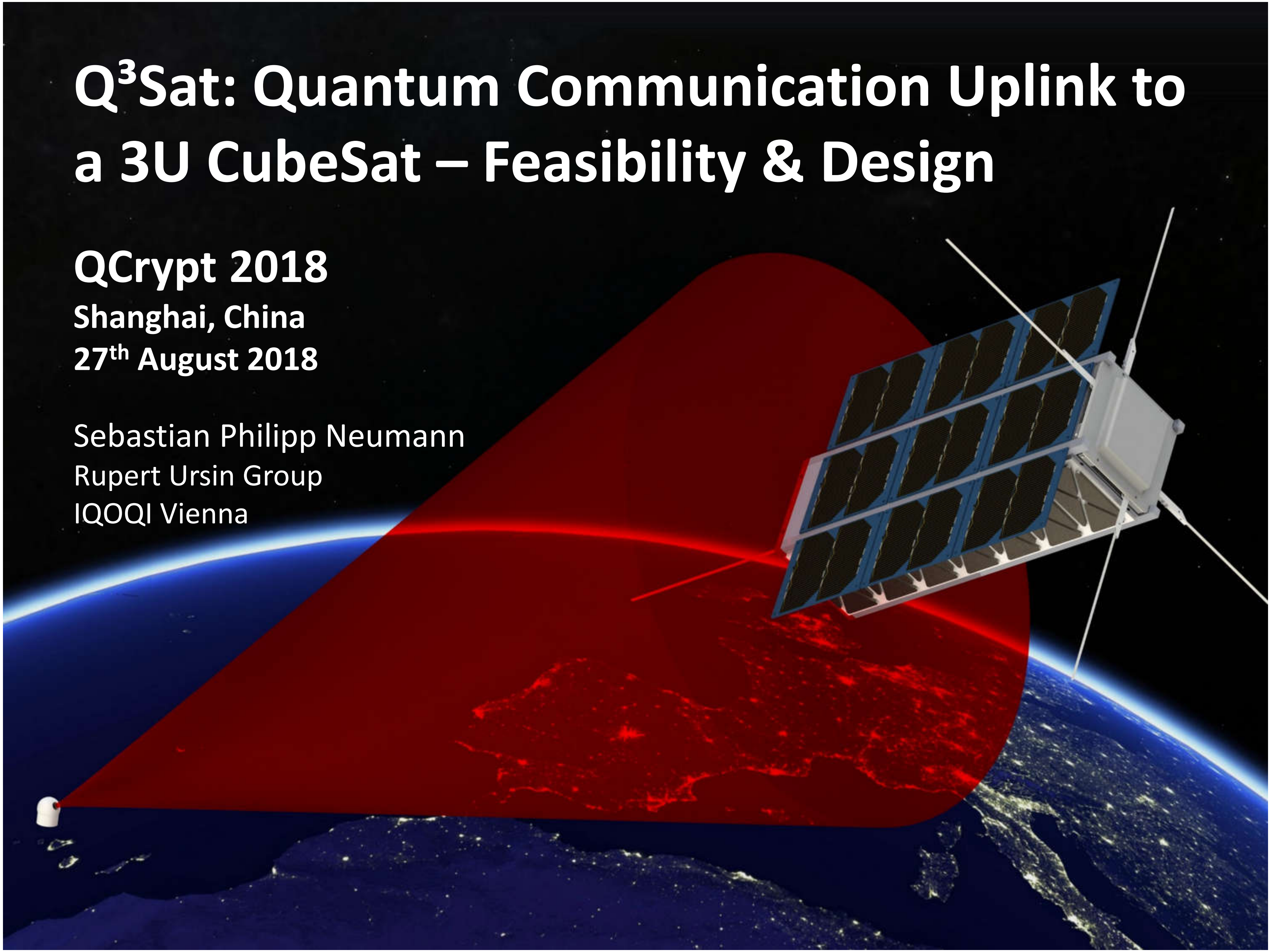
Q³Sat: Quantum Communication Uplink to a 3U CubeSat – Feasibility & Design

QCrypt 2018

Shanghai, China
27th August 2018

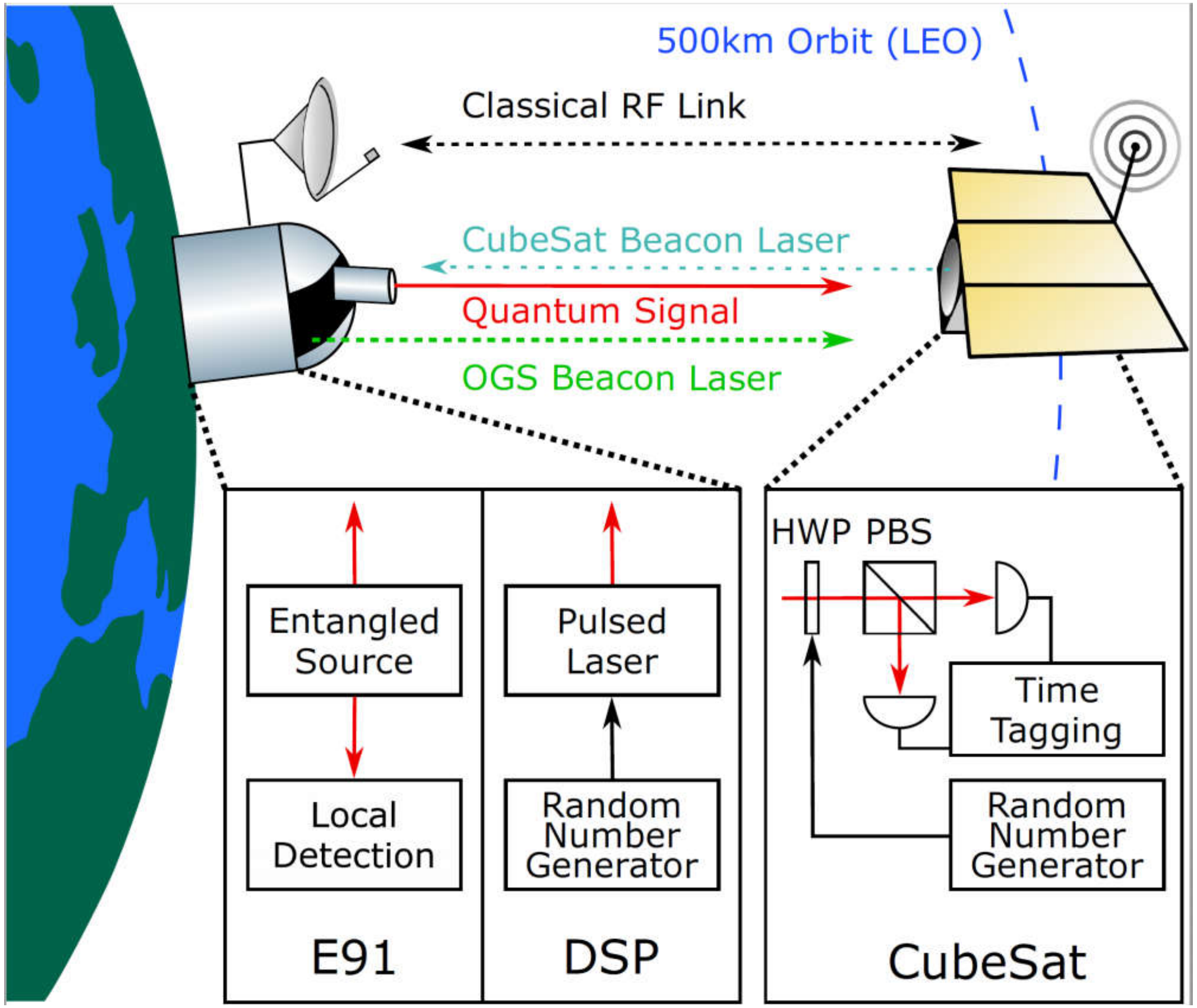
Sebastian Philipp Neumann
Rupert Ursin Group
IQOQI Vienna



