Universität Rostock

Traditio et Innovatio

HOM coupler sensitivity analysis and uncertainty quantification for FCC-ee operation points’ cavity assemblies

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Motivation

Coaxial higher-order mode (HOM) couplers can be designed to high precision, which would reduce errors due to uncertainties. However,

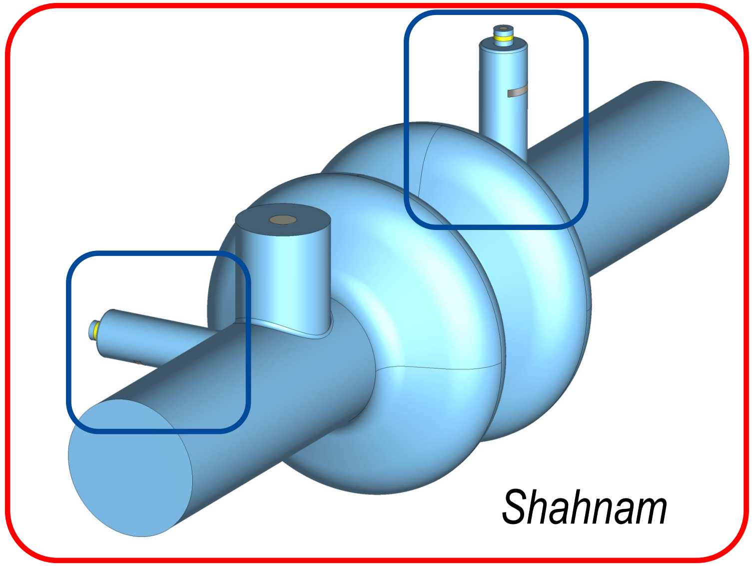
- Some geometric perturbations may occur
  - during the installation
  - during operation, due to background vibrations or
  - electromagnetic pressure due to the Lorentz force
- Owing to the orientation of the HOM coupler on the cavity, there may be some deflections induced by gravity

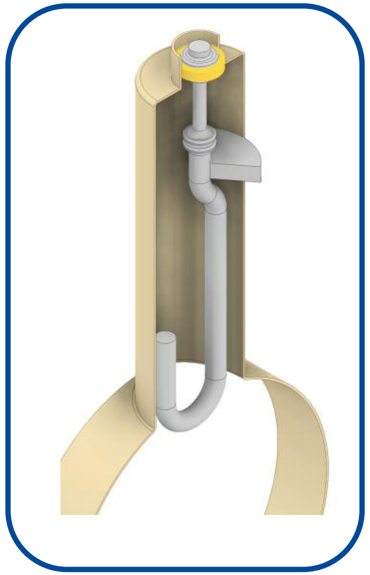
Aim

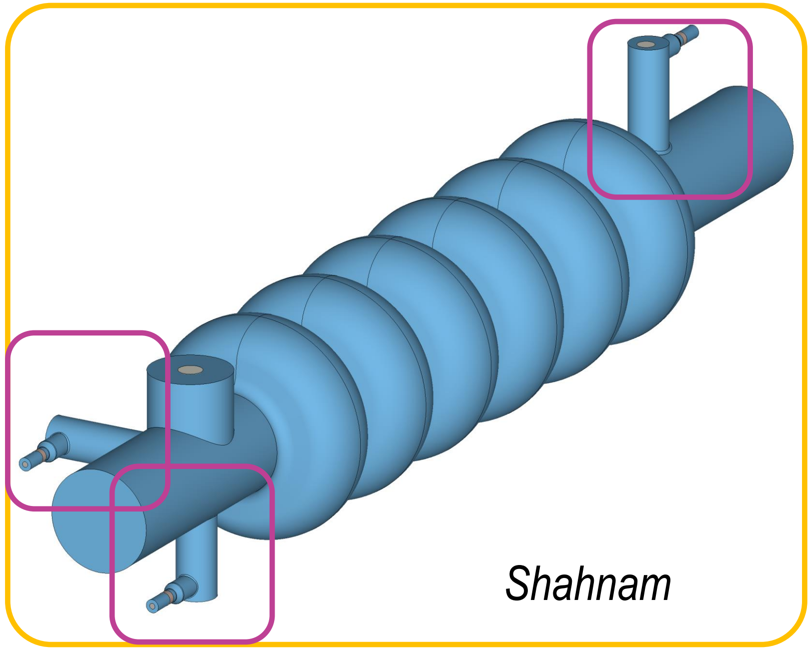
Sensitivity analysis of FCC-ee cavity assemblies

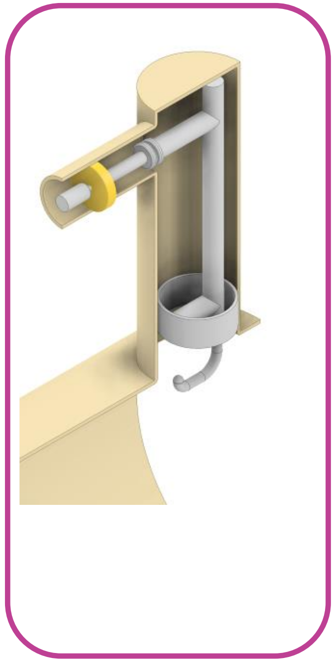
- 2-cell 400 MHz cavity equipped with two hook-type HOM couplers for the Z, W and H operating points

- 6-cell 800 MHz cavity equipped with four double quarter-wave (DQW) HOM couplers for the $t\bar{t}$ operating point





