

50-ps MPGD-based TOF Detector for High-Energy Neutrons

MPGD-nTOF

March 4th, 2026

Xinzhan Bai

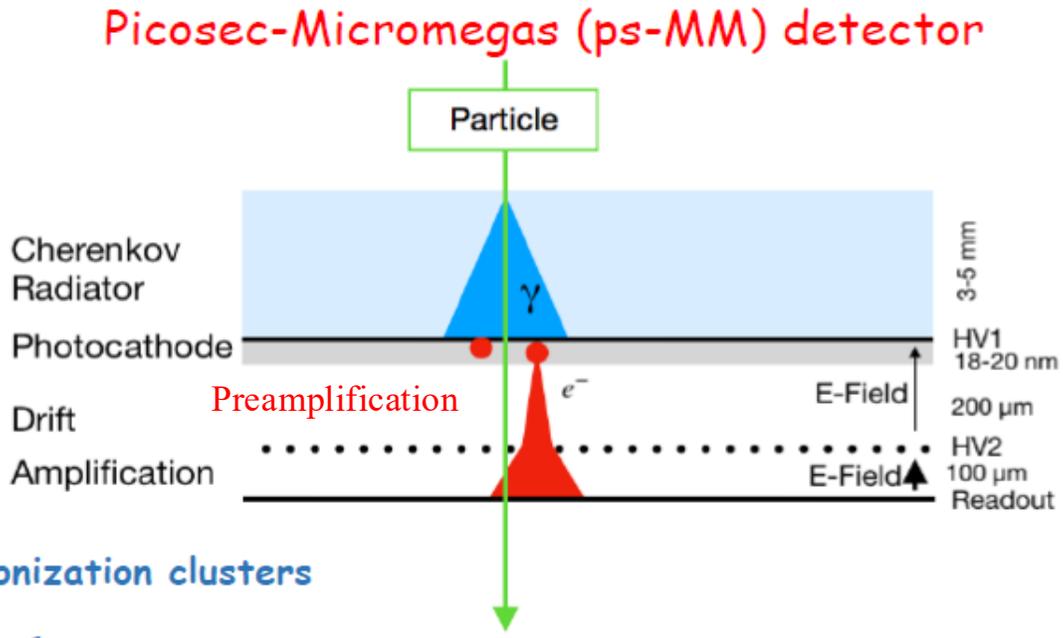
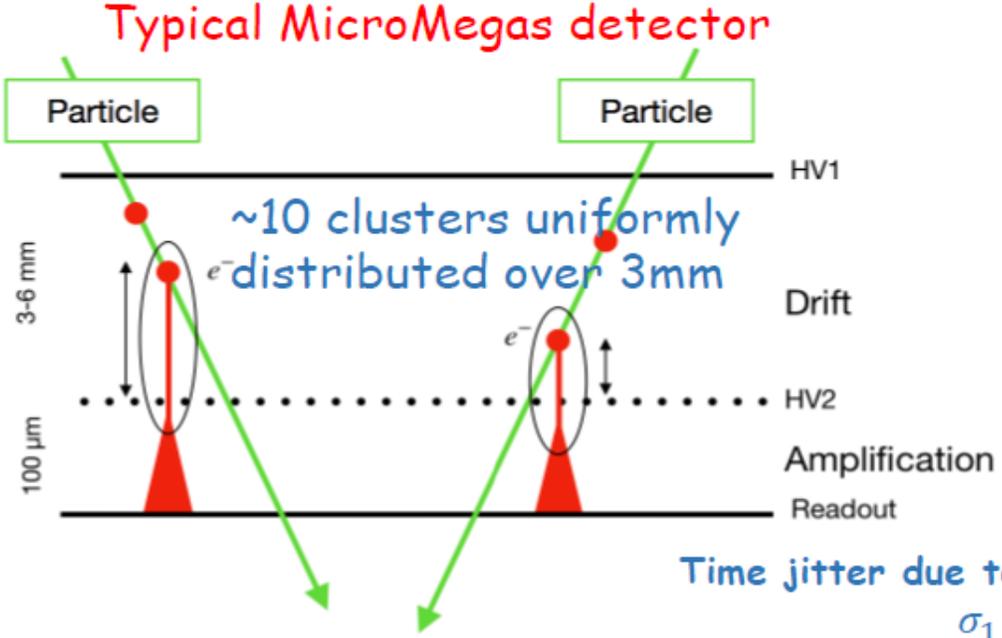
Radiation Detector & Imaging Group (RD&I)



Outline

- MPGD Detectors for Fast Timing TOF
- MPGD-nTOF concept for fast timing neutron TOF
- Simulation on Timing Performance
- Photocathode Development
- Conclusion and Outlook

Concept of MPGD-based picosecond Detector : MM-PICOSEC



Time jitter due to multiple ionization clusters

$$\sigma_t = \frac{\sigma_1}{v_e} \sim \frac{300 \mu m}{50 \frac{mm}{\mu s}} = 6 ns$$

- The time resolution is mainly limited to the direct initial ionization in the drifting zone:
- ◆ Uncertain of the collision position
 - ◆ Small velocity of electrons
 - ◆ Spread of electrons during the drifting progress

- Novel fast time Micromegas detectors:
- ◆ Reducing the directly initial ionization by reducing the length of drifting zone
 - ◆ Increasing the electric field
 - ◆ Cerenkov Radiator and Photocathode produce photoelectrons, small longitudinal diffusion

Courtesy Xu Wang, MPGD-China 2017

PICOSEC Collaboration

AUTH (Greece) I. Angelis, K. Kordas, C. Lampoudis, I. Maniatis, I. Manthos, K. Paraschou, D. Sampsonidis, A. Tsiamis, S. E. Tzamarias

CEA-IRFU, LIST, LIDYL(France) S. Aune, D. Desforge, I. Giomataris, T. Gustavsson, F. Jeanneau, A. Kallitsopoulou, M. Kebbiri, P. Legou, T. Papaevangelou, M. Pomorski, E. Scorsonne

CERN (Switzerland) J. Bortfeldt, F. Brunbauer, C. David, D. Janssens, K.J. Floethner, M. Lupberger, M. Lisowska, H. Müller, E. Oliveri, G. Orlandini, F. Resnati, L. Ropelewski, L. Scharenberg, T. Schneider, M. van Stenis, R. Veenhof

