PETRA IV.
NEW DIMENSIONS

SC - A Toolkit for Simulated Commissioning

Thorsten Hellert

LEL 2022 – 3rd Workshop on Low Emittance Lattice Design

ALBA, Barcelona, 27.06.22

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

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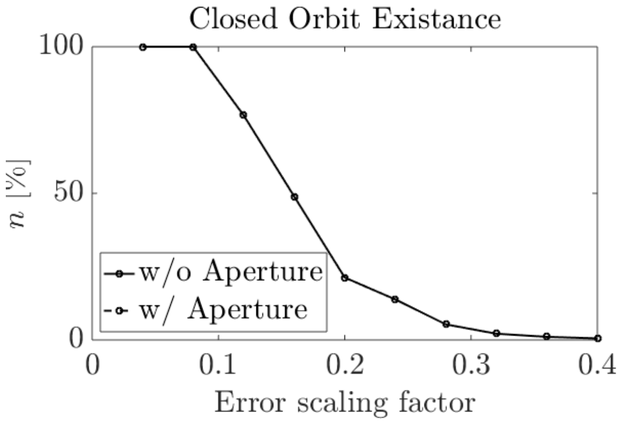
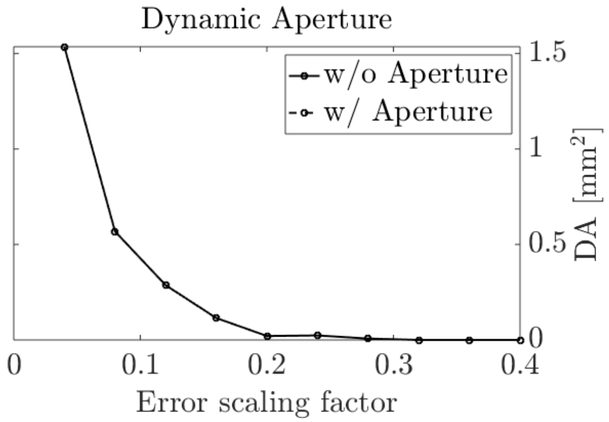
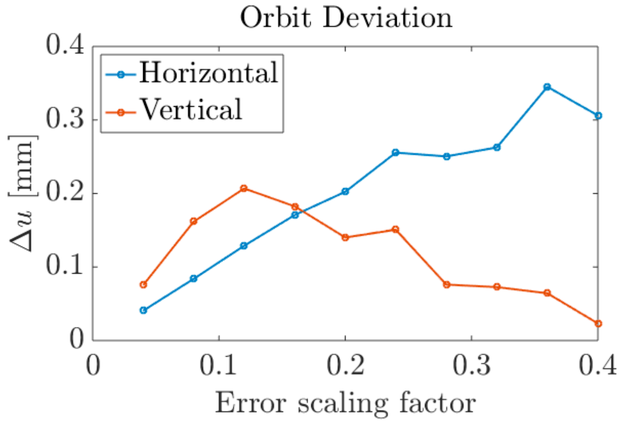
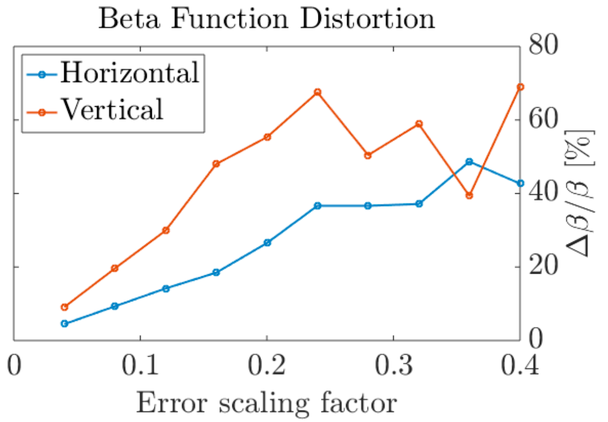
Conventional Methods For Establishing Error Tolerances Don't Work

ALS-U Storage Ring

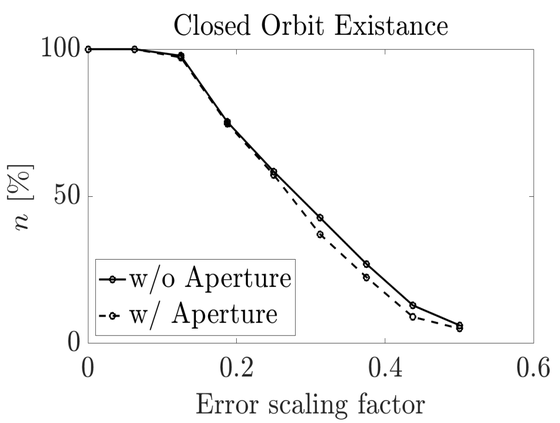


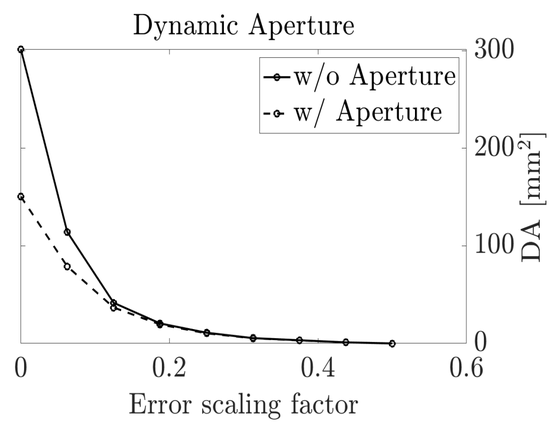


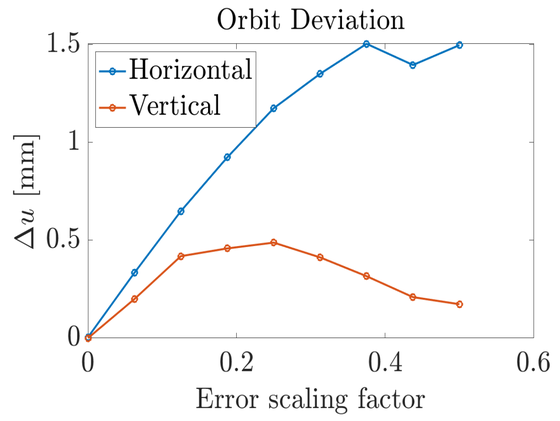


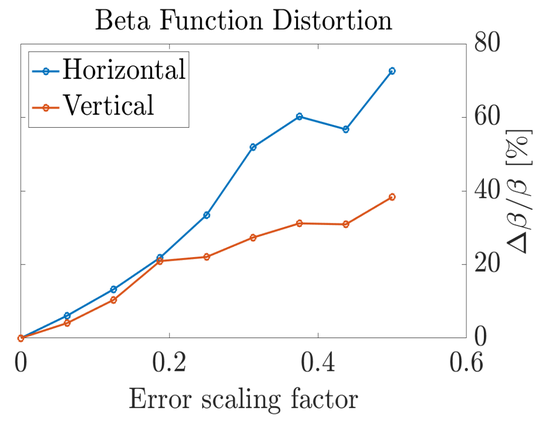


PETRA-IV





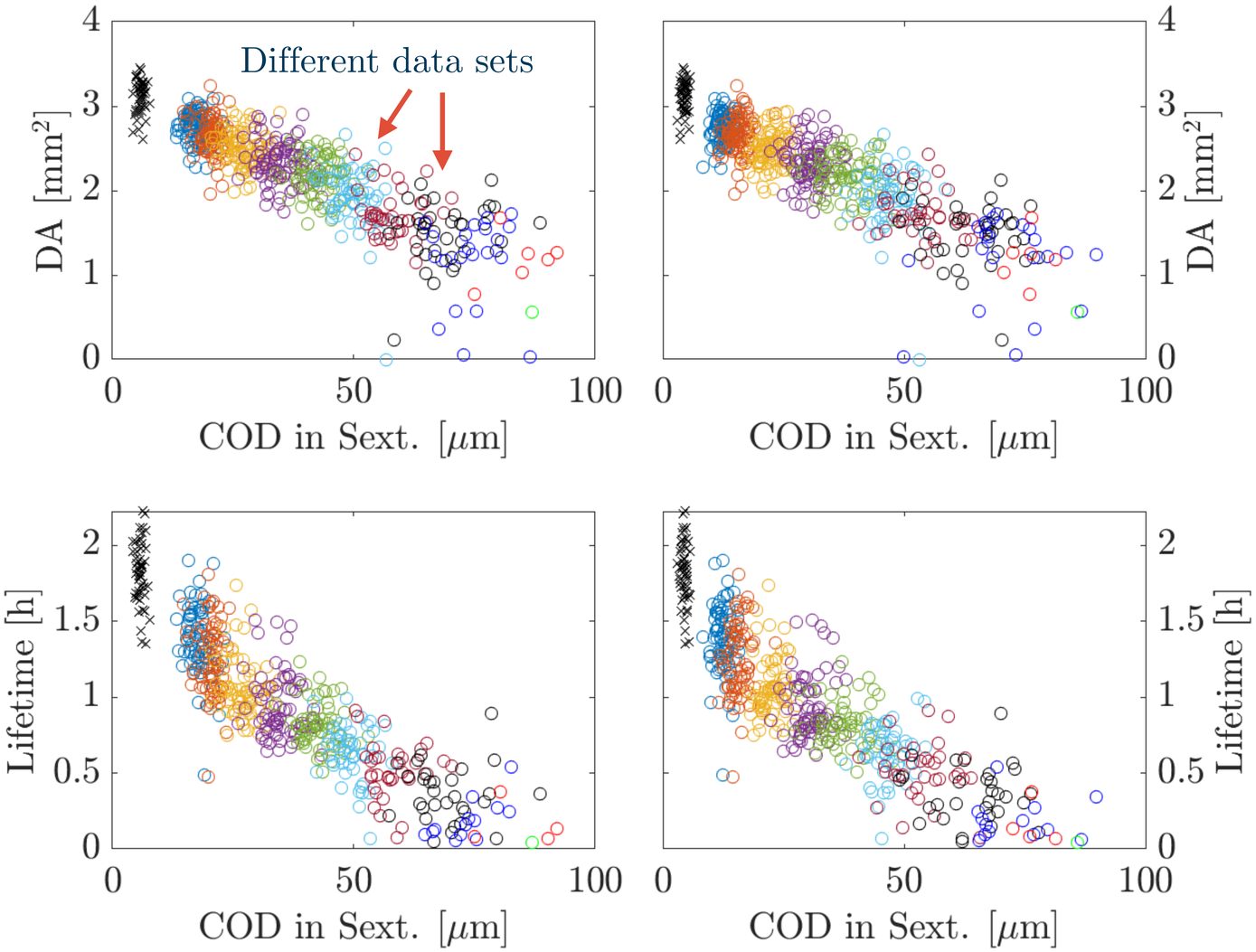




- **Unstable lattice when including errors without correction**

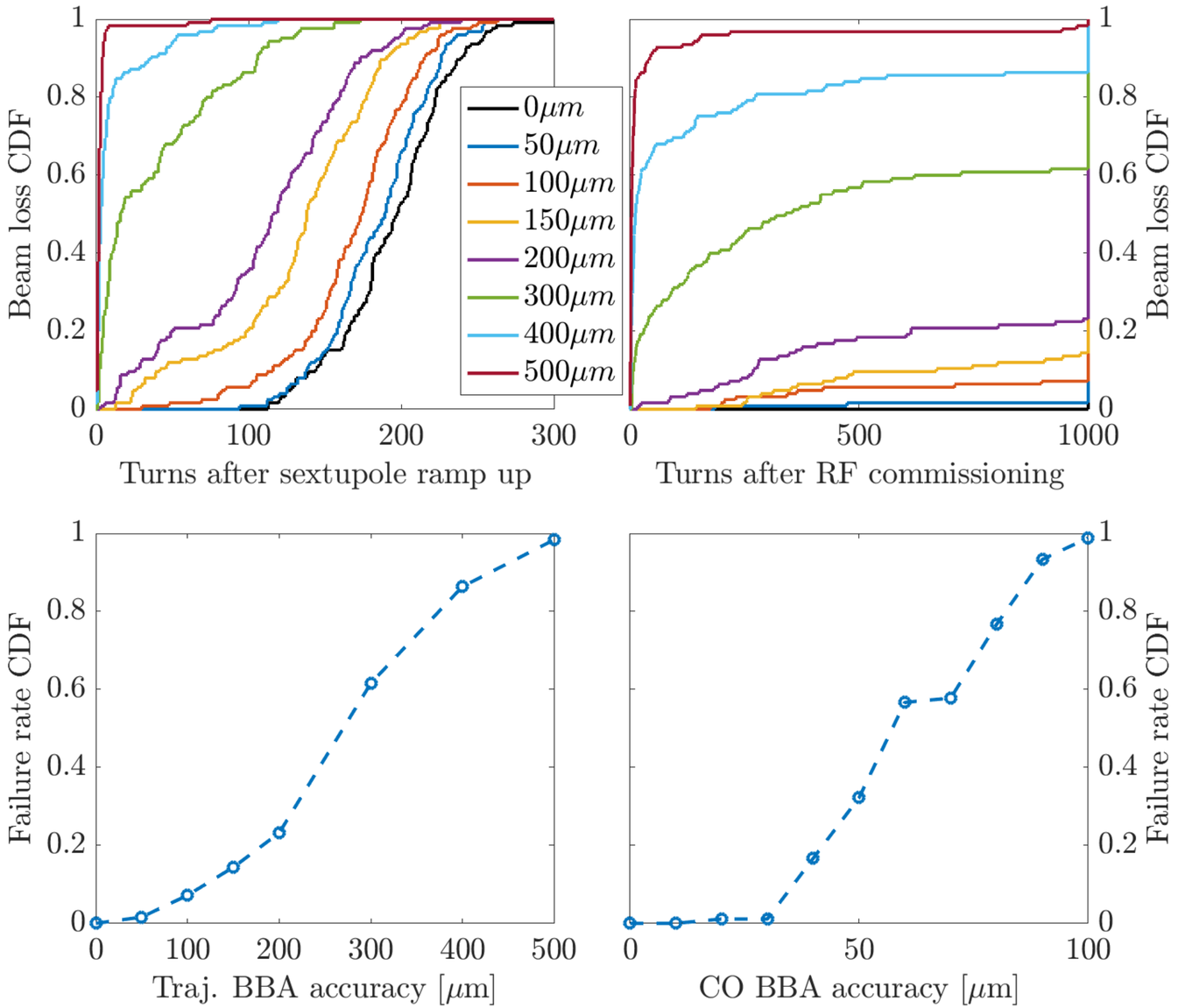
Lattice Performance Degradation due to Sextupole Offsets at ALS-U SR

- **Errors included in all commissioning simulations:**
  - RF, Injection, Diagnostic
  - Sys. multipoles, magnet strength and roll errors
- **Errors varied in simulations:**
  - Girder and magnet offset
  - Simulated BBA accuracy
- **Findings:**
  - Correlation between pre-LOCO closed orbit deviation in sextupole magnets and post-LOCO performance
  - Lifetime virtually zero above COD of 50 µm rms
- **Conclusion:**
  - Small COD in sextupoles crucial for lattice performance



Demanding BPM Offset Requirements During Commissioning

- **Errors included in all commissioning simulations:**
  - RF, Injection, Diagnostic
  - Sys. multipoles, magnet strength and roll errors
  - Magnet and Support Structure Misalignments
- **Errors varied in simulations:**
  - Simulated turn-by-turn and stored beam BBA accuracy
- **Findings:**
  - Achievable number of turns strongly dependent on turn-by-turn BBA accuracy, 500um rms BPM offset not feasible
  - Stored beam BBA accuracy <35um needed to successfully perform optics correction
- **Conclusion:**
  - Realistic modelling of (turn-by-turn) BBA procedure required in commissioning simulation