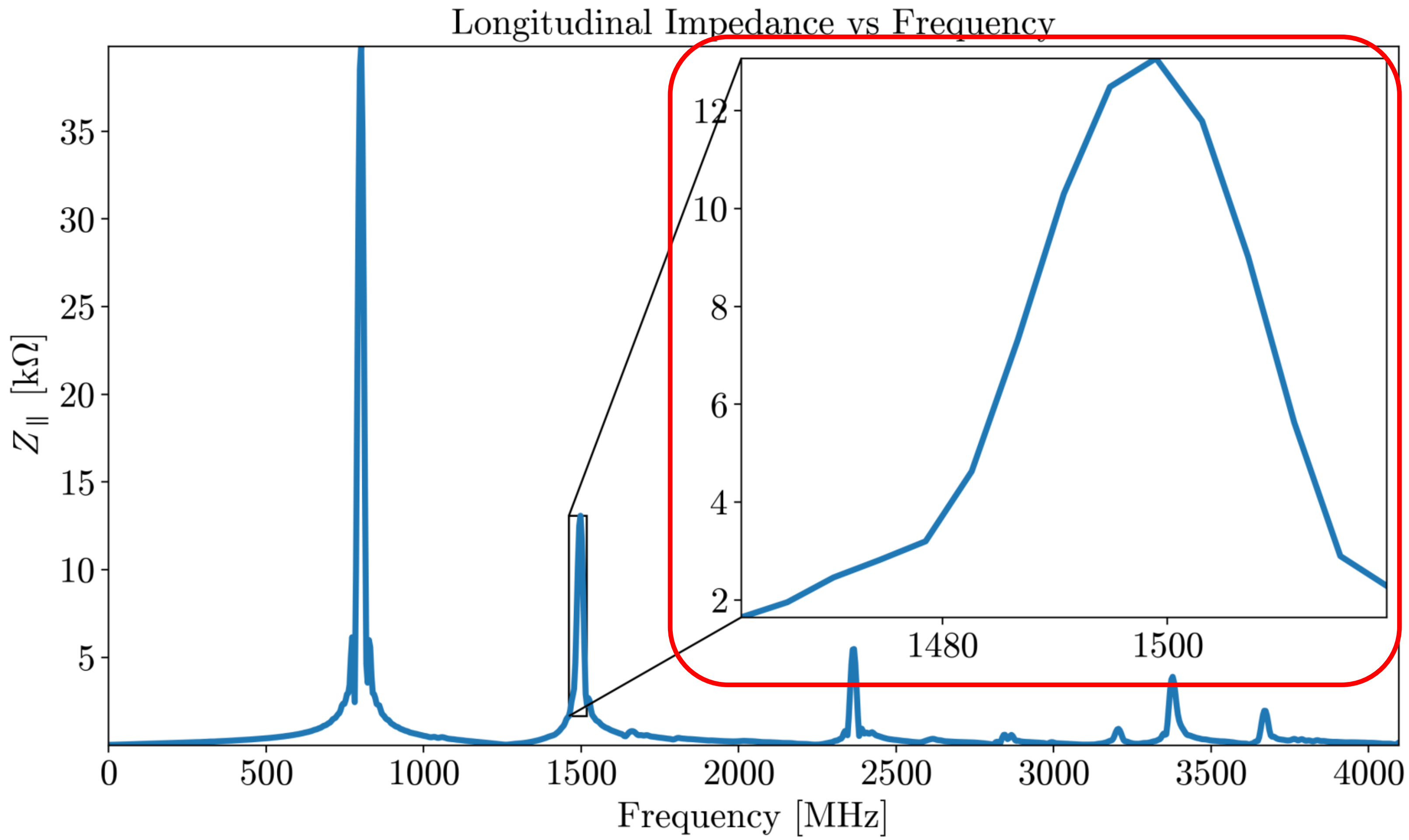




Quantities of interest

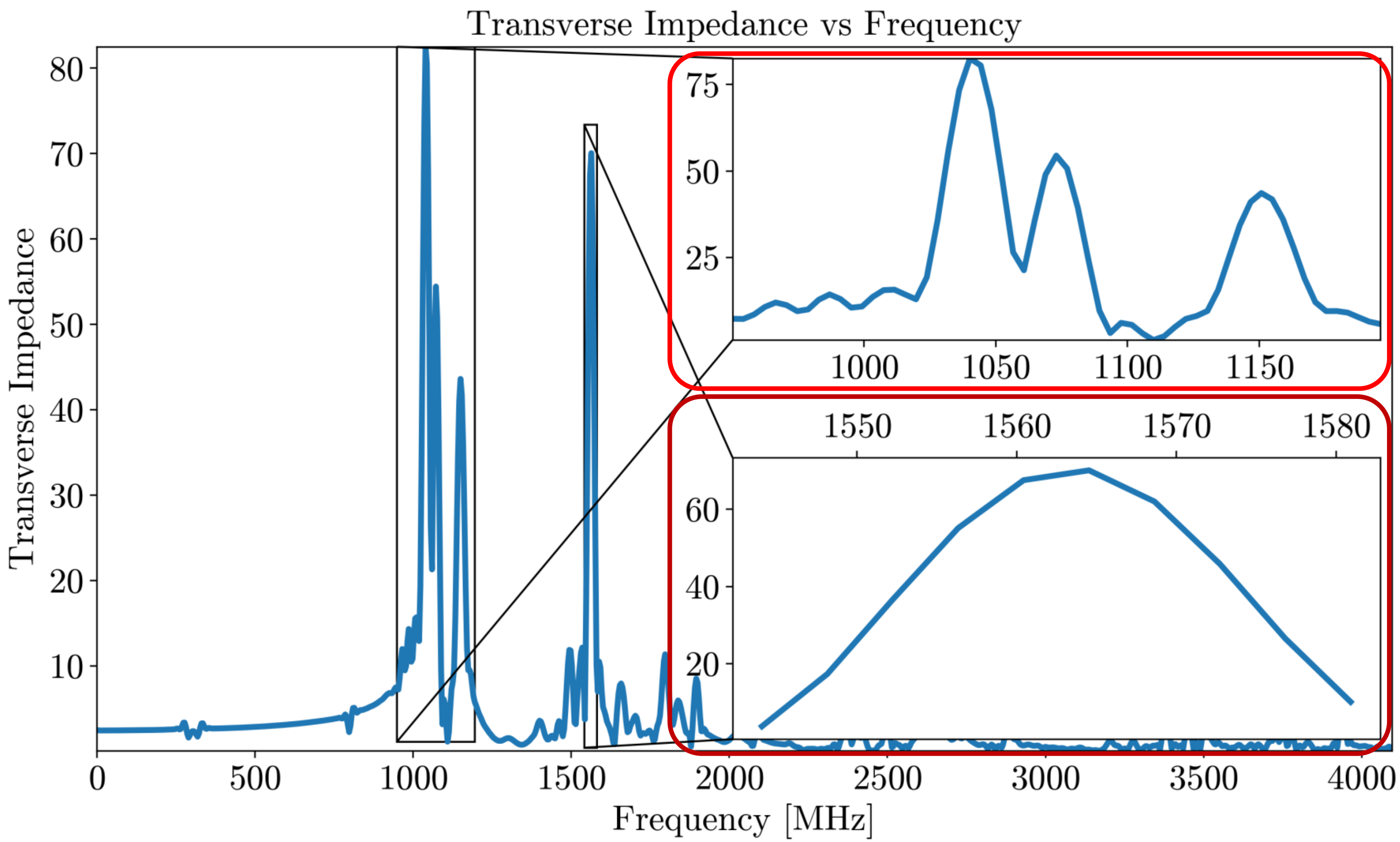
- Fundamental mode (FM) frequency f_{FM} and external quality factor (Q_{ext})

- Max longitudinal impedance $Z_{\parallel}$ in first higher-order (HOM) monopole passband

