Collaborations on lunar and satellite laser ranging research with Frascati National Labs

MoonLIGHT-2 Project

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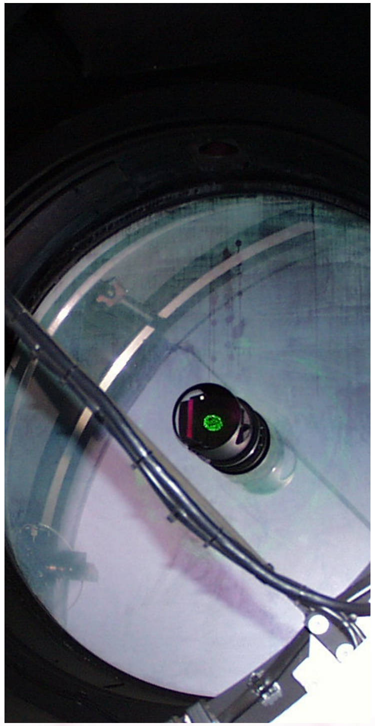
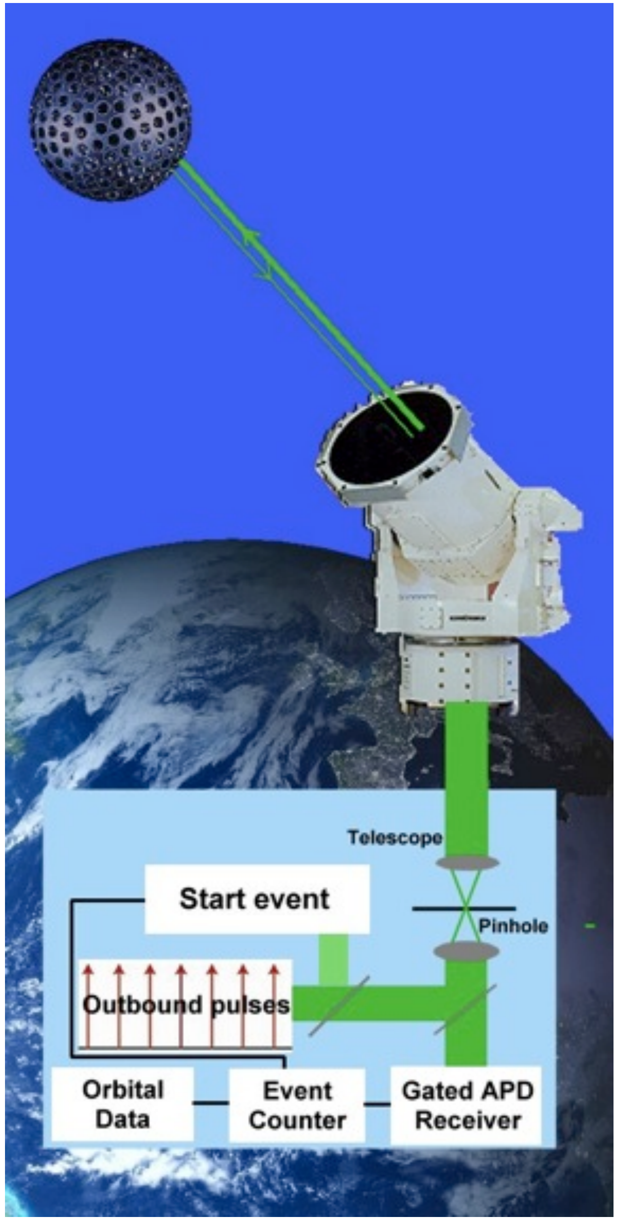
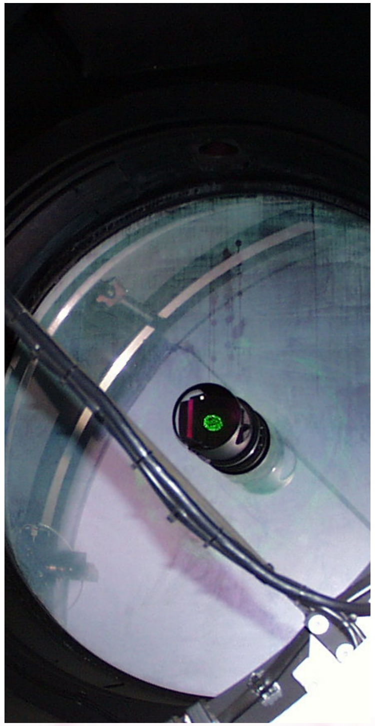
Synergy with the LNF team



- Il Gruppo di ricerca SCF_Lab coordinato da S. Dell'Agnello è attivo da anni nello studio dei retroriflettori spaziali(CCR) per laser ranging.
- QuantumFuture ha utilizzato CCR dal 2003 a Matera





MoonLIGHT-2 @ LNF – Gr. 2

Da Simone Dell’Agnello LNF
Studi sistematici sull'influenza della polarizzazione del laser su LLR return, o cosiddetto laser-link budget, per riflettori Apollo, Lunokhod, e MoonLIGHT
Uni-Pd ha esperienza unica della stazione MLRO ed in particolare della gestione della polarizzazione.

1. Studio della polarizzazione ottimale da usare per LLR su MoonLIGHT
2. Campagne misure sperimentali a MLRO del link budget in funzione di varie stati di polarizzazione, con satelliti e la Luna
3. Studi sistematici sull'influenza della durata dell'impulso laser, della scelta dei filtri, della banda; studio dell'effetto della dispersione in lambda per impulsi corti, studio della diffrazione dell'impulso in funzione della durata impulso.
4. *test di ottiche dello SCF_Lab* (e.g. ottiche con aperture CA fino a 200 mm) alle Canarie
5. presa dati LLR a MLRO assieme con INFN-LNF SCF_Lab, Apollo/Lunokhod adesso e MoonLIGHT dal 2016.