Overview

- Q^3Sat mission setup
- Why a CubeSat?
- Satellite design
- Choice of orbit
- Crucial parameters for high SNR and key rate
- Expected performance

Uplink Mission Setup

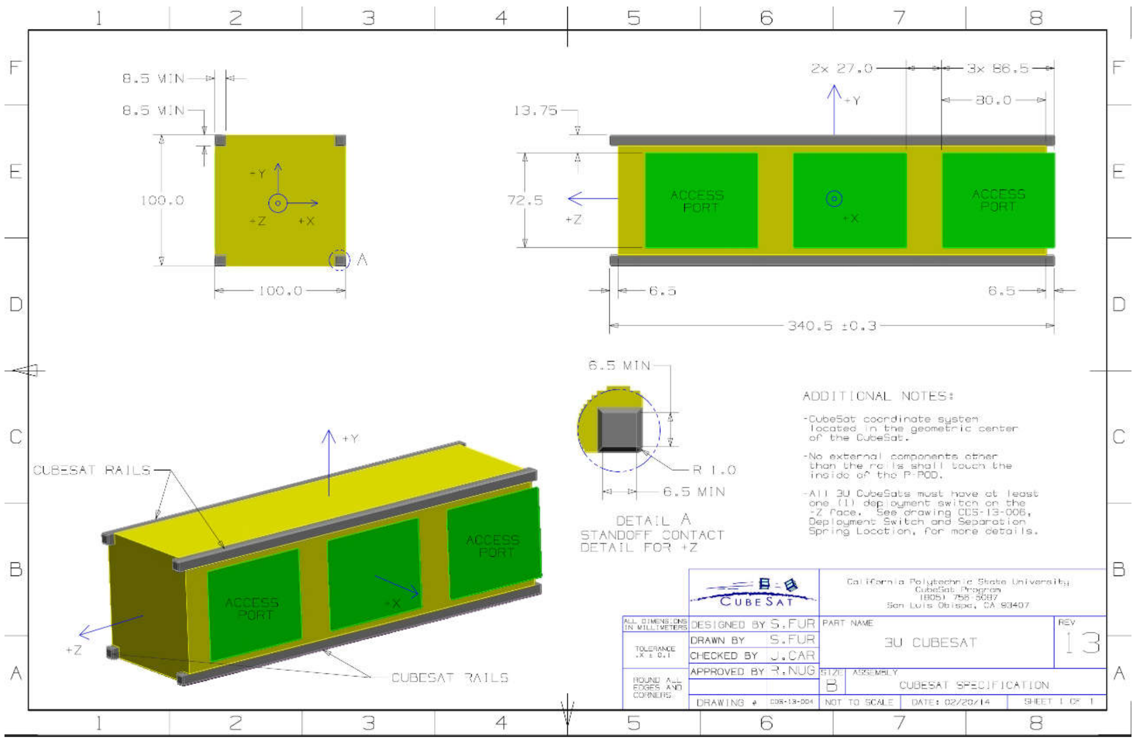


Why uplink?

- Simple setup on satellite
- Usable for several protocols

Why a CubeSat?

