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Gas Induced Q Degradation in ISAC-II Operation

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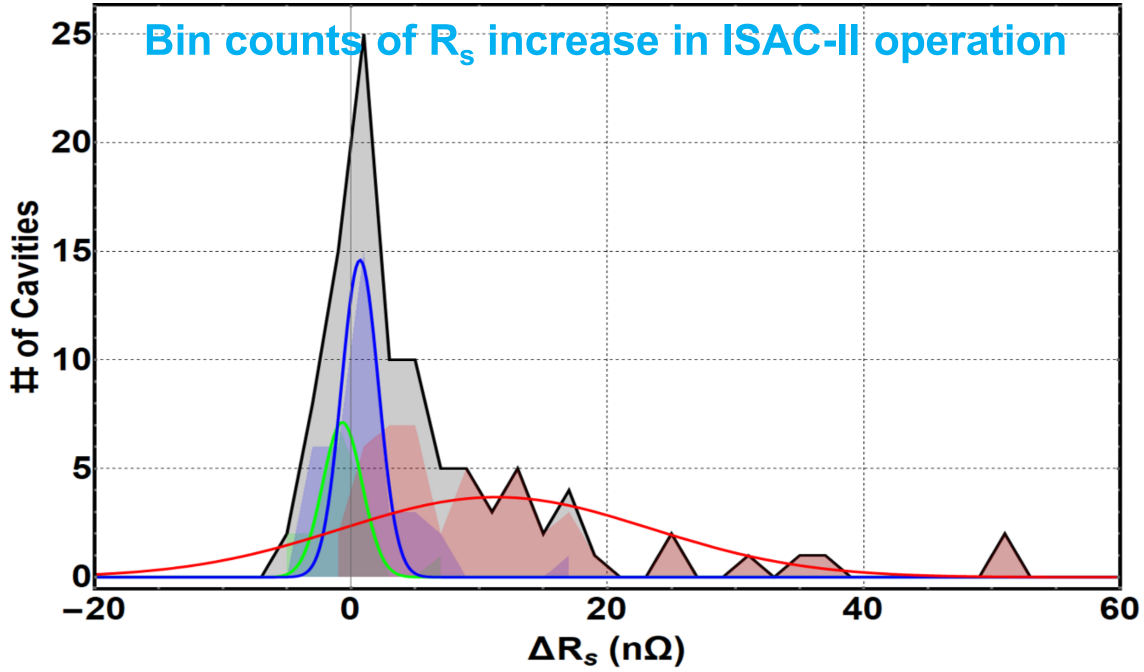
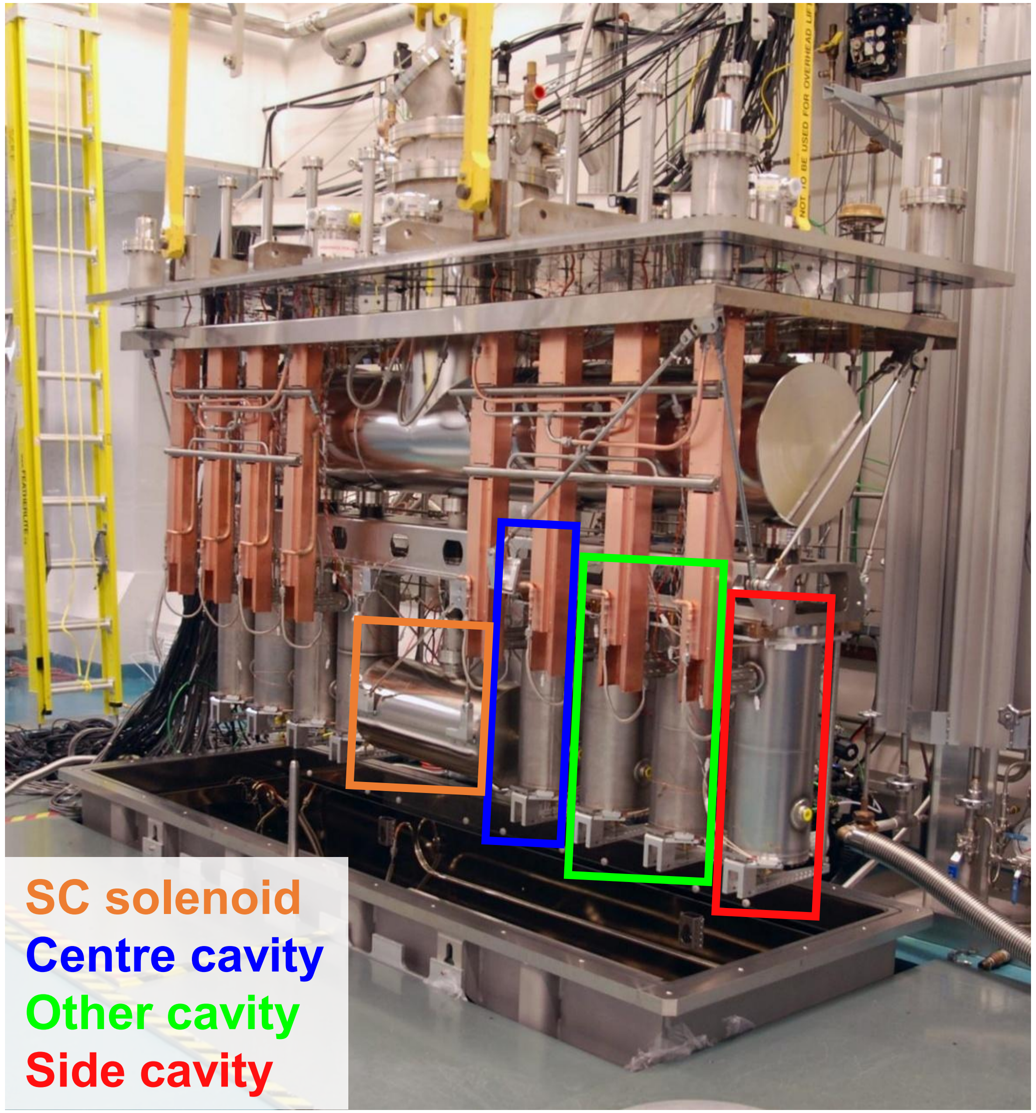
Observations

