# Advanced Picosecond Precision RF Timer of keV Electrons

Simon Zhamkochyan for RF Timer collaboration
A.Alikhanyan National Science Laboratory (Yerevan Physics Institute), Yerevan, Armenia

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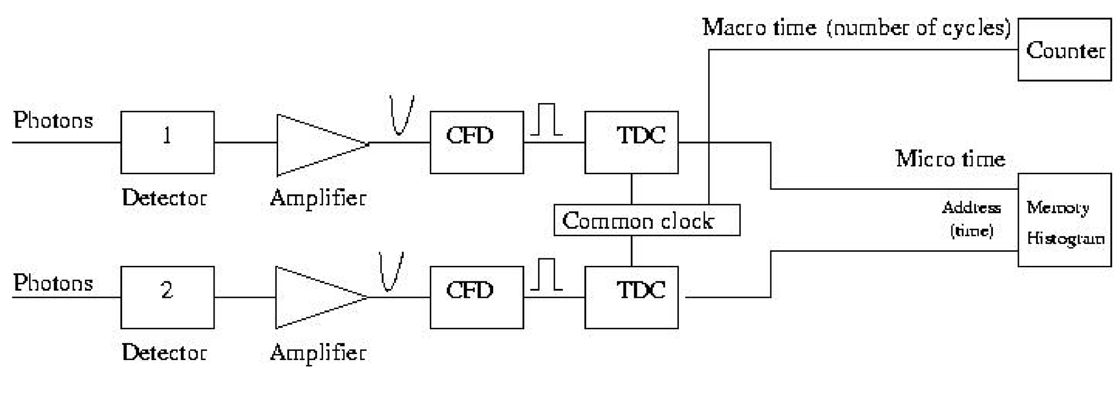
## Precise measurements of time intervals between physical events

**Regular Timing Technique** is based on measuring the time interval between two ns pulses, provided by detectors such as PMT, SiPMT, APD, HPD, SNSPD.




*Schematic layout of regular timing technique*

**Typical time resolution ~ few tens of picoseconds,**

**Time resolution limit ~ few picoseconds with SNSPD.**

**Rate ~ MHz**

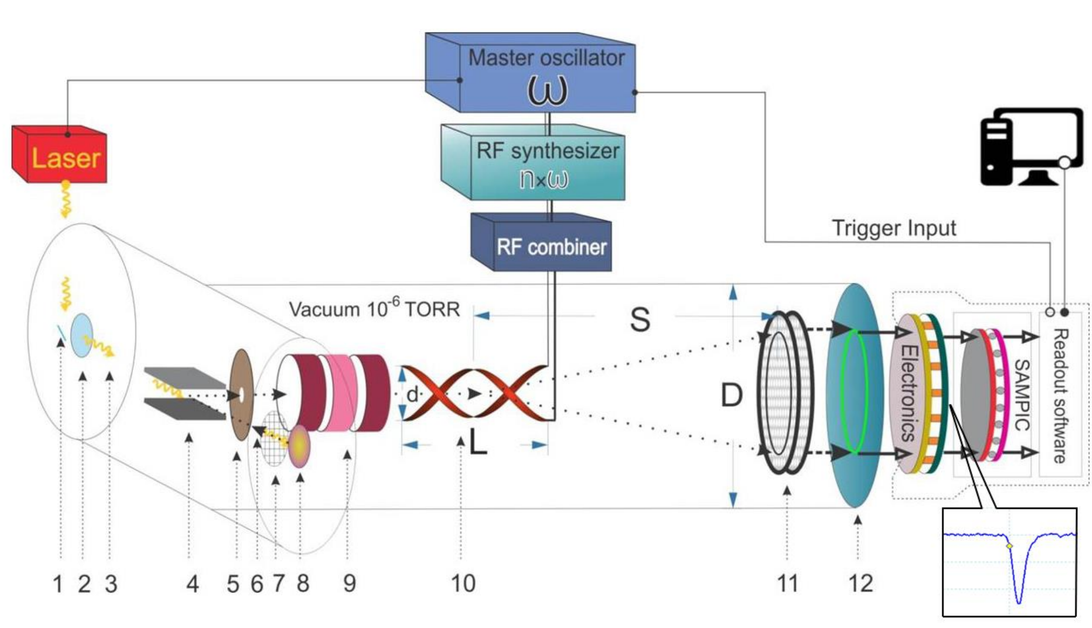
**Radio Frequency Timing Technique** is based on the conversion of information in the time domain to a spatial domain by means of RF field. For example, the arrival time of a photon may be scanned on to a circle image of photoelectrons on a CCD sensor, where the scanning phase angle ϕ is linear in time.

