Identification and calibration of one - way biases in SLR system

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Presented at

One-day Introductory and Refresher Course
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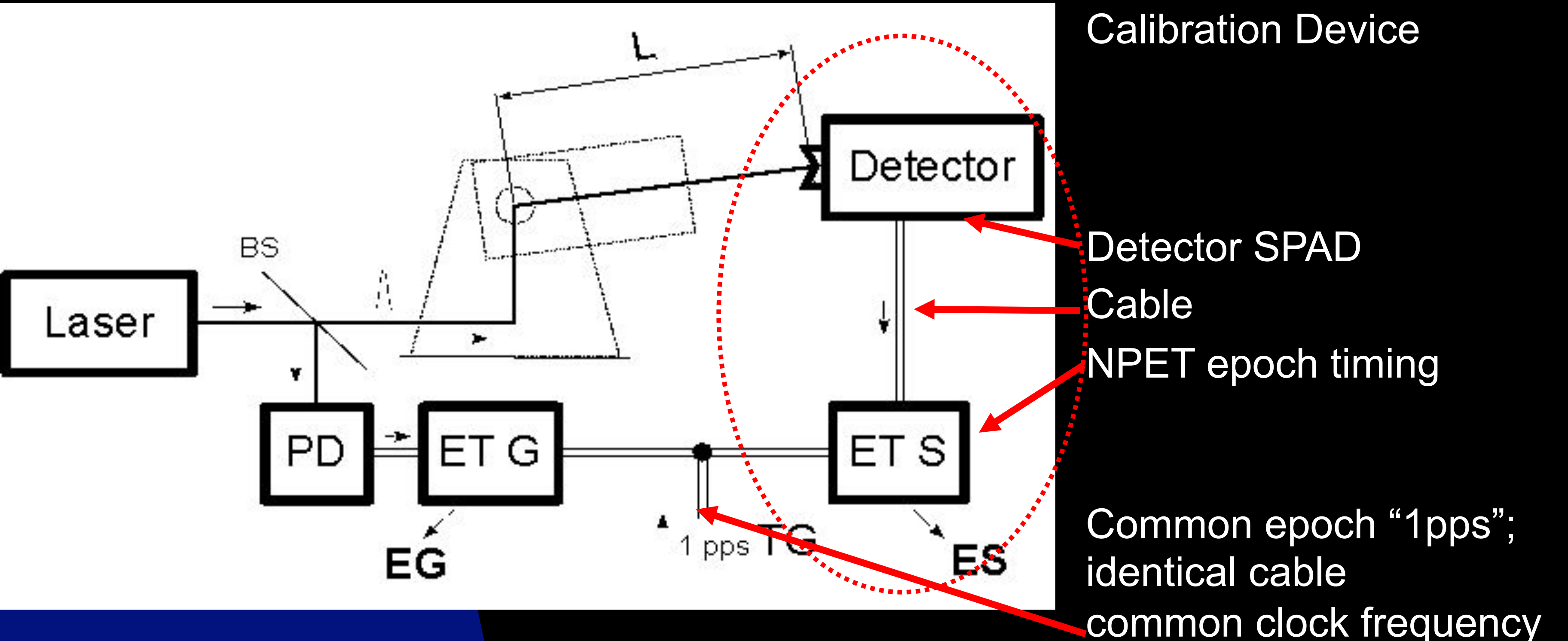
Why should we do it ?

- As a standard for 50 years the SLR system is calibrated by a laser ranging to a ground target of a precisely known distance.
- It works OK down to ~ ps / sub-mm level.
  The laser fire epoch is recorded within 100 ns versus UTC
- New SLR applications:
  - Laser Time Transfer (LTT)
  - one-way laser ranging
  - bi- and multi-static laser ranging

  require identification and calibration of one-way T / R biases
- In addition the T / R epochs must be referred to UTC < 1 ns

Transmit delay measurements
Scheme developed for European Laser Timing



- The epoch is referred to the "1pps" inputs of epoch timing devices
- The Calibration Device delays may be determined with ~ 20ps accuracy
- Considering the Calibration Device delays and a real distance ***L*** the transmit delay related to "1pps" input may be determined with the same accuracy

