Photon Detector for AFP

Amur Margaryan
Alikhanyan National Science Laboratory, Yerevan, Armenia

LHC forward physics meeting, August 27

Outline

- **LHC AFP: Experimental Challenges**
- **Radio Frequency Photomultiplier Tube: principles of operation**
- **Measured and simulated performance**
- **Pixelated anode: new photon timing technique**
- **MCP+MPPC forward to THz photon detector**
- **AFP Cherenkov counters with RF Photomultiplier Tube**

LHC AFP Timing System Requirements

- **10ps or better resolution**
- **Acceptance that fully covers the proton tracking detectors**
- **Efficiency near 100%**
- **High rate up to 100 MHz capability**
- **Multi-proton timing in a 200ps duration bunch-crossing**
- **Level 1 trigger capability**
- **Radiation tolerant**
- **Robust and reliable**

Timing System Components

i) The Detector (radiator and photon detector)

ii) The readout electronics

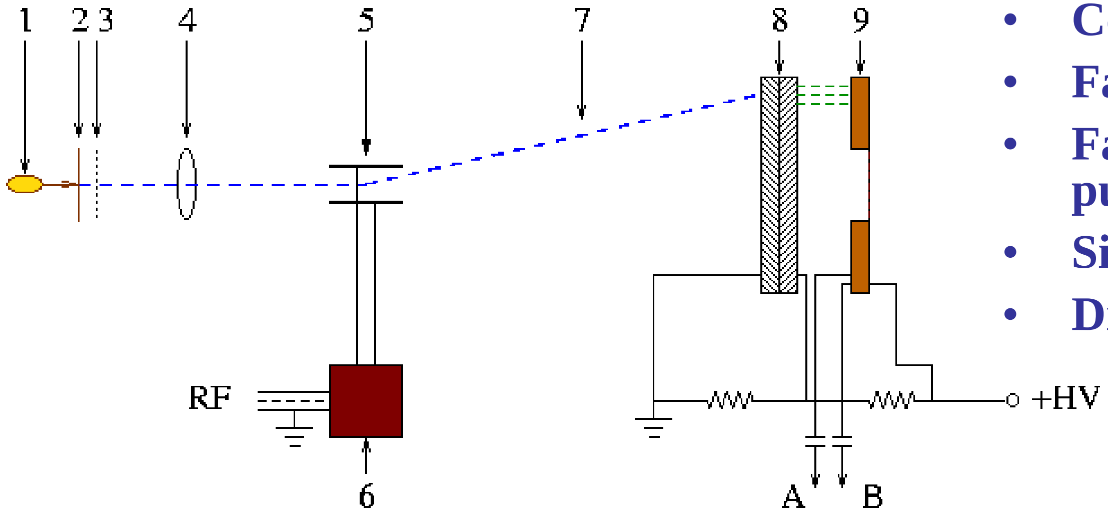
iii) The reference timing system

We propose to use

- **Cherenkov GASTOF or QUARTIC as a radiator**
- **The RF PMT with dedicated readout system as a photon detector**
- **The LHC RF system as a reference clock**

The Radio Frequency Photomultiplier Tube

Point Cathode RFPMT Schematic



- **Circular sweep RF deflection of PEs**
- **Convert time to spatial dependence**
- **Fast position sensitive PE detector**
- **Fast, nanosecond range, output pulse**
- **Single photon counting possible**
- **Different anode structure possible**

Operates similar to circular scan streak camera but produces ns output pulses like regular PMT

1-Photon pulse, 2-Photocathode, 3-Accelerating electrode, 4-Electrostatic lens, 5-RF deflector, 6-λ/4 RF resonator, 7-Photoelectrons, 8-Dual MCPs, 9-Position sensitive anode, A and B nanosecond signals

