Precise timing with PICOSEC µRWELL & Micromegas detector

(On behalf of PICOSEC collaboration)

Akash Pandey

Radiation Detectors & Imaging Group (RD&I Group), Jefferson Lab

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Outline

- **Detection concept of µRWELL & Micromegas PICOSEC**
- **Test beam setup**
- **Preliminary results from Test beam-2023 (**Single channel µRWELL- PICOSEC prototype**)**
- **Preliminary results from Test beam-April 2024 (**New housing & design of single channel µRWELL- PICOSEC prototype**)**
- **Plan for Test beam-July 2024**
- **Updates from PICOSEC Micromegas**
- **Summary**

Working principle

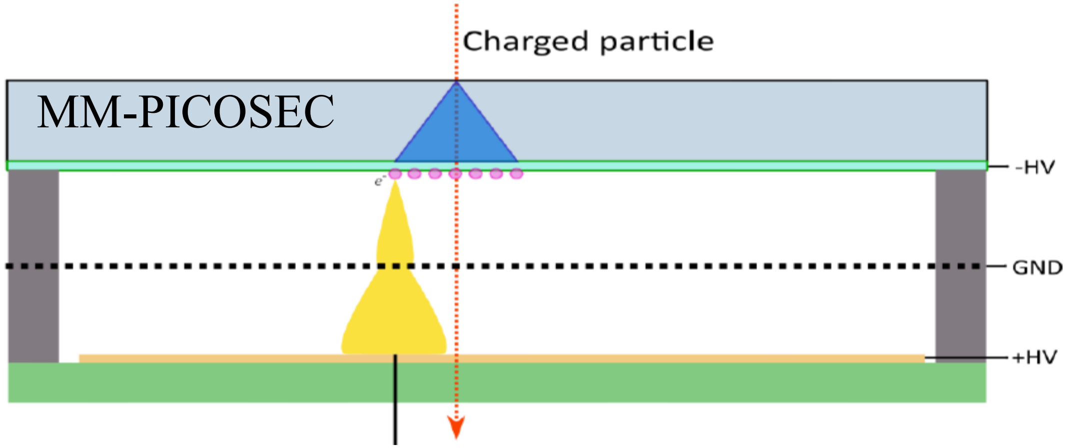
1. Cherenkov photons: relativistic charged particle creates Cerenkov photons ➔ prompt photons i.e., timing resolution.

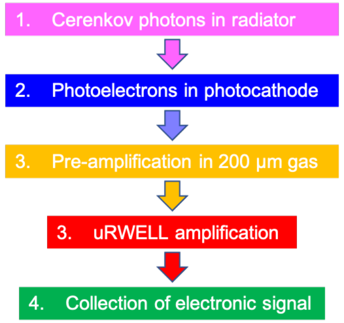
2. Photoelectrons: convert the Cerenkov photons into electrons, all electrons created at the same z position ➔ timing resolution

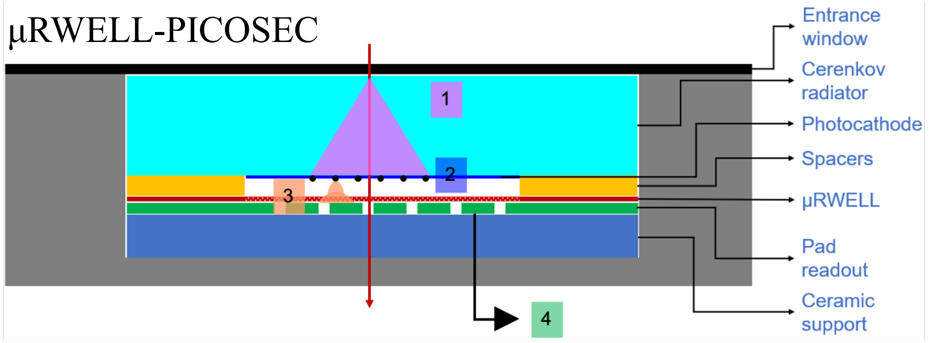
3. Pre-amplification: First amplification of electrons 100 to 200 µm gas in high drift field region (~20 kV/cm)

4. Amplification : Final electron amplification in µRWELL gain structure ➔ high electric field (>40 kV/cm)

5. Electronic Signal: Arrival of the amplified electrons to the anode creates a signal.



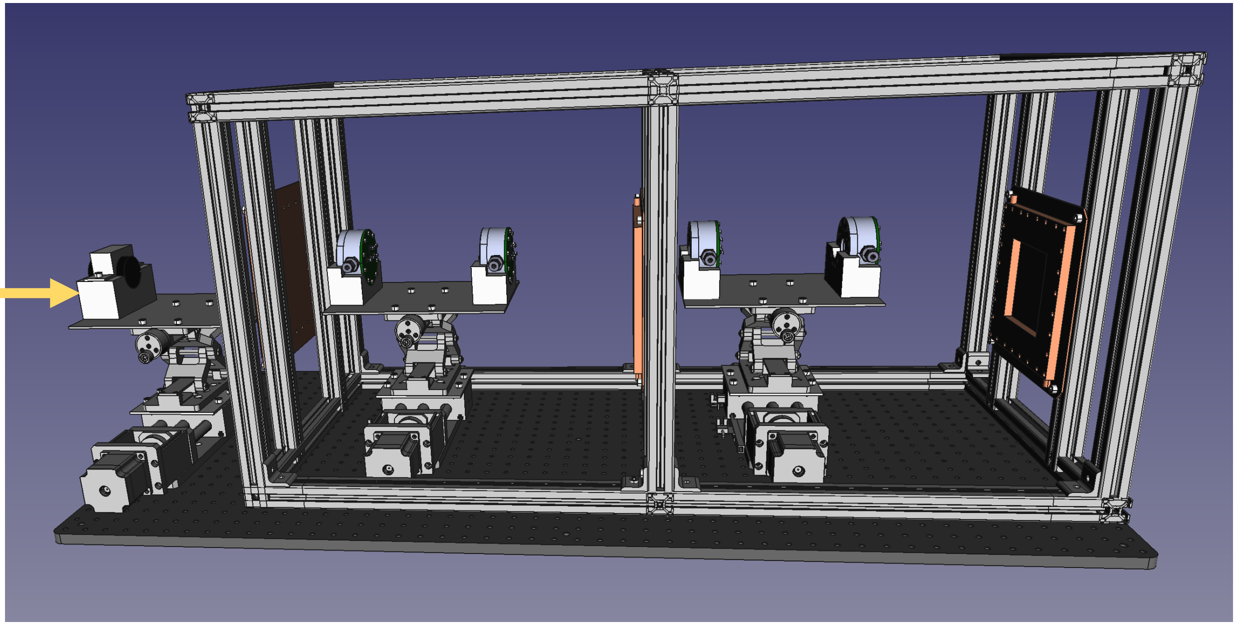


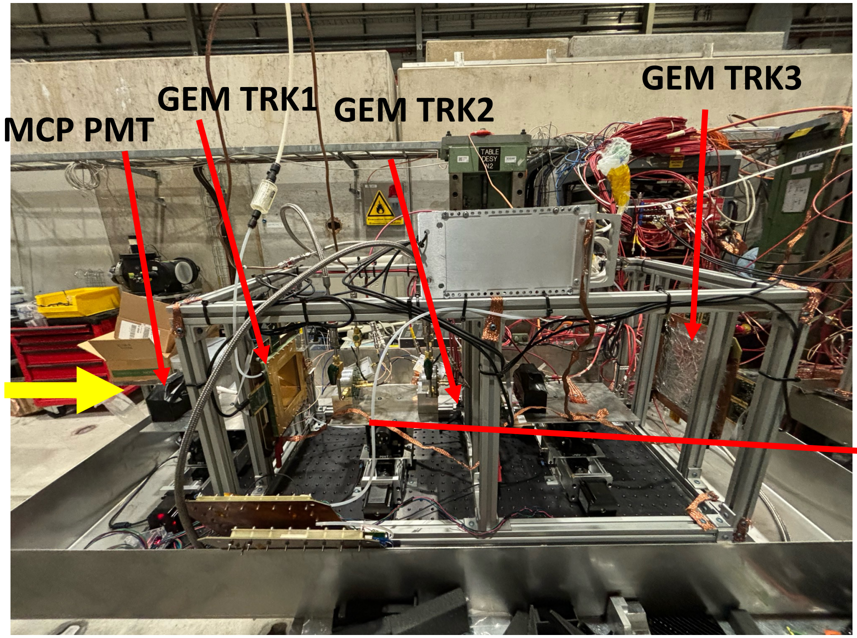


	MM-PICOSEC	µRWELL-PICOSEC
Radiator / photocathode	Both technologies share the same devices	Both technologies share the same devices
Readout structure	Both technologies share the same devices	Both technologies share the same devices
Amplification structure	mesh ➔ 128 µm gap	Cu-clad Kapton foil ➔ 50 µm gap
Resistive vs. metallic	Both options available	Only resistive
Segmentation MPGD	Segmentation of the mesh will be challenging	µRWELL Cu-electrode can be segmented

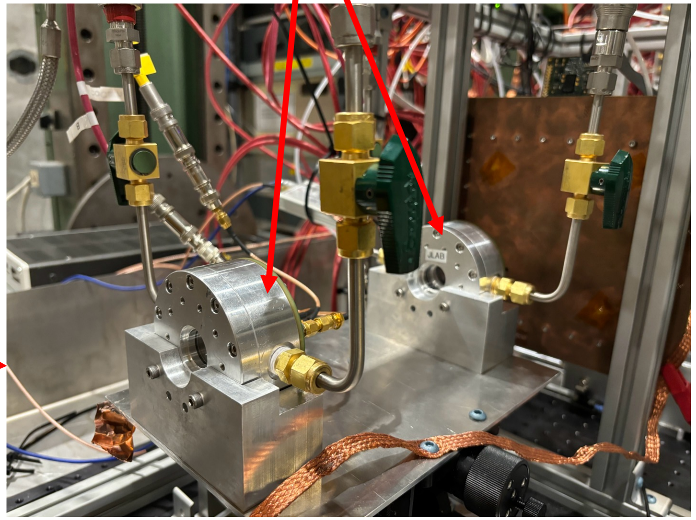
Test beam setup of single channel single channel µRWELL-PICOSEC

