U.S. DEPARTMENT OF ENERGY
Office of Science

BERKELEY LAB

ALS-U
ADVANCED LIGHT SOURCE

Recent Developments of the Toolkit for Simulated Commissioning

Thorsten Hellert

Future Light Sources Workshop
August 29
Luzern

Outline

- Introduction
  - Historical Context of Commissioning Simulations
- Simulated Commissioning Toolkit Design Features
  - Workflow
  - Error Model
  - Examples
- Recent Developments
  - SC to elegant corrected lattice converter
  - pySC
  - Automated startup scripts using MML

Error Analysis in Storage Ring Design - Past and Present

- Generate Error Ensembles
  - Gradient errors, misalignments, girders, etc.
- Evaluate Lattice Performance
  - Beta beat, orbit error
  - Limit error amplitudes to provide acceptable performance

Construction of the DESY Synchrotron, 1961

Error Analysis in Storage Ring Design - Past and Present

- Generate Error Ensembles
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- Correct Lattice
  - Closed orbit correction
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  - Beta beat, orbit error
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  - Calculate statistics of lattice performance
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Closed Orbit Distortion Before and After Correction for ALS

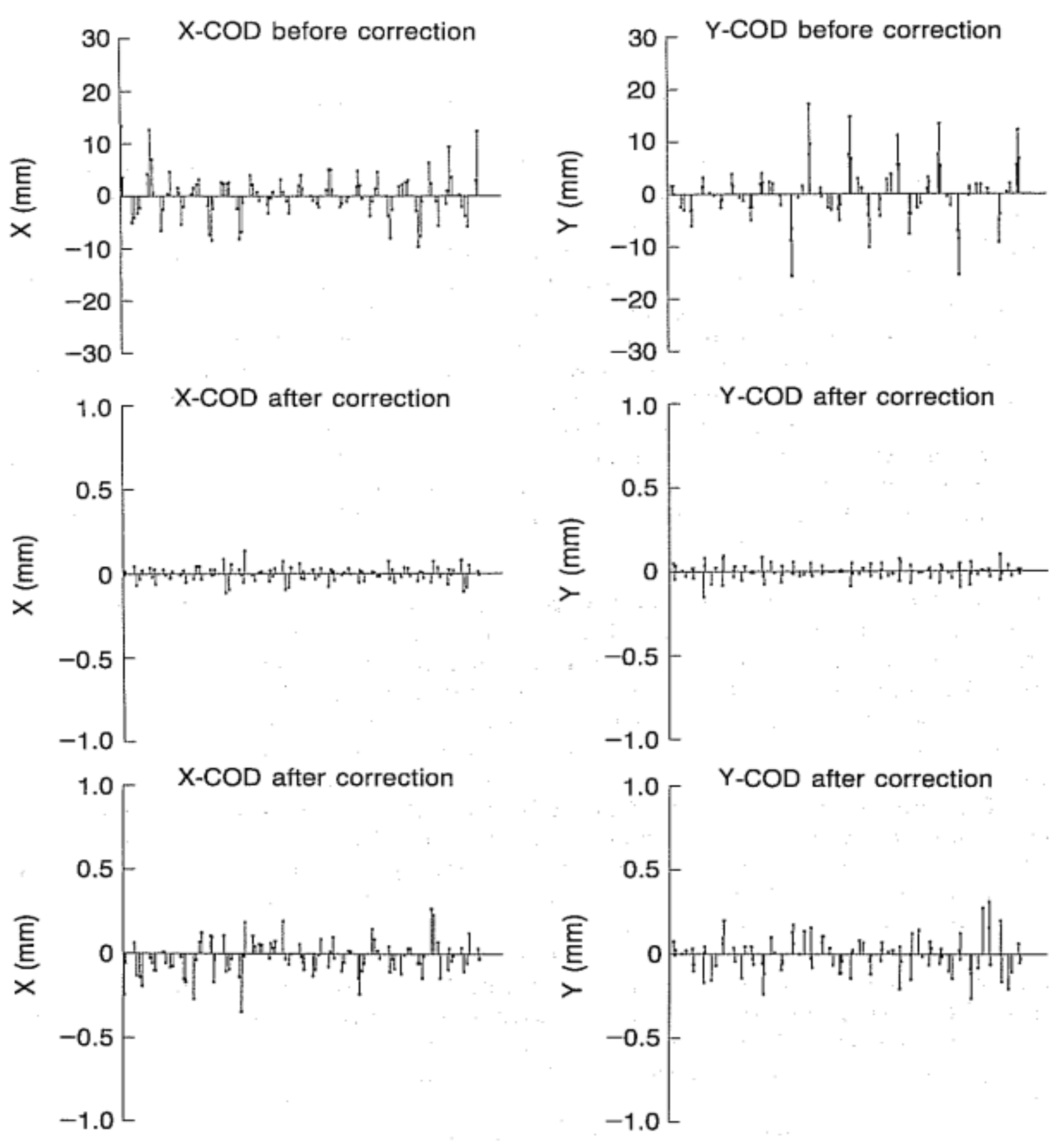

Fig. 3-15. Orbit distortions at 96 locations for one set of errors before correction (top), after correction (middle), and after correction but assuming random monitor displacements (bottom).

ALS CDR (**1986**)

(Magnet misalignments = 150μm)

Error Analysis in Storage Ring Design - Past and Present

- Generate Error Ensembles
  - Gradient errors, misalignments, girders, etc.
- Correct Lattice
  - Closed orbit correction
  - Linear optics correction
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Closed Orbit Distortion and Dispersion Error for PETRA-III

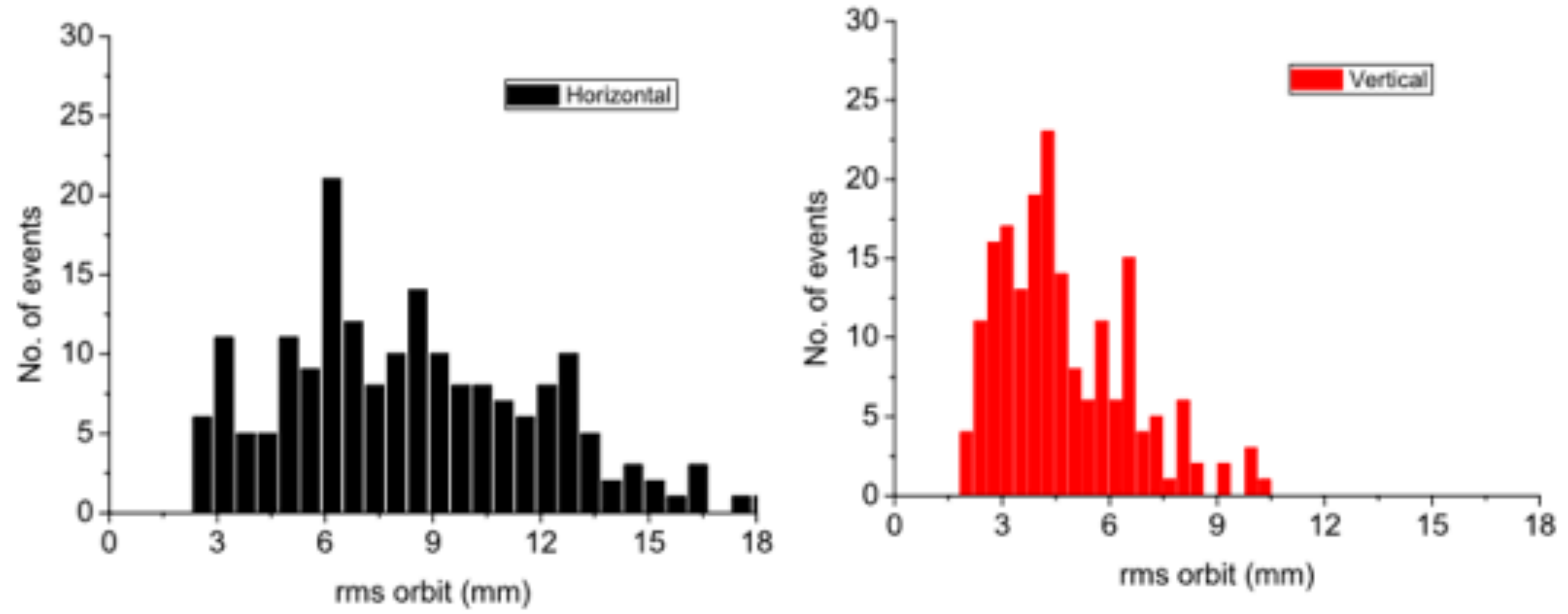

Figure 3.2.15: The horizontal and vertical rms COD produced by 200 sets of random errors before correction.

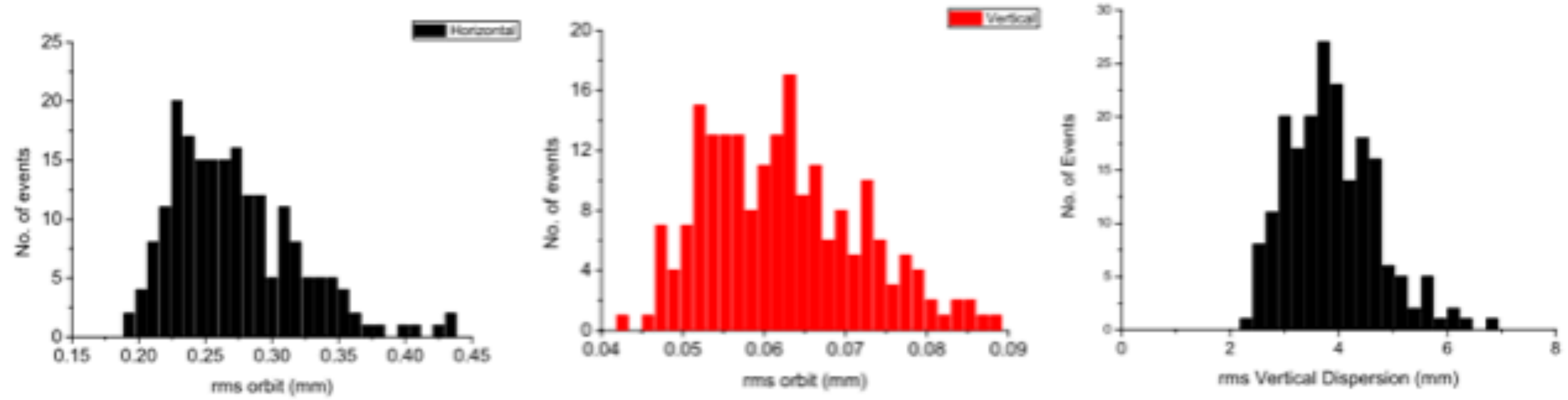

Figure 3.2.18: Calculated rms closed orbit distortion and spurious dispersion produced by 200 sets of random errors (after correction).

PETRA-III TDR (***2004***)

(Magnet misalignments = 250µm)

Error Analysis in Storage Ring Design - Past and Present

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Dispersion-, Coupling- and Beta-Beat-Free Steering for SuperB

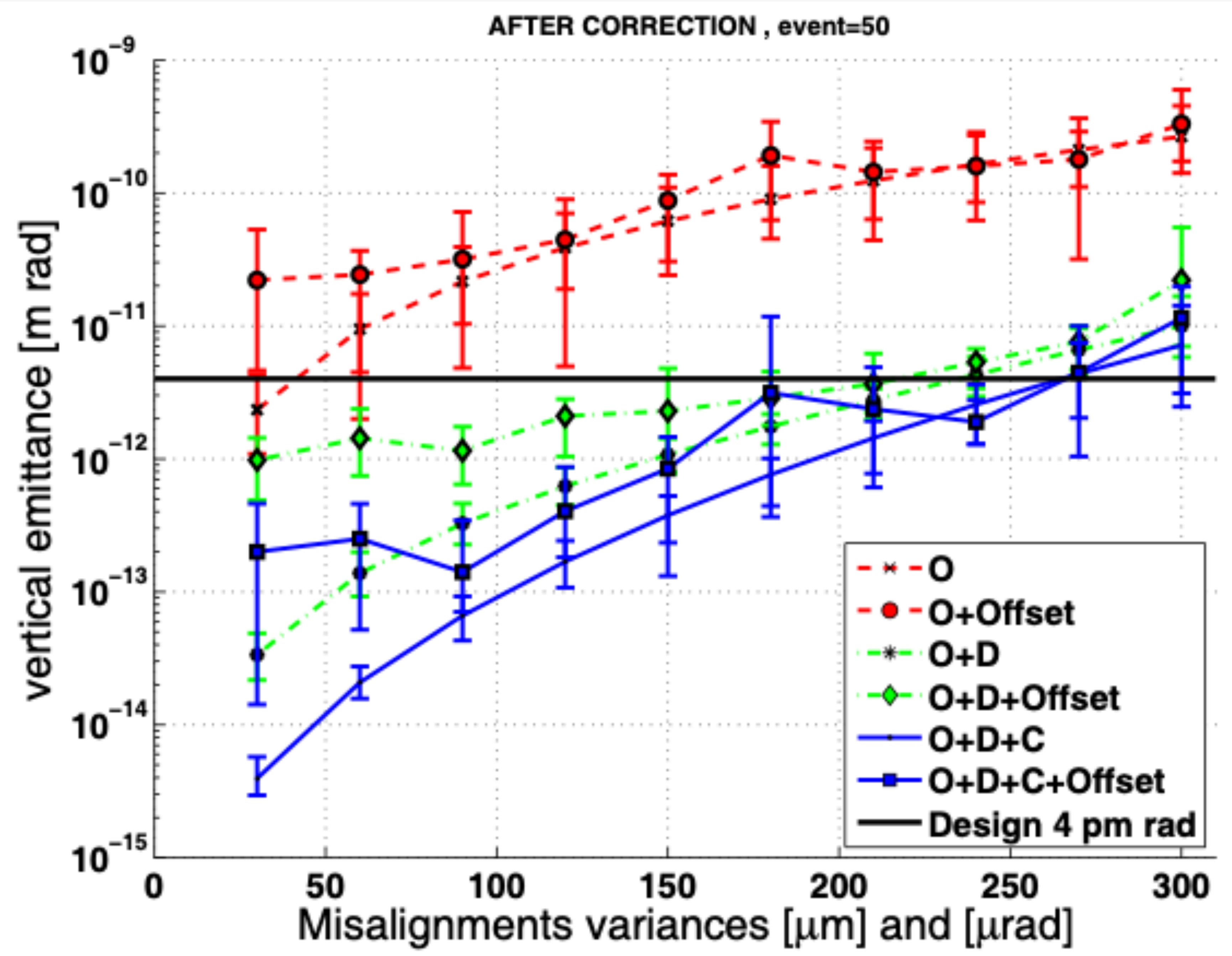

Figure 2: Vertical emittance (m) for machine misalignment from 30 to 300μm H and V for Sext and Quad and qudrupole Tilts of 30-300 μrad. Orbit (O), Dispersion (D) and Coupling and Beta-beating (C) Free Steering are compared

S. Liuzzo et al., TUPEB007 (IPAC *2010*)

(Magnet misalignments < 300μm)

Error Analysis in Storage Ring Design - Past and Present

- Generate Error Ensembles
  – Gradient errors, misalignments, girders, etc.
- Correct Lattice
  – ~~Closed orbit correction~~ => *no closed orbit!*
  – Linear optics correction
- Evaluate Lattice Performance
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  – Injection efficiency, dynamic aperture, lifetime
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  – Calculate statistics of lattice performance
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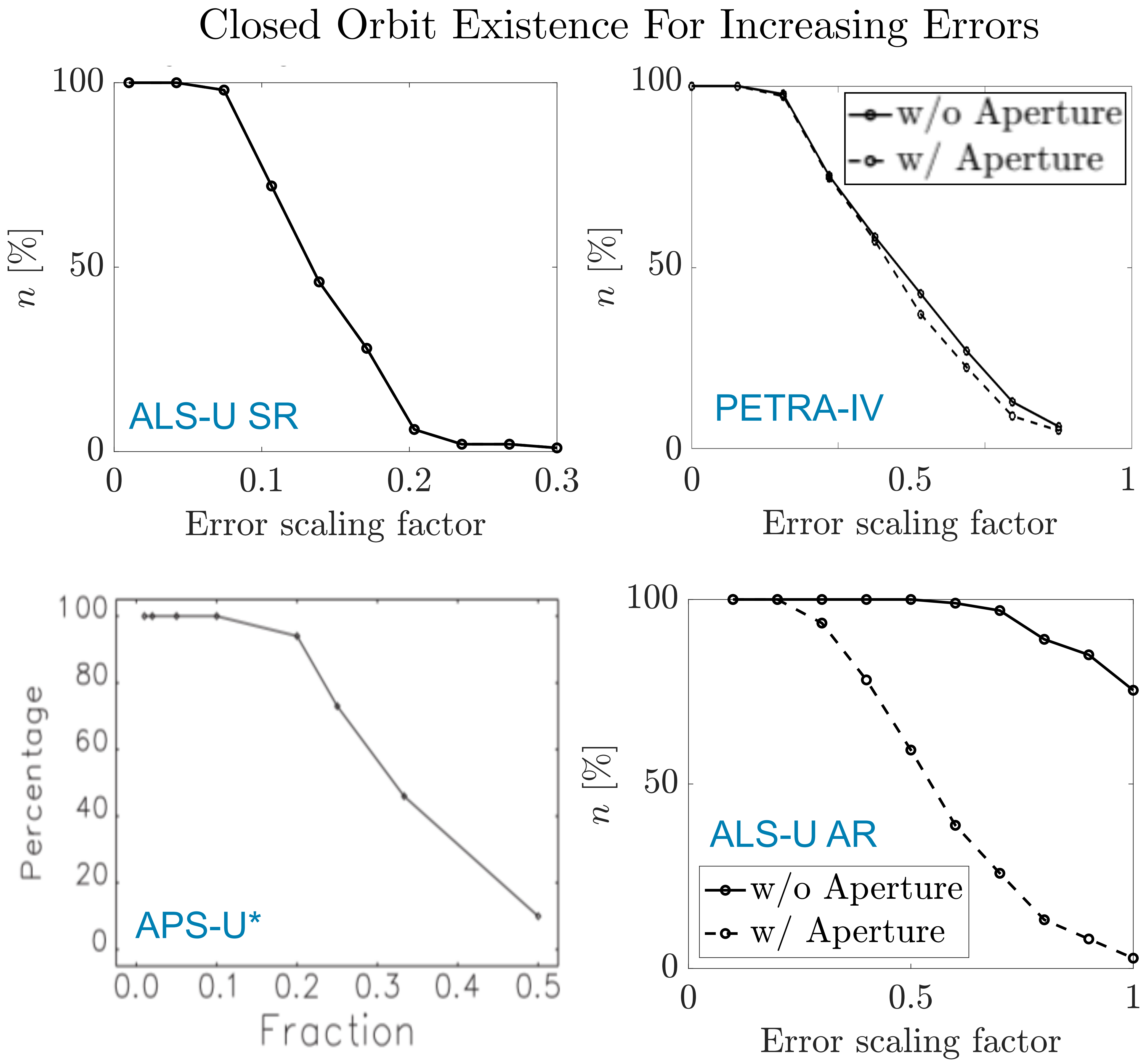

