

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

NP FOA FY20

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

December 07, 2023

PI: Carlos Hernandez-Garcia

Co-PI: Matthew Poelker

Postdoctoral fellow: Gabriel Palacios-Serrano

Center for Injectors and Sources

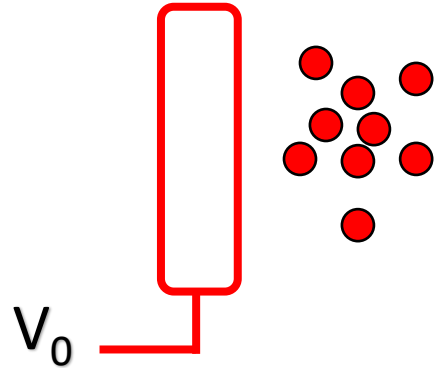


Why higher voltage?

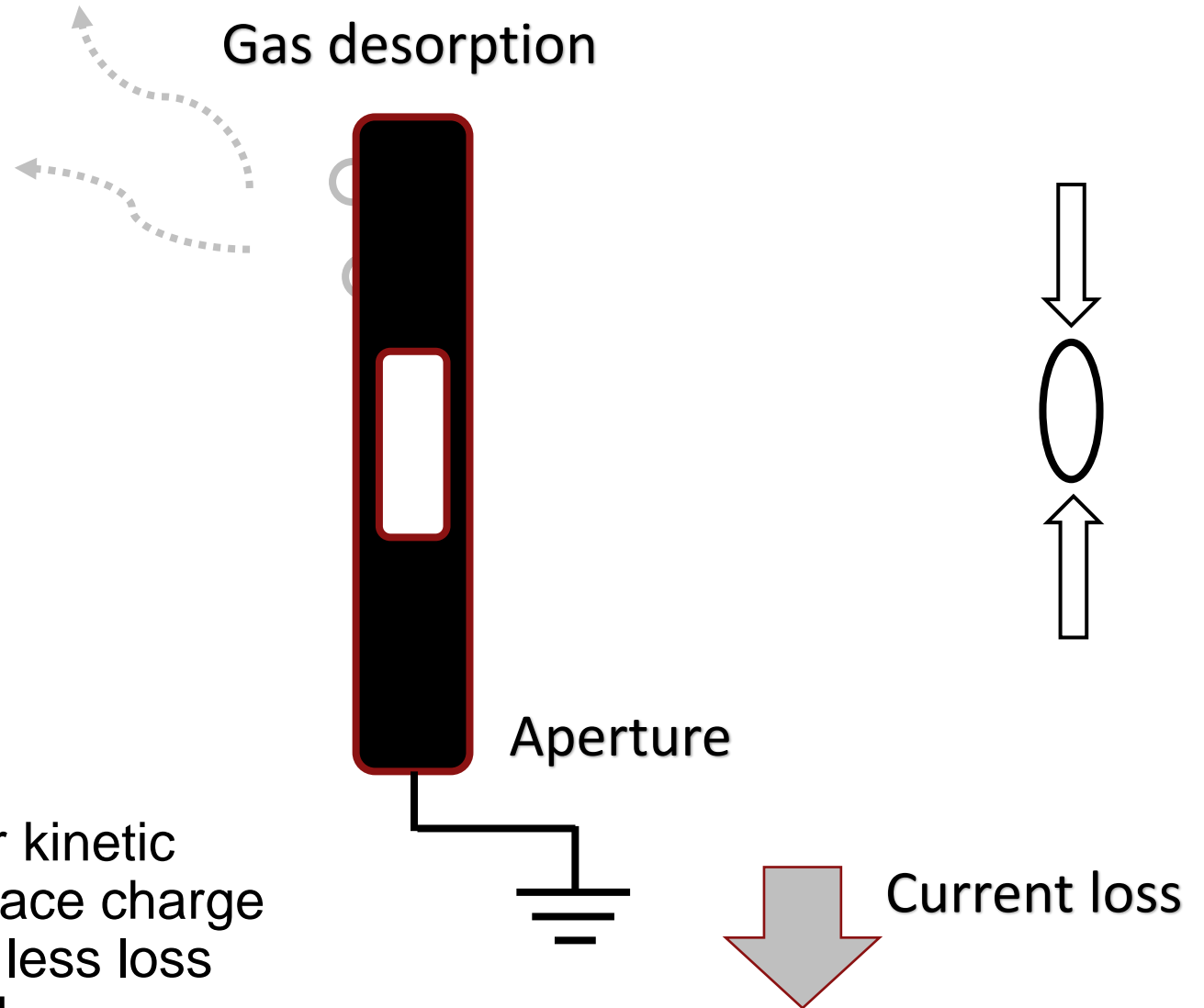
Space charge

$$E_r(r) = \frac{e\lambda_0 r}{2\pi\epsilon_0 a^2 \gamma^2}$$

Photocathode



- **Higher voltage** -> higher kinetic energy -> decreased space charge -> less beam dilution -> less loss on apertures -> reduced systematics



Project description

- Main goal:

Demonstrate an **inverted insulator + high voltage cable assembly** 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
- the developed system **could be implemented in a future photogun** capable of delivering spin polarized beam from GaAs photocathodes at 400 kV without measurable field emission.

