SC - A Toolbox for Simulated Commissioning of Light Sources

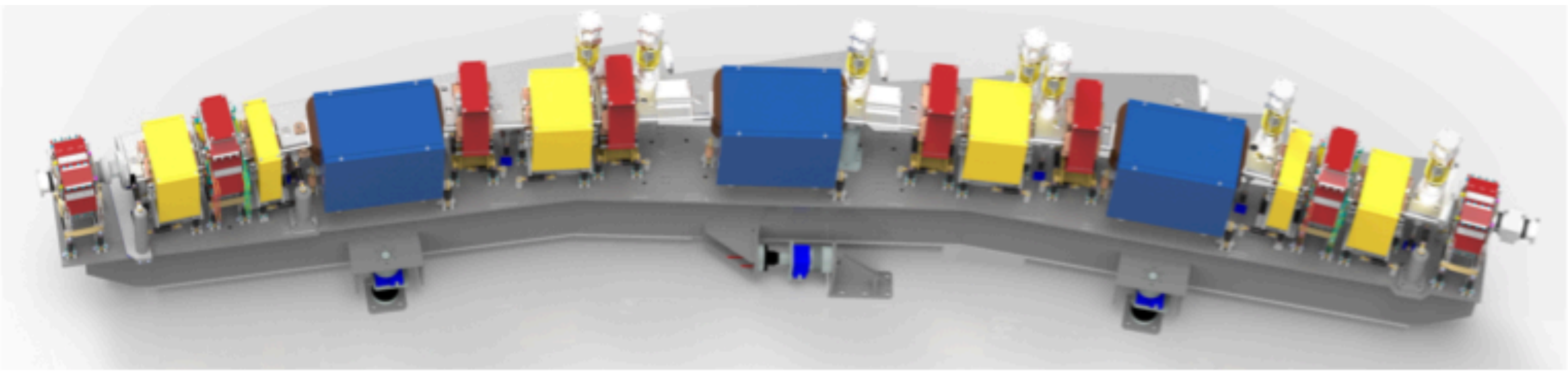
Thorsten Hellert

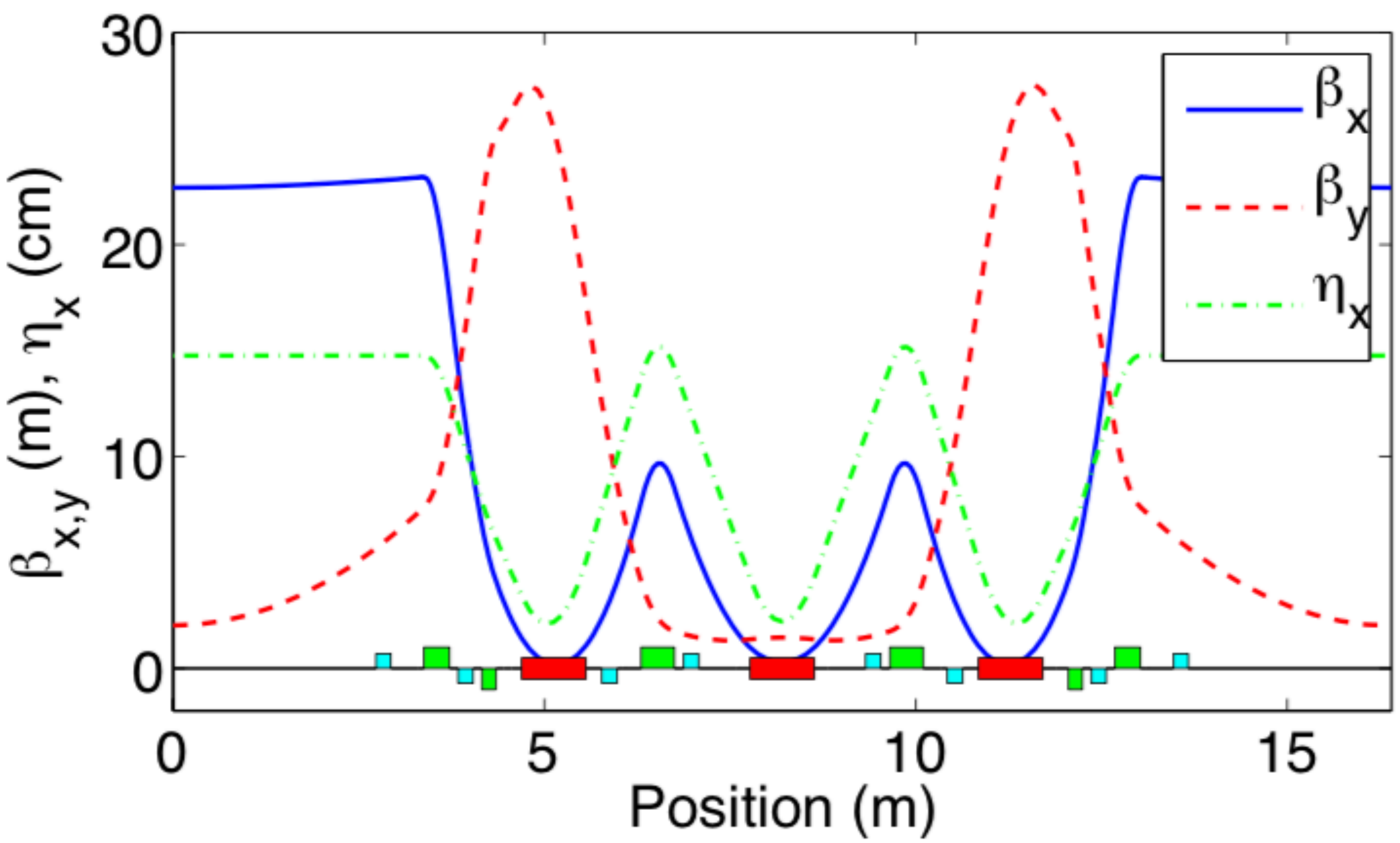
Beam Tests and Commissioning Workshop,
KIT, Feb 19, 2019

