The EQM of a high efficient entangled Photon Source for QKD

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The Quantum Era

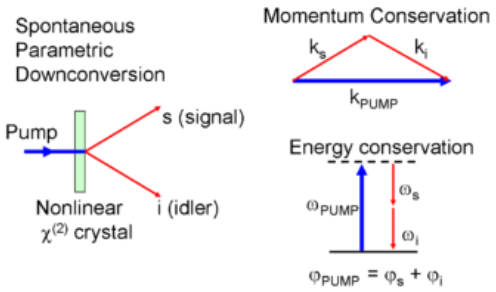
Quantum Technologies–from Knowledge to Applications

[..] our growing ability to manipulate quantum effects […] is paving the way for a 2nd **quantum revolution**.

European Quantum Manifesto

Quantum technologies […] will lead to a wave of new technologies that will create **many new businesses** […] and will be the decisive factor for success in many industries and markets.

Quantum Technologies Flagship Intermediate Report



Entangled Photon Pair Generation by SPDC

Computing	Communication	Sensing/ Imaging
Correlated Quantum Systems (Qubits)	Communication by Correlation, Entanglement	Sensitive Quantum States
e^n increased computing Power	No Deciphering possible	Entangled Photons
Decryption	Tap-proof Communication	Super-Resolution, -Sensitivity
Data Bases		Adaption to different λ
Beyond-Moore		
Solid State Platforms	Fiber-Com	Application Demonstration
Scaling (n)	Space-Com	
	Systems Development	

Solutions with Light

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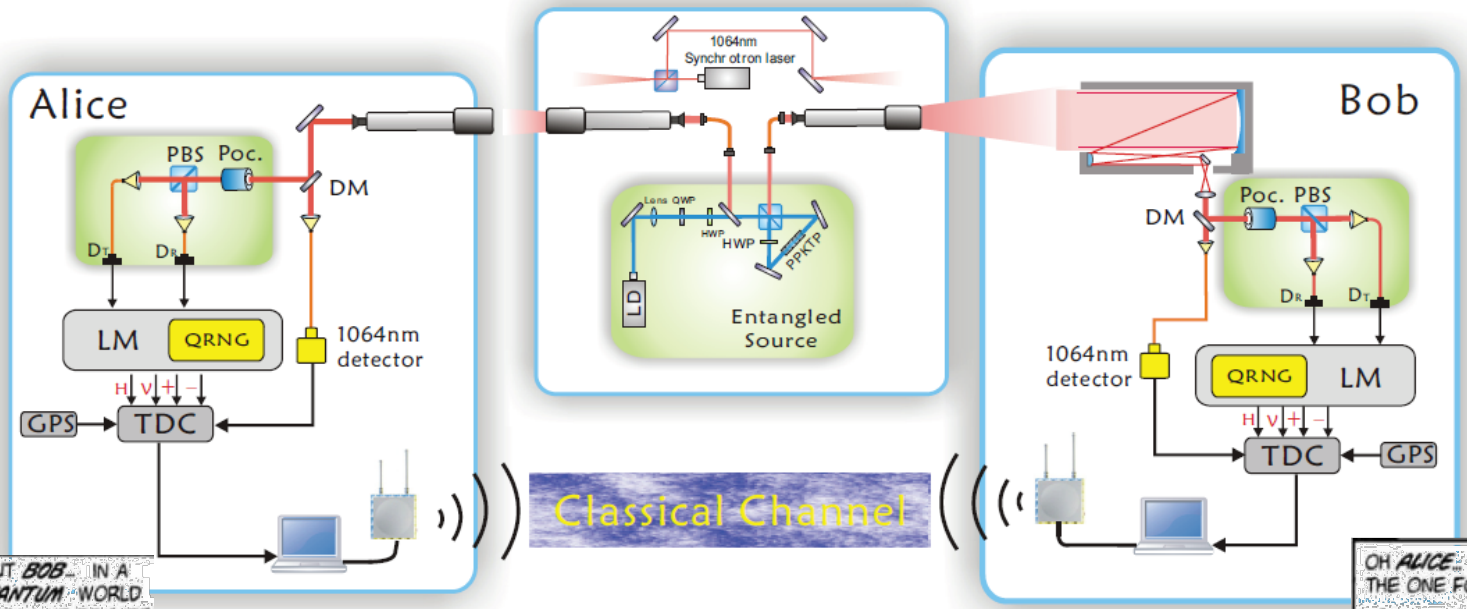
Target – Quantum Communication