**Best time resolution: ≤ 1 picoseconds**

**Slow readout: few kHz**

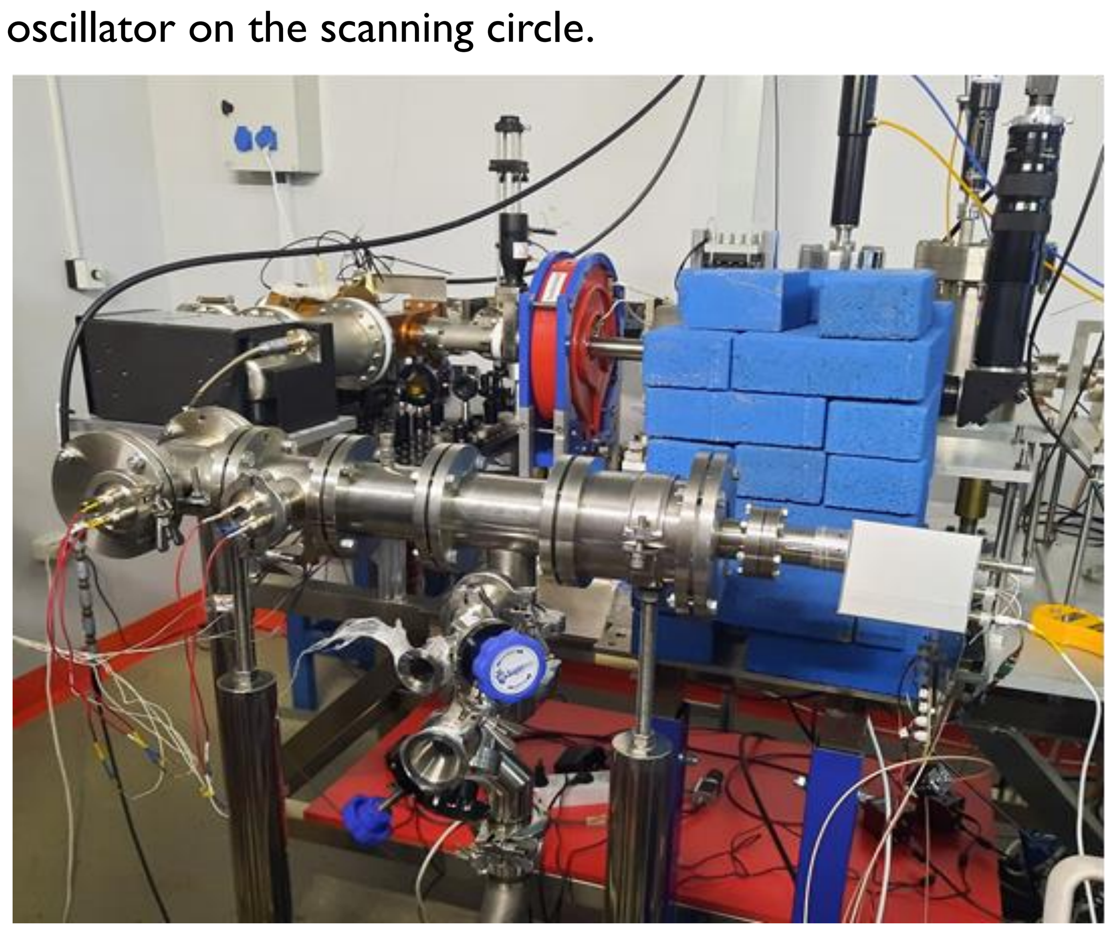
## Advanced RF Timer

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




*Schematic of the Advanced RF Timer. 1- mirror; 2 - quartz window; 3 - photons; 4 - magnet; 5 - collimator; 6 - photoelectron; 7 - accelerating electrode; 8 -photocathode; 9 - electrostatic lens; 10 - RF deflector; 11 - MCP detector; 12 - delay line anode*

