U.S. DEPARTMENT OF ENERGY
Office of Science

BERKELEY LAB

ALS-U
ADVANCED LIGHT SOURCE

Development of a DLSR Commissioning Simulation Toolkit and its Applications to the ALS-U Accumulator and Storage Ring

Thorsten Hellert

Research Scientist

Lawrence Berkeley National Laboratory

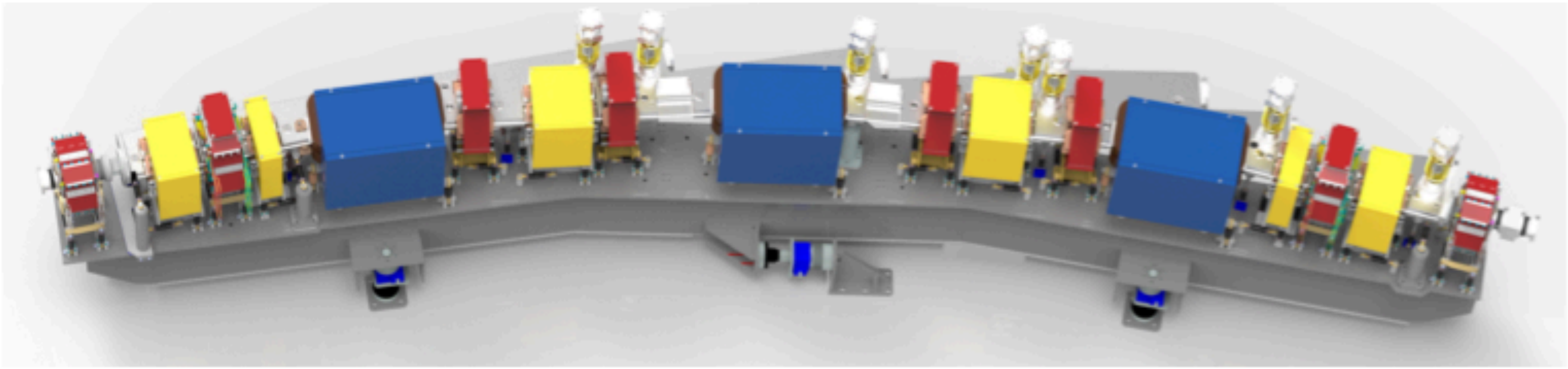
Low Emittance Rings Workshop October 26 2020, INFN-LNF

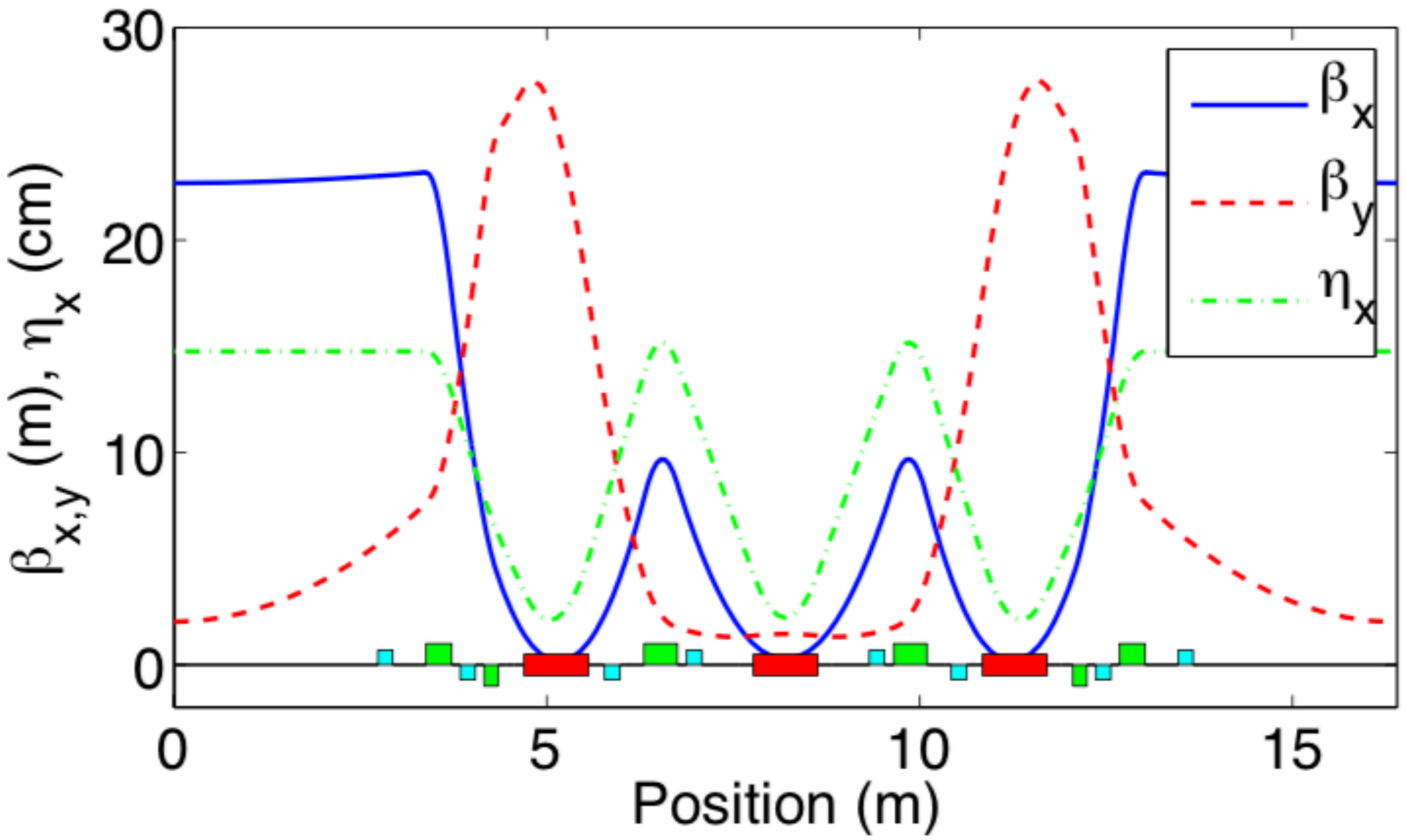
Outline

- Overview of the Advanced Light Source Upgrade
  - Lattice
  - Timeline
- SC - Toolkit Design
  - Workflow
  - Features
- Application Examples
  - Error Sensitivity
  - Injection Studies
  - Beam Based Alignment
  - ID Compensation