3U: 10x10x34cm, 4kg; ideal for precursor missions

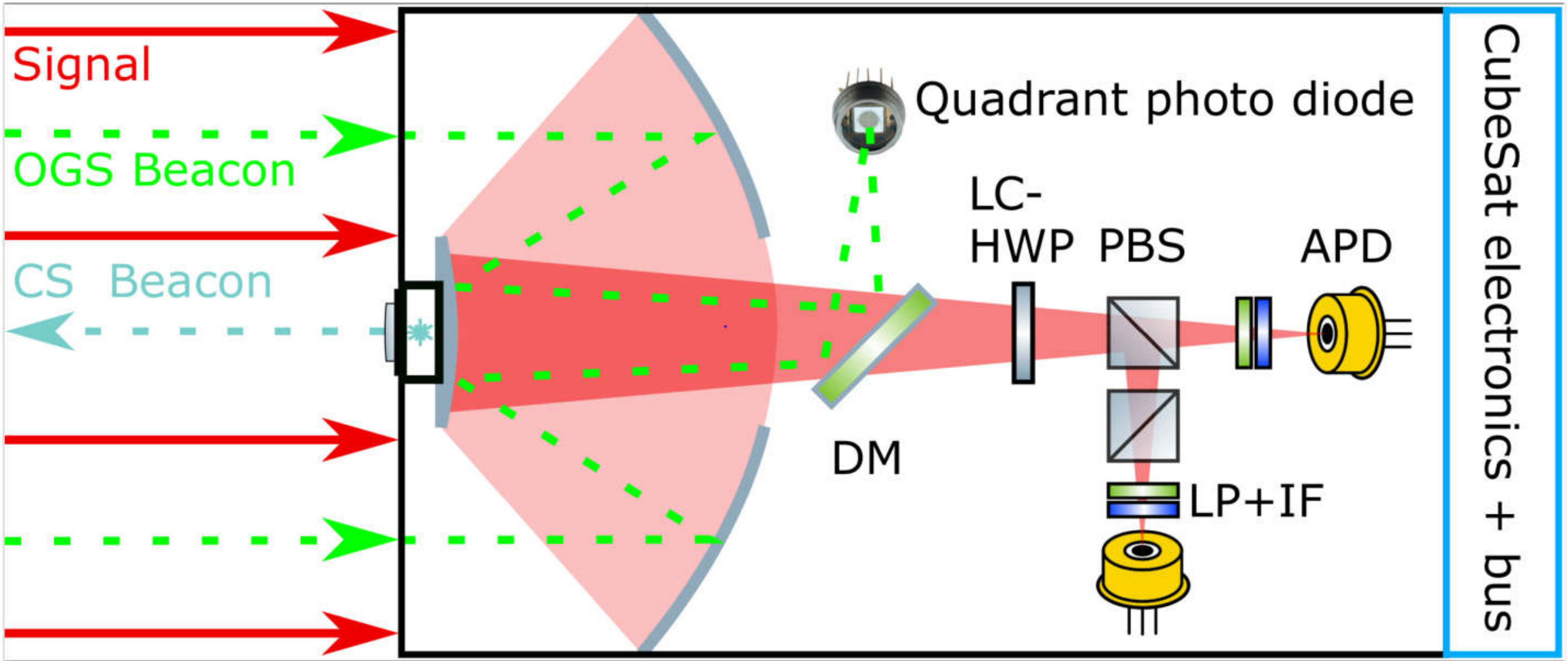


DETAIL	CONTAINERIZED		
PAYLOAD TYPE	3U	6U	12U
LENGTH (CM)	34.05	34.05	34.05
HEIGHT/DIA (CM)	10	10	22.63
WIDTH (CM)	10	22.63	22.63
MASS (KG)	5	10	20
PRICE-LEO	$295	$545	$995
PRICE-GTO	$915	$1,400	$2,750

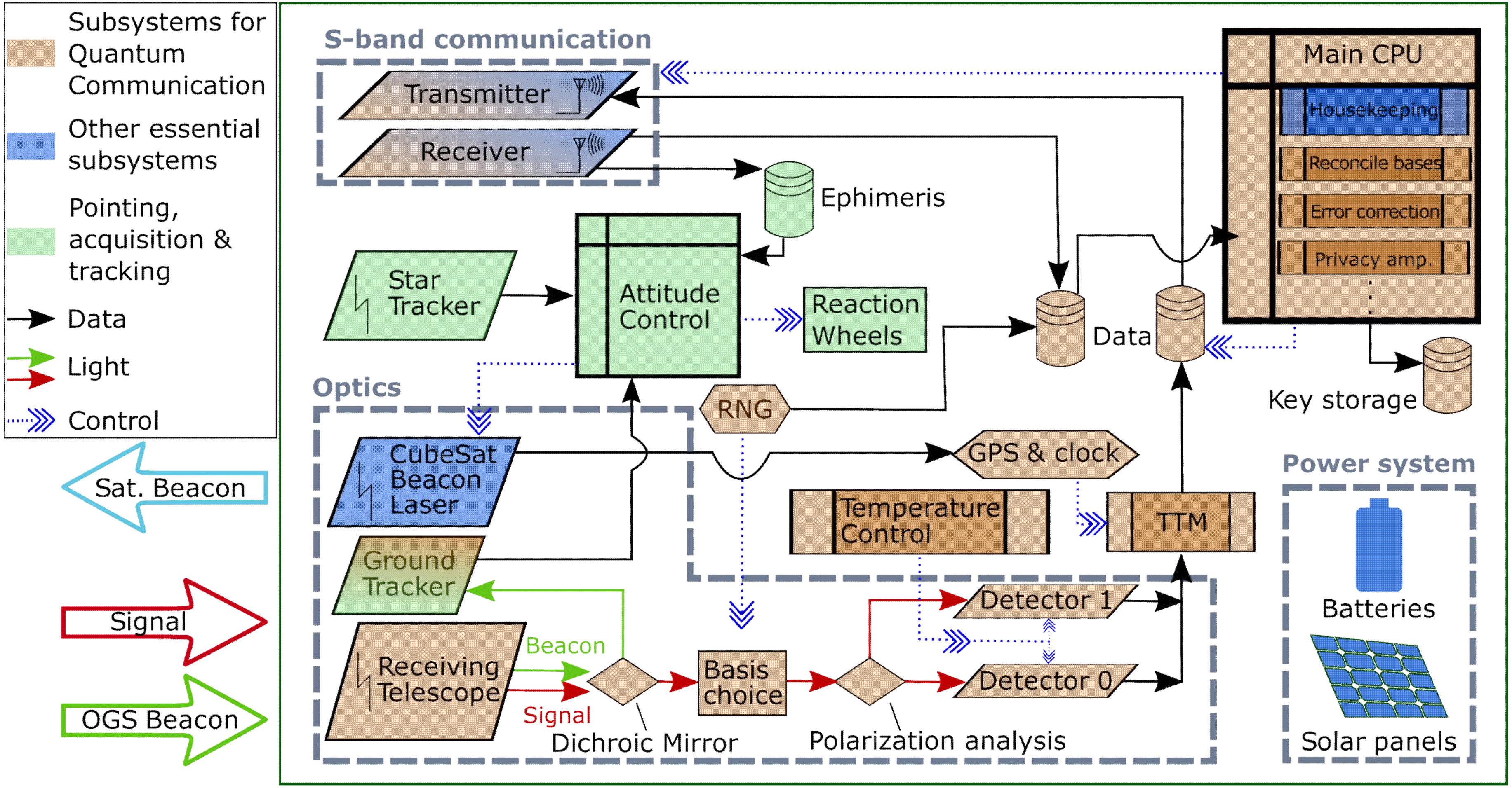
Pricing in thousands (USD)

Figures: CubeSat design specification sheet by CalTech and http://spaceflight.com/schedule-pricing/

