Towards Traceable Few Photon Radiometry

G. Brida, J. Cheung, I. Degiovanni, M. Gramegna,
T. Kübarsepp, M. G. Mingolla, I. Mueller,
G. Porrovecchio, M. L. Rastello, M. Smid and L. Werner

METROSERT CMI iNRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA PTB NPL National Physical Laboratory

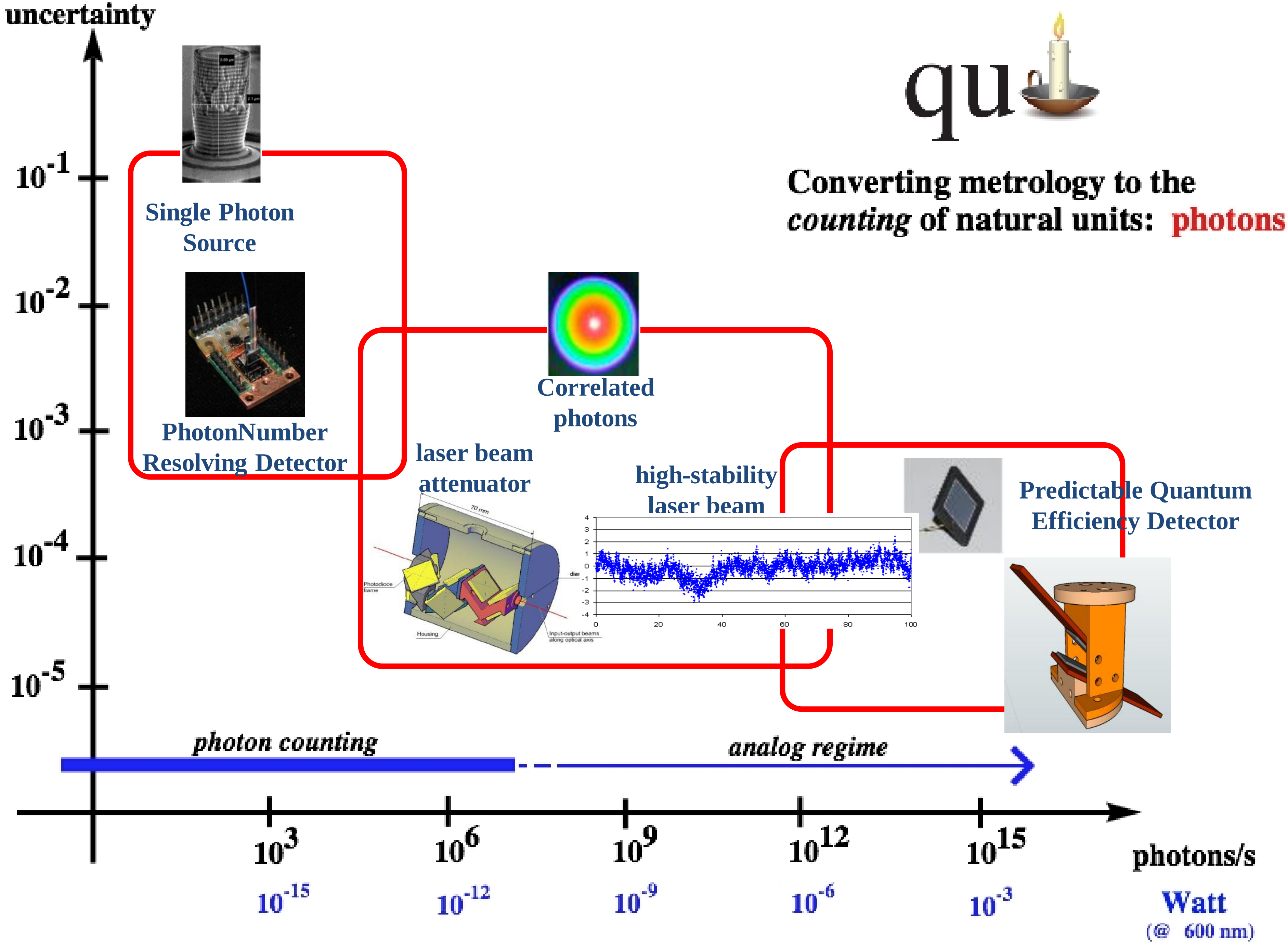
NEWRAD 2011, 22/09/2011

Outline

1. *Introduction*
2. *Calibration against a Trap Transfer Detector*
3. *Calibration with correlated photon pairs (PDC)*