Recent results on SLR

Towards Quantum Communication from Global Navigation Satellite System

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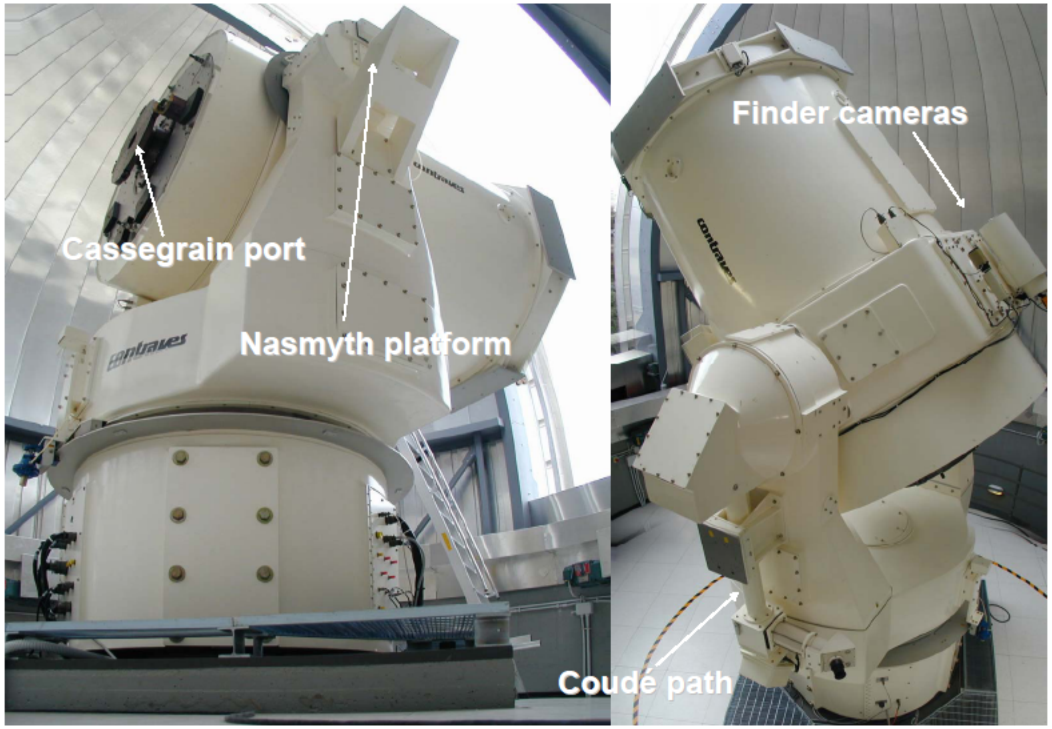
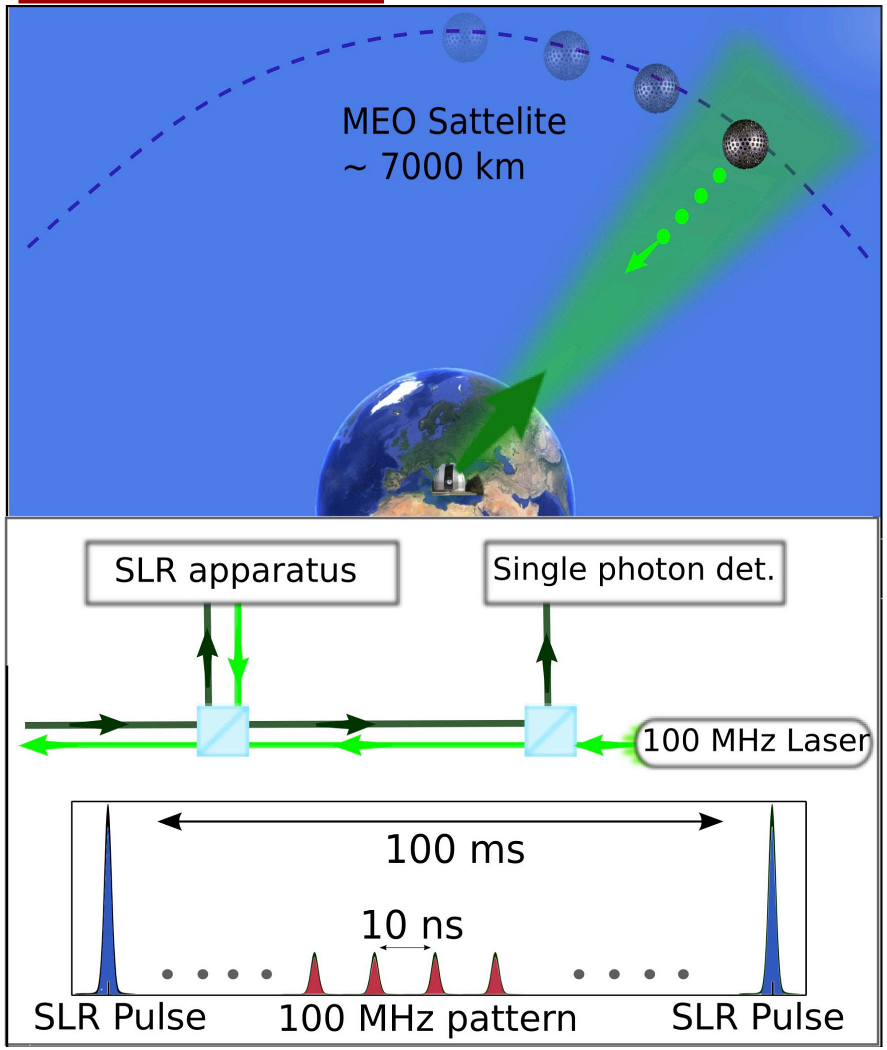
arXiv:1804.05022v1 [quant-ph] 13 Apr 2018

