Electrical Design and Voltage Holding Analyses of the MITICA Beam Source Mock-up and its Intermediate Electrostatic Shield

T. Patton

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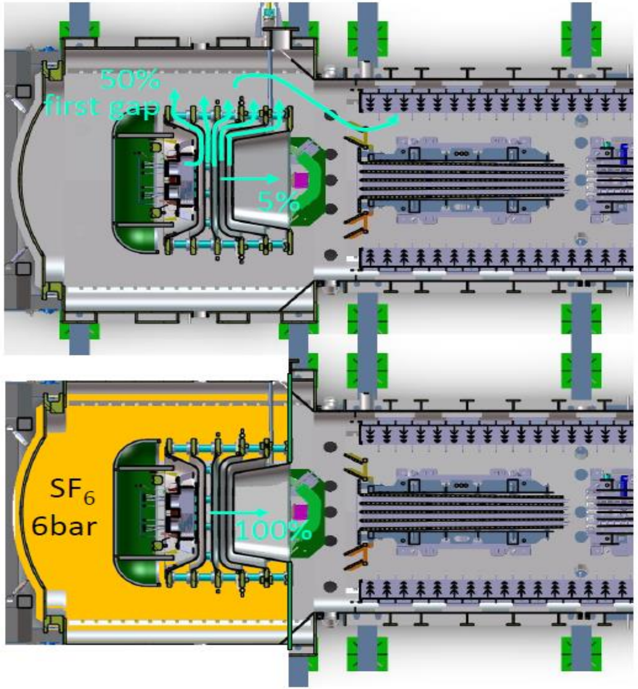
Outline

- Work rationale
- Model adopted: VHPM
  - Comsol Algorithm Implementation
- Intermediate SHIELD working principle
- MITICA VHPM analyses
- Mockup-design and assesment
  - Additional flat anode (AFA) size
  - Water pipes managing
  - Mock-up of the intermediate electrostatic shield

Work rationale

ITER HNB: due to neutron environment, this will be the first beam source at -1MV with vacuum insulation instead of SF_6 gas insulation.



Lateral pumping of the accelerator helps a lot in reducing stripping losses inside the beam source

$L_s = \int -\sigma(U(x)) n_g(x) dx$, where $n_g(x)$ is the background gas density, and σ is the total stripping cross-section

All the gas flows along the accelerator, the density can be reduced by means big apertures in the mounting flanges of the grids.

