

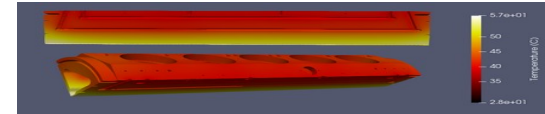
ESS-Bilbao contribution to ESSnuSB+ WP4, 06Oct2026 Meeting

ESSnuSB+ WP4 ESS-Bilbao

- Update of activities

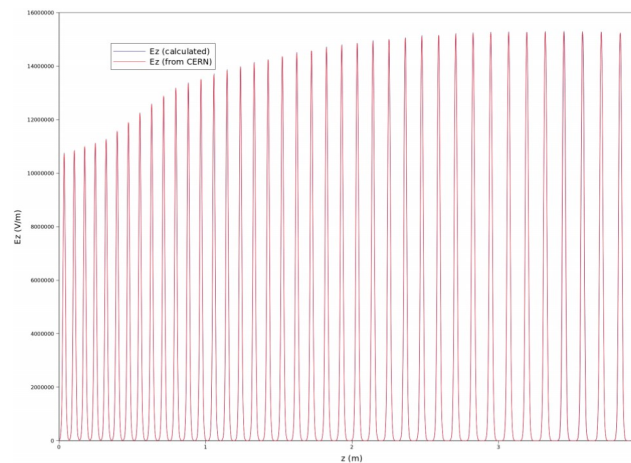
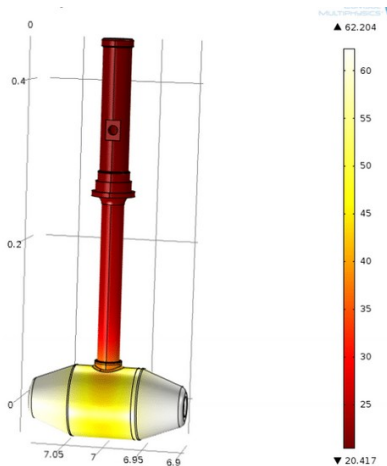
- RFQ:

- 3D simulations of detuning
- Proposed modifications on current design for higher estability



- DTL

- Drift Tube analysis at higher power



ESSnuSB+ WP4 ESS-Bilbao

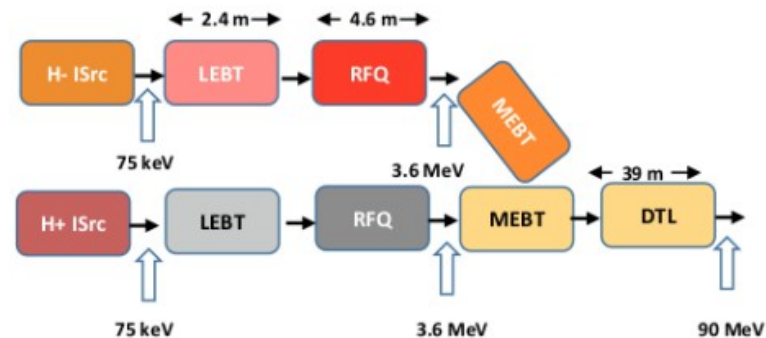
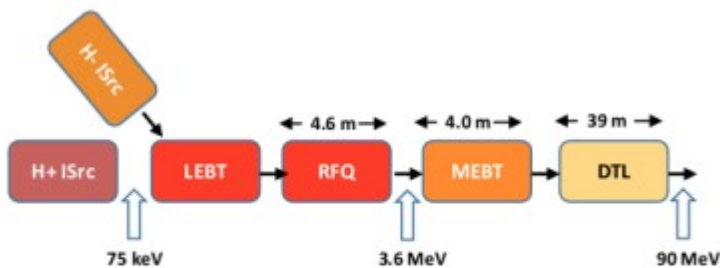
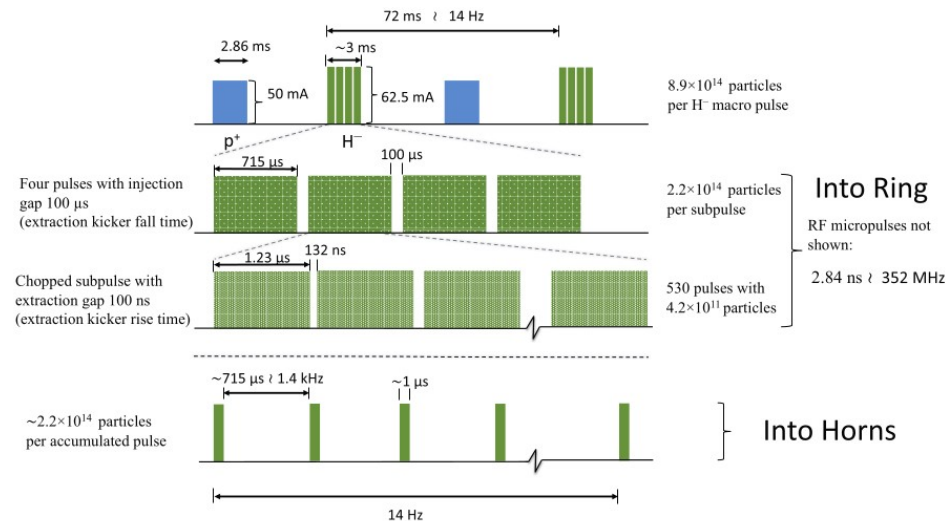
- For its use with ESSnuSB, the ESS Linac would need to operate at double power, to share the linac between neutron and neutrino production
- Beam pulses of H^- will be interleaved with the p pulses for the generation of the neutrino superbeam

Table 3.1: Nominal ESS design parameters versus ESSνSB upgrade*

	Nominal Linac	ESSνSB Linac	Units
Species	p	p and H^-	
Energy	2.0	2.5	GeV
Current	62.5	$62.5 \cdot 50 (p) / (H^-)$	mA
Average beam power	5	10	MW
Linac length	352.2	~ 423	m
Macro pulse length	2.86	$> 2.86 (p) / 2.9 (H^-)$	ms
Protons per pulse	10^{15}	$8.3 \cdot 10^{14} (p) / 8.9 \cdot 10^{14} (H^-)$	
Sub-pulse length	N/A	~ 0.65	ms
Repetition rate	14	$28^\dagger$	Hz
Beam duty cycle	4	8	%
Total losses	< 1	< 1	W/m

*The baseline pulsing scheme is assumed here, see Fig. 3.2 Option A+.

† 14 Hz proton + 14 Hz H^- , with the H^- pulses consisting of four subpulses.



ESS RFQ quick review

- Plunger tuners are used to compensate deviations in order to get the desired electric field profile along the beam axis. Tuners also set the adequate frequency in the cavity.
 - This is a **static tuning** of the RFQ. Once all the tuners penetration are frozen, they do not change during operation. (A change in a tuner will change ω , but also $E_z(z)$)
- **Dynamic tuning** (frequency deviations correction during operation) is done by controlling the cooling water temperature or **LLRF frequency tracking**.

