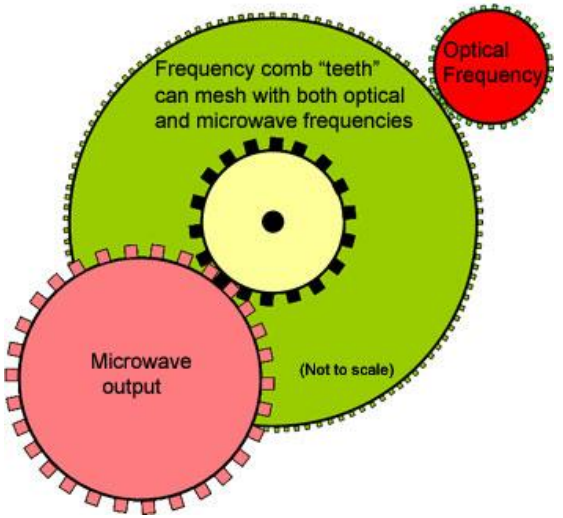
Zorats qarer - 10000 BC?

Zvartnots - 7 Century



Optical Frequency Comb - 21 Century

Advanced RF Timer of Electrons, Photons and Heavy Ions

Amur Margaryan
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Outline

- Introduction
- Regular timing technique
- RF timing technique
- Advanced RF timing technique
- Test studies
- Spiral scanning
- RFPMT
- RFPMT based Cherenkov detectors
- RF Timer, Spiral Scanning and TPX3Cam
- RFPMT and Optical Frequency Comb
- RF Timer based Heavy Ion Detector
- Applications
- Expectations

Introduction

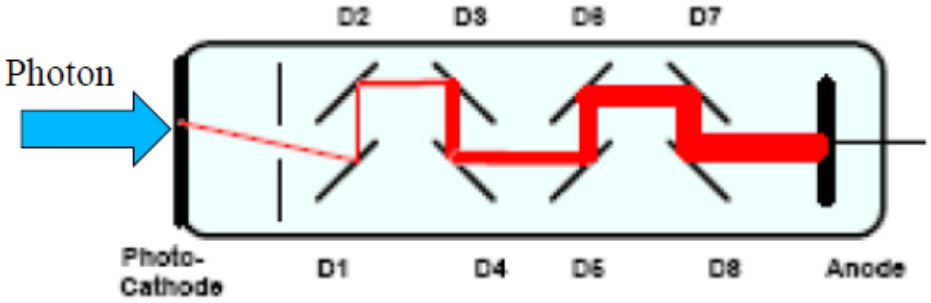
20th century was century of first-generation Quantum Technologies (lasers, nanosecond electronics, atomic clock….)

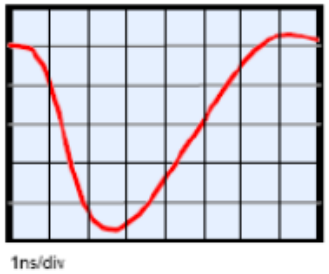
21st century will be century of second-generation Quantum Technologies: PHOTONICS, NANOTECHNOLOGIES

(more than 7 Nobel Prizes of this century is related to PHOTONICs)

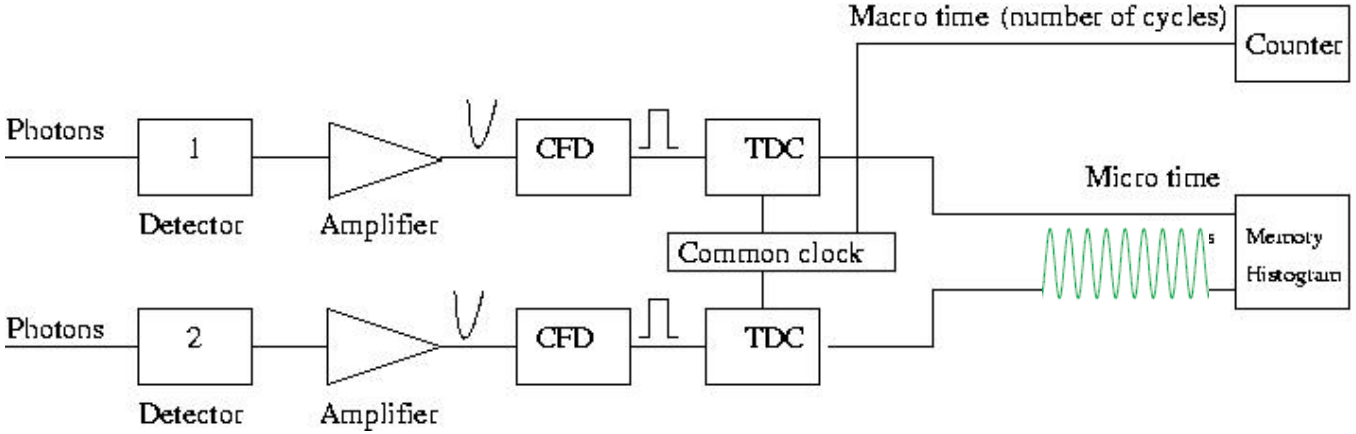
Single Photon Detection and Timing is a crucial part of PHOTONICS

Regular Timing Technique





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



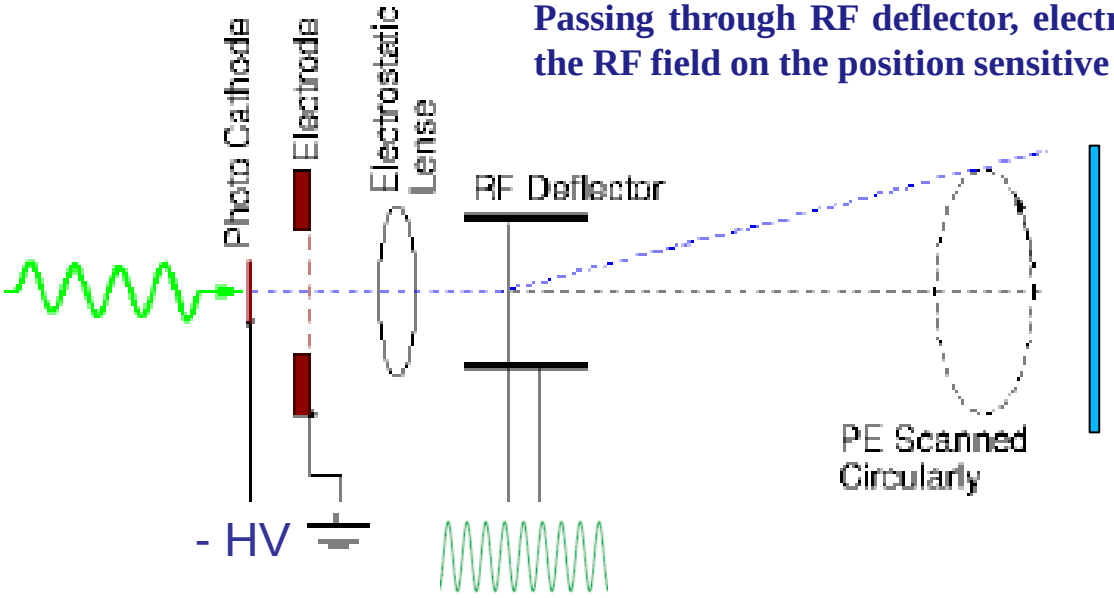
The timing jitter of the regular timing electronics is ~ 1 ps.

