The Power of Photons - From Many To Just One

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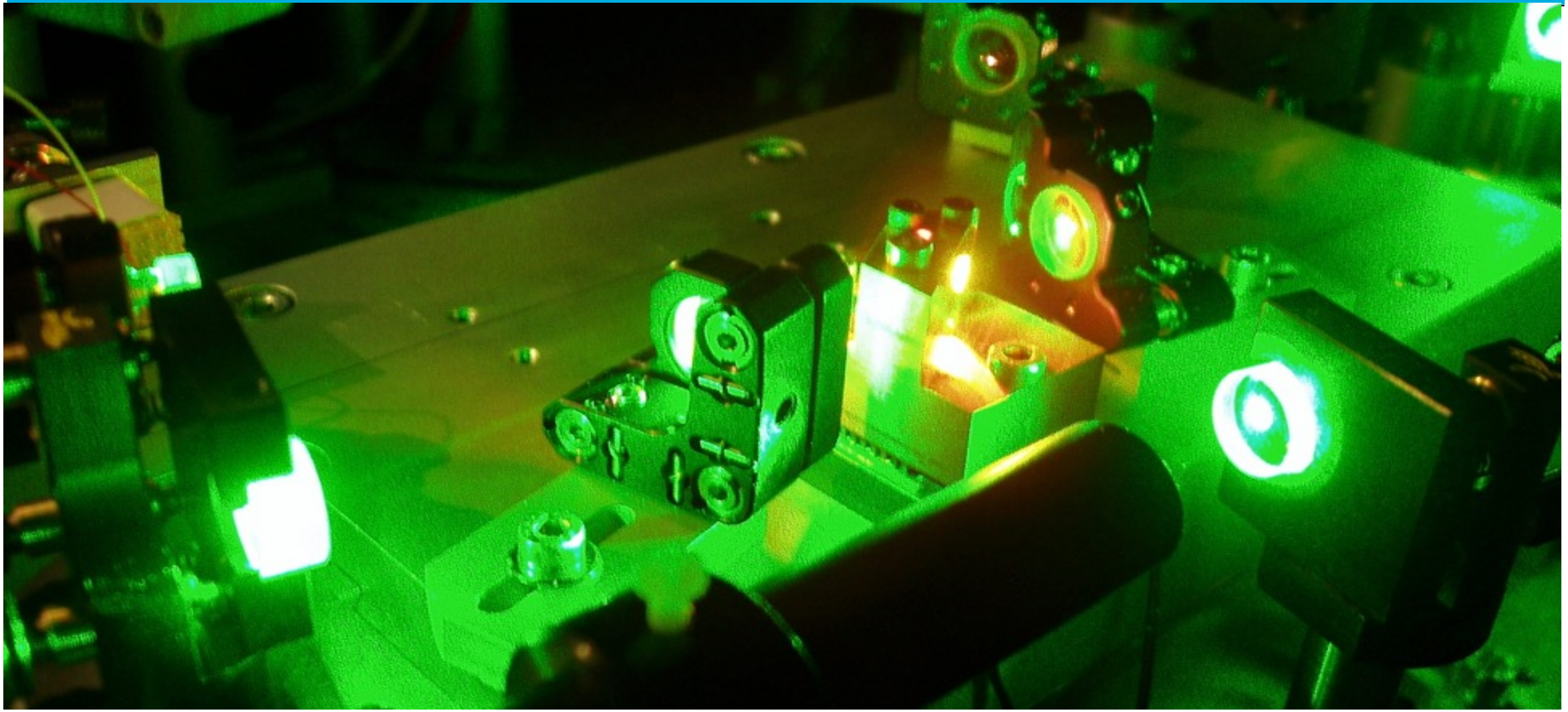

Thanks to my team

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Oceanic LIDAR: Temperature Profile

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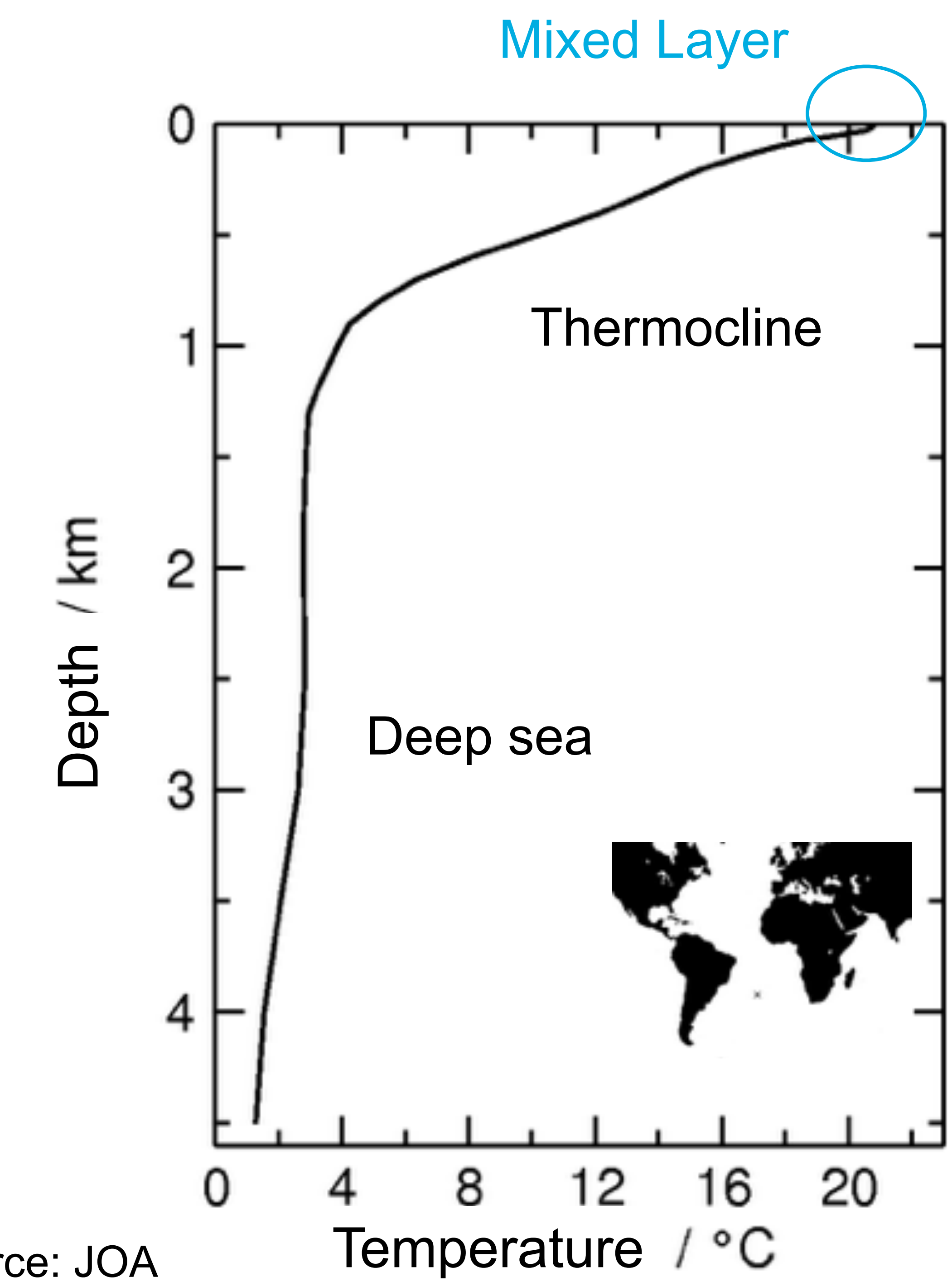
- Characteristic Zones
  - Mixed Layer
  - Thermocline
  - Deep sea
- Interesting range approx. 10 - 200 m
  - Climate research:
    Ocean – Atmosphere coupling
  - Oceanography:
    Dynamics of mixed layer
  - Speed of Sound, Temperature Profile



Source: JOA

DFG Deutsche Forschungsgemeinschaft

Oceanic LIDAR: Temperature Profile

- Characteristic Zones
  - Mixed Layer
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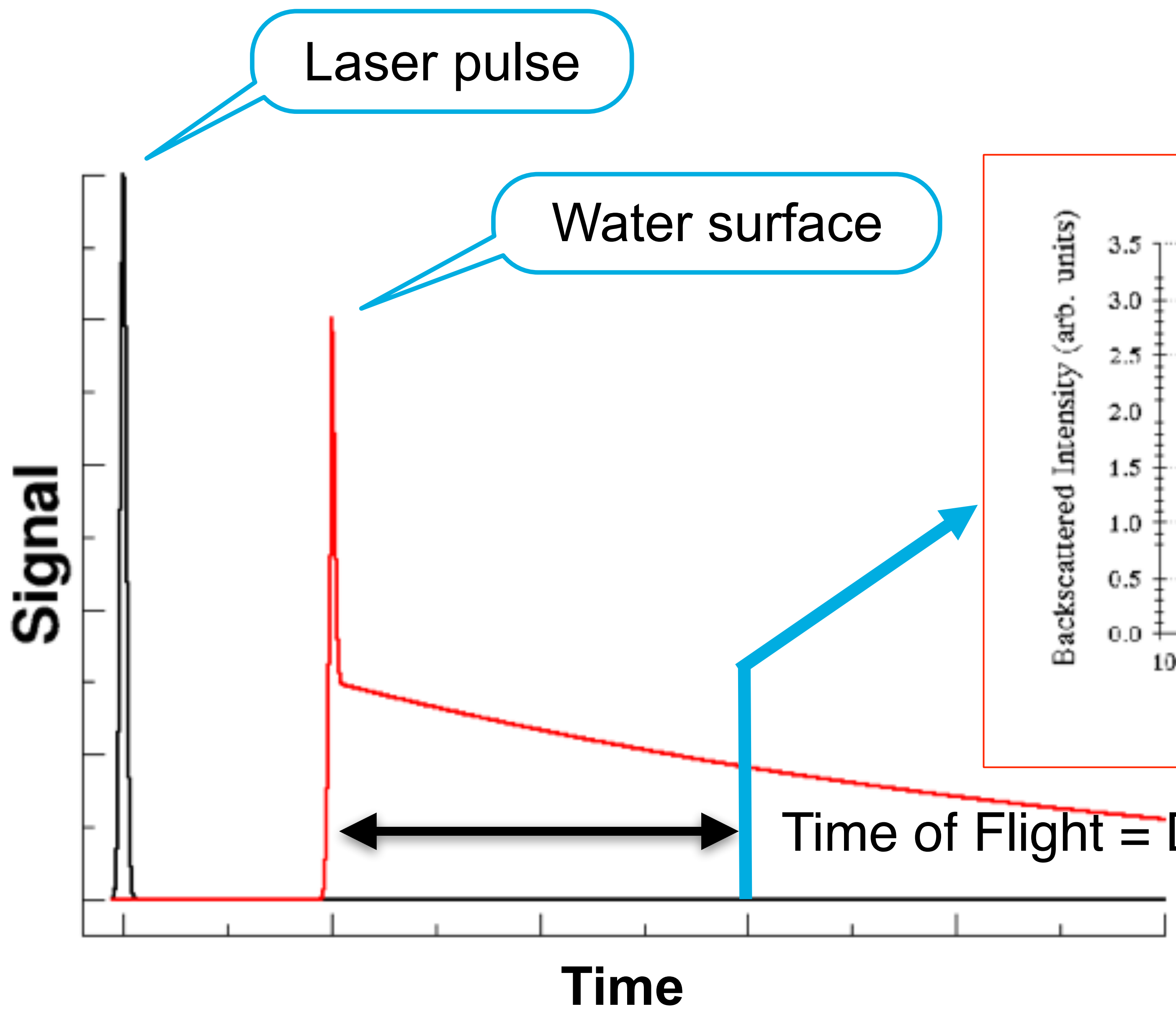
    Dynamics of mixed layer
  - Speed of Sound, Temperature Profile
- Contact based techniques
- Remote sensing method desirable
- Brillouin Scattering
  - J.L. Guagliardo, Dufilho, Rev. Sci. Instrum. **51**, (1980) 79
  - Hickman *et al.*, Remote Sens. Environ. **36**, (1991) 165

