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

Lab 20-2310 FOA

Accel R&D for Next-Generation NP Accelerator Facilities

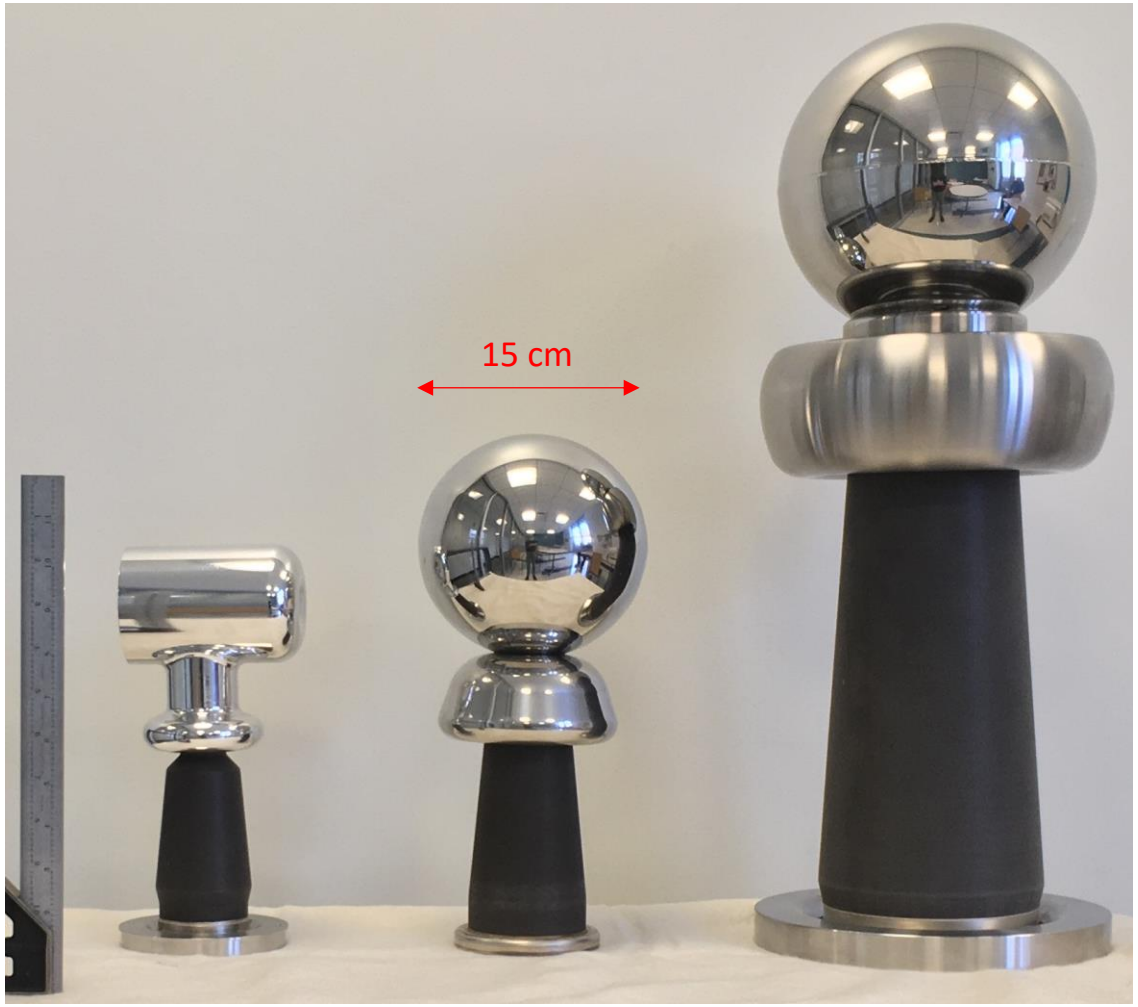
Virtual Office of Nuclear Physics (NP) Principal Investigator (PI) Exchange meeting for Accelerator R&D award recipients

December 02, 2024

PI: Carlos Hernandez-Garcia

Co-PI: Matthew Poelker

Note: Project concluded September 30th, 2023 after 1 year NCE.



Center for Injectors and Sources

Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

JSA

Project overview (slide presented at the PI Exchange meeting, Nov 30, 2021)

- 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.*

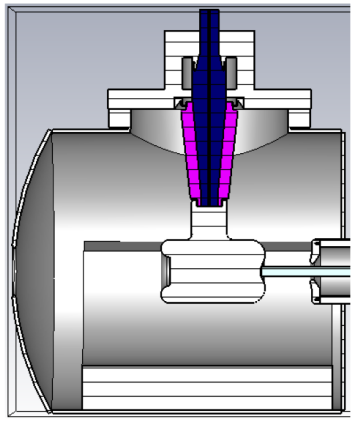
- Motivation: A future photogun based on the resultant 500 kV feedthrough design could then be used in a ***350 kV photogun with margin for high voltage conditioning*** to generate ***high bunch charge spin-polarized electron or positron beams***.

