BNL-211217-2019-TECH

NSLSII-ASD-TN-285

BPM Offset of NSLS-II Storage Ring Based on BBA Measurement

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September 2018

Photon Sciences

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC), Basic Energy Sciences (BES) (SC-22)

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NSLS II TECHNICAL NOTE BROOKHAVEN NATIONAL LABORATORY	NUMBER NSLSII-ASD-TN-285
AUTHOR Jinhyuk Choi	DATE 09/28/2018
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Introduction

Beam based alignment (BBA) is the final calibration of the Beam position monitor (BPM) readings based on the quadrupole centers and it becomes essential process for the modern synchrotron light sources. For the convenient BBA implementation, usually BPMs are placed close to the quadrupoles and the beam is adjusted to pass the center of the quadrupoles. Therefore, measured BPM BBAs are, in fact, the BPM offsets relative to the quadrupole centers, and by observing their variations, we can estimate the relative movements of the BPMs.

In NSLS-II, the BPM BBAs are measured whenever the beam-time allows and the variations are being observed. However, because changing BBAs in the BPM readings has direct and significant impact on the machine operation as well as the user experiments, they are not applied instantly. Instead, in NSLS-II, the official BBA values are managed by the snapshot archiving and retrieving system, called MASAR (MAchine Snapshot Archiving and Retrieve) [?], so that they are well organized and can be easily set to any stored set of BBAs values.

NSLS-II is implementing MASAR as a part of EPICS control system for the convenient and mistake-free machine operation. Each snapshot is a group of key-value pairs where keys are EPICS Process Variables (PVs). The snapshots are organized by configurations where each configuration has specific PV sets. And each configuration saves snapshots with titles corresponding their purposes such as normal user operations or specific beam studies. Anyone with control system account can save snapshots and they can be restored whenever needed.

One of the configurations is “SR_BPM_BBAS" and the configuration includes the set of EPICS PVs for the storage ring BPM BBA values. This configuration also includes the BBAs of the in the straight sections, called ID (insertion device) BPMs playing important roles in user experiments. The ID BPM BBAs are also directly engaged in the active interlock (AI) machine protection system[?], which prevents the mechanical damage from the ID radiation. However, in estimating ID BPM BBAs, because there is no quadrupoles around them, interpolations from the surrounding sector BPM BBAs are used.

This note focusses on the BPM offset variations based on the BBA measurement data and does not discuss about the ID BPM BBAs because they are not the direct measures of the offsets.

The plots of all the available BBA measurement data and their variations can be found are shown in the Appendix. As can be seen in the plots, some BPMs are showing significant variations in the offsets of ~ 0.1 mm order and even $\sim$ mm order.

First of all, the measurement itself can have reliability issues. As we measure the BBAs, the linear fittings of all 180 BPMs are used and, in many cases, they are inconsistent and have big error bars. In addition to the big error bars, some of the BBA measurements have repeatability issues. As mentioned, the gaps between the BBA measurements are months at least, and it is not easy to track down the causes of the unreasonable differences.

On the other hand, there are also many reliable datasets showing consistent variations. One could argue that the variations are coming from the real mechanical movements from the quadrupole centers. However, during the period when the BBAs are actively measured, the survey measurements do not show any variation. In fact, the BPM survey data are far more limited. First of all, the storage ring survey process is quite complicated and cannot be produce the data as frequently as BBA measurements. Furthermore, BPMs do not have their own fiducial points and they are assumed to be moving together with the chamber and the assumption is not unreasonable. Still, the BBA variations are too big to say that the major contributions are coming from the mechanical movements.

Changes in electronic characteristics also contribute to the variations. Their impacts are believed to be bigger than those from the real mechanical movements. Especially, when BPM electronics are replaced, we should remeasure the BBAs and recalibrate all the related systems. Unfortunately, however, the documents about the electronics are not available and this note does not include the study of the relations between them.

Many factors can be involved in the BBA offset variations, and the full understandings are not available yet. In this note, we summarizes the measurement algorithms and changes in MASAR snapshots. And, even though the number of data is quite limited, we tried to identify the BPM offset issues using the statistical analysis. As mentioned, the full measurement results are shown as plots in the Appendix at the end of the note.

BBA Measurement Algorithm

We adopted the BBA measurement algorithm which is being used in most accelerator facilities and it is included in the high-level application [?], the middle-layer python[?] toolkit of the NSLS-II control system.

For a given pair of BPM and quadrupole, the most effective correctors are chosen for the horizontal and vertical plane. With 2 different quadrupole power supply currents, the data from all the BPMs are taken scanning the correctors. From the fact that the closed orbit does not depend on the quadrupole strength if the beam passes the center of the quadrupole, we can assume that at some corrector strength the beam position readings will not be changed with the quadrupole strength. Because the target BPM and quadrupole pair are located close enough (they are considered already in the design phase), the beam position at the given BPM which gives no variation is identified as the BBA offset of the BPM. And the process repeats for all the BPMs in both planes.

For the BBA measurement at the NSLS-II storage ring, we scan the correctors from -1.5 A to 1.5 A with 4 steps centered at the current set-point values. And the quadrupole power supply current is increased by 2 A to give the offset variation.

For each measurement, using the fitting algorithm, we obtain the linear beam position dependencies at all BPMs on the beam position at the target BPM, which corresponds to the offset from the quadrupole center. Then the x-axis intercept can be assumed as the offset of the target BPM. The first plot in Fig. 1 shows the collection of all the results from the BPMs. The plot has the bowtie shape and we finally obtain the statistical result for target BPM BBA.