Quantum Key Distribution (QKD)



Entangled photons – tap and intrusion proof base for key distribution – Basis for Encryption

Cartoon: Wim van Dam, University of Oxford

Y. Cao, H. Liang, J. Yin, H. Yong, F. Zhou, Y. Wu, J. Ren, Y. Li, G. Pan, T. Yang, X. Ma, C. Peng, and J. Pan, "Entanglement-based quantum key distribution with biased basis choice via free space," Opt. Express 21, 27260-27268 (2013).

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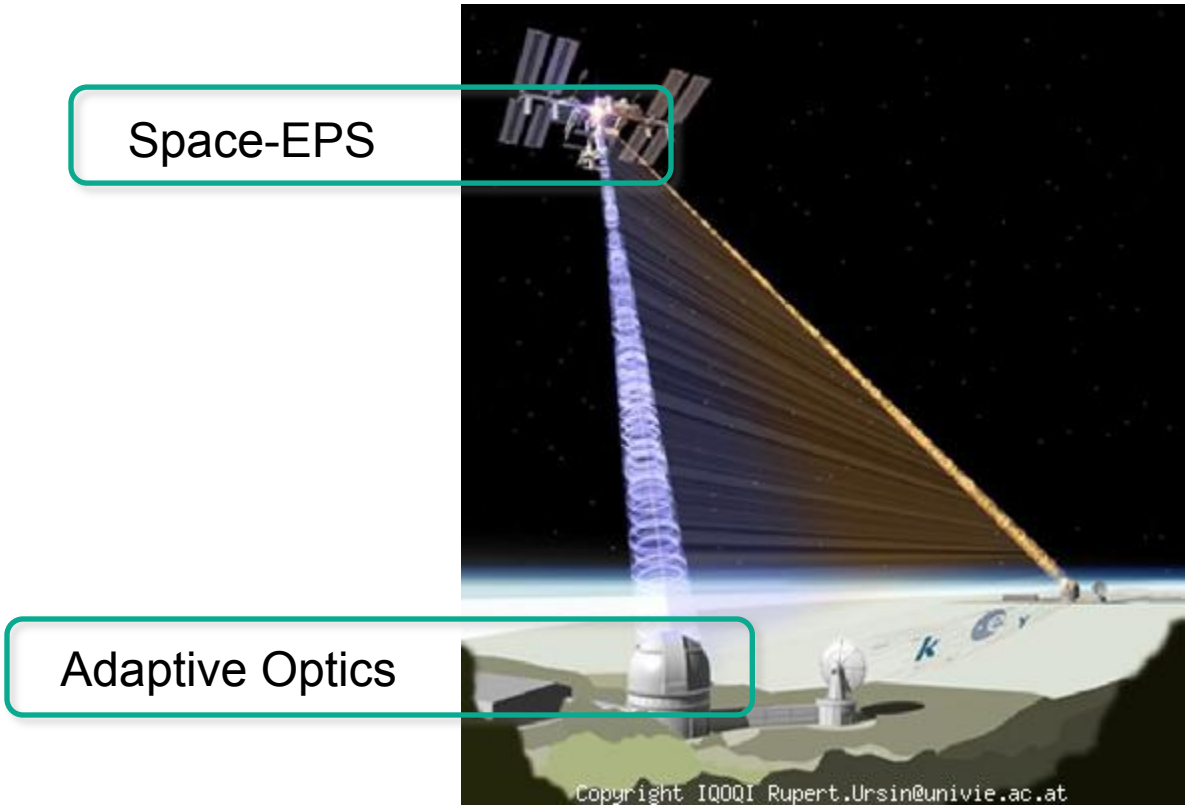
Example – Quantum Communication

