2017 ILRS Technical Workshop
3 October 2016, Latvijas Universitāte

SLR error sources in the kHz repetition era: How should we improve the range measurement and the products?

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Inspired from a series of “rainy-day” seminars
at NERC-BGS Space Geodesy Facility in 2016.

NERC
SCIENCE OF THE ENVIRONMENT

SGF Herstmonceux “Seminar room” 22 July 2016.
Otsubo stayed in UK from May to August 2016.

What are major error sources?

Station Managers,

Imagine that:

Now you can replace/upgrade 3 components in your SLR system to improve the measurement accuracy.

Budget unlimited.

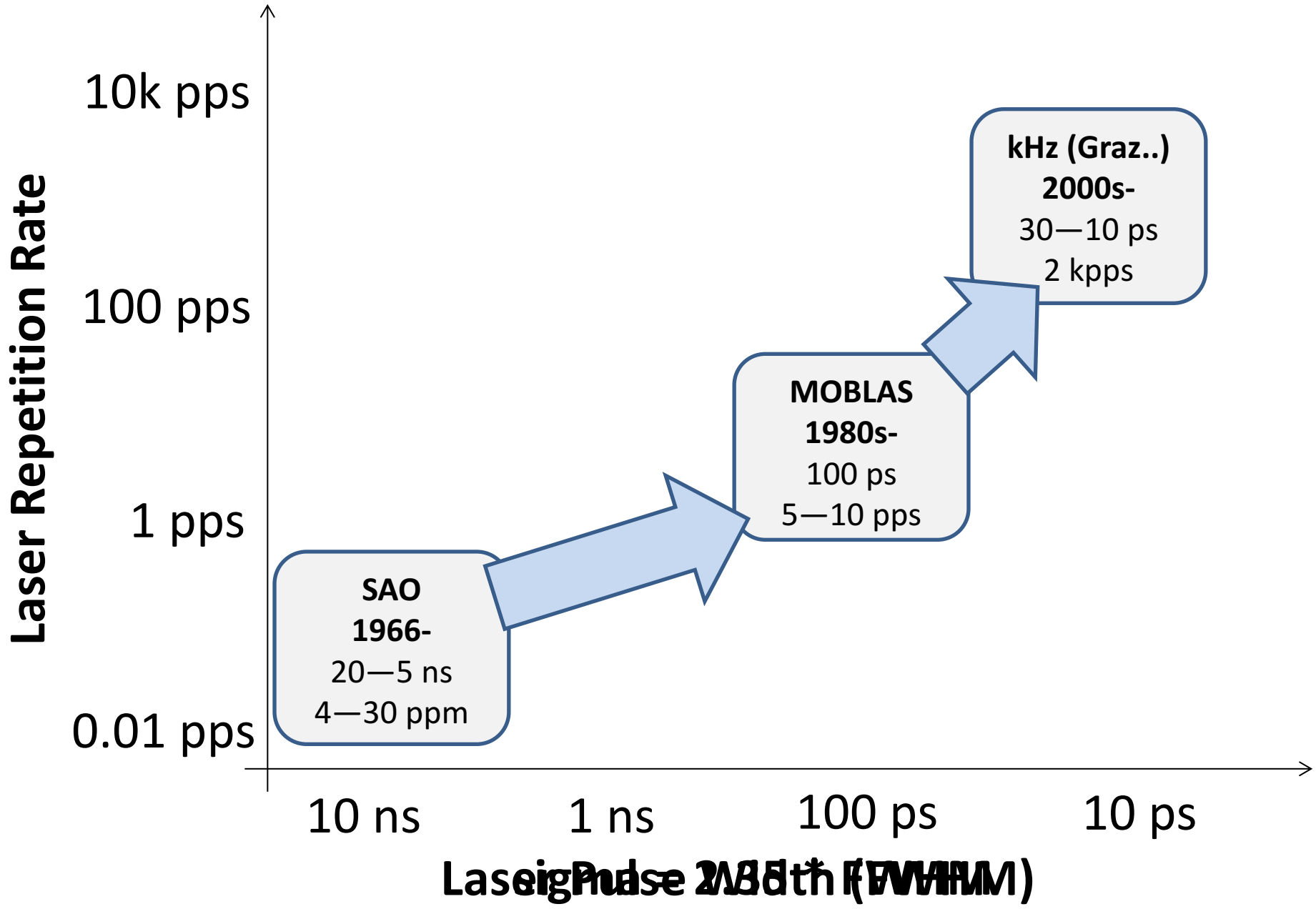
List them.

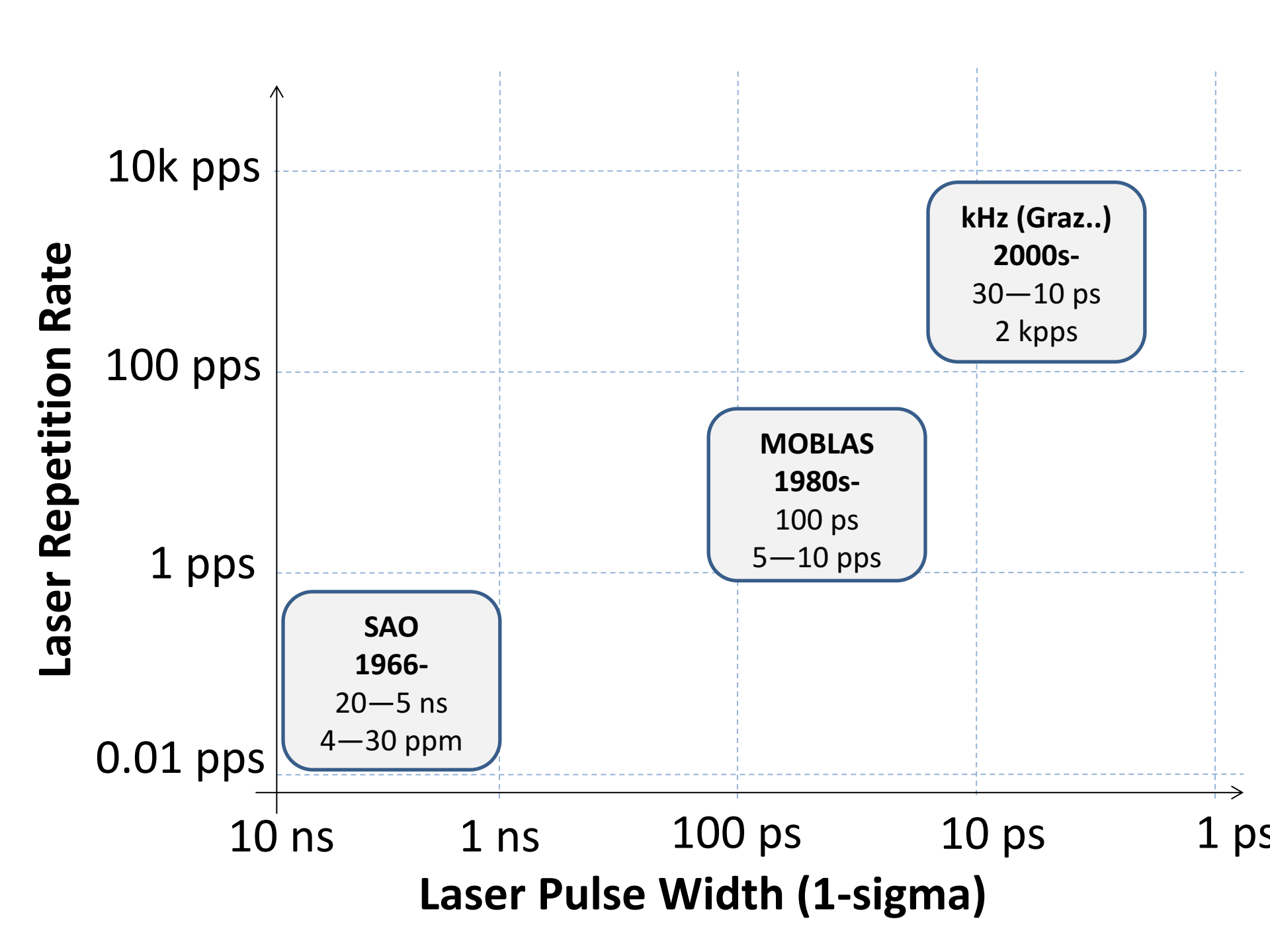
1.

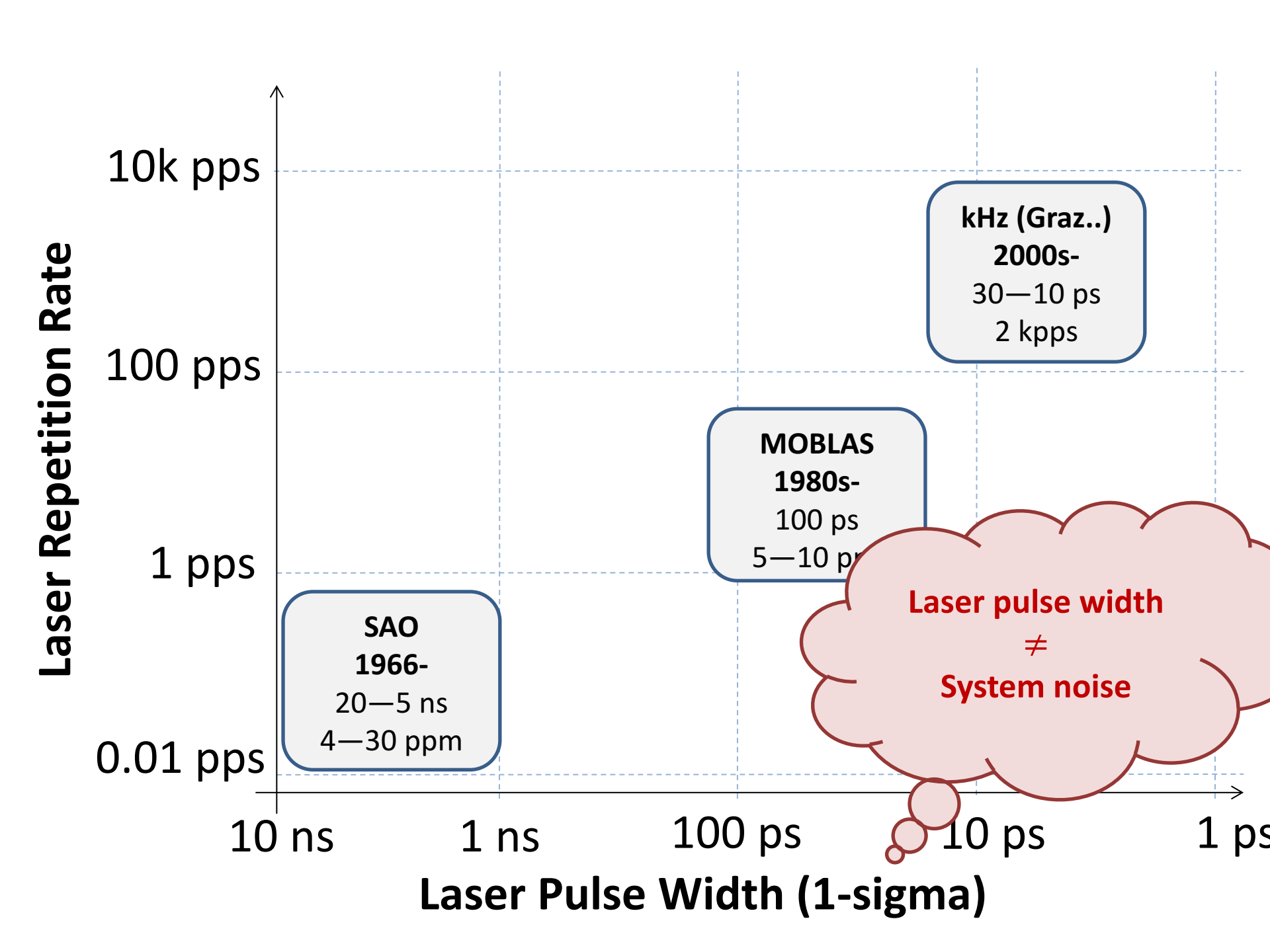
2.

