

## Online orbit fit at RHIC - A tutorial

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# **ONLINE ORBIT FIT AT RHIC – A Tutorial**

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# ONLINE ORBIT FIT AT RHIC – A TUTORIAL

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## OVERVIEW

The OnlineOrbitFit algorithm is based on the concept (unpublished) by Paul Emma (SLAC) which was re-derived and encoded into RhicOrbitDisplay [1] by Chuyu Liu [2]. The algorithm has numerous applications including localization of errors in the beam trajectory or in the beam optics model. Examples are given in this report.

## HOW THE ALGORITHM WORKS

The formalism for the online fitting algorithm is described in Ref. [2]. In essence, the online model is used to fit a measured orbit trajectory. For a given plane (cross-plane coupling is neglected), the set of initial coordinates (position and angle), which results in best agreement between the orbit calculated with these initial conditions and the measured orbit, is determined using a least-squares minimization algorithm. The “fit orbit” interface in RhicOrbitDisplay allows selection of a fit range of interest. In RhicOrbitDisplay the raw data and the fitted orbit may be viewed. The fitted orbit shows the orbit calculated over the specified fit range and propagated around the entire RHIC circumference.

## ERROR LOCALIZATION

These data analysis techniques (applied in the examples given next) are helpful in localizing an error:

- A. Establishing good viewing conditions for the raw data when applicable.
- B. Selecting a limited fit range of interest (required since the interaction regions evidence multiple error sources).
- C. Establishing good viewing conditions for the results by plotting the difference of measured and fitted orbits.
- D. Double-checking a suspect error location using both forward-propagated solutions (error is downstream of fit region) and backward-propagated solutions (error is upstream of fit region).

## EXAMPLE 1: ERROR IN BEAM TRAJECTORIES - D0 MAGNET OSCILLATIONS

In this example from early commissioning of the E-Lens optic<sup>1</sup>, unstable Yellow beam conditions were first detected<sup>2</sup> as complications with the 10 Hz feedback system. The regularly monitored rms orbits (OrbStatBlue.logreq, OrbStatYellow.logreq), shown in Fig. 1, also evidenced abnormal conditions - in this case fluctuations in the Yellow beam horizontal rms (Figs. 1b, 1d).