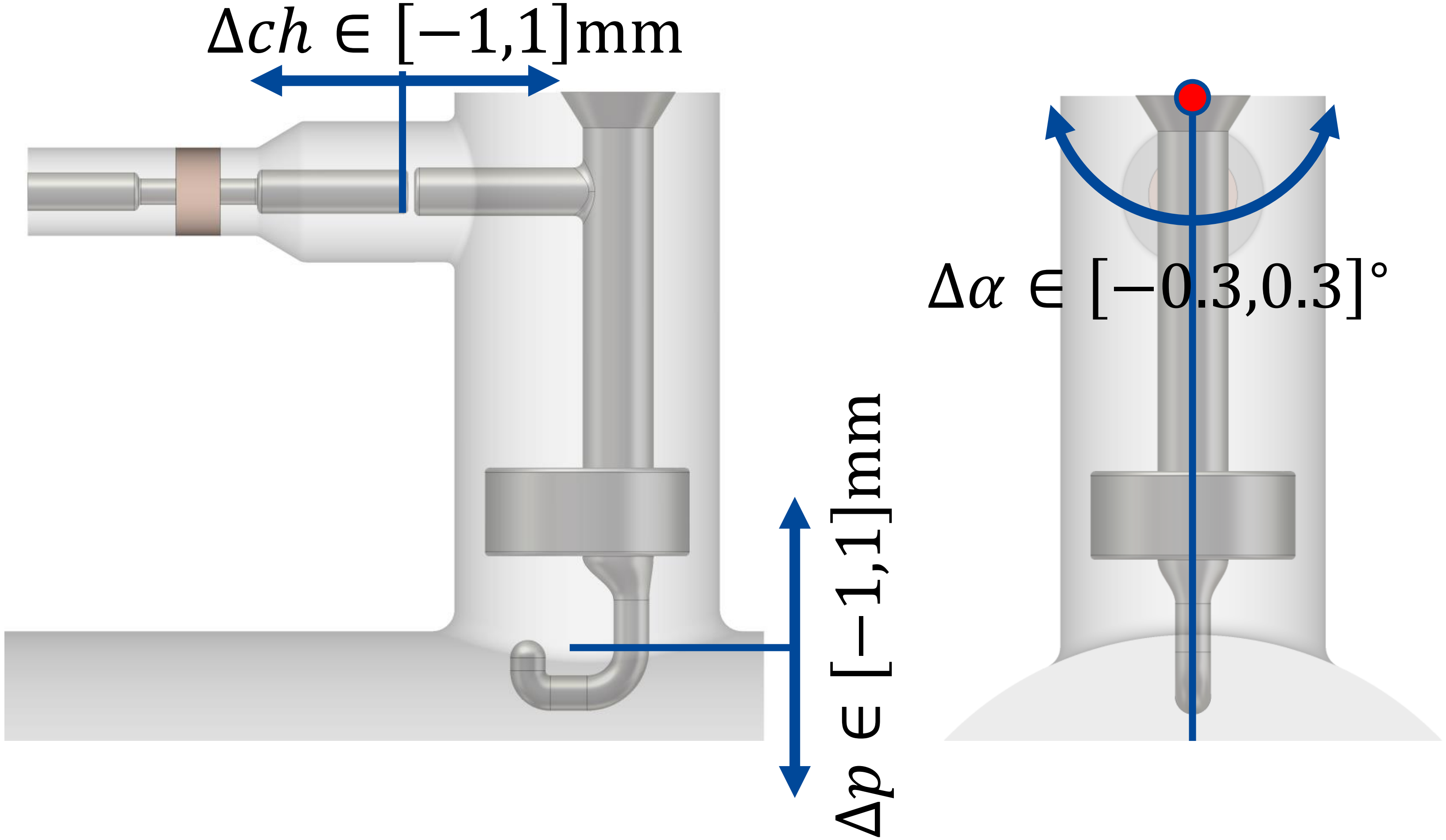


Quantities of interest

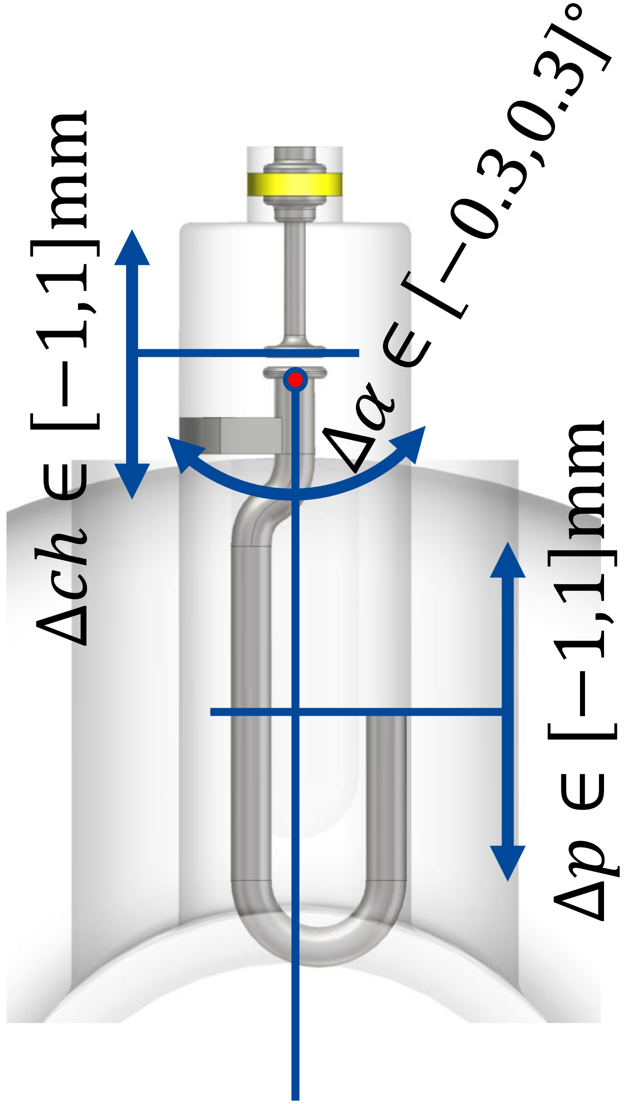
- Max transversal impedance $Z_{\perp,1}$ in first higher-order dipole passband
- Max transversal impedance $Z_{\perp,2}$ in second higher-order dipole passband



Geometric parameters



Double Quarter-Wave HOM Coupler



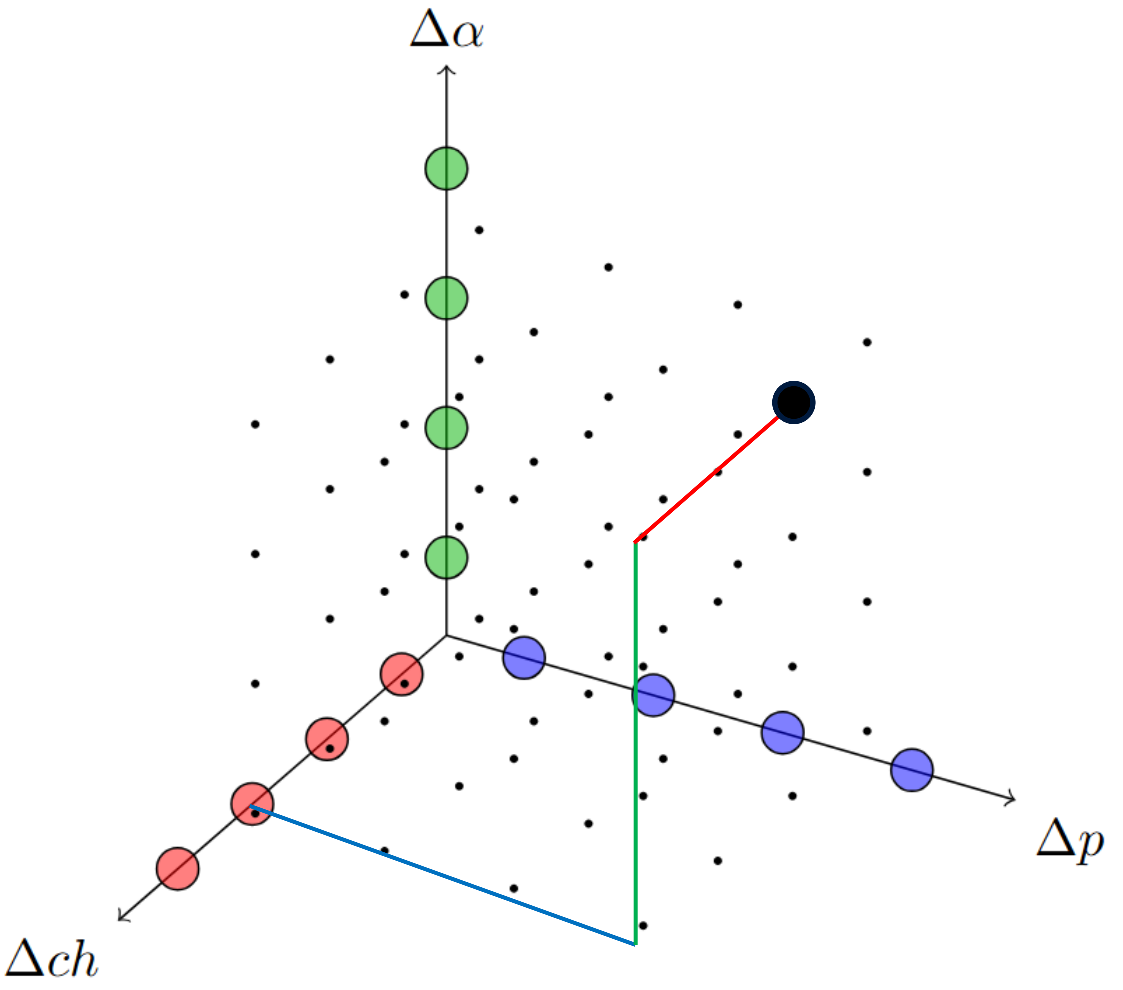
Hook-Type HOM Coupler

Method

- A tensor product is constructed from Gaussian quadrature points for the three geometric parameters

