Gas breakdown investigation and mitigation in complex geometries

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Outline

- **Introduction**
- Gas breakdown in complex geometry
- Breakdown mitigation techniques: grounded limiting discs
  - Experiments
  - Simulations
- Conclusions

Towards high-voltage satellite systems

From current bus voltages in the range **28-100 V**, evaluation of interest in using higher voltages, **up to 300-600 V**, is under way.

A**dvantages**:

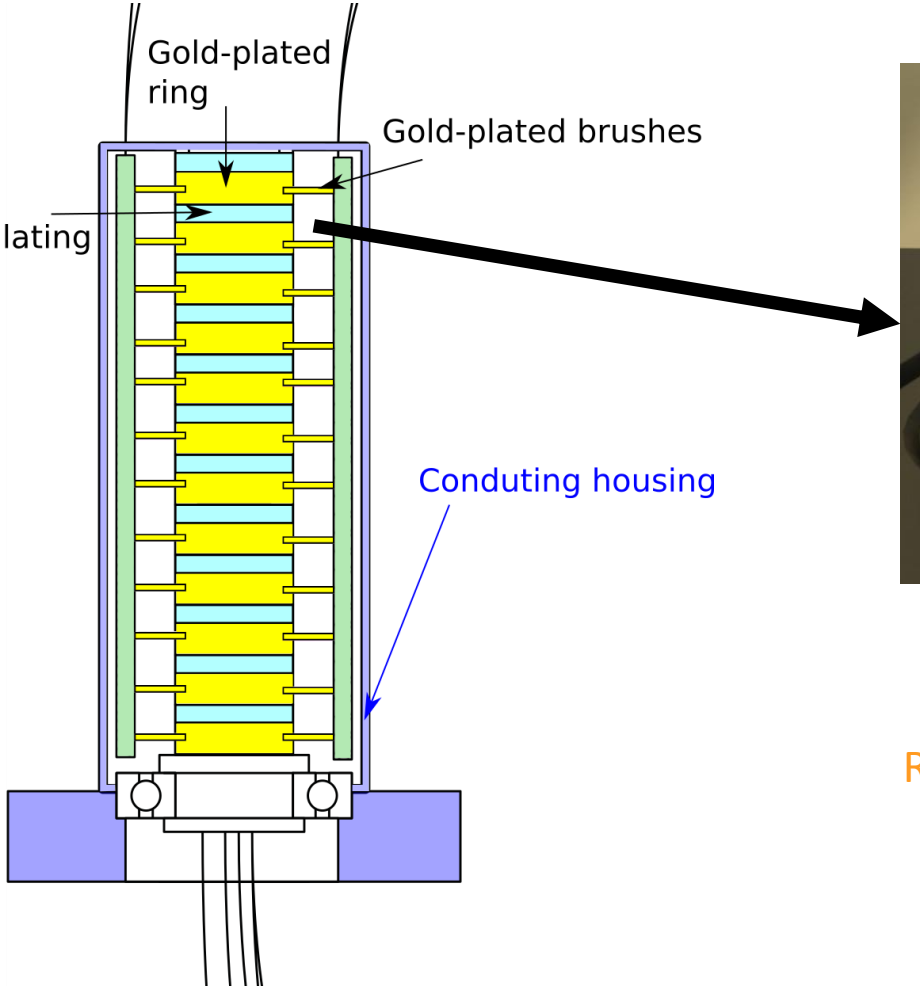
- Required for new generations of ion and Hall effect **thrusters.**
- Improved **power efficiency**
- **Cost reduction** (up to 30%)
- **Mass savings** (up to 50%)

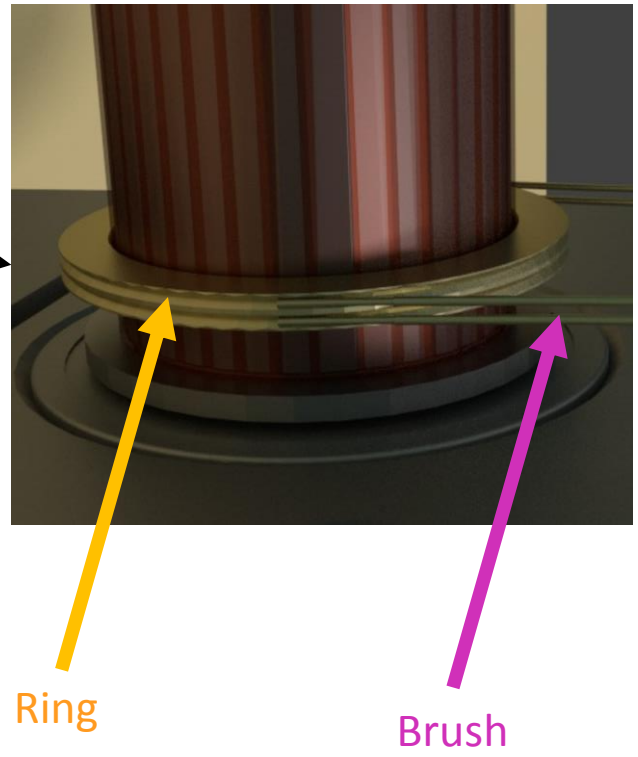
This implies a much higher **risk of electrical breakdown** at the solar panel level, or **in the slip ring assembly** (SRA).

HV-EPSA
HIGH VOLTAGE ENHANCED POWER SYSTEM ARCHITECTURE

Standard satellite slip ring design

Slip rings allow power transmission from the solar panels to the satellite, via gold-plated brushes slipping on gold-plated rings.