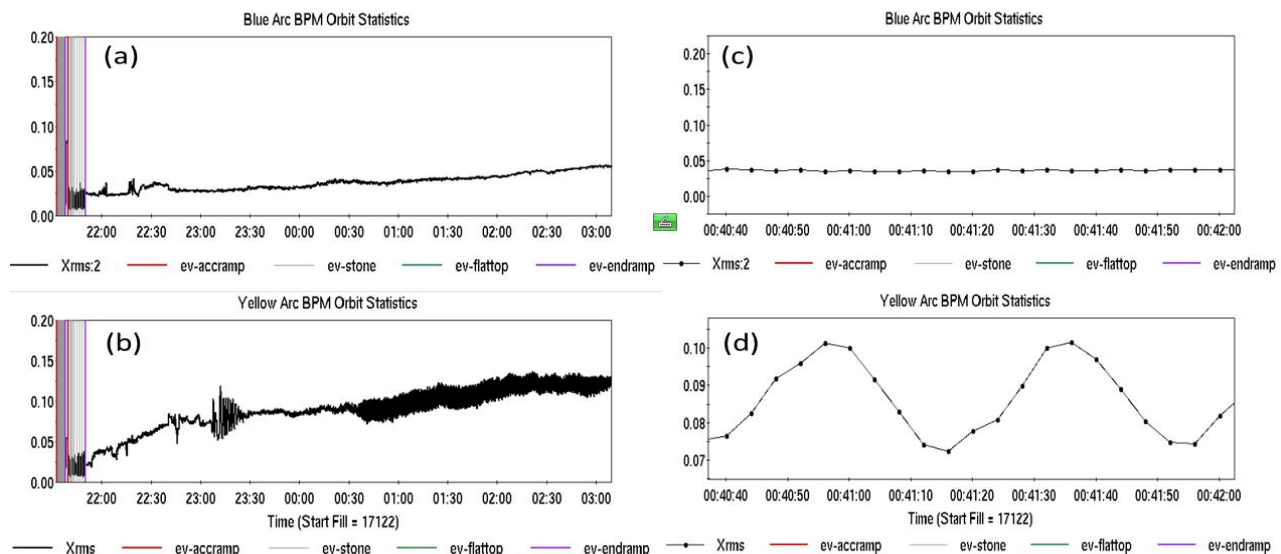


Figure 1: Blue and Yellow ring horizontal rms orbits during store (a,b) with expanded view (c,d).

<sup>1</sup> Fill 17122 (02/27/13).

<sup>2</sup> [http://www.cadops.bnl.gov/cgi-bin/elog/viewMain.pl?elog=rhic-pp\\_2013&shiftlog=Wed\\_Feb\\_27\\_2013\\_16:41:58\\_PM#20130127231043](http://www.cadops.bnl.gov/cgi-bin/elog/viewMain.pl?elog=rhic-pp_2013&shiftlog=Wed_Feb_27_2013_16:41:58_PM#20130127231043)

## (A) ESTABLISHING GOOD VIEWING CONDITIONS FOR THE RAW DATA

In RhicOrbitDisplay, the Yellow beam orbits corresponding to maximum position deviations in Fig. 1 were uploaded as shown in Fig. 2 (left). For good viewing conditions of the raw data, the trajectory to be fitted was formed by taking the difference between these two orbits. To do this:

- 1) From the pulldown menu, select File → Load Orbit → select the fill number 17122.
- 2) Load the orbits corresponding to the desired times (for example, 00:41:00 and 00:41:16, reference Fig. 1).
- 3) From the pulldown menu, select Orbit → Create Difference Orbit and select the two orbits of interest.
- 4) For the display, deselect the raw orbits (change the + to – in the small box before the orbit number listed in the Name column), then zoom in to provide a good view of the desired difference orbit, as shown in Fig. 2 (right).

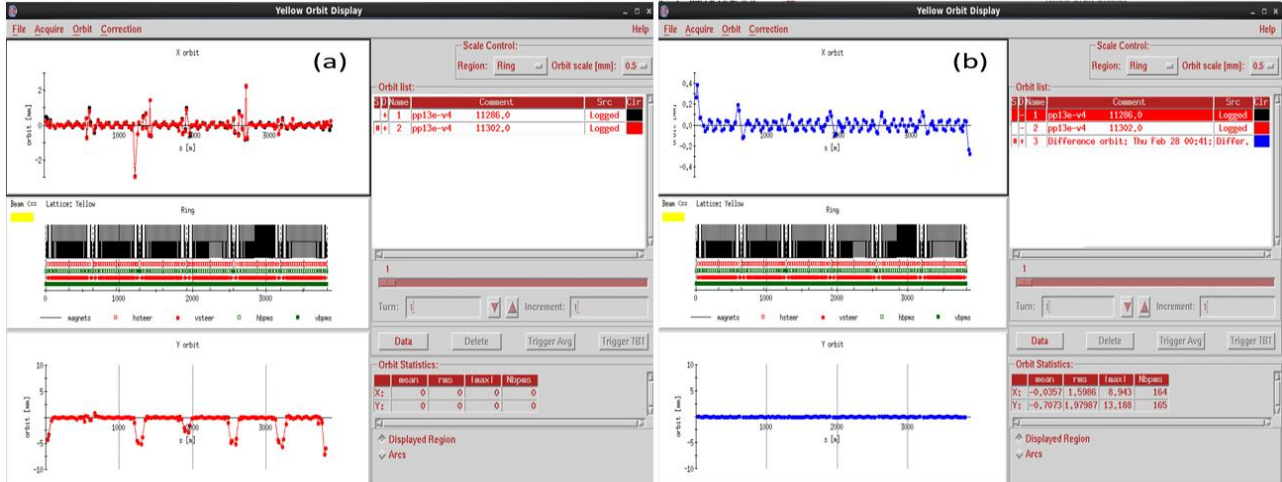


Figure 2: Measured Yellow ring orbits – two raw orbits (a) and difference between those orbits (b).

