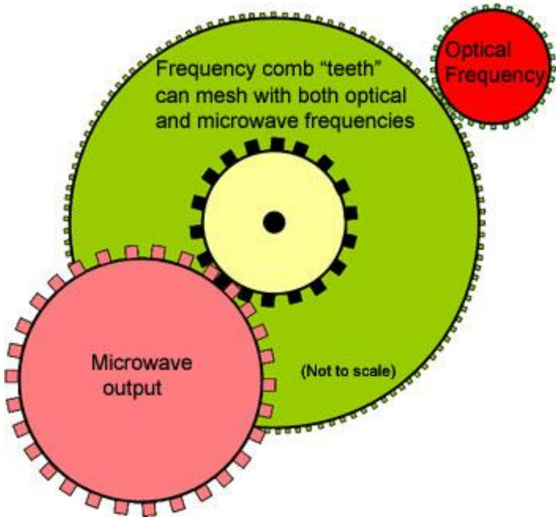
  

Advanced Radio Frequency Timing AppaRATus Applications in Material Science and Life Science

Amur Margaryan

This presentation is dedicated to:

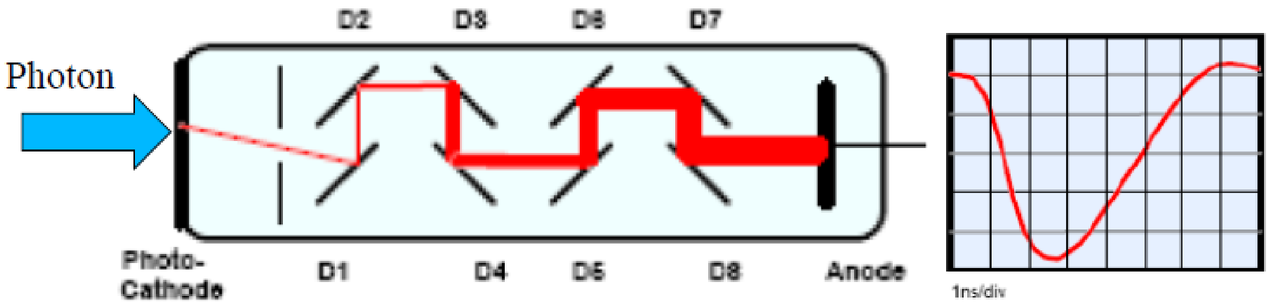
Vasili

friend and colleague

Content

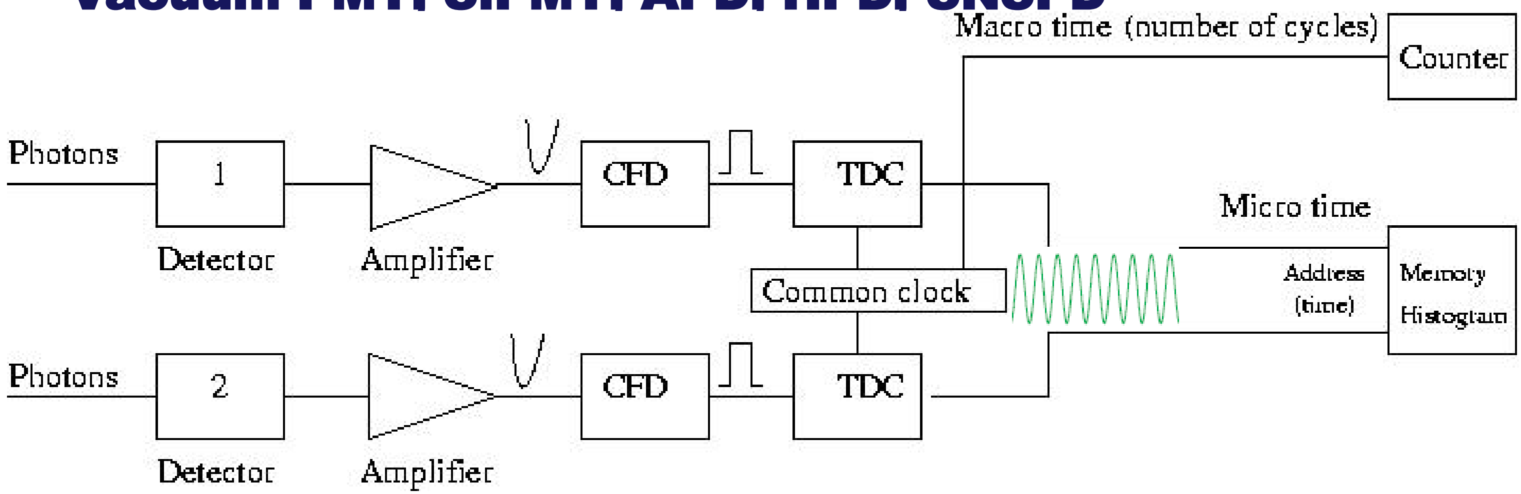
- Regular timing technique
- Streak Camera principle
- Advanced timing technique
- Radio frequency photomultiplier tube
- Test at CANDLE
- Possible applications in material science and life science