BEAM

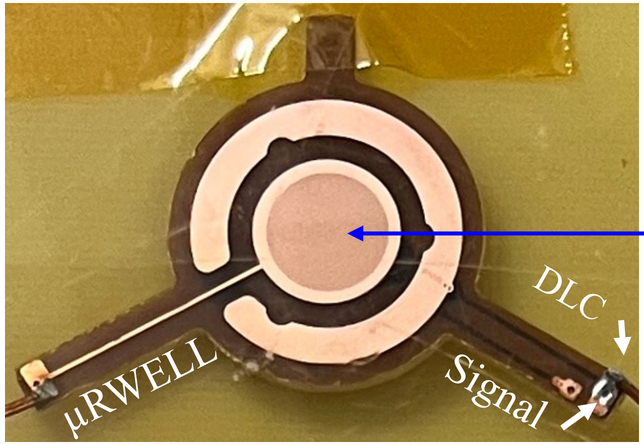




Single channel µRWELL PICOSEC protypes



Single channel µRWELL protoypes (Test beam-2023)



µRWELL-PICOSEC prototype

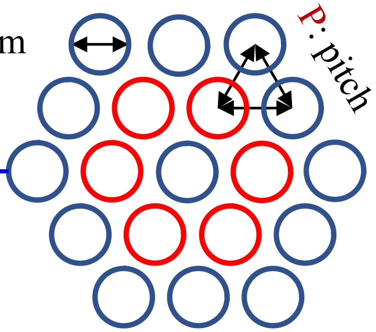
Nomenclature of the prototypes:

T150-P140-D70

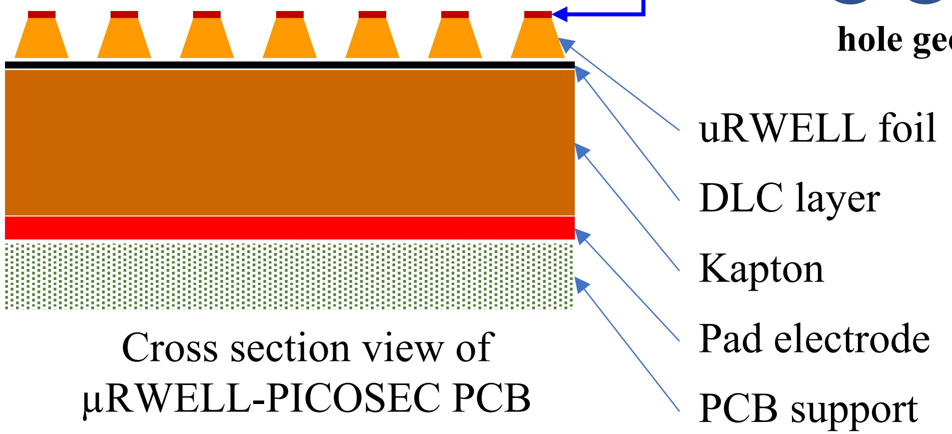
T = 150 µm ➔ Kapton thickness

P = 140 µm ➔ Hole pitch

D = 70 µm ➔ Hole Outer Diam.

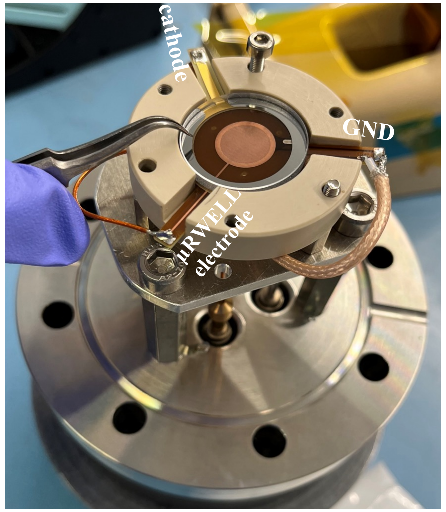


hole geometry

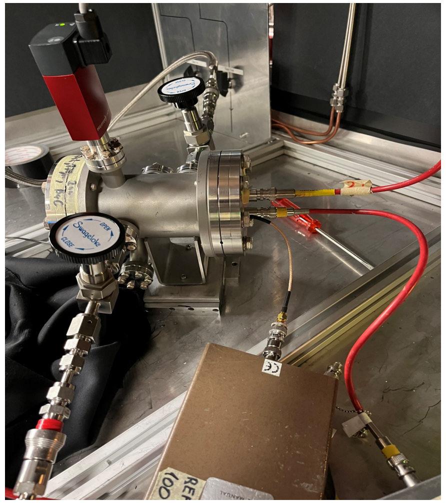


Cross section view of µRWELL-PICOSEC PCB

batch	Prototype	T (µm)	P (µm)	D (µm)	d (µm)
I	T50-P140-D70	50	140	70	50
II	T150-P140-D70	150	140	70	50
II	T150-P140-D85	150	140	85	65
II	T150-P120-D70	150	120	70	50
II	T150-P120-D85	150	120	85	65

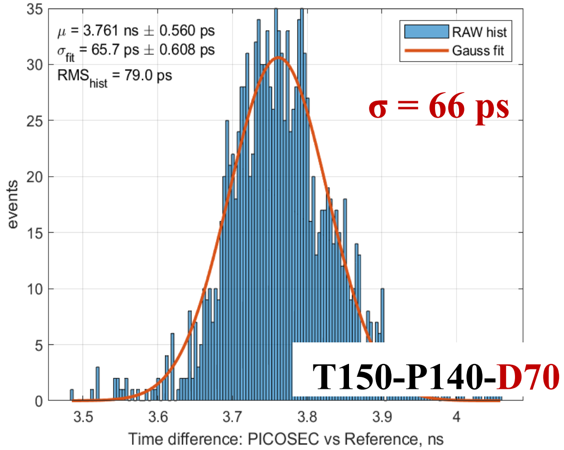


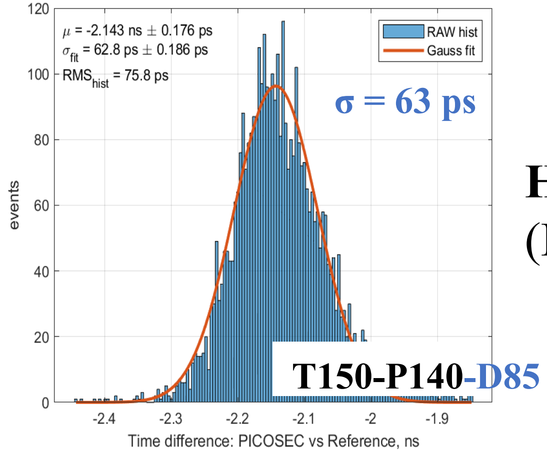
Single-pad µRWELL-PICOSEC prototype



Prototype on test bench at CERN GDD Lab

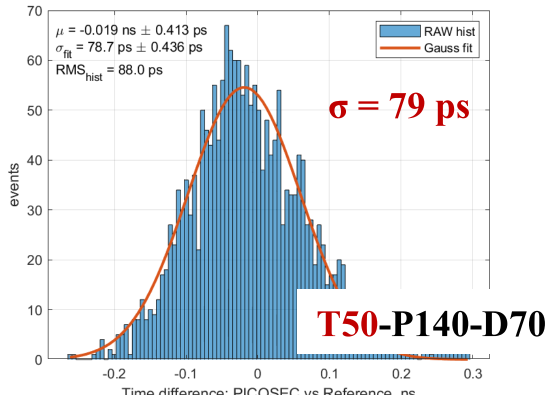
Preliminary results (Test beam-2023)

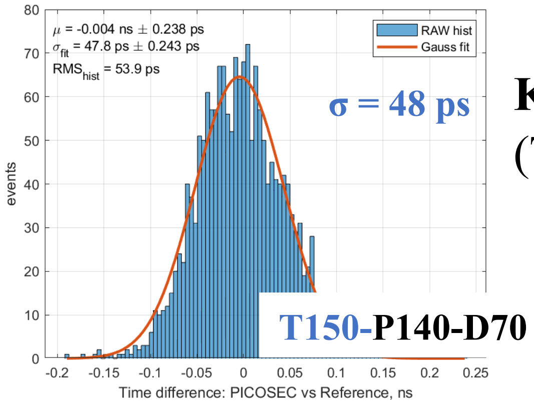




Hole diameter comparison

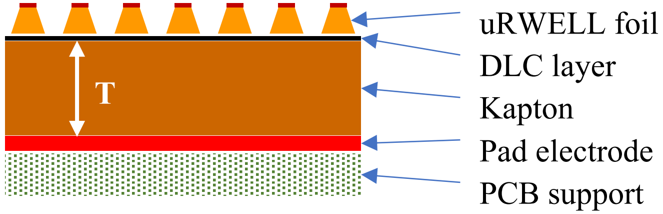
(Larger holes for same pitch ➔ better timing)



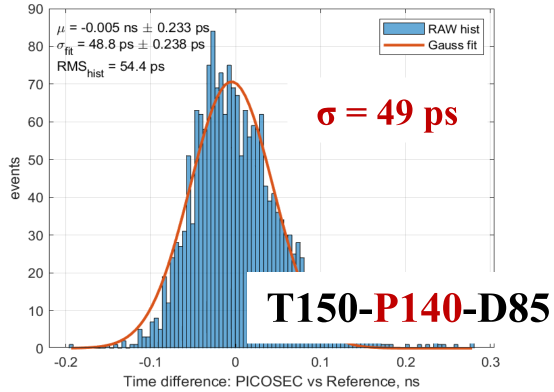


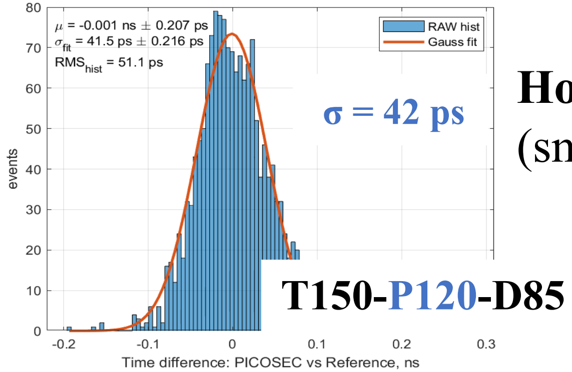
Kapton thickness comparison

(Thicker Kapton ➔ better timing)



