Vacuum breakdown voltage distributions between different contact arrangements and materials

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Overview

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- Vacuum interrupters (VI's) have standard requirements to withstand high voltage pulses.
- Codified in BIL (U_p) voltage test.
- Detailed studies often use up-down method.
- Explored always breakdown method.
- Provided similar results, and much quicker.
- Comparison to linear collider breakdown models.
- Comparison of field emission from VI's/macroscopic contacts to microscopic field emission arrays (FEA's).
- Can connect VI's, linear colliders, and FEA's.

Vacuum interrupter (VI) design

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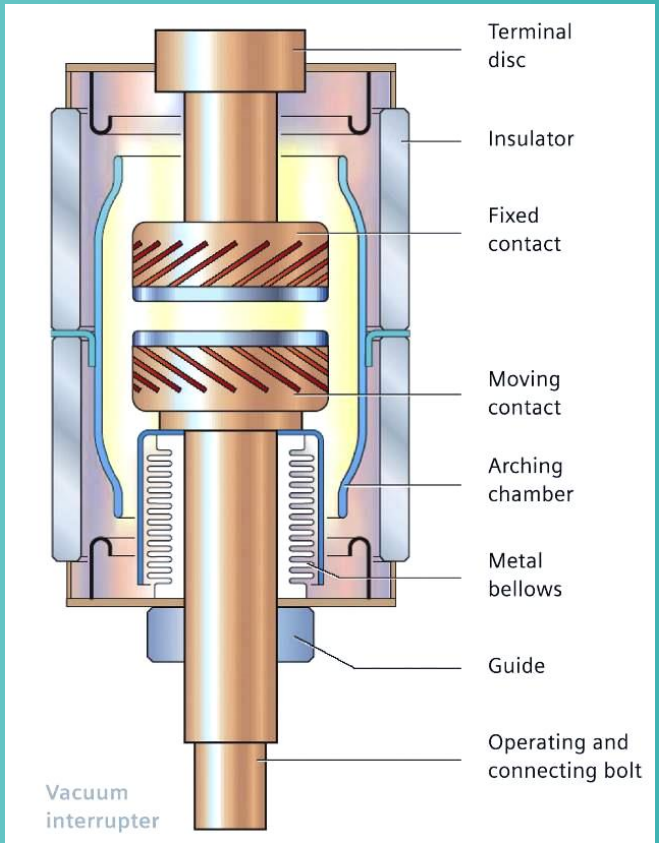
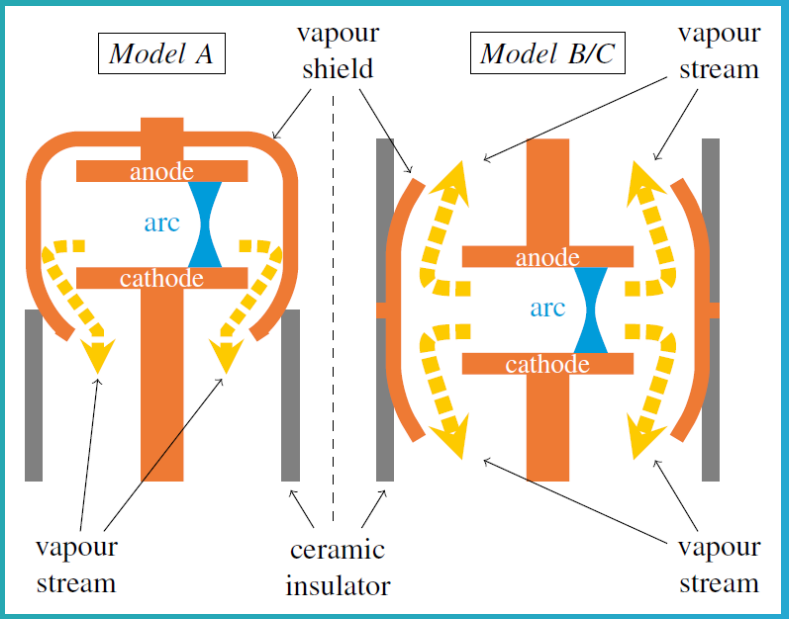
Typical VI layout



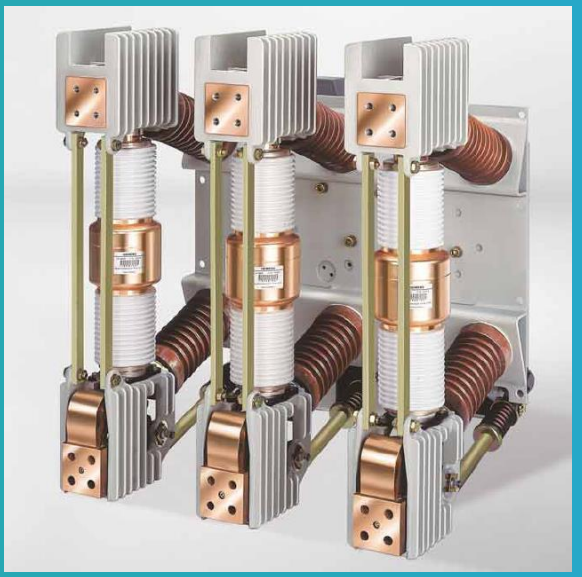
Range of VI's for different applications

