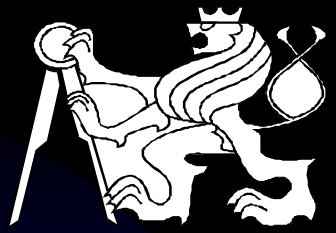


SLR Station Biases

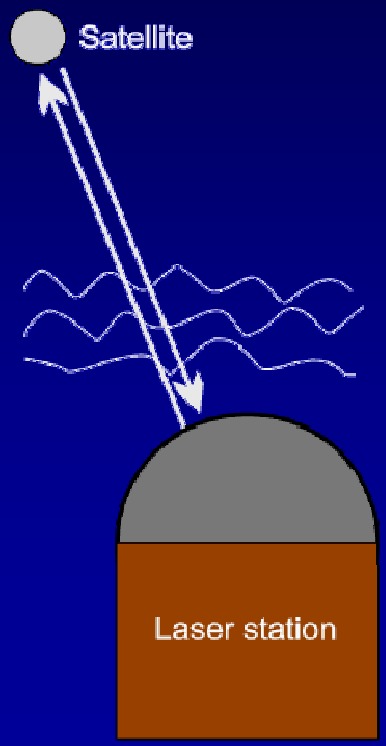
Ivan Procházka

Presented at:

2015 ILRS Technical Workshop, Matera, Italy, October 2015

Czech Technical University in Prague, Czech Republic

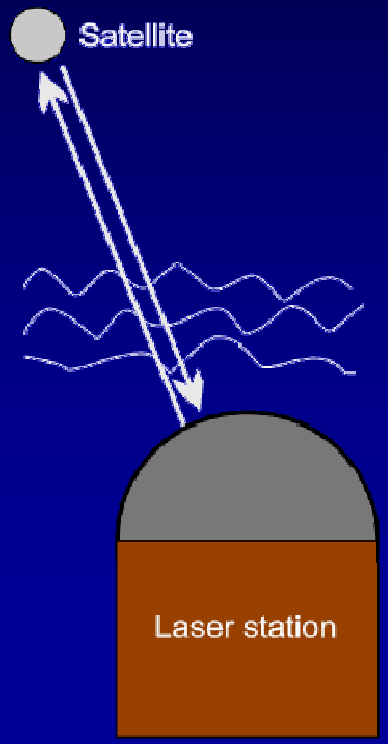
General



- SLR is a space measuring technique which provides UNIQUE feature of DIRECT range / time measurement
- Its role is inevitable in ITRF definition and calibration of numerous other techniques (GNSS….)
- GGOS requirements 1 mm & 0.1 mm / yr
- All the SLR hw chain components must be calibrated for their absolute delays with (sub) mm accuracies

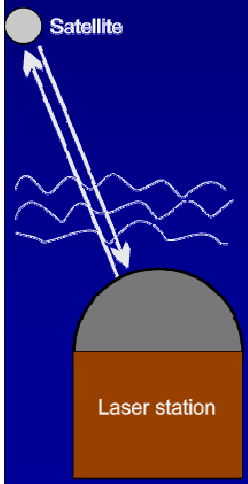
Workshop goals #1

- Which biases should be seen at the stations?
- How do we stabilize calibration?



Accuracy – Biases
"never ending story.."

