UW IEC Group 2014: Preparing for 300 kVDC Operation

System Stability Studies and Component Selection

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University of Wisconsin IEC Group

Work supported by the Grainger and Greatbatch Foundations

U.S. -- Japan 2014 IEC Workshop
University of Wisconsin, Madison, Wisconsin, USA

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‡ - name inadvertently omitted from abstract (please note)

University of Wisconsin
Fusion Technology Institute
Inertial Electrostatic Confinement Group

Motivations for this Presentation

- To keep our colleagues informed of the progress of our efforts to move into operating regimes of up to 300 kV DC

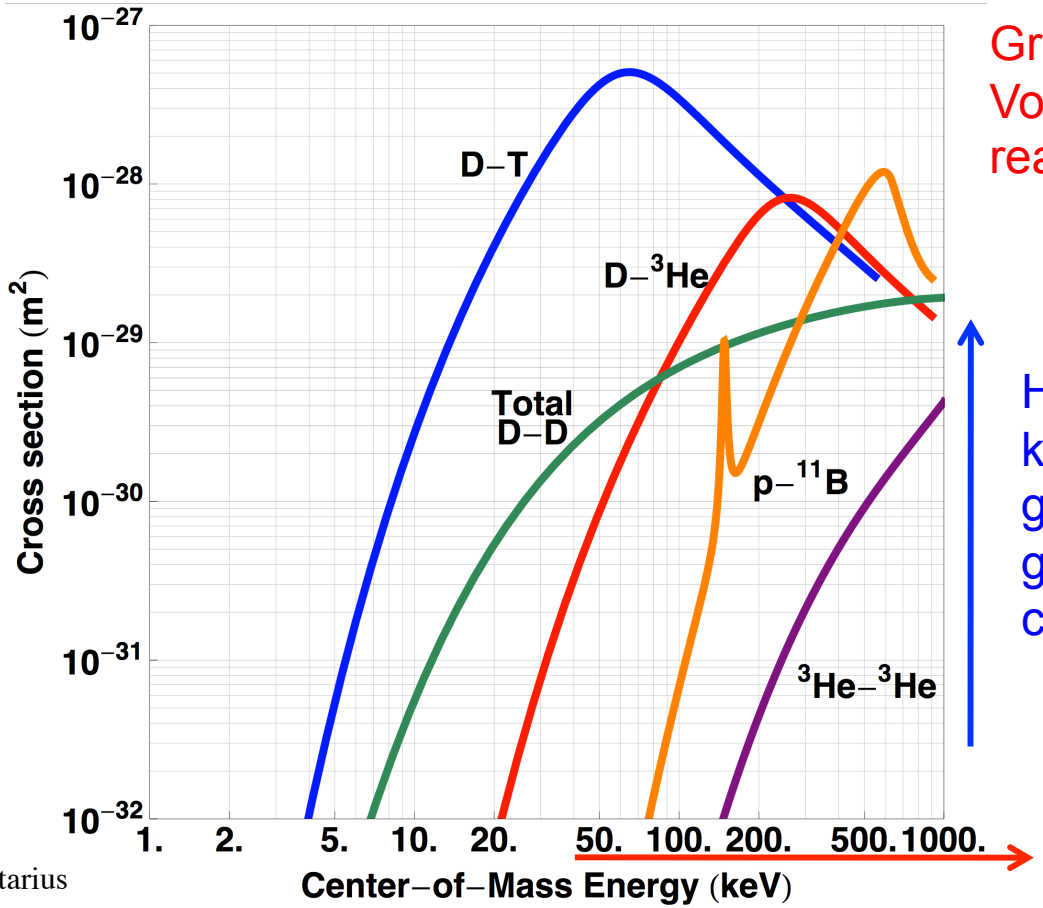
- To inform our colleagues considering operating at higher voltages of challenges that they may encounter as a consequence

Presentation Outline

- Brief review of the motivation to go to 300 kVDC operation (see also Michalak presentation)
- Summary of adaptations required, and the current status thereof
- Review of System Stability Issues, as noted in previous workshops, and to date

Motivation for Using Greater Cathode Voltages

Improved access to Advanced Fuel Fusion Regimes



Source: J. F. Santarius

Greater Cathode Voltages ➔ higher reactant kinetic energies

Higher reactant kinetic energies generally imply greater collision cross-sections

Adaptations for 300 kVDC

Completed:

- High-voltage power supply upgrade
- Vacuum feed-through assemblies (first designs)
- Construction of HVDC switch / series-resistance assembly
- Re-design of HELIOS feed-through
- Acquisition of additional high-voltage cabling

Interrupted:

- Testing and “debugging” of HVDC switch
- Re-design of HOMER high-voltage feed-through

In Progress:

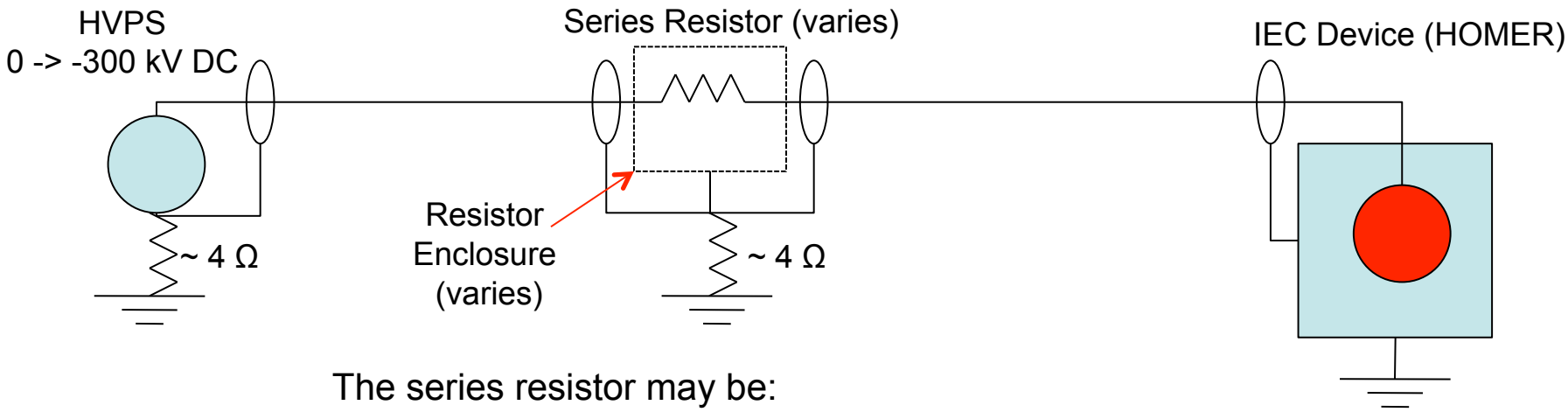
- System stability studies, focusing on the series impedance placed between the HVPS and an IEC device
- Adapting the revised HELIOS vacuum feed-through for use as a temporary feed-through for HOMER (see Fancher presentation 11:30 Thursday)

Anticipated: Cathode grid adaptation

System Stability

- Review of observations, previously reported, from recent years
- What has been found since
- The planned next steps

System Configurations Referenced:



The series resistor may be:

- The present / old resistor barrel: A 250 kΩ string mounted in 55-gallon drum (used for at least 7 years).
- A resistor embedded in a high-voltage switch assembly, having values between 0 and 1 MΩ.
- A temporary resistor array suspended in the switch enclosure, in place of the switch mechanism.

A Brief Review of Prior Results of High Potential (no plasma) Testing:

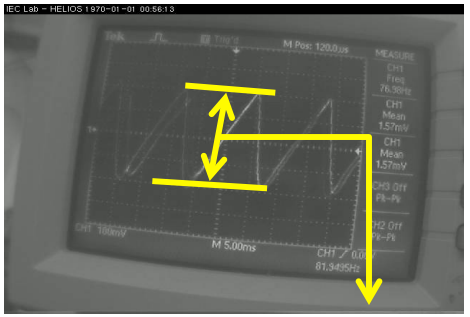
- Present Resistor Barrel → No arcs in IEC device during the test
  現在の抵抗器バレル：テスト中には IEC デバイスのなかで電気アークは発生しなかった

- New Switch and Resistor → Arcs and auto-shutdown in IEC device @ 60 kV DC
  新しいスイッチと抵抗器：電気アークおよび IEC デバイス の自動シャットダウン（60 kV DC）

A Brief Review of Prior Results of High Potential (no plasma) Testing:

Signal on HV feed-through
(AC–coupled measurement)

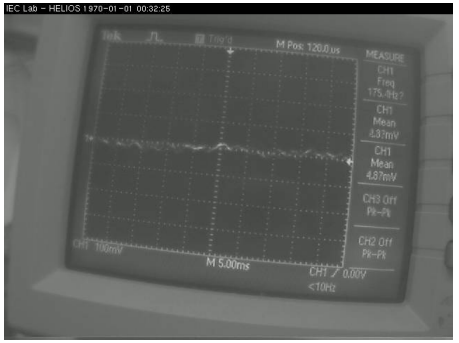
When the HVPS was connected via the switch to an IEC device, the system functioned like a **relaxation oscillator**.
高圧電源（HVPS）をこのスイッチを介して慣性静電閉じ込め（IEC）装置に接続すると、システムは弛緩発振回路として機能した。



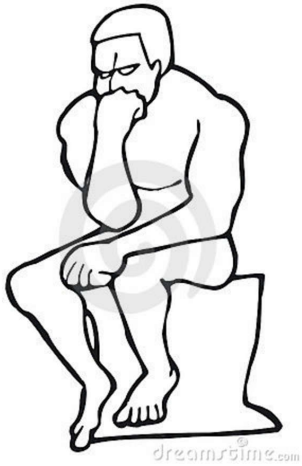
6900 Vp-p

➔ Sawtooth Oscillation!