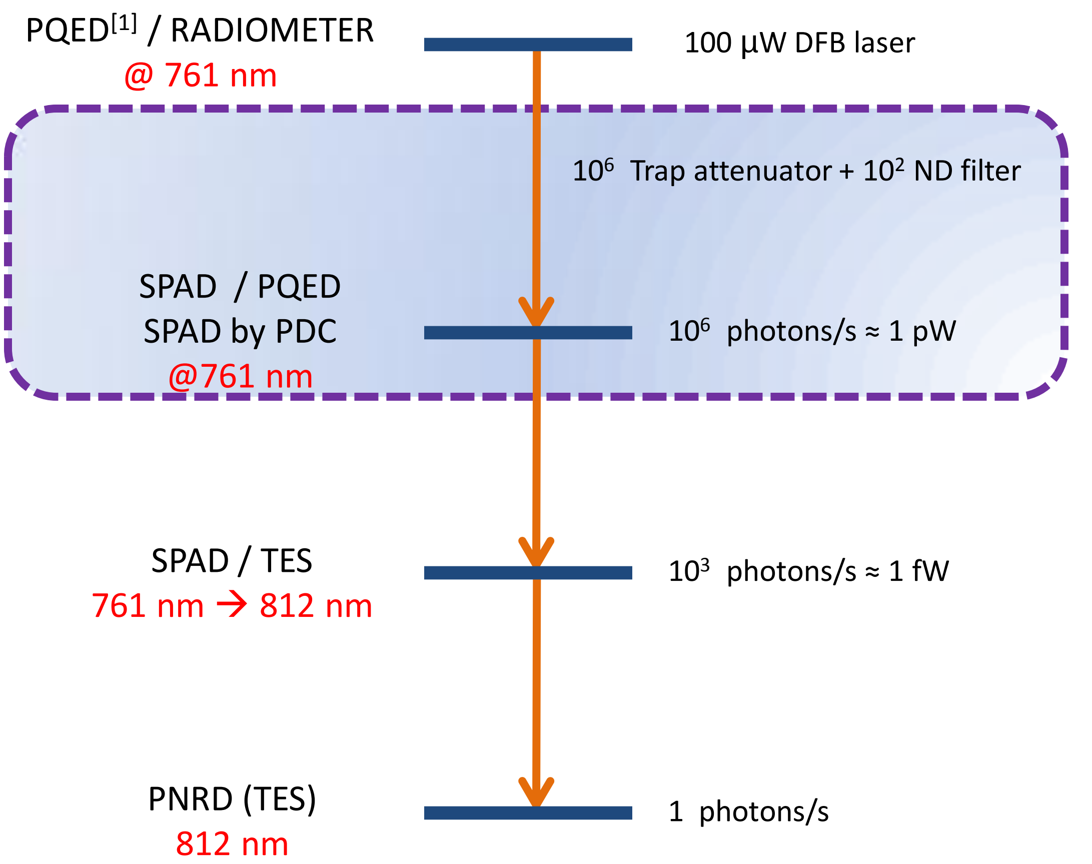
1. Introduction

the qu-candela project



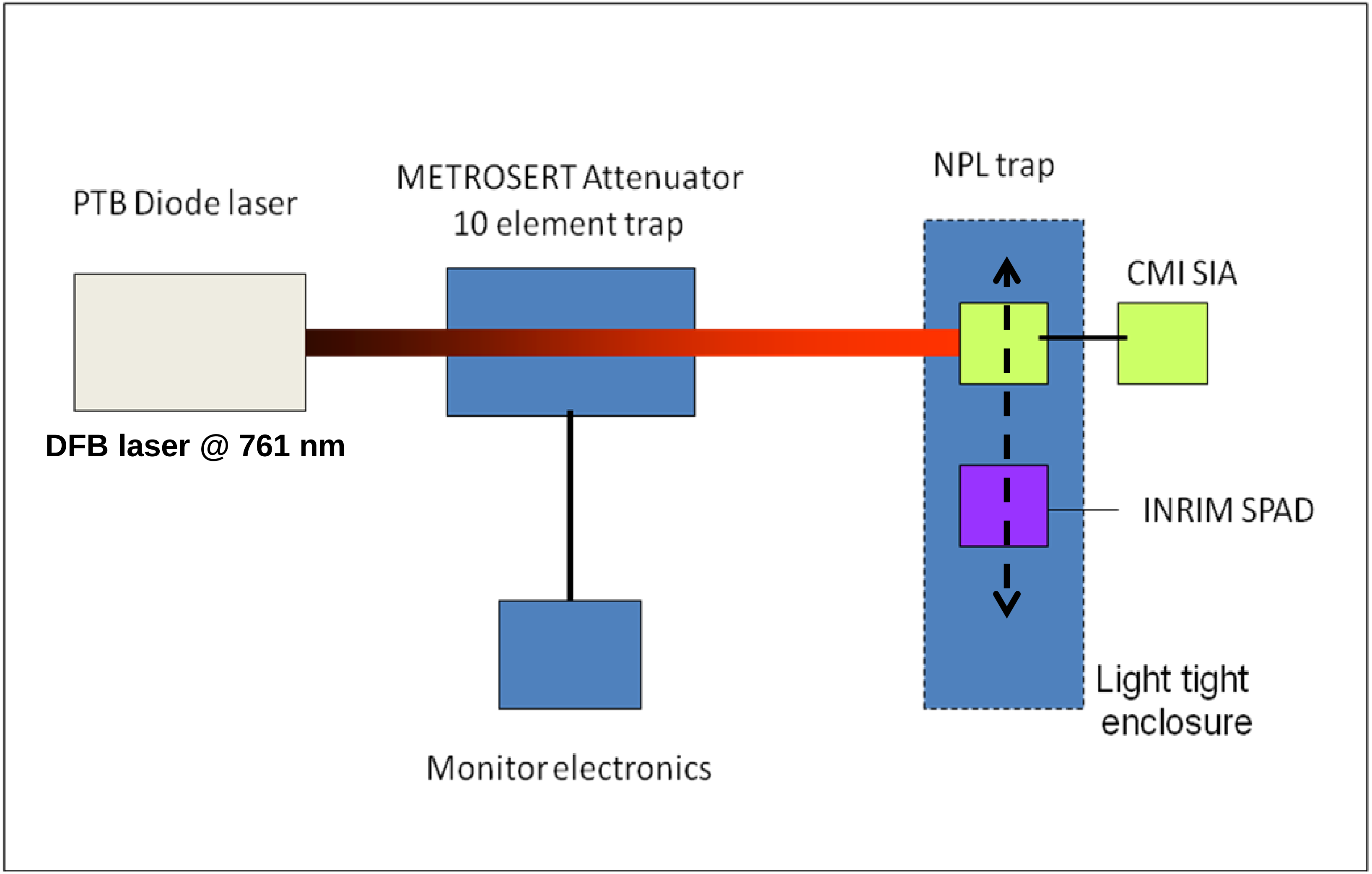
uncertainty
qu
Converting metrology to the
counting of natural units: photons
10^-1
10^-2
10^-3
10^-4
10^-5
Single Photon Source
PhotonNumber Resolving Detector
Correlated photons
laser beam attenuator
high-stability laser beam
Predictable Quantum Efficiency Detector
photon counting
analog regime
10^3
10^6
10^9
10^12
10^15
photons/s
10^-15
10^-12
10^-9
10^-6
10^-3
Watt
(@ 600 nm)

Linkage



PQED[1] / RADIOMETER
@ 761 nm
100 μW DFB laser
10^6 Trap attenuator + 10^2 ND filter
SPAD / PQED
SPAD by PDC
@761 nm
10^6 photons/s ≈ 1 pW
SPAD / TES
761 nm → 812 nm
10^3 photons/s ≈ 1 fW
PNRD (TES)
812 nm
1 photons/s

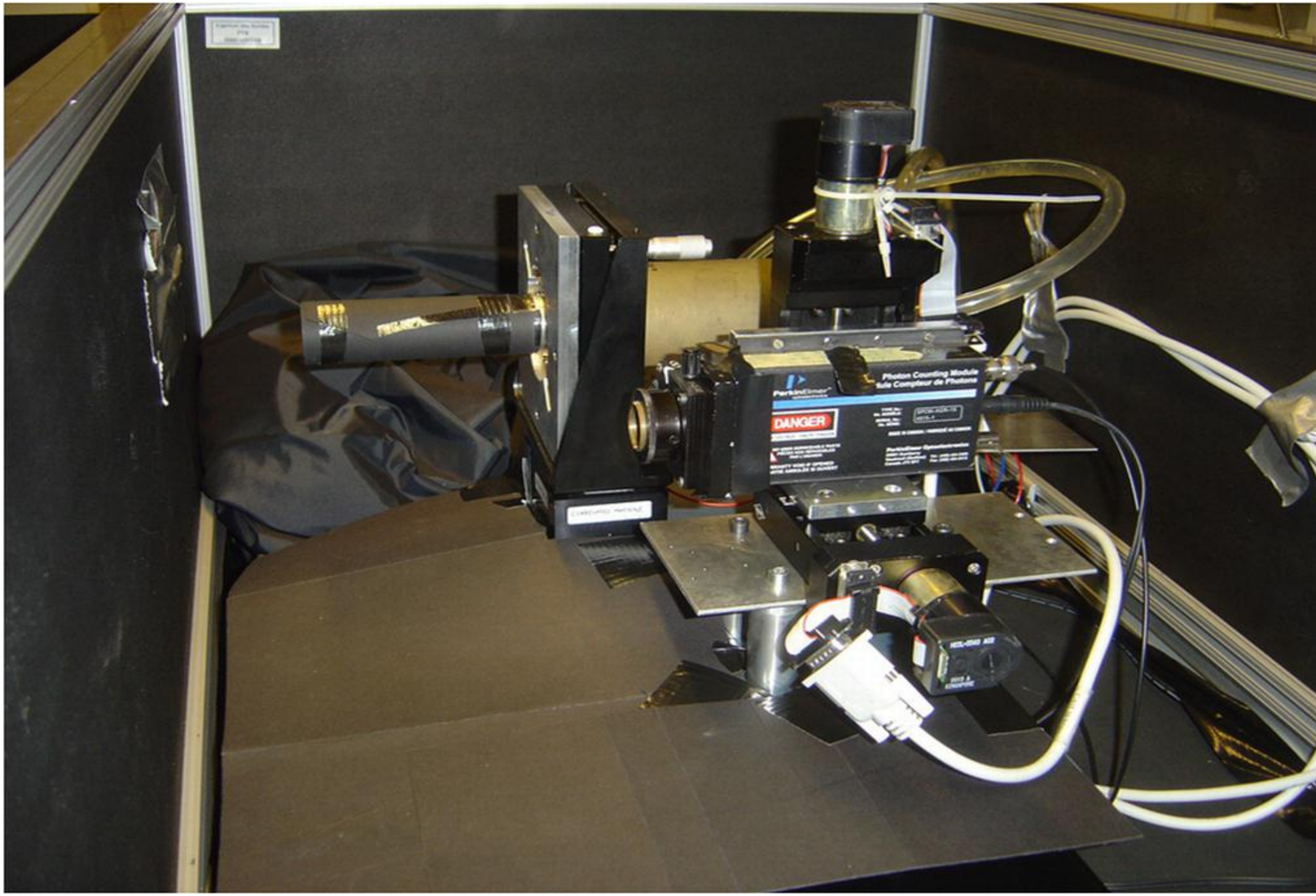
2. Calibration against a Trap Transfer Detector