A typical QKD Layout – Source in Space



A. Fedrizzi et al: High-fidelity transmission of entanglement over a high-loss free-space channel. Nature Physics 5, 389 - 392 (2009)

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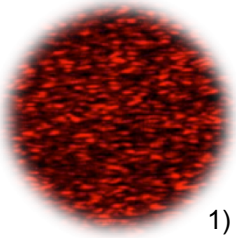
Adaptive Optics for QKD

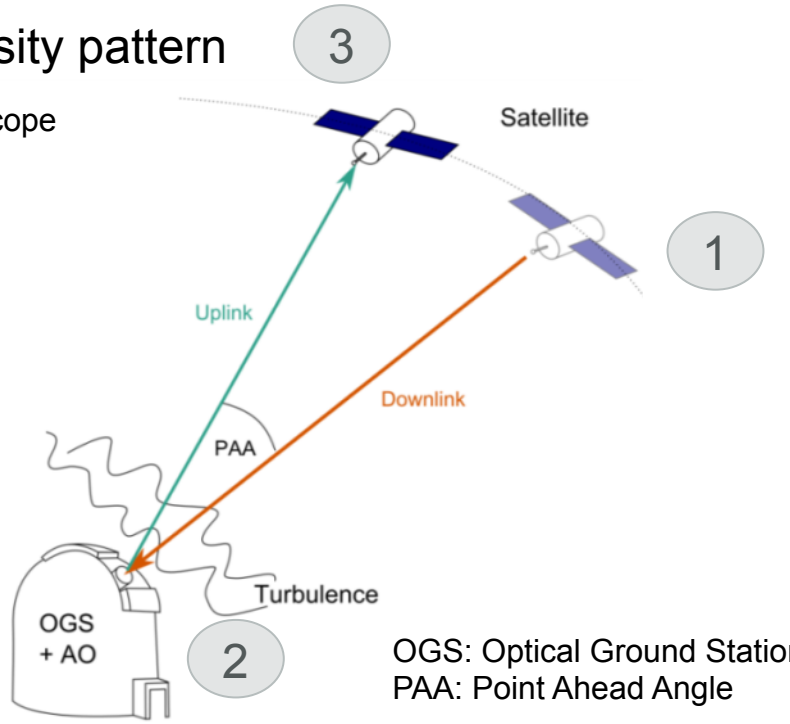
Satellite Link Point-ahead Compensation



1)

Speckle intensity pattern

$ø_{speckle} > ø_{Telescope}$



SOA: apply n-beams to homogenize intensity @ 3

SOA: Post-compensate downlink

OGS: Optical Ground Station
PAA: Point Ahead Angle

AO-Box to simultaneously compensate UPLINK & DOWNLINK by DOWNLINK measurements

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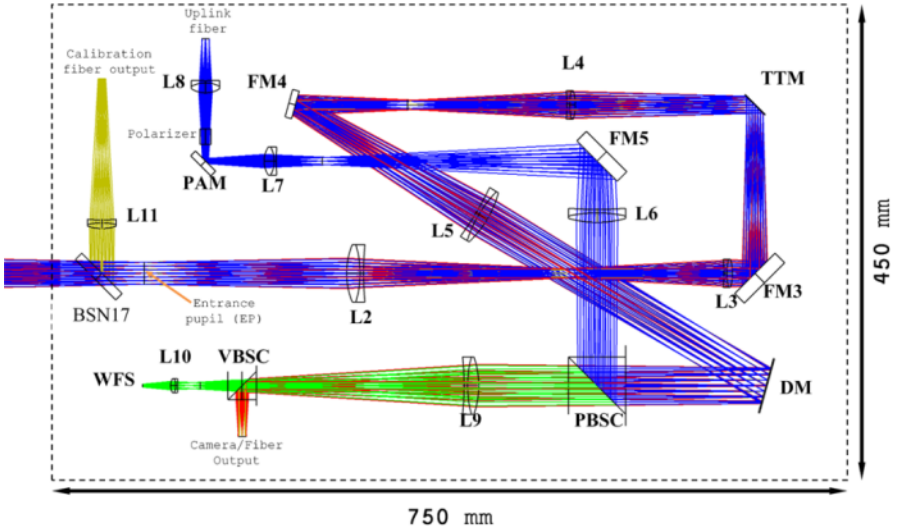
Adaptive Optics for QKD