It does not do this if connected via the old resistor barrel.
しかし、従来のレジスタ・バレルを介して接続した場合は、そのように機能することはない。



➔ NO oscillation



WHY ?!?

なぜですか？!?

Course of Action:

- Remove switch internals and place on rack for “off-line” analysis and, as necessary, modification.

- Design and build a temporary simple, temporary, non-switched resistor network and place in the switch tank to use while this is being done.

HOWEVER, *this process was suspended as we suddenly needed to re-direct our efforts and resources to implement a sudden laboratory expansion.*

Since last year’s (2013) conference, this expansion and adaptation is almost complete.

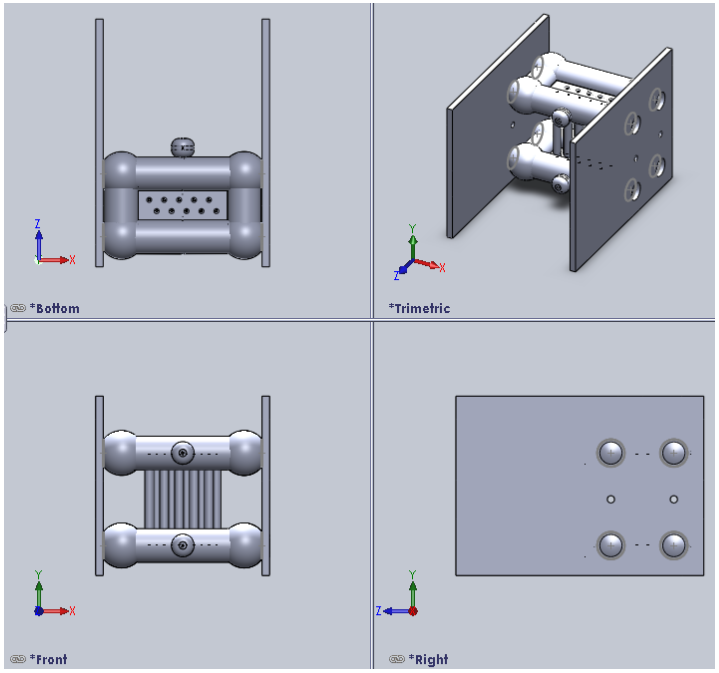
Interim Series Resistor in lieu of HV switch

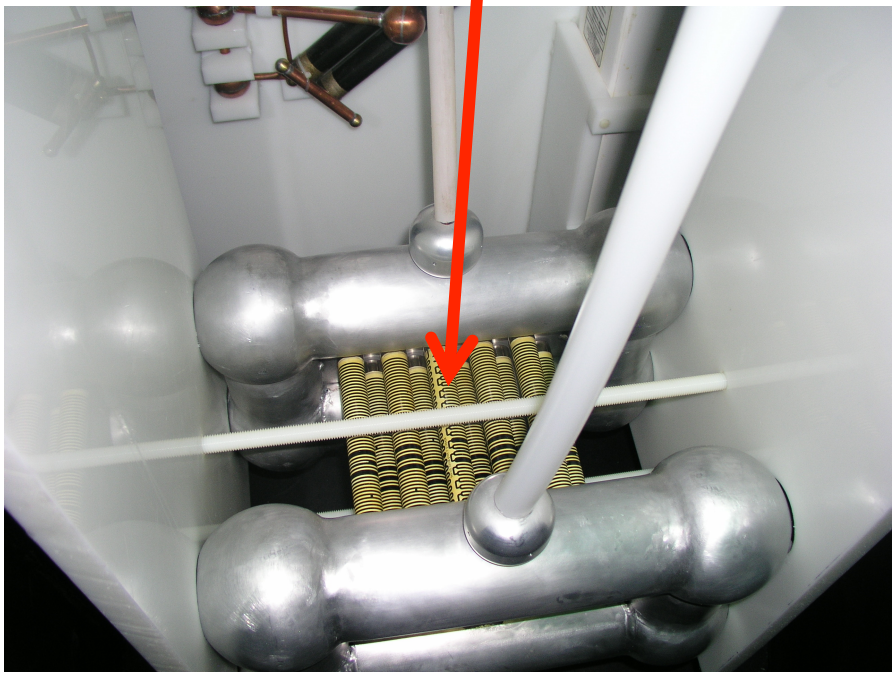
As the system operates stably via the old resistor barrel, it was thought that a simple 300 kV resistor array would likely also allow for stable operation in the interim. Specifications:

- Fixed resistance (50 kΩ)
- Low-inductance
- 200 mA capacity in oil
- Good to 300 kV DC in oil while in the switch tank
- Can be interfaced to pulsing capacitor

Interim Series Resistor in lieu of HV switch

10 resistors in parallel, each 500 kΩ 100 W (air rating) low-inductance, polyamide (oil resistant) coating

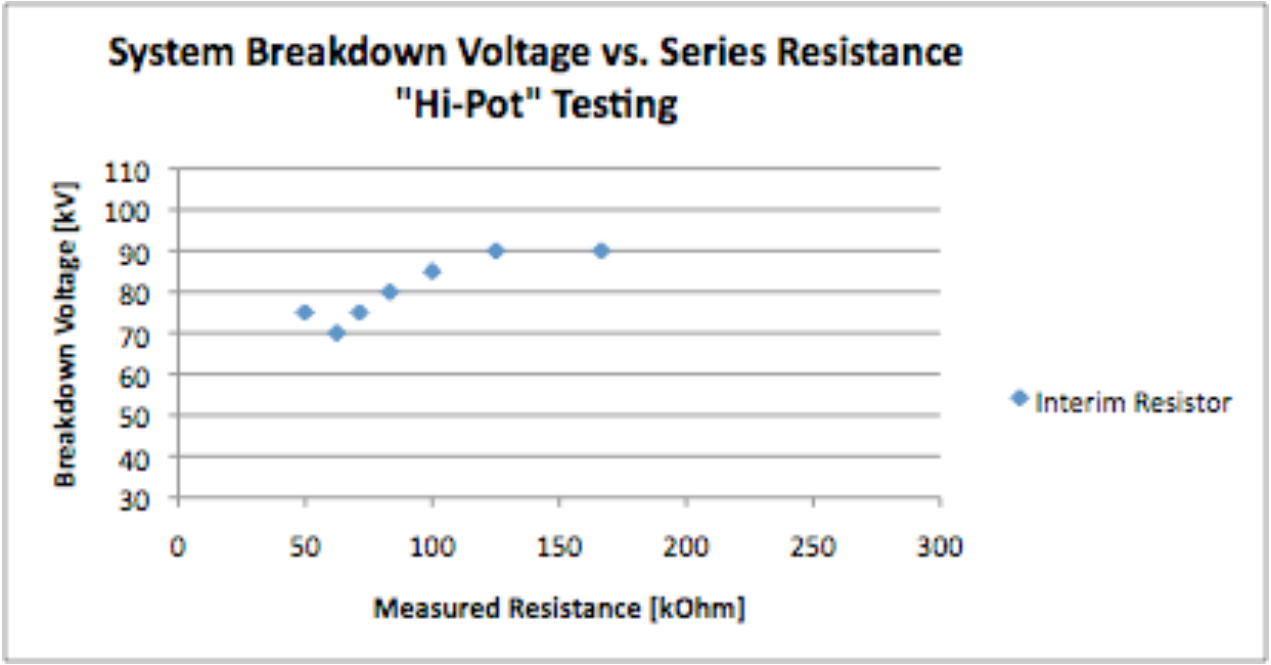




The interim resistor array, like the switch, passed “hi-pot” tests to 100 kV in air when **NOT** connected to an IEC device.

