Advanced Picosecond Precision RF Timer of keV Electrons

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for

RF Timer Collaboration

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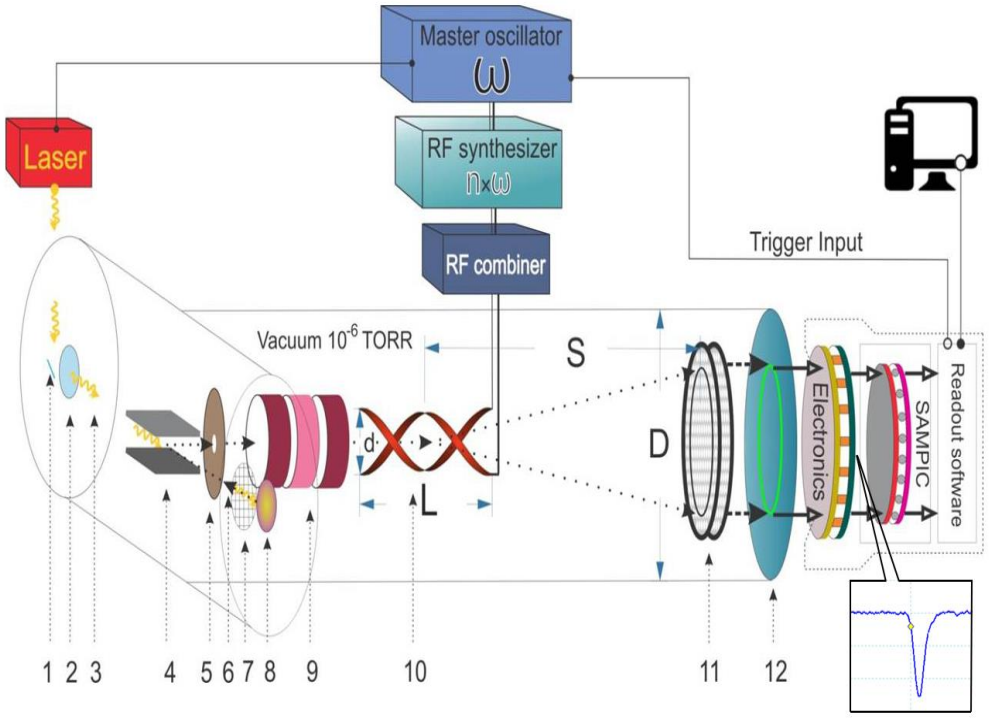
Precise time measurements

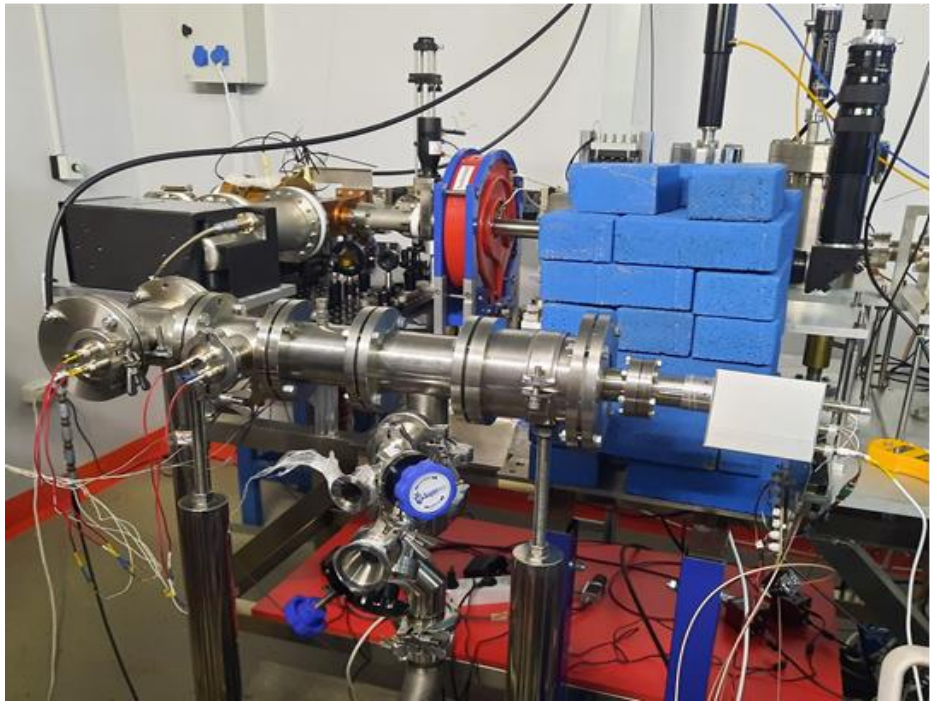
	Time Resolution	Counting Rate	Readout
PMT, APD, HPD	25 ps	Few MHz	Fast
Streak Camera	1 ps	Few 10 KHz	Slow
RF PMT	1 ps	Few MHz	Fast

