

Beamline Modeling Tools

Stephen Molloy*

(with much help from Glen White)

SLAC

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Overview

- Development of a beamline modeling “toolkit”
 - A suite of matlab routines to help with tuning and trouble-shooting of ATF2 lattice
 - Developed within Flight Simulator
 - Part of the base FS installation
- Will discuss each of these in turn
 - Begin with “simple” tools, and progress to more complex
 - Usage instructions for these tools
 - Show some examples of simulated results

Tools under development

- BPM display
- Twiss calculation
 - Theoretical & measured
- Bump generation
- Beam based alignment
 - Quads (Ext & FF) and sexts (FF)
 - Movers or beam bumps
- Lattice verification
 - $R_{(1/3,2/4)}$ measurement and magnet strength fitting

A few details

- Generic set of tools for use with the FS
 - Integrated with FS **right from the start.**
 - Developed entirely within the FS environment to ease transition to ATF2 control room
- Tracking or modeling calls use Lucretia libraries
- Most tools are already uploaded to Lucretia CVS server
 - Various stages of development, and testing

BPM Display

Paused

CLICK TO RUN

Orbit configuration

Absolute

Take reference

Differ...

Saved orbit

Averaging?

Yes Number of points to average

10

No

Plot RMS

x Scale

Auto-scale

Manual

Min: -0.2

Max: +0.2

y Scale

Auto-scale

Manual

Min: -0.1

Max: +0.1

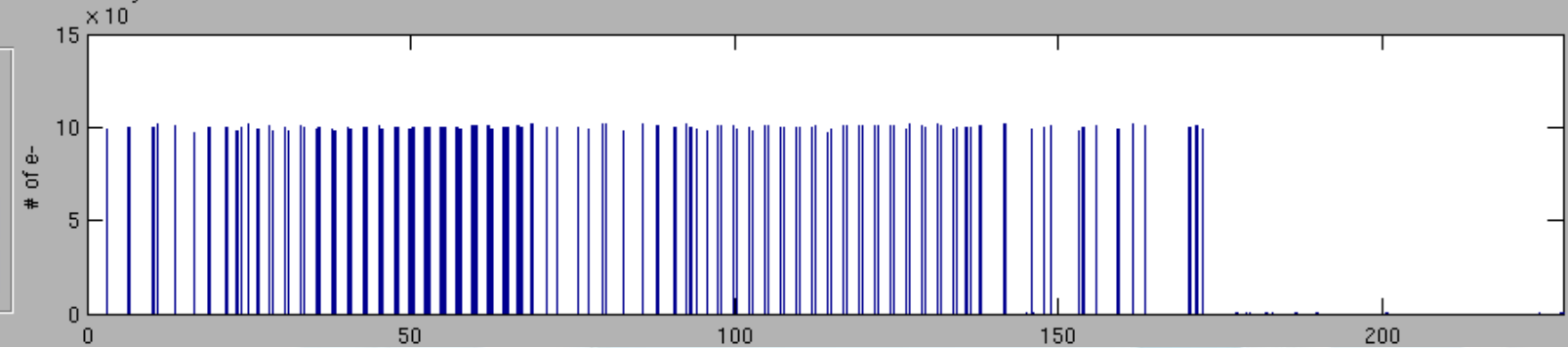
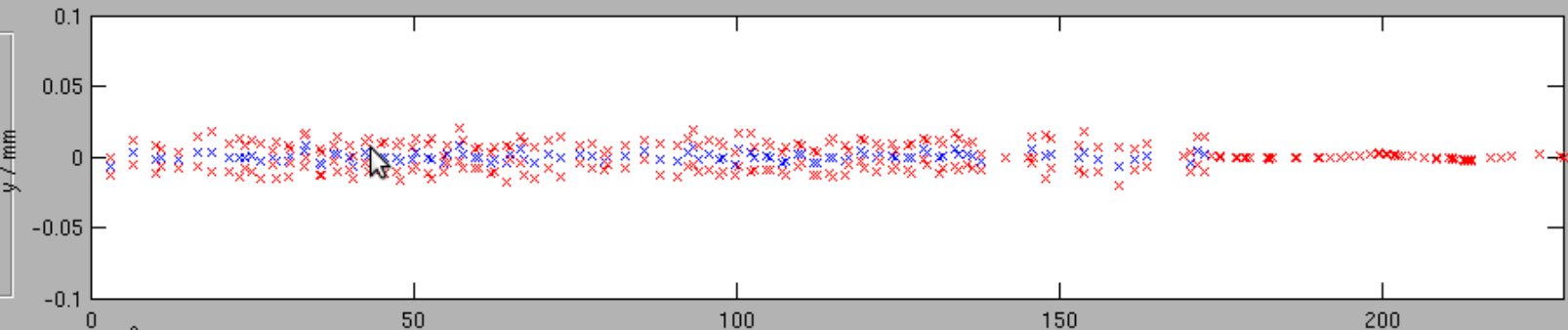
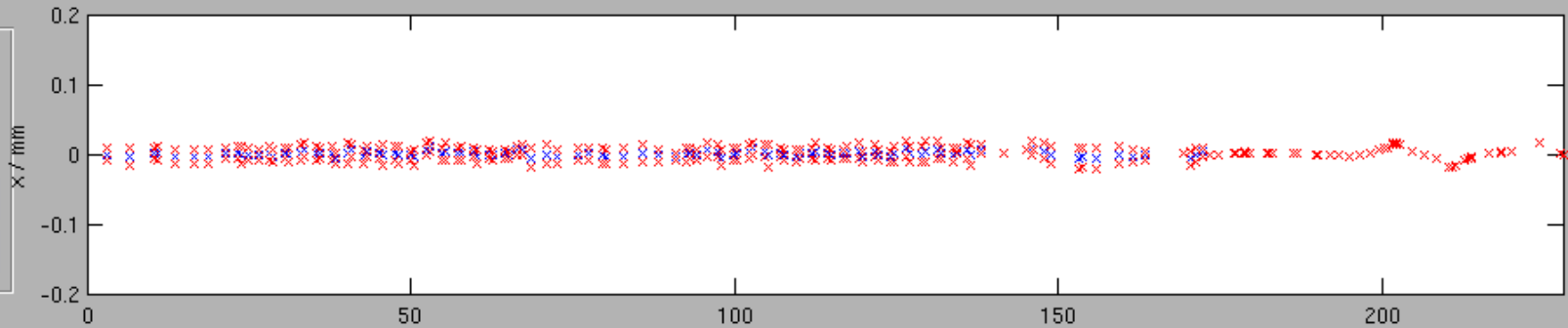
Q Scale

