Accuracy assessment of CoM corrections for Etalon geodetic satellites

José Rodríguez, Graham Appleby,
Toshimichi Otsubo, Peter Dunn

Current Etalon centre-of-mass models

- No ground tests conducted
- Fixed value for centroid detection from early studies (1)
- Impulse response functions from single photon tracking available (2)
- Current CoM tables based on work above, e.g:

```
7840 31 03 1983 31 03 1992 100  PMT NCF  3.0  35  45 612 602 607  1
7840 31 03 1992 31 12 2050 100 CSPA CS   3.0   6  15 567 563 565  1
7840 01 02 2007 31 12 2050  10 CSPA CS   2.5   3   9 567 563 565  2
```


(1) **Mironov N. T.** et al, “ETALON-1, -2 center of mass correction and array reflectivity”; *Proc. 8th International Workshop on Laser Ranging Instrumentation, 6.9-6.32, 1992*

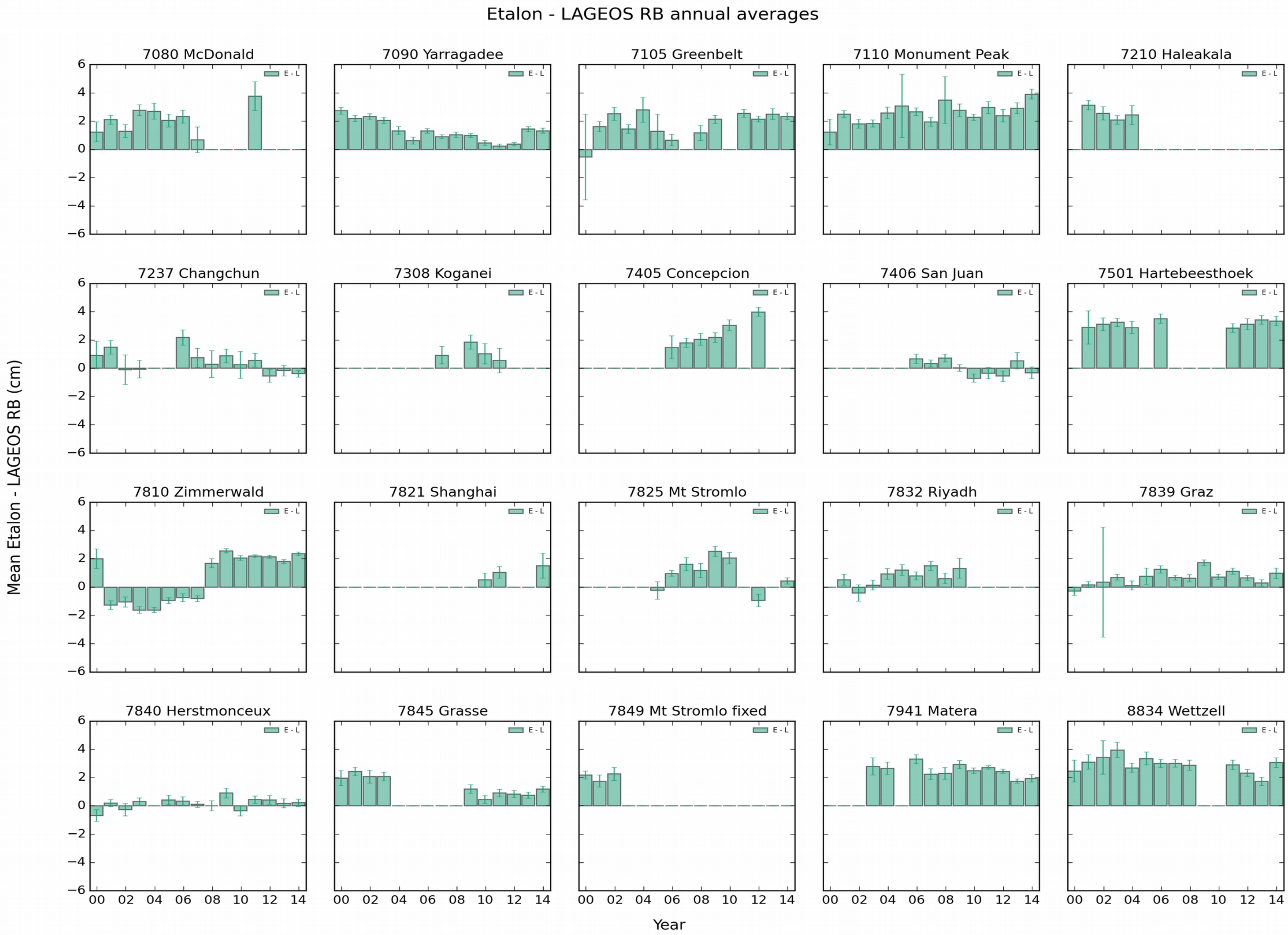
(2) **Otsubo & Appleby**, “System-dependent centre-of-mass correction for spherical geodetic satellites”; *Journal of Geophysical Research, vol 108, NO. B4, 2201, 2003*

