Engineering-assessed SLR Range biases

Graham Appleby

Space Geodesy Facility, Herstmonceux, UK

Acknowledgements:
ILRS Signal Processing WG (T Otsubo)
P Gibbs, M Wilkinson (SGF), D Arnold

NATURAL ENVIRONMENT RESEARCH COUNCIL

Unified Analysis Workshop Monterey, 5th Dec 2007

International Laser Ranging Service

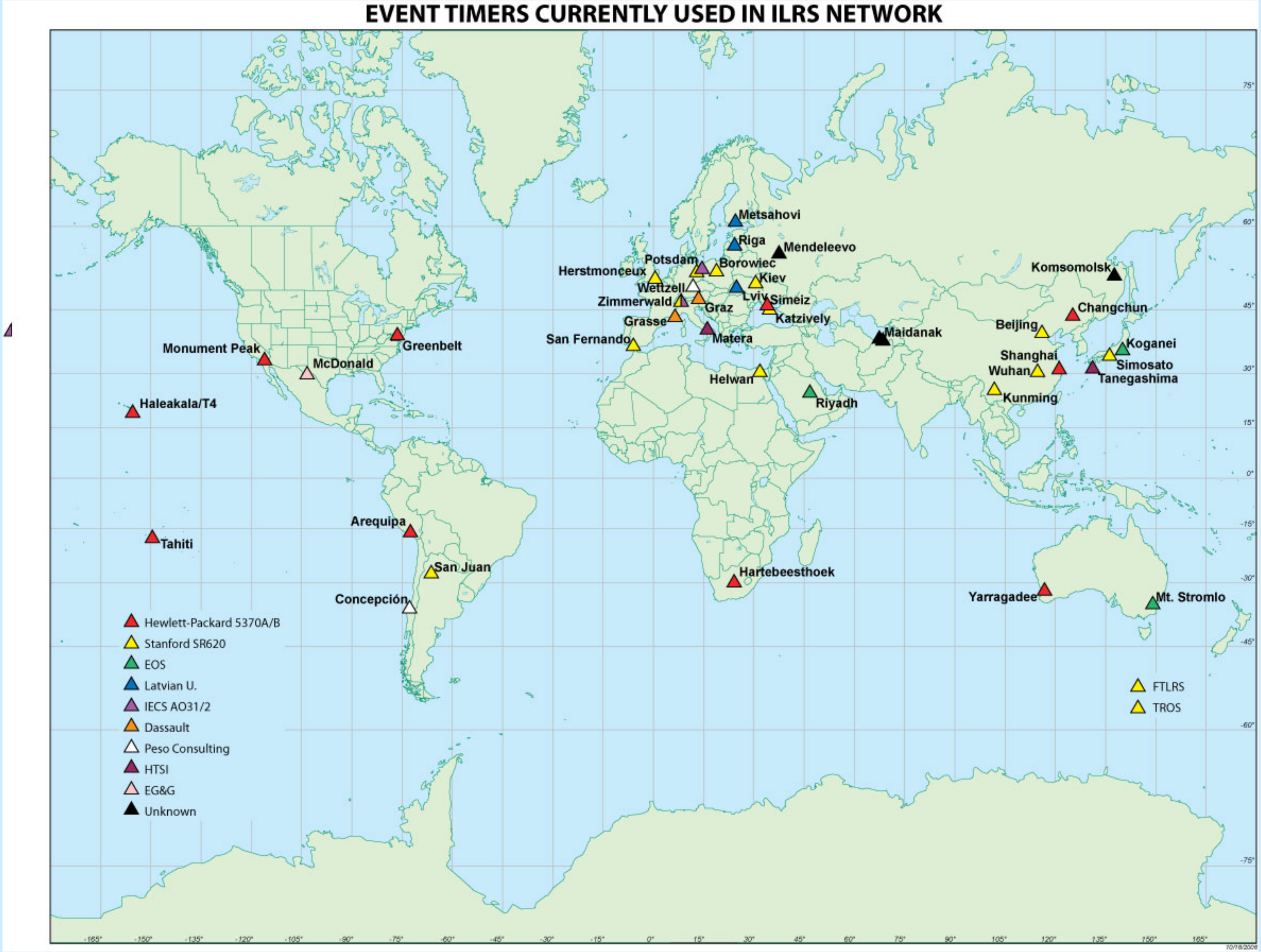
Outline

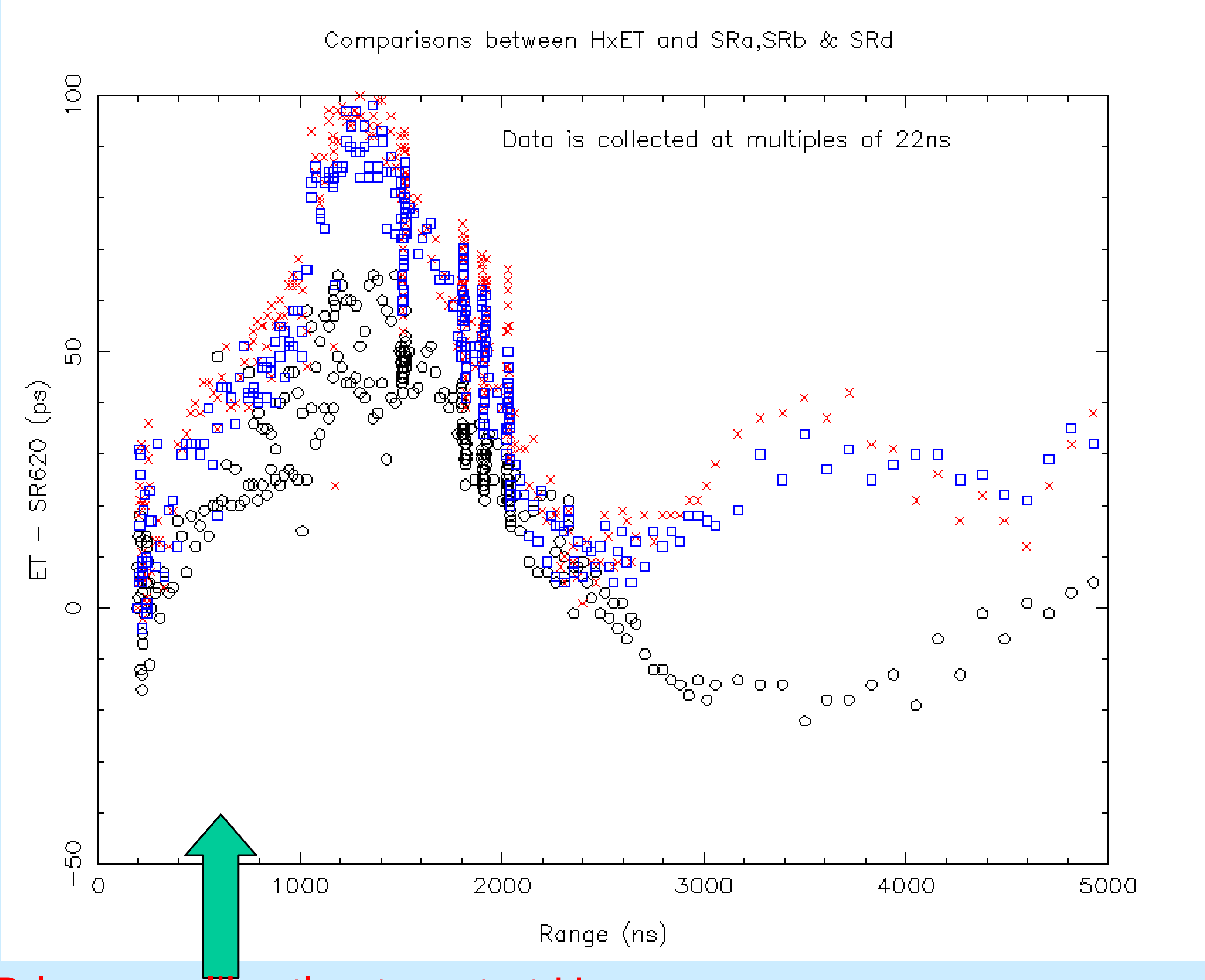
- Laser ranging has a well-known potential for mm-level accuracy which is independent of distance – LEO to Lunar and beyond;
- In the last few years, two issues have emerged that might have threatened this strength for ITRF work:
  - Non-linearity effects in (some) time-of-flight counters;
  - Lack of models for accurate centre of mass corrections for LAGEOS (and ETALON)
- We discuss status of both these issues

Tests on (Stanford) 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 has been carried out on *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.