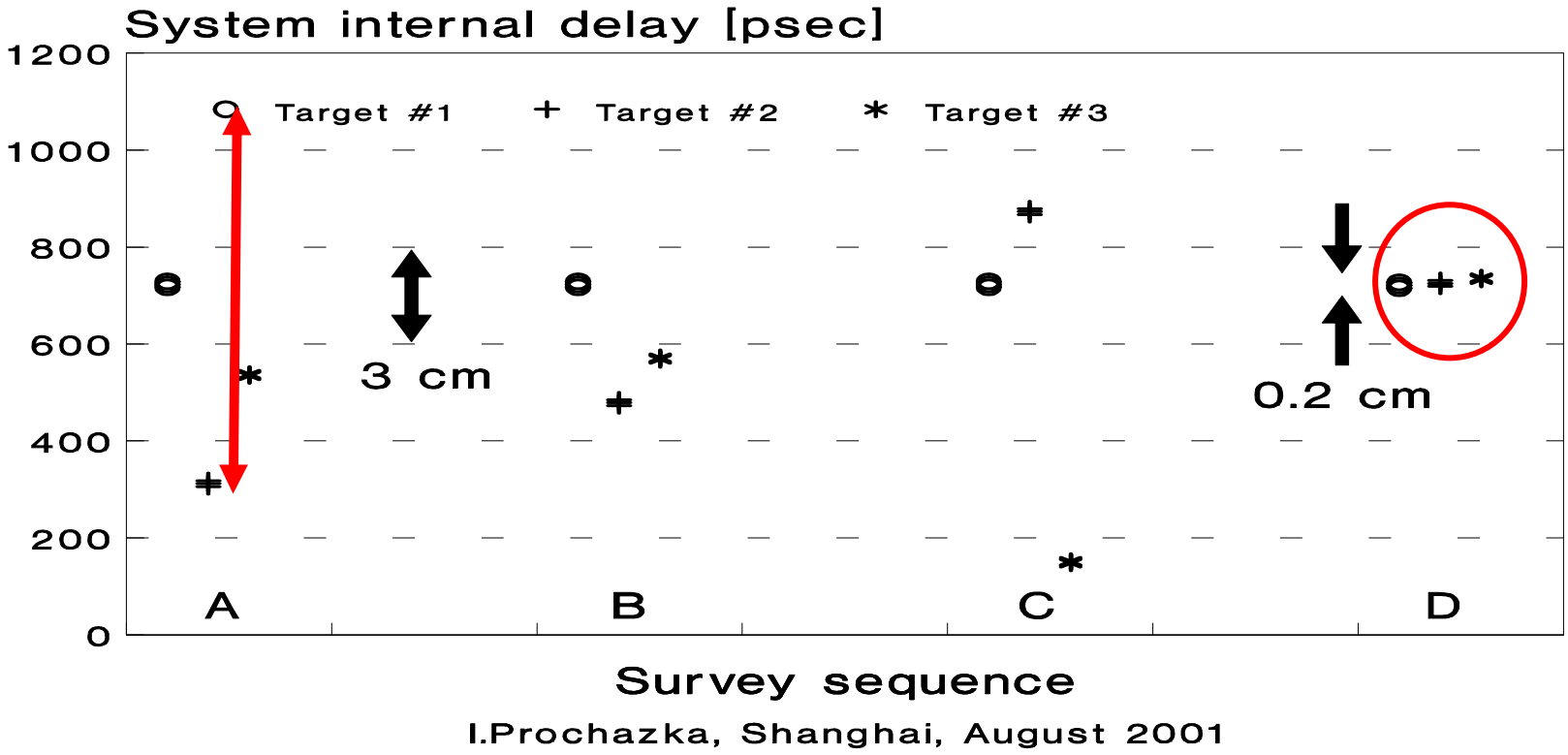
- GENERAL TECHNIQUE - Comparison to more accurate value
- HOWEVER - for SLR check such a value is not available
- SOLUTION - characterizing all (!) individual hw error budget contributors, their precision and biases
  (M. Pearlman, System characterization parameters, Herstmonceux, 1984)
- PROBLEMS
- - contributors list
- - how to calibrate each contributor ?
- - is our contributors list complete ?



“Ranging machine” error budget contrib.#1
Ground target calibration

Calibration & target setup	T/R optics configuration parallax, FoV, ….
Target distance	range accuracy, target depth, ref. point
Laser wavefront	near / far field pattern
Optical arrangement	near field, 1 Photon
RF interference	for short distances
Receiver setup	range gating, echo signal strength
Timing system linearity	

”Ranging machine” biases identification



The 3 cal. targets /hollow 2D retros/ have been re-surveyed and the calibration procedure tuned until the the system internal delay value consistency of 2 mm has been achieved.
The 2mm level was a precision limit for the system