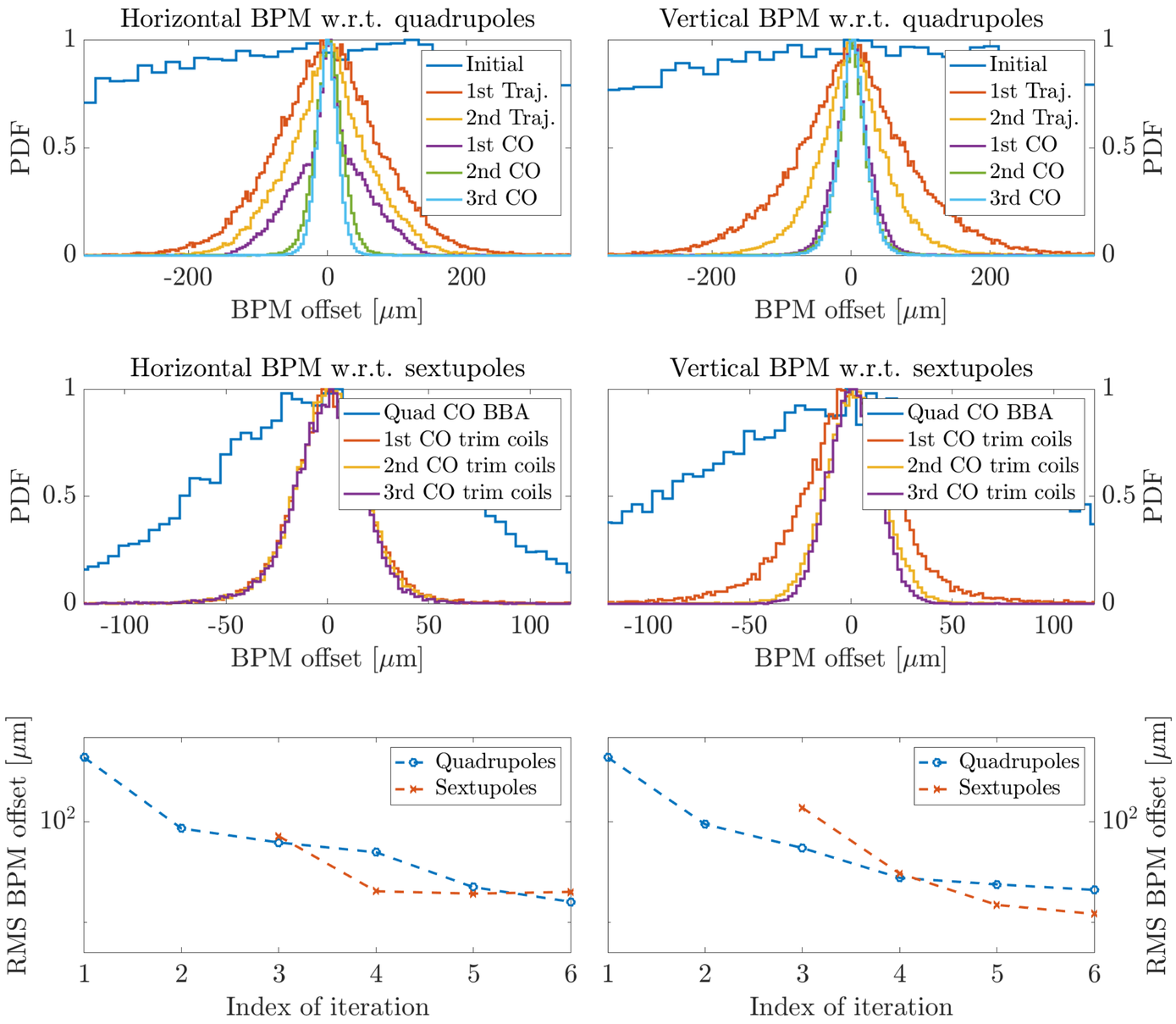


Commissioning Simulation: Quadrupole Trim Coils on Sextupoles Required

- **Initial Transmission**
  - Achieve first turn transmission
  - 2-turn trajectory correction
- **Multi-Turn Transmission**
  - Trajectory based BBA
  - Static injection error correction

  ← 2 Iterations
- **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

  ← 3 Iterations
- **ID Compensation**
  - Close IDs and include kick maps
  - Global optics correction
  - Evaluation of lattice properties



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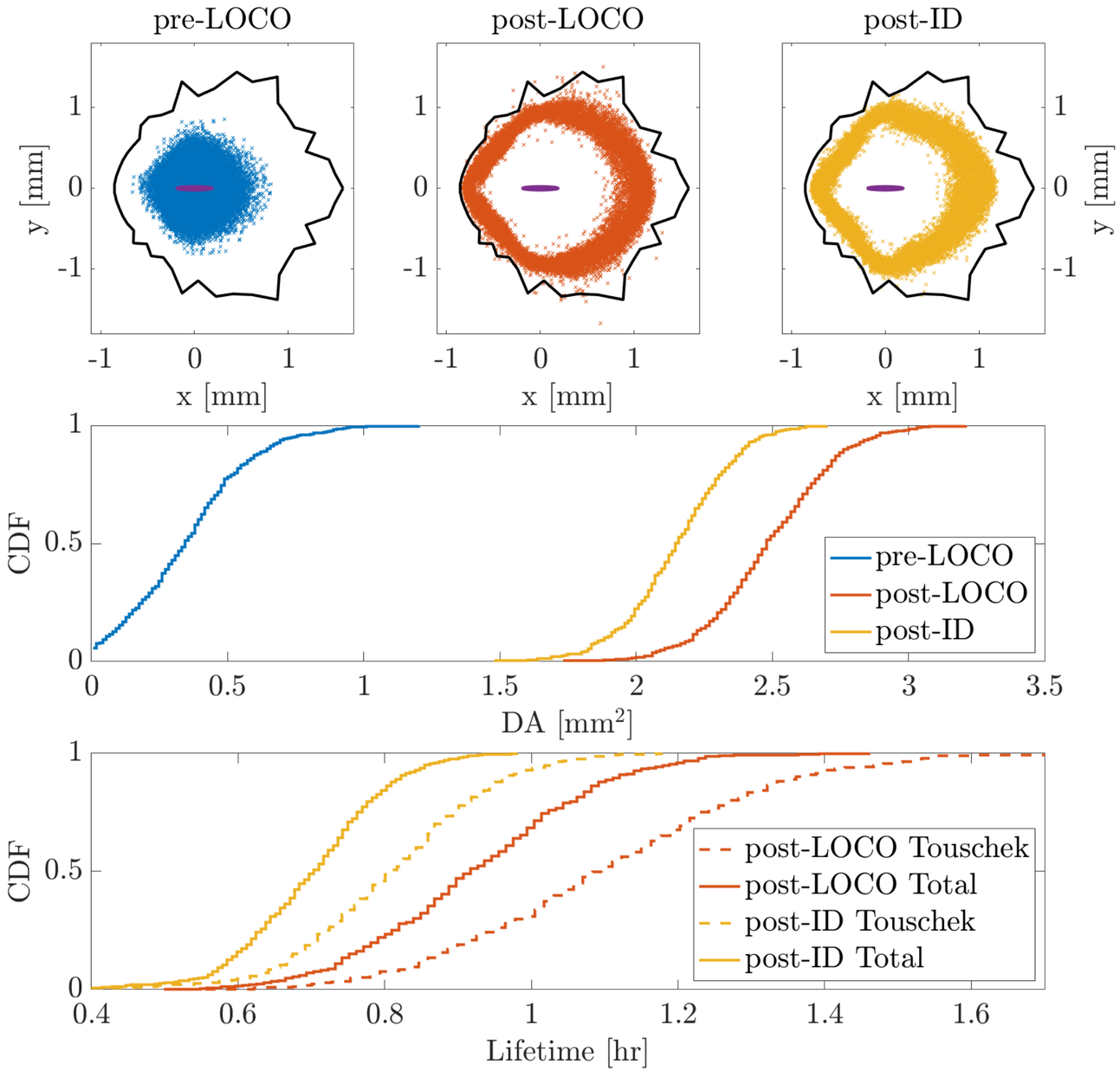
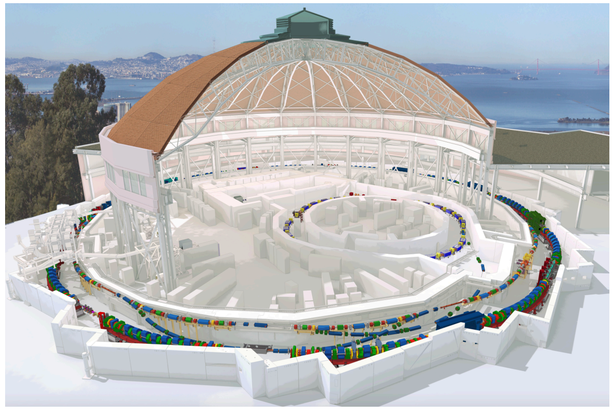


Toolkit Design Features

Limited Accessibility of Machine Parameters

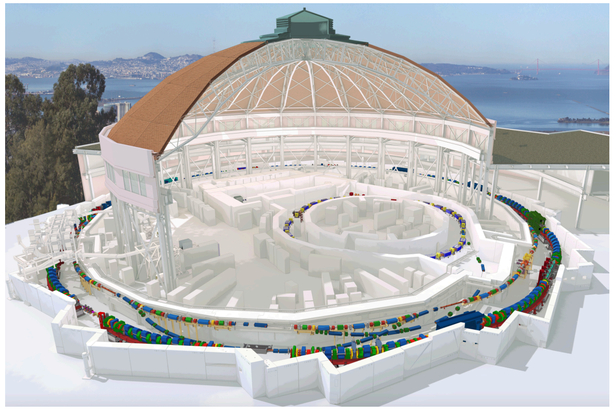
Operating machine



High level controls

Limited Accessibility of Machine Parameters

Operating machine



Magnetic fields
Particle trajectories
Magnet offsets
...

High level controls

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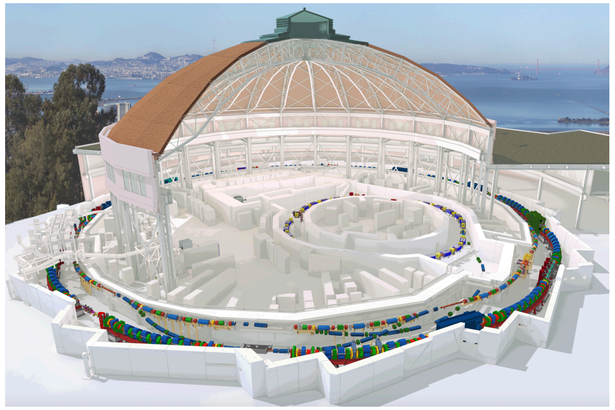

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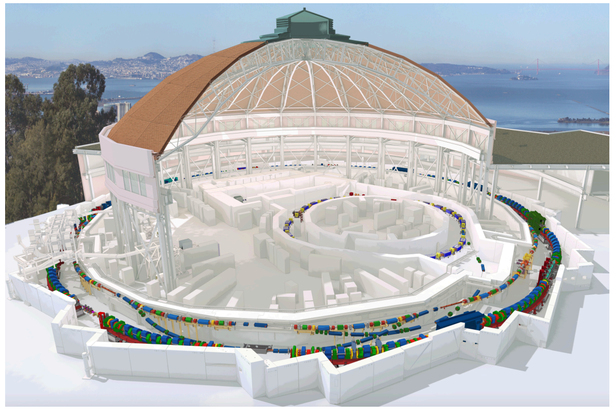
Power supplies

Operating machine



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Setpoints and read back values

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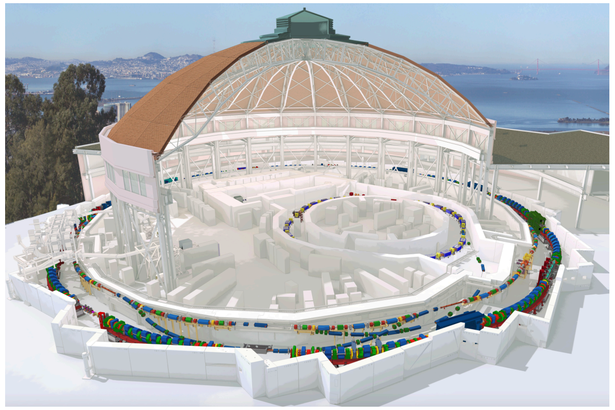


Diagnostic devices

High level controls

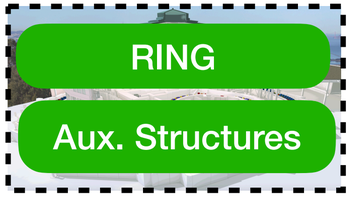
Magnetic fields
Particle trajectories
Magnet offsets
...

Limited access!

Setpoints and read back values

Realistic Workflow of Toolkit Important

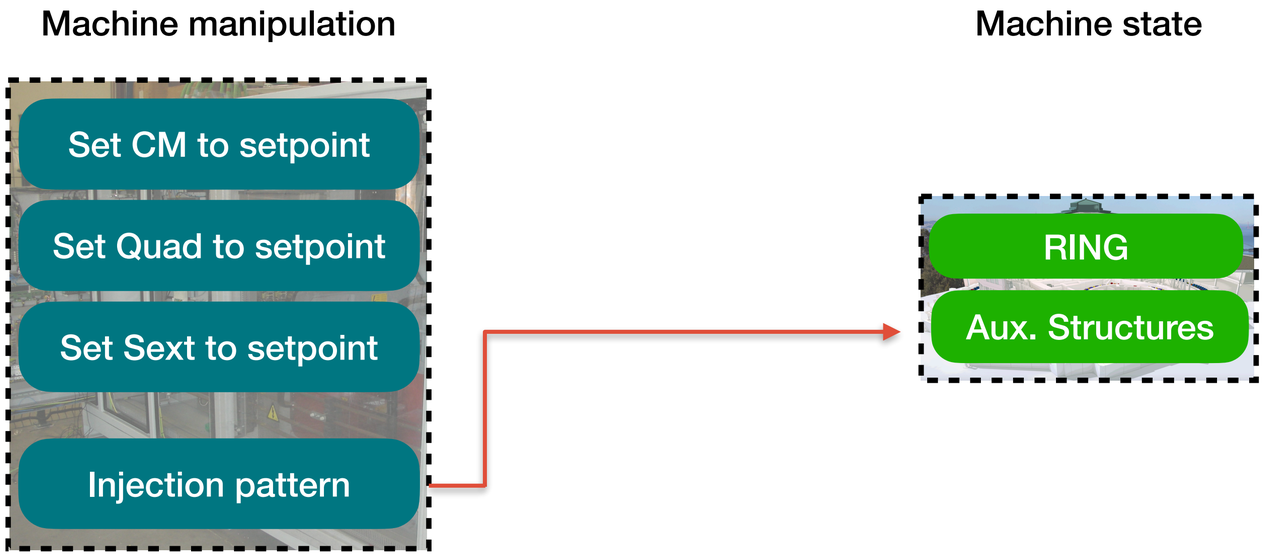
Machine state



Auxiliary structures

- Diagnostic errors
- Injected beam trajectory
- Injection pattern

Realistic Workflow of Toolkit Important



Set Quad to setpoint

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

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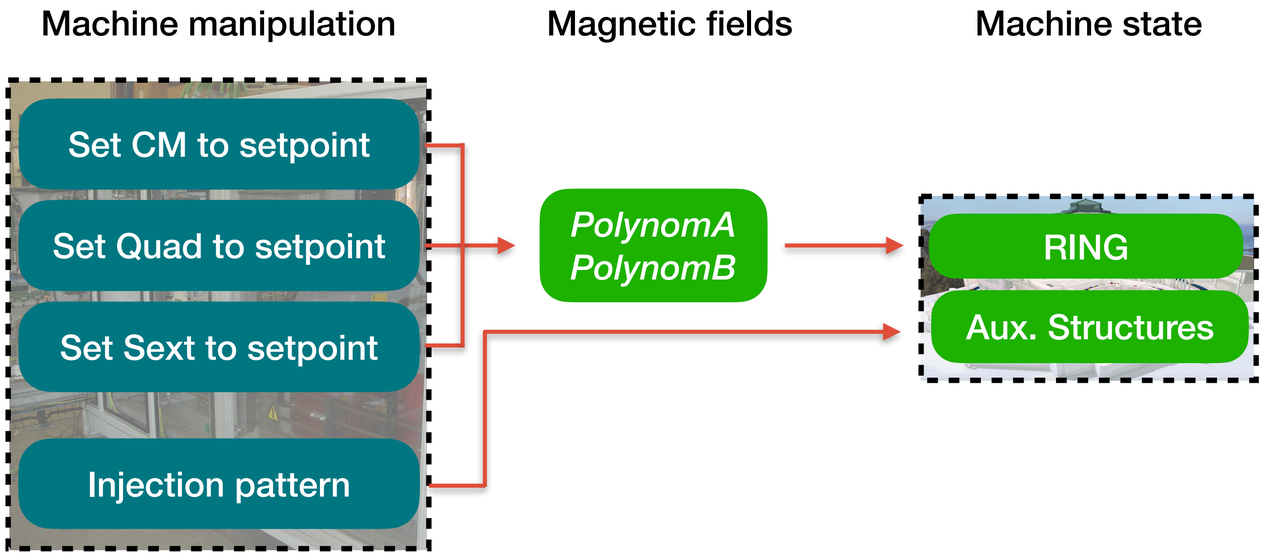