*) V. Sajaev, PRAB 22,040102

Error Analysis in Storage Ring Design - Past and Present

- Generate Error Ensembles
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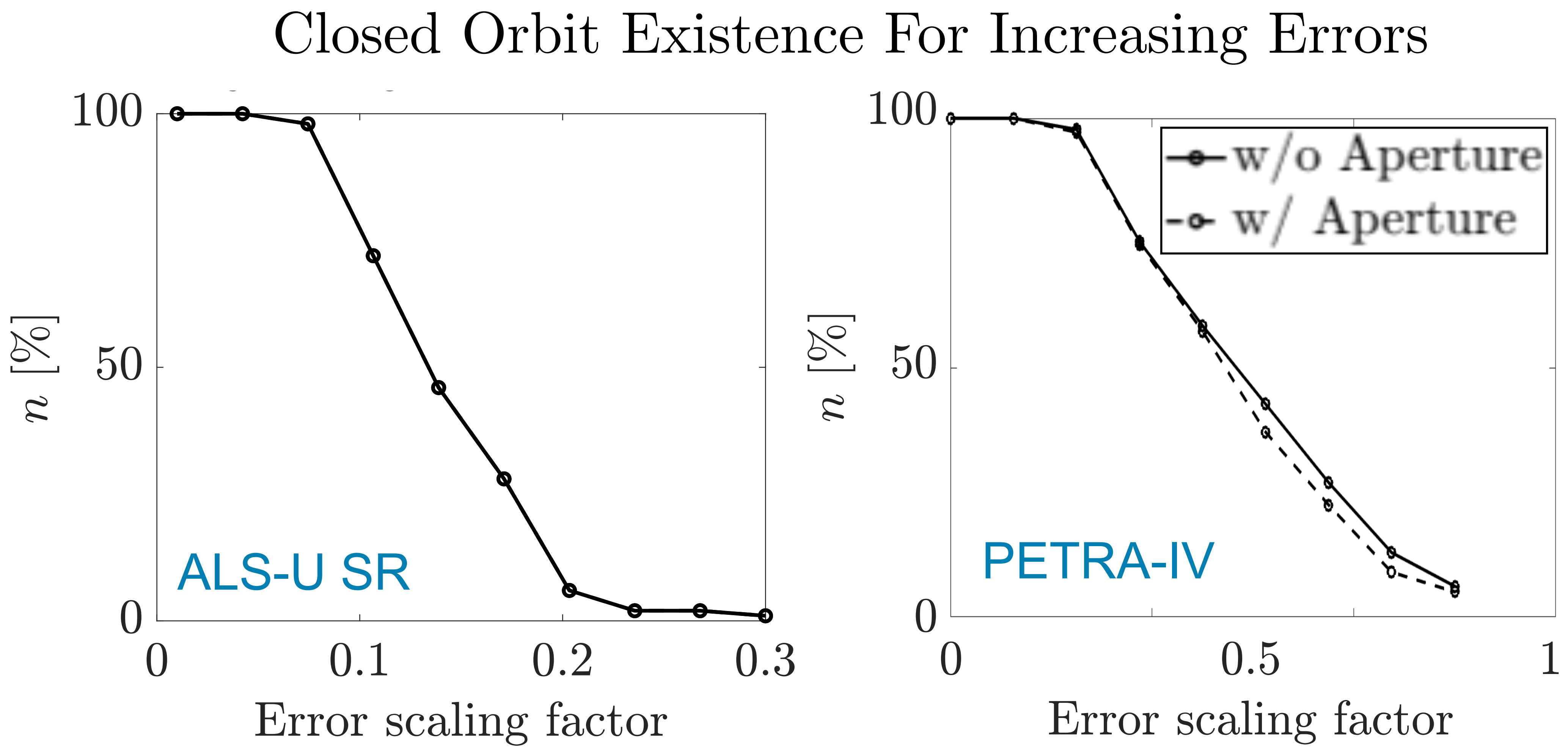


	Girder to Girder	Magnet to Magnet
ALS-U	30µm/50µm	30µm
APS-U	100µm	30µm
PETRA-IV	100µm	30µm
Diamond-II	150µm	35-50µm
SOLEI-II	50µm	30µm
ALBA II	50-100µm	30µm

Error Analysis in Storage Ring Design - Past and Present

- Generate Error Ensembles
  - Gradient errors, misalignments, girders, etc.
- Correct Lattice
  - Start to finish commissioning simulation as realistic as possible*
- Evaluate Lattice Performance
  - Beta beat, orbit error
  - Injection efficiency, dynamic aperture, lifetime
- Statistical Evaluation
  - Calculate statistics of lattice performance
  - Limit error amplitudes to provide acceptable performance

ALS-U SR

- **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 and 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

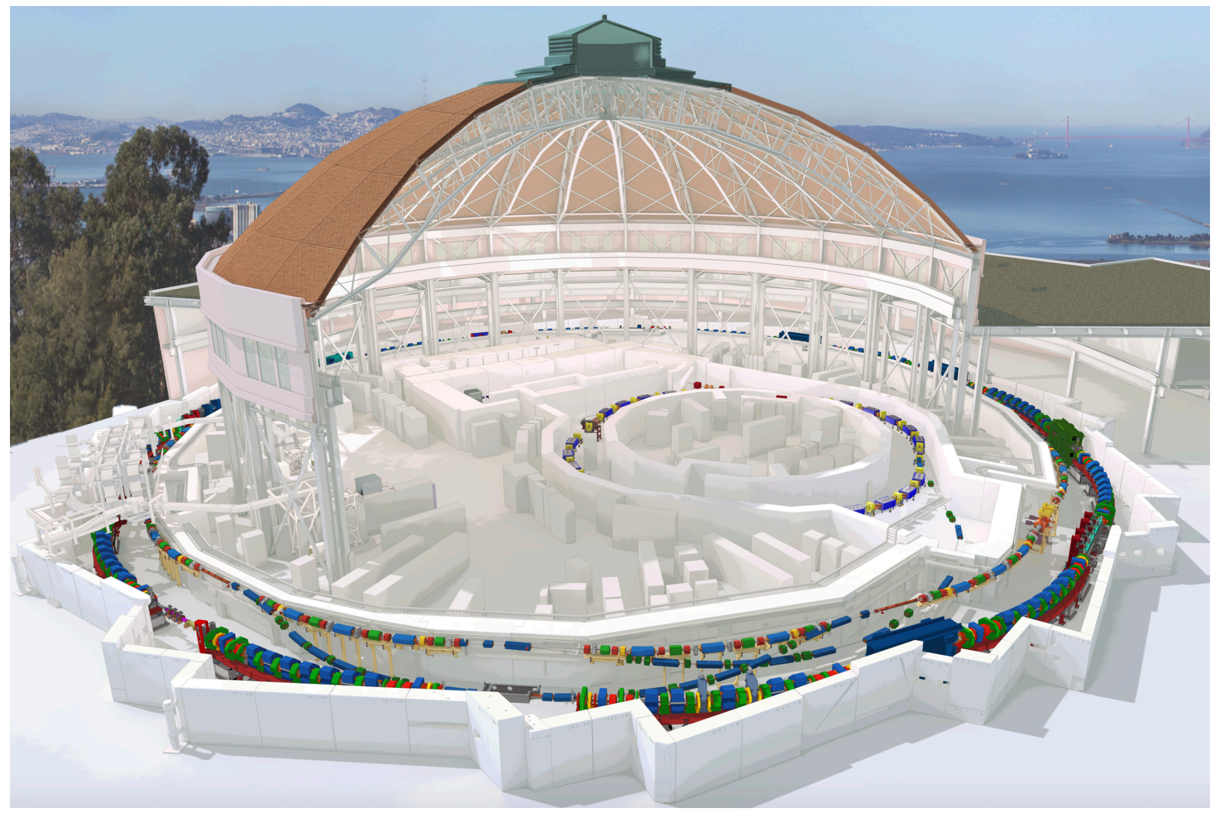
*) V. Sajaev et al., MOPMA010 (2015)
*) S. Liuzzo et al., WEPIK061 (2017)
*) T. Hellert et al., THPMF078 (2018)

Simulated Commissioning Toolkit Design Features

Limited Accessibility of Machine Properties

Power supplies

Operating machine



Diagnostic devices

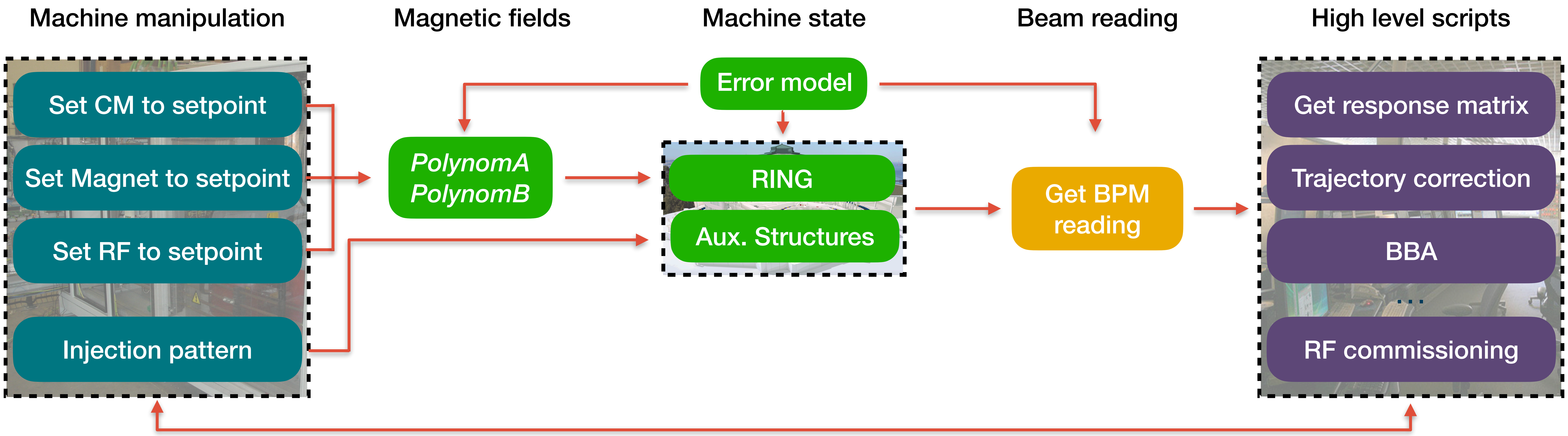
High level controls

Magnetic fields
Particle trajectories
Magnet offsets
...

Limited access!

Setpoints and read back values

Realistic Workflow of Toolkit 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)

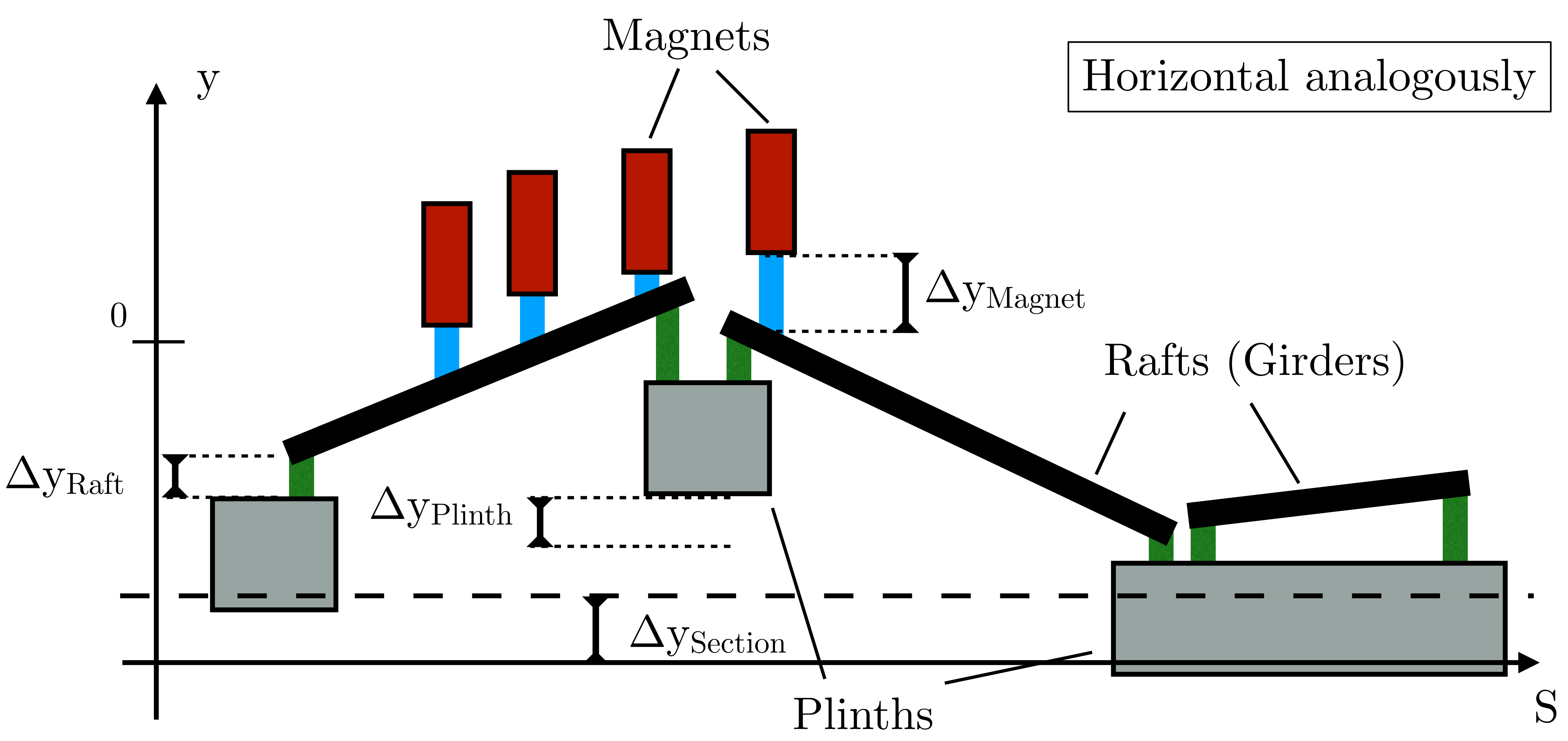
Auxiliary structures
- Diagnostic errors
- Injected beam trajectory
- Injection pattern

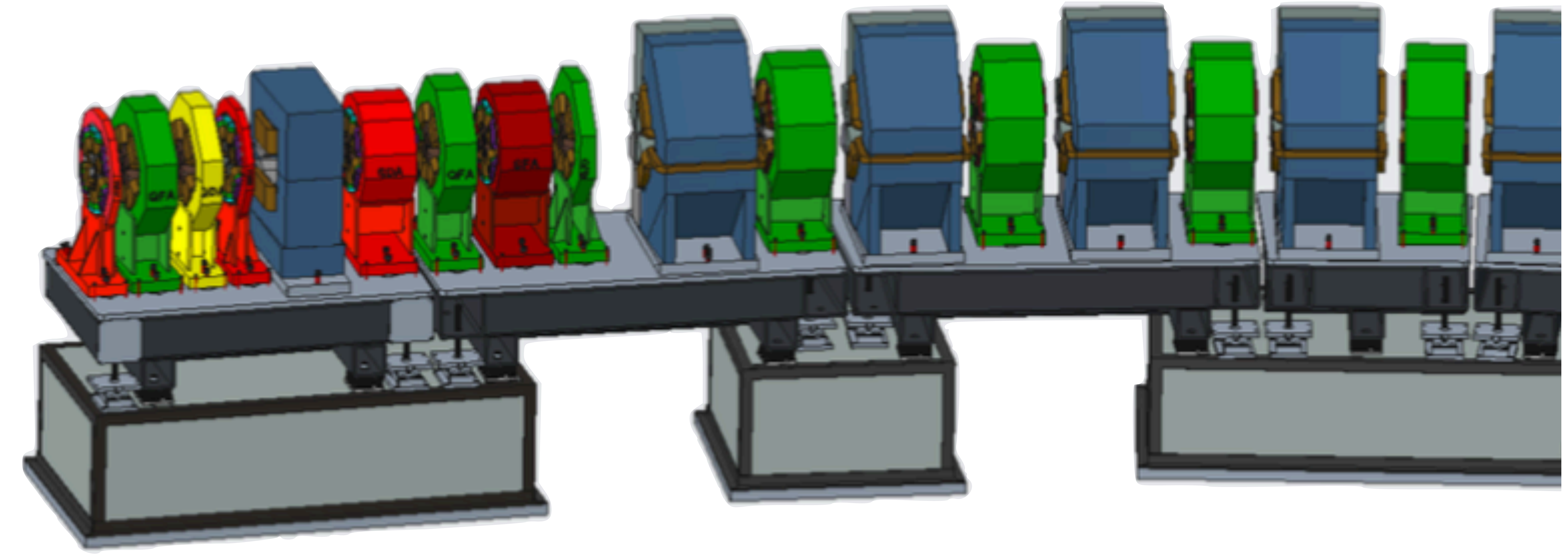
Get BPM reading
- Performs tracking including aperture
- Gets BPM signal from ensemble of particle trajectories

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
  - BPM sum signal
  - CM cal. error
  - CM roll
  - CM / skew-quad limits
- Support Structure
  - Rafts, Plinths, Sections
  - 3D Roll & Offsets
- Circumference
- Higher Order Multipoles
  - Systematic for arbitrary coil excitations
  - Random
- Magnets
  - 3D Offset
  - 3D Roll
  - Strength
  - Calibration
- RF Errors
  - Phase
  - Frequency
  - Voltage
- Injection
  - Static
  - Jitter





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  - Frequency
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  - Static
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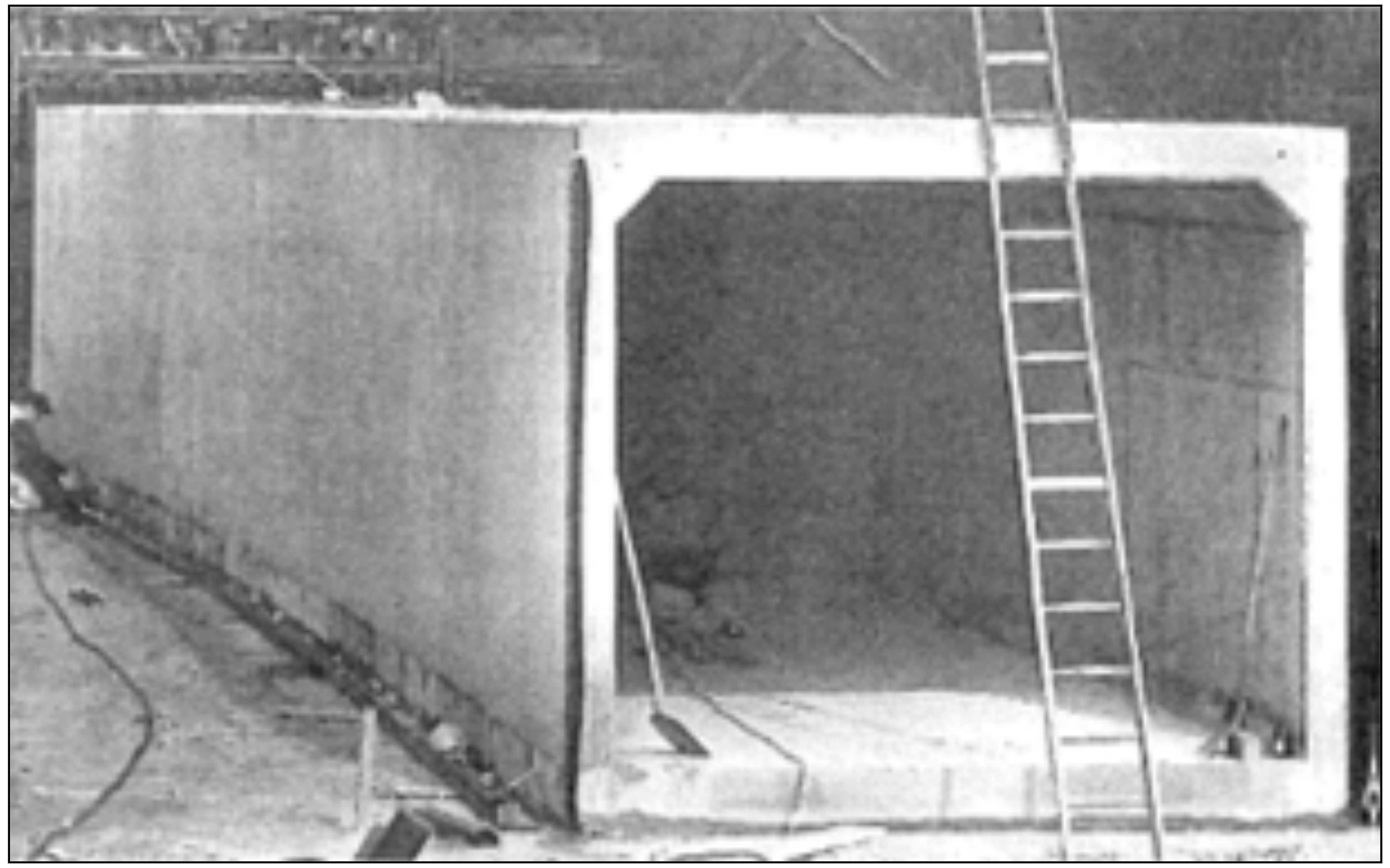
Tunnel Cracks for PETRA-IV