A. Margaryan et al., Nucl. Instr. and Meth. 566, 321, 2006; US Patent 8138460

0.5-1.0 GHz RF Scanning System

Evacuated Test Tube with Thermionic Cathode

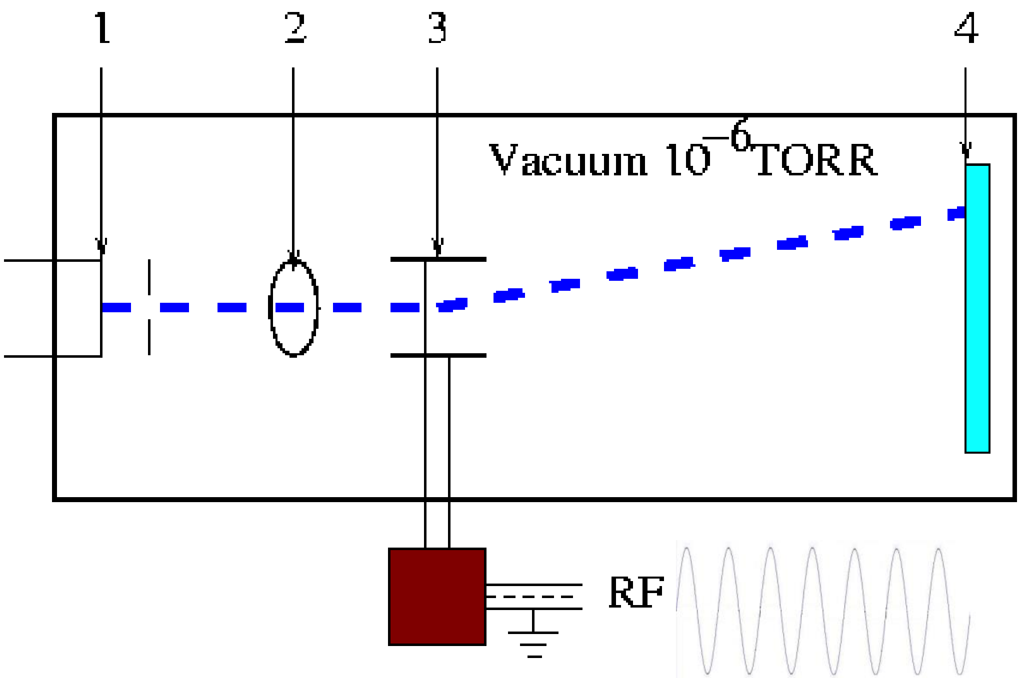
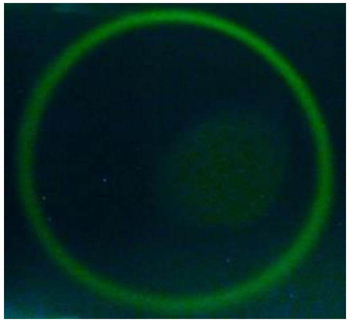


Image of CW 2.5 keV electron beam circle with radius ~20 mm



Sinusoidal voltage Vpp = 20 V
Scan radius 1mm/V or 0.1 rad/$W^{1/2}$

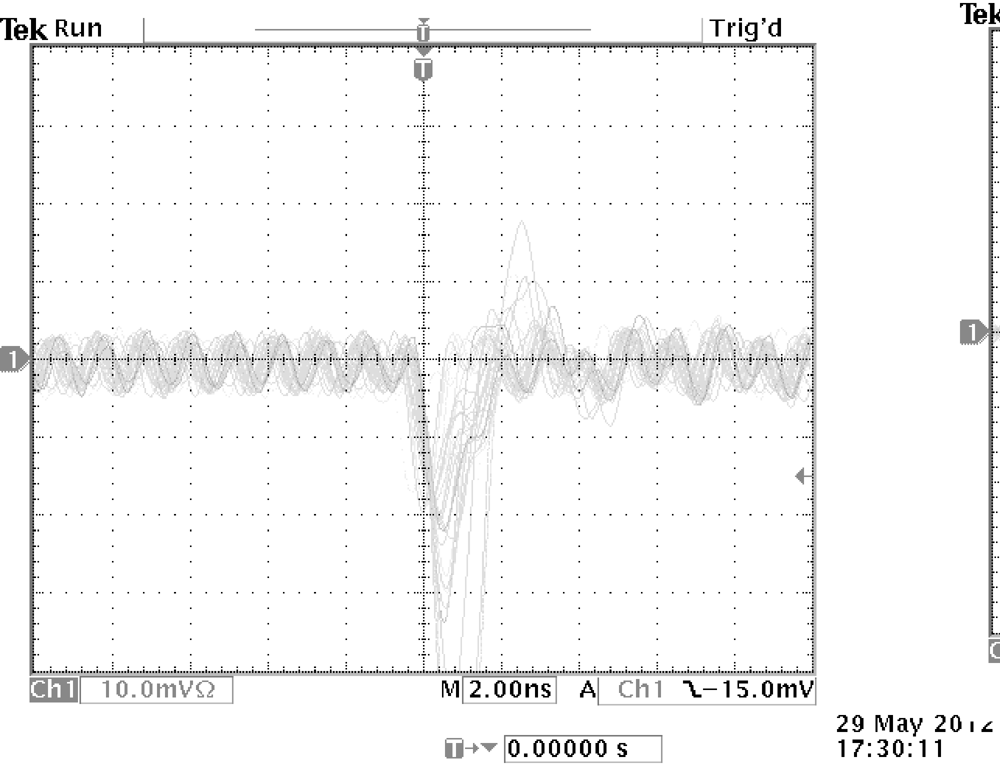
1- Electron gun 2- Electrostatic lens
3- RF deflector 4-Phosphor screen

