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

NP FOA FY20

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

November 30, 2021

PI: Carlos Hernandez-Garcia

Center for Injectors and Sources

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 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

Project overview

FY2020: $269.4k awarded

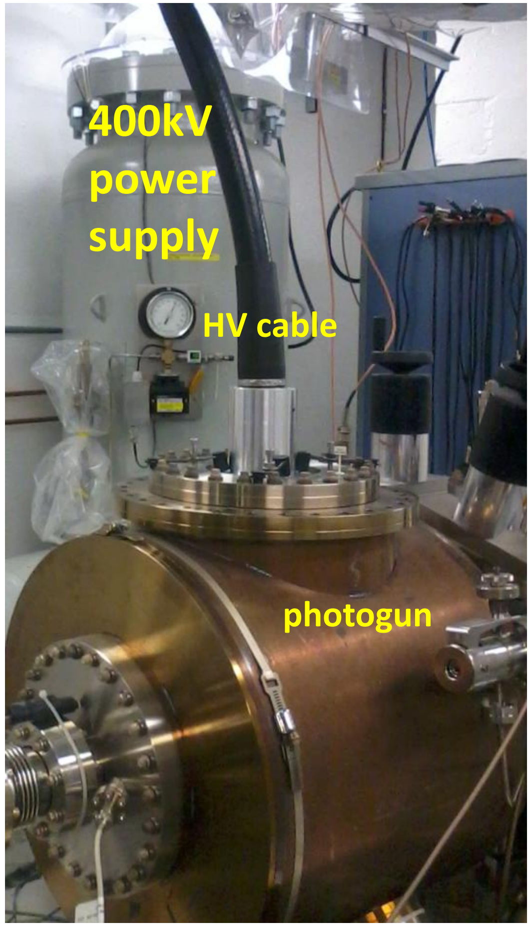
Staffing: Postdoc+Sci+Tech: 1 FTE | ME: 0.2 FTE	1.20 FTE
✓ Hire postdoc & procure software	Q1
✓ Concept 1: Long insulator + SF_6 intervening layer design	Q2
✓ ~Fabrication & assembly (in progress)	Q3
• High voltage testing in SF_6 chamber	Q4

FY2021: $269.4k awarded

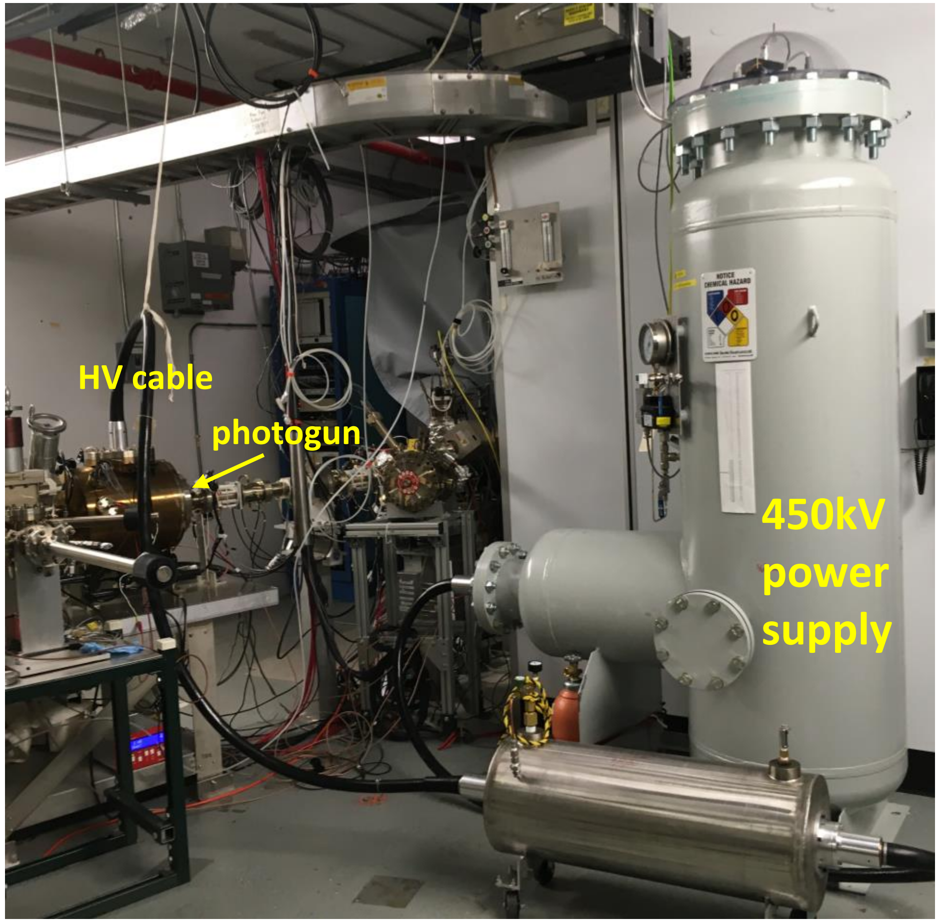
Staffing: Postdoc+Sci+Tech: 1.25 FTE | ME 0.20 FTE	1.45 FTE
• Concept 2: Custom HV plug design & procurement	Q1
• High voltage testing in SF_6 chamber	Q2
• “Ultimate” concept: custom insulator + commercial connector	Q3
• Custom insulator teflon prototype + commercial connector fab & HV testing in SF_6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

