Considerations for an Optical Link for the ACES Mission

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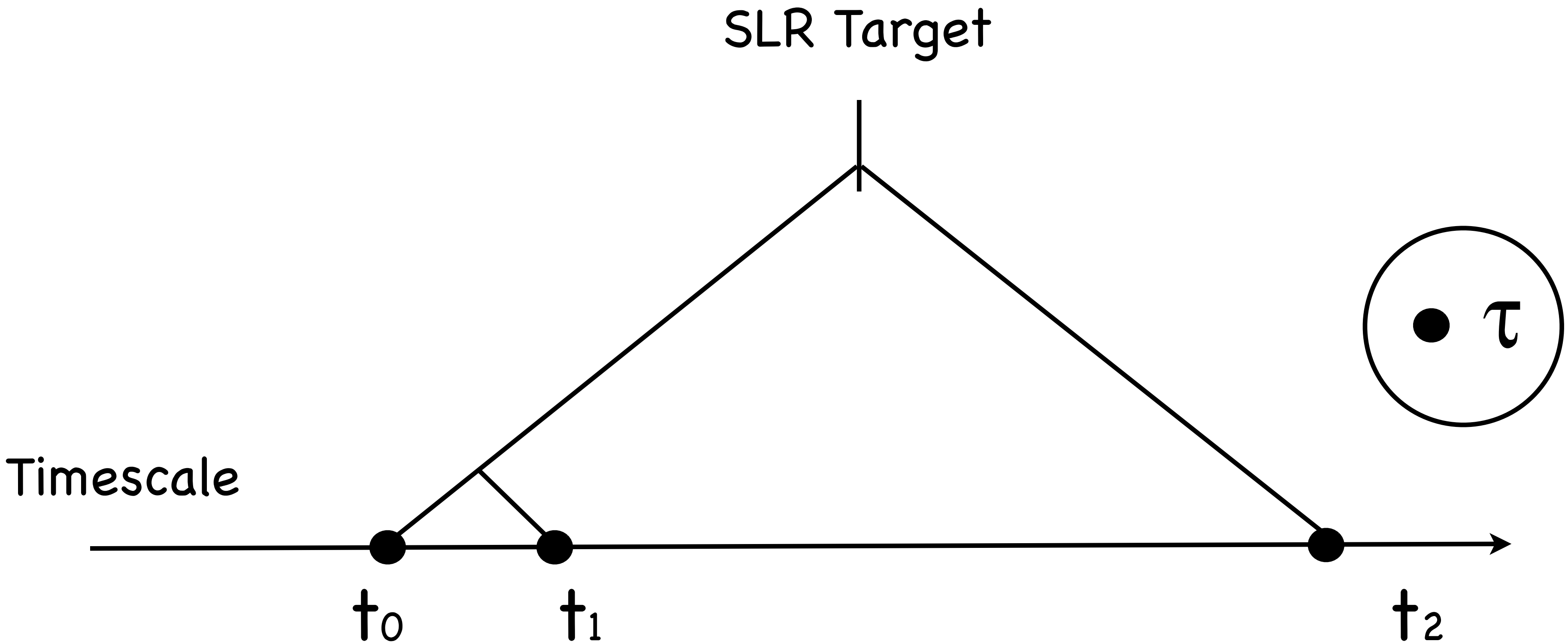
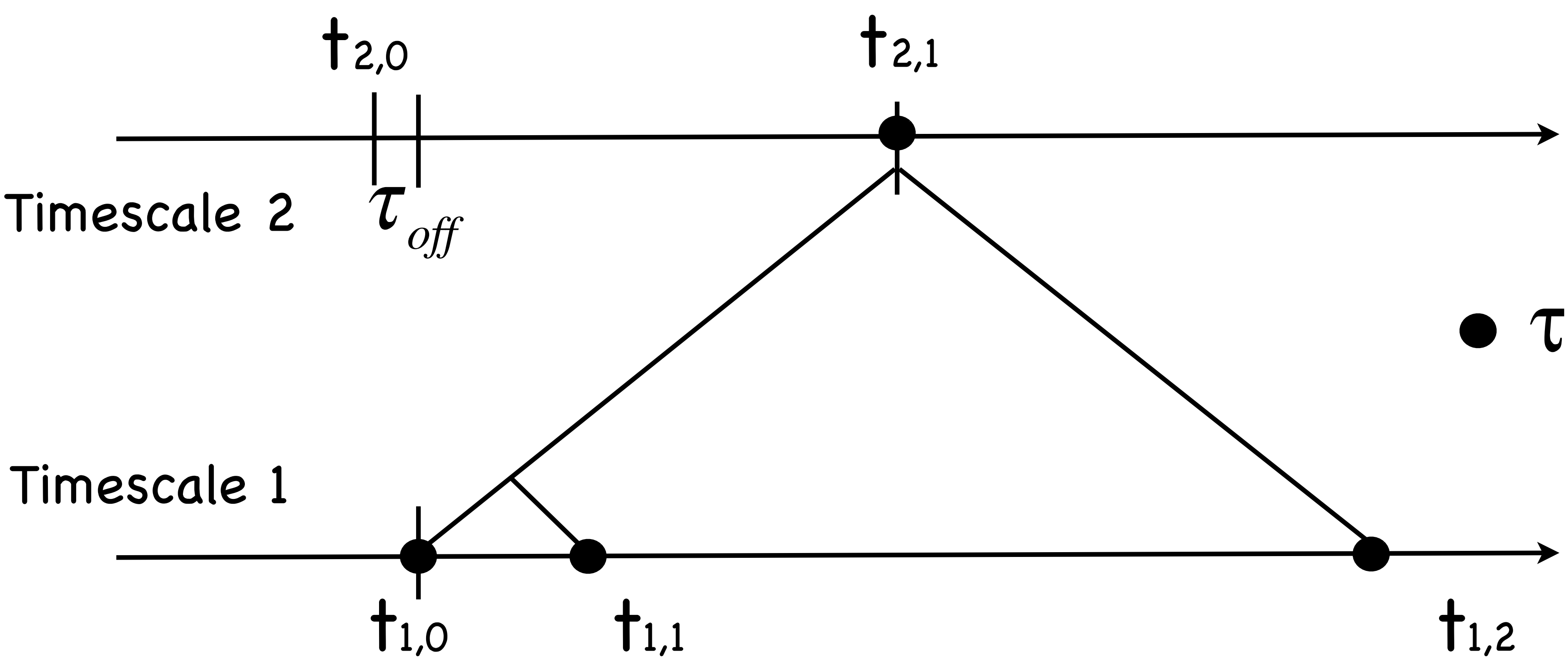
SLR Konfiguration