Calibration Device

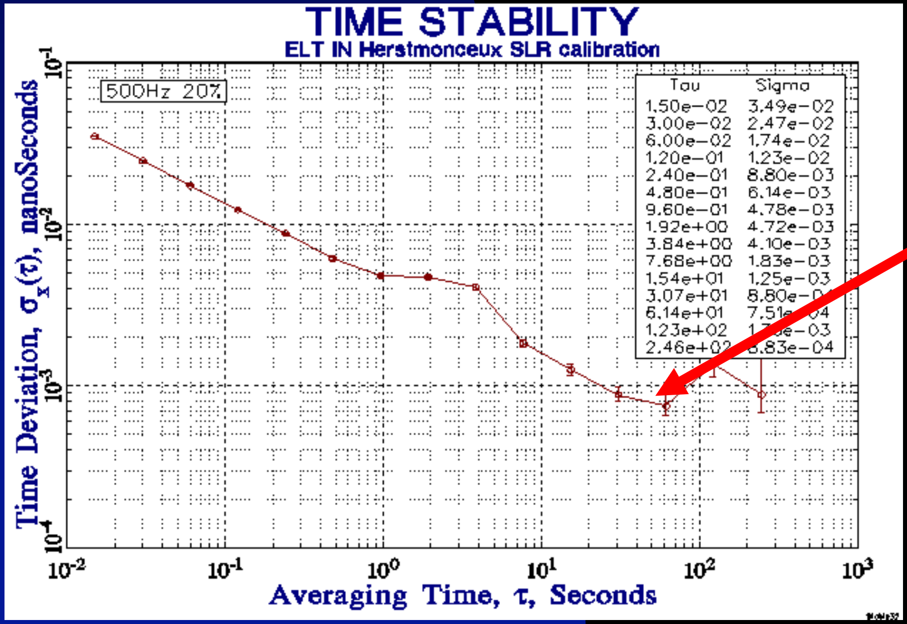
- The ELT Calibration Device was developed for ACES – ELT
- All the signal propagation delays were calibrated with ~15 ps accuracy and long term stability.
- The receiving part one-way calibration ***R*** may be simply calculated from standard ground target calibration ***G*** and transmit part bias ***T***.

ELT Calibration Mission; SLR Herstmonceux UK

Completed May 23-27, 2016

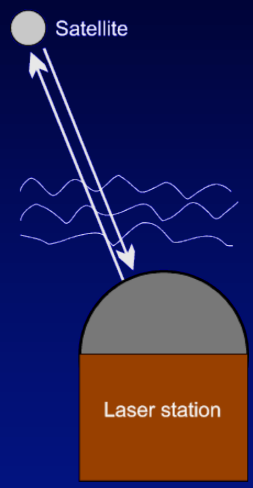
Single ~ 26 ps rms

ELT Calibration constant Transmit
T = − 1.57 ± 0.03 ns.



TDEV < 1 ps @ 25s

Accurate timing; how do we get it? How good is it? What improvements are coming?



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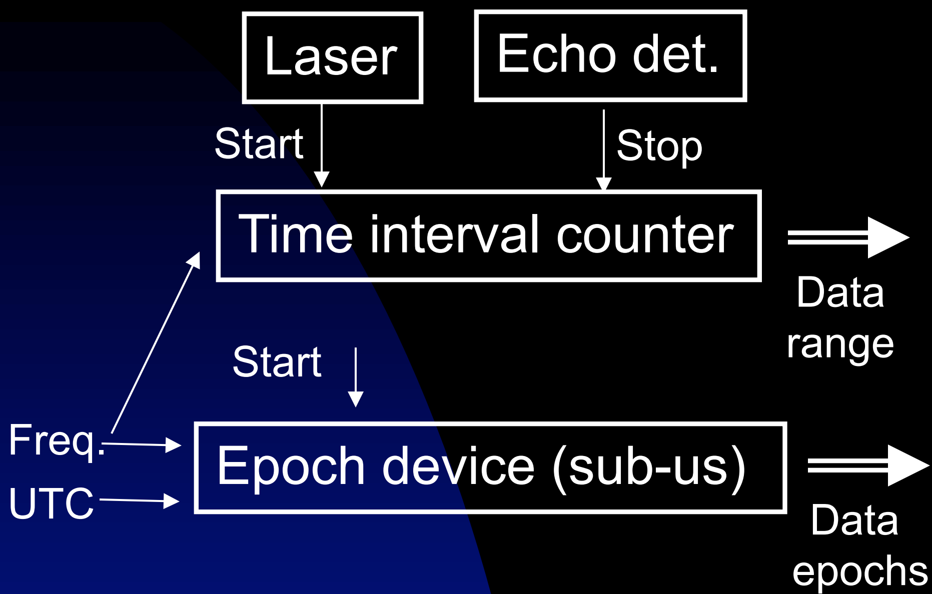
Accurate timing for SLR - Two key concepts
1 - Time Interval Counter