- Status:

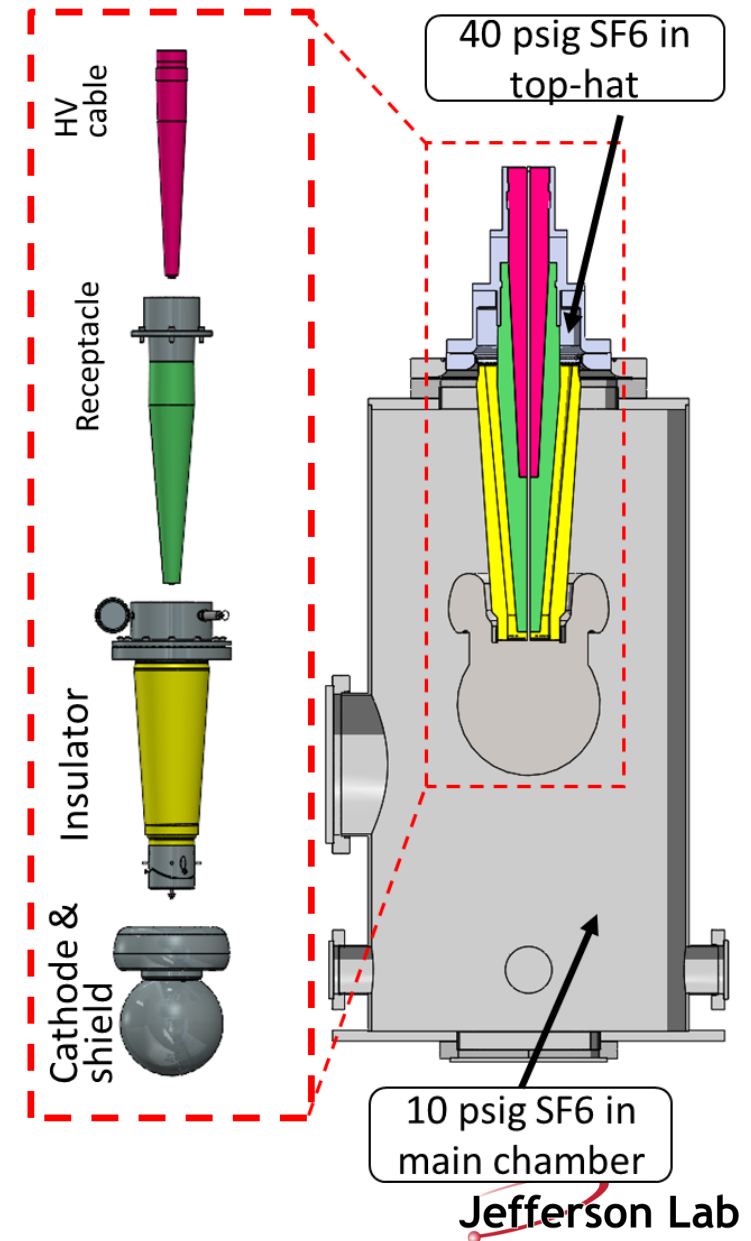
- ✓ High voltage apparatus assembled, installed, and tested at **500 kV**.

- ✓ Milestones

- Operation voltage >450 kV for ~113 hrs (4 days and 17 hrs),
- Max voltage 500 kV for 7 hrs.

- Limiting factor

- Contaminated SF₆

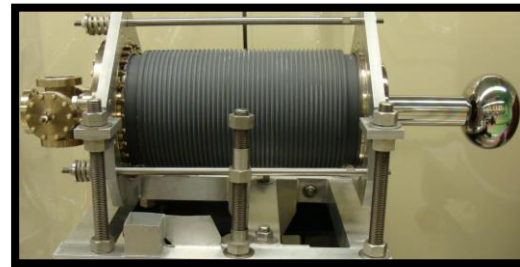
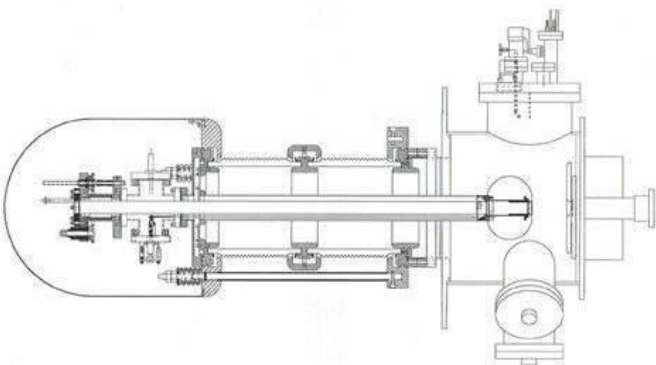


