ATF2 IP-BPM - piezo movers calibration (2016.10.04 – 2016.10.13)

1. Horizontal movers calibration
2. Vertical disp. when lateral scanning (XY coupling)
3. Vertical movers calibration (linear fit)
4. Vertical movers calibration (non-linear fit)
5. Vertical movers stability (movers resting at mid-stroke)

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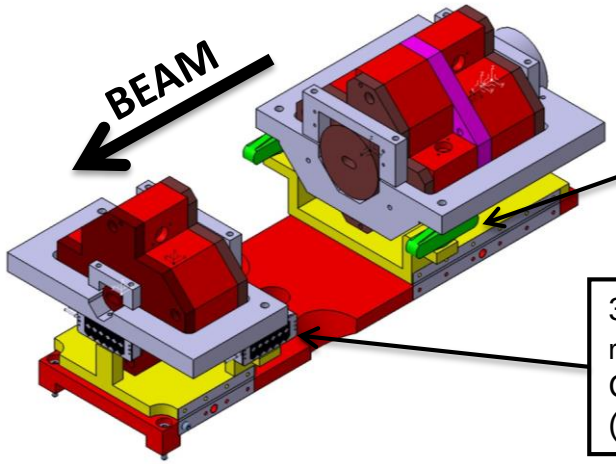
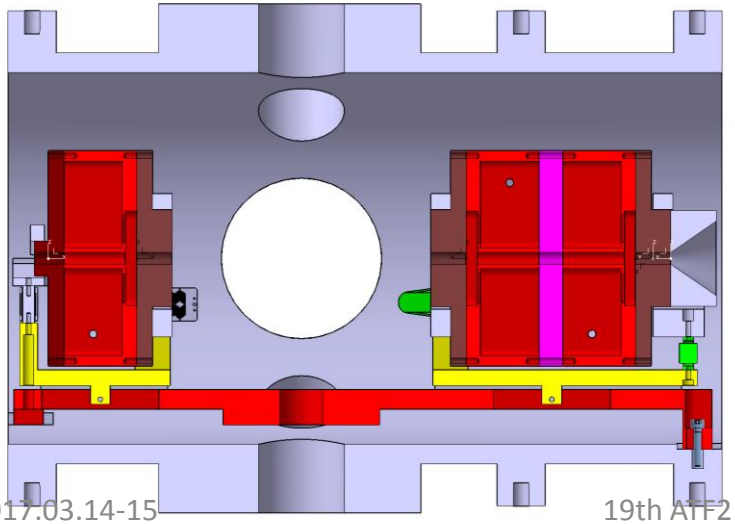
BPMs displacement system (to bring vertical and horizontal disp + a bit of roll and pitch)



3 Cedrat APA200M piezo actuators (nom. stroke / close loop res. : 230 / 2.3 μm) acting as a tripod for BPM-AB vertical disp.
(plus 1 actuator for horizontal disp. [not shown])

3 PI P-602.3S0 piezo actuators (nom. stroke / resolution : 300 / 3 μm) acting as a tripod for BPM-C vertical disp.
(plus 1 actuator for horizontal disp. [not shown])



BEAM

BPMs disp. system in the chamber install at IP - cross section

Setup for movers calibration

BPMs displacement system installed in a frame holding distance meters

Vertical calibration done at IP with SIOS interferometer (*) (sub nanometric resolution) for :

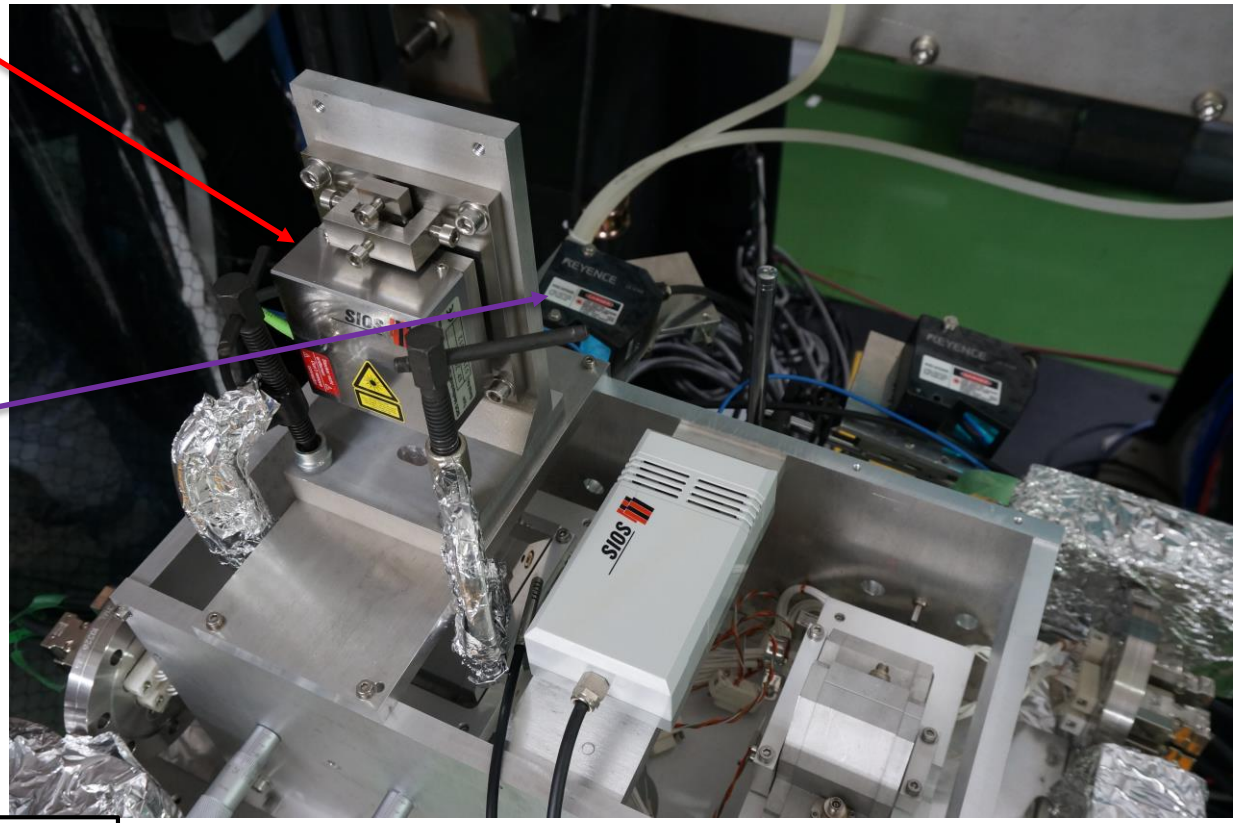
- BPM-AB Cedrat vertical movers system
- BPM-C PI vertical movers system

(Mirror for interferometry measurement set on BPM's top, therefore calibration is done for the tripod system, not for each movers)

Horizontal calibration done at IP with Keyence lasermeter (sub micrometric resolution) for :

- BPM-AB Cedrat mover (no new calibration available, data seems to have been erased by PI data)
- BPM-C PI mover

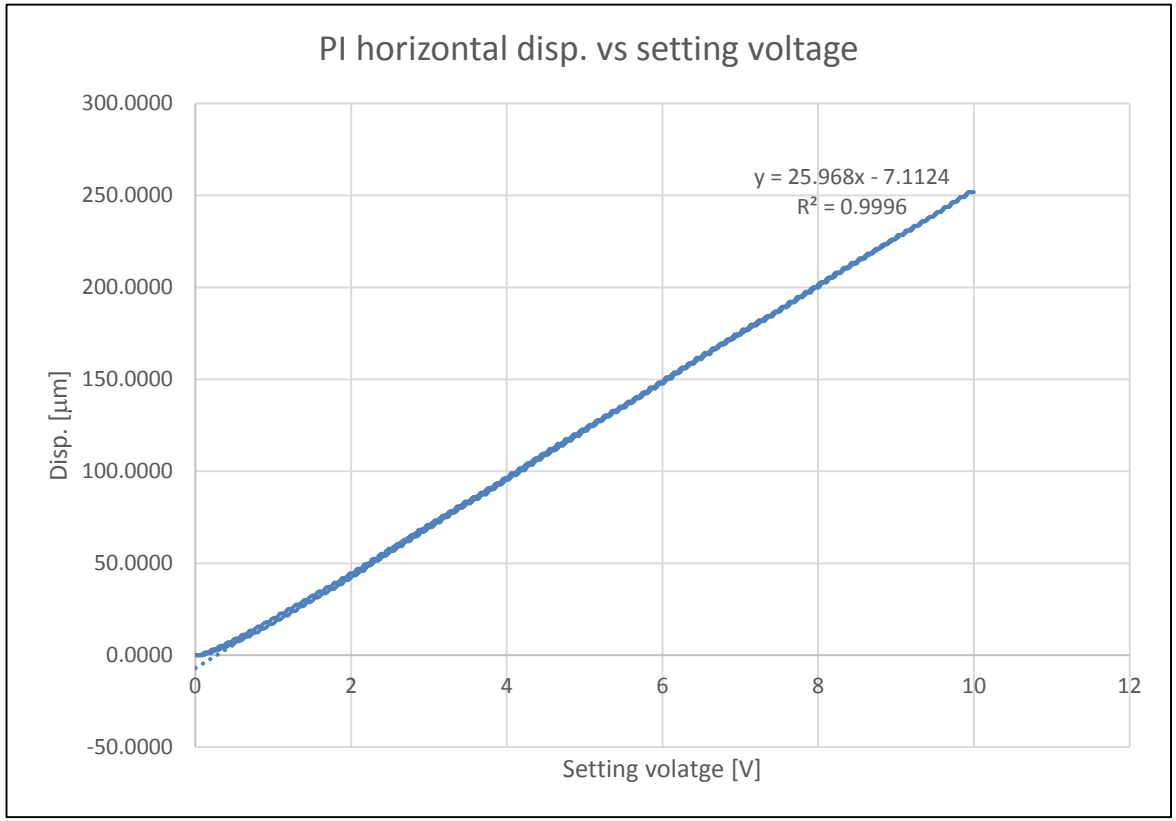
(*) Interferometer and BPMs assy installed on the frame laying on a metallic table ("bench") near IP.



Specs for measurements :
- 0.1 V step (0.5 V for PI factory calibration)
- 3 sec holding time (same for PI factory calibration)
- 5 Hz acquisition
- 10 to 13 measurements kept at every steps (measurements when moving from step to another are rejected)

For each setting voltage, 10 to 13 measurements are displayed on the following plots (i.e. not error bar).

