FONT Meeting

Friday 3 August 2018

Stripline BPM results

(June 2018)

Douglas BETT

Data covered this presentation

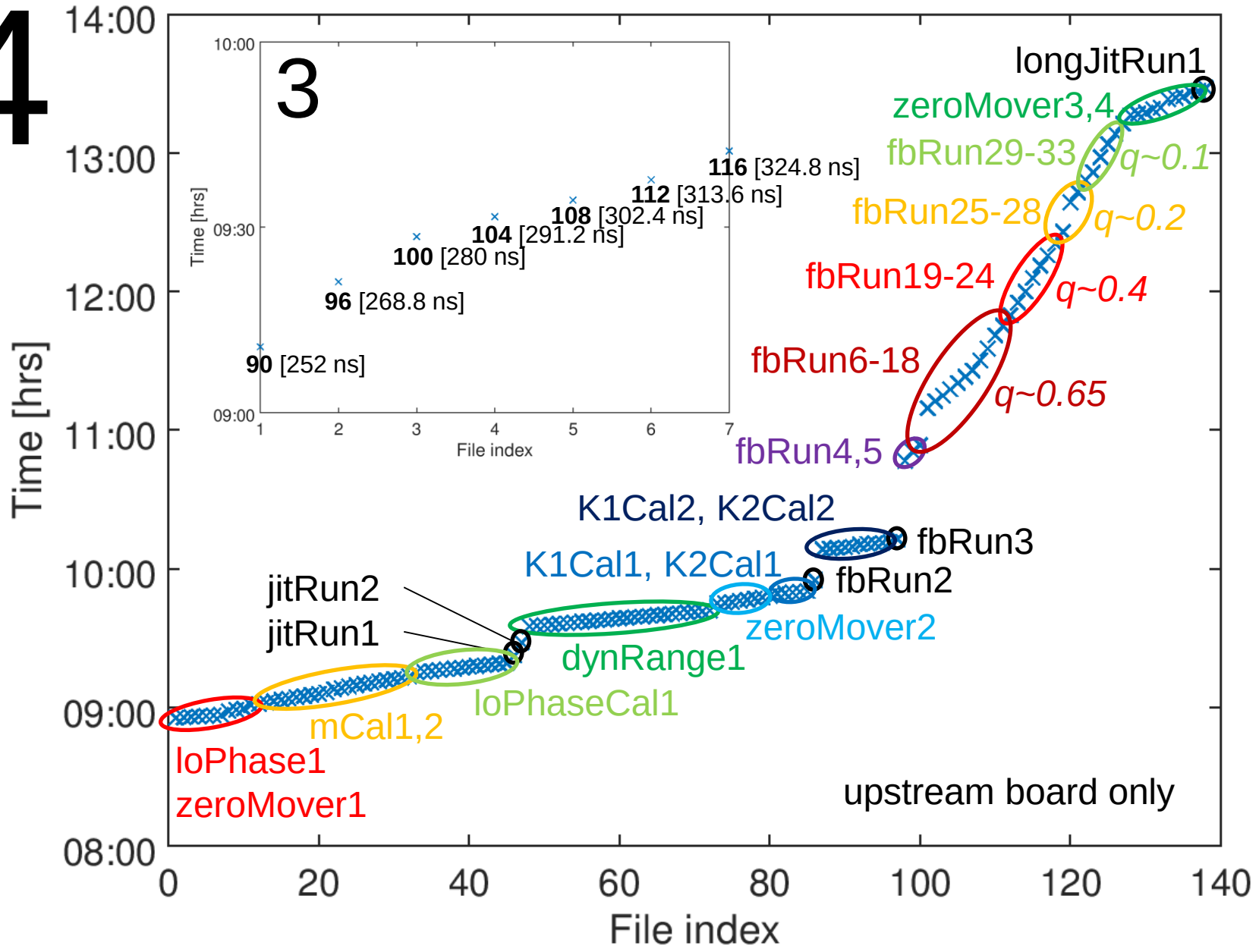
<u>Bunch spacing scan</u>
(slides 3-8)

from day shift Thu 21 June 2018

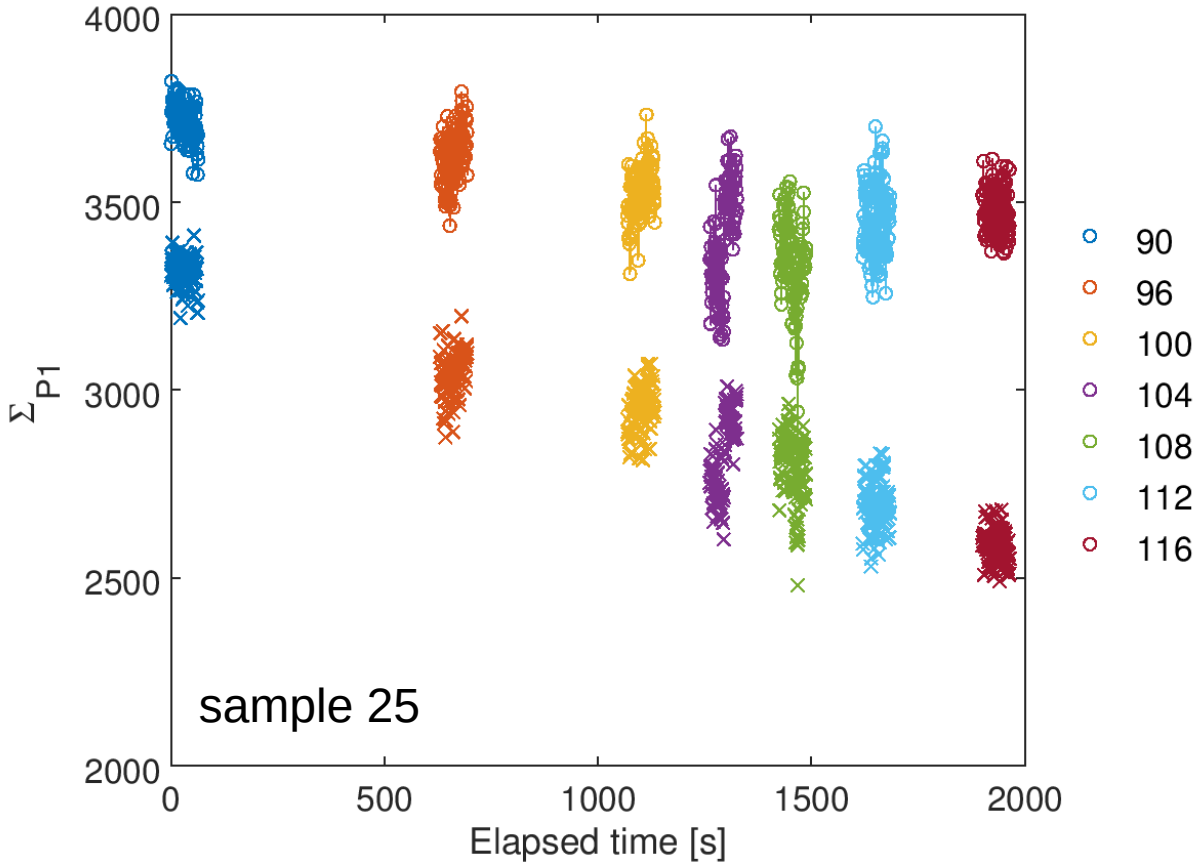
<u>Stripline system diagnostics</u> with diode processor on P1 and working stripline phase shifters (slides 9-25)

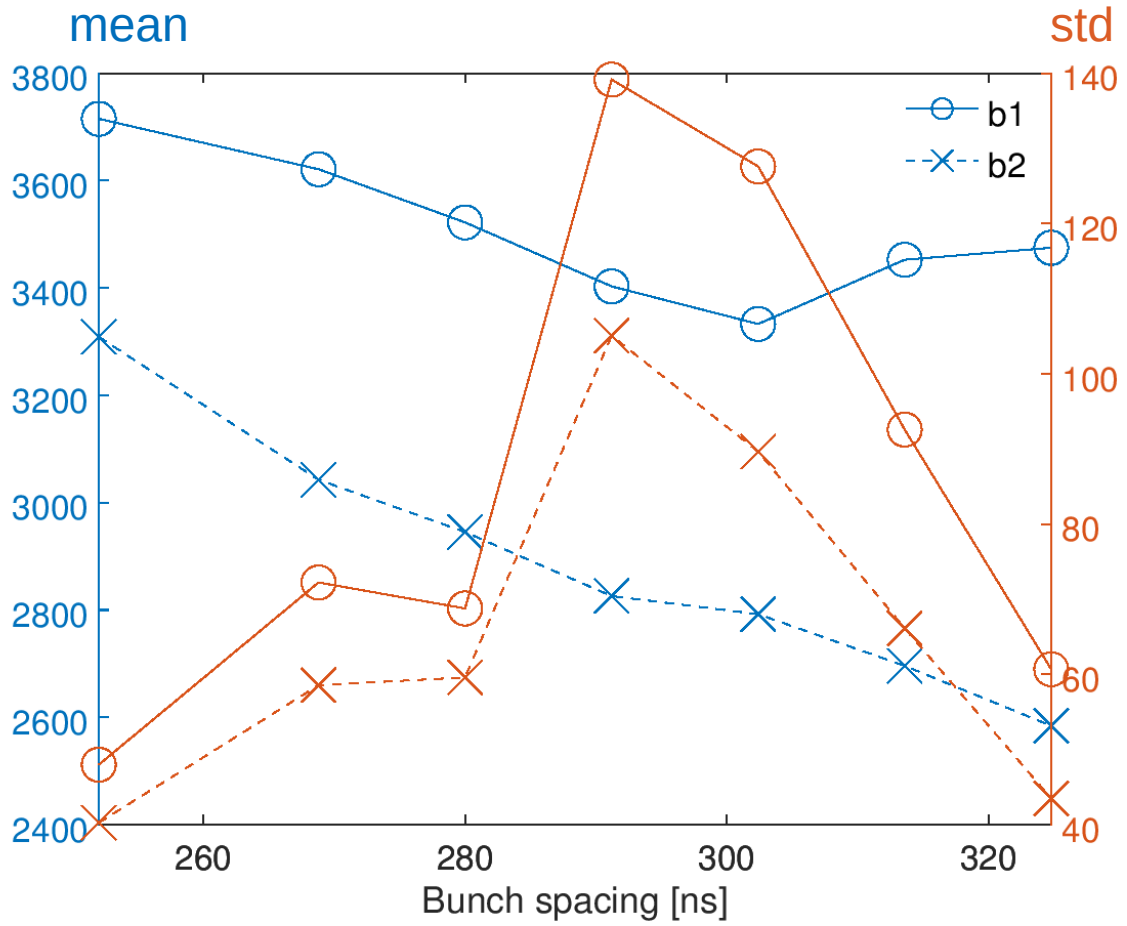
<u>Results of upstream feedback</u>
(slides 26-41, Appendix A)

from day shift Fri 22 June 2018



Bunch spacing scan: bunch charge

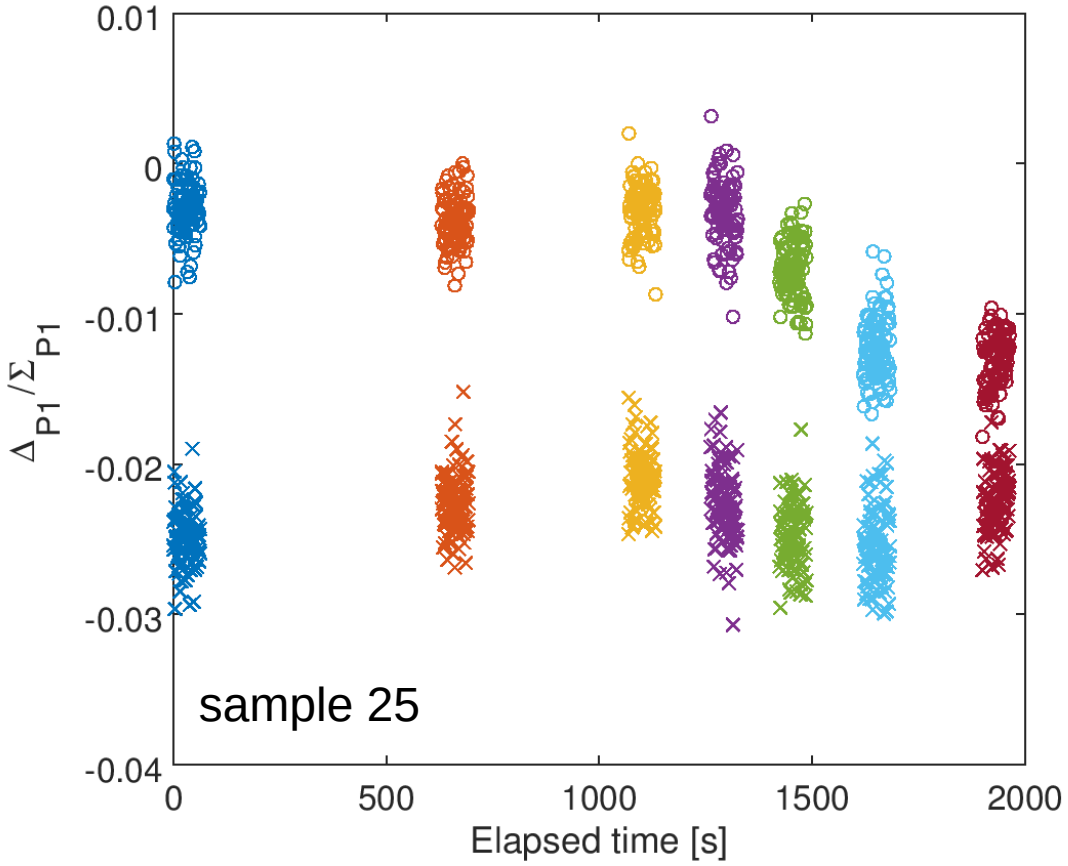


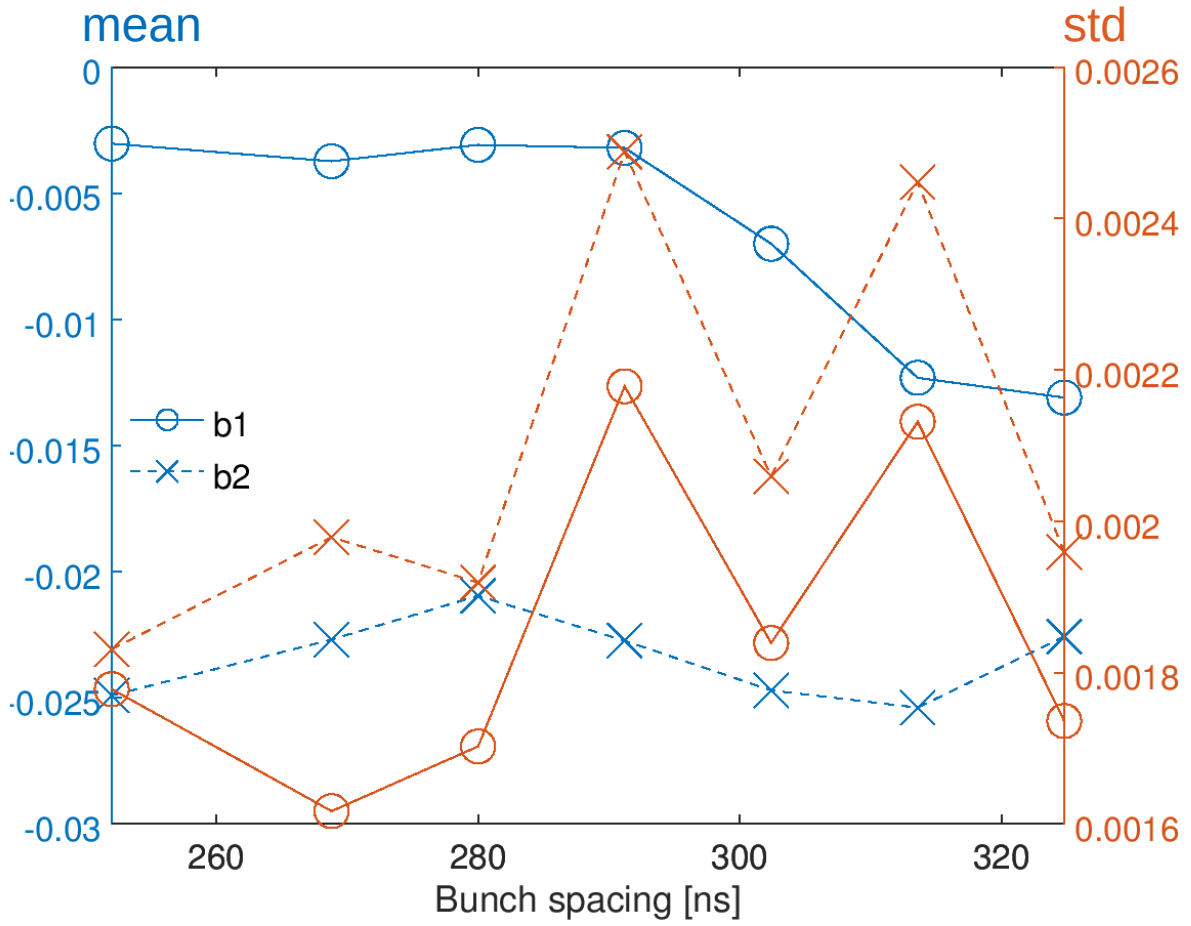


N = 100

phase compensation: n/a

Bunch spacing scan: P1 position

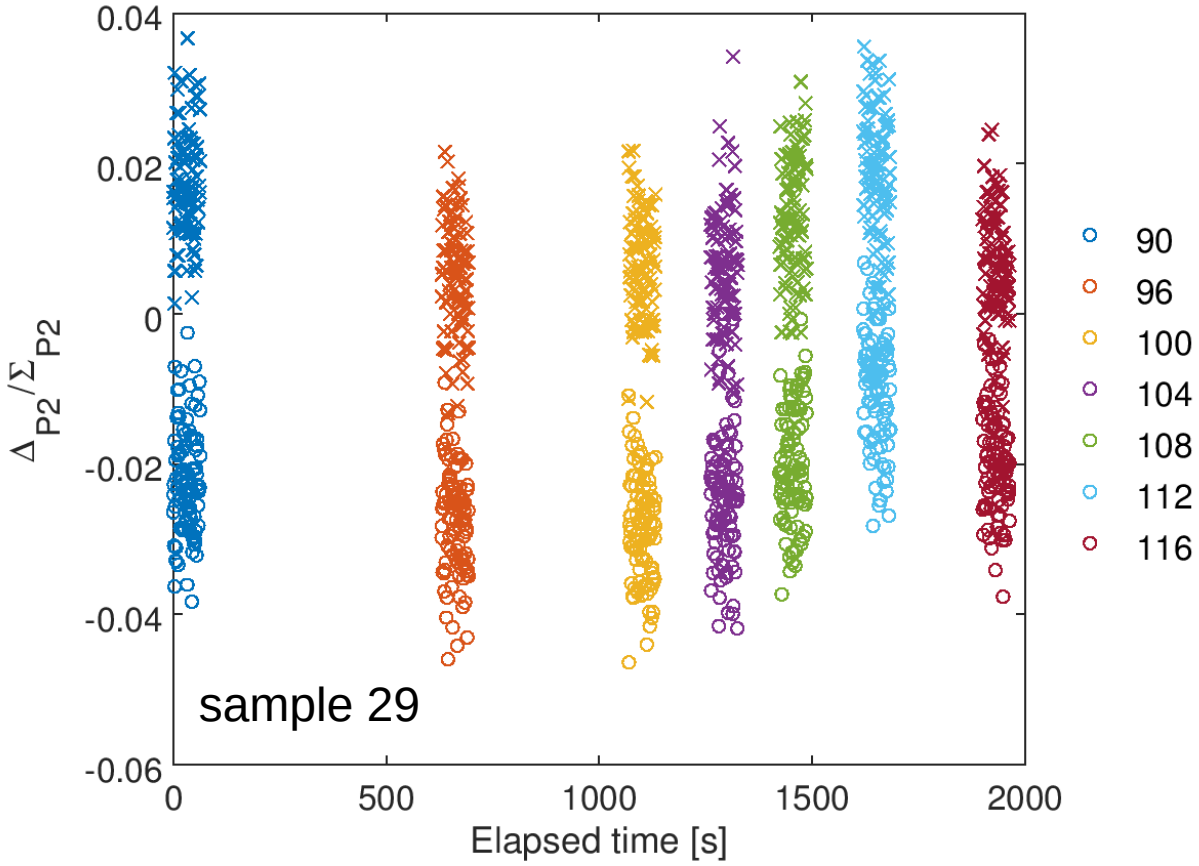


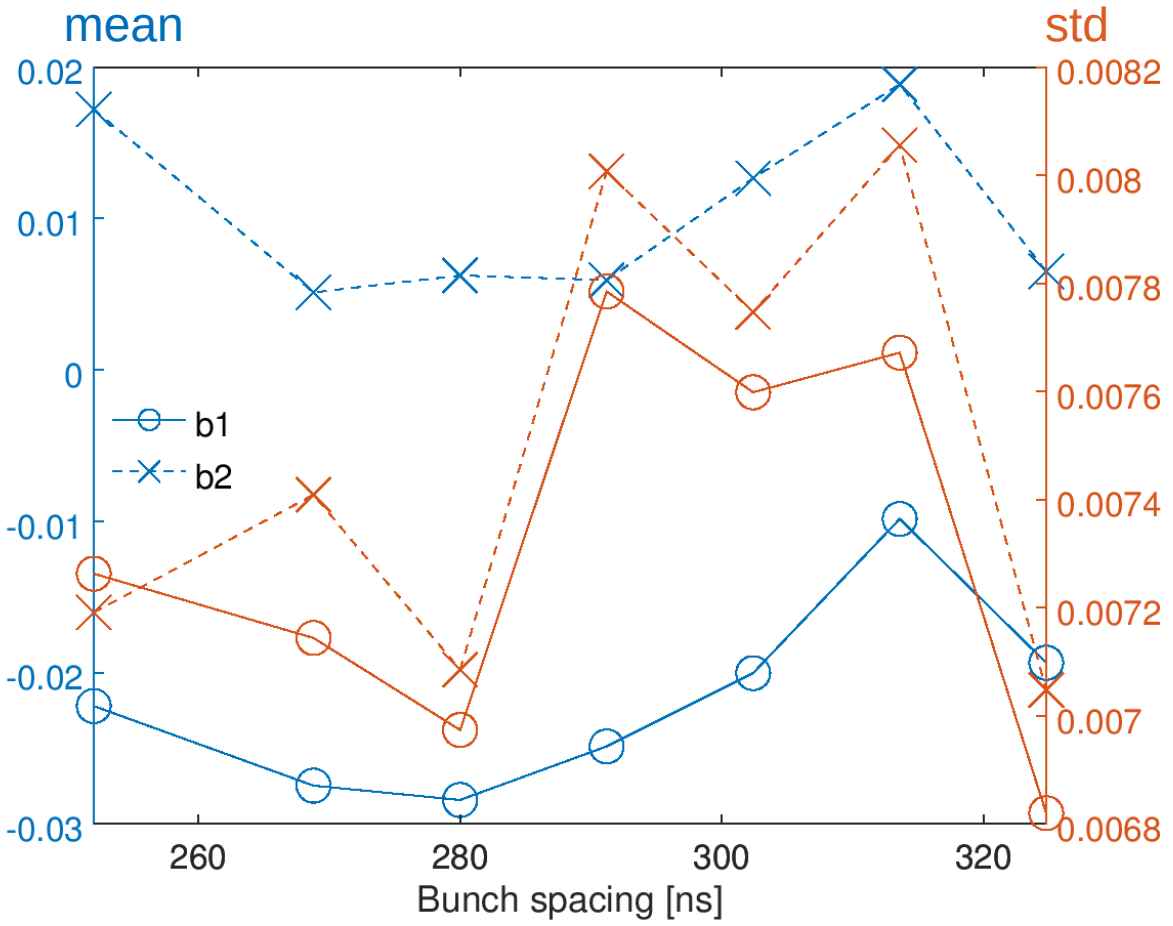


N = 100

phase compensation: none

Bunch spacing scan: P2 position

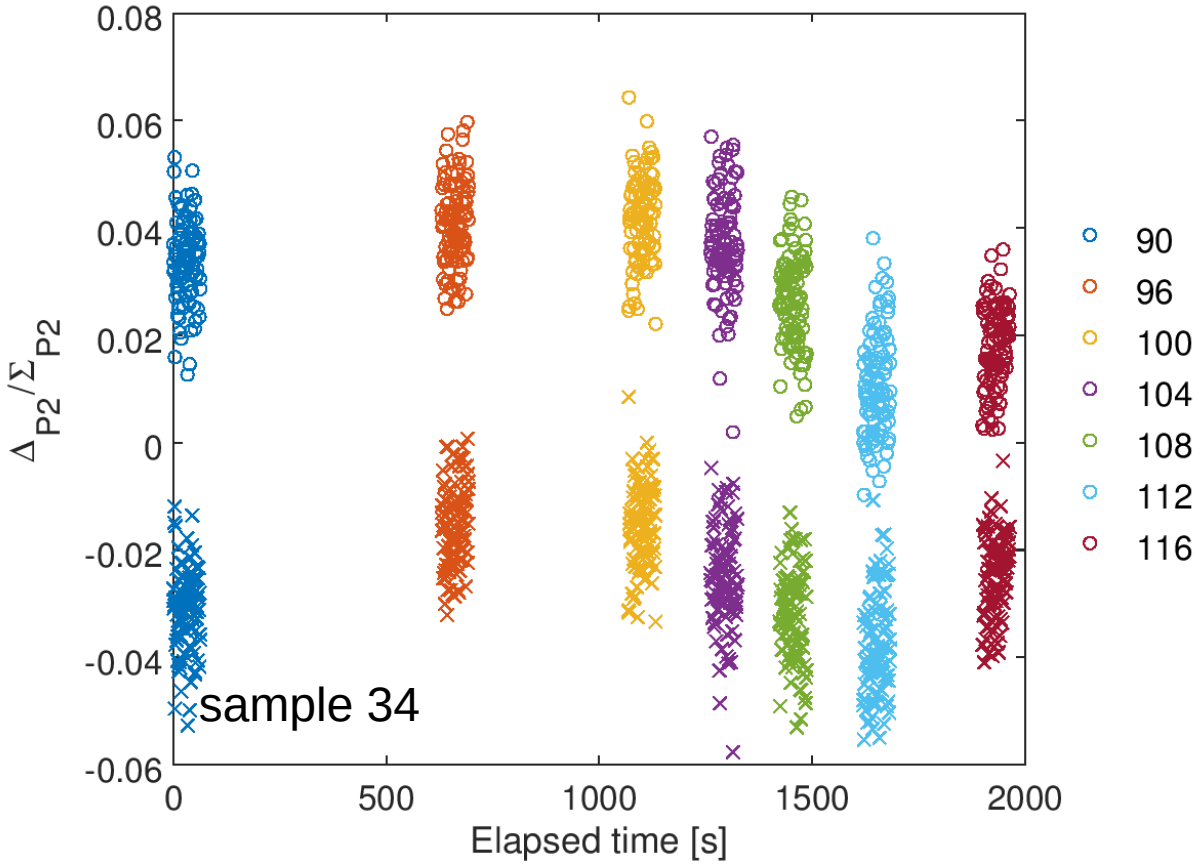


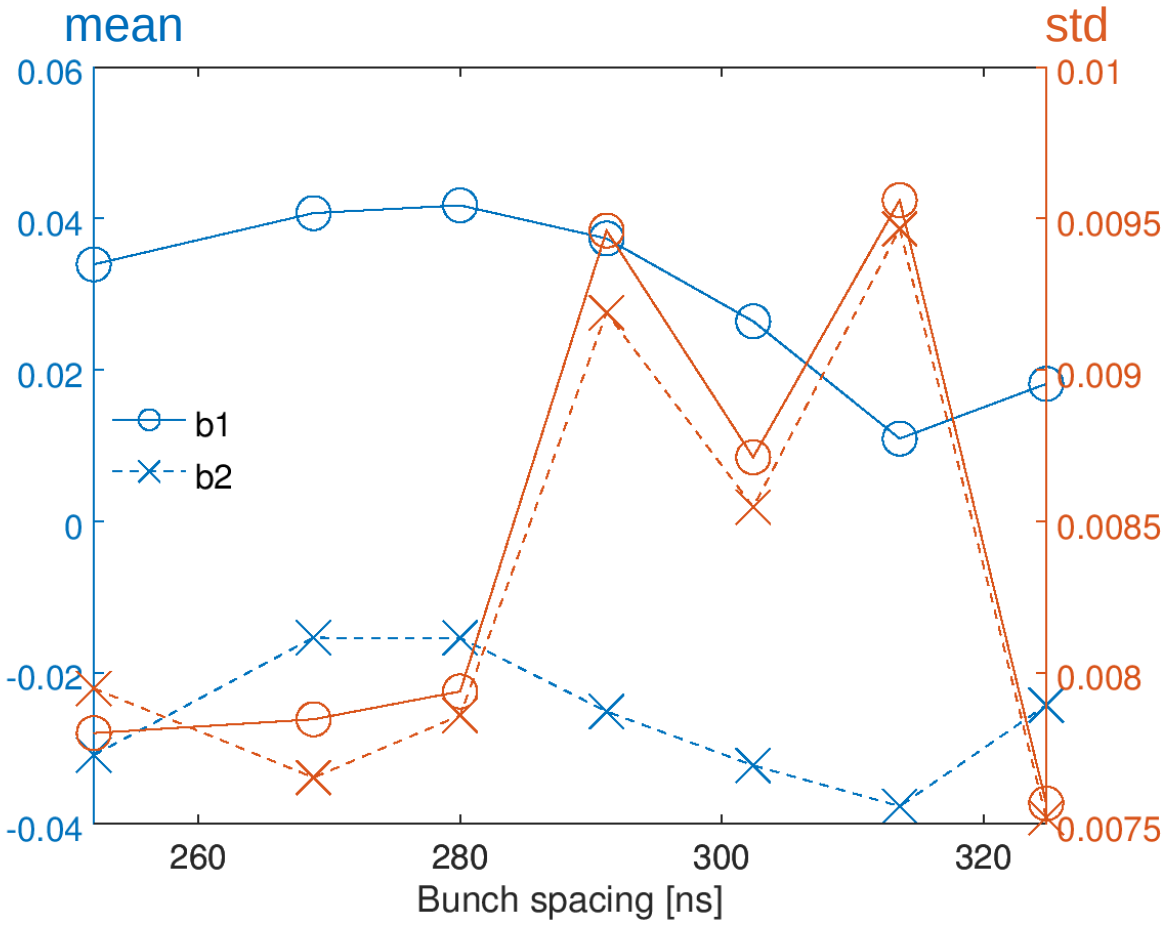


N = 100

phase compensation: none

Bunch spacing scan: P3 position





N = 100

Bunch spacing scan: bunch correlation

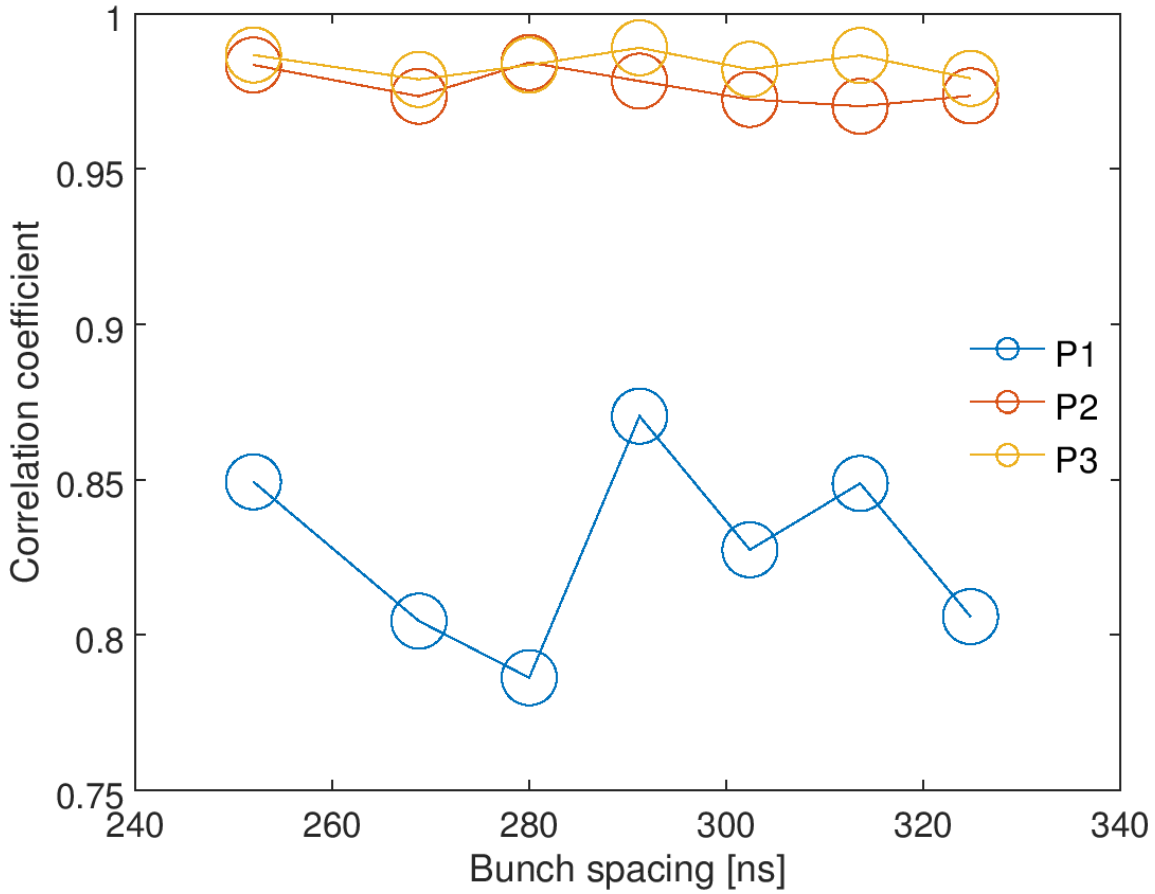


Table 1. Correlation coefficient ρ

	P1	P2	P3
252.0	0.849	0.983	0.987
268.8	0.804	0.973	0.979
280.0	0.786	0.984	0.983
291.2	0.870	0.978	0.989
302.4	0.827	0.972	0.982
313.6	0.849	0.970	0.987
324.8	0.806	0.974	0.979