Etalon RB analysis

- We computed weekly combined LAGEOS + Etalon solutions for the period 1995-2014, estimating orbits, station coordinates, EOPs and range biases
- Two combined RB parameters per station: LAGEOS 1+2, Etalon 1+2
- The number of observations to the Etalon satellites is about 10% of those available for LAGEOS, which therefore dominate the solutions (no special weighing employed)
- Range bias time series for Etalon quite reasonable, given sparse coverage

Etalon RB analysis

- In order to remove potential issues at the station we looked at the *differences* between the range biases estimated for LAGEOS and Etalon
- N.B.: possible differences related to the return rate intensities to these two satellite pairs not considered here
- Annual averages of the RB differences shown in the next plot, for some stations (and years) that have a minimum number of observations for both LAGEOS and Etalon

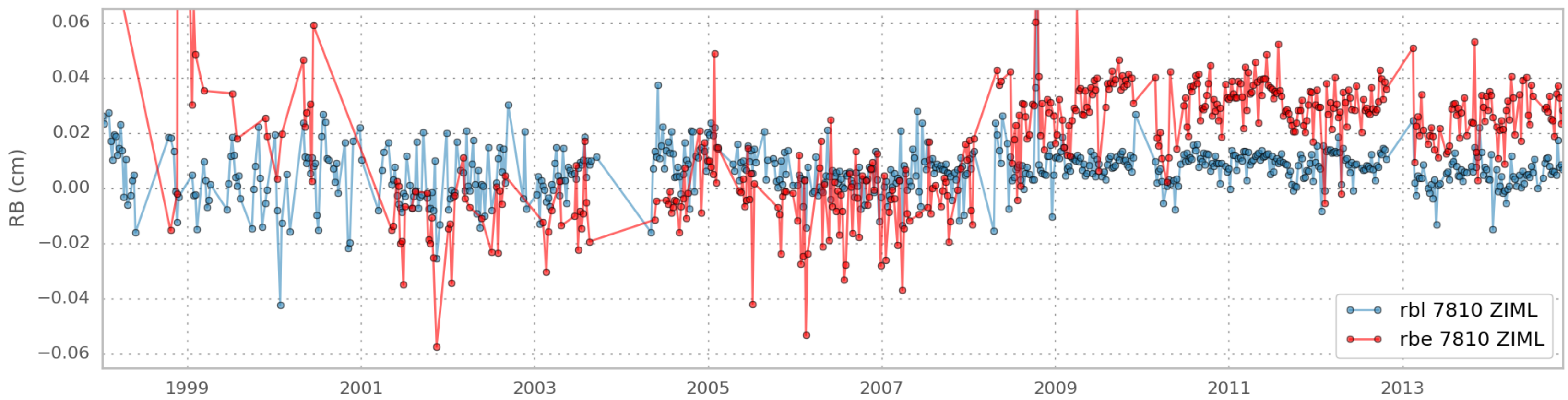

Etalon - LAGEOS RB annual averages
7080 McDonald
7090 Yarragadee
7105 Greenbelt
7110 Monument Peak
7210 Haleakala
7237 Changchun
7308 Koganei
7405 Concepcion
7406 San Juan
7501 Hartebeesthoek
7810 Zimmerwald
7821 Shanghai
7825 Mt Stromlo
7832 Riyadh
7839 Graz
7840 Herstmonceux
7845 Grasse
7849 Mt Stromlo fixed
7941 Matera
8834 Wettzell
E - L
Mean Etalon - LAGEOS RB (cm)
Year
00 02 04 06 08 10 12 14
6 4 2 0 −2 −4 −6

Etalon RB analysis

- Found unexpected positive biases of up to 2.5 cm for Etalon
- Mostly for stations operating at multi-photon levels of return
  and using MCP/PMT detectors
- Situation more mixed for low power stations, but smaller biases found in this case