Converting Metrology to the counting of natural units: photons

-**source**: DFB laser 761 nm;
std. dev. optical power < 5 ppm
- **attenuator**: ten element trap detector;
retain beam shape quality
-**Trap** transfer detector
cooled (14 °C) to reduce dark-current noise
- **Switching Integrating Amplifier** ≈ $8*10^{10}$ Ω
- tight light enclosure to reduce background light

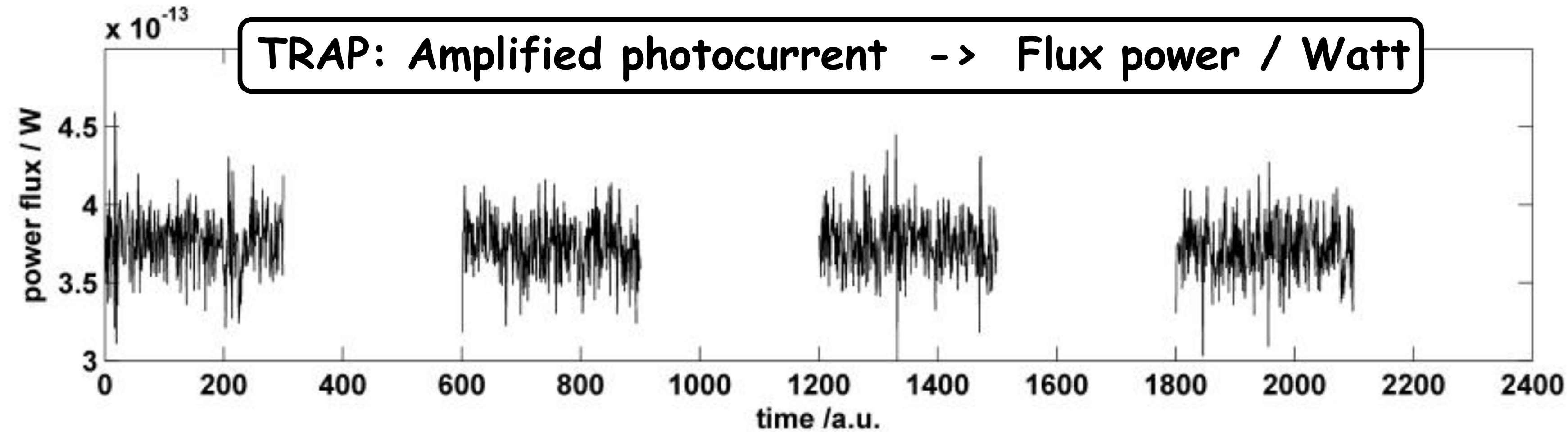
- 1st measurement @ 4 Mcounts/s (≈ 2 pW)
- 2nd measurement @ 1 M counts/s (≈ 370 fW) (overnight)

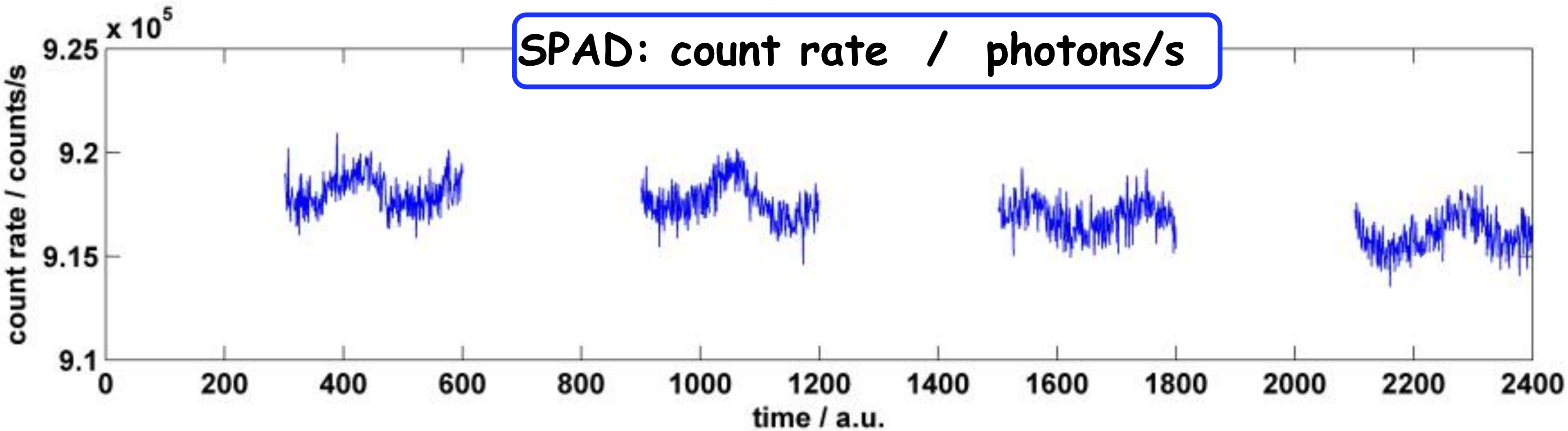


Converting Metrology to the counting of natural units: photons

Converting Metrology to the counting of natural units: photons

Raw data from the long measurement (overnight) @ 370 fW





Converting Metrology to the counting of natural units: photons

$\eta = 0.5562$

@1.88 pW (f ≅ 4 Mcounts/s)

$\eta = 0.6373$

@ 370 fW (f ≅ 1 Mcounts/s)