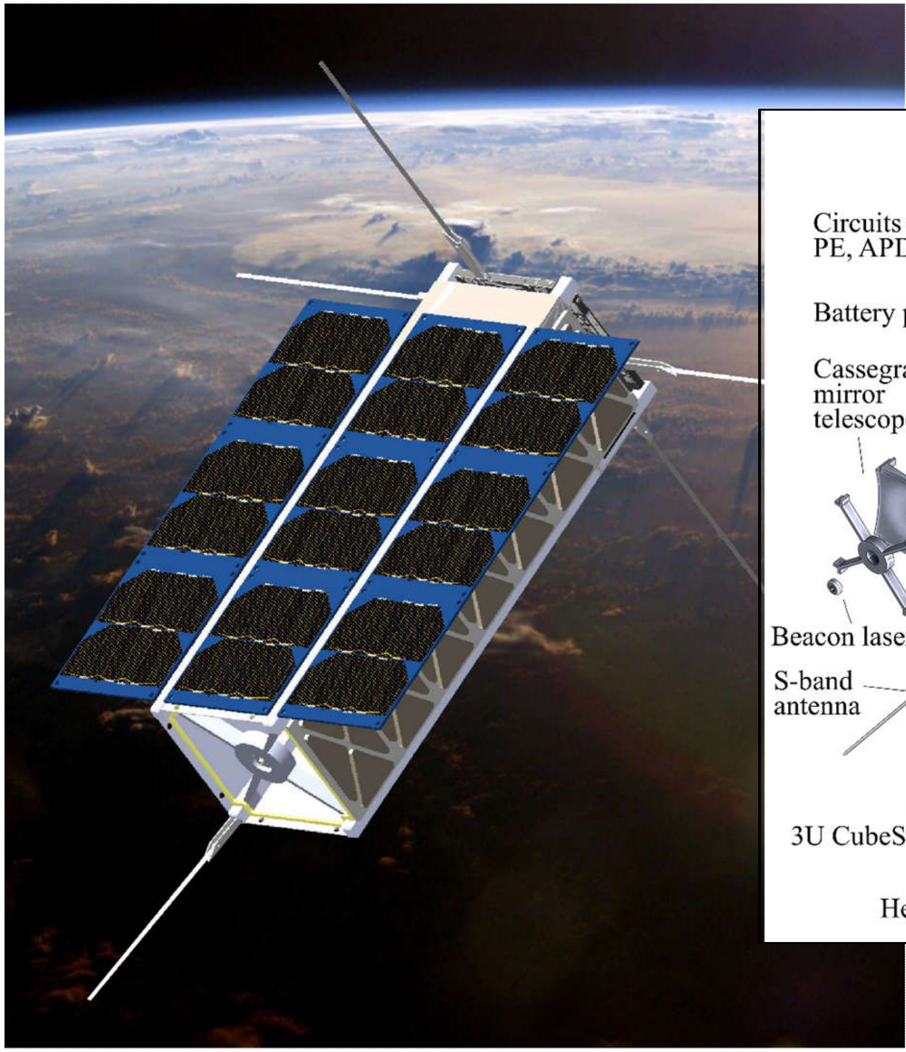
CubeSat-Design

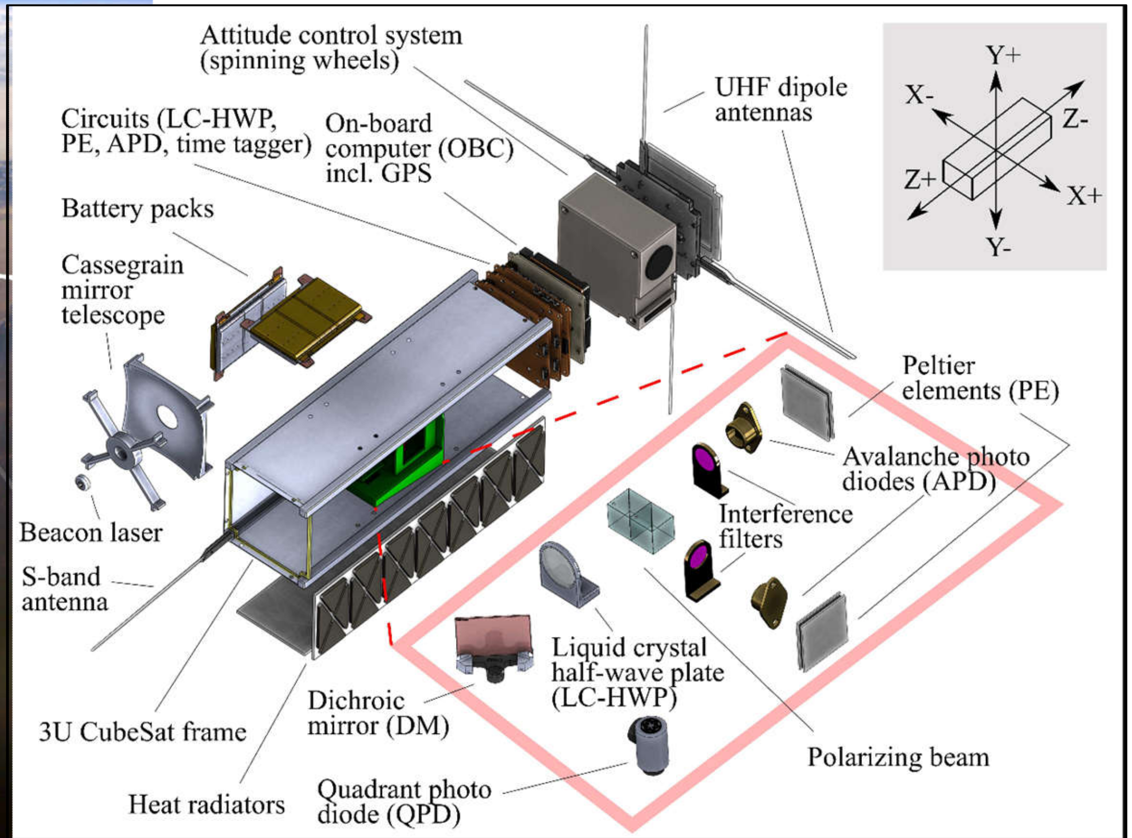


Block diagram



Preliminary CAD drawing

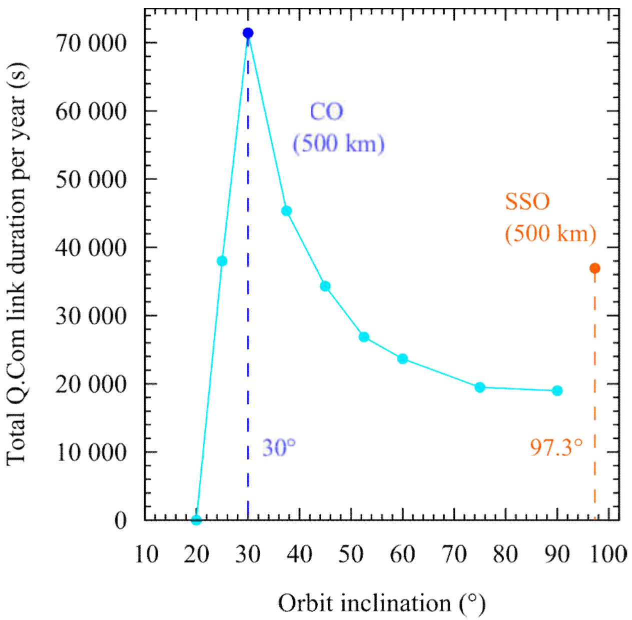


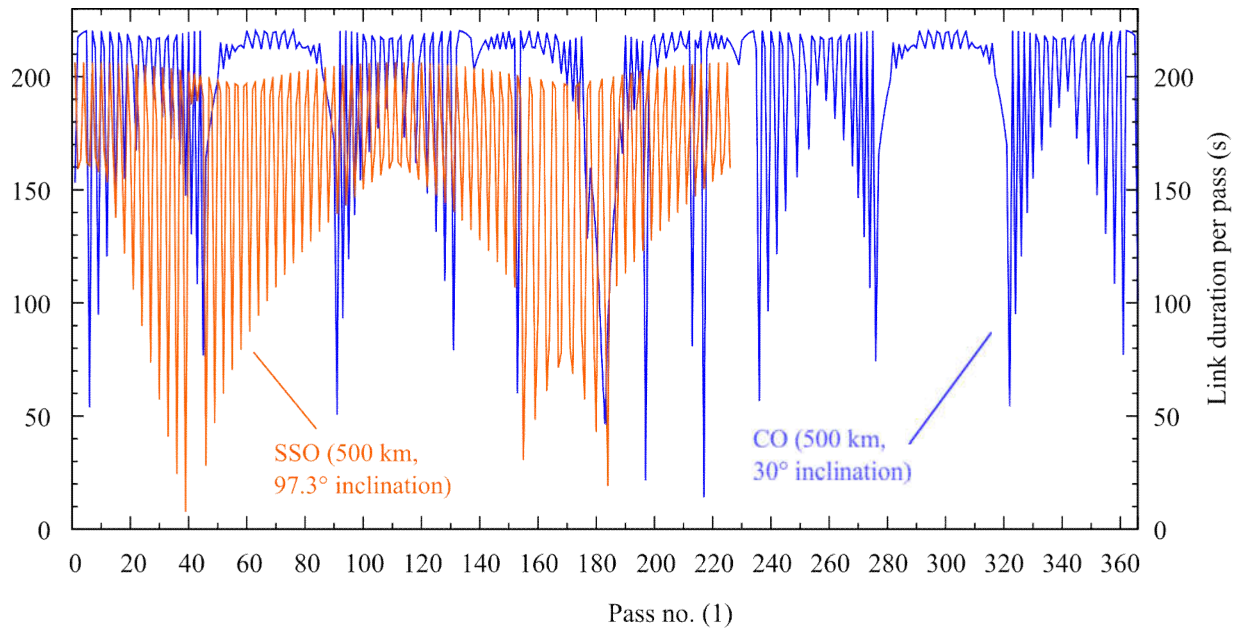


LEO Orbit Calculations

LEO:
- 500 km
- >30° elevation
- night only

→ Link duration calculations by group of Carsten Scharlemann (FH Wiener Neustadt):





