High repetition rate SLR at GRSM

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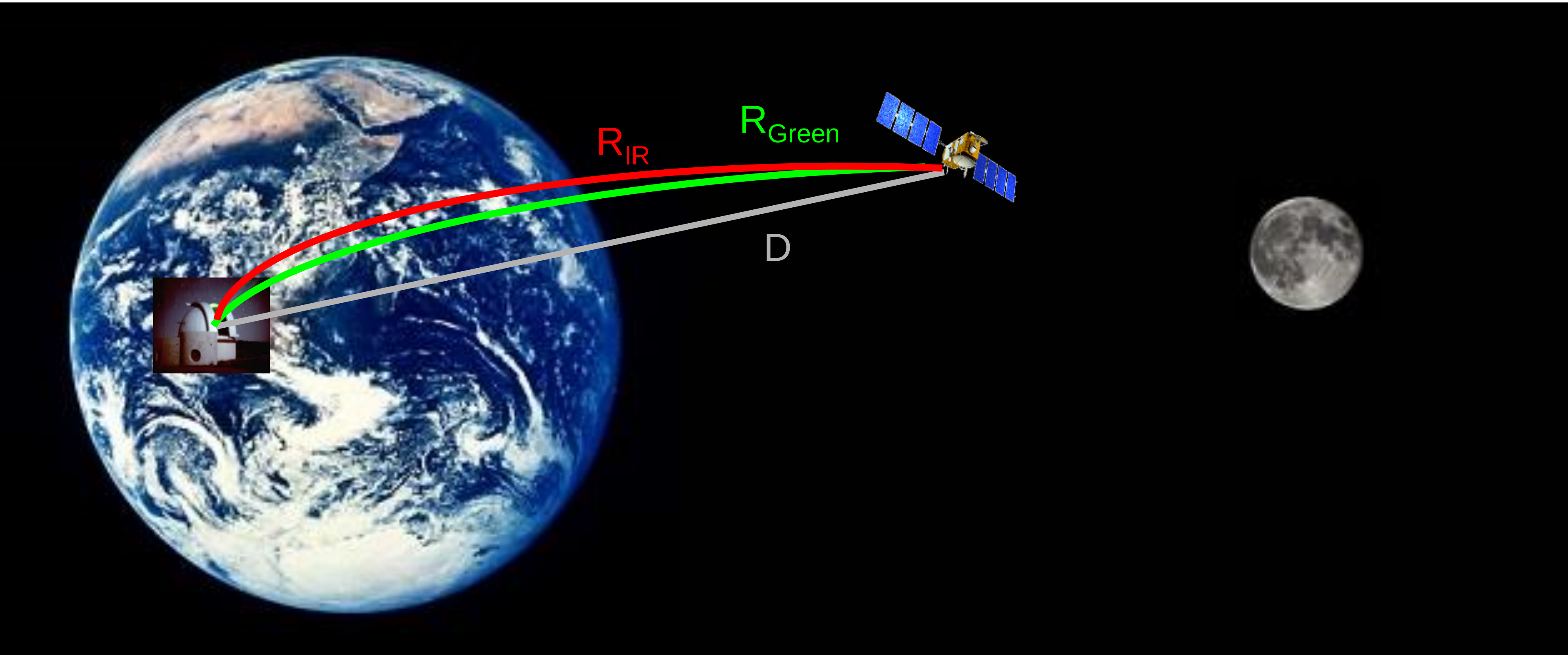
Why increasing the repetition rate ?

Our motivation: 2 colors measurement at the mm level

$$2D = R_{Green} + a\,(R_{\mathrm{Green}} - R_{\mathrm{IR}})$$

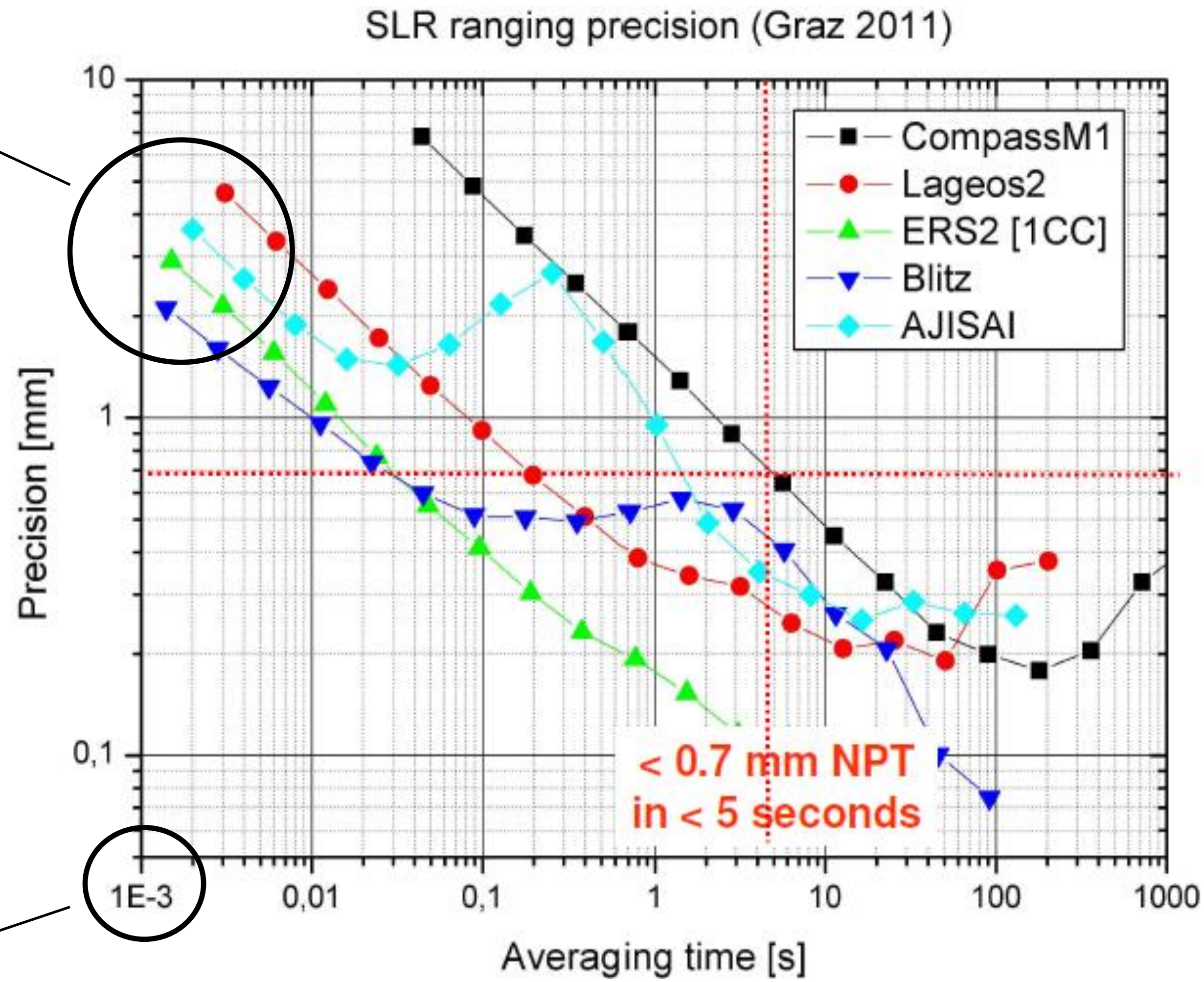
=>

It requires an high improvement of the time-of-flight measurement on the both wavelength.



Why increasing the repetition rate ?

[I. Prochazka, 17th ILRS Workshop, 2011]



Limitations :

- *Multi corner cubes target*
- *Timing jitter of SPAD* => $\sigma_{single-shot} = 15\ ps$
- *Atmospherical dispersion & spectral width of pulses* => limit the use of pulse width between 5 ps - 20 ps

Limitations :

- *Atmospherical backscattering & turbulence*

One solution in single-photon mode:

Try to increase the repetition rate of the measurements to push the TVAR on the left

What is it necessary to implemented ?

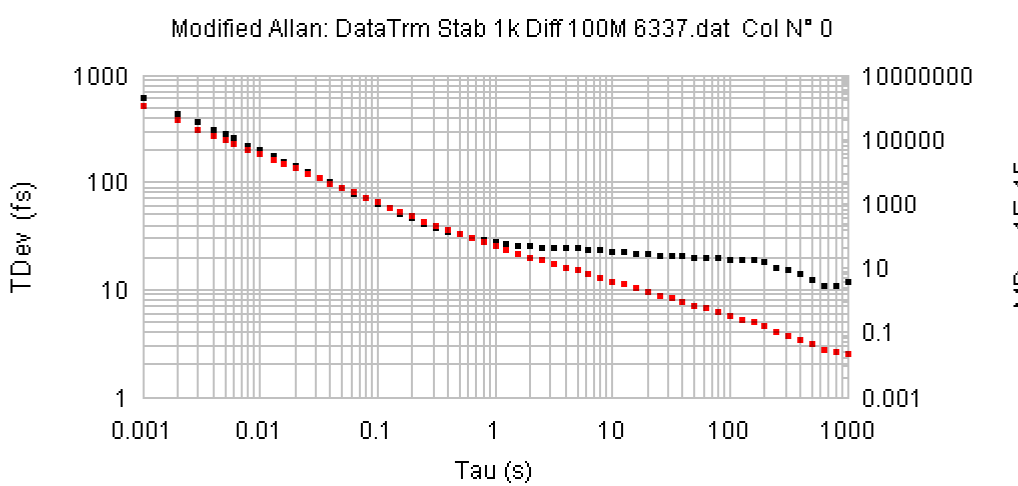
High repetition rate picosecond laser => 100 MHz HighQ laser

High repetition rate event timer

We have a

sub-picosecond STX 301 event timer (puchased now by SigmaWorks) acquired during the T2L2 mission.

- Time Stability @ 1000s: < 20 fs
- Linearity: 0.3 ps rms.
- Thermal Sensit. < 200 fs/°C
- Repeatability error
  - Synchronous : 600 fs rms
  - Random : 700 fs rms
- Rate
  - Dead time: 130 ns
  - Continuous rate 35 kHz



What is it necessary to implemented ?