HIP (Finland) F. García

Jefferson Lab (USA) K. Gnanvo

LIP (Portugal) M. Gallinaro

NCSR Demokritos, (Greece) G. Fanourakis

NTUA (Greece) Y. Tsiopolitis

Ruder Boškovic Institute(Croatia) : A. Utrobicic

Stony Brook University (USA) J.Datta

USTC (Hefei, China) J. Liu, Y. Meng, X. Wang, Z. Zhang, Y. Zhou

University of Zagreb(Croatia) M. Kovacic,

University of Pavia (Italy) D. Fiorina, M. Brunoldi

Univeristy of Virginia (USA) S. White



National Technical
University of Athens



ARISTOTLE
UNIVERSITY OF
THESSALONIKI



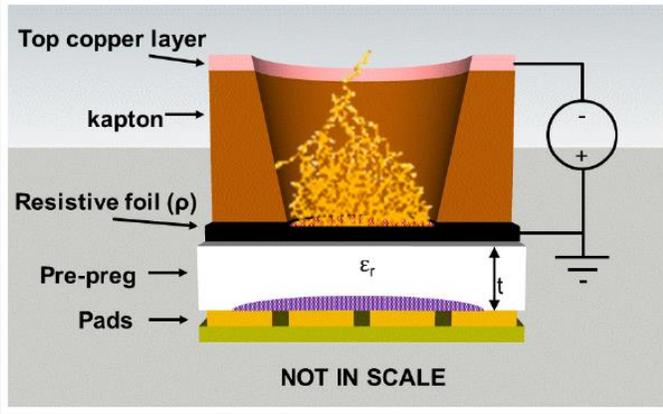
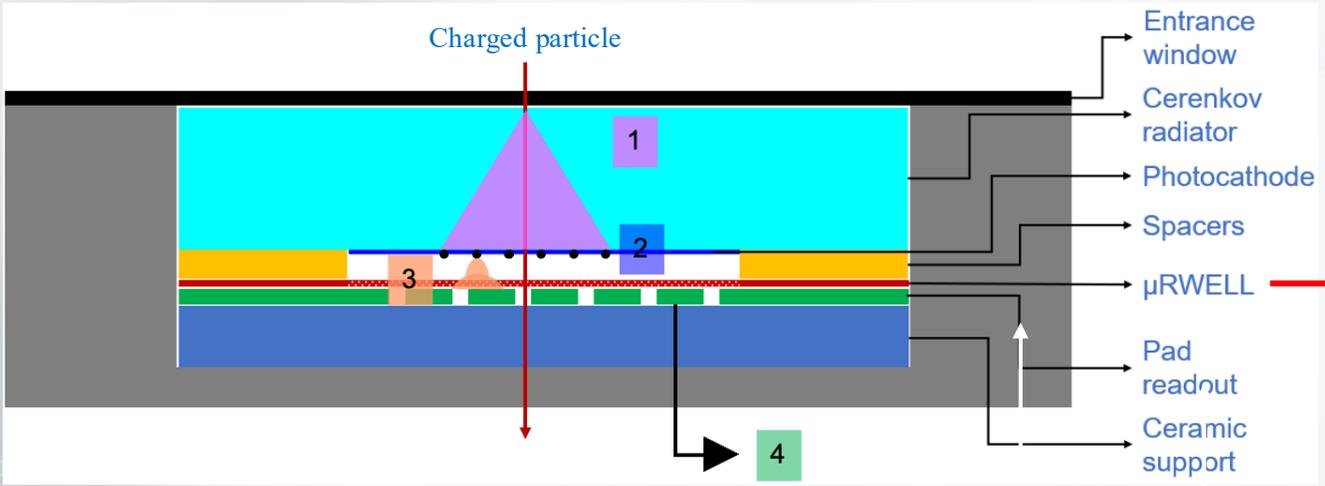
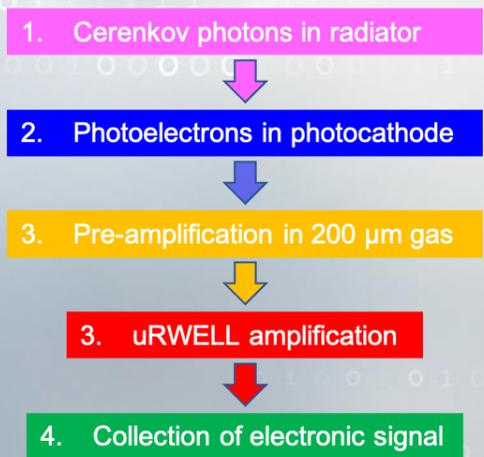
LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia



μ RWELL-PICOSEC Detector Completed JLab-LDRD (FY2023 & FY2024). PI: Kondo Gnanvo

Concept of μ RWELL-PICOSEC: fast timing gaseous detector using μ RWELL amplification \rightarrow timing resolution: ~ 10 ps

1. **Cherenkov photons:** prompt Cherenkov photons from relativistic charged particles
2. **Photoelectrons:** photocathode convert photons to electrons, all created at the location
3. **Pre-amplification:** first electron amplification in $\sim 100 \mu\text{m}$, high electric field drift region ($\sim 20 \text{ kV/cm}$)
4. **Amplification:** final electron amplification in μ RWELL detector, high electric field ($\sim 40 \text{ kV/cm}$)
5. **Electronic signal:** arrival of the amplified electrons to the anode

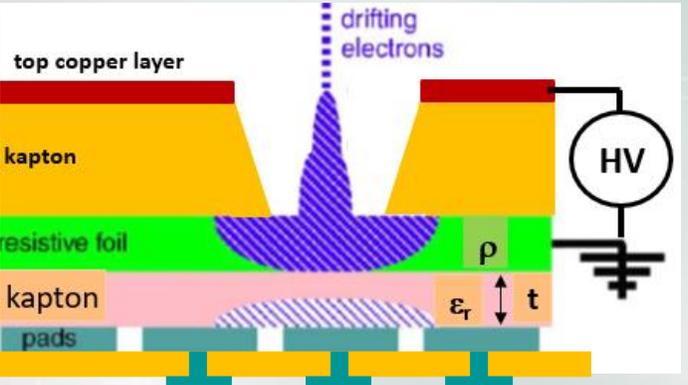


μ RWELL PCB

Typical gas mixture for Gaseous PICOSEC Neon : C₂H₆ : CF₄ = 80 : 10 : 10 (at ambient pressure)