## (B) FITTING THE ORBIT WITH A LIMITED FIT RANGE

With good viewing conditions of the raw data now established, a fit range of interest is to be selected next. Since the predictive power of the online model compared to data is quite excellent in the RHIC arcs, experience has shown that a fit region in the arcs spanning 300 meters (3-4 betatron oscillations) works well. After determining a suitable fit range, apply OnlineOrbitFit. To do so:

- 1) Determine the fit range of interest by zooming into an arc region. If a location of perturbation is suspect, select an adjacent arc (an example is shown in Fig. 3a for which the 9 o'clock region was selected, being close to the suspect new E-Lens magnets). A fit range is good if a realistic sinusoidally varying oscillation is observed.
- 2) To apply OnlineOrbitFit, first highlight the orbit of interest (shown highlighted in Fig. 3a). Under the Orbit pulldown menu, select “Fit Orbit” (see Fig. 3b).

The procedure to follow next depends on whether the analysis is real-time (meaning that the loaded machine optics match those presently on the accelerator) or whether the analysis uses past data, as is the case here.

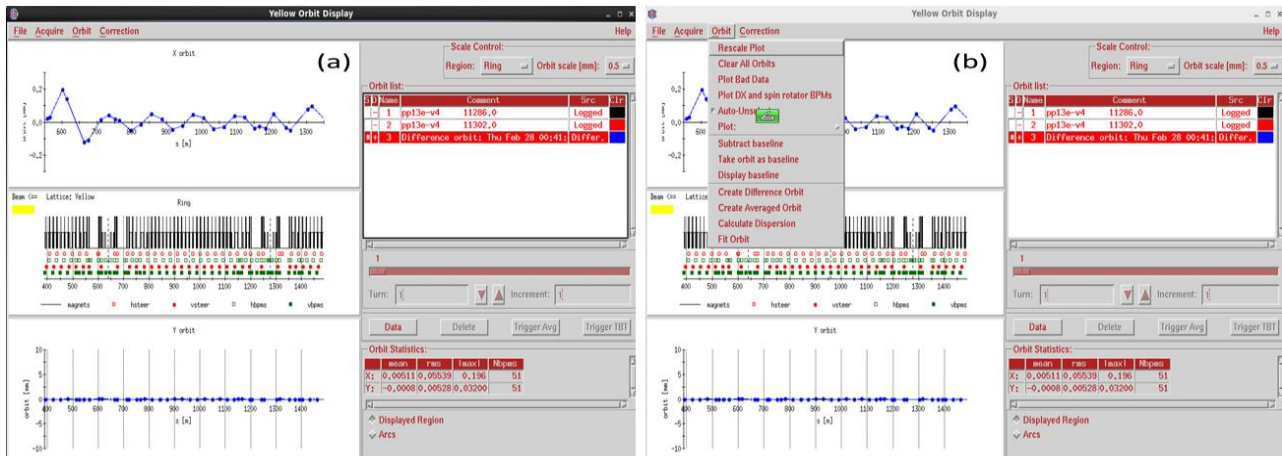


Figure 3: Selecting the fit range (a) and accessing OnlineOrbitFit (b).

If applied real-time (the easy case): In the “Blue/Yellow Ring Fit Window” that appears (Fig. 4):

- 3a) Select: Load highlighted.
- 3b) Select: Get Data.



Figure 4: OnlineOrbitFit interface for real-time analysis.

If applied for data acquired previously: In this case the optics corresponding to the time of the data acquisition needs to be specified. In the “Blue/Yellow Ring Fit Window” that appears (Fig. 5):

- 3a) Select: Load highlighted.
- 3b) Select: Specified Stone in “Get corrector data from”.
- 3c) Specify Ramp name<sup>3</sup> (in this example pp13e-v4).
- 3d) Specify StepStone as determined from RampEditor<sup>4</sup> (in this example, 30 corresponding to store energy).
- 3e) Select Get Data.