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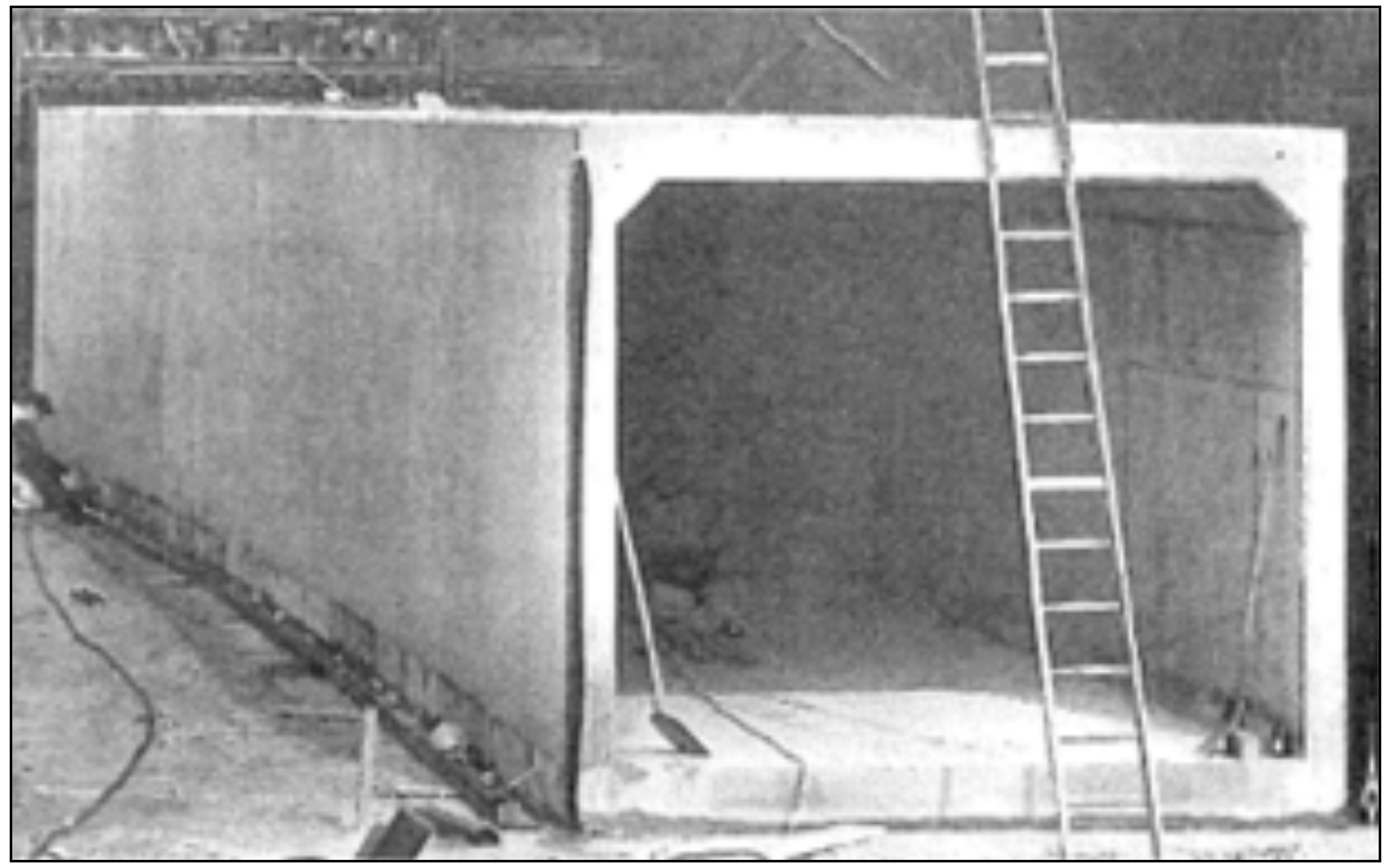
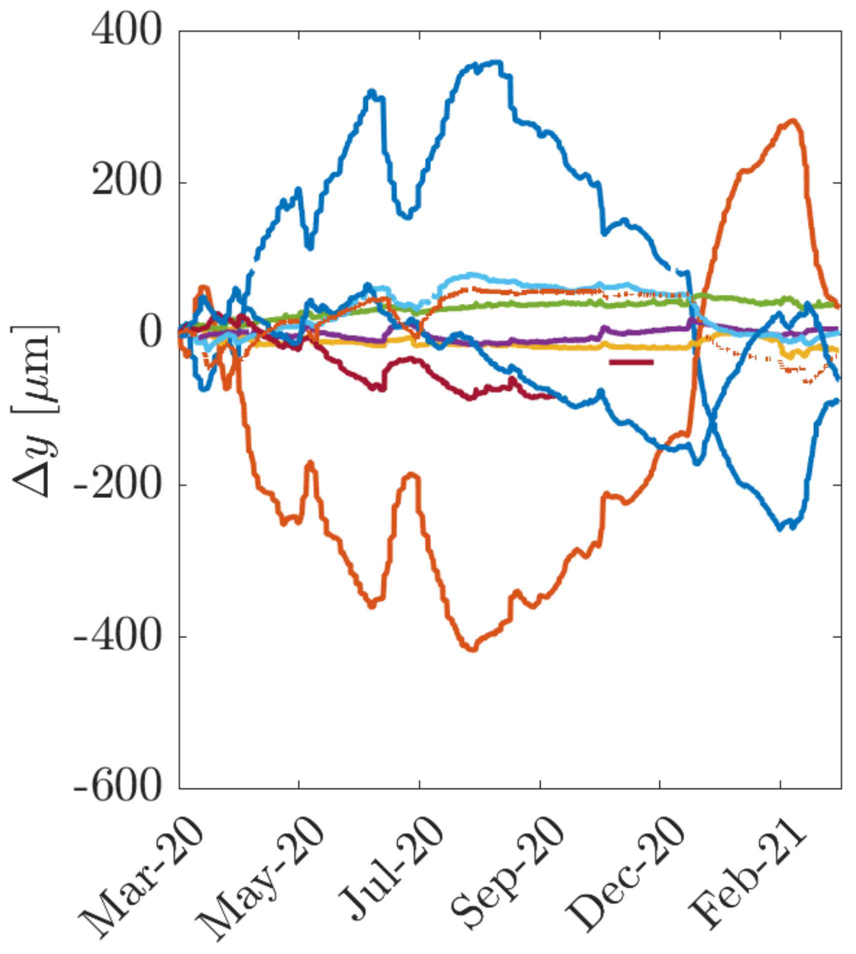
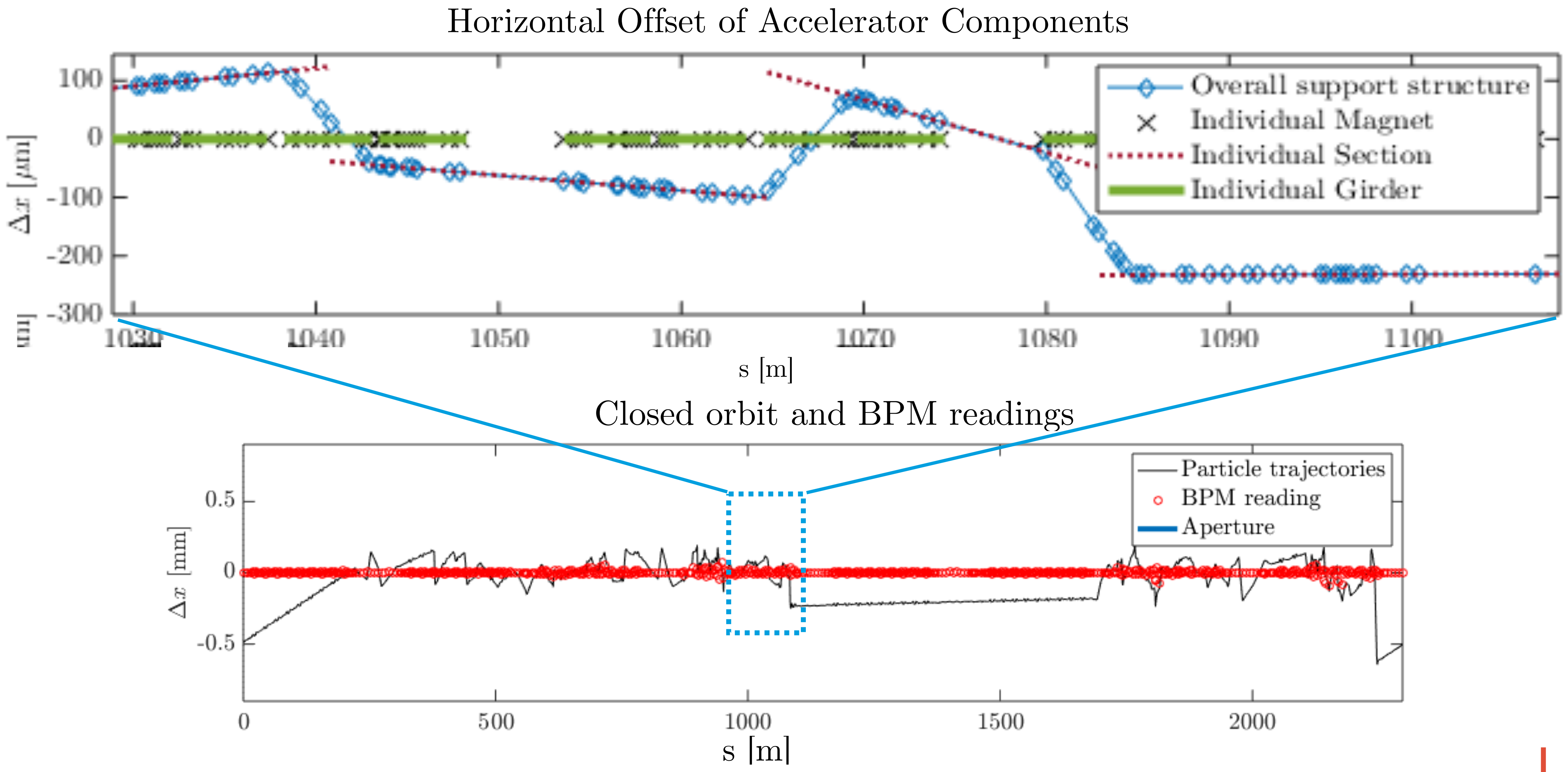
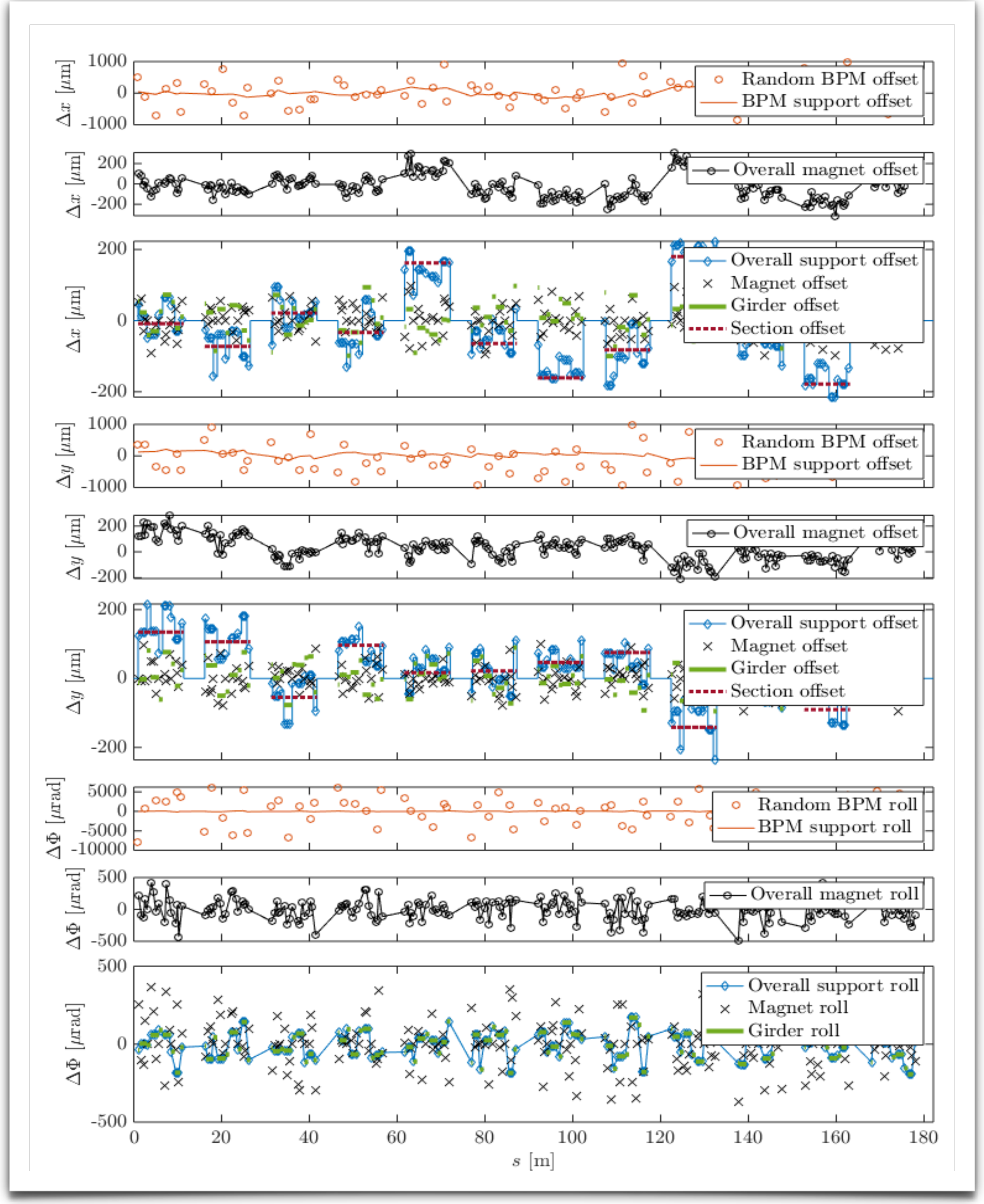




