8th IVEW in Bad Honnef

Application of the Voltage Holding Prediction Model to floating and fixed shield vacuum interrupters

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Voltage Holding in Vacuum Interrupters

Example of requirements in a typical application:

- Ur = 24 kV rated voltage
- ➢ Upf = 50 kV rated power frequency withstand voltage
- ➢ LIV = 125 kV rated lightning impulse voltage

Voltage Holding Prediction Model (VHPM)

Statistical approach to evaluate the **voltage holding capability** of complex system in high vacuum. It assumes:

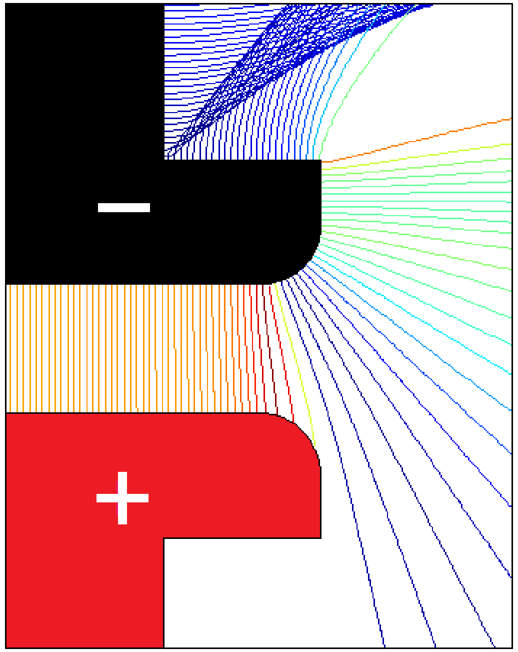
- a number N of electrodes polarized at different voltages V_i;
- a breakdown probability associated to the macroscopic area A_i of the i_{th} electrode equal to

$$p_i = n_i \cdot A_i \tag{1}$$

with density of micro-particles that potentially can produce a breakdown n_i;

- the breakdown probability for the whole system (**failure analysis theory**) is

$$P = 1 - \prod_{i=1}^{N}(1 - p_i) \approx 1 - e^{-\int_A n \cdot dA} \tag{2}$$



- the **Slivkov–Cranberg criterion** [Slivkov 1957] as the event triggering the breakdown and thus:

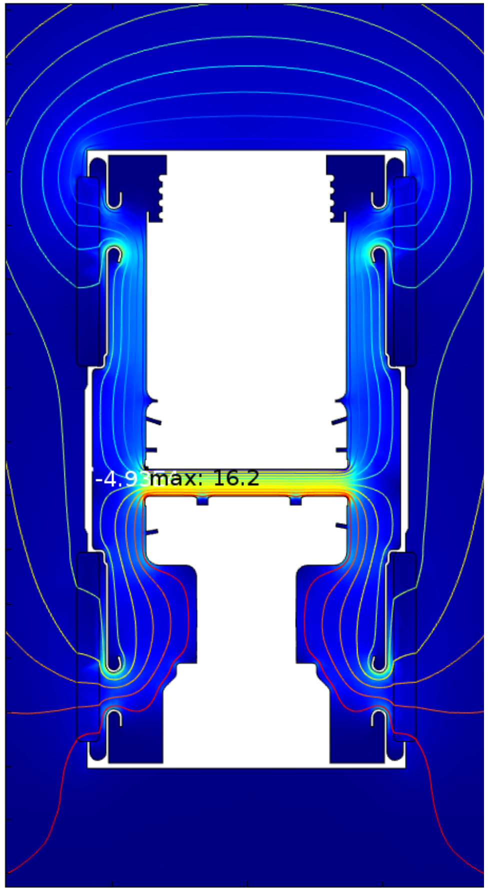
$$W = E_C \cdot E_A^{2/3} \cdot \Delta V > W_s \tag{3}$$

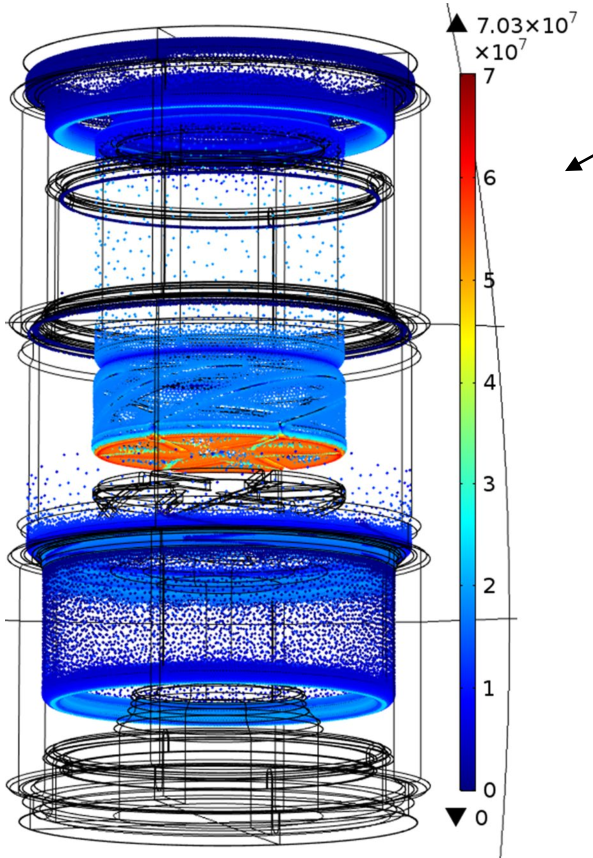
- **Weibull's distribution** assumed for the number of micro-particles that potentially can produce a breakdown

$$n(W) = \left(\frac{W}{W_0}\right)^m \tag{4}$$

Modelling

- Electrostatic analysis
- Particle tracing (massless, for v_0 = 0 and non-relativistic motion)
- Triple product $E_C E_A^{2/3} \Delta V$ assigned to each trajectory



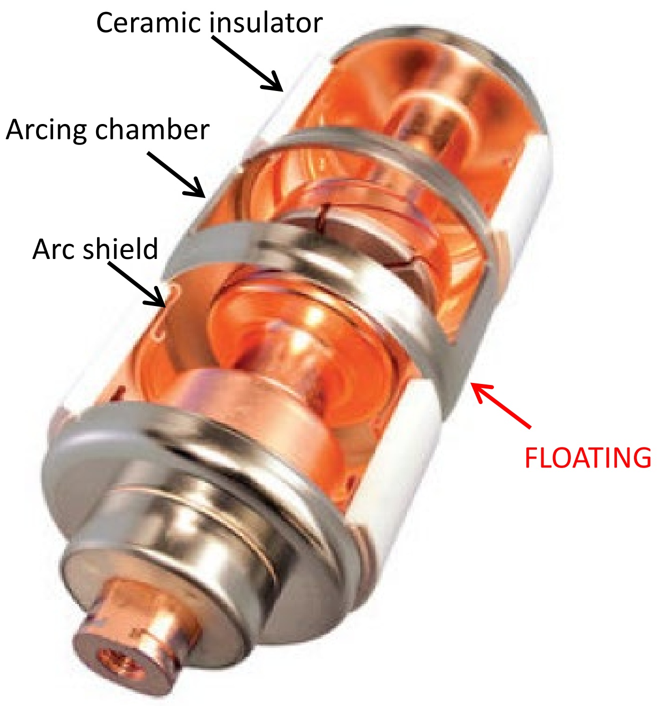


W plot at cathode (t=0)

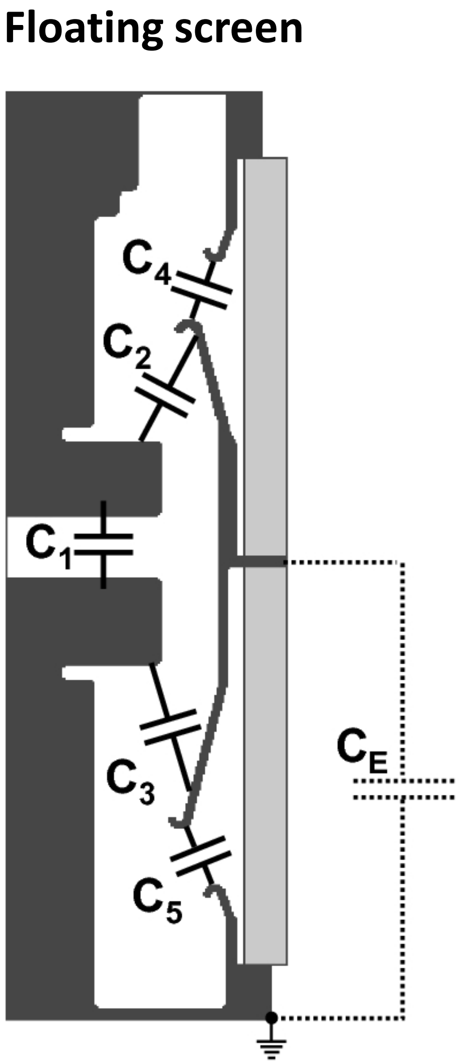
Geometry/boundary conditions:

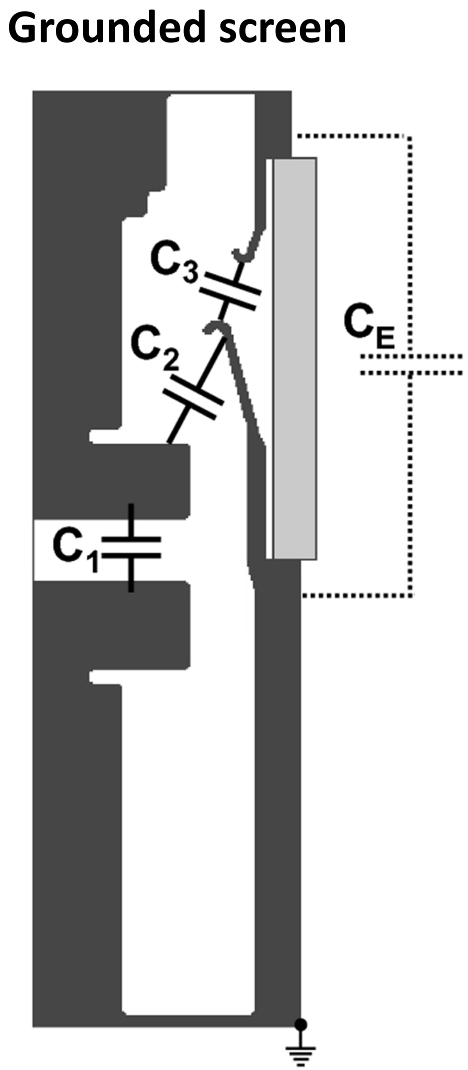
- 0.1 mm fillet radius on sharp edges
- Aluminium oxide: ε = 10
- $V_{moving\ electrode}$ = ±100 kV
- $V_{fixed\ electrode}$ = $V_{external\ shell}$ = 0 V
- Vapour shield = floating potential (Dirichlet with Q=0)

Comparison of floating and fixed shield vacuum interrupters



Similar electrode design but different shield concepts



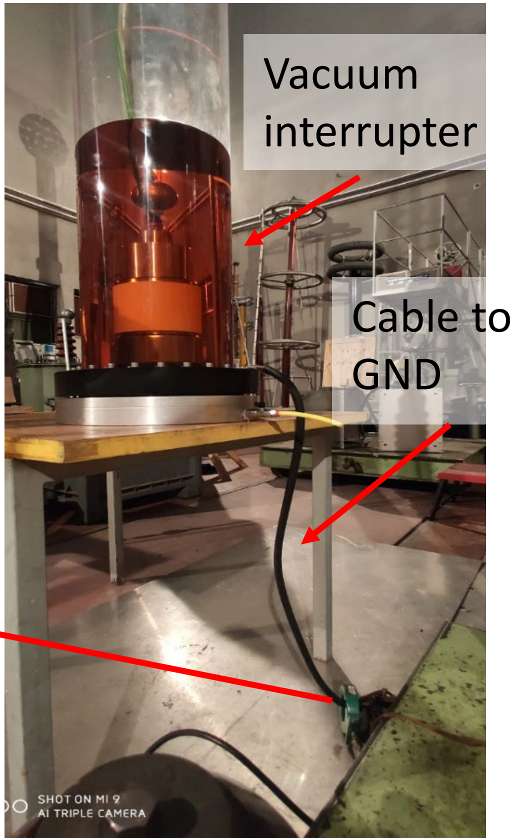


Comparison useful to:

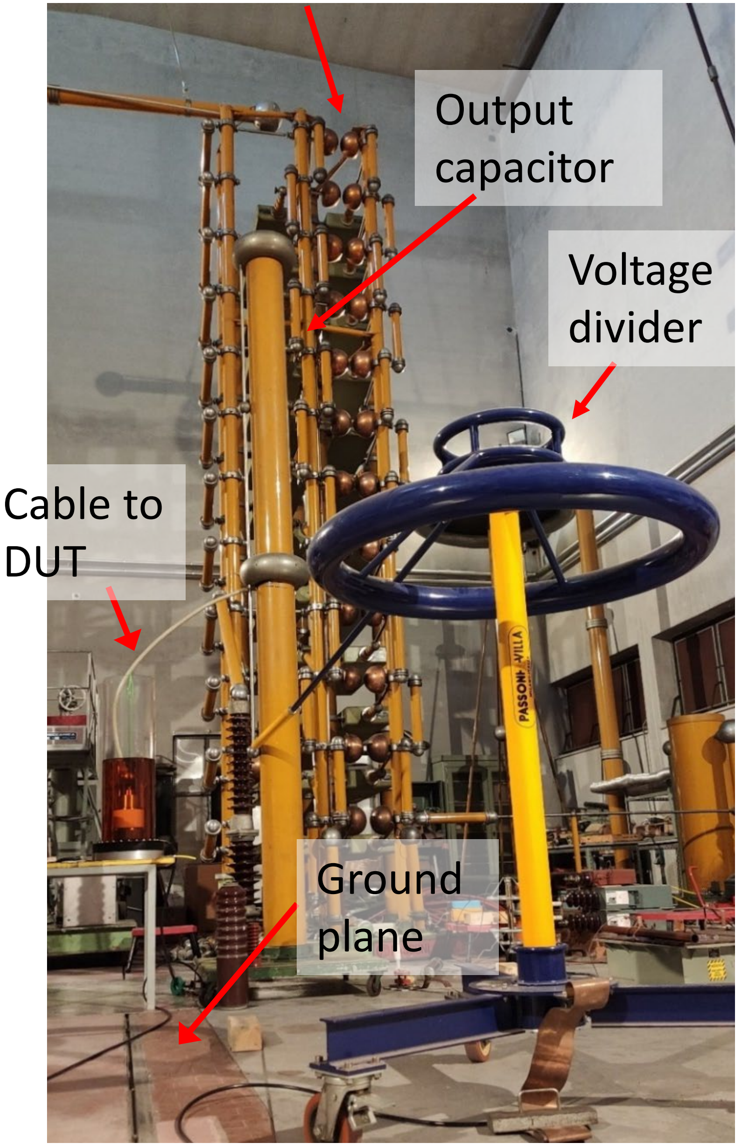
- verify prediction capability of VHPM
- analyse shield contribution

Experimental setup

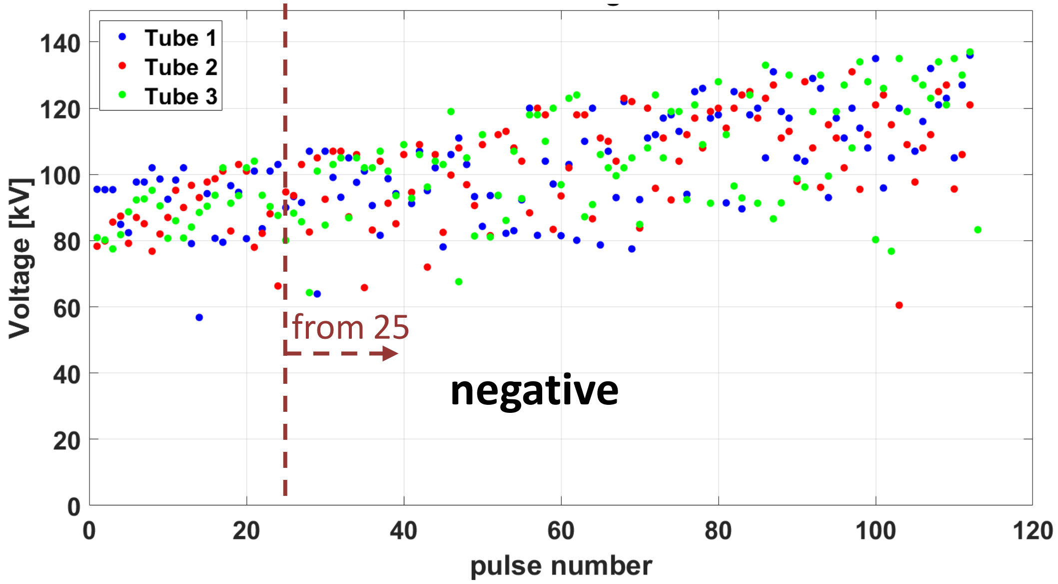
- Marx generator with 4/12 active stages of 200 kV each ($\eta = \frac{V_{peak}}{V_{charge}} = 0.86$)
- Fixed electrode at ground potential
- Positive/negative LIV applied to the movable contact
  - Peak voltage depending on the gap distance, after 1.2 µs
  - Half-value back tail time approx. 50 µs
- VIs hosted in a tank filled with insulating fluid (FC-40), to prevent external flashover
- Precise mechanical system to measure the electrode gap at:
  - 4 mm – short gap (~140 kV)
  - 10 mm – normal gap (~280 kV)
  - 15 mm – long gap (~340 kV)
- Current monitor (Pearson 1025, only for GS VI) to take into account the involved energy