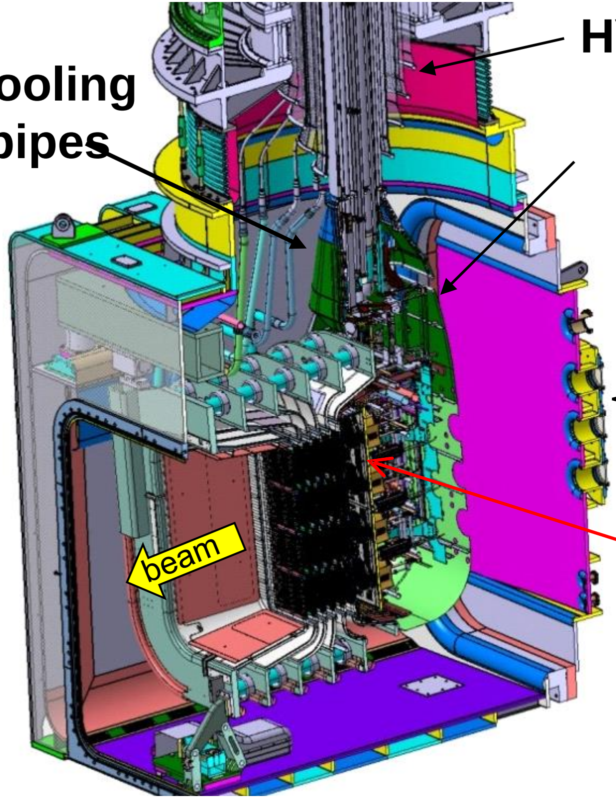
Work rationale:MITICA Beam Source

Cooling pipes

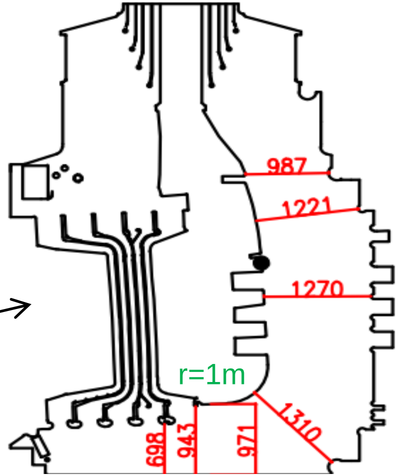
HVB

1MV ES shield

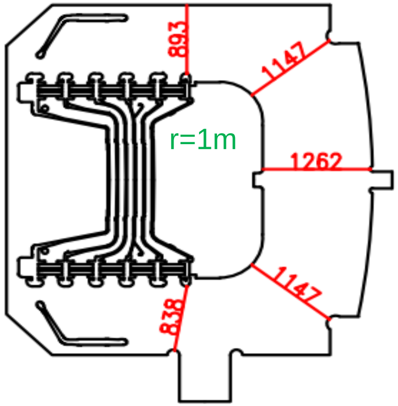
Ion Source



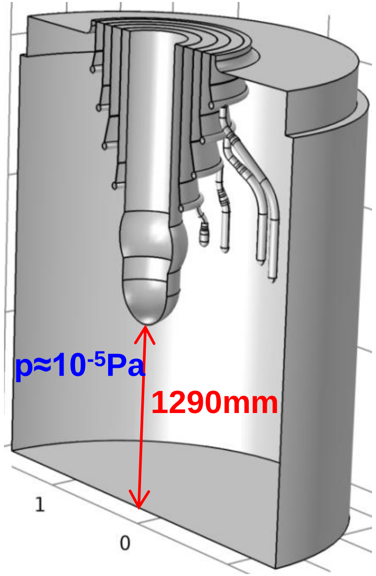
Vertical cross section

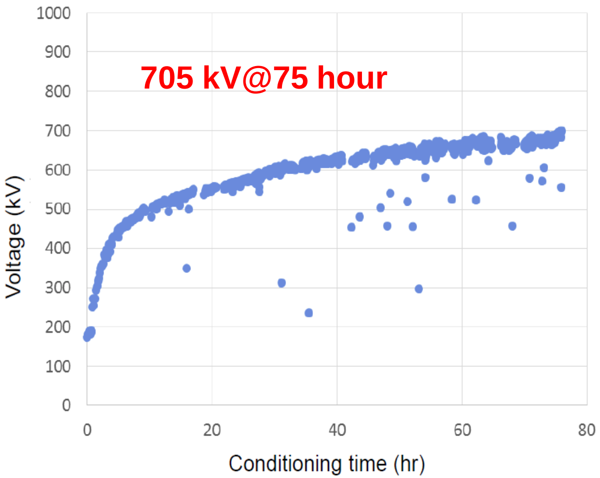


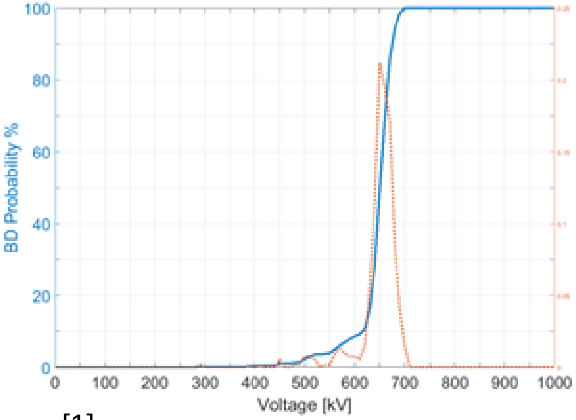
Horizontal cross section



Work rationale:HVB acceptance test at HITACHI







[1]

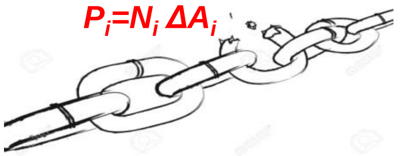
For the **MITICA** geometry:

- Gap min (1MV-GND) =**0.94m**
- -1MV parts with smaller curvature radius (e.g the EG mounting flange)

→ **Breakdowns in high vacuum may occur at operating voltages below 1MV!!!!**

[1] N. Pilan ; A. Kojima ; R. Nishikiori et.al, Numerical–Experimental Benchmarking of a Probabilistic Code for Prediction of Voltage Holding in High Vacuum, IEEE Transactions on Plasma Science (Volume: 46, Issue: 5, May 2018

Voltage Holding Prediction Model



Reliability $R = \prod_1^N (1 - N_i\,\Delta A_i) \approx e^{-\sum_1^N N_i\,\Delta A_i} \approx e^{-\int_A N\,dA}$

Breakdown probability $P = 1 - e^{-\int_A N(W)\,dA}$

The number *N* of the particles per surface unit that can induce the breakdown is monotonic with the quantity *W*.

Total voltage effect

Polarity effect

Area effect

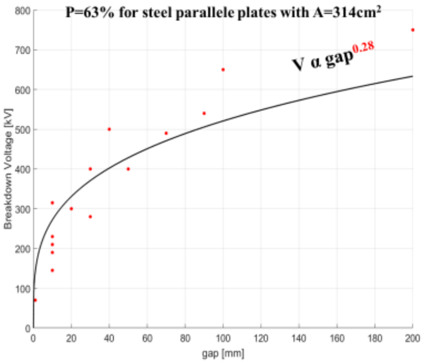
Probabilistic

$$\mathbf{P} = 1 - e^{-\int_A \left(\frac{Ec^{\gamma} Ea^{\propto} U}{W_0}\right)^m dA}$$

m, W_0 they depend only upon the quality of the electrode (material, finishing, conditioning) and of the environment (vacuum level, type of residual gas).

*(α=0.1, γ=0.29, W_0=1.98*10^8 from LSF on literature data, m=25 [1])*

α, γ, W_0 from experimental data fit on simple geometries



[2]

$$\mathbf{P(U) = 1 - e^{-\nu U^{m(\gamma+\propto+1)}}}$$

with $\nu = \dfrac{\int_A \left(\frac{Ec^{\gamma} Ea^{\propto} U^*}{W_0}\right)^m dA}{(U_M{}^*)^{m(\gamma+\propto+1)}}$

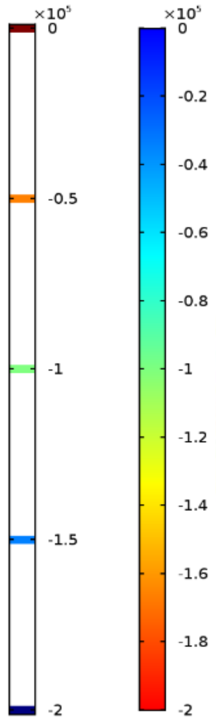
Assumption:

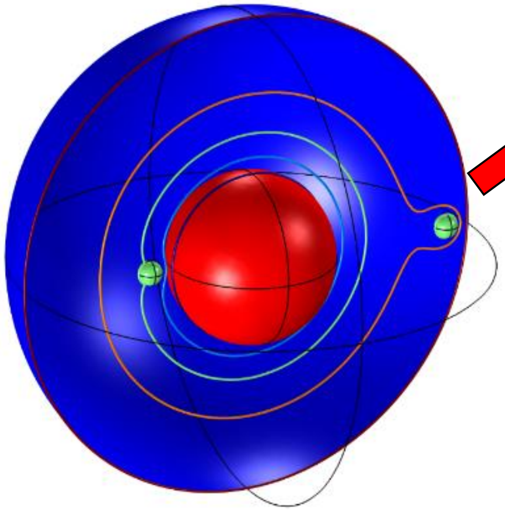
potentials are scaled proportionally and only E field is considered

($U_M{}^*$ and U^* are the maximum and clump voltages in the ES simulation)

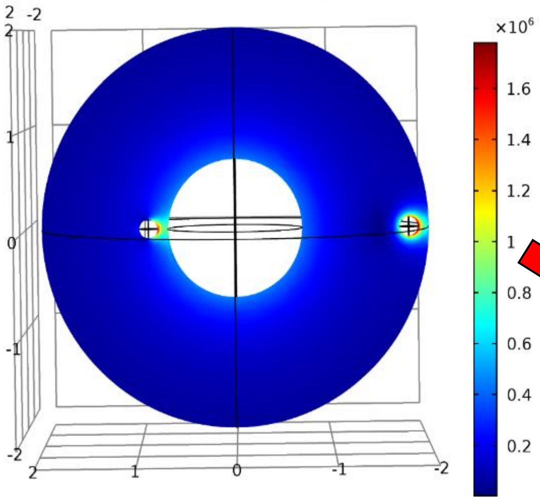
VHPM: 3D model Comsol®+Matlab® implementation

