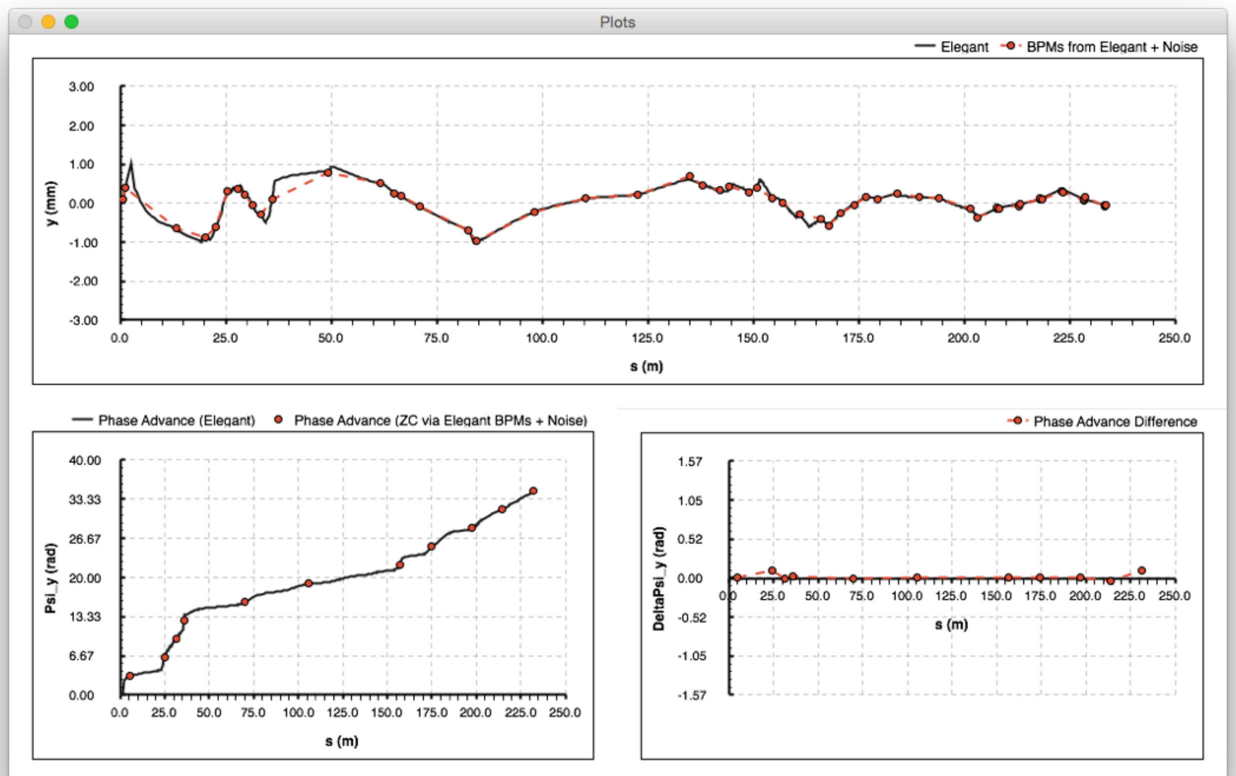
Follow-up on:
Studies on a diagnostic pulse for FLASH



Frank Mayet, R. Assmann, S. Schreiber, M. Vogt

FEL Seminar – 11.11.2014

Outline

- Introduction (Method)
- *FLASH Studies Beam Time* Summary
- Current Status
- Proposal / Outlook

Introduction (Method)

Beam-Based Monitoring of the SLC Linac Optics with a Diagnostic Pulse*

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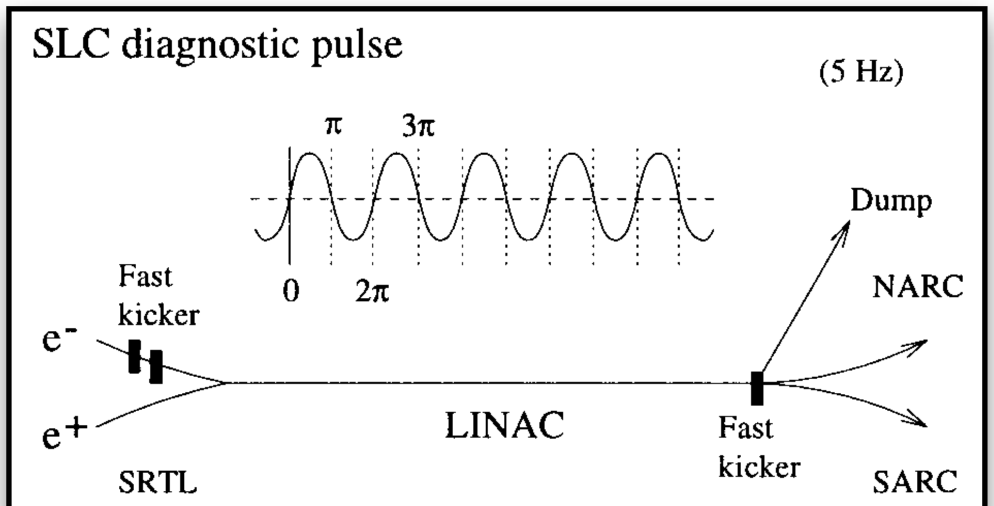


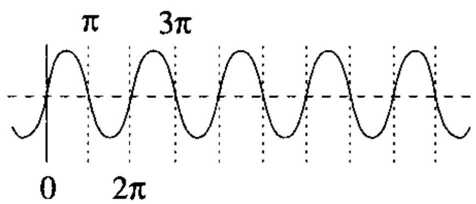
Automated procedure to monitor the beam optics routinely and non-invasively

Kick selected pulses at a fixed time interval – measure the induced betatron oscillations

Introduction (Method)

Online analysis: Calculate the phase advance and the oscillation amplitude via fast 0-crossing method

$$x(s) = \sqrt{\epsilon\beta(s)} \cdot \cos(\Psi(s) + \phi)$$



Ideally: Extract Twiss Parameters via trajectory fit (two kicks with $\Delta\Psi \approx \pi/2$ needed!)

$$(x_1, x_1')_i = \mathbf{R} \cdot (x_1, x_1')_0 \quad \text{and} \quad (x_2, x_2')_i = \mathbf{R} \cdot (x_2, x_2')_0$$

$$\psi = \arctan\left(\frac{R_{12}}{R_{11}}\right) \quad \text{and} \quad A = \sqrt{\det(\mathbf{R})} \cdot \sqrt{\frac{E}{E_0}}$$

Mini ORM → ***Compare to theoretical optics*** → ***Compile a long-term history***

Introduction (Method)

Mini ORM → ***Compare to theoretical optics*** → ***Compile a long-term history***