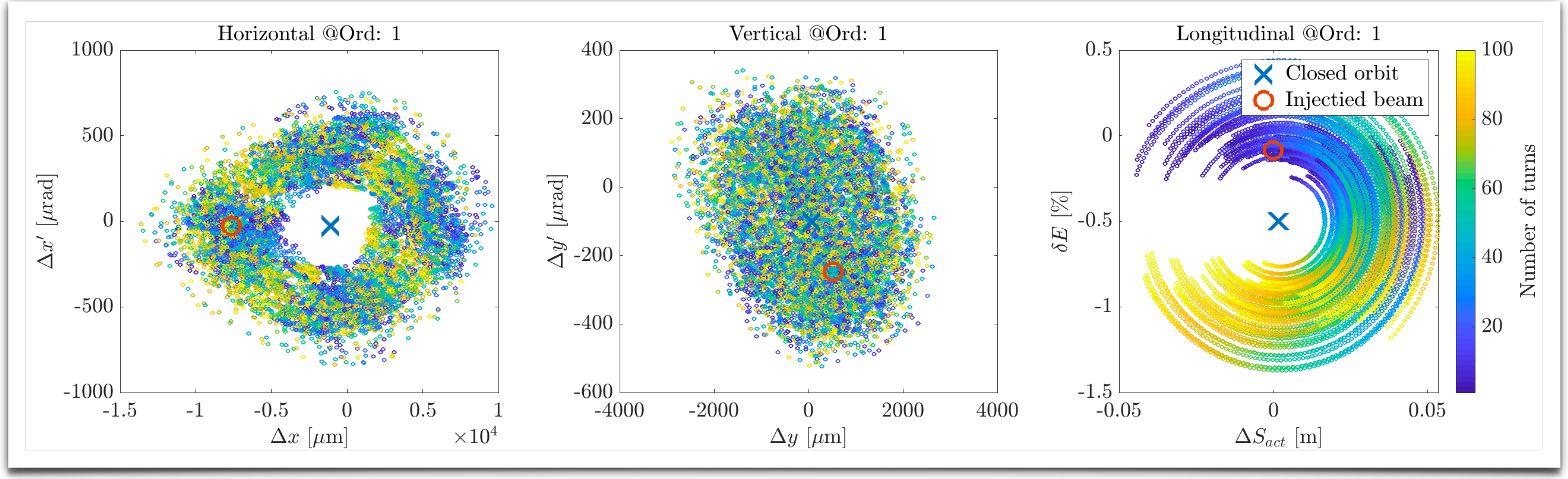


Various Visualization Tools for Easy R&D

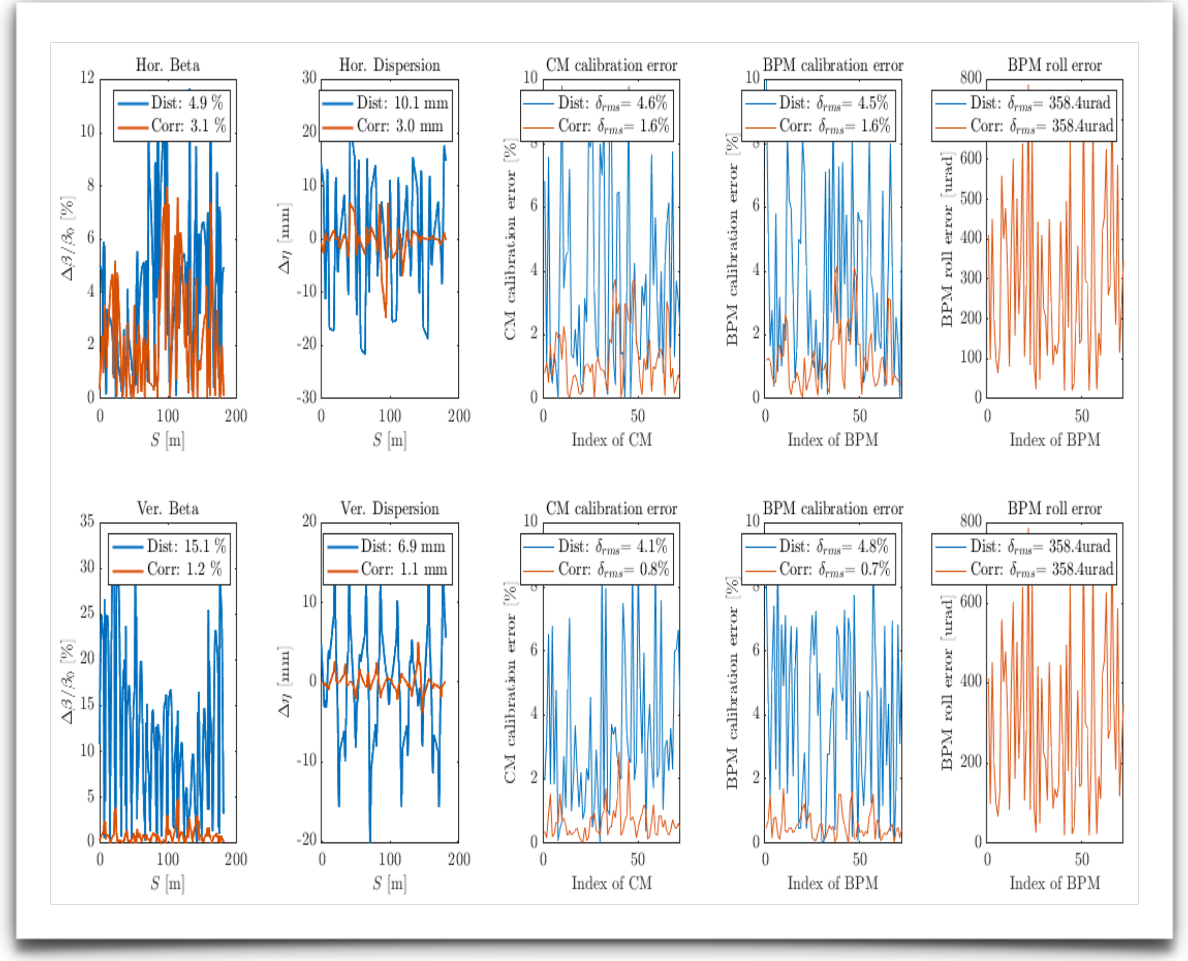
Misalignments



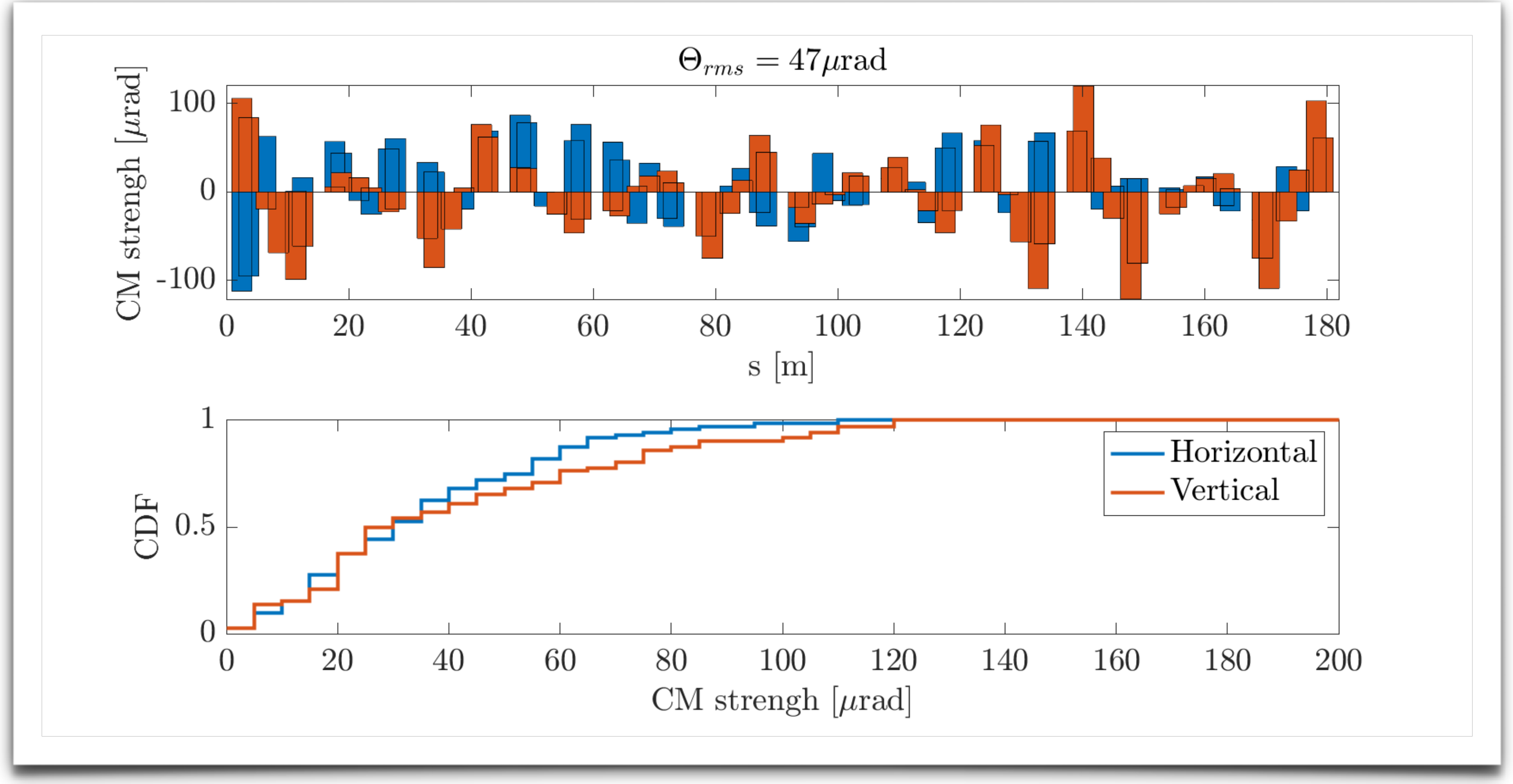
Turn-by-turn Phase Space



LOCO Status

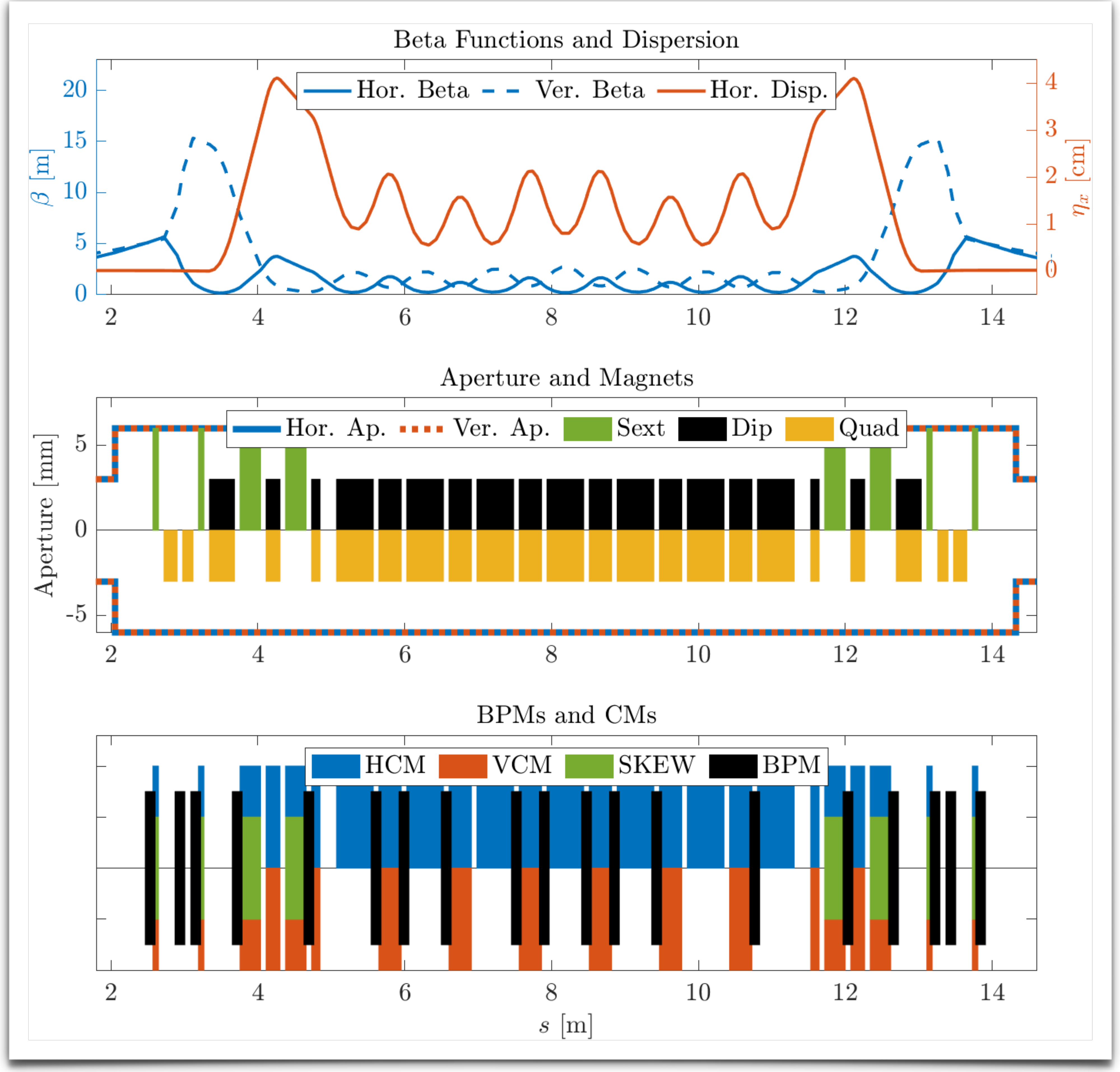


Corrector Strength

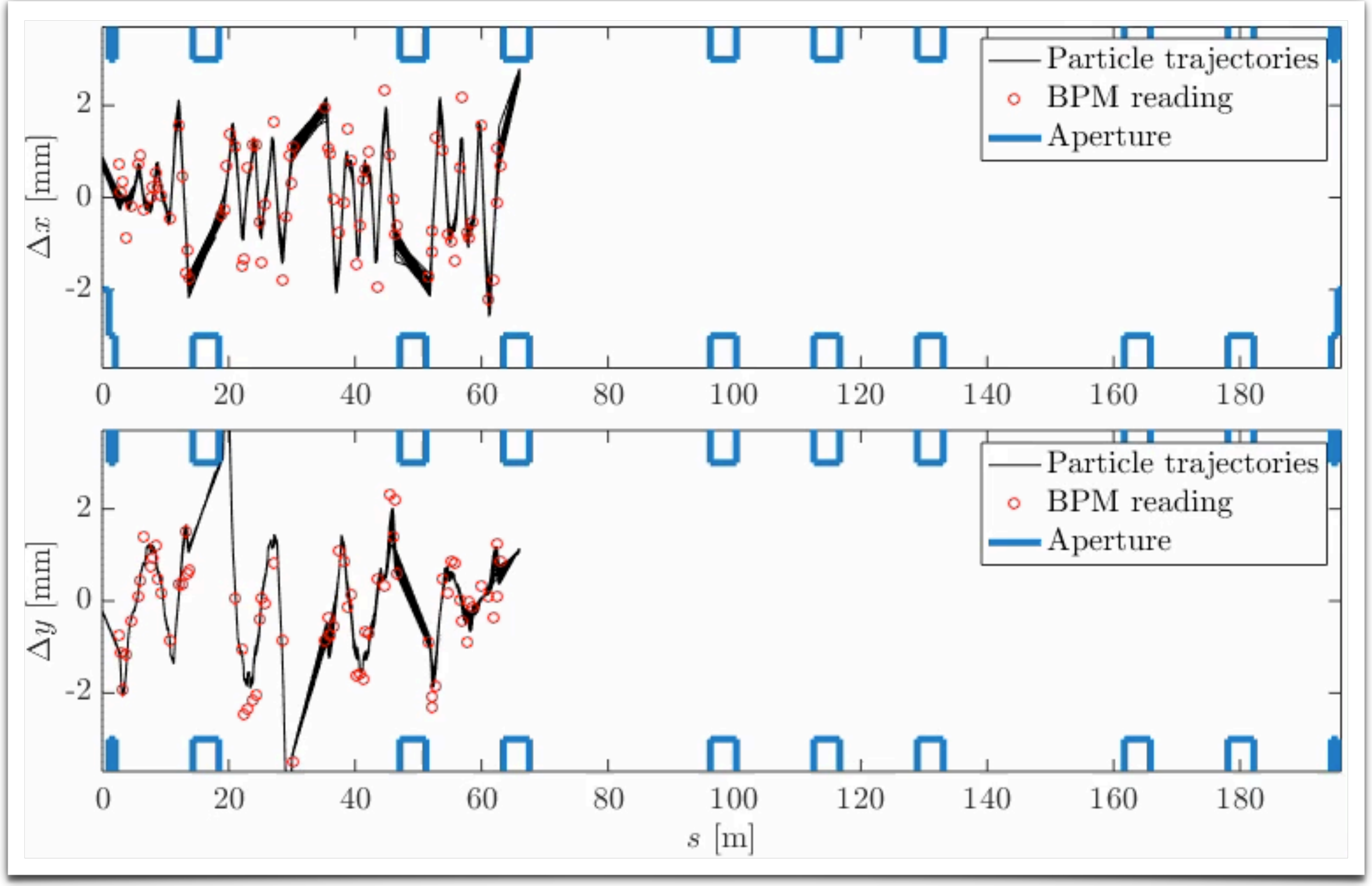


Various Visualization Tools for Easy R&D

Lattice and Element Registration in Toolkit



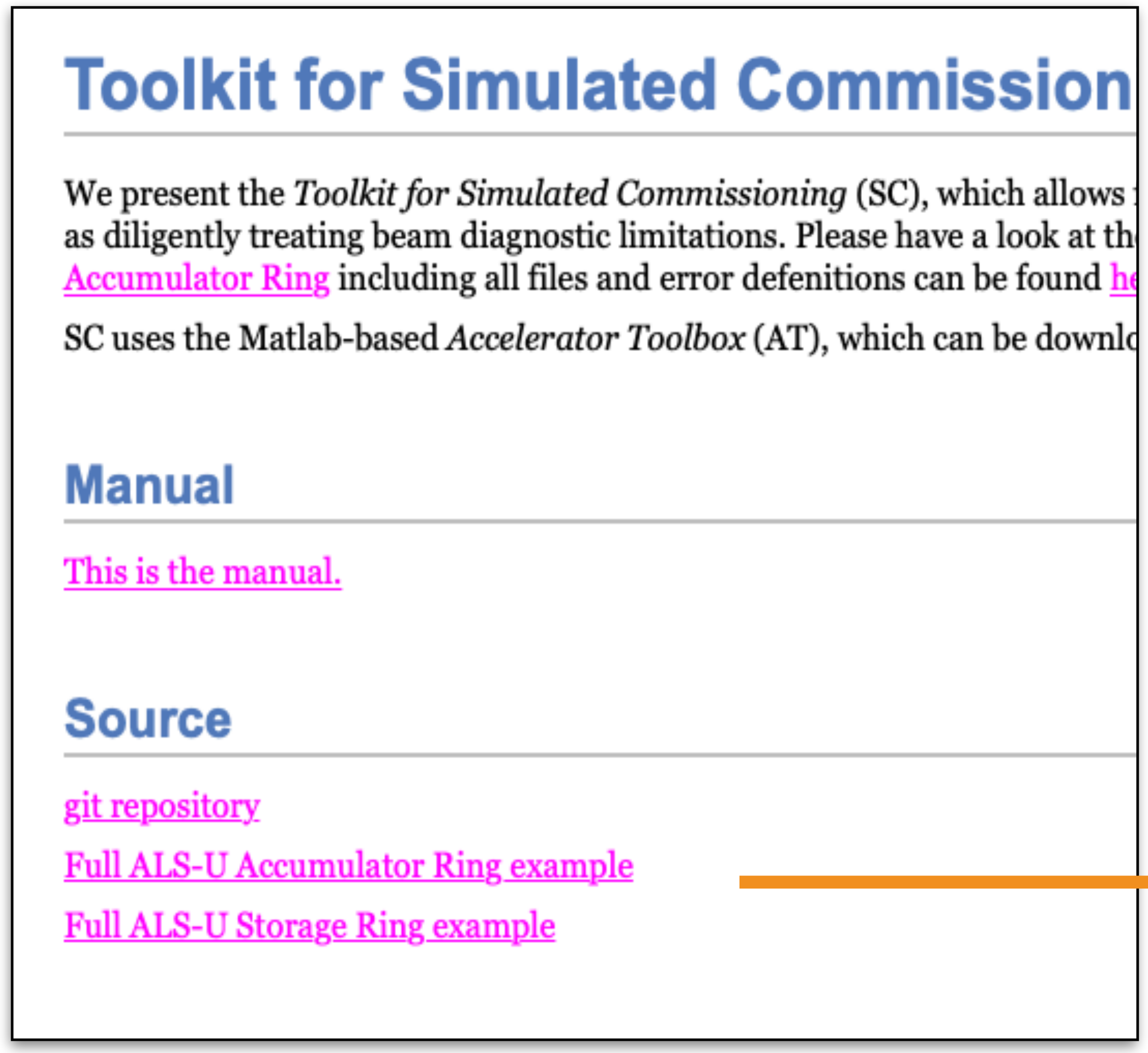
Trajectories/Orbit and BPM Readings



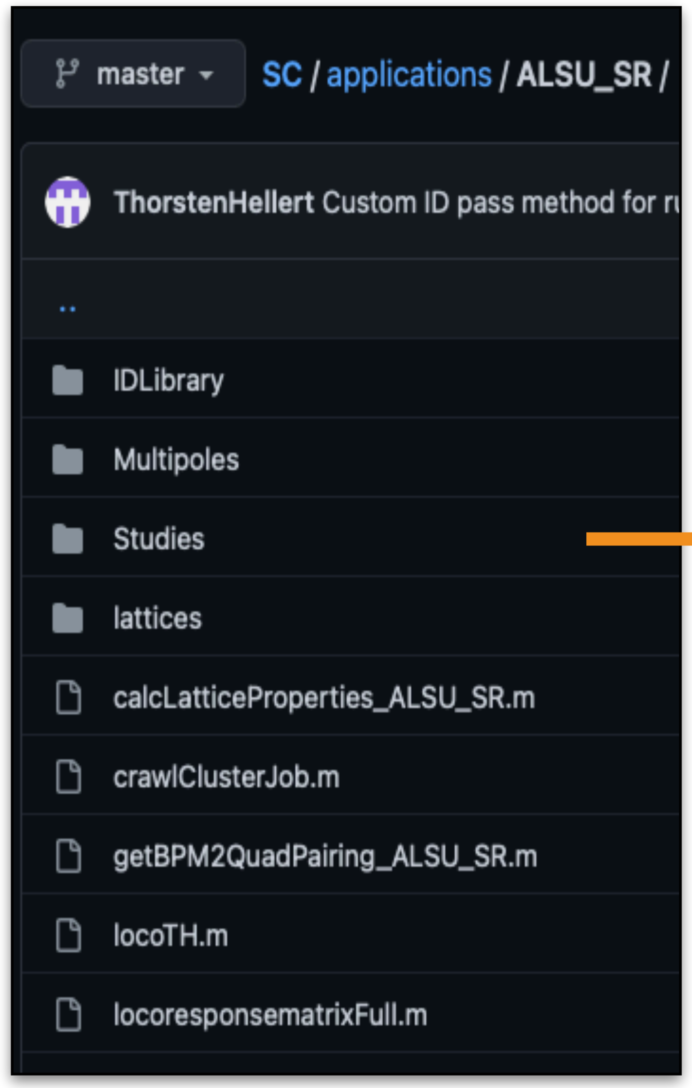
Easy Accessibility For New Users: Manual & Example Scripts

- Detailed Description of Code and Example Workflows:
  - Comprehensive toolkit manual
  - Each function given with examples
  - Full annotated correction chain for both ALS-U Accumulator and Storage Ring online

