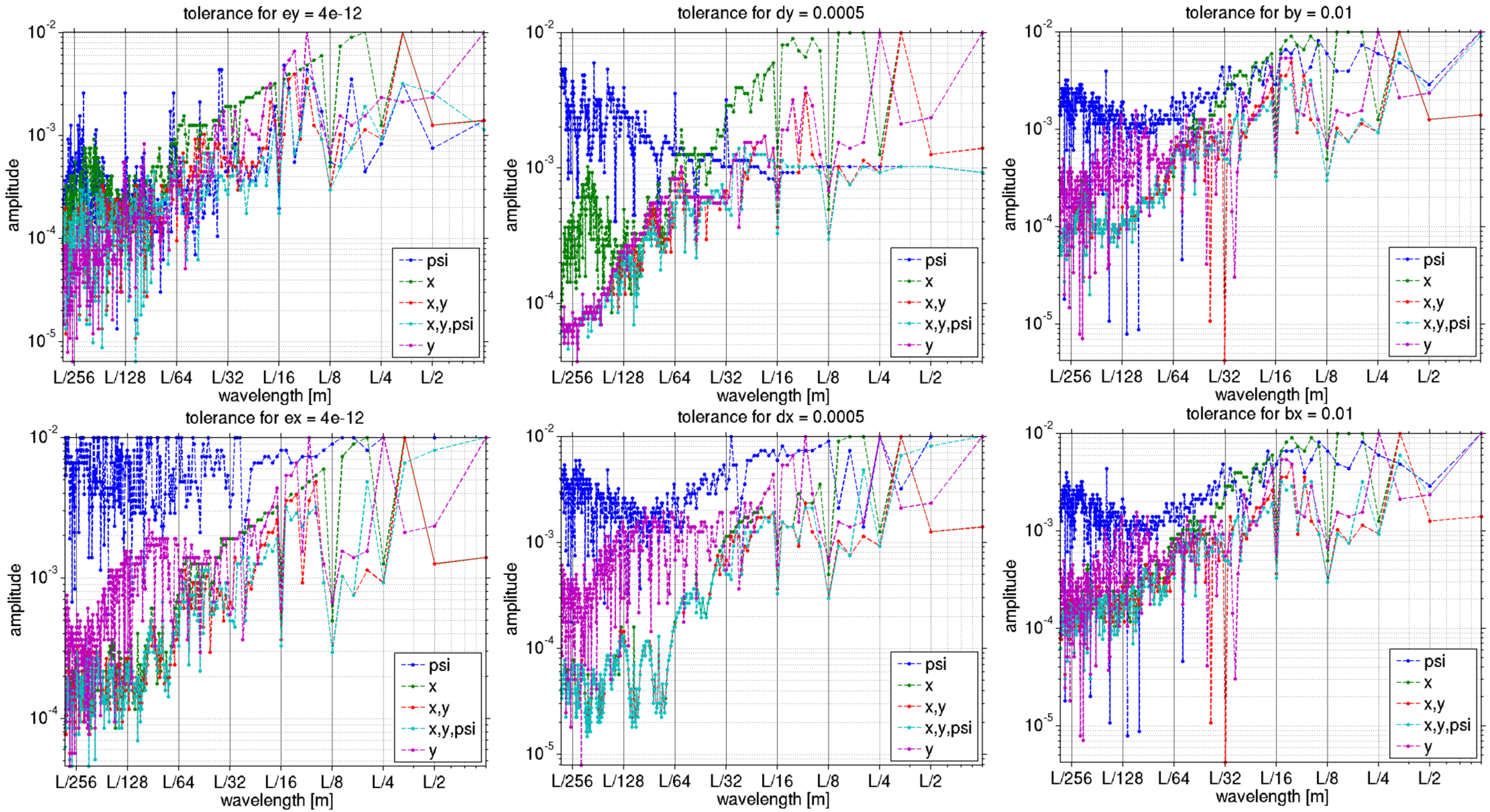


COMPARISON OF VARIOUS ERROR SOURCES TO OBTAIN 30 UM ORBIT





COMPARISON OF VARIOUS ERROR SOURCES (OTHER PARAMETERS)



DRAFT TABLE OF TOLERABLE RMS OF ERROR DISTRIBUTIONS

Error (S28 Table)	TDS value	New value
Dipole DPSI	300 mrad	Splitted
Dipole DX	50 μm	Splitted
Dipole DY	50 μm	Splitted
Quadrupole DX	50 μm	Splitted
Quadrupole DY	100 μm	Splitted
Quadrupole DPSI	350 μrad	Splitted
Sextupole DX	50 μm	70
Sextupole DY	75 μm	50
Sextupole DPSI	-	500 μrad
Girder DX	50 μm	Removed
Girder DY	50 μm	Removed
Girder DPSI	200 μrad	Removed
BPM X-offset	50 μm	Separated
BPM Y-offset	50 μm	Separated
Dipole DK0/DK0	$10\ 10^{-4}$	$10\ 10^{-4}$
Quadrupole DK1/K1	$5\ 10^{-4}$	$5\ 10^{-4}$
Sextupole DK2/K2	$35\ 10^{-4}$	$35\ 10^{-4}$