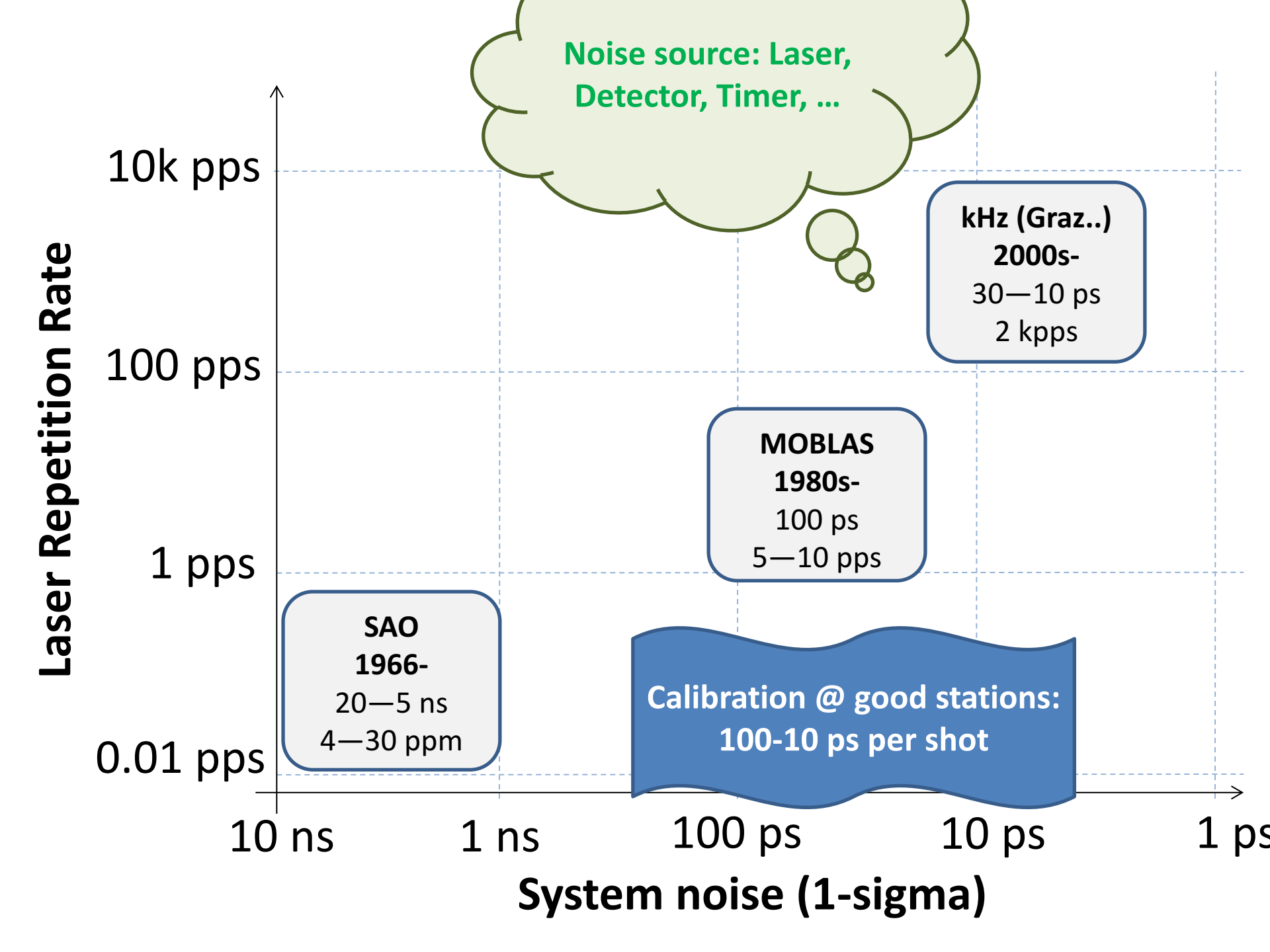
3.

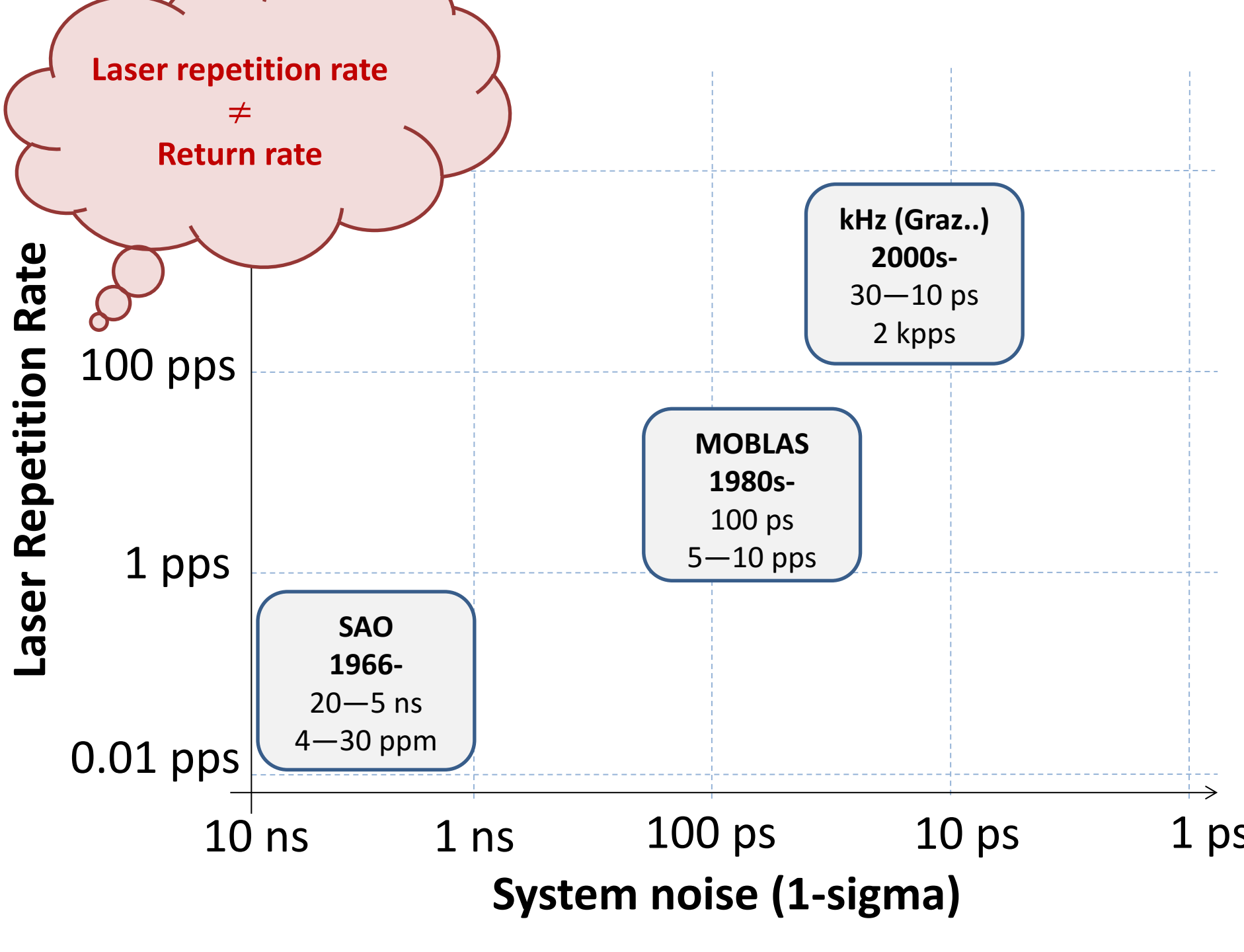
The answer will be different for every station.
My own view for Herstmonceux is shown at the end of this talk.