Rate ~ 1 MHz

Vacuum PMT; SiPMT; APD; HPD: typical time resolution ~ few tens ps

Single photon detection with less than 10 ps resolution is possible by means: SNSPDs- Superconducting Nanowire Single-Photon Detectors

Radio Frequency Time Measuring Technique or Streak Principle



Passing through RF deflector, electrons deflected and fixed the phase of the RF field on the position sensitive detector as a point.

Time ➡ (X,Y)

Position Sensitive Detector, e.g. CCD

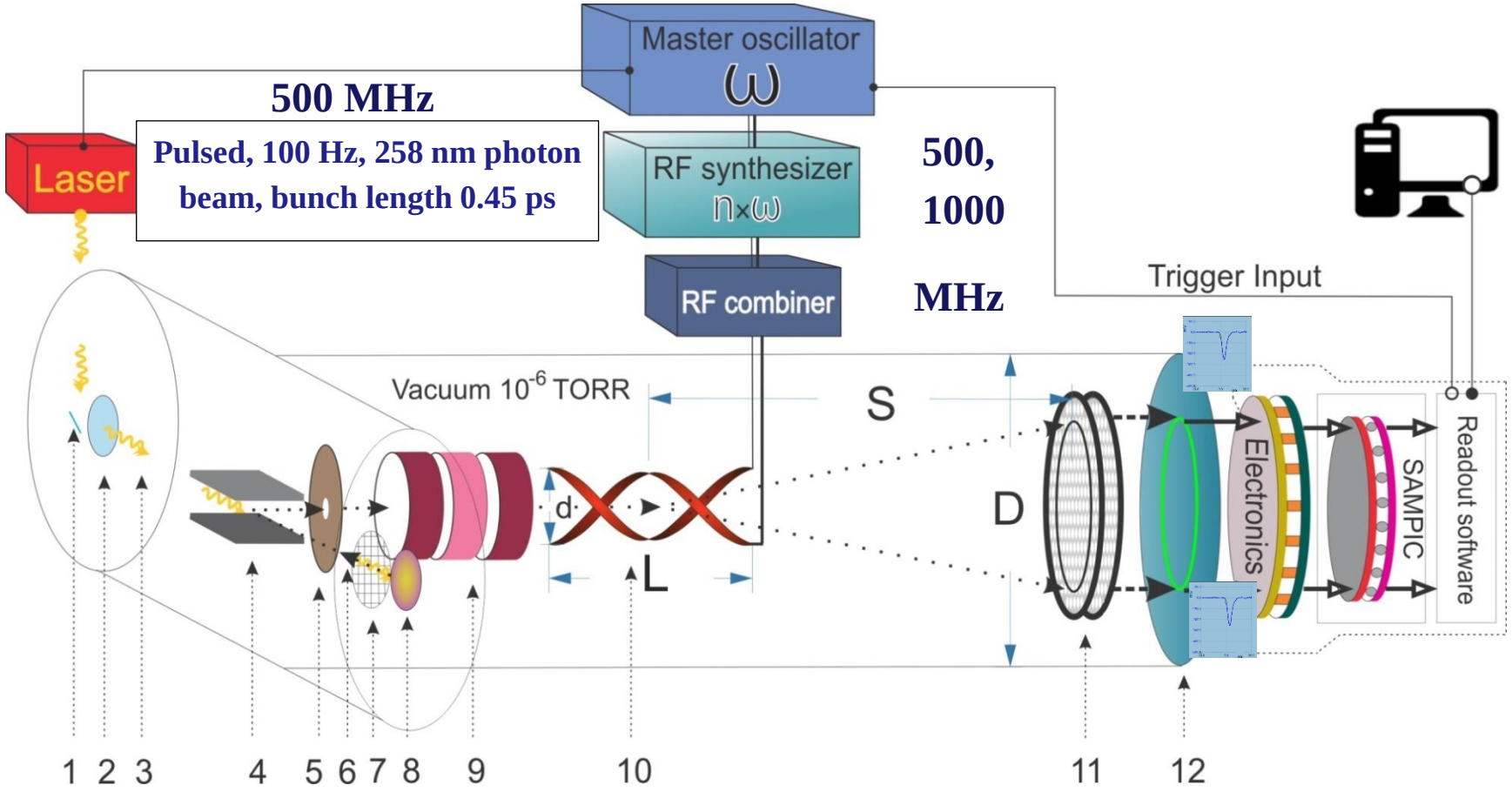
Slow readout few kHz

Schematic of the RF timing technique

Timing jitter of the commercial Streak Cameras ~ 0.2 ps

Theoretical prediction of the timing jitter is less than 0.1 ps

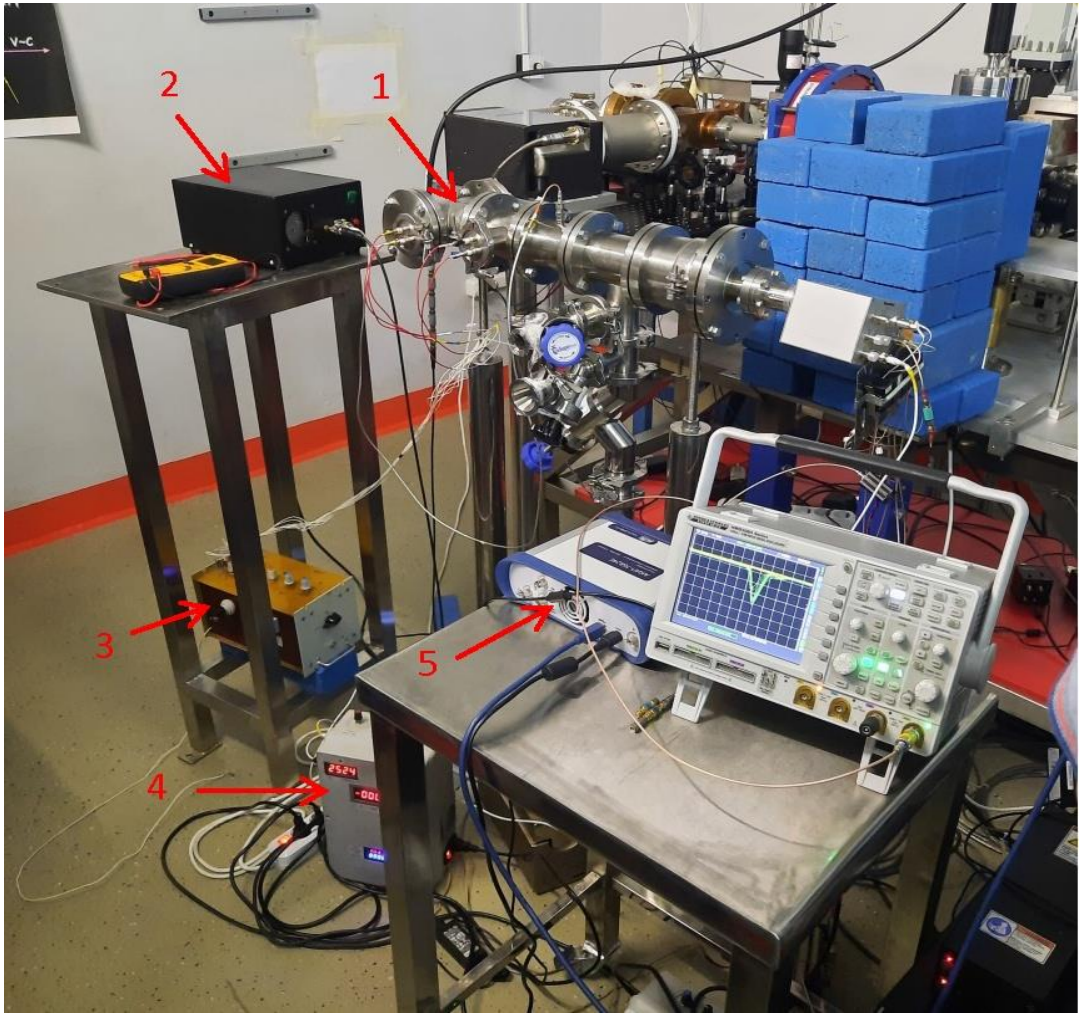
Advanced RF Timing Technique



Schematic of the technique

