DOE COVER PAGE

Project Title:
High Voltage Insulators and Electrodes for 500 kV DC High Voltage Photogun with Inverted Insulator Design

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Research area (site) identified in Section I of this Announcement:
Transformative accelerator R&D in next generation ion and electron sources.

High Voltage Insulators and Electrodes for 500 kV DC High Voltage Photogun with Inverted Insulator Design

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PROJECT NARRATIVE

Background/Introduction

Soon after the first demonstration of spin polarized electron beams from GaAs, DC high voltage photoguns were built to conduct nuclear physics experiments at SLAC, MIT-Bates, the Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab (JLab), Bonn-ELSA, Mainz University MAMI, NIKHEV and Nagoya University – all of these photoguns operated at approximately 100 kV bias voltage. Today, only the photoguns at Mainz and CEBAF still regularly produce spin-polarized beams at 100 and 130 keV, respectively [1,2]. These voltages are sufficient to satisfy the electron beam requirements of the accelerators they serve.

More recently, interest in light sources, with stringent emittance requirements, spurred R&D devoted to operating DC high voltage photoguns at much high voltages. The photogun used to drive the JLab Free Electron Laser (FEL) provided milliampere beams at 350 keV [3] using a concentric cathode electrode support, with the biggest drawback of this gun design being the absence of a load lock for photocathode activation and replacement. KEK and Cornell University added load-locked vacuum chambers using a side-insulator design [4,5], and they solved the very challenging problem of high voltage breakdown that sometimes results in insulator punch-through, by using segmented insulator rings with interior metal shields. With their designs, there is no line-of-sight for field emitted electrons to reach the surface of the insulator where they can cause severe damage.

Highlights of the achievements demonstrated using the KEK and Cornell University DC high voltage photogun designs include 2 mA CW beam delivery at 500 kV bias voltage [6], record level average current of 65 mA CW with photogun biased at 250 kV [7], and most recently sustained ~ 30 mA CW beam delivery at 400 kV bias voltage to demonstrate bunched beam cooling at RHIC [8]. Without intending to diminish these remarkable achievements, all of these photoguns including the JLab FEL 350 kV vent/bake photogun, exhibit field emission that would be problematic for polarized beam production.

At Jefferson Lab, we have chosen an "inverted-insulator" high voltage design, where the insulator extends into the vacuum chamber from the top serving as the cathode electrode support structure. With the inverted insulator perpendicular to the beam line axis, the photocathode load-lock chamber naturally attaches to the back end of the photogun, just like the photoguns with large cylindrical insulators. But high voltage is applied to the cathode electrode using a commercial high voltage cable that connects to a power supply, providing some flexibility in terms of positioning the required SF_6 tank. Because the insulator serves as the electrode support structure, the photogun design is compact, which can result in improved vacuum compared to other designs, and it is small enough to fit in places where there are tight vertical space constraints. And finally, there is comparatively small metallic surface biased at high voltage, which serves to minimize the possibility of field emission.

The 130 kV spin-polarized inverted-insulator photogun at CEBAF [2] shown in figure 1 is very compact, provides exceptional vacuum (low 10^{-12} Torr) and exhibits NO field emission.

These properties provide a charge lifetime in the range of 200 to 400 Coulombs, which is sufficient to satisfy the beam delivery requirements of the CEBAF nuclear physics program using only one photocathode activation, from start to finish of the run (the laser is moved to fresh photocathode quantum efficiency locations during the run).

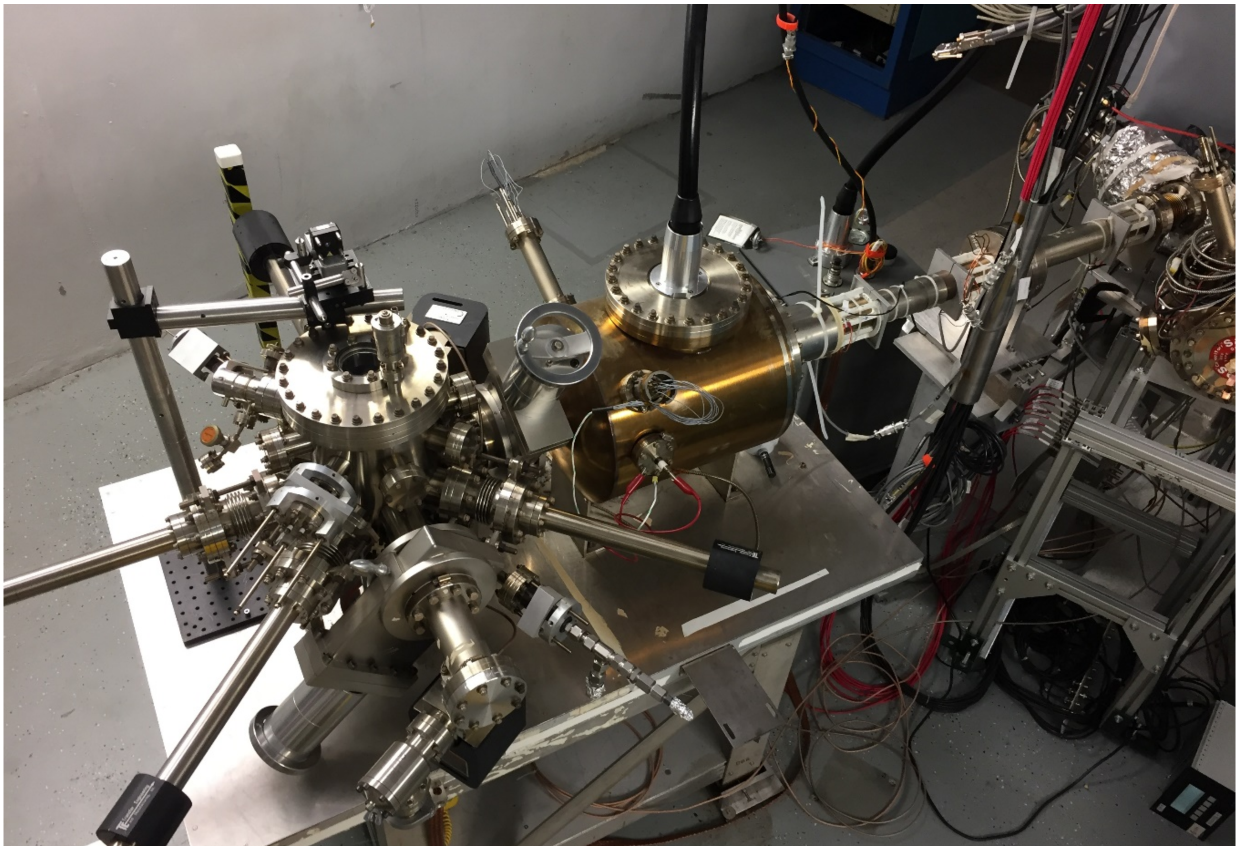

Figure 1: Top view of the CEBAF 130 kV inverted insulator DC high voltage photogun. The photocathode preparation/load-lock chamber is seen to the left of the picture. The high voltage cable connects to the inverted-insulator on top of the photogun high voltage chamber, which appears golden due to the week-long 400^{o} C vacuum firing. The beam line can be seen extending out of the photogun axis towards the right of the picture.

A larger version of this photogun design shown in Figure 2 operates at 300 kV bias voltage and successfully makes tens of milliamperes of unpolarized beam using alkali-antimonide photocathodes [9]. To operate at 300 kV, the photogun was processed to 360 kV, but even with 60 kV of high voltage "headroom", it was insufficient to COMPLETELY eliminate field emission – there is still nanoampere levels of field emission current which poses no problem for making unpolarized magnetized beams with alkali-antimonide photocathodes, however this would be problematic for a GaAs photocathode illuminated with light near the band-gap necessary for generating polarized beam. Photocathode lifetime would be insufficient to maintain a User-based physics program and we are reluctant to apply higher voltage to "process out" the field emitters – experience suggests ~ 350 kV is the limit of the present inverted insulator size used in this design [10].