- ISAC-II has 40 QWRs in 8 CMs operating at 4K with warm sections between CMs
- Cavity performance tracking revealed Q degradation after a few months of operation.
- Side cavities exhibit a higher probability and larger magnitude of Q degradation compared to others.
- Hypothesis is the gas molecule deposition on the RF surfaces leads to increased dielectric power losses.
- Observations and a conceptual model were reported in TTC24 and SRF25.





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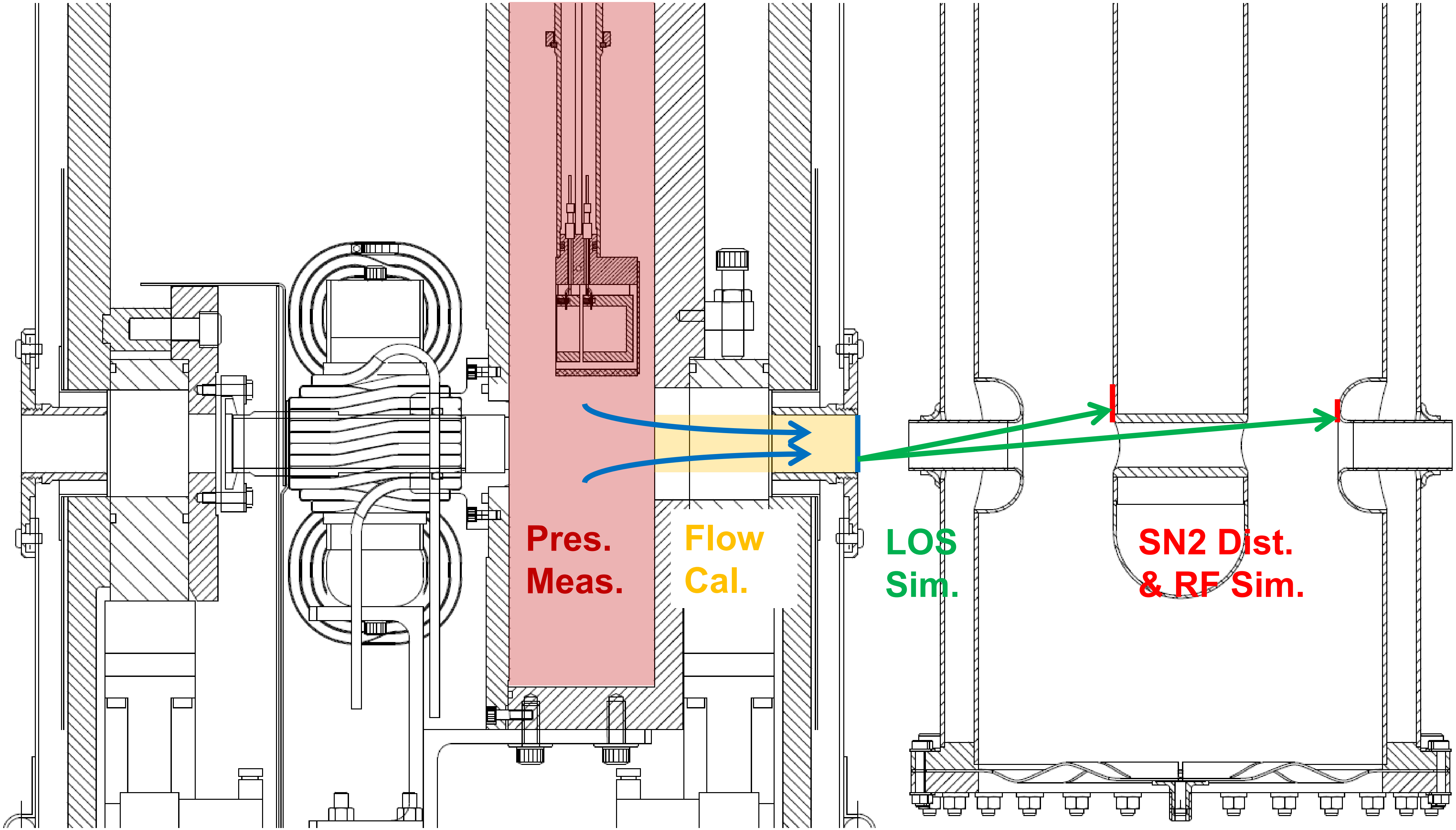
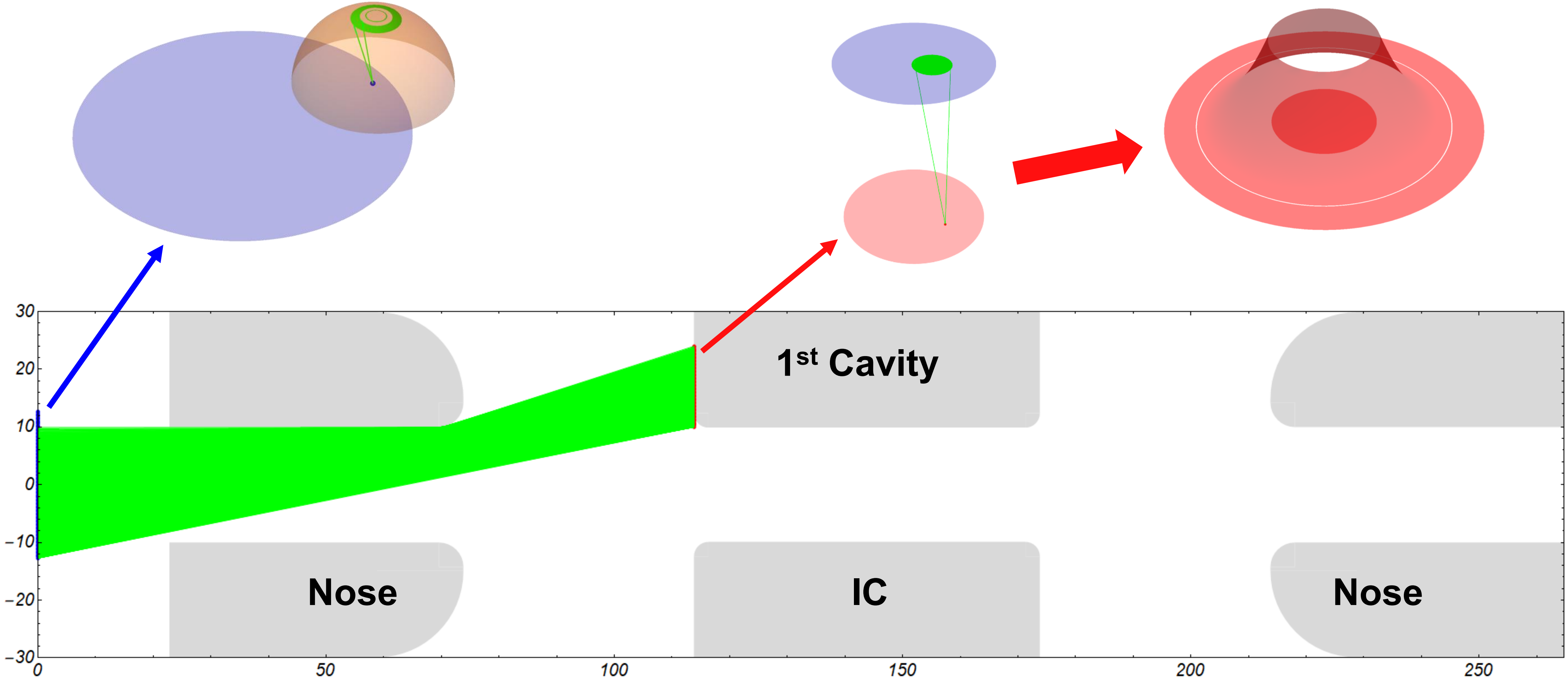
Hypothesis



