

CBPM resolution

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CBPM meeting
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Averaging, correlation and resolution

Recap' – Averaging data

Using data from machine study on November 13, 2019: [instrumentation elog 1835](#)

x 131,072 turn collected with 60 Hz synchronous trigger

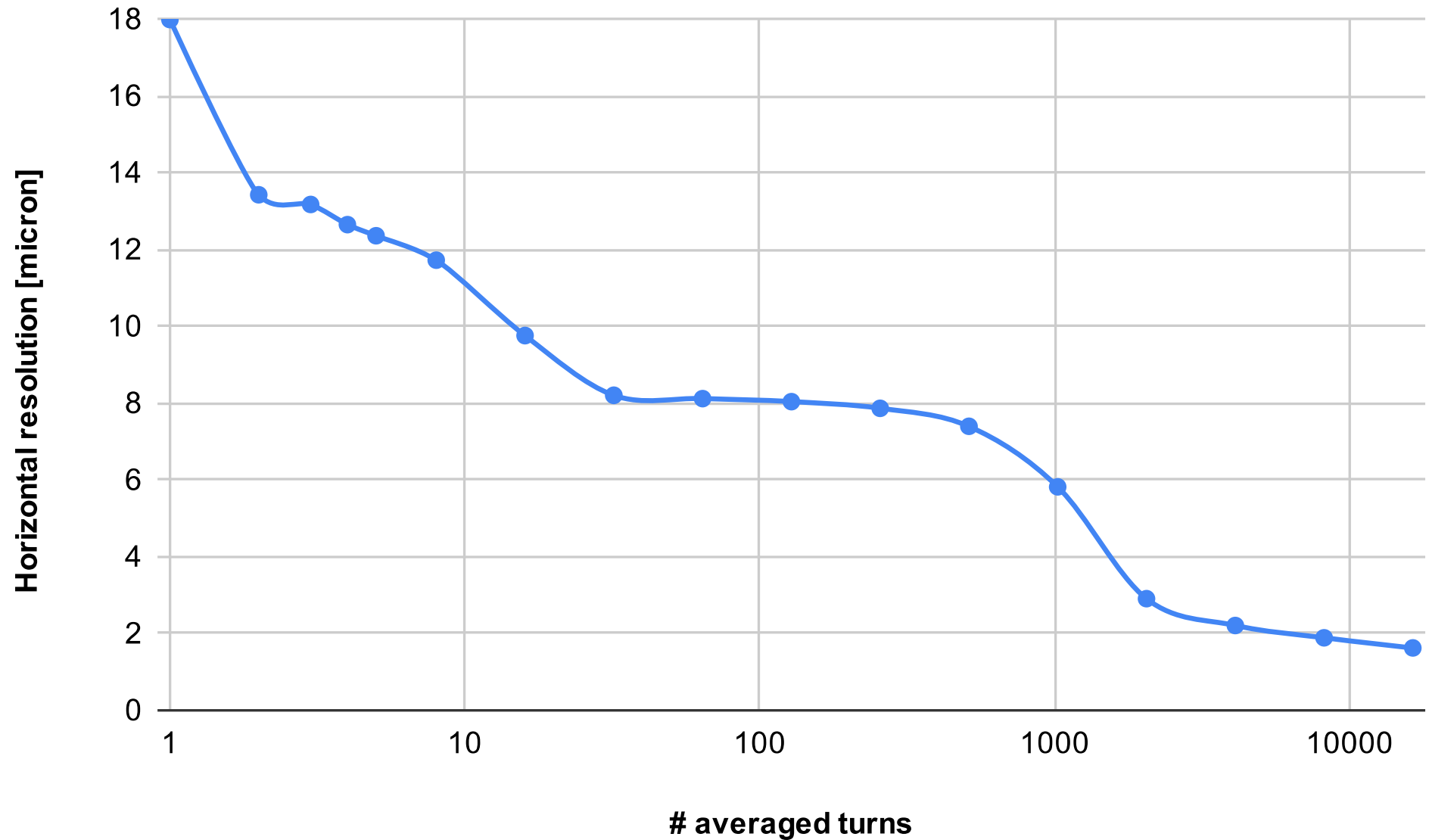
x beam current of 0.92 mA → best measured burn-by-turn resolution so far

