FY 2022 LDRD Proposal

Program: DRD

Proposal Title: Development of large area picosecond timing detectors based on resistive micro-well detector technology for future experiments at Jefferson Lab and at the EIC.

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Budget ($K)	Total	FY23	FY24	FY25
	551.584	283.537	268.047	

Development of large area picosecond timing detectors based on resistive micro-well detector technology for future experiments at Jefferson Lab and at the EIC.

Kondo Gnanvo, Physics Division

1. Proposal Abstract

Timing detectors with time resolution of a few tens of picoseconds are critical components for particle identification detectors (PID) such as photon detectors for Cerenkov detectors or Time of Flight (TOF) detectors for minimum ionizing particles (MIPs). Several detector technologies are under development for detector equipment upgrade in Nuclear Physics (NP) facilities such as the high luminosity and high energy upgrade of the Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab for the anticipated second detector as well as the expected upgrade of detector 1 of the future Electron Ion Collider (EIC) at BNL. The development of Micro Pattern Gaseous Detector (MPGDs) with picosecond timing resolution [1] is a promising alternative to existing technologies for TOF measurement of MIPs and photosensors options for Cerenkov detectors. Resistive micro well detectors (µRWELL) [2] is the most recent technology in the MPGD family, typically used as trackers for MIPs. A special configuration of µRWELL which combines a Cherenkov radiator and photocathode with an ultra-thin gas amplification gap, can deliver large-area, cost-effective fast timing sensors with ~25 and 50 ps level time resolution. In addition, this µRWELL-based picosecond detector that we call µrPICOSEC is expected to demonstrate stable performance in magnetic field. New generation of Positron Emission Tomography (TOF-PET) detectors in the medical field also benefit from µrPICOSEC development. The goal of the proposal is to develop the µrPICOSEC detector concept and demonstrate the timing and position resolution performance of the concept with prototypes.

2. Background and Significance

The goal of the proposal is to develop a large-area, cost-effective, fast-timing gaseous detector called µrPICOSEC using µRWELL structure for amplification and providing picosecond level timing resolution. The applications include NP experiments as timing detectors for MIPs and photosensors for Cerenkov detectors. The cartoons in Figure 1 are cross sectional views of a standard µRWELL detector for tracking of charge particle versus novel µrPICOSEC with its various constituents such as the Cerenkov radiator, the photocathode, the µRWELL gain structure and the pad readout PCBs. The key difference is the replacement of the cathode plane of the µRWELL tracker by the coupling of a Cerenkov radiator and photocathode to produce photoelectrons. The 3 mm gas ionization volume of a µRWELL tracker for the primary ionization is therefore no longer necessary and only a 100 - 200 µm gas volume between the photocathode and the µRWELL amplification structure is used as pre-amplification stage. The Cerenkov photons created in the radiator when a charge particle traverses the

