Photon counting detectors for future space missions

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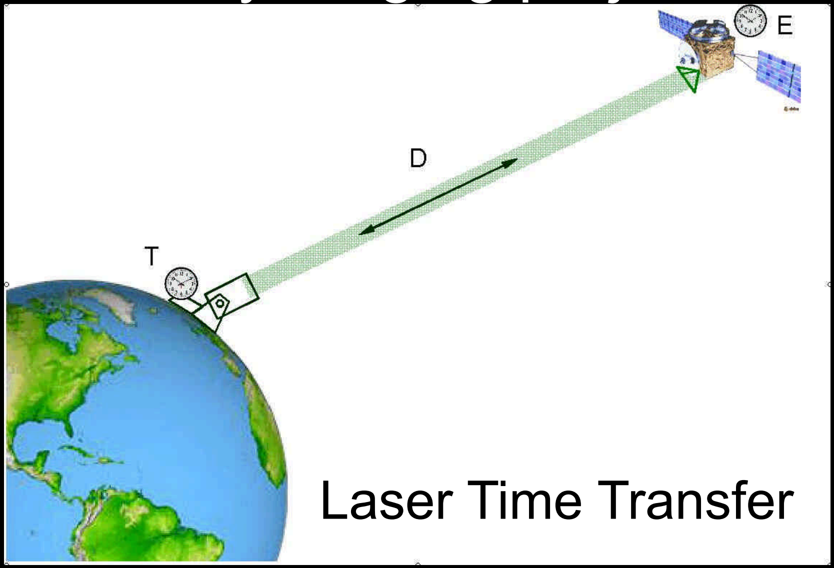
Outline

- Laser Time Transfer and one way ranging projects



- Detector requirements
- Detector version # 1 low (ISS orbit)
- # 2 high (GPS orbit)
- # 3 Lunar orbit (and beyond)

Laser time transfer and one way ranging projects

- Compass M1 Beidou by China
  laser time transfer
  GPS like orbit, 21 ooo km range
  since 2007 (see Yang et all..)

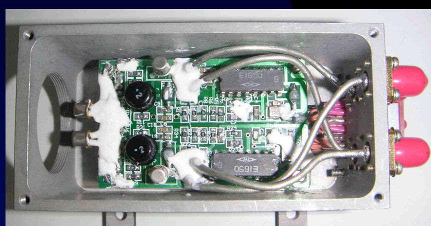
- Atomic Clock Ensemble in Space ACES by Europe
  laser time transfer, frequency and epoch comparison
  Columbus-ISS orbit, ~ 400 km range
  difficult tracking, short passes, high dynamic range
  launch 2012

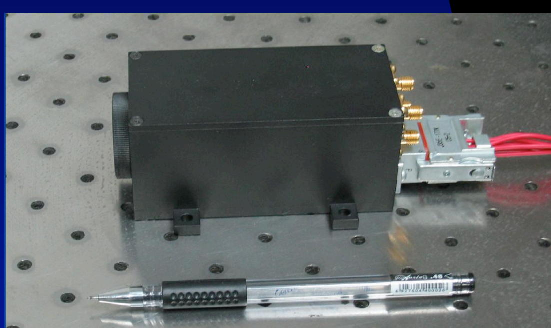
- One way laser ranging to Lunar orbiter, German Space Agency
  positioning, frequency and epoch comparison
  Lunar orbit, ~ 380 ooo km range
  launch 2012 (?)

Detector Requirements
sorted according to priority

1.	Timing stability	~ 10 ps or higher / depends on mission
2.	Background photon flux	operational up to $3*10^{12}$ phot./s 1 mm^2
3.	Complexity	LOW (Keep it simple in space !)
4.	Dynamic range	up to 1 : 1000 (mission dependent)
5.	Lifetime in space	no shielding, signal overload, > 5 yrs
6.	Timing resolution	< 100 ps rms
7.	Detection efficiency	> 0.1 (S/N is independent of detector eff.)
8.	Dark count rate	< 1 MHz (high background anyway)