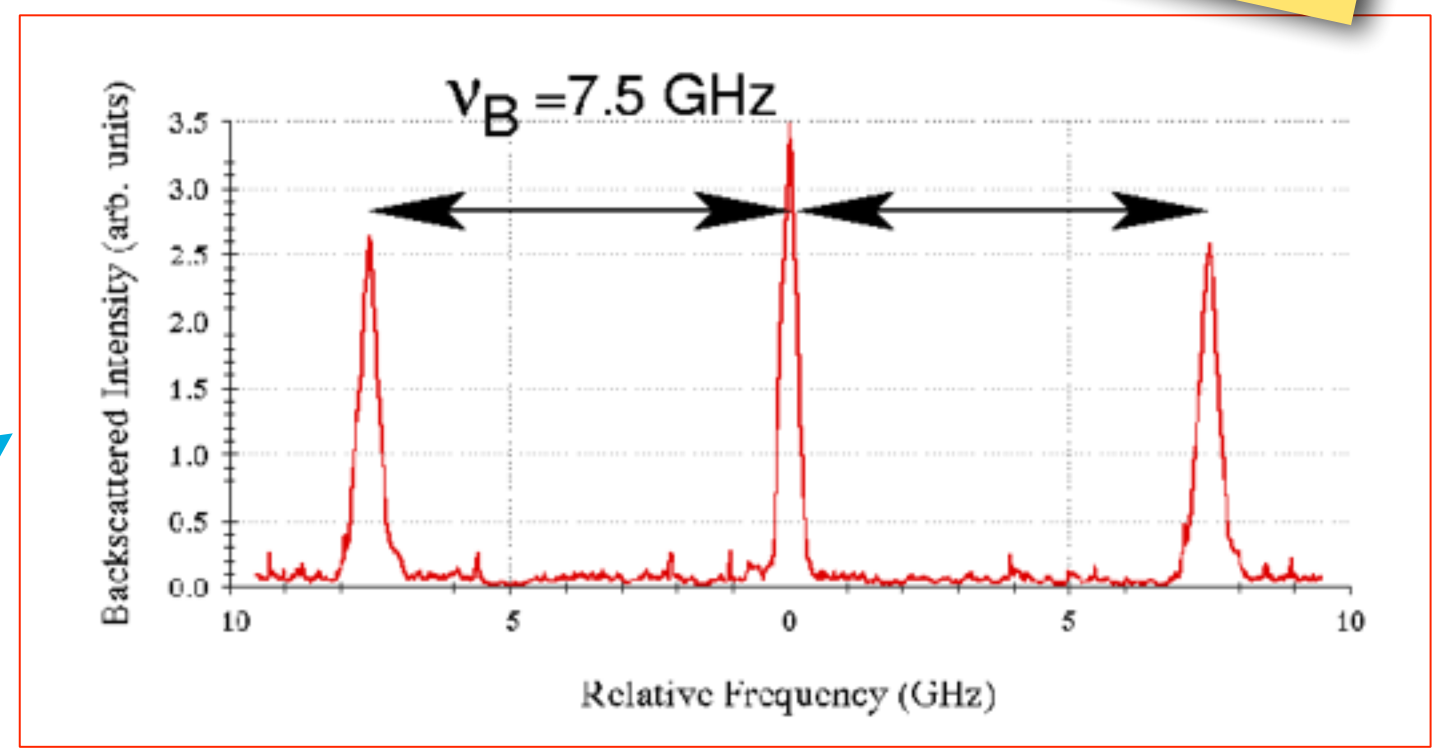
Basic Idea

- Pulsed stable laser
- Spectral and timing resolution of the detect

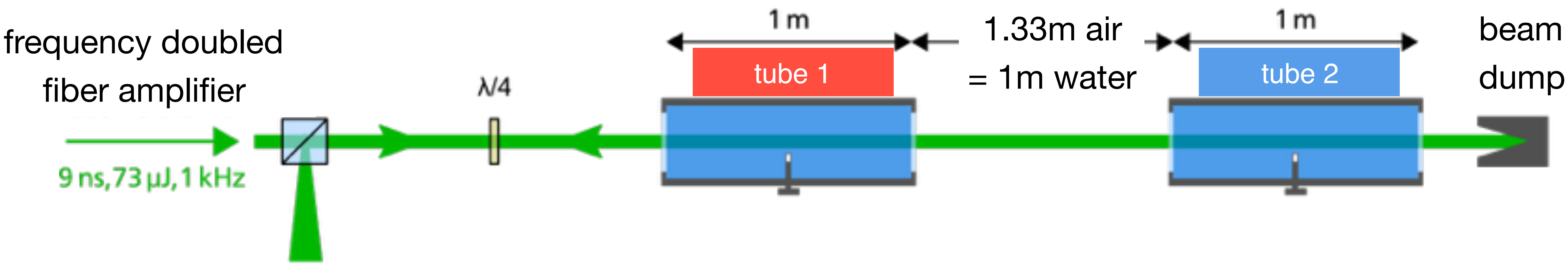
- Analysis of Scattered Light for
  - Time
- Spectral Content

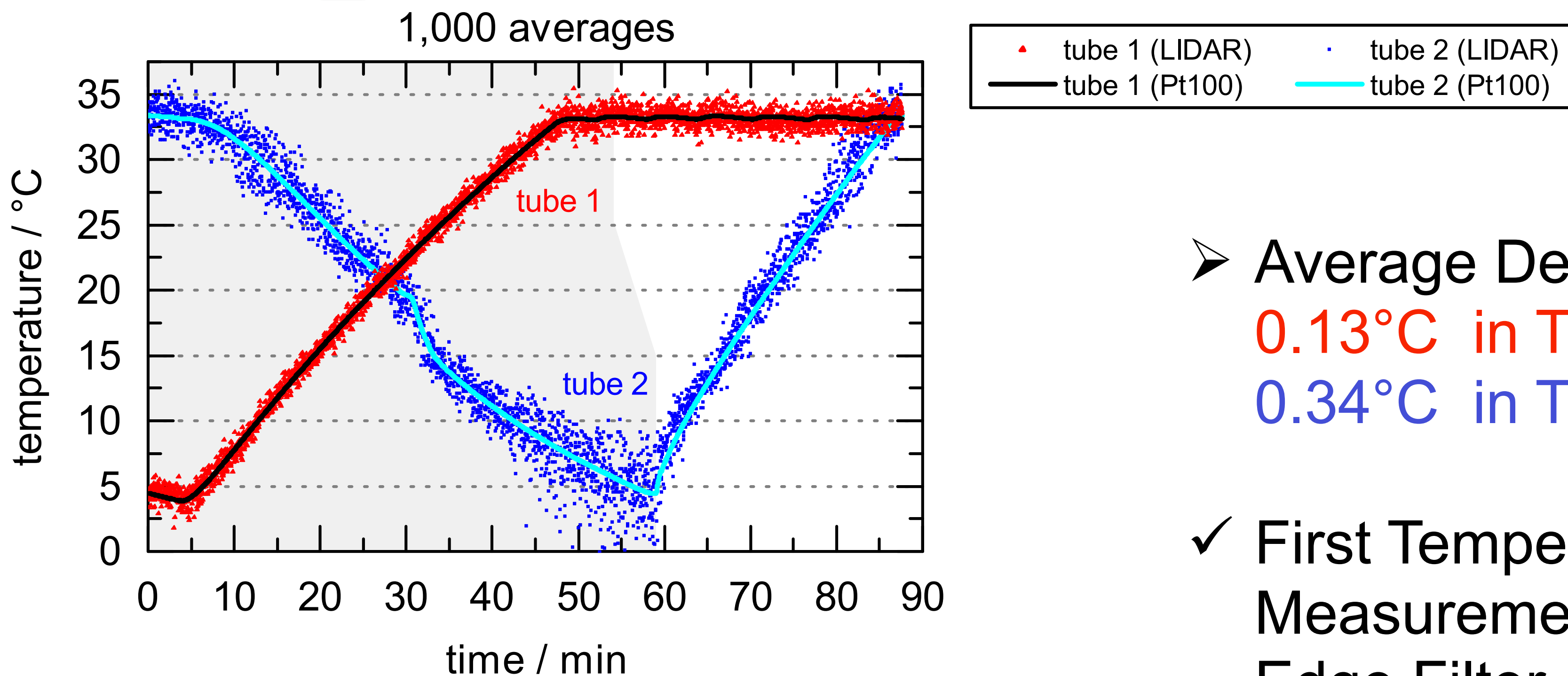


Brillouin-Scattering



Experimental Results
Temperature Accuracy





- ➢ Average Deviation
  0.13°C in Tube 1
  0.34°C in Tube 2

- ✓ First Temperature Measurement with calibrated Edge Filter

A. Rudolf, ThW, Opt. Eng. **53** (2014) 051407

Experimental Results
Temperature Accuracy

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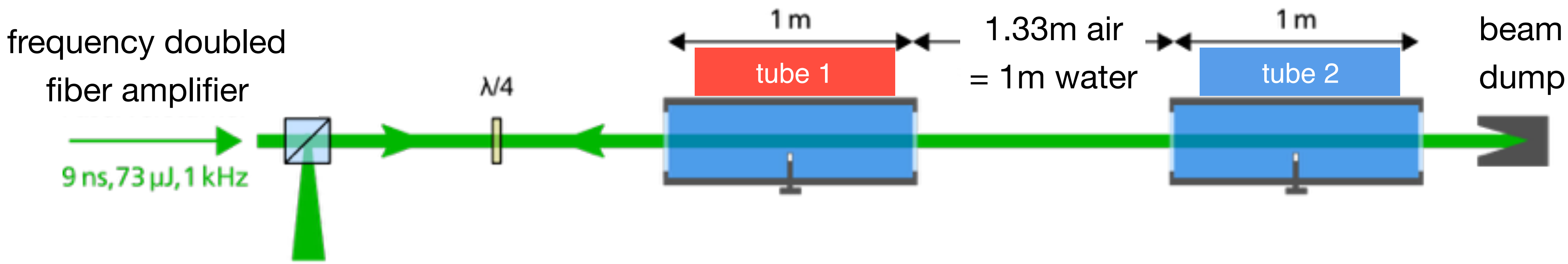

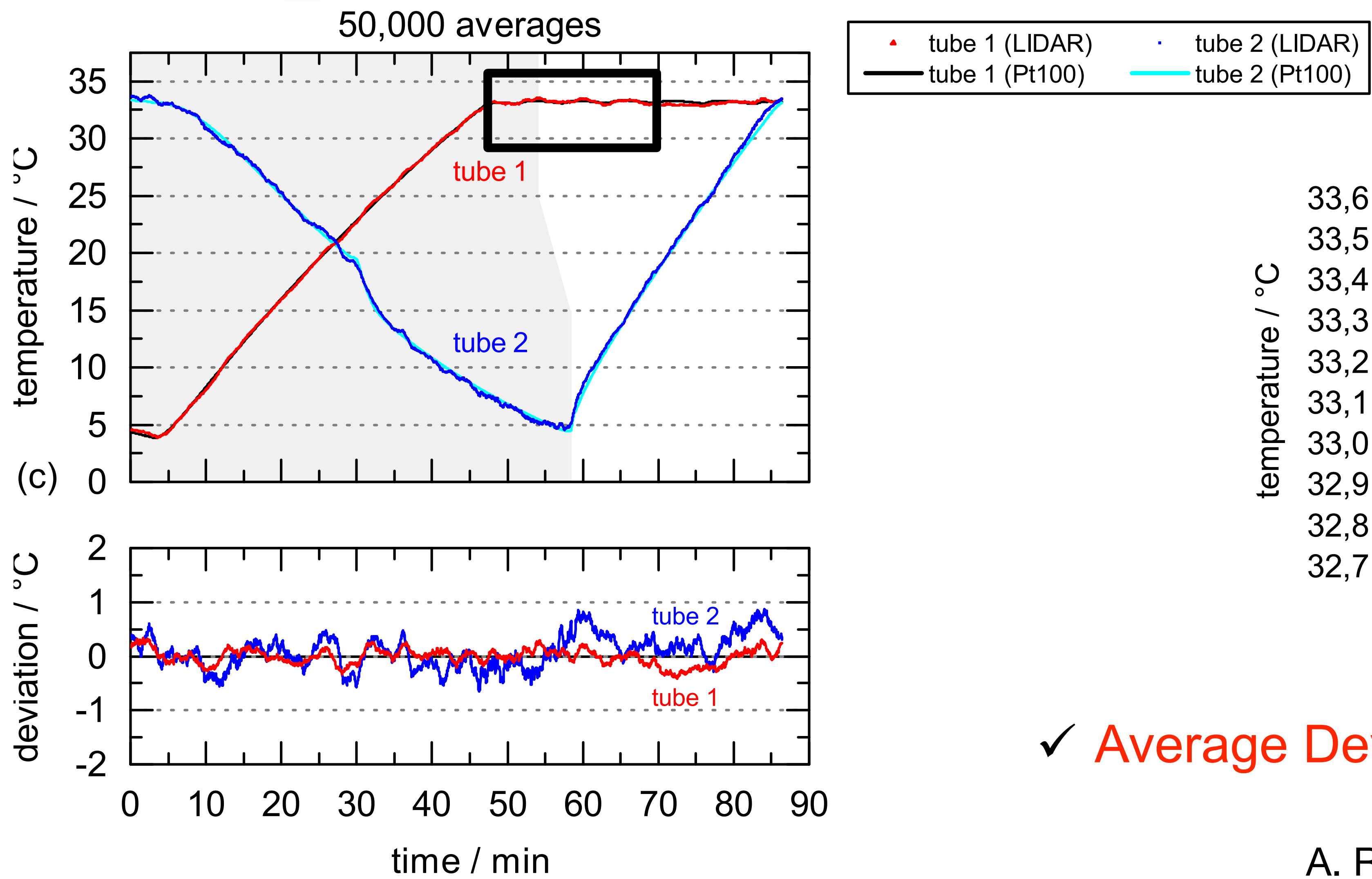

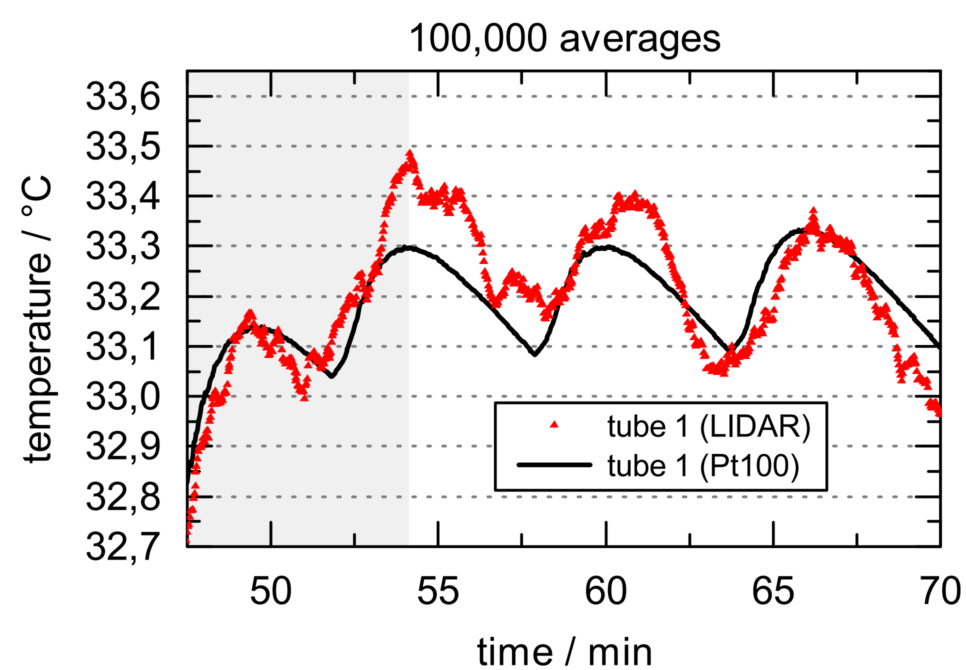

✓ Average Deviation 0.07°C (≙ 810 kHz)