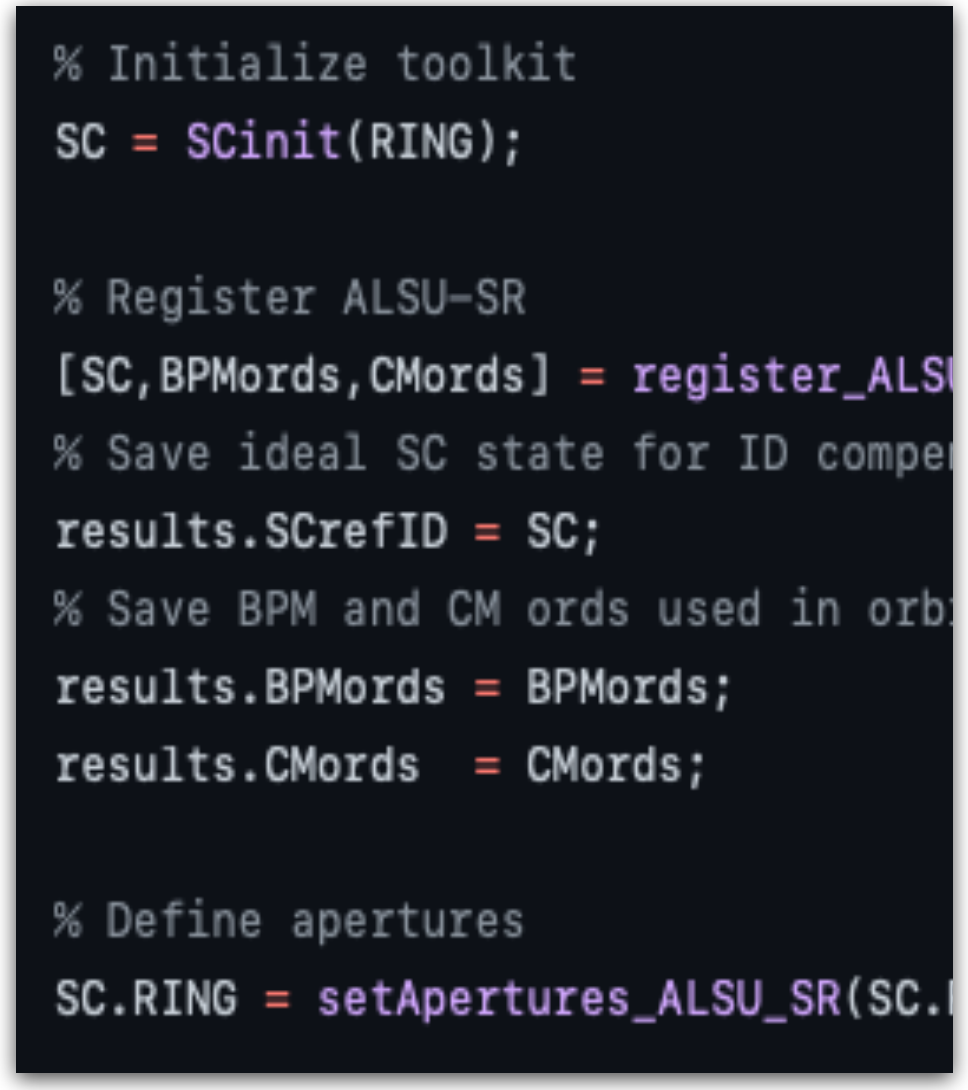
Toolkit Webpage



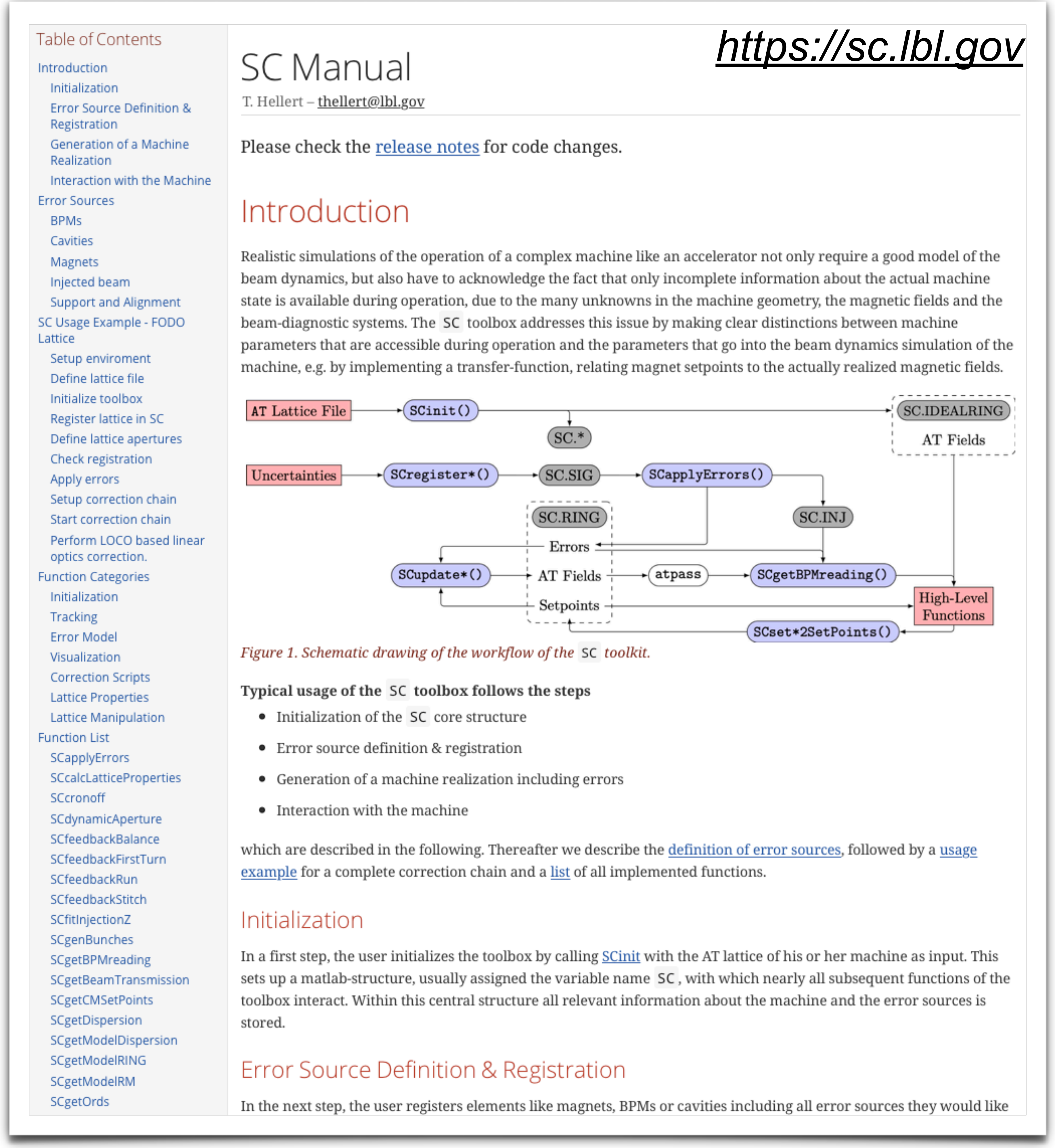
Git Repository



Annotated Scripts

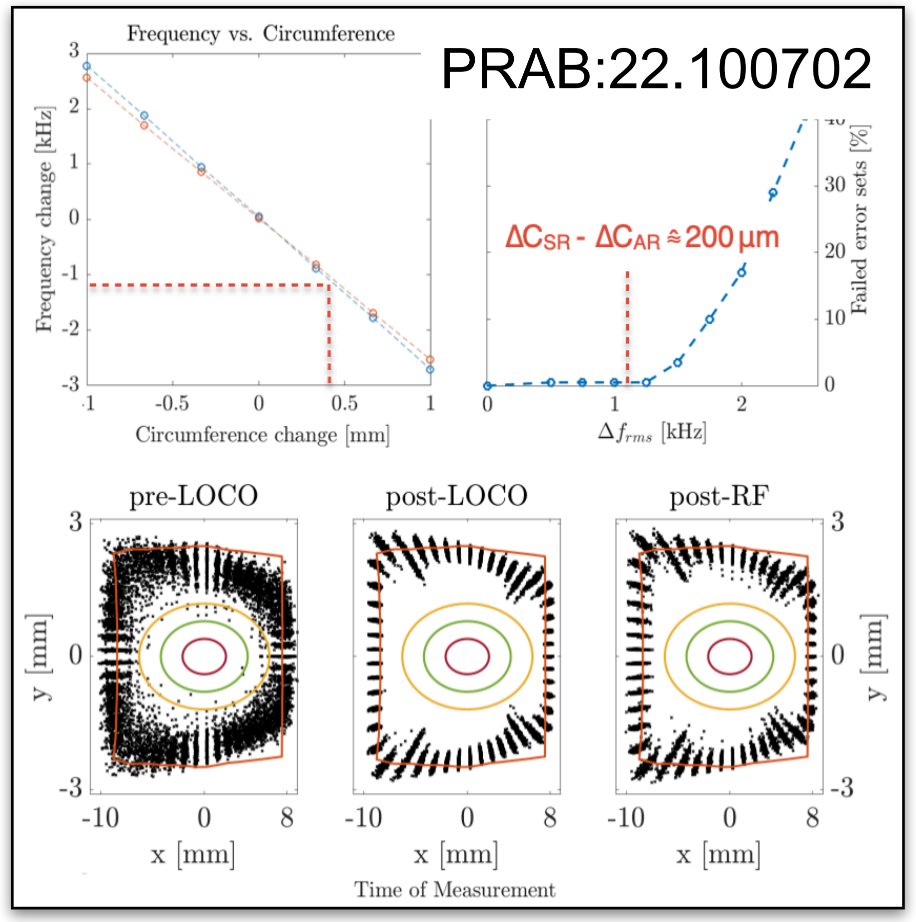


Online Manual

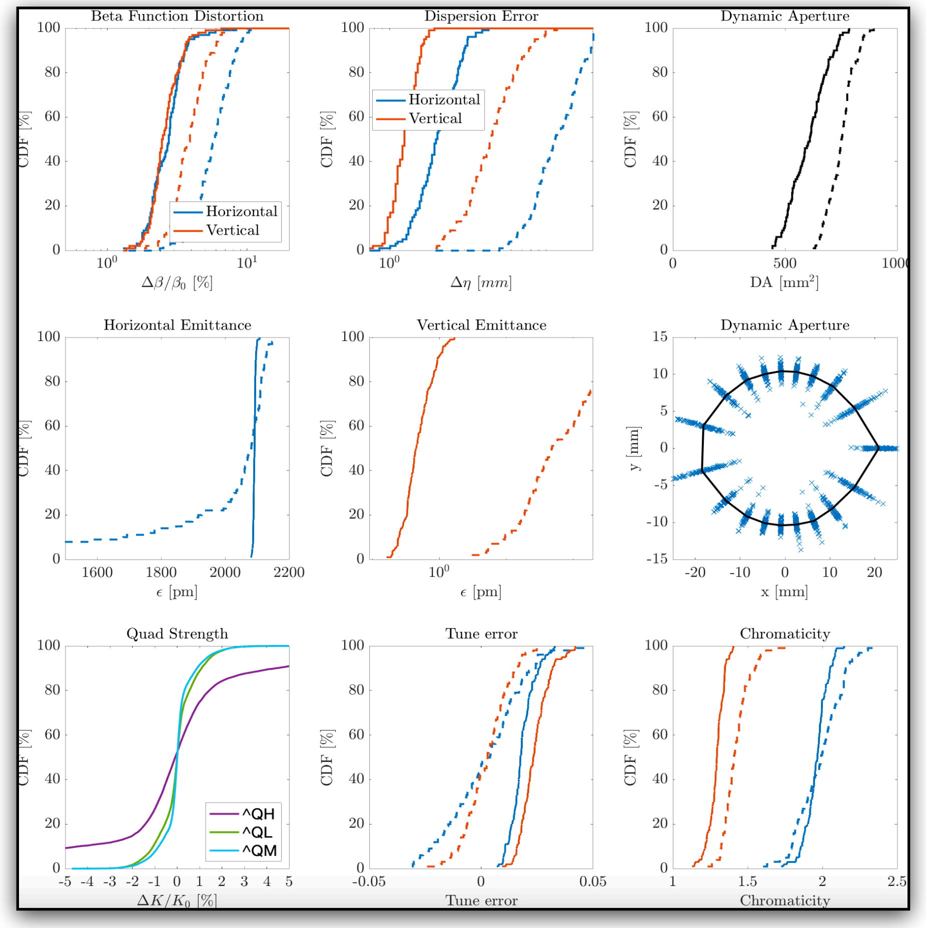


Toolkit Used in Design Process at Various Laboratories

ALS-U (*T. Hellert*)



NSLS-II (*A. Khan*)



Diamond-II (*H. Chao*)

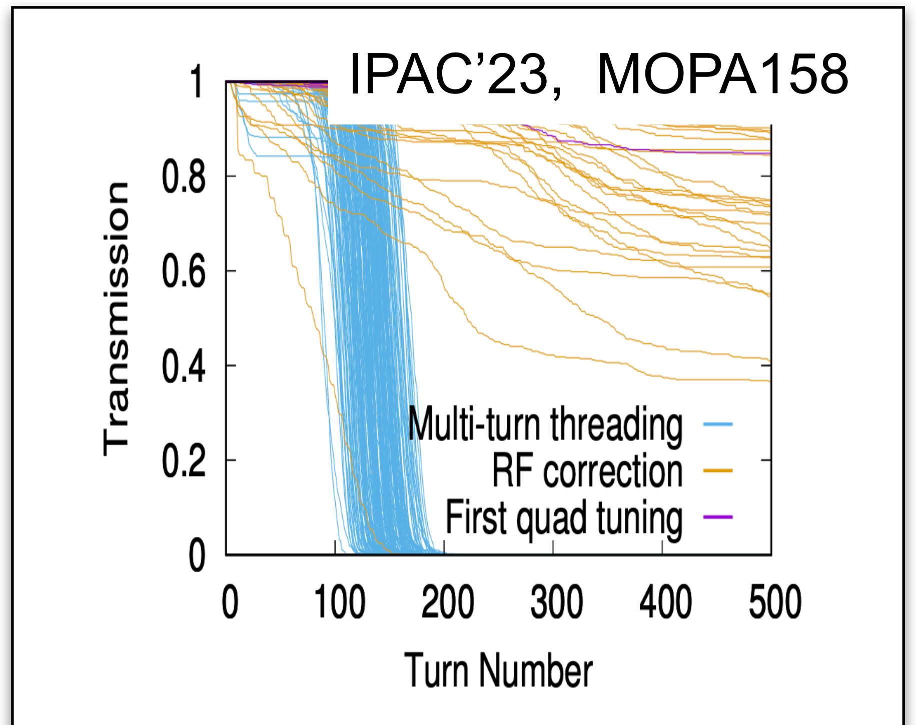
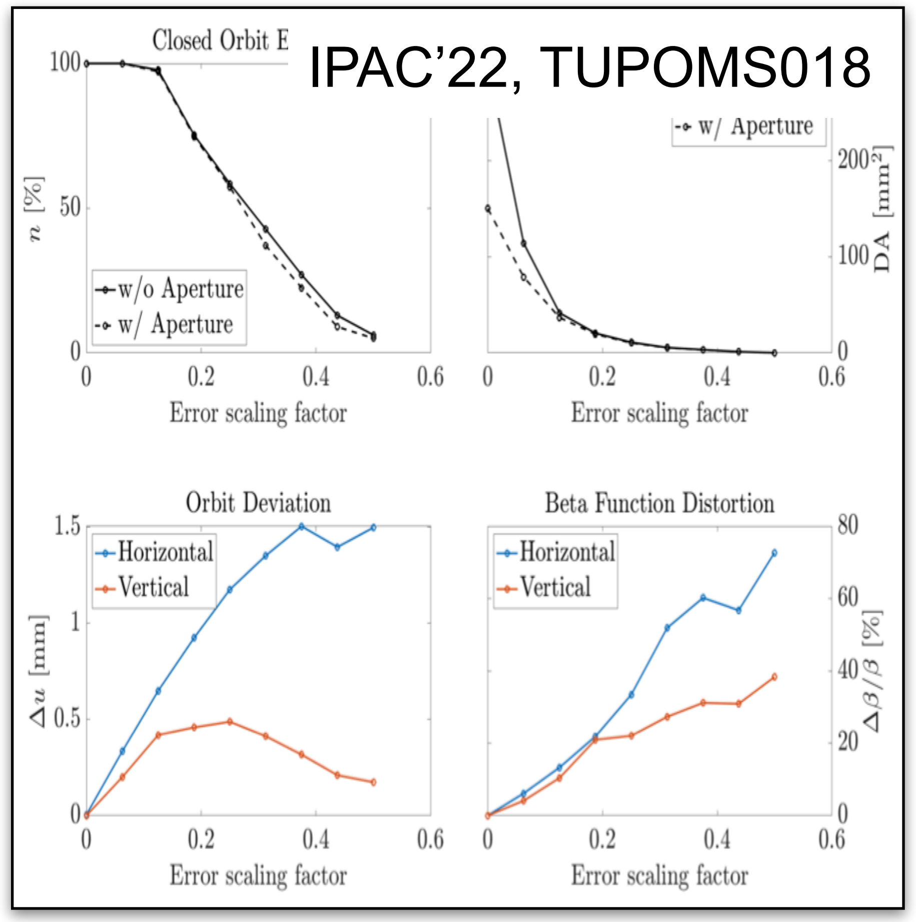


Figure 1: The beam transmission rates versus revolution turns at different stages.