Advanced Light Source Upgrade: Lattice

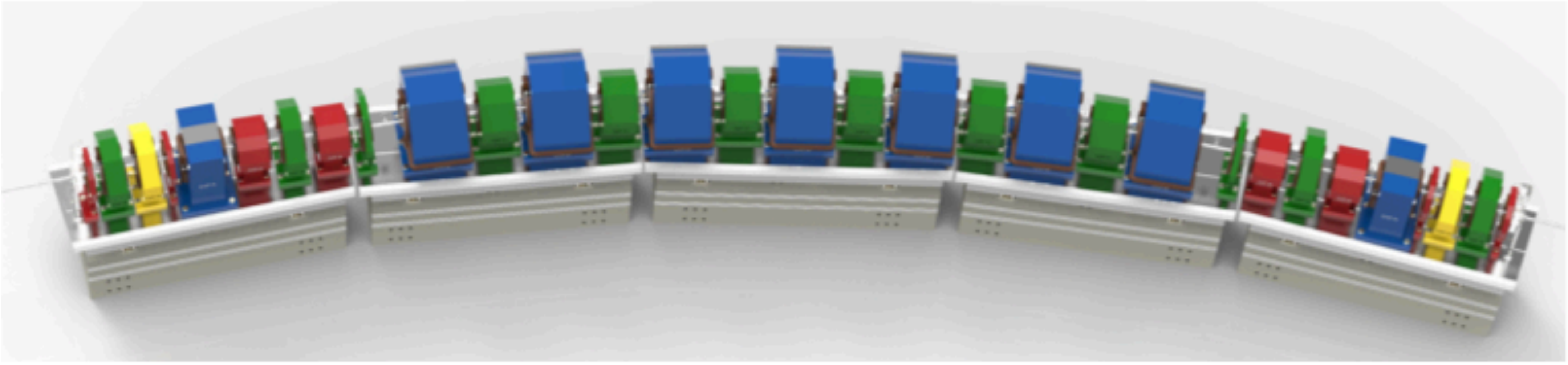
ALS today: triple-bend achromat

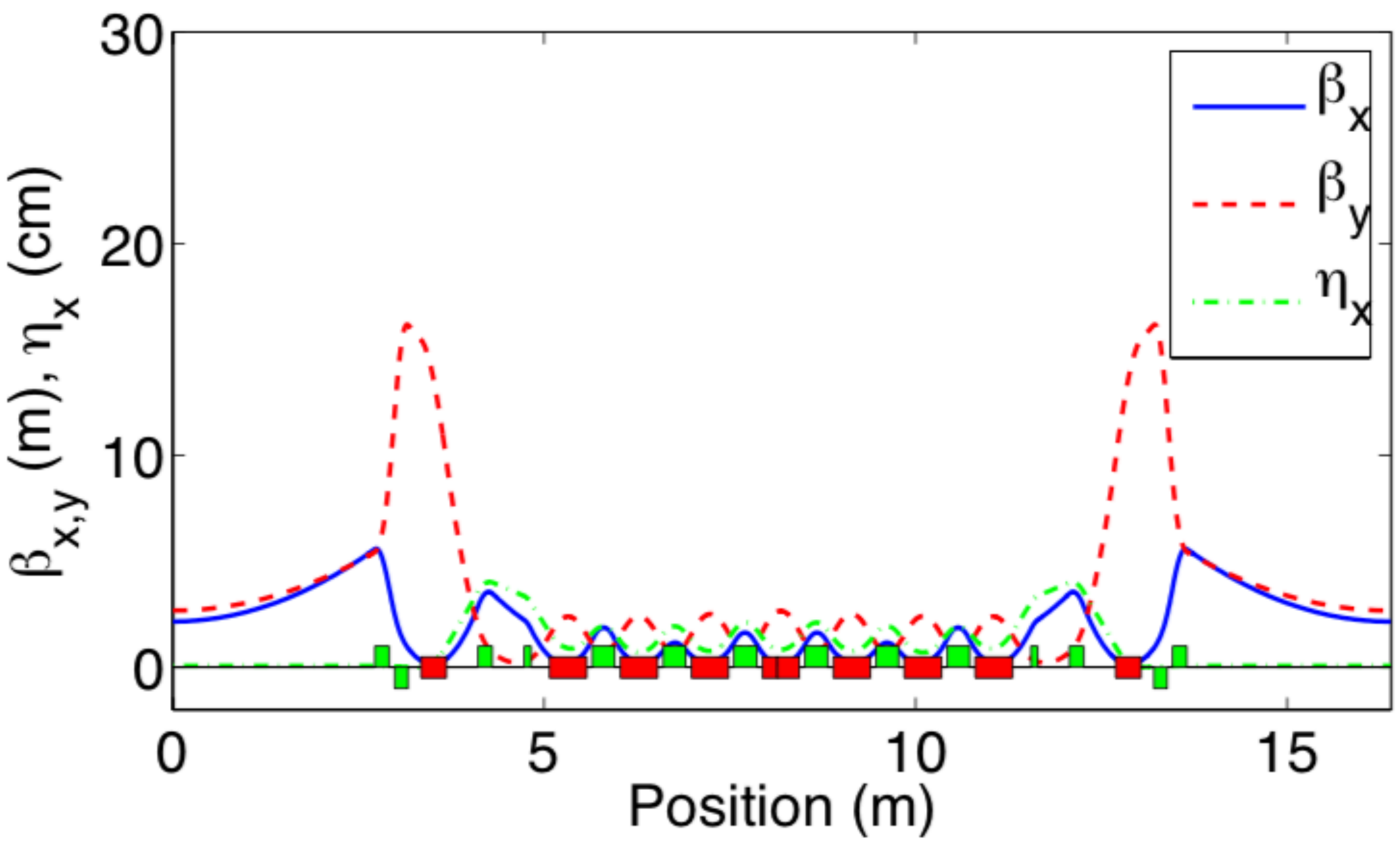




$\epsilon_x \approx$ 2000 pm-rad at 1.9GeV

ALS-U: nine-bend achromat with reverse bends

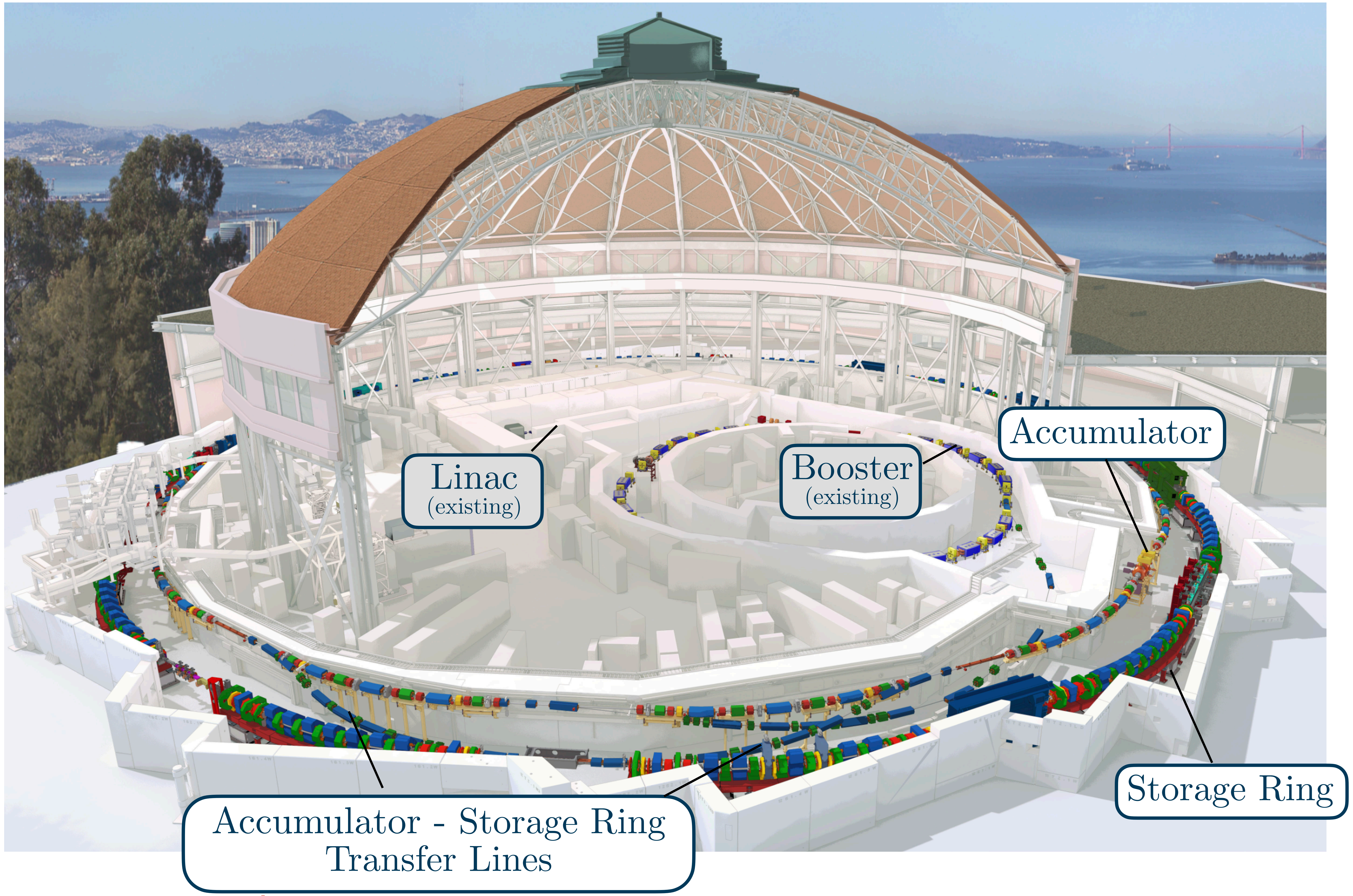




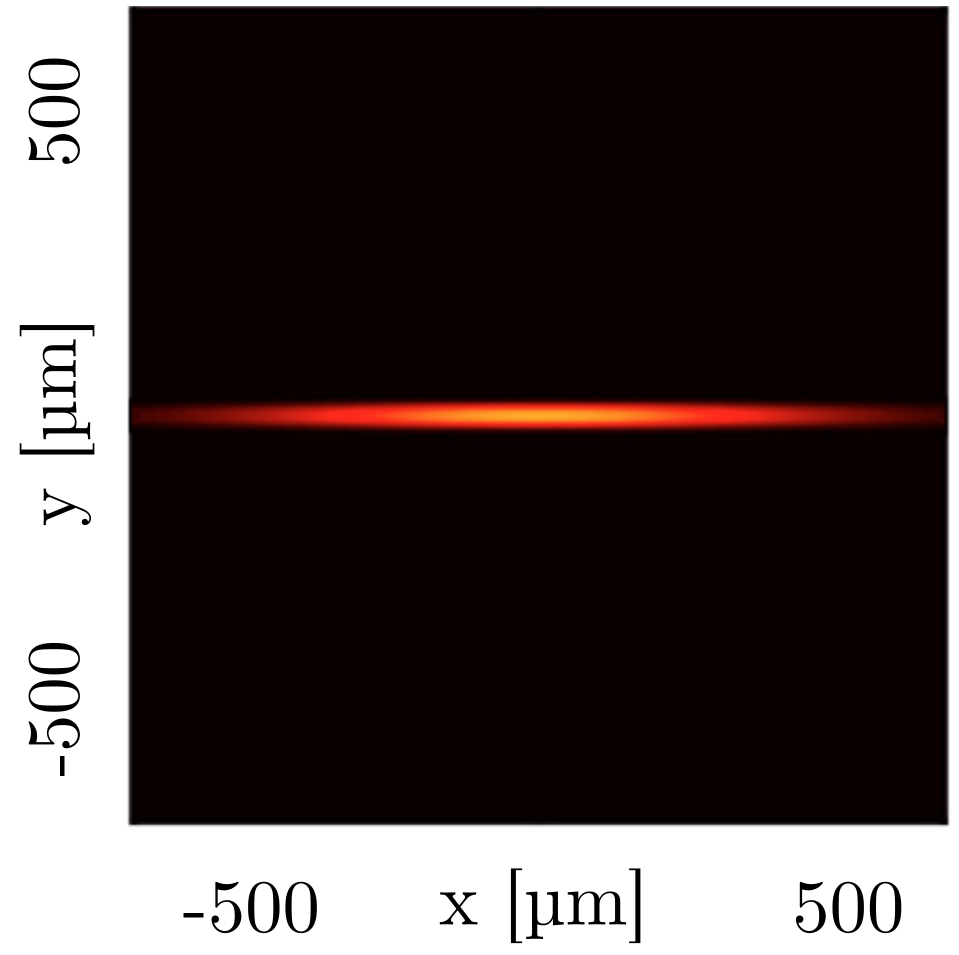
$\epsilon_x <$ 70 pm-rad at 2.0GeV

Advanced Light Source Upgrade: Machine

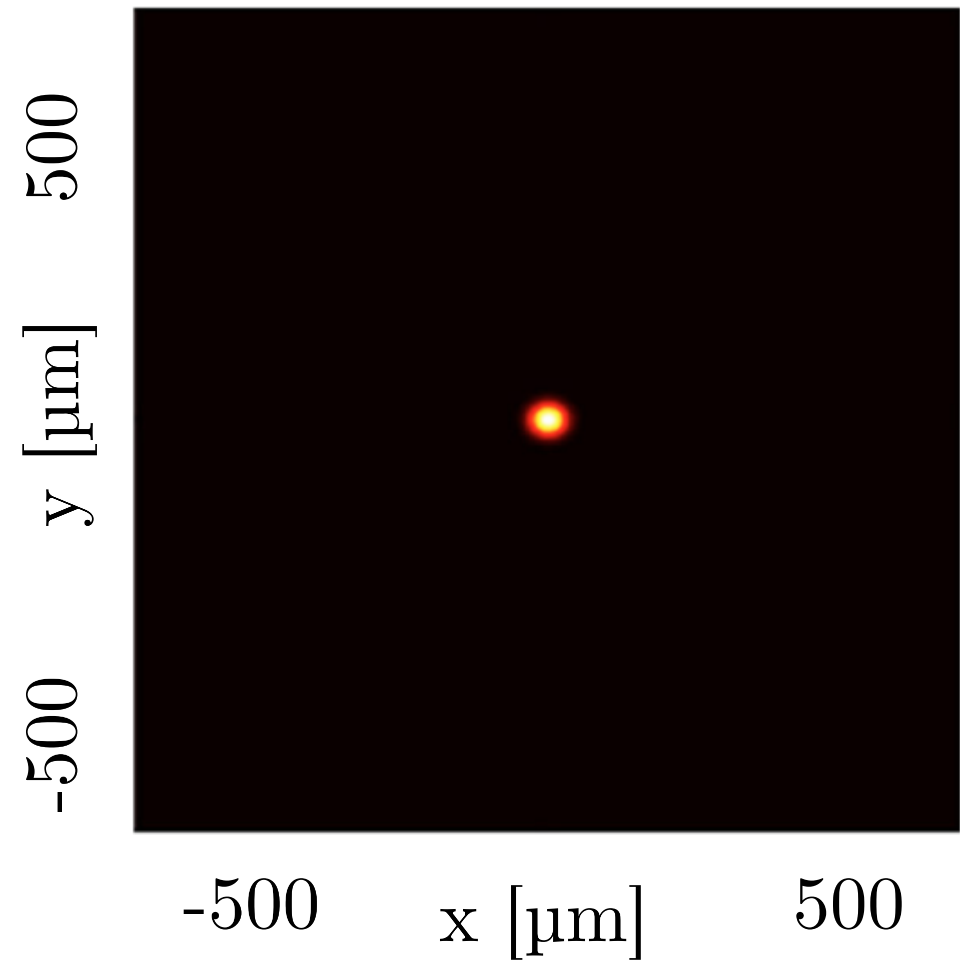
Advanced Light Source Upgrade (ALS-U)



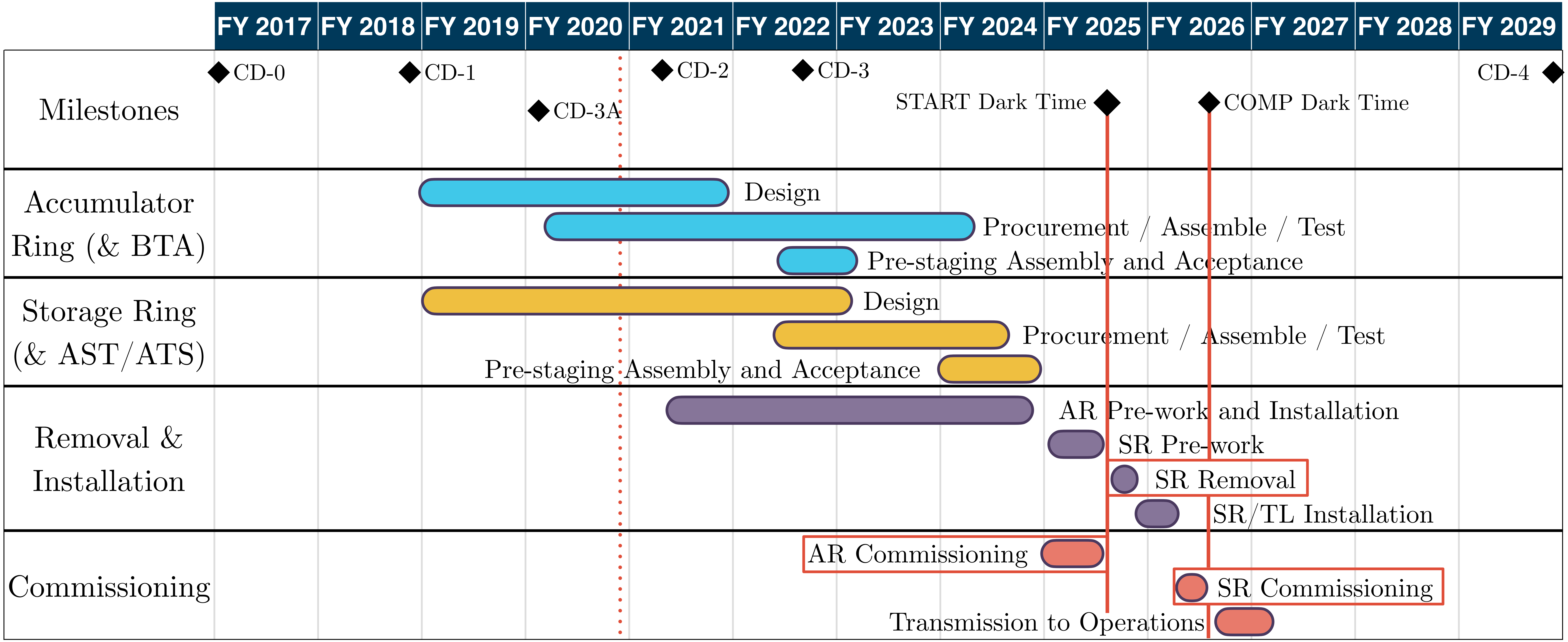
ALS beam size



ALS-U beam size

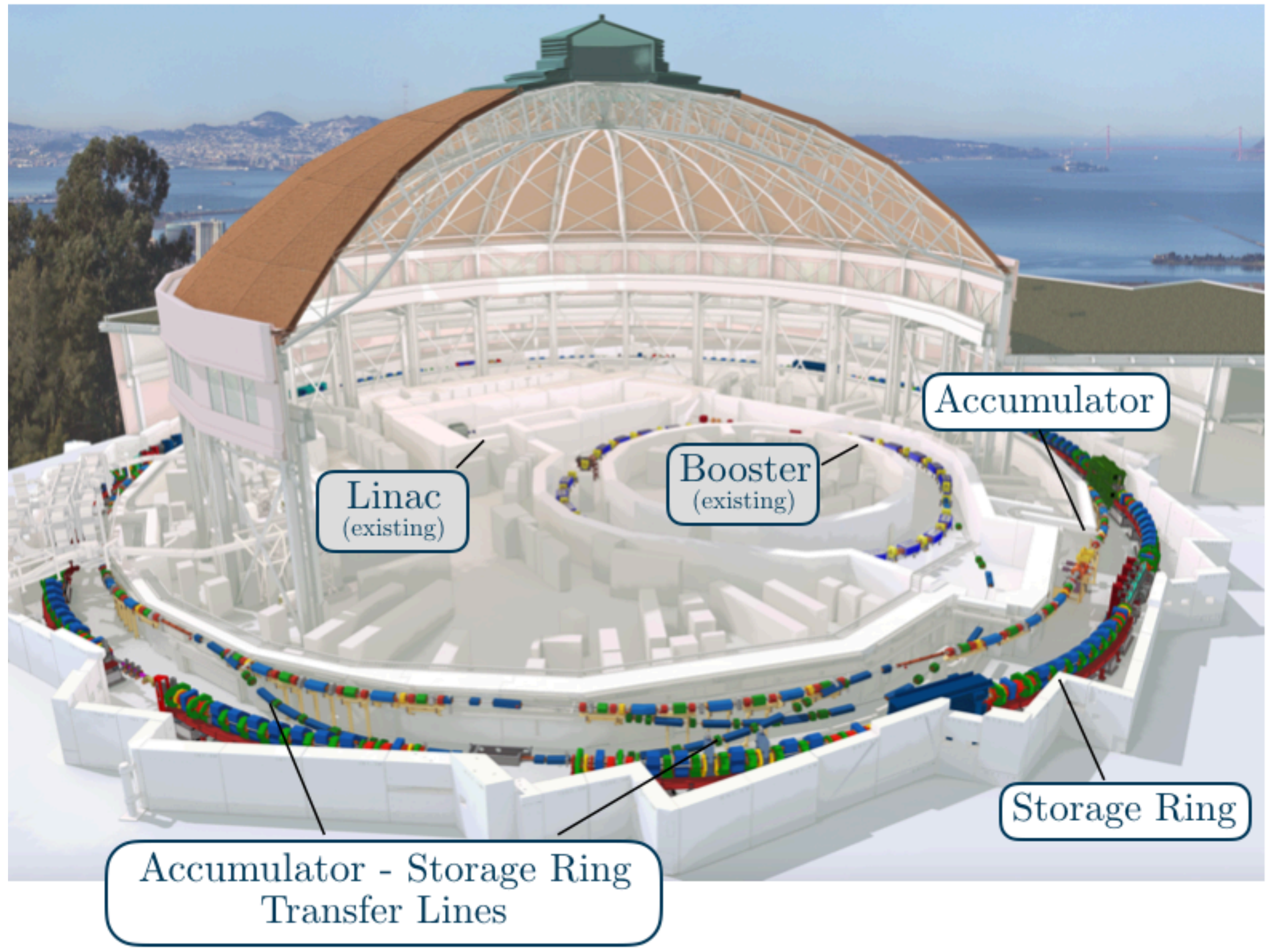


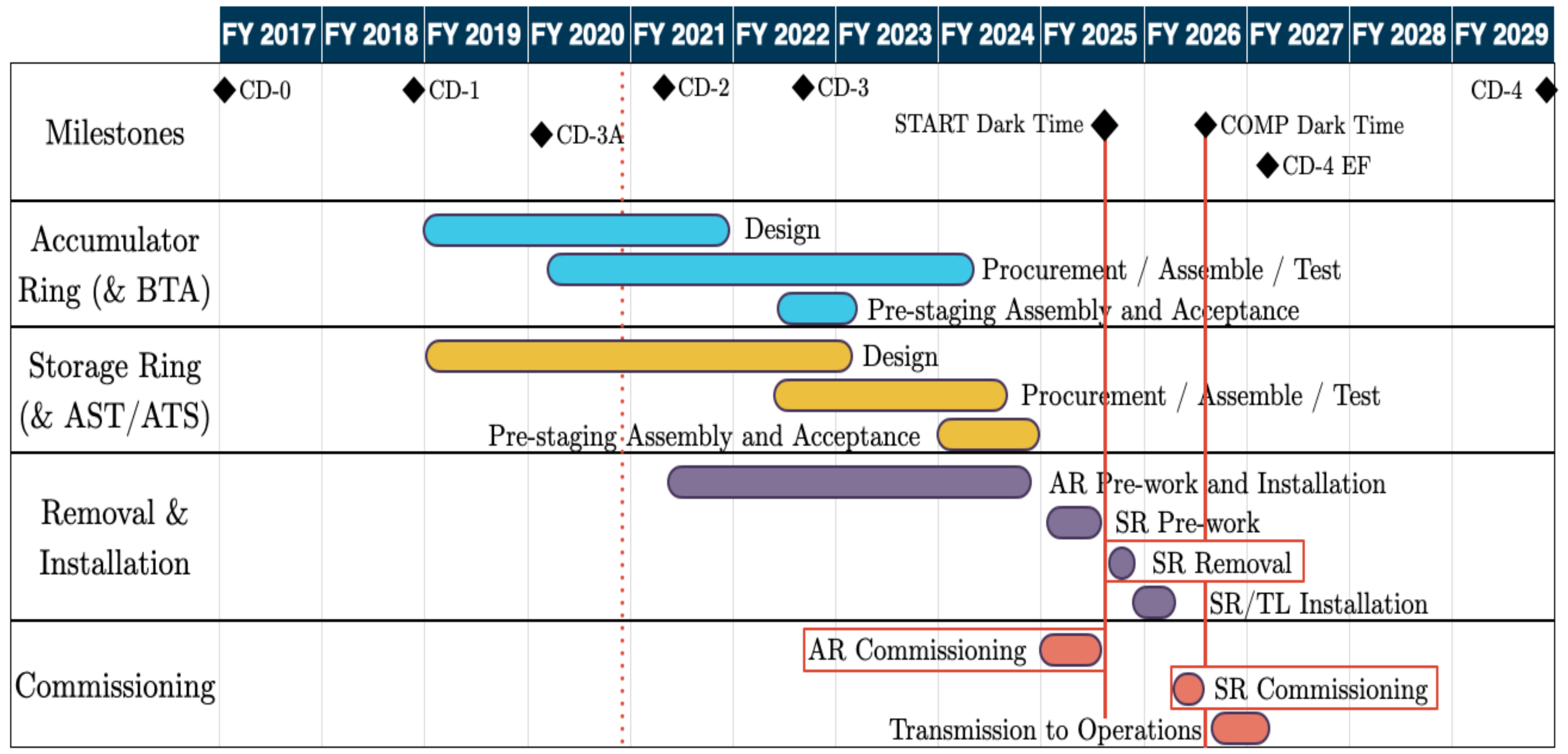
Advanced Light Source Upgrade: Timeline



Need For Realistic Commissioning Simulations

- Challenging lattice of future light sources
  - Strong focussing & small aperture
  - High sensitivity of machine to magnet errors
  - Getting from first injection to stored beam with realistic alignment tolerances is not straight forward
  - 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 implementation
  - 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 ALS