Experimental Space Q-Comms hub Matera ASI-MLRO



- *Giuseppe Colombo* Space Geodesy Centre of Italian Space Agency - Matera Laser Ranging Observatory (MLRO)
- Director Dr. Giuseppe Bianco President of ILRS
- World highest accuracy in SLR: mm-level for about 10^7 m range
- Accurate lunar ranging

Limits in Q-Comms in Space



✓ 100 MHz, 100 mW laser @532 nm is generated at MLRO and pointed toward the satellite.

The high loss in the uplink reduce the intensity to μ_{sat}~1 photon per pulse. The single photon signal is retroreflected toward the ground station, where it is detected.

✓ PMT single photon detectors, 22 mm dia. , ~50 Hz dark counts, 10% efficiency

✓ A beam splitter merges the 100 MHz laser with the stronger 10 Hz Satellite Laser Ranging (SLR) pulses.

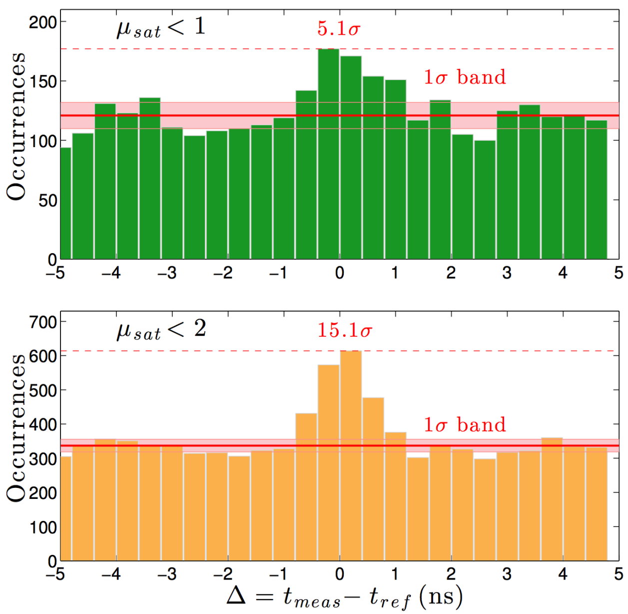
The SLR signal is used for pointing and as a synchronization reference.

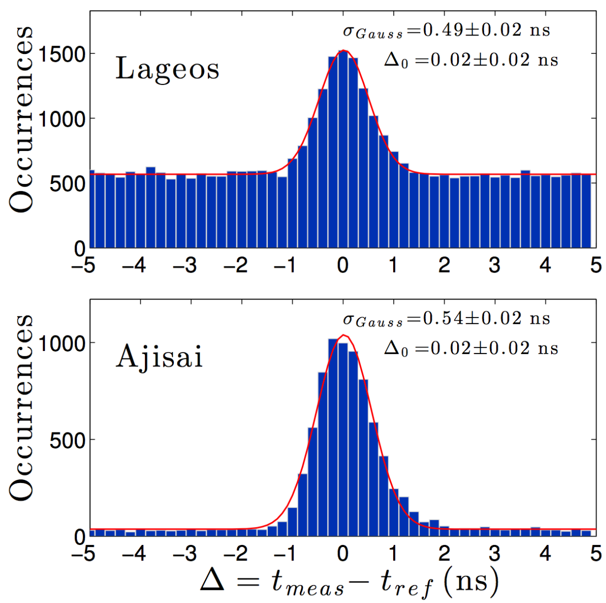
Single photon exchange

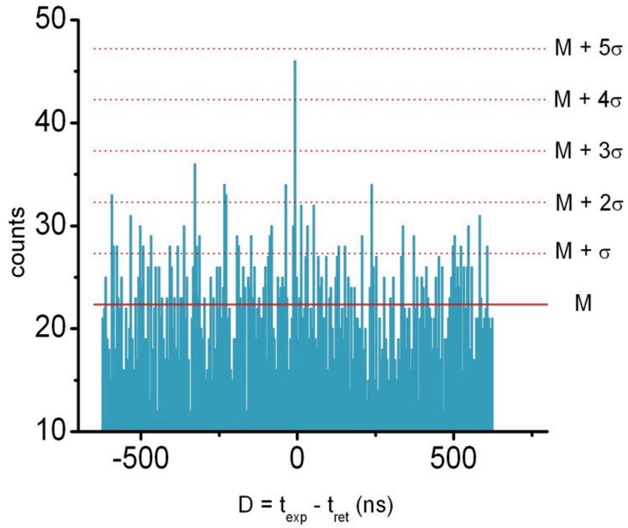
Ajisai 2008

Lageos 2015

Difference of the measured time tags of a complete passage with the nearest tref calculated by the ancillary SLR pulses.