BBA in MASAR

After some test period, official BBA values are stored and restored using the NSLS-II MASAR system from June, 2015 with the configuration name, "SR_BPM_BBA". The horizontal and vertical variations of MASAR BBA values for all the sector BPMs are shown Fig. 2. The configuration includes also the ID

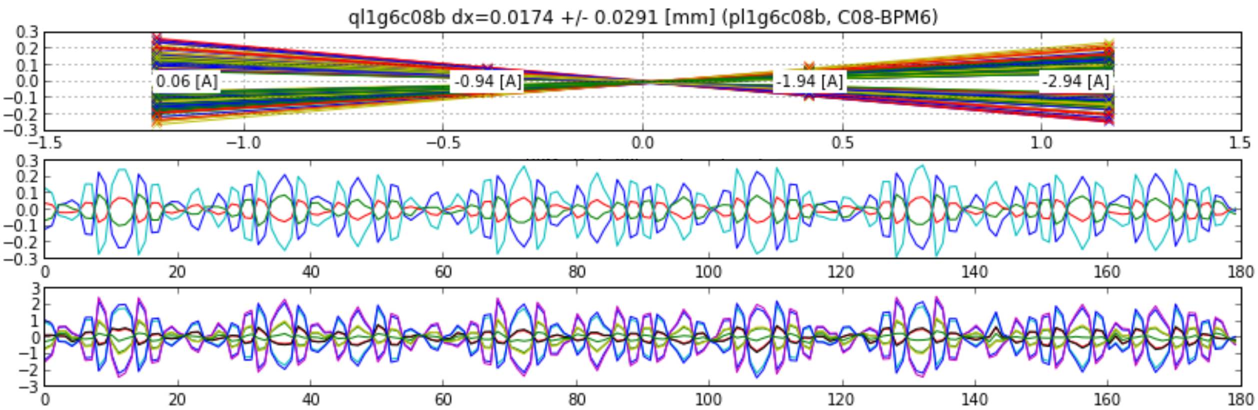

Figure 1: The typical plots for the BBA measurement. The first plot shows the bowtie plot showing the scanned position differences at different quadrupole strengths. The interpolated horizontal intercept is the measured value. The third plot is the collection of all position measurements scanning the position at the target BPM with 2 different strengths of given quadrupoles. The second plot is showing the beam position differences with different quadrupole strengths. BPM C08-6 was measured in the horizontal plane and the result BBA is 0.0174±0.0291 mm

BPMs which should have frequent readjustments from the safety reason but they are not shown in the figure.

As can be seen in Fig. 2, except the scattered big changes which are considered as beam study tests, for about 3 years after the MASAR is applied to maintain the BBA values, there was only one major update. This does not mean that the BPM offsets did not change. Because the change in BBA set values at MASAR can directly impact the operation condition and the user experiment, we just tried to minimize the number of impacts. Even at this major upgrade, BPMs surrounding the straight sections (BPM 1 and 6), which are used in the interpolations for the ID BPM BBA estimations, were not included so that the users experiments would not be affected.

Fig. 3 shows the most recent operational MASAR BBA values active at the end of September, 2018. The black marks represent the BPM 1 and 6 for each cell which are related to the ID user experiments. As mentioned, those BBA values of BPM 1 and 6 have never been changed and are same for years from the time when the MASAR included the BBAs. We can notice that most of the vertical BBA values, including the black dotted ones, are negative and that means the vertical BBAs were negative dominant from the day when the official BBA values are defined in MASAR.

Even though the MASAR maintains working values, as explained above, they do not represent the real BPM offsets and we do not discuss them any more.

Variation of BPM Offsets

While the MASAR values are the control values to keep the consistent beam positions, the measured BBA values represent the BPM offsets from the quadrupole centers. The BBA measurement can be performed only several times a year because of the limited beam time and, monitoring and adjusting the BBAs does not have high priority unless the operation conditions are suddenly changed.

The plots from all the available data can be found in the Appendix. The data were taken from Jun. 2016 to Sep. 2018 and, even in this period, there are many missing points because, when the full measurement cannot be performed, there are some priorities in the measurements. For example, the BBAs of BPM 1 and 6 for each cell are always measured first in the usual measurements.

With the given data, we analyzed them and found some meaningful results. First, we directly compared