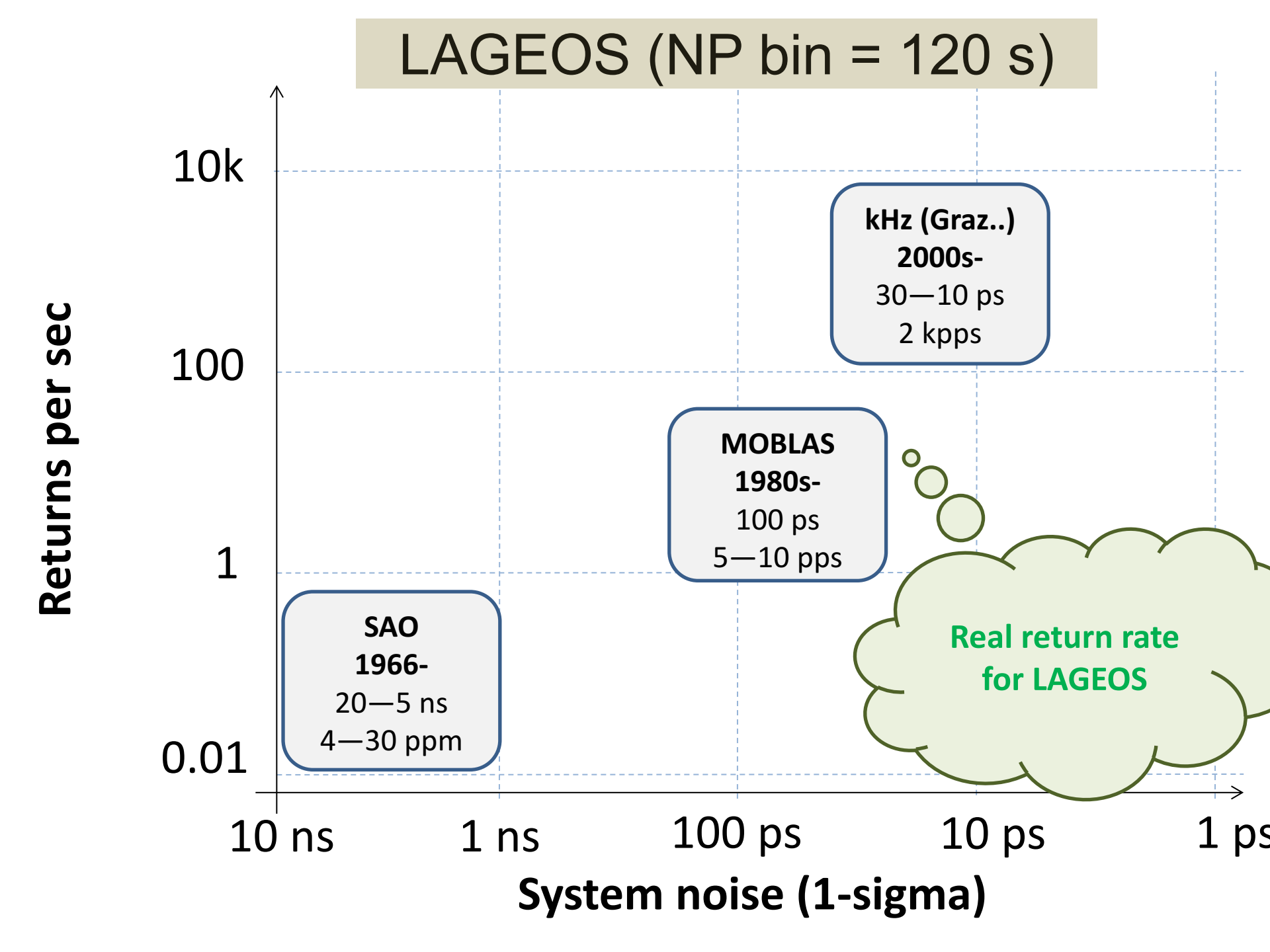

Laser Repetition Rate
10k pps
100 pps
1 pps
0.01 pps
SAO
1966-
20—5 ns
4—30 ppm
MOBLAS
1980s-
100 ps
5—10 pps
kHz (Graz..)
2000s-
30—10 ps
2 kpps
10 ns
1 ns
100 ps
10 ps
Laser Pulse Width (FWHM)

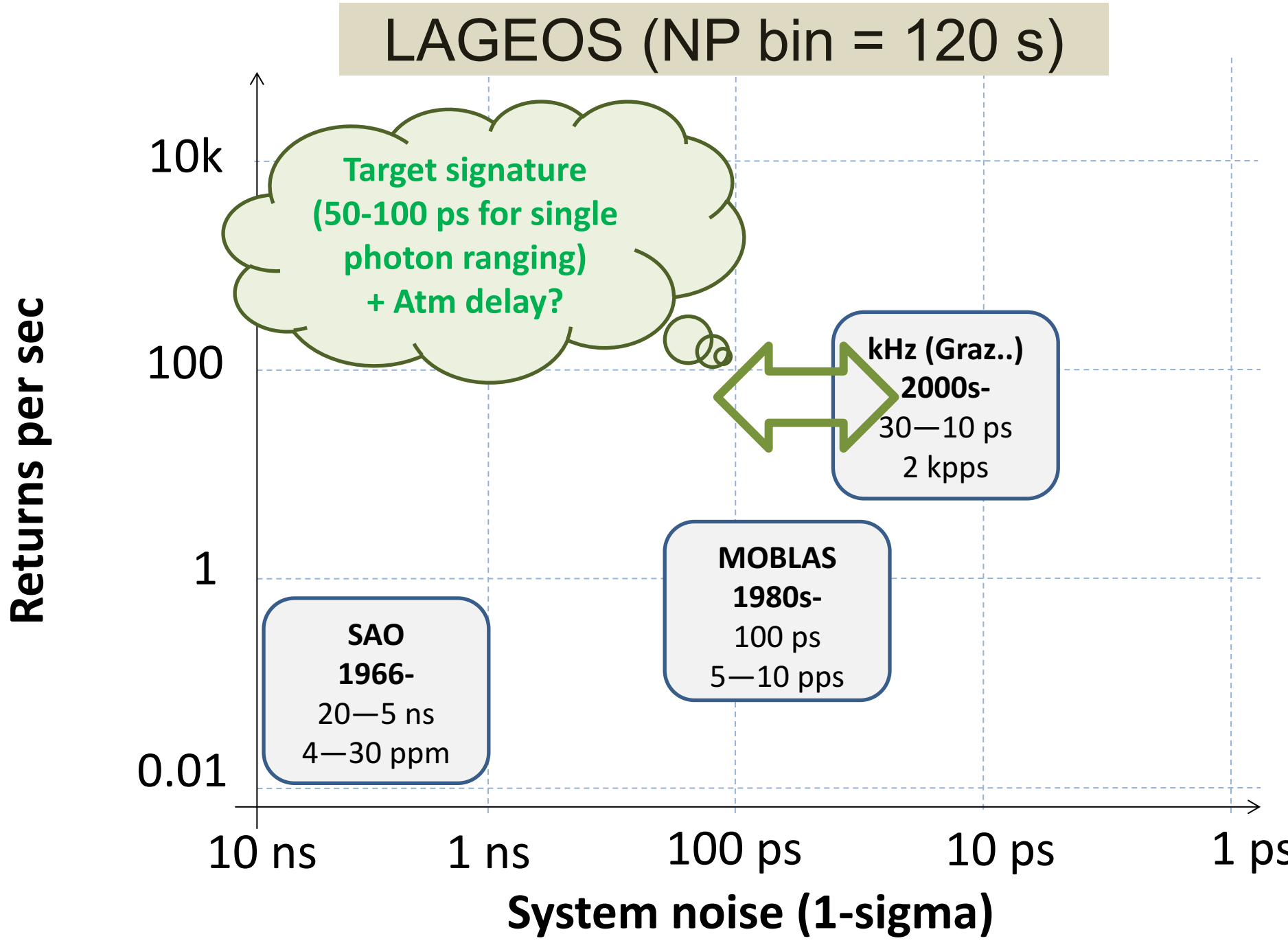

Laser Repetition Rate
10k pps
100 pps
1 pps
0.01 pps
kHz (Graz..)
2000s-
30—10 ps
2 kpps
MOBLAS
1980s-
100 ps
5—10 pps
SAO
1966-
20—5 ns
4—30 ppm
10 ns
1 ns
100 ps
10 ps
1 ps
Laser Pulse Width (1-sigma)

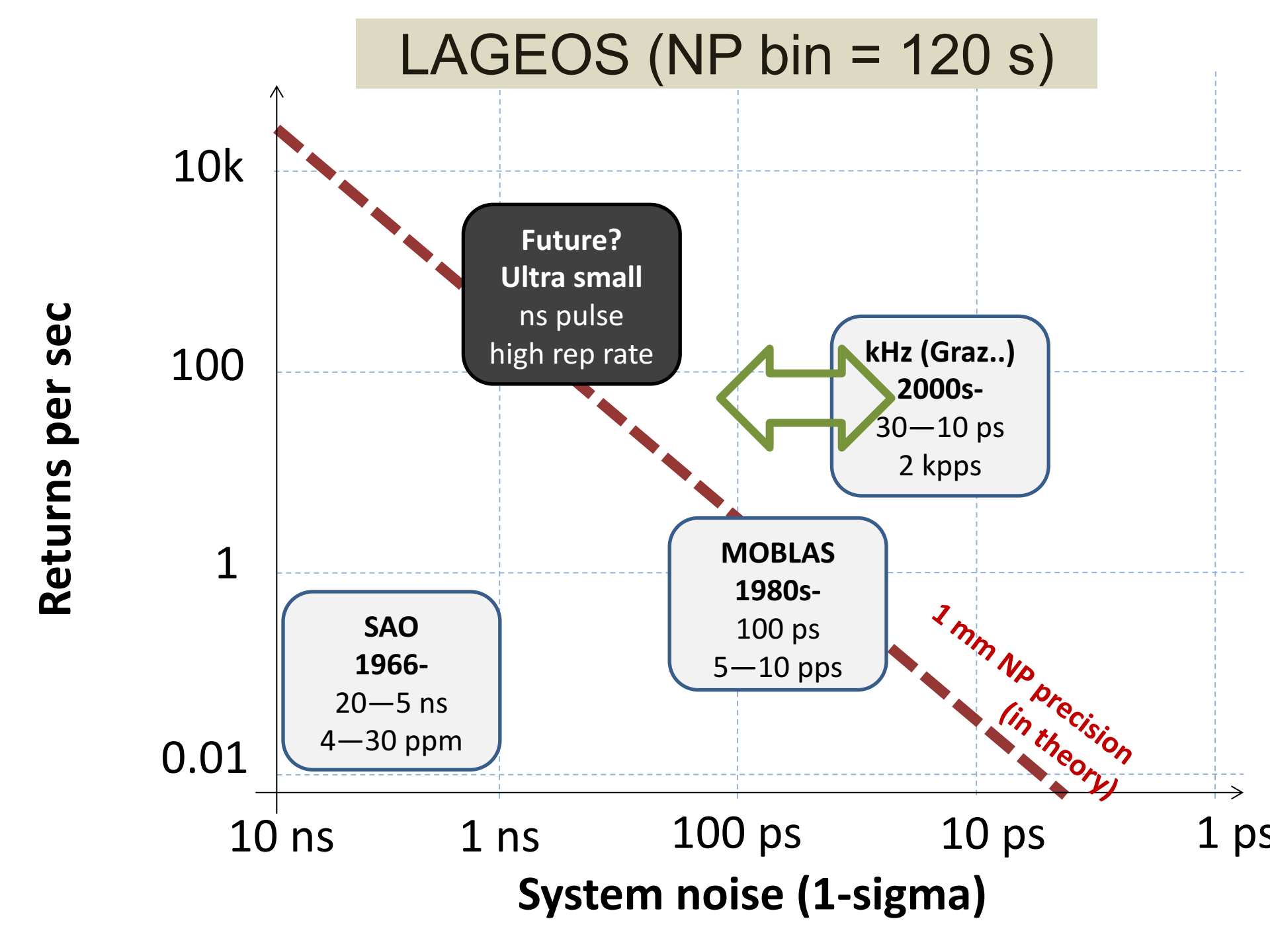

Laser Repetition Rate
10k pps
100 pps
1 pps
0.01 pps
kHz (Graz..)
2000s-
30—10 ps
2 kpps
MOBLAS
1980s-
100 ps
5—10 p
SAO
1966-
20—5 ns
4—30 ppm
Laser pulse width
≠
System noise
10 ns
1 ns
100 ps
10 ps
1 ps
Laser Pulse Width (1-sigma)