1. Horizontal movers calibration (linear fit)

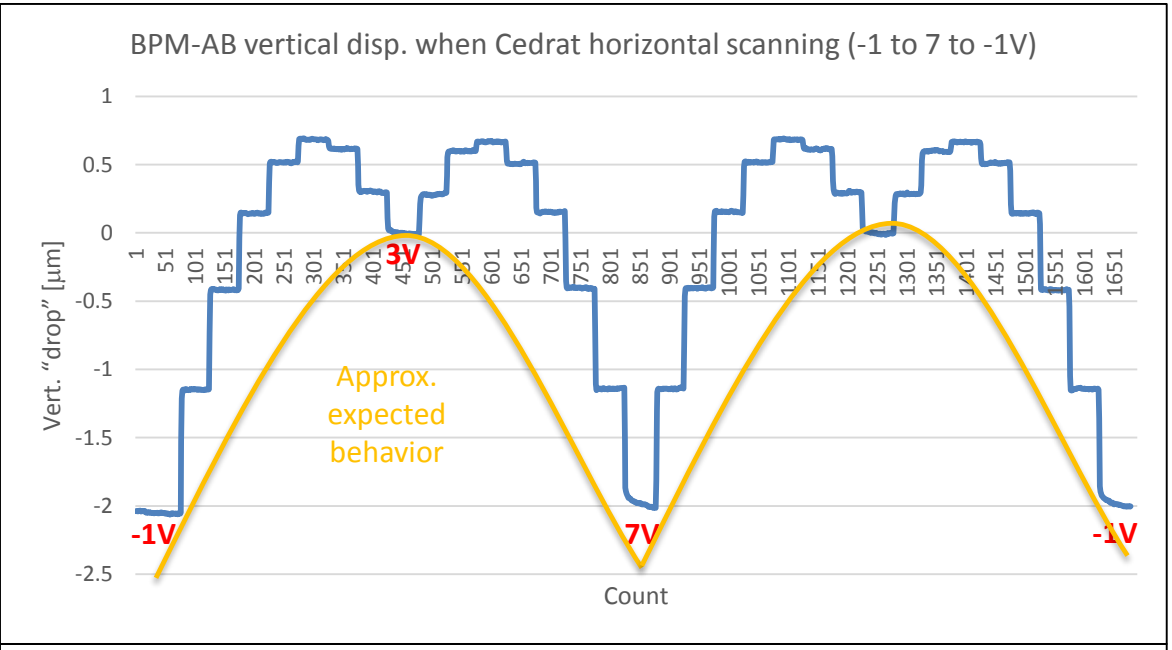


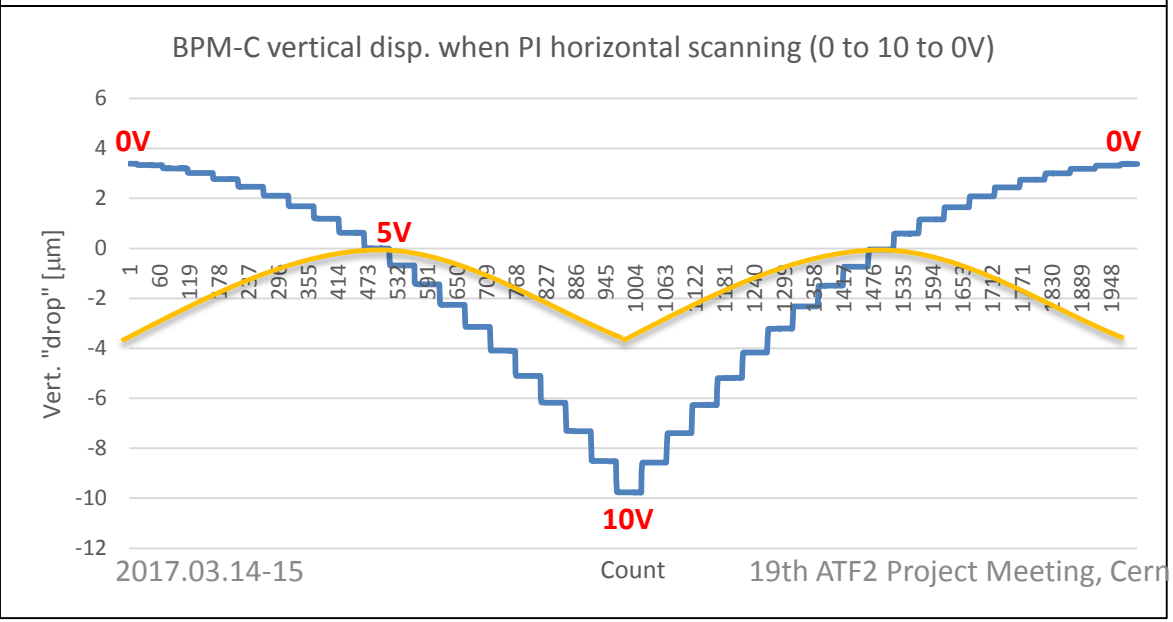
Measurements done with KEK laser-meter (sub µm resolution)

PI piezo mover :
- Can not reach expected 300 µm stroke, only 252 to 268 µm (mover is pre-stressed by elastic hinge);
- Mover behaves in continuous manner (see fig.);
- Consequently, actual gain is smaller than factory one : 25.97 µm/V

Cedrat mover : no data (erased by PI data during measurements)

2. Vertical disp. when lateral scanning (XY coupling)





Measurements done with LAL interferometer

Cedrat mover :

Little unusual behavior around 3V (mid-stroke), as vertical displacement should be negative for overall range.

Specs : 1V step, 10 sec holding time

PI piezo mover : obvious flaw

Because horizontal mover pushes on hinge (see limited stroke due to pre-stressed), vertical disp. is no longer symmetrical with respect of 5V setting voltage (mid-stroke).
Consequently, BPM-C "drop" is higher than expected (~ Cedrat value).

Specs : 0.5V step, 10 sec holding time

3. Vertical movers calibration (linear fit)

(R^2> 0.9996)

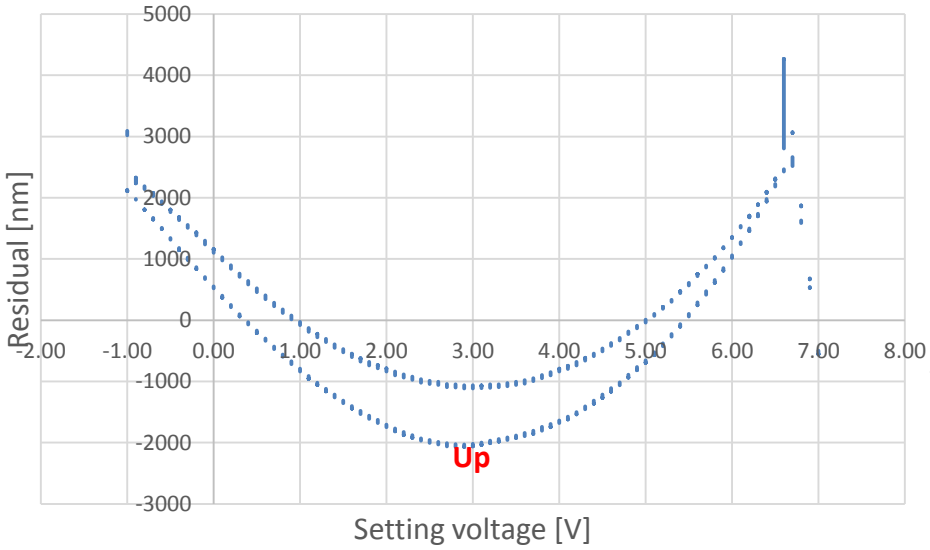
		(Cedrat)		(PI)	
		Setting voltage range [V]			
		-1 to 7	2 to 4	0 to 10	4 to 6
		Gain (slope) [μm/V]			
Cycle (or special note)	Direction (up=inc. Voltage)	Y_IPA-IPB	Y_IPA-IPB	Y_IPC	Y_IPC
1	up	30.6649	30.4838	29.9912	30.0559
1	down	30.6418	30.4955	29.9787	30.1042
2	up	30.6260	30.4899	29.9757	30.0947
2	down	30.6370	30.4938	29.9789	30.1028
3	up	30.6257	30.4965	29.9708	
3	down	30.6695	30.4972	29.9789	
4	up	30.6247	30.5016	29.9716	
4	down	30.6711	30.4913	29.9798	
Avg gain [μm/V] (arith. mean from above data)		**30.6451**	**30.4937**	**29.9782**	**30.0894**
SD [μm/V] (from above data)		0.0203	0.0054	0.0063	0.0227
Gain [μm/V] (overall fit for a 4 cycle path)		30.6454	30.4943	29.9782	30.0855

	Gain from factory calibration in close loop [mm/V]		
mover	Cedrat (2012.11.06)	PI	mover
CH1-07013	30.42	missing	1
CH2-07013	30.59	missing	2
CH3-07013	30.67	missing	3
CH1-11014	30.34	missing	4

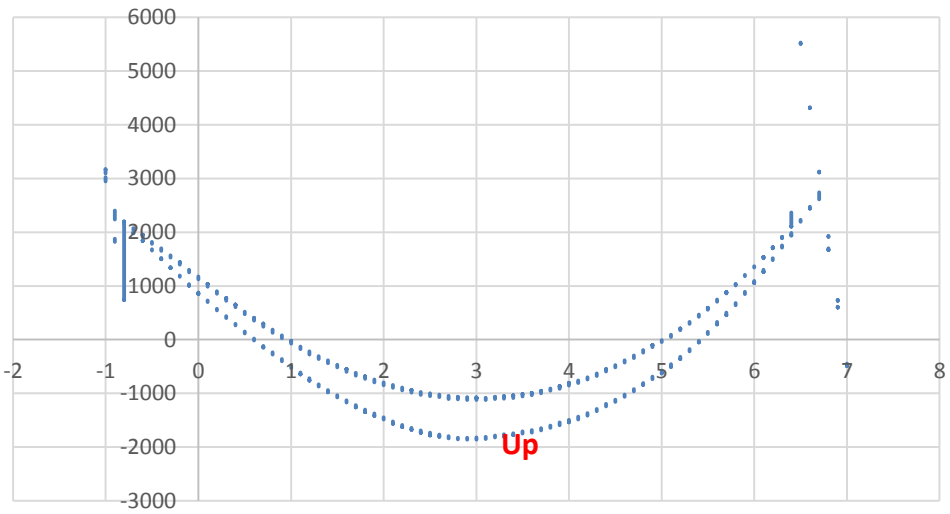
Vertical Cedrat mover system - residual (-1 to 7V)

(Residual = measured displacement minus calculated disp. from linear fit)