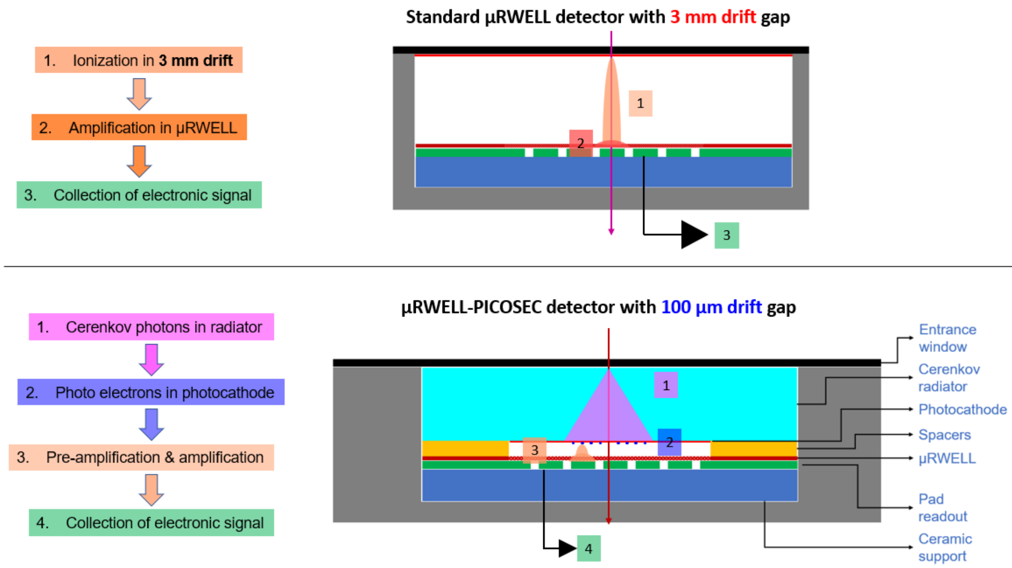

Figure 1: Cross sectional view of (top:) standard µRWELL with 3 mm gas volume (bottom:) µrPICOSEC concept with Cerenkov radiator, photocathode and 100 µm gas volume

detector are converted into photoelectrons in the photocathode then pre-amplified in the 200 µm gas before a second amplification in the µRWELL structure. Because the production of the photoelectron is very localized in the photocathode, the arrival time of the signal to the electronics is defined with excellent resolution expected. The principle is illustrated at the bottom half of Figure 1.

	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	< 1mm
Performance in B-field	yes	yes	yes
module size	20 cm × 20 cm	N/A	20 cm × 20 cm
Cost ($ M / m^2)	0.2 – 0.4	High	0.2 – 0.4

Table 1: *Performance of state of the art TOF technologies vs. expected µrPICOSEC performances*

	SiPMs	MAPMTs	MCP-PMTs	LAPPDs	µrPICOSEC
Time resolution (ps)	< 100	> 300	< 100	50	50
Position resolution (mm)	> 1	> 1	1	0.3 - 1	< 1
Performance in B-field	Yes	No	Yes	< 1T	Yes
Radiation hardness	dark current	No			Yes
Cost ($ M / m^2)	0.8 - 1	0.5 - 1	> 1	0.8 - 1	0.2 – 0.4

Table 2: Performance of state of the art photosensors technologies vs. expected µrPICOSEC performances

The development of µrPICOSEC will add MPGD-based fast timing detectors to the current technologies for TOF applications such as AC-coupled Low Gain Avalanche Detectors AC-LGAD [3], MRPCs [4] and for photosensors such as Silicon Photomultipliers (SiPMs), Multi Channels Plates Photomultipliers MCP-PMT [5] and Large Area Picosecond Photodetectors LAPPDs [6]. If successful, µrPICOSEC device is expected to provide a cost effective, fast timing detector with high-rate capability, radiation hardness, stable performance in magnetic field. Additionally, the device will potentially achieve a position resolution capability for PID applications in future NP experiments of high luminosity and an energy upgraded of the CEBAF at Jefferson lab. Additionally, the device will potentially achieve a position resolution capability for PID applications in future NP experiments of high luminosity and an energy upgraded CEBAF at Jefferson lab as well as providing technology options for future EIC detectors.

The project's S&T goal is to demonstrate time resolutions of 25 and 50 ps for MIPs and single photon detection respectively for TOF devices and photosensors for Cerenkov detectors aimed at applications in NP and nuclear medicine by developing two multi-channel, fast-timing gaseous µrPICOSEC prototype 10 cm × 10 cm detectors based on µRWELL technology. The operation of MPGD detectors as timing device in the picosecond range requires fast collection of the charges from the cathode to the amplification structure by reducing the drift path of the charges in the gas from typically a few mm to ~100 µm. Maintaining uniformity in 100 µm gas volume over a large detector area is a major undertaking, posing serious R&D challenges for mechanical structure design, operation stability with high gain and uniformity of performance that requires a formidable R&D effort.

We have three specific aims.

1. Our first specific aim is to design and construct and characterize µrPICOSEC prototypes with µRWELL amplification device and multi-pad readout structures.
2. The next aim is to investigate and develop radiator materials and photocathodes for specific applications in NP and nuclear medicine.
3. The final specific aim is to design and implement multi-channel fast timing readout electronics.