Auto-scale

Manual

Min: 0

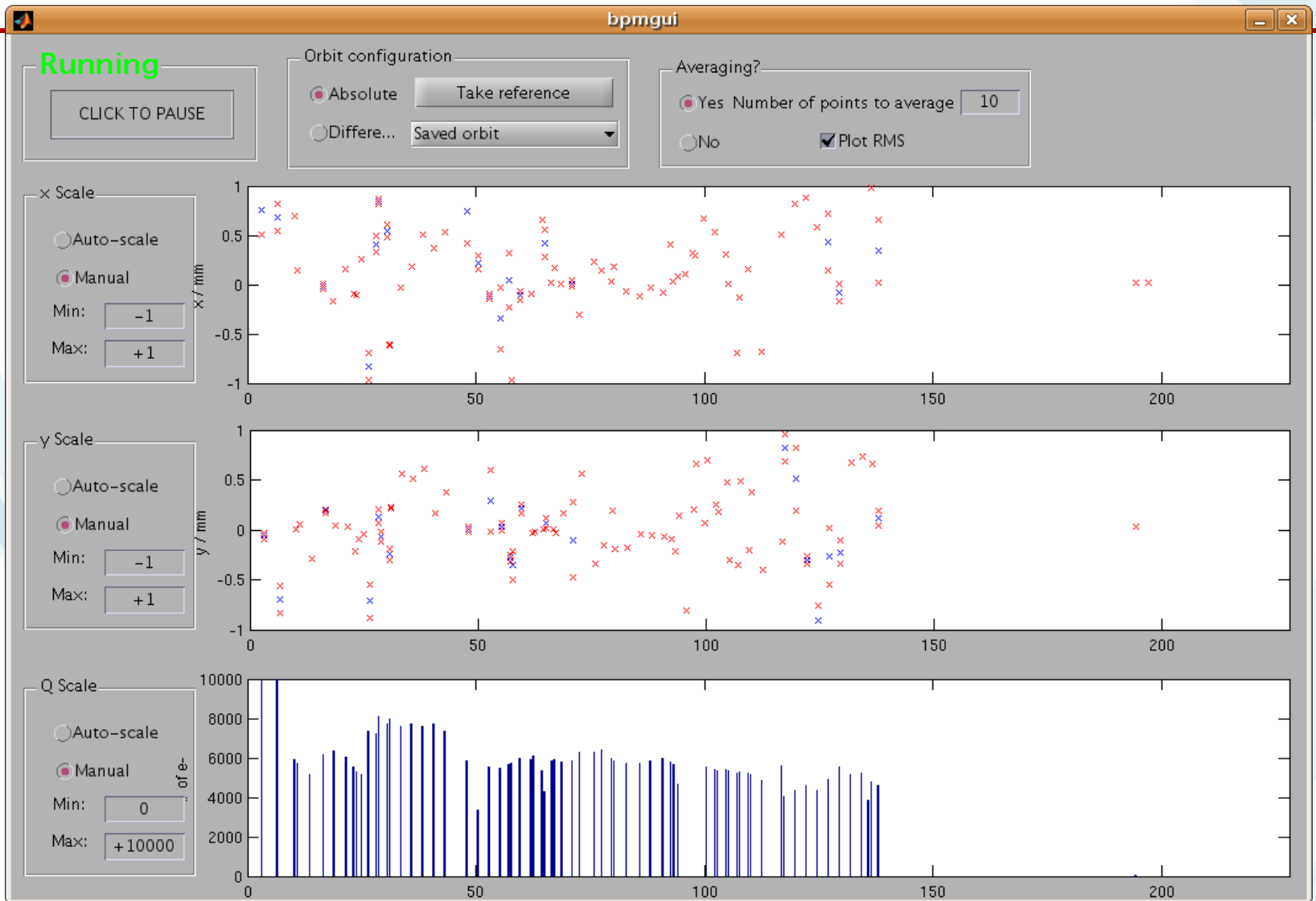
Max: +1.1



BPM Display

- Current functionality
 - Display all BPMS
 - Single-shot, or averaging
 - Mean and rms
 - Absolute or difference to a reference
 - Auto/manual scaling
- Still to do
 - Only plot one region
 - e.g. only FF BPMs
 - Save reference to file
 - Orbit fitting

BPM Display – real beam!



Multibunch beam & uncalibrated BPMs

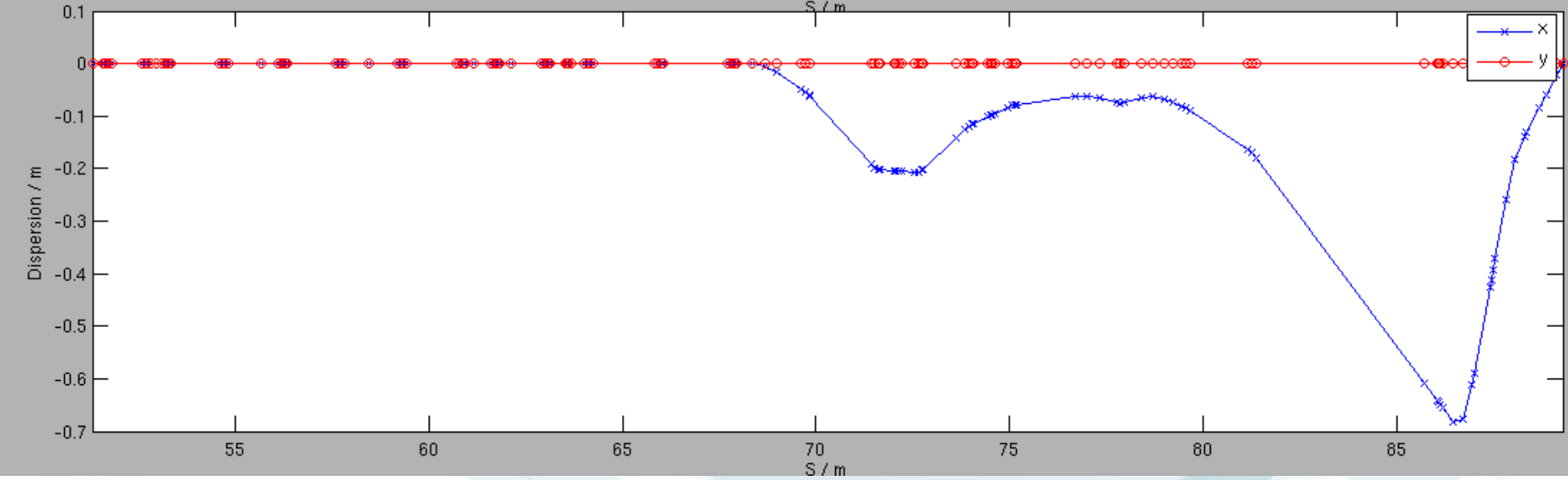
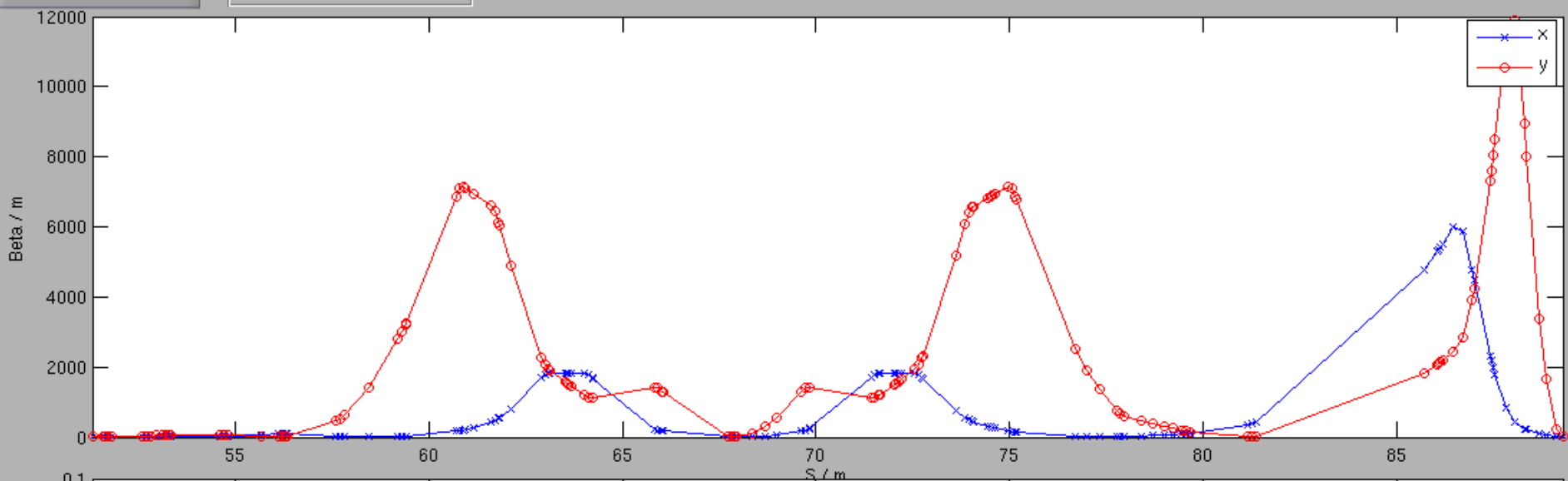
Twiss Calculation (very basic)