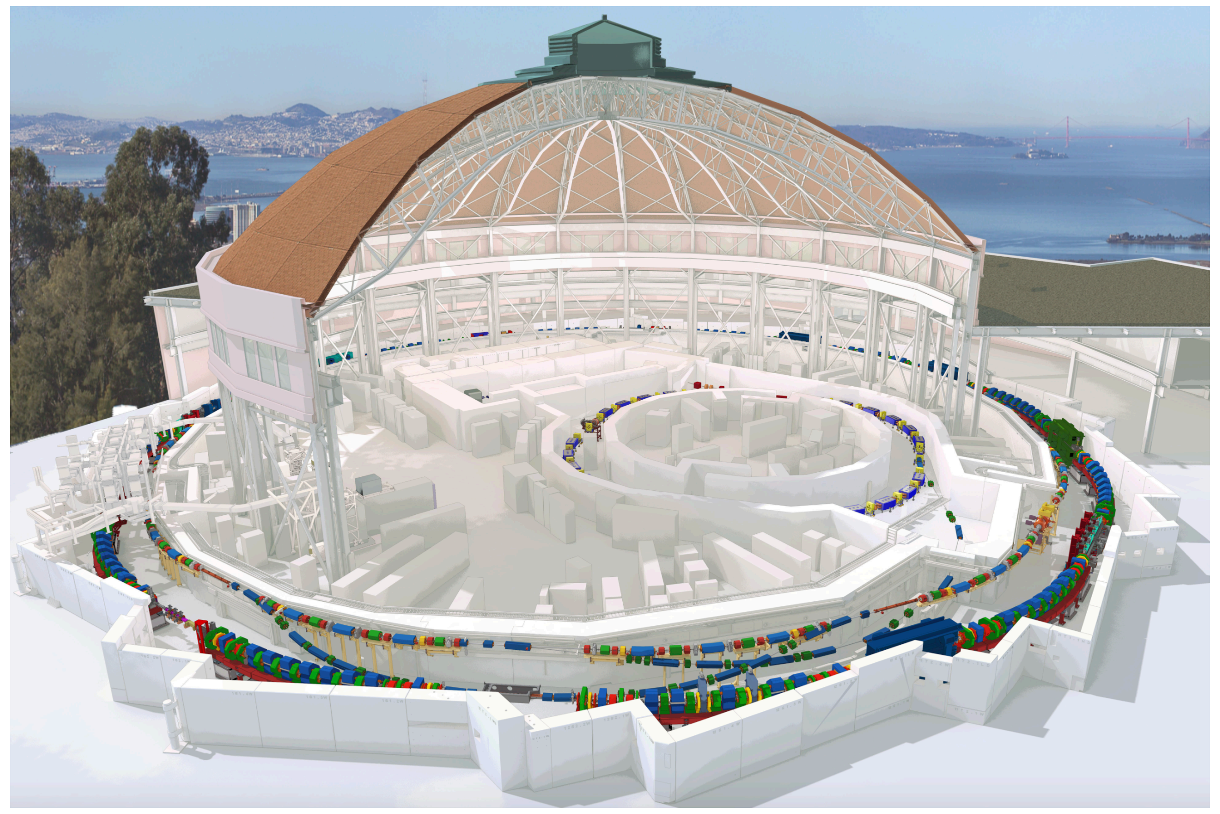


Toolkit Design

Limited Accessibility of Machine Properties

Power supplies

Operating machine



Diagnostic devices

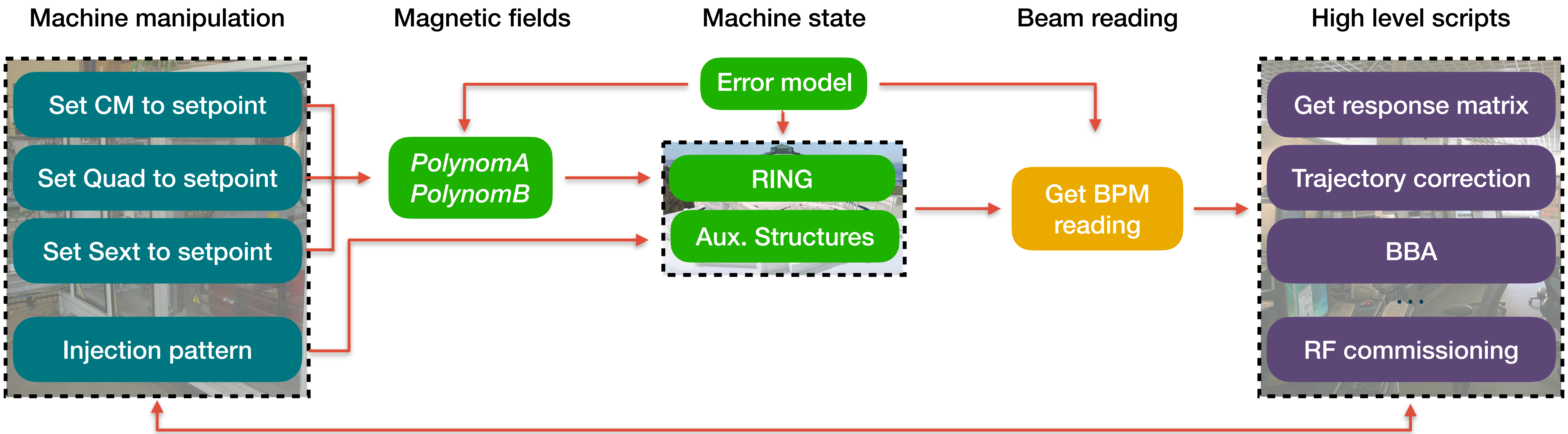
High level controls

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

Get BPM reading

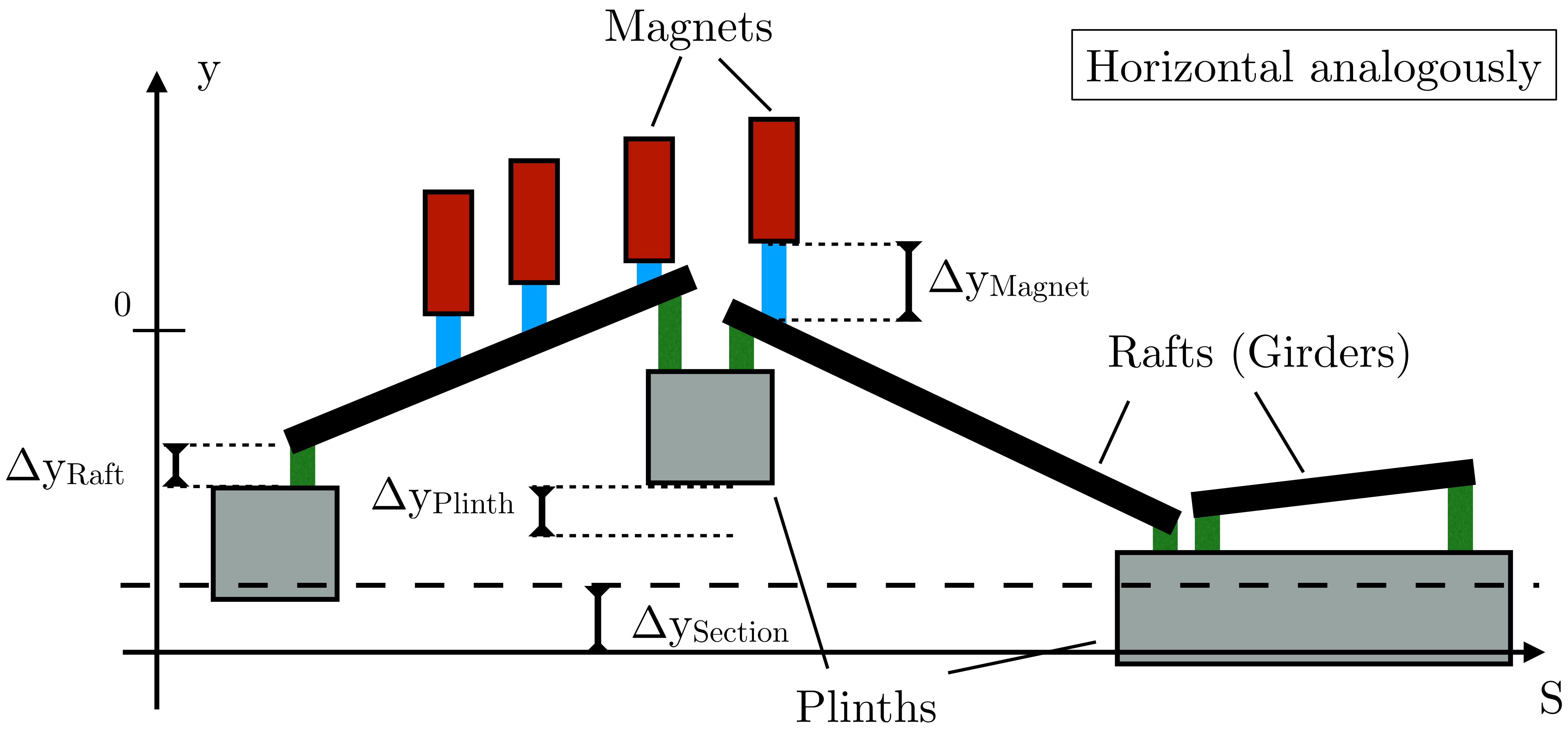
- Performs tracking including aperture
- Gets BPM signal from ensemble of particle trajectories

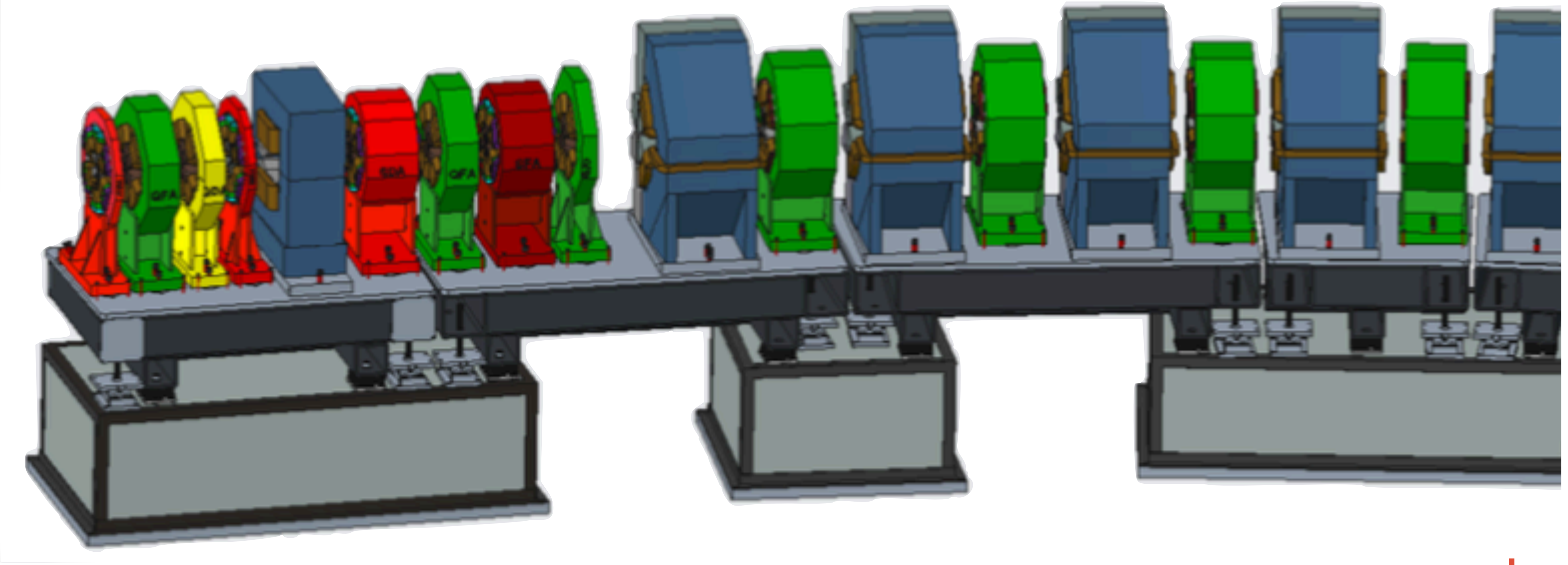
High level

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

Large Number of Error Sources Included

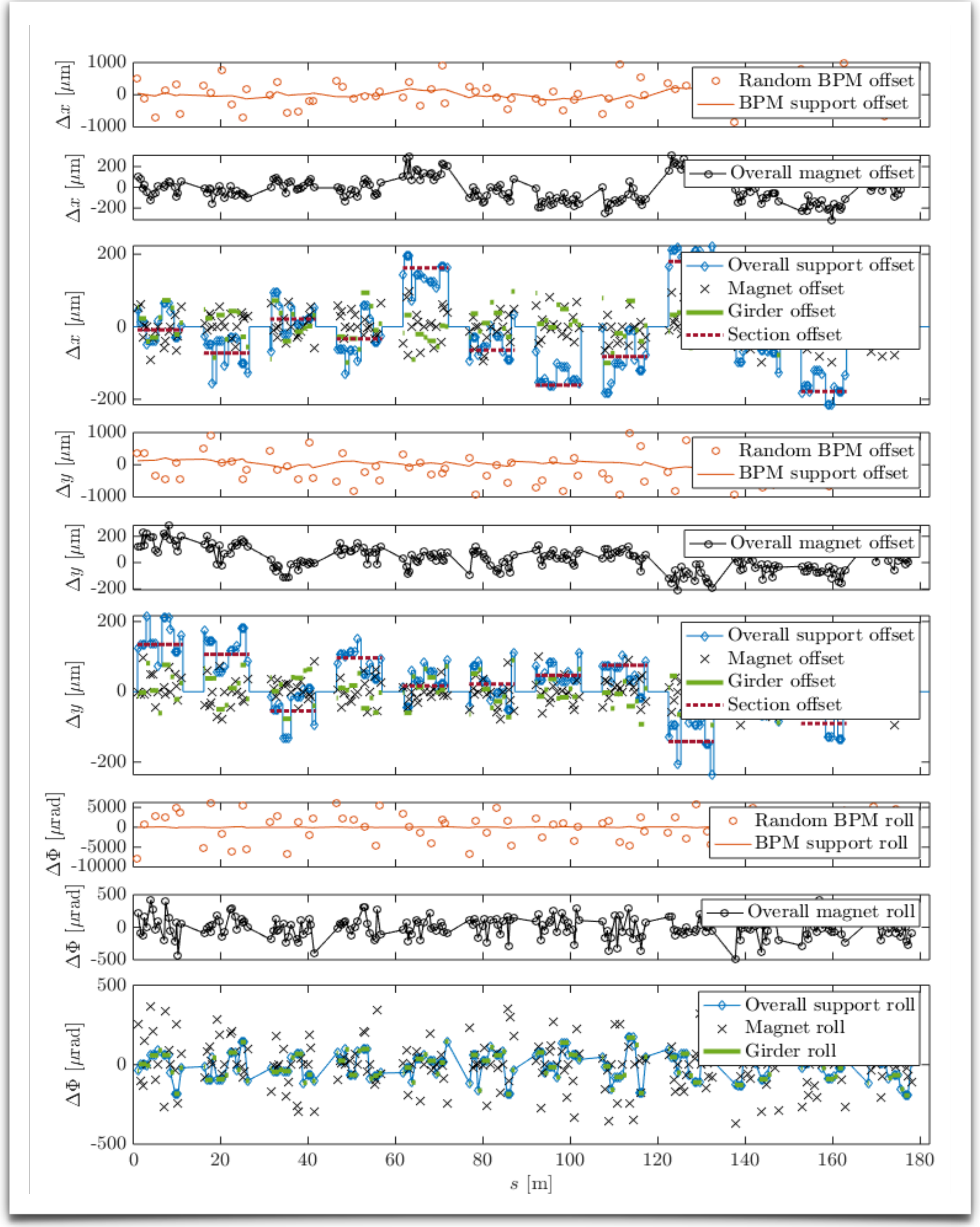
- Diagnostic errors
  - BPM offset
  - BPM cal. error
  - BPM noise (TbT/CO)
  - BPM roll
  - CM cal. error
  - CM roll
  - CM / skew-quad limits
- Support Structure
  - Rafts, Plinths, Sections
  - Roll & Offsets
- Circumference
- Higher Order Multipoles
  - Systematic
  - Random
- Magnets
  - Offset
  - Roll
  - Strength
  - Calibration
- RF errors
  - Phase
  - Frequency
  - Voltage
- Injection
  - Static
  - Jitter



