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

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Center for Injectors and Sources

Jefferson Lab

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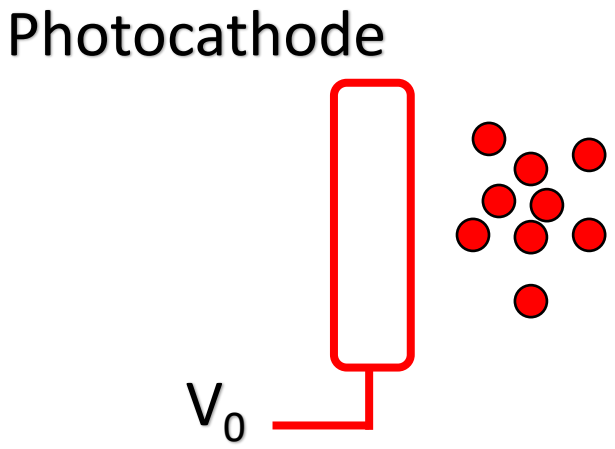
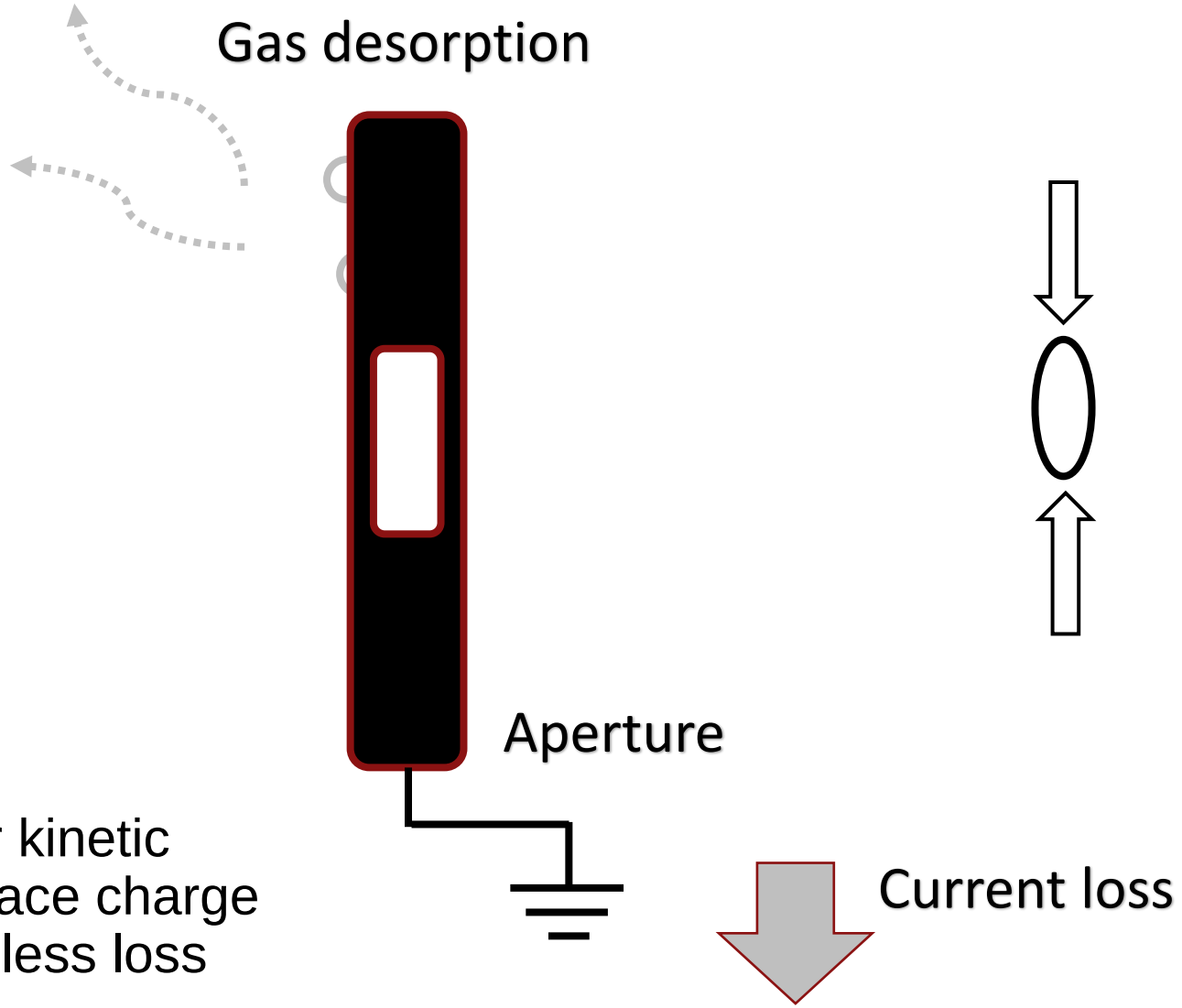
Why higher voltage?

Space charge

$$F_r(r) = \frac{e\lambda_0 r}{2\pi\varepsilon_0 \; a^2 \gamma^2}$$





- 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.