Etalon RB analysis

Evidence of CoM mismodelling

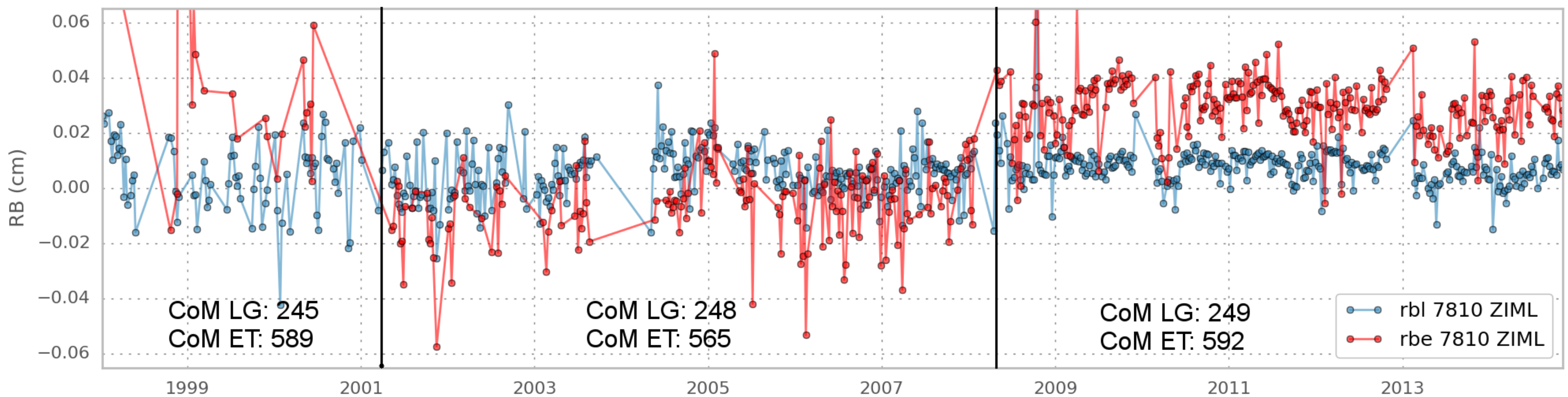


In this example we have a fairly small average LAGEOS RB throughout the whole period...

but obvious jumps in Etalon RB in two occassions

Etalon RB analysis

Evidence of CoM mismodelling



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but obvious jumps in Etalon RB in two occassions

CoM changes introduced to accommodate system upgrades clearly offsetting the measurements

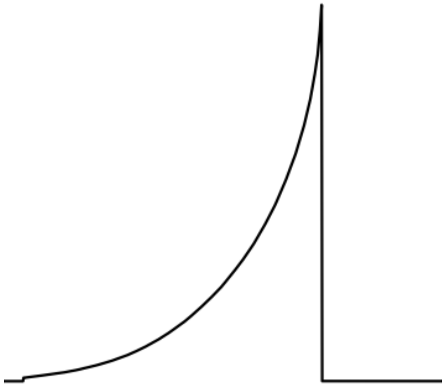
Shortcomings in current modelling:

- Given the lack of knowledge of the behaviour of the hardware components in use, a pragmatic approach had to be followed
- The whole system response was modelled with a single Gaussian function
- The "pulse width" adopted was that of the only component known with reasonable certainty for ***all*** stations: the optical pulse length
- Pulse transformations caused by the electronic multiplication process and signal amplification, electronic and timing jitter not taken into account

These shortcomings suggest that the “pulse width” parameter in the CoM model for MCP/PMT detectors is underestimated/understated

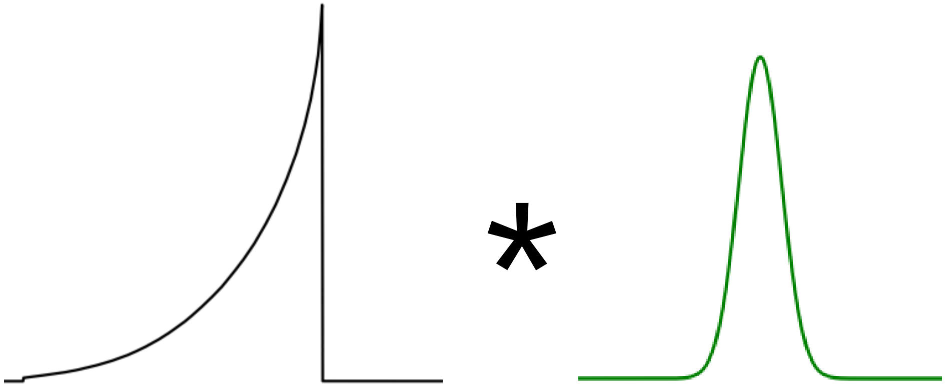
Longer “pulse widths” displace the CoM correction towards lower values, hence the positive RB results found here would be reduced