Counters in use in ILRS stations

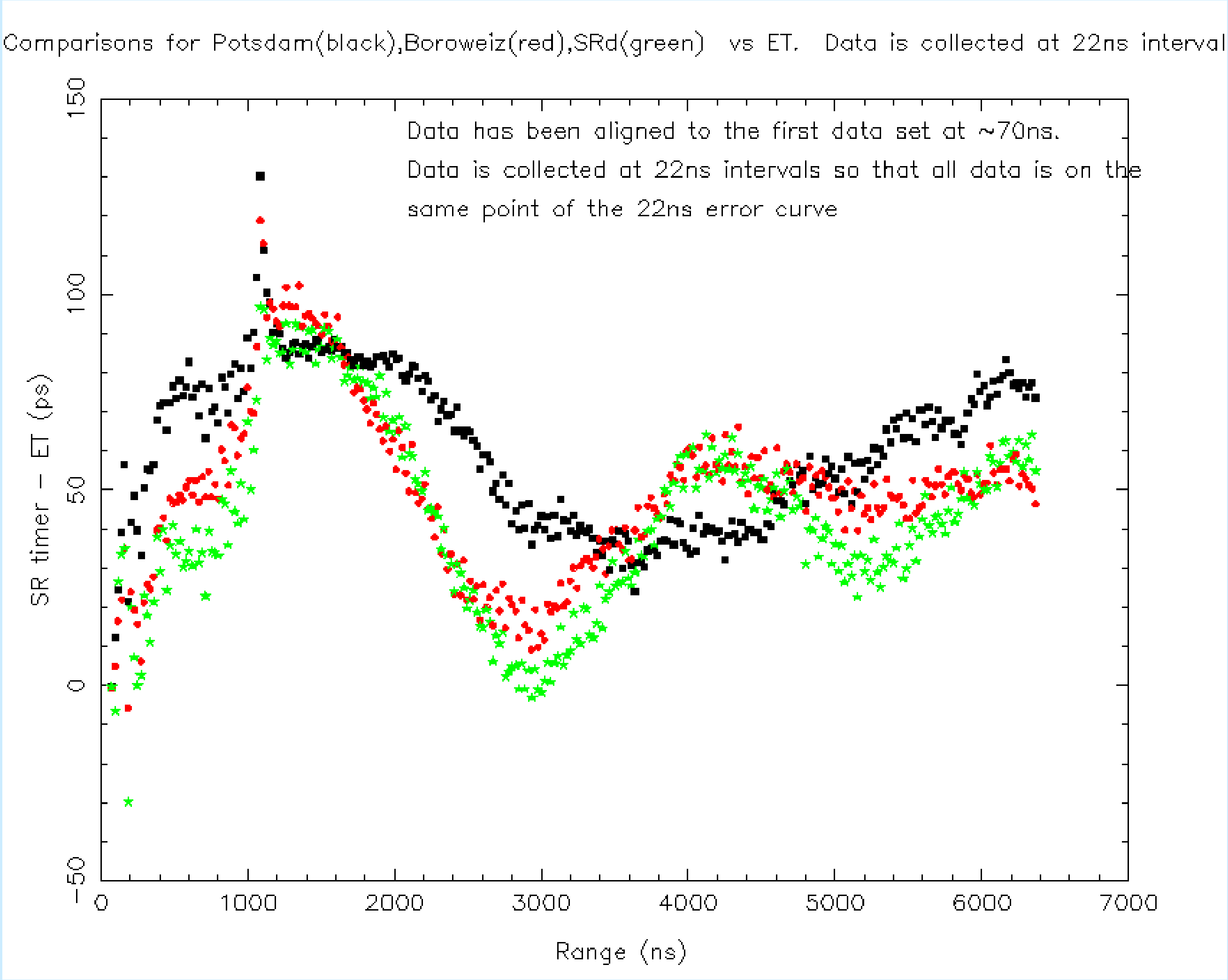


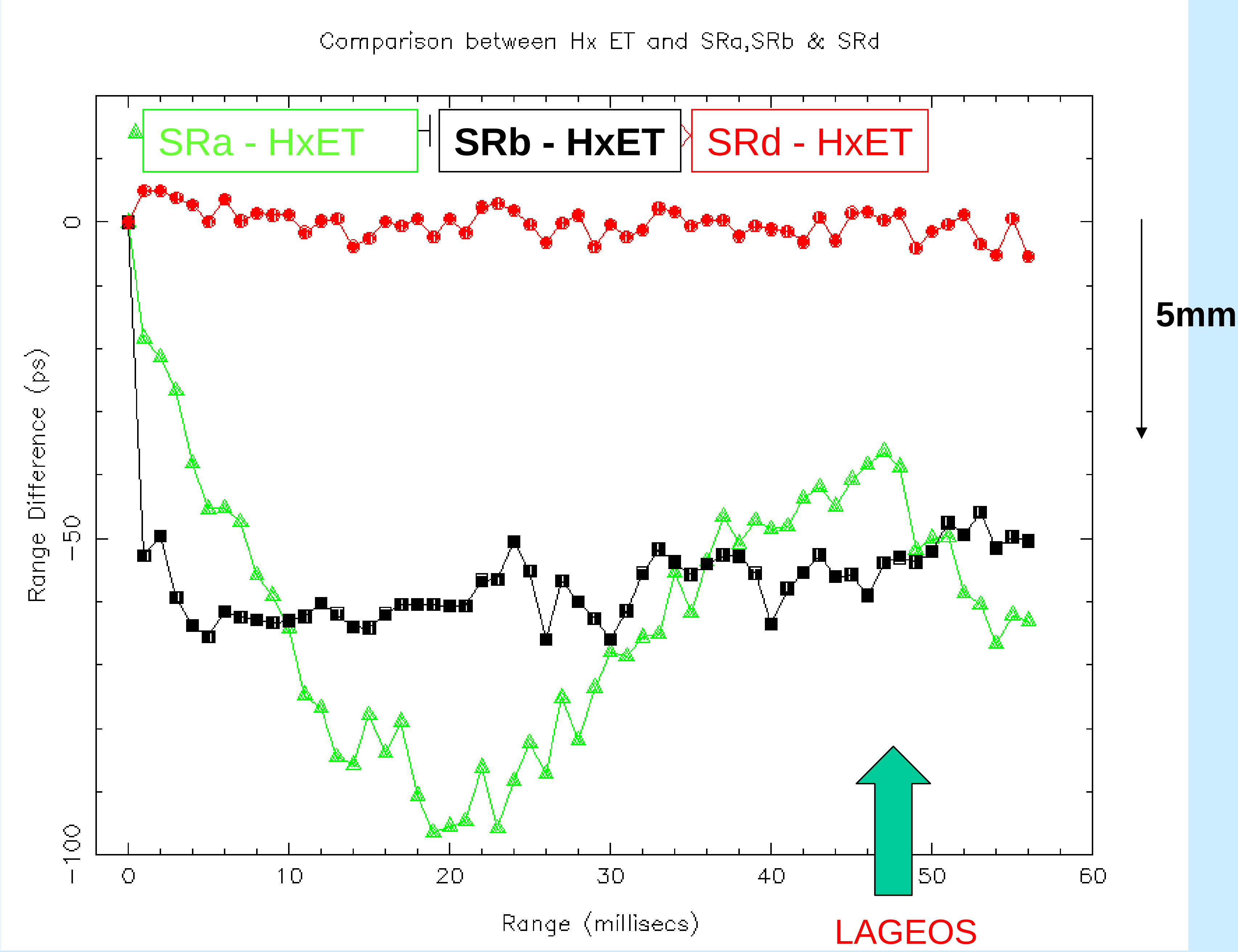


Primary calibration target at Hx

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

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





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

Example: 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 <u>**calibration**</u> 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

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

- At distance of <u>LAGEOS</u>, 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 <u>LAGEOS</u> ranges

- **This correction applies to the period 1994 October 1 to 2002 January 31**

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

Estimates for other stations

- Stanford counters;

- Using the methodology outlined above;
- We have made ‘worst case’ **estimates** of calibration error and total range error at LAGEOS for all ‘Stanford stations’:

