Updates to the Sextupole Data Analysis and new CesrV Stuff

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CESR Accelerator Group Meeting

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1) Custom orbit constants: batch script

```
#! /bin/bash -v
#$ -l mem_free=2.0G
#$ -m a
#$ -M jac243@cornell.edu
#$ -N opt_28607
#$ -o /home/critten/bss/analysis/gridlogs
#$ -e /home/critten/bss/analysis/gridlogs
#$ -q all.q
#$ -l arch=lx-amd64
#$ -v CESR_CUSTOM_ORBIT_CONST_DIR=/home/critten/bss/ms/16jan2022/custom_orbit_constants
source /nfs/acc/libs/cesr/cesr_online.bashrc
date
cd /home/critten/bss/analysis/
cesrv no_mpm -custom_calib custom_calibrations.cal call optimize_and_write_output_files_xyoffsets.cesrv 28607  10 0
```

[jac243@lnx120 analysis]$ qsub batch_script

Custom orbit constants: CesrV log file

Lattice is: CHESS-U_6000MEV_20190904

Species is: Positron

Begin group setup...

Note: BIGGRP set IS 0

[Info will be taken from the DataBase]

End group setup. dTime (sec): 0.0

nonlin_bpm: Initializing bpm48 lookup table... using input file

nonlin_bpm: Initializing ARC lookup table... using input file

nonlin_bpm: Initializing CHESS-U lookup table... using input file

nonlin_bpm: initializing quad offsets

Opened CESR constants file

/home/critten/bss/ms/16jan2022/custom_orbit_constants/offset.bpm

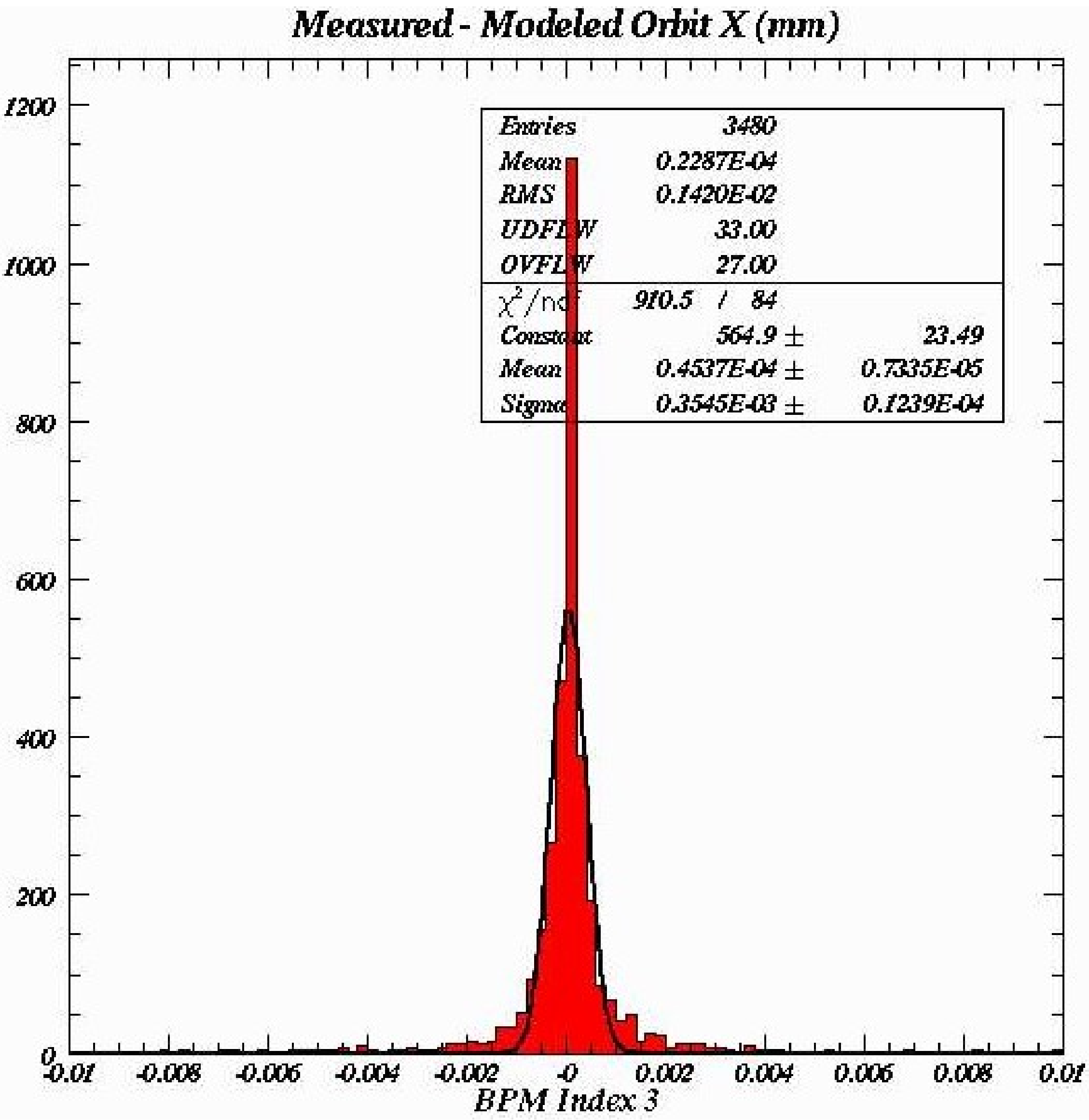
nonlin_bpm: Initializing button calibration