High repetition rate SPAD

Collaboration in 2014 with

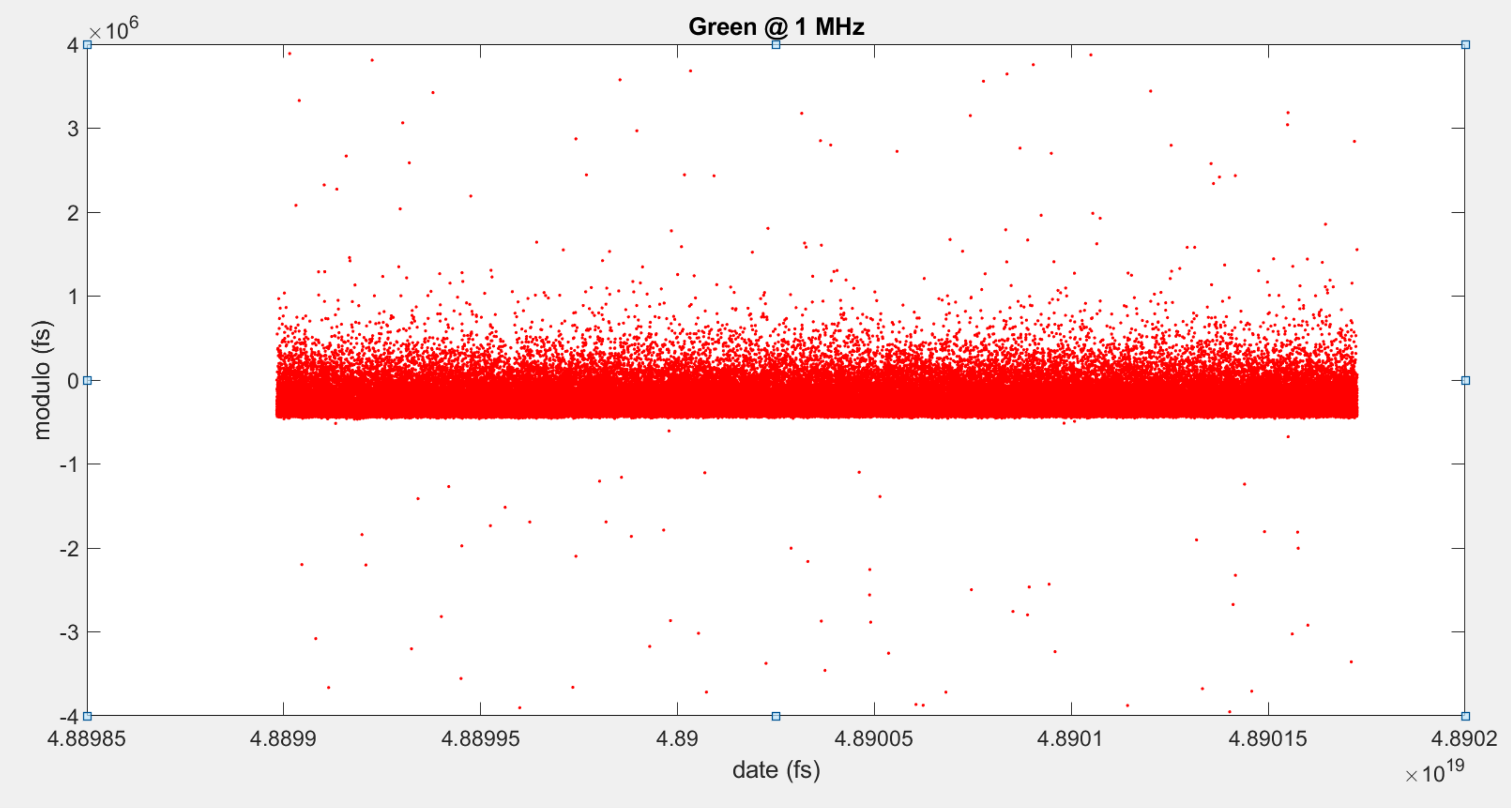
And with the help of the

Development of two high repetition rate SPAD detections

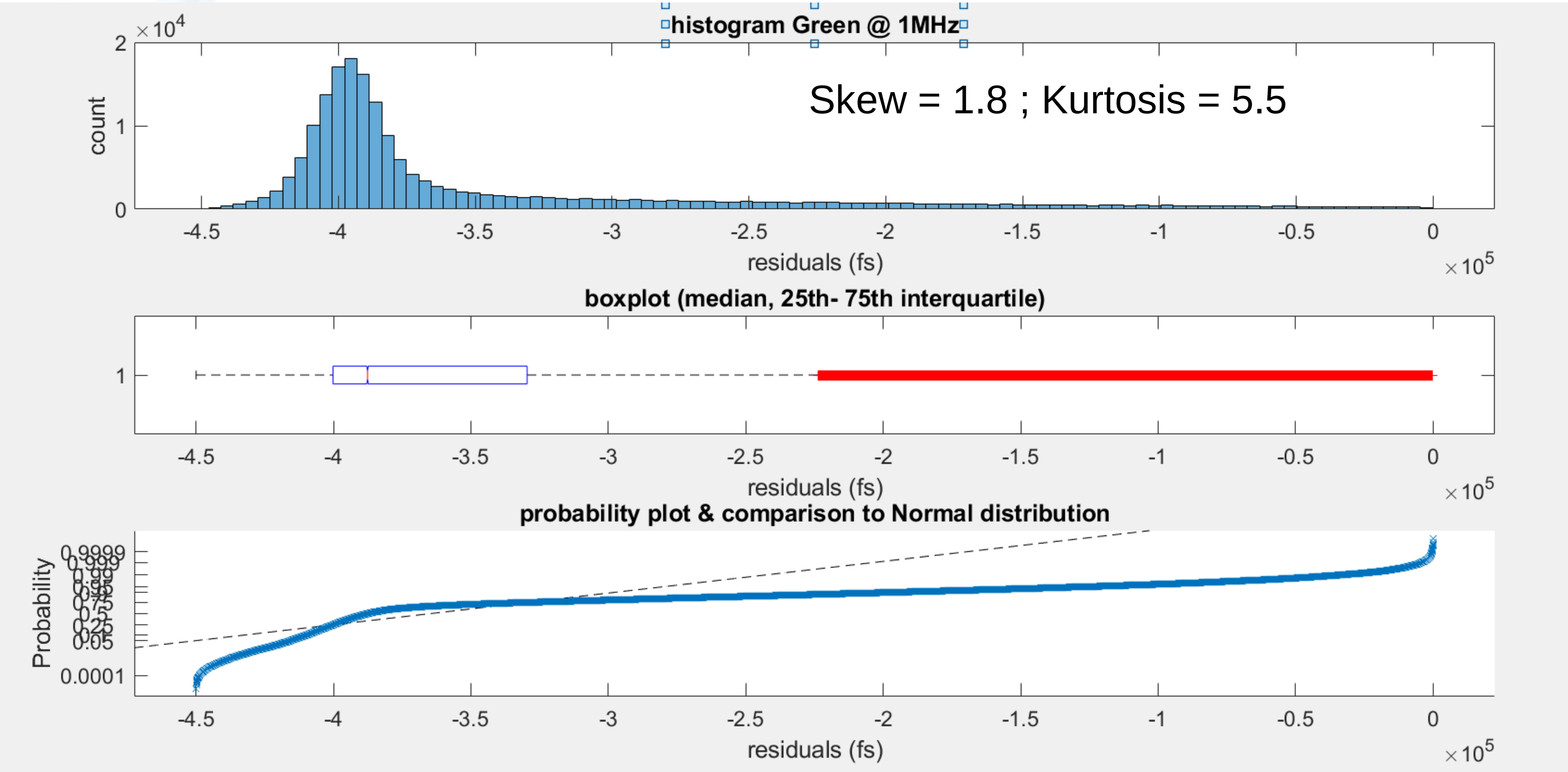
Si-SPAD	
Active area diameter	100 µm
Max repetition rate	1 MHz
Timing jitter	33 ps FWHM
DCR @ 7 V	74 Hz
Quantum efficiency	53% @ 532 nm

InGaAs-SPAD	
Active area diameter	50 µm
Max repetition rate	100 kHz
Timing jitter	76 ps FWHM
DCR @ 7 V	200 kHz
Quantum efficiency	47% @ 1064 nm

Green SPAD @ 1MHz

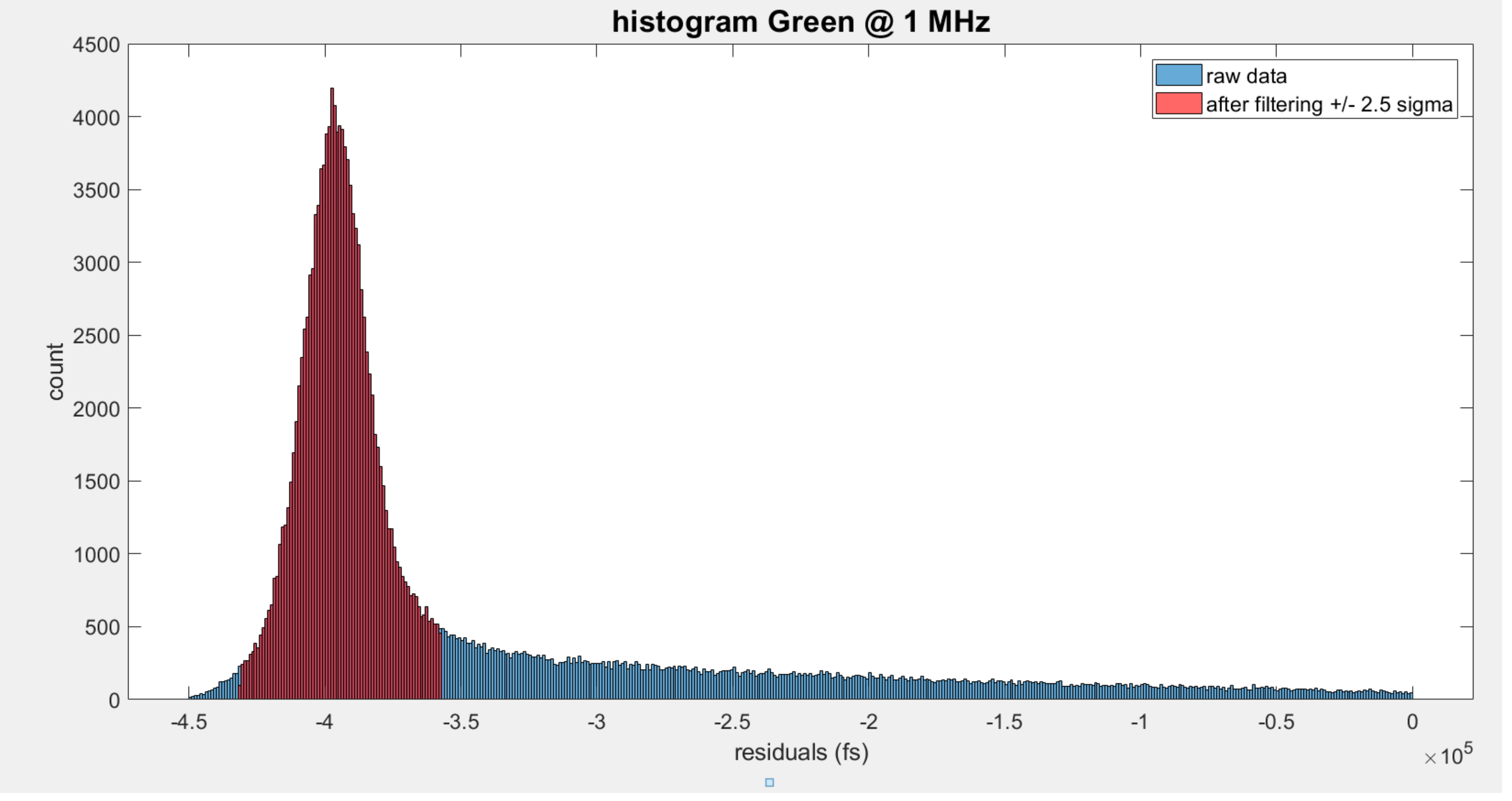


Green SPAD @ 1MHz

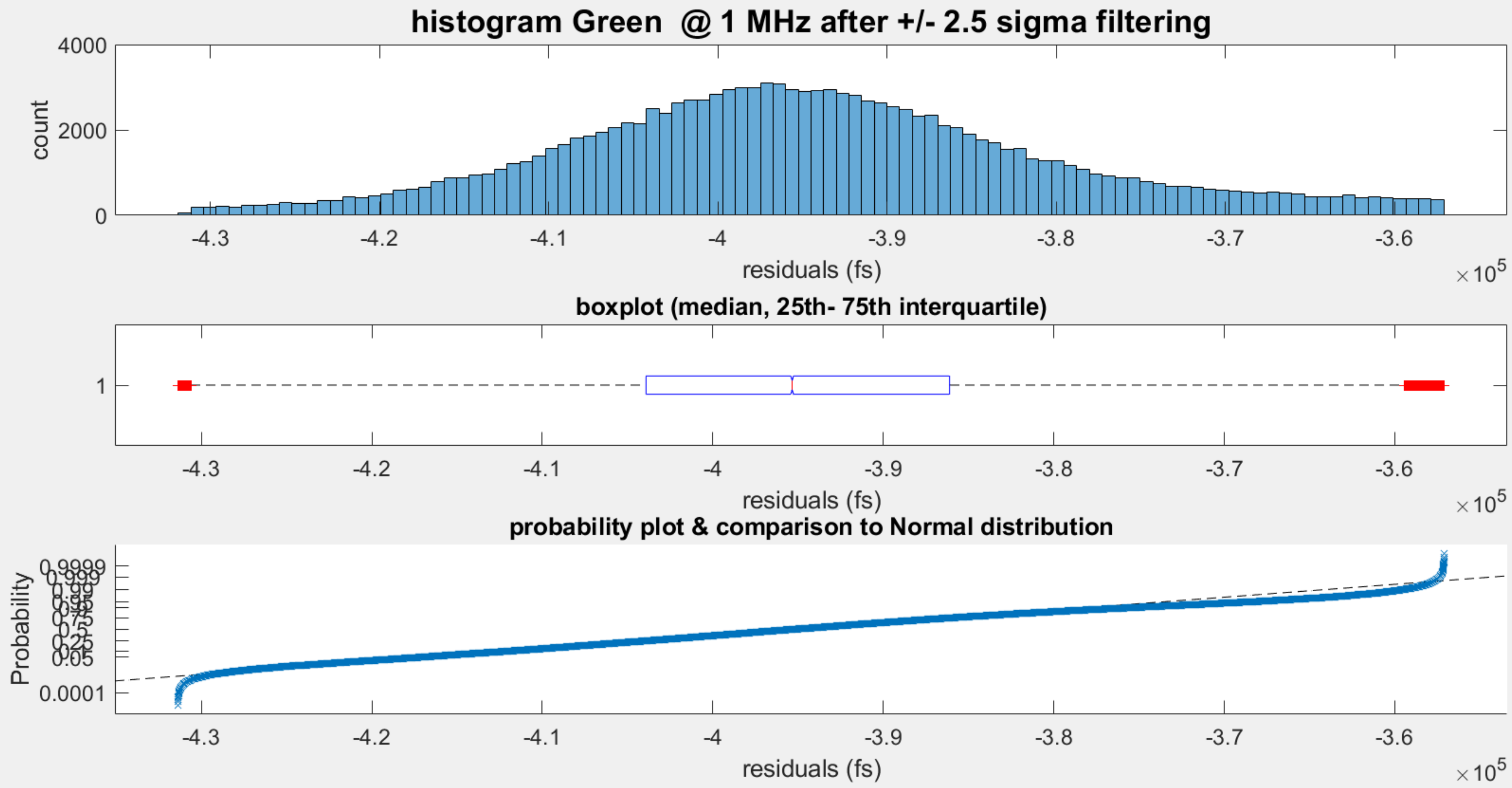


Clearly not a Normal distribution !

