Picosecond Photon Detectors for the LHC-AFP

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Outline

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

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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

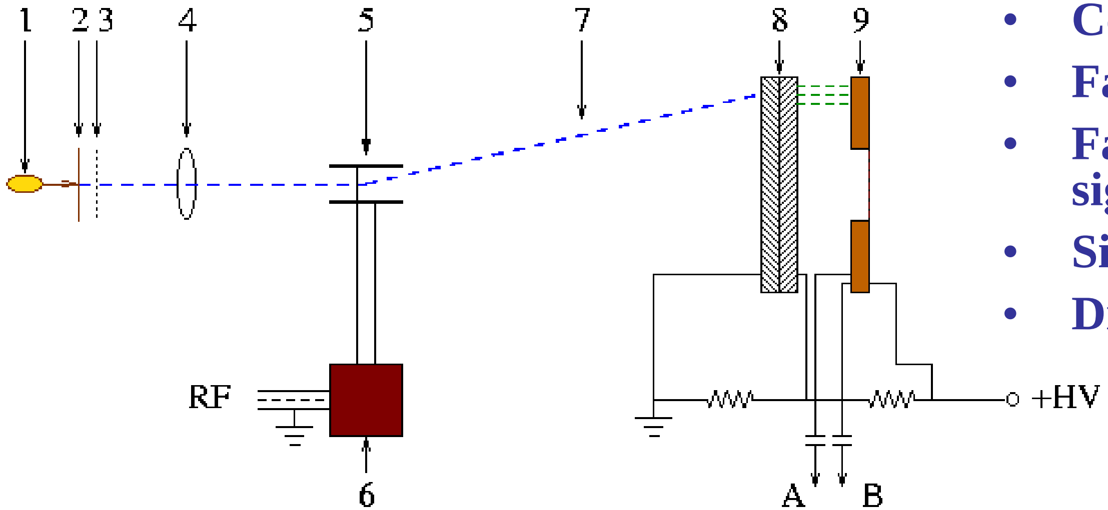
iii) The reference timing system

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, electrical signal**
- **Single photon counting possible**
- **Different anode structure possible**

Operates similar to circular scan streak camera
but
produces ns scale electrical signals like regular PMT

1-Photon pulse, 2-Photocathode, 3-Accelerating electrode, 4-Electrostatic lens, 5-RF deflector, 6-$\lambda/4$ 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

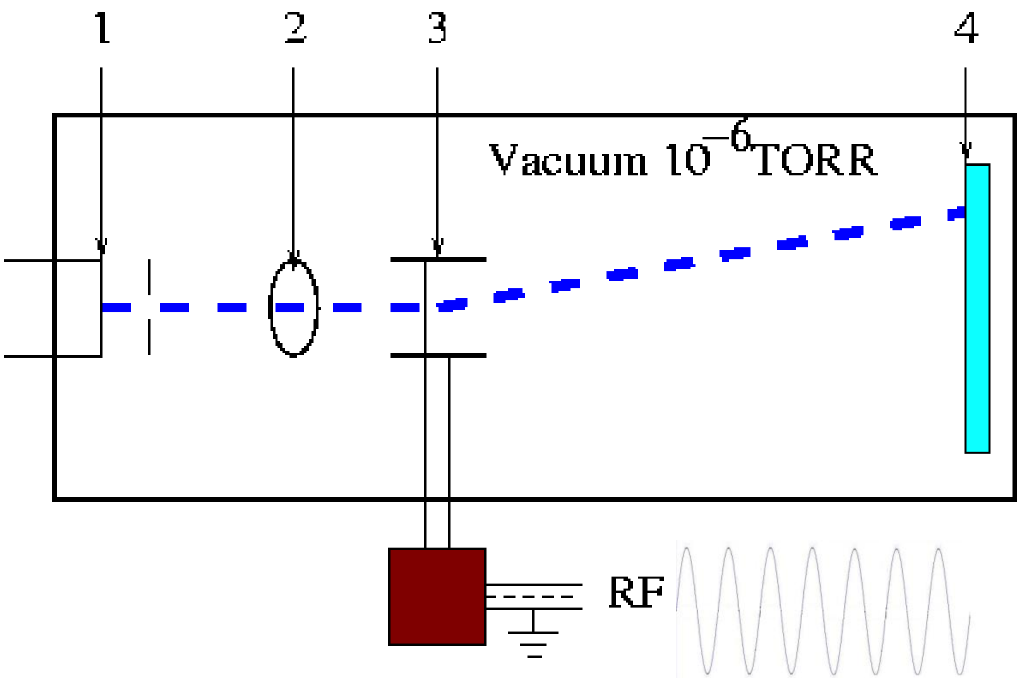
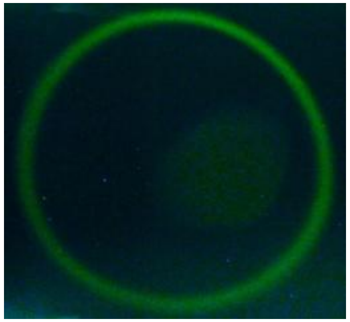


