LD2309 – FY23: µRWELL-PICOSEC - Development of Fast Timing Detector based on Resistive Micro Well Detector

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Introduction

Background & Rationale:

- Develop fast timing detector (picosecond) based on Resistive Micro-Well (µRWELL) technology.

Application: Time-Of-Flight (TOF) detector for PID

- High-luminosity / high-energy upgrades @ JLab
- ePIC Detector upgrade & EIC Detector II:

Consolidate Jlab high-profile physics program

- Exploration of application medical field

µRWELL-PICOSEC: LDRD R&D Goals

Time of Flight (TOF) detectors (This R&D target)

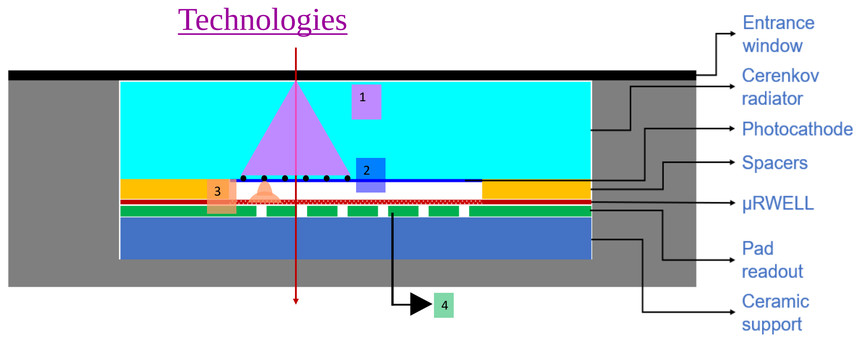
	MRPCs	AC-LGAD	µrPICOSEC
Time resolution (ps)	20 – 70 ✓	20 ✓	25 ✓
Rate (MHz / cm^2)	0.05 ×	N/A	> 1 ✓
Position resolution (mm)	~ 10 ×	0.030 ✓ (claim)	< 1mm ✓
Performance in high B-field	Yes	Yes	Yes ✓
module size	20 × 20 cm^2 ✓	N/A	20 × 20 cm^2 ✓
Cost ($ M / m^2)	0.2 – 0.4 ✓	High ×	0.2 – 0.4? ✓

Photosensors for Cerenkov detectors (This R&D target)

	SiPMs	MCP-PMTs	LAPPDs	µrPICOSEC
Time resolution (ps)	< 100	< 100	50 ✓	50 ✓
Position resolution (mm)	> 1 ×	1 ×	0.3 – 1 ✓	< 1 ✓
Performance in high B-field	Yes	Limited	Limited	Yes ✓
Radiation hardness	dark current ×	N/A	N/A	Yes ✓
Cost ($ M / m^2)	0.8 – 1 ×	> 1 ×	0.8 – 1 ×	0.2 – 0.4 ✓

Technologies

1. Cerenkov photons in radiator
2. Photoelectrons in photocathode
3. Pre-amplification in 200 µm gas
3. uRWELL amplification
4. Collection of electronic signal



Concept of µrPICOSEC: Fast timing gaseous detector based on µRWELL amplification

Cherenkov photons: by relativistic charged particle ➔ prompt photons i.e., time resolution.

Photoelectrons: convert the photons into electrons, at same position in z ➔ timing resolution

Pre-amplification: 1st electrons amplification in high electric field in ~200 µm gas volume

Amplification : 2nd amplification in µRWELL structure high electric field (40 kV/cm)

Electronic Signal: Collection of the induced charges on pick up pad electrode.

Cerenkov radiators & Photocathodes

Radiator: Magnesium Fluoride (MgF2)

Transparency in vacuum ultraviolet (VUV) but low photon yield & large Cerenkov angle = poor spatial information ➔ Will investigate alternative materials:

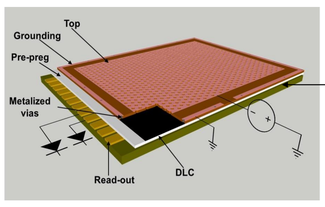
Photocathode: Cesium Iodide (CsI)

High quantum efficiency (QE) in vacuum ultraviolet (VUV) region which is most radiated by any radiator medium but Sensitivity to water and to Ion bombardment (IBF) of CsI is challenging for high rate

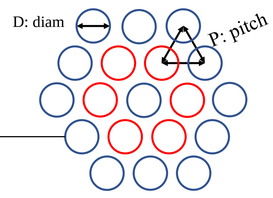
➔ Investigating alternative materials with similar QE:

- Candidates are B4C, DLC and Nano diamond (ND)
- Radiation hardness and unsensitivity to humid condition