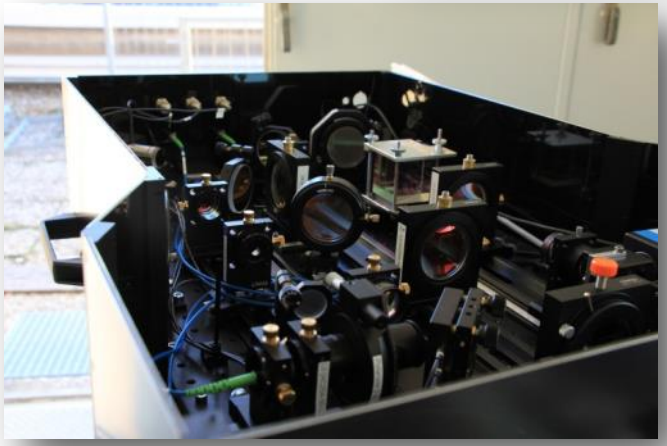
AO Box for Pre- and Post- Compensation

Portable AO Box coupled with any telescope

Turbulence mitigation for both Downlink and Uplink

Outgoing Uplink is precompensated





Leonhard, N ; Berlich, R. ; Minardi, St. ; Barth, A. ; Mauch, St. ; Mocci, J. ; Goy, M. ; Appelfelder, M. ; Beckert, E. ; Reinlein, C.: Real-time adaptive optics testbed to investigate point-ahead angle in pre-compensation of Earth-to-GEO optical communication. In: Optics Express 24 (2016), Nr.12, S.13157-13172

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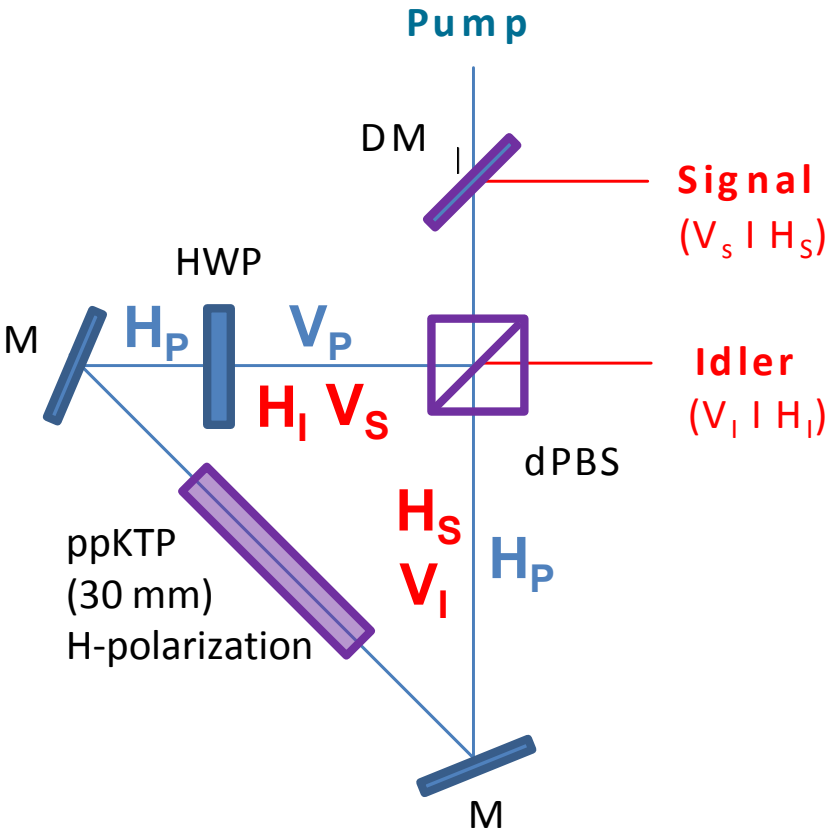
Sources for QKD