The development of µrPICOSEC detector technology will consolidate the status of the lab in its mission for a successful execution of the high-profile physics program for the high luminosity and energy upgrade of CEBAF machine as well as for detector technologies options at the future EIC. Moreover, Radiation Detector and Imaging group will leverage on the acquired experience and expertise during the µrPICOSEC technology development to consolidate the lab's position in medical instrumentation field with the development of new generation of fast timing PET devices, thus promoting further the diversification pathways for Jefferson Lab.

3. Research Plan

For the DRD program we plan to take full advantage of the permanent beam test setup within the PICOSEC collaboration at CERN. The setup includes GEMs for tracking, MCP-PMTs for timing, scintillators counters for trigger, fast readout electronics and analysis software package, 1.5 T dipole magnet for characterization of the prototype in a magnetic field.

In the year 1, we will concentrate our effort in the design and assembly of PICOSEC prototype using µRWELL technology as amplification structure. This prototype, µrPICOSEC proto I, will establish the proof of the concept with the goal of time resolution performance of ~50 ps for MIPs.

In year 2, we will optimize the design with µrPICOSEC proto II. We will investigate different Cerenkov radiators and photocathode materials options for dedicated applications as TOF detectors for MIPs and photosensors for Cerenkov detectors. We will develop multi-channel readout / DAQ system for µrPICOSEC detectors.

Our approaches to address our three specific aims are as follows.

1. **The µRWELL amplification and readout structure:**
   The functions of electron amplification and pad readout pick-up electrode PCB layers for the charge collection of the µrPICOSEC detector are both combined into a composite flexible PCB made of a stack of three key elements: The first is the µRWELL foil which is made of 50 µm thick polyimide foil with 5 µm copper layer on its top side and a high-density GEM-like holes for electron amplification. The second element is a thin resistive layer, the Diamond-Like Carbon (DLC), glued to the bottom side of the µRWELL foil and primarily used to quench discharge rate and energy from the amplification structure. A potential between the DLC and the top Cu electrode of the µRWELL foil creates a high electric field in the GEM-like holes of the µRWELL foil that generate the electron amplification. The third element is the pad segmentation pick-up electrode readout layer for the collection of the charges from the detector amplification structure to the pre-amplifiers of the front electronics of the DAQ system.

   For this proposed project, one of the critical challenges for the development of µrPICOSEC detector is to achieve and maintain a gap on the order of 100 µm over a large detector area between the µRWELL / readout composite foil and the radiator / photocathode as shown on Figure 1, which assures uniformity of the detector timing response and resolution. Precision of the detector mechanical structure of a few microns is necessary [1] to achieve the required timing performance uniformity of 25 ps over a detector area of 10 cm × 10 cm. This level of mechanical precision includes fabrication the µRWELL / readout device itself as well as its support structure and housing, the gas distribution system and the interface for the connection to the readout electronics. The R&D effort of year 1 of the project will focus on the design and fabrication of the first µrPICOSEC prototype (proto I) with the goal of addressing the challenges associated with mechanical structures and the impact on the performances of the prototype. As part of the PICOSEC collaboration, we will benefit from all the R&D already conducted with PICOSEC-MM prototypes to optimize the design of µrPICOSEC proto I. Just like PICOSEC-MM, we will use 3 mm thick MgF2 crystal for the Cerenkov radiator and cesium iodide (CsI) as photocathode and integrate a similar 100-pad readout structure into the uRWELL / readout composite foil of µrPICOSEC proto I. However, several areas with major differences between PICOSEC-MM and µrPICOSEC will require dedicated R&D. These include:
   - µRWELL amplification: Impact of gain uniformity on detector performance.
   - Resistive layer DLC: Impact of thickness uniformity on detector performance.

- Studies of pre-amplification / amplification dynamics with μrPICOSEC detector.