Estimating CoM corrections:
the impulse response function approach



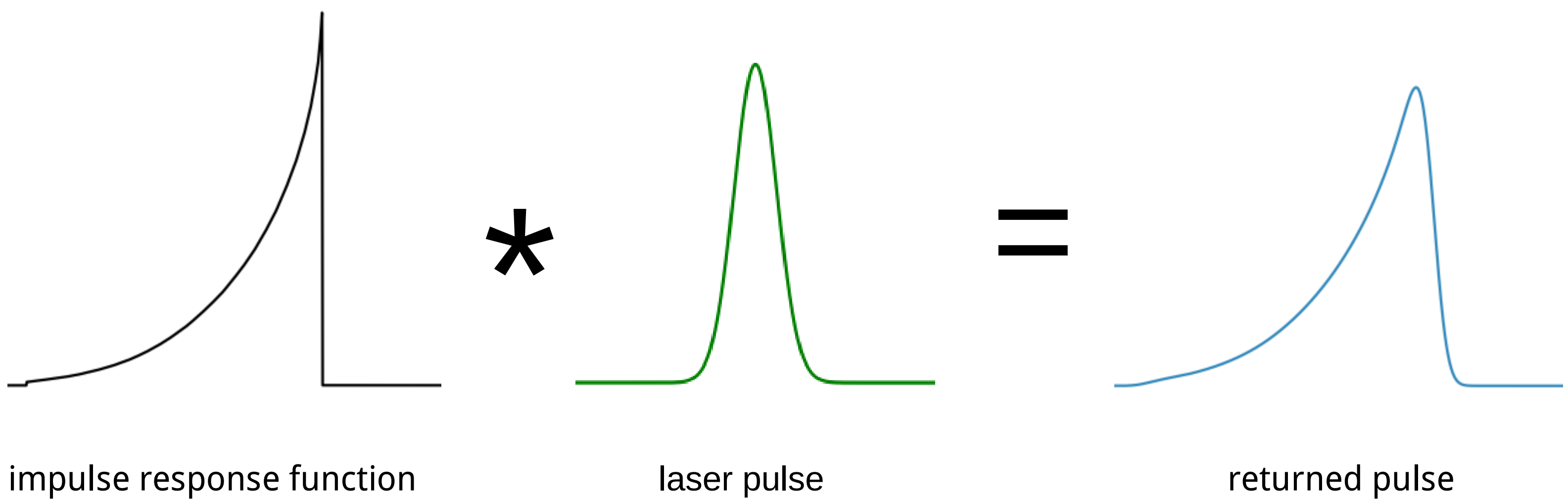
impulse response function

Estimating CoM corrections:
the impulse response function approach

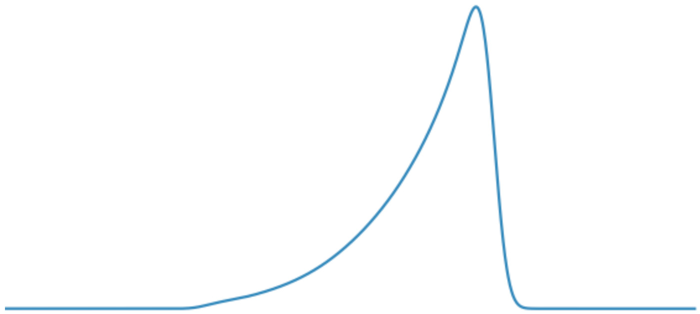


impulse response function laser pulse

Estimating CoM corrections:
the impulse response function approach

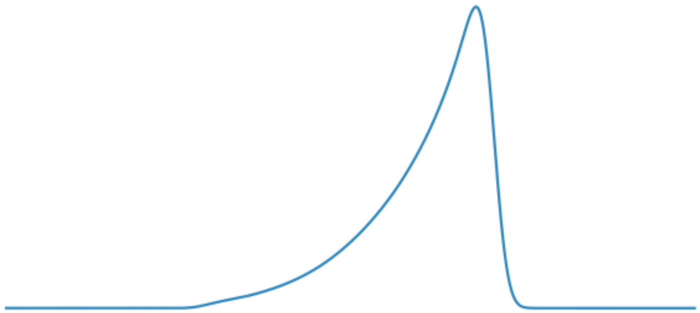


Estimating CoM corrections:
the impulse response function approach



Returned pulse

Estimating CoM corrections:
the impulse response function approach



* ?

Returned pulse

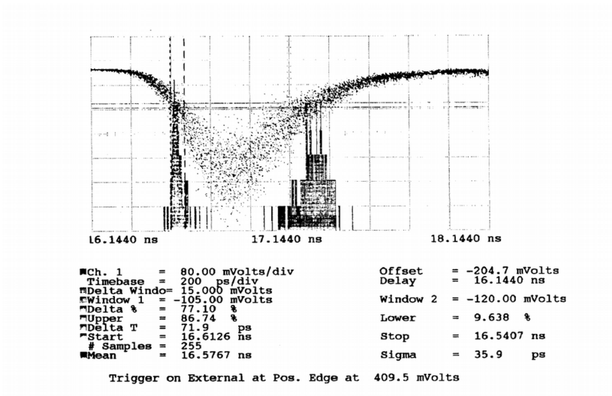
Detector response

System log info:

```
6.01.02 Primary Chain
        Wavelength            [nm]: 532
        Detector Type             : MCP
          Manufacturer            : Photek
          Model                   : PMT209 s/n 23990701
          Quantum Efficiency [%]: 12.59
          Nominal Gain            : 1E+06
          Rise Time           [ps]: < 120
          Jitter (Single PE)[ps]: 30
          Field of View        ["]: 60
          Date Installed          : 2005-10-20
          Date Removed            : 2007-02-19
        Signal Processing         : CFD
          Manufacturer            : Tennelec
          Model                   : TC454
          Date Installed          : 2000-01-01
          Date Removed            : (yyyy-mm-dd)
          Amplitude Measurement : YES
          Return-rate Controlled: NO
          Mode of Operation       : Multi photons
        Time of Flight Observ.  : EVENT
          Manufacturer            : HTSI
          Model                   :
          Resolution          [ps]: <1
          Precision           [ps]: <2
          Date Installed          : 2000-01-01
          Date Removed            : (yyyy-mm-dd)
        Additional Information  : The amplitude measurements are made
                                  : using a Peak Amplitude Detector
                                  : manufactered by Honeywell Technology
```