Error (S28 Table)	TDS value	New value
DL DPSI	300	500 μrad
DL DX	50	100 μm
DL DY	50	100 μm
DL DS	-	1000 μm
DQ and QF6-8 DPSI	300	200 μrad
DQ and QF6-8 DX	50	50 μm
DQ and QF6-8 DY	50	70 μm
DQ and QF6-8 DS	-	500 μm
Octupole DX	-	100 μm
Octupole DY	-	100 μm
Octupole DPSI	-	500 μrad
Octupole DS	-	1000 μm
Q [D-F] [1-5] DPSI	350	500 μrad
Q [D-F] [1-5] DX	50	100 μm
Q [D-F] [1-5] DY	100	85 μm
Q [D-F] [1-5] DS	-	500 μm
Sextupole DS	-	1000 μm

DS = longitudinal displacement

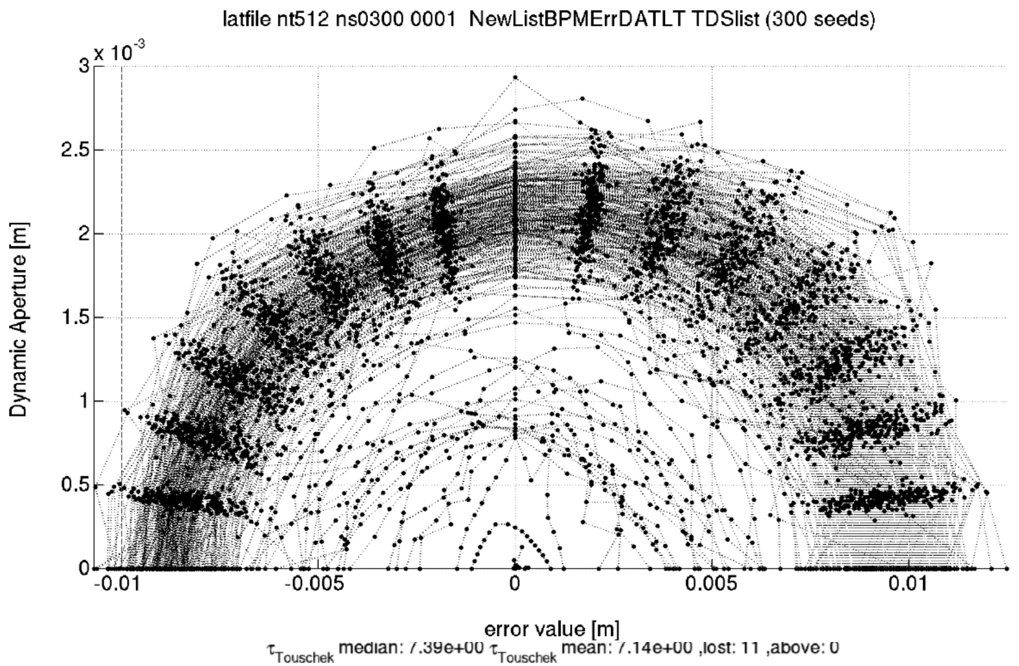
DX = radial displacement