Regular Timing Technique



Gain ~ 10^6 -10^7
Fast ~ns output pulse

Vacuum PMT; SiPMT; APD; HPD, SNSPD



Schematic layout of the regular timing technique

Typical time resolution ~ few tens picoseconds

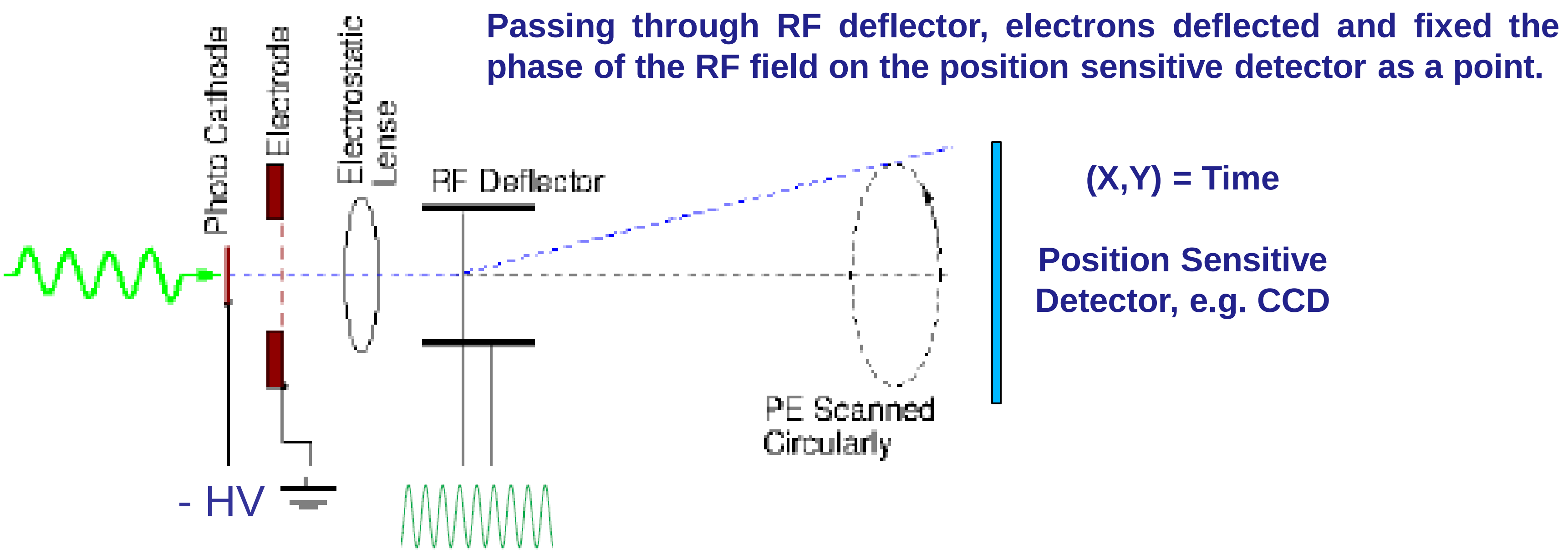
Time resolution limit ~ few picosecond with SNSPD

Rate ~ MHz

Radio Frequency Time Measuring Technique or Streak Principle

We go forward following Arthur Schawlow's advise

"Never measure anything but frequency" ⇨ "Never measure anything but phase"