In year 2 of the DRD proposal, we will to develop the second μrPICOSEC (proto II) which will constitute an optimization of proto I with additional specific R&D efforts including the development of:

- new types of Cerenkov radiators and photocathodes materials.
- 25-pad capacitive-sharing readout [7] for both timing and position resolution optimization.
- optimization of the mechanical packaging and compactness of the prototype

Both μrPICOSEC prototypes will be fully characterized in beam test at CERN making use of the dedicated PICOSEC beam test setup. We will leverage on the expertise within PICOSEC-MM collaboration to develop the software tools and analysis techniques required for producing the results with μrPICOSEC prototypes beam test data. The post-doctoral research scientist will carry out the effort of prototyping, characterization of the prototypes in beam tests and in the lab bench test in the RD&I group at Jefferson Lab as well as and the analysis of the data.

2. **Investigating and developing radiator materials and photocathodes for specific applications:** At the present stage PICOSEC-MM detectors are based on MgF2, CsI, and MicroMegas, as the Cerenkov radiator, the photocathode and the gain structure, respectively. Successful operations of prototypes in the past year and ongoing test beam efforts support the enormous potential of PICOSEC detector concept as TOF detectors and photodetectors. Drawbacks of the present technologies are [8]:
    - relatively low photon yield of the Cerenkov radiator
    - stability issues of the photocathode
    - stability issues of the gain structure

    In particular, the photon yield of the radiator drives the timing and position resolution performance of the detector when used as a TOF device. A search of a radiator material that delivers both, higher photon yields as well as focusing of the photons would increase the performance of the detector. The latter would be beneficial for the concentrated collection of photoelectrons and therefore the ability to improve the position resolution of the track point. However, since the photon yield is related via a $\sin^2(\theta_C)$ dependence the improvement in one aspect would degrade the other aspect. A focusing element can be investigated so that these opposing effects could be compensated.

    The photocathode material converts photons into electric signals that are processed with readout electronics. This concerns the operation in both configurations, the radiator photoconverter as well as the single photoconverter for photodetector purposes. At present, CsI provides the most promising photocathode material because of its relatively high quantum efficiency (QE). Furthermore, CsI is sensitive to photon wavelength in the vacuum ultraviolet (VUV) region which is most abundantly radiated by any radiator medium. Drawbacks are that the radiator medium has to be VUV transparent. CsI has another drawback as it is very sensitive to water leading to degraded performance when exposed to humid conditions. In addition, CsI suffers from Ion Backflow (IBF) created effects. In a gaseous environment, a large IBF is created due to the MPGD gain structure. It would be beneficial to investigate alternative photocathode materials with comparable QEs than CsI and with sensitivity to longer wavelengths. Several alternatives are under consideration, like Boron Carbide (B4C), Diamond-Like Carbon (DLC), and NanoDiamond (ND).

    We are proposing to investigate and develop different radiator materials that will improve the photon yield and consequently the timing performance of the MPGD based PIOCSEC devices. We further propose the investigation and development of photocathodes that will increase the detection of photoelectrons and therefore increase the performance of MPGD based PICOSEC detectors as TOF and photodetection devices.

Stony Brook University (SBU) will provide an Ion-Beam Assisted Physical Vapor Deposition (IBA-PVD) apparatus in an Ultra-High Vacuum (UHV) vessel to perform the above-mentioned investigations. SBU group has produced all photocathode-based Cerenkov detectors for the PHENIX experiment at RHIC in the form of the Hadron Blind Detector (HBD) and a windowless RICH detector prototype. Both detectors had CsI covered GEMs as the photocathode and GEMs as the following amplification device. The group upgraded the evaporator device to an electron beam evaporator and is producing thin film depositions for other purposes. In order to improve the UHV status of the evaporator device and to prepare for the investigations as described above, Stony Brook group needs a cryogenic vacuum pumping device. Stony Brook also requires a functioning PICOSEC-MM prototype and supplies to perform the above-described investigations. The acquisition of a functioning prototype based on the PICOSEC-MM principle is needed for exchanging the different radiator and cathode materials as described in the proposal. PICOSEC-MM prototype will be used to verify the performance of different materials and for calibration of the μrPICOSEC against a well establish reference detector.