System Stability and Series Resistance

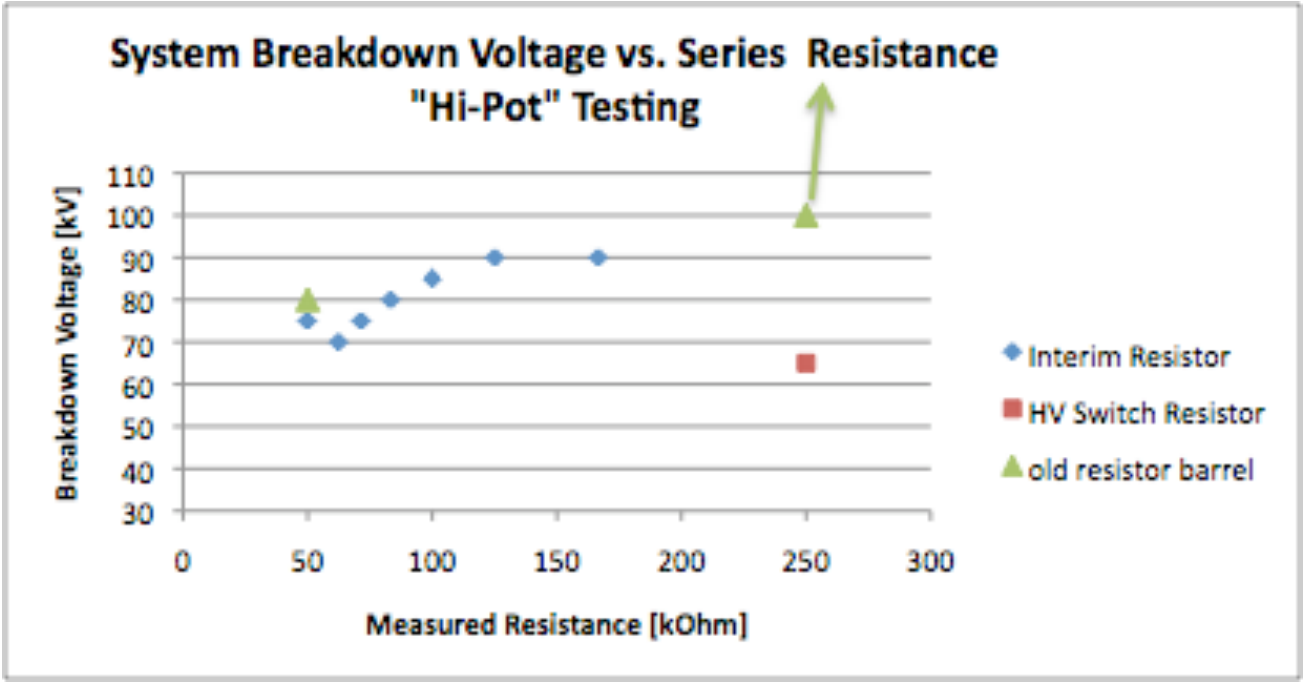
The resistance of the interim resistor array was varied by removing individual resistors from the array, with these results:



The system with the interim resistor assembly is not stable either! Breakdown voltages generally increased with increasing resistance.

System Stability and Series Resistance

The interim resistor array gives more system stability than the switch resistor, but does not give the system the stability it has with the old resistor barrel with the a 250 kΩ string.



If the old resistor barrel is modified to have only 50 kΩ resistance, then the system is also unstable

System Stability and Series Resistance

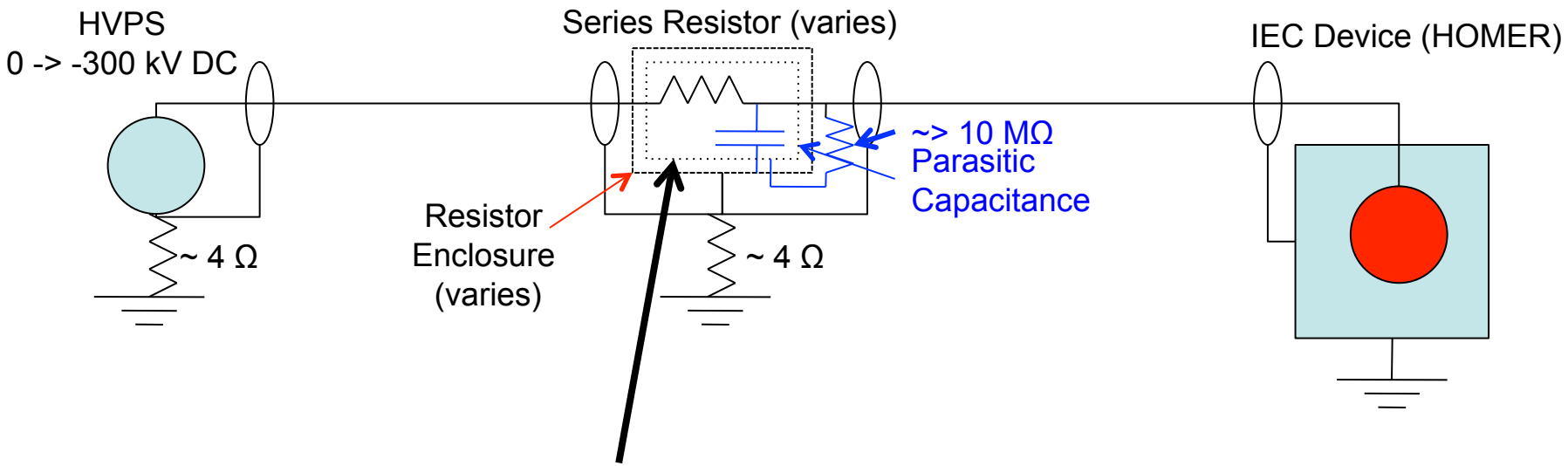
- The system is stable to above 200 kV DC with the old resistor barrel in its normal 250 kΩ configuration.
- The system is NOT stable if the old barrel resistance is reduced to 50 kΩ.
- The system is NOT stable to that level with the interim resistor array.
- The system is NOT stable with the switch resistor, at any attempted resistance.
- However, it is **desirable** to be able to run with lower series resistances to avoid large voltage drops and high power dissipation when running at higher currents.

The Next Steps

•Our suspicion continues to be that the greater parasitic capacitance resulting from the larger conductor sizes in the switch, and, to a lesser extent, in the interim resistor array, are somehow facilitating the formation or sustaining of the observed micro-arcs.

•In addition to attempting to critically damp such arcs, we will also experiment with using driven guard shielding to reduce the parasitic capacitance.

Driven Guard Shield Concept



A driven guard shield, properly designed, should greatly reduce the parasitic capacitance that exists between the series resistor assembly and the enclosure.

Concluding Summary

- Unanticipated system stability issues arising as an apparent consequence of electrode dimensions and parasitic capacitance have been encountered by the UW IEC group

- The group is continuing to work to understand and over come this challenge, along with the other challenges involved in expanding our operational parameter space into the 200-300 kV DC range.

Acknowledgements

Grainger and Greatbatch Foundations
for their support of this research group's efforts

Dr. Jim Davis, UW – Madison
ウィスコンシン大学工学部のジェームス・デーヴィス教授
Yuri Chujo Davis
中條夕里
for assistance with translations into Japanese
英日翻訳

Questions?