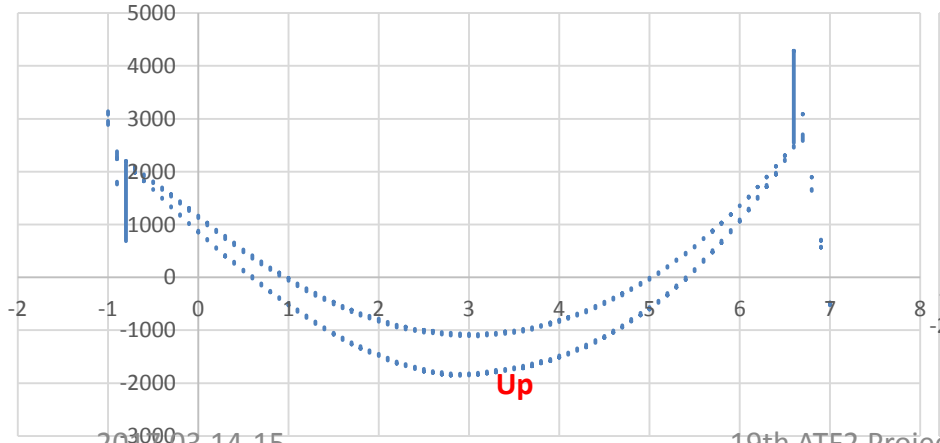
Cycle #1 - Residual [nm] vs setting voltage [V]



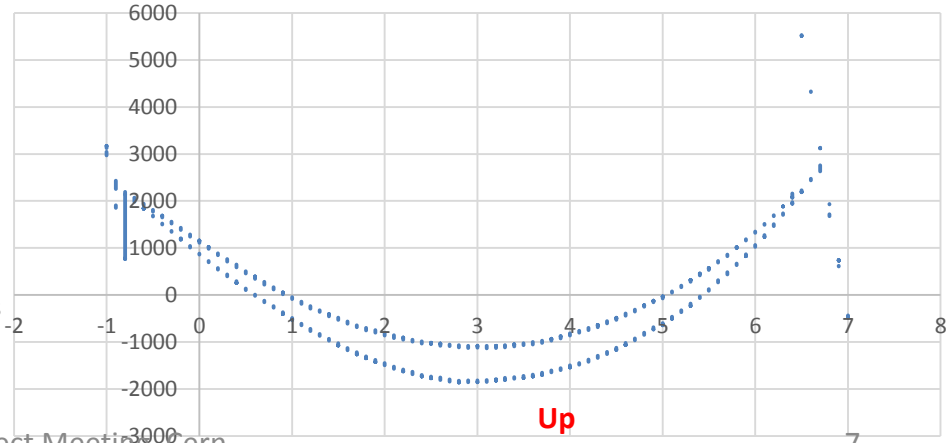
Cycle #3 - Residual [nm] vs setting voltage [V]



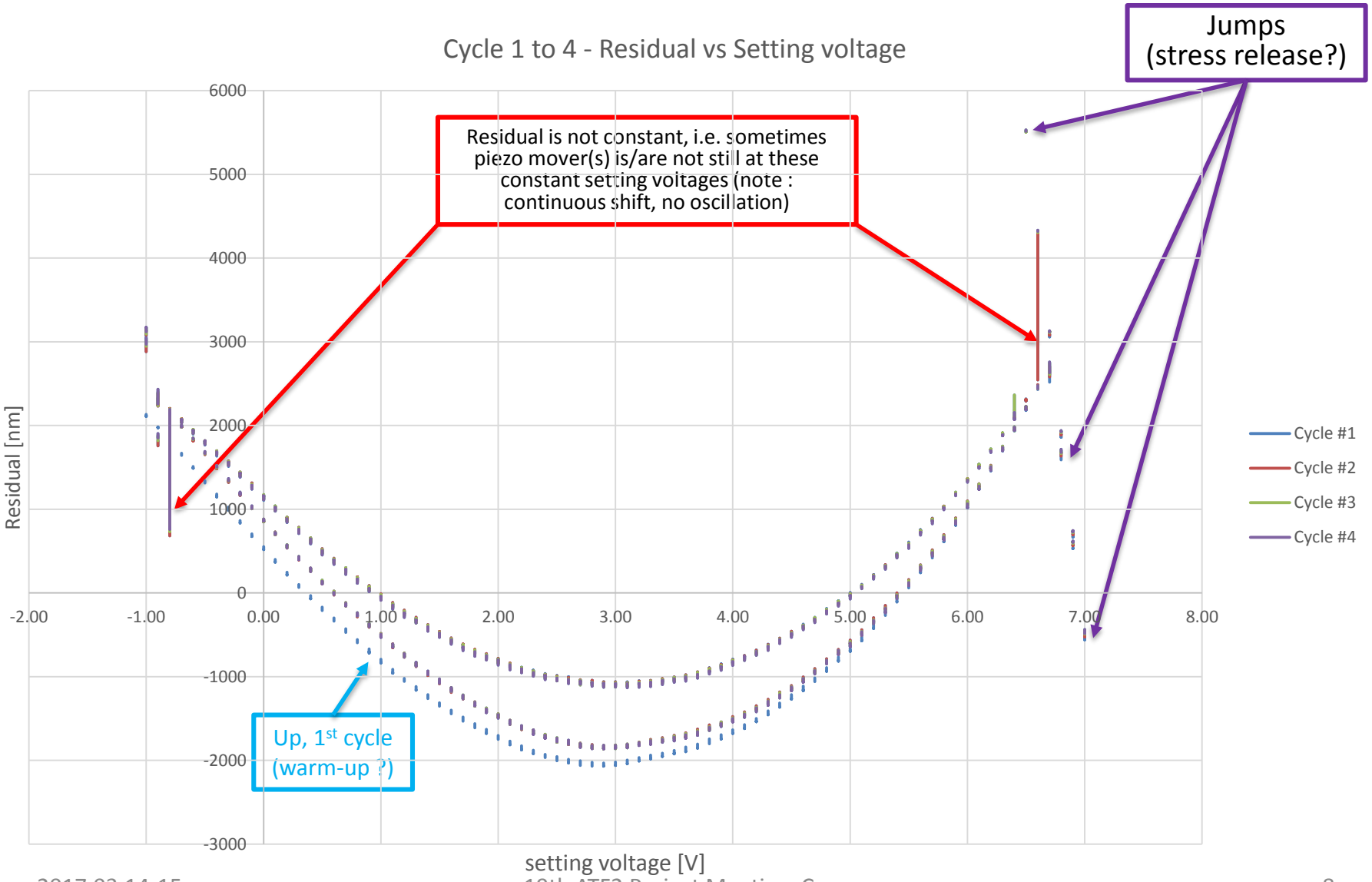
Cycle #2 - Residual [nm] vs setting voltage [V]



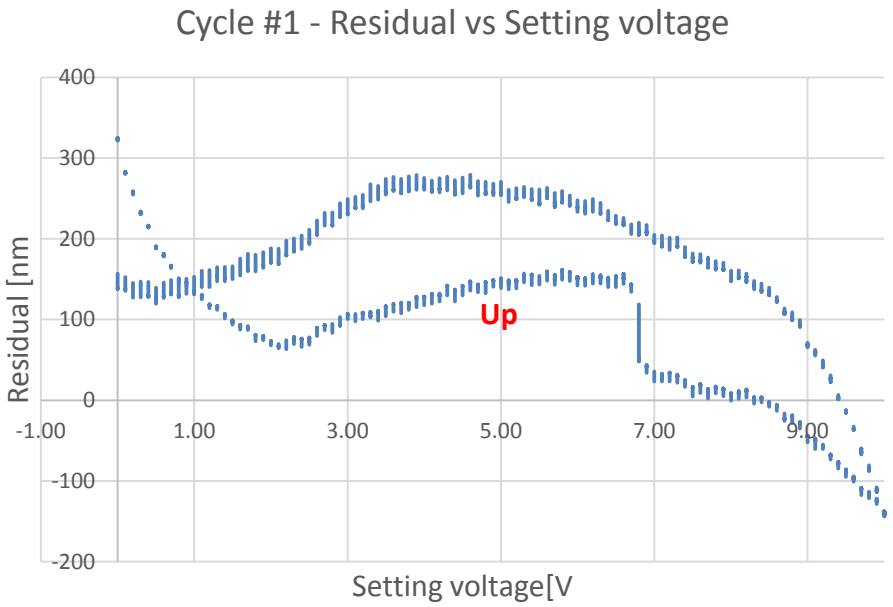
Cycle #4 - Residual [nm] vs setting voltage [V]

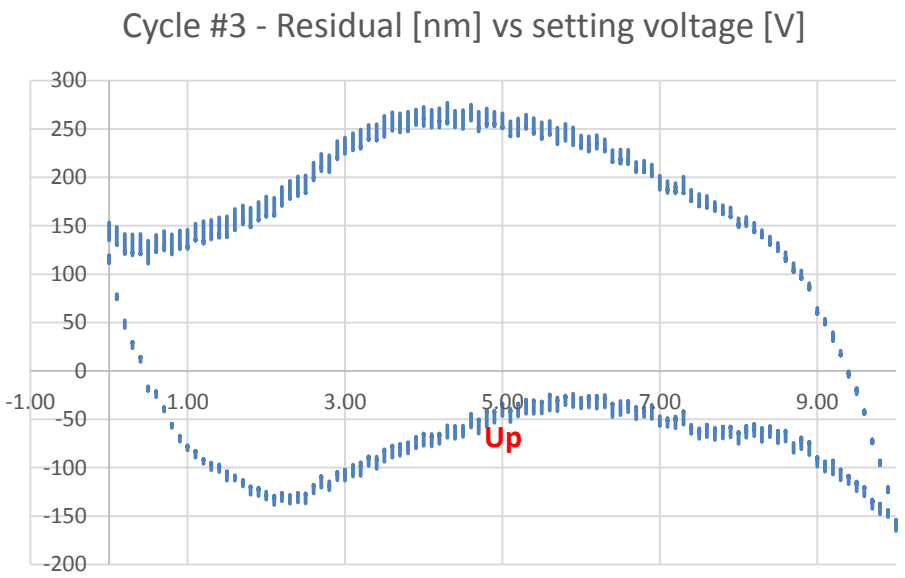


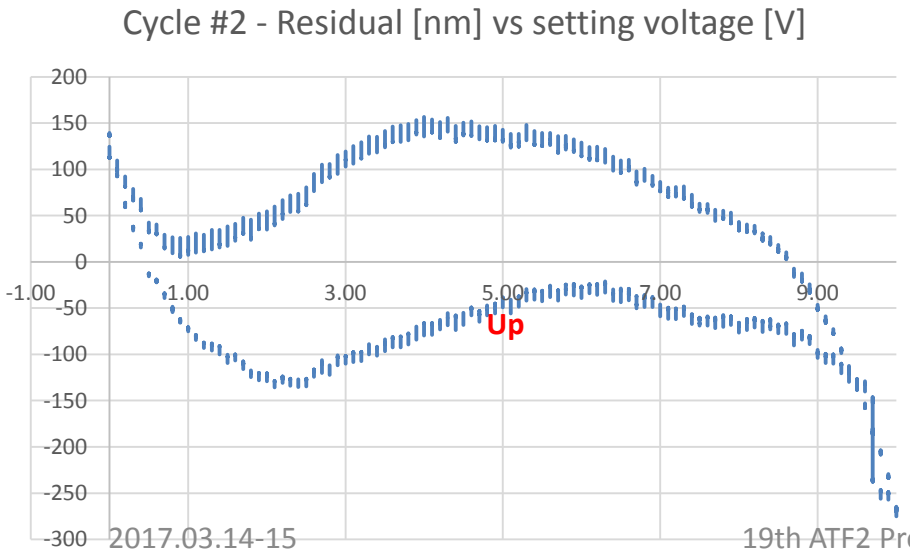
Vertical Cedrat mover system - residual (-1 to 7V ; 4 cycles)