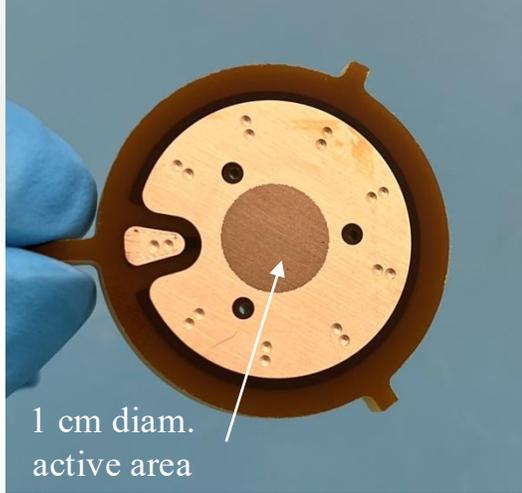
Plot Courtesy of Kondo Gnanvo

μ RWELL-PICOSEC Detector: Small prototypes



μ RWELL PCB

Readout pad contact

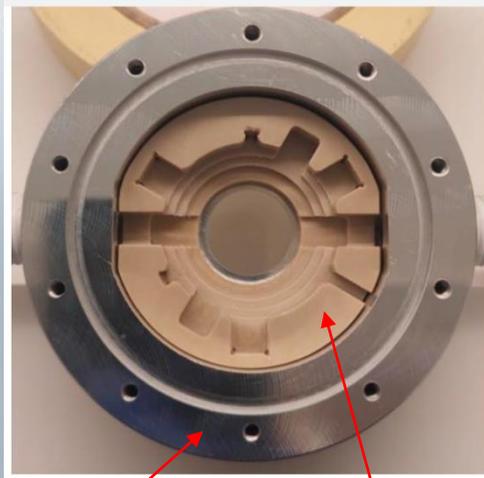


1 cm diam. active area

μ RWELL PCB front side

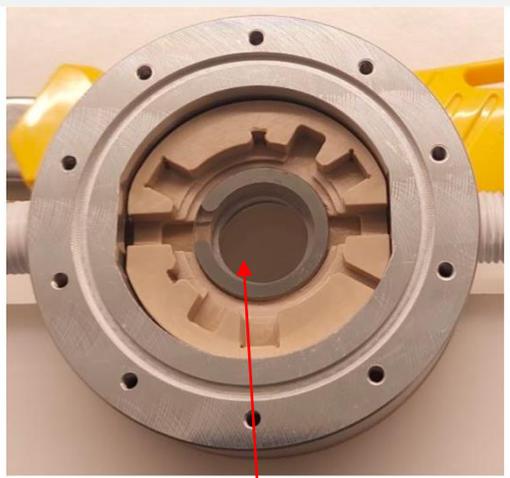


Prototype in Al chamber

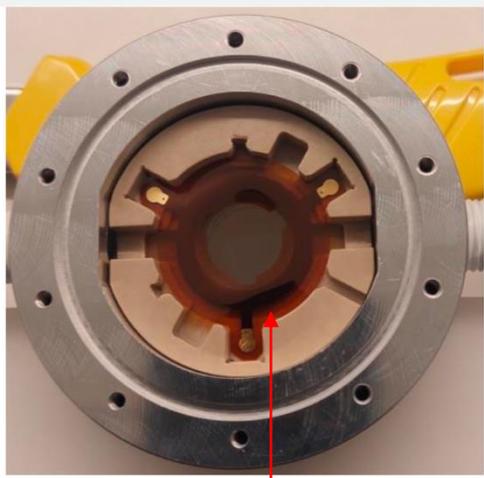


3/4/2026 Al chamber

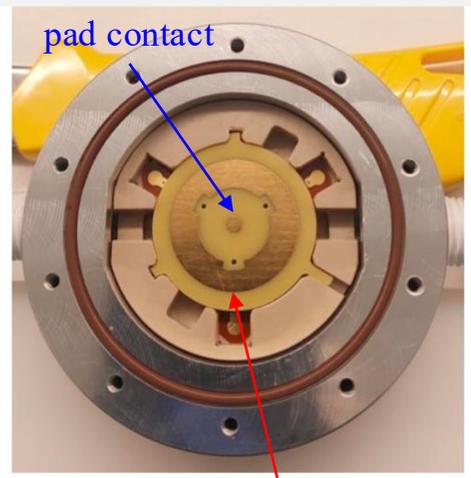
PEEK insert



3mm MgF₂ crystal with 18nm CsI / 2nm DLC photocathode



Spacer / cathode contact



μ RWELL PCB back side

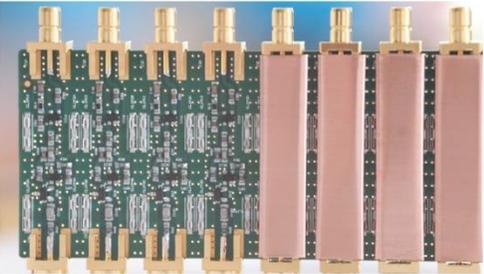


Outer board

μ RWELL-PICOSEC Detector: Large (10cm X 10 cm) prototypes

1. 100-pad μ RWELL-PICOSEC with 120 μ m pitch, 100 μ m outer diameter and 80 μ m inner diameter assembled
2. The back of the large μ RWELL-PCB connected to the outer readout PCB through pogo pins
3. Instrumented with fast electronics based on customized pre-amplifiers coupled with multi-channel SAMPIC digitizer readout

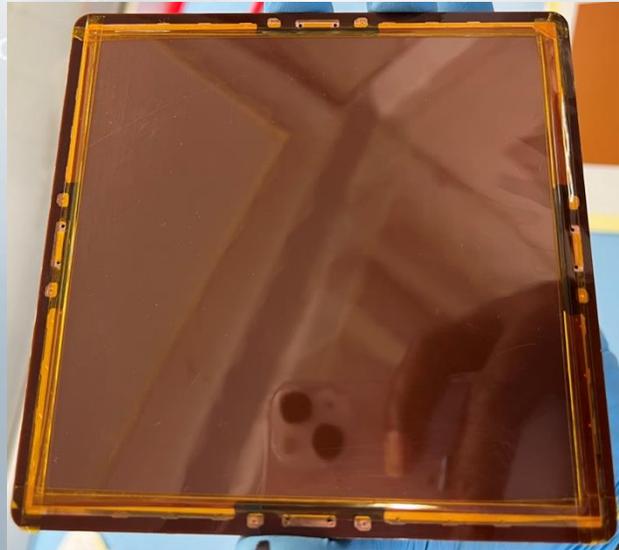
Plot Courtesy of **Kondo Gnanvo**



preamplifier

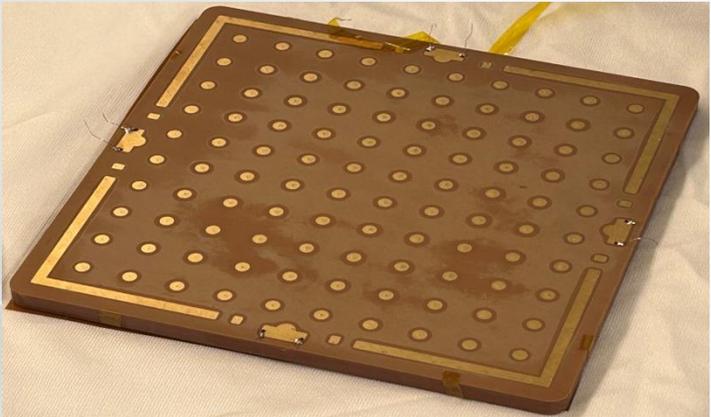


64-channels SAMPIC

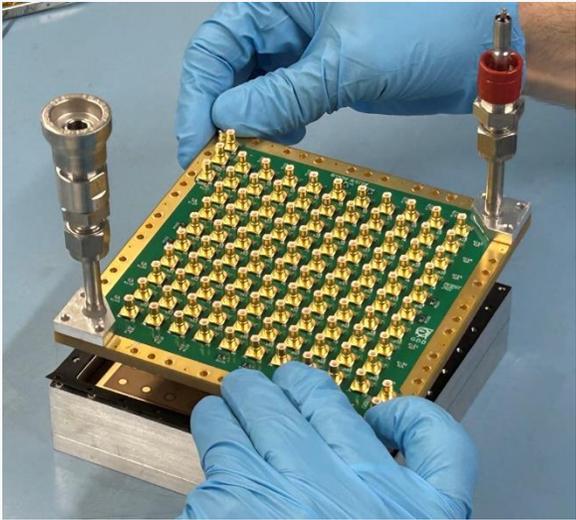


Top side of the μ RWELL-PCB

3/4/2026



Back side of the μ RWELL PCB

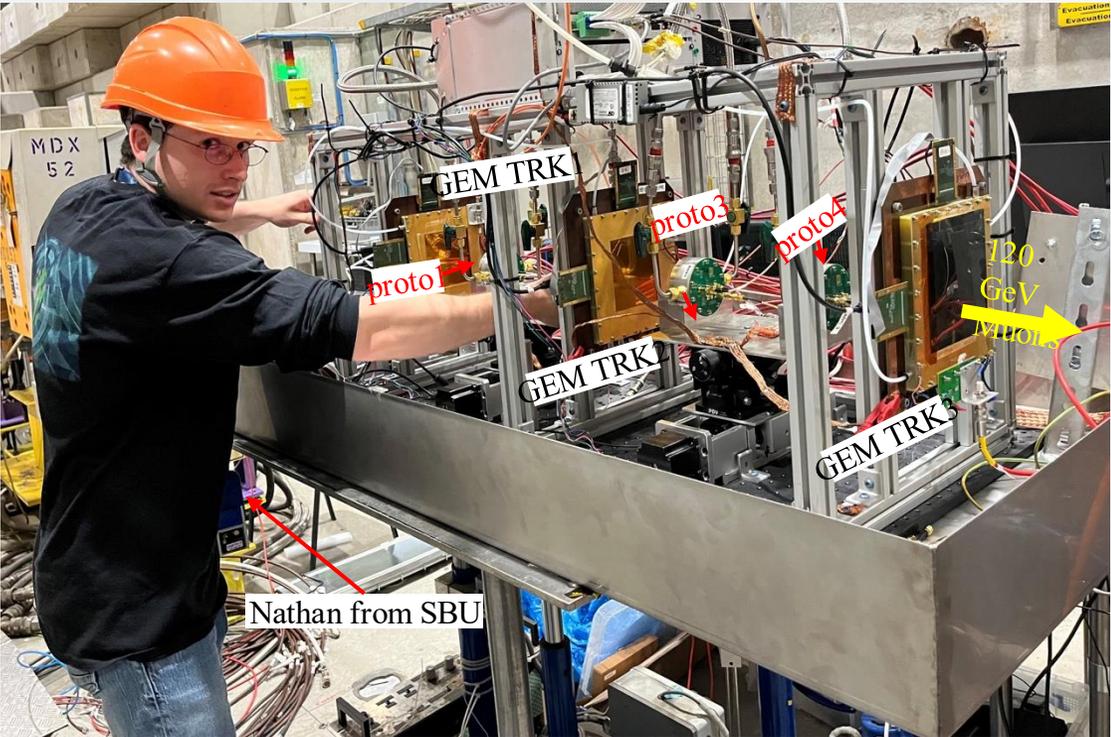
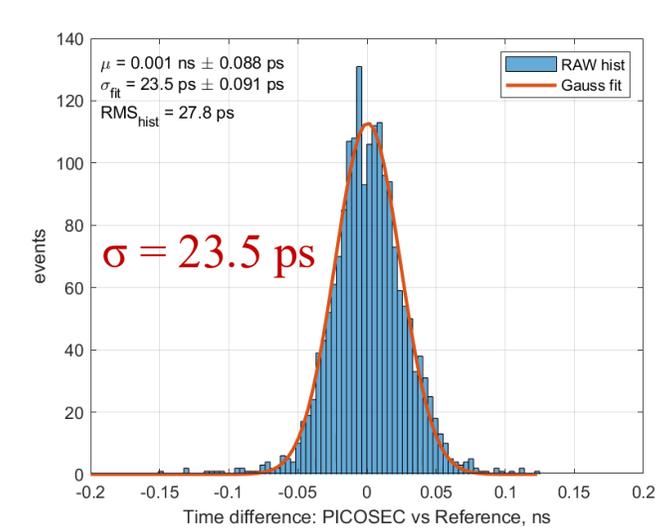
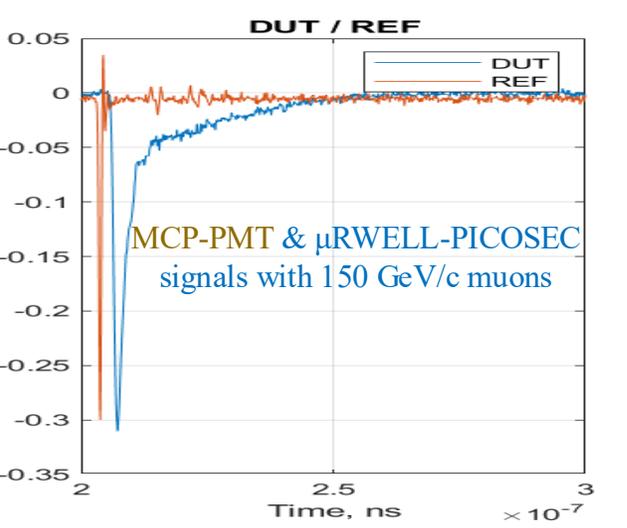