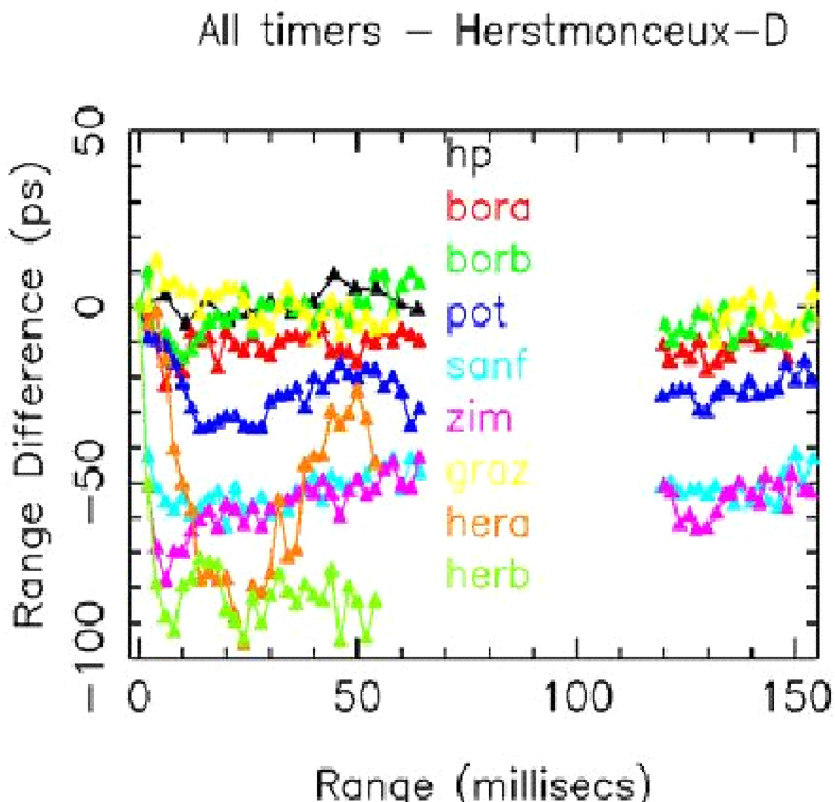
- Two independent devices:
  Time Interval Counter
  Epoch reading
- Used since very beginning
- Common devices
  HP5370B, SR620
- Limitations:
- low rep.rate 1…10 Hz
- linearity, stability (> 10 ps)
- low resolution epoch (> 10ns)

"Ranging machine" biases identification

RANGING COUNTERS COMPARISON TO P-PET

P. Gibs, Herstmonceux, 2002

- Shown here is a summary plot of all the devices.