VERTICAL		Resolution [micron]					Ratio		1/sqrt(#)	sqrt(#)/ Triplet
		12W2	12W3	12W	Combined	Triplet	Combined	Triplet		
# averaged turns	1	6.375	9.354	8.773	8.268	8.892	--	1	1	--
	2	5.031	7.365	6.81	6.479	6.764	0.78	0.76	0.71	0.93
	3	4.459	6.453	5.885	5.662	5.733	0.68	0.64	0.58	0.90
	4	4.132	5.934	5.365	5.198	5.111	0.63	0.57	0.50	0.87
	5	3.926	5.555	5.015	4.879	4.649	0.59	0.52	0.45	0.86
	8	3.649	4.99	4.46	4.401	3.918	0.53	0.44	0.35	0.80
	16	3.387	4.408	3.861	3.908	3.115	0.47	0.35	0.25	0.71
	32	3.249	4.079	3.541	3.639	2.584	0.44	0.29	0.18	0.61
	64	3.18	3.885	3.338	3.481	2.222	0.42	0.25	0.13	0.50
	128	3.139	3.757	3.209	3.38	1.964	0.41	0.22	0.09	0.40
	256	3.105	3.656	3.118	3.303	1.772	0.40	0.20	0.06	0.31
	512	3.0242	3.524	3.014	3.303	1.564	0.40	0.18	0.04	0.25
	1024	2.873	3.235	2.804	2.977	1.264	0.36	0.14	0.03	0.22
	2048	2.446	2.773	2.226	2.492	0.895	0.30	0.10	0.02	0.22
	4096	1.102	1.406	1.016	1.187	0.655	0.14	0.07	0.02	0.21
8192	0.536	0.792	0.613	0.656	0.45	0.08	0.05	0.01	0.22	

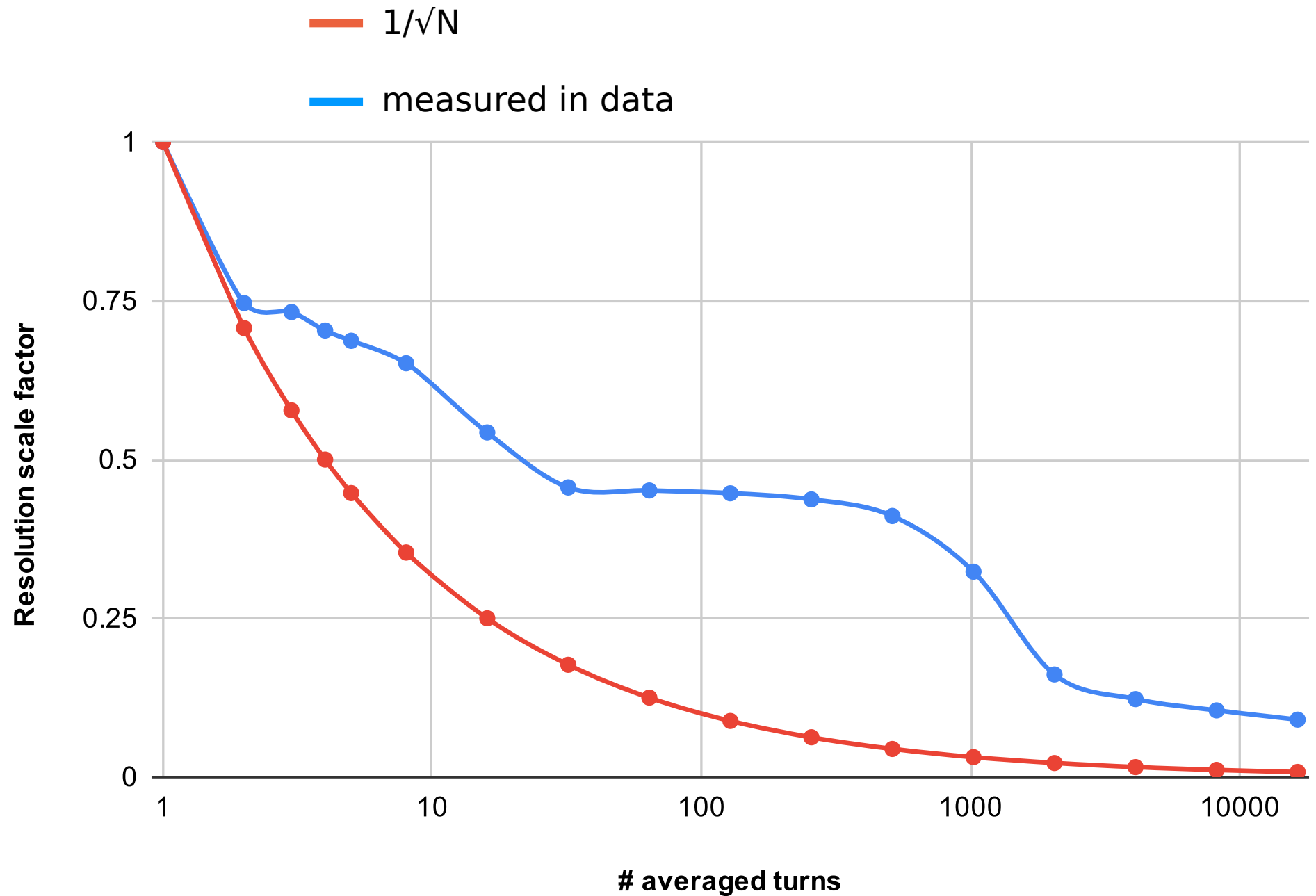
Data's resolution does not scale as well as ideally expected