- 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 **estimated** nature of this table;

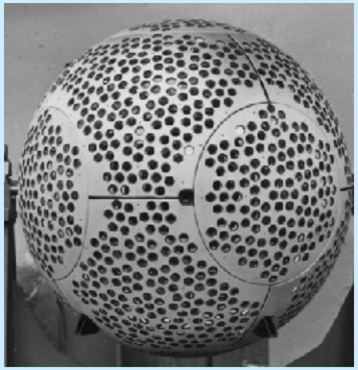
  e.g. the 3 Herstmonceux Stanford counters show large inter-counter differences;

- Difficult to test other counters;
  - Either no longer available or still vital to operations
  - Unlikely to make significant further progress
- Several of the stations have already **upgraded** to higher-quality counters.

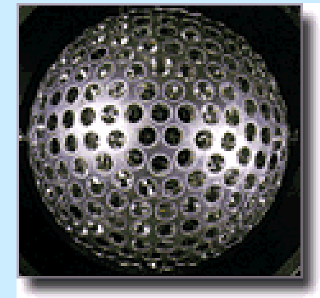
Summary/outlook

- We also note that:
- The stations are a subset of the full ILRS network, but do contain some core sites;
- It is also estimated (Zhong, 1998) that the **HP** counters in common use have non-linearity effects at ~3mm level
  - Needs further investigation

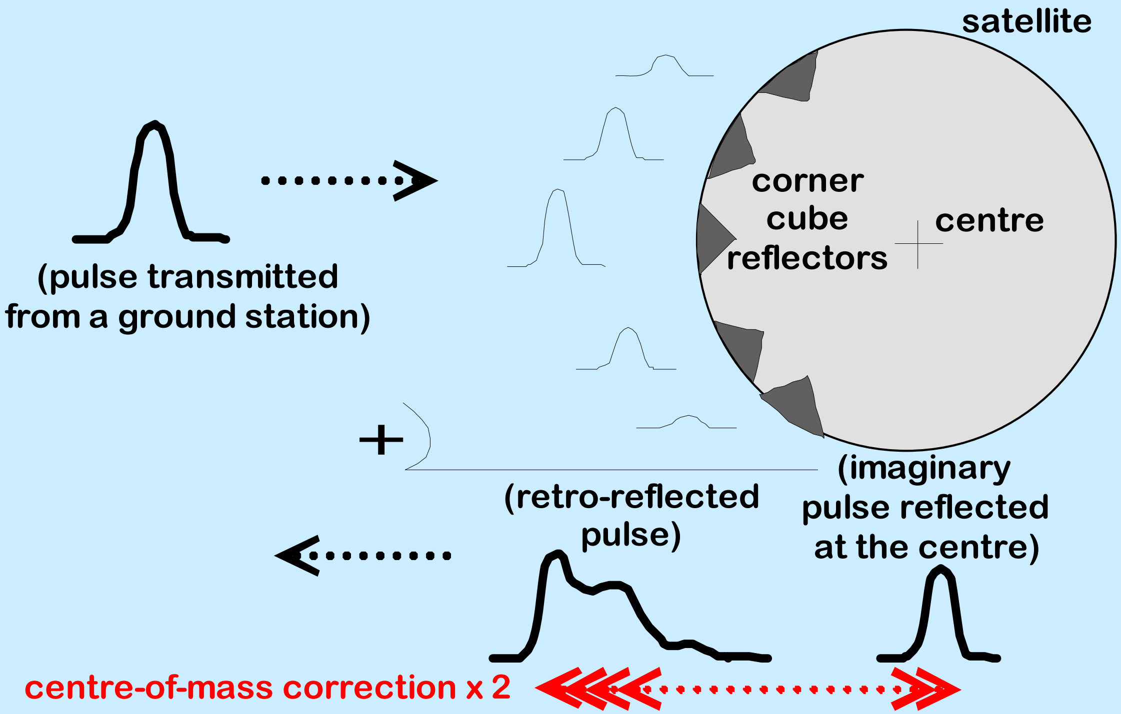
Centre of Mass corrections: Satellite 'signature' contribution



ETALON



LAGEOS



On average, over many shots, returning pulse-shape can be modelled as a convolution of laser pulse-shape with the satellite response function.