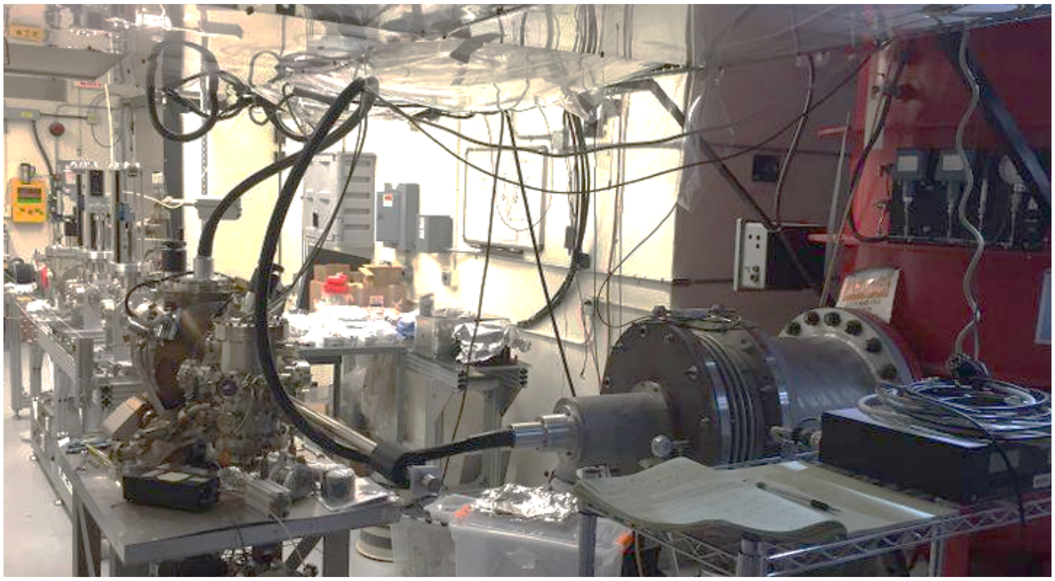

Figure 2: JLab 300 kV inverted insulator DC high voltage photogun used to make unpolarized magnetized beam. The picture shows the high voltage cable connecting the power supply inside the SF_6 red tank on the right, to the photogun top flange.

Positrons are in demand and at Jefferson Lab, we would like to make polarized positron beams using the PEPPo technique [11], where the polarization of an electron drive beam is transferred to a positron beam via pair production within a conversion target. A 10 mA CW, 0.3 nC bunch charge, polarized electron beam drive for polarized positron beams motivates the need for an inverted insulator photogun operating reliably – without field emission – at 350 kV to manage space charge.

This proposal seeks funding to extend the JLab inverted-insulator photogun design to higher operating voltage by developing a longer insulator with a more reliable interface to the high voltage cable. A load-locked polarized electron source operating at 350 kV – without field emission – could replace the vent/bake photogun at the Jefferson Lab Low Energy Recirculator Facility (formerly the JLab FEL) to develop a polarized positron source. 350 kV is the minimum photogun voltage required to capture the electron beam by the 5-cell, 1497 MHz SRF cavity in the existing facility's injector booster. The JLab inverted insulator design is a viable choice for this application, and from a practical point of view, it represents one of the few load lock gun designs that can fit within the Low Energy Recirculator Facility vault - the vault ceiling is not high enough to install a photogun based on the KEK or Cornell University designs.

<u>How much voltage headroom is required to operate at 350 kV with NO field emission?</u>

To commission a new DC high voltage photogun, electrodes are first polished smooth [12], then attached to insulators and then installed inside the photogun vacuum chamber which is then baked to achieve ultrahigh vacuum. Following bakeout, the photogun must be high-voltage processed, first in the presence of inert gas such as helium or krypton [13,14] and then under vacuum conditions. Introducing Kr gas to the photogun vacuum chamber in the range of 10^{-6} to 10^{-4} Torr has proven very effective in the high voltage processing of field emitters at lower voltages than those needed under vacuum conditions, posing lower risk of insulator/cable breakdown. In this process, Kr gas is ionized by field emitted electrons. Ions are accelerated towards the cathode electrode bombarding the field emission site and flattening its profile (larger emitter tip radius, lower electric field). In addition, Kr ions are implanted increasing the electrode metal work function. Since field emission current is proportional to the emitter electric field squared and is inversely proportional to the metal work function, Kr serves a dual role to eliminate field emission. The process can take many days and there is always concern that the insulator will be damaged.

During high voltage processing, some level of current is required from the power supply to remove field emitters, and sometimes new emitters develop typically when a field emitter explodes. To prevent insulator damage during these type of processing events, a *conditioning* resistor is connected at the output of the power supply, which is set to trip OFF at a preset current level. The following questions are frequently asked when discussing high voltage processing:

- How much current is required to process an emitter?
- What value to set the power supply current-limit?
- How large should the conditioning resistor value be?
- How quickly can high voltage processing be performed?
- How much excess voltage is required to completely process the gun to observe NO field emission at the desired operating voltage?

Figure 3 shows two examples of photogun high voltage processing using krypton gas. The plots show the photogun bias voltage (blue lines) and radiation as measured using Geiger Muller tubes placed around the photogun vacuum chamber. On the left side, the intended operating voltage was 200 kV using the CEBAF inverted insulator photogun for polarized beam. On the right side, the intended operating voltage was 300 kV using a larger version photogun for magnetized un-polarized beam. The important message related to high voltage conditioning is that sometimes significantly higher voltage must be applied to the cathode electrode than the intended operating voltage to successfully eliminate all traces of field emission at the operating voltage. In fact, our experience suggests spin-polarized DC high voltage photoguns must be designed to support bias voltages at least ~20% higher than the operating voltage for effective elimination of field emission. For example, it was necessary to reach 230 kV to burn OFF the field emitter during the conditioning of the CEBAF photogun, as shown in the left side of Fig. 3, near the 21 h mark, when radiation peaked tripping OFF the power supply on over-current. Upon recovering voltage to the intended operating value 200 kV, radiation levels were finally at background. Similar behavior was observed for the 300 kV gun, with field emitters removed at ~ 350 kV.

There are no easy answers to the questions posed above. Every time a new photogun assembly is high voltage conditioned, the maximum voltage required to eliminate field emission is different, as is the conditioning time that it takes to reach that voltage. If the current trip limit is set to the maximum capacity of the power supply, the risk of arcing along the insulator/cable interface is significant. If on the other hand, the current trip limit is set too low, there is insufficient power to burn OFF field emitters.

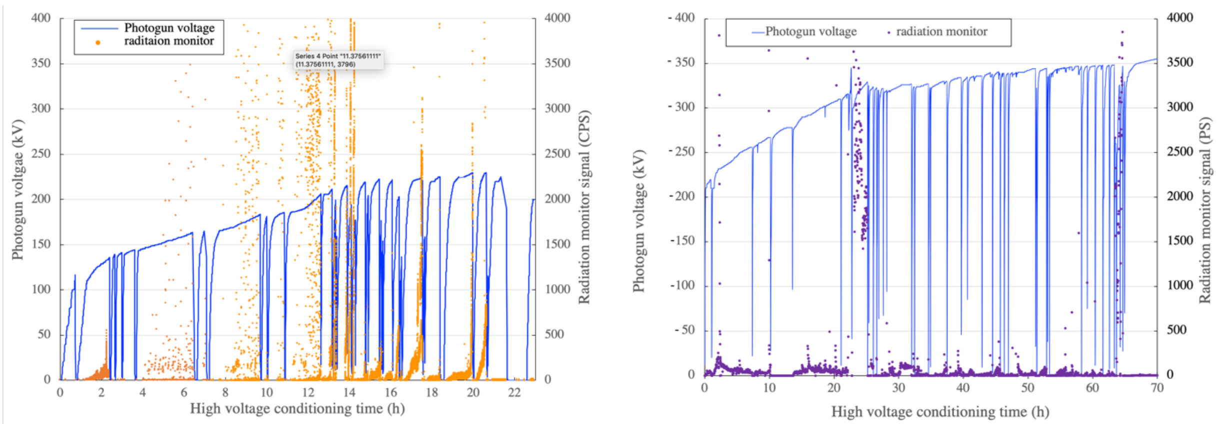

Figure 3. Left: CEBAF inverted insulator photogun high voltage conditioning intended for 200 kV operation. Right: High voltage conditioning of a larger version inverted insulator photogun intended for 300 kV operations.