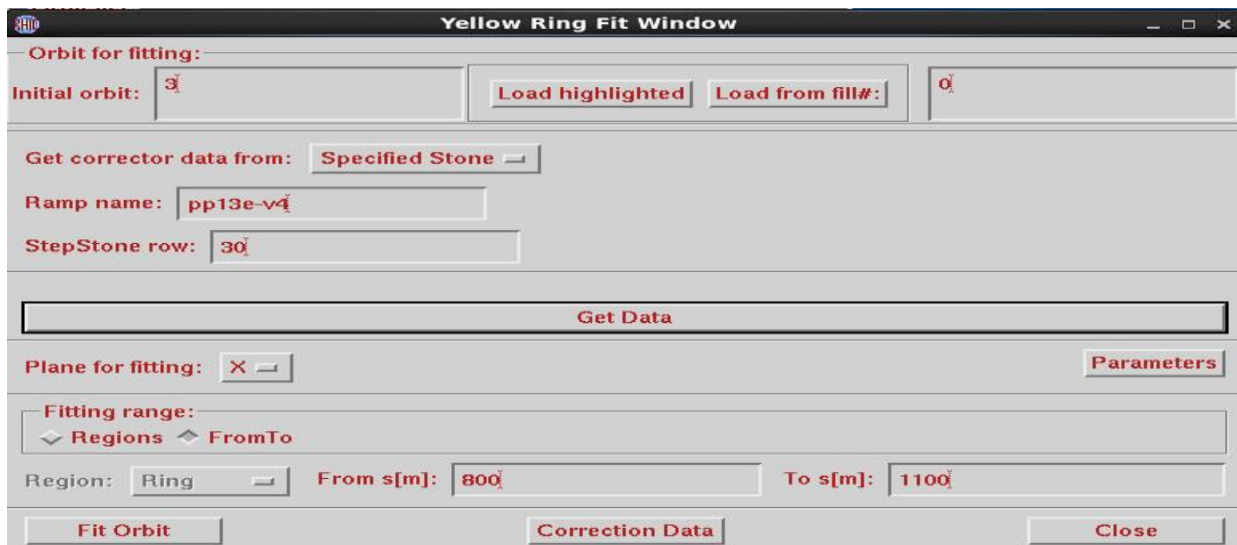


Figure 5: OnlineOrbitFit interface for analysis when ramp and beam energy do not match conditions used for orbit to be analyzed.

<sup>3</sup> The optics file name for times other than the present may be found as recorded in the Instrumentation Wiki at the top link under the “Machine Development and APEX Sessions – Run XX” link, where XX represents the year of interest; e.g. in this example, here: [http://www.cadops.bnl.gov/Instrumentation/InstWiki/index.php/Machine\\_Development\\_and\\_APEX\\_Run-13#Proton\\_Run\\_28optics.2C\\_planning\\_and\\_summary\\_reports.29](http://www.cadops.bnl.gov/Instrumentation/InstWiki/index.php/Machine_Development_and_APEX_Run-13#Proton_Run_28optics.2C_planning_and_summary_reports.29)

<sup>4</sup> The number of the StepStone at store energy may be found from RampEditor by selecting the optic file name (pp13e-v4 in this example) in the “Ramp” pulldown menu (upper left).

The correct optics are now, in either of the above two scenarios, loaded. For the fitting procedure, next:

- 4) Select: Plane for fitting, X in this case (X=horizontal or Y=vertical).
- 5) Select: Fitting range “FromTo”.
- 6) Specify Fitting range: fit range, enter “from s[m]” 800, enter “to s[m]” 1100 (reference Fig. 3).
- 7) Select: Fit Orbit.
- 8) View the result: return to the main RhicOrbitDisplay application. The result is shown in Fig. 6a. Using the usual “zoom all data points” option, the result will appear as shown in Fig. 6b.