Close W

CALCULATE & PLOT

Region

Final Focus only



Twiss Calculation

- Current functionality
 - Calculate and display model Twiss
 - Beta & dispersion (x/y)
 - Choose region
 - EXT, FF, both
- Still to do
 - Measurement
 - Extrapolate from model
 - Try to fit machine errors
 - e.g. quad errors causing mismatch
 - Display alternative twiss
 - e.g. alpha, phase advance.

Bump Generation

Please choose a bump type

3 Corrector (Position OR Angle bump
4 Corrector (Position AND Angle bump

OK

Cancel

Choose the region for the

EXT
FF

OK

Cancel

- Call directly from the command line
- Or, step through a series of dialogue boxes
 - Bump type, location, plane, correctors, etc.
- Makes a Lucretia knob
 - Use directly in FS

Bump in x or y?

x

y

Bump in position or angle?

x

x'

SLAC

Element F Sec Th Fourth corrector

Bump location

- IEX
- KEX1A
- IP01
- KEX1B
- L001
- QM6R
- QM6R
- L002A
- COLL
- L002B
- MB1X
- L002C
- QM7R
- QM7R
- L003
- BS1XA
- ZS1X
- BS1XB
- L004
- BS2XA
- ZS2X
- BS2XB
- L005A
- MB2X
- L005B
- BS3XA
- ZS3X
- BS3XB
- L006A
- OTR1X
- L006B
- ZV 1X
- L006C
- QS1X
- QS1X
- L006D
- QF1X
- QF1X
- L007A
- MQF1X
- L007B
- MS1X
- L007C

Choose

- ZS1X
- ZS2X
- ZS3X
- ZX1X
- ZH1X
- ZH2X
- ZX2X
- ZX3X

Choose

- ZH2X
- ZX2X
- ZX3X

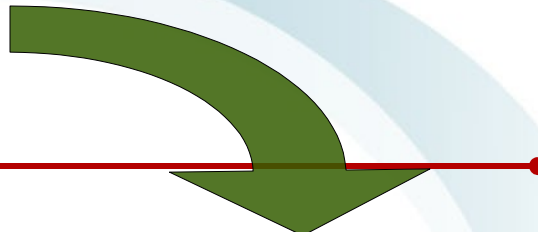
Choose

- ZH3X
- ZH4X
- ZH5X
- ZH6X
- ZH7X
- ZH8X
- ZH9X
- ZH10X
- ZH1FF

Choose the 4th corrector

- ZH4X
- ZH5X
- ZH6X
- ZH7X
- ZH8X
- ZH9X
- ZH10X
- ZH1FF

OK Cancel




Comment

Please enter a comment describing this knob

fourcorrector_xbump

OK Cancel



Save knob file

Save In: savedbumps

- CVS

File Name:

Files of Type: MAT-files (*.mat)

Save Cancel

Bump Generation

- Calculate bump from command-line options, or GUIs
 - Code makes checks on inputs
 - e.g. bump location must be between correctors!
- Generates a Lucretia “knob”
 - A matlab structure containing corrector names, ratios, etc.
 - Can be used with Lucretia functions
 - “*SetMultiKnob*”, “*IncrementMultiKnob*”, & “*RestoreMultiKnob*”

Bump Generation

- Current functionality
 - 3 or 4 correctors
 - Position or angle (x/y)
 - Save to file
 - Command-line function
 - For integration into other apps
 - Correct input verification
- Still to do
 - Assumes non-coupled lattice
 - Useless in strongly coupled regions
 - *Assumes linear transfer matrices*
 - *Sexts are problematic*

Beam-Based Alignment

bpmquad_offsetGUI

CLICK TO RUN

SAVE ALL DATA

LOAD DATASET

Points per scan:

Averages per point:

Quads **Sexts**

QM13FF
QM12FF
QM11FF
QD10BFF
QD10AFF
QF9BFF
QF9AFF
QD8FF
QF7FF
QD6FF
QF5BFF
QF5AFF
QD4BFF
QD4AFF
QF3FF
QD2BFF
QD2AFF
QF1FF
QD0FF

Device

BPM1 = No device
BPM2 = No device
BPM3 = No device
BPM4 = No device

Shunt value: %

Scan Range: +/- mm

Plane: x Plane y Plane

Status: Ready...

Scan type: Use mover if available Always use bumps

Plots

The GUI displays four empty plots for beam-based alignment. The top-left plot shows MQF5AFF vs MQF5BFF. The top-right plot shows MQF5AFF vs MQF5BFF. The bottom-left plot shows MQD4BFF vs MQF5BFF. The bottom-right plot shows MSD4AFF vs MQF5BFF.