Opened CESR constants file

/home/critten/bss/ms/16jan2022/custom_orbit_constants/bad_bpm_buttons.dat

/home/critten/bss/analysis/logs/phase_28607_cesrv.log

2) Presentation 21 Feb 2024: Example of Residuals for All Data (X6C)



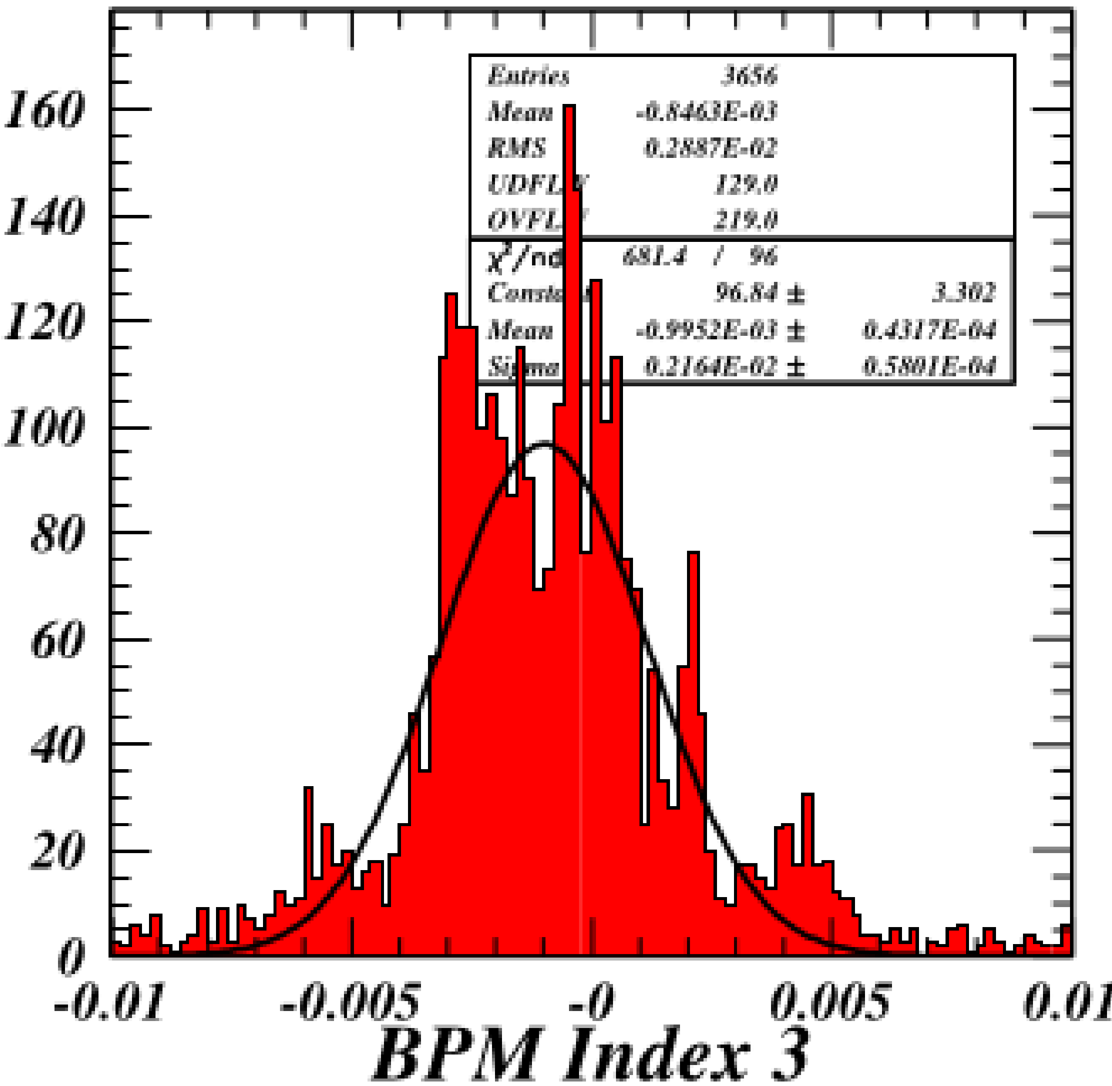
The analysis used very tight clipping from 12/18/23 to 5/1/24.
Orbit final clip was 0.04 mm, for example.

The logic was that we wanted to use only well-calibrated BPMs (gains and quad offsets).

Starting in July 2024, this approach was abandoned, because the sextupole scan analysis was ruined if the BPM at the sextupole was rejected.

One also sees here that the Gaussian RMS spread of 0.0003 mm is much smaller than the BPM resolution.
The few remaining BPMs after the clipping are pulling the fit.

Current status of BPM residuals analysis (X6C)



Measured – Modeled Orbit X

The current analysis in August uses a final clip of 0.7 mm in order to account for fluctuating offsets.