$$r = \frac{c((t_2 + \tau_2) - (t_0 + \tau_0))}{2} = \frac{c(t_2 - t_0 + \Delta\tau)}{2}$$

$$r_{cal} = c(t_1 - t_0 + \Delta\tau) \quad \rightarrow \quad \Delta\tau = \frac{r_{cal} - c\Delta t}{c}$$

Transponder Configuration



time comparison
(static case)

$$t_{2,1} = t_{1,0} - \tau_{off} + \frac{r}{c} + \tau_{2,1}$$

no drift in clocks

no relativistic effects

General Considerations

- Frequency Transfer (narrow bandwidth)
- Time Transfer (broad bandwidth)
- Atmosphere:
    - Dispersion (critical on radio waves)
    - Absorption (transmission: critical in the optical regime)
    - Speckle (substantial variability in signal strength)

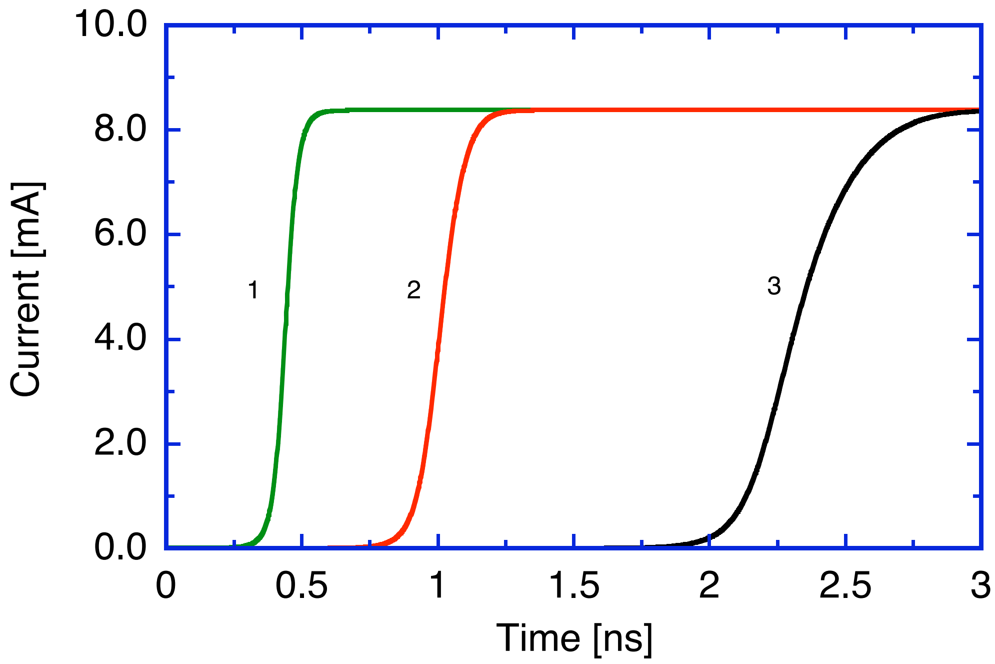
Problems

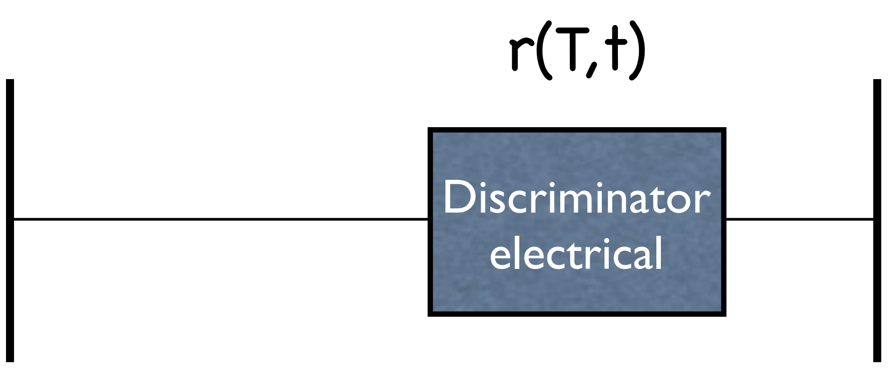
- Pulse conversion (optical - electrical) [τ]
  - low signal level
    (Time - Angle conversion not satisfactory)
- Dynamic range of optical pulse
  - Timewalk: $\tau(I,T)$

Timewalk

The internal detector delay is depending on the intensity of the input light

(bypass of multiplication process)