Prototype in Al housing, closed by outer readout PCB

μRWELL-PICOSEC Detector: Beam Test Results

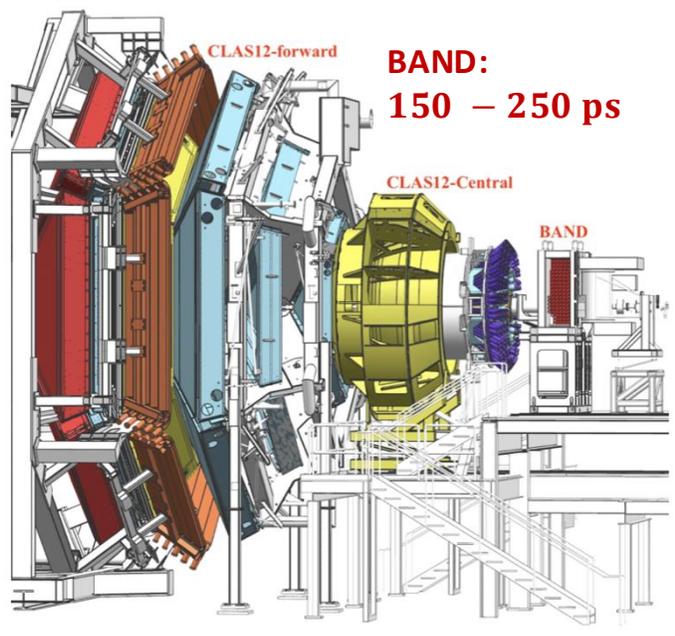
- MCP-PMT as reference timing (timing resolution ~ 4ps)
- Time difference = $(t_{proto} - t_{ref}) - t_{walk}$
- CFD (Constant Fraction Discrimination) Analysis
- Time walk correction is applied before subtracting from the reference time
- Result is shown for **CsI photocathode**

Results and Plot courtesy of **Kondo Gnanvo**



μRWELL-PICOSEC Telescope used in April and July 2024 test beam at CERN

Current Neutron TOF Detector (Scintillator + PMT)



E.P. Segarra, et al; arXiv:2004.10339v2



**NeuLAND:
150 ps**

K. Boretzky, I. Gašparić, M. Heil et al.
NIM-A 1014 (2021) 165701



**LANA:
210 ps**

Kuan Zhu
PhD thesis (2020) – Michigan State University

MPGD-nTOF : Concept

Physics Motivation

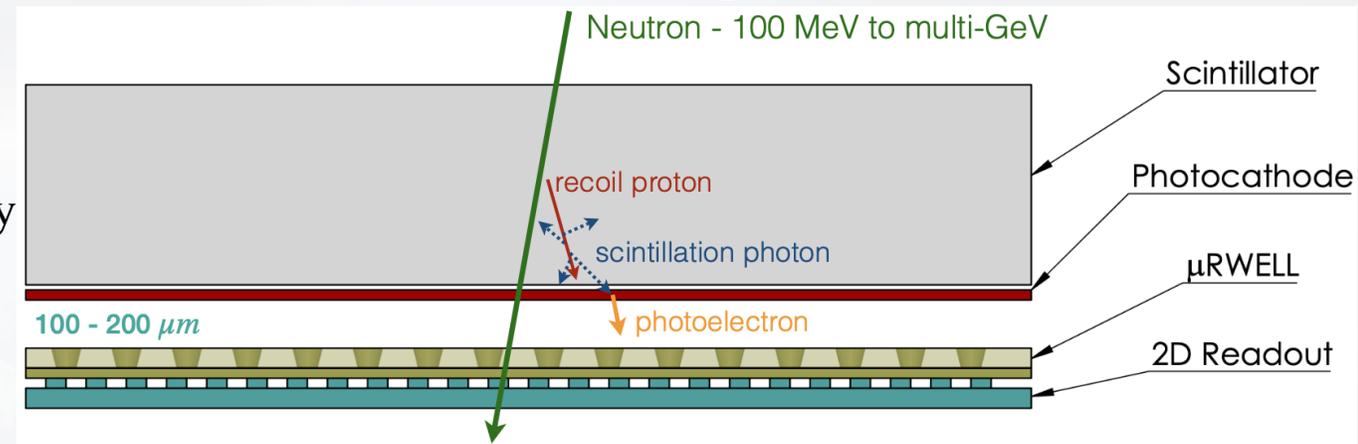
- Fast timing resolution (50 ps) neutron TOF
- Scalable, large-area solution compatible with high-rate environments

Detector Concept

- **Plastic scintillator** for light generation from recoil proton & **UV/visible light sensitive photocathode** for photoelectron conversion
- A thin drift region (100 – 200 μm) coupled with a μRWELL Detector for electron amplification and 2D readout
- Fast timing response