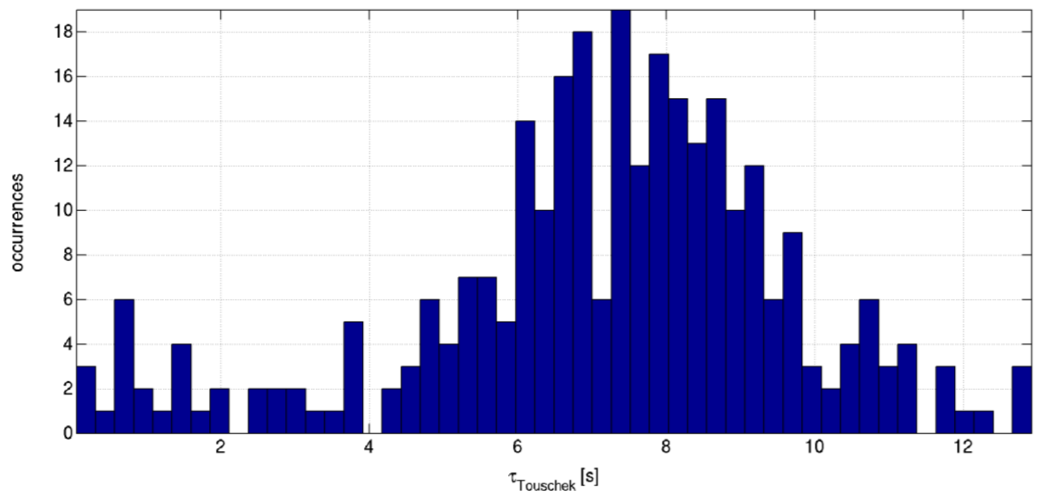
DY = vertical displacement

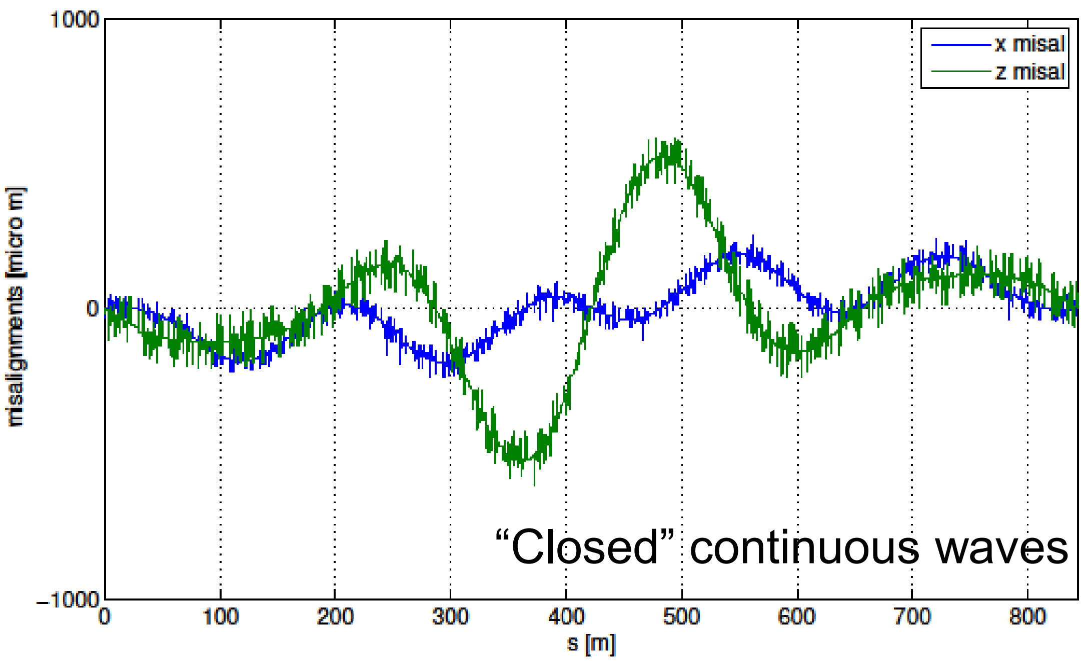
DPSI = rotation about beam axis

Girder errors replaced by smooth wave summing first 4 long wavelengths with 0.6mm amplitude.

D.A. AND LIFETIME: TABLE ABOVE + WAVES + BPM ERRORS 50 UM RMS





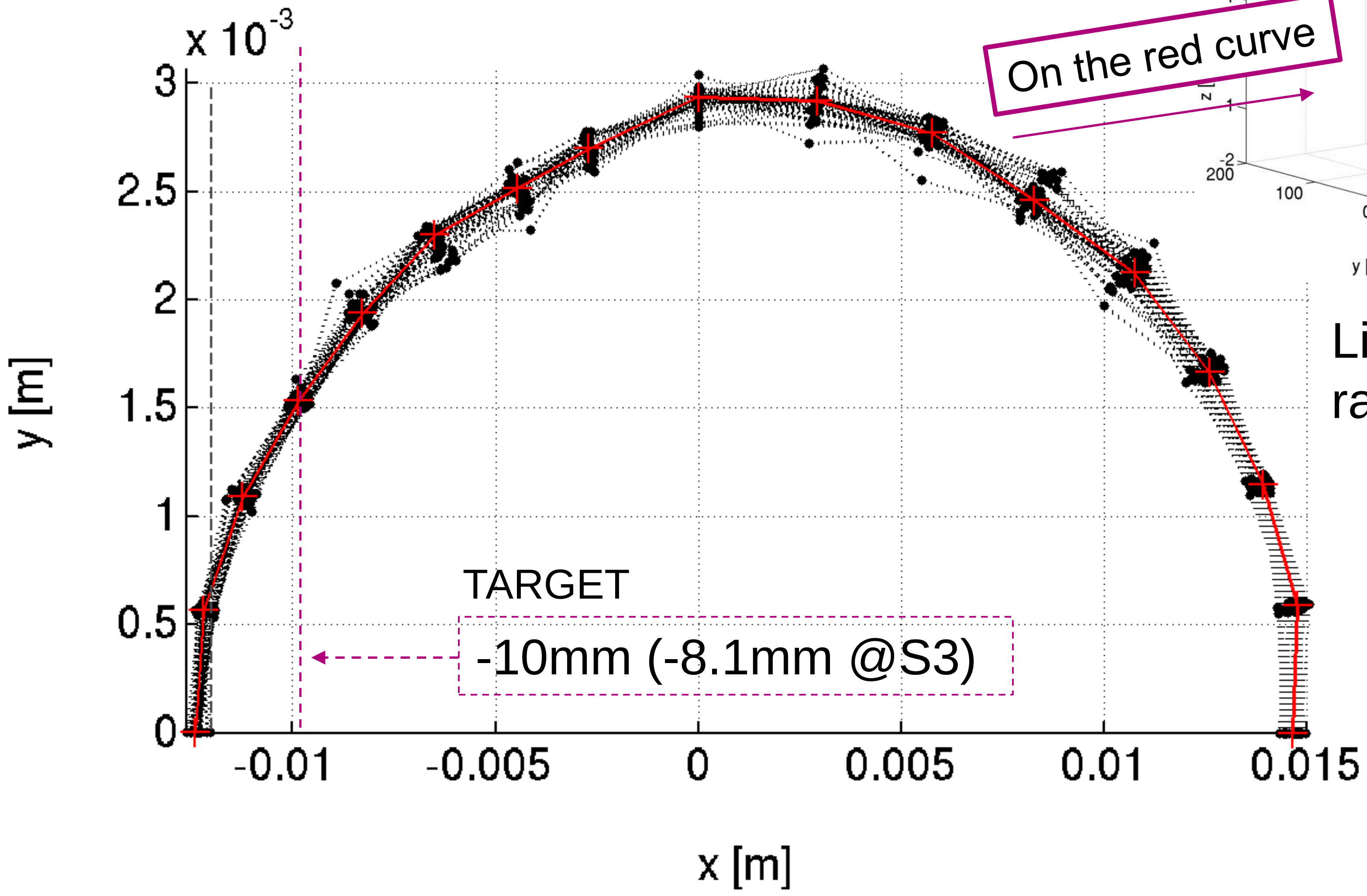


DA about 7mm at S3 septum.
Some seeds have bad DA and some are lost. Work in progress to recover them. this may change the above list of tolerable errors.
Lifetime is about 7h.