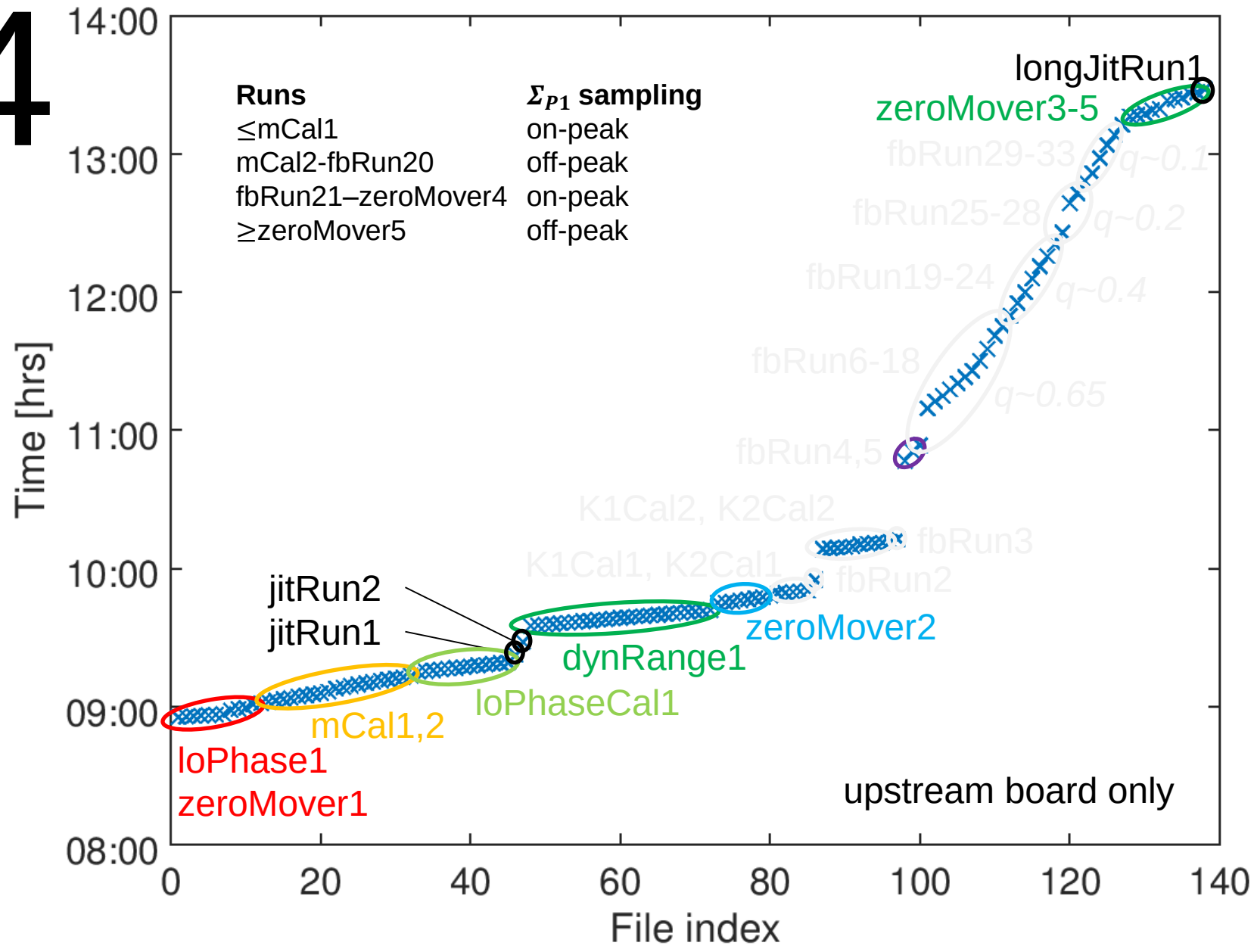
N = 100

Bunch spacing scan: summary

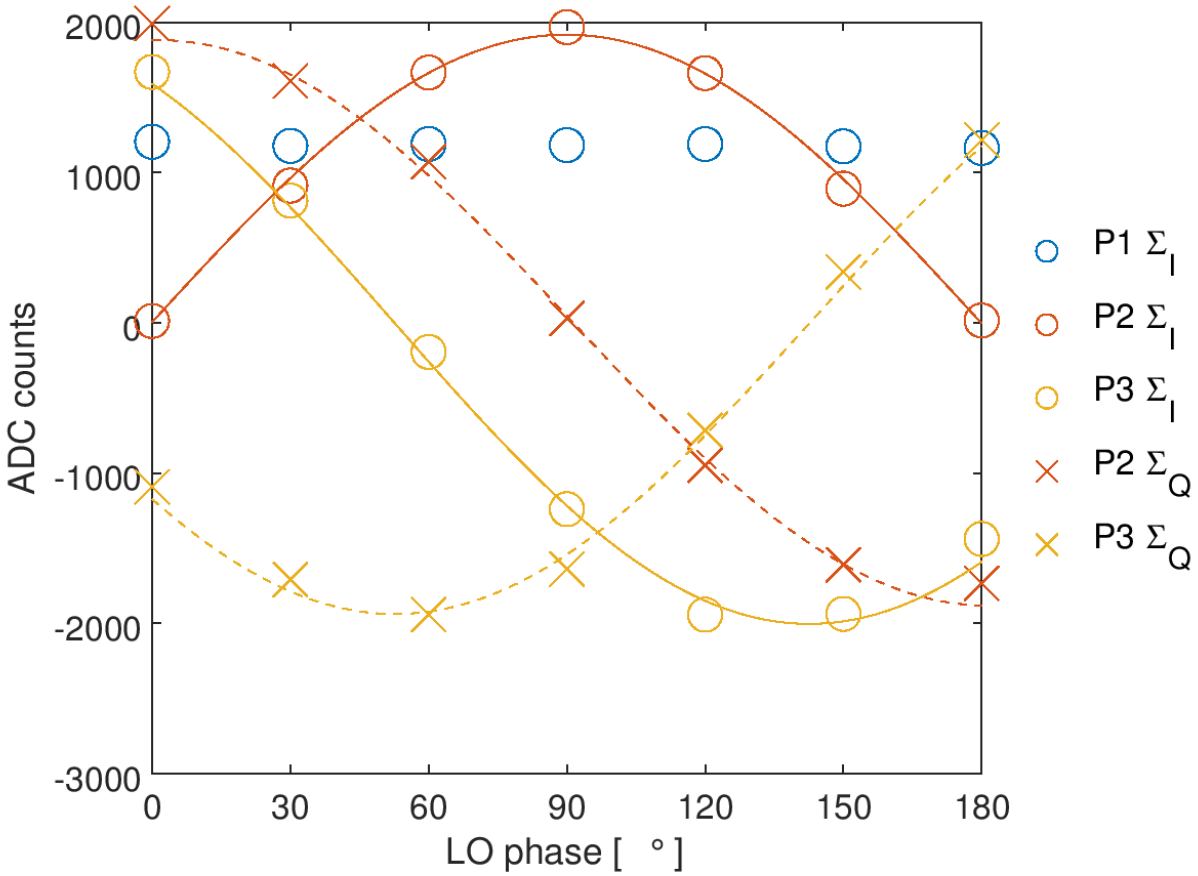
- Correlation coefficient at P2, P3 > 0.97 for every bunch spacing
  - Note that shifts were dedicated to tuning the orbit of the second bunch
  - Stripline phase shifters already set
- Correlation coefficient at P1 much lower
  - P1 instrumented with diode processor but could simply be beam optics

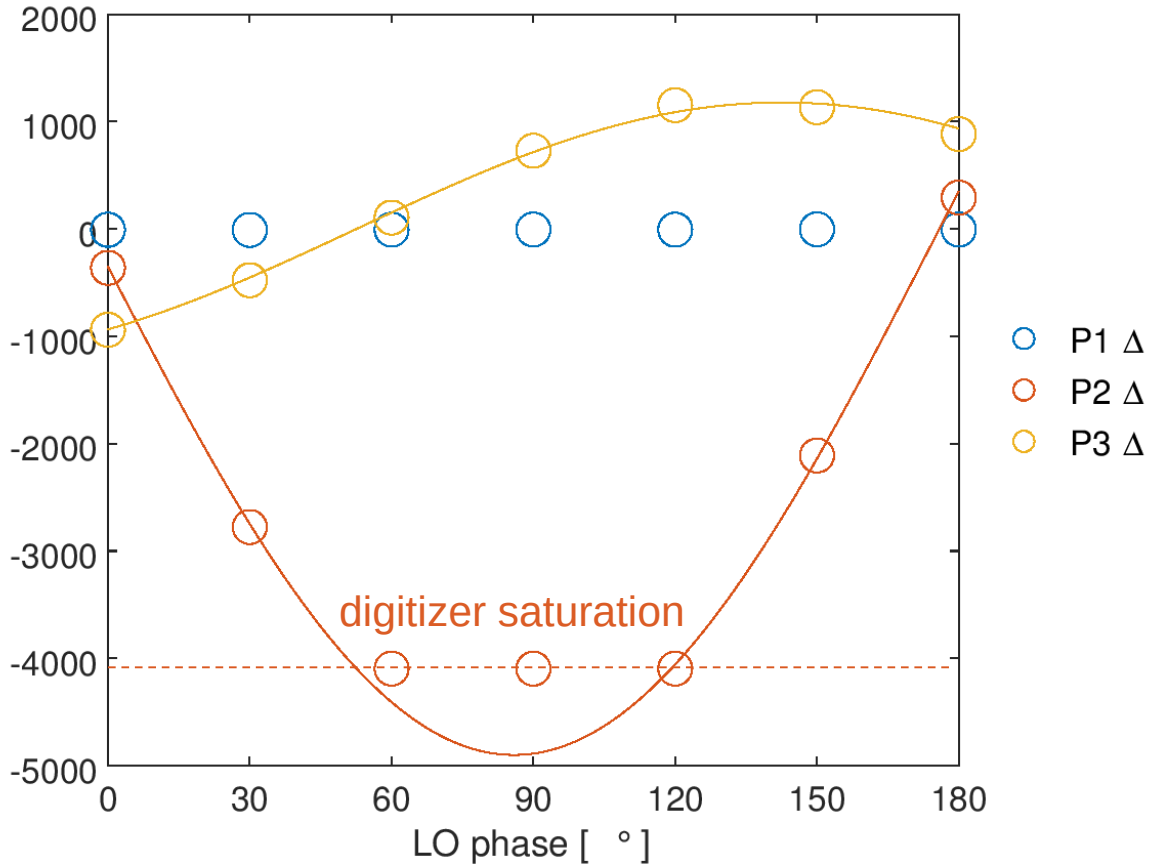
- Two bunch functionality for ATF BPMs prefers longer spacing
- …but Okugi-san selected 302.4 ns for the study (108 samples)

4


Runs
≤mCal1
mCal2-fbRun20
fbRun21–zeroMover4
≥zeroMover5
Σ_{P1} sampling
on-peak
off-peak
on-peak
off-peak
longJitRun1
zeroMover3-5
fbRun29-33 q~0.1
fbRun25-28 q~0.2
fbRun19-24 q~0.4
fbRun6-18 q~0.65
fbRun4,5
K1Cal2, K2Cal2
fbRun3
K1Cal1, K2Cal1
fbRun2
jitRun2
jitRun1
zeroMover2
dynRange1
loPhaseCal1
mCal1,2
loPhase1
zeroMover1
upstream board only
Time [hrs]
14:00
13:00
12:00
11:00
10:00
09:00
08:00
0
20
40
60
80
100
120
140
File index

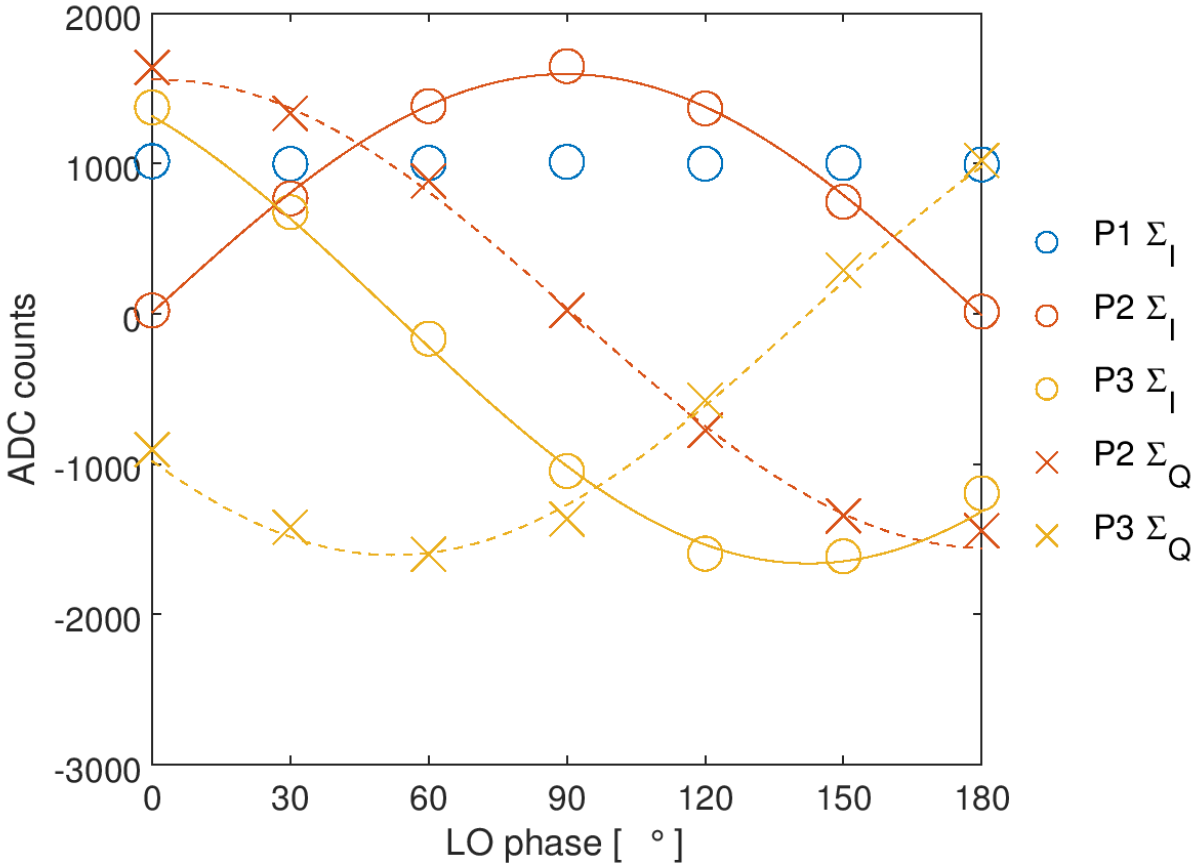
Upstream diagnostics: loPhase1 (b1)

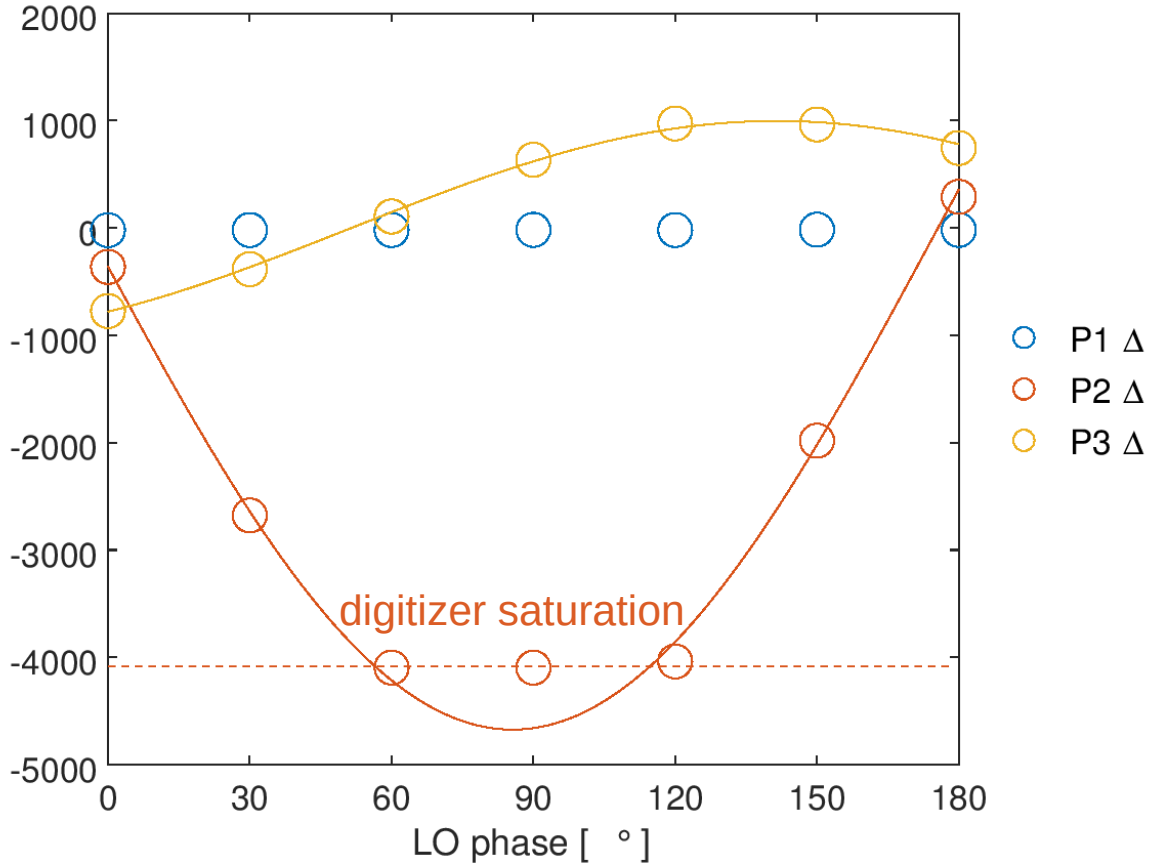




N = 20

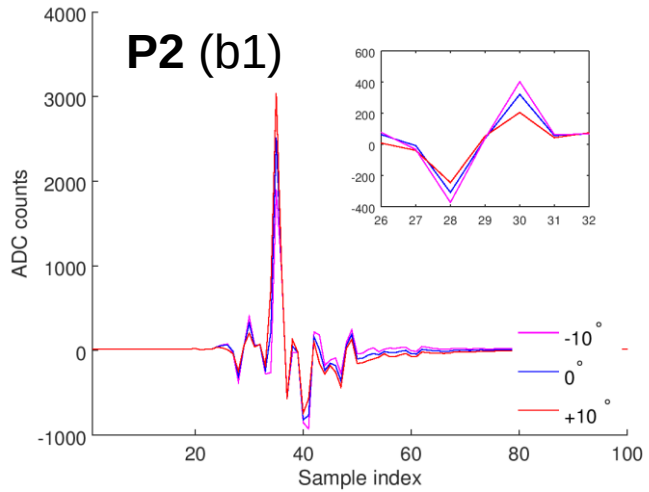
Upstream diagnostics: loPhase1 (b2)

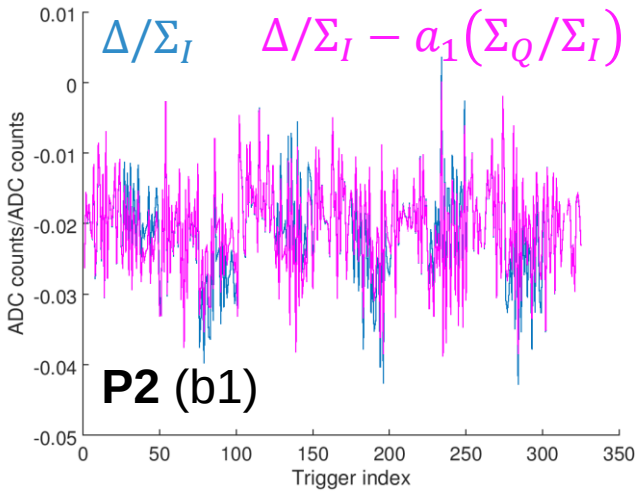


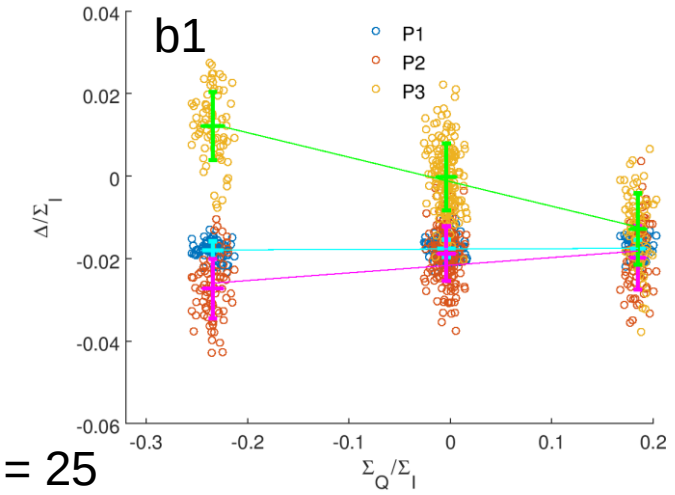


N = 20

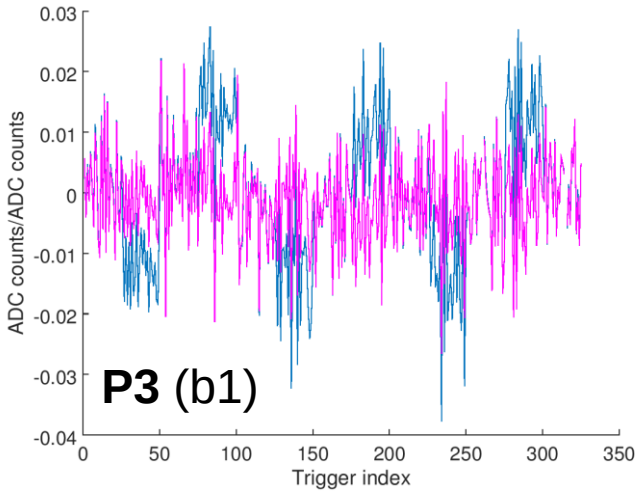
Upstream diagnostics: loPhaseCal1







N = 25

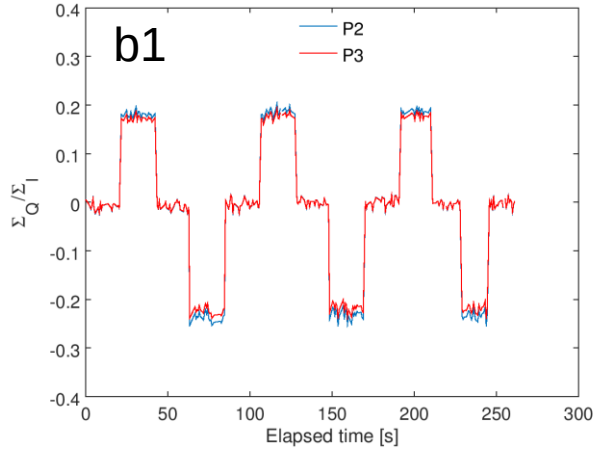


stripline phase shifters optimized “by eye”

Table 2. phase sensitivity: $\left(\frac{\Delta}{\Sigma_I}\right)/\left(\frac{\Sigma_Q}{\Sigma_I}\right)$

	P2	P3
b1	0.01885	-0.06301
b2	0.02266	-0.06350
*	*4.0405*	*-0.6070*

* BETT, 29 June 2018
“Diode processor resolution”

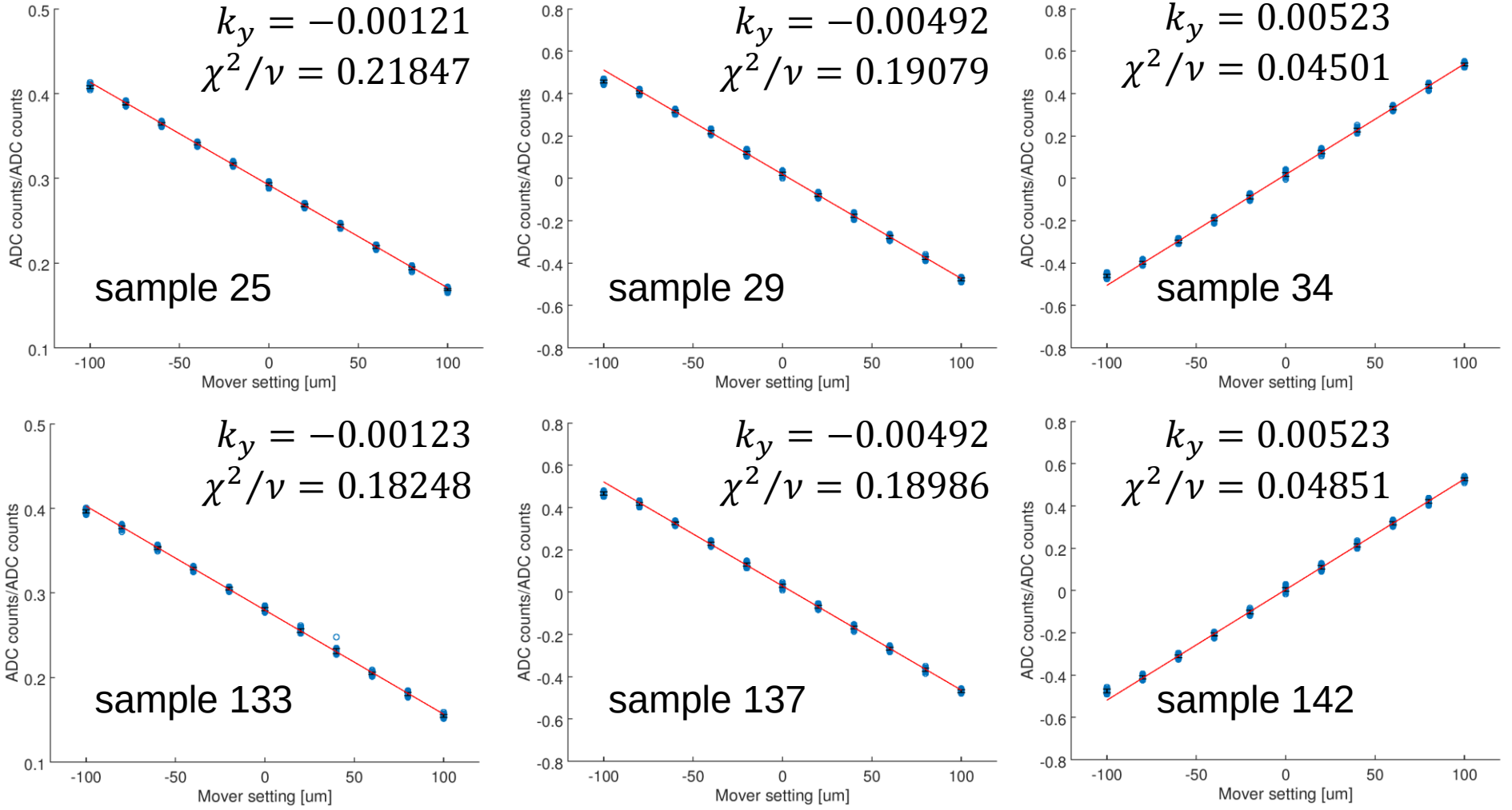


phase compensation: linear (P2, P3) [loPhaseCal1]

±100 um points omitted from fit

Upstream diagnostics: mCal1

	P1	P2	P3
b1	$k_y = -0.00121$ $\chi^2/\nu = 0.21847$	$k_y = -0.00492$ $\chi^2/\nu = 0.19079$	$k_y = 0.00523$ $\chi^2/\nu = 0.04501$
b2	$k_y = -0.00123$ $\chi^2/\nu = 0.18248$	$k_y = -0.00492$ $\chi^2/\nu = 0.18986$	$k_y = 0.00523$ $\chi^2/\nu = 0.04851$



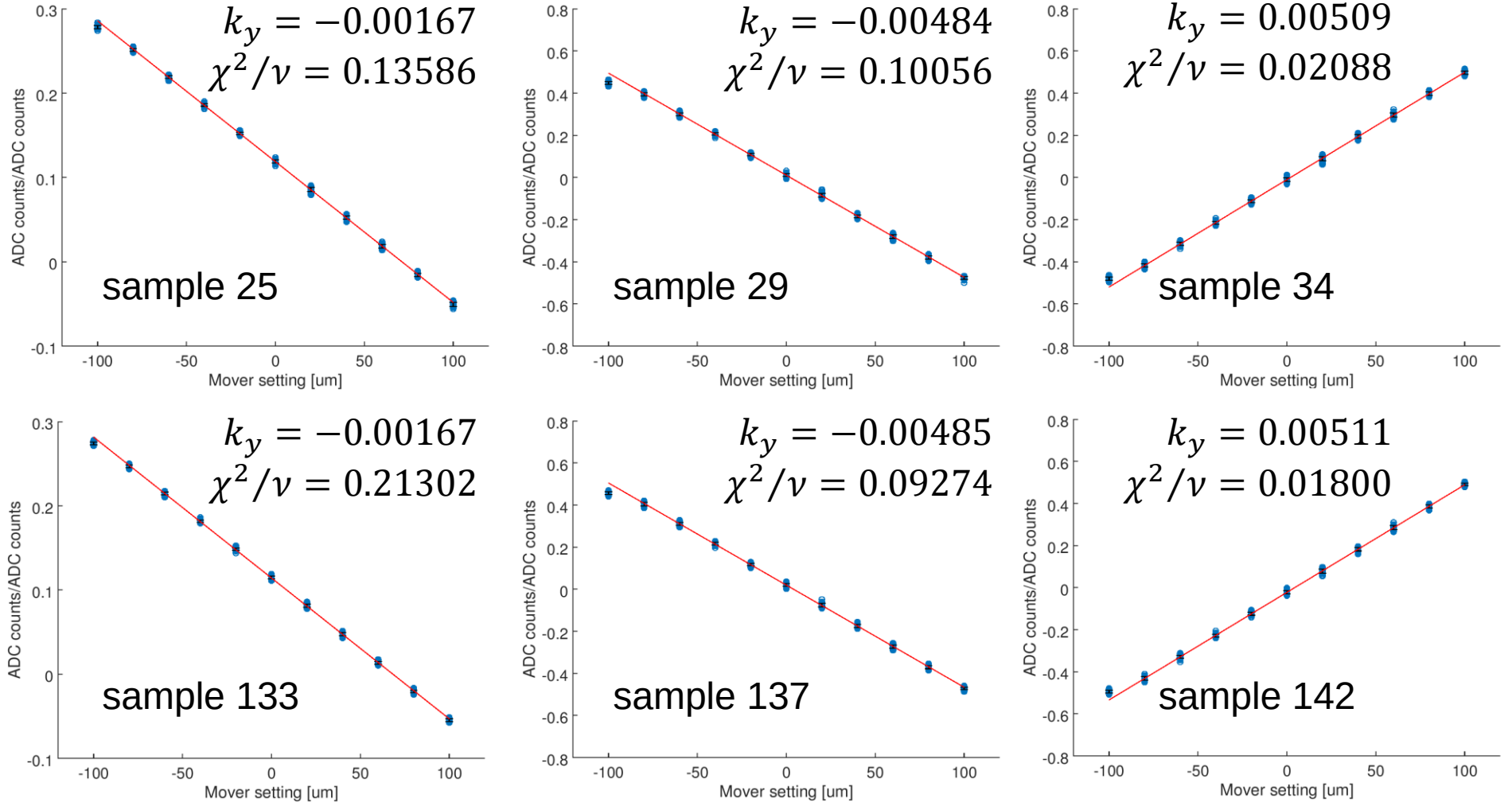
N = 50

phase compensation: linear (P2, P3) [loPhaseCal1]

±100 um points omitted from fit

Upstream diagnostics: mCal2

	P1	P2	P3
b1	$k_y = -0.00167$ $\chi^2/\nu = 0.13586$ sample 25	$k_y = -0.00484$ $\chi^2/\nu = 0.10056$ sample 29	$k_y = 0.00509$ $\chi^2/\nu = 0.02088$ sample 34
b2	$k_y = -0.00167$ $\chi^2/\nu = 0.21302$ sample 133	$k_y = -0.00485$ $\chi^2/\nu = 0.09274$ sample 137	$k_y = 0.00511$ $\chi^2/\nu = 0.01800$ sample 142



N = 50

Upstream diagnostics: calibration summary

3 dB of attenuation on P1 insufficient at high charge
→ use scan delay to deliberately sample off-peak

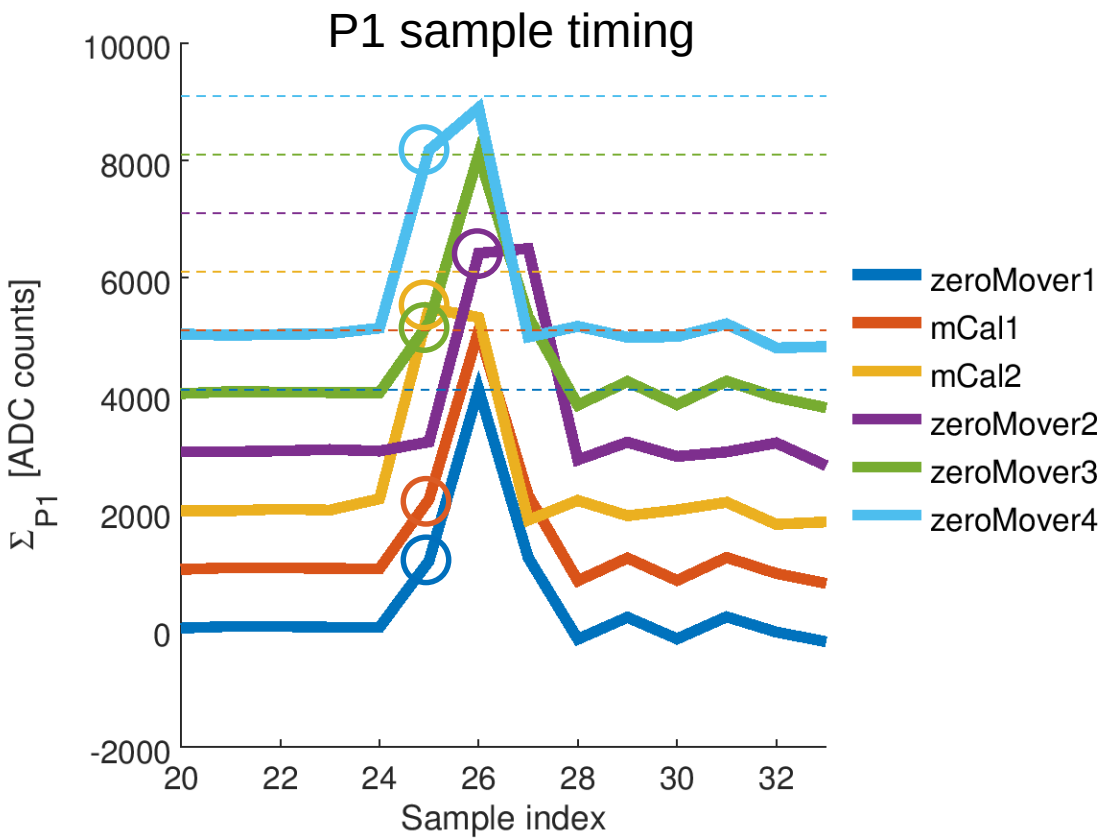


Table 3. Position calibration constant $k_y \times 10^6$

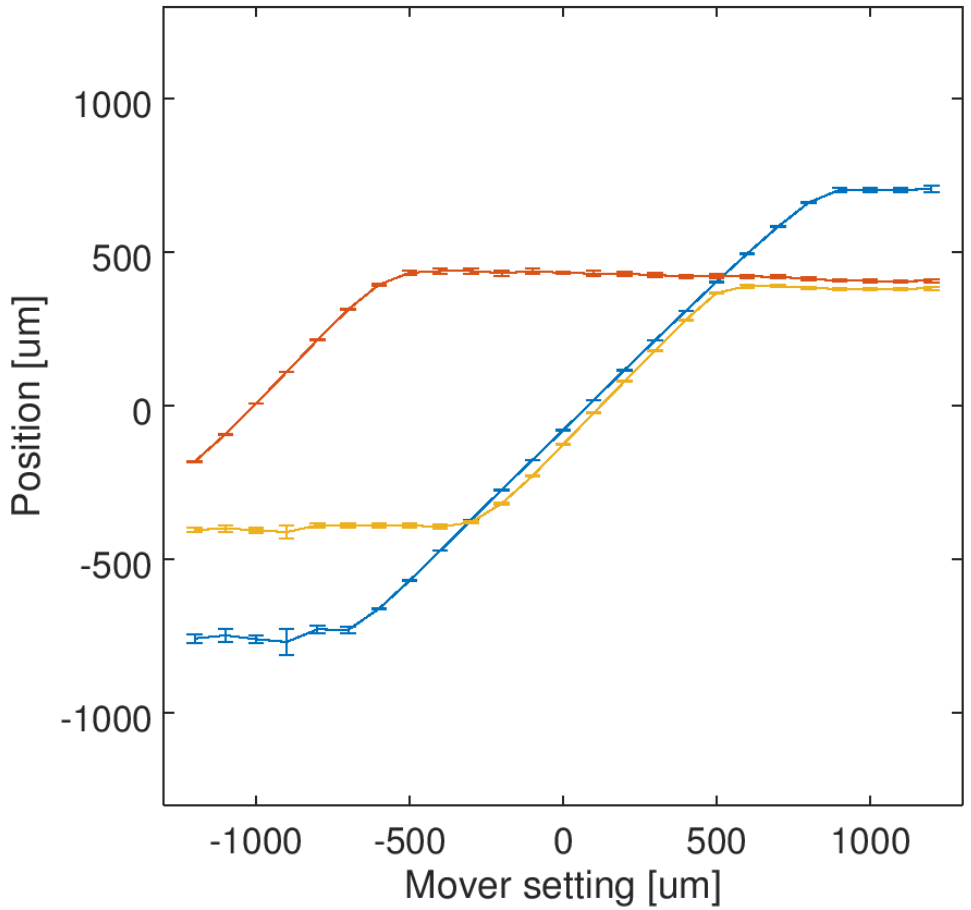
	P1	P2	P3
zeroMover1	-1189 ± 3 -1202 ± 3	-4727 ± 21 -4723 ± 21	5064 ± 15 5072 ± 14
mCal1	-1213 ± 1 -1230 ± 1	-4922 ± 3 -4929 ± 3	5229 ± 1 5229 ± 2
mCal2	-1669 ± 1 -1674 ± 1	-4844 ± 2 -4854 ± 2	5093 ± 1 5114 ± 1
zeroMover2	-1595 ± 4 -1605 ± 4	-4707 ± 35 -4712 ± 35	5017 ± 25 5024 ± 26
zeroMover3	-1185 ± 3 -1199 ± 3	-4697 ± 23 -4696 ± 23	5045 ± 18 5063 ± 17
zeroMover4	-1544 ± 4 -1556 ± 5	-4695 ± 23 -4696 ± 23	5024 ± 15 5029 ± 15