Detector for LTT project, China

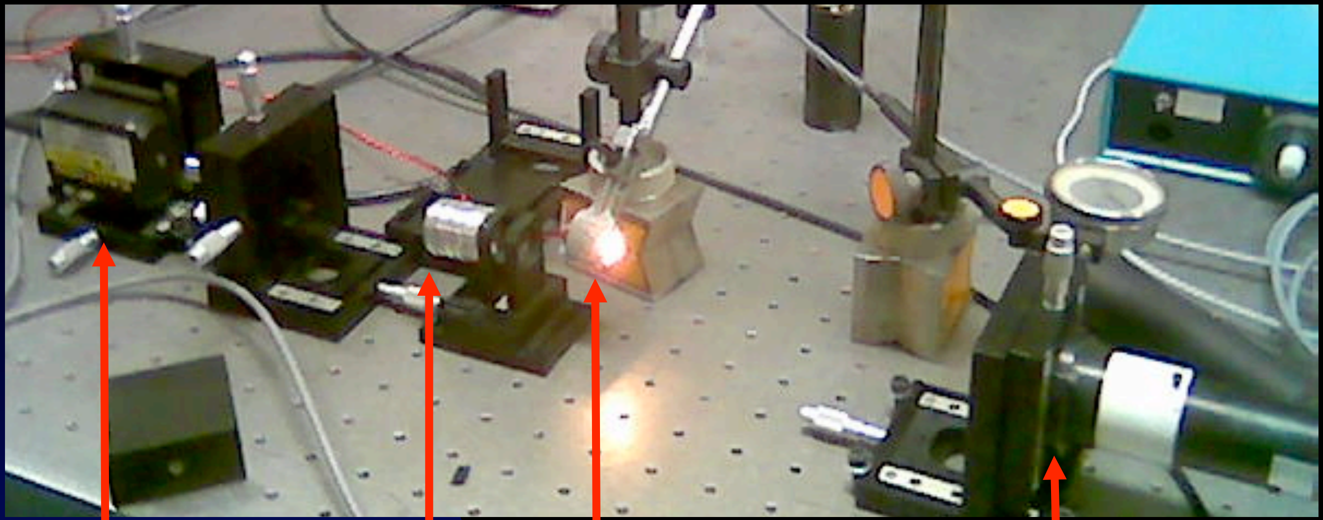


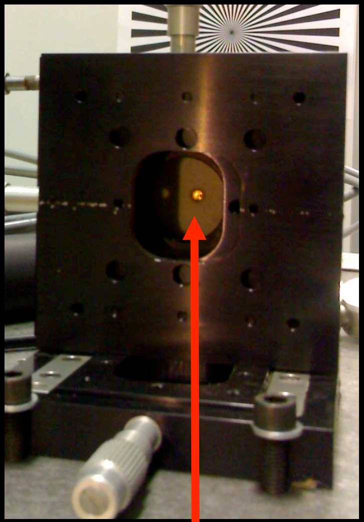


- SPAD K14, 25 um diam., dual / redundancy / NO collecting optics, FoV ~30^{o}, 10 nm filter
- Operated 0.7..1.0 Volt above breakdown
- Gated and not gated operation (2008)
- Detection efficiency ~ 0.1
- Jitter < 100 ps
- Stability ~ 10 ps
- Dark count rate 10 kHz / +20^{o}C

- OPERATING CONDITIONS
  Signal ~ 1 photon / shot
  Background flux up to 300 M phot. / s (!) on SPAD input
- = > Gating ~ 30 ns before (!)