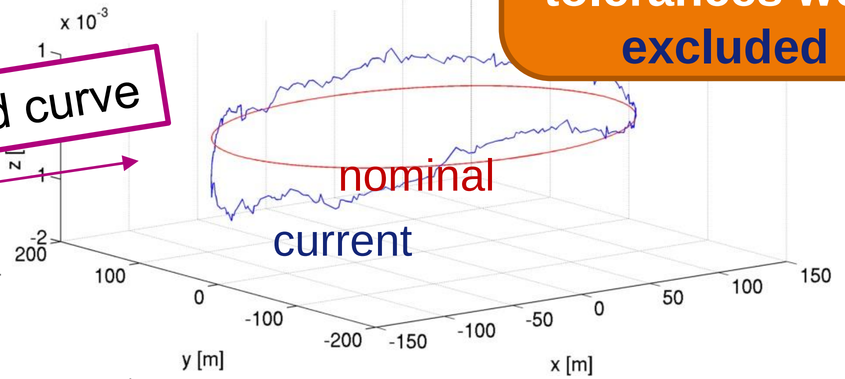
DYNAMIC APERTURE AND LIFETIME

How GIRDER and LONG RANGE tolerances were excluded

The above curves are interpolated to set the errors in the S28A lattice.



On the red curve

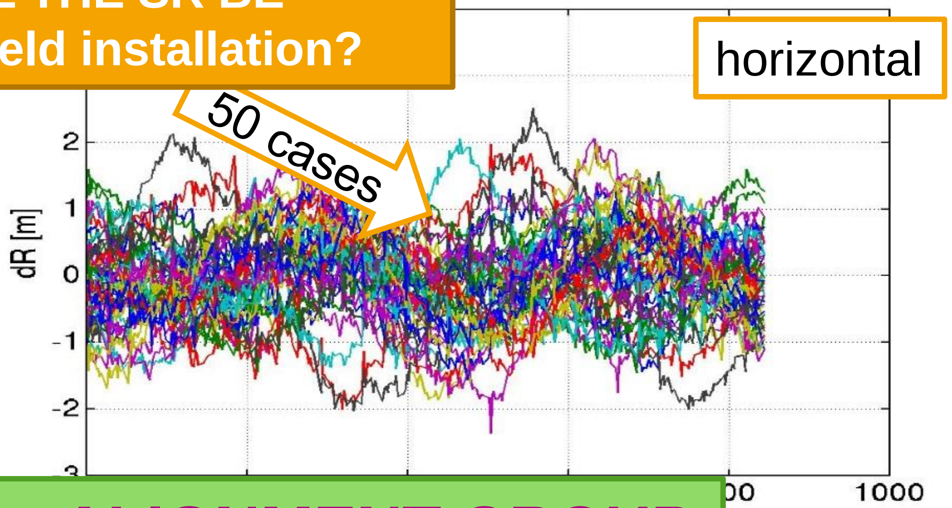


Lifetime: 16.7h
range:[16.6 17]