Uncertainty: 0.2 %

The uncertainty budget is dominated by the std. dev. of the trap photocurrent

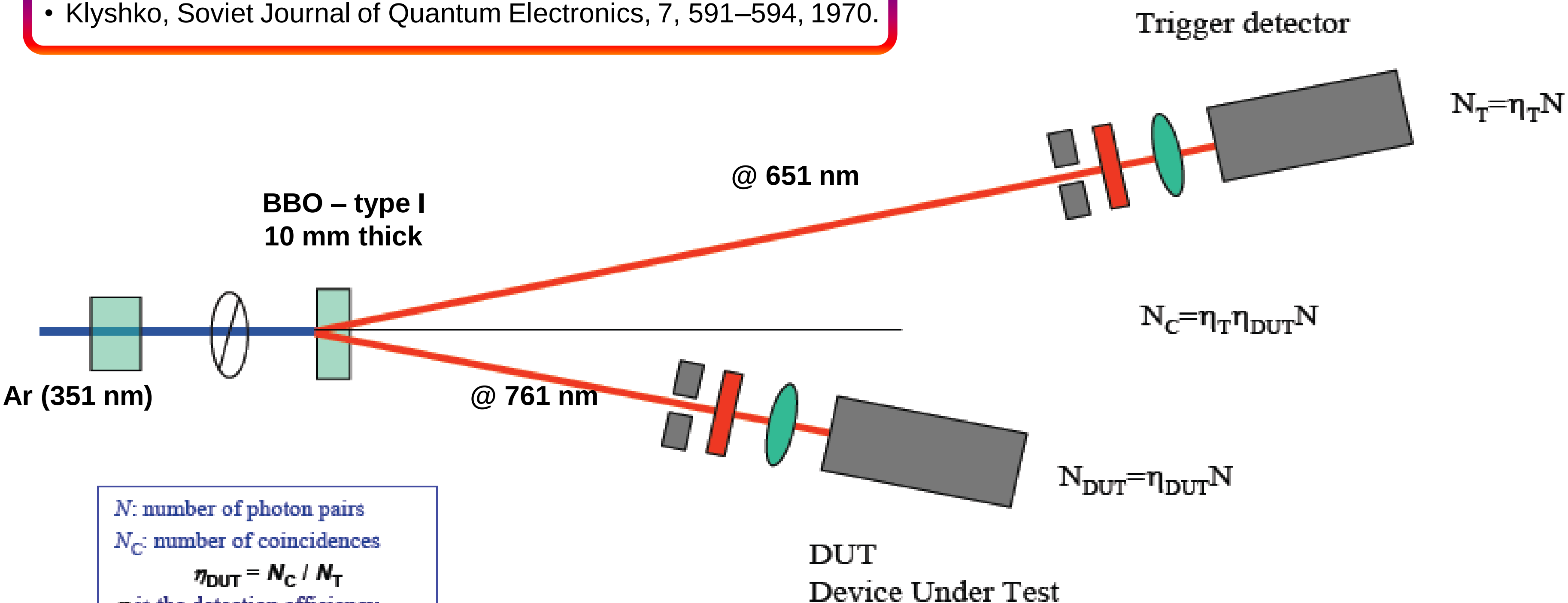
qu

3. Calibration with correlated photon pairs (PDC)

Calibration with correlated photons: *inherently absolute measurement technique*

From the proposals…

- Burnham and Weinberg, Physical Review Letters, 25, 84–87, 1970;
- Klyshko, Soviet Journal of Quantum Electronics, 7, 591–594, 1970.



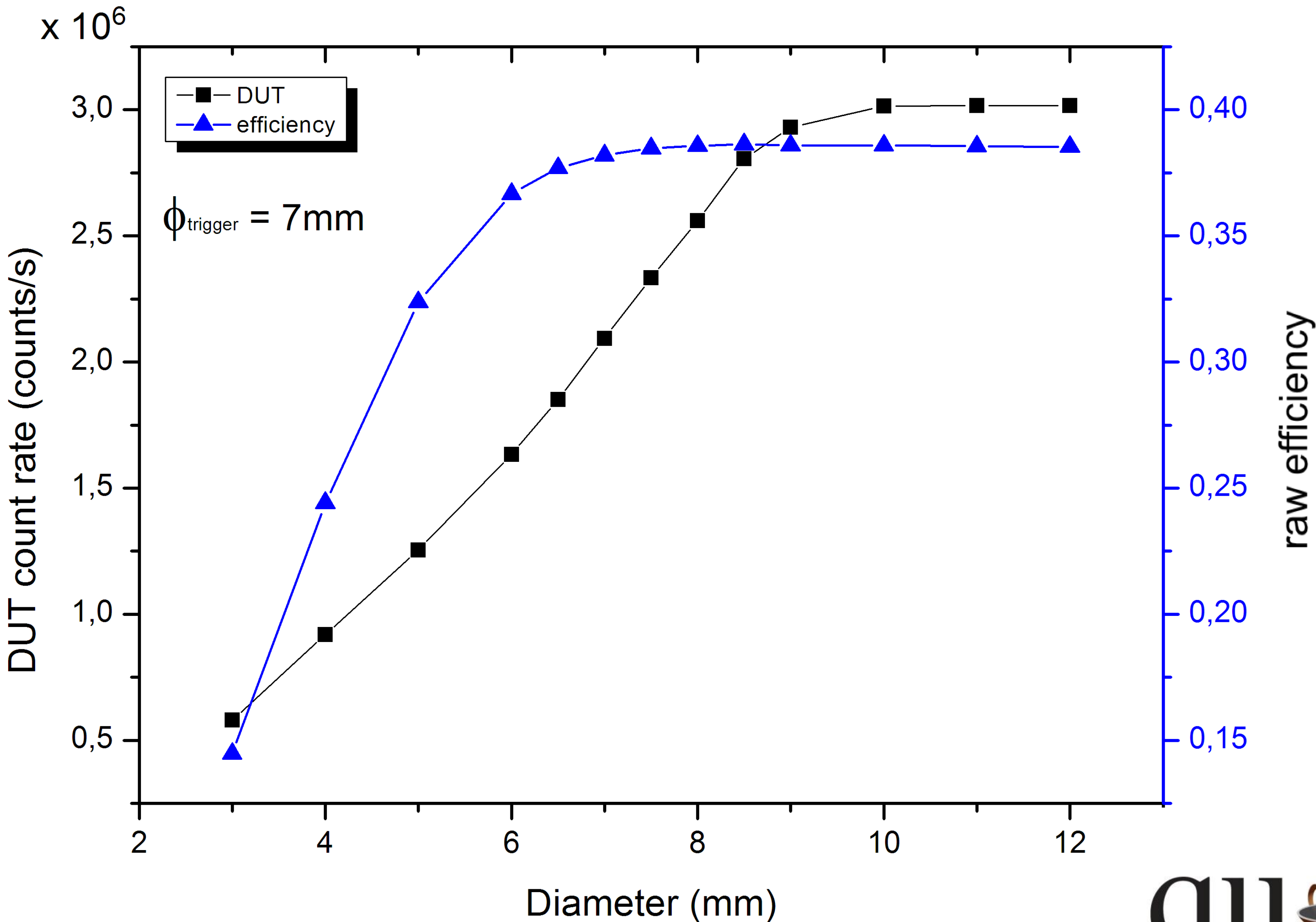
N: number of photon pairs
N_C: number of coincidences
$$\eta_{DUT} = N_C / N_T$$
η is the detection efficiency

…to metrology:

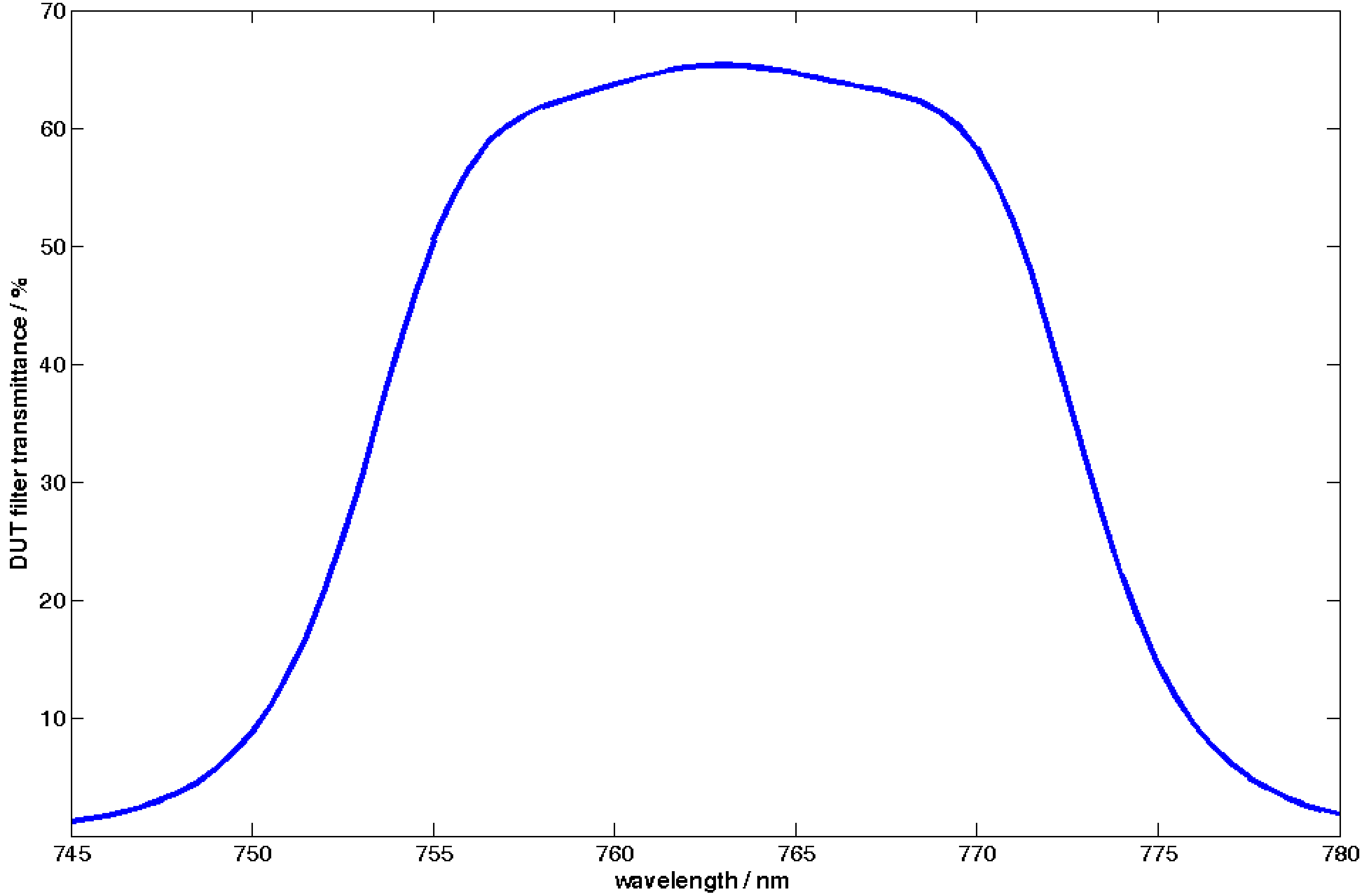
- A.N. Penin, A.V. Sergienko, Appl. Opt. 30,3582 (1991);
- G. Brida, *et alia* Metrologia 37, 625 (2000);
- S. V. Polyakov, A. L. Migdall, Optics Express, Vol. 15 Issue 4, pp.1390 (2007);
- J.Y. Cheung, C.J. Chunnillal, G. Porrovecchio, M. Smid, E. Theocarous, *submitted to Opt. Exp.*

qu

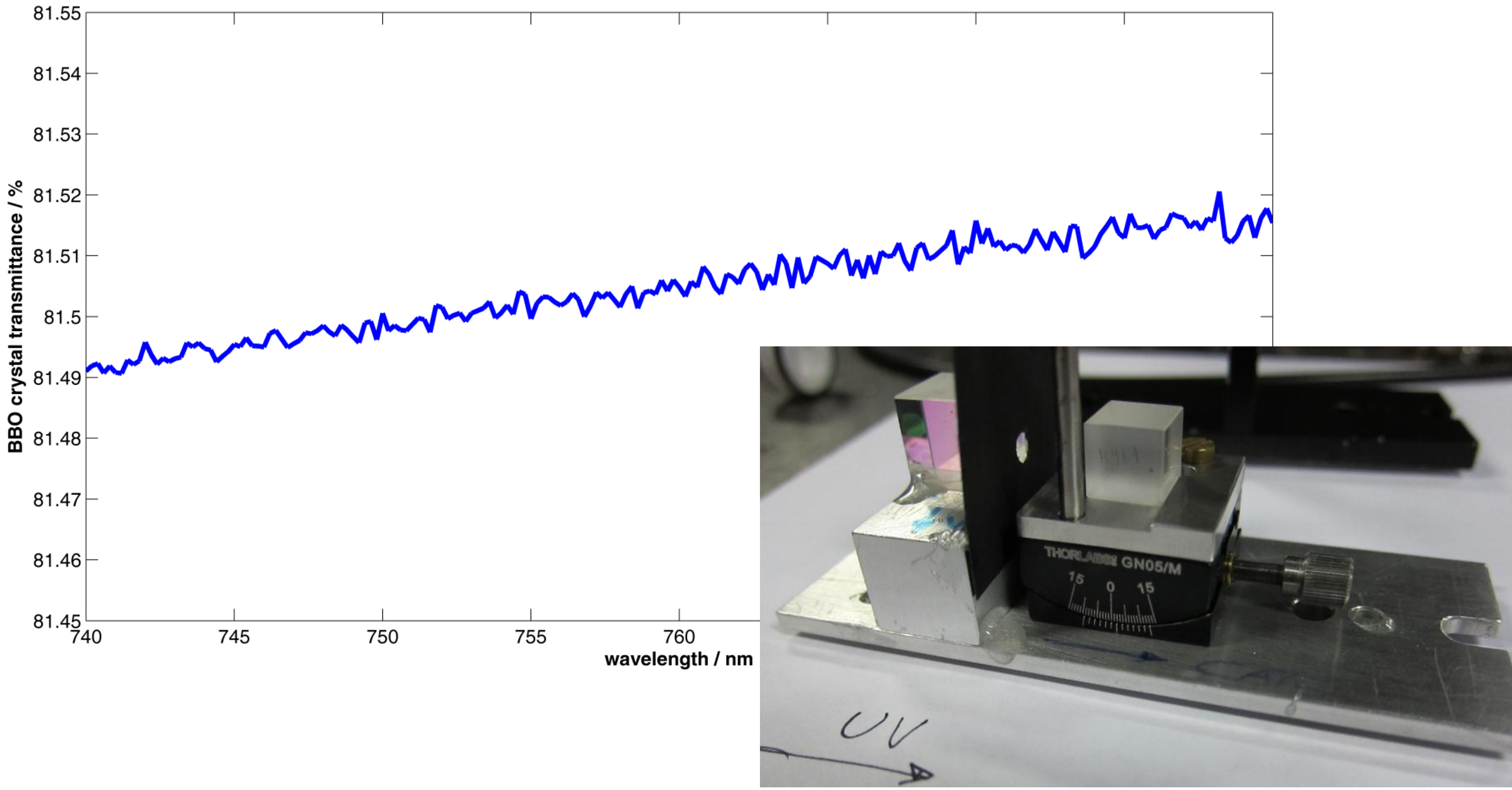
Collecting all correlated photon pairs …