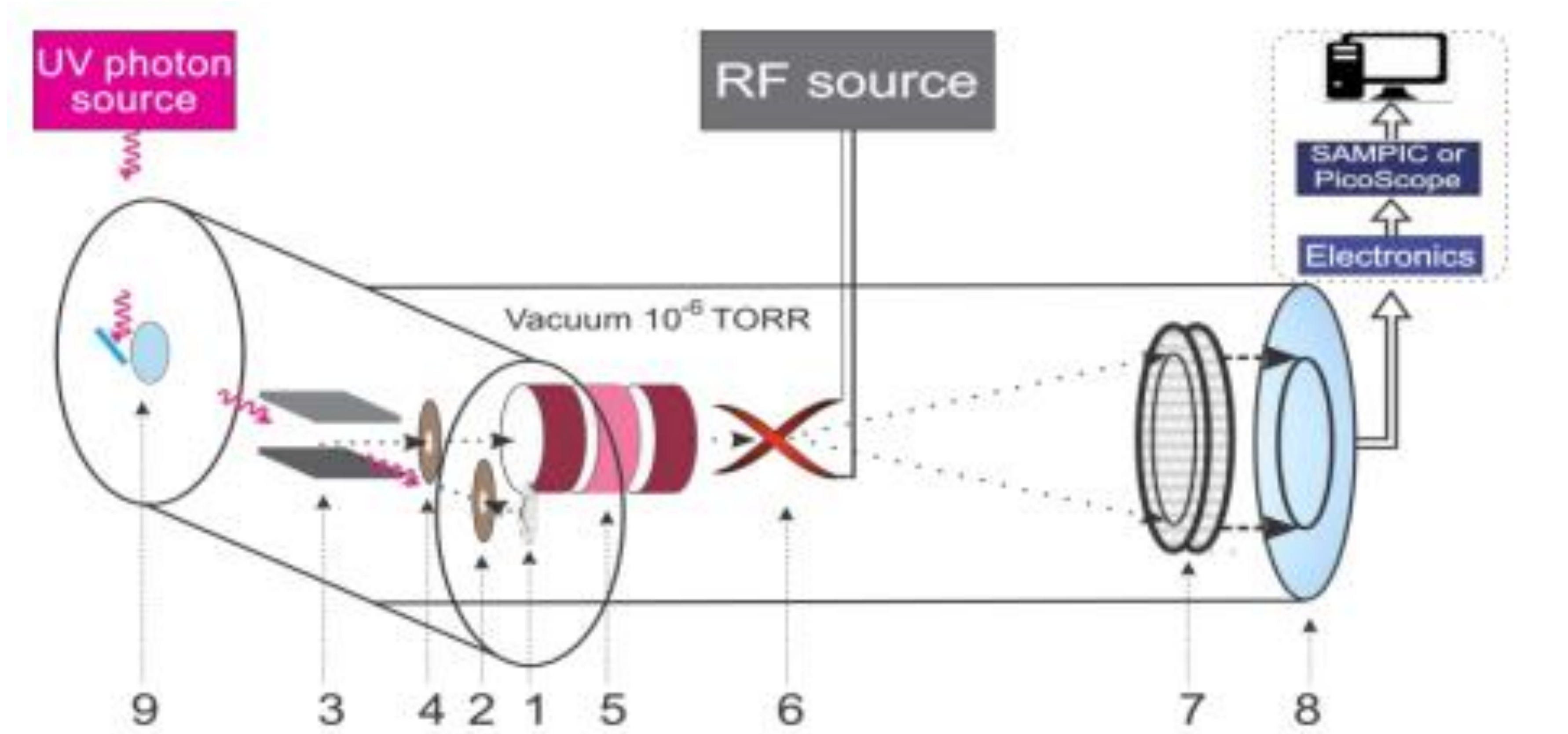
Schematic of the RF timing technique

Best time resolution: ≤ 1 picoseconds

Slow readout: few kHz

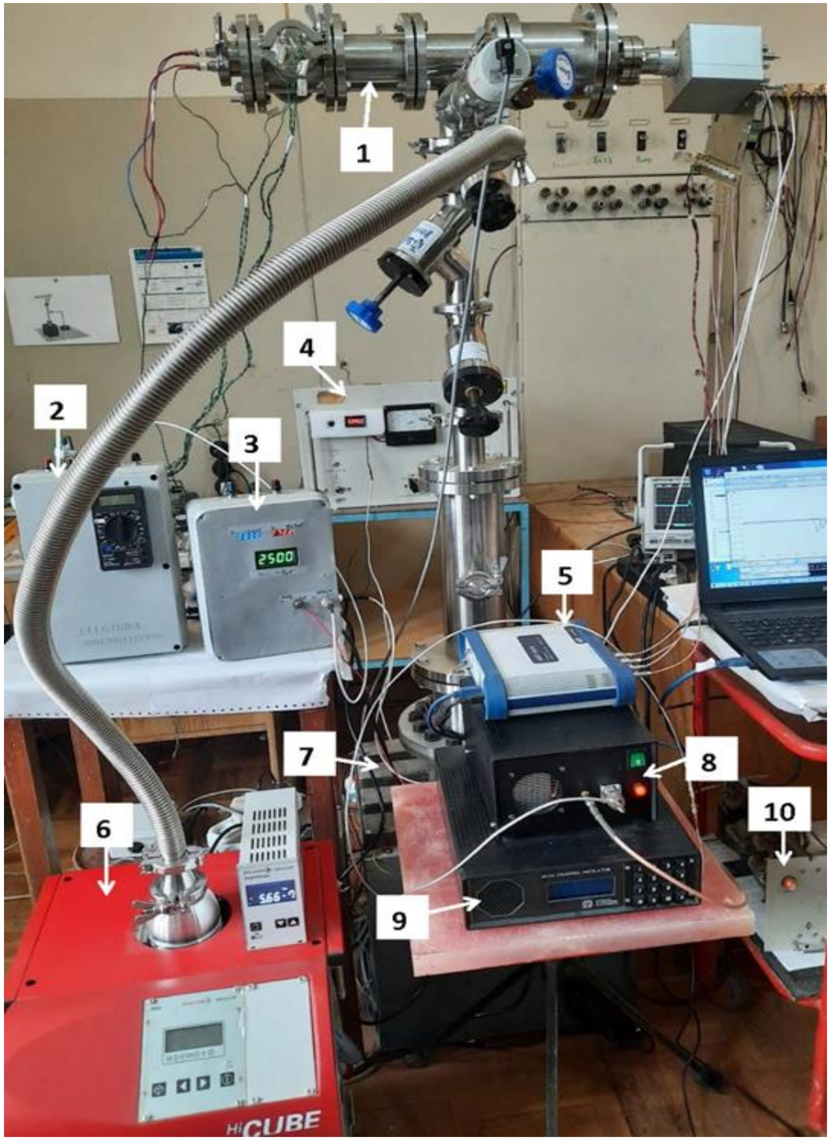
Advanced RF Timer of Electrons and Photons

Combines regular and RF timing techniques resulting High resolution, High rate and Highly stable timing technique for single electrons and photons



Schematic of a new RF timing technique: 1-photocathode; 2-accelererating electrode; 3-magnet; 4-collimator; 5-electrostatic lens; 6-RF deflector; 7-MCP detector; 8-delay line anode; 9-quartz window

General view of the Advanced RF Timer and Test Setup



1-RF Timer;

2-power supply for electrostatic lens;

3-HV power supply for accelerating electrode and MCP detector;