Beam-Based Alignment

The screenshot shows the **bpmquad_offsetGUI** window. It features a control panel on the left with buttons for **CLICK TO RUN**, **SAVE ALL DATA**, and **LOAD DATASET**. Below these are input fields for **Points per scan** (set to 5) and **Averages per point** (set to 10). A list of magnet types is shown, with **QF5BFF** selected. The main area contains three empty plots for **MSF5FF**, **MQF5AFF**, and **MSD4FF** versus **MQF5BFF**. A status bar at the top right shows **Ready...** and **Scan type** options.

Start measurement

Data collection options

Type of magnet

Magnet to test

Device

- BPM1 = No device
- BPM2 = No device
- BPM3 = No device
- BPM4 = No device



Beam-Based Alignment

The screenshot shows the **bpmquad_offsetGUI** window. It features a control panel on the left with buttons for **CLICK TO RUN**, **SAVE ALL DATA**, and **LOAD DATASET**. Below these are input fields for **Points per scan** (set to 5) and **Averages per point** (set to 10). A list of devices is shown, with **QF5BFF** selected. The main area contains four plots: **MQF5AFF**, **MQF5BFF**, **MQD4BFF**, and **MSD4AFF**. The top right shows a **Status** field with **Ready...** and **Scan type** options: **Use mover if available** (selected) and **Always use bumps** (unselected). The **Shunt value** is set to 80% and the **Scan Range** is +/- 1 mm. The **Plane** selection is set to **x Plane**.

CLICK TO RUN

SAVE ALL DATA

LOAD DATASET

Points per scan: 5

Averages per point: 10

Quads: QM13FF, QM12FF, QM11FF, QD10FF, QD10AFF, QF9BFF, QF9AFF, QD8FF, QF7FF, QD6FF, **QF5BFF**, QF5AFF, QD4BFF, QD4AFF, QF3FF, QD2BFF, QD2AFF, QF1FF, QD0FF

Device: BPM1 = No device, BPM2 = No device, BPM3 = No device, BPM4 = No device

Shunt value: 80 %

Scan Range: +/- 1 mm

Plane: x Plane, y Plane

Status: Ready...

Scan type: Use mover if available, Always use bumps

Plots: MQF5AFF, MQF5BFF, MQD4BFF, MSD4AFF

Range of beam scan (for bumps)

Status messages

Magnet shunt amount (for quad measurement)

x or y measurement

Force measurement to always use bumps, or use movers if possible



BBA – Quads without movers

- Calculate a 4-corrector bump around the quad
 - Makes use of the bump GUI tool
- Record BPM data at several bump settings
 - At associated BPM, & four closest downstream BPMs
 - Fit straight line through this data
- Shunt the quad, and repeat bump measurement
- Quad centre is at the crossing point of the fits

BBA – Ring quadrupole

bpmquad_offsetGUI

Shunt value: %

Scan Range: +/- mm

Plane: x Plane y Plane

Status: Centre = -12.291 +/- 5.765 um

Scan type: Use mover if available Always use bumps

CLICK TO RUN

SAVE ALL DATA

LOAD DATASET

Points per scan:

Averages per point:

Quads **Sexts**

- QM6R1
- QM7R1
- QM8R1
- QM9R1
- QM10R1
- QM11R1
- QM12R1
- QM13R1
- QM14R1
- QM15R1
- QM16R1
- QM17R1
- QM18R1
- QM19R1
- QM20R1
- QM21R1
- QM22R1
- QM23R1
- QF1R8
- QF2R8

Device

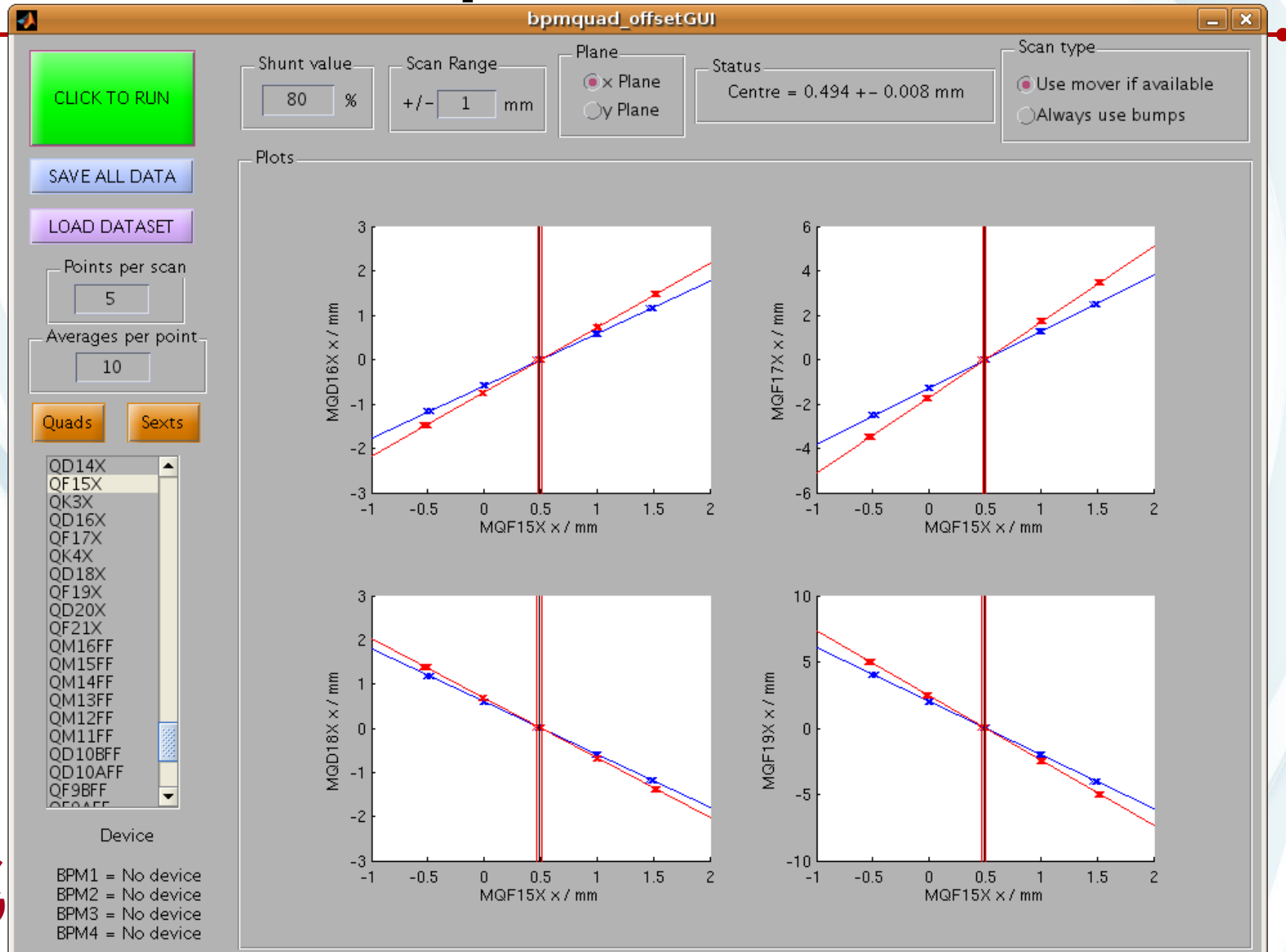
BPM1 = No device
BPM2 = No device
BPM3 = No device
BPM4 = No device