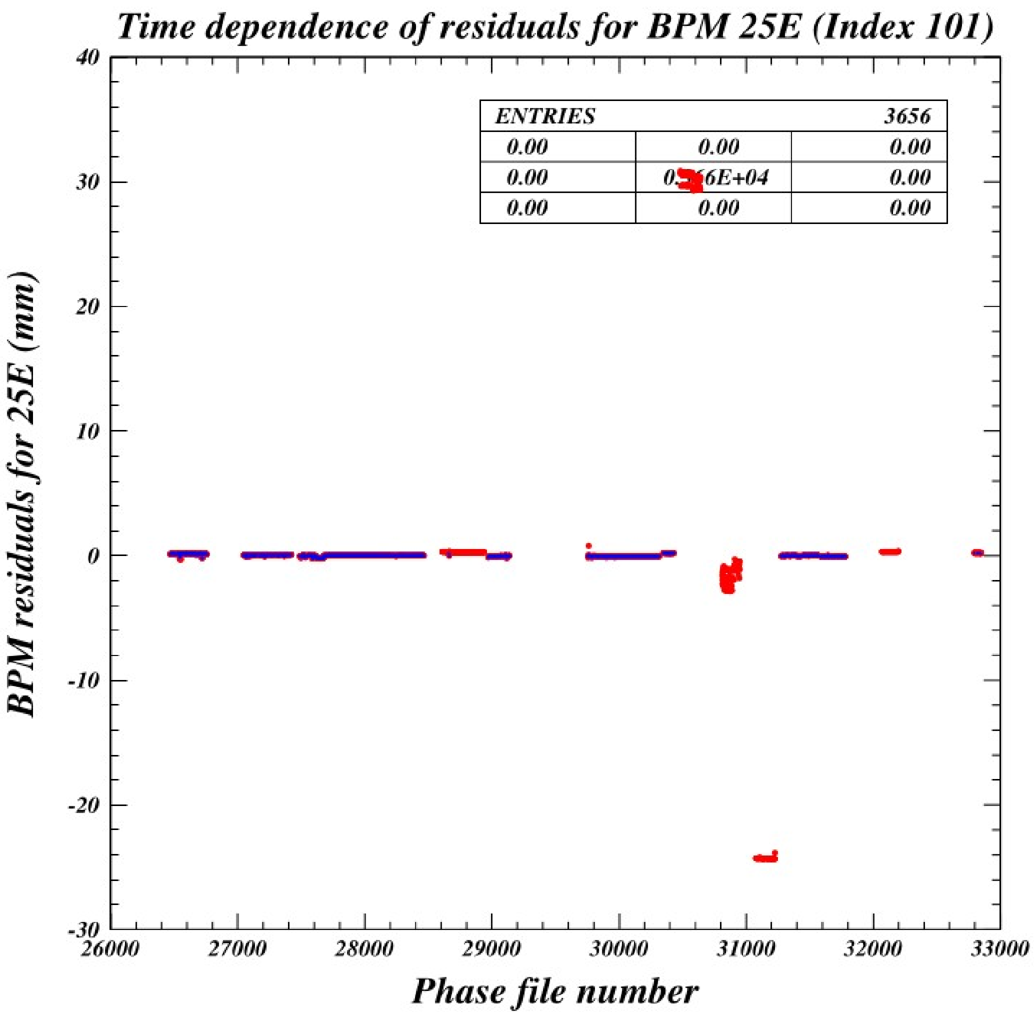
The distribution for all data has a more reasonable RMS value of about 2-3 microns.

There also appears to be a time dependence in the offset which was previously not seen because the fit was being pulled.

The Y residuals in the south arc still show sub-micron RMS values and sub-micron time-dependent offsets.

Presentation 21 Feb 2024: Time dependence of BPM residuals for 25E

```
offset.bpm.20231127:  74,   -0.09,    9.41,    0.00,    0.00, 2020-10-21 19:22:33  p:26150  p:26151
offset.bpm.20240119:  74,   -0.34,    2.89,    0.00,    0.00, 2023-11-27 13:14:20  p:31877  p:31878
```

