Progress on Systematic Effects in Stanford counters used for Laser Ranging Observations

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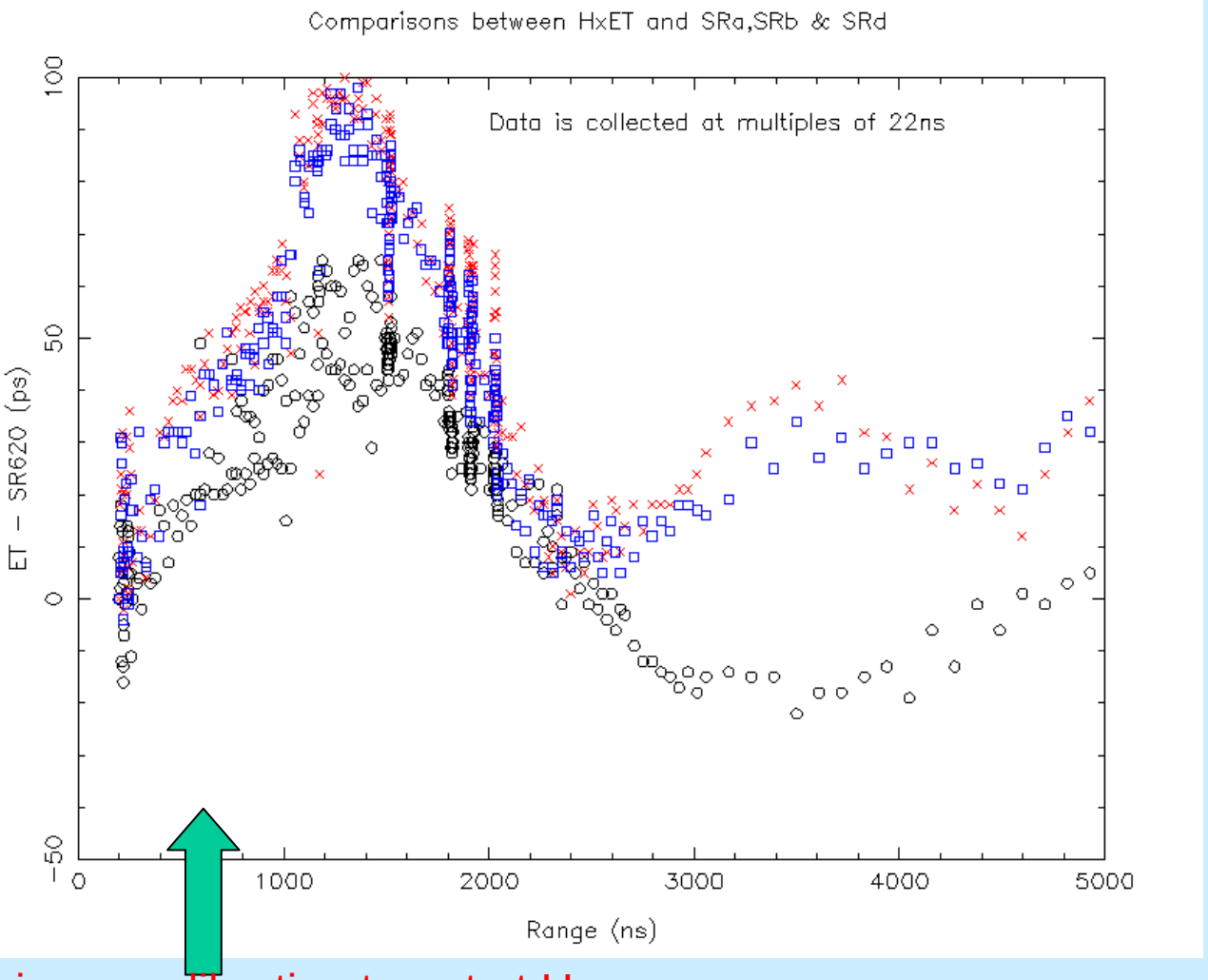
Tests on counter linearity

- Relative to a 'perfect' time-of-flight counter, what are the characteristics of the counters in common use over the last 15+ years?
- Work was started by a careful examination of *Stanford* counters in use at Herstmonceux, relative to a high-spec, ps-level event timer.
- Counters from Potsdam and Boroweic also tested at Herstmonceux.
- Studied effects at LAGEOS and at local calibration target distances.
- This work corrects results reported at Canberra with the wrong sign and adds results from additional stations' counters.