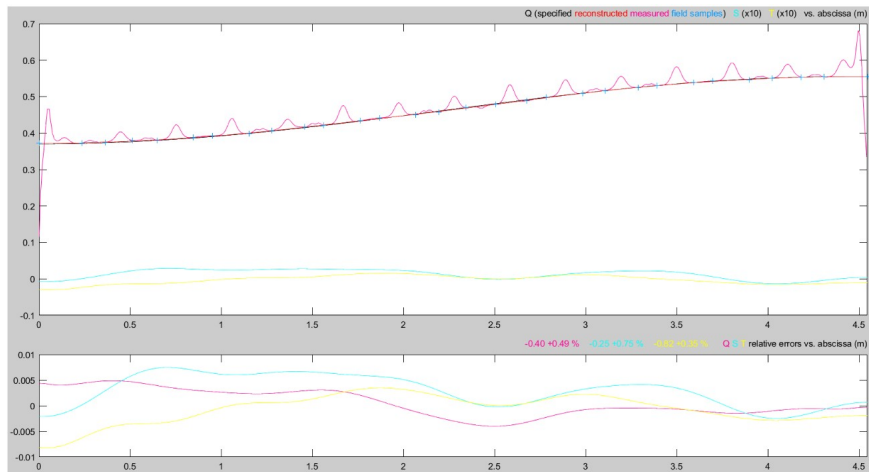
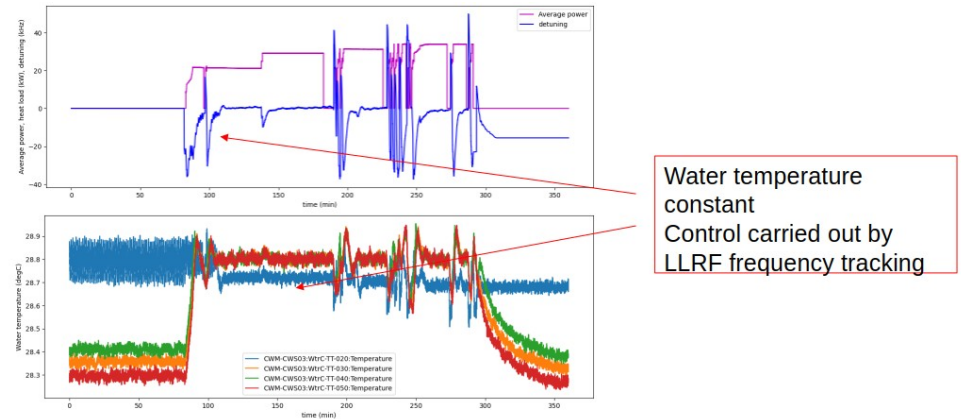
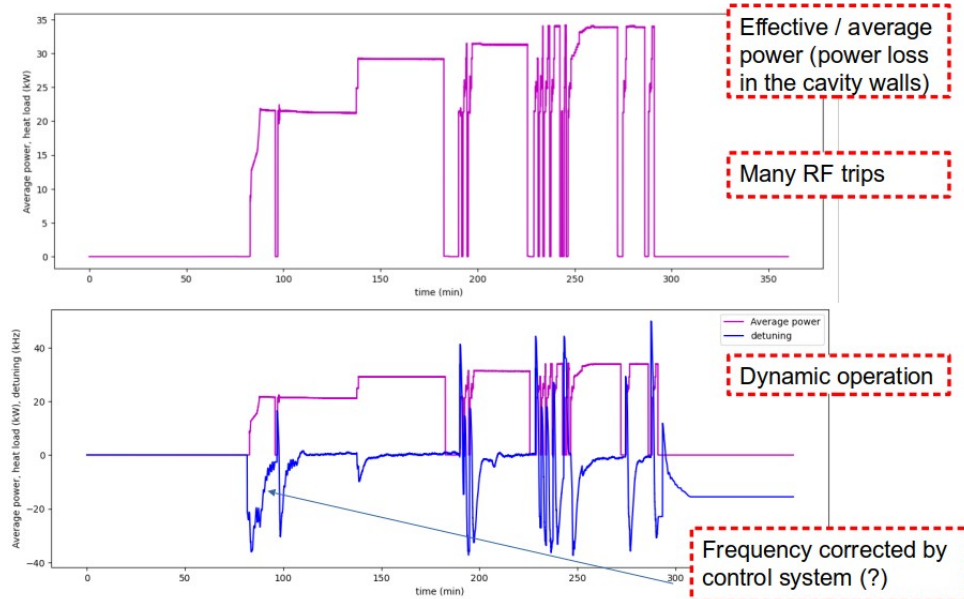


Figure 22: RFQ after tuning

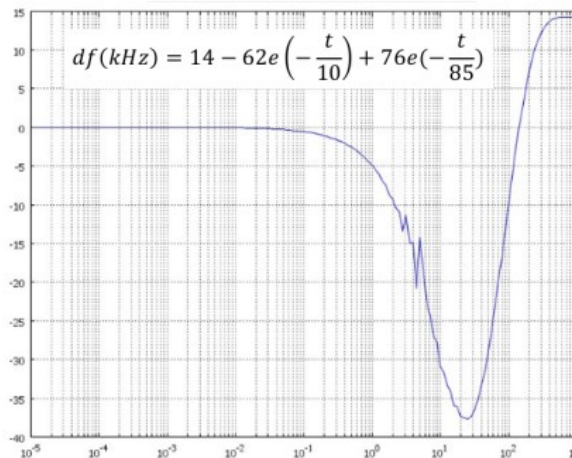
ESSnuSB+ WP4 ESS-Bilbao

- ESS RFQ thermal detuning analysis at 5% and extrapolated to 10%



On the other hand, don't worry too much about the water temperature recovery time and transient. It is easier to rely on "frequency tracking" in LLRF, instead of using water temperature to tune RFQ. At RFQ trip, if trip > 10 seconds, the cavity always get detuning of 50kHz, this amount is very hard to tune by water(which might need half hour). In our case at any RFQ trip, we always switch LLRF frequency tracking, so RF frequency always follows cavity frequency. Then we increase RF power and repetition rates and pulse length, to gradually get to the nominal power and duty cycle. It takes often 1-3 minutes to reach nominal power and duty cycle, then we close the loop and ready for beam.

Detuning [kHz] vs time [s]



Unit step
response function

$$H(s) = \frac{Y(s)}{X(s)} = \frac{\mathcal{L}\{y(t)\}}{\mathcal{L}\{x(t)\}}$$

Laplace transform

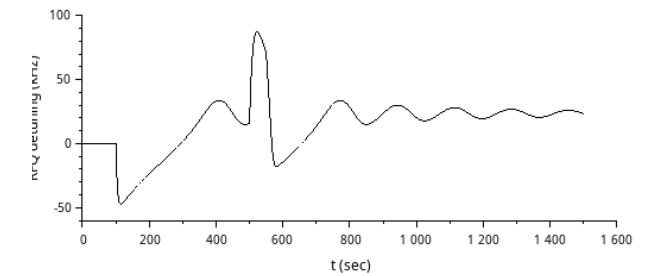
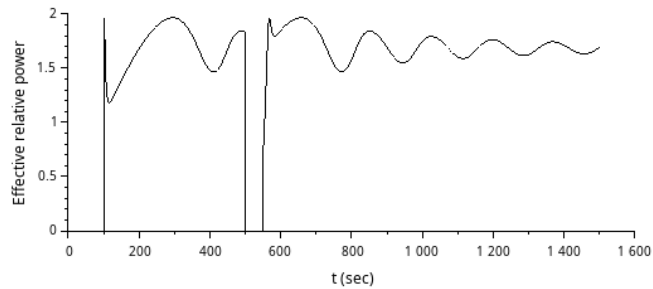
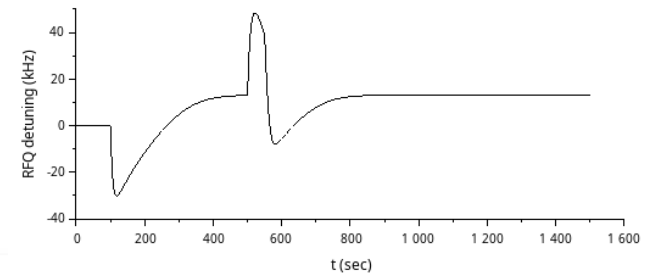
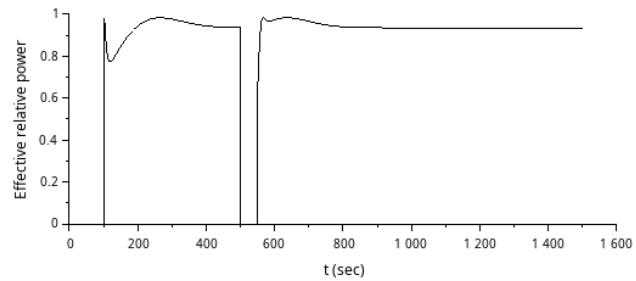
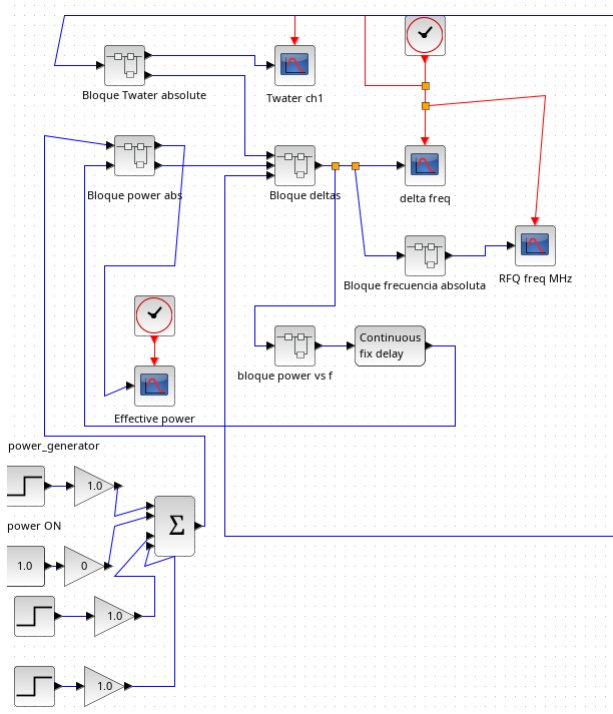
$H(s)$

Transfer function

M. Desmons "Study of the feed-back loop stability into the resonant frequency control system", CEA-ESS-RFQ-NT-0008, CEA/Irfu, University of Paris-Saclay, France, Feb. 2017.