Molecule Distribution

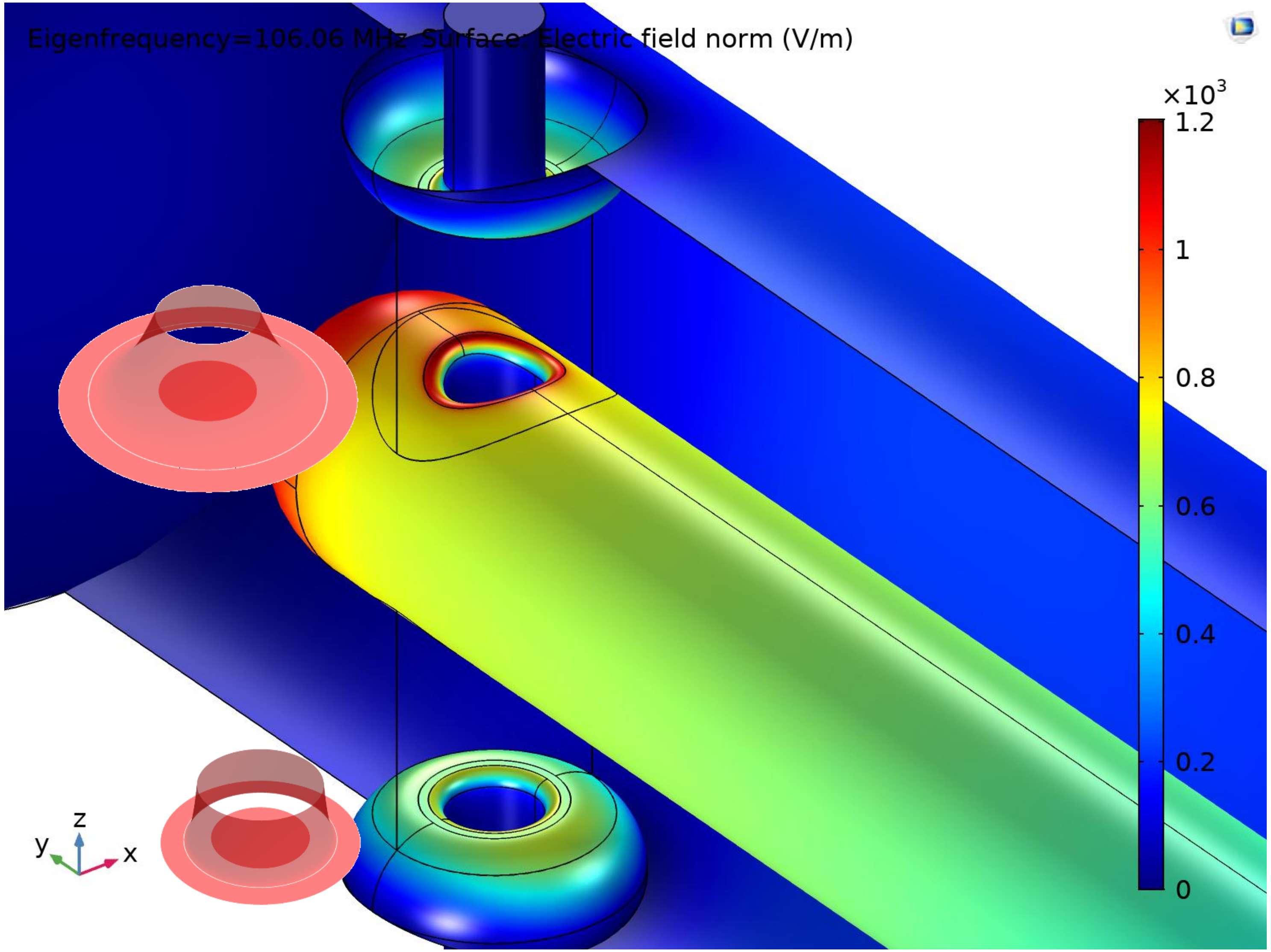
Angular coverage of emitter gives the percentage of molecules deposited on the RF surfaces