1-mirror; 2-quartz window; 3-ultrafast laser photon pulse; 4-magnet; 5-collimator; 6-photoelectron; 7-accelerating electrode; 8-photocathode; 9-electrostatic lens;10-RF deflector; 11-MCP detector; 12- delay line anode

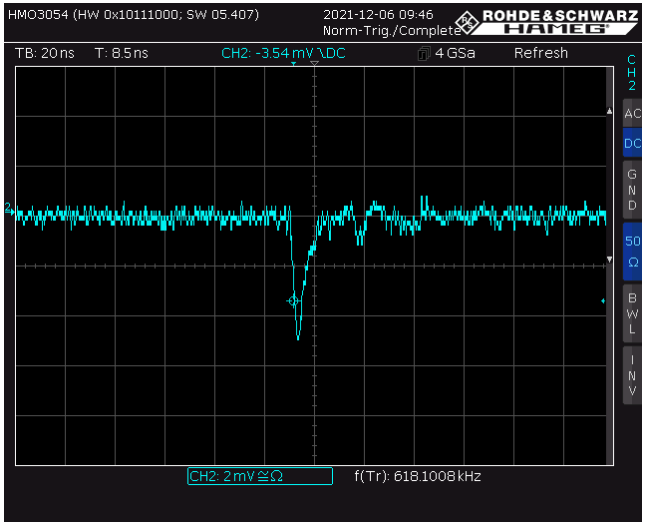
General view of the setup at the CANDLE Institute



1-RF Timer prototype; 2-RF amplifier; 3-power supply for electrostatic lens; 4-power supply accelerating electrode and MCP detector, 5-PICOSCOPE.

The signals from the position sensitive anode

a



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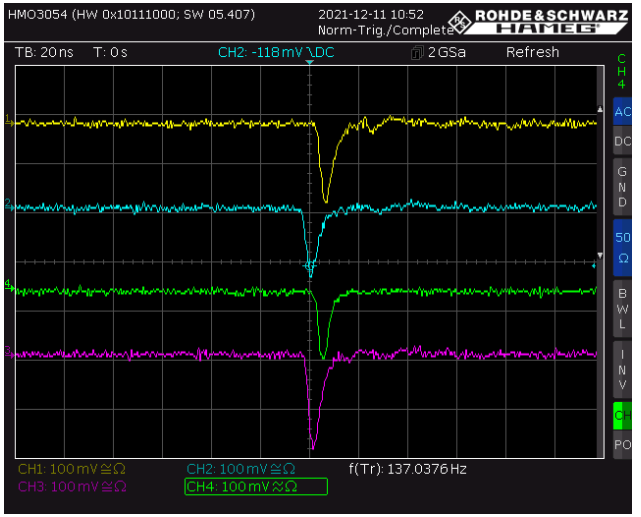

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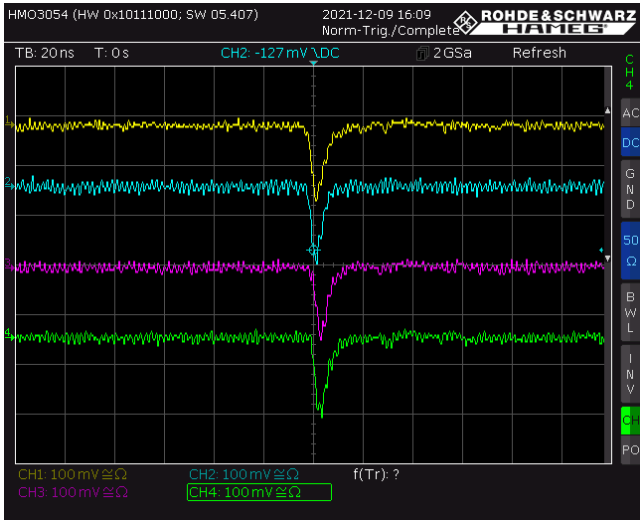
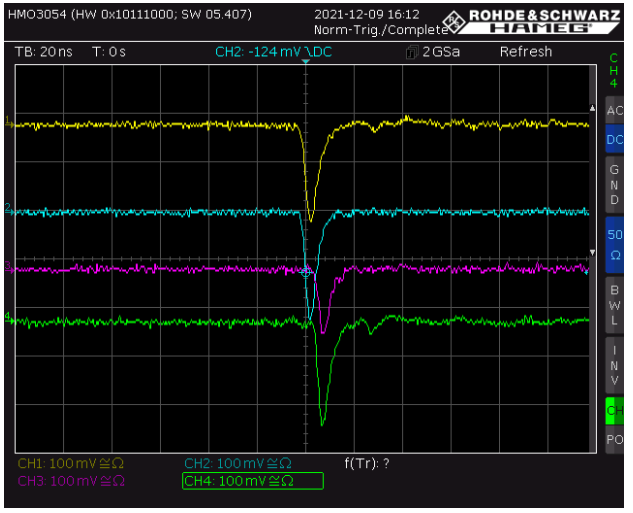
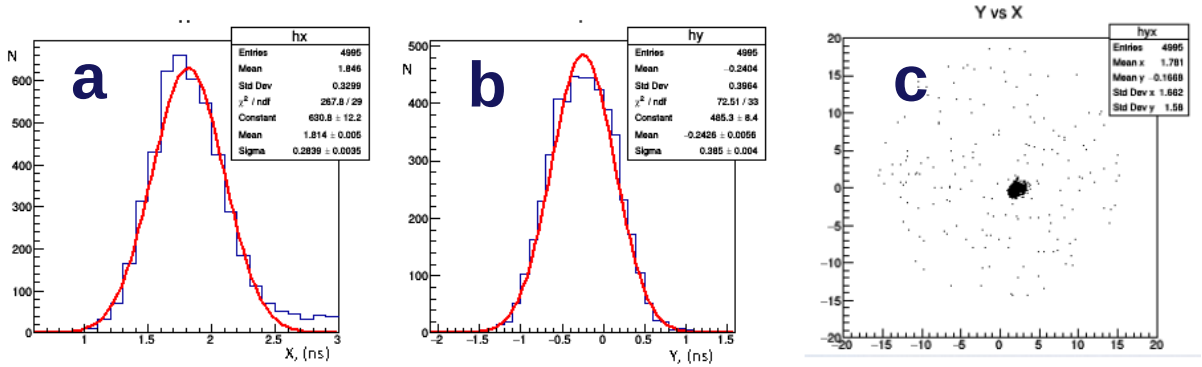