Inverted insulator polarized photogun

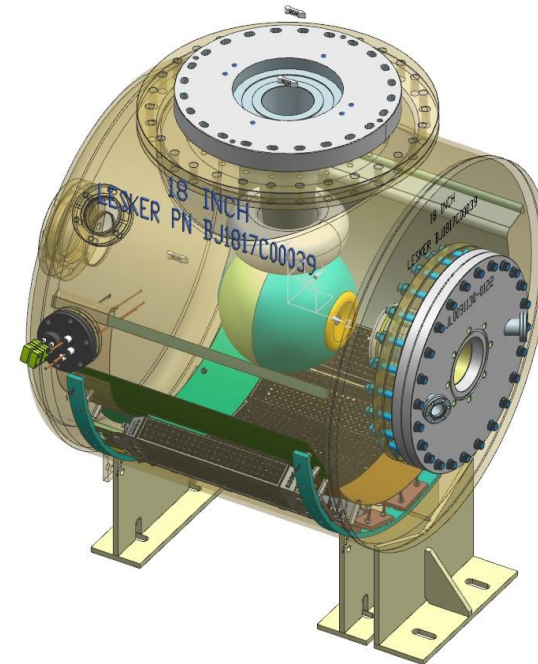
- “Inverted-insulator” high voltage design: the insulator extends into the vacuum chamber from the top serving as the cathode electrode support structure.
- Exceptional vacuum $\sim 10^{-12}$ Torr vacuum
- Less metal aids in minimizing field emission

- Load-lock attaches to the back end.
- Compact design.
- Uses commercial high voltage cable.

JLab FEL cylindrical insulator photogun



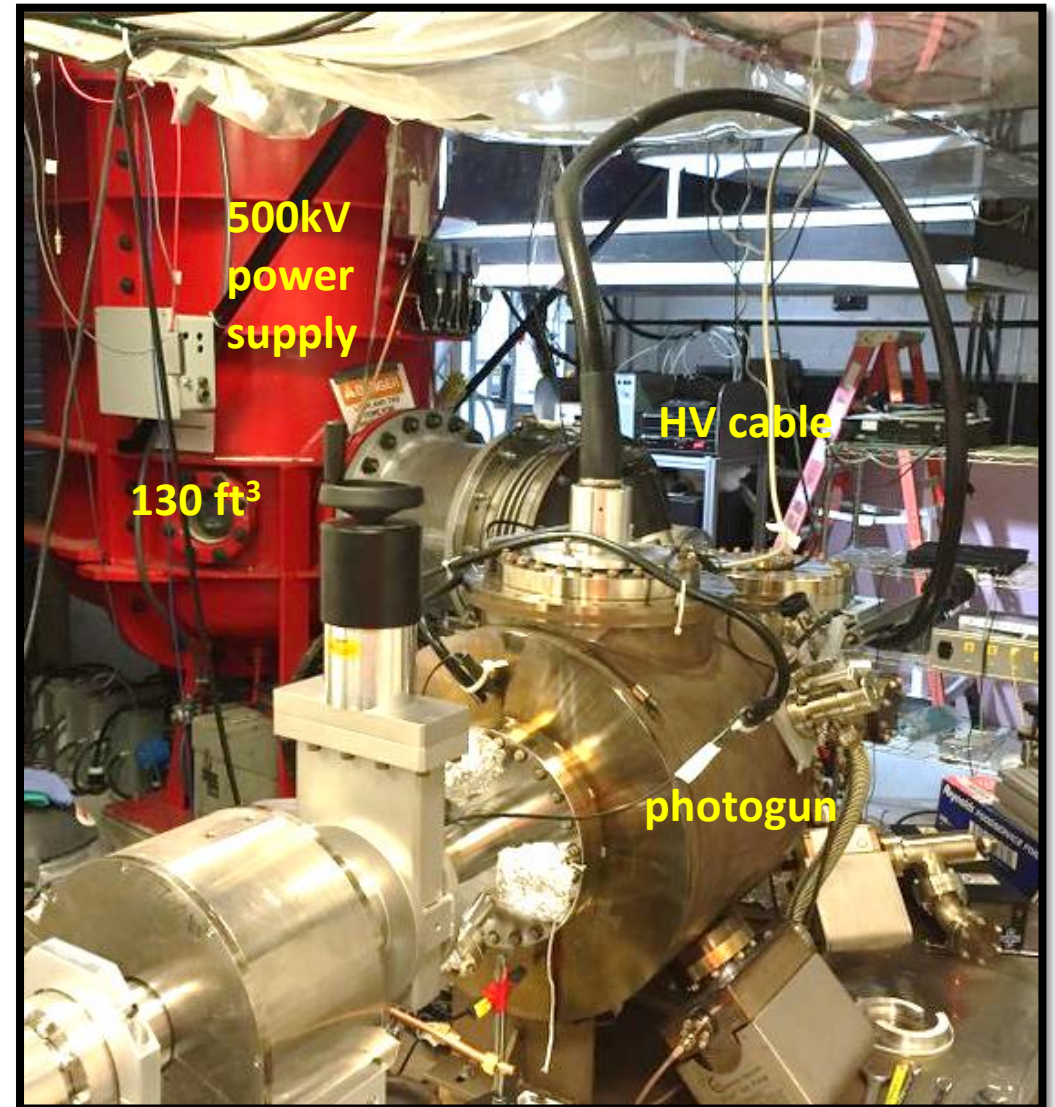
8 in



6 in

Inverted insulator polarized photogun

- The 130 kV spin-polarized inverted-insulator photogun at CEBAF is very compact, provides exceptional vacuum and exhibits NO field emission.
- A larger version of this photogun design operates at 300 kV bias voltage
- 2/3 of SF₆ gets eliminated by **using cable**