- Description: This work relies heavily on:
  - A postdoctoral appointee for developing the electrostatic design and for conducting high voltage test of various feedthrough approaches. ✔
  - Engagement with industry for manufacturing custom high voltage cable connectors. ✔

- Deliverables:
  - **Robust HV connector** approach for **500 kV** without breakdown. ✔
  - **Prototype 500 kV feedthrough** design that fits commercial cable for potential SBIR with US manufacturer. ✔

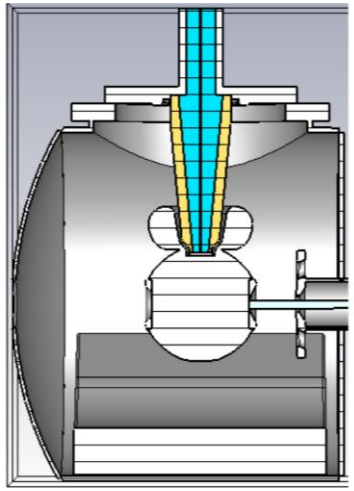
The work was proposed based on JLab's experience developing and operating high intensity, high polarization photoguns using inverted geometry insulators

R28 insulator



CEBAF 130 keV 0.2 mA CW >
80% polarized beam

R30 insulator



Gun Test Stand (GTS)
300 keV, 5 mA CW magnetized beam

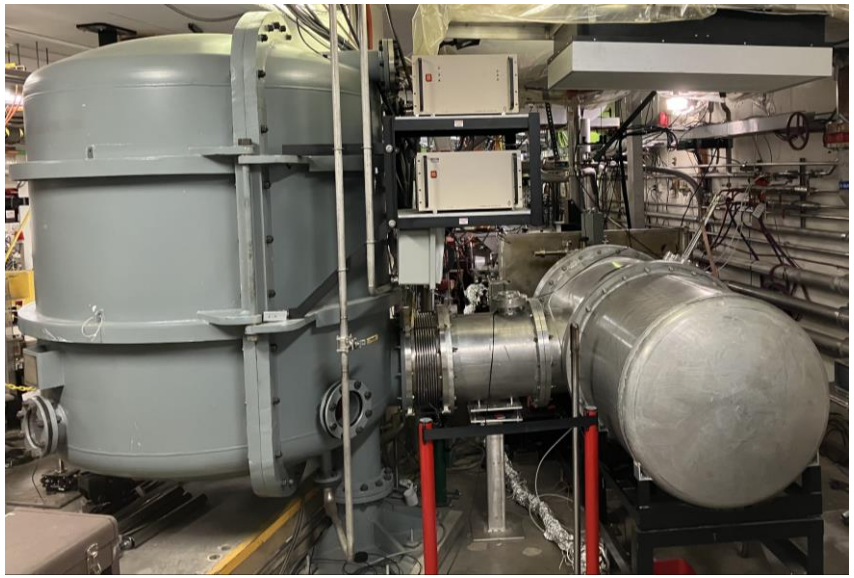
This work

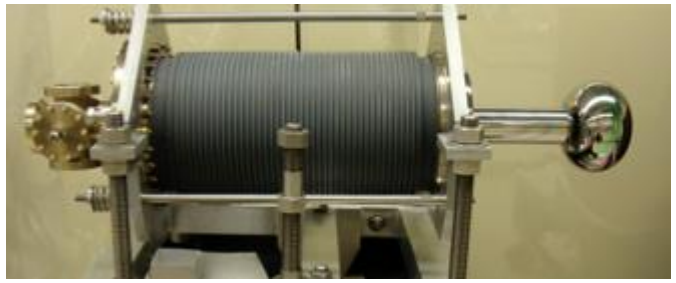
Maximum applied voltage without breakdown

CEBAF GTS SF_6 intervening volume test

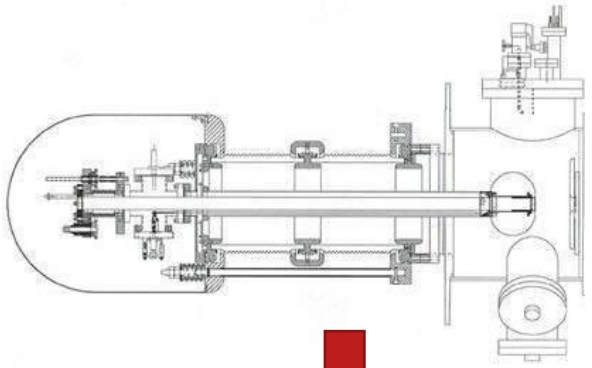
Motivation: compact insulators for polarized photoguns at LERF need ~ 100 kV margin for high voltage conditioning