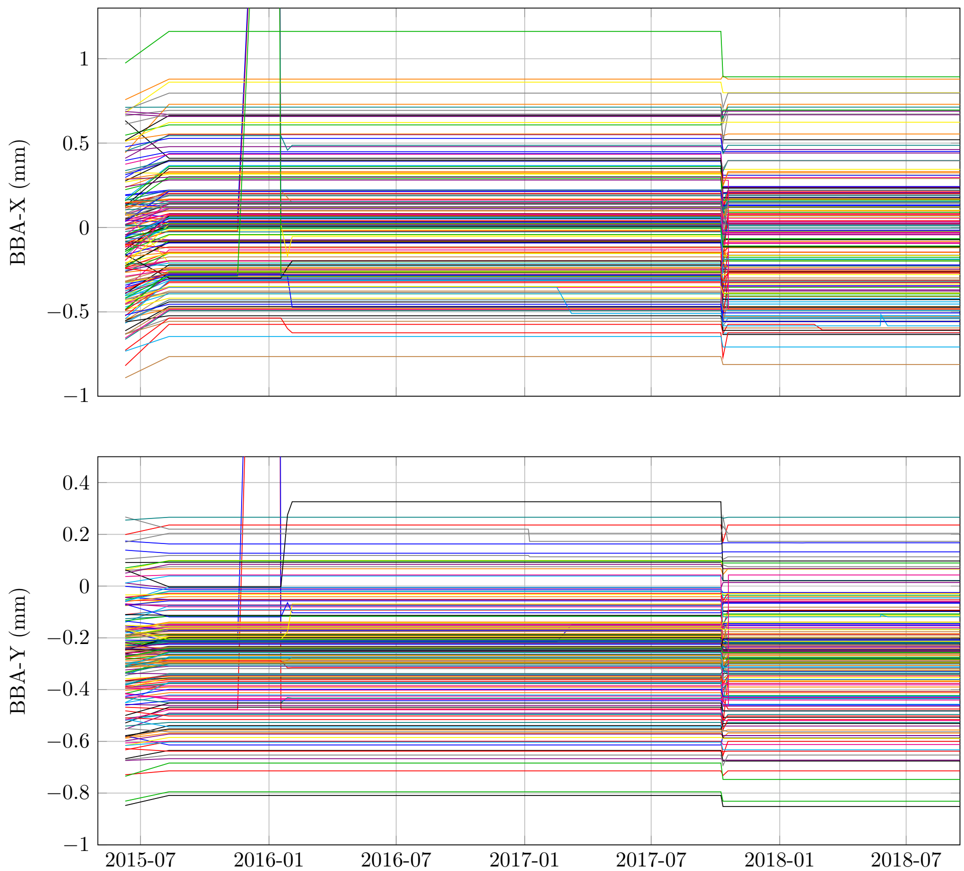

Figure 2: Masar BBA from Jun. 2015 to Sep. 2018

the measured BPM offsets. Fig. 4 shows the first and last measured offsets and their differences. Here, we should understand that not all the offsets in the same plot are not measured at the same time. The first data were taken in Jun. or Aug. 2016 and for the last data, some of the them were obtained in Nov. 2017, some of them were measured in Sep. 2018, and the rest were taken in between the two dates.

Furthermore, for the better analysis, we filtered out the most outlied sample in each BPM offset data set and if the first or last data are filtered out, the measurement time of Fig. 4 can be changed.

In Fig. 4 also, as in Fig. 3, the BPMs 1 and 6 are marked black. As in Fig. 3, we see the vertical offsets, shown in Fig. 4(b), are overall negative. Fig. 4(c) shows the differences in BPM offsets between the first and the last day measurements. If the difference is bigger than 0.18 mm, the points are marked red and the BPM names are printed. In general, there are bigger changes in the horizontal direction.

In addition to the offsets and their differences, even if we have too few data for any statistical treatment, using the linear fitting, we estimated the offset variation rate per day for each BPM and the results are shown in Fig. 5. The rates are turned out to be order of femto meter (10^{-15} m) per day and, in the process, we filtered out one outlier in each dataset.

The average of the horizontal and vertical variations are about -0.067 and -0.076 fm/day, respectively. That is, over the whole ring, the BPM offsets are very stable and there is hardly any overall movement in the horizontal or vertical directions. But when we take the absolute values, the averages become 1.27 and 0.60 fm/day. with the horizontal variation rates becoming about twice of the vertical ones.

The standard deviations for the absolute variation rates are 1.88 and 1.59 fm/day in horizontal and vertical planes, and we mark the BPMs red and print the names in Fig. 5 if the absolute rate is above 2.5 fm/day in the horizontal plane and above 1.5 fm/day in the vertical plane.

Comparing the offset differences in Fig. 4(c) and the variation rates in Fig. 5, as expected, we can find many BPMs are red marked in both figures. By studying the red marked BPMs in detail using the

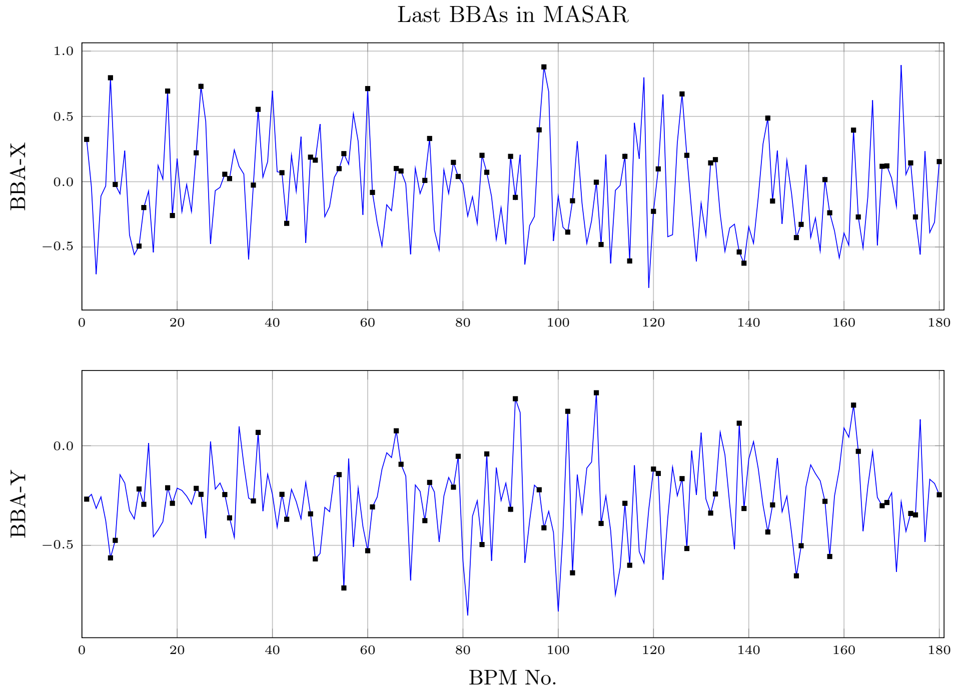

Figure 3: BBA values at MASAR as of end of Sep. 2018. The points marked black represent BPM 1 and 6 surrounding the straight sections.

individual data in the Appendix, we could identify some BPMs whose offset variations are relatively big and consistent. Especially, the variation rates of BPM 23-3 are about 20 fm/day in both planes which are too big and their points are not shown in the Fig. 5 for the better axis range. These values amount more than 10 times of the average of the absolute rates.

BPMs with Possible Offset Movement Issues

In this section, we show the results of investigations about the red marked BPMs in Fig. 4(c) and 5. Because many BPMs in the cell 23 are marked red, we start with the BPMs in the region. The measured data of BPM C23-3, which shows the big movements in both planes, look reasonable. Not only for BPM C23-3, the measured movements of the read marked horizontal BPM C23-2,4,5 and vertical BPM C23-4 are based on the consistent data. However, their movements are all in the opposite direction to the BPM C23-3 movements.