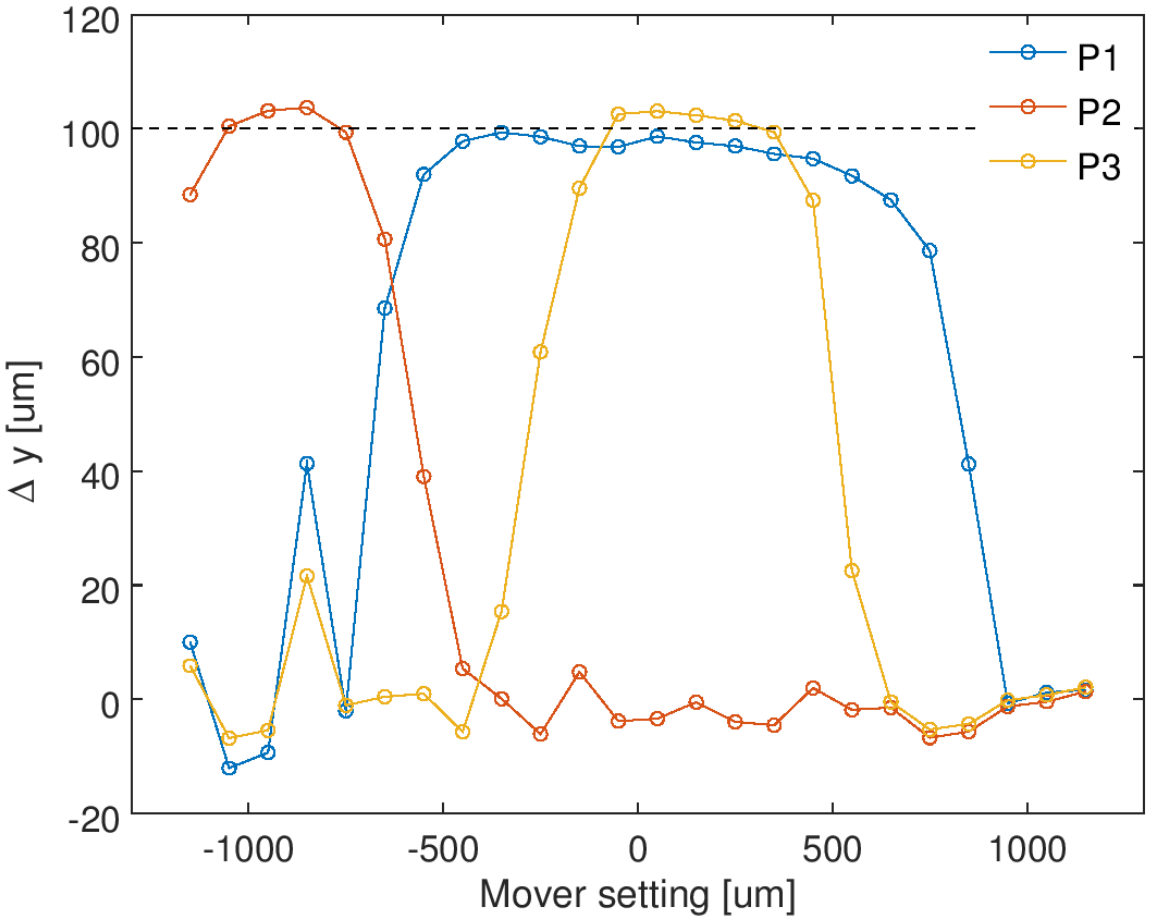
zeroMover Short scans used to centre beam in each BPM. Data taken at (relative) mover settings of -100 µm, 0 µm and +100 µm.
Not suitable for calibration due to saturation but quoted anyway.

phase compensation: linear (P2, P3) [loPhaseCal1]

calibration: [mCal2]

Upstream diagnostics: dynamic range (bunch 1)



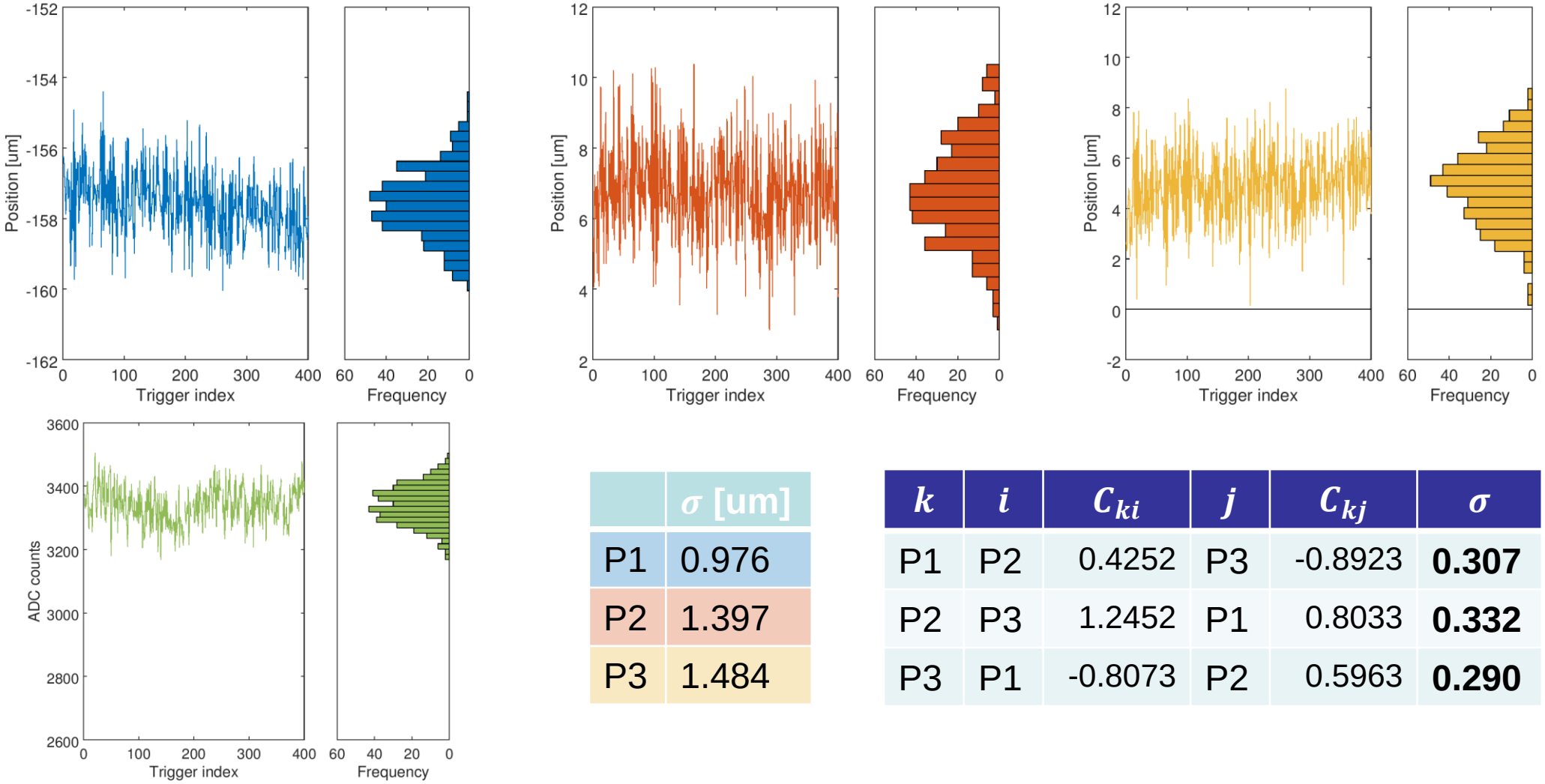


N = 25

phase compensation: linear (P2, P3) [loPhaseCal1]

calibration: [mCal2]

Resolution: jitRun1 (b1)



	σ [um]
P1	0.976
P2	1.397
P3	1.484

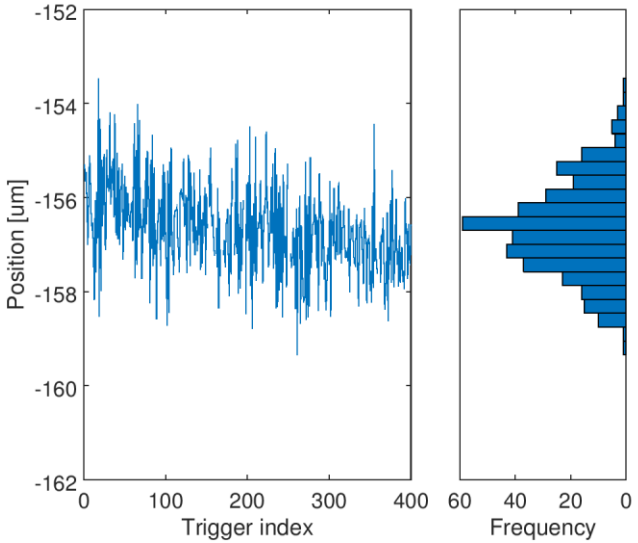
k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.4252	P3	-0.8923	**0.307**
P2	P3	1.2452	P1	0.8033	**0.332**
P3	P1	-0.8073	P2	0.5963	**0.290**

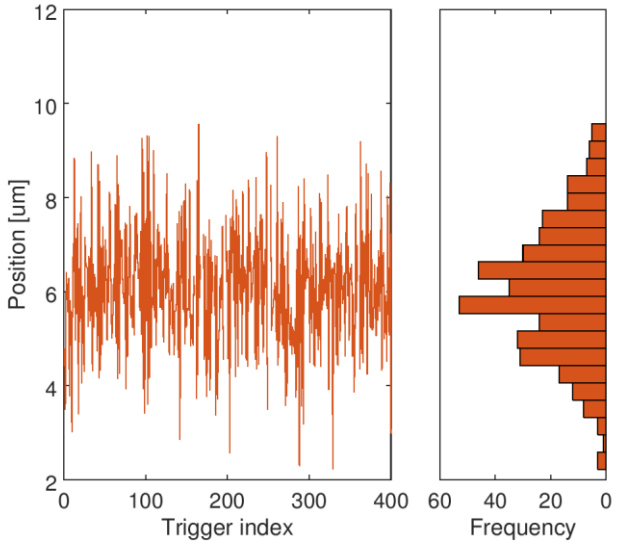
N = 400

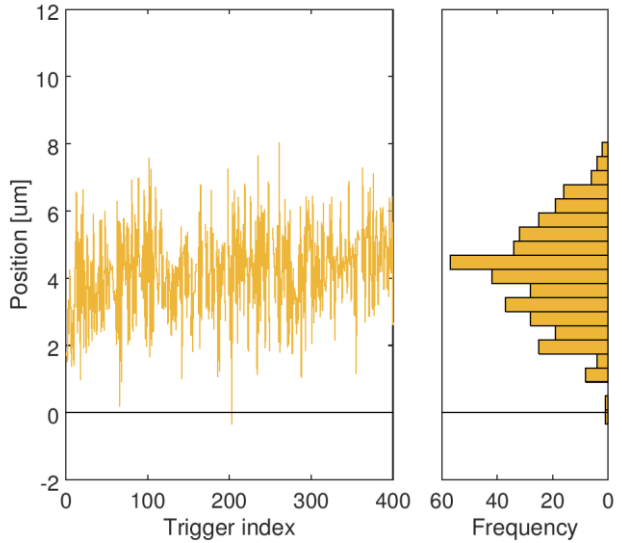
phase compensation: linear (P2, P3) [loPhaseCal1]

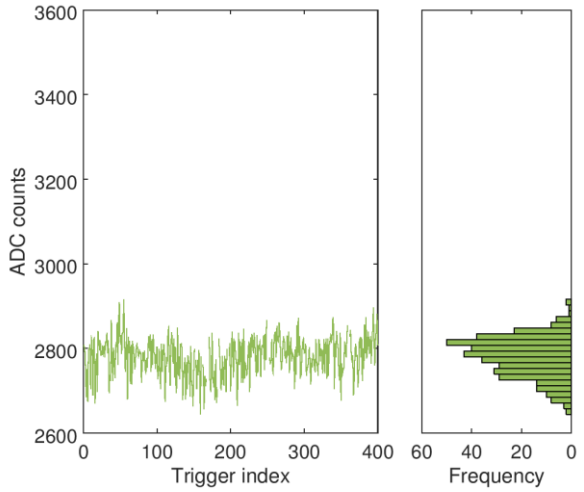
calibration: [mCal2]

Resolution: jitRun1 (b2)









	σ [um]
P1	0.978
P2	1.386
P3	1.459

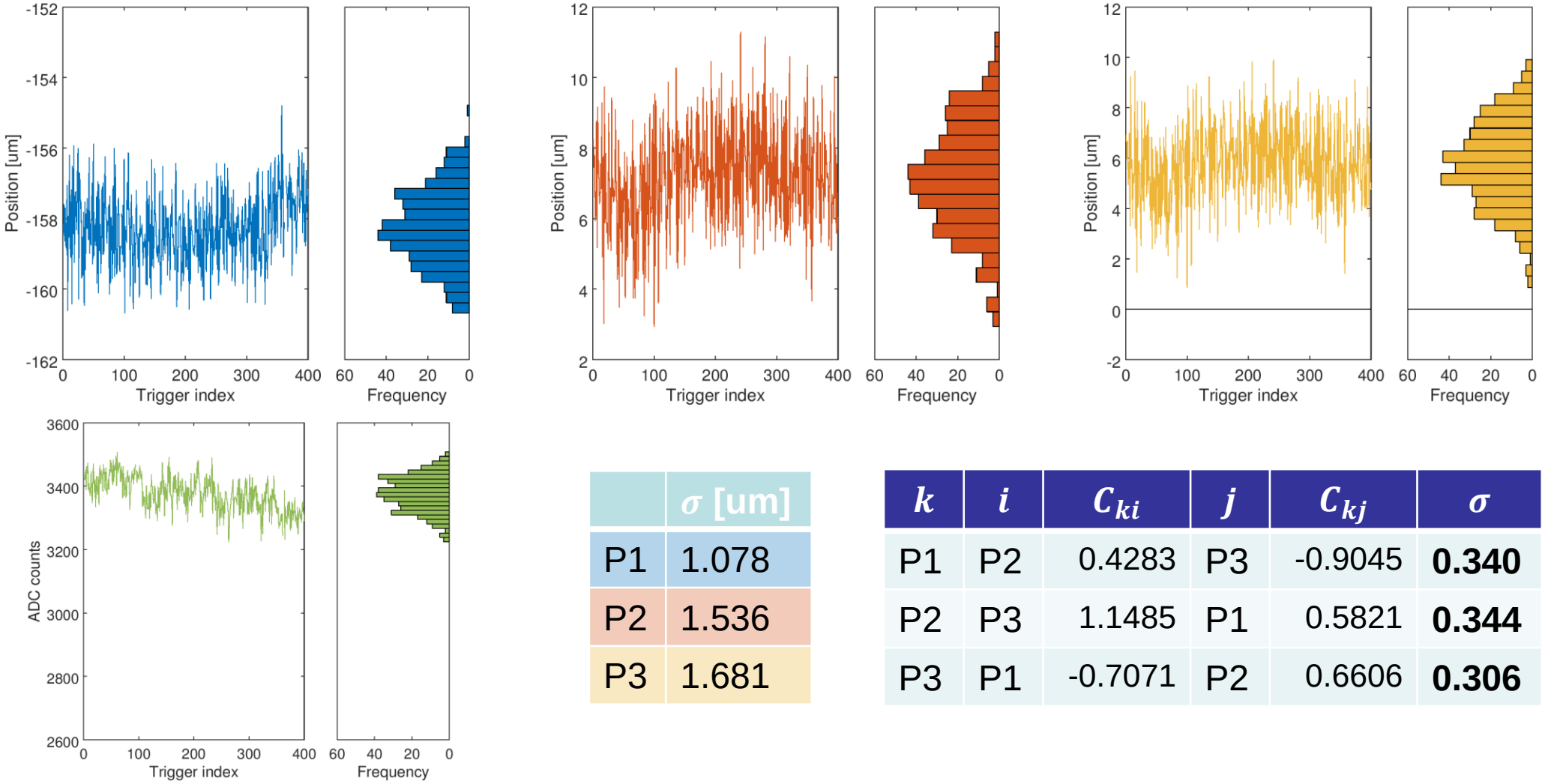
k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.4029	P3	-0.8869	**0.321**
P2	P3	1.2274	P1	0.7475	**0.348**
P3	P1	-0.7873	P2	0.5873	**0.301**

N = 400

phase compensation: linear (P2, P3) [loPhaseCal1]

calibration: [mCal2]

Resolution: jitRun2 (b1)



	σ [um]
P1	1.078
P2	1.536
P3	1.681

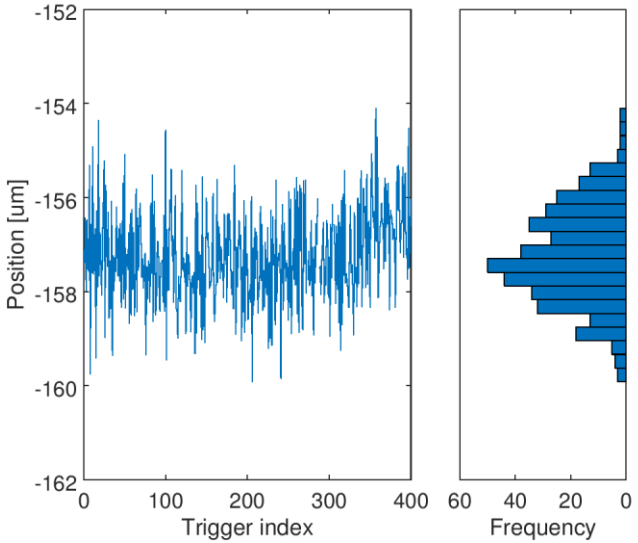
k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.4283	P3	-0.9045	**0.340**
P2	P3	1.1485	P1	0.5821	**0.344**
P3	P1	-0.7071	P2	0.6606	**0.306**

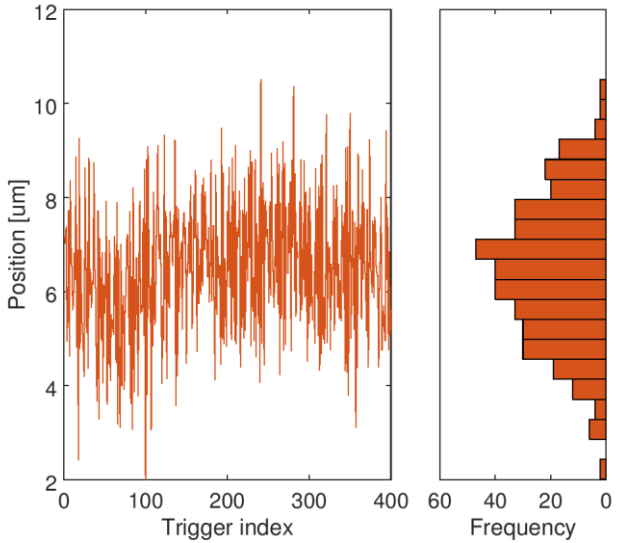
N = 400

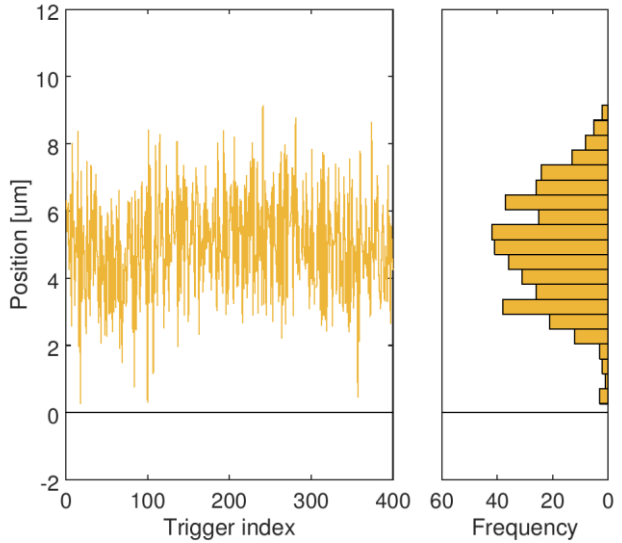
phase compensation: linear (P2, P3) [loPhaseCal1]

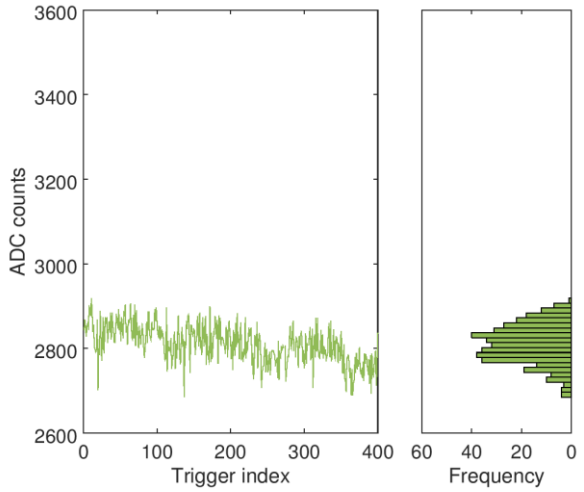
calibration: [mCal2]

Resolution: jitRun2 (b2)









	σ [um]
P1	1.044
P2	1.519
P3	1.648

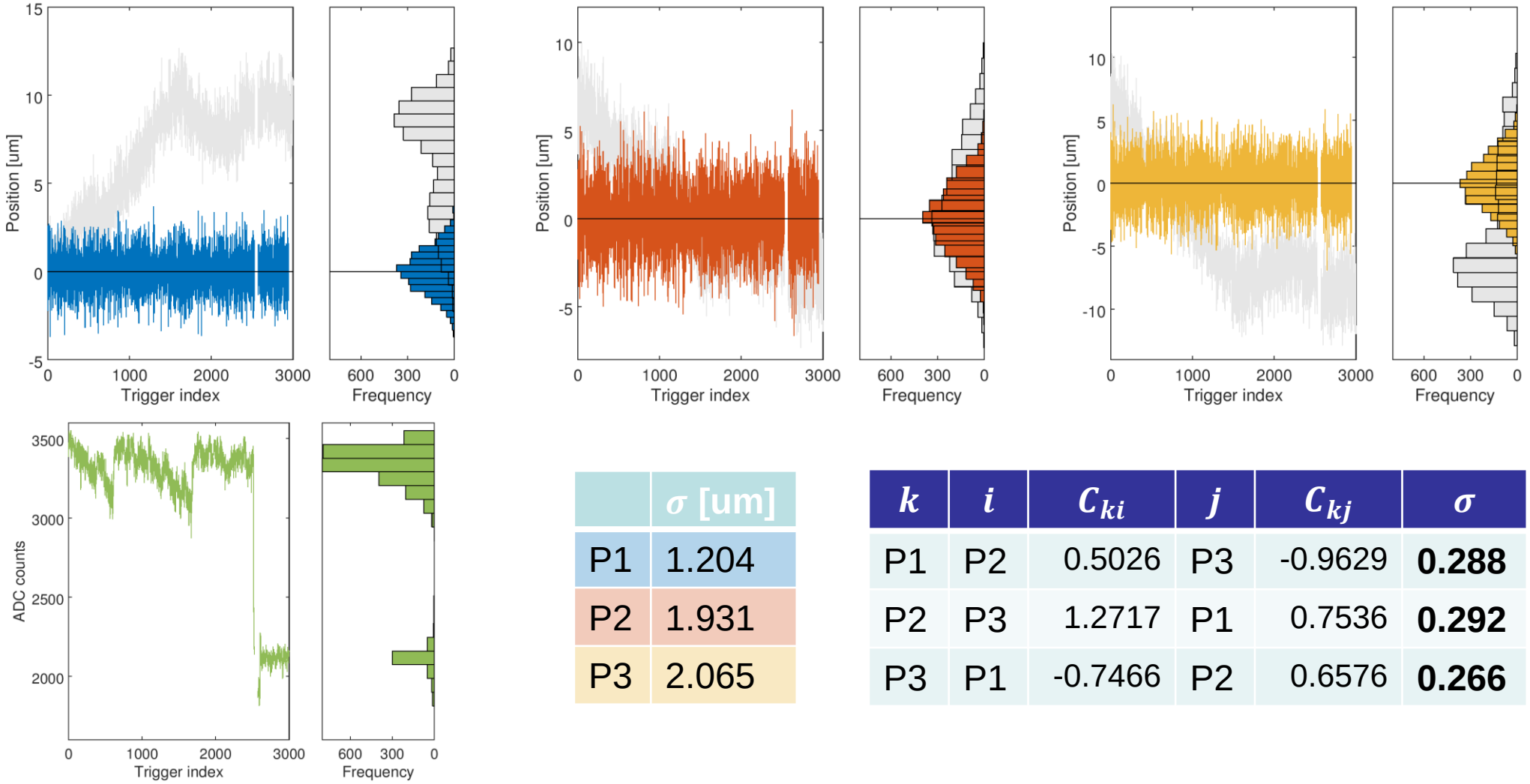
k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.4397	P3	-0.9165	**0.320**
P2	P3	1.1642	P1	0.5881	**0.321**
P3	P1	-0.6991	P2	0.6641	**0.287**

N = 400

phase compensation: linear (P2, P3) [loPhaseCal1]

calibration: [mCal2]

Resolution: longJitRun1 (b1)



	σ [um]
P1	1.204
P2	1.931
P3	2.065

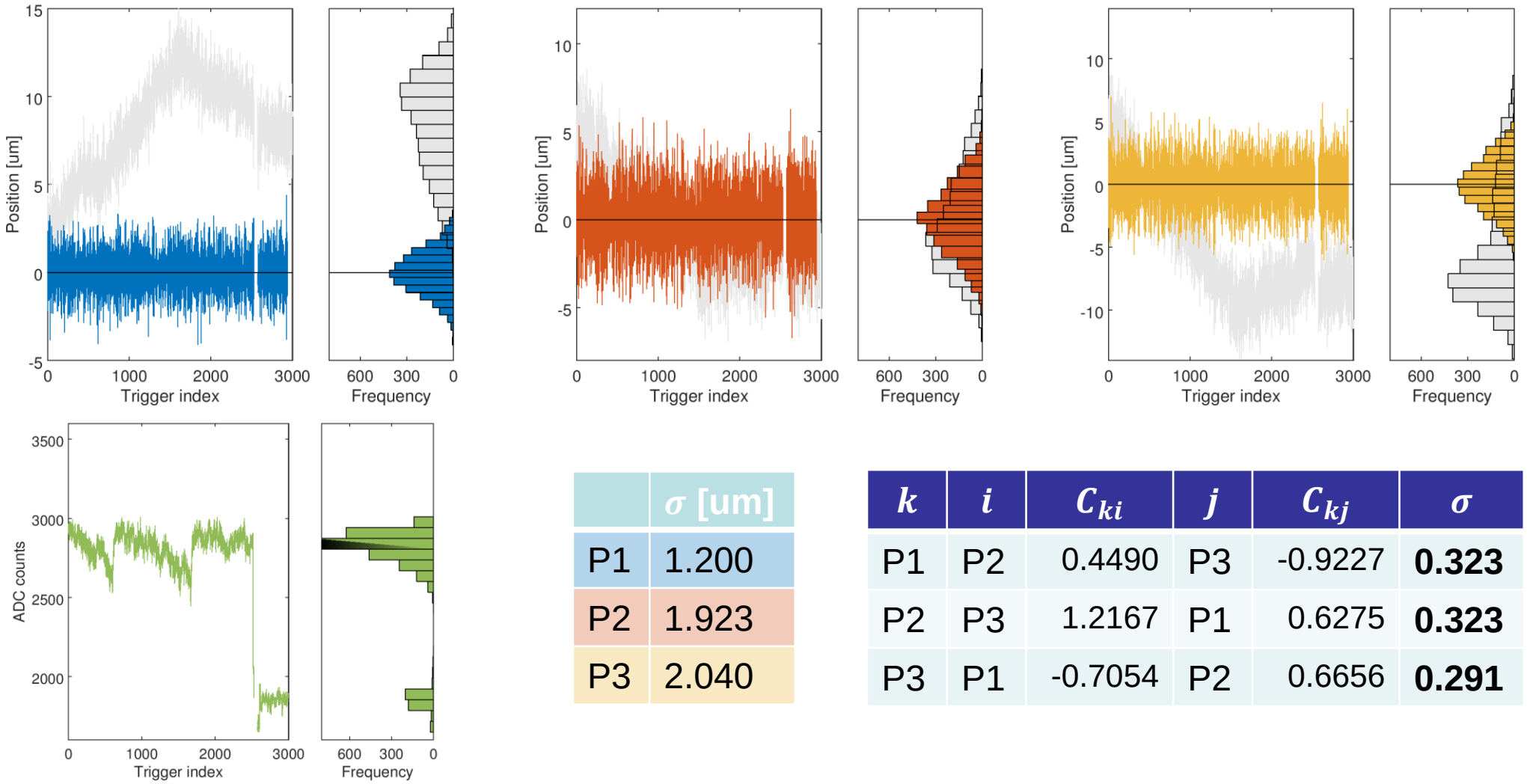
k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.5026	P3	-0.9629	**0.288**
P2	P3	1.2717	P1	0.7536	**0.292**
P3	P1	-0.7466	P2	0.6576	**0.266**

N = 3000

phase compensation: linear (P2, P3) [loPhaseCal1]

calibration: [mCal2]

Resolution: longJitRun2 (b2)



	σ [um]
P1	1.200
P2	1.923
P3	2.040

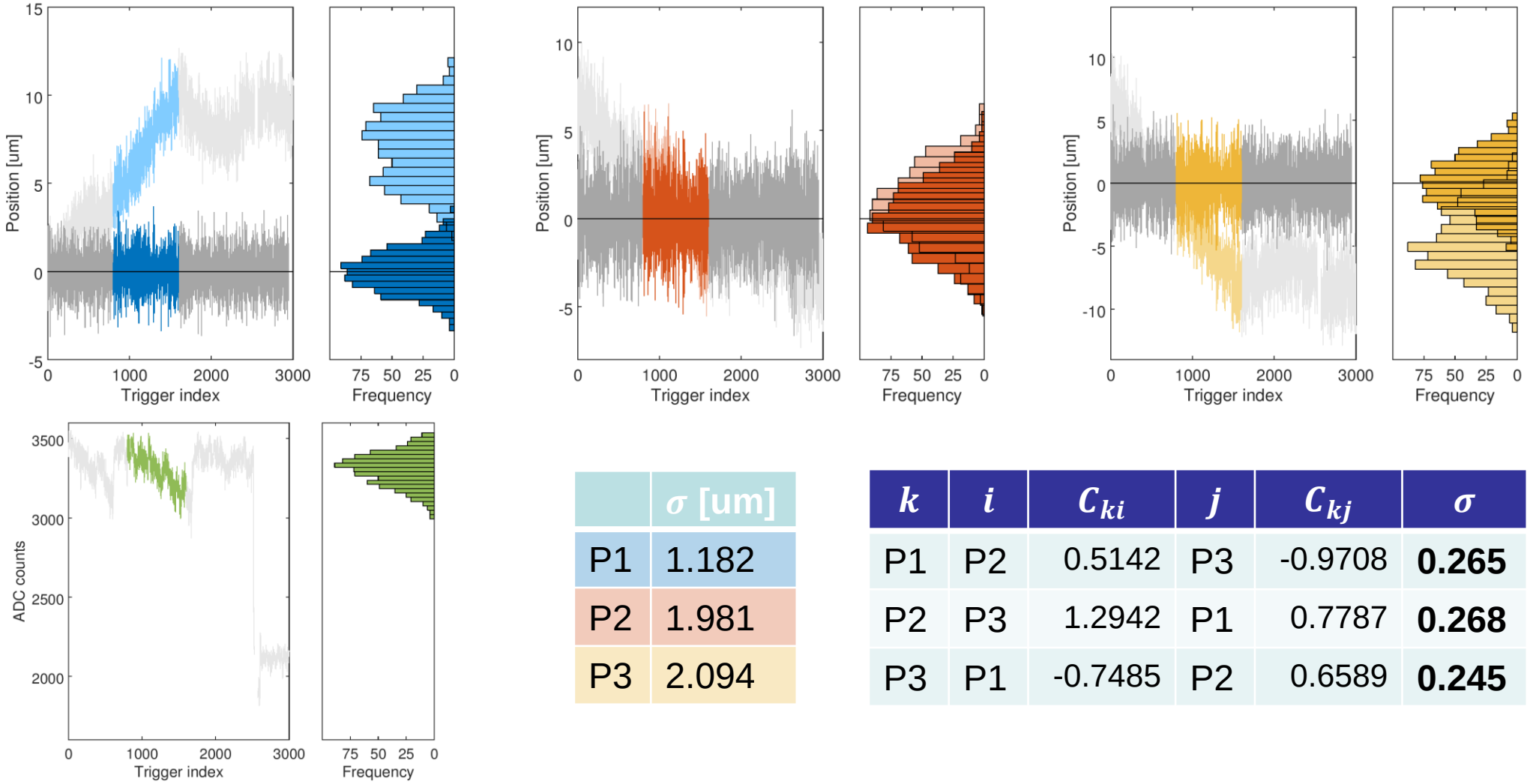
k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.4490	P3	-0.9227	**0.323**
P2	P3	1.2167	P1	0.6275	**0.323**
P3	P1	-0.7054	P2	0.6656	**0.291**

N = 3000

phase compensation: linear (P2, P3) [loPhaseCal1]

calibration: [mCal2]

Resolution: longJitRun1 (b1) [window]



	σ [um]
P1	1.182
P2	1.981
P3	2.094

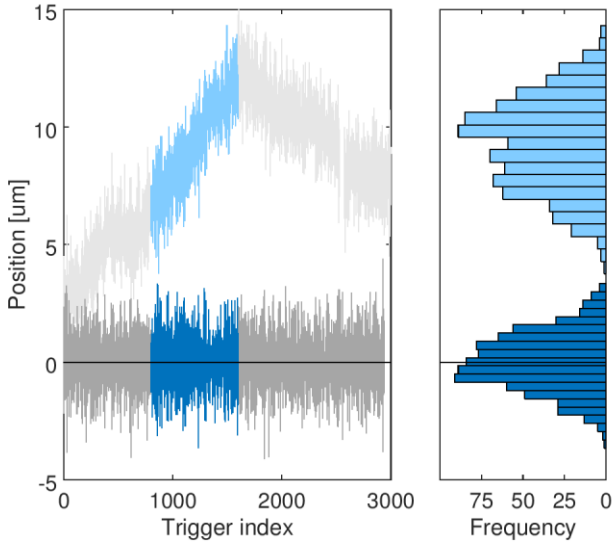
k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.5142	P3	-0.9708	**0.265**
P2	P3	1.2942	P1	0.7787	**0.268**
P3	P1	-0.7485	P2	0.6589	**0.245**