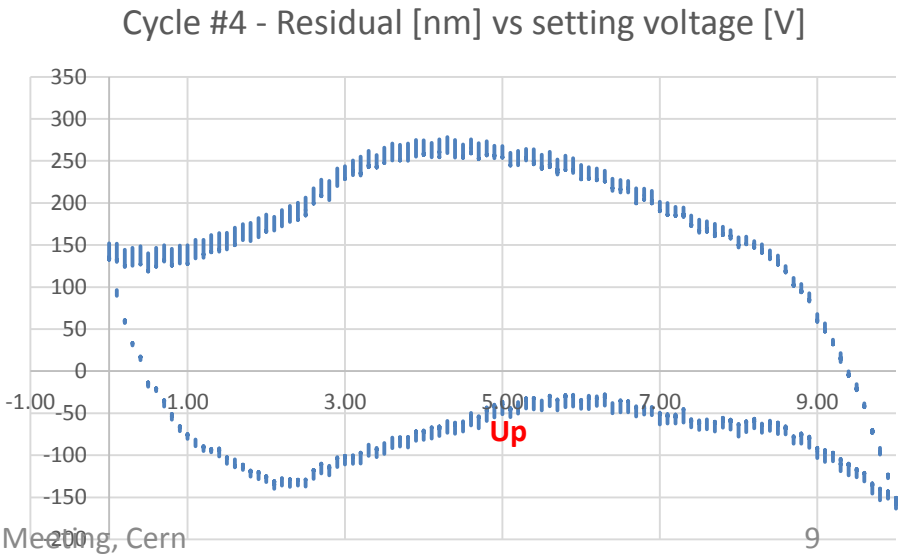


Vertical PI mover system - residual (0 to 10V)

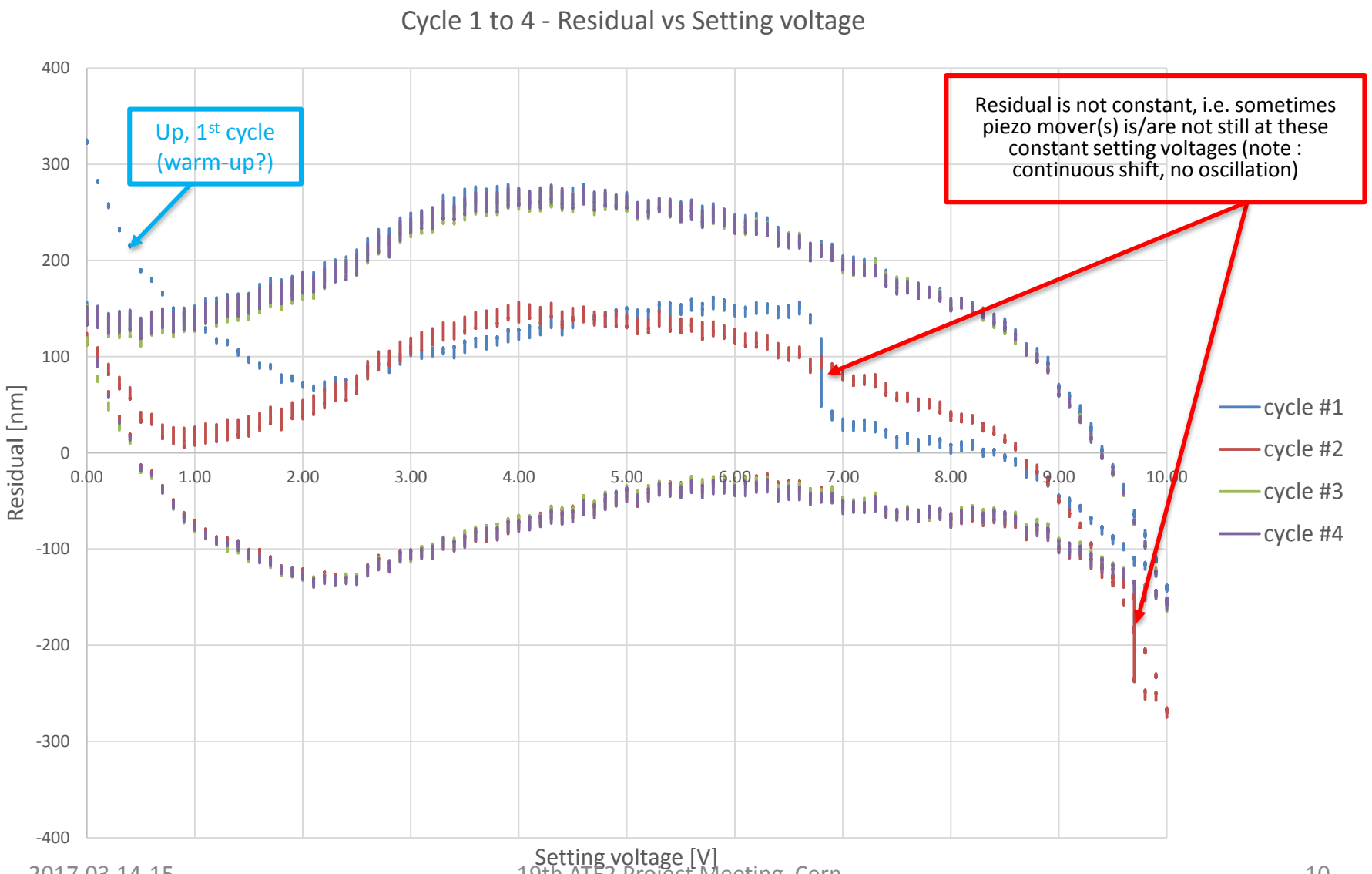








Vertical PI mover system - residual (0 to 10V ; 4 cycles)



Vertical calibrations (full range, linear fit) – analysis

a) At full range, smaller gain standard deviation for PI than Cedrat (0.0063 vs 0.0203 μm/V), but lack of data to be relevant (only 4 cycles).

b) Cedrat : Accident in the ranges -1 to -0.8V and 6.4 to 7V. With reduced range (i.e. previous ranges excluded), tripod system raw accuracy is -2.1/+1.9 μm (max deviation from linear fit) → accuracy ~ 1/120 of stroke (reduced stroke) when ~ 1/700 is expected (for a single actuator) !

c) PI : Good accuracy for the tripod system : -0.28/+0.32 μm for full range operation, reduced to -0.14/+0.27 μm when rejecting 0 to 0.5V (warm up?) and 9.5 to 10V (shift) → accuracy ~ 1/1000 of stroke as expected.

4. Vertical movers calibration

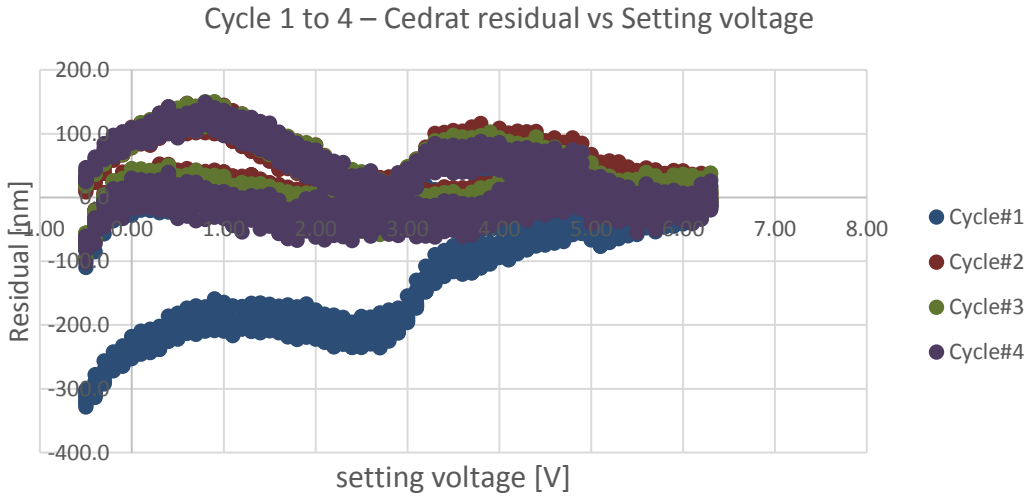
(non-linear fit + slightly reduced stroke)

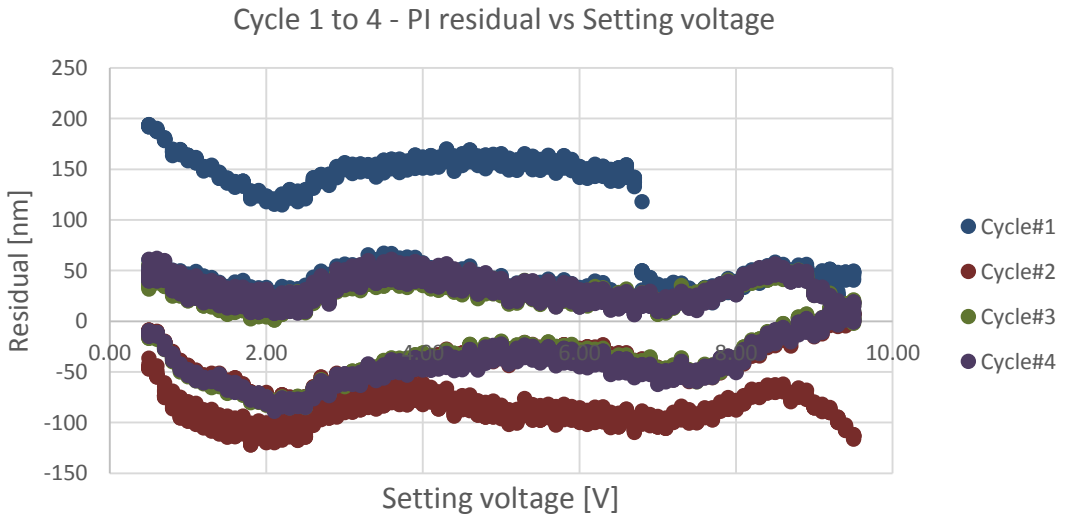
Residual from cubic polynomial fit

	Cedrat polynomial fit coeffs (-1 to 7 to -1V travel ; calculated without -1 to 0.4V and 6.4 to 7V data)			
	a [nm/V^3]	b [nm/V^2]	c [nm/V]	d [nm]
4 ups	9.63397	222.106	29013.5	29234.1
4 downs	6.52030	198.9	29255.2	29594.1