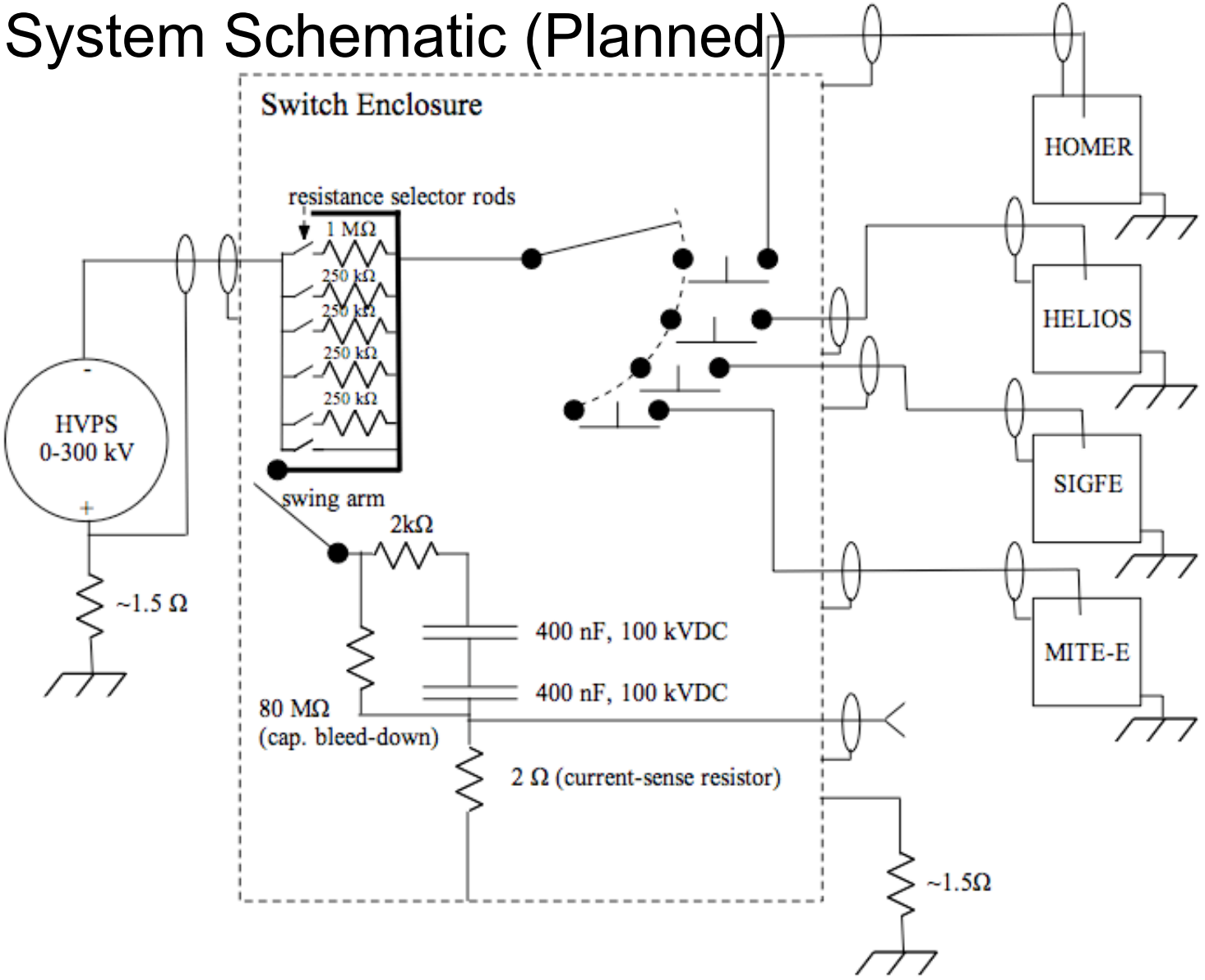
BACK-UP SLIDES

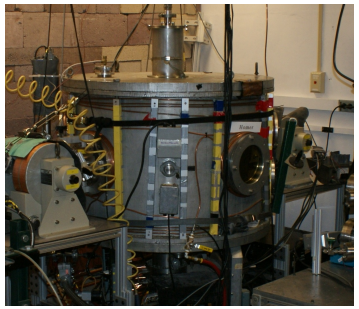
High Voltage Switch and Series Resistance Assembly

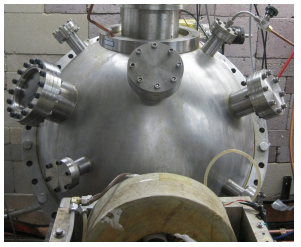
Specifications:

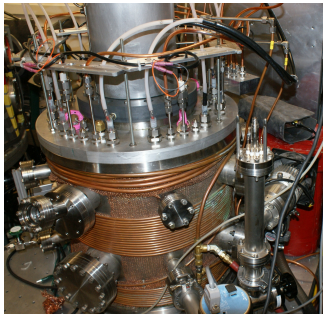
1. Cold-switch the high-voltage power supply among four different devices.
2. Removing and replacing cables not to be required.
3. Non-inductive series resistor of 50 kΩ able to carry 200 mA current in steady state.
4. Resistor to be adjustable to higher resistances (though at a lower current), and completely by-passable.
5. Pulsing capacitor and related equipment is to be in the same enclosure as the switch.

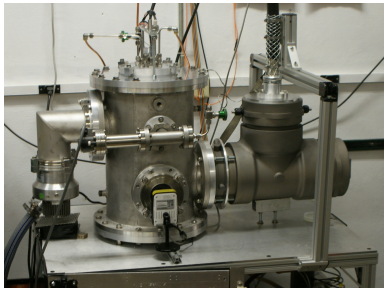
System Schematic (Planned)