PETRA IV (*T. Hellert*)



ALBA-II (*Z. Marti Diaz*)

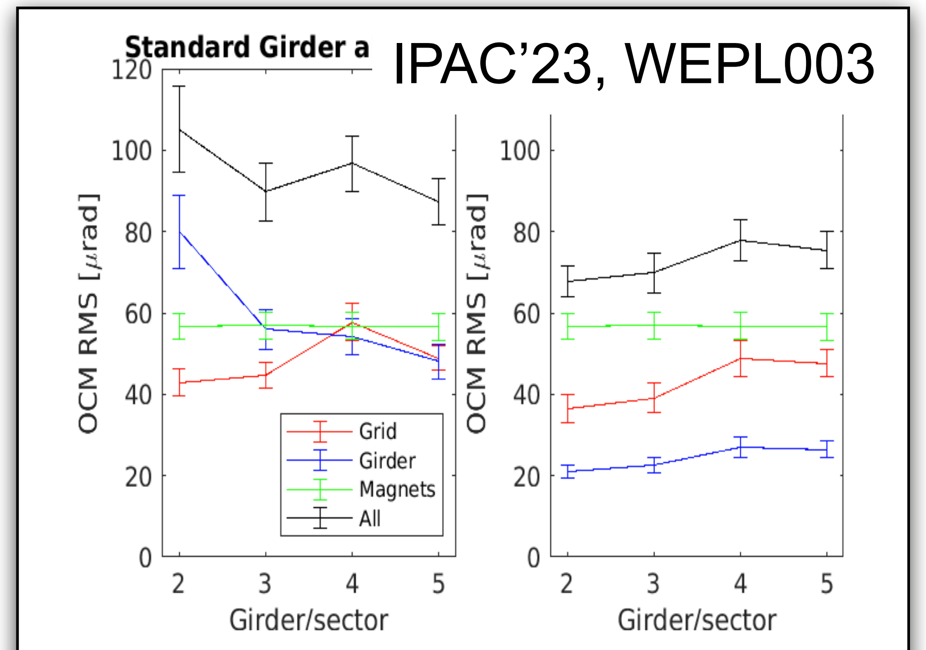
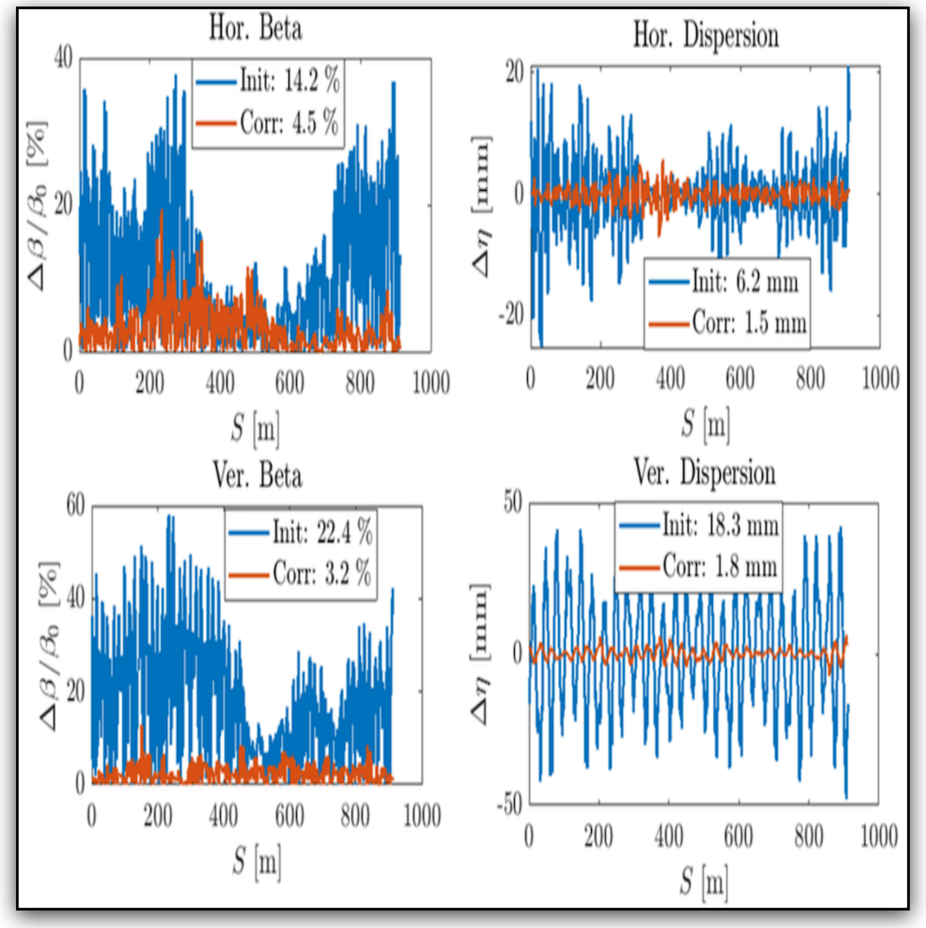
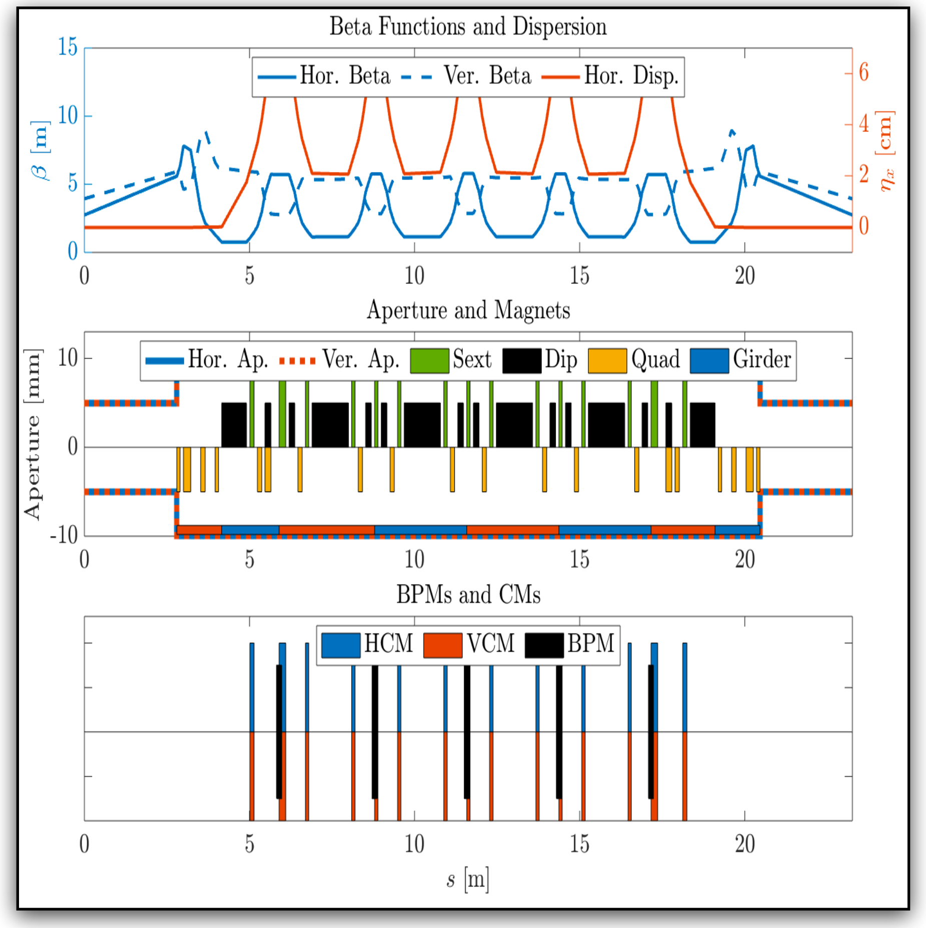


Figure 4: RMS OCM strength as a function of the number of girders. The lines in color represent the result only including one of the three misalignment components of Table 1 The black lines correspond to the result including all misalignment components.

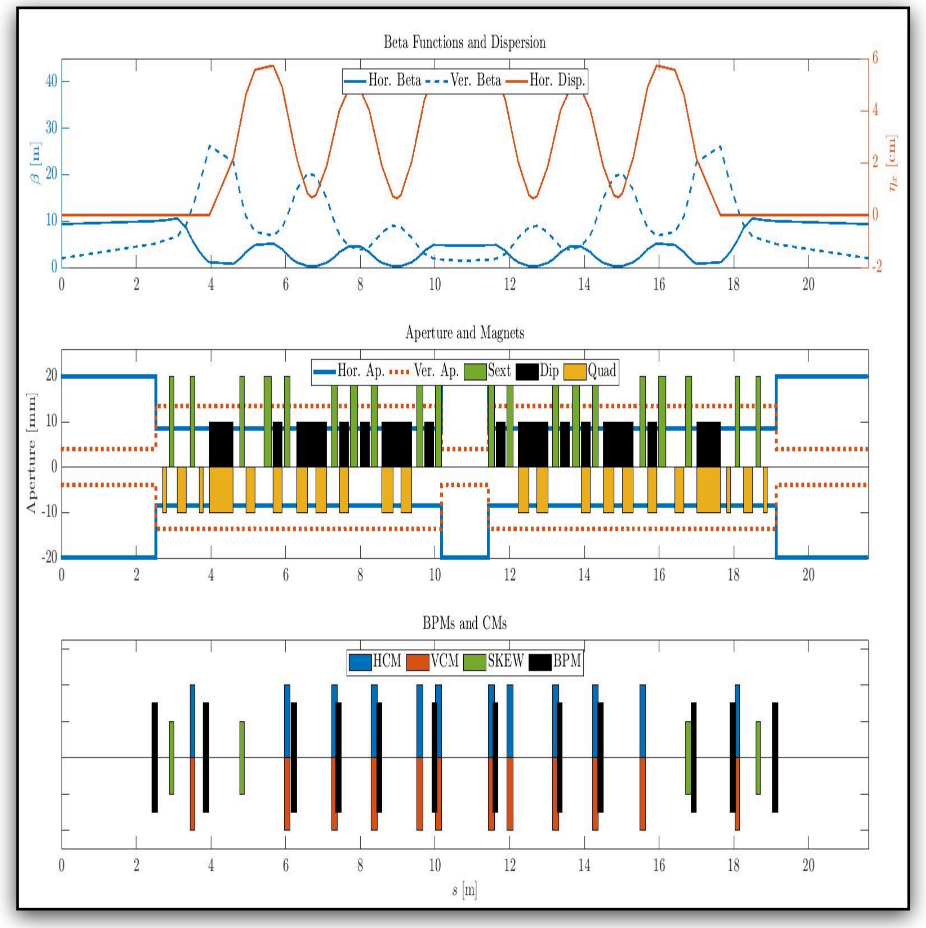
HBSRS (*S. Prakash*)



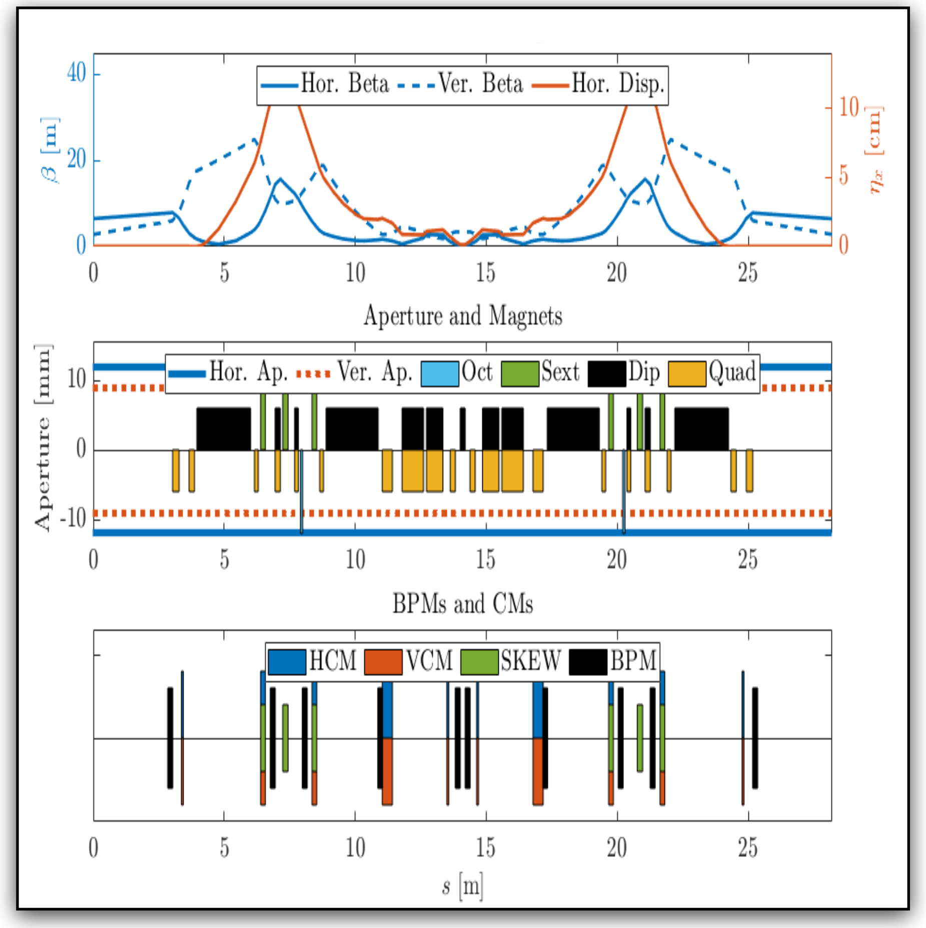
BESSY III (*B. Kuske*)



Elettra 2.0 (*S. Dastan*)



Korean 4GSR (*J. Kim*)



SOLEIL U (*O. Garcia*)

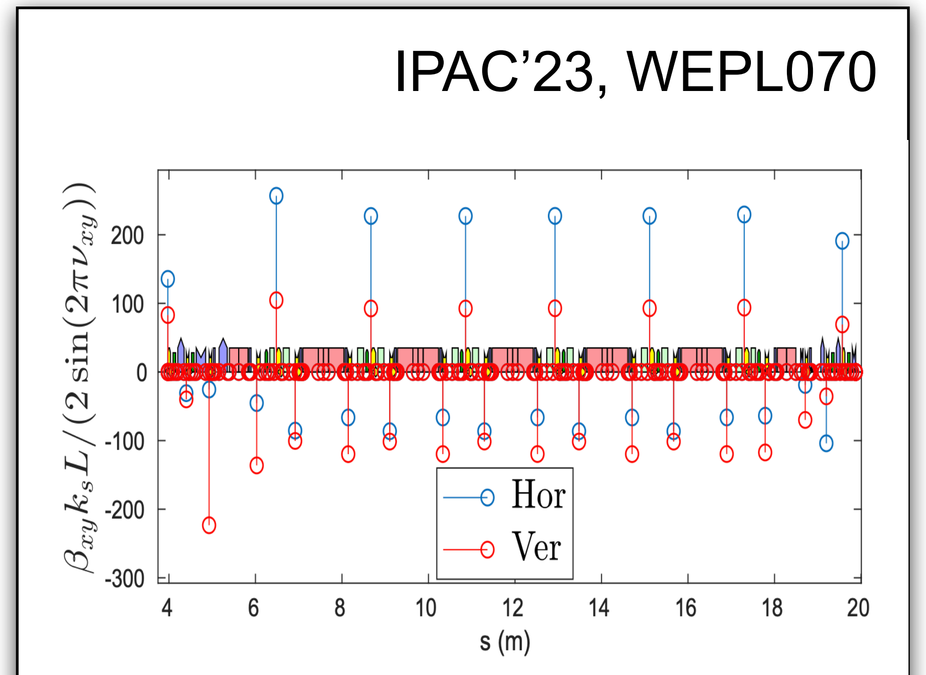
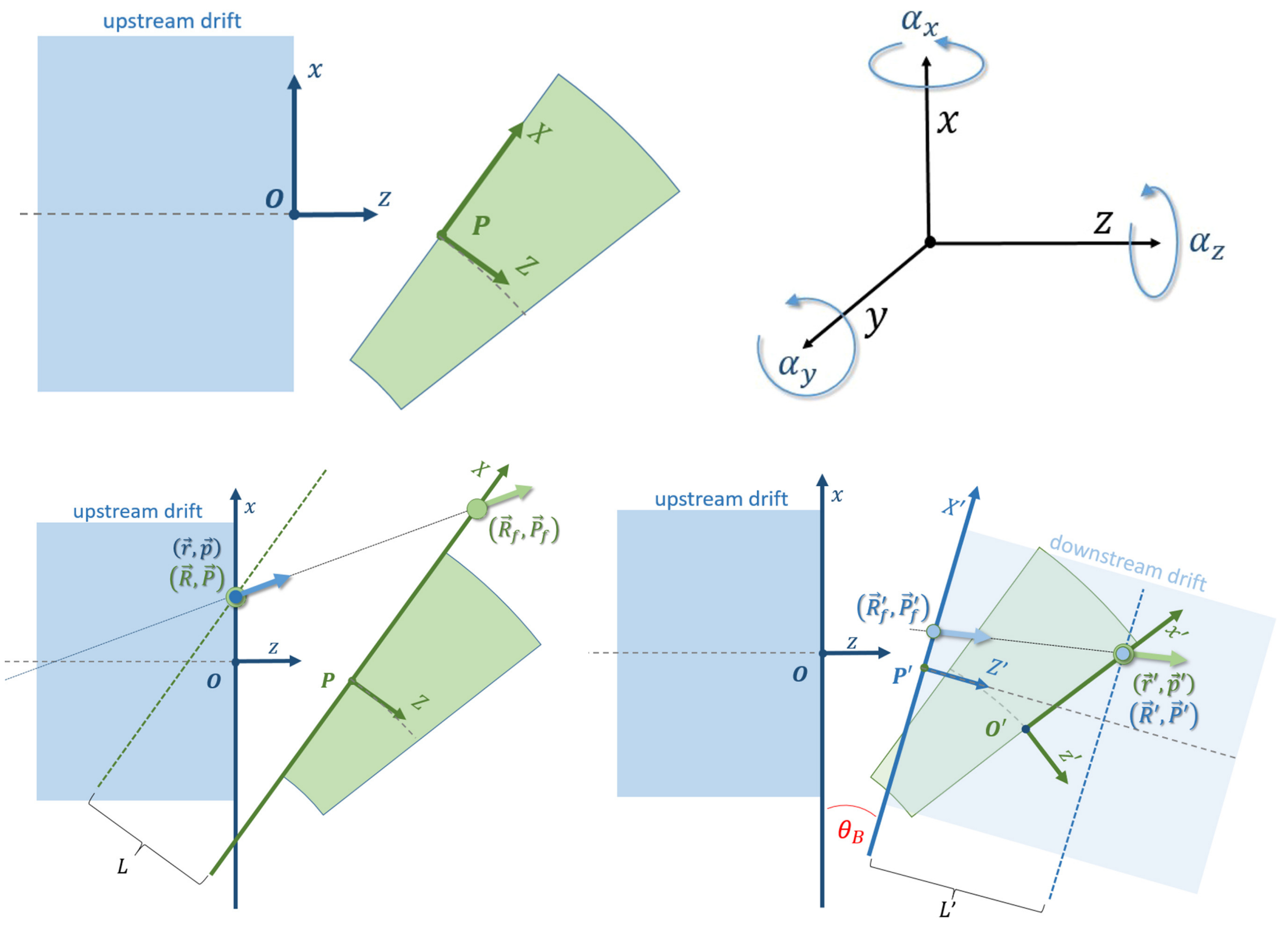
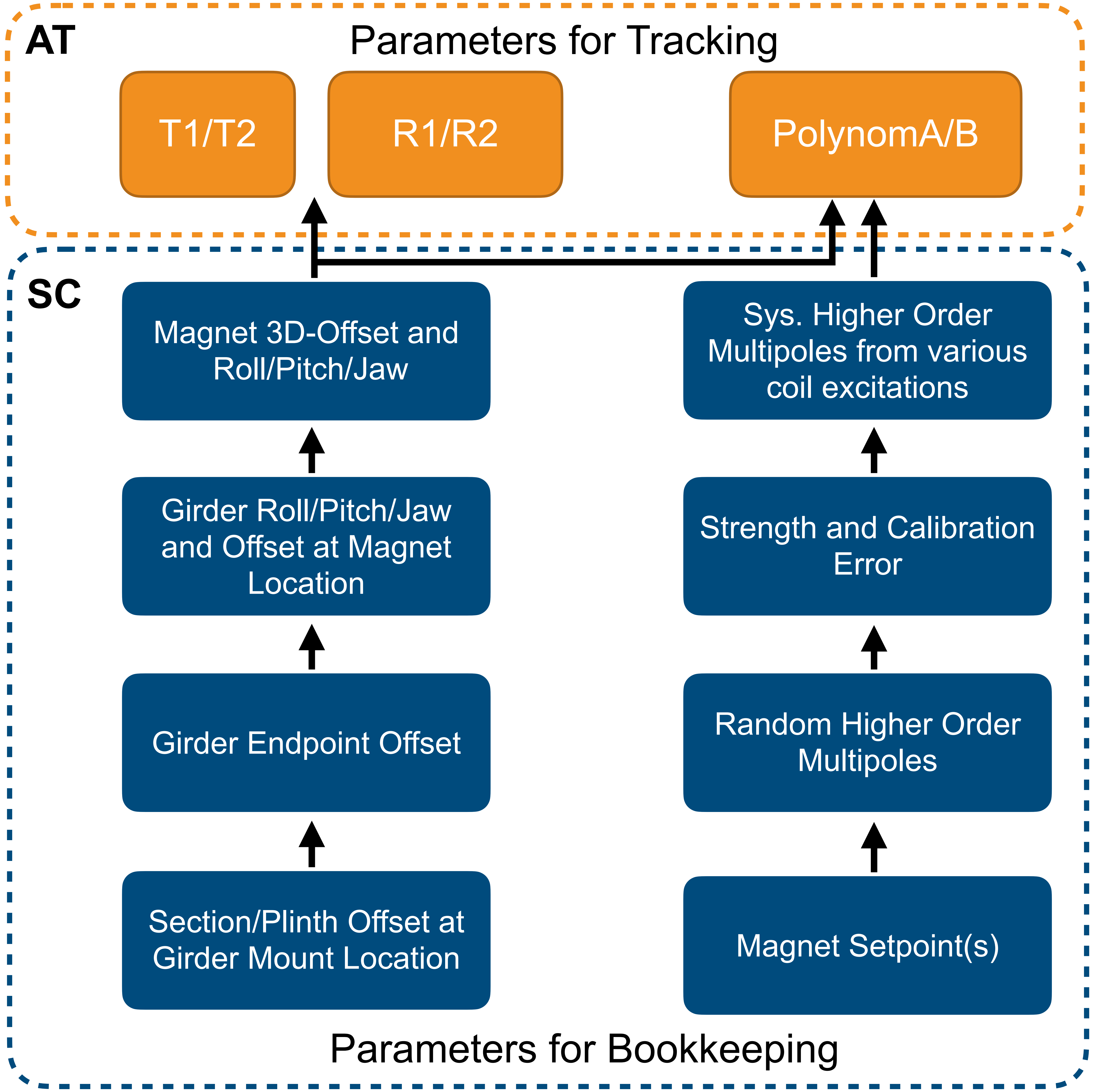


Figure 2: Example of a 7BA (top) quadrupolar and (bottom) sextupolar amplification factors.