Multi-potential system

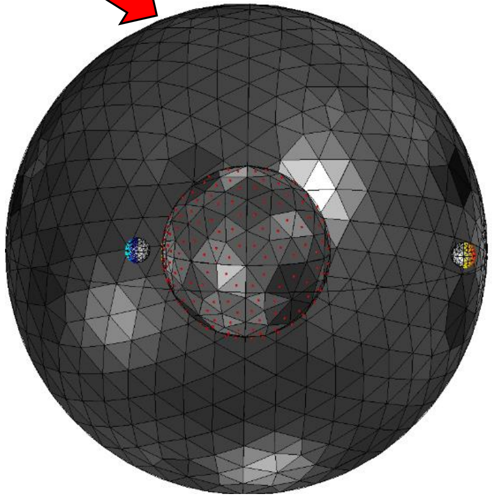




Electrostatic field distribution



Charged particle tracing trajectories



VHPM: 3D model Comsol®+Matlab® implementation

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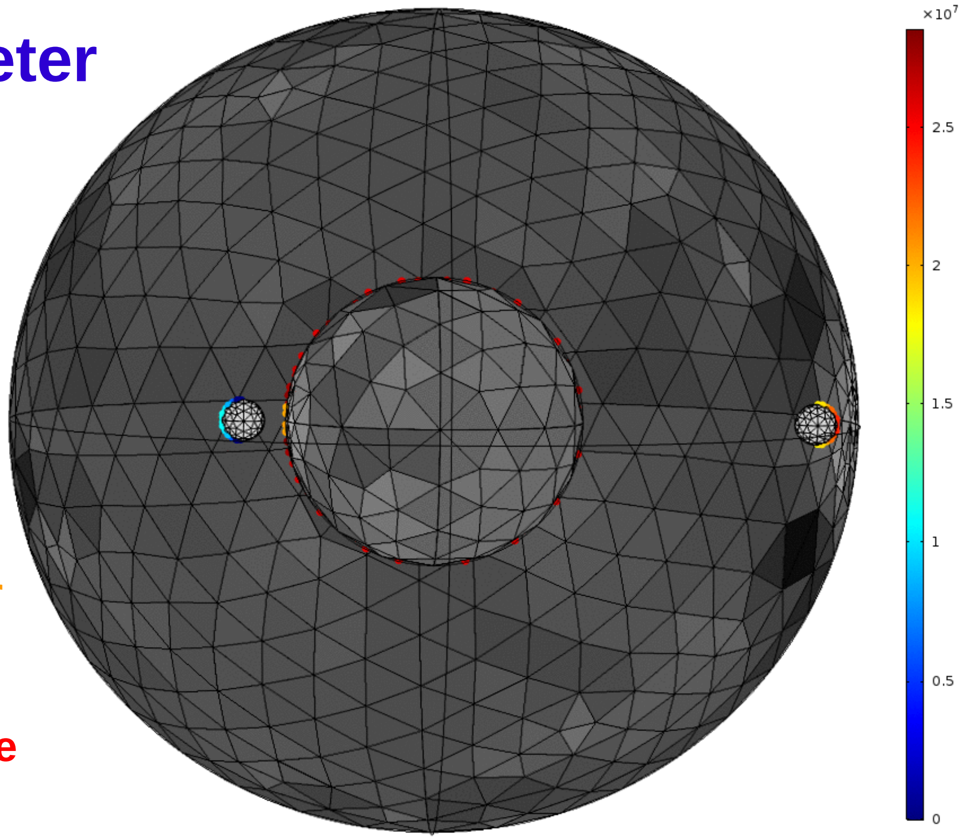
Breakdown parameter plot

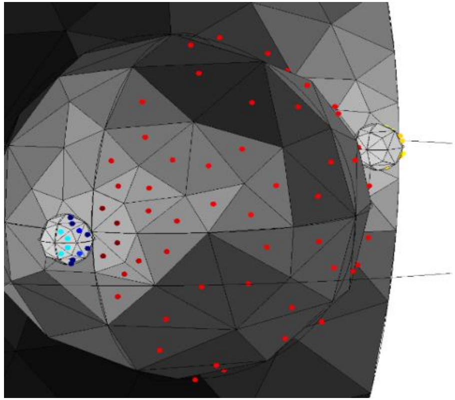
$$W = E_c^{\gamma} E_a^{\propto} U$$



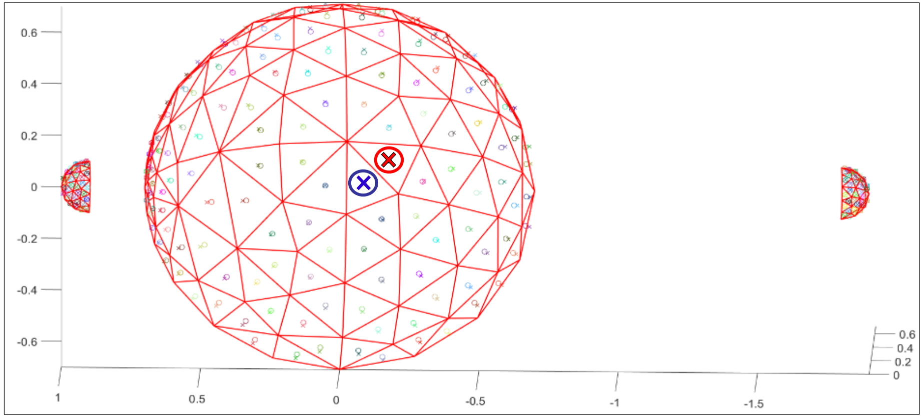
- The right hand side small sphere is more dangerous than the other since the higher electric field is at the cathode

- The most critical trajectories do not involve the high electric field zones!