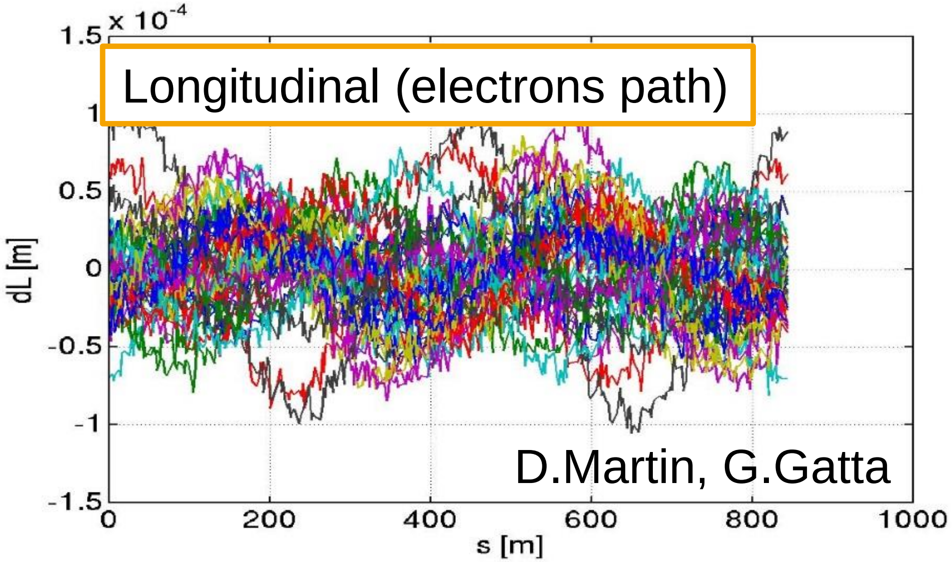
IDEAL SURVEY SET IN THE LATTICE AND TESTED FOR DA/LIFETIME AFTER CORRECTION

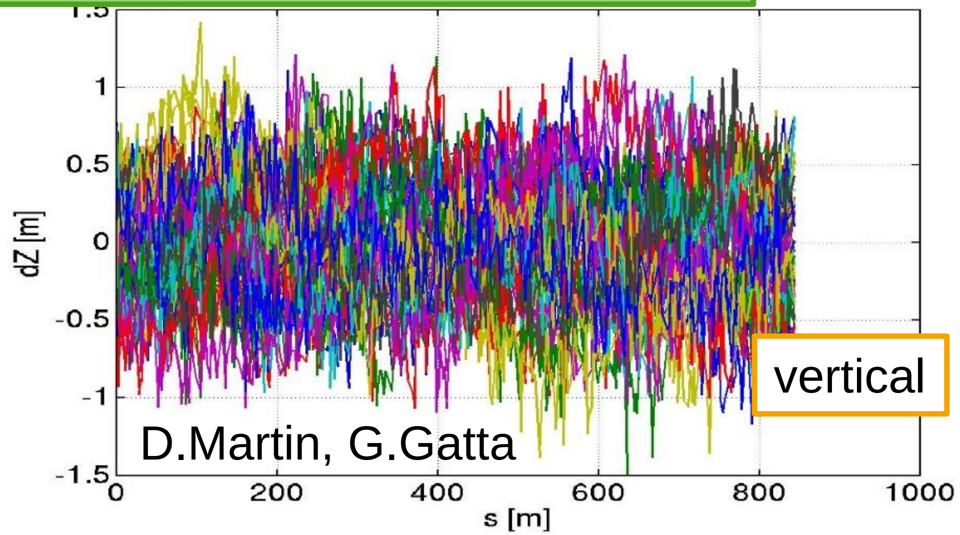
ALIGNMENT SURVEY ERRORS, OPTION 3 (THE MODERN WAY): SIMULATED SURVEYS (IDEAL POSITION)

WHERE WILL THE SR BE after green field installation?



DATA from ALIGNMENT GROUP





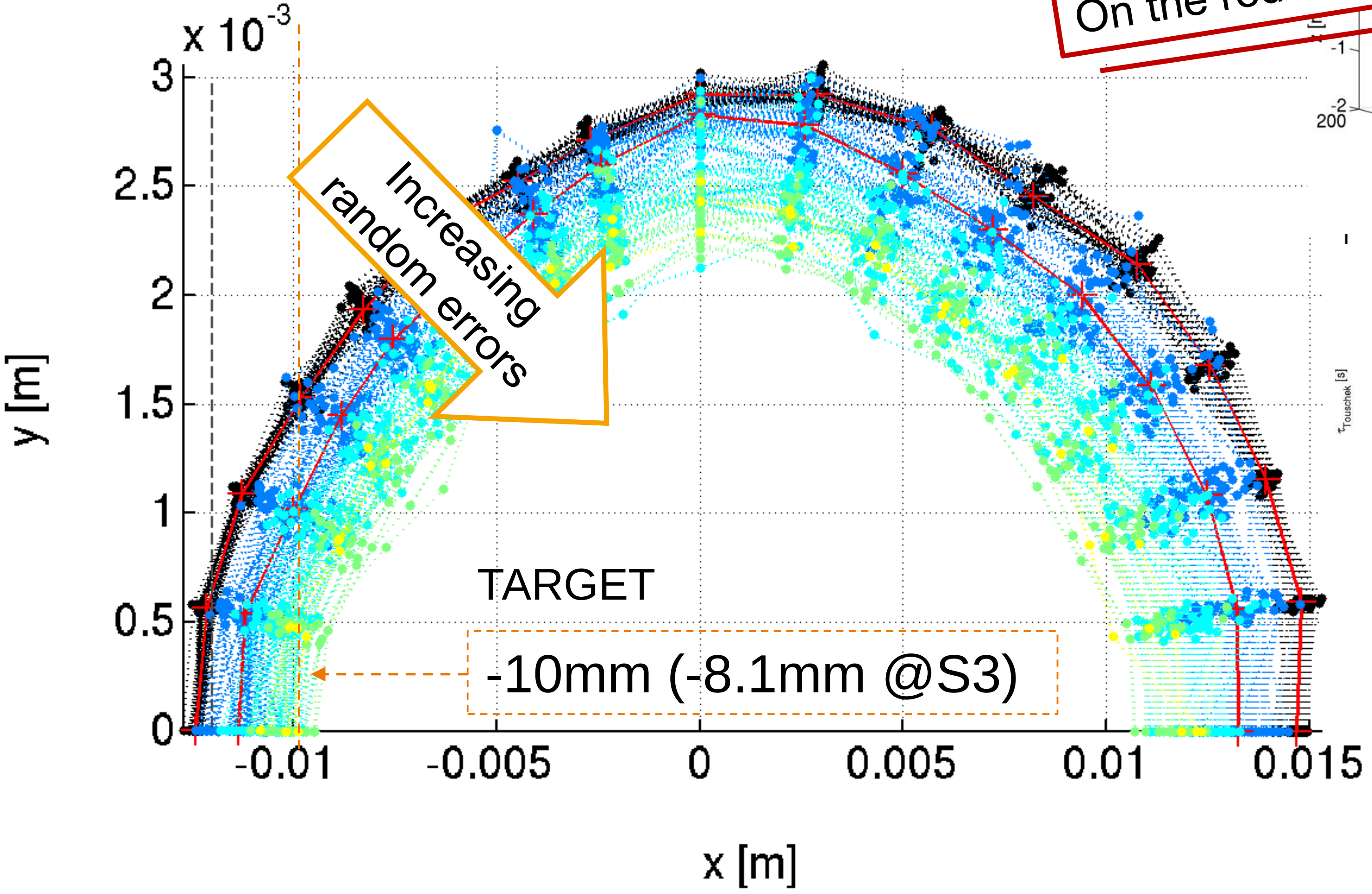
Simulated survey errors about the nominal position of the lattice.