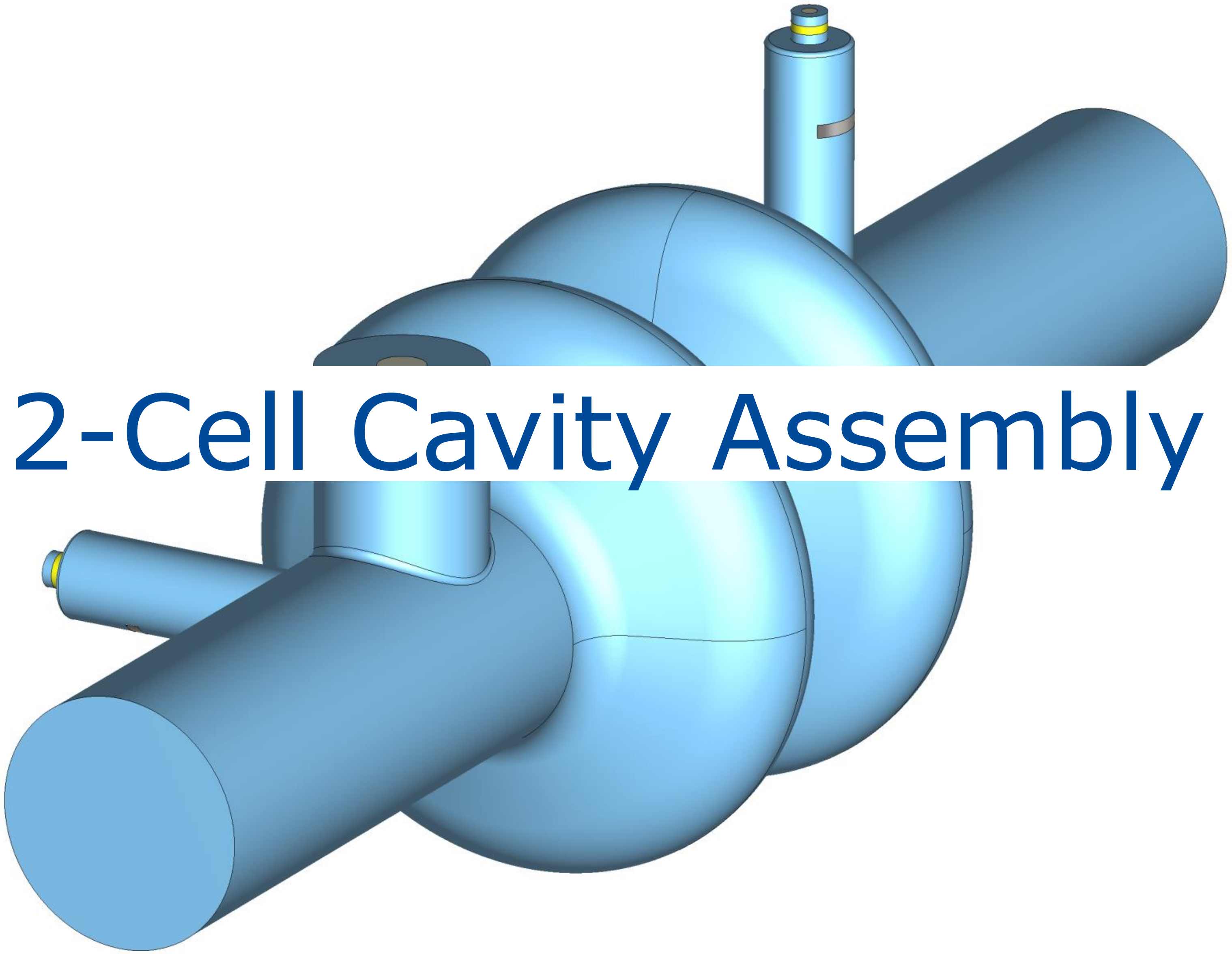
- Each dimension has four Gaussian nodes → 64 total design points

- Guarantees integration accuracy up to polynomial order 7



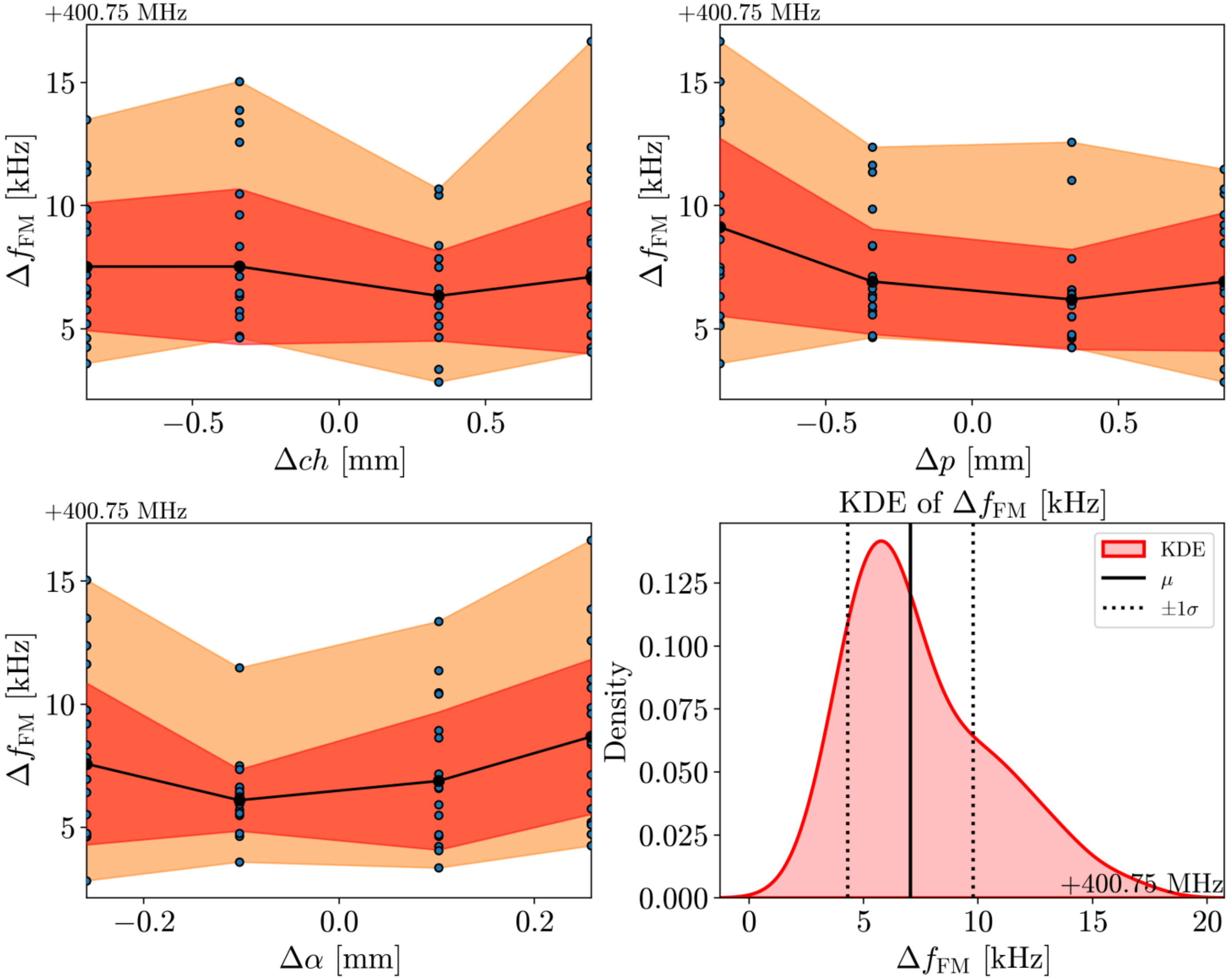
$$\mathcal{X} = \mathcal{G}_{n_U}(U) \otimes \mathcal{G}_{n_V}(V) \otimes \mathcal{G}_{n_W}(W)$$