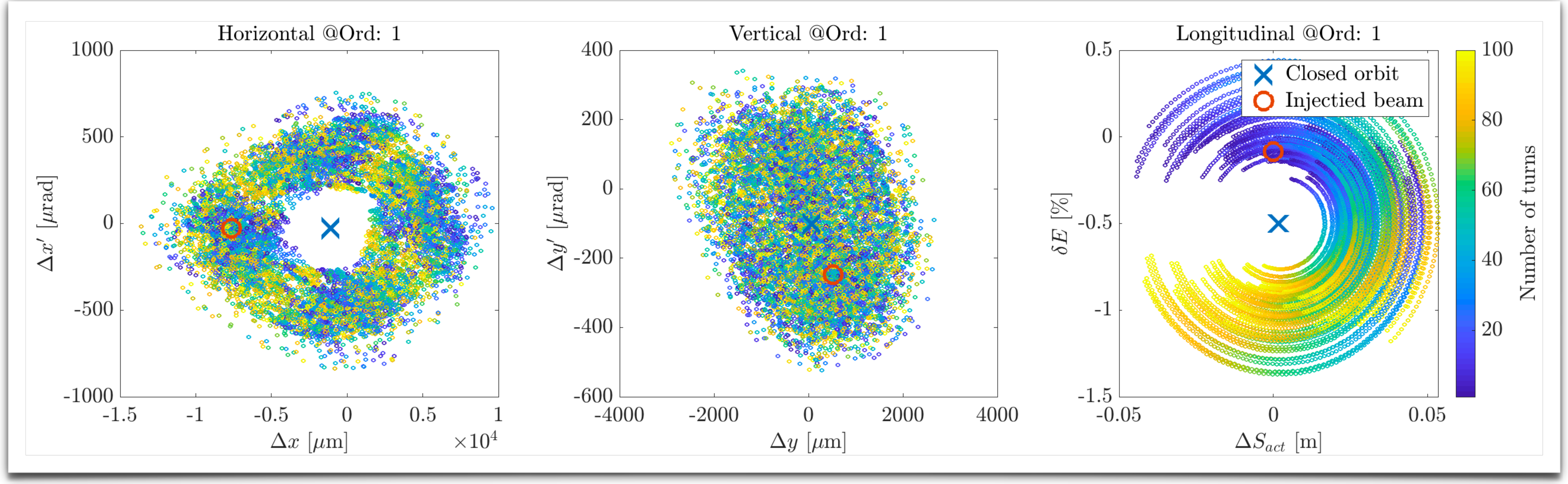


Visualization Tools

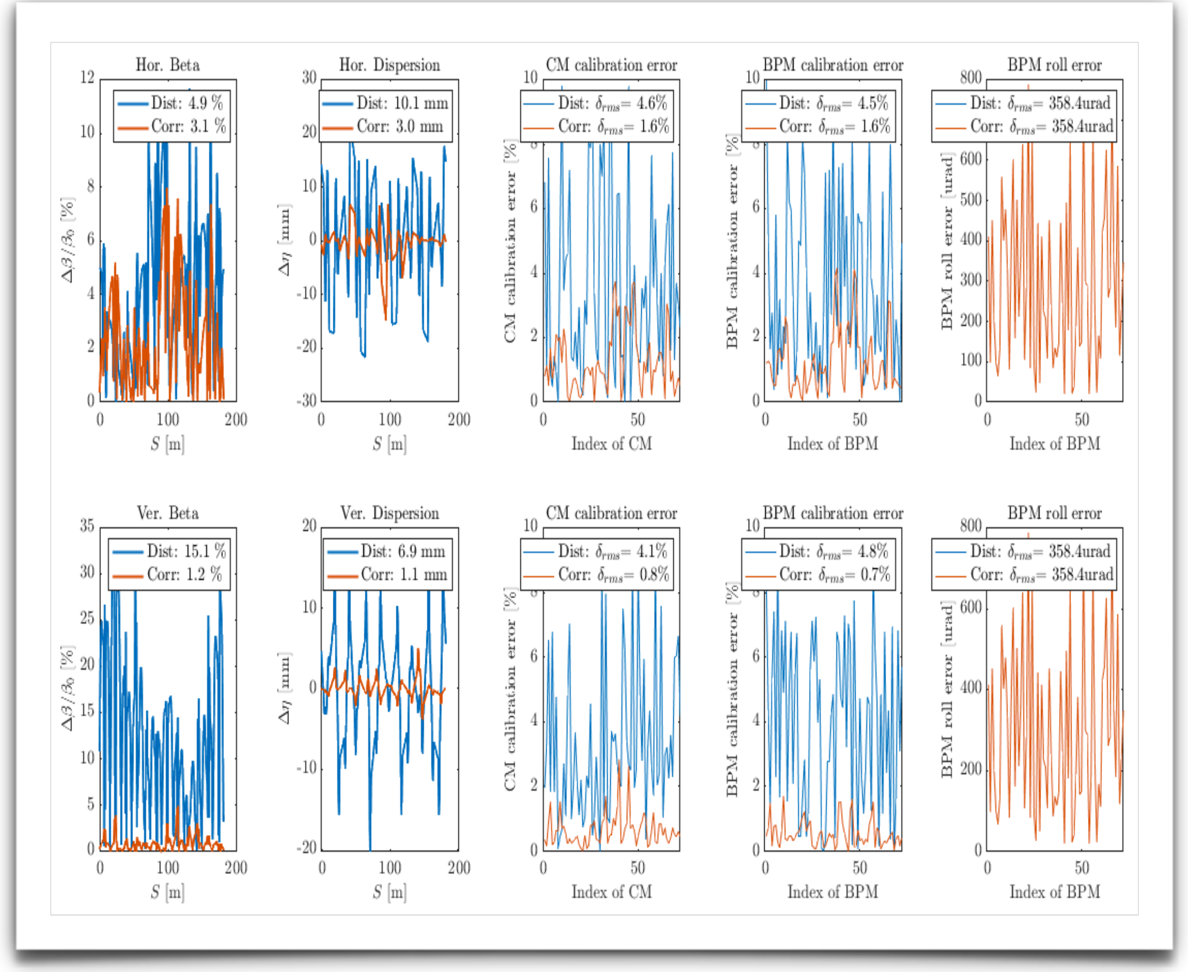
Misalignments



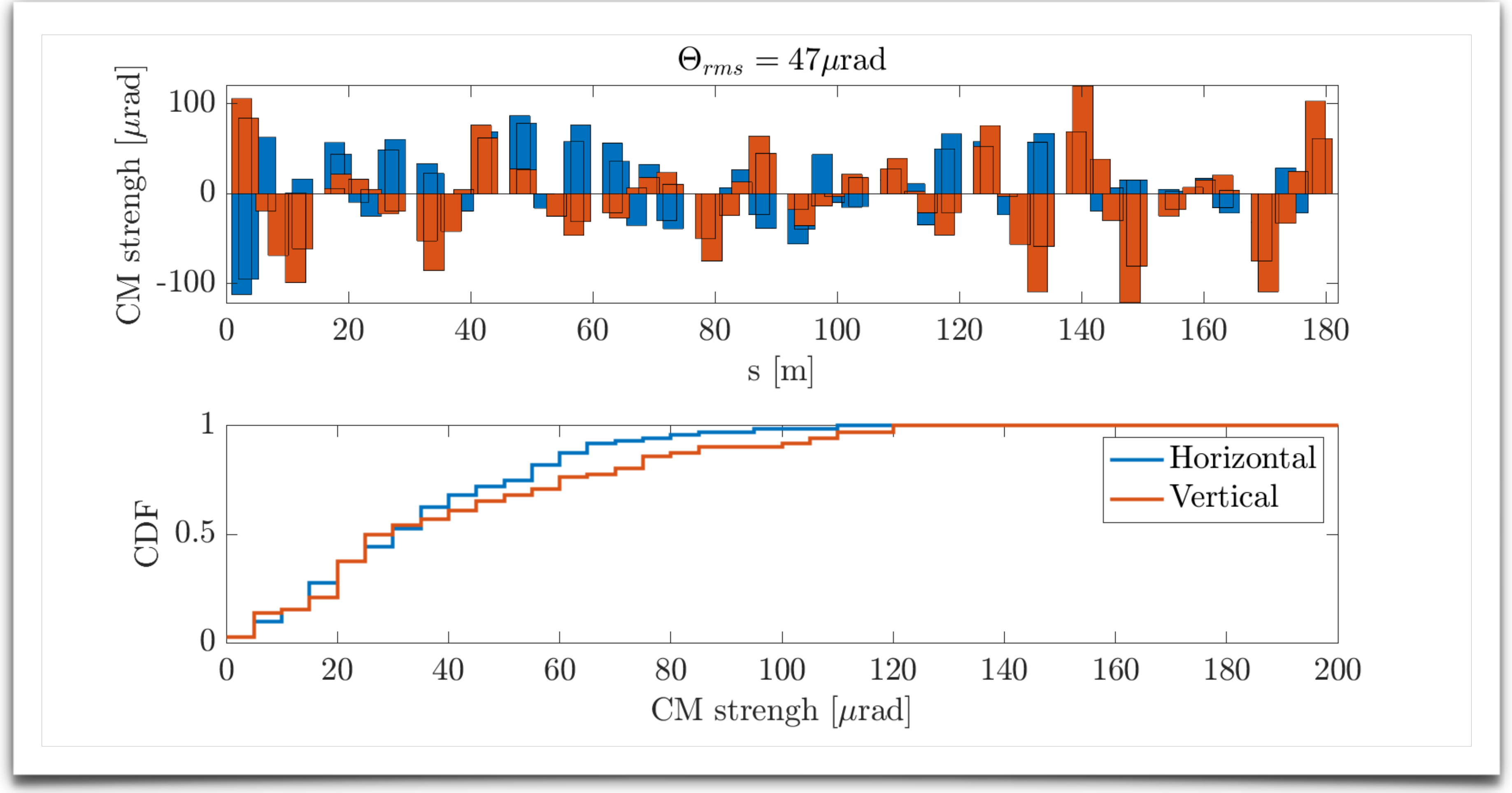
Turn-by-turn Phase Space



LOCO Status

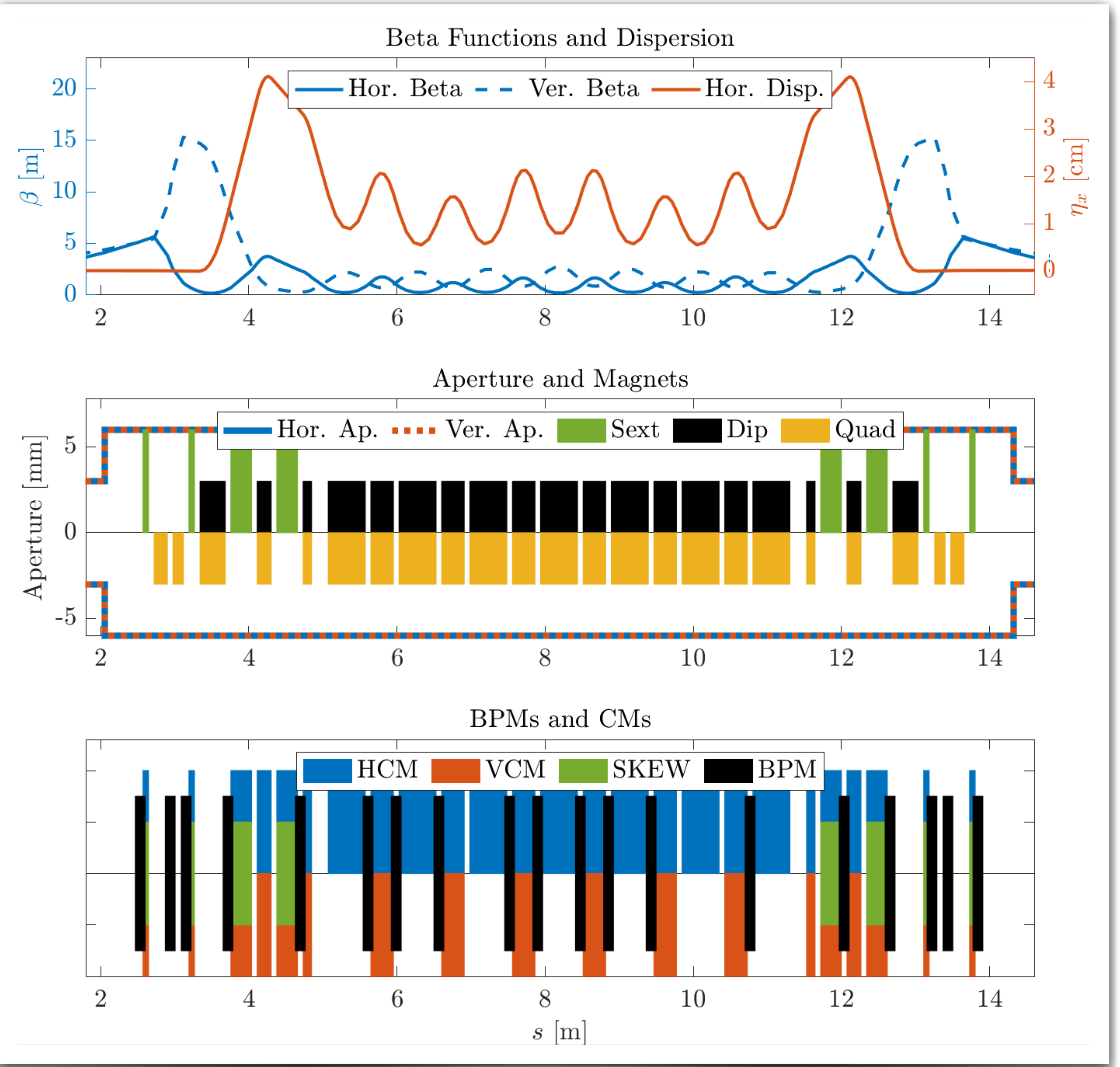


Corrector Strength

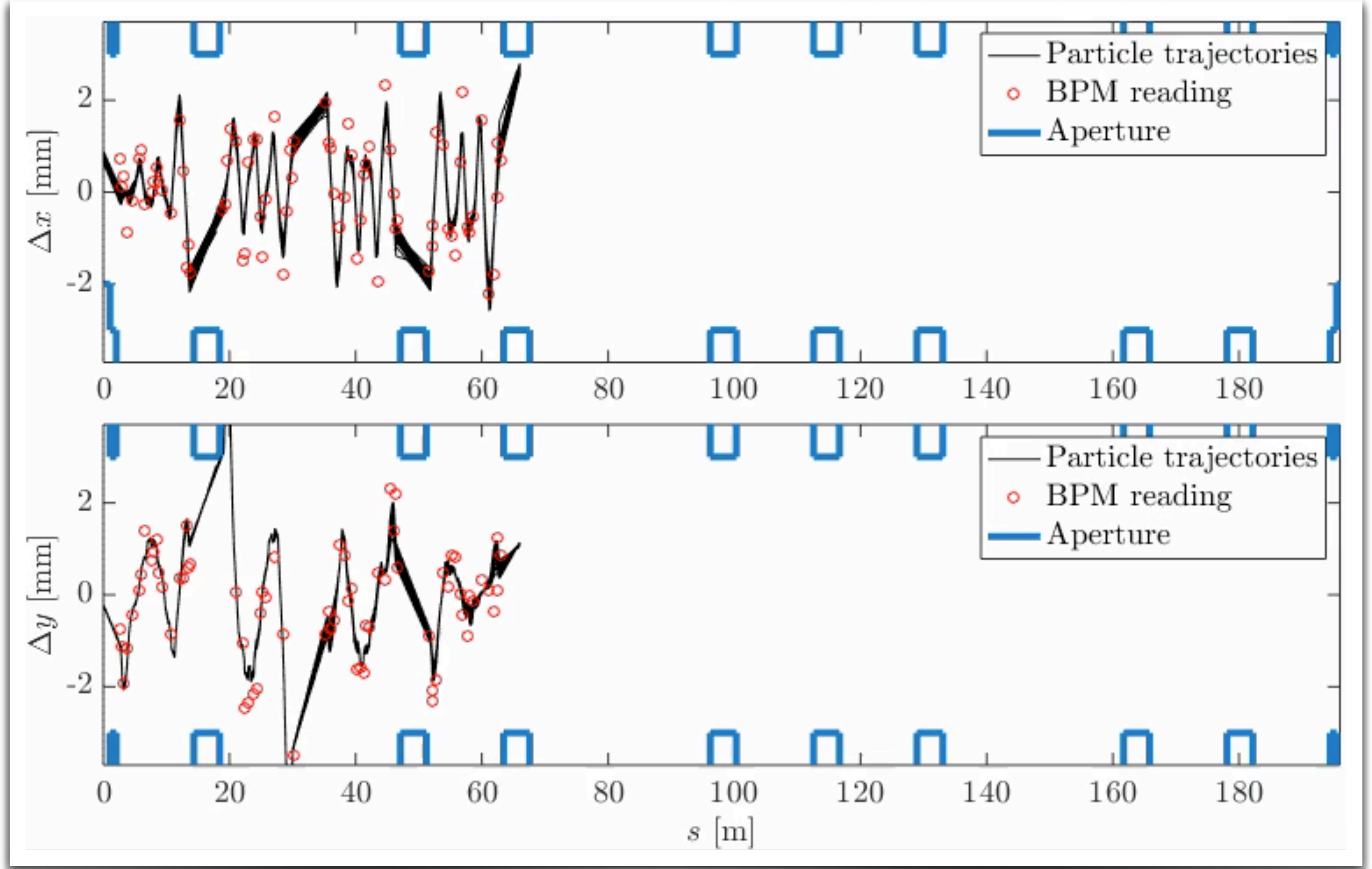


Visualization Tools

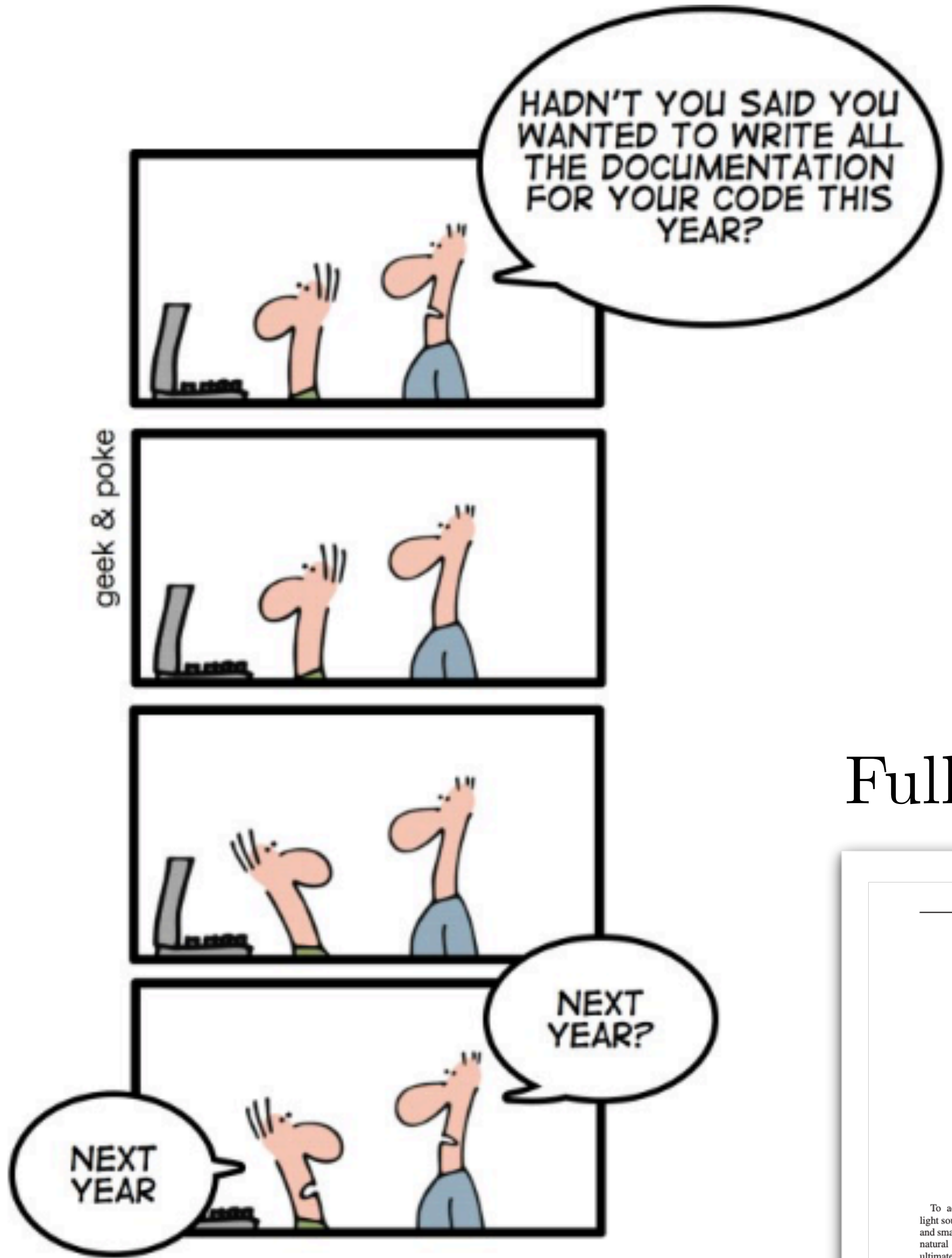
Lattice and Element Registration in Toolkit



Trajectories/Orbit and BPM Readings



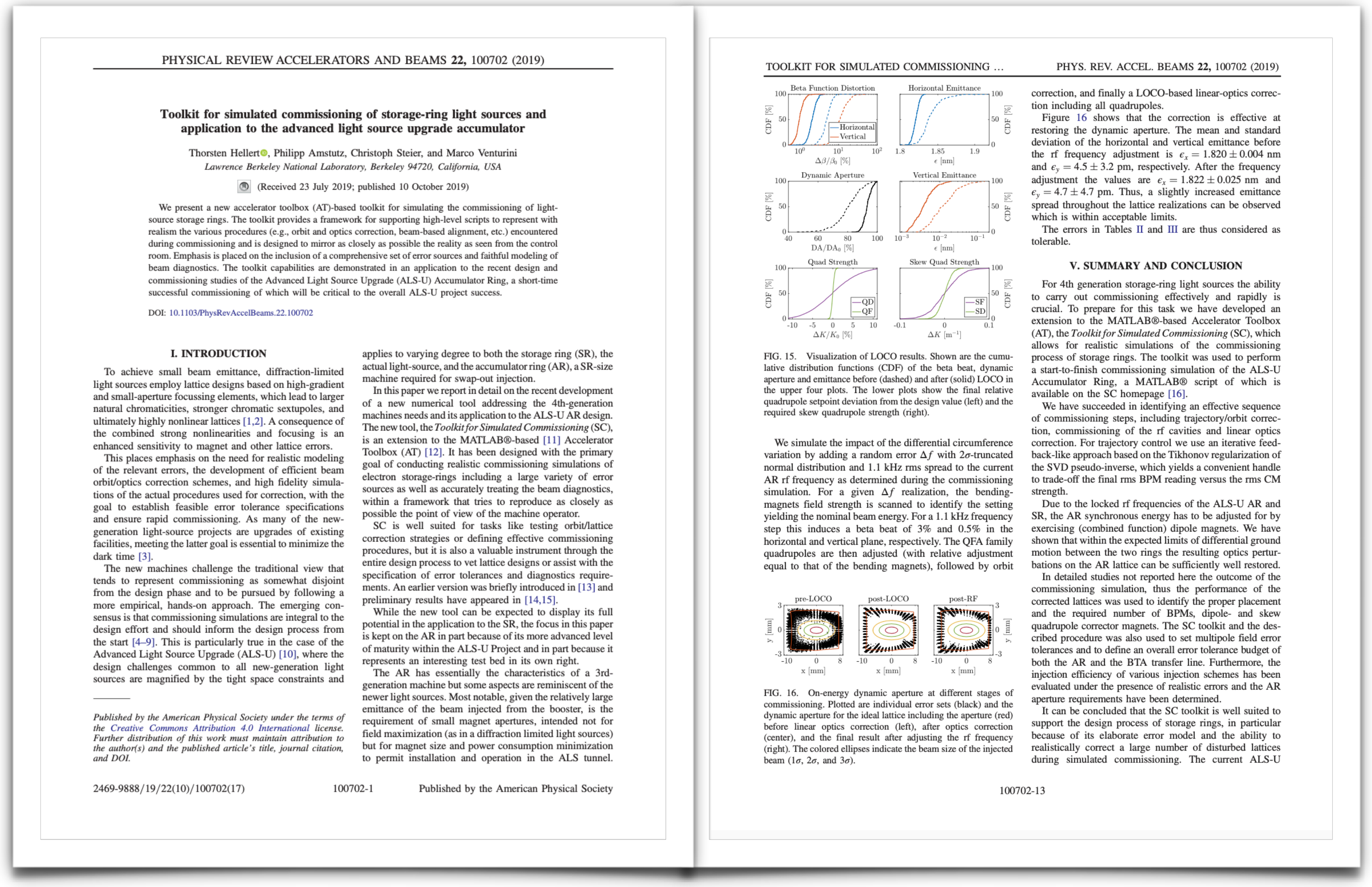
Comprehensive Source Code Documentation



Extensive Code Comments

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

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

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

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

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

Full ALS-U AR Scripts (PRAB 22/100702)



Version Control

Online Manual

SC Manual

T. Hellert – thellert@lbl.gov

Please check the release notes for code changes.

Introduction

Realistic simulations of the operation of a complex machine like an accelerator not only require a good model of the beam dynamics, but also have to acknowledge the fact that only incomplete information about the actual machine state is available during operation, due to the many unknowns in the machine geometry, the magnetic fields and the beam-diagnostic systems. The `SC` toolbox addresses this issue by making clear distinctions between machine parameters that are accessible during operation and the parameters that go into the beam dynamics simulation of the machine, e.g. by implementing a transfer-function, relating magnet setpoints to the actually realized magnetic fields.