Approximation: assume Gaussian function with matching rise time

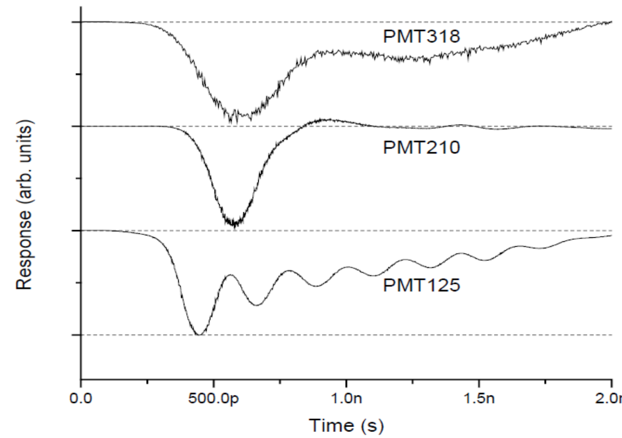
Better: information available elsewhere:



MULTIPHOTOELECTON (8–10) RESPONSE OF SAMPLIING SCOPE MEASUREMENTS OF THE ITT MCP–PMT (F4129F).

DEVICE CHARACTERISTICS

FEATURE	HAMAMATSU R 2566 U-7	ITT MCP-PMT 4129f
Microchannel Plate	2-Stage (V-Type)	3-Stage (Z-Type)
Microchannel Dia	6um	12um
Max. Operating Voltage	-4600V	-3700V
Max. MCP Gain	$3x10^6$	$1x10^6$
Rise Time	≈108ps	~350ps
Fall Time	≈100ps	≈500ps
Full Width	≈160ps	≈550ps
Single Photoelectron Jitter	≈25ps	≤100ps



Varghese T., Selden M., Oldham T. “Performance comparison of high-speed microchannel plate photomultipliers”; *NASA GSFC, 8th International Workshop on Laser Ranging Instrumentation, 1993*

Milnes J. and Howorth J. “Picosecond time response characteristics of micro-channel plate PMT detectors”; *Proceedings of the SPIE, Volume 5580, p. 730-740, 2005*

Published detector impulse response measurements performed with short (<50 ps FWHM) laser pulses at multiphoton levels

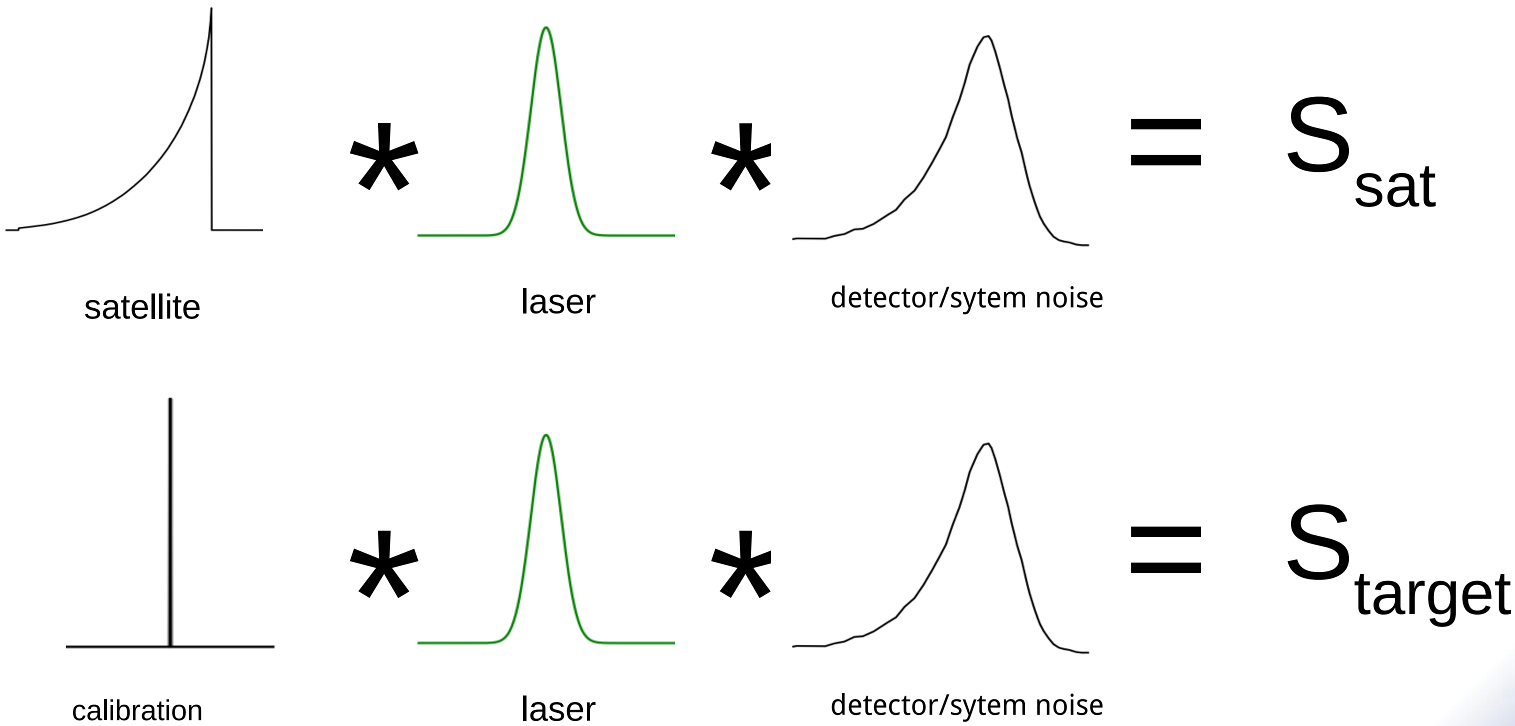
Given the much longer system responses, these pulse widths have little impact on the overall signal width, so no attempt was made to deconvolve them (treated as delta functions)

