Lego Radio Frequency Timer for KeV Energy Electrons

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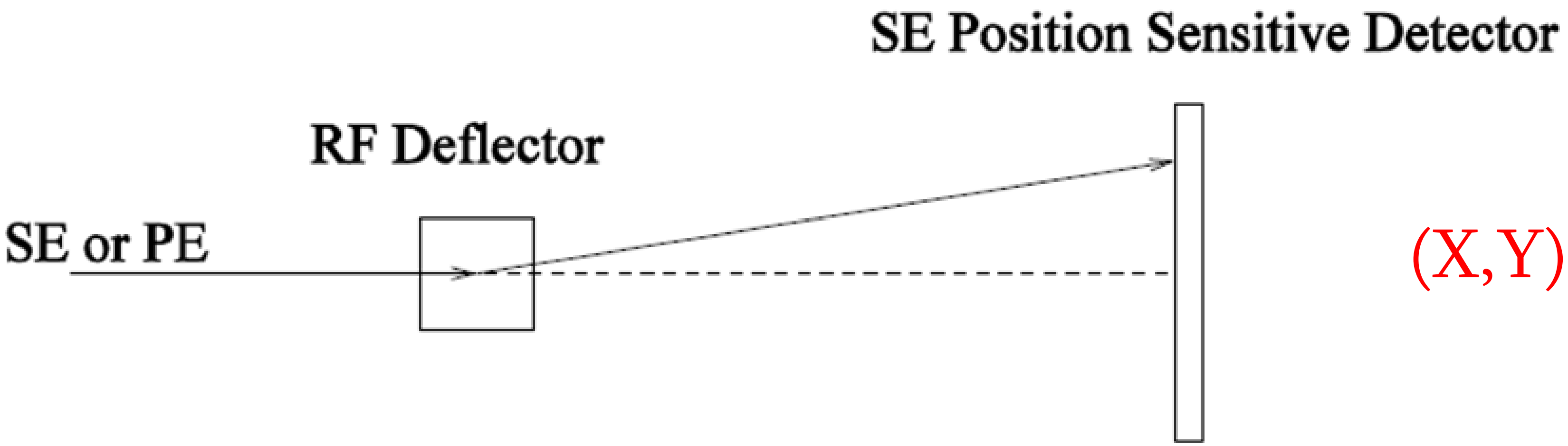
Outline

- Radio Frequency Timing: principles of operation
- Helical Shape RF Circular Scanning Deflector
- Spiral Scanning: Application of 2 RF Deflectors
- Theoretical studies
- Experimental studies
- Possible applications
- Future plans

Principles of RF timing technique

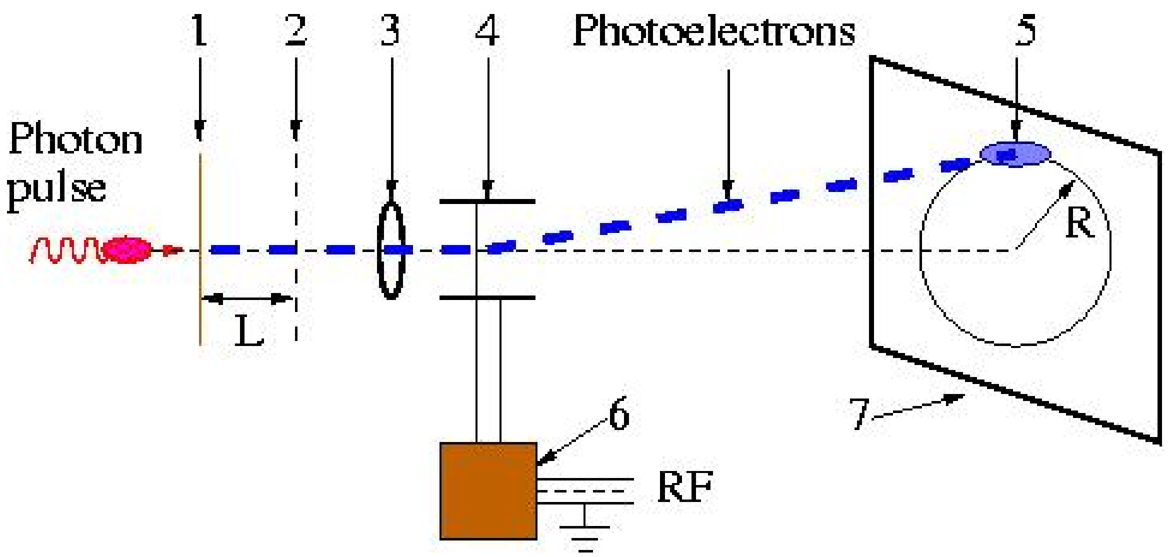
- Time information is transferred by SE or PE
- The electrons are accelerated and deflected by means of RF fields
- The obtained spatial information reproduces initial time information

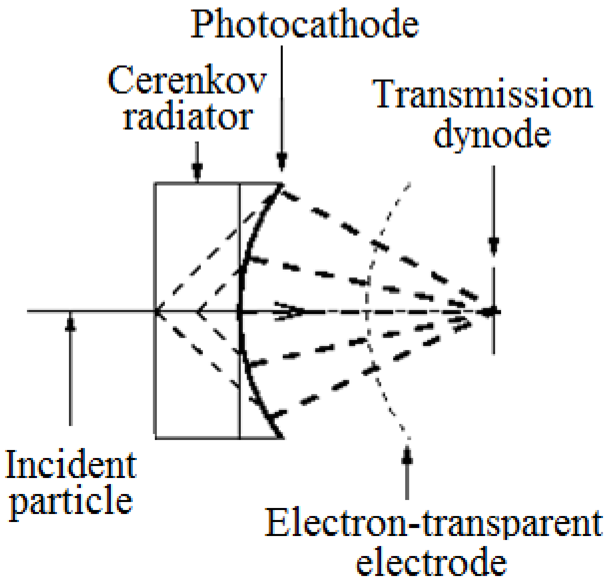


(X,Y) ⇔ Time

RF PMT With Circular Scanning

Time information transforms into position on a circle





1 - photo cathode; 2 - accelerating electrode; 3 - electrostatic lens; 4 - RF deflection electrodes; 5 - image of scanned Electrons; 6 - RF cavity; 7 - electron detector