4-HV power supply for vacuum pump;

5-PICOSCOPE;

6-Pfeiffer vacuum pump;

7-“Titanium” vacuum pump;

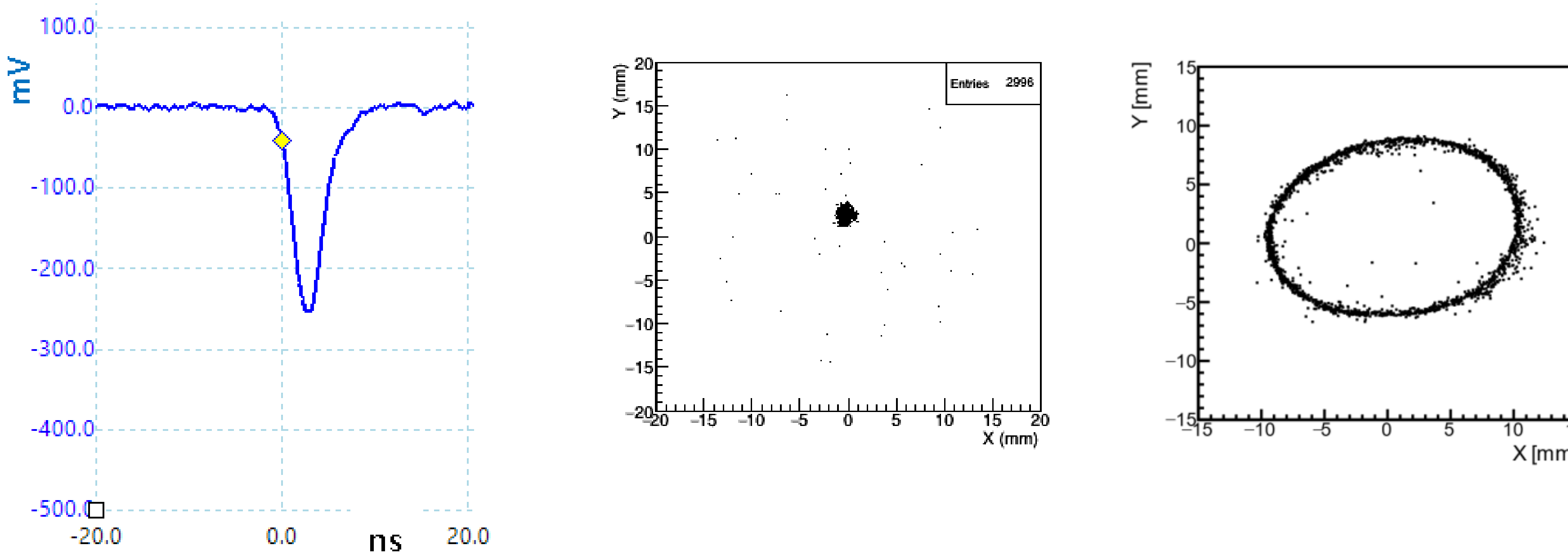
8-RF amplifier;

9-RF power source;

10-power supply for signal amplifiers.

Internal components of the RF Timer displayed in a previous slide are situated inside the high-vacuum prototype assembly (component 1) at the top of the photograph.

RF Timer: test with CW electrons and photons

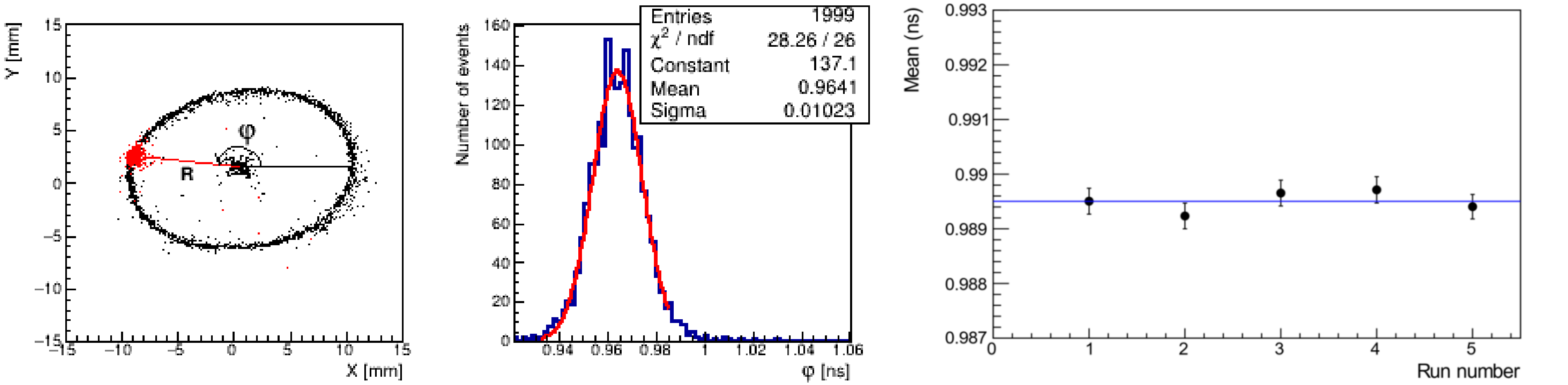


Left: Typical amplified signal from the DL anode;

Middle: 2D image of the focused electrons (RF is OFF). In streak cameras this RF-off mode of operation is known as focus mode;

Right: 2D image of the scanned electrons (RF is ON).

