# Self-Consistent, Absolute Calibration Technique for Photon-Number-Resolving Detectors

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ISTITUTO NAZIONALE DI RICERCA METROLOGICA

# The Group

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# Motivation

**Klyshko's Absolute Technique for Quantum Efficiency Measurement [Exploiting heralded single photon source based on PDC]**

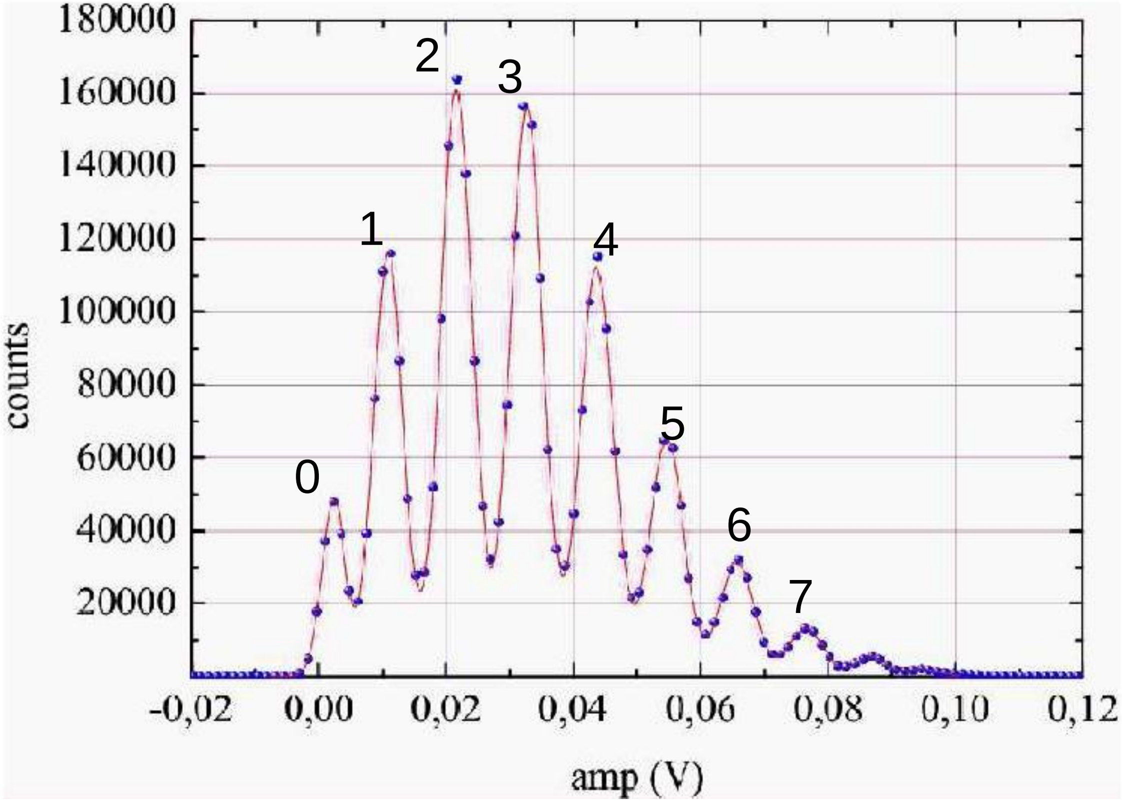
- **Provide an efficient measurement solution in photon counting regime**
- **Well developed for "click/non-click" detector**
- **Extension to the calibration of PNR detector straightforward**

**Drawback: Klyshko's technique is not able to exploit the PNR ability of the detector**

**Proposal and demonstration of an absolute technique for measuring quantum efficiency, based on an heralded single photon source, but exploiting the PNR ability of the detector**

# Theory (1)

**Typical output of a PNR detector: an histogram of the relative frequency of detection events of a certain number of photons.**



# Theory (2)

$P(i)$ **Probability of observing *i* photons per heralding count in the presence of the heralded photon**

$\mathcal{P}(i)$ **Probability of observing *i* photons per heralding count in the absence of the heralded photon (i.e. of observing *i* "accidental" counts)**