JLab inverted insulator photoguns use commercial HV cables

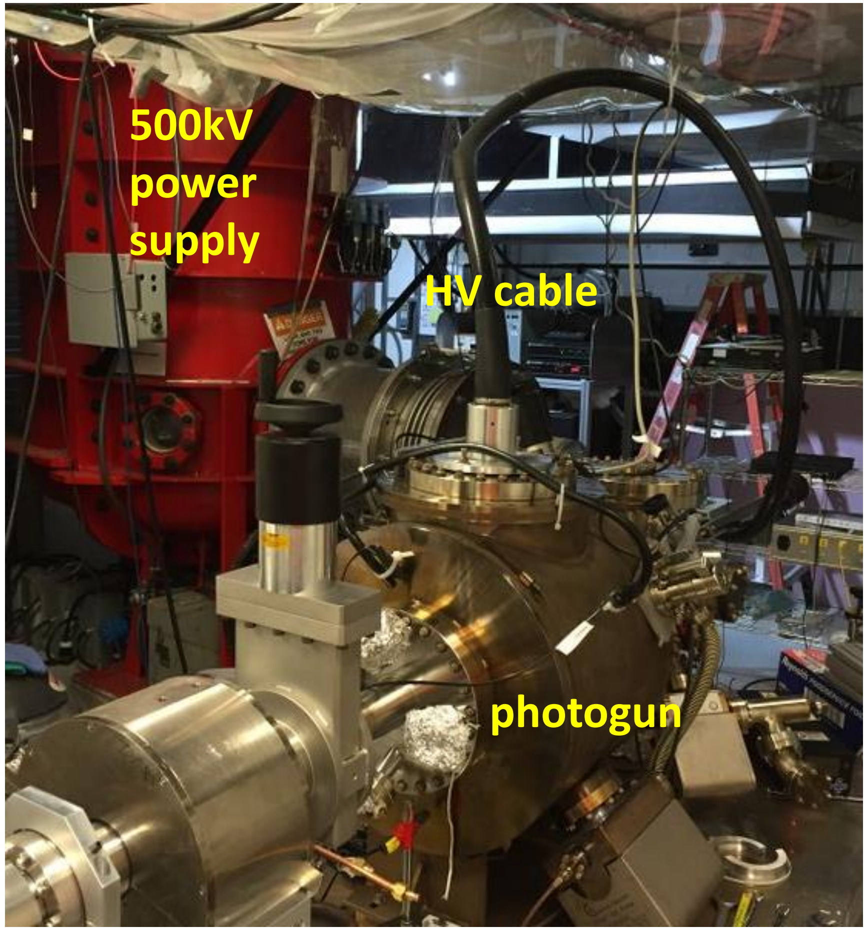
UITF 200 kV



CEBAF 200 kV



GTS 300 kV



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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

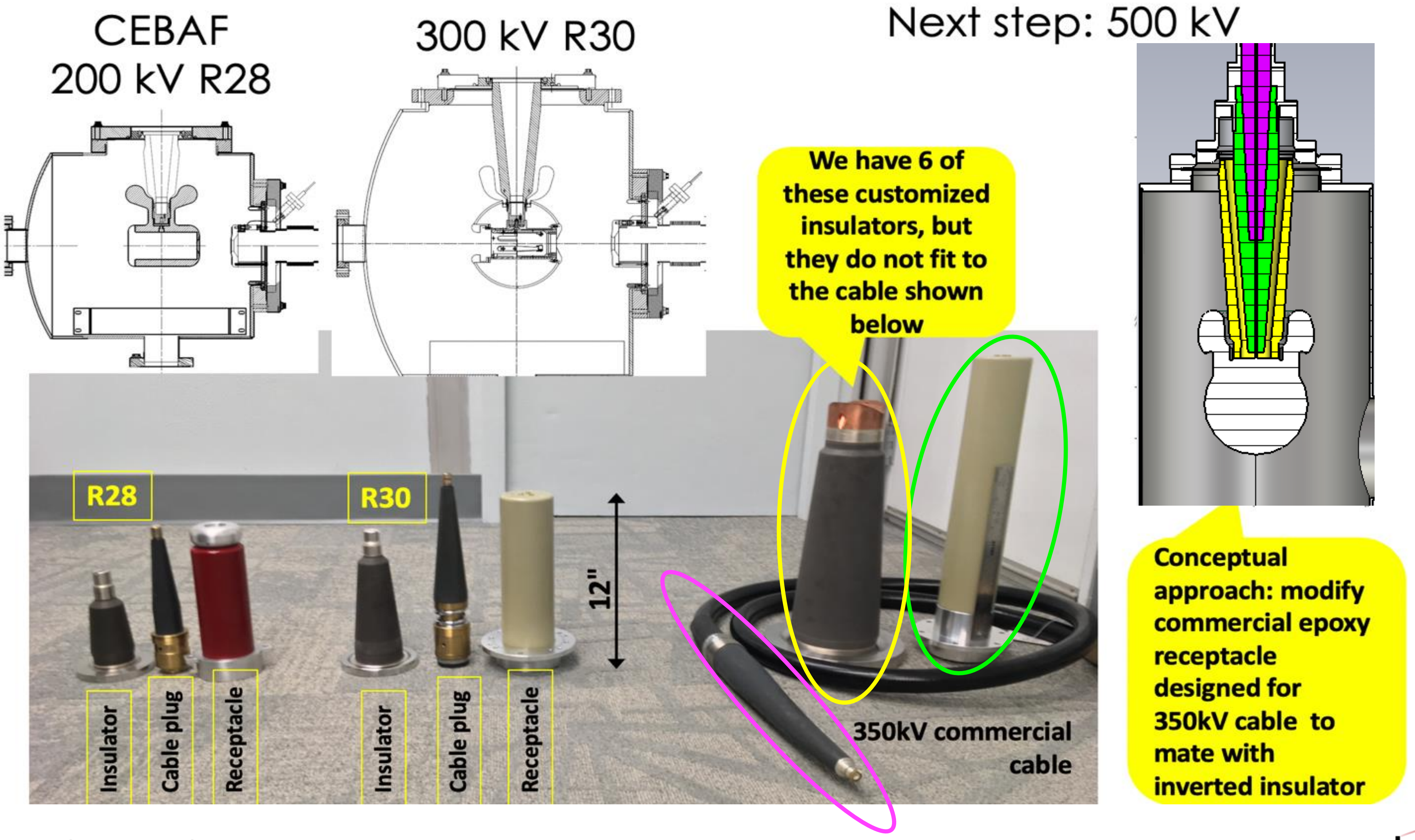
- Commercial cable connectors are rated to ~ 400 kV max in SF_6, and have never been tested > 350 kV connected to inverted insulators in vacuum*

- 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.