Marx Generator



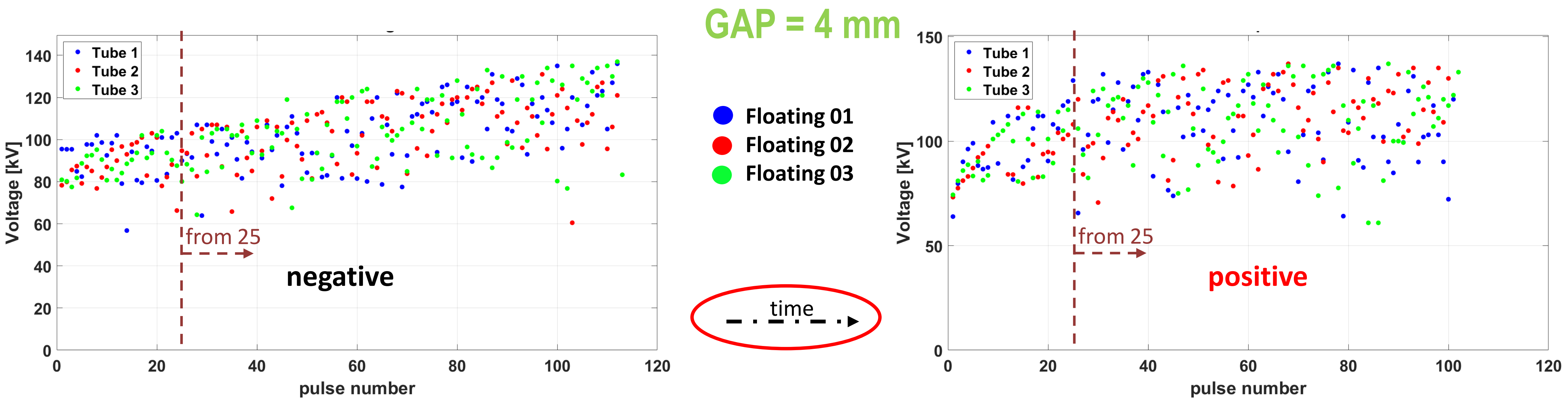
Always breakdown method



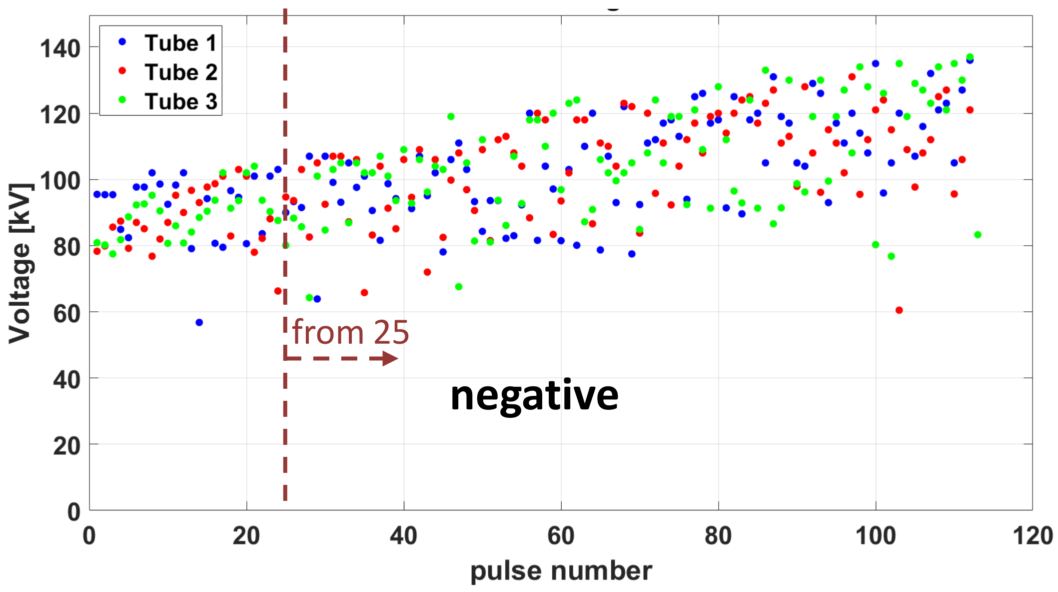
GAP = 4 mm

- Floating 01
- Floating 02
- Floating 03

Always breakdown method



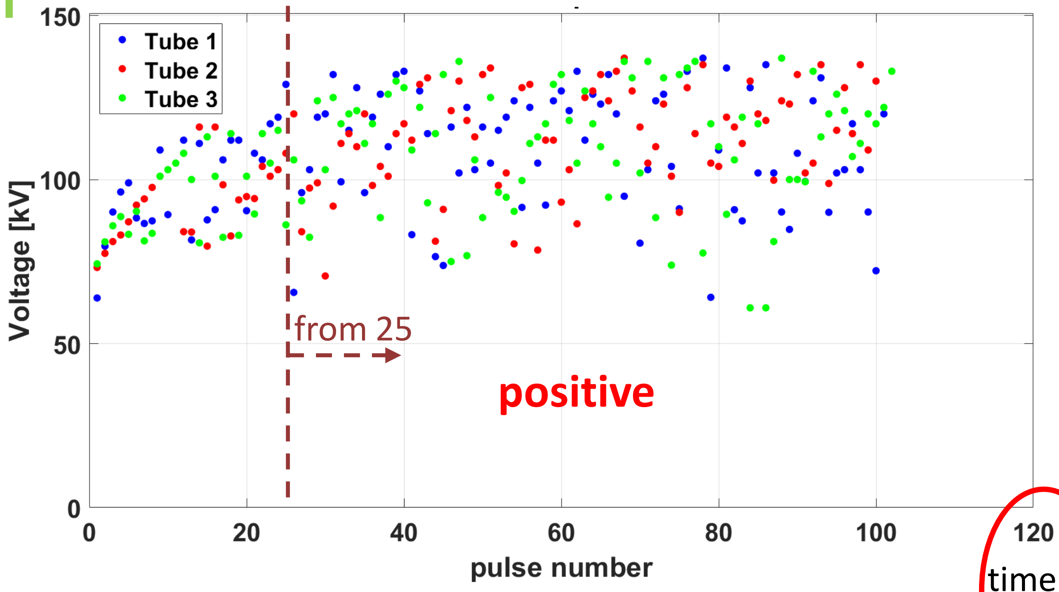
Always breakdown method



GAP = 4 mm

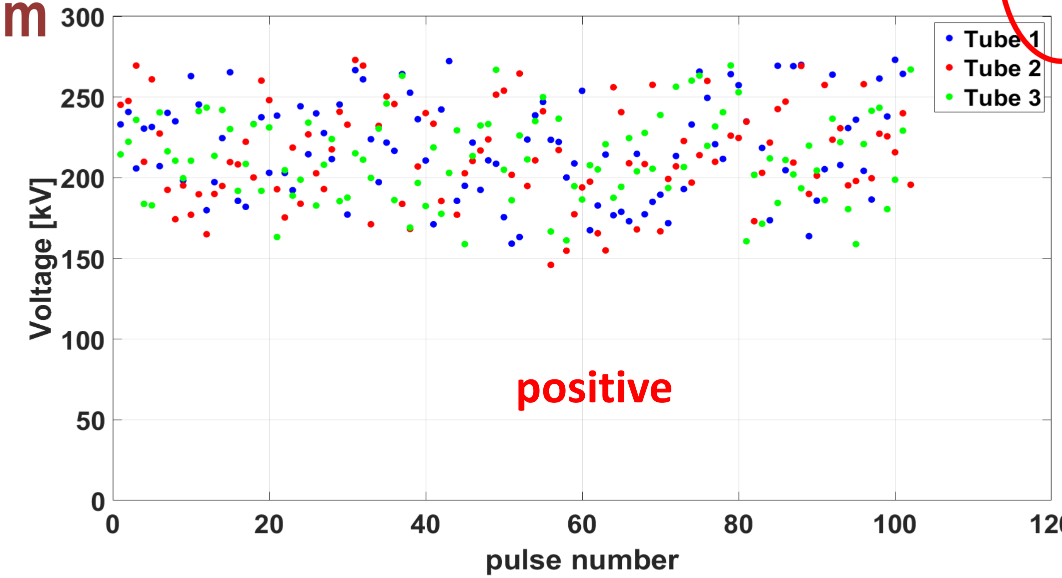
Floating 01
Floating 02
Floating 03