Spectral transmittance of the DUT filter



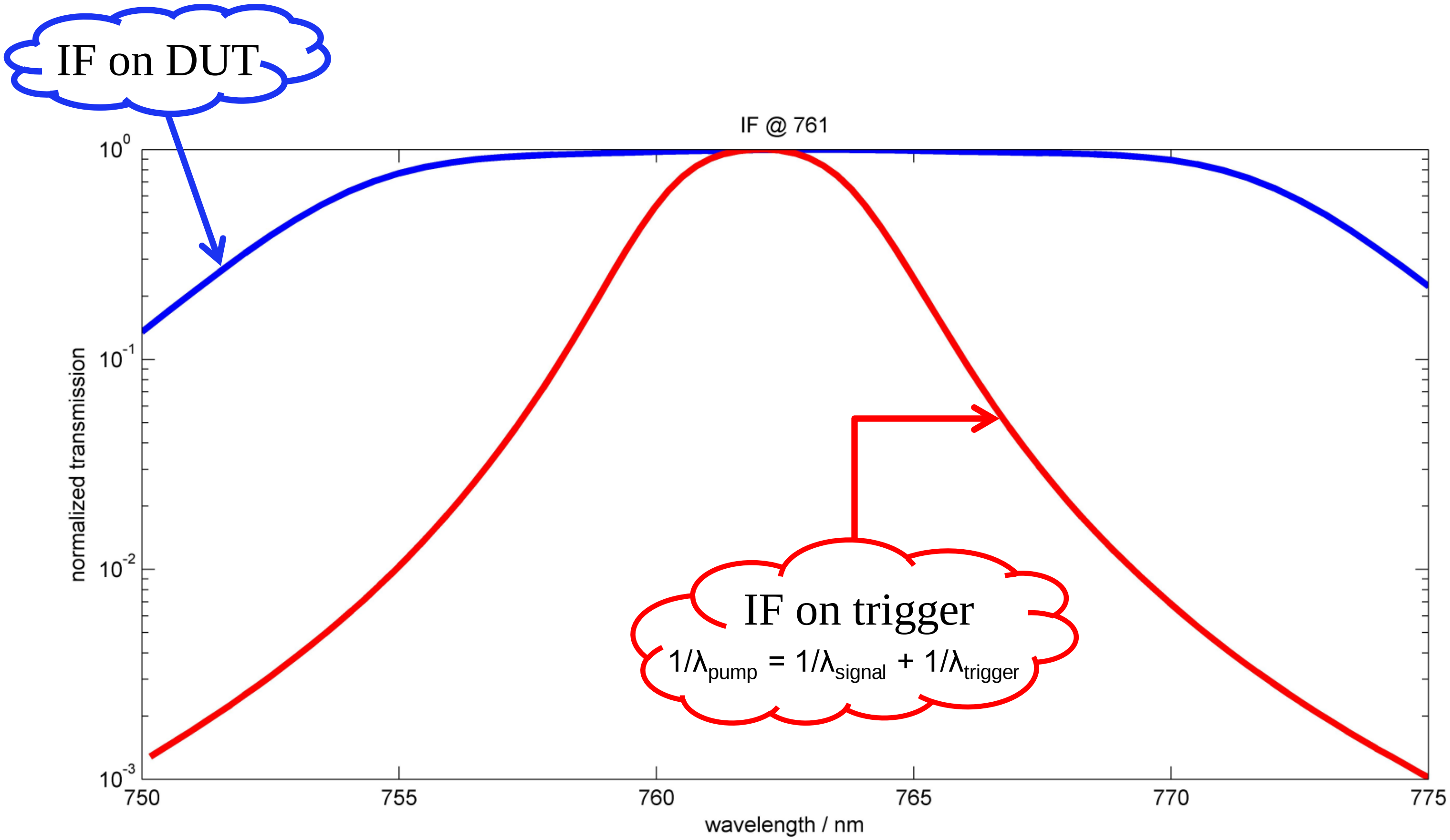
Spectral transmittance of the BBO crystal