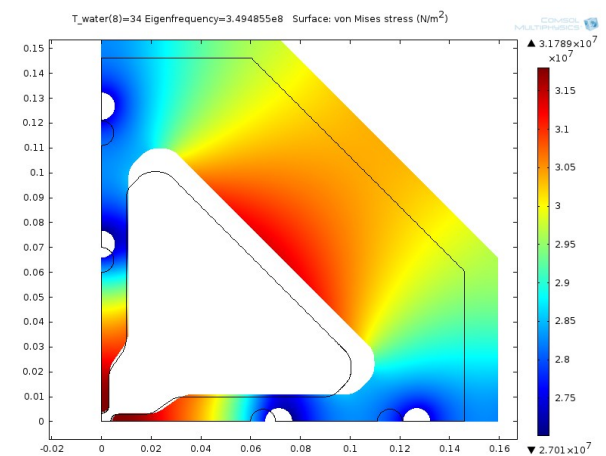
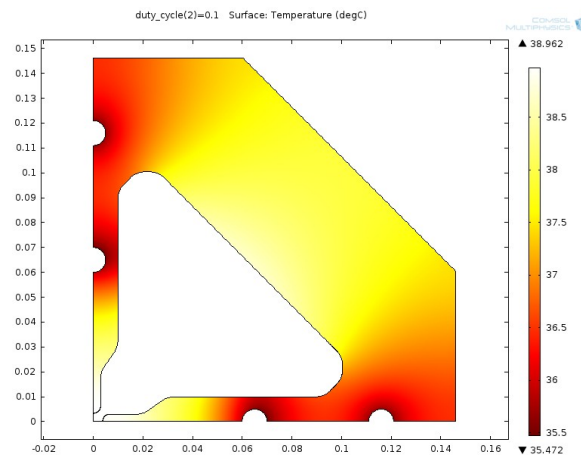
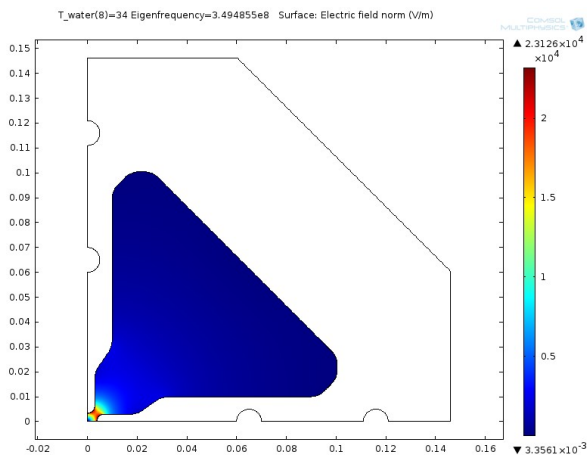
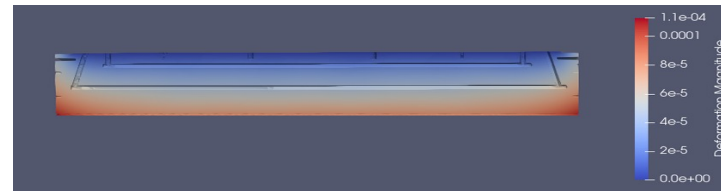
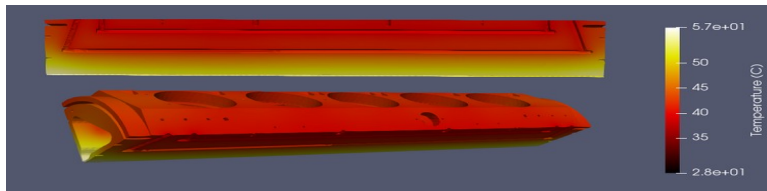
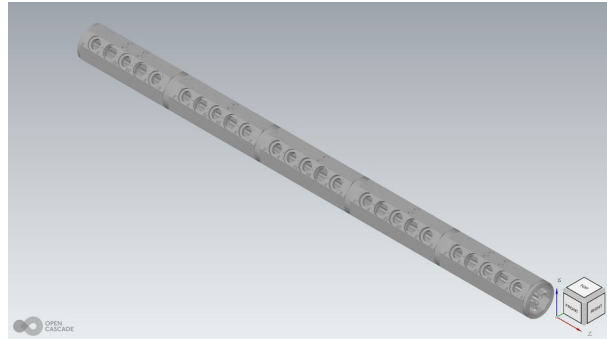
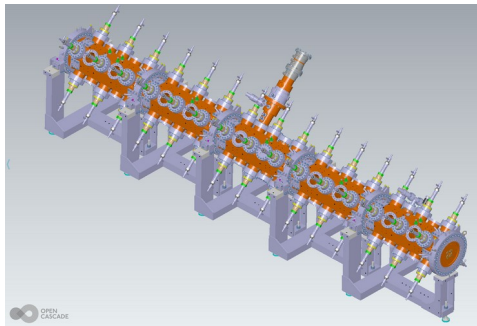
ESSnuSB+ WP4 ESS-Bilbao

- ESS RFQ thermal detuning analysis at 5% and extrapolated to 10%
- ESS RFQ seems to be unstable at 10% operation