Horizontal resolution versus # averaged turns

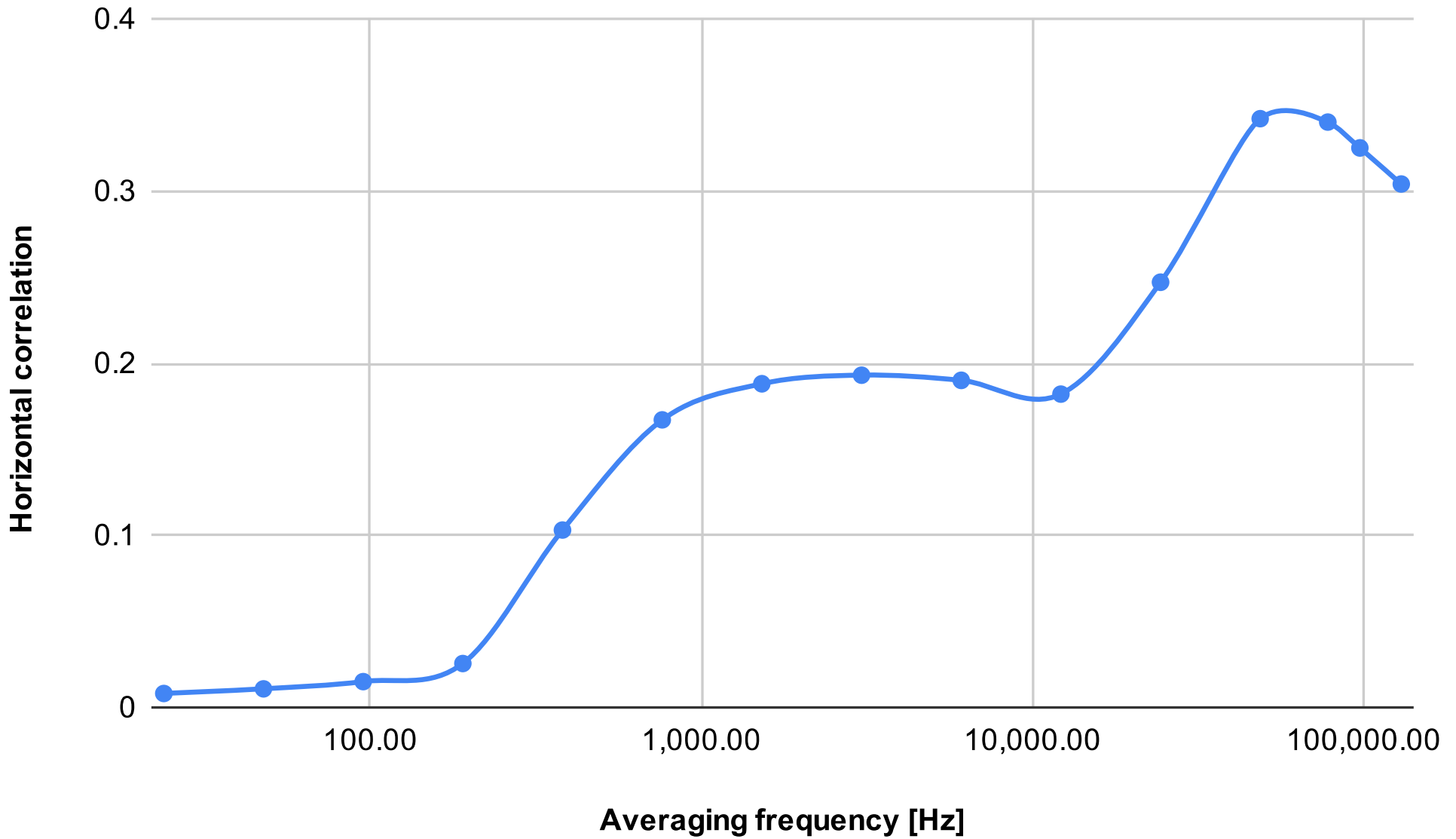
→ resolution down to 2 microns averaging 4096 turns