d

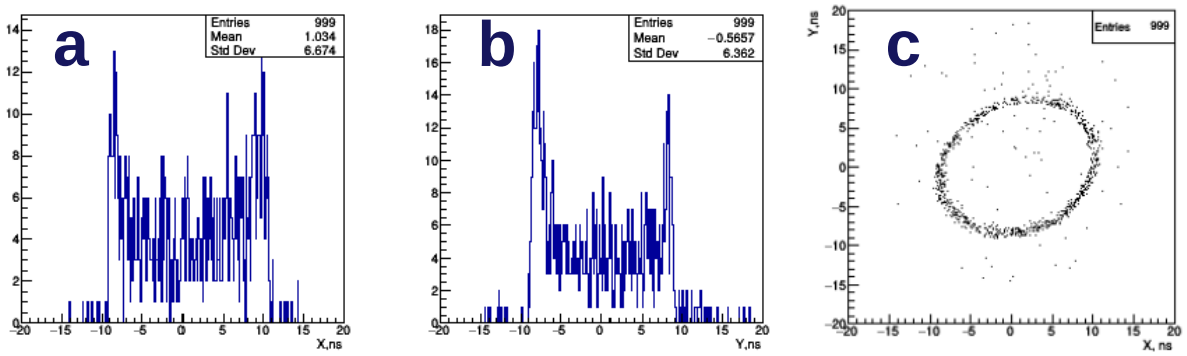


(a) typical raw signal; (b) typical amplified signals, RF off; (c) typical signals with 500 MHz RF on; (d) typical signals with 1000 MHz RF on.

RF timer of keV electrons: test with thermo-electrons

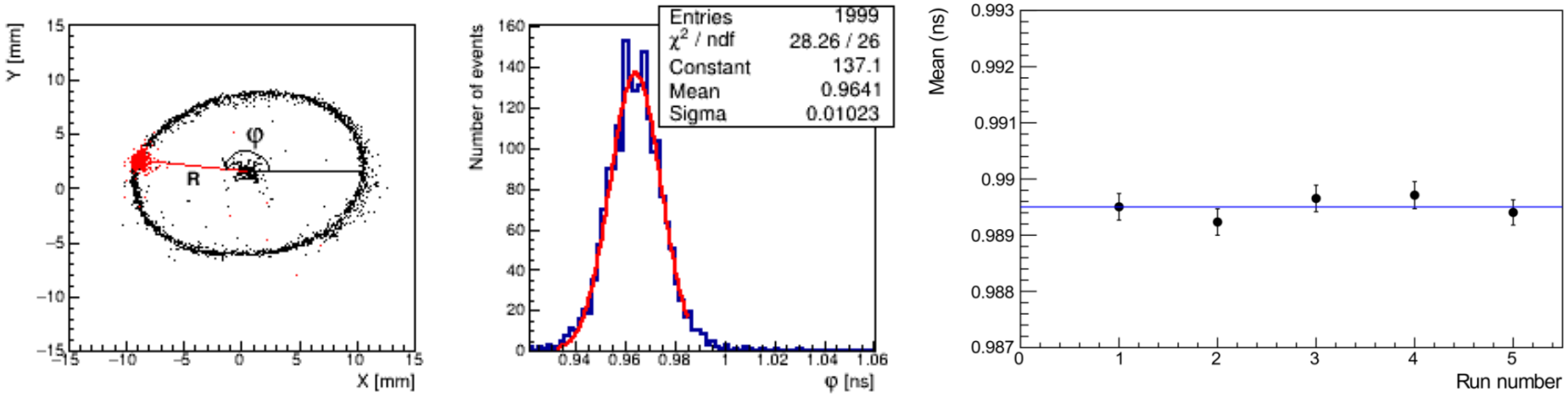


Distribution of time intervals between signals of x (a) and y (b) directions and 2D image (c) of the 2.5 keV electrons (RF off).



Distribution of time intervals between signals of x (a) and y (b) directions and 2D image (c) of the 2.5 keV electrons (500 MHz RF on).

