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

NP FOA FY20

Second annual NP Accelerator R&D + Data Science AI/ML virtual PI Exchange meeting

November 29, 2029

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Center for Injectors and Sources

Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

JSA

Project overview

- Objective: Develop an ***inverted insulator feedthrough + high voltage cable connector*** that can be used to reliably apply ***500 kV*** bias voltage to a test electrode, with ***no high voltage breakdown*** inside or outside the vacuum chamber. *Such a feedthrough does not exist to date.*
- Motivation: A future photogun based on the resultant 500 kV feedthrough design could then be used in a ***400 kV photogun with margin for high voltage conditioning*** to generate ***high bunch charge spin-polarized electron beams***.
- Performance:
  - ✓ Progress made:
    - Postdoctoral positioned filled for developing the electrostatic design, apparatus assembly and high voltage testing
    - High voltage apparatus assembled and installed
  - ✓ Milestones
    - First ~200 kV applied
  - Issues
    - ~200 kV is significantly lower voltage than expected
    - SF_6 pressure in the custom design HV connector seems too low at 10 PSIG original design
  - Risk mitigation
    - Higher pressure (50 PSIG) custom connector designed and pressure evaluated, ready for high voltage testing
    - Alternative to solid rubber plug using HV silicone based compound identified and ready for procurement
    - No Cost Extension granted in April 2022 to Sept 30th 2023

Using an inverted insulator for a polarized photogun is essential to achieve XHV conditions for delicate SSL photocathode thanks to smaller footprint compared to large bore ceramic photoguns

- Helps achieving ~10^{-12} Torr vacuum because there is less surface area to contribute a gas load
- Serves to minimize field emission because there is less metal biased at high voltage

JLab inverted insulator photogun

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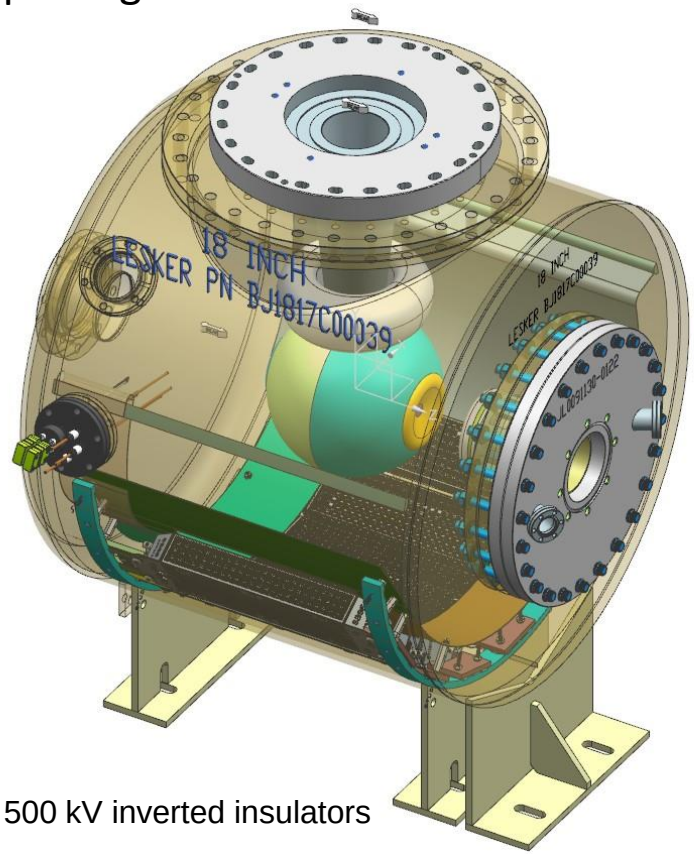
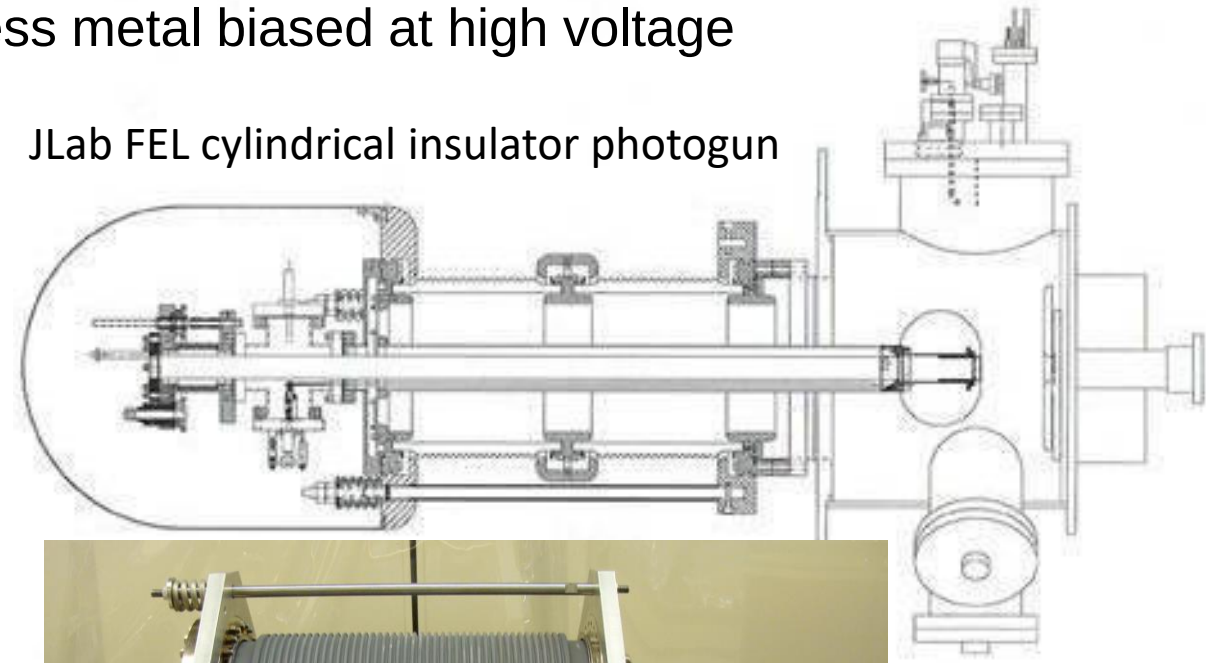
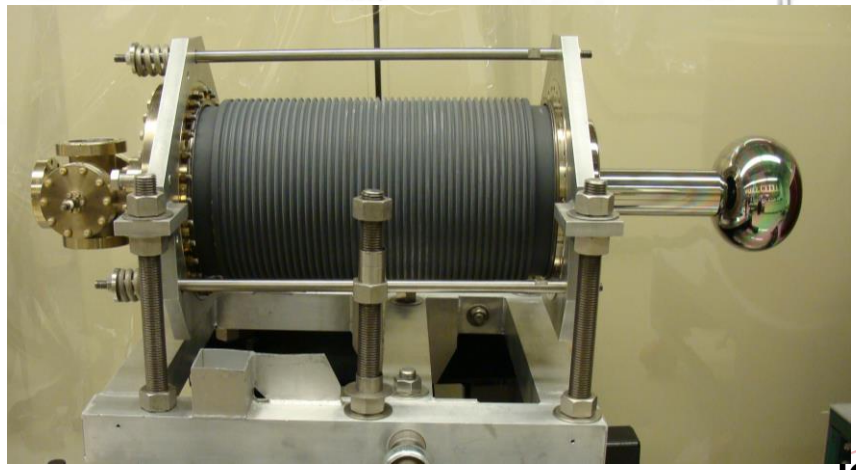


