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Attempt to Further Enhance Ranging Accuracy to Lageos through De-Convolution of the Target Response

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Lageos Lab Measurements – Revisiting 20 years later

- Motivation:
  1. GGOS requires SLR data to be at the 1mm accuracy;
  2. Lageos 1 & 2 (L1, L2) are pivotal to Future Space Geodesy.
- Key Questions:
  1. Can we achieve the 1 mm ranging accuracy required for GGOS on Lageos 1, 2?
  2. What technologies, observing, and processing techniques permit 1 mm measurements?
  3. How can we ensure that we have consistent 1mm accuracy at the normal point level?
- Challenges:
  1. L1 & L2 are targets with significant and variable depth function;
  2. There are different laser transmitter and receiver detection schemes that can be deployed;
  3. Needs deeper understanding of the physics/engineering of the device technologies;
  4. Operating /available Signal levels can be quite different;
  5. Coherent interaction and atmospheric propagation effects are also factors;

Optical Characterization of LAGEOS 2

Original Characterization Effort

1. LAGEOS 2 lab measurements and analysis at GSFC performed to determine CoM and Lidar Cross section utilizing three different measurement techniques.
2. Functional dependencies on many Ground segment parameters;

Current Effort

1. Reanalyze LAGEOS 2 data with particular attention to the current./emerging SLR context;
2. Analyze the detection schema at low and high signal return levels (single and multiple photo-electron (PE) levels);

Streak Camera-based Target Signature Detection

Measurement methodology

1. Measurements performed in the FFDP annulus with a pinhole to represent the observing system;
2. Streak camera digitized waveform is essentially a delta function impulse response of the detector convoluted with the satellite optical response
3. Timing reference pulse transferable to the surface of the satellite or the face of cube normal to the incident beam via a calibration cube fixture.
4. Streak camera waveform is a differential measurement of satellite and reference pulses;
5. Acceptable waveforms are synchronized (via reference pulse) and averaged (typically 210)
6. Timing computations are performed for peak-to-peak, half max-to-half max, and centroid-to-centroid of the averaged waveform.
7. Streak camera sweep nonlinearity correction (typically +/- 0.7 picoseconds) is applied from a look up table for each of the 3 detection techniques.
8. A correction for latitude sag error applied to all measurements as needed (~ ±1.5mm @ ± 45 deg).

Lageos – On-orbit Range Accuracy Dependencies

Normal Point Range Correction to the CoM will be affected by a combination of the Ground Station and LRA parameters:

ΔR_{NPT} = f(x1, x2, x3, x4, x5, x6, …….x13)

x1 = Laser - Wavelength (λ);

x2 = Laser - Pulse width;

x3 = Laser - Polarization State;

x4 = LRA - Geometry + Mounting structure;

x5 = LRA - Cube physical and optical properties;

x6 = LRA - Cube dihedral offset;

x7 = LRA - Thermal gradients;

x8 = LRA (Satellite) Spin rate – indirectly affecting the averaging of the FFDP;

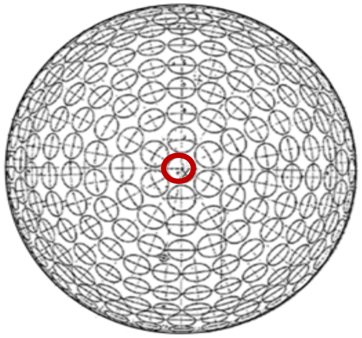
x9 = LRA (Satellite) Spin orientation - (Station Visibility);