Key R&D Focus

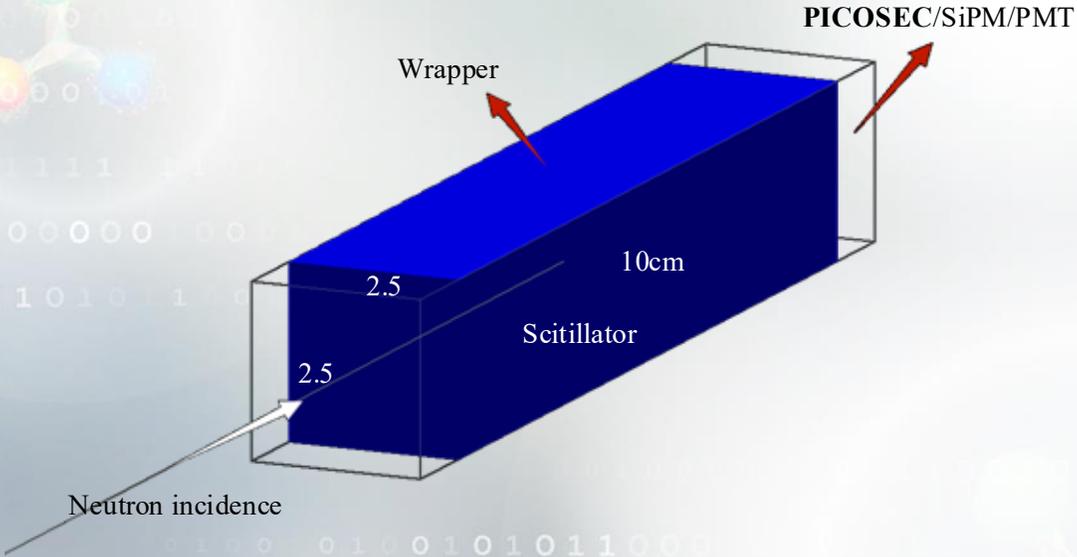
- UV/visible light sensitive photocathode stability in gas environment
- Photocathode QE
- Large-area scalability



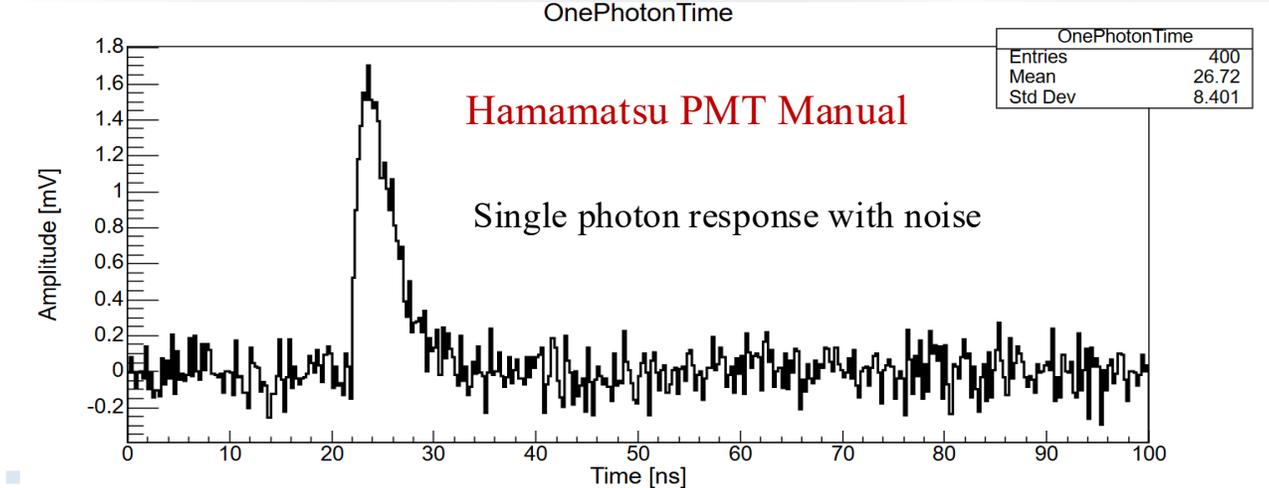
Cross sectional view of the MPGD-nTOF detector

Simulation on Timing Performance

- Simulation study to assess optical photon transportation in fast plastic scintillators (Using EJ232)
- Evaluate light collection under realistic conditions to benchmark timing performance
- Results indicate the design can achieve 50 ps timing resolution with 10 cm scintillator bar



Detector Geant4 Setup

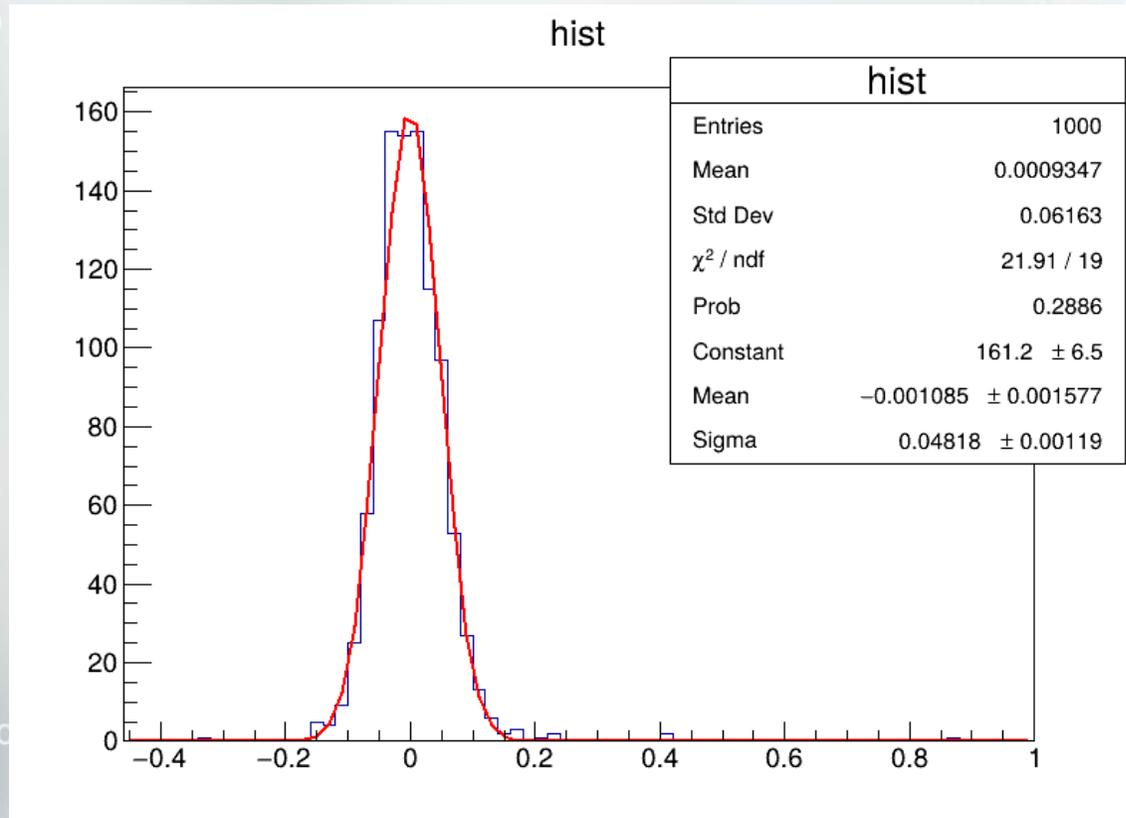


- Transit Time Spread (T.T.S)
- Wave Peak Fluctuation
- Baseline Noise
- Dark Counts