JLab FEL cylindrical insulator photogun





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C. Hernandez-Garcia – JLab 500 kV inverted insulators

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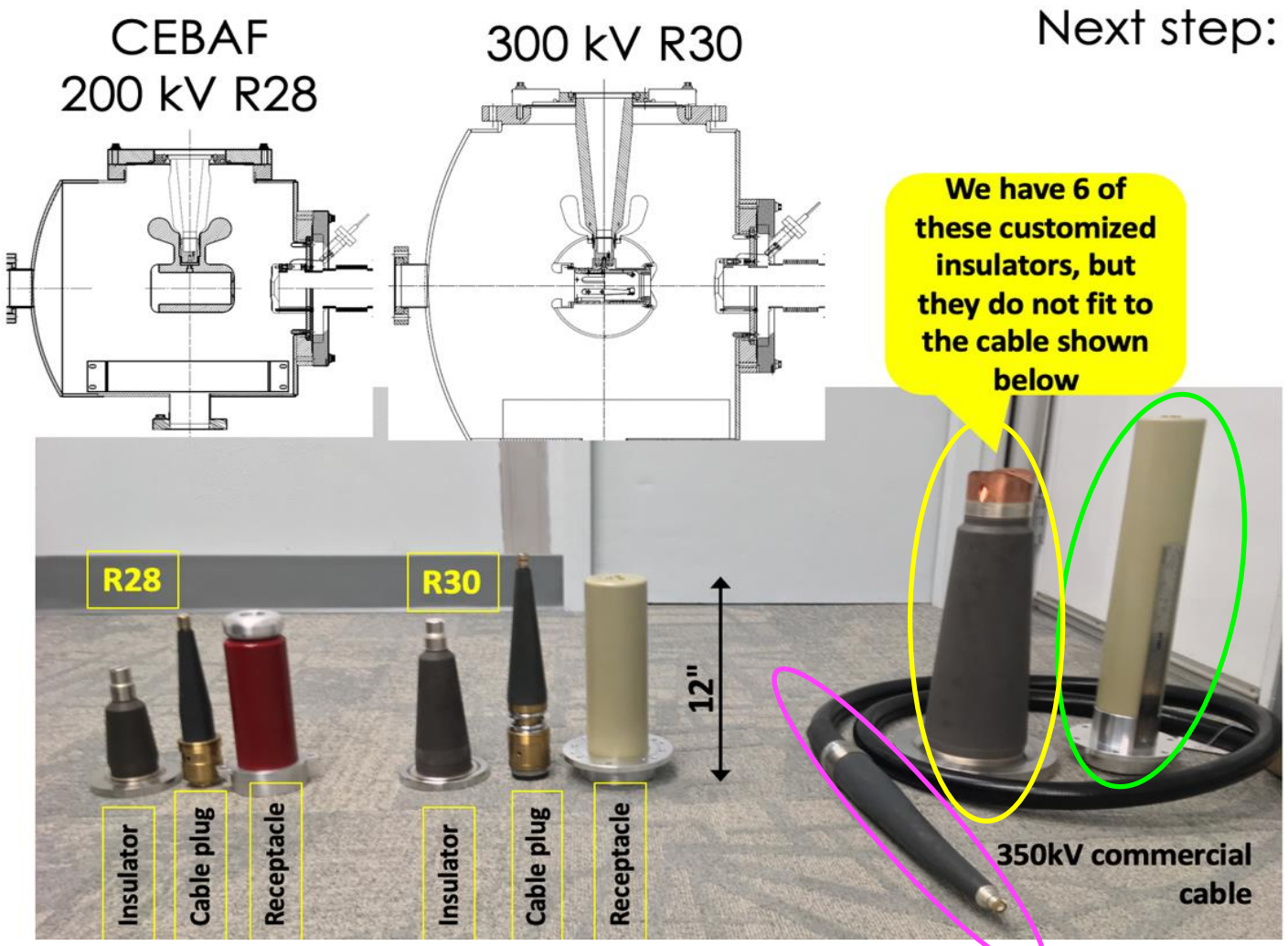
Challenge