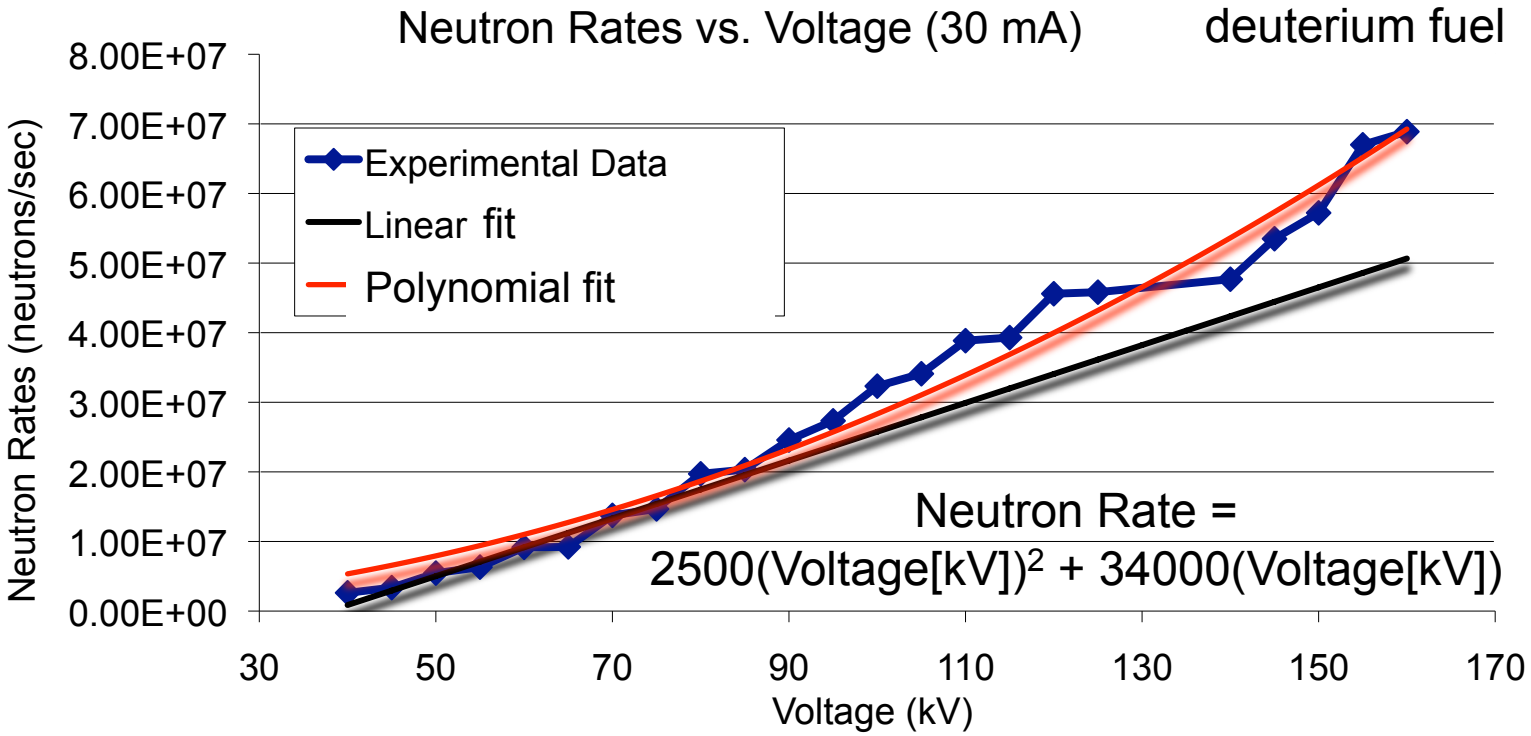






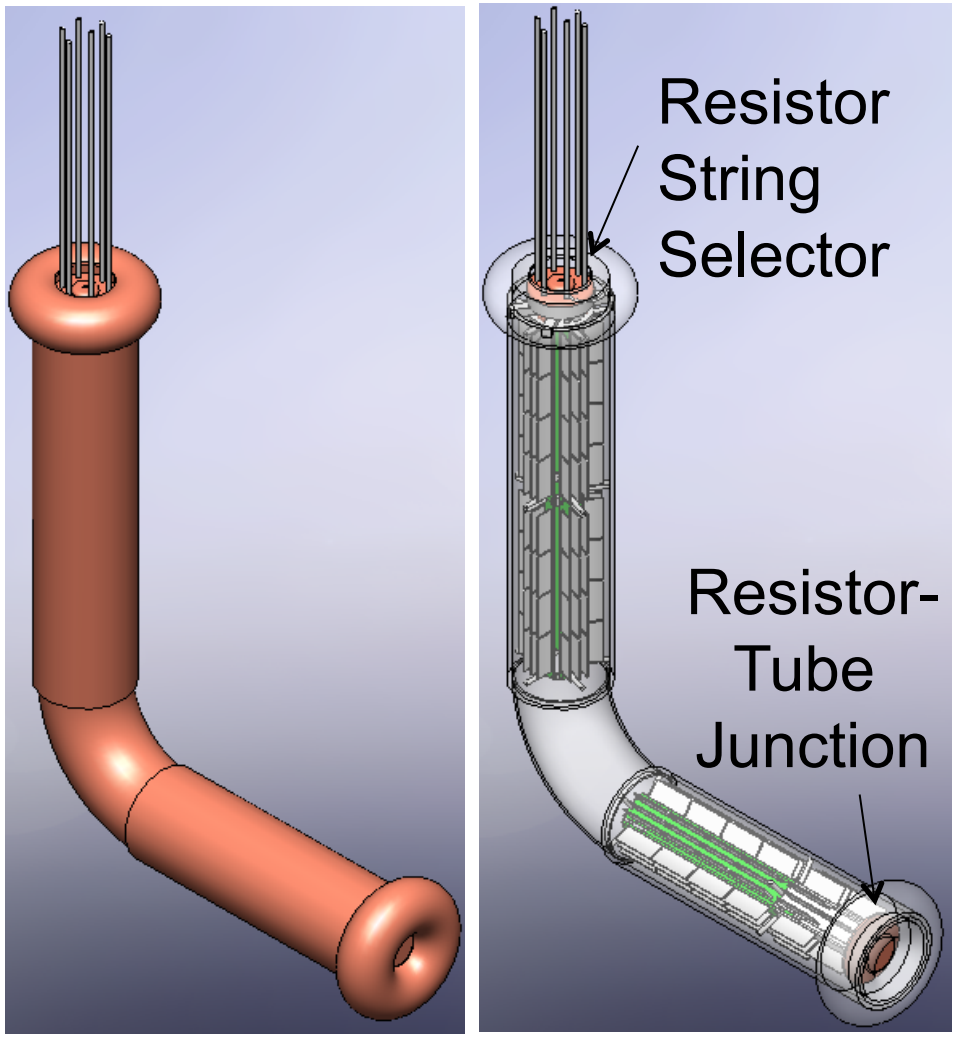
Motivation for Using Greater Cathode Voltages

- Neutron flux appears to be monotonically increasing with voltage (greater voltage ==> more neutrons)

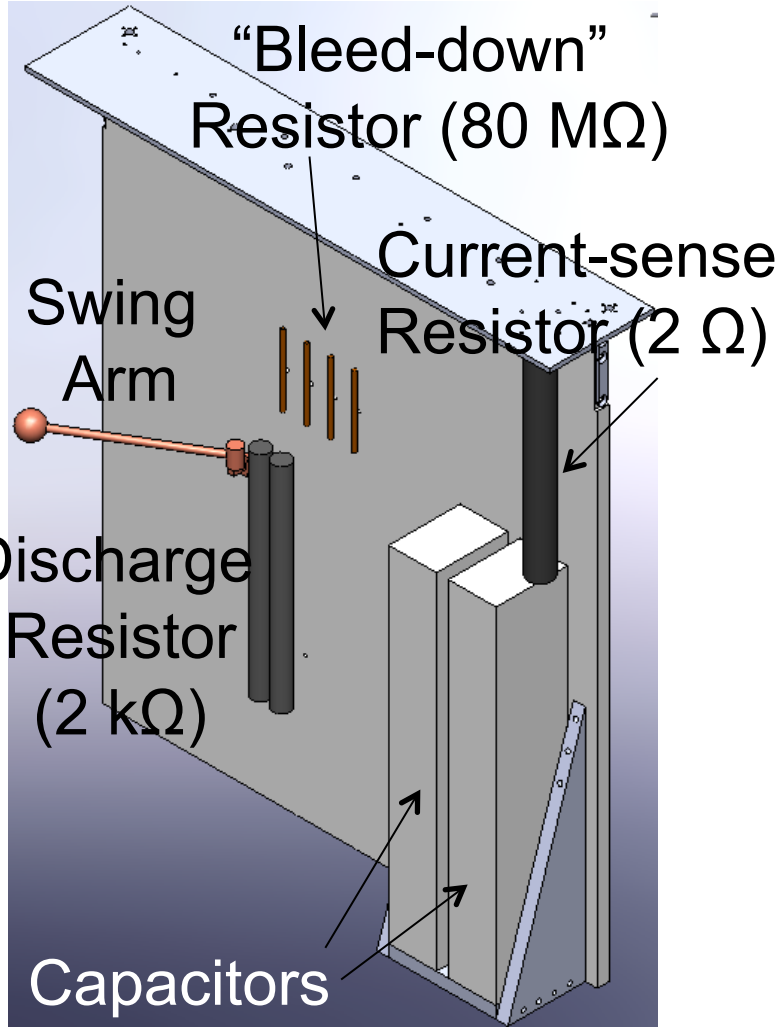


From 2008 Workshop Donovan presentation (WE-08)