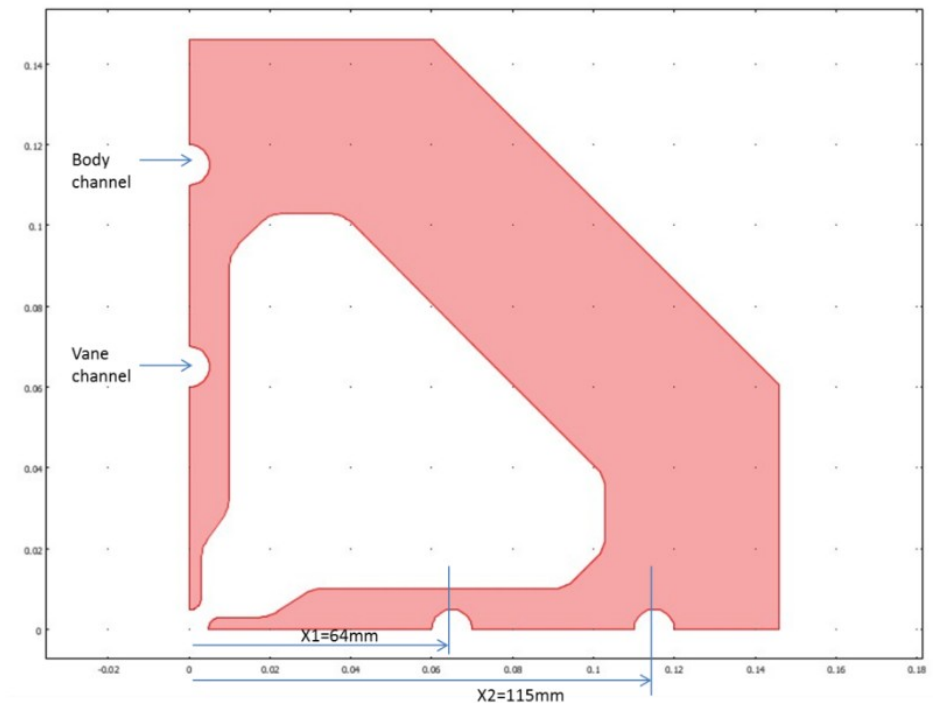
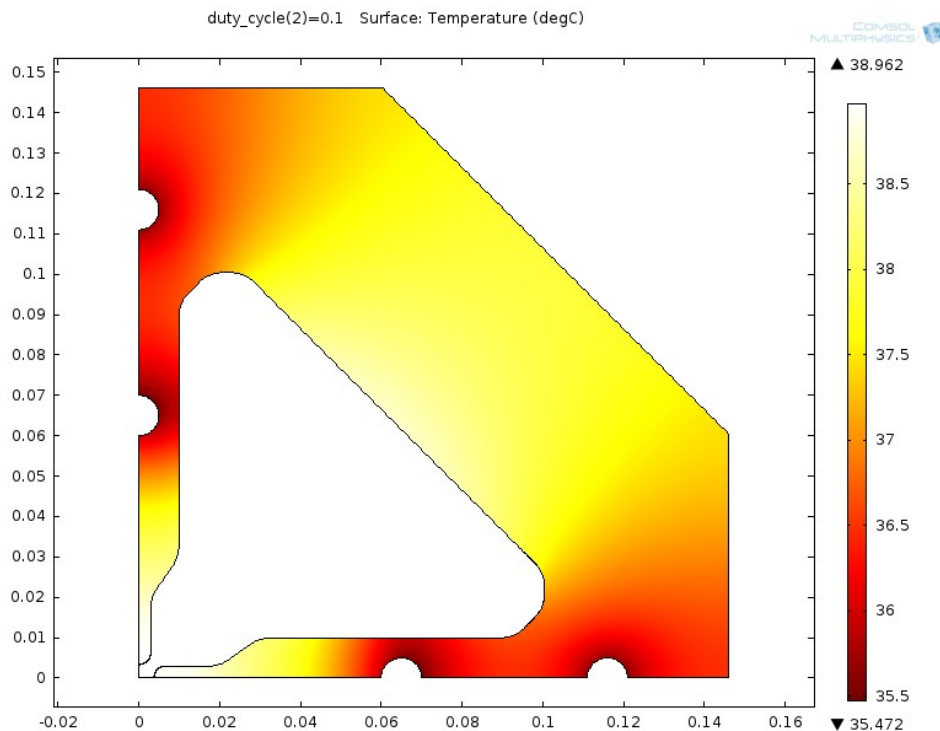
ESSnuSB+ WP4 ESS-Bilbao

- Simulations RF → Thermo-mechanical → Deformed mesh → RF



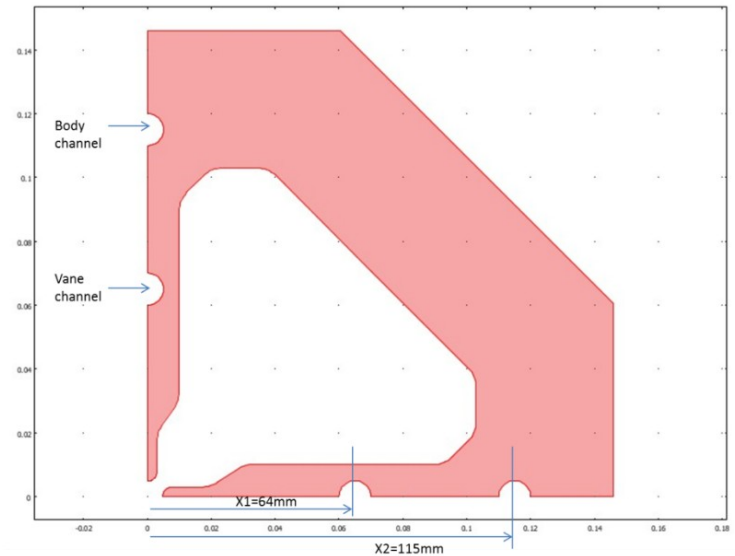
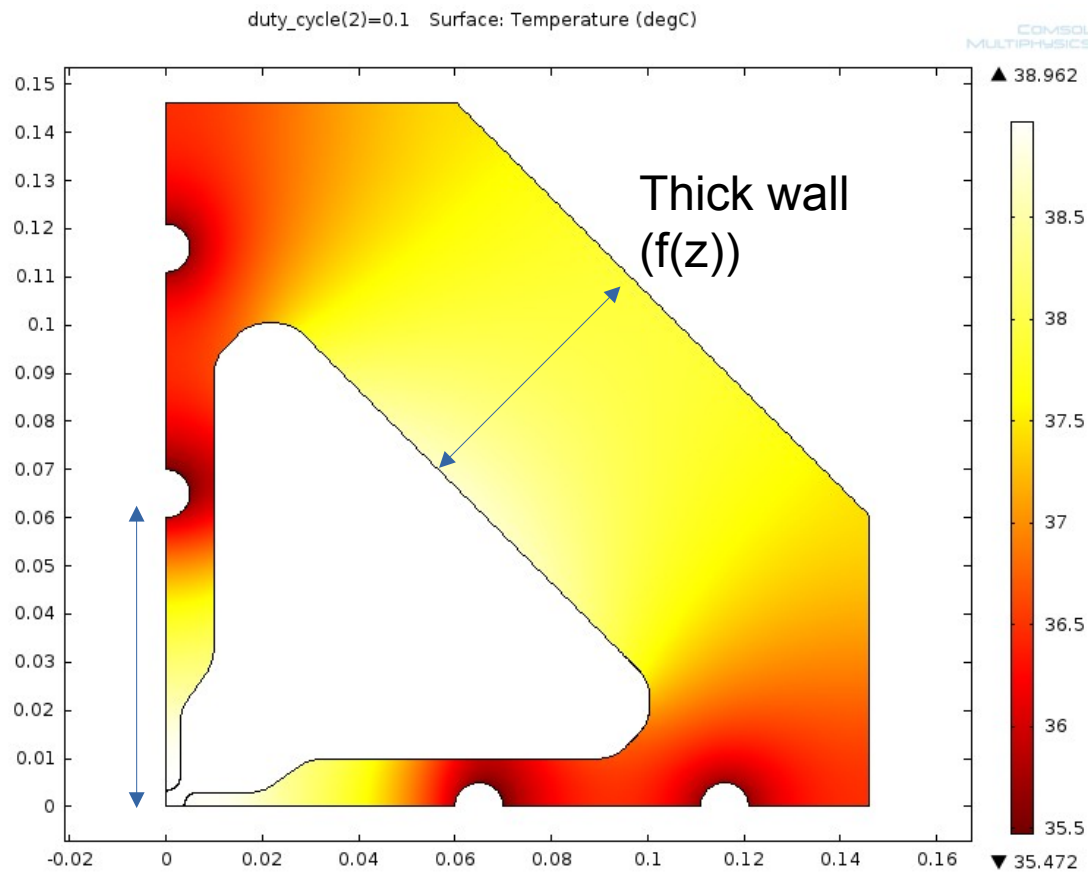
ESSnuSB+ WP4 ESS-Bilbao

- Simulations RF → Thermo-mechanical → Deformed mesh → RF
 - Boundary conditions as in “M. Desmonds ‘ESS RFQ Study of the feed-back loop stability into the resonant frequency control system’”
- 1) Positive frequency detuning with increase of body temperature and negative frequency detuning with increase of vane temperature. The thermal sensitivities are not constant along the RFQ but the average values are $df/dT_{\text{vane}} = -20\text{kHz}/^\circ\text{C}$ and $df/dT_{\text{body}} = +14\text{kHz}/^\circ\text{C}$.