Proposed Research and Methods

Two styles of inverted insulators in combination with two electrode configurations have been studied at Jefferson Lab, shown in Fig. 4 [10]. The objective of the study was to find an insulator/electrode combination capable of reaching ~ 370 kV DC without breakdown. The small insulator (4.5” long) mates with industry standard R28 high voltage cable. The larger insulator (7.5” long) mates with industry standard R30 high voltage cable. All inverted insulators used at JLab have been manufactured by the French company SCT Ceramics. We have also studied two insulator materials: pure alumina (white) and alumina doped with a proprietary recipe (black) to introduce some degree of conductivity for charge drainage. Any insulator subjected to an electrical potential builds up charge. In addition, field emitted electrons from the cathode electrode striking the vacuum chamber walls generate x-rays, which also build up charge in the insulator.

An essential component of insulator testing is the cathode electrode at the high voltage end of the insulator. For testing purposes, the ideal electrode shape is a sphere. The spherical electrode diameter was designed to minimize the electric field within the constraints imposed by the vacuum chamber size. Electrostatic modeling was initially done with POISSON SuperFish [15], but because the cathode/insulator configuration is perpendicular to the axis of the cylindrical photogun vacuum chamber, CST MicroWave Studio [16] is better for 3D electrostatic modeling.

Figure 4. Inverted insulators and electrode configurations studied at JLab. Left: Pure alumina large R30 insulator (7.5” tall) with spherical and screening electrode. Center: Doped alumina large R30 insulator with spherical electrode only and welded to 10” CF flange, next to small R28 doped alumina insulator (4.5” tall). Right: Doped alumina R28 small insulator with spherical electrode only and welded to 10” CF flange.

Our results indicate that tailoring the conductivity of the insulator material, and/or adding a cathode triple-junction screening electrode, effectively serve to increase the hold-off voltage from 300 kV (pure alumina R30 insulator, no screening electrode) to more than 375 kV (pure or doped alumina R30 insulators) with triple-junction screening electrode [10]. In addition to significantly reducing the electric field parallel to the insulator surface, electrostatic field maps suggest these configurations serve also to produce a more uniform potential gradient along the insulator.

Remarkably, the small insulator reached 360 kV without breakdown and without the use of a screening electrode. We suspect the size of the spherical electrode and it proximity to the triple junction served as a screening electrode. The voltage on this insulator was not increased any further to preserve the insulator for future use.

The design of the triple junction screening electrode is intrinsic to the design of an inverted insulator photogun and it is an iterative process to minimize the gradient not only at the triple junction but also on the overall screening electrode profile. Field-emitted electrons from the triple junction can initiate pre-breakdown currents that often lead to arcing along the ceramic insulator at the insulator/cable-plug interface. The height of the screening electrode influences the potential along the insulator, especially at the interface between the insulator and the high-voltage cable plug. A taller screening electrode creates a more linear change in the potential, but it will increase the field strength at its cusp because it has moved closer to the grounded vacuum chamber wall. The cusp should also have a large radius to minimize gradient, but the radius of the screening electrode should be kept smaller than that of the spherical electrode radius to minimize distortions to the electric field in the anode-cathode gap for a photogun design. This process has proven effective for the small and large inverted insulator designs utilized in JLab photoguns operating at 200 and 300 kV respectively.

We intent to implement a similar iterative approach for the proposed larger inverted insulator design capable of reaching 500 kV for reliable operation in a polarized beam photogun at 350 kV without field emission. Figure 5 summarizes the highest voltages achieved at Jefferson Lab using inverted insulators with a variety of electrodes and screening electrodes. The size of available insulators is shown on the right of Fig. 5.

* With screening electrode	R28	R30	JLab FEL
Pure Alumina Voltage Achieved	280 kV	325 kV 375 kV *	N/A
Semi-conductive Voltage Achieved	360kV	365 kV *	TBD
Commercial Cable	Y	Y	N

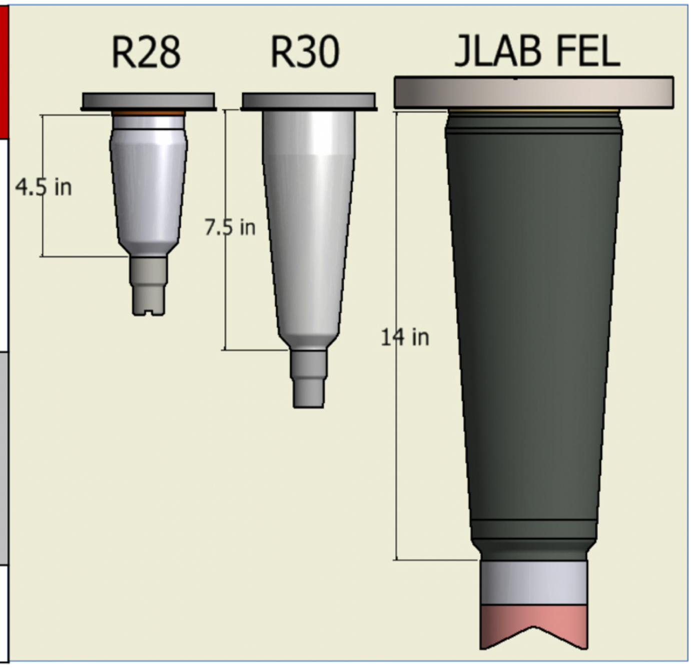

Figure 5. Left: Table summarizing the highest voltage reached at JLab using inverted insulators in a photogun vacuum test chamber. The asterisk indicate configurations with screening electrode. Right: Size comparison between the three types of inverted insulators on hand at Jefferson Lab.

The largest inverted insulator at JLab was also made by SCT Ceramics a decade ago for a proposed FEL 500 kV DC photogun with a custom design plug immersed in the SF_6 environment of the power supply [17]. This concept was never implemented for various reasons, but six inverted insulators are available, although not one has been tested because there is no commercial cable that fits the air-side, unlike the commercial insulator sizes R28 and R30. For reliable operation without arcing, it is critical that the cable plug conforms to the insulator profile to prevent air gaps. This is why cable plugs are made of relatively soft vulcanized rubber and are spring-loaded into the air-side of inverted insulators. A layer of silicon grease is typically applied to the cable plug for "squeezing out" any potential air pockets in the insulator-plug interface.

At the high voltage power supply end, cables mate to epoxy receptacles. Epoxy receptacles have large dielectric constant and large dielectric breakdown strength. These are very rugged compared to insulators, but cannot be used in the extreme high vacuum environment of polarized beam photoguns due to their outgassing nature in vacuum. Rarely do receptacles get damaged, at least when connected to the power supplies inside SF_6-pressurized tanks. Epoxy receptacles are commercially available in three sizes that fit commercial cable plugs: R28, R30, and also a larger size and higher-rated voltage cable designated as R350, which is used in all of the inverted insulator photogun power supplies at JLab. The other side of the high voltage cable is terminated either with an R28 or an R30 plug to fit the respective inverted insulator. Figure 6 shows the high voltage assemblies used successfully in photoguns at JLab, along with a preliminary approach to extend the inverted-insulator DC high voltage photogun design to higher operating voltage.