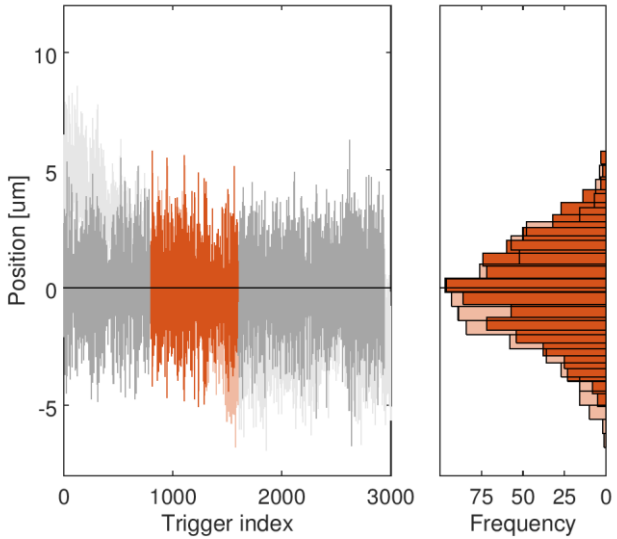
N = 800

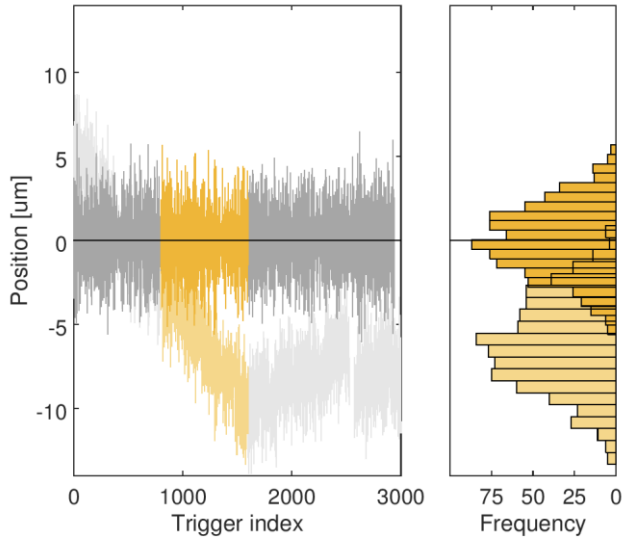
phase compensation: linear (P2, P3) [loPhaseCal1]

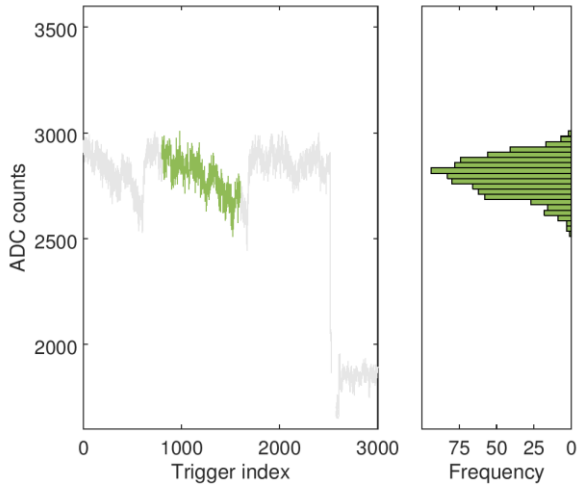
calibration: [mCal2]

Resolution: longJitRun2 (b2) [window]







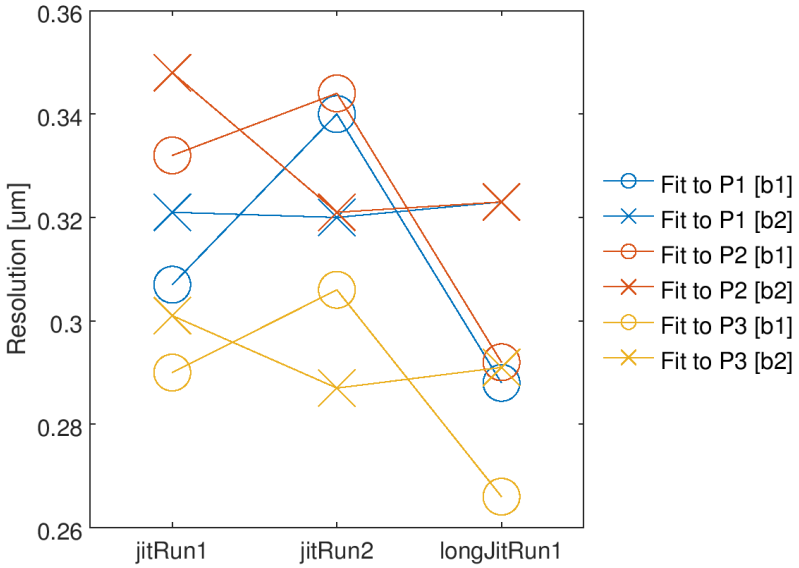


	σ [um]
P1	1.197
P2	1.976
P3	2.075

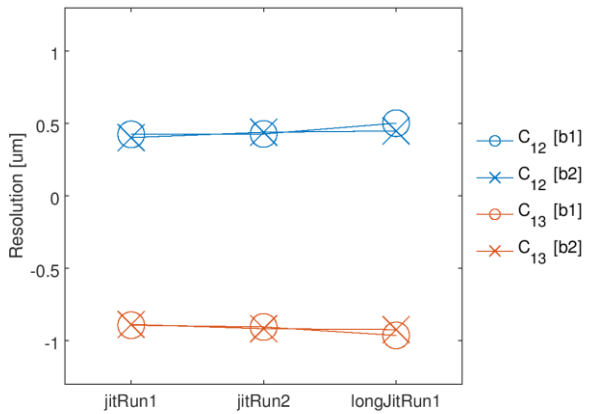
k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.4364	P3	-0.9134	**0.314**
P2	P3	1.2250	P1	0.6193	**0.313**
P3	P1	-0.7024	P2	0.6638	**0.281**

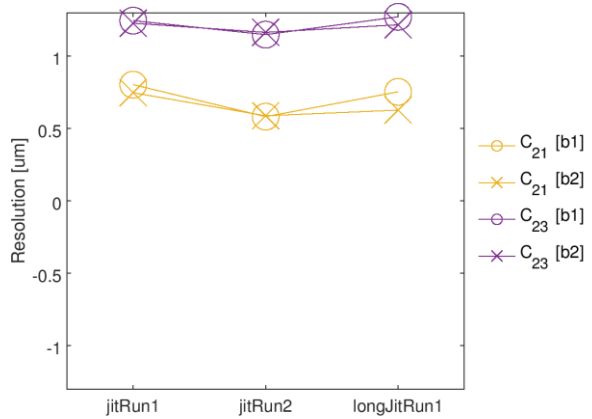
N = 3000

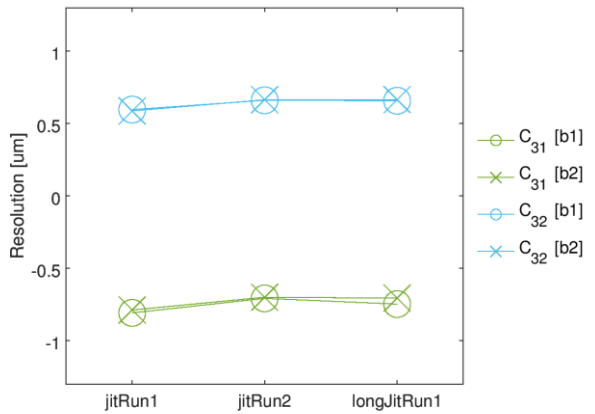
Resolution: Summary



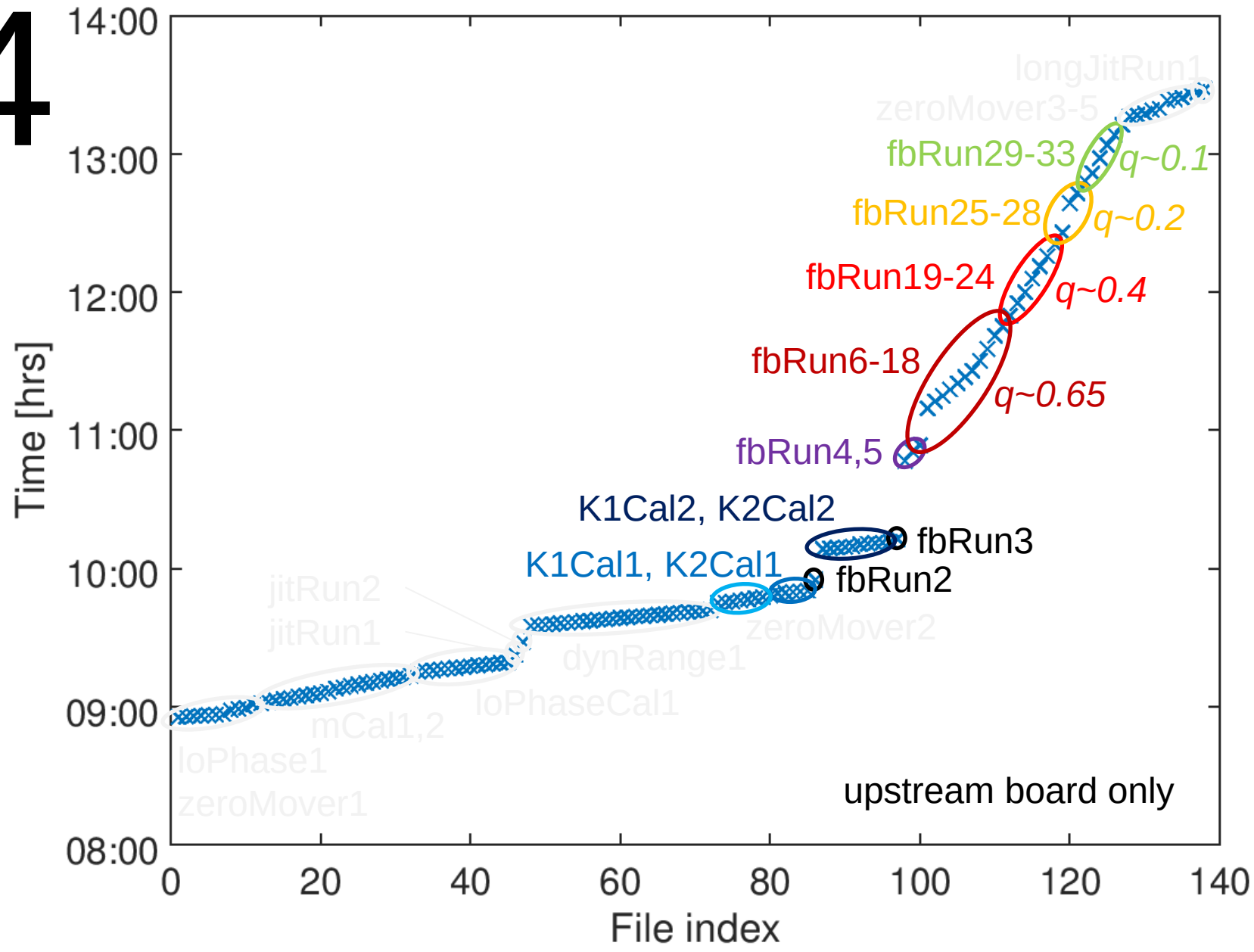
- Estimated resolution of 3-BPM system = **311 ± 5 nm** (combination of all results)
- Fit coefficients stable within 17.5%
  - excluding C_{12} and C_{21}, stable within 9%







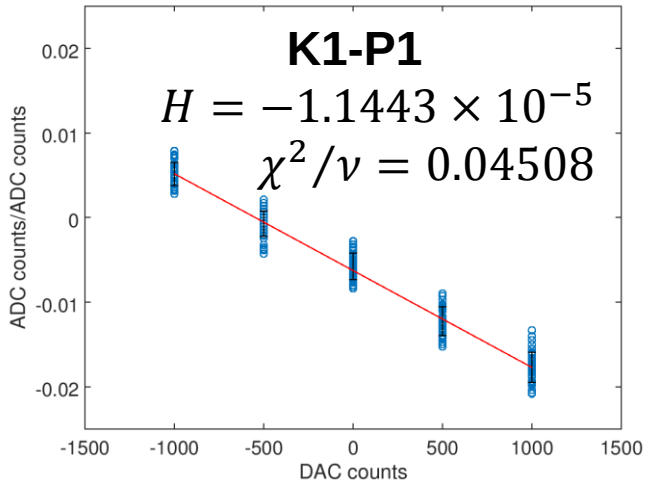
4

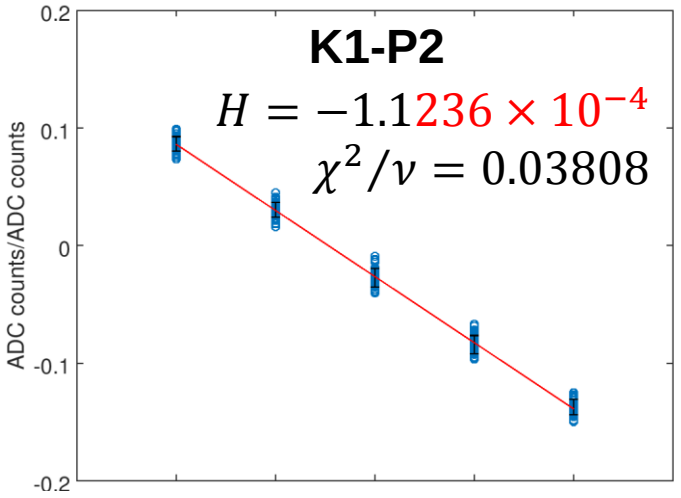

14:00
13:00
12:00
11:00
10:00
09:00
08:00
Time [hrs]
0
20
40
60
80
100
120
140
File index
longJitRun1
zeroMover3-5
fbRun29-33
q~0.1
fbRun25-28
q~0.2
fbRun19-24
q~0.4
fbRun6-18
q~0.65
fbRun4,5
K1Cal2, K2Cal2
fbRun3
K1Cal1, K2Cal1
fbRun2
jitRun2
jitRun1
zeroMover2
dynRange1
loPhaseCal1
mCal1,2
loPhase1
zeroMover1
upstream board only

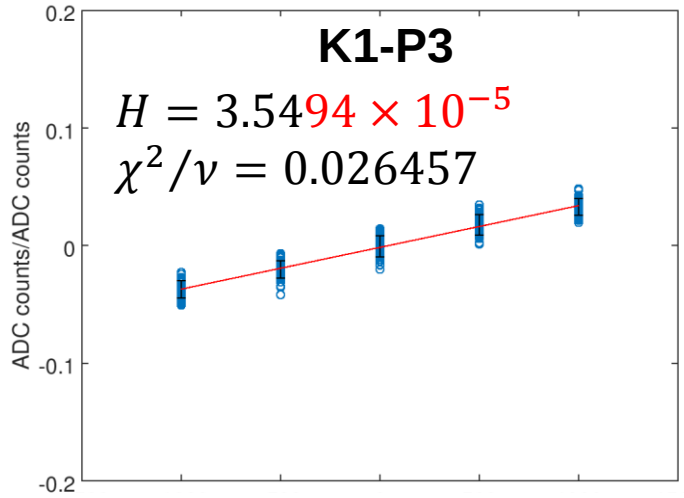
phase compensation: none

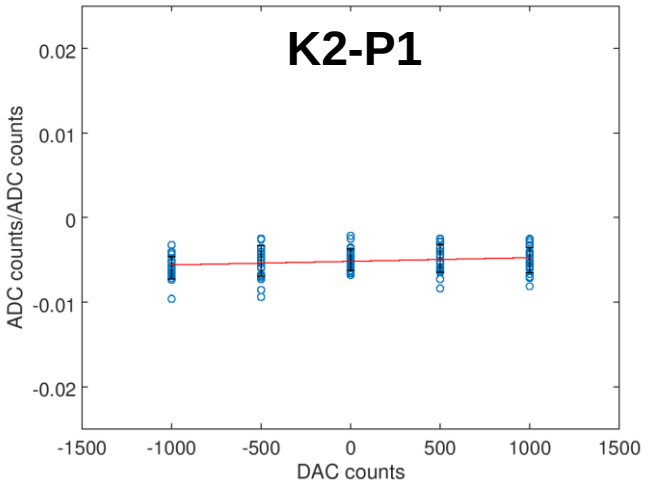
calibration: none

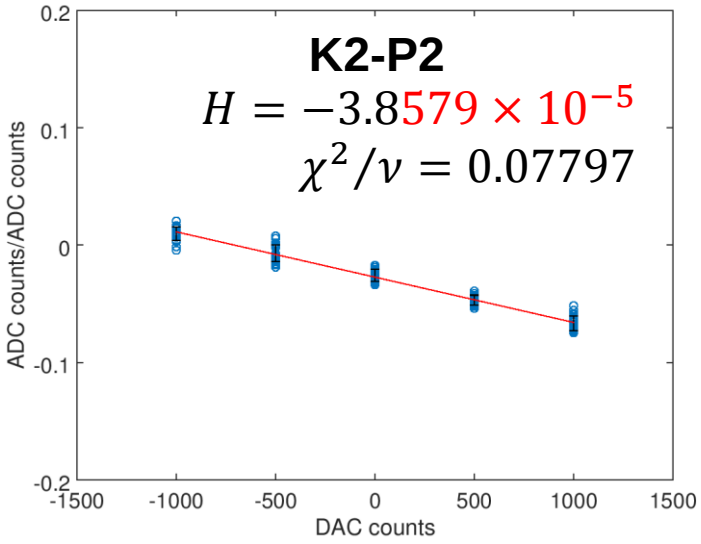
Feedback: KCal1

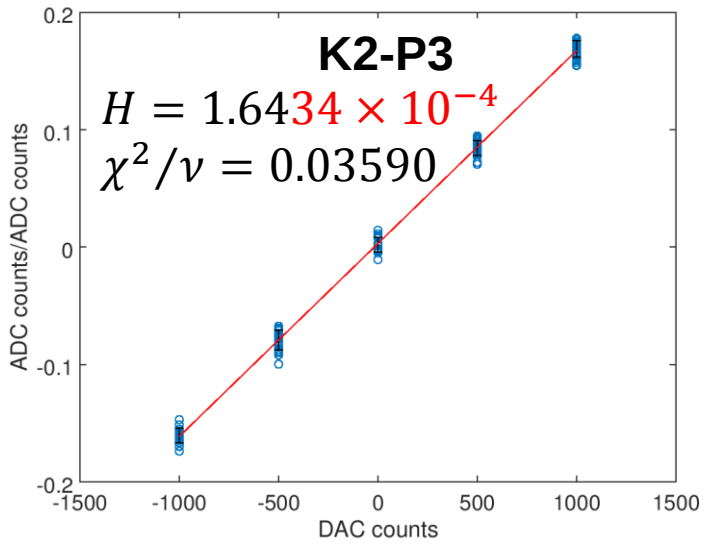












Feedback: gain calculation

Gain parameters = coefficients for BPM position in expression for kicks:

$$\begin{pmatrix} v_{K1} \\ v_{K2} \end{pmatrix} = \begin{pmatrix} G_{P2K1} & G_{P3K1} \\ G_{P2K2} & G_{P3K2} \end{pmatrix} \begin{pmatrix} y'_{P2} \\ y'_{P3} \end{pmatrix}$$

Corrected position is equal to uncorrected position plus a term for each kicker; feedback condition requires it be zero:

$$\begin{pmatrix} Y''_{P2} \\ Y''_{P3} \end{pmatrix} = \begin{pmatrix} y''_{P2} \\ y''_{P3} \end{pmatrix} + \begin{pmatrix} H_{K1P2} & H_{K2P2} \\ H_{K1P3} & H_{K2P3} \end{pmatrix} \begin{pmatrix} v_{K1} \\ v_{K2} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}$$

Assuming $y'_{P2} = y''_{P2}$ equating the vector of kicks gives the result:

$\boldsymbol{G} = -\boldsymbol{H}^{-1}$ where $\boldsymbol{H}^{-1} = \frac{1}{|\boldsymbol{H}|} \begin{pmatrix} H_{K2P3} & -H_{K2P2} \\ -H_{K1P3} & H_{K1P2} \end{pmatrix}$

So that the individual expressions for the gain parameters are:

$G_{P2K1} = -\frac{H_{K2P3}}{|\boldsymbol{H}|}$, $G_{P3K1} = \frac{H_{K2P2}}{|\boldsymbol{H}|}$, $G_{P2K2} = \frac{H_{K1P3}}{|\boldsymbol{H}|}$, $G_{P3K2} = -\frac{H_{K1P2}}{|\boldsymbol{H}|}$

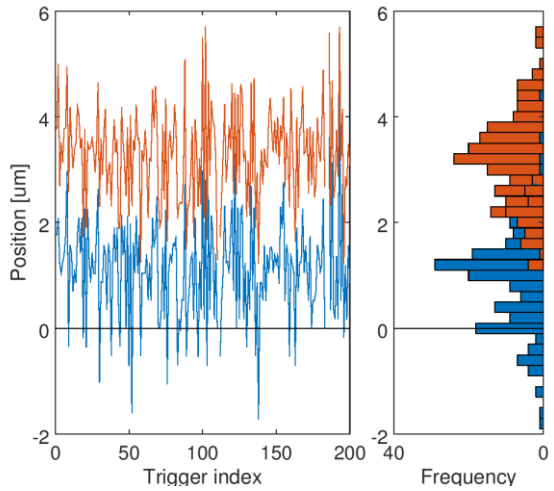
Feedback: fbRun2

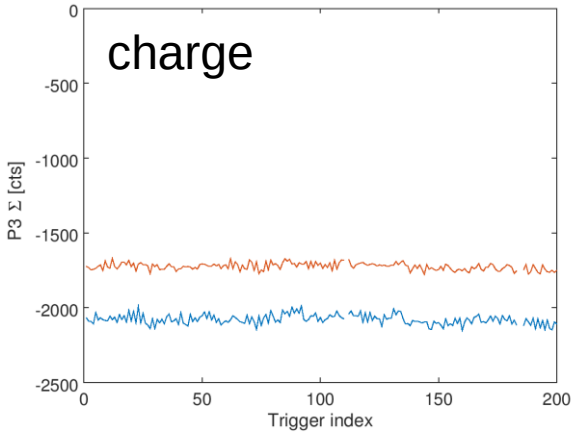
High charge: ~0.65×10^{10}

N = 200

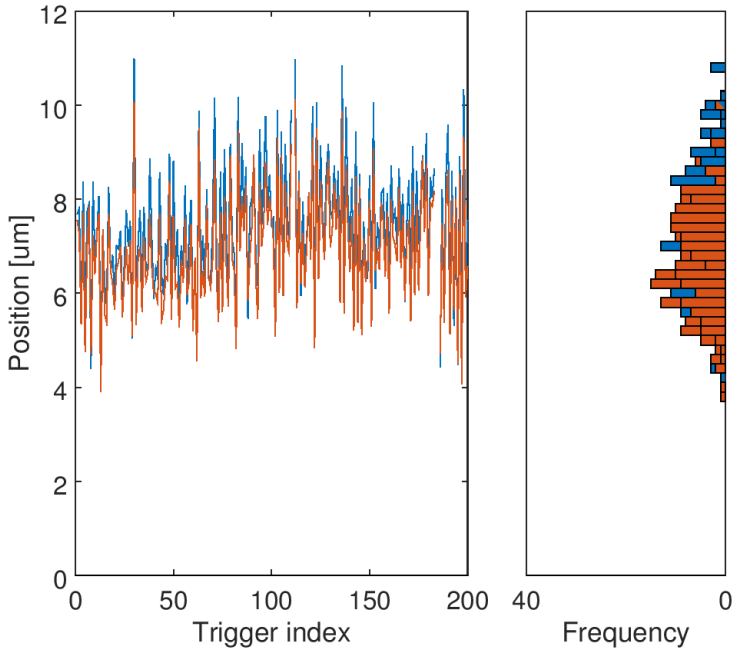
	K1	K2
P2	9613	2265
P3	-2078	-6572

P1

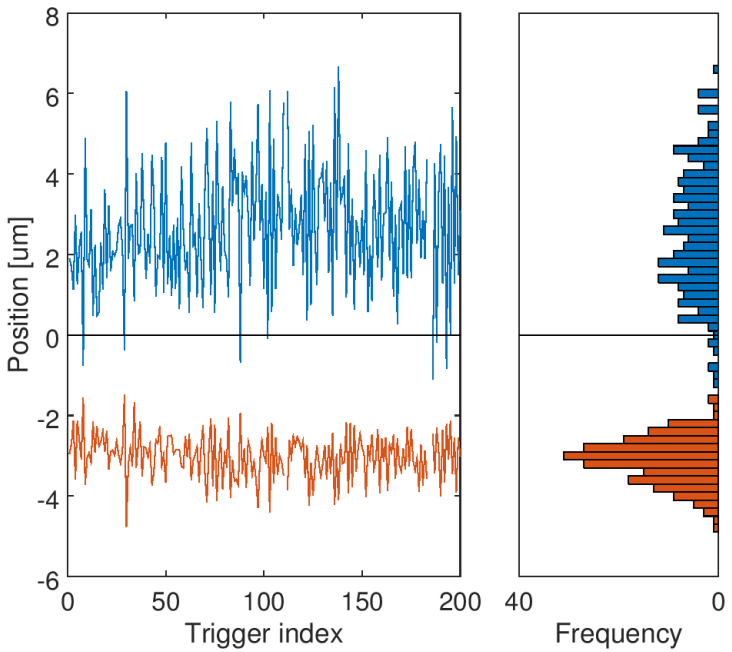




P2



P3



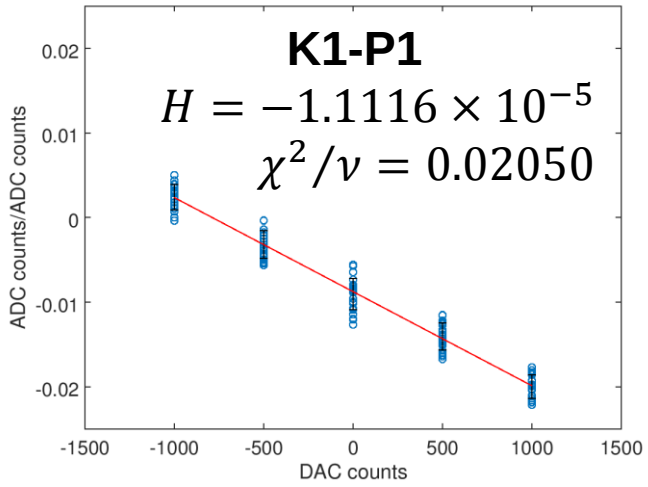
	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	0.984	0.903	0.888
P2	1.420	1.265	0.973
P3	1.583	0.576	-0.857

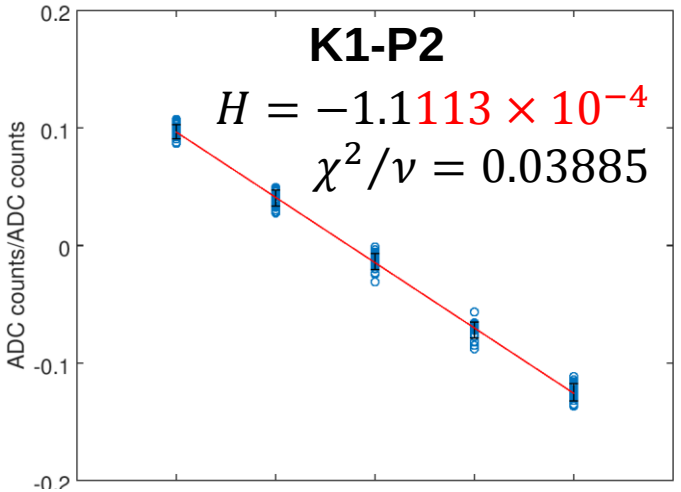
k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.4420	P3	-0.8814	**0.322**
P2	P3	1.1257	P1	0.6066	**0.326**
P3	P1	-0.7307	P2	0.6800	**0.291**

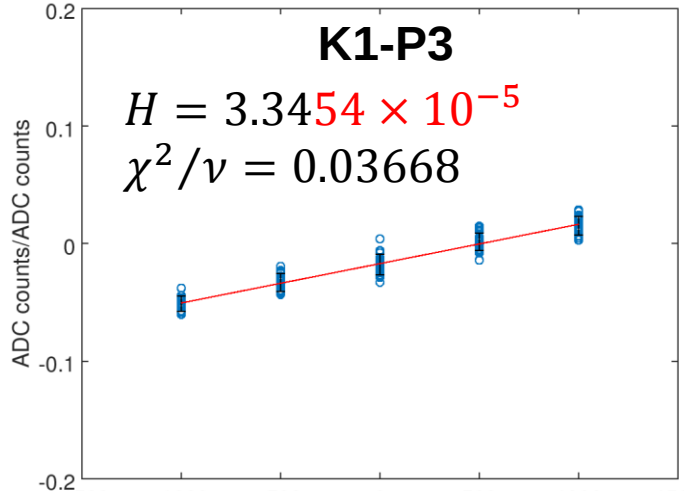
phase compensation: none

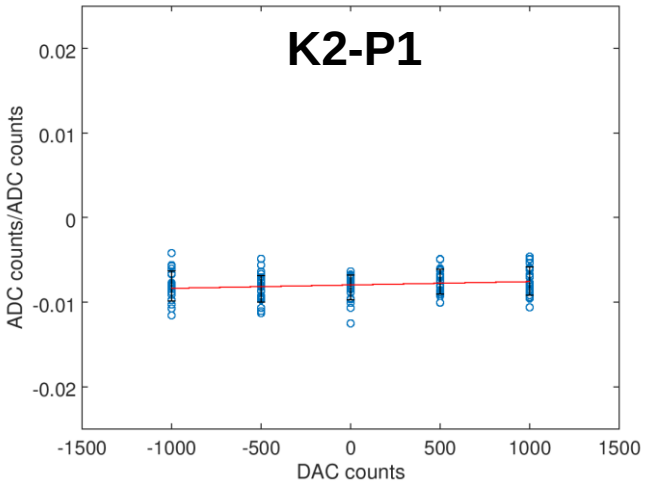
calibration: none

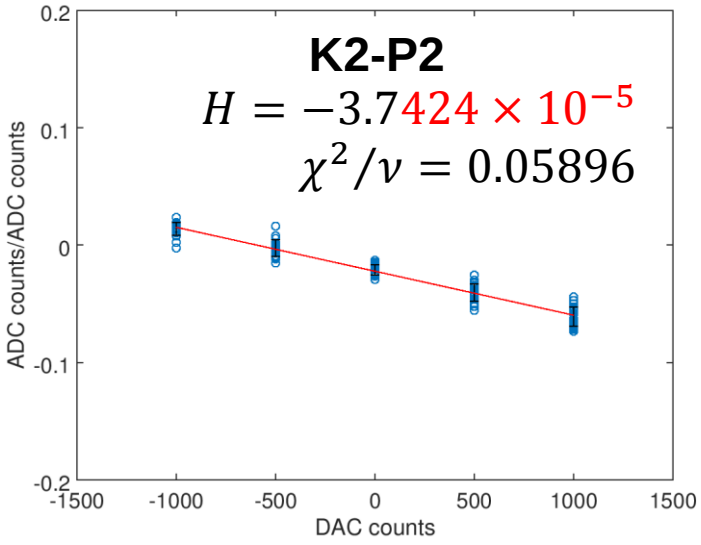
Feedback: KCal2

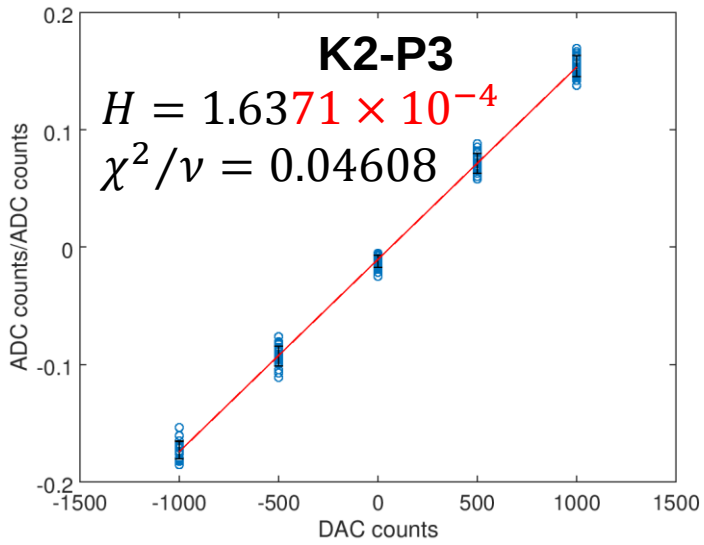












Feedback: fbRun3

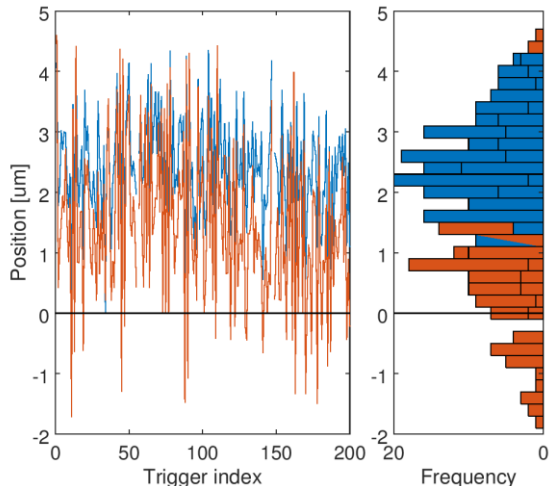
High charge: ~0.65×10^{10}

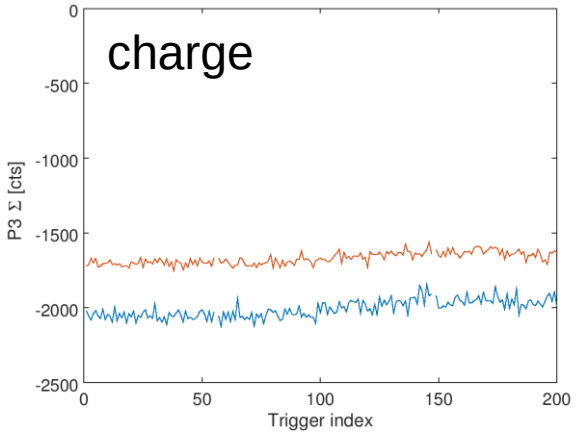
N = 200

	K1	K2
P2	9724	2223
P3	-2191	-6609

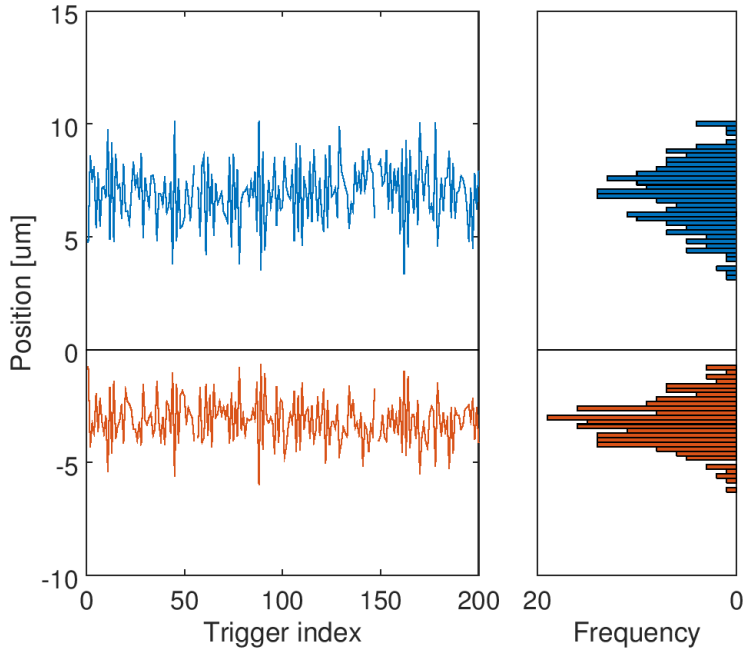
tweak gains

P1

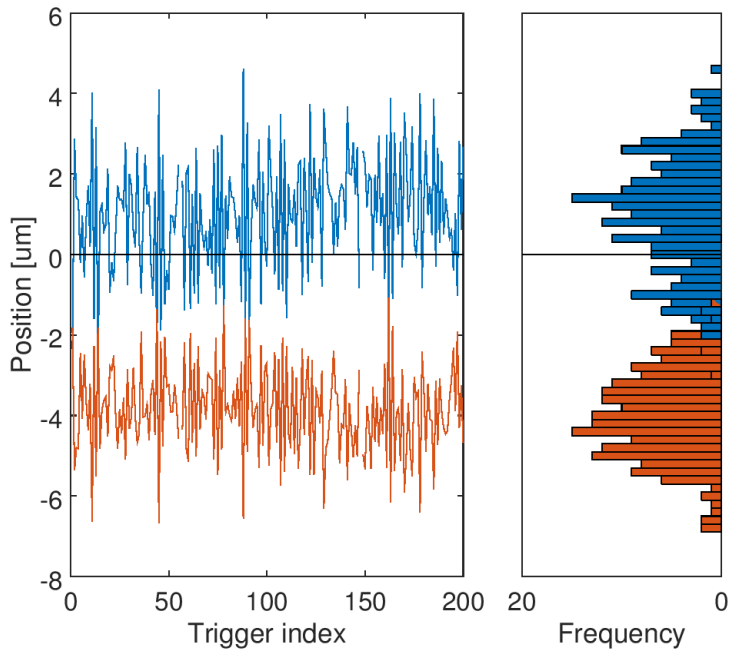




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	0.926	1.362	0.884
P2	1.362	1.031	-0.934
P3	1.501	1.146	-0.928