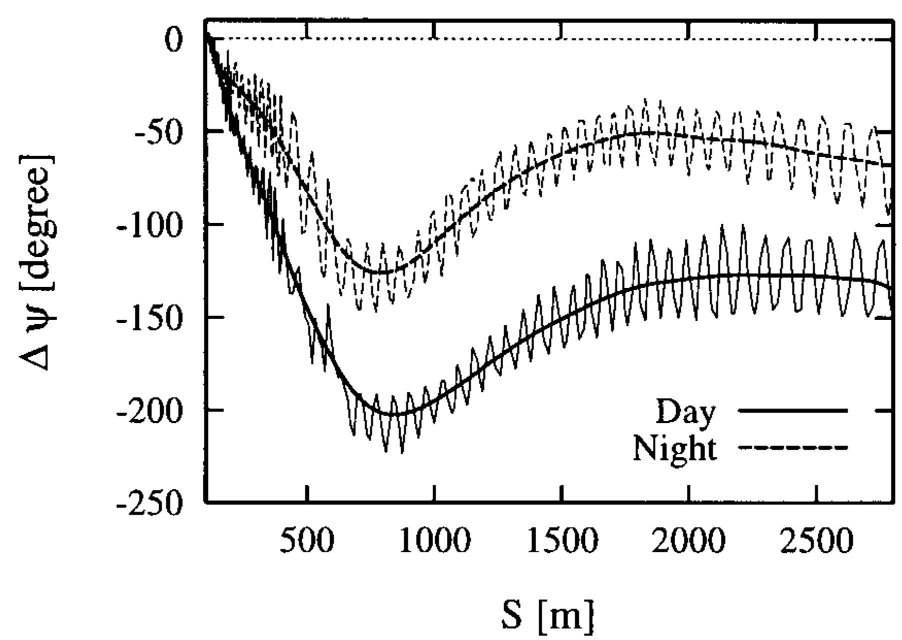


Figure 3 Measured beam phase advance difference in the SLC linac with respect to the machine optics during day and night of May 11th, 1996

Introduction (Method)

Mini ORM → ***Compare to theoretical optics*** → ***Compile a long-term history***

- Fast and *non-invasive* procedure to monitor beam optics stability
- The procedure can be automated and implemented as a server
- Additional diagnostic tool to help identify/localize beam optics errors

FLASH Studies Beam Time Summary

Two 4h measurement shifts

Took data using *slow* steerer magnets

Steerer 1	Steerer 2	ΔΨ (deg)
H5DBC2@29.75 m	H9DBC2@33.65 m	92.38
V6DBC2@30.74 m	V10DBC2@35.73 m	90.08

DAQ tool running on the console

Automated measurement

Took a *short long-term history*

FLASH Studies Beam Time Summary

Processed the recorded data using both zero-crossing and trajectory fit method

Zero-crossing results look promising, reveal interesting features

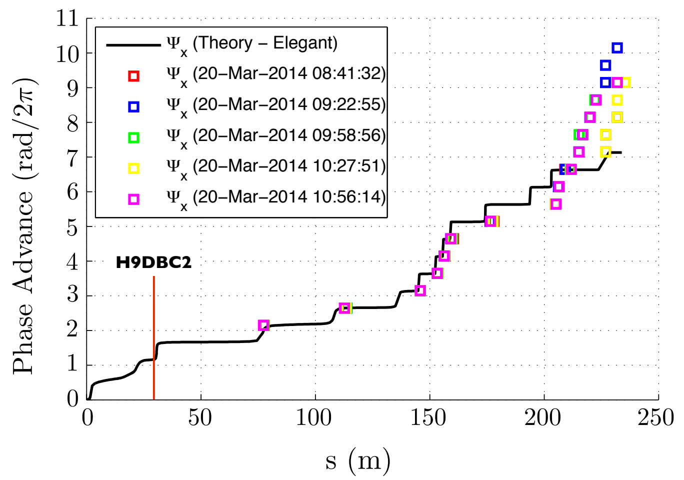


Figure 3: Horizontal phase advance vs. longitudinal position for a positive kick in the x plane using the steerer magnet H9DBC2. Multiple measurements are shown (note: data points are hidden behind the last data set (violett)).

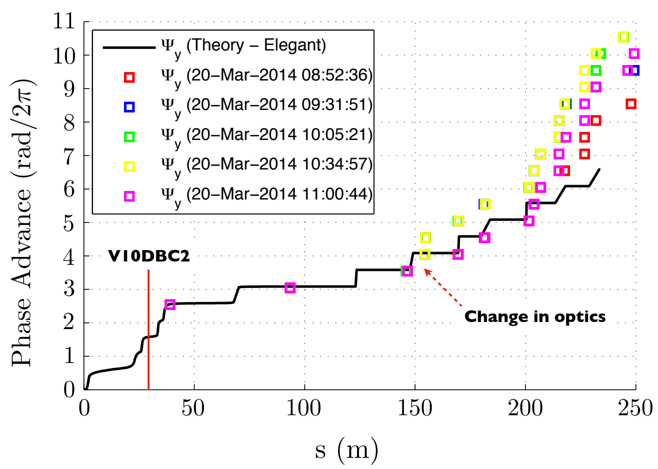


Figure 4: Vertical phase advance vs. longitudinal position for a negative kick in the y plane using the steerer magnet V10DBC2. Multiple measurements are shown (note: data points are hidden behind the last data set (violett)).

Follow-up on: *Studies on a diagnostic pulse for FLASH*

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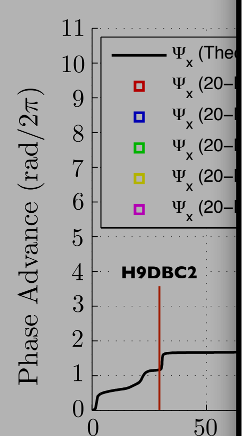
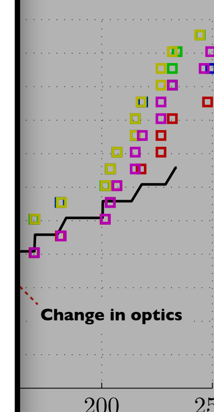
FLASH ... ary

Processed the recor ... rajectory fit method

Zero-c ... eatures





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IPAC'14

STUDIES ON A DIAGNOSTIC PULSE FOR FLASH

F. Mayet, R. Assmann, S. Schreiber, M. Vogt, DESY, Hamburg, Germany

Abstract

The long-term stability of the beam optics at FLASH is crucial for all connected experiments and the operation of the new second beamline FLASH2. It is therefore desirable to have a simple procedure to monitor the beam optics routinely and at the same time minimally invasive. This way user operation is not disturbed. An automated procedure, which has been successfully employed at the SLAC linac is presented in the context of FLASH. The betatron oscillations of selectively kicked pulses are recorded using BPMs at a fixed time interval. An online algorithm is then used to extract the betatron phase advance, as well as potential growth of the betatron oscillation amplitude and the Twiss parameters beta and alpha. Using this method, the long-term beam optics stability can be monitored in order to identify potential sources of drifts.

INTRODUCTION

The high-gain free-electron laser FLASH at DESY, Germany produces ultra-short X-ray pulses with a duration less than 30 fs FWHH. These pulses are generated by the SASE process using a high brightness electron beam, which can be tuned to energies between 370 MeV and 1.25 GeV. This corresponds to a photon wavelength range between roughly 45 nm and 4 nm. Electron bunches are created by a laser-driven photoinjector and then accelerated by seven 1.3 GHz superconducting accelerator modules (*TESLA-type*). X-ray pulses are then generated inside the 27 m long undulator section. Figure 1 shows a schematic layout of the FLASH machine. [1–3]

Since FLASH is a user facility, the long-term stability of the beam optics is crucial for all connected user experiments and the operation of the new second beamline FLASH2. In addition to that the seeding experiment sFLASH also demands for high beam optics stability. In the following a simple procedure to monitor the beam optics routinely and at the same time minimally invasive is proposed, with the goal to provide the operators an additional tool to monitor the overall machine stability. First test measurements are presented.