Fixed and floating shield designs



Janssen, et al., ISDEIV 2018

Vacuum interrupter applications



BIL voltage test (U_p) and test methods

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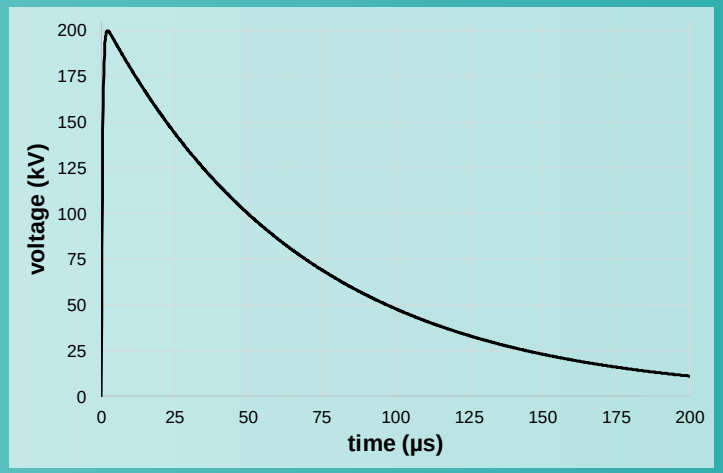
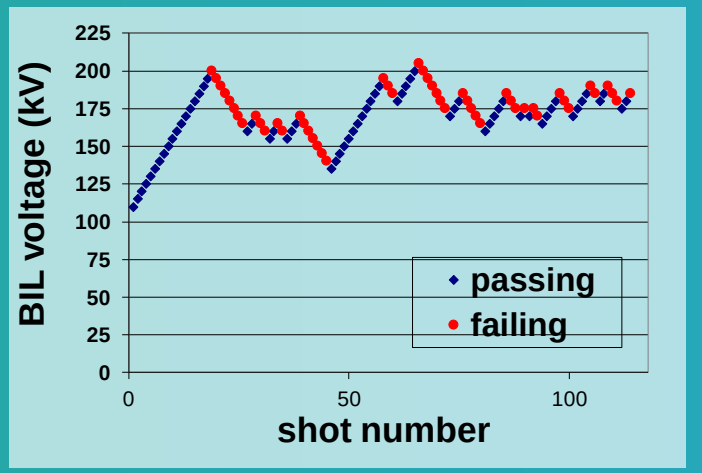
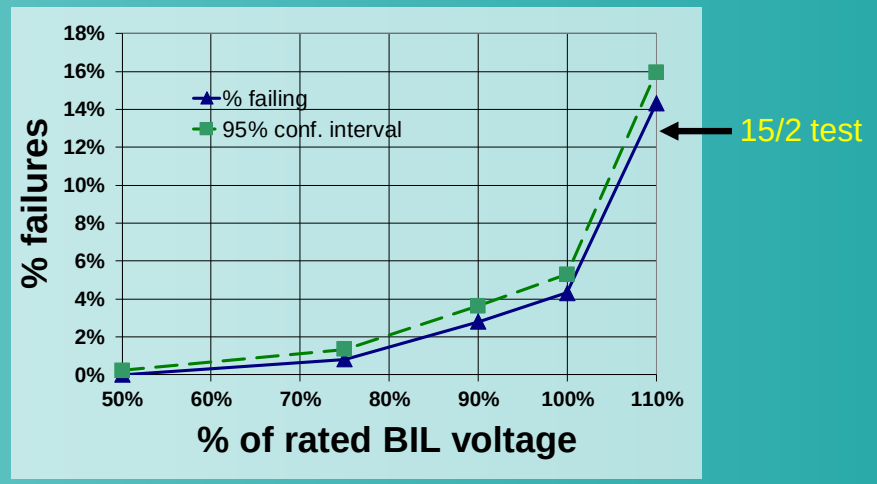
Standard BIL voltage 1.2µs/50µs pulse