"Spherical-Capacitor" type immersion lens for large size photocathode applications

Time resolution of RF PMT

- **Physical time resolution of the photocathode**

For the typical thickness of semitransparent bialkali photocathode $\Delta l \cong 20nm$ and $\Delta\varepsilon = 1eV$

$\Delta\tau_p \leq 10^{-12}s$

- **Physical and technical time resolution of the electron tube**

in a carefully designed system these can be minimized to be in ps range

- **Technical time resolution of the RF deflector**

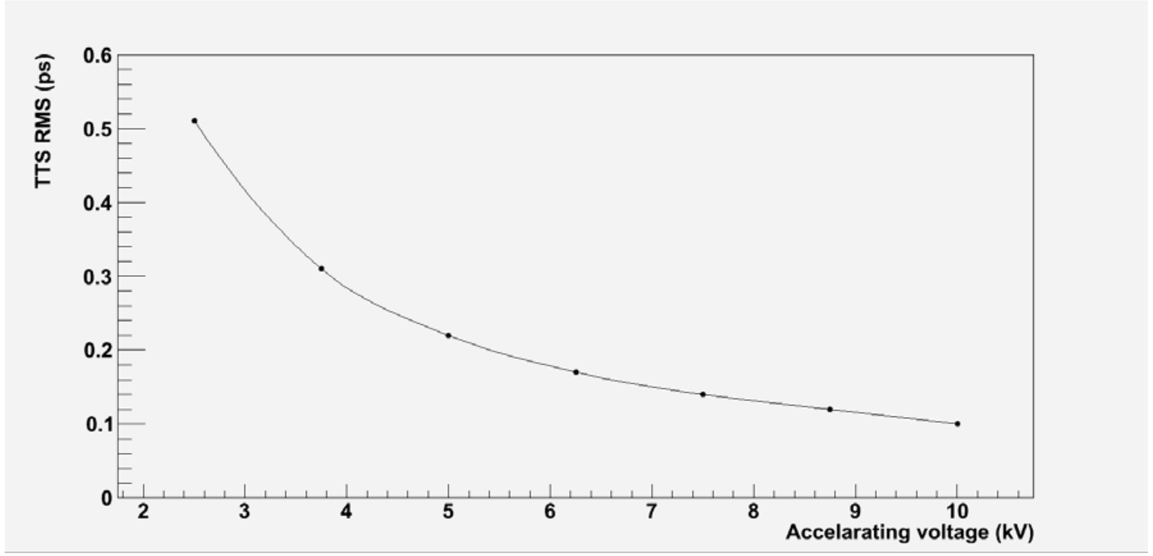
$\Delta\tau_d = d/v$

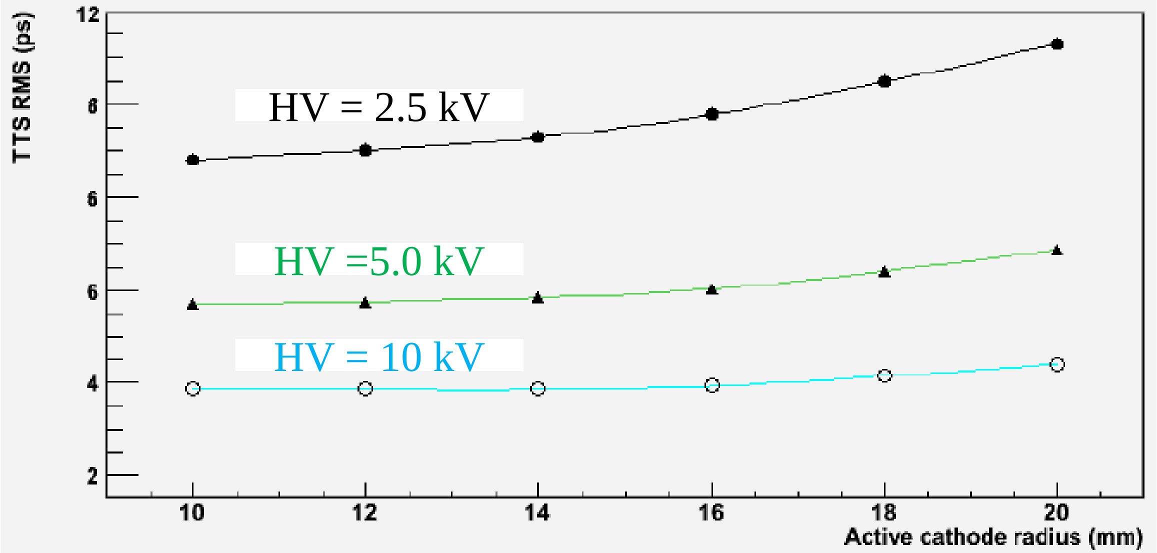
d - convolution of the size of the electron beam spot and the position resolution of the electron detector, $v = 2\pi R/T$; with $d = 0.01cm$, $R = 2$cm and $T = 10^{-9}\ s$