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.3202	P3	-0.7984	**0.329**
P2	P3	1.1035	P1	0.5009	**0.346**
P3	P1	-0.7271	P2	0.6425	**0.297**

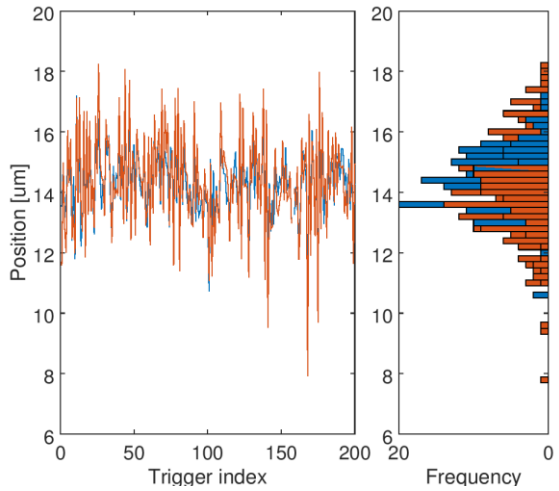
	K1	K2
P2	9724	2223
P3	-2191	-6609

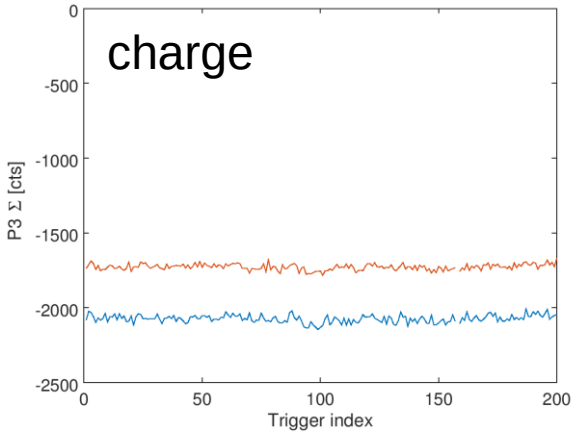
Feedback: fbRun5

High charge: ~0.65×10^{10}

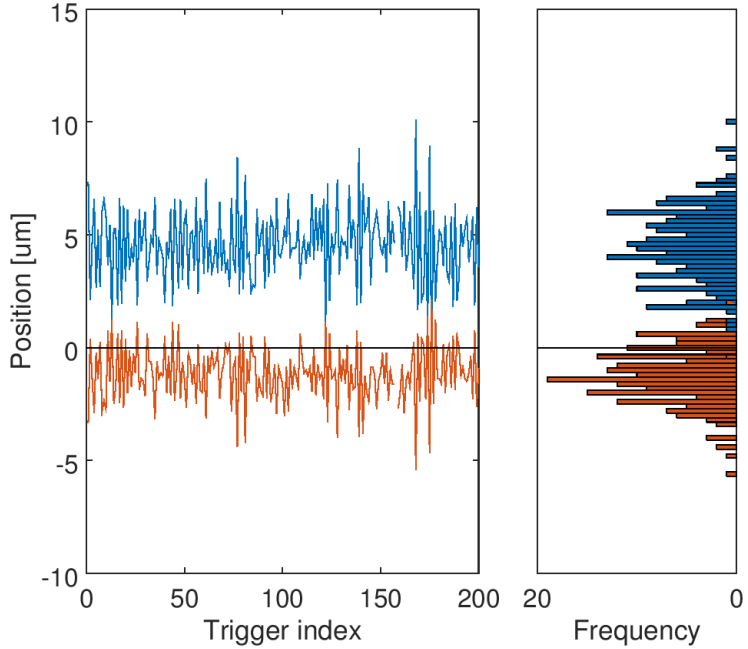
N = 200

P1

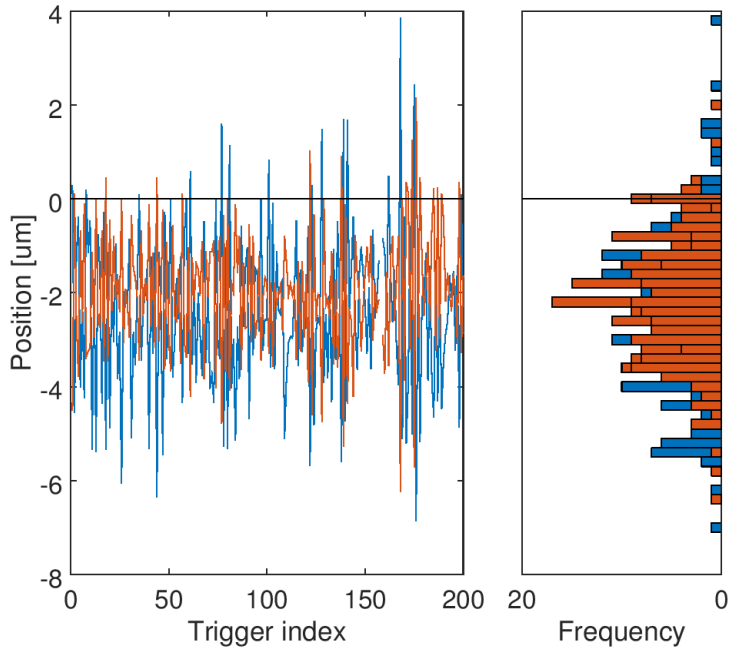




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.166	1.697	0.896
P2	1.677	1.266	-0.941
P3	1.805	1.387	-0.931

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.4338	P3	-0.9250	**0.353**
P2	P3	1.1817	P1	0.6014	**0.358**
P3	P1	-0.7031	P2	0.6480	**0.318**

Feedback: fbRun6

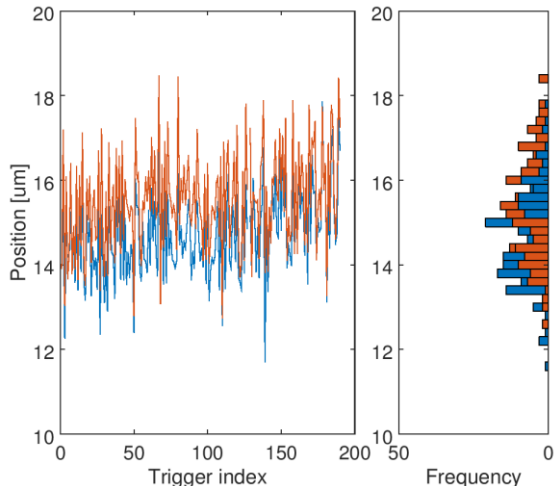
High charge: ~0.65×10^{10}

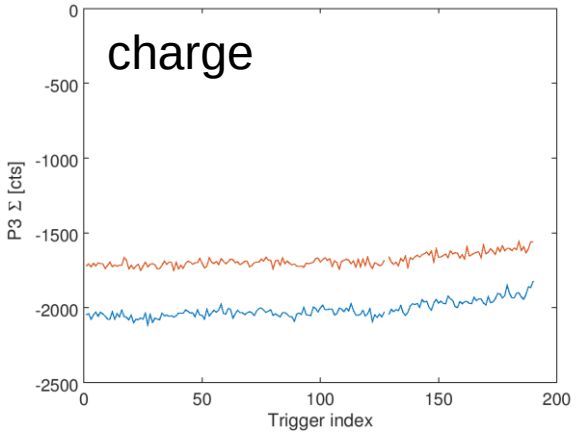
N = 200

	K1	K2
P2	4862	1112
P3	-1096	-3305

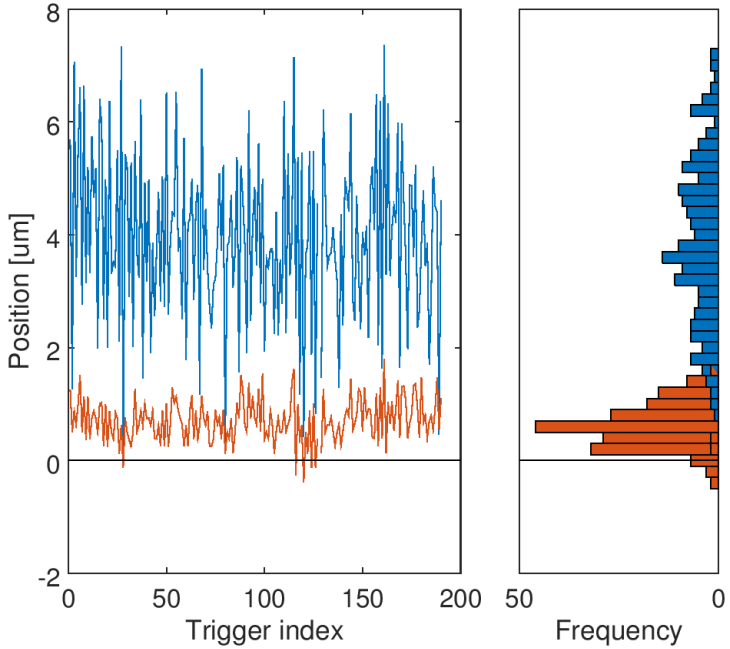
half gains

P1

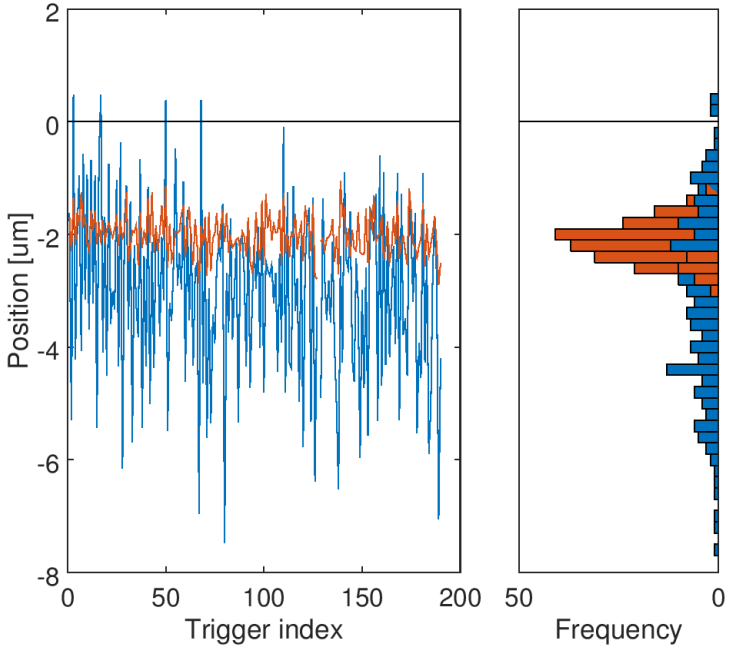




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.065	1.226	0.882
P2	1.547	0.386	0.616
P3	1.628	0.373	0.577

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.5413	P3	-0.9897	**0.349**
P2	P3	1.1646	P1	0.5814	**0.333**
P3	P1	-0.6362	P2	0.6969	**0.307**

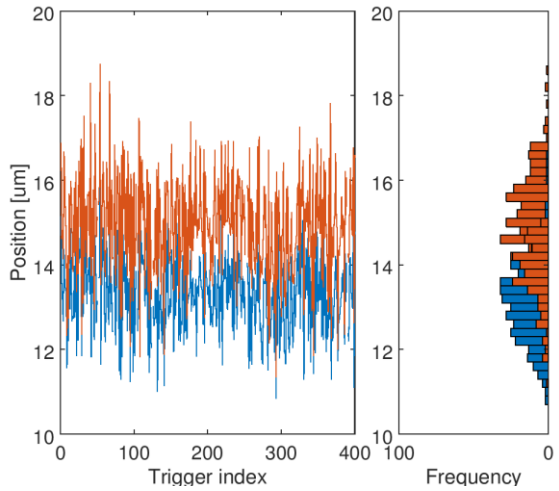
Feedback: fbRun18

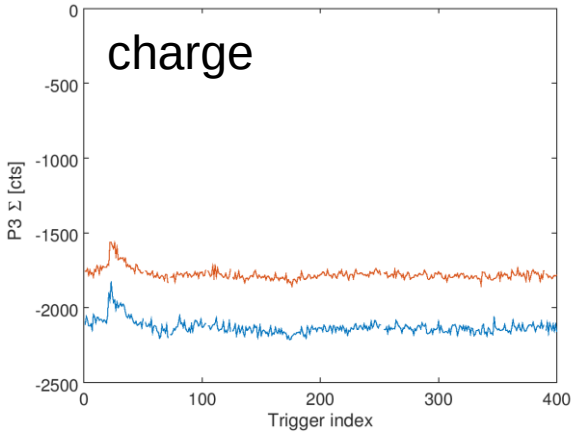
High charge: ~0.65×10^{10}

N = 400

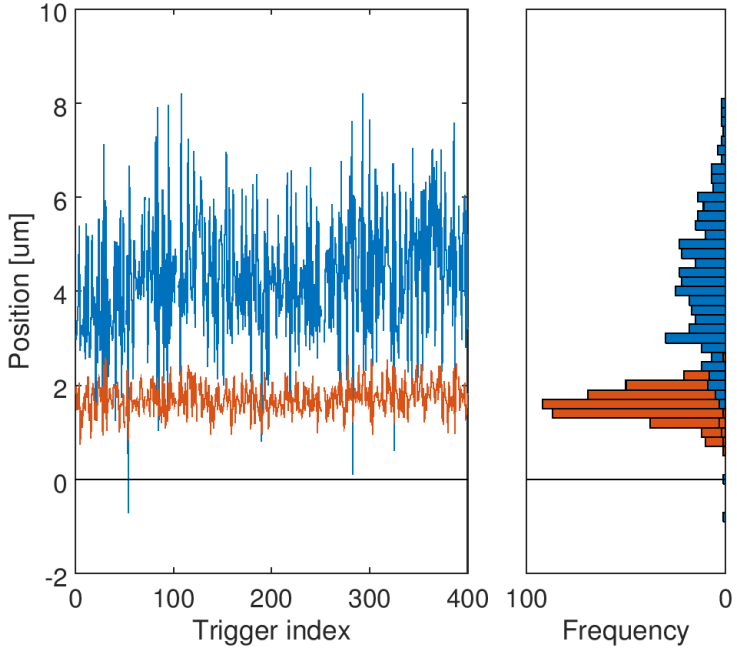
	K1	K2
P2	4862	1112
P3	-1096	-3305

P1

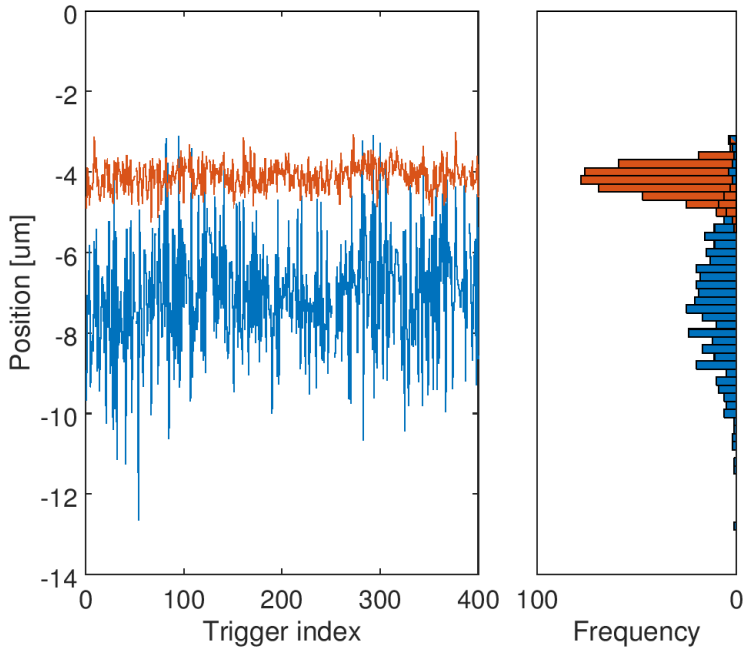




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.003	1.234	0.877
P2	1.444	0.348	0.533
P3	1.570	0.366	0.560

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.4380	P3	-0.9088	**0.328**
P2	P3	1.1310	P1	0.5392	**0.322**
P3	P1	-0.6729	P2	0.6802	**0.289**

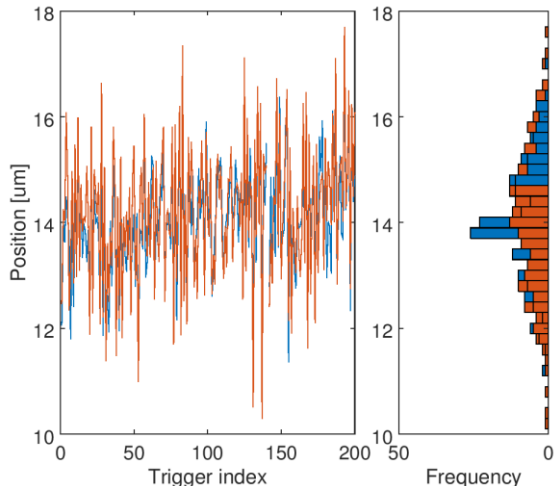
Feedback: fbRun19

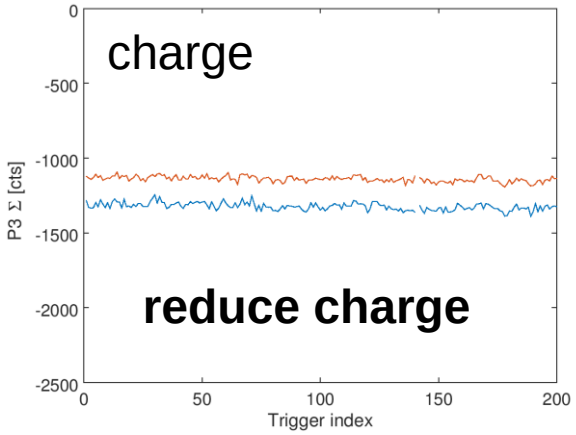
Mid charge: ~0.4×10^{10}

N = 200

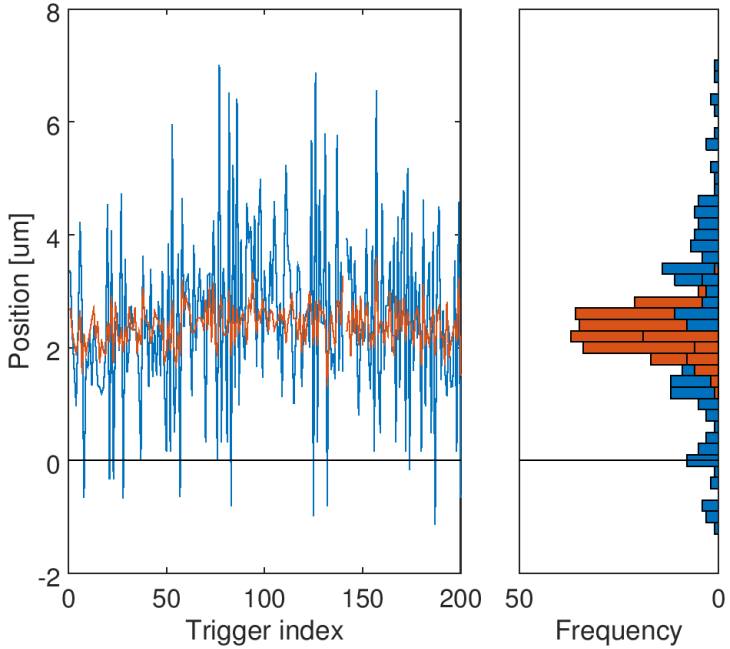
	K1	K2
P2	4862	1112
P3	-1096	-3305

P1

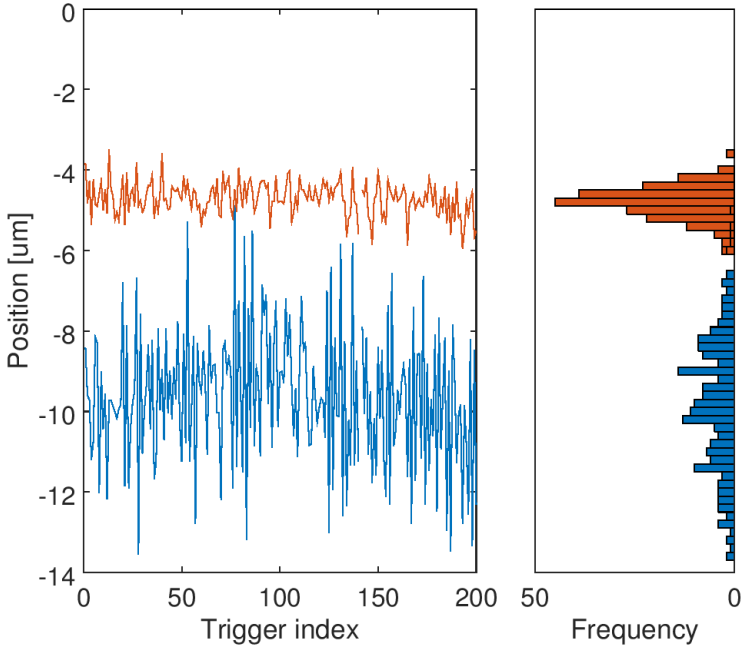




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.099	1.374	0.847
P2	1.639	0.379	0.496
P3	1.753	0.421	0.455

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.4748	P3	-0.8966	**0.415**
P2	P3	1.0939	P1	0.4986	**0.387**
P3	P1	-0.6228	P2	0.7236	**0.356**

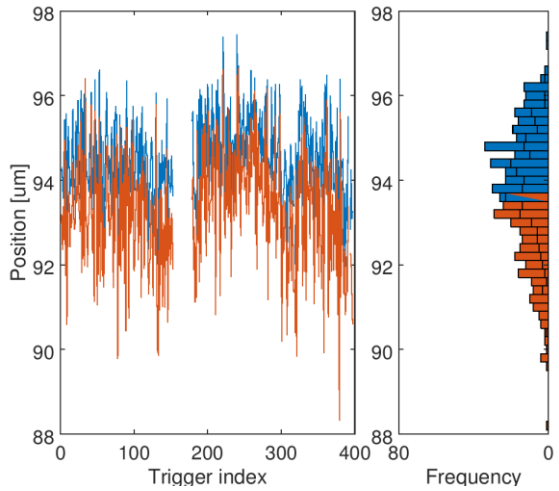
	K1	K2
P2	4862	1112
P3	-1096	-3305

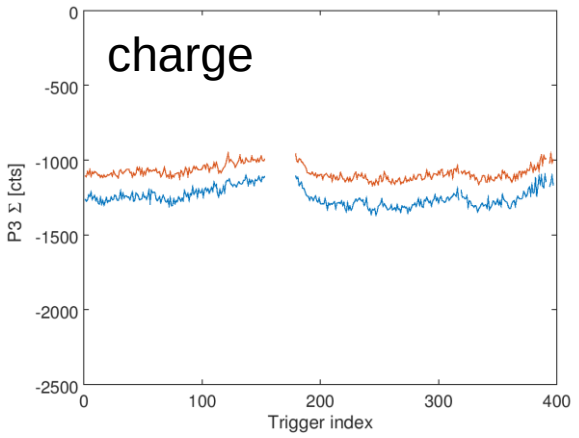
Feedback: fbRun21

Mid charge: ~0.4×10^{10}

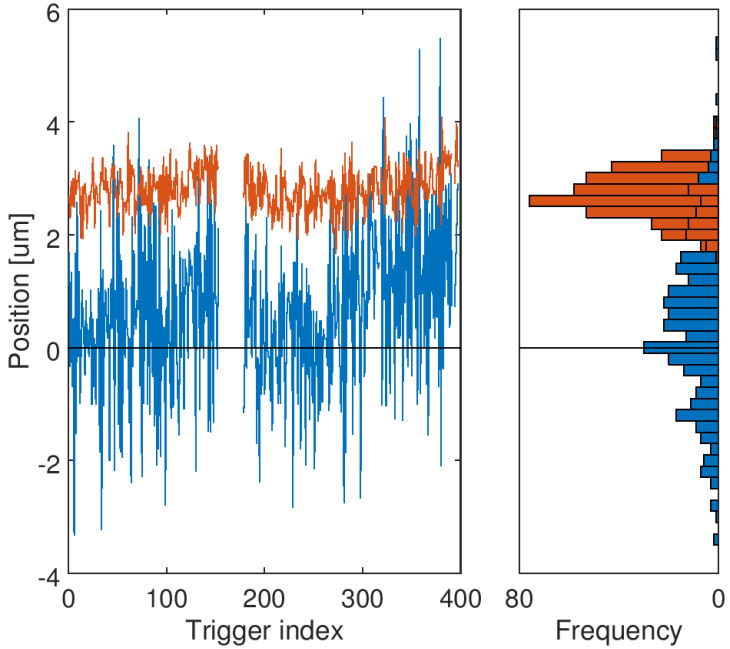
N = 400

P1

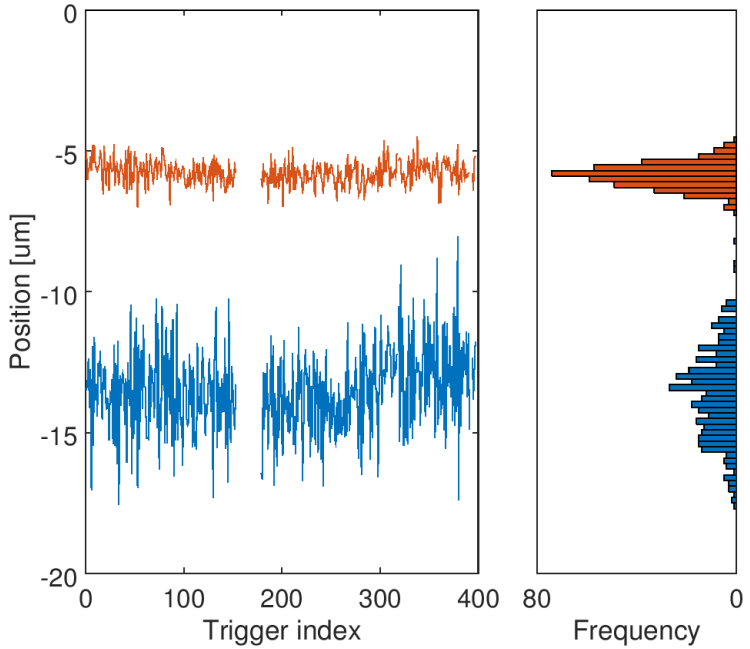




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.103	1.406	0.900
P2	1.519	0.413	0.468
P3	1.588	0.440	0.455

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.2879	P3	-0.7953	**0.486**
P2	P3	1.0263	P1	0.3306	**0.464**
P3	P1	-0.5874	P2	0.6599	**0.455**

Charge low enough to resume on-peak sampling of P1 signals. Use mCal1 with $y_{P1} = \Delta_{P1}/\Sigma_{P3}$

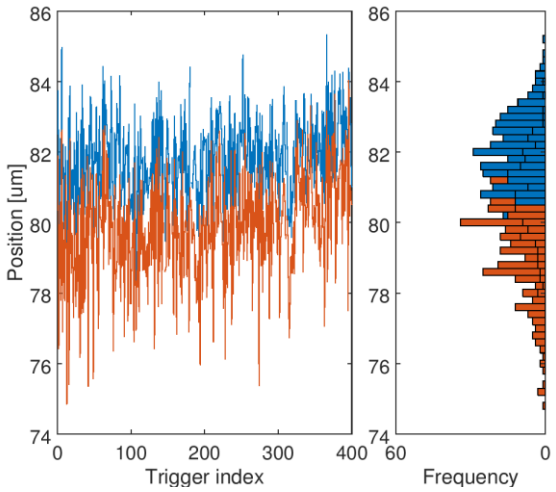
Feedback: fbRun25

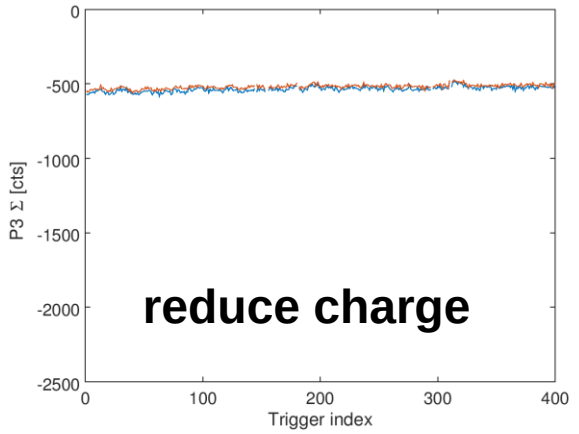
Low charge: ~0.2×10^{10}

N = 400

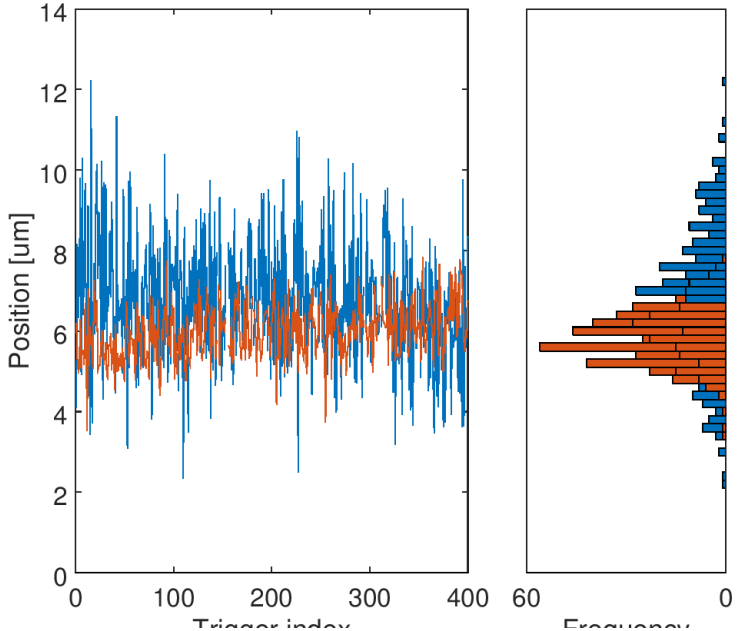
	K1	K2
P2	4862	1112
P3	-1096	-3305

P1

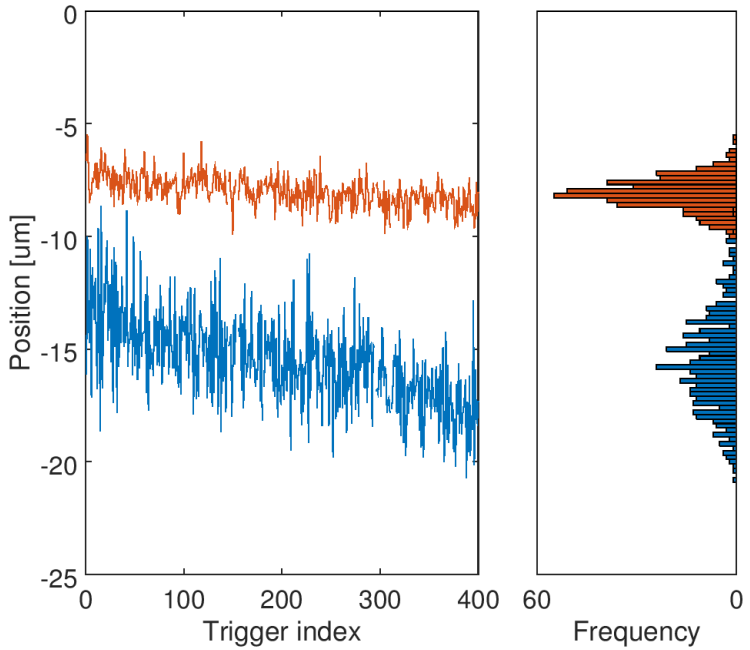




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.317	1.590	0.821
P2	1.656	0.699	0.158
P3	2.129	0.713	0.424

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	-0.2096	P3	-0.3072	**0.856**
P2	P3	0.4956	P1	-0.2560	**0.881**
P3	P1	-0.5450	P2	0.7201	**0.902**

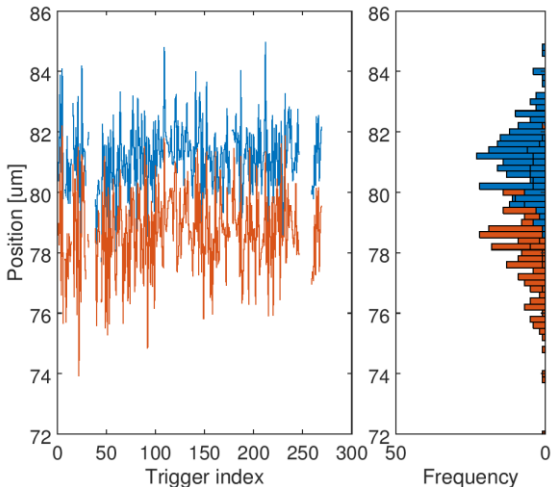
Feedback: fbRun28

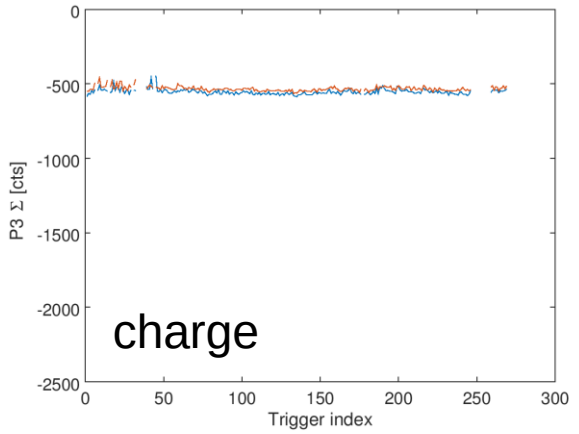
Low charge: ~0.2×10^{10}

N = 296 (aborted)