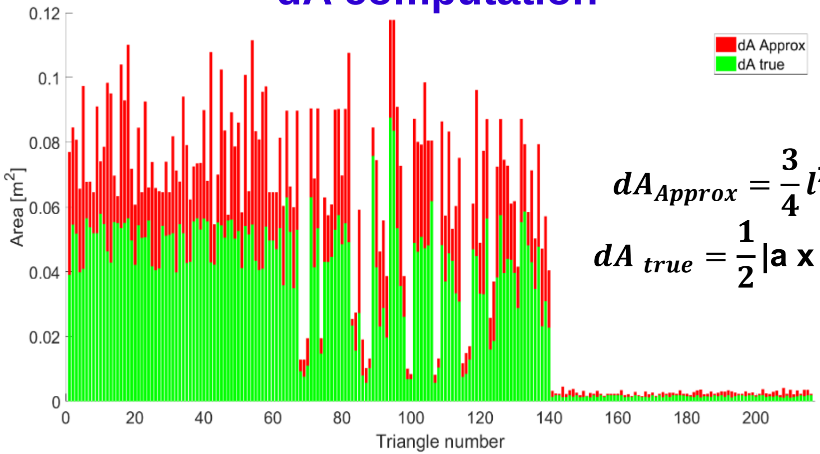
VHPM:Matlab Post Processing



Particle-triangle association



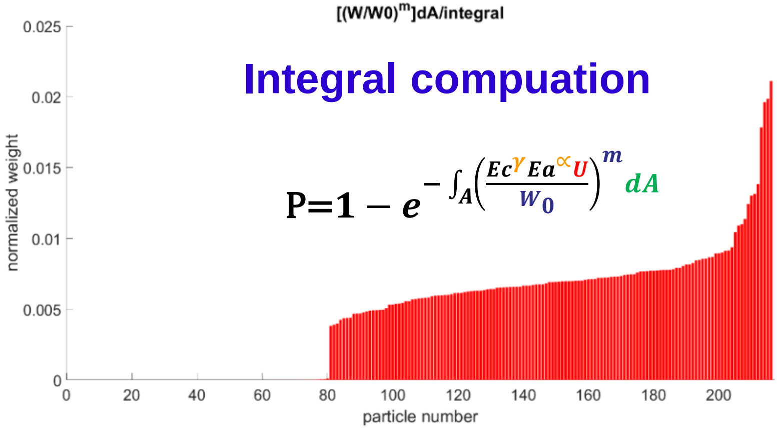
dA computation



$$dA_{Approx} = \frac{3}{4} l^2$$

$$dA_{\ true} = \frac{1}{2} |a \times b|$$

Integral compuation



$$P = 1 - e^{-\int_A \left(\frac{Ec^{\gamma} Ea^{\propto} U}{W_0}\right)^m dA}$$

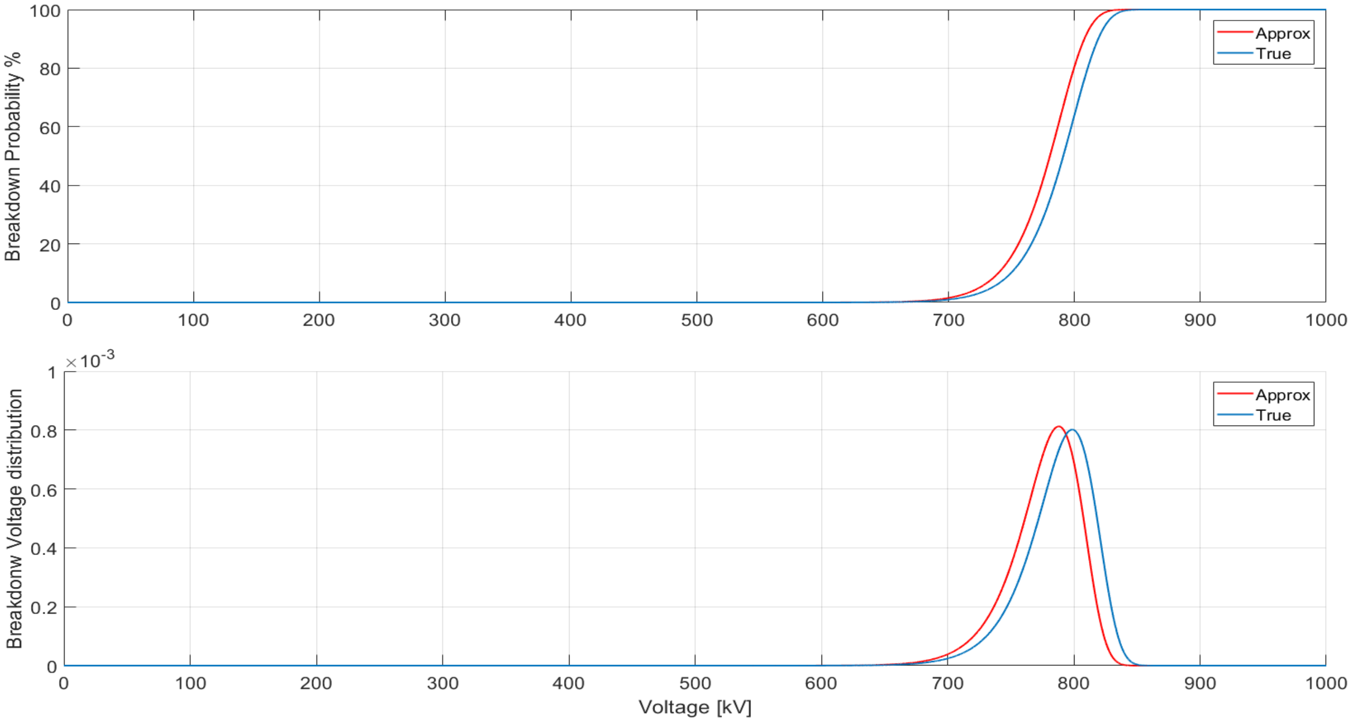
VHPM: Breakdown probability vs voltage

Assumption: potentials are scaled proportionally and only E field is considered

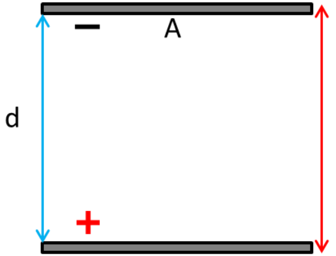
Consequences

- Trajectory paths are unchanged
- Ea,Ec scales proportionally

Probability vs maximum applied voltage from just 1 FEM simulation!