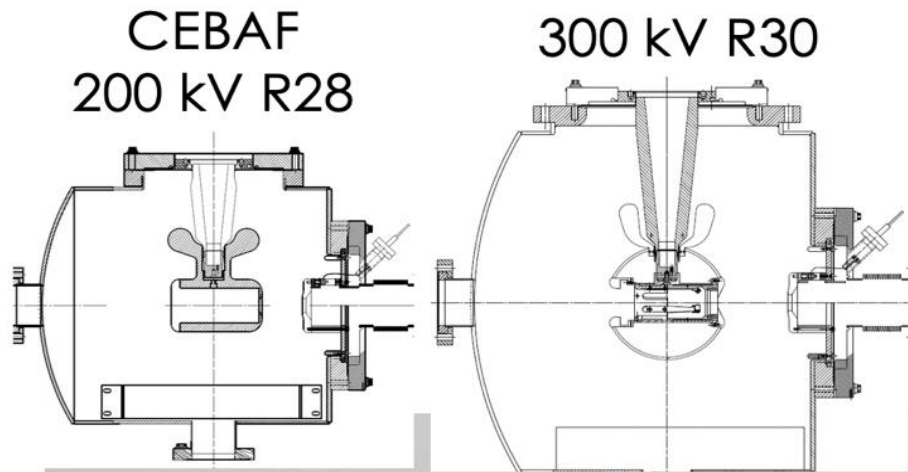
Challenge

- 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 SF₆, 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

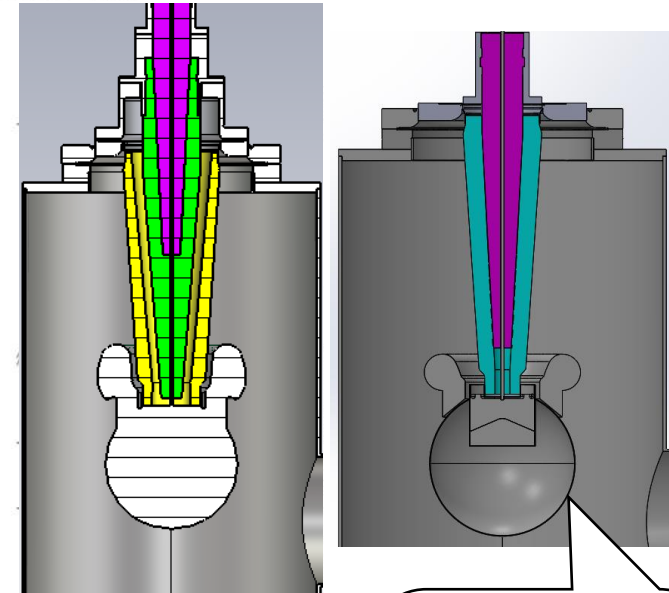
Technical approach

- 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

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



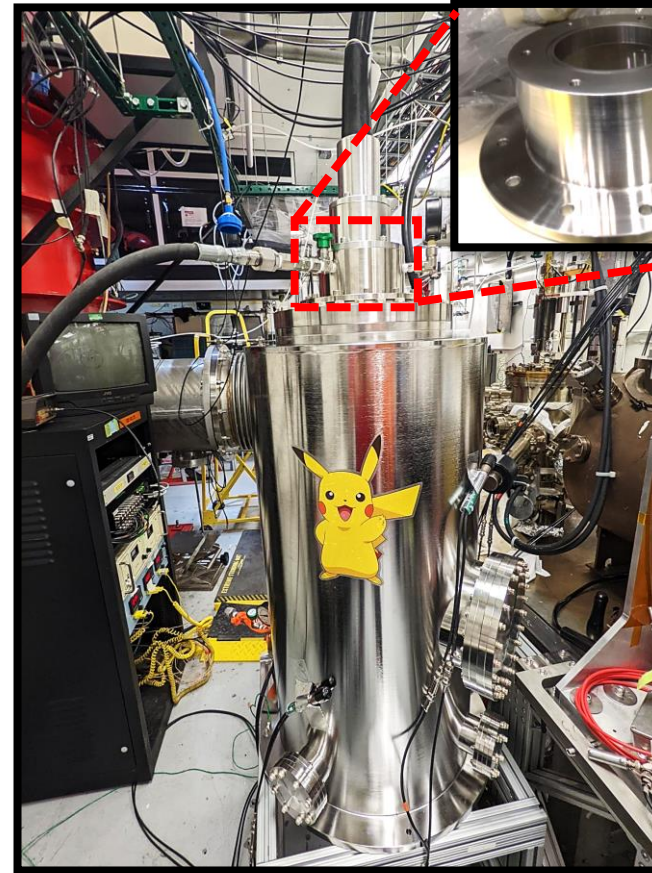
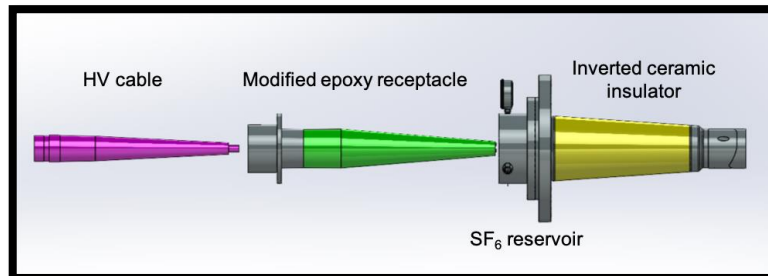
Conceptual approach: modify commercial epoxy receptacle designed for 350kV cable to mate with inverted insulator

