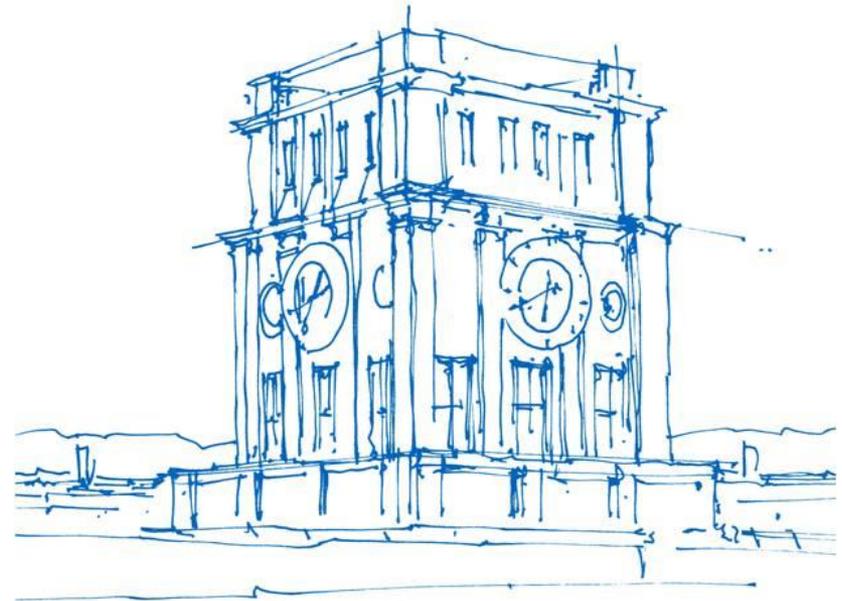# Simulation study on ELT time transfer

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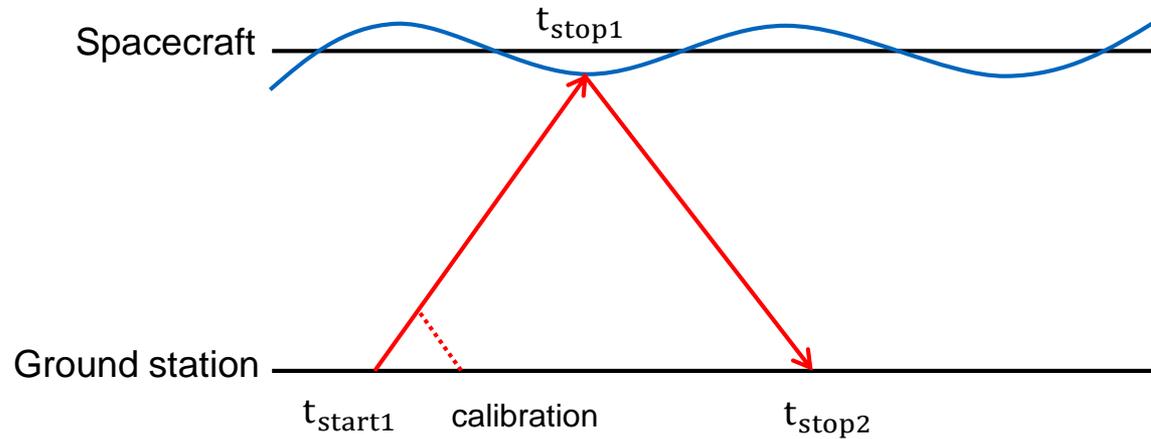
30th June 2017

Introduction

- Aim of ELT: Establishing of an optical time transfer between SLR station clocks and the ACES clock with picosecond accuracy.

- A Classical two-way (round trip) and an additional one-way optical link shall be established, based on timing via ultra-short laser pulses

- Space based ELT hardware: Single photon avalanche diode (SPAD), corner cube retro-reflector (CCR) and an event timer connected to the ACES time scale
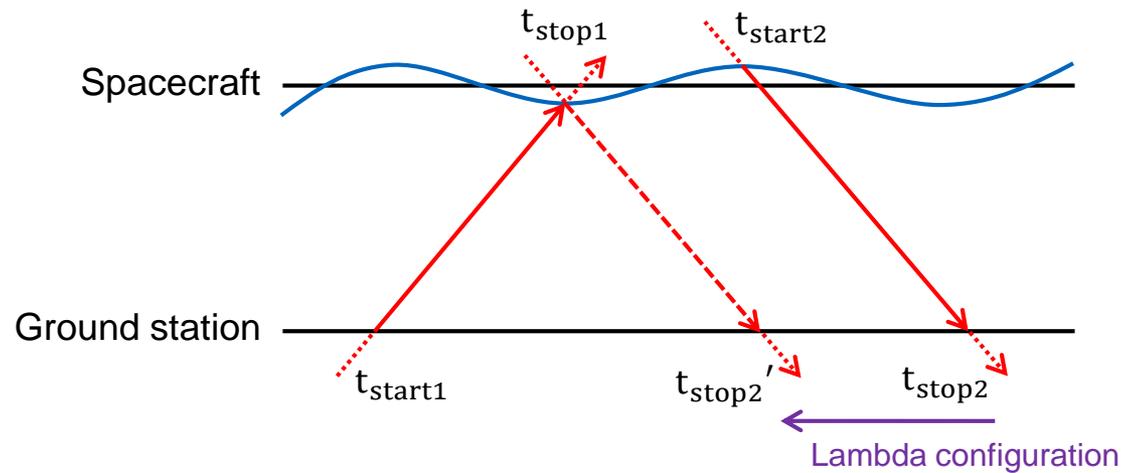
Principle of ELT

Optical link:

Microwave link:

Spacecraft t_{stop1}

Ground station t_{start1} calibration t_{stop2}

Spacecraft t_{stop1} t_{start2}

Ground station t_{start1} t_{stop2}' t_{stop2}

Lambda configuration

One and two way signal time of flight

- One way:

$$tof = R_{tr} + \tau_{troposphere} + \tau_{Sagnac} + \tau_{Shapiro} + \tau_{attitudeDetector}$$
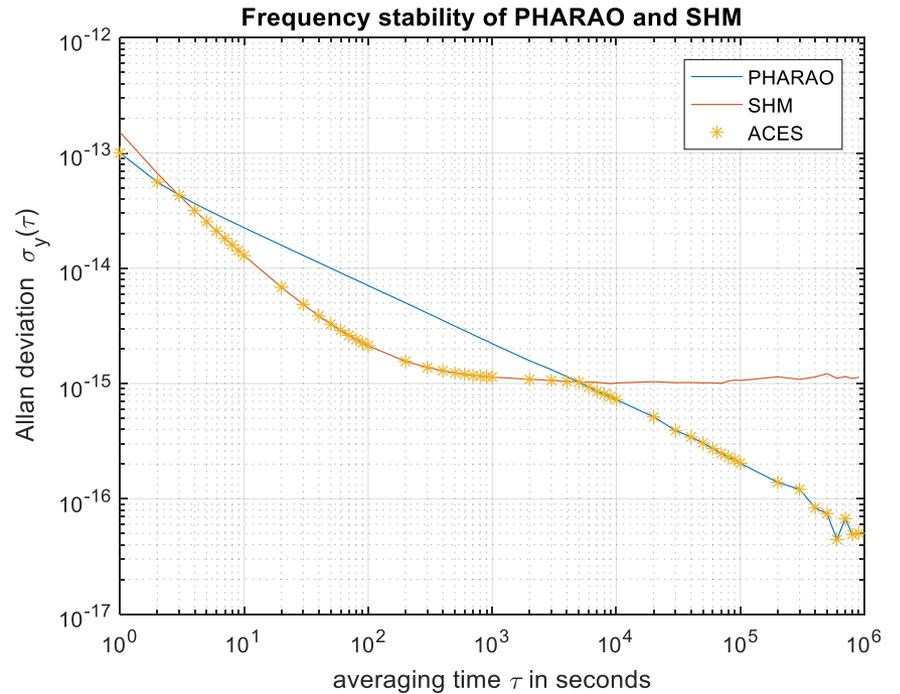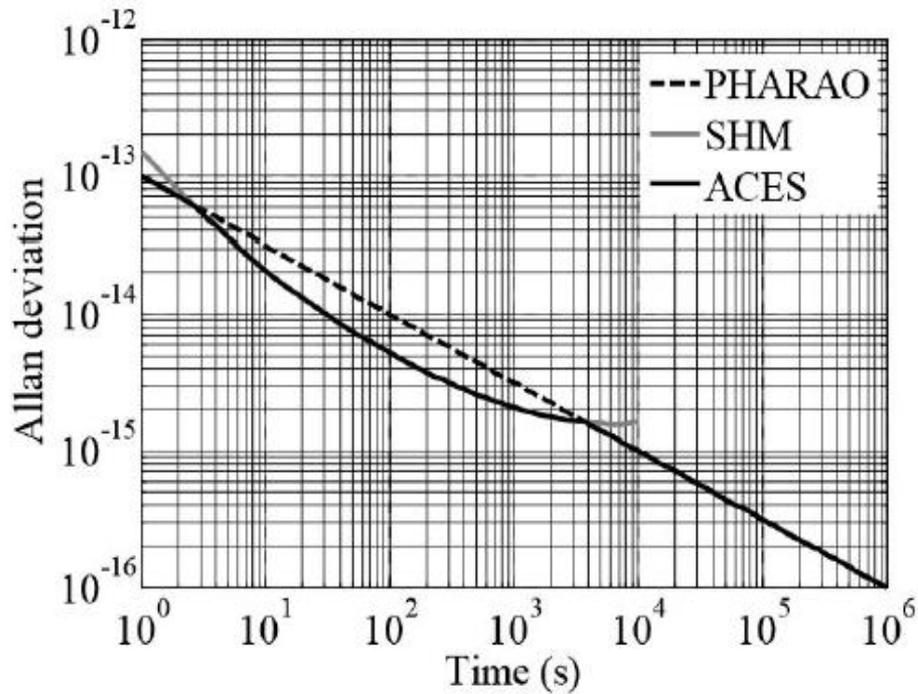
- Two way:

$$tof = 2 * \left(R_{tr} + \tau_{troposphere} + \tau_{Shapiro} + \tau_{attitudeReflector}\right) + \tau_{Reflector}$$

with R_{tr}: Distance between space and ground station references

Simulation and evaluation program

- Input: Simulated ISS orbit data as predictions

- Possibility to add disturbances in radial, along-track and cross-track direction
  ➡ true orbit

- Customizable parameters (for instance):
  - one- and two-way detection probability
  - detector gate width
  - background noise rate
  - laser pulse length and detector parameters
  - repetition rate of the laser
  - satellite body rotation
  - detector and reflector offsets relating to center of mass
  - clock offset and noise
  - station specific parameters (e.g. station range bias and meteorological data)

Simulation of the ACES clock

Simulation and evaluation program

- Evaluation work flow:

  - Two-way ranging

  - Correction of orbit disturbances

  - One-way ranging

  - Filtering of ELT detector residuals
    - Exponential fit
    - Pre-filtering around 1 ns
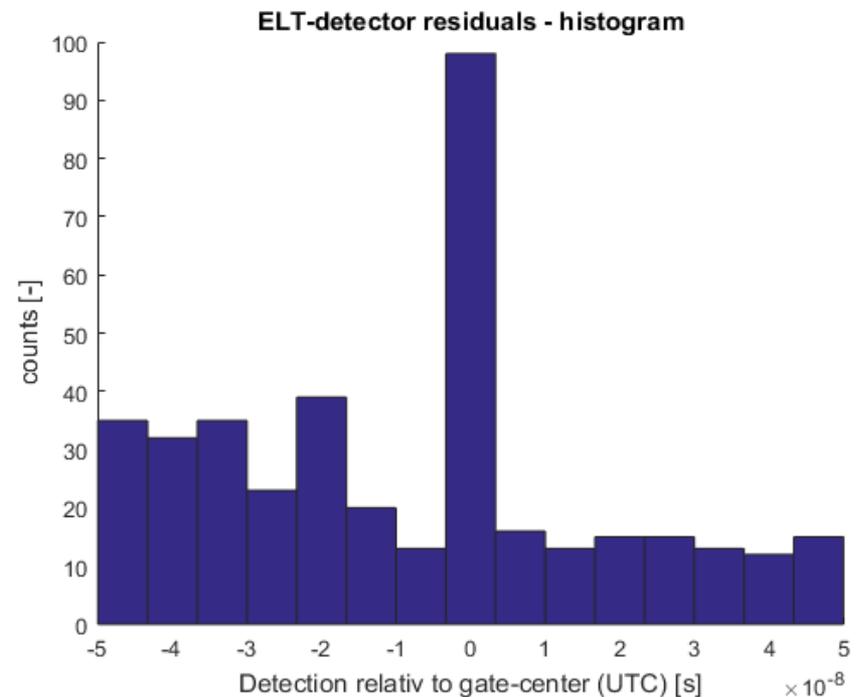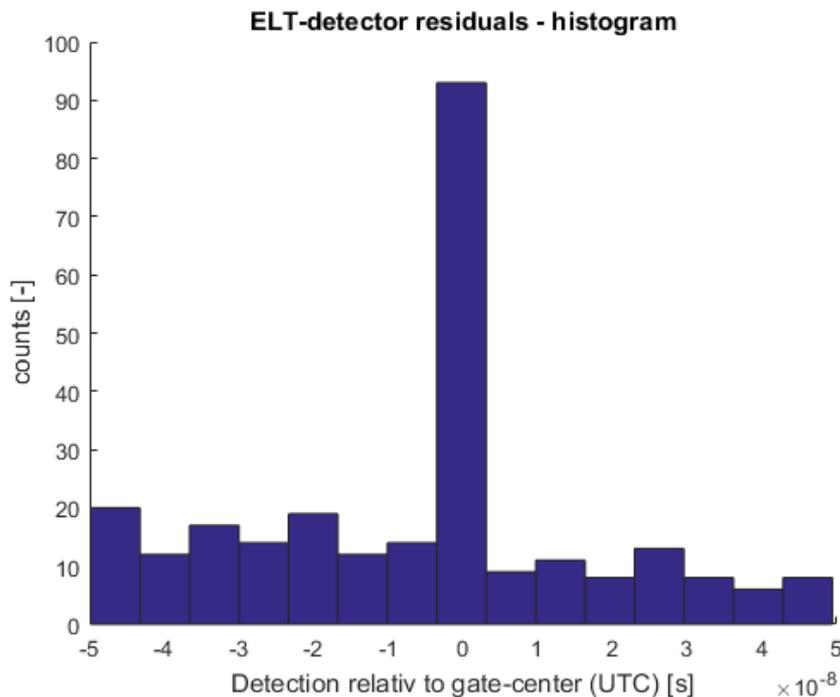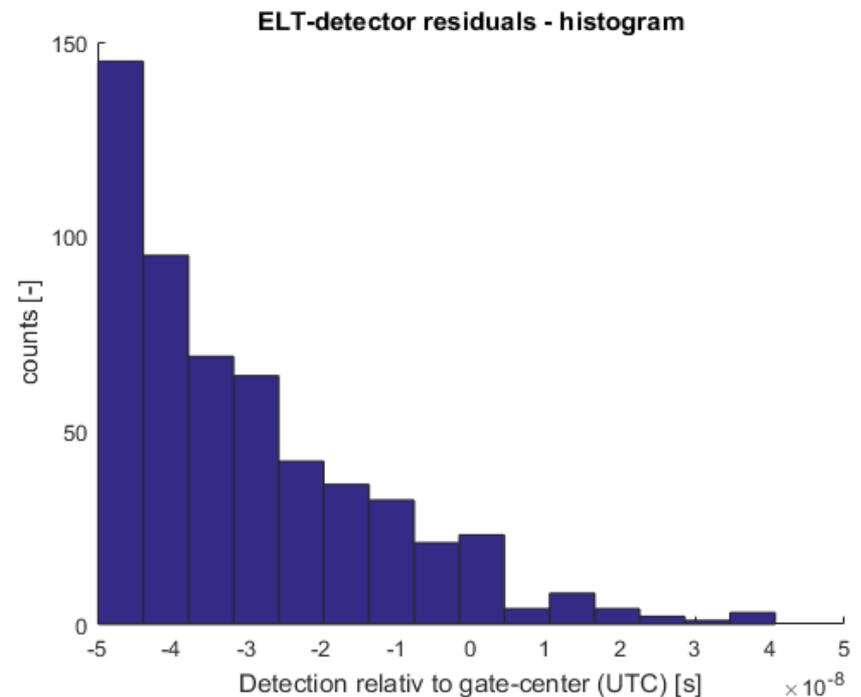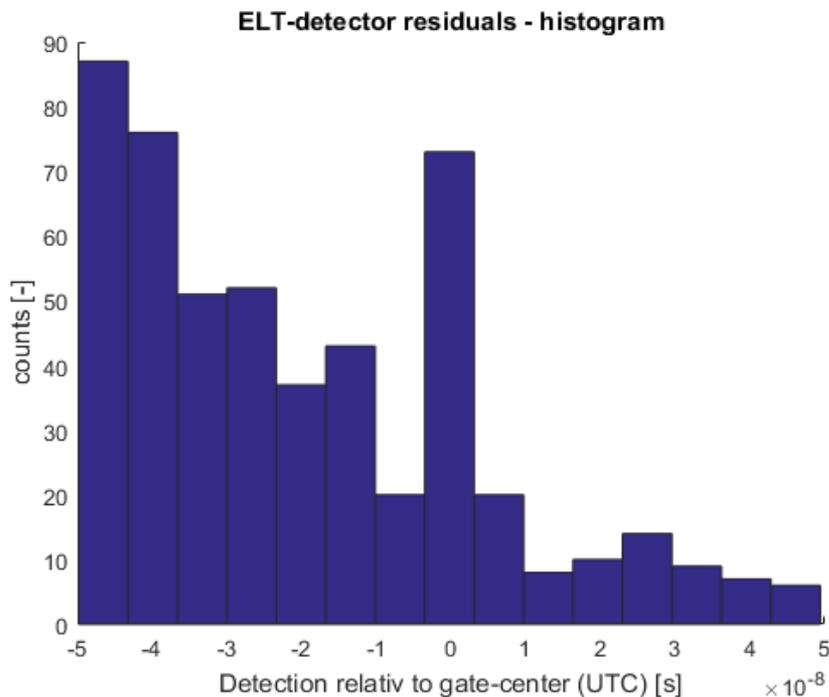   - Gaussian curve according to 2,3 σ

    - Calculating data triplets

Simulation and evaluation of background noise

Background noise rate [1/s]:

$5 * 10^6$ $1 * 10^7$

Simulation and evaluation of background noise

Background noise rate [1/s]:
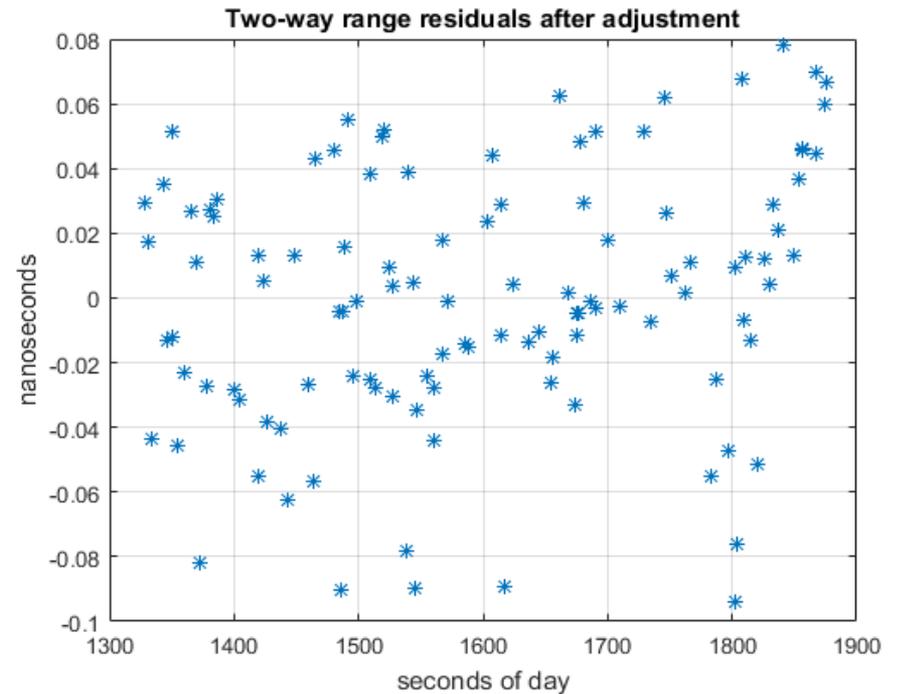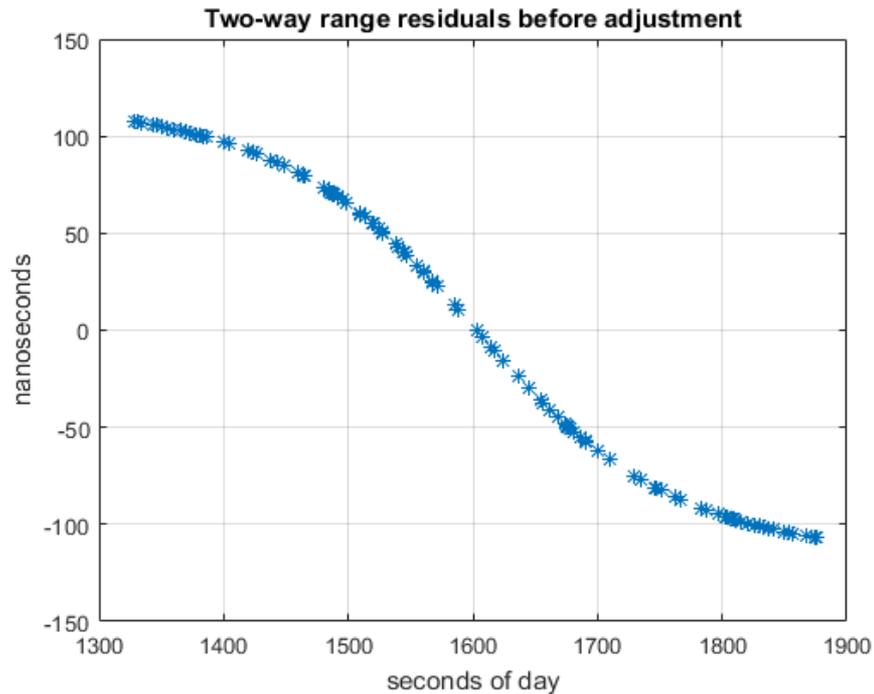
$$2{,}5 * 10^7$$

$$5 * 10^7$$

Simulation and evaluation of orbit disturbances

- Along-track error 2 m
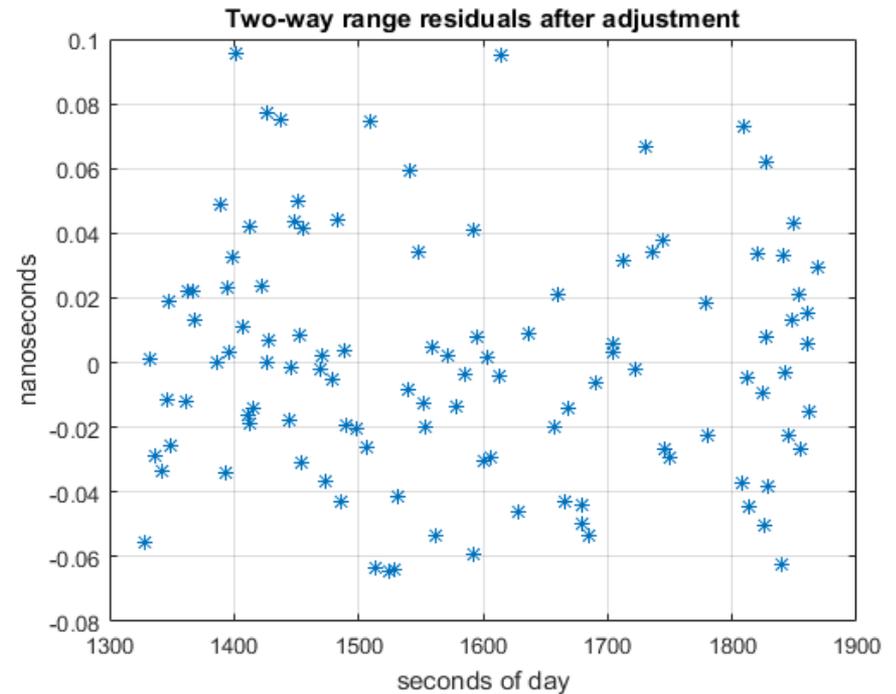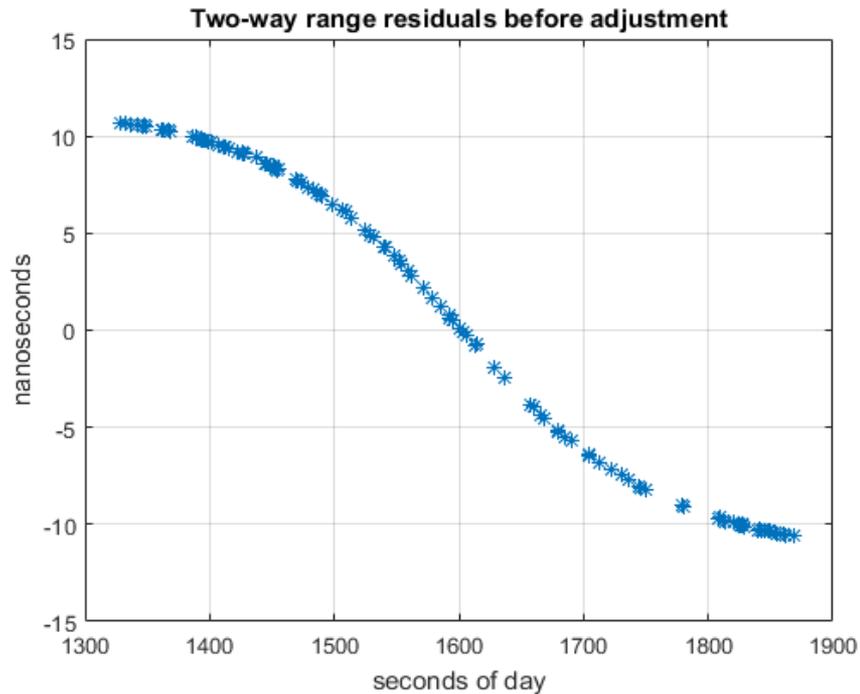
Two-way range residuals before adjustment