RFPMT: test with femtosecond pulsed laser

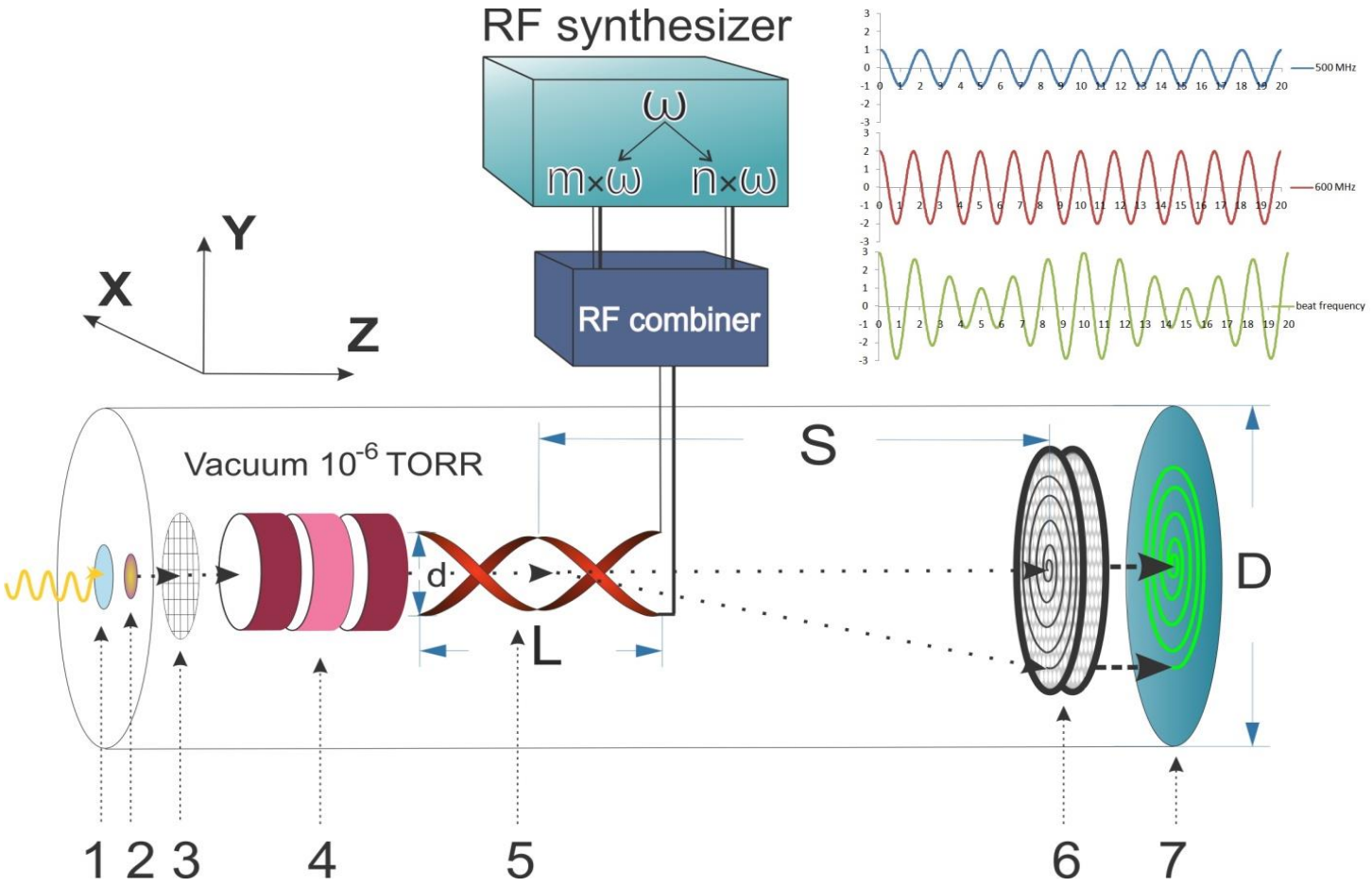


Left: 2D image of anode hit positions. The point in the center of the circle is an image of electrons with RF turned OFF. The circle is an image of the scanned electrons when the 500 MHz RF is ON but not synchronized with the laser. The red spot on the circle corresponds to phase distributions of RF-synchronized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

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

A. Margaryan et al., Nucl. Instr. & Meth. A1038, 166926 (2022)

The Radio Frequency Photomultiplier Tube-RFPMT

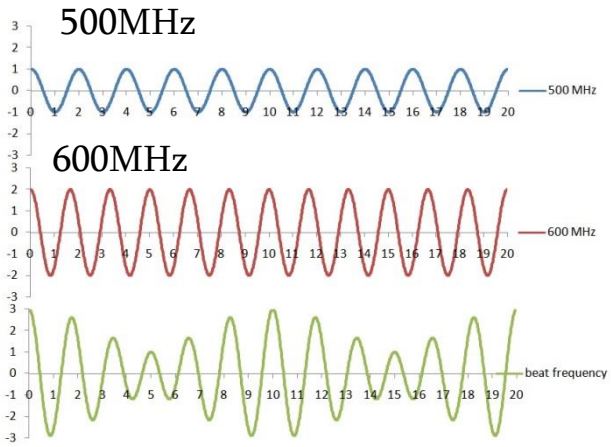


Schematic of the technique

1-quartz window; 2-photocathode; 3-accelerating electrode; 4-electrostatic lens; 5-RF deflector; 6-MCP detector; 7-position sensitive anode