METHOD

The diagnostic pulse method - which has already been successfully employed at the SLAC linac [4] - is based on the idea of extracting beam optics stability information by measuring kicker magnet induced betatron oscillations of selected pulses periodically. These oscillations are measured by all available beam position monitors downstream the location of the kick. An online tool then analyzes the data. This way a long-term history of beam optics stability can be compiled.

The aim of the method is to reveal the cause of beam optics errors, which lead to symptoms like the loss of SASE signal or a trigger of the machine protection system. Figure 2 shows an *Elegant* [5] calculation of the betatron phase advance difference between the design optics and a scenario were one power supply delivers the wrong output current. Errors like this should easily be detectable by the diagnostic pulse method.

In order to be able to calculate beam optics related physical quantities from the BPM data it is necessary to induce the oscillations at two different positions (1 and 2) along the linac. The distance in phase advance should be close to $\pi/2$. The transport of the two oscillations is given by

$$\begin{pmatrix}x_1\\x_1'\end{pmatrix}_i = \mathbf{R}_i\cdot\begin{pmatrix}x_1\\x_1'\end{pmatrix}_0, \qquad \begin{pmatrix}x_2\\x_2'\end{pmatrix}_i = \mathbf{R}_i\cdot\begin{pmatrix}x_2\\x_2'\end{pmatrix}_0 \tag{1}$$

where 0 indicates the initial point and i all of the downstream locations. From this data it is now possible to calculate the R-matrix elements by solving the set of equations given by equation 1. Due to the fact that only the spatial coordinates are recorded by the BPMs, the angular coordinates (x_i') must be obtained by a least square trajectory fit. From equation 1 it can be seen that the fit problem can be expressed in matrix formalism as

$$\mathbf{X} = \hat{\mathbf{M}}\cdot\mathbf{p}, \tag{2}$$

where $\mathbf{X}$ is an n-dimensional vector of positional data obtained by n downstream BPMs, $\hat{\mathbf{M}}$ is a an $n\times 2$ matrix of fixed model parameters (here: R-matrix elements taken from optics calculations using *Elegant*) and $\mathbf{p}$ is an 2-dimensional vector of the free parameters (here: x and x'). Therefore it is possible to calculate $\mathbf{p}$ by analytically minimizing χ^2 [6] and hence

$$\mathbf{p} = (\hat{\mathbf{M}}^{\mathrm{T}}\hat{\mathbf{M}})^{-1}\hat{\mathbf{M}}^{\mathrm{T}}\mathbf{X}. \tag{3}$$

Having obtained the *measured* R-matrix elements it is now possible to calculate the Twiss parameteres α, β, as well as the betatron phase advance Ψ, oscillation amplitude A and the mismatch parameter B_{mag} per plane x and y (see **APPENDIX**).

Zero-Crossing Method

Another way to obtain the betatron phase advance is to fit the positions of the zero-crossings of the betatron oscillations. This method allows the fast evaluation of the data in steps of π.

Both the analytical trajectory fit and the zero-crossing method are implemented in the online tool.

FLASH Studies Beam Time Summary

Trajectory fit results: Difficult to interpret, especially the extracted *Twiss Parameters*

Carefully prepared *Elegant* calculations using machine read back values (magnets, RF, etc.)

$$\Psi_l = \arctan\left(\frac{\tilde{R}_{12}}{\tilde{R}_{11}}\right), \qquad \beta_l = \frac{(c\tilde{R}_{11} + s\tilde{R}_{12})^2}{\det(\mathbf{R})} \cdot \beta,$$

$$A_l = \sqrt{\det(\mathbf{R})} \cdot \sqrt{\frac{E}{E_0}}, \qquad \alpha_l = \frac{(c\tilde{R}_{11} + s\tilde{R}_{12}) \cdot (c\tilde{R}_{21} + s\tilde{R}_{22})}{\det(\mathbf{R})} + \frac{\beta_l}{\beta} \cdot \alpha,$$

$$B_{\text{mag}} = \frac{1}{2} \cdot \left[\frac{\beta}{\beta_l} + \frac{\beta_l}{\beta} + \beta\beta_l\left(\frac{\alpha_l}{\beta_l} - \frac{\alpha}{\beta}\right)^2\right]$$

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↓

Could not match to the model data using read back values!!

↓

Known problem?? (cf. M.Sc. thesis by Thorsten Hellert)

Current Status

Zero-crossing method works as expected

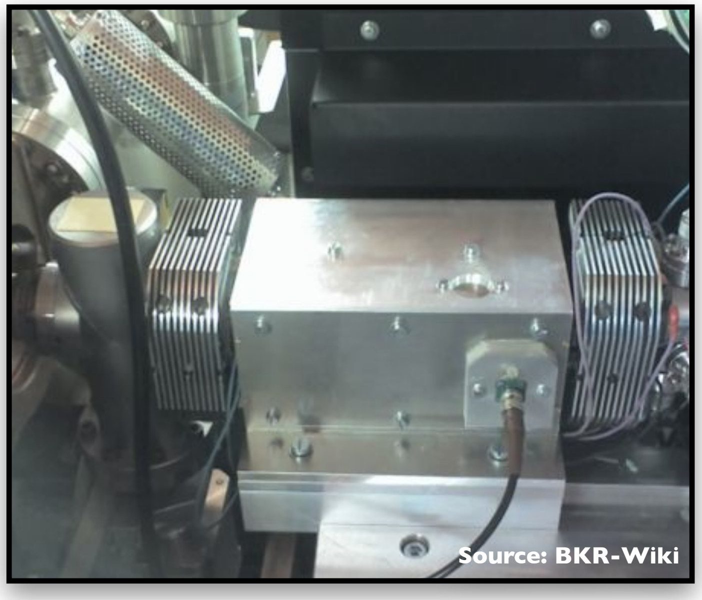
Trajectory fit proves to be difficult due to lack of knowledge of the optics
(read back values cannot be inserted into the model – unphysical results – *feasibility*?)

Non-invasive method would require the installation of new fast kickers – *space constraints*?