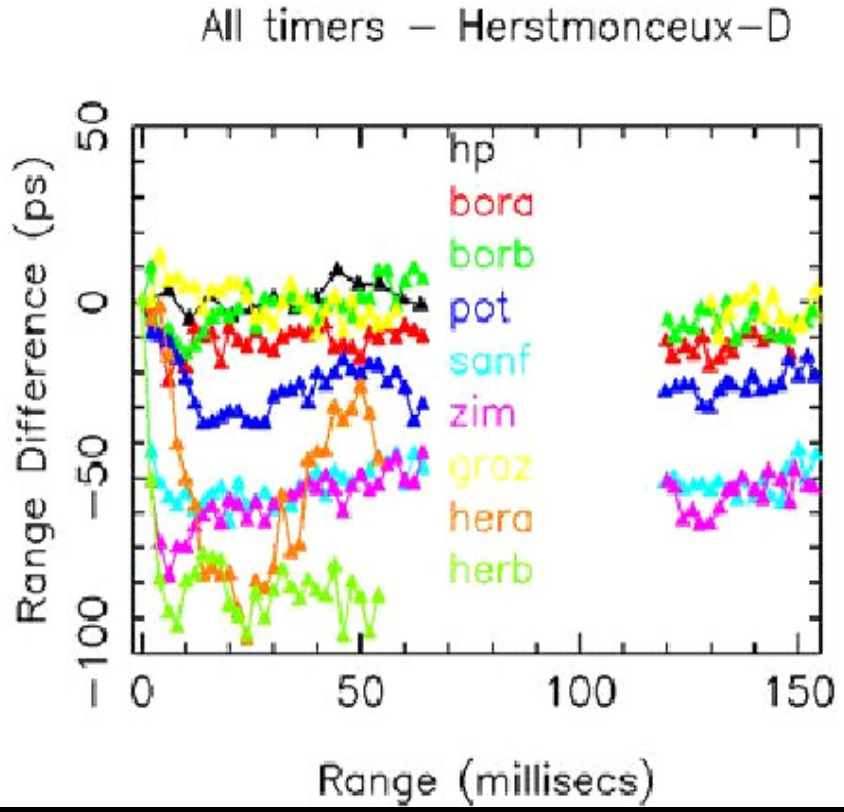
I.Prochazka, 2015 ILRS Workshop, Matera, October 2015

”Ranging machine” biases identification

RANGING COUNTERS COMPARISON TO P-PET

P. Gibs, Herstmonceux, 2002

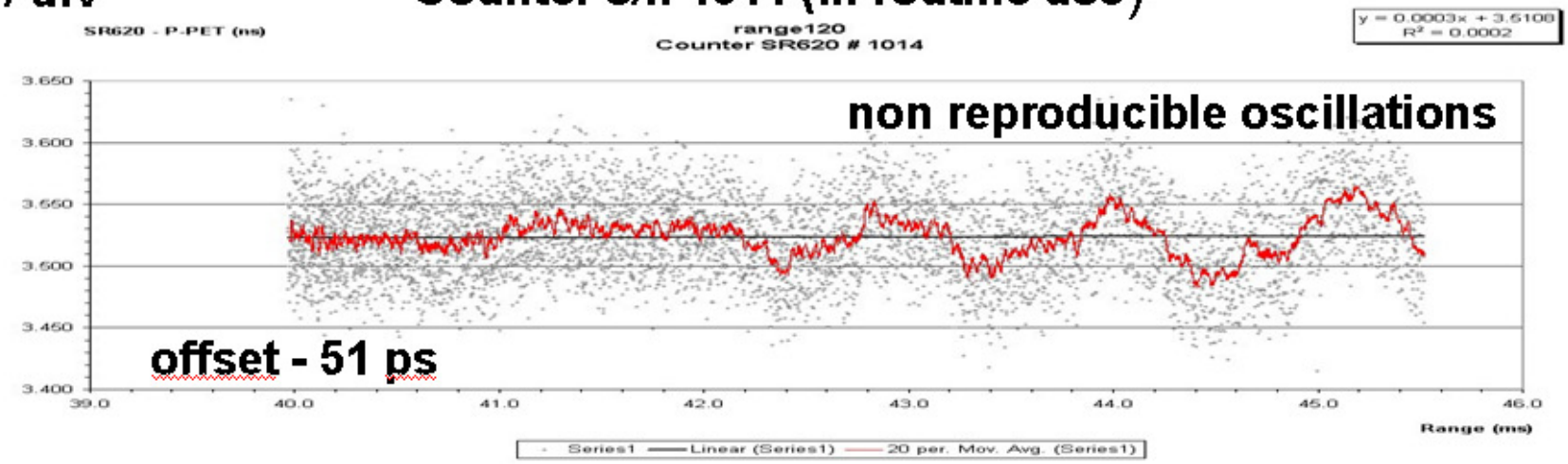
- Shown here is a summary plot of all the devices.