RF Timer: test with femtosecond pulsed laser



Left: 2D image of anode hit positions. The point in the center of the circle is image of electrons with RF turned OFF. The circle is an image of the scanned electrons when the 500 MHz RF is ON, but not synchronized with the laser. The red spot on the circle correspond to phase distributions of RF-synchronized photoelectrons for a fixed phase;
Middle: Distribution of phase (φ) of the scanned electrons in the case of RF synchronized laser;
Right: The mean values of sequentially measured time distributions in a one-hour period.

A new HIGH RESOLUTION (≤ 10 ps), HIGH RATE (~MHz) and HIGHLY STABLE (≤ 0.5 ps, FWHM) timing technique for single electrons and photons.

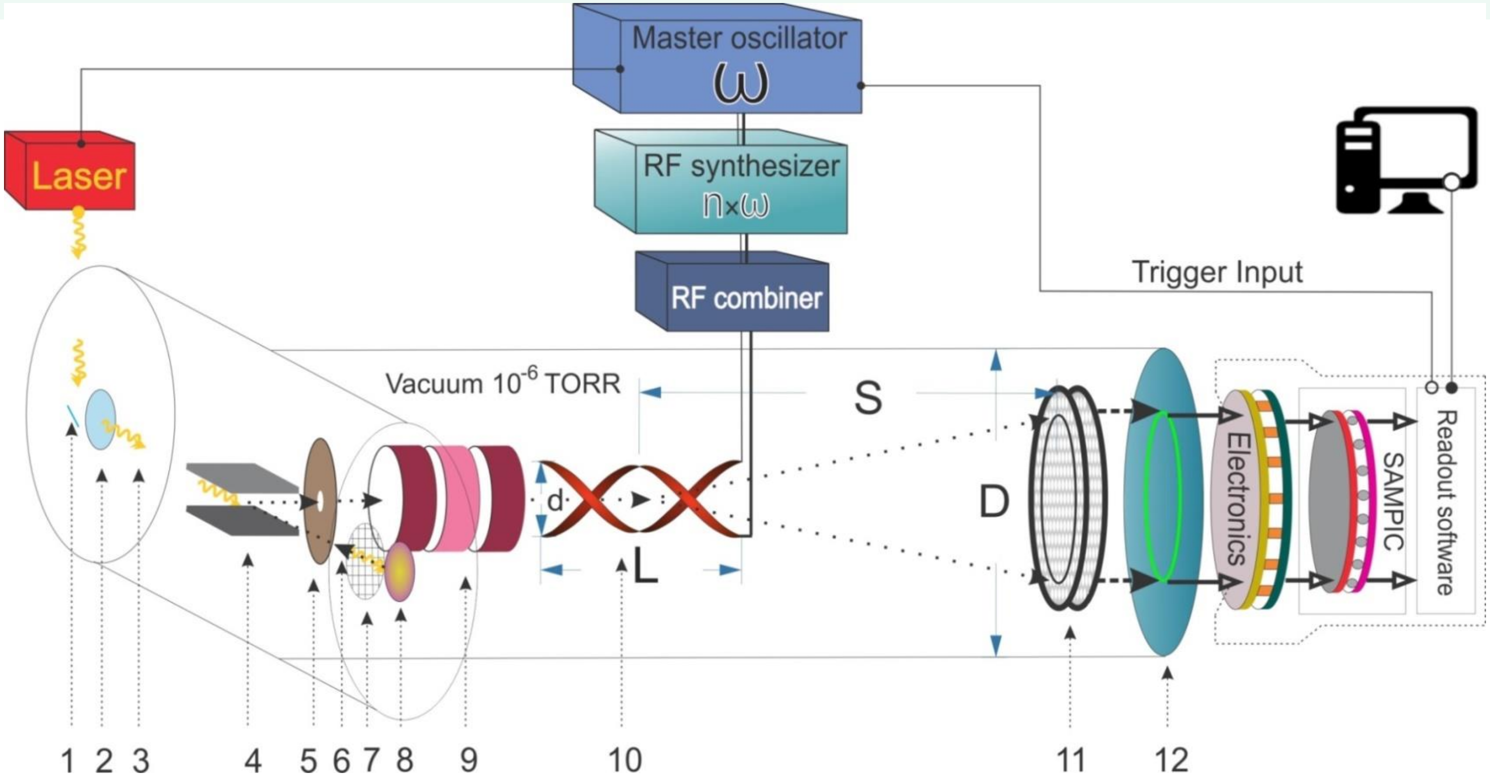
Electrons or photons detected and timed simultaneously in the same device.