Angular coverage of target gives the distribution of deposited molecules on the RF surfaces



Dielectric Loss

- Apply SN2 distribution to the RF model in order to obtain the dielectric contribution to cavity Q
- $Q_d = \frac{1}{tan\delta}\frac{1}{\epsilon_r}\frac{\int_v |E|^2 dv}{\int_{v_d} |E|^2 dv}$
- Dielectric constant (ϵ_r) and loss tangent ($tan\delta$) of SN2 in the frequency range of the accelerator applications are required



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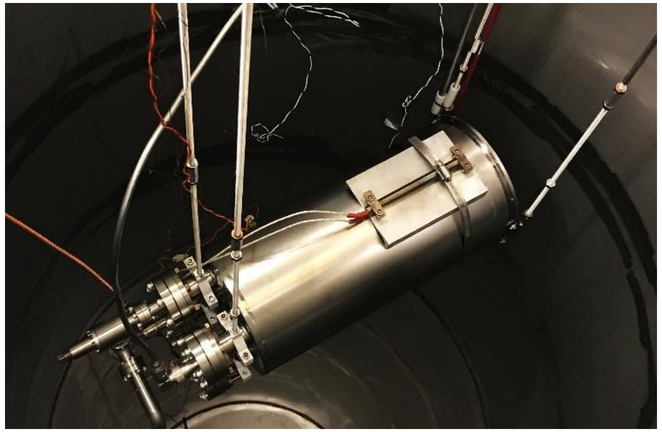
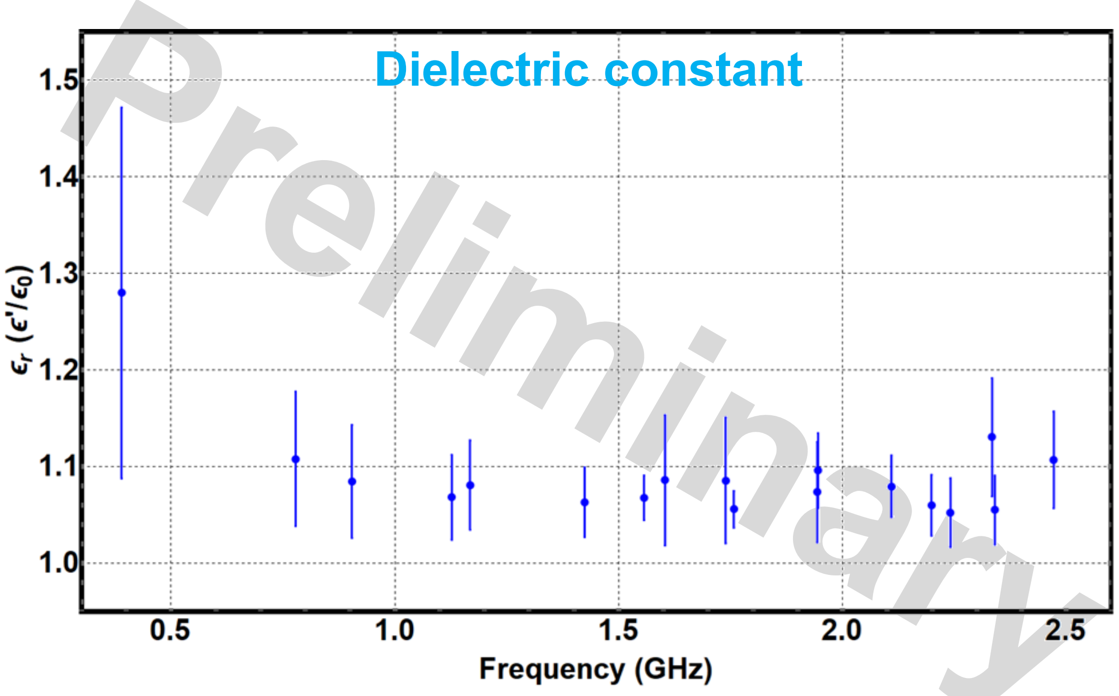