FLASH runs several different energy/wavelength settings
– phase advance between the two kickers changes

Current Status

Online implementation could be realized using the *DC-Kicker* at the start of the machine (between steerers *V1GUN* and *H2GUN*)



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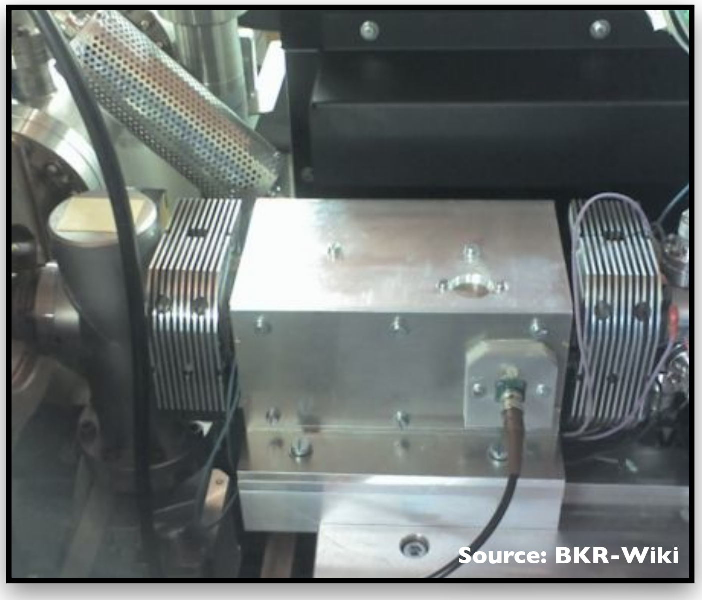


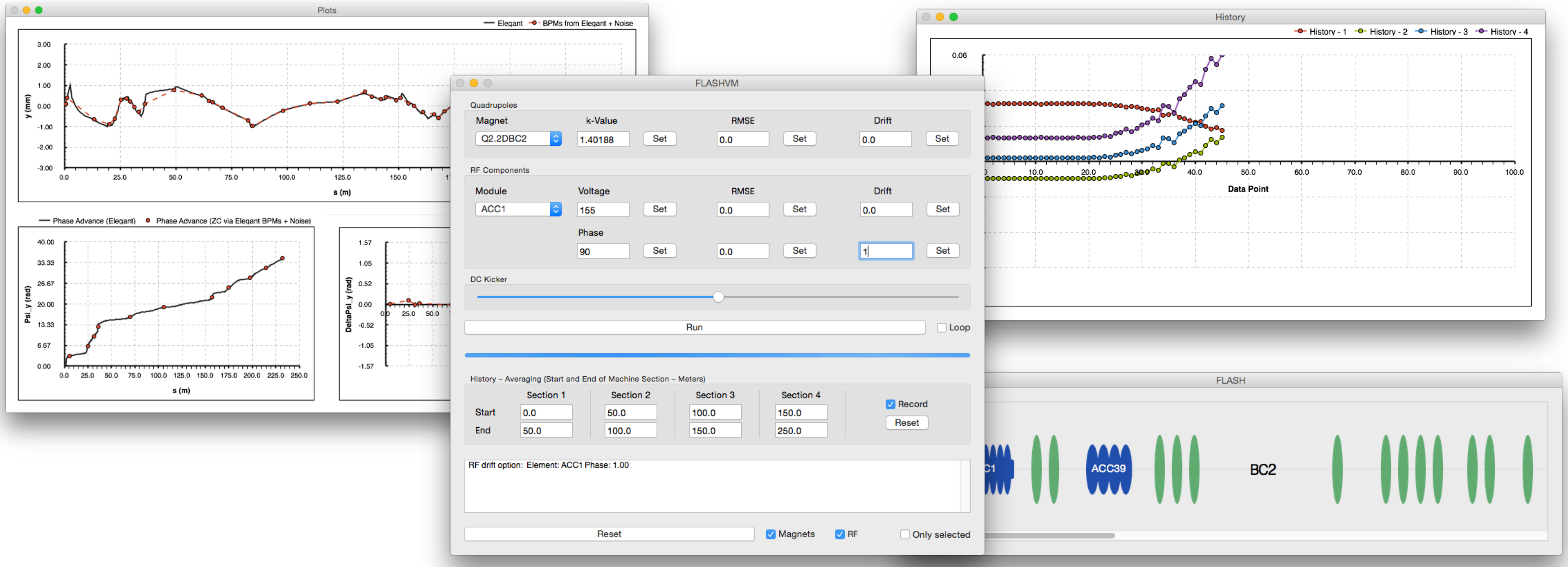
Using this setup only the 0-crossing method and only the y-direction is possible

Do not use the optics model as a reference, but fine-tuned/real-life measured references (reset after each wavelength change) – *After all a relative optics stability measurement is sufficient*

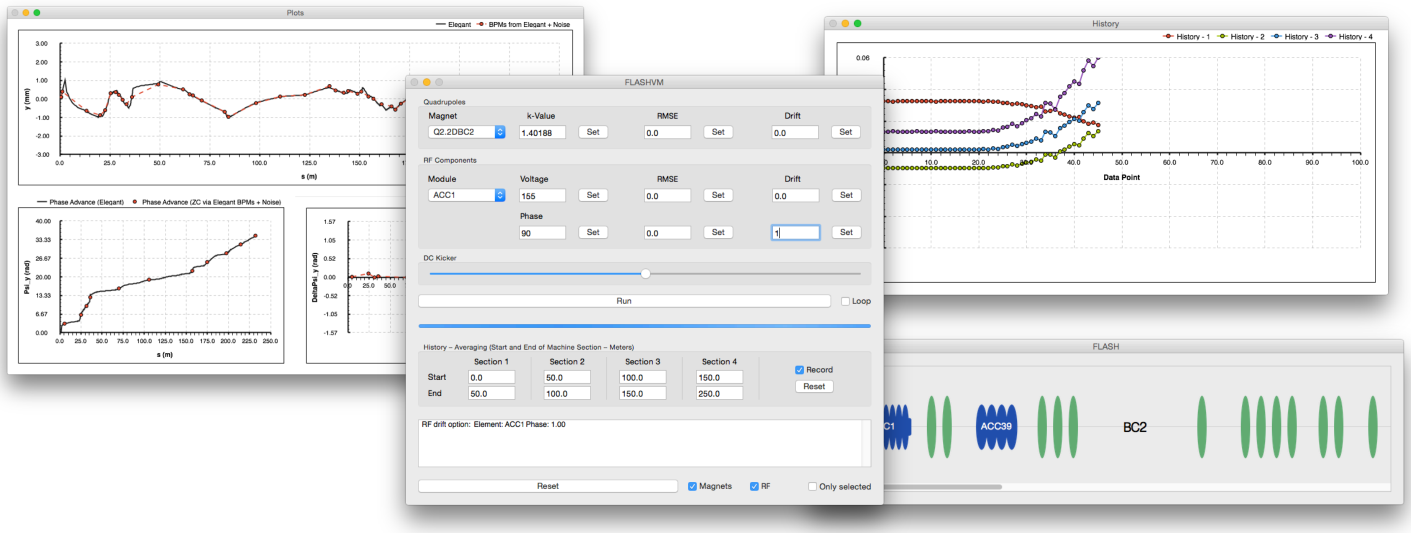
Could be implemented either as a native console tool, or as a DOOCS server

Proposal / Outlook

Theoretical studies using an *Elegant-based* virtual FLASH machine software.
What can be achieved using a DC-Kicker setup?



FLASHVM.app



- *Elegant* based (uses the most recent FLASH 1 files by M. Scholz) – ObjC OS X
- Creates *Elegant* input files, runs the calculation and reads in the results
- Records data assuming the *DC-Kicker Case*
- Does all relevant *Diagnostic Pulse* calculations (zero-crossing method)
- Plots the data
- Allows the manipulation of magnet and RF settings *on the fly*
- Can apply random errors and drifts to specific components
- Records average phase advance difference (compared to a *pre-recorded* reference) in a specified regions/sections of the machine (***History***)
- Applies *Gaussian* BPM noise (as recorded during our measurement shifts)

FLASHVM.app

How to interpret the history data?