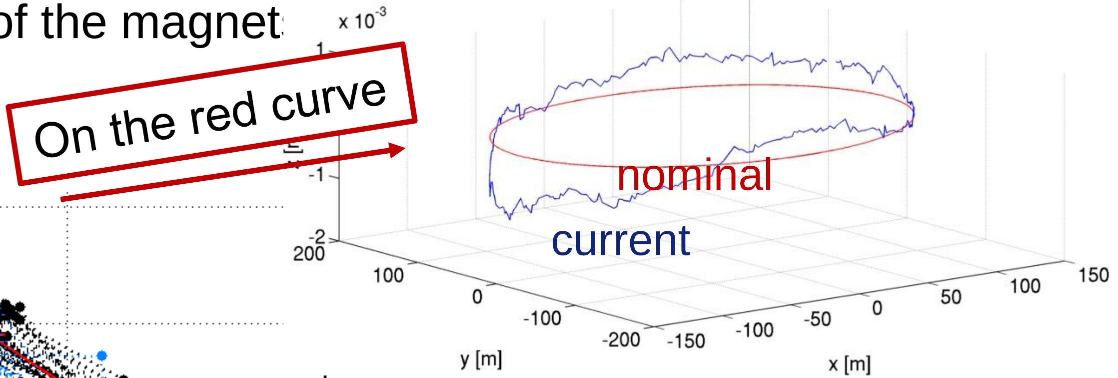
Rotations are random, but for a 21urad systematic outward tilt.

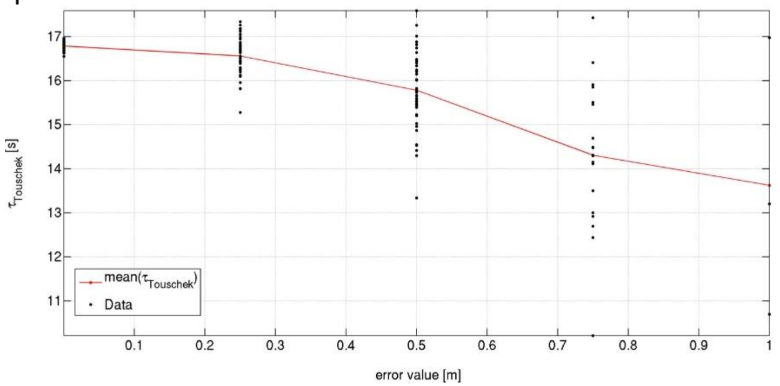
Data provided in 320 points for the ~~current~~ lattice.

PREVIOUS

Additional random errors are still required to describe the error on the position of the **magnetic centers** of the magnets