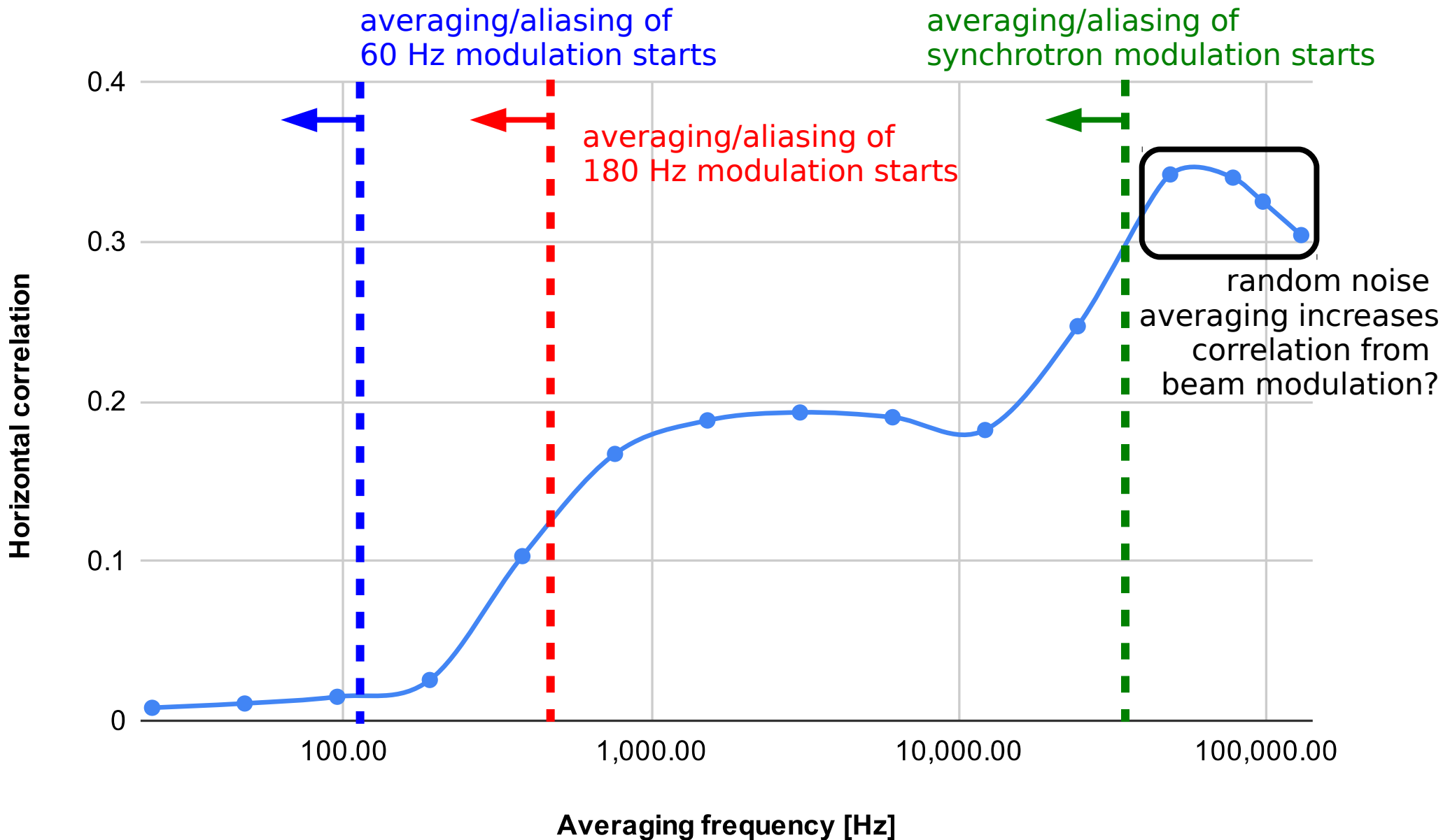
Horizontal resolution scaling with # averaged turns



Horizontal resolution vs averaging frequency



Horizontal resolution vs averaging frequency



→ correlation (resolution) decreases (improves) averaging beam modulation(s)

Recap' – Correlation: how does it work?