Signal-to-Noise Ratio

FFG Austrian Research Promotion Agency

IQI

$$SNR = \frac{R_s}{R_n} = \frac{\Lambda R_P(1-e_{opt}) + \frac{1}{2}R_{acc}}{\frac{1}{2}R_{acc} + R_{opt}}$$

> 4.8 for Bell test

> 8.8 for QKD

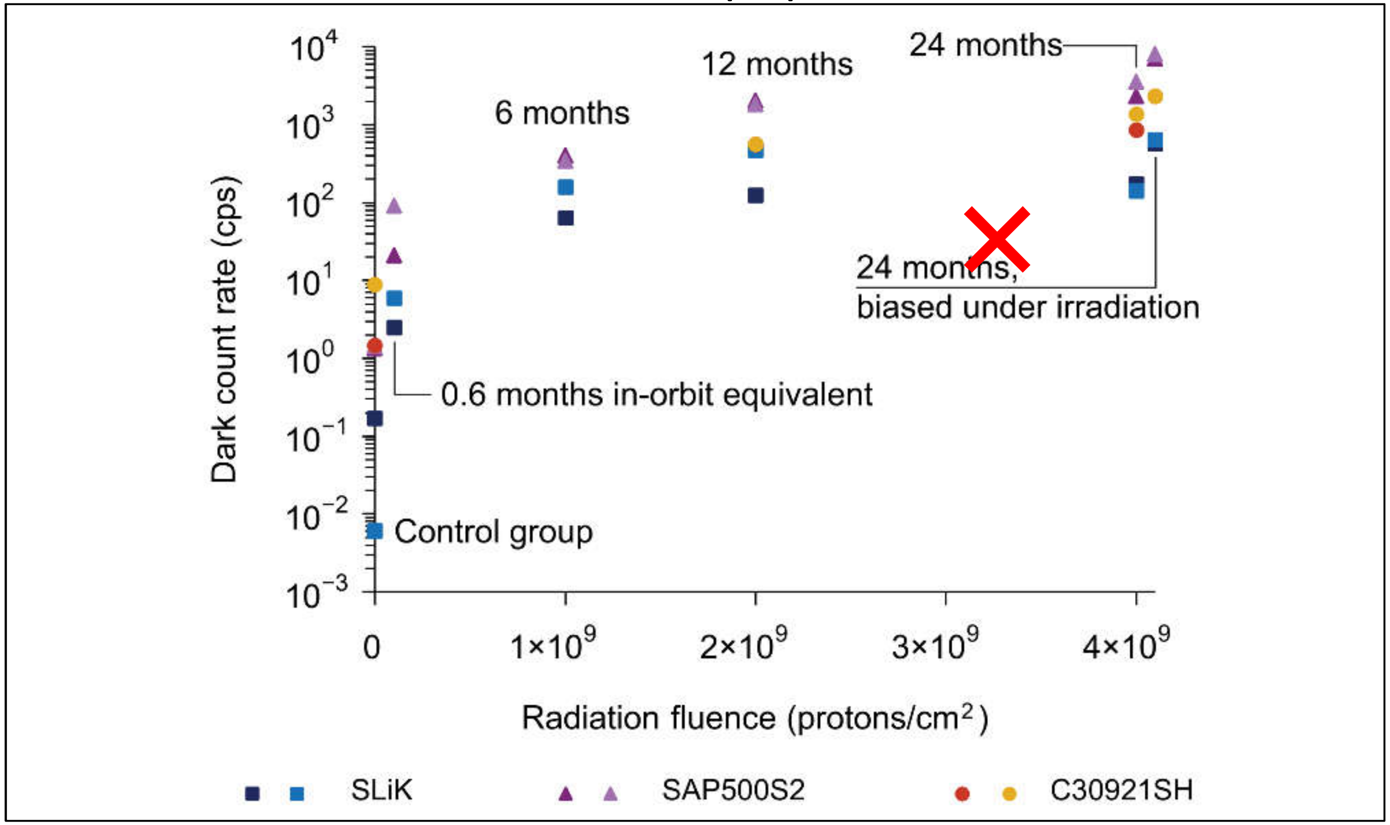
- $R_{acc} \propto 2R_P \boldsymbol{R_{NC}} \boldsymbol{\tau}$ accidental rate
- $R_{opt} = \Lambda R_P e_{opt}$ optical error counts