$\gamma = \tau\eta$ **"Total" Quantum Efficiency of the PNR detector (accounting both for losses and for proper Quantum Efficiency)**

$\xi$ **Probability of having a True Heralding Count (not due to stray-light or dark counts)**

# Theory (3)

**The probability of observing *0* photons per heralding count in the presence of the heralded photon is the sum of two terms:**

**1)(the probability of non-detection of the heralded photons ) X (the probability of having no accidental counts in the presence of a true heralding count)**

**2)(the probability of having no accidental count in the presence of a heralding count due to stray light or dark counts)**

$$P(0) = \xi[(1-\gamma)\mathcal{P}(0)] + (1-\xi)\mathcal{P}(0)$$

$\gamma = \tau\eta$ **"Total" Quantum Efficiency of the PNR detector**

$\xi$ **Probability of having a True Heralding Count**

# Theory (4)

The probability of observing *i* photons per heralding count in the presence of the heralded photon is the sum of three terms:

1)the joint probability of non-detection of the heralded photons and the probability of having *i* accidental counts

2)the joint probability of detection of the heralded photons and the probability having *i -1* accidental counts both in the presence of a true heralding count

3)the probability of having *i* accidental count in the presenc[e of] dark counts

$$P(i) = \xi[(1-\gamma)\mathcal{P}(i) + \gamma\mathcal{P}(i-1)] + (1-\xi)\mathcal{P}(i)$$

# Theory (5)

**The probability of observing *i* photons per heralding count in the presence of the heralded photon:**

$$P(i) = \xi[(1-\gamma)\mathcal{P}(i) + \gamma\mathcal{P}(i-1)] + (1-\xi)\mathcal{P}(i)$$

**From each $P(i)$ a value of "Total" Quantum Efficiency can be estimated (*Consistency Test*)**

**From the probability of *0*** →

$$\gamma_0 = \frac{\mathcal{P}(0) - P(0)}{\xi\mathcal{P}(0)}$$

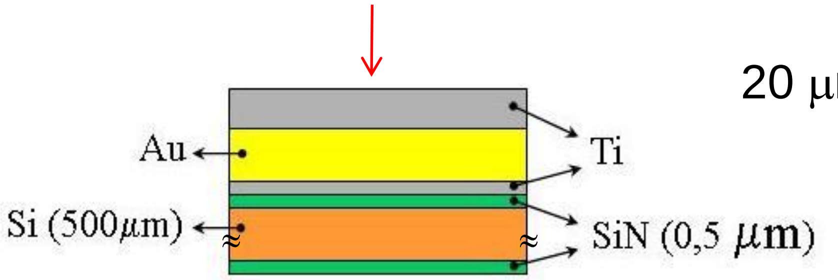
**From the probability of *i*** →

$$\gamma_i = \frac{P(i) - \mathcal{P}(i)}{\xi(\mathcal{P}(i-1) - \mathcal{P}(i))}$$

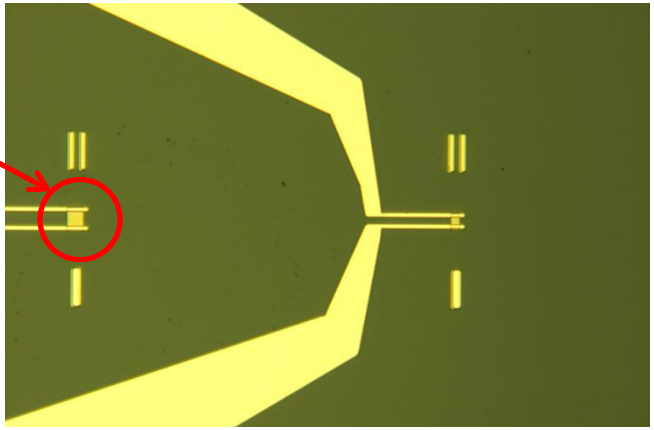
**NOTE: Same Hp.s of the Klyshko's Technique**