Intermediate SHIELD working principle



$\Delta V_1 = k\, d^{\frac{\alpha+\gamma}{1+\alpha+\gamma}}$

Assumptions:

- The plates thickness is neglected,
- gaps length d/n keeps in the long gap range

$\Delta V_2 = n * k \left(\frac{d}{n}\right)^{\frac{\alpha+\gamma}{1+\alpha+\gamma}}$

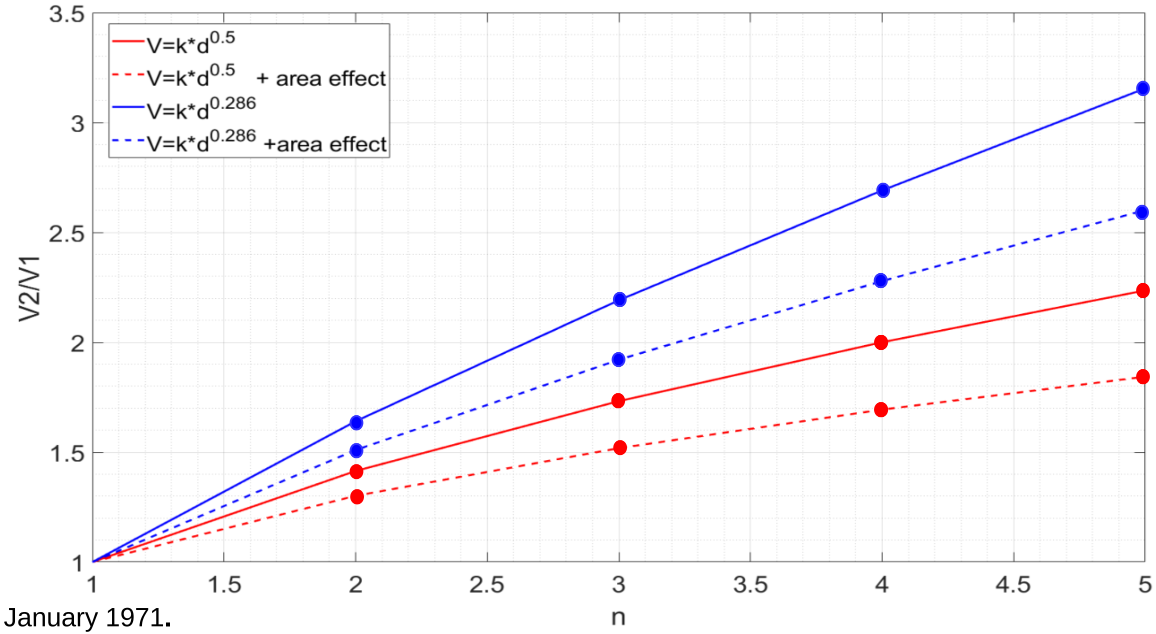
No area effect

$$\frac{\Delta V_2}{\Delta V_1} = n\left(\frac{1}{n}\right)^{\frac{\alpha+\gamma}{1+\alpha+\gamma}}$$

With area effect

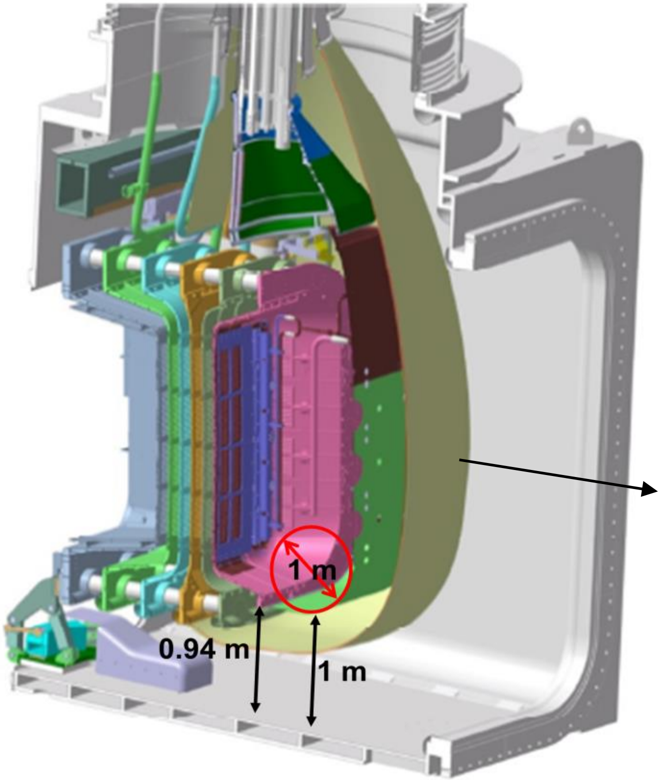
$$\frac{\Delta V_2}{\Delta V_1} = \left(\frac{A}{n\,A}\right)^{\mu} n\left(\frac{1}{n}\right)^{\frac{\alpha+\gamma}{1+\alpha+\gamma}}$$

μ≈0.1 for s.s [2]

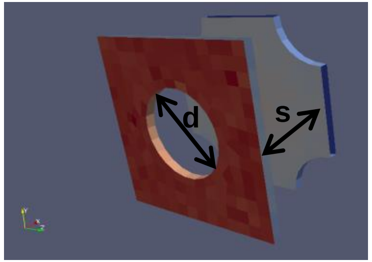


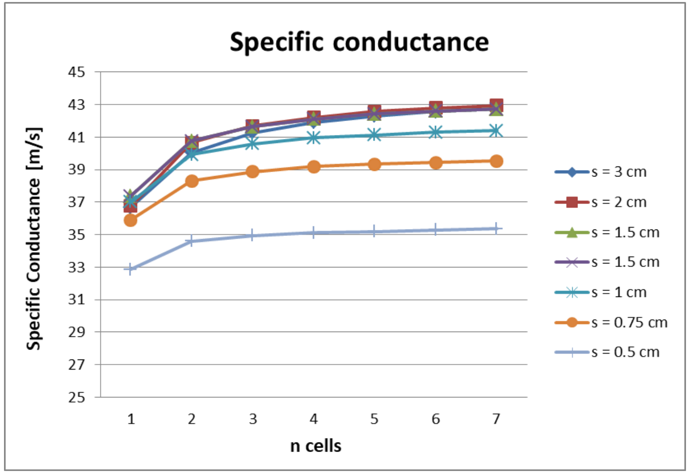
[2] F. Rohrbach, "Isolation sous Vide," CERN Report 71-5, January 1971.