BERKELEY LAB
U.S. DEPARTMENT OF ENERGY | Office of Science
ALS-U ADVANCED LIGHT SOURCE

ALS-U Lattice

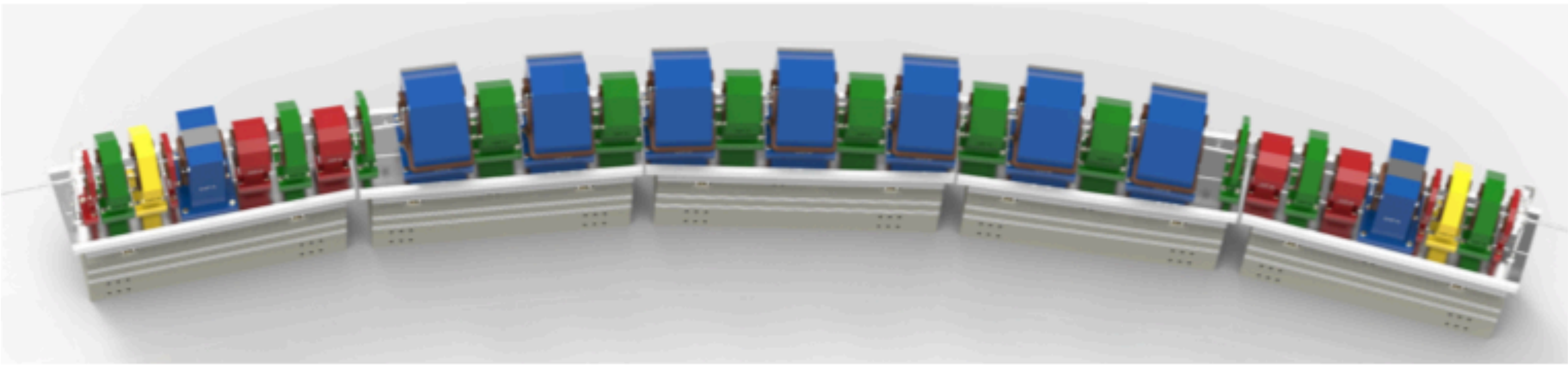
ALS today: triple-bend achromat

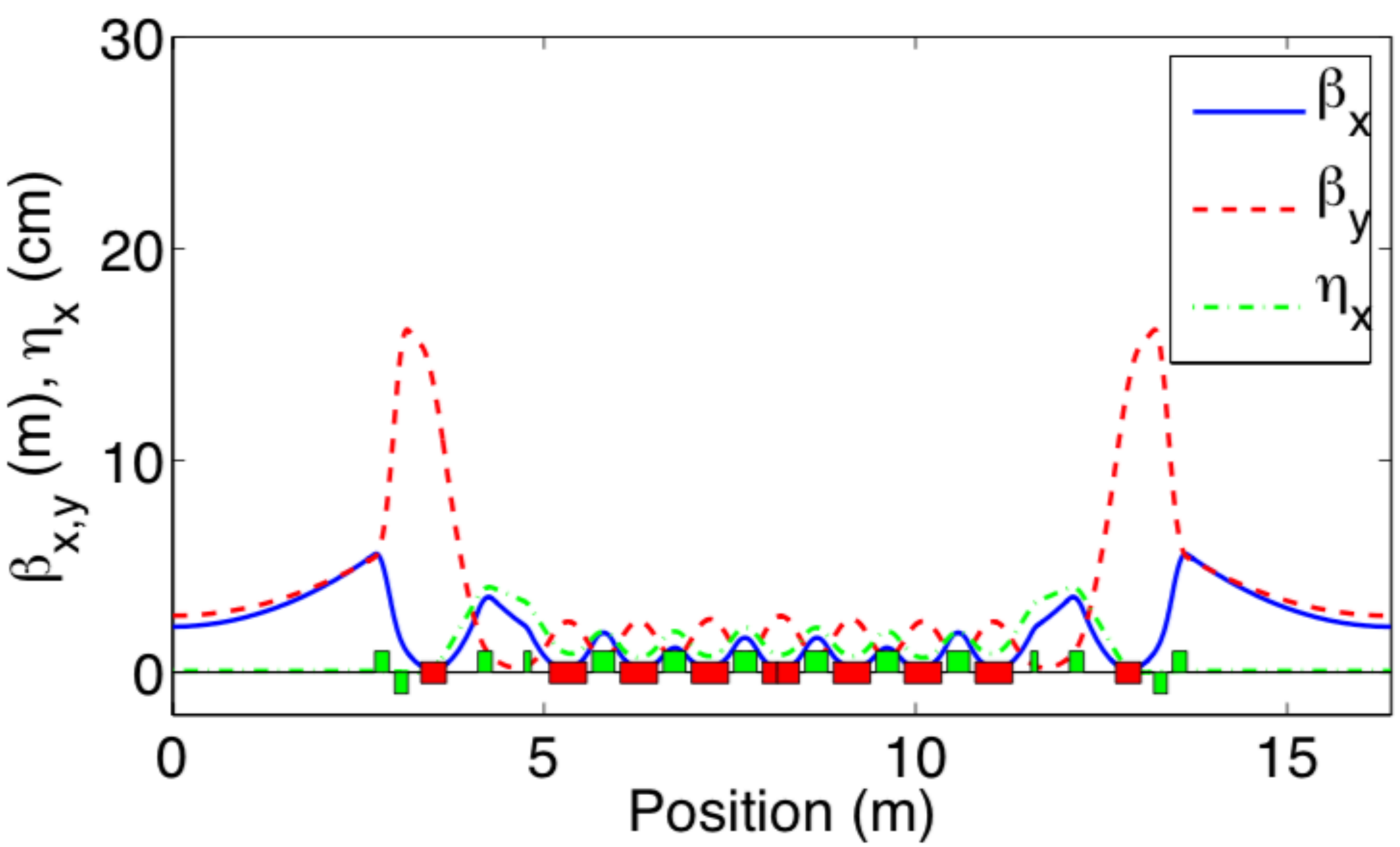




$\varepsilon_x \approx$ 2000 pm-rad at $1.9 GeV$

ALS-U: nine-bend achromat with reverse bends

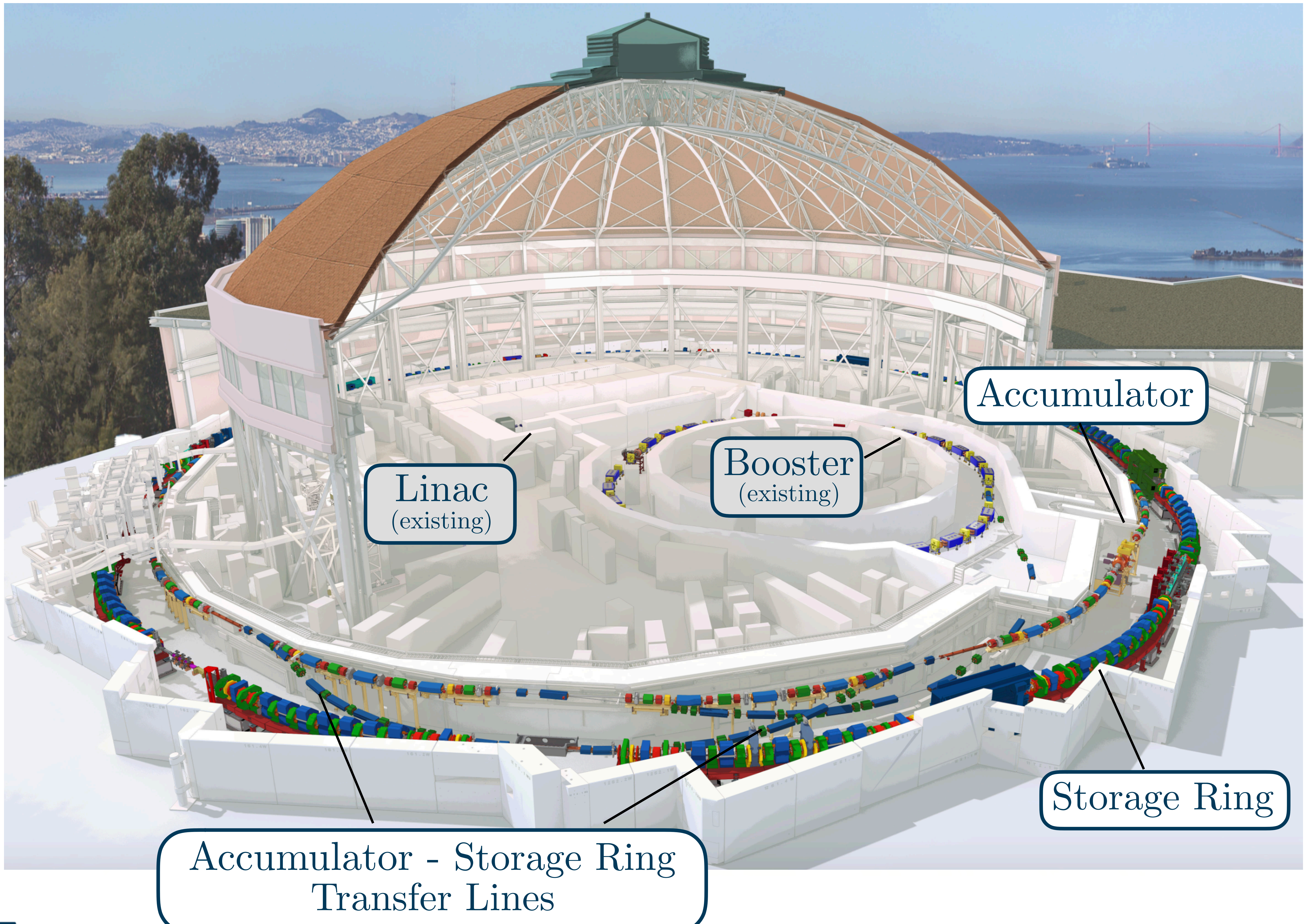




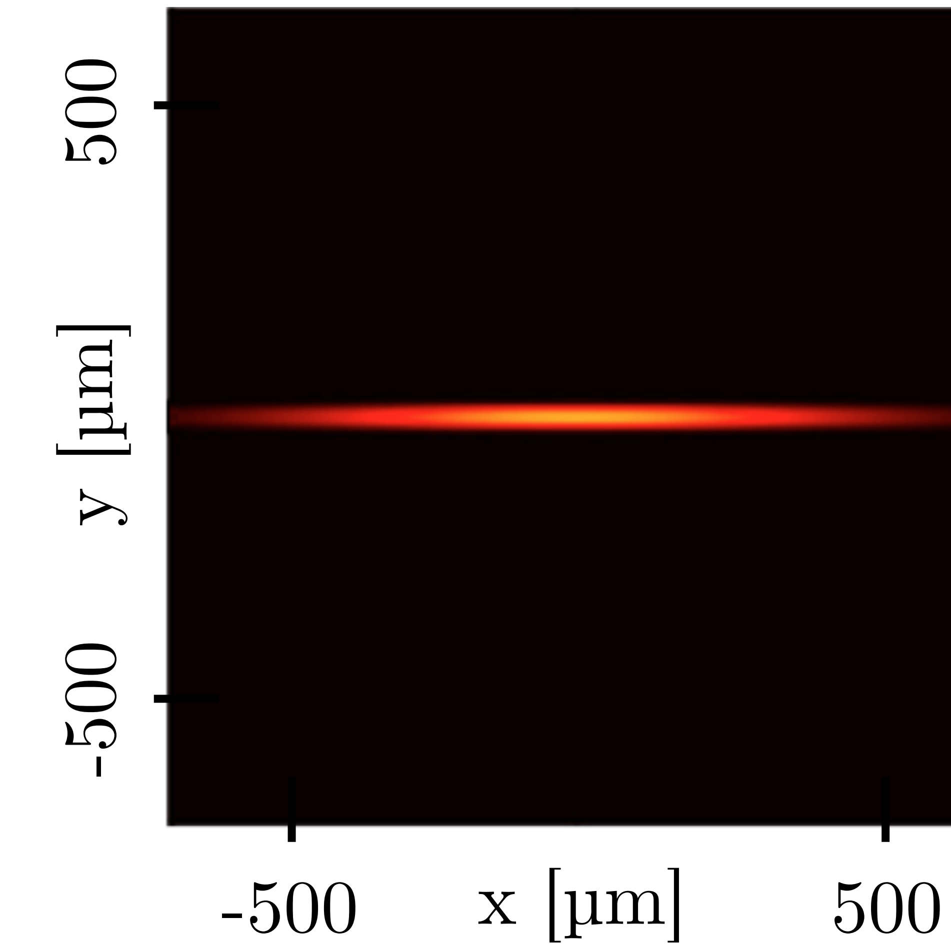
$\varepsilon_x <$ 70 pm-rad at $2.0 GeV$

Overview of ALS-U Accelerator Facility

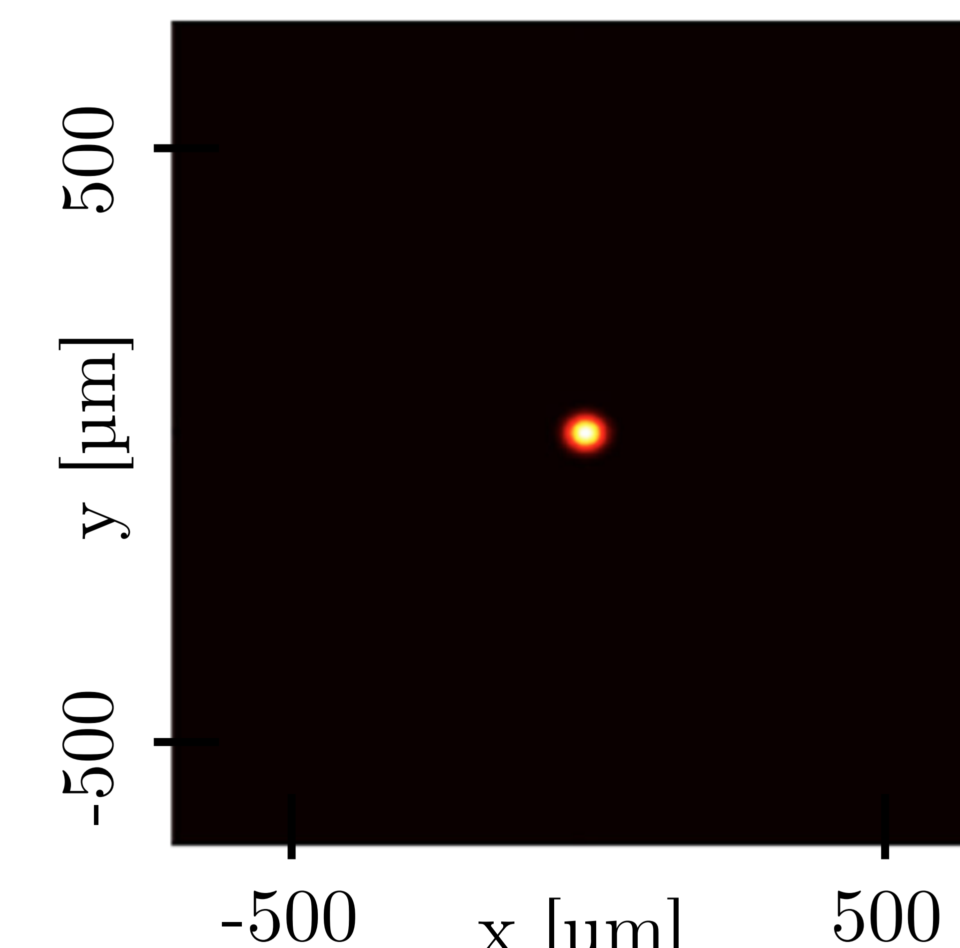
Advanced Light Source Upgrade (ALS-U)