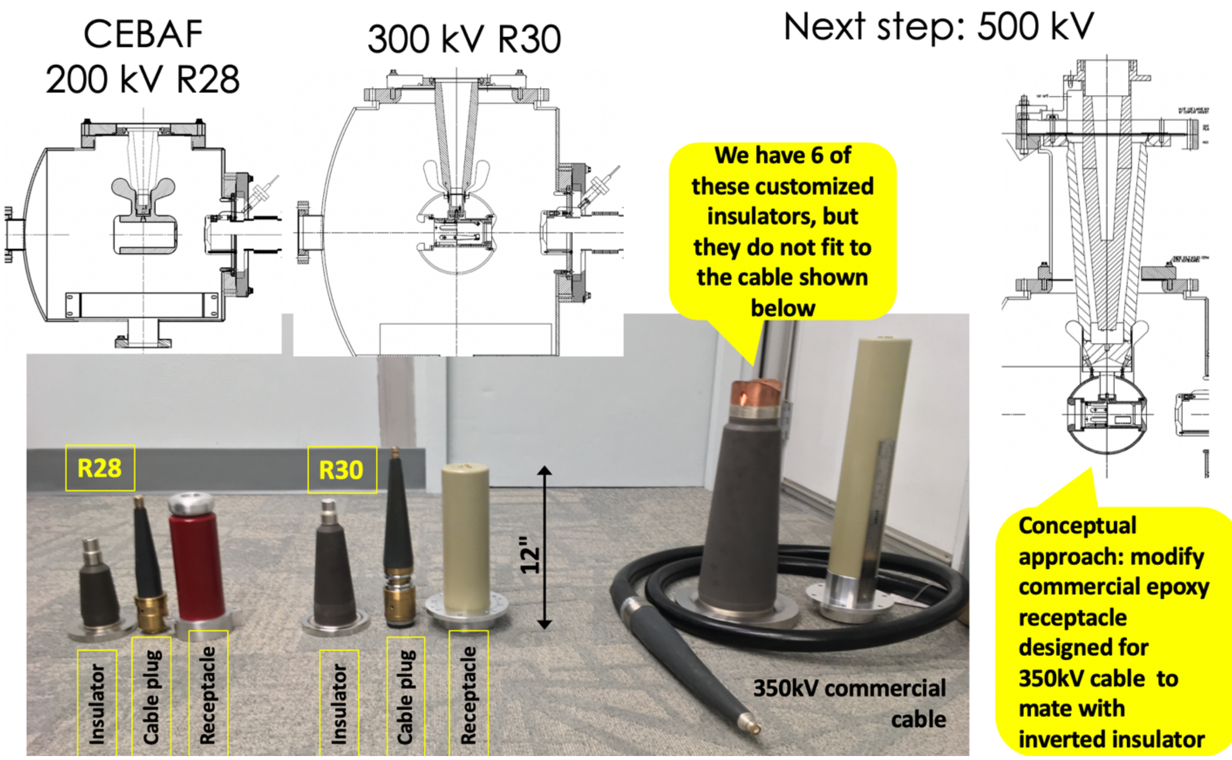

Figure 6. High voltage assemblies implemented successfully at JLab showing the insulator, cable plug, and epoxy receptacle used in the power supply end for the indicated photogun design and operating voltage.

Statement of Work

The primary efforts of the project will focus on electrostatic design and fabrication of electrodes and a high voltage assembly. As described in the background section, electrode design is essential to minimize gradient for preventing electrical breakdown and field emission at the desired operating voltage. Similarly, electrostatic modeling using proper dielectric constants for each component (cable plug, insulator, etc.) is critical for guiding the design of the whole assembly. Electrostatic modeling will be performed by the postdoctoral appointee using the CST Microwave Studio electrostatic solver and SolidWorks CAD modeling. These software tools have become essential due to the non-symmetric design of our inverted insulator photoguns. The postdoctoral appointee will also coordinate engineering design and manufacturing with the mechanical engineer. The electrodes will be barrel polished to mirror-like surface finish [12] by the senior technologist using a tumbler machine available at the JLab SRF institute (see Appendices 4 and 5).

There are three proposed avenues of testing:

a) Use the existing long custom insulator with a modified R350 epoxy receptacle and with intervening SF_6 layer.

We plan on implementing this approach first to qualify the performance of the long custom insulators, as those have not been tested yet. They key element will be using an R350 cable plug that mates to a commercial epoxy receptacle and an intervening SF_6 layer as a combined high voltage plug assembly. The receptacle will be machined to match the taper of the inverted insulator, leaving a gap for SF_6 shared with a pressurized SF_6 reservoir sealed at the top of the insulator/receptacle assembly, as shown in the preliminary concept in Fig. 7. The reason behind using SF_6 instead of silicon grease is twofold. First, the epoxy receptacle is smaller in diameter than the inverted insulator ground end (open to air) leaving a large gap to be filled with silicon grease prone to air pockets; and second, the receptacle is rigid in contrast to the rubber cable plug which conforms air-tight to the ceramic shape with an intervening thin silicon grease film like in the smaller R28 and R30 insulators.

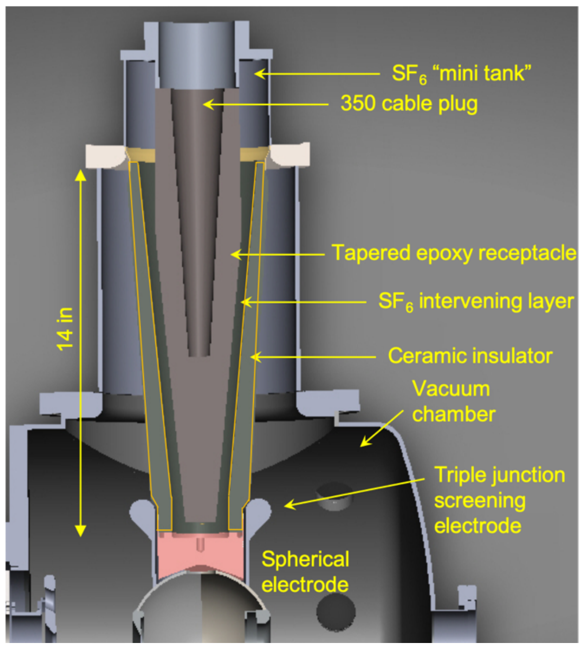

Figure 7. Schematic showing a preliminary concept for testing the existing long custom insulator with a modified R350 epoxy receptacle and with intervening SF_6 layer and pressurized reservoir on top of the inverted insulator.

High voltage testing will utilize a vacuum chamber already manufactured by Kurt J. Lesker filled with SF_6 for initial assessment of electrical breakdown. Upon success, high voltage tests will continue under vacuum conditions to qualify the performance of the triple junction screening electrode in preventing breakdown, and to quantify field emission levels as a function of bias voltage. High voltage processing under vacuum conditions typically takes about 100 hours (cumulative time) to reach 350 kV. We expect it will take three times as long to reach 500 kV, mainly due to voltage induced gas desorption [14,18]. Empirical observations show that when the voltage is higher than 250 kV, hydrogen gas molecules adhered to the vacuum chamber walls that were not removed during the vacuum bake out, are pulled towards the electrode by the electrostatic potential. Upon striking the electrode, they release secondary electrons that in turn strike the vacuum chamber releasing more gas molecules in a cascade process that is extinguished only by active pump down during high voltage processing. Depending on the size of the vacuum chamber and available pumping speed, we have observed with the JLab FEL vent/bake photogun in the range of 1 hour per 1 kV increase to pump down the released amount of hydrogen [14].

b) Use the existing long custom insulator and work with the high voltage cable company Dielectric Sciences Inc. to design the appropriate mating cable plug.