Cross section view of µRWELL-PICOSEC PCB



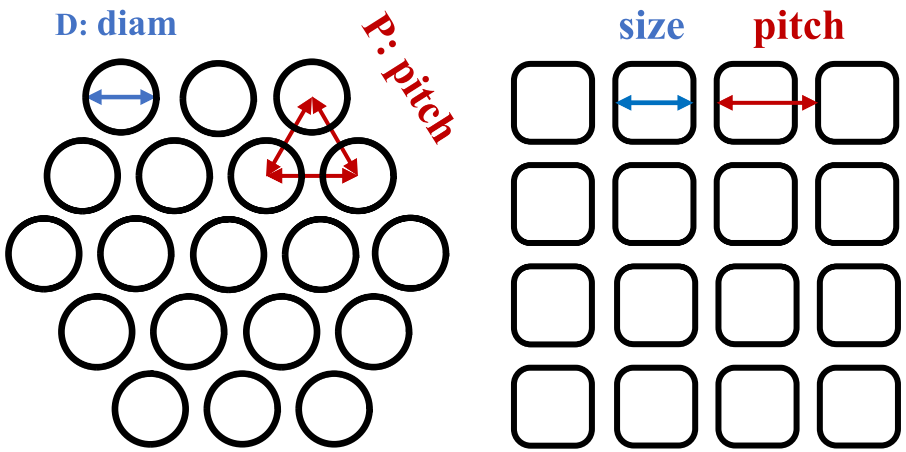


Hole pitch comparison

(smaller pitch ➔ better timing)

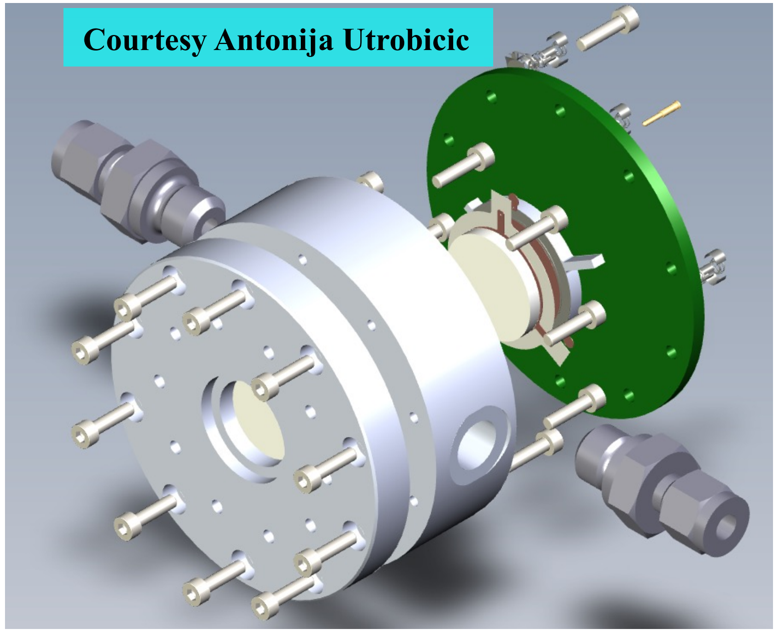
New mechanical housing and design of single channel µRWELL-PICOSEC (Test beam-April 2024)

New hole geometries



Round holes (RD)   Square holes (RD)

Prototype	Shape	P	D	d
SQ-T150-P120-D100	square	120	100	80
RD-T150-P120-D100	round	120	100	80
RD-T150-P100-D80	round	100	80	60
RD-T150-P80-D60	round	80	60	40

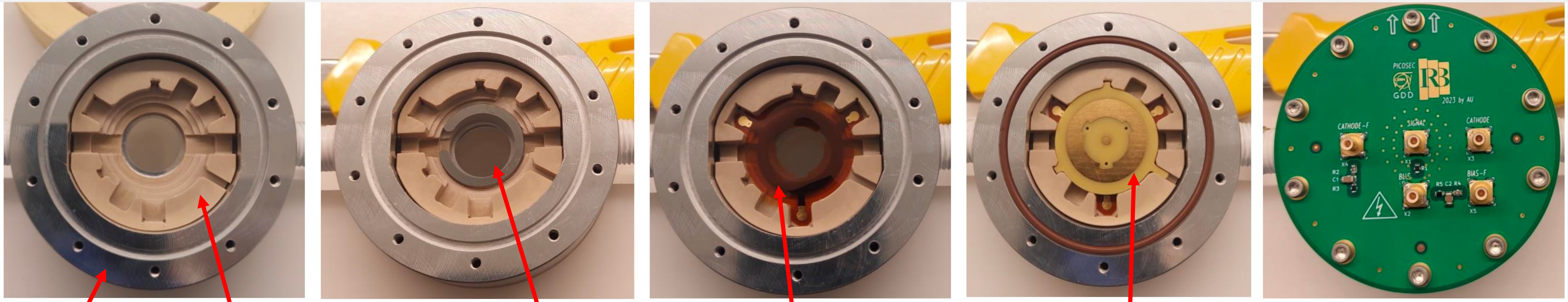


New mechanical housing

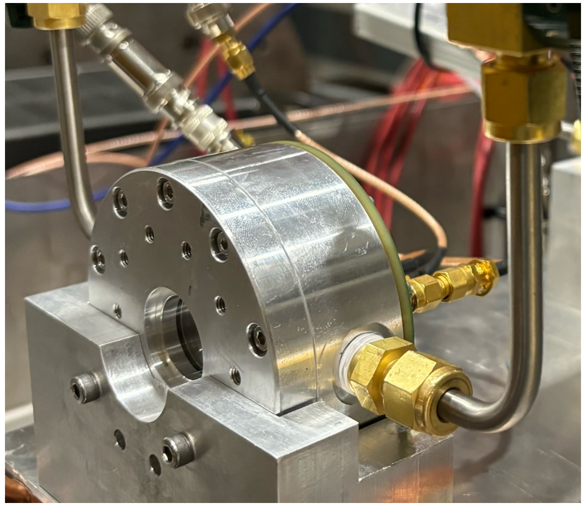
- ❖ Minimize external source of noise (i.e grounding, cables pick-up antenna …)
- ❖ Makes it easier to quickly exchange prototypes (replacement of µRWELL-PCBs, photocathodes) during beam test

New mechanical housing of single channel μRWELL-PICOSEC (April Test beam 2024)

Courtesy Antonija Utrobicic



Al chamber PEEK insert MgF_2 spacer μRWELL PCB Outer board



Our μRWELL prototype in the housing

We have tested the following combinations of single channel µRWELL-PICOSEC protypes:

1. uRWELL7 (CsI batch 2), Round P:120 H(o):100 H(i):80, Spacer: 170 um, Readout: Grided
uRWELL5 (CsI batch 4), Round P:120 H(o):100 H(i):80, Spacer: 170 um, Readout: Plain

2. uRWELL9 (CsI batch 2), Round P:100 H(o):80 H(i):60, Spacer 170 um, Readout: Plain
uRWELL11 (CsI batch 4), Round P:100 H(o):80 H(i):60, Spacer 170 um, Readout: Grided

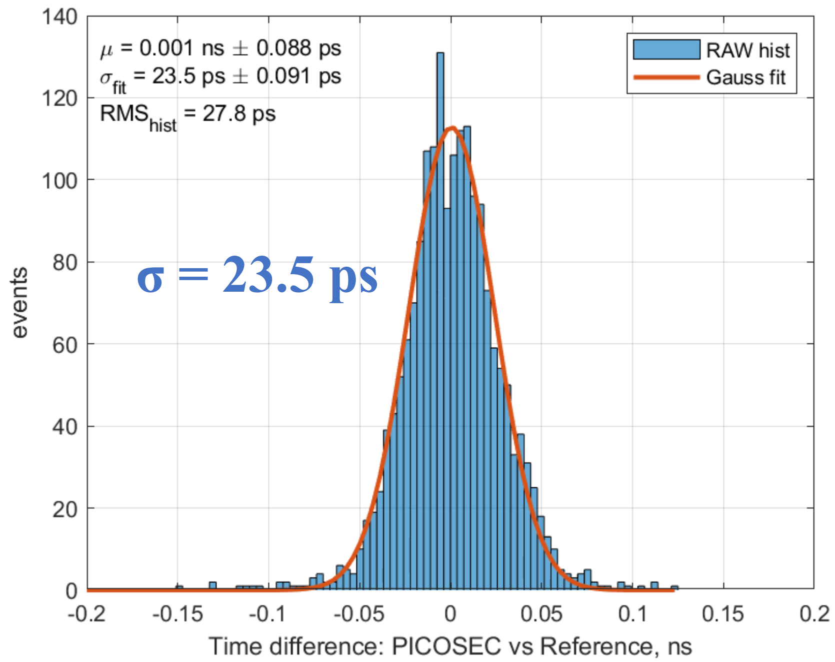
3. uRWELL1 (CsI batch 4), Square P:120 H(o):100 H(i):80, Spacer 170 um, Readout: Plain
uRWELL3 (CsI batch 4), Square P:120 H(o):100 H(i):80, Spacer 170 um, Readout: Grided

4. uRWELL5 (CsI batch 4), Round P:120 H(o):100 H(i):80, **Spacer 120 um**, Readout: Plain
uRWELL9 (CsI batch 4), Round P:100 H(o):80 H(i):60, **Spacer 120 um**, Readout: Plain

5. uRWELL13 (CsI batch 4), Square P:80 H(o):60 H(i):40, Spacer 170 um, Readout: Plain
uRWELL9 (CsI batch 4), Round P:100 H(o):80 H(i):60, **Spacer 120 um**, Readout: Plain

Preliminary results (Test beam-April 2024)

- Fused silica window, MgF_2 as crystal and CsI photo cathode
- Gas mixture of Neon: C_2H_6 : CF_4 = 80: 10:10
- The result has been obtained for the prototype with 120 µm pitch, 100 µm OD and 80 µm ID and plain pad



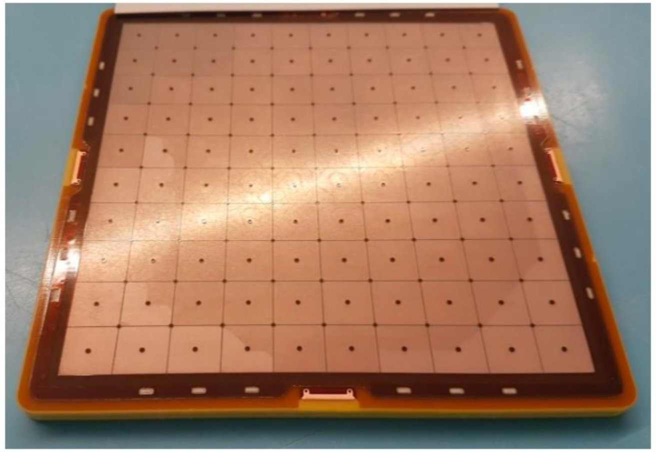
Time resolution of single channel µRWELL- PICOSEC with 170 µm preamplification gap.