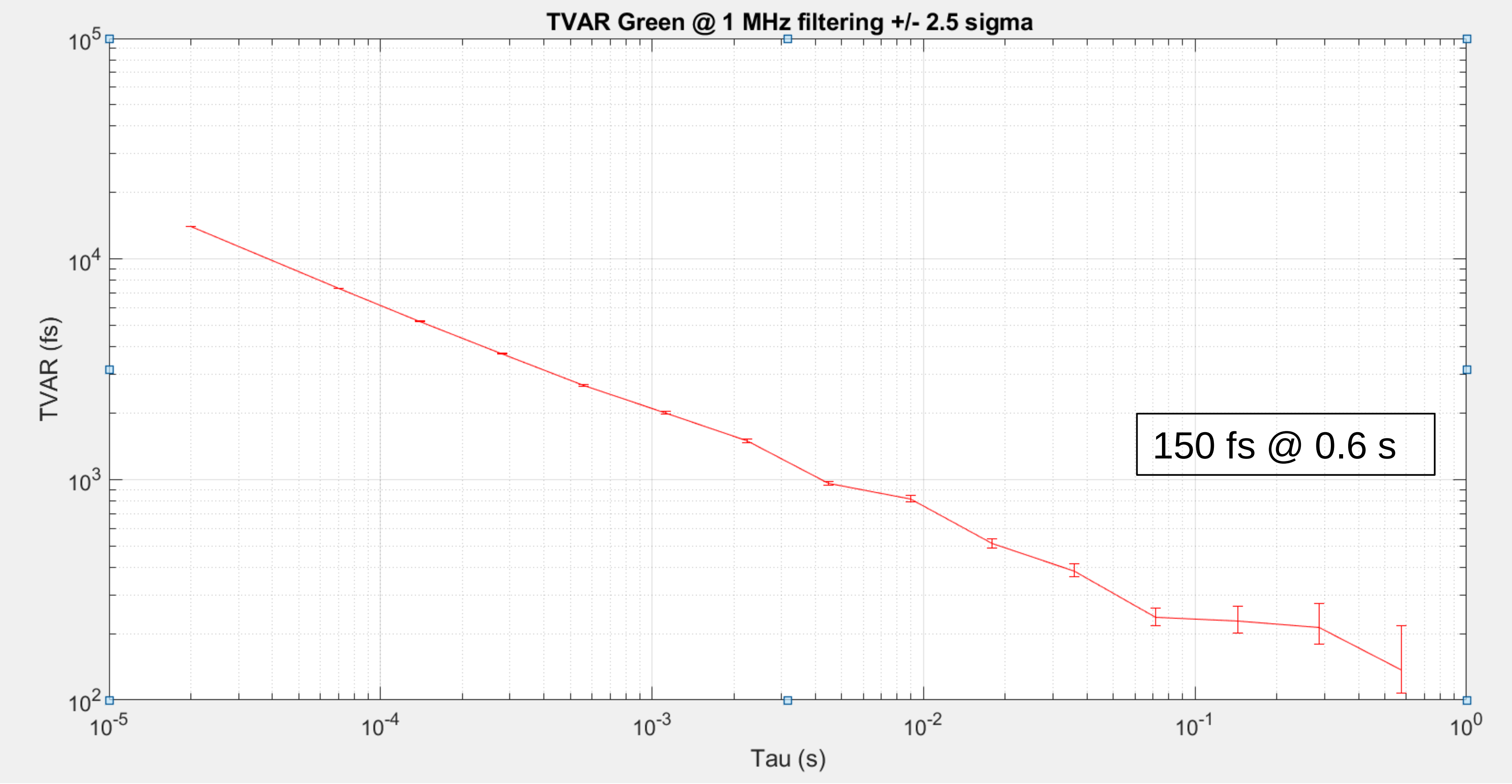
Green SPAD @ 1MHz



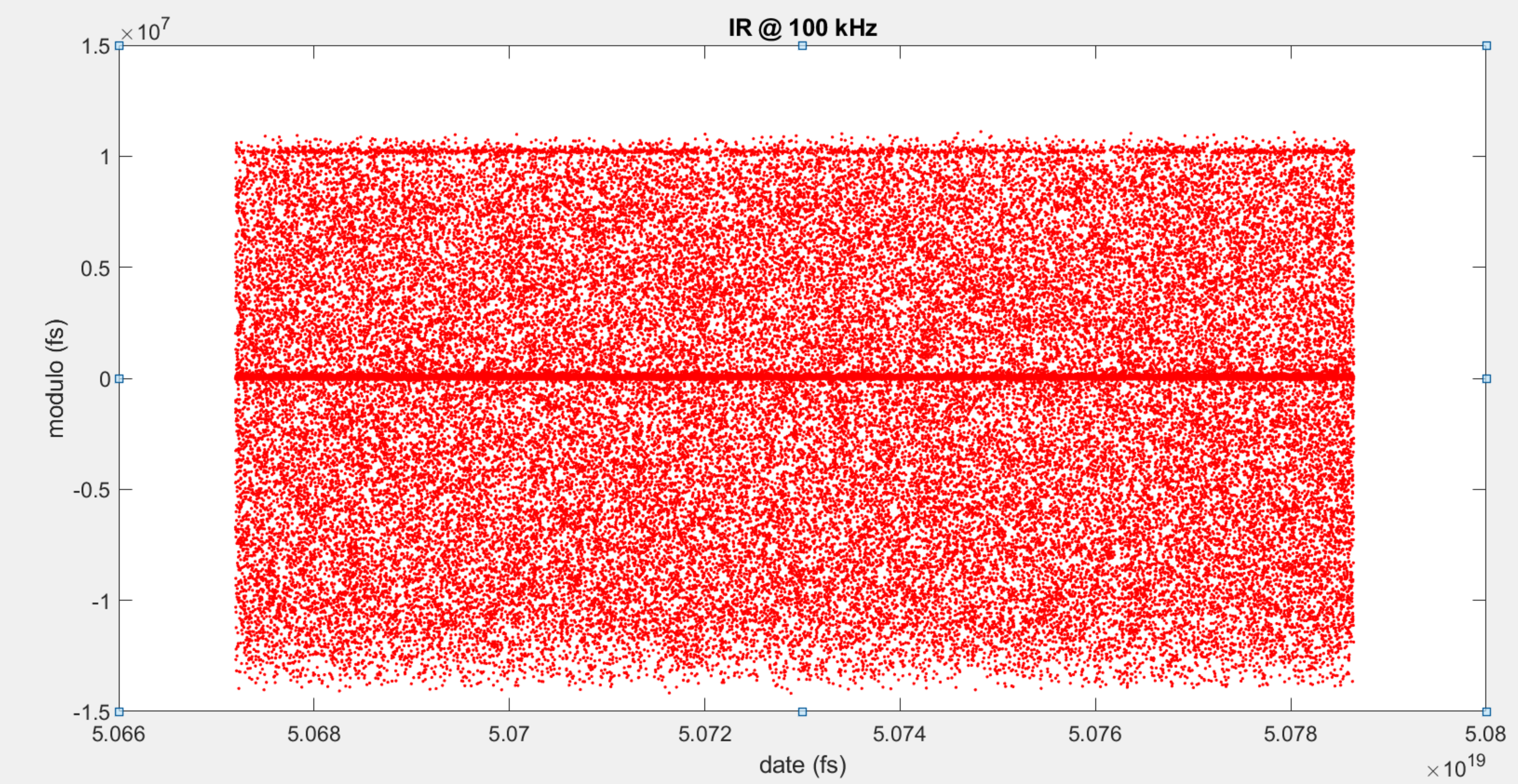
Green SPAD @ 1MHz



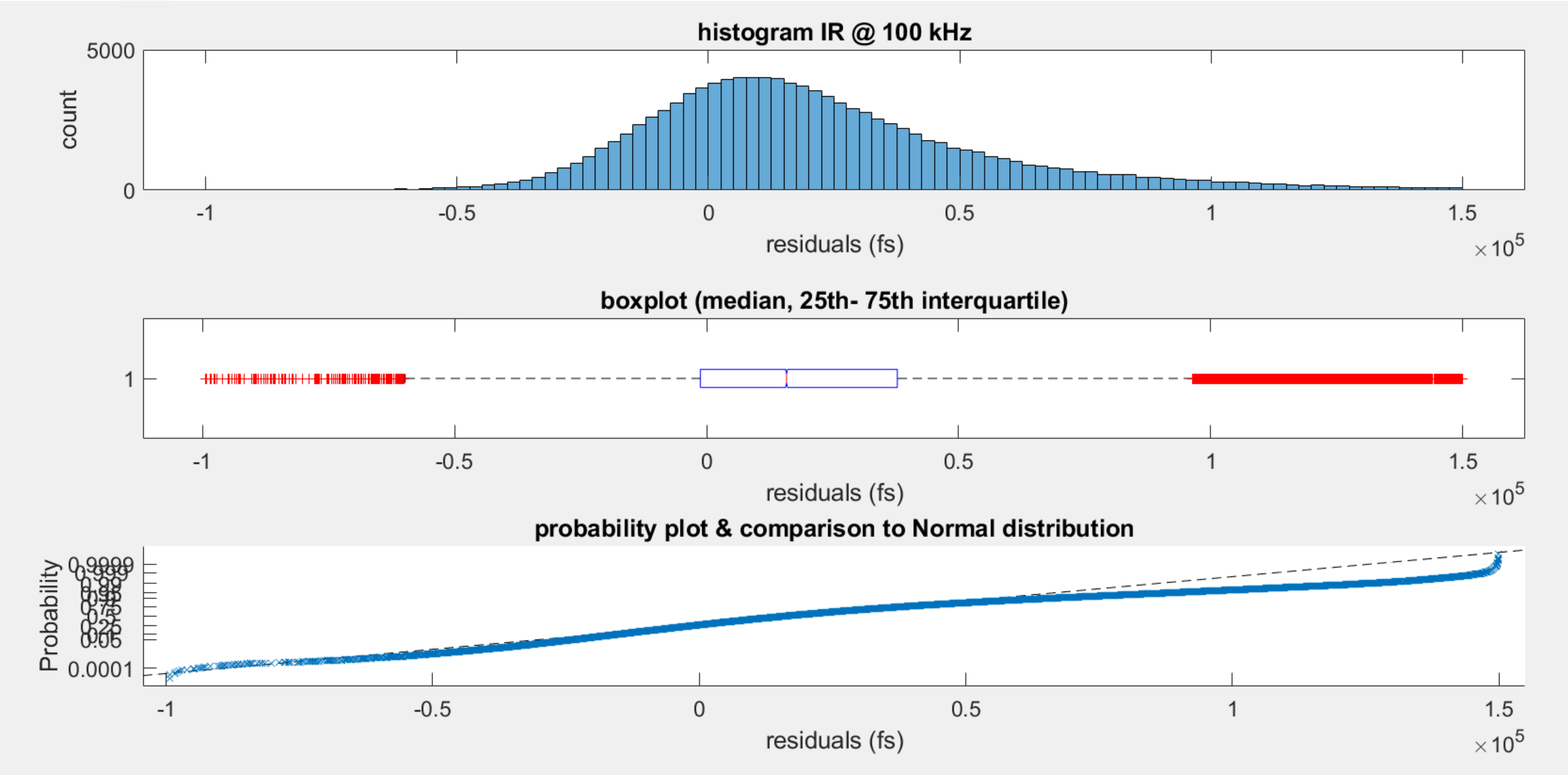
Green SPAD @ 1MHz



IR SPAD @ 100 kHz

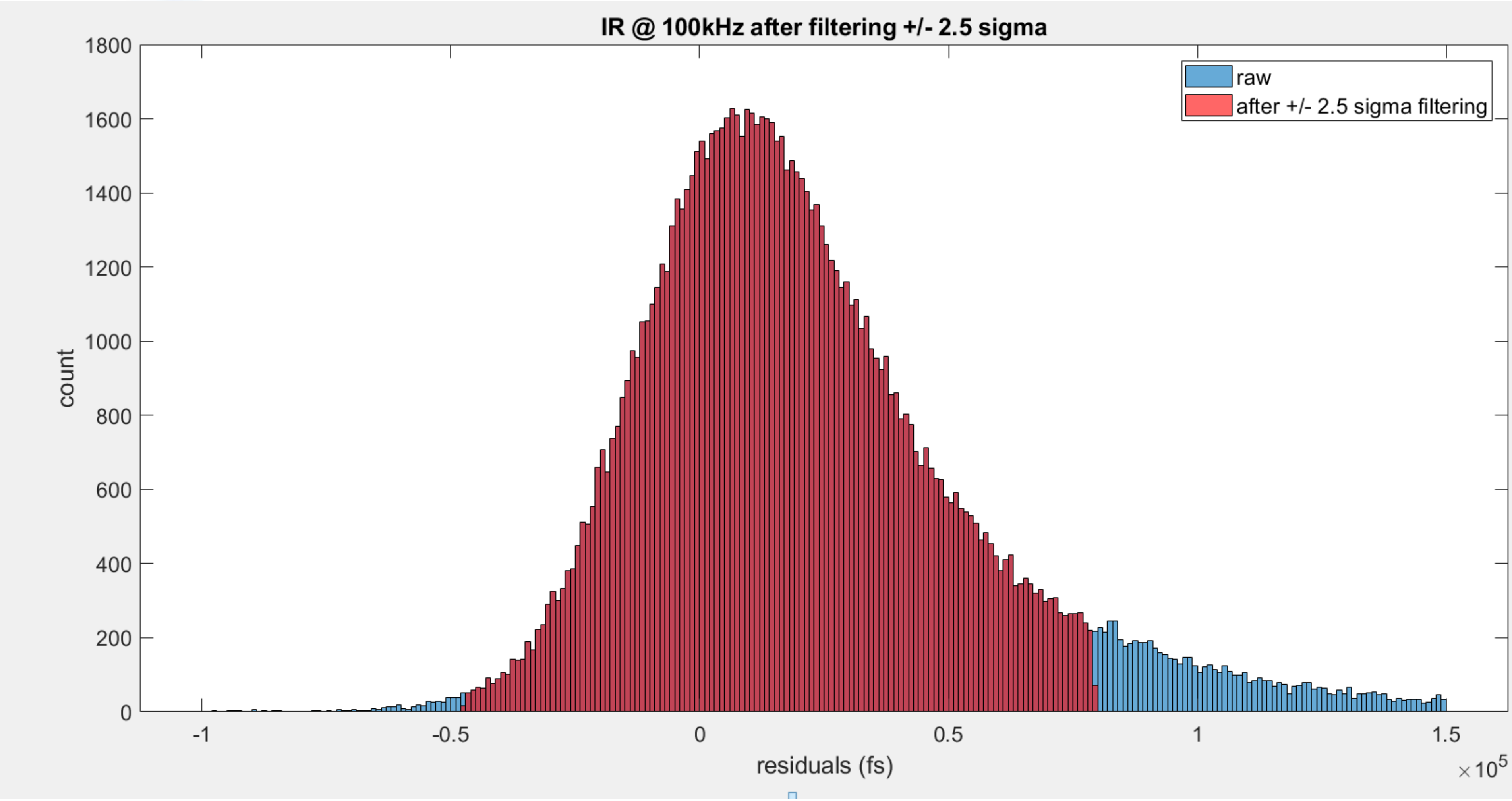


IR SPAD @ 100 kHz

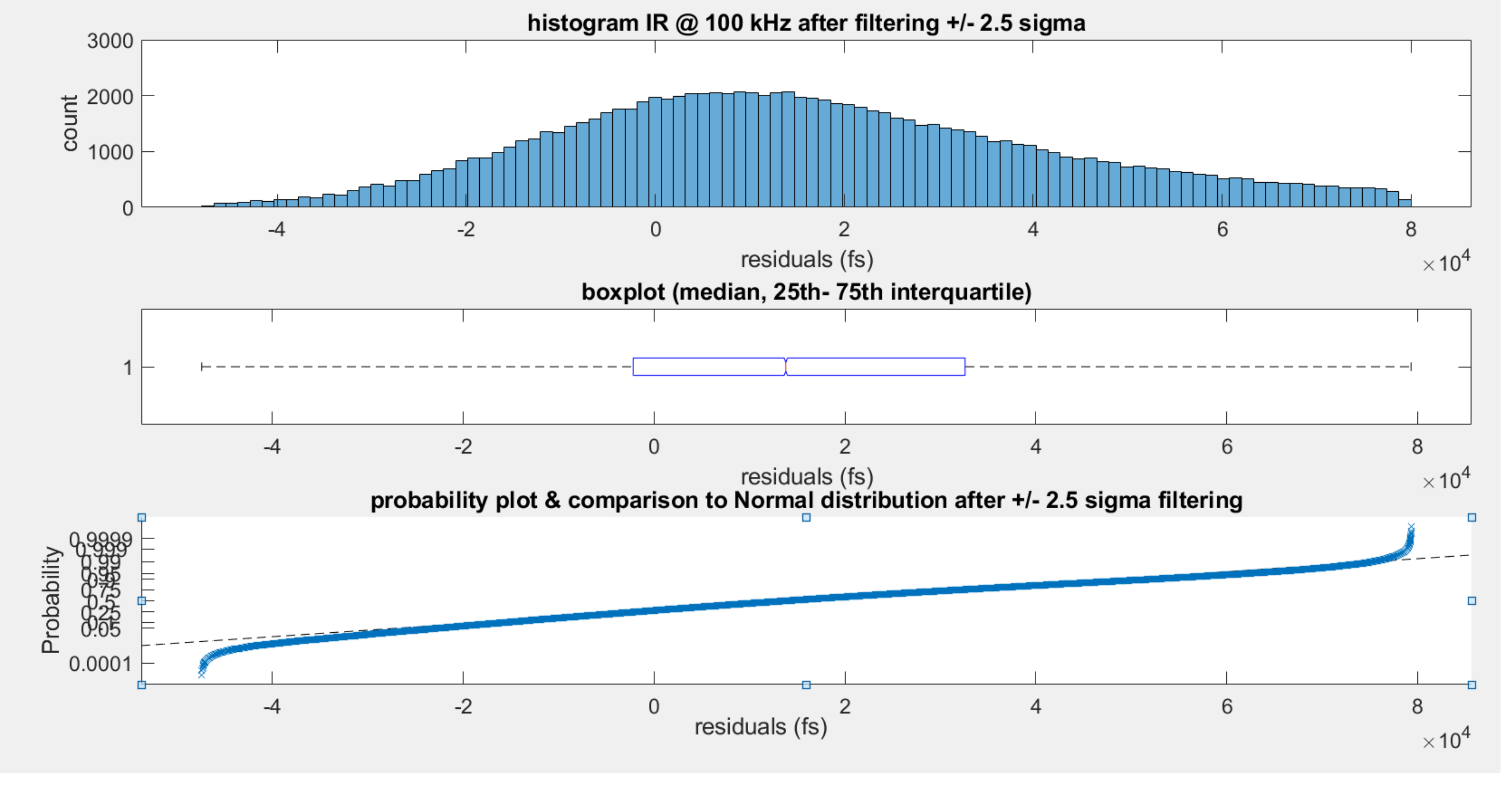


Skewness =0.9 ; Kurtosis = 4.2