2-Cell Cavity Assembly



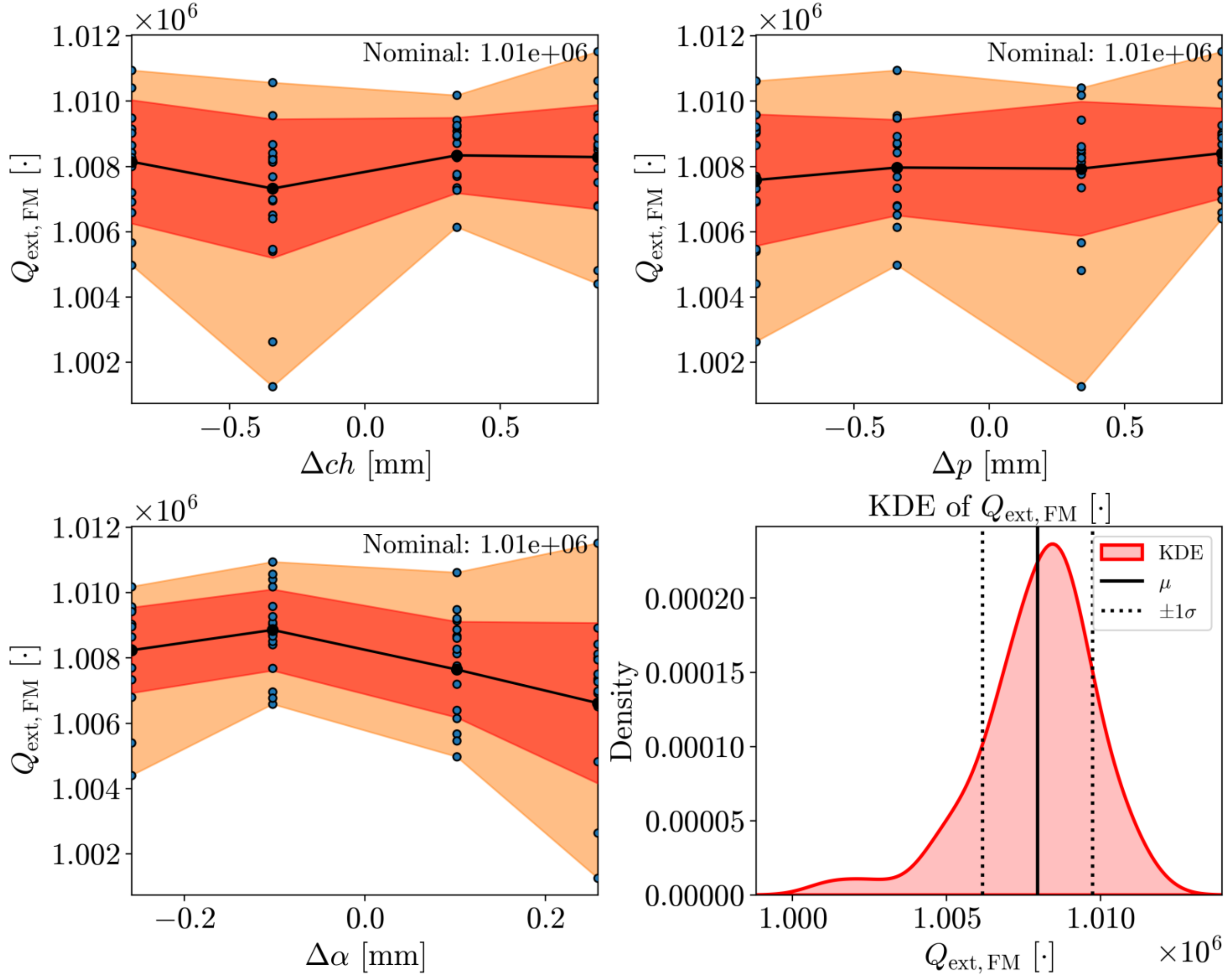
FM Frequency

- FM frequency change Δf_{FM} in tens of kilohertz
- Maximum $|\max - \min|$ FM frequency change across all variables is about 10 kHz



FM Qext

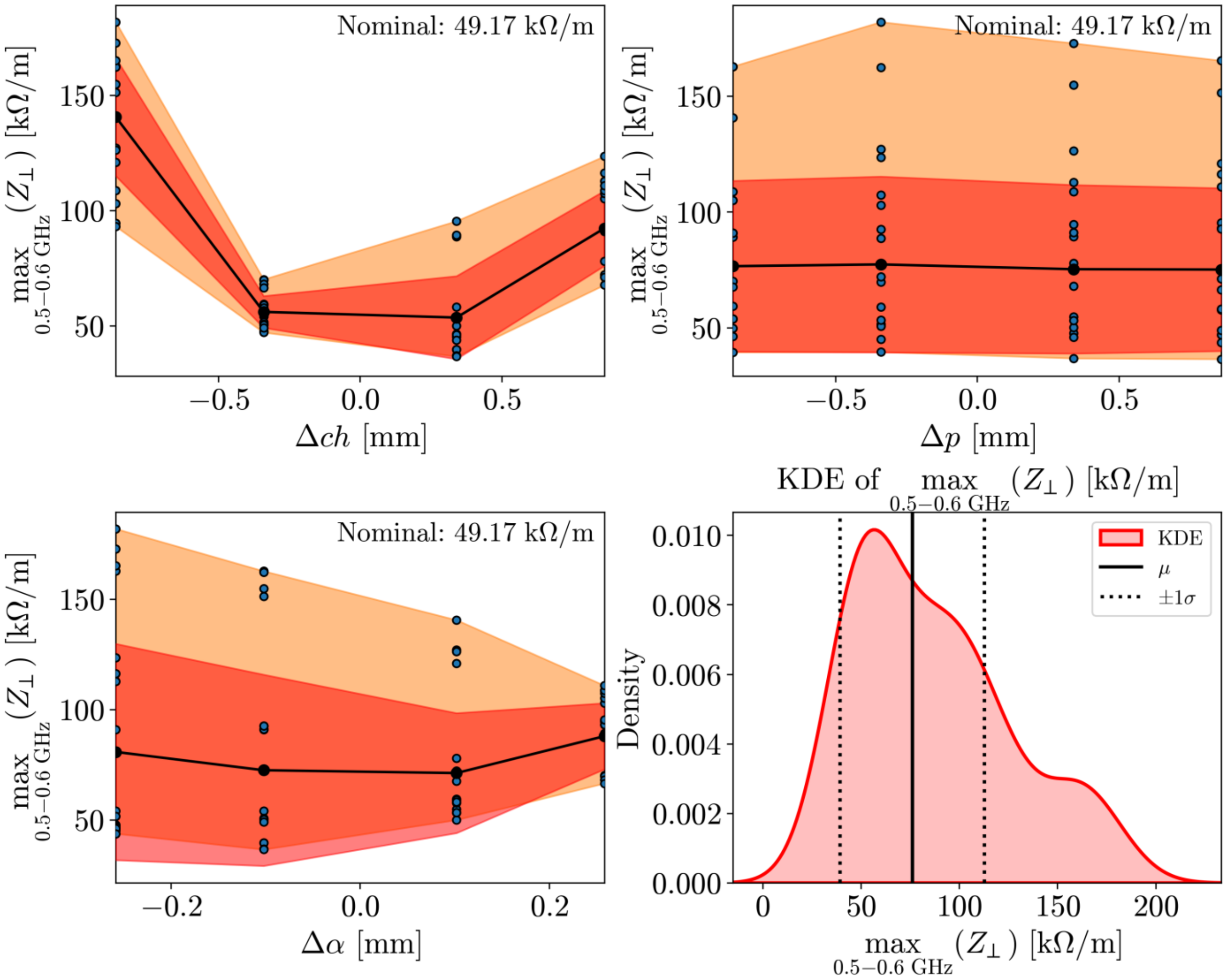
- Negligible effect on the fundamental mode Q_{ext}
- All Q_{ext} in the same order of magnitude as the nominal value $1.01\mathrm{E}6$