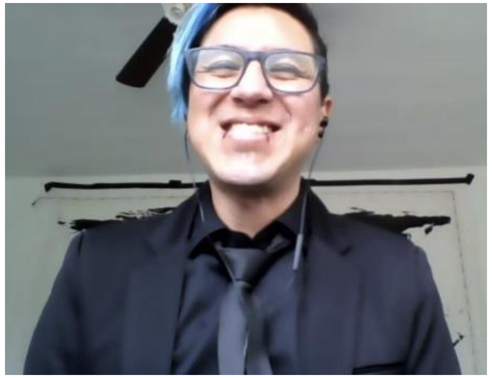
Progress: program

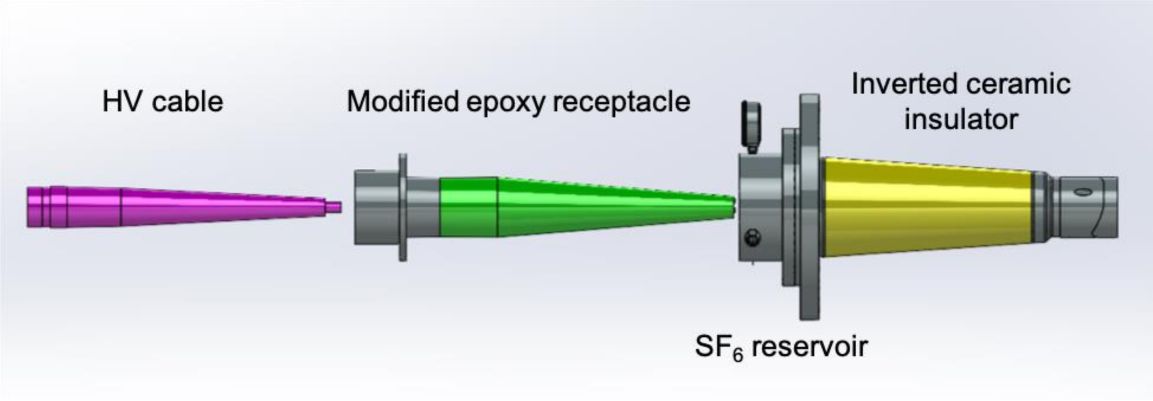
- Gabriel Palacios-Serrano was hired as a postdoctoral fellow on 06/16/21

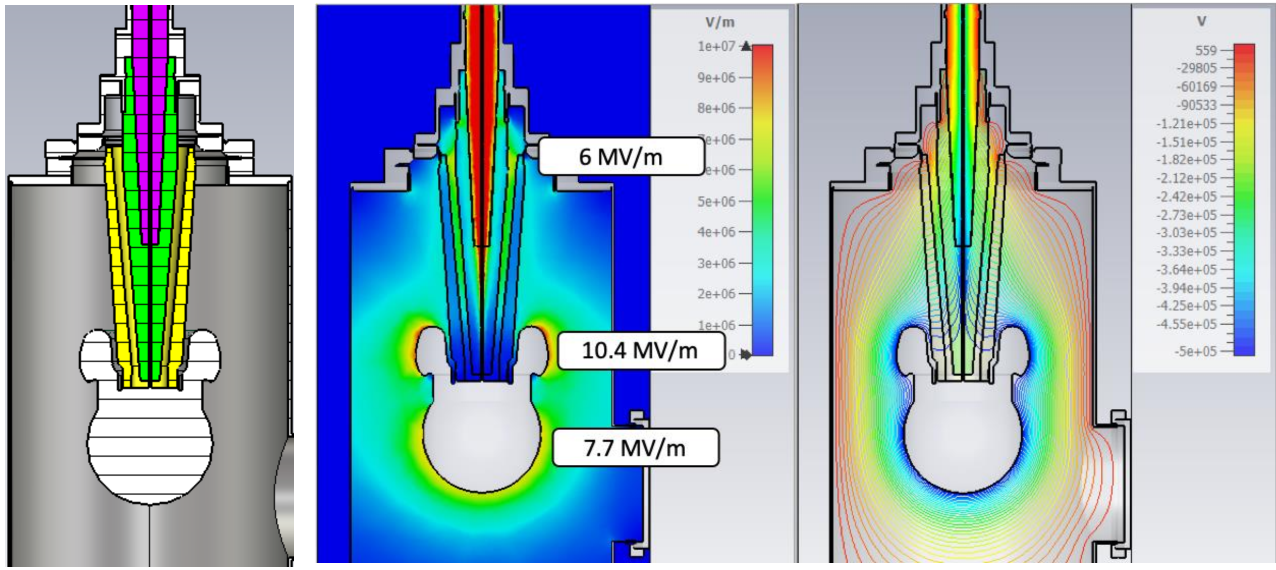
- CST EM studio + Solidworks procured on 04/15/21

- Electrostatic model with modified HV receptacle and intervening SF_6 layer completed

- Electrostatic design of electrode + triple point junction shield (to prevent arcing) completed