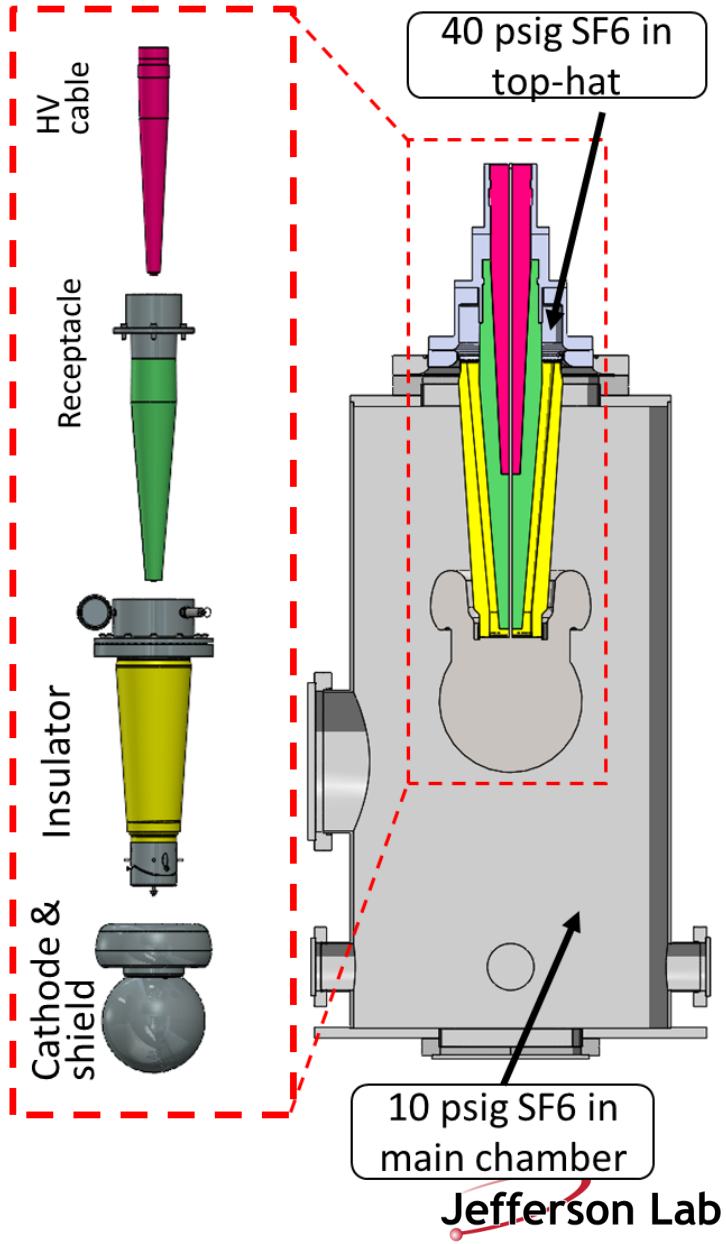
- Status:

✓ 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 SF_6



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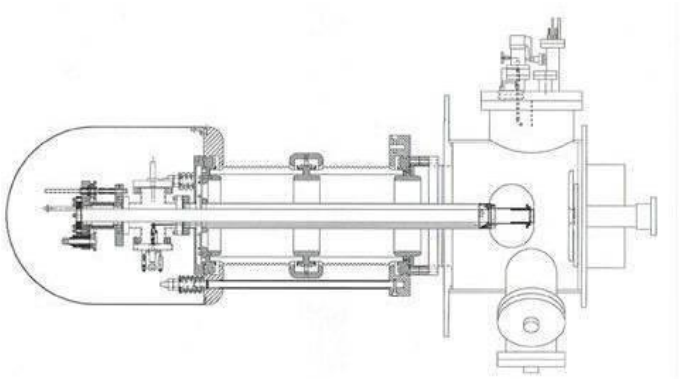
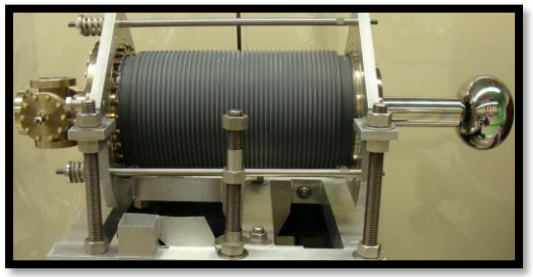
Inverted insulator polarized photogun

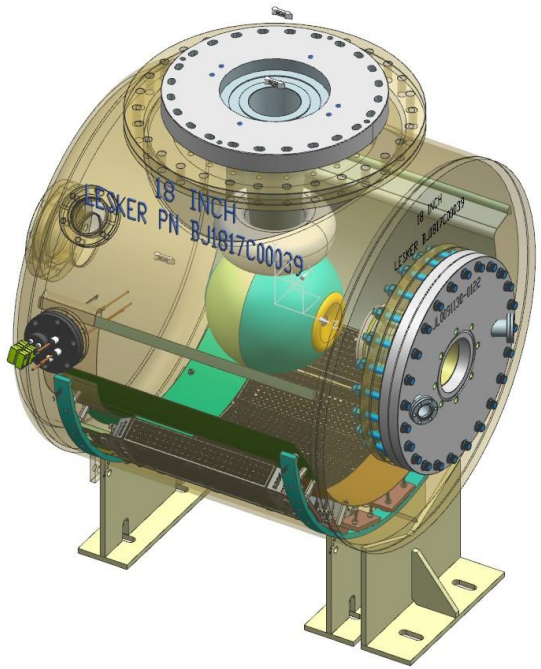
- “Inverted-insulator” high voltage design: the insulator extends into the vacuum chamber from the top serving as the cathode electrode support structure.
- Exceptional vacuum ~10^{-12} Torr vacuum
- Less metal aids in minimizing field emission