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



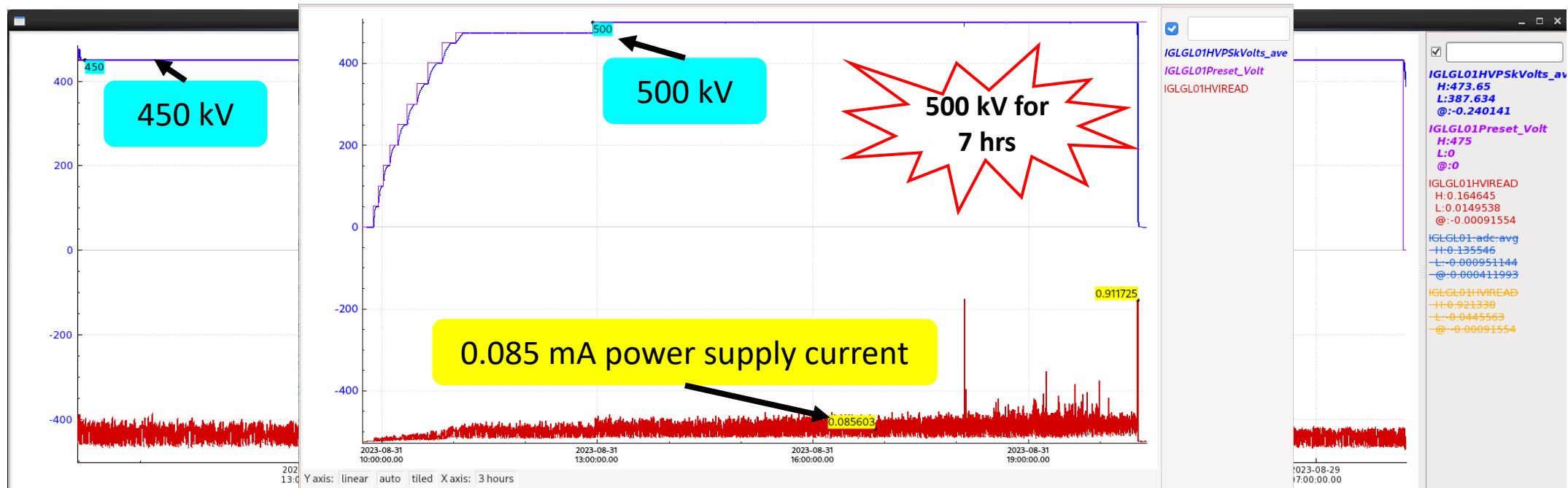
Progress: program

- 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 SF₆ layer
 - Electrostatic design of electrode + triple point junction shield (to prevent arcing)
 - Wide HV cable, cylindrical HV cable, no-receptacle
- Manufactured: SF₆ reservoir and electrostatic shield, modified epoxy receptacle.
- System assembled, and ... drum roll!



Progress: High voltage test successful!

- The test chamber was filled with SF₆ gas to nominal 10 PSIG, the separate feedthrough reservoir containing the volume of the SF₆ intervening layer between the receptacle and the insulator was filled to 40 PSIG.
- 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 current peaks were observed at 500 kV until an over-current trip. The current readings are in mA.



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.

2C-P2C

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

C. Hernández-García, G. Palacios-Serrano, P. Adderley, D. Bullard, J. GAMES, M. A. Mamun, M. Poelker, M. Stutzman, R. Suleiman, Y. Wang, and S.A.K. Wijethunga¹
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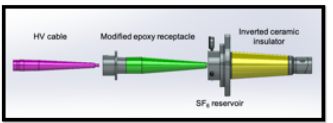
ABSTRACT

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.

500 kV INSULATOR with SF₆ intervening layer

Exploded 3D model of the HV array. SF₆ at 10 psig fills a gap between the epoxy cable receptacle and the insulator




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

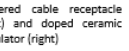


HIGH VOLTAGE TESTING


The power supply is a 500 kV, 5 mA dc Cockcroft-Walton generator inside a vessel filled with SF₆ gas at 10 psig. A 300 Mega-Ohm resistor in series with the high voltage power supply will be utilized for the tests.

