The New 100-Hz Laser System in Zimmerwald: Concept, Installation, and First Experiences

Werner Gurtner
Eugen Pop
Johannes Utzinger

Astronomical Institute, University of Bern, Switzerland

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Evaluation of the new laser

- Higher repetition rate:100Hz to few kHz
- Pulse length < 40ps
- Participation in one-way ranging and transponder experiments
  - → back to Nd:YAG (532 nm)
  - → single pulse energy not to low

- Call for tender December 2006 for Nd:YAG-System
- Four offers:
  - 3 kHz systems (High Q, Time Bandwith, Expla)
  - 1 100 Hz system (Thales)

- Decision: 100 Hz system by Thales with TimeBandwidth Oscillator

Rationale for Decision

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- 100 Hz good compromise
  - Limit number of returns to strong targets
  - Total energy: >800 mJ per second (532 nm)
  - Single-shot applications still possible (8 mJ per pulse)
  - Flexibility in applications (firing rate, synchronization)
    - E.g., 28 Hz for LRO
  - Diode-pumped. Promises very stable operation
  - Monostatic system: Protection of the receiver against back-scatter (→ rotating shutter possible: modulation 100%)

- Two-color ranging: Outcome was not overwhelming
  - Still possible at 1064 nm (pending suitable sensors)
  - Total energy: 1.8 J per second (green + IR)!

Protection of the receiver

- Monostatic system
- Protect receiver (SPAD / PMT) from backscatter
- 10 Hz: Rotating shutter
- 100 Hz:
  - Liquid crystal shutter
    - Response time ca. 100 μs Max. transmission 30 %
  - LC optical gate with polarizer (Degnan)
    - Response time ca. 10 μs Max. transmission 90%
    - Rather bulky for our system
  - Boost up rotating shutter (600 →3000 or 6000 rpm)
    - Max. transmission 100%

Upgrade History

- Laser ordered end of March 2007 (Delivery: Oct. 2007)
- Additional components:
  - Rotating shutter: Inhouse design and fabrication
  - New optical components for 532/1064 nm: Mid 2007 till early 2008
  - PC card with FPGA by Graz Observatory: Fall 2007
  - Pulse distribution comparators (FH Deggendorf): Early 2008

- Implementation of FPGA card and rotating shutter
- Observation with old system until Feb 2008
- Installation new Laser: March/April 2008 (!)
- First echos: April 7 / Routine operation: April 24

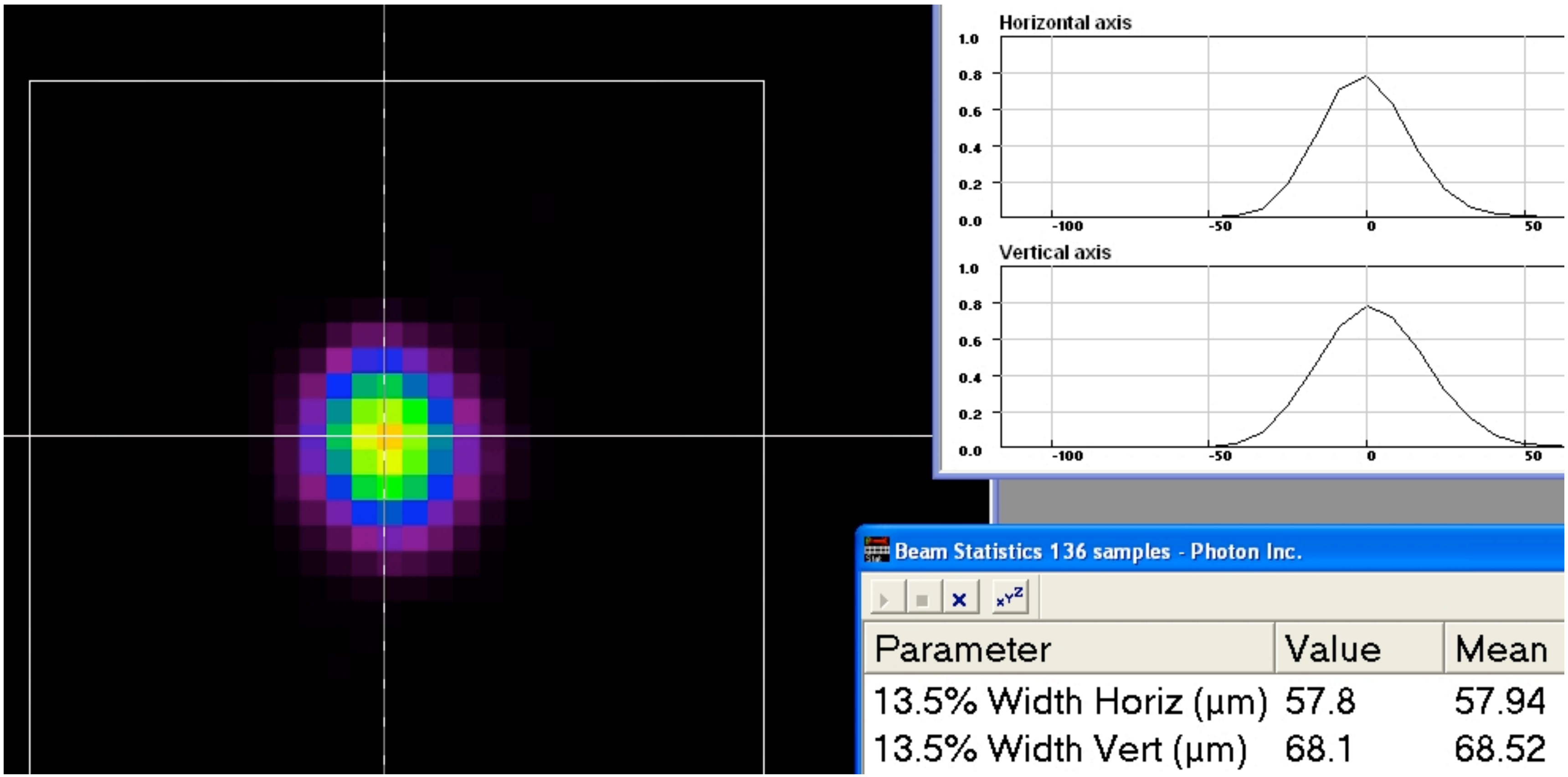
Upgrade Costs

• Laser	EUR	270'000.–
• System modifications		70'000.–
▪ New coatings		
▪ Optical components		
▪ Electronic components		
• Total		340'000.–

Laser: Main Specifications (1)