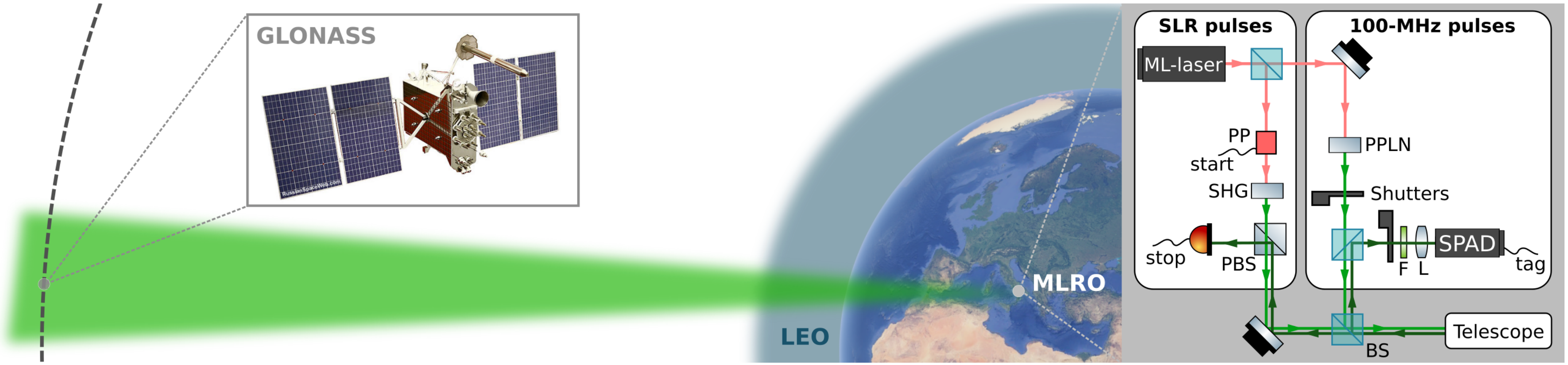


D. Dequal et al. *Experimental single photon exchange along a space link of 7000 km*, 2016

P. Villoresi et al. *Experimental verification of the feasibility of a quantum channel between space and Earth*,
New J. Phys. **10** 033038 (2008)

GNSS orbit reached at 20000km: GLONASS returns

GNSS satellites are crucial assets for navigation and time stamping on a variety of applications.



L. Calderaro et al. *Towards Quantum Communication from Global Navigation Satellite System*, arXiv 1804.05022 (**April 2018**).

GNSS orbit reached at 20000km: GLONASS returns

two GLONASS terminals equipped with an array of corner-cube retroreflectos (CCRs), namely Glonass-134 and Glonass-131 (Space Vehicle Number: 802 and 747, respectively)

The targeted GNSS satellites are part of different generations, GLONASS-K1 for Glonass-134 and GLONASS-M for Glonass-131, both equipped with a planar array of CCRs, with circular and rectangular shape respectively

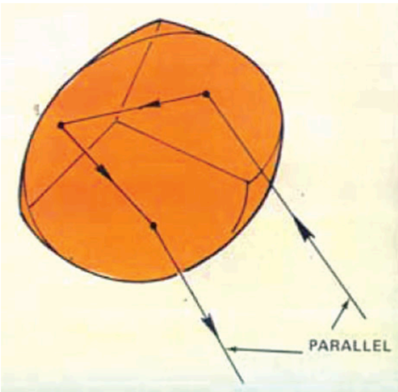
Their CCRs are characterized by the absence of coating on the reflecting faces, such that the light is back reflected by total internal reflection (TIR). This implies a far field diffraction pattern (FFDP) which is quite different from the simple Airy disk given by a circular aperture

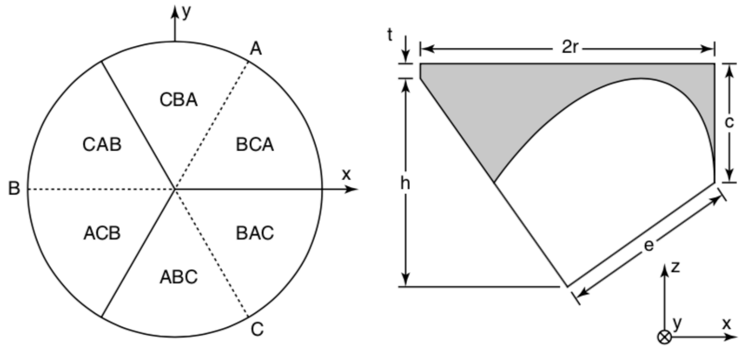
L. Calderaro et al. *Towards Quantum Communication from Global Navigation Satellite System*, arXiv 1804.05022 (**April 2018**).

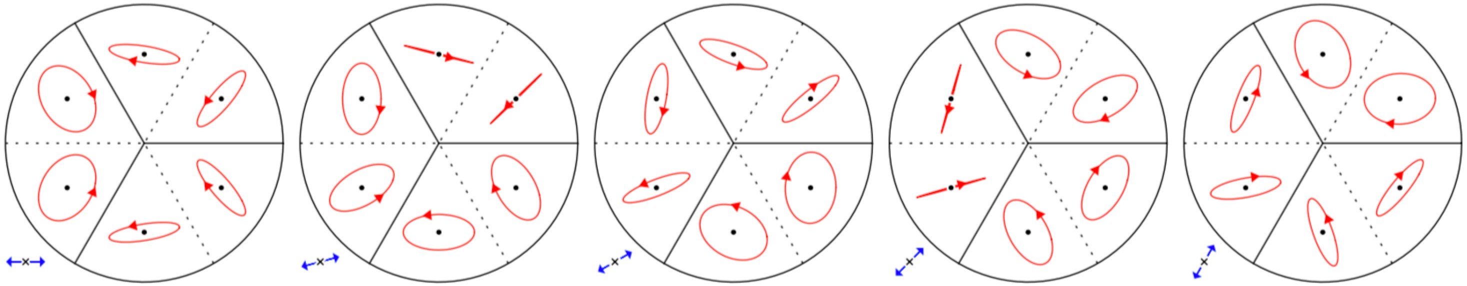
GLONASS return modeling

Total internal reflection from corner cubes - no back-coating

the polarisation is not preserved







T. W. Murphy and S. D. Goodrow, Polarization and far-field diffraction patterns of total internal reflection corner cubes, Appl. Opt **52** 177 (2013)