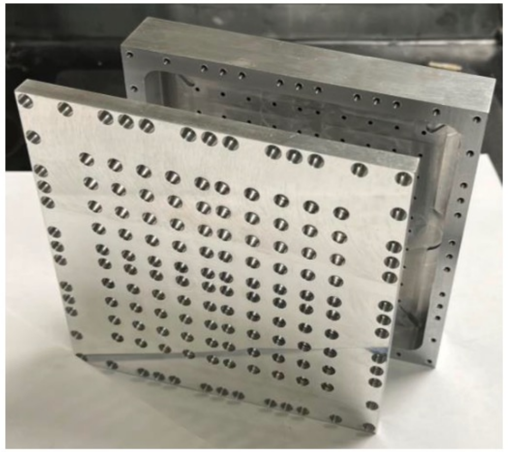
Timing resolution gets improved (~23 ps) with new mechanical housing & design of single channel µRWELL- PICOSEC

Plans for Test beam-July 2024

Testing of Large-area (10 cm × 10 cm) μRWELL-PICOSEC prototype with 100-pads readout

Large 100-pad prototypes (Micromegas & μRWELL)



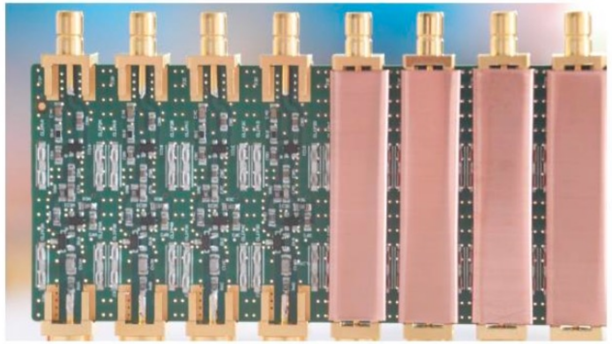


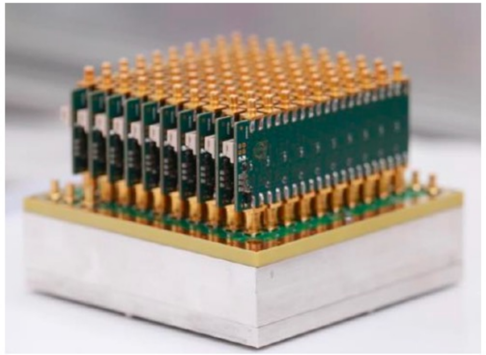
- 100-pad μRWELL-PICOSEC & MM-PICOSEC prototypes
- Parameters based on single-channel prototypes studies
- Mechanical housing fabricated in the JLab machine shop
- Same housing for MM-PICOSEC & μRWELL-PICOSEC
- Multi-channel readout PCB interface board under development
- MM-PICOSEC used as reference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

Multi channel digitizer SAMPIC (D. Breton, CEA Saclay)

https://indico.cern.ch/event/396441/contributions/1836629/attachments/794757/1089389/02_SAMPIC_Prague.pdf

Multi-channel custom-made pre-amplifier (M. Kovacic, U. of Zagreb)





Updates from PICOSEC Micromegas

Precise timing with PICOSEC Micromegas

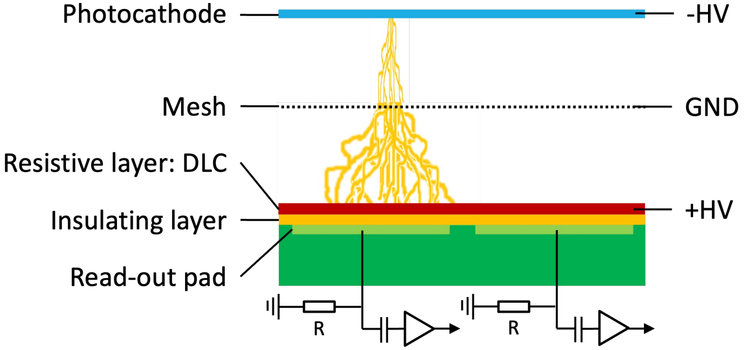
Resistive Micromegas

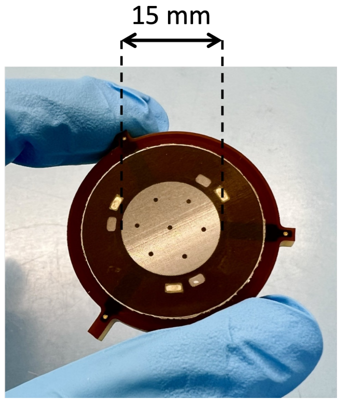
- **Advantages:**

  + protecting detector from highly ionizing events

  + ensuring stable operation under intense particle beams

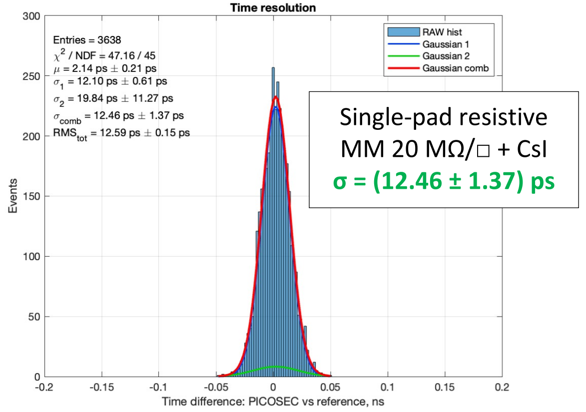
  + achieving better position reconstruction by signal sharing

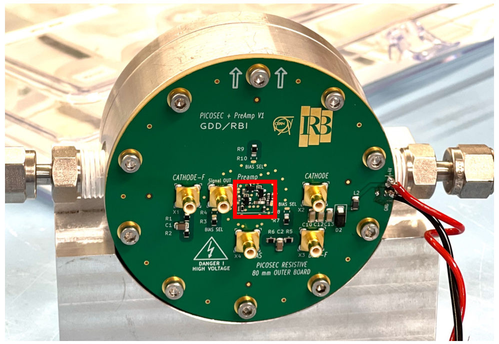




Resistive single-pad prototype

- **Single-pad resistive MM of 20 MΩ/□** equipped with a CsI photocathode obtained equivalent precision to a non-resistive prototype, exhibiting **an excellent time resolution of σ ≈ 12 ps**

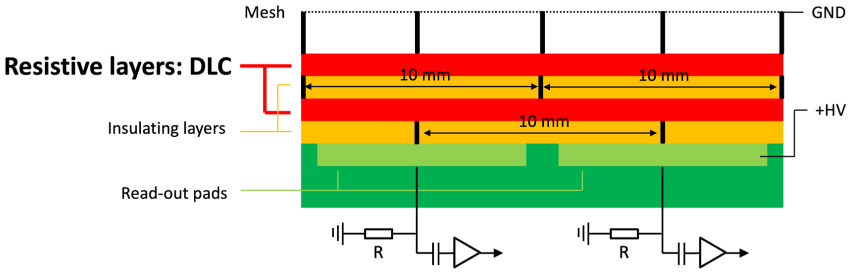




Amplifier integrated on the outer PCB

- Single-pad resistive MM assembled with **a preamplifier integrated on the outer PCB** showed comparable timing properties

- **Next step:** production of a high-rate 10×10 cm^2 MM with double-layer DLC for vertical charge evacuation and evaluation of rate capability



Slide reference: **Marta Lisowska** (marta.lisowska@cern.ch)

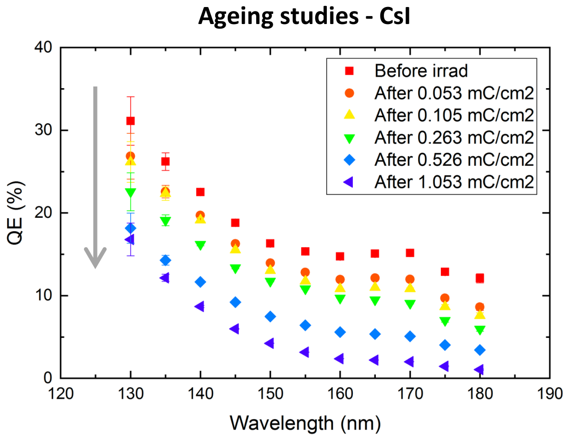
Precise timing with PICOSEC Micromegas

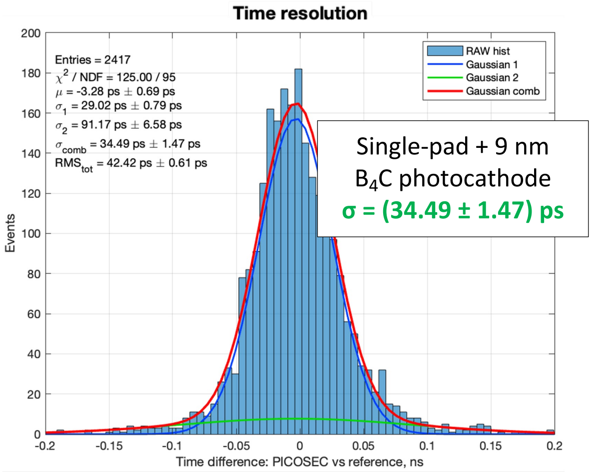
Robust photocathodes

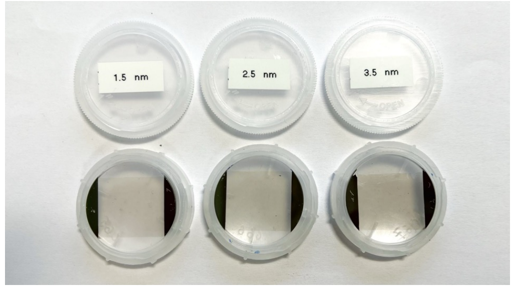
- First single-pad prototype: Cesium Iodide