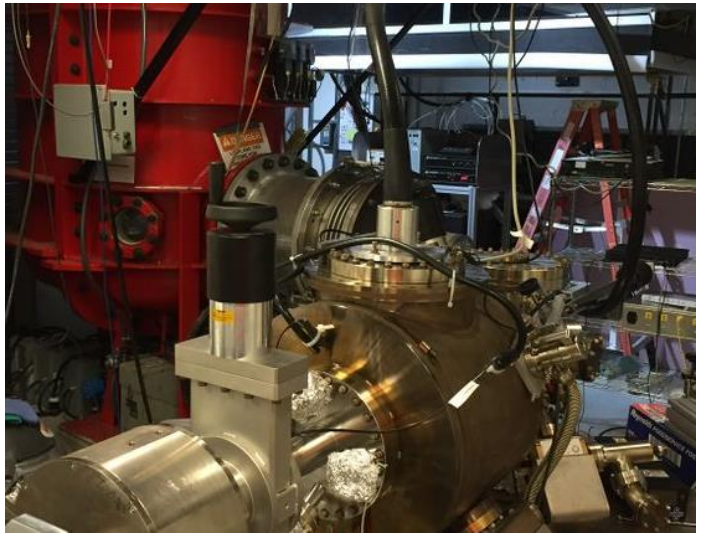
A prototype inverted insulator photogun *capable of injecting 350 keV polarized electrons* into the LERF SRF booster could replace the un-polarized beam vent-bake photogun



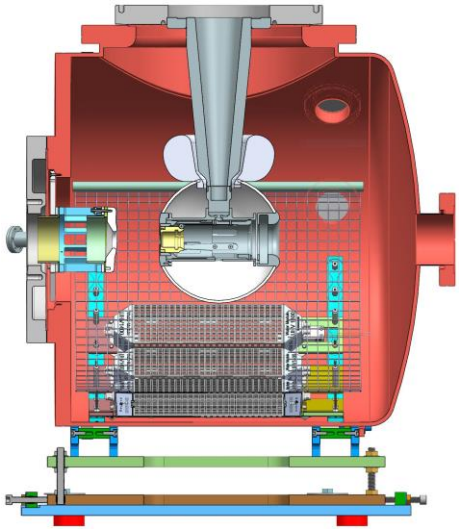


LERF 350 keV unpolarized vent-bake photogun

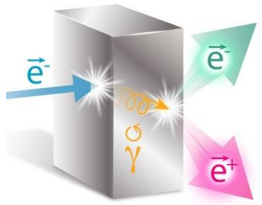




GTS 300 keV unpolarized load-lock photogun with inverted insulator



Low Energy Recirculation Facility (LERF)



JLab proposed e+ source: Ce+BAF

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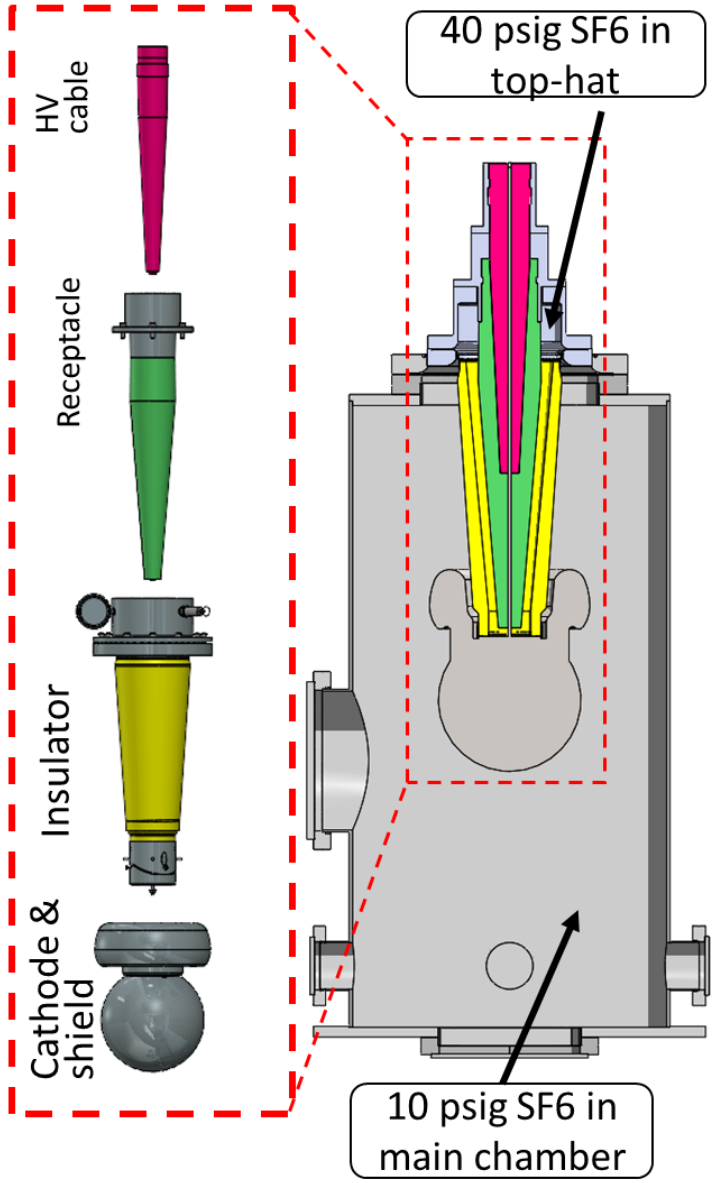
Project description