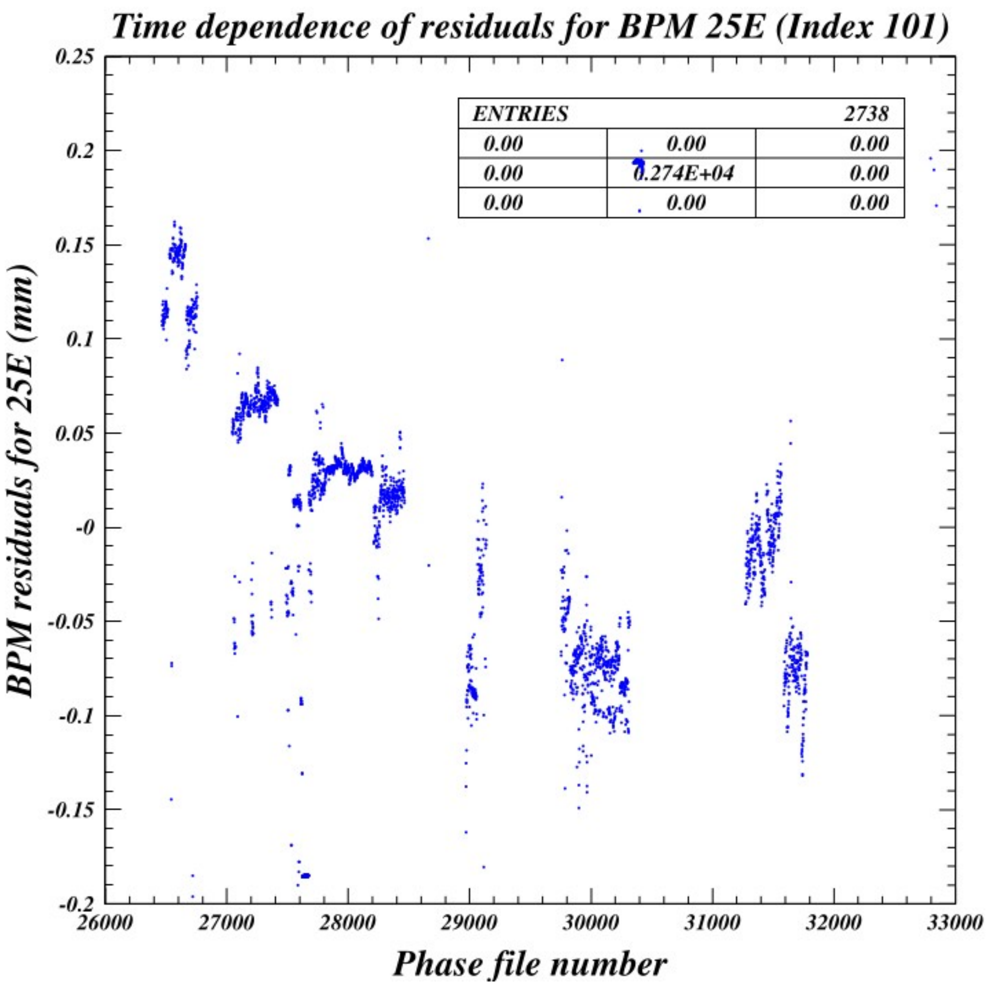


The talk of 2/21/2024 also showed some strange values in the offset.bpm files for BPM 25E (9 mm offset!).

In the meantime, I included the USED value in the residuals data base.

This plot shows all residuals in red and the cases USED=True in blue.
Anomalous readings were rejected by the clipping procedure.

Presentation 21 Feb 2024: Time dependence of BPM residuals for 25E



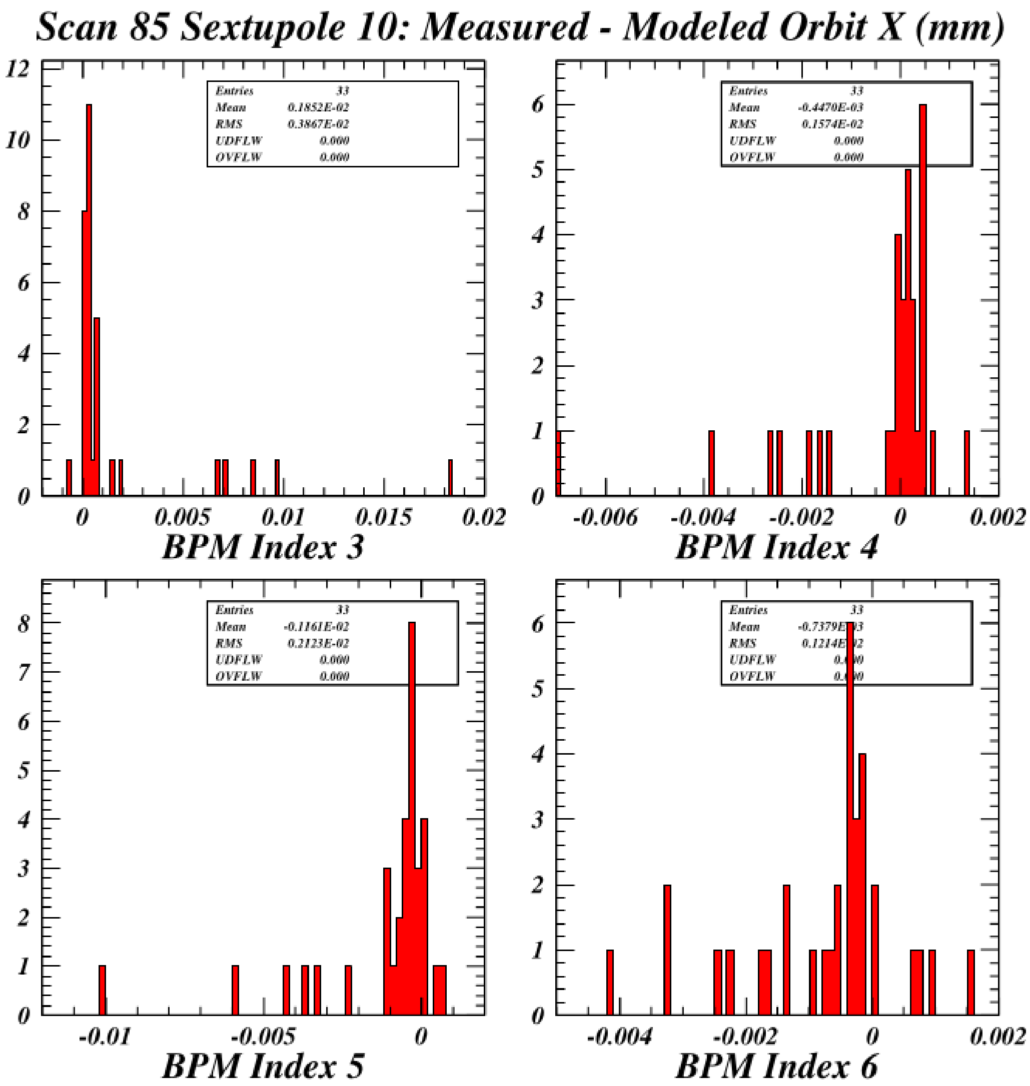
The reason to use custom values for the offset.bpm and bad_buttons files was to use the values in effect when the data was recorded.

Here we see that the re-analysis using custom orbit constants does not remove offsets at the 0.1-0.2-mm level.