- Λ: total loss
- R_P: pair rate
- e_{opt}: optical errors
- **$\boldsymbol{\tau}$: coincidence window**
- **$\boldsymbol{R_{NC}}$: noise count rate**

Λ ~ 60dB → low $\boldsymbol{R_{NC}}$ and short $\boldsymbol{\tau}$ are crucial!

Noise Counts

- **Dark** counts: radiation → tiny 20µm detectors, shielding optional
  thermal → passive cooling
  in total max. 200 cps per detector



E. Anisimova *et al.*, "Mitigating radiation damage of single photon detectors for space applications," *EPJ Quantum Technology*, vol. 4, no. 1, p. 10, 2017.

Attitude Control: XACT

- **Background** counts: prop. to field of view (FOV) → has to be as small as possible (~100µrad)

Pictures + table from www.bluecanyontech.com

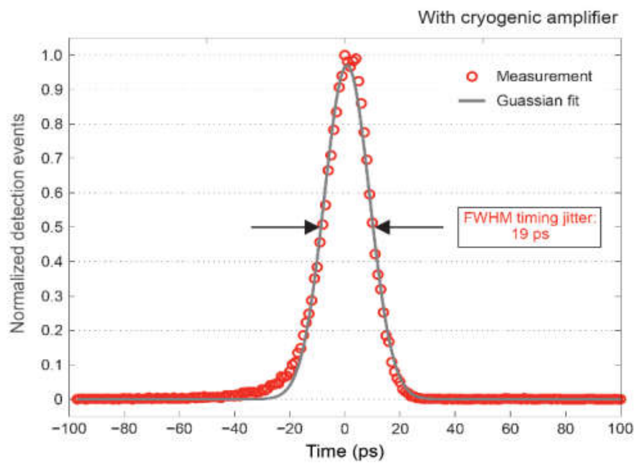
Spacecraft Pointing Accuracy	±0.003 deg (1-sigma) for 2 axes; ±0.007 deg (1-sigma) for 3rd axis
Spacecraft Lifetime	
Mass	0.91 kg
Volume	10 x 10 x 5 cm (0.5U)
Electronics Input Voltage	12V
Data Interface	RS-422, RS-485 & SPI
Slew Rate	≥10 deg/sec (4kg, 3U CubeSat)

Space heritage, ~40µrad precision *without* tracking!

→ In total, $R_{NC} \sim$ **480 cps (zenith)**
580 cps (30° elevation)

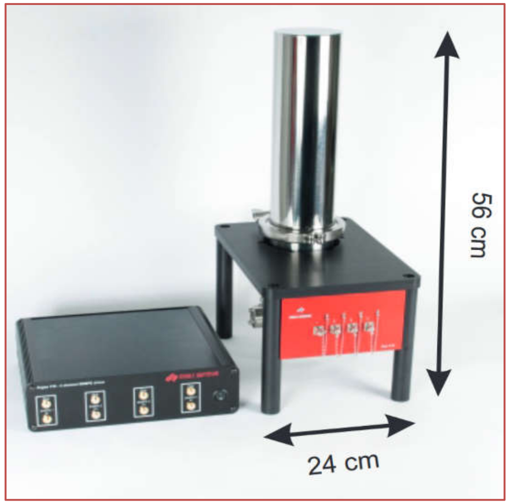
Coincidence Window

- for E91 (entangled photon pairs):
  - On ground: Superconducting nanowire SPD, 19ps jitter (rms), “no” dark counts
  - On CubeSat: PDM: 35ps jitter, <5Hz dark counts
  - Time taggers: 3ps on ground / 20ps on Q³Sat