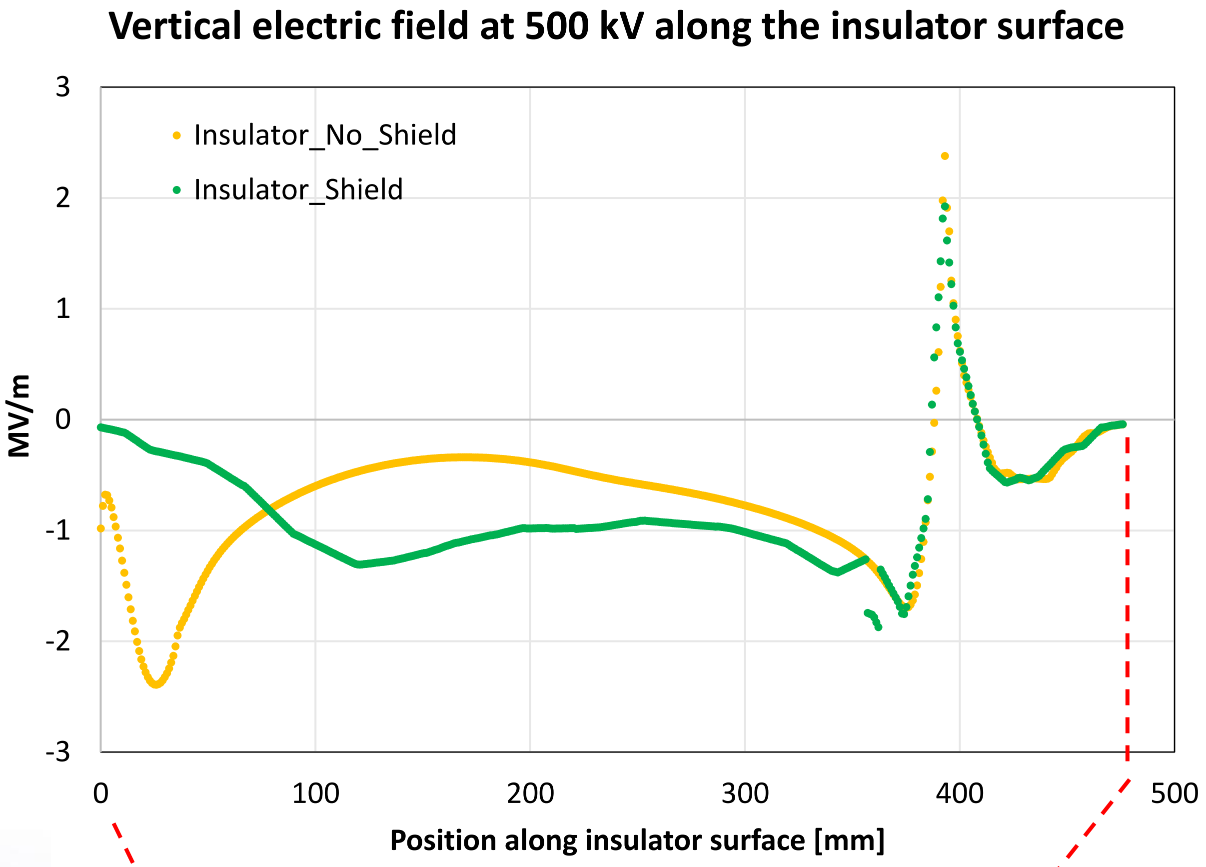


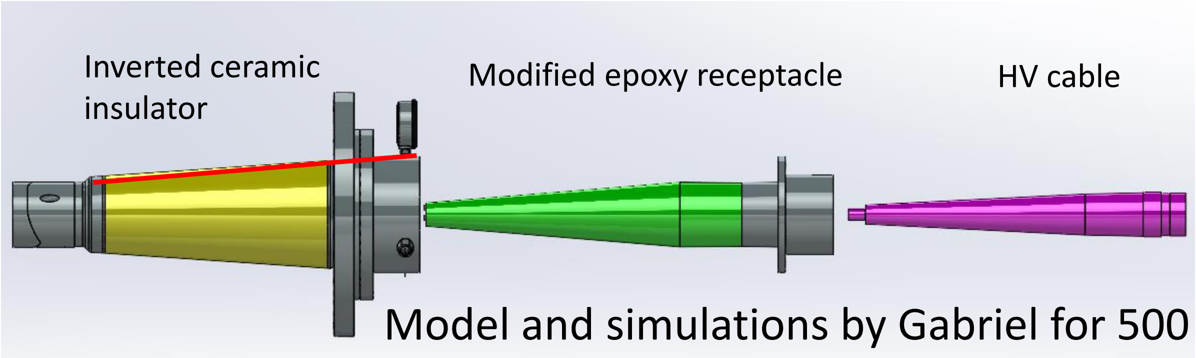


Model and simulations by Gabriel for 500 kV

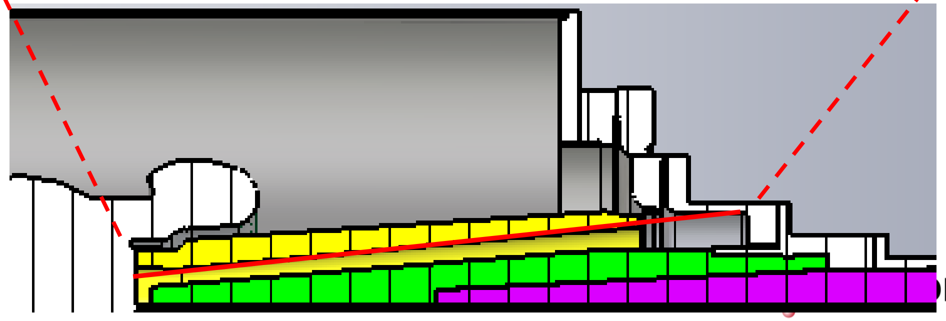
Progress: electrostatic simulations

- The simulations show how the shielding electrode is critical in minimizing the electric field at the triple junction (metal-insulator-vacuum)
- Insulator electrical breakdown is thought to originate at the triple junction by high electric field parallel to the surface of the insulator
- The shape and size of the shielding electrode was optimized to minimize electric field at the cusp, thus reducing risk of field emission



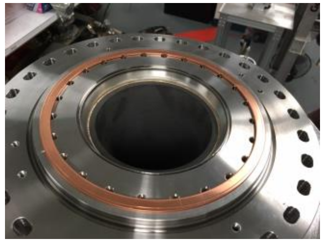


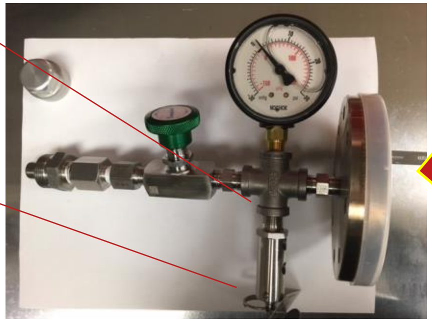
Model and simulations by Gabriel for 500 kV