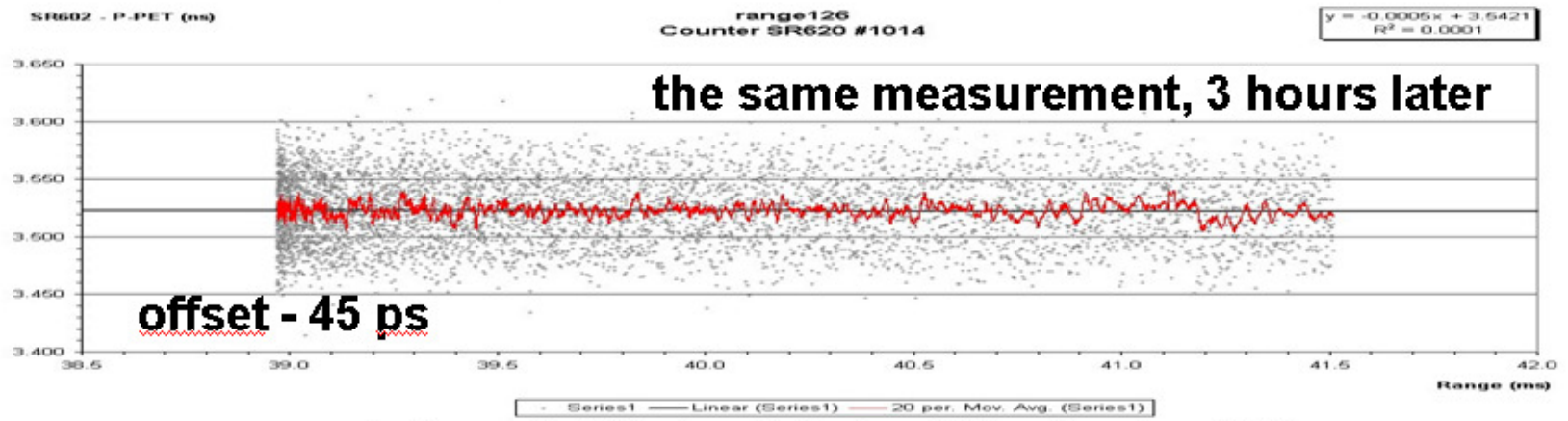


SR620 / P-PET Counter Linearity
Potsdam, 2001, LAGEOS pass

50 ps / div

Counter s/n 1014 (in routine use)





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

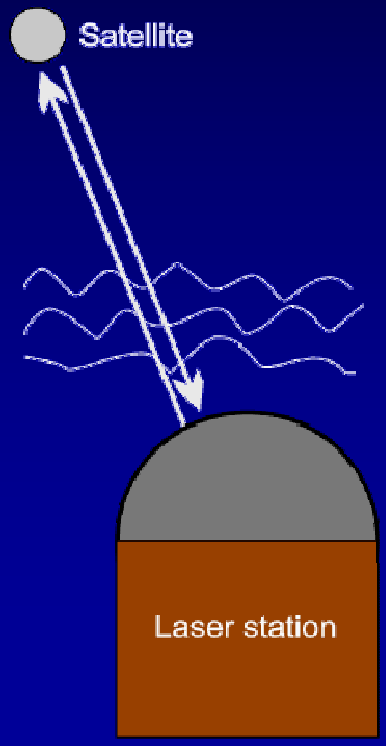
”Ranging machine” error budget contrib. #2
Local conditions and atmosphere

- Meteo sensors — calibration, stability
- “Local atmosphere” — pollution, in-homogenity,..
- Local ties — relation to coordinates

”Ranging machine” error budget contrib.#3
Epoch timing

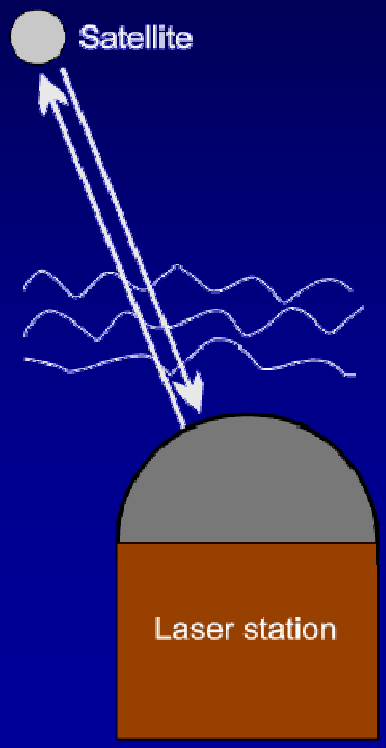
Time scale	source, distribution,..
Clock frequency	source, stability relation to “1pps”
SLR Time reference	“1pps”, trig.level, BW,..…
Epoch calibration constant	laser fire epoch versus pulse cross. invariant point