Up-down voltage test

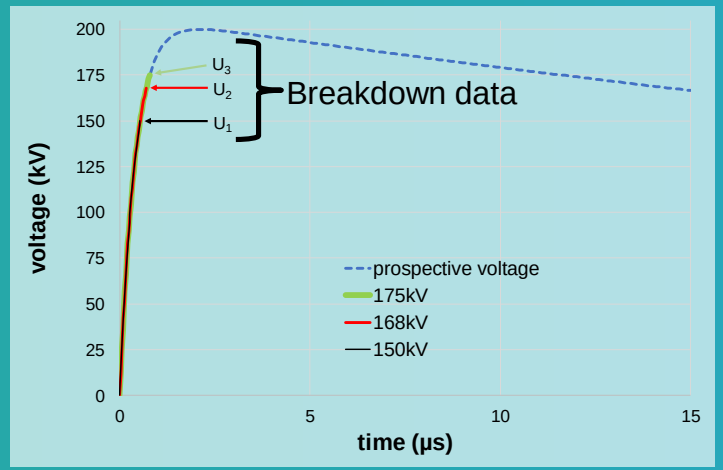


Typical BIL performance



Taylor, Slade, ISDEIV 2006

Always breakdown test



Breakdown data for VI's

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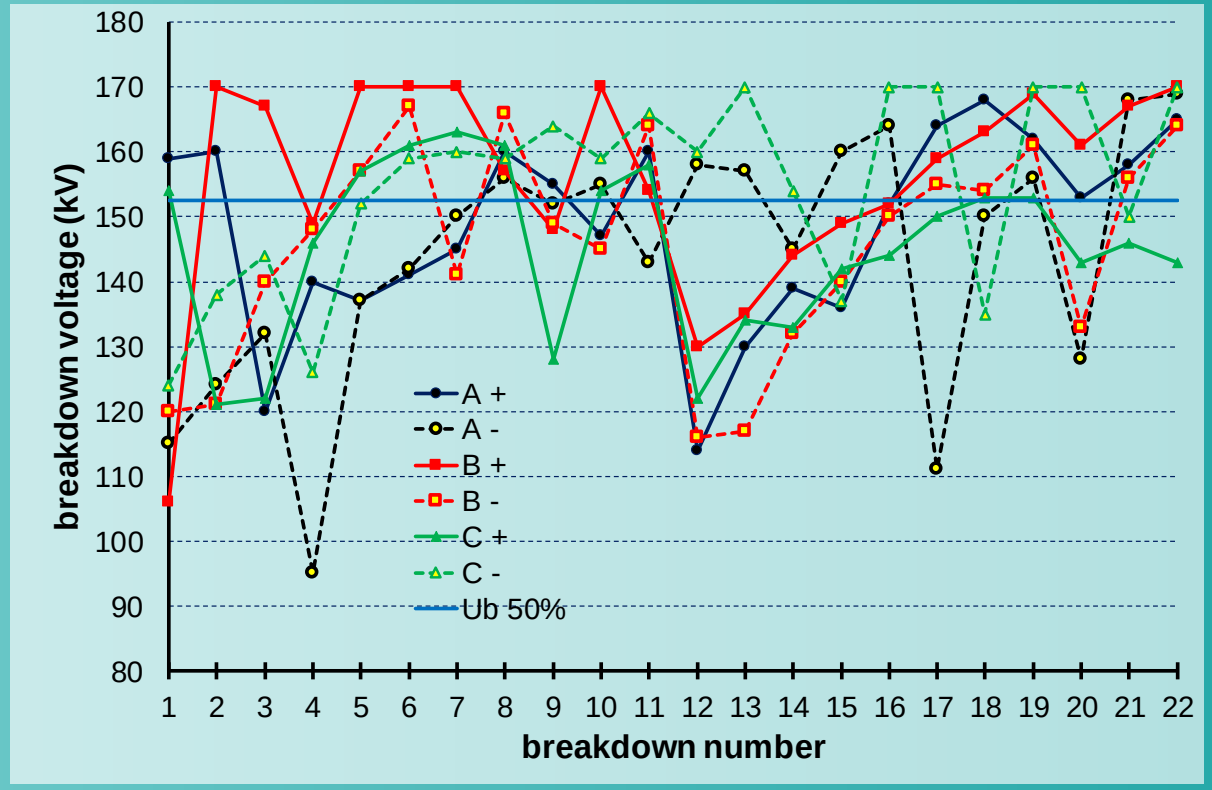
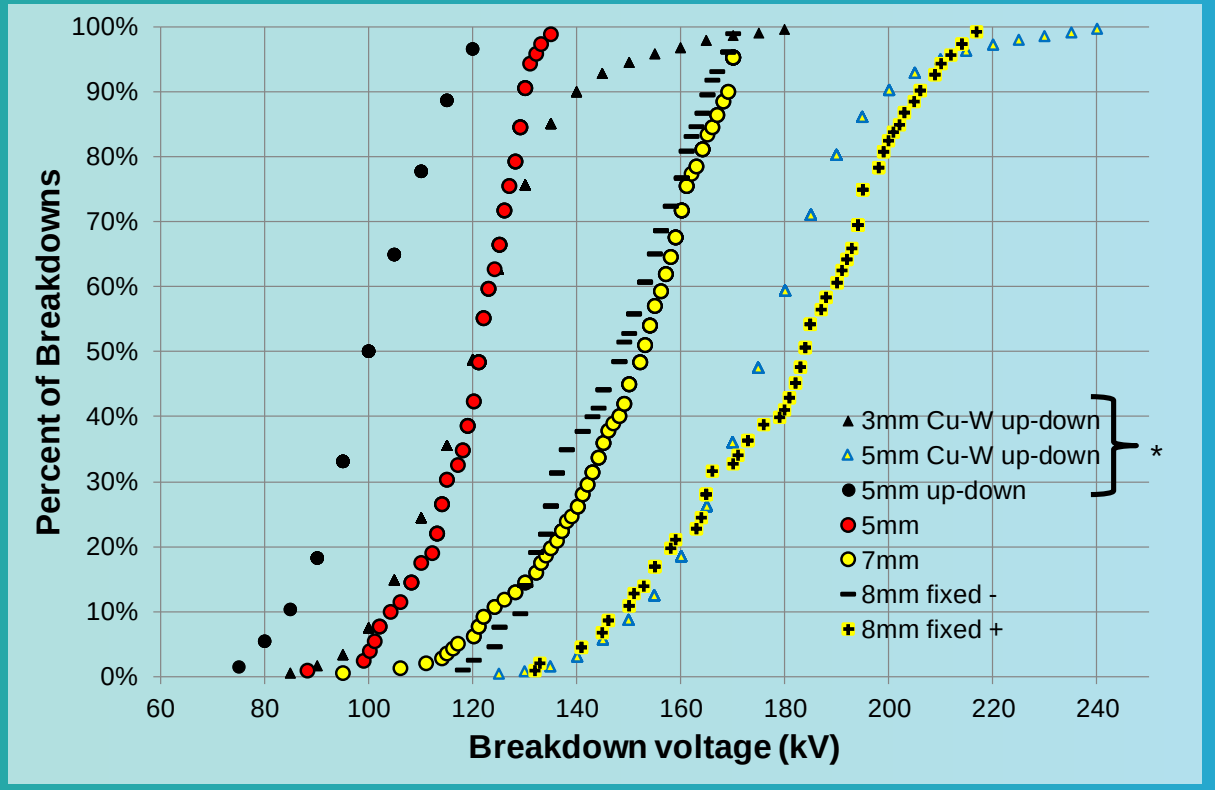
Scatter of breakdown voltages (7mm) – limited conditioning