Image of CW 2.5 keV electron beam circle with radius ~20 mm



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

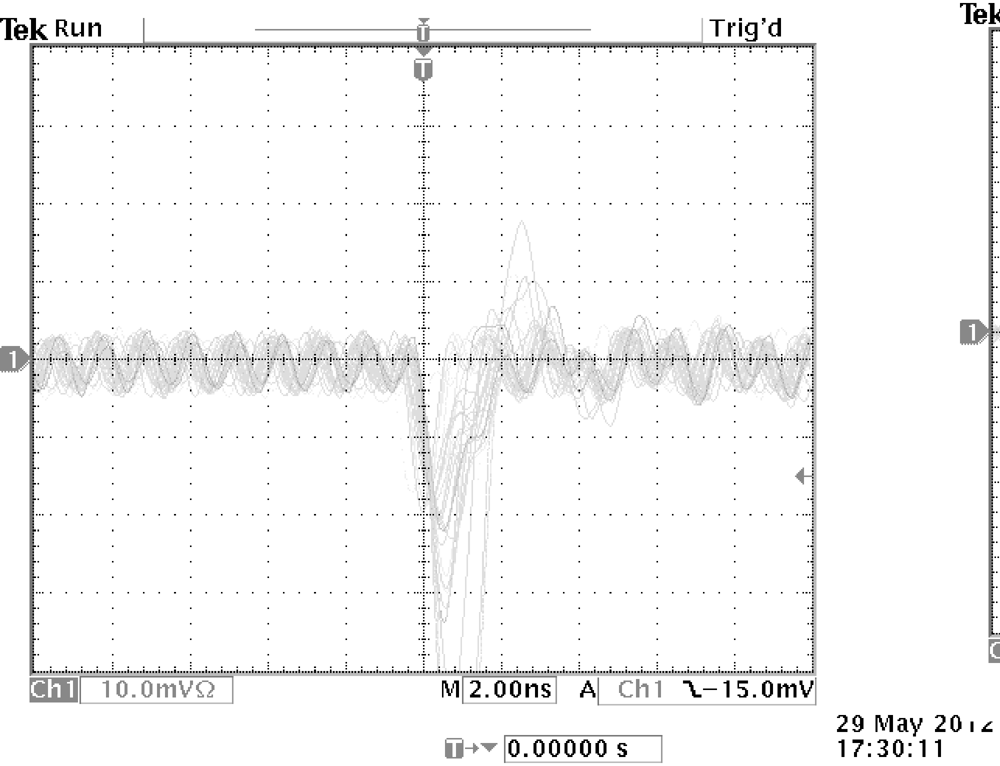
1- Electron gun 2- Electrostatic lens
3- RF deflector 4-Phosphor screen

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

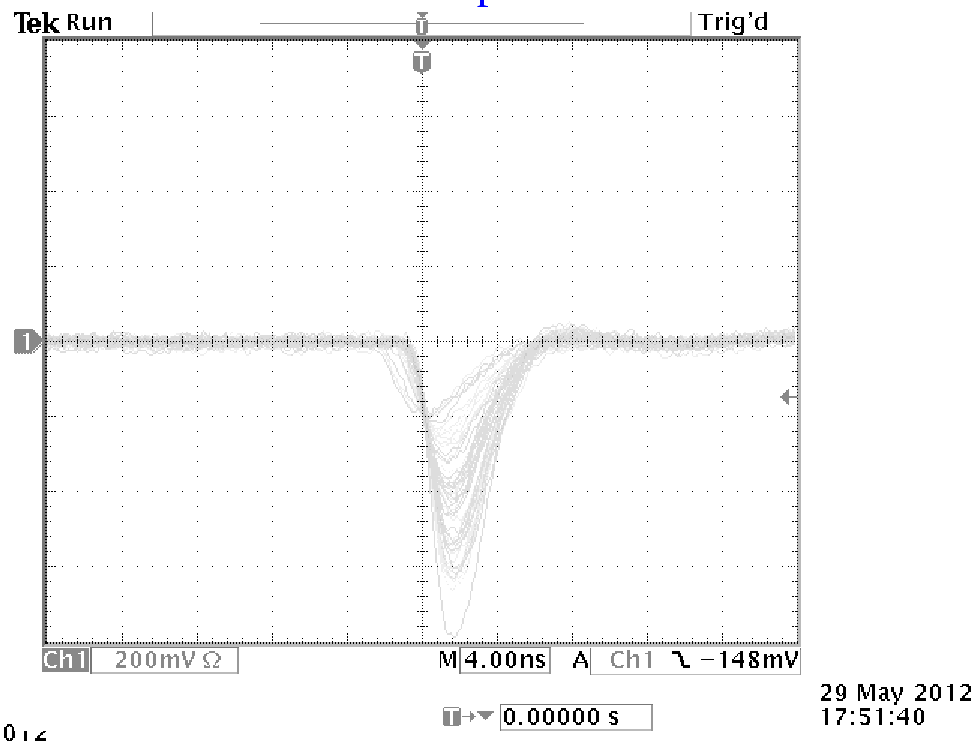
1 GHz RFPMT Output Pulses: Resistive Anode