- **The RF PMT is a sensitive photo-detector, capable of registering single photons:** optical photons produce electrons on a photo cathode, which are accelerated to keV energies, multiplied and detected.
- **Conversion of information in the time domain into a spatial domain:** Scanning photo-electrons by means of helical RF deflectors.
- **Fast signal output** as with regular PMTs
- **Picosecond level timing resolution** as with streak cameras

The new RF Timer combines the advantages of regular and the RF timing techniques, resulting in High Resolution, High Rate and High Stability for single electrons and photons.

The RF PMT





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

Time resolution of the RF PMT

➢ Physical time resolution of the photocathode

The time spread of the photoelectrons at the surface of the photocathode. For the typical thickness of semitransparent bialkali photocathode

$\Delta l \cong 20nm$ and $\Delta\varepsilon = 1eV$ – $\boldsymbol{\Delta\tau_p \leq 10^{-12}s}$

➢ Physical and technical time resolution of the electron tube

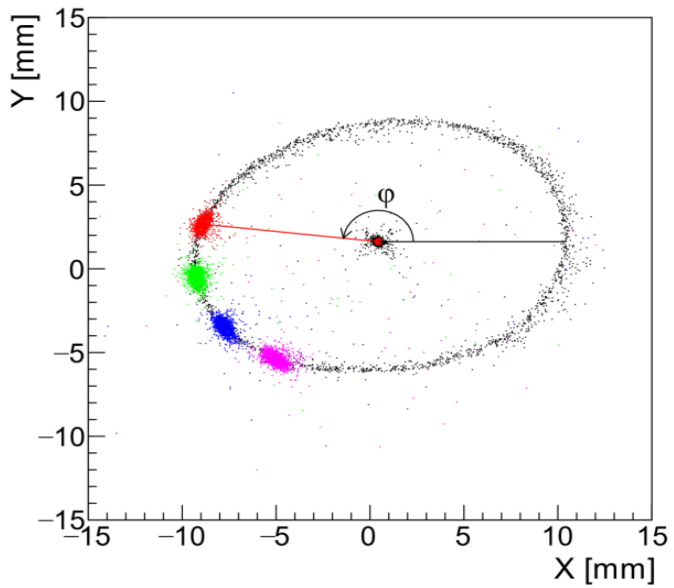
Transit time spread and of the photoelectrons and electron beam spot size at the PSD.

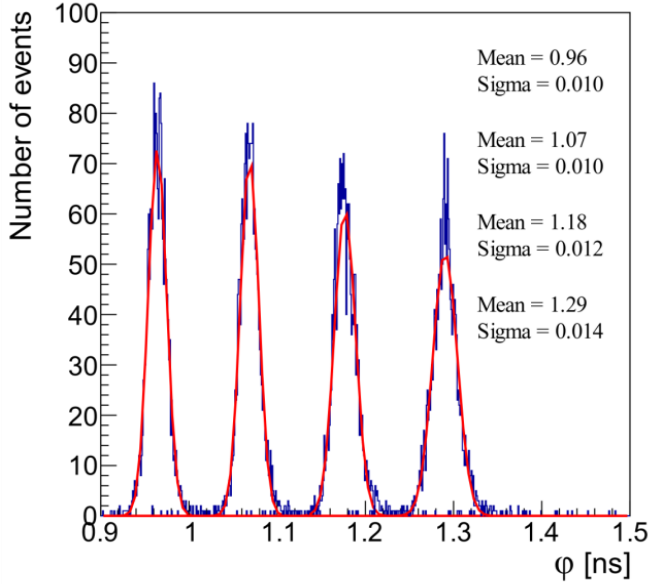
➢ Technical time resolution of the RF deflector