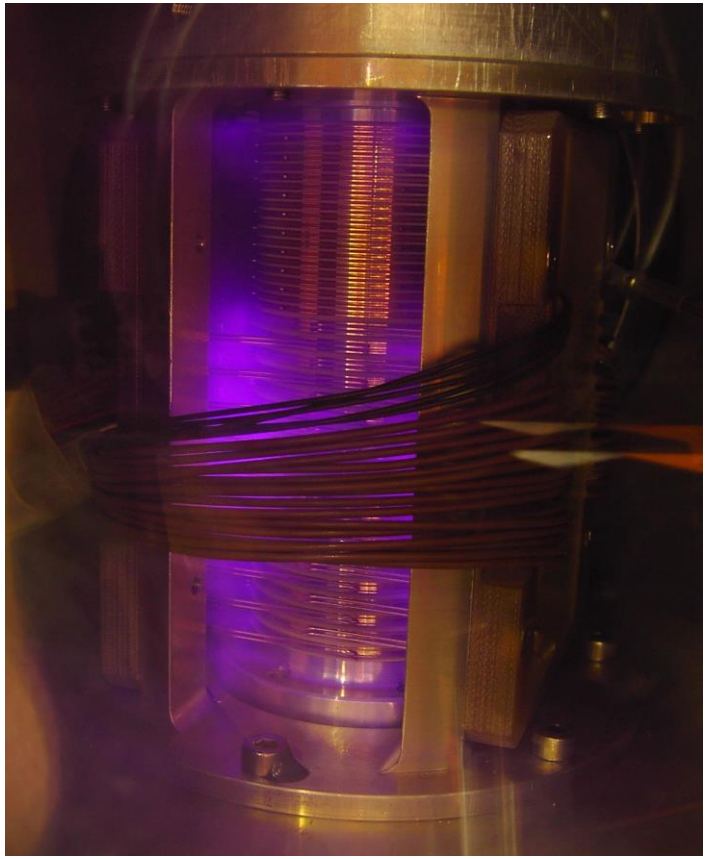




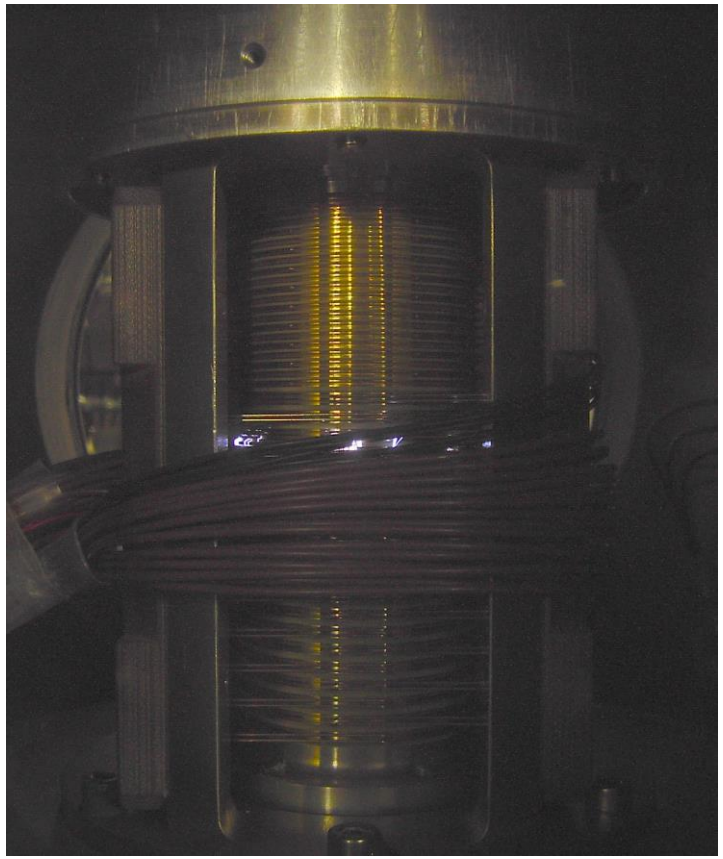
Breakdown in a slip ring

HV-EPSA
HIGH VOLTAGE ENHANCED POWER SYSTEM ARCHITECTURE

Diffuse corona

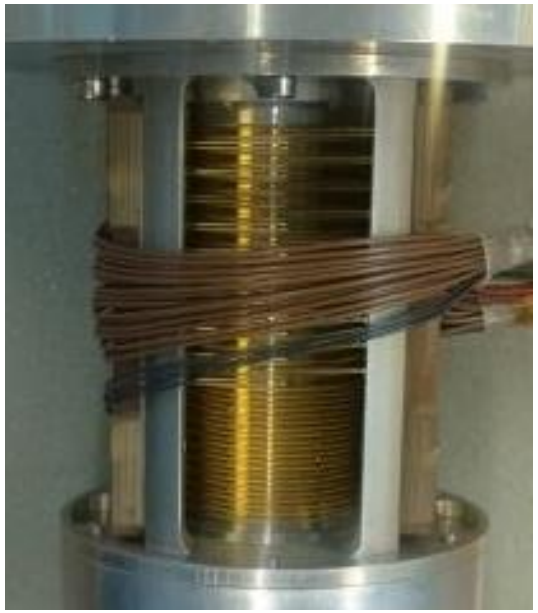


Localized arc

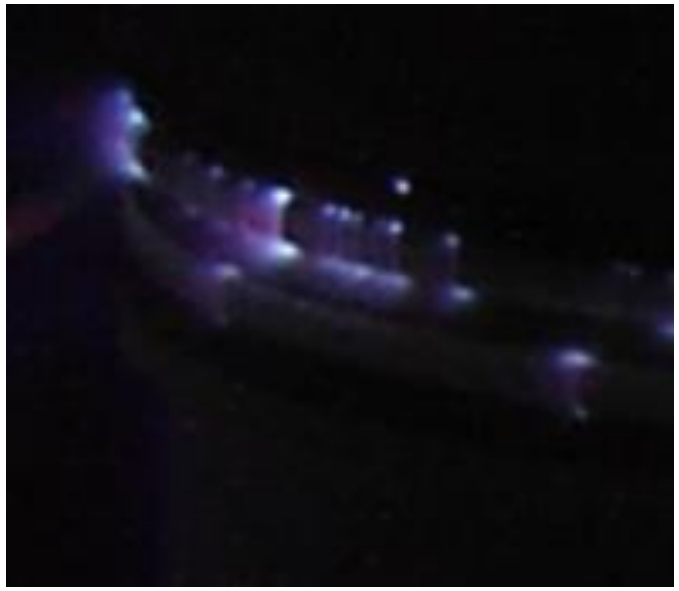


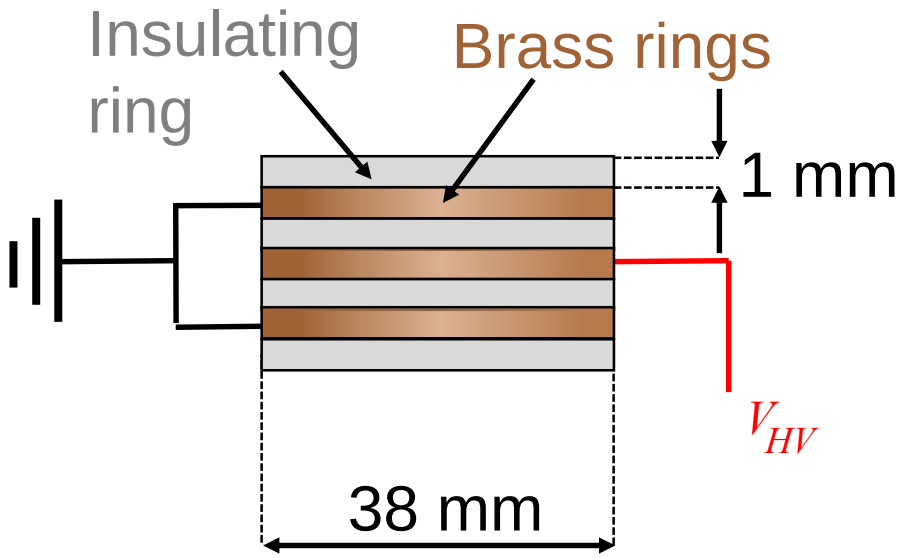
Slip ring mockup

Real slip ring assembly

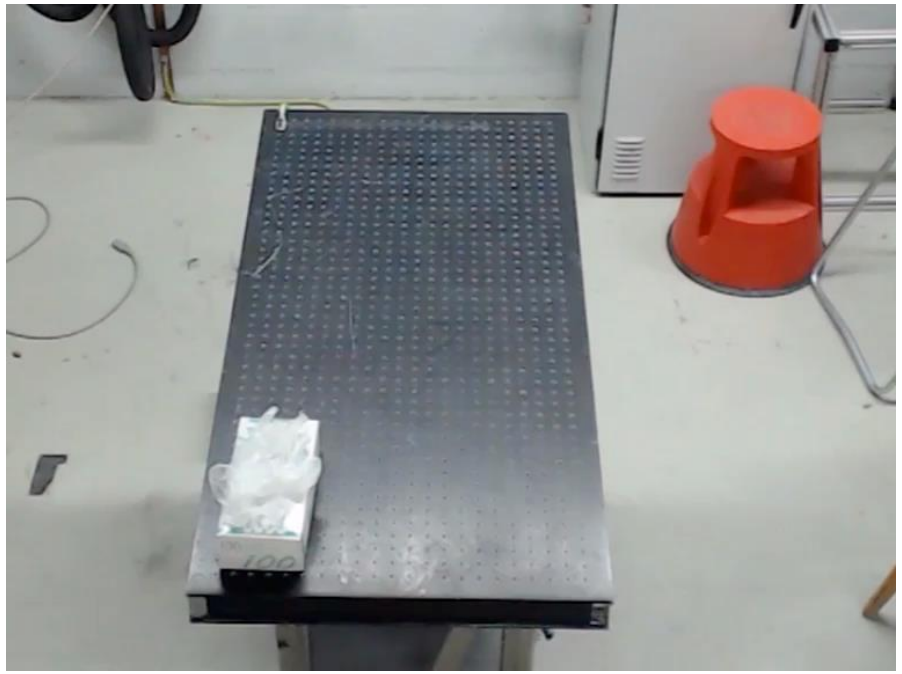


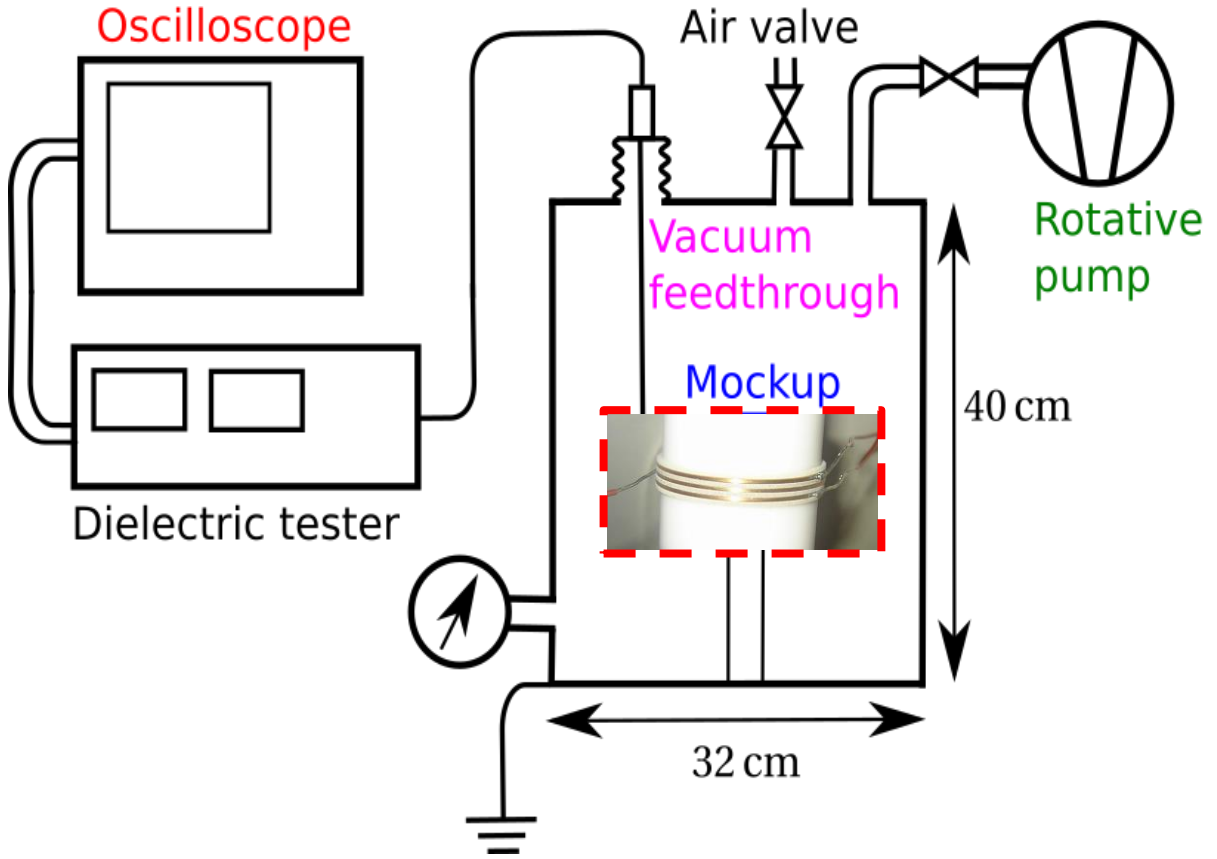
Slip ring assembly mockup



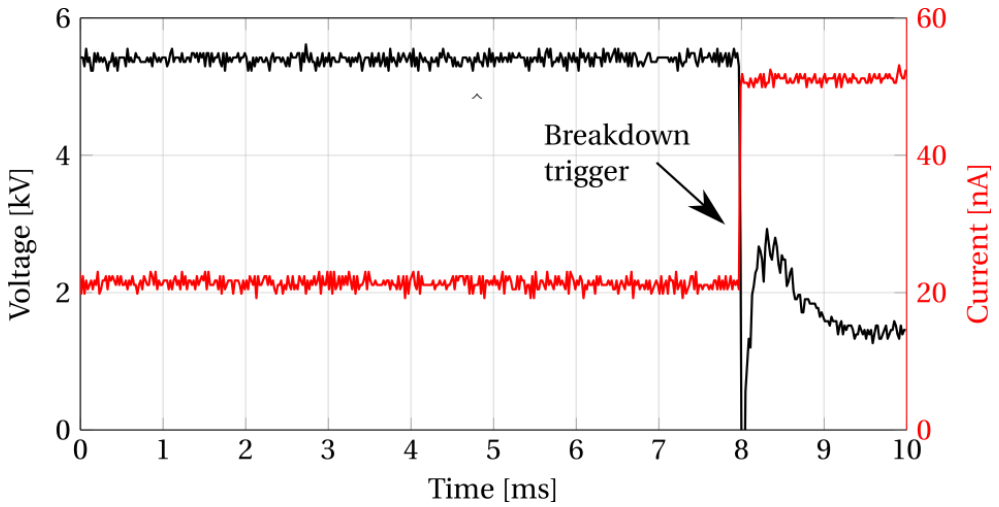


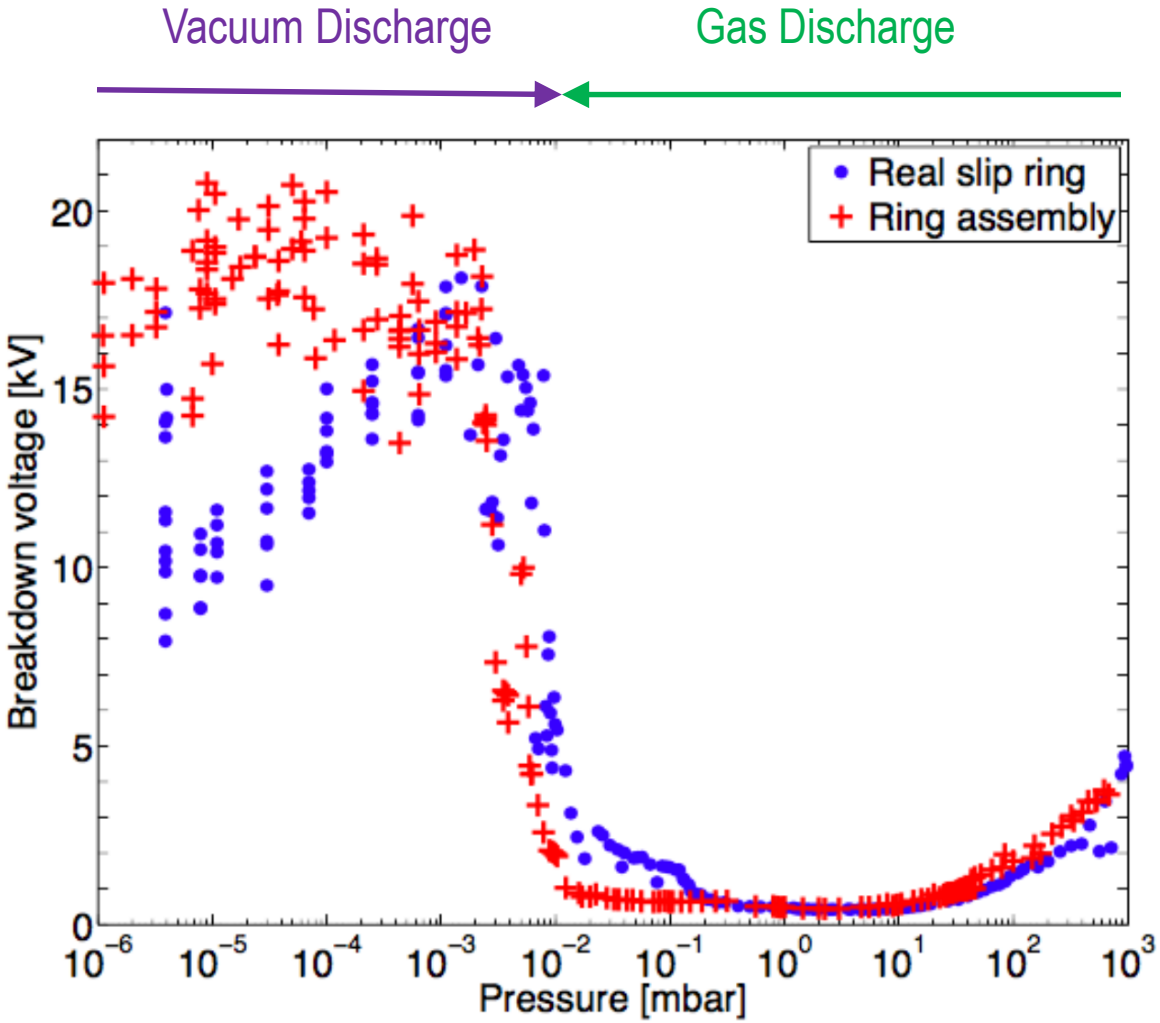
Experimental setup





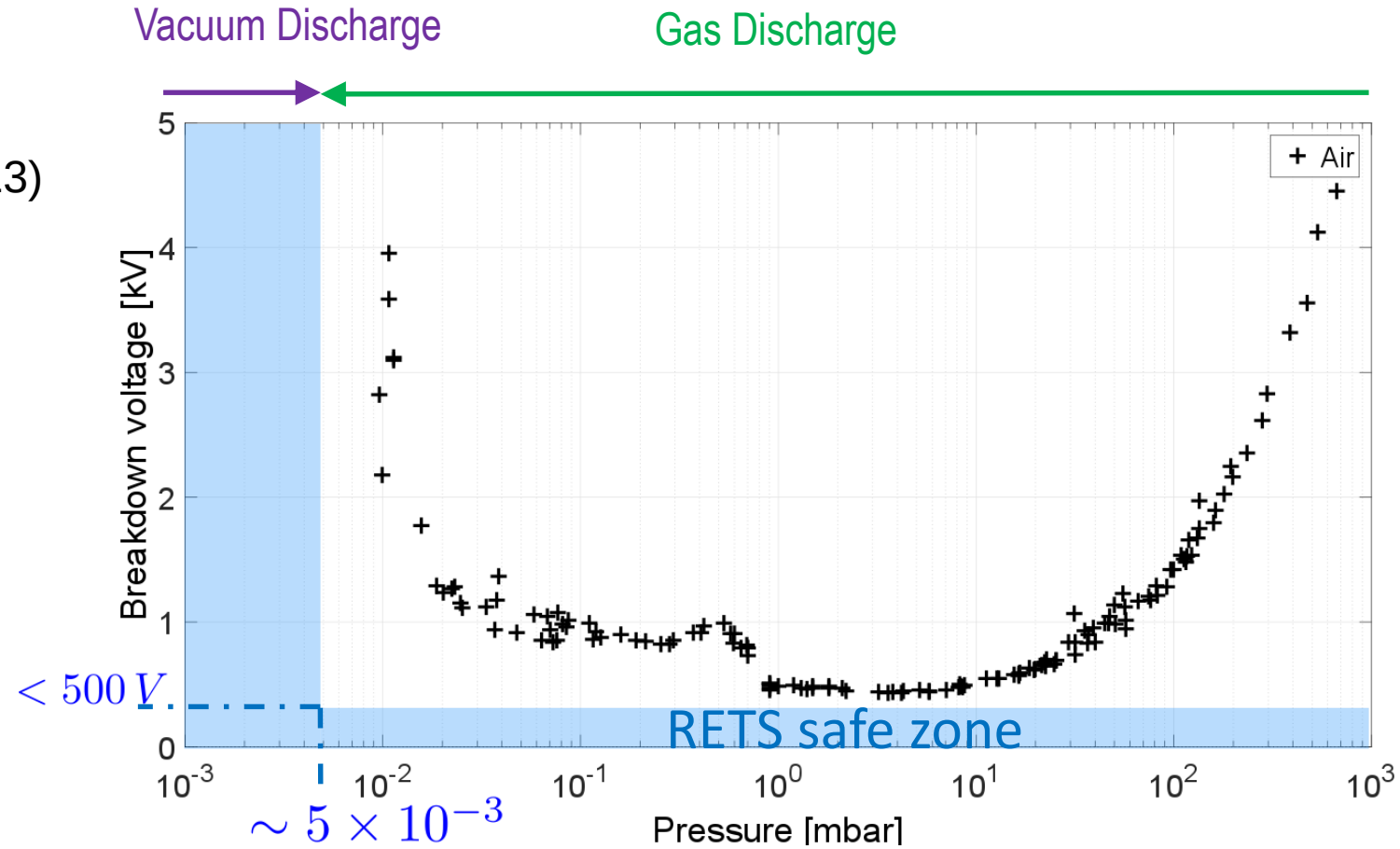
Breakdown curve of a slip ring in Air





“Robust Electrical Transfer System” safe zone

Schnyder et al.
J. Phys. D: Appl. Phys. **46** (2013)



OUR GOAL?