arXiv:2203.09194

Nano-science: Study of quantum states with ps lifetimes

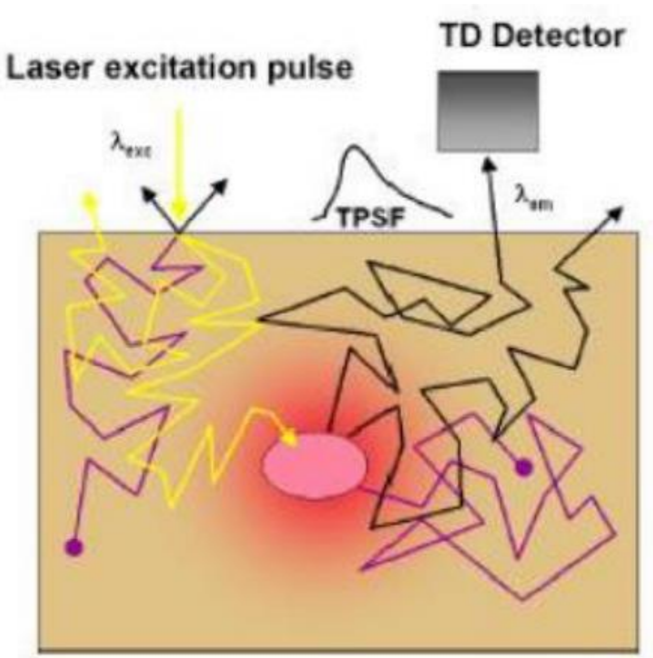
The lifetimes of quantum states in nanostructures upon photo-excitation dictates the practicality of these materials in many applications such as solar energy conversion, surface chemistry, photonics and optoelectronics.

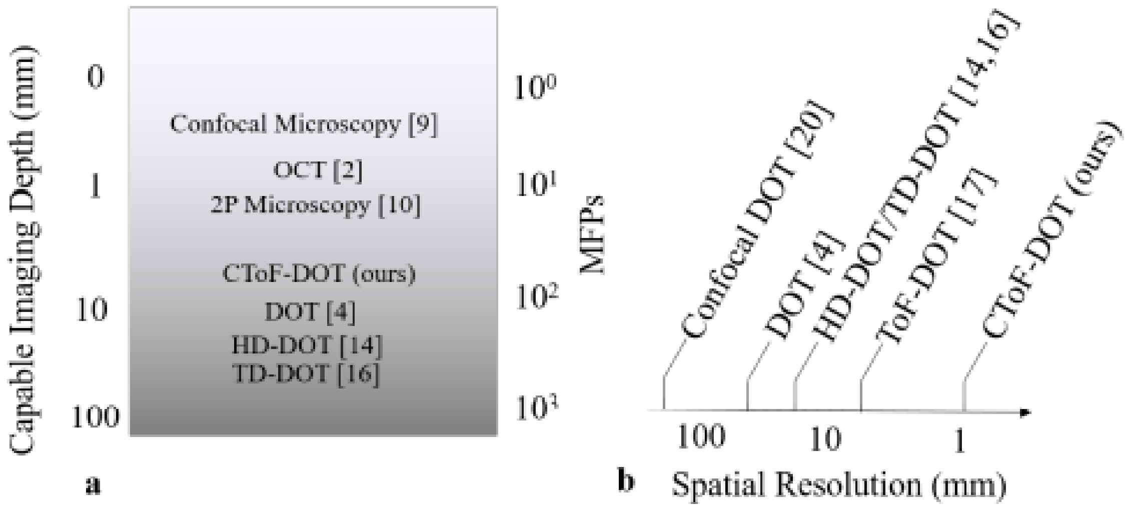
This picoseconds precision setup soon will operate at the Alikhanyan Lab



Schematic layout of the device: (1) mirror, (2) quartz-glass window, (3) incident photons, (4) permanent magnet, (5) collimator, (6) photoelectron, (7) electron transparent electrode, (8) graphene, (9) electrostatic lens, (10) RF deflector, (11) MCP detector, (12) position sensitive anode.

Time-of-Flight Diffuse Optical Tomography (TOF- DOT)





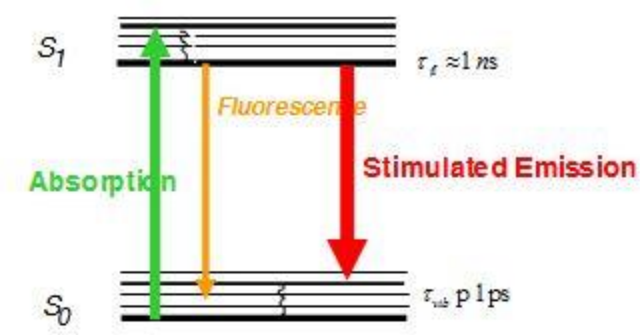
Photon propagation in tissue and principle of time-resolved detection of diffusely reflected light

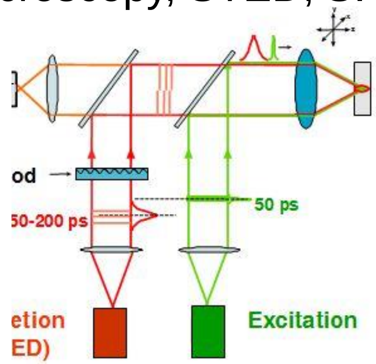
With SPAD (50 ps time-resolution) at a depth 7 mm absorption changes in a 1 mm^3 volume can be reconstructed. Andreas Hielscher et al., 2021

Synchronized laser and RFPMT as a single photon detector and timing system is ideally suited to TOF- DOT application