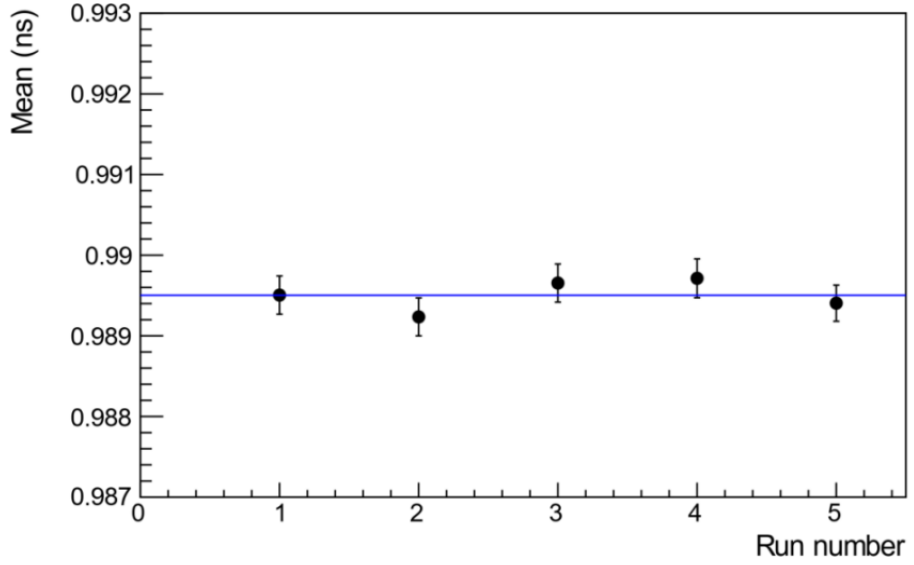
$$\boldsymbol{\Delta\tau_d = d/v}$$

d - convolution of the size of the electron beam spot and the position resolution of the electron detector, $v = 2\pi R/T$.

Studies with synchronized femtosecond pulsed laser at CANDLE facility







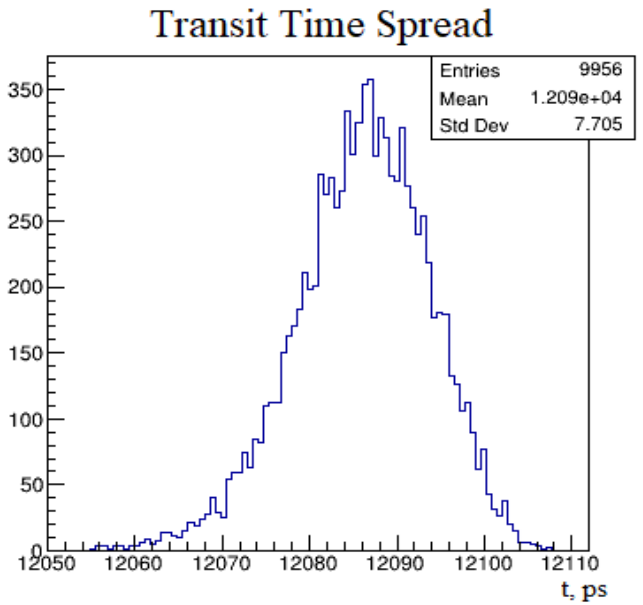
Left: *2D image of anode hit positions. The point in the center of the circle is image of electrons with RF turned OFF. The circle is an image of the scanned electrons when the 500 MHz RF is ON, but not synchronized with the laser. The color spots on the circle correspond to phase distributions of the scanned, RF-synchronized photo-electrons for four different fixed phases.*

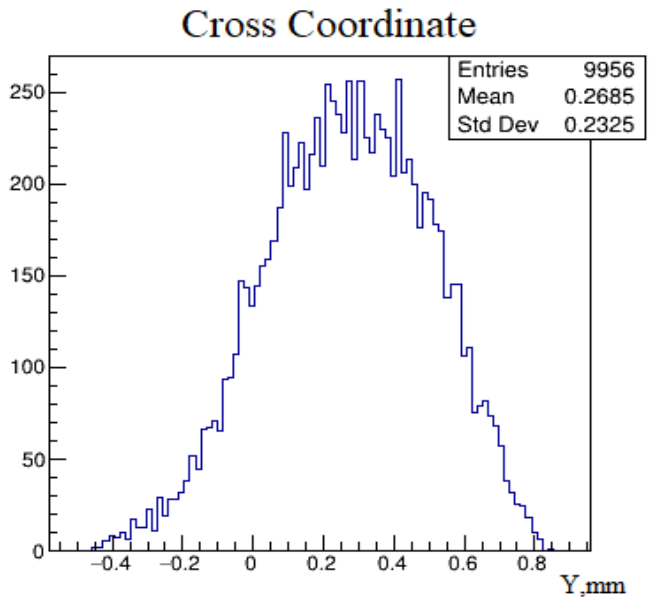
Middle: *Distribution of phases (φ), converted into ns, of the scanned electrons in the case of RF synchronized laser.*