Stations using these detectors normally operate at the “few” to “multi-photon” levels, and the threshold settings ensure a minimum number of photoelectrons

If the return signals are too low, the entire illumination function (laser * satellite response) is sampled, increasing the time jitter and decreasing the CoM value as a result

For multi-photon returns, a convolution approach including the measured detector response is adequate

Estimating CoM corrections:
the impulse response function approach



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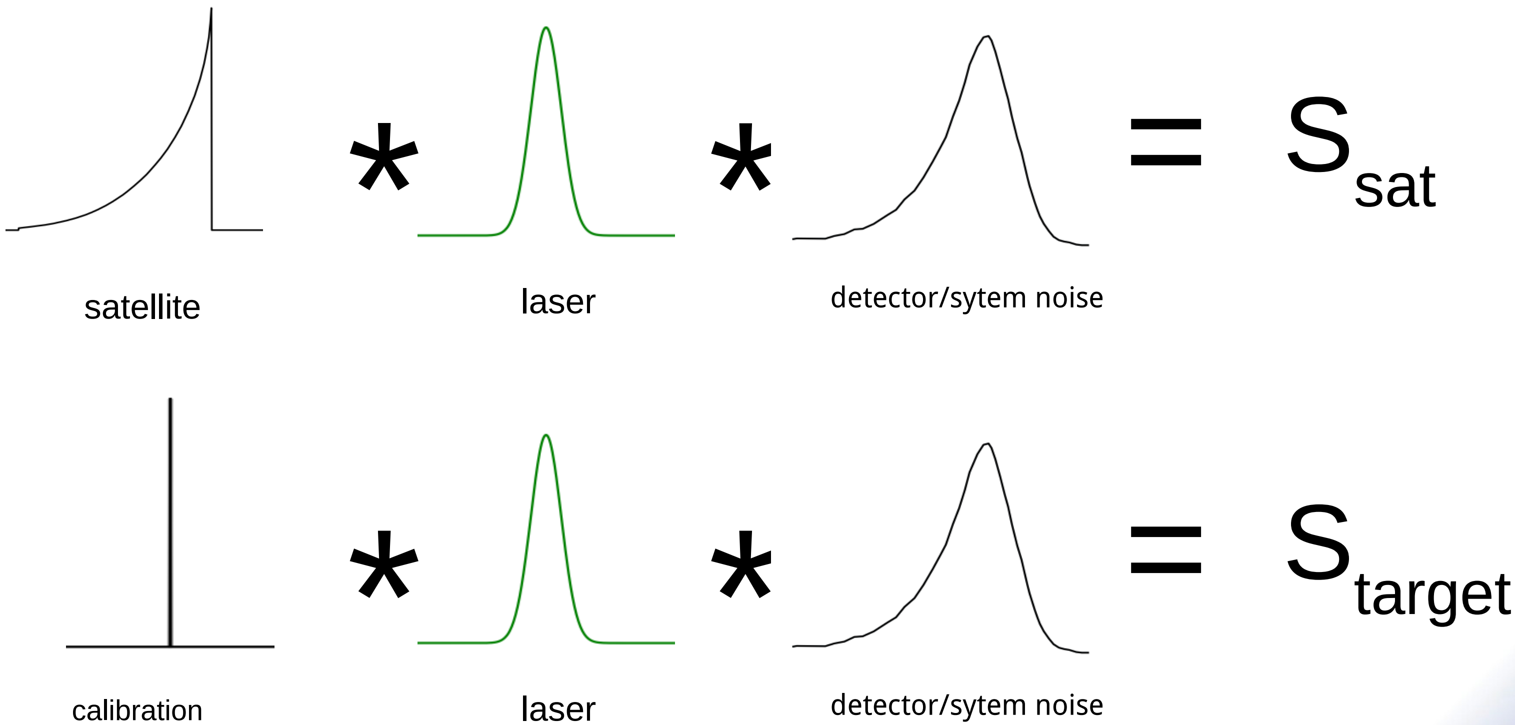


$$\text{CoM} = \text{ref.point}(S_{sat}) - \text{ref.point}(S_{target})$$

The reference point of the detected signal depends on the timing strategy employed (e.g. peak, leading edge, constant fraction)