Detector for LTT project, China
Background photon flux tests





Laser

12 W bulb

SPAD package

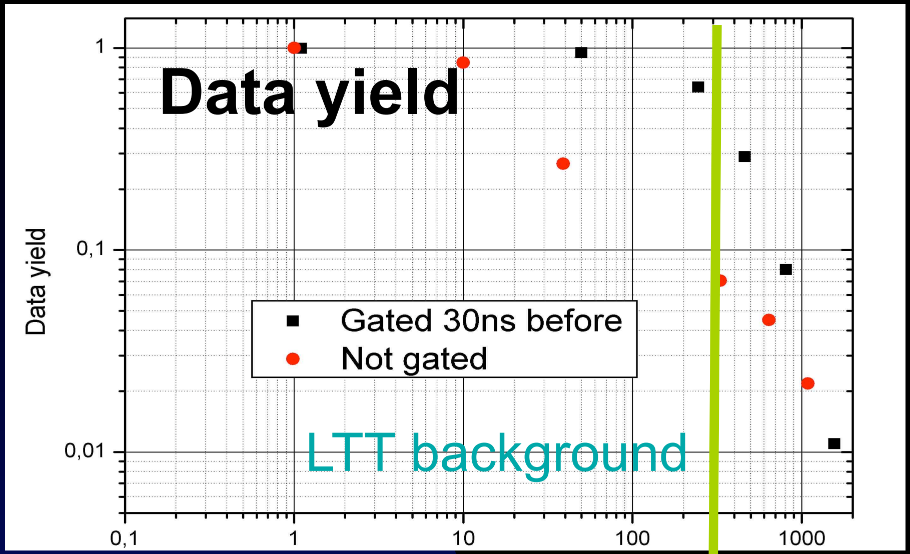
SPAD active area

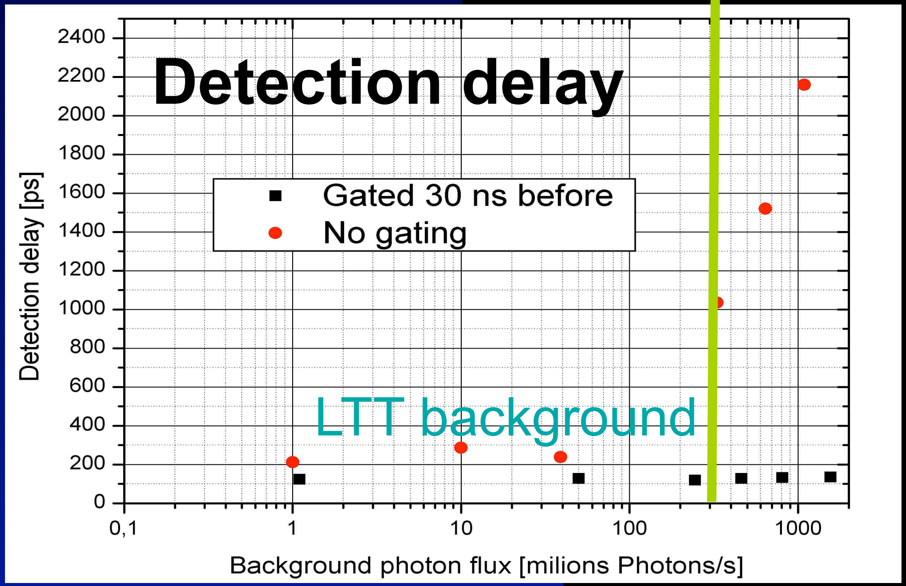
Attenuator ND
=> 1 photon / shot / SPAD

The setup enables ps photon counting with background photon flux levels up to 10^{13} photons / s / mm^2