Another region, where relatively many red marked BPMs are located, is cell 12. In this region, the measurement data for the horizontal BPM C12-5 are quite unreliable. But, for the vertical offsets of BPM C12-3 and 4, the movements has reasonable data. For C12-3, we can see the offset is suddenly increasing from mid 2017.

Among other red marked BPMs in Fig. 4(c) and 5, the BPMs BPM C18-1, C20-2, C21-5, C22-2, and C29-5 are showing relatively consistent movements in horizontal plane. In the vertical direction, only BPM C22-4 is showing the consistent movement.

For other marked BPMs, it is difficult to justify any special movements from the given data.

Summary

To maintain and control the beam transverse positions based on the quadrupole centers is very important requirement in operating 3rd generation light sources. The BBA is the direct tool that can be used to

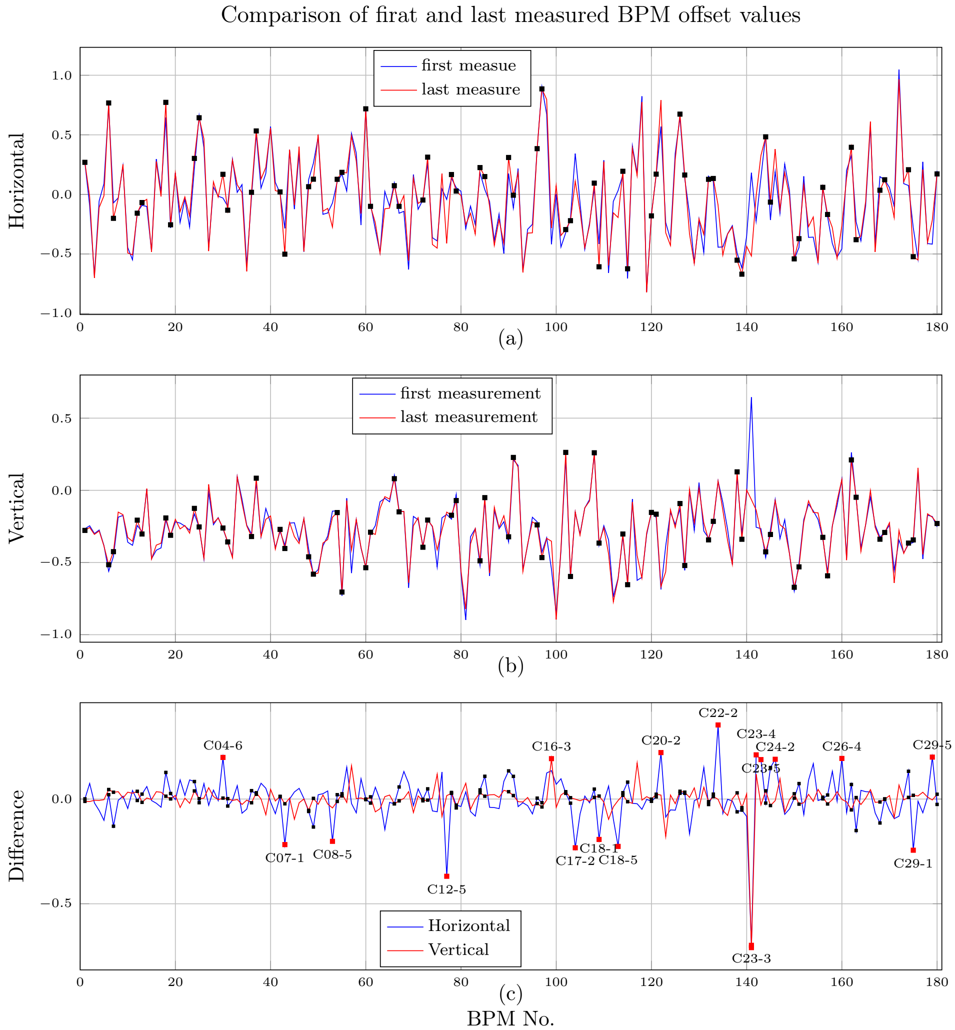

Figure 4: The BBA measurements of the first and last day. (a) The horizontal BPM offsets measured on the first and the last days. (b) The vertical BPM offsets measured on the first and the last days. (c) The horizontal and vertical BPM offset differences between the data measured on the first and last days. The points marked black represents BPM 1 and 6 surrounding the straight sections. The points marked red with the BPM names have the differences bigger than 0.18 mm.

optimize the beam positions and the their values are direct measure of the beam offsets from the quadrupole centers. In NSLS-II, the BPM BBAs are measured periodically and this note analyzed the collected data.

Because of the strictly limited number of data and the high uncertainties of the measurements, the reliability of the analysis can be argued and, also, we admit many ambiguous and non-scientific terms are abused in the note.

Still, we tried to find any meaningful movements in the BPM offsets and described the results. Among others, we'd like to point out that we need to pay attention for the BPM offset movements in the cell 23 region, especially the variation rates of BPM C23-3 are very big and consistent.

About the negative BBAs in the vertical plane, we can say that they are not moving to the negative direction but the offsets were measured as negative from the first day.

We also gave a close look at the offset movements of BPM C16-6 because it is well known as "bad BPM" with significant noise. From the BBA measurement data, we cannot see any unusual fluctuation nor any offset movement issue for the BPM.