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

JLab FEL cylindrical insulator photogun







JLab inverted insulator photogun

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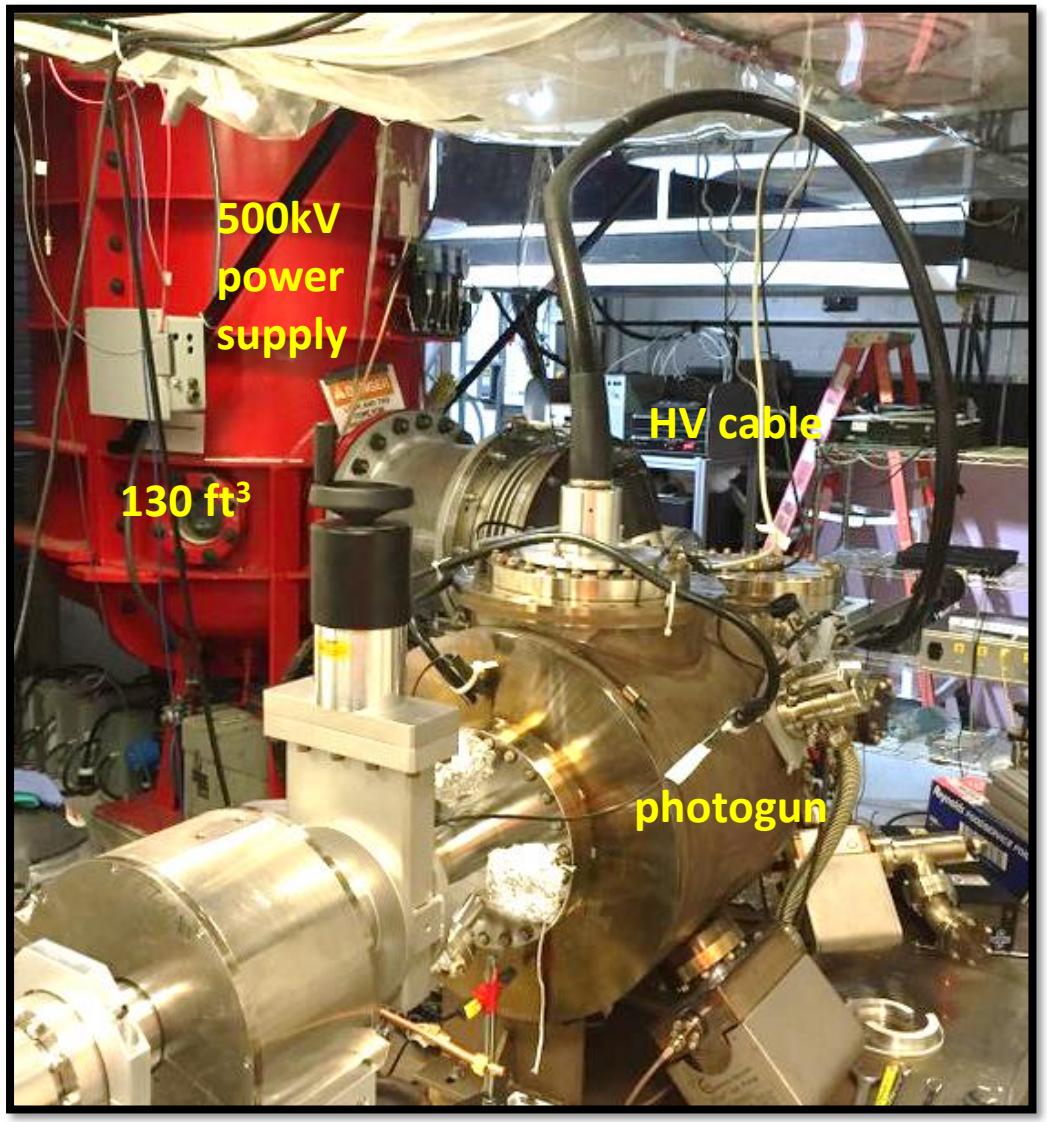
Inverted insulator polarized photogun

- 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 SF_6 gets eliminated by **using cable**



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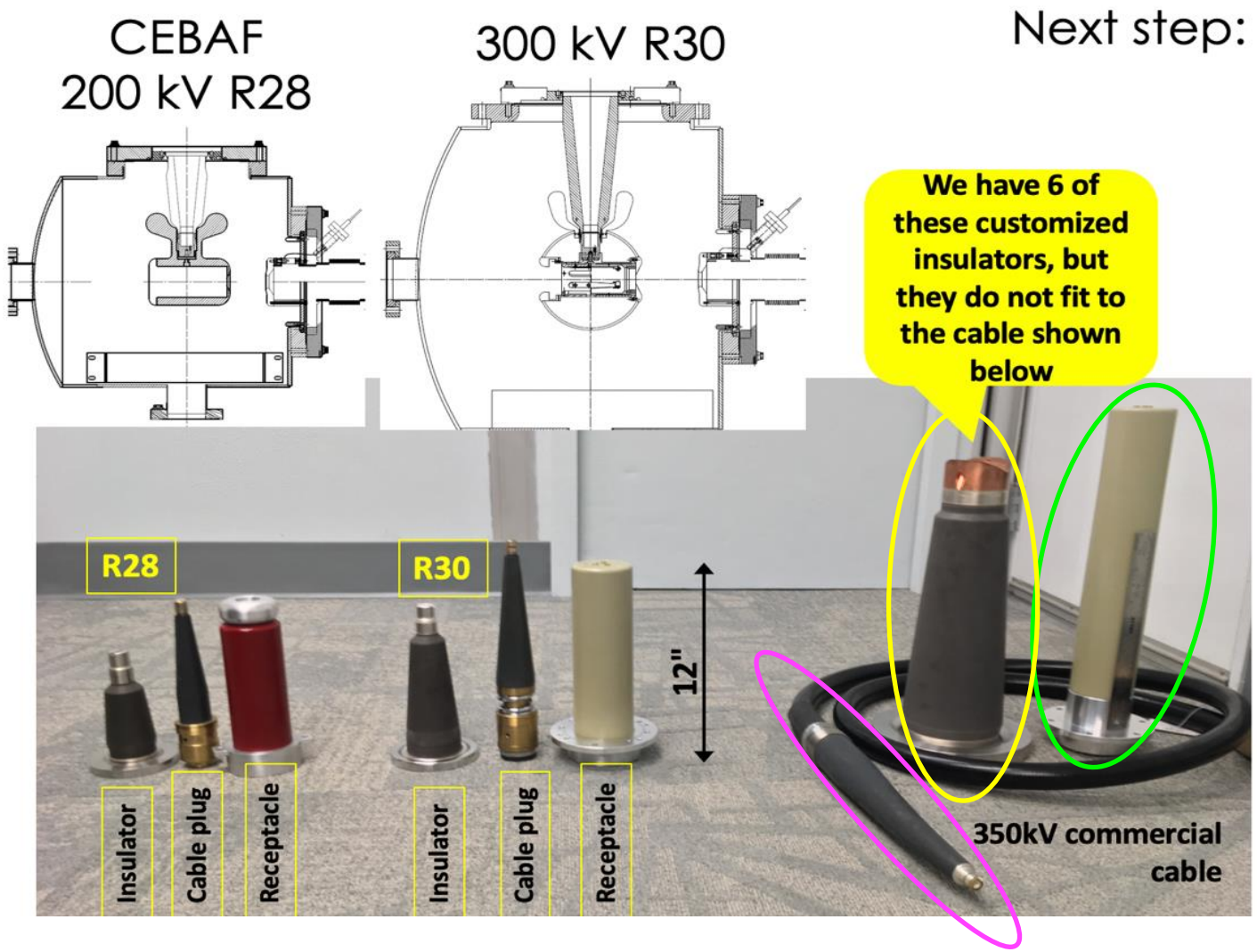
Challenge