With cubic polynomial fit and reduced stroke (see in red), Cedrat and PI movers are almost in the same range of accuracy (roughly +100/-200 nm or +200/-100 nm)

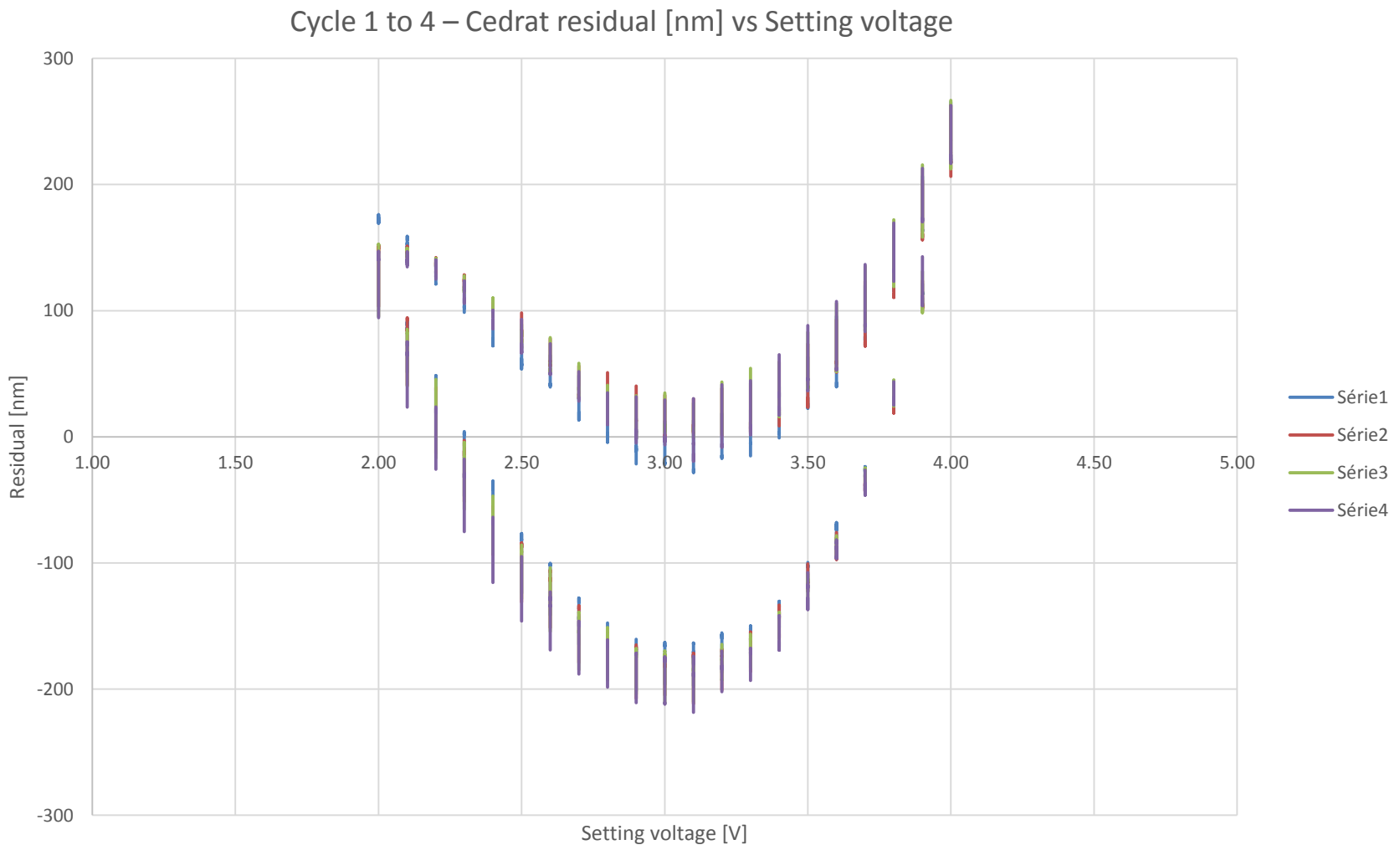
	PI polynomial fit coeffs (0 to 10 to 0V travel ; calculated without 0 to 0.4V and 9.6 to 10V data)			
	a [nm/V^3]	b [nm/V^2]	c [nm/V]	d [nm]
4 ups	-1.63945	21.8446	-30055.1	-293.296
4 downs	-0.49394	-2.33170	-29919.0	-272.911





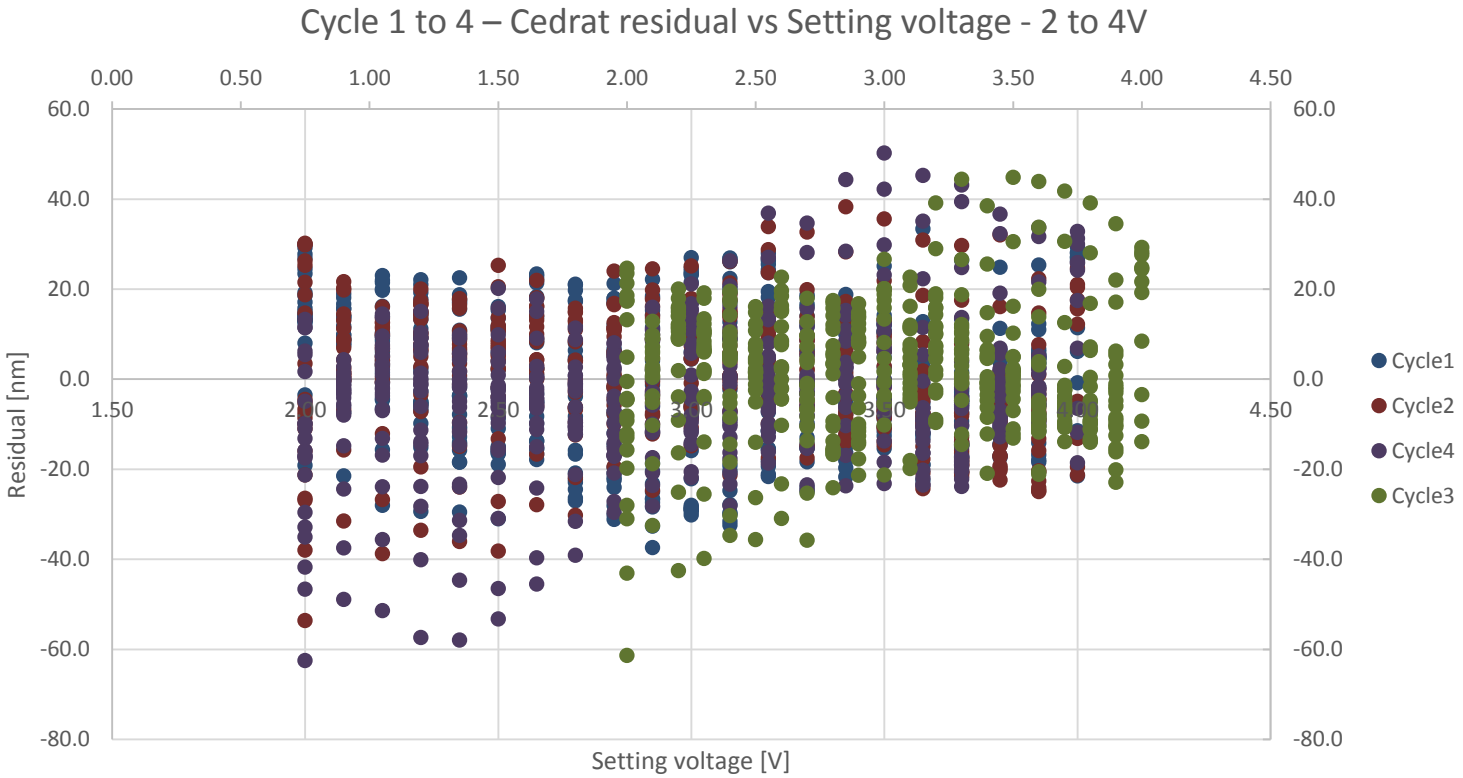
Working around mid stroke

Vertical Cedrat movers system – residual from linear fit (2 to 4V ; 4 cycles)



Working around mid stroke

Vertical Cedrat movers system – residual from cubic polynomial fit (2 to 4V ; 4 cycles)