Entangled Photon Source for Space



- Hybrid setup for polarization entanglement
  - Sagnac Interferometer
  - Spontaneous parametric down-conversion (SPDC) in bulk periodically poled ppKTP
  - Pumped at 405 nm
- Space suitable for down- (up-)link configuration

Specification	Goal
Total Mass	≤3 kg
Total Size	≤ 150 x 150 x 100 mm³
Total Power Consumption	≤ 10 W (peak)
Visibility	**> 98 % in 0º/90º and +45º/-45º basis**
Detection rate*	0.64e6 photon pair events/s

* estimated for 25 mW pumping power

S. Ramelow, A. Mech, M. Giustina, S. Gröblacher, W. Wieczorek, J. Beyer, A. Lita, B. Calkins, T. Gerrits, S. Nam, A. Zeilinger, and R. Ursin, "Highly efficient heralding of entangled single photons," Opt. Express 21, 6707-6717 (2013).

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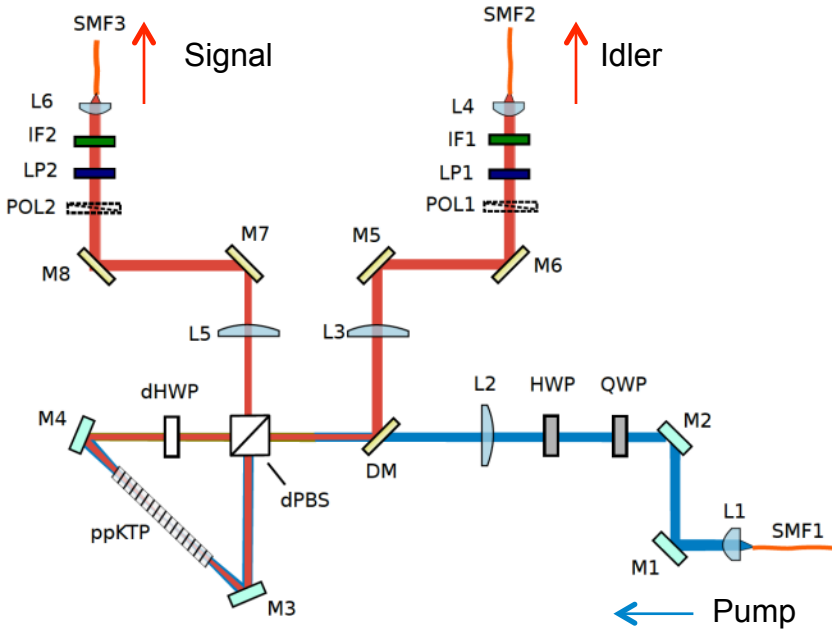
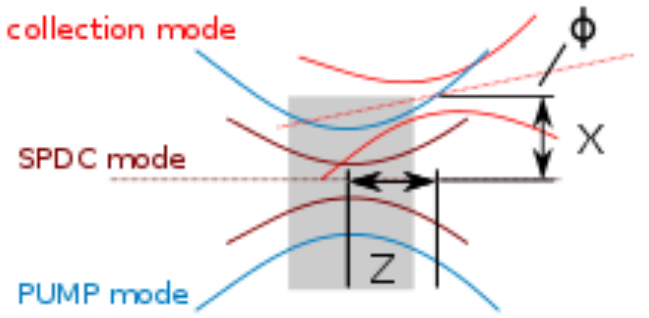
Sources for QKD
System Engineering