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Specifications

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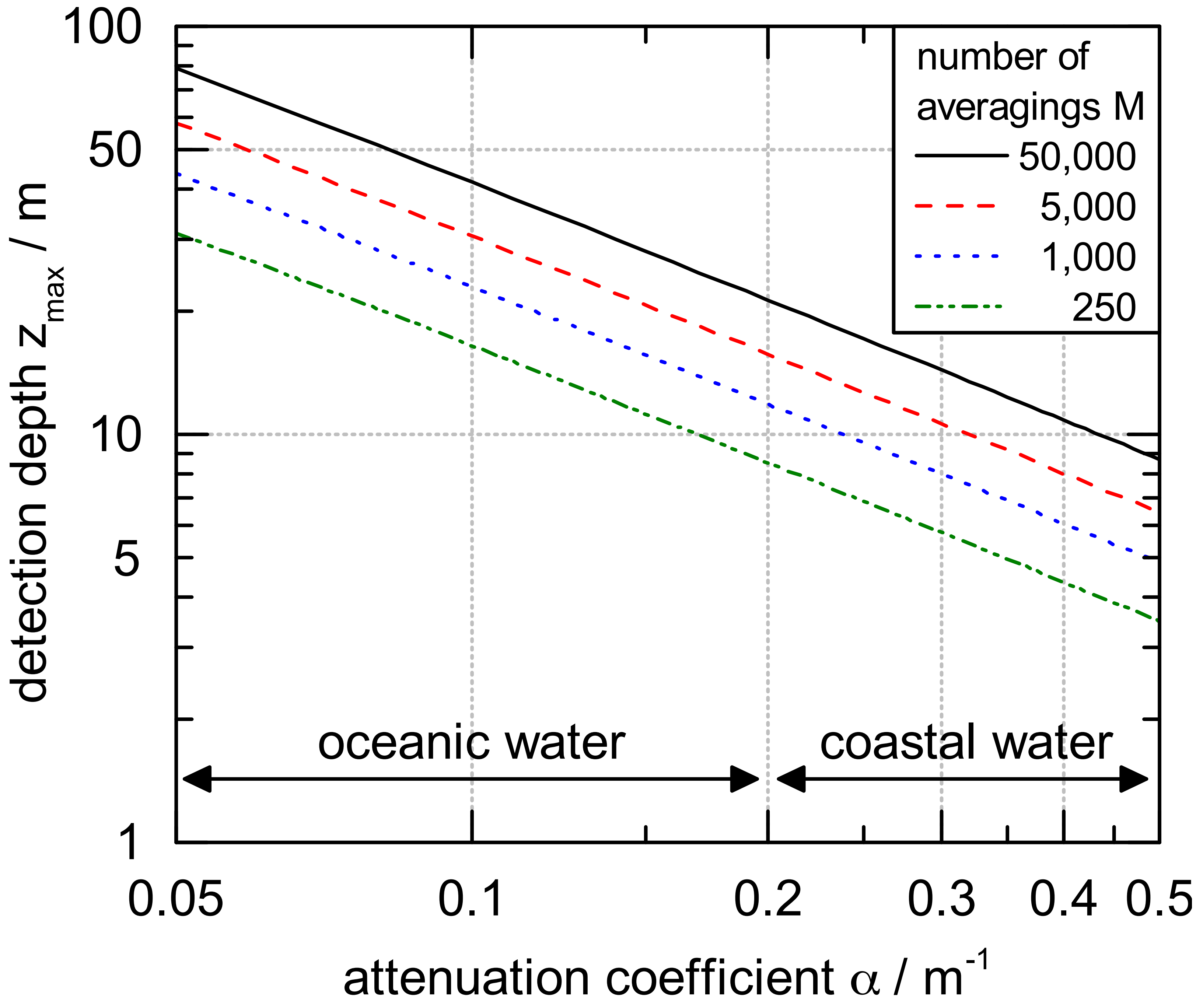

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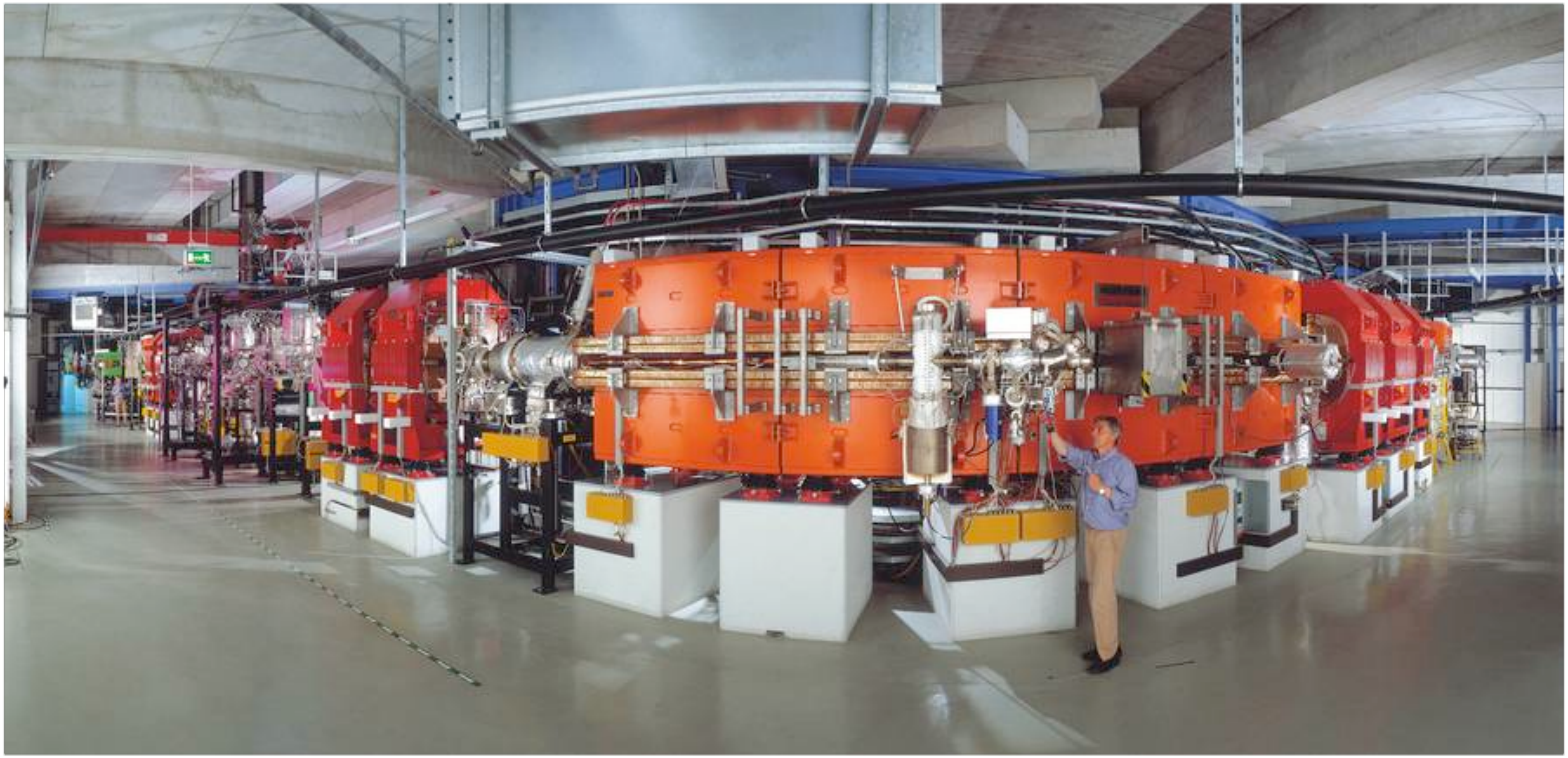
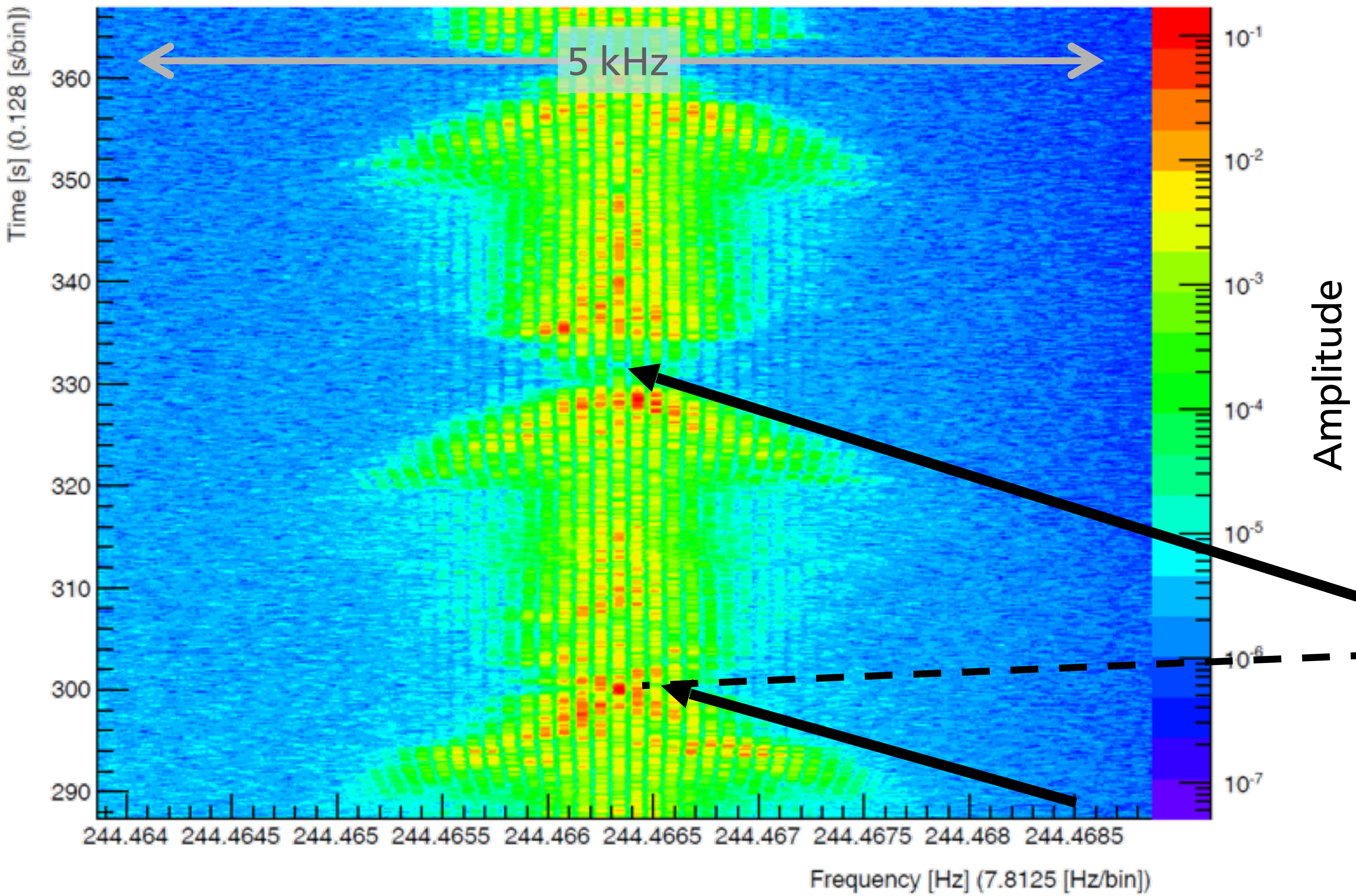
Cooling of Relativistic Ion Beams @ ESR, GSI