Period and Sensitivity
0.5 GHz → 2 ns → 16ps/mm
1.0 GHz → 1 ns → 8ps/mm

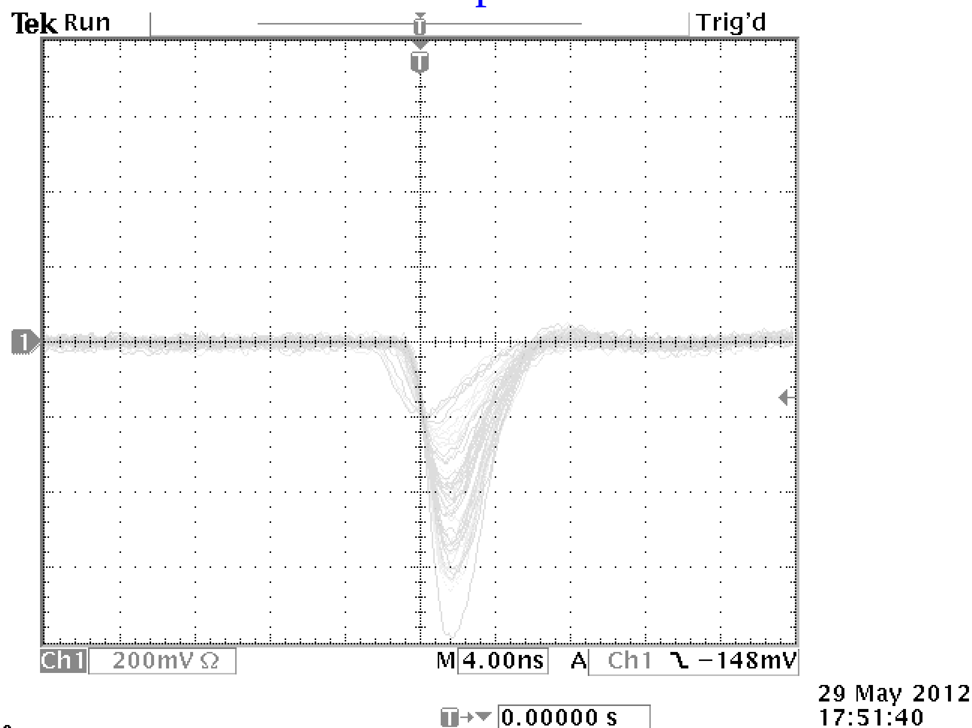
1 GHz RFPMT Output Pulses: Resistive Anode

Circularly scanned 2.5 keV electrons incident on
Baspik, 25-10y, Chevron MCP array

Output signal of RFPMT anode



After amplifier

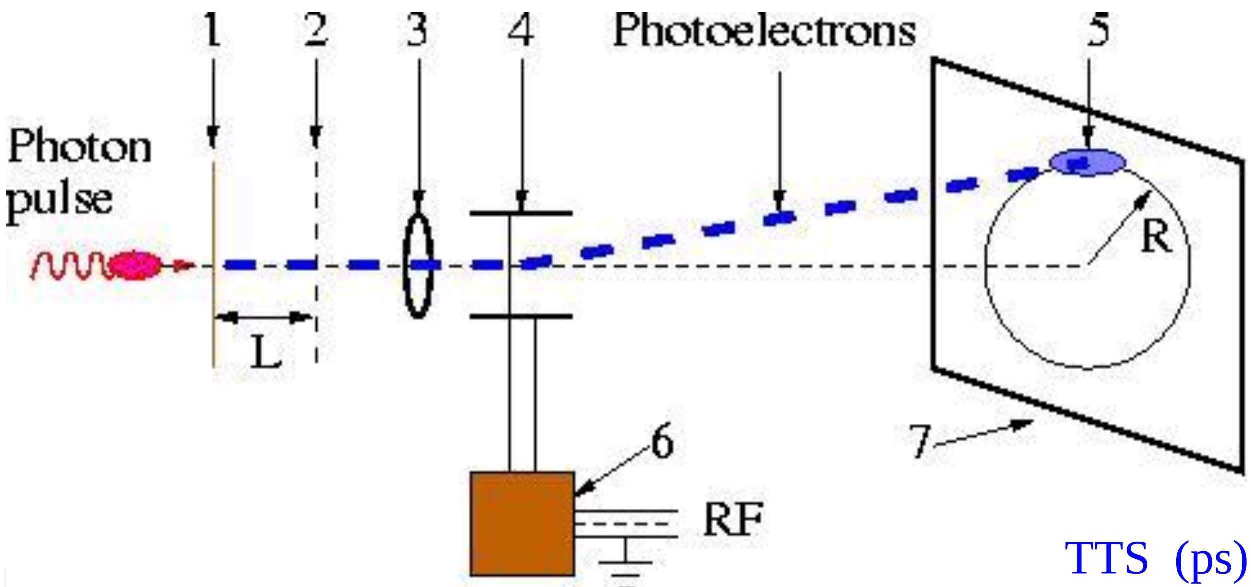


Recorded by TDS3054B, 500 MHz

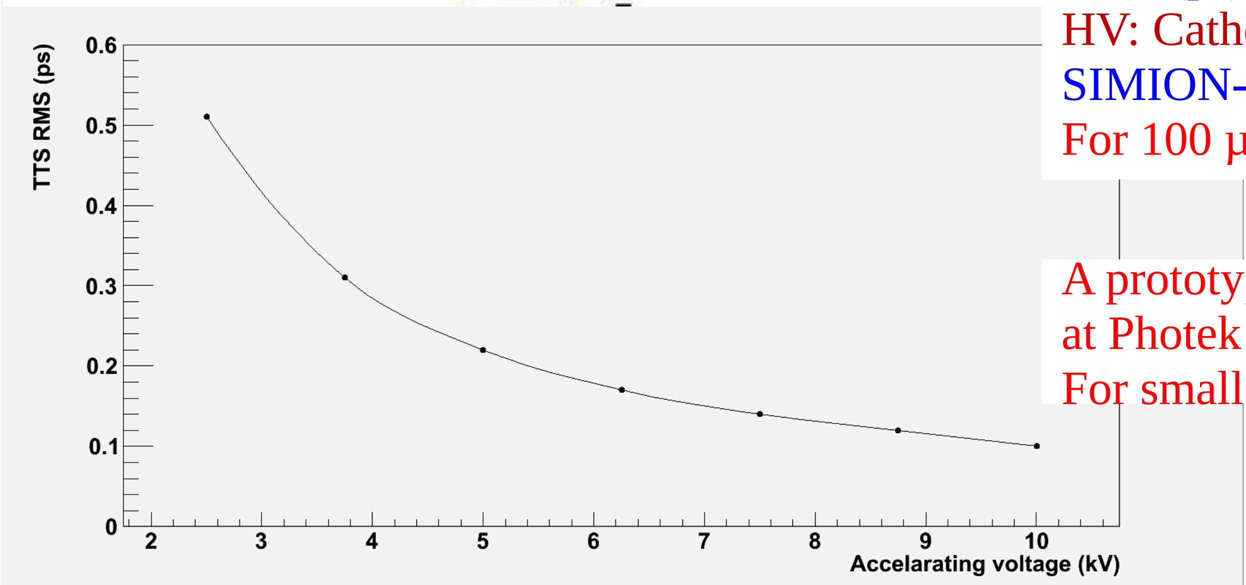
A. Margaryan et al., PhotonDet2012, Saclay, France