- Technology: Diode pumped solid state laser (DPSSL)
- Pulse generation: SESAM technology oscillator (**SE**miconductor **S**aturable **A**bsorber **M**irror)
- Wavelengths: 1064 + 532 nm (Nd:YAG)
- Pulse rate: 90–110 Hz, adjustable with external trigger Additional decimation with pockels cell
- Configuration: Oscillator, regenerative amplifier, multipass amplifier **(actual: double pass)**
- Pulse energy: >20 mJ @ 1064 nm **(actual: 18 mJ)** 10 mJ @ 532 nm **(actual: 8.3 mJ)**
- Pulse width: < 40 ps (FWHM) **(actual: 58 ps)**

Far–field distribution @ 532 nm

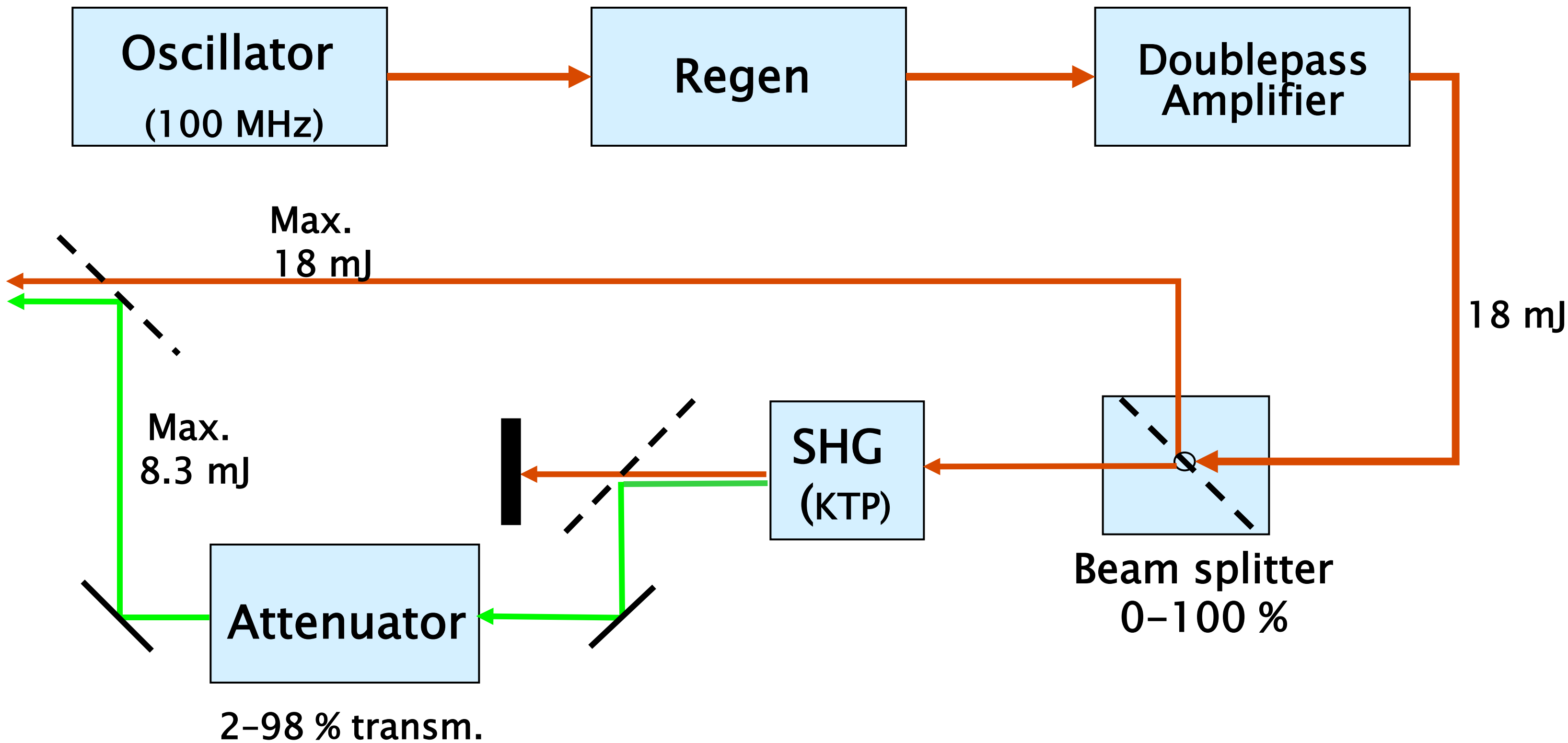


Parameter	Value	Mean
13.5% Width Horiz (µm)	57.8	57.94
13.5% Width Vert (µm)	68.1	68.52

Laser: Main Specifications (2)

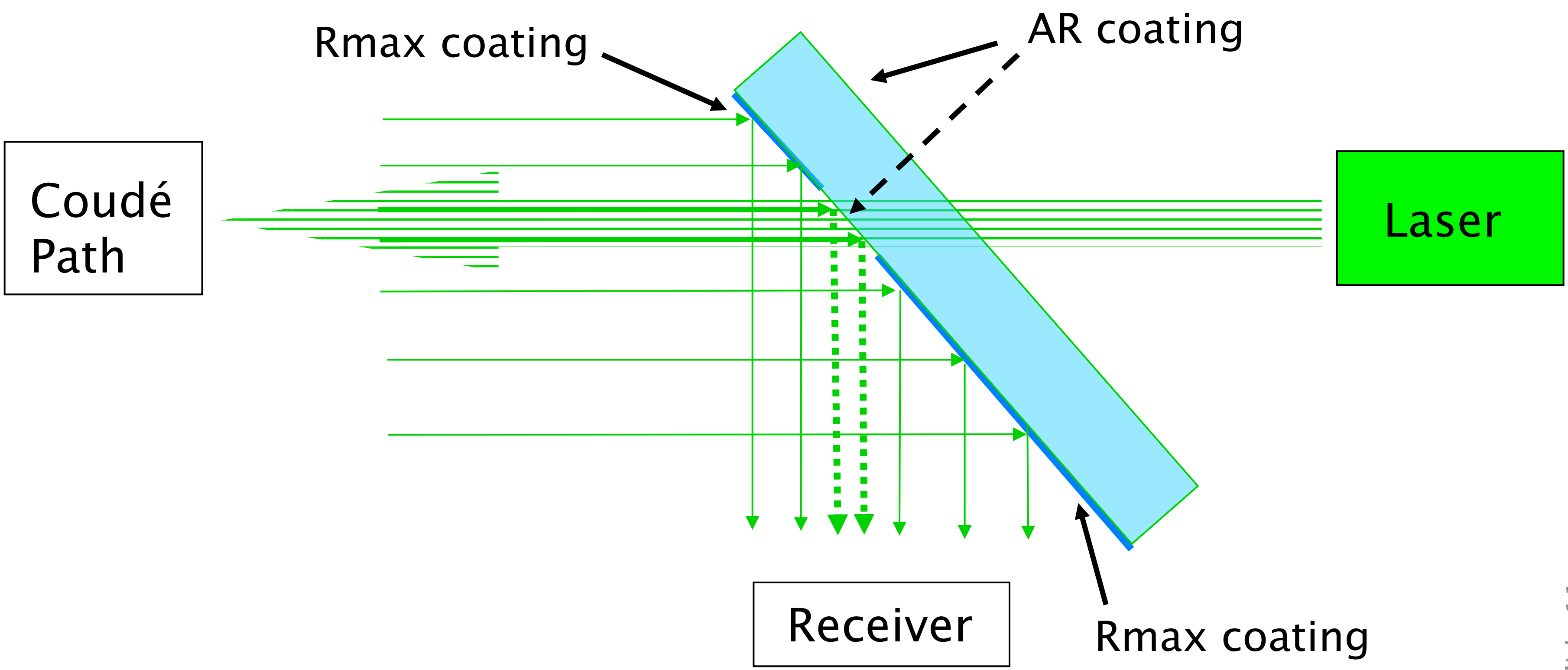
- Pulse contrast: < 1/200
- Beam diameter: 6 mm
- Stability of energy: < 1%
- Pointing stability: < 5 arc sec