Bunched ion beams

Doppler Cooling with counter propagating laser beam

Beamtime 2012 – Cooling of Bunched Beams



Status and Goals

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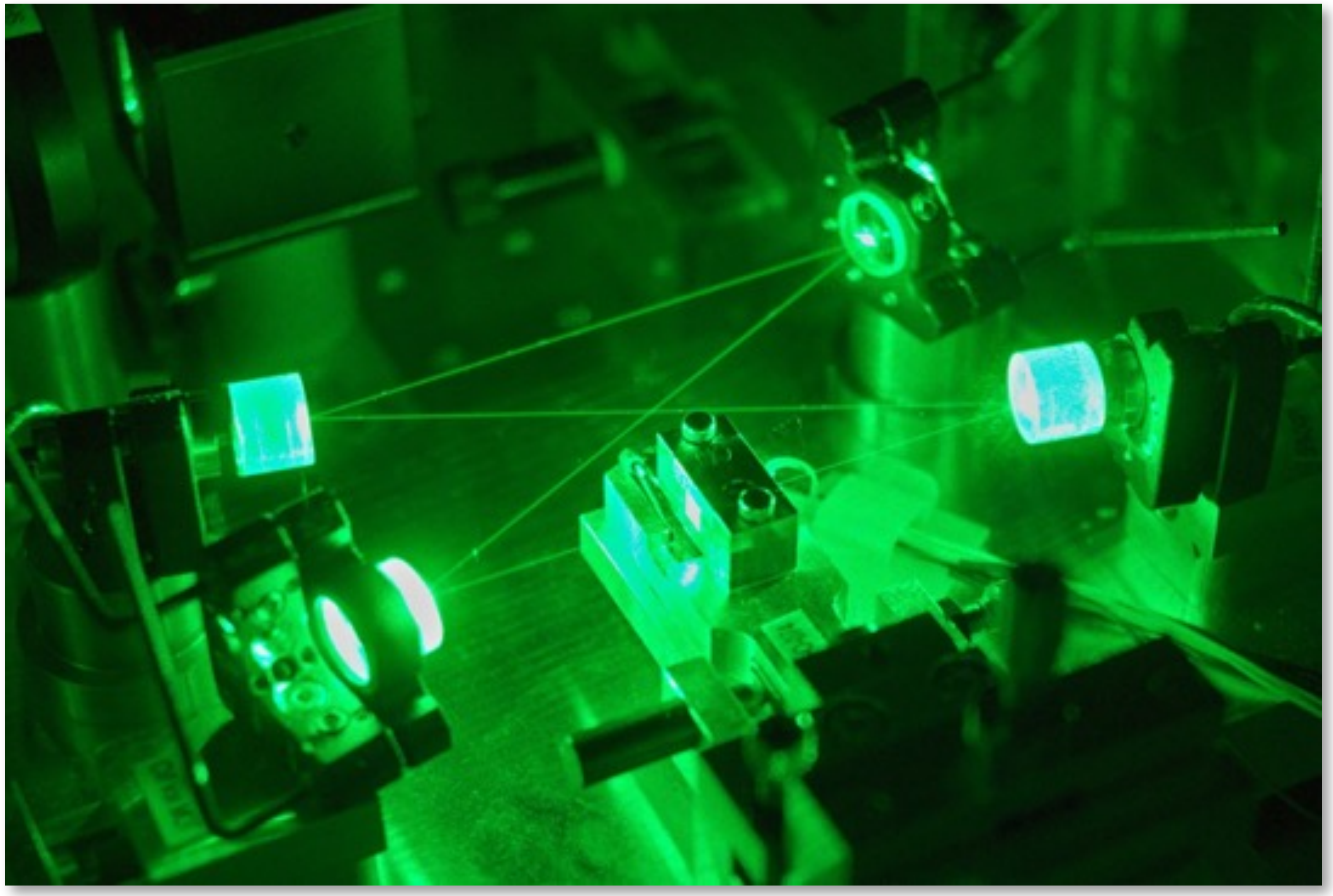
Status

Laser System

- ECDL, Fiber Amplifier, FHG
- Power
- Linewidth
- Reliability

Demonstration of Cooling

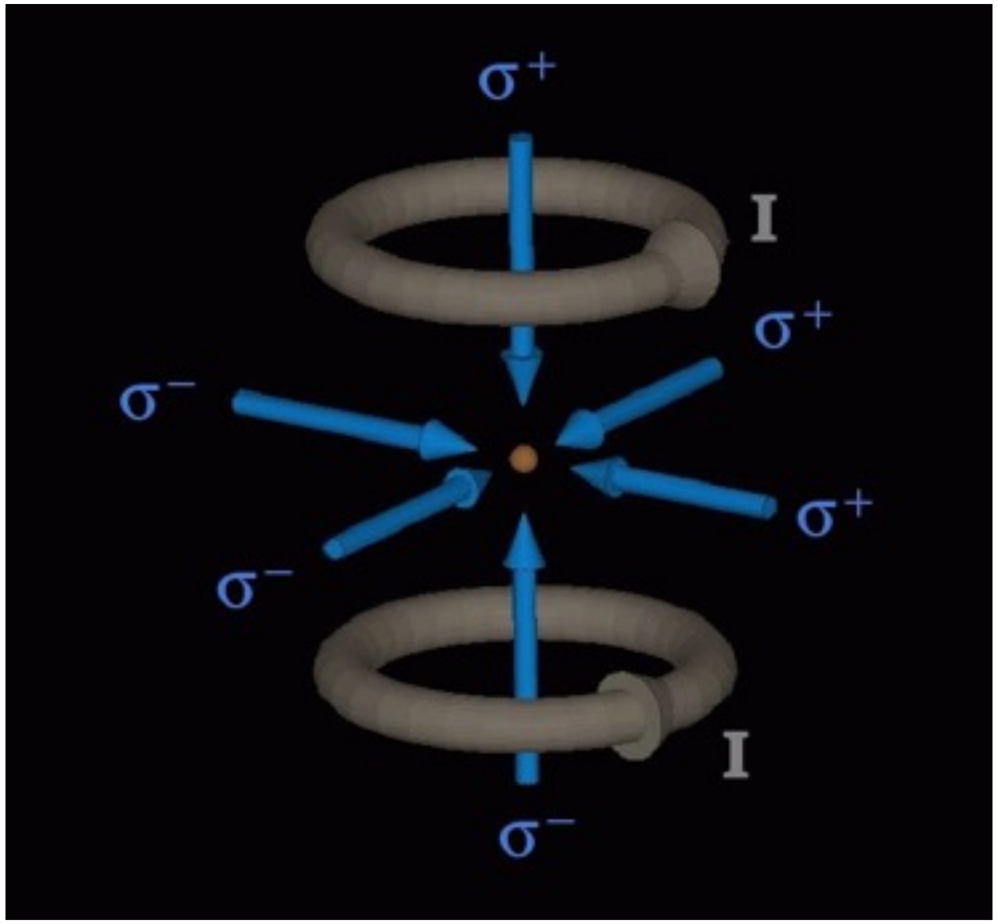
White-light Cooling (pulsed System)



Goals

“Perls on a String”
High Luminosity Beams
High Precision Experiments

Cooling and Trapping of Neutral Atoms



Trapping Laser in σ^+- σ^--Configuration (velocity dependent force)

Inhomogeneous magnetic fields (spatially dependent force)

Interplay between transition rules and Zeeman effect

σ^+- Light $\Rightarrow \Delta m = +1$

σ^-- Light $\Rightarrow \Delta m = -1$

Mercury MOT

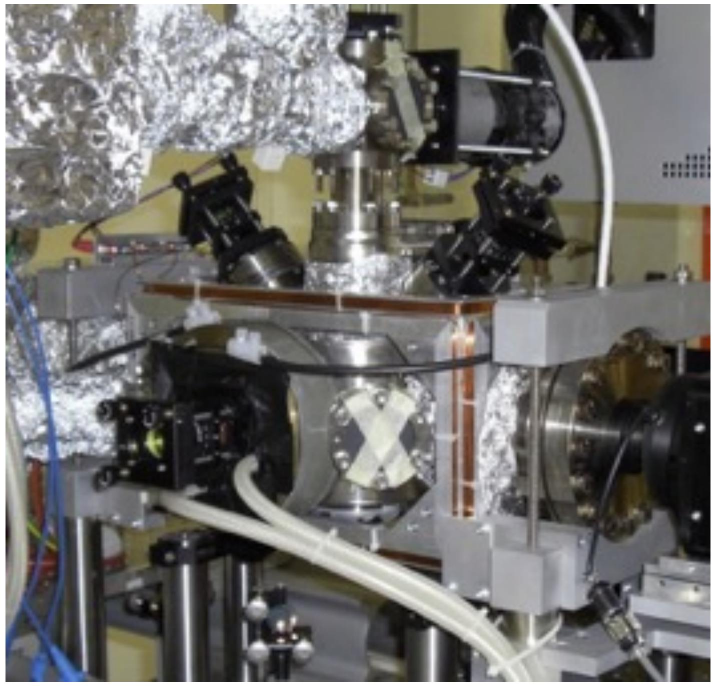
Motivation

- Photo-association of ultra-cold molecules, cold chemistry
- Entanglement between Atoms, Einstein-Podolsky Rosen Exp.

Status

- Loading time 1 s, diameter 500 µm
- Temperature (327±80) µK

MOT

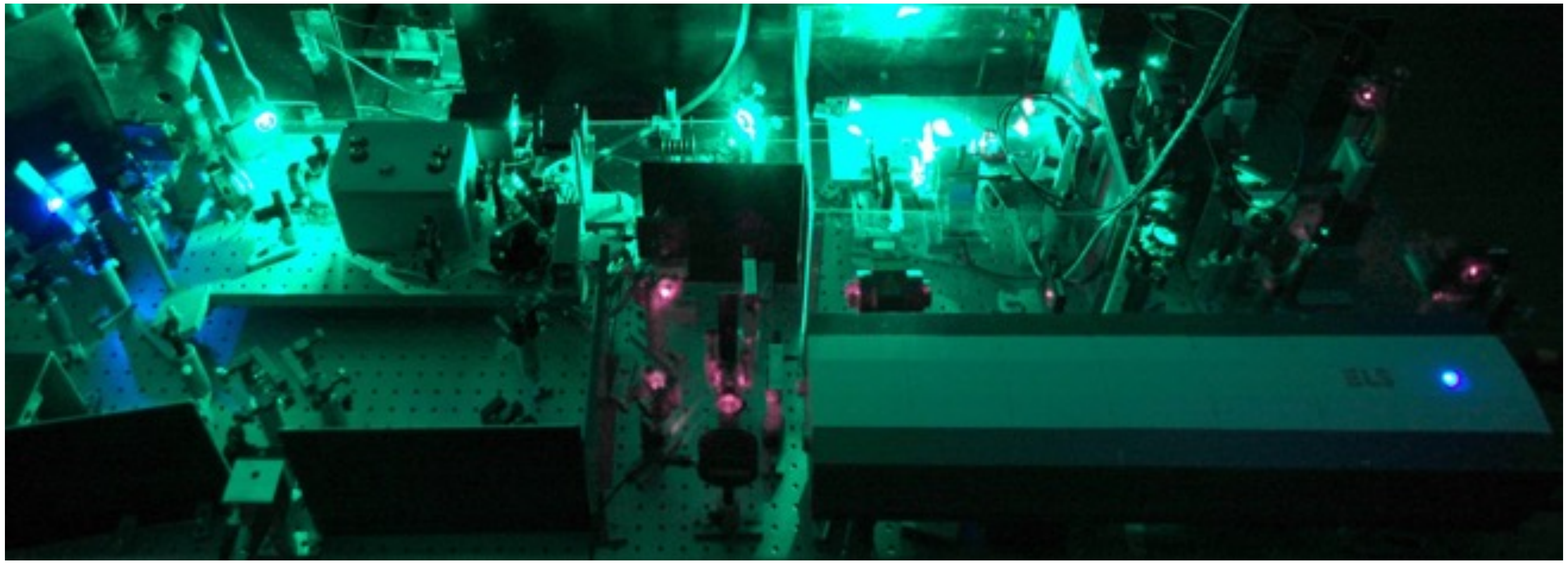


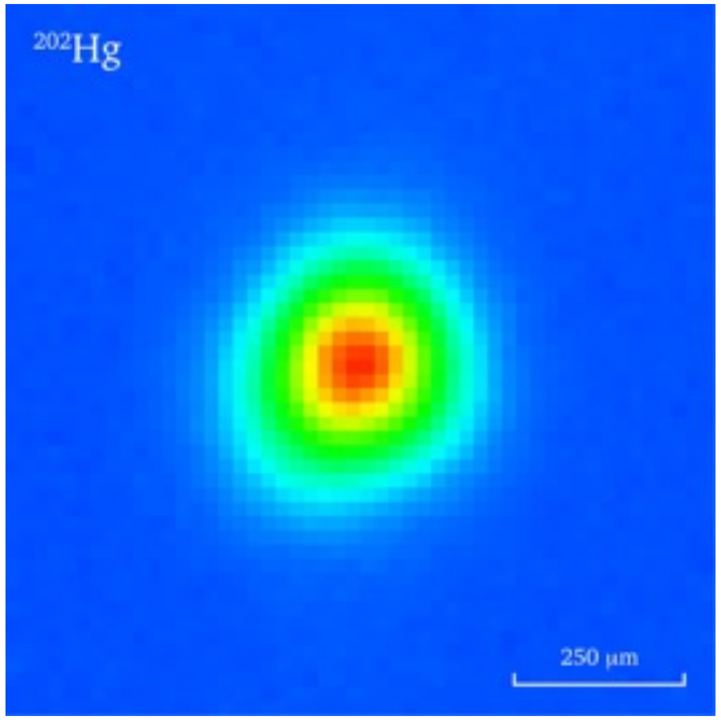
^{202}Hg (Boson)

- Number $(3.2\pm0.3)\times10^{6}$
- Density $(4.8\pm1.4)\times10^{10}$ atoms/cm^{3}