Converting Metrology to the counting of natural units: photons

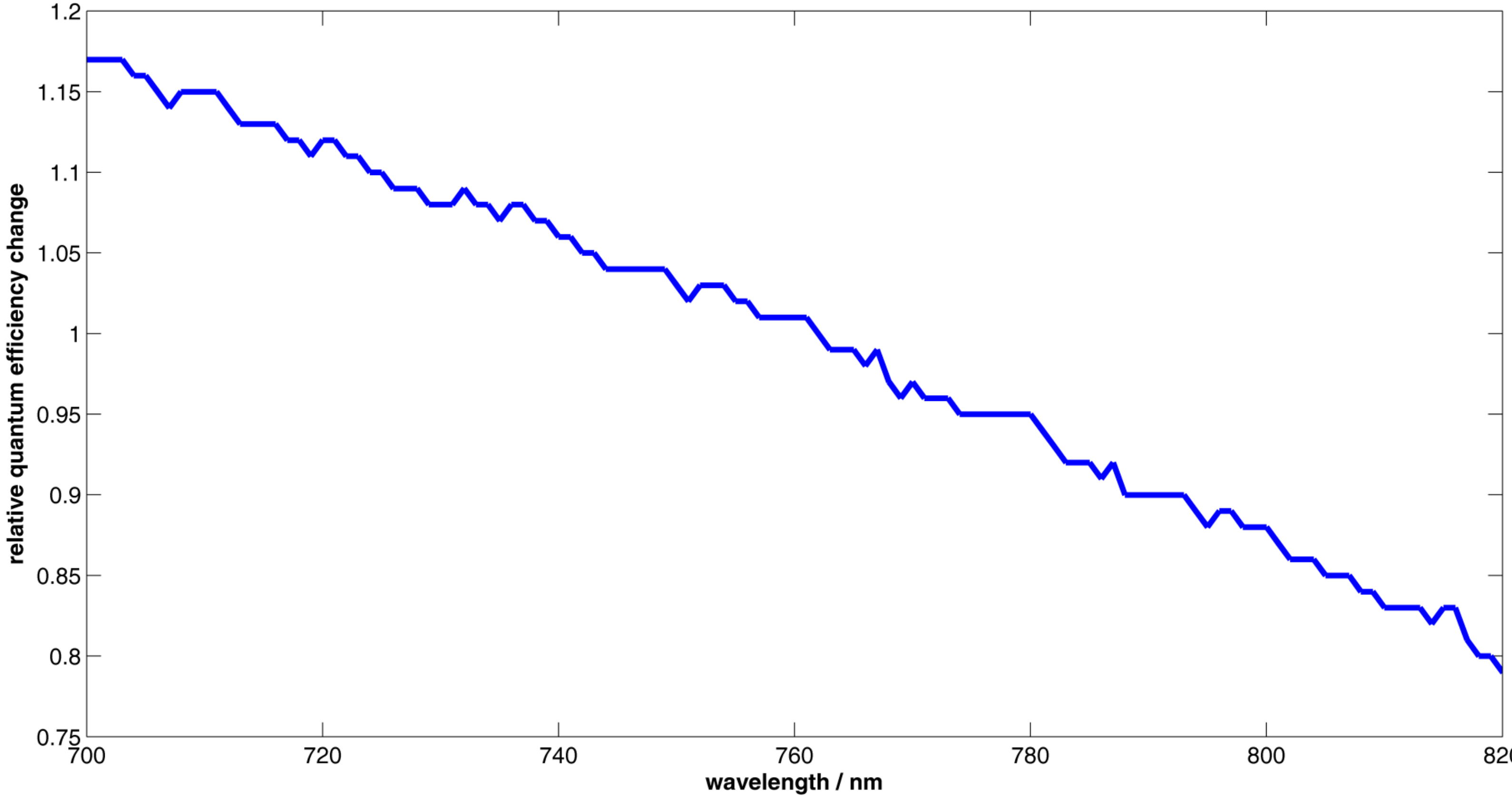
qu

Spectral selection of coincidence events

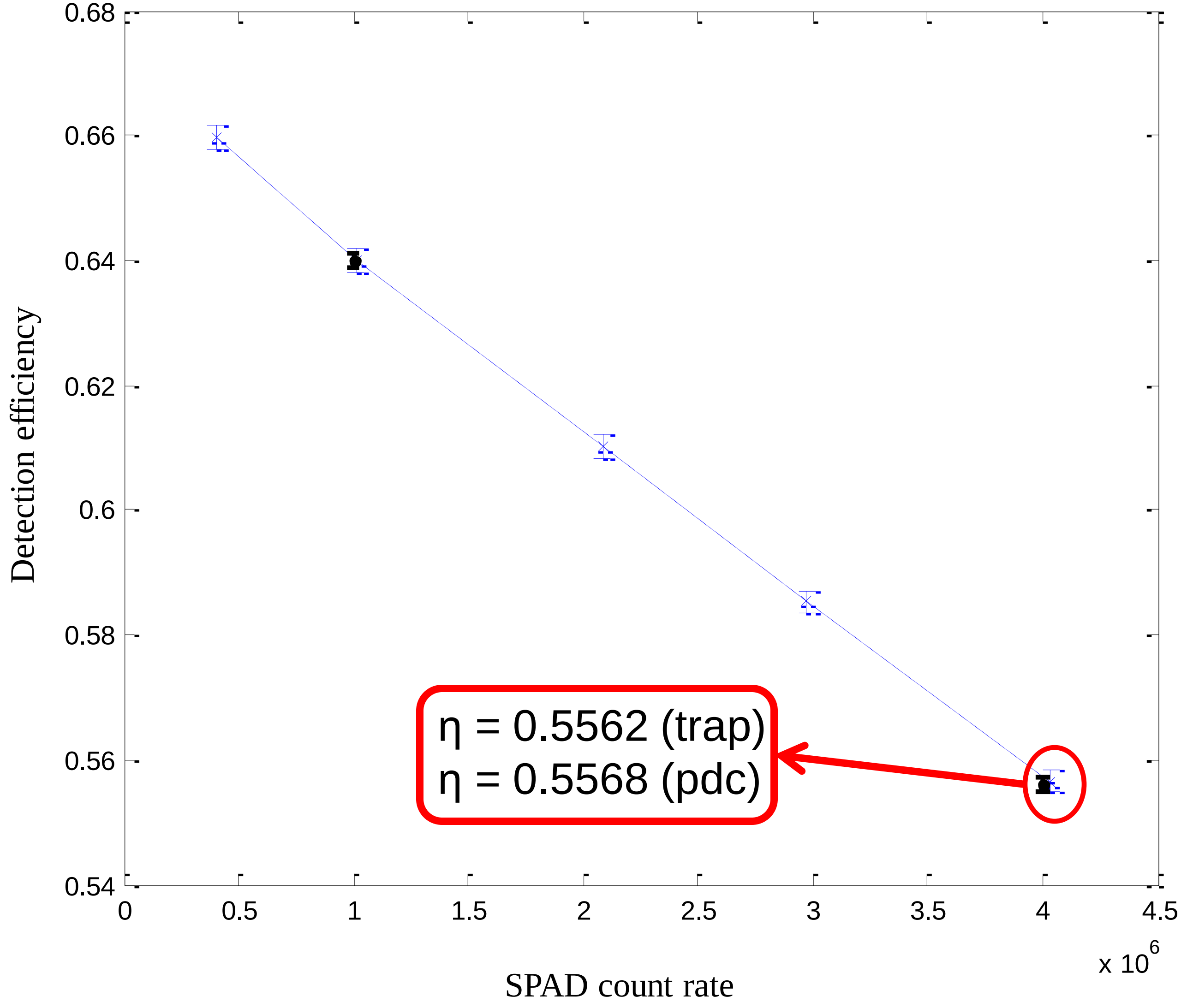


Converting Metrology to the counting of natural units: photons

Wavelength calibration mismatch



Converting Metrology to the counting of natural units: photons

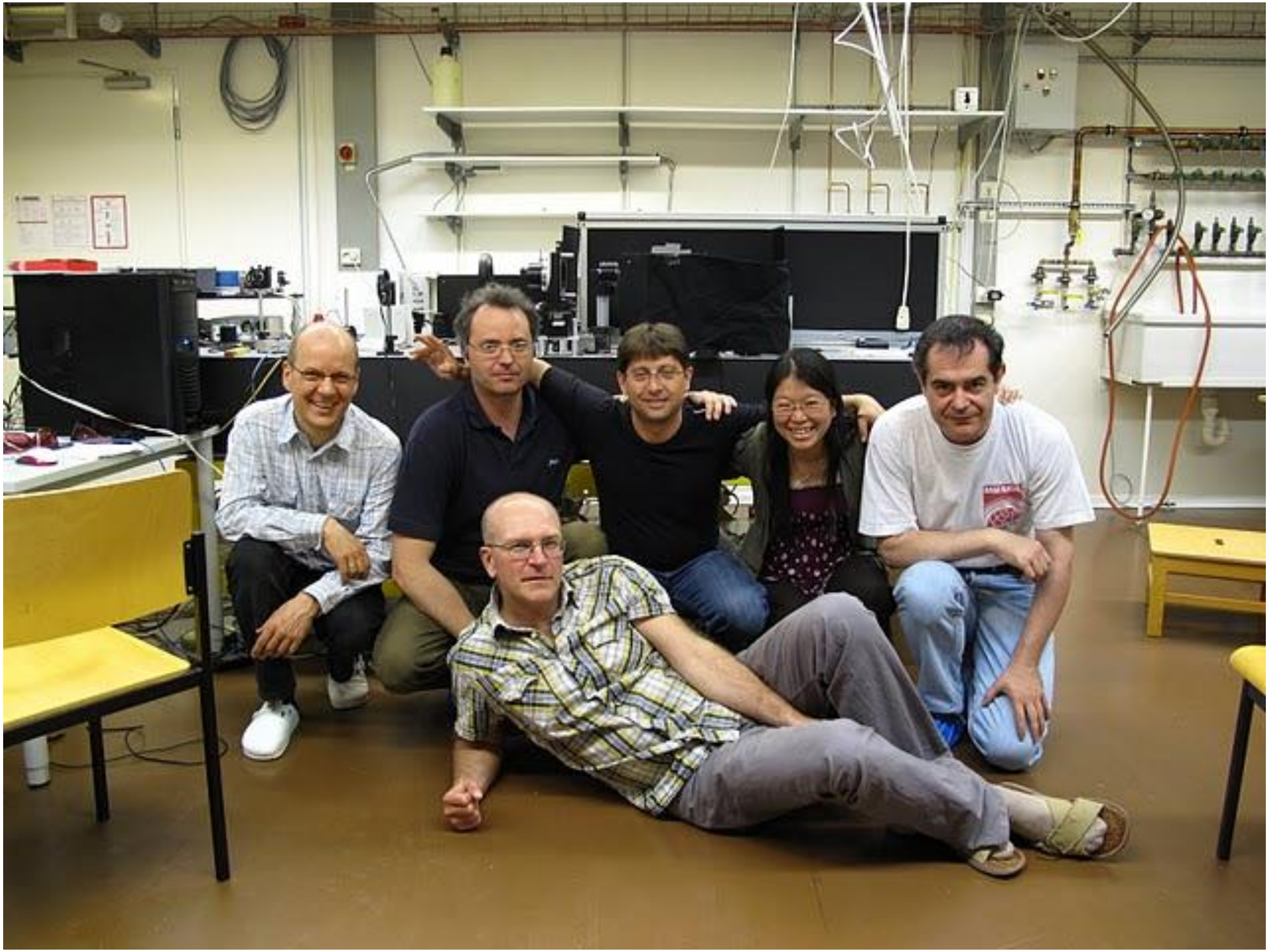


Converting Metrology to the counting of natural units: photons

qu

Calibration with correlated photon pairs uncertainty budget

Component	**Relative uncertainty (k = 1)**
Counting	0.060 %
DUT interferential filter loss	0.050 %
BBO crystal loss	0.080 %
Wavelength mismatch	0.020 %
Overall uncertainty	0.114 %



SPAD vs TRAP comparison @ 1 pW (PTB/Berlin, june 2010):

Lutz Werner(**PTB**); Geiland Porrovecchio, Marek Smid (**CMI**); Jessica Cheung (**NPL**); Giorgio Brida (**INRiM**), Toomas Kubarseep (**Metrosert**)

JRP IND 06 MIQC

Metrology for Industrial Quantum Communications

MIQC is a metrology framework that will foster development and market take up of quantum communication technologies aimed at achieving maximum impact for the European industry in this area.