	Beam Parameters				Calc. efficiency		Est. Exp. Rates		99% TOLERANCE			95% TOLERANCE		
	ζp	ζs	wp/µm	ws/µm	η	pairs/nm	rate	@ 20mW	X/µm	Z/mm	ϕ/µrad	X/µm	Z/mm	ϕ/µrad
Optimal Brig	2,84	2,84	18	26	0,75	1,00	1,86	Mcps	2,6	1,0	490,0	5,9	2,5	1100,0
Trade-off 1	1,00	1,60	31	35	0,79	0,86	1,60	Mcps [1]	3,5	1,9	364,0	7,9	4,4	823,0
Trade-off 2	0,55	1,20	42	40	0,85	0,70	1,30	Mcps	4,4	3,2	302,0	10,0	7,3	683,5
Trade-off 4	0,10	0,68	98	53	0,90	0,24	0,45	Mcps	5,3	4,4	240,0	12,0	10,1	544,0
Optimal Her	0,03	0,20	178	98	0,97	0,09	0,14	Mcps [2]	10,0	15,8	127,0	22,6	36,0	288,0

Critical Components

- Temperature control ppKTP
- Fiber collimators

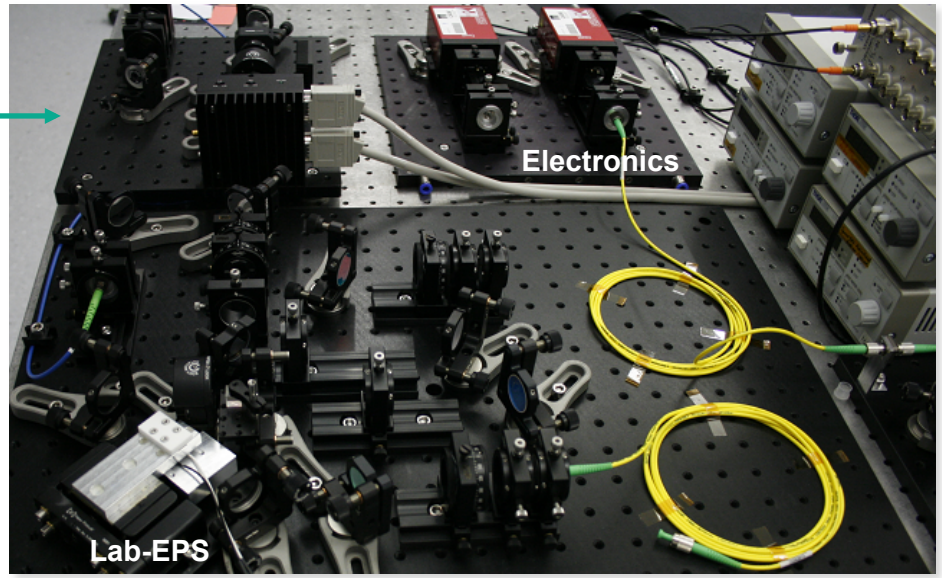
Critical Alignment

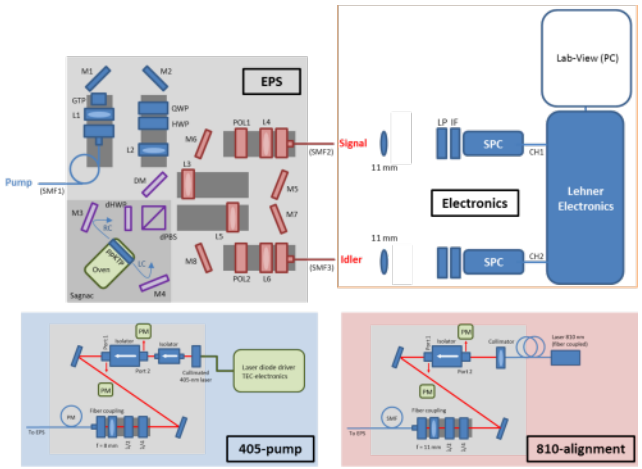
- Pump, SPDC and collection mode in crystal
- Trade-off efficiency vs. tolerances