Circularly scanned 2.5 keV electrons multiplied in
Baspik, 25-10y, Chevron MCP array, readout from resistive anode

Output signal of RFPMT anode



After amplifier

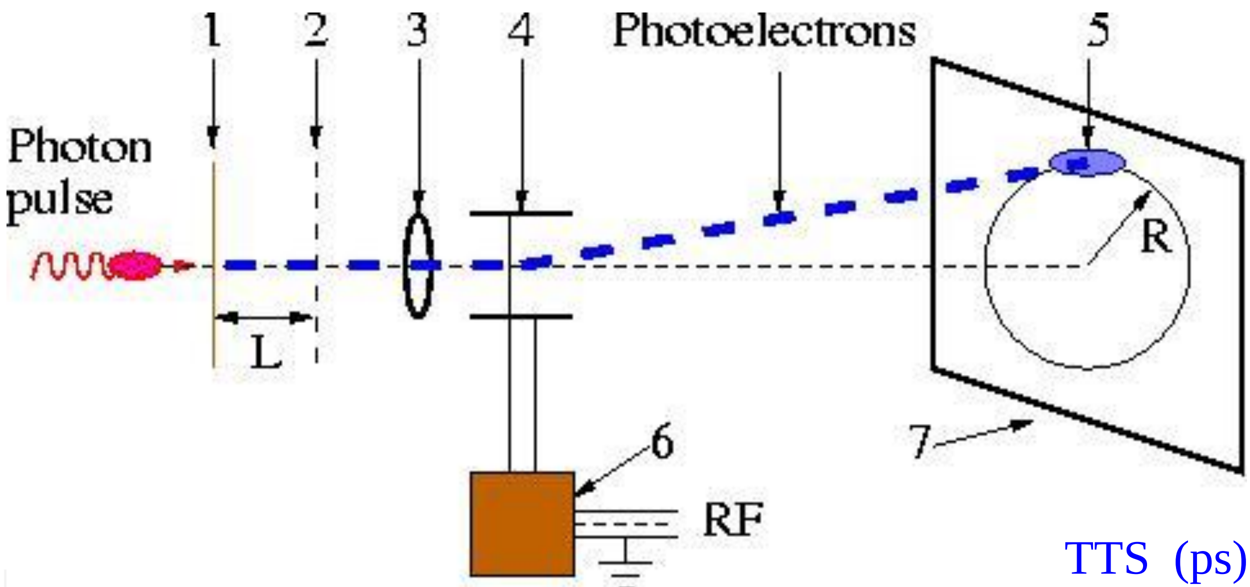


Recorded by TDS3054B, 500 MHz

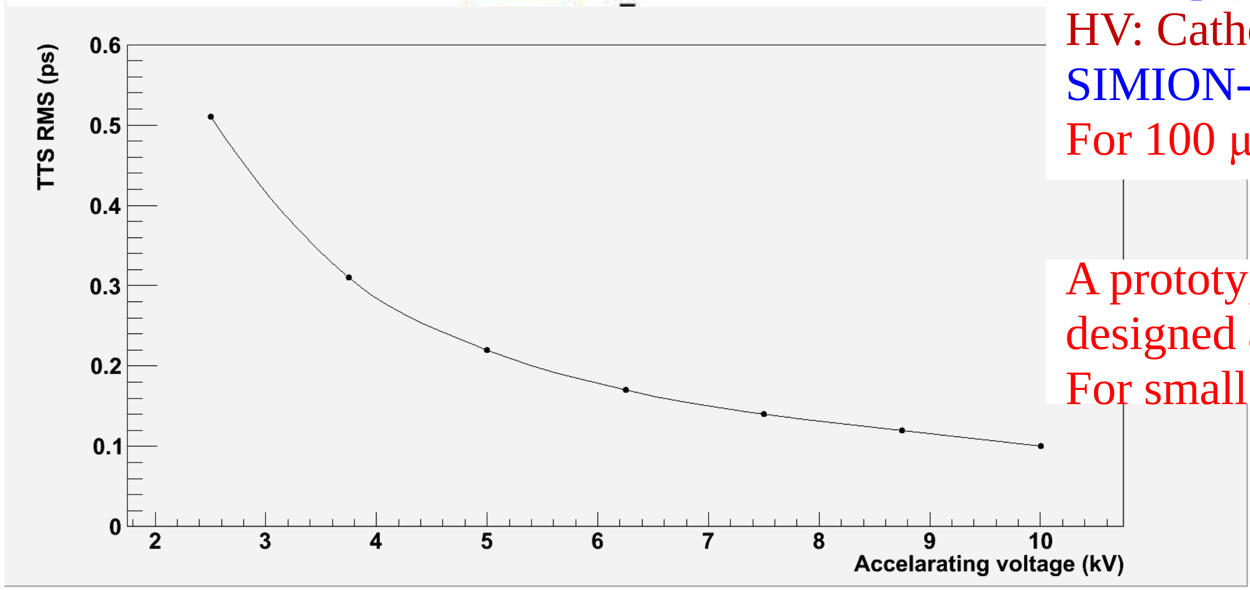
A. Margaryan et al., PhotonDet2012, Saclay, France