WARNING do not try the same using PMT

Detector for LTT project, China
Background photon flux tests # 2

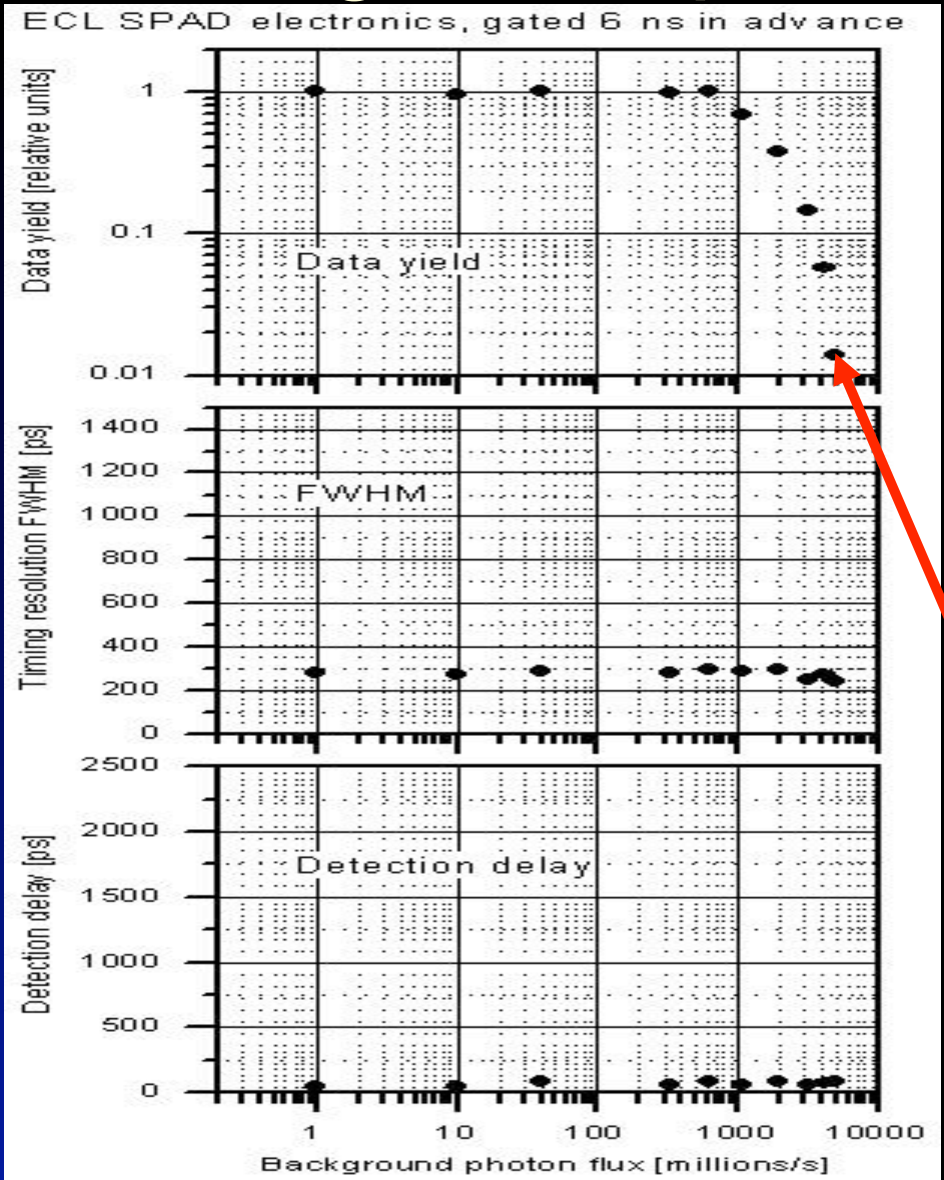




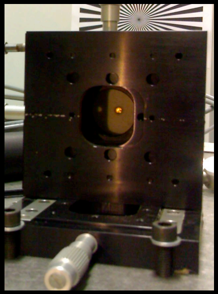
- Gating 30 ns before results in comparison to not gated setup in :
- Data yield increase 3 – 9 x
- Bias reduction 900 ps => 10 ps
- Timing jitter independent on flux

Detector for LTT project, China

Background photon flux tests # 3

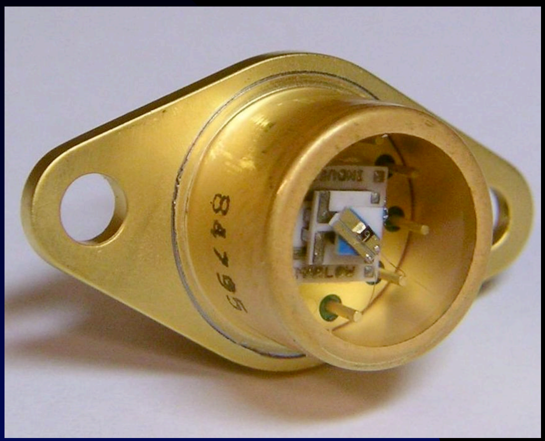


- The detector performance was tested in even higher background fluxes 10^{10} ph/s hitting SPAD active area
- Gating 6 ns in advance (not realistic for field use)
- Data yield > 1% at flux <u>5 * 10^9 photons / s / SPAD</u> see photo