Right: *The mean values of sequentially measured time distributions in a one hour period.*

Monte-Carlo Simulations

- The SIMION 8 based model was developed to replicate the experiment at Candle.
- The simulations take into account the detector's precise geometry, applied voltages, electrons' initial direction and energy spread.



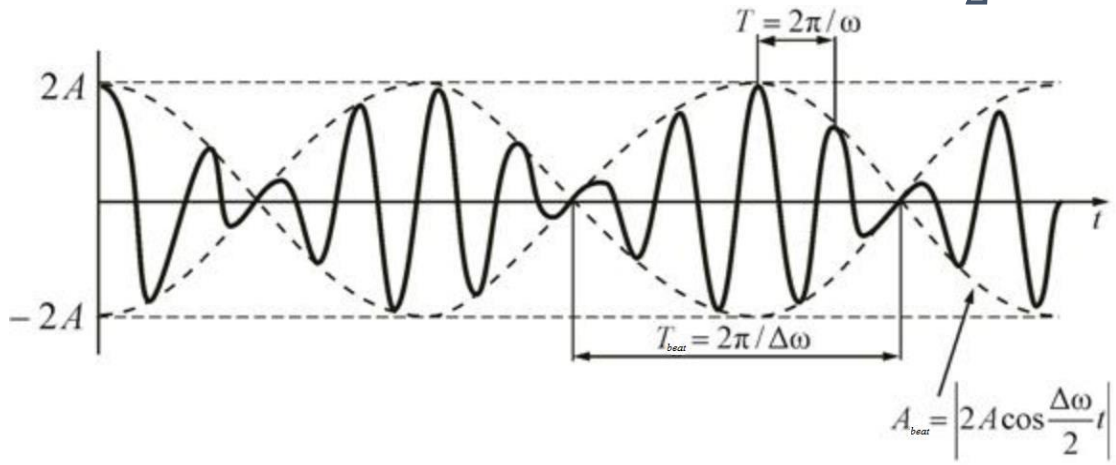


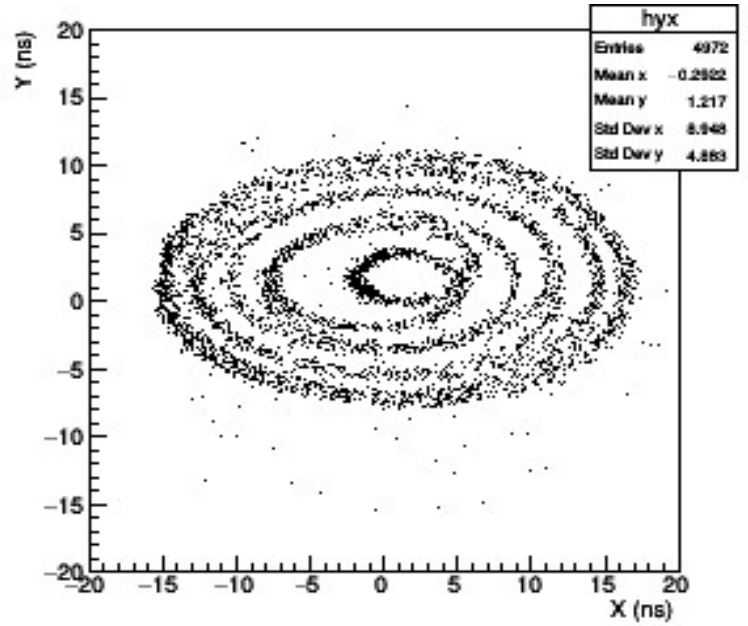
- Predicted transit time spread: **~8 ps**
- Predicated beam size: **~0.2 mm**, which corresponds to **~6.5 ps** technical resolution.
- In quadrature they amount to **10.3 ps** total detector time resolution is in good agreement with the experimental results