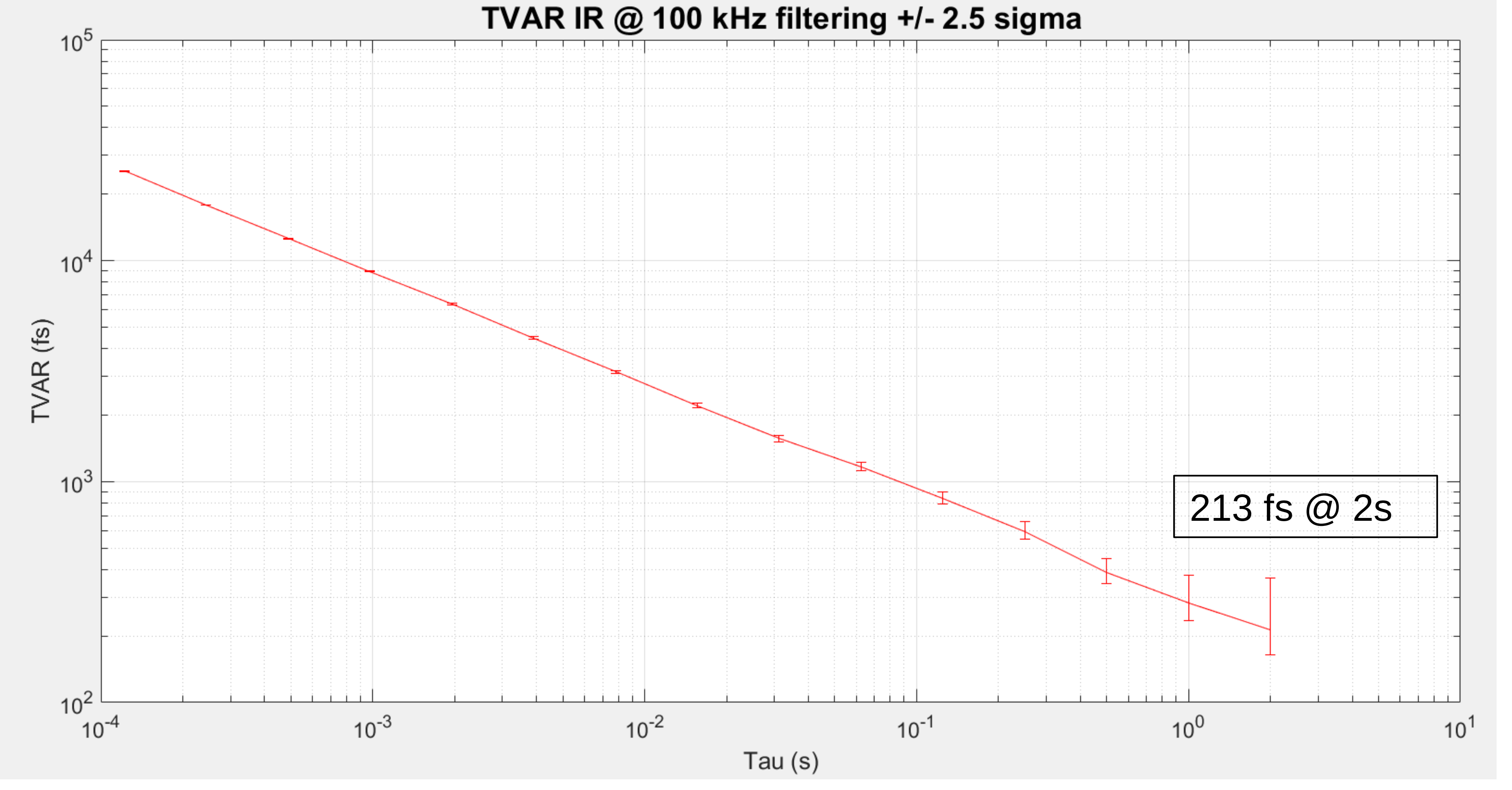
IR SPAD @ 100 kHz



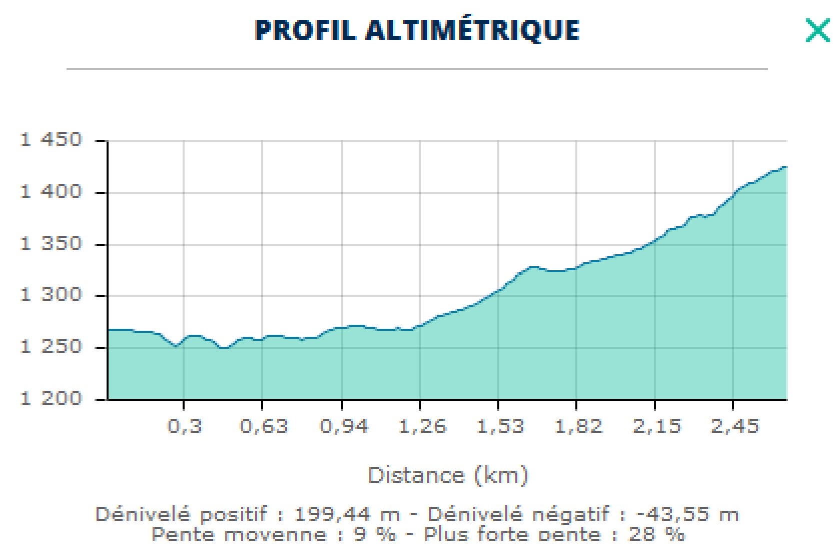
IR SPAD @ 100 kHz



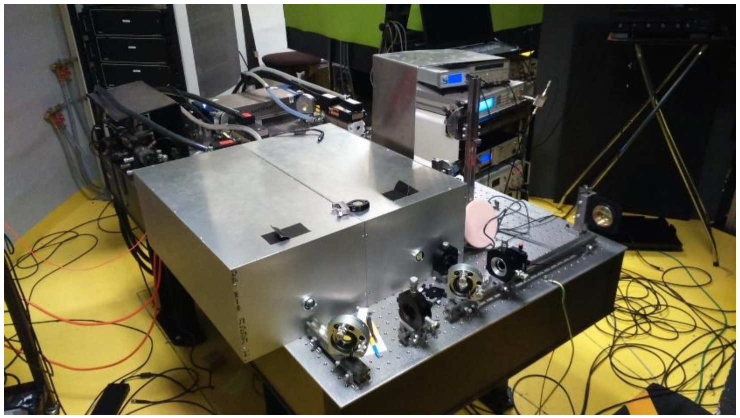
IR SPAD @ 100 kHz

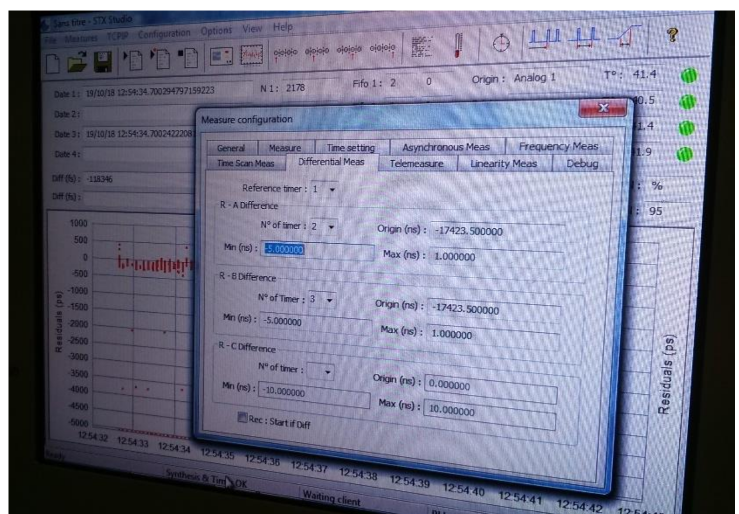


High repetition rate on a ground-ground link

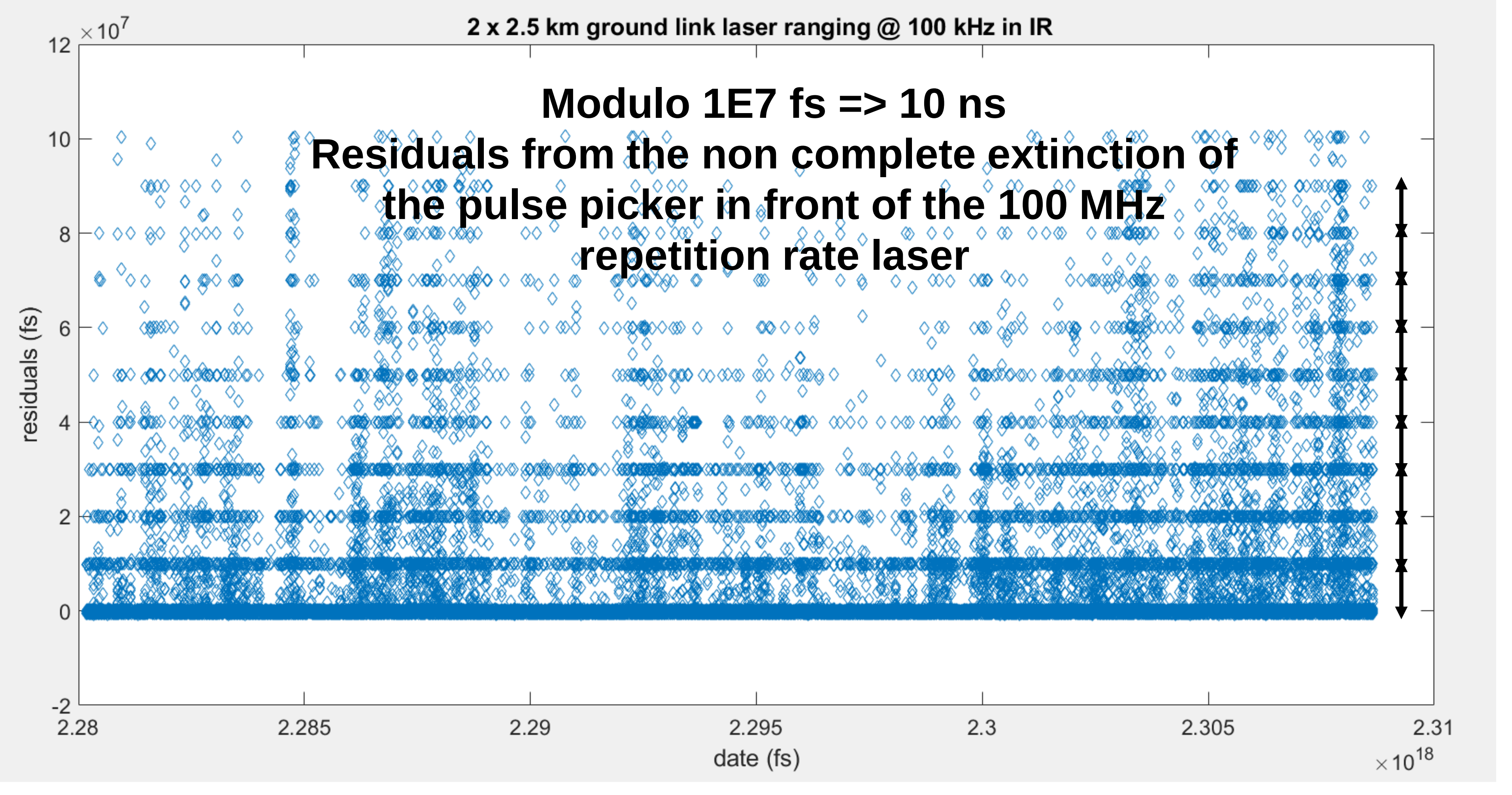