ESSnuSB+ WP4 ESS-Bilbao

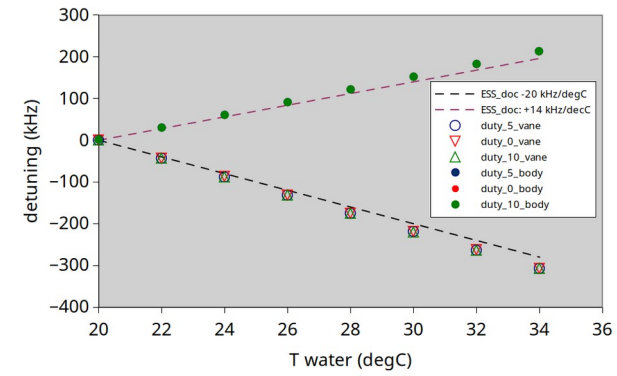
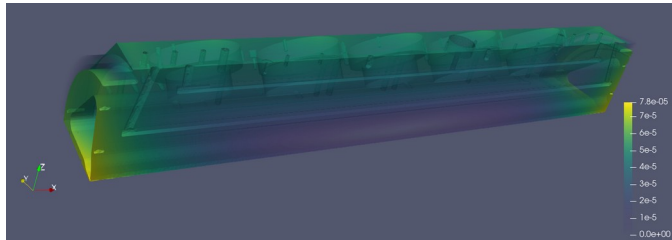
- Simulations RF → Thermo-mechanical → Deformed mesh → RF



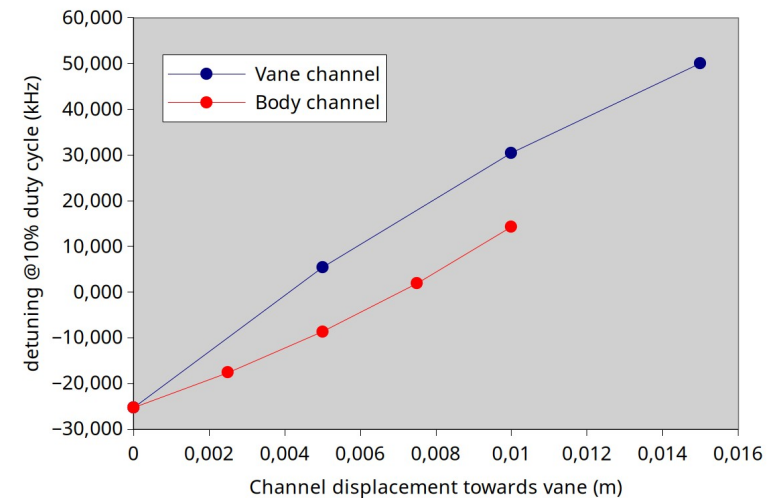
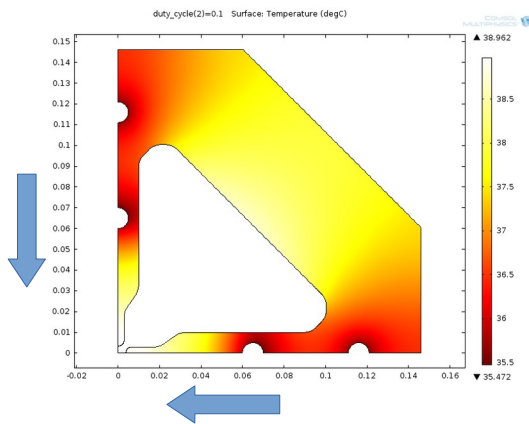
Far from vane tip

ESSnuSB+ WP4 ESS-Bilbao

- Simulations RF → Thermo-mechanical → Deformed mesh → RF
 - Steady state (3d simulations)

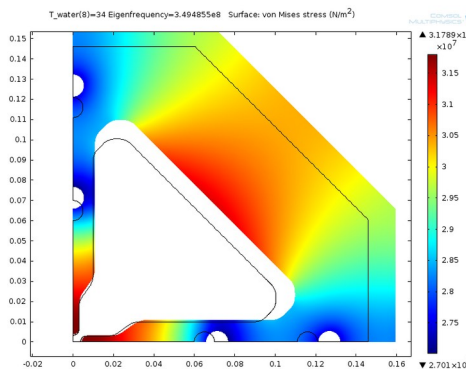
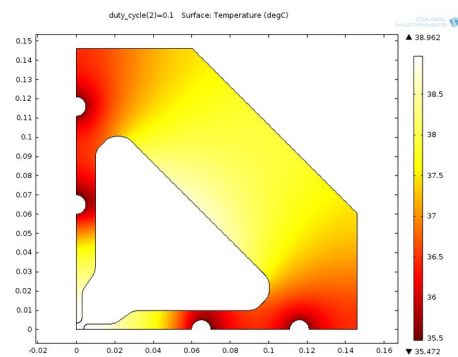
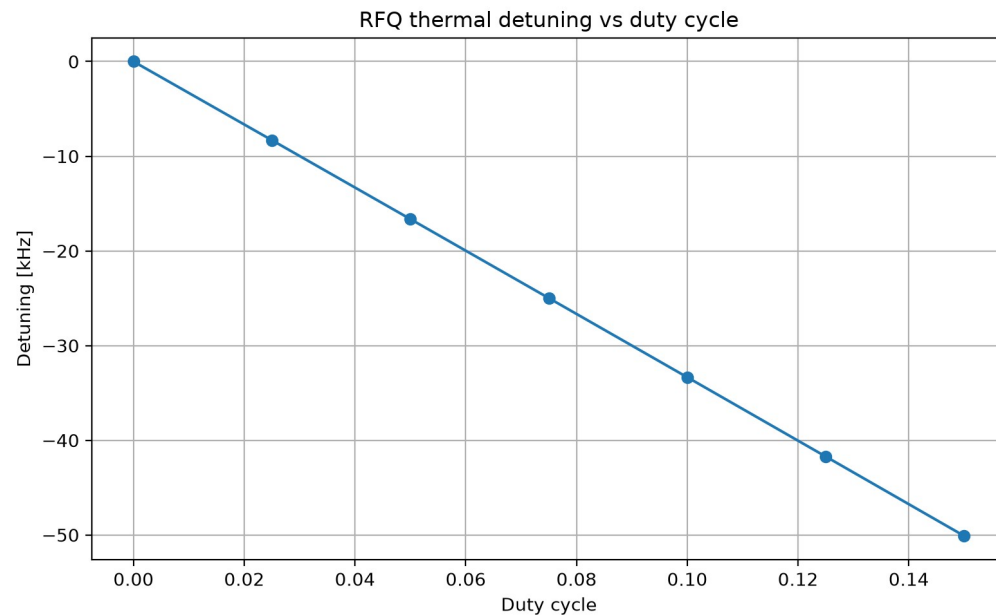


- Steady state (2d for optimization)



ESSnuSB+ WP4 ESS-Bilbao

- We focused in optimizing ESS RFQ response by minimizing detuning caused by a RF power change.
- This results in a proposed 3D RFQ design that should be tested as posible candidate for ESSnuSB+ RFQ



ESSnuSB+ WP4 ESS-Bilbao

- Differential Evolution algorithm to optimize channels placement and diameter (python SciPy + COMSOL (RF → thermomechanical → deformed mesh → RF))