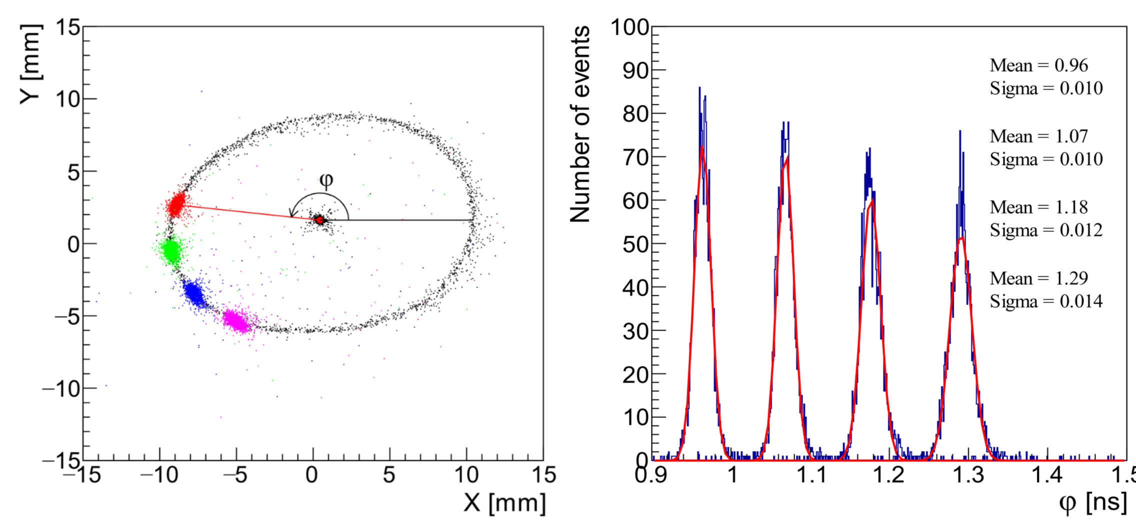
Photoelectrons (6) produced in the cathode (8), are accelerated by the electrode (7), deflected by the magnet (4) and focused on the position sensitive detector (11) by the electrostatic lens (9). Along the way the electrons pass through the RF deflector and fix the phase of the RF oscillator on the scanning circle.



*Photograph of the new RF Timer experimental setup at the CANDLE facility*

## Experimental Studies

**Studies with the femtosecond synchronized laser.** The studies were done at CANDLE UV laser facility (Yerevan) with 258 nm (4.8 eV) and 0.45 ps duration photon pulses, synchronized to a 500 MHz oscillation, at a repetition rate of 100 Hz. The photon pulses from the laser were directed to the Tantalum disc cathode and the 500 MHz RF was used to power the RF deflector and operate it synchronously with the 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 color spots on the circle correspond to phase distributions of the scanned, RF-synchronized photo-electrons for four different fixed phases.*
***Right:** Distribution of phases (φ), converted into ns, of the scanned electrons in the case of RF synchronized laser.*