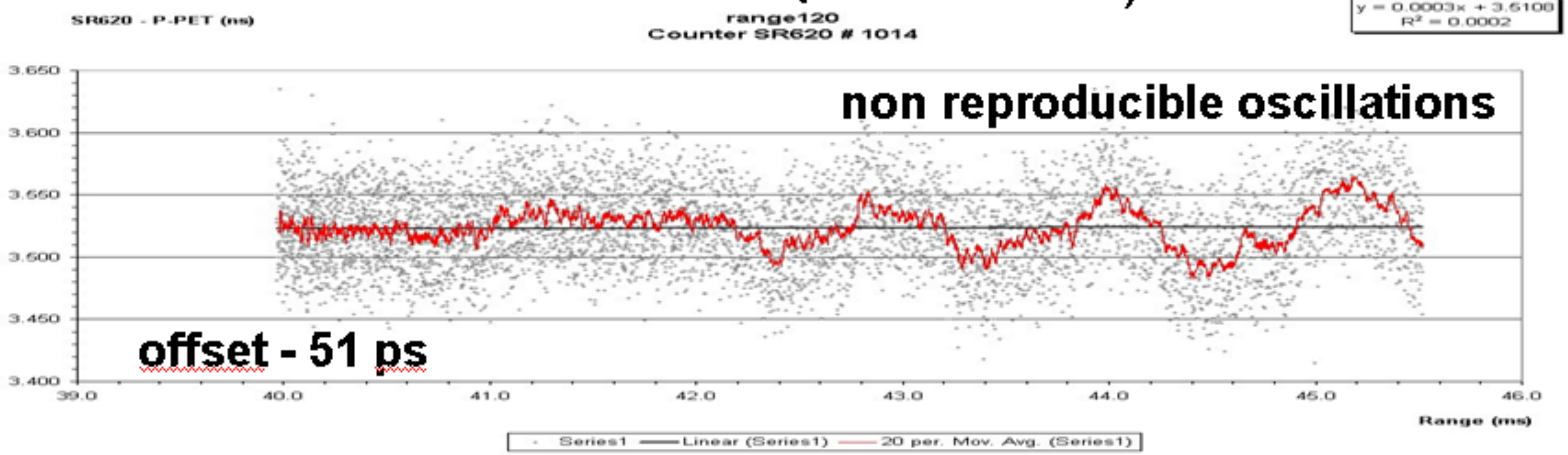


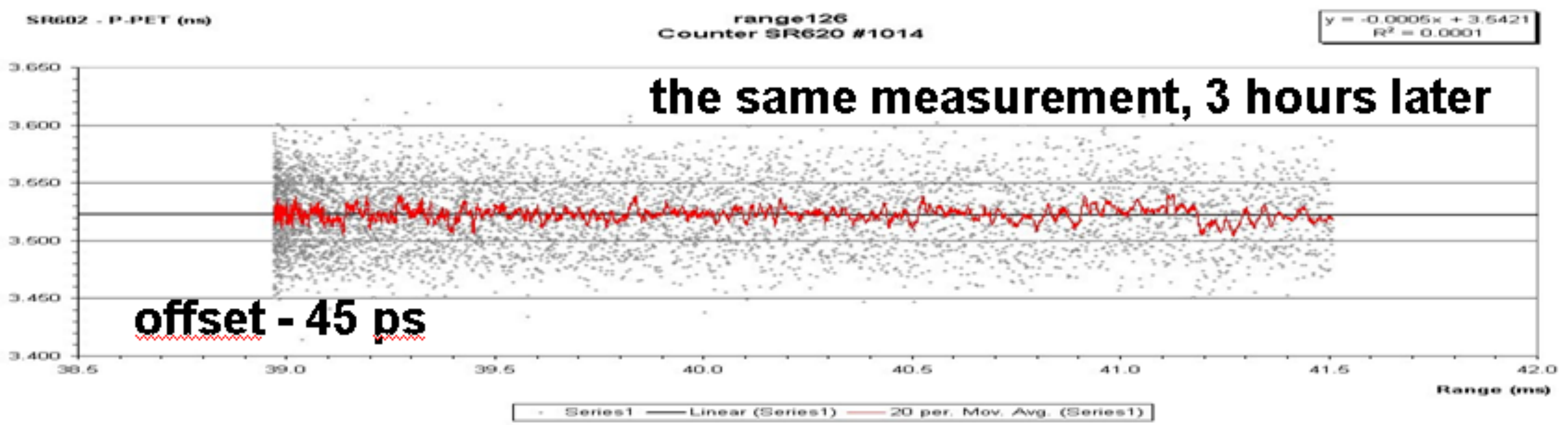
SR620 / P-PET Counter Linearity

Potsdam, 2001, LAGEOS pass

50 ps / div

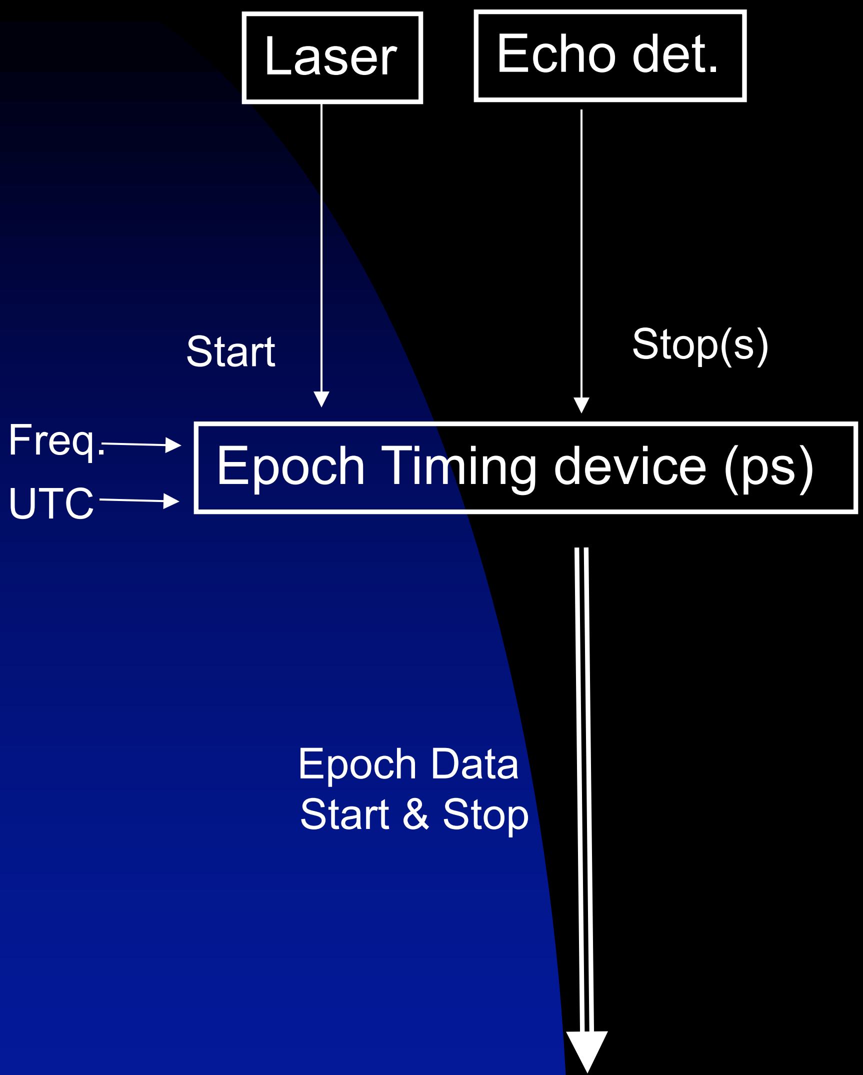
Counter s/n 1014 (in routine use)