Improve the slip ring safe zone between 10^{-3} – 100 mbar

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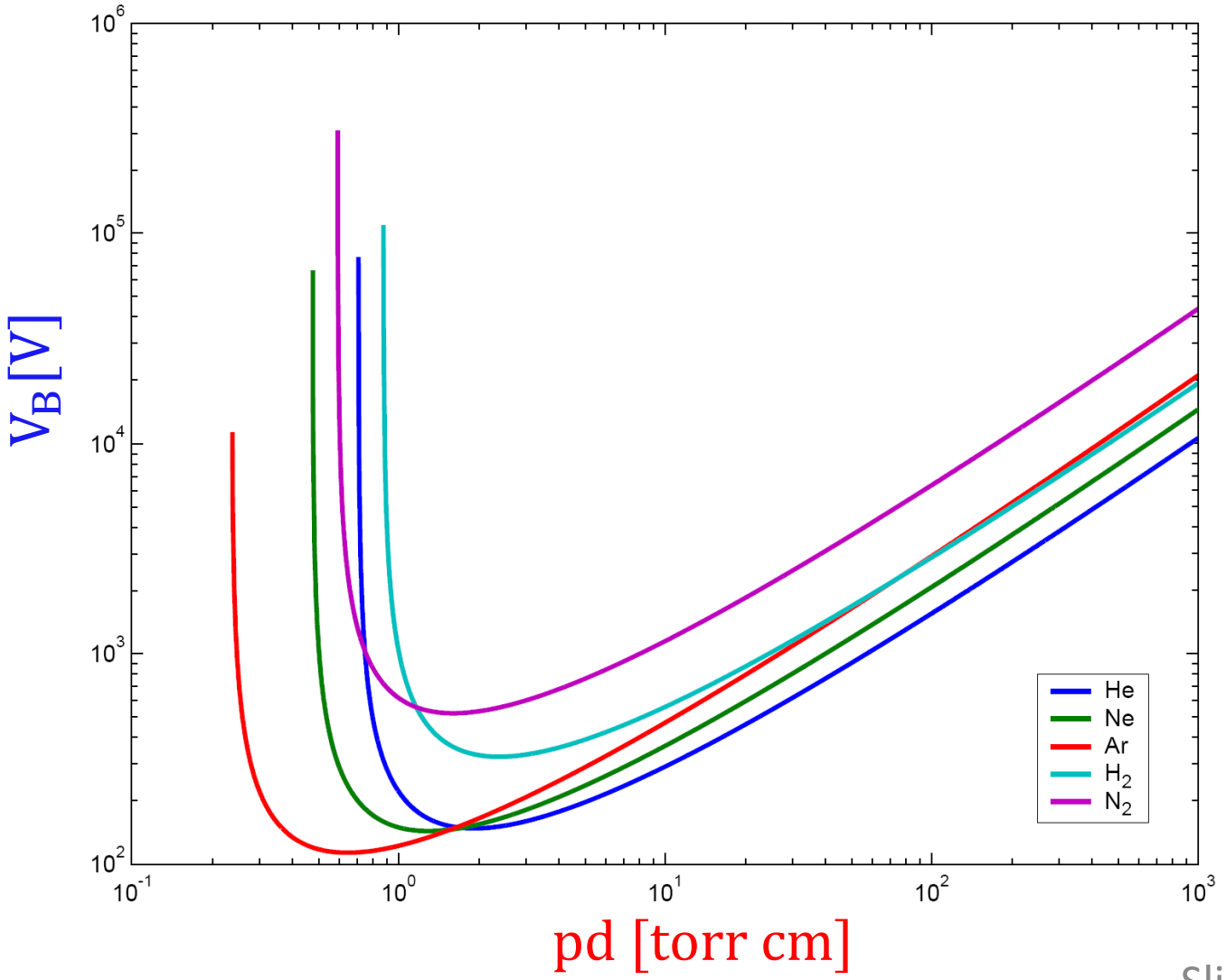
Paschen's law

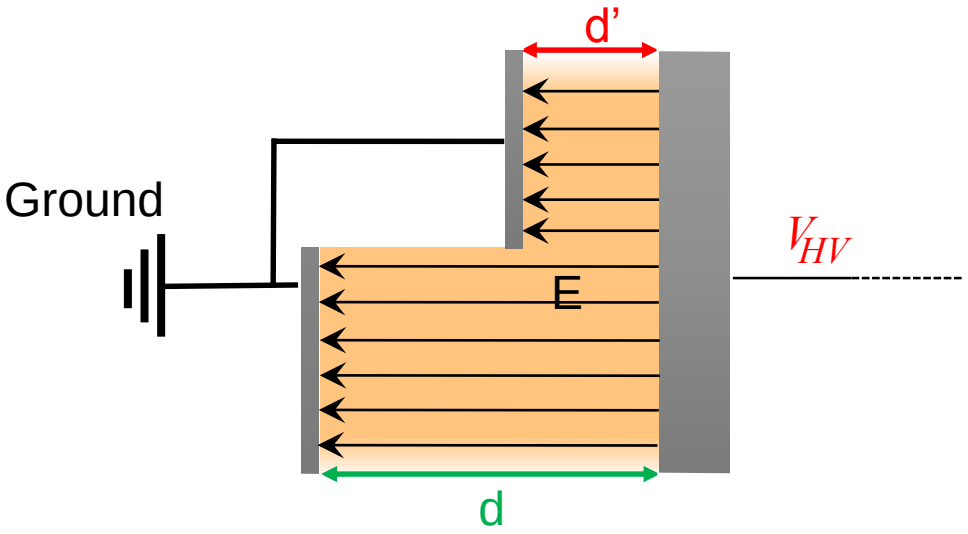
$$V_B = \frac{Bpd}{\ln(Apd) - \ln\left(\ln\left(1 + \frac{1}{\gamma}\right)\right)}$$