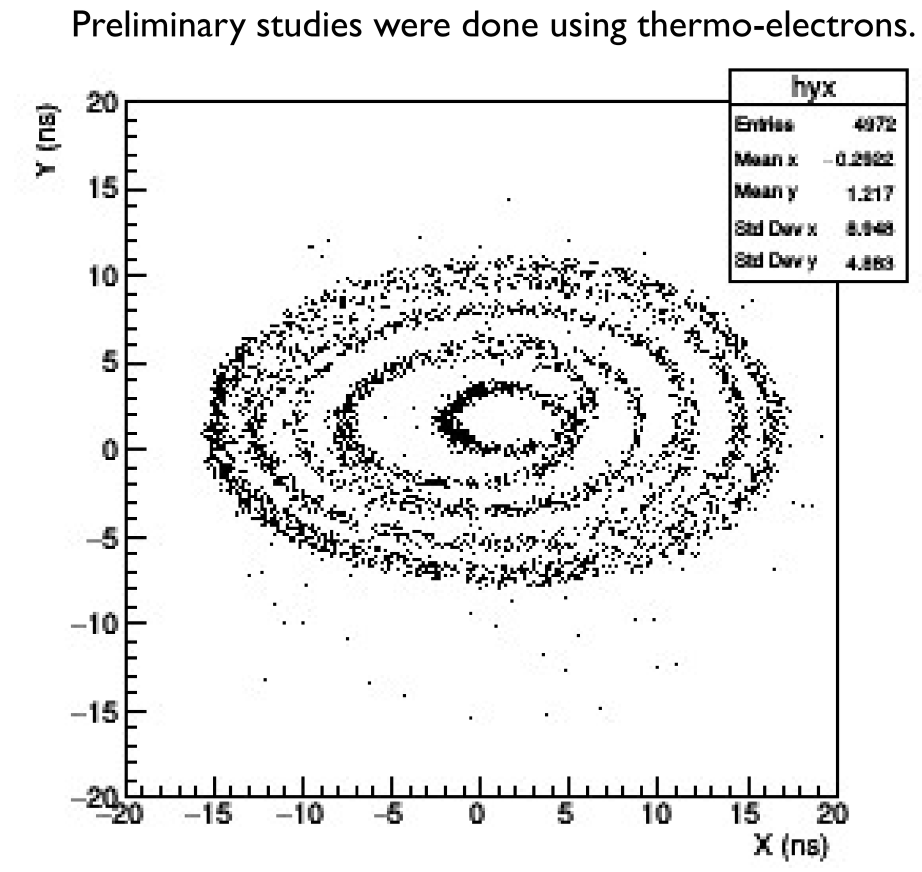
As the laser pulse length is short, in the synchronized mode all photoelectrons effectively have the same phase and a spot on the scanning circle is obtained. The ~**10 ps** spread in phase of such point represents the overall time resolution of the system, which includes factors related to the laser, the laser and RF oscillator synchronization device and the intrinsic time resolution of the RFPMT. The time stability of the RF Timer over a period of ~1 hour is about **0.5 ps**, FWHM.

*A.Margaryan et al., "An RF timer of electrons and photons with the potential to reach picosecond precision", NIM A, V1038, 166926, 2022*

**Spiral scanning studies.** Using two circular scanning RF deflectors with slightly different frequencies results in spiral scanning due to "amplitude beating" effect.

$$A\cos\omega t + A\cos(\omega + \Delta\omega)t = (2A\cos(\Delta\omega t/2))\cos\omega t$$

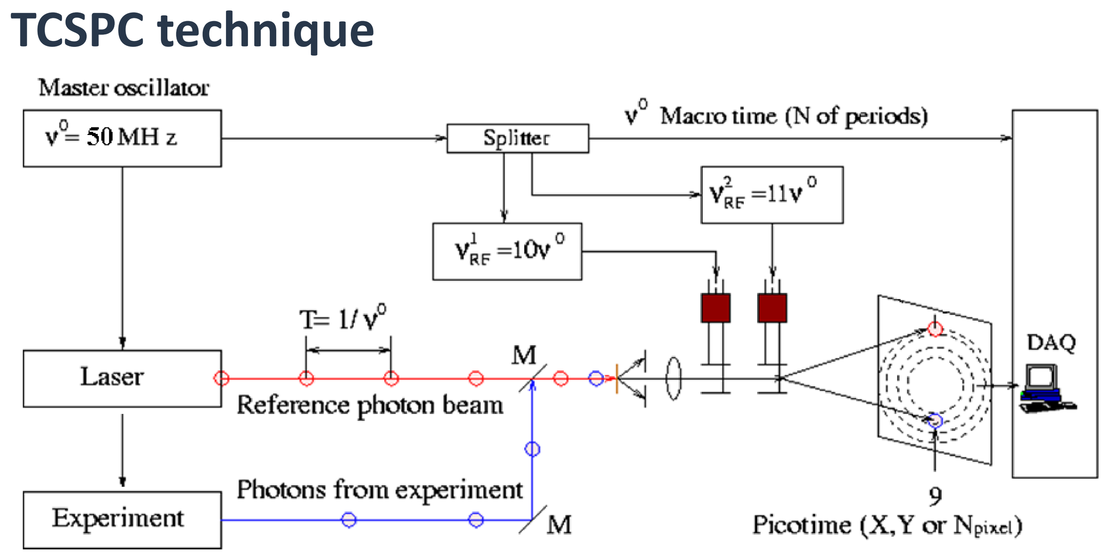
Preliminary studies were done using thermo-electrons.