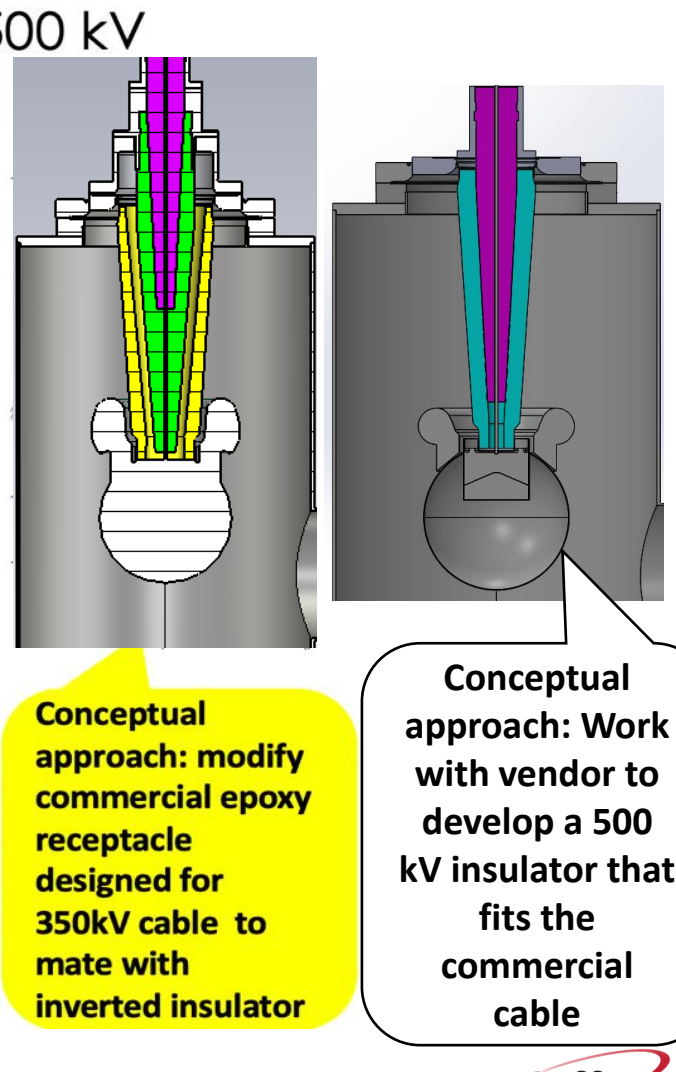
- An envisioned 400 kV DC photogun design requires reliable 500 kV feedthrough to provide margin for high voltage conditioning
- There is no inverted insulator feedthrough capable of 500 kV that fits commercial cable connectors
- Commercial cable connectors are rated to ~ 400 kV max in SF_6, and have 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

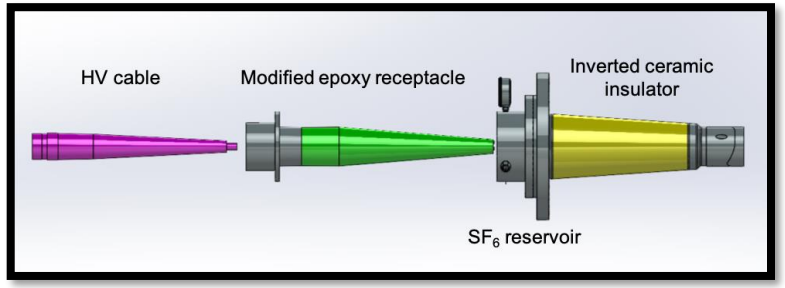
- The proposed plan is an evolution from our experience developing and operating high voltage inverted insulator photo-guns connected to power supplies using commercial components.