Laser ranging on a fixed target at a distance of 2.5 km @ 100 kHz at 1064 nm





Laser ranging on a fixed corner cube at a distance of 2.5 km @ 100 kHz at 1064 nm



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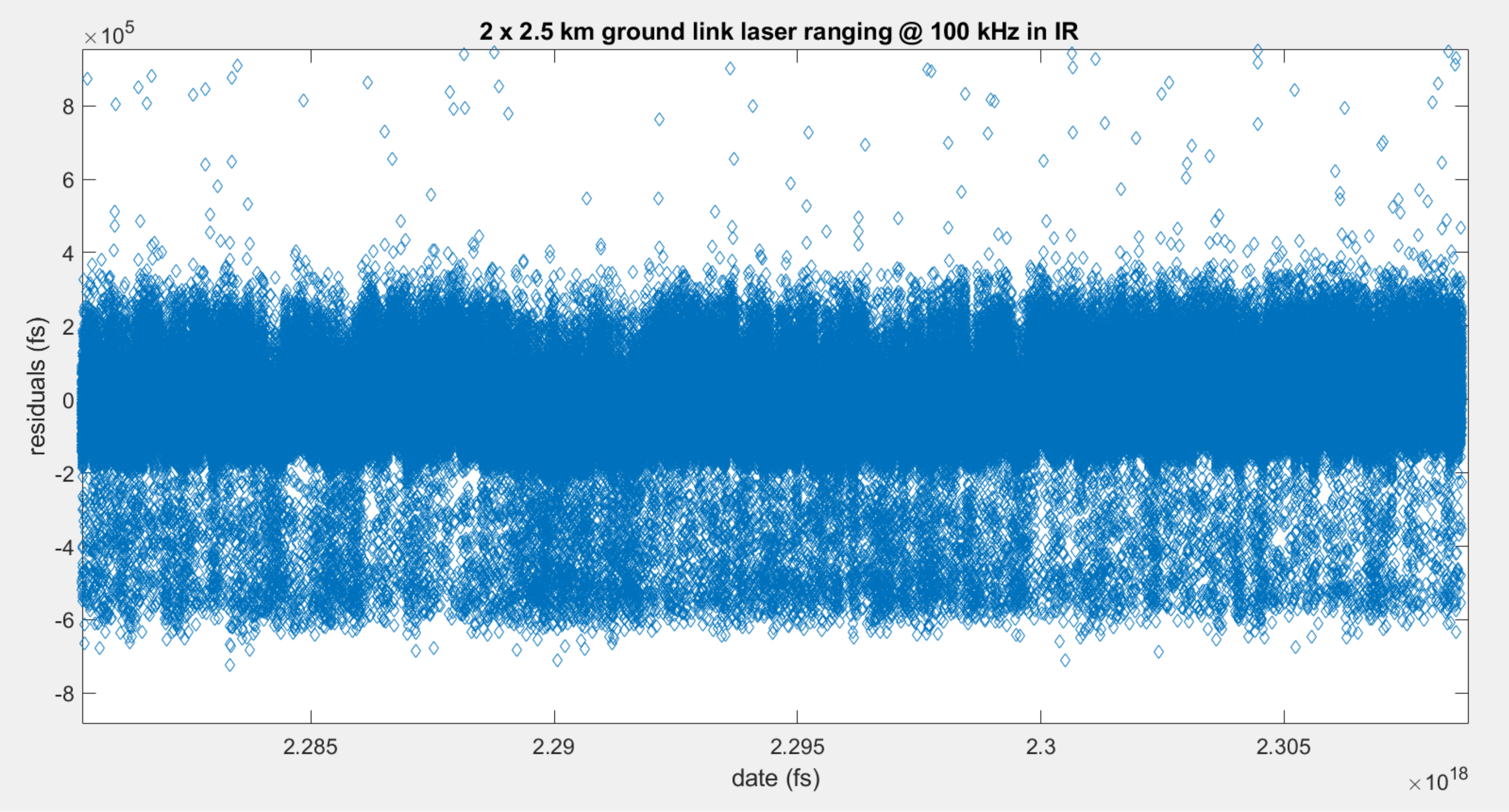

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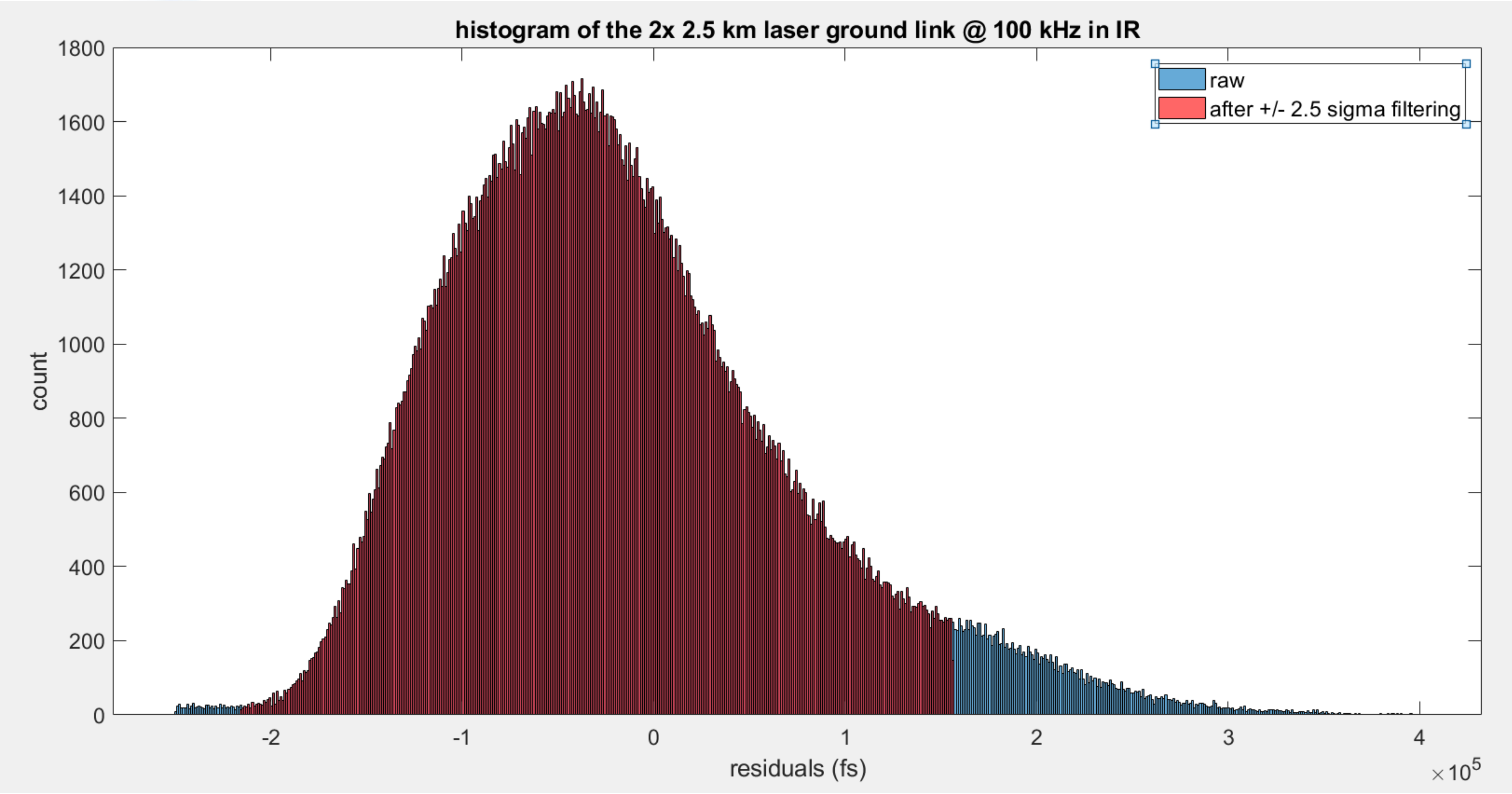