Noise source: Laser, Detector, Timer, …
kHz (Graz..)
2000s-
30—10 ps
2 kpps
MOBLAS
1980s-
100 ps
5—10 pps
SAO
1966-
20—5 ns
4—30 ppm
Calibration @ good stations:
100-10 ps per shot
10k pps
100 pps
1 pps
0.01 pps
Laser Repetition Rate
10 ns
1 ns
100 ps
10 ps
1 ps
System noise (1-sigma)


Laser repetition rate
≠
Return rate
kHz (Graz..)
2000s-
30—10 ps
2 kpps
MOBLAS
1980s-
100 ps
5—10 pps
SAO
1966-
20—5 ns
4—30 ppm
Laser Repetition Rate
100 pps
1 pps
0.01 pps
10 ns
1 ns
100 ps
10 ps
1 ps
System noise (1-sigma)


LAGEOS (NP bin = 120 s)
Returns per sec
10k
100
1
0.01
kHz (Graz..)
2000s-
30—10 ps
2 kpps
MOBLAS
1980s-
100 ps
5—10 pps
SAO
1966-
20—5 ns
4—30 ppm
Real return rate
for LAGEOS
10 ns
1 ns
100 ps
10 ps
1 ps
System noise (1-sigma)

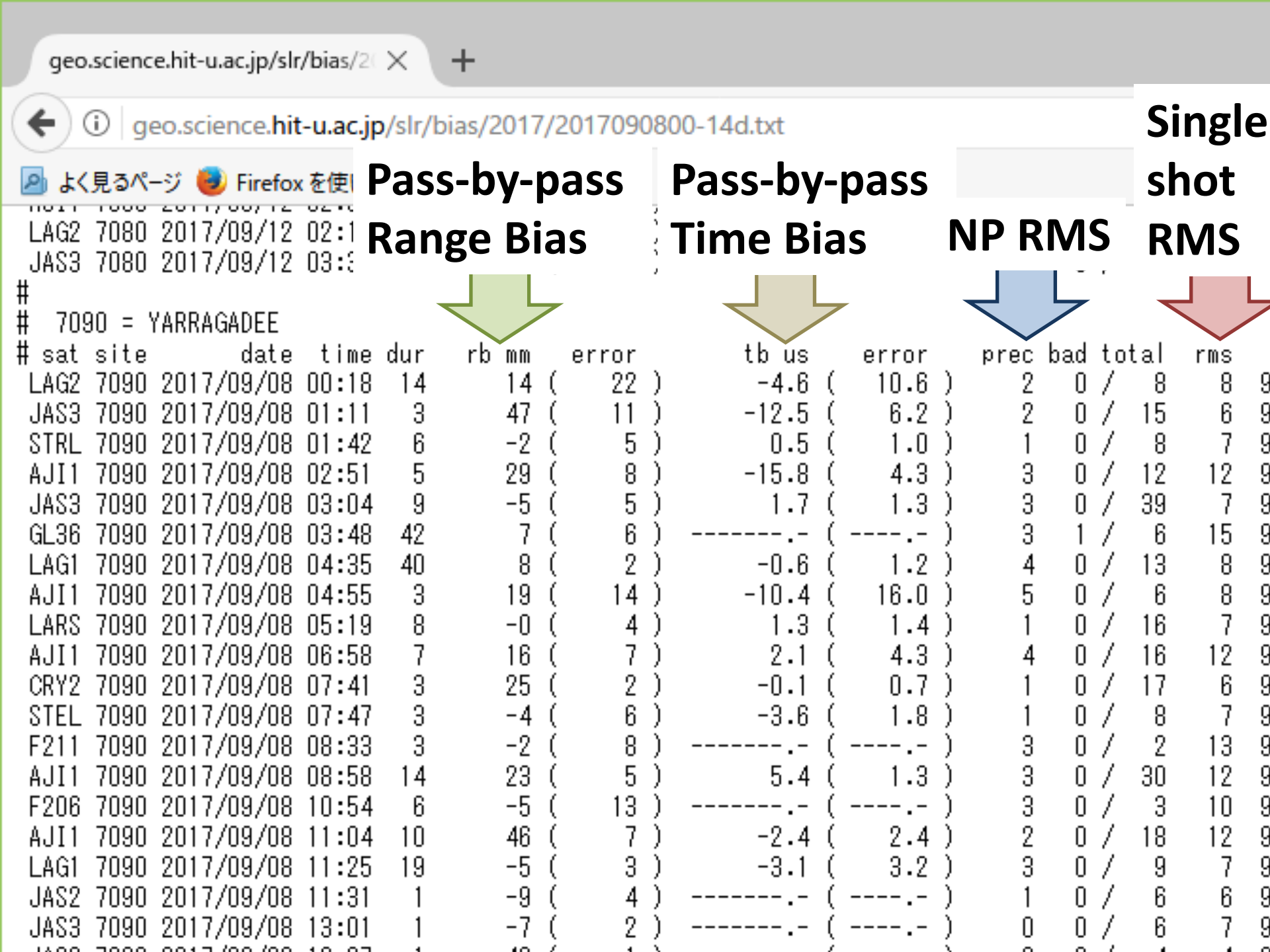

LAGEOS (NP bin = 120 s)
Returns per sec
10k
100
1
0.01
Target signature
(50-100 ps for single
photon ranging)
+ Atm delay?
kHz (Graz..)
2000s-
30—10 ps
2 kpps
MOBLAS
1980s-
100 ps
5—10 pps
SAO
1966-
20—5 ns
4—30 ppm
10 ns
1 ns
100 ps
10 ps
1 ps
System noise (1-sigma)


LAGEOS (NP bin = 120 s)
Returns per sec
10k
100
1
0.01
Future?
Ultra small
ns pulse
high rep rate
kHz (Graz..)
2000s-
30—10 ps
2 kpps
MOBLAS
1980s-
100 ps
5—10 pps
SAO
1966-
20—5 ns
4—30 ppm
1 mm NP precision
(in theory)
10 ns
1 ns
100 ps
10 ps
1 ps
System noise (1-sigma)

What do we want to improve?

“Quality” means?

- Single-shot RMS
- NP RMS
- Pass-by-pass bias RMS
- Station position time series
- Agreement with VLBI, GNSS, DORIS…



LAG2 7080 2017/09/12 02:1
JAS3 7080 2017/09/12 03:3

#
7090 = YARRAGADEE
sat site date time dur rb mm error tb us error prec bad total rms

sat	site	date	time	dur	rb mm	error	tb us	error	prec	bad	total	rms	
LAG2	7090	2017/09/08	00:18	14	14	(22)	-4.6	(10.6)	2	0	/ 8	8	9
JAS3	7090	2017/09/08	01:11	3	47	(11)	-12.5	(6.2)	2	0	/ 15	6	9
STRL	7090	2017/09/08	01:42	6	-2	(5)	0.5	(1.0)	1	0	/ 8	7	9
AJI1	7090	2017/09/08	02:51	5	29	(8)	-15.8	(4.3)	3	0	/ 12	12	9
JAS3	7090	2017/09/08	03:04	9	-5	(5)	1.7	(1.3)	3	0	/ 39	7	9
GL36	7090	2017/09/08	03:48	42	7	(6)	-------.-	(----.-)	3	1	/ 6	15	9
LAG1	7090	2017/09/08	04:35	40	8	(2)	-0.6	(1.2)	4	0	/ 13	8	9
AJI1	7090	2017/09/08	04:55	3	19	(14)	-10.4	(16.0)	5	0	/ 6	8	9
LARS	7090	2017/09/08	05:19	8	-0	(4)	1.3	(1.4)	1	0	/ 16	7	9
AJI1	7090	2017/09/08	06:58	7	16	(7)	2.1	(4.3)	4	0	/ 16	12	9
CRY2	7090	2017/09/08	07:41	3	25	(2)	-0.1	(0.7)	1	0	/ 17	6	9
STEL	7090	2017/09/08	07:47	3	-4	(6)	-3.6	(1.8)	1	0	/ 8	7	9
F211	7090	2017/09/08	08:33	3	-2	(8)	-------.-	(----.-)	3	0	/ 2	13	9
AJI1	7090	2017/09/08	08:58	14	23	(5)	5.4	(1.3)	3	0	/ 30	12	9
F206	7090	2017/09/08	10:54	6	-5	(13)	-------.-	(----.-)	3	0	/ 3	10	9
AJI1	7090	2017/09/08	11:04	10	46	(7)	-2.4	(2.4)	2	0	/ 18	12	9
LAG1	7090	2017/09/08	11:25	19	-5	(3)	-3.1	(3.2)	3	0	/ 9	7	9
JAS2	7090	2017/09/08	11:31	1	-9	(4)	-------.-	(----.-)	1	0	/ 6	6	9
JAS3	7090	2017/09/08	13:01	1	-7	(2)	-------.-	(----.-)	0	0	/ 6	7	9

What do we want to improve?