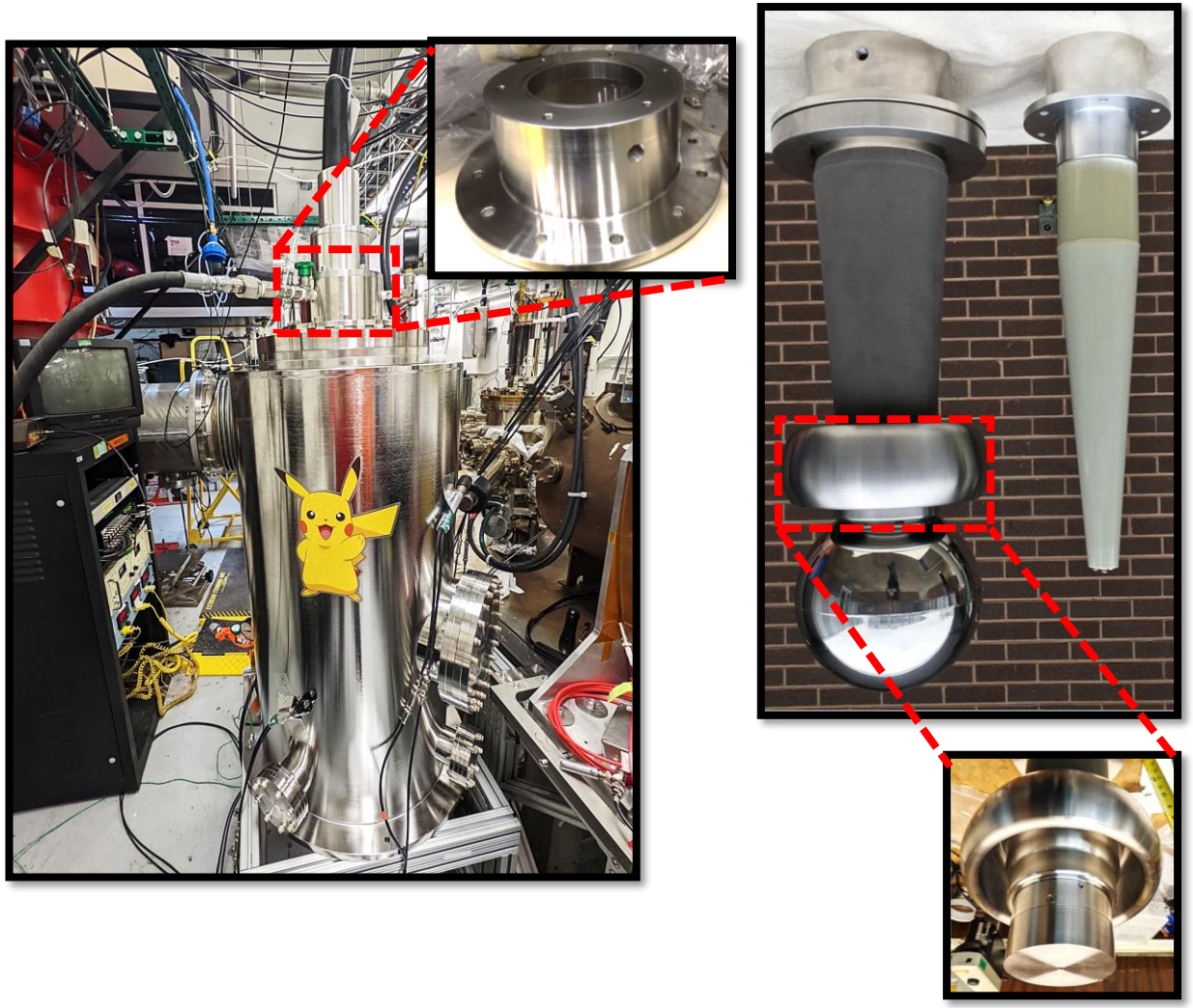




Progress: program

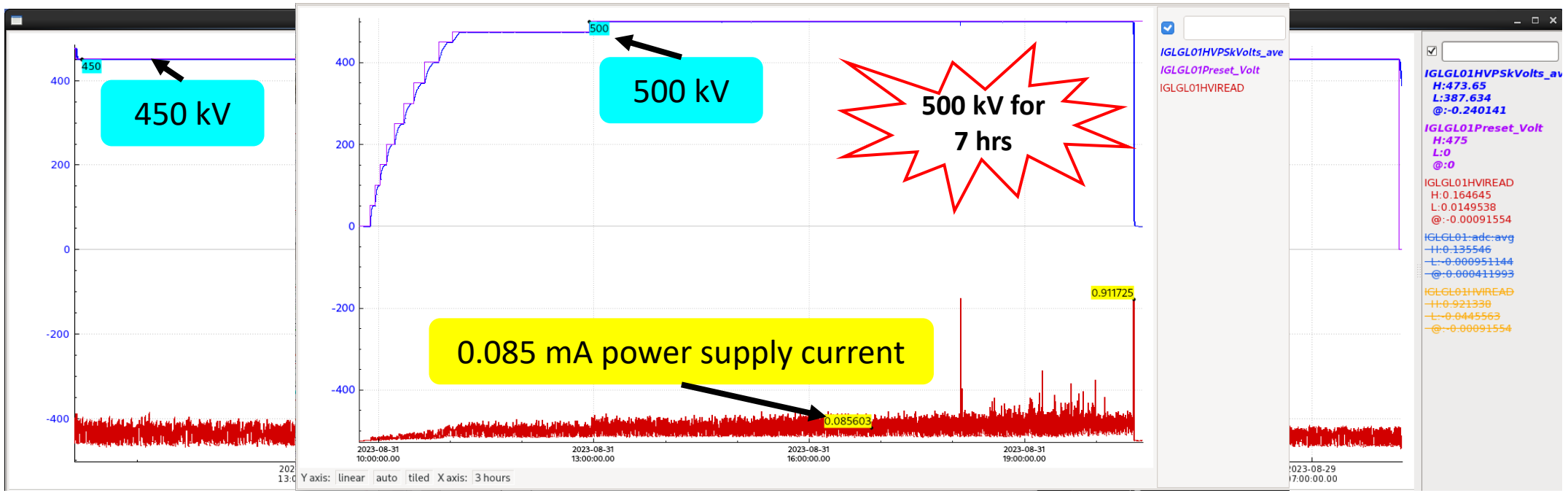
- Gabriel Palacios-Serrano was hired as a postdoctoral fellow on 06/16/21
- CST EM studio + Solidworks procured on 04/15/21, and license renewed 04/16/22
- Electrostatic models completed:
  - Modified HV receptacle and intervening SF_6 layer
  - Electrostatic design of electrode + triple point junction 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 … drum roll!