$\Delta\tau_d = 1ps$

Transit Time Spread Simulations

Simulations were carried out my means of SIMION 8

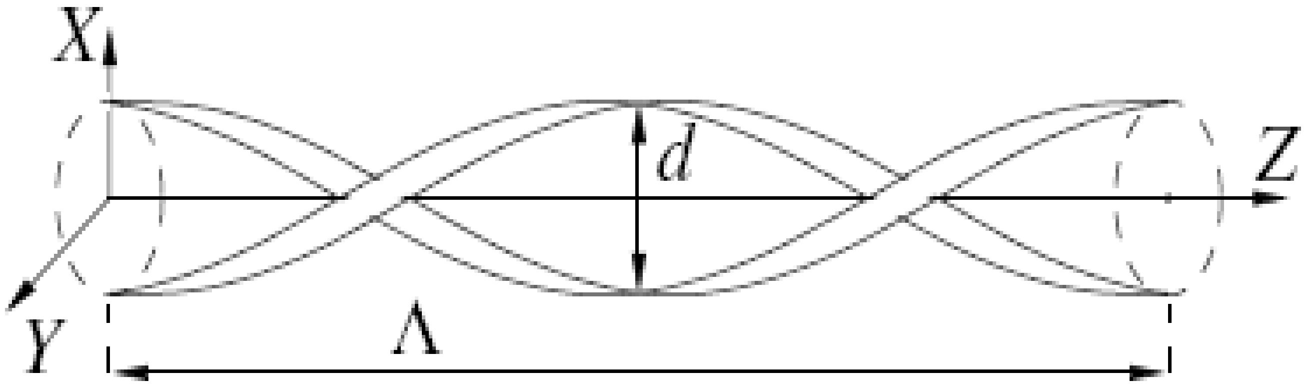




For small size (100 µm) cathode TTS is in subpicosecond range

For large size cathode TTS to crossover is ~10ps

Helical Shape RF Deflector



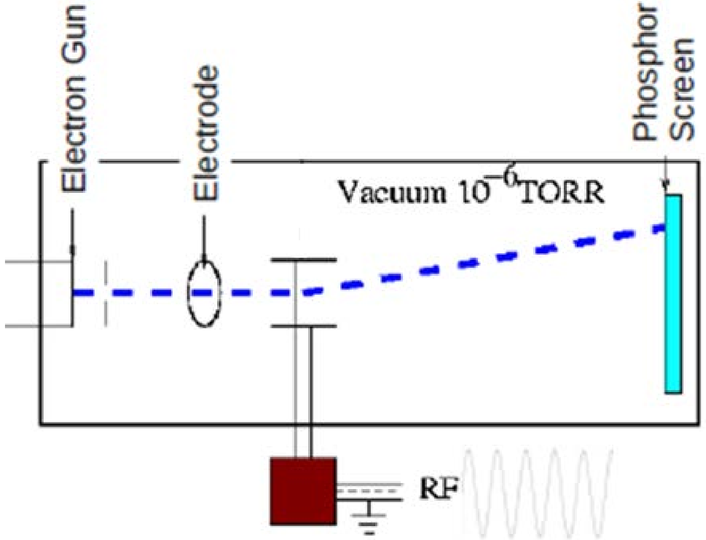
A pair of helical electrodes of periodic length Λ and separation *d*

$T = \Lambda/v$ - Resonance condition; **no reduction of the deflector sensitivity due to transit time**

v – Electron velocity
T – RF Voltage period
Λ – Perod of deflector

Deflector side view. L. Gevorgian et al., Nucl. Instr. Meth. A 785 (2015)

RF Scanning system
Evacuated Test Tube With Thermionic Cathode



20 V sinusoidal voltage

0.5 – 1.0 GHz frequency (2ns – 1ns period)

Scan radius 1mm/V or 0.1 rad/$W^{1/2}$

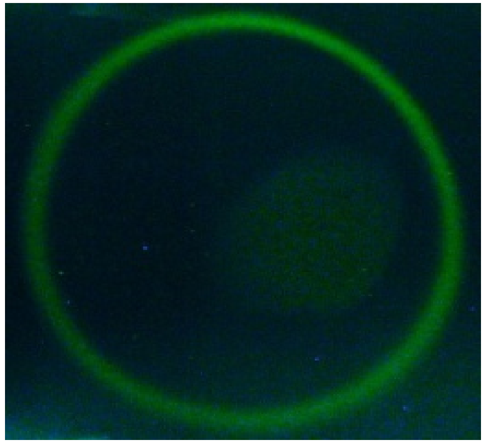
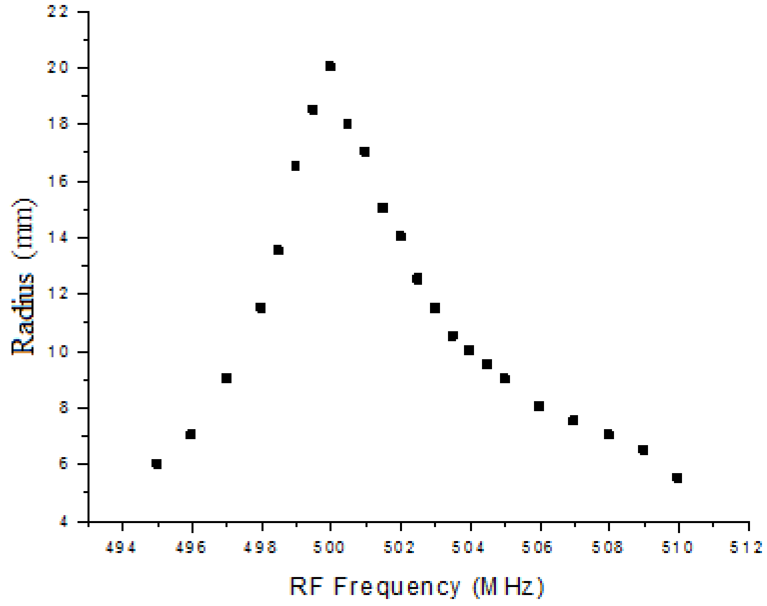