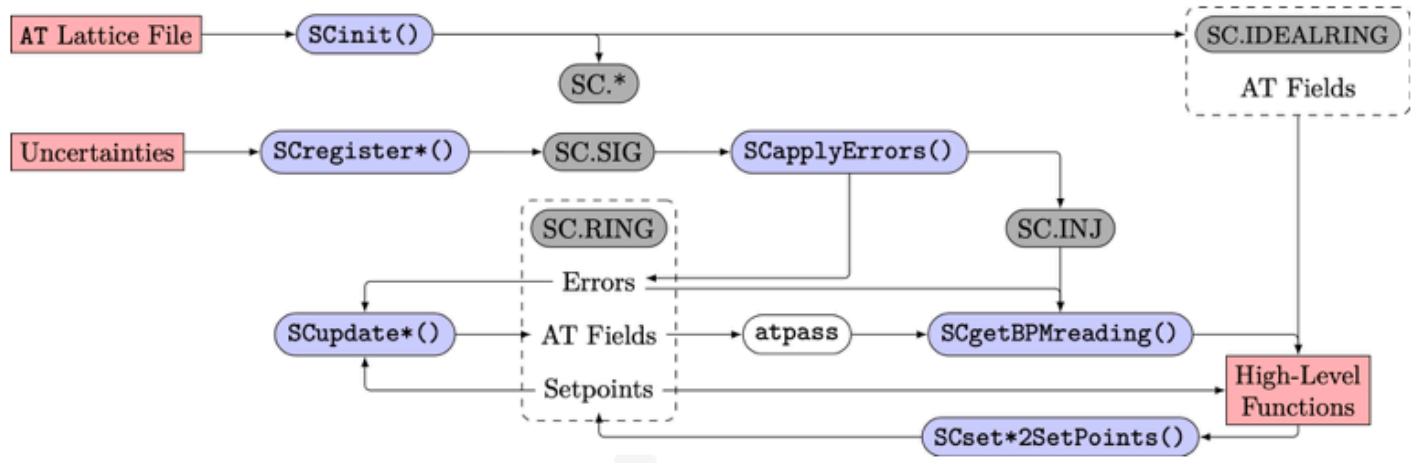


Figure 1. Schematic drawing of the workflow of the `SC` toolkit.

Typical usage of the `SC` toolbox follows the steps

- Initialization of the `SC` core structure
- Error source definition & registration
- Generation of a machine realization including errors
- Interaction with the machine

which are described in the following. Thereafter we describe the definition of error sources, followed by a usage example for a complete correction chain and a list of all implemented functions.

Initialization

In a first step, the user initializes the toolbox by calling SCinit with the AT lattice of his or her machine as input. This sets up a matlab-structure, usually assigned the variable name `SC`, with which nearly all subsequent functions of the toolbox interact. Within this central structure all relevant information about the machine and the error sources is stored.

Error Source Definition & Registration

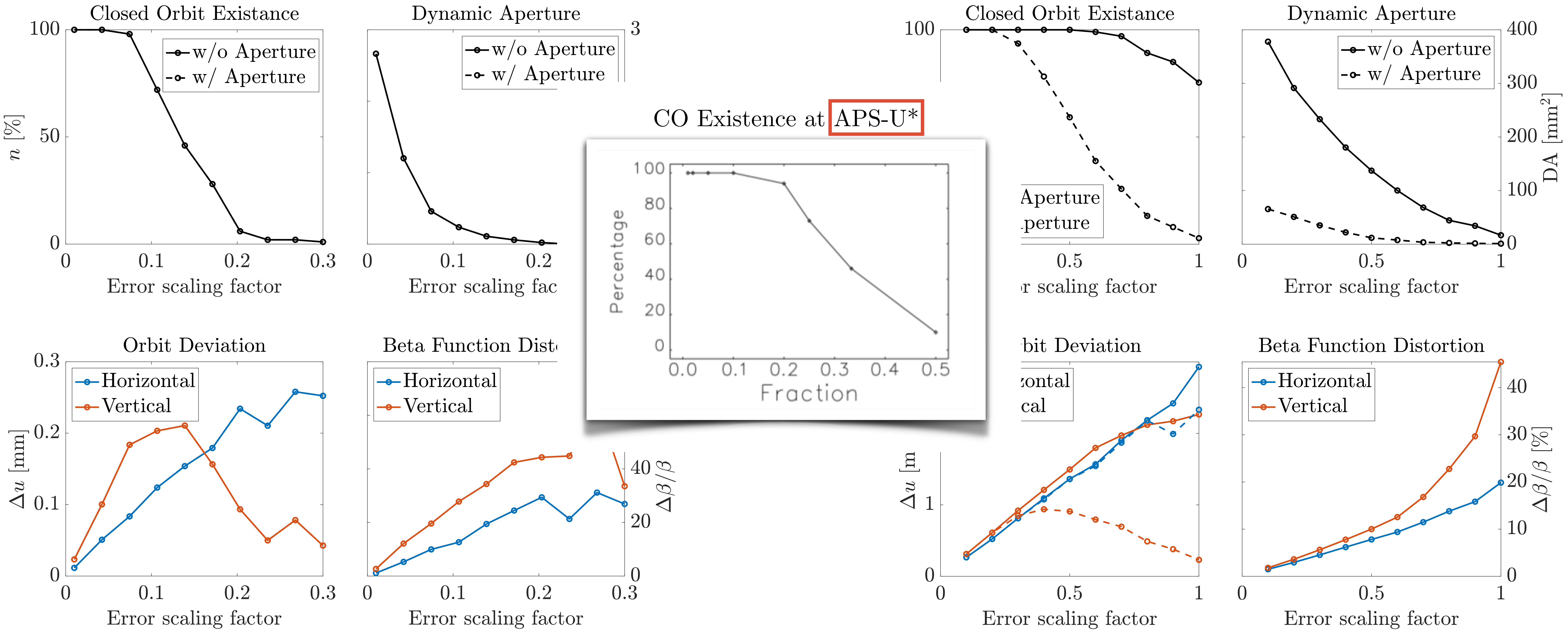
In the next step, the user registers elements like magnets, BPMs or cavities including all error sources they would like

Application Examples

Machine Sensitivity to Errors

ALS-U Storage Ring

ALS-U Accumulator Ring



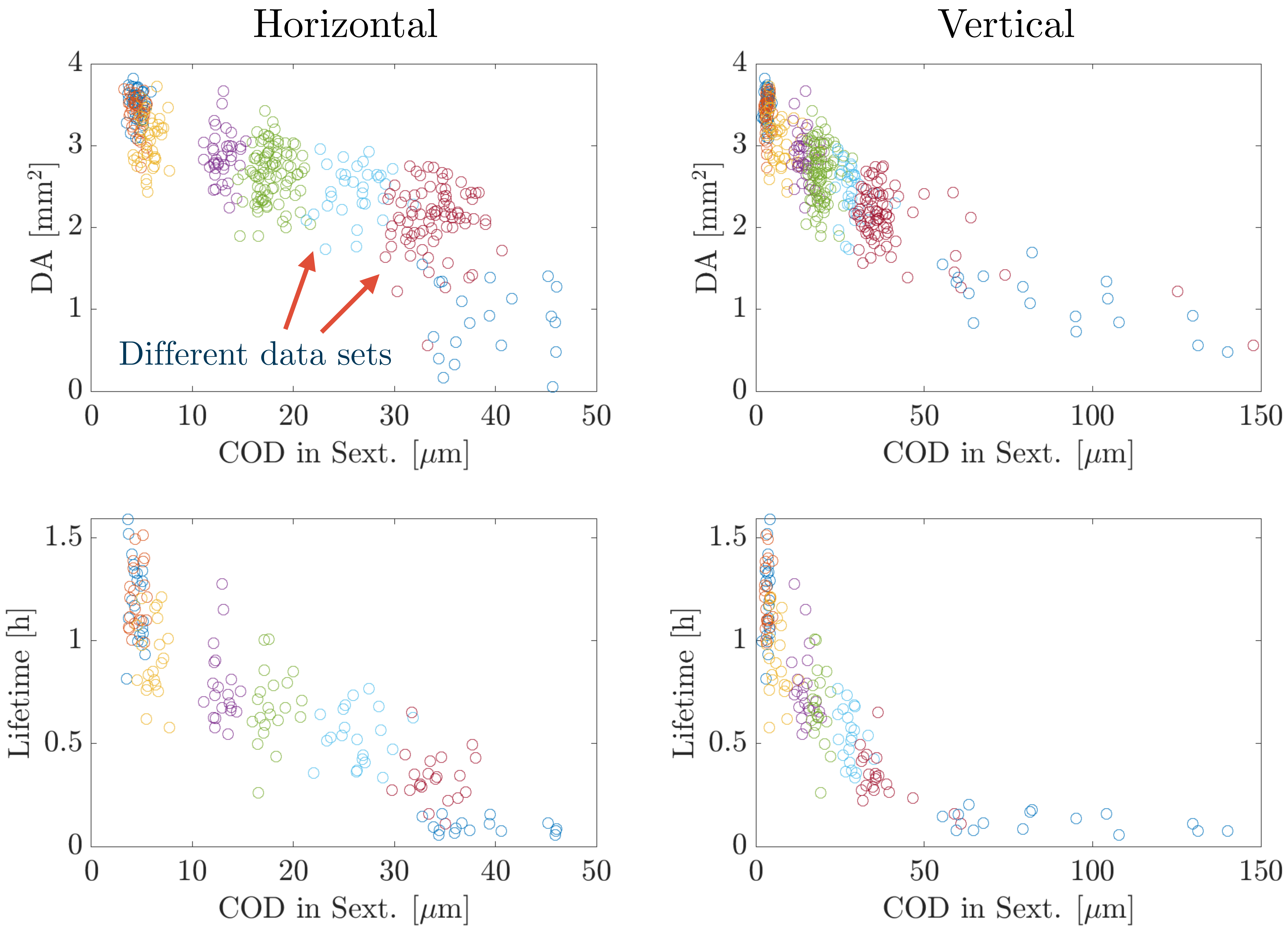
*) V. Sajaev, PRAB 22,040102

Correction Chain for ALS-U SR Commissioning

- Initial Transmission
  - Achieve first turn transmission
  - 2-turn trajectory correction
- Multi-Turn Transmission
  - Trajectory based BBA
  - Static injection error correction
- Sextupole Ramp-Up
  - In loop with 2-turn trajectory correction
- Achieve Beam Capture
  - RF phase correction
  - RF frequency correction
  - Tune scan
- Linear Optics Correction
  - Beam based alignment
  - Closed orbit correction
  - LOCO based optics correction
- ID Compensation
  - Close IDs and include kick maps
  - Global optics correction
  - Evaluation of lattice properties

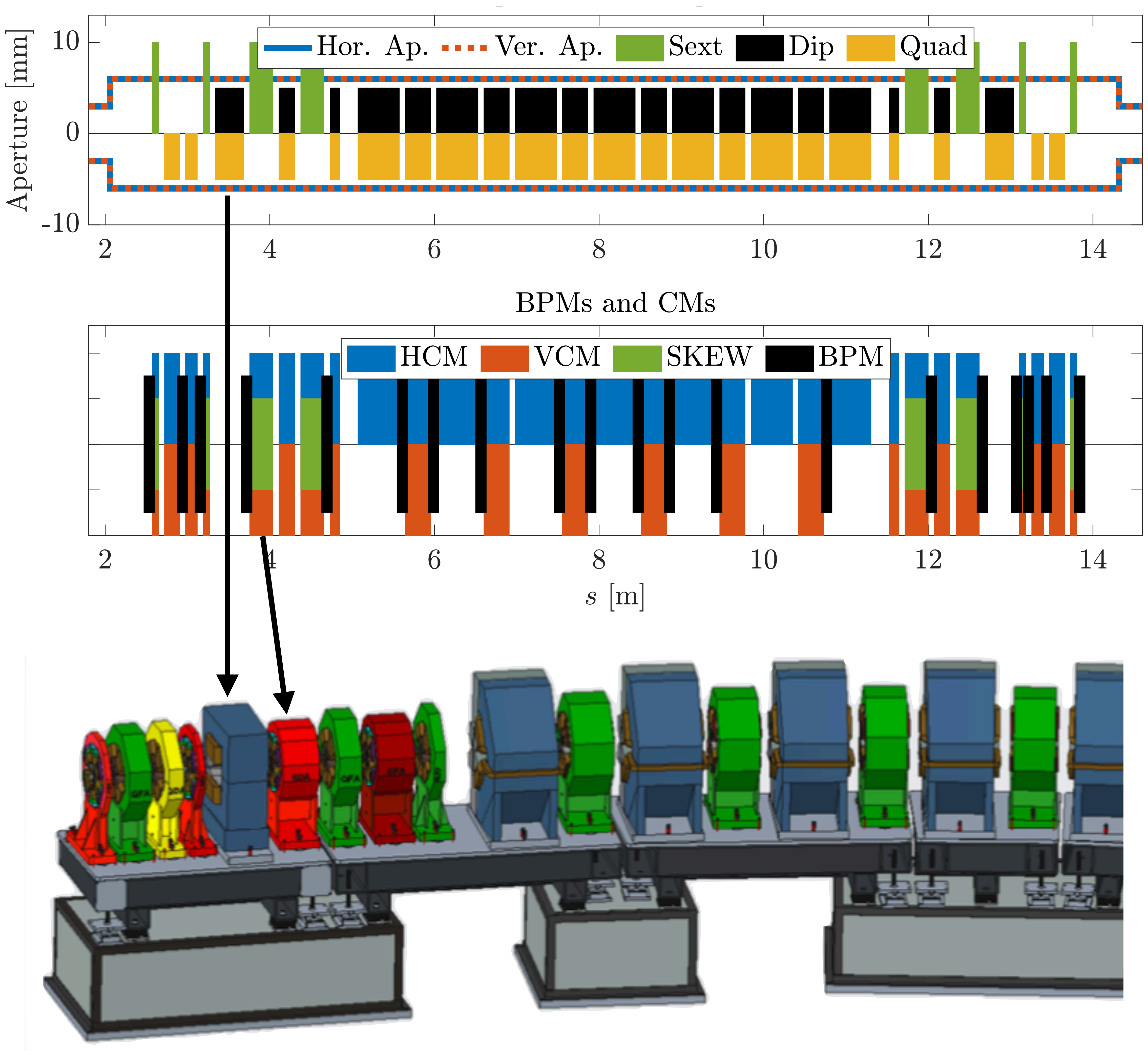
Importance of Orbit Offsets in Sextupoles

- Errors included in all runs:
  - RF, Injection, Diagnostic
  - Sys. multipoles, magnet strength and roll errors
- Errors varied in all runs:
  - Girder/Plinth/Magnet offset
  - Assumed BBA accuracy
- Findings:
  - Correlation between pre-LOCO closed orbit deviation in sextupole magnets and post-LOCO performance
  - Lifetime virtually zero above COD of 40 µm rms
- Conclusion:
  - Small orbit deviation in sextupoles crucial for lattice performance



Beam Based Alignment on Quadrupole Trim Coils

- Detailed Study of BBA Possibilities Performed:
  - **Regular BBA on quadrupoles**
  - Using main sextupole coils with stored beam
  - Using **quadrupole trim coils in sextupoles** with trajectories (2 turn) & **with stored beam**
  - Assumed K values for quadrupole trim coils: +/- 0.26 m^{-2}
- Sextupole magnets generally off (trajectory-based BBA using 2-turn transmission):
  - Exercise sextupole coils of targeted sextupole magnet. BBA accuracy: ~60 μm
  - Exercise quadrupole coils of targeted sextupole magnet. BBA accuracy: ~25 μm