Resistor System

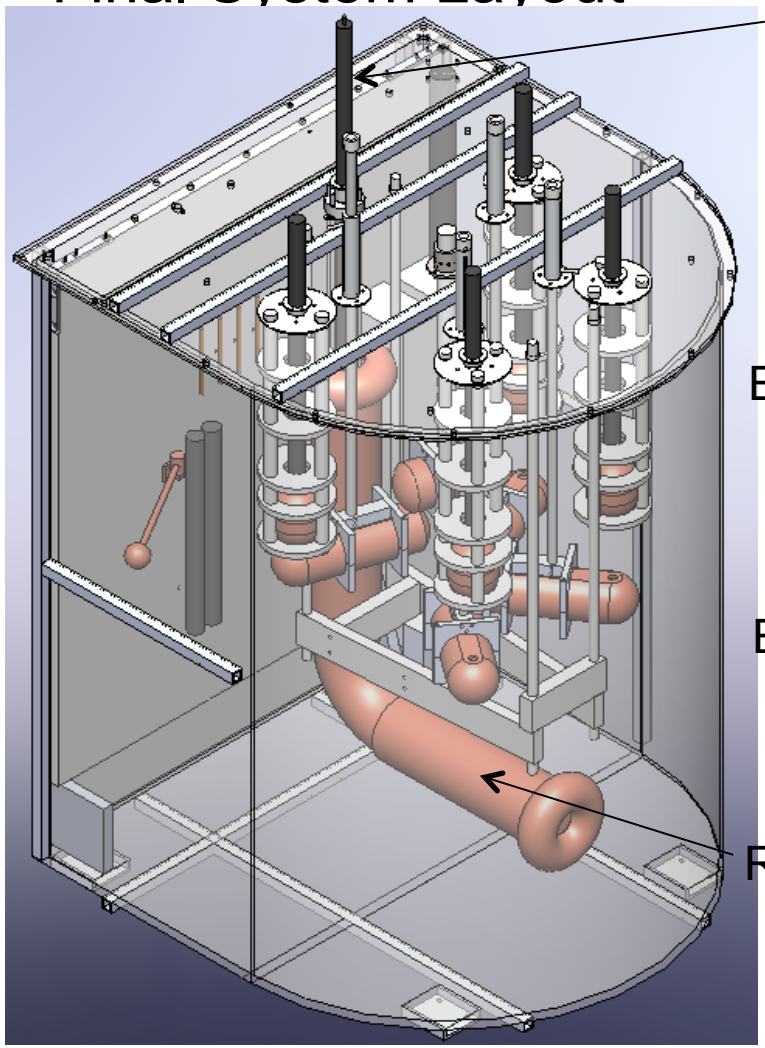


Capacitor System

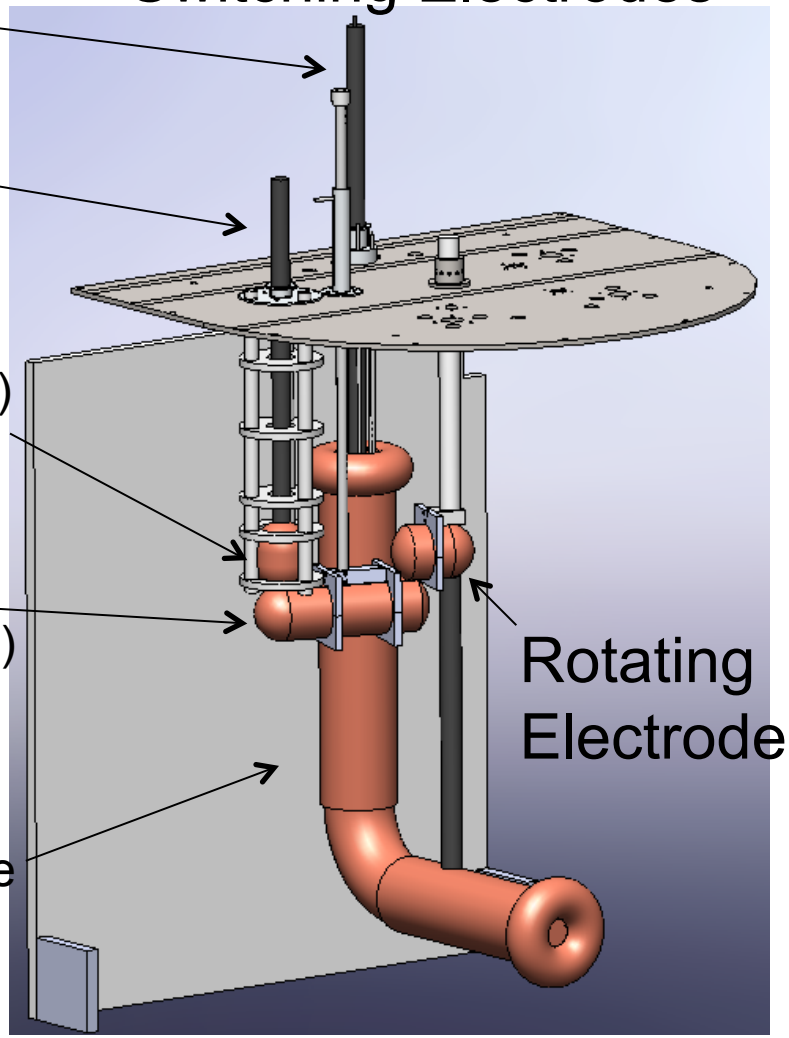


HV Switching

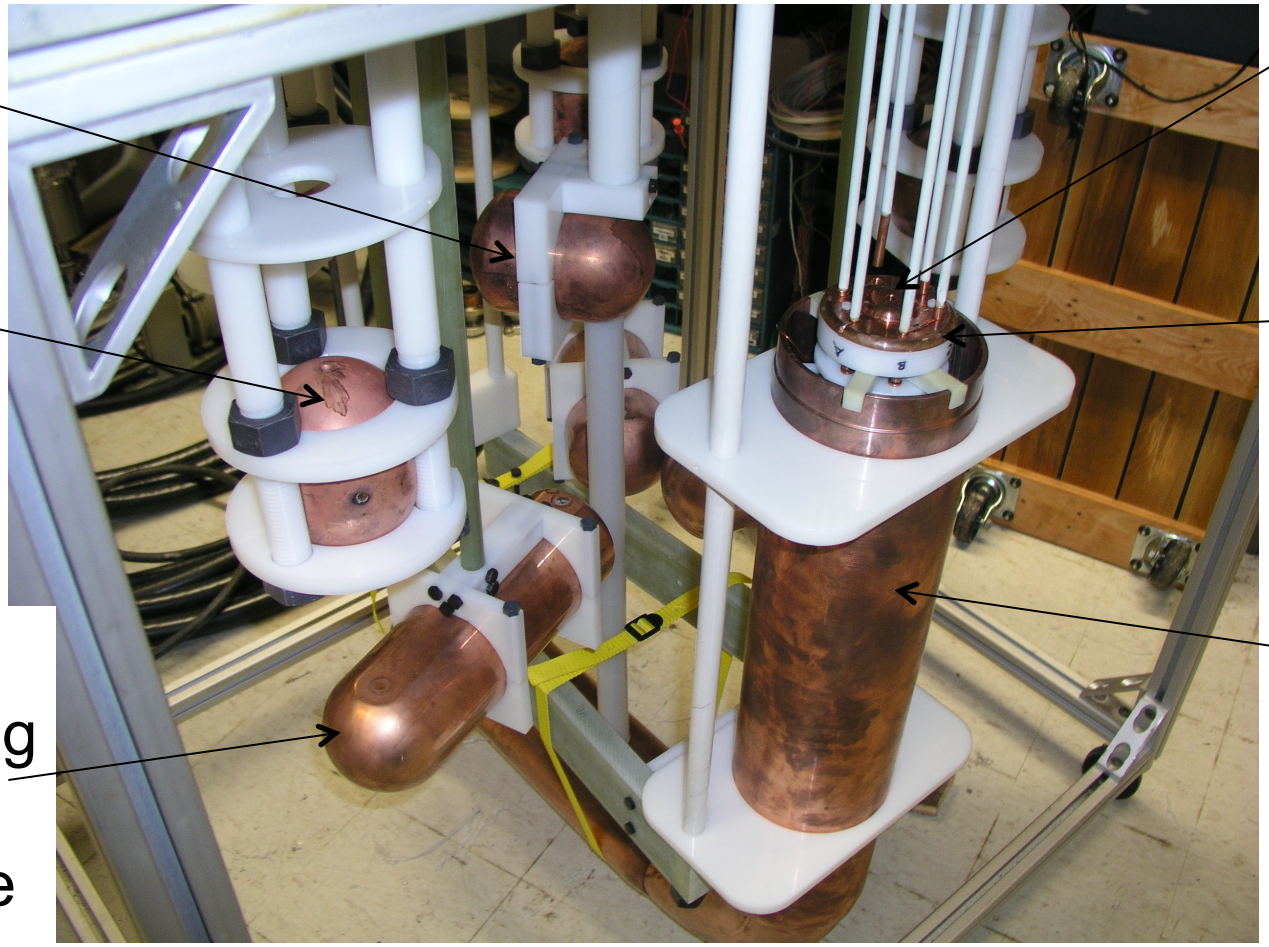
Final System Layout



Switching Electrodes



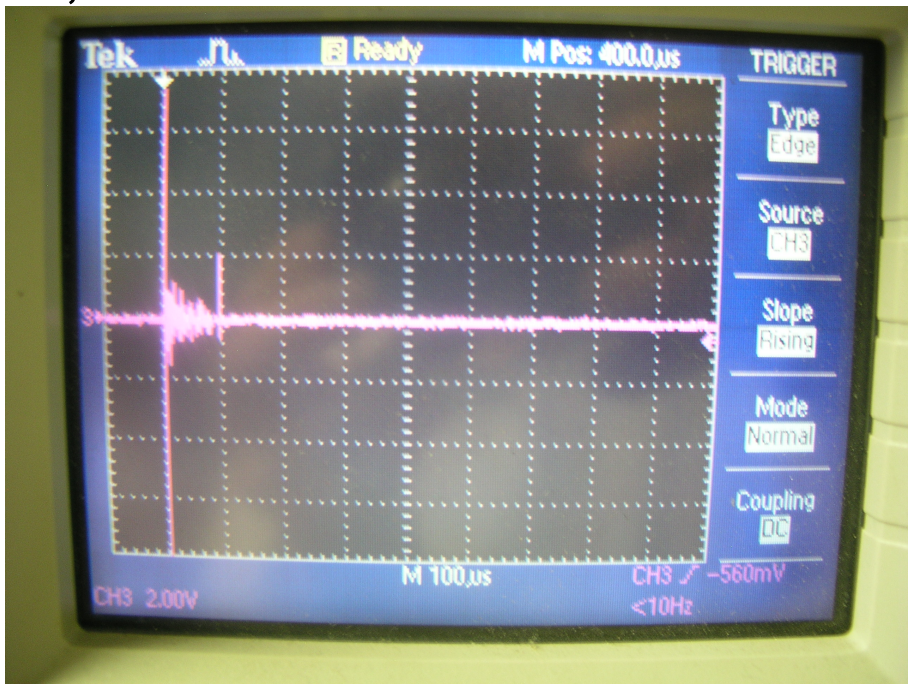
Implementation: Electrode Assembly



System Testing: High-Potential Test to 100 kV without Dielectric Oil with Switch in line

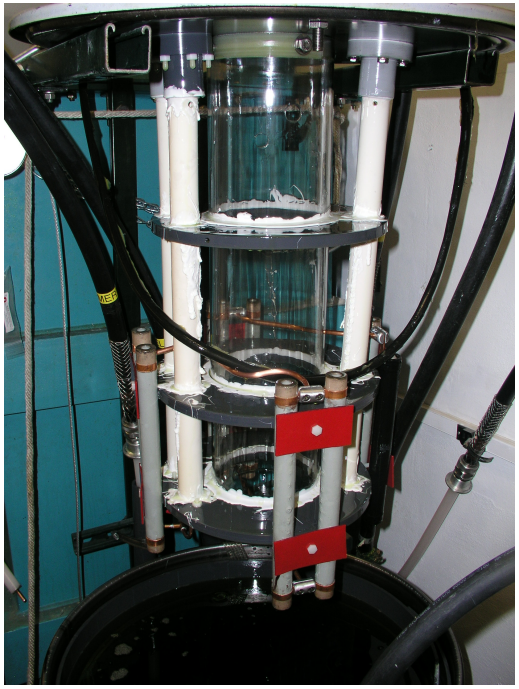
Result: Unexpected, very short-time-scale arcs occurred in IEC devices (NOT in the switch) when they were connected via the new switch, but not otherwise!