Image of CW 2.5 keV electron beam circle with radius ~20 mm



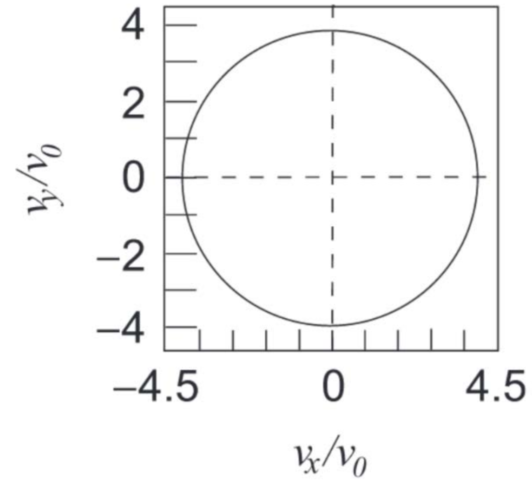
Radius of the scanning circle as a function of RF frequency for 2.5 keV electrons.

Helical Shape RF Deflector

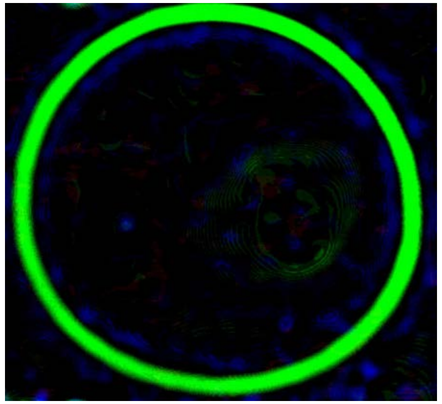
Theory

Experiment

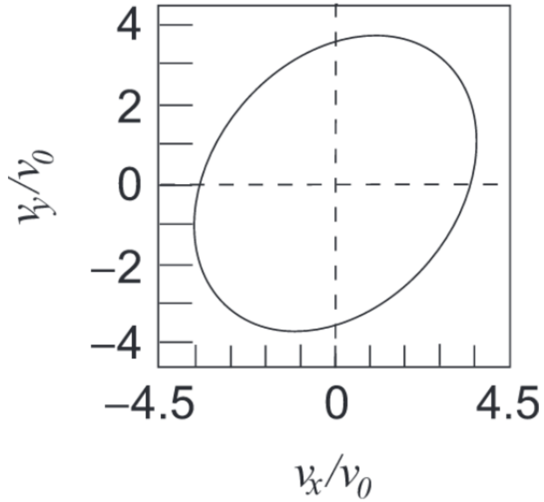
k = 1.0, n = 4



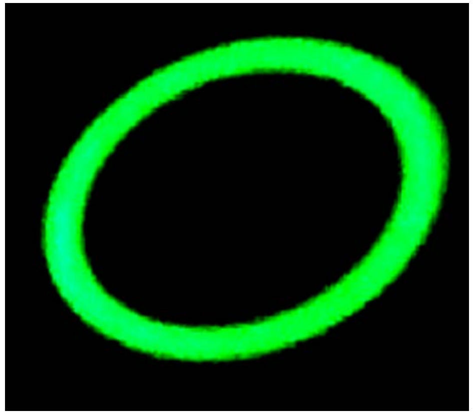
1000 MHz



k = 0.75, n = 4



750 MHz



$k = \omega/\omega_c$, $n = l/\Lambda$, $\omega_c = 2\pi / \Lambda t$

The parameters of the deflector and test set up are:

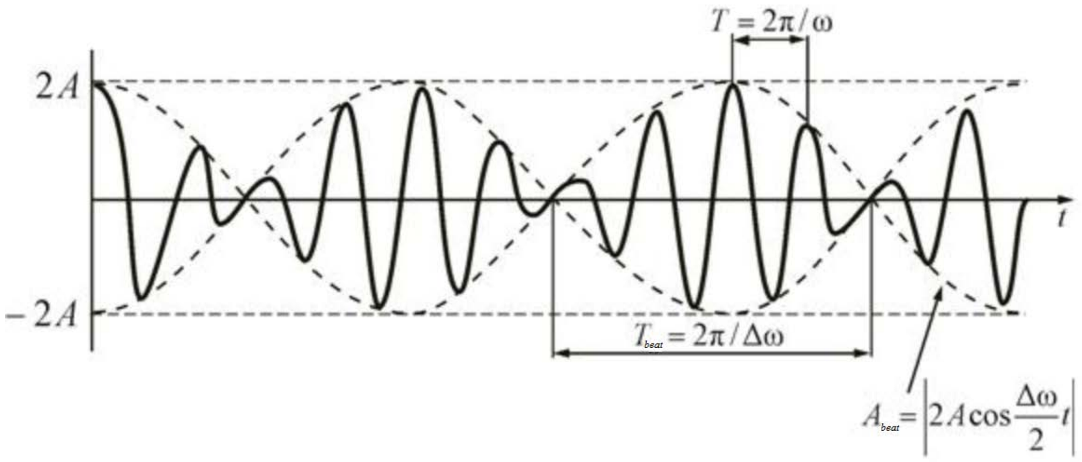
$\Lambda = 6cm,\ d = 1cm,\ U_d = 20\ V,\ U_a = 2.5kV,\ D = 12\ cm$