Simulation of Transit Time Spread

Small size photocathode RFPMT



1 - photo cathode
2 - accelerating electrode
3 - electrostatic lens
4 - RF deflection electrodes
5 - image of PEs
6 - λ/4 RF coaxial cavity
7 - SE detector

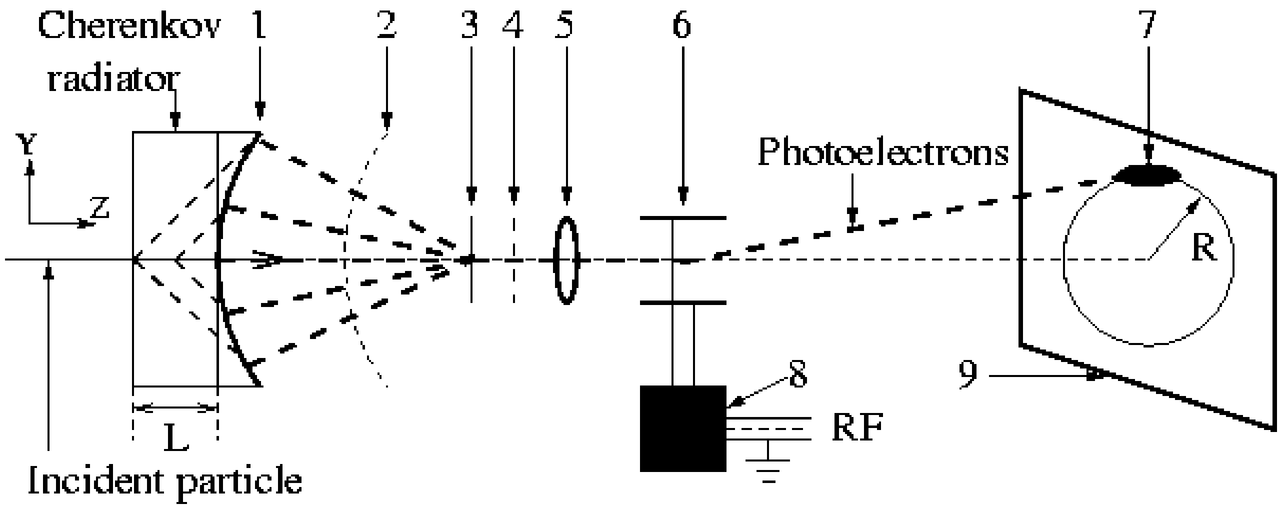


TTS (ps) to MCP electron detector
HV: Cathode (1) to Electrode (2)
SIMION-8
For 100 μm cathode TTS = 1ps

A prototype RFPMT has been designed at Photek Ltd
For small size photocathode TTS = 1ps