- DE: Bounded parameter ranges but continuous variables

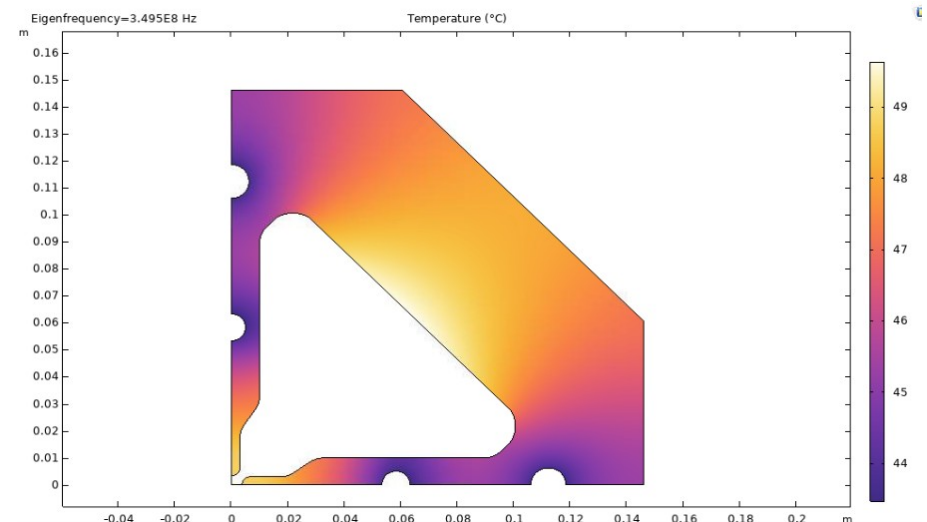
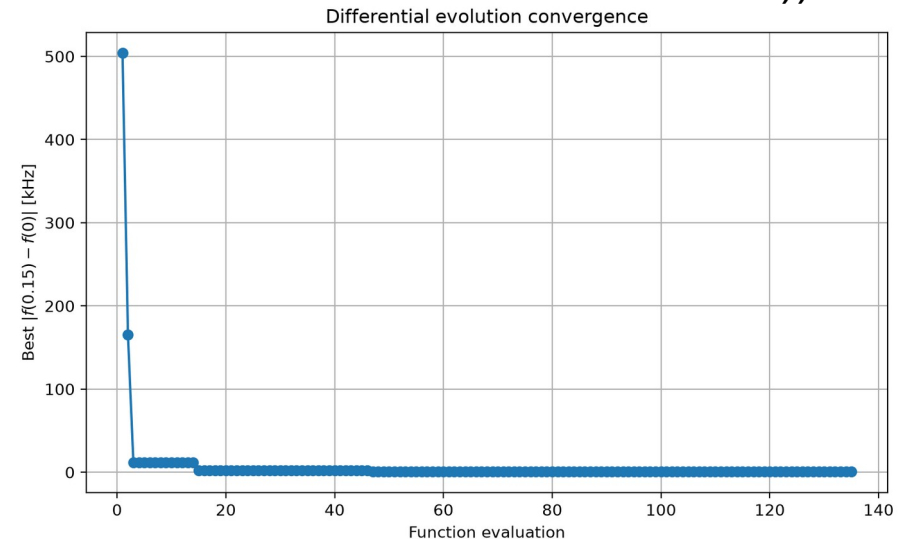
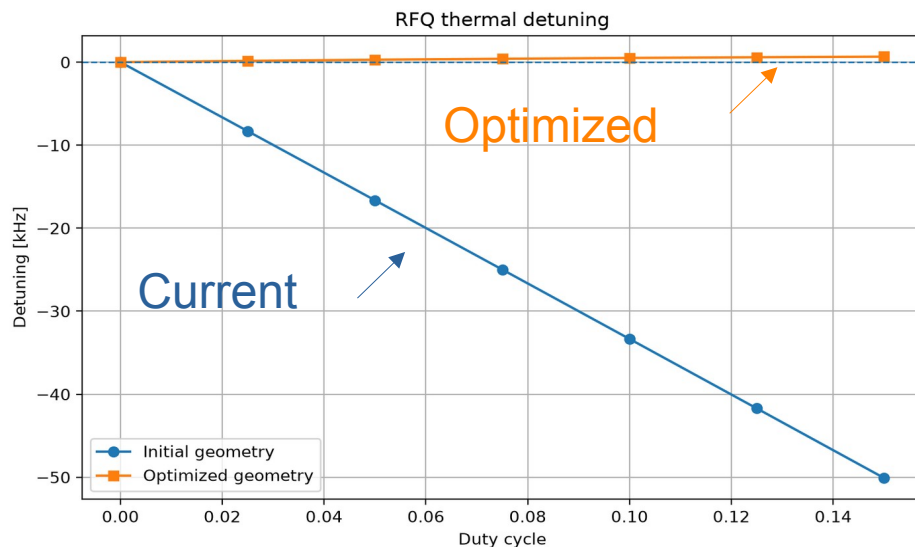
Optimization bounds [m]

BOUNDS = [

(-0.020, 0.020), # delta_vane

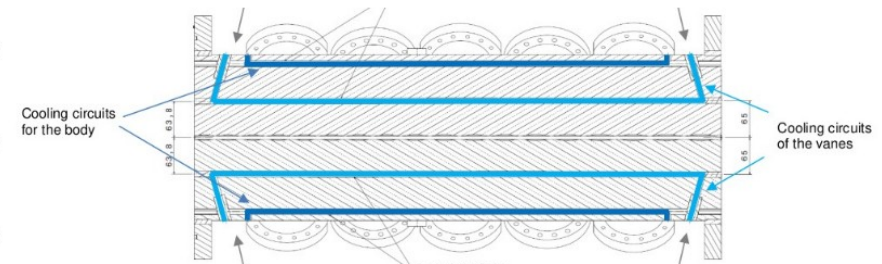
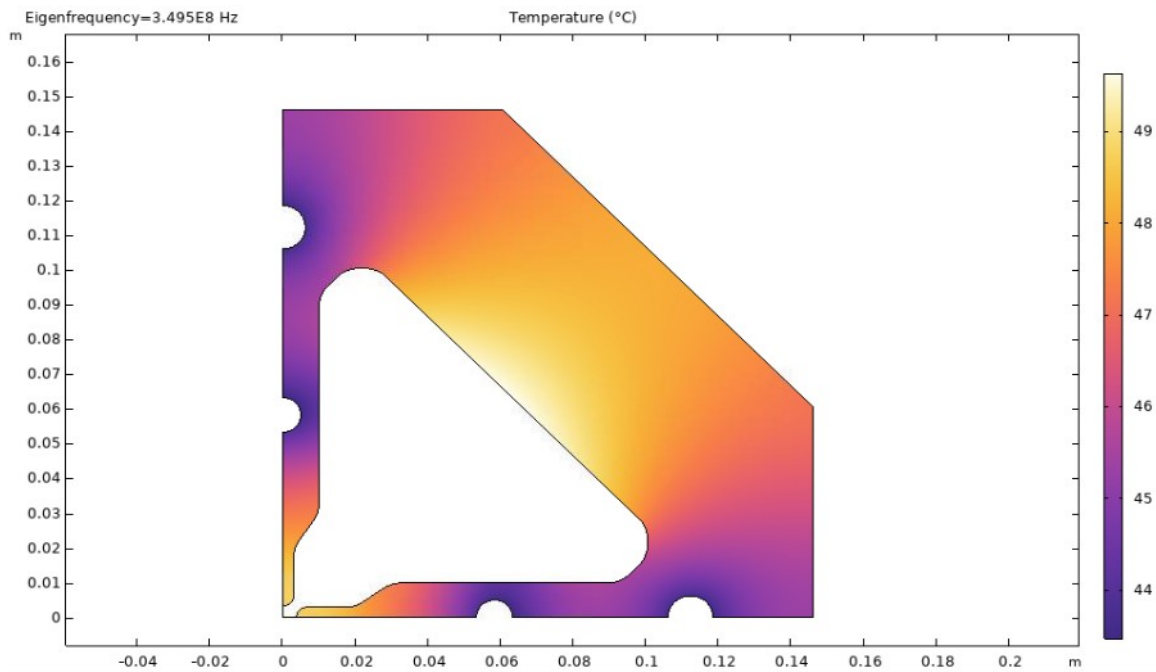
(-0.020, 0.020), # delta_body

(0.005, 0.008), # radius_body]