Since phase, coupling, orbits and tunes are fit simultaneously, the relative weights for constraints are important. These were obtained using the optimization for difference functions, as described in Secs. 4.6.2 and 5.3. The weights used correspond to precision values of 0.1 mm for the orbits, 0.02° for the phase functions, 0.02 for the coupling $\bar{C}_{12}$, and 0.001 for the tune Q. The precision in the coupling measurements was assumed to be the same as for the phase function, since the residual analysis for the quadrupole and skew quadrupole terms obtained similar values (see Sec. 4.6). In the case of the orbit precision, the precision values of a few microns were found in the fits to the difference functions 5.3. The weights for the optimizations for the reference functions were increased to 0.1 mm to account for systematics in the determination of the BPM offsets relative to the quadrupole centers and for contributions from the button gain measurements. The latter were found to depend on the thermal state of the machine, varying over 12 hours after the begin of full-current operation. The sextupole scan data was obtained in the cold state of the machine.

The offsets could be removed, and the weights correspondingly increased, by using these values in the analysis.
A first step is done: calculating the average offset for each BPM during each sextupole scan.
The RMS is also available, allowing to address how the resolutions vary from BPM to BPM.

Average and RMS values for BPM residuals for each scan



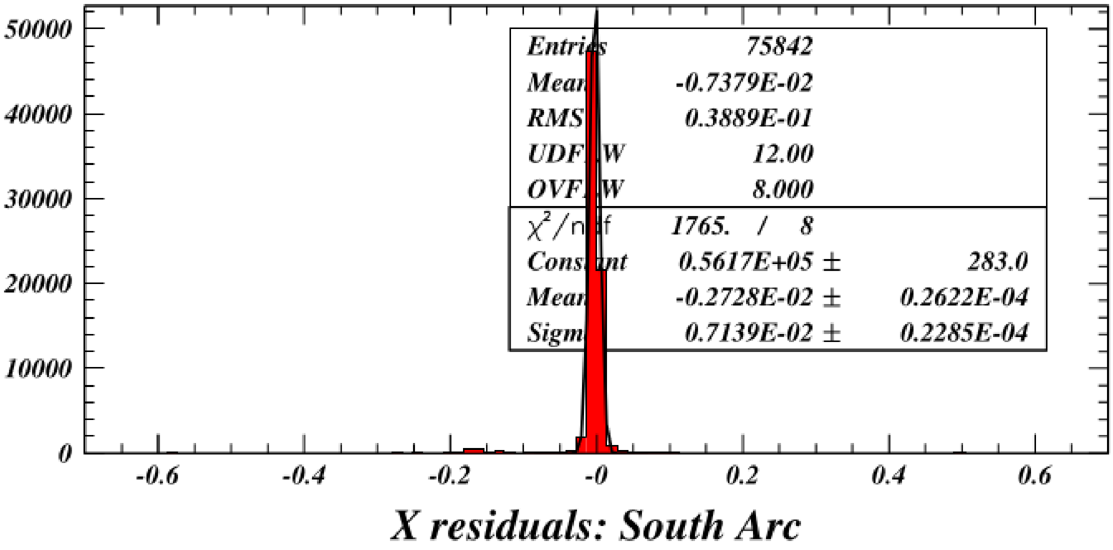
Average and RMS values for BPM residuals for each scan

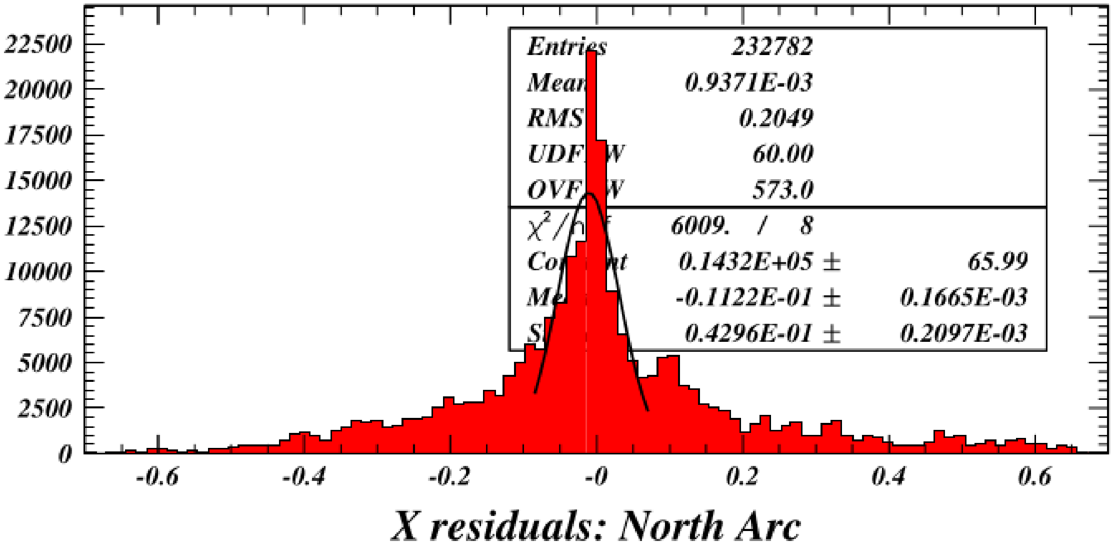
For example, for this scan X6C (index 3) and an average value of 1.9 microns and and RMS width of 3.9 microns.

The south arc BPM data is so precise that the rounding at 0.1 micron in the CesrV output file is clearly seen!

We may need to add a significant figure.

BPM residuals for full data set





All X residuals for fits where the BPM was included in the final set after all clipping

These distributions include the effects of the fluctuating quad offset values.