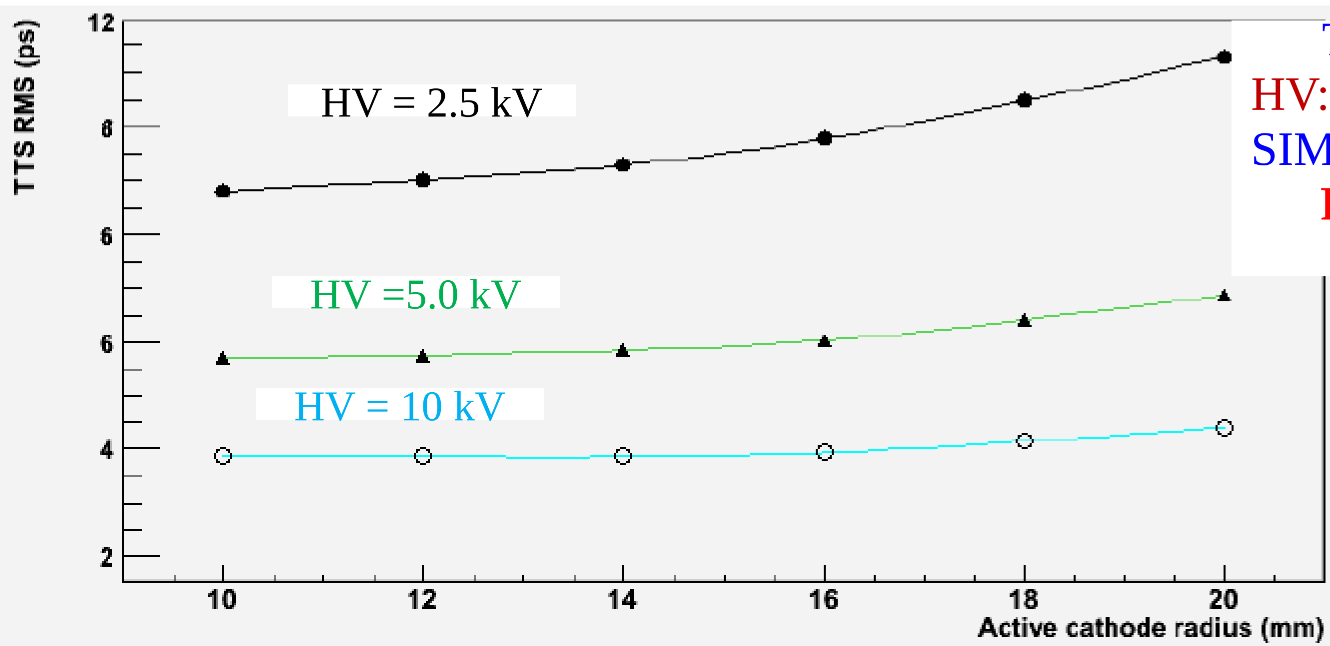
TTS: Large Size Photocathode RF PMT

The large size photocathode is based on “spherical-capacitor” type immersion lens



1 - photo cathode
2 - electron-transparent electrode
3 - transmission dynode
4 - accelerating electrode
5 - electrostatic lens
6 - RF deflection electrodes
7 - image of PEs
8 - $\lambda/4$ RF coaxial cavity
9 - PE detector

Simulation does not consider time dispersion of Cherenkov photons



TTS (ps) to cross-over

HV: Cathode (1) to Electrode (2)