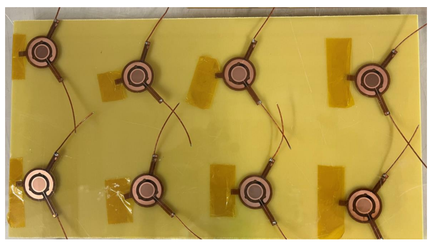
µRWELL foil: amplification device



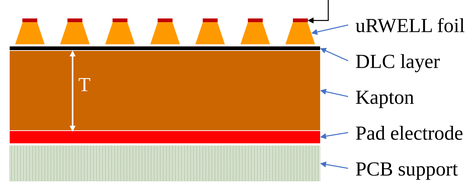
µRWELL concept



µRWELL hole geometry



Single-channel µRWELL-PICOSEC prototypes with different parameters



Cross section view of µRWELL-PICOSEC PCB

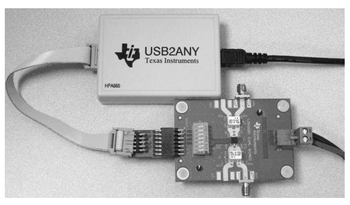
Nomenclature of µRWELL-PICOSEC prototype: T150-P140-D70

(Kapton thickness) T = 150 µm

(Hole pitch) P = 150 µm

(Holes Outer Diam) D = 70 µm

Multi-channel Readout & DAQ



LMH6881: Programmable differential amplifiers

+

CAEN FERS-5203: 64-ch Pico-TDC

- Provide 64 TDC channels :
- ~7 ps RMS timing resolution
- LVDS input differential signals
- 3.5 Gbits/s Optical ethernet bus

Test of the LMH6881 evaluation board (Wenze Xi)

Lab test of single channel prototypes

Rohde & Schwarz, RTP164B

High performance oscilloscope:

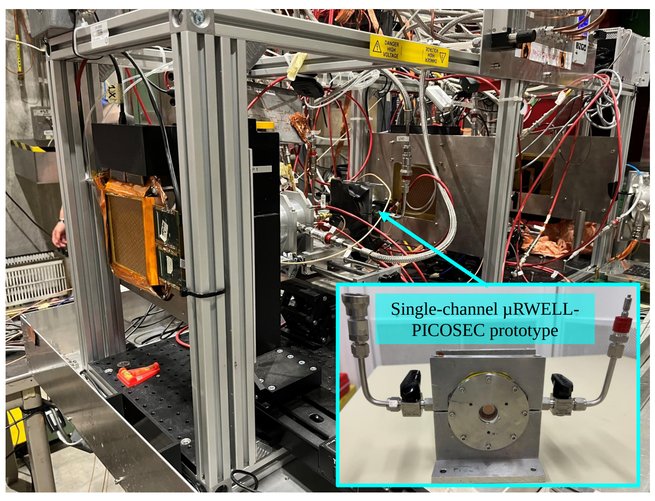
- 2 × 16 GHz bandwidth channels for sub-ps timing resolution
- 40 GSamples/s & 16 bits measurement precision

Alternative options

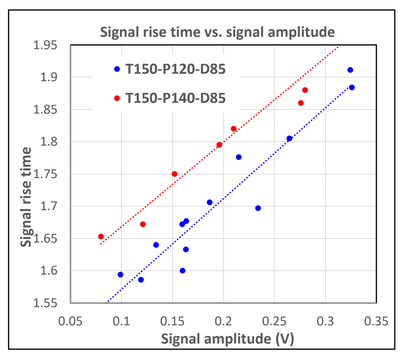
- Multi channel digitizer SAMPIC (D. Breton, CEA Saclay)
- Multi-channel custom-made pre-amplifier (M. Kovacic, U. of Zagreb)

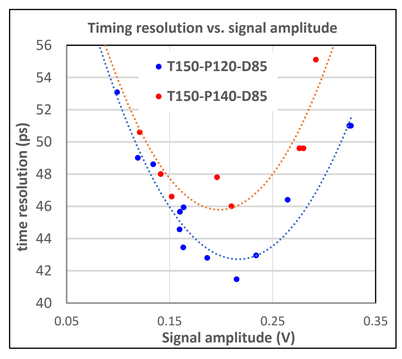
Test beam @ CERN & Preliminary results

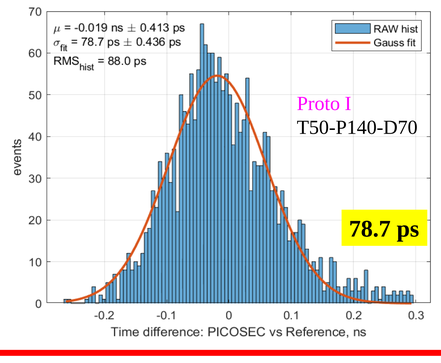
MM-PICOSEC Coll. Test beam setup @ CERN (July 2023)