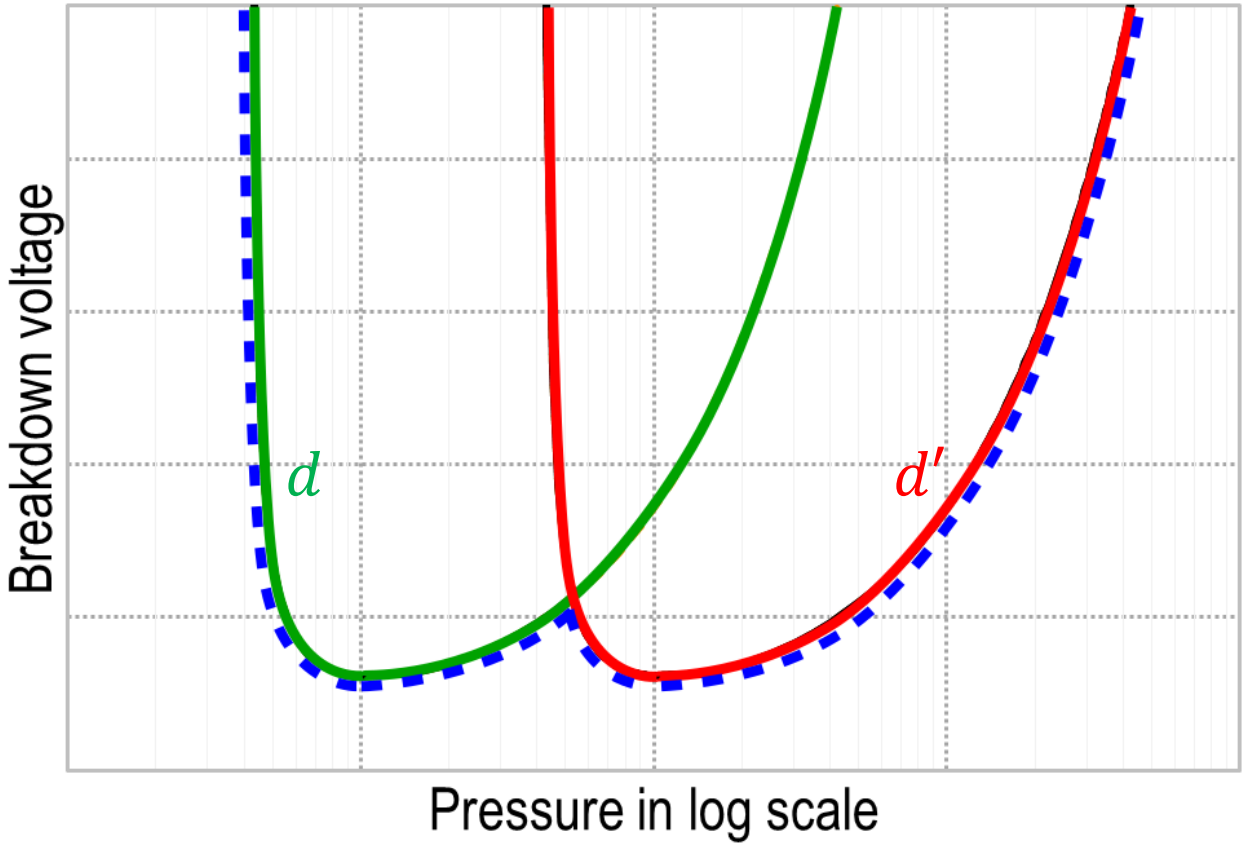
A, B = empirical coefficients

γ = secondary emission coefficient

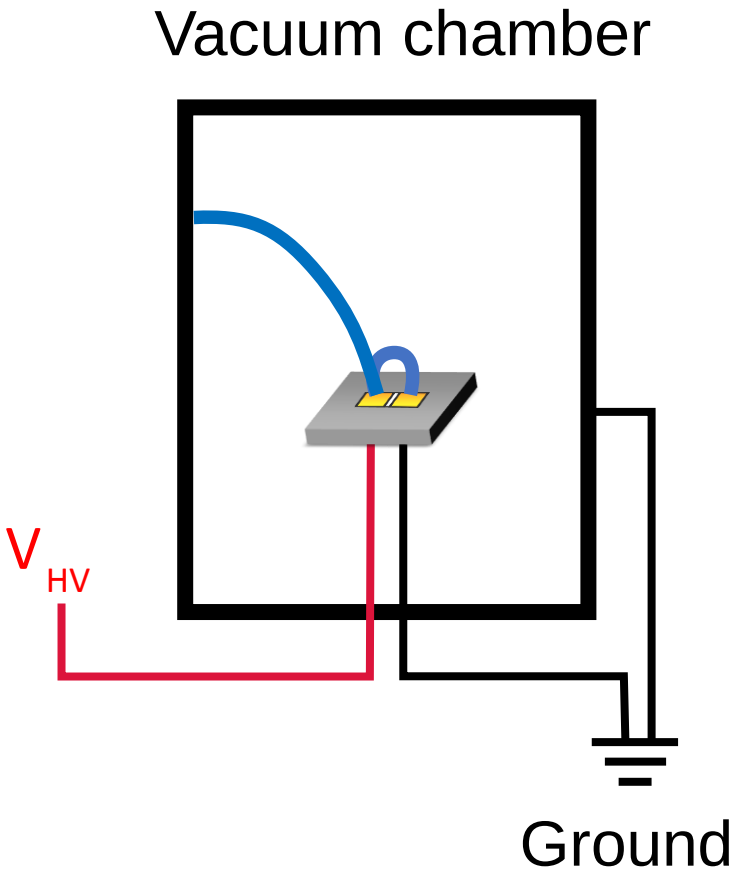


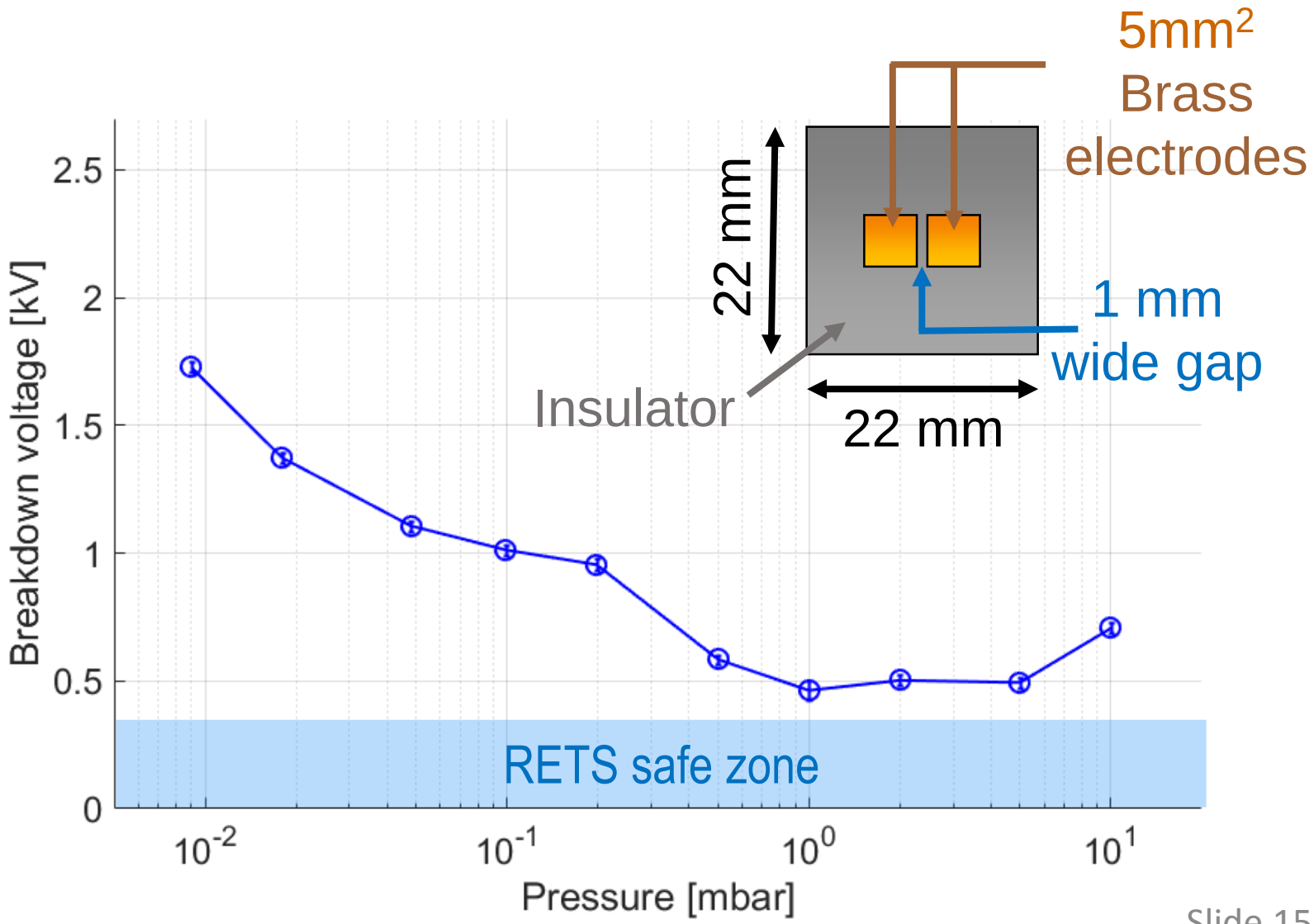
Paschen's law in complex geometries



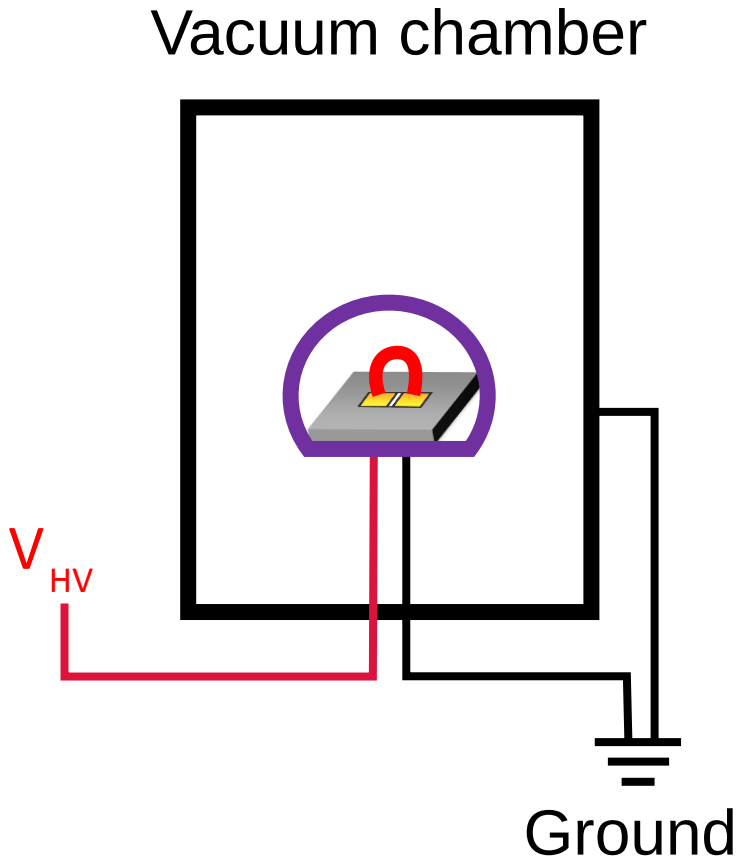


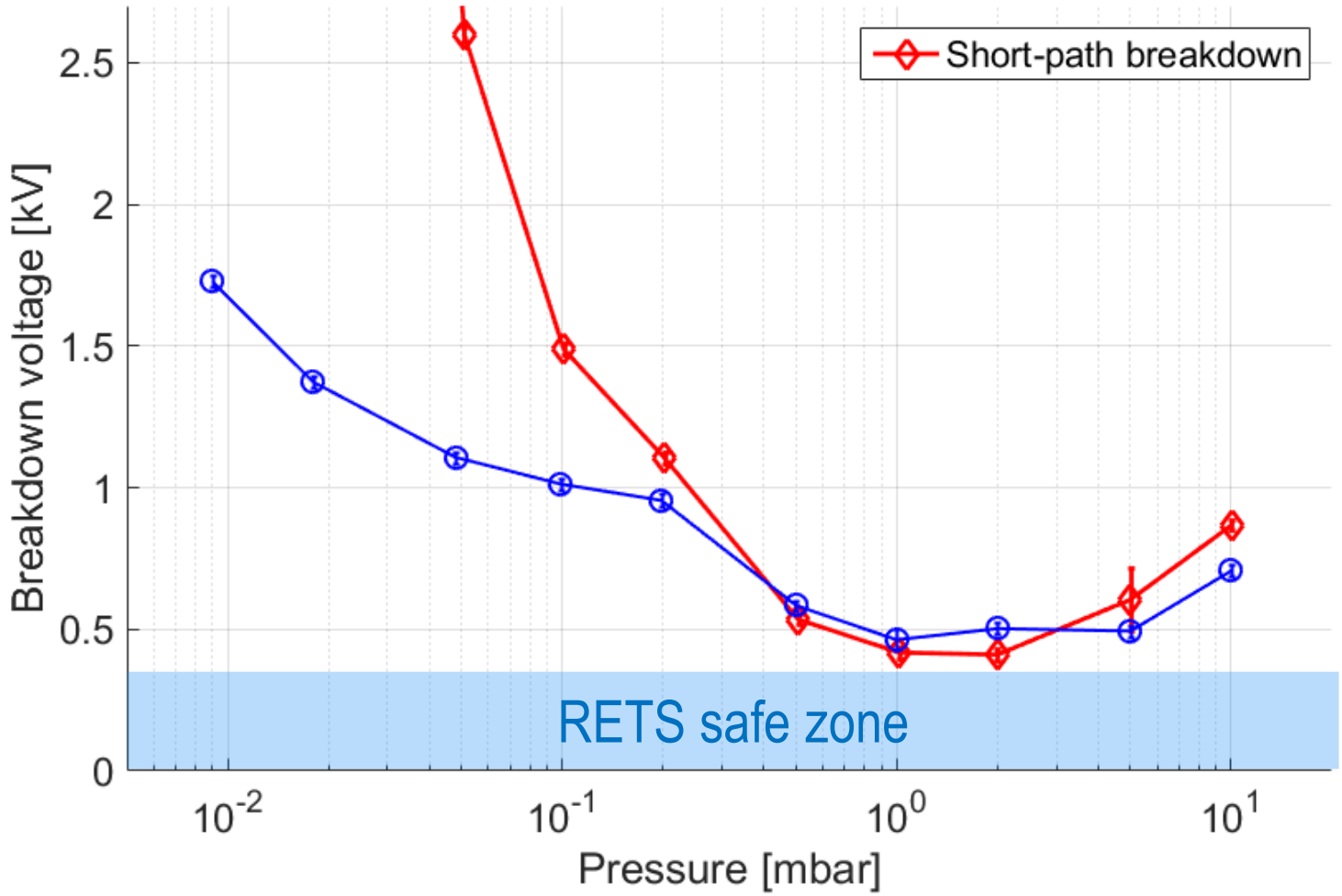
Short/Long-path breakdown curve



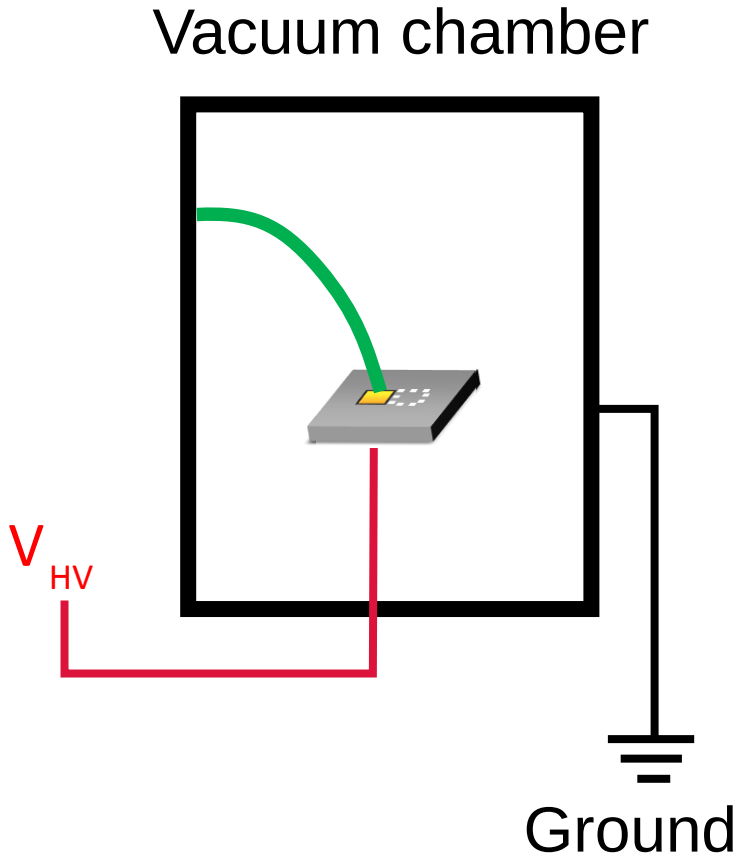


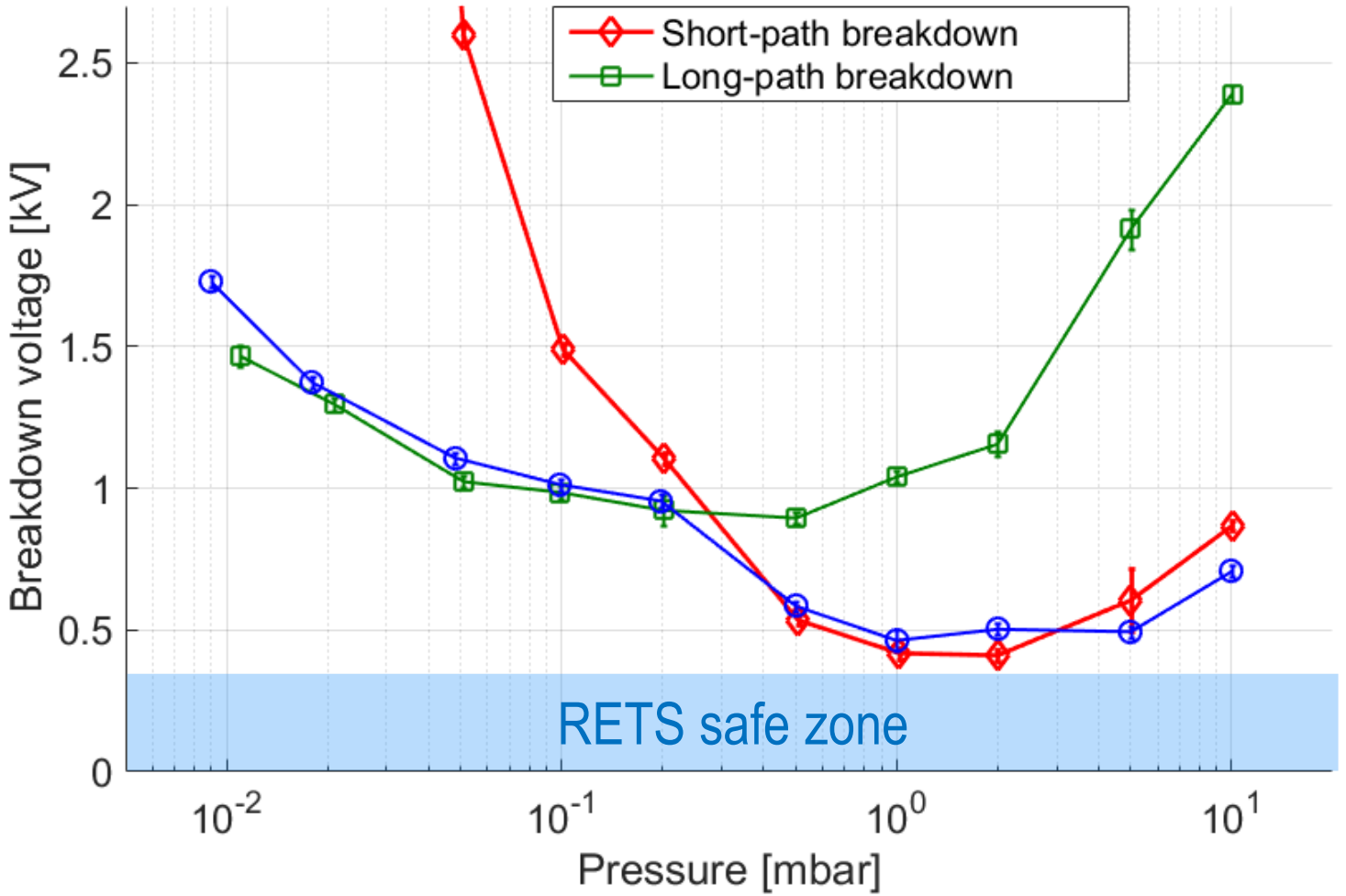
Short-path breakdown curve



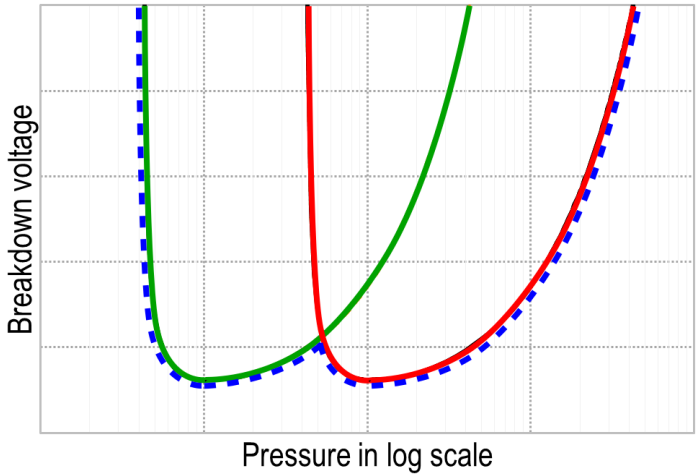


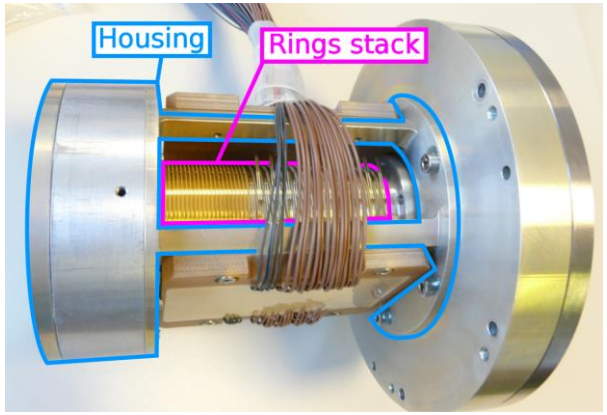
Long-path breakdown curve

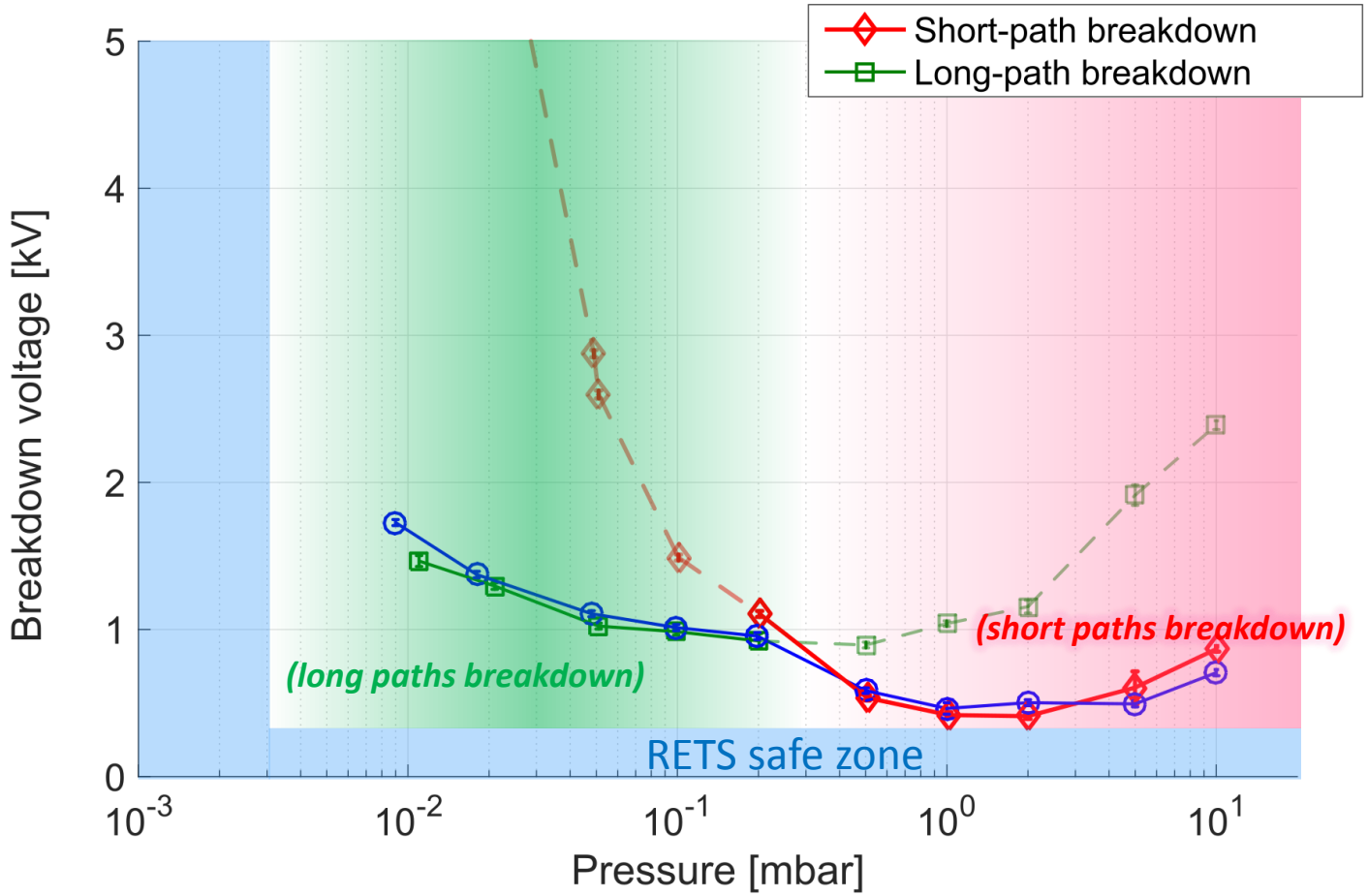