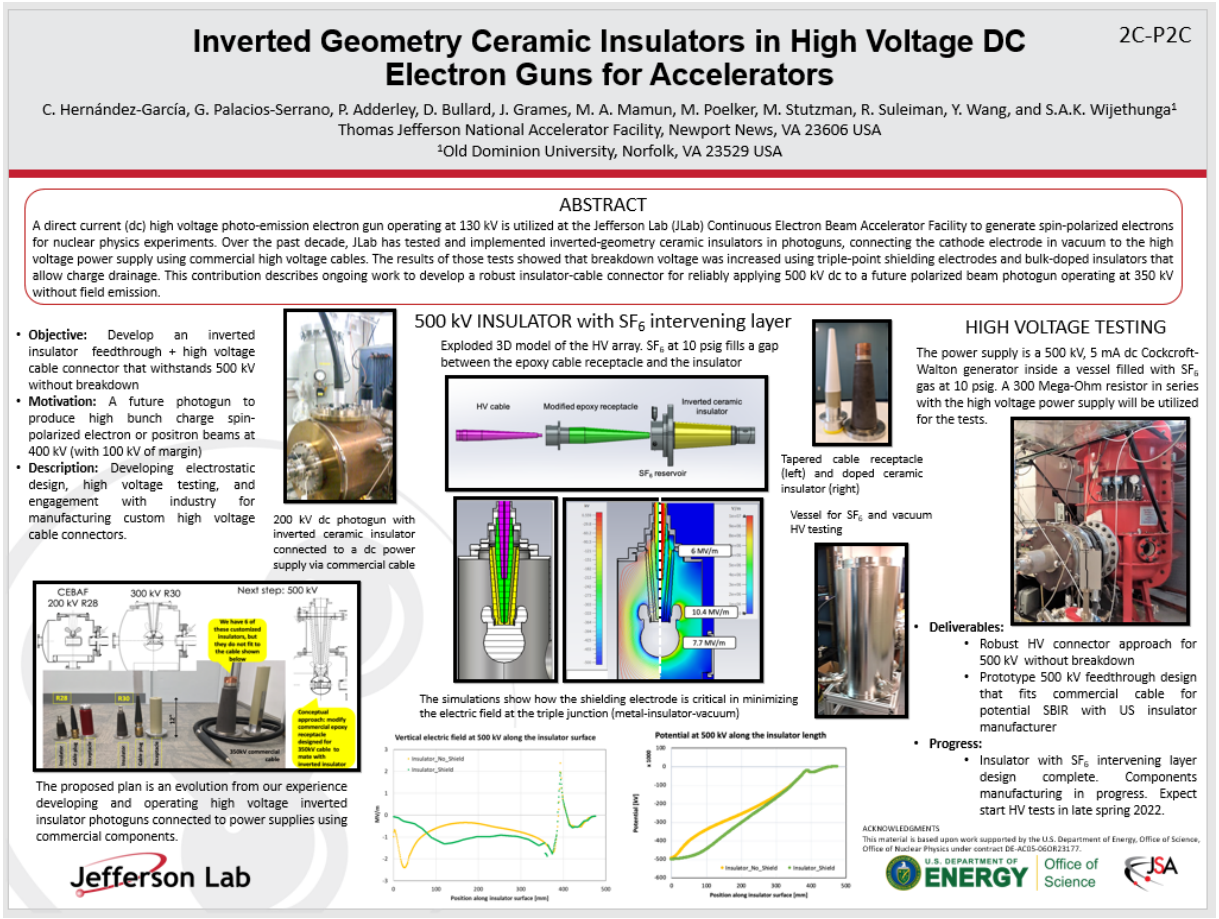
Progress: High voltage test successful!

- The test chamber was filled with SF_6 gas to nominal 10 PSIG, the separate feedthrough reservoir containing the volume of the SF_6 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.



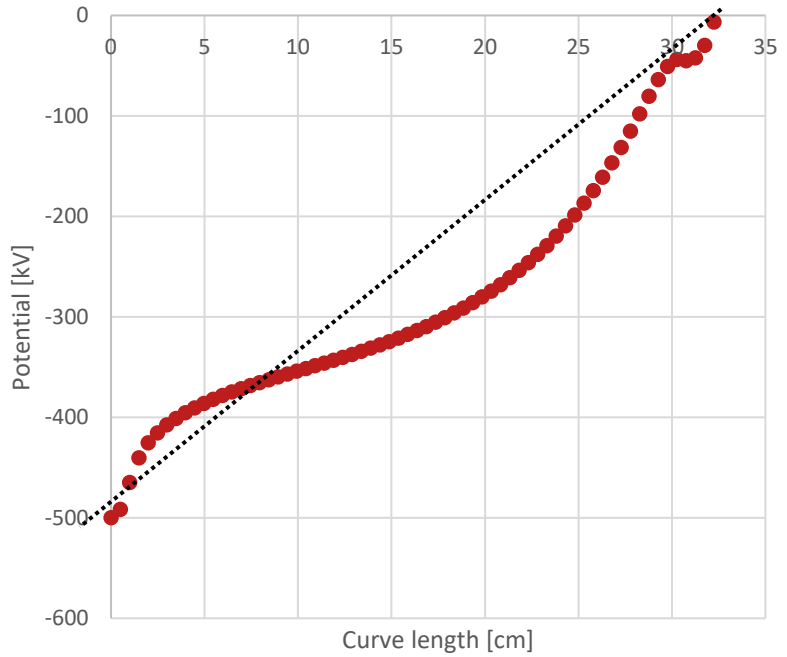
Progress: Conferences and papers

- 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.