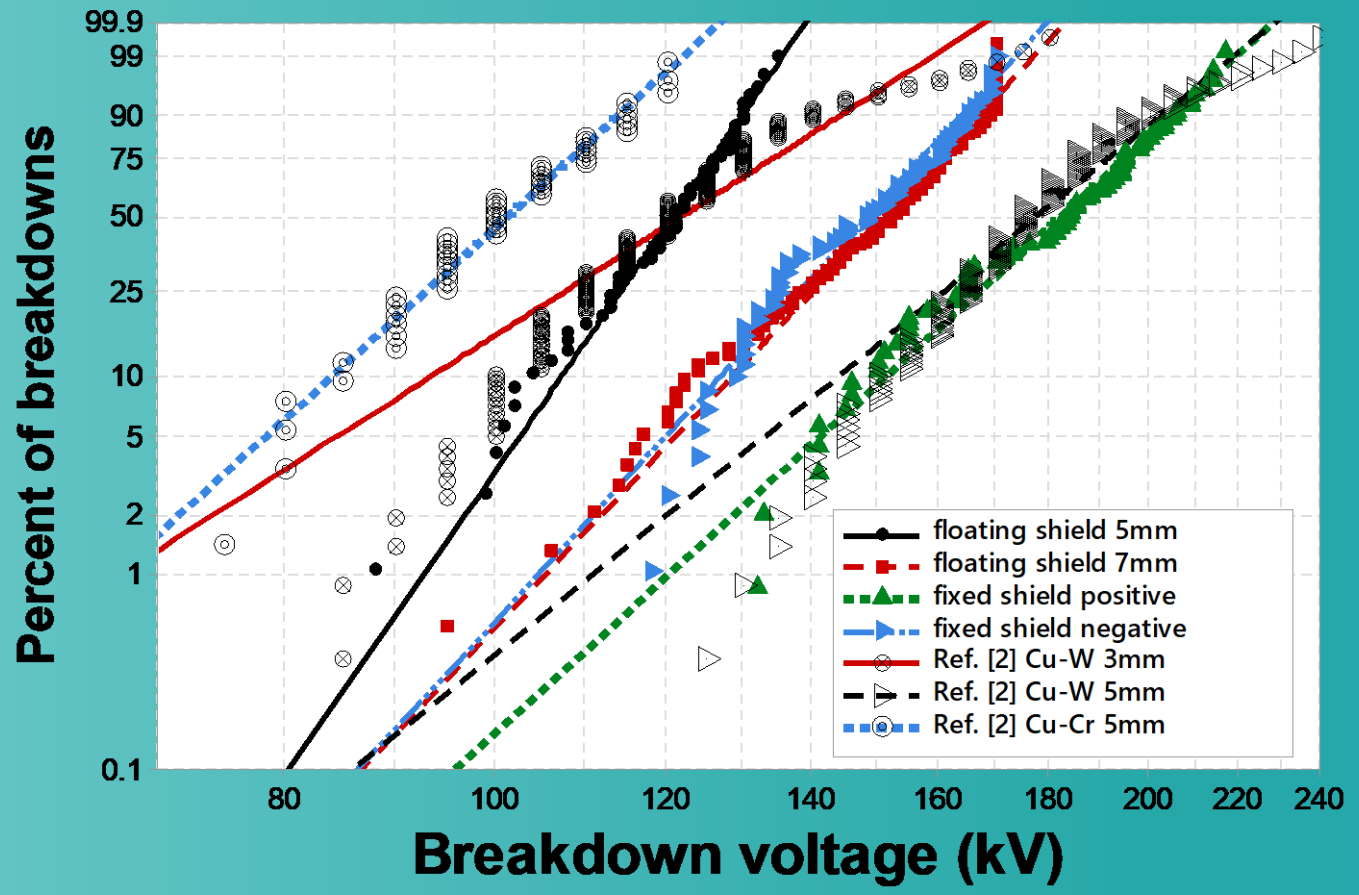
Cumulative breakdown distributions for different VI's



* Taylor, Slade, ISDEIV 2006

Taylor, et al., ICEPE-ST 2019

Fitting data to Weibull distributions



data source	Weibull parameter shape	scale (kV)	50% (kV)
floating shield 5mm	16.2	124	121
floating shield 7mm	11.8	156	151
fixed shield positive	10.2	189	182
fixed shield negative	12.1	153	149
Ref. [2] Cu-W 3mm	7.1	128	122
Ref. [2] Cu-W 5mm	9.0	185	178
Ref. [2] Cu-Cr 5mm	10.2	105	101

Empirical breakdown voltage models

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voltage
Shape parameter
Scale parameter

$$F(x) = 1 - e^{-(x/\lambda)^k}$$

Weibull cumulative breakdown distribution

~30
Electric field magnitude

$$BDR \sim E_a^{\gamma}$$

Breakdown rate for linear colliders *

$$F(x) = (x/\lambda)^{\gamma}$$

Possible extension of collider model

$$\lim_{x/\lambda \to 0} \frac{1-e^{-(x/\lambda)^k}}{(x/\lambda)^{\gamma}} = \frac{1-\left(1-(x/\lambda)^k\right)}{(x/\lambda)^{\gamma}} = 1$$