GLONASS return modeling

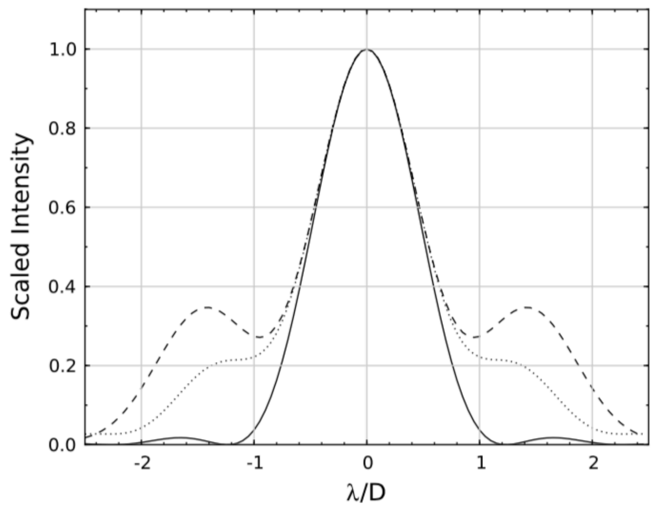
far-field diffraction pattern calculated by Fourier transforming the reflected field from the CCR

$$I(\chi,\eta) = \left| \iint_{\text{aperture}} S(u,v)\exp\left[i\phi(u,v)\right]\exp\left[ik(\chi u + \eta v)\right]\mathrm{d}u\mathrm{d}v \right|^2$$

coordinates: *u* and v in CCR plane, χ and η far-field angles, k=2π/λ

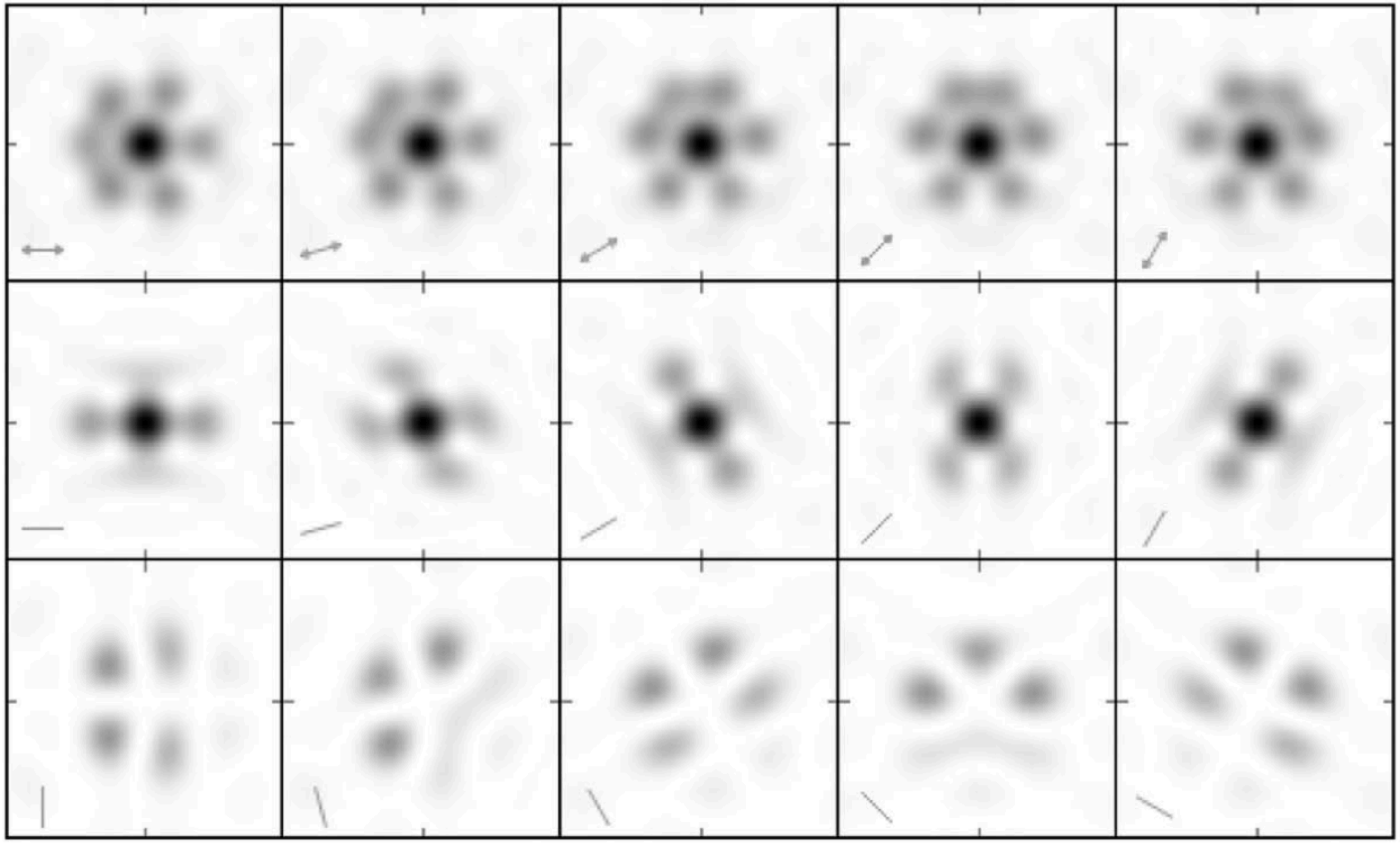
from this: **top-hat radius of 2.56λ/D - Airy pattern of 1.27λ/D**