History data allows for quick examination of the 4 (or more) pre-defined sections of the machine

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Data is associated with a reference orbit (setting)

Could also think of abstract way of showing the data:
‚Something happend in section x' – ‚Deviation probably caused by module y'

Monitor long-term stability – Additional diagnostic *if something fails*

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Monitor long-term stability – Additional diagnostic *if something fails*

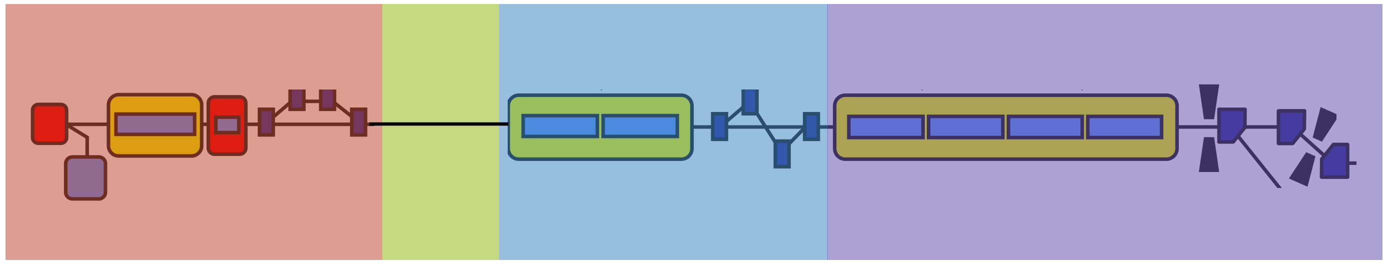
Since the purpose of the tool is to detect severe changes or drifts, the resolution is not a big issue!

↕

Low-level feedbacks are already in place and *working*!