Plots from Weizhi Xiong's Group

Simulation on Timing Performance

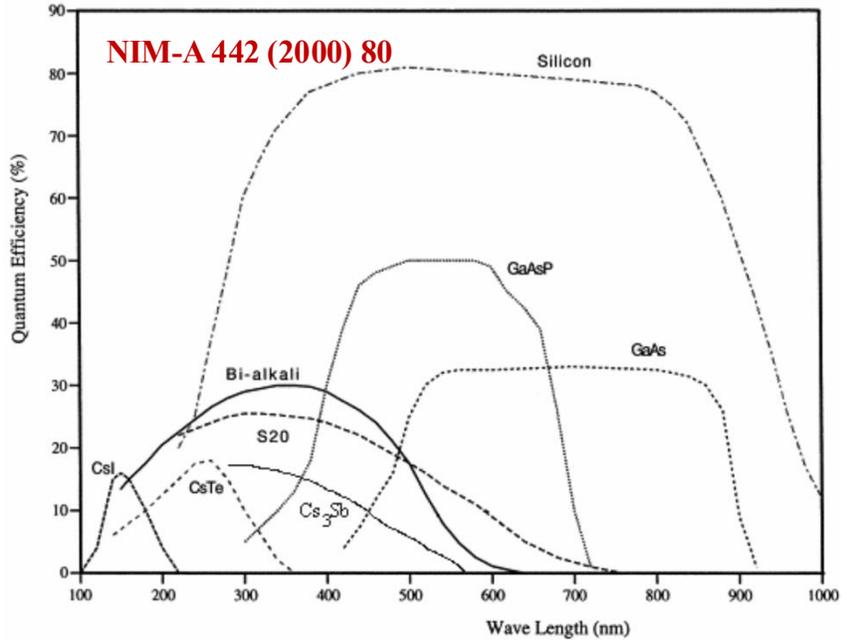
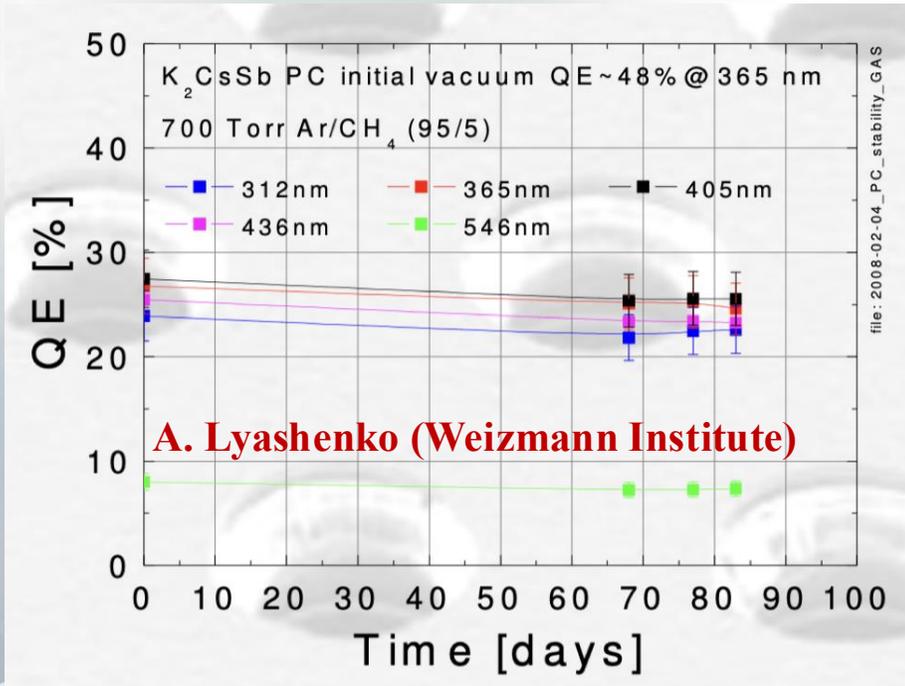
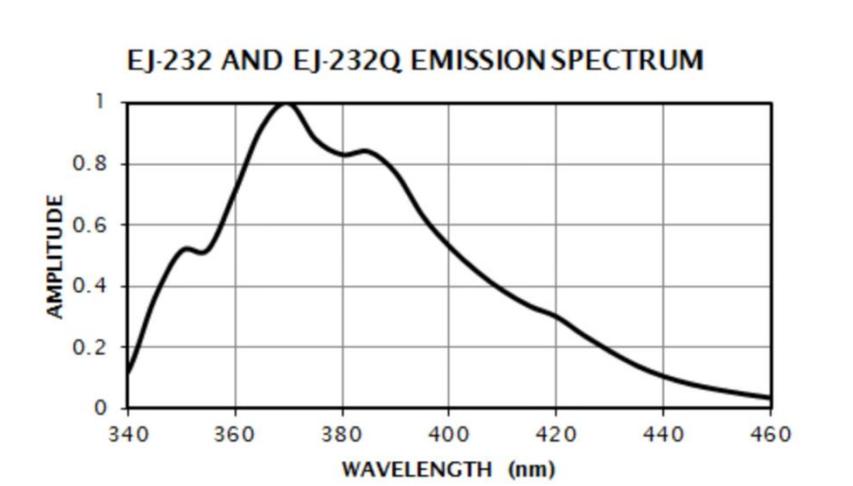
- using leading-edge fitting indicates 50 ps timing resolution for a 10 cm long plastic scintillator bar



Plots Courtesy of Weizhi Xiong

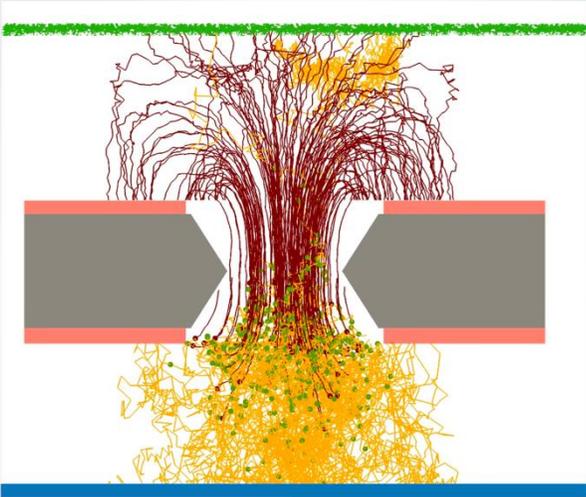
MPGD-nTOF : Photocathode

- Plastic scintillator photon spectrum – UV and visible light range
- Bi-alkali photocathode (e.g. K_2CsSb , $Na_2KSb:Cs$) is the only photocathode that match the spectrum
- CsI, DLC photocathode ($\mu RWELL - PICOSEC$) zero QE



MPGD-nTOF : Photocathode Challenges

- Alkali photocathode stability in gas environment
 - Usually require vacuum work environment
 - Extremely sensitive to O₂, H₂O, CO₂
- Ion Back Flow
 - Normal Ion Back Flow ~ 60% per GEM foil
 - Long term stable operation: IBF 10⁻³ ~ 10⁻⁴



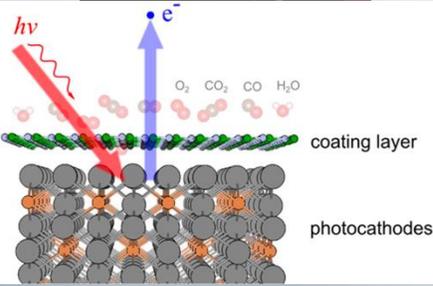
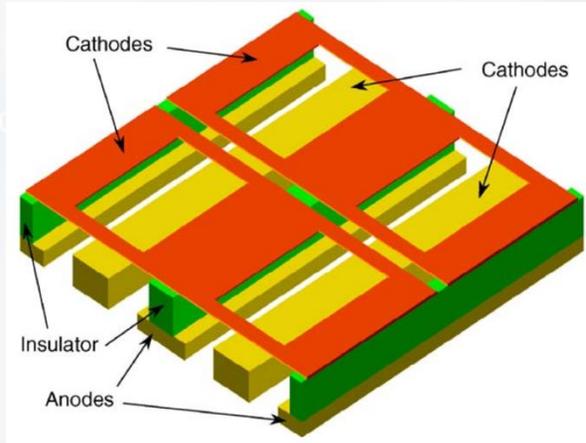
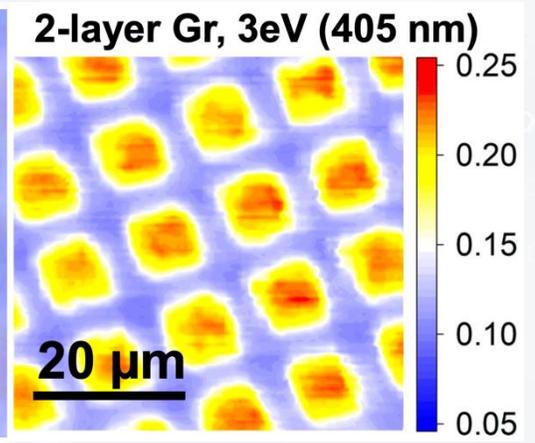
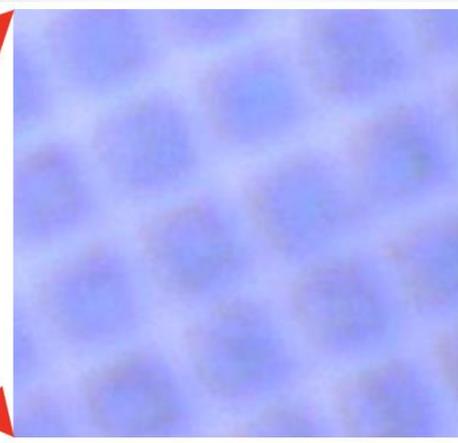
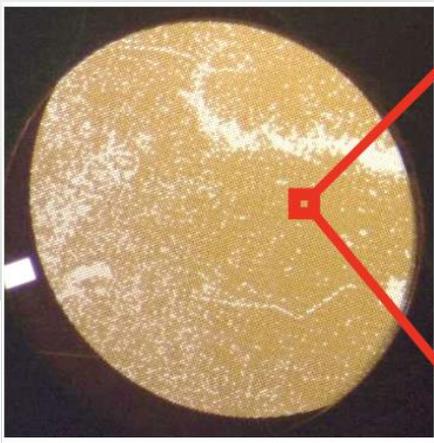
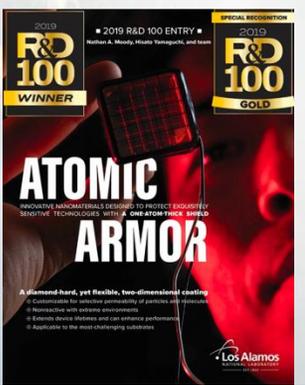
$$IBF = \frac{I_{cathode}}{I_{anode}}$$