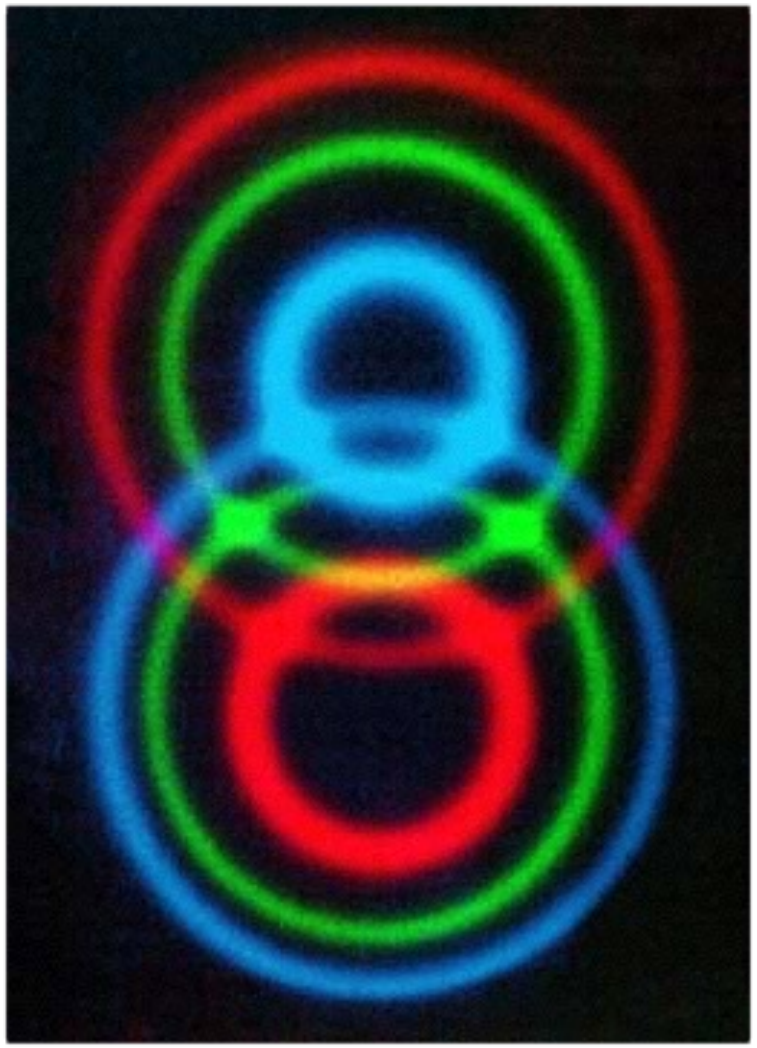
^{199}Hg (Fermion)

- Number $(8.2\pm0.7)\times10^{5}$
- Density $(1.2\pm1.4)\times10^{10}$ atoms/cm^{3}





Quantum Key Distribution

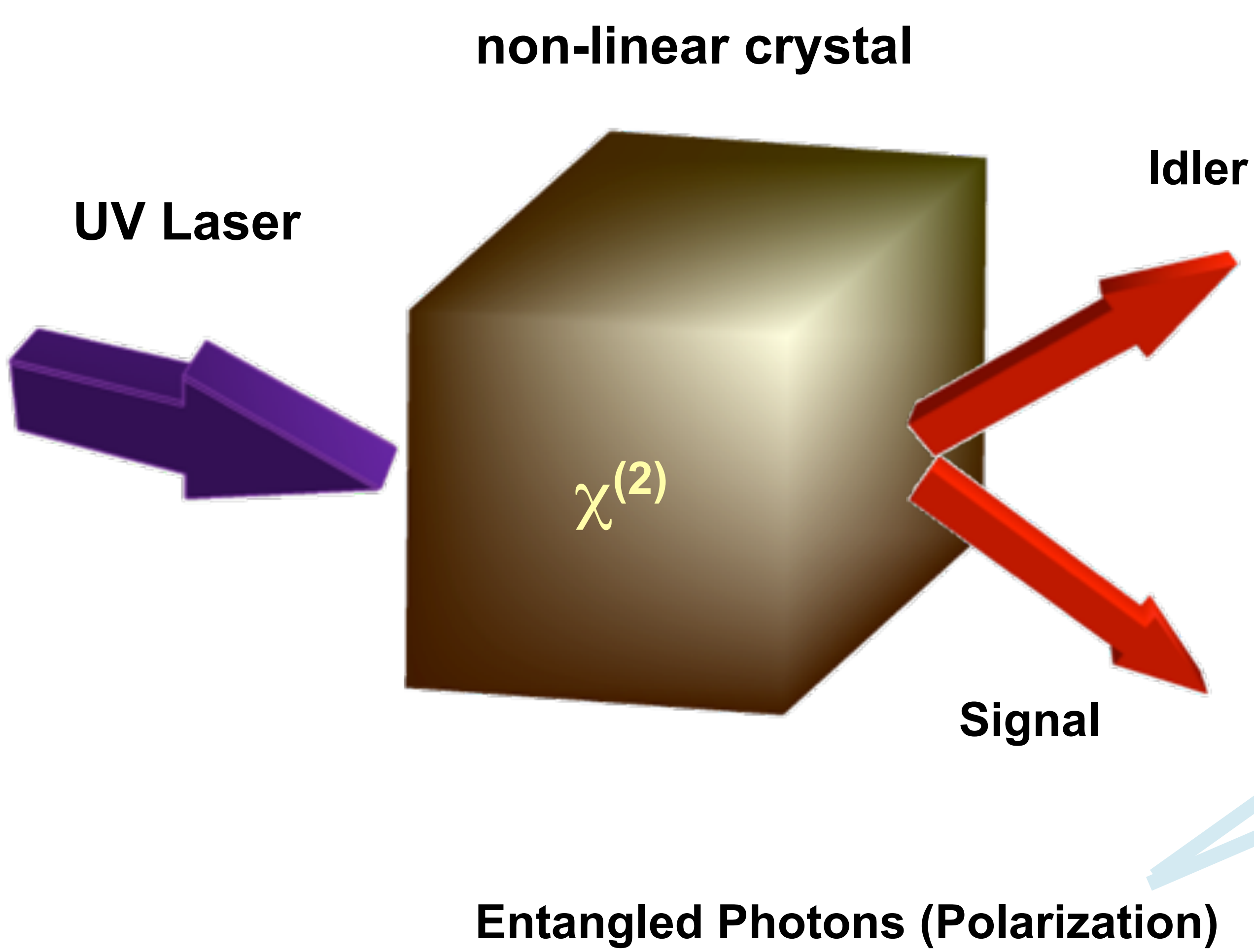


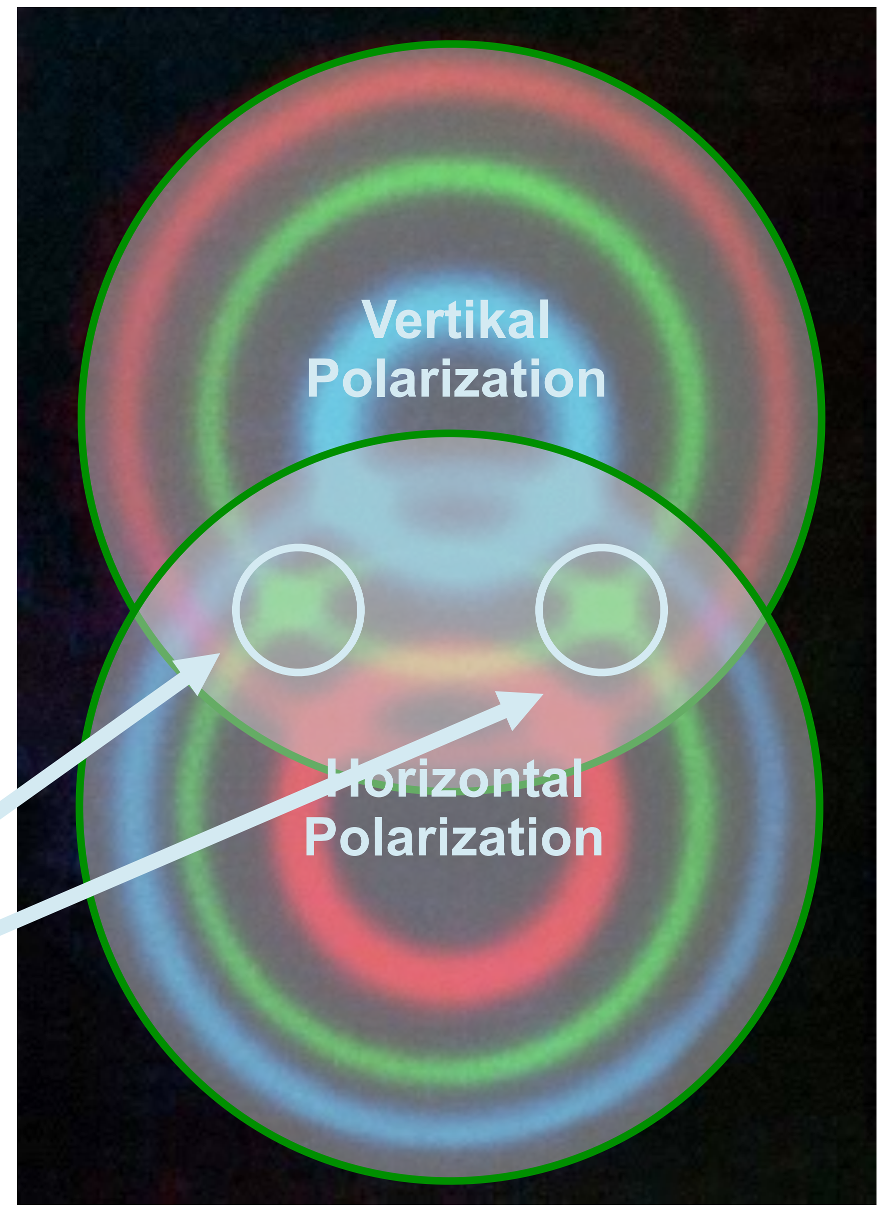
Basics:

- Superposition
- Entanglement

Source of Entangled States

Spontaneous Parametric Downconversion



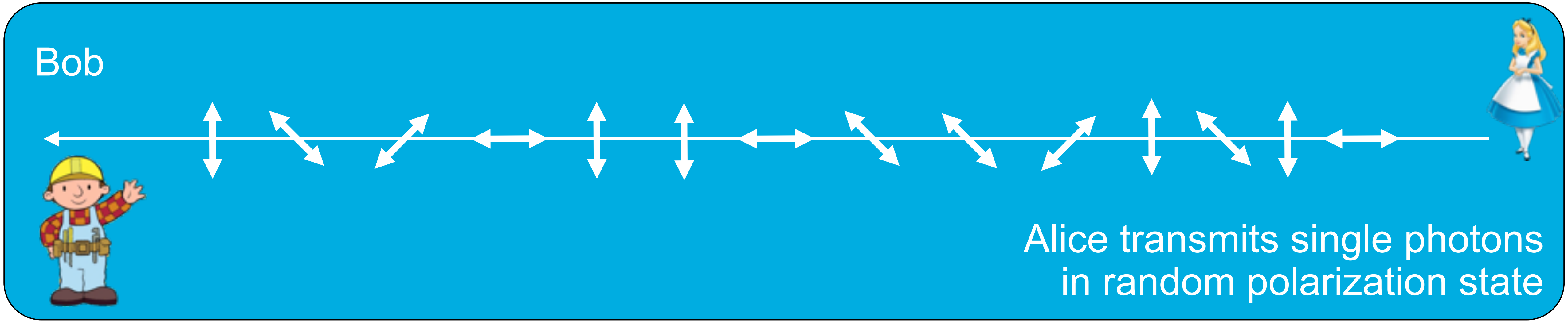


Z.Y. Ou and L. Mandel, PRL **61** (1988) p. 50
J. G. Rarity and P.R. Tapster, PRL **64** (1990) p. 2495
P.G. Kwiat, K. Mattle, H. Weinfurter, A. Zeilinger, A.V. Sergienko, and Y. Shih, PRL **75**, (1995) p. 4337