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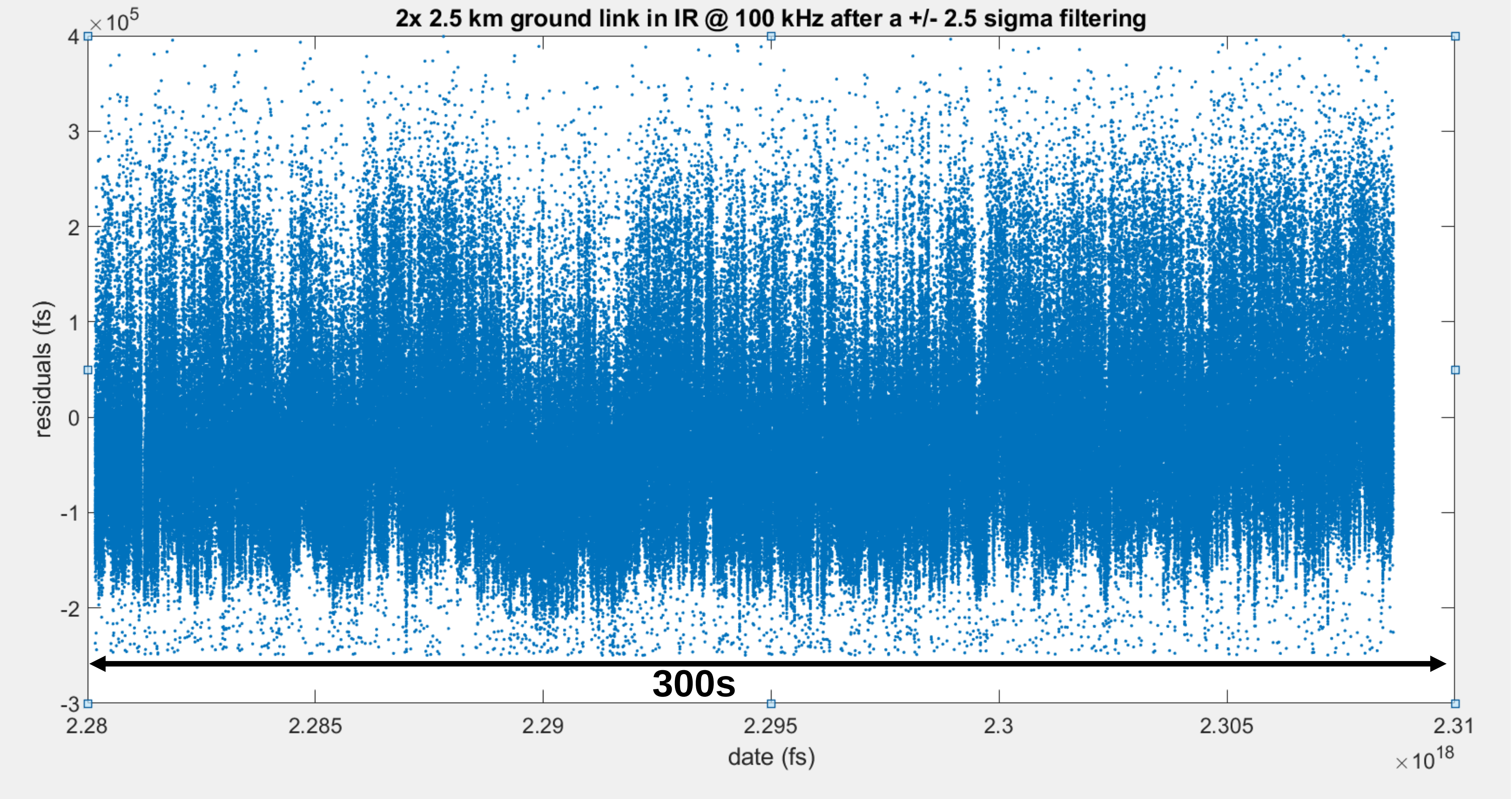

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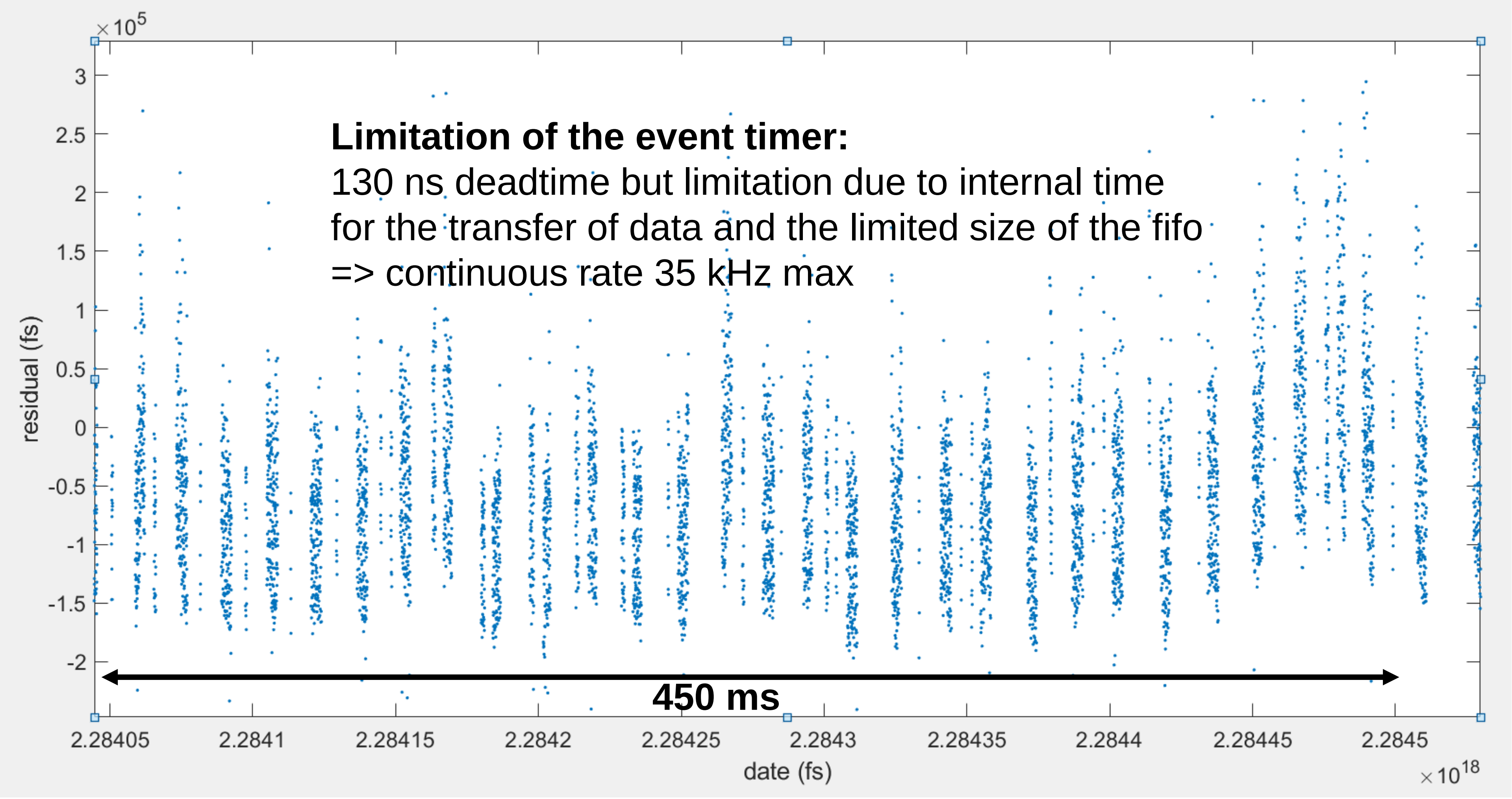
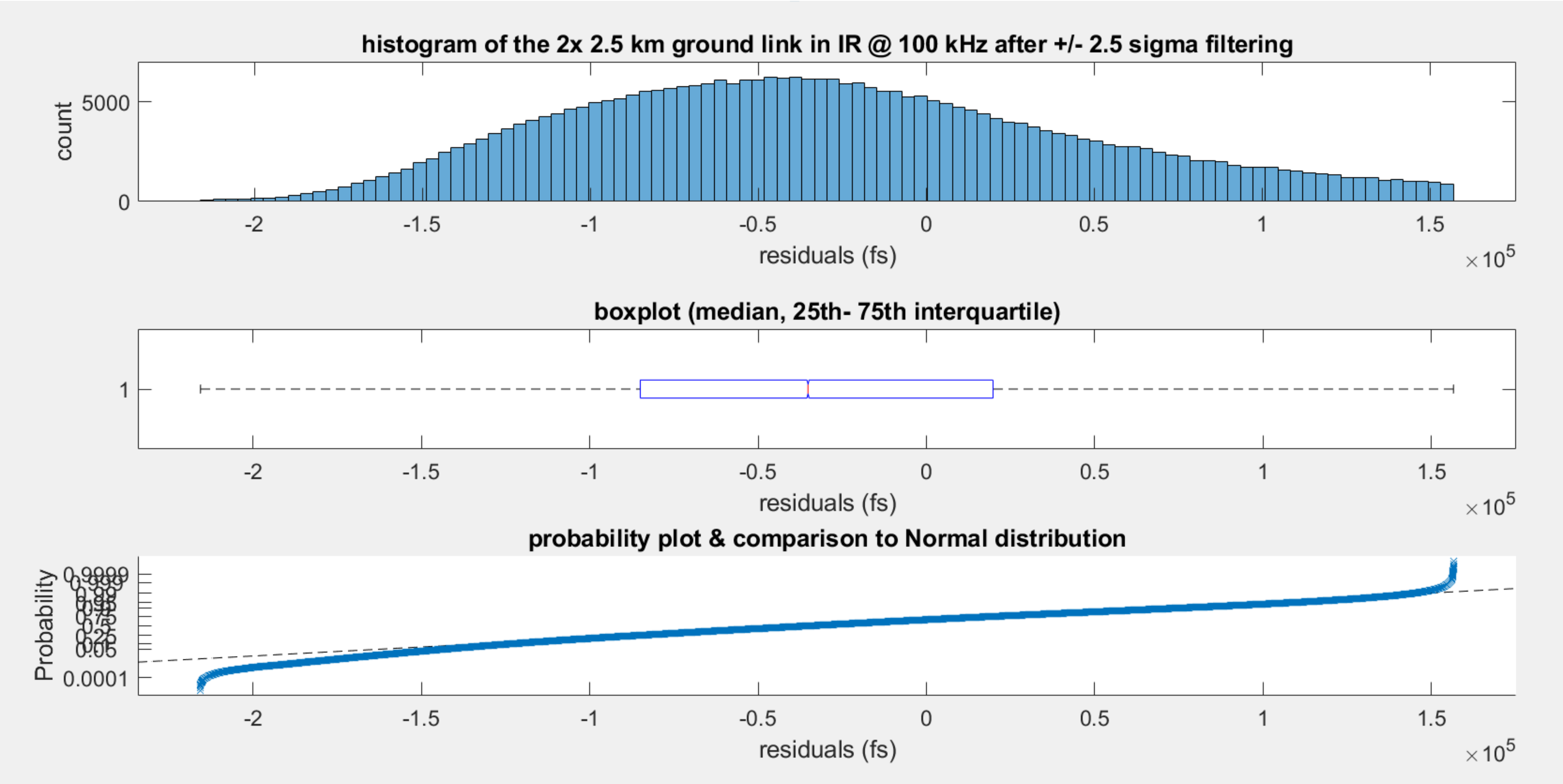
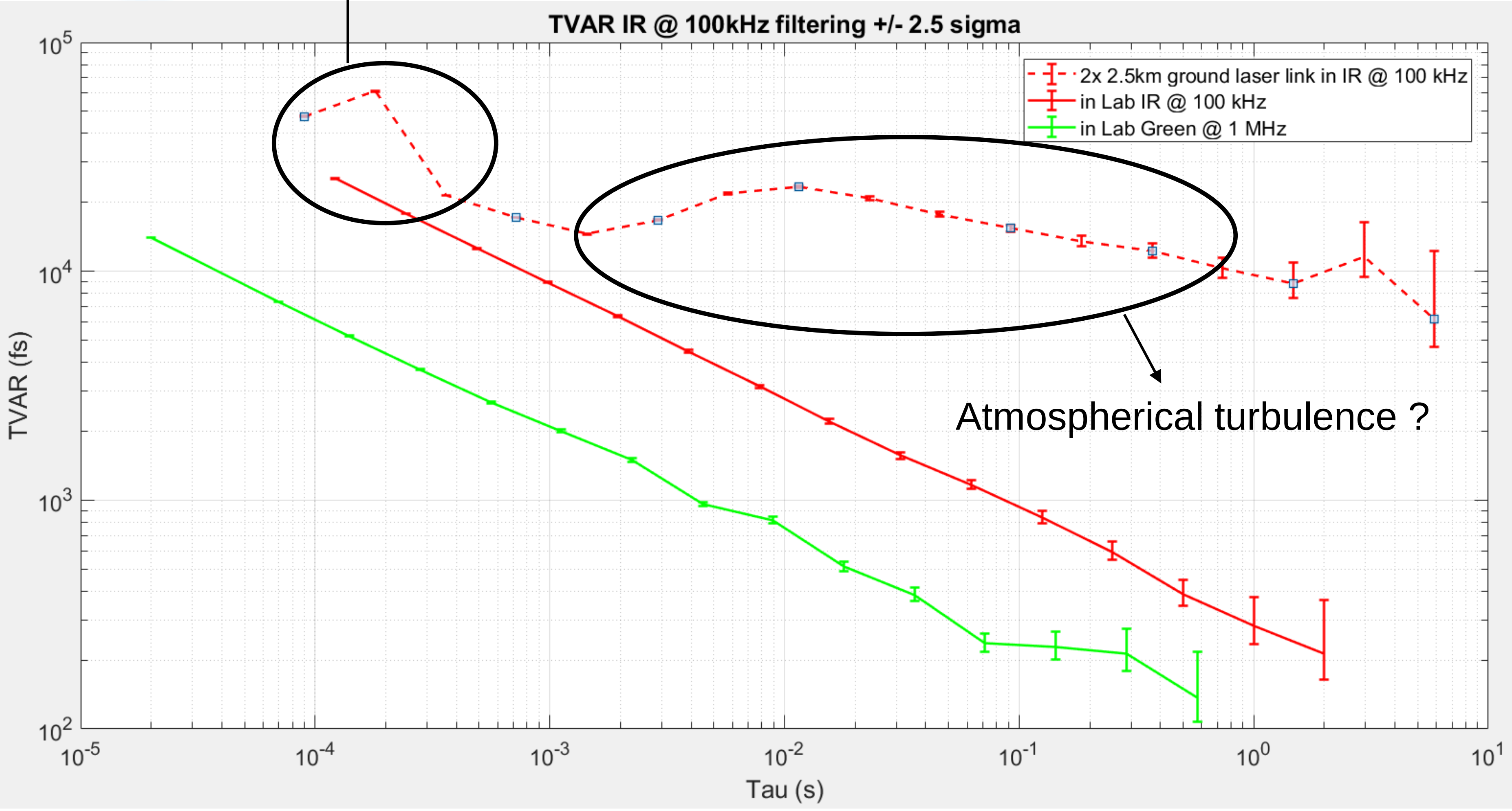