This approach builds on the previous test plan and although requires customization of commercially available cable plugs, it simplifies the inverted insulator connection to the high voltage cable by eliminating the use of SF_6 insulating layer and pressurized reservoir on top. For this phase, we plan to engage with Dielectric Sciences Inc, the company from which we buy high voltage cables and receptacles for the smaller R28 and R30 inverted insulators. With the long custom insulator qualified in the first set of testing described above, the objective of this phase is to design, fabricate, and test a large custom plug fitted to the long custom inverted insulator as a new assembly to 500 kV, first with the test chamber filled with SF_6 and then under vacuum conditions. As described in test plan a), we expect the high voltage condition phase to 500 kV in vacuum to take approximately 300 cumulative hours.

c) Design a 500 kV insulator compatible with commercial R350 high voltage cable.

Presently, we have only 6 of the long custom inverted insulators manufactured a decade ago by SCT Ceramics in France. Even if the custom high voltage cable approach described above is successful, there are no other commercial inverted insulators with the required dimensions to operate at 500kV and that mate to commercial high voltage cables. We consider this concept to be the ultimate solution as it simplifies and reduces the size of the proposed 350kV inverted photogun connection to the power supply. The last phase of the project will focus on electrostatic design and on demonstrating proof of principle. We plan to machine the designed insulator shape out of a solid rod of PTFE plastic (polytetrafluoroethylene, dielectric constant of 2.1 and dielectric breakdown strength of 55 MV/m), and then high voltage test it inside the SF_6 pressurized test chamber with a commercial R350 cable plug.

Although the engineering design and fabrication of this new type of inverted ceramic insulator goes beyond the scope of the proposed work, upon the project completion we expect to have developed a conceptual 500 kV inverted insulator design that mates to the R350 commercial high voltage cable, and therefore be in a position to collaborate with an insulator company in the United States for developing the engineering design and manufacturing of such insulator through SBIR/STTR initiatives. For example, MPF Products Inc, a Ceramic-to-Metal Electrical Feedthroughs for Ultra-High Vacuum Systems manufacturer based in Gray Court, SC, has expressed interest in collaborating with us, but their vacuum furnaces are not sufficiently large for the firing and brazing of the proposed 500 kV inverted ceramic insulator.

Timetable of activities

Activities start after receiving awarded funds. At the end of each year, and/or when milestones are achieved, results will be disseminated in form of peer-reviewed papers and contributed oral talks/posters in workshops and conferences.

Major tasks and deliverables

1. Hire postdoctoral appointee.

2. Procure and install CST MicroWave studio solver and SolidWorks CAD software packages.
3. Perform electrostatic design of high voltage assembly comprised of electrodes mounted to the existing long custom insulator with modified receptacle and intervening SF_6 layer.
    - Electrostatic design package ready for engineering design.
4. Produce engineering drawings for electrodes, modified epoxy receptacle, and SF_6 pressurized reservoir on top of long custom inverted insulator.
    - Engineering drawing package ready for manufacturing.
5. Fabricate components.
    - Electrodes, modified epoxy receptacle, and SF_6 reservoir flange ready for installation.
6. Assemble components and integrate to test chamber.
    - High voltage test chamber assembled and connected to high voltage power supply.
7. Test high voltage assembly in SF_6.
    - Report on test results.
8. Test high voltage assembly in vacuum.
    - Report on test results qualifying the high voltage performance of the long custom inverted insulator with SF_6 intervening layer and modified epoxy receptacle.
9. Perform electrostatic design of custom high voltage cable plug to fit long custom insulator.
    - Electrostatic design package ready for discussion with high voltage cable vendor.
10. Work with Dielectric Sciences on designing custom high voltage cable plug to fit long custom insulator.
    - Procure custom high voltage cable plug.
11. Test high voltage assembly in SF_6.
    - Report on test results.
12. Test high voltage assembly in vacuum.
    - Report on test results qualifying the high voltage performance of the long custom inverted insulator with custom high voltage cable plug.
13. Perform electrostatic design of 500 kV inverted insulator concept based on PTFE plastic compatible with R350 commercial high voltage cable.
    - Electrostatic design package ready for engineering design.
14. Produce engineering drawings for manufacturing PTFE plastic inverted insulator concept.
    - Engineering drawing package ready for manufacturing.
15. Fabricate 500 kV inverted insulator concept from machined PTFE plastic compatible with R350 commercial high voltage cable.
    - PTFE plastic inverted insulator concept ready for installation.
16. Test high voltage assembly in SF_6.
    - Report on test results and evaluation of 500kV inverted insulator PTFE plastic concept compatible with R350 commercial high voltage cable as a potential design for a ceramic inverted insulator.

Estimated task schedule starting after receiving awarded funds.

Tasks Year 1	**Q1**	**Q2**	**Q3**	**Q4**
1. Hire postdoctoral appointee				
2. Purchase and install software packages				
3. Electrostatic design: electrodes + long insulator + SF6 intervening layer				
4. Engineering design				
5. Fabricate components				
6. Assemble components				
7. Test high voltage assembly in SF6				
8. Test high voltage assembly in vacuum				

Tasks Year 2	**Q1**	**Q2**	**Q3**	**Q4**
9. Electrostatic design: custom high voltage plug for long insulator				
10. Work with Dielectric Sciences on custom high voltage plug				
11. High voltage test long insulator + custom cable plug in SF6				
12. High voltage test long insulator + custom cable plug in vacuum				
13. Electrostatic design: 500kV insulator concept + R350 commercial cable				
14. Engineering design				
15. Fabricate 500 kV insulator concept out of PTFE plastic + R350 HV cable				
16. Test high voltage plastic insulator concept + R350 HV cable in vacuum				

Project Objectives

This proposal seeks two-year funding for a postdoctoral appointee to develop an insulator/cable concept that operates reliably at 500 kV, extending the JLab inverted-insulator DC high voltage photogun design to 350kV operating voltage with NO field emission for polarized electron beams from delicate GaAs-based photocathodes.

Upon the project completion, the intention is to work with an insulator company in the United States for developing the engineering design and manufacturing of such insulator through SBIR/STTR initiatives.

Appendix 1: Biographical Sketches

DR. CARLOS HERNANDEZ-GARCIA

Dr. Carlos Hernandez-Garcia is a Senior Staff Scientist at the Center for Injectors and Sources within the Accelerator Division at Jefferson Lab. He received his PhD in 2001 from Vanderbilt University with the thesis "*Photoelectric Field Emission from Needle Cathodes induced by CW and Pulsed Lasers*". Shortly afterwards he joined the JLab Free Electron Laser (FEL) team. In 2004 Carlos was appointed Head of FEL Injector/Gun Systems. In 2007 he led the photoinjector efforts to generate 10mA CW beam current for the Jefferson Lab FEL 14 kW CW lasing power world record. In2007 the team under his leadership was first to demonstrate 1 nC bunch charge production with Cs:GaAs photocathode in the FEL DC photogun test stand. In 2013 Carlos was on sabbatical leave at DESY's Photo Injector Test Facility (PITZ), Zeuthen site, studying electron emission from Cs2Te photocathodes in radio frequency electron injectors. In 2014 he transitioned to the Center for Injectors and Sources group where he leads the high voltage R&D on compact DC photoguns based on inverted geometry insulators. For the past ten years Carlos has served as facilitator between the Mexican Physical Society and various US National Laboratories to develop a plan for the first synchrotron light source in Mexico, based on training of a new generation of Mexican students in accelerator physics.