3. **Multi-channel fast timing readout electronics:**
We propose to design and implement an intermediate amplification stage following the approach of [4] which makes use of a programmable differential amplifier (PDA) coupled to the low-voltage differential signaling (LVDS) input of a high-speed time-to-digital converter TDC. The PDA (LMH6881) accomplishes both the conversion from single-ended to differential signal and allows variable level discrimination. This approach, developed by the University of Science and Technology (USTC) has been demonstrated at CERN [9] with a timing resolution of ~20 ps taking advantage of the wideband gain-selectable differential output amplifier coupled to a high clock rate differential digital interface - the front end of an FPGA-based TDC. The method takes advantage of well-defined threshold levels in the LVDS inputs and phase-shifted clocking in the FPGA-based TDC to achieve end-to-end timing on the order of 20 ps. As demonstrated by USTC the differential amplifier output can be connected to two LVDS input sets with different biasing offsets, allowing the fastest timing with a low threshold and discrimination of a real signal with a higher threshold.
In our approach we will explore a similar arrangement, but with the TDC function provided by the newly released 128-channels picoTDC DAQ system (CAEN FERS-5203) [10], which includes a CERN developed proprietary ASIC for LVDS signal discrimination with TDC, and FPGA-based TDC signal processing. The manufacture claimed timing resolution for each channel of about 7 ps.
To summarize, we propose (1) to develop a PCB board with the PDA to match detector and DAQ system signal requirements, and (2) to interface the PDA-based PCB board with CAEN TDC DAQ.
Our goal is to achieve ~30 ps required timing-resolution which makes the resistive micro-well detector technology (μrPICOSEC) an excellent candidate for future experiments at Jefferson Lab and at the EIC**.**

We have divided the milestones by quarters for each FY. For each quarter, we have a list of specific tasks to be completed. We have identified 5 major tasks and all the goals for the DRD program and assign a lead person for each task in the breakdown of the quarterly milestones:

- Task 0: Research and hiring of the post-doctoral candidate.
  Lead: Kondo Gnanvo (**KG**) and RD&I group
- Task 1: Design, procurement of the parts and fabrication of the two μrPICOSEC prototypes.
  Lead: Kondo Gnanvo (**KG**) and Klaus Dehmelt (**KD**) for radiator and photocathode.

- Task 2: Characterization and beam test campaigns for the two prototypes.
  Lead: Kondo Gnanvo (**KG**) and Klaus Dehmelt (**KD**), Post-Doctoral (**PD**).
- Task 3: Development and characterization of multi-channel readout and DAQ system.
  Lead: Wenze Xi (**WX**) and Jack McKisson (**JM**)
- Task 4: Investigation of new Cerenkov radiator and photocathode materials.
  Lead: Klaus Dehmelt (**KD**).
- Task 5: Analysis of beam test data, presentation at conferences and preparation for submission to peer-review journal.
  Lead: Kondo Gnanvo (**KG**), Post-Doctoral (**PD**).

Milestones for FY23

Q1:

- Identify and /or hire a post-doctoral [PD] (Task 0, WD & RD&I group)
- Procurement of the cryogenic vacuum pump (Task 1, KG, KD)
- Design of 100-pads 100 cm^2 µrPICOSEC proto 1 (Task 1, KG)
- Look for parasitic opportunity to test and characterize of single-channel µrPICOSEC for proof of concept (Task 2, KG)
- Purchase LMH6881 chips and design a 4- to 8- channel prototype of the LMH6881 interface PDA-PCB board for testing ((Task 3, WX)

Q2:

- Finalize the design and mechanical drawing of proto 1 (Task 1, PD, KG, KD)
- Participation in the analysis of the beam test data within the micromegas-PICOSEC collaboration to familiarize with the analysis tool and concept (Task 2, PD, KG)
- Use opportunity for beam test at CERN of single-channel µrPICOSEC (Task 2, PD, KG)
- PCB layout of PDA-PCB interface board and fabrication of PDA-PCB (Task 3, WX, JM)

Q3:

- Procurement of various parts of the µrPICOSEC proto I (Task 1, KG, KD).
- Set up PICOSEC test bench in RD&I lab for characterization of proto 1 (Task 2, PD, KG)
- 2nd prototyping (if required) of PDA-PCB and integration with CAEN picoTDC DAQ system ➔ we plan to borrow CAEN picoTDC module for the initial test (Task 3, WX, JM)

Q4:

- Assembly and characterization of proto I at RD&I lab (Task 2, PD, KG)
- Prepare for beam test including inside a magnetic field at CERN (Task 2, KG, KD, PD)
- Testing joint PDA-PCB board and CAEN picoTDC DAQ assembly (Task 3, WX, JM)
- Initial design and layout of 25-channel PDA-PCBs (Task 3, WX, JM)

- **Milestone for FY24**

Q1:

- Procurement of CAEN 128-channel picoTDC DAQ & characterization of performance of the PDA-PCB & CAEN picoTDC DAQ system with a fast detector (Task 3, WX, KG)
- Design of µrPICOSEC proto II, leverage on lessons from proto I (Task 1, KG, KD, PD)
- Investigate application-specific radiators and photocathodes options (Task 4, KD)
- Analysis of beam test data with proto II and preliminary results (Task 2, PD, KG)
- Fabrication of 25-channel PDA-PCB (Task 3, WX, JM)

Q2:

- Complete the design of 25-pads 100 cm^2 µrPICOSEC proto II and procurement of µRWELL- readout PCB and mechanical structure (Task 1, KG, PD)
- Start procurement of application-specific set of radiators and photocathodes for both TOF and Cerenkov photosensors application (Task 4, KD)
- Preparation for beam test including in B field at CERN (Task 2, PD, KG)
- Assembly of 25-channel PDA-PCB (Task 3, WX, JM)

Q3:

- Complete procurement of the µrPICOSEC proto II parts (Task 1, KG, KD).
- Assembly and preliminary test in RD&I lab of proto II (Task 2, PD, KG)
- Continue preparation for beam test of both prototypes including the integration of multi-channel readout electronic at CERN (Task 2, PD, KG)

Q4:

- Test of the prototypes I & II in beam including in magnetic field and with multi-channel readout electronics at CERN (Task 3 & 4, PD, KG, WX)
- Analysis of beam test data and presentation of the results at domestic and international conferences and preparation for publication in peer-reviewed journal (Task 5, PD, KG)

4. Summary

Rationale: We propose to develop a new concept of a large-area fast-timing gaseous detector (µrPICOSEC detector) based on the resistive micro-well amplification (µRWELL) technology and coupled with multichannel capacitive-sharing pad readout with the goal of achieving a time resolution of 25 ps with minimum ionizing charged particles and 50 ps with single photon detection. µrPICOSEC detectors will be used as large-area, cost-effective time of flight (TOF) detectors or photosensors for Cerenkov detectors for particle identification in instrumentation of future high profile NP experimental program such as the ones anticipated for the High Luminosity and High Energy upgrade of CEBAF at Jefferson Lab and the detectors of the future EIC facility at BNL. The novel technology is expected to show strong performance in NP experimental environment where alternative technologies such as SiPMs, MRPCs and LAPPDs have severe limitation such as radiation hardness, high-rate capabilities, operation in a high magnetic field. Moreover, µrPICOSEC technology would be developed with large-area capabilities at significantly lower cost than alternative options such as MCP-PMTs or AC-LGADs.

Impact of the project: For this DRD proposal, we plan to establish the proof of concept of µrPICOSEC detector with a first large area (10 cm × 10 cm) prototype that will be fully characterized both in a lab bench test setup and in a beam test at CERN. A second prototype with improved and performance will be developed in year 2 of the DRD program for optimization for TOF and photosensors detector applications. We will characterize the timing and spatial position resolution capability of the prototypes as well as performance stability in a magnetic field and the optimization of the mechanical structure for a large detector. The work will be carried out in most part within the Jefferson Lab Radiation Detector & Imaging Group and will consolidate the group's expertise in the development of Micro Pattern Gaseous Detectors (MPGD) technologies beyond the development of large area tracking detectors. The RD&I group will investigate applications of µrPICOSEC technology for new generations of high-resolution Positron Emission Tomography (PET) imagers in the medical instrumentation field.

Tangible outcomes / products by which the project will be measured upon completion: Establish the proof of concept of µrPICOSEC for fast timing application in NP experiments. While we are ultimately aiming for timing performance of 50 ps for single photon detection and 25 ps for MIPs, a demonstration of timing better than 100 ps for single photon detection and 40 ps for MIPs with the first large area, capacitive-sharing readout prototypes will constitute nominal success.