Workshop goals #2



- "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 GNSS

Workshop goals #3



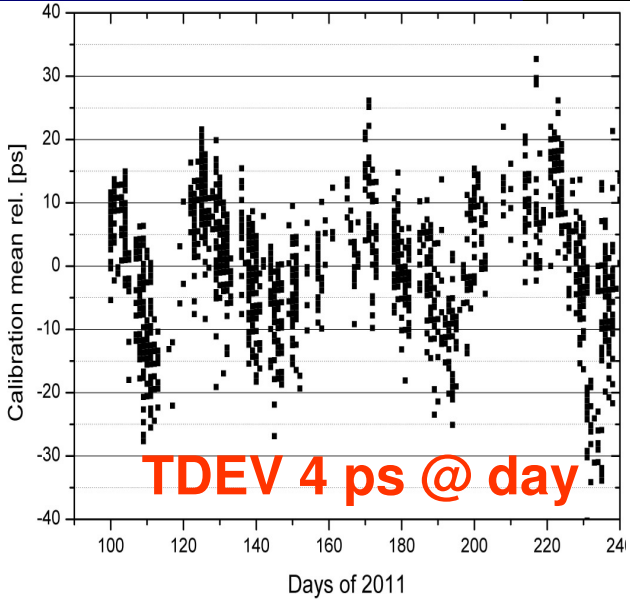
- "What station hardware, equipment, software, etc. would give the stations greater ability to detect biases ? "
- In general – greater stability is a prerequisite for smaller biases

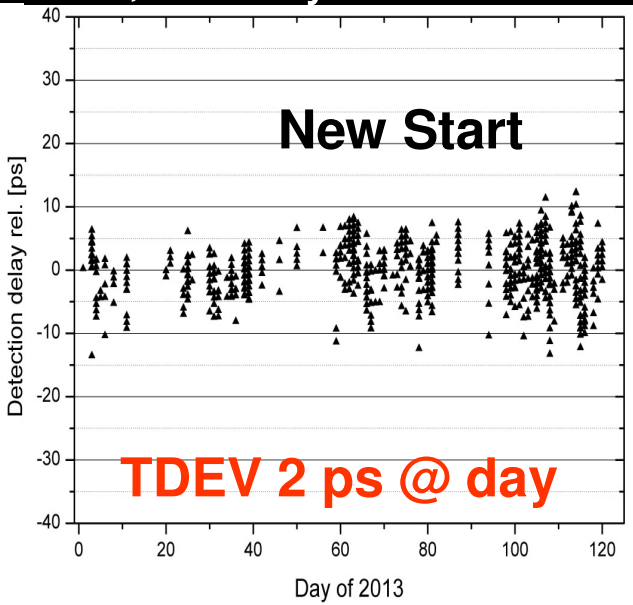
New Start detector + discriminator

- fully integrated solution
- Drift ~< 350 fs / K (!)
- Jitter < 1 ps
- output NIM fall times ~ 60 ps