Spiral scanning studies

- Using two circular scanning RF deflectors with slightly different frequencies results in spiral scanning due to “amplitude beating” effect.
- Spiral scanning allows increasing the dynamic range of the RF Timer by an order of magnitude

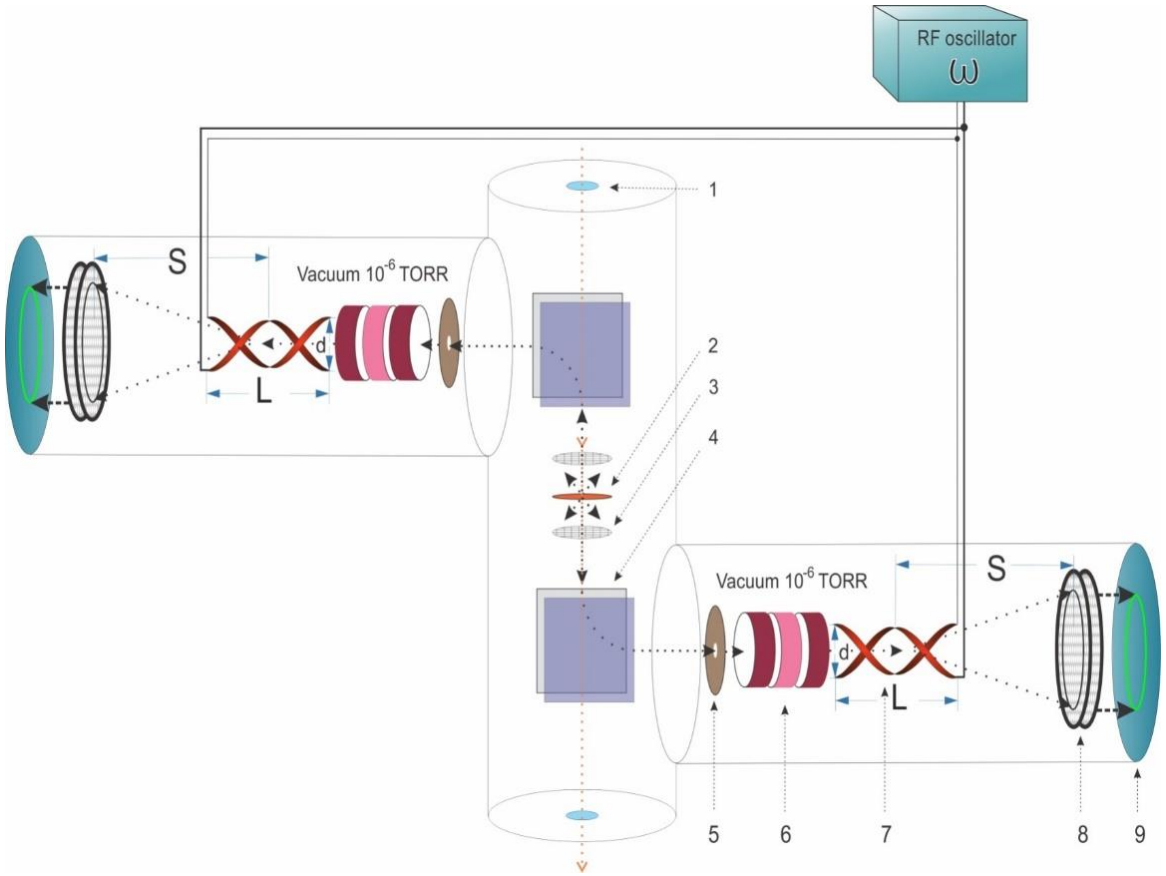
$$A \cdot \cos \omega t + A \cdot \cos(\omega + \Delta\omega)t = 2A \cdot \cos \frac{\Delta\omega t}{2} \cdot \cos \omega t$$