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Calculate fields

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

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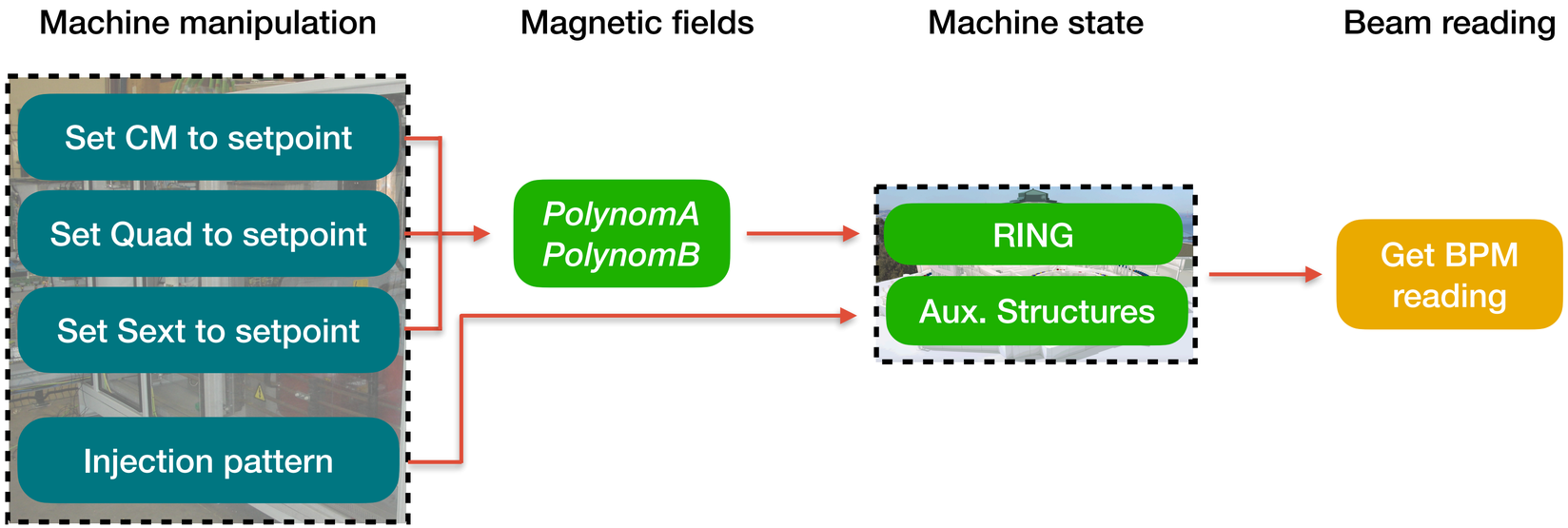

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Get BPM reading

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

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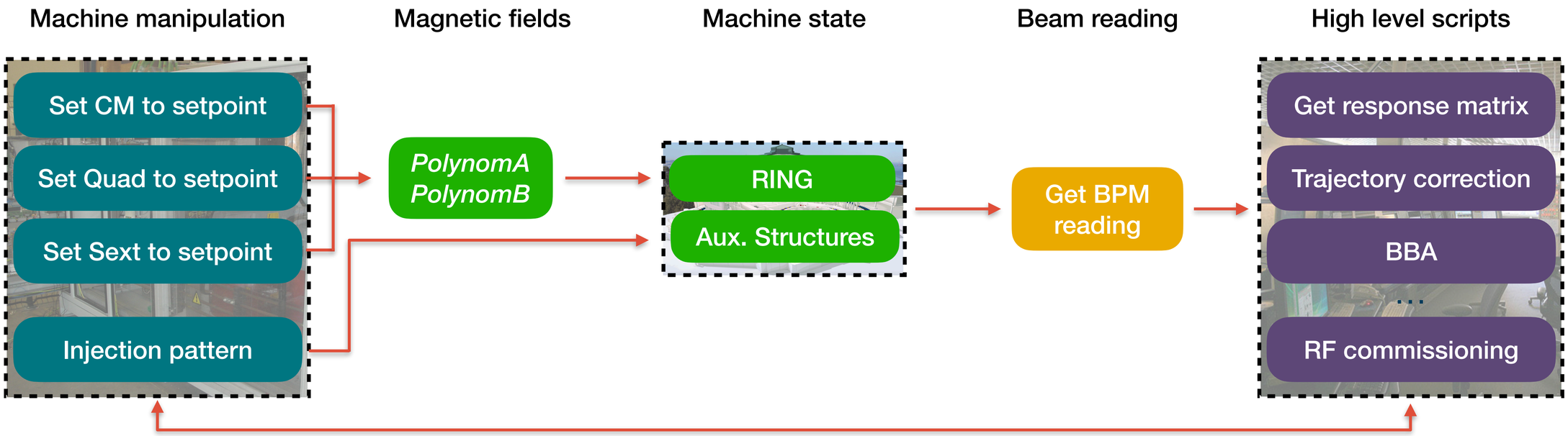

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High level

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

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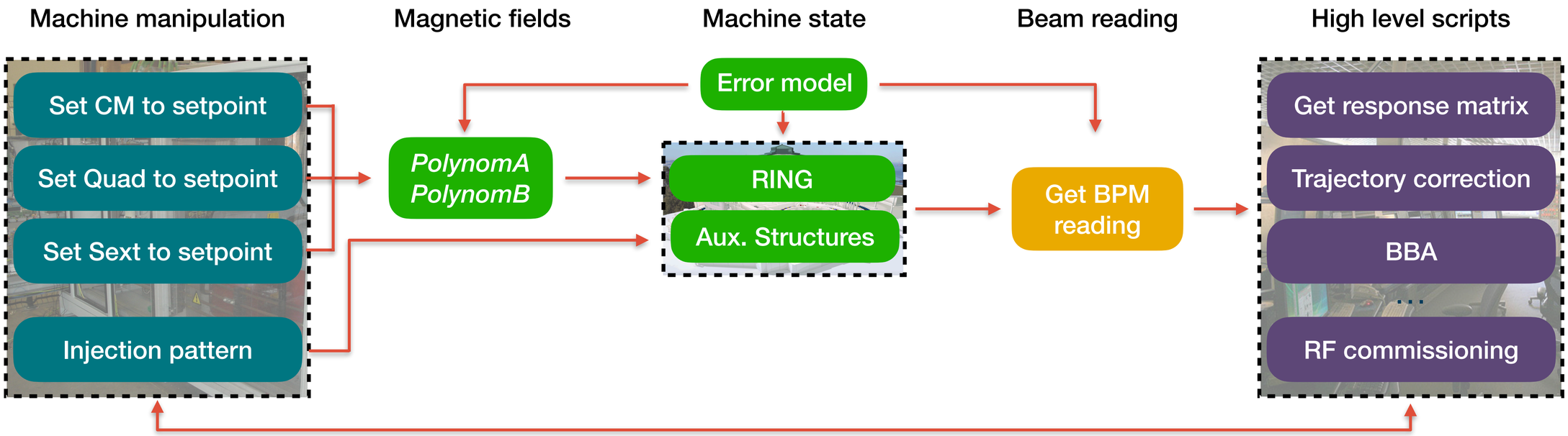

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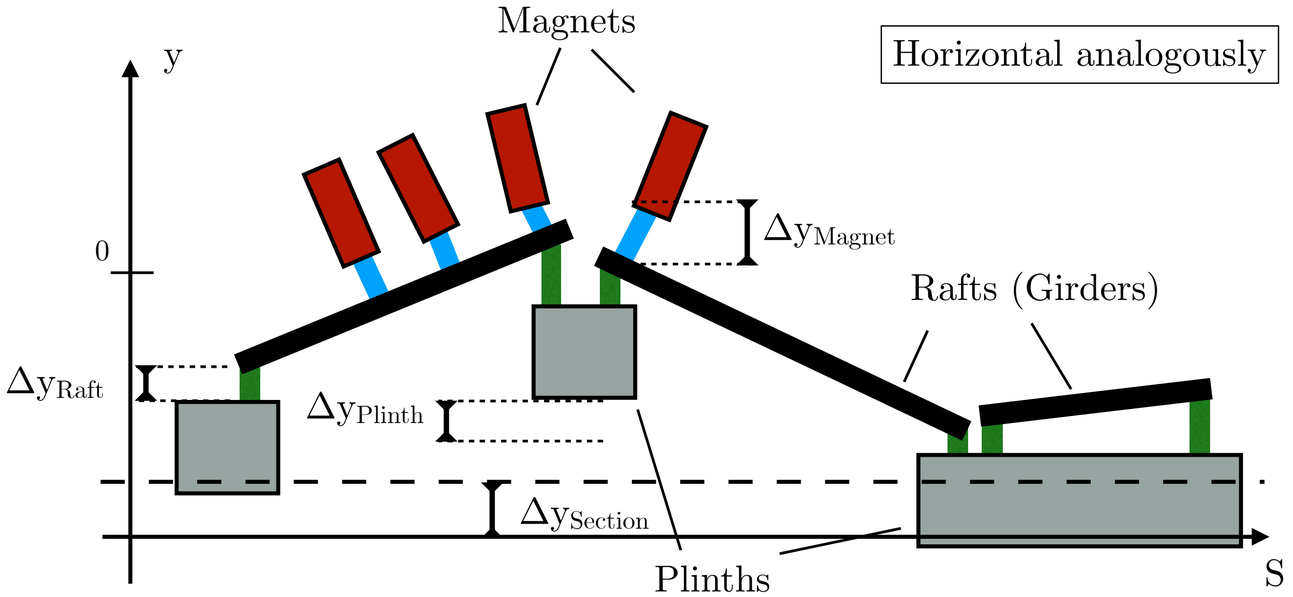
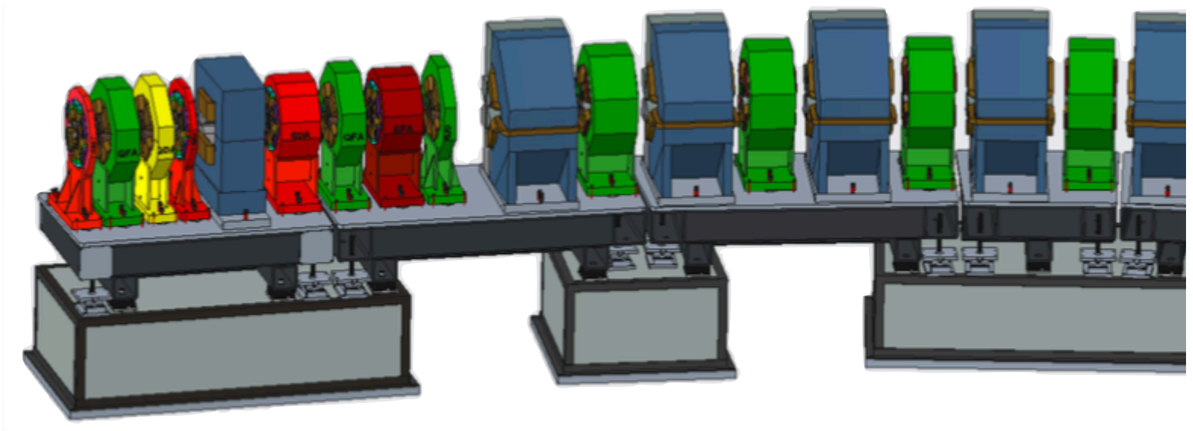
Large Numbers of Error Sources Included

- **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
  - Pitch & Jaw
- **Circumference**
- **Higher Order Multipoles**
  - Systematic for arbitrary coil excitations
  - Random

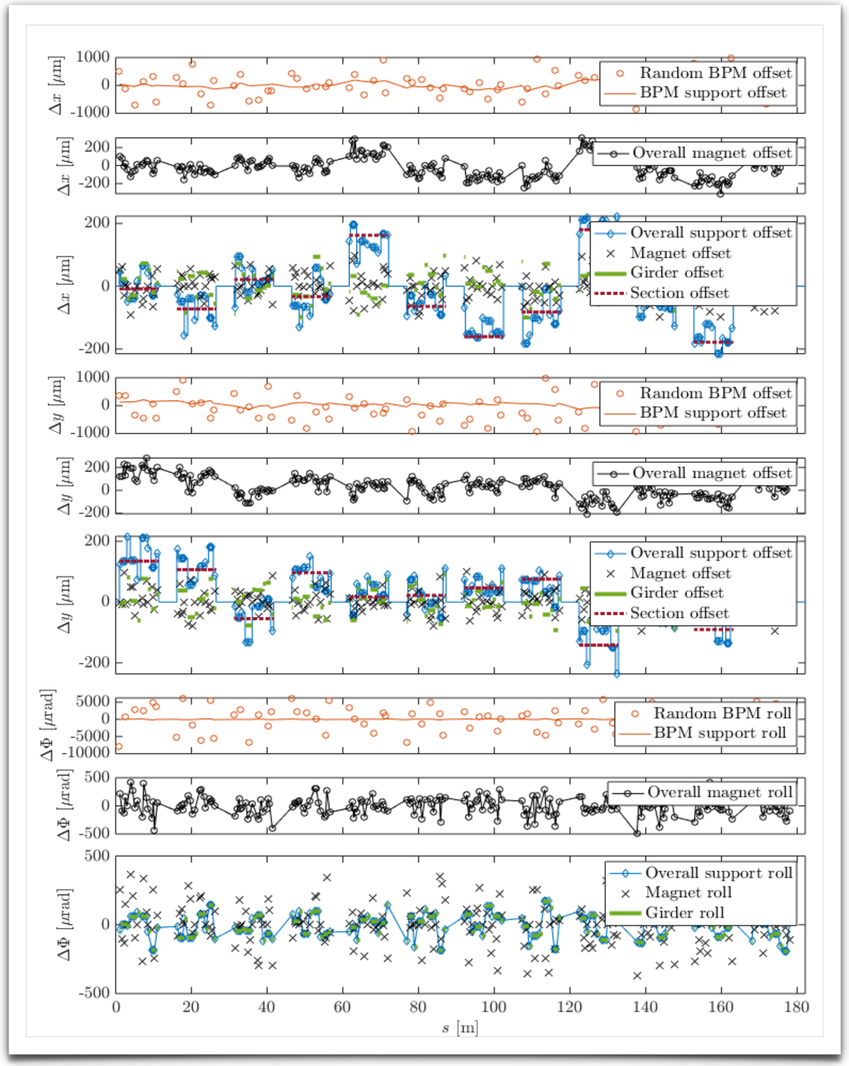
- **Magnets**
  - Offset (x/y/z)
  - Roll, pitch, jaw
  - Strength
  - Calibration
- **RF Errors**
  - Phase
  - Frequency
  - Voltage
- **Injection**
  - Static
  - Shot-by-shot jitter