Progress: equipment and components

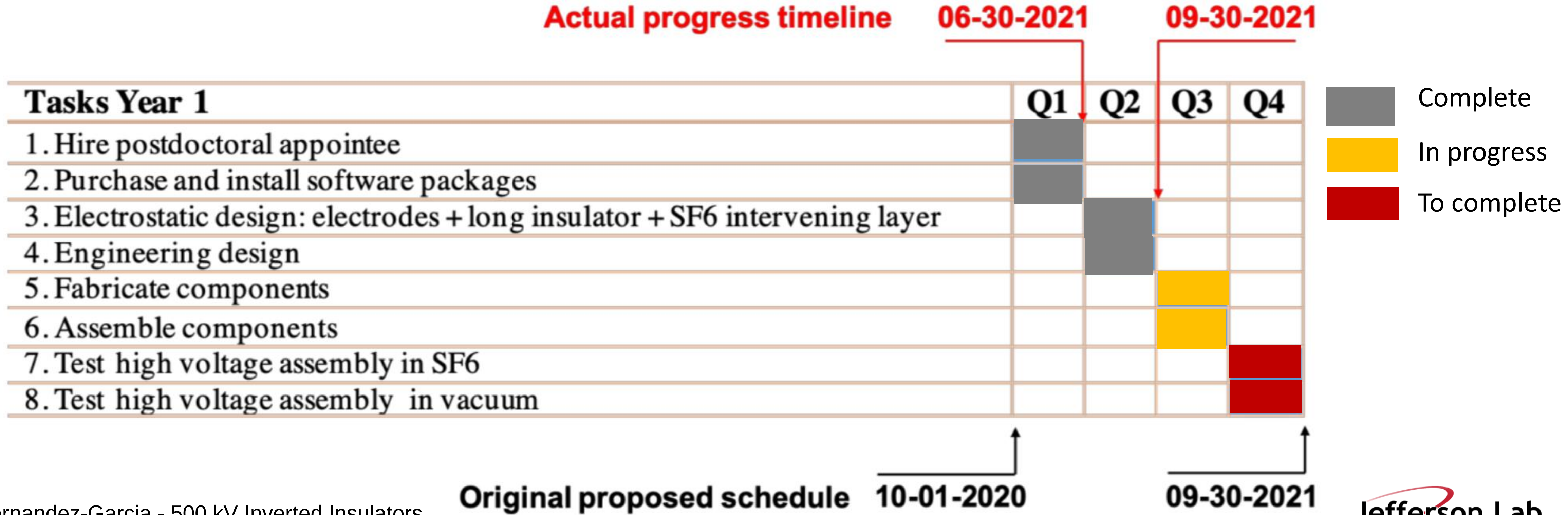
- Insulator has been welded to its flange (6 insulators made in 2010)
- Insulator assembly has been bolted to the HV test chamber
- HV test chamber with insulator was pumped down and checked leak free
- HV receptacle has been machined to fit into the ceramic insulator
- HV test chamber has **been pressure tested** for **10 PSIG operations**
- **Relief valves** have been **pressure tested**
- Pumpdown/SF_6 backfilling manifold has been designed and built
- Top hat SF_6 reservoir has been designed and is being manufactured
- HV assembly test chamber pressure test + components have been **documented** in the **pressure systems folder** as an **alteration** to DILO SF_6 gas handling system





Concerns

- Difficulty in filling the postdoctoral position effectively delayed the start of the project by 6 months
- We are experiencing supply chain issues with custom HV components. Dielectric Sciences is keen to work with us on this project, but they are overwhelmed with back orders. This might become a serious delay in starting high voltage tests if not resolved
- Some delay in components design experienced due to limited available time by ME matrixed labor



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FY 2022 schedule: optimistic, highly dependent on vendor custom HV components

1	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	Custom HV rubber plug procurement and fabrication											
8	Custom HV receptacle procurement and fabrication											
9	HV test chamber assembly w/o electrode for SF6 testing											
10	Electrode-insulator assembly into HV test chamber											
11	High voltage testing custom HV receptacle											
12	High voltage testing custom rubber plug											
13	Anlysis of HV test results to establish baseline for "ultimate" 500 kV ineverted ceramic insulator design											

In progress

To complete

Budget

	FY20 ($k)	FY21 ($k)	Totals ($k)
a) Funds allocated	269.4	269.4	538.8
b) Actual costs to date 11/29/2021	135.9	0	135.9

	FY 2020 (k$)	FY 2021 (k$)	FY 2022 (k$)	FY 2023 Carryover (k$)	Total (k$)
Funds allocated	269.4	269.4	0	0	538.8
Actual cost to FY20	135.9	0			
Estimate to complete			309.5	93.4	402.9

Carlos Hernandez-Garcia

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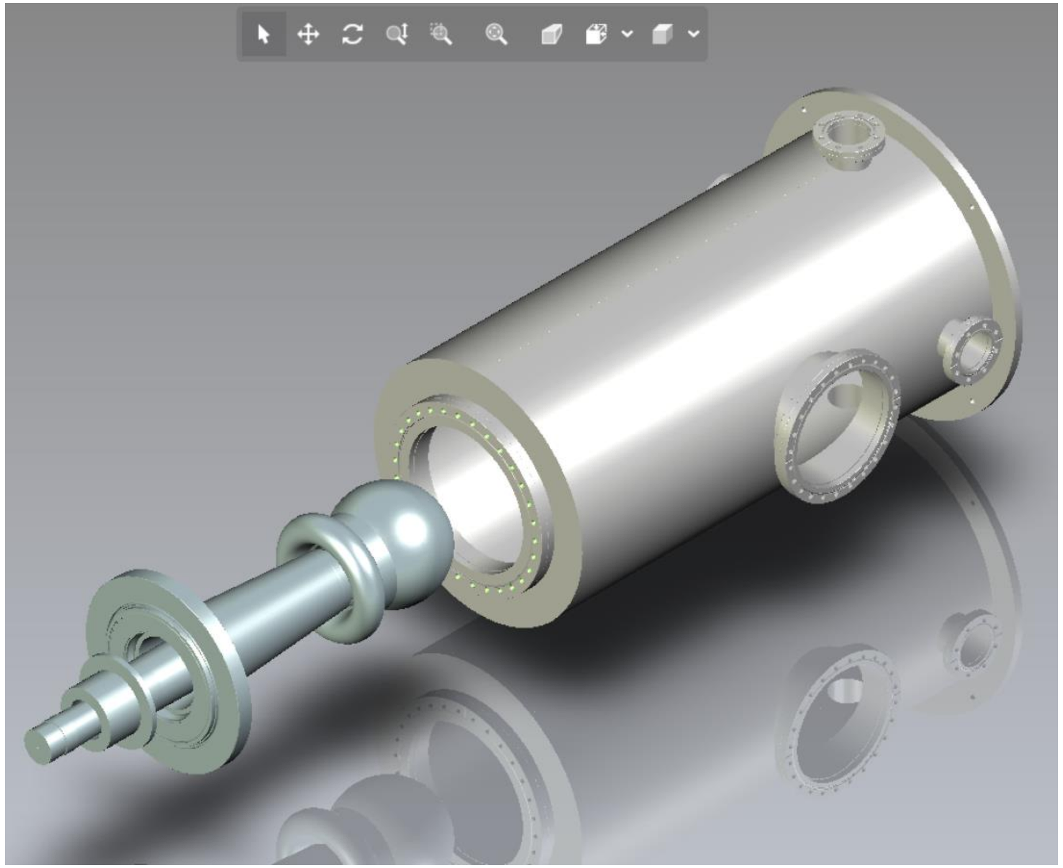
Summary