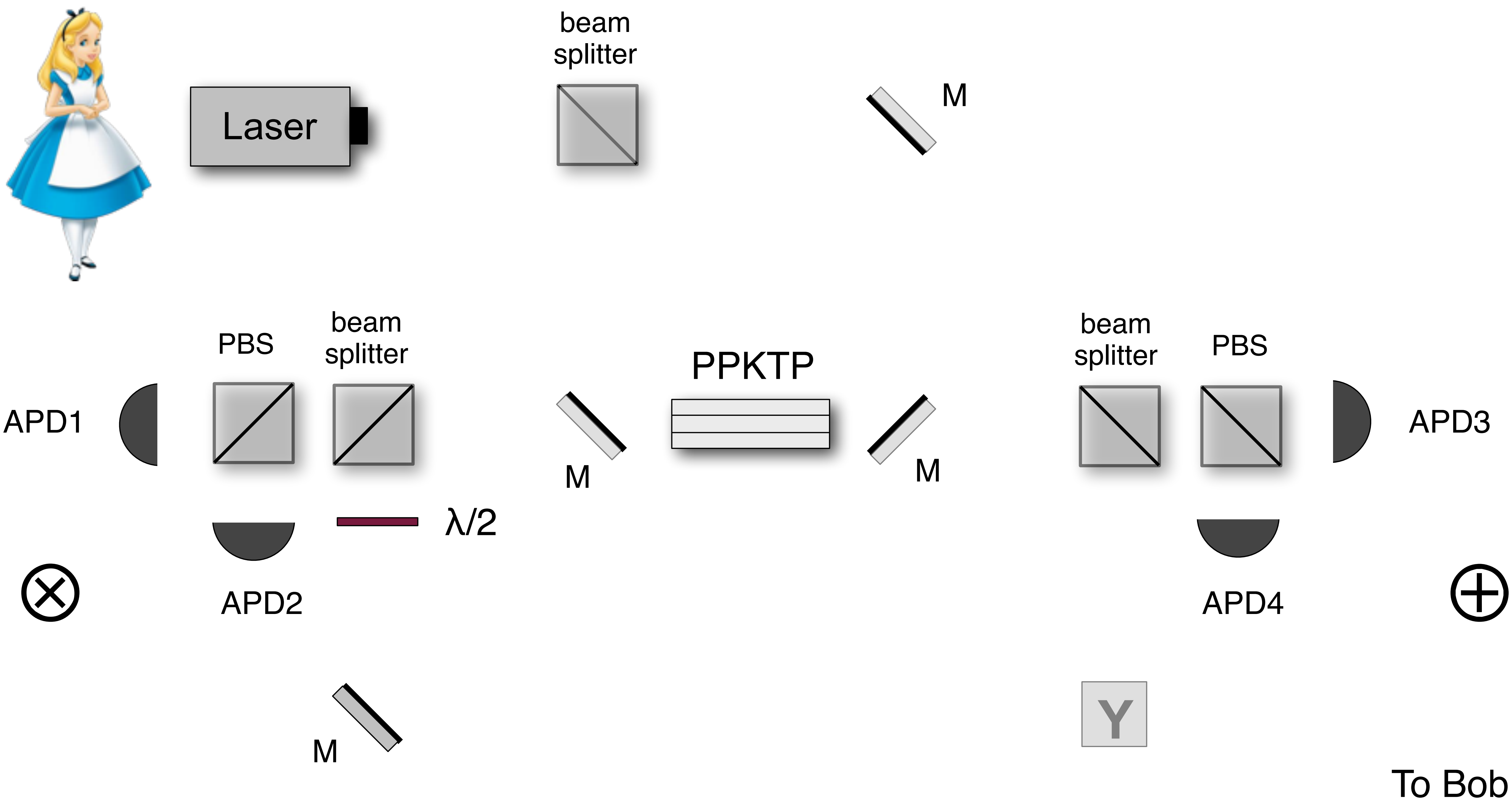
QKD – BB84 Protocol

- Single Photons
- Random
- No-Cloning
- „Sifting“
- Error Correction
- Privacy Amplification

	$\oplus$		$\otimes$	
4 Quantum States (Polarization)	$\updownarrow$	$\leftrightarrow$	$\nwarrow\!\!\searrow$	$\swarrow\!\!\nearrow$
	=0	=1	=0	=1



„Alice“
Heralded type-II SPDC Single Photon Source



„Alice“
Heralded type-II SPDC Single Photon Source

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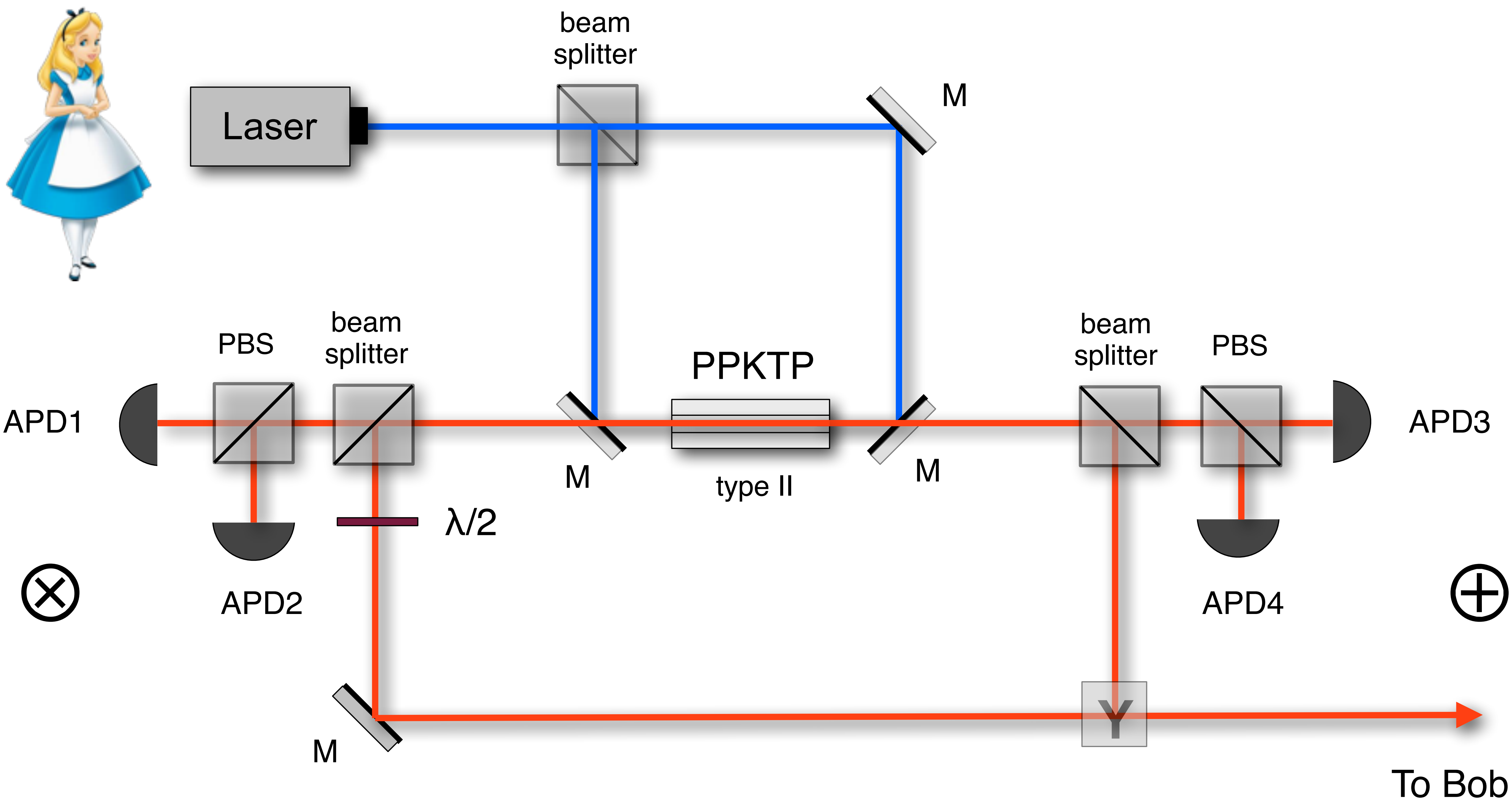
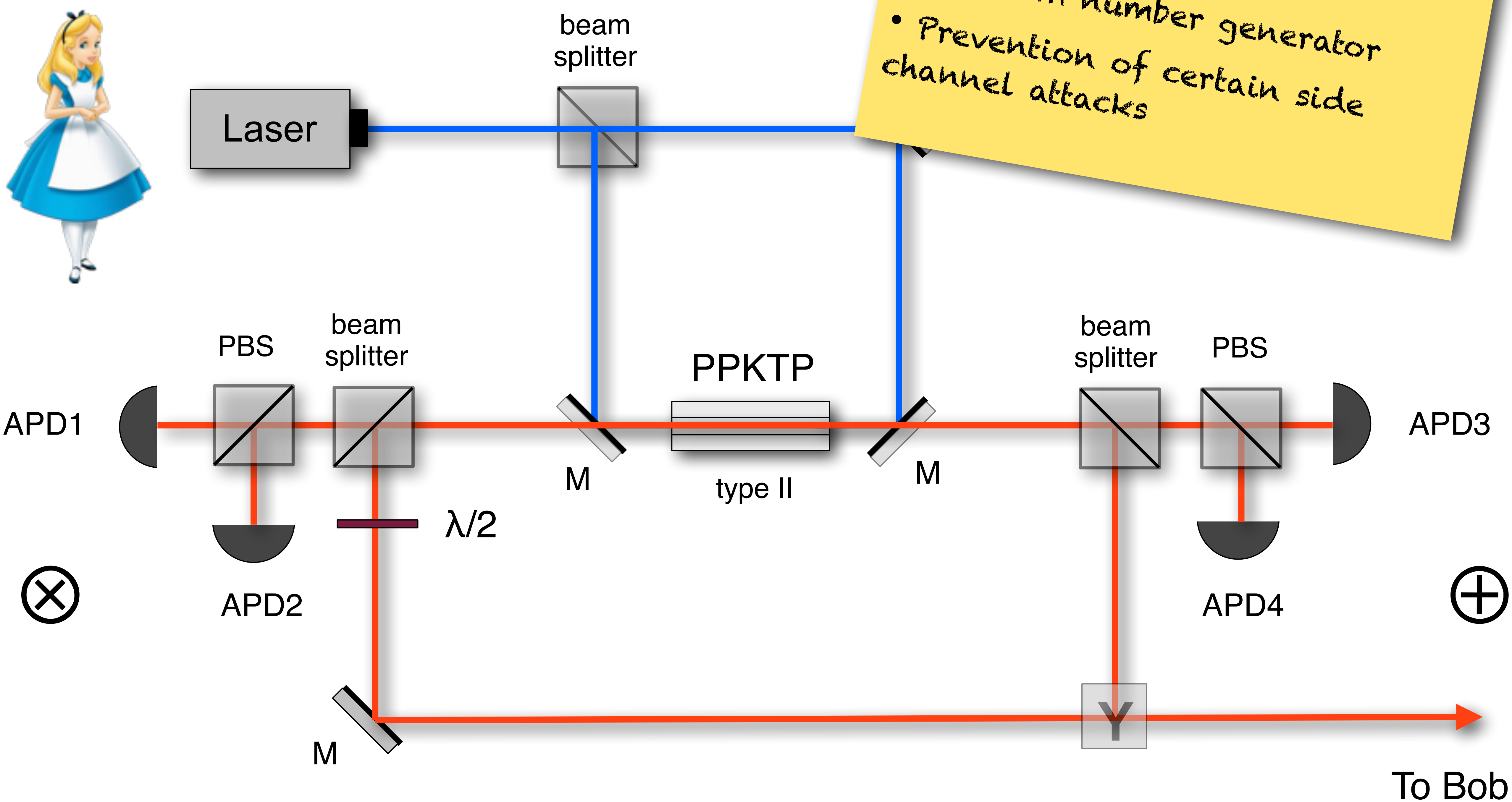


CASED

„Alice“
Heralded type-II SPDC Single Phot

Advantage:
- No active elements
- Random number generator
- Prevention of certain side channel attacks



QKD in Darmstadt

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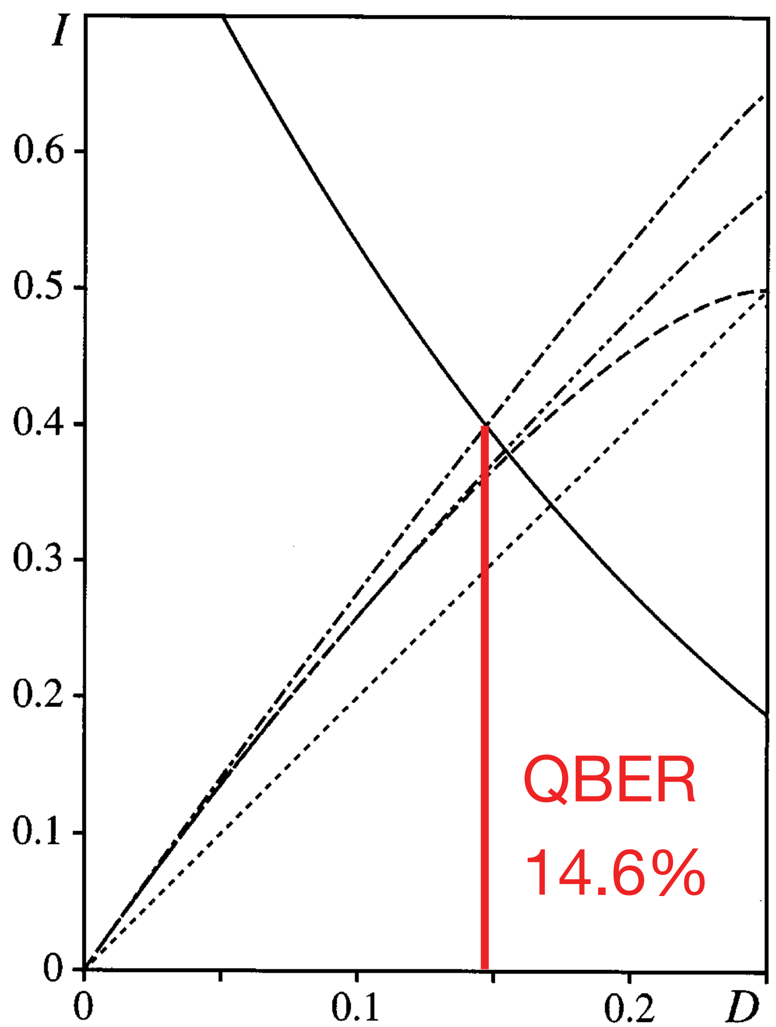
C. Fuchs, N. Gisin, R. Griffiths, C.-S. Niu and A. Peres.
Physical Review A **56** (1997) 1163



-------- intercept-resend strategy [4]

----- optimum without waiting for basis [5]

-·-·-·- improved 2-dimensional probe [7]