Potential STED Applications

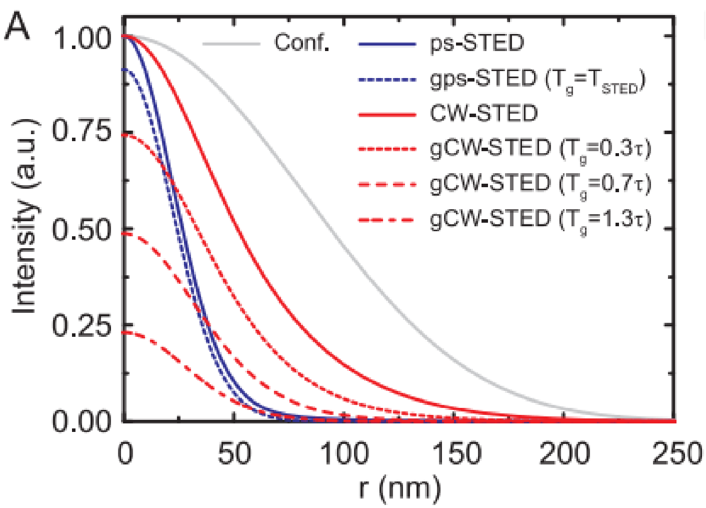
Stimulated Emission Depletion Microscopy, STED, S. W. Hell, Nobel lecture, 2014





In a STED microscope the region in which fluorescence markers can emit spontaneously shrinks with STED beam. It can be realized in different ways.

Jablonski diagram Schematic of the STED device



Observation volume in different STED Applications. G. Vicidomini et al., 2013

- All pulsed STED technique complex & expensive
- CW STED beam easier & cheaper than pulsed STED laser
- Gated CW STED optimum time coordinate $T_g > t_{fluor}$, SNR degraded.

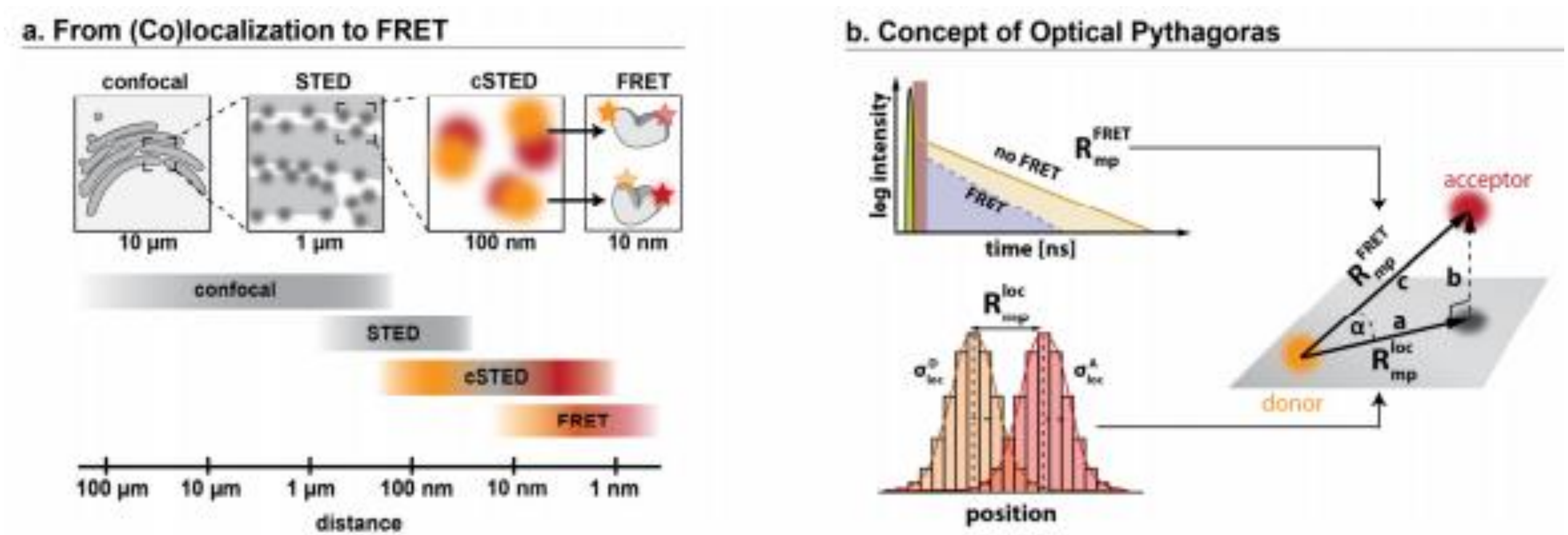
RF Nanoscope

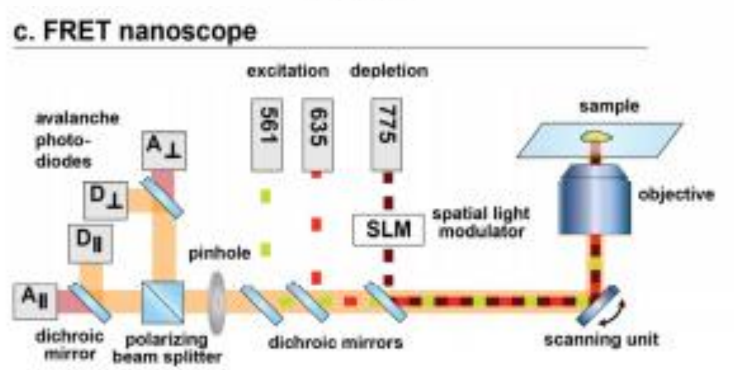
- RFPMT record all photons early and late photons
- RFPMT: ps photon intervals SPAD: 100’s ps on/off
- RFPMT: very fast data collection