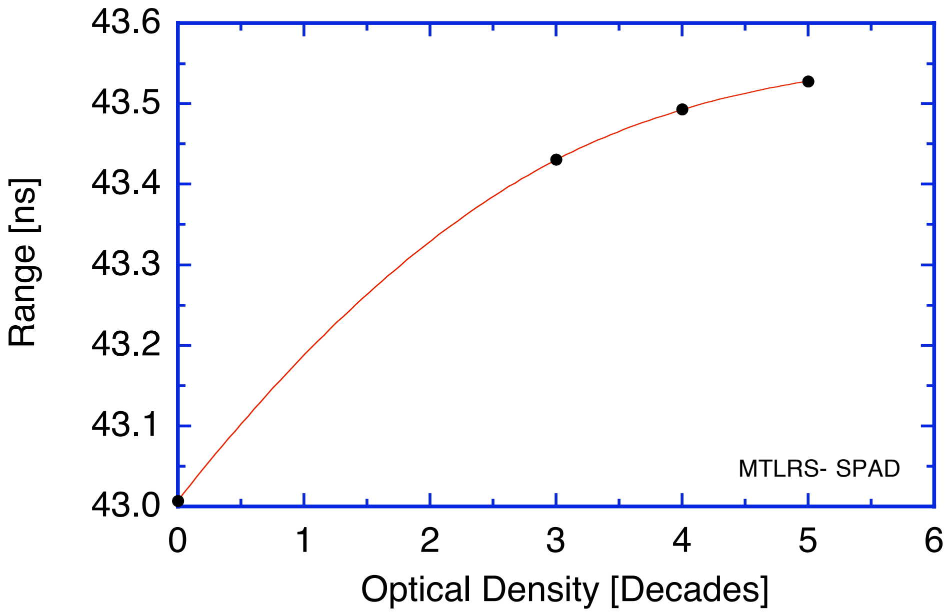


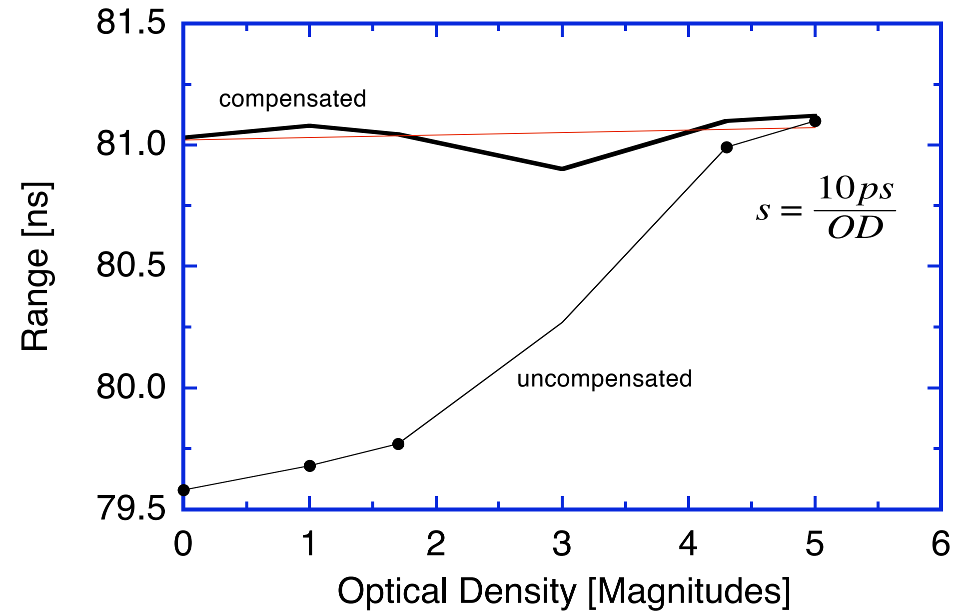


Discriminator contribution to timing: τ ≈ 10 ns

(0.1% stability corresponds to 10 ps)

Timewalk (Compensation)

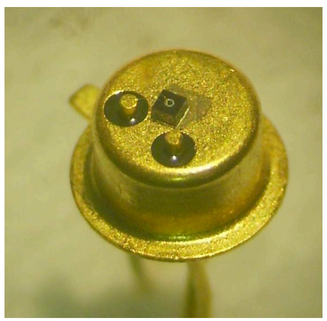




- PMTs have lower Bandwidth and less dynamic range
- Different types of APDs have vastly different timewalk
- Recipe: Use best available APD and work strictly in the "single photon regime"