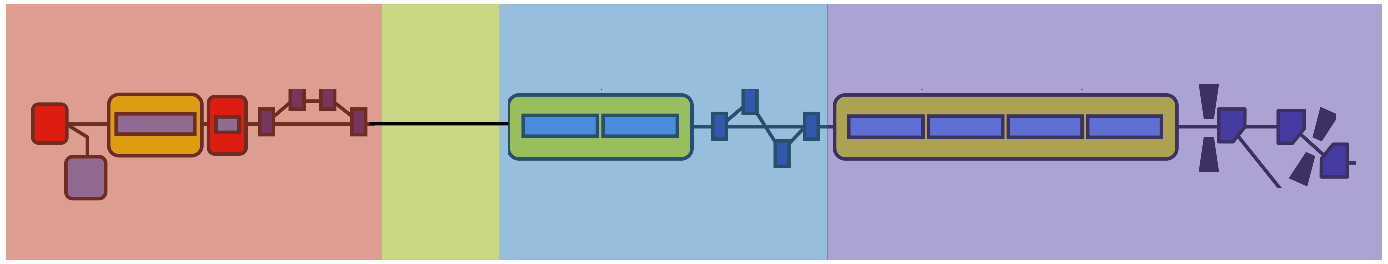
FLASHVM.app

Examples

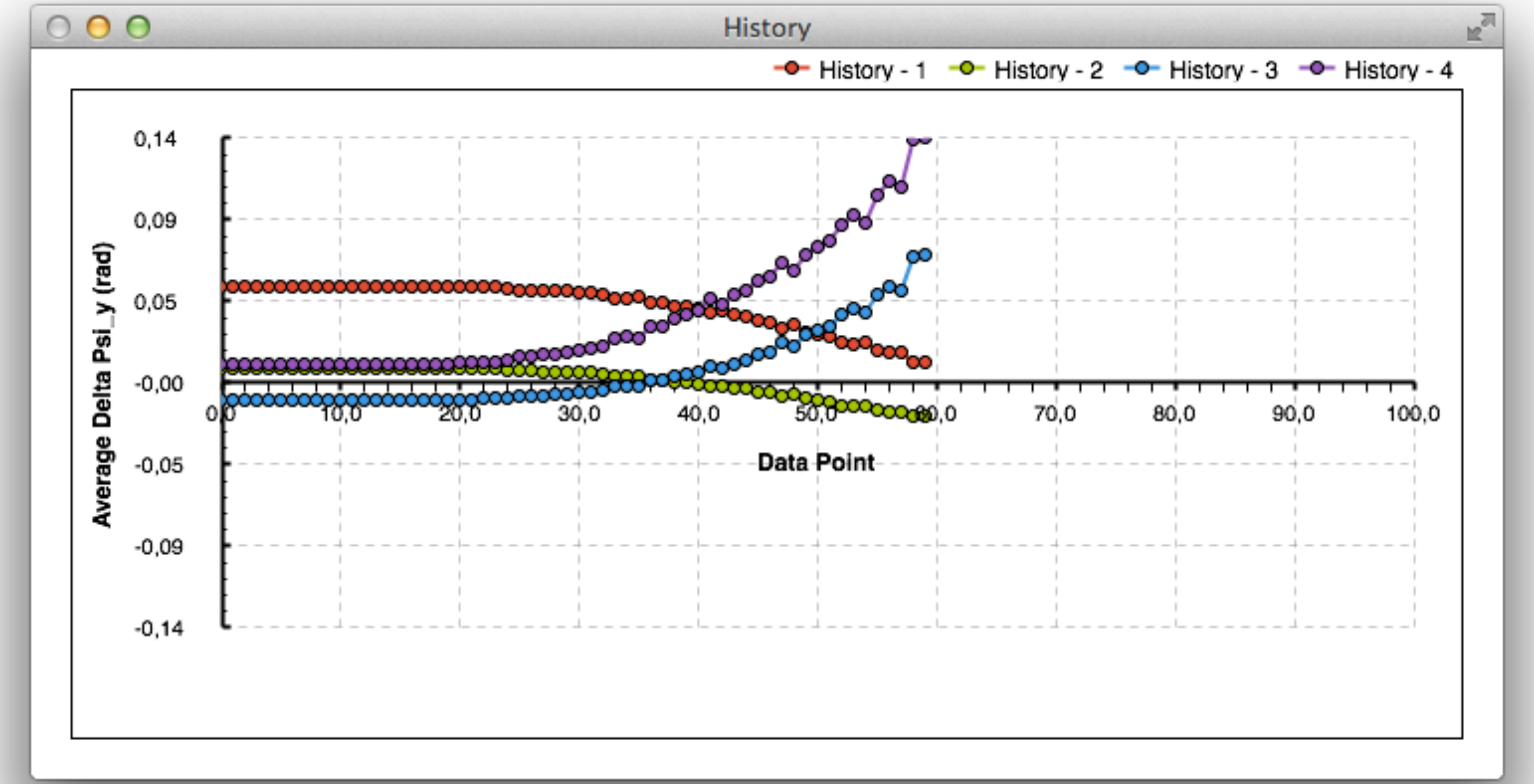


FLASHVM.app

Examples

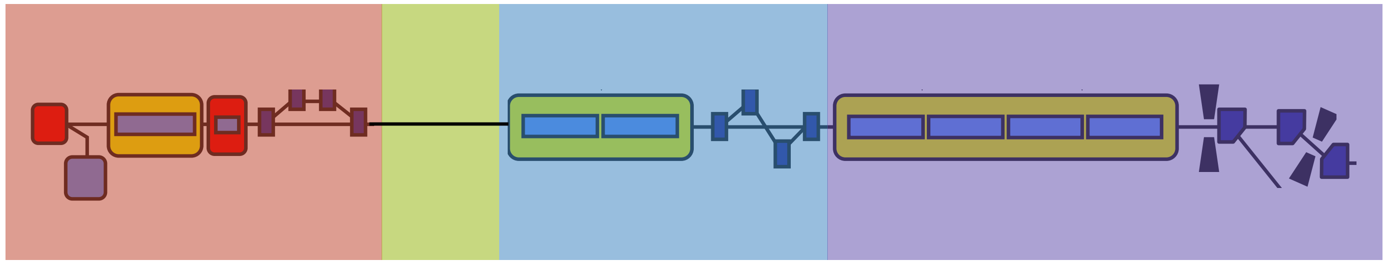


Phase drift in ACC1 + 1% Noise

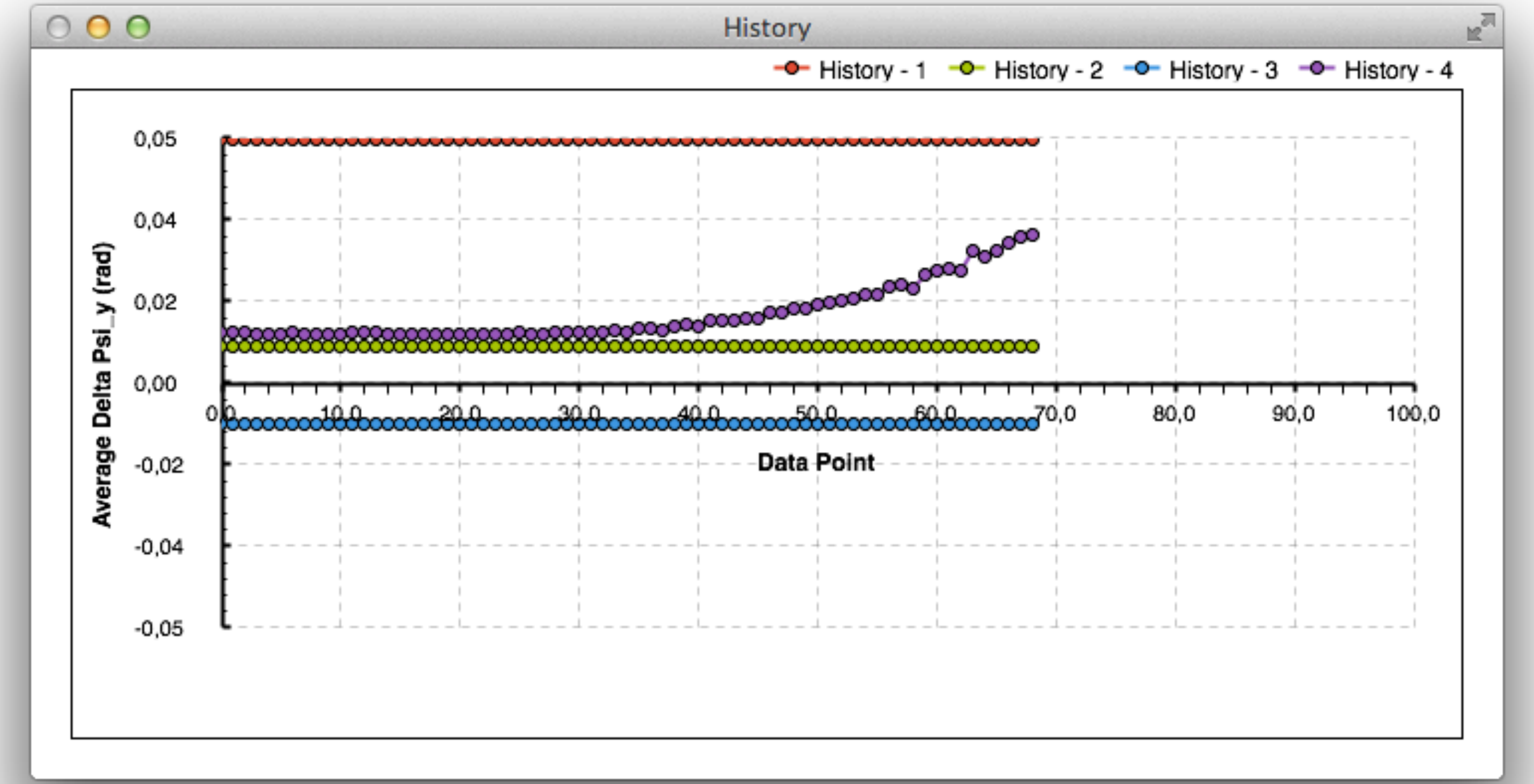


FLASHVM.app

Examples

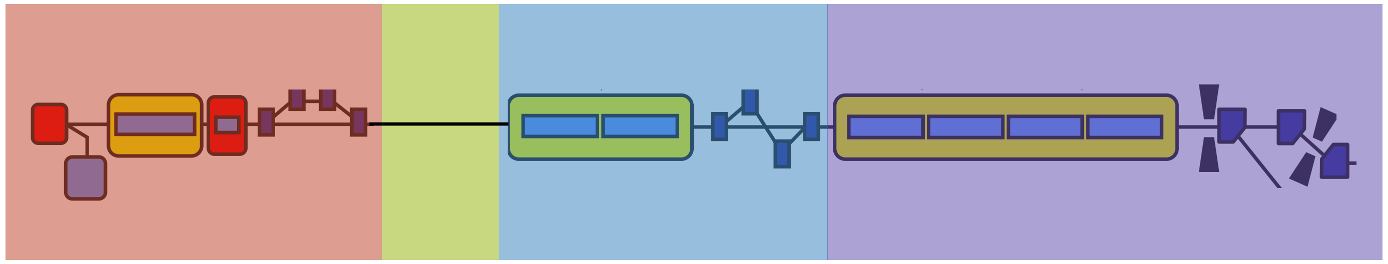


Phase drift in ACC45 + 1% Noise

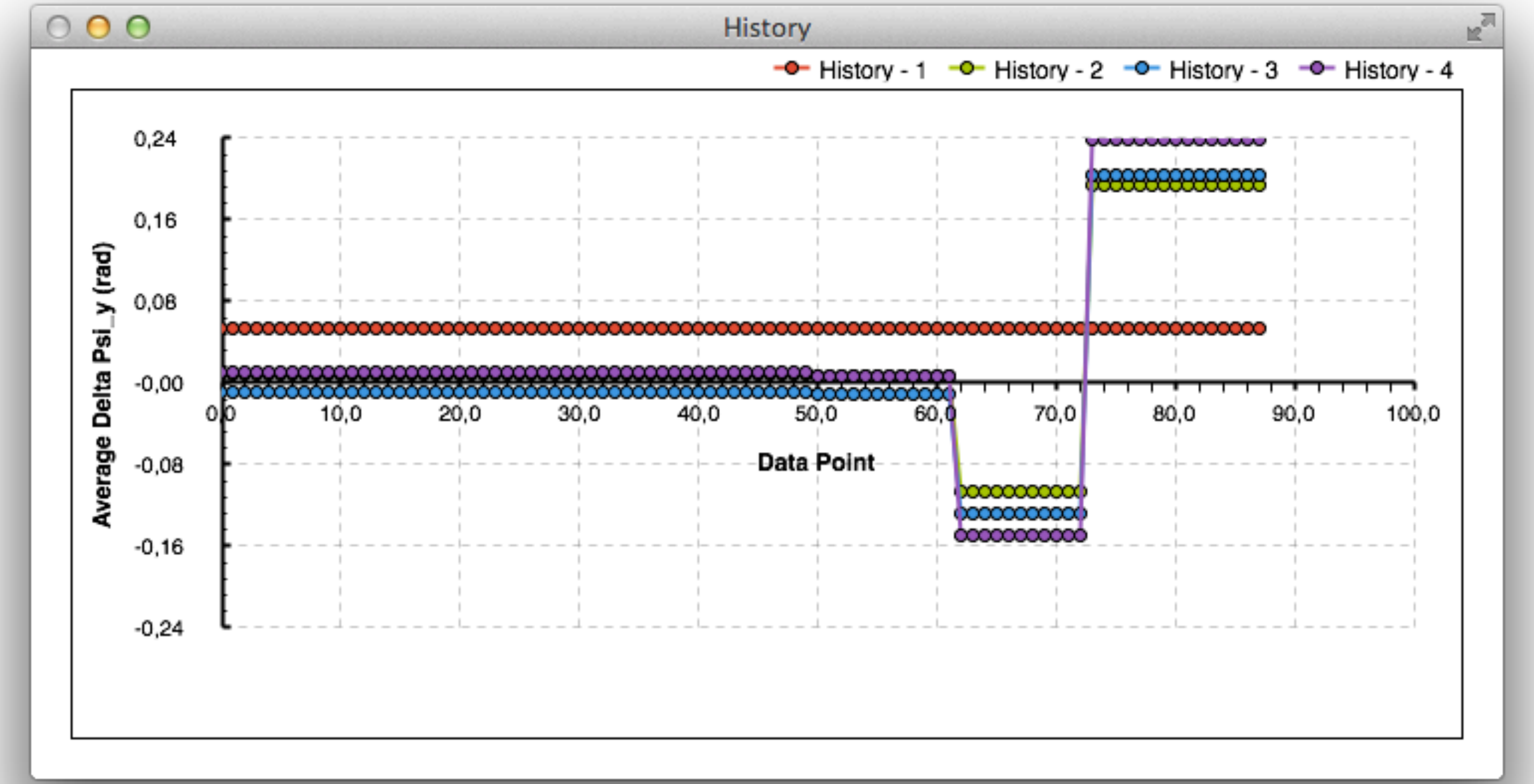


FLASHVM.app

Examples

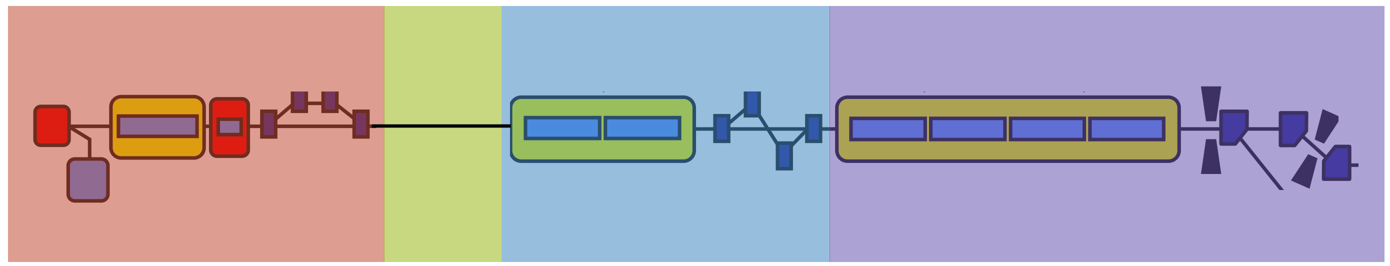


Q3DBC2 k-Value Error

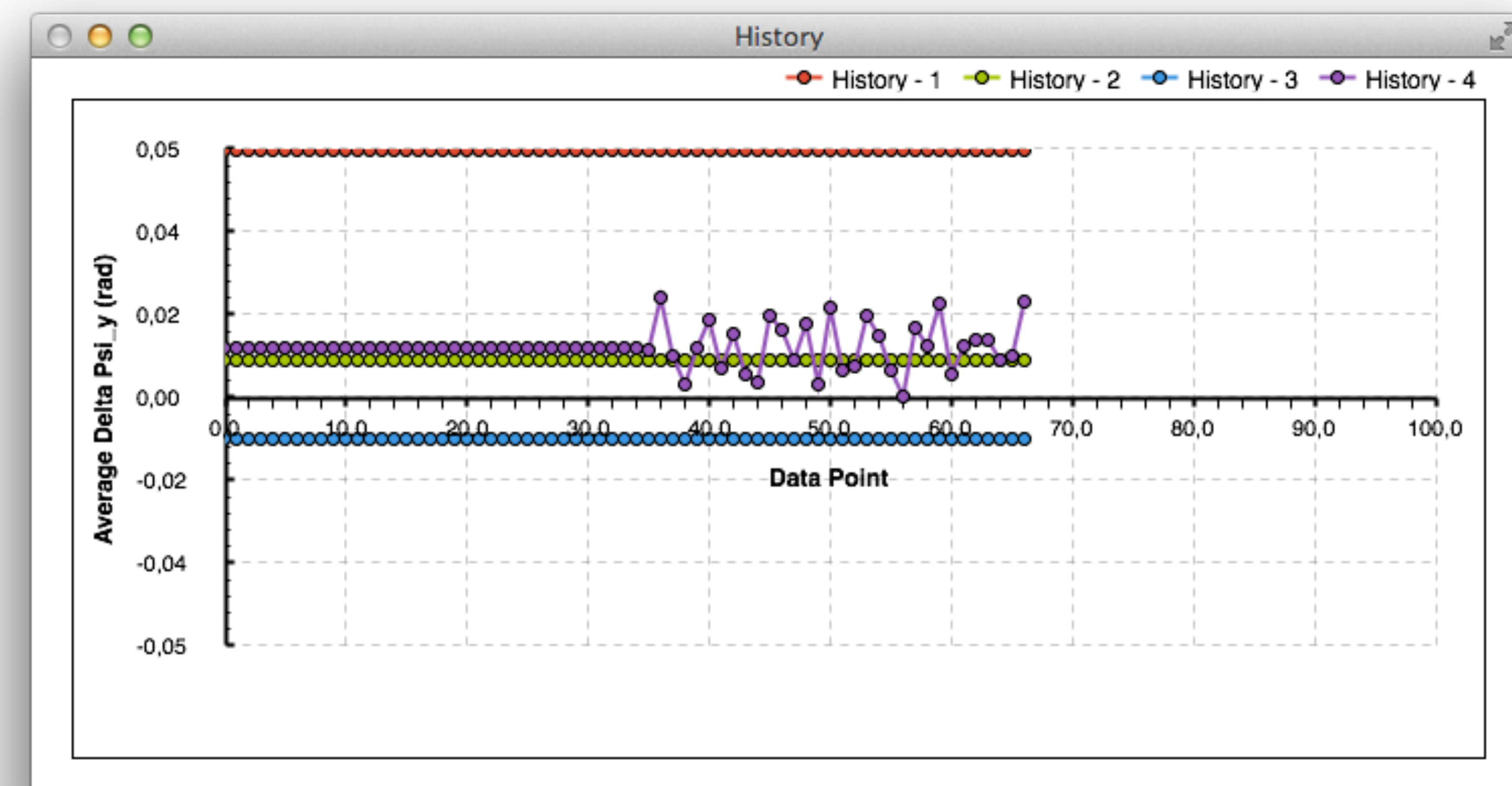


FLASHVM.app