- An envisioned 400 kV DC photogun design requires reliable 500 kV feedthrough to provide margin for high voltage conditioning
- There is no inverted insulator feedthrough capable of 500 kV that fits commercial cable connectors
- Commercial cable connectors are rated to ~ 400 kV max in SF_6, and have never been tested > 350 kV connected to inverted insulators in vacuum*
- Vendor recommends using Mega-volt cable, but there are no connectors for this type of cable

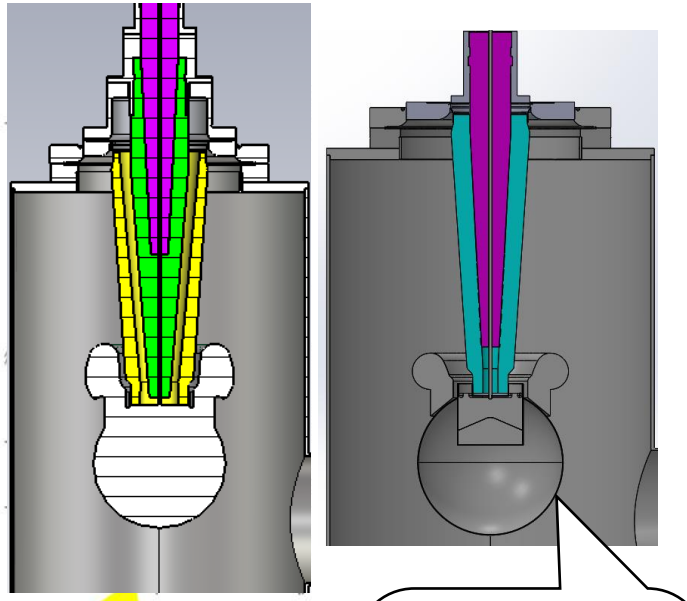
*C. Hernandez-Garcia, B.M. Poelker and J.C. Hansknecht,
"High Voltage Studies of Inverted-Geometry Ceramic Insulators for a 350kV dc Polarized Electron Gun", IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 23, No. 1; February 2016

Technical approach

- The proposed plan is an evolution from our experience developing and operating high voltage inverted insulator photo-guns connected to power supplies using commercial components.



Next step: 500 kV



Conceptual approach: modify commercial epoxy receptacle designed for 350kV cable to mate with inverted insulator

Conceptual approach: Work with vendor to develop a 500 kV insulator that fits the commercial cable