Single-shot RMS

NP RMS

Pass-by-pass bias RMS

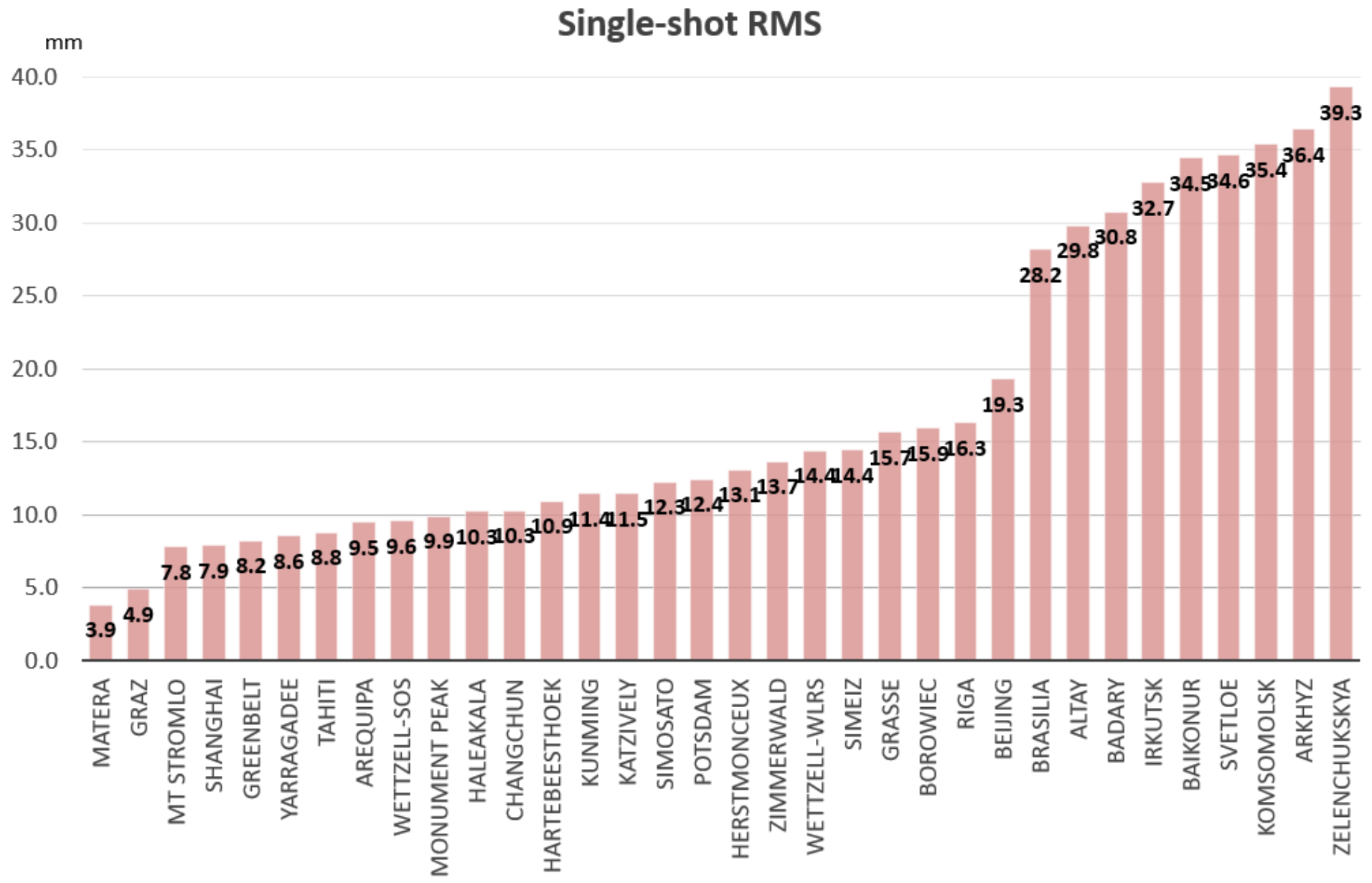
Station position time series

Agreement with VLBI, GNSS, DORIS…

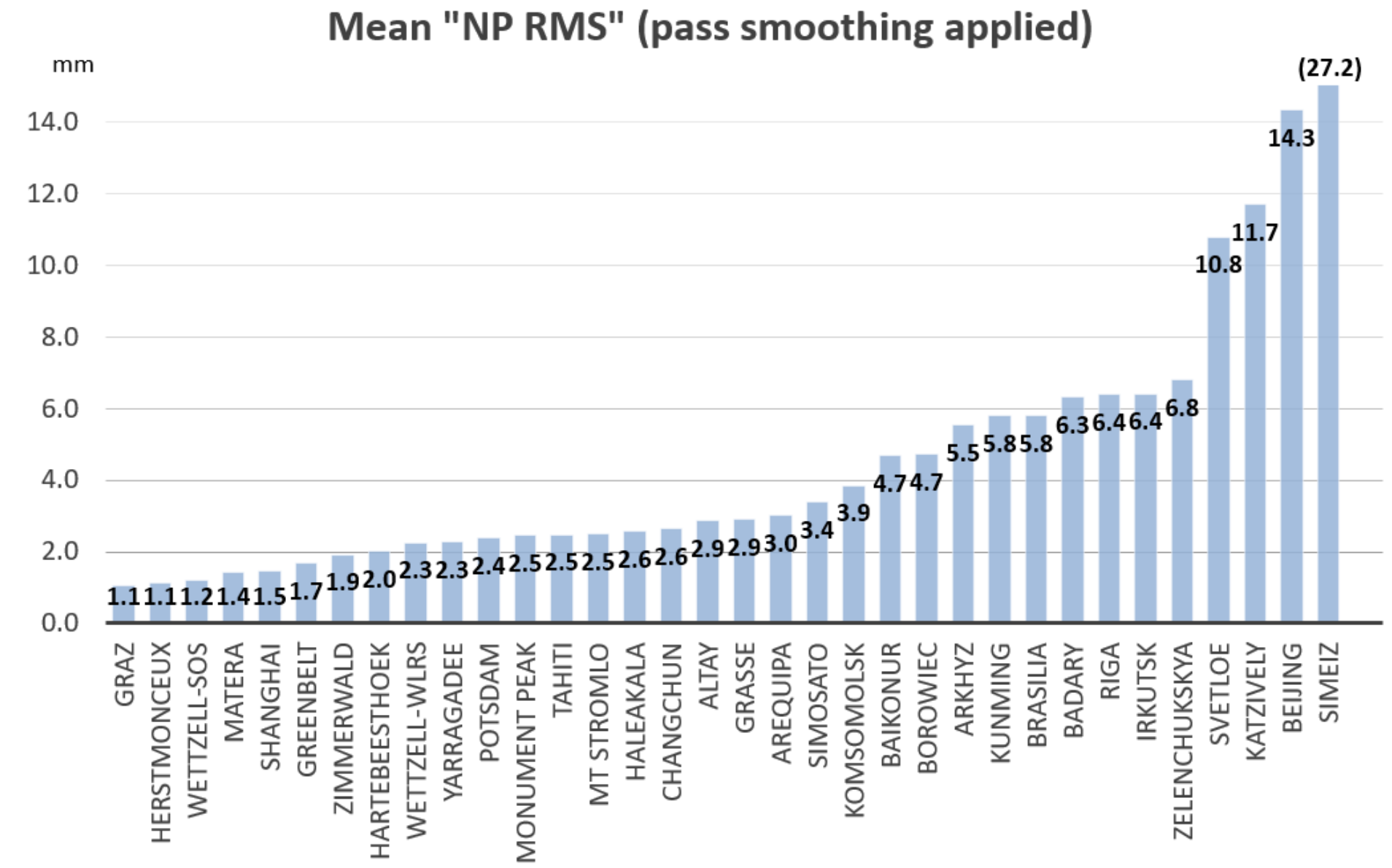
Behaviour of error:

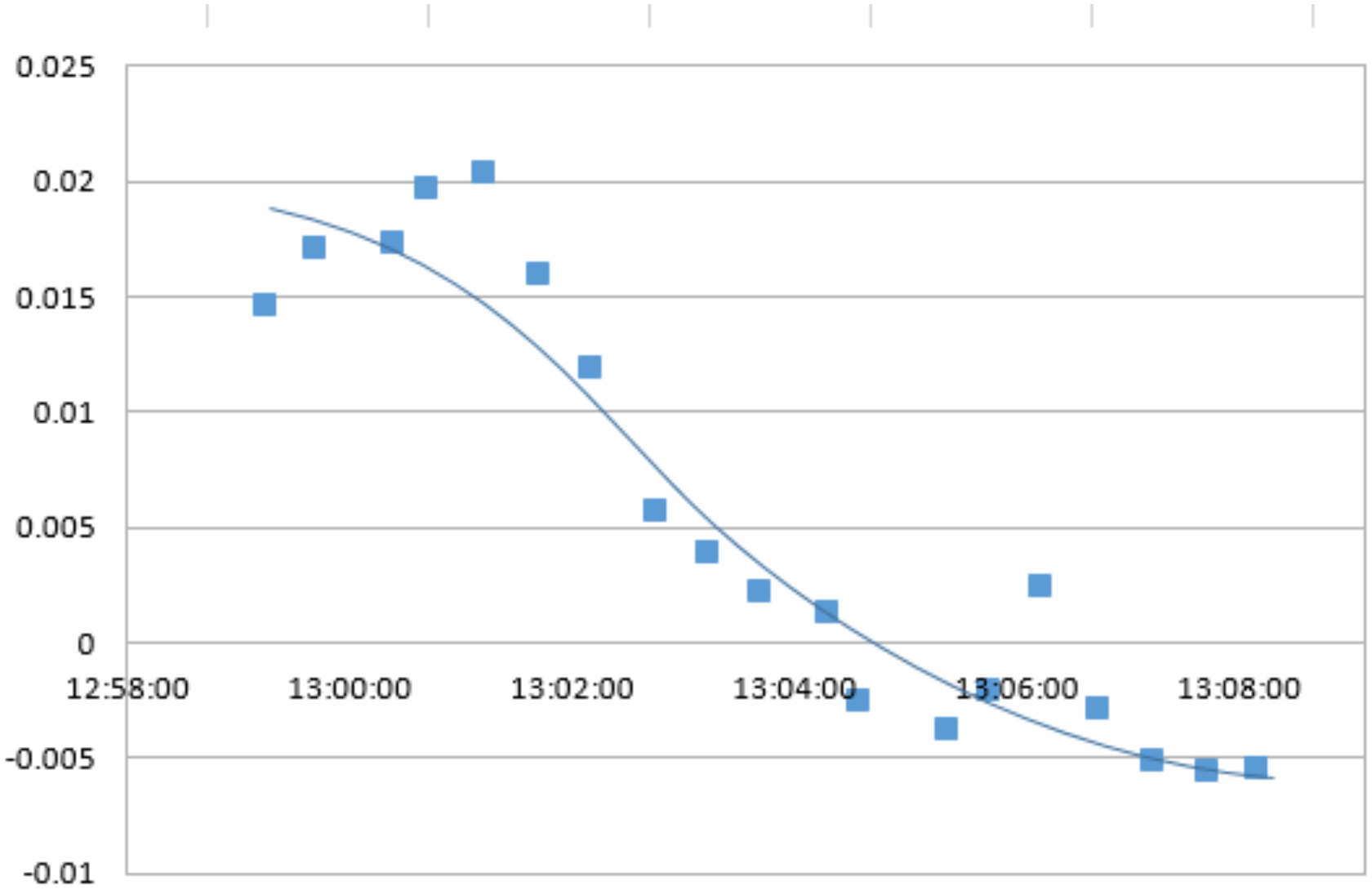
- Random (over what time span?)
- Constant
- Cyclic (daily, yearly…)
- Sporadic
- Drift
- Jump