- Main goal: Demonstrate an **inverted insulator + high voltage cable assembly with SF6 intervening layer** that can be used to reliably apply 500 kV bias voltage to a test electrode

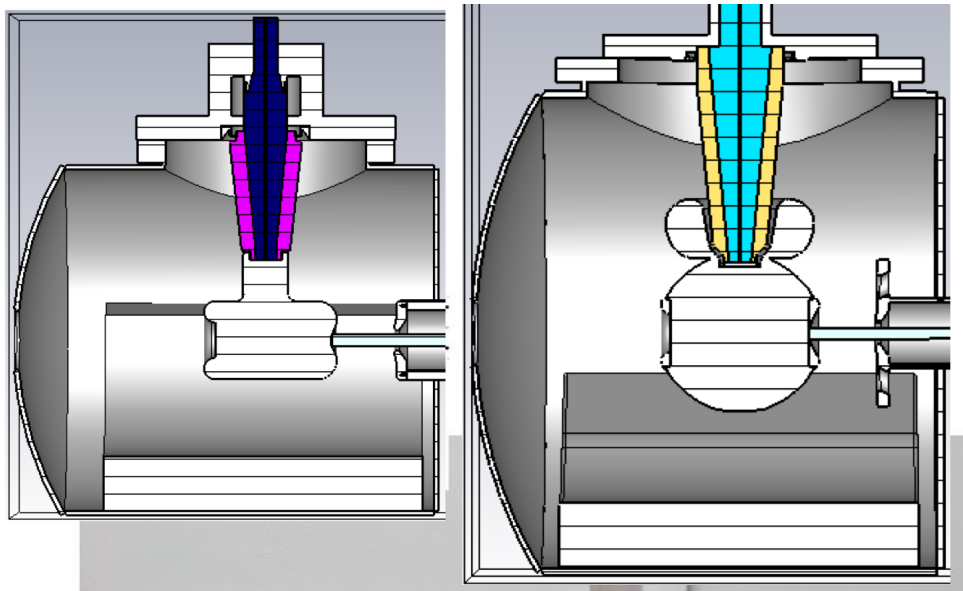
- No high voltage breakdown inside or outside the vacuum chamber

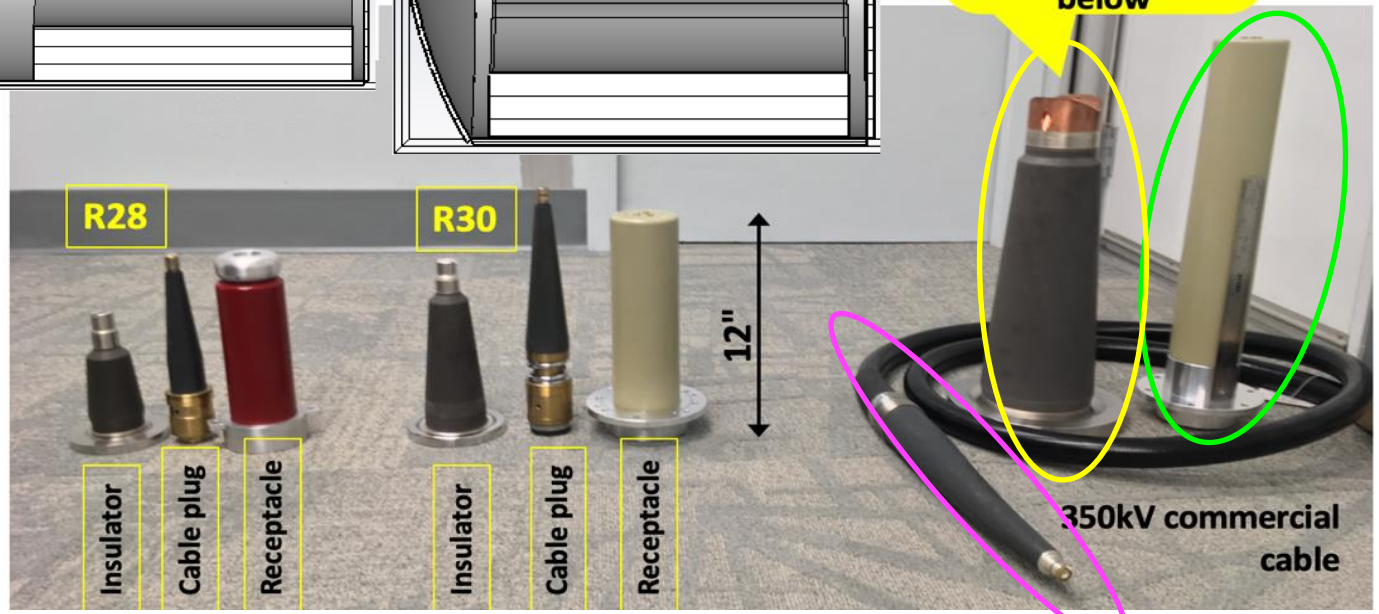
- Proof of principle **could be implemented in a future photogun** capable of delivering spin polarized beam from GaAs photocathodes at > 350 kV without measurable field emission.