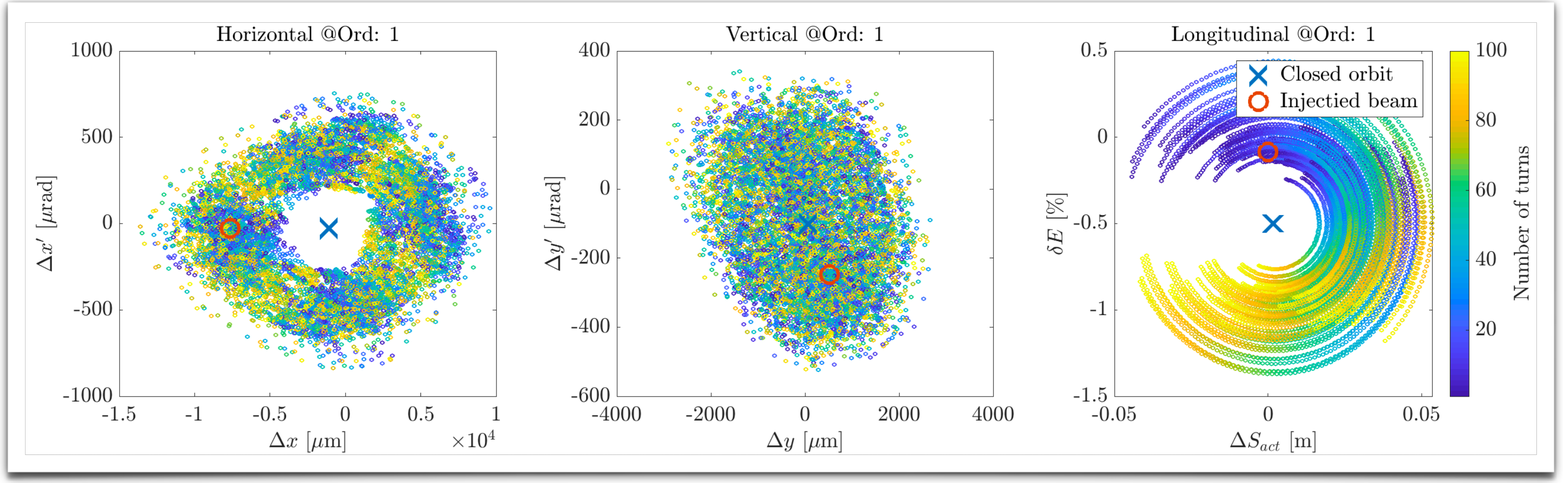


Various Visualisation Tools for Easy R&D

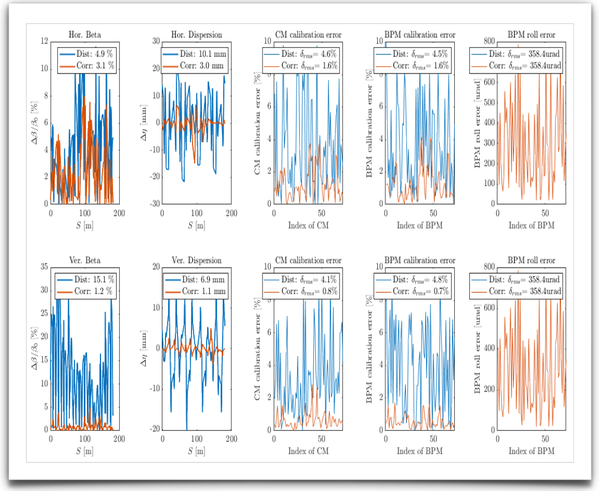
Misalignments



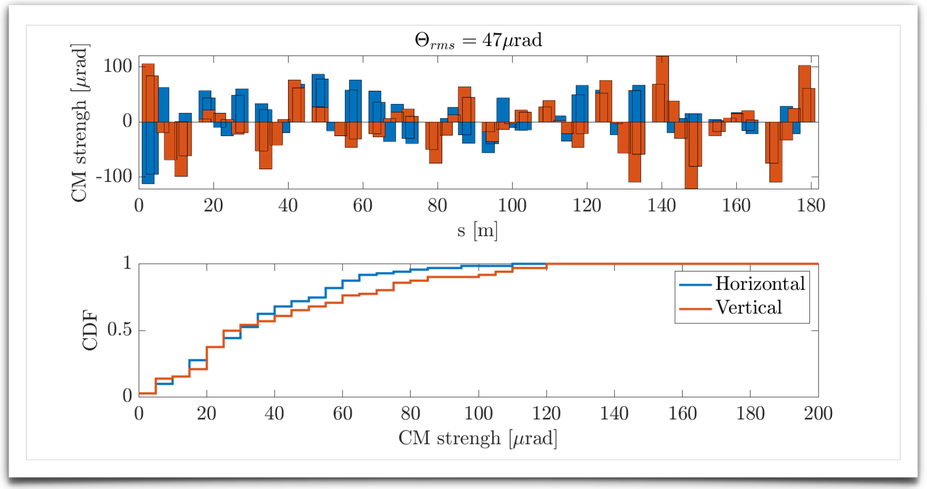
Turn-by-turn Phase Space



LOCO Status

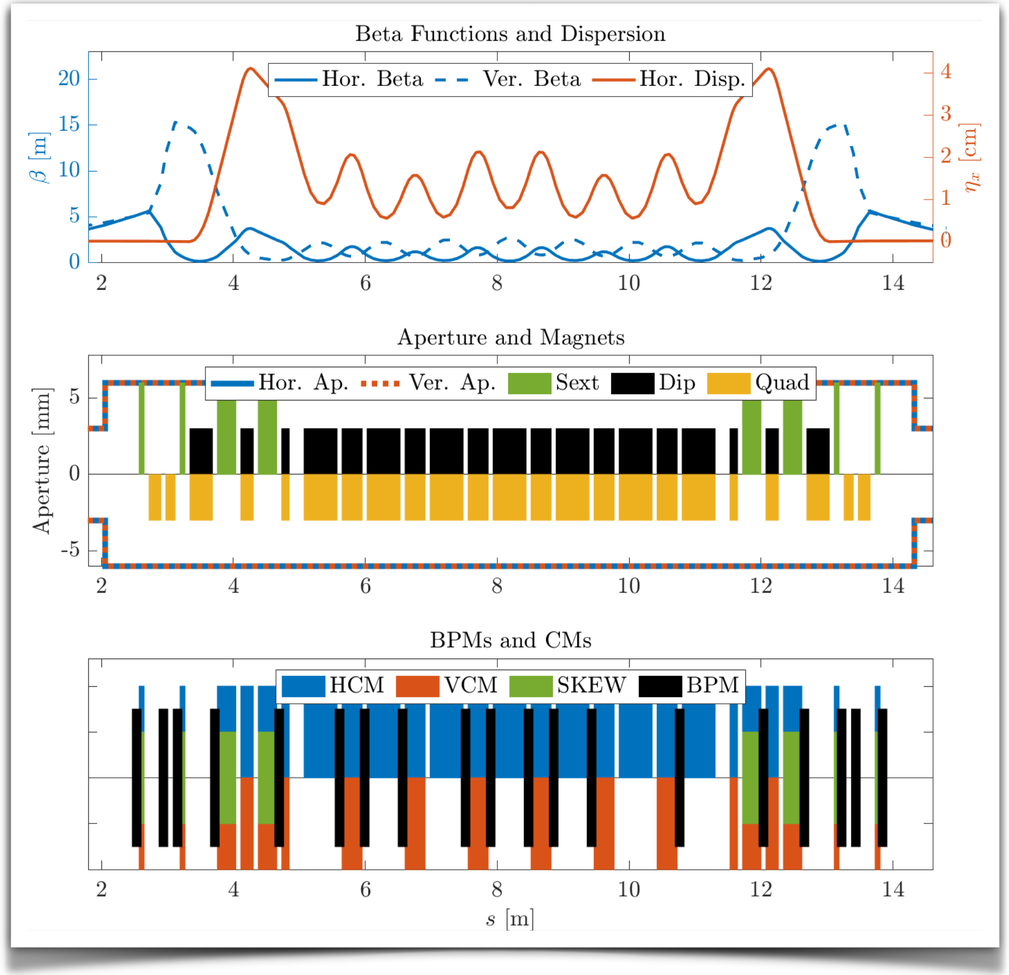


Corrector Strength

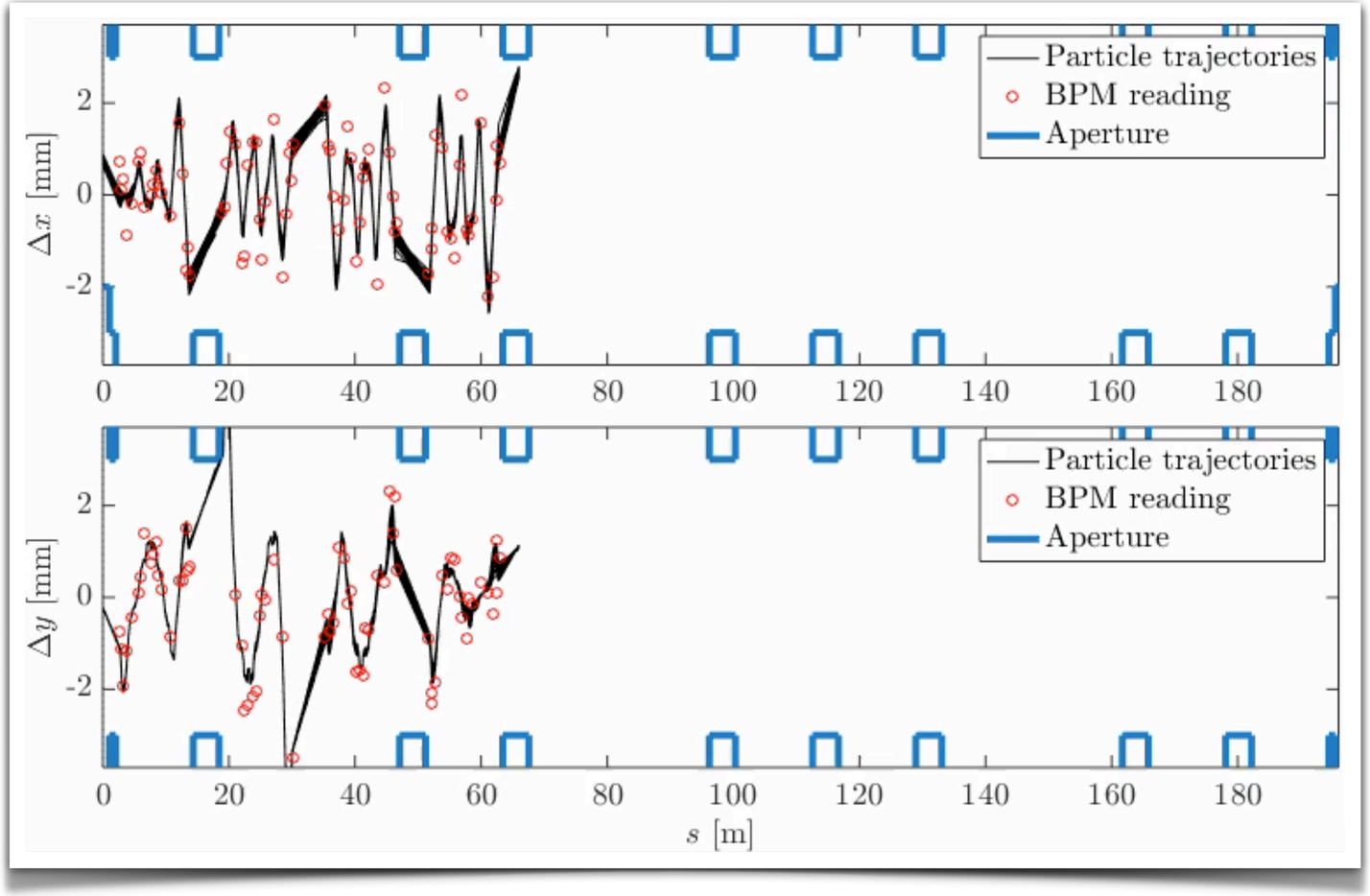


Various Visualisation Tools for Easy R&D

Lattice and Element Registration in Toolkit



Trajectories/Orbit and BPM Readings



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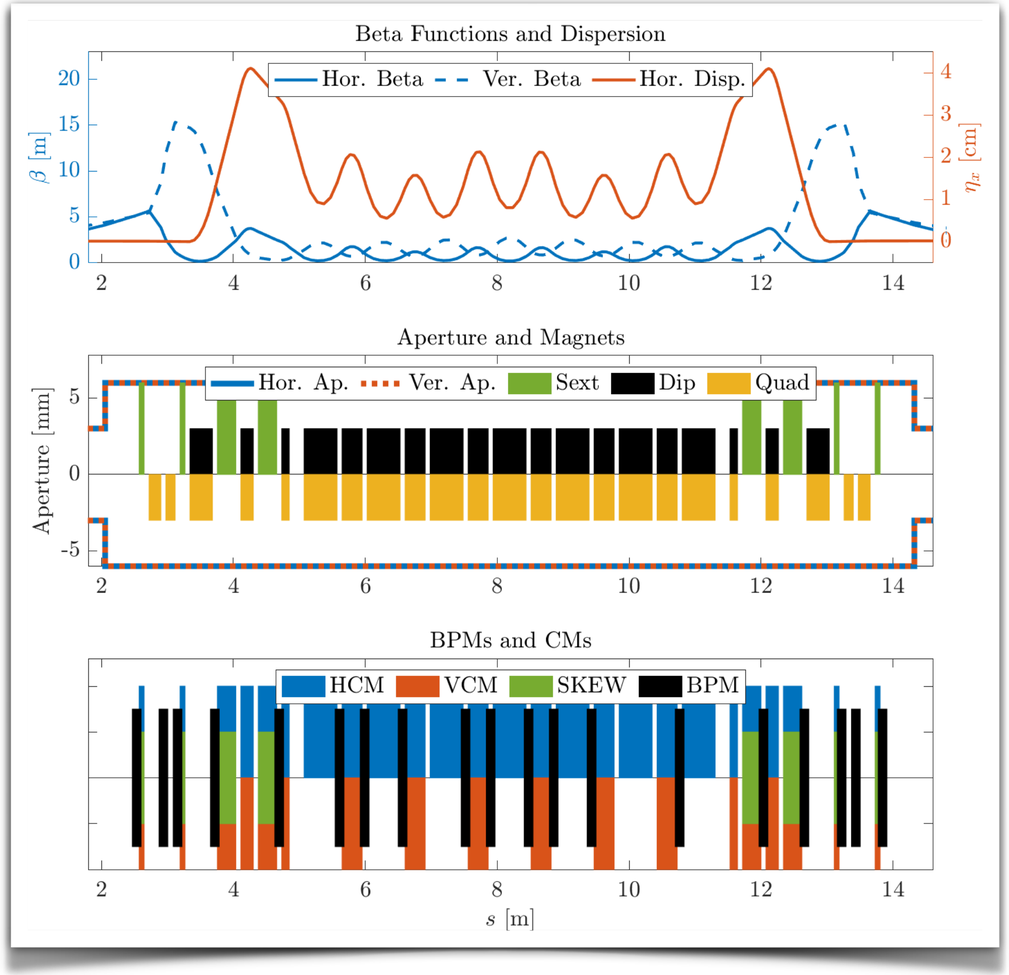

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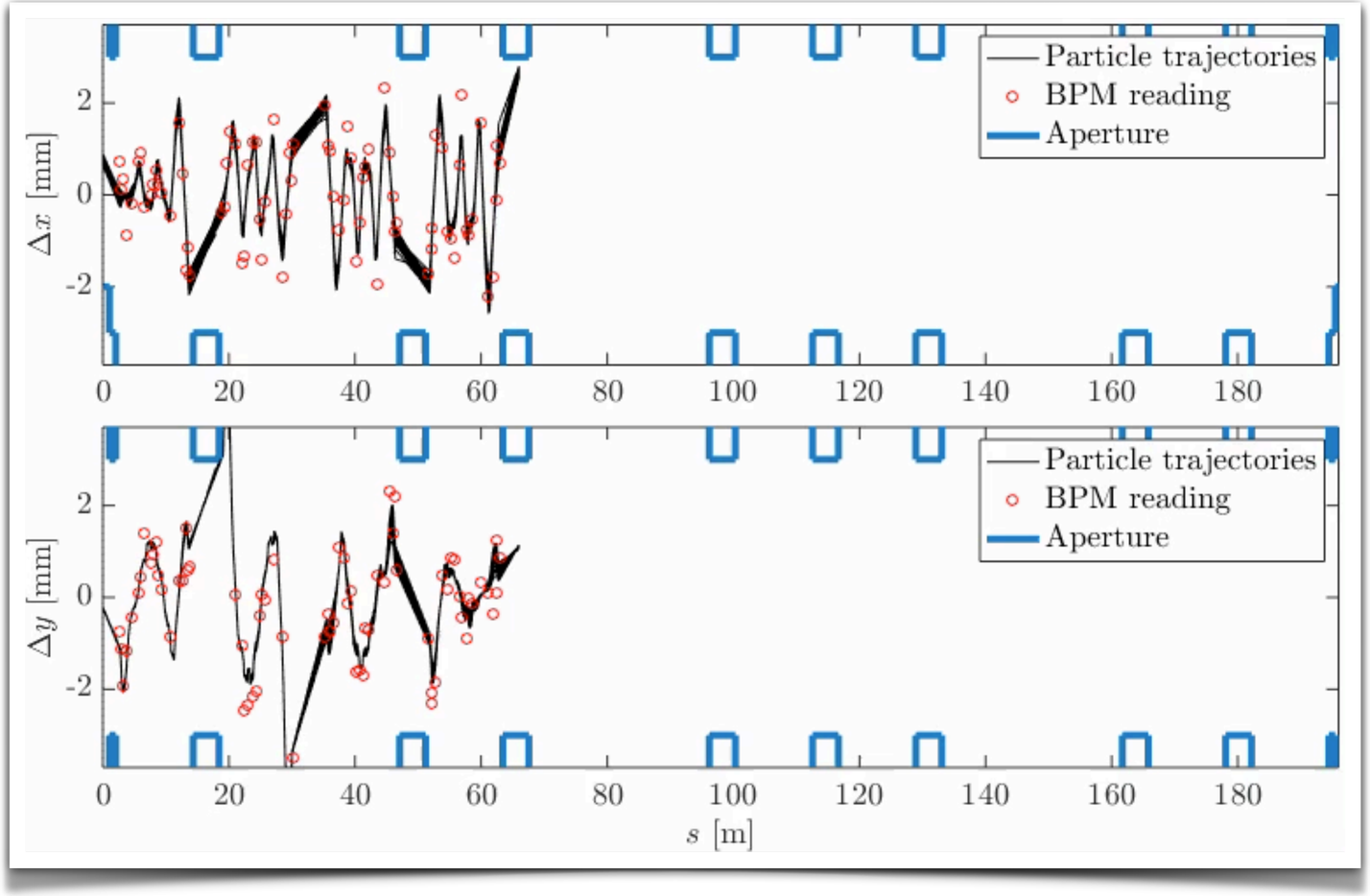
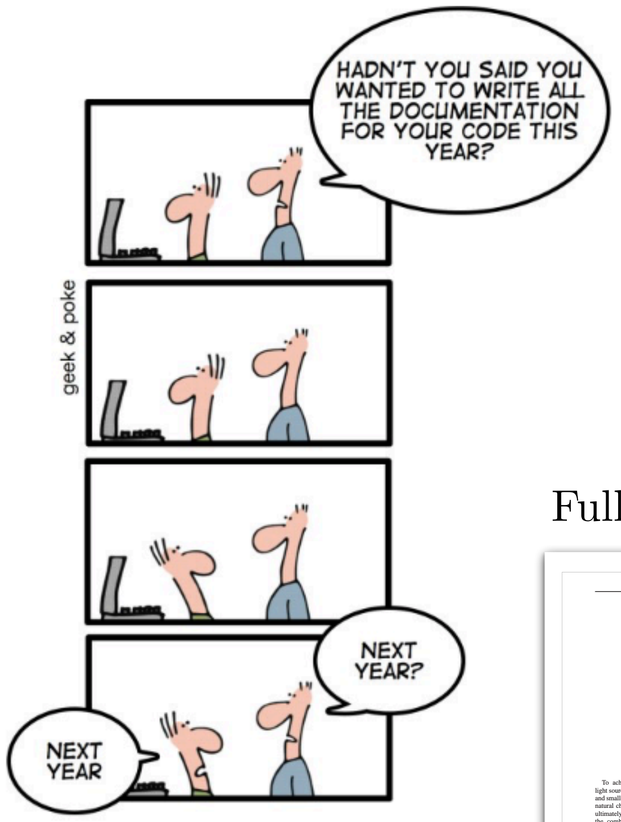