  + high QE (~12 p.e./μ) in comparison to other materials

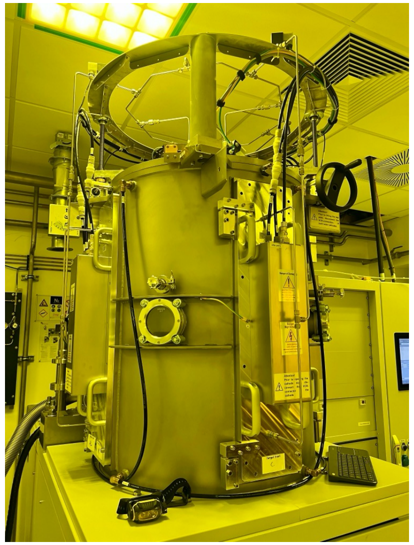
  – vulnerable to damage from ion backflow, discharges and humidity
- **Alternative photocathodes:** B_4C, DLC, carbon-based nanostructures
- Previous measurements conducted with B_4C photocathodes exhibited the best time resolution of σ ≈ 34.5 ps for the 9 nm layer
- **First depositions of DLC photocathodes carried out at the CERN MPT workshop** using a magnetron sputtering technique
- The best results for a single-pad detector achieved with a **1.5 nm DLC photocathode**, yielding **a time resolution of σ ≈ 32 ps**
- **Next step:** evaluation of a 10×10 cm^2 robust photocathode



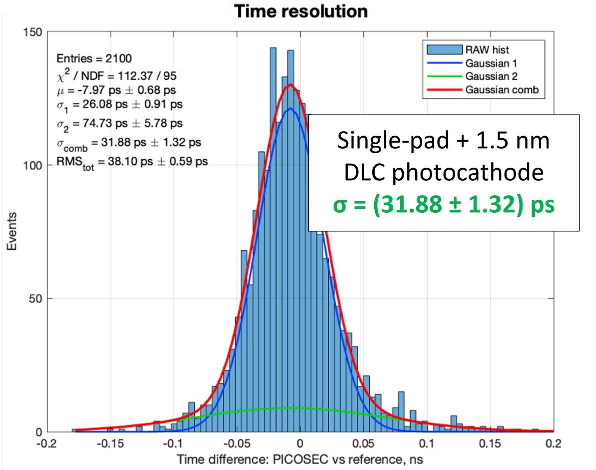




DLC photocathodes of different thicknesses



Pulsed DC magnetron vacuum deposition machine



Slide reference: Marta Lisowska (marta.lisowska@cern.ch)

Gas studies

Standard mixture:

Neon / ethane (C_2H_6) / CF_4 90% /10% /10%

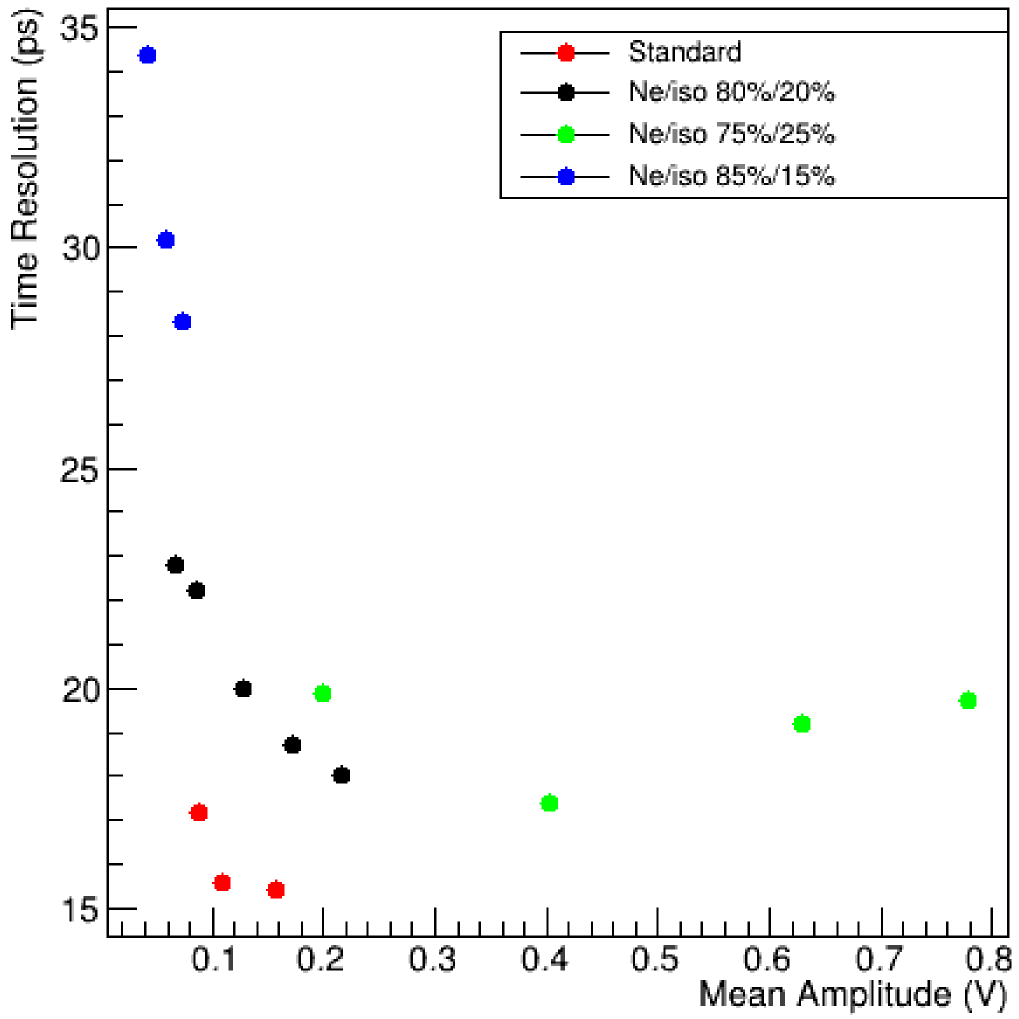
- Expensive
- Flammable
- High GWP (~ 740)

New mixtures:

Neon / Isobutane (iC_4H_{10}) different ratios

Preliminary results:

- Reached ~17ps with the 75/25 mixture and ~19 with the 80/20 (~15ps with the standard mixture)
- Need to determine precisely the concentration inside the detector due to problems with the gas mixing system
- Ne/iso mixture good candidates to achieve good time resolution with low GWP (order of 1)



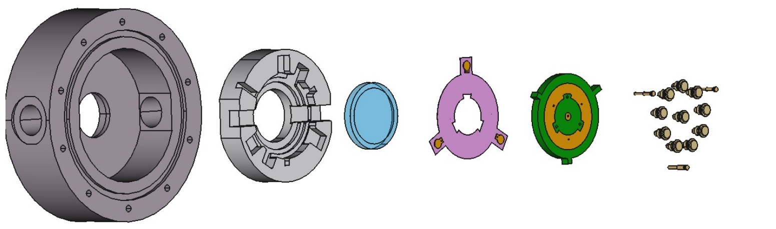
Voltage scan performed with different gas mixtures. Detector with non-resistive micromegas and CsI photocathode. The last point of every curve is the one obtained with the highest achievable gain.

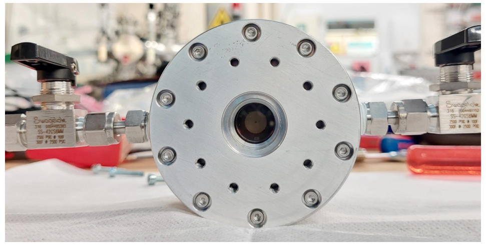
Slide reference: **Matteo Brunoldi** (matteo.brunoldi@cern.ch)

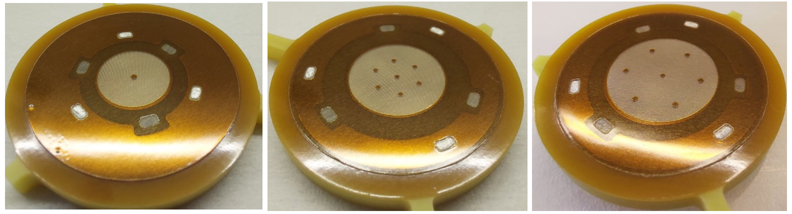
New single channel PICOSEC Micromegas (MM) detector

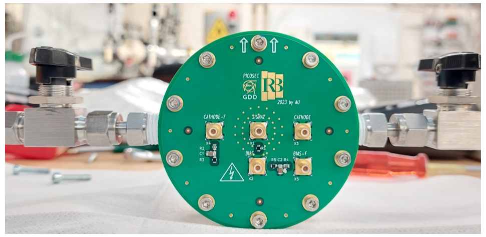
- The new detector housing and three different size of MM boards with 10 mm, 13 mm and 15 mm diameter active area that are compatible with same housing were designed and produced.
- Focus on improving stability, reducing noise, ensuring signal integrity and uniform time response over entire active area.
- Fast assembly procedure: quick and easy replacement of detector elements.
- Successfully commissioned with MIP at SPS H4 beamline. Test beam results showed that all three prototypes can operate stable with very uniform time response.
- The 10 mm detector achieved an outstanding time resolution of **12.5 ps**, while larger detectors followed with a resolution at a level of 18 ps in the central pad region (MCP jitter not subtracted).

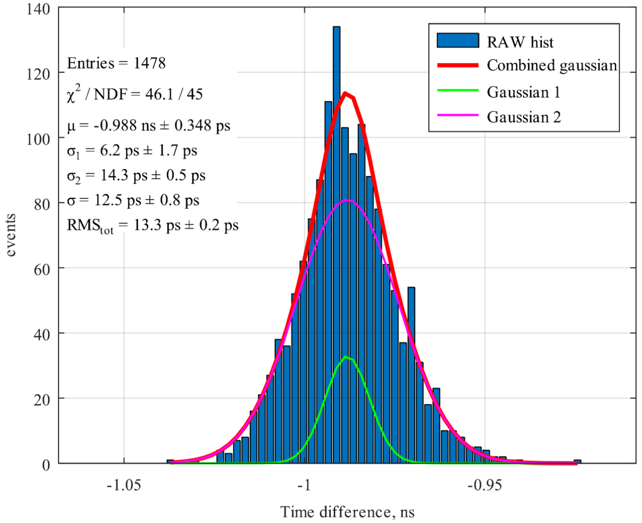
- **Ongoing and planned activities:**
  - Development of a resistive MM prototype with 10 mm and 15 mm diameter active area (first beam tests with 150 GeV/c muons done in April 2024.).
  - Preamplifier integration to the detector housing.
  - System level optimization of the detector, amplifier and digitizer.