OnlineOrbitFit calculates the best set of initial conditions (position and angle) that produces a calculated orbit that best matches the data over the fit range specified. The so-found solution is then propagated both forwards and backwards around the entire RHIC circumference.

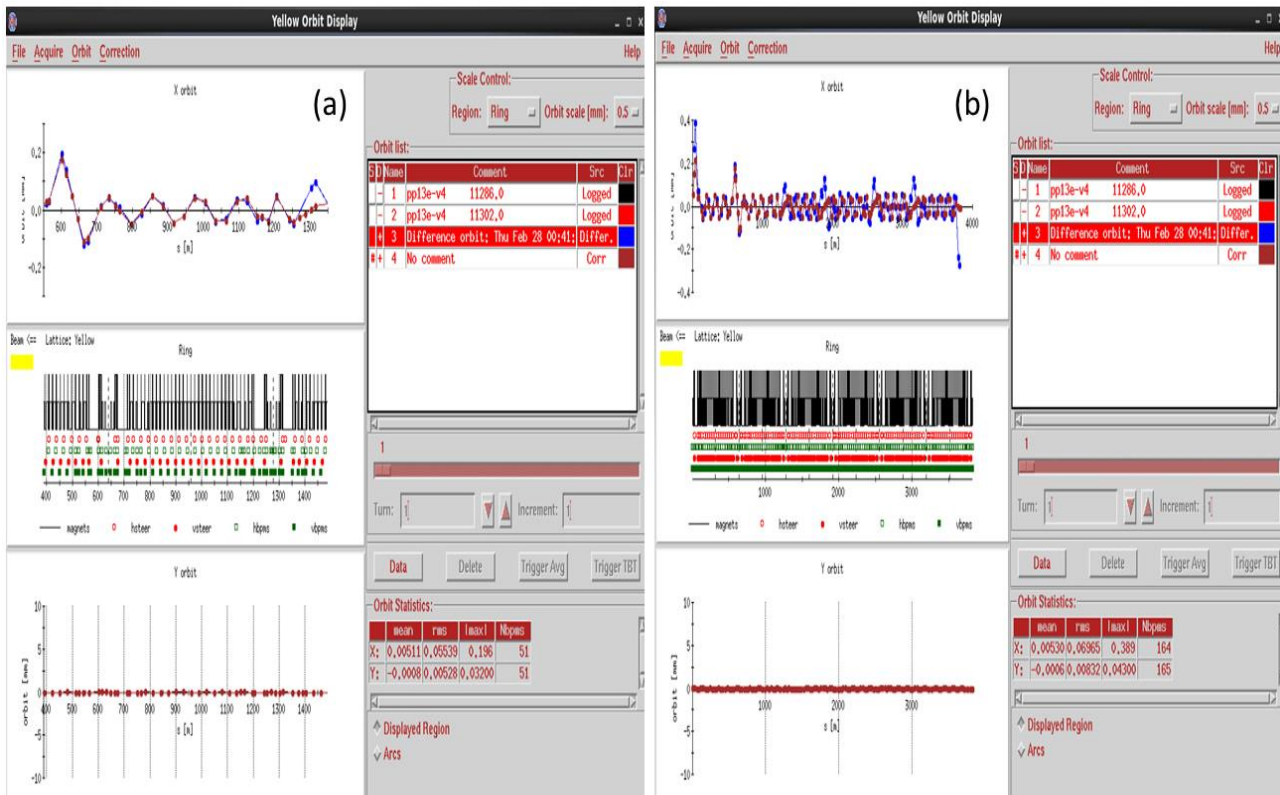


Figure 6: Measured difference orbit and fitted difference orbit around specified fit range (a), measured difference orbit viewed over entire RHIC circumference and fitted orbit with solution propagated both forward and backward along entire circumference.