Technical approach

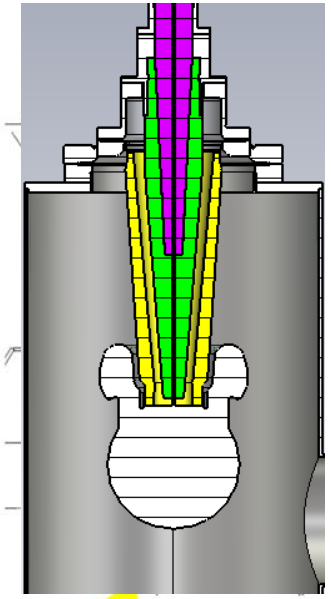
- The project was based on JLab's experience developing and operating high voltage inverted insulator photo-guns connected to power supplies using commercial components.

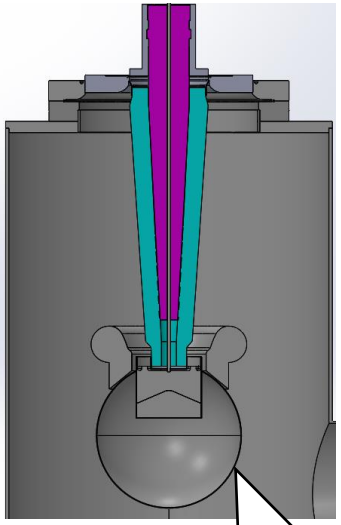




We have 6 of these customized insulators, but they do not fit to the cable shown below