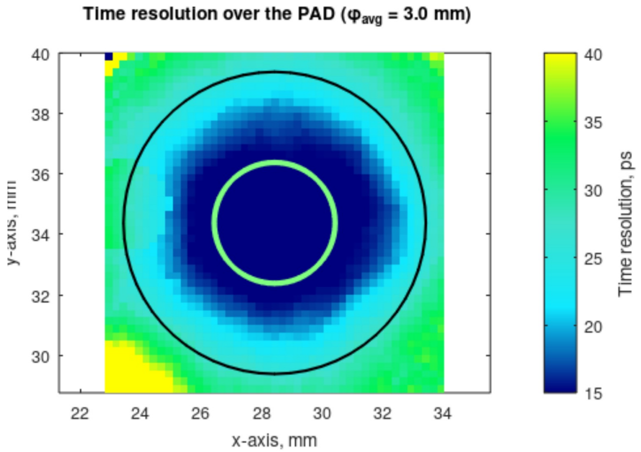


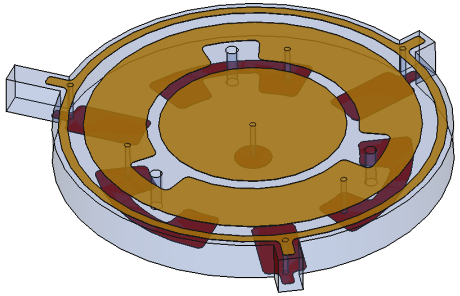




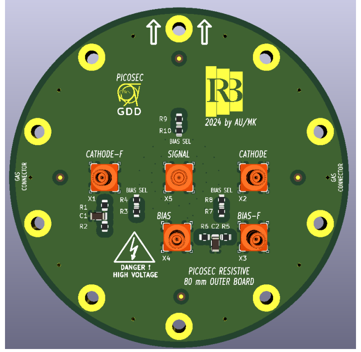








Resistive MM detector substrate layout



Resistive detector Outer board design

Slide reference: **Antonija Utrobicic** (antonija.utrobicic@cern.ch)

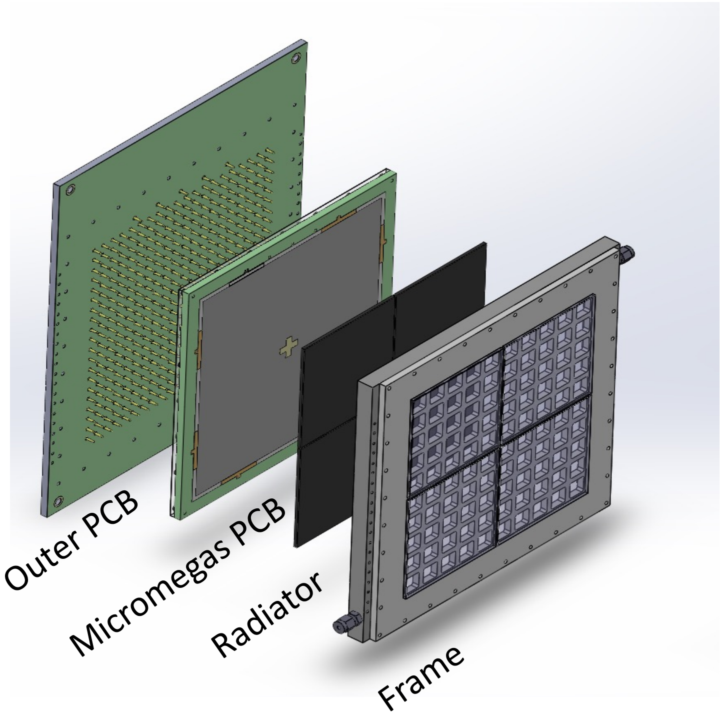
Large Area 20*20 PICOSEC

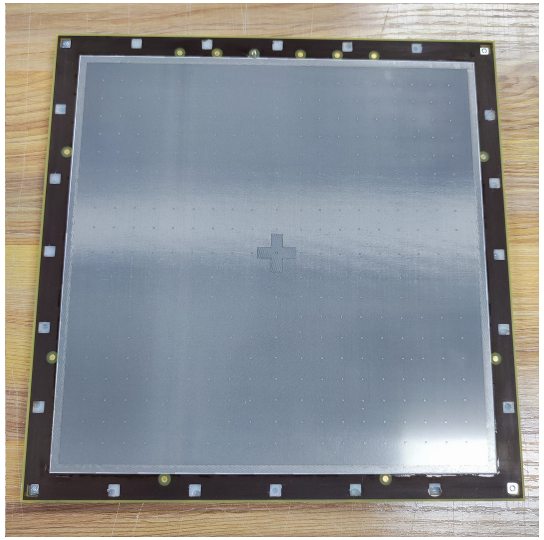
First 20*20 PICOSEC Micromegas:

- 400 pads on 200mm*200mm Micromegas
- resistive micromegas by thermobonding method
- Joint of four 104*104mm MgF2
- Four photocathodes applying HV independent

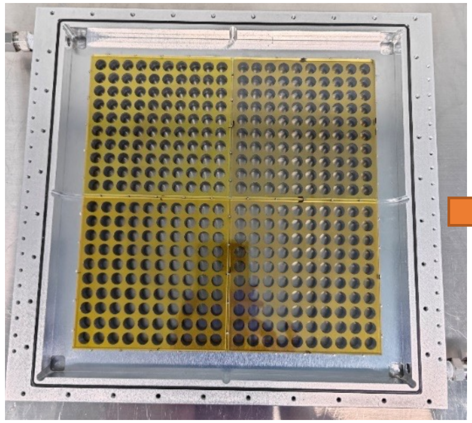
Preliminary Beam Test Results (Beamtest April 2024):

- Tested 3 different photocathodes with different pads
- Best timing from CsI is 25.4ps (510/270)
- DLC with 36.5ps (690/260)
- B4C (Boron Carbide) with 37.6ps (660/260)

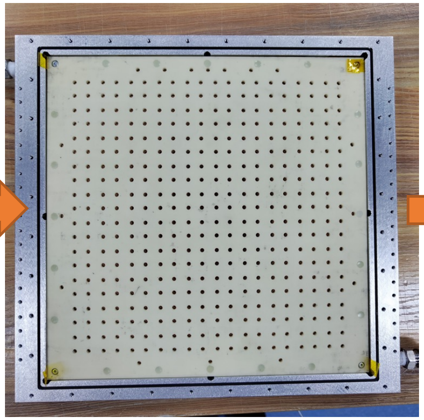




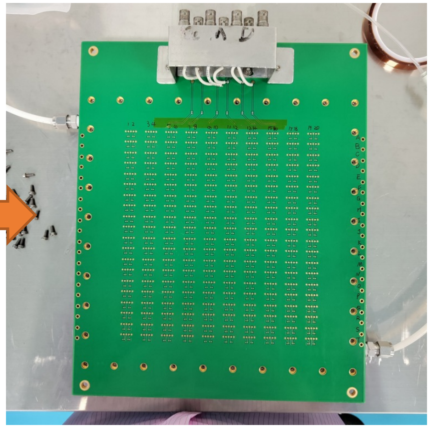
Thermobonding Micromegas



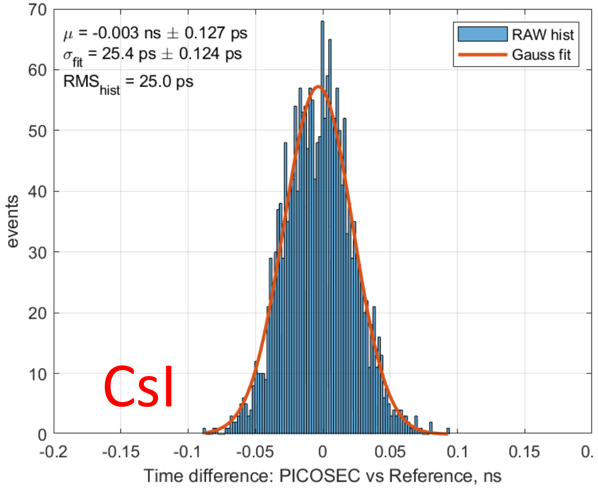
Frame & MgF2 photocathode

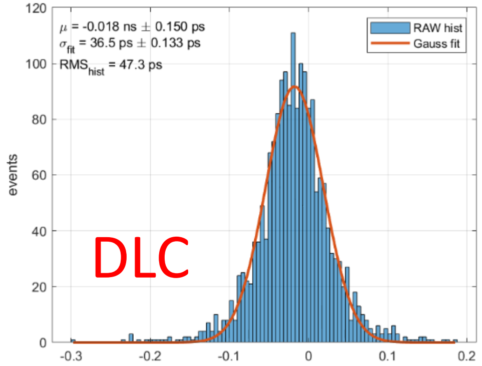


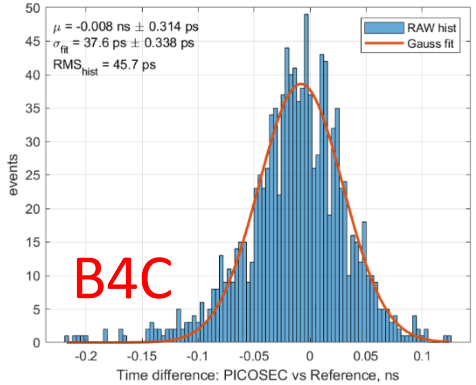
Micromegas board



Outer PCB







Slide reference: Yue Meng (mallory4869@mail.ustc.edu.cn)

JLab group PICOSEC members

Kondo Gnanvo,

Brian Kross,

Jack McKisson,

Drew Weisenberger,

Wenze Xi

Summary

- **In the April 2024 test beam at CERN, several combinations of the well's pitch, outer diameter, and inner diameter have been tested with new mechanical housing of single channel µRWELL-PICOSEC prototype .**
- **Different types of well shapes, including square and round, as well as plain and strip readout pads, have been also investigated for the single channel uRWELL-PICOSEC prototypes.**
- **More than 60 runs of 50k event each has been taken in April 2024 test beam ➔ analysis ongoing**
- **A time resolution of 23.7 ps has been achieved with the new housing and new geometery of single channel µRWELL-PICOSEC prototype having round shaped hole with 120 µm pitch, 100 µm as outer diameter, 80 µm as inner diameter and 170 µm as a preamplification gap.**

The research described in these slides was conducted under the Laboratory Directed Research and Development (LDRD) Program at Thomas Jefferson National Accelerator Facility for the U.S. Department of Energy

LDRD @ Jefferson Lab

Backup

Applications of µRWELL- PICOSEC detector

- Develop fast, precise, and cost-effective gaseous detectors for particle physics and medical applications with properties like stability, radiation hardness, large area coverage, and segmented readout capabilities.
- The MM-PICOSEC collaboration has proven the concept using Micromegas technology, and picosecond detectors based on µRWELL technology show great potential.
- µRWELL-PICOSEC technology offers promising alternatives for PID systems, TOF detectors for charged particles, and Cerenkov photosensor technologies.
- Potential applications include future projects like the Electron Ion Collider (EIC) Detector II, the ePIC upgrade, future experiments at Jefferson Lab, and medical instrumentation such as TOF-PET devices.