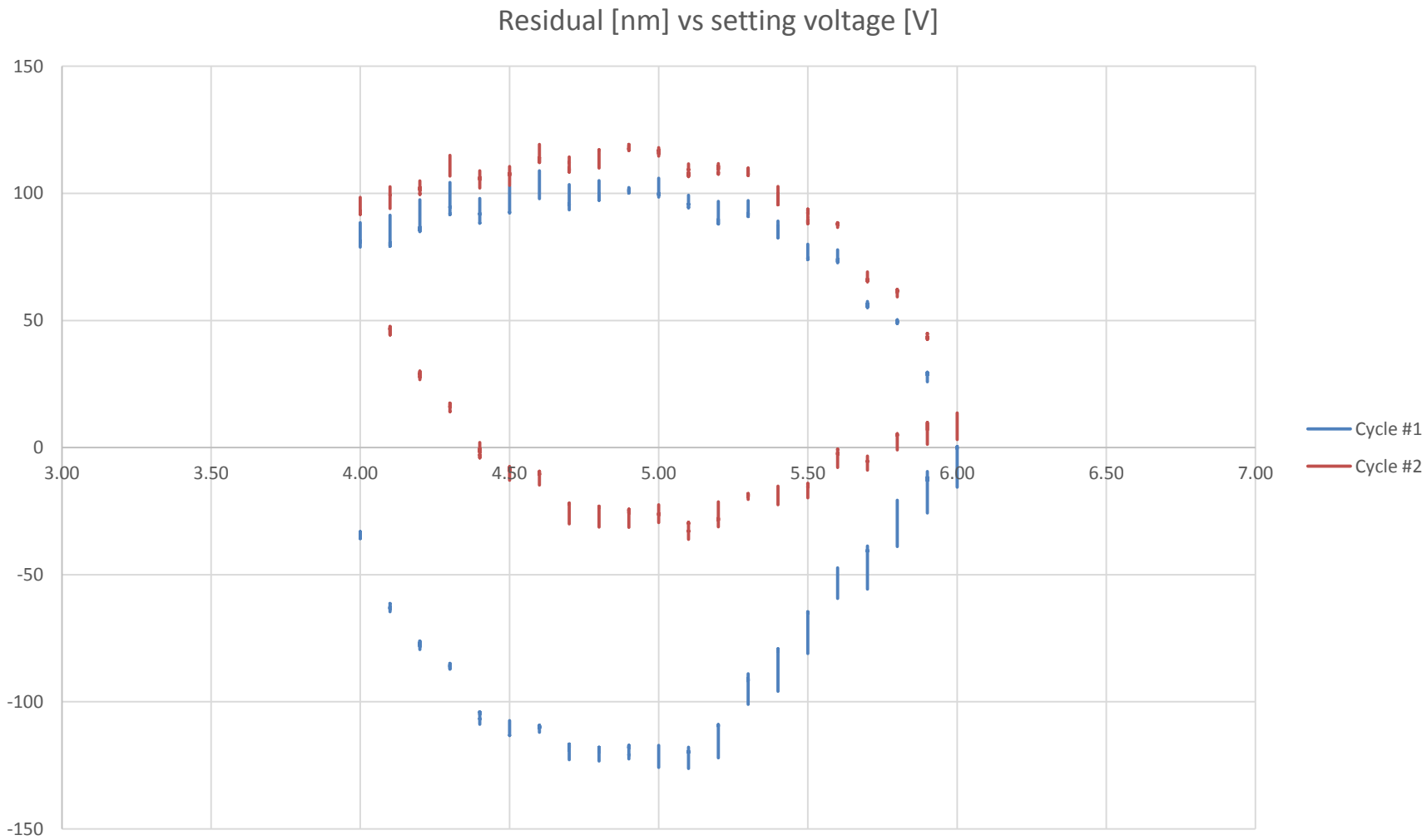


	Cedrat polynomial fit coeffs (2 to 4V travel)			
	a [nm/V^3]	b [nm/V^2]	c [nm/V]	d [nm]
4 ups	100.914	-718.608	32021.1	-61998.8
4 downs	73.6114	-315.872	30362.7	-60108.8

Working around mid stroke

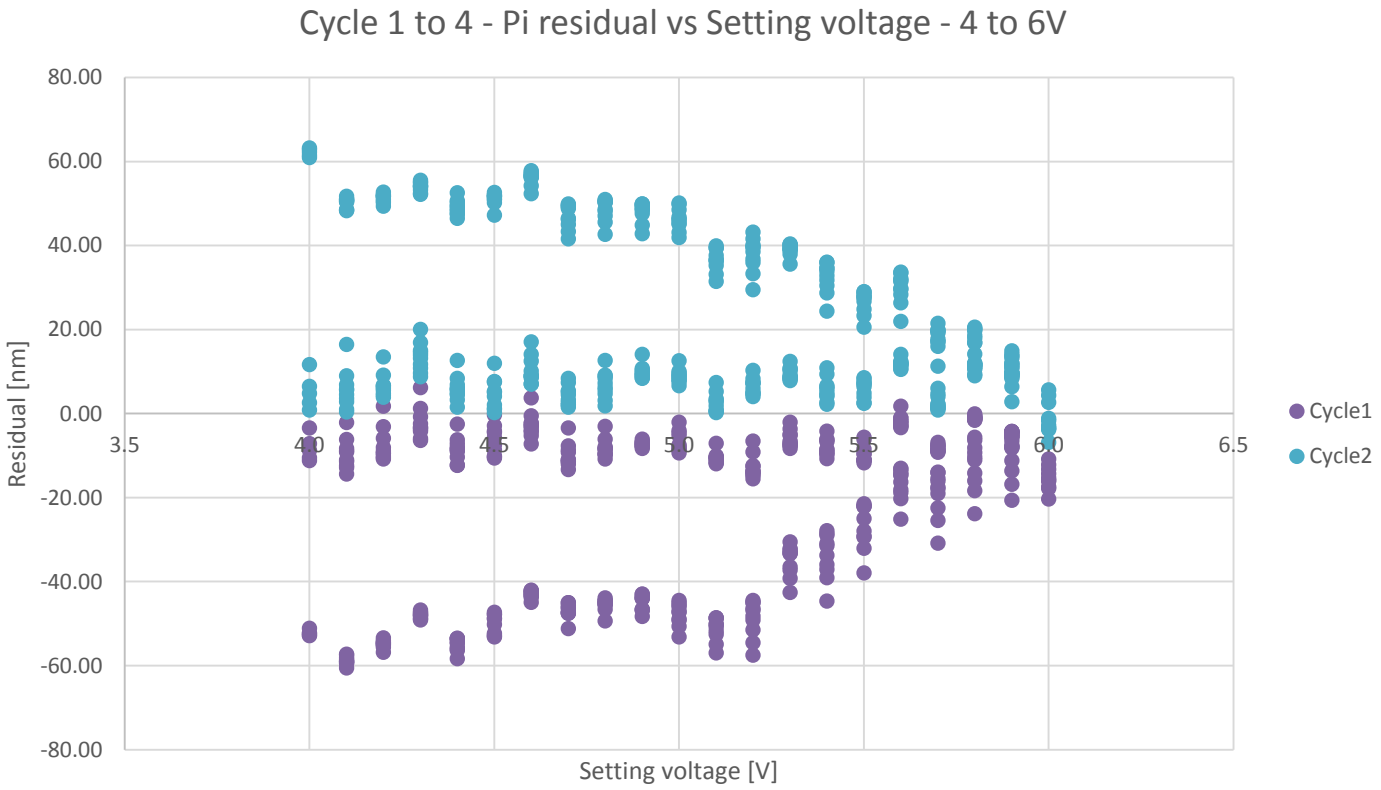
Vertical PI movers system – residual from linear fit

(2 to 4V ; 2 cycles over 4 [corrupted data])



Working around mid stroke

Vertical PI movers system – residual from cubic polynomial fit (2 to 4V ; 2 cycles)



	PI polynomial fit coeffs (4 to 6 to 4V travel)			
	a [nm/V^3]	b [nm/V^2]	c [nm/V]	d [nm]
2 ups	-31.4916	556.339	-33253.6	126186
2 downs	-28.3160	370.133	-31664.9	122681

Vertical calibrations (cubic polynomial fit) – analysis

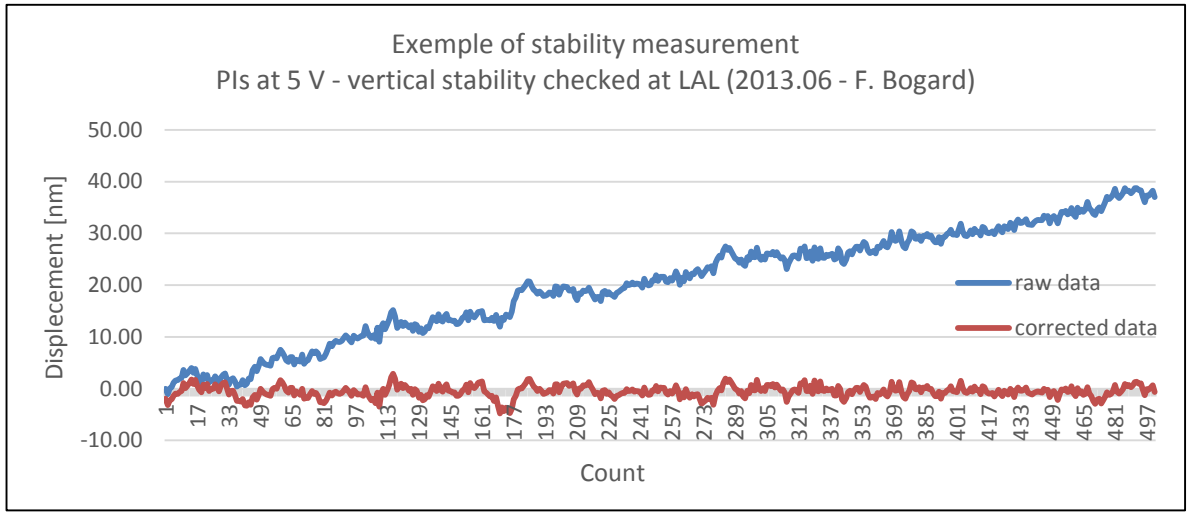
Cedrat's systematic error can be dramatically reduced with cubic polynomial fit. In this case, Cedrat is close to the PI's accuracy level, especially with short range around mid-stroke.

Full range with rejected data :
PI → raw rel. accuracy ~8×10^{-4} (200 nm / 270μm)
Cedrat → raw rel. accuracy ~1.1 to 1.7×10^{-3} (200 or 300 nm / 174μm)
Raw accuracy = no statistical analysis (only 4 cycles taken)

Around mid-stroke, 2V range :

Lack of data for PI (only 2 cycles), but both Cedrat and PI tend to be within a band of +/- 60 nm for the same reduced stroke (60 μm).
→ raw rel. accuracy ~10^{-3} (60 nm / 60μm)

5. Vertical movers stability at mid stroke



Stability checks were done at
- LAL in 2013.06 (F. Bogard)
(just before shipping goods to KEK)
- KEK in 2016.10 (S. Wallon).

Set-up / method (2013)

Raw data corrected by subtracting linear component (16 hits moving windows) to compensate shifting measurements. Measurement at 5Hz during 100 sec.

Origin of shifting

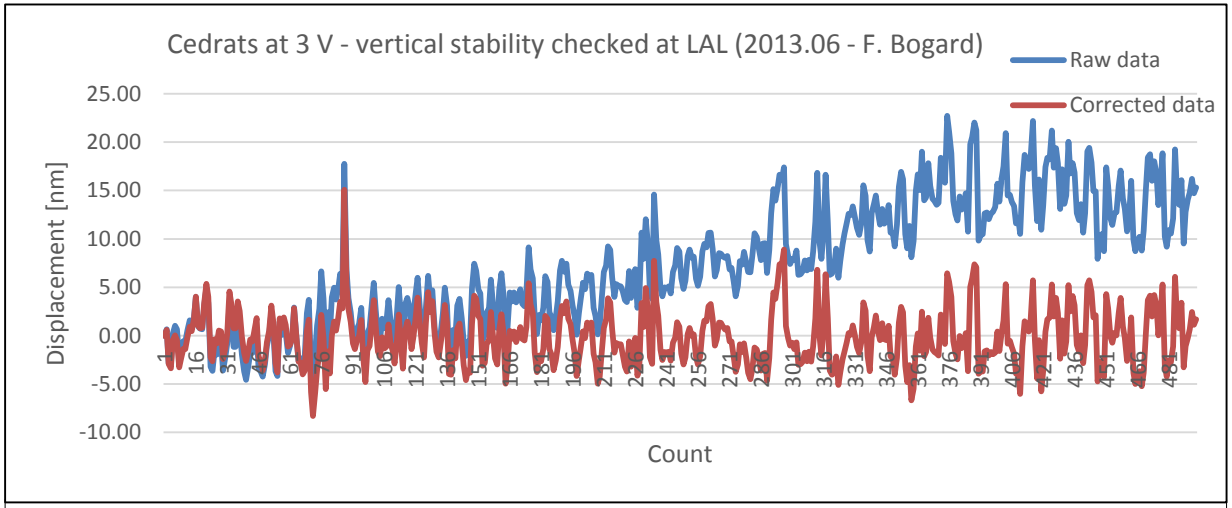
Probably mostly comes from the thermal dilation of the mechanical parts (interferometer head support).
(Laser wave length shift is compensated. Interferometer head is made of invar.)