Next step: 500 kV



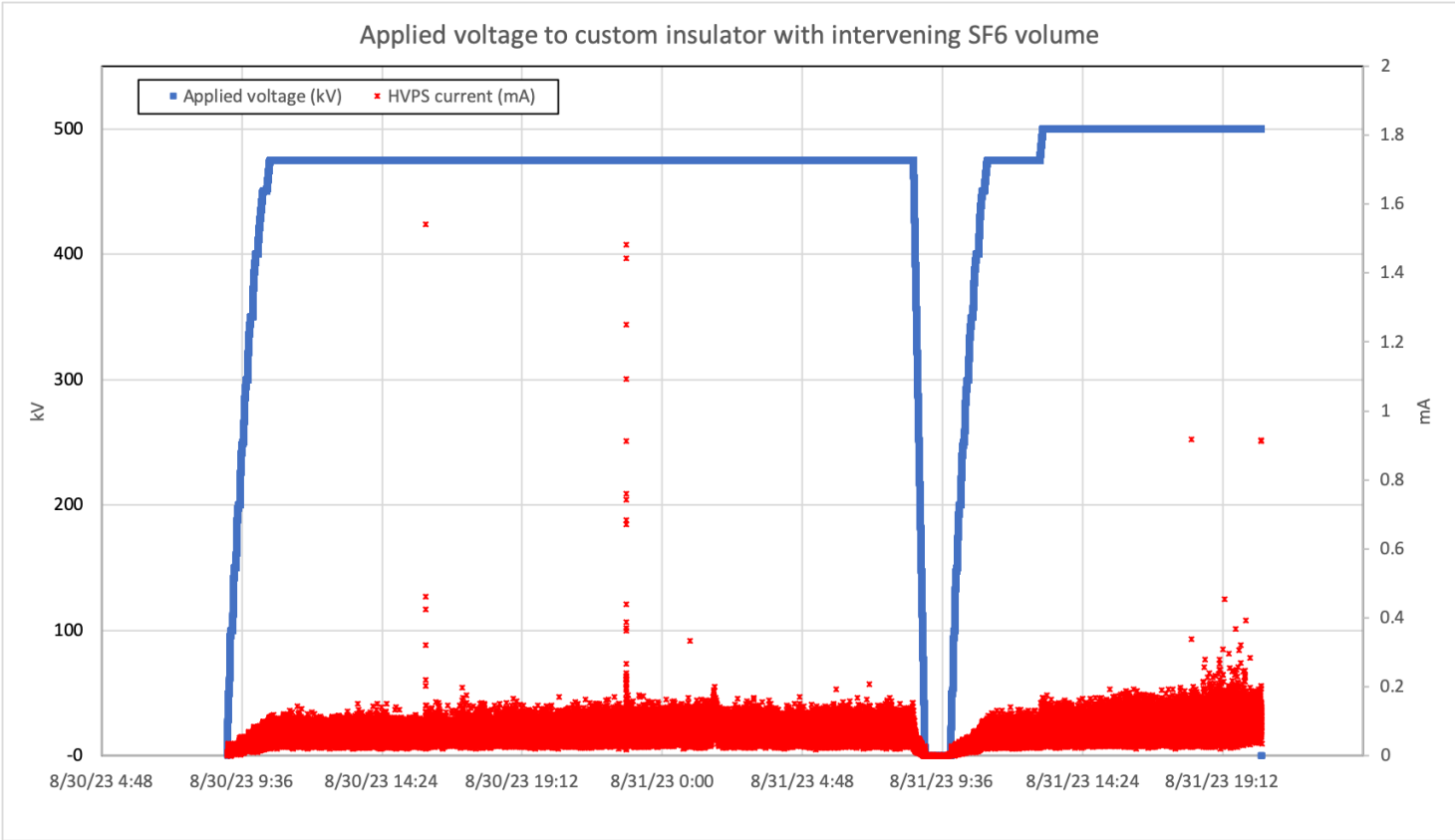


Conceptual approach: modify commercial epoxy receptacle designed for 350kV cable to mate with inverted insulator

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

Project status

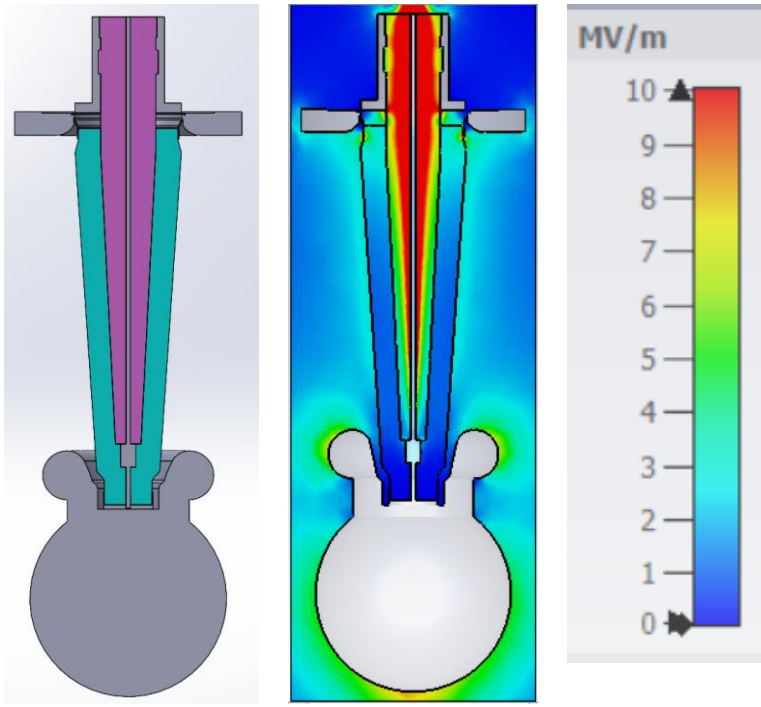
- FY20: Gabriel Palacios-Serrano was hired as a postdoc. Electrostatic and ME designs completed
- FY21: Apparatus manufactured and assembled
- FY22 NCE, project conclusion: Demonstrated proof of principle by applying 500 kV to a test electrode using a very large, custom inverted insulator *with SF_6 intervening volume* mating to a modified HV cable receptacle.