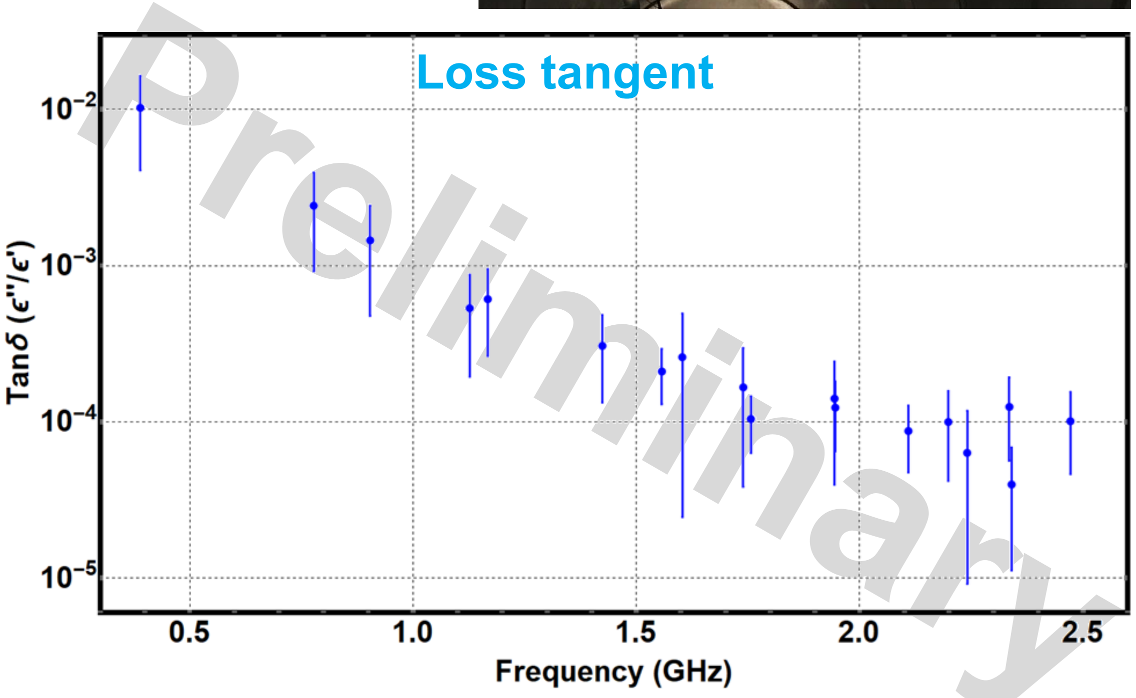
Complex Permittivity of SN2

- Fill HWR with nitrogen at room temperature and freeze nitrogen on RF surface during cooldown
  - Measure fundamental mode at 390MHz and available HOMs up to 2.5GHz to extrapolate frequency dependence
  - Use different field distributions between modes to determine SN2 distribution on RF surface
  - Use frequency and Q shifts between tests w/ and w/o nitrogen to extract the complex permittivity of SN2
- Dielectric constant is around 1.1 in the measured frequency range, while loss tangent has strong frequency dependence < 1.5GHz