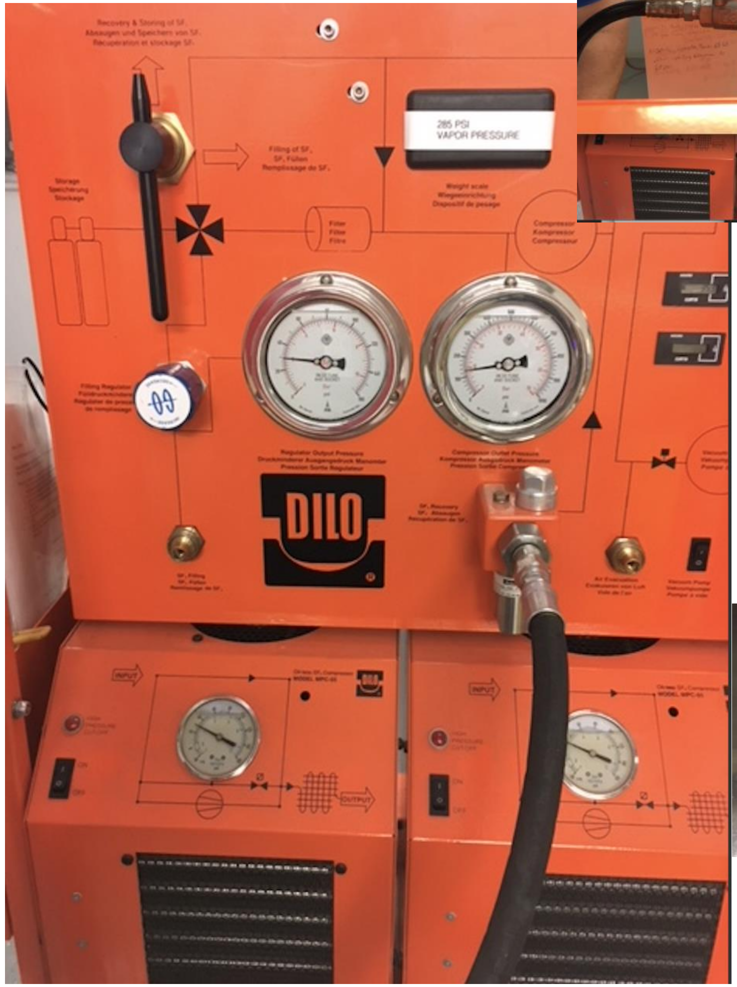
- Objective: **Design & test 500 kV insulator/cable connector approach to provide HV conditioning margin for future implementation in a 400 kV DC photogun**
- Progress: Postdoctoral position filled. Connector concept # 1 design complete. Components manufacturing in progress. Expect start HV tests in late spring 2022.
- 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 are starting to impact project schedule
- 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

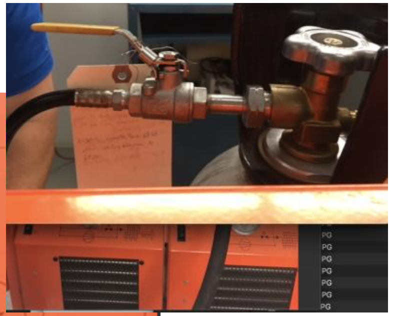


Backup slides

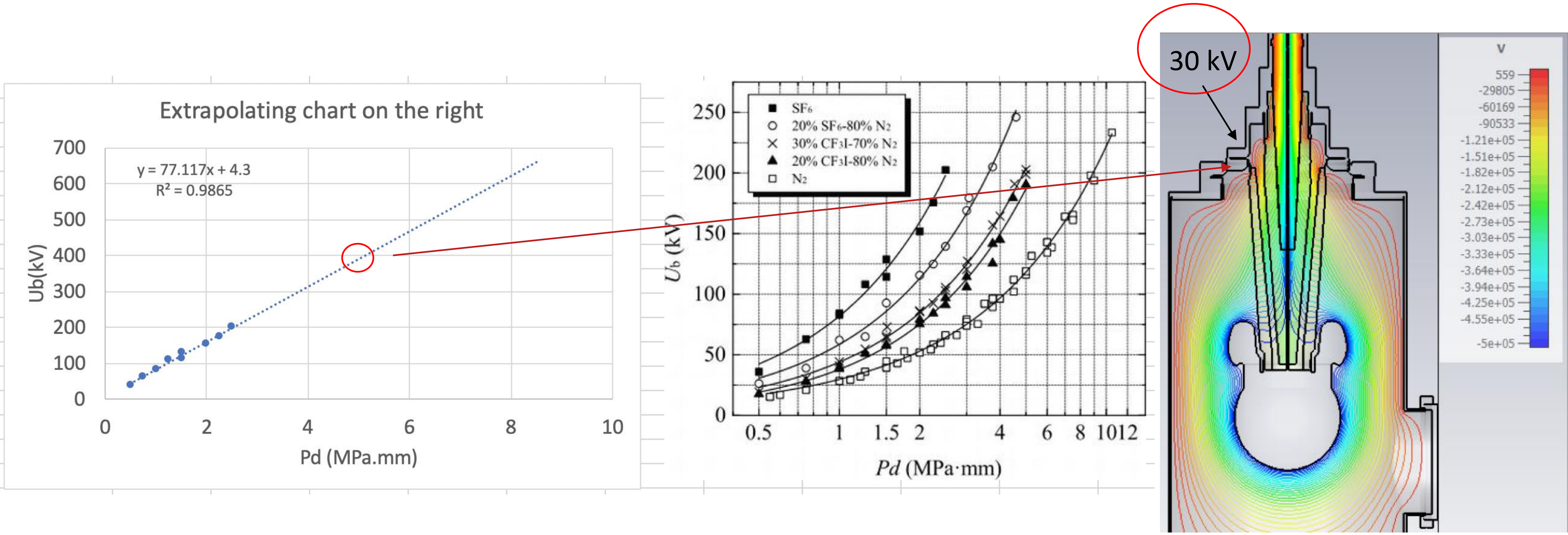
SF6 gas recovery / backfill system to prevent SF_6 losses