Laser: Main Components



Transmit/Receive Switch Mirror

- Laser side: AR coating
- Telescope side: Rmax coating plus elliptic AR coating



Rotating Shutter (1)

- Task: mechanical range gate / window
  - Protects the receiver from backscatter during satellite ranging
  - Opens receiving path only for expected returns
- Disk with two holes right after the field stop (pinhole)
  - → Rotating frequency: 50 Hz (=3000 rpm)
  - → Speed (r=70mm): 22 mm/ms (=79 km/h)
  - → Hole Diameter: 6 mm (open for 280 µs)
  - Driven by DC Servo motor with integrated controller operated in stepper mode
- Tests in closed-loop control showed:
  - Epoch of shutter wrt to return +-50 µs (1% of 10ms)

Rotating Shutter (2)

- Shutter control (by Control PC via FPGA card)
  - Phase and frequency depending on current ranging parameters

- Shutter safety monitor (hardware implemented)
  - Assures that shutter is unintendedly opened at firing time
  - Checks speed and position 2 ms before firing time.
  - Blocks laser if conflict to be expected
    - 1) by disabling pockels cell (Regen)
    - 2) by fast mechanical shutter

Rotating Shutter (3)

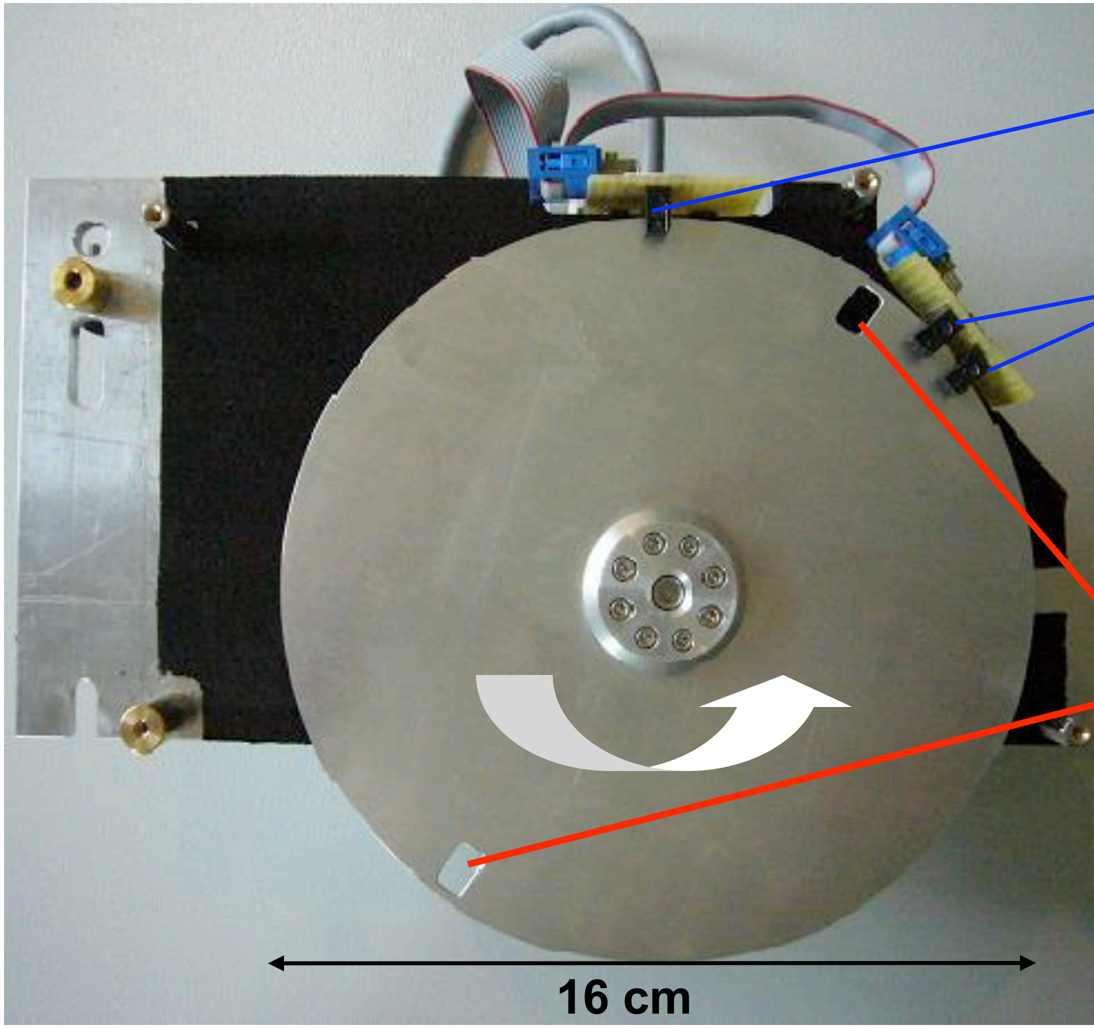


Photo sensor 3
„OPEN“

Photo sensor 1+2
for prelim. speed
and position check

2 holes

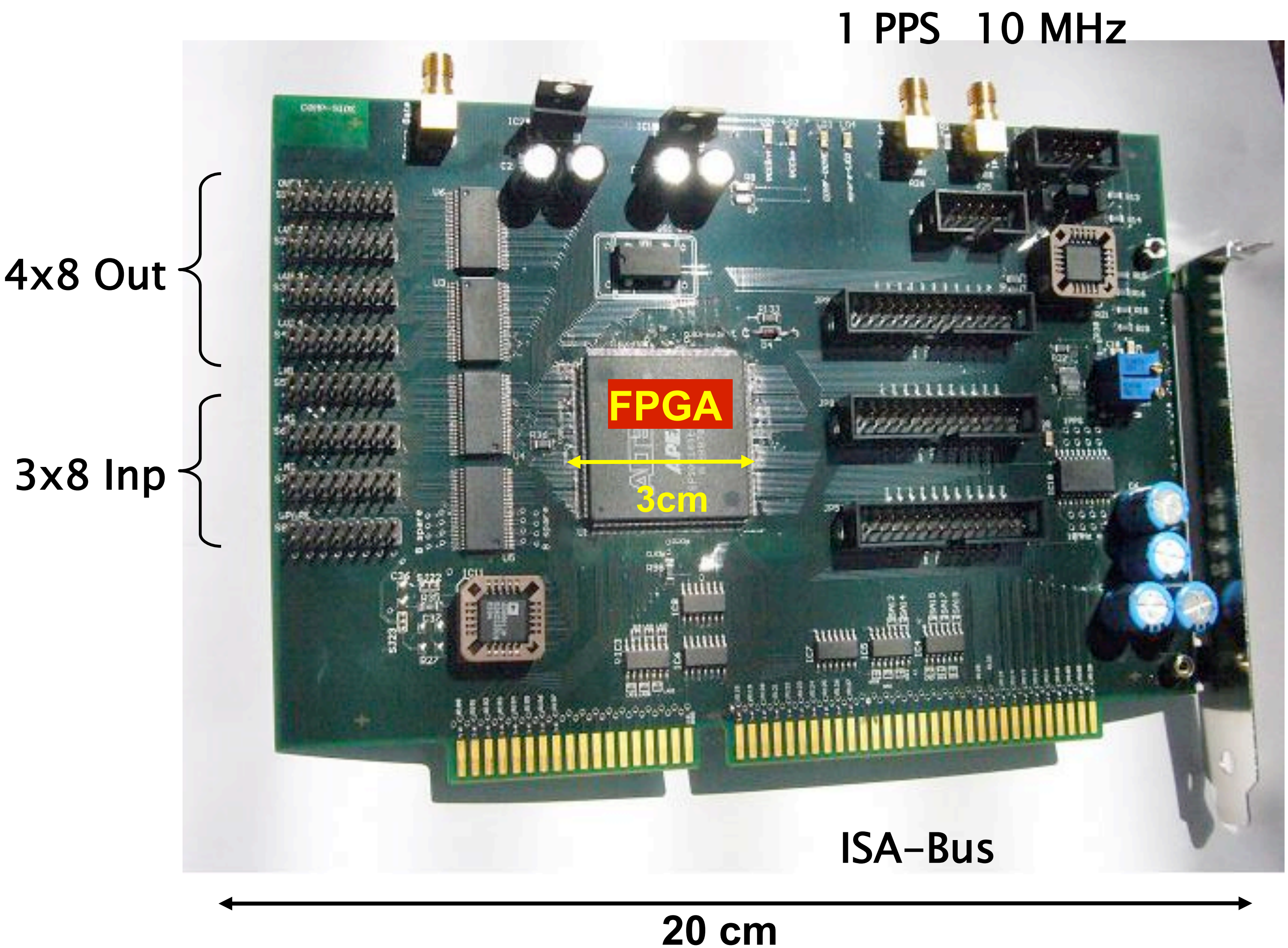
PC Interface Card with FPGA

- Built/programmed by TU Graz (F. Koidl)
- Main functions:
  - Laser firing rate (Period: 9 to 11 ms, Res: 10 μs)
  - Digital range gate/window (2 ch.) (Res: 5 ns)
  - Clock for current epoch (Res: 1 μs)

  - Rotating shutter open pos. epoch (Res: 1 μs)
  - Var. frequency generator for rotating shutter control
  - Laser firing pre-pulses (rot. shutter safety monitoring)

  - Control register to enable
    - Laser pump diodes / Pockels cell / Safety shutter etc.
  - Several auxiliary I/O channels

FPGA PC card (ISA-Bus)



Laser Control

- Provided by Thales Laser:
  - FPGA based control unit with clock generator
  - Special notebook with LabView user interface for
    - Individual (manual) control of laser components
      - Oscillator, Amplifiers, Masterclock, Control unit
    - TCP/IP server component

- Client program on Linux station computer
  - Connection by TCP/IP over LAN
  - Control commands and status requests
  - Laser ON, OFF, Status, Error resets

- Firing order and pockels cell control by electrical signals from FPGA card on request by Control PC

Range Gate Control (Control PC<->FPGA)

- FPGA: generates firing order (defined by Control PC)

- PC: For each laser pulse (100 Hz cycle time):
  - Waits for start pulse flag from FPGA card
  - Immediately reads start epoch
  - Computes expected stop pulse epoch from actual start epoch and range prediction
  - Sends stop pulse epoch to FPGA
  - Keeps start and expected stop pulse epochs in ring buffer for later use

- FPGA generates range gate (SPAD) and window (PMT)