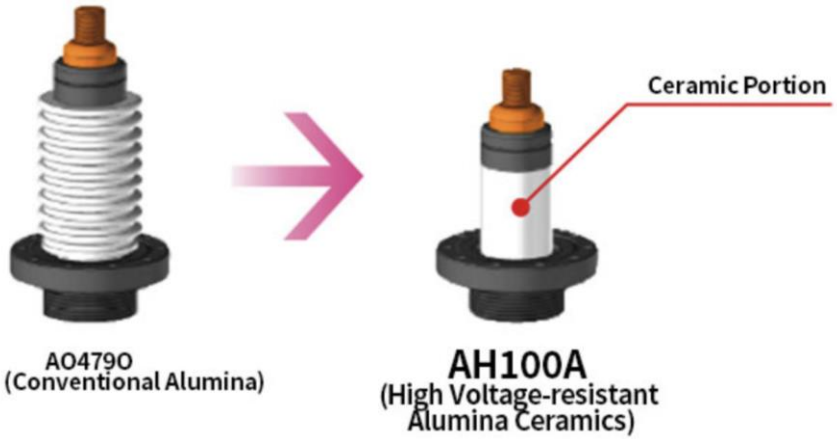


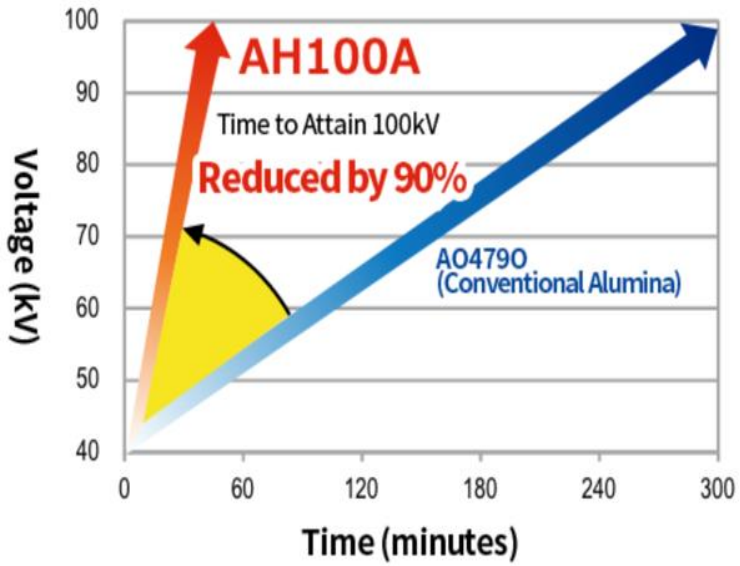
- FY23:
  - Added a floating anode to vacuum chamber, evacuated the chamber and verified voltage was applied to the cathode electrode (anode responded to cathode biasing image charge)
  - Under vacuum, the applied voltage was limited to 250 kV due to field emission from cathode electrode
  - Journal paper describing this work in progress
  - Completed design of prototype 500 kV insulator that mates directly with the largest commercial HV cable connector
  - Working with industry to manufacture prototype 500 kV insulator, *in a staged approach*

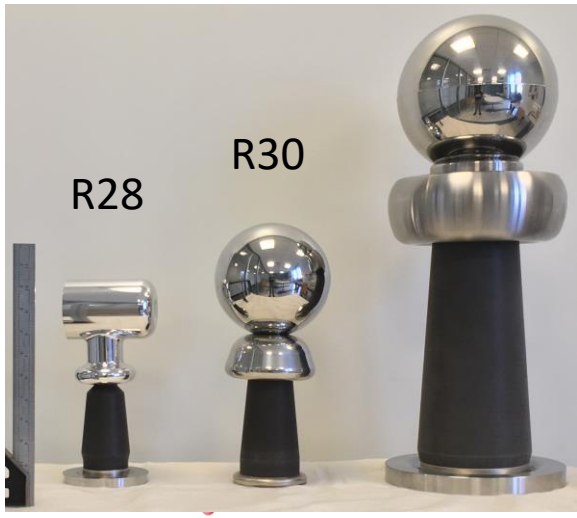
Developments beyond the FY20 NP funded project: 2023-2024

- We developed an electrostatic model of an insulator matching largest commercial cable connector (without SF_6 intervening layer).
- Manufacturing such a large insulator is very challenging.
- Kyocera has developed a novel alumina material with lower secondary electron yield. This new material could potentially be utilized to manufacture inverted insulators for DC photoguns, but the voltage breakdown limit is unknown.





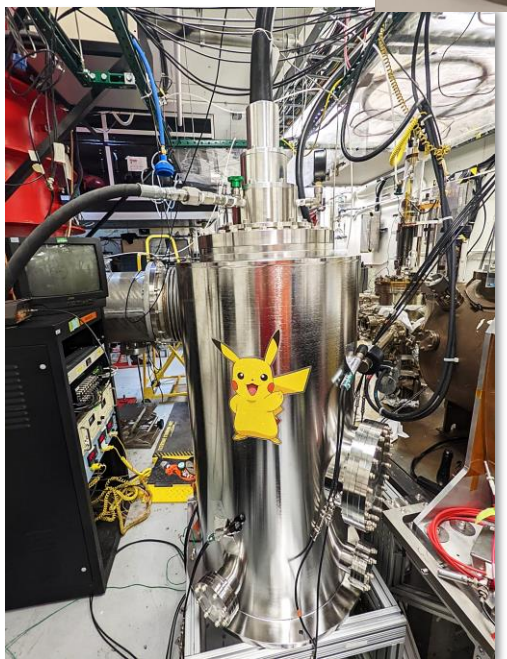




Plans for continuing HV compact inverted insulator R&D beyond the FY20 NP funded project

- Motivation: Establish supply chain for insulators capable of reliable operation at ~ 400 kV for use in HV DC photoguns
- Supported through HEP U.S. - Japan FOA, SLAC funded fabrication of a test R28 insulator made with novel low secondary electron yield material.
- A sample insulator has arrived at JLab.
- JLab is in a unique position to test these novel low SEY insulators in the Gun Test Stand.