x10 = Station line of sight orientation (Az, El) wrto the satellite,

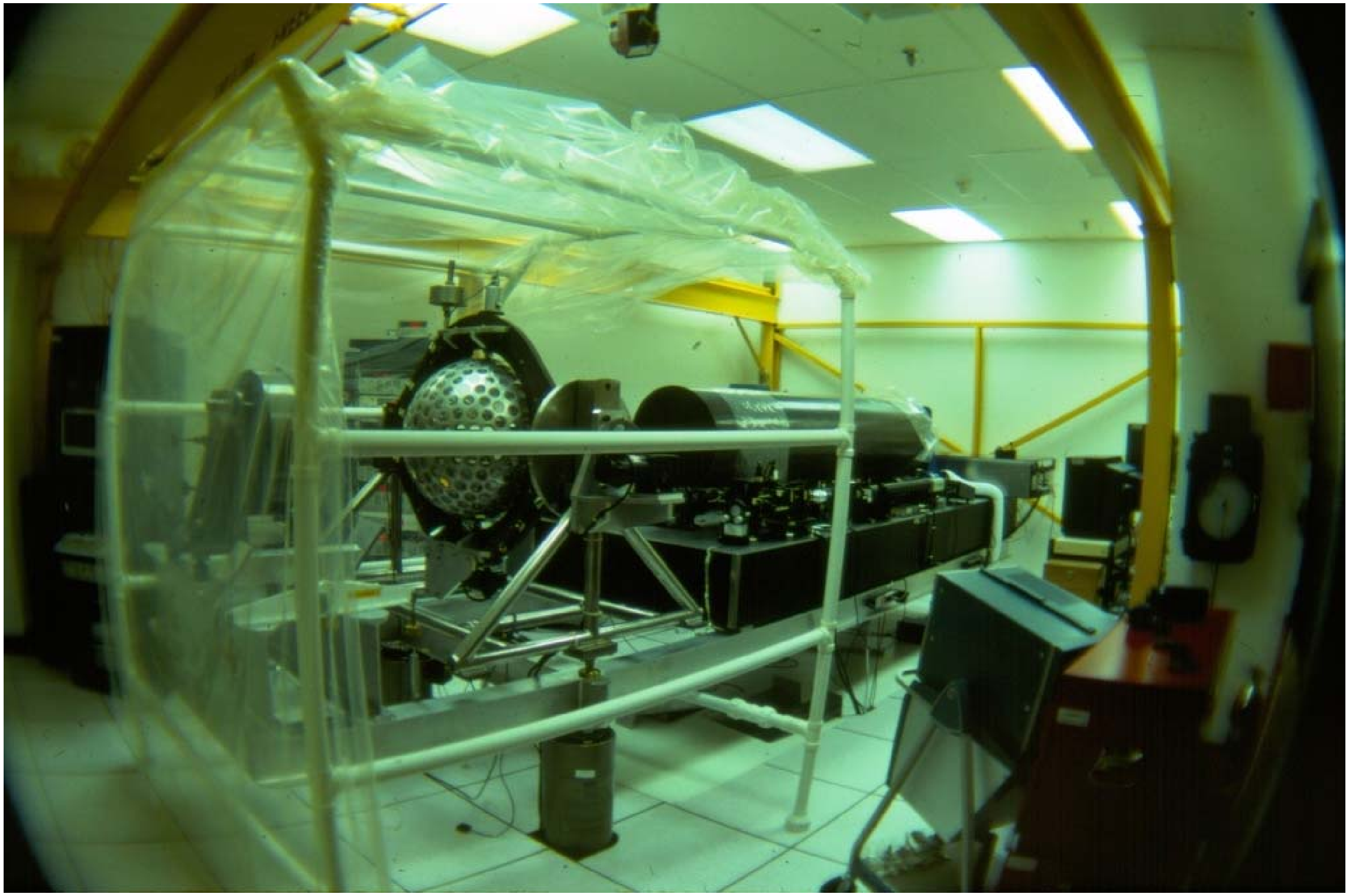
x11 = Detection Schema;

x12 = Detection Signal Strength Level;

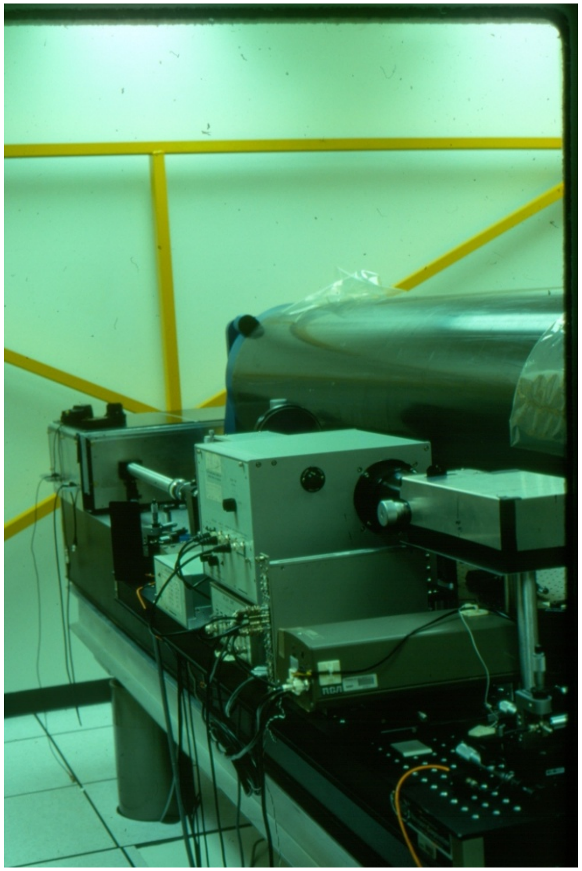
x13 = Data Filtering/ Editing Criteria;