time



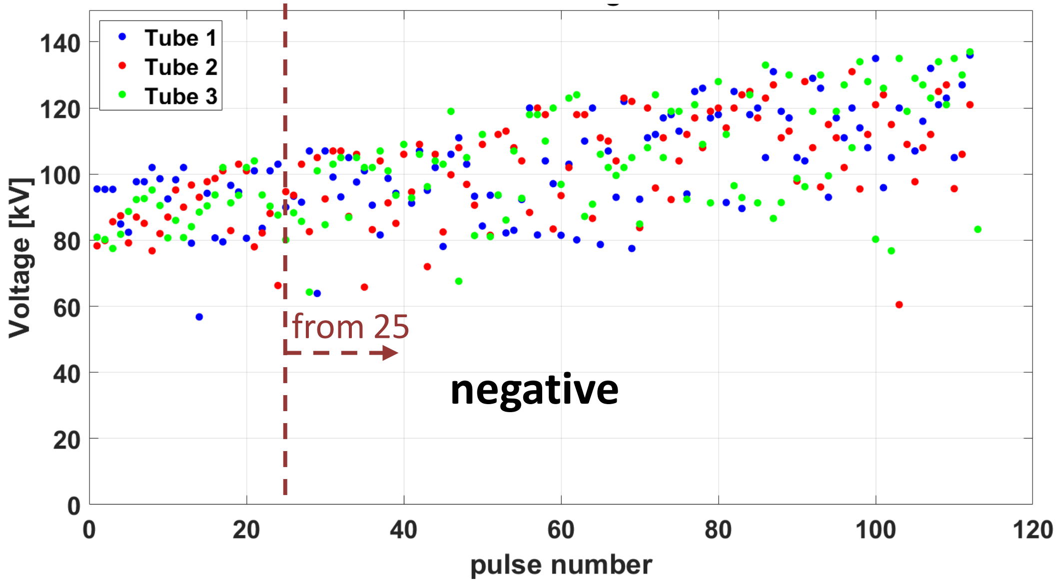
time

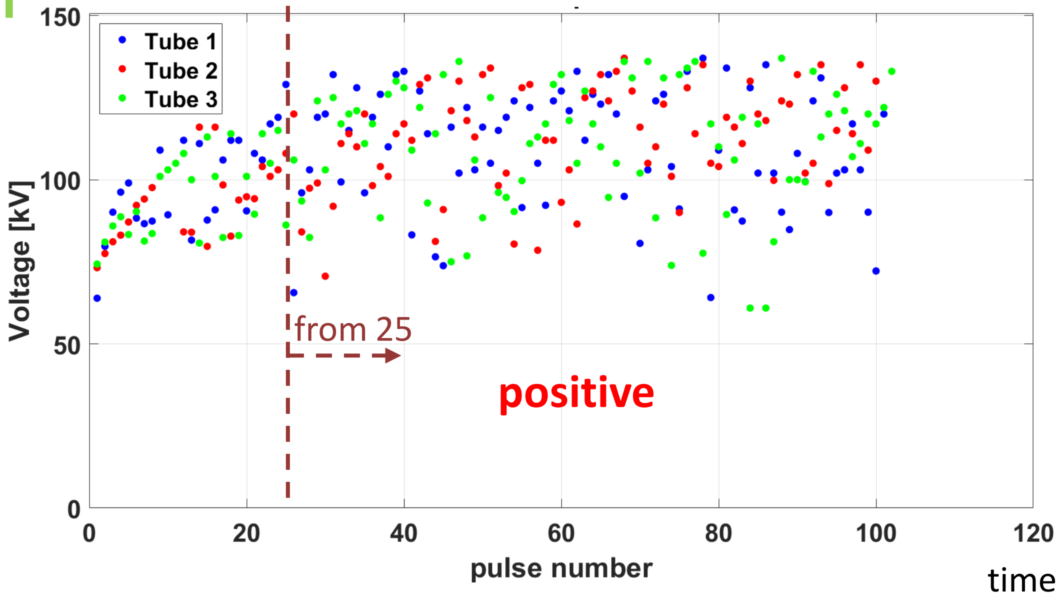
GAP = 10 mm



Always breakdown method

GAP = 4 mm



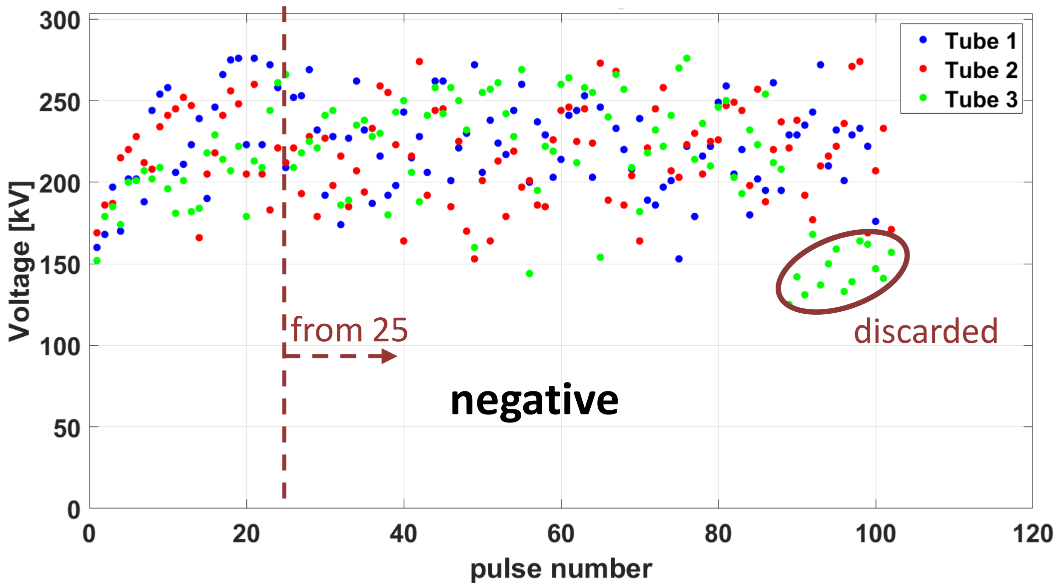


Floating 01
Floating 02
Floating 03

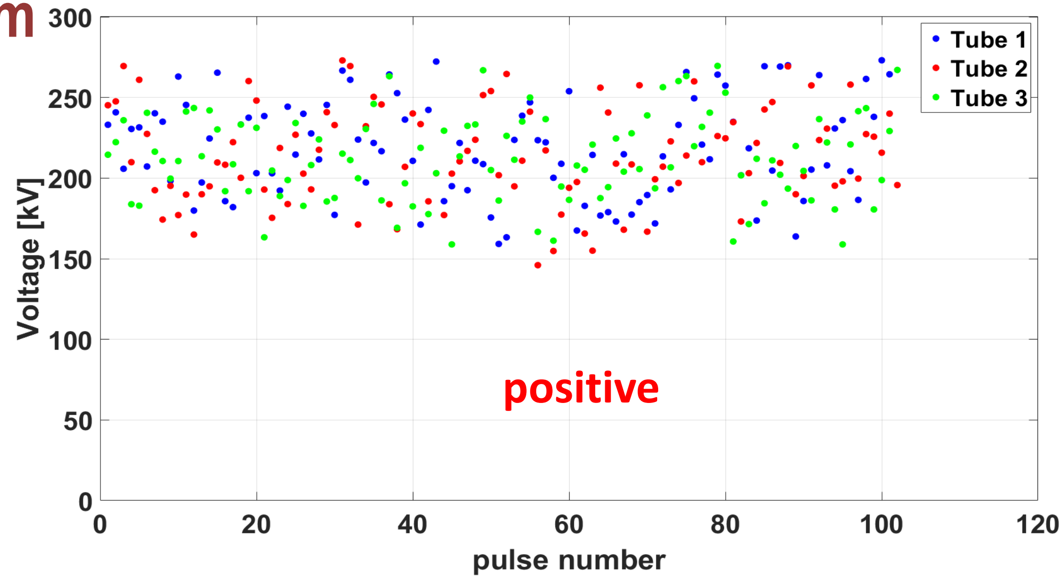
time

time

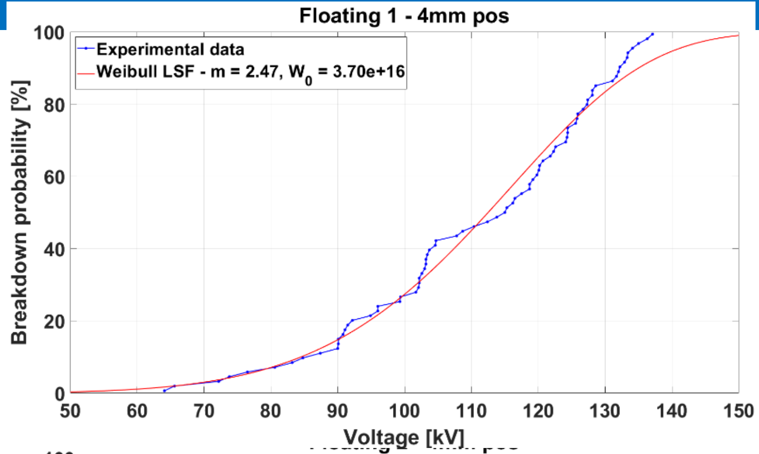
GAP = 10 mm