- We use a commercial SF_6 gas recovery / backfill system to transfer SF_6 from the high voltage apparatus (power supply, resistor tank, test chamber) into storage bottles.
- The gas is pushed into the bottles via two compressors
- The high voltage apparatus is vented to atmosphere when the compressor inlet pressure reads 30 in-Hg vacuum
- Once work is complete, we use a vacuum pump to evacuate the high voltage apparatus to 30 in-Hg
- Then the SF_6 is transferred back from the storage bottles to the high voltage apparatus using a regulator integrated to the transfer system

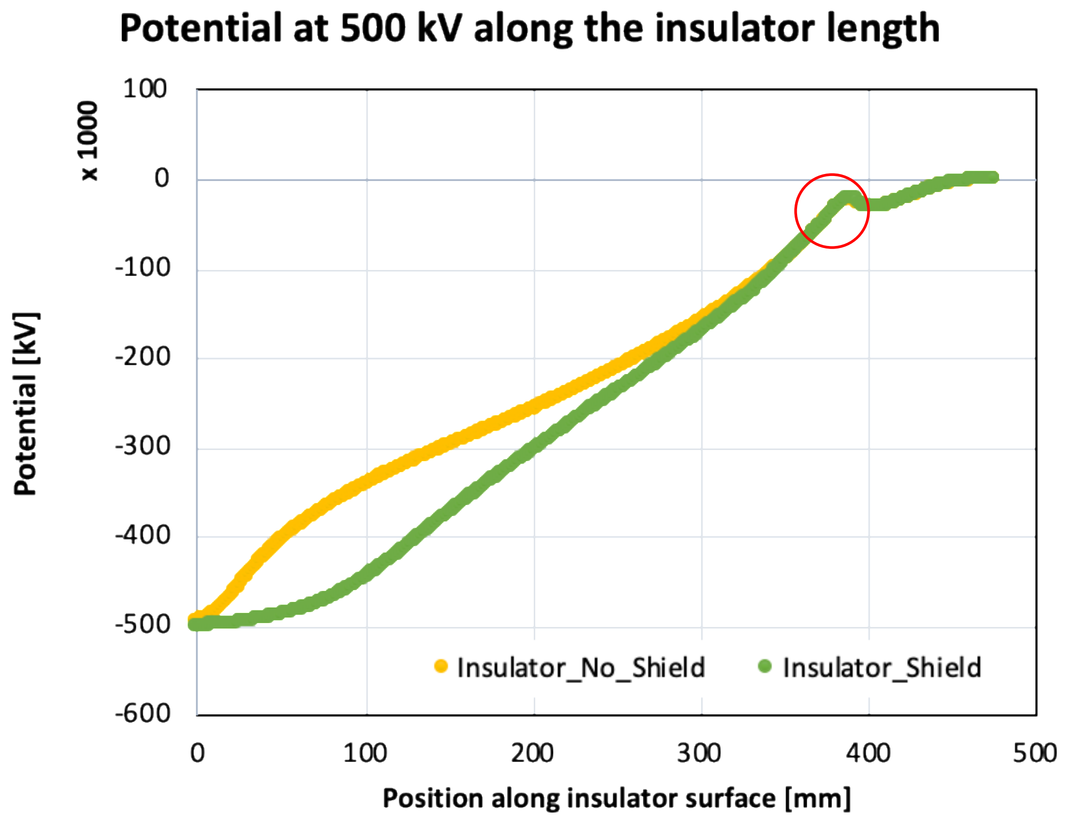


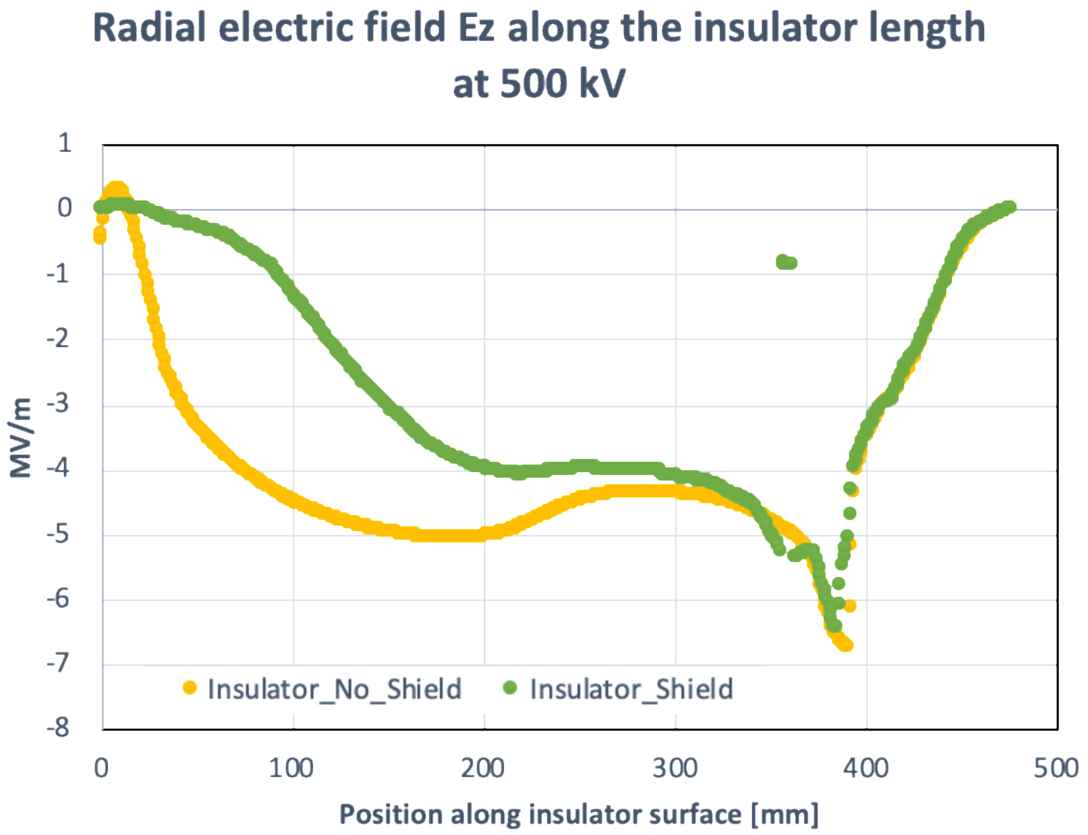