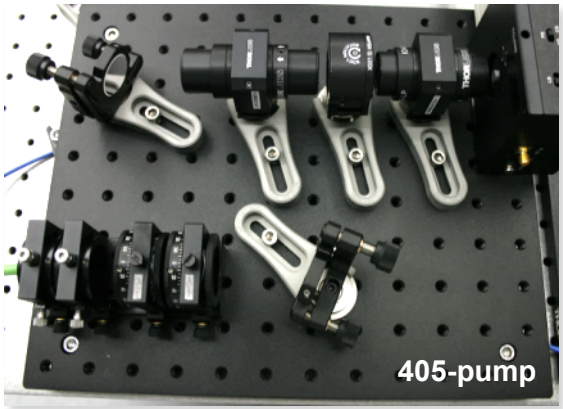
Steinlechner, F. ; Vries, O. de ; Fleischmann, N. ; Wille, E. ; Beckert, E. ; Ursin, R.: Development of a space-proof polarization-entangled photon source. In: Optical Society of America -OSA-, Washington/D.C.: CLEO: QELS Fundamental Science : Part of CLEO: 2016

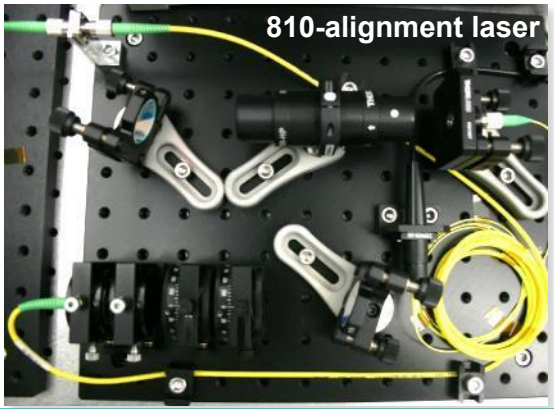
Sources for QKD

From Lab Model to the Engineering Qualification Model









Lab Model

- Photon Source
- Pump
- Detectors - SPC
- Alignment tools

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Sources for QKD

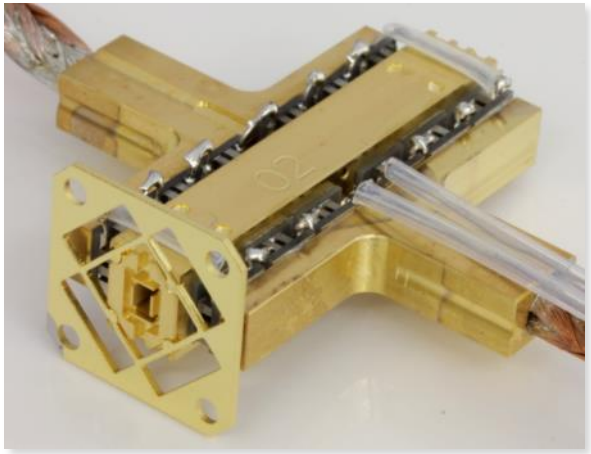
The EQM – Critical Components

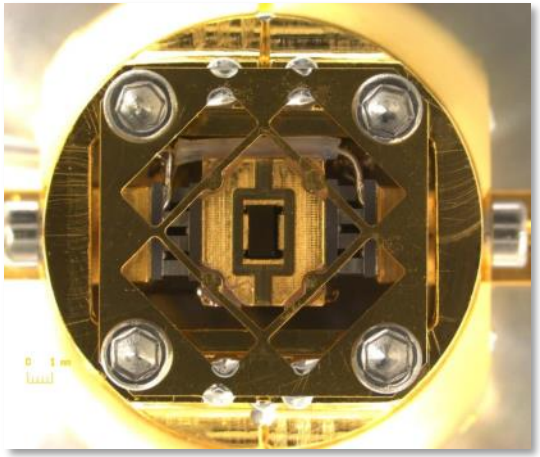
- INVAR Housing
- Electroplated Ni/ Pd/Au
- Defined Thickness 5..10 µm
  - NiP 7,5µm±20%
  - Pd 0,3µm±30%
  - Au 0,01µm - 0,06µm