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

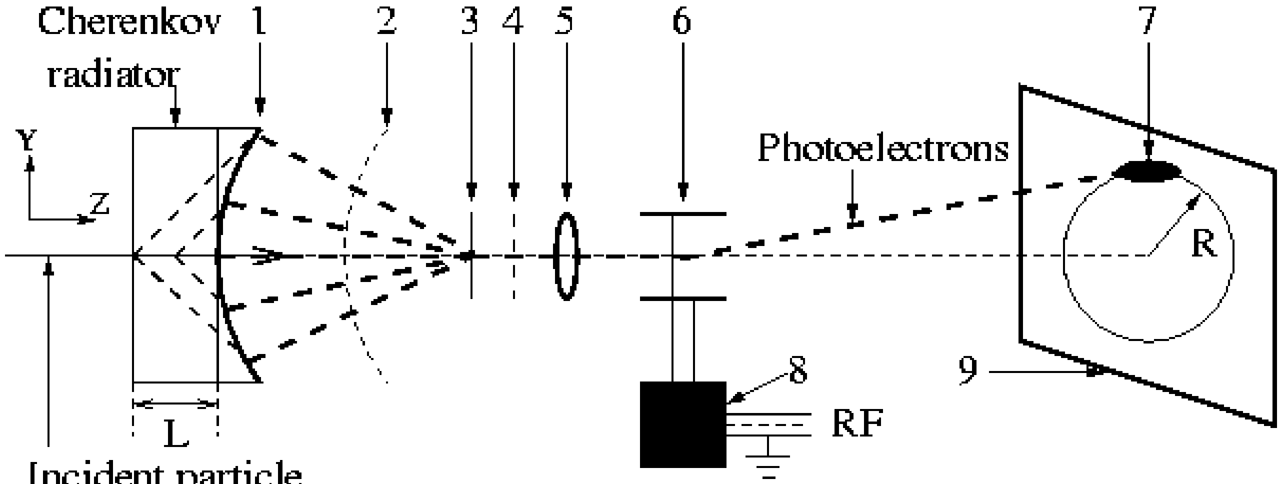


TTS (ps) to MCP electron detector
HV: Cathode (1) to Electrode (2)
SIMION-8
For 100 μm cathode TTS = 1ps