L. Grunwald, R.Neubert, H.Fischer, H.Pino, Potsdam, 2001

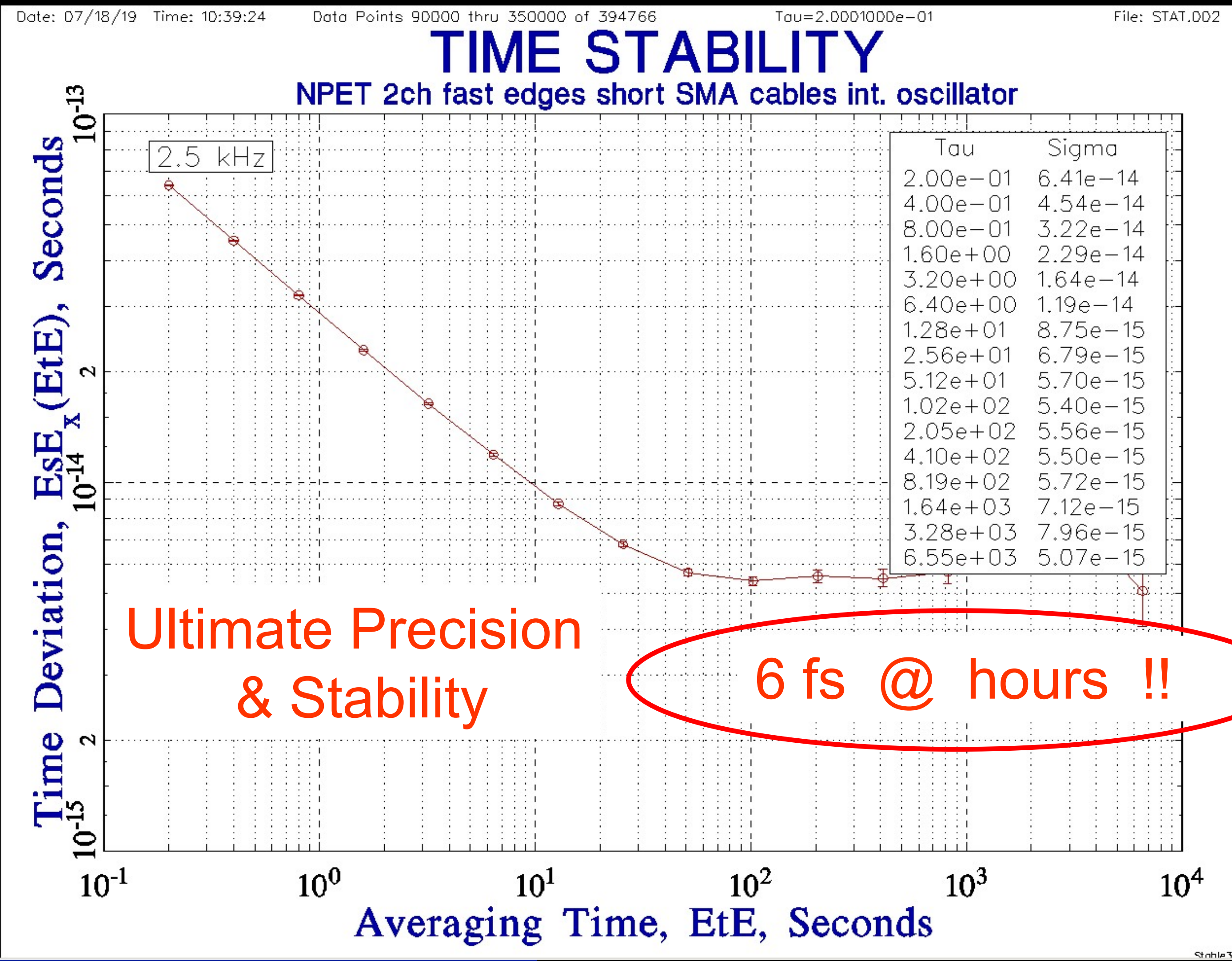
Accurate timing for SLR - Two key concepts
1 – Epoch Timing Devices



- ps resolution & (sub)-ps stability
- kHz reprates
- OR independent ET for Start & Stop
- multiple Stops possible
- no limitations on intervals
- more complex, higher costs
- Thales Dassault, NPET

- OR common ET for both
- Intervals > ~ 50 ns
- simple, lower costs
- Eventech Riga

What improvements are comming ?
ET for Laser Time Transfer ground - space



Ultimate Precision & Stability

6 fs @ hours !!