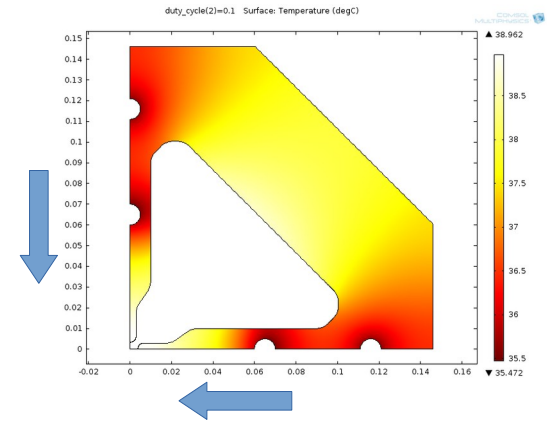
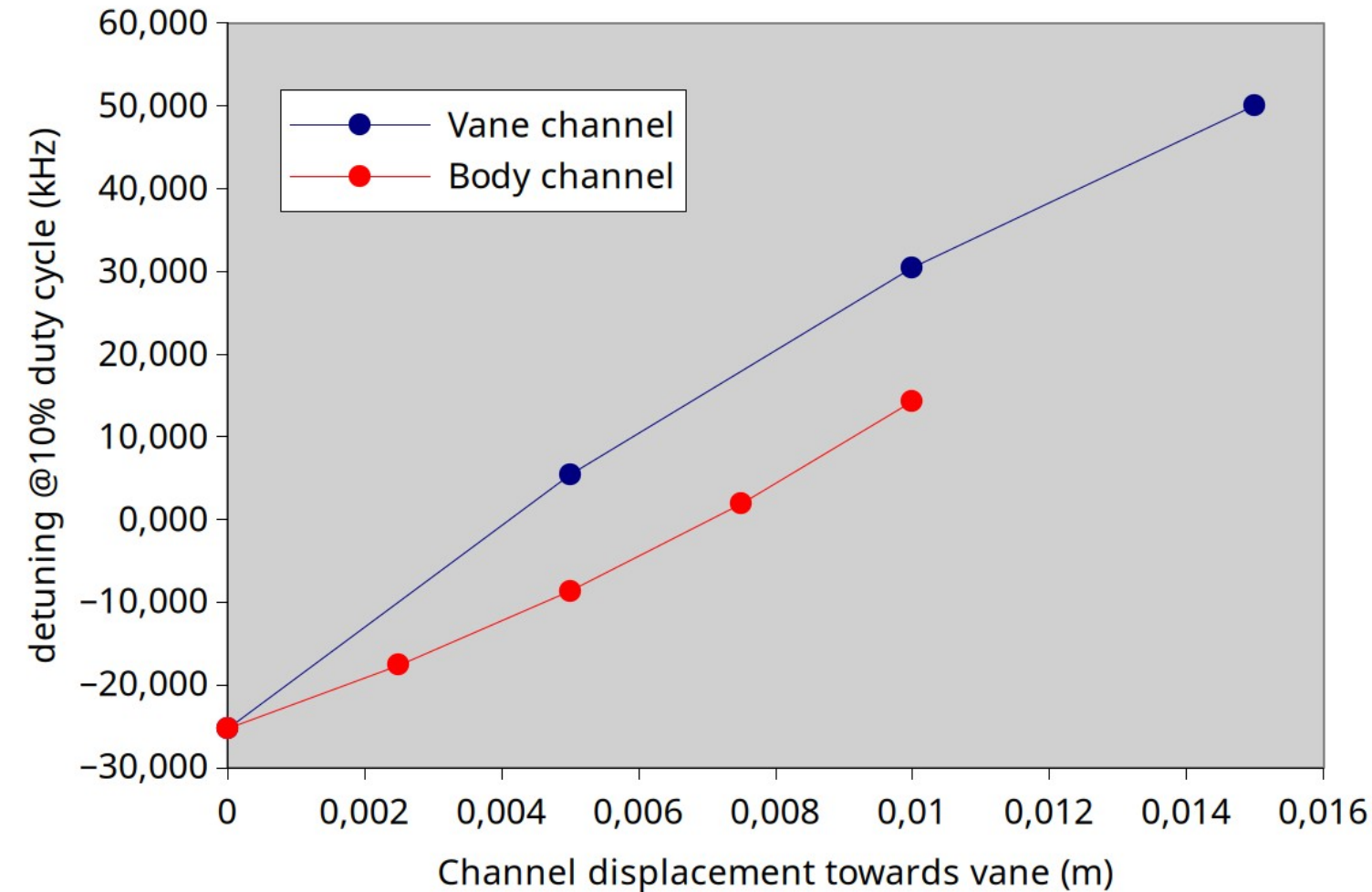
ESSnuSB+ WP4 ESS-Bilbao

- More stable RFQ, for 5% or 10% operation, with little mechanical modifications
- RFQ modulation, length, ports, etc remain the same as the current design (so beam dynamics for the LINAC is not modified)
- This approach should be validated with full cavity modelling



ESSnuSB+ WP4 ESS-Bilbao

- Moving vane channel closer to the vane



ESSnuSB+ WP4 ESS-Bilbao

- ESS DTL analysis (ongoing). Using similar design (LINAC4) up to now
- Initial meeting with F. Grespan (INFN), more activities on ESS DTL will follow

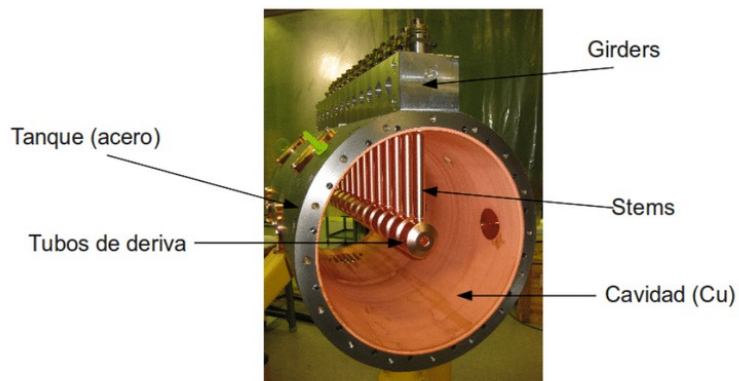


Figure 1.2: Linac4 DTL prototype.

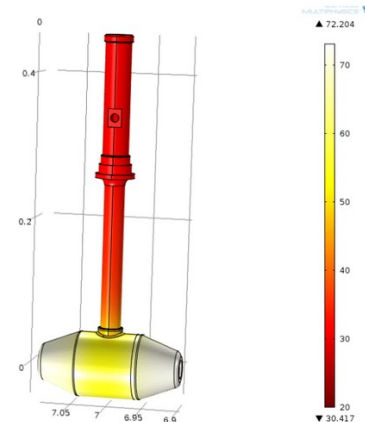
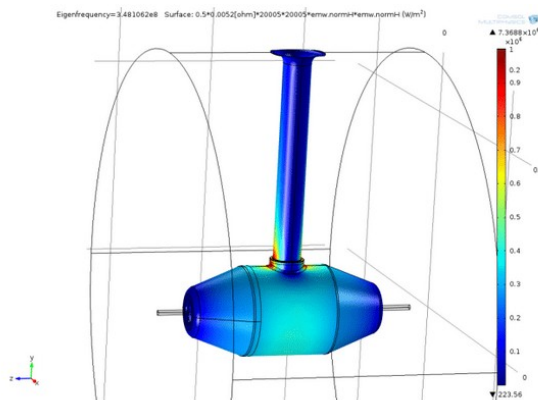
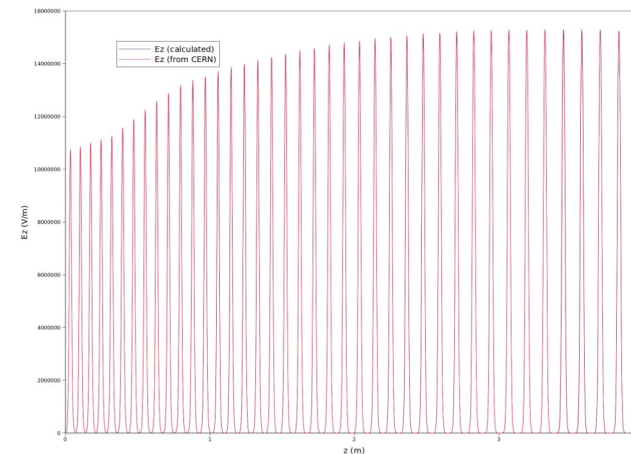
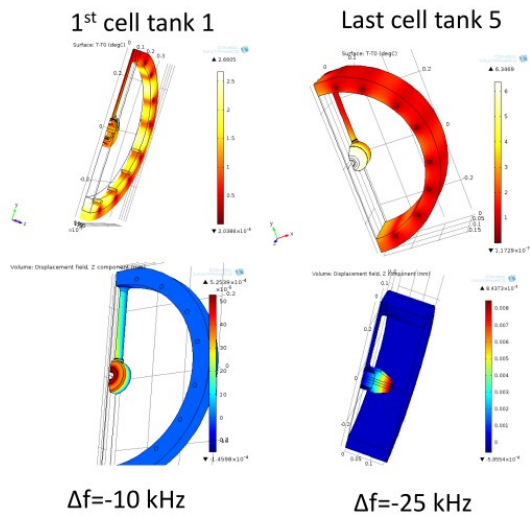


Figure 3.9: Temperature for the last drift tube of tank 3 (longest in the DTL) at 10% duty cycle and a cooling water temperature of 20°C(left) and 30°C(right). Simulations are done using conjugate heat transfer solver assuming a constant heat transfer coefficient to the water.