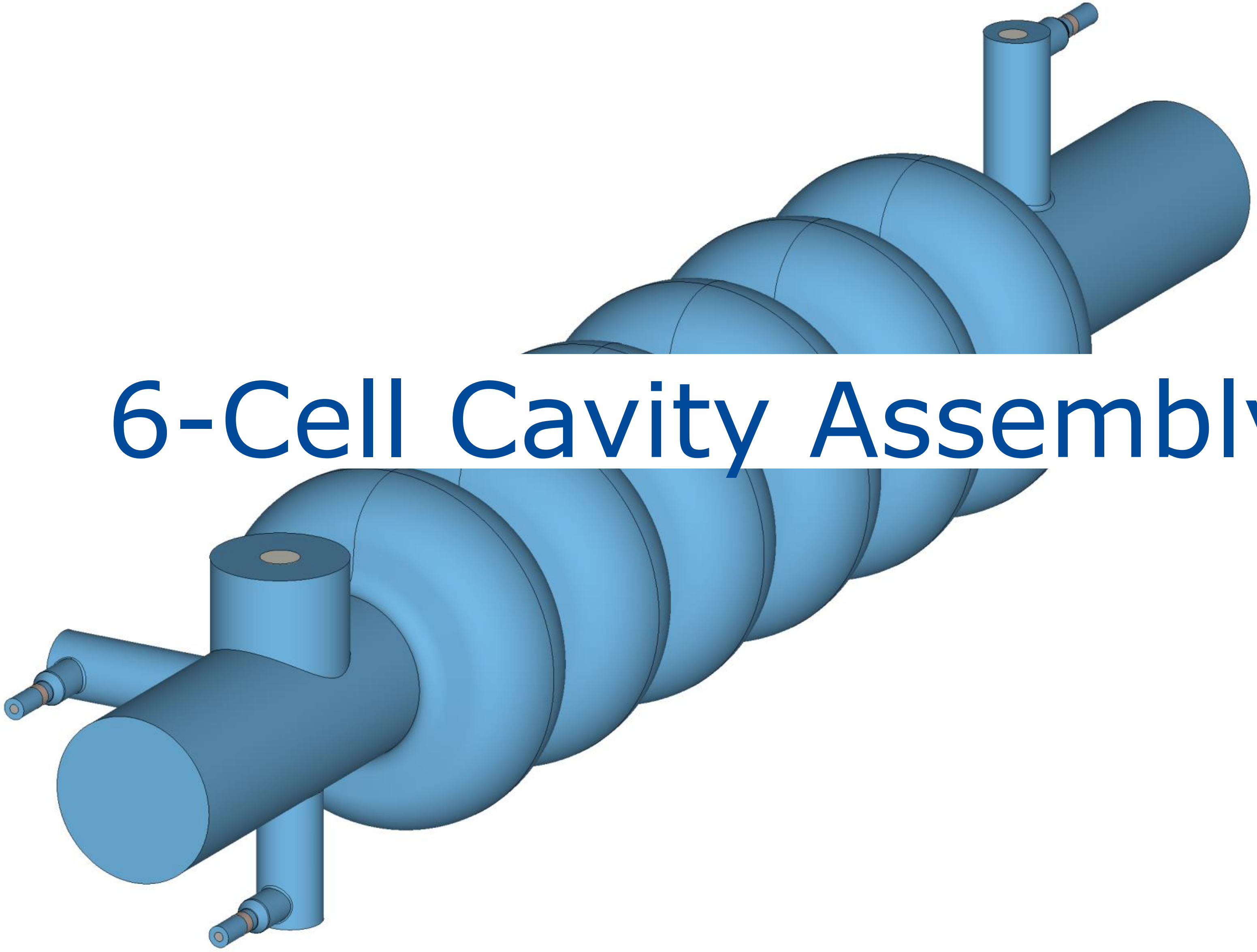


Max Transverse Impedance – First HOM Dip. Passband

- Non-negligible effect on the maximum first dipole passband impedance $\max(Z_\perp)$