Preliminary studies were done using thermo-electrons

Heavy Ion Detector

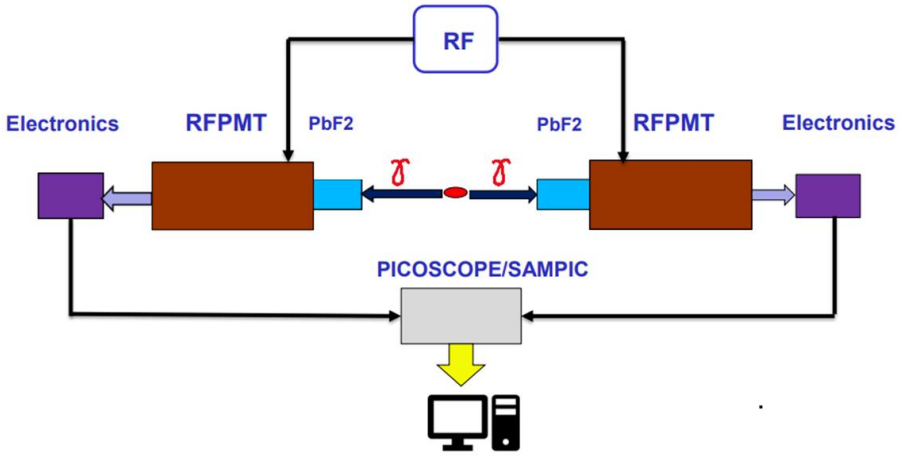


Heavy Ion Detector, based on the RF Timer, will be used for Λ Hypernuclei and fission isomer studies

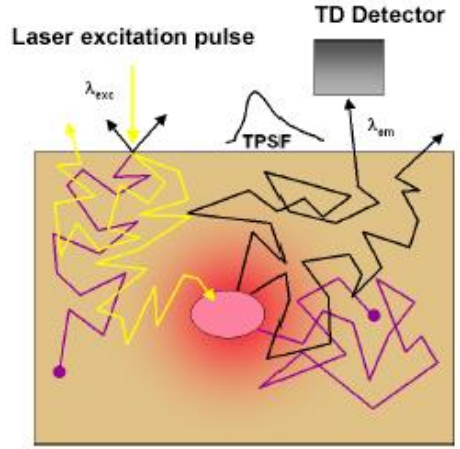
1 – beam window, 2 – Target, 3 – Accelerating electrode, 4 – Magnet, 5 – Collimator, 6 – Electrostatic lens, 7 – RF deflector, 8 – MCP detector, 9 – Readout electronics

RF PMT applications include PET, DOT, TCSPC

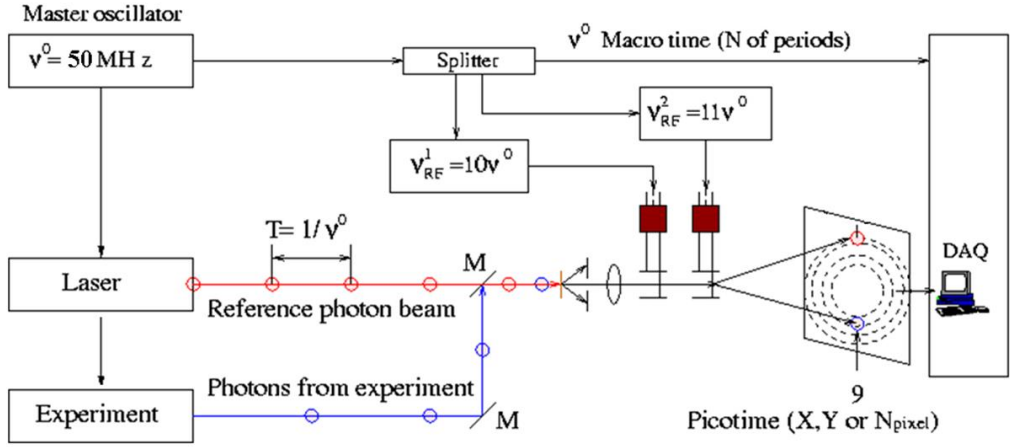
Positron Emission Tomography (PET)



Diffuse Optical Tomography (DOT)



Time-Correlated Single Photon Counting (TCSPC)



Summary

New ultra-high precision single photon timing device (Radio-Frequency Photo-Multiplier Tube, **RF PMT**), based on RF circular scanning, is developed and tested.

The RFPMT provides:

- **≤ 10 ps** time resolution
- **MHz** counting rate
- **0.5 ps/h** (FWHM) stability

After optimization we expect to achieve **1 ps** time resolution.