SC -> ELEGANT Corrected Lattice Converter

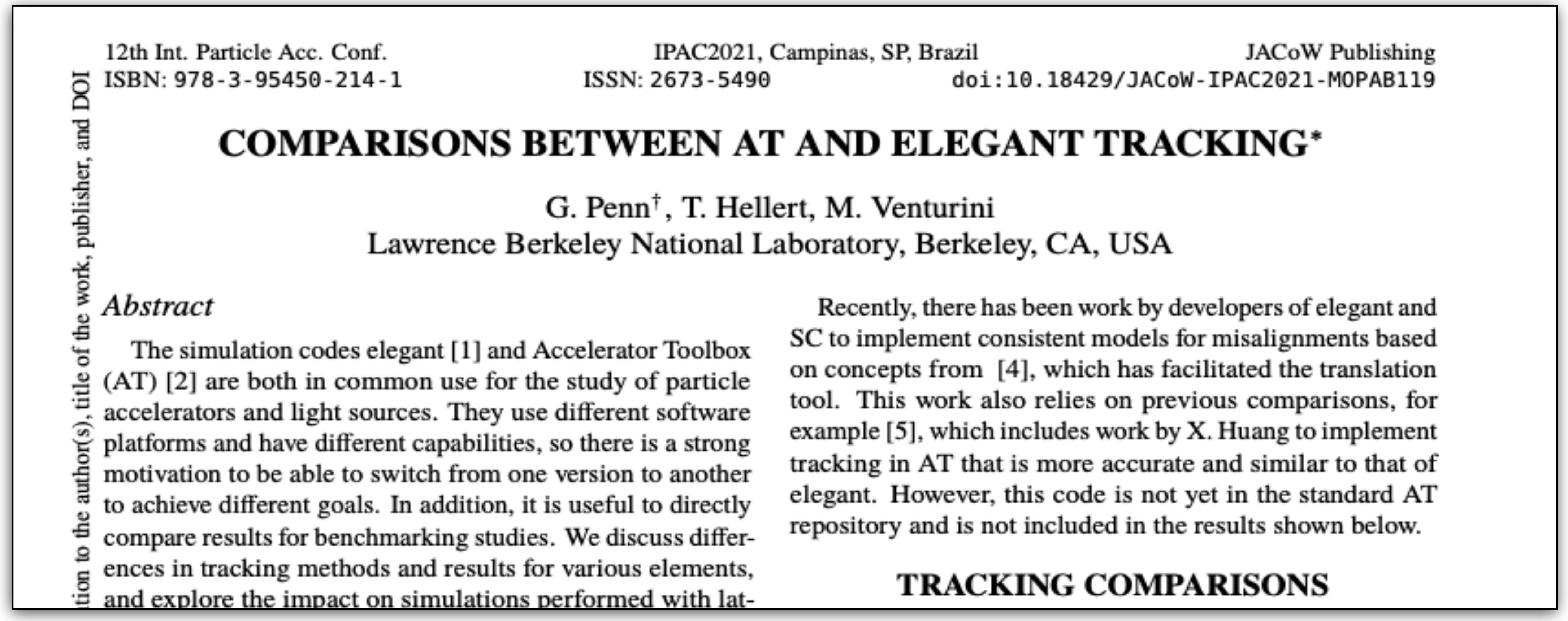


M. Venturini and T. Hellert: 'Particle dynamics and misaligned lattice elements in accelerators', NIM-A 1044:167487, 2022



SC -> ELEGANT Corrected Lattice Converter

- AT/elegant
  - SC allows for easy error model- and correction chain setup
  - Elegant allows for more advanced tracking studies than AT
- Corrected Lattice Converter
  - Set up errors and correction chain with SC
  - Convert final lattice to elegant
  - Perform e.g. collective effects studies
  - Preliminary converter available on SC webpage



12th Int. Particle Acc. Conf. IPAC2021, Campinas, SP, Brazil JACoW Publishing
ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB119

COMPARISONS BETWEEN AT AND ELEGANT TRACKING*

G. Penn†, T. Hellert, M. Venturini
Lawrence Berkeley National Laboratory, Berkeley, CA, USA

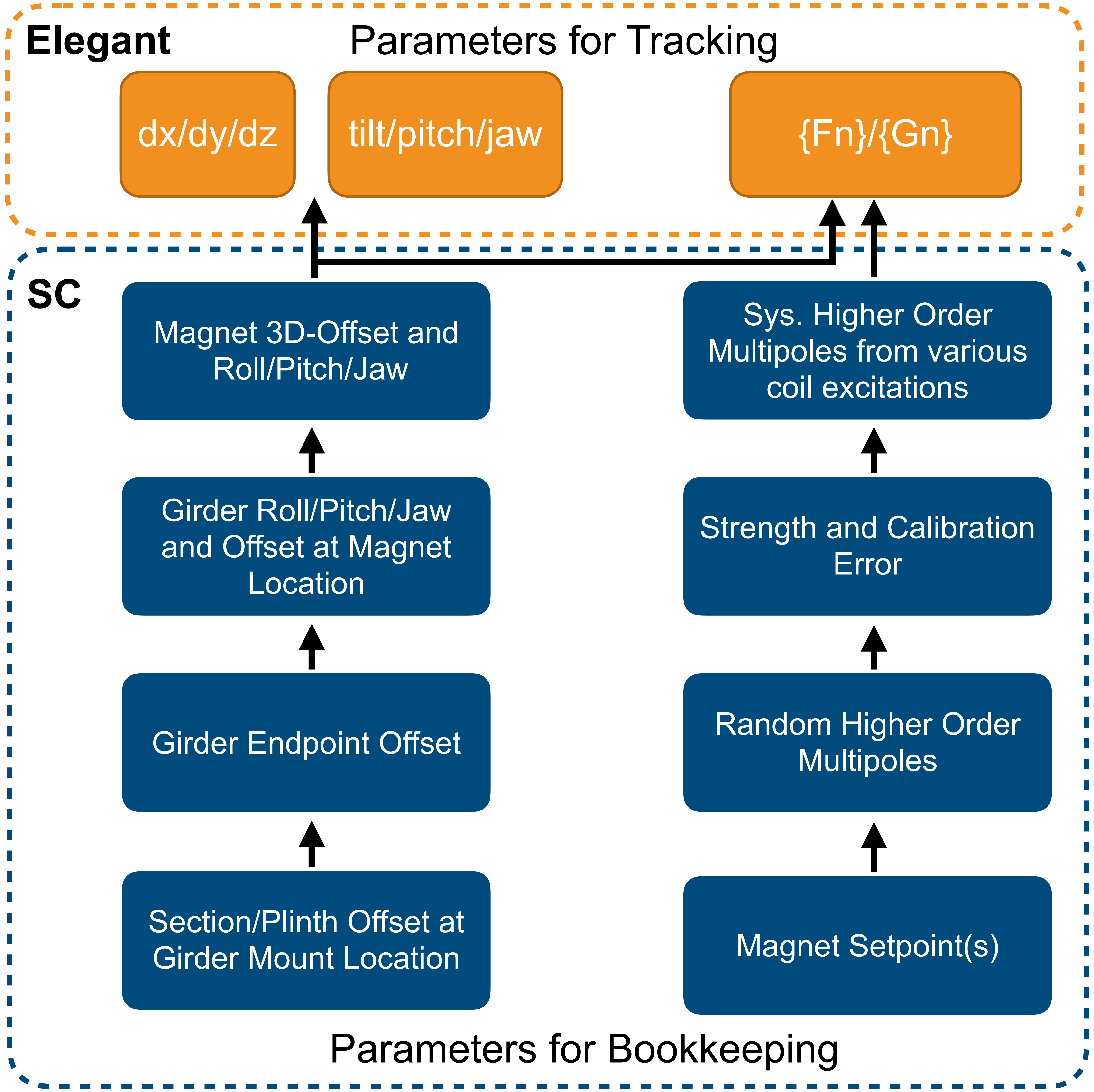
Abstract

The simulation codes elegant [1] and Accelerator Toolbox (AT) [2] are both in common use for the study of particle accelerators and light sources. They use different software platforms and have different capabilities, so there is a strong motivation to be able to switch from one version to another to achieve different goals. In addition, it is useful to directly compare results for benchmarking studies. We discuss differences in tracking methods and results for various elements, and explore the impact on simulations performed with lat-

Recently, there has been work by developers of elegant and SC to implement consistent models for misalignments based on concepts from [4], which has facilitated the translation tool. This work also relies on previous comparisons, for example [5], which includes work by X. Huang to implement tracking in AT that is more accurate and similar to that of elegant. However, this code is not yet in the standard AT repository and is not included in the results shown below.

TRACKING COMPARISONS

G. Penn et al., MOPAB119, IPAC'21



pySC - A Python Implementation of the SC Toolkit

- Choice of Matlab Implementation of SC
  – ALS(-U) is/will be operated with *Matlab Middle Layer* (MML)
  – Matlab based implementation of ALS-U commissioning allows for straight forward experiments at ALS
  – However: cost of Matlab licenses often prevents full utilization of HPC clusters for parallelization of commissioning simulation
- Python Allows for more Advanced Code Development
  – Object based implementation of the SC toolkit
  – Unit tests integration in source control
  – Maximum parallelization possible
  – Open source accessibility for all laboratories
- pySC Development Status
  – Code translation underway since March'23 in DESY/ESRF/LBNL cooperation
  – First major overhaul of the SC toolkit since its publication
  – Significant improvements compared to original implementation
  – Expected publication of pySC at ICALEPS'23 by Lukas Melina*

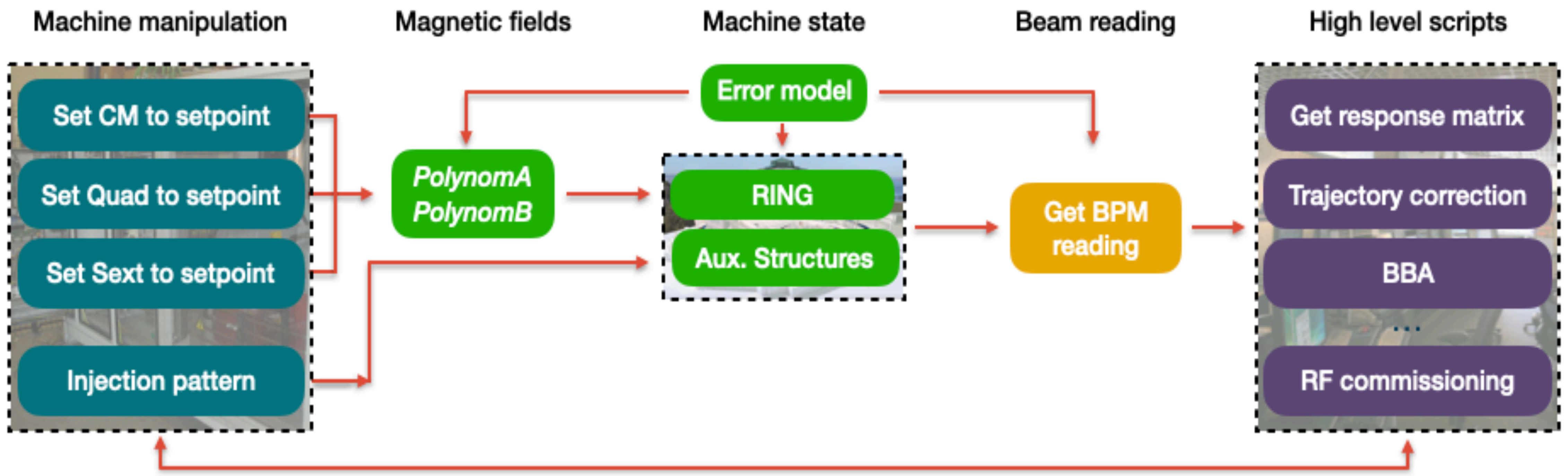
Advertisement: AT workshop at ESRF in October 2023

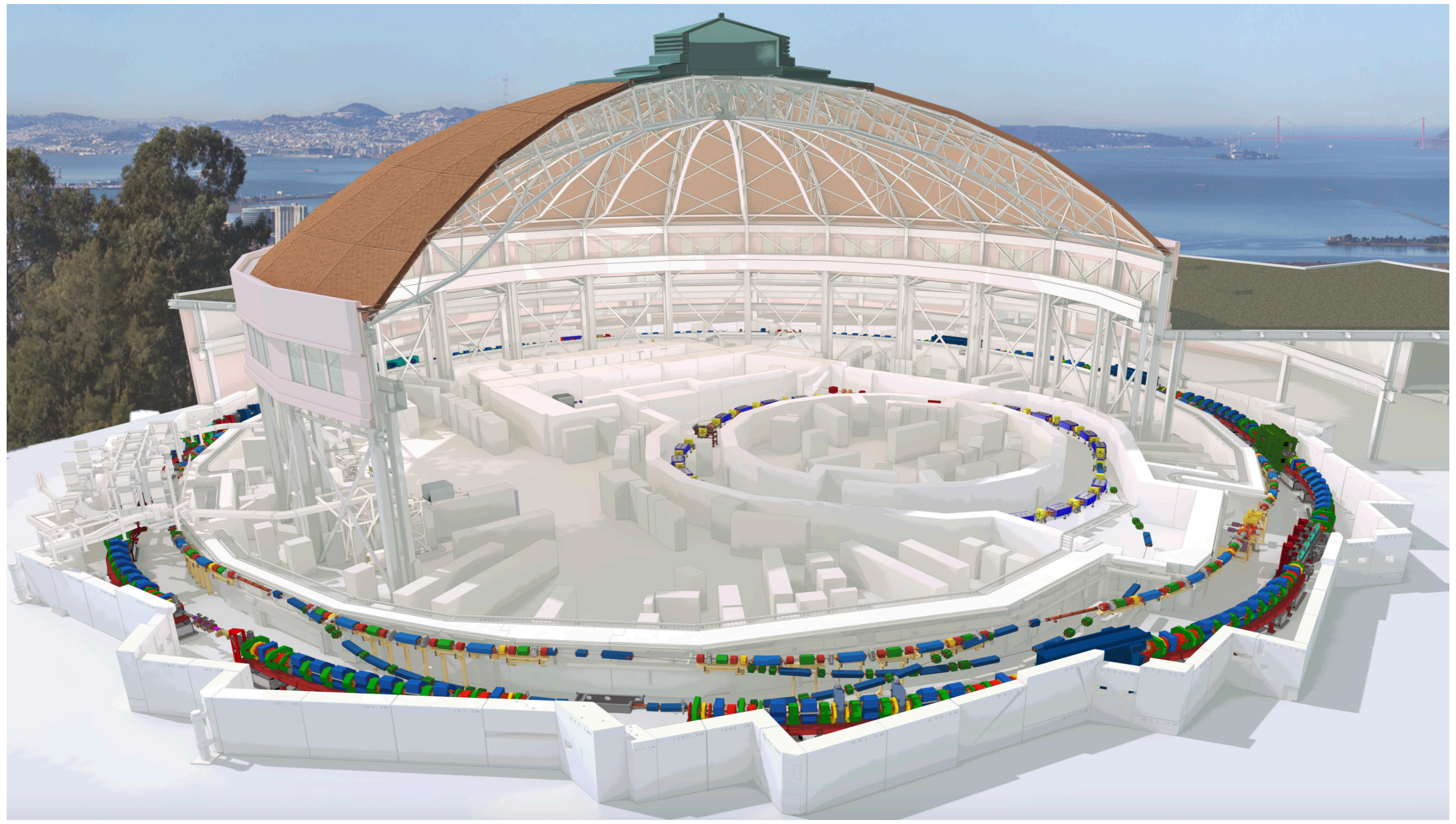
https://indico.esrf.fr/event/93/

*) L. Malina et al: "Python library for simulated commissioning of storage-ring accelerators" to be presented at ICALEPS 2023

Automated Startup and Commissioning Tests at ALS

- Automated startup and commissioning scripts will be essential for ALS-U
  - Lattice too non-linear to achieve stored beam with conventional methods
  - Scheduled commissioning time for AR and SR very short compared to the operational complexities
- SC Toolkit developed for simulated commissioning and error analysis studies
  - Comprehensive automated lattice correction tools to get from first injection to stored beam
  - Workflow mimics machine operation from the control room