Vertical scale is 1 A / division: arc peak current is off scale!



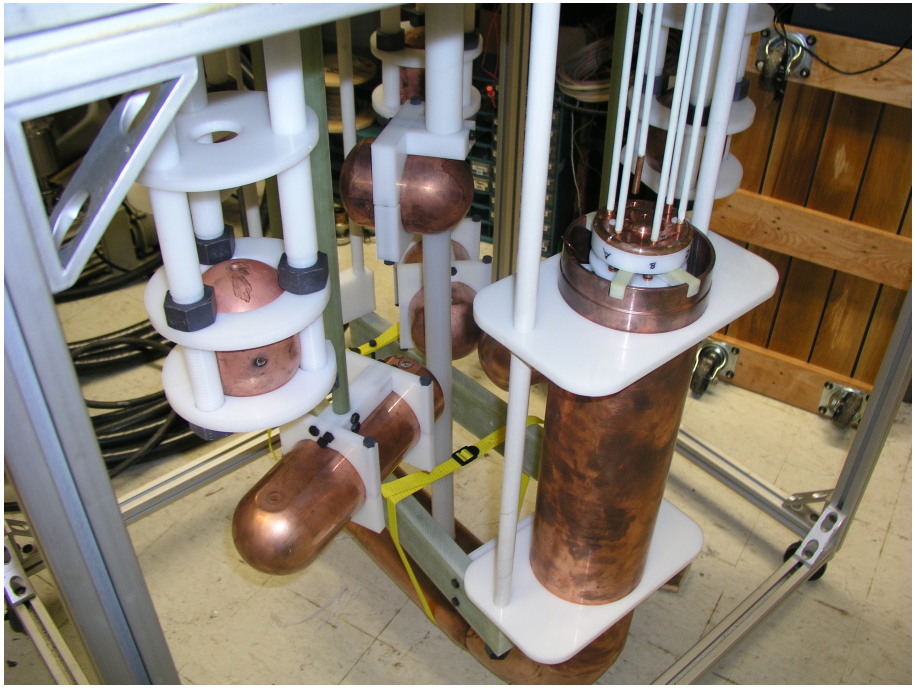
Arc duration is approx. 100 µsec.

System High Potential Test to 100 kV DC (no oil)
システムテスト: 高いポテンシャル 100 kV DC (まで; 油を使用せずに)



Present Resistor Barrel → No arcs in IEC device during the test

現在の抵抗器バレル: テスト中には IEC デバイスのなかで電気アークは発生しなかった



New Switch and Resistor → Arcs and auto-shutdown in IEC device @ 60 kV DC

新しいスイッチと抵抗器: 電気アークおよび IEC デバイス の自動シャットダウン (60 kV DC)

Switch Progress and Status at that Time

- After much analysis and simulation, attempts were made to mitigate the arcing by using damping resistors in various locations, or by filtering the signal sent to the HVPS control system monitor.
- **These attempts failed. No mitigation of the micro-arcs and shutdown was achieved.**
- We decided to perform some direct observations of the output of the HVPS when connected through the switch using a high-voltage probe and an oscilloscope …

When the HVPS was connected via the switch to an IEC device, the system functioned like a **relaxation oscillator**.

高圧電源（HVPS）をこのスイッチを介して慣性静電閉じ込め（IEC）装置に接続すると、システムは弛緩発振回路として機能した。

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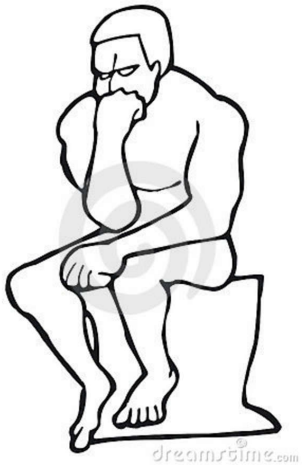
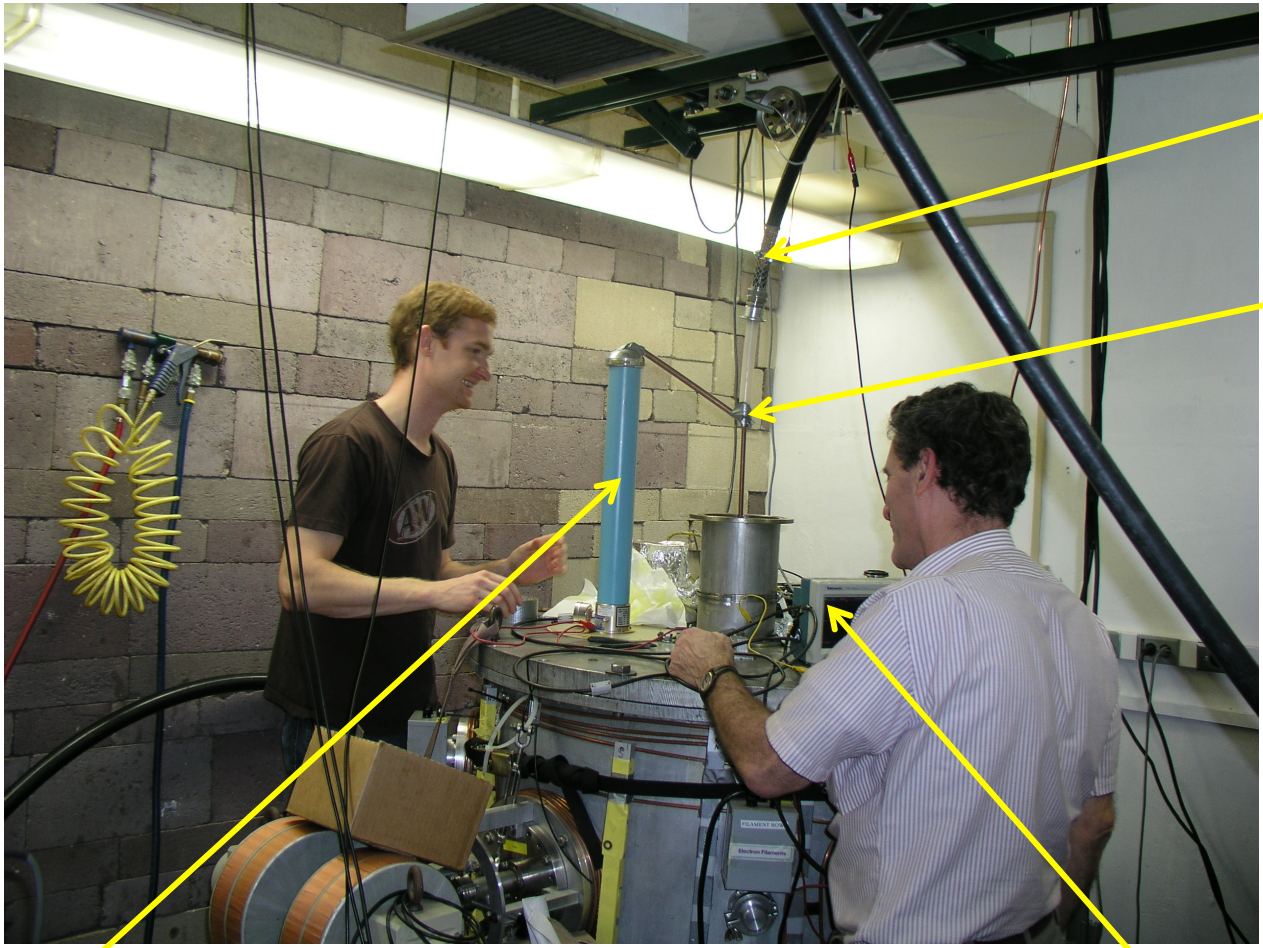


Again, WHY?!?