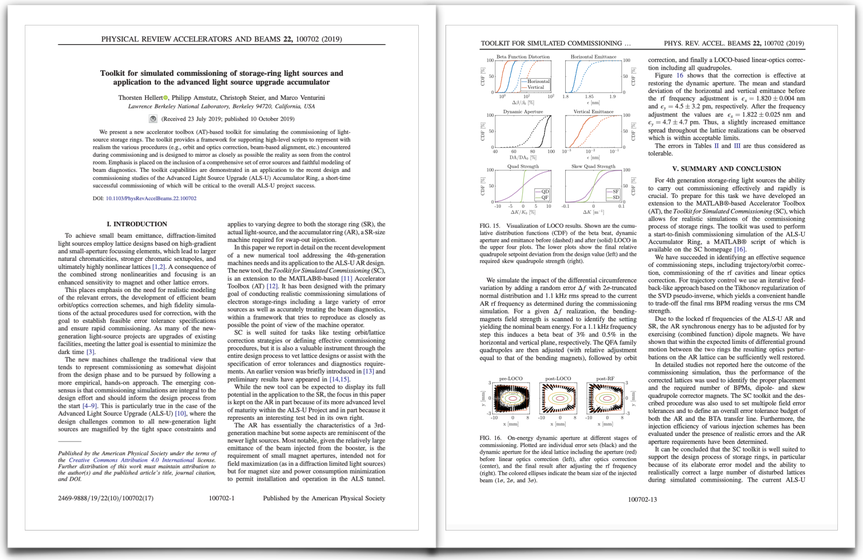
Comprehensive Source Code Documentation



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 Examples (PRAB 22/100702)



PHYSICAL REVIEW ACCELERATORS AND BEAMS **22**, 100702 (2019)

Toolkit for simulated commissioning of storage-ring light sources and application to the advanced light source upgrade accumulator

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(Received 23 July 2019; published 10 October 2019)

We present a new accelerator toolbox (AT)-based toolkit for simulating the commissioning of light-source storage rings. The toolkit provides a framework for supporting high-level scripts to represent with realism the various procedures (e.g., orbit and optics correction, beam-based alignment, etc.) encountered during commissioning and is designed to mirror as closely as possible the reality as seen from the control room. Emphasis is placed on the inclusion of a comprehensive set of error sources and faithful modeling of beam diagnostics. The toolkit capabilities are demonstrated in an application to the recent design and commissioning studies of the Advanced Light Source Upgrade (ALS-U) Accumulator Ring, a short-time successful commissioning of which will be critical to the overall ALS-U project success.

DOI: 10.1103/PhysRevAccelBeams.22.100702

I. INTRODUCTION

To achieve small beam emittance, diffraction-limited light sources employ lattice designs based on high-gradient and small-aperture focussing elements, which lead to larger natural chromaticities, stronger chromatic sextupoles, and ultimately highly nonlinear lattices [1,2]. A consequence of the combined strong nonlinearities and focussing is an enhanced sensitivity to magnet and other lattice errors.

This places emphasis on the need for realistic modeling of the relevant errors, the development of efficient beam orbit/optics correction schemes, and high fidelity simulations of the actual procedures used for correction, with the goal to establish feasible error tolerance specifications and ensure rapid commissioning. As many of the new-generation light-source projects are upgrades of existing facilities, meeting the latter goal is essential to minimize the dark time [3].

The new machines challenge the traditional view that tends to represent commissioning as somewhat disjoint from the design phase and to be pursued by following a more empirical, hands-on approach. The emerging consensus is that commissioning simulations are integral to the design effort and should inform the design process from the start [4–9]. This is particularly true in the case of the Advanced Light Source Upgrade (ALS-U) [10], where the design challenges common to all new-generation light sources are magnified by the tight space constraints and applies to varying degree to both the storage ring (SR), the actual light-source, and the accumulator ring (AR), a SR-size machine required for swap-out injection.

In this paper we report in detail on the recent development of a new numerical tool addressing the 4th-generation machines needs and its application to the ALS-U AR design. The new tool, the *Toolkit for Simulated Commissioning* (SC), is an extension to the MATLAB®-based [11] Accelerator Toolbox (AT) [12]. It has been designed with the primary goal of conducting realistic commissioning simulations of electron storage-rings including a large variety of error sources as well as accurately treating the beam diagnostics, within a framework that tries to reproduce as closely as possible the point of view of the machine operator.

SC is well suited for tasks like testing orbit/lattice correction strategies or defining effective commissioning procedures, but it is also a valuable instrument through the entire design process to vet lattice designs or assist with the specification of error tolerances and diagnostics requirements. An earlier version was briefly introduced in [13] and preliminary results have appeared in [14,15].

While the new tool can be expected to display its full potential in the application to the SR, the focus in this paper is kept on the AR in part because of its more advanced level of maturity within the ALS-U Project and in part because it represents an interesting test bed in its own right.

The AR has essentially the characteristics of a 3rd-generation machine but some aspects are reminiscent of the newer light sources. Most notable, given the relatively large emittance of the beam injected from the booster, is the requirement of small magnet apertures, intended not for field maximization (as in a diffraction limited light sources) but for magnet size and power consumption minimization to permit installation and operation in the ALS tunnel.

FIG. 15. Visualization of LOCO results. Shown are the cumulative distribution functions (CDF) of the beta beat, dynamic aperture and emittance before (dashed) and after (solid) LOCO in the upper four plots. The lower plots show the final relative quadrupole setpoint deviation from the design value (left) and the required skew quadrupole strength (right).

We simulate the impact of the differential circumference variation by adding a random error Δf with 2σ-truncated normal distribution and 1.1 kHz rms spread to the current AR rf frequency as determined during the commissioning simulation. For a given Δf realization, the bending-magnets field strength is scanned to identify the setting yielding the nominal beam energy. For a 1.1 kHz-frequency step this induces a beta beat of 3% and 0.5% in the horizontal and vertical plane, respectively. The QFA family quadrupoles are then adjusted (with relative adjustment equal to that of the bending magnets), followed by orbit correction, and finally a LOCO-based linear-optics correction including all quadrupoles.

Figure 16 shows that the correction is effective at restoring the dynamic aperture. The mean and standard deviation of the horizontal and vertical emittance before the rf frequency adjustment is $\epsilon_x = 1.820 \pm 0.004$ nm and $\epsilon_y = 4.5 \pm 3.2$ pm, respectively. After the frequency adjustment the values are $\epsilon_x = 1.822 \pm 0.025$ nm and $\epsilon_y = 4.7 \pm 4.7$ pm. Thus, a slightly increased emittance spread throughout the lattice realizations can be observed which is within acceptable limits.

The errors in Tables II and III are thus considered as tolerable.

V. SUMMARY AND CONCLUSION

For 4th generation storage-ring light sources the ability to carry out commissioning effectively and rapidly is crucial. To prepare for this task we have developed an extension to the MATLAB®-based Accelerator Toolbox (AT), the *Toolkit for Simulated Commissioning* (SC), which allows for realistic simulations of the commissioning process of storage rings. The toolkit was used to perform a start-to-finish commissioning simulation of the ALS-U Accumulator Ring, a MATLAB® script of which is available on the SC homepage [16].

We have succeeded in identifying an effective sequence of commissioning steps, including trajectory/orbit correction, commissioning of the rf cavities and linear optics correction. For trajectory control we use an iterative feedback-like approach based on the Tikhonov regularization of the SVD pseudo-inverse, which yields a convenient handle to trade-off the final rms BPM reading versus the rms CM strength.

Due to the locked rf frequencies of the ALS-U AR and SR, the AR synchronous energy has to be adjusted for by exercising (combined function) dipole magnets. We have shown that within the expected limits of differential ground motion between the two rings the resulting optics perturbations on the AR lattice can be sufficiently well restored.

In detailed studies not reported here the outcome of the commissioning simulation, thus the performance of the corrected lattices was used to identify the proper placement and the required number of BPMs, dipole- and skew quadrupole corrector magnets. The SC toolkit and the described procedure was also used to set multipole field error tolerances and to define an overall error tolerance budget of both the AR and the BTA transfer line. Furthermore, the injection efficiency of various injection schemes has been evaluated under the presence of realistic errors and the AR aperture requirements have been determined.

It can be concluded that the SC toolkit is well suited to support the design process of storage rings, in particular because of its elaborate error model and the ability to realistically correct a large number of disturbed lattices during simulated commissioning. The current ALS-U

FIG. 16. On-energy dynamic aperture at different stages of commissioning. Plotted are individual error sets (black) and the dynamic aperture for the ideal lattice including the aperture (red) before linear optics correction (left), after optics correction (center), and the final result after adjusting the rf frequency (right). The colored ellipses indicate the beam size of the injected beam (1σ, 2σ, and 3σ).

Version Control

Online Manual

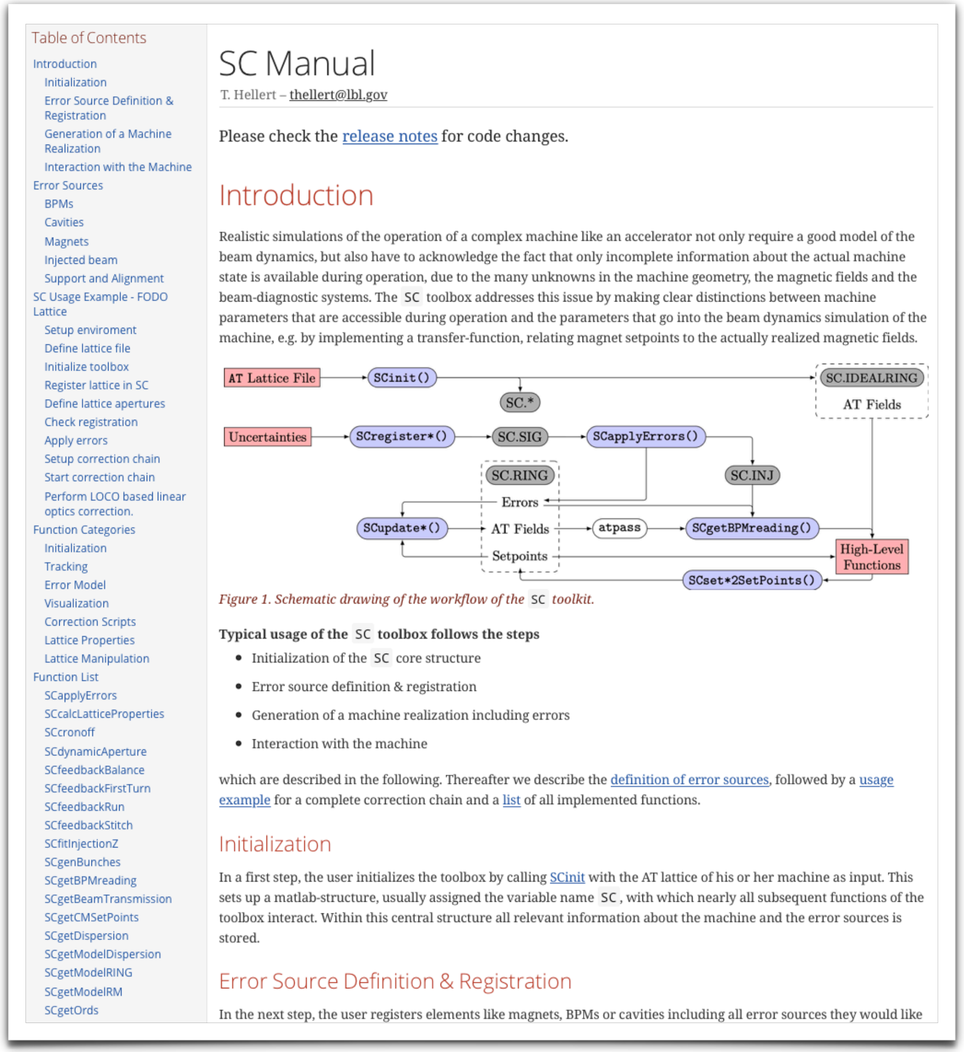


Table of Contents

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

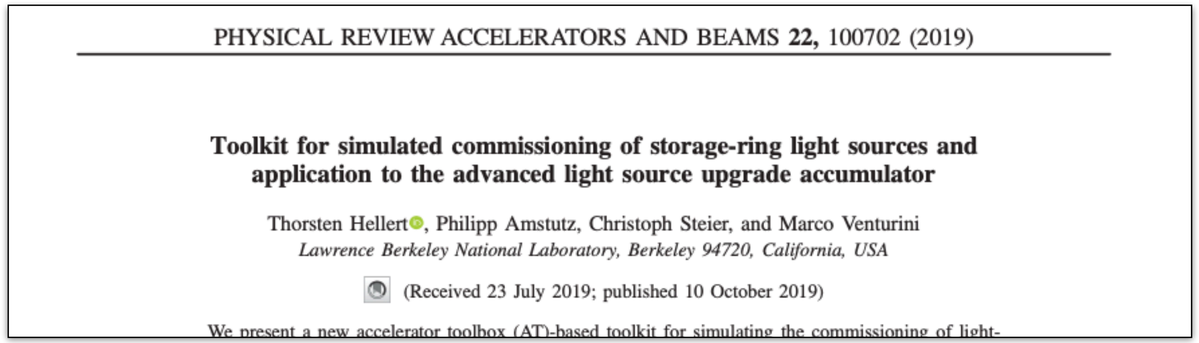
In a first step, the user initializes the toolbox by calling SCinit with the AT lattice of his or her machine as input. This sets up a matlab-structure, usually assigned the variable name `SC`, with which nearly all subsequent functions of the toolbox interact. Within this central structure all relevant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

Easy Accessibility For New Users with Full Example Scripts

PRAB Paper for ALSU-AR



PHYSICAL REVIEW ACCELERATORS AND BEAMS **22,** 100702 (2019)

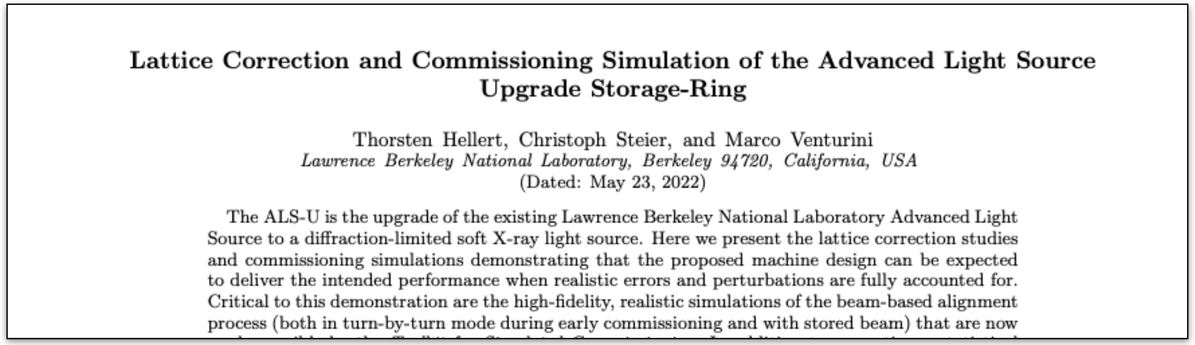
Toolkit for simulated commissioning of storage-ring light sources and application to the advanced light source upgrade accumulator

Thorsten Hellert, Philipp Amstutz, Christoph Steier, and Marco Venturini
Lawrence Berkeley National Laboratory, Berkeley 94720, California, USA

(Received 23 July 2019; published 10 October 2019)

We present a new accelerator toolbox (AT)-based toolkit for simulating the commissioning of light-

PRAB Paper for ALSU-SR (under review)

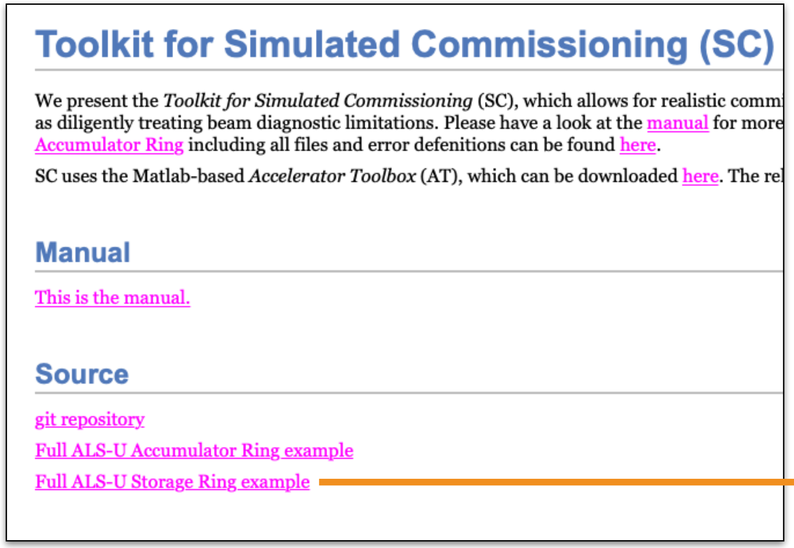


Lattice Correction and Commissioning Simulation of the Advanced Light Source Upgrade Storage-Ring

Thorsten Hellert, Christoph Steier, and Marco Venturini
Lawrence Berkeley National Laboratory, Berkeley 94720, California, USA
(Dated: May 23, 2022)

The ALS-U is the upgrade of the existing Lawrence Berkeley National Laboratory Advanced Light Source to a diffraction-limited soft X-ray light source. Here we present the lattice correction studies and commissioning simulations demonstrating that the proposed machine design can be expected to deliver the intended performance when realistic errors and perturbations are fully accounted for. Critical to this demonstration are the high-fidelity, realistic simulations of the beam-based alignment process (both in turn-by-turn mode during early commissioning and with stored beam) that are now

Toolkit Webpage



Toolkit for Simulated Commissioning (SC)

We present the *Toolkit for Simulated Commissioning* (SC), which allows for realistic comm
as diligently treating beam diagnostic limitations. Please have a look at the manual for more
Accumulator Ring including all files and error defenitions can be found here.