In the south arc the width excluding outliers is 7 microns. The effect of the quad offset values is smaller.

In the north arc the effect of the quad offset values is more severe, contributing about 0.2 mm. The residuals for most of the NA data have a width of less than 0.04 mm.

The Y residual distributions (not shown) exhibit very similar widths. The 2X smaller vertical dimension of the vacuum chamber does not seem to make a difference.

New weighted clipping feature in CESRV

CLIP {<plane>} <where> {<level>}

CLIP WEIGHTED {<plane>} <where> {<level>}

Where:

• <plane> = [X, or Y]

• <where> = [<Region Name>, or <Data Name>]

(Note: HELP REGION and HELP DATA commands gives more info)

• <level> = value over which data is clipped. Default is plot maximum.

CLIP vetoes displayed data locations where the absolute value of what is plotted is over <level>. <where> can only be omitted with a wave plot. If <plane> is omitted then both X and Y plots are clipped.

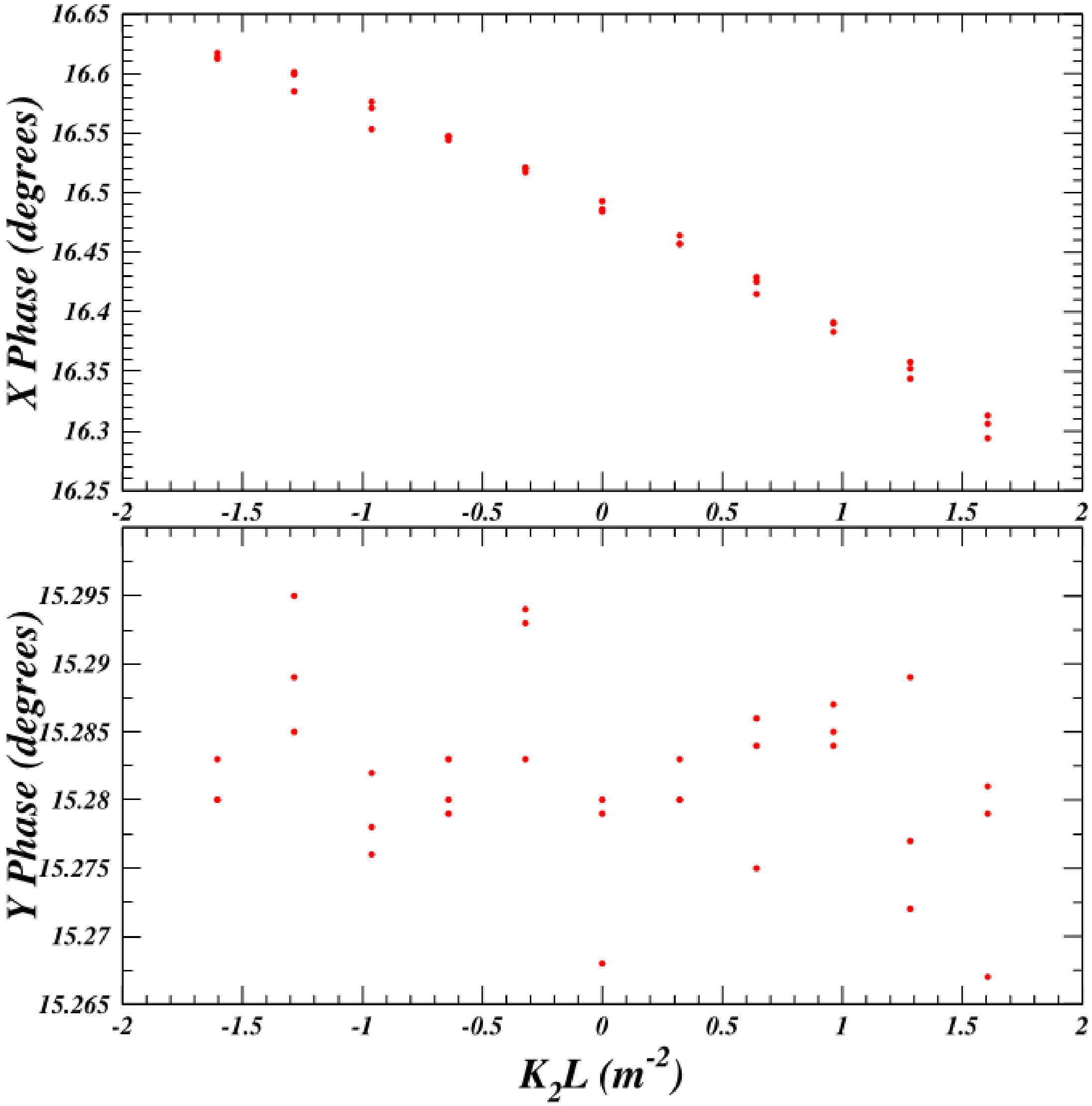
If WEIGHTED is present, a datum value is scaled by sqrt(weight) where weight is the merit function weight used for the datum. This results in clipping rejecting datums which deviate by some number of sigma.