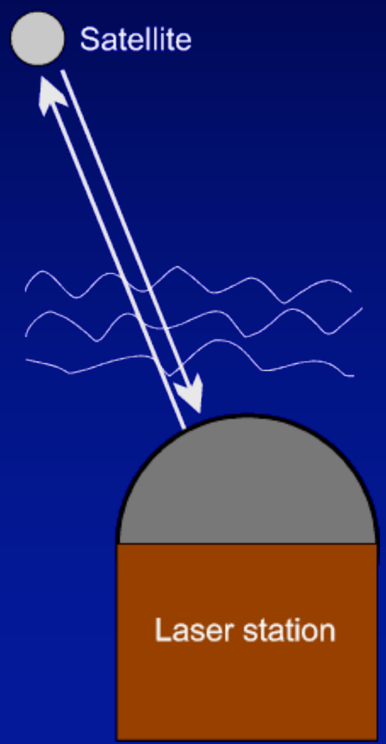
2 channel NPET

Per channel

Jitter < 700 fs

Linearity < 500 fs

Echo signal strength issue



- "What changes in procedures and processes would give the stations greater ability to detect biases ? "
- ANSWER
  "1 photon only " approach
- => missing time walk effects
- => reducing target spread problems

SLR systems performance comparison

- Based on *Quarterly Global Report Cards* published by ILRS www pages.
- Simple averages over 4Q 2016… 2Q2017 all 5 data centers
- Selected 6 SLR sites as typical and highly productive:

1	Yaragadee	multi photon
2	Changchun	single – multi photon
3	Mt.Stromlo 2	single – multi photon
4	Herstmonceux	single photon only
5	Graz	single – multi photon
6	Matera	multi photon