Magnitude of effect

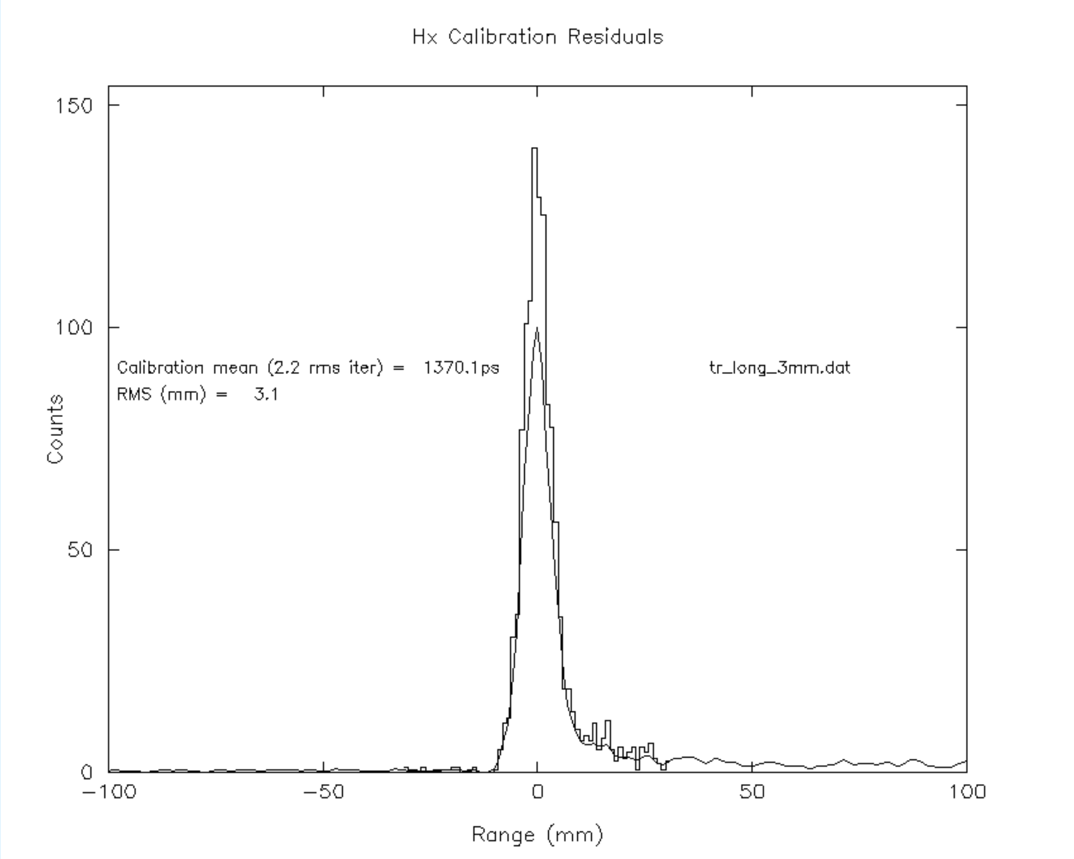
- Depending upon the stations' technology:

  - there is a range of appropriate CoM values;
  - for LAGEOS the total range is ~6mm (Minott *et al*, 1993, Otsubo & Appleby, 2003)

- Station technology:
  - multi-photon returns:
    - photomultiplier or first-photon detection
  - single photon return