Models converge as voltage decreases -

$$k = \gamma$$

when γ is equal to shape parameter

* Grudiev, et al, Phys. Rev. ST Accelerators Beams, 2009

Comparison of empirical models and data

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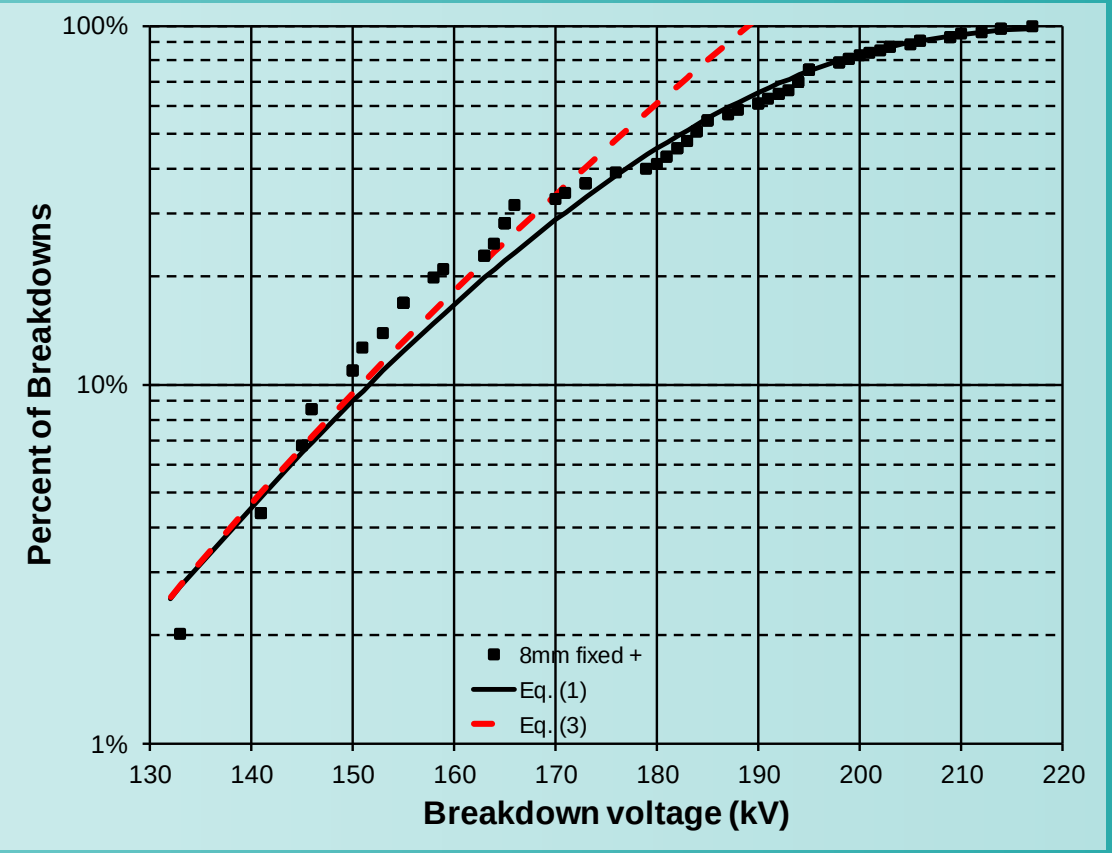
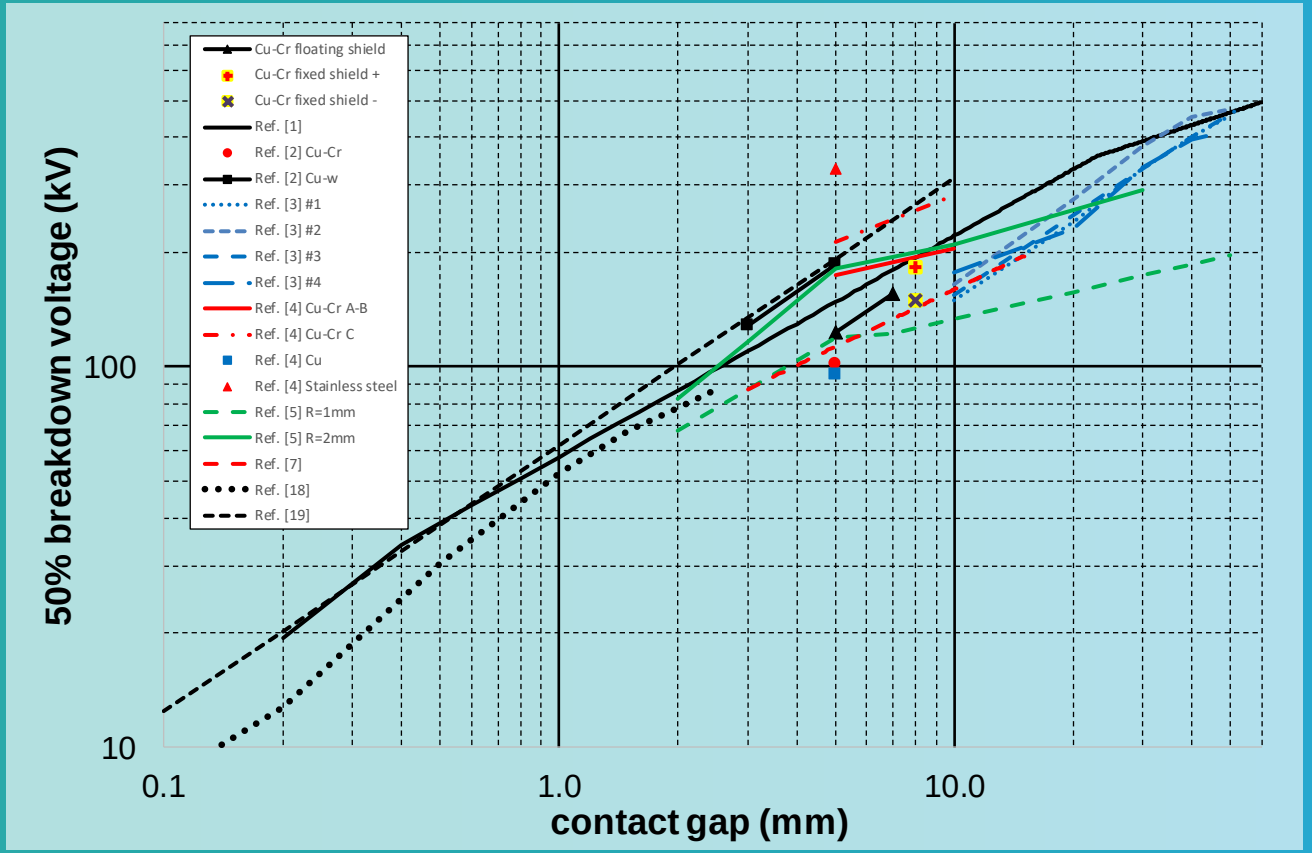
Example of VI data and models from previous slide