Timing system of single photons based on the RF synchronized laser and RFPMT Is ideally suited practically to all STED applications

FRET Nanoscope

From the STED microscope to the FRET nanoscope



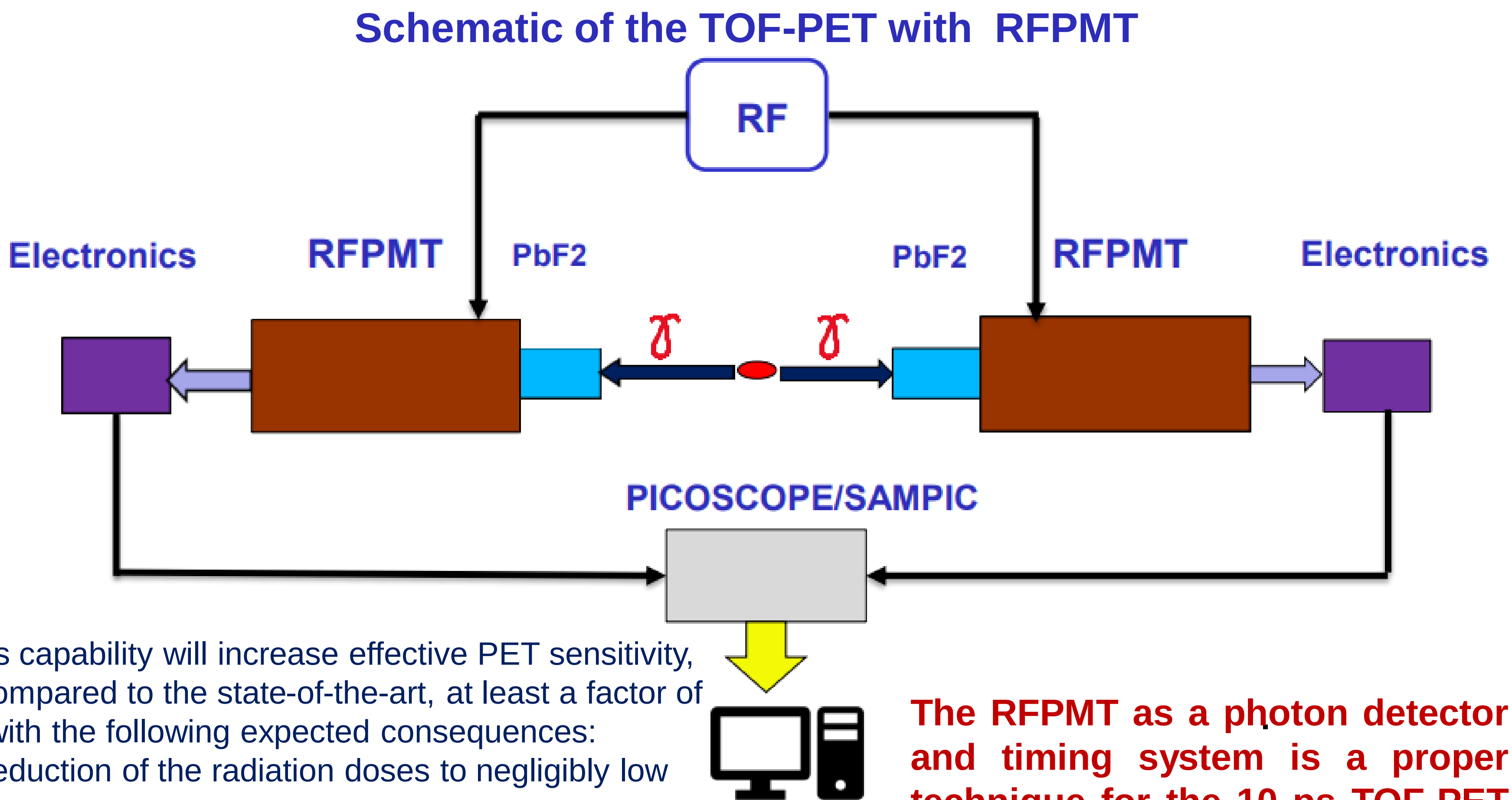


Depicted from JH Budde et al., arXiv: 2108.00024

Combination of the multiparameter (spectral, time-resolved, polarization, and intensity informations) STED microscopy with the FRET spectroscopy results into a FRET nanoscopy which enables seamless imaging of molecular assemblies with sub-nanometer resolution.

With a RFPMT, time measurement in the STED microscopy and FRET nanoscopy can be realized with a resolution better than 10 ps. Lifetimes can be measured with a precision better than 0.5 ps, FWHM.

10 ps TOF- PET Challenge



10 ps capability will increase effective PET sensitivity, as compared to the state-of-the-art, at least a factor of 16, with the following expected consequences:
1. Reduction of the radiation doses to negligibly low levels;
2. Reduction of the synthesized quantity of radiopharmaceutical needed for each examination, and thus of the relatively high cost currently associated with in-vivo molecular imaging procedures;
And more…

The RFPMT as a photon detector and timing system is a proper technique for the 10 ps TOF-PET challenge.

https://the10ps-challenge.org

Participants of test studies at CANDLE

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Thank you for your attention