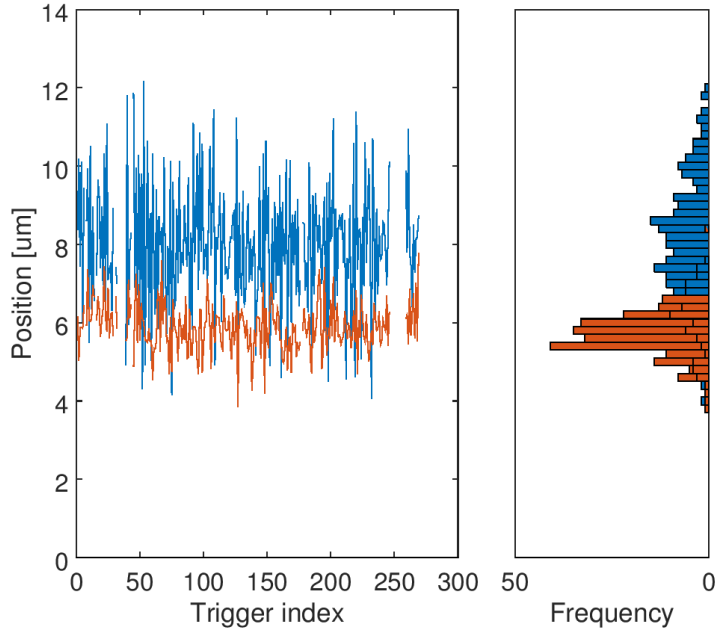
	K1	K2
P2	4862	1112
P3	-1096	-3305

P1

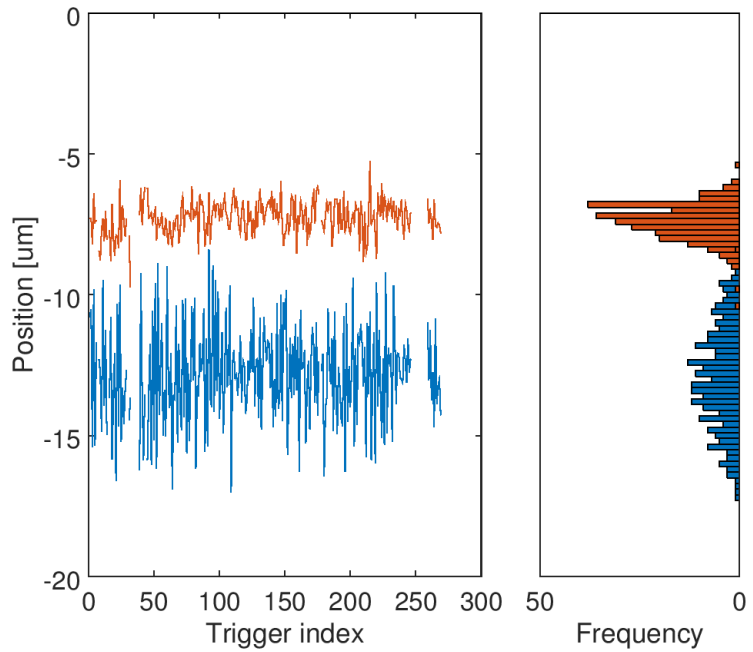




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.283	1.598	0.791
P2	1.668	0.649	0.186
P3	1.851	0.659	0.216

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	-0.2396	P3	-0.2562	**0.926**
P2	P3	0.6070	P1	-0.2453	**0.830**
P3	P1	-0.3154	P2	0.7301	**0.852**

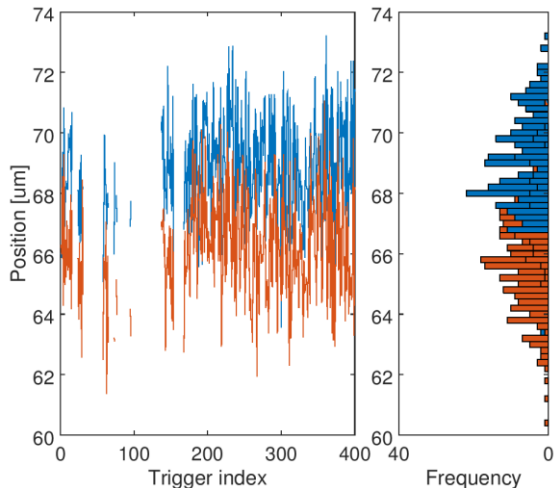
	K1	K2
P2	4862	1112
P3	-1096	-3305

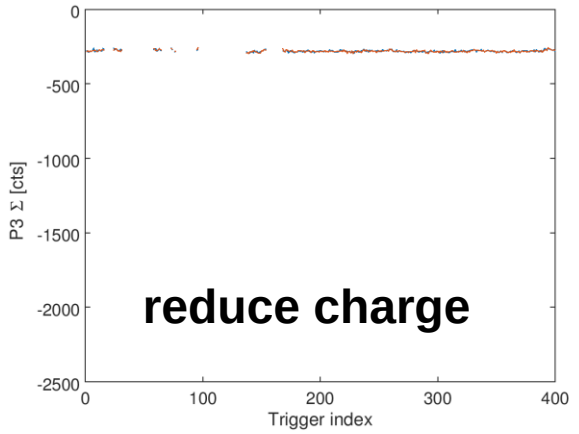
Feedback: fbRun29

V. low charge: ~0.1×10^{10}

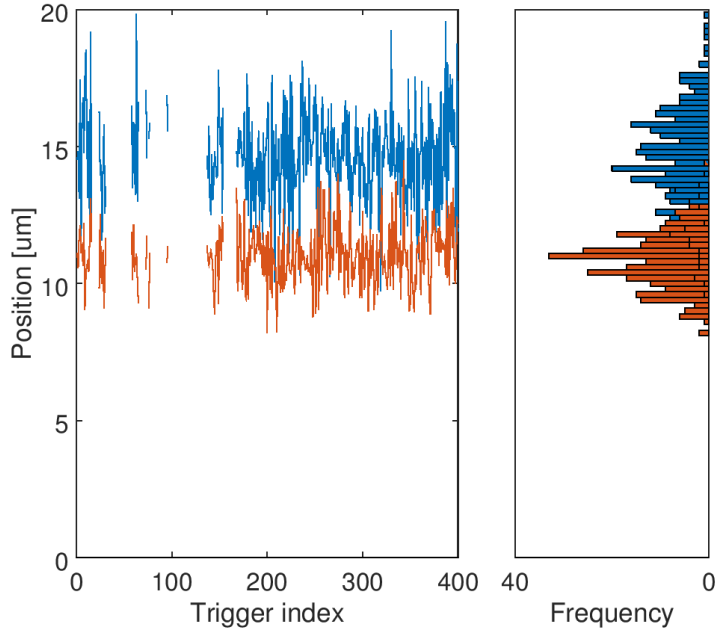
N = 400

P1

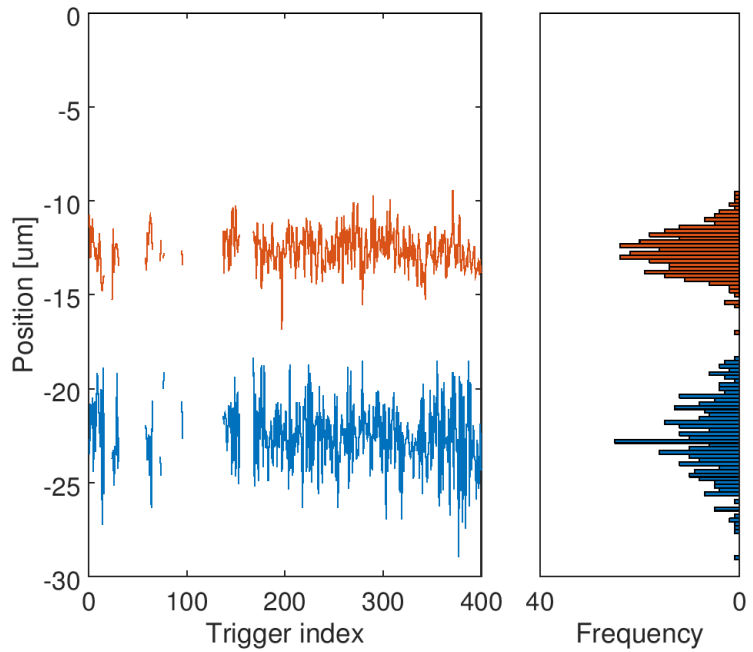




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.743	1.846	0.610
P2	1.857	1.124	-0.060
P3	1.928	1.099	0.014

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	-0.3341	P3	-0.2255	**1.345**
P2	P3	0.5273	P1	-0.2730	**1.127**
P3	P1	-0.2081	P2	0.5957	**1.178**

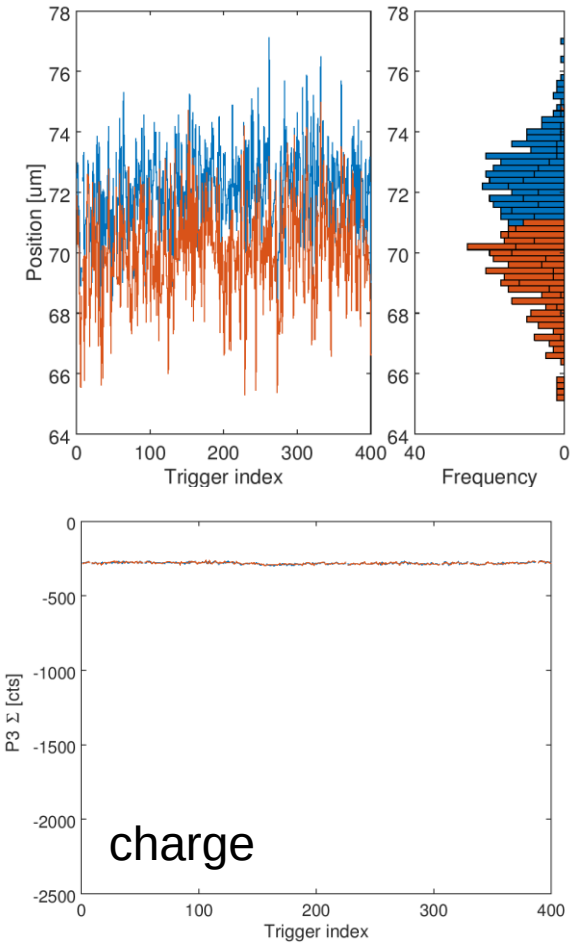
Feedback: fbRun31

V. low charge: ~0.1×10^{10}

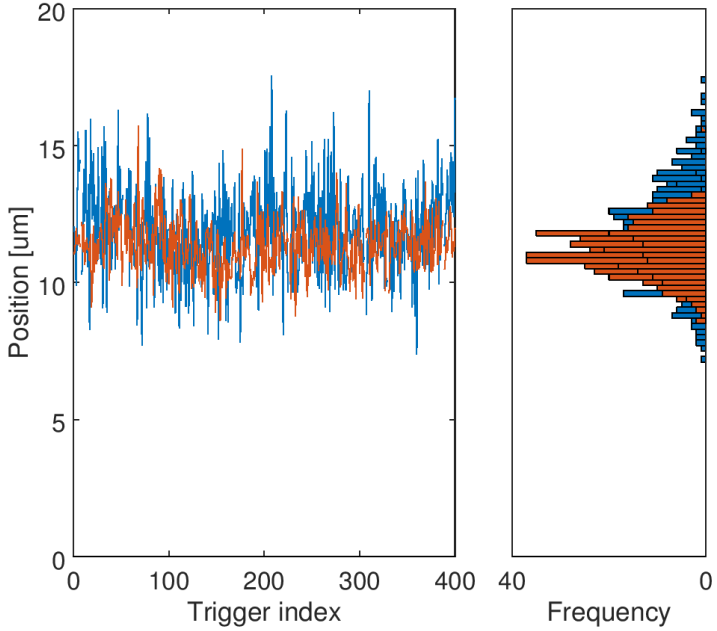
N = 400

	K1	K2
P2	4862	1112
P3	-1096	-3305

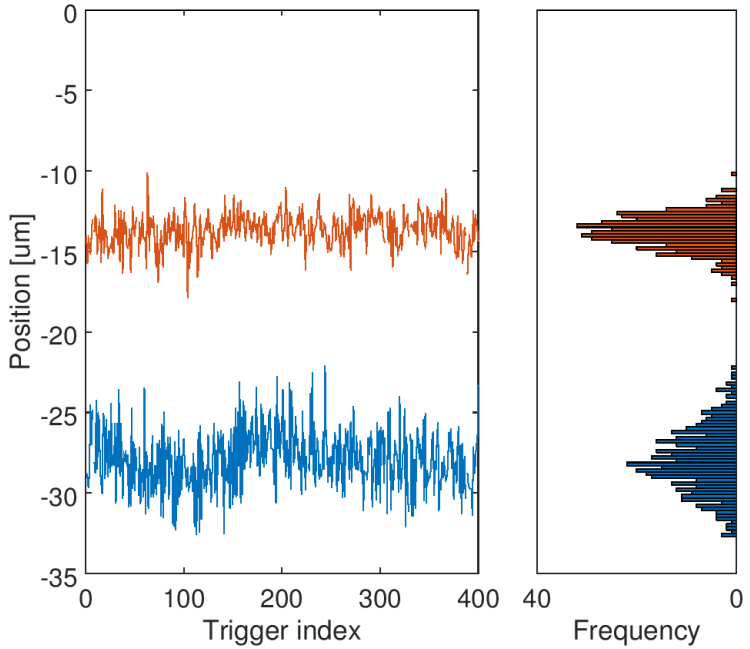
P1



P2



P3

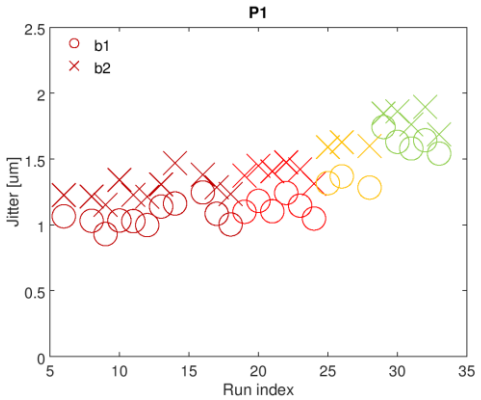


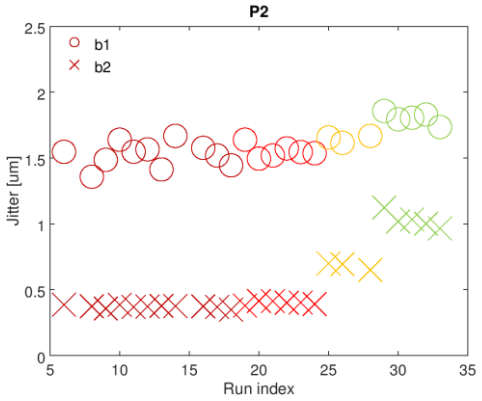
	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.580	1.763	0.605
P2	1.806	1.033	-0.008
P3	1.972	1.084	0.091

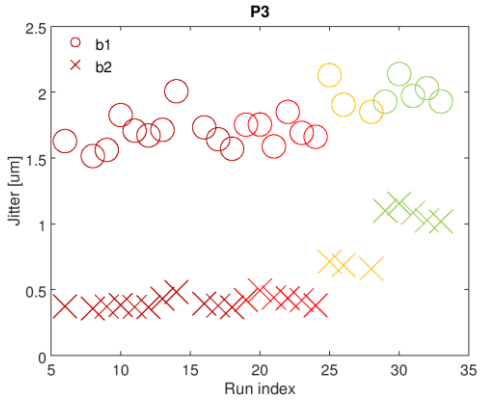
k	i	C_{ki}	j	C_{kj}	σ
P1	P2	-0.2415	P3	-0.2732	**1.229**
P2	P3	0.4939	P1	-0.2484	**1.161**
P3	P1	-0.3249	P2	0.5709	**1.192**

Feedback: Summary

jitter







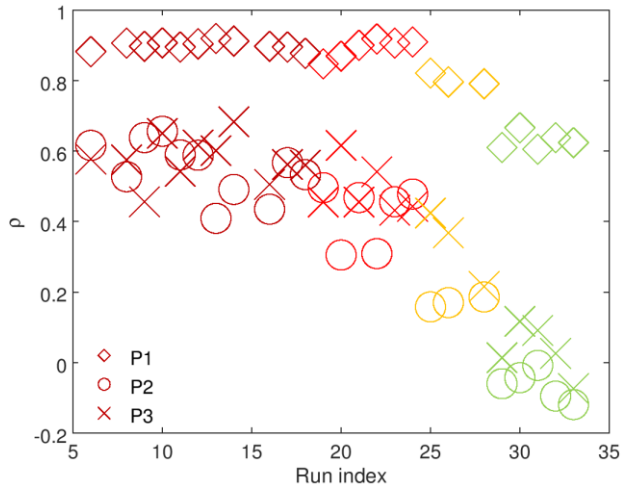
Ignoring low charge results ($f = \sigma_1/\sigma_2$)

$f_{P2} = 4.03 \pm 0.06$

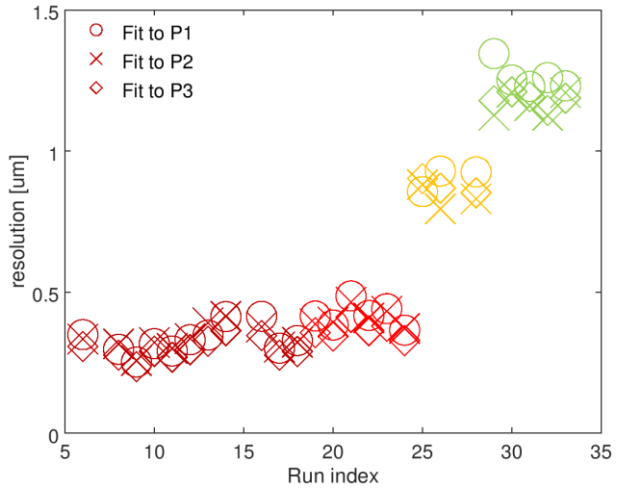
$f_{P3} = 4.23 \pm 0.08$

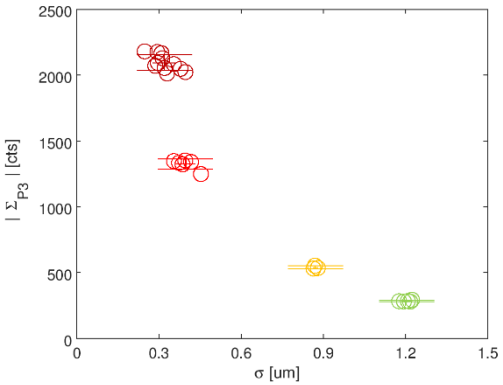
	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.091 ± 0.021	1.323 ± 0.025	0.896 ± 0.005
P2	1.534 ± 0.019	0.381 ± 0.004	0.504 ± 0.025
P3	1.698 ± 0.029	0.404 ± 0.010	0.545 ± 0.019

correlation

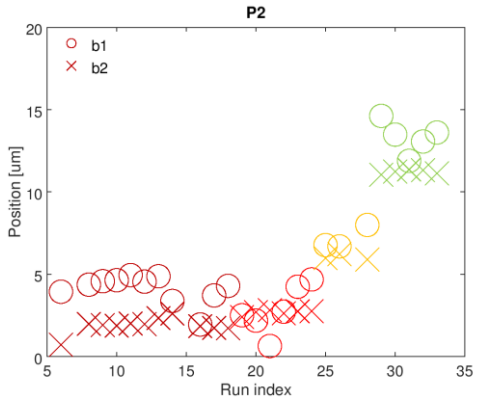


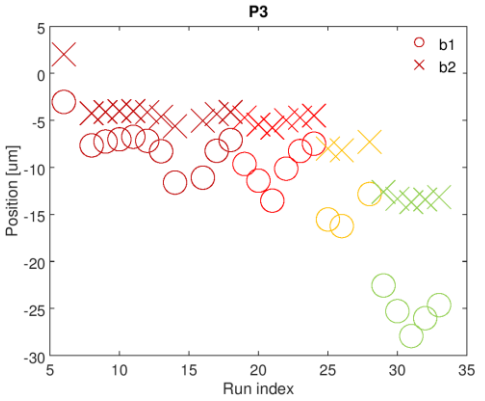
resolution





mean position





Grand Summary

- Bunch spacing scan
  - High bunch-to-bunch correlations (> 0.97) observed at feedback BPMs for selected bunch spacing settings in the range 252 ns – 324.8 ns
- Upstream diagnostics
  - Phase sensitivity reduced to ~½ μm per degree using upstream phase shifters
  - Dynamic range of diode processor with 3 dB attenuation ~1 mm
  - Resolution of 3BPM system including diode processor on P1 = 311 ± 5 nm
    cf. result from paper = 291 ± 10 nm
- Feedback results
  - Feedback correction factor > 4 achieved; consistent with observed bunch correlation
  - Mysterious factor of 2 between calculated gains and gains observed to work in practice

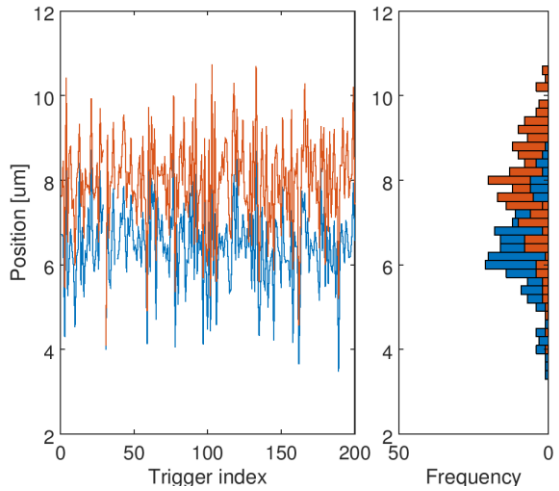
Feedback: fbRun8

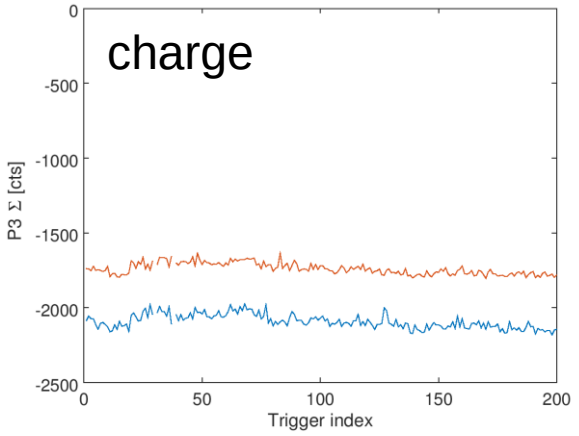
High charge: ~0.65×10^{10}

N = 200

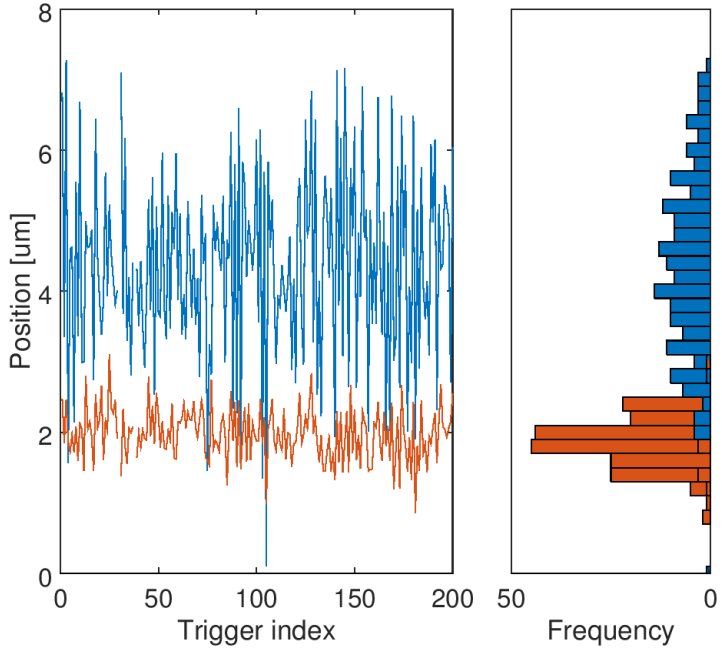
	K1	K2
P2	4862	1112
P3	-1096	-3305

P1

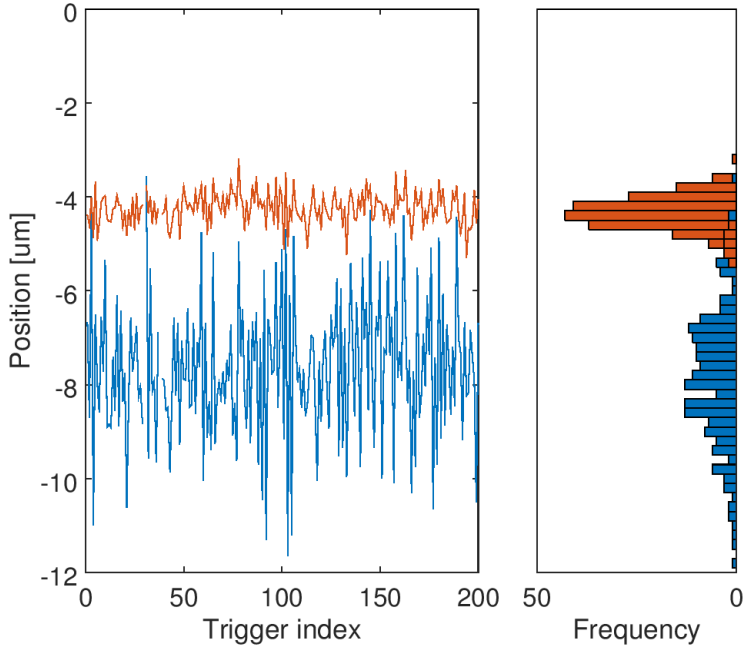




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.031	1.215	0.906
P2	1.358	0.374	0.527
P3	1.515	0.357	0.575

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.4444	P3	-0.9359	**0.297**
P2	P3	1.2078	P1	0.7226	**0.316**
P3	P1	-0.7726	P2	0.6132	**0.276**

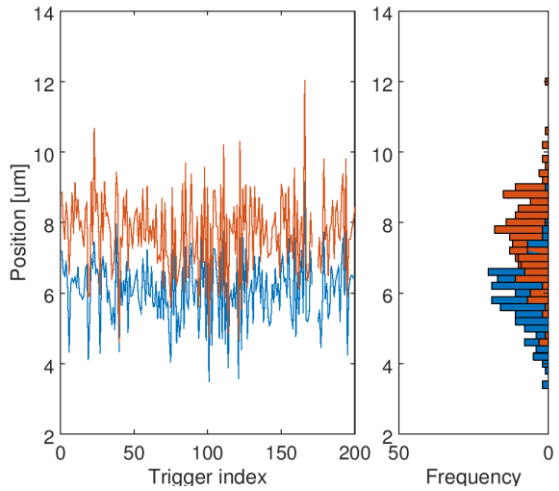
Feedback: fbRun9

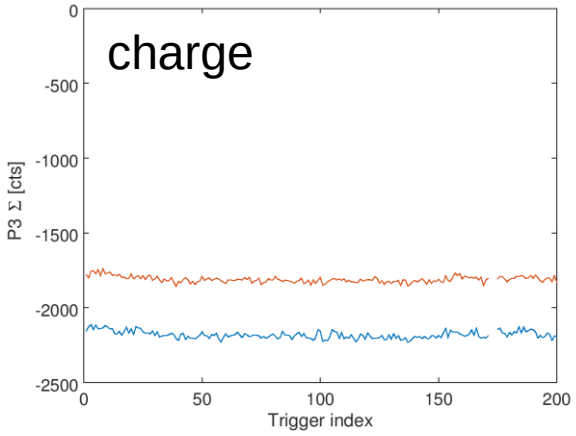
High charge: ~0.65×10^{10}

N = 200

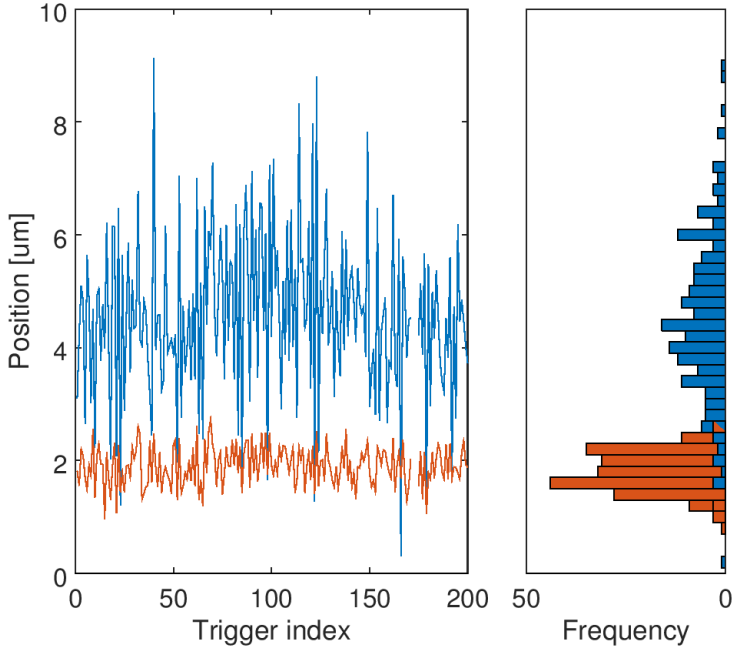
	K1	K2
P2	4862	1112
P3	-1096	-3305

P1

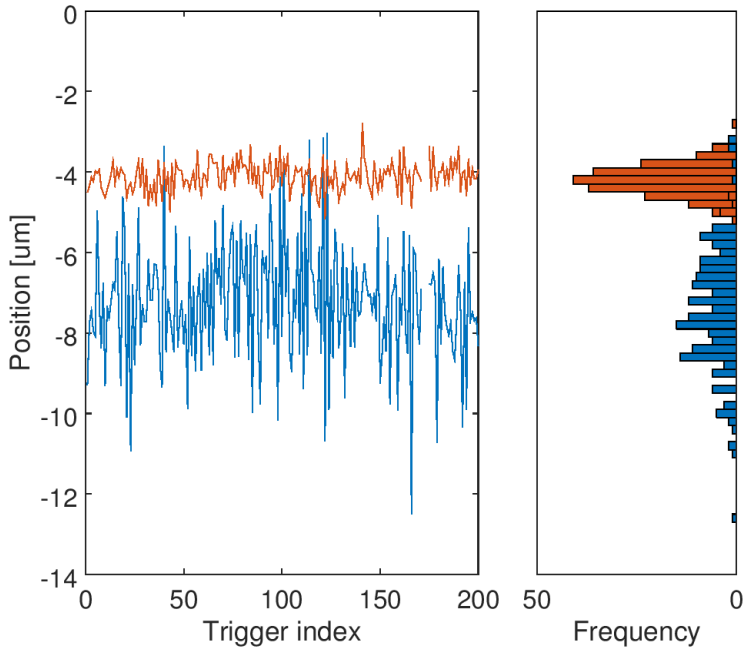




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	0.930	1.152	0.897
P2	1.486	0.357	0.638
P3	1.561	0.372	0.456

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.5139	P3	-0.9545	**0.252**
P2	P3	1.2765	P1	0.8023	**0.257**
P3	P1	-0.7623	P2	0.6529	**0.235**

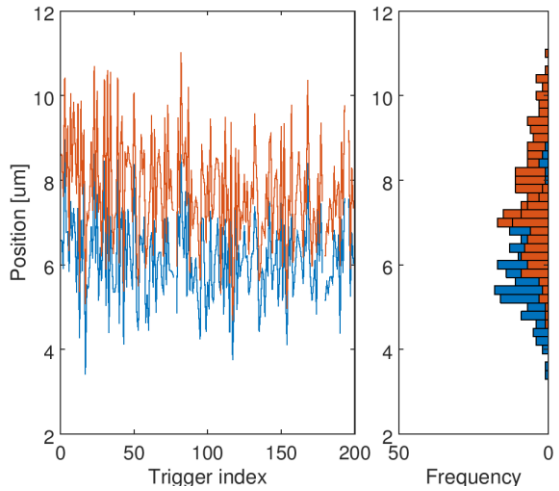
Feedback: fbRun10

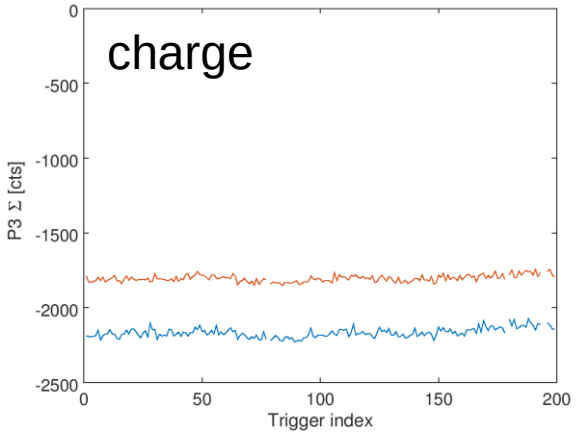
High charge: ~0.65×10^{10}

N = 200

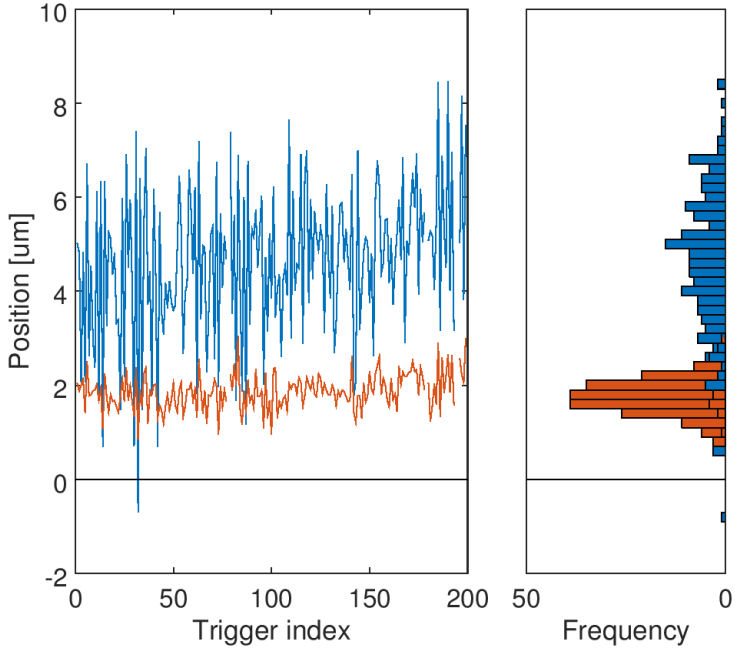
	K1	K2
P2	4862	1112
P3	-1096	-3305

P1

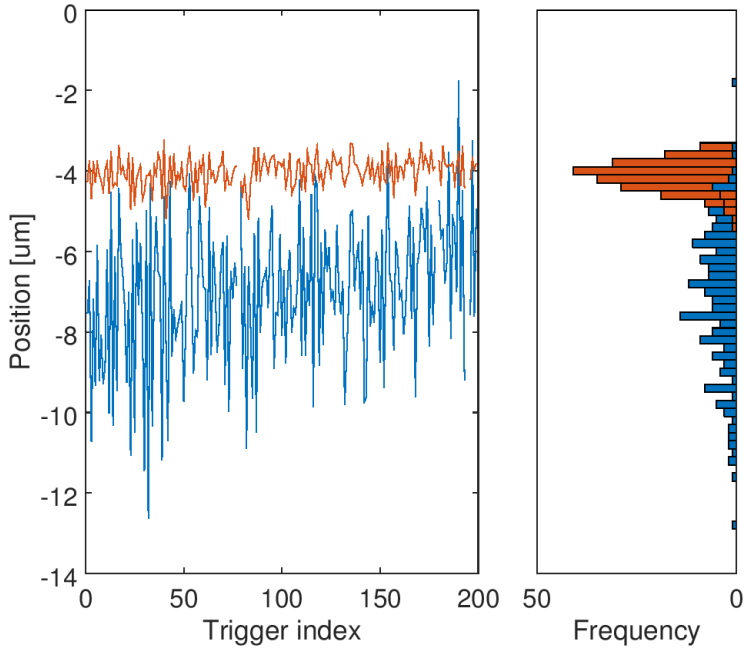




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.033	1.341	0.907
P2	1.639	0.385	0.656
P3	1.826	0.383	0.650

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.4617	P3	-0.8655	**0.317**
P2	P3	1.1498	P1	0.6693	**0.321**
P3	P1	-0.7637	P2	0.6999	**0.290**