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

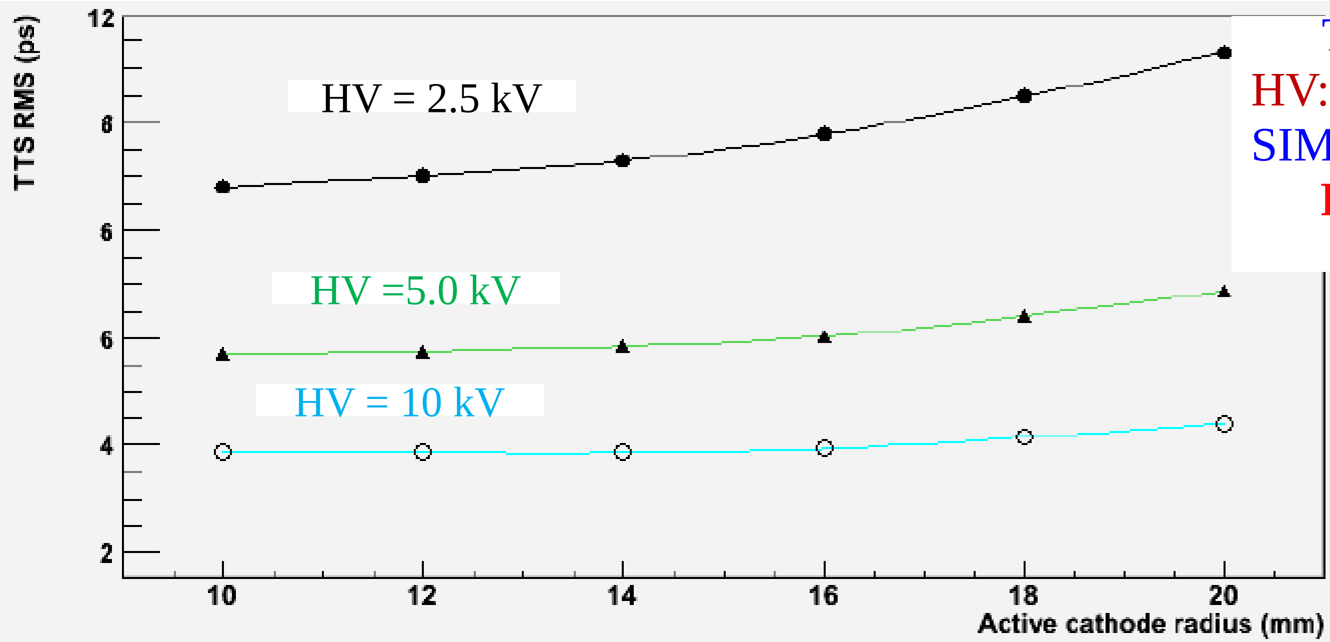
TTS: Large Size Photocathode RF PMT

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)