SC uses the Matlab-based *Accelerator Toolbox* (AT), which can be downloaded here. The re

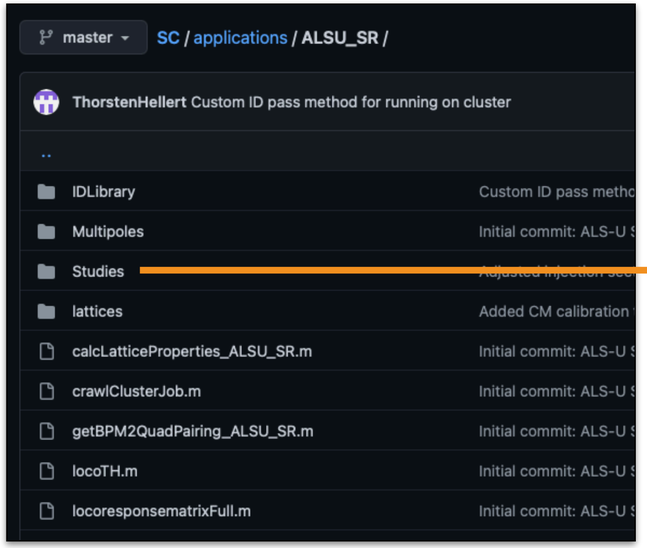
Manual

This is the manual.

Source

git repository
Full ALS-U Accumulator Ring example
Full ALS-U Storage Ring example

Git Repository



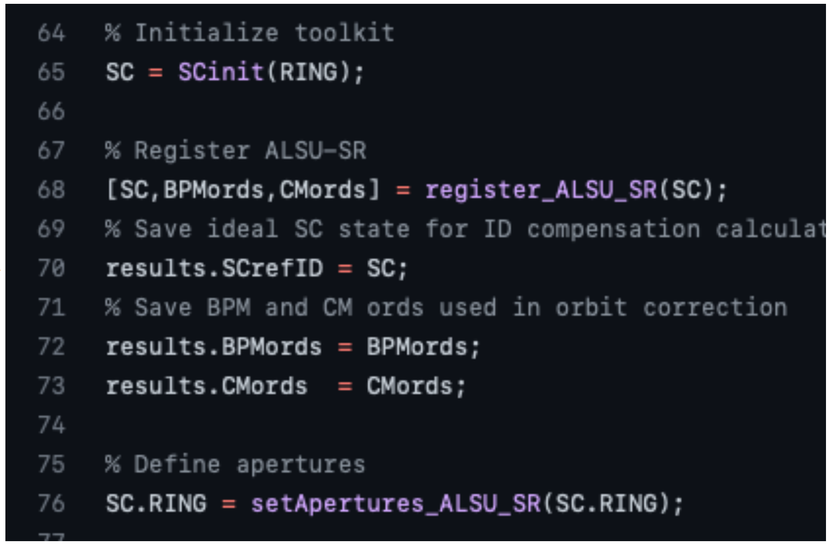
master SC / applications / ALSU_SR /

ThorstenHellert Custom ID pass method for running on cluster

..

IDLibrary	Custom ID pass metho
Multipoles	Initial commit: ALS-U
Studies	
lattices	Added CM calibration
calcLatticeProperties_ALSU_SR.m	Initial commit: ALS-U
crawlClusterJob.m	Initial commit: ALS-U
getBPM2QuadPairing_ALSU_SR.m	Initial commit: ALS-U
locoTH.m	Initial commit: ALS-U
locoresponsematrixFull.m	Initial commit: ALS-U

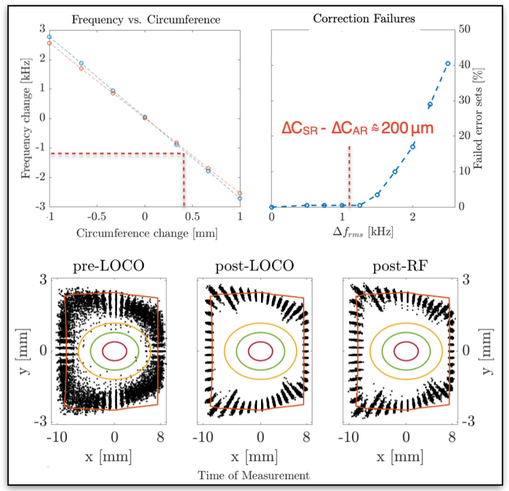
Annotated Scripts



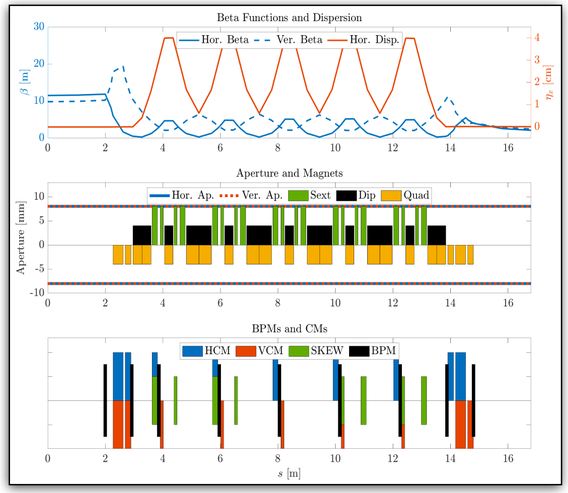
```
64  % Initialize toolkit
65  SC = SCinit(RING);
66
67  % Register ALSU-SR
68  [SC,BPMords,CMords] = register_ALSU_SR(SC);
69  % Save ideal SC state for ID compensation calculat
70  results.SCrefID = SC;
71  % Save BPM and CM ords used in orbit correction
72  results.BPMords = BPMords;
73  results.CMords  = CMords;
74
75  % Define apertures
76  SC.RING = setApertures_ALSU_SR(SC.RING);
```

Toolkit Used for Guiding Design Process at Various Machines

ALS-U AR (*T. Hellert*)



ALBA-II (*Z. Marti Diaz*)



Diamond-II (*D. Amorin*)

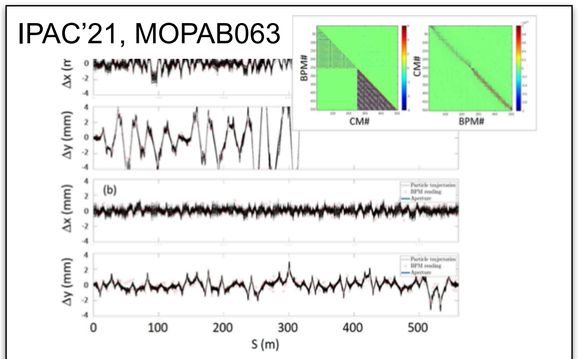
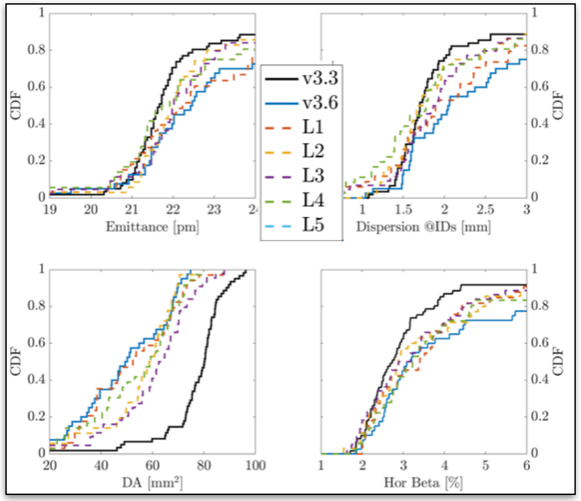
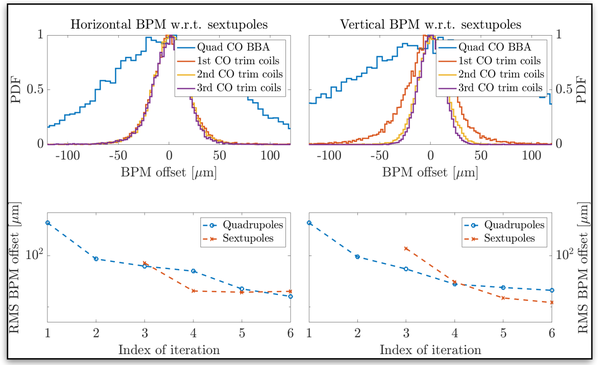


Figure 3: First turn threading in the Diamond-II SR. (Top) initial attempt with total loss of the beam, (bottom) 1st turn transmission completed with beam ready for a 2-turn threading. Inset: 1-turn RM and its pseudo-inverse.

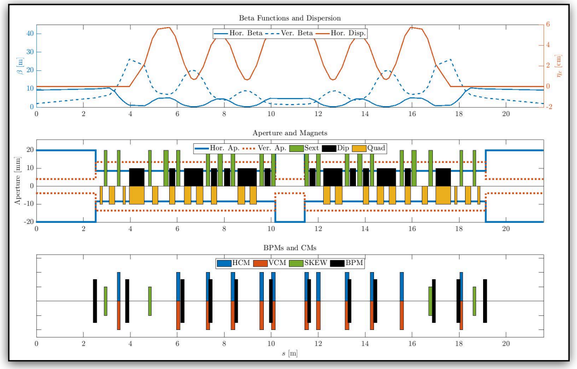
PETRA-IV (*T. Hellert*)



ALS-U SR (*T. Hellert*)

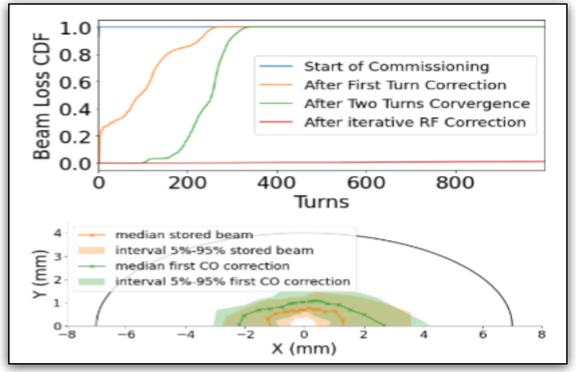


Elettra 2.0 (*S. Dastan*)

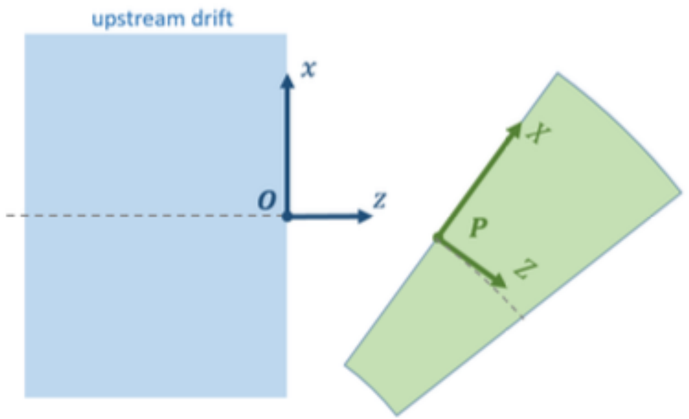


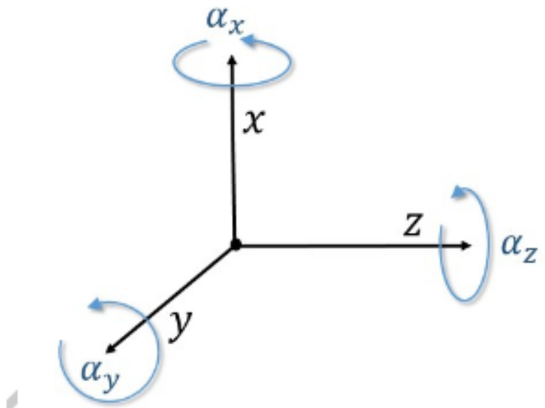
NSLS-II (*A. Kahn*)

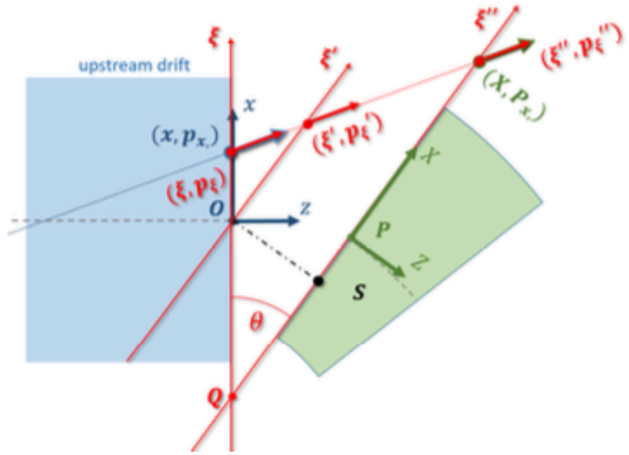
SOLEIL Upgrade (*O. Garcia*)