Education and training:

2001 Ph.D. Physics, Vanderbilt University, Nashville TN, USA

1998 USPAS, H. Wiedemann "*Electromagnetic radiation*", MIT, Cambridge, MA

1997 M. S. Physics, Vanderbilt University, Nashville TN, USA

1997 USPAS, H. Wiedemann "*Accelerator Fundamentals*", Stanford Univ., Palo Alto, CA

1993 B.S. Industrial Physics Ennginneering, Instituto Tecnologico y de Estudios Superiores de Monterrey, Monterrey NL, Mexico

Professional Experience:

2018 – present Senior Staff Scientist, Accelerator Division, Jefferson Lab, Newport News, VA
2013 – 2017 Staff Scientist III, Accelerator Division, Accelerator Division, Jefferson Lab
2013 – 2014 Sabbatical leave, Photo Injector Test Facility (PITZ) Deutsche Elektronen-Synchtrotron (DESY), Zeuthen Germany
2004 – 2013 Staff Scientist II, FEL Division Injector System Project Manager, Jefferson Lab
2001 – 2004 Staff Scientist I, FEL Division, Jefferson Lab

Selected Publications:

[1] C. Hernandez-Garcia, B. Bullard, J. Benesch, J. Grames, J. Gubeli, F. Hannon, J. Hansknecht, J. Jordan, R. Kazimi, G. A. Krafft, M. A. Mamun, M. Poelker, M. L. Stutzman, R. Suleiman, M. Tiefenback, Y. Wang, and S. Zhang; A. Valerio Lizarraga R. Montoya Soto; A. Canales Ramos; G. Palacios-Serrano, S. Wijethunga, J. T. Yoskowitz "Compact -300kV dc inverted insulator photogun with biased anode and alkali-antimonide photocathode", Phys. Rev. Accel. Beams **22**, 113401 (2019).
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[3] C. Hernandez-Garcia, D. Bullard, F. Hannon, Y. Wang, and M. Poelker, "High voltage performance of a dc photoemission electron gun with centrifugal barrel-polished electrodes," Rev. Sci. Instrum, **88**, 093303 (2017).
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Synergistic Activities:

2019 Review panel member, NSF Center for Bright Beams, Cornell University, Ithaca, NY
2010 – present Organizing committee member, Photocathode Physics for Photoinjectors Workshop series
2005 – present Reviewer, Department of Energy SBIR/STTR Program

Collaborators and co-editors:

M Herbert (T.U. Darmstadt), E. Wang (Brookhaven National Laboratory), H. Baumgart (Old Dominion University), D. Bullard, J. Benesch, J. Gubeli, F. Hannon, J. Hansknecht, J. Jordan, R. Kazimi, G. A. Krafft, M. A. Mamun, M. Poelker, M. L. Stutzman, R. Suleiman, M. Tiefenback, Y. Wang, S. Zhang, (Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, USA); A. Valerio Lizarraga (Facultad de Ciencias Físico-matemáticas Universidad Autónoma de Sinaloa, Culiacan, Mexico); R. Montoya Soto, M. Napsuciale, H. I. Maury-Cuna (Departamento de Física, Universidad de Guanajuato, Mexico); A. Canales Ramos (Universidad Nacional Autónoma de Mexico, Mexico),

Graduate and Postdoctoral Advisors and Advisees:

- Mr. G. Palacios, Department of Electrical Engineering, Old Dominion University, USA (advisee: PhD expected 2021)
- Mr. D. K. Koppunuru, Department of Electrical Engineering, Old Dominion University (Advisee: M. Sc. 2007)
- Mr. N. D. Theodore, Department of Applied Science, The College of William and Mary, USA (advisee: PhD 2006)
- Dr. C. A. Brau, Vanderbilt University, USA, (graduate advisor)

DR. MATTHEW POELKER

Dr. Matthew Poelker is the group leader of the Center for Injectors and Sources at Jefferson Lab where he has worked since 1994, with key responsibility being the maintenance and upgrade of the CEBAF spin polarized electron source. Areas of research interest include photoguns, spin polarized electron and positron beams, photocathodes, high voltage, drive lasers and vacuum. Recent focus has been the construction of a compact 10 MeV spin polarized accelerator for testing the HDIce polarized target, and development of high current electron guns that make magnetized beam. Before working at Jefferson Lab, Dr. Poelker was a post-doctoral assistant in the Medium Energy Physics group at Argonne National Lab where he worked on a laser-driven target of polarized hydrogen and deuterium gas.

Education and Training:

1992 Ph.D. Electrical Engineering, Northwestern University, Evanston, IL
1988 M.S., Electrical Engineering, Northwestern University, Evanston, IL
1983 B.S., Engineering Physics, University of Illinois, Champaign/Urbana, IL

Professional Experience:

1994 - present Senior Staff Scientist and Group Leader Center for Injectors and Sources, Thomas Jefferson National Accelerator Facility
1992 – 1994 Postdoctoral research associate, Physics Division, Argonne National Lab

Selected Publications:

1) C. Hernandez-Garcia, B. Bullard, J. Benesch, J. Grames, J. Gubeli, F. Hannon, J. Hansknecht, J. Jordan, R. Kazimi, G. A. Krafft, M. A. Mamun, M. Poelker, M. L. Stutzman, R. Suleiman, M. Tiefenback, Y. Wang, and S. Zhang (Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, USA); A. Valerio Lizarraga (Facultad de Ciencias Físico-matemáticas Universidad Autónoma de Sinaloa, Culiacán 80010, Mexico); R. Montoya Soto (Departamento de Física, Universidad de Guanajuato, León 37150, Mexico); A. Canales Ramos (Universidad Nacional Autónoma de Mexico, Mexico City 04510, Mexico), G. Palacios-Serrano, S. Wijethunga, J. T. Yoskowitz (Old Dominion University, Norfolk, Virginia 23529, USA) "*Compact −300kV dc inverted insulator photogun with biased anode and alkali-antimonide photocathode*", Phys. Rev. Accel. Beams **22**, 113401 (2019)
2) Xincun Peng, Zhidong Wang, Yun Liu, Dennis M. Manos, Matt Poelker, Marcy Stutzman, Bin Tang, Shukui Zhang, and Jijun Zou, "*Optical-Resonance-Enhanced Photoemission from Nanostructured GaAs Photocathodes*", Phys. Rev. Applied **12**, 064002 (2019)
3) Marcy L. Stutzman, Philip A. Adderley, Md. Abdullah A. Mamun, and Matt Poelker, "*Nonevaporable getter coating chambers for extreme high vacuum,*" J. Vac. Sci. Technol. A **36**, 031603 (2018)
4) M.A. Mamun, M. R. Hernandez-Flores, E. Morales, C. Hernandez-Garcia, and M. Poelker, "*Temperature Dependence of Alkali-Antimonide Photocathodes: Evaluation at Cryogenic Temperatures,*" Phys. Rev. Accel. Beams **20**, 103403 (2017)
5) Wei Liu, Matt Poelker, Xincun Peng, Shukui Zhang, and Marcy Stutzman, "*A comprehensive evaluation of factors that influence the spin polarization of electrons emitted from bulk GaAs photocathodes*", J. Appl. Phys., **122**, 035703 (2017)
6) Wei Liu, Yiqiao Chen, Wentao Lu, Aaron Moy, Matt Poelker, Marcy Stutzman, and Shukui Zhang, "*Record-level quantum efficiency from a high polarization strained GaAs/GaAsP superlattice photocathode with distributed Bragg reflector*", Appl. Phys. Lett. **109**, 252104 (2016)
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K. E. Mesick, T. Michaelides, R. Michaels, B. Moffit, D. Moser, C. Muñoz Camacho, J.-F. Muraz, A. Opper, M. Poelker, J.-S. Réal, L. Richardson, S. Setiniyaz, M. Stutzman, R. Suleiman, C. Tennant, C. Tsai, D. Turner, M. Ungaro, A. Variola, E. Voutier, Y. Wang, and Y. Zhang, "*Production of Highly Polarized Positrons Using Polarized Electrons at MeV Energies*", Phys. Rev. Lett., 116, 214801 (2016)