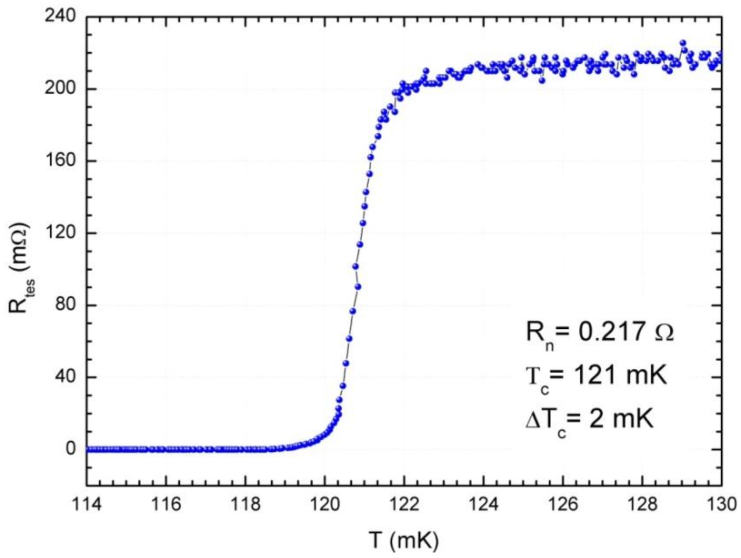
# The PNR detector cosidered is a …

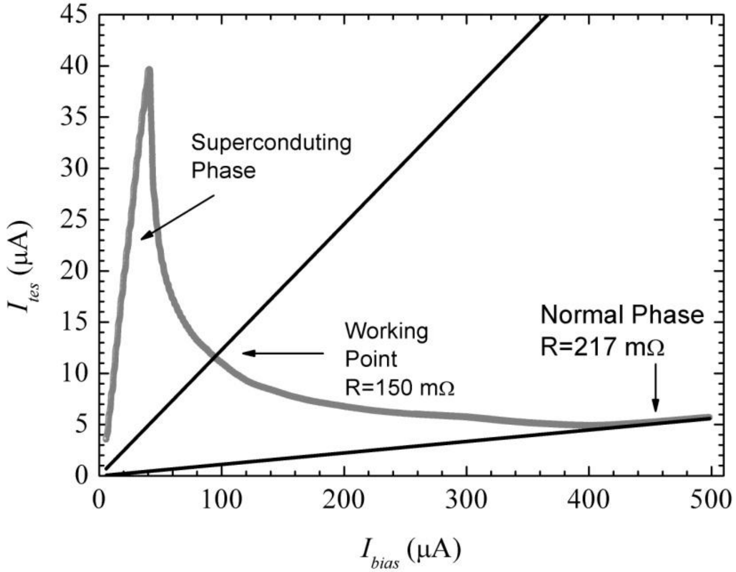
# TES (1)