Amplitude beating

Combining two harmonic signals with close frequencies *($\Delta\omega << \omega$):*

$$A\cos\omega t + A\cos(\omega + \Delta\omega)t \approx (2A\cos\frac{\Delta\omega}{2}t)\cos\omega t\ ;$$

$$A_{beat} = |2A\cos\frac{\Delta\omega}{2}t|$$ - **beat amplitude**



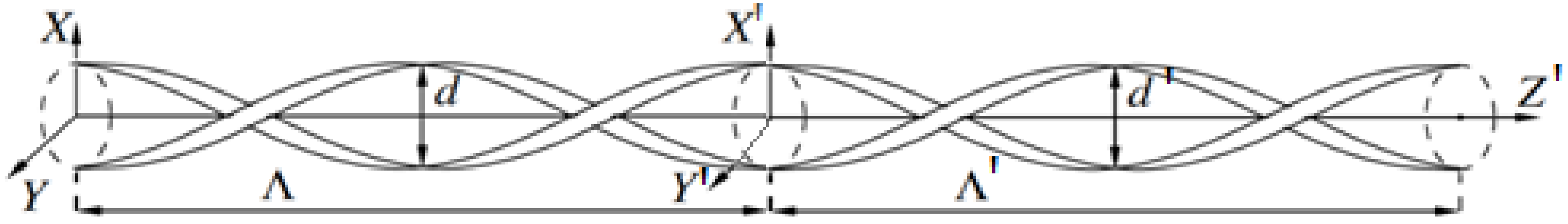
Using 2 RF deflectors with slightly different

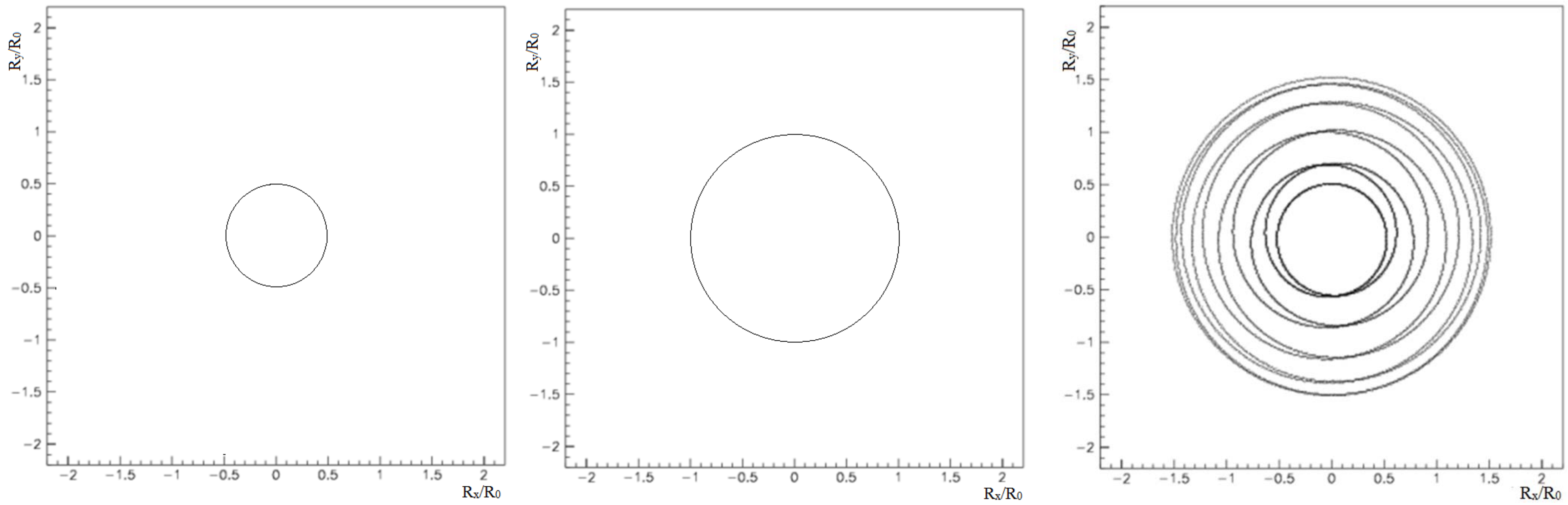
frequencies results “amplitude beating” effect