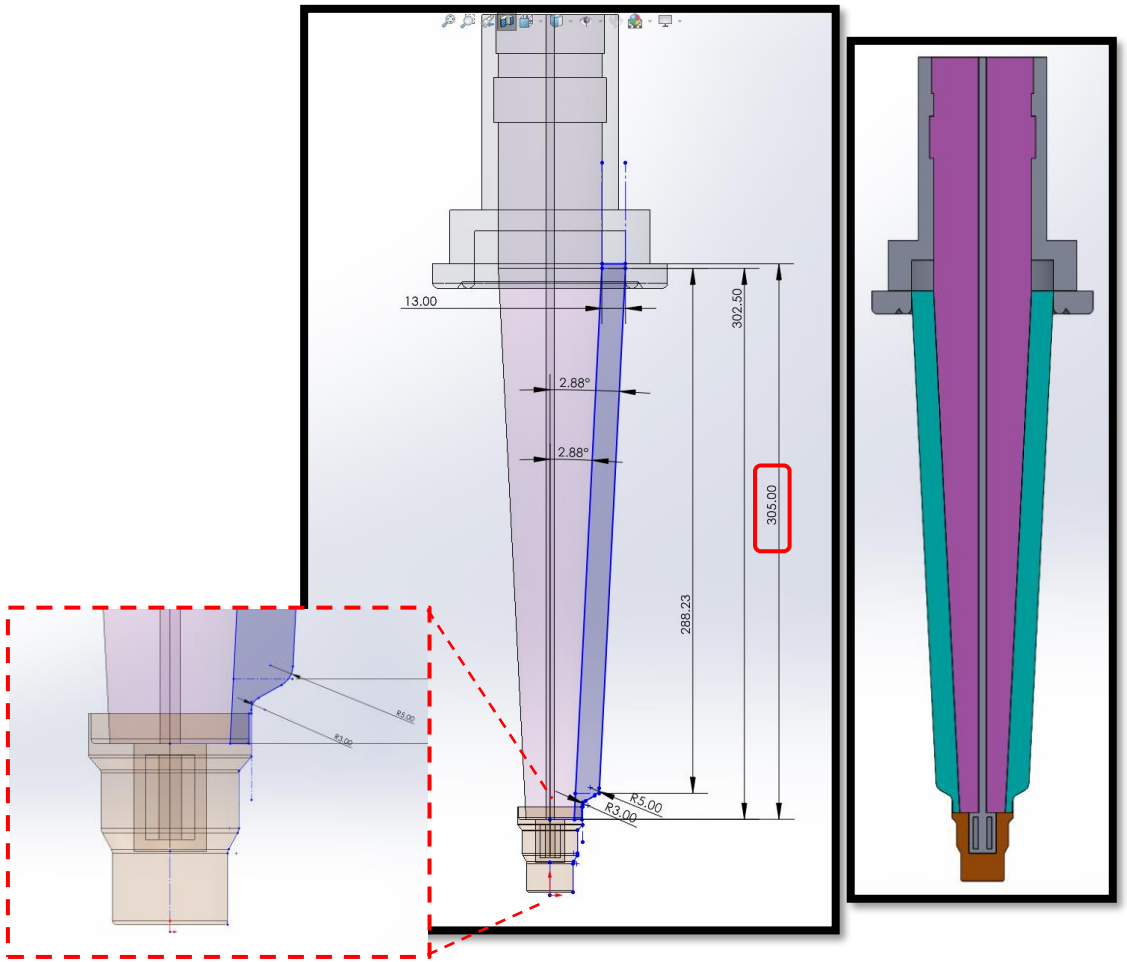


Next steps

- 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	Costed & Committed	Estimate To Complete	Estimated Total Cost
		(AY$)	(AY$)	(AY$)	(AY$)
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