K14 SPAD is the detector of Choice

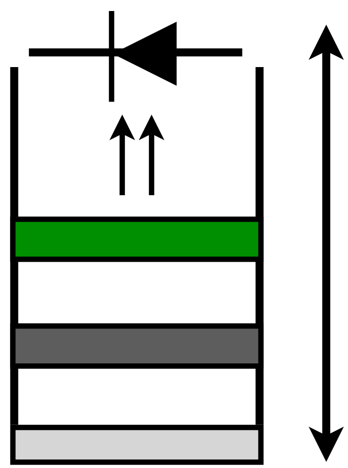
Proposed Configuration



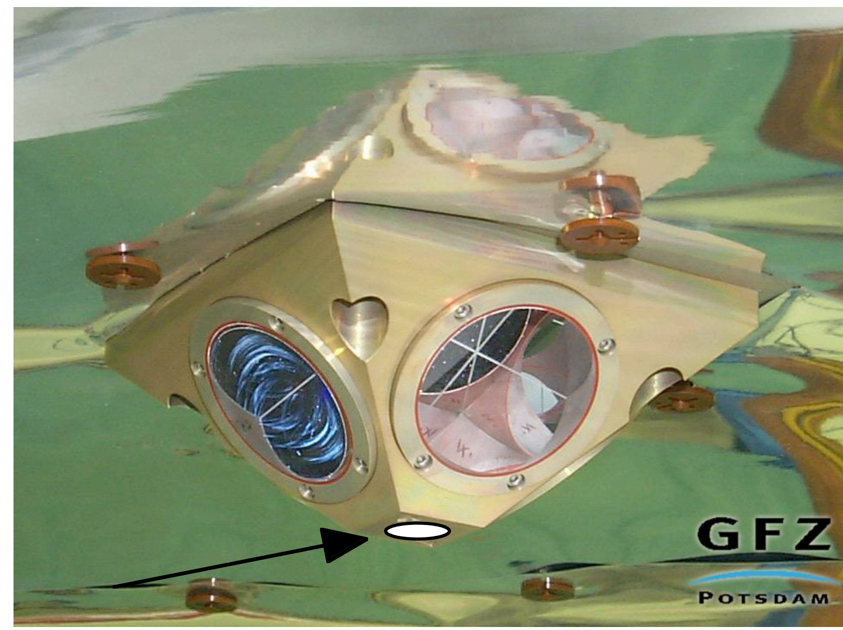
Spectral Filter

ND Filter

Diffusor Plate



Attenuation by Spacing

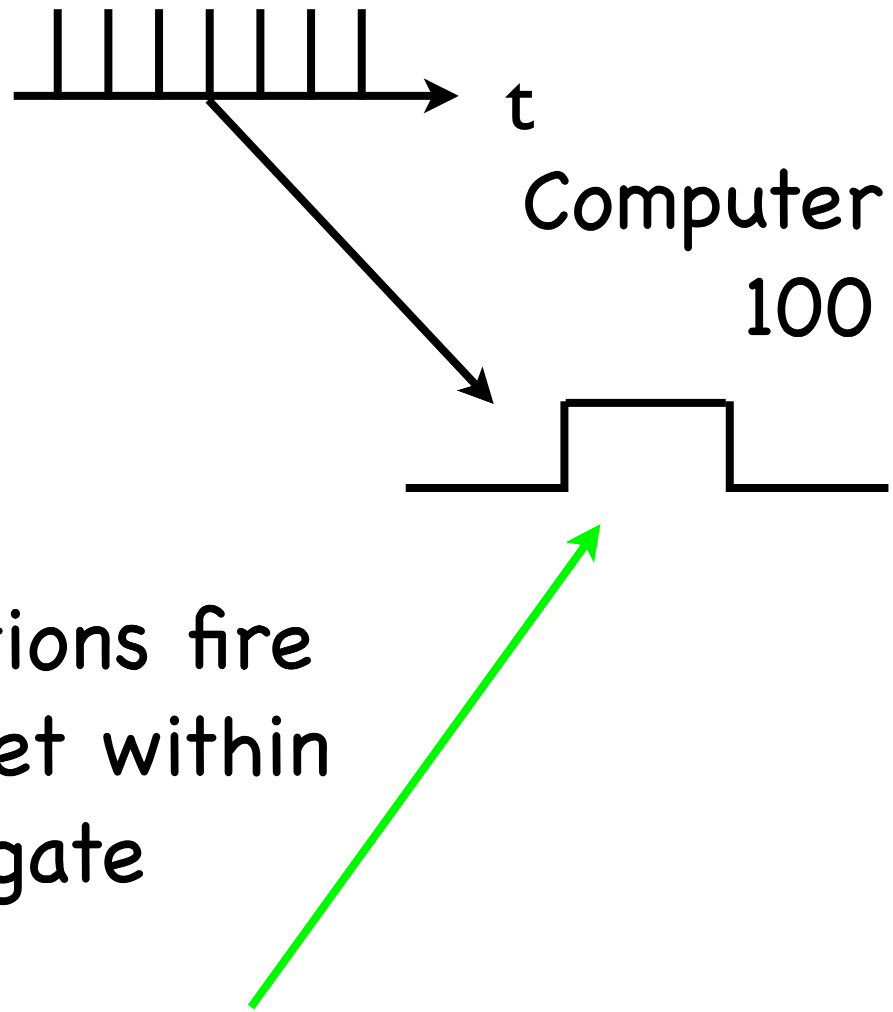


Field of View / Link Equation

- No receiver telescope
- Acceptance angle ≈ 1rad
- Eye safe operations due to highly divergent beam
- high background noise (coherent detection scheme)

$$n_{pe} = \frac{n_{ph} \cdot \eta_q \cdot \eta_r \cdot T \cdot A}{\Omega \cdot R^2}$$