Because electronics are involved in the BPM reading processes and the results depend on their charac-

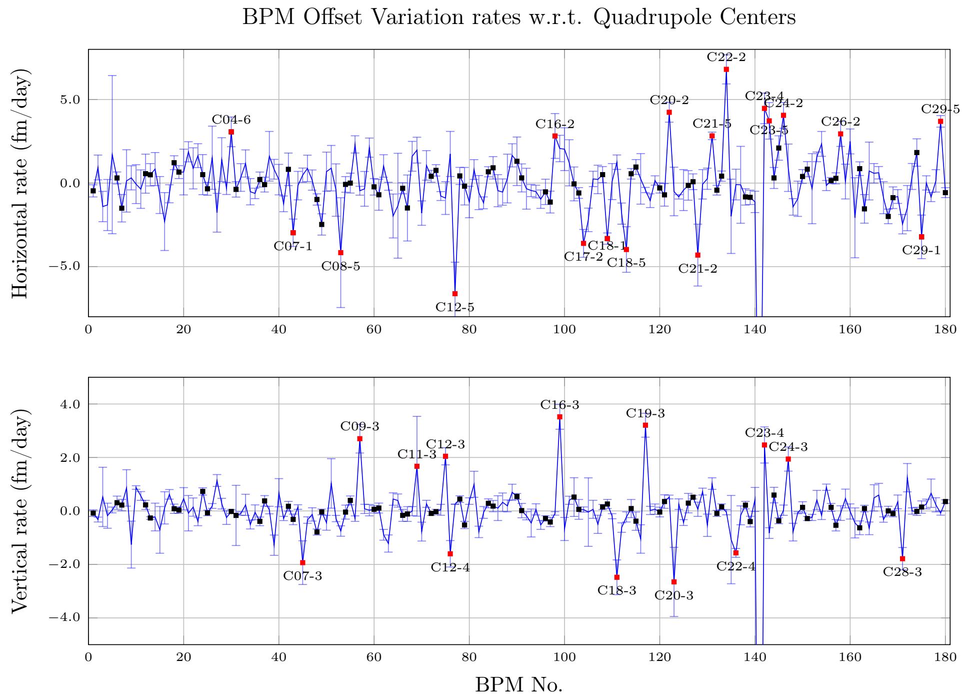

Figure 5: BPM offset variation rate in (fm/day) from the linear fitting. For each dataset, the biggest outlier is excluded. The black marked points are BPM 1 and 6. The red marked points represent the BPMs with high rates, above 2.5 fm/day in the horizontal plane and 1.5 fm/day in the vertical plane.

teristics, we wanted to see the relations between the offset variation and any changes or findings in the electronics but, unfortunately, those documents were not available at the time when the note was written.