Mission relevance and evidence of strengthened scientific leadership position: When fully established, µrPICOSEC technology is expected to play a critical role as PID devices in experimental equipment for the anticipated high luminosity upgrade and high energy upgrades program of CEBAF facility at Jefferson Lab. Jefferson Lab also has a strong partnership with BNL for the EIC program and is assuming a critical leadership role in the development and optimization of EIC detectors (both the anticipated detector II as well as future detector I upgrade). Novel detector technologies such as µrPICOSEC are critical for successful completion of physics programs at the EIC. In-house development of µrPICOSEC technology in the Radiation Detector and Imaging (RDI) group will consolidate the status of the lab in technology areas relevant to its mission of successful execution of the high-profile physics program at Jefferson Lab and at the EIC. The RD&I group will leverage the acquired experience with µrPICOSEC technology to develop new generations of high-resolution position emission tomography (PET) imagers for possible application in the field of nuclear medicine imaging. This will also advance Jefferson Lab's position in the medical applications, promoting diversification pathways for the lab.

Potential funding opportunities: A successful outcome of the development proposed in the LDRD will benefit for future Jefferson Lab upgrade programs well as the development of the future EIC detector. Applications in medical field are also anticipated with potential funding opportunities.

5. Budget

Name of Investigator	Role (PI, Co-I, etc.)	FY23 Budget ($K)	FY23 Effort (% FTE)	FY24 Budget ($K)	FY24 Effort (% FTE)	Total Budget ($K)	Total Effort (%FTE)
Kondo Gnanvo	PI	49.01	25	49.87	25	98.88	50
Wenze Xi	Co-PI	14.34	8	14.59	8	28.93	16
Jack McKisson	contributor	12.89	5	13.12	5	26.01	10
Brian Kross	contributor	10.19	5	10.37	5	20.56	10
Subtotal for effort		86.43	43	87.96	43	174.39	86%
Equipment	Capital	25		12		37	
	Non-capital	5				5	
New hire	Post-doc	120.54	100	122.65	100	243.19	200
Materials / Supplies		33.5		27.5		61	
Machine shop		4		3		7	
Travel		8		10		18	

6. Budget Justification

Team Member	Role	Project Contribution	Specific Aims (tasks)
Kondo Gnanvo	PI	Design and characterization of the µrPICOSEC prototypes, oversee project as PI	1, 2, 4, 5
Wenze Xi	Co-I	Investigate multichannel readout electronics options for the prototypes	3, 2, 5
Jack McKisson	contributor	Development of multichannel readout electronics options for the prototypes	3, 2
Brian Kross	contributor	Mechanical design and support of the prototypes	1, 2
TBD	Post-doc	Design, prototyping, characterization, data analysis of data, presentation of results at conferences	1, 2, 5
Klaus Dehmelt	External contributor	Cerenkov radiators & photocathodes	4 (and 1, 2, 5)

Requested New Hires:

Name of Hire	Type of hire (strategic, staff, PD)	Position Description/Justification	Projected Cost ($K/FY)	Expected timeline
TBD	Post-doc	CAD design, characterization and test in beam of the prototypes, develop data analysis tools and analysis of data, presentation of results (Task 1, 2, 5)	120.5 / FY23 122.6 / FY24	2 years (+ 3rd year if funds available)

Equipment:

Equipment	Justification	Projected Cost ($K in FY23)
cryogenic vacuum pumping device	Required for the Ion-Beam Assisted Physical Vapor Deposition (IBA-PVD) apparatus in UHV at Stony Brook University for the deposition of the photocathode layers on radiator substrates for µrPICOSEC prototypes: The equipment is essential for the successful outcome of the project	~$25K / FY23
128-channels picoTDC DAQ system (CAEN FERS-5203)	Key component of the DAQ system of the multi-channel readout electronics of µrPICOSEC prototypes	~$12K / FY24
DAQ computer	µrPICOSEC DAQ, HV Power control & data analysis	$3K / FY23
Laptop computer	Working laptop computer for the post-doc	$2K / FY23