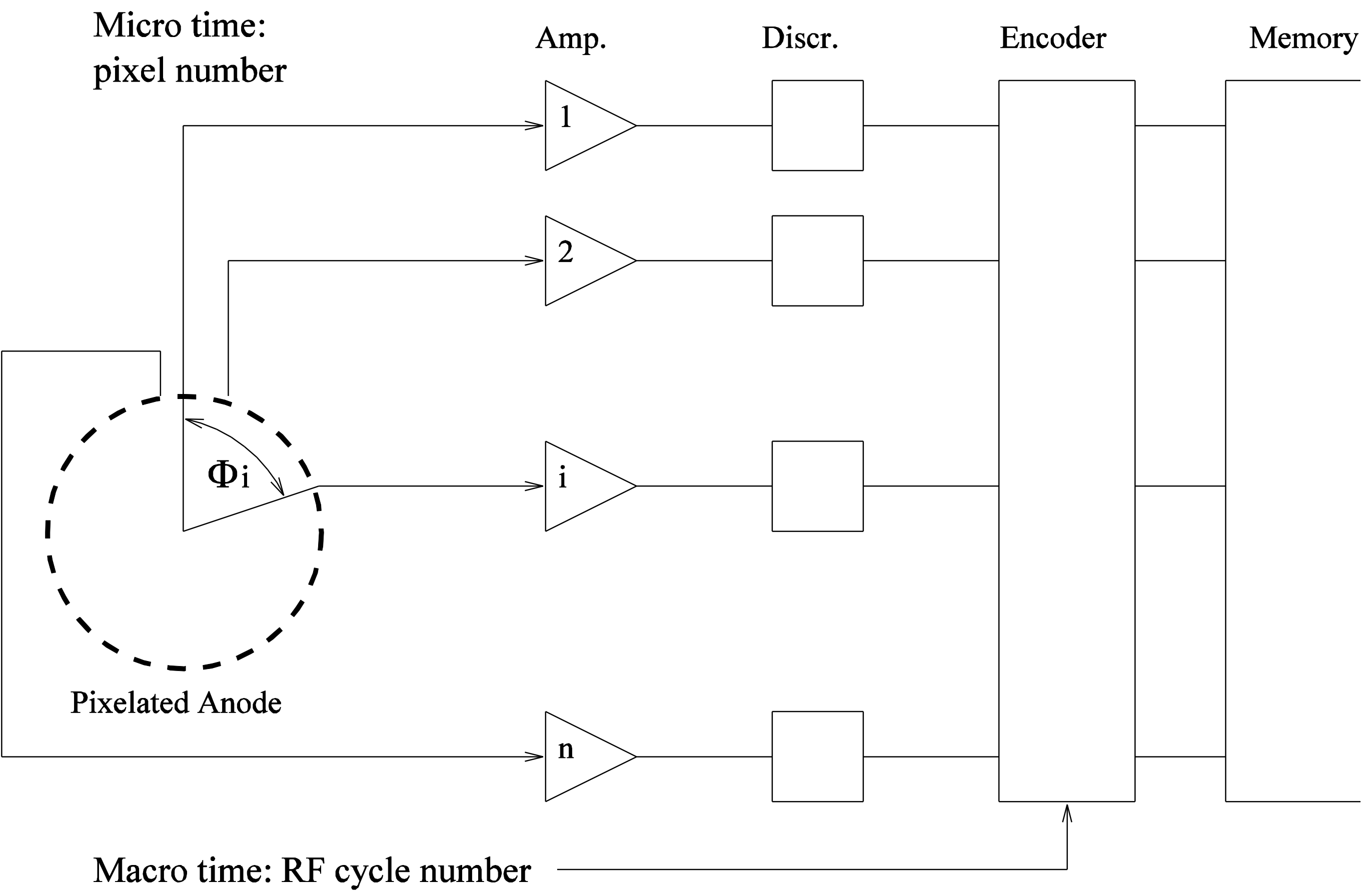
SIMION-8

For extended cathode

TTS < 10ps

R&D continued

Pixelated anode: read time directly



- Position of hit on anode directly related to hit time
- 1st tubes use charge division from resistive anode to obtain Φ
- Pixelated anode records time directly
- Records short flash with high precision
- Or record the time dependence of an extended signal, e.g. Cherenkov flash of several protons from single bunch crossing at LHC

Time = $\Phi/2\pi\nu$

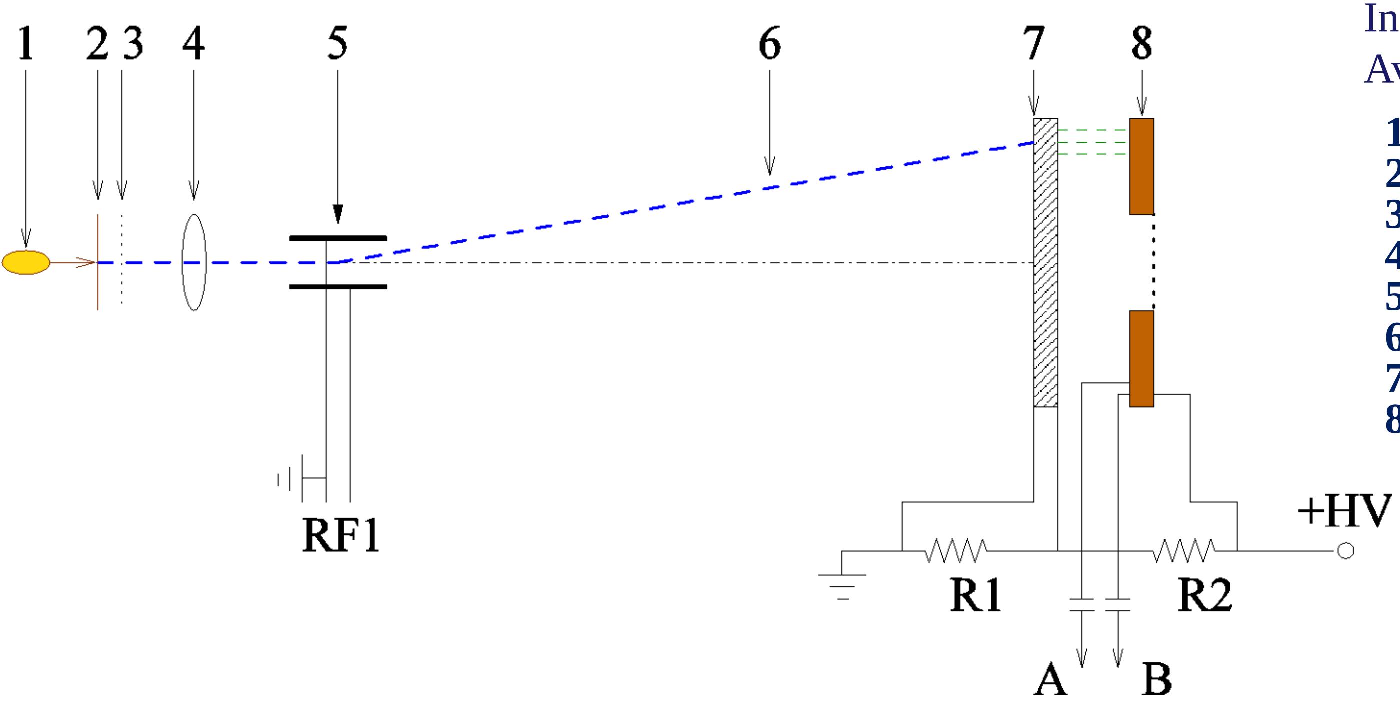
Time resolution = $\Delta\Phi/ 2\pi\nu$

ν is a RF frequency

ν = 800 MHz, 20 mm radius, 10ps/mm

No TDC necessary

MCP+MPPC forward to THz photon detector



Time resolution ~1 ps
Instant rate →100 GHz
Average rate→1GHz

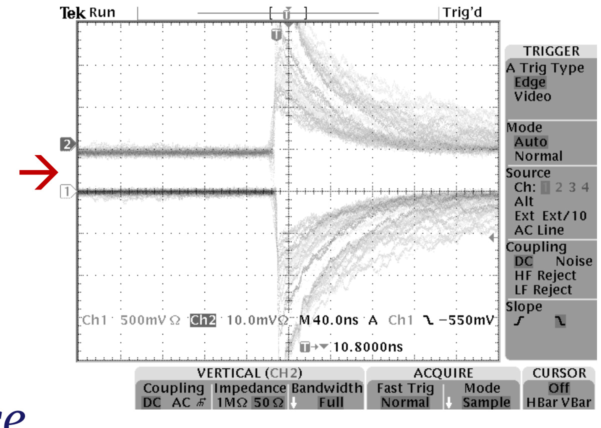
1 - photon flash
2 - photo cathode
3 - accelerating electrode
4 - electrostatic lens
5 - RF deflection electrodes
6 - deflected PEs
7 - single MCP plane
8 - array of MPPC (multipixel APD photon counters)