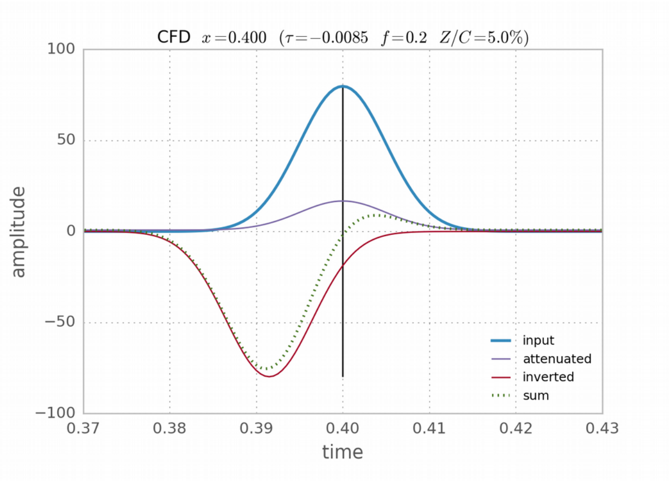
Fast constant fraction discriminators (CFDs) are a popular choice for precise timing and counting

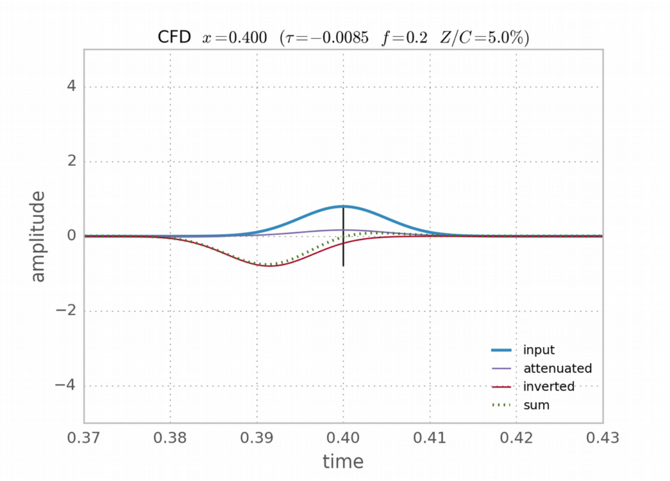
By triggering at a constant fraction of the input pulse, amplitude-dependent time-walk is greatly minimised as long as the shape of the input is similar

CFDs require setting up for the features of the expected input signals

Simple CFD *timing* simulation carried out (split signals, attenuation/inversion, sum, zero-crossing determination)

Amplitude changes in the input signal do not affect the triggering point:





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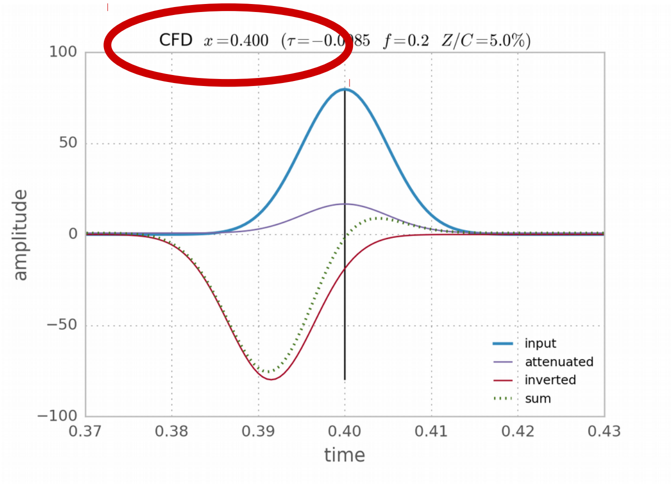