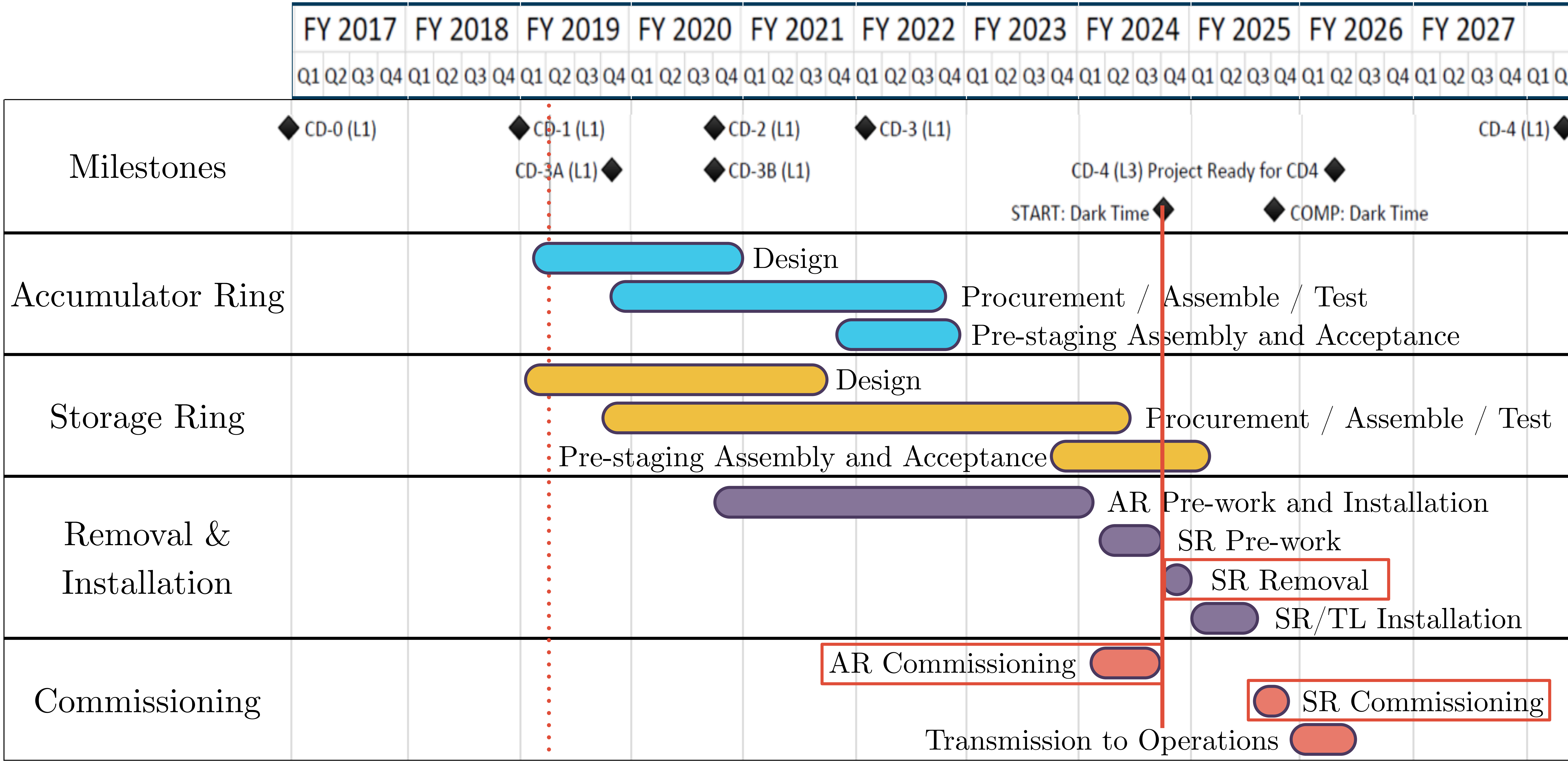
ALS beam size



ALS-U beam size



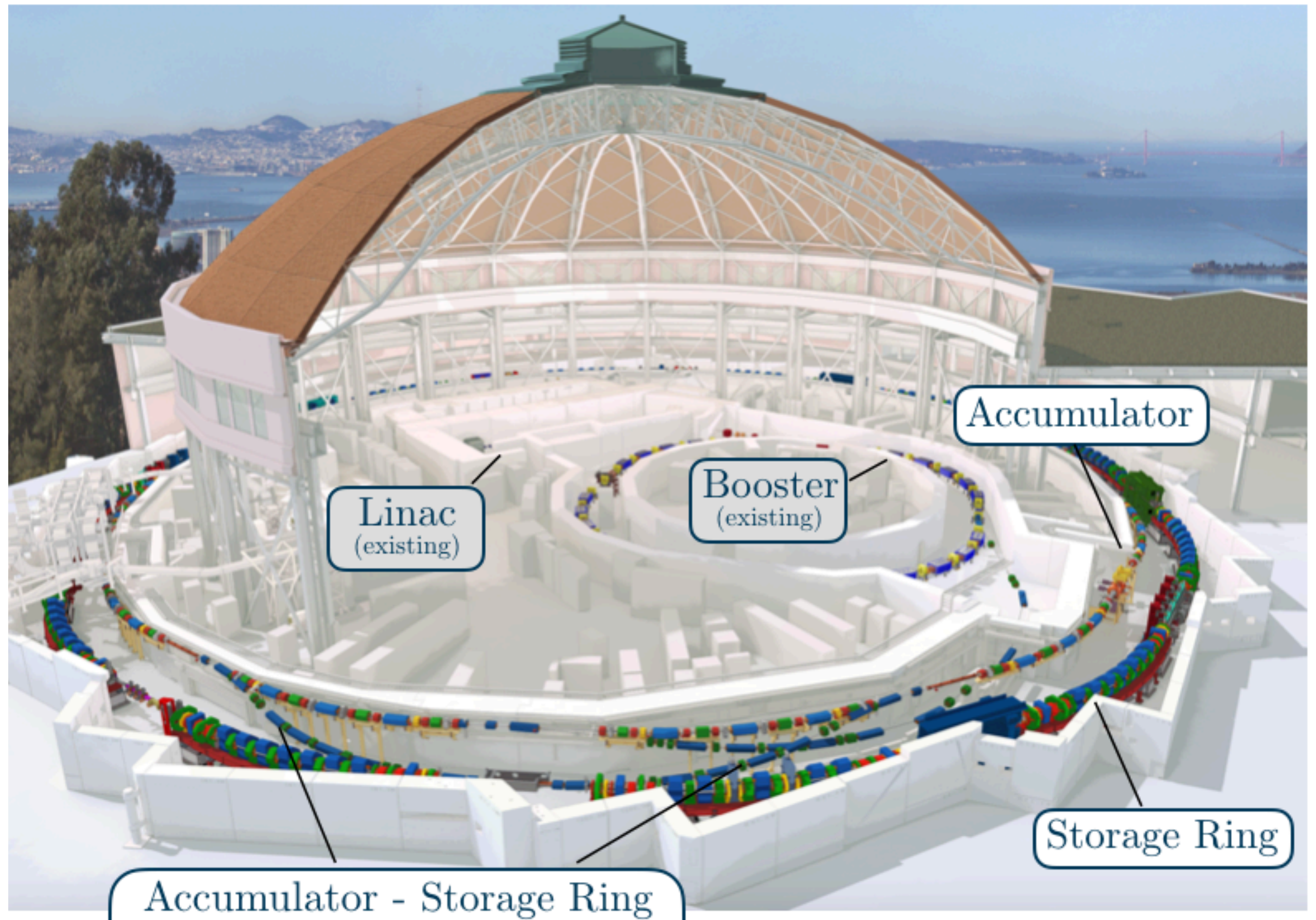
ALS-U Accelerator Systems Schedule

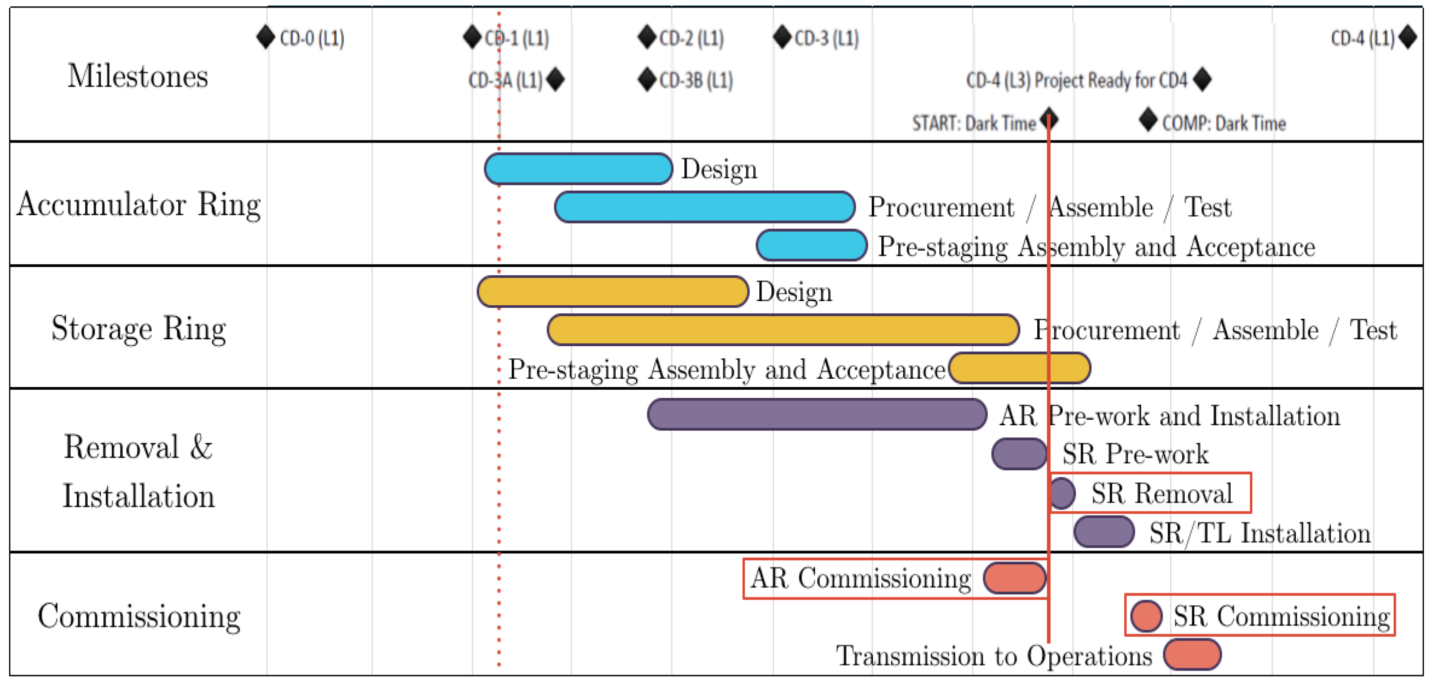


Motivation for the development of a toolbox

- ## Challenging ALS-U commissioning schedule
  - Tight commissioning schedule
  - ***Storage Ring:*** Strong focussing & small aperture
  - ***Accumulator:*** Small aperture & minimum diagnostics
  - Standard approach of setting error tolerances does not work
- ## Realistic simulation of commissioning process required
  - Realistic error model
  - Efficient trajectory/orbit/linear optics correction strategies
  - Set requirements for lattice correction capabilities
  - Evaluate robustness of lattice and set tolerances for errors
- ## Choice of toolbox implementation
  - Commissioning simulation required for two different machines
  - ALS-U will be operated with *Matlab Middle Layer* (MML)
  - Easy communication between MML and *Accelerator Toolbox* (AT)
  - AT implementation of ALS-U commissioning allows for experiments at current ALS

Advanced Light Source Upgrade (ALS-U)

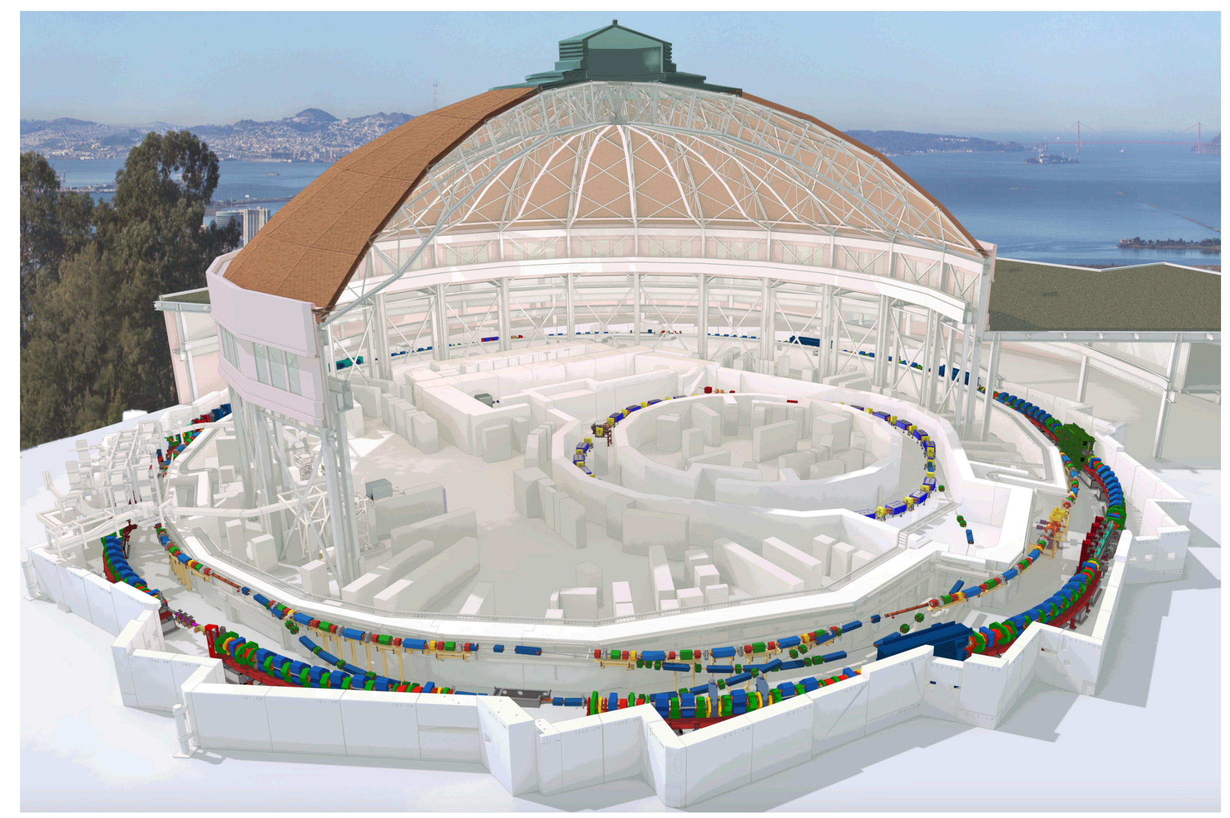




Limited accessibility of machine properties

Power supplies

Operating machine



Diagnostic devices

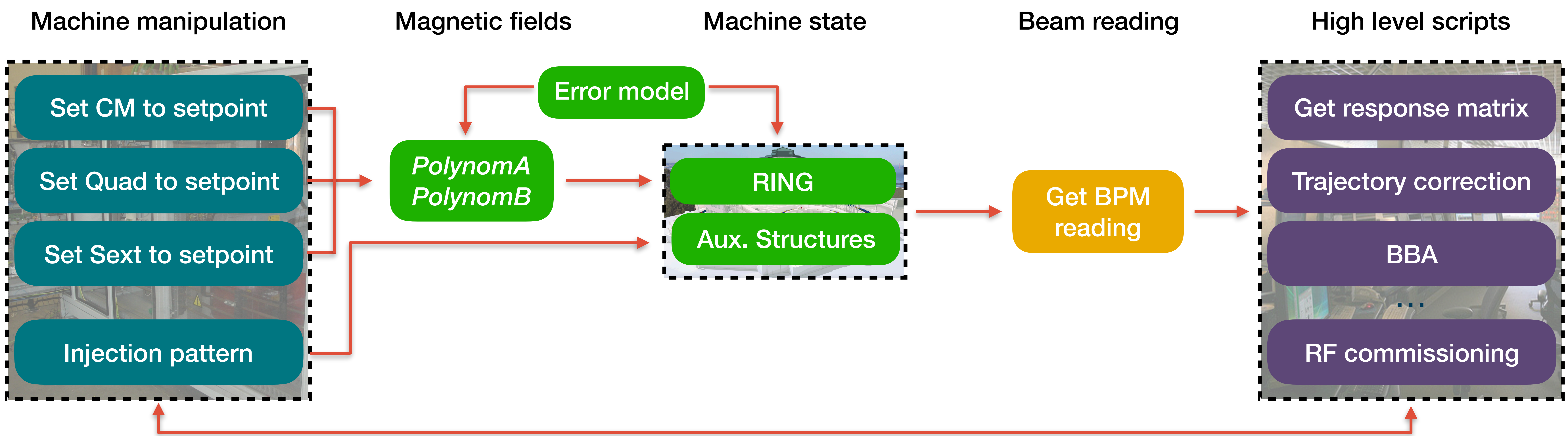
High level controls

Magnetic fields
Particle trajectories
Magnet offsets
...

Limited access!

Setpoints and read back values

Realistic workflow of toolbox important



Set Quad to setpoint

- Compensates bending angle difference by setting horizontal CM
- Checks for CM range (clipping)

Calculate fields

- Calibration errors of all components
- Includes dipole kick from bending angle (set-point & roll)

Auxiliary structures

- Diagnostic errors
- Injected beam trajectory
- Injection pattern
- Current CM limits

Get BPM reading

- Performs tracking including aperture
- Gets BPM signal from ensemble of particle trajectories

High level

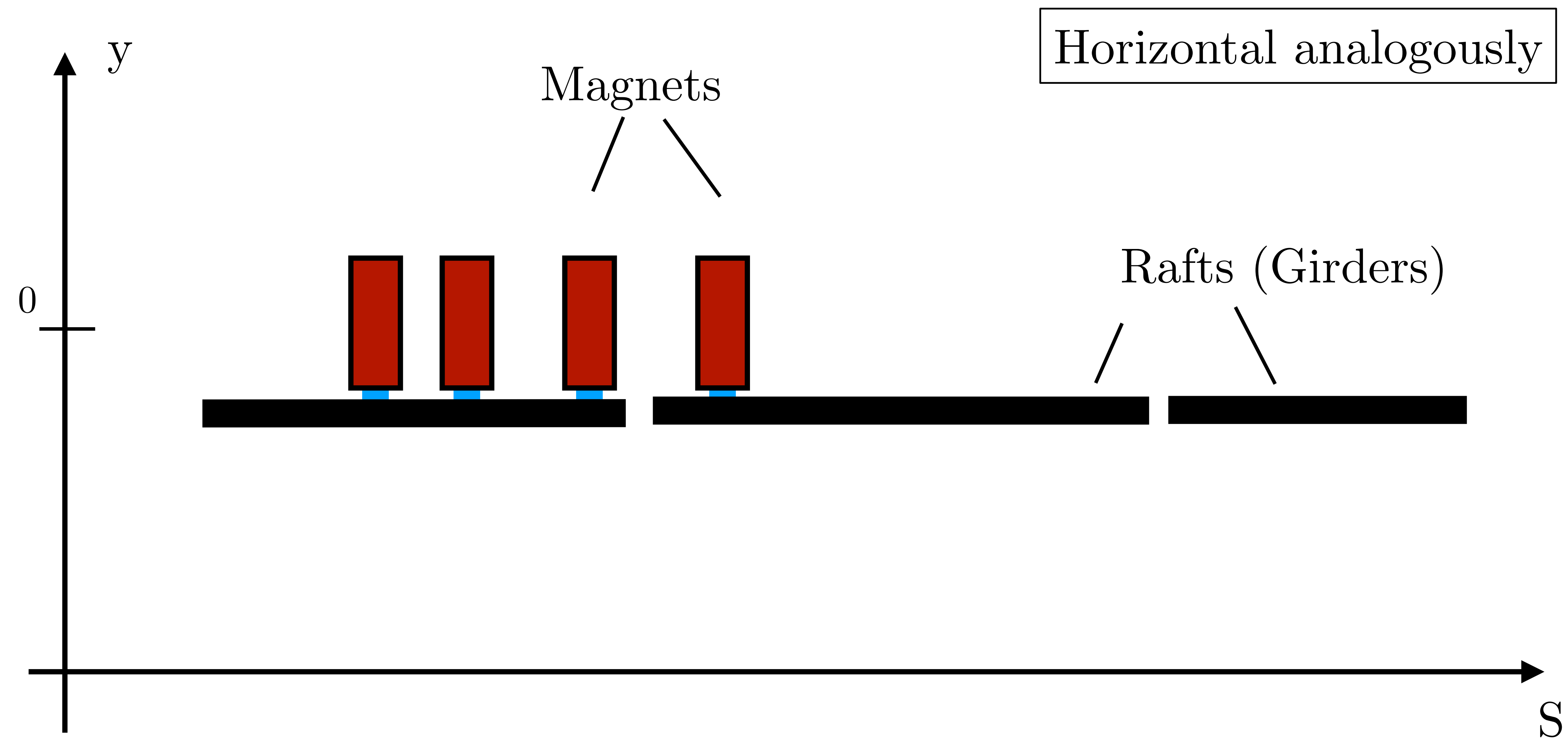
- High level functions use only BPM and setpoints as input
- High level functions write only setpoints