Chamber equivalent to slip-ring housing







Gas breakdown in complex geometry

Increasing the distance between electrodes does not necessarily increase the breakdown voltage. It depends on the pressure!

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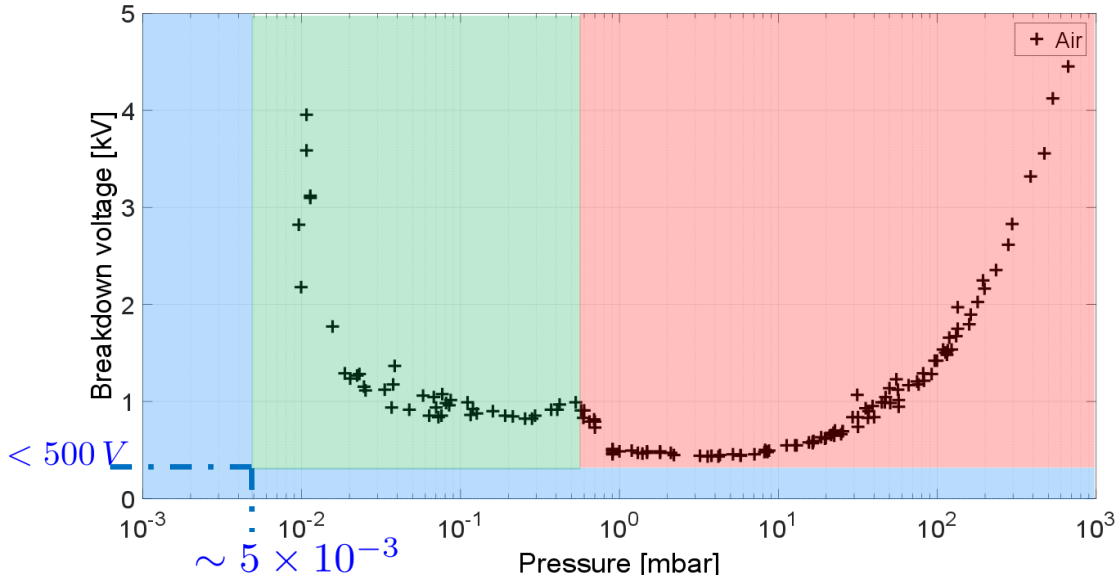
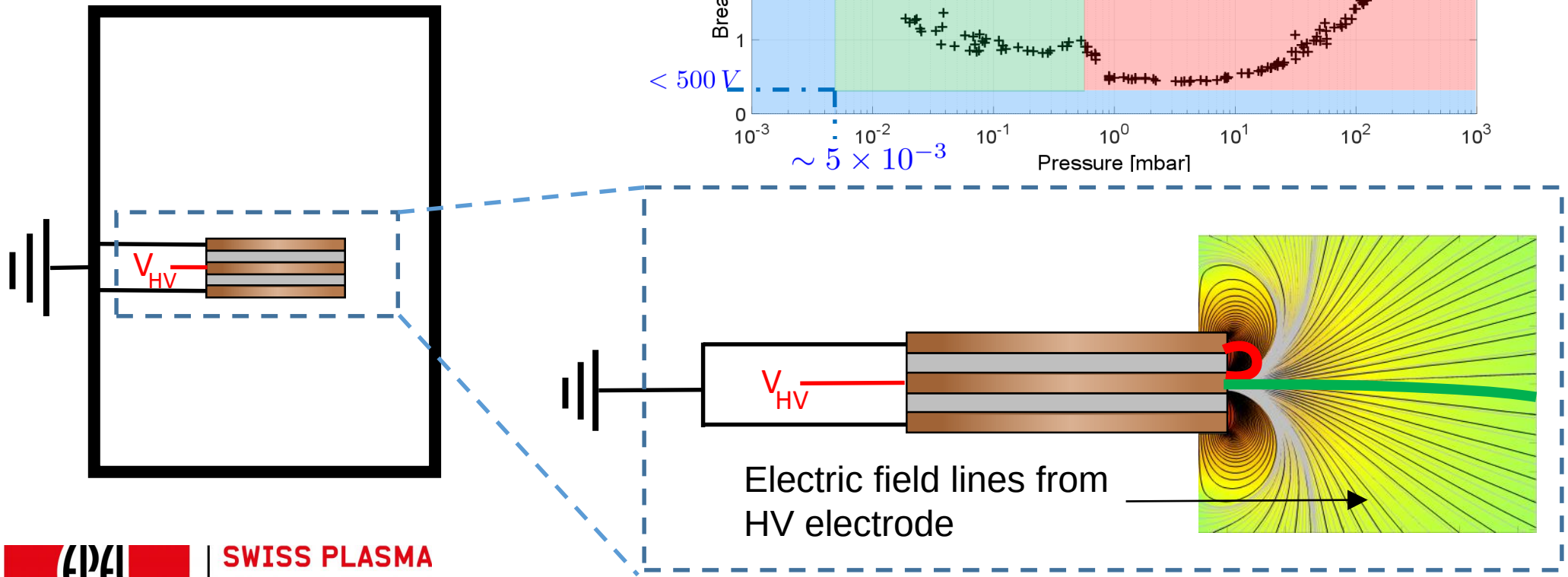
How to block long-path breakdown





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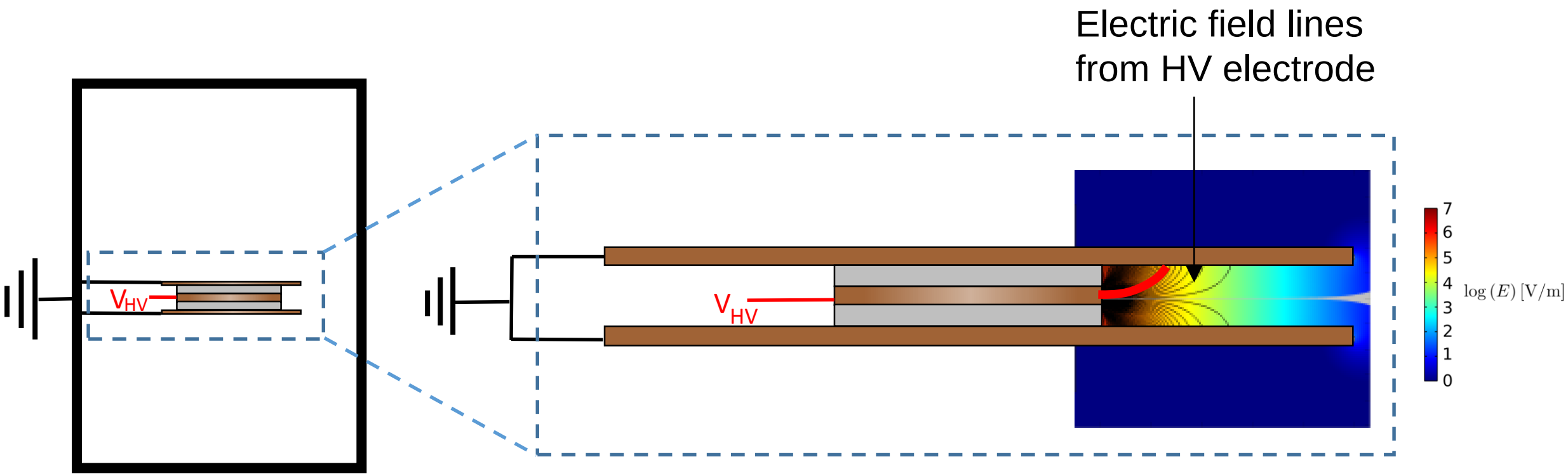
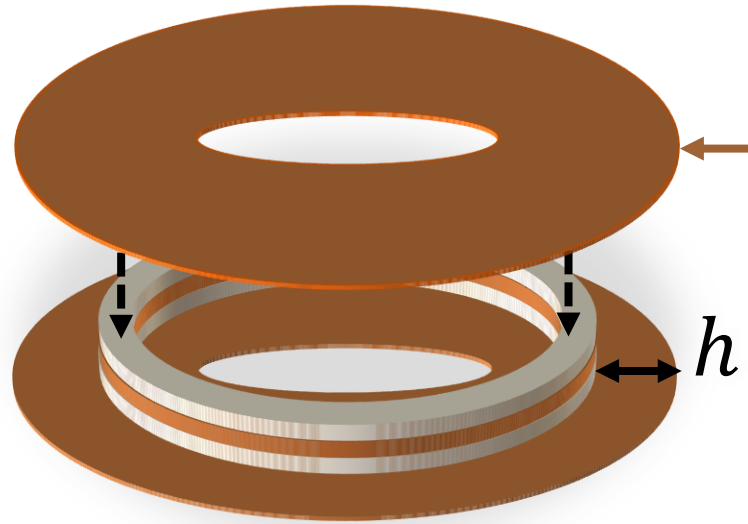
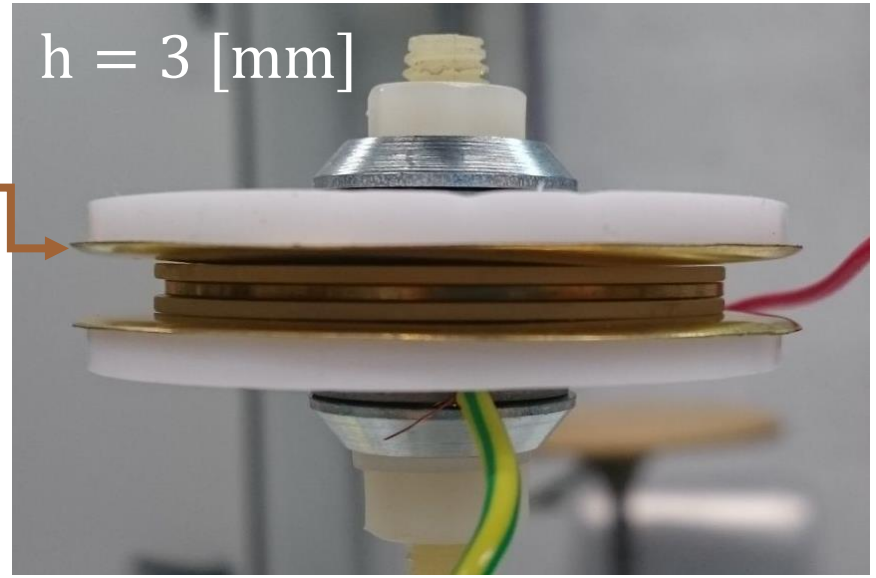
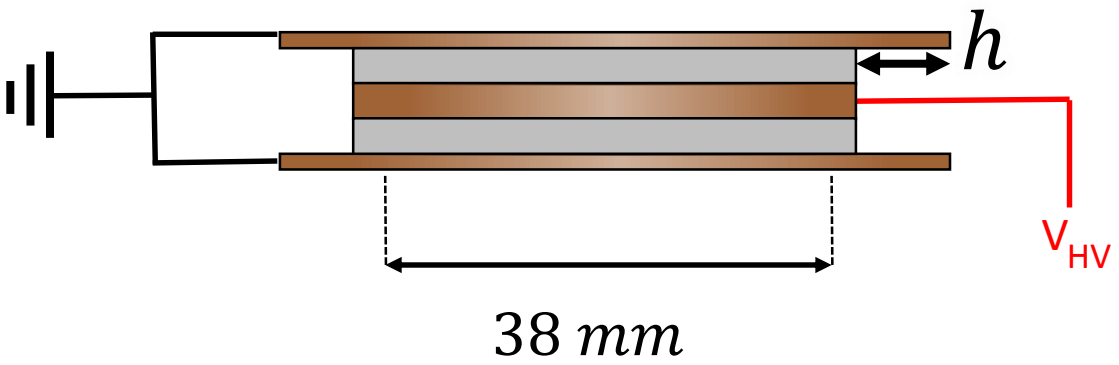