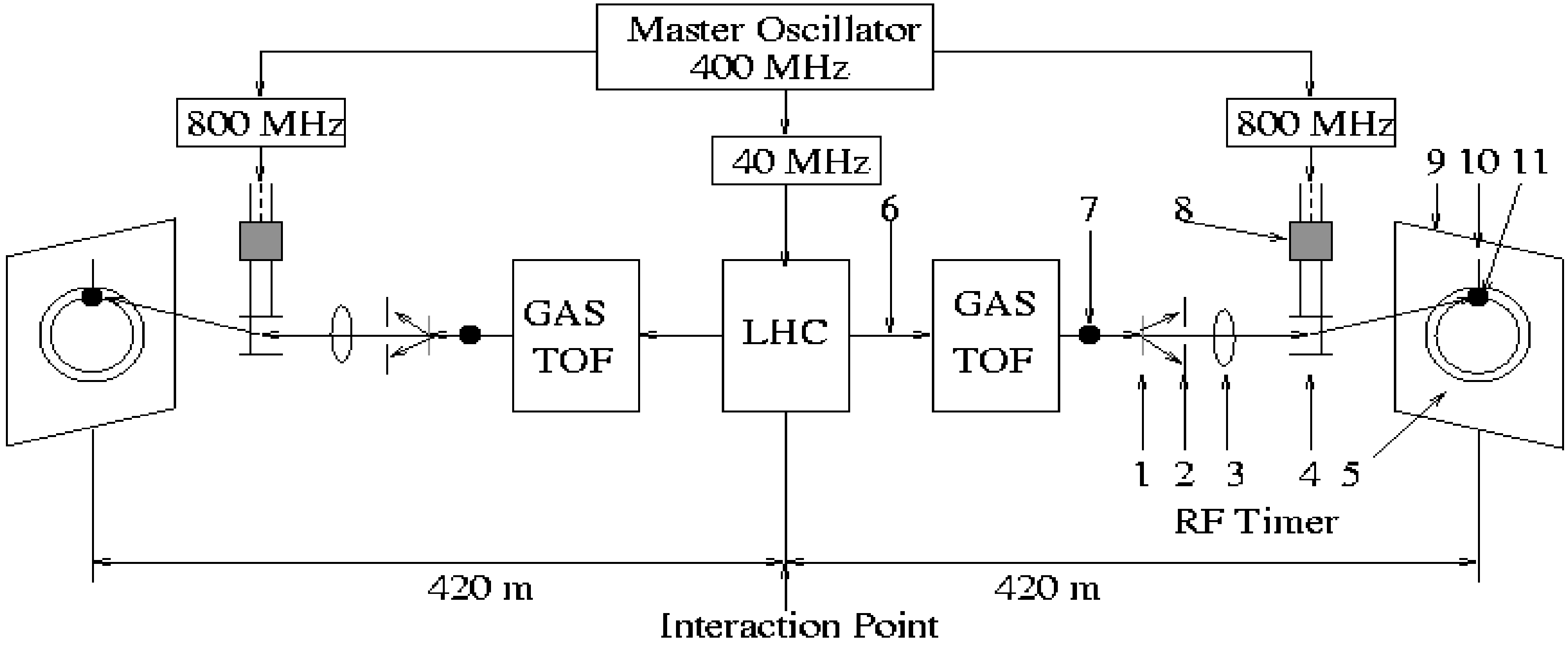
SIMION-8

For extended cathode

TTS < 10ps

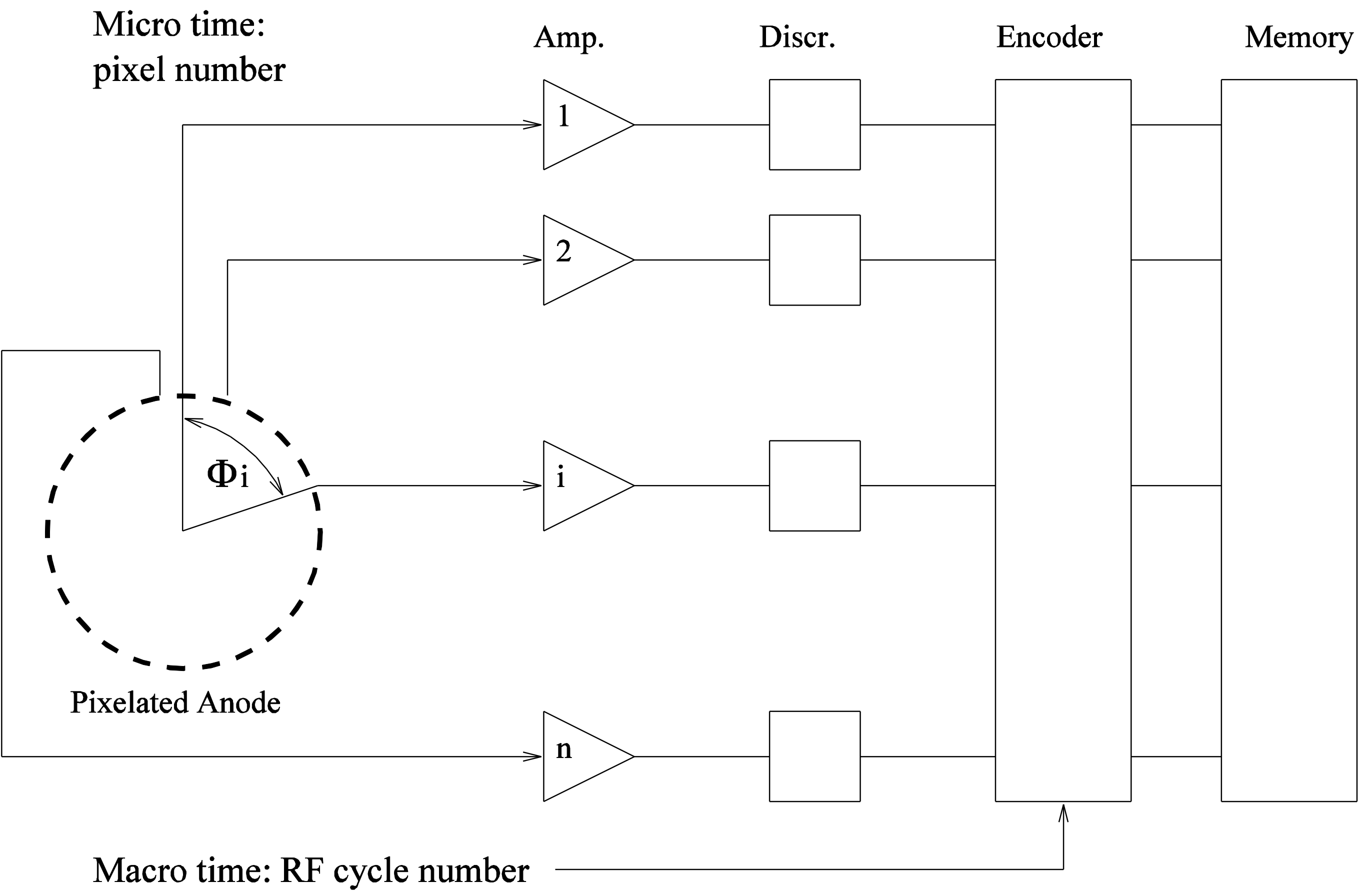
R&D continued

Application at LHC AFP



- **Cherenkov Radiators (GASTOF or QUARTIC) + RF PMT: Times T1 & T2.**
- **Use LHC RF for synchronized operation of RF PMT with LHC bunches. The attainable phase stability (jitter) is 2ps or less (from streak camera synchroscan operation with accelerators, K. Scheidt, 2000).**
- **Timing calibration from independent vertex measurement.**
- **Background rejection from interaction point from T1-T2 and T1+T2.**

Pixelated anode



- Pixel number directly related to the hit time or RF phase Φ
- No TDC is necessary for timing
- Pixels are phase locked and can be operated parallel
- Records short Cherenkov flash of several protons from single 200 ps bunch crossing at LHC