Large number of error sources included

- Magnet errors
  - Magnet offset = 30 μm
  - Raft offset = 25 μm
  - Plinth offset = 100 μm
  - Arc offset = 100 μm
  - Magnet roll = 0.2 mrad
  - Magnet strength = 0.1%
- Diagnostic errors
  - BPM offset = 500 μm
  - BPM cal. error = 5%
  - BPM noise (TbT) = 3 μm
  - BPM noise (CO) = 1 μm
  - BPM roll = 0.4 mrad
  - CM cal. error = 5%
  - CM roll = 0.4 mrad
- Static injection errors
  - Δx = 500 μm
  - Δx' = 200 μrad
  - Δy = 500 μm
  - Δy' = 200 μrad
  - ∂E = 0.1 %
- Injected beam size
  - Δx = 64 mm
  - Δx' = 32 μrad
  - Δy = 8 μm
  - Δy' = 3 μrad
  - ∂E = 0.1 %
  - Δt = 15 ps
- Circumference
  - ΔL = 2 mm
- Injection jitter
  - Δx = 10 μm
  - Δx' = 6 μrad
  - Δy = 1 μm
  - Δy' = 0.5 μrad
  - ∂E = 0.01 %
  - Δϕ = 0.1°
- RF errors
  - Δf = 0.1 kHz
  - ΔV = 0.1 %
  - Δϕ = π/2
- Higher order multipoles
  - Primary components
  - Corrector coils (CM and skew quad)
  - Random errors

High fidelity misalignment model

- Lateral misalignment model typically used in simulations:
  - Transverse magnet offsets
  - Transverse raft offsets



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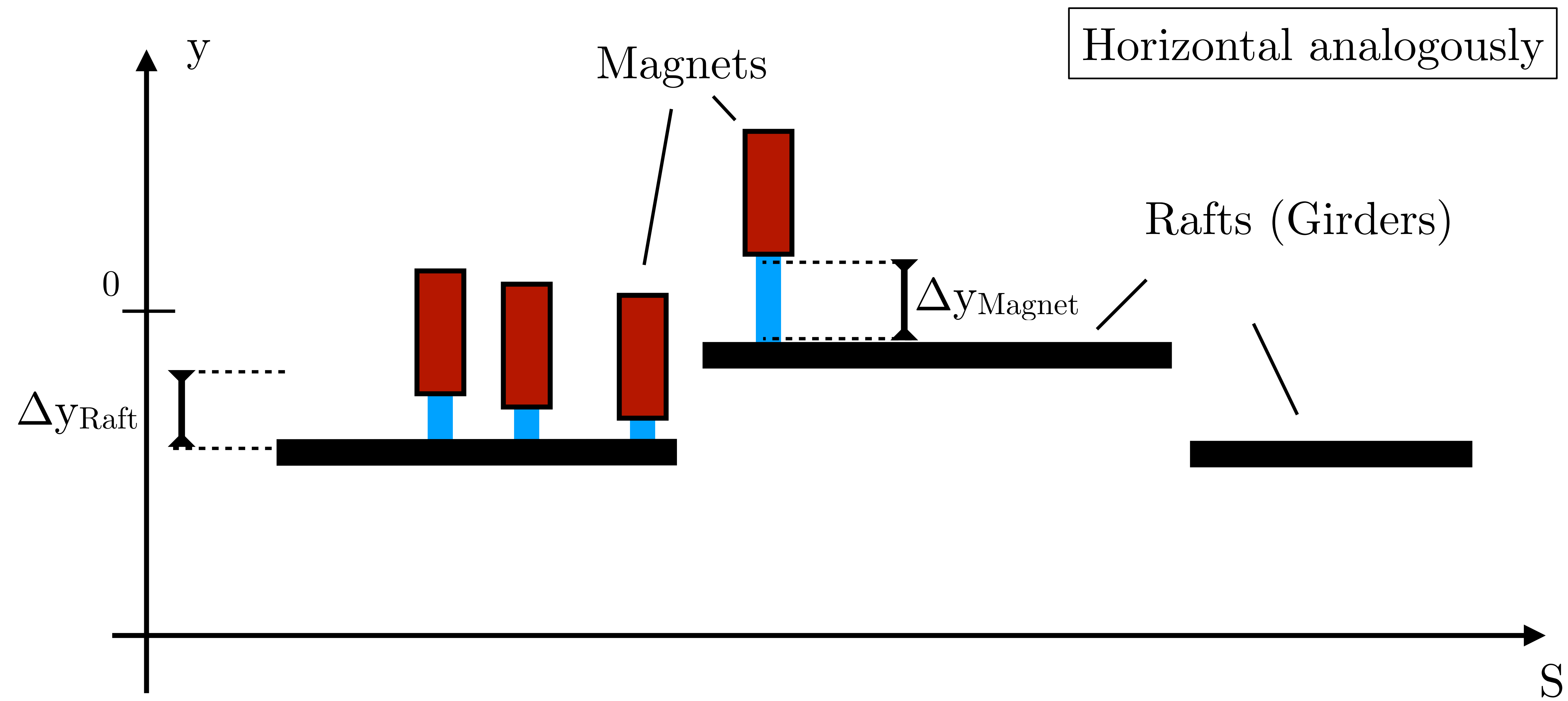
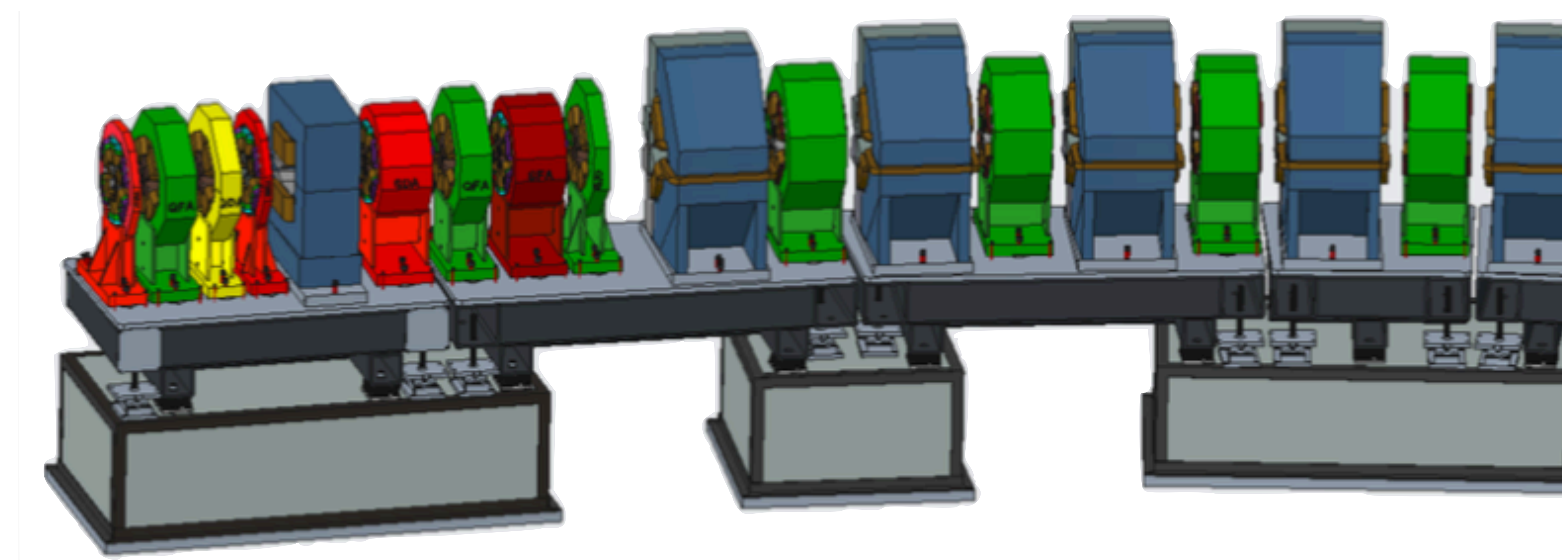
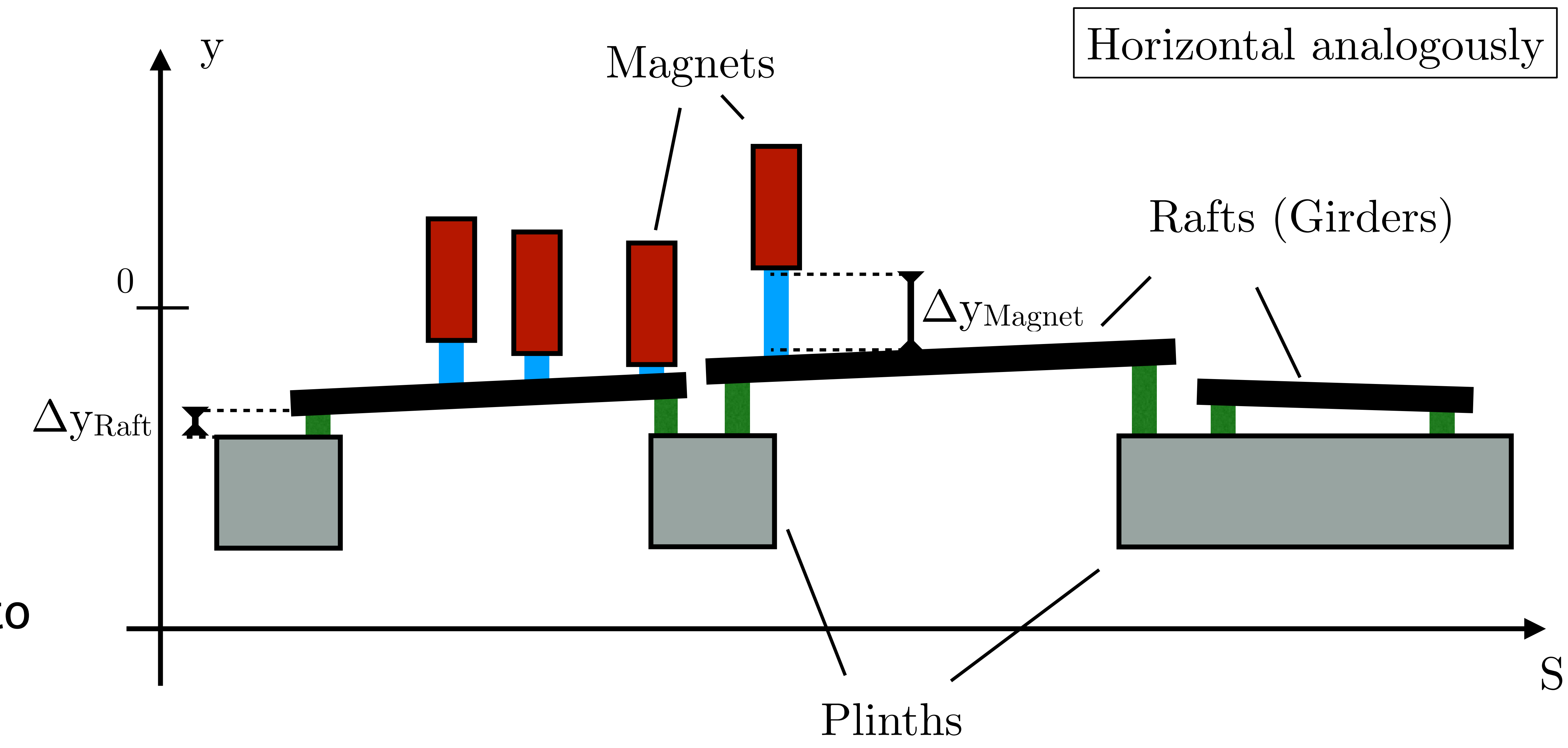