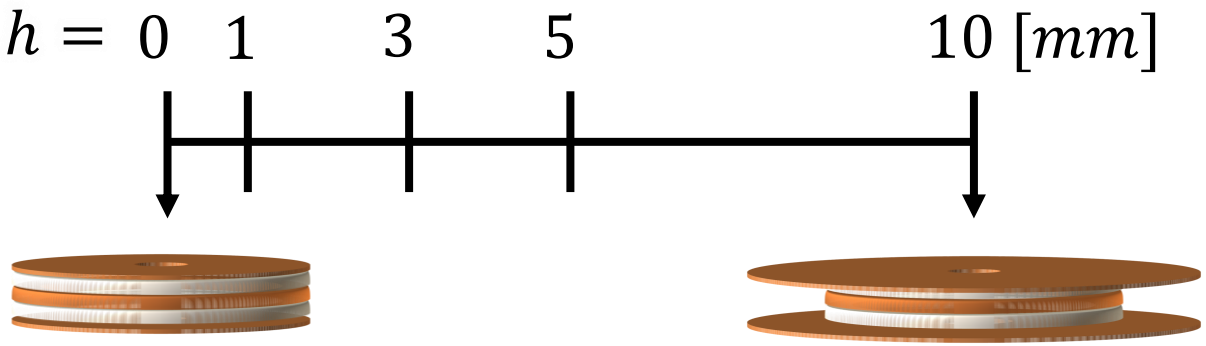
Grounded limiting discs mockup



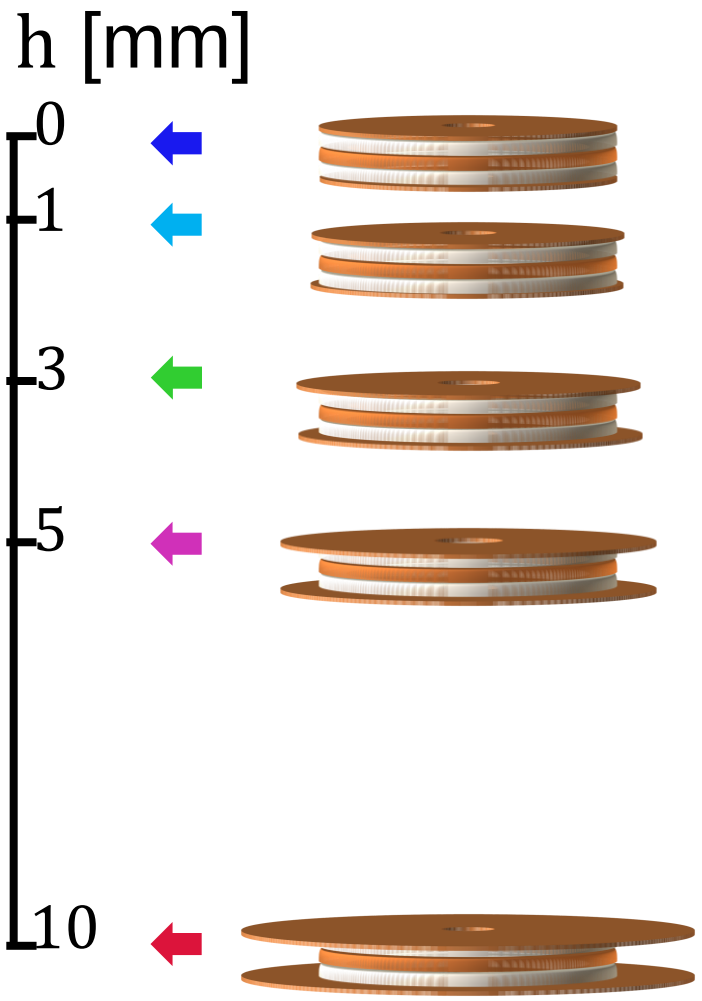
0.2 [mm] thick brass discs

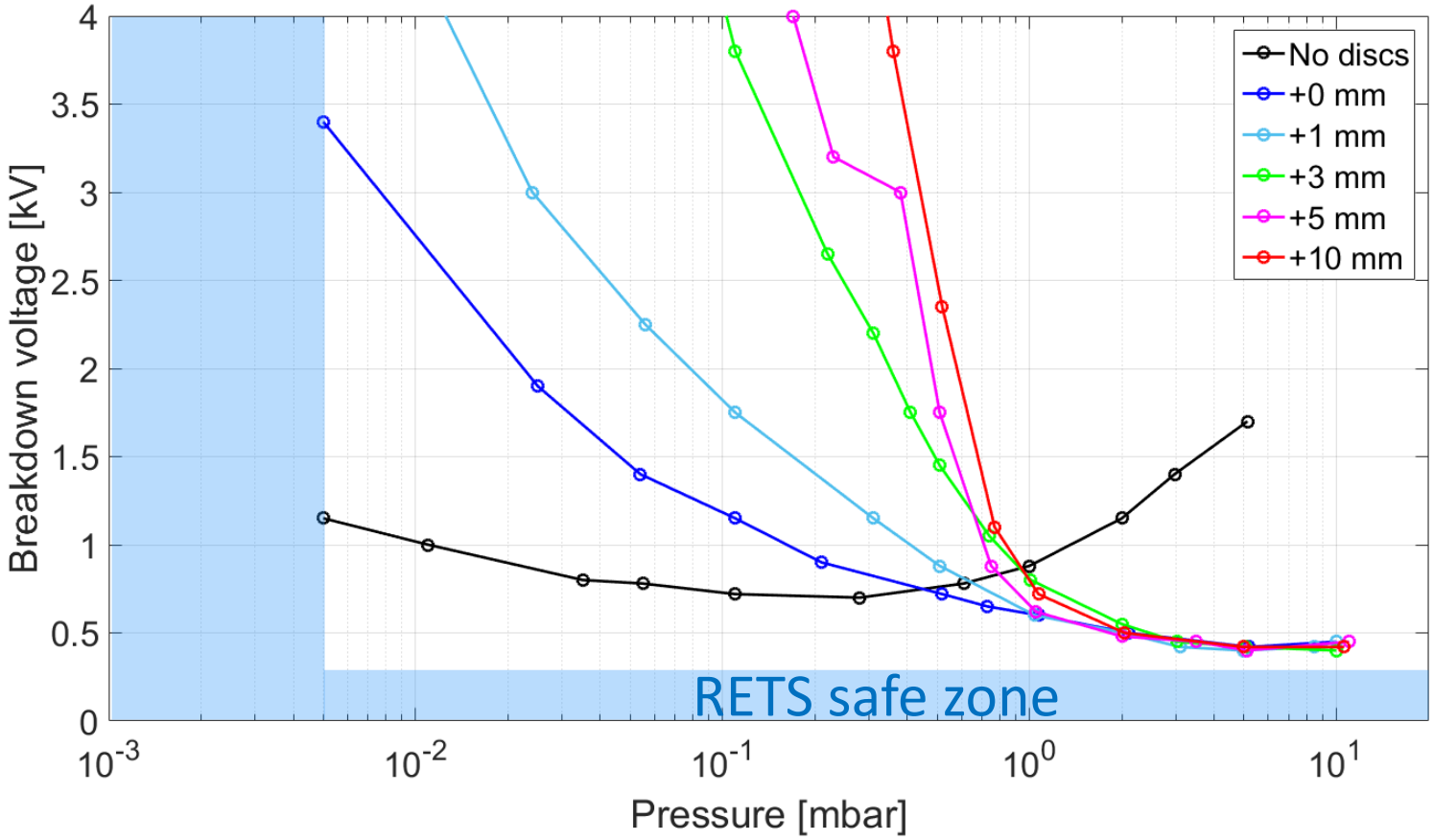






Safe zone is improved by increasing “h”