1 year (July 2016-June 2017), LAG1+LAG2

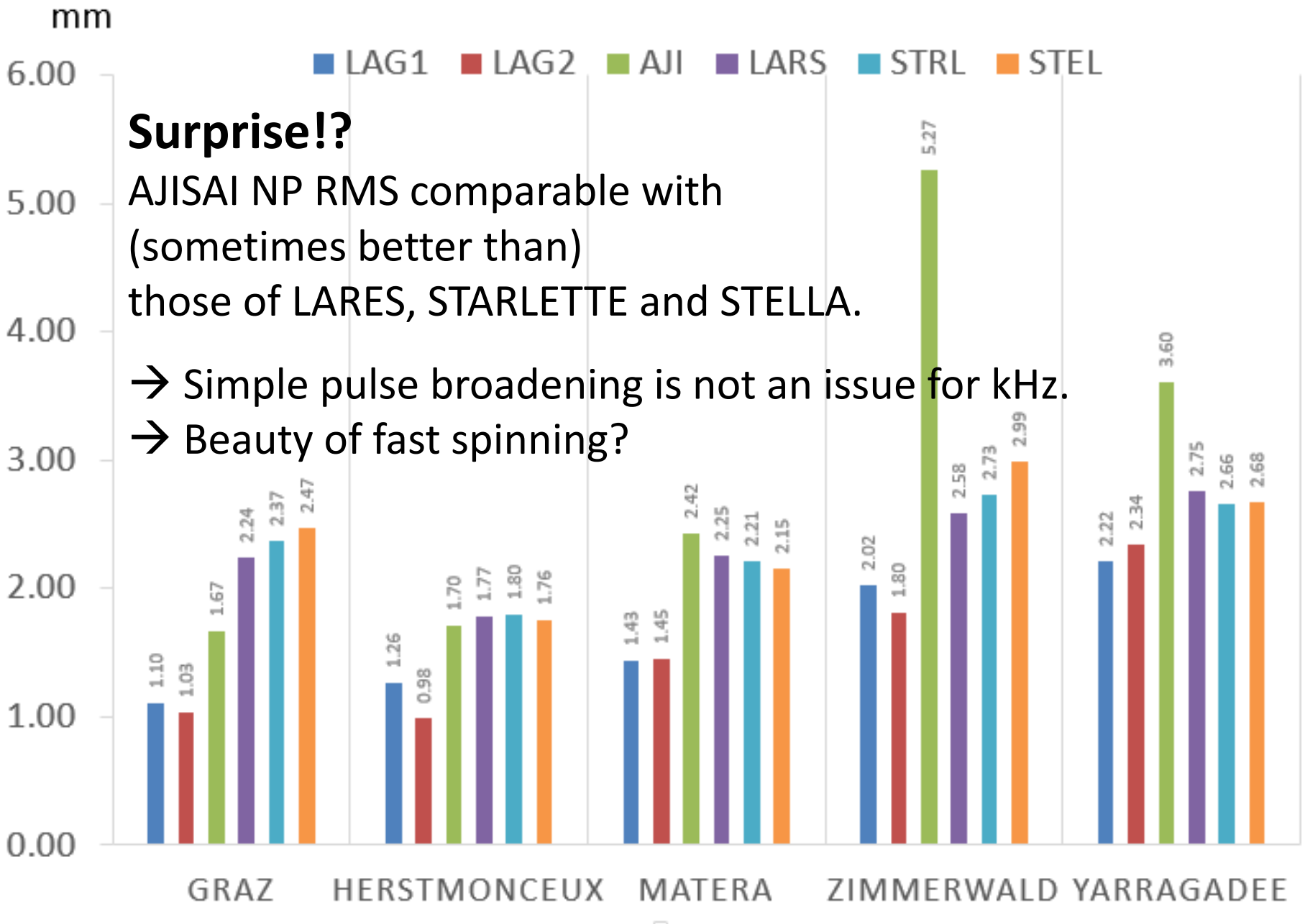


1 year (July 2016-June 2017), LAG1+LAG2.
RB only or RB+TB or RB+RBd+TB smoothing applied for POD (c5++) post-fit residuals.

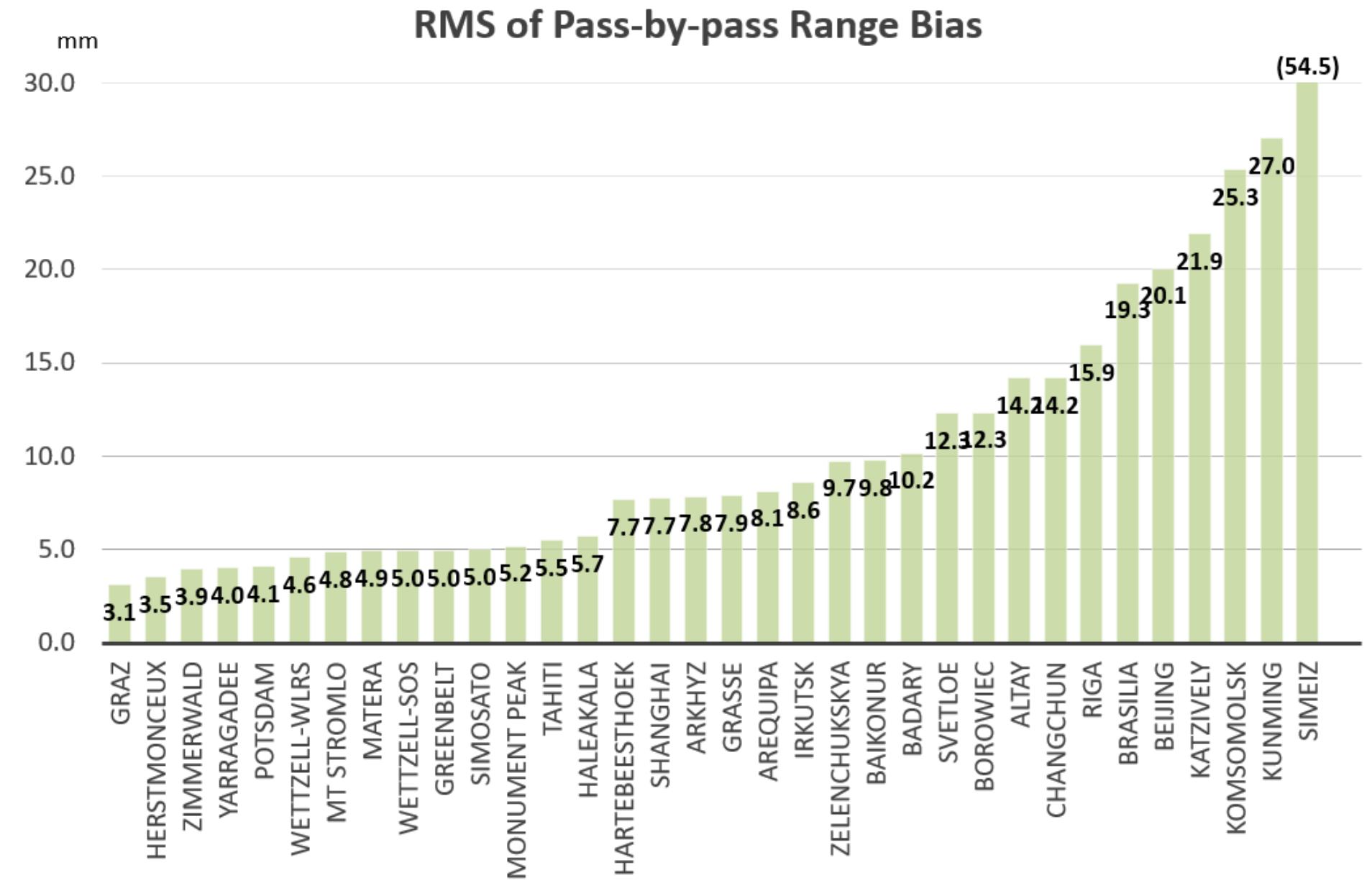



0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
12:58:00
13:00:00
13:02:00
13:04:00
13:06:00
13:08:00

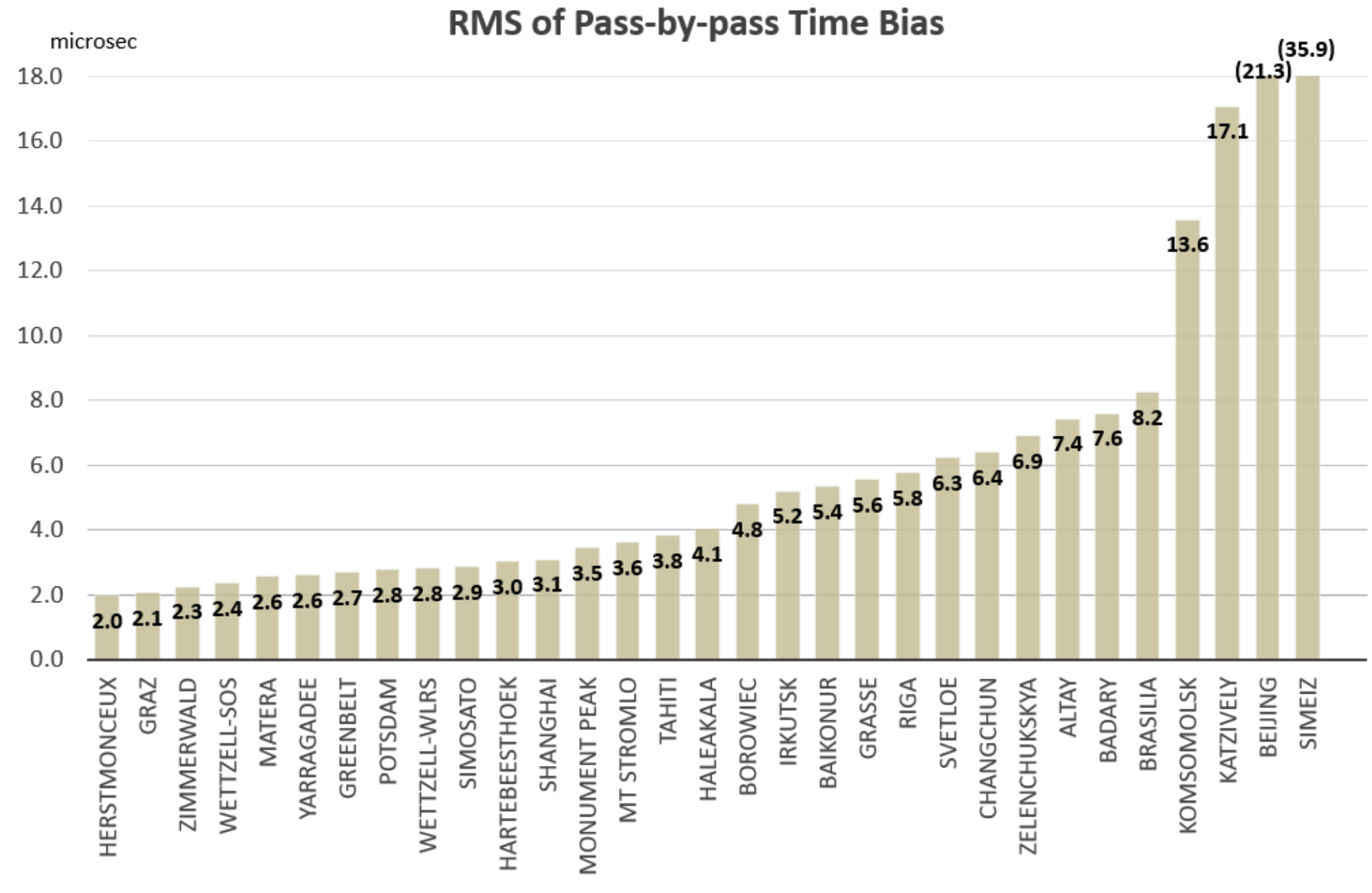
1 year (July 2016-June 2017), 6 satellites.
RB only or RB+TB or RB+RBd+TB smoothing applied for POD (c5++) post-fit residuals.