8) C. Hernandez-Garcia, M. Poelker, and J. Hansknecht, "*High Voltage Studies of Inverted-geometry Ceramic Insulators for a 350 kV dc Polarized Electron Gun*", IEEE Transactions on Dielectrics and Electrical Insulation, Vol. **23**, No. 1; February 2016
9) M. BastaniNejad, A.A. Elmustafa, E. Forman, J. Clark, S. Covert, J. Grames, J. Hansknecht, C. Hernandez-Garcia, M. Poelker, and R. Suleiman, "*Improving the performance of stainless-steel DC high voltage photoelectron gun cathode electrodes via gas conditioning with helium or krypton*." Nucl. Instr. And Meth. A **762**, (2014), pp.135-141
10) Md. Abdullah A. Mamun, Abdelmageed A. Elmustafa, Marcy L. Stutzman, Philip A. Adderley, Matthew Poelker, "*Effect of heat treatment and coatings on the outgassing rate of stainless steel chambers*." Journal of Vacuum Science and Technology A **32(2)**, (2014), pp.021604, 1-8

Awards, Honors, and Acknowledgement

- APS Fellowship, 2015 (nominated by the Division of Physics of Beams)
- E. O. Lawrence Award Recipient, 2011
- Member BNL C-AD R&D Machine Advisory Committee since 2015
- Member Super KEKB Accelerator Review Committee since 2014
- Member University of Chicago "Godparent" review committee, large area photodetector project managed by Prof. Henry Frisch
- Member of the International Spin Physics Committee since 2012

Collaborations

(i) Elmustafa, Abdelmageed and Baumgart, Helmut, Old Dominion University (student projects)
Gay, Tim, University of Nebraska-Lincoln (polarimetry, vortex beams)
Smedley, John, Brookhaven National Laboratory (photocathodes)
Bubble Chamber Collaboration, Medium Energy Physics Dept., Argonne National Lab (astrophysics measurements)
HDIce polarized target group at Jefferson Lab
Cultrera, Luca, Cornell University (photocathodes)
Paschke, Kent, University of Virginia and other parity violation experimenters
Rai Weiss and LIGO collaboration on vacuum topics
Ring EDM collaboration at COSY/Juelich (high voltage electrodes)
Numerous small businesses via the SBIR/STTR program

(ii) Graduate Advisors and Postdoctoral Sponsors (Total # of Advisors: 2)
Advisor: Prof. Prem Kumar, Northwestern University, Evanston, IL
Post-doctoral Advisor: Roy Holt, Argonne National Lab, IL

(iii) Dissertation Advisor (Total # of Students: 4)
James McCarter, Mahzad BastaniNejad, Abdullah A. Mamun, Wei Lui

Appendix 2: Current and Pending Support

DR. Carlos Hernandez Garcia and Dr. Matt Poelker

(this proposal)
Title: High Voltage Insulators and Electrodes for 500 kV DC High Voltage Photogun with Inverted Insulator Design

PI: C. Hernandez-Garcia (Jefferson Lab), Co-Investigator: M. Poelker (Jefferson Lab)
Source of Support: DOE Office of Science, Office of Nuclear Physics
Project Location: Jefferson Lab
Amount: $641,612.56
Period of Performance: 9/15/2020-09/14/2022

Title of award: Accelerator Physics Education Outreach with Mexican
Sponsor: Jefferson Science Associates, LLC (JSA)
Award ID: JSA Initiatives Fund Program Universities
Total value of sub-award for this work: $5.5k for student lodging and meals
Award period: May 25, 2020 – August 1, 2020
Description of work: Every year since 2010 the Mexican Physical Society selects one undergraduate student amongst the top 100 students in Mexican Universities for an internship at JLab. The selected student is assigned a research project and a mentor. The internship aims to train undergraduate students from Mexico in accelerator physics topics providing hands-on experience and close collaboration with JLab scientists, engineers and technicians.

Appendix 3: Bibliography and references cited

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[9] C. Hernandez-Garcia, B. Bullard, J. Benesch, J. Grames, J. Gubeli, F. Hannon, J. Hansknecht, J. Jordan, R. Kazimi, G. A. Krafft, M. A. Mamun, M. Poelker, M. L. Stutzman, R. Suleiman, M. Tiefenback, Y. Wang, and S. Zhang; A. Valerio Lizarraga R. Montoya Soto; A. Canales Ramos; H. Baumgart, G. Palacios-Serrano, S. Wijethunga, J. T. Yoskowitz "Compact -300kV dc inverted insulator photogun with biased anode and alkali-antimonide photocathode", Phys. Rev. Accel. Beams **22**, 113401 (2019).

[10] C. Hernandez-Garcia, B.M. Poelker and J.C. Hansknecht, "High Voltage Studies of Inverted-Geometry Ceramic Insulators for a 350kV dc Polarized Electron Gun", IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 23, No. 1; February 2016

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Appendix 4: Facilities and Other Resources

At Jefferson Lab, we have access to welders and to chemical cleaning facilities large enough to accommodate the electrodes and vacuum chamber flanges. The electrode and ceramic will be assembled in a clean room class 1000 located in our vacuum laboratory that has spigots with dry nitrogen for dusting off vacuum components.

JLab counts with state-of-the-art machine shop facilities, where most of the DC electron guns for CEBAF and for the FEL have been manufactured. The shop will be employed to machine the test electrodes, inverted insulator top flanges, and PTFE plastic inverted insulator model.

The surface polishing and heat treatment of all test electrodes will be performed at the JLab's SRF Institute which hosts a variety of laboratory space with a tumbler polisher and a vacuum furnace (see Appendix 5). The SRF facilities and our vacuum lab are located in the Test Lab building where the cryo-module construction, assembly and testing takes place.

High voltage testing will be performed in the Gun Test Stand (GTS), a fully operational radiation shielded enclosure adjacent to the JLab Low Energy Recirculation facility vault (formerly the JLab FEL). The GTS enclosure has a fully functional personal safety system (PSS) certified twice a year by JLab's Safety Systems Group. The PSS is integral to the remote operation of the high voltage power supply and test chamber inside the GTS enclosure.

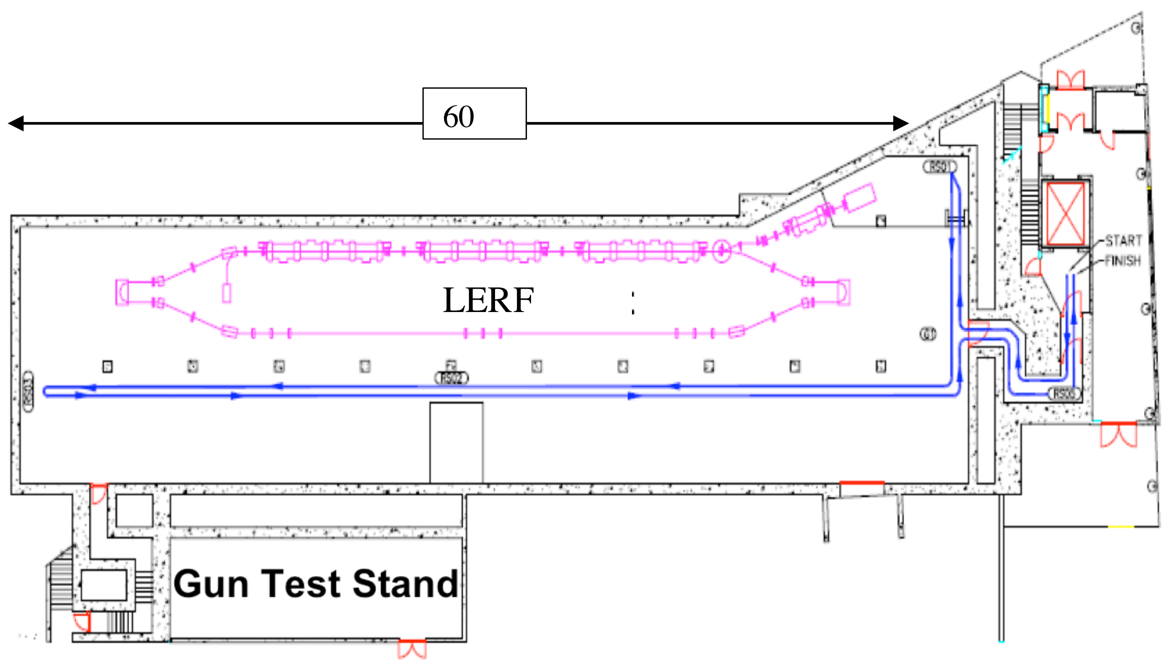

Fig. A4.1. Facilities drawing showing the low energy recirculation facility (LERF) vault and the Gun Test Stand enclosure where proposed high voltage testing will be performed.