Herstmonceux counters

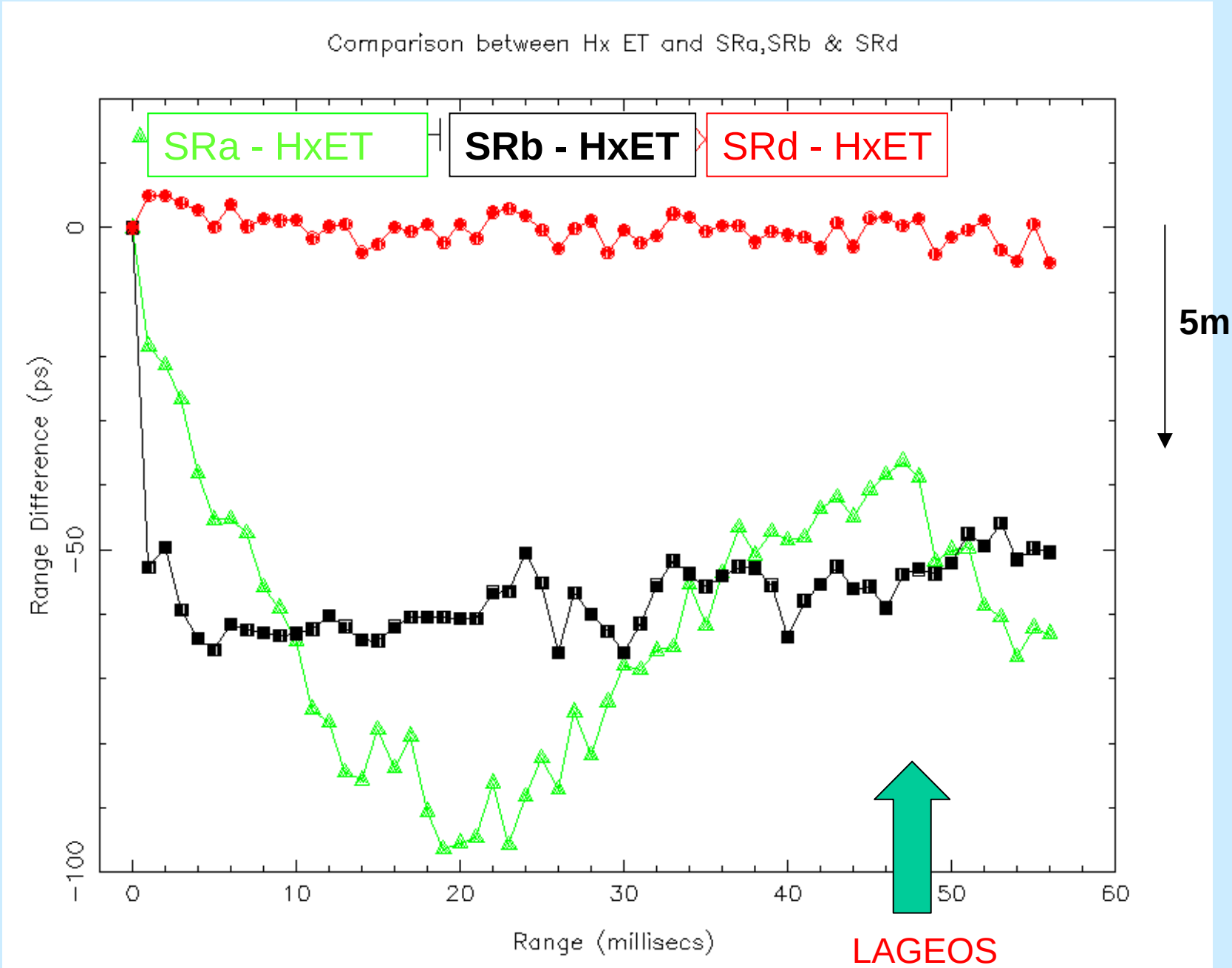
- A ps-level event timer (HET) has been built in-house from *Thales* clock units;
- A prerequisite for the upcoming kHz operations.