References

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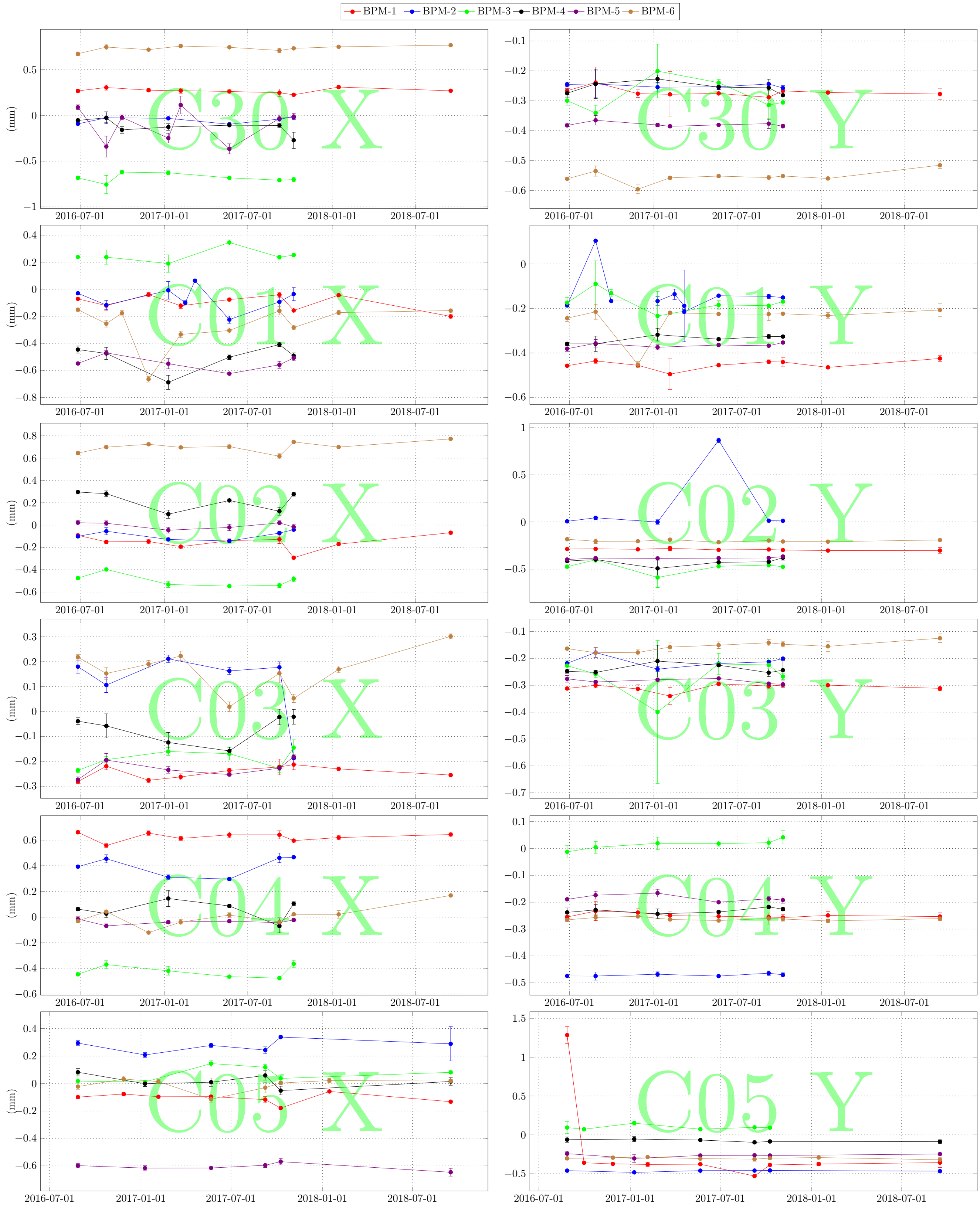
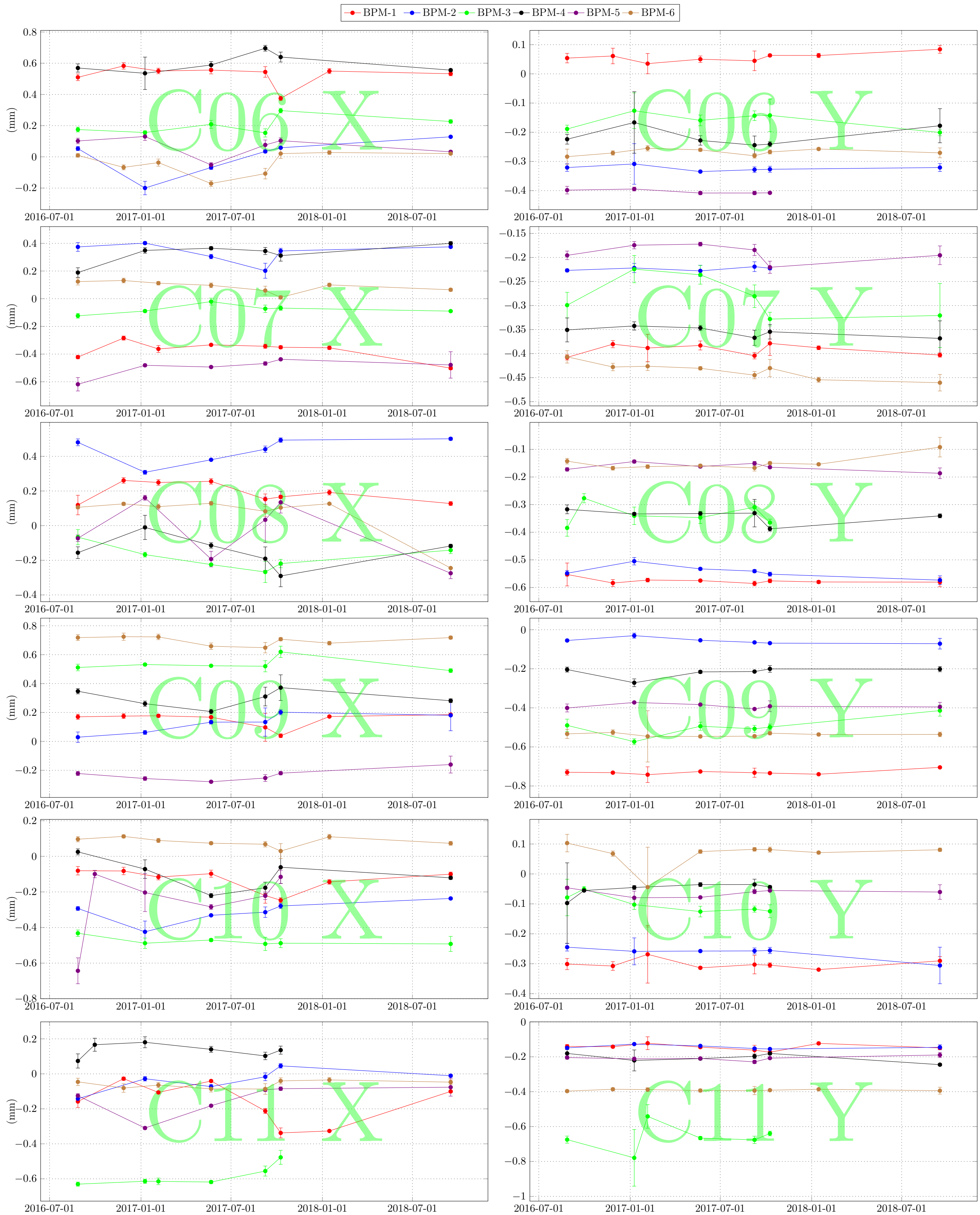
[2] S. Seletskiy, J. Choi, K. Ha, R. Smith, “Upgrade of NSLS-II Active Interlock System,” Proceedings of IPAC2016, Busan, Korea, p. 4140

[3] L. Yang, J. Choi, Y. Hidaka, G. Shen and G. Wang, “Development Progress of NSLS-II Accelerator Physics High Level Applications,” Proceedings of IPAC2012, New Orleans, Louisiana, USA, p. 4005, 2012