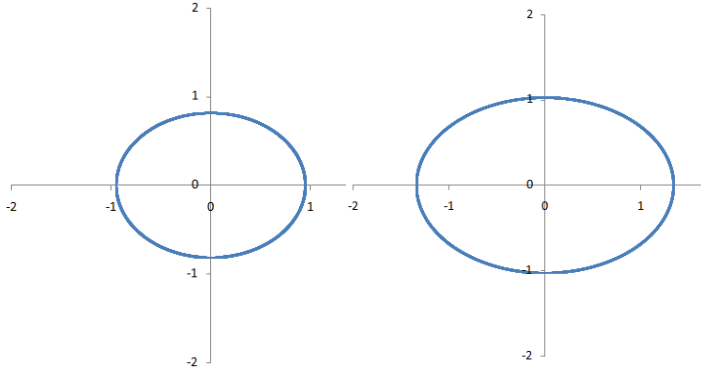
Spiral Scanning RF Timer with DL anode

Theory



500&600 MHz = Beat Frequency

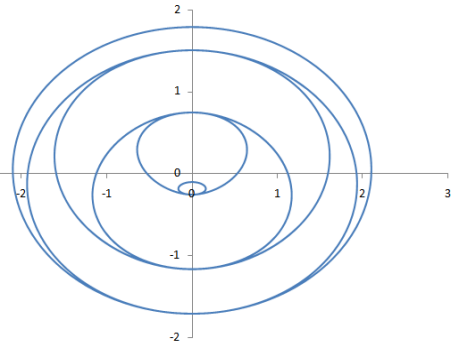
Circular/elliptical scanning



$f_1 = 500$ MHz

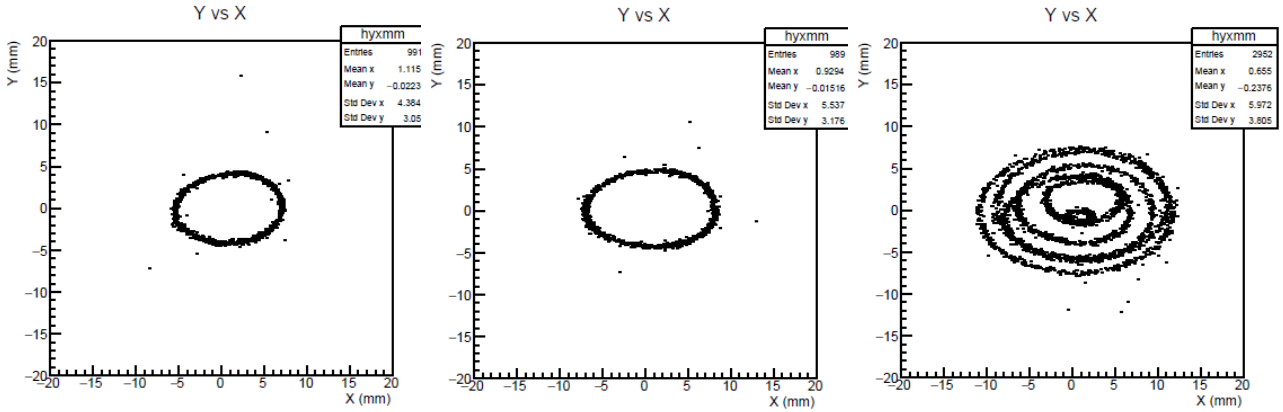
$f_2 = 600$ MHz

Spiral scanning



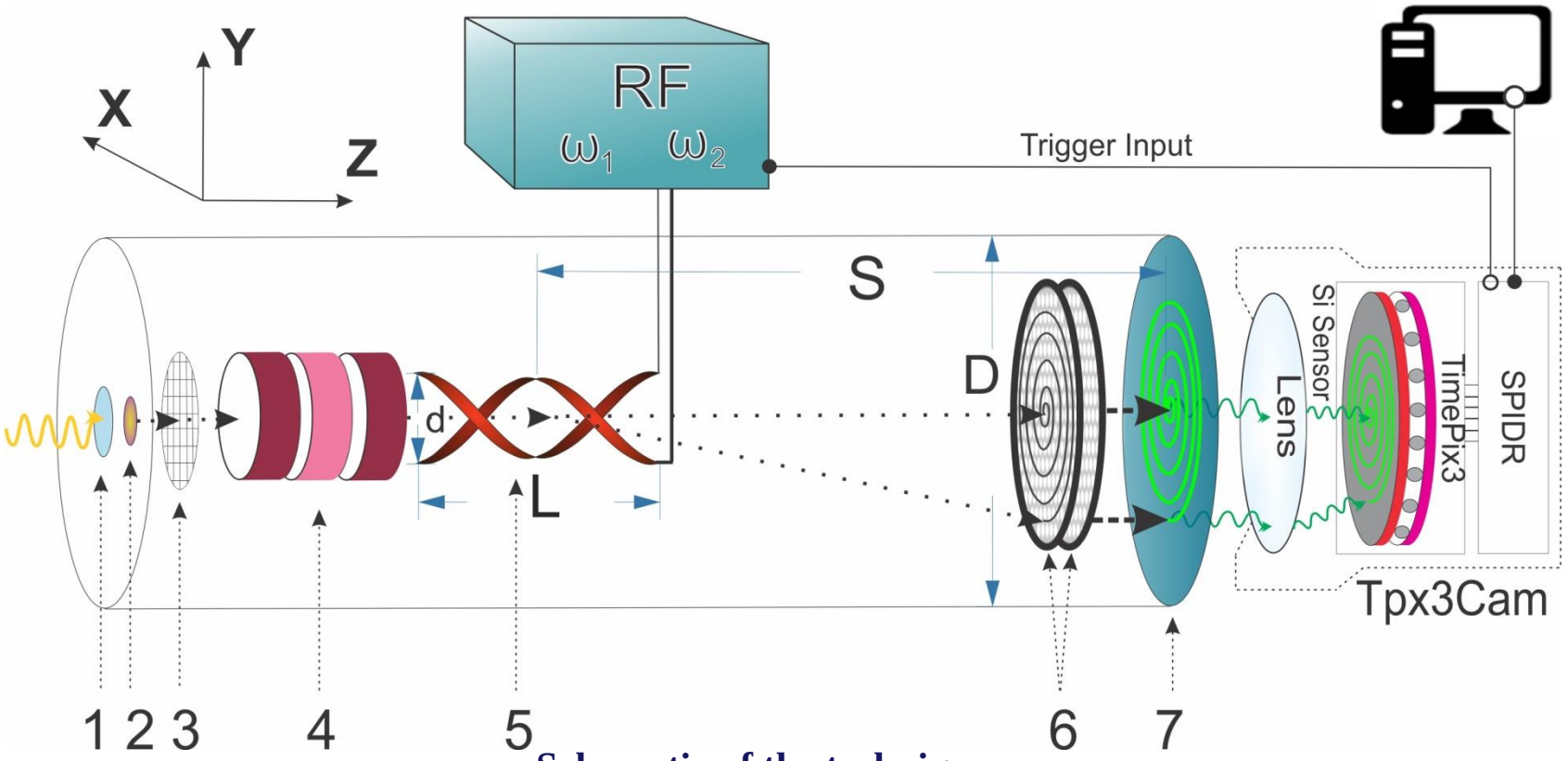
500 & 600 MHz

Experiment



Spiral scanning RF Timer is a Doorway into the High Resolution, High Rate and Highly Stable Continues Timing Technology

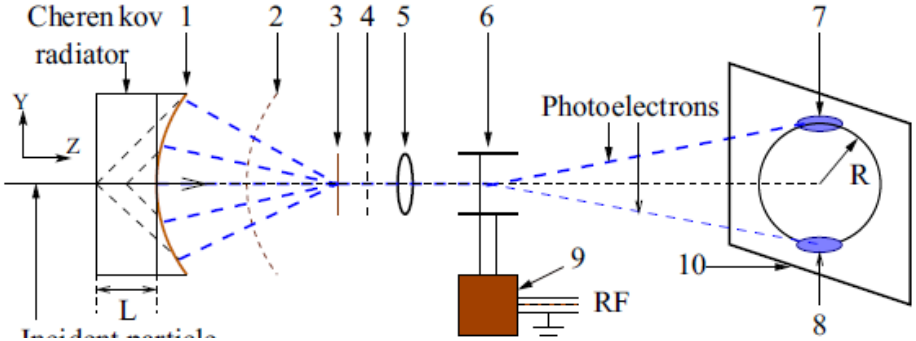
RF Timer with spiral scanning and fast pixelated detector



Schematic of the technique

1-quartz window; 2-photocathode; 3-accelerating electrode; 4-electrostatic lens; 5-RF deflector; 6-MCP detector; 7-phosphor screen

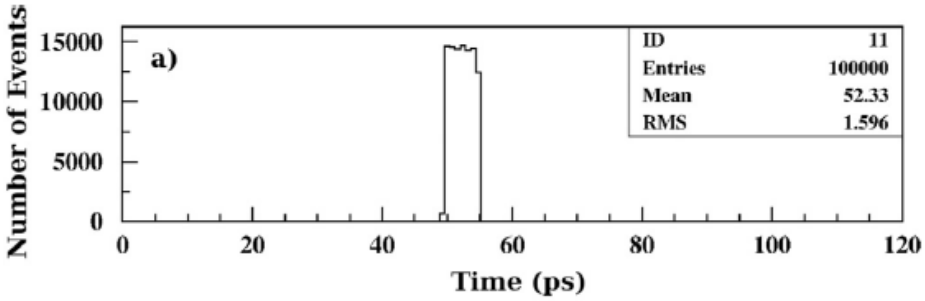
Spiral scanning RF Timer with a fast pixelated detector, e. g. TPX3Cam is a Doorway into the High Resolution, High Rate, Highly Stable and Dead Time free Continues Timing Technology

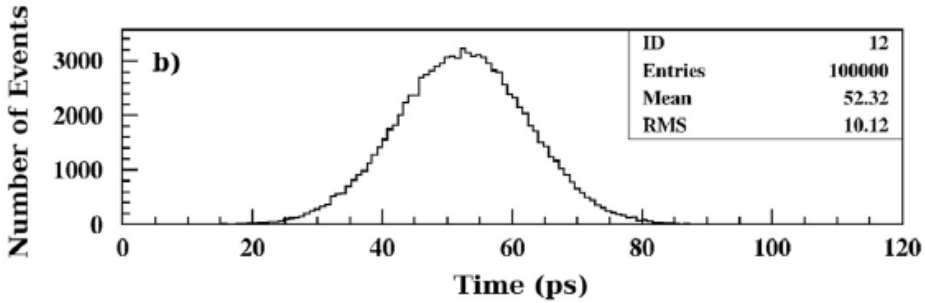


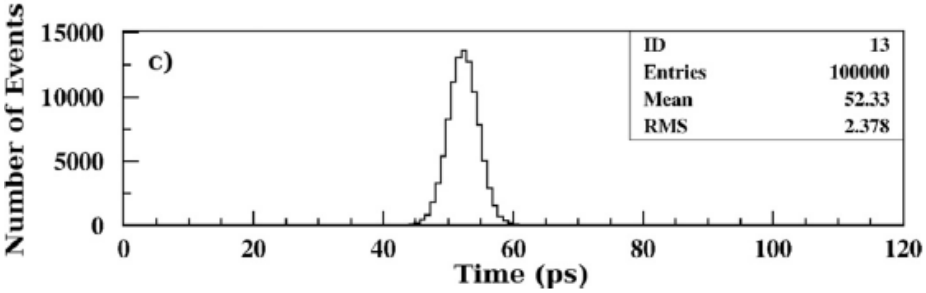
A schematic layout of the Cherenkov TOF detector with large size photocathode RFPMT