- Timing resolution and detection delay does not change ~ 10 ps

Detector for ACES project, ESA 2012
Atomic Clock Ensemble in Space



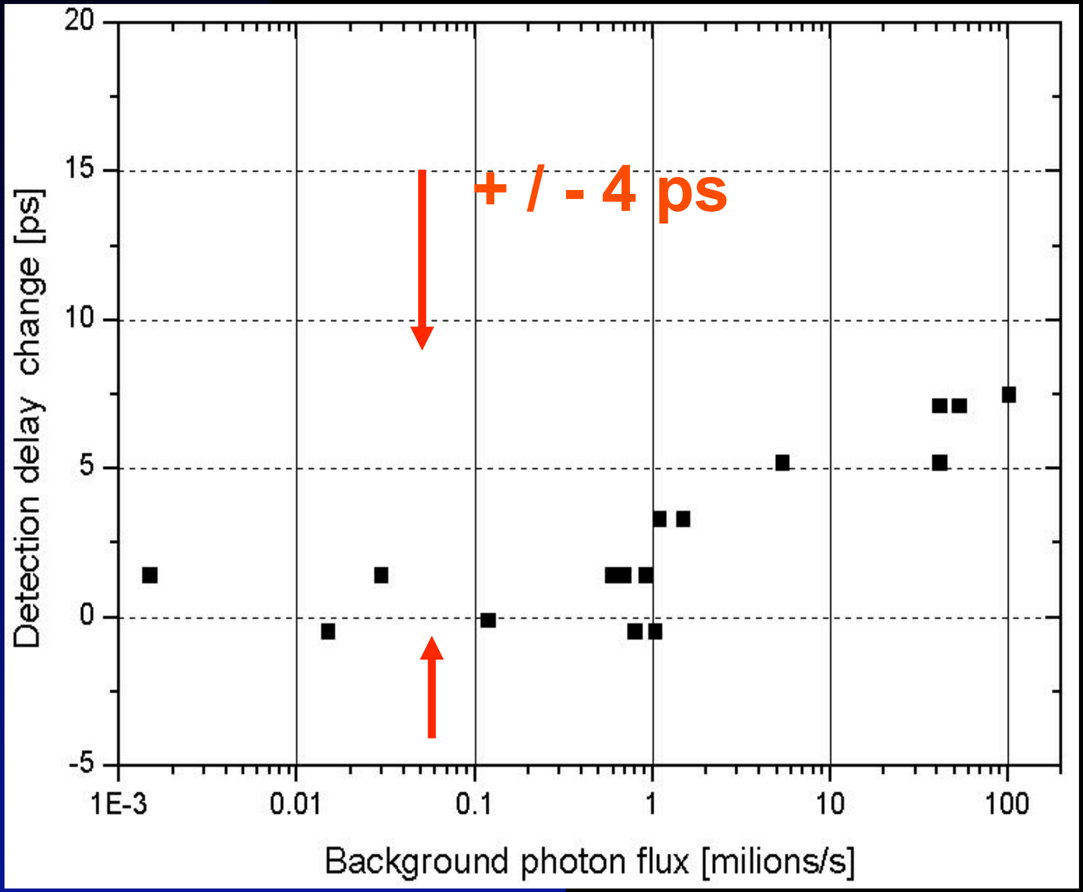
- SPAD K14, 200 um, TE3 cooled+ stabilized
  NO collecting optics, FoV~120deg, 1 nm filter
  Attenuated ~ 10^4 x

- Operated 5 Volts above breakdown, gated
- Photon number estimate
- Detection efficiency ~ 0.4 @ 532 nm
- Jitter < 30 ps
- Stability ~ 1 ps
- Dark count rate 20 kHz / +20^{o}C

- OPERATING CONDITIONS
  Signal 1 – 1000 photon / shot
  Background flux up to 100 M phot. / s (!)
  on SPAD input (daytime)
  Gate ~ 100 ns before (daytime)
  ~ 10 us wide (nighttime)