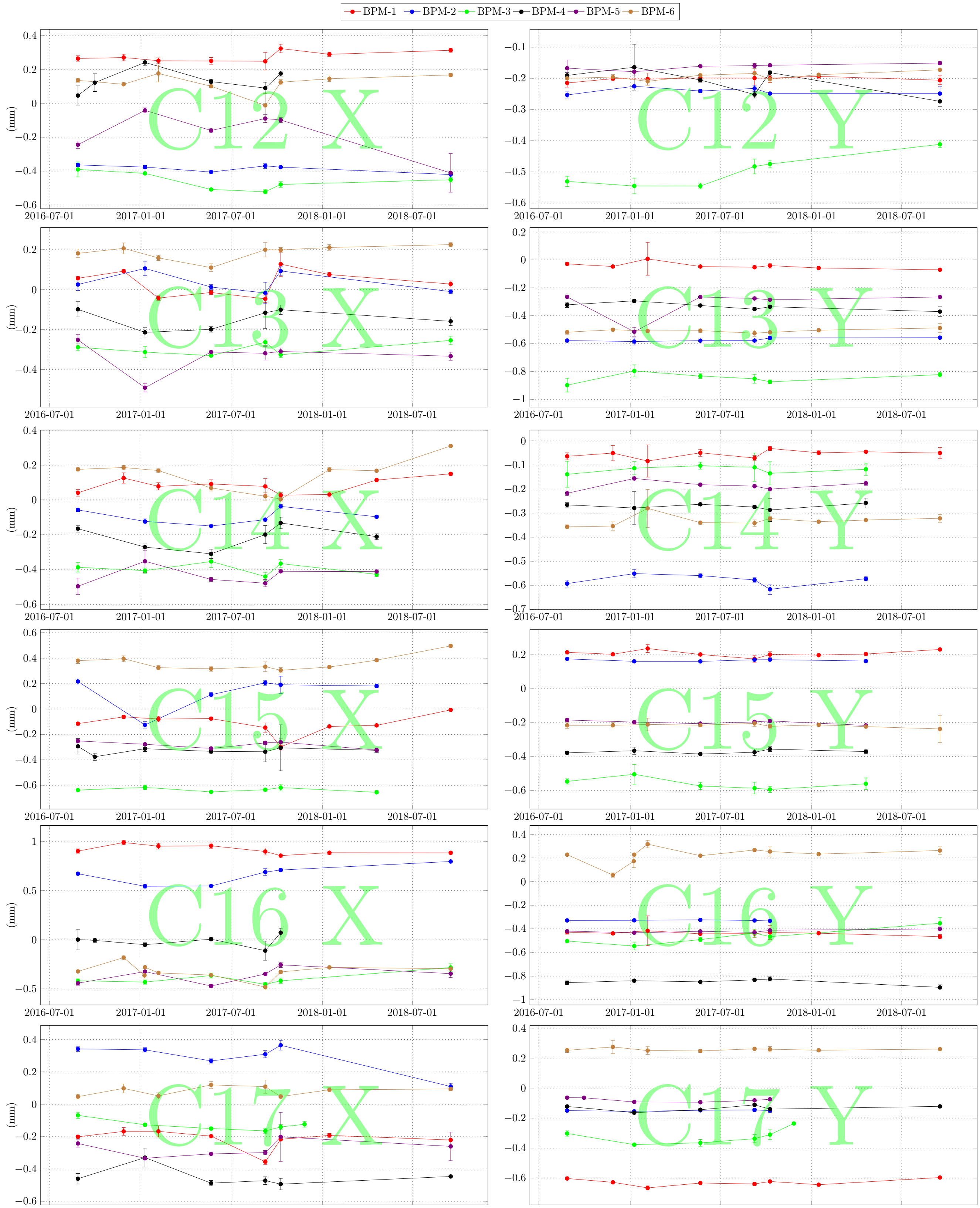
[4] Python, `https://www.python.org/`

Appendix: Plots of BBA Measurement Data (BPM Offsets)





BPM-1
BPM-2
BPM-3
BPM-4
BPM-5
BPM-6
C06 X
C06 Y
C07 X
C07 Y
C08 X
C08 Y
C09 X
C09 Y
C10 X
C10 Y
C11 X
C11 Y
(mm)
2016-07-01
2017-01-01
2017-07-01
2018-01-01
2018-07-01


BPM-1
BPM-2
BPM-3
BPM-4
BPM-5
BPM-6
(mm)
C12 X
C12 Y
C13 X
C13 Y
C14 X
C14 Y
C15 X
C15 Y
C16 X
C16 Y
C17 X
C17 Y
2016-07-01
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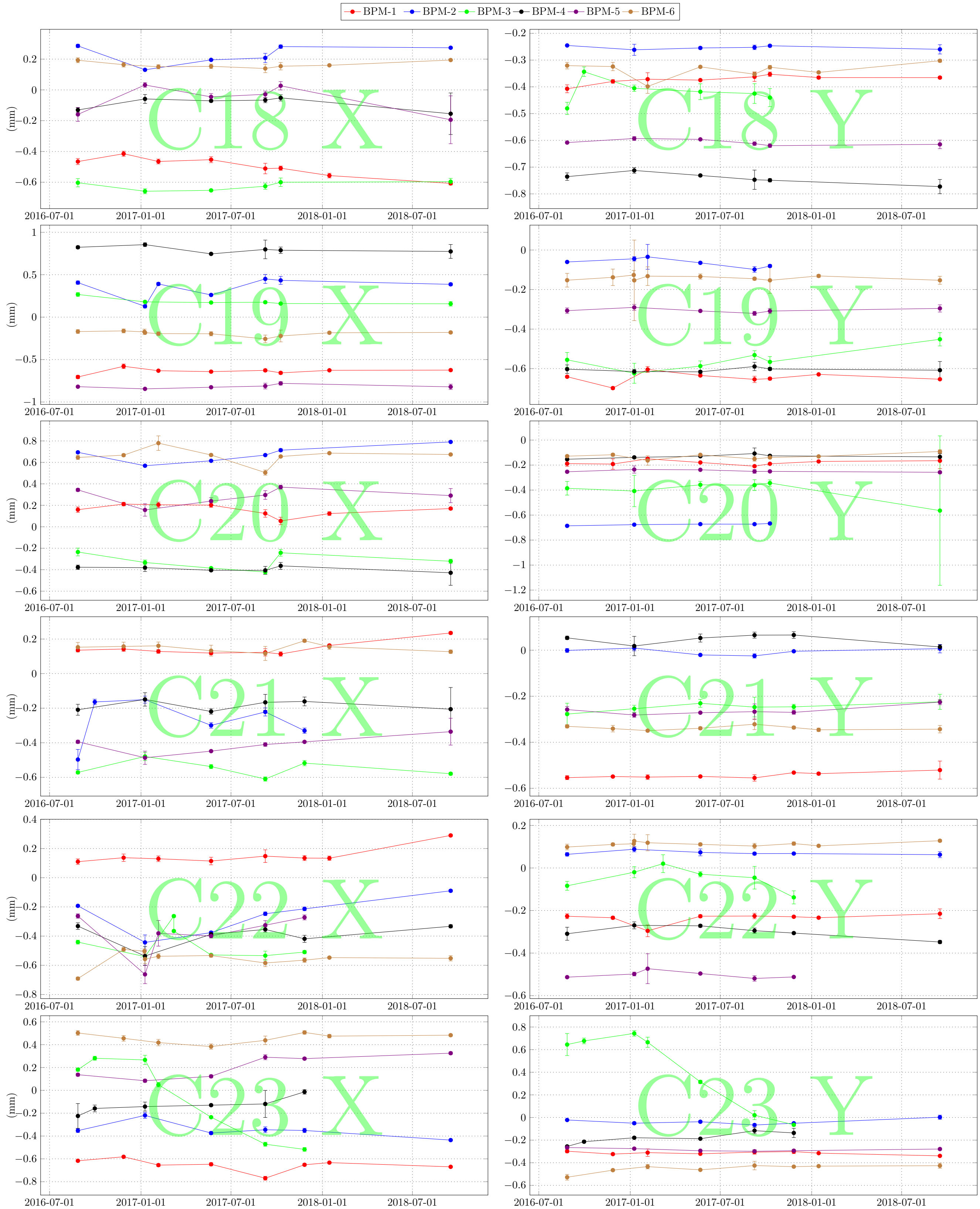
2018-01-01
2018-07-01