In axis: **24.5 %** wrt the Airy pattern of an equivalent disc of 26 mm



T. W. Murphy and S. D. Goodrow, Polarization and far-field diffraction patterns of total internal reflection corner cubes, Appl. Opt **52** 177 (2013)

GLONASS far-field diffraction pattern



Each frame is 50λ/7D radians across

T. W. Murphy and S. D. Goodrow, Polarization and far-field diffraction patterns of total internal reflection corner cubes, Appl. Opt **52** 177 (2013)

Modeling GLONASS returns

The lobes are displaced from the center of the FFDP

$\theta_d \approx 1.4\lambda/D_{CCR}$ (26 mm) ≈ **29 μrad**

velocity aberration of GNSS satellite is around **26 μrad**

lateral lobes: intensity ≈ 30% of central peak

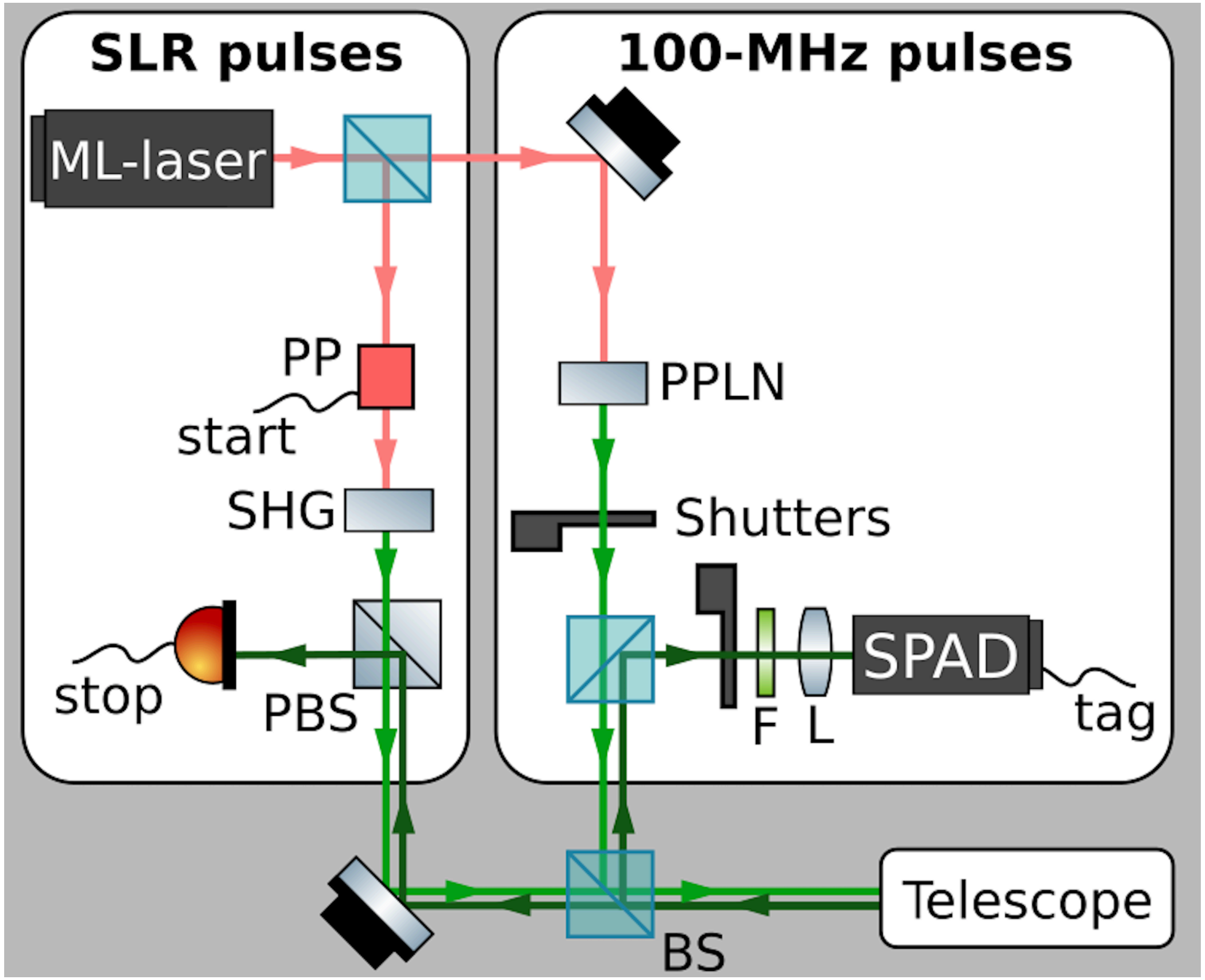
If A_{tel} is the telescope gathering area, the transmittivity is

$$t_{\text{diff}} = 0.264 \cdot 0.3 \frac{A_{\text{CCR}} A_{\text{tel}}}{\lambda^2 R^2}$$