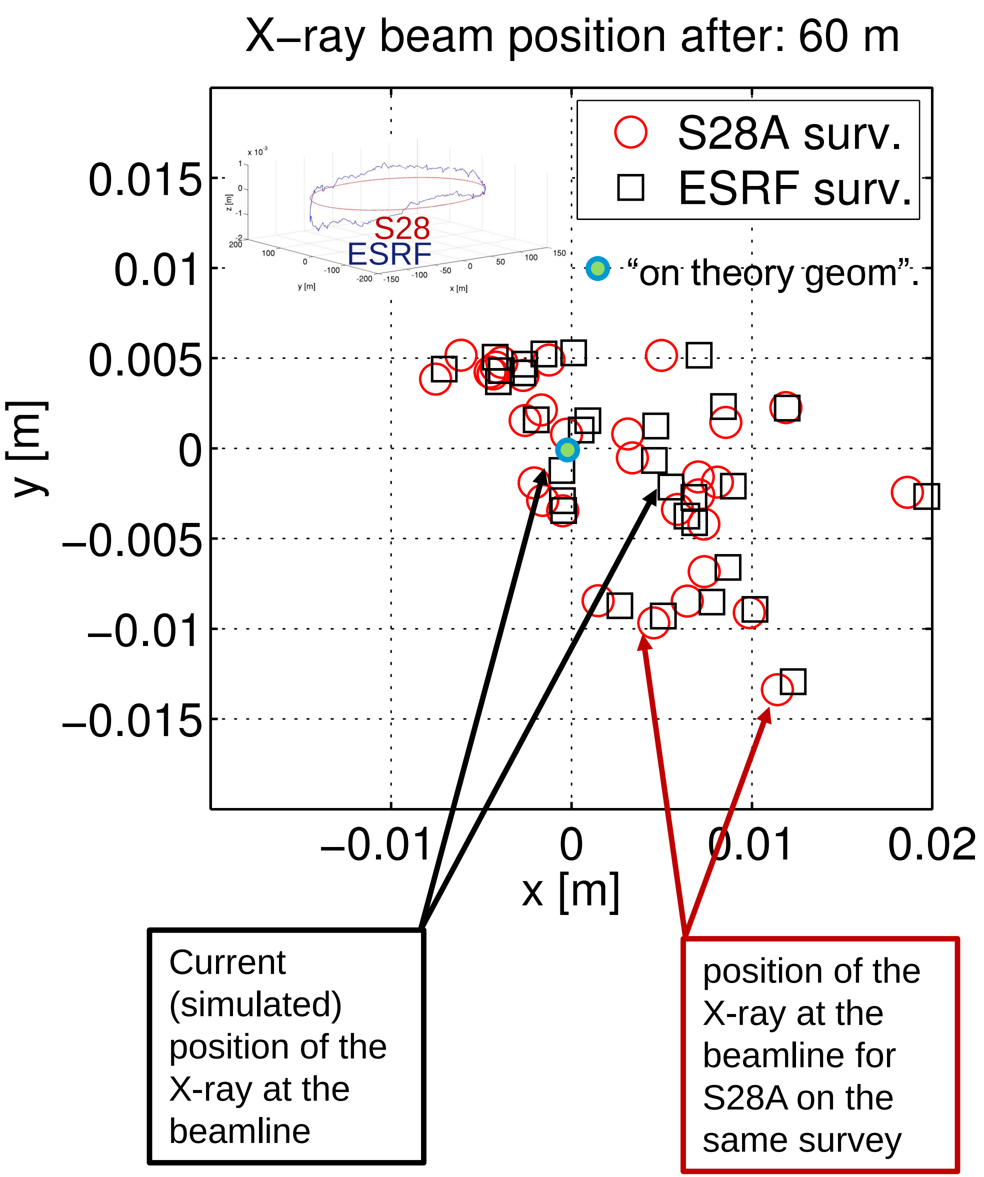




Lifetime goes from 16.7h to about 13h with many lost seeds and increasing range.

IDEAL SURVEY + RANDOM ERRORS SET IN THE LATTICE AND TESTED FOR DA/LIFETIME AFTER CORRECTION

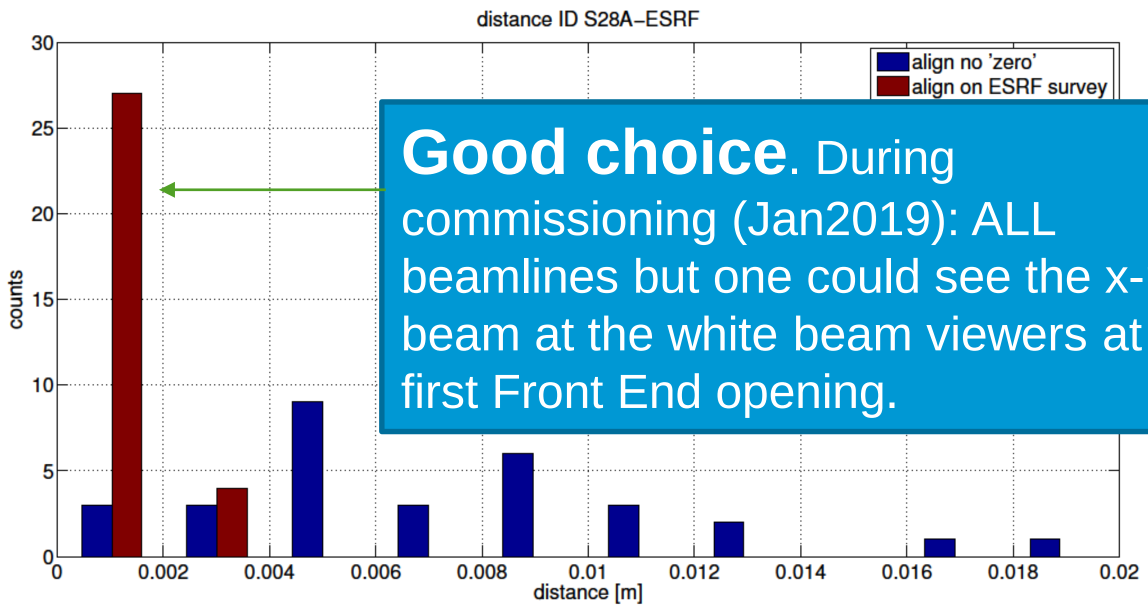
X-RAY BEAM POSITION AT ID (60 METERS) : DECISION TO PLACE THE NEW SR WHERE THE OLD WAS.



All ID are assumed to be at 60m from the source.

The position of the beam after 60m is very similar for ESRF and S28A considering the current survey measurement.

The position if the ring was aligned on the reference circumference would be about (0,0) for al ID.



Good choice. During commissioning (Jan2019): ALL beamlines but one could see the x-ray beam at the white beam viewers at very first Front End opening.