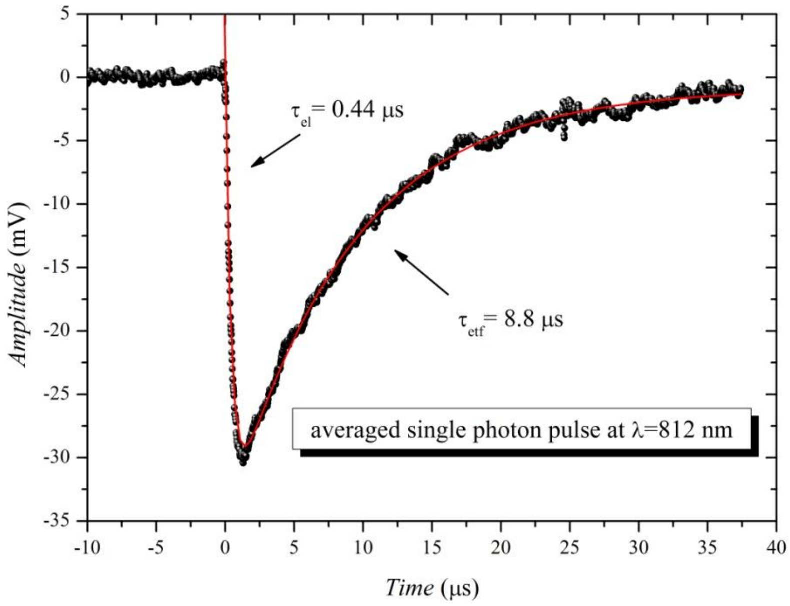

20 μm x 20 μm



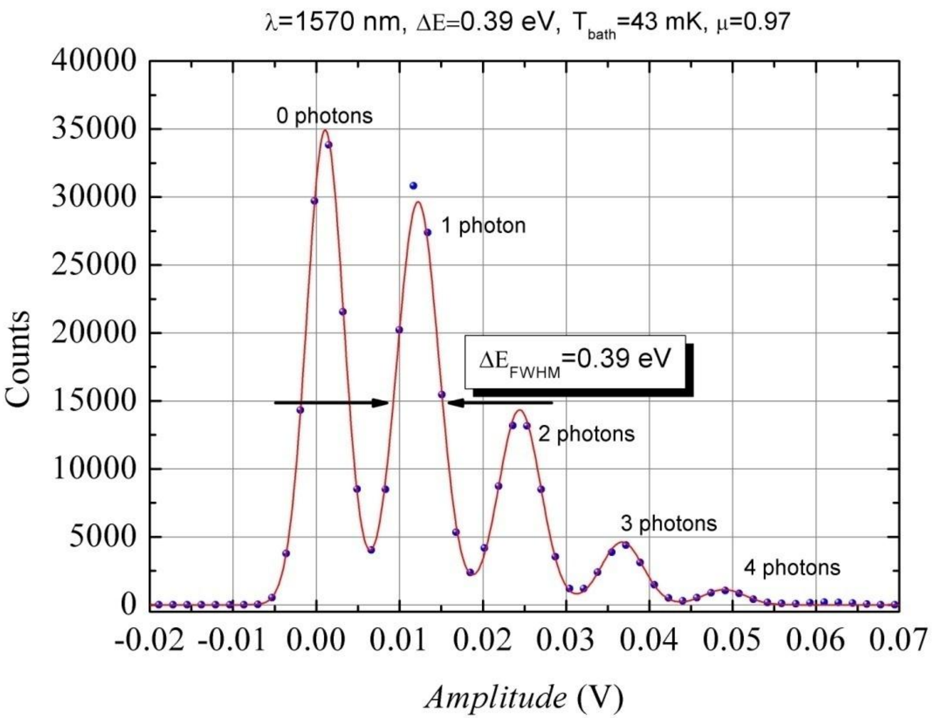


# TES (2)




Histogram



# Experimental Setup (1)

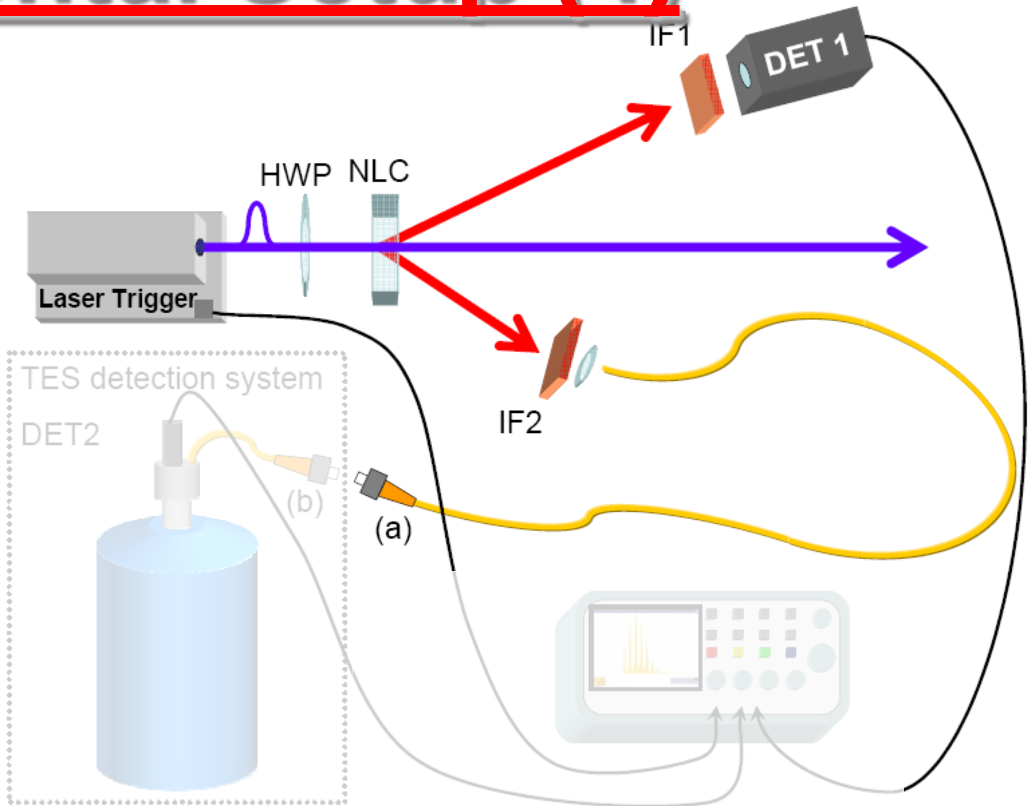