Let's take an exaggerated case using toy MC simulation. Let's pretend:

x beam undergoes a 7 mm vertical motion at a 60 Hz rate

x beam undergoes a 3 mm vertical motion at 75 kHz

x triplet CBPMs 12W2, 12W3 and 12W see an averaged digitized amplitude of:

➤ 17,958 ADU

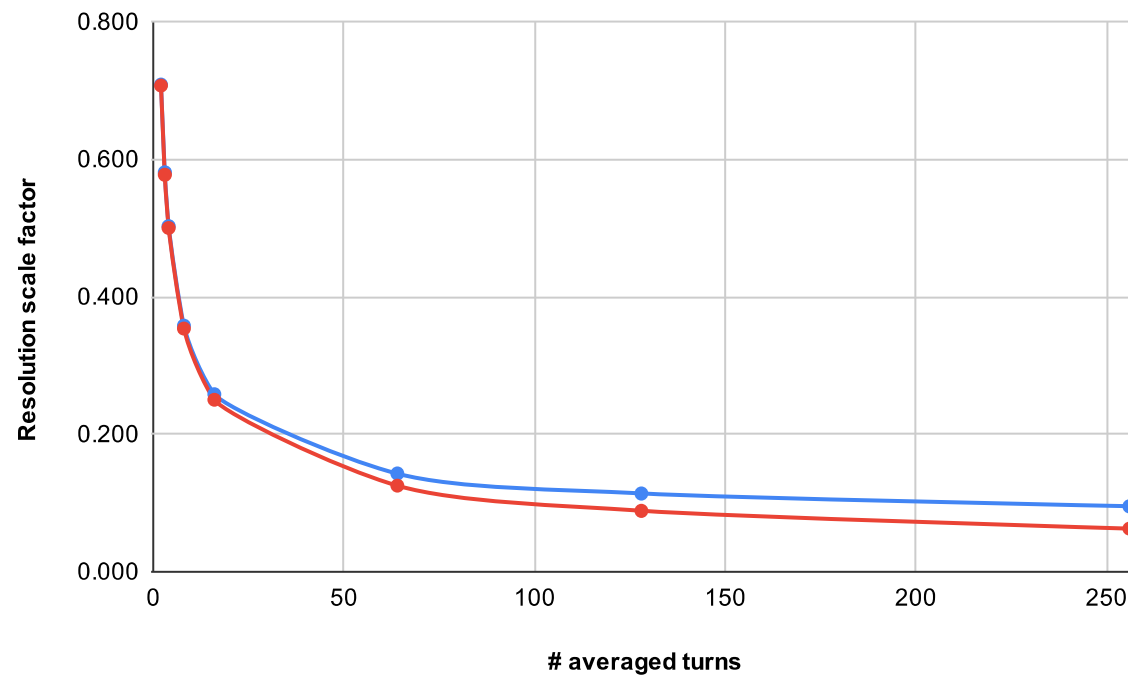
➤ 5,534 ADU

➤ 17,958 ADU

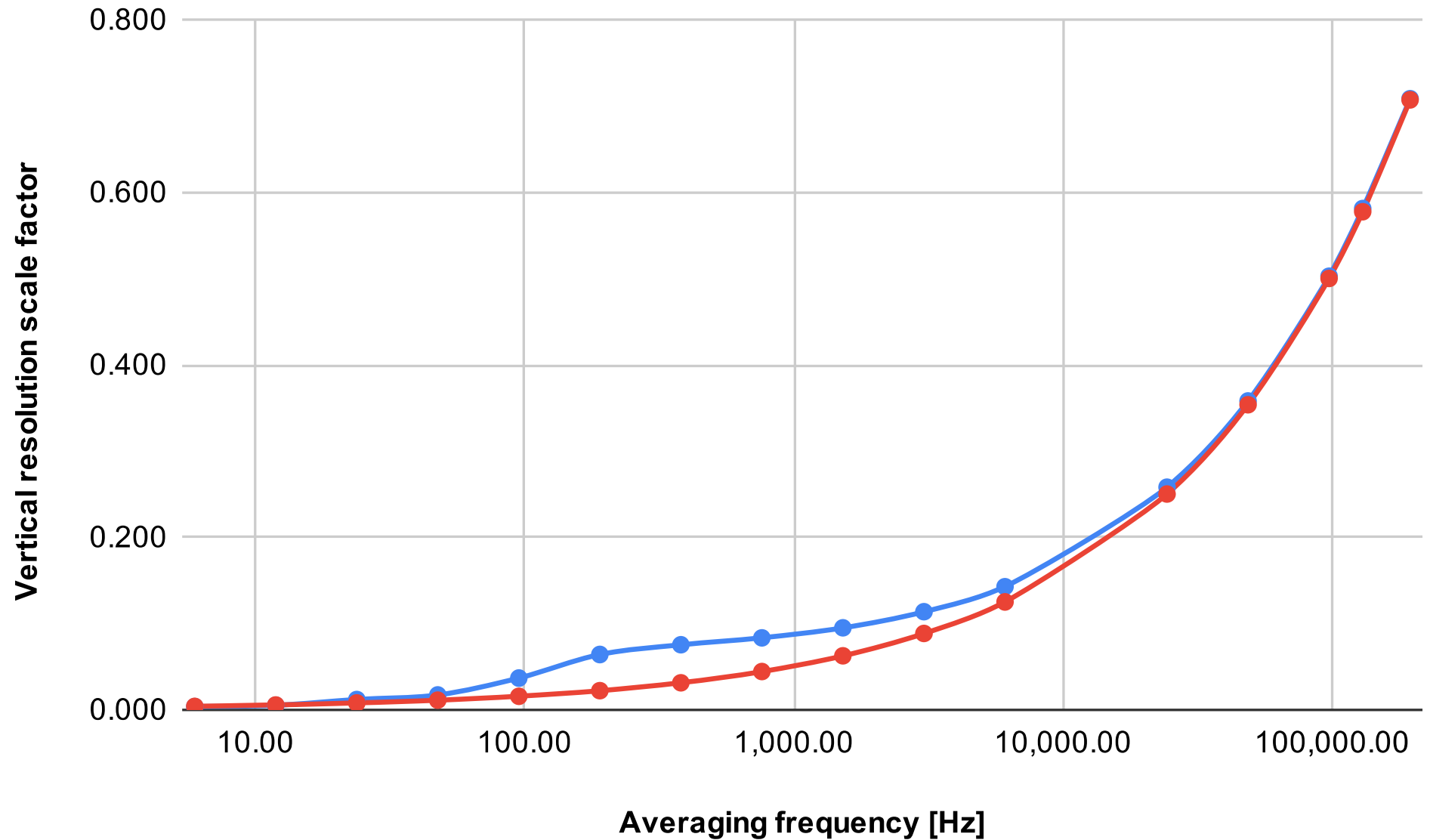
Recap' - Averaging

VERTICAL	vertical precision [micron]					Averaging/No Averaging	1/sqrt(# turn)
	12W2	12W3	12W	Average	Triplet		
No averaging	5377	5379	5377	5378	14.189	--	--
2	5256	5257	5256	5256	10.052	0.708	0.707
3	5120	5121	5120	5120	8.245	0.581	0.577
4	5026	5027	5026	5026	7.132	0.503	0.500
8	5011	5012	5011	5011	5.078	0.358	0.354
16	4992	4993	4992	4992	3.661	0.258	0.250
64	4991	4992	4991	4991	2.024	0.143	0.125
128	4989	4989	4989	4989	1.612	0.114	0.088
256	4979	4979	4979	4979	1.347	0.095	0.063