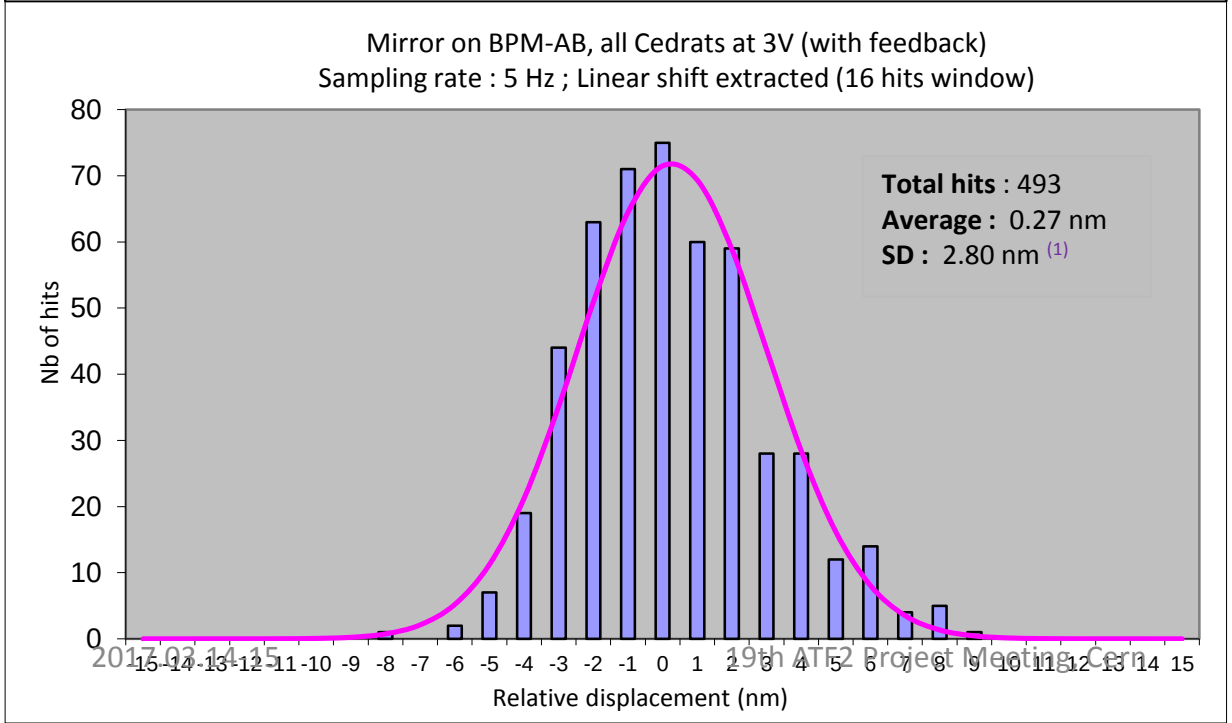
Set-up / method (2016)

2013 method was reused to compare 2013 and 2016 results (except 200 sec records in 2016, i.e expected BPMs scanning time with beam on).
… But raw data were used too, as thermal shifting is not obvious : on one hand, resultant thermal dilation is reduced thanks a shorter support for the 2016 setup ; on the other hand, 2016 measurements (following pages) do not show a correlation between temp. and measured displacement during 200 sec records.

Cedrat vertical movers stability at mid stroke

(at LAL in June 2013)





SD [nm] :

1st meas. : 5.93 (1) / 6.26 (2)

2nd meas. : 5.98 / 7.74

3rd meas. : 5.49 / 5.56

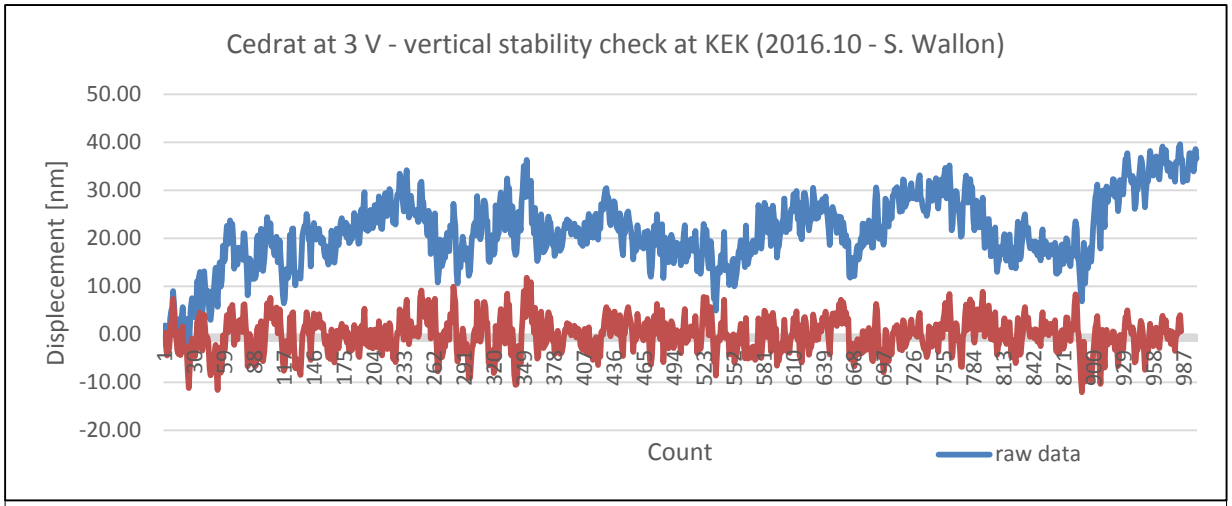
4th meas. : 2.80 / 2.82

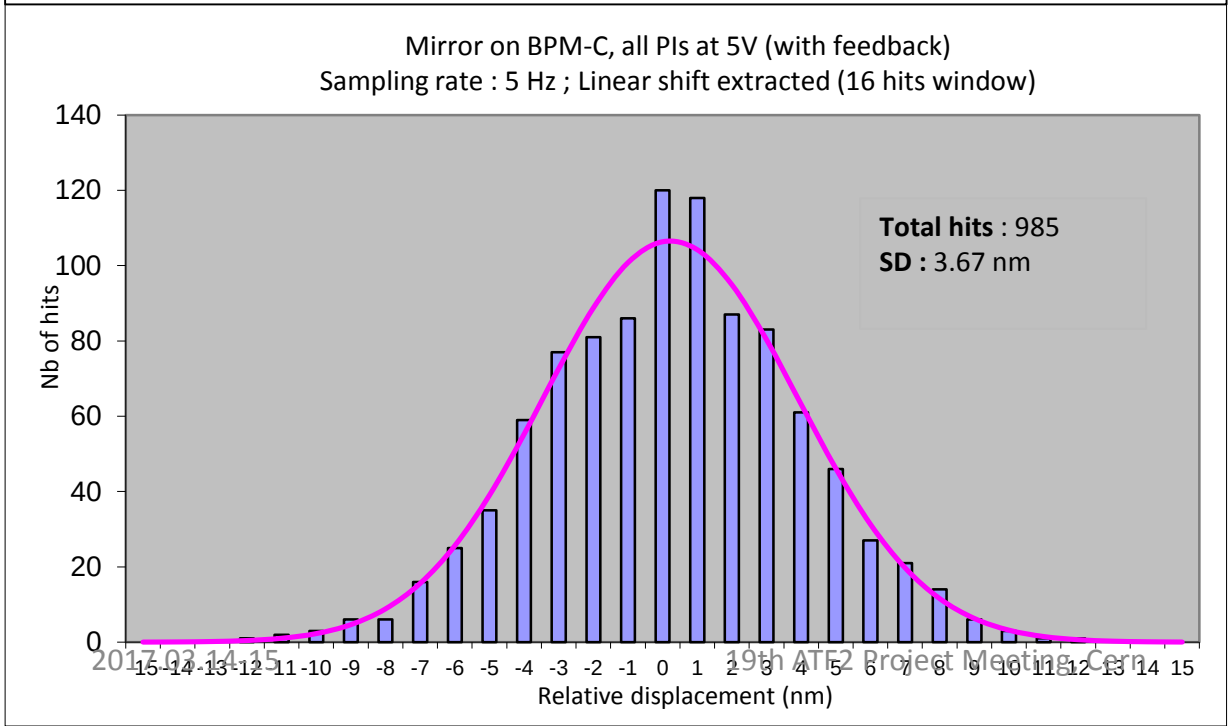
(1) From histogram

(2) Recalculated in 2017 from 2013 corrected data (with 15 last corrected data rejected)

Cedrat vertical movers stability at mid stroke

(at KEK in Oct. 2016)





SD = 3.67 nm (corrected data)