1 year (July 2016-June 2017), LAG1+LAG2.
POD (c5++): station pos solved for. U-Strasbg atm+hyd loading applied.



1 year (July 2016-June 2017), LAG1+LAG2.
POD (c5++): station pos solved for. U-Strasbg atm+hyd loading applied.



	Best	10th	20th
Single-shot RMS	4 mm	10 mm	14 mm
NP RMS	1 mm	2 mm	3 mm
Pass RB RMS	3 mm	5 mm	9 mm
Pass TB RMS	2 μs (~ 10 mm)	3 μs (~ 15 mm)	6 μs (~ 30 mm)

	Best	10th	20th
Single-shot RMS	4 mm	10 mm	14 mm
NP RMS	1 mm	2 mm	3 mm
Pass RB RMS	3 mm	5 mm	9 mm
Pass TB RMS	2 μs (~ 10 mm)	3 μs (~ 15 mm)	6 μs (~ 30 mm)

1

NPs scatter less than single shots (no surprise).

1

However it does not follow the Sqrt(N) rule.

(NP RMS is projected to ~0.1 mm when N = 10000.)

← Smoothing functions (RB+TB) not perfect.

← Atmospheric delay? Target spin & signature?

← Noise reduction / tail clipping procedure?

	Best	10th	20th
Single-shot RMS	4 mm	10 mm	14 mm
NP RMS	1 mm	2 mm	3 mm
Pass RB RMS	3 mm	5 mm	9 mm
Pass TB RMS	2 μs (~ 10 mm)	3 μs (~ 15 mm)	6 μs (~ 30 mm)

2

2

Pass-by-pass bias scatters more than NPs.

← POD: Acc models, Displ models, Atm delay,…

← Obs: Stability? Calibration?

International Laser Ranging Service forum
Networks and Engineering Standing Committee

September 16, 2017, 03:42:40 PM

Toshimichi Otsubo
Newbie
Posts: 3

Station Performance 2016-2017 (Riga Workshop Spoiler)

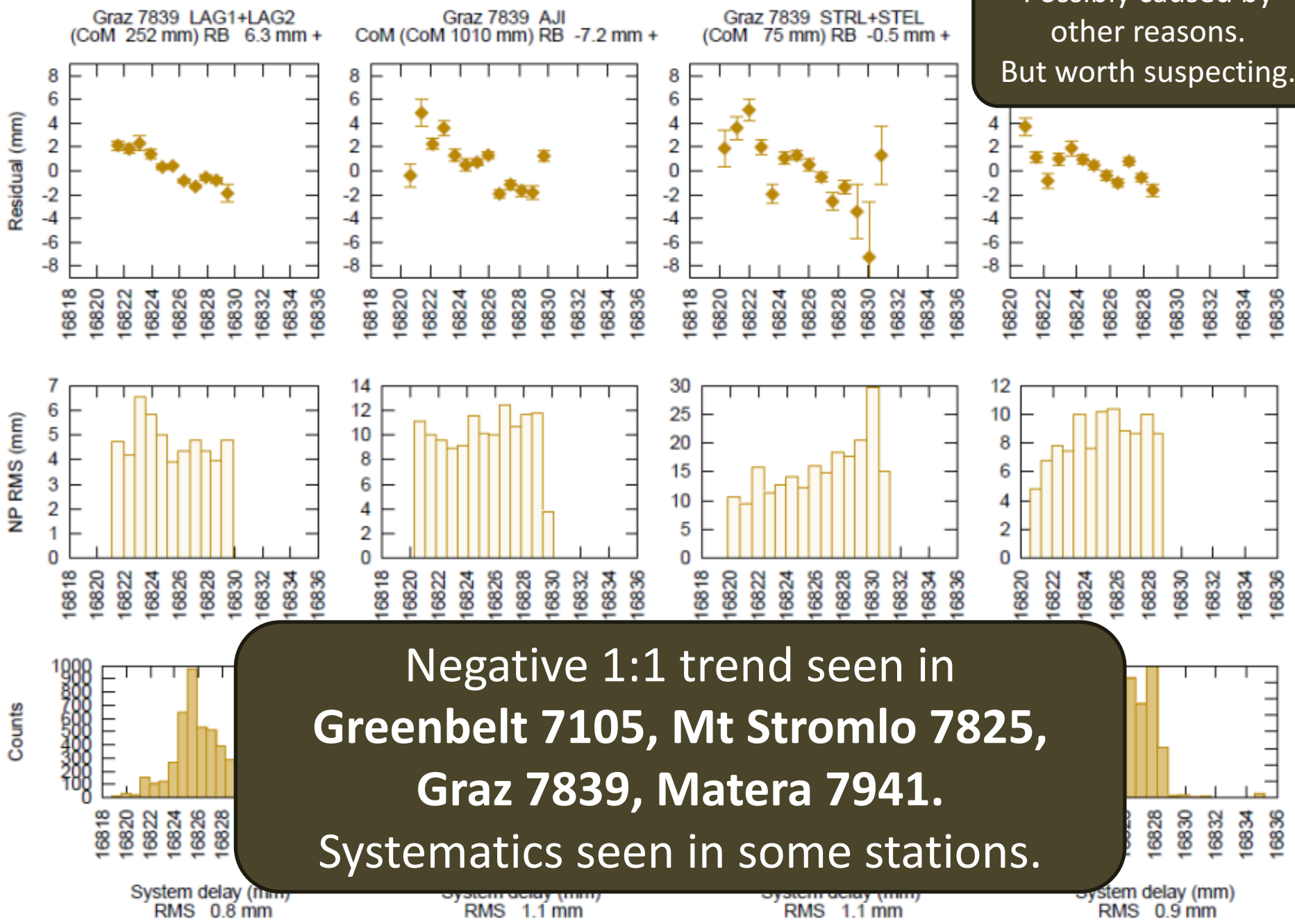
« **on:** September 16, 2017, 03:42:40 PM »

Dear Worldwide Laser Ranging Colleagues,

Hello from Tokyo.

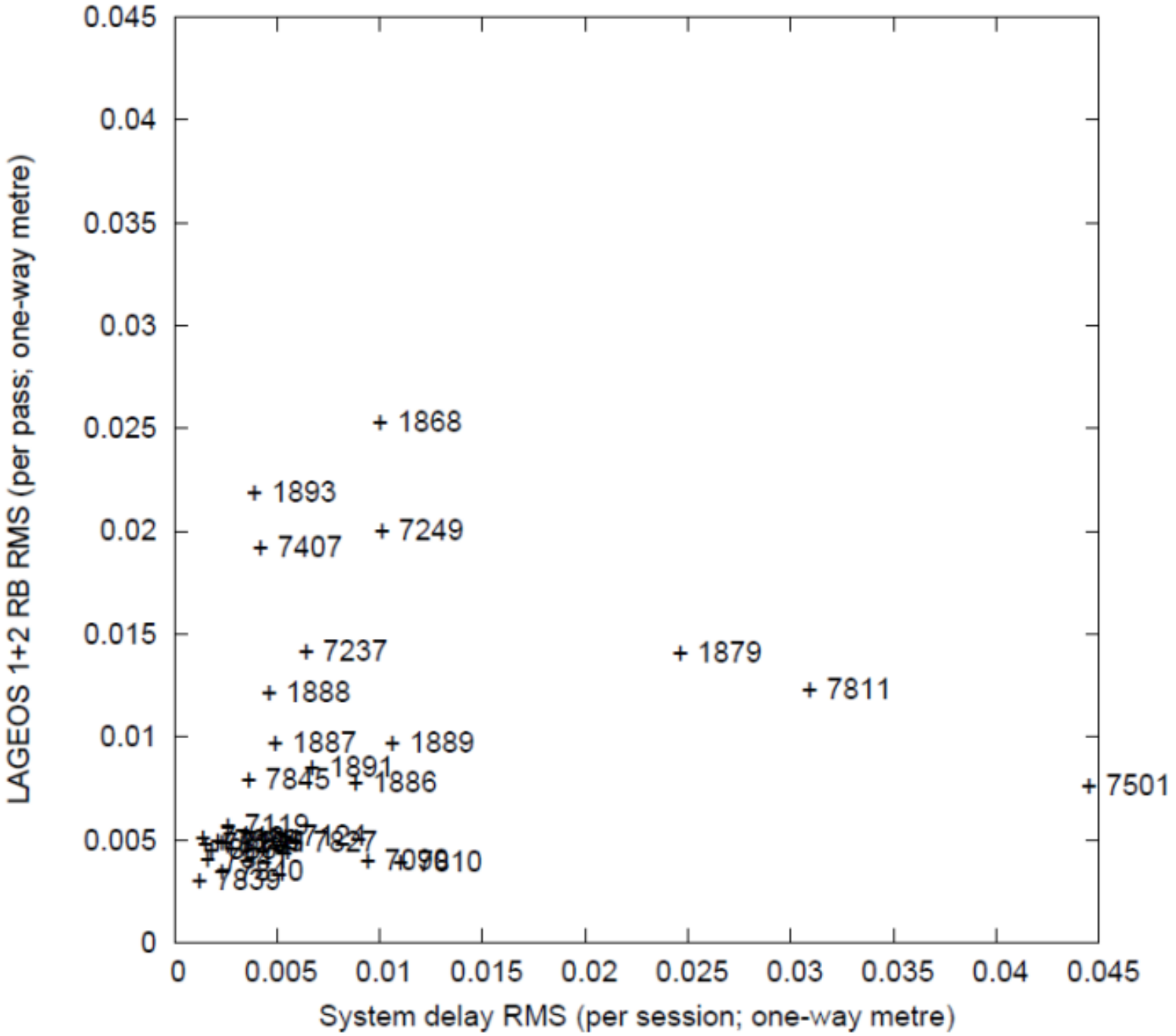
In preparation for 2017 ILRS Technical Workshop in Riga http://www.ilrstw2017.lu.lv, I have just generate uploaded a number of charts on station performance from various aspects.