Two-way range residuals after adjustment

Simulation and evaluation of orbit disturbances

- Along-track error 20 m

Two-way range residuals before adjustment

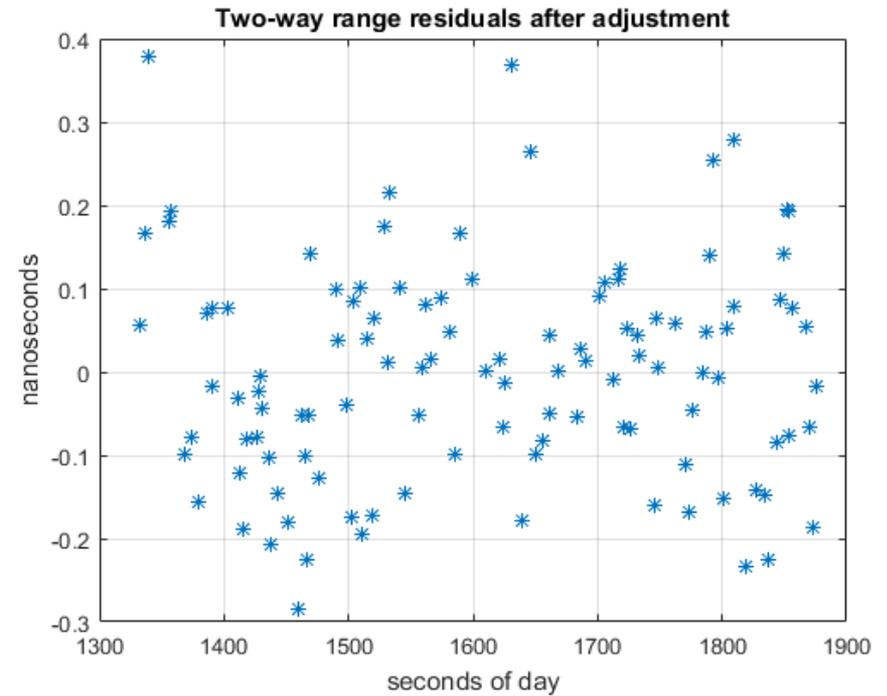Two-way range residuals after adjustment

Simulation and evaluation of orbit disturbances

- Along-track error 50 m
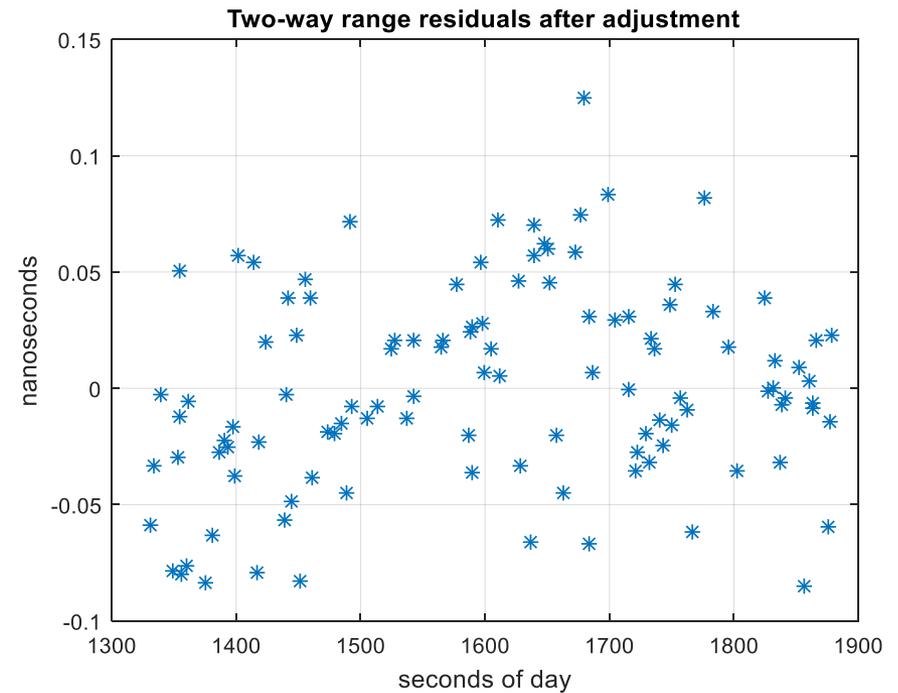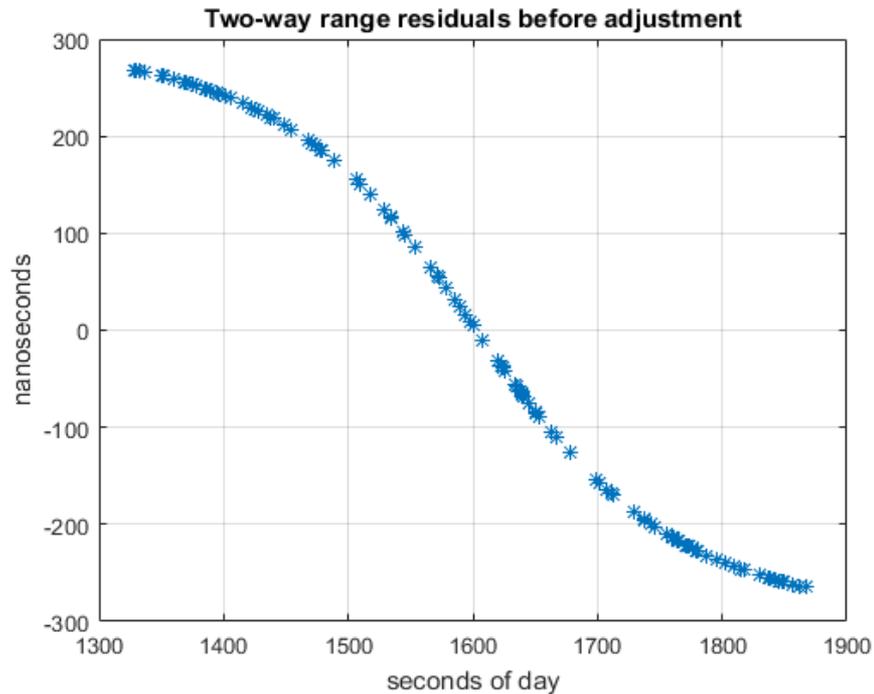
Laser pulse length
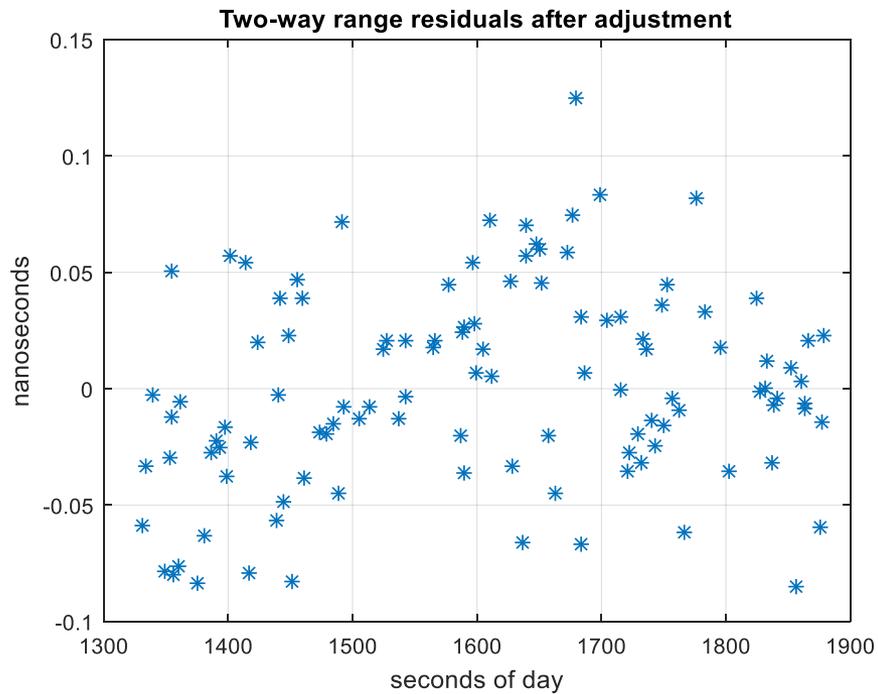
20 ps