MITICA INTERMEDIATE ELECTROSTATIC SHIELD



d=1cm
p=2cm

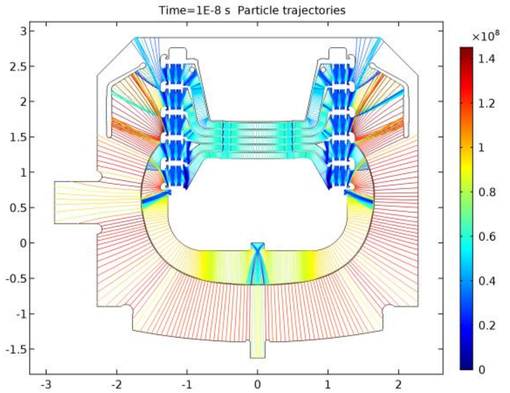


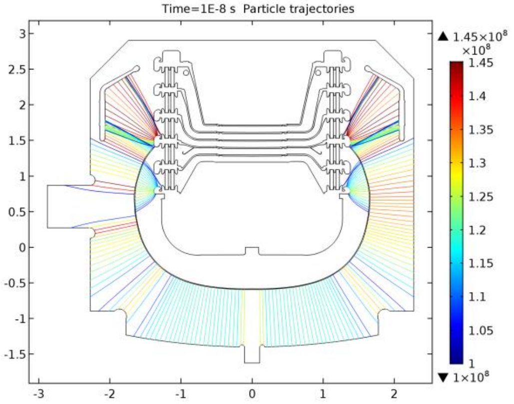


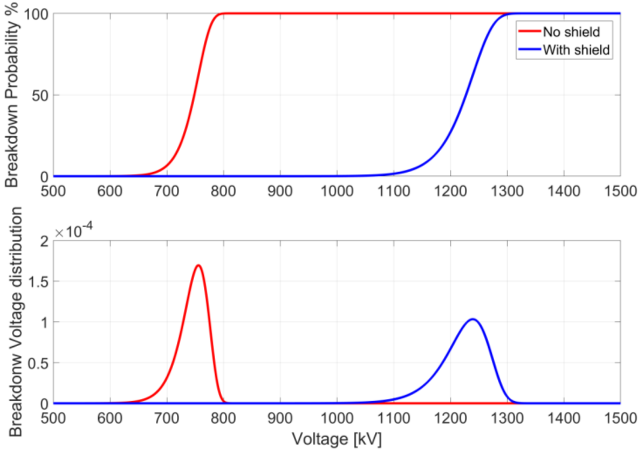
$$C = \frac{\Delta p}{Q} \qquad c = \frac{C}{A} = \frac{1}{4} \cdot \sqrt{\frac{8RT}{\pi M}} Tp$$

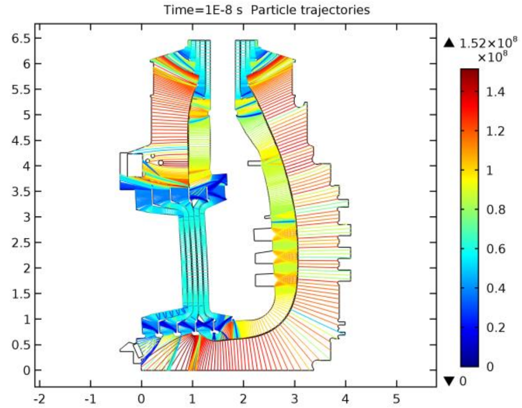
$$c = \frac{\overline{v}}{4} T_p = \frac{1}{4} \cdot \sqrt{\frac{8RT}{\pi M}} \, T_p \left[\frac{m}{s}\right]$$