PacTech
member of nagase group

Sources for QKD

The EQM – Critical Components





Temperature Control for ppKTP

Fiber Collimators

Technologies

- Simulation based optimization
- Alignment turning
- Soldering of optics
- Flexures for decoupling

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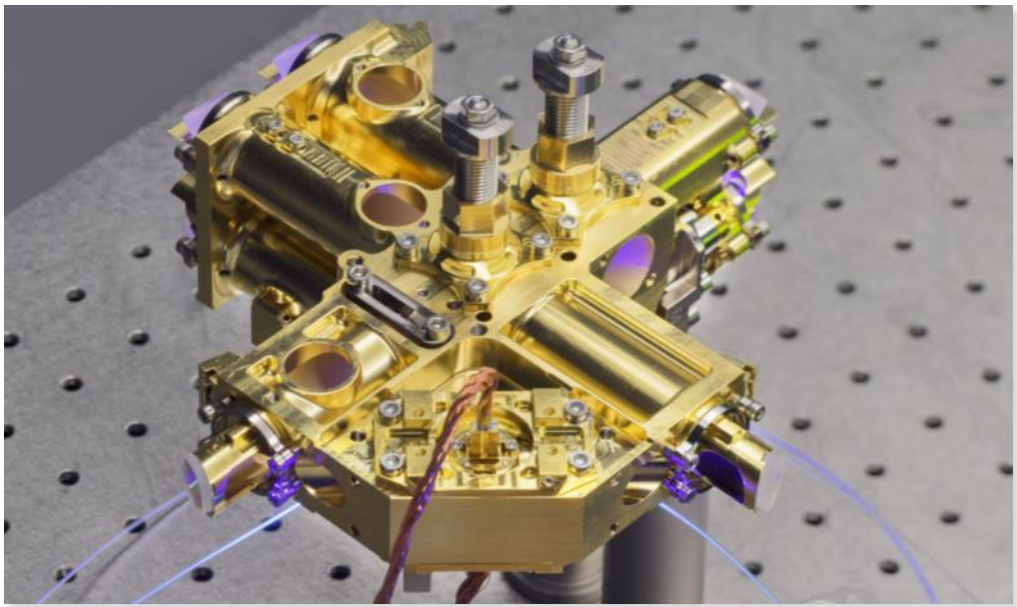
Sources for QKD
The EQM – First Results



Pump power **4.6 mW**, T_{ppKTP} = 36°C

V_DA [%] =	96,9837	Error V_DA [%] =	0,0155
V_HV [%] =	99,0565	Error V_HV [%] =	0,0084
Power (in EPS) /mW:	4,60		
Pair-Counts (over 60s):	18992277		
Pair-Counts (per second) =	316538		
Laser diode current /mA:	55,000		
Laser diode NTC /kOhm:	11,000		
Crystal oven NTC /kOhm:	6,265		

Goal parameters:

→ Count-Rate >100.000 s^{-1}

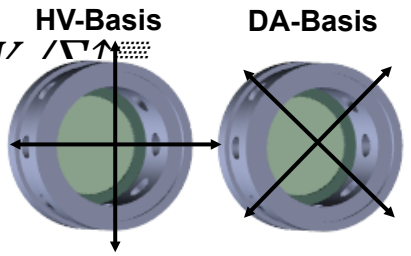
→ Visibility HV-Basis ≥ 98 %

→ Visibility DA-Basis ≥ 98 %

HV-visibility: $V_{H/V} = \frac{n_{H/V} + n_{V/H} - n_{H/H} - n_{V/V}}{n_{ij}}$

DA-visibility: $V_{D/A} = \frac{n_{D/A} + n_{A/D} - n_{D/D} - n_{A/A}}{n_{ij}}$

Settings Pol1/2:



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Conclusions

- Optics enables Quantum Science
- KnowHow – Components and Systems for Quantum
  - Single and entangled Photon Sources
  - Adaptive Optics
- Demonstration
  - Space-EPS and follow-UP: ARTES 3.4 / ScyLight
- Opportunity – Quantum Lab @ IOF, Sources + Free Space Prop.


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Research for the Future