1- photocathode, 2- electron transparent accelerating electrode,
3- transmission dynode, 4- accelerating electrode, 5- electrostatic lens,
6- RF deflection electrodes, 7- image of PE's from electron,
8- image of PE's from pion, 9- RF coaxial cavity, 10- SE detector.

A. Margaryan, J.R.M. Annand, P. Achenbach et al., 2017







MC simulated time distributions of

(a) single Cherenkov photons;

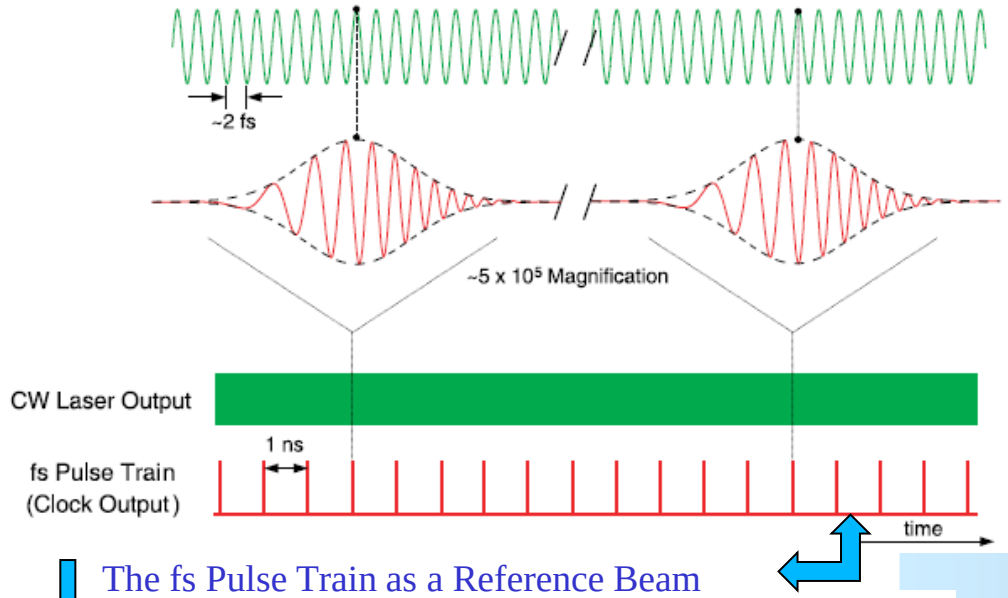
(b) PE's for tracks of p = 133 MeV/c pions;

(c) the mean time of 20 PE's.

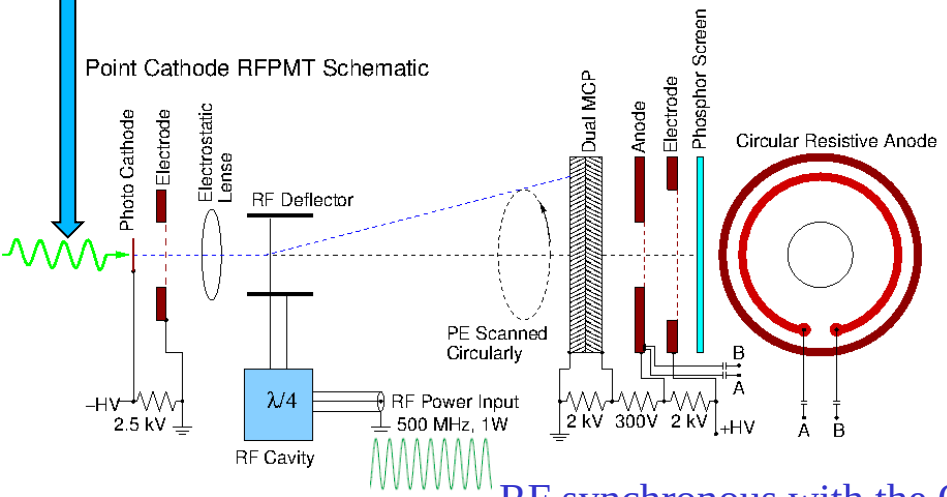
A. Margaryan, O. Hashimoto et al., Nucl. Instr. & Meth., 2008
A. Margaryan, 2011
A. Margaryan et al. 2014