- Impedance value can go as high as 3.5 times the nominal value



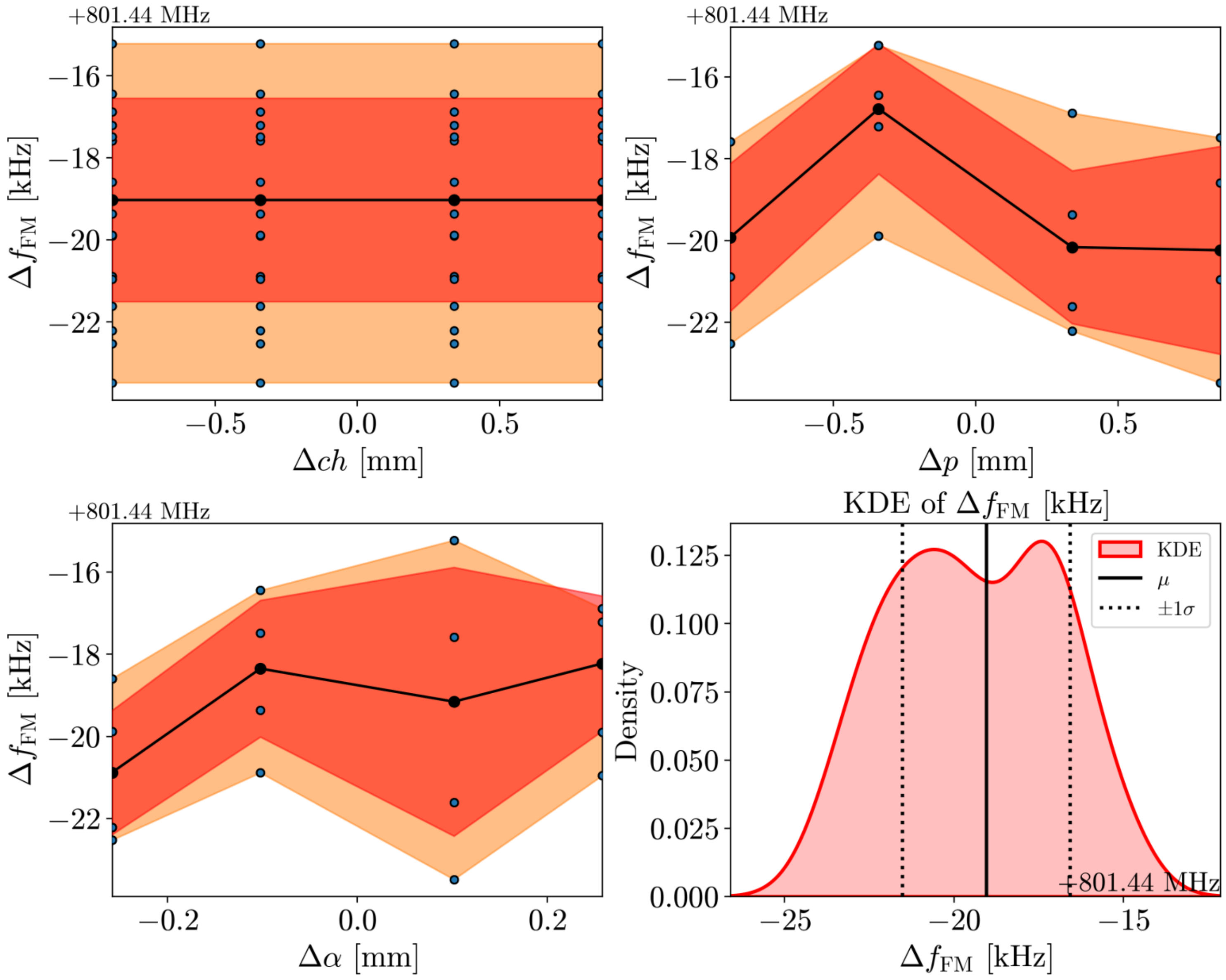


6-Cell Cavity Assembly

FM Frequency

- FM frequency change Δf_{FM} in tens of kilohertz*

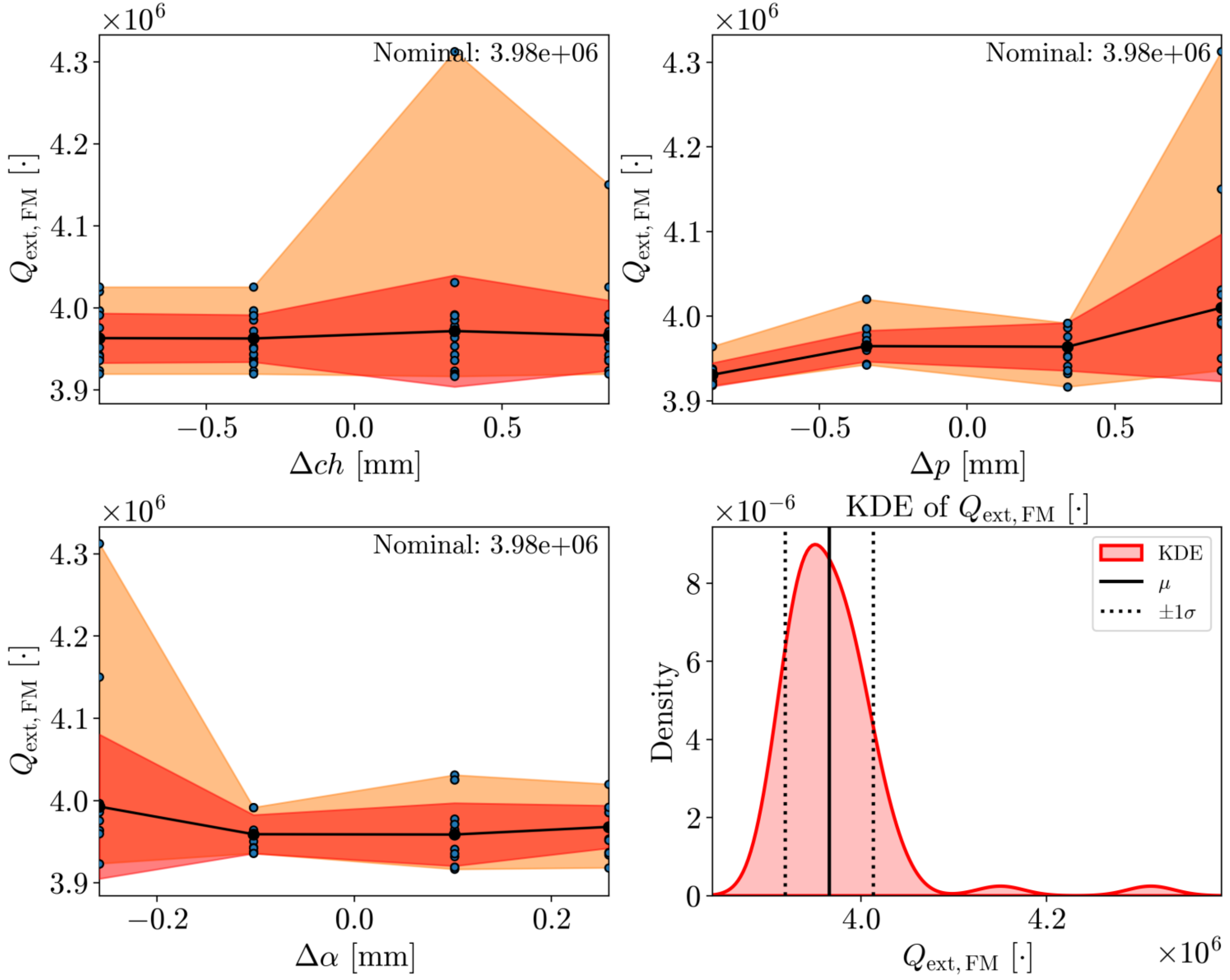
- Maximum $|\max - \min|$ FM frequency change across all variables is about 8 kHz



FM Qext

- Negligible effect on the fundamental mode Q_{ext}

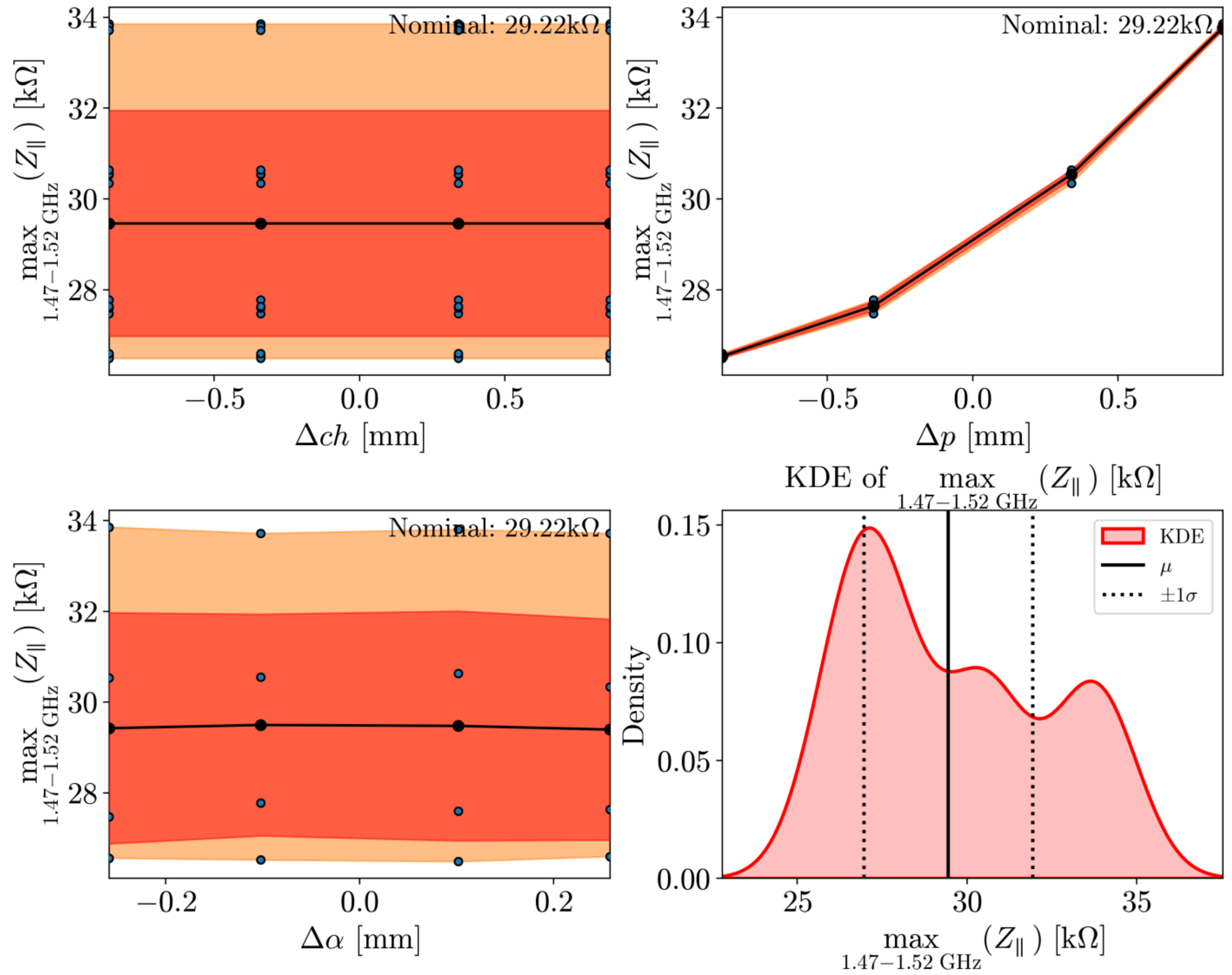
- All Q_{ext} in the same order of magnitude as the nominal value $3.98\mathrm{E}6$