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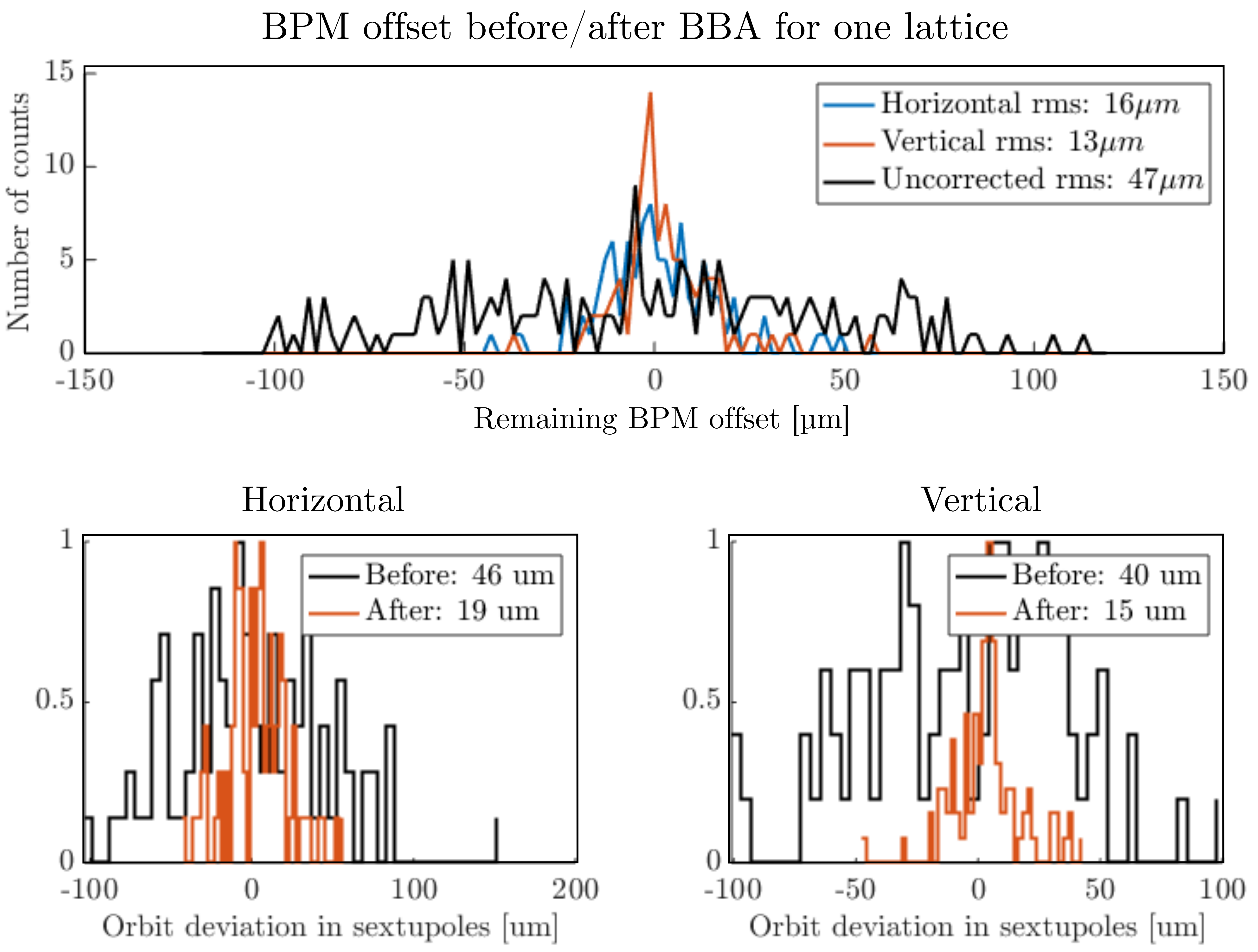
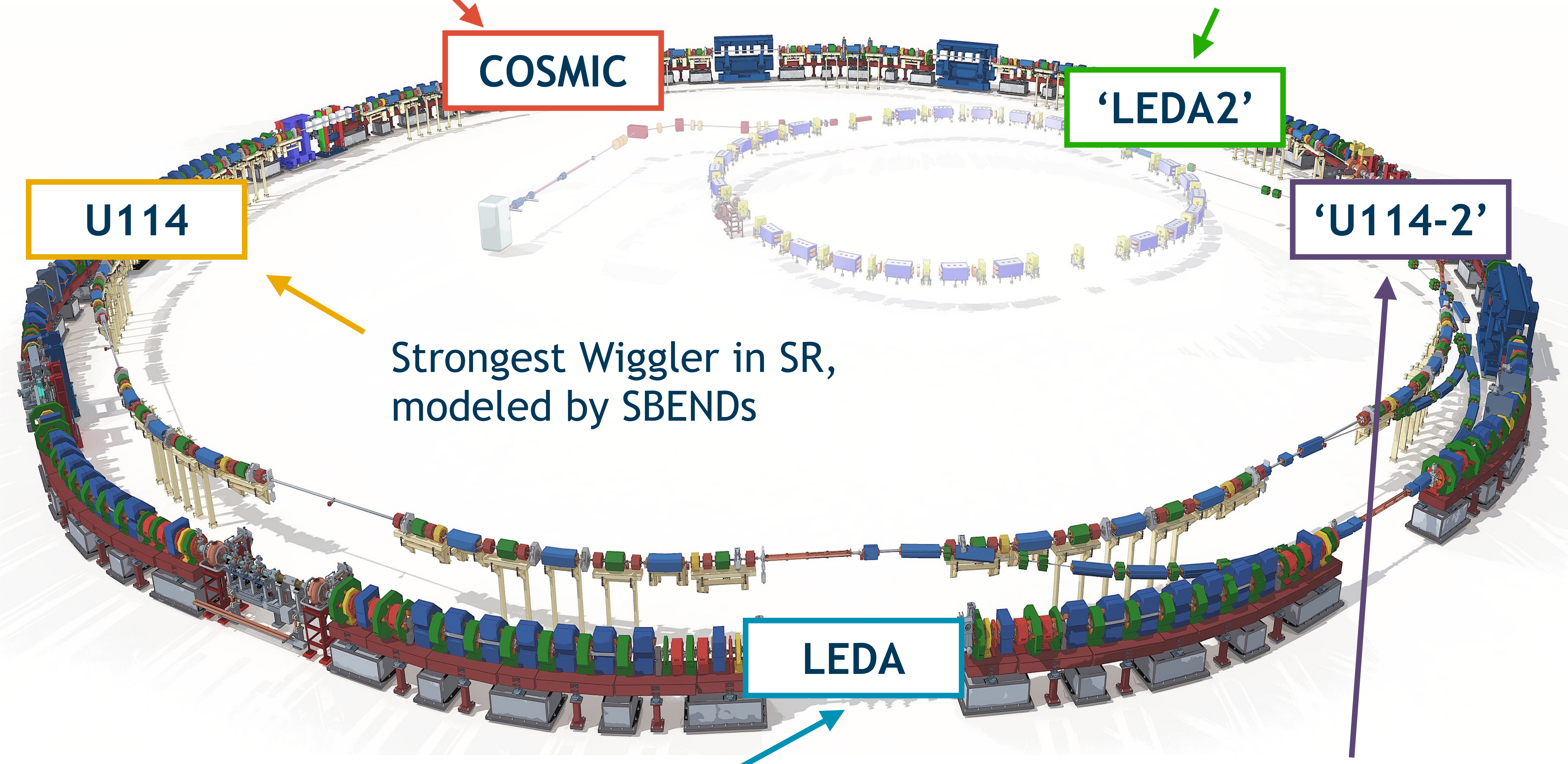
- Sextupole magnets generally off (trajectory-based BBA using 2-turn transmission):
  - Exercise sextupole coils of targeted sextupole magnet. BBA accuracy: ~60 µm
  - Exercise quadrupole coils of targeted sextupole magnet. BBA accuracy: ~25 µm
- Sextupole magnets generally on (closed-orbit-based BBA):
  - Exercise sextupole coils of targeted sextupole magnet. BBA accuracy: ~30 µm
  - Exercise quadrupole coils of targeted sextupole magnet. BBA accuracy: ~15 µm
- Conclusion:
  - BBA accuracy of 15 µm achievable at BPMs adjacent to sextupole magnets



Realistic Modeling of ID Compensation Important

- Simplified Set of IDs
  - 5 out of 14 IDs clearly dominate dynamics
  - 3 kick maps
  - 2 series of SBENDs
- Impact of IDs Thoroughly Analyzed
  - Dominating: lin. local phase advance distortion
  - Dynamic multipoles higher than linear focusing and typical ID multipoles not very relevant
- Global Optics Correction*
  - Using all quadrupoles and global response matrix of beta beat and tune shift at sextupole magnets, SVD
  - Including tune, chromaticity, orbit correction



*) T. Shaftan et al., *Conf.Proc.C* 060626 (2006) 3490-3492

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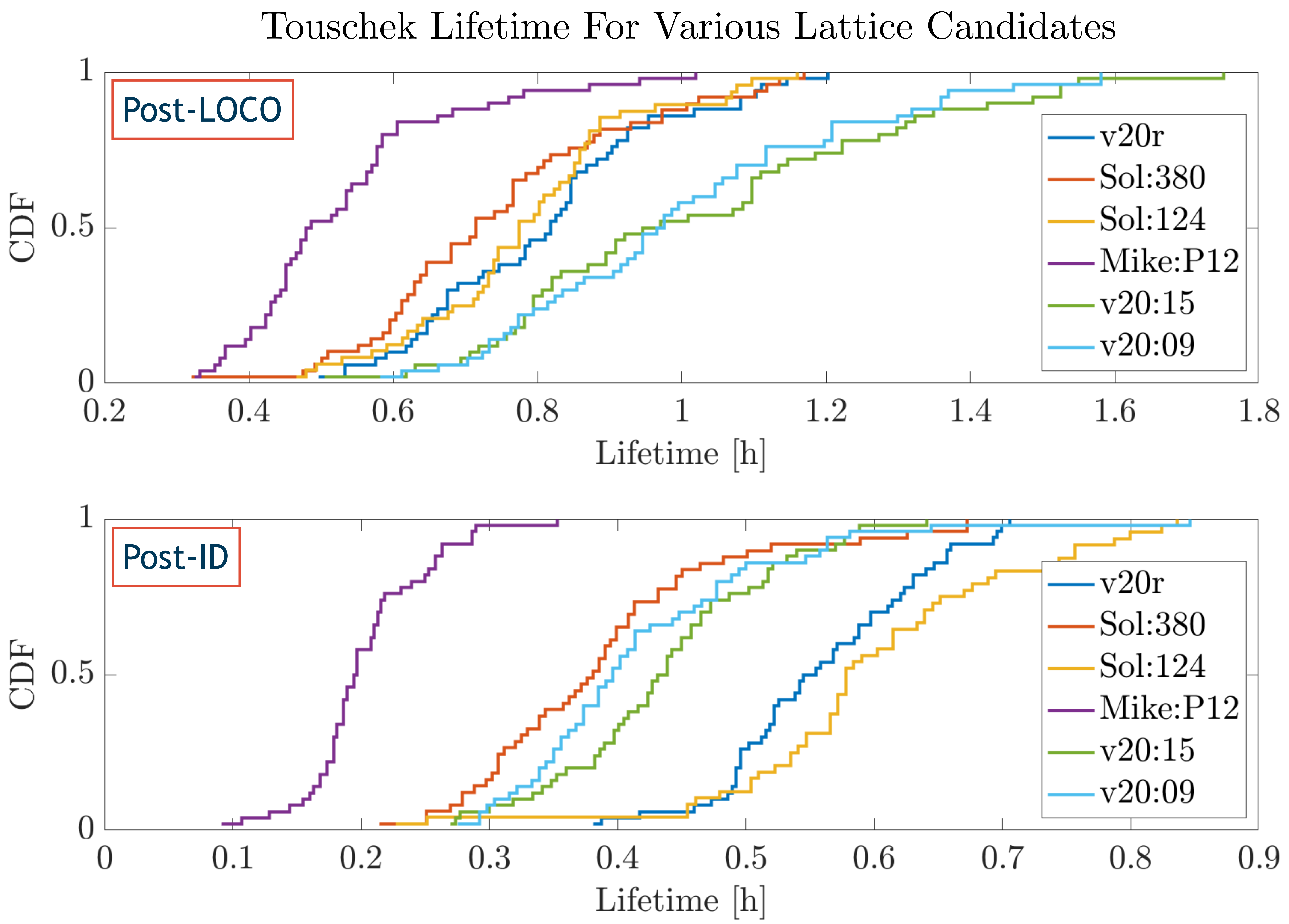
  - Including tune, chromaticity, orbit correction
- Final Results Guide Lattice Selection
  - Relative lattice performance after ID compensation differs significantly from 'post-LOCO' state



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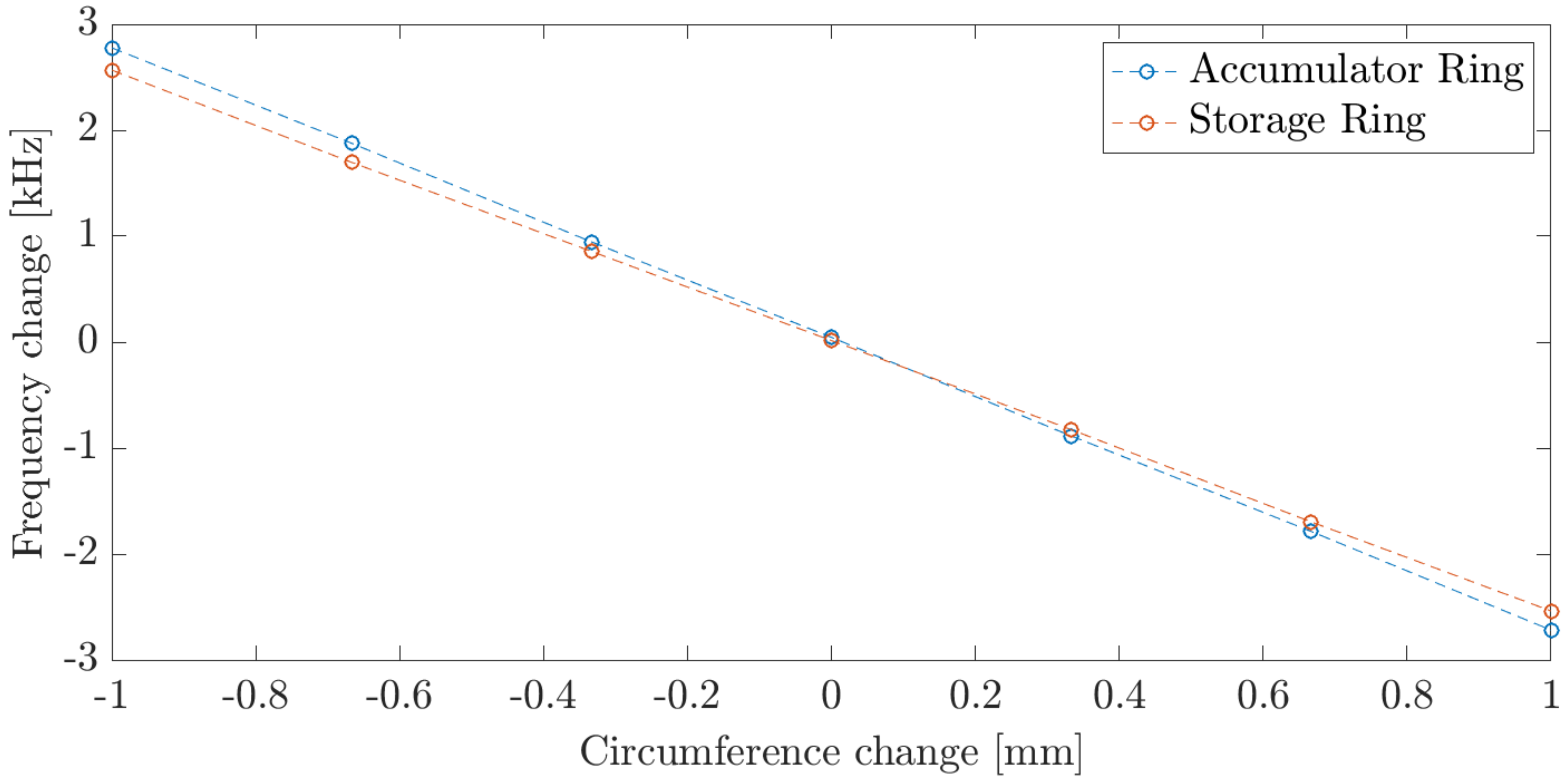
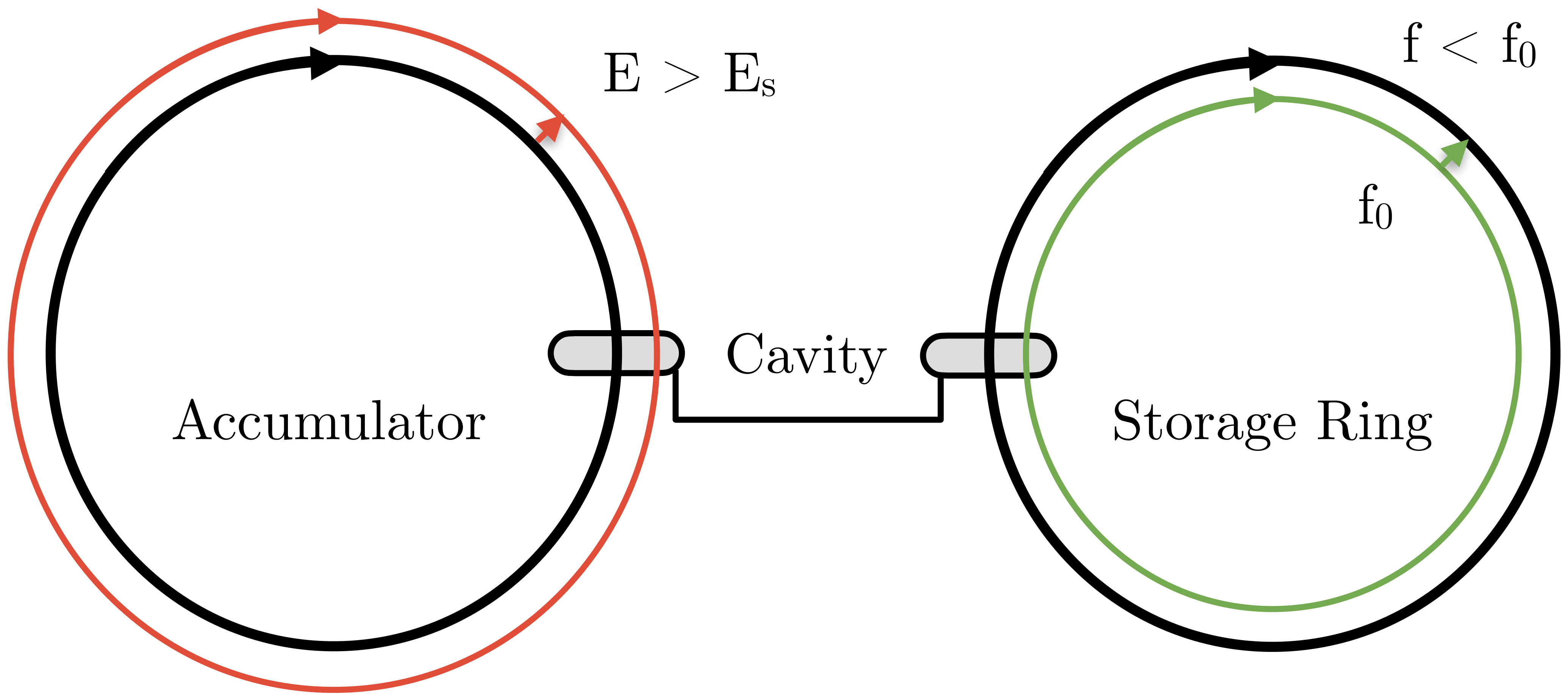
AR-SR Differential Circumference Change

- Locked Frequencies in SR and AR
  - Due to synchronization between AR and SR
- AR Energy Adjusted by Dipoles
  - AR frequency defined by SR circumference
  - AR dipoles used to change AR energy