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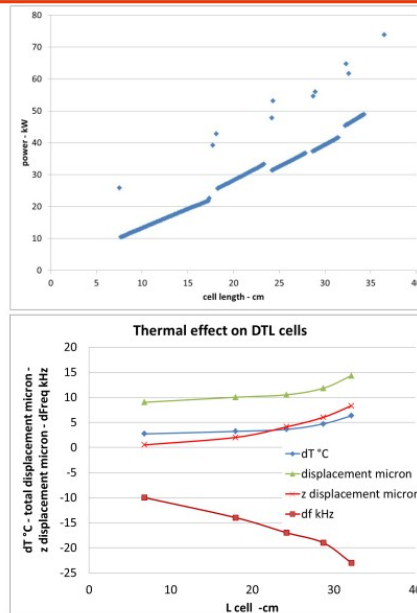
- Information kindly provided by F. Grespan (INFN)

Thermo mech. simulation



LNL - 2015_06_22 CDR

F. Grespan

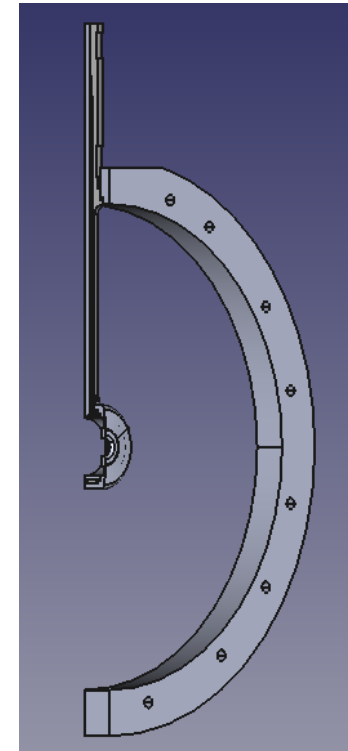
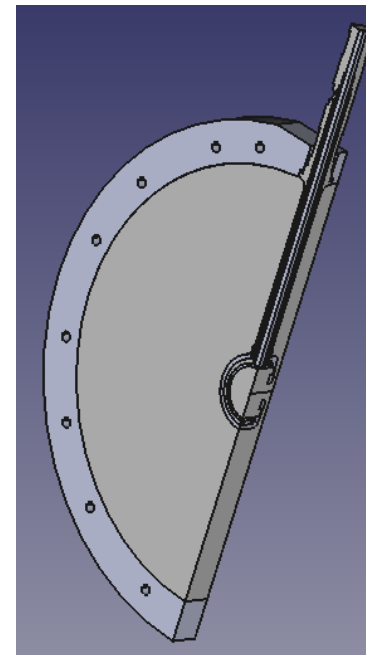


Proceedings of IPAC2017, Copenhagen, Denmark

THPVA046

THERMO MECHANICAL STUDY OF THE ESS DTL

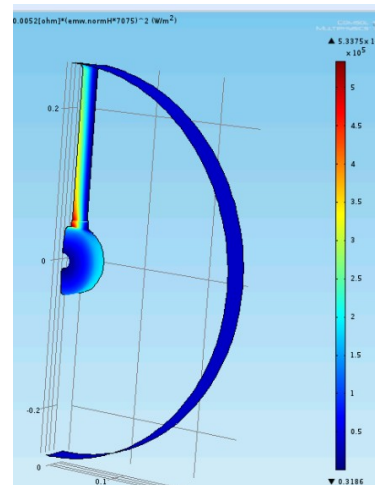
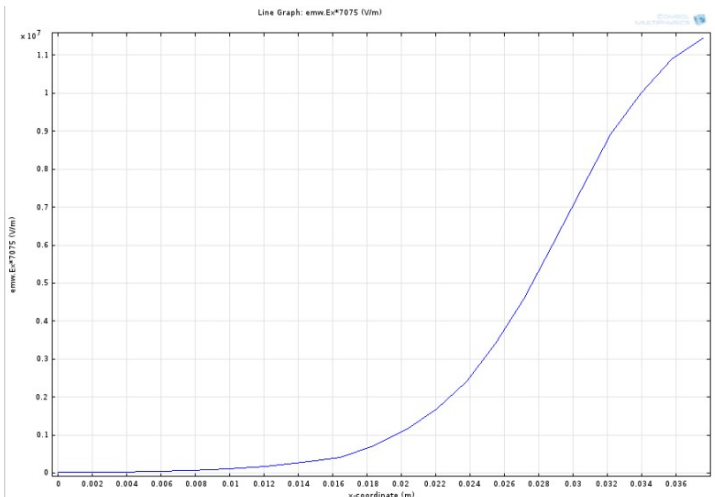
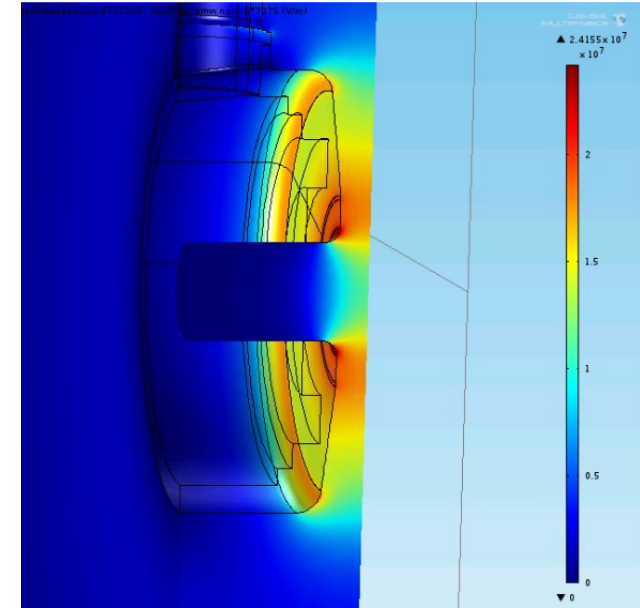
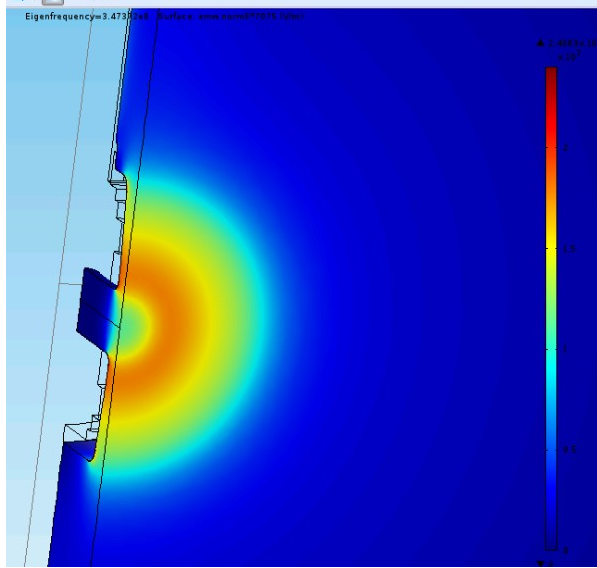
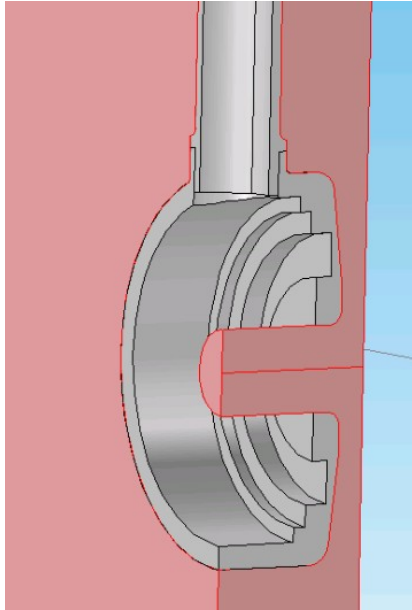
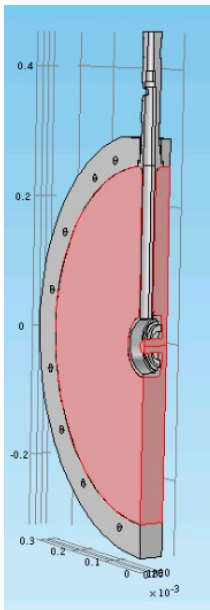
P. Mereu*, M. Mezzano, C. Mingioni, M. Nenni, INFN, Torino, Italy
F. Grespan, A. Palmieri, A. Pisent, INFN-LNL, Legnaro, Padova, Italy



3D models (STEP files) for the first cell of the DTL

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