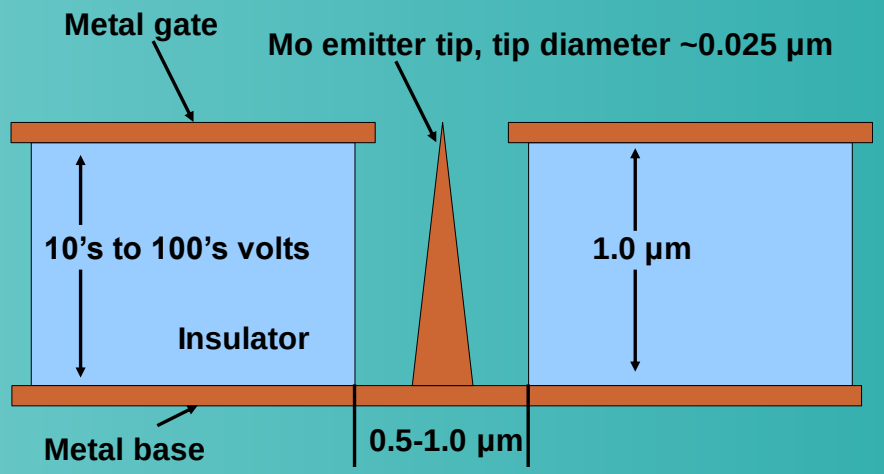


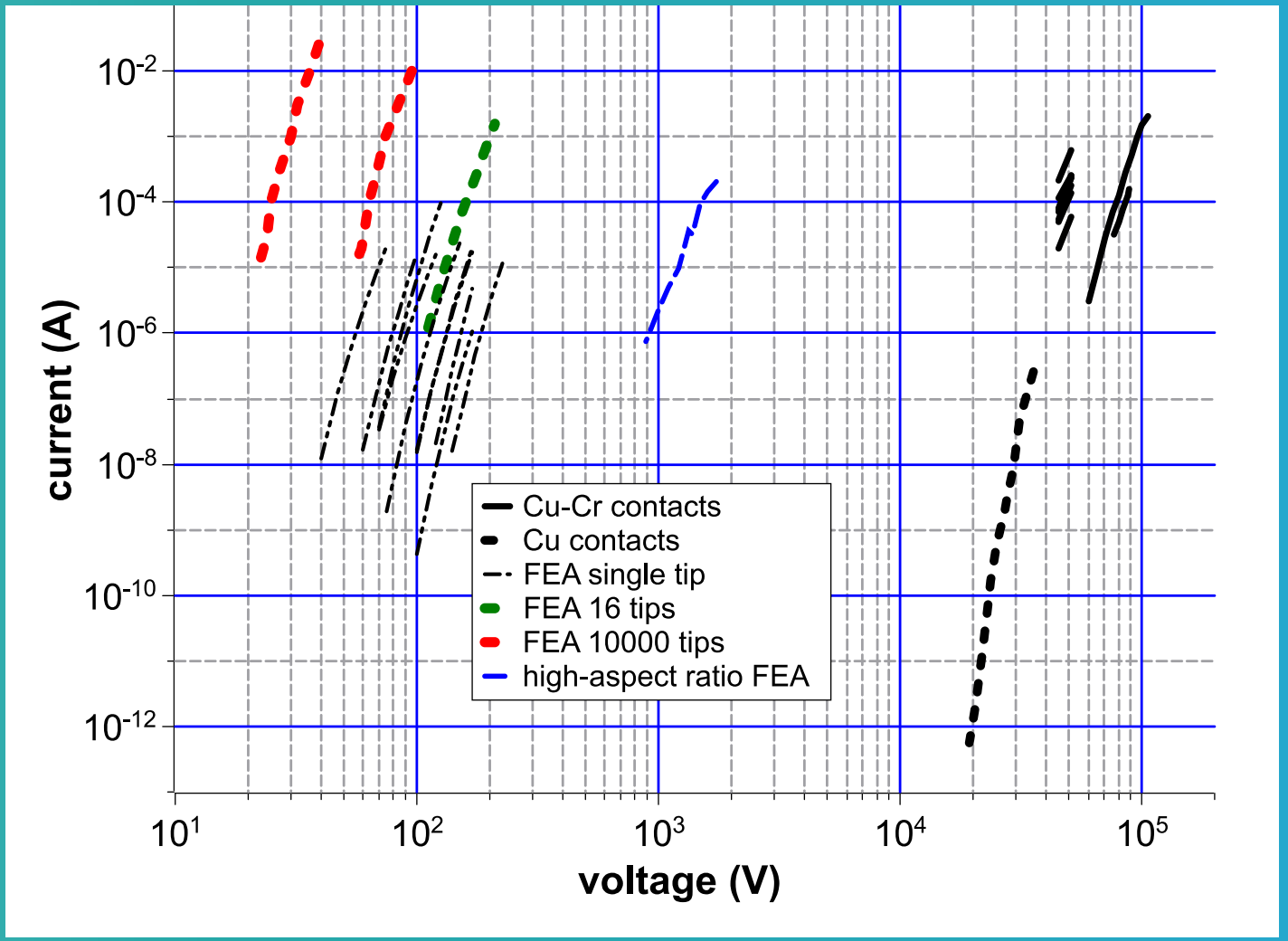
50% breakdown voltage (data/models) vs. Ref. [1]