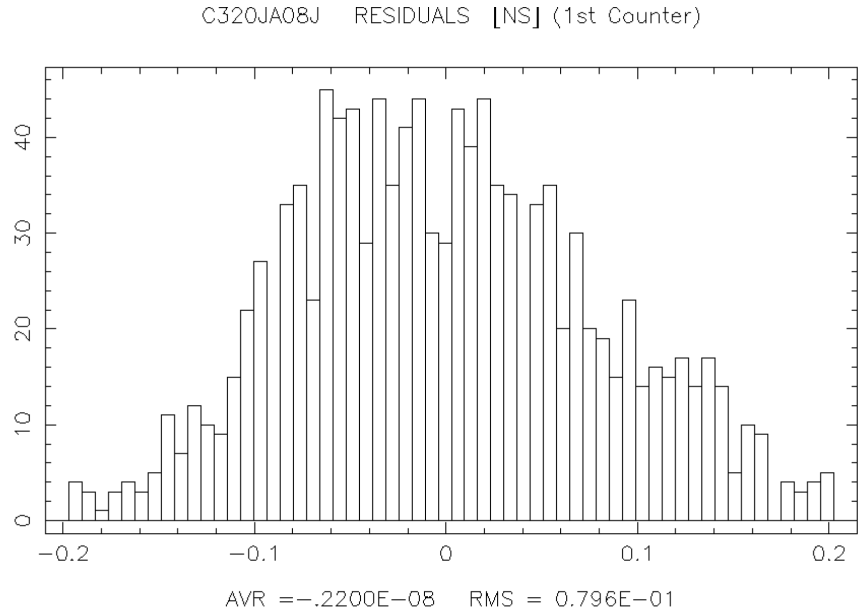
Overlap Avoidance

- 100 Hz: Whenever flight time is multiple of 10 ms:
  - Stop pulse arrives at same time as a start pulse is generated
  - Receiver will see backscatter of start pulse
  - Receiver could be damaged or at least measurement made impossible
- Avoid overlaps:
  - Cut out parts of the passes (about 5 percent loss)
  - Adjust firing epochs by inserting short delays (Graz)
  - Change firing rate once shortly before overlap would occur (by Control PC via FPGA card)

Calibrations (old – new system)