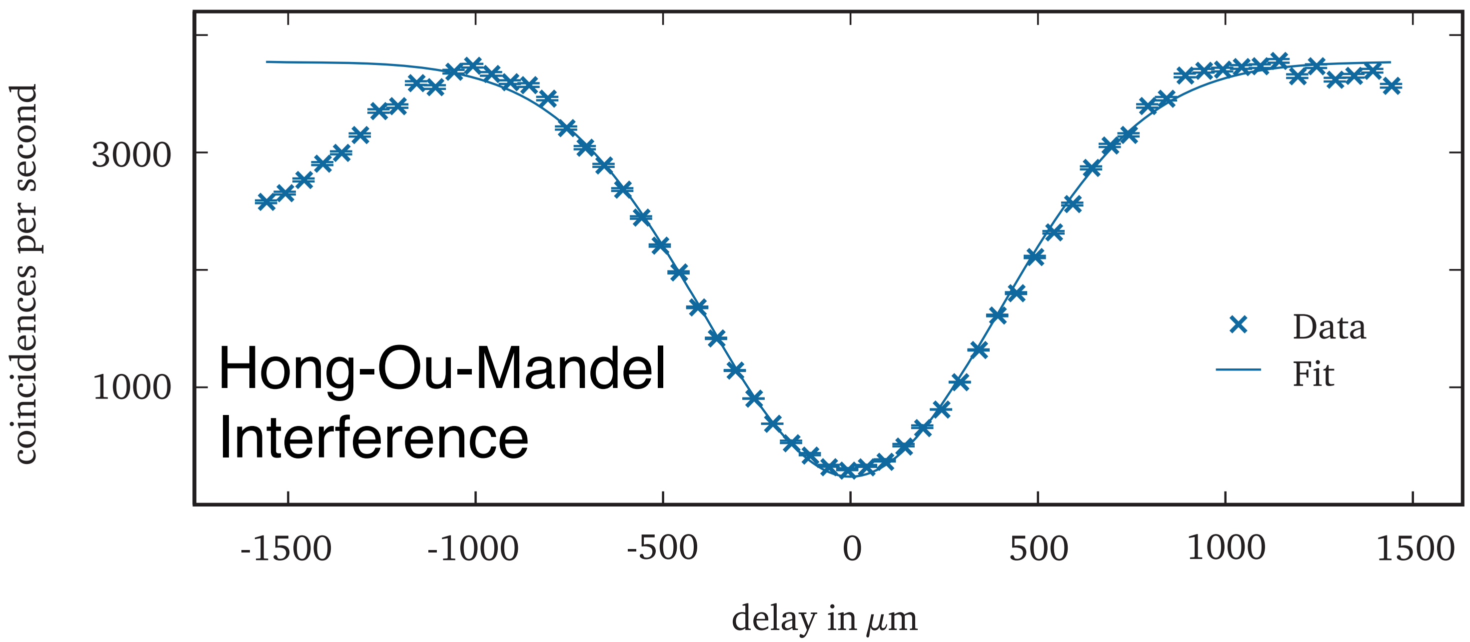
-·-·-·- optimal eavesdropping: Eq. (65)

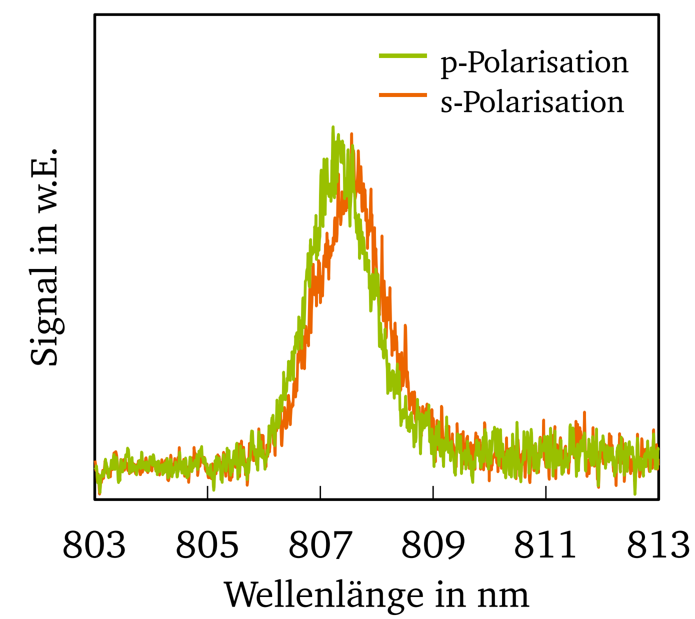
—— I_{AB}: Eq. (74)

FIG. 2. Information vs disturbance for various eavesdropping methods.

CASED

QKD in Darmstadt





The Darmstadt QKD Experiment

Sifted Key 1800 Bits/s (1200 Bits/s)

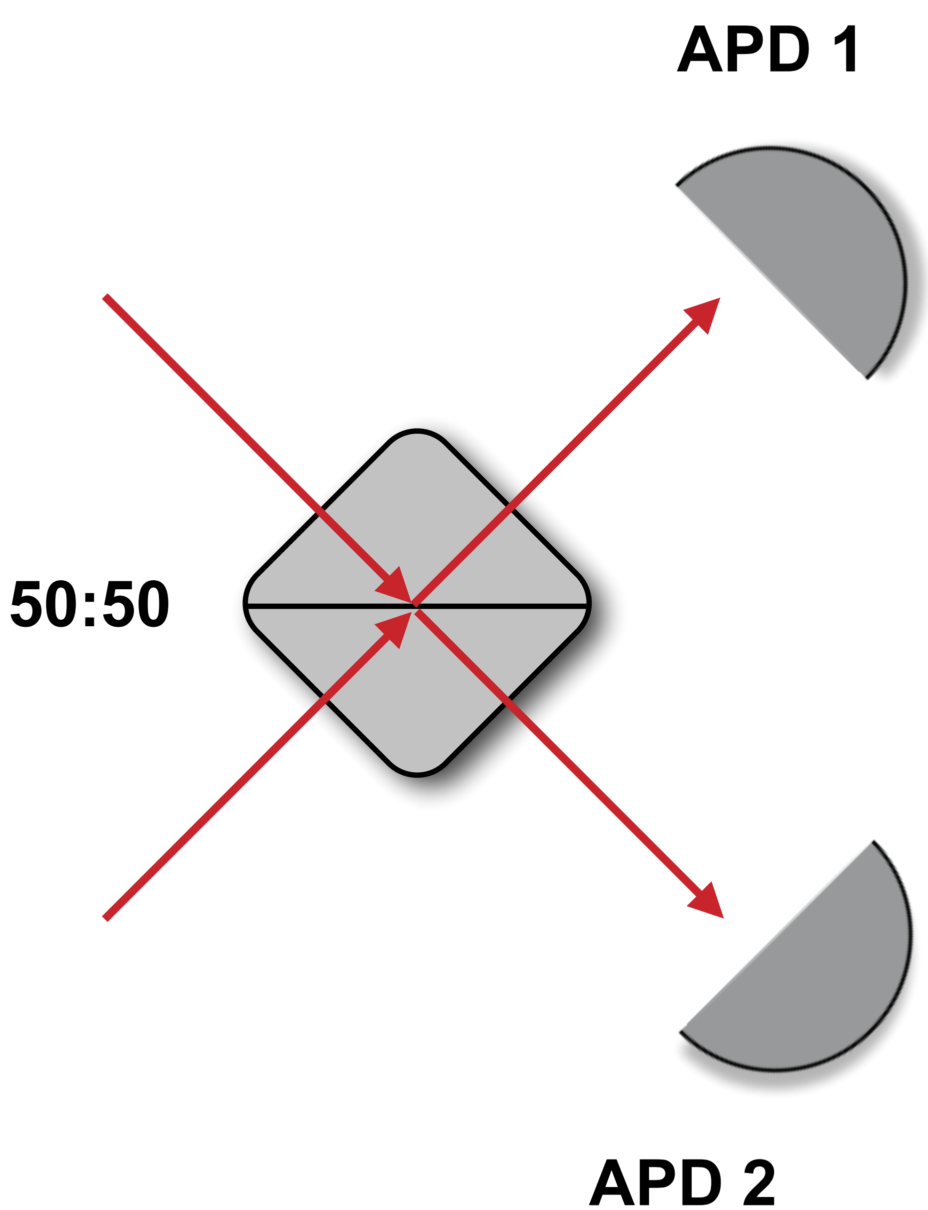
QBER 12.06% (11.04%)

Distance 1 m

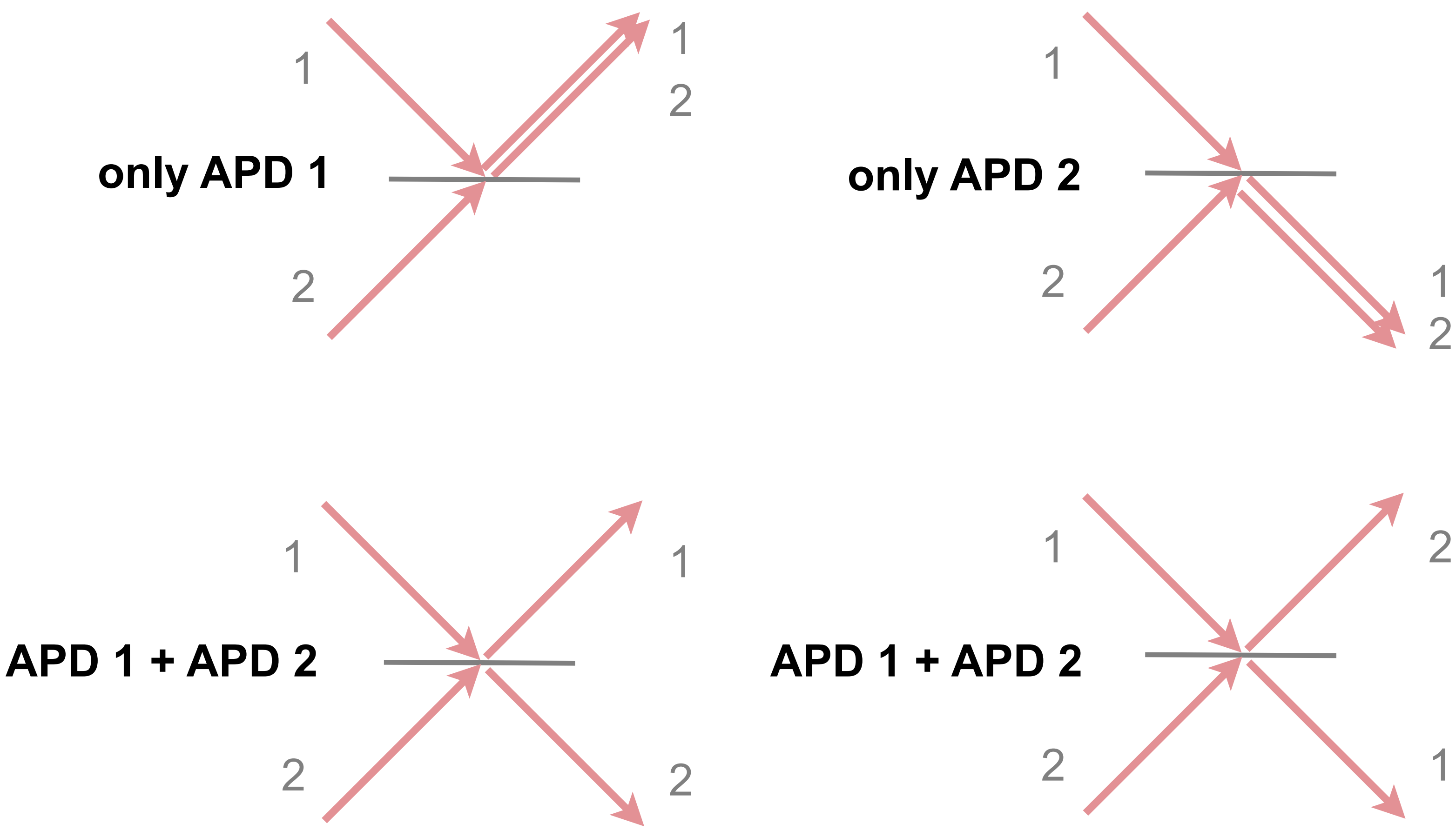
Limitation: Bob-Module

How to decide the indistinguishability of 2 photons?