References in Taylor, et al., ICEPE-ST 2019

Comparison to other extreme of dimensions - FEA





Comparison to F-N equation

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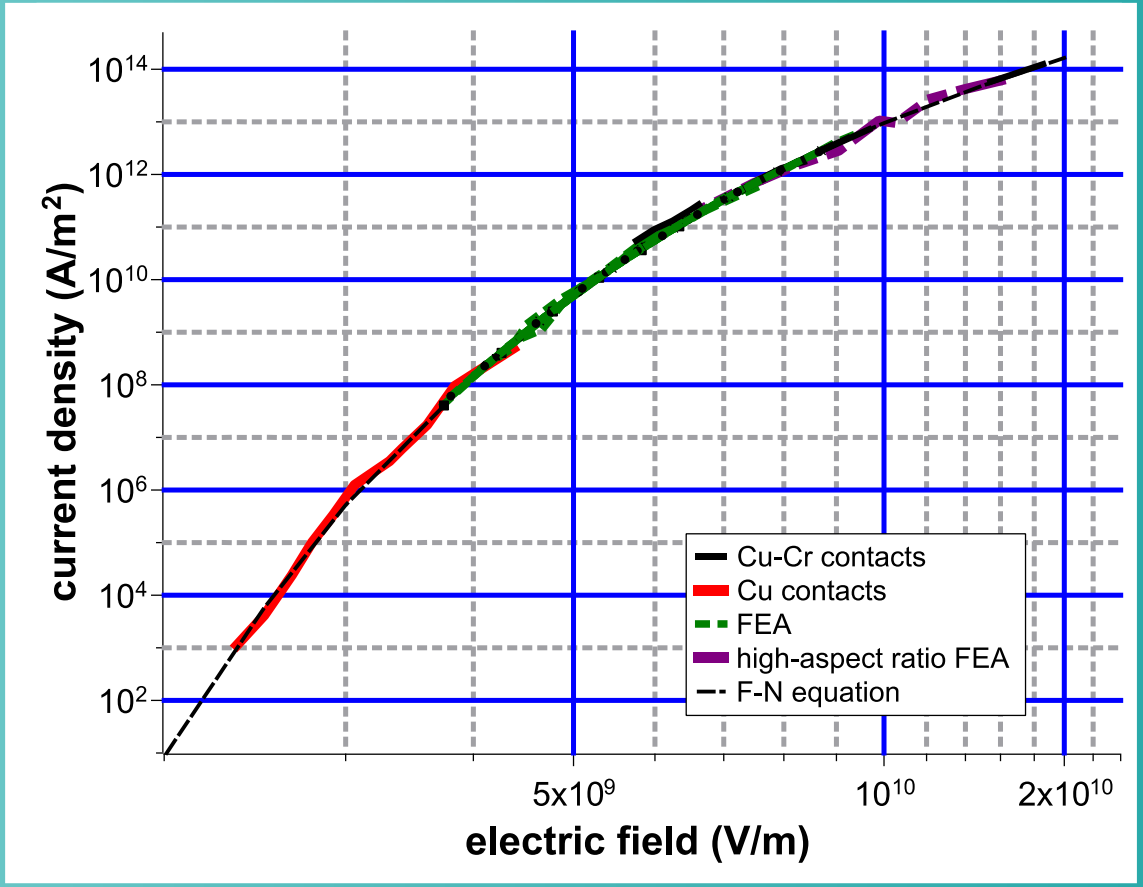