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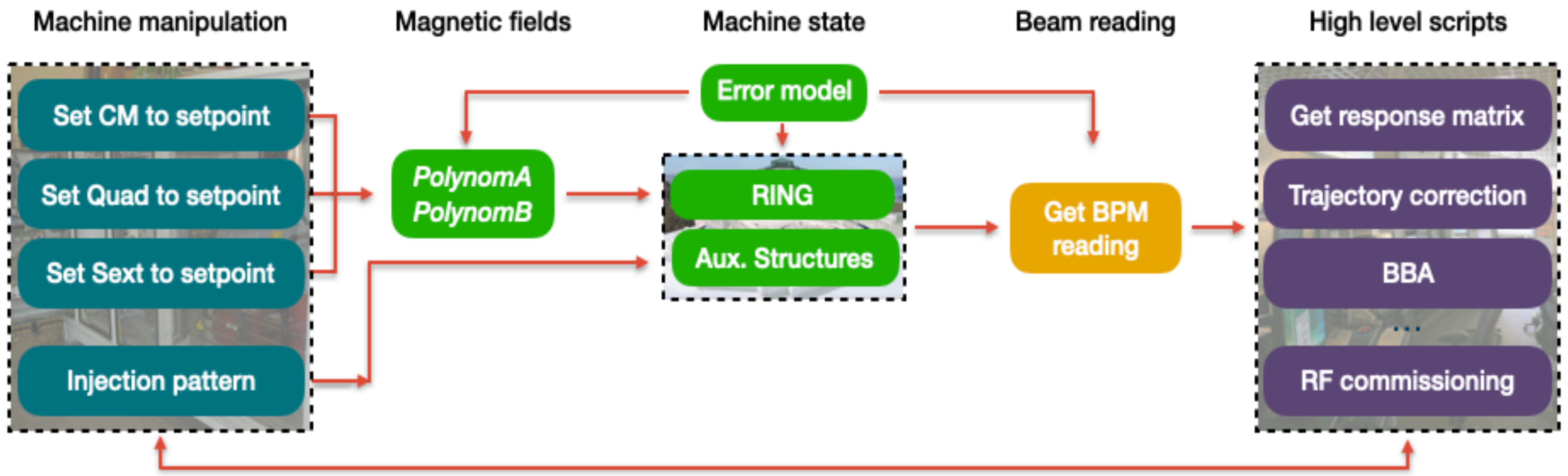
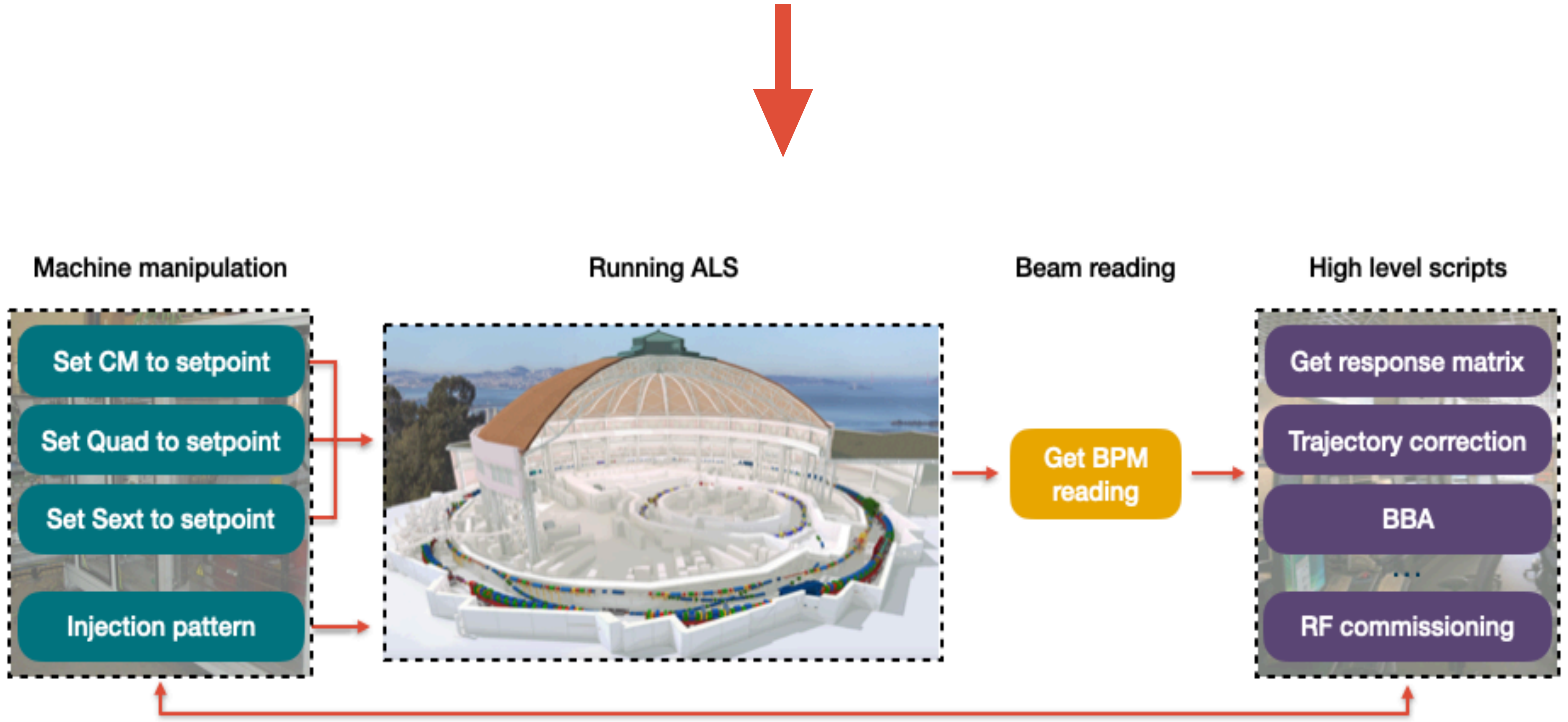
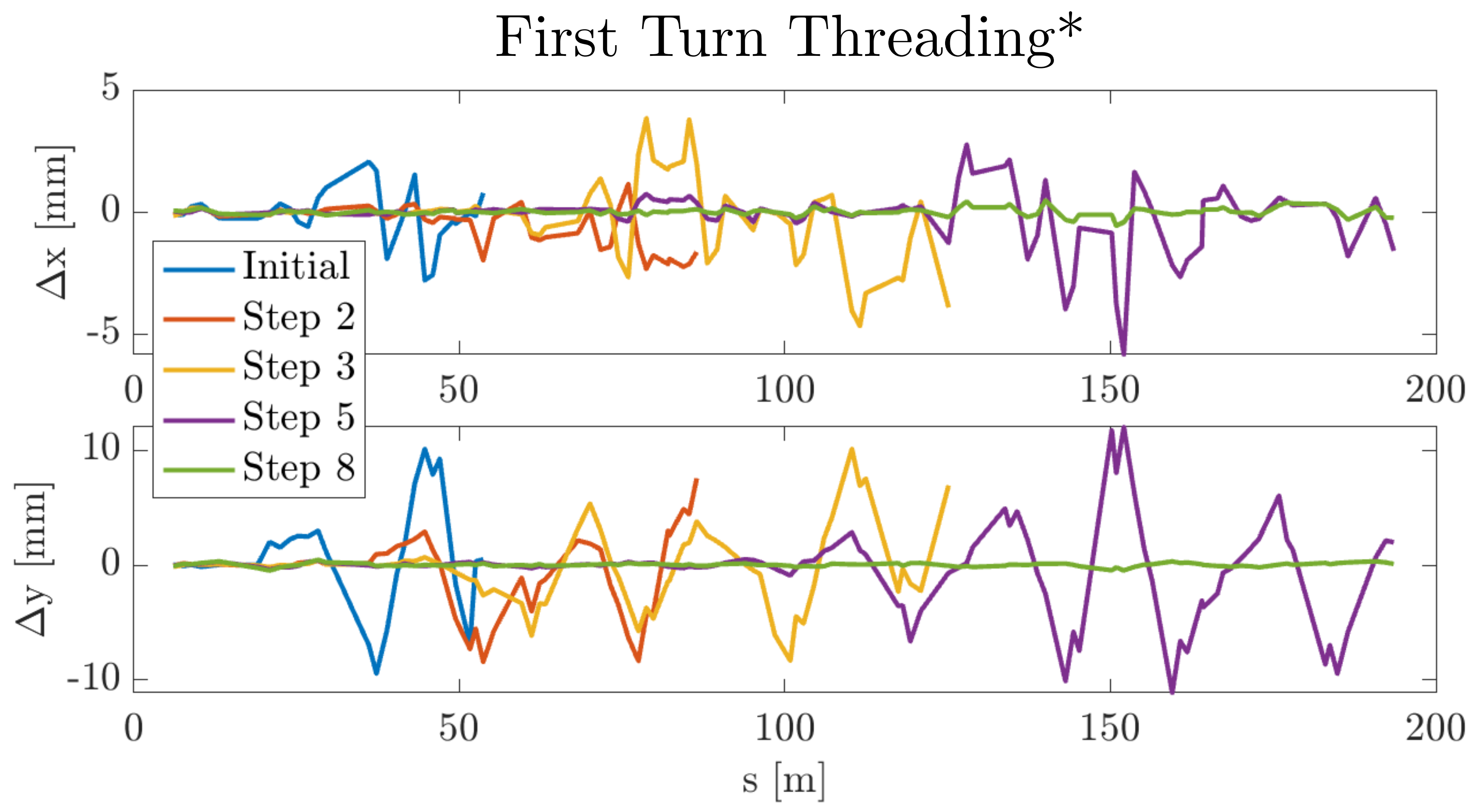
- SC Toolkit developed for simulated commissioning and error analysis studies
  - Comprehensive automated lattice correction tools to get from first injection to stored beam
  - Workflow mimics machine operation from the control room
- Integrating SC Toolkit into the control system
  - ALS and ALS-U operated with MML, toolkit written in Matlab
  - ALS lattice very similar to ALS-U AR lattice

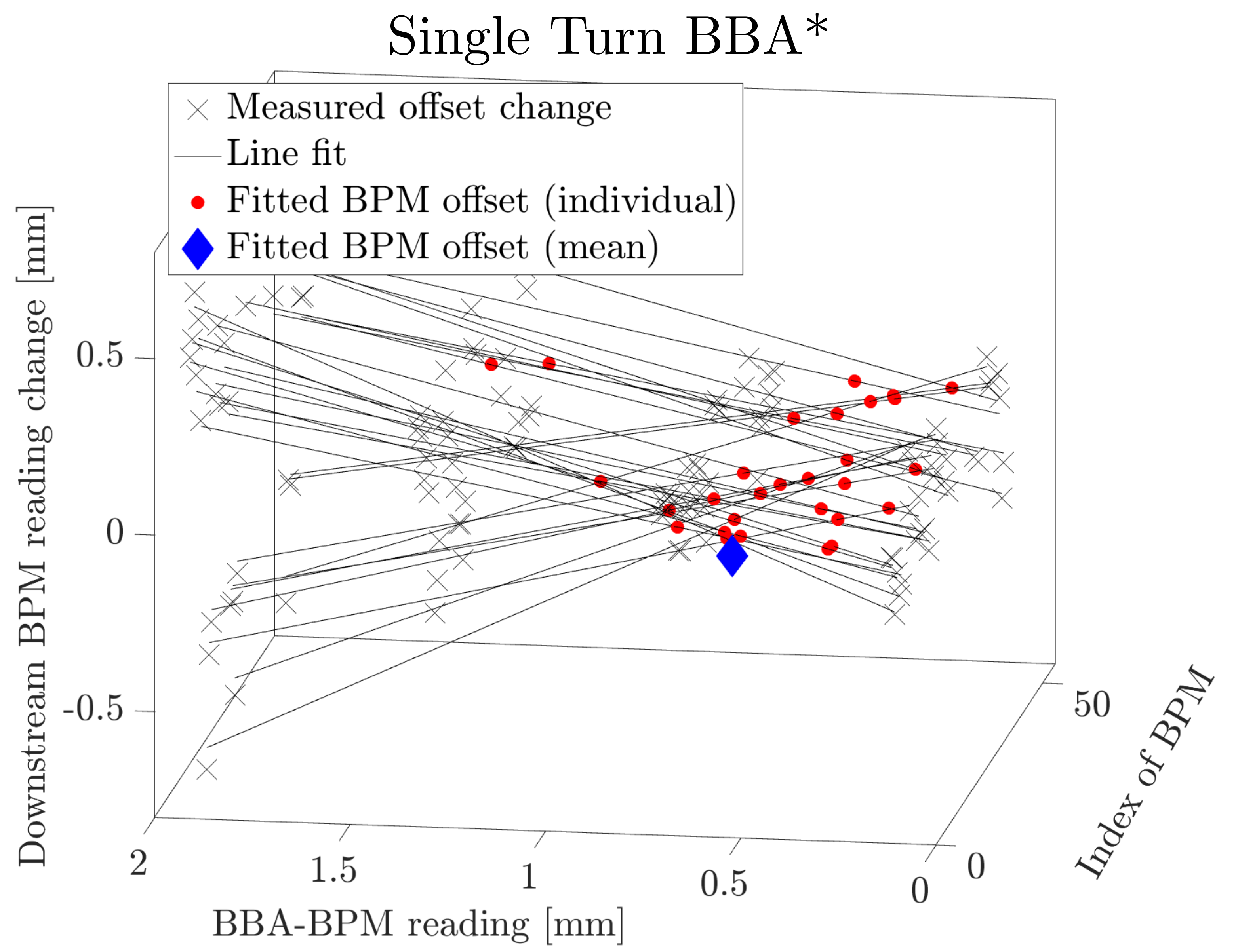




Automated Startup and Commissioning Tests at ALS

- Automated startup and commissioning scripts will be essential for ALS-U
  - Lattice too non-linear to achieve stored beam with conventional methods
  - Scheduled commissioning time for AR and SR very short compared to the operational complexities
- SC Toolkit developed for simulated commissioning and error analysis studies
  - Comprehensive automated lattice correction tools to get from first injection to stored beam
  - Workflow mimics machine operation from the control room
- Integrating SC Toolkit into the control system
  - ALS and ALS-U operated with MML, toolkit written in Matlab
  - ALS lattice very similar to ALS-U AR lattice
- Experimental commissioning tests and code development at ALS in progress
  - First turn threading
  - Multi-turn trajectory/orbit control
  - Single turn beam based alignment

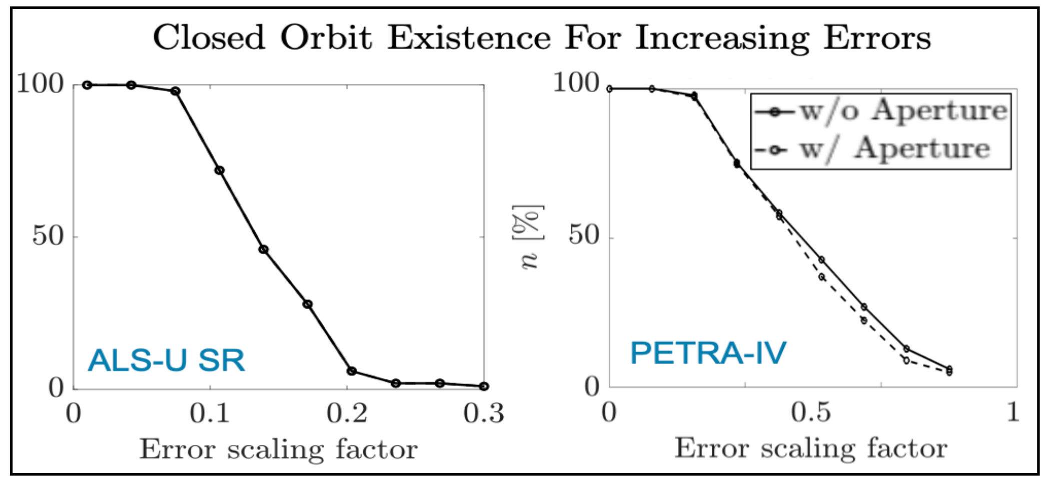


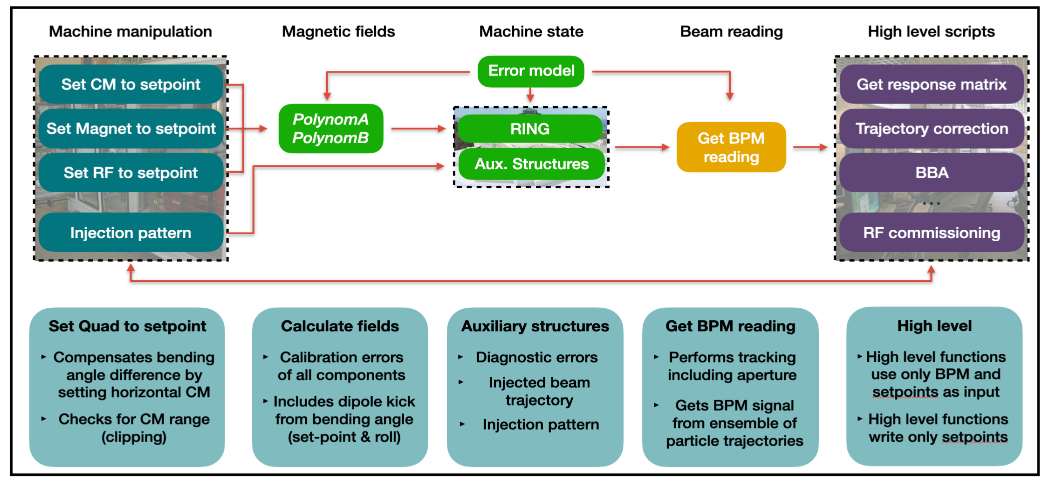


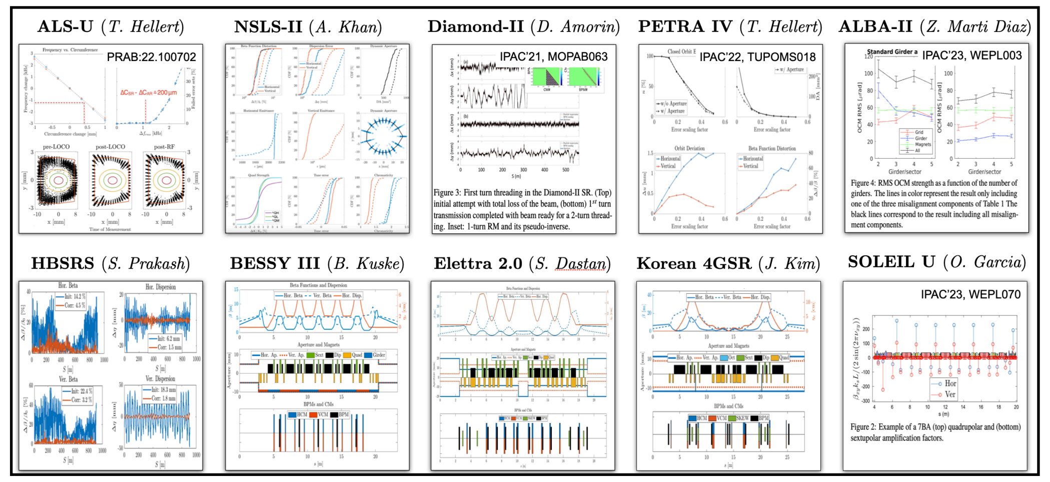
*) T. Hellert et al.: MOPM010, IPAC'23

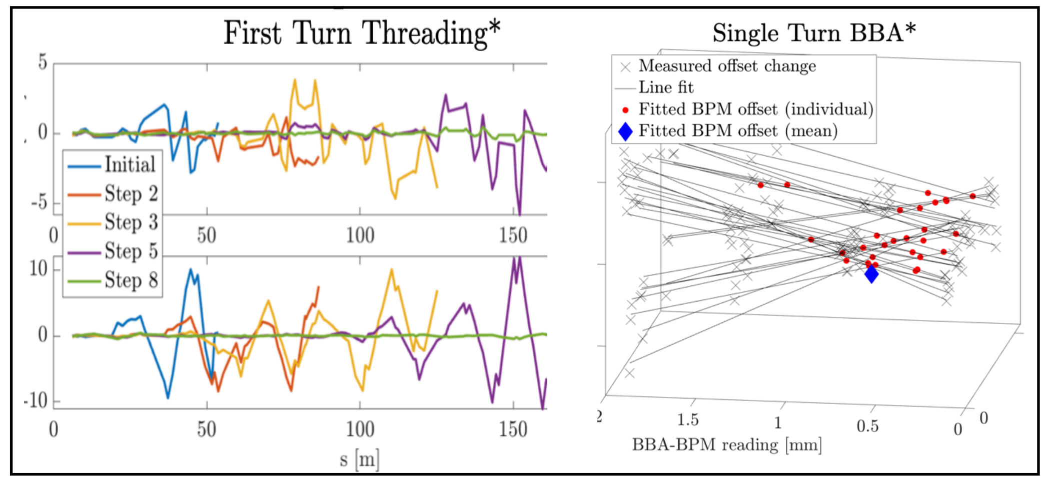
Summary

- Commissioning Simulations are Essential for the Design of Future Storage Ring Light Sources
  - 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 successfully demonstrated at multiple machines
- Several Code Developments Underway
  - SC to elegant corrected lattice converter
  - Python implementation (pySC)
  - Automated startup and commissioning scripts by integrating the SC toolkit into the MML control system









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