Coherent Detection Scheme

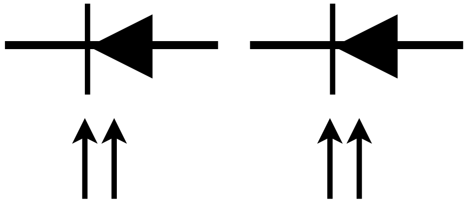


Computer adjustable Gate
100 ns - 10 μs

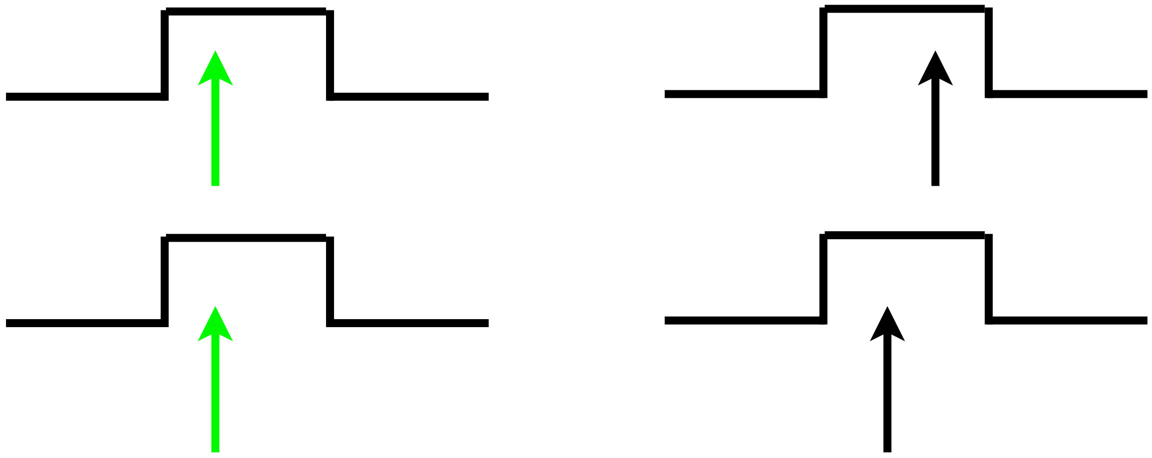
Laser Stations fire
to hit target within
open gate