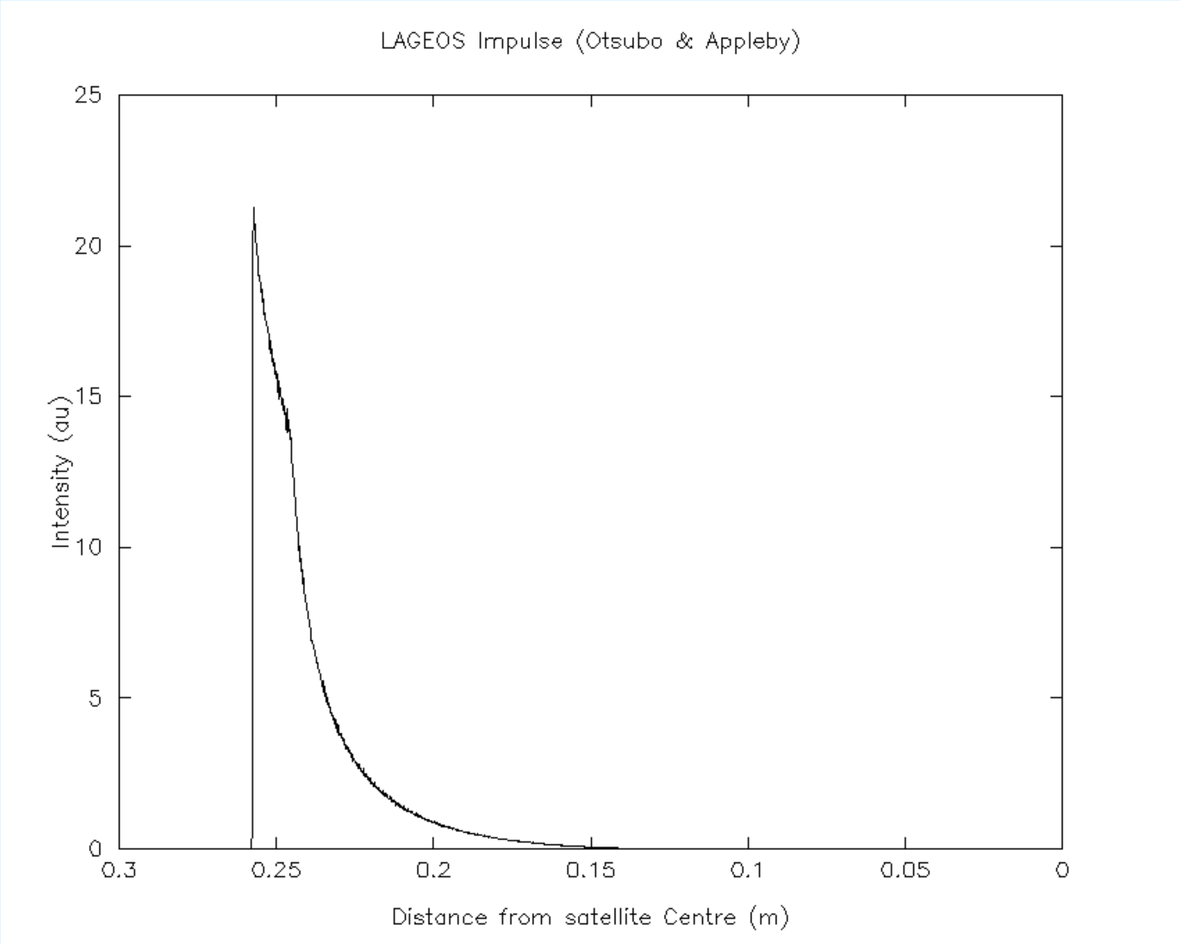
- Development of a model, illustrated using a low return-energy system (single photons):

At **single-photon**, expect distribution of range residuals to be convolution of whole-system response with LAGEOS impulse