- Extensive use of HET to calibrate existing cluster of *Stanford* counters prior to routine use of HET;
- In particular we wish to **back-calibrate** data from 1994-present.



Primary calibration target at Hx

Comparisons between HxET and the Stanford counters for calibration boards' distances;
Behaviour very similar to spec;
Errors up to 100ps (15mm), with some systematic detailed structure


Comparison between Hx ET and SRa,SRb & SRd
SRa - HxET
SRb - HxET
SRd - HxET
Range Difference (ps)
0
−50
−100
0
10
20
30
40
50
60
Range (millisecs)
5mm
LAGEOS

Summary of effect on range measurements at Herstmonceux (1994-2007)

- The non-linearity of the Stanfords:
- imparts an average of ~-5.5±2mm error onto the observed **calibration** range;
  - The calibrations are too short;
  - Hence calibrated satellite ranges are **too long by 5.5mm**.
- Value is dependent on the target range, electronic delays and on the particular Stanford;
  - Hence the inherent 2mm uncertainty in this correction

Summary of effect on range measurements at Herstmonceux (1994-2002)

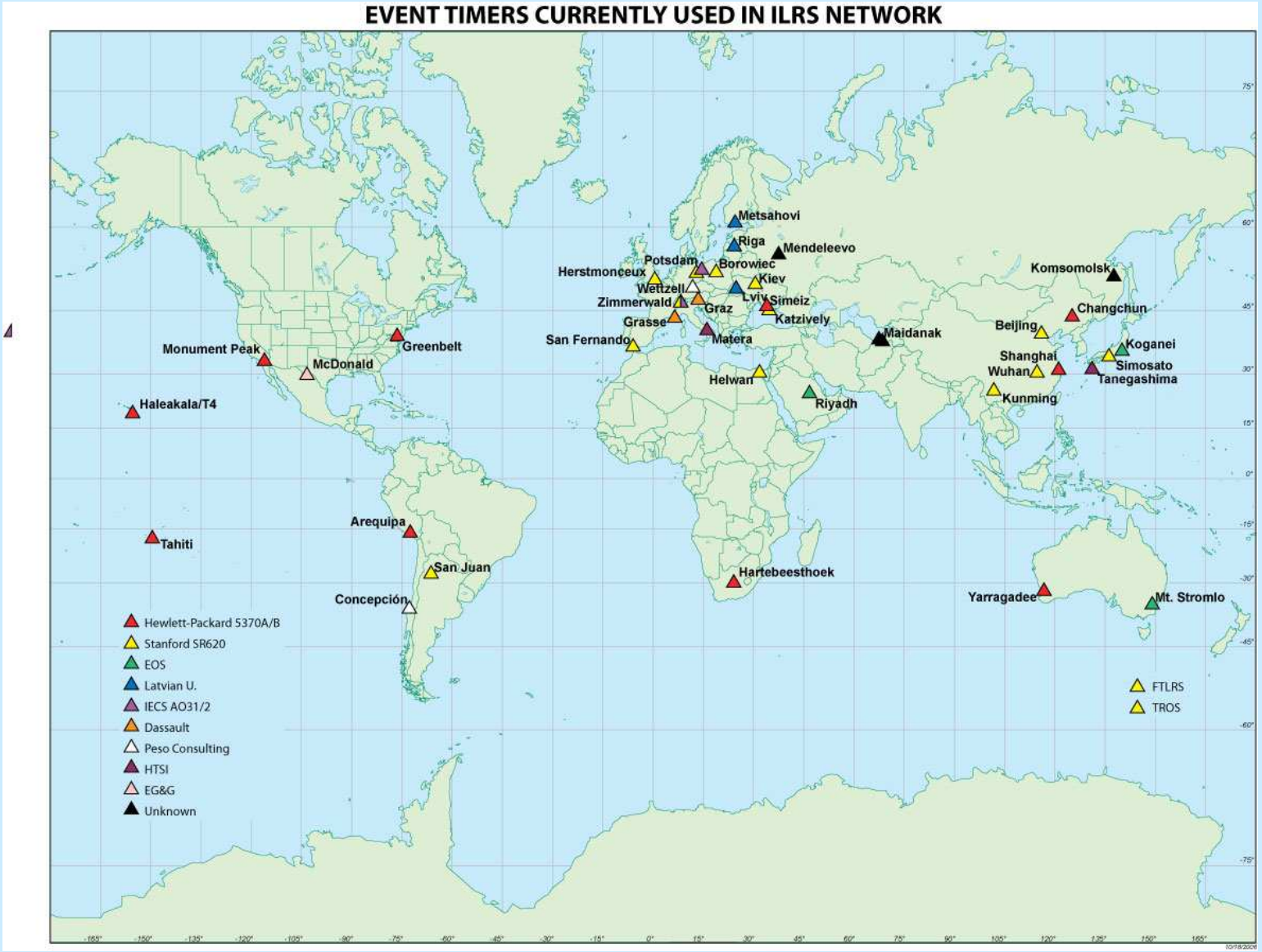
- At distance of **LAGEOS**, range error is ~-8±2mm;
  - observed raw LAGEOS ranges are too short
- **So total range error is:**
  - + 5.5 - 8.0 = - 2.5 ±3mm
  - i.e. need to **add** 2.5mm to LAGEOS ranges
- **This correction applies to the period 1994 October 1 to 2002 January 31**