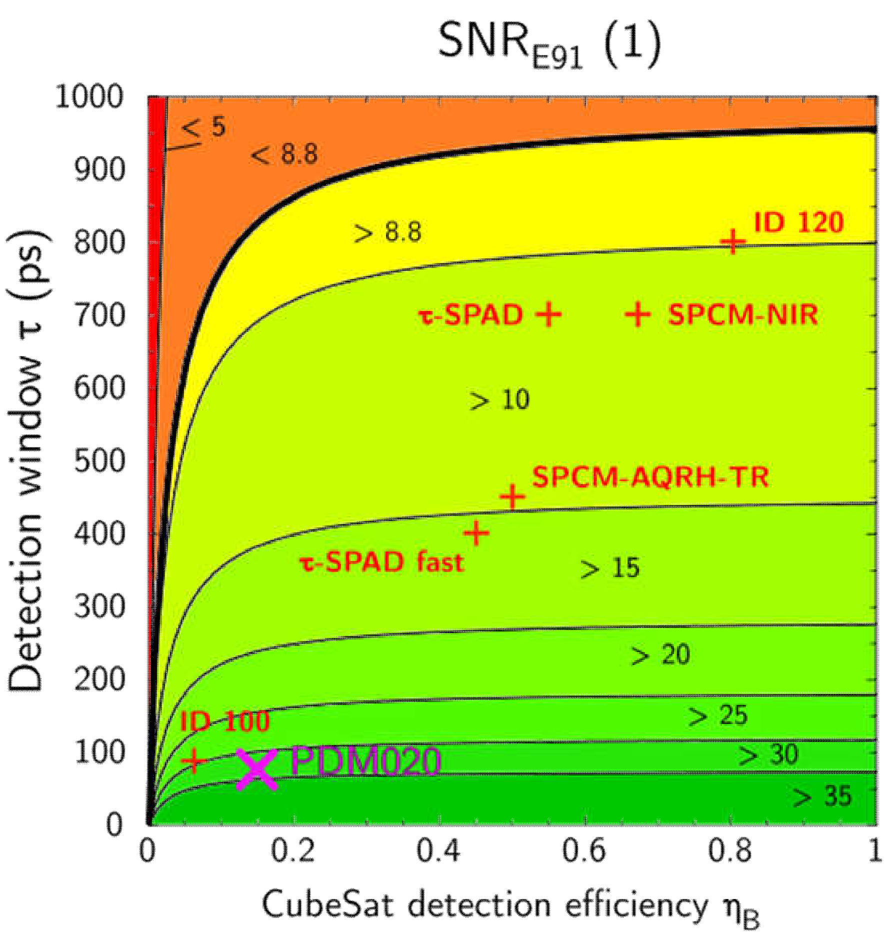
→ $\boldsymbol{\tau_{E91}} = 2\sqrt{\tau_{DCS}^2 + \tau_{TTCS}^2 + \tau_{DOGS}^2 + \tau_{TTOGS}^2} = \boldsymbol{90ps}$

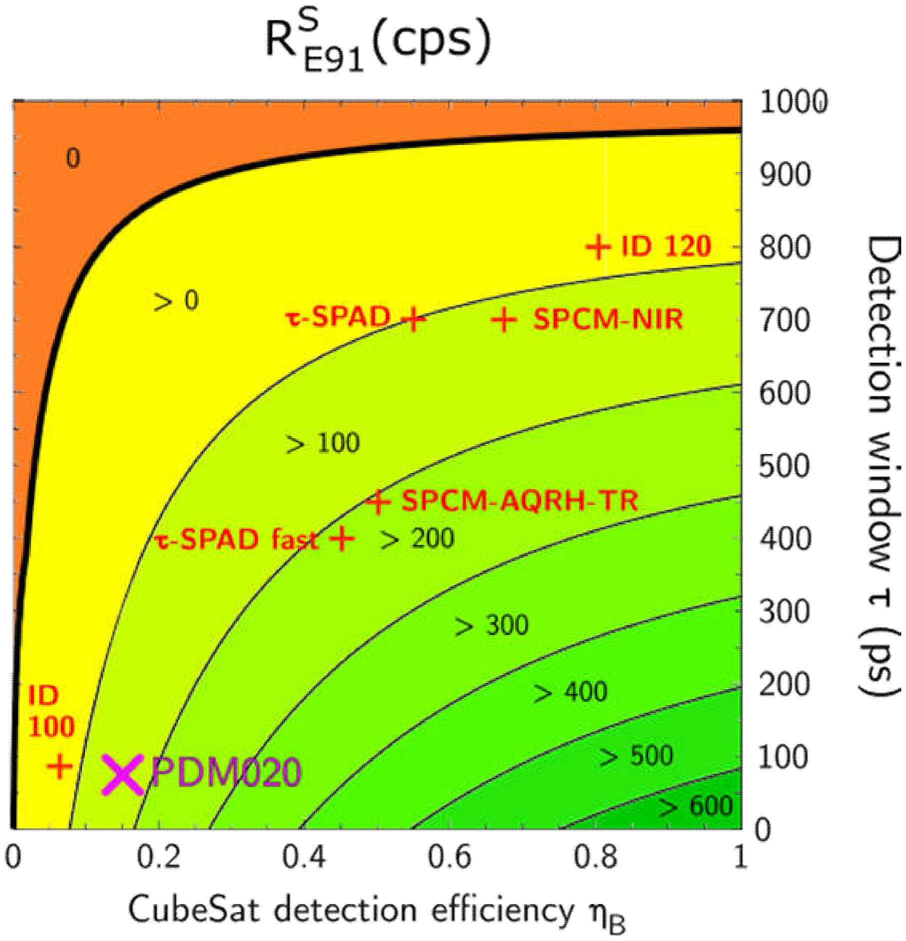
- for DSP (decoy):
  - No detection on ground necessary, just limited by electronics