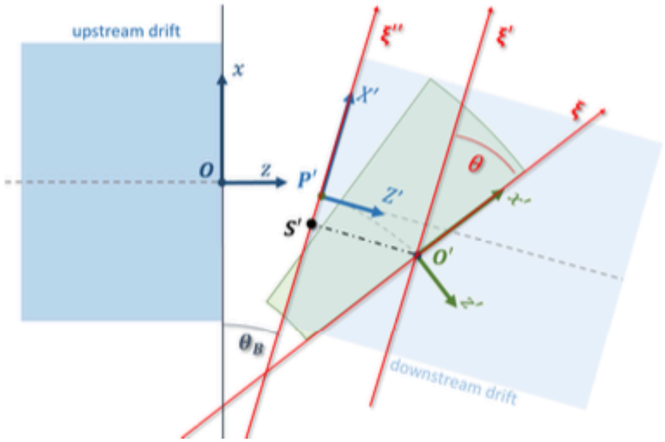


SC -> ELEGANT Corrected Lattice Converter

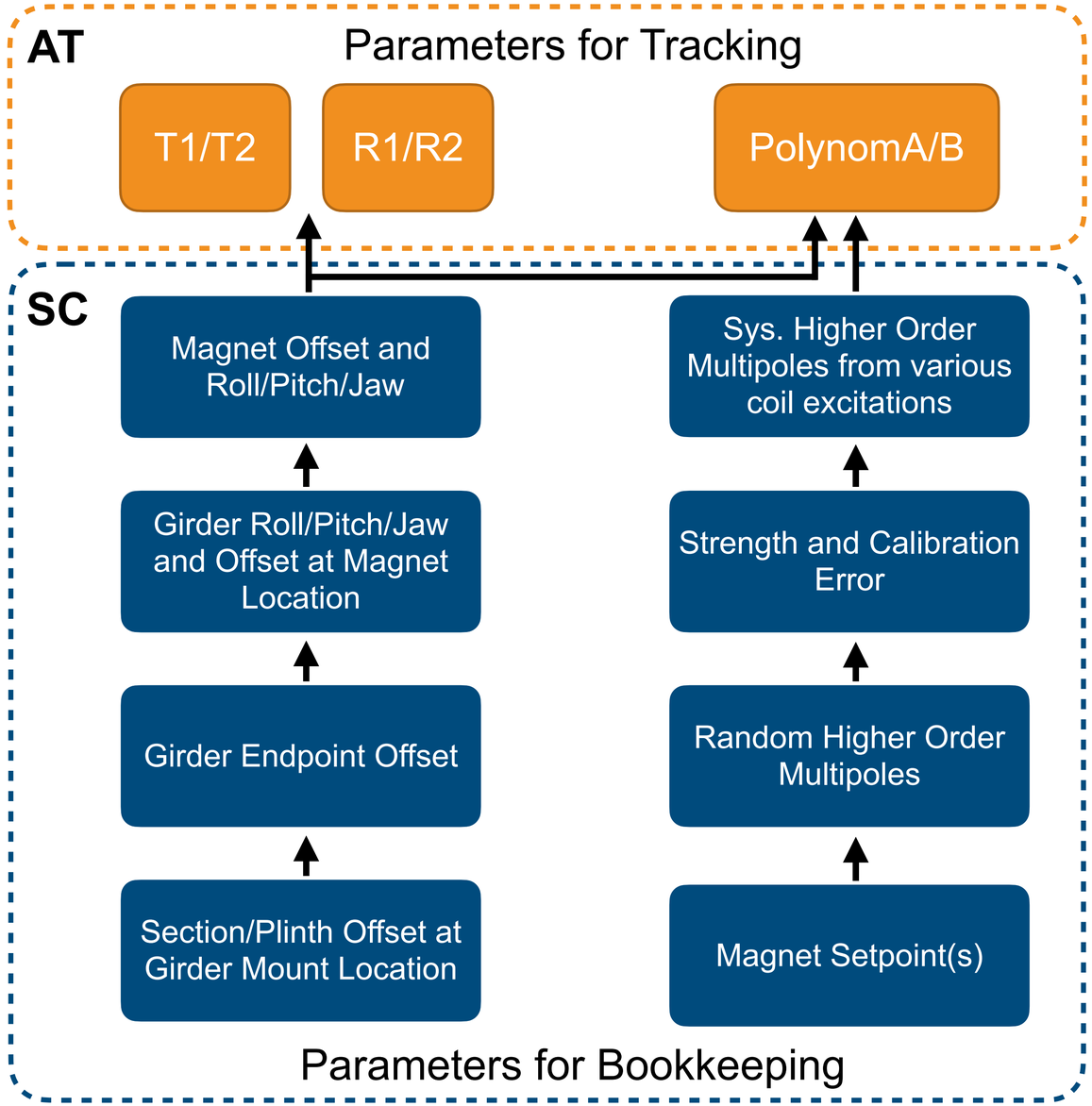






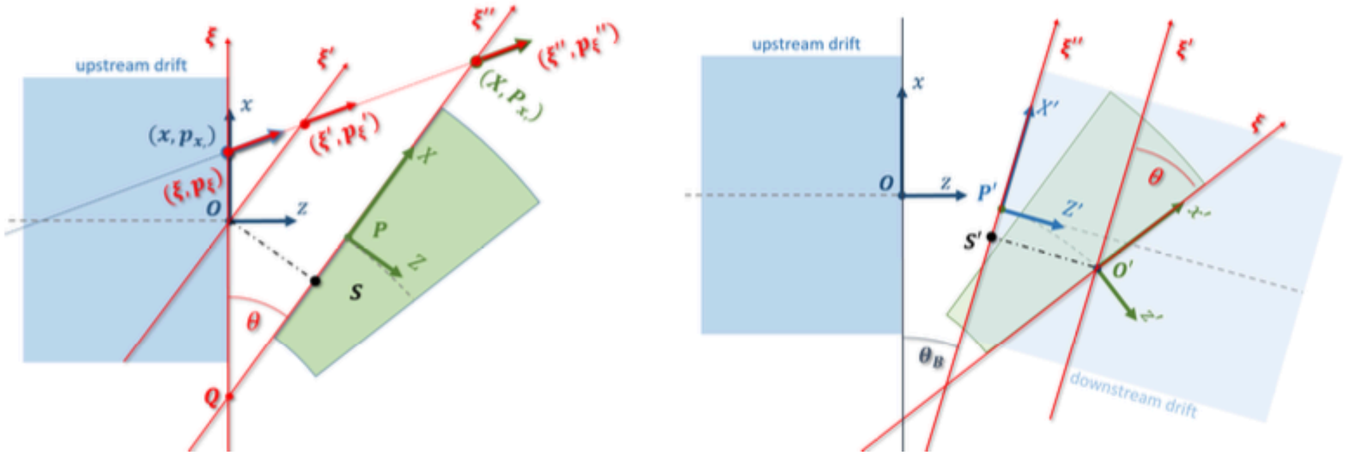


M. Venturini et al., 'Particle dynamics and misaligned lattice elements', ALS-U Tech-Note

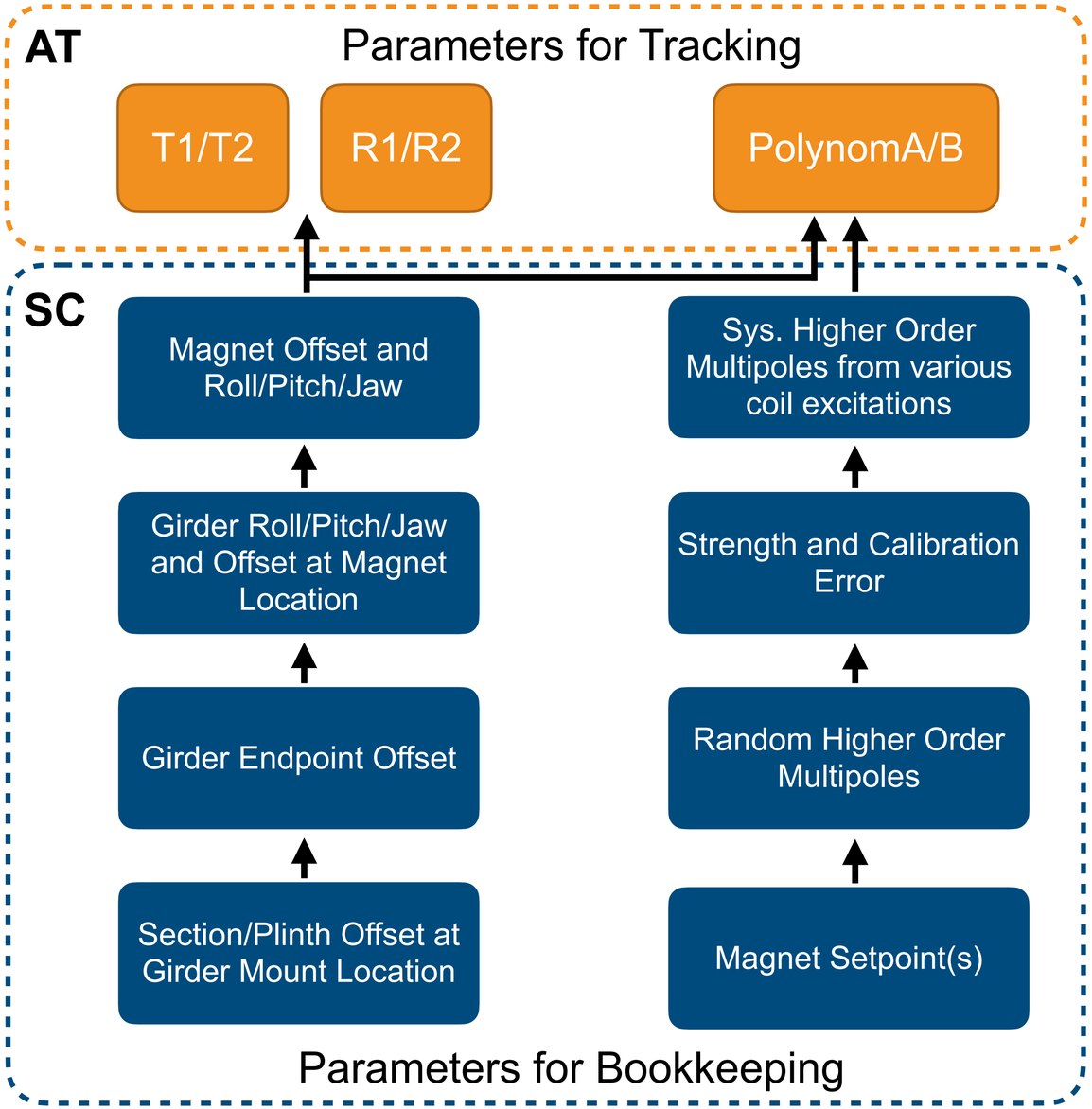


SC -> ELEGANT Corrected Lattice Converter

- **AT/elegant**
  - SC allows for easy error model- and correction chain setup
  - Elegant allows for more advanced tracking studies than AT

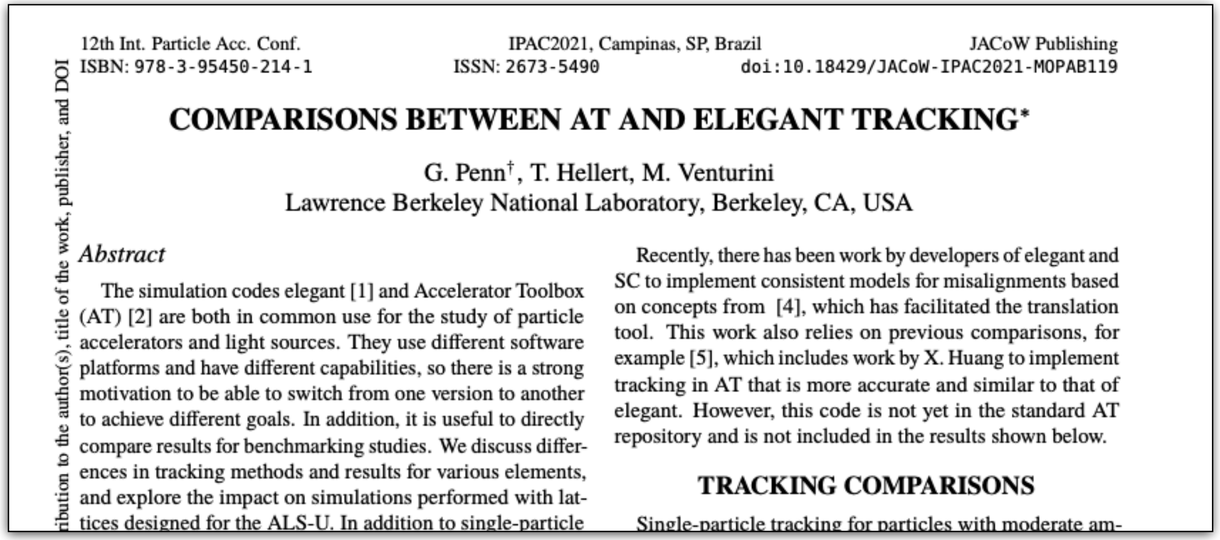


M. Venturini et al., 'Particle dynamics and misaligned lattice elements', ALS-U Tech-Note



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
  - Converter now 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

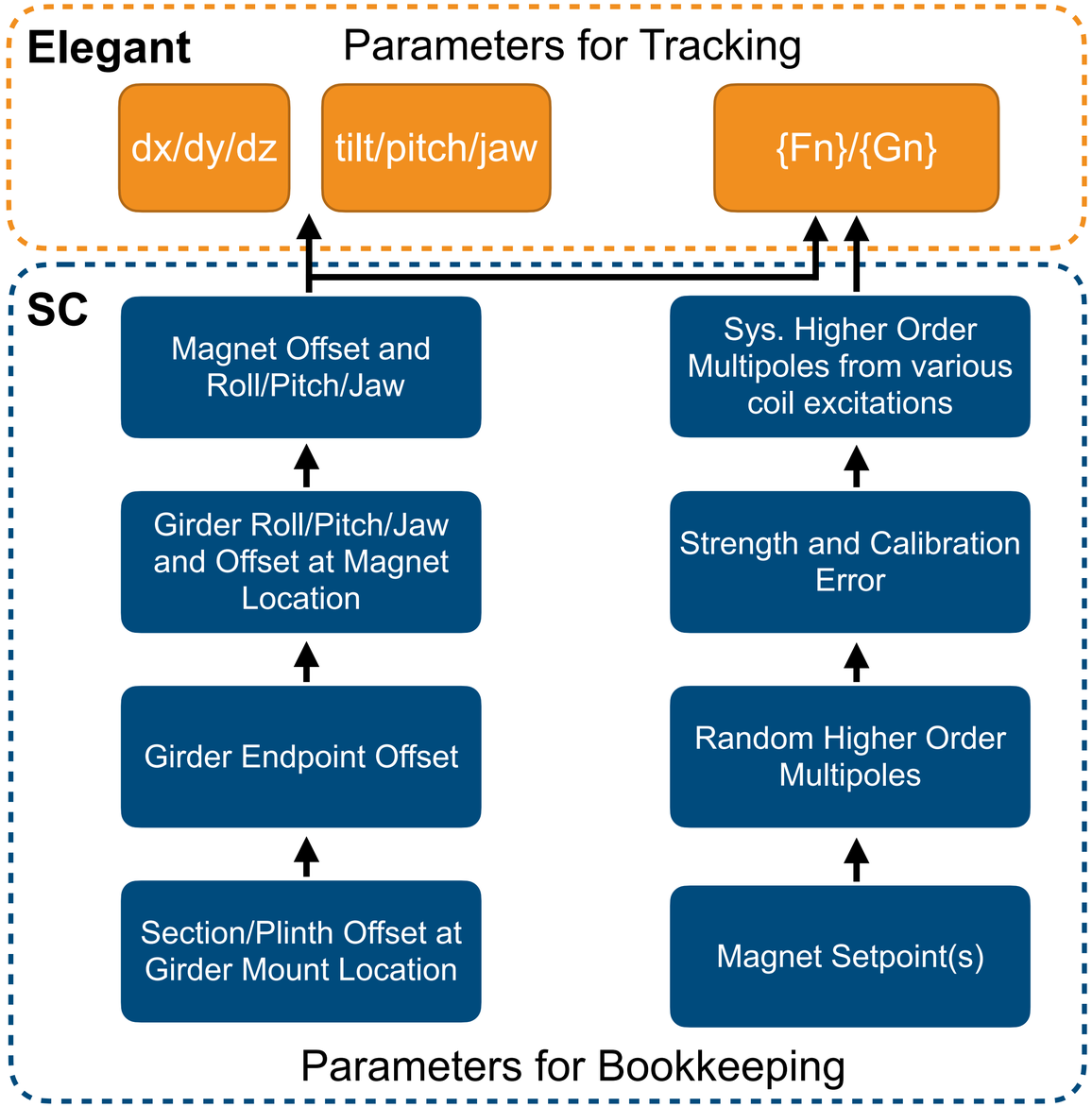
The simulation codes elegant [1] and Accelerator Toolbox (AT) [2] are both in common use for the study of particle accelerators and light sources. They use different software platforms and have different capabilities, so there is a strong motivation to be able to switch from one version to another to 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 lattices designed for the ALS-U. In addition to single-particle

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

Single-particle tracking for particles with moderate am-

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

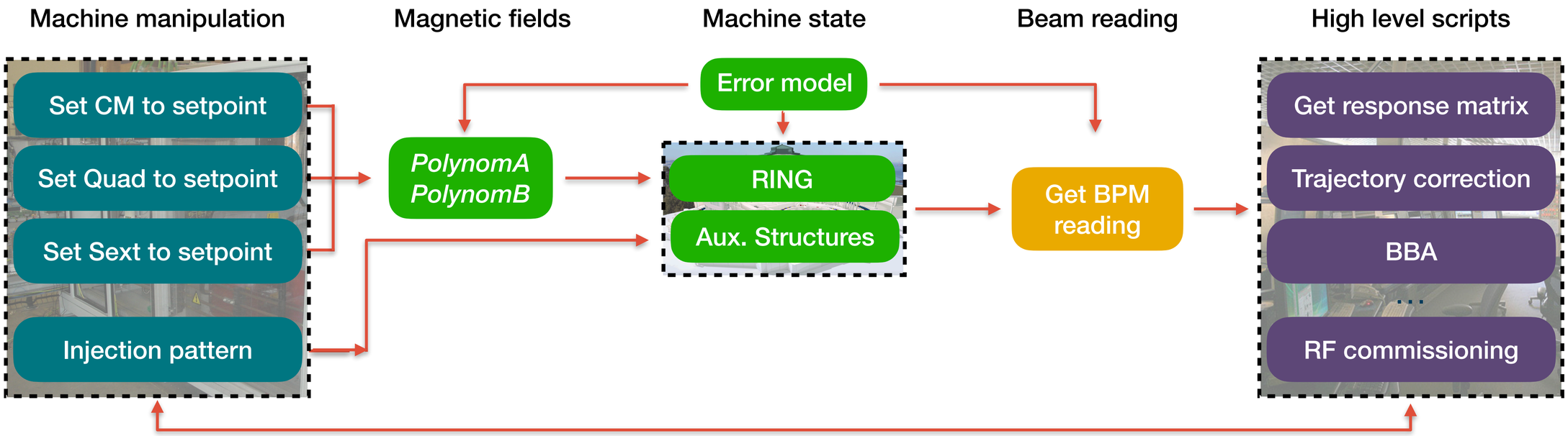


Commissioning Tests Using SC and Matlab Middle Layer (MML)