Old

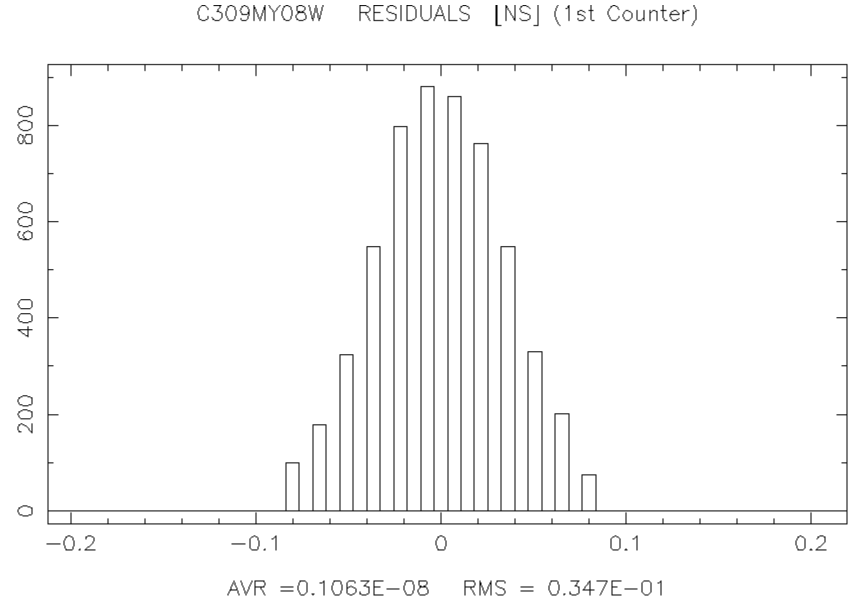
423 nm



RMS = 80ps

New

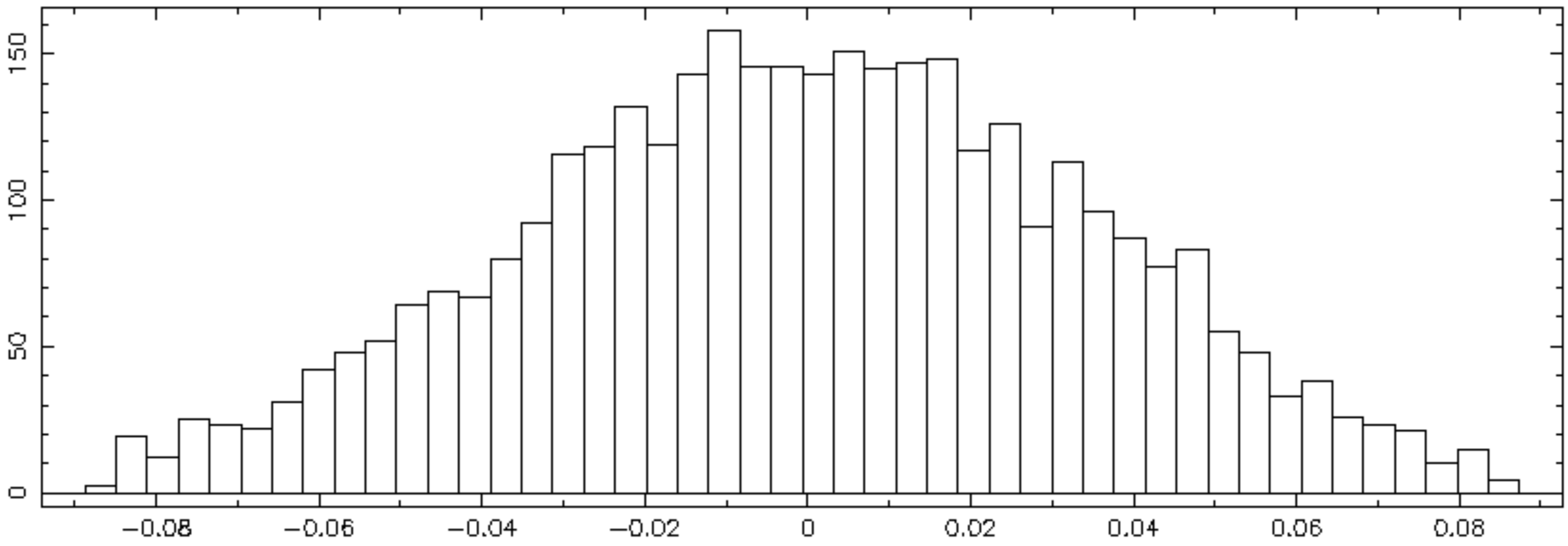
532 nm



RMS = 35ps

Range Precision: Good Target

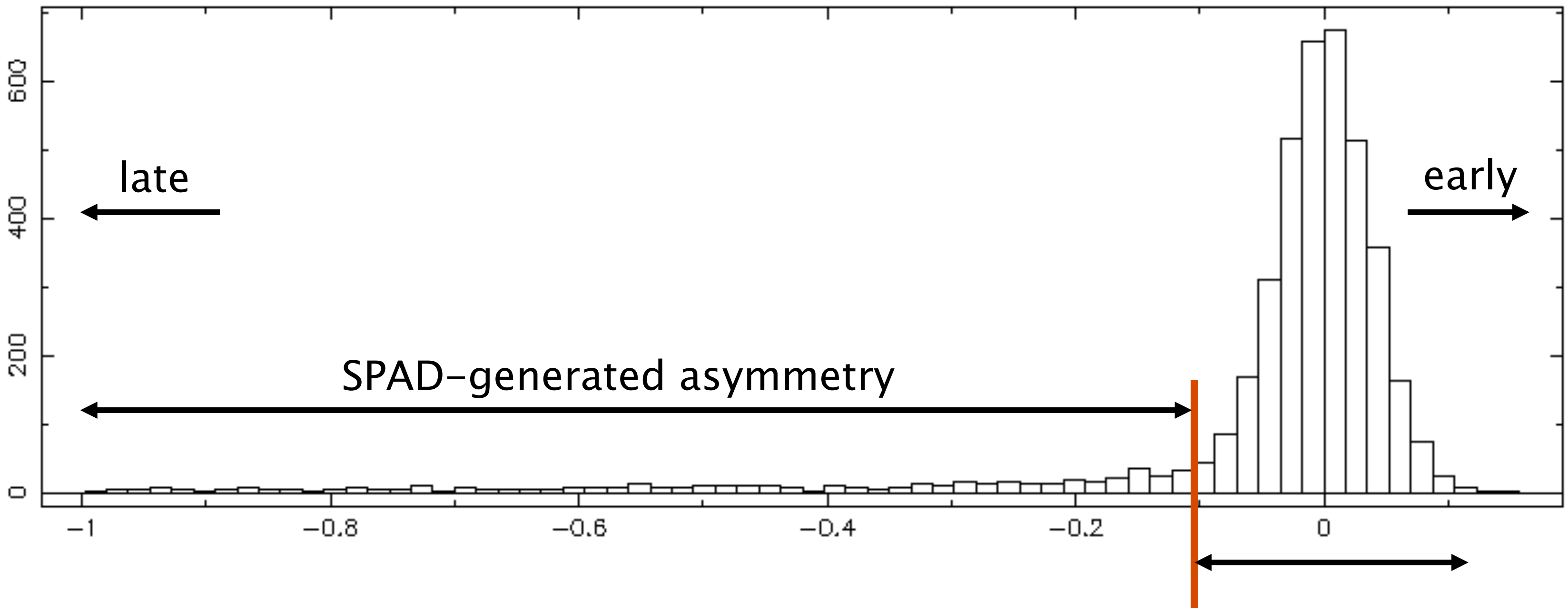
Satellite: Champ



Single-shot RMS
34 ps = 5.1 mm
Single photon regime