Detector for ACES project

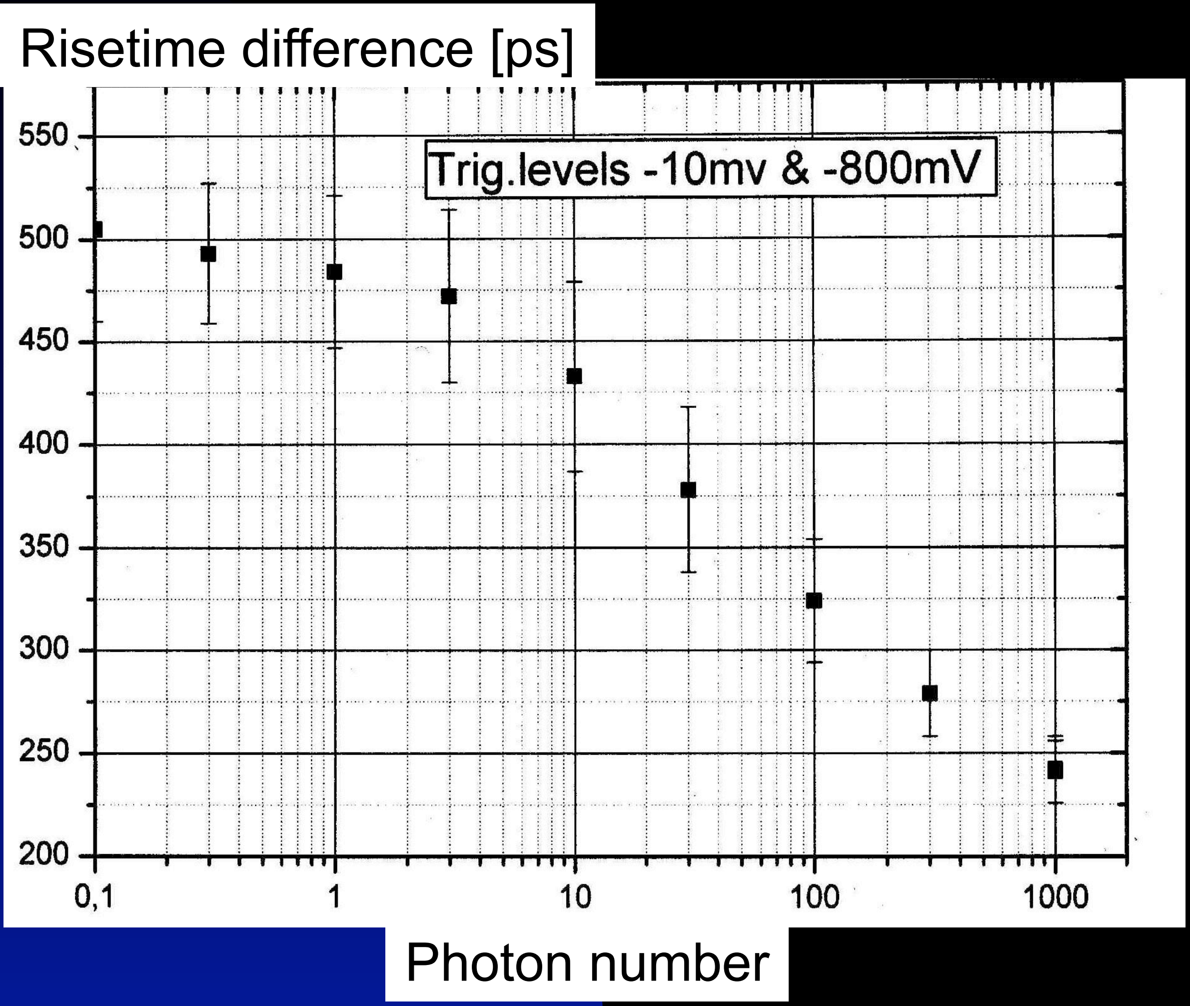
Detection delay versus background photon flux Single photons only



- Detection delay
  night +/- 1 ps
  day +/- 4 ps
- Detection jitter independent on background photon flux
- Data yield corresponds to statistics
  night (10 us gate) > 0.9
  day (0.1us gate) > 0.1

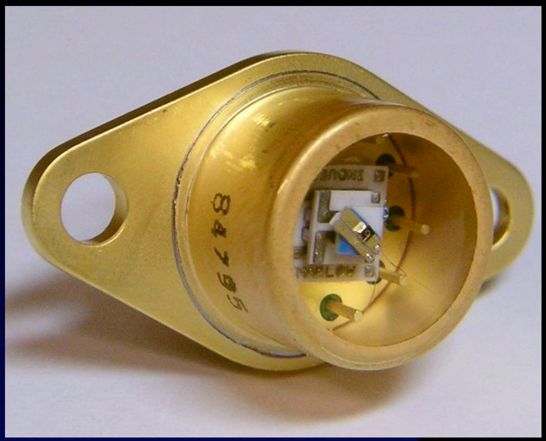
Detector for ACES project

Photon number estimate on SPAD



- New SPAD electronics for avalanche processing
- Two detector outputs
  - Timing
  - Risetime
- Photon number estimated on the basis of risetime
- ~ 8 x improvement to original Graz scheme
- 20 ps timing is sufficient
- The existing on-board timing device 2nd chan used for energy monit.

Detector for Lunar orbiter
LEO, DLR



- SPAD K14, 200 um, TE3 cooled+ stabilized
  NO collecting optics, 10 nm filter
- Operated 3 Volts above breakdown, Gated
- Detection efficiency ~ 0.3 @ 532 nm
- Jitter < 30 ps
- Stability ~ 1 ps
- Dark count rate 20 kHz / +20^{o}C

- OPERATING CONDITIONS
- Signal 1 photon / shot only
- Background flux up to 50 M phot. / s (!) on SPAD input
- Gate ~ 200 ns before

Conclusion

- Three photon counting detectors have been designed for laser time transfer missions (LTT, ACES) and one way ranging mission (LEO)

- Timing stability 10 to 1 ps half peak to peak and timing resolution 30 to 100 ps rms is achievable

- All the detectors are capable to operate under extremely high background photon flux conditions,
  => photon counting with wide FoV (120^o)
  realistic opt.band-pass filter

- The dynamical range of 1 to 10 ooo photons / echo photon number estimate is available

- Very simple & rugged design