100 ps

One-way ranging and filtering
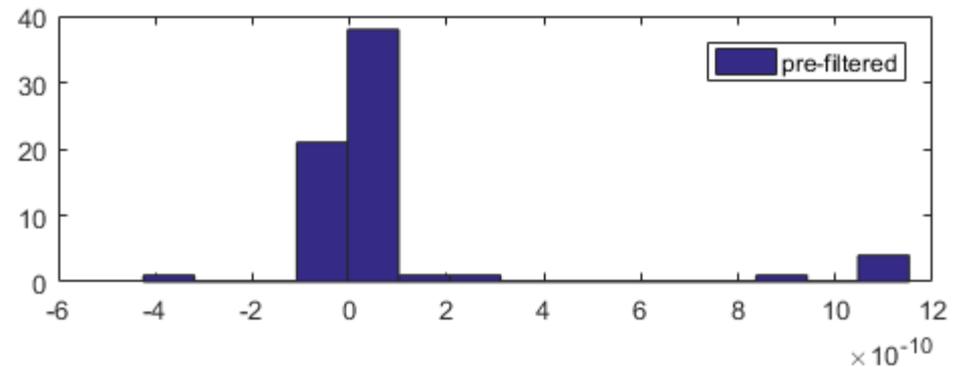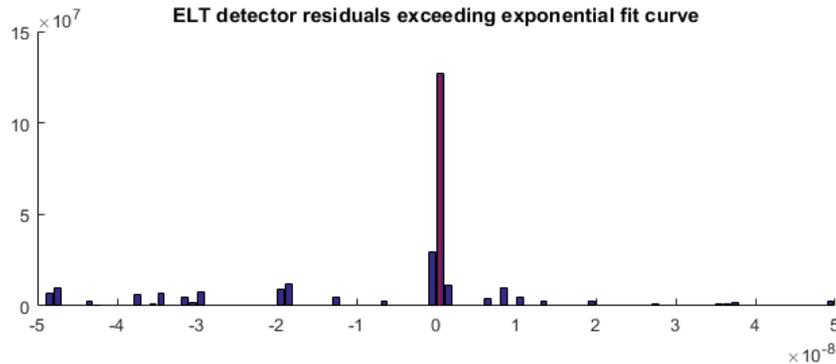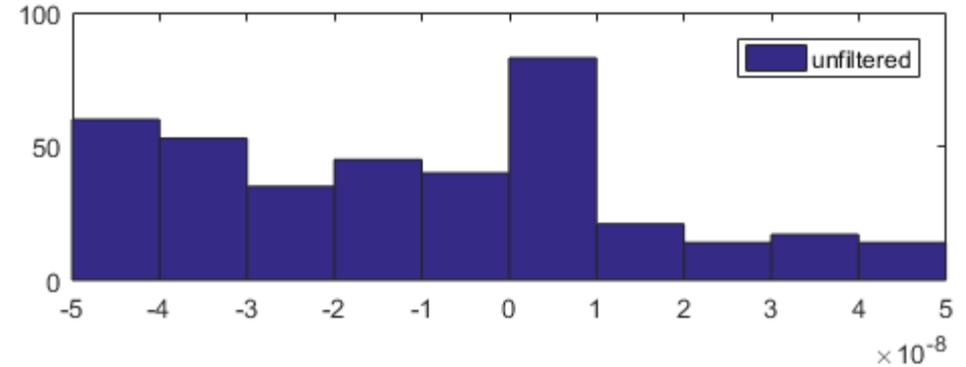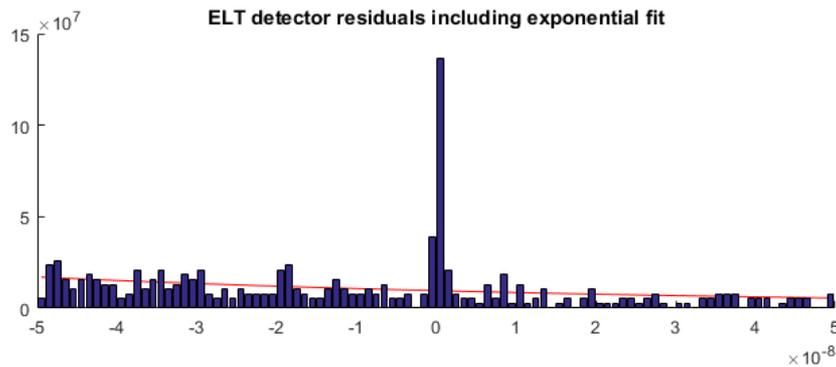
- Background noise rate: $1 * 10^7 \frac{1}{s}$