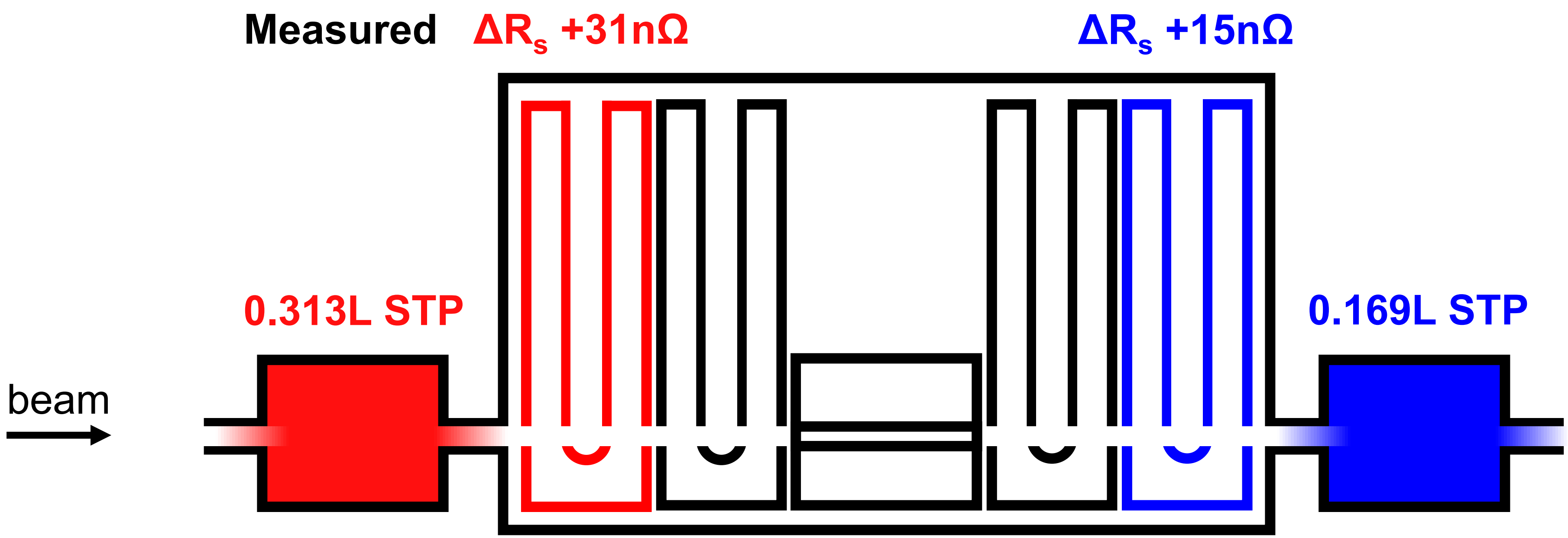






Verification

- On-line test
  - Leak nitrogen gas into a cold CM through both warm sections
  - Control pressure in the warm sections and the duration
  - Measure Q curves of all cavities before and after
  - Q degradation only observed on side cavities
  - Ratio of ΔR_s equal to ratio of leaked gas volume ~2
- Prediction model
  - 0.13% gas molecules frozen on the RF surfaces
  - Apply $\epsilon_r = 1.1$ (average) and $\tan\delta = 0.01$ (at 390MHz) from the preliminary results to the model
  - **Predicated** ΔR_s **+56nΩ** and **+30nΩ** for side cavities, overestimated by a factor of ~2
  - 100 times less degradation in the second cavity



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Summary

- Observation – consistent Q degradations in the side cavities after a few months' operation in ISAC-II
- Hypothesis – gas molecules from the warm sections enter cryomodule, are frozen on the RF surfaces, and cause dielectric losses
  - Complex permittivity of the solid nitrogen at 4K
    - Preliminary results in the frequency range from 390MHz to 2.5GHz
    - More tests (reduce uncertainties, various gases, field dependences) in the queue
  - Prediction model based on molecular flow and dielectric loss
    - Verified with an on-line test in ISAC-II
    - Relative degradations match with experimental data
    - Absolute degradations are overestimated by a factor of 2
      - Permittivity at 100MHz could make it
- Mitigation – improve beamline vacuum or partial thermal cycle

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Thank you
Merci

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Questions

- Have similar degradations been observed in other facilities?
  - Cryogenic load increases overtime
  - Side cavities affected more
  - Could be mitigated by a full or partial thermal cycle
- Which parameter(s) would determine more?
  - Beamline vacuum, type of beam, cavity/cryomodule geometry, operating frequency or temperature
- Would frozen gas affect FE or electronic quench as well?