Motivation and Scope of SC-MML Connection

- **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 underway since June ‘21

Current Development: SC-MML Connection



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

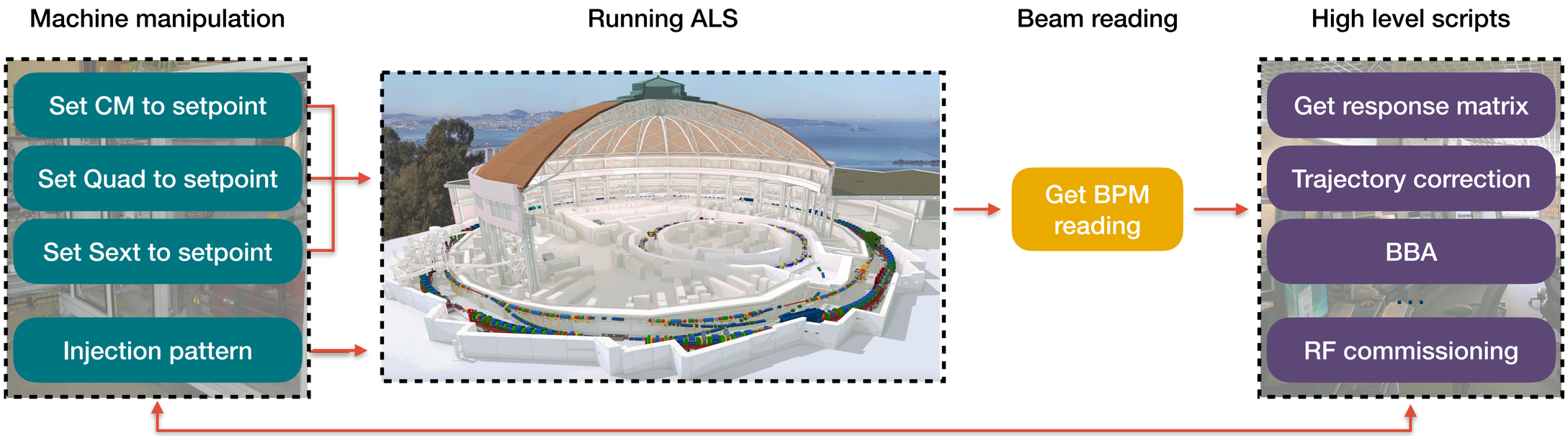
Get BPM reading

- 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

Current Development: SC-MML Connection



Set Quad to setpoint

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

Machine manipulation

- Toolkit calls MML functions to change magnet set points

Get BPM reading

- Toolkit calls MML functions to read BPM readings

High level

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

Current Development: SC-MML Connection

- High level- and user defined scripts only call SCgetBPMreading()
- Global variable '*isExp*' to check if simulation or real machine

SCgetBPMreading *(public on GitHub)*

```
% SEE ALSO
% --------
% *SCgenBunches*, *SCregisterBPMs*, *SCplotBPMreading*


    global plotFunctionFlag isExp

    % Check if experimental mode is switched on
    if isExp
        [B,T] = SCexp_getBPMreading(SC,varargin{:});
        return
    end

    % Parse optional arguments
    p = inputParser;
    addOptional(p,'BPMords',[]);
```

Current Development: SC-MML Connection

- High level- and user defined scripts only call SCgetBPMreading()
- Global variable '*isExp*' to check if simulation or real machine
- User supplied function to read BPM readings at their machine

SCgetBPMreading *(public on GitHub)*

```
% SEE ALSO
% --------
% *SCgenBunches*, *SCregisterBPMs*, *SCplotBPMreading*


    global plotFunctionFlag isExp

    % Check if experimental mode is switched on
    if isExp
        [B,T] = SCexp_getBPMreading(SC,varargin{:});
        return
    end

    % Parse optional arguments
    p = inputParser;
    addOptional(p,'BPMords',[]);
```

SCexp_getBPMreading *(public on GitHub)*

```
function [B,T] = SCexp_getBPMreading(SC,varargin)

    % Please insert your custom function for getting BPM readings
    % from your machine here

    [B,sum] = SCexp_ALS_getBPMreading(SC,varargin{:});

    T = sum;
end
```

Current Development: SC-MML Connection

- High level- and user defined scripts only call SCgetBPMreading()
- Global variable '*isExp*' to check if simulation or real machine
- User supplied function to read BPM readings at their machine
- All control parameters (number of turns, TBT/ORB, etc) within SC framework

SCexp_ALS_getBPMreading *(custom for ALS)*

```
if strcmp(SC.INJ.trackMode,'TBT') || strcmp(SC.INJ.trackMode,'pORB')
    for n=1:SC.INJ.nShots
        % Arm BPMs
        SCexp_ALS_armBPMs(SC);
        pause(1);

        % Trigger injection
        SCexp_ALS_injectBeam(SC);
        pause(1);

        % Ensure bunch is removed
        setbunchcleaning_local('On')
        pause(1);

        % Get BPM reading
        [tmpB,tmpSum] = SCexp_ALS_readoutBPMs(SC);
```

SCgetBPMreading *(public on GitHub)*

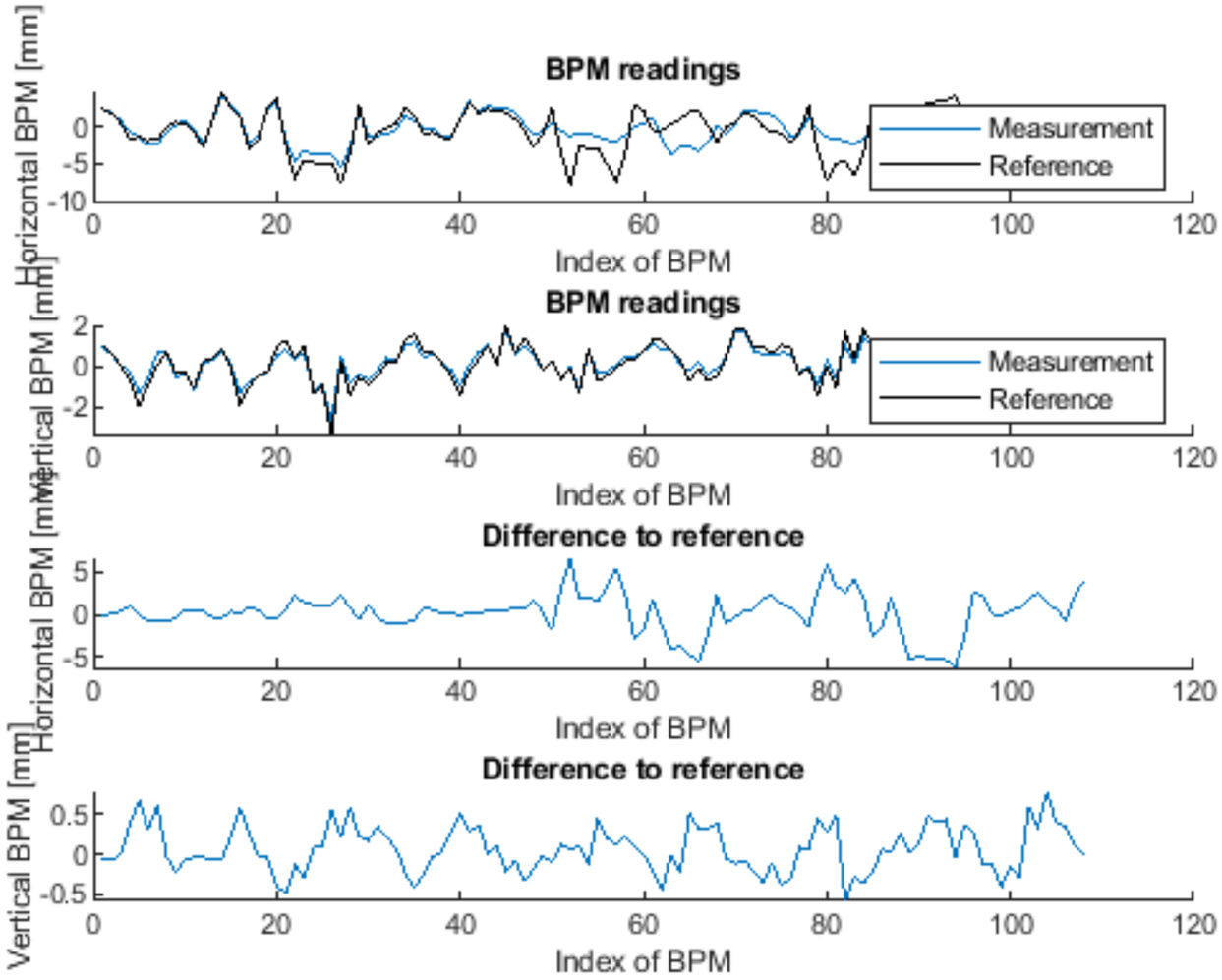
```
% SEE ALSO
% --------
% *SCgenBunches*, *SCregisterBPMs*, *SCplotBPMreading*


    global plotFunctionFlag isExp

    % Check if experimental mode is switched on
    if isExp
        [B,T] = SCexp_getBPMreading(SC,varargin{:});
        return
    end

    % Parse optional arguments
    p = inputParser;
    addOptional(p,'BPMords',[]);
```

SCexp_getBPMreading *(public on GitHub)*

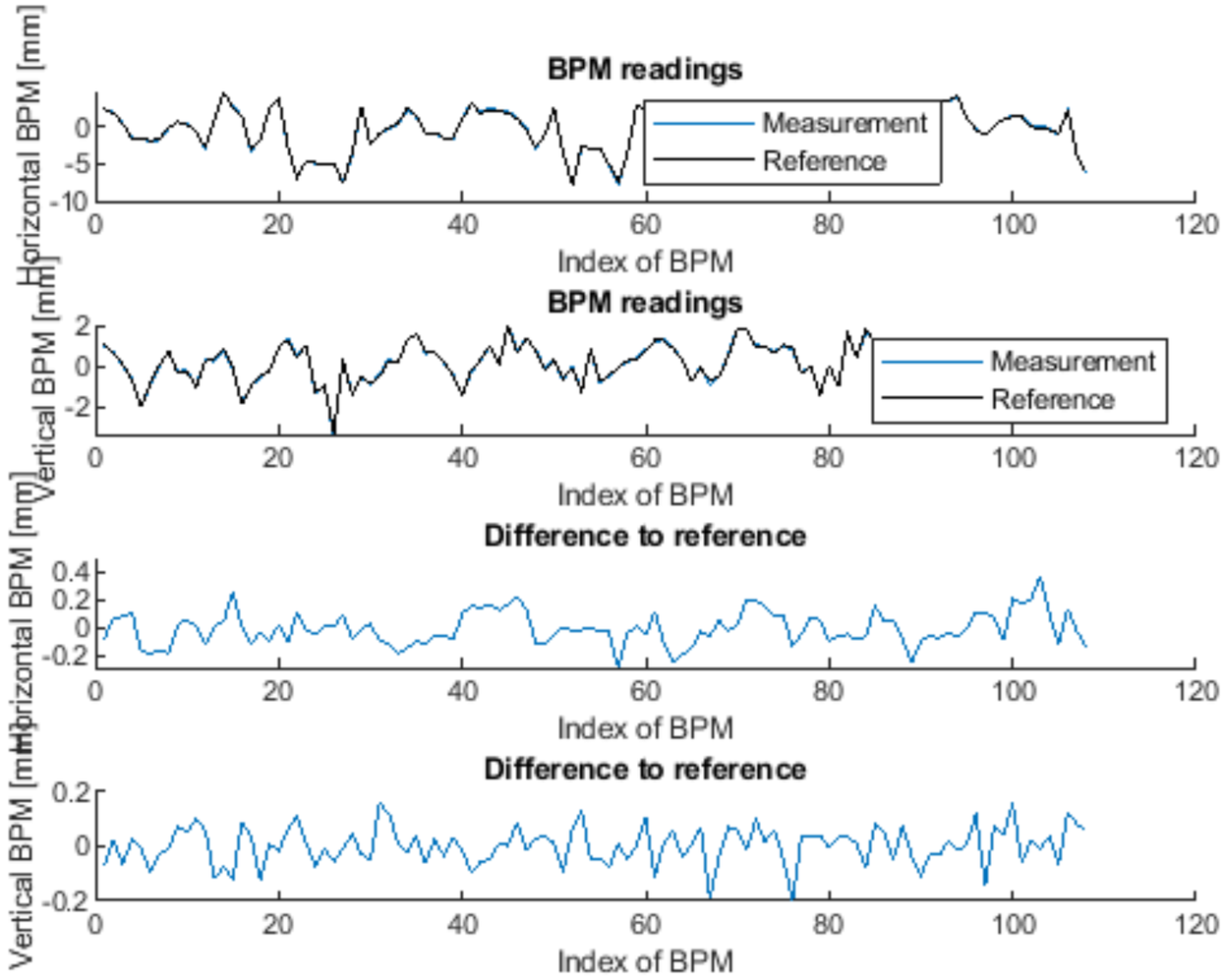
```
function [B,T] = SCexp_getBPMreading(SC,varargin)

    % Please insert your custom function for getting BPM readings
    % from your machine here

    [B,sum] = SCexp_ALS_getBPMreading(SC,varargin{:});

    T = sum;
end
```

Successful Multi-Turn Trajectory Feedback

Injection with one disturbed CM

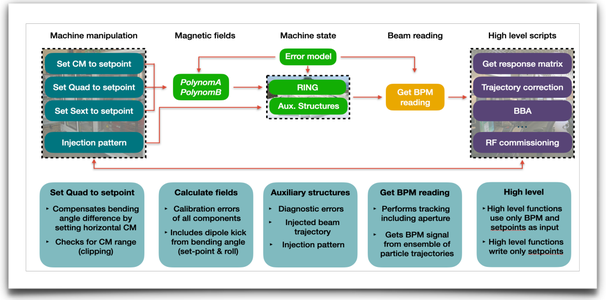


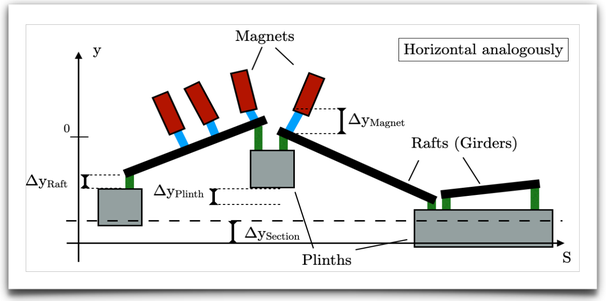
Injection after correction

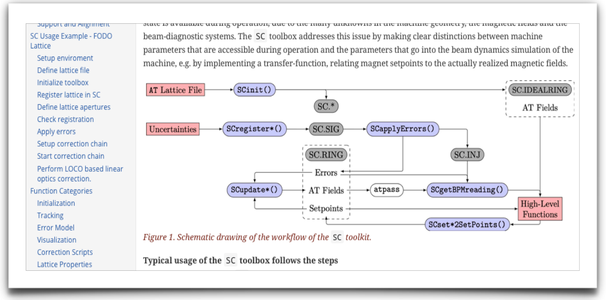


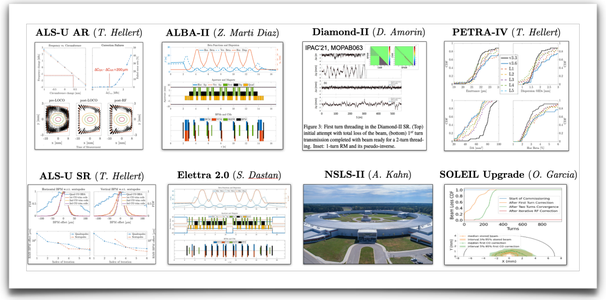
Summary

- **Commissioning simulations are essential for the design of ultra low emittance storage rings**
  - 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 multiple machines
- **Integrating SC Toolkit into the control system**
  - Automated startup and commissioning scripts needed for future light sources
  - Experimental commissioning tests and code development at ALS underway









https://sc.lbl.gov

Appendix: If I had more time I would work on implementing…

- **Realistic Errors in Split Magnets**
  - Future light sources will likely rely more and more on sophisticated longitudinal field profiles
  - Cross talk between magnets likely to increase due to space constraints
  - Currently no tracking/bookkeeping code available for arbitrary errors on arbitrary magnet slices
- **‘Non-Linear Errors’**
  - BPM saturation at high amplitudes
  - Magnet saturation and hysteresis effects
  - Wrong polarity BPMs/Magnets, etc
- **Time Depending Errors**
  - Toolkit already includes various types or magnet support structures and their errors
  - Including time dependent misalignment and power supply errors should be relatively easy
- **Exploring Machine Learning Options for Commissioning**
  - Surrogate models to accelerate beam threading?
  - First turn optics correction?