Rate is determined by PE detector

Single plane MCP + MPPC (Hamamatsu S10362) covered by 20 μm scintillator foil

MCP Gain could be about 10

Direct and Amplified signals



A. Margaryan et al., PhotonDet2012, Saclay, France

Potential RFPMT Applications

High Energy Physics

- Cherenkov Detector
- High precision time of flight measurements
- Momentum measurement, Particle ID
- Proposed use at JLab (e.g. PR12-10-001 experiment)

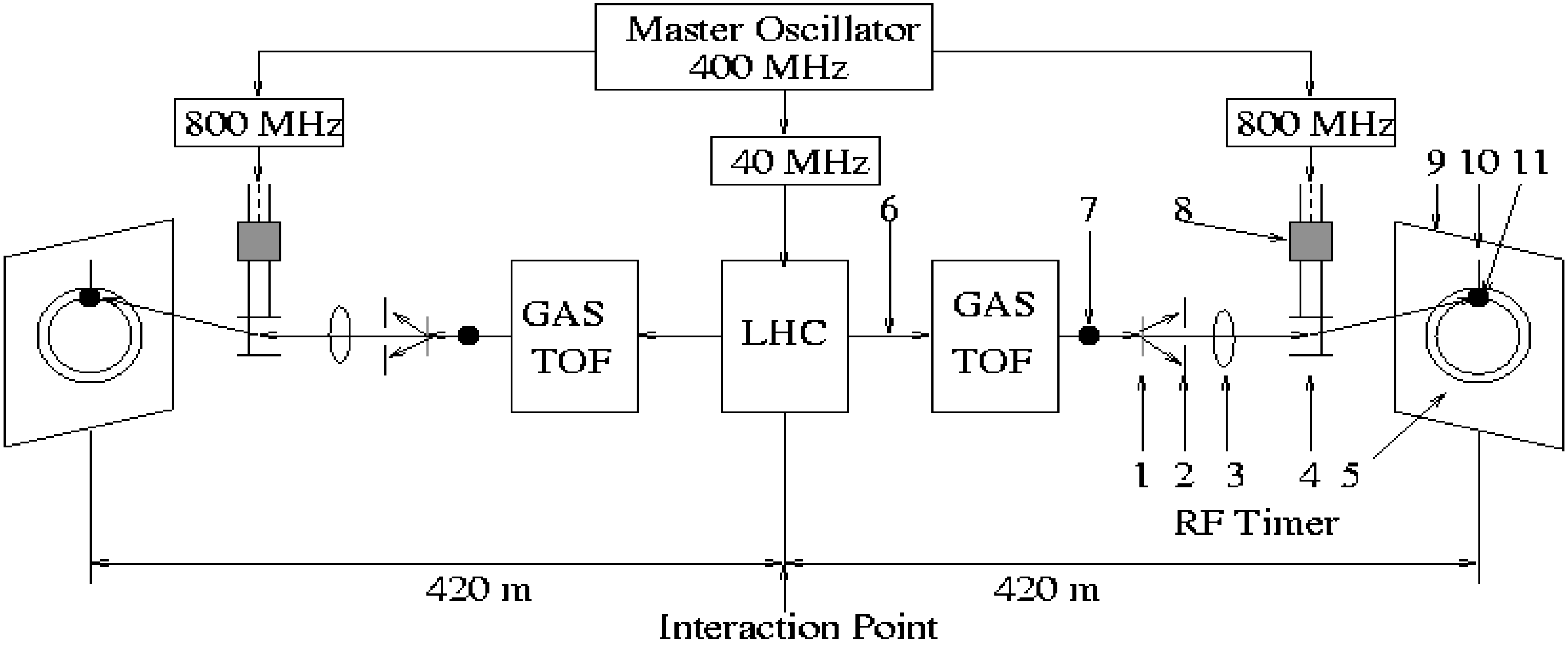
Medical Imaging

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

Other Applications

- Gravitational Red-Shift measurement
- Laser ranging
- Ultrafast science (e.g. photochemical processes in sub-ps range)
- And etc