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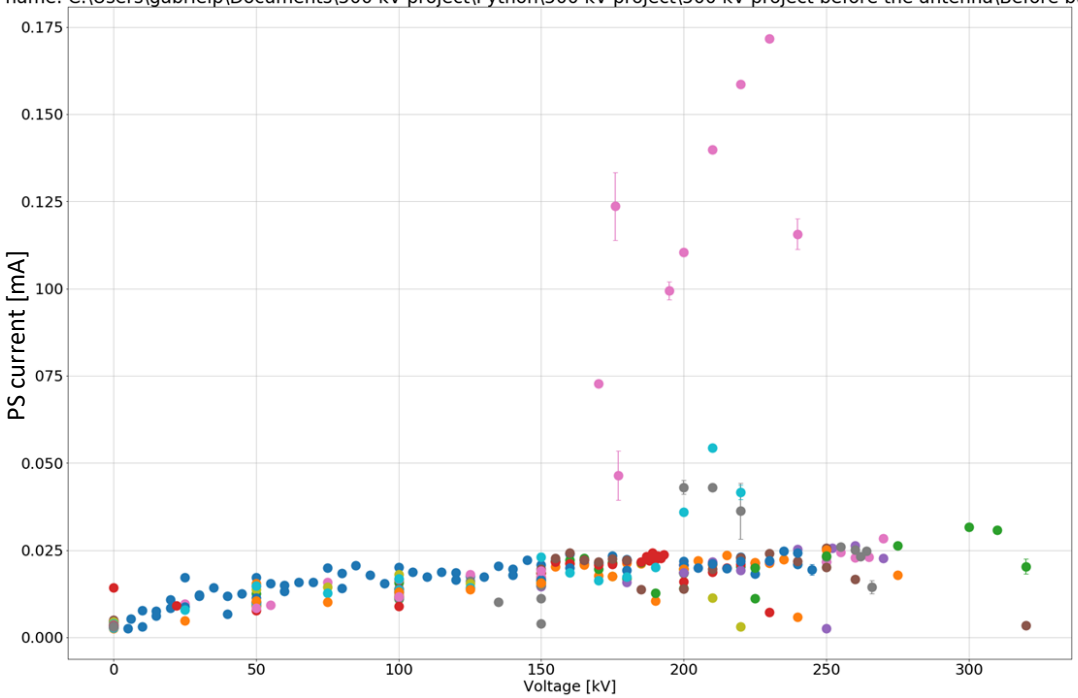
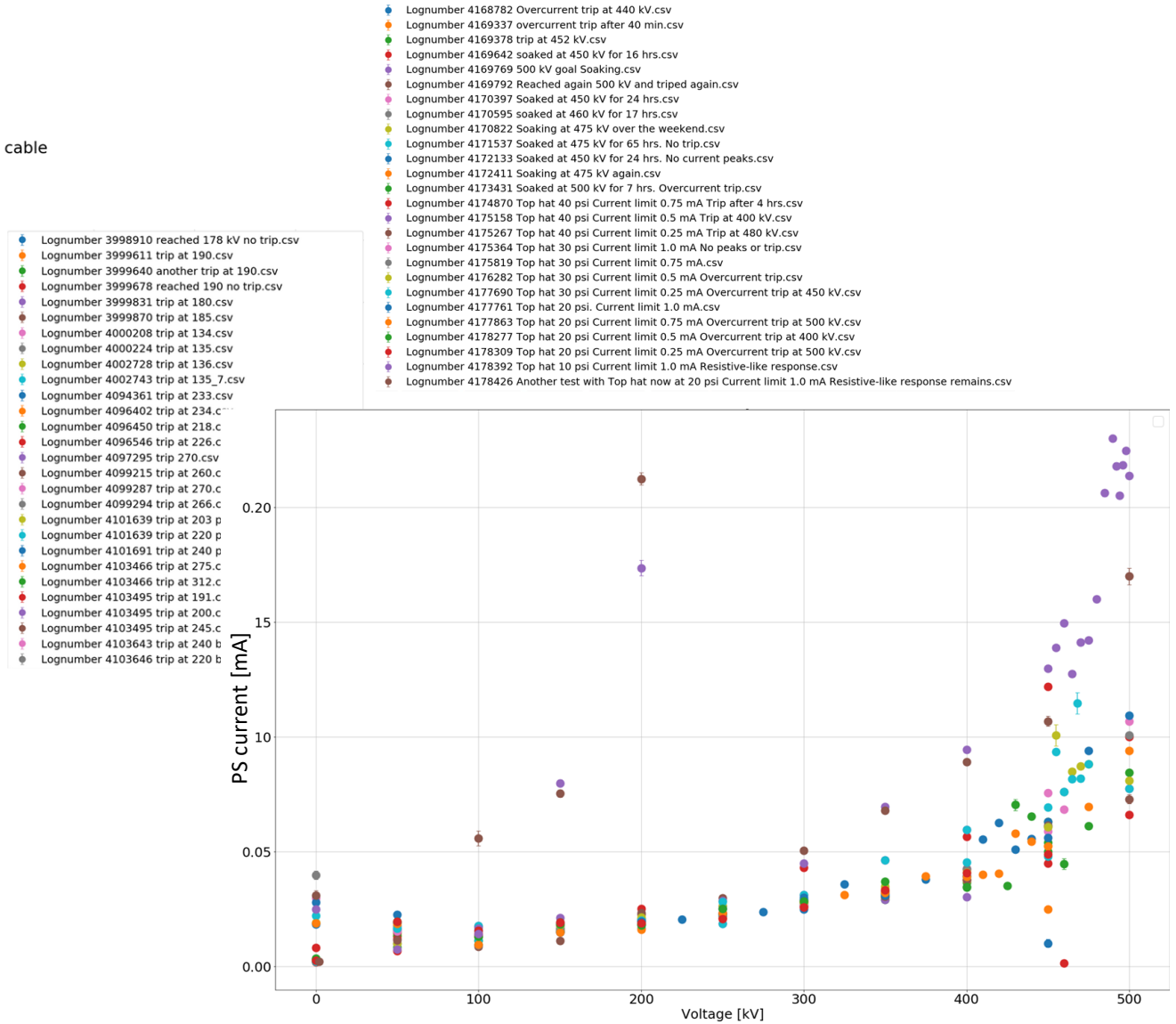
Extra

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





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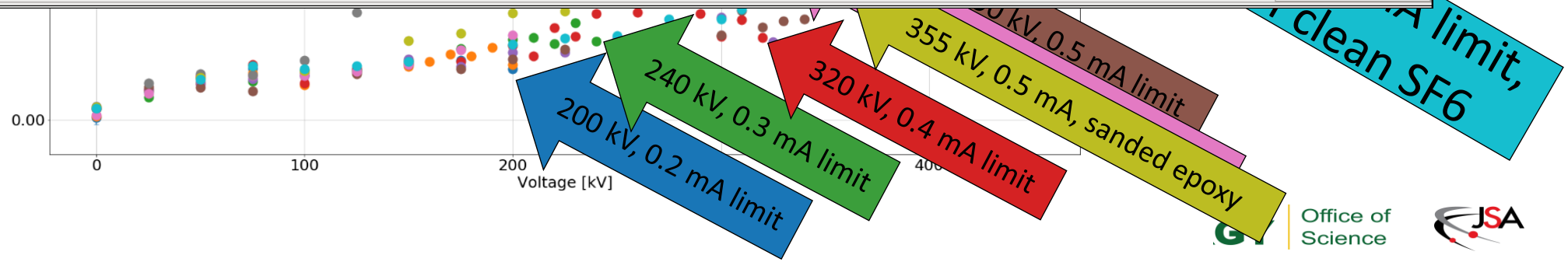
Extra

Found the issue: Not-pure SF6



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