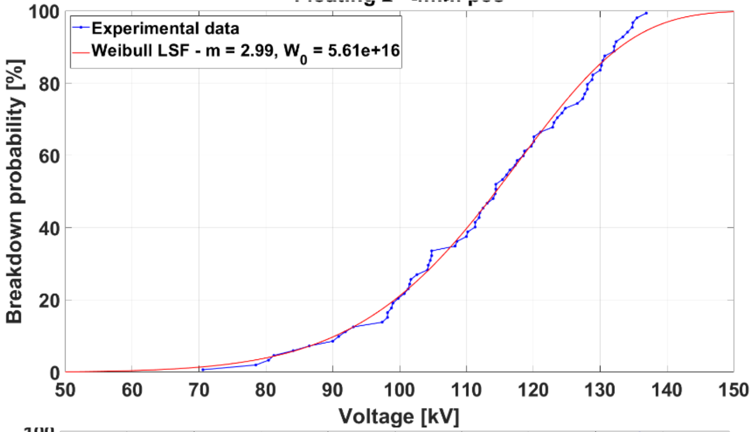


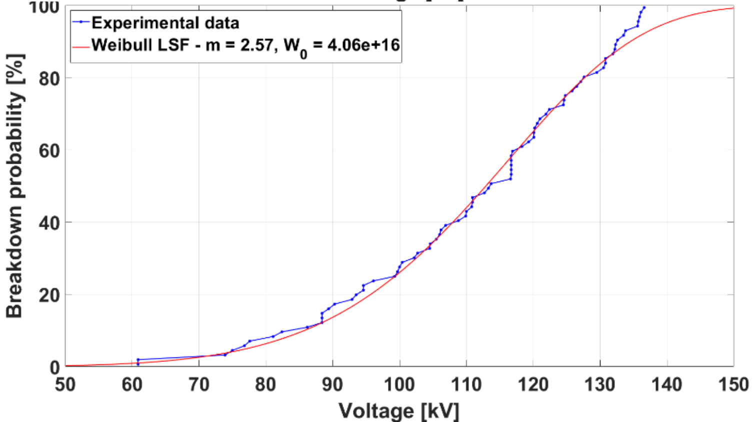
time



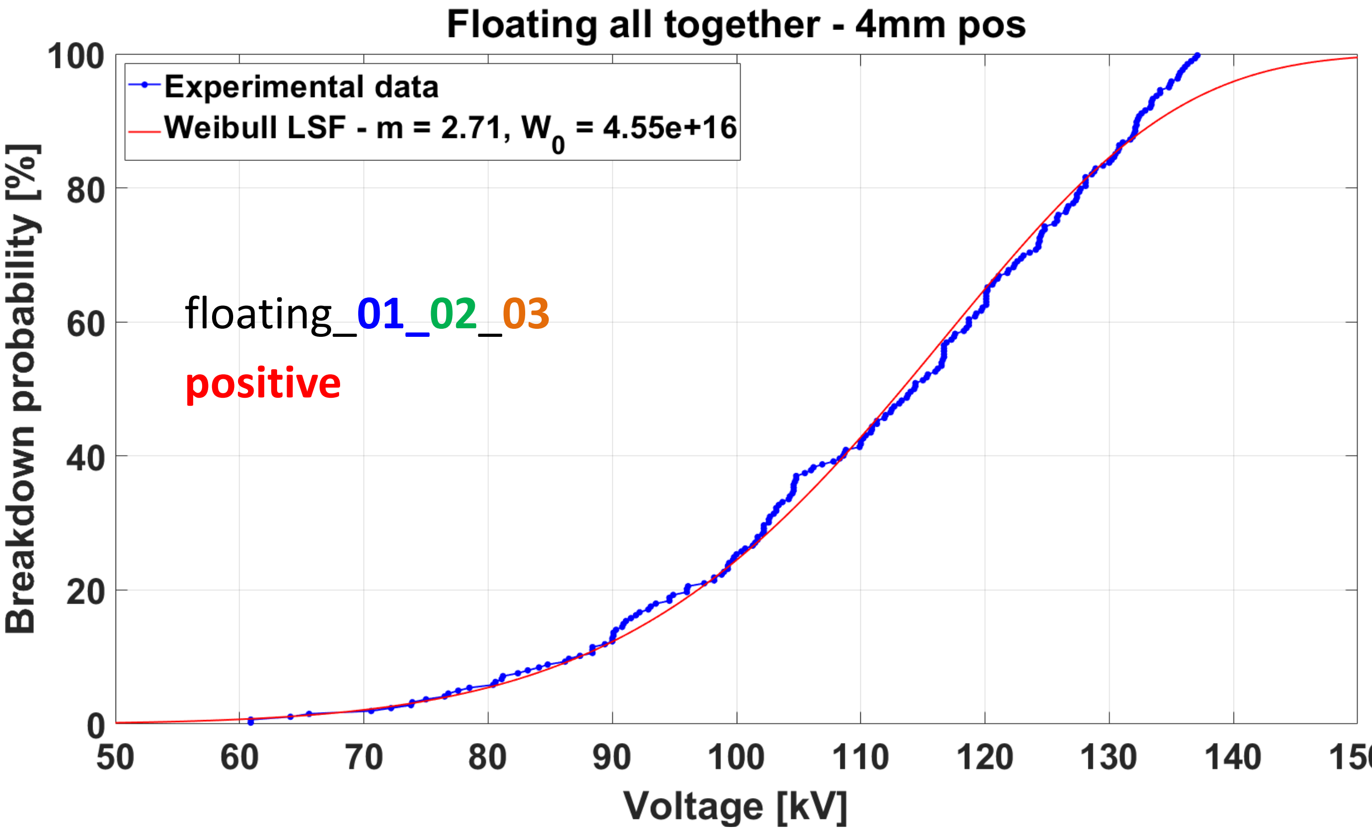
Weibull scale and shape parameters computation: 4mm gap







$$P = 1 - e^{-\left(\frac{U^{(8/3)}}{W_0 d^{(5/3)}}\right)^m \int_{A_c} \left[E_c \frac{d_{ref}}{U_{ref}} \left(E_a \frac{d_{ref}}{U_{ref}}\right)^{2/3}\right]^m \frac{dA}{A_{ref}}}$$