*PE image from RFPMT with two frequencies applied: 500MHz and 550 MHz*

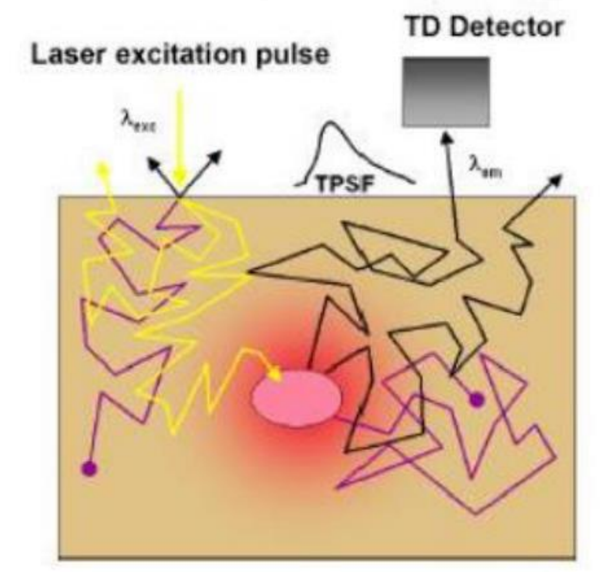
## Applications

### TCSPC technique




*Laser pulse will serve as an excitation photon beam and as a time reference*

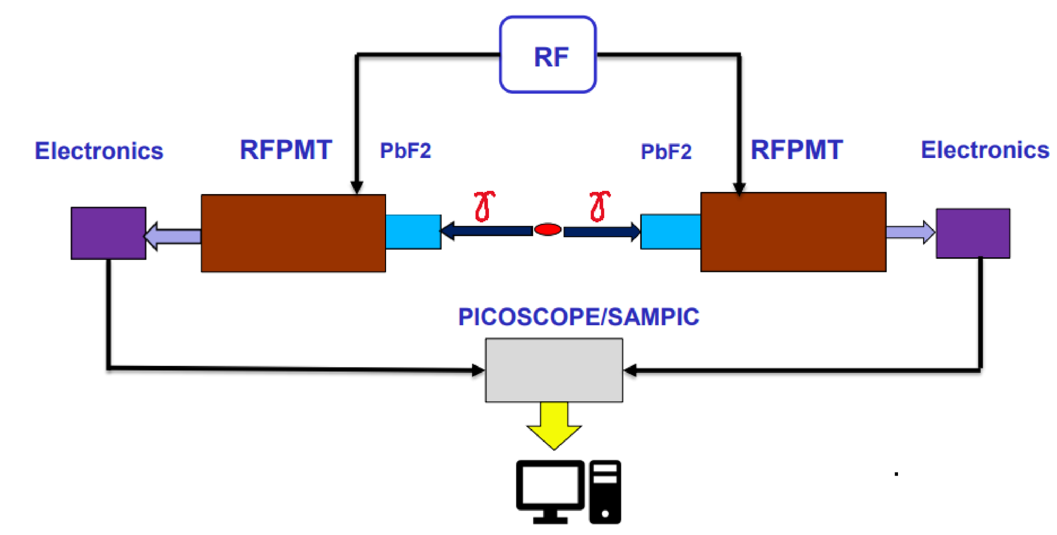
### Diffuse Optical Tomography




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

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

### Positron Emission Tomography

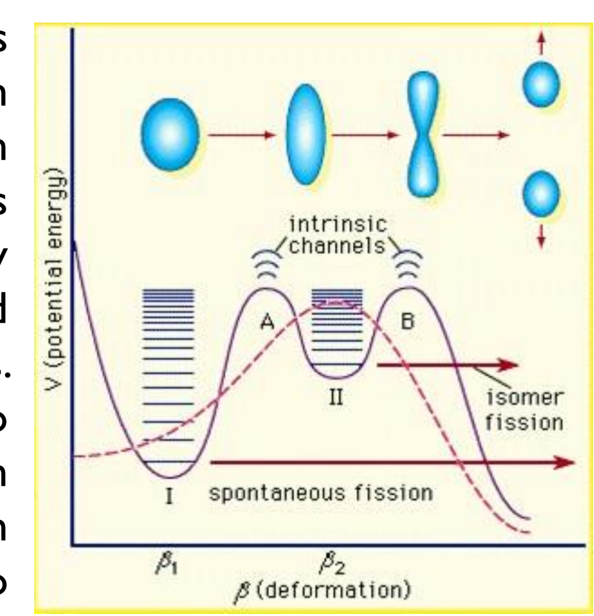



*Schematic of the TOF-PET with RFPMT*

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

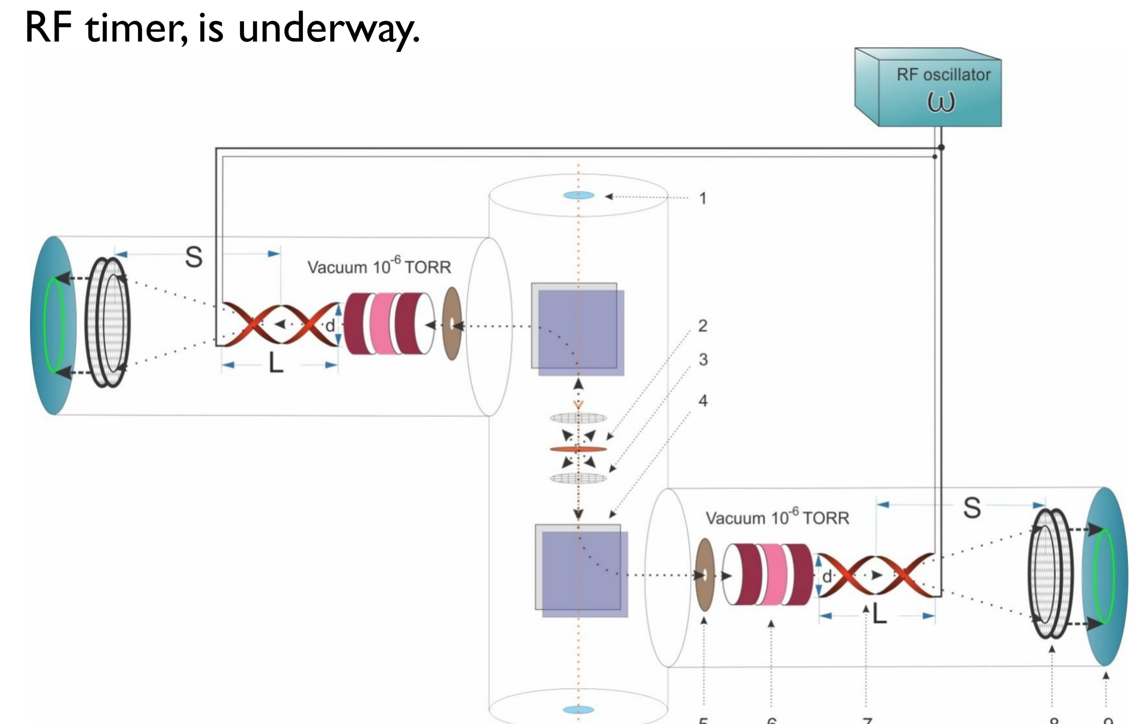
### Heavy Ion Timer

**A nuclear isomer** is a metastable state of an atomic nucleus, in which one or more nucleons occupy higher energy levels than in the ground state of the same nucleus. These states may undergo spontaneous fission with half-life in the range from few picoseconds to milliseconds. Out of more than 30 fission isomers only few are known in a picosecond range.




*Schematic view of double-humped and single-humped fission barriers*

**Λ Hypernuclei** are bound states of nucleons and Λ hyperons. The hyperon–nucleon interactions, which play crucial role in neutron star astrophysical models, can be studied in experiments by precisely measuring the lifetimes of Λ-hypernuclei. The experiment, based on the Heavy Ion RF timer, is underway.




*Schematic of RF Heavy Ion Timer based experimental setup. 1 – beam window; 2 - Target, 3 - Accelerating electrode, 4 - Magnet, 5 - Collimator, 6 - Electrostatic lens, 7 - RF deflector, 8 - MCP detector, 9 - Readout electronics*

## Summary

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

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

After optimization we expect to achieve 1 ps time resolution.