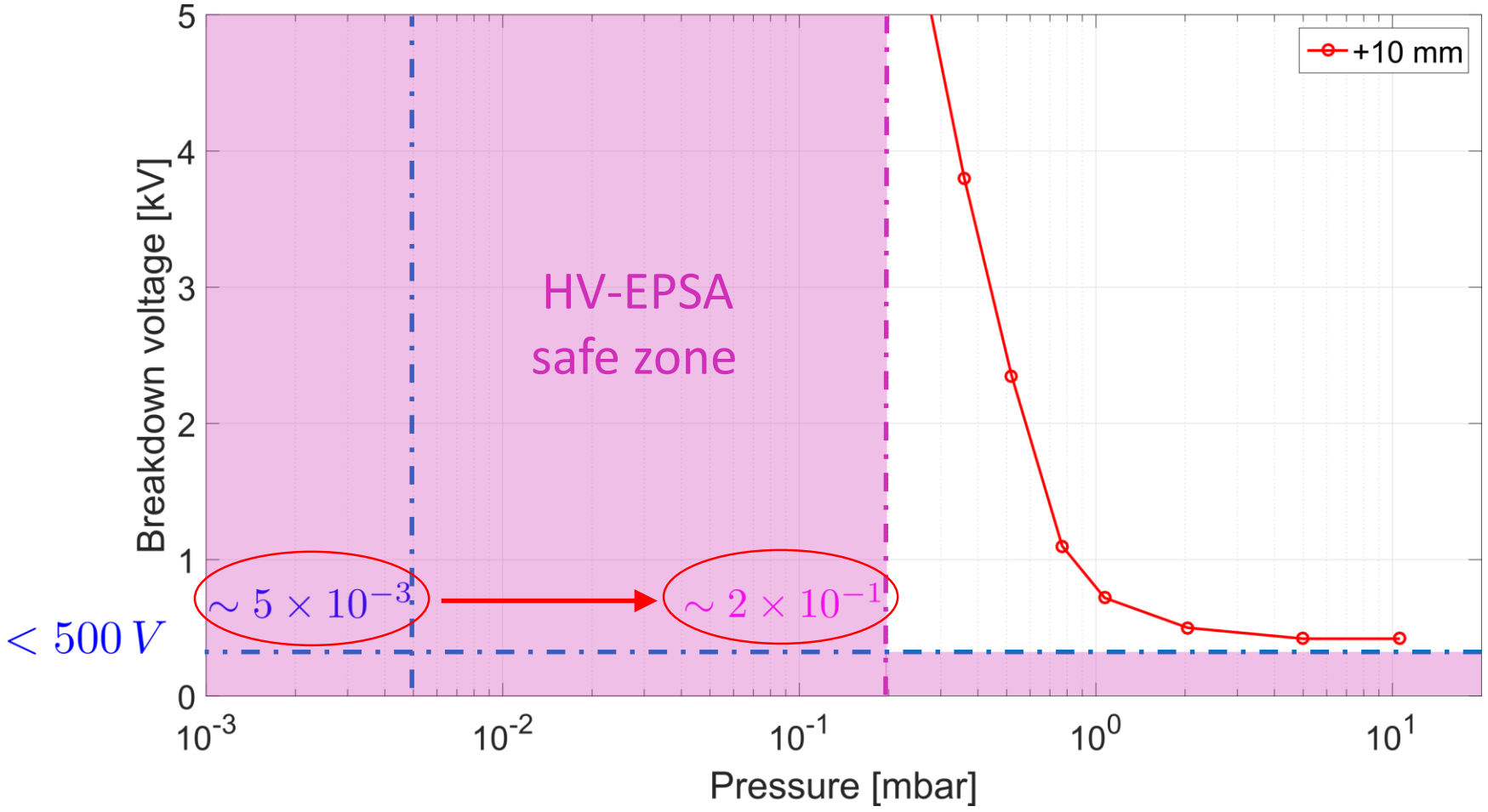




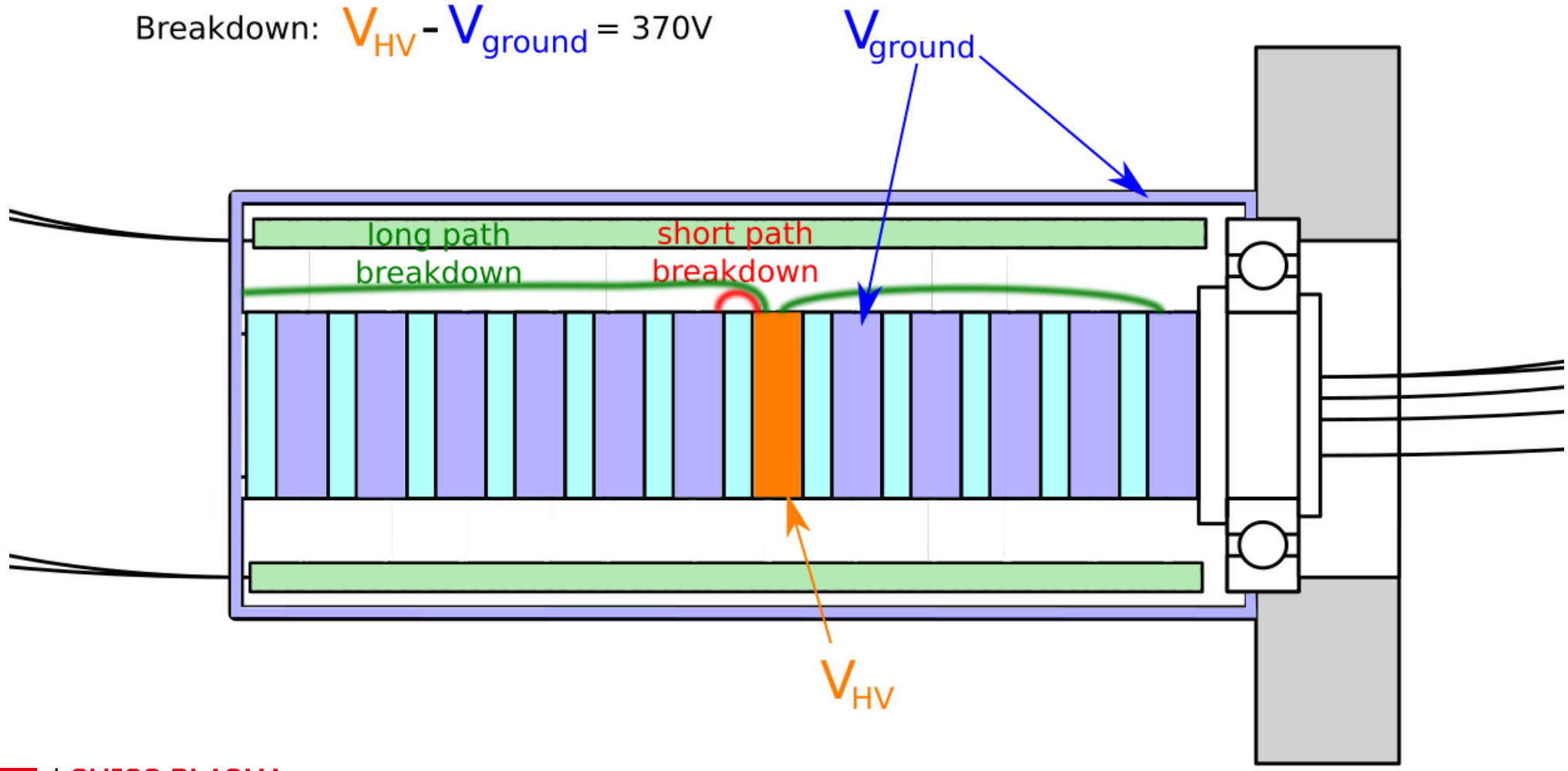
HV-EPSA improved safe zone

$h = 10\ [mm]$

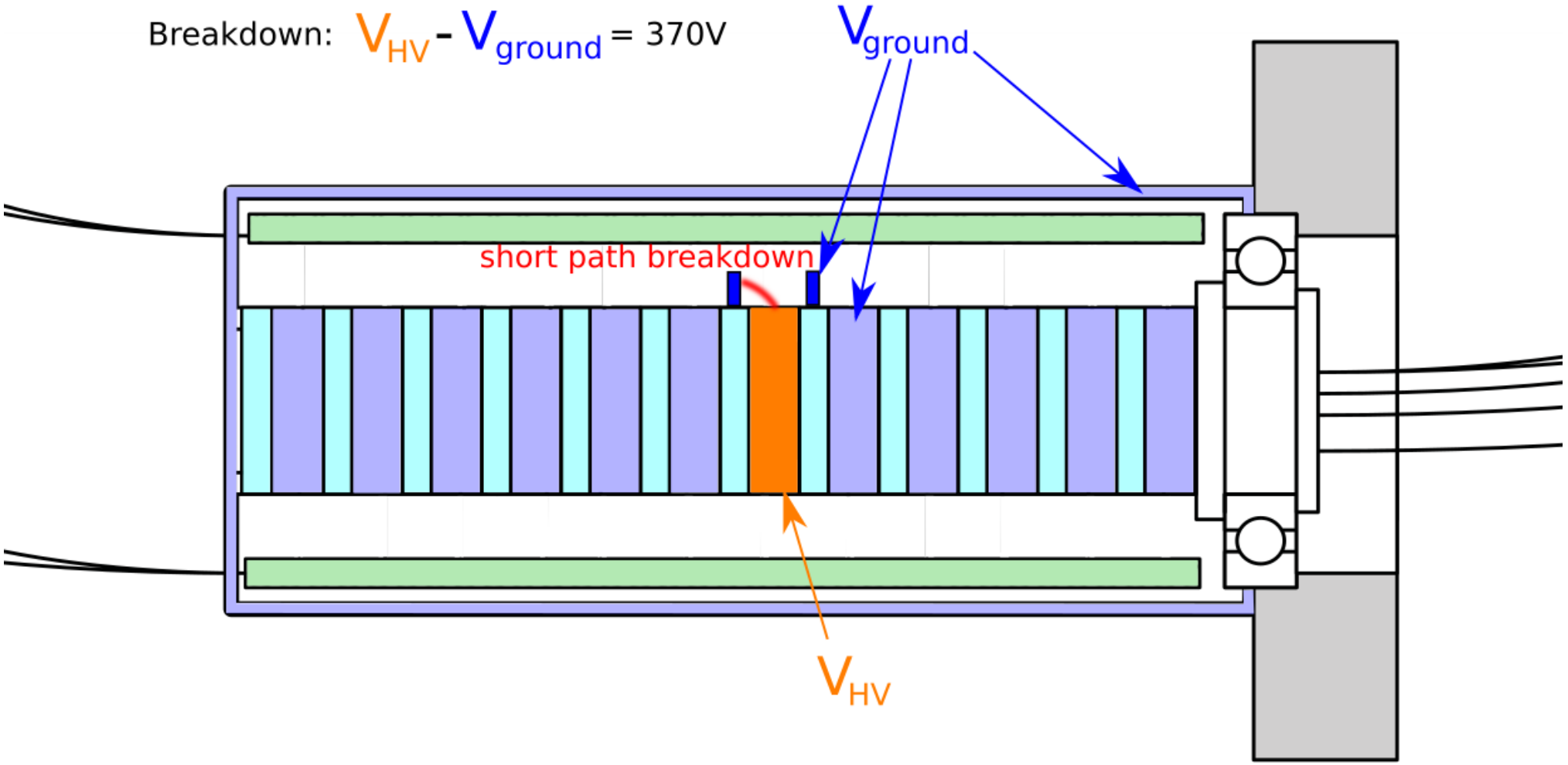
Satellite slip ring **safe zone** can be **improved** in terms of pressure by almost **2 orders of magnitude**



Original slip ring design



New slip ring design



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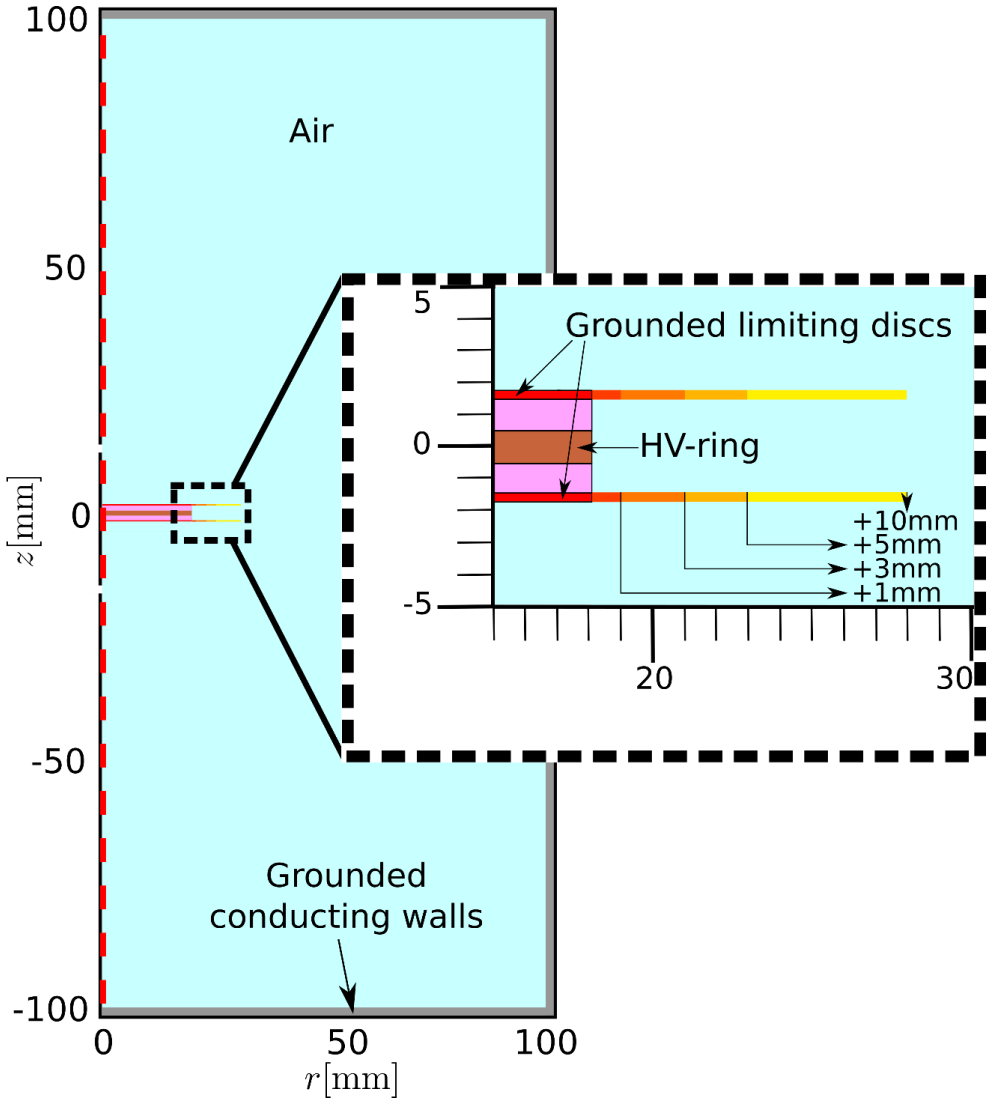
COMSOL simulations

In 2D axisymmetric system



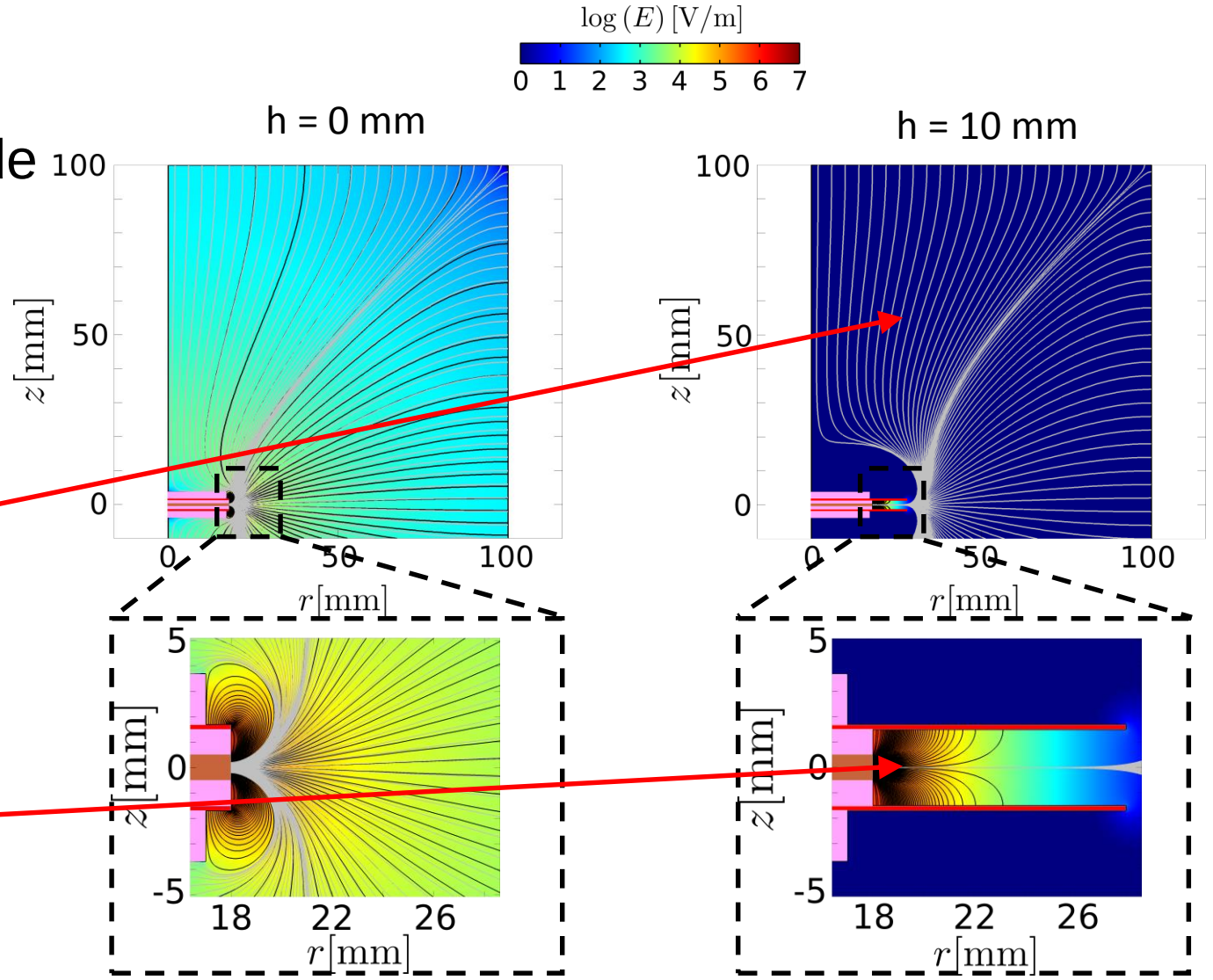
Electric field spatial distribution

V_{HV} = 1kV on the central electrode

By increasing the diameter of the limiting discs:

1. Lower electric field in the main chamber volume

2. Most of the field lines leaving the anode surface are constrained within the limiting discs



COMSOL fluid simulations

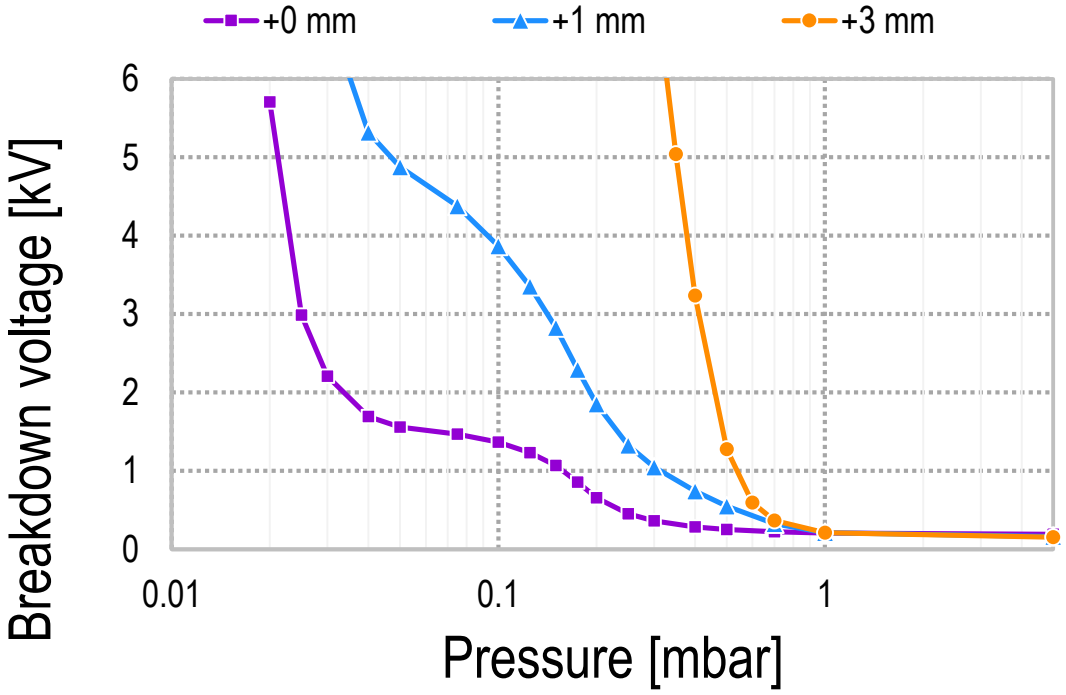
Physics model developed during the RETS project:

$$\frac{dn_j}{dt} + \vec{\nabla} \cdot \vec{\Gamma}_j = S_j ,$$

$$\vec{\Gamma}_j = \vec{\Gamma}_j^{\text{conv}} + \vec{\Gamma}_j^{\text{diff}}$$

$$S_j = \alpha \cdot \Gamma_e^{\text{conv}} + S^{\text{cosmic}}$$

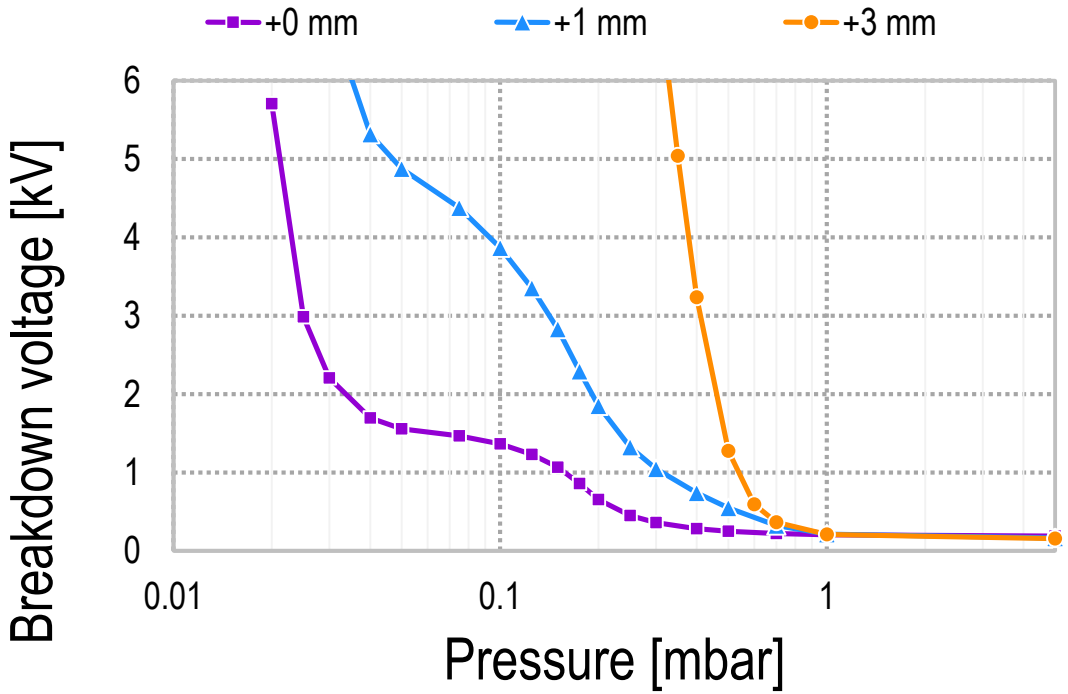
$$\vec{n} \cdot \vec{\Gamma}_e^{\text{cathode}} = -\gamma_{\text{se}} \vec{n} \cdot \vec{\Gamma}_i^{\text{cathode}}$$



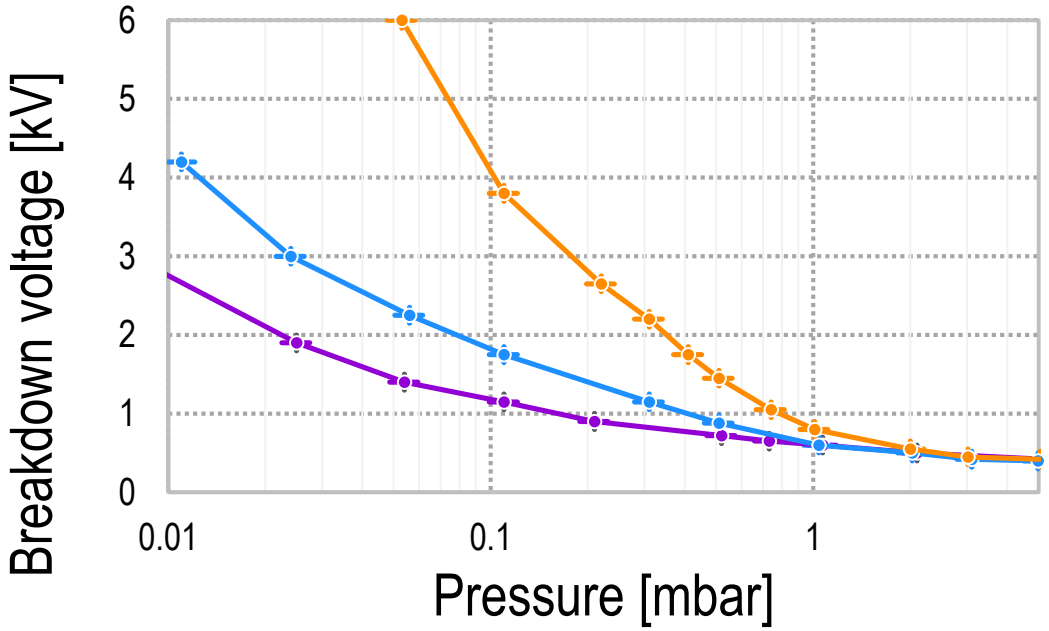
Simulation-Experiment comparison

COMSOL simulations qualitatively reproduce our experimental results
The model is not predictive because Townsend's coefficients are poorly defined

COMSOL



Experiment



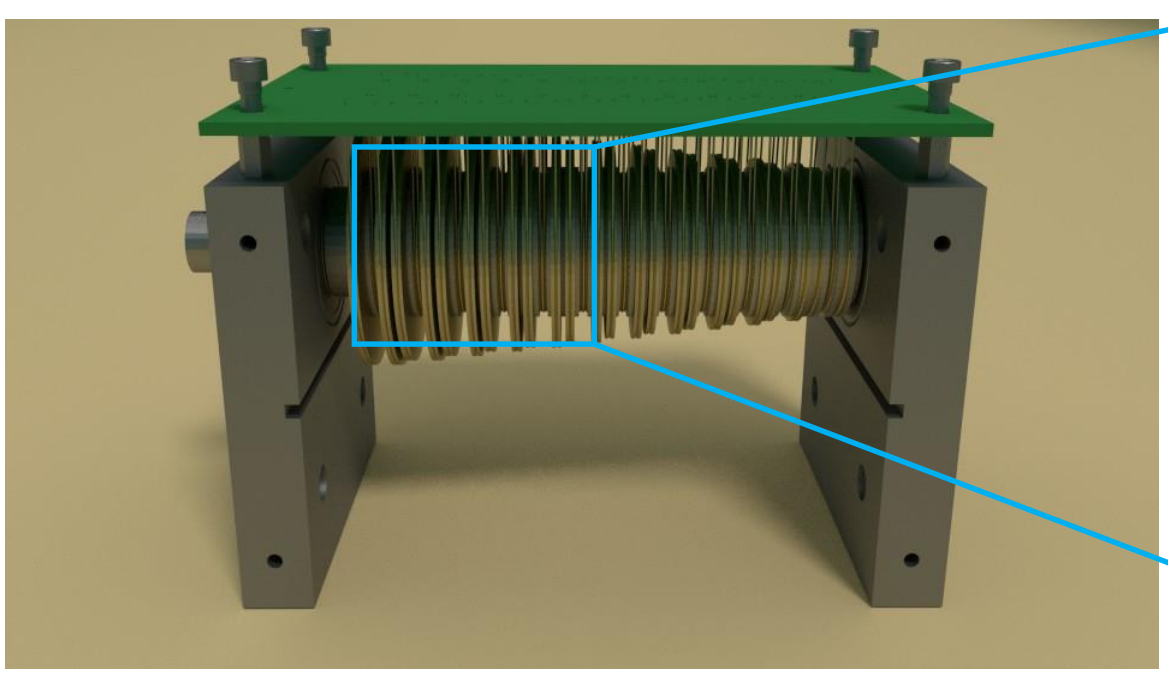
Conclusions

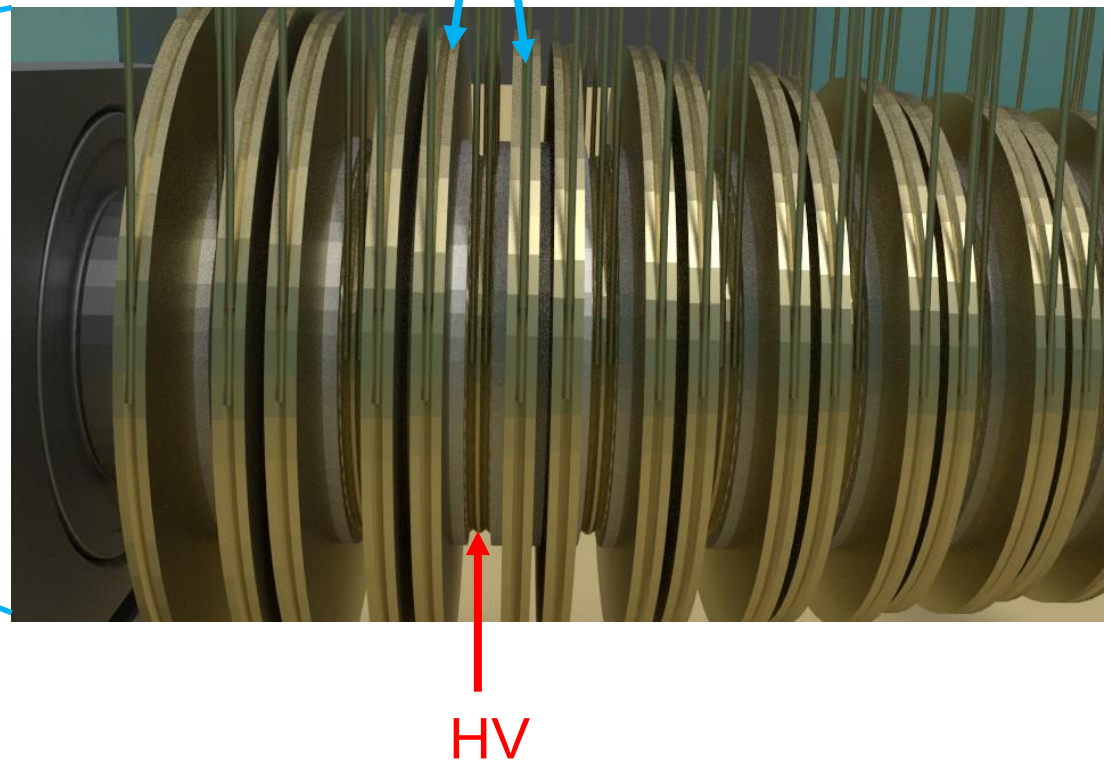
1. Investigated gas breakdown in complex geometry, confirming the role of the surrounding vacuum chamber / slip ring housing

2. Tested **grounded limiting discs (pressure improvement)**:
   - Low-pressure (long-path) breakdown has been inhibited, improving the safe zone in terms of pressure by **almost 2 orders of magnitude,** up to $2x10^{-1}$ mbar
   - Experimental results qualitatively confirmed by COMSOL fluid simulations

Outlook (1)

Verify our results with a breadboard developed by RUAG, reproducing the satellite slip ring geometry: sequence of rings with progressively increasing size





Outlook (2)

Tested **floating** and **passively biased limiting discs.**