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

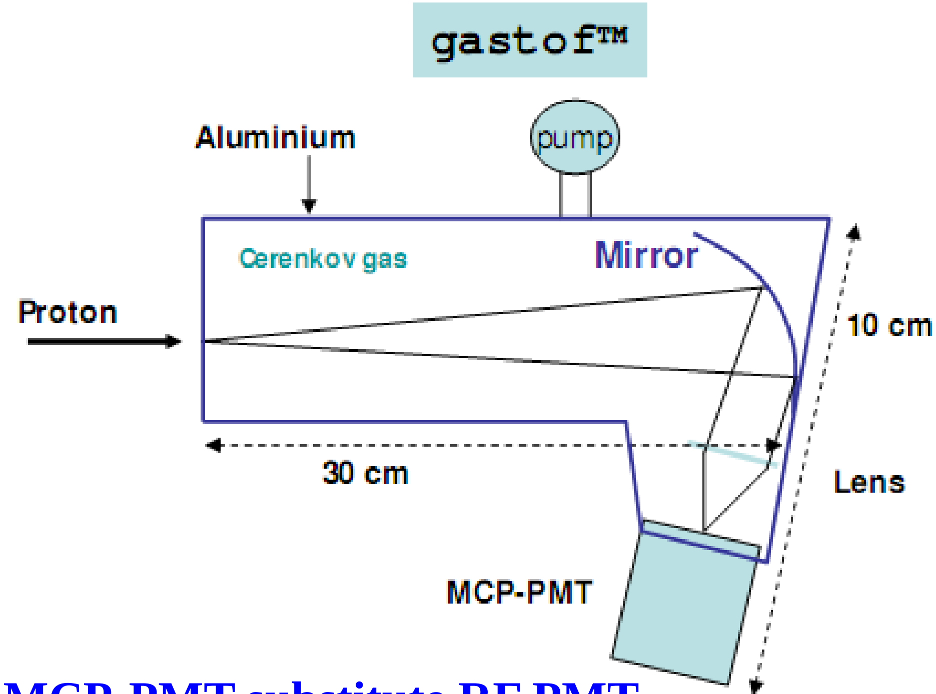
Time resolution = $\Delta\Phi/ 2\pi\nu$

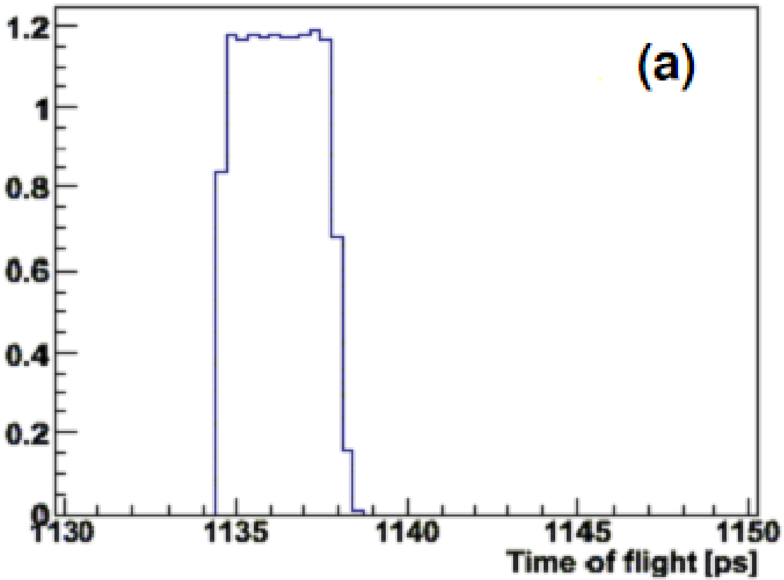
ν is a RF frequency

ν = 800 MHz, 20 mm radius, 10ps/mm

LHC AFP420 Cherenkov GASTOF + RF PMT

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





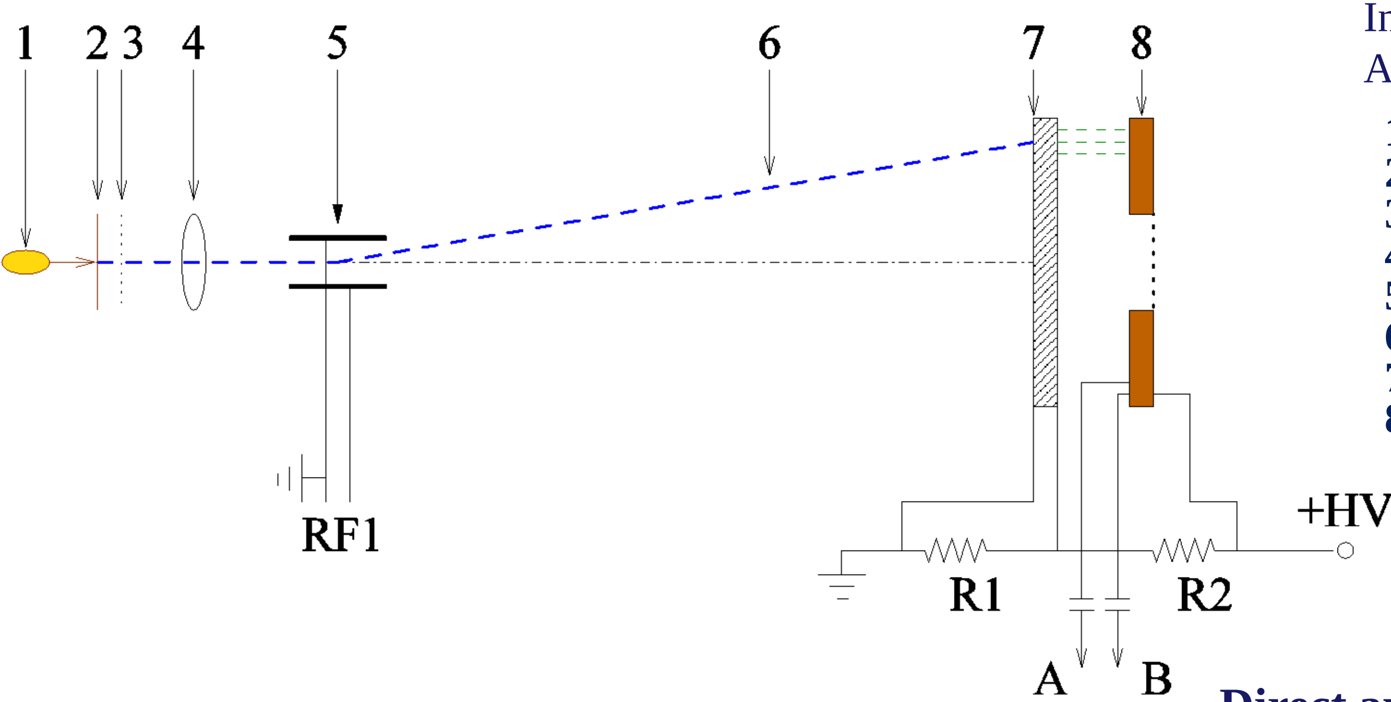
MCP-PMT substitute RF PMT

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

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

MCP+MPPC forward to THz photon detector



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

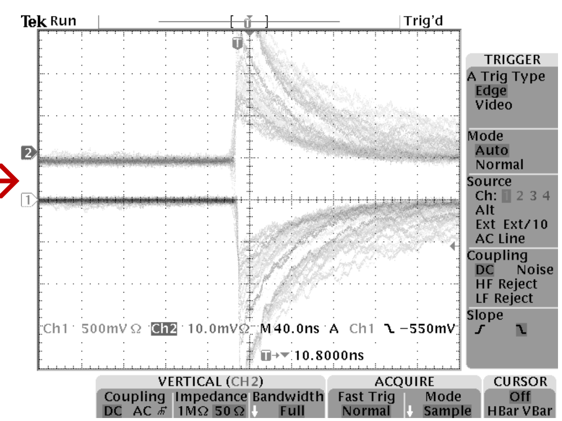
1 - photon flash
2 - photo cathode
3 - accelerating electrode
4 - electrostatic lens
5 - RF deflection electrodes
6 - deflected PEs
7 - single MCP plane
8 - scintillator and array of MPPC (multipixel APD photon counters)

Rate is determined by PE detector

Single plane MCP + MPPC (Hamamatsu S10362) covered by 20 μm plastic scintillator foil; MCP Gain could be in the range 10-100

C. Joram et al., NIM A(2010) consider luminescent anode made from a LYSO scintillator

Direct and Amplified signals



Other Potential Applications

Time Correlated Single Photon Counting Technique with chevron MCP based RF PMT (MCP based RF PMT parallel was designed by Photek Ltd.)

- Rate: 500 kHz
- Resolution
  0.1 mm size photocathode: 1 ps
  few cm size photocathode: <10 ps
- Stability: synchroscan operation ~ 1 ps

Medical Imaging

Time Domain Single Photon Imaging

- Diffuse Optical Imaging
- Fluorescence Lifetime Imaging
- Foster Resonance Energy Transfer
- Time-gated Stimulated Emission Depletion nanoscopy
- Cherenkov radiation based TOF-PET

Summary and Outlook

- **Dedicated circular scanning system 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**
- **Average rate of the RF PMT with single MCP plane + MPPC PE detector can reach GHz**
- **RF PMT with single MCP plane + MPPC PE detector looks as ideal for LHC AFP application**
- **A prototype with small size photocathode RF PMT, chevron MCP array and resistive anode has been parallel designed at Photek Ltd.**

  Need in funding to start a small-scale production and quantitative testing
- **Potential applications in other fields are 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.

Thanks for your attention