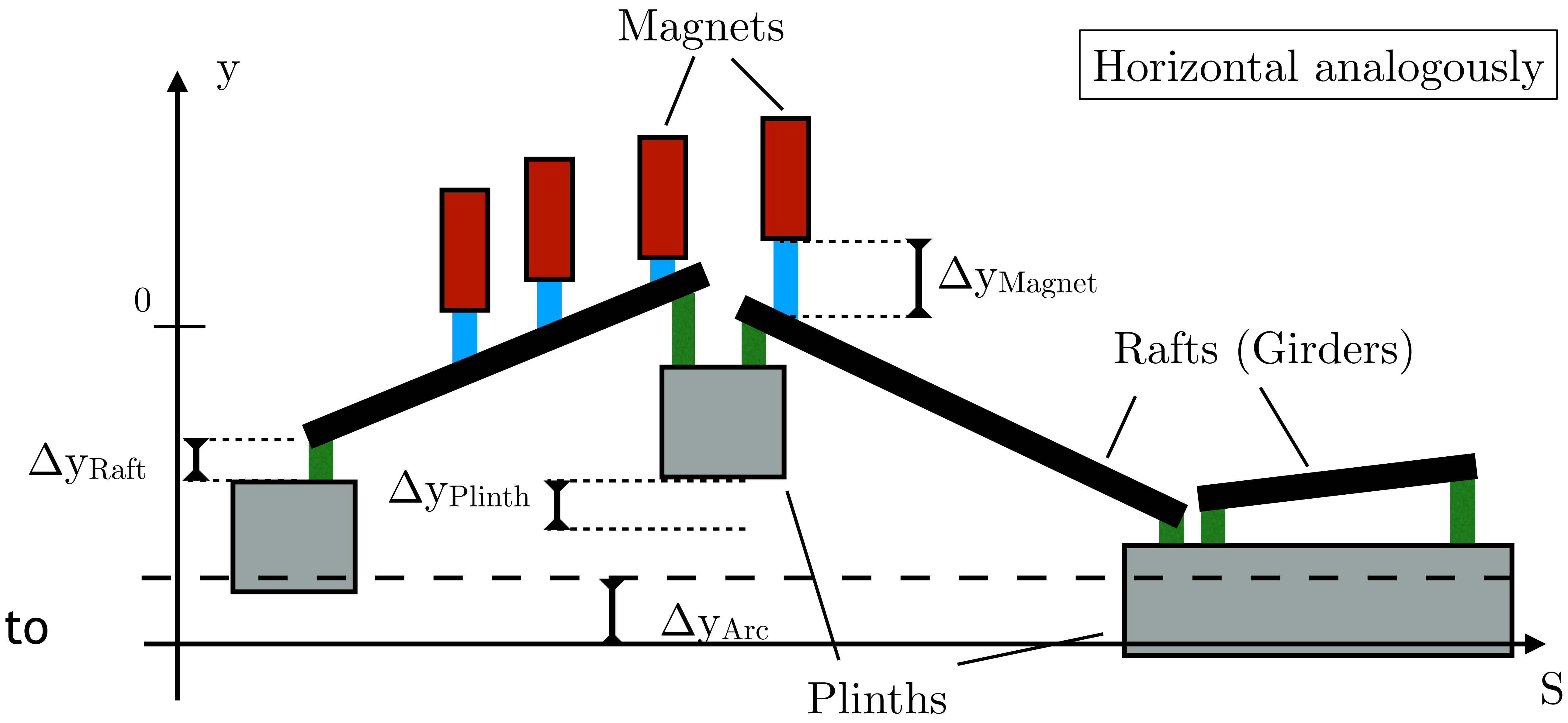
High fidelity misalignment model

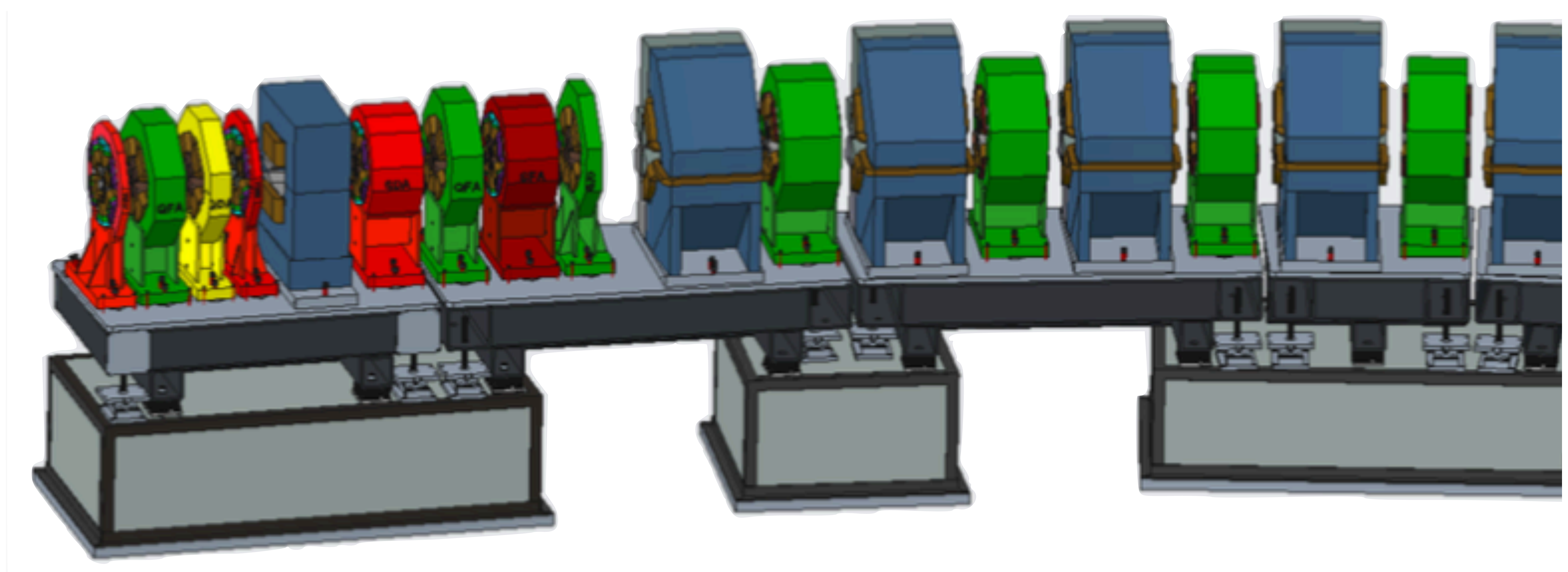
- Lateral misalignment model typically used in simulations:
  - Transverse magnet offsets
  - Transverse raft offsets
- ALS-U support system with plinths and rafts
  - Adjacent rafts cannot move freely due to ground settlement



High fidelity misalignment model

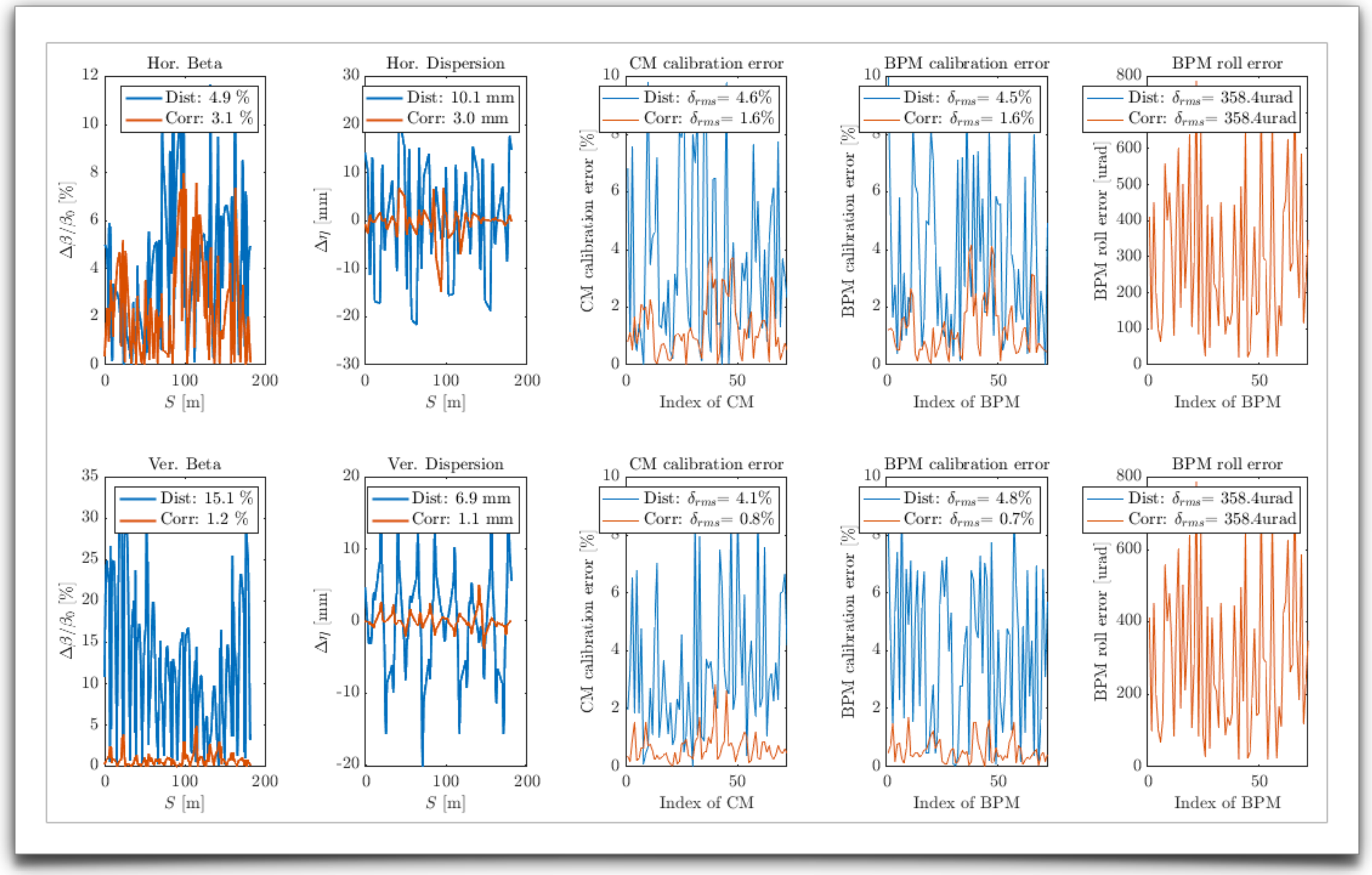
- Lateral misalignment model typically used in simulations:
  - Transverse magnet offsets
  - Transverse raft offsets
- ALS-U support system with plinths and rafts
  - Adjacent rafts cannot move freely due to ground settlement
- Realistic error model follows magnet support system
  - Magnets
  - Rafts & Plinths
  - Entire arcs