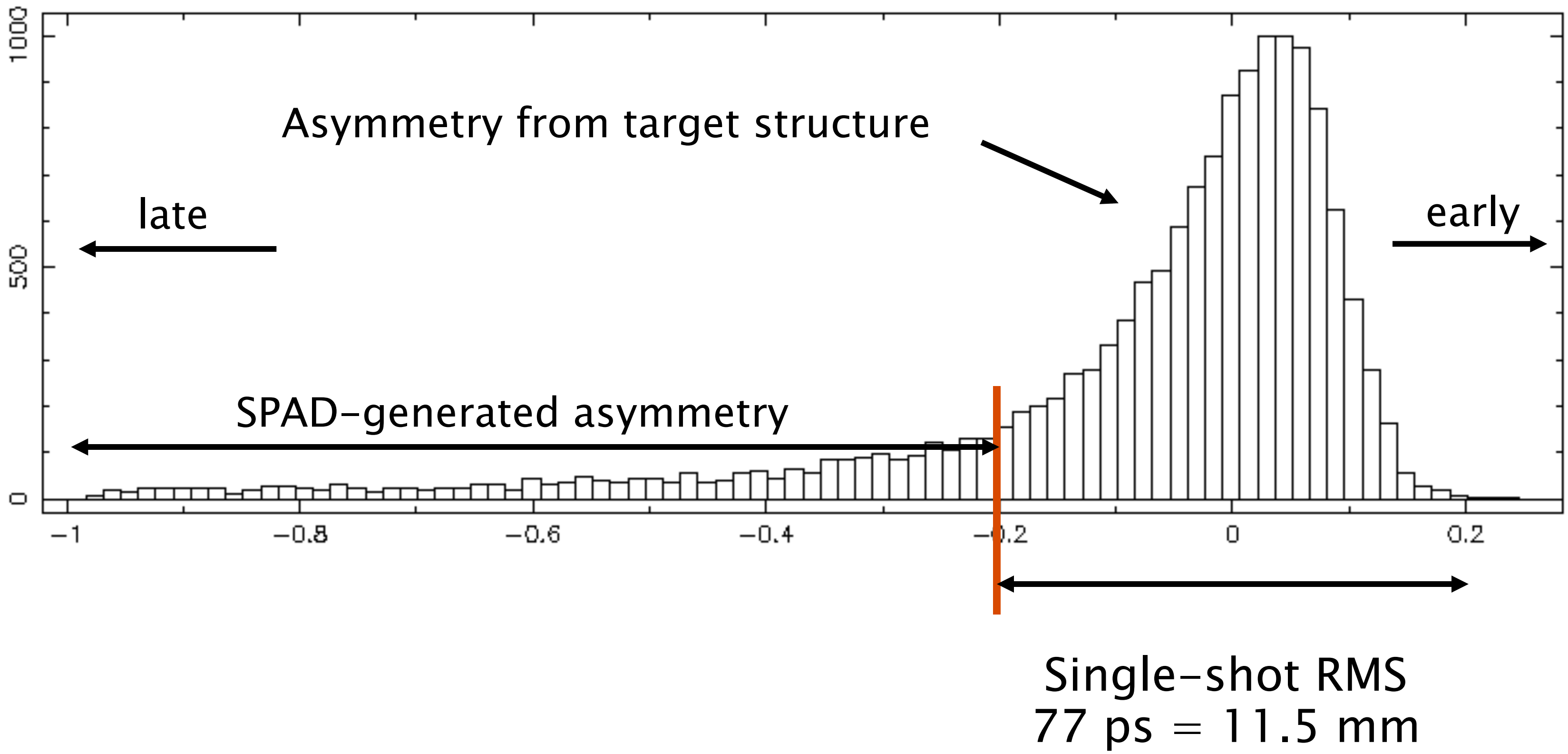
Range Precision: Good Target

Satellite: Champ, single-photon mode



Single-shot RMS
34 ps = 5.1 mm

Range Precision: Lageos



Target signature (retroreflectors at different target depths) plus SPAD asymmetric behaviour

Performance on GNSS Satellites (Glonass)