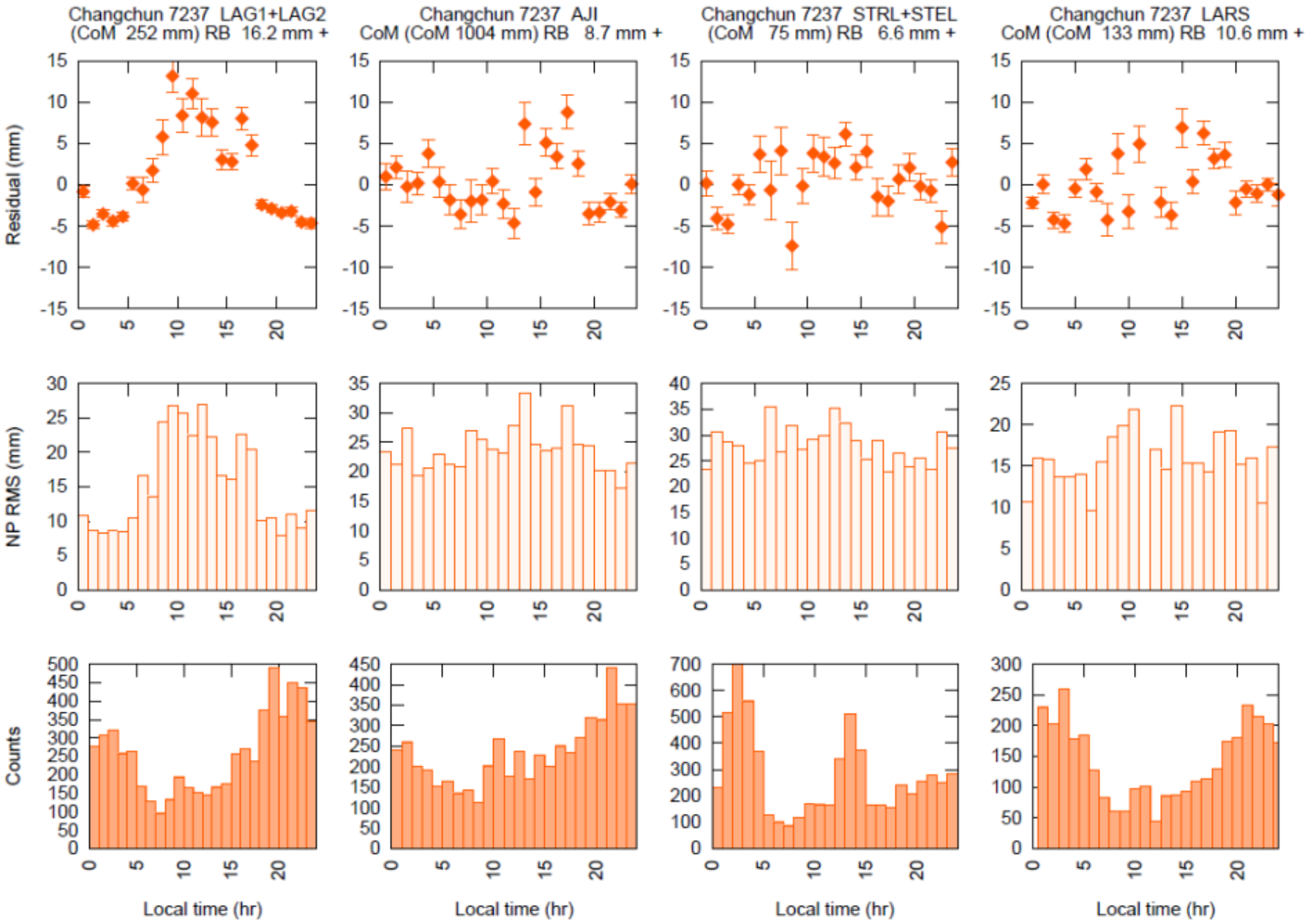
- **LAGEOS-1 & 2 "precision" charts:**
  Single-shot RMS, NP RMS, Pass Range Bias (RB) RMS and Pass Time Bias (TB) RMS
  http://geo.science.hit-u.ac.jp/slr/bias/2017sp/variousrms.pdf
  (Single-shot RMS taken from CRD, NP RMS smoothed by a simple function (RB only, RB + TB, or RB TB) per pass, RB/TB RMS taken from pass-by-pass biases)
- **LAGEOS-1+2: Pass RB RMS vs Session-by-session system delay RMS**
  (Page 1 >> ZOOM >> Page 2 >> ZOOM >> Page 3)
  http://geo.science.hit-u.ac.jp/slr/bias/2017sp/DelayVsLag7.pdf
  (Good performing stations are mostly stable in calibration too.)
- **6-Sat: POD residuals vs Applied system delay**
  http://geo.science.hit-u.ac.jp/slr/bias/2017sp/SortDelay7.pdf
  (Negative 1:1 trend indicates untrue variation in calibration.)
- **6-Sat: POD residuals vs Intensity (returns per NP bin)**
  http://geo.science.hit-u.ac.jp/slr/bias/2017sp/SortIntensity7.pdf
  (Negative trend indicates intensity dependence.)
- **6-Sat: POD residuals vs Single shot RMS**
  http://geo.science.hit-u.ac.jp/slr/bias/2017sp/SortRms7.pdf
  (Positive trend indicates the mean being affected by the tail clipping.)
- **6-Sat: POD residuals vs Local time**
  http://geo.science.hit-u.ac.jp/slr/bias/2017sp/SortHour7.pdf
  (Day-night observability and stability.)

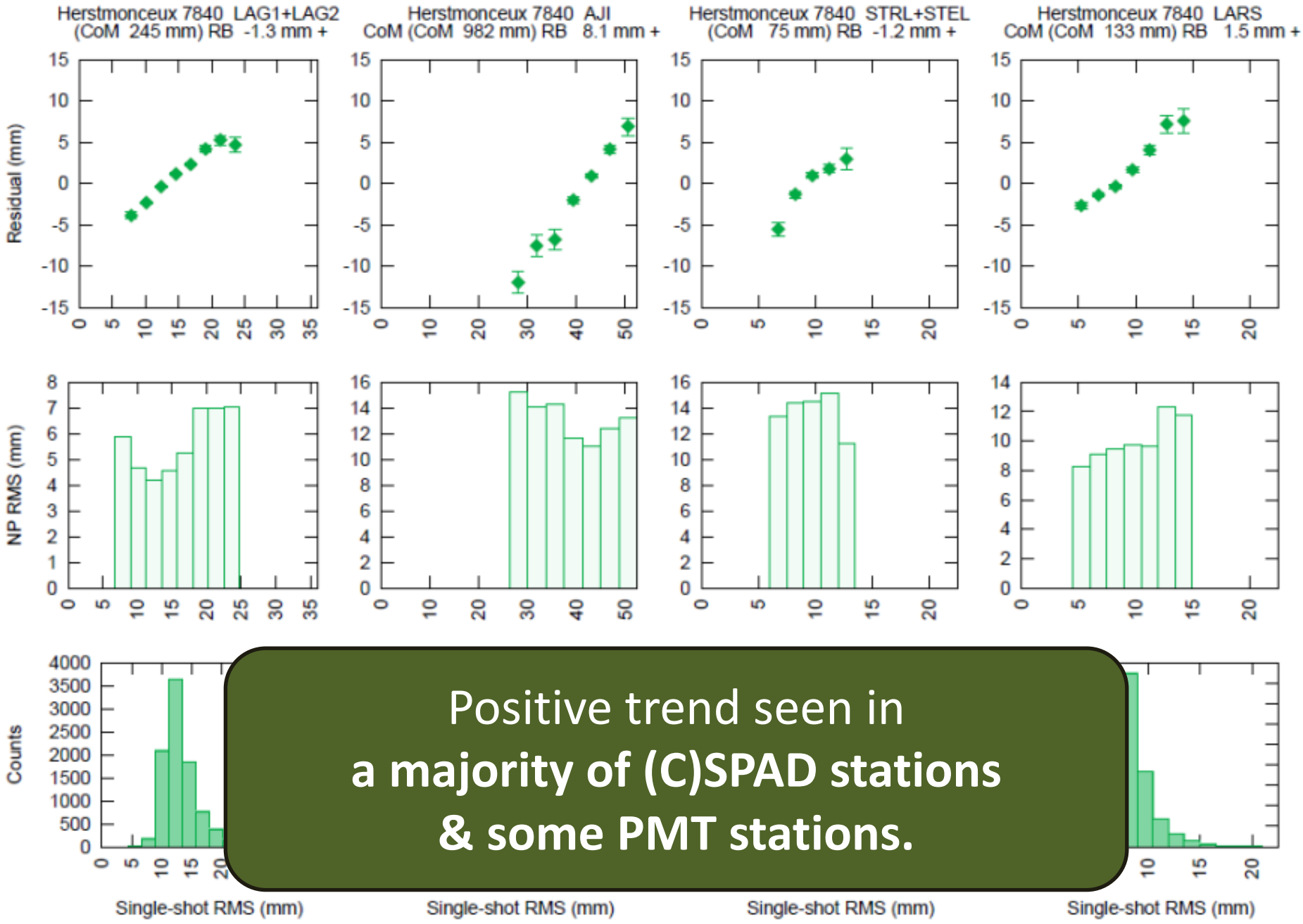


Possibly caused by other reasons.
But worth suspecting.

Negative 1:1 trend seen in
Greenbelt 7105, Mt Stromlo 7825, Graz 7839, Matera 7941.
Systematics seen in some stations.


LAGEOS 1+2 RB RMS (per pass; one-way metre)
System delay RMS (per session; one-way metre)
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
+ 1868
+ 1893
+ 7249
+ 7407
+ 7237
+ 1879
+ 7811
+ 1888
+ 1887
+ 1889
+ 1891
+ 7845
+ 1886
+ 7501
+ 7119
+ 7839


Changchun 7237 LAG1+LAG2
(CoM 252 mm) RB 16.2 mm +
Changchun 7237 AJI
CoM (CoM 1004 mm) RB 8.7 mm +
Changchun 7237 STRL+STEL
(CoM 75 mm) RB 6.6 mm +
Changchun 7237 LARS
CoM (CoM 133 mm) RB 10.6 mm +
Residual (mm)
NP RMS (mm)
Counts
Local time (hr)
Local time (hr)
Local time (hr)
Local time (hr)



Positive trend seen in
a majority of (C)SPAD stations
& some PMT stations.

What are major error sources?

Station Managers,

Imagine that:

Now you can replace/upgrade 3 components in your SLR system to improve the measurement accuracy.

Budget unlimited.

List them.

My own view for Herstmonceux was:

1. **Data reduction (NP generation) software (→ Rodriguez).**
2. **Calibration, local tie, (very?) local displacement.**
3. **Detector (if no skew, less noise products are available).**

0. **POD Software.**

Final Remarks

All stations should suspect every component.

Find out what is the major error sources.

Consider what is averaged out and what is not.

[Spin off] AJISAI NP precision matches other satellites.

A huge variety of charts on station performance are available at:

- **ILRS NESC Forum** http://sgf.rgo.ac.uk/forumNESC

Visit & be visited --- I am happy to go & see!