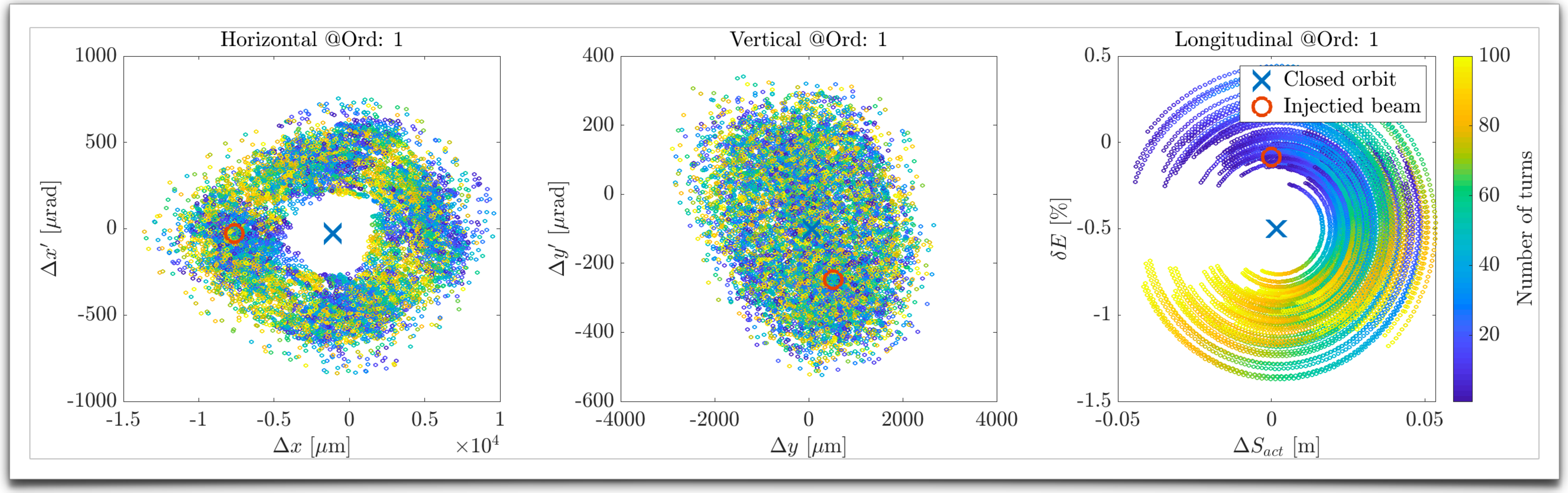


Visualization tools

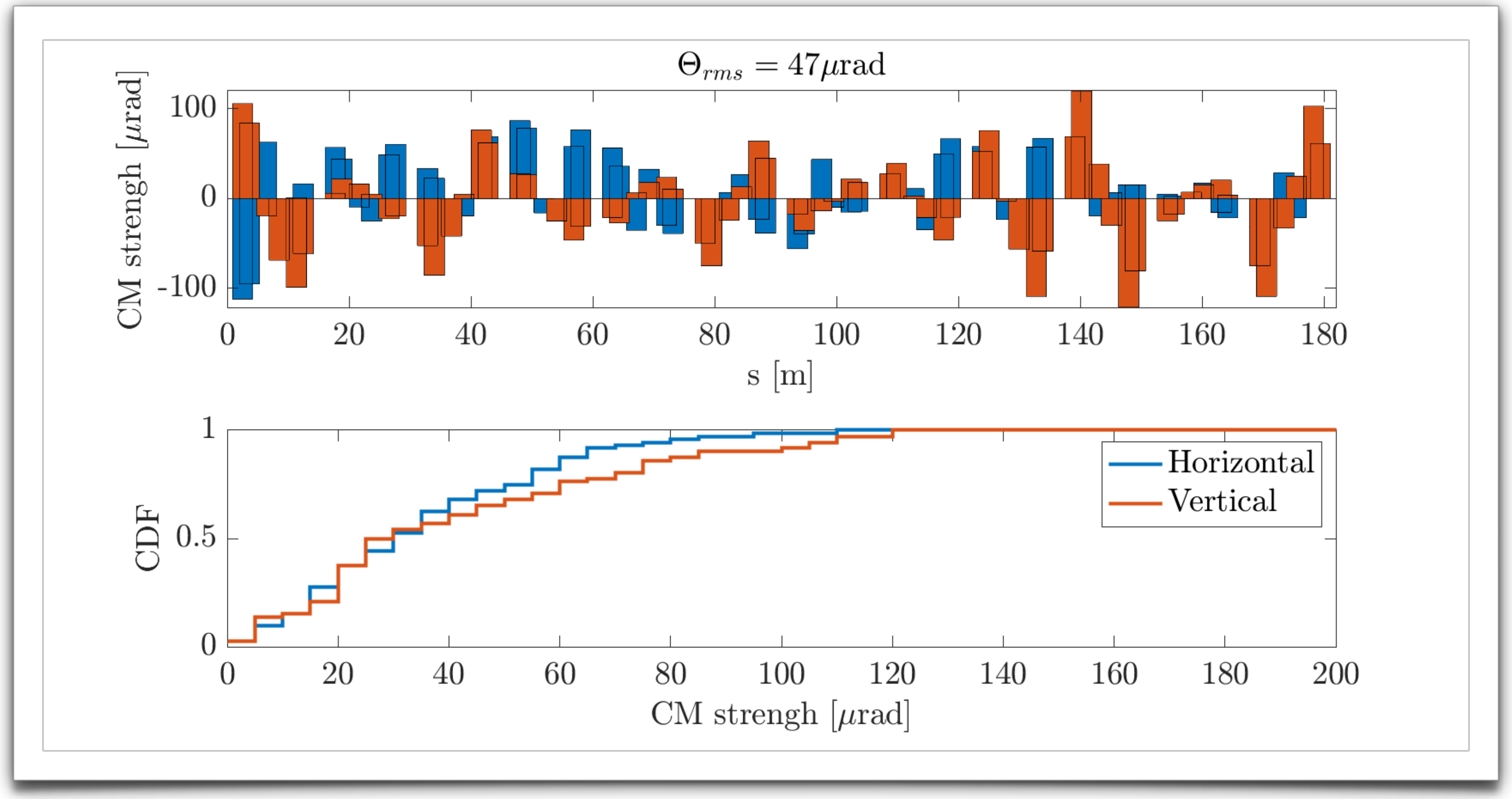
LOCO status



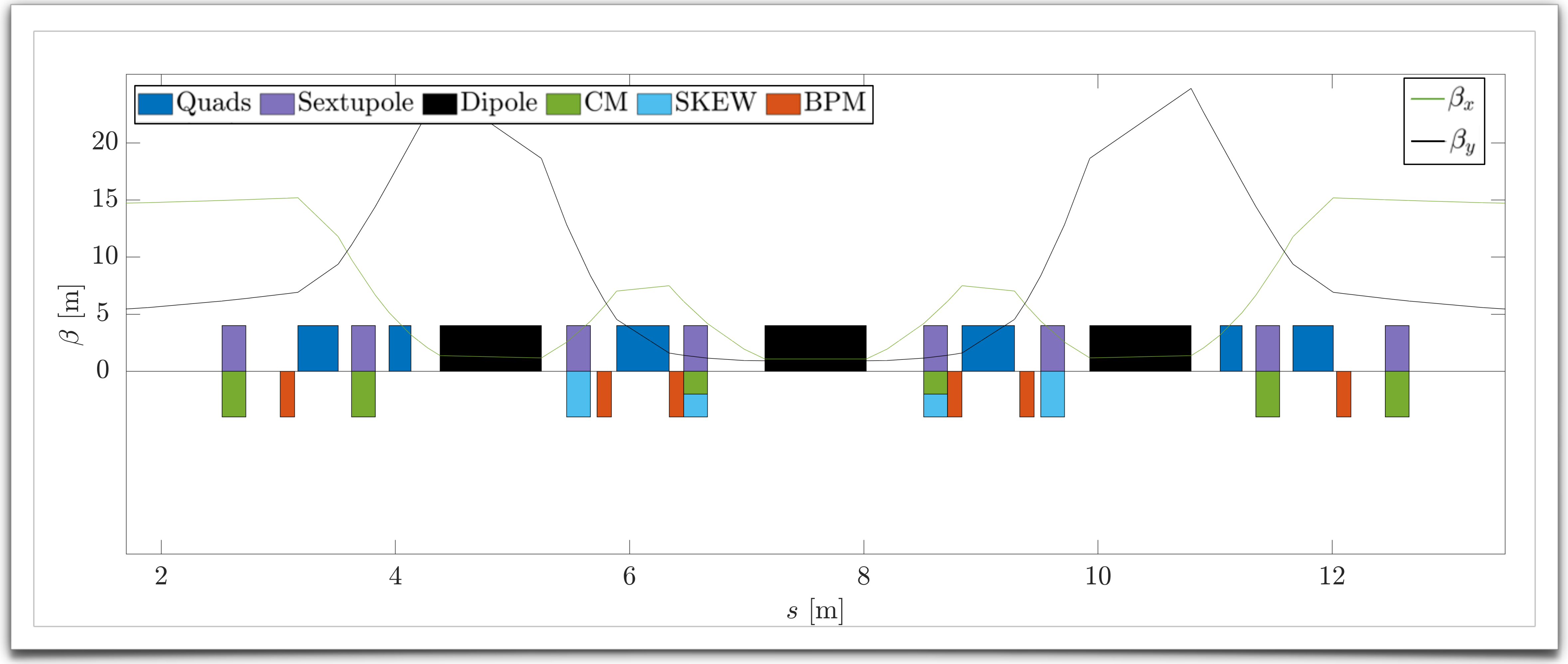
Phase Space



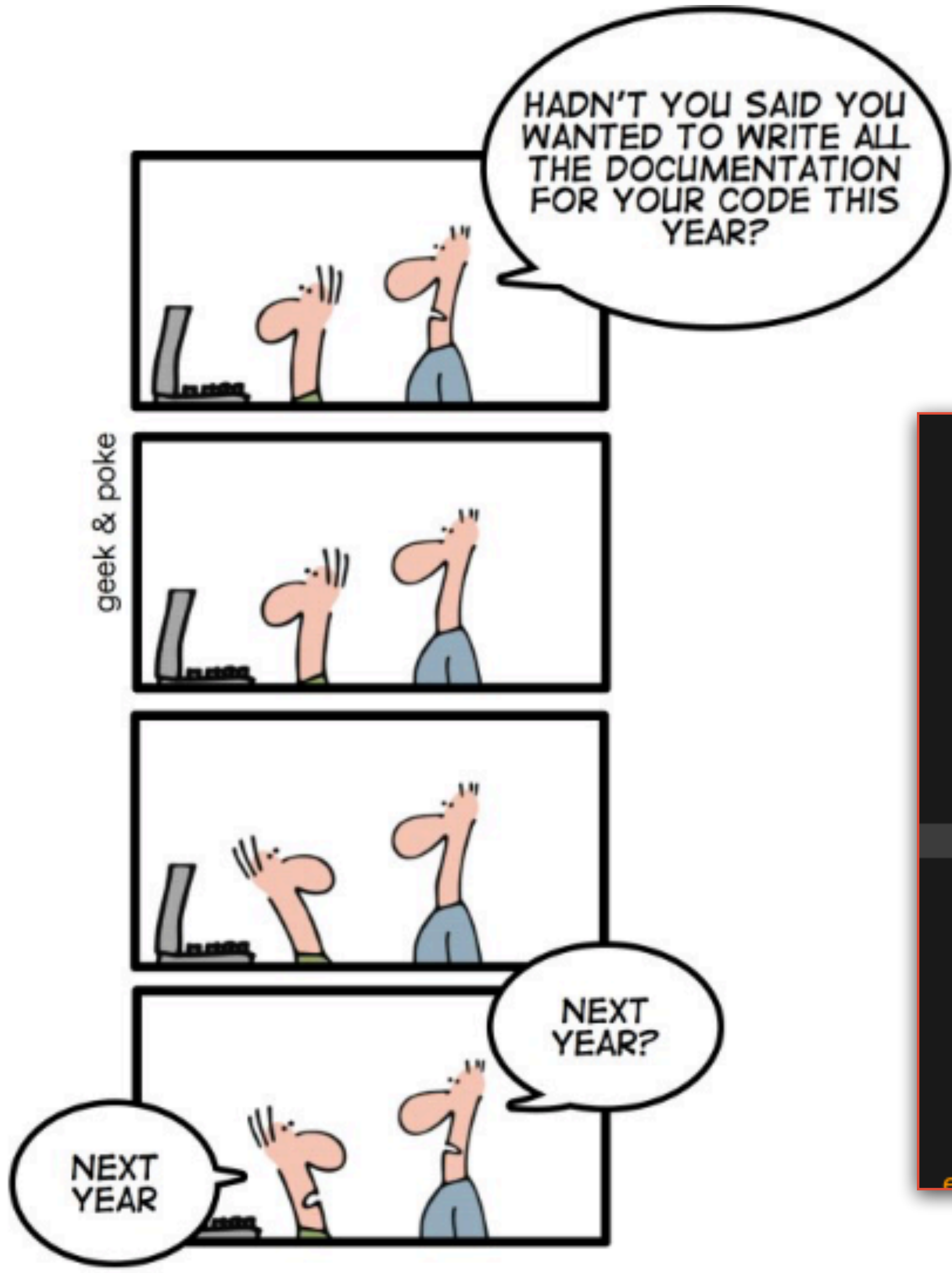
Corrector Strength



Lattice Layout



Comprehensive Source Code Documentation



Code commentaries

```
    % Compensate for bending kick difference.
    if dipCompensation && SC.RING{idx}.BendingAngle ~= 0 && ismember(idx,SC.ORD.cm{1})

        % Calculate bending kick differnece for ideal magnet. See note-y18m08d20.
        idealKickDifference = ( ( polSP - ( SC.RING{idx}.SetPointB(2)-SC.RING{idx}.NomPolynomB(2

        % Apply quadrupole setpoint.
        SC.RING{idx}.SetPointB(2) = polSP;

        % Set dipole setpoint accordingly.
        [SC,~] = SCsetCMs2SetPoints(SC,idx, -idealKickDifference*SC.RING{idx}.Length ,1,'add');
    else
        % Apply quadrupole setpoint.
        SC.RING{idx}.SetPointB(2) = polSP;
    end

    % Update magnets.
    SC = SCupdateMagnets(SC,idx);

    % Update loop index
    i = i + 1;
end
```

ALS-U Technical Nodes

Technical Note ALSU-AP-TN-2019-04

Model independent 2-turn BBA procedure for early commissioning of the ALS-U storage ring

Thorsten Hellert

Source control

git

Asciidoc manual

SCsetQuads2SetPoints

NAME

SCsetQuads2SetPoints - Sets quadrupole magnets to different setpoints

SYNOPSIS

SC = **SCsetQuads2SetPoints**(*SC*, *MAGords*, *setpoints* [,OPTIONS])

DESCRIPTION

Sets quadrupole magnets to setpoints. The setpoints may be given relative to their nominal value or in absolute terms of K. If the considered quadrupole is a combined function magnet with non-zero bending angle and the kick compensation flag is switched on, the appropriate bending angle difference is calculated and the horizontal CM setpoint is changed accordingly to compensate for that for dipole kick difference.

INPUTS

SC
: SC base structure

MAGords
: [1 x n] array of quadrupole ordinals in the lattice structure

setpoints
: [1 x n] array of quadrupole setpoints

OPTIONS

rel
: Use setpoints relative to nominal value

abs
: Use absolute setpoints

add
: Add setpoints to current values

dipCompensation
: If there is a horizontal CM registered in the considered quadrupole, the CM is used to compensate the bending angle difference if the quadrupole setpoints differs from its design value