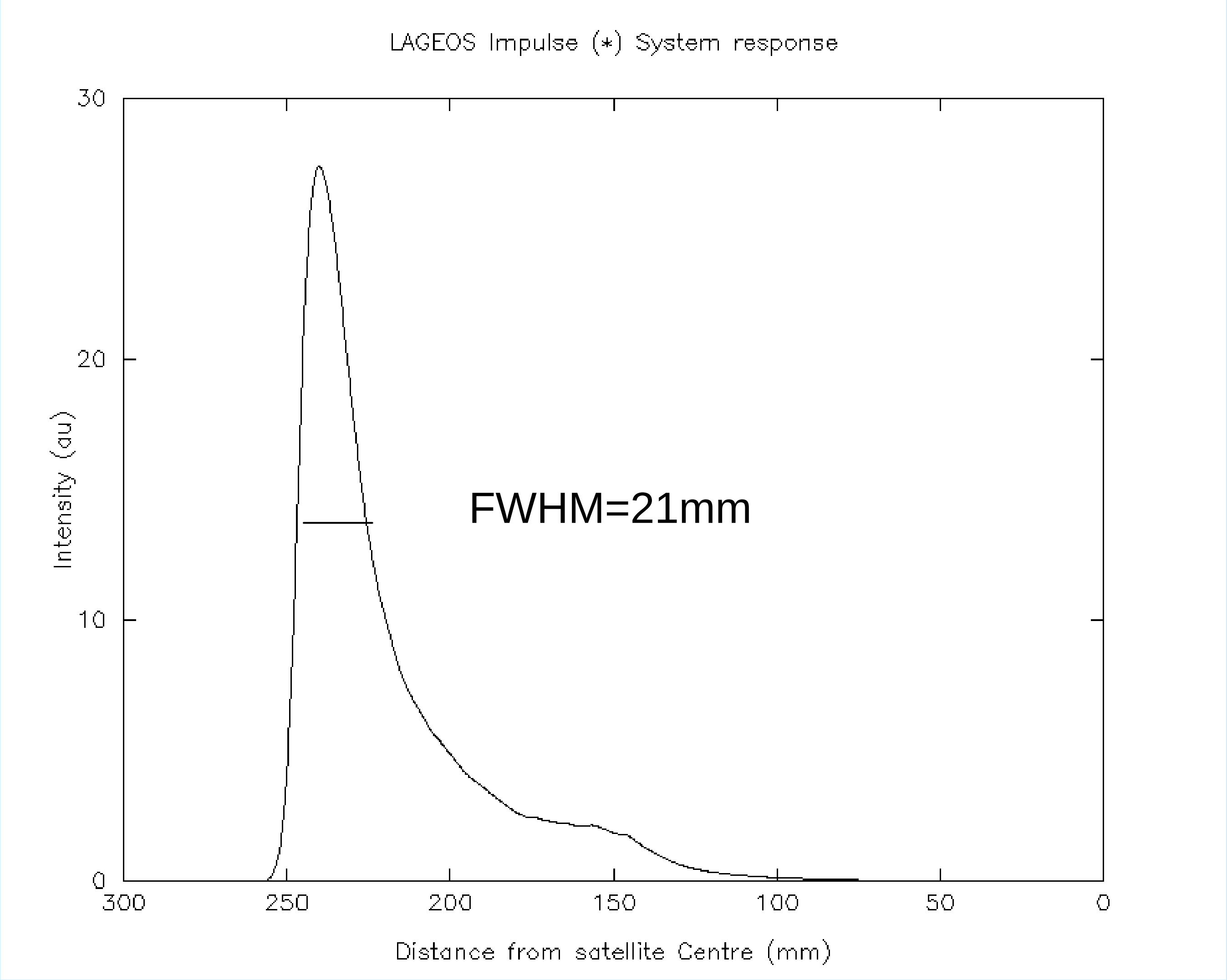


System response obtained from target-board ranging at << single photons

LAGEOS impulse (Otsubo & Appleby, 2003)

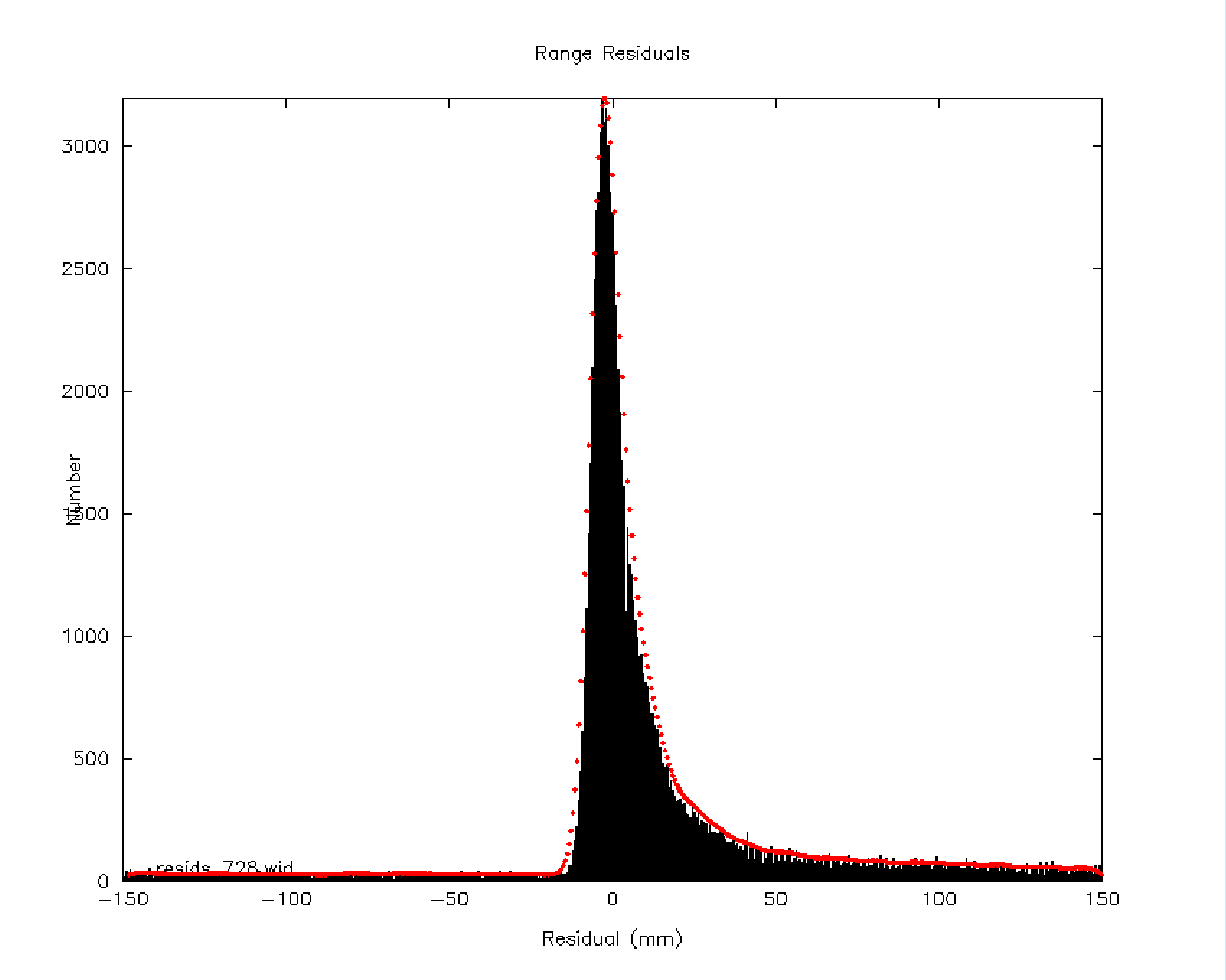


System (*) LAGEOS



Real data from a pass at **<< single photons**.