## Heralded Single-Photon Source

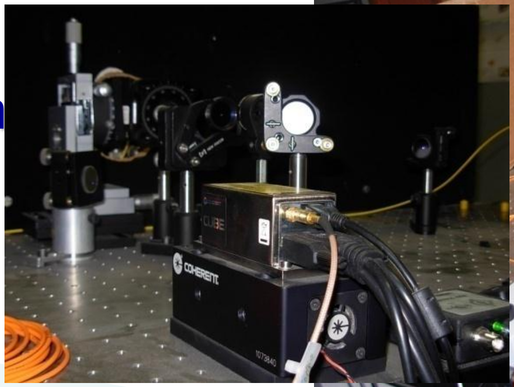
**Pulsed Pump @ 406 nm**
**20 KHz, pulse 80 ns long**
**(□*TES Deadtime and Jitter*)**

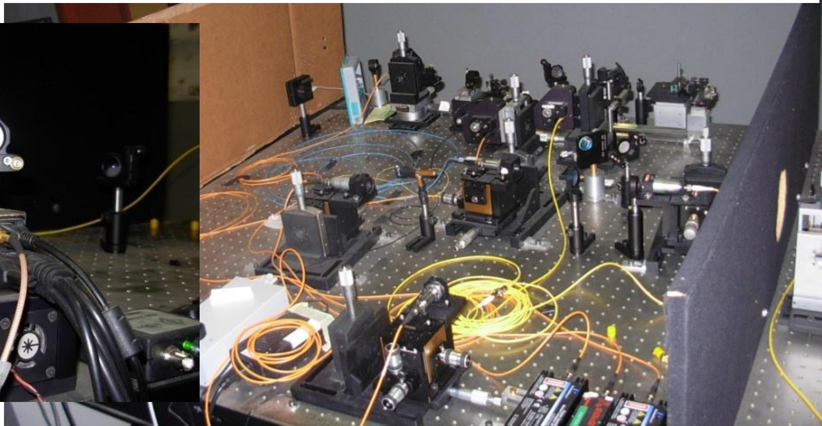
**Non-collinear Degenerate PDC (@ 812 nm)**