Summary of effect on range measurements at Herstmonceux (2002-2007)

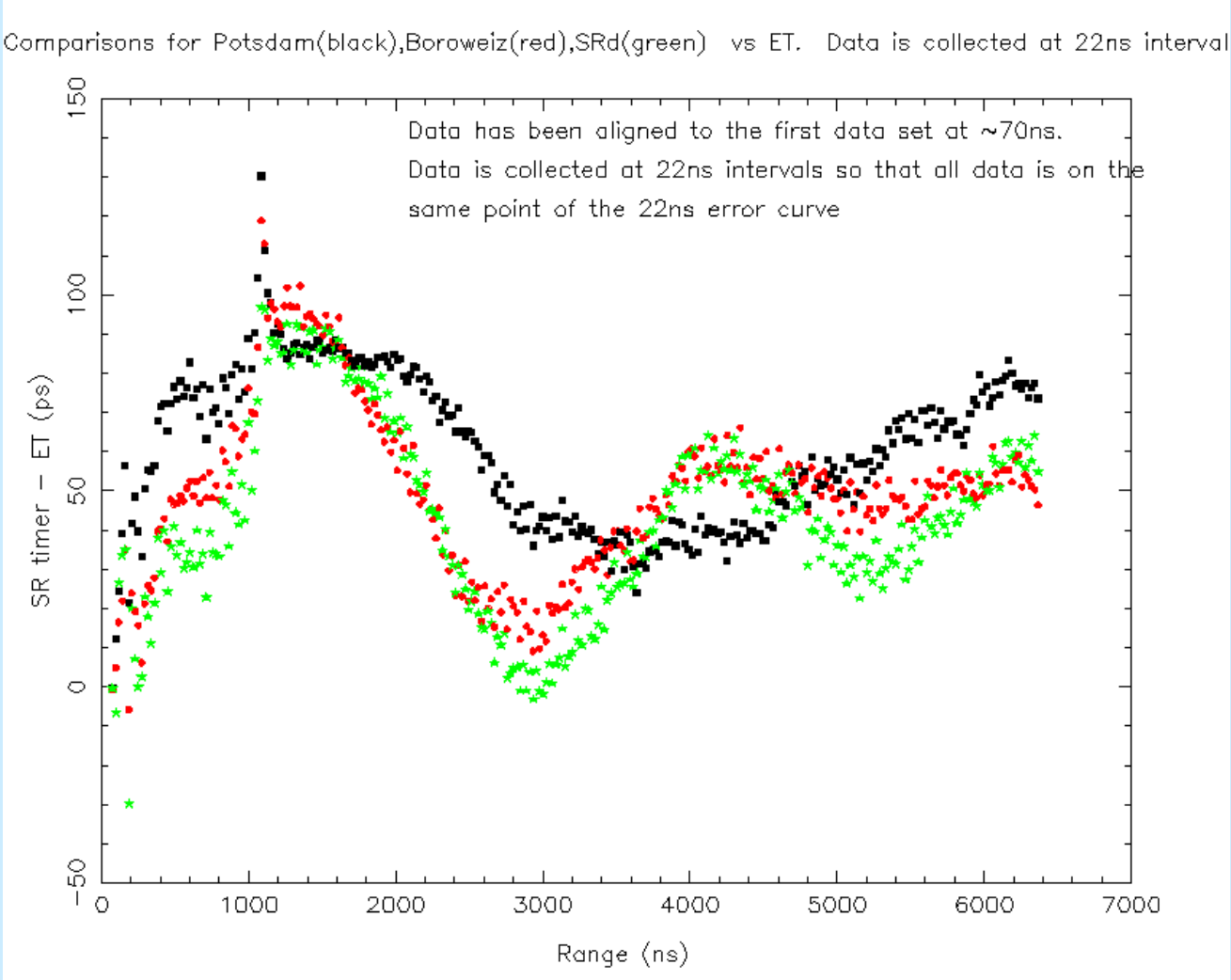
- From 2002 February 1 the satellite-range-dependent correction has been applied on-site
- The calibration error has **not been applied**
- So for the period 2002 February 1- 2007 February 10:
  - Subtract 5.5mm from **all satellite ranges** from Herstmonceux