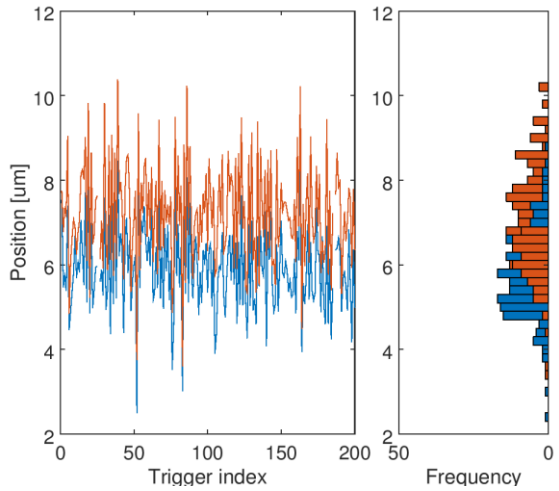
Feedback: fbRun11

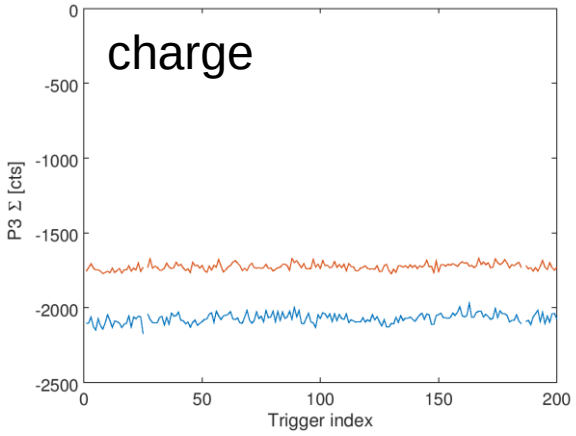
High charge: ~0.65×10^{10}

N = 200

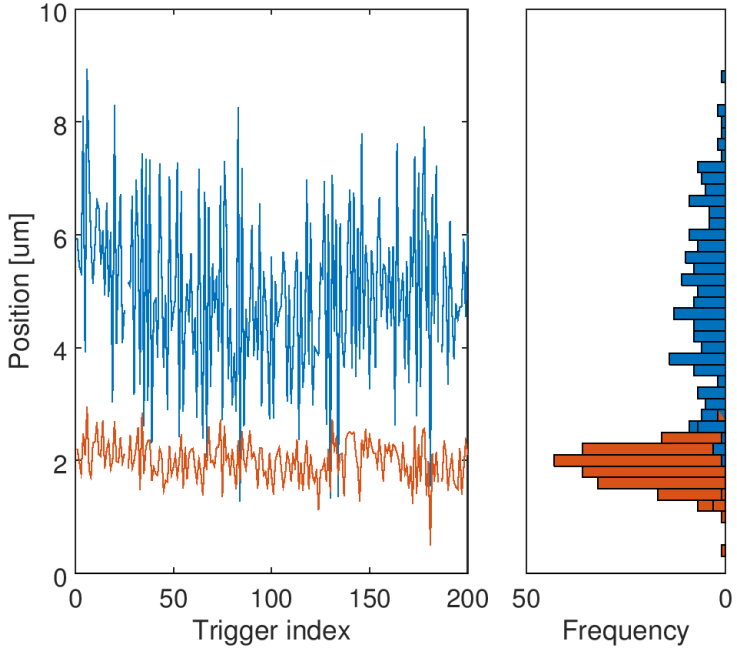
	K1	K2
P2	4862	1112
P3	-1096	-3305

P1

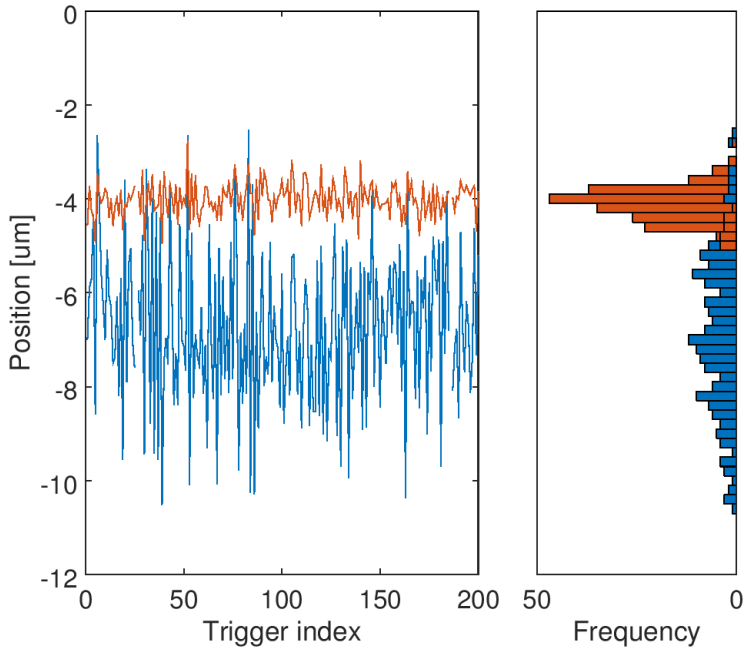




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.028	1.228	0.895
P2	1.548	0.369	0.589
P3	1.708	0.369	0.542

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.4705	P3	-0.9107	**0.291**
P2	P3	1.2019	P1	0.7190	**0.300**
P3	P1	-0.7684	P2	0.6637	**0.269**

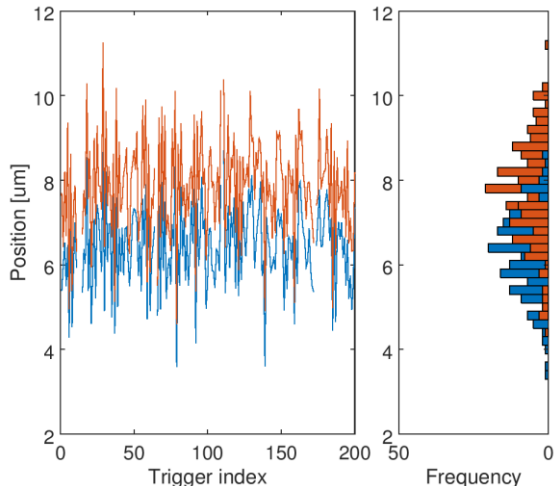
Feedback: fbRun12

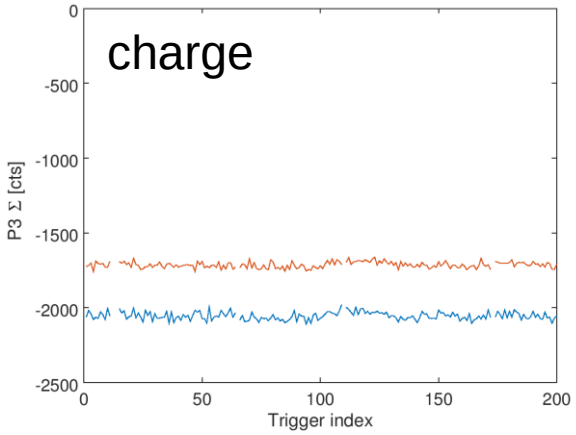
High charge: ~0.65×10^{10}

N = 200

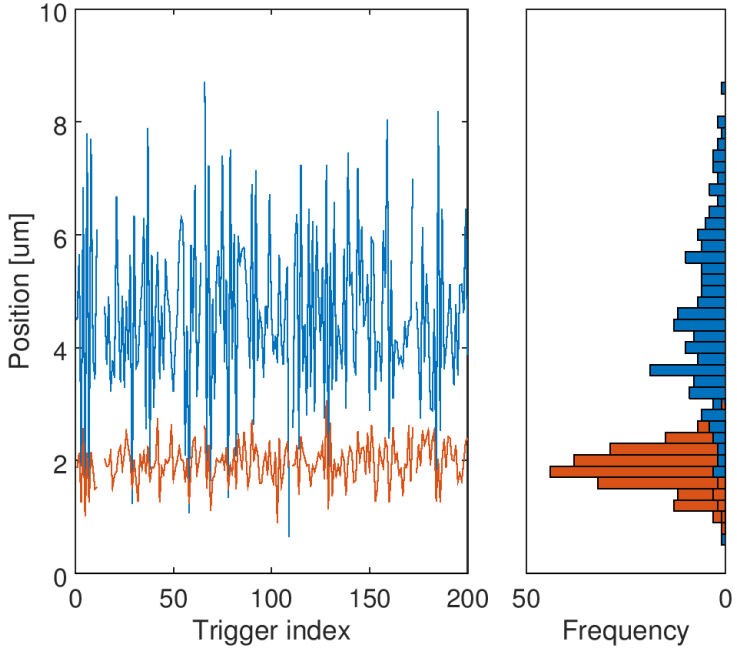
	K1	K2
P2	4862	1112
P3	-1096	-3305

P1

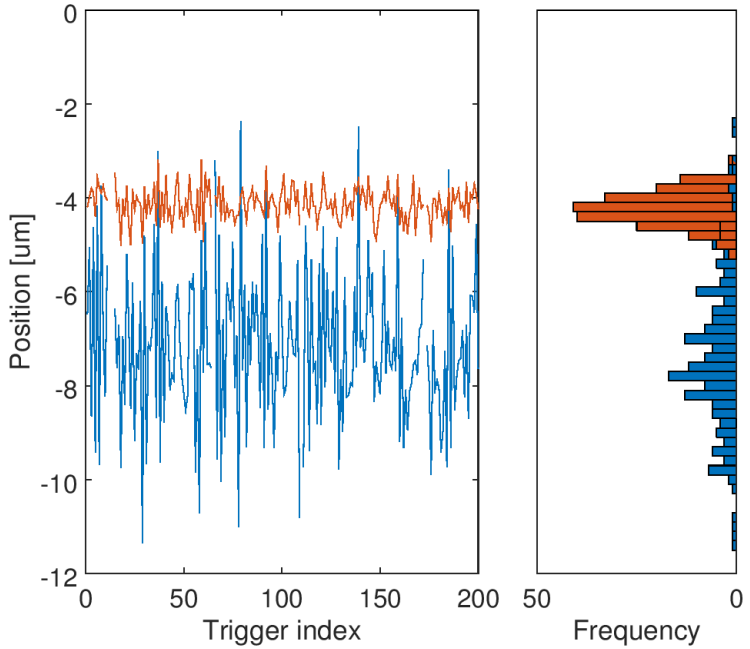




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	0.998	1.213	0.904
P2	1.566	0.372	0.588
P3	1.671	0.367	0.617

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.3815	P3	-0.8432	**0.331**
P2	P3	1.1478	P1	0.5547	**0.335**
P3	P1	-0.7102	P2	0.6650	**0.296**

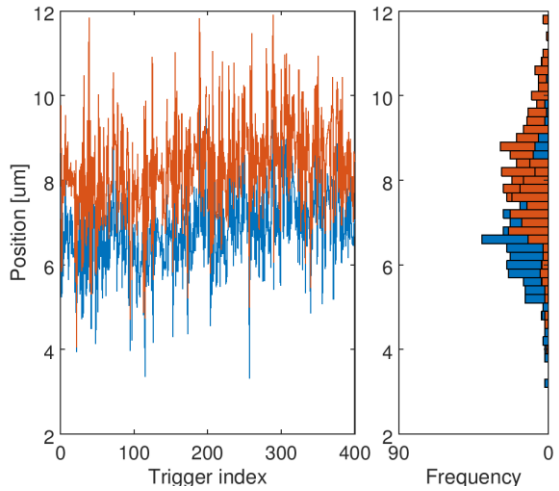
Feedback: fbRun13

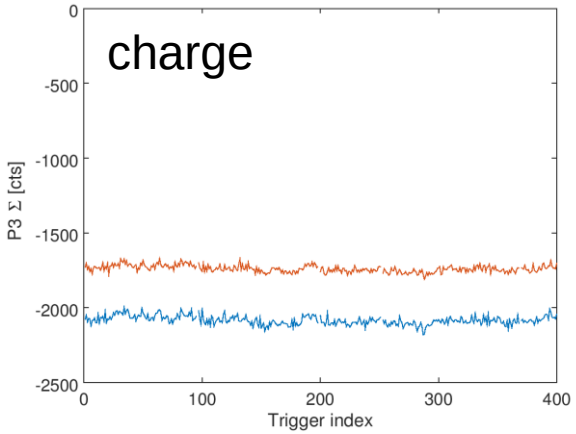
High charge: ~0.65×10^{10}

N = 400

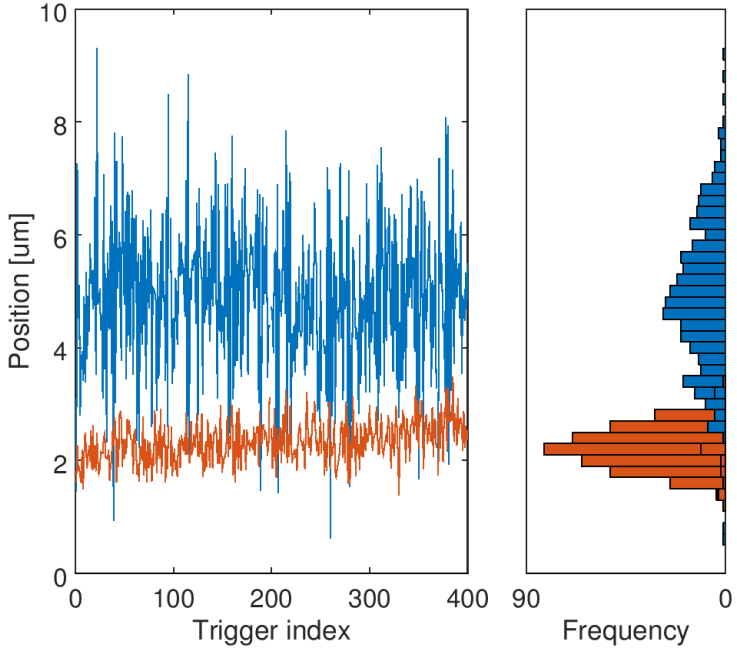
	K1	K2
P2	4862	1112
P3	-1096	-3305

P1

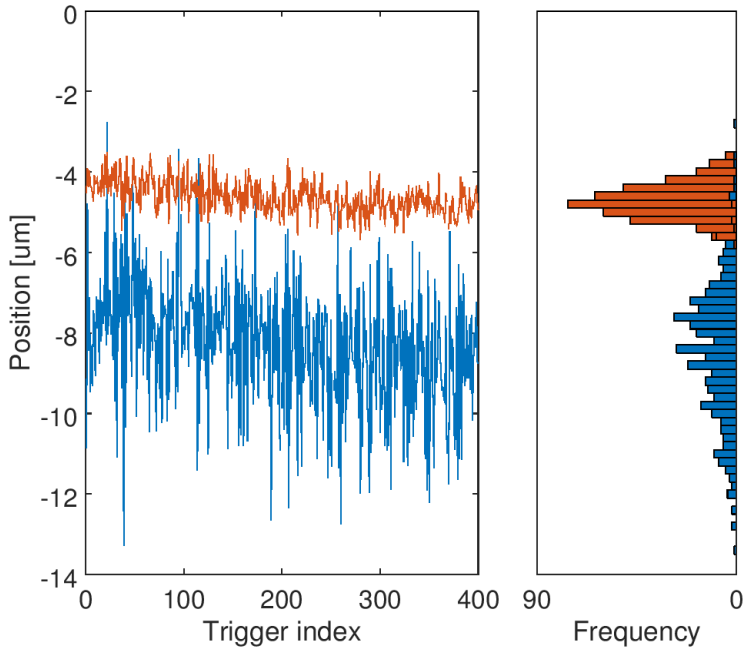




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.139	1.307	0.919
P2	1.413	0.377	0.409
P3	1.714	0.431	0.601

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.3476	P3	-0.8381	**0.347**
P2	P3	1.0750	P1	0.6083	**0.391**
P3	P1	-0.8308	P2	0.6088	**0.325**

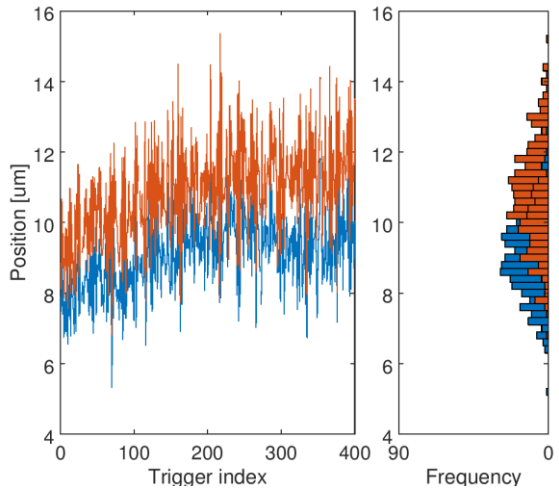
Feedback: fbRun14

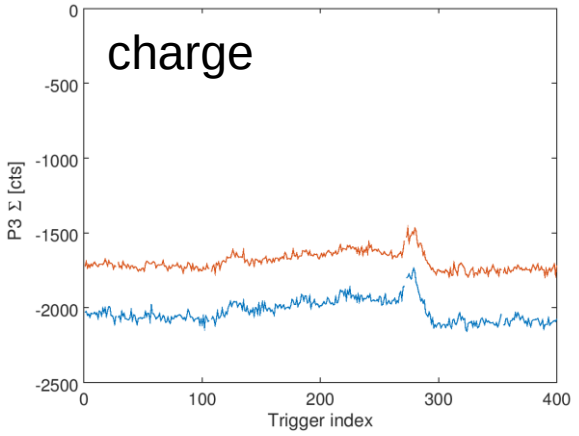
High charge: ~0.65×10^{10}

N = 400

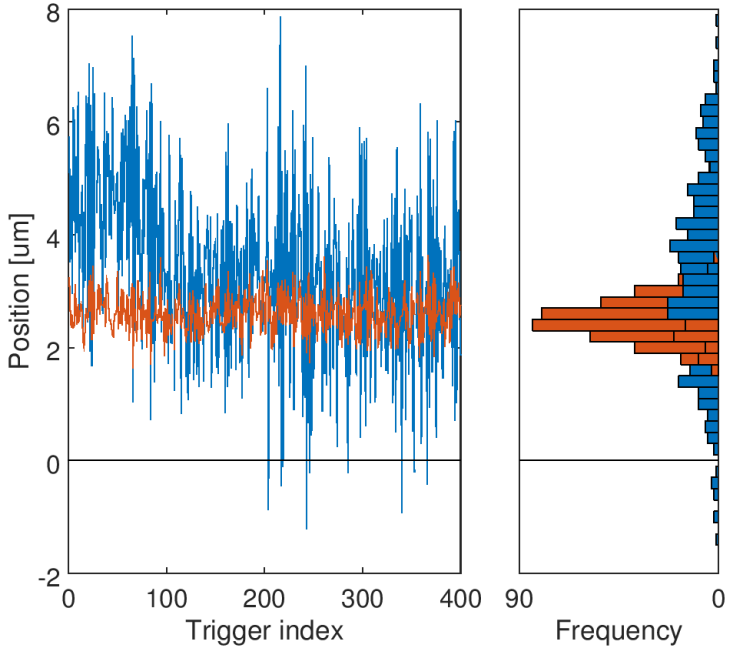
	K1	K2
P2	4862	1112
P3	-1096	-3305

P1

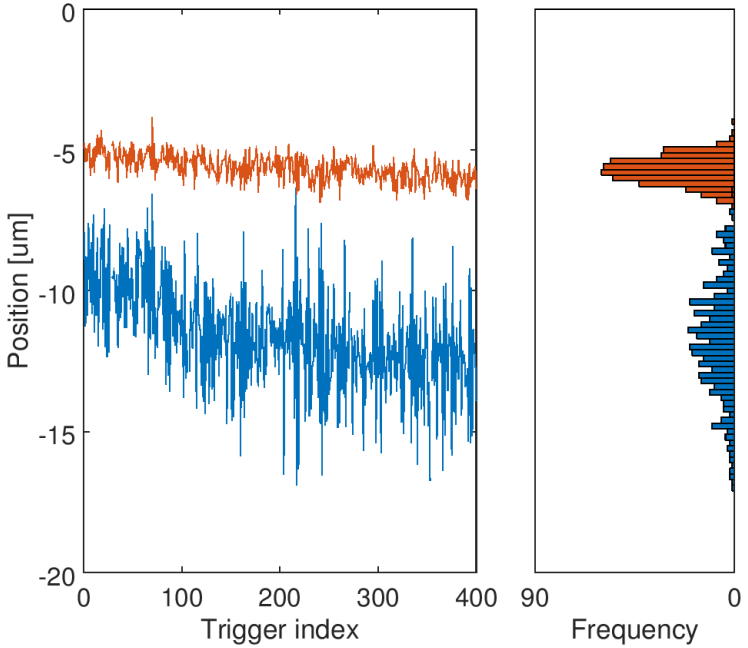




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.162	1.469	0.912
P2	1.668	0.375	0.491
P3	2.007	0.482	0.683

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.3051	P3	-0.7409	**0.413**
P2	P3	0.9651	P1	0.3882	**0.414**
P3	P1	-0.7209	P2	0.7381	**0.363**

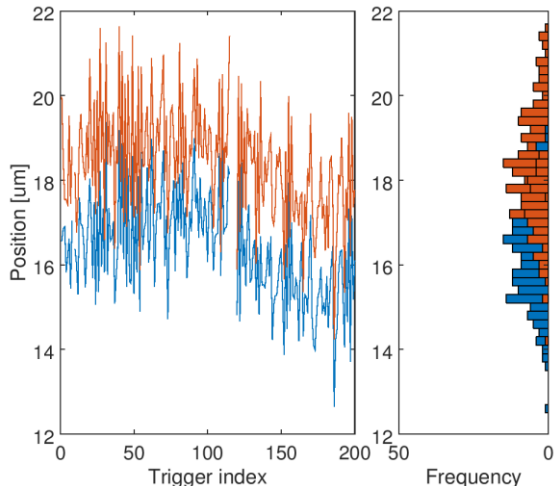
	K1	K2
P2	4862	1112
P3	-1096	-3305

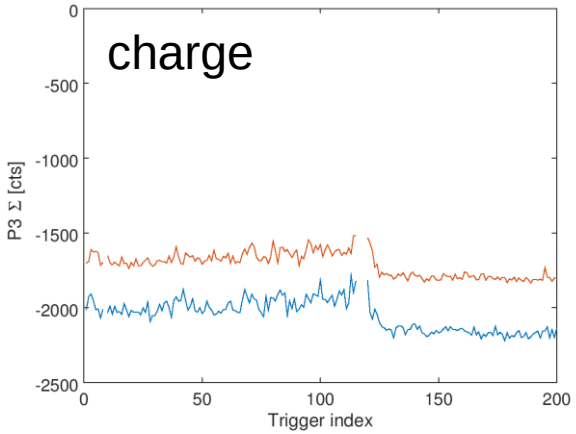
Feedback: fbRun16

High charge: ~0.65×10^{10}

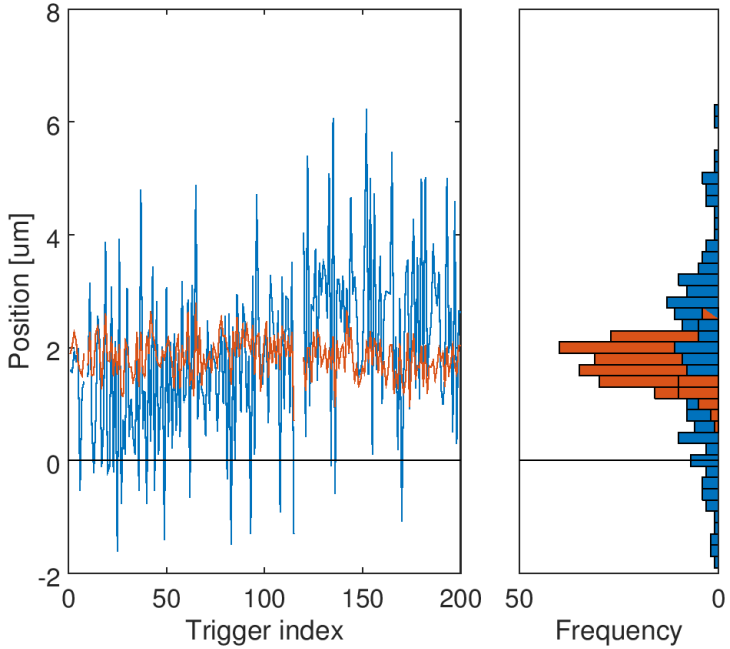
N = 200

P1

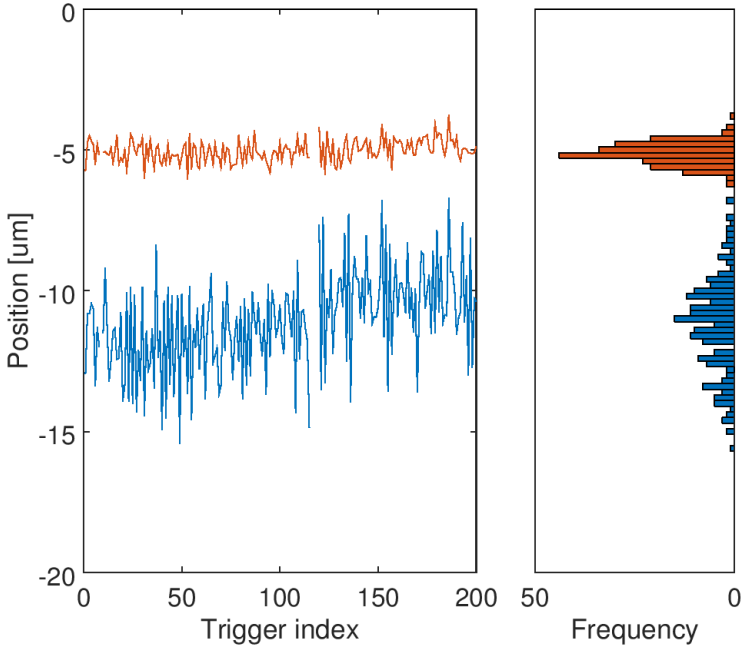




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.246	1.381	0.897
P2	1.577	0.373	0.435
P3	1.733	0.394	0.505

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.5029	P3	-1.0088	**0.414**
P2	P3	1.0846	P1	0.4334	**0.376**
P3	P1	-0.5703	P2	0.7115	**0.346**

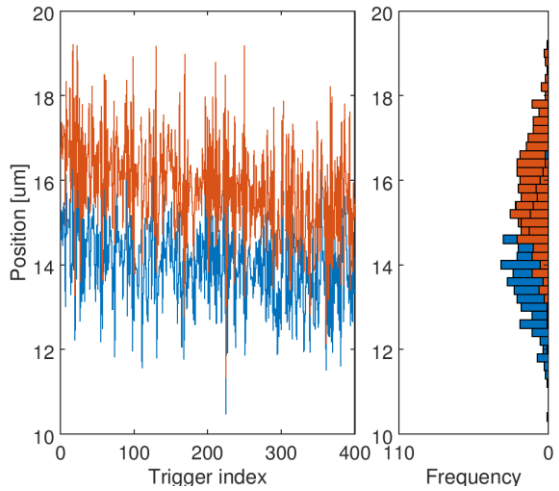
Feedback: fbRun17

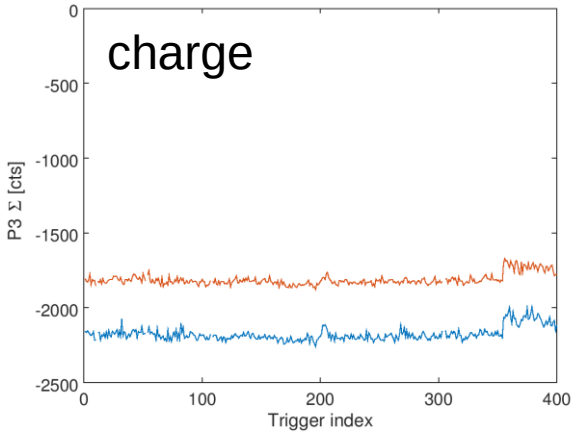
High charge: ~0.65×10^{10}

N = 400

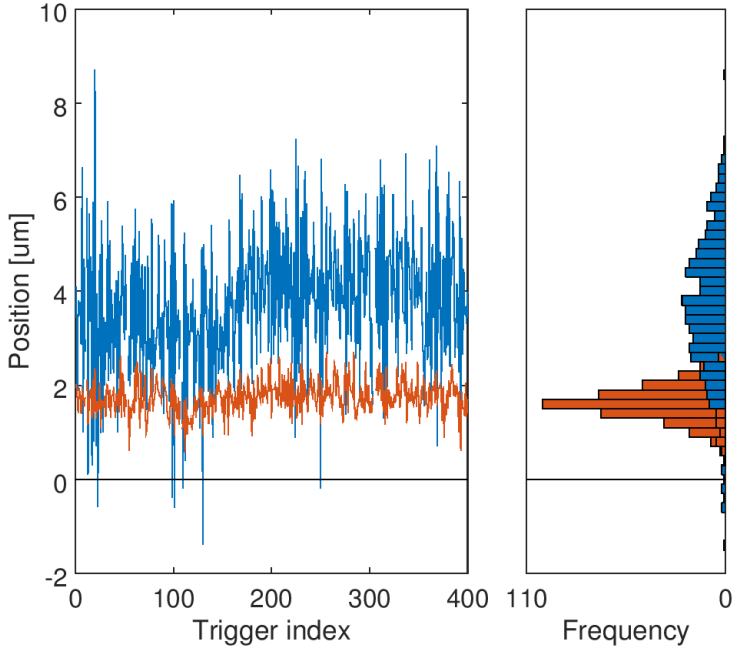
	K1	K2
P2	4862	1112
P3	-1096	-3305

P1

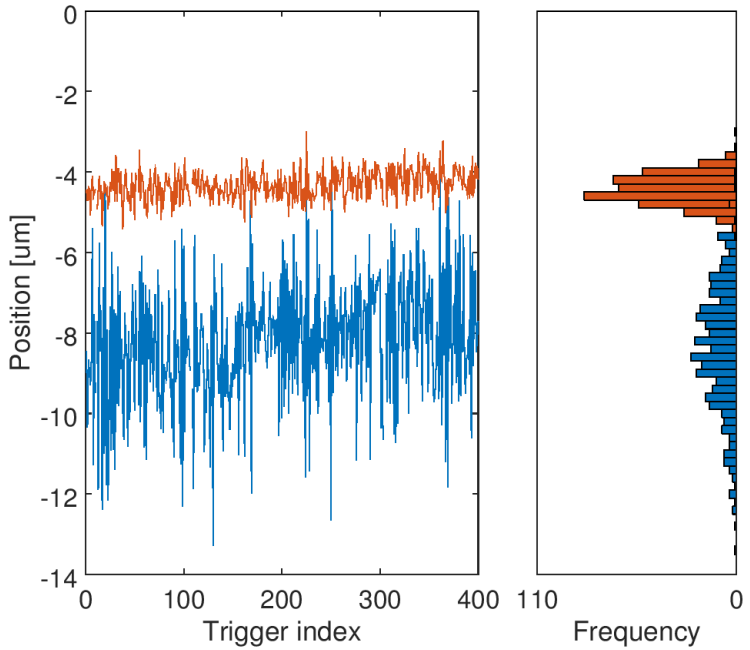




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.084	1.285	0.895
P2	1.519	0.369	0.567
P3	1.642	0.379	0.562

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.5113	P3	-0.9898	**0.301**
P2	P3	1.2314	P1	0.7067	**0.305**
P3	P1	-0.7197	P2	0.6478	**0.276**

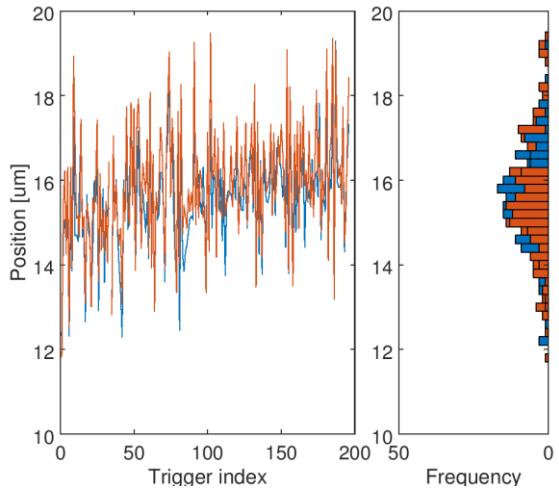
Feedback: fbRun20

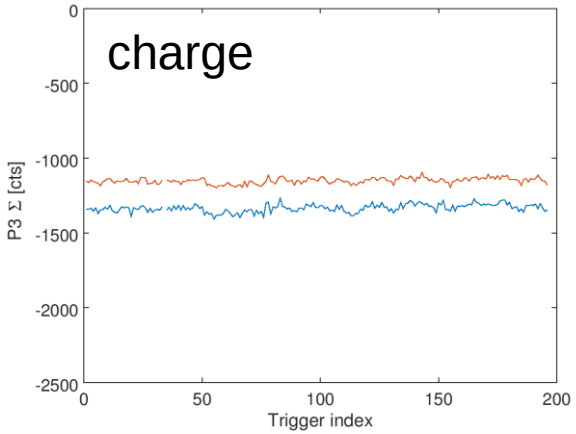
Mid charge: ~0.4×10^{10}

N = 200

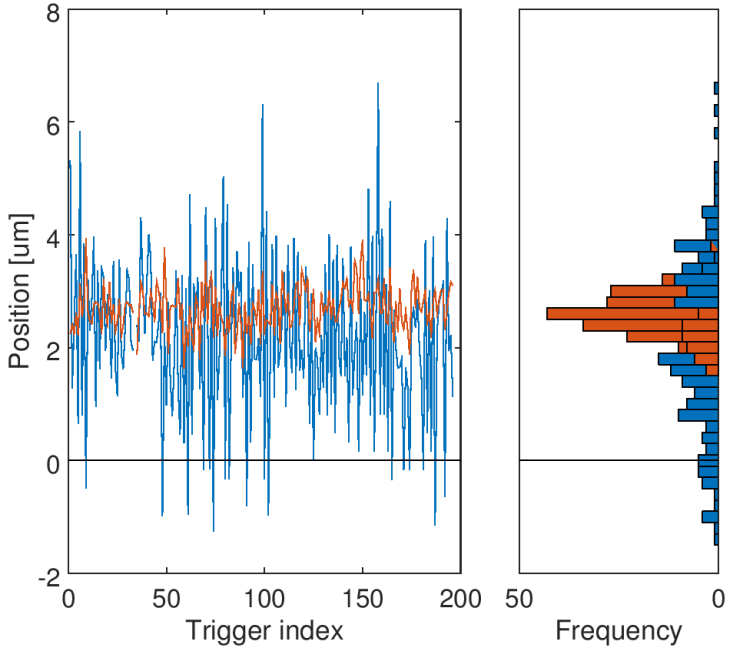
	K1	K2
P2	4862	1112
P3	-1096	-3305

P1

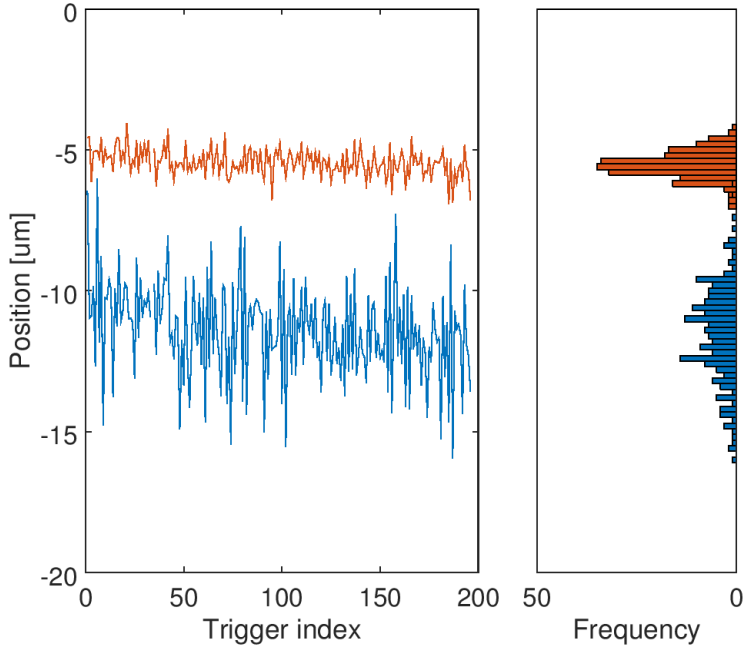




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.182	1.448	0.869
P2	1.495	0.414	0.305
P3	1.754	0.495	0.616

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.3950	P3	-0.8817	**0.383**
P2	P3	1.0575	P1	0.5122	**0.393**
P3	P1	-0.7200	P2	0.6660	**0.344**