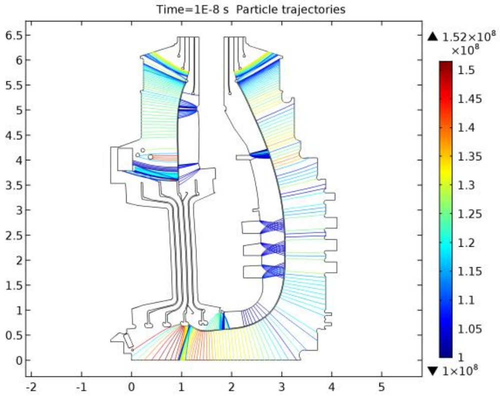
MITICA VHPM analyses

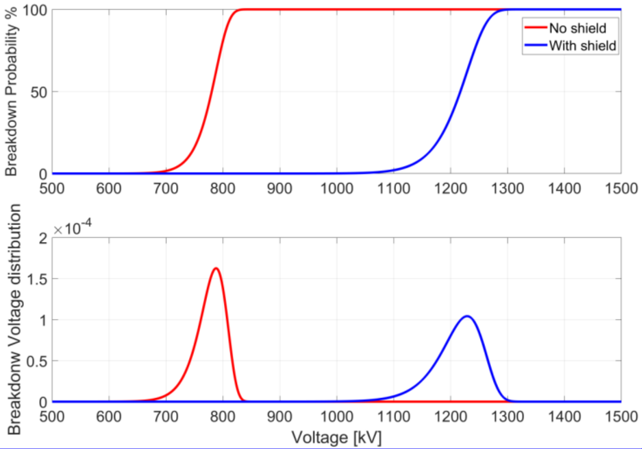












Mockup-design and assesment: MBS

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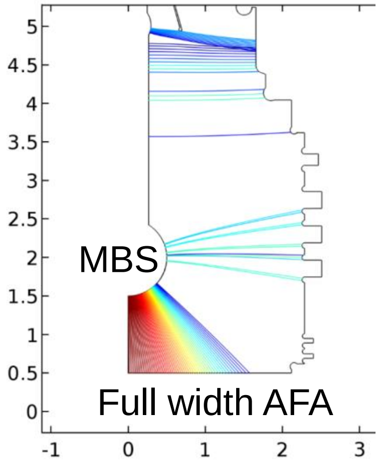
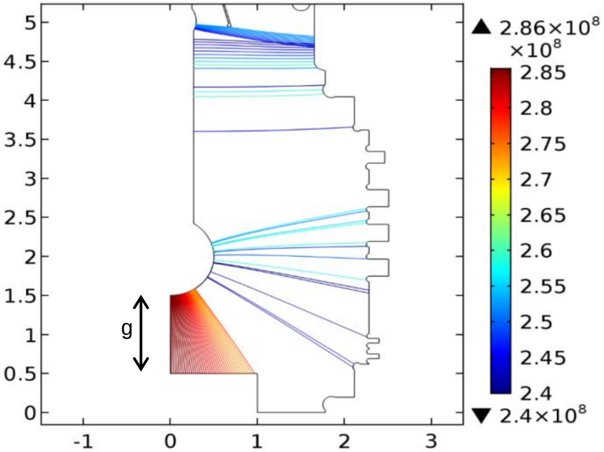
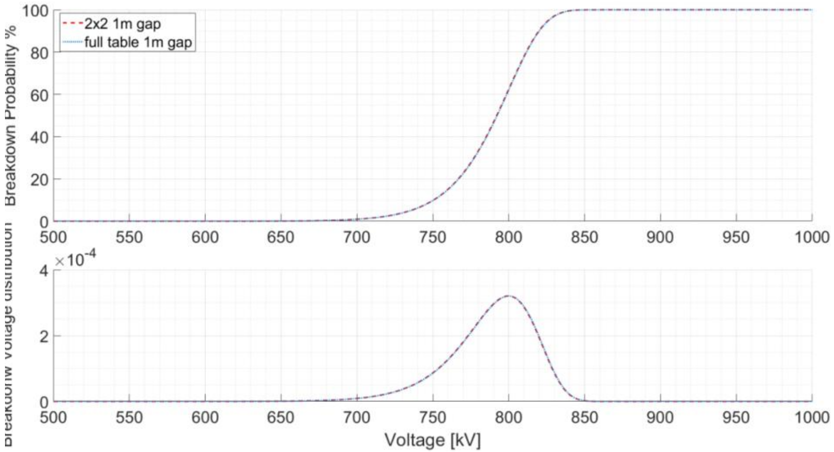
Main purposes:

- Characterize V_{BD} vs gap for long gaps in high vacuum → Improvement of VHPM predictive capability
- Assessment of the expected VH capability of MITICA with a simple configuration representative of the round part of the MV shield
- Assessment of the pressure effect for long gaps→ extrapolation for MITICA to evaluate the safety margin (pressure range vs magnitude)







The most stressed part with 1m gap (worst case) is still between the MBS and AFA

1m radius AFA seems to be enough to characterize the V_{BD} vs gap relation (same estimated breakdown probability)

Mockup-design and assesement: Water pipes effect

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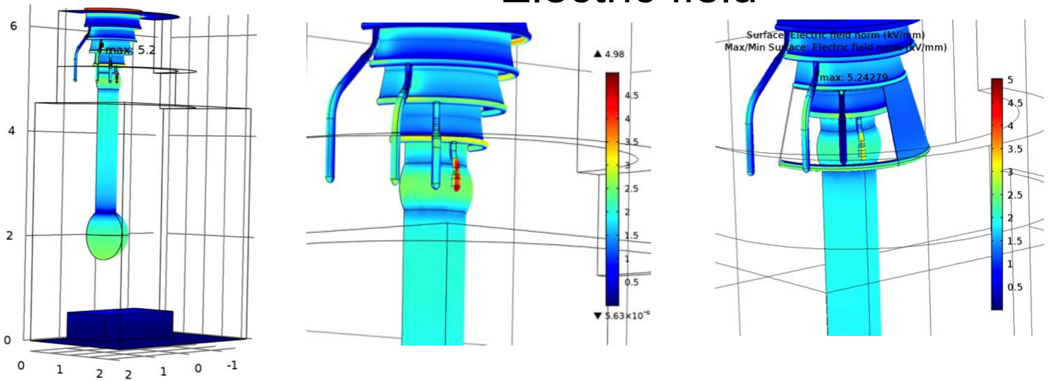
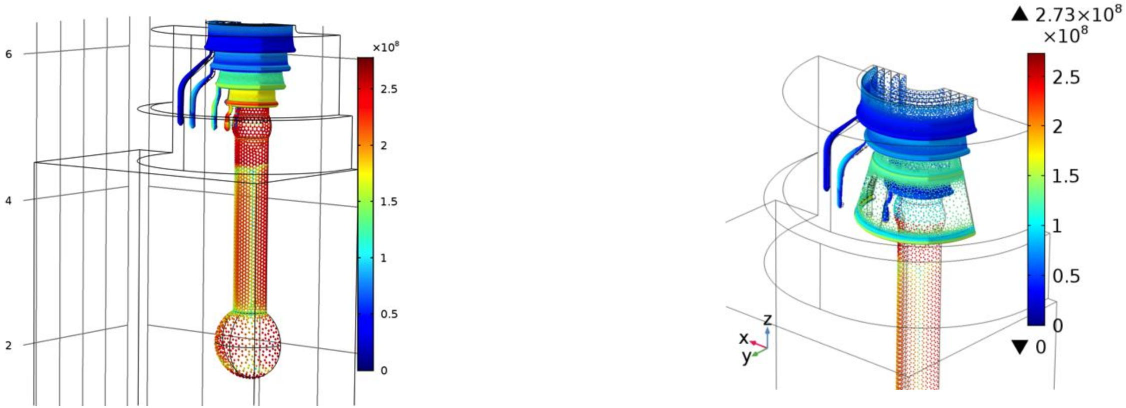
Electric field



Breakdown parameter plot



The -800kV water pipe is subjected to high electric field (5 kV/mm)

→ the associated W is of the order of that of the bottom part of the sphere

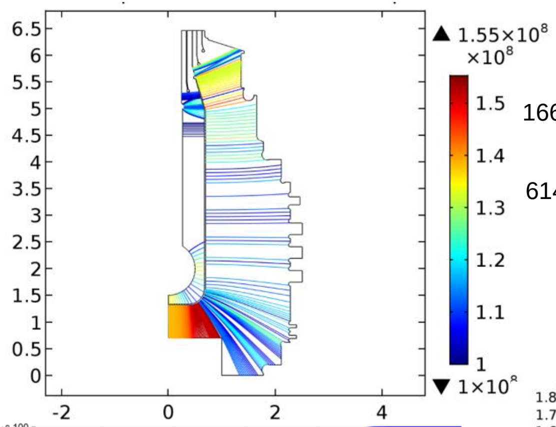
→ A skirt-like shield has been designed to reduce the electric field on the pipe and thus the BD probability on the pipe