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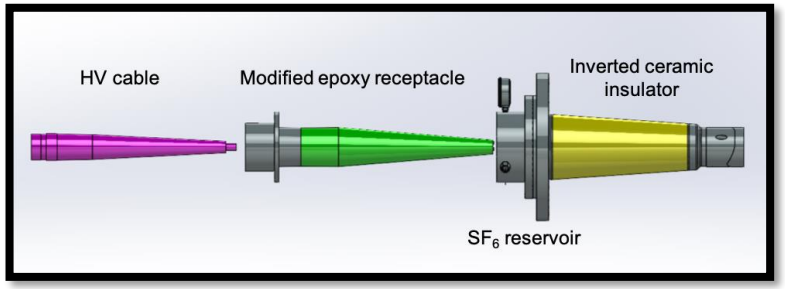
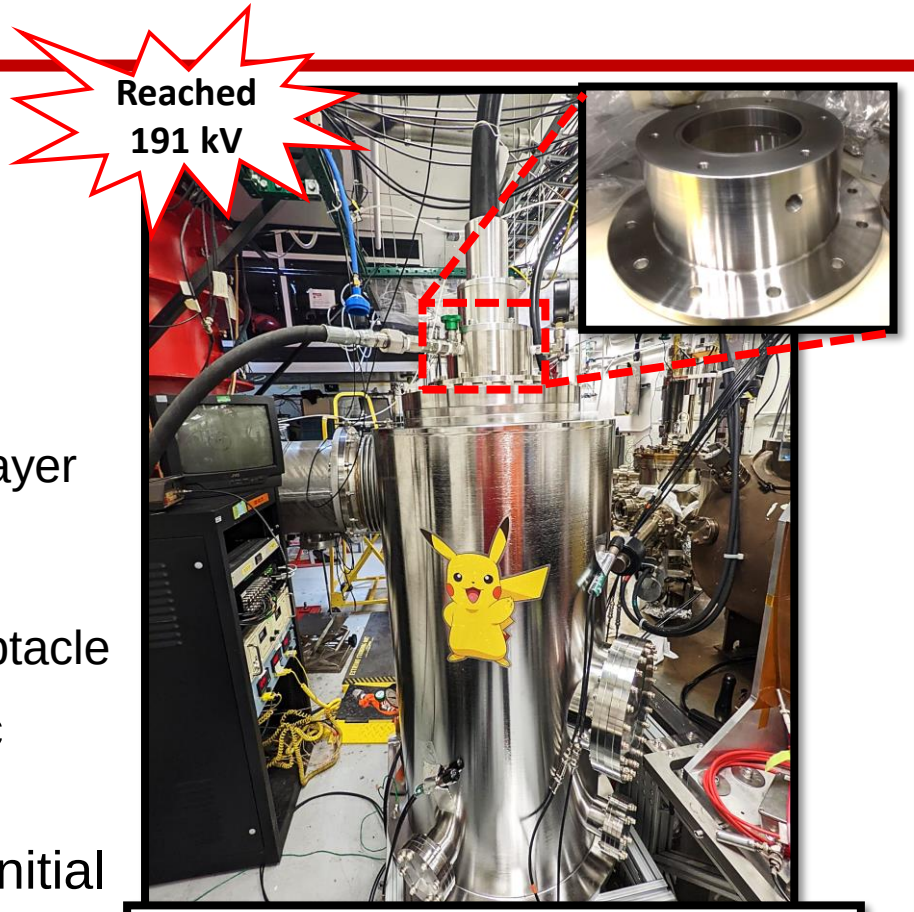
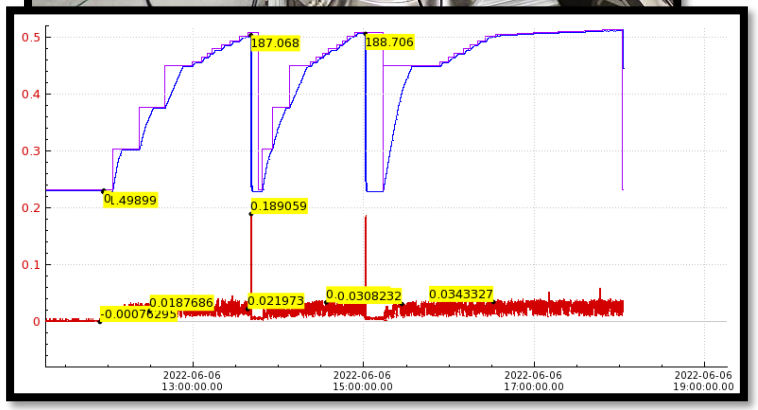
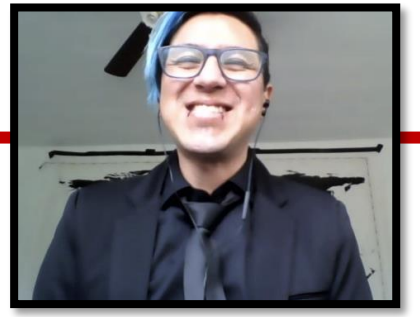
Progress: program

- Gabriel Palacios-Serrano was hired as a postdoctoral fellow on 06/16/21
- CST EM studio + Solidworks procured on 04/15/21, and license renewed 04/16/22
- Electrostatic models completed:
  - Modified HV receptacle and intervening SF_6 layer
  - Electrostatic design of electrode + triple point junction shield (to prevent arcing)
  - Wide HV cable, cylindrical HV cable, no-receptacle
- Manufactured: SF_6 reservoir and electrostatic shield, modified epoxy receptacle.
- System assembled, and achieved 191 kV in initial tests.