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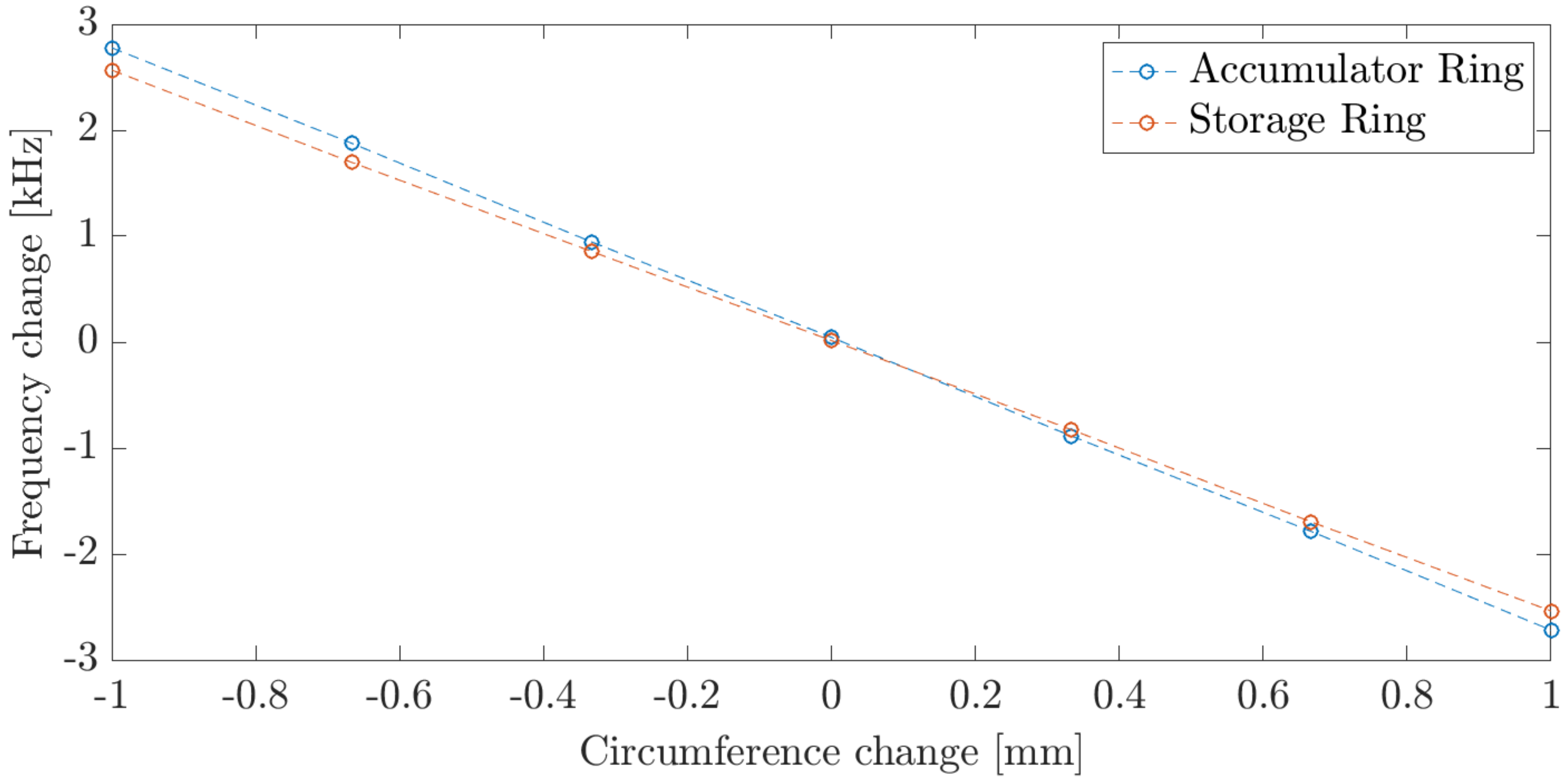
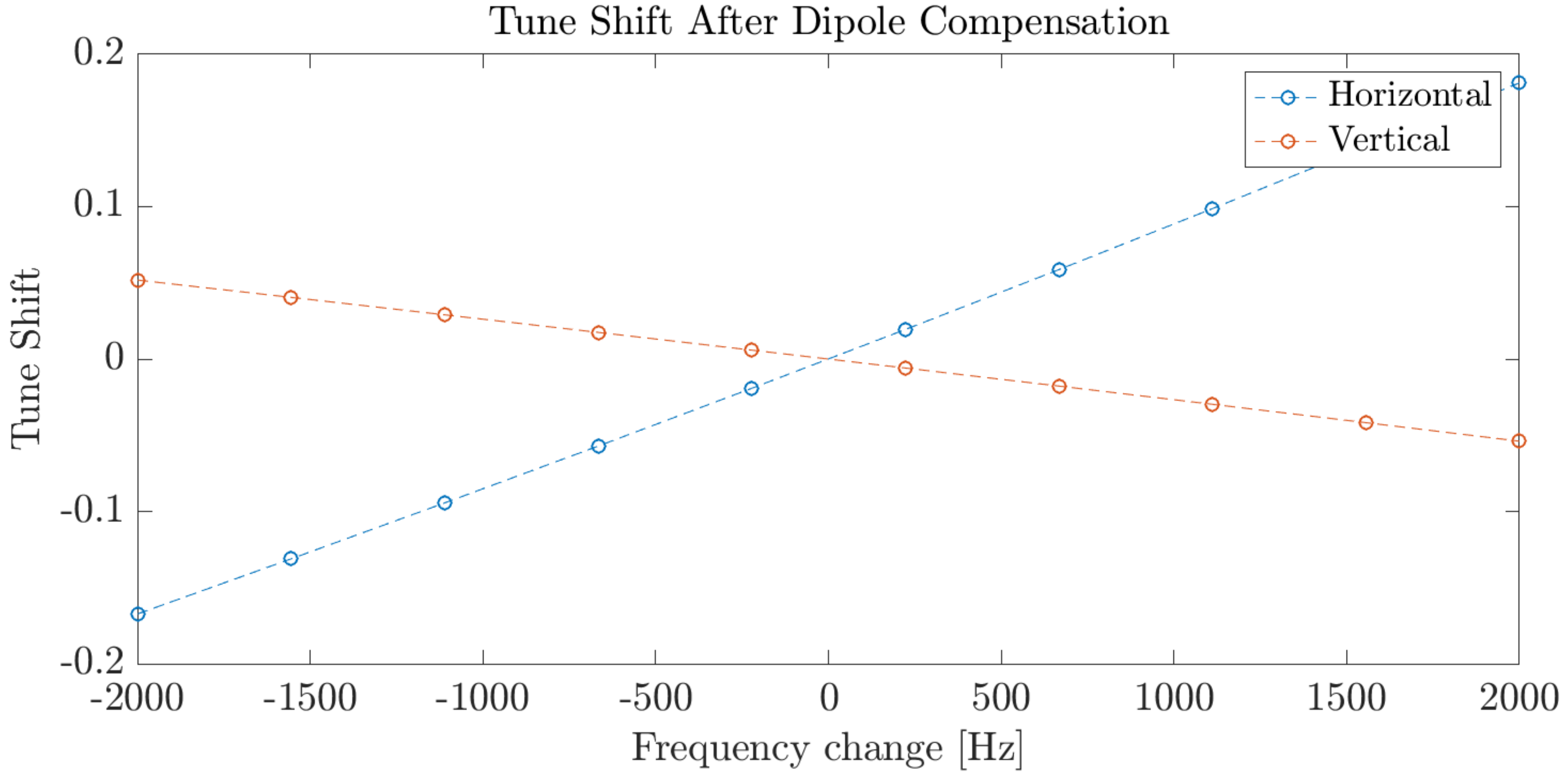
- AR Combined Function Dipoles
  - Significant tune shift after adjustment
  - Must be corrected by other quadrupoles





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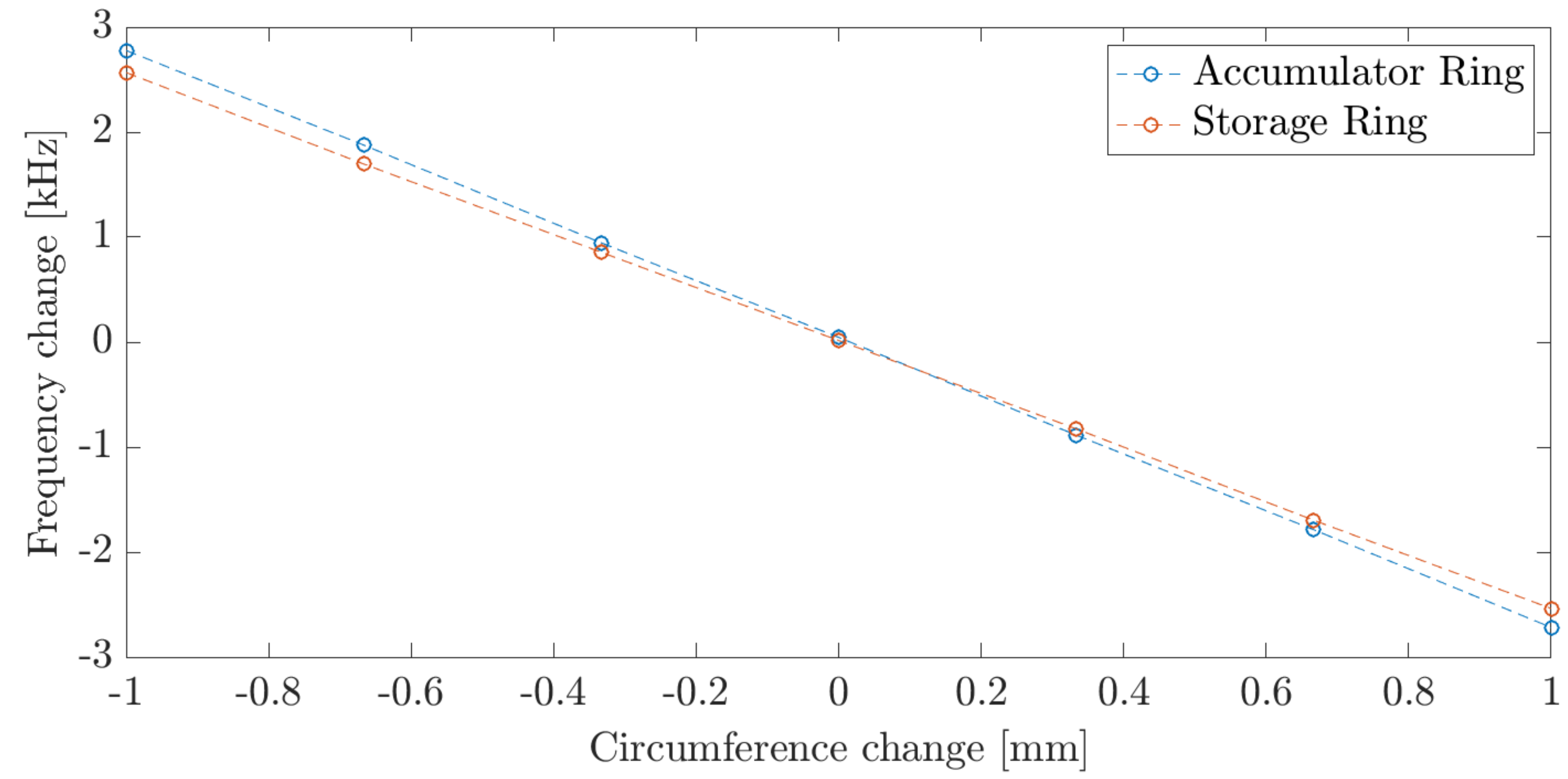
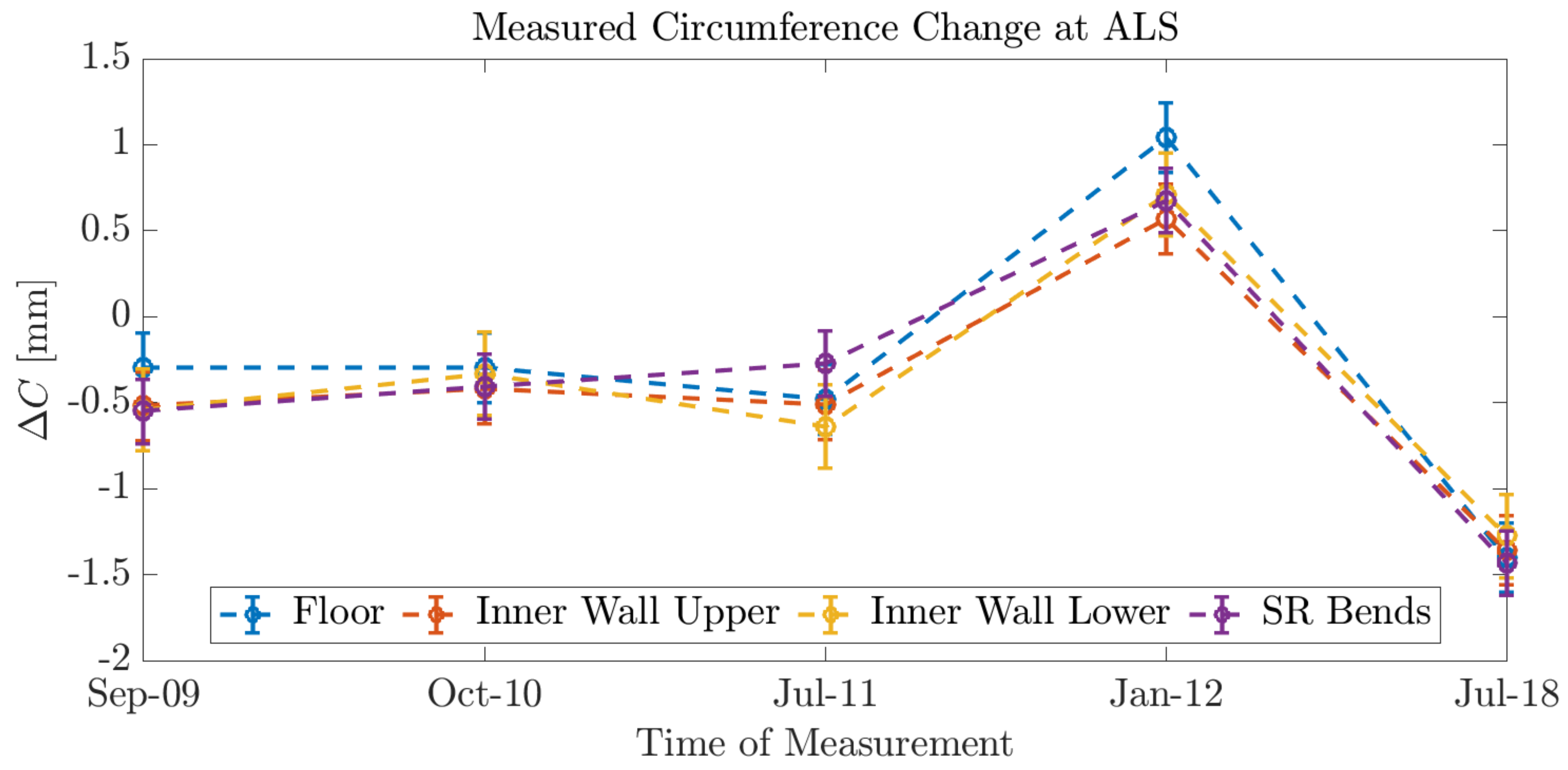
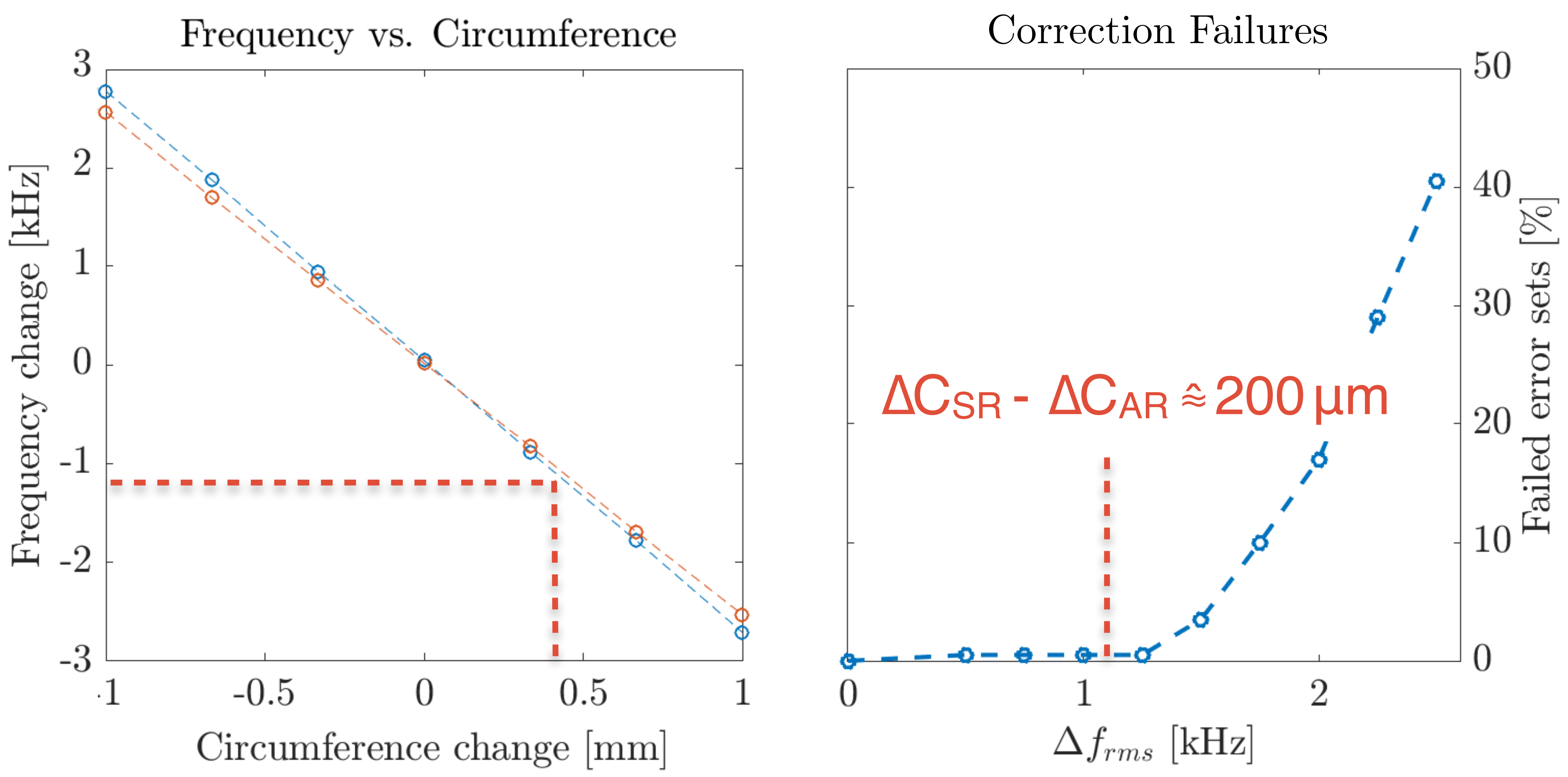
- ALS Circumference Measurements
  - 200 µm initial circumference error of both rings
  - Annual ground motion ≈ 2 mm
  - 125 µm rms between BEND and wall monuments