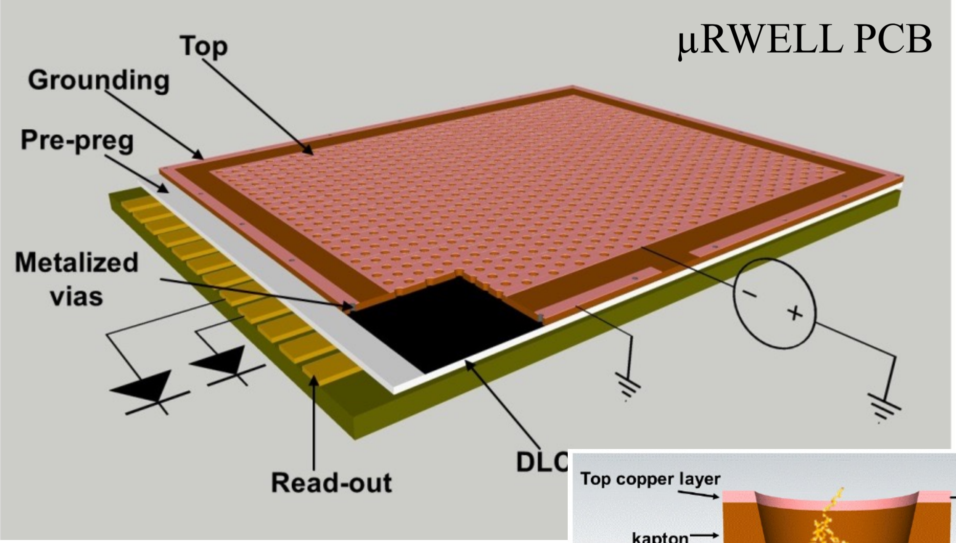
μRWELL-PICOSEC: Amplification structure

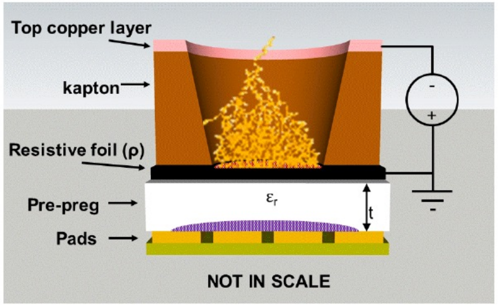
Design of μRWELL foil

- ❖ Single layer amplification MPGD
  - ▪ Simple amplification structure using same material as GEM foil
  - ▪ Resistive technology ➔ intrinsically robust against spark
  - ▪ Large area capability
- ❖ Specially well suited for PICOSEC technology
  - ▪ μRWELL is a resistive MPGD ➔ improve detector stability
  - ▪ Segmented μRWELL (PEP) ➔ improve rate capability & timing

backup

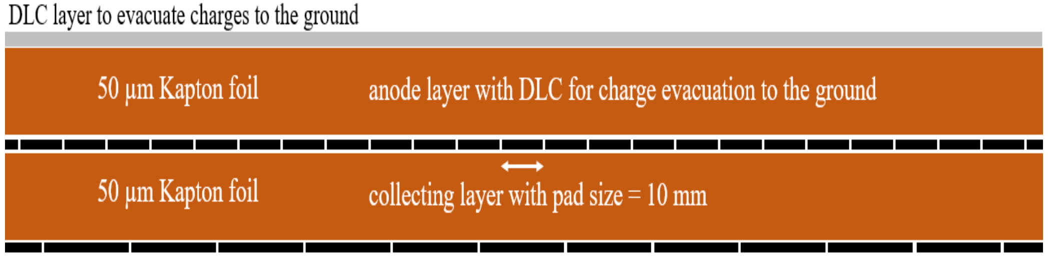
G. Bencivenni et al 2015 JINST 10 P02008





Integration of capacitive-sharing readout structures

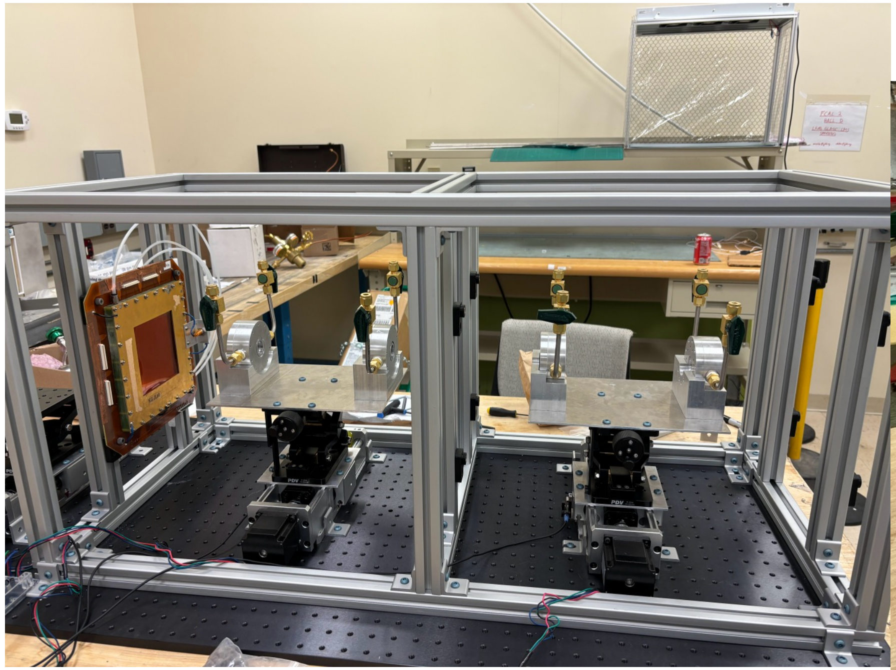
- ❖ Capacitive-sharing pad readout will allow precise position information capability with limited readout channel number
- ❖ Combining segmented μRWELL and capacitive-sharing ➔ best of both world
  - ▪ Segmented μRWELL: excellent timing resolution
  - ▪ Capacitive-sharing readout: excellent position resolution

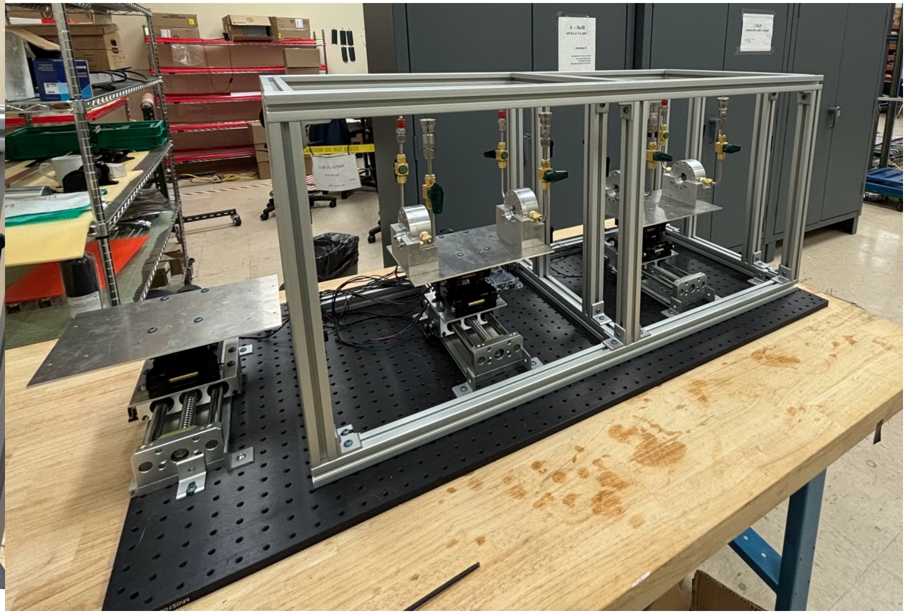


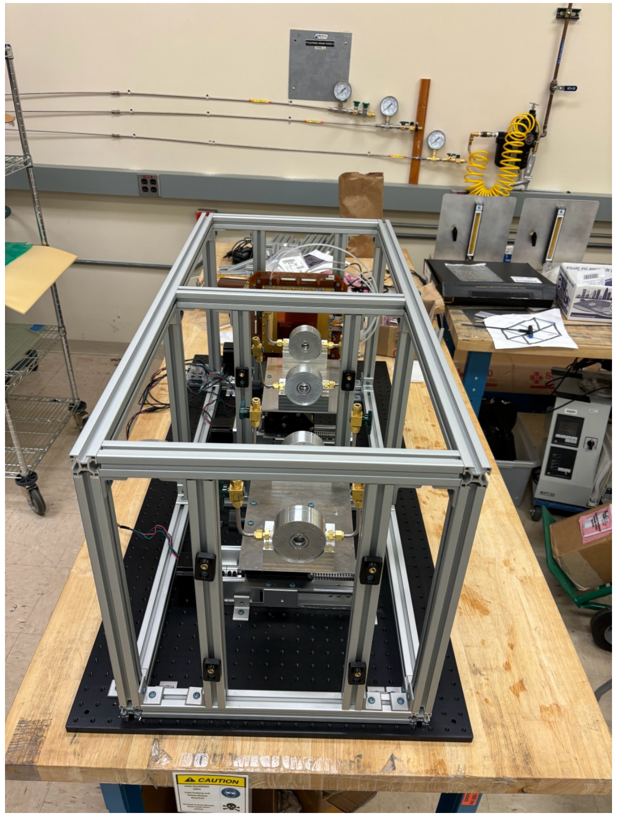
Concept capacitive-sharing pad readout

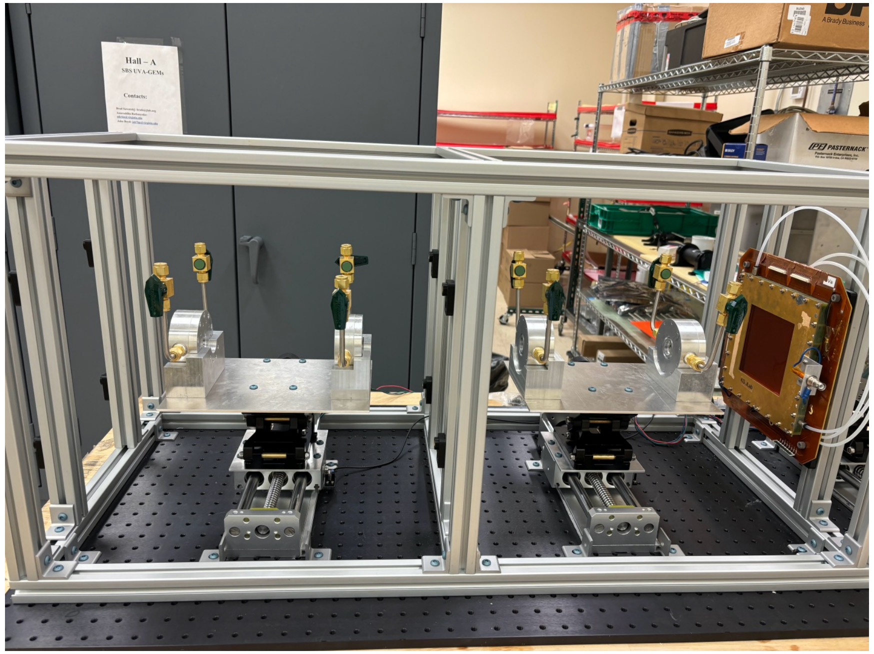
K. Gnanvo et al., NIM A, 1047 (2023) 167782