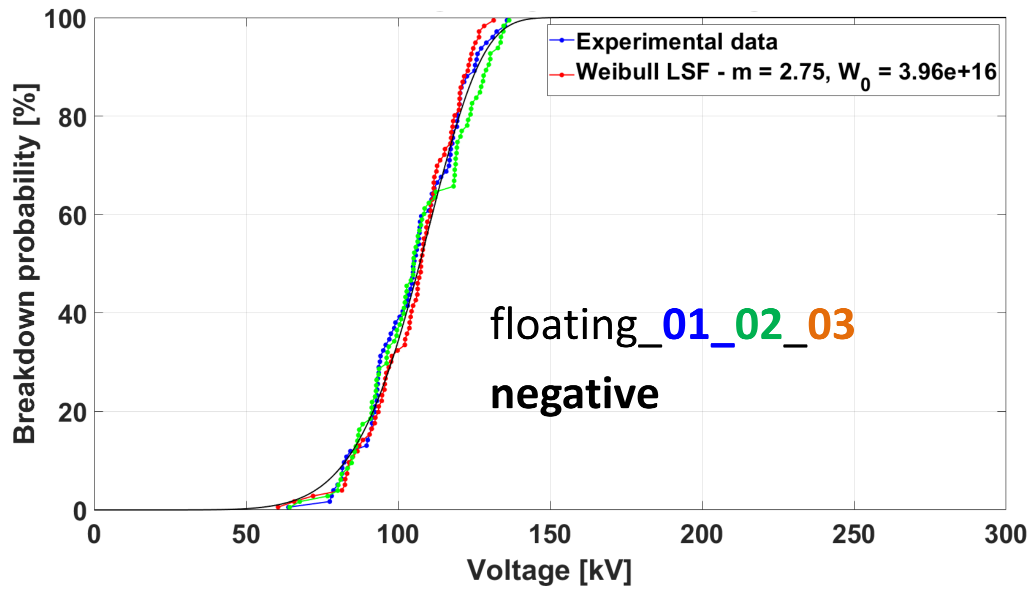


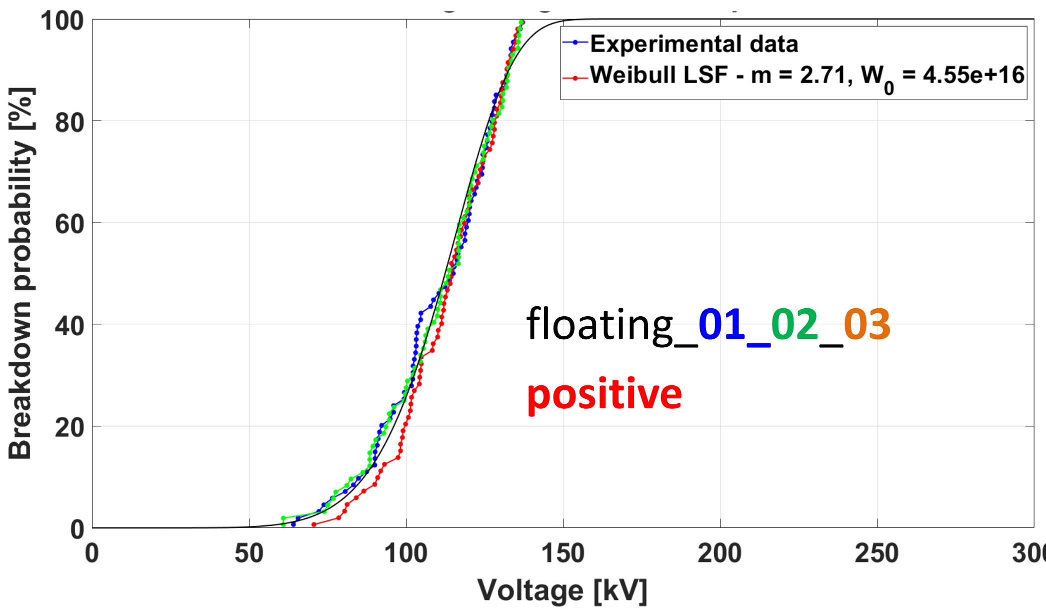
Purposes:

- using m, W_0 from floating vapour shield tube to predict the BD probability of fixed shield tube having the same gap with the same test sequence
- evaluating shield effect on Weibull parameter values

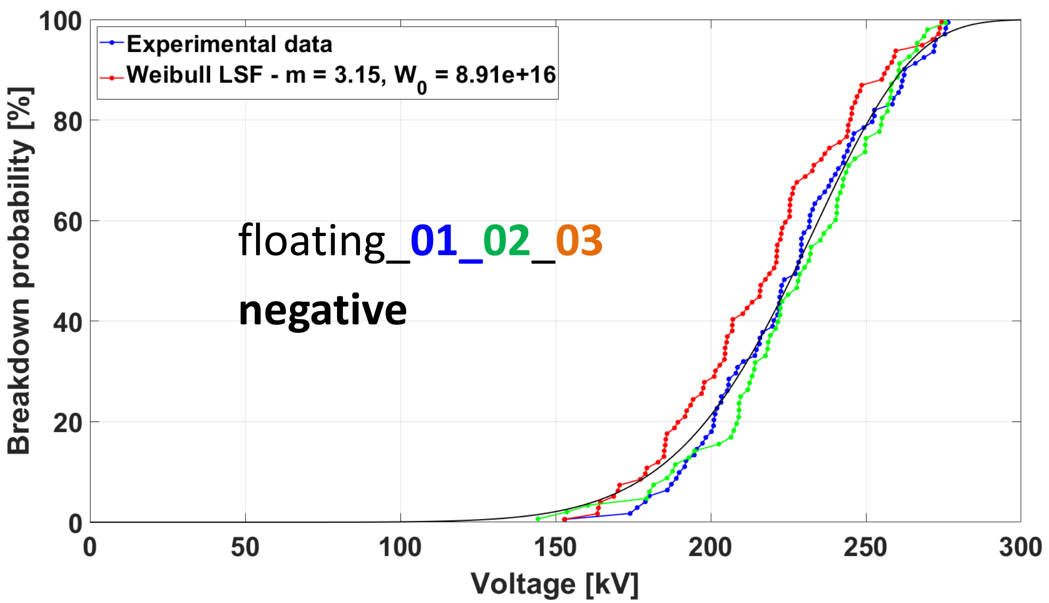
Weibull scale and shape parameters computation