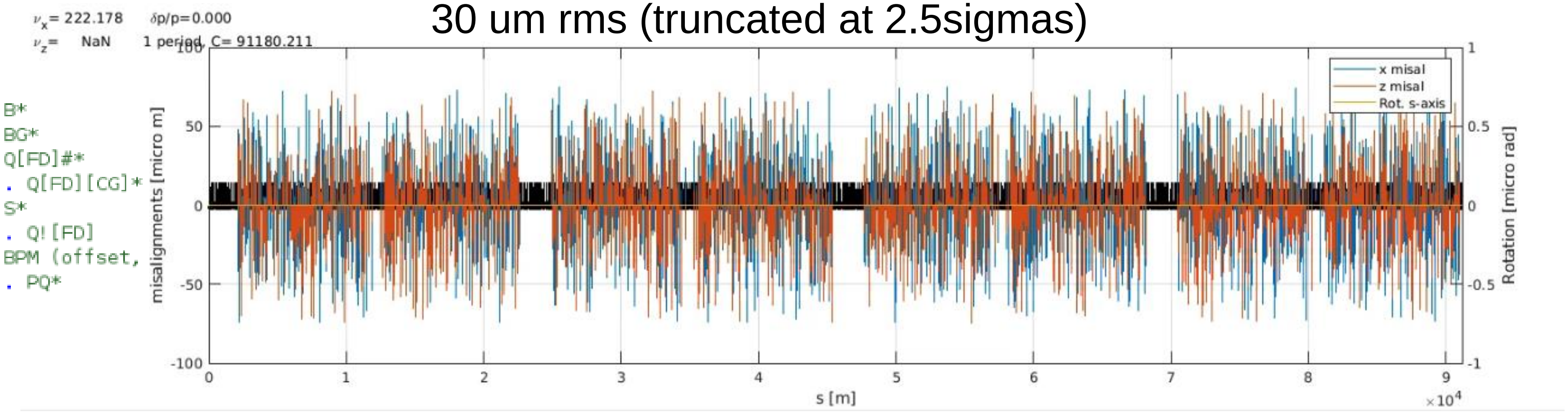
4TH APAC 2014

LARGER ERRORS ON MORE MAGNETS

```
errset= 0.3 * [...H, V, rot, field
    [ 100e-6,  100e-6, 100e-6,   5e-4, 0, 0];... B*
    [ 100e-6,  100e-6, 100e-6,   5e-4, 0, 0];... BG*
    [ 100e-6,  100e-6, 100e-6,   5e-4, 0, 0];... Q[FD]#*
    0*[ 100e-6,  100e-6, 100e-6,   5e-4, 0, 0];... Q[FD][CG]*
    [ 100e-6,  100e-6, 100e-6,  35e-4, 0, 0];... S*
    0*[ 100e-6,  100e-6, 100e-6,   5e-4, 0, 0];... Q![FD]
    [ 100e-6,  100e-6, 100e-6,      0, 0, 0];... BPM (offset,
    0*[ 100e-6,  100e-6, 100e-6,   5e-4, 0, 0];... PQ*
    ]; %
```

1/10 seeds failed

30 um rms (truncated at 2.5sigmas)



PROCEDURE FOR OPTICS CORRECTION

```
%% RDT+DISPERSION CORRECTION from lattice error model

    % fit lattice errors model
    [rfit]=FitResponseMatrixAndDispersionEBSsimple(...
        rerr,...
        r0,...
        inCOD,...
        indBPM,...
        indHCor(1:9*2:end),... % 4 correctors, 1 every 8 cells
        indHCor(1:9*2:end),...  % 4 correctors, 1 every 8 cells
        [neigQuadFit,neigDipFit,neigSkewFit,neigDipFit],...
        4,...
        [speclab 'fitrm']);

    % get change of strength of correctors
    fq=atgetfieldvalues(rfit,indQuadCor,'PolynomB',{1,2});
    fs=atgetfieldvalues(rfit,indSkewQuadCor,'PolynomA',{1,2});

    % correct RDT and dispersion of fitted error model
    [~,inCOD,fcq,fcs]=atRDTdispersioncorrection(...
        rfit,... <<--- fitted error model! not lattice with errors!
        r0,...
        indBPM,...
        indQuadCor,...
        indSkewQuadCor,...
        inCOD,...
        [[floor(linspace(1,neigQuad,5)),neigQuad,neigQuad];...
        [floor(linspace(1,neigSkew,5)),neigSkew,neigSkew]]',...
        [true],...
        1.0,...
        [0.8 0.1 0.8],...
        ModelRM);

    %fcq=atgetfieldvalues(rfitcor,indQuadCor,'PolynomB',{1,2});
    %fcs=atgetfieldvalues(rfitcor,indSkewQuadCor,'PolynomA',{1,2});

    % store proposed correction
    dcq(1,:)=(fcq-fq);
    dcs(1,:)=(fcs-fs);
```

Fit of “measured” partial Orbit Response Matrix (slow)
→ **FITTED OPTICS MODEL**

Computation of normal and skew quadrupoles RDTs + dispersion and correction
→ **Normal and skew quadrupole correction strengths**

This is LOCO equivalent (+ RDTs)

Linear problem + generalize potentially different fit and correction locations

33. A. Franchi, L. Farvacque, J. Chavanne, F. Ewald, B. Nash, K. Scheidt, and R. Tomás, *Vertical emittance reduction and preservation in electron storage rings via resonance driving terms correction*, Phys. Rev. ST Accel. Beams **14**, 034002 (2011).