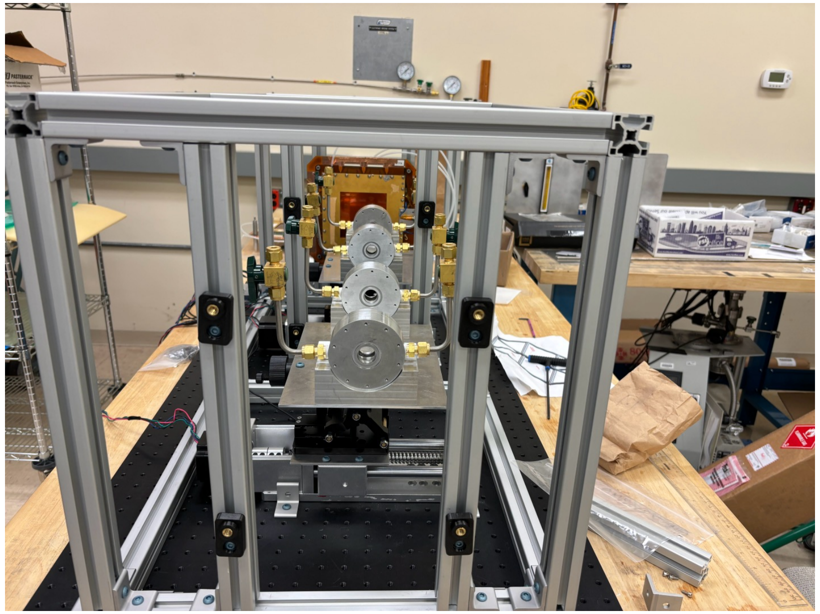
Assembly of µRWELL-PICOSEC telescope at JLab











μRWELL-PICOSEC: Radiators and photocathodes

Photocathode:

Current technology: Cesium Iodide (CsI)

Pros:

- High quantum efficiency (QE) in vacuum ultraviolet (VUV) region which is most radiated by any radiator medium

Cons:

- Sensitivity to water ➔ performance rapidly deteriorates
- Ion bombardment (IBF) of CsI is challenging for high rate

We will investigate materials with similar level of QE:

Candidates are B4C, DLC and Nano diamond (ND)

- Goal is to achieve similar level of QE ➔ Extensive R&D
- Radiation hardness and unsensitivity to humid condition

Radiator:

Current technology: Magnesium Fluoride (MgF2)

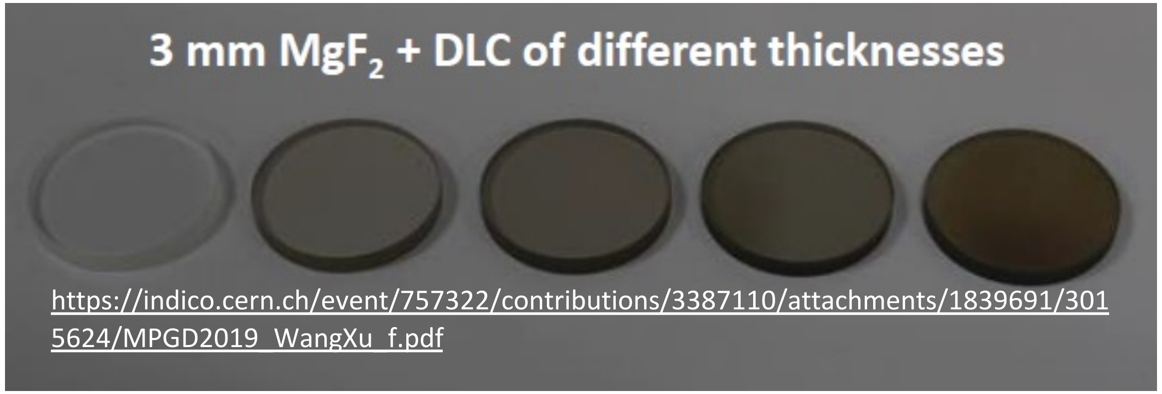
Pros:

- Transparency in vacuum ultraviolet (VUV) region which is most radiated by any radiator medium

Cons:

- Low photon yield
- large Cerenkov angle sin (Θ_c) ➔ poor spatial information
- Smaller Θ_c material will results in even lower photon yield

We will investigate radiator materials for higher photon yield capability



Run no	Prototype 1	Anode/cathode Voltage (V)	Prototype 2	Anode/cathode Voltage (V)
Run272J	uRWELL7	250/440	uRWELL5	250/440
Run275J	uRWELL7	250/450	uRWELL5	250/450
Run276J	uRWELL7	250/460	uRWELL5	250/460
Run277J	uRWELL7	255/440	uRWELL5	255/440
Run278J	uRWELL7	255/450	uRWELL5	255/450
Run279J	uRWELL7	255/460	uRWELL5	255/460
Run286J	uRWELL7	260/440	uRWELL5	260/440
Run289J	uRWELL7	260/450	uRWELL5	260/450
Run293J	uRWELL7	260/430	uRWELL5	260/430
Run305J	uRWELL7	250/460	uRWELL5	250/460
Run307J	uRWELL7	255/450	uRWELL5	255/450
Run309J	uRWELL7	250/450	uRWELL5	250/450

Run no	Prototype 1	Anode/cathode Voltage (V)	Prototype 2	Anode/cathode Voltage (V)
Run310J	uRWELL7	255/460	uRWELL5	255/460
Run311J	uRWELL7	240/450	uRWELL5	240/450
Run312J	uRWELL7	240/460	uRWELL5	240/460
Run323J	uRWELL7	250/440	uRWELL5	250/440
Run324J	uRWELL7	255/440	uRWELL5	255/440
Run326J	uRWELL7	255/430	uRWELL5	255/430
Run328J	uRWELL7	260/430	uRWELL5	260/430
Run332J	uRWELL7	260/440	uRWELL5	260/440
Run334J	uRWELL7	260/450	uRWELL5	260/450
Run362J	uRWELL9	250/440	uRWELL11	250/440
Run363J	uRWELL9	255/450	uRWELL11	255/450
Run365J	uRWELL9	250/460	uRWELL11	250/460

Run no	Prototype 1	Anode/cathode Voltage (V)	Prototype 2	Anode/cathode Voltage (V)
Run366J	uRWELL9	250/440	uRWELL11	250/440
Run367J	uRWELL9	255/450	uRWELL11	255/450
Run369J	uRWELL9	255/460	uRWELL11	255/460
Run371J	uRWELL9	260/450	uRWELL11	260/450
Run372J	uRWELL9	260/440	uRWELL11	260/440
Run382J	uRWELL1	250/440	uRWELL3	250/440
Run384J	uRWELL1	250/450	uRWELL3	250/450
Run386J	uRWELL1	250/430	uRWELL3	250/430
Run390J	uRWELL1	255/430	uRWELL3	255/430
Run392J	uRWELL1	255/440	uRWELL3	255/440
Run394J	uRWELL1	255/450	uRWELL3	255/450
Run396J	uRWELL1	260/430	uRWELL3	260/430

Run no	Prototype 1	Anode/cathode Voltage (V)	Prototype 2	Anode/cathode Voltage (V)
Run398J	uRWELL1	260/440	uRWELL3	260/440
Run410J	uRWELL5	250/320	uRWELL9	250/320
Run411J	uRWELL5	250/330	uRWELL9	250/330
Run413J	uRWELL5	250/340	uRWELL9	250/340
Run415J	uRWELL5	250/350	uRWELL9	250/350
Run417J	uRWELL5	250/400	uRWELL9	250/400
Run419J	uRWELL5	252/400	uRWELL9	252/400
Run421J	uRWELL5	254/400	uRWELL9	254/400
Run422J	uRWELL5	256/400	uRWELL9	256/400
Run423J	uRWELL5	258/400	uRWELL9	258/400
Run424J	uRWELL5	260/400	uRWELL9	260/400
Run425J	uRWELL5	260/405	uRWELL9	260/405

Run no	Prototype 1	Anode/cathode Voltage (V)	Prototype 2	Anode/cathode Voltage (V)
Run426J	uRWELL5	260/410	uRWELL9	260/410
Run427J	uRWELL5	255/410	uRWELL9	255/410
Run428J	uRWELL5	250/410	uRWELL9	250/410
Run429J	uRWELL5	250/340	uRWELL9	250/340
Run431J	uRWELL5	255/405	uRWELL9	255/405
Run436J	uRWELL13	250/440	uRWELL9	250/400
Run437J	uRWELL13	250/450	uRWELL9	250/405
Run438J	uRWELL13	250/460	uRWELL9	250/410
Run439J	uRWELL13	255/440	uRWELL9	260/398
Run441J	uRWELL13	255/450	uRWELL9	260/396
Run442J	uRWELL13	255/460	uRWELL9	260/394
Run443J	uRWELL13	260/430	uRWELL9	260/392

Run no	Prototype 1	Anode/cathode Voltage (V)	Prototype 2	Anode/cathode Voltage (V)
Run444J	uRWELL13	260/440	uRWELL9	260/390
Run445J	uRWELL13	260/450	uRWELL9	260/388