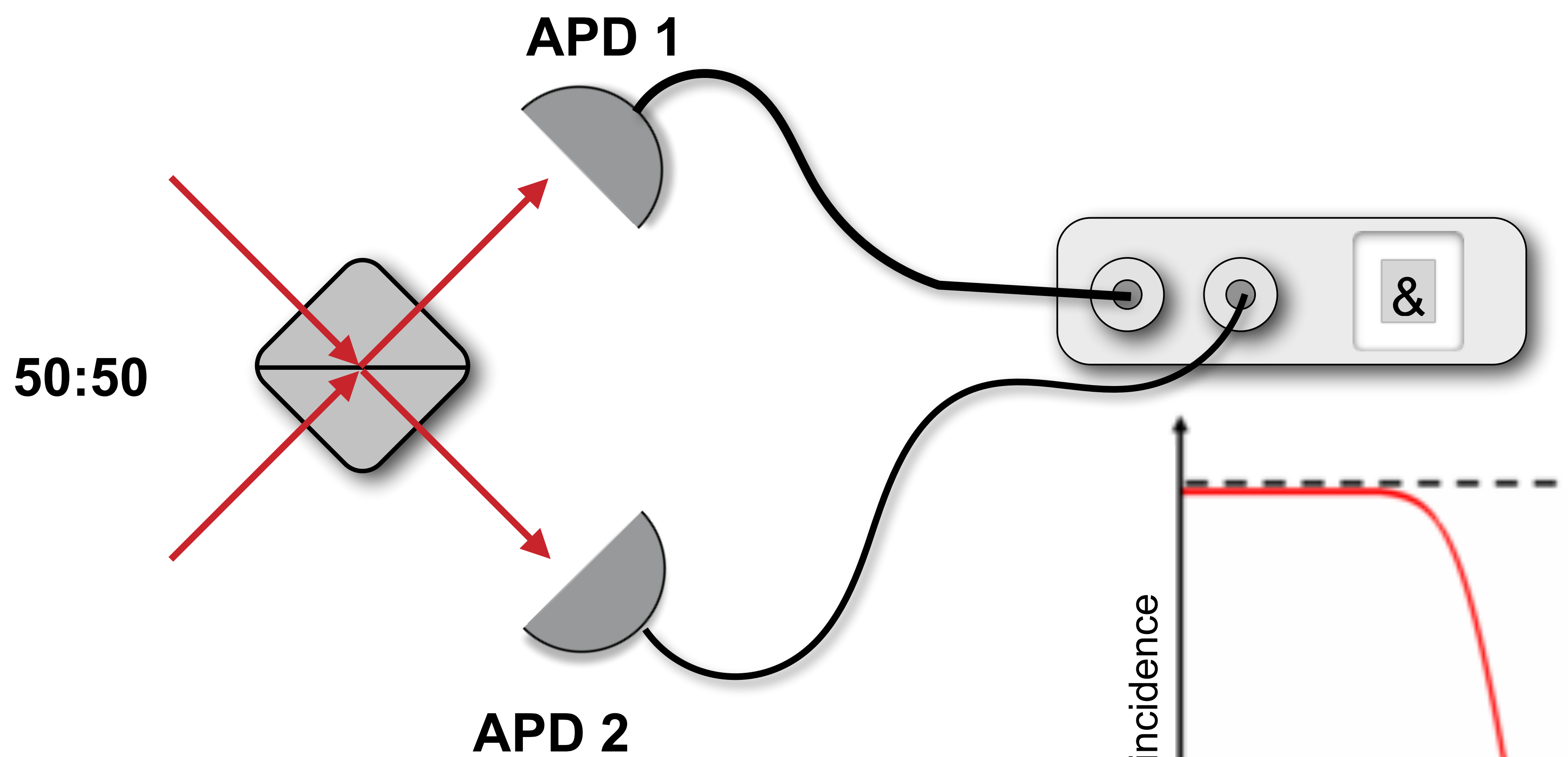
2 indistinguishable Photons



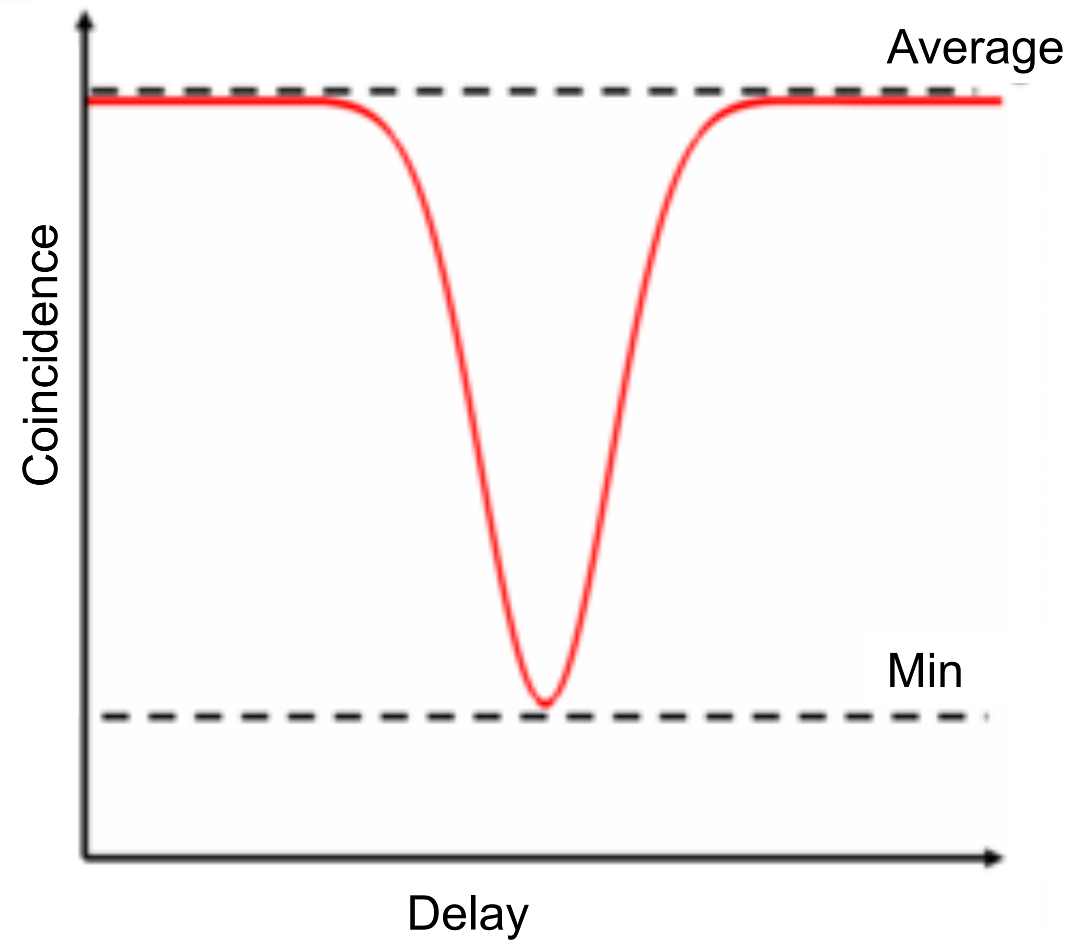
4 cases

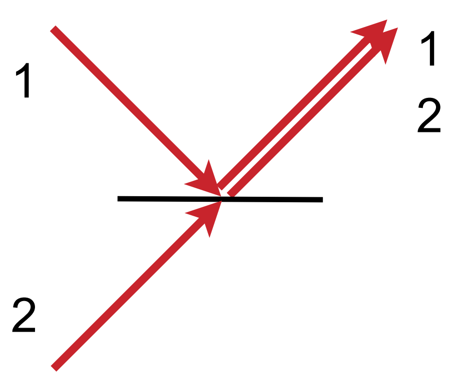


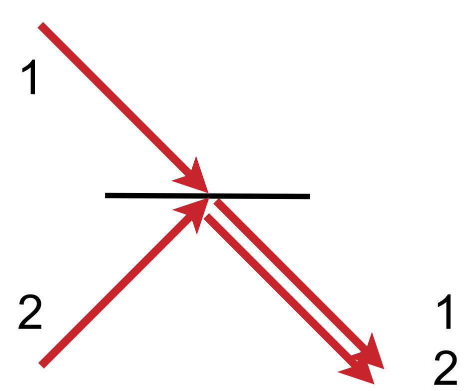
Hong-Ou-Mandel-Interference



4 cases? NO

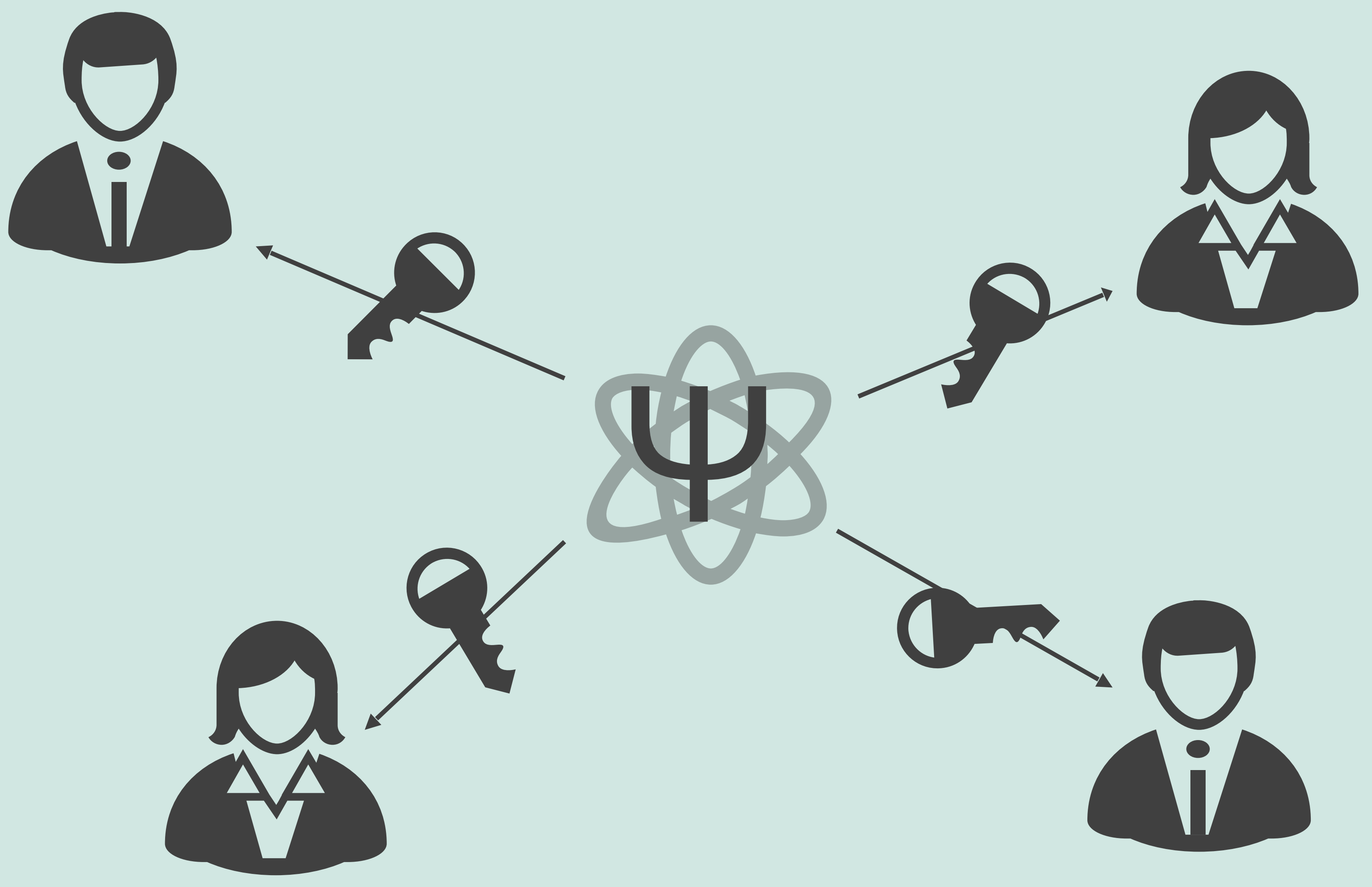






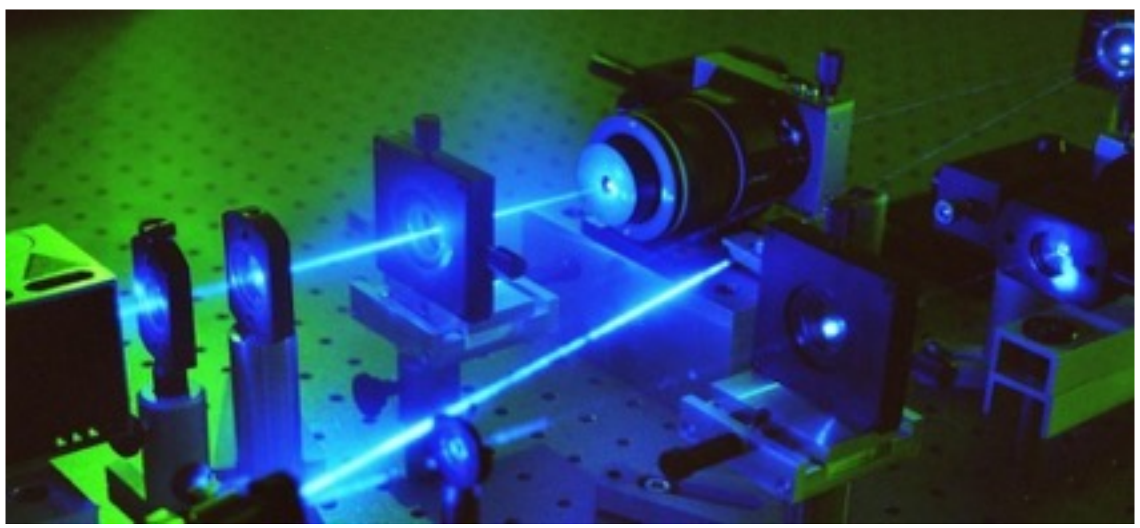
P4: Goal and challenges

Development of multi-partite QKD



Goal

Development of multi-partite QKD



Experimental exploration	Theoretical investigation	
Basic quantum features	Multipartite correlations	Security for device in-dependent scenario

Quantum Hub

PI: Th. Walther

PI: G. Alber

Experimental exploration	Theoretical investigation
Experimental setup based on SPDC at telecom wavelength Simultaneous key exchange between any two parties Characterization: rates, QBER, scalability stability and quantum features	Description of multipartite Entanglement Conditions of device independent security Elimination of trust Theoretical description of experimental setup Security