**Heralding Ch.:** IF1 FWHM= 1nm
Det1: SPCM-AQR-14
True HC $\xi = 0.98793 \pm 0.00007$

**Heralded Ch.:** IF2 FWHM=10nm
Optical and Coupling losses: $\tau$





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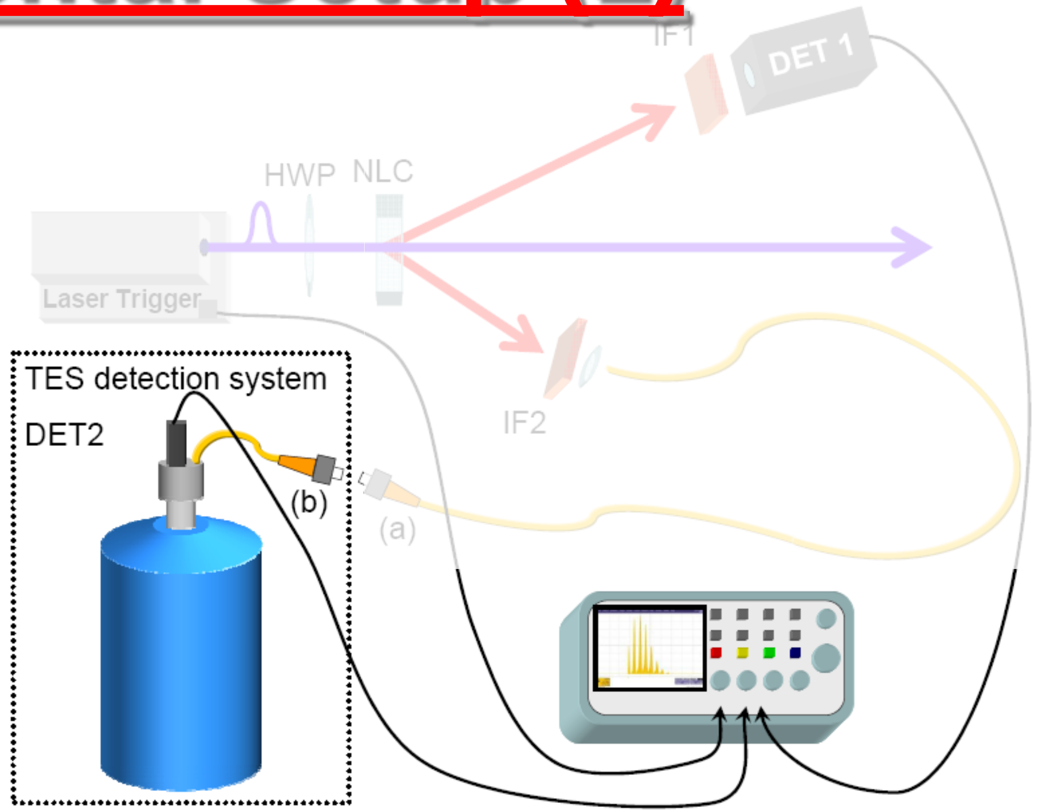
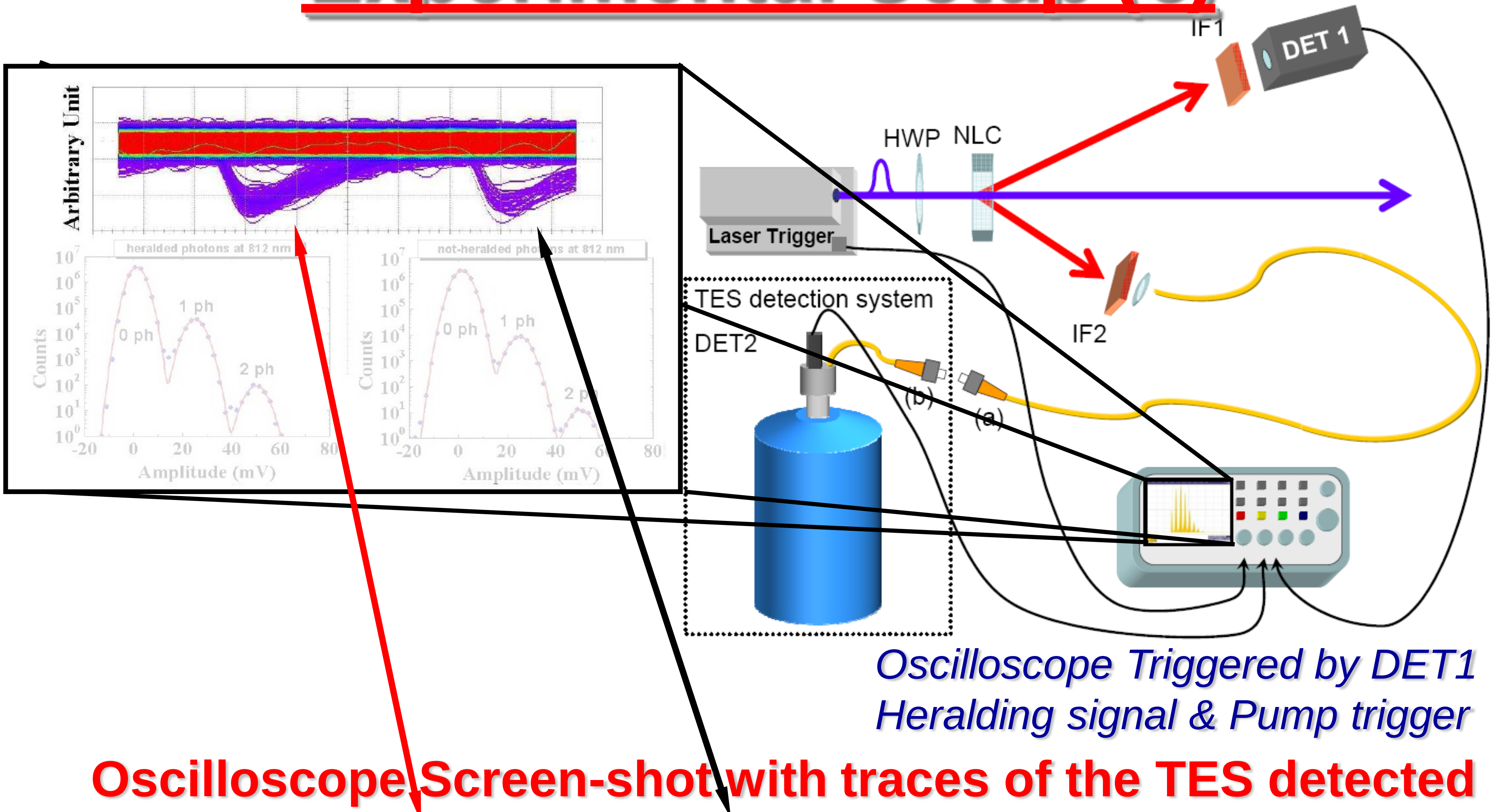
# Experimental Setup (2)