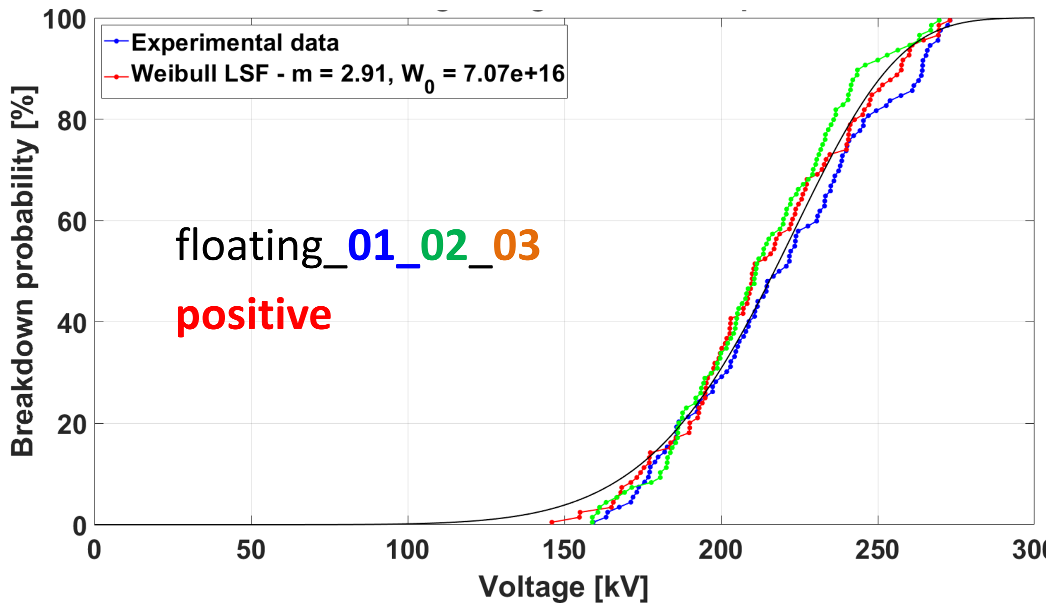
4mm gap





10mm gap





Weibull scale and shape parameters computation

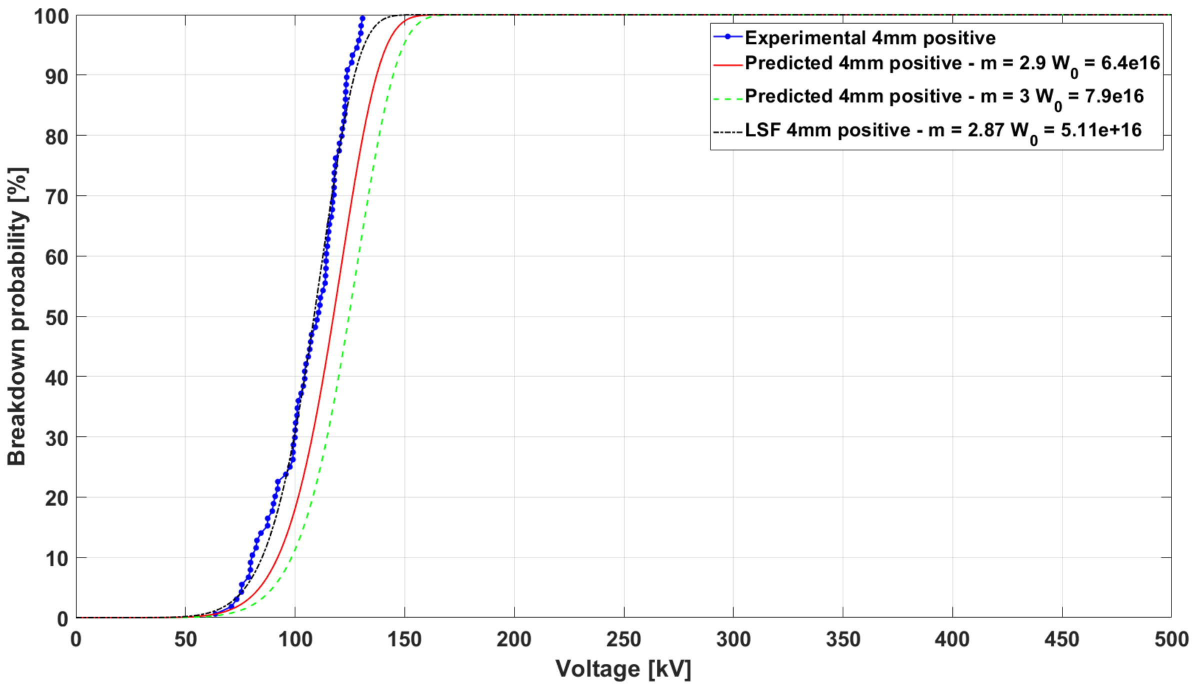
	m	W_0
Averaged W_0, m parameters	2.9	6.40E+16
Averaged only 10 mm param.	3	7.9E+16

Prediction for fixed shield tube with W_0, m from floating one: 4mm gap

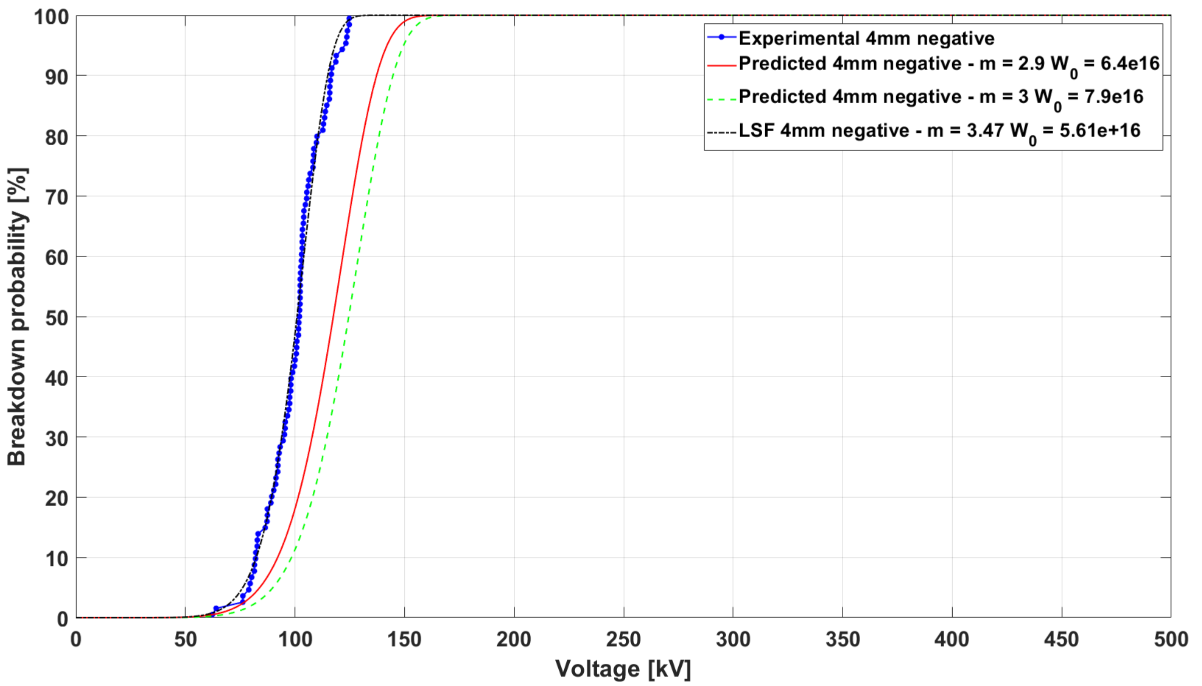
- Experimental data from a single GS tube

	m	W_0
Averaged W_0, m parameters	2.9	6.40E+16
Averaged only 10 mm param.	3	7.9E+16

positive polarity



negative polarity



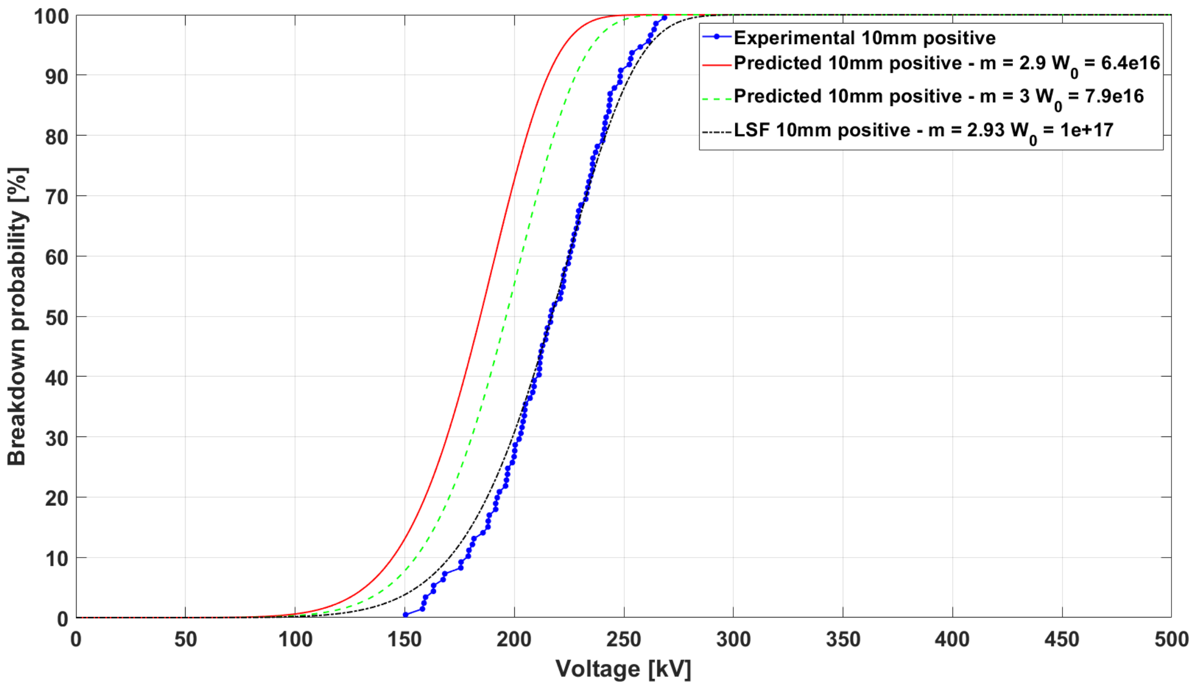
- Fair agreement between experimental and predicted BD probabilities
- The predicted BD probabilities results optimistic