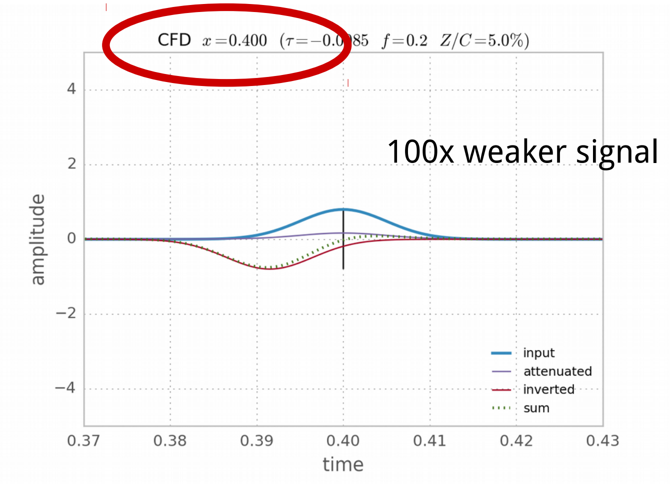

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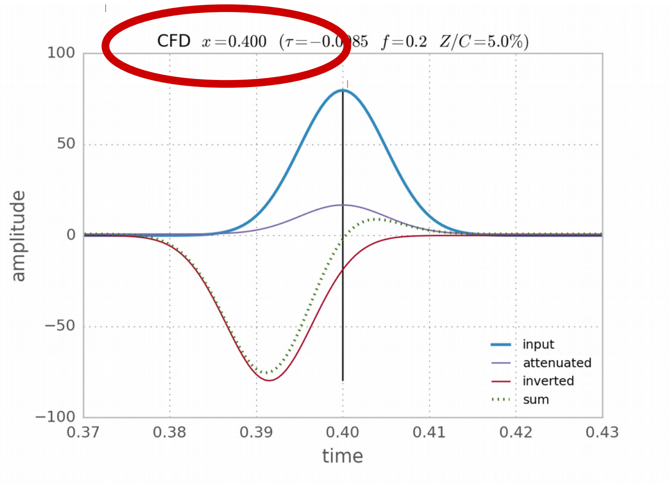
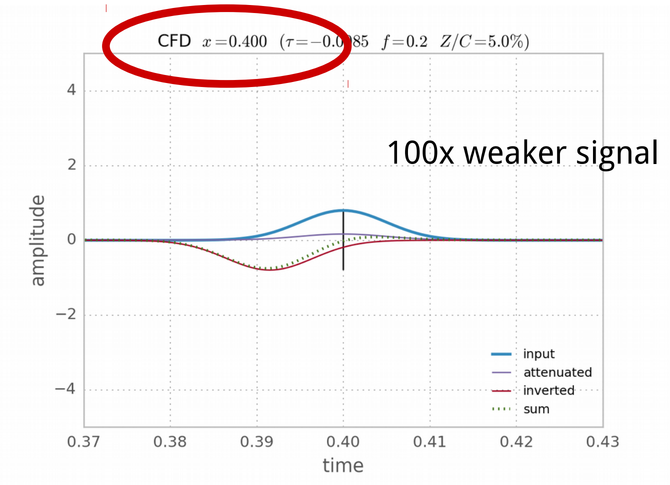
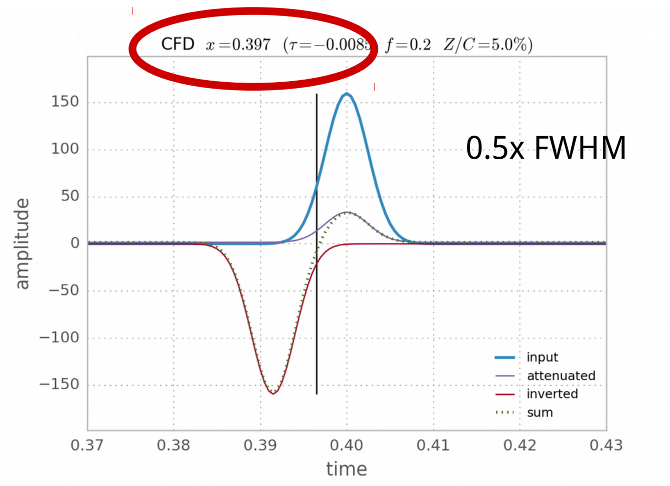




Unless the rise time is different:



Following the procedure outlined above (separation of optical/electronic parts, use of measured impulse system responses, simulation of CFD timing), Etalon CoM corrections were derived for two example configurations:

1. 150 ps FWHM laser + ITT F4129f MCP/PMT (multi-photon, constant fraction=0.2)
2. 50 ps FWHM laser + Photek210 MCP/PMT (multi-photon, constant fraction=0.2)

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	Etalon CoM (mm)	
	current	this work
150 ps FWHM ITT F4129f	603 (5)	587
50 ps FWHM Photek210	610 (3)	600

These values appear to be an improvement over the current ones, accounting for a significant amount of the estimated RB for Etalon for stations with configurations similar to those considered here

However, the implication of changing the modelling approach is that there is an impact on the CoM corrections for all other satellites, although of a lower magnitude given their smaller radii

For example, LAGEOS CoM values change at the few mm-level, which has obvious consequences for height estimation:

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For example, LAGEOS CoM values change at the few mm-level, which has obvious consequences for height estimation:

	LAGEOS CoM (mm)	
	current	this work
150 ps FWHM ITT F4129f	249 (1)	245
50 ps FWHM Photek210	250 (2)	248

Limitations…

The time response characteristics of some of the devices in the receiver chain have not been modelled (pre-amplifiers and timing amplifiers, if at all used)

If the return rates *approach* single-photon the statistics of detection at the photocathode must be taken into account

Non-linear behaviour of the discriminators outside their dynamic range: system characterisation when operating at these conditions needed

Traceability: if stations operate using a range of hardware settings we should be able to know what those are (thresholds, gains, amplifiers)…

or *at least* be able to make some simplifying assumptions (e.g. single photoelectron threshold + high gain for everything beyond LAGEOS)

Conclusions

Following the approach presented here, we can generate new CoM corrections for "high-energy" systems (and revise all the others while at it if appropriate)

Gathering response curves and plowing through the system logs may be a bit time consuming

mm-accuracy for Etalon is most likely not achievable, but we can improve on the cm-level biases we currently see

Modelling strategy employed for Etalon transferable to other targets

Thank you