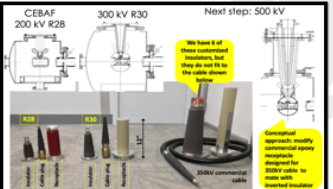


Tapered cable receptacle (left) and doped ceramic insulator (right)




Vessel for SF₆ and vacuum HV testing

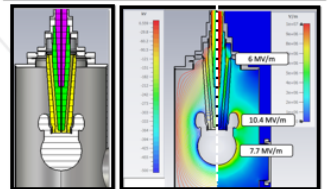




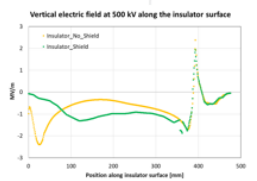
The proposed plan is an evolution from our experience developing and operating high voltage inverted insulator photoguns connected to power supplies using commercial components.



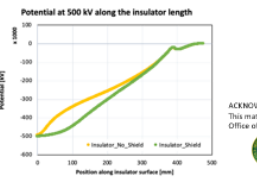
The simulations show how the shielding electrode is critical in minimizing the electric field at the triple junction (metal-insulator-vacuum)



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

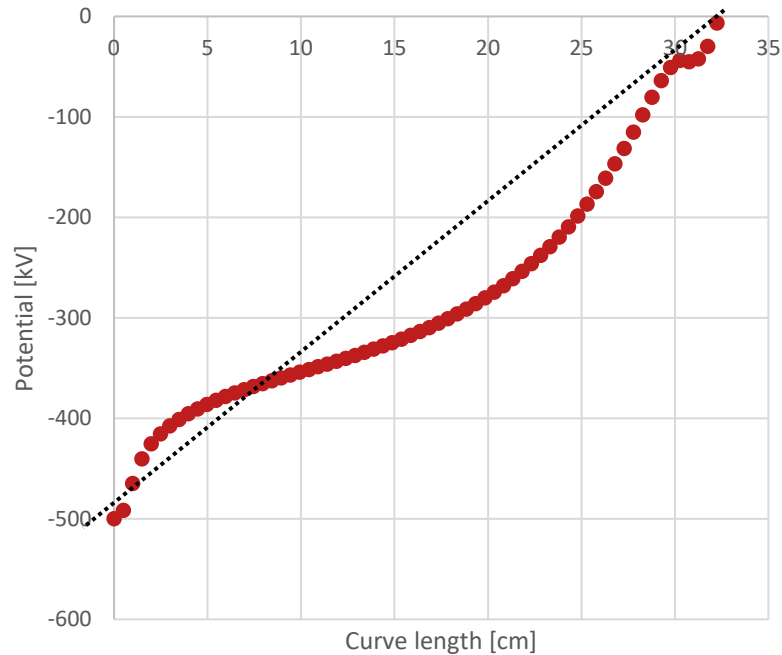
Progress:

- Insulator with SF₆ intervening layer design complete. Components manufacturing in progress. Expect start HV tests in late spring 2022.

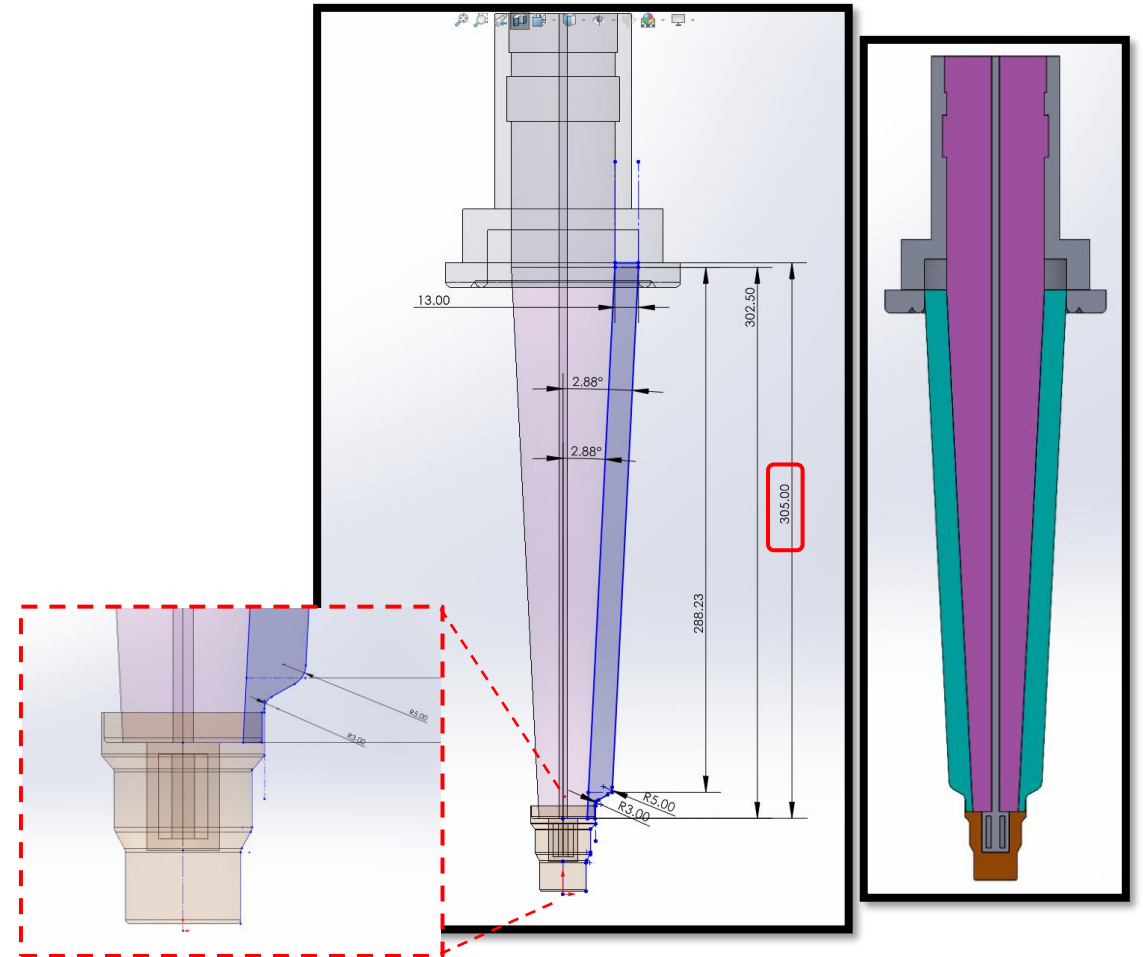
ACKNOWLEDGMENTS
 This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under contract DE-AC05-06OR22477.
 U.S. DEPARTMENT OF ENERGY | Office of Science | JSA