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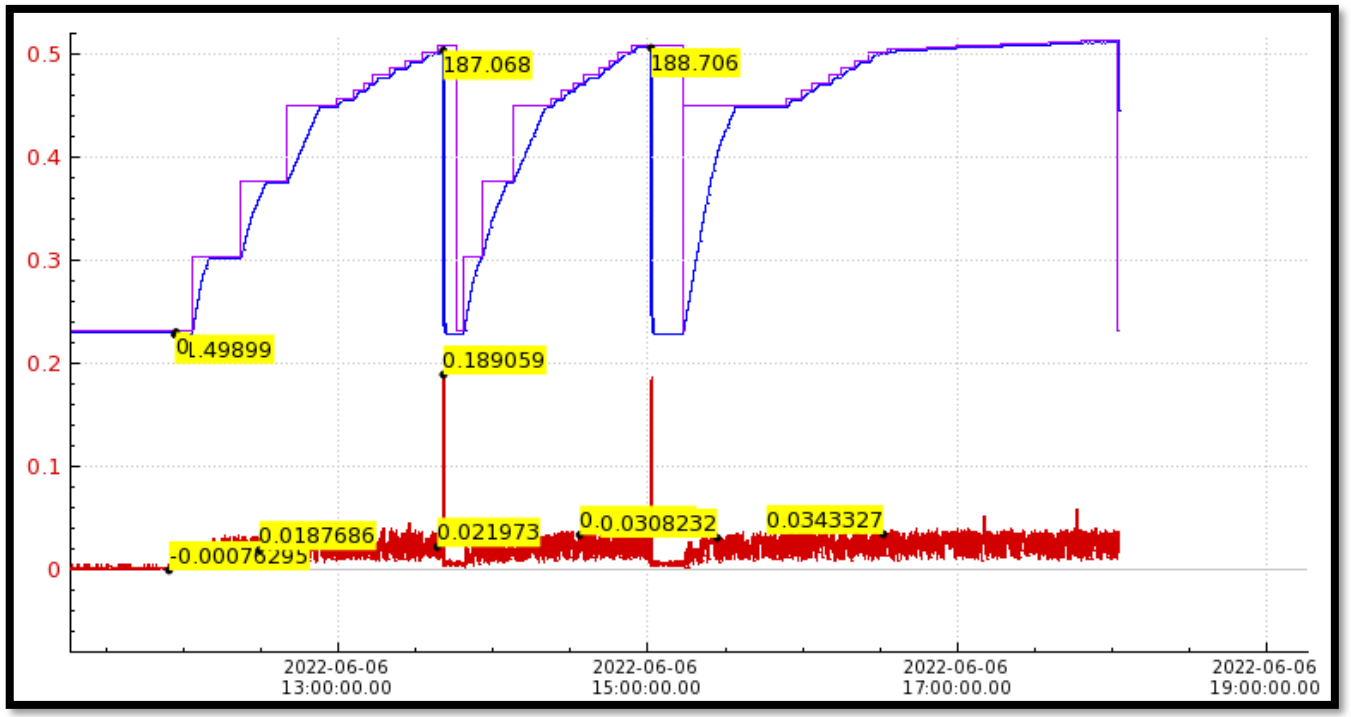
Progress: High voltage applied!

- The test chamber was then filled with SF_6 gas to nominal 10 PSIG, as well as the separate reservoir containing the volume of the SF_6 intervening layer between the receptacle and the insulator.

- The power supply was set to trip on over-current at 0.2 mA. Voltage was applied incrementally at a rate of 5 kV/min in steps of 25 kV up to 150 kV, then at a rate of 1 kV/min in steps of 5 kV.

- The graph shows the voltage steps in blue, and the high voltage power supply current (from the internal measuring stack) in red. A couple of over-current trips were observed at ~ 190 kV. The current readings are in mA.