“Beat” in superposed response modulates radius of scanned circle

Scanning period: *if* $\omega_2 = 1.1\omega_1$, $T = 1/(T_2\text{-}T_1) = 10T_1$

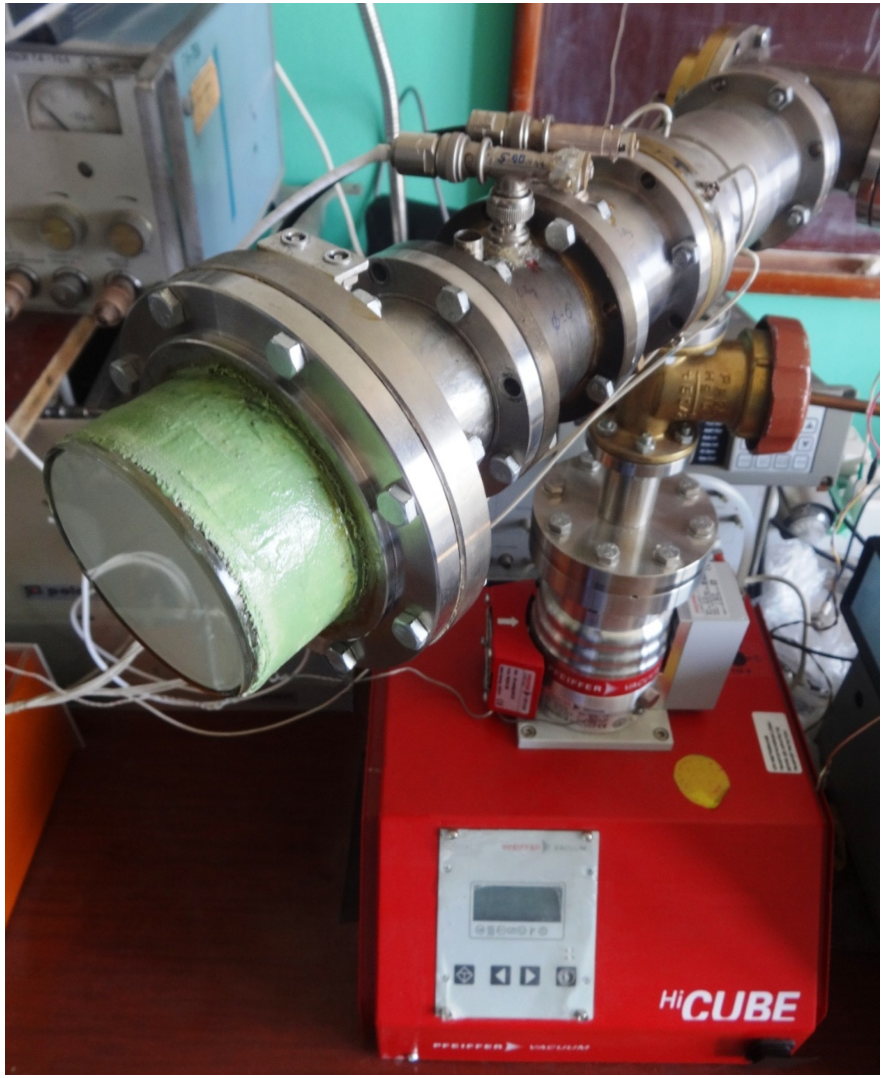
Spiral scanning with 2 RF deflectors



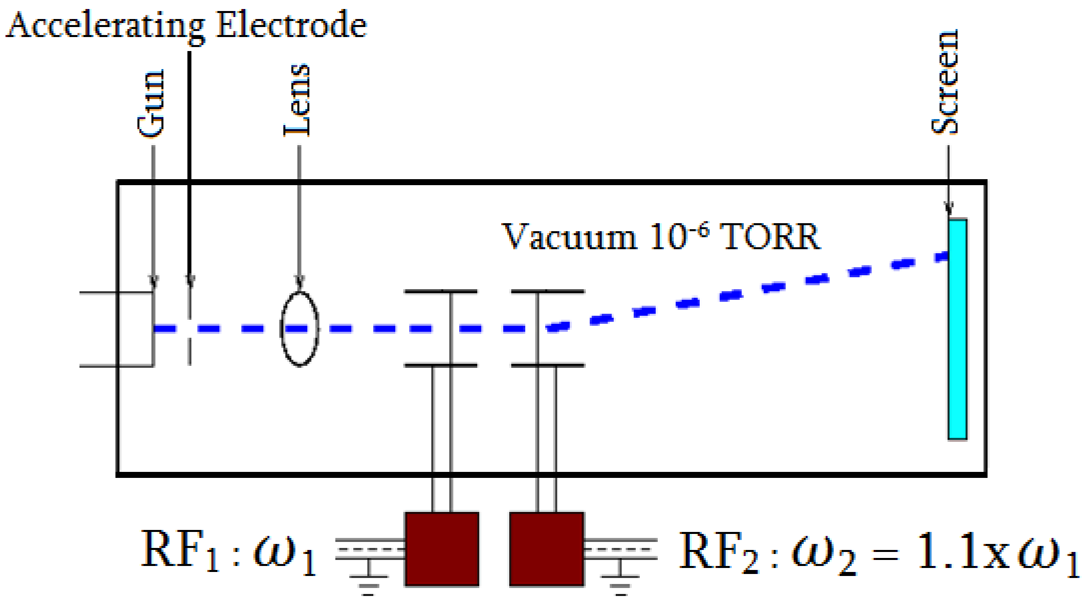