BPM-1
BPM-2
BPM-3
BPM-4
BPM-5
BPM-6
C18 X
C18 Y
C19 X
C19 Y
C20 X
C20 Y
C21 X
C21 Y
C22 X
C22 Y
C23 X
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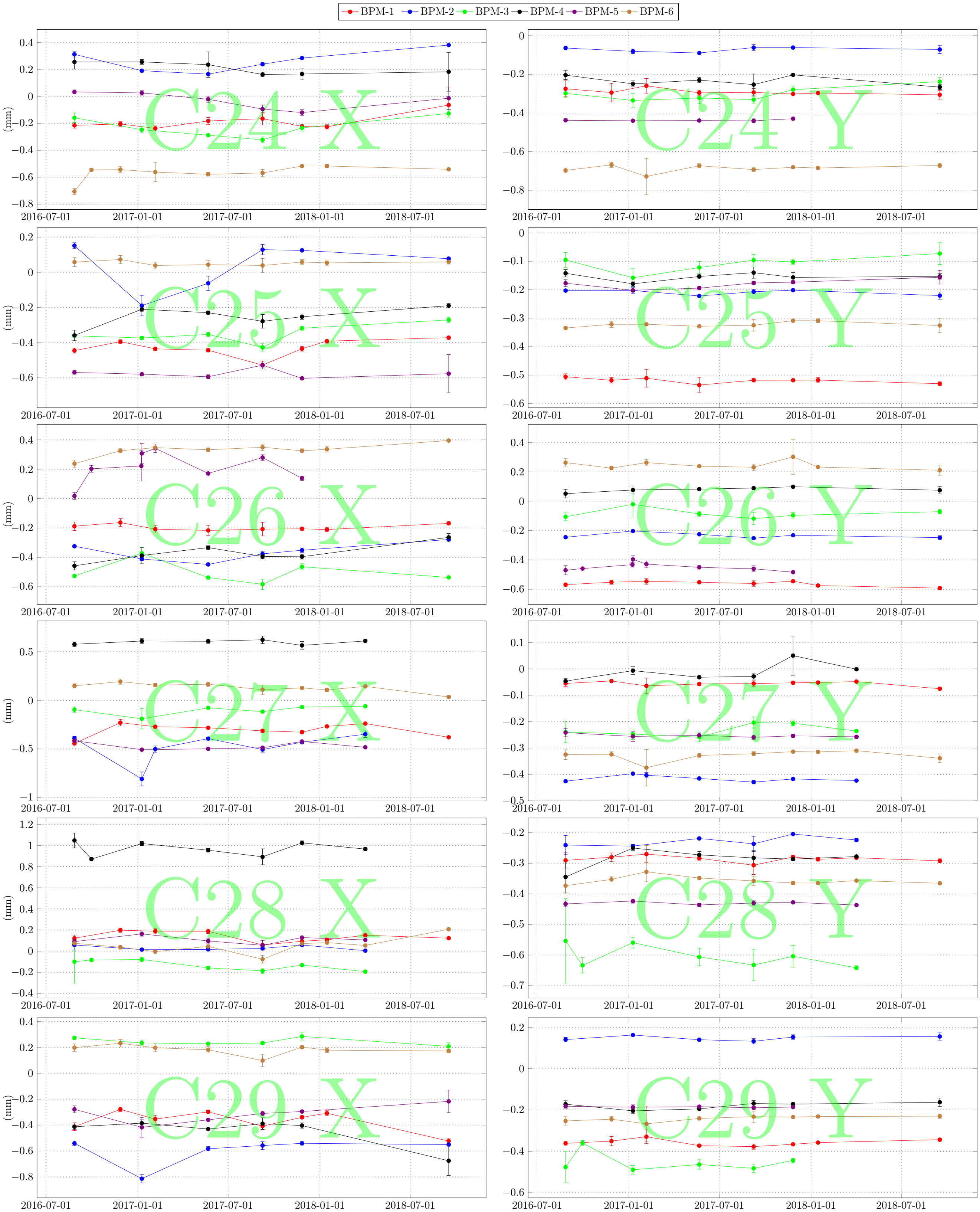
2018-01-01
2018-07-01


BPM-1
BPM-2
BPM-3
BPM-4
BPM-5
BPM-6
C24 X
C24 Y
C25 X
C25 Y
C26 X
C26 Y
C27 X
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C29 X
C29 Y
(mm)
2016-07-01
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