Laser ranging on a fixed corner cube at a distance of 2.5 km @ 100 kHz at 1064 nm

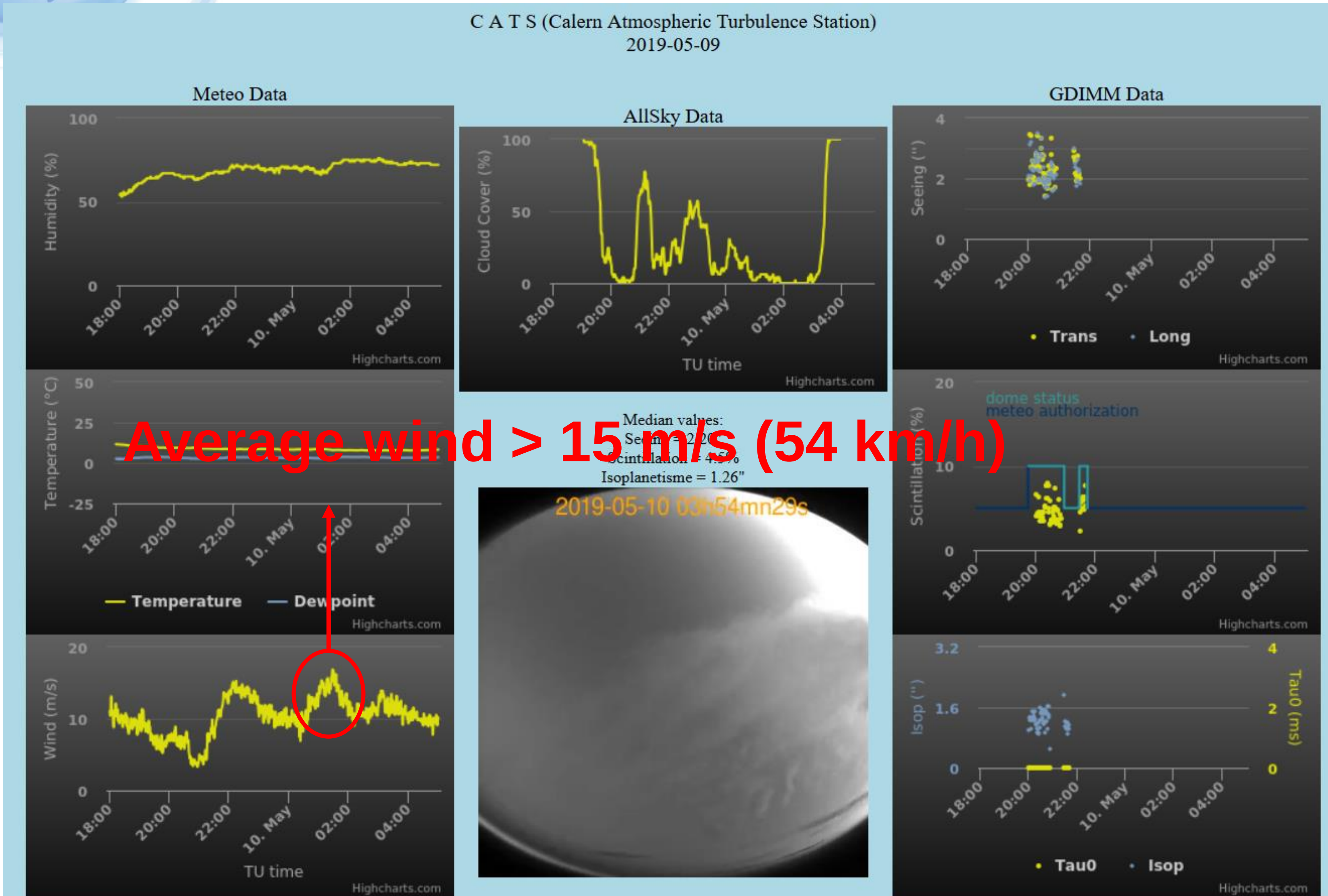


Laser ranging on a fixed corner cube at a distance of 2.5 km @ 100 kHz at 1064 nm

Maybe pb with the laser lock-in on the external clock



Laser ranging on a fixed corner cube at a distance of 2.5 km @ 100 kHz at 1064 nm



Conclusion & Perspectives

- We characterized two high repetition rate SPAD working:
  - at 1 MHz in Green
  - at 100 kHz in IR

- We measured a white noise behaviour for our two detection channels in Lab with:
  - 150 fs @ 0.6 s for the green SPAD
  - 213 fs @ 2s for the IR SPAD

- We will have to confirm that high repetition rate laser ranging allow to see the impact of the atmospherical turbulence on the range measurements

- Lot of works in perspective on all the SLR sub-system !!

- A new laser dedicated for SLR should arrive soon !

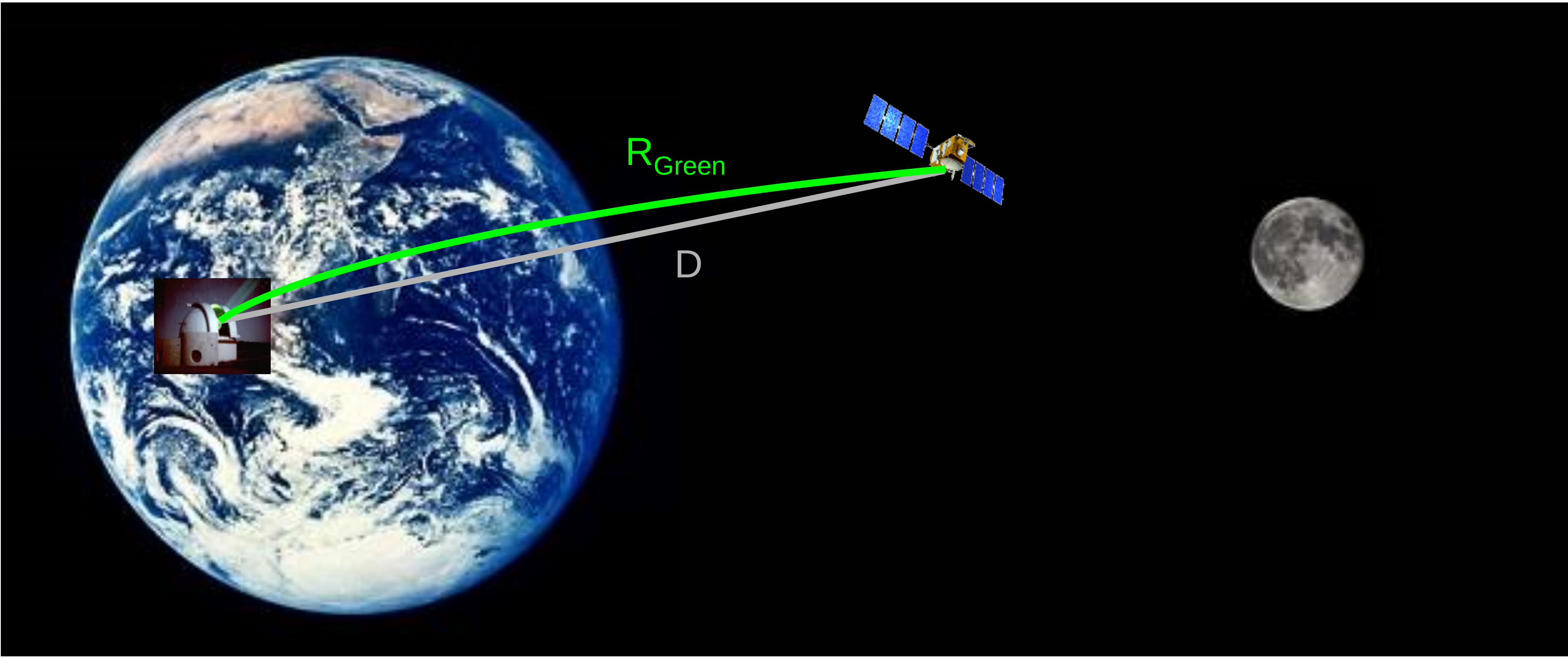
Thanks for your attention

Motivation

Currently:

$$2D = R_{Green} \quad \text{with} \quad R_{Green} = \frac{(t_{return} - tstart).c_0}{n(\lambda, T, Pv, Pa, CO_2)}$$