Max Long. Impedance – First HOM Mon. Passband

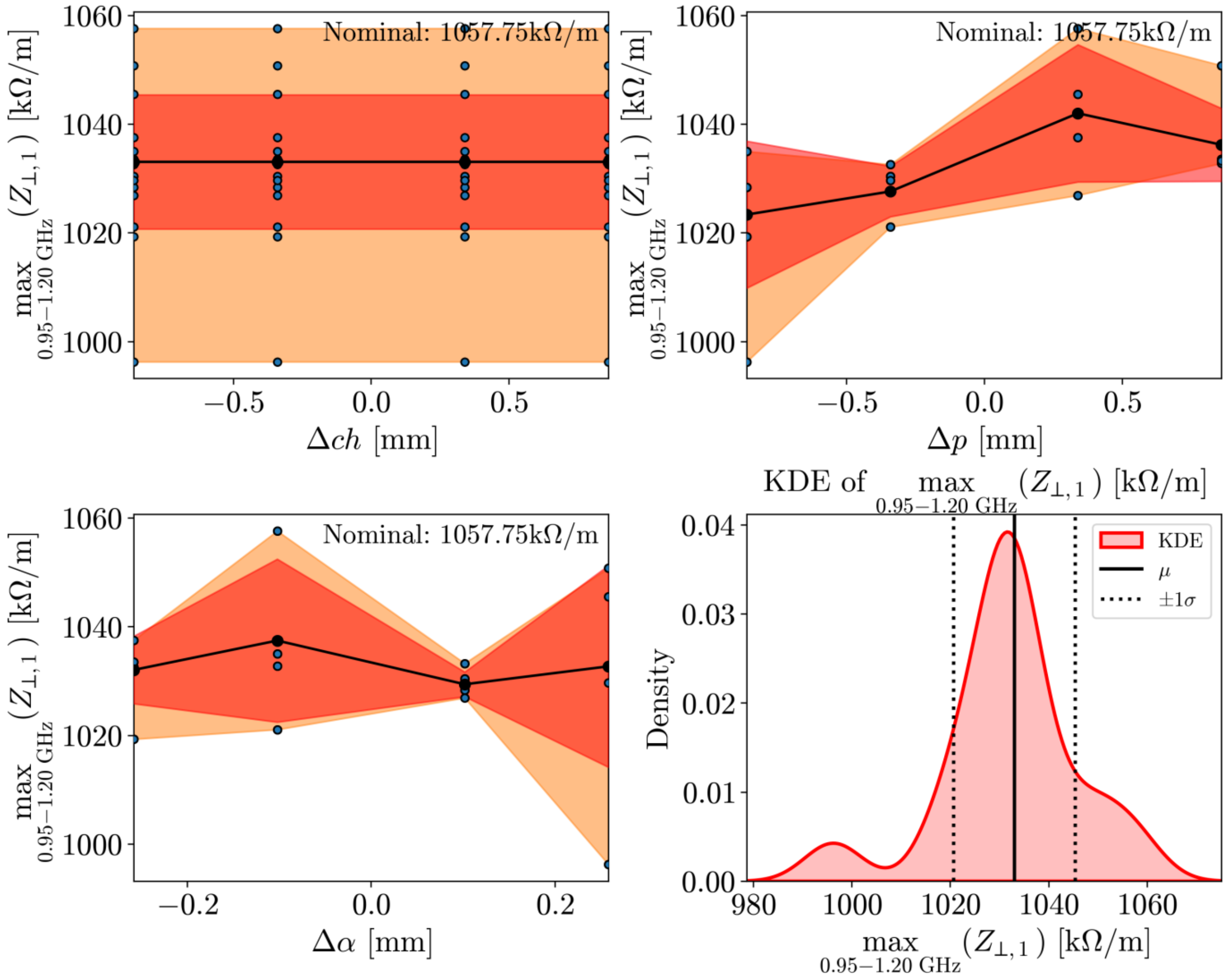
- Max longitudinal impedance sensitive to penetration depth Δp

- Maximum value attained $34\ \mathrm{k\Omega/m}$, which is about a 15% increase from the nominal value



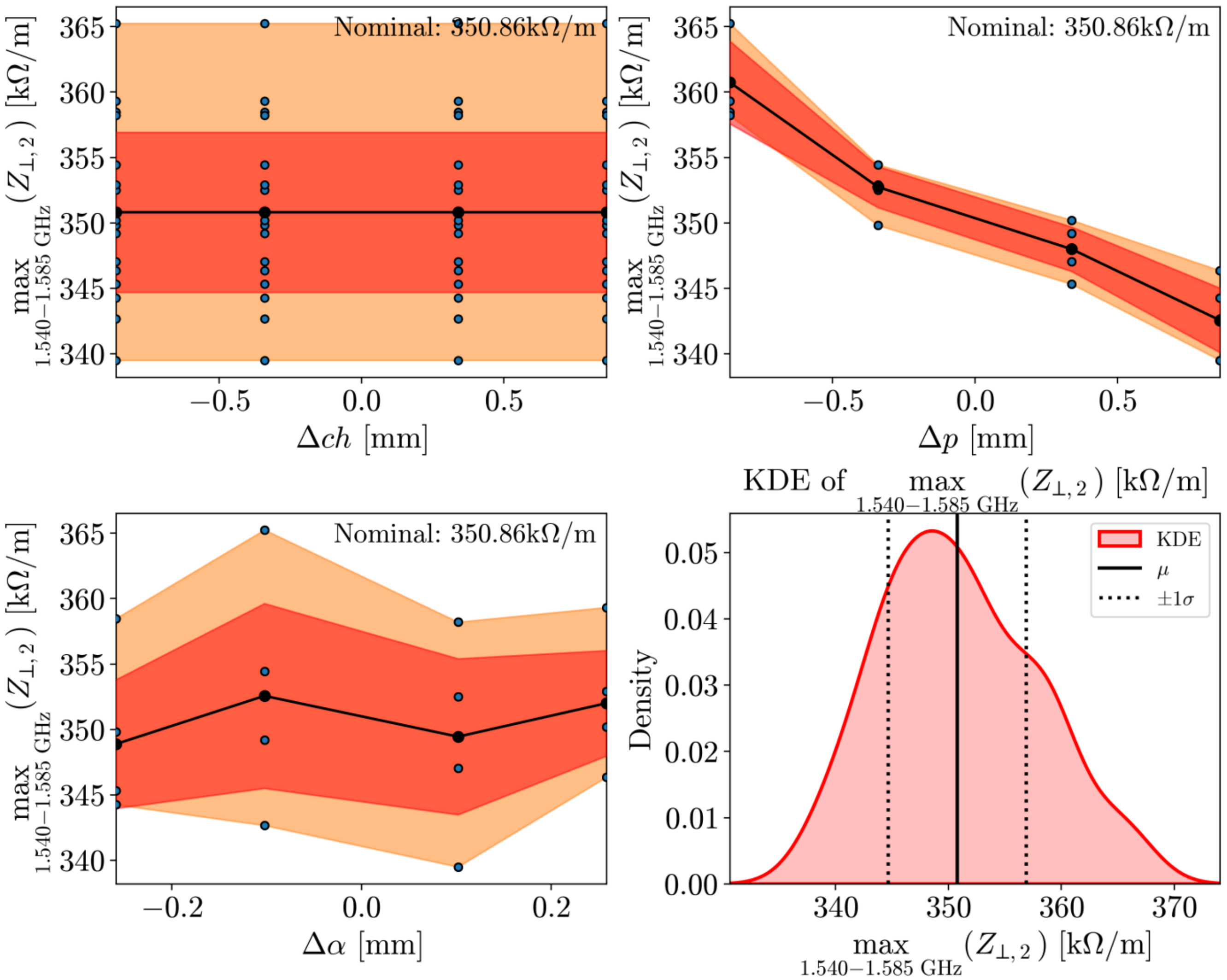
Max Trans. Impedance – First HOM Dipole Passband

- Negligible effect on the maximum first HOM dipole passband impedance $\max(Z_{\perp,1})$
- Overall maximum impedance value only about 0.3% the nominal value



Max Trans. Impedance – 2nd Dip. Passband

- Negligible effect on the maximum first HOM dipole passband impedance $\max(Z_{\perp,2})$
- Overall maximum impedance value only about 5% the nominal value
- Penetration depth has the most influence



Conclusion

- For almost all of the considered quantities, deviations in the considered HOM coupler geometric parameters do not lead to a substantial change in the analysed quantities of interest

- The maximum transverse impedance due to perturbation of the 2-cell cavity assembly is 3.5 times the design value. This may be problematic if the mode is the performance-limiting mode