Plots

The plots show the relationship between the horizontal position of the quadrupole (MB28R x / mm) and the vertical position of the beam (MB30R x / mm, MB31R x / mm, MB32R x / mm, and MB33R x / mm). The plots are arranged in a 2x2 grid. Each plot shows a linear fit (red line) and data points (blue stars and red crosses). A vertical red line is drawn at MB28R x / mm = 0.

MB28R x / mm	MB30R x / mm	MB31R x / mm	MB32R x / mm	MB33R x / mm
-0.8	-2.2	-2.8	2.5	1.8
-0.4	-1.0	-1.5	1.2	0.8
0.0	0.0	0.0	0.0	0.0
0.4	1.0	1.5	-1.2	-0.8
0.8	2.2	2.8	-2.5	-1.8

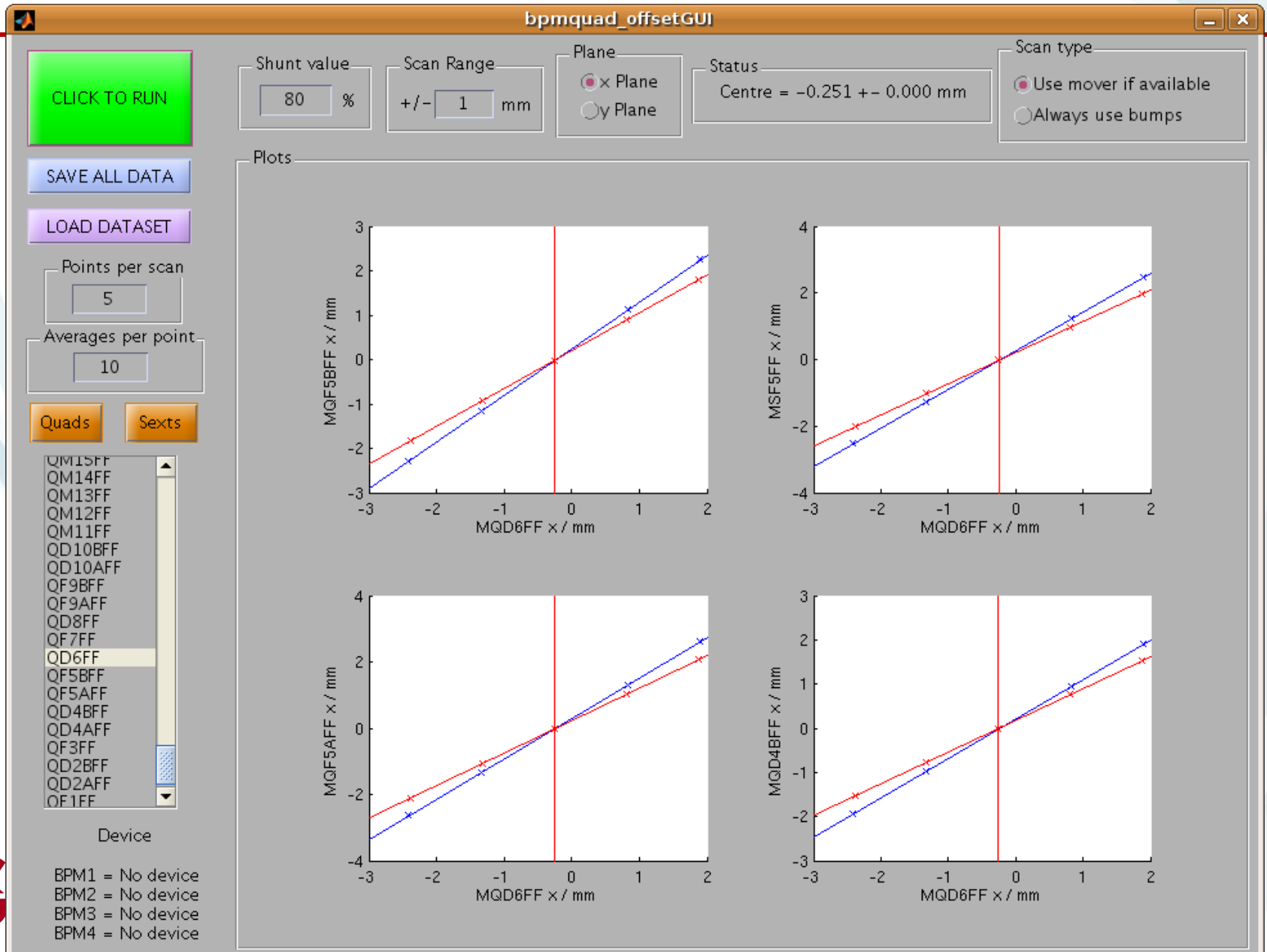
BBA – EXT quad with 0.5 mm error



BBA – Quads with movers

- Quads on movers may be aligned without bumping the beam
 - Step the mover through its max range of motion
 - Calculate the range from the current cam positions
 - Ignore the front panel “Scan Range” field
 - Record BPM data
 - Associated BPM, and next four
 - Shunt the quad, and repeat
- Centre is at crossing point

BBA – FF Quad, -0.25 mm error



BBA – sextupoles

- Only working on FF sexts
 - If necessary I can include ring sexts
 - All on movers, so no need to bump beam
- Step mover through a range of positions
 - Based on number of steps, and max range possible
- Fit parabola to **all** downstream BPMs
 - Find the min (or max) of each
 - Centre is error-weighted mean of these results

BBA – sextupoles

bpmquad_offsetGUI

CLICK TO RUN

SAVE ALL DATA

LOAD DATASET

Points per scan: 7

Averages per point: 10

Quads | Sexts

SF6FF
SF5FF
SD4FF
SF1FF
SD0FF

Device

BPM1 = No device
BPM2 = No device
BPM3 = No device
BPM4 = No device

Shunt value: 80 %

Scan Range: +/- 1 mm

Plane: x Plane, y Plane

Status: Centre = -7.751 +/- 0.019 um

Scan type: Use mover if available, Always use bumps

MSD4FF / mm $\times 10^{-3}$

MQD4AFF / mm

MQF3FF / mm

MQD2BFF / mm

MQD2AFF / mm

MSF1FF / mm

MQF1FF / mm

MSD0FF / mm

M1₂P / mm

Lattice Verification

- Two steps

- Measurement and fitting

1 Measurement

- Tweak each corrector in turn, recording BPMs
 - Close bump if necessary
 - Tweak quad movers to measure FF

2 Fitting

- Calculate difference between predicted and measured response
- Fit quad errors to minimise this difference

Lattice Verification – Measurement

START!