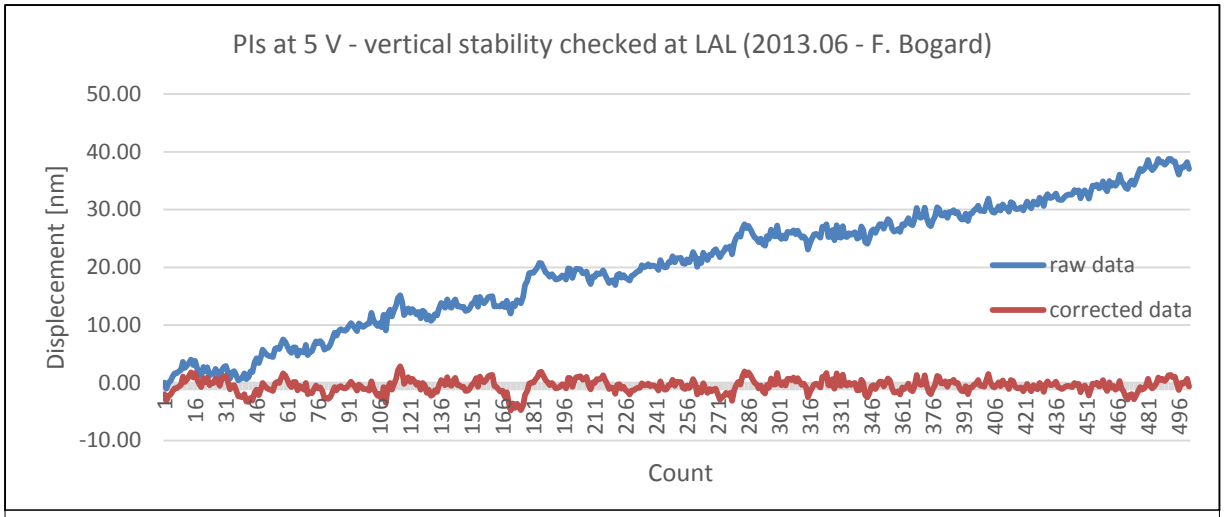
→ SD remains in the same range as in 2013

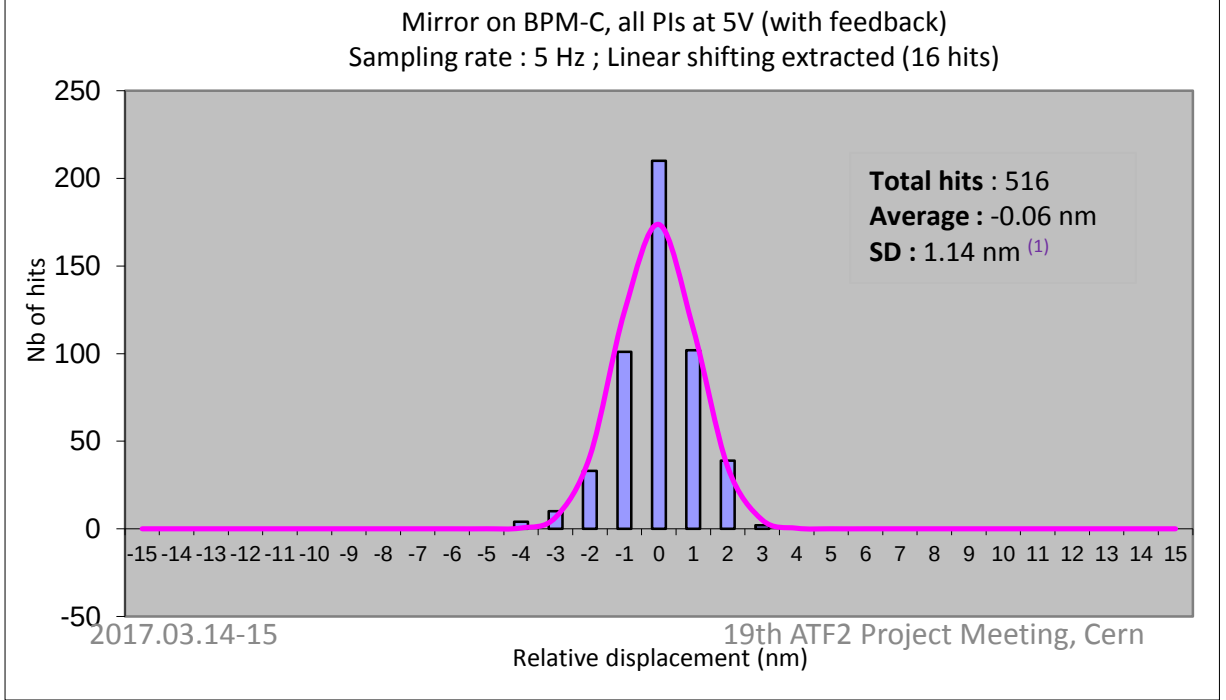
… But during measurement, air temp. was quasi-constant : 27.126 °C to 27.125°C.
A 1/1000 °C temp. rise leads to about 2 nm thermal expansion for a 10 cm long Al part.
→ measurements shift is not a thermal expansion issue.

SD = 7.37 nm (raw data)

PI vertical movers stability at mid stroke

(at LAL in June 2013)



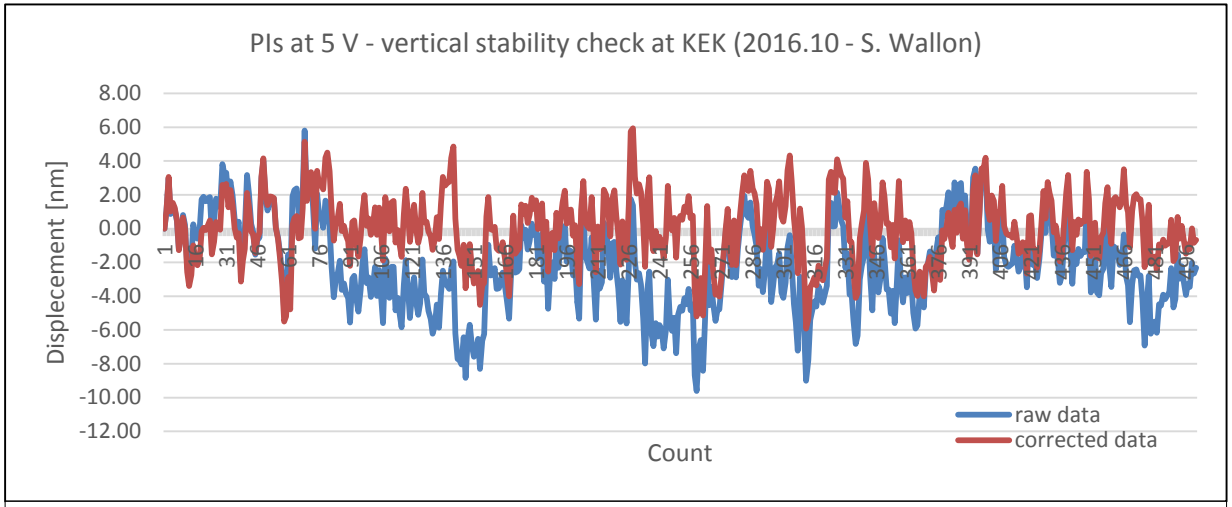


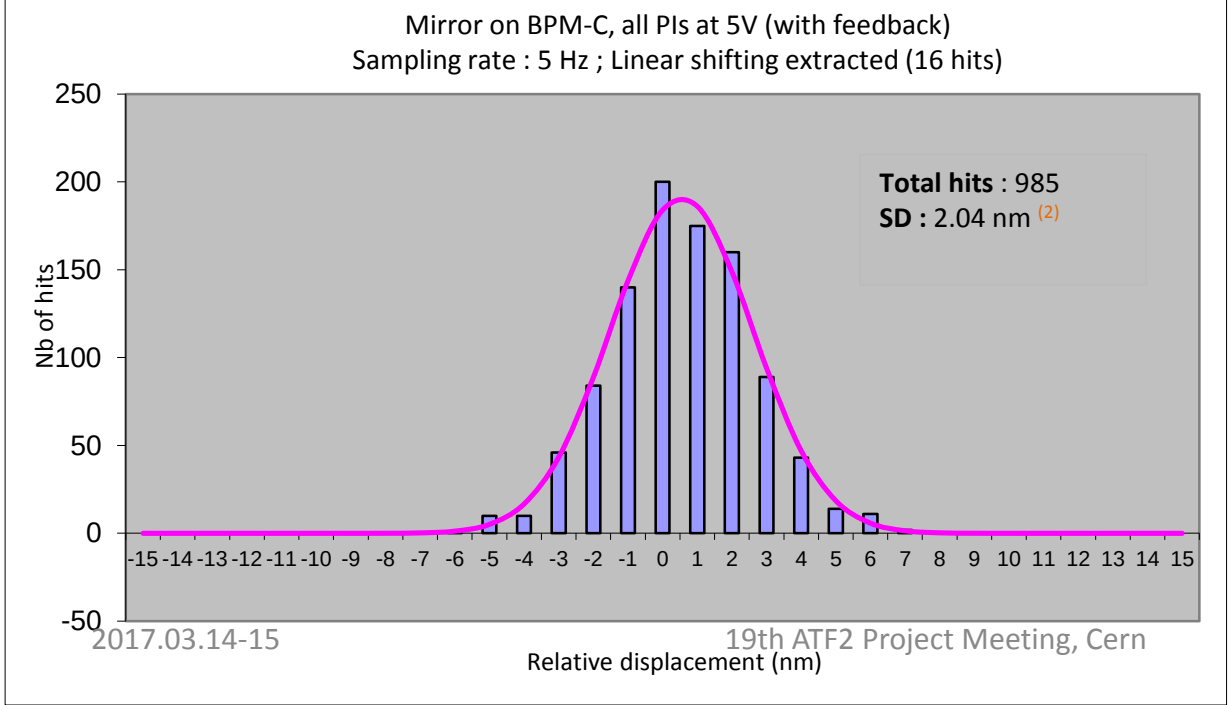
Measurements shift despite air sensor probe giving a constant temp. (2.683 to 2.684°C).

(Two other trials were done at that time with very close standard deviations).

PI vertical movers stability at mid stroke

(at KEK in Oct. 2016)





SD = 2.04 nm
(from raw data SD = 3.30 nm)

→ SD remains in the same range as in 2013

Temperature :
During measurement, temp. continuously went up from 27.264°C to 27.292°C

Conclusion

1. Lateral PI mover has a slightly limited stroke (max disp. 252 to 268 mm), but works continuously.
2. XY couplings not as expected, especially for PI (large positive and negative "drop").
3. Vertical calibrations

   With linear fit, PI movers tripod system meet the "expected" specs (rel. accuracy ~ 1/1000 of stroke), but not the Cedrat one (~ 1/1000 , far from no less than 1/700).

   Some leads for Cedrat movers (but useful for PI):
   a) Eliminate the systematic error to improve accuracy by using 2 cubic polynomial fits (one for up, one for down) instead a single cst (gain).
   → rel. acc. ~8×10^{-4}/1.1 to 1.7×10^{-4} (PI/Cedrat).

   b) Work within a short range (2V) around mid-stroke → rel. acc. ~10^{-3} for both movers

   c) Avoid scanning at max voltage (keep a 0.5V at end of range, even 0.6V for Cedrat).

4. Vertical stability (worse case SD) at 3.3 nm (PI) and 7.4 nm (Cedrat).
   Stability expected to be better when BPMs disp. system installed in the chamber at IP (than done on a table on the ground).
5. Campaign of measurements done too quickly in Oct. 2016.
   More data should have been gathered (→ statistical study, warm up effect analysis).
   New campaign of measurements to be done ?