### (C) ESTABLISHING GOOD VIEWING CONDITIONS OF THE RESULTS

To pinpoint the location of the error, establish good viewing conditions by displaying the difference between the orbit that was fitted (in this example, orbit #3 in the namelist) and the fitted orbit (orbit #4). To do so:

- 1) As before, from the pulldown menus, select Orbit → Create Difference Orbit, then select the two orbits of interest.
- 2) Deselect these two orbits from the view so that only the final difference orbit is displayed, as shown in Fig. 7a.
- 3) As shown in Fig. 7b zoom into the region which localizes the region where the data and model disagree.

The error is seen to be localized in the region somewhere close to the 10 o’clock interaction point suspiciously close to, but definitely upstream, of the location<sup>5</sup> of the E-lens. (The coordinates of the ends of the Blue E-Lens solenoid are 1273.7 and 1275.6 m.)

<sup>5</sup> The location of E-lens devices may be found by typing at the command line: names\_ascii - b | grep elens (or with -y, in place of -b, for the Yellow Ring).

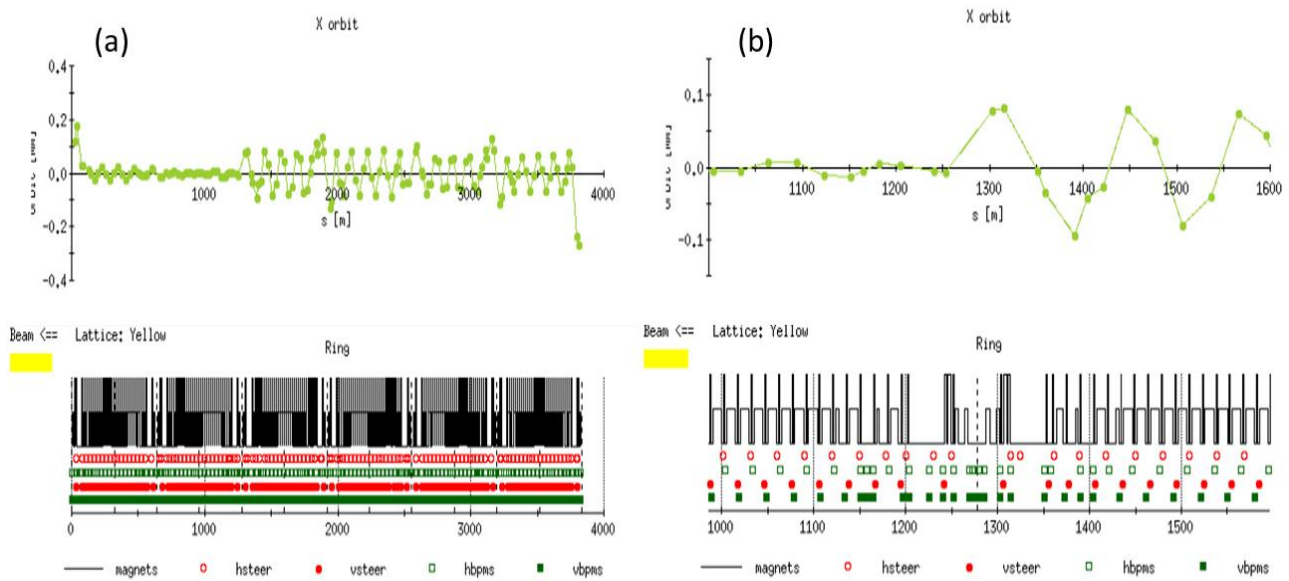


Figure 7: Result plotted along entire ring circumference (a) and with expanded view (b).

In this case where the error is seen to be close to the interaction region, the location of the error may be localized further by enabling use of the DX BPMs in the RhicOrbitDisplay application by selecting under the Orbit pulldown menu the “plot DX and spin rotator BPMs” option. Repeating the above process produces the result shown in Fig. 8a (to be compared with Fig. 7b). The error is now pinpointed to being located between about 1250-1270 m.