SF6 breakdown at 10 PSIG and 30 mm gap to ground: 400 kV



Electrostatic simulations: Potential and radial electric field along insulator



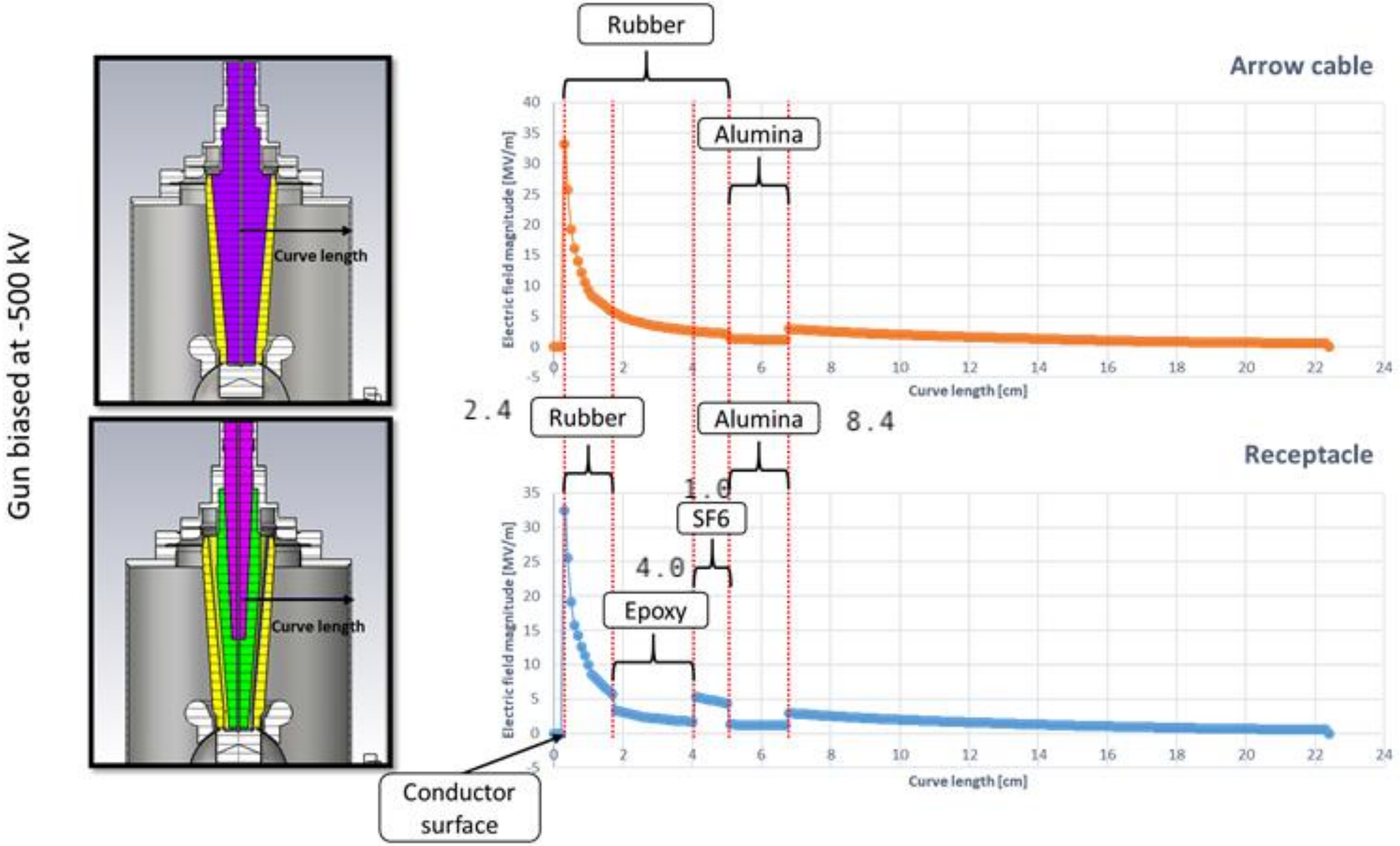


The potential along the insulator is more linear with the triple point junction shield

The radial electric field is lower overall with the triple point junction shield

Simulations by Gabriel for 500 kV

Progress: electrostatic simulations



- Varying dielectric constants in each material component induce discontinuities in the radial electric field

- The implications of this effect will be studied in upcoming high voltage tests with the two planned connector configurations

Simulations by Gabriel for 500 kV