Photocathode	QE (370 nm)	Sensitive to gas residue H ₂ O
Cs ₃ Sb	10-15%	< 100 ppb
Na ₂ KSb:Cs	10-20%	< 10s ppb
K ₂ CsSb	30%-40%	< 10 ppb (single digit preferred)

- Low or Negative Electron Affinity Photocathode
 - Back flowing ions cause secondary electron emission
 - Secondary photoelectrons also has ion back flow
 - Cascade reaction – avalanche process – discharge

Strategies to Overcome Photocathode Challenge

- Develop protective photocathode coatings (coating material: graphene, DLC, thin metal films, etc)
 - Active on-going R&D for accelerator studies at BNL, LANL, SLAC, and others
 - Leverage external expertise through collaboration with researchers experienced in photocathode coating studies
- Detector structure improvement (Ion Trap)
 - Related work reduced Ion Feedback to below 4%



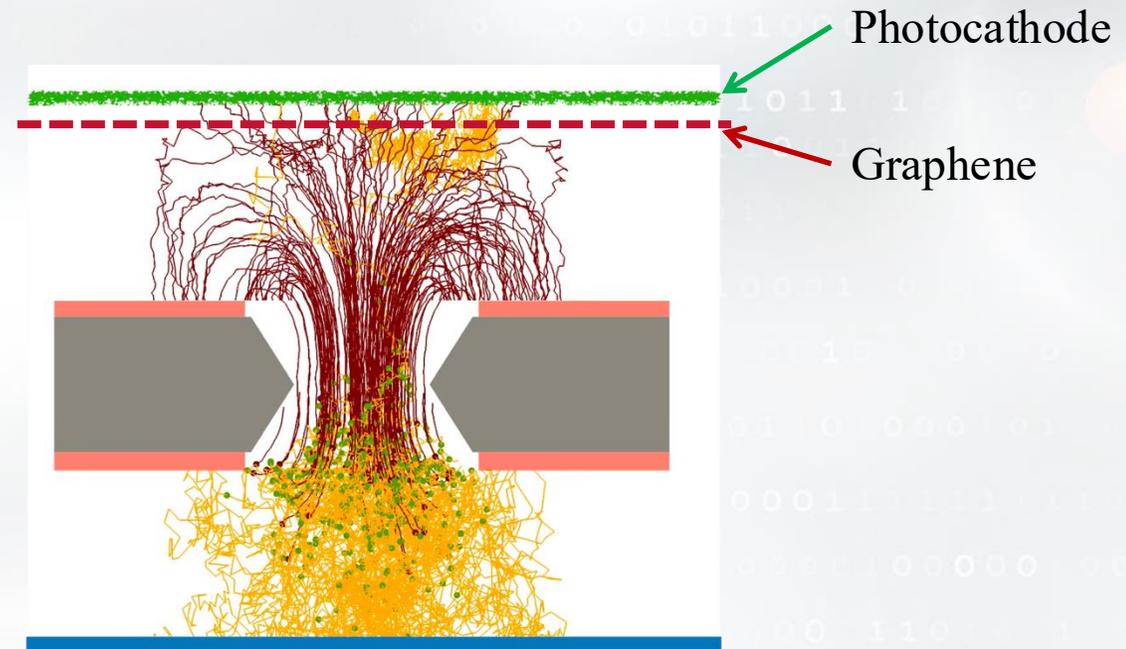
The Atomic Armor – Hisato Yamaguchi (LANL)

Ion Trap – Oleg Bouianov, NIM-A 526 (2004) 413-419

G. Wang and N. Moody et al.
 NPJ. 2D Materials and Applications 17 (2018)
 3/4/2026

MPGD-nTOF : Graphene-coated Photocathode

- Graphene – 2D material
- Mono-layer Graphene has > 90% electron transmission rate
- Completely blocks the transmission of ions, gas molecules
- Ideal material for photocathode protection
 - Ion back flow
 - Gas impurities
- **Two paths**
 - Free-standing Graphene – LANL – **Atomic Armor**
 - Intercalation method – BNL

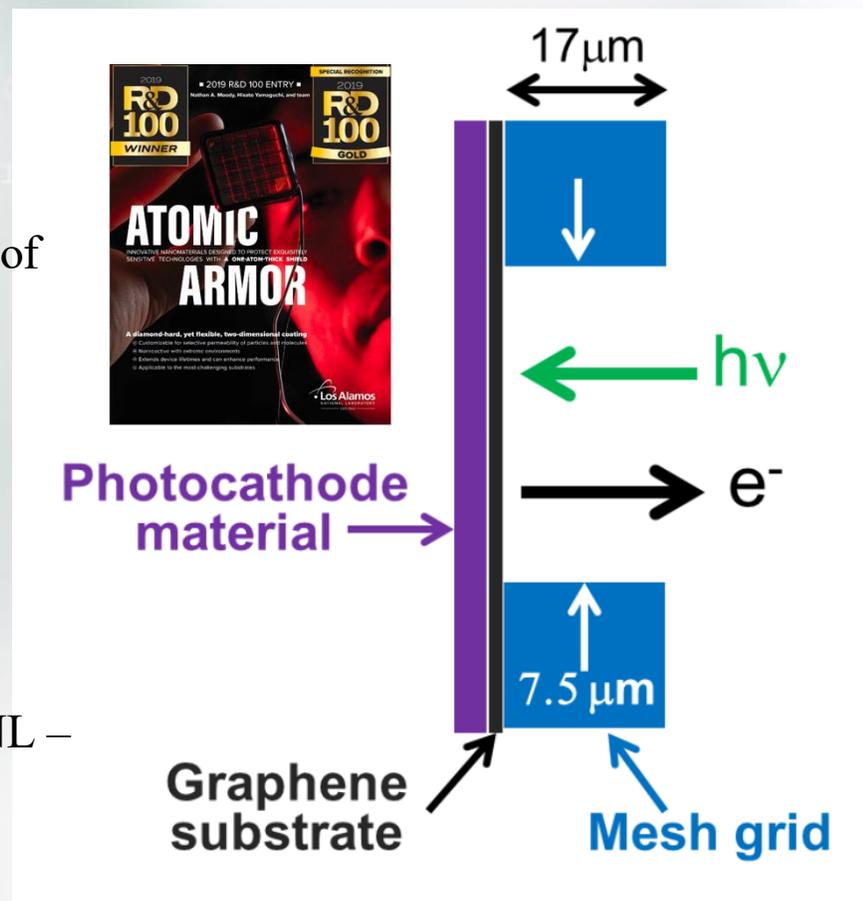


H.Yamaguchi et al. *Advanced Materials Interfaces* (2018)