σ = 8.5mm: (data will be rejected at -12 and +25mm

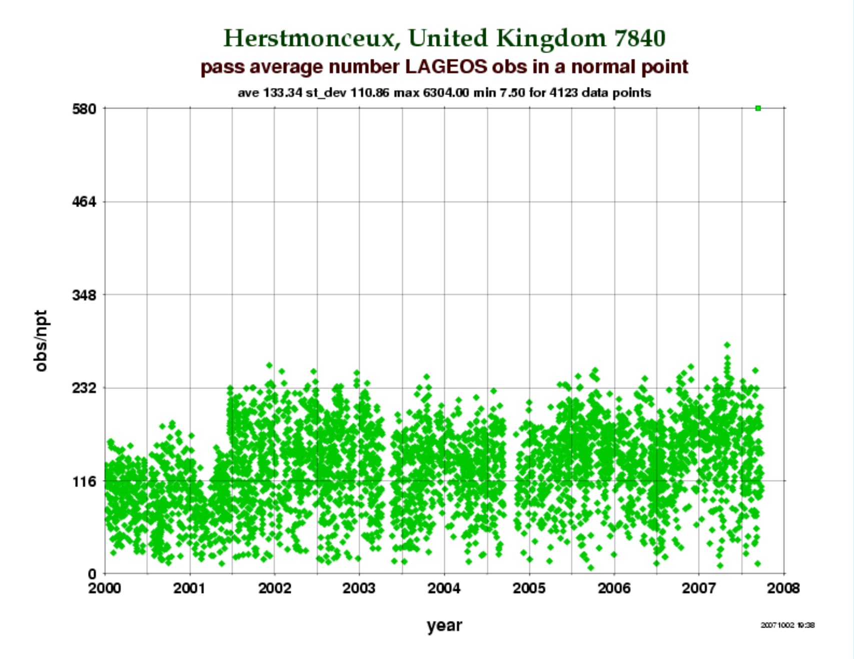


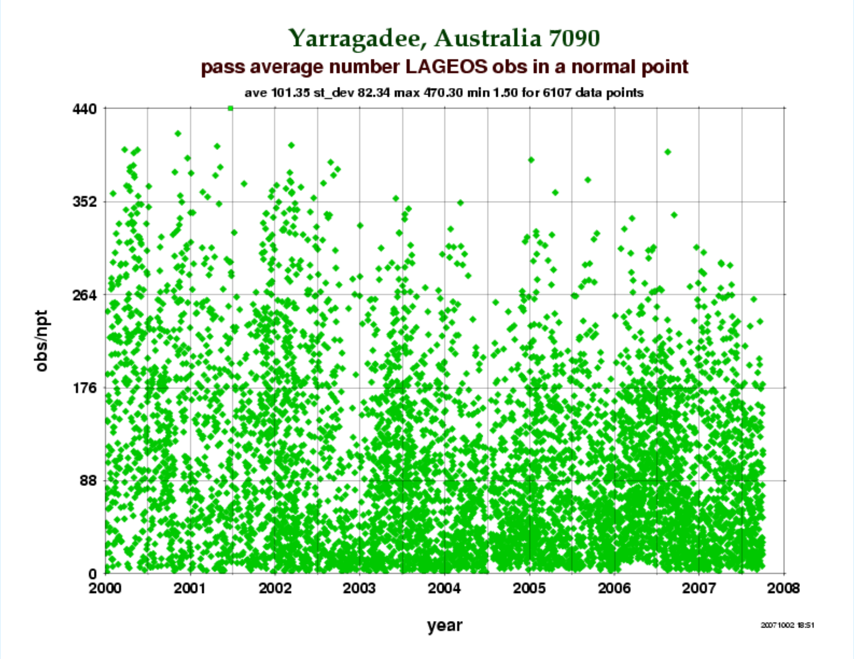
For this case, possible to compute **from the model** an **average** CoM value accurate to ~1mm (=245mm)

Centre of mass corrections >> single photons

- For NASA systems, for example, returns peak at several hundreds of photons (est. from link models, e.g. Degnan, 1993)
- Models for CoM depend upon characteristics of electronic discriminators;
- Cannot use statistical method for CoM as for single-photon systems
  - But can **estimate** from the model distributions (leading edge), to give CoM 248 ±2 mm
  - This compares with ground tests on LAGEOS-2 giving 249 mm (Minott, 1993)

Single-photon vs multi-photon yield





Single-photon, consistent

Multi-photon, variable

In summary:

There exist different CoM values dependent on the stations' technology.

- Single photon systems have smallest uncertainty: **±1mm**

- Com for high-energy systems have an estimated uncertainty of ± 2mm
    - take account of unknown effect of discriminators at different stations;
    - effect is to increase effective pulse-length

- A table of values will be produced:

- CoM for typical single photon station 245mm
- Com for typical, majority, high-energy station 248mm

- Relative to 'standard' 251mm, change of ~0.3ppb.

Conclusion

- With improved
  - estimates of counters' effects in the sub-network;
  - knowledge of band of appropriate CoM values throughout the network:
    - LAGEOS is not a mm-level target for >single photons
- Should include these effects in future re-analyses efforts towards:
  - TRF;
  - GM: a change of CoM from 251 to 248 is 0.5ppb
  - Constrained RB for stations based on informed CoM band and counter characteristics.
- **NB** New technology (event timer, kHz) systems fulfil 'best practice' requirements.