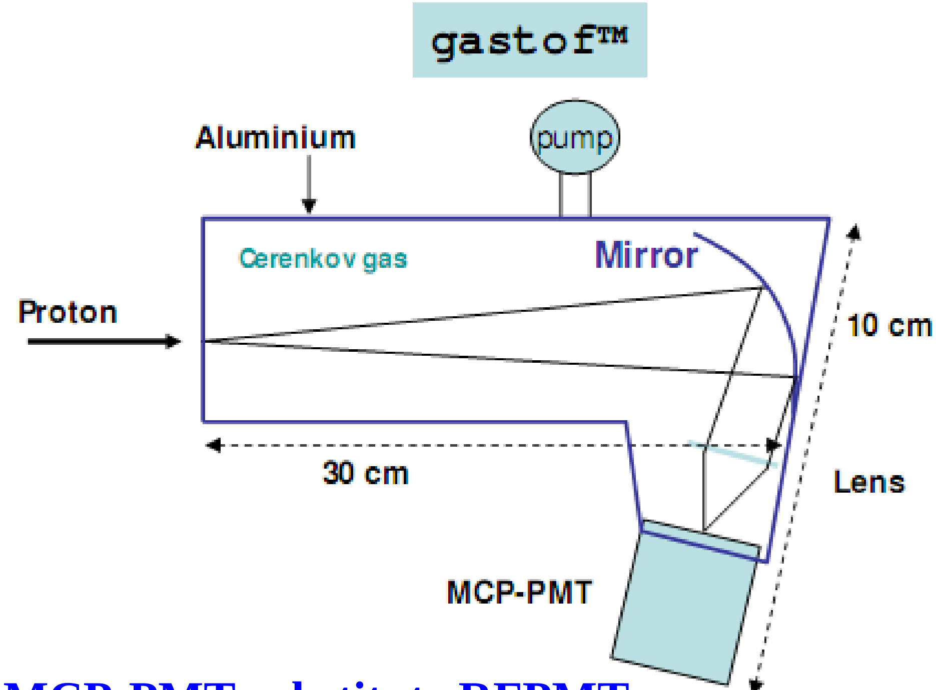
Application at LHC AFP420

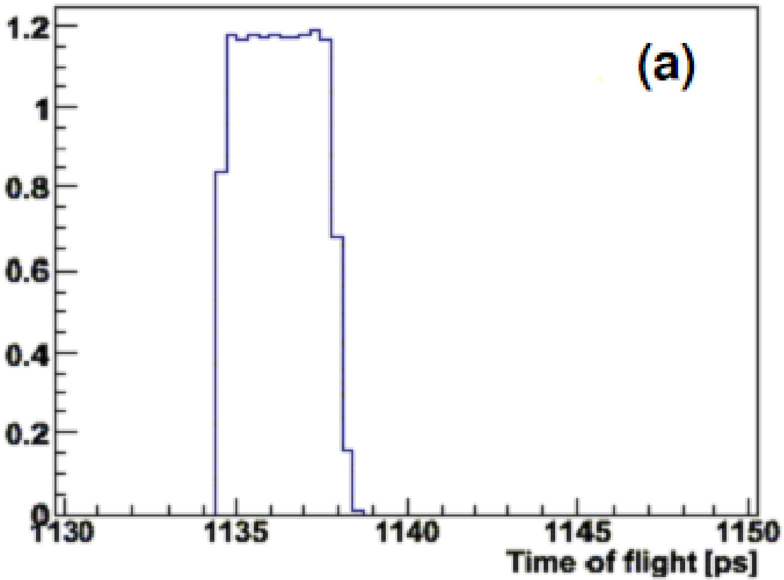


- Measure forward protons produced in collisions at ATLAS by left/right Cherenkov Detectors (GASTOF or QUARTIC). Times T1 & T2.
- Use LHC RF for synchronized operation of RFPMT with LHC bunches.
- Timing calibration from independent vertex measurement.
- Background rejection from interaction point from T1-T2 and T1+T2.

LHC AFP420 Cherenkov GASTOF

M.G. Albrow et al., arXiv:0806.0302v2 [hep-ex]





MCP-PMT substitute RFPMT

Cherenkov GASTOF (left) and MC time distribution of Cherenkov photons at MCP-PMT photocathode (right)

Separation of multi-proton events in each arm , originated in bunch-crossing zone

$\Delta z \approx$ 5.5cm($\approx$180ps) with arrival time, if the Cherenkov flash is shot

Requirements to the Cherenkov light generation and collection

*** Should provide a minimal time jitter of the outgoing photons to the entry of photon detectors , otherwise will be no need in detectors with superior time resolution.**

***The Cherenkov light should be focussed into RFPMT photocathode with minimized spot size/small cathode diameter, allowing the best performance of RFPMT.**

*** Both, the QUARTIC and GASTOF detectors can be used with RFPMT. No need in radiator sampling and corresponding quantity of fast electronics. The single layer/single bar of QUARTIC seems is enough for 100% registration efficiency (to be investigated).**

*** The Cherenkov light generation and collection should be investigated and optimized.**

Summary and Outlook

- **Extensive testing with thermionic electron source**
  RF deflector works effectively; achieves ~0.1 rad/$W^{1/2}$ (1 mm/V)

- **Dedicated circular scanning works up to 1 GHz**

- **Simulation predicts a small transit time jitter , ~1ps for small size (100 μm) cathode and around 5-10ps for extended one with diameter app. 40mm.**

- **RFPMT with MCP+MPPC PE detector looks as ideal for LHC AFP GASTOF/QUARTIC timing detectors**

- **A prototype with small size photocathode RFPMT, chevron MCP array and resistive anode has been designed at Photek Ltd. Need in funding to start a small-scale production and quantitative testing of timing precision (can be performed at Yerevan by using experimental setups at ANSL and at CANDLE)**

- **Potential applications in many other fields is identified**

- **Development is continuing at Yerevan, but the way for fastest application is the organization of R&D at CERN with interested groups involved**

Special thanks to Hrachya Hakobyan and Christophe Royon for continues discussions. We are looking forward to possible collaboration.

Thanks for your attention