Jyoti Biswas, Mengjia Gaowei et. al, *APL Mater.* 10, 111115 (2022)

MPGD-nTOF : Graphene-coated Photocathode

- Graphene – 2D material
- Mono-layer Graphene has > 90% electron transmission rate
- Completely blocks the transmission of ions, gas molecules
- Ideal material for photocathode protection
 - Ion back flow
 - Gas impurities
- **Two paths**
 - Free-standing Graphene – LANL – **Atomic Armor**
 - Intercalation method – BNL



H.Yamaguchi et al. *Advanced Materials Interfaces* (2018)

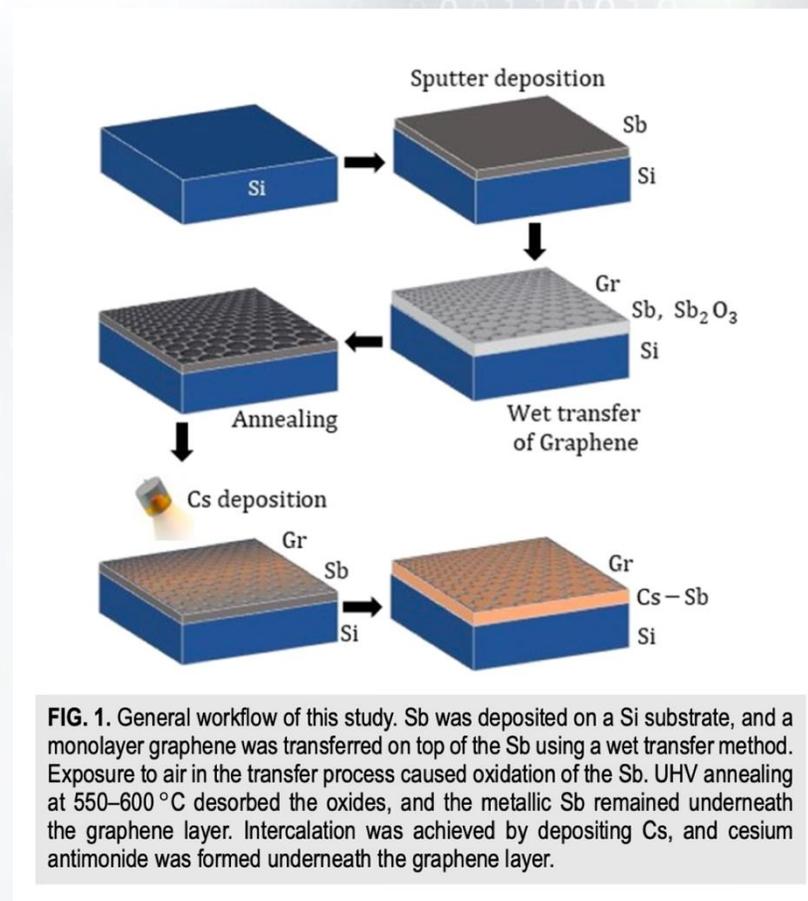


FIG. 1. General workflow of this study. Sb was deposited on a Si substrate, and a monolayer graphene was transferred on top of the Sb using a wet transfer method. Exposure to air in the transfer process caused oxidation of the Sb. UHV annealing at 550–600 °C desorbed the oxides, and the metallic Sb remained underneath the graphene layer. Intercalation was achieved by depositing Cs, and cesium antimonide was formed underneath the graphene layer.

Jyoti Biswas, Mengjia Gaowei et. al, *APL Mater.* 10, 111115 (2022)

MPGD-nTOF : Path Forward

- Develop Graphene-coated K_2CsSb photocathode in the 1st year
 - QE Measurement
 - Evaluate Robustness under gas environment
- Fabricate Sb-coated Silica substrate at ODU
- Grow graphene-coated K_2CsSb photocathode in BNL using the published intercalation method – **April 2024**
- **Beam test at BNL NSLS-II**
- In-house capability for photocathode manufacture at JLab
 - Vacuum Deposition chamber

ODU ARC equipment



JLab CIS Group Deposition Chamber



MPGD-nTOF Personnel

- Jefferson Lab
 - Xinzhan Bai, Cameron Clarke, Kondo Gnanvo, Seungjoon Lee, Jack McKission, Md Abdullah Mamun, Drew Weisenberger, Bogdan Wojtsekhowski
- BNL
 - Mengjia Gaowei
- SLAC
 - John Smedley
- ODU
 - Prof. Abdelmageed Elmustafa



Summary

- μ RWELL-PICOSEC has demonstrated 23-ps timing resolution in beam tests, validating MPGD-based picosecond timing capability
- MPGD-nTOF targets 50 ps neutron timing, offering cost-effective, high-rate alternative solution
- Simulation Confirms \sim 50 ps neutron timing is achievable, supporting MPGD-nTOF concept under realistic conditions
- Graphene-protected bialkali photocathodes are the key to enable stable gas operation and large area deployment



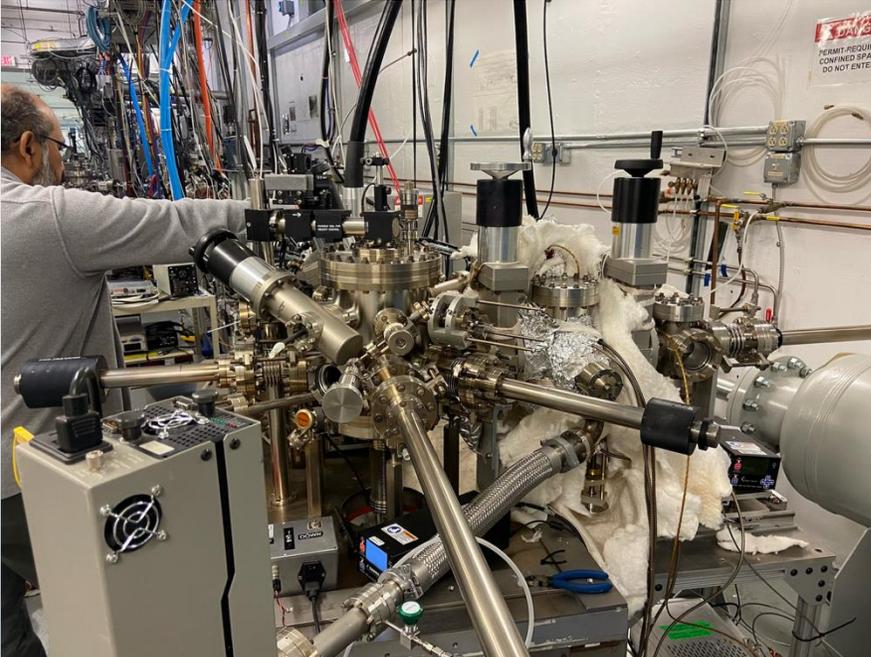
This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under contracts DE-AC05-06OR23177

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 US Department of Energy – LD2614

QUESTIONS?

Infrastructure at JLab

- Vacuum deposition chamber at JLab CIS group
- Used to manufacture K₂CsSb photocathode (decommissioned)



Deposition Chamber in JLab UITF



Deposition Chamber for K₂CsSb



Vacuum Suitcase

Photosensor Cost Comparison

Slide from Kondo Gnanvo

Time of Flight (TOF) detectors

	MRPCs	AC-LGAD	μ rPICOSEC
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

	SiPMs	MCP-PMTs	LAPPDs	μ rPICOSEC
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 ✓