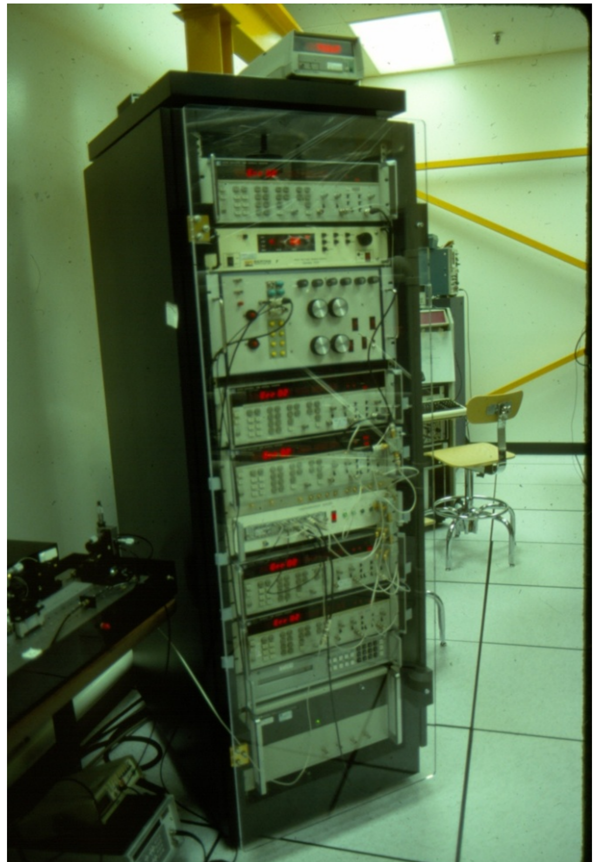


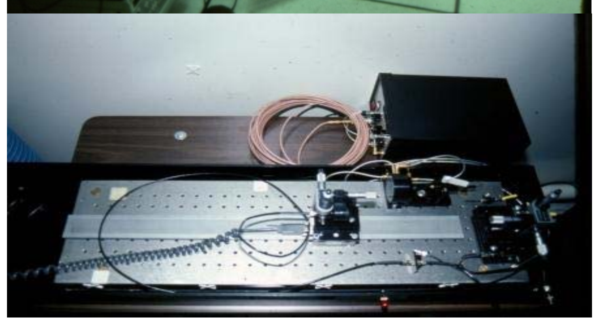
Lageos 2 – NASA GSFC Laboratory Measurement set-up



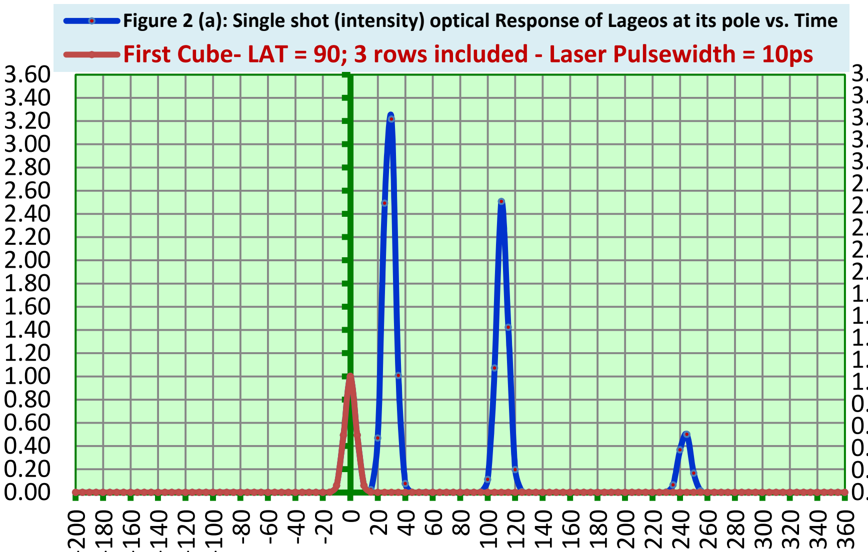
Lageos 2 – Pulsed Measurement - Instrumentation