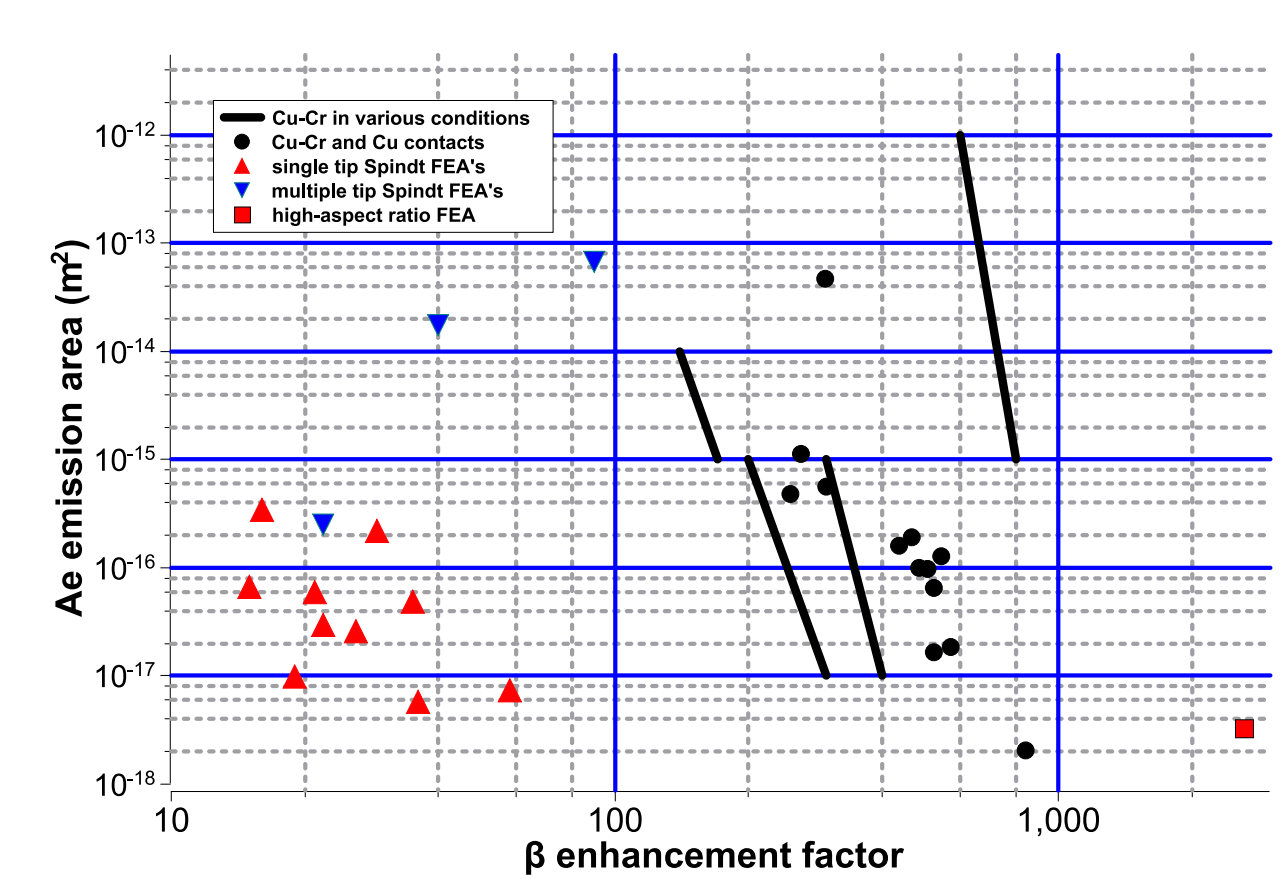

Summary

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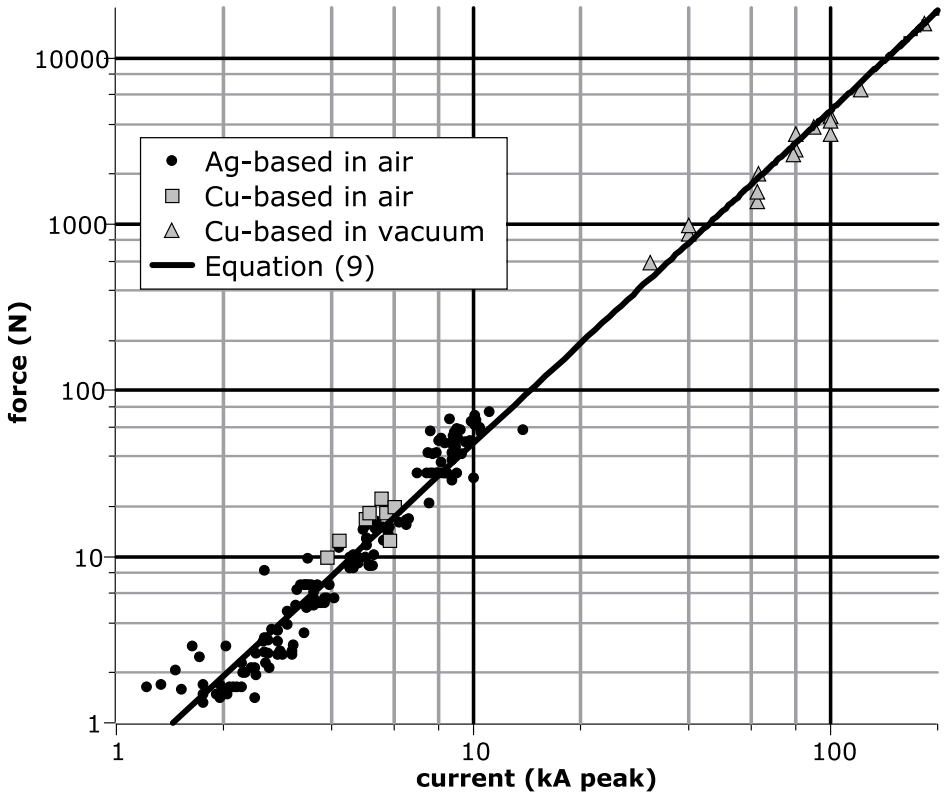
- Can connect results from vacuum interrupters, linear colliders, and microscopic FEA's.
- Always breakdown method quickly provided breakdown data.
  - Limited / no signs of (de-)conditioning during the test.
- Data generally fits Weibull distribution and extension of linear collider model when using the shape parameter.
  - Both VI's and colliders have very steep shape parameters.
  - VI's have values from 9-16, compared to ~30 for colliders.
  - But VI data does suggest a steeper value below a few percent.
  - Work continuing at Padua.
- Similar field emission behavior in VI's and FEA's, despite very large differences in dimensions, structure, and voltages.
- Meaningful breakdown model would need to include the variation in the breakdown voltage as well as rare but observed breakdowns at much higher than expected voltages.

Contact information



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