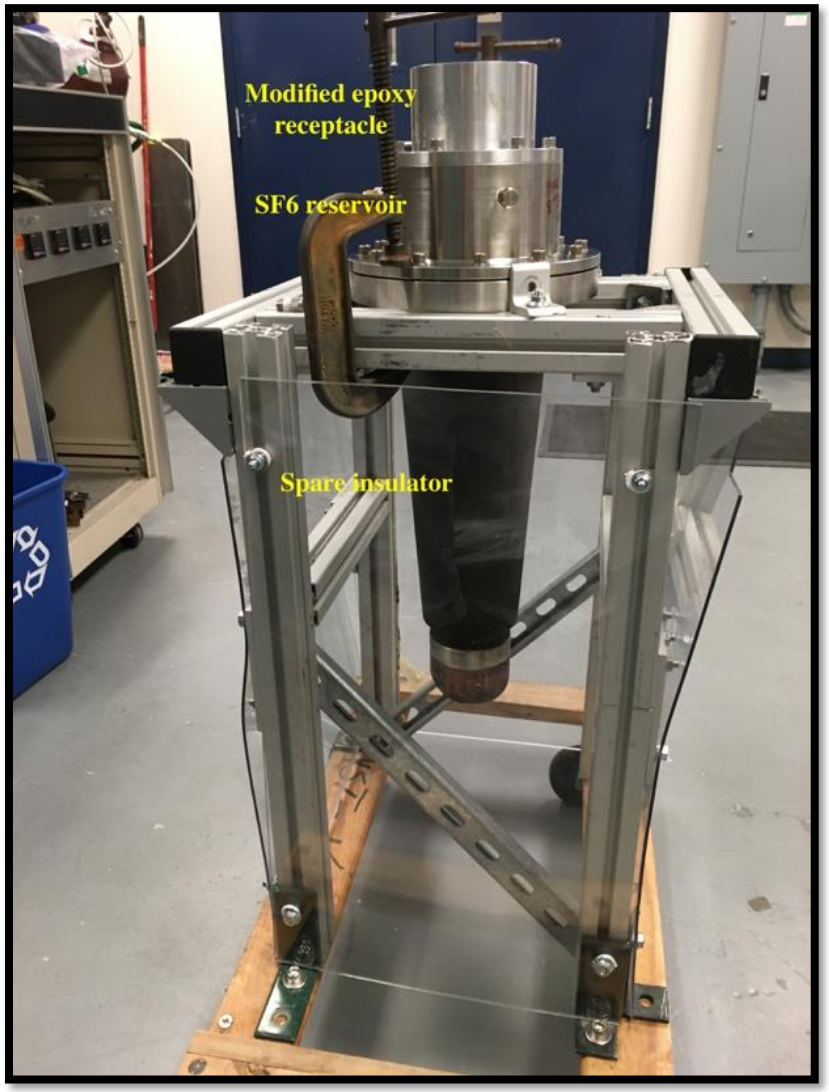


- A couple of arcing marks were found on the SF_6 side of the insulator. These were easily cleaned off and the insulator restored to operation.
- From these findings, it was clear the SF_6 intervening layer had to be higher than 10 PSIG.

Progress: equipment and components

- Due to the necessity to increase SF_6 pressure:
  - The system was hydrostatically pressure tested to 98 PSIG in the intervening 2 liter volume between the insulator and the tapered epoxy receptacle occupied nominally by SF_6 during high voltage testing

The test assemblage with the added weight, the manual water pump connected to the setup ready for the hydrostatic pressure test, and pressure gauge showing 98 PSIG of water pressure



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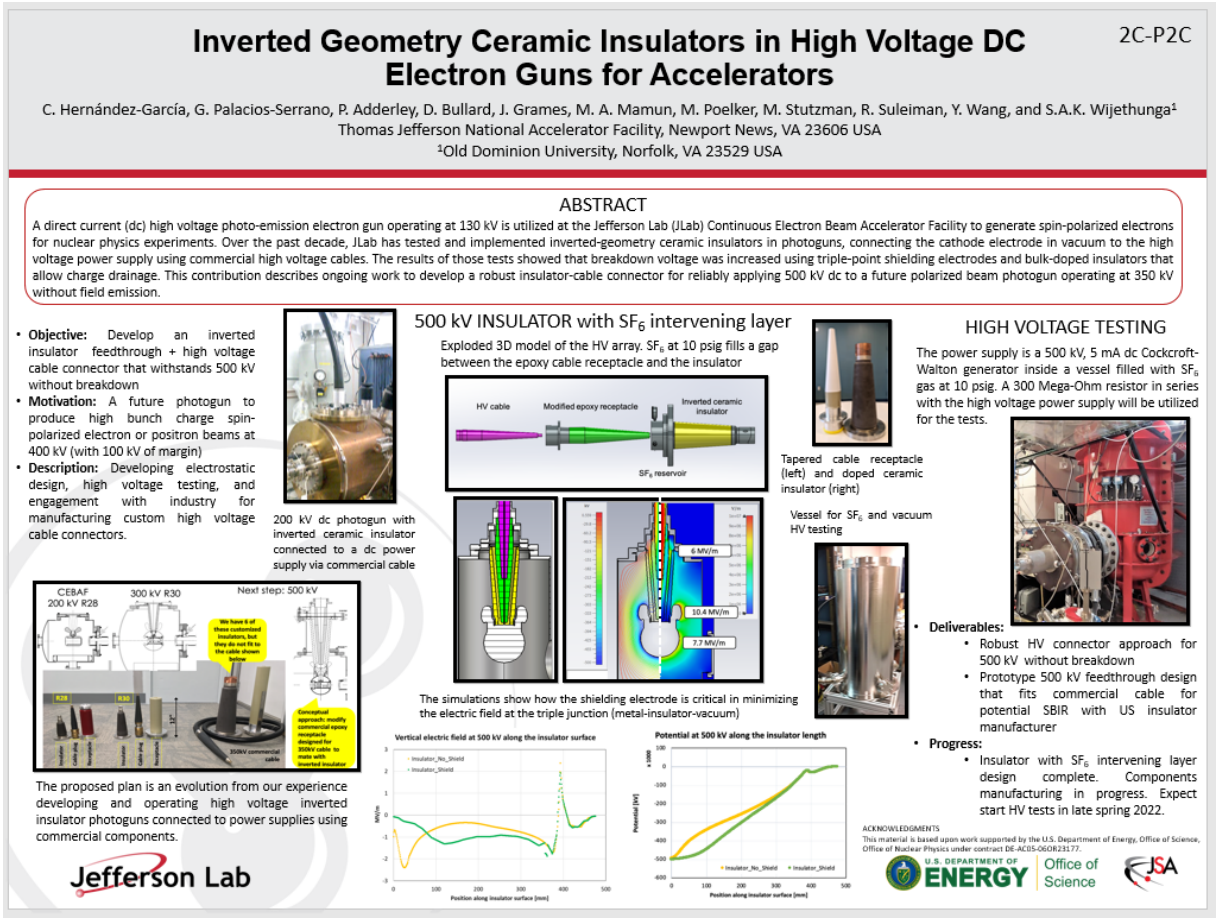
Progress: Conferences and papers

- Gabriel presented a poster about the project remotely via zoom at the 2021 IEEE Conference on Electrical Insulation and Dielectric Phenomena (CEIDP), 12-15 December.
- Gabriel was invited and presented (online) his progress on this project at his *alma mater*, at the wavelet seminar of the Engineering and Basic Science Division of the Autonomous Metropolitan University – Azcapotzalco, Mexico, March 10, 2022.
- Carlos presented our work in the 2022 North American Particle Accelerator Conference in Albuquerque, New Mexico. 7-12 August 2022.