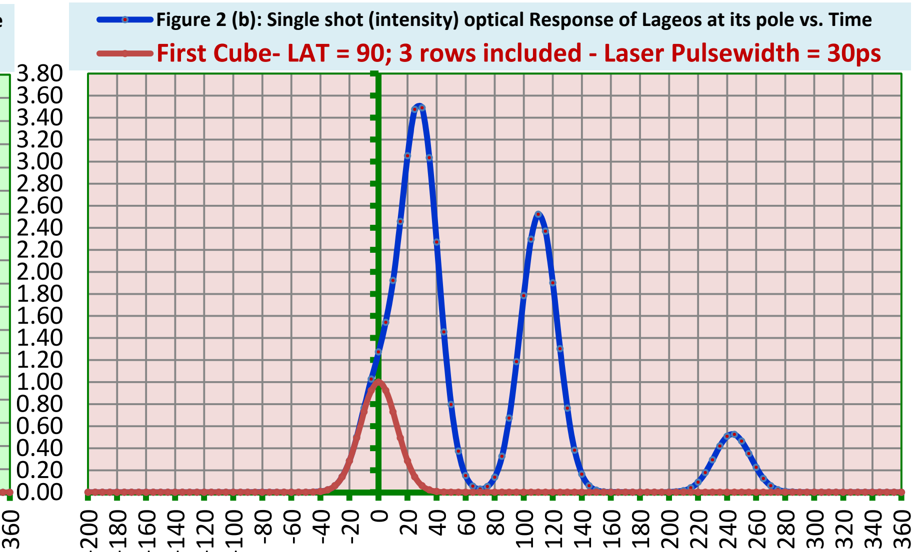


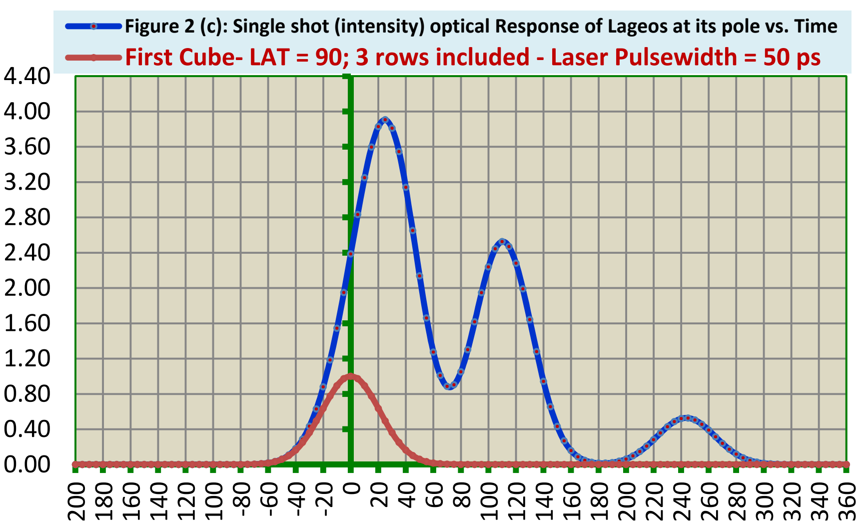


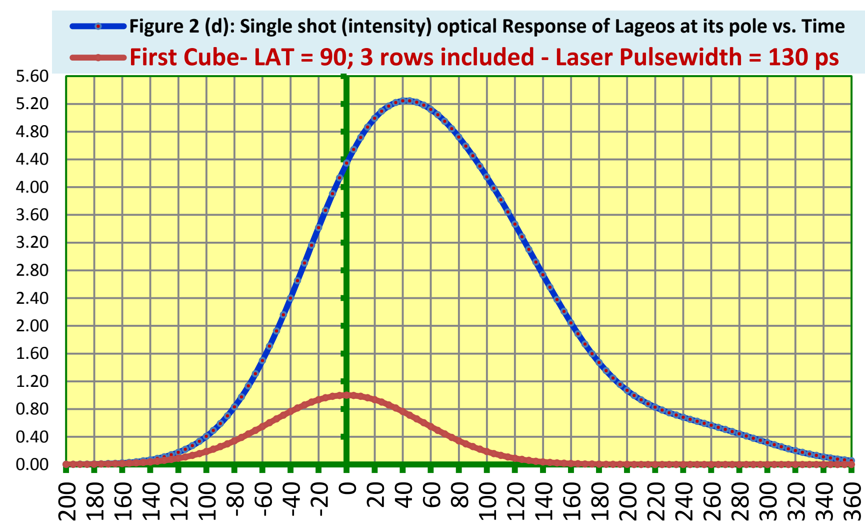


Lageos 2 – Temporal Structure at the pole vs. Pulse width

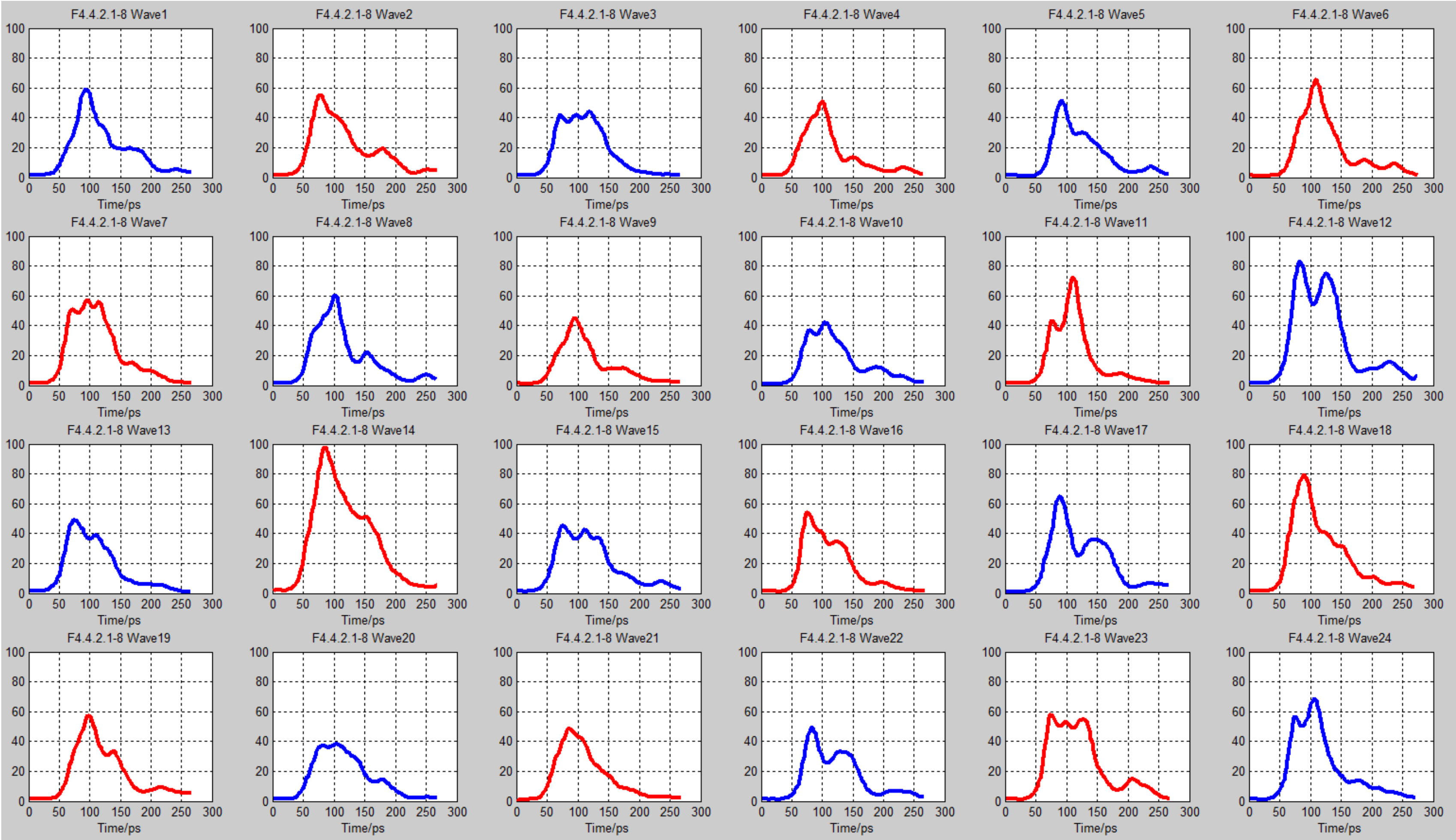






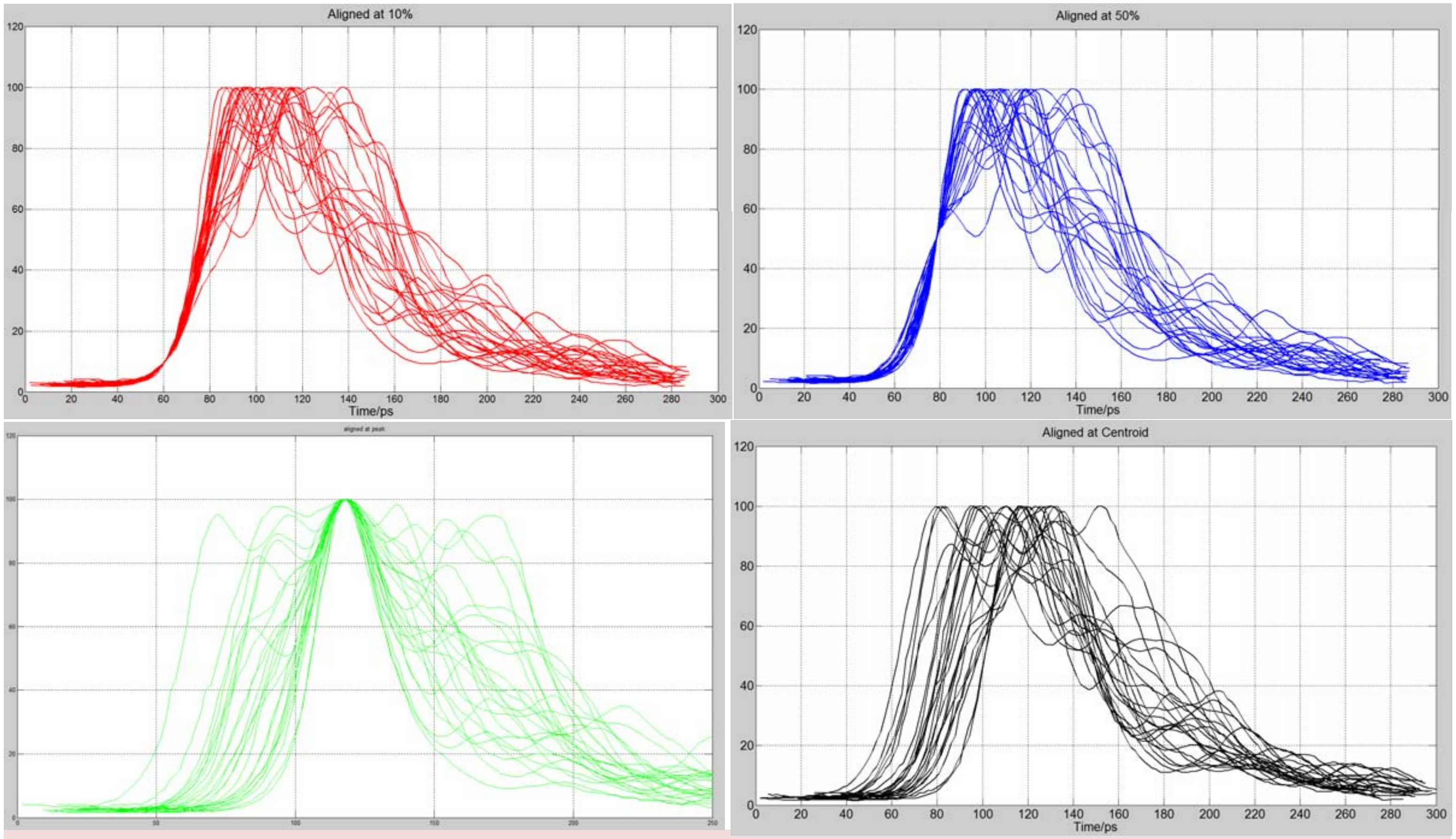


Lageos – Averaged Temporal Structure vs. Orientation



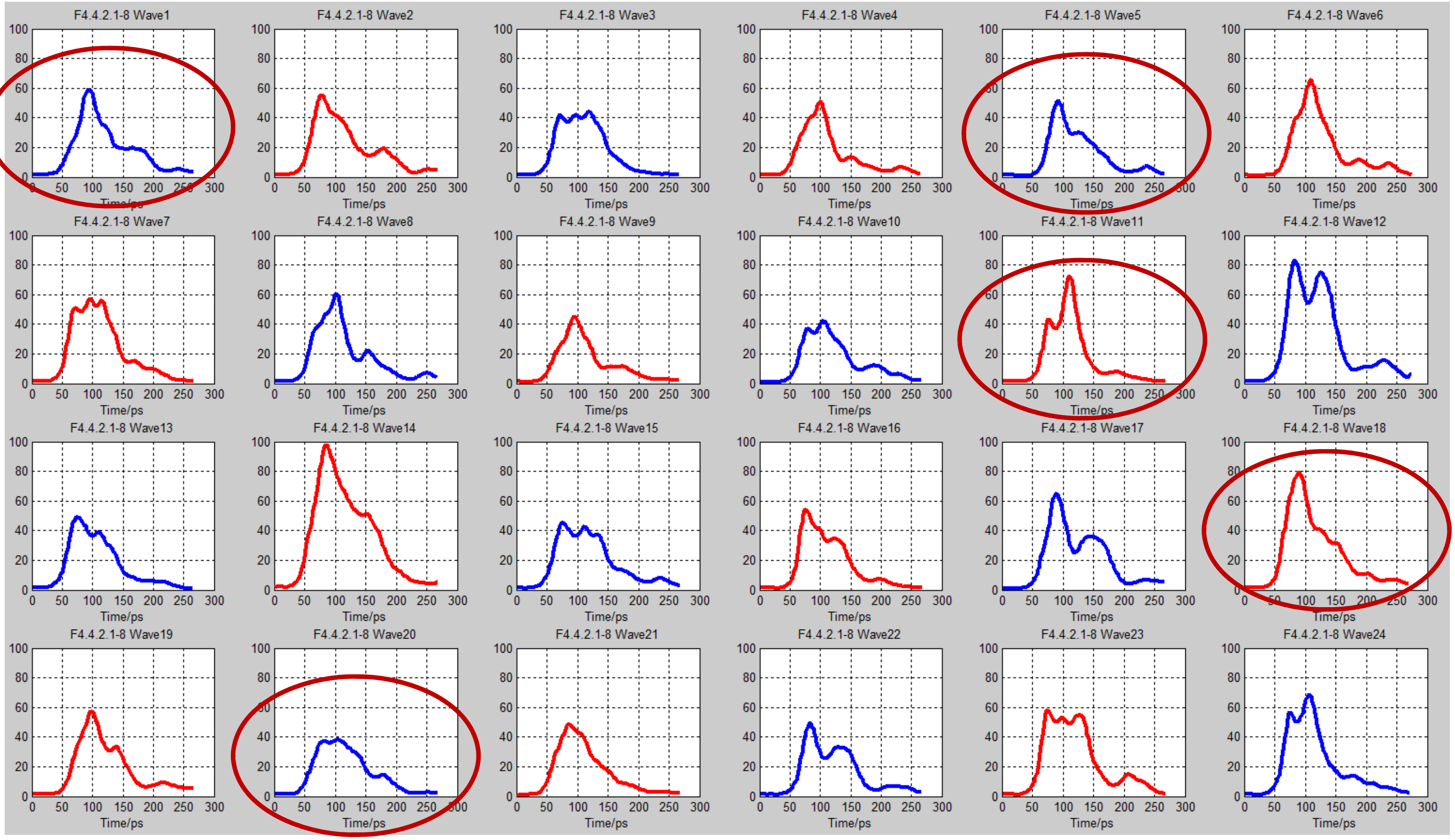
1. Effect of coherent Interaction as seen from the complex structure of the 200+ Avg. waveform;
2. Data taken with a pinhole in the annulus to represent SLR system in the FFDP

Lageos – Waveforms for different Satellite Orientation Aggregated



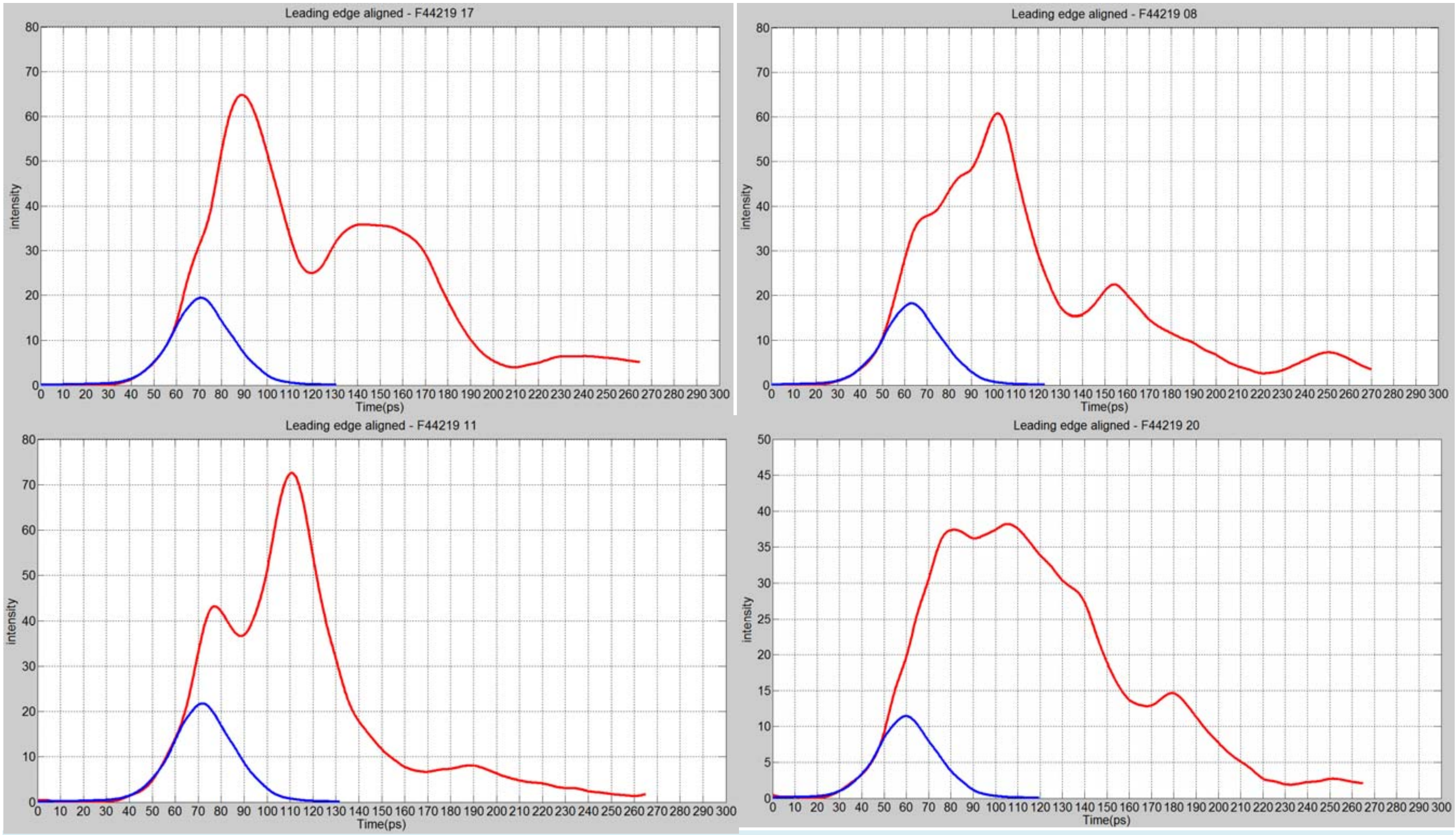
1. Satellite Return (24 random orientations) under different detection schemes for comparison;

Lageos – Averaged Temporal Structure vs. Orientation



1. Effect of coherent Interaction as seen from the complex structure of the 200+ Avg. waveform;
2. Similar to a 1 minute normal point

Lageos – Closest Cube, Satellite Pulse Alignment



1. BLUE Pulse: Avg. reference pulse; ~1 min of data; 200+ pulses avg, sub-mm timing for PW <10ps
2. RED Pulse: Avg. satellite response for 4 orientations; ~1 min of data; 200+ pulses avg; sub-mm timing

Lageos 2 – Laser Transmitter Observations

- Pulse width – Picosecond Pulses
  - Short pulse width provides the most deterministic millimeter results for CoM correction;
  - If the pulsewidth of the laser is <10ps, then the 1σ of the ensuing data has the potential to reach sub-mm precision and accuracy in the strong signal regime;
- Polarization – linear vs. Circular
  - Symmetry in the FFDP for circular polarization for the entire satellite indicate that circular polarization is better for Lageos Ranging;
- Wavelength – Visible spectrum to near IR
  - No large dependencies (<1mm) for CoM correction on wavelength;

Lageos 2 – Detection Schema Observations

- Centroid – Pulse Shape effects handled by the algorithm

  1. Centroid stability and accuracy depend strongly on the consistency of the pulse shape;
  2. Data quantity in the NPT bin needs to be large for statistical robustness of CoM correction;
  3. Sparse data, data truncation/ filtering will bias the centroid correction in the “single PE” regime;

- Peak Detection (PD) – Pulse shape symmetry required for zero bias

  1. Peak Detection is not stable for millimeter Lageos ranging
  2. Multiple Peaks generate uncertainty for Center of Mass (CoM) correction;

- Leading edge (LE) – Defines the most deterministic part of the Lageos response function

  1. Early part of the Leading edge is immune form the multi-cube effect;
  2. Under strong signal conditions, early part of the leading edge provides the best timing amongst all techniques;

Lageos Analysis - Summary

- NPT level Range Accuracy at the sub-mm level is possible with the right selection of the laser pulse width and detection schemes;
- Ability to resolve the array exists with special detection electronics and data screening/ processing;
- High Power, short pulse lasers guarantee the closest cube/s ranging to provide the best accuracy
- Circularly polarized light preferred over Linear Polarization for reduced variability/ skewness;