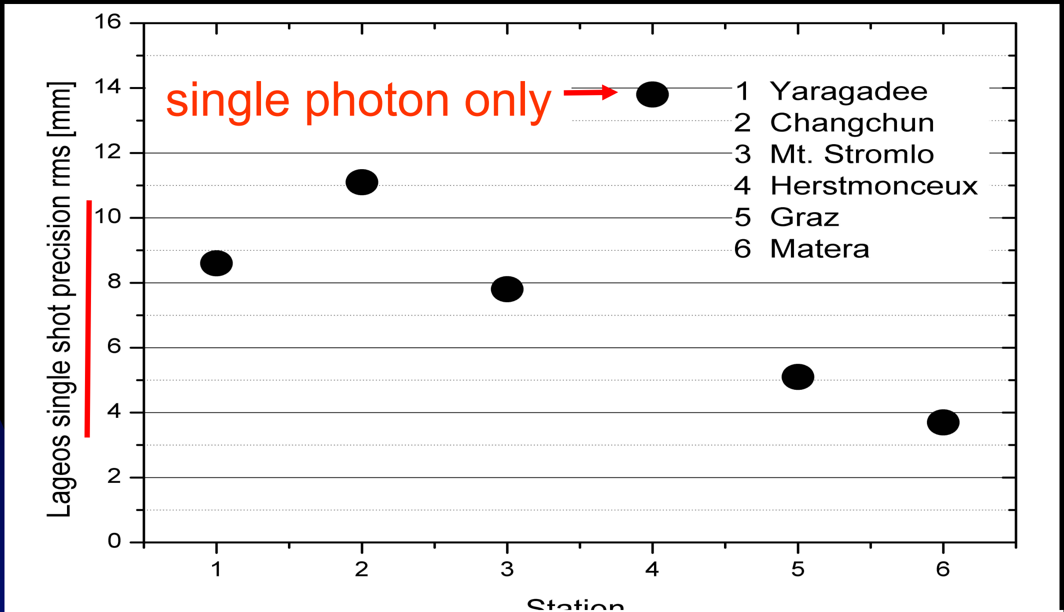
~ identical HW

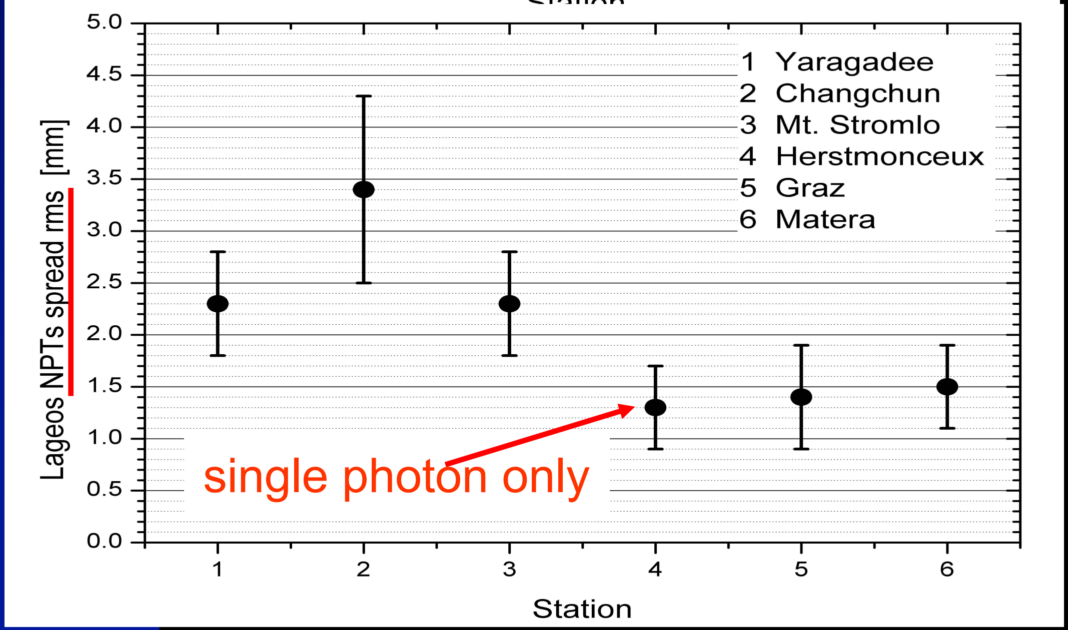
Table 2

Site Information		DGFI Orbital Analysis				Hitotsubashi Univ. Orbital Analysis				JCET Orbital Analysis				MCC Orbital Analysis				SHAO Orbital Analysis			
Station Location	Station Number	LAG NP RMS (mm)	short term (mm)	long term (mm)	% good LAG. NP	LAG NP RMS (mm)	short term (mm)	long term (mm)	% good LAG. NP	LAG NP RMS (mm)	short term (mm)	long term (mm)	% good LAG. NP	LAG NP RMS (mm)	short term (mm)	long term (mm)	% good LAG. NP	LAG NP RMS (mm)	short term (mm)	long term (mm)	% good LAG. NP
Baseline		**10.0**	**20.0**	**10.0**	**95**	**10.0**	**20.0**	**10.0**	**95**	**10.0**	**20.0**	**10.0**	**95**	**10.0**	**20.0**	**10.0**	**95**	**10.0**	**20.0**	**10.0**	**95**
Yarragadee	7090	3.3	14.9	3.0	100.0	2.0	7.1	1.5	100.0	2.2	14.0	3.0	99.3	2.2	17.2	2.9	98.8	1.9	7.8	1.5	93.7
Changchun	7237	4.5	24.1	5.2	99.9	3.1	27.5	5.4	100.0	2.1	33.3	7.3	95.9	2.9	21.0	5.4	97.3	4.5	27.2	9.1	94.7
Mount_Stromlo_2	7825	3.0	17.3	2.9	100.0	2.3	9.7	1.9	100.0	1.8	13.2	3.7	99.7	2.8	15.2	3.4	97.5	1.7	10.4	2.1	95.8
Herstmonceux	7840	1.8	10.8	2.3	100.0	1.0	6.5	1.3	100.0	1.1	10.3	2.6	100.0	1.6	10.3	1.9	99.7	0.8	6.5	2.8	97.7
Zimmerwald_532	7810	2.7	11.1	3.0	100.0	1.7	7.5	1.5	100.0	1.9	10.8	3.1	99.8	2.9	11.9	1.7	97.5	1.7	7.6		94.8
Wettzell	8834	3.0	13.1	6.5	100.0	2.3	8.9	6.2	100.0	1.8	12.2	5.9	99.6	2.5	10.5	7.4	98.3	1.6	10.9	8.2	95.0
Graz	7839	2.0	9.1	3.5	100.0	1.5	6.2	2.3	100.0	0.9	11.1	4.0	99.3	1.8	8.5	3.5	97.1	0.6	8.8	2.5	96.1