CANCEL

SAVE LOAD

All

All

Correctors

Kick size / mrad

0.1

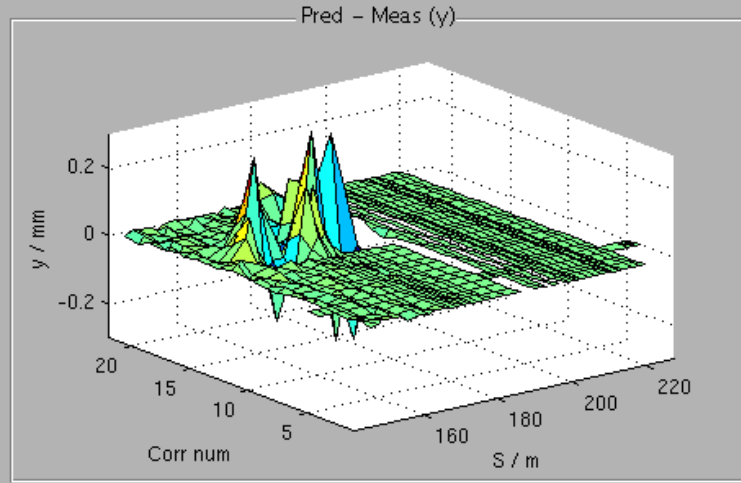
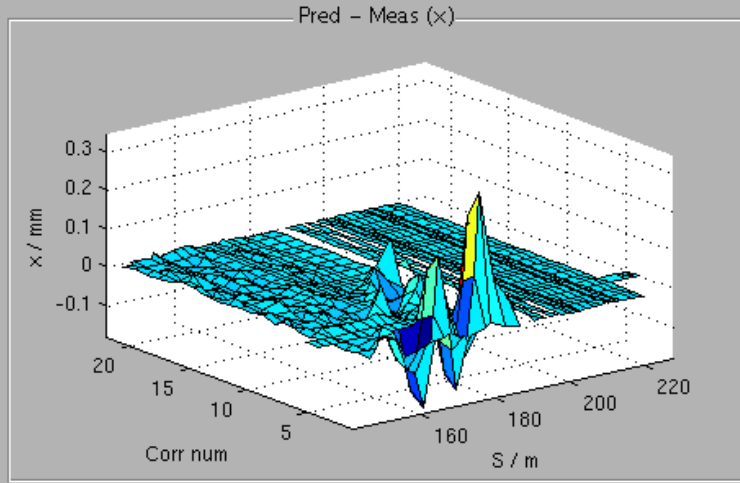
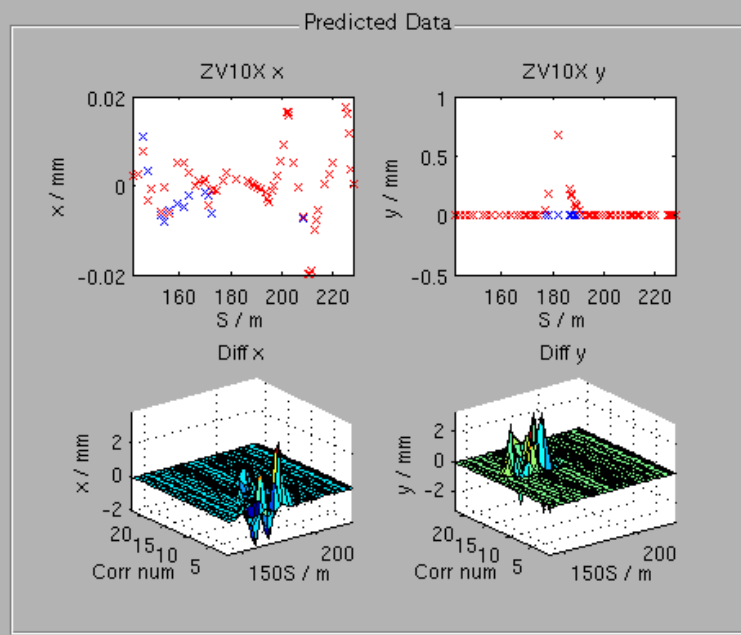
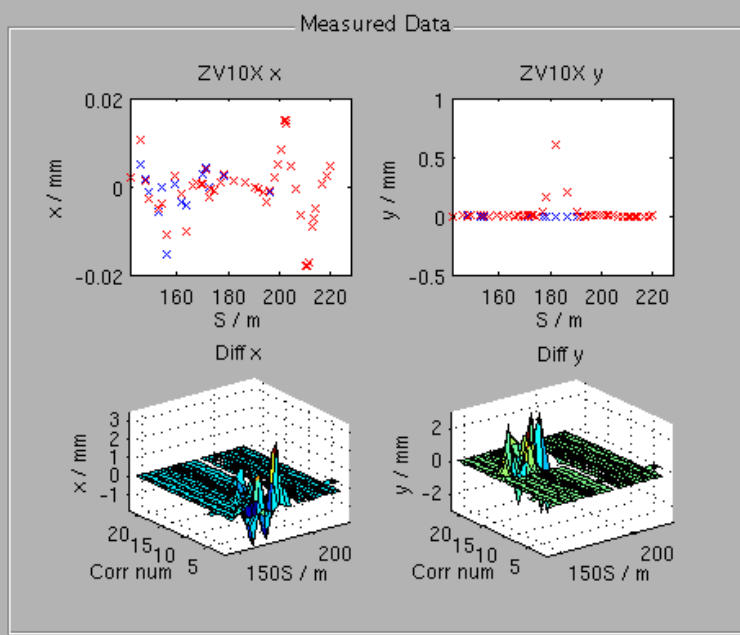
of points to average

10

Devices

- ZH1X
- ZH2X
- ZX2X
- ZX3X
- ZH3X
- ZH4X
- ZH5X
- ZH6X
- ZH7X
- ZH8X
- ZH9X
- ZV 1X
- ZV 2X
- ZV 3X
- ZV 4X
- ZV 5X
- ZV 6X
- ZV 7X
- ZV 8X
- ZV 9X
- ZV 10X

Pop out plots



Lattice Verification – Measurement

The image shows a software interface for lattice verification measurement. The interface includes a control panel on the left with buttons for 'START!' (green), 'CANCEL' (grey), 'SAVE' (purple), and 'LOAD' (blue). Below these are dropdown menus for 'All', 'All', and 'Correctors'. There are input fields for 'Kick size / mrad' (0.1), '# of points to average' (10), and 'Devices'. A list of devices is shown at the bottom left, including ZH1X through ZH9X and ZV1X through ZV10X. A 'Pop out plots' button is at the bottom left.