- Along track error: 50 m
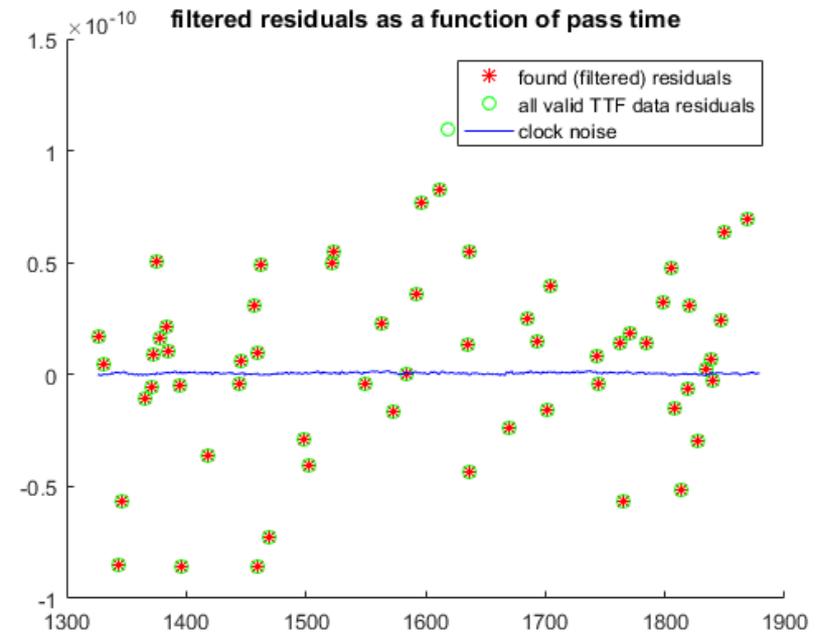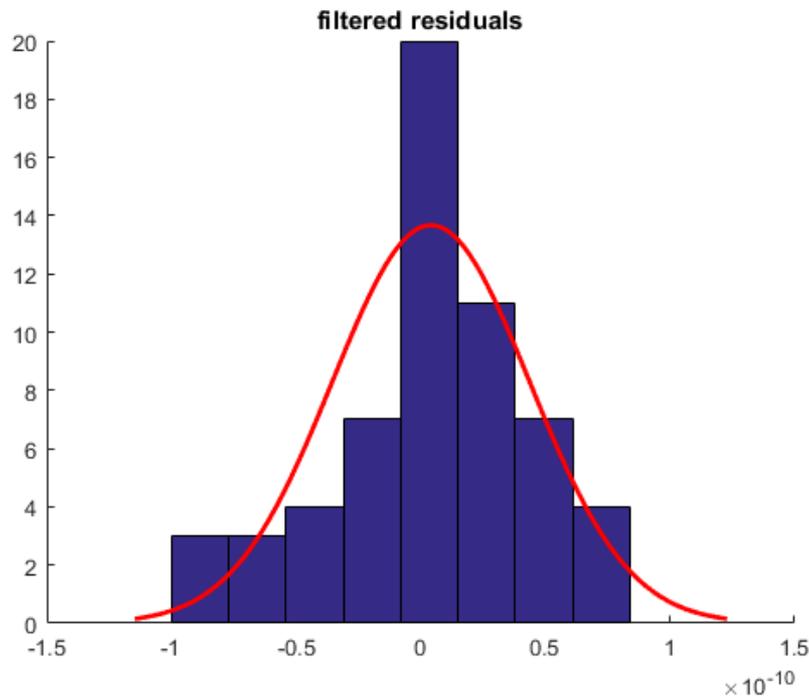- Laser pulse length: 20 ps
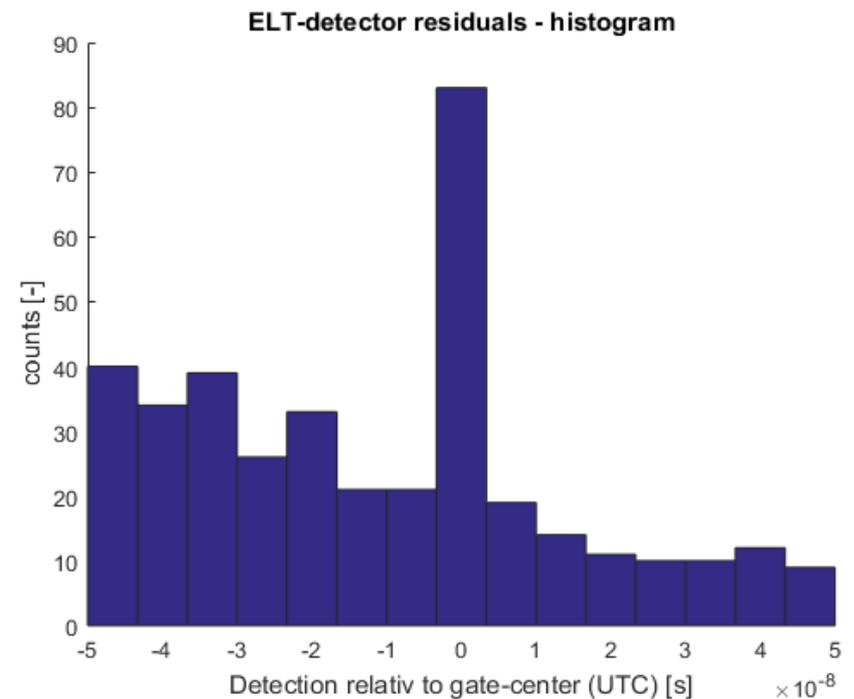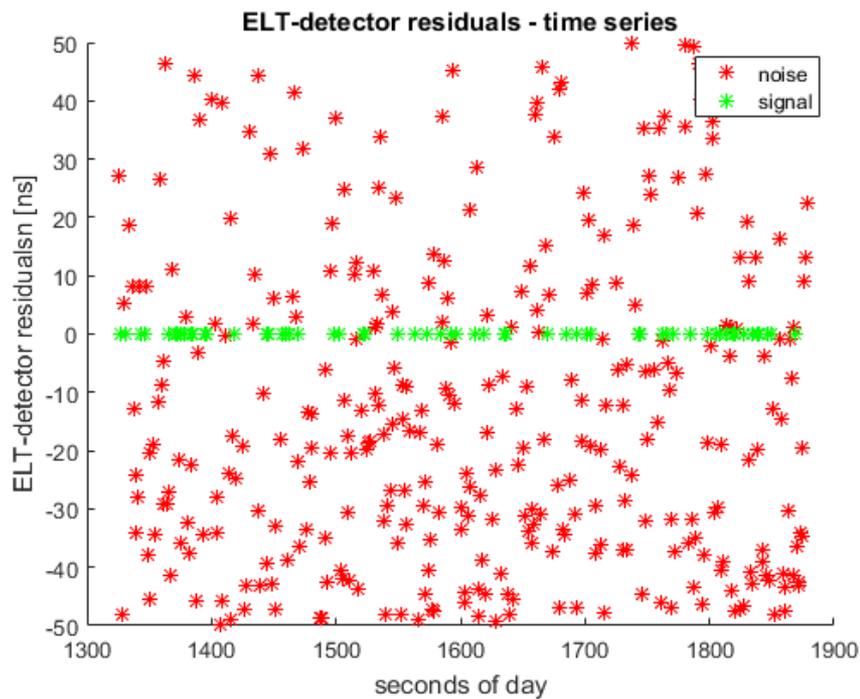
One-way ranging and filtering