Prediction for fixed shield tube with W_0, m from floating one: 10mm gap

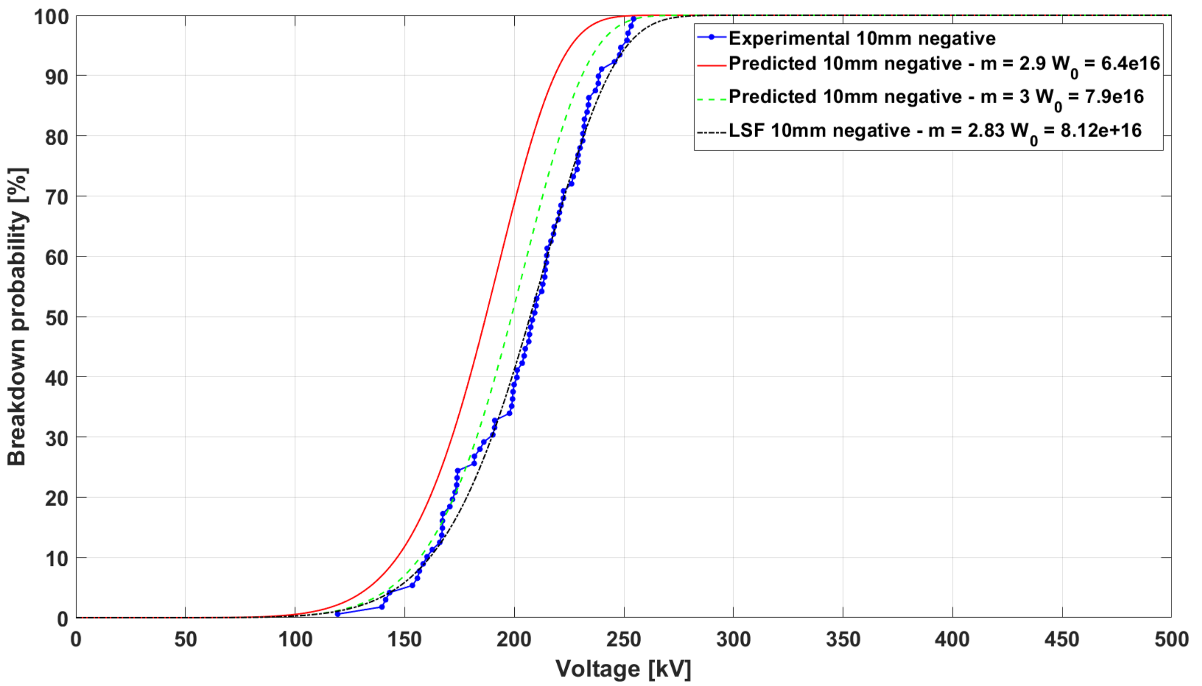
- Experimental data from a single GS tube

	m	W_0
Averaged W_0, m parameters	2.9	6.40E+16
Averaged only 10 mm param.	3	7.9E+16

positive polarity



negative polarity



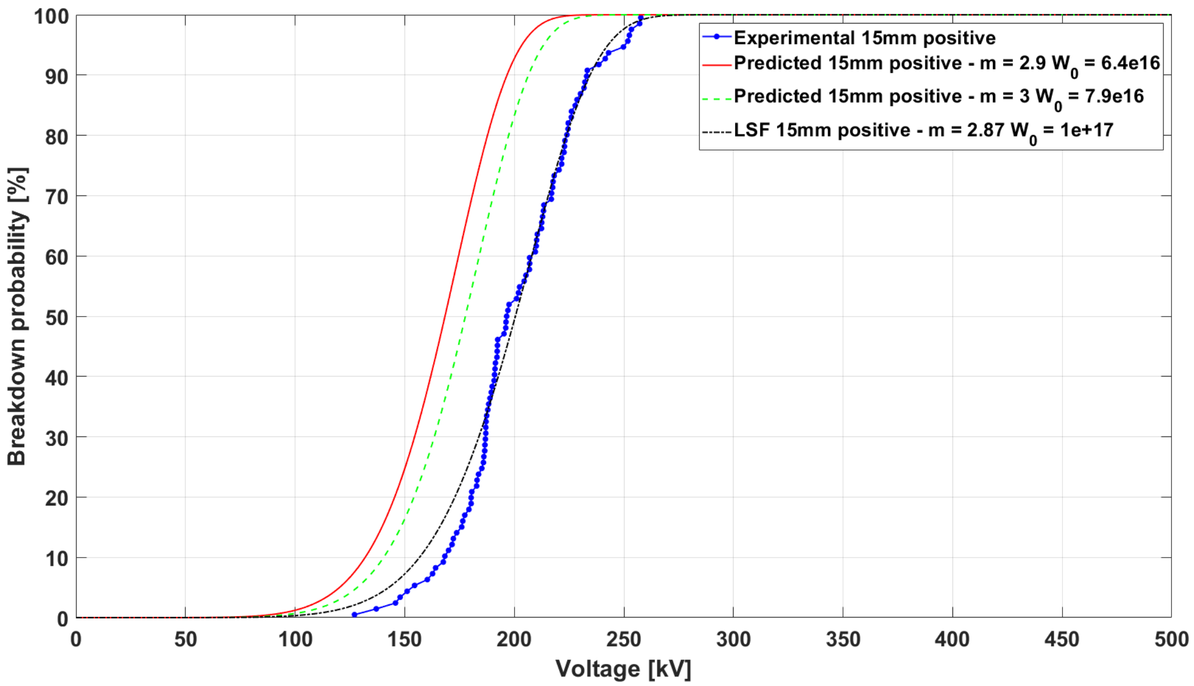
- The predicted BD probabilities results conservative

Prediction for fixed shield tube with W_0, m from floating one: 15mm gap

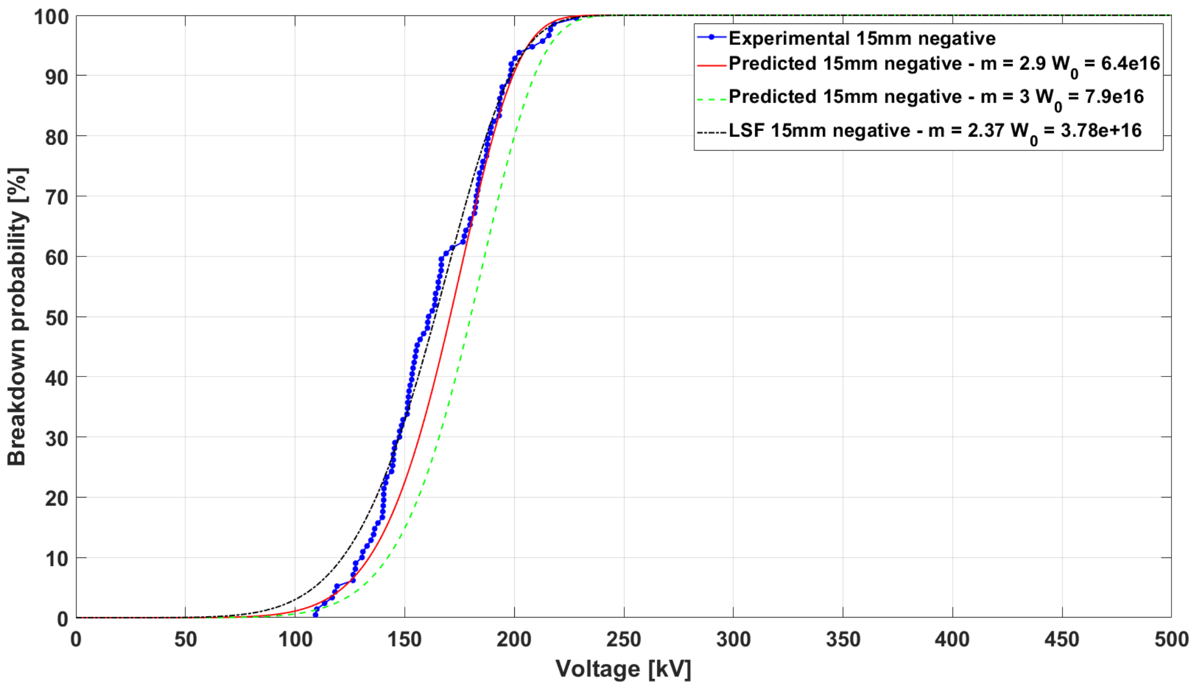
- Experimental data from a single GS tube

	m	W_0
Averaged W_0, m parameters	2.9	6.40E+16
Averaged only 10 mm param.	3	7.9E+16

positive polarity



negative polarity



- The predicted BD probability correctly “move back”

Conclusions

- The capability of the VHPM to predict the VI tubes insulation properties under LIV application has been tested with the collaboration of Siemens VI factory Berlin
- Similar medium voltage tubes with floating and fixed vapour shield used, the first as reference for model fitting, the second to test its prediction capability
- The benchmark between VHPM and experimental data has given fair results:
  - + Quite good predictions are found with negative polarized electrode
  - + Voltage holding capability trend with respect to gap length correctly predicted
  - – Worse overlap between experiment and estimation with positive polarization (about 10% error)
  - ➢ Different behaviour for small and large gap might be ascribed to different materials
  - ➢ More grounded shield tubes will be tested to improve statistic and verify the effect of conditioning

Thank you for your attention!