- **From 2007 February 11, range error for all satellites is ~zero, using new event timer**

Effect present in other ILRS stations?



Tests at Hx with Potsdam (7836) and Borowiec counters – at calibration ranges



Tests at Hx with Potsdam (7836) and Borowiec counters – at calibration and LAGEOS ranges

- We find similar behaviour at 'calibration' ranges between the two counters and when compared with Stanford manual and with Hx counters;
- For Potsdam 7836 for 1992 May onwards, **add** 3mm to LAGEOS ranges;
- For Potsdam 7841, estimate that between 2001 July and 2004 February **add 5mm** to LAGEOS ranges (counter no longer available to test);
- For Borowiec for 2002 May onwards **subtract 9mm** from LAGEOS ranges.

Summary

Station	Dates	Range Correction (mm)
7840 HERL	1994/10/01 – 2002/01/31	+2.5
7840 HERL	2002/02/01- 2007/02/10	-5.5
7836 POTS	1992/05/01 ->	+3.0
7841 POTS	2001/07/01 – 2004/02/28	+5
7811 BORL	2002/05/01 ->	-9

Effect present in other ILRS stations?

- At this stage, we confine our investigation to Stanford counters;
  - Our limited experience with *e.g.* HP timers suggests they do not have problem – used by NASA network
- We have made 'worst case' **estimates** of calibration error and total range error at LAGEOS for all 'Stanford stations':
- We take target range from Log files and calibration values from ILRS NP headers;
- Thus estimate *tof* for calibration ranging, hence Stanford error.
- Use worst-case estimate at LAGEOS range.

- Error span is -9 to +11mm, frequent error +10mm
- Uncertainty in these **estimates** could be up to ~5mm

Worse-case error estimates (mm)

Station		ID	Calibration error	LAGEOS error	Total error
BEIL	Beijing	7249	-12	+10	- 2
BORL	Borowiec	7811	- 9	+ 0 meas	- 9
BREF	Brest	7604	-10	+10	0
GLSV	Kiev	1824	- 6	+10	+ 4
HELW	Helwan	7831	0	+10	+10
KTZL	Katzively, Ukraine	1893	0	+10	+10
KUNL	Kunming, China	7820	- 9	+10	+ 1
POT3	Potsdam	7841	0	+ 5	+ 5
POTL	Potsdam	7836	0	+ 3 meas	+ 3
SFEL	San Fernando	7824	0	+ 8 meas	+ 8
SISL	Simosato, Japan	7838	+1	+10	+11
SJUL	San Juan	7406	0	+10	+10
WUHL	Wuhan	7231	0	+10	+10
ZIML	Zimmerwald	7810	-3	+ 8 appl	- 3
Closed sites					
GRSL	Grasse	7835	- 1	10	11

meas = measured on particular Stanford counters; **appl** = applied at station

Comments

- We emphasise the preliminary nature of this table;
  - The plots of the 3 Herstmonceux Stanford counters show large inter-counter differences;
- Calibration of each stations' counter(s) is valuable but not absolute – still uncertainty in 'zero point'.
- Interested to get other examples;
- Particularly important to look at San Juan, San Fernando

Summary/outlook

- We also note that:
- The stations are a subset of the full ILRS network, but do contain some core sites;
- Counter characteristics remain static over time;
- Several of the stations have already upgraded to higher-quality counters.