J. Kodet et al, ***Rev. of Sci. Instruments****. 2012, Vol.83/3*

Graz SLR calibration mean,120 days each



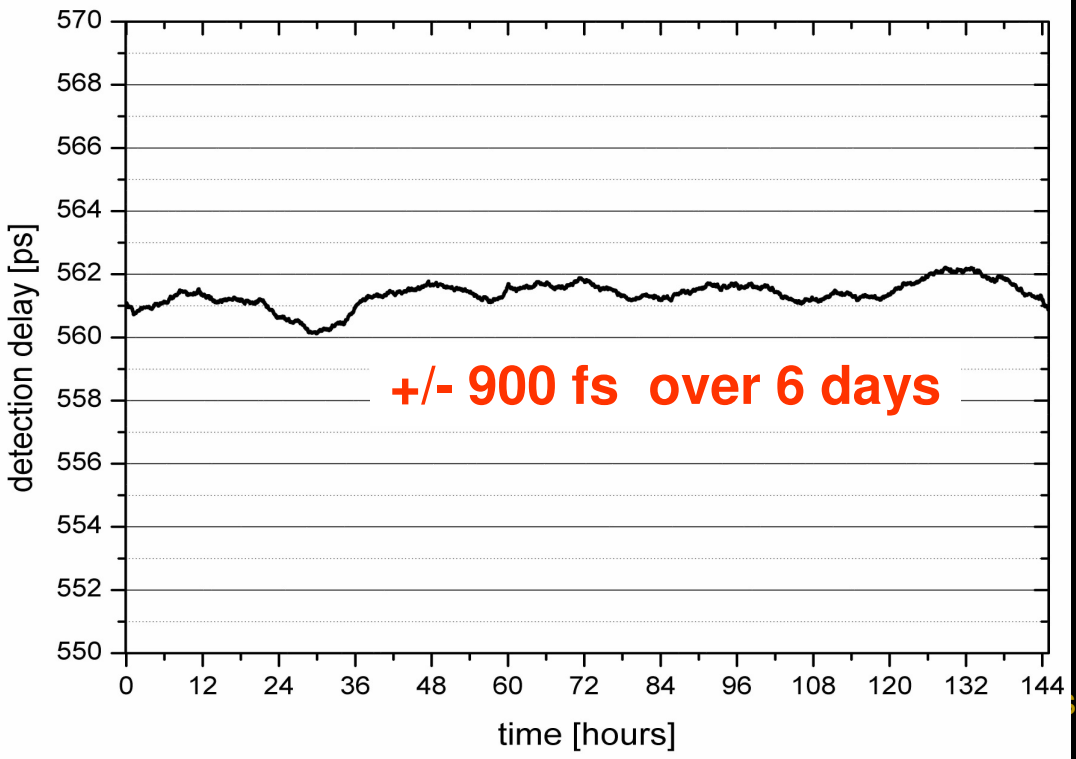


Single shot
16.5 ps =>13.2 ps

October 2015

SPAD detector package
1- photon version
Low temperature drift

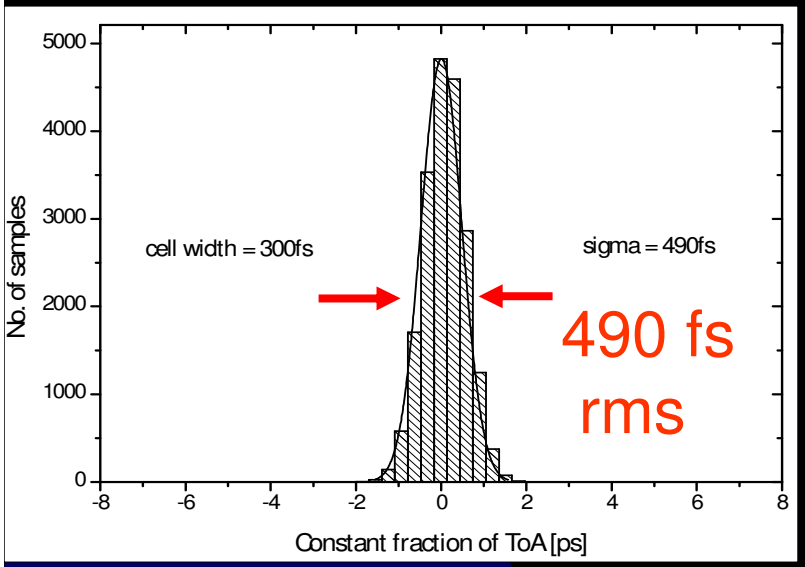
- New control electronics,
- Fully passive temperature control
- Outputs rise / fall times ~ 100 ps
- = > jitter < 15 ps
- drift **260 fs / K (!!)**



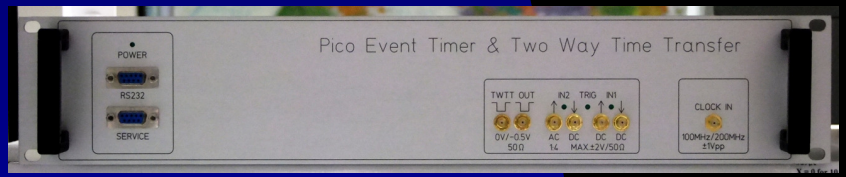
New SPAD + Start + NPET detection delay over 6 days, +/- 2 K