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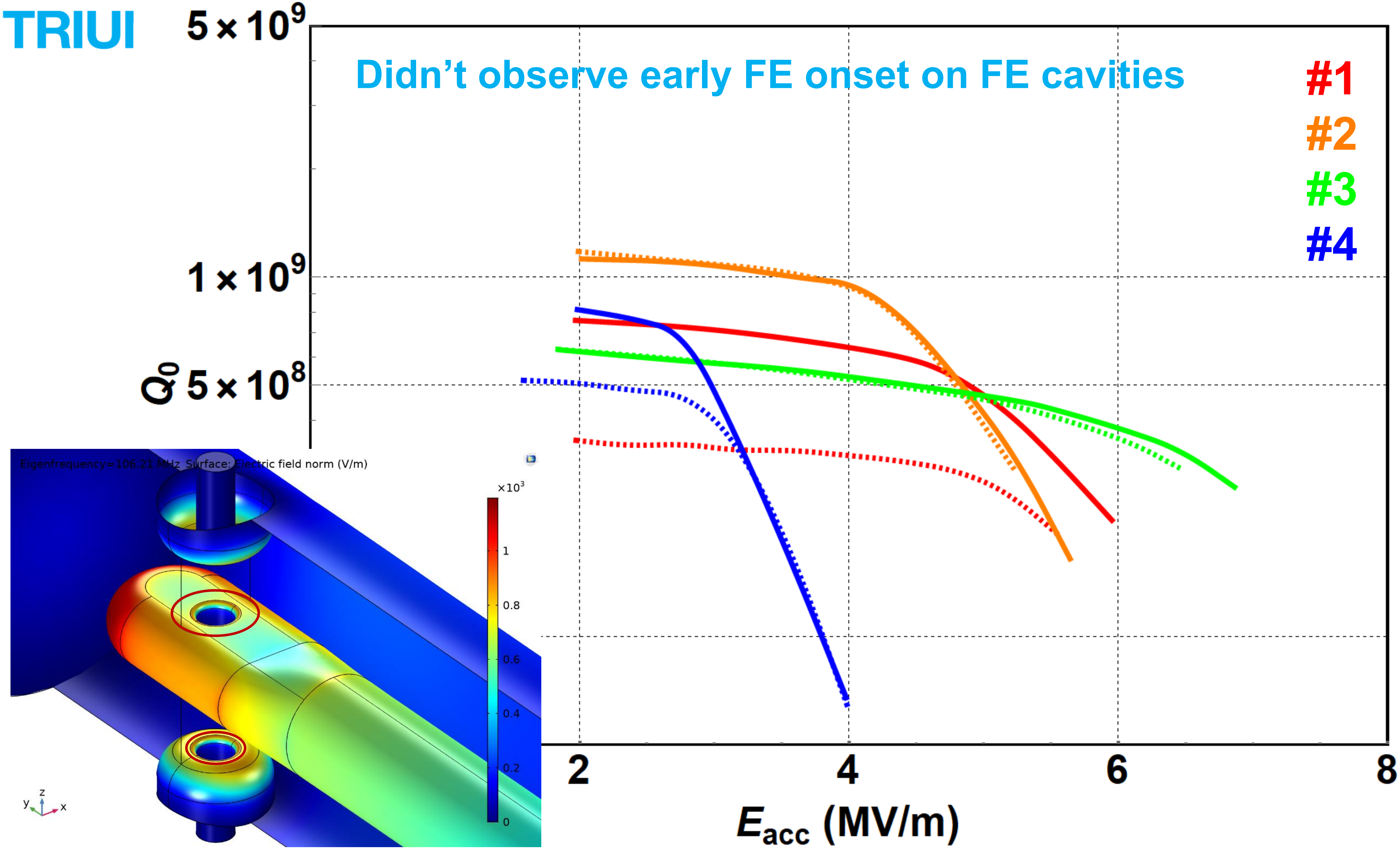

Didn’t observe early FE onset on FE cavities
#1
#2
#3
#4
5×10^9
1×10^9
5×10^8
Q0
2
4
6
8
Eacc (MV/m)
Eigenfrequency=106.21 MHz Surface: Electric field norm (V/m)
×10^3
1
0.8
0.6
0.4
0.2
0