Next steps

- We have started conversations with industries to design and evaluate a 500 kV insulator compatible with our available 350kV commercial cable
- Testing under vacuum conditions



500 kV insulator prototype



Budget

Summary of total expenditures:

ID #	Item/Task	Baseline Total Cost (AY\$)	Costed & Committed (AY\$)	Estimate To Complete (AY\$)	Estimated Total Cost (AY\$)
000001.04.05.030.001 HVINS	500kV Inverted Insulator	\$538,800	\$530,718	\$8,082	\$538,800
Totals:		\$538,800	\$530,718	\$8,082	\$538,800

Summary of expenditures by fiscal year (FY):

FOA Funding	FY 2020	FY 2021	Total
a) Funds allocated	\$269,400	\$269,400	\$538,800
b) Actual costs to date	\$269,400	\$261,318	\$530,718
c) Uncosted commitments	\$0	\$0	\$0
d) Uncommitted funds (d=a-b-c)	\$0	\$8,082	\$8,082

Schedule:

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				

Conclusion



- An **inverted insulator + high voltage cable assembly** was tested to a maximum of 500 kV.
- The highest HV ever achieved on alumina insulators connected to commercial cables!

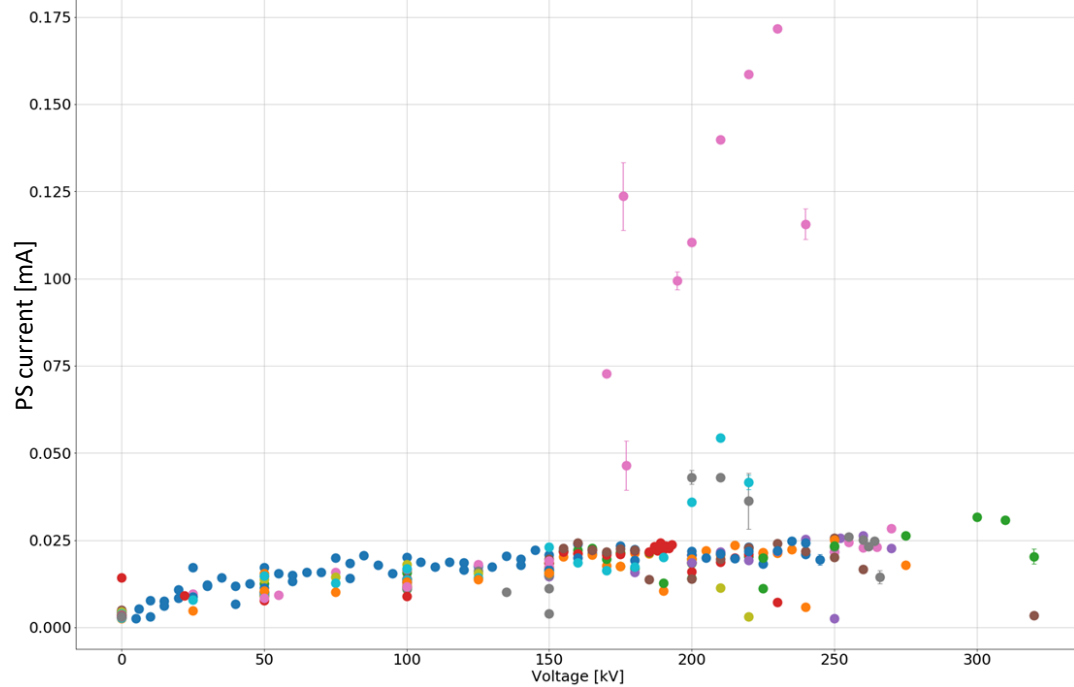
Fin

Carlos Hernandez-Garcia, Matt Poelker, Gabriel Palacios Serrano

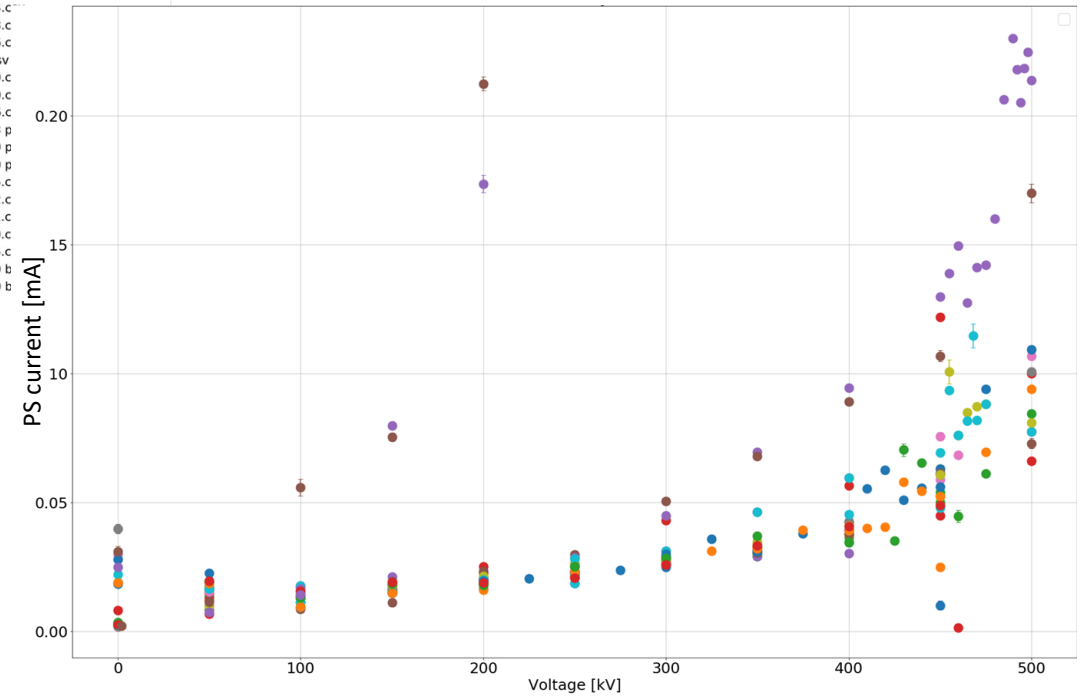
chgarci@jlab.org, poleker@jlab.org, gabrielp@jlab.org

Extra

file name: C:\Users\gabrielp\Documents\500 kV project\Python\500 kV project\500 kV project before the antenna\Before burnt cable



- Lognumber 4168782 Overcurrent trip at 440 kV.csv
- Lognumber 4169337 overcurrent trip after 40 min.csv
- Lognumber 4169378 trip at 452 kV.csv
- Lognumber 4169642 soaked at 450 kV for 16 hrs.csv