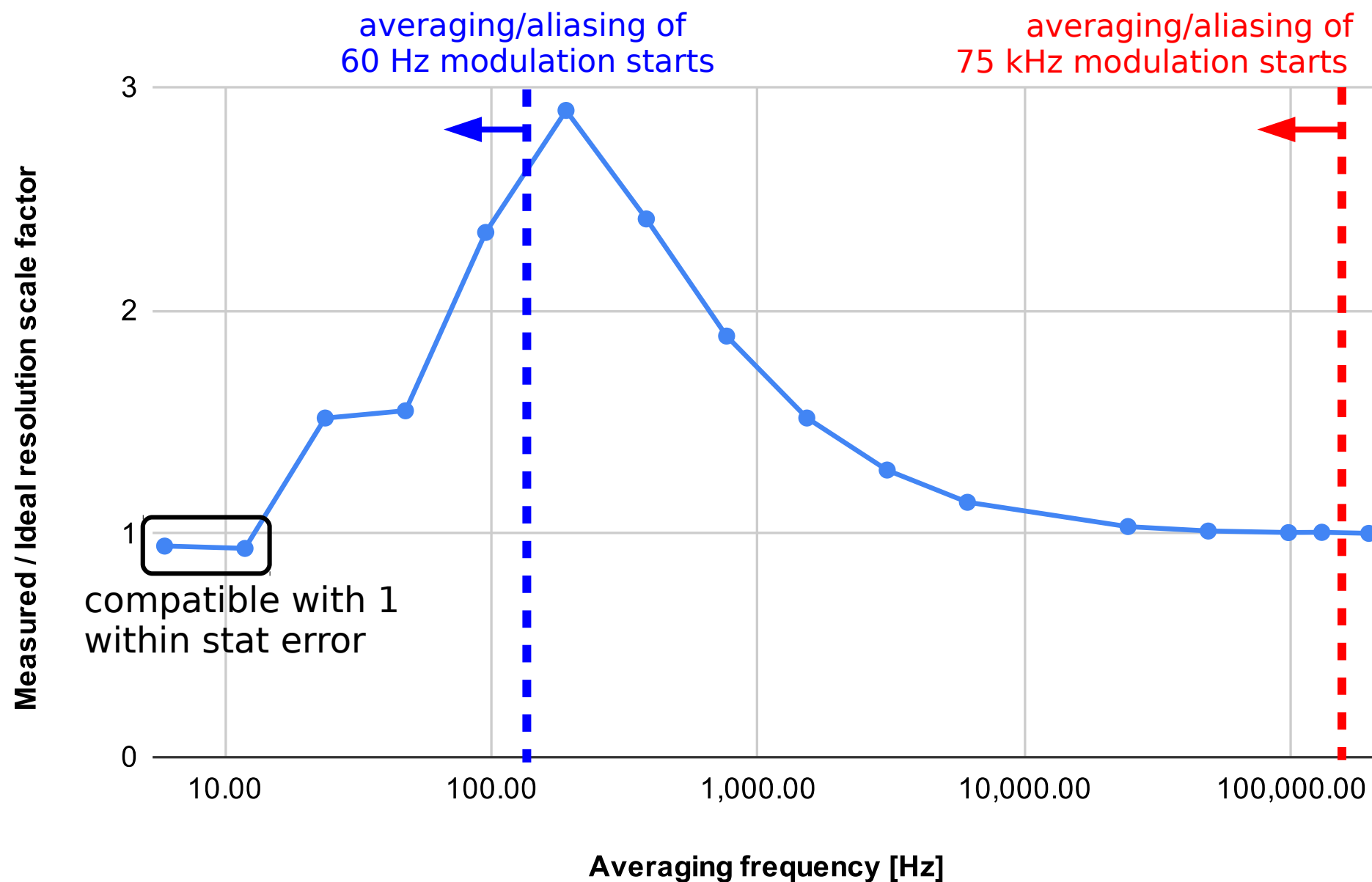
— $1/\sqrt{N}$
 — measured in MC



Vertical resolution scaling with averaging frequency



Ratio of measured/ideal scaling versus averaging frequency



Ratio > 1 means the resolution in the data averages poorer than $1/\sqrt{N}$

Recap' – Takeaways

x resolution in the data is correlated:

- peaks in the resolution FFT
- no $1/\sqrt{N}$ scaling observed
- demonstrated with toy MC
- measured non-zero correlations between buttons

x correlation decreases with increasing turn averaging:

- for large averaging → scaling closing to $1/\sqrt{N}$
- due to washing/averaging-out of the various observed modulation?
- but did not observe scaling to reach $1/\sqrt{N}$ → want to collect the maximum number of turns to try largest possible averaging (remember that there is an uncertainty associated with the resolution that grows with less data points, i.e., more averaging). Can try in toy MC : will the $1/\sqrt{N}$ be reached after averaging enough 60 Hz modulations?
- **my bet** : 10 Hz averaging could provide $1/\sqrt{N}$ scaling

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it all seems
to add up!