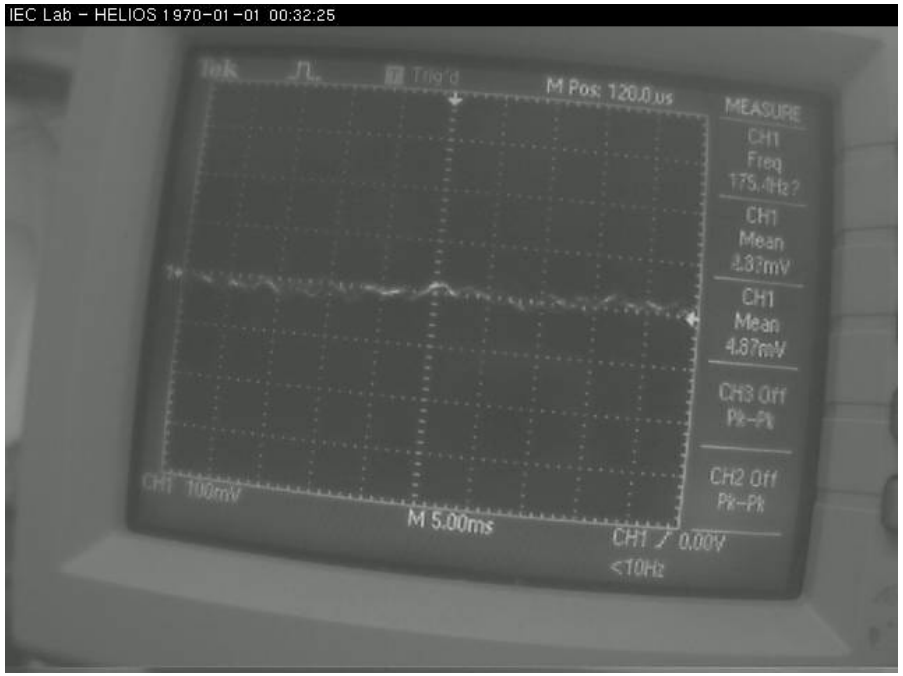
いったいなぜなのか？！？

The Set-Up


Active HV Cable
In-Air Junction
High-Voltage Probe
Oscilloscope

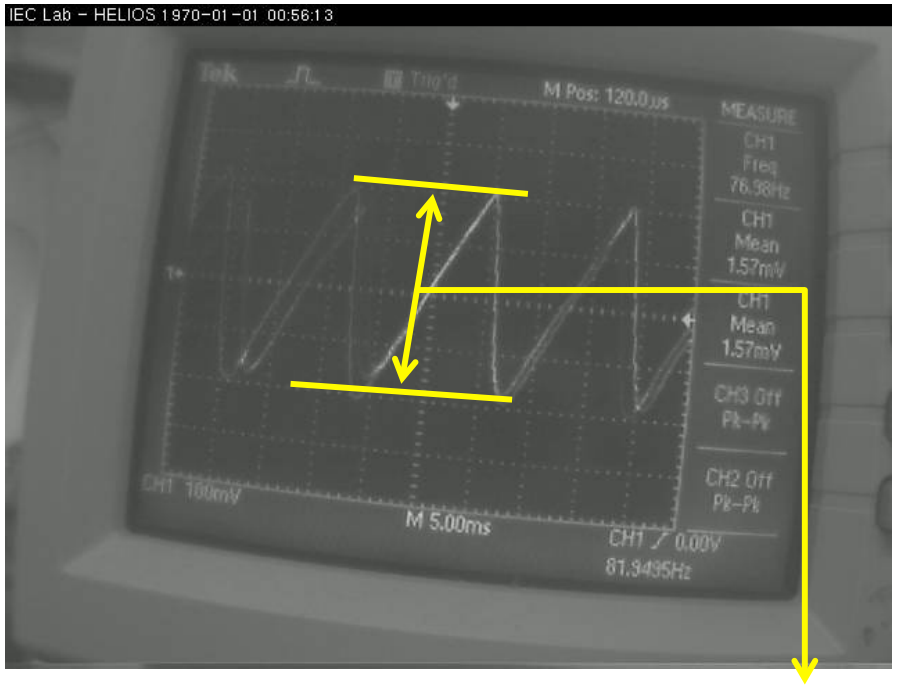
Direct observation yielded another surprise…

Through Present Resistor Barrel (30 kVDC)



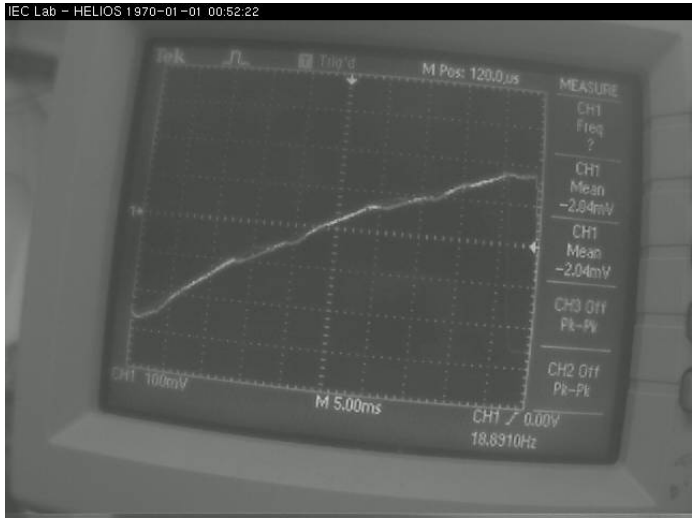
➔ NO oscillation

Through Switch (40 kVDC)



6900 Vp-p

➔ Sawtooth Oscillation!



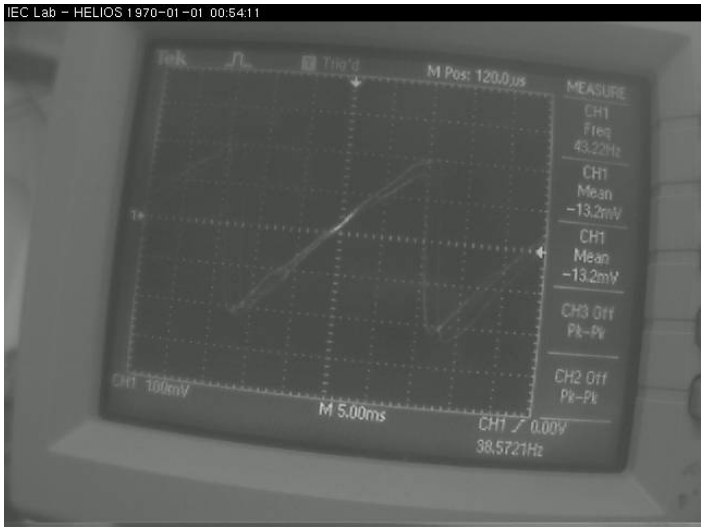
10 kV → 18.8 Hz

Observed:

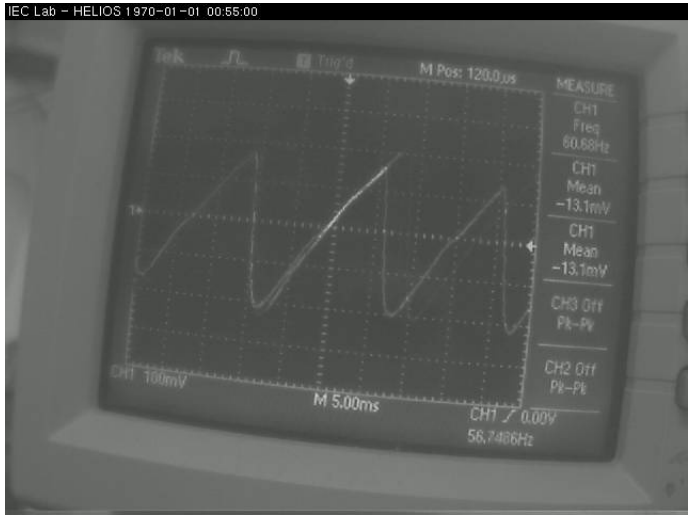
Increasing DC bias voltage

leads to

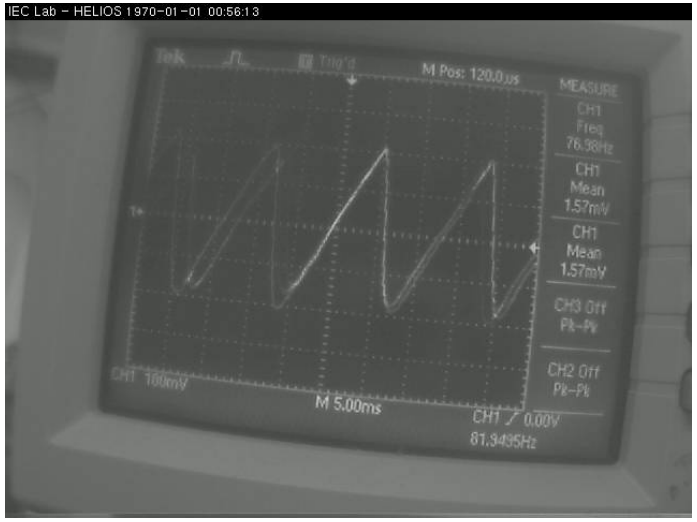
increasing sawtooth component frequency



20 kV → 38.6 Hz



30 kV → 56.7 Hz



40 kV → 61.3 Hz