$$R_{max} = R_1 + R_2, \quad R_{min} = |R_1 - R_2|$$

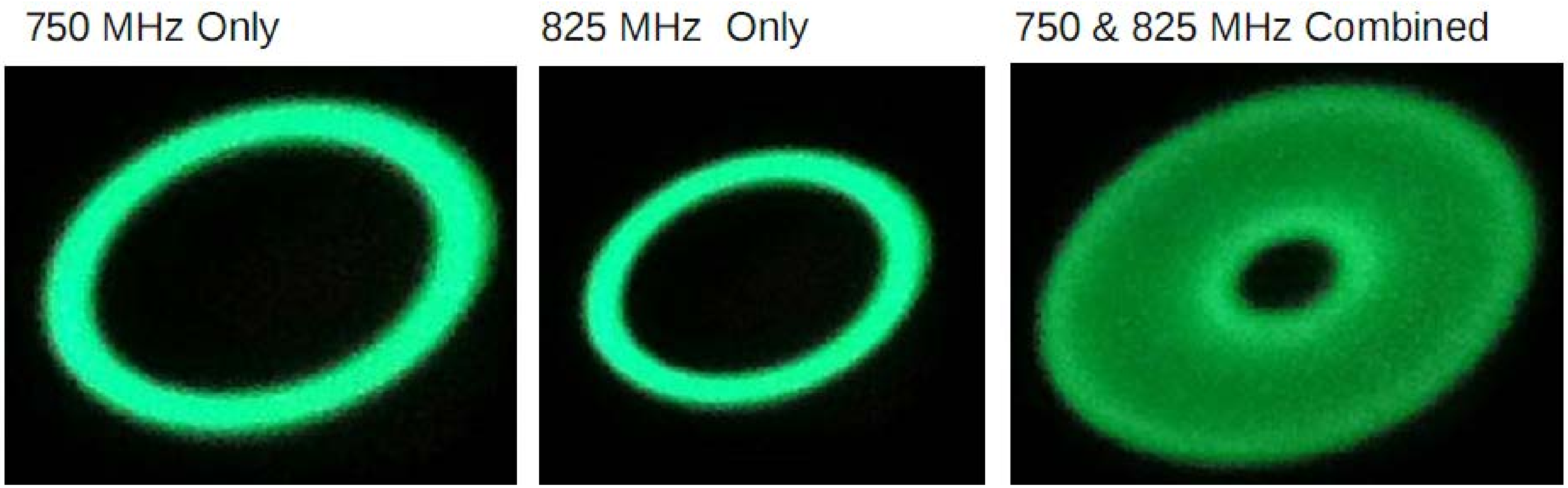
Experimental setup at ANSL



Spiral Scanning: Experiment with phase-independent deflectors



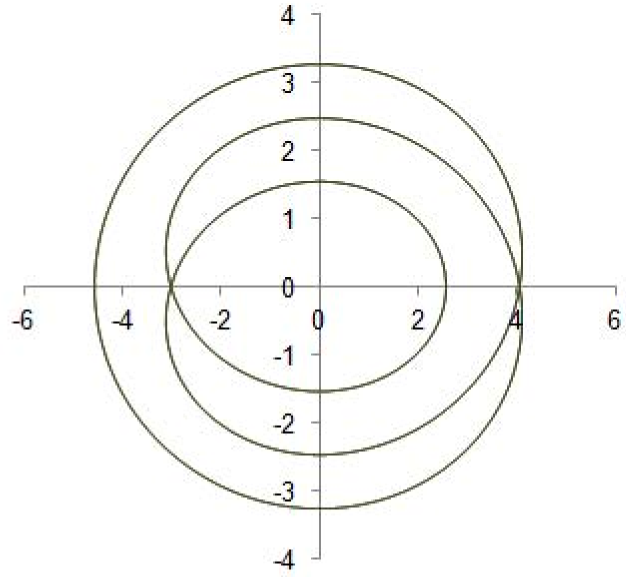
Uniform discoid image is a spiral with overlapped contours