corresponding to **62 dB for downlink losses**

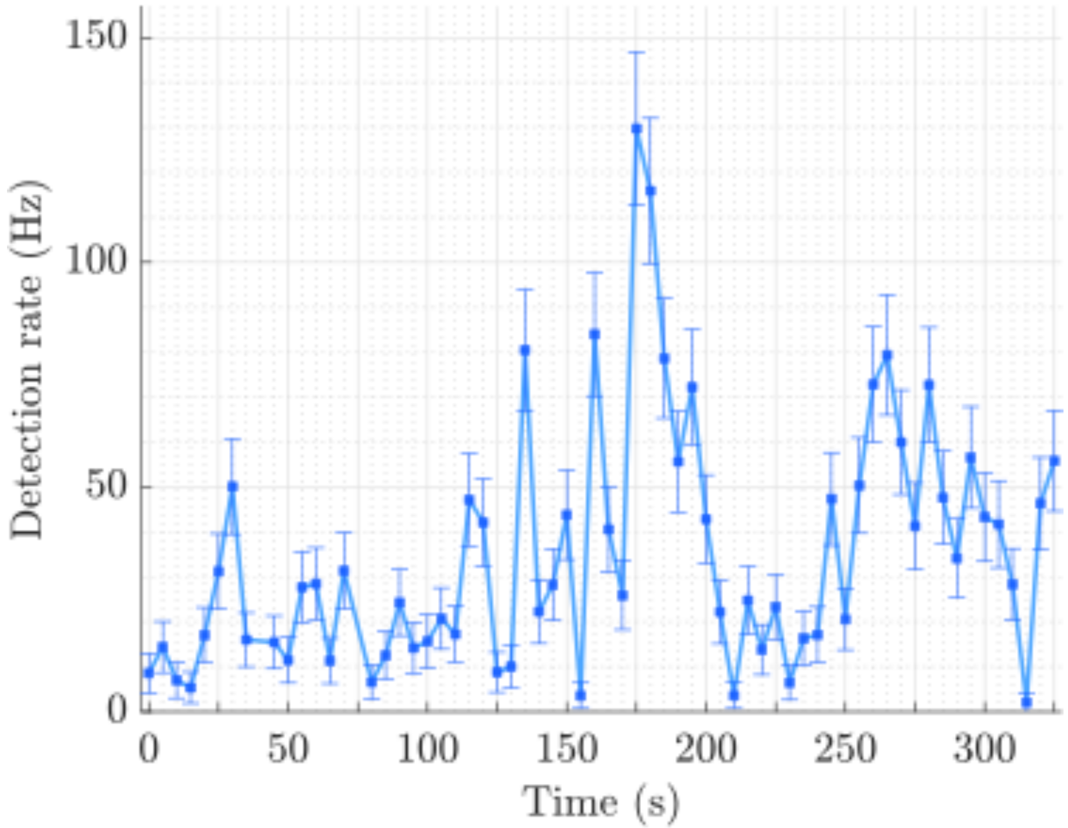
This value is in agreement with the cross-section assessment derived from standard SLR modeling

J. J. Degnan, *Millimiter Accuracy Satellite Laser Ranging: A Review* Geodynamics Series 25, 133 (1993)



G. Vallone et al, *Experimental Satellite Quantum Communications,* Physical Rev
L. Calderaro et al. Towards Quantum Communication from Global Navigation S

GLONASS observed returns

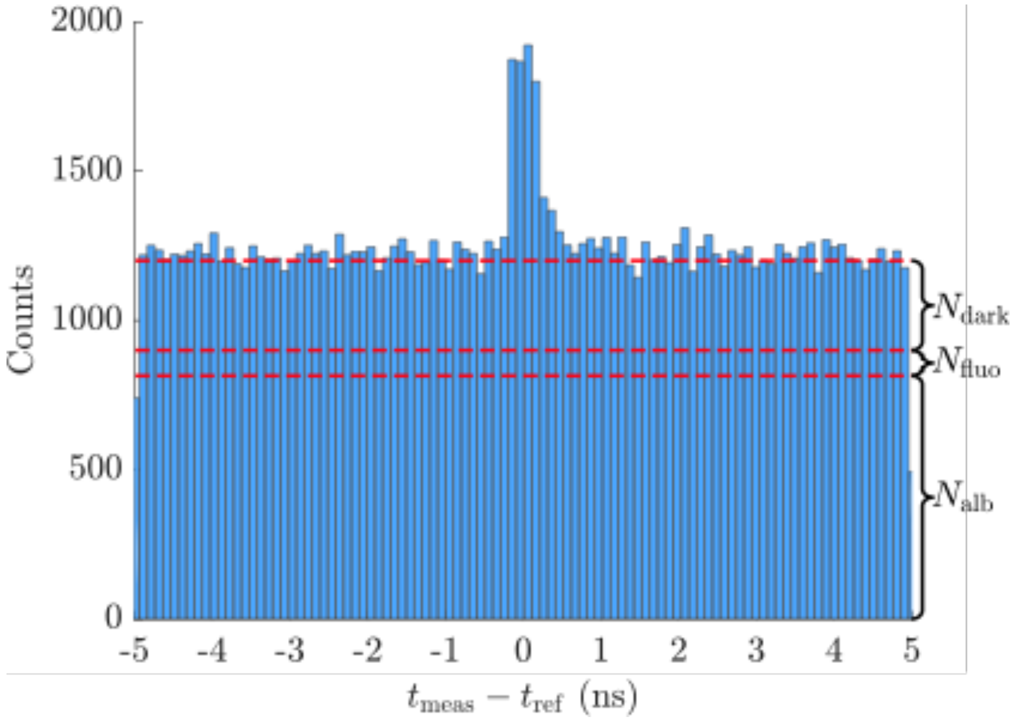


Detection rate from **Glonass-134** at 19,500 km slant distance

Each point integrated for 5 s - around 400ps of ETA (40ps det. jitter)

L. Calderaro et al. *Towards Quantum Communication from Global Navigation Satellite System*, arXiv 1804.05022 (**April 2018**).