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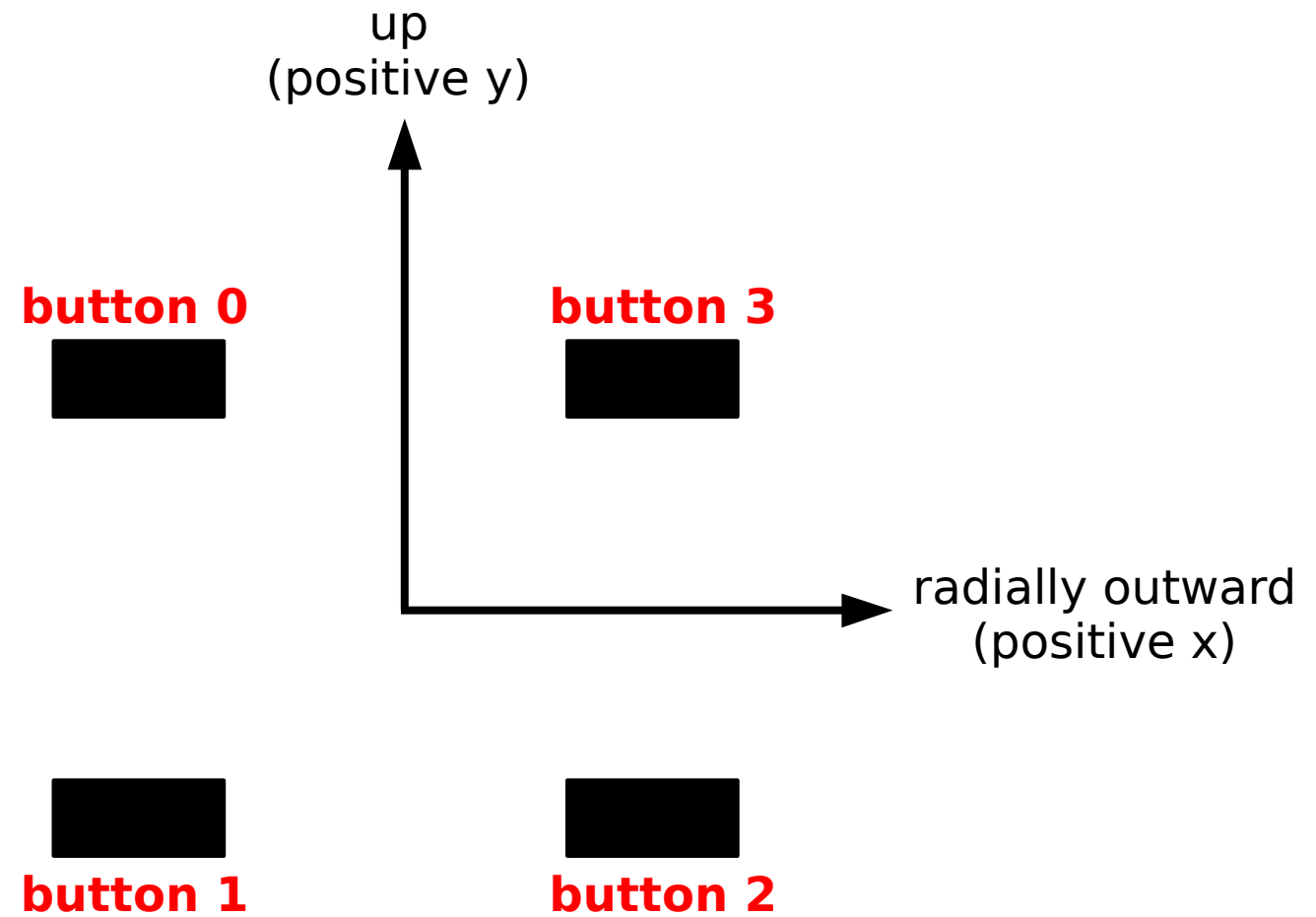
Going forward?

If somehow we could get rid of the lower frequency modulation (60 Hz, 180 Hz...), the resolution would scale better with averaging a large number of turn...

The more modulations and the widest the frequency range, the poorer the averaging does

Additional materials

CBPM convention



Horizontal and vertical centroids

$$y = k_y \frac{(b_0 + b_3) - (b_1 + b_2)}{b_0 + b_3 + b_1 + b_2}, \quad k_y = 19.8 \text{ mm}$$

$$x = k_x \frac{(b_2 + b_3) - (b_0 + b_1)}{b_2 + b_3 + b_0 + b_1}, \quad k_x = 25.9 \text{ mm}$$