- Technical approach:
  - Characterize the HV performance of the Kyocera low SEY R28 insulator by testing at JLab.
  - Work with industry to:
    - manufacture R30 insulator prototypes and test. Target voltage > 400 kV, and
    - re-establish insulator supply chain



Concluding remarks

- This proposal succeeded in demonstrating that commercial cable components can be utilized to bias photogun electrodes to 500 kV via custom insulator with intervening SF_6 layer.
- However this method is not practical. Our proposal included designing an insulator that mates directly to existing HV cables. Manufacturing such an insulator is very challenging. That said…
- For the past decade, finding vendors to provide the R30 insulators we use today at both CEBAF and at BNL/EIC has been very difficult.
- Continuing the legacy of this funded proposal, JLab is in a unique position to work with industry for developing and testing insulator prototypes:
  - Address the supply chain issues for present and future high polarization/high intensity beam photoguns, and
  - Develop a prototype to replace the un-polarized beam photogun in LERF with a polarized beam photogun

Schedule. *Project's period of performance ended September 30, 2023.*

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				
7. Test high voltage assembly in SF6				
8. Test high voltage assembly in vacuum				

Budget Project: HVINS

FOA LAB 20-2310 Accel R&D for Next-Generation NP Accelerator Facilities

FY25: Fiscal Period 01

Costed numbers are contract-to-date as of October 2024 (FY25 Fiscal Period 01)

Note: Project's period of performance ended September 30, 2023. Last costs were in FY23.

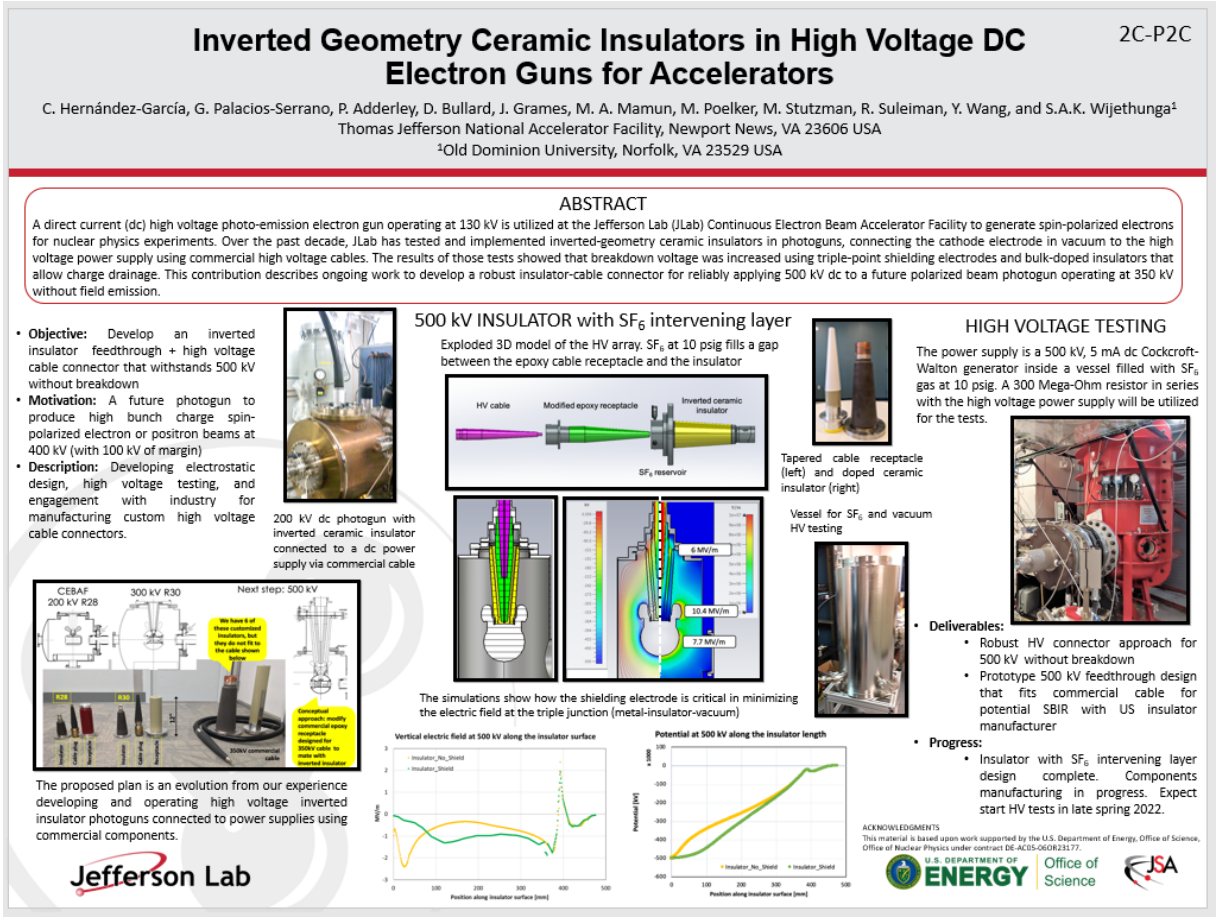
PI	ID #	Item/Task
Carlos Hernandez-Garcia	000001.04.05.030.001 (HVINS)	500kV Inverted Insulator

Summary of expenditures by fiscal year (FY):

	FY21 ($k)	FY22 ($k)	Totals ($k)
a) Funds allocated	$269	$269	$539
b) Actual costs to date	$269	$261	$531

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.



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