The RFPMT and Optical Frequency Comb

S. Diddams et al, Science, 2001



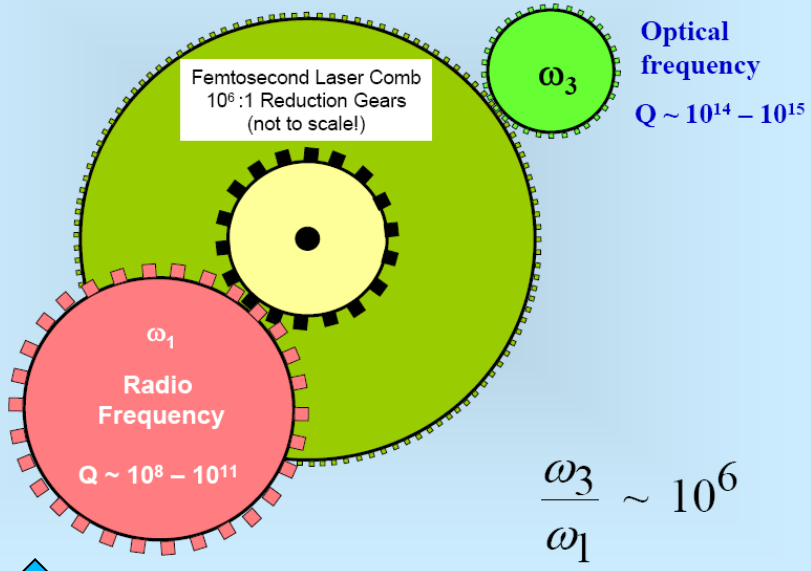
The fs Pulse Train as a Reference Beam



RF synchronous with the OFC

J. L. Hall, Nobel lecture, 2005

Phase coherent distribution

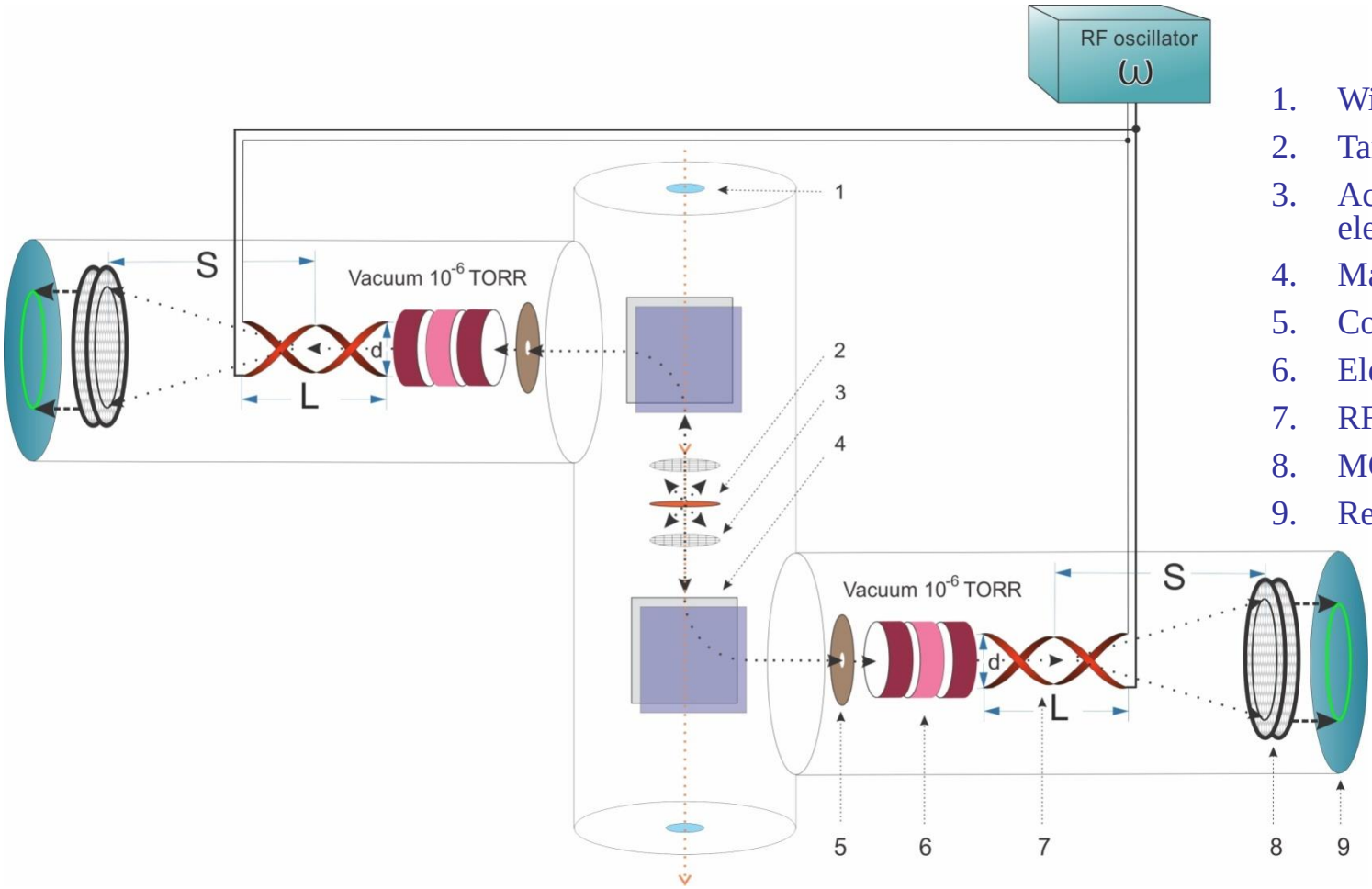


$$\frac{\omega_3}{\omega_1} \sim 10^6$$

RFPMT + OFC Results:
High Resolution
High Rate
Highly Stable
Time Correlated Single Photon Counting Technique

A. Margaryan, 2010, Nucl. Instr. Meth. A652 (1) 504–507.

RF Timer based Heavy Ion Detector



1. Window
2. Target
3. Accelerating electrode
4. Magnet
5. Collimator
6. Electrostatic lens
7. RF deflector
8. MCP detector
9. Readout electronics

Schematic of the RF Timer based Heavy Ion Detector
Expected time resolution ≤ 10 ps, time stability ≤ 0.2 ps

Applications

- Fundamental Studies - Comparison of Clocks
- Astrophysics - Brown -Twiss experiments
- High Energy and Nuclear Physics - Cherenkov TOF
- Heavy Ion precise timing
- FLIM - Fluorescence Lifetime Imaging
- FRET - Foster Resonance Energy Transfer
- STED - Stimulated Emission Depletion super resolution microscope
- DOI - Diffuse Optical Imaging
- TOF - PET - 10 ps Challenge
- PALS - Positronium Annihilation Lifetime Spectroscopy
- LIDAR - Laser Imaging Detection & Ranging

Expectations

We can start developing and producing prototype vacuum sealed RFPMTs and RFHIDs and scientific devices based on them.

Preliminary discussions with Photek Ltd. inspire hope that with adequate funding, the RFPMT prototypes could be ready in a few years.

Advanced RAdio Frequency Timing AppaRATus

Amur Margaryan[a], Ani Aprahamian[a,i,1,8], Vahe Gurzadyan[a,6], Armen Allahverdyan[a,7],Vanik Kakoyan[a,1,2], Simon Zhamkochyan[a,1,2], Sergey Abrahamyan[a,4,5], Hayk Elbakyan[a,2], Samvel Mayilyan[a,3,5], Garnik Ayvazyan[a,3,5], Hasmik Rostomyan[a,2,5,8,10], Anna Safaryan[a,2,5,10], Arpine Piloyan[a,2,9], Bagrat Grigoryan[b,1,5], John Annand[c,2,3,5], Kenneth Livingston[c,2,3,5], Rachel Montgomery[c,2,3,5], Patrick Achenbach[d,1,2,5,8], Josef Pochodzalla[e,5,8], Dimiter L. Balabanski[f,5,8], Satoshi N. Nakamura[g,2,5,8], Viatcheslav Sharyy[h,2,5,9], Dominique Yvon[h,2,5,9], Khachatur Manukyan[i,2], Maxime Brodeur[i,2,3,5,8]

a) A.I. Alikhanyan National Science Laboratory, b) CANDLE Synchrotron Research Institute, c) School of Physics & Astronomy, University of Glasgow, d) Thomas Jefferson National Accelerator Facility, e) Institut für Kernphysik, Johannes Gutenberg-Universität Mainz, f) Extreme Light Infrastructure- Nuclear Physics (ELI-NP), g) Department of Physics, Graduate School of Science, the University of Tokyo, h) Département de Physique des Particules Centre de Saclay, i) Department of Physics and Astronomy, University of Notre Dame

Activities: 1 management, 2 R&D, 3 hardware, 4 software, 5 test studies, 6 fundamental studies, 7 quantum technologies, 8 nuclear physics, 9 imaging, 10 material science

Thank you for your attention