Five callout boxes highlight specific features:

- Region:** Points to the 'All' dropdown menu.
- Choose devices:** Points to the 'Correctors' dropdown menu.
- Device type (correctors or movers):** Points to the 'Kick size / mrad' input field.
- Perturbation size:** Points to the '# of points to average' input field.
- Number of averages:** Points to the 'Devices' list.

The main area displays 'Measured Data' and 'Predicted Data' for ZV10X x and y. Each data set includes a 2D scatter plot of 'x / mm' vs 'S / m' and 'y / mm' vs 'S / m', and a 3D surface plot of 'Diff x' and 'Diff y' vs 'Corr num' and 'S / m'. The 3D plots show a central peak with a grid of points. The 'Pred - Meas (x)' and 'Pred - Meas (y)' plots show the difference between predicted and measured data, with a 3D surface plot showing a central peak.

Lattice Verification – Measurement

START!

Most recent measurement

All

Correctors

Kick size / mrad

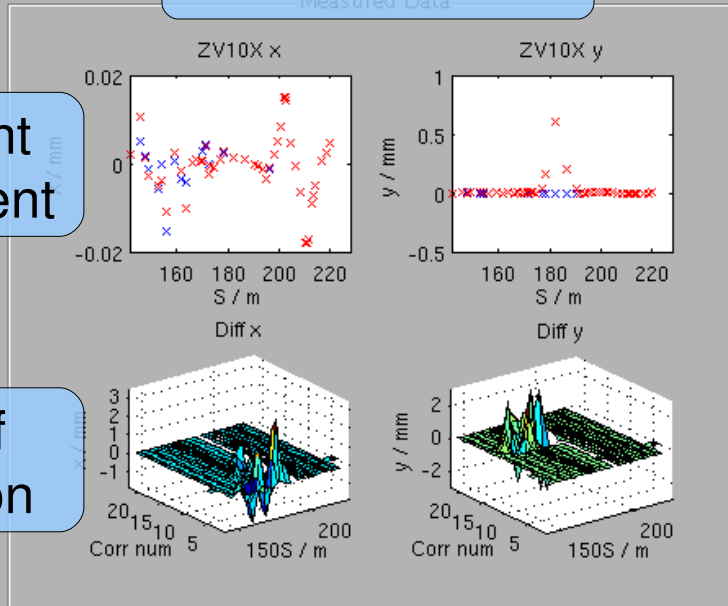
3D plot of perturbation

ZH1X
ZH2X
ZX2X
ZX3X
ZH3X
ZH4X
ZH5X
ZH8X
ZH9X
ZV1X
ZV2X
ZV4X
ZV5X
ZV6X
ZV7X
ZV8X
ZV10X

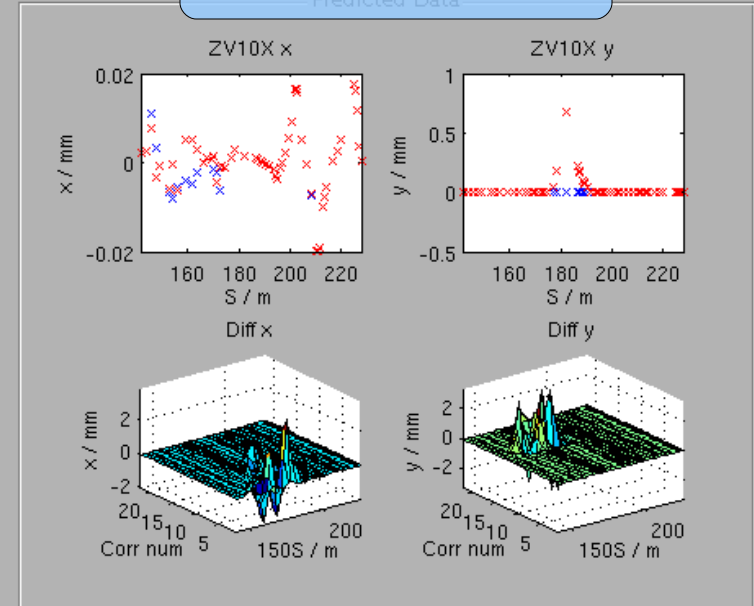
Difference between measured and predicted

Pop out plots

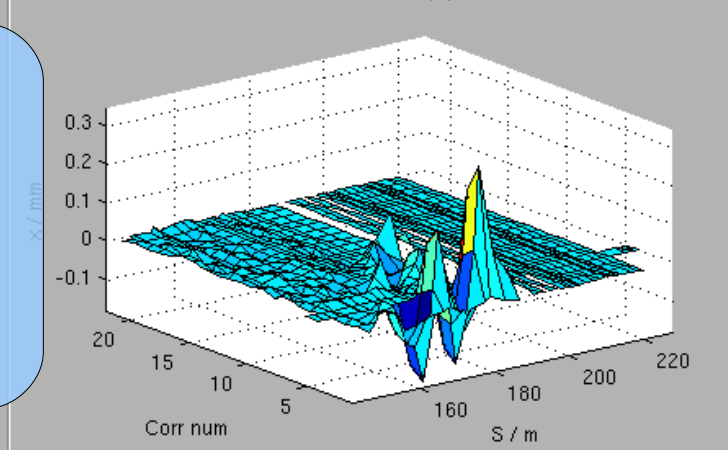
Measured



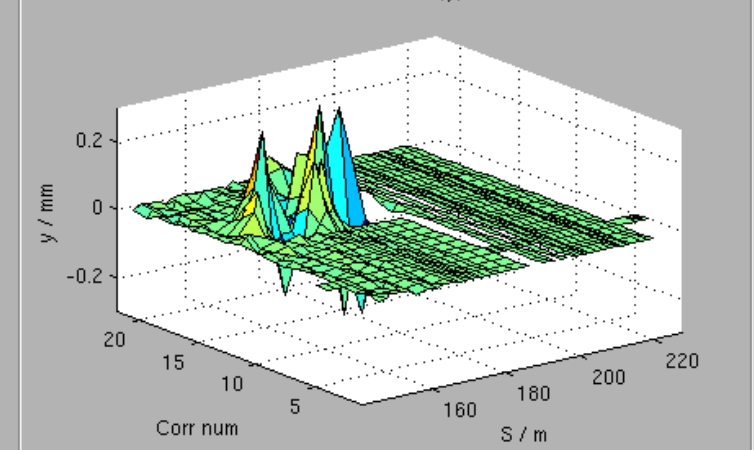
Predicted



Pred - Meas (x)



Pred - Meas (y)