Examples:

```
CLIP TOP 5              ! For the top plot: Veto all locations where
                        !        |Plotted phase data| > 5
CLIP X PHASE            ! For the phase plot: Veto all locations where
                        !        |plotted x data| > X_PLOT_MAX
CLIP PHASE X            ! Same as above
CLIP WEIGHT X PHASE 50  ! Same as above when phase X weight is 1e2 = (0.1 degree)^-2
                        ! i.e. clip on 50 sigma.
CLIP                    ! With a wave plot: Veto all locations where
                        !        |plotted data| > PLOT_MAX
CLIP ORBIT Y 1.0        ! For the orbit plot: Veto all locations where
                        !        |Plotted orbit data| > 1.0
CLIP WEIGHT ORBIT Y 1.0 ! Same as above when orbit Y weight is 1e6 = (1e-3 m)^-2.
                        ! i.e. clip on 1 sigma.
                        ! NB: Orbit data carry units of mm.
                        !     Orbit weights carry units of m^-2.
```

This new feature makes it possible to follow Antoine's suggestion to reject anomalous measurements relative to the resolution of the BPM.

3) Phase residuals analysis: scatter plots



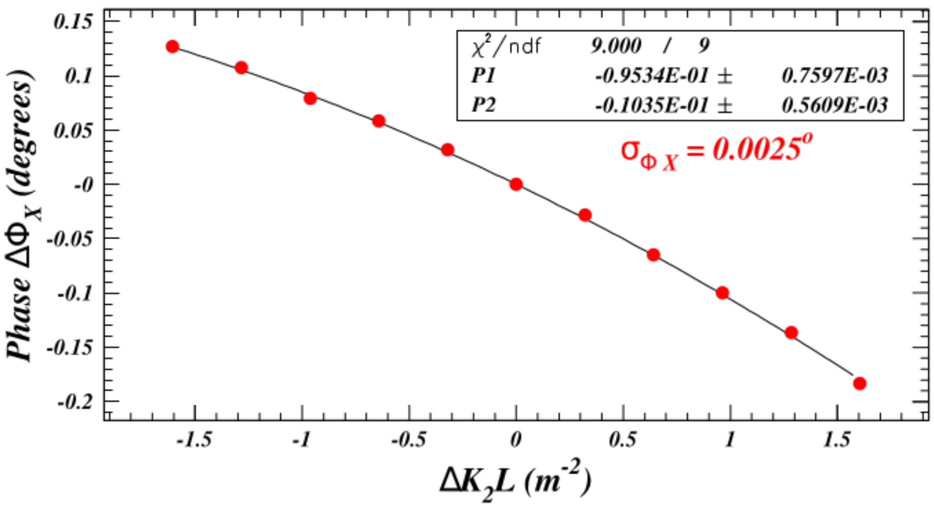
Scatter plots

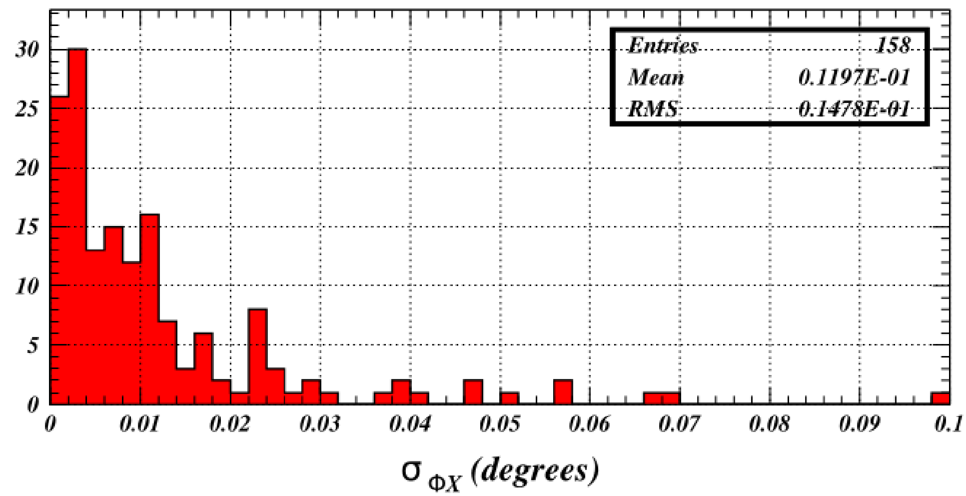
Scatter plots using the three repetitions of the phase, coupling, and orbit measurements at each K_2 setting of the sextupole serve to give a rough idea of the repeatability and to easily identify anomalous optimization results.

The variation of the sextupole strength results in changes to the phase at the sextupole by changing the focusing when the beam is not at the horizontal center of the sextupole.

Here we see that the change in Φ_X is about 0.3 degrees over the full range of the K_2 change. The change in Φ_Y is less than to the repeatability in the measurement, which is about ±0.015 degrees for both Φ_X and Φ_Y.