*(D) DOUBLE-CHECKING SUSPECT ERROR LOCATION*

In the example above, the fit range was selected to be 800-1100 meters and the fitted orbit was propagated around the entire ring. The error was seen to be in the region downstream of the fit range by means of the forward-propagated solution. This location can be double-checked by performing the fit over a different range downstream of the suspected error location. The results of this, together with the zoomed in, now backward-propagated solution, is shown in Fig. 8b. For the backward-propagated solution a fit range of 1500-1800 m was selected. Fig. 8c shows an overlay of the forward and backward propagated orbits. The location of the error was confirmed to be between 1250-1270 m (in the region between two consecutive beam position monitors). The source of the error, as confirmed also using pscompare, was oscillations in the D0 magnet located at ~1255m.

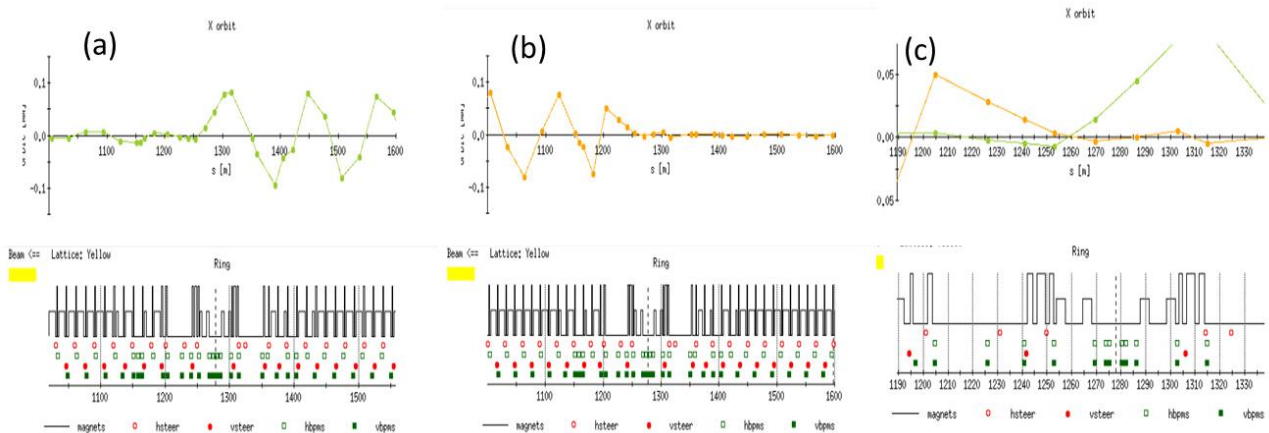


Figure 8: Localization of beam transport error using forward-propagated solution (a), backward-propagated solution (b) and both solutions together (c).



## EXAMPLE: ERROR IN BEAM OPTICAL MODEL DUE TO SIBERIAN SNAKES

This example illustrates a model-to-reality error due in this case to an imperfect optical model. The results, from the blue ring with polarized protons at injection energy, are given in Fig. 9. In this case<sup>6</sup>, orbit distortions were intentionally applied during post-shutdown startup to check for beam position monitor polarity and/or gain errors. There were no errors detected however OnlineOrbitFit showed a much larger error. Using the methodology presented previously, error localization revealed the sources of discrepancies to be due to the presence of the Siberian snakes (with optics not included in the online RHIC optical model).