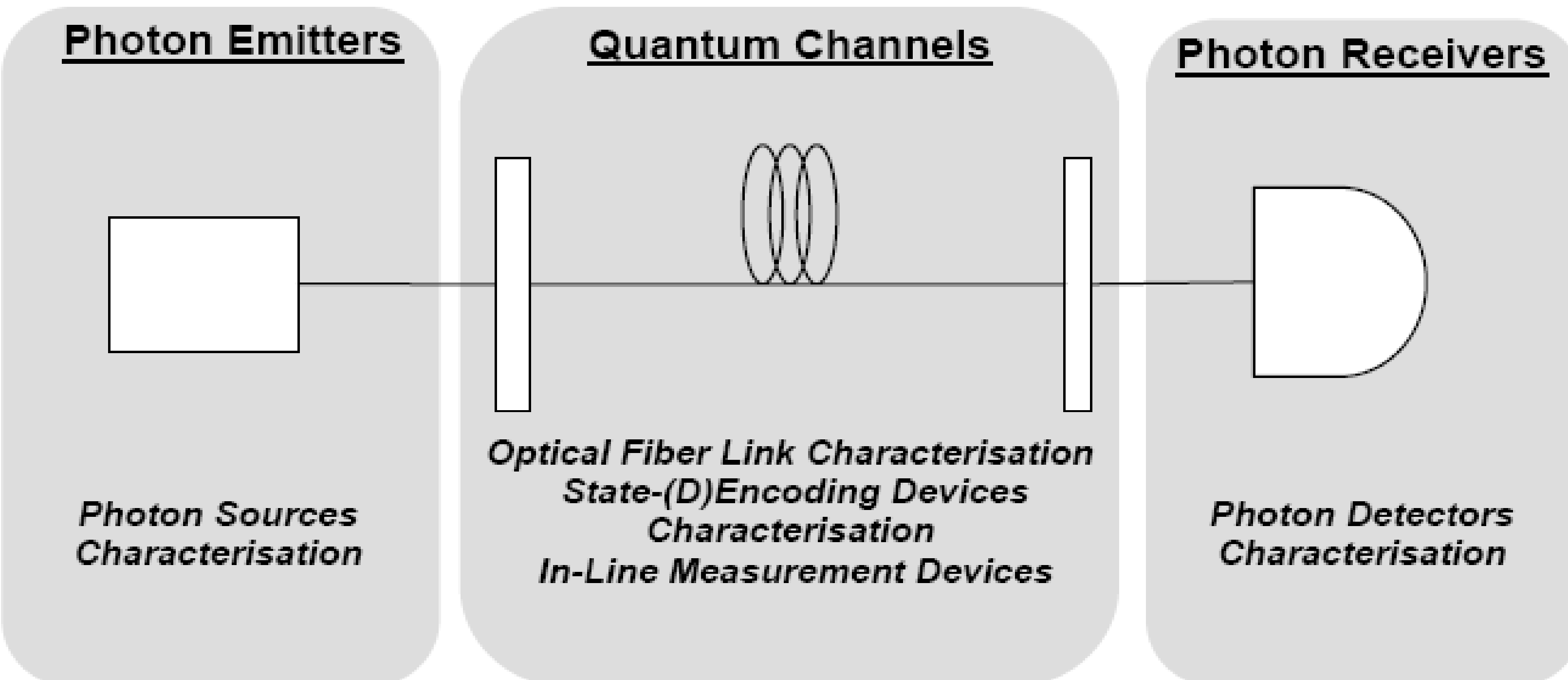
MIQC is focussed on Quantum Key Distribution technologies, the most advanced towards practical application.

Quantum key distribution is a way of sending cryptographic keys with absolute security. It does this by exploiting the ability to encode photons with quantum states that are noticeably disturbed if an eavesdropper is present in the channel.

QKD kits are available commercially and in that respect the EU is a world lead. There are currently no independent measurement standards and definitions for this industry and MIQC aims to address this.

A QKD system is composed of

- quantum physical devices (quantum sources, quantum channels and quantum detectors) and
- classical (and well-established) information technology.


Photon Emitters
Quantum Channels
Photon Receivers
Photon Sources Characterisation
Optical Fiber Link Characterisation
State-(D)Encoding Devices Characterisation
In-Line Measurement Devices
Photon Detectors Characterisation