- Lognumber 4169769 500 kV goal Soaking.csv
- Lognumber 4169792 Reached again 500 kV and triped again.csv
- Lognumber 4170397 Soaked at 450 kV for 24 hrs.csv
- Lognumber 4170595 soaked at 460 kV for 17 hrs.csv
- Lognumber 4170822 Soaking at 475 kV over the weekend.csv
- Lognumber 4171537 Soaked at 475 kV for 65 hrs. No trip.csv
- Lognumber 4172133 Soaked at 450 kV for 24 hrs. No current peaks.csv
- Lognumber 4172411 Soaking at 475 kV again.csv
- Lognumber 4173431 Soaked at 500 kV for 7 hrs. Overcurrent trip.csv
- Lognumber 4174870 Top hat 40 psi Current limit 0.75 mA Trip after 4 hrs.csv
- Lognumber 4175158 Top hat 40 psi Current limit 0.5 mA Trip at 400 kV.csv
- Lognumber 4175267 Top hat 40 psi Current limit 0.25 mA Trip at 480 kV.csv
- Lognumber 4175364 Top hat 30 psi Current limit 1.0 mA No peaks or trip.csv
- Lognumber 4175819 Top hat 30 psi Current limit 0.75 mA.csv
- Lognumber 4176282 Top hat 30 psi Current limit 0.5 mA Overcurrent trip.csv
- Lognumber 4177690 Top hat 30 psi Current limit 0.25 mA Overcurrent trip at 450 kV.csv
- Lognumber 4177761 Top hat 20 psi. Current limit 1.0 mA.csv
- Lognumber 4177863 Top hat 20 psi Current limit 0.75 mA Overcurrent trip at 500 kV.csv
- Lognumber 4178277 Top hat 20 psi Current limit 0.5 mA Overcurrent trip at 400 kV.csv
- Lognumber 4178309 Top hat 20 psi Current limit 0.25 mA Overcurrent trip at 500 kV.csv
- Lognumber 4178392 Top hat 10 psi Current limit 1.0 mA Resistive-like response.csv
- Lognumber 4178426 Another test with Top hat now at 20 psi Current limit 1.0 mA Resistive-like response remains.csv



Extra

Found the issue: Not-pure SF6