RETURN VALUES

SC
: The base structure containing lattice with modified setpoints

SEE ALSO

SCupdateMagnets, **SCsetCMs2SetPointsAdd**

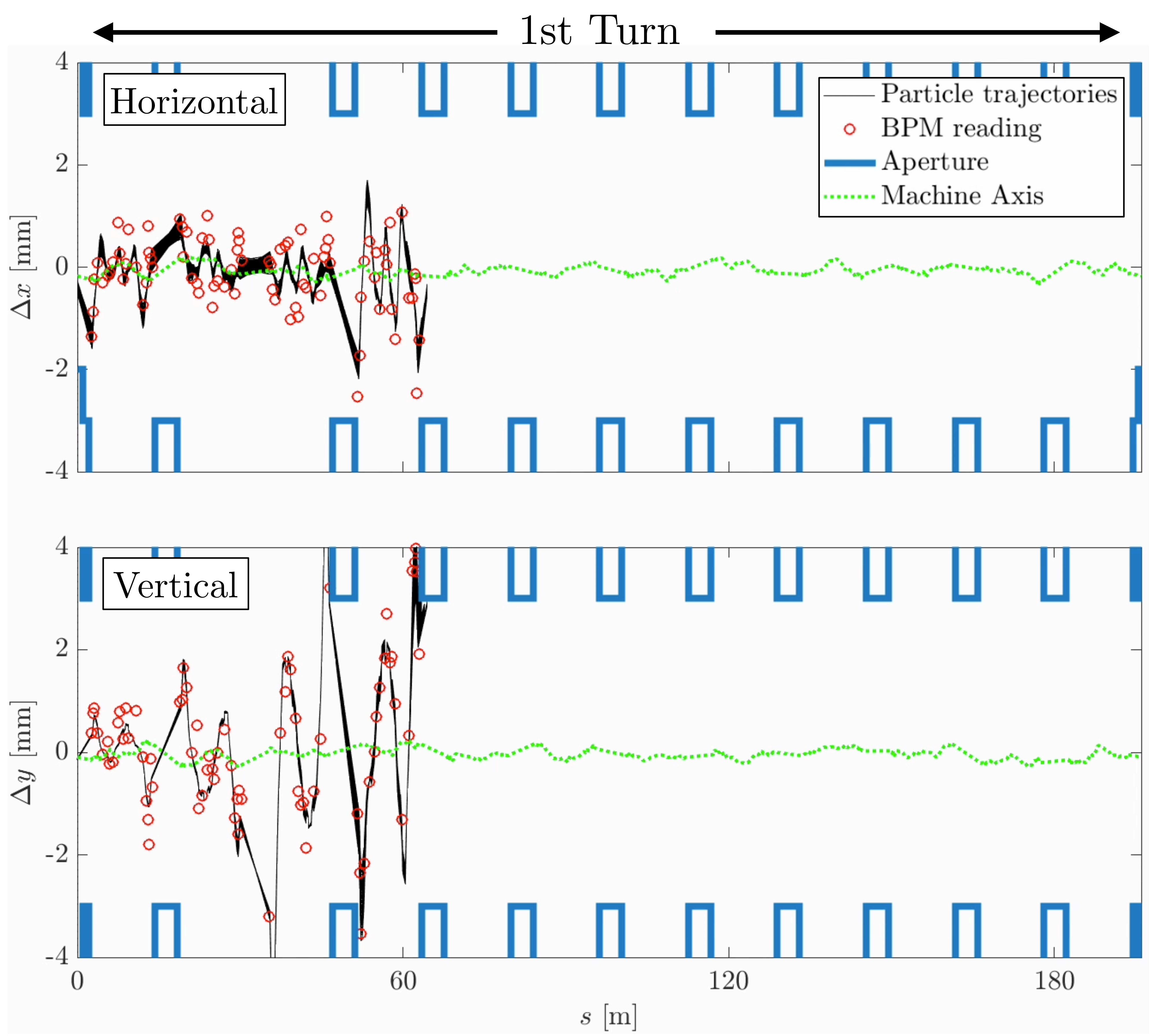
NOTES

Created y18m11d06. y18m08d25 THellert: Created y19m01d28 THellert: Modified

Last updated 2019-02-07 19:20:11 PST

Example: correction chain of the ALS-U SR

- Initial transmission
  - Achieve first turn transmission
  - Trajectory correction for multi-turn transmission
- Improving multi-turn transmission
  - Perform beam based alignment
  - Correct injected trajectory error
- Closed orbit correction
  - Match injection trajectory
  - Commissioning of RF cavities
  - Synchronous energy correction
- Achieve beam capture
  - Ramp up sextupoles
  - Trajectory based optics correction
- Achieve light source KPPs
  - LOCO based optics correction
  - ID closing
  - …



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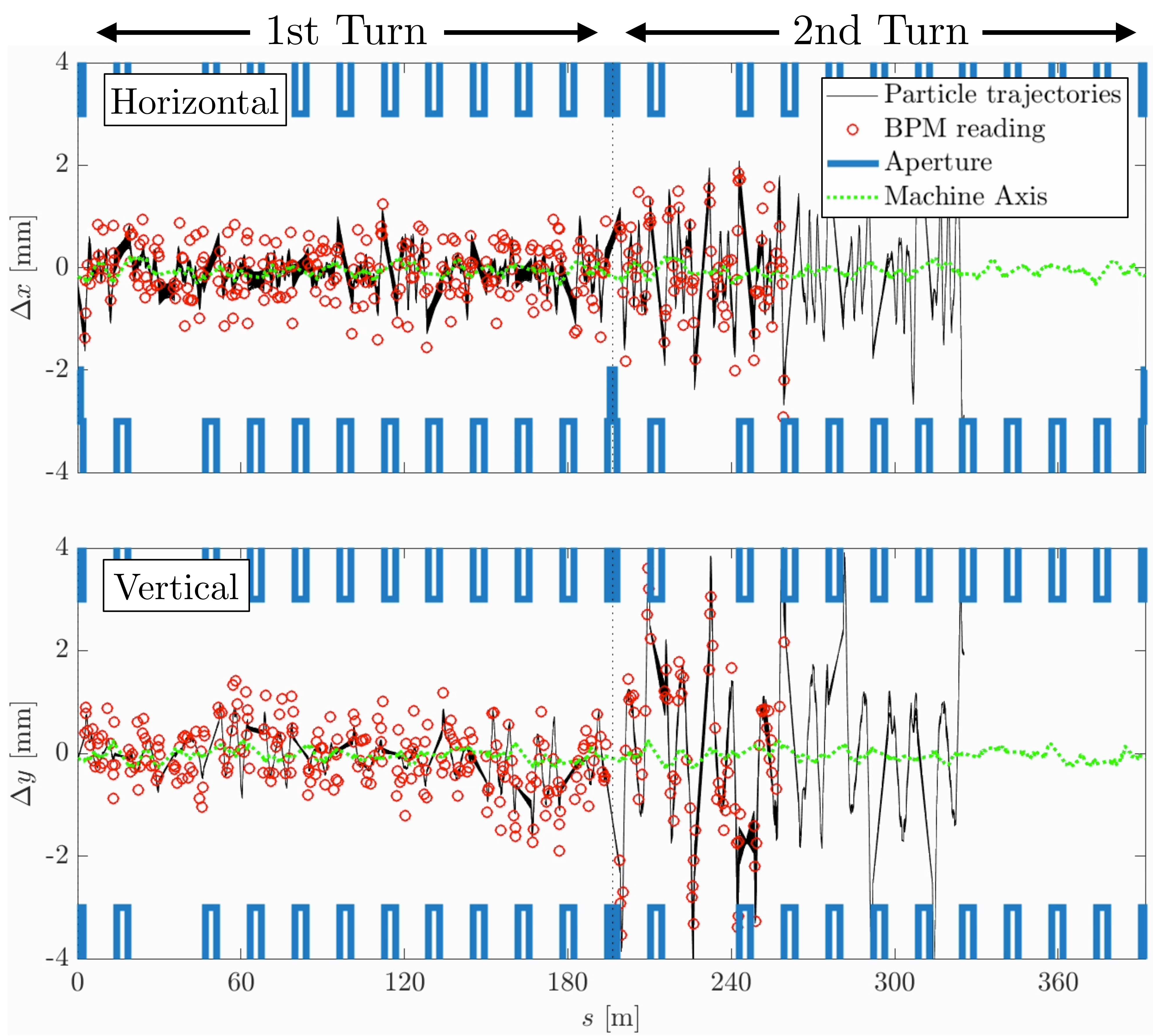

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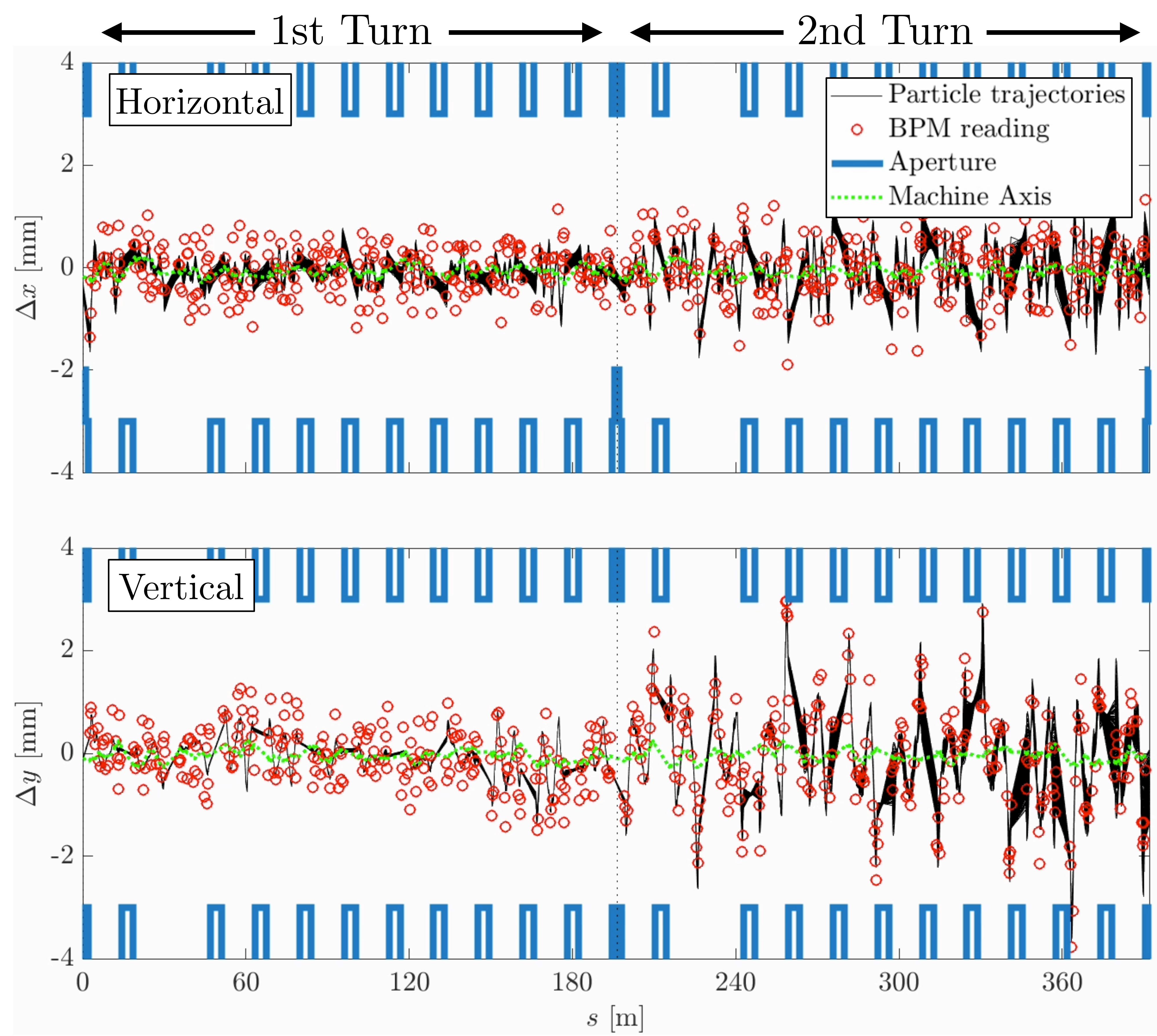