Appendix 5: Equipment

The CST MicroWaveStudio solver and SolidWorks CAD software packages will be installed in a dedicated PC Dell Precision 5820 tower with Processor Intel Xeon W-2135 CPU at 3.70GHz (6 core processors) and 3696 Mhz (12 Logical Processors), 32 GB installed physical memory and two hard drives 465 GB each. The PC has an estimated value of $3,500.

High voltage testing will be performed using our Glassman 600 kV, 5 mA DC gas insulated (SF_6) power supply with 300 Mega-Ohm resistor connected to a R350 epoxy receptacle. The power supply is installed and operational in our Gun Test Stand (Appendix 4) and is ready for connection with high voltage cables. This power supply is fully functional via the remote computer-controlled EPICS system and has been used for a 300 kV DC inverted insulator photogun to generate un-polarized electrons from multi-alkali photocathode for magnetized beam studies. It is difficult to assign a dollar value to the power supply and associated custom SF_6 tank because it was procured more than 20 years ago for the JLab FEL, but based on current pricing of similar systems, the estimated value is $60,000.

The polishing and vacuum degassing of the test electrodes will be performed using the JLab SRF's R&D tumbler polisher and vacuum furnace, shown in Figure A5.1.

SF_6 gas transfer to/from storage bottles, test chamber and reservoir on top of the inverted insulator will be handled with our group's recovery/storage system by DILO with an estimated value of $20,000

Radiation levels from x-rays during high voltage processing will be monitored with a fully functional Geiger-Muller tube radiation monitoring system designed in-house and integrated to EPICS. Up to 8 radiation probe tubes can be mounted around the high voltage test chamber.

A vacuum chamber for high voltage testing has already been manufactured with a value of $8,000.

Pump down and vacuum bake outs of the high voltage test chamber will be performed using one of our turbo pump systems with integrated Kr reservoirs, vacuum gauges and regulators for gas high voltage processing, with an estimated value of $5,000.

In 2010, we procured 6 custom size long inverted insulators made by SCT Ceramics (France) with a total estimated value of $60k. This type of insulator does not mate with commercial high voltage cable plugs.

We also have the following vacuum components available for the proposed project:

Ion pump 6" CF and 100 l/s pumping speed with a value of $4,000
Turbo pump 6" CF and 300 l/s pumping speed with a value of $12,000
Pneumatic 6" CF gate valve with a value of $12,000

The estimated total value of available equipment for the proposed project is: $184,500

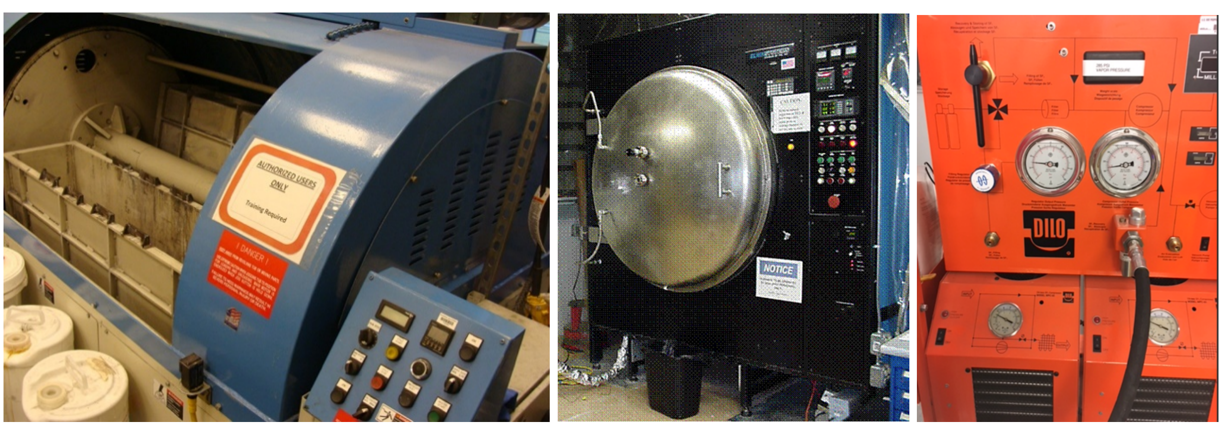

Fig. A5.1. Left: Barrel polisher tumbler. Center: Vacuum furnace. Right: SF_6 recovery/storage system.

Appendix 6: Data Management Plan

Dissemination of research results is a critical part of modern research and development, Jefferson Lab supports the concept of data sharing and prolifically presenting research results at international conferences and regularly publishes research results in peer-review journals. However, any release of data is done in such a way to be compliant with any export control mandates and to protect intellectual property (IP) and proprietary information where appropriate. Jefferson Lab does not believe this technology contains any export controlled information, however, if it is determined to be so, we will conduct an export control review as appropriate.

Types of Data Produced

The data types generated by the research described in this project include:

- ☐ Design notes, calculations, algorithms and computer simulations
- ☐ Processes and controls
- ☐ Processed data (e.g., analyzed data, tables, graphs)
- ☐ Drawings and schematics
- ☐ Publications, talks and documents (e.g., papers in refereed journals, conferences and workshops, internal technical notes, competitive incentive proposals)

The data management system will offer the following minimum capabilities:

- ☐ Data capture and storage
- ☐ User-friendly graphical access to laboratory, industry and international collaborators
- ☐ Backup and archiving of data
- ☐ Compatibility with multiple formats (e.g., documents, spreadsheets, graphics, presentations)
- ☐ Access controls

Plans for archiving and preservation

The products of this research will published in the open literature. The main venues are:

- Physical Review Special Topics – Accelerators and Beams
- Review of Scientific Instruments
- IEEE Transactions on Dielectrics and Electrical Insulation,
- Proceedings of the International Particle Accelerator Conference
- Proceedings of the International Conference on High Voltage Engineering

All the electronic files generated for this project will be preserved according to Jefferson Lab's record management policy and DOE's Research and Development Records Schedule.

Policies for access and sharing, and provisions for appropriate protection/privacy

Documents generated and classified in the course of this project will be shared among collaborators from the start of the project, and will be continually upgraded and updated. E-mail will be the most common method to share information. Prior to making them available for wider distribution, such as through journal publications or conference presentations, applications for the protection of Intellectual Property would be filed, as agreed upon by all collaborators.

Electronic documents created during this project will be stored in a project folder on a network drive maintained and backed-up daily by Jefferson Lab's IT Division. Jefferson Lab has robust cyber security processes and policies in place which will ensure data integrity and prevent unauthorized access.

Policies and provisions for re-use re-distribution

Allocation of Intellectual Property rights will be in accordance with JSA's Prime Contract with the U.S. Department of Energy or under a separate CRADA between the Participants.

With the exception of items that have potential for Intellectual Property rights, data and expertise acquired during this program will be either published, presented at conferences, or both. Information will be made available to researchers elsewhere when the Intellectual Property rights are secured.