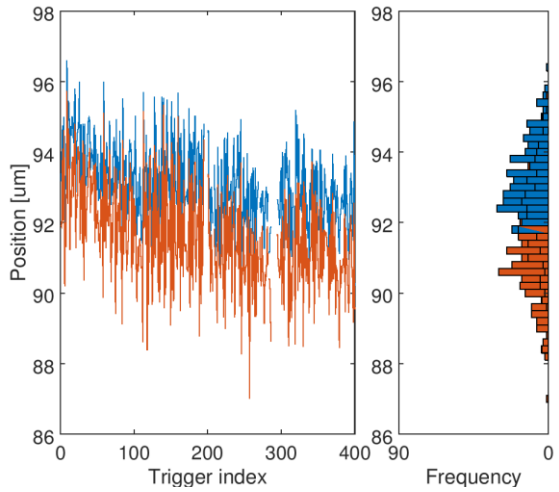
	K1	K2
P2	4862	1112
P3	-1096	-3305

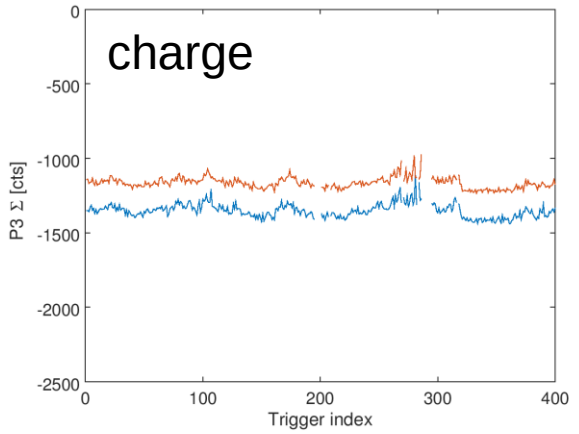
Feedback: fbRun22

Mid charge: ~0.4×10^{10}

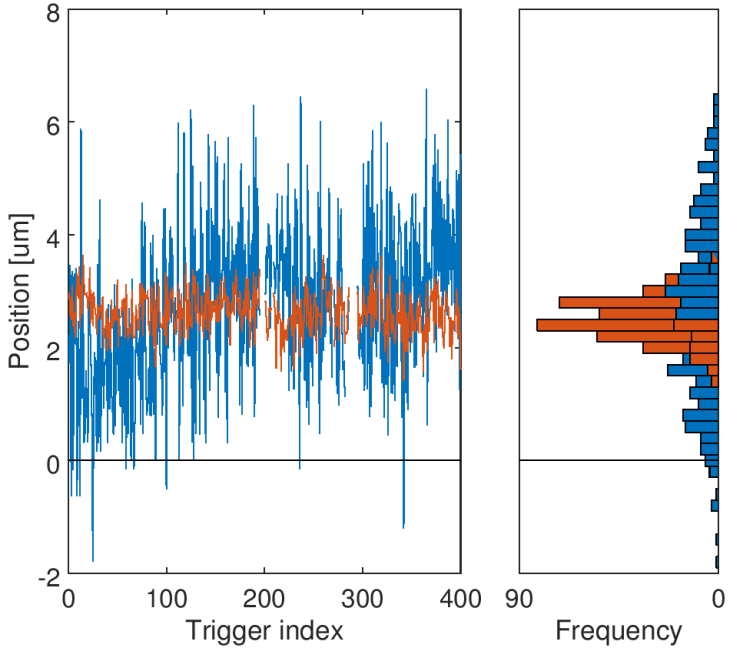
N = 400

P1

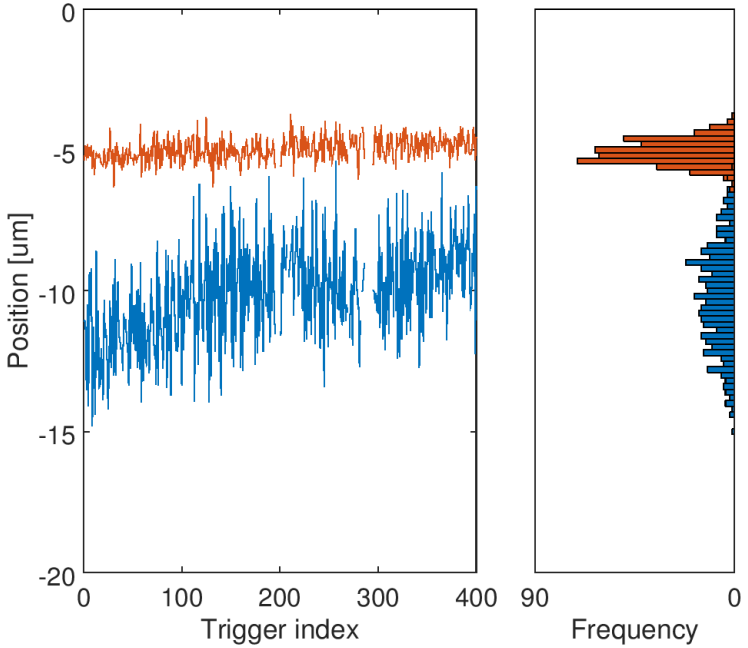




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.242	1.475	0.918
P2	1.573	0.400	0.309
P3	1.850	0.435	0.541

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.3898	P3	-0.8774	**0.417**
P2	P3	1.0190	P1	0.4313	**0.408**
P3	P1	-0.6680	P2	0.7011	**0.363**

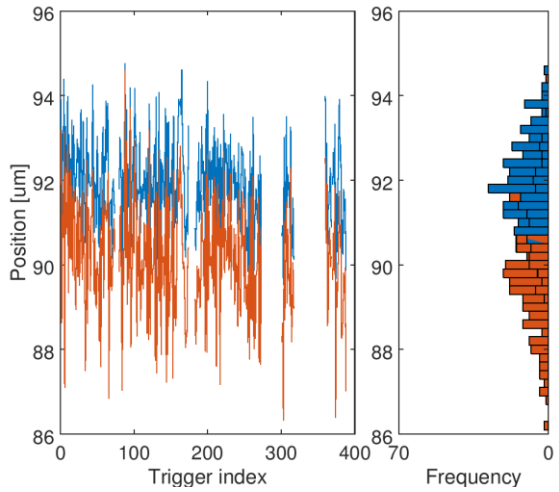
Feedback: fbRun23

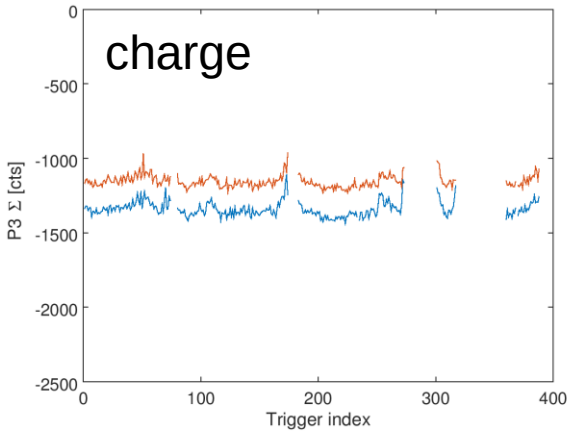
Mid charge: ~0.4×10^{10}

N = 400

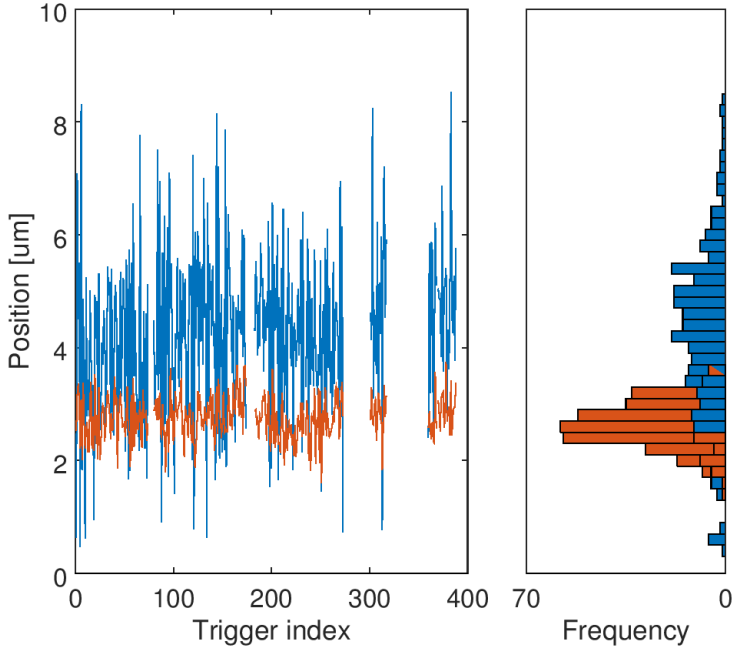
	K1	K2
P2	4862	1112
P3	-1096	-3305

P1

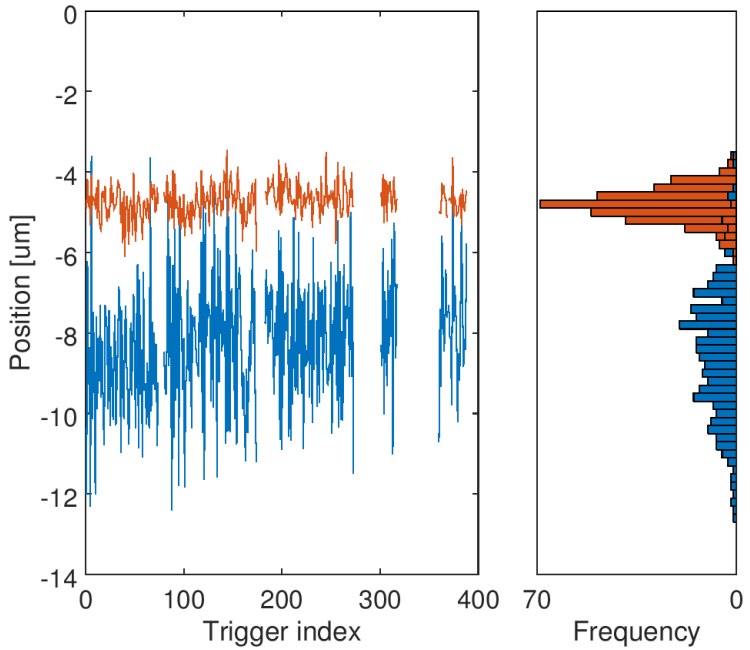




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.146	1.421	0.906
P2	1.545	0.402	0.456
P3	1.691	0.420	0.432

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.3068	P3	-0.8208	**0.441**
P2	P3	1.0290	P1	0.3659	**0.432**
P3	P1	-0.6337	P2	0.6661	**0.379**

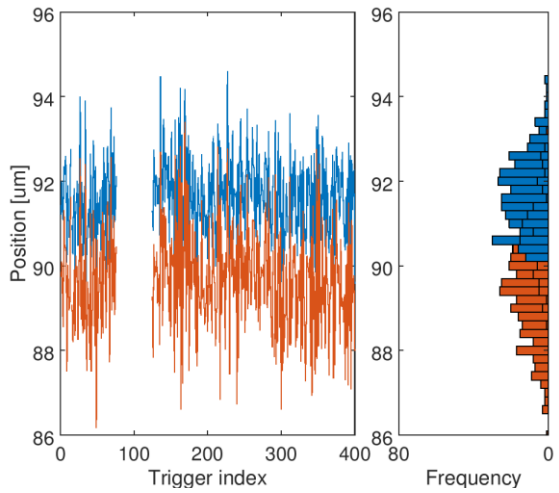
Feedback: fbRun24

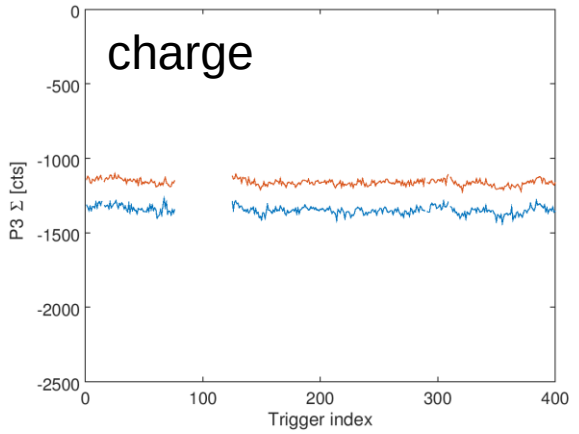
Mid charge: ~0.4×10^{10}

N = 400

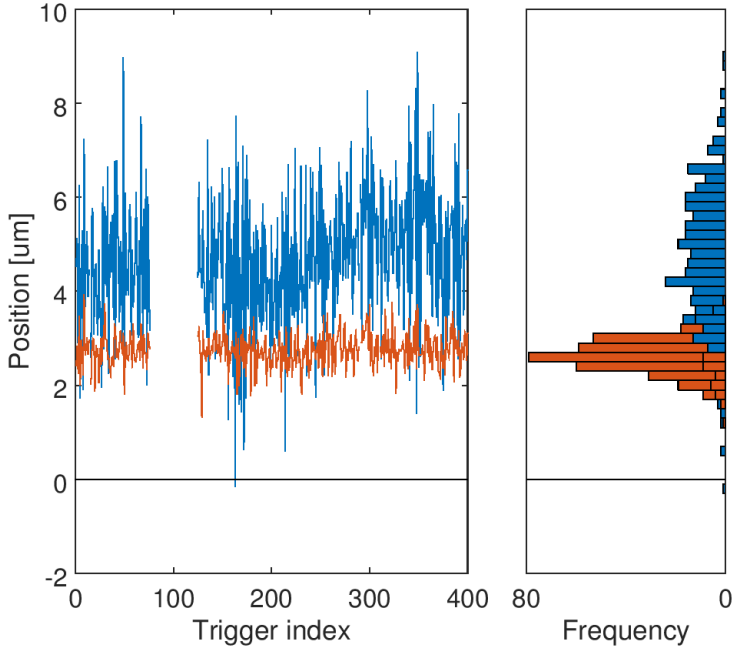
	K1	K2
P2	4862	1112
P3	-1096	-3305

P1

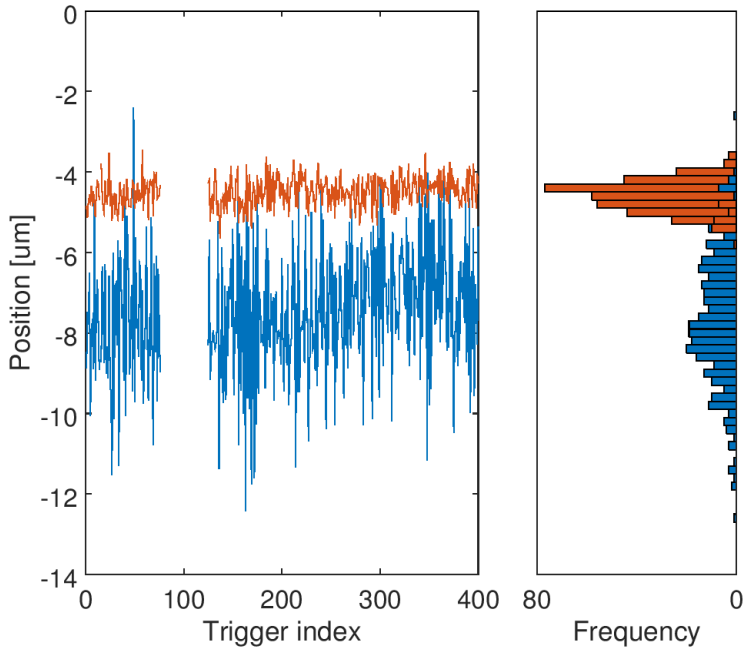




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.048	1.312	0.909
P2	1.536	0.390	0.478
P3	1.661	0.381	0.443

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	0.3962	P3	-0.8592	**0.365**
P2	P3	1.1260	P1	0.5569	**0.371**
P3	P1	-0.7087	P2	0.6607	**0.328**

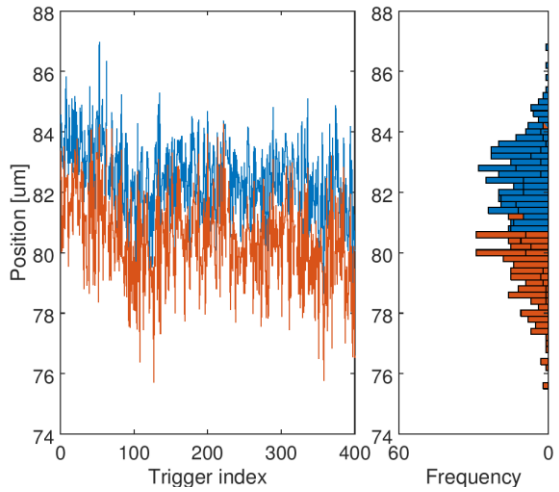
	K1	K2
P2	4862	1112
P3	-1096	-3305

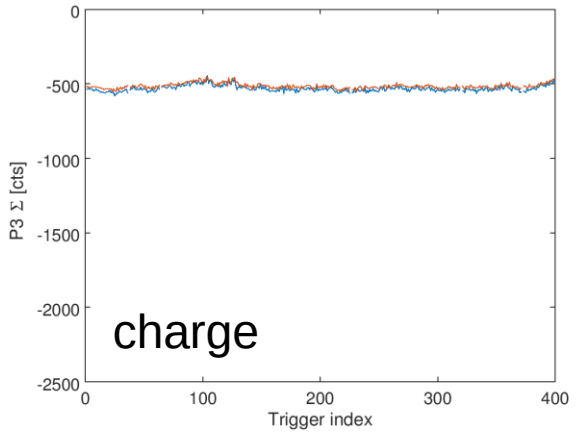
Feedback: fbRun26

Low charge: ~0.2×10^{10}

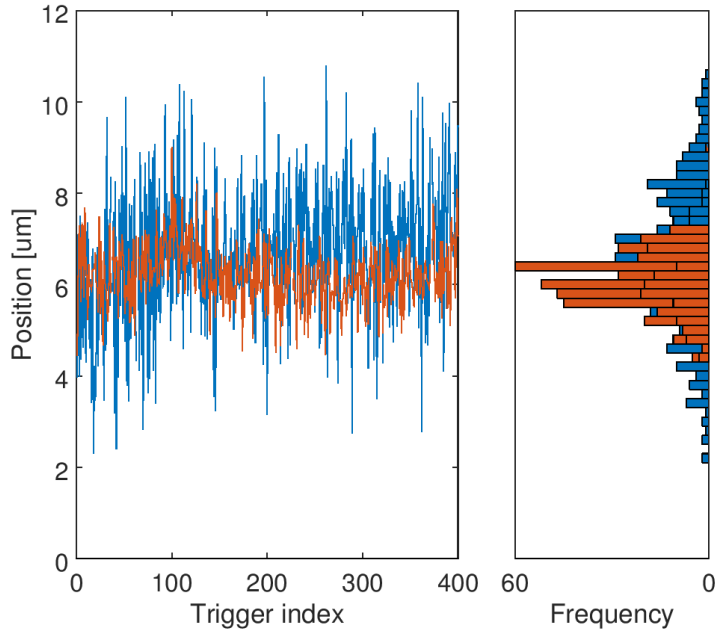
N = 400

P1

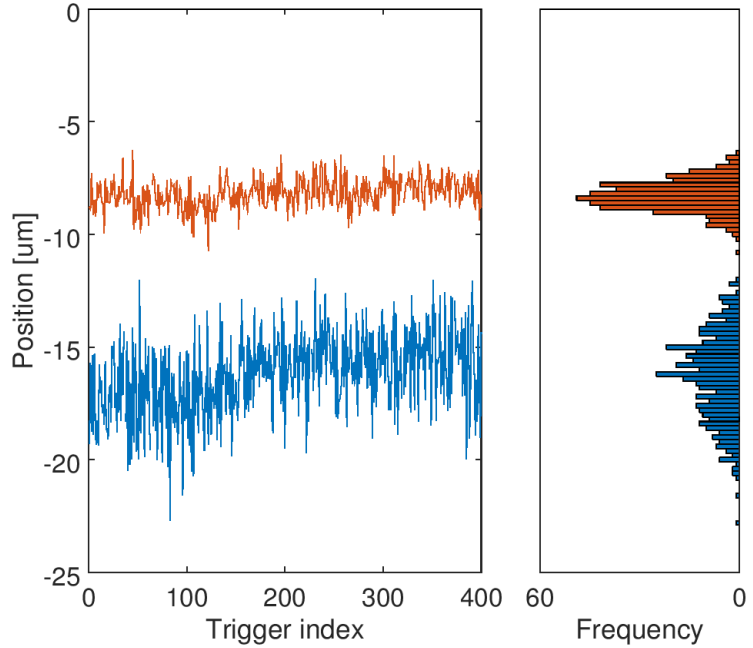




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.368	1.627	0.796
P2	1.615	0.694	0.170
P3	1.905	0.685	0.368

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	-0.3496	P3	-0.2176	**0.929**
P2	P3	0.5353	P1	-0.3014	**0.795**
P3	P1	-0.2743	P2	0.7826	**0.868**

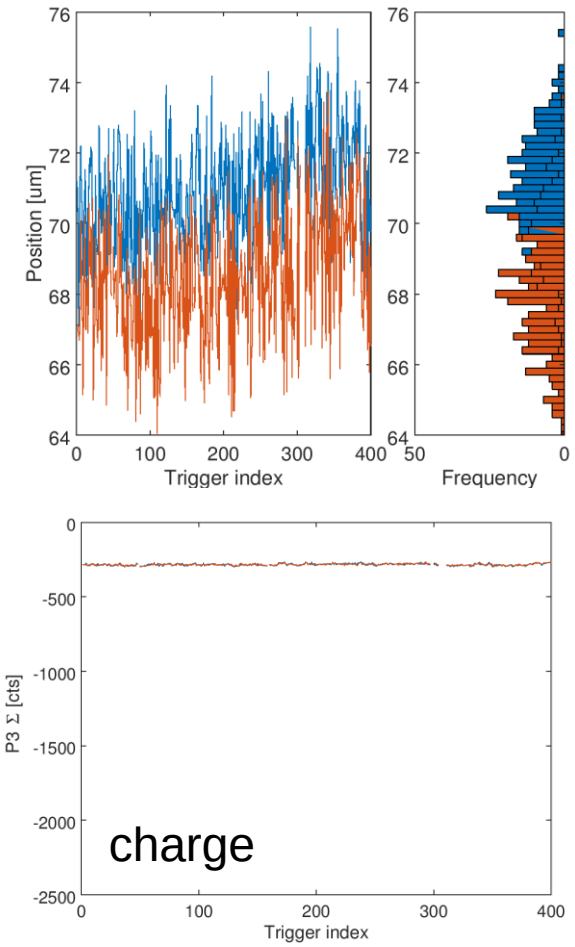
Feedback: fbRun30

V. low charge: ~0.1×10^{10}

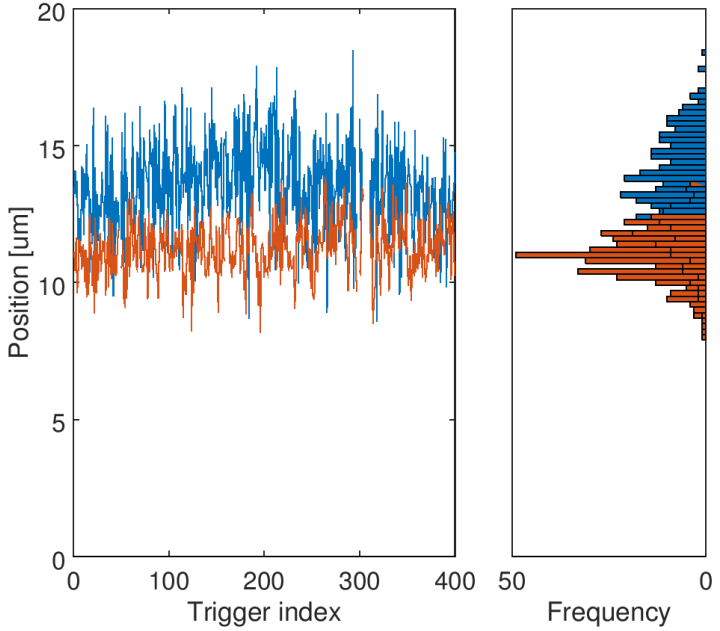
N = 400

	K1	K2
P2	4862	1112
P3	-1096	-3305

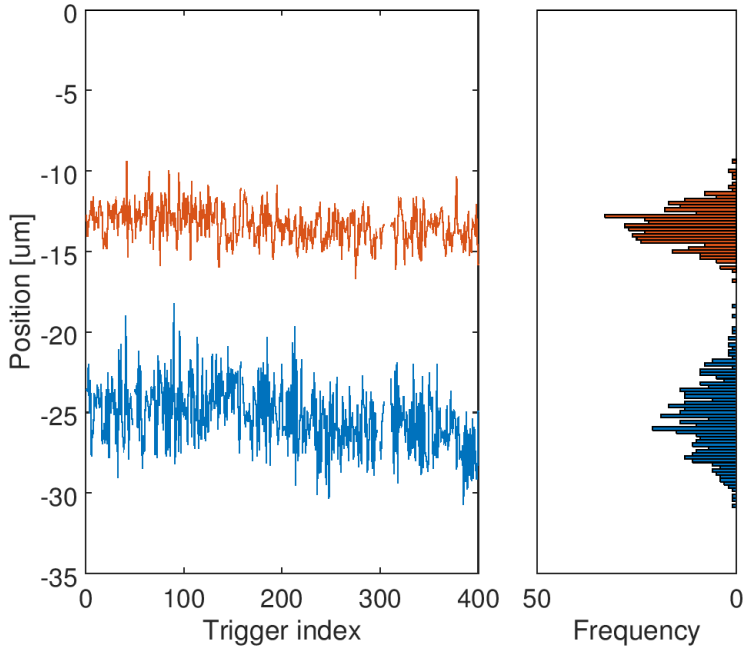
P1



P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.630	1.862	0.666
P2	1.794	1.017	-0.043
P3	2.138	1.154	0.117

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	-0.1472	P3	-0.3456	**1.252**
P2	P3	0.4789	P1	-0.1505	**1.208**
P3	P1	-0.4362	P2	0.5912	**1.210**

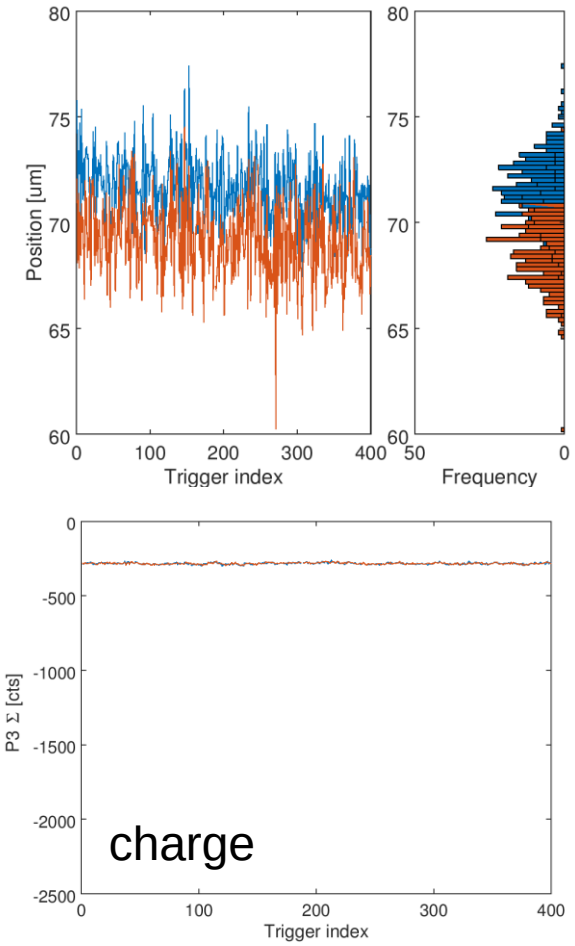
Feedback: fbRun32

V. low charge: ~0.1×10^{10}

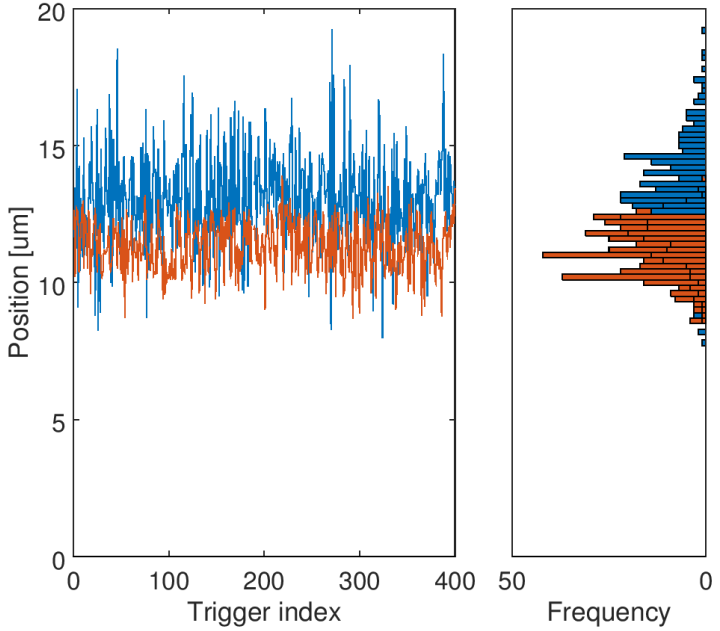
N = 400

	K1	K2
P2	4862	1112
P3	-1096	-3305

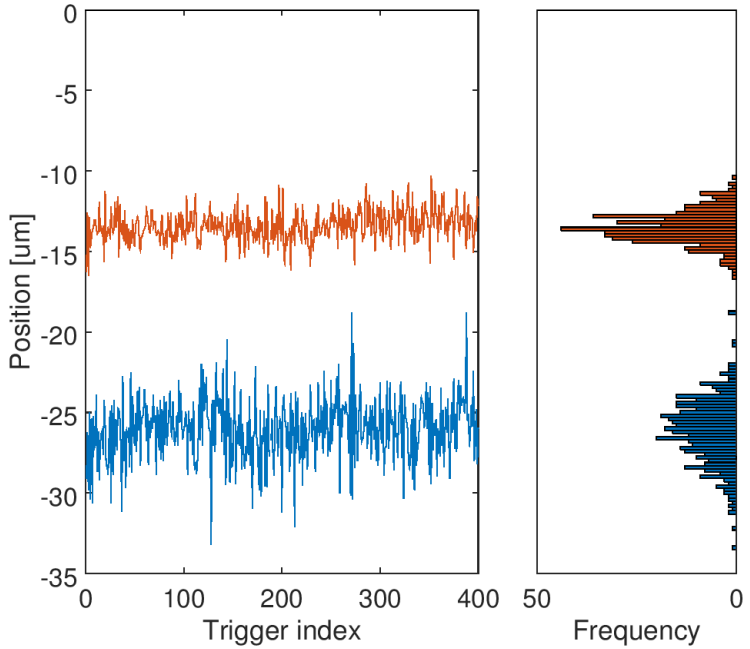
P1



P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.642	1.896	0.638
P2	1.830	1.001	-0.095
P3	2.030	1.026	0.026

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	-0.2175	P3	-0.3064	**1.260**
P2	P3	0.5324	P1	-0.2018	**1.126**
P3	P1	-0.3291	P2	0.6162	**1.143**

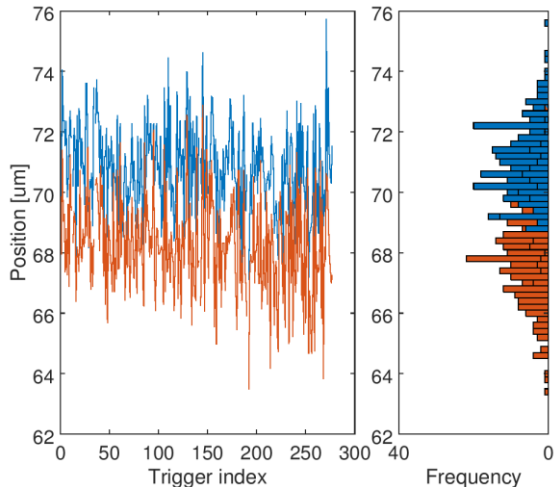
Feedback: fbRun33

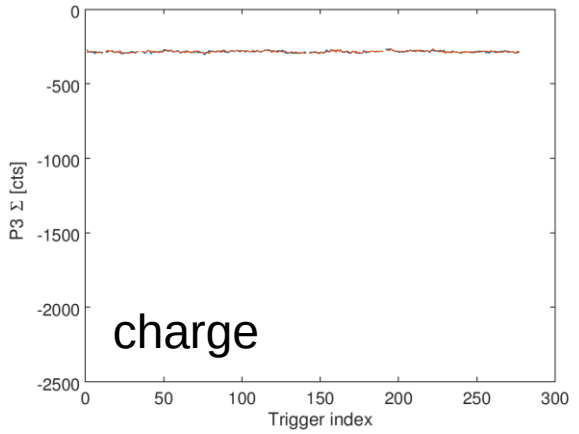
V. low charge: ~0.1×10^{10}

N = 277 (aborted)

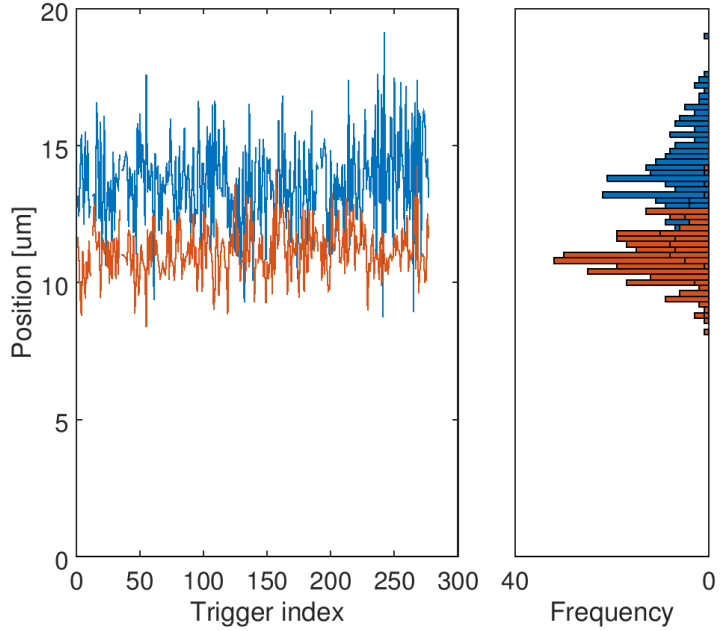
	K1	K2
P2	4862	1112
P3	-1096	-3305

P1

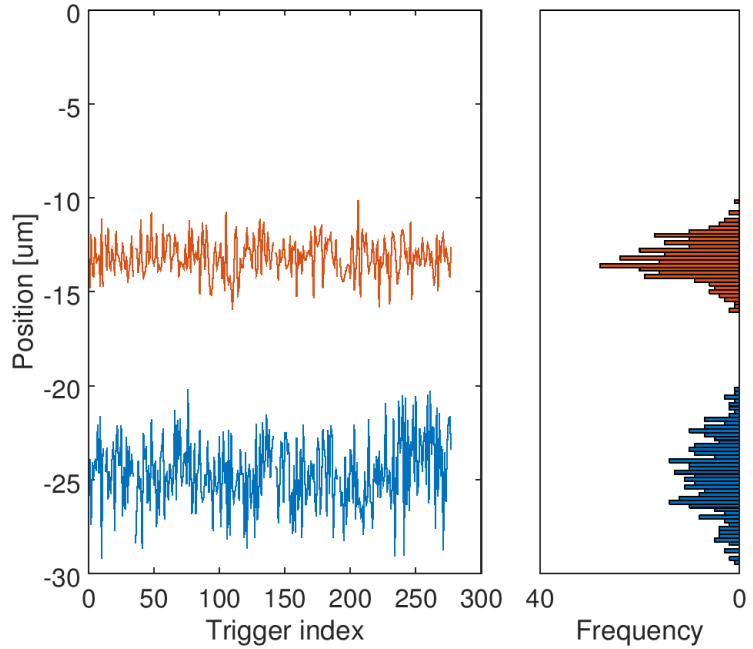




P2



P3



	σ_1 [um]	σ_2 [um]	ρ_{12}
P1	1.541	1.687	0.624
P2	1.735	0.965	-0.119
P3	1.929	1.018	-0.074

k	i	C_{ki}	j	C_{kj}	σ
P1	P2	-0.1465	P3	-0.3285	**1.231**
P2	P3	0.4861	P1	-0.1574	**1.207**
P3	P1	-0.3894	P2	0.5364	**1.187**