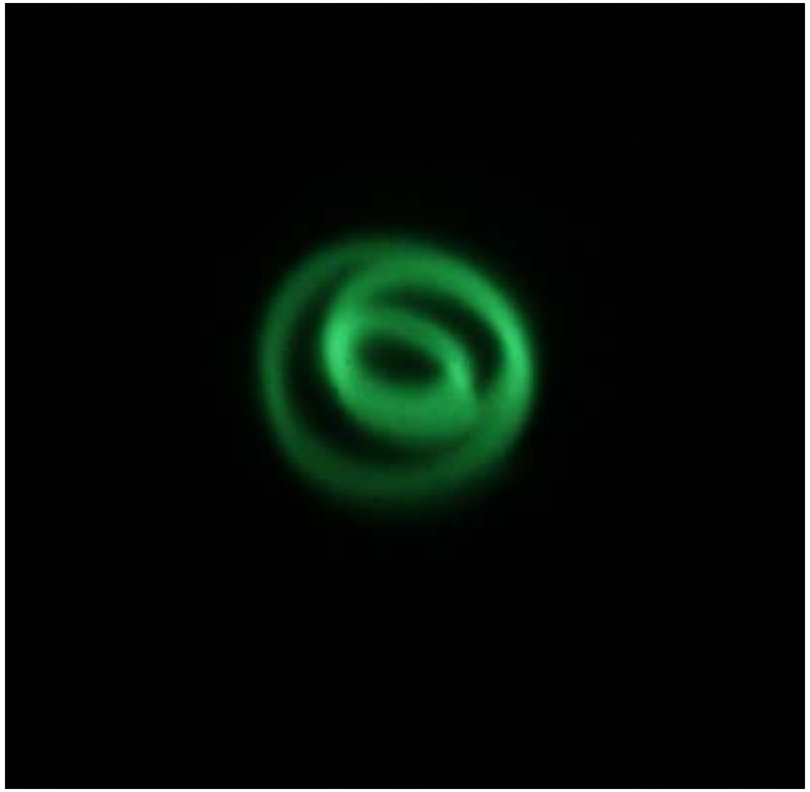


Experiment with Phosphor Screen

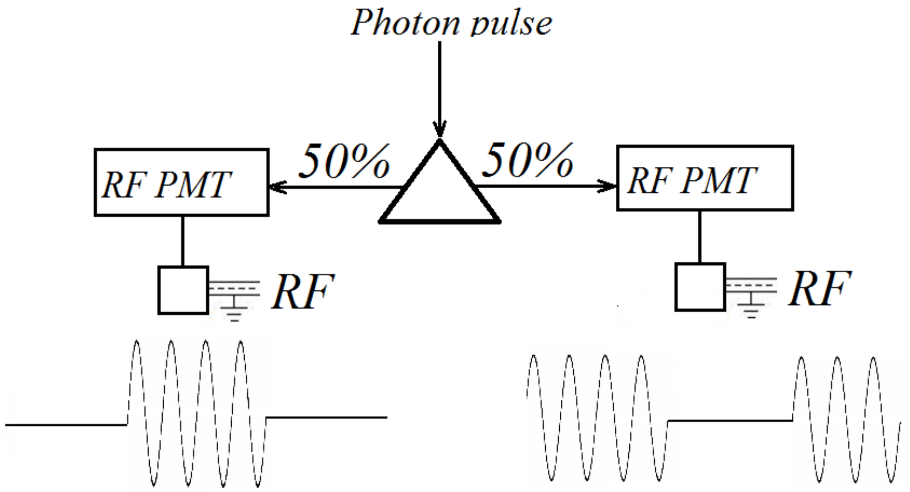
RF_1 and RF_2 are phase-locked

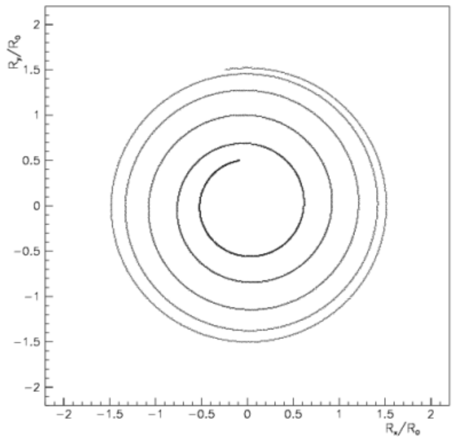
500 & 750 MHz combined

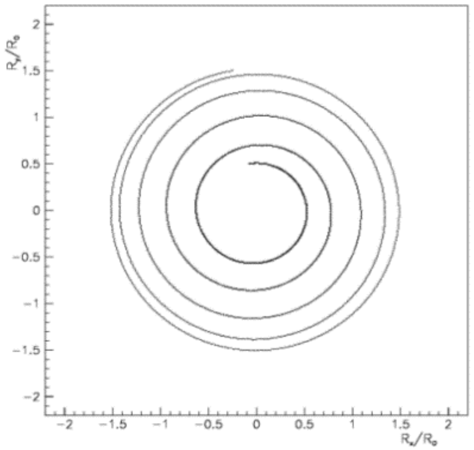


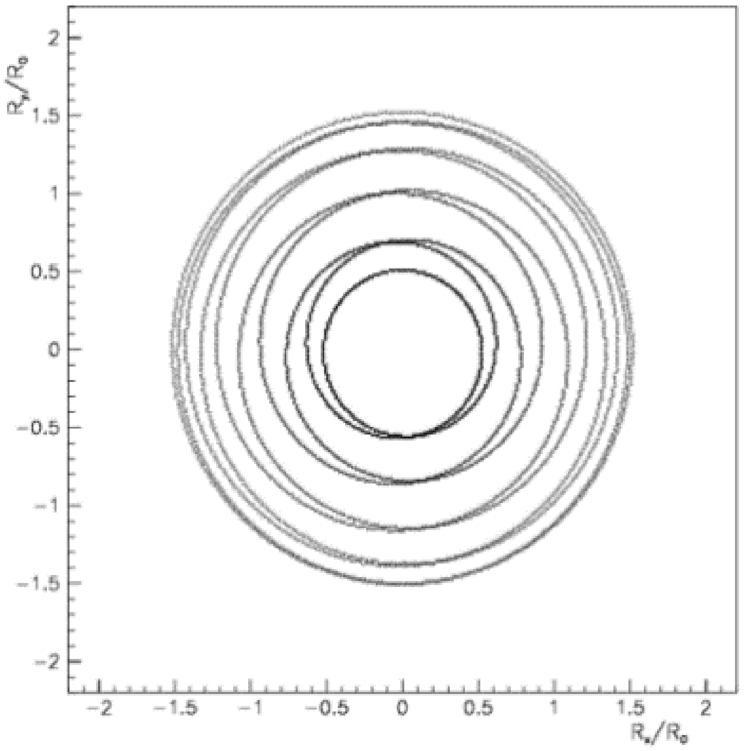


Overlapping can be avoided by using gated detectors









Full period

Expected performance

- Time resolution is in picosecond range
- Period of the spiral can range from few 10 ns to few 100 ns -> THz bandwidth, THz sampling rate
- Dynamic range: with regular nanosecond readout electronics, it’s virtually unlimited

Possible Applications

High Energy Physics
- **Bunch length detection**
- **High precision time of flight measurements**
- **Momentum measurement, Particle ID**

Medical Imaging
- **Positron Emission Tomography**
- **Diffuse Optical Tomography**
- **Fluorescence Lifetime Imaging**

- **Positron annihilation spectroscopy**

Summary and Outlook

- Circular scanning (0.5 - 1 GHz) helical RF deflector for keV energy electrons is developed (theory and experiment)

- Mk1 of the circular scanning RFPMT recently constructed by Photek Ltd. (UK) using finances provided by the Scottish Universities Physics Alliance. Commissioning and testing of this new device will be a collaborative effort between UGLA, ANSL and CANDLE

- Theory of spiral scaning with 2 RF deflectors is developed

- Spiral scaning is demonstrated with 2 independent RF deflectors

- Development of spiral scanning with 2 phase locked RF deflectors is continuing at ANSL to construct and test the Lego RF Timer based on the air resistive photocathodes, multipixel anodes and Timepix readout electronics

Thank you for attention