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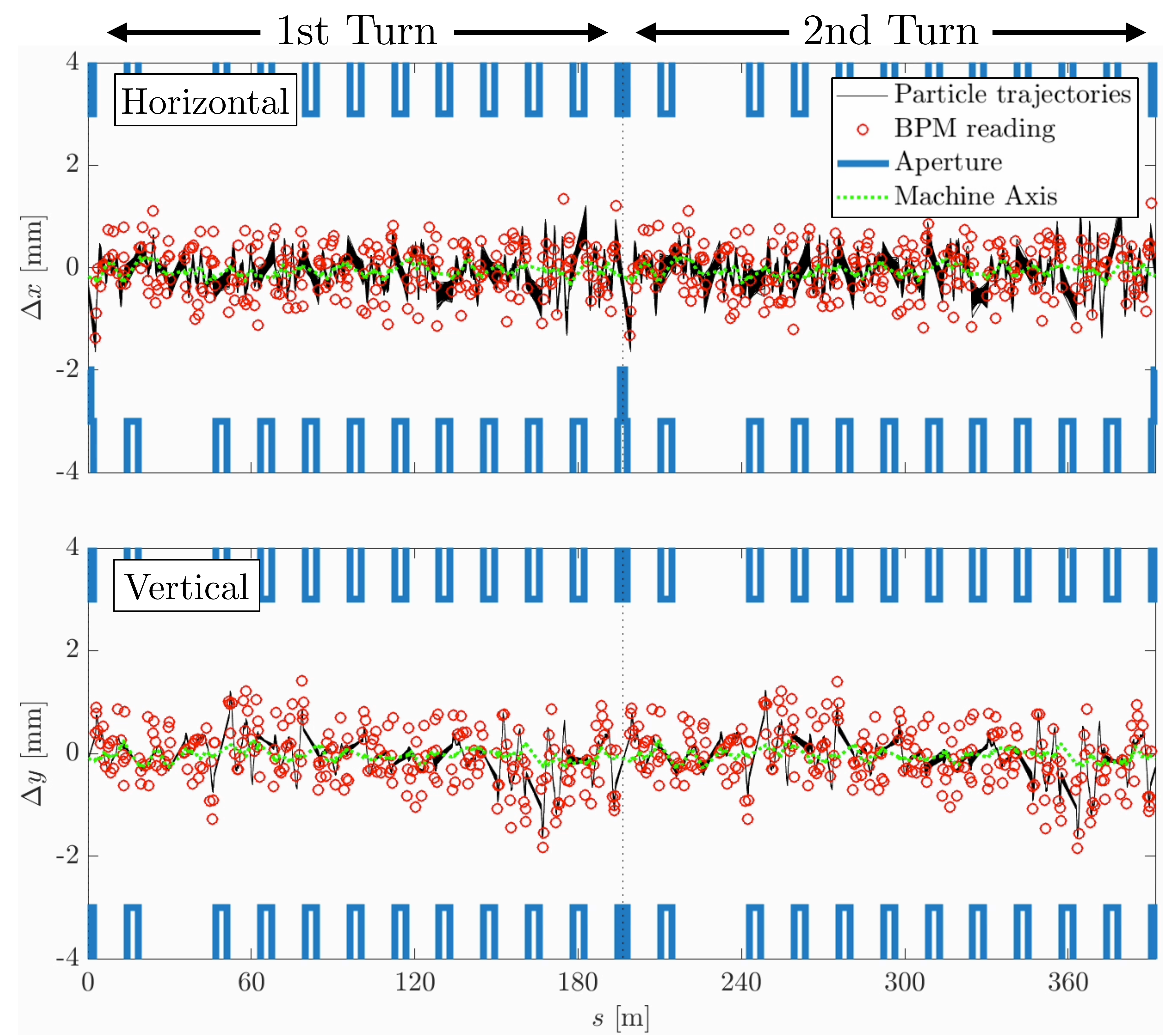
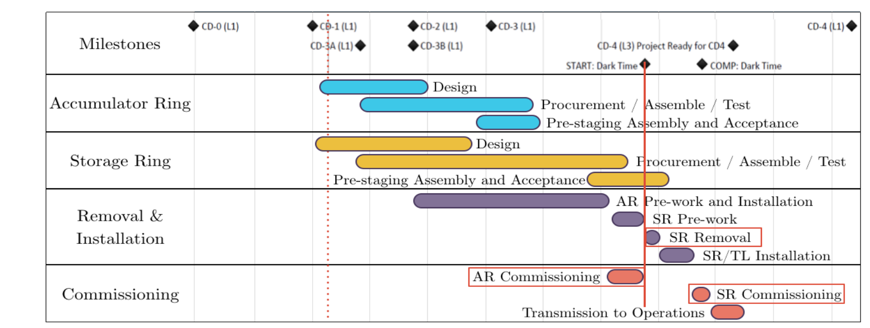
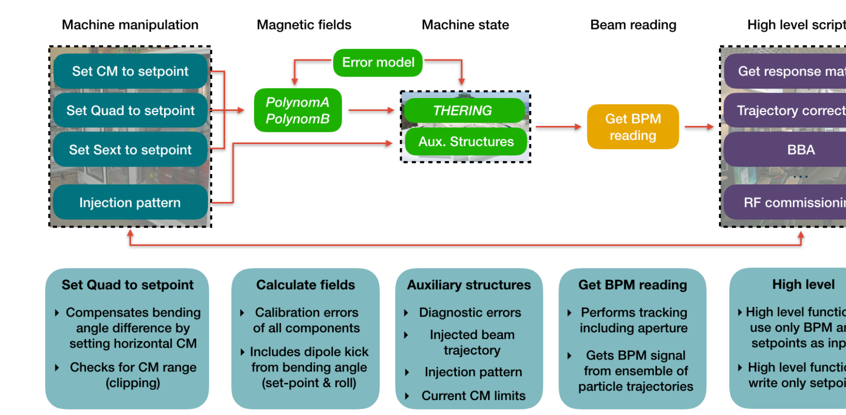
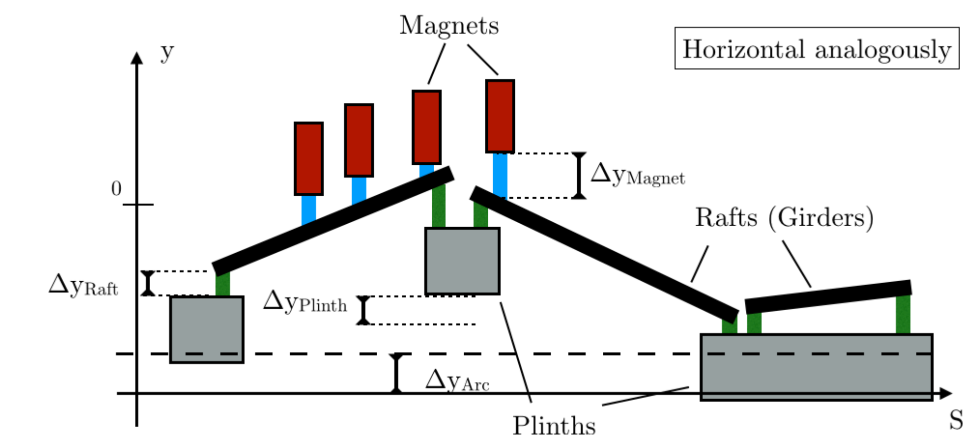


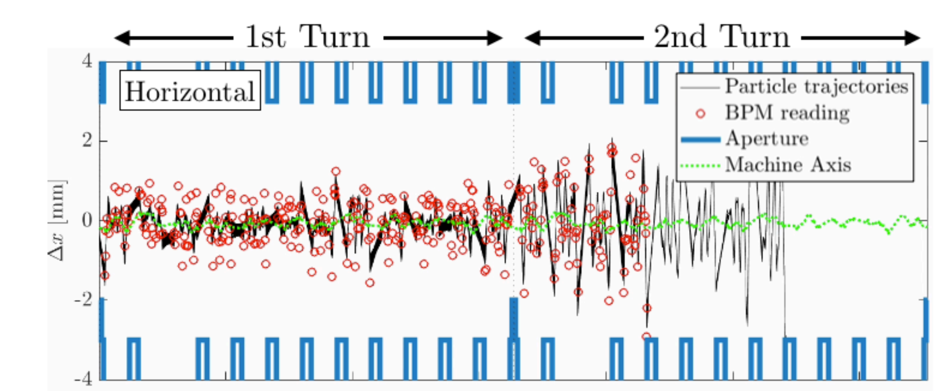
Summary

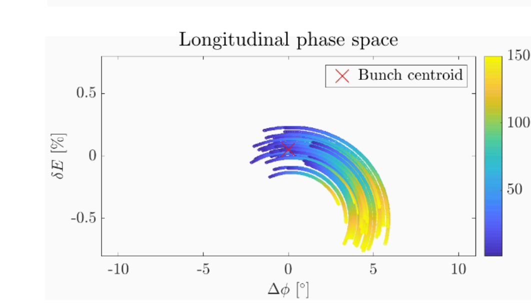
- Realistic simulation of commissioning process required
  - Challenging lattice of future light sources
  - Tolerances studies must include commissioning process
  - Simulation must reflect reasonable information flow
- Development of start-to-end commissioning simulation toolbox
  - High fidelity error model
  - Realistic workflow
  - Comprehensive documentation
- Effective correction chain established for 2 machines
  - Feedback-like trajectory correction scheme
  - Model independent single pass BBA procedure
  - 6D closed orbit correction
  - LOCO based optics correction
- Toolbox to be published at IPAC2019
  - Beta-test with other lattices very welcome!

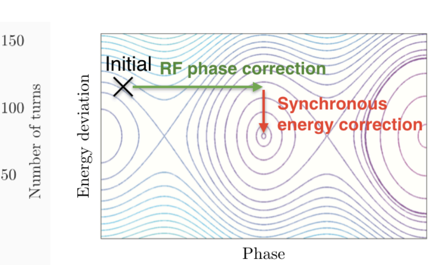












References

Proceedings of IPAC2017, Copenhagen, Denmark WEPIK061

LATTICE TUNING AND ERROR SETTING IN ACCELERATOR TOOLBOX

S. M. Liuzzo, N. Carmignani, L. Farvacque, B. Nash, ESRF, Grenoble, France

Abstract

New lattice designs need to be studied in the presence of magnetic and alignment errors and appropriate lattice tuning procedures. For this reason a set of tools to perform a commissioning-like sequence has been developed for the ESRF-EBS [1],[2] upgrade in Accelerator Toolbox (AT) [3] and is now generalized to be used for other accelerators lattice design. The functions presented here allow to correct first turn trajectory, orbit, tune, chromaticity, optics and coupling, in any order. A set of functions to define errors is introduced to address, among others, the issues of: misalignment of magnets modeled by several slices, multiple errors setting on the same magnet and spatially recursive errors along the lattice.

INTRODUCTION

We present in this paper some tools added in the AT 1.4 [4] pubtools as first steps to a more complete and exhaustive set of tools for error setting and correction of lattices. The tools presented have been used for the definition of error tolerances for the ESRF-EBS upgrade

ERROR SETTING

Only the additional functions introduced in version 1.4 are described below.

Longitudinal alignment errors Longitudinal alignment errors require to change the length of adjacent drift spaces. For Dipoles also a change of trajectory needs to be considered. Figure 1 shows a lattice layout with a displaced dipole (pale blue). The length of the lattice changes when displacing longitudinally dipoles.

Figure 1: Dipole longitudinally displaced.

Rotation of a dipole about the s-axis Dipoles change the reference frame but their field is usually ignored. To make the effect of dipole rotation and field errors visible, those must be expressed in terms of *PolynomA* and *PolynomB*. The function *atsettiltdipole* implements this feature, and sets the field PolynomB and PolynomA in a dipole to represent the distortion introduced by the rotated bending magnet. In the figures below the effect of the rotation of a dipole are shown in three cases: rotation of a straight multipole using *atsettilt* (Fig. 2), rotation of a dipole using *atsettiltdipole* (Fig. 3), rotation of a dipole using *atsettilt* (Fig. 4).

Figure 2: Dipole modeled as kick (PolynomB(1) not zero) rotated using *atsettilt*.

Figure 3: Dipole modeled as bend (BendingAngle not zero) rotated using *atsettiltdipole*.

Figure 4: Dipole modeled as bend (BendingAngle not zero) rotated using *atsettilt*. (vertical dispersion is non zero after the rotated bend).

There is no difference between Fig. 2 and Fig. 3, while the tilt implemented rotating the reference system does not show the expected orbit distortion. The same considerations are true for the rotation of a combined function dipole-quadrupole.

BPM errors BPM errors are: offset, rotation, gain and reading precision (random). Those are set in the lattice with the function *atsetbpmerr*. Figure 5 shows an example of closed orbit and BPM readings. To obtain BPM readings including the errors the function *findorbit4Err* and *findorbit6Err* are used. Future AT versions will try to implement this in a dedicated PassMethod in C, to increase the speed of this transformation and avoid the use of extra functions for orbit with errors.

S.M. Liuzzo et al, IPAC (2017) WEPIK061

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COMMISSIONING SIMULATIONS FOR THE APS UPGRADE LATTICE*

V. Sajaev, M. Borland, ANL, Argonne, IL 60439, USA

Abstract

A hybrid seven-bend-achromat lattice that features very strong focusing elements and a relatively small vacuum chamber has been proposed for the APS upgrade. Achieving design lattice parameters during commissioning will need to be accomplished quickly in order to minimize dark time for APS users. The paper will describe start-to-end simulation of the machine commissioning beginning from first-turn trajectory correction, progressing to orbit and lattice correction, and culminating in evaluation of the nonlinear performance of the corrected lattice.

INTRODUCTION

Several existing synchrotron light source facilities are considering replacing operating storage rings in order to increase the brightness of delivered photon beams. These light sources have large user communities who insist that facility "dark time" is minimized. APS, for example, is targeting 12 months for removal, installation, and commissioning. Of this 12 month period, only three months are set aside for commissioning of the new multi-bend achromat ring.

The proposed lattice [1] has natural emittance that is 40 times smaller than the present APS ring, which is achieved by much stronger focusing than in the present ring. For example, maximum quadrupole strengths increase nearly fivefold in the new lattice. Stronger focusing inevitably leads to larger natural chromaticity and thus a nearly seven-fold increase in sextupole strength is needed, resulting in rather small dynamic aperture and short lifetime even for the ideal lattice. Misalignments of the strong quadrupoles generate large orbit errors, which in the presence of very strong sextupoles leads to huge lattice and coupling errors. Add to this smaller vacuum chamber gaps that are required to achieve high gradients in the magnets, and the required rapid commissioning seems doubtful. In this paper, we address this issue using a highly realistic simulation of the commissioning.

SIMULATION PROCEDURE

While the effect of individual lattice imperfections on accelerator performance can be estimated or calculated analytically, including all errors together is beyond the realm of analytical estimations. To understand how various errors combine together and impact commissioning, a start-to-end simulation of machine commissioning was performed taking into account as many errors as possible. All simulations were done using `elegant` [2]. Table 1 gives the list of errors included in the simulations (official specification for girder alignment is 100 μm which was found to be equally workable in earlier runs).

Table 1: Rms Values for Various Errors Used for Start-to-end Commissioning Simulation

Girder misalignment	50 μm
Elements within girder	30 μm
Dipole fractional strength error	$1 \cdot 10^{-3}$
Quadrupole fractional strength error	$1 \cdot 10^{-3}$
Dipole tilt	0.4 mrad
Quadrupole tilt	0.4 mrad
Sextupole tilt	0.4 mrad
Initial BPM offset error	500 μm
BPM gain error	5%
BPM orbit measurement noise	1 μm
Corrector calibration error	5%

The simulation procedure closely follows the steps that will be performed during commissioning. We assume that before setting up the lattice, the betatron tunes are adjusted away from integer and coupling resonances (the design fractional tunes are 0.12 in both planes, they are adjusted to 0.18 and 0.24). The procedure consists of the following major steps: (1) Generate errors for all elements according to Table 1 using Gaussian distributions with 2σ cut off. (2) Correct trajectory until closed orbit is found. If needed, optimize tunes and low-order beta function harmonics. (3) Correct closed orbit down to acceptable level. (4) Correct optics and coupling.

The entire simulation procedure was automated, allowing commissioning to be simulated for 200 different error sets. The procedure was able to correct orbit and optics in 98% of all cases. The correction results were statistically analyzed for residual orbit and lattice perturbations, corrector strengths, emittances, etc. For each error set, various performance measures (e.g., rms horizontal beta error) are computed. These are then histogrammed over all error sets. Before presenting such results, we first discuss the detailed commissioning procedure.

Trajectory Correction

Simple estimations show that in order to expect a reasonable probability of the closed orbit not exceeding the vacuum chamber dimensions, magnet alignment tolerances must be three times tighter than in Table 1. Since this is considered prohibitively expensive, trajectory correction will need to be performed first in order to find a closed orbit.

Trajectory correction consists of two steps. First, `elegant`'s one-to-best method is applied, wherein steering is performed by pairing one corrector with the BPM that has the best response to this corrector. Only four correctors

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