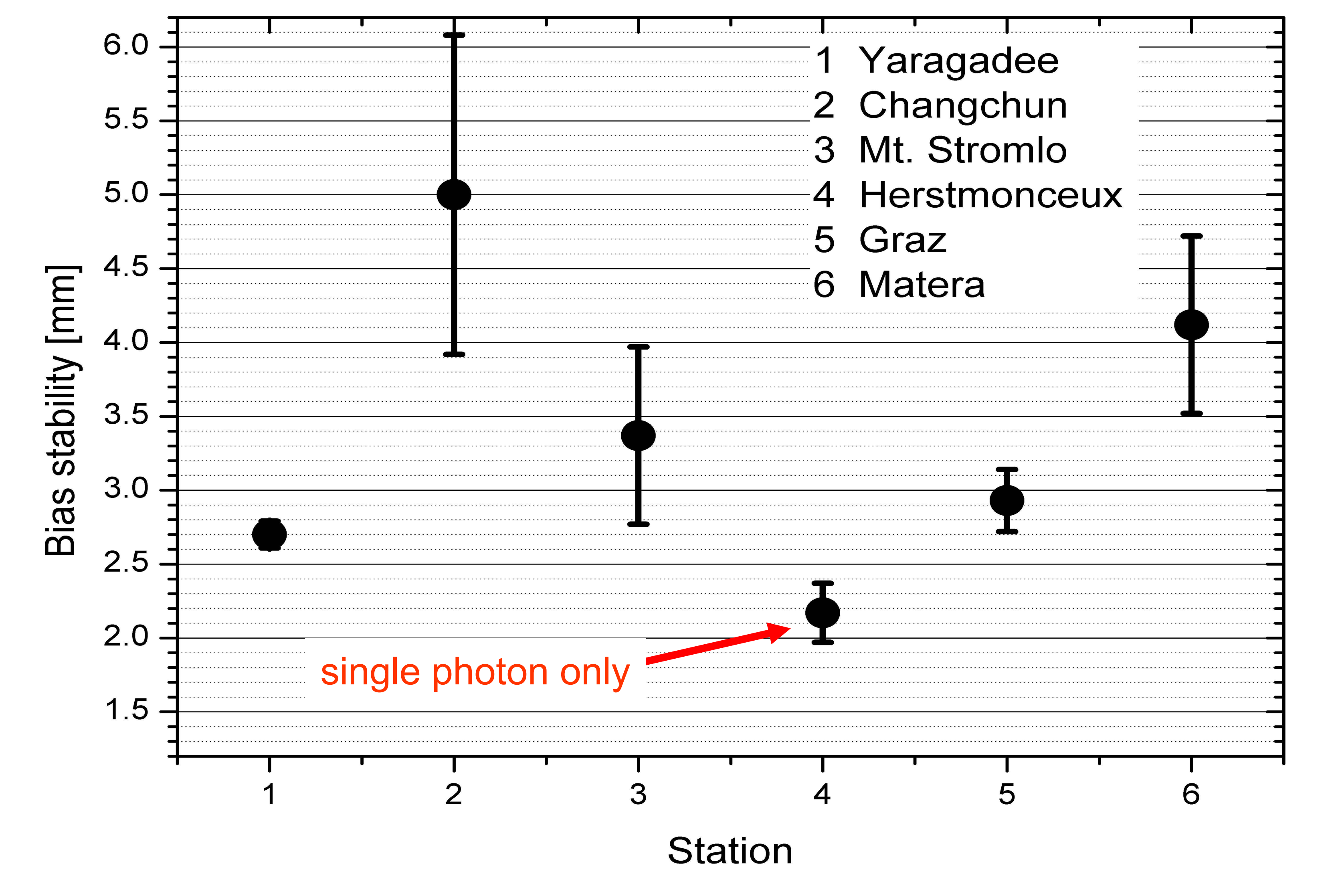
SLR systems performance comparison # 1

Lageos Precision





SLR systems performance comparison # 2
Bias long term stability



SUMMARY
General Recommendations

- Operate the SLR on 1 photon level only
- Higher system stability is a prerequisite for smaller biases
- Maintain maximum system delay stability
  (selection of components, environment, procedures..)
- Permanently try to identify new possible bias sources
  ".. Suspect everything .." Jose Rodrigues, Matera, 2015
- Repeatedly check the individual contributors
  using more accurate references

SUMMARY # 2
SLR system calibration

- Use **optically correct calibration targets**
  2D hollow retro recommended for separate T/R
- Use efficient **spatial filtering**
  small FoV suppresses spurious reflections
- Ensure **perfect alignment** of the receiver optics
  (star tracking / scanning is a good check)
- Use **multiple targets** at different az and range
  check the system delay consistency
- **Re-survey the targets** geometry regularly
  use various scales, techniques,…..
- **Keep detailed record** of all system modifications,
  report any modification to ILRS