Materials:

Name of Material	Description	Cost per FY	Total Cost
LMH6881 100 channels + PDA-PCB parts	Multi-channel front end chips & PDA-PCB board fabrication	$5K / FY23	$5K
PICOSEC-MM detector	PICOSEC-MM prototype for validation of photocathode and radiator materials and calibration of µrPICOSEC prototypes	$8K / FY23	$8K (cost estimated from PICOSEC-MM collaboration)
MgF2 and entrance window	Radiator material and entrance window for µPICOSEC prototype I	$3K / FY23	$3K
Radiators & photocathodes	Radiator material and entrance window for µPICOSEC proto II	$10K / FY24	$10K
µRWELL PCBs	Production of µRWELL / RO composite flexible PCBs for µPICOSEC proto I & II	$10K / FY23 $10K / FY24	$20K
Mechanical & support structure	Support structures for µPICOSEC proto I & II	$5K / FY23 $5K / FY24	$10K
Lab supplies	Lab equipment and supplies to set up a test bench for characterization of the µrPICOSEC proto (The costs are estimate for each FY)	$2.5K / FY23 $2.5K / FY24	$5K

Sub-Contracts

We don't request funding for subcontract for this proposal, however, Dr. Klaus Dehmelt's group at Stony Brook University (SBU) will be leading the R&D effort regarding the investigation and development radiator materials and photocathode of the prototypes. Dr. Dehmelt will oversee the photocathode layer depositions on different radiator substrates for the two prototypes using SBU's Ion-Beam Assisted Physical Vapor Deposition (IBA-PVD) apparatus in an Ultra-High Vacuum (UHV). To perform the task, the UHV of the evaporator apparatus requires the cryogenic vacuum pump acquired for this project. In the event this proposal is awarded we will work with the Jefferson Lab Research and Technology Partnerships Office to initiate a "no funds in" CRADA with SBU. The CRADA will be a vehicle to establish the collaboration and provide the ability to loan SBU the cryogenic vacuum pump to be purchased in Q1.

Travel: List anticipated travel for the proposal including purpose of travel (and number of days), destination, name of travelers, and estimated cost.

Activity	Destination	Name of travelers	Estimated Cost
Beam test at CERN – FY23	Geneva (Switzerland)	Kondo Gnanvo	$3000
Beam test at CERN – FY23	Geneva (Switzerland)	Post-doctoral	$3500
Domestic conference (IEEE-NSS-MIC) – FY23	Vancouver (Canada)	Kondo Gnanvo	$1500
Beam test at CERN – FY24	Geneva (Switzerland)	Kondo Gnanvo	$2000
Beam test at CERN – FY24	Geneva (Switzerland)	Post-doctoral	$3500
International conference (Vienna, Pisa, MPGD…) – FY24	TBD	Kondo Gnanvo	$3000
Domestic conference (IEEE-NSS-MIC) – FY24	TBD	Wenze Xi	$1500

Current and Pending FY 2023 and FY 2024 Funding: In the following table, list current and pending funding profiles in FY 2022 and FY 2023 for each team member for whom funding is requested in this proposal as % FTE effort. (Begin with this DRD proposal; total must add up to 100%. If you do not know the source for a percentage of your funding, please state "Unfunded XX%".)

Team Member	**Project Number, Sponsor**	**FY23 %FTE Anticipated**	**FY24 %FTE Anticipated**
Kondo Gnanvo	This DRD project	25	25
	DRD - CLAS12 High-Luminosity upgrade	5	5
	Radiation Detector & Imaging - DETGEN	70	70
Wenze Xi	This DRD project	8	8
	Commonwealth of Virginia	16.67	16.67
	Commonwealth of Virginia	8.33	8.33
	Radiation Detector & Imaging - DETGEN	67	67
Jack McKisson	This DRD project	5	5
	Radiation Detector & Imaging - DETGEN	95	95
Brian Kross	This DRD project	5	5
	Radiation Detector & Imaging - DETGEN	95	95

** Identify the name of the "Other" funding source here*

7. References (Not included in page count)

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