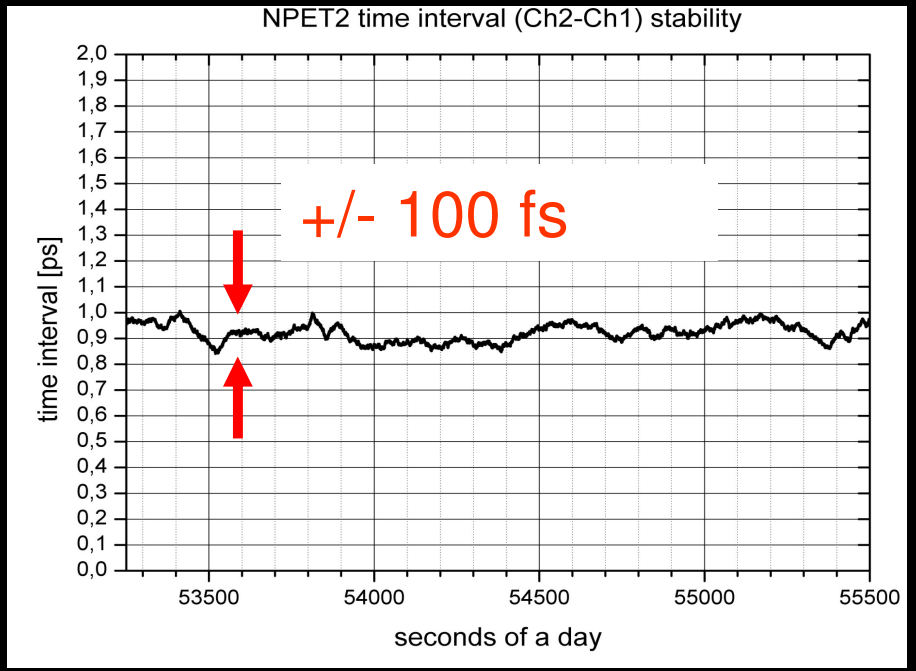
I. Prochazka et al, ***Rev. Sci. Instrum.*** *84, 046107 (2013)*

Sub-ps Timing System NPET for SLR

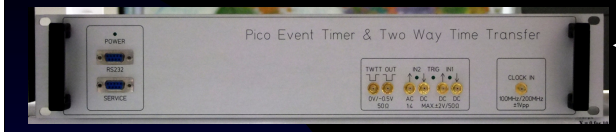


- Compact & robust & user friendly
- Jitter < 0.9 ps rms
- Non-linearity < 0.5 ps
- **Temp. epoch drift < 0.5 ps / K**
- **Time int. stab. +/- 0.1 ps /hour**

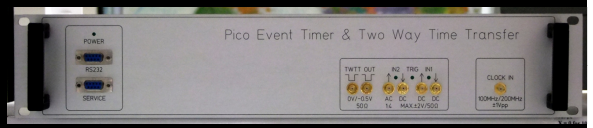




Two Way Time Transfer
via single coaxial cable



Coaxial cable, variable delay



Time scale #1

Time scale #2

External events

External events

- Comparison of two independent time scales #1 and #2
- Sub-ps precision & few ps accuracy
- Comparison in parallel to event timing in the same device
- Attractive for accurate epoch (“1pps”) reference distribution within the observatory

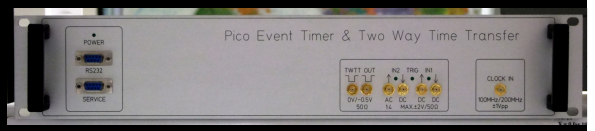
I.Prochazka et al, ***Rev.Sci. Instr****. (2012)*

Conclusion – (hw) stability

- New Start detector improves the long term SLR system stability to a (sub) ps level

- Single Photon Avalanche Detector was optimized for long term stability of detection delay

- NPET timing system was optimized for SLR provides sub-ps precision and stability



- Two way time transfer option built in NPET provides time synchronization to local time scale with few ps accuracy

Recommendations #1
General

- Operate the SLR on 1 photon level only
- Maintain maximum system delay stability
  (selection of components, environment, procedures..)
- Permanently try to identify new possible bias sources
  ".. Suspect everything .." Herstmonceux, 2015
- Repeatedly check the individual contributors
  using more accurate references

Recommendations #1
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,…..