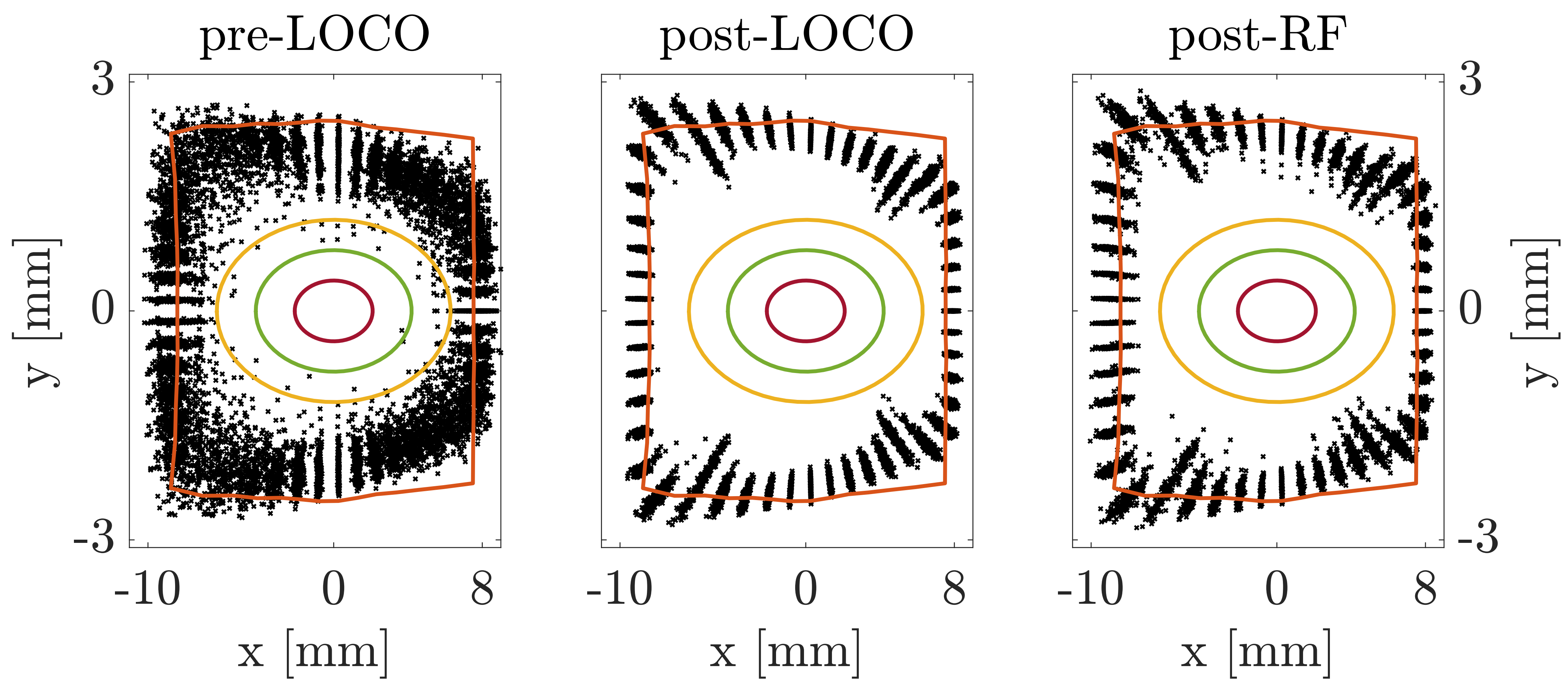




AR-SR Differential Circumference Change

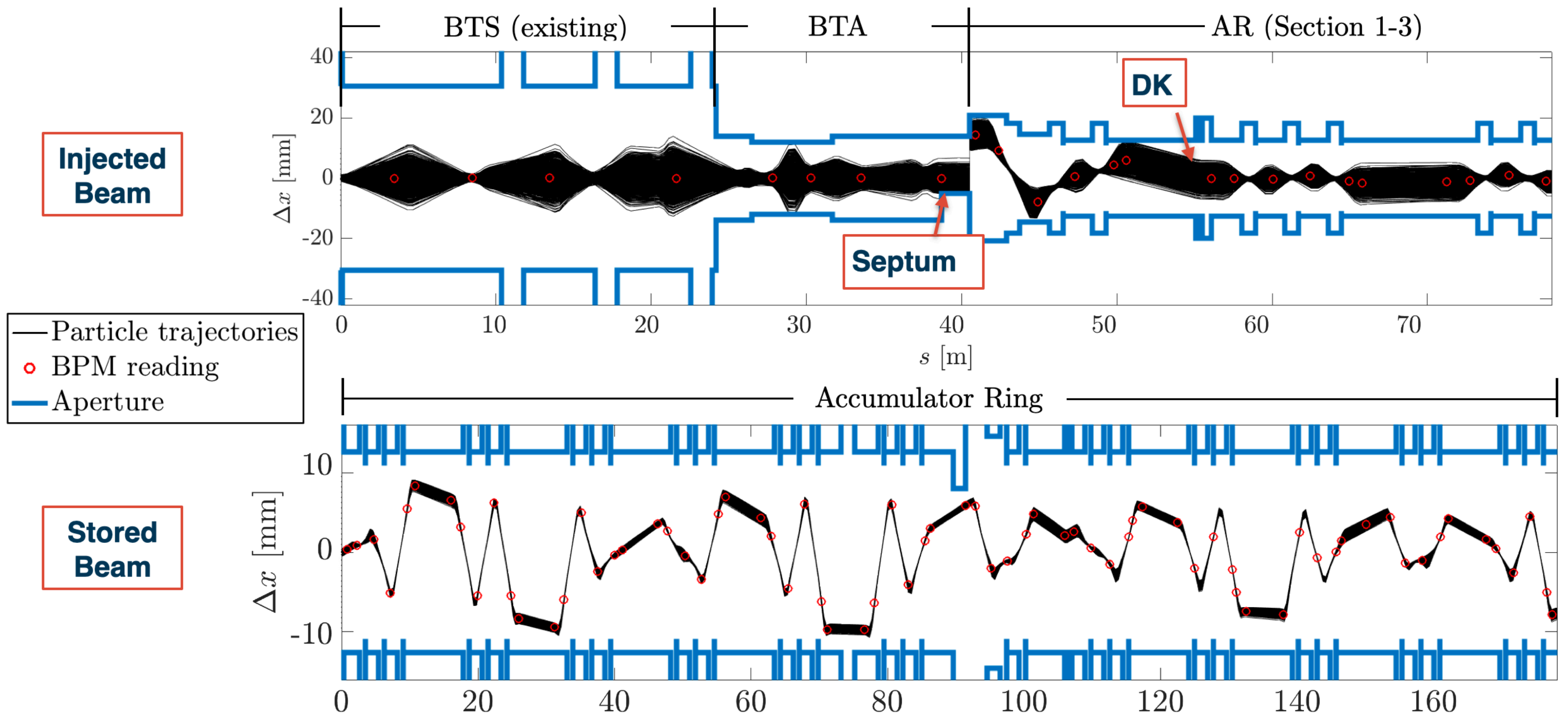
- Locked Frequencies in SR and AR
  - Due to synchronization between AR and SR
- AR Energy Adjusted by Dipoles
  - AR frequency defined by SR circumference
  - AR dipoles used to change AR circumference
- AR Combined Function Dipoles
  - Significant tune shift after adjustment
  - Must be corrected by other quadrupoles
- ALS Circumference Measurements
  - 200 µm initial circumference error of both rings
  - Annual ground motion ≈ 2 mm
  - 125 µm rms between BEND and wall monuments
- Realistic Simulation of LOCO Process
  - Correction works reliably within 1kHz rms
  - Allows for ≲ 240 µm differential circumference change

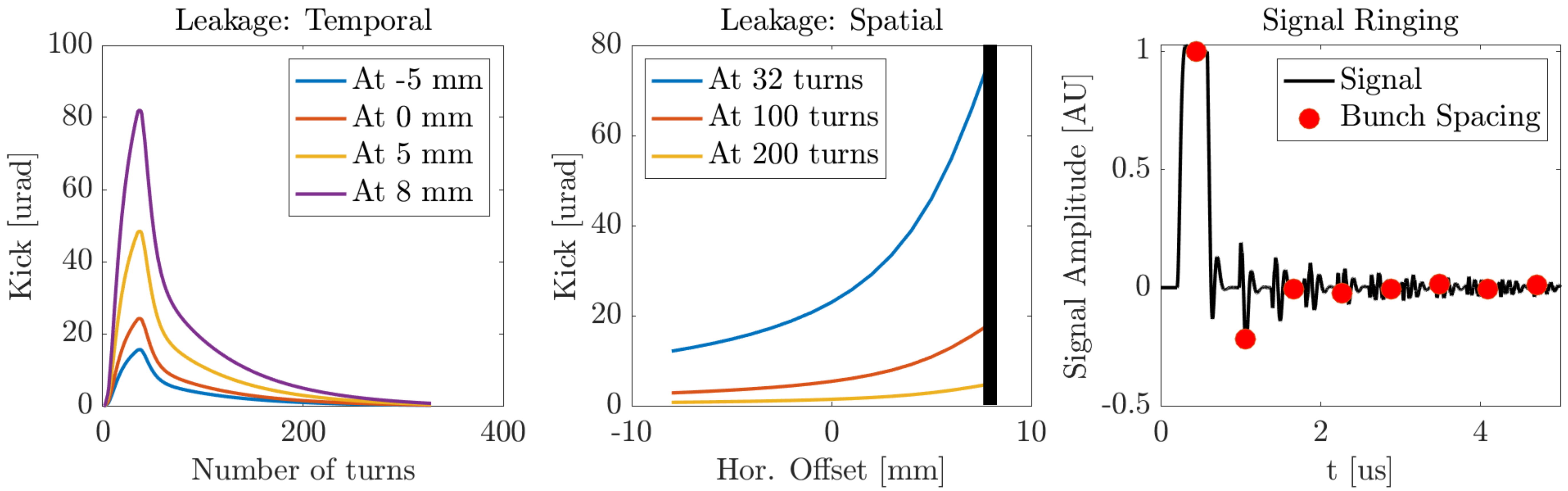




AR Injection Efficiency Studies

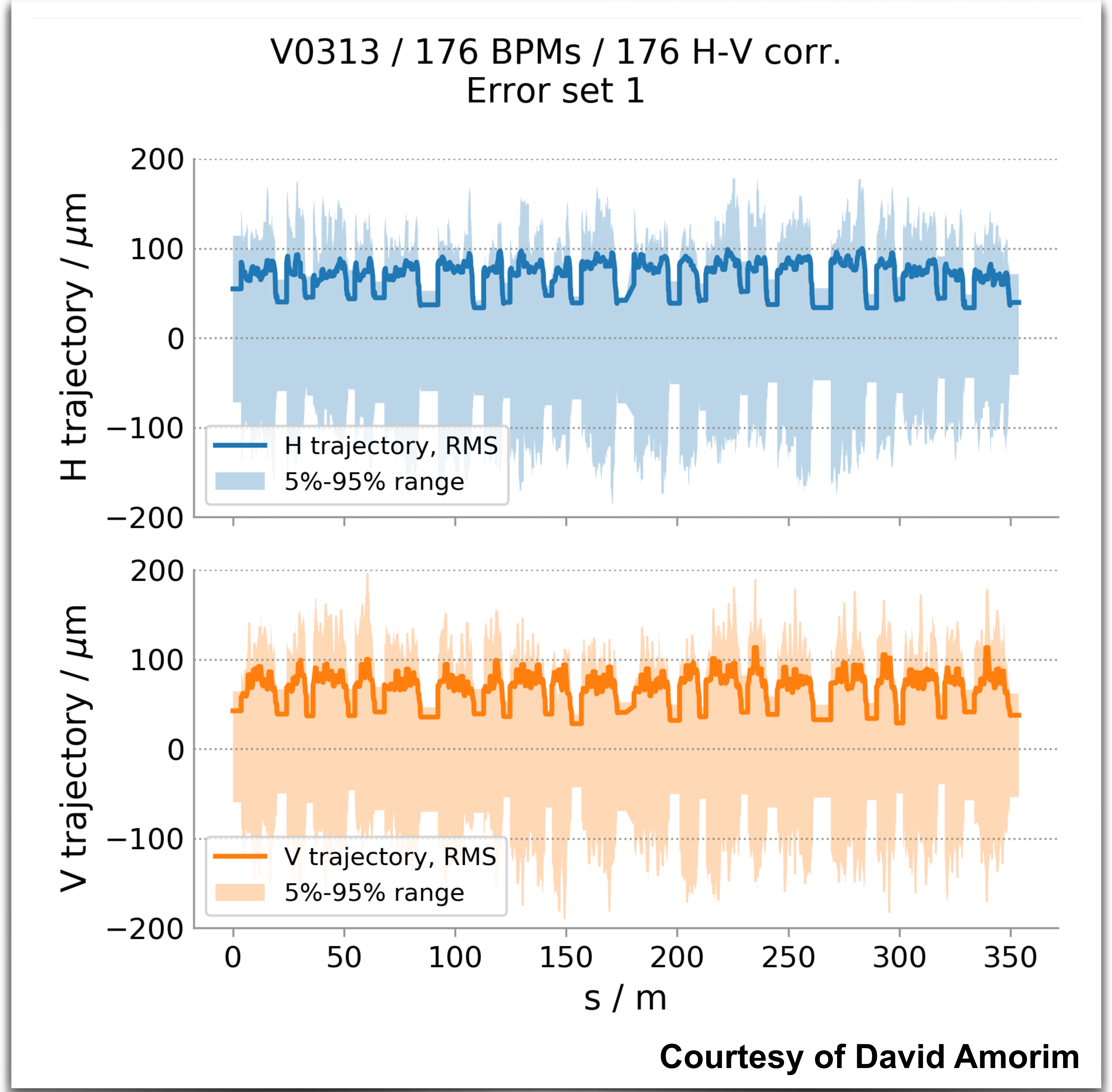
- Demanding Specification on Injection
  - Storage ring lifetime and injector limitations require >95% booster into AR injection efficiency
- Different Injection Schemes Studied
  - NLK, 2-DK, **3-DK**, 4-DK
- Evaluation with Realistically Corrected Machine Errors
  - Evaluation on post-commissioning lattices
  - AR and Booster-to-Accumulator transfer line
  - Time- and spatially varying septa leakage fields
  - Pulsed kicker signal ringing
- Final Specifications Include
  - BPM and CM requirements in transfer lines
  - Septa leakage field amplitudes
  - Pulsed kicker misalignments and strength errors
  - Aperture requirements in BTA and AR



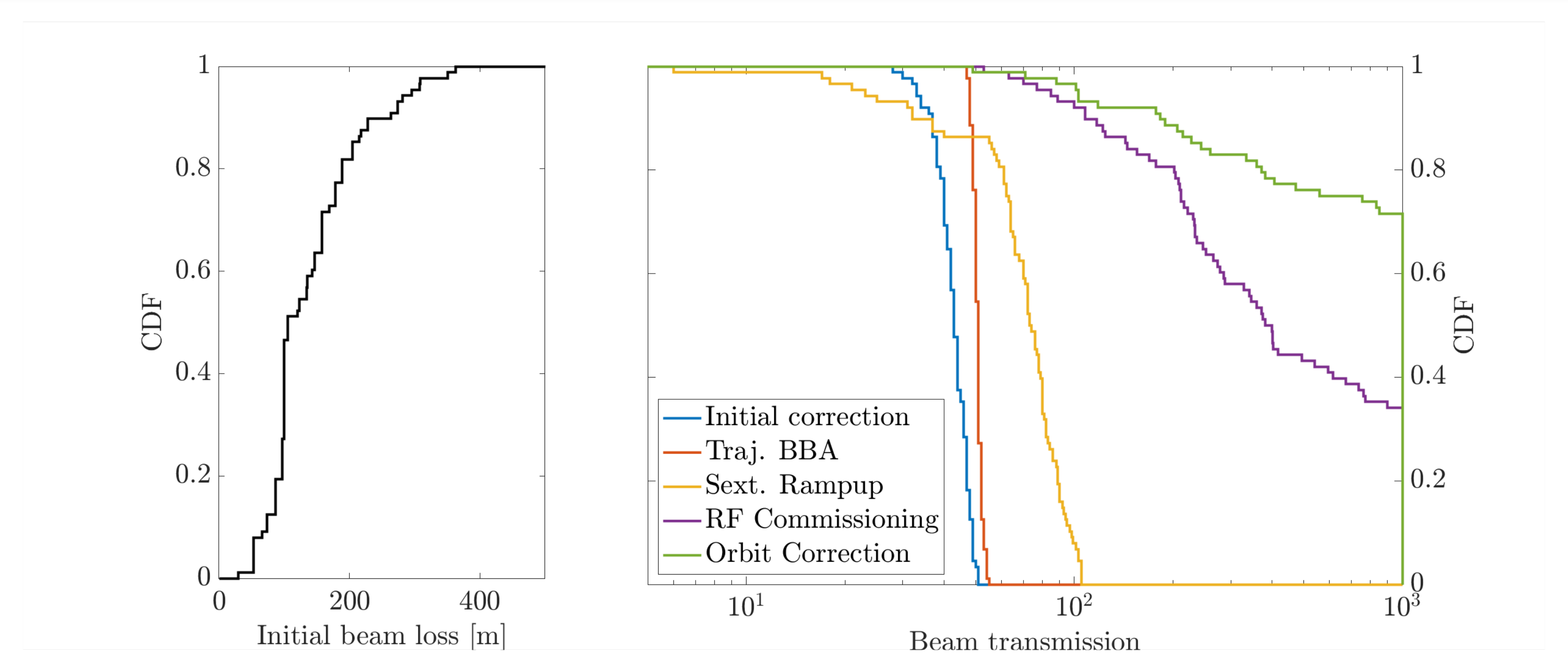


SC Application at PETRA-IV and SOLEIL Upgrade

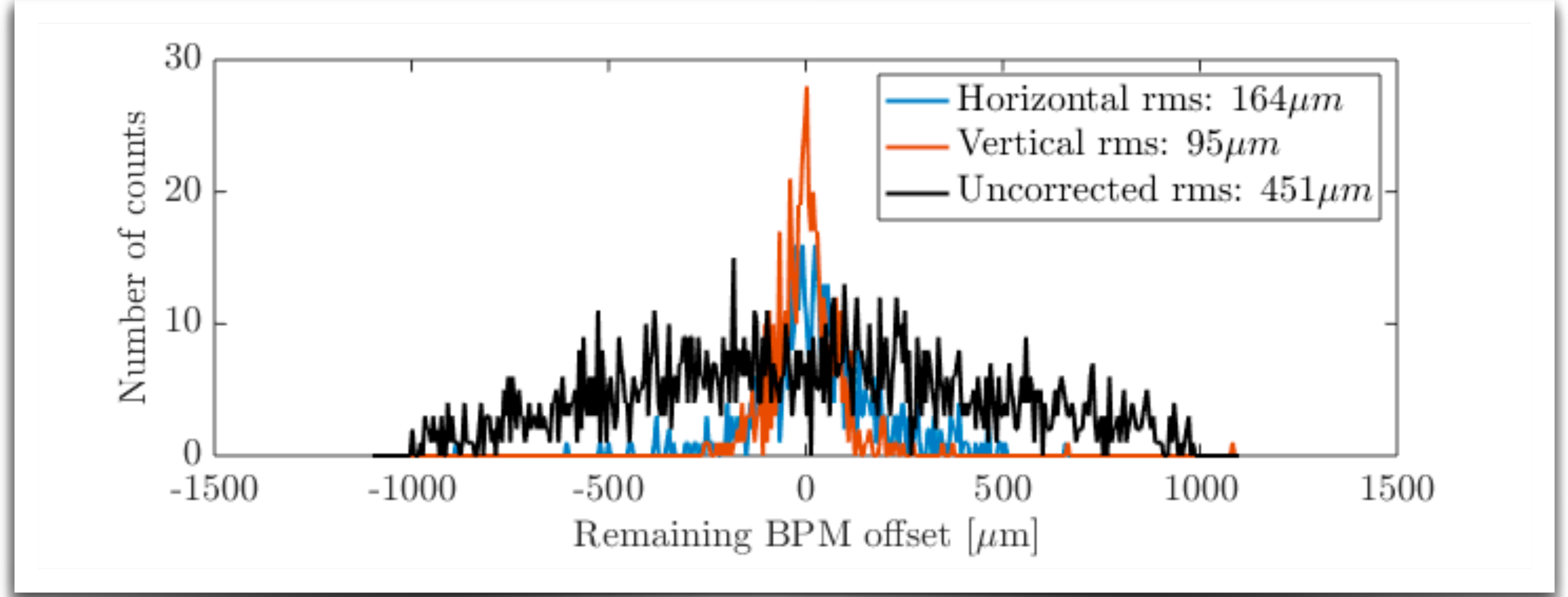
Closed Orbit After Correction Chain at SOLEIL



Beam Transmission Throughout Correction Chain at PETRA-IV



2-turn BBA Results at PETRA-IV



Summary

- Realistic Simulation of Errors and Commissioning Process Required
  - Challenging lattice of future light sources
  - Tolerances studies must include commissioning process
  - Simulation must reflect reasonable information flow
- Development of Commissioning Simulation Toolkit
  - High fidelity error model
  - Realistic workflow
  - Comprehensive documentation
- Wide Range of Application Demonstrated at 4 Machines
  - Error sensitivity
  - Injection efficiency studies
  - Beam based alignment procedures
  - LOCO based optics correction
  - ID compensation

Thanks For Your Attention!

Want a more technical introduction or help with setting up the toolkit with your machine?

thellert@lbl.gov // https://sc.lbl.gov