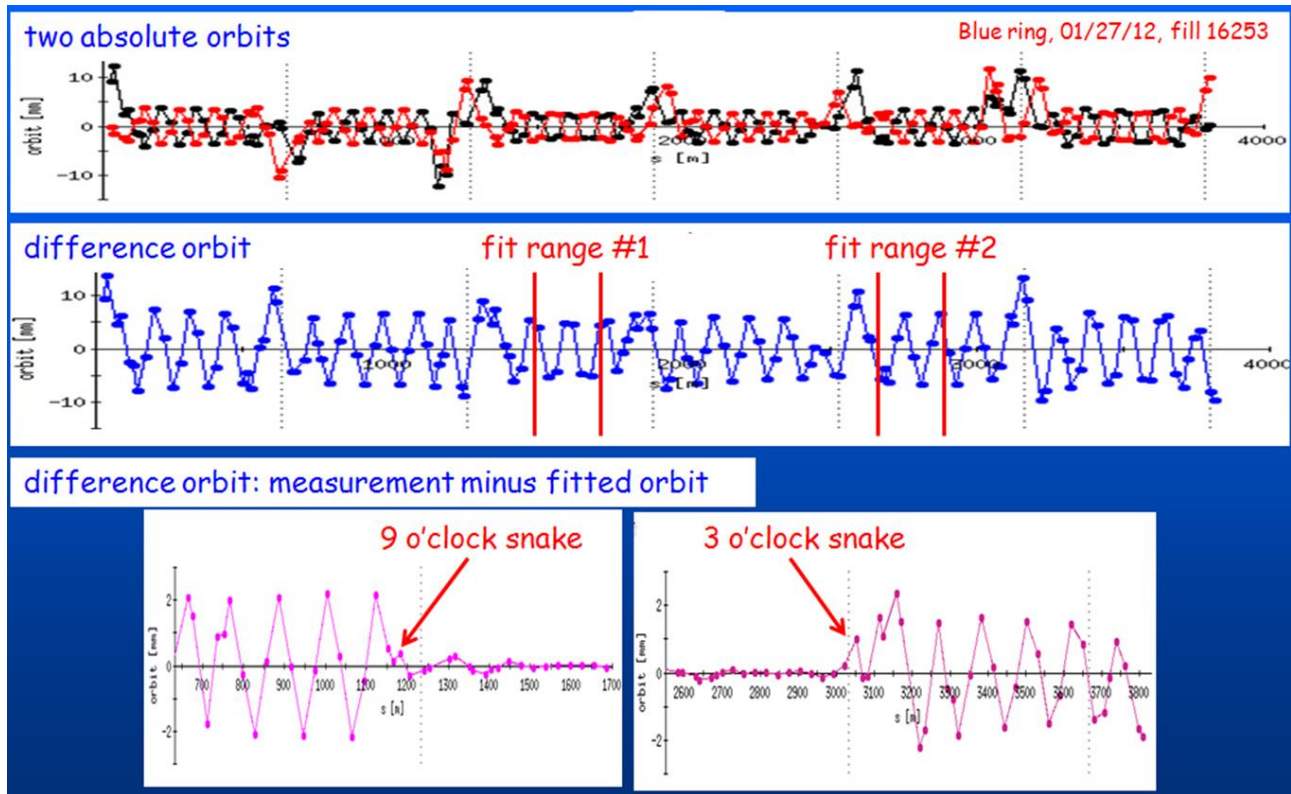


Figure 9: OnlineOrbitFit application revealing model-to-reality errors in the presence of the Siberian snakes.

## SUMMARY

Two applications of OnlineOrbitFit [2] were presented in tutorial fashion. The first demonstrated localization of a beam trajectory error due to component misbehaviour. The second evidenced deficiencies in the online optical model. This report was written to hopefully educate on the utility of this new feature as suspected to be applicable in the future to help diagnose possible anomalies which could conceivably arise due to influences, not known to the RHIC control system, arising for example from stray fields from new, nominally decoupled installations.

## ACKNOWLEDGEMENTS

The concept was developed by P. Emma (SLAC) and encoded into V. Ptitsyn's RhicOrbitDisplay [1] by C. Liu [2]. Concerning this tutorial, D. Maffei's initial interest in this application's capabilities and valuable review of this report are very much appreciated.

## REFERENCES

1. RhicOrbitDisplay, by V. Ptitsyn with enhancements by C. Liu, N. Malitsky, A. Marusic and T. Satogata.
2. [An orbit fit program for localizing errors in RHIC](#), C. Liu, M. Minty, V. Ptitsyn, C-A/AP/#440 (10/2011).

<sup>6</sup> Fill 16253 (01/27/12).