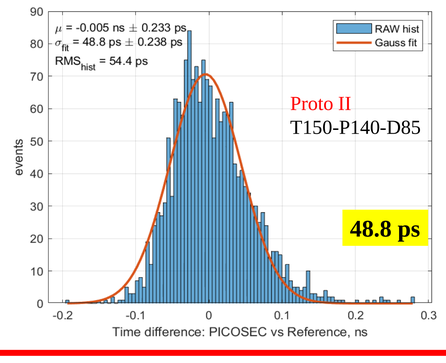


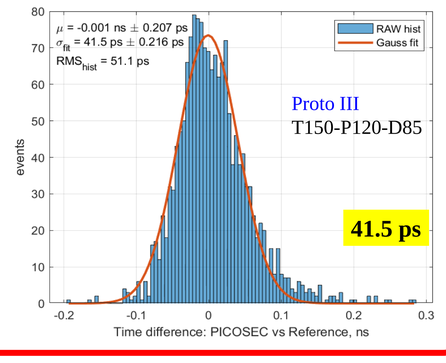
- Join the PICOSEC Coll. 2 test beam campaigns @ CERN in July 2023 & Aug. –Sept. 2023
- Several single-channel µRWELL-PICOSEC prototypes with different parameters were tested
- HV scan on both the cathode (pre-amplification) and anode (µRWELL amplification)
- Signal rise time and time resolution as function of signal amplitude
- **µRWELL-PICOSEC K150-H120-85-65 shows best time resolution of 41.5 ps**





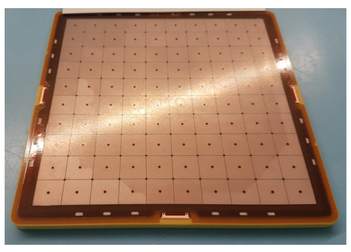


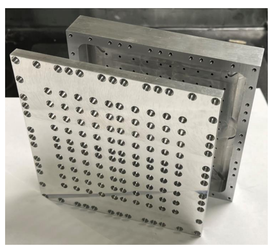




What's next? – Large µRWELL-PICOSEC prototype & Optimization of timing performance

Multi-pad PICOSEC prototypes (Micromegas & µRWELL)



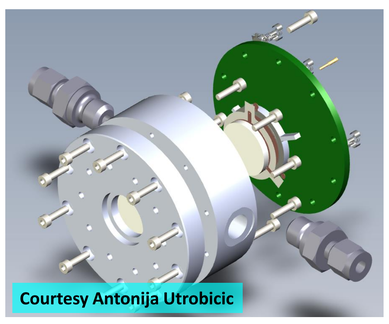


- 100-pad µRWELL-PICOSEC & MM-PICOSEC prototypes
- Parameters based on single-channel prototypes studies
- Mechanical housing fabricated in the JLab machine shop
- Same housing for MM-PICOSEC & µRWELL-PICOSEC
- Multi-channel readout PCB interface board under development
- MM-PICOSEC used as reference detector
- Large prototypes will be tested in beam at CERN in FY24

PICOSEC test bench setup @ RD&I Detector Lab

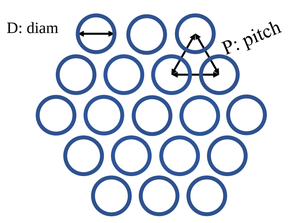
- We will set up PICOSEC test bench in RD&I MPGD lab EEL126
- Gas mixture system Ne-C_2H_{10}-CF_4 (80-10-10) & Vacuum pump
- High bandwidth oscilloscope & low noise amplifier (CIVIDEC)
- LED & laser sources for single photon detection measurement
- Telescope with GEM trackers & MCP-PMT timing reference

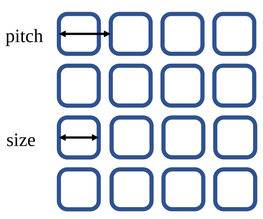
New mechanical housing for single-channel µRWELL-PICOSEC prototype



- Minimize external source of noise (i.e grounding, cables pick-up antenna …)
- Makes it easier to quickly exchange prototypes (replacement of µRWELL-PCBs, photocathodes) during beam test

New µRWELL-PICOSEC prototypes with various holes geometries





Minimize capacitance and time resolution: Minimize µRWELL Cu-to-holes ratio

- Square holes vs. round holes
- Pitch vs. hole diameter, different hole diameters
- Increase Kapton thickness between uRWELL and pick-up pad electrode

Summary & Perspectives

- The progress on single-channel µRWELL-PICOSEC for fast timing has been encouraging for the Year 1 of the LDRD program
- Timing of 41.5 ps was achieved in beam test and the performance is expected to be improved with some design modifications
- In Year 2, we will extend the development to large multi-channel µRWELL-PICOSEC prototypes based on the performances results from with single-channel & the development of the associated multi-channel readout & DAQ
- We will complete the setup of µRWELL-PICOSEC test bench in the RD&I MPGD lab in EEL126 for prototype characterisation
- We plan to present the results at international conferences and publish in peer-reviewed paper by the end of Year 2
- We will seek funding opportunities to continue the R&D on µRWELL-PICOSEC technologies beyond the LDRD program

Acknowledgement:

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