Lattice Verification – Analysis (1st attempt)

$$\begin{pmatrix} \Delta R_{1,2}^{cor1 \rightarrow bpm1} \\ \Delta R_{1,2}^{cor1 \rightarrow bpm2} \\ \Delta R_{1,2}^{cor1 \rightarrow bpm3} \\ \Delta R_{1,2}^{cor2 \rightarrow bpm1} \\ \Delta R_{1,2}^{cor2 \rightarrow bpm2} \\ \Delta R_{1,2}^{cor2 \rightarrow bpm3} \end{pmatrix} = M \cdot \begin{pmatrix} \Delta B^{quad1} \\ \Delta B^{quad2} \\ \Delta B^{quad3} \end{pmatrix}$$

Lattice Verification – Analysis (1st attempt)

$$\Delta R_{1,2}^{cor1 \rightarrow bpm1}$$

$$\Delta R_{1,2}^{cor1 \rightarrow bpm2}$$

$$\Delta R_{1,2}^{cor1 \rightarrow bpm3}$$

$$\Delta R_{1,2}^{cor2 \rightarrow bpm1}$$

$$\Delta R_{1,2}^{cor2 \rightarrow bpm2}$$

$$\Delta R_{1,2}^{cor2 \rightarrow bpm3}$$

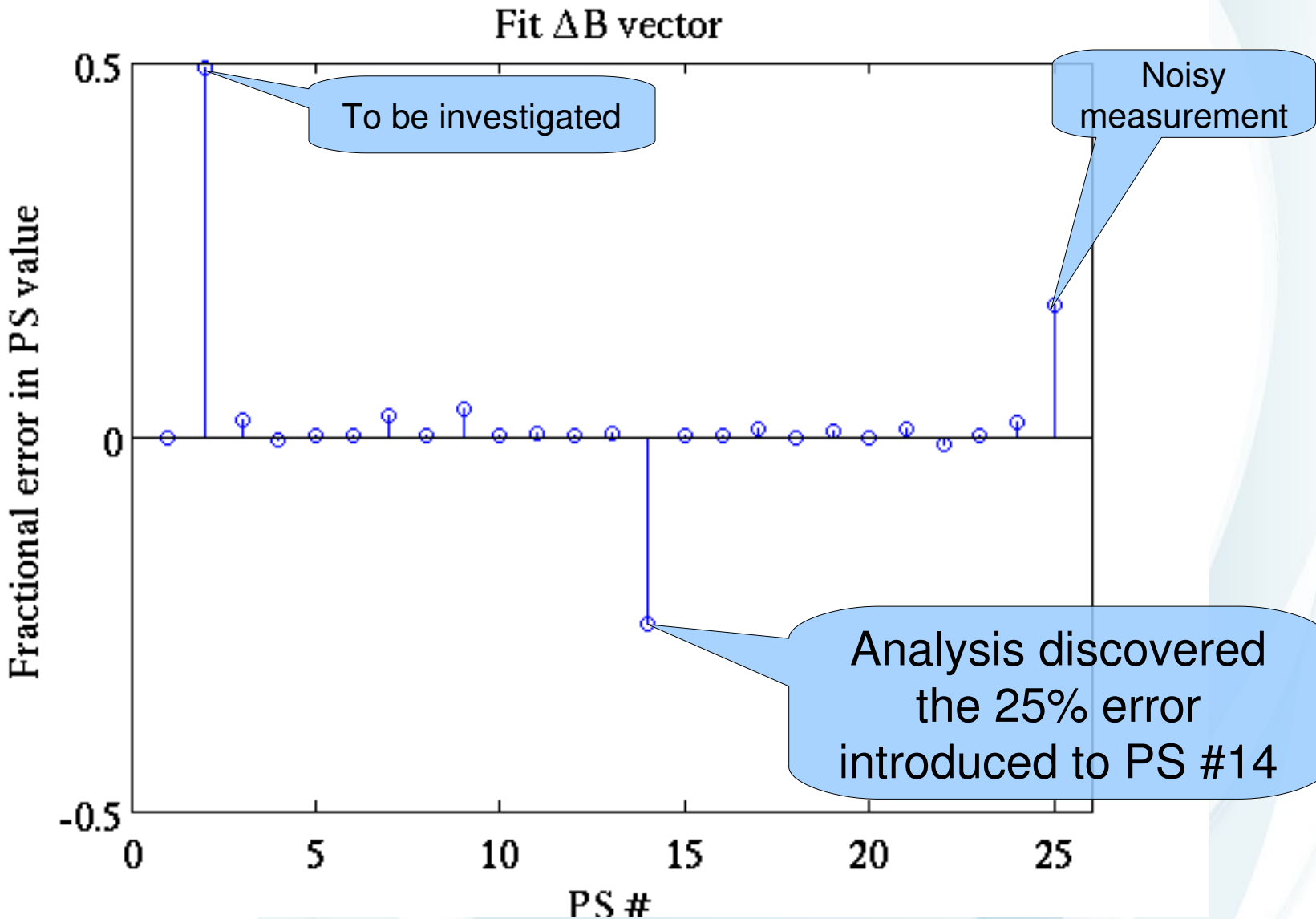
Calculated from
model (Lucretia)

$$= M \cdot \begin{pmatrix} \Delta B^{quad1} \\ \Delta B^{quad2} \\ \Delta B^{quad3} \end{pmatrix}$$

Measured (from GUI)
minus predicted (from
model)

Fit to minimise
magnitude of ΔR vector

Simulated results (preliminary)



Lattice Verification

- Current functionality
 - Tweak correctors or movers to measure orbit distortion
 - Close bumps if necessary
 - Fit to fractional quad PS error
- Still to do
 - Extra corrector/mover steps to investigate higher-order fields
 - Sextupoles, multipole distortions
 - Additional fit parameters
 - Quad tilts, bends, sexts, etc.

Summary (1/3)

- Several tools developed
 - Included in base installation of Flight Simulator
 - Tested in simulation
 - Beam tests tomorrow!
- 1 **BPM display**
 - Absolute/difference, single-shot/averaging, etc.
- 2 **Twiss display**
 - Predicted, comparison with measurement
- 3 **Bump calculation**
 - Linear, non-coupled, bump generation.
 - GUI or command-line operation

Summary (2/3)

4 Beam-based alignment

- With corrector bumps
 - Bump around quad, shunt quad, then bump again
 - Centre is crossing point of these lines
- With movers
 - For quads, same method as above, but with quad moves instead of bumps
 - For sexts, scan with mover, and fit to parabola. (Shunting is unnecessary.)

5 Lattice verification

- Measure orbit distortion due to corrector tweaks or quad moves
- Fit to quad strengths to determine any errors
- Additional fit parameters, constraints, can be added

Summary (3/3)

- All tools made available to FS as soon as possible
 - Even if functionality is limited
 - I try to avoid uploading broken code!
 - I hope others can make use of these tools
- Interested in hearing ideas:
 - Other tools?
 - Extension of these tools?
 - ...
 - Email me (smolloy@slac.stanford.edu) with ideas!