Inverted Geometry Ceramic Insulators in High Voltage DC Electron Guns for Accelerators

2C-P2C

C. Hernández-García, G. Palacios-Serrano, P. Adderley, D. Bullard, J. Grames, M. A. Mamun, M. Poelker, M. Stutzman, R. Suleiman, Y. Wang, and S.A.K. Wijethunga[1]
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ABSTRACT

A direct current (dc) high voltage photo-emission electron gun operating at 130 kV is utilized at the Jefferson Lab (JLab) Continuous Electron Beam Accelerator Facility to generate spin-polarized electrons for nuclear physics experiments. Over the past decade, JLab has tested and implemented inverted-geometry ceramic insulators in photoguns, connecting the cathode electrode in vacuum to the high voltage power supply using commercial high voltage cables. The results of those tests showed that breakdown voltage was increased using triple-point shielding electrodes and bulk-doped insulators that allow charge drainage. This contribution describes ongoing work to develop a robust insulator-cable connector for reliably applying 500 kV dc to a future polarized beam photogun operating at 350 kV without field emission.

- **Objective:** Develop an inverted insulator feedthrough + high voltage cable connector that withstands 500 kV without breakdown
- **Motivation:** A future photogun to produce high bunch charge spin-polarized electron or positron beams at 400 kV (with 100 kV of margin)
- **Description:** Developing electrostatic design, high voltage testing, and engagement with industry for manufacturing custom high voltage cable connectors.

200 kV dc photogun with inverted ceramic insulator connected to a dc power supply via commercial cable

500 kV INSULATOR with SF_6 intervening layer

Exploded 3D model of the HV array. SF_6 at 10 psig fills a gap between the epoxy cable receptacle and the insulator

HV cable, Modified epoxy receptacle, Inverted ceramic insulator, SF_6 reservoir

Tapered cable receptacle (left) and doped ceramic insulator (right)

Vessel for SF_6 and vacuum HV testing

HIGH VOLTAGE TESTING

The power supply is a 500 kV, 5 mA dc Cockcroft-Walton generator inside a vessel filled with SF_6 gas at 10 psig. A 300 Mega-Ohm resistor in series with the high voltage power supply will be utilized for the tests.

CEBAF 200 kV R28, 300 kV R30, Next step: 500 kV

The proposed plan is an evolution from our experience developing and operating high voltage inverted insulator photoguns connected to power supplies using commercial components.

The simulations show how the shielding electrode is critical in minimizing the electric field at the triple junction (metal-insulator-vacuum)

Vertical electric field at 500 kV along the insulator surface

Potential at 500 kV along the insulator length

- **Deliverables:**
  - Robust HV connector approach for 500 kV without breakdown
  - Prototype 500 kV feedthrough design that fits commercial cable for potential SBIR with US insulator manufacturer
- **Progress:**
  - Insulator with SF_6 intervening layer design complete. Components manufacturing in progress. Expect start HV tests in late spring 2022.

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

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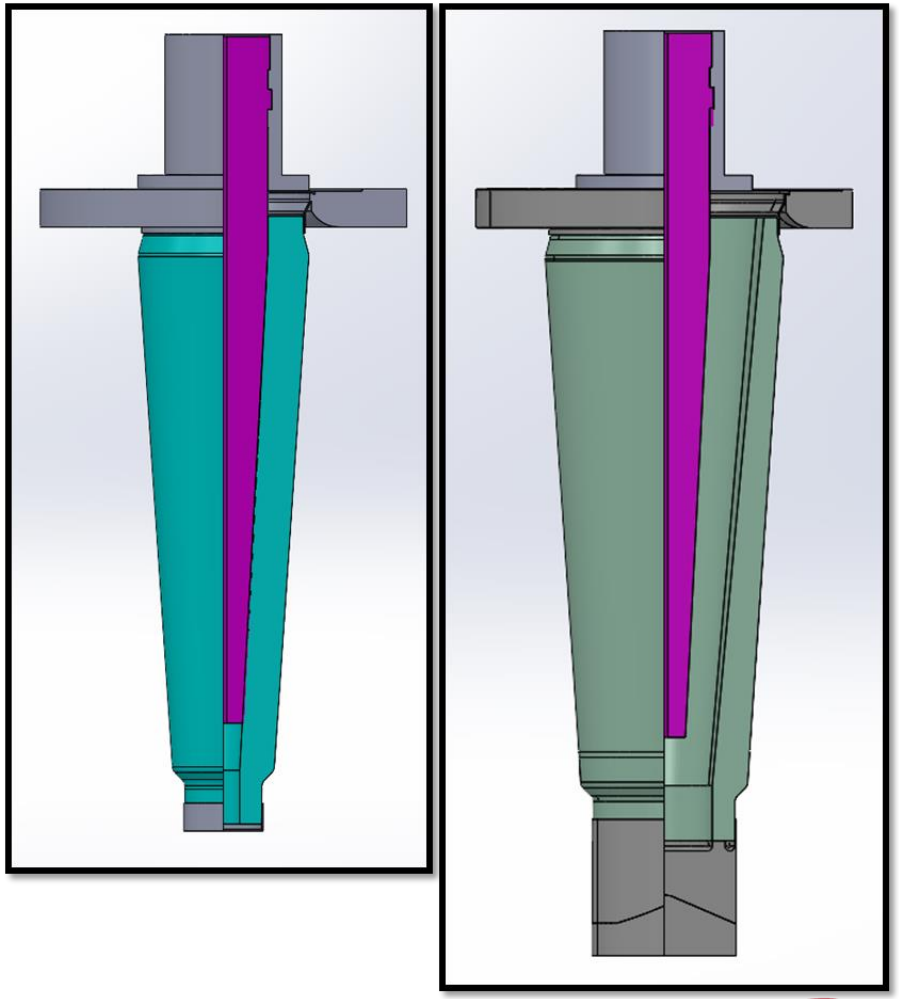
Next steps