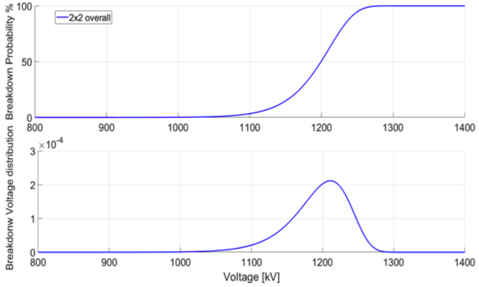
→ The skirt is the same for MES

Mockup-design and assesement: MES

Main purposes:

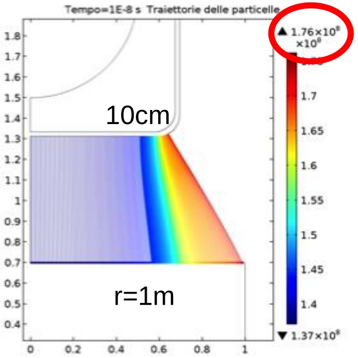
- Validate the design criterion of the MITICA intermediate electrostatic shield with a simple mockup with the same holes pattern
- The electrostatic stress (W) around the shield shall be of the order of that for MITICA
- The highest electrostatic stress can be changed on the bottom part by moving the AFA

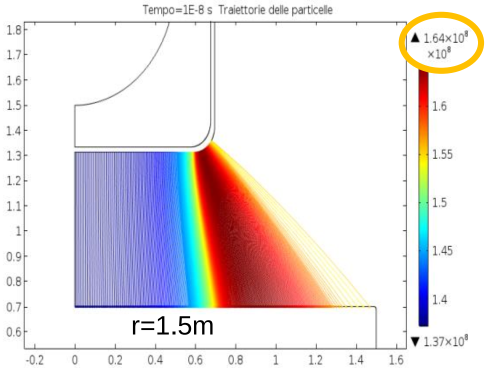


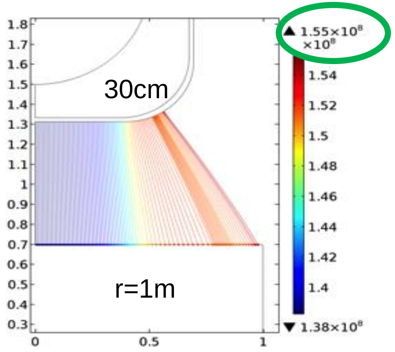


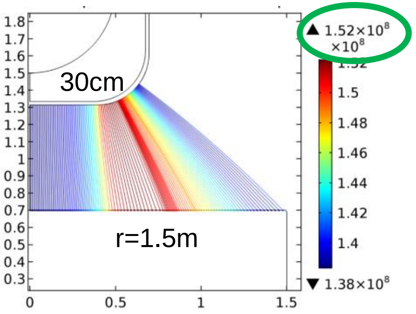
166mm

614mm









W surrounding MES is (1.1-1.3 [S.I])

With MES-AFA gap=614mm W_{max}≈ 1.5 [S.I] depending on fillet radius

The best choice in terms of W uniformity is 0.3 m fillet radius with 2m<AFA<3m diameter

With MBS-AFA gap=166mm W_{max} ≈ 1.3 [S.I]

Sketch of the tests

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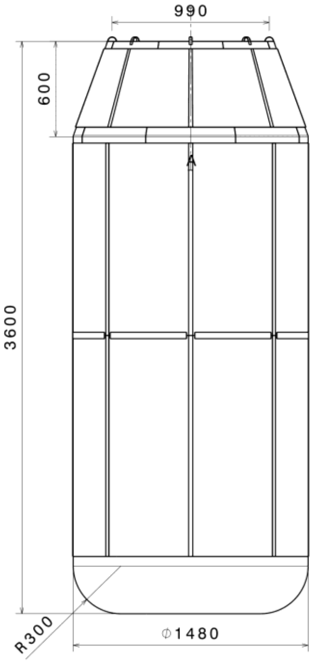

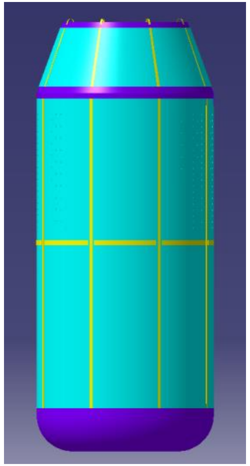

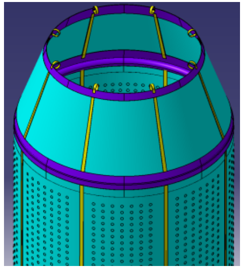

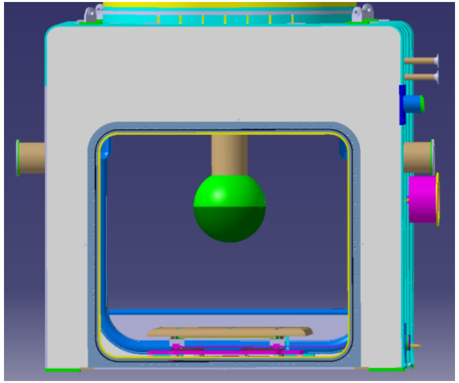

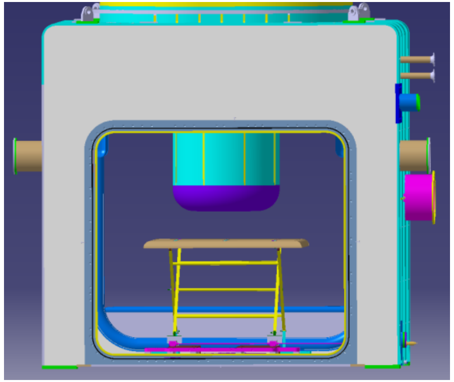

More details during the poster session, discussions and suggestions will be also very welcome…