Bin Number	Number of Obs per Bin	Residual (ns)	RMS (ns)	Residual (mm)	RMS (mm)
1	575	0.007	0.007	1.0	1.1
2	1348	0.000	0.005	0.0	0.7
3	1320	0.003	0.005	0.5	0.7
4	786	-0.018	0.006	-2.8	0.9
5	1312	-0.001	0.003	-0.2	0.5
6	2434	-0.002	0.002	-0.3	0.4
7	970	-0.003	0.004	-0.5	0.7
8	1918	0.003	0.003	0.5	0.4
9	3884	0.001	0.002	0.2	0.4
10	3577	-0.002	0.002	-0.3	0.4
11	3769	0.002	0.002	0.4	0.3
12	3074	-0.001	0.002	-0.2	0.4
13	2217	0.004	0.003	0.7	0.4
14	3302	0.001	0.002	0.1	0.3
15	2832	-0.002	0.002	-0.4	0.3
16	3040	0.000	0.002	0.0	0.3
17	1703	0.003	0.003	0.4	0.4
18	1589	-0.006	0.003	-0.9	0.4
19	1691	-0.002	0.003	-0.2	0.4
20	3460	0.005	0.002	0.7	0.3
21	2594	-0.009	0.002	-1.3	0.3
22	2699	0.001	0.002	0.1	0.3
23	475	0.003	0.005	0.5	0.7

Maximum 13 % return rate

Up to 4000 returns per normal point

Performance on GNSS Satellites (Giove-A)

Bin Number	Number of Obs per Bin	Residual (ns)	RMS (ns)	Residual (mm)	RMS (mm)
1	53	0.005	0.016	0.8	2.4
2	104	-0.024	0.007	-3.6	1.1
3	1655	-0.003	0.002	-0.5	0.3
4	115	0.011	0.006	1.6	1.0
5	1271	0.002	0.002	0.3	0.3
6	2368	0.006	0.002	1.0	0.2
7	1834	-0.003	0.002	-0.4	0.3
8	1152	0.003	0.002	0.4	0.3
9	830	-0.003	0.003	-0.5	0.4
10	1628	-0.014	0.002	-2.1	0.3
11	117	0.010	0.007	1.5	1.1
12	1063	0.006	0.003	0.9	0.4
13	2510	0.006	0.002	1.0	0.3
14	1682	0.004	0.002	0.6	0.3
15	1606	-0.003	0.002	-0.5	0.3
16	2353	-0.006	0.002	-0.9	0.3
17	294	-0.002	0.006	-0.2	0.9
18	1772	0.003	0.002	0.5	0.4

Maximum 8 % return rate

18 normal points stored. Bin width: 300 sec

Performance on GNSS Satellites (GPS-36)

Bin Number	Number of Obs per Bin	Residual (ns)	RMS (ns)	Residual (mm)	RMS (mm)	
1	391	0.002	0.002	0.3	0.3	80 deg elev
2	947	0.000	0.001	0.1	0.2	
3	2437	-0.001	0.001	-0.2	0.1	
4	2861	0.000	0.001	0.0	0.1	
5	2870	0.001	0.001	0.2	0.1	Maximum 9 % return rate
6	543	0.003	0.002	0.4	0.3	70 deg elev
7	1835	-0.002	0.001	-0.3	0.2	
8	161	0.001	0.003	0.2	0.5	
9	2127	-0.001	0.001	-0.1	0.2	
10	1213	0.000	0.001	-0.1	0.2	60 deg elev
11	840	-0.001	0.002	-0.1	0.3	
12	1053	-0.001	0.002	-0.1	0.2	
13	1699	0.003	0.001	0.5	0.2	
14	1336	0.001	0.001	0.1	0.2	50 deg elev
15	1912	0.001	0.001	0.1	0.2	
16	1965	-0.004	0.001	-0.6	0.2	
17	413	0.005	0.003	0.8	0.4	
18	1511	0.000	0.001	0.0	0.2	
19	390	0.005	0.003	0.7	0.4	40 deg elev

Summary

- 100 Hz Nd:YAG solid state laser system
  - Stable energy and pointing
- 8.3 mJ / pulse @ 532 nm with excellent far field profile
  - Suitable for one-way ranging and transponder experiments
- Single shot RMS: 35 ps / 5 mm @ 532 nm for good targets
- Up to 13% RR on high satellites
  - Observation also possible through haze or thin cirrostratus
- Backscatter protection with 100% modulation (rot. Shutter)
  - PMT are also possible detectors
- Prepared for two-colour ranging
  - if a suitable detector is available in future