3) Phase residuals analysis: polynomial fit





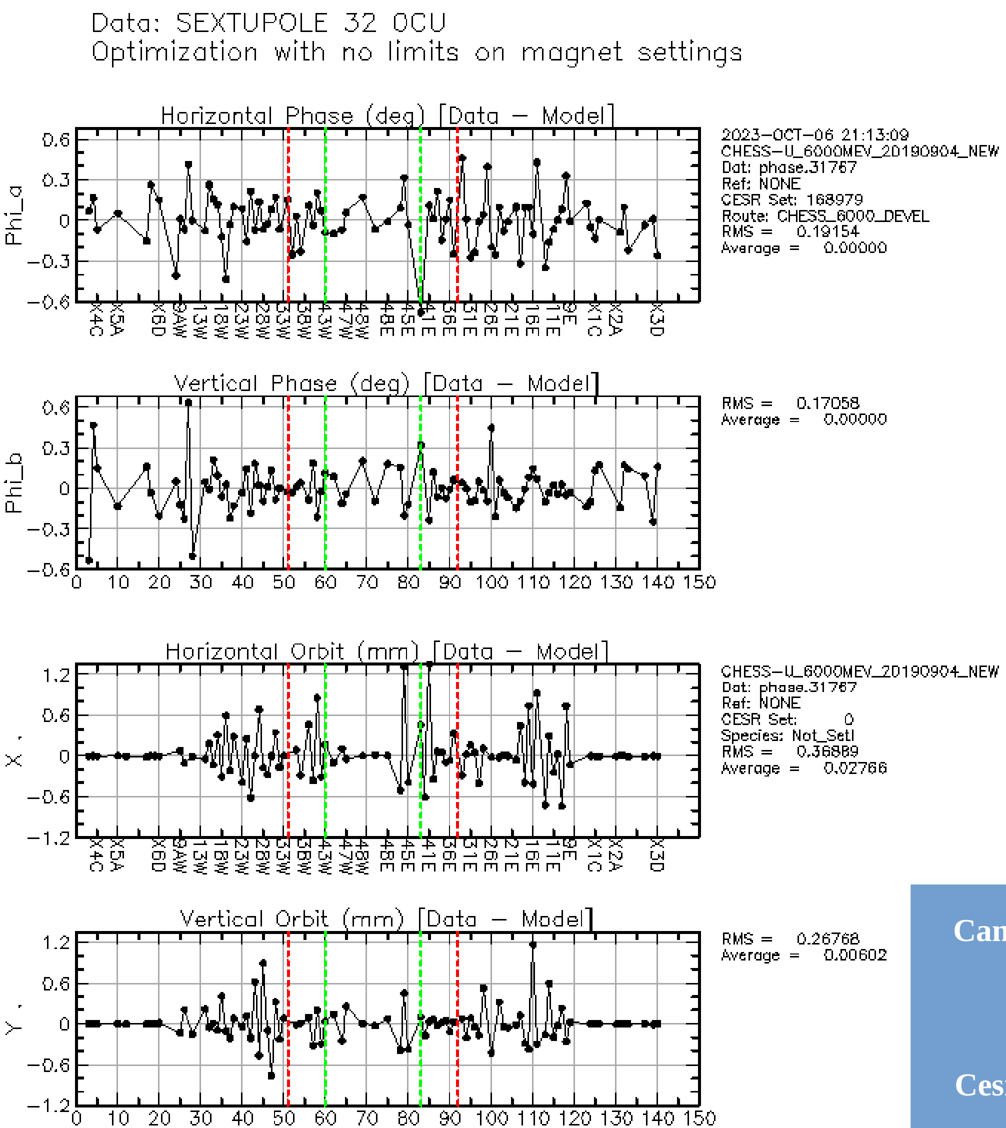
The polynomial fit to the average of the three phase measurement changes shows that terms up to quadratic suffice to approximate the dependence at our level of precision.

Adjusting the weights to set χ^2/NDF to unity indicates that the resolution is 0.0025 degrees in this case of scan 85 for sextupole 10AW.

Such a value is frequent but smaller than typical.
The average value over all 158 scans is 0.012 degrees. The RMS variation is 0.014 degrees.

Sagan, Meller, Littauer and Rubin (PRSTAB Vol. 3, 092801 (2000)) estimated the phase noise contribution from the betatron clock to be 0.005 degrees.

4) CesrV feature to write and read limits files
Interesting application to optimizations



Typical optimization with limits off

Phase residuals 0.2 degrees
Orbit residuals 0.4 mm.

Orders of magnitude larger than the known precisions.

Use tight clipping to choose only well-calibrated BPMs to get these residuals at the level of the known precisions.

Top10 merit			Top10 derivative			Top10 delta		
Name	ix	Value	Name	ix	Derivative	Name	ix	delta
Orbit_X	85	1.817E+00	Horiz	51	6.578E+04	Horiz	90	427283.4
Orbit_X	79	1.727E+00	Horiz	50	5.310E+04	Horiz	92	-310908.4
Orbit_Y	110	1.358E+00	Horiz	54	-5.187E+04	Horiz	91	-234313.2
Orbit_X	111	8.533E-01	Horiz	69	-5.083E+04	Horiz	10	-197338.2
Orbit_Y	45	7.903E-01	Horiz	75	-4.682E+04	Vert	112	-112970.5
Orbit_X	58	7.180E-01	Horiz	45	-4.650E+04	Horiz	8	111550.3
Orbit_Y	47	5.794E-01	Horiz	52	4.551E+04	Horiz	103	-99580.4
Orbit_X	117	5.447E-01	Horiz	65	4.540E+04	Vert	106	-81867.0
Orbit_X	109	5.429E-01	Horiz	48	4.512E+04	Horiz	88	-80818.2
Orbit_X	118	5.360E-01	Horiz	61	-4.337E+04	Vert	113	-59229.9

Merit: 2.019E+01

Can we find magnet settings within hardware limits to match the high-precision data?

Some success. Needs work. Required new CesrV> READ/WRITE LIMITS command because no access to data base when running offline.

5) Future Work

1 Optimization improvements

1.1 BPM offset correction . . . .

1.2 Weighting . . . .

1.3 Remove clipping and use weights instead . . . .

2 Residuals

2.1 Phase functions . . . .

2.2 Coupling $\bar{C}_{12}$ . . . .

2.3 Relative clipping implemented but not used yet . . . .

3 ArXiv submission status

3.1 Complete first draft awaiting comments from GHH and DCS .

3.2 Replace figures and text if significant progress with optimizations

3.3 Study multipole content of anomalous source of X,Y angle changes . . . .

4 2001-2024 project directory document