- The system is ready for HV testing at higher (30 psig) SF_6 pressure
- Substituting the relief valve for a burst disk will allow even higher pressure tests (50 psig).
- Yet another option is being analyzed, were the SF_6 layer will be substituted by HV Insulator Coating Compound with arc-resistant filler that inhibits arc growth.
- We have started conversations with industries to design and evaluate a 500 kV insulator compatible with our available 350kV commercial cable

500 kV “skinny” insulator preliminary design (left) and existing 500 kV insulator. Both show the cross section on their respective right sides.



Project overview

FY2020: $269.4k awarded

Staffing: Postdoc+Sci+Tech: 1 FTE | ME: 0.2 FTE	1.20 FTE
✓ Hire postdoc & procure software	Q1
✓ Concept 1: Long insulator + SF_6 intervening layer design	Q2
✓ Fabrication & assembly	Q3
• High voltage testing in SF_6 chamber (in progress)	Q4

FY2021: $269.4k awarded

Staffing: Postdoc+Sci+Tech: 1.25 FTE | ME 0.20 FTE	1.45 FTE
• Concept 2: Custom HV plug design & procurement	Q1
• High voltage testing in SF_6 chamber	Q2
• "Ultimate" concept: custom insulator + commercial connector	Q3
• Custom insulator teflon prototype + commercial connector fab & HV testing in SF_6	Q4

Now in FY2023

Schedule:

	Task	Nov-21	Dec-21	Jan-22	Feb-22	Mar-22	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22
2	Fabricate SF6 reservoir tophat											
3	Triple point junction shield ME design											
4	Triple point juncton shield manufacturing drawings											
5	Electrode manufacturing and polishing											
6	Custom HV plug electrostatic and mechanical design											
7	**12 month No Cost Extension granted**											
8	Custom HV rubber plug procurement and fabrication											
9	Custom HV receptacle procurement and fabrication											
10	HV test chamber assembly w/o electrode for SF6 testing											
11	Electrode-insulator assembly into HV test chamber											
12	High voltage testing custom HV receptacle											
13	High voltage testing custom rubber plug											
14	Anlysis of HV test results to establish baseline for "ultimate" 500 kV ineverted ceramic insulator design											

Complete

In progress

To complete

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Budget

	FY20 ($k)	FY21 ($k)	Totals ($k)
a) Funds allocated	269.4	269.4	538.8
b) Actual costs to date	269.4	98.83	368.23

	FY 2020 (k$)	FY 2021 (k$)	FY 2022 (k$)	FY 2023 Carryover (k$)	Total (k$)
Funds allocated	269.4	269.4	0	0	538.80
Actual cost to FY20	269.4	98.83			368.23
Estimate to complete				170.57	170.57

Carlos Hernandez-Garcia

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Summary

- Objective: **Design & test 500 kV insulator/cable** connector approach to provide **HV conditioning margin** for **future** implementation in a **400 kV DC photogun**
- Progress:
  - Postdoctoral position filled.
  - HV testing apparatus with SF6 intervening layer fully assembled
  - High voltage applied up to 200 kV
  - High voltage testing to resume with higher SF6 pressure
  - Custom high voltage insulator electrostatic design in progress
- Concerns:
  - Difficulty in filling the postdoctoral position effectively delayed the start of the project by 6 months
  - Supply chain issues with sole custom HV components US vendor added 3 month delay
  - Modifying custom connector for higher pressure took several months due to JLab engineering resources limited availability
- Deliverables:
  - **Robust HV connector** approach for **500 kV** without breakdown
  - **Prototype 500 kV feedthrough** design that fits commercial cable for potential SBIR with US insulator manufacturer