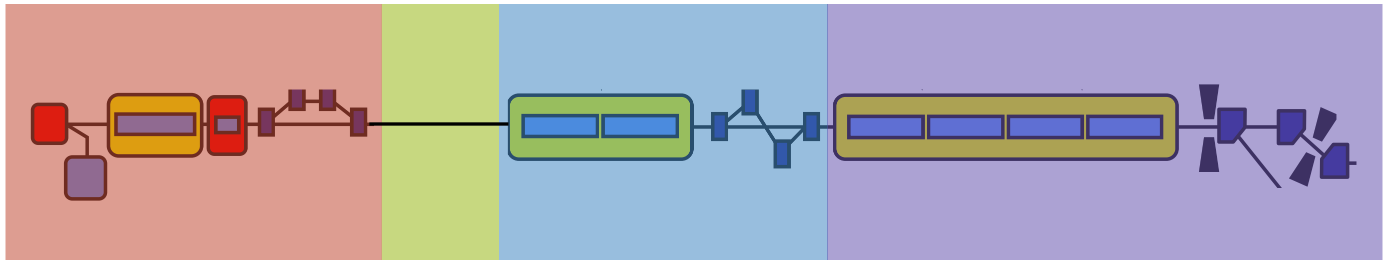
Examples



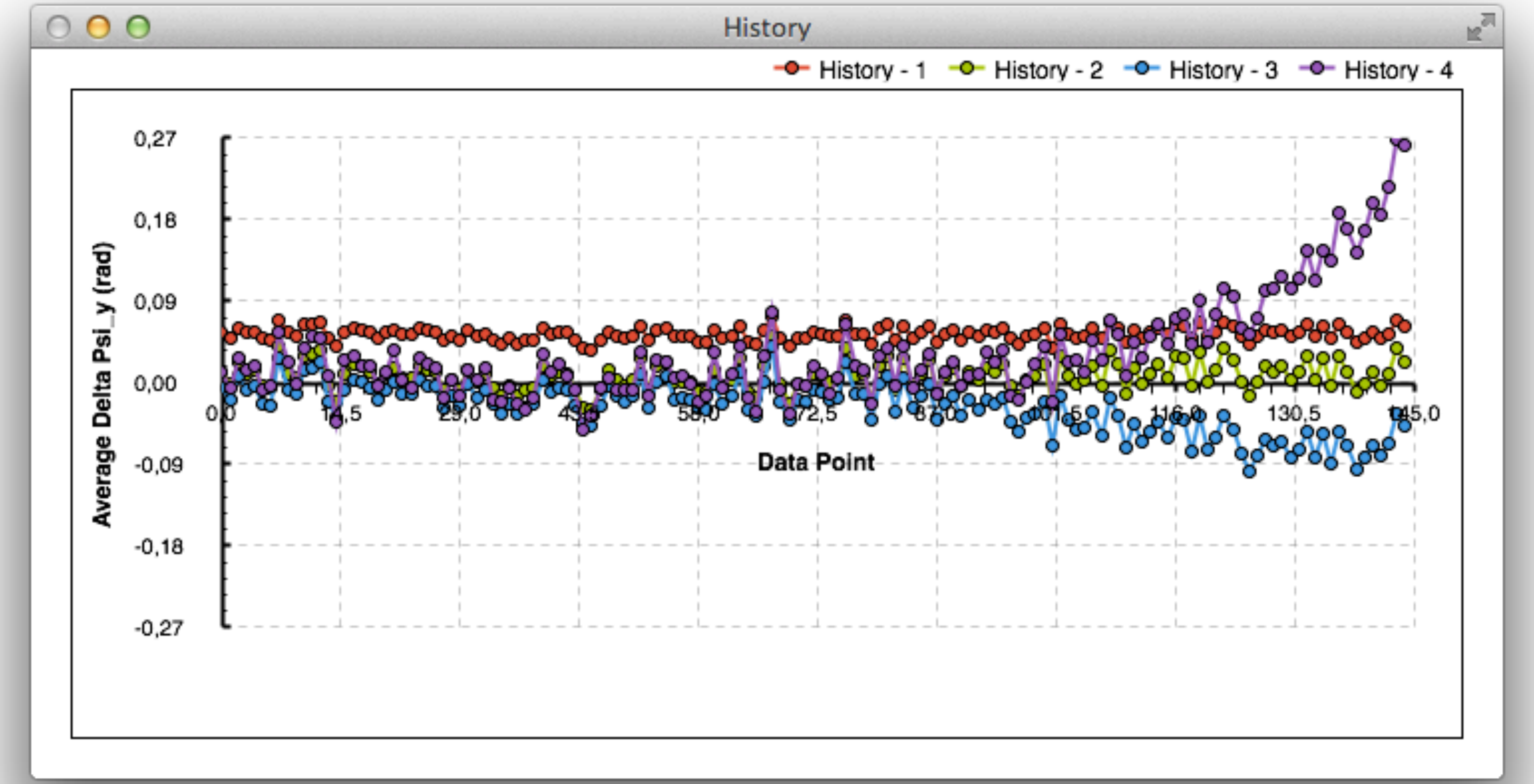
Q10ACC6 – 1% Noise



FLASHVM.app
Examples



Q9ACC1 – 1% Noise + ACC23 Phase Drift



Proposal / Outlook

Possible structure of a DOOCS/TINE server

*FLASH/DIAG/DiagPulse/**ReferenceOrbit***
*FLASH/DIAG/DiagPulse/**Energy***
*FLASH/DIAG/DiagPulse/**Orbit***
*FLASH/DIAG/DiagPulse/**PhaseAdvance***
*FLASH/DIAG/DiagPulse/**DeltaPsi_Sec_1***
*FLASH/DIAG/DiagPulse/**DeltaPsi_Sec_2***
*FLASH/DIAG/DiagPulse/**DeltaPsi_Sec_3***
*FLASH/DIAG/DiagPulse/**DeltaPsi_Sec_4***

Implementation Options

Proposal: 1 measurement every hour

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  - Measurement would take < 5 sec
  - *minimal-invasive*
  - x- and y-direction
  - Trajectory fit theoretically possible
  - Maybe need to choose different steerers for specific energy settings

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- **Install new fast kickers**
  - *Spatial constraints?*

Thank you!

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Questions?

Comments?