→ $\boldsymbol{\tau_{DSP} = 80ps}$

Trade-Off SNR vs. R_{sec}

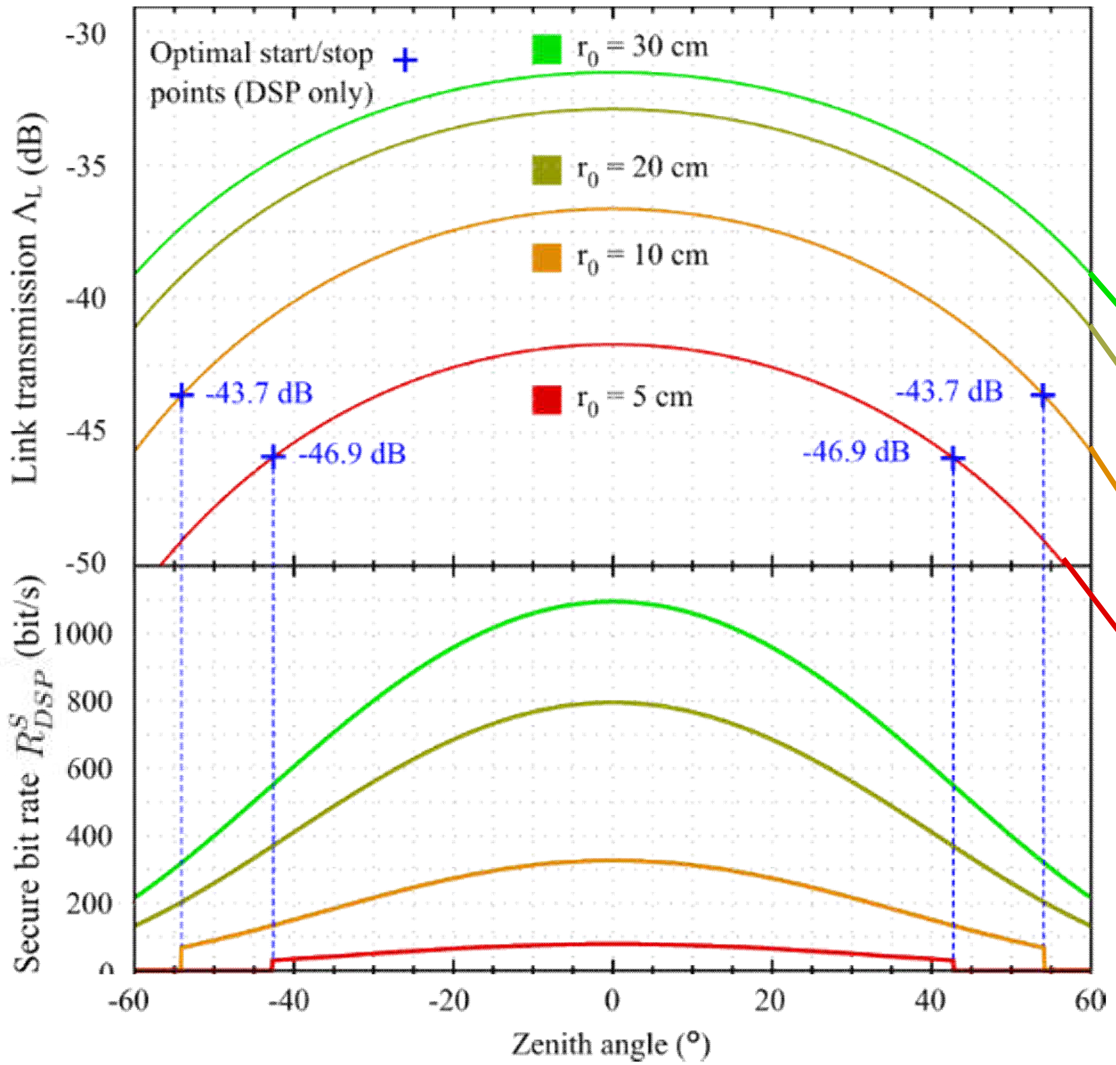




FFG Austrian Research Promotion Agency

Link Quality

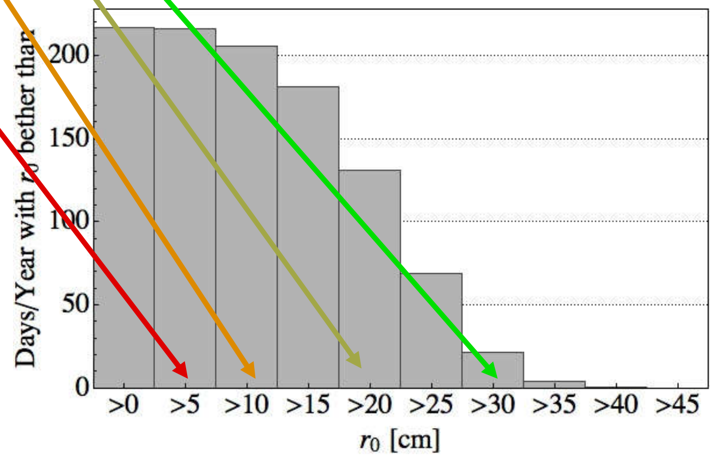
IQI



→ Total key per year: **13 Mbit**

→ **20€**/kbit (launch & hardware only)

r_0: Fried parameter



Fried parameter data taken from http://catserver.ing.iac.es/robodimm/

Performance

- 71 435s link time / year
  - 13.0 Mbit / year with decoy
  - 4.0 Mbit / year with E91
- Launch + material cost: 500k€

  → 20 € / kbit assuming lifetime of 2 years, but low threshold costs

Publication

Neumann et al. *EPJ Quantum Technology* (2018) 5:4
https://doi.org/10.1140/epjqt/s40507-018-0068-1

EPJ.org

EPJ Quantum Technology
a SpringerOpen Journal

RESEARCH Open Access

Q^3Sat: quantum communications uplink to a 3U CubeSat—feasibility & design

Sebastian Philipp Neumann[1,2†], Siddarth Koduru Joshi[1,2†], Matthias Fink[1,2], Thomas Scheidl[1,2], Roland Blach[1], Carsten Scharlemann[3], Sameh Abouagaga[3], Daanish Bambery[3], Erik Kerstel[4], Mathieu Barthelemy[4] and Rupert Ursin[1,2*]

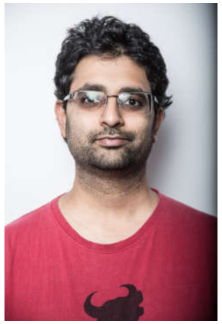
*Correspondence: rupert.ursin@oeaw.ac.at
[1]Institute for Quantum Optics and Quantum Information Vienna, Vienna, Austria
[2]Vienna Center for Quantum Science and Technology, Vienna, Austria
Full list of author information is available at the end of the article
[†]Equal contributors

Abstract
Satellites are the most efficient way to achieve global scale quantum communication (Q.Com) because unavoidable losses restrict fiber based Q.Com to a few hundred kilometers. We demonstrate the feasibility of establishing a Q.Com uplink with a 3U CubeSat, measuring only 10 × 10 × 34 cm^3, using commercial off-the-shelf components, the majority of which have space heritage. We demonstrate how to leverage the latest advancements in nano-satellite body-pointing to show that our 4 kg CubeSat can generate a quantum-secure key, which has so far only been shown by a much larger 600 kg satellite mission. A comprehensive link budget and

FFG
Austrian
Research Promotion Agency

Co-Authors

IQI



Siddarth K. Joshi

Matthias Fink

Thomas Scheidl

Rupert Ursin

FH University of Applied Sciences TECHNIKUM WIEN

Carsten Scharlemann

Sameh Abouagaga

Daanish Bambery

UNIVERSITÉ Grenoble Alpes

Erik Kerstel

Mathieu Barthelemy

Thank you for your attention!