$\eta$ **Quantum Efficiency of the TES detector: TES detector is the system from the fibre end (b) to the sensitive area (*as this represents the real detector for applications*)**



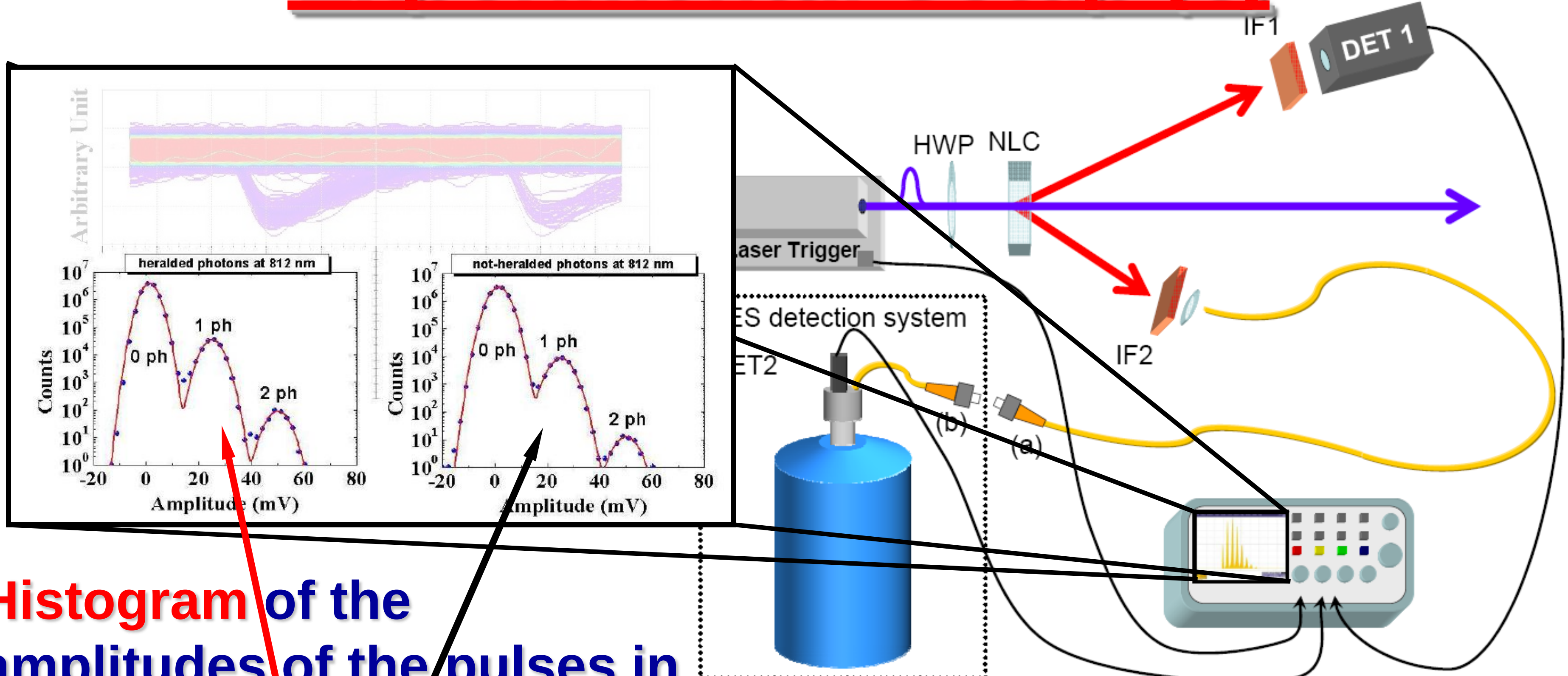

# Experimental Setup (3)




*Oscilloscope Triggered by DET1*
*Heralding signal & Pump trigger*

**Oscilloscope Screen-shot with traces of the TES detected events in the presence (absence) of heralded photon**

# Experimental Setup (3)




**Histogram of the amplitudes of the pulses in the presence (absence) of heralding signals.** *(Gaussian fits)*

**Number of counted events corresponding to $i$ detected photons in the presence $C(i)$ (absence $\mathcal{C}(i)$)**

$$P(i) = C(i) / \sum_i C(i)$$
$$\mathcal{P}(i) = \mathcal{C}(i) / \sum_i \mathcal{C}(i)$$

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# Results

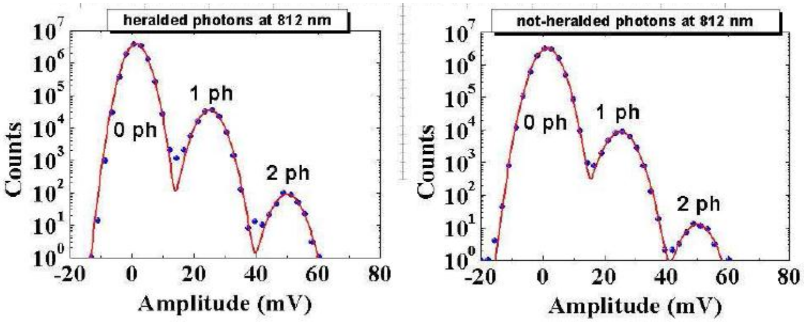
## Measured "Total" Quantum Efficiency

$$\gamma_0 = (0.709 \pm 0.003)\%$$
$$\gamma_1 = (0.709 \pm 0.003)\%$$
$$\gamma_2 = (0.65 \pm 0.05)\%$$

*6 Repeated measurements, each 5 hr. long, corresponding to 5 $10^6$ HC*

*High uncertainty in $\gamma_2$ due to poor statistics*

*All the values are in agreement within the uncertainty ($k$=1)*



# Conclusion

## Comparison with the Klyshko's Method

$$\gamma_{Klyshko} = (0.707 \pm 0.003)\%$$

*Considering the PNR detector as a Click/Non-Click detector*

- The evaluation $\gamma$, instead of $\eta$ allows us a better comparison between the new technique, and the Klishko's one as the additional independent measurement of $\tau$ is common

- The results obtained with the two techniques are in agreement within the uncertainties

- Expected relative uncertainty after losses estimation: $10^{-3}$

# THE END

Thank you for your attention!

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