GLONASS returns binned



Detection rate from **Glonass-134** at 19,500 km slant distance
Estimated time of arrival (ETA) from SLR measure, done in parallel
Each point integrated for 5 s - around 400ps of ETA (40ps det. jitter)

L. Calderaro et al. *Towards Quantum Communication from Global Navigation Satellite System*, arXiv 1804.05022 (**April 2018**).

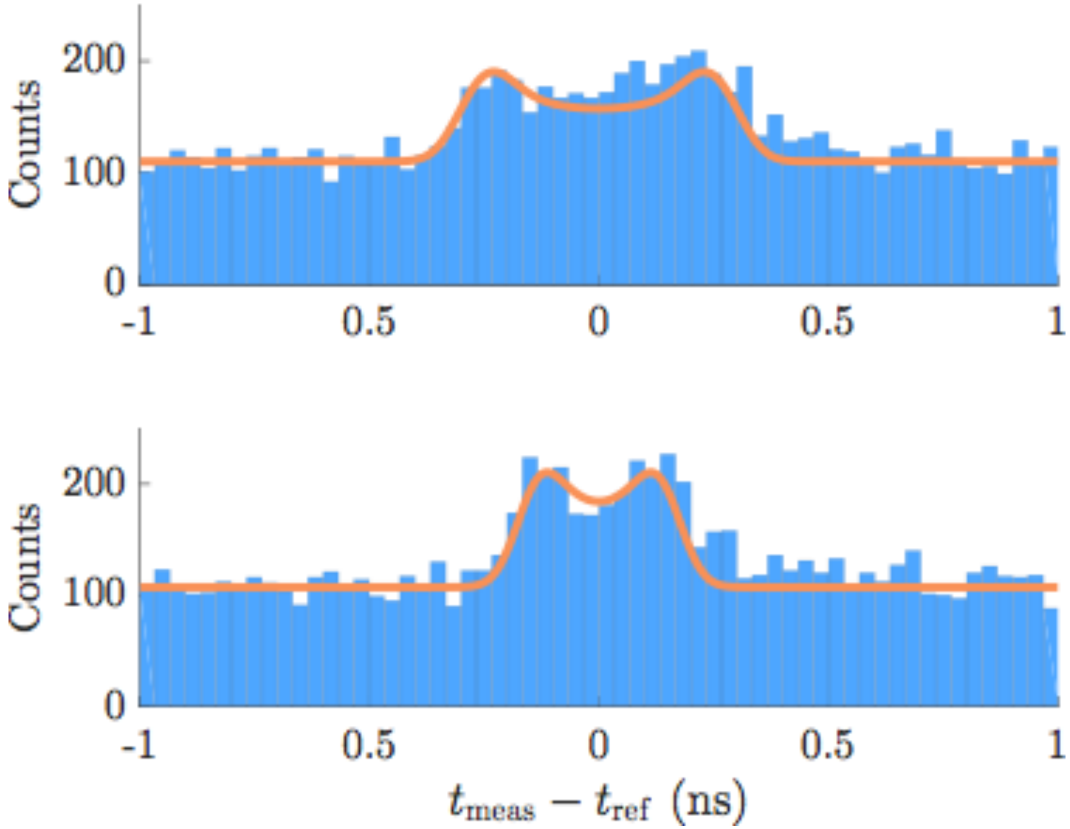
GLONASS returns summary

Satellite passage	Slant distance (km)	Detector	$\overline{R}_{\rm det}$ (Hz)	SNR	$\overline{\mu}_{\rm sat}$	$l_{\rm down}$ (dB)	$l_{\rm rec}$ (dB)
Glonass-134	19,500	SPAD	58	0.53	15	62.1	11.8
	20,200	SPAD	59	0.41	16	62.5	11.8
Glonass-131	20,250	SPAD	27	0.43	15	62.6	14.8
		PMT	6	0.21	16	62.6	21.8

L. Calderaro et al. *Towards Quantum Communication from Global Navigation Satellite System*, arXiv 1804.05022 (**April 2018**).

GLONASS temporal footprint

The incident angle of the beam on the array: 9 deg and 5 deg



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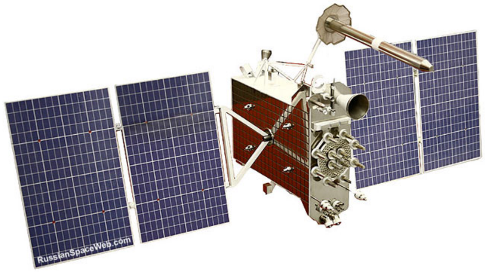
Conclusions



- First exchange of few photons per pulse (μsat ≃ 10) along a channel length of 20,000 km demonstrated
- Matera Laser Ranging Observatory confirmed as optimal hub for satellite QKD
- SNR about 0.5 and a detection rate around 60 Hz.
- Specification of the active source performances
- Our findings demonstrate that QC from GNSS satellite is feasible with current state-of-the-art technology
- Interesting platform also for fundamental tests of Quantum Mechanics and Gravitation

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Preventivi 2019

- il 2019 si profila come un anno di intesa sperimentazione, conseguente al lancio del CCR da parte del Coordinatore LNF.
- Sono quindi previste prolungate sessioni sperimentali presso MLRO a Matera e coordinamento con LNF (15k + 5k SJ).
- Si punta a migliorare la determinazione del tempo di volo con un innovativo sistema di rivelazione a singolo fotone a ridotto jitter (<40ps) e taglio della coda esponenziale.
- Si chiede quindi il finanziamento di un sensore e del materiale di consumo per il suo adattamento nel sistema coudè di MLRO e controllo fine della focalizzazione (25k sensore – da confermare e 15k+3k SJ consumo).