Options

Simultaneous Operation
of 2 detectors



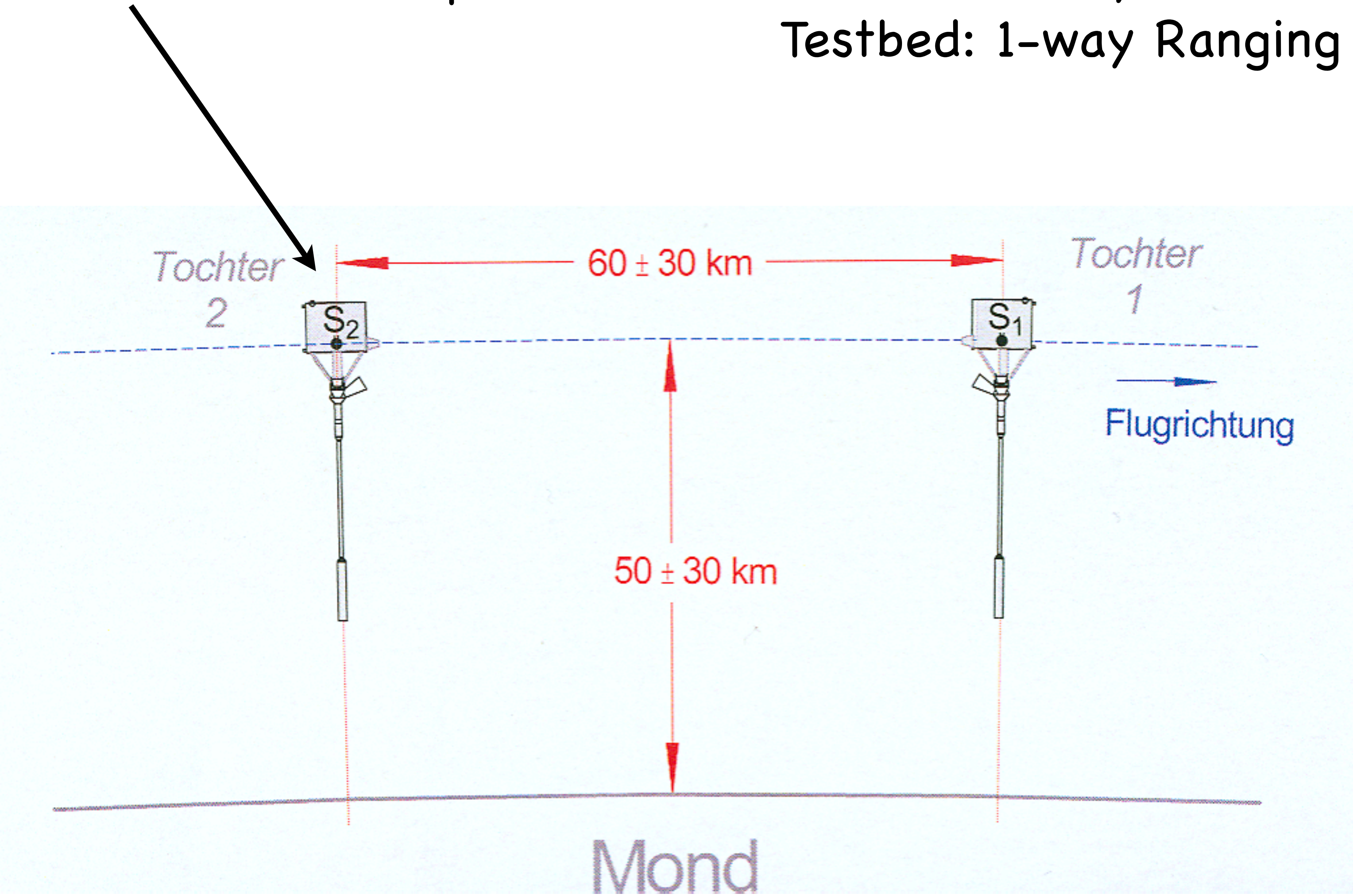
Coincidence detection:



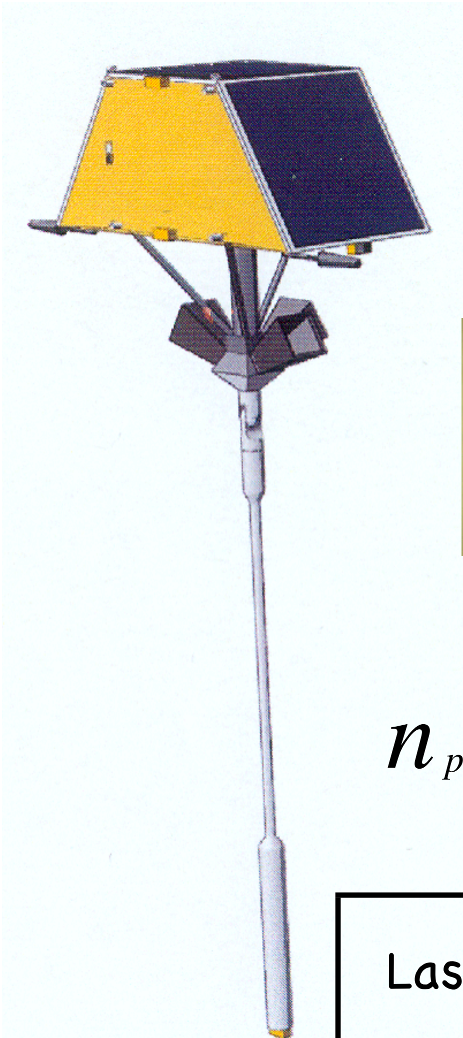
If noise level too high:

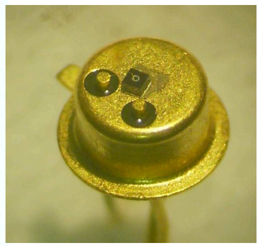
On board (software)
evaluation of coincident
events reduces
telemetry requirements
substantially

Lunar Exploration Orbiter (Gravimetry Mission)
Testbed: 1-way Ranging



LEO Ranging





200μm

$$n_{pe} = \frac{n_{ph} \cdot \eta_q \cdot \eta_r \cdot T \cdot A}{\Omega \cdot R^2}$$

- Angle > 1rad
- Coherent Application (Background Light: 1MHz/10nm)
- Demonstration 1-way Ranging (Subsatellites are synchr. wrt Timescale, MWL)

Laser Energy (mJ)	N_{ph} (5″ Div.)	N_{ph} (10″ Div.)	N_{ph} (20″ Div.)
20	13	3	≈1
50	34	8	2
100	68	17	4
200	137	34	8

Optical signal strength Ground - ACES

Standard Satellite Laser Ranging system, 532 nm, ps pulses

Laser	20 mJ, 200’’	0.2 mJ, 20’’
Range	540 km	540 km
Photons / m^2	$3 * 10^{11}$	$3 * 10^{11}$
Aperture		
1 mm	$3 * 10^5$	$3 * 10^5$
200 µm	10 ooo	10 ooo
25 µm	200 phot.	200 phot.

The worst case estimate

Background photon flux - ACES

Solar flux 0.2W/m^2/0.1 nm ~ 10^{18} phot/s/m^2/0.1 nm

Earth albedo 0.1

Field of View ~1 radian , ~ 400 km altitude

1. Direct Sun light > 1 * 10^{10} ph / s on detector
   photon counting not possible, no damage

2. Daylight – Earth albedo in entire footprint

1 mm	3 * 10^{12} ph / s / 10 nm
200 μm	1 * 10^{11} ph / s / 10 nm
25 μm	2 * 10^{9} ph / s / 10 nm

3. Night time in entire footprint (estimate < 0.001 daylight)

1 mm	< 3 * 10^{9} ph / s / 10 nm
200 μm	< 1 * 10^{8} ph / s / 10 nm
25 μm	< 2 * 10^{6} ph / s / 10 nm

The worst case estimate

Proposed detector configuration

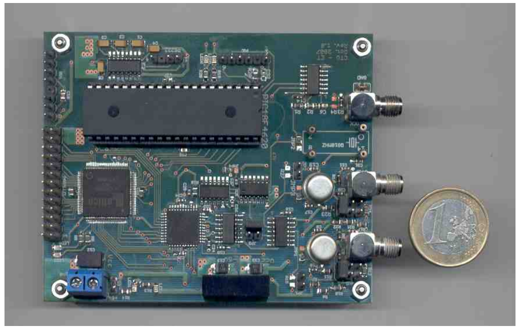
- K14 SPAD cooled detector package
- Active aperture 200 µm
- Coincidence option on sw level on-board
- Gated operation mode, synchronous with local 10 pps
- Interference filter 1 nm, aperture limited FOV
- Additional attenuation x1000 (geometry)

- MAIN PARAMETERS

- timing resolution	50 ps / shot	
- timing stability	~ 10 ps	
- power / mass	< 1 W, < 300 g	
- temp. range	- 30 … +50 C, no stabilisation needed	
- Gate ON time	> 0.1 µs	daylight
	> 20 µs	night time

Proposed detector features

- POSITIVE
  - based on proven technology
  - extremely simple, rugged, easy to adjust
  - low power, low mass
  - acceptable timing resolution, stability, reproducibility
  - operates day (some SLR) and night time (~ all SLR)
  - overload resistant , long lifetime in space
  - ground HW & operation compatible with other mission
  - photon number estimate



- NEGATIVE
  - synchronous operation required (100 ns /10 µs)
  - small additional HW required for ground SLR
    (prototype is existing in our labs)
  - downlink data rate ~ 400 bits/s
    (may be reduced by coincidence option)