Unknown parameter
=> uncertainty at the cm level

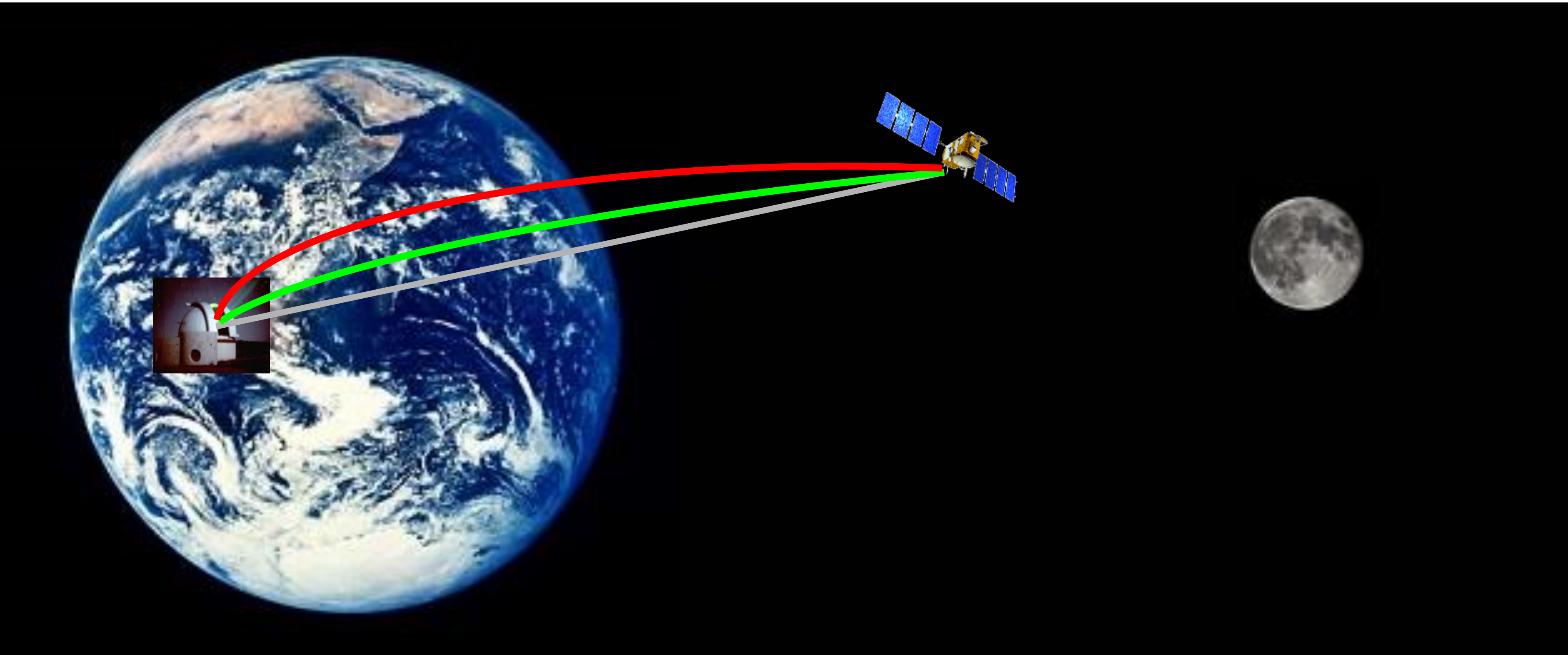


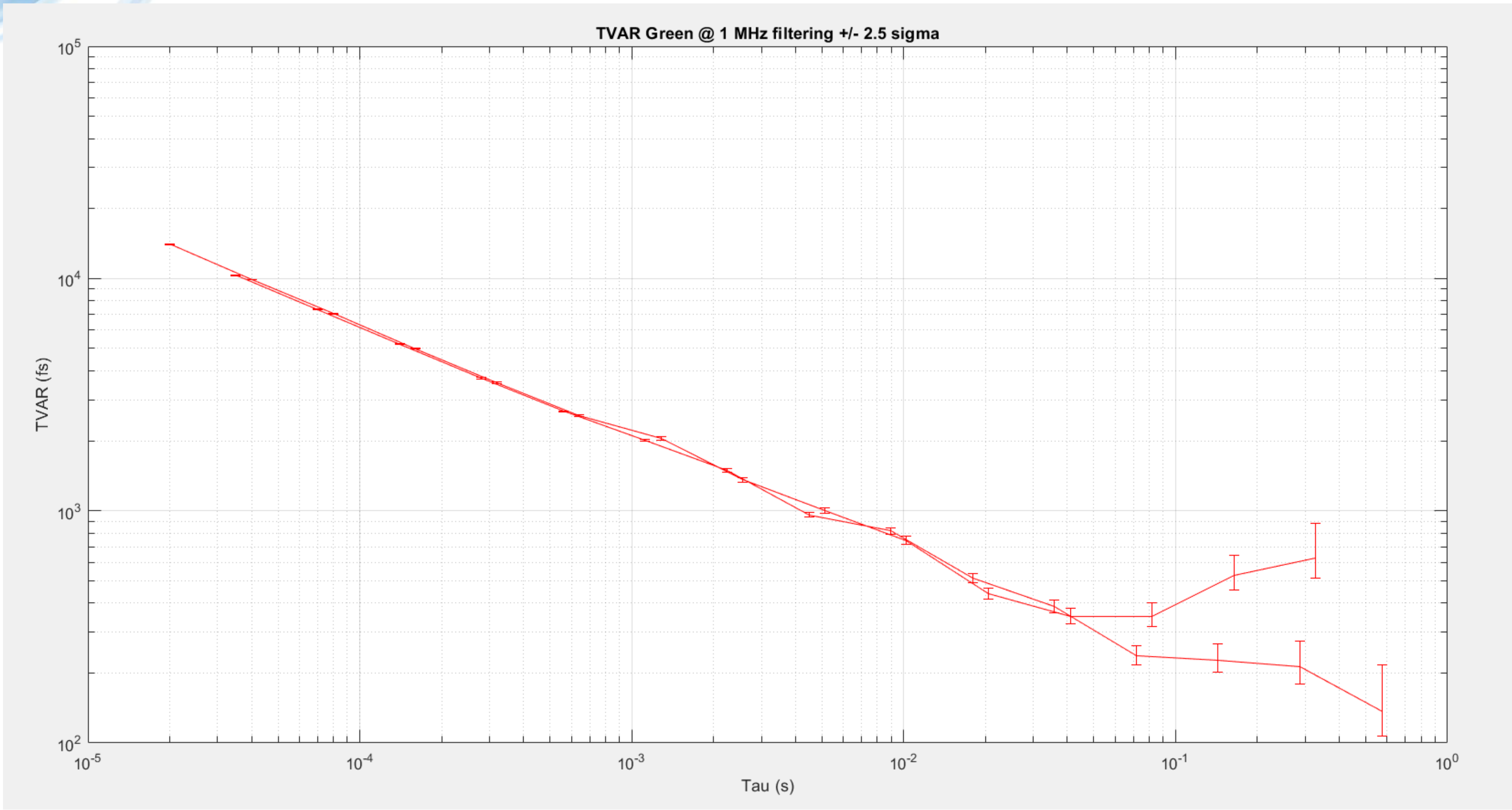
Motivation

Our objective: **2 colors measurement at the mm level**

$$2D = R_{Green} + a\,(R_{Green} - R_{IR})$$

Correction term => Dispersion effect (due to dry atmosphere)




TVAR Green @ 1 MHz filtering +/- 2.5 sigma
TVAR (fs)
Tau (s)
10^5
10^4
10^3
10^2
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0

Improve accuracy in SLR

$$D = \frac{(t_{arrival} - t_{depart}).c}{2}$$

avec $c = \dfrac{c_0}{n(\lambda, T, Pv, Pa, CO_2)}$

Idea of 2 colors
(K. B. Earnshaw and E. Norman Hernandez, 1972 ; Abshire, 1980)

Send simultaneously pulses at 2 different wavelengths.

Not used routinely by most of the ILRS stations:
- *Technological limits*
- *Global performances of the same order of index models*

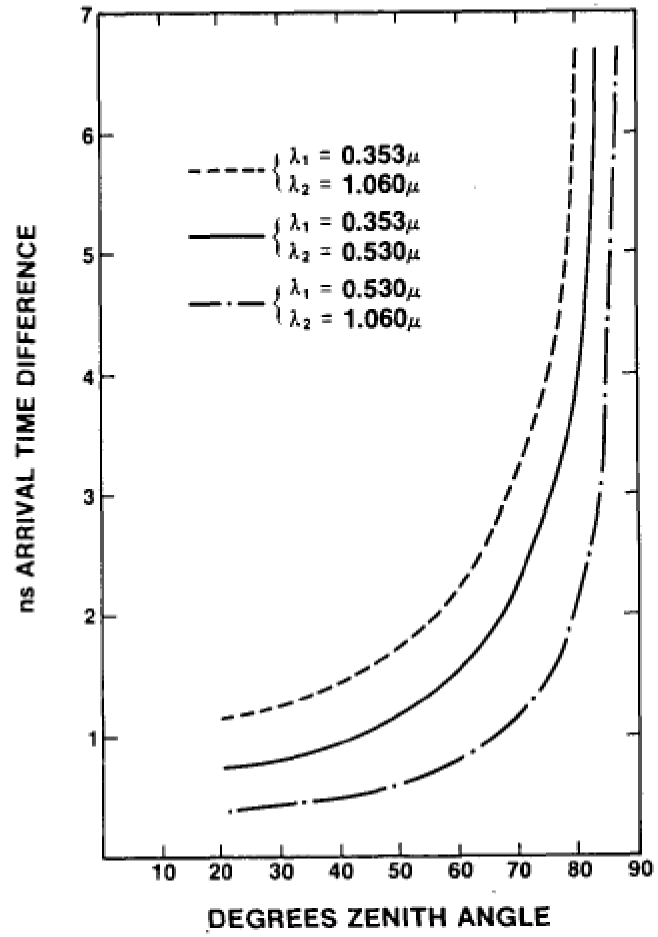
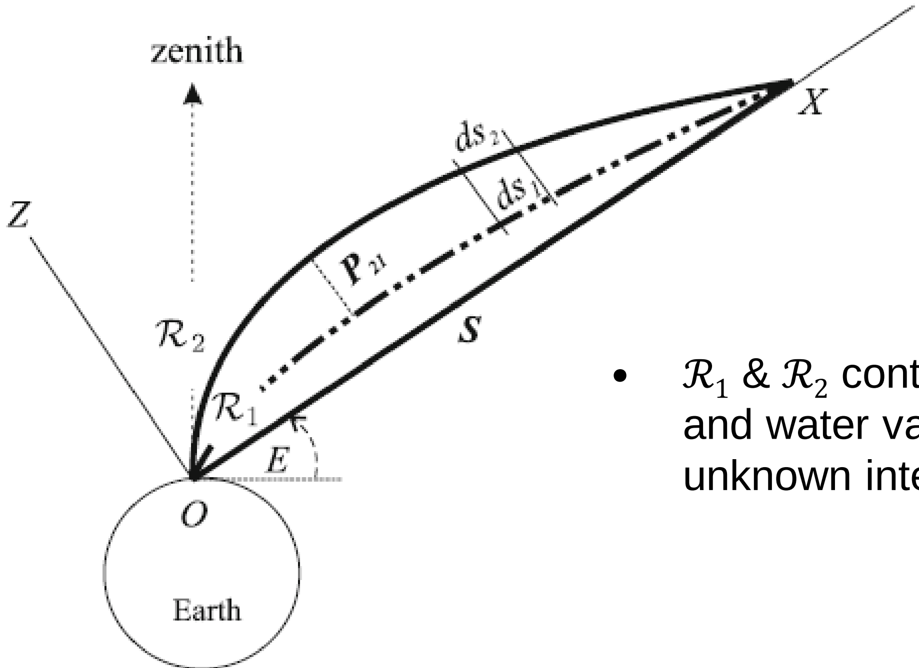


Fig. 3. Differential atmospheric delay time for a one-way traversal vs zenith angle for the three possible pulse pairs.

J. B. Abshire, October 1980 / Vol. 19, No. 20 / APPLIED OPTICS

Improve accuracy in SLR



From D. D. Wijaya et Al., Springer Verlag, 2011

- $\mathcal{R}_1 = \int_{p1}^{\cdot} n(f_1, \overrightarrow{r_1}) ds_1$
- $\mathcal{R}_2 = \int_{p2}^{\cdot} n(f_2, \overrightarrow{r_2}) ds_2$

- $\mathcal{R}_1$ & $\mathcal{R}_2$ contains the same quantities of total atmospheric and water vapor density, the same curvature effects. The unknown integral $\int_{p1}^{\cdot} \rho_t(\overrightarrow{r_1}) ds_1$ can be rigorously eliminated

2 colors measurement

$$2S = R_1 + \nu(R_1 - R_2) + (\upsilon P_{21} - \kappa_1) + H_{21} SIWV$$

*P*21 represents the propagation corrections from the ray path *p*2 to *p*1
κ1 is the arc-to-chord correction for the ray path *p*1 which accounts for the curvature effect
*v t*he power of dispersion
*H*21 the water vapor factor
SIWV the slant integrated water vapor

Improve accuracy in SLR

Dispersion effect (term due to dry atmosphere)
Curvature of optical paths
Water vapor density effect

	En mm	En mm	En mm
E (°)	$\nu(\mathcal{R}_1 - \mathcal{R}_2)$	$(\nu P_{21} - \kappa_1)$	$H_{21} \cdot SIWV$
3	$-36{,}782.5 \pm 162.2$	-390.1 ± 11.3	30.8 ± 10.4
5	$-25{,}574.7 \pm 99.8$	-143.2 ± 3.6	19.8 ± 6.8
10	$-14{,}069.6 \pm 49.9$	-25.2 ± 0.6	10.4 ± 3.5
15	$-9{,}639.8 \pm 33.4$	-8.2 ± 0.2	7.0 ± 2.4
20	$-7{,}351.9 \pm 25.3$	-3.4 ± 0.1	5.3 ± 1.8
30	$-5{,}057.9 \pm 17.3$	-1.0 ± 0.0	3.6 ± 1.2
40	$-3{,}942.3 \pm 13.4$		2.8 ± 1.0
60	$-2{,}930.1 \pm 10.0$	<-0.3	2.1 ± 0.7
90	$-2{,}538.7 \pm 8.6$		1.8 ± 0.6

How to achieve millimetric accuracy in SLR with 2-colors measurements?

Millimeter accuracy possible with a significant precision improvement

Precision to reach at each wavelength

λ_1/λ_2 (µm)	$\sigma_{\mathcal{R}_1}$ (µm)	$\sigma_{\mathcal{R}_2}$ (µm)	σ_ν (−)	σ_{κ_1} (mm)	$\sigma_{P_{21}}$ (µm)	$\sigma_{H_{21}}$ ($m^3 kg^{-1}$)	σ_{SIWV} (kg m^{-2})
0.532/1.0684	47.16	45.03	6.61×10^{-4}	1	45.03	2.89×10^{-6}	7.4017
0.4235/0.847	76.60	71.15	3.80×10^{-4}	1	71.15	3.05×10^{-6}	7.5444

From D. D. Wijaya et al., Springer Verlag, 2011