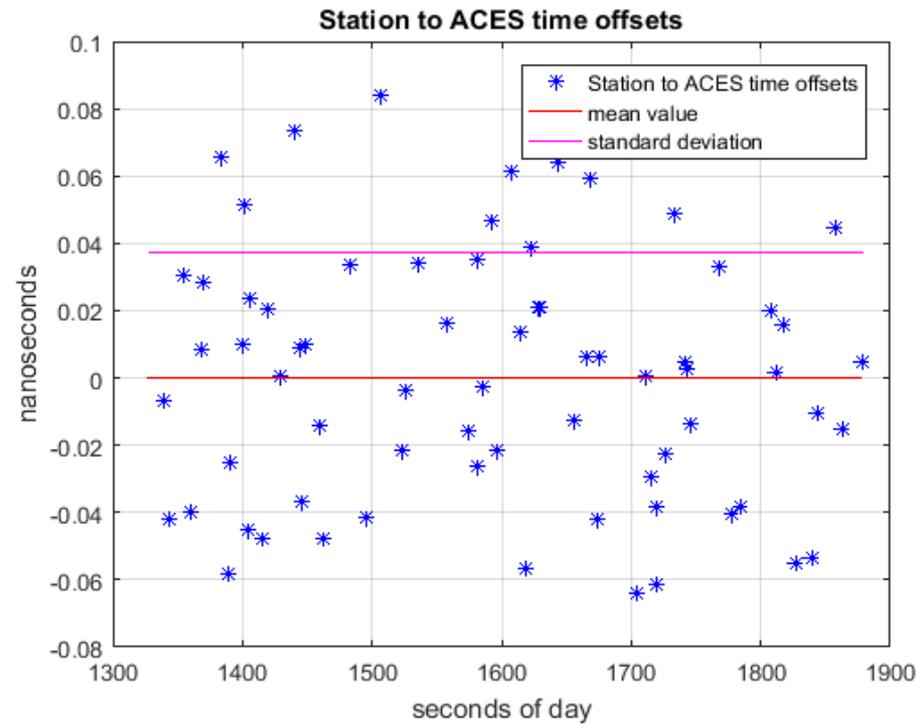- Detector residuals pre-filtering: Exponential fit and cutting around 1 ns

One-way ranging and filtering

- Gaussian curvature: Filtered residuals according to 2,3 σ
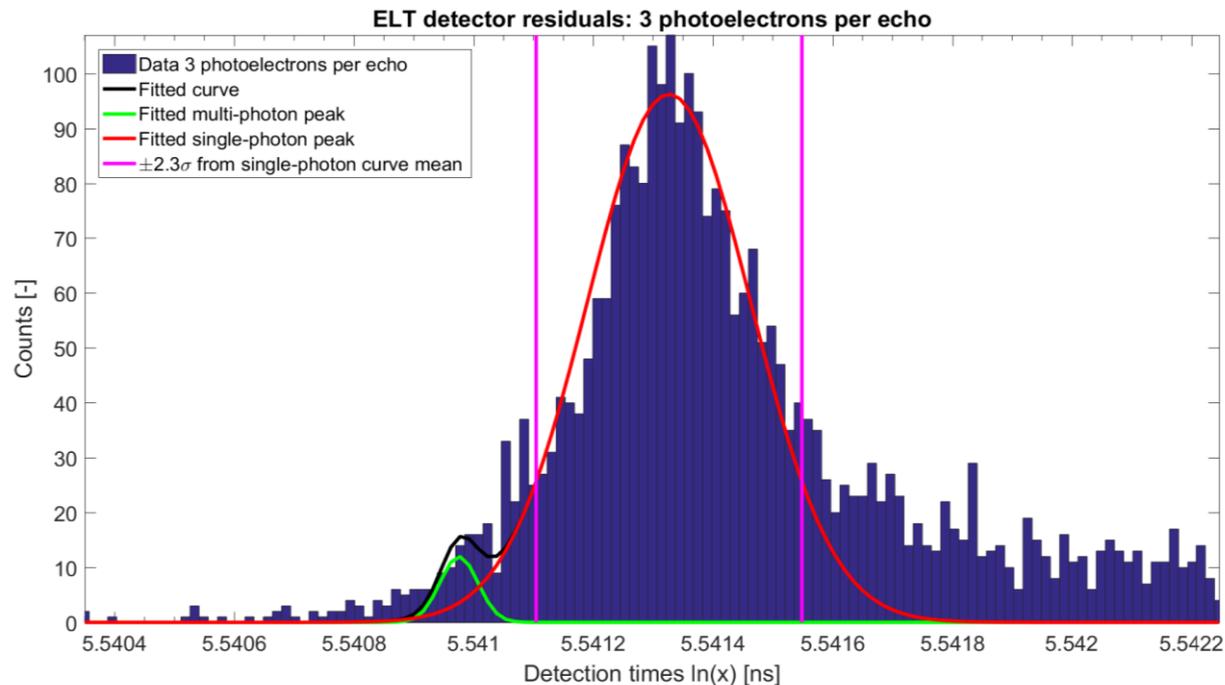
Data triplets

Summary

- Correction of orbit disturbances works quite well

- For larger pulse lengths the orbit correction becomes worse

- For a to flat background noise no exponential fitting

- For a to large background noise the peak disappears in noise

- Filtering provides the signal quite well (using 2,3 σ)

- Optimal case assumed

Outlook:
Single photon mode and multi-photon peak

- High precision photon arrival time tagging (very important in time transfer)
- High background photon flux
- With multi photons the accuracy is limited due to time walk effect

Thank you!