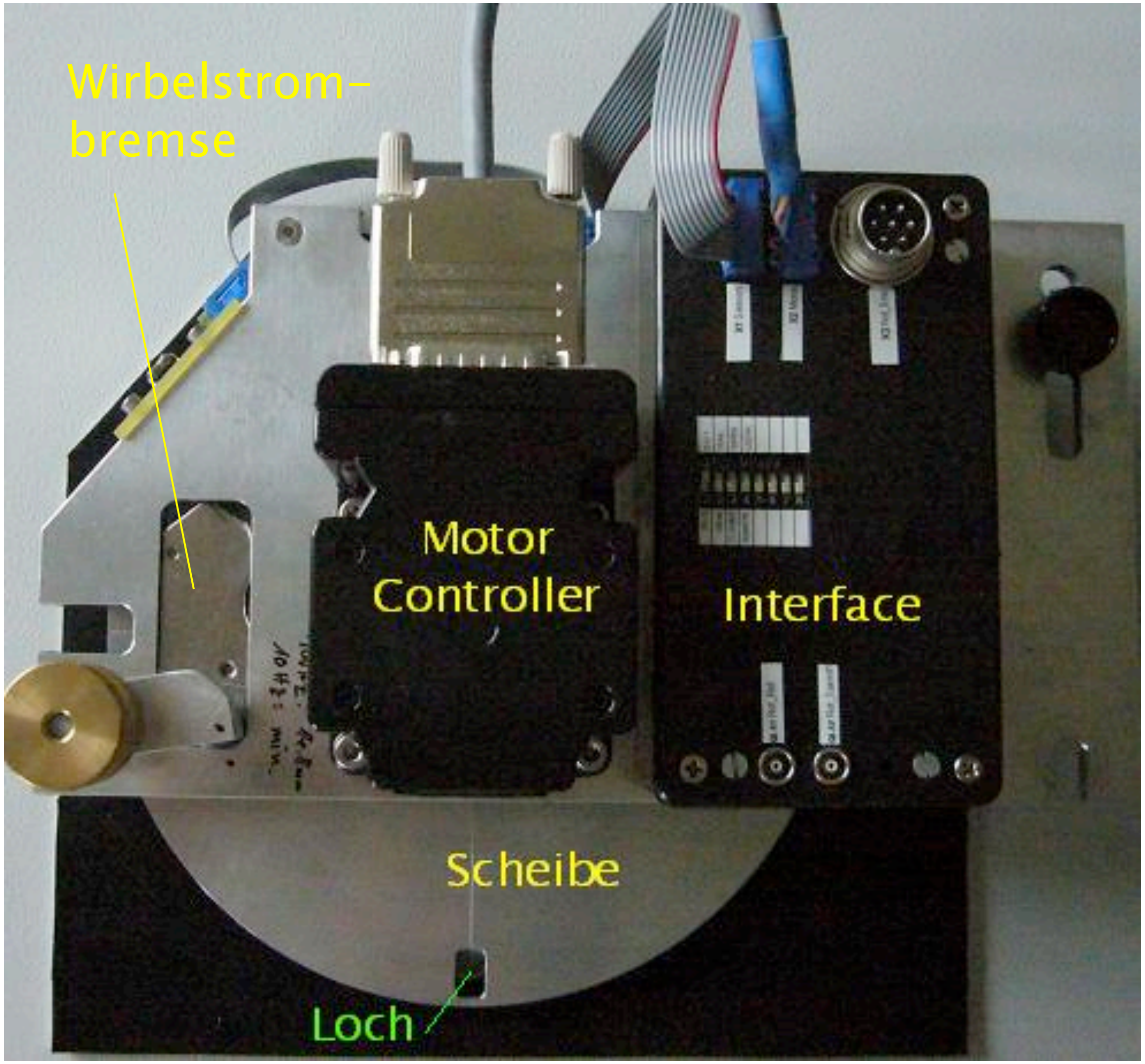
End

Thank you !

Timing system

- Time Base
  - 5MHz Quartz + Freq. Doubler (Oscilloquartz SA, Neuenburg) free running, compensated only once per day for aging (New: 10 MHz Quartz implemented shortly)
  - 10MHz distribution (FH Deggendorf)
  - Divider chain and distribution for clock pulses
    - 1 PPS
    - 100 PPS
    - Other rates
  - GPS timing receiver (Truetime) for synchronization by time comparison
- Event timer for start and stop epochs (Riga)

Rotating Shutter

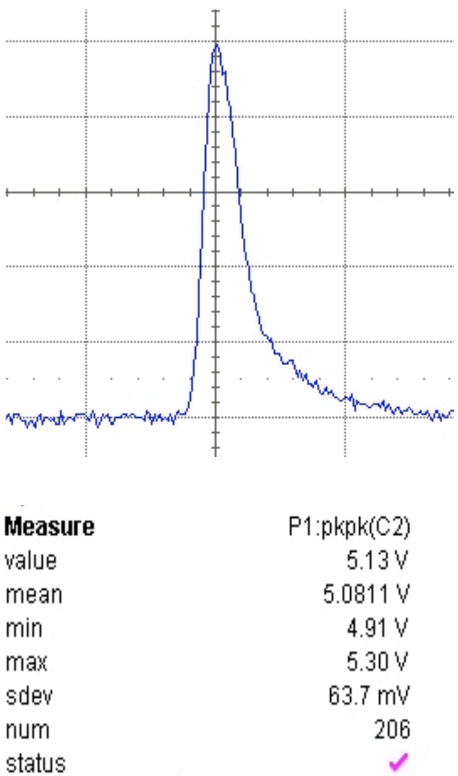


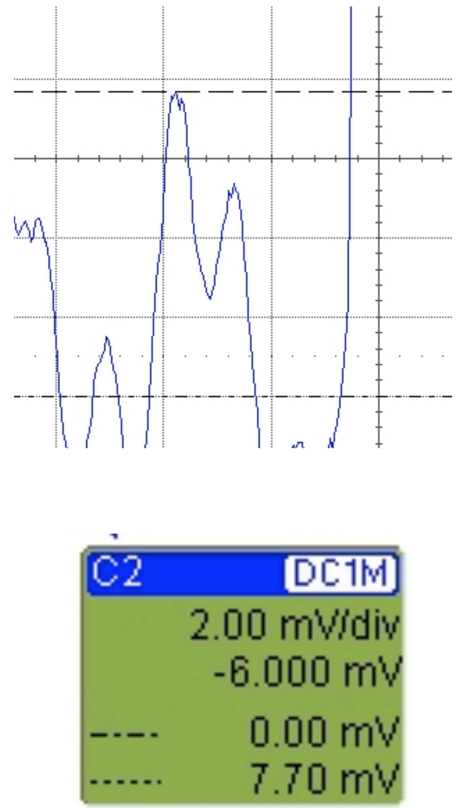
Status End of 2007

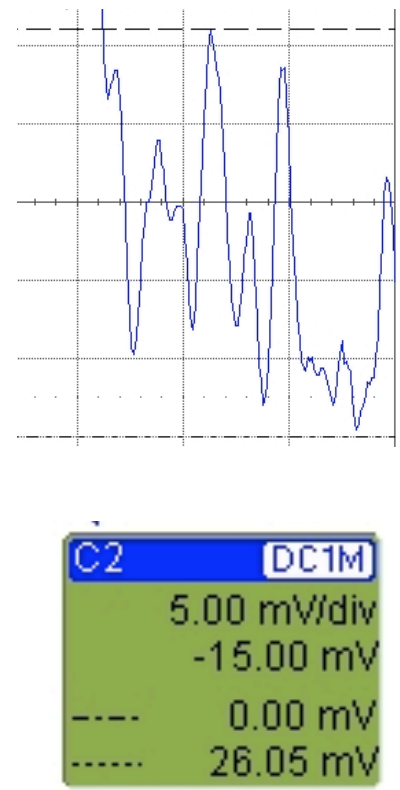
- Two-color 10 Hz system (Ti:Saph-Laser)
- Accuracy
  - Single-shot 10 mm blue (423nm), 20-25 mm IR (846nm)
  - Range biases: Blue< 1 cm, IR < 2 cm
  - Bias betwen blue and IR 10-15 mm: Origin probably internal IR calibration
- Maintenance and operation
  - Relatively high maintenance costs of laser
  - Aging of components, difficulty with spare parts
  - Frequent readjustments (every day or every few days)
- Availability
  - Ca. 11 months per year

Pulse contrast at 532 nm

4 nm 1:650 14 nm 1:195







Measurement of the pulse width

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Diode current (A)	Pulse width (ps)
1.0	54.7
1.1	52.6
1.2	53.2
1.3	54.9
1.4	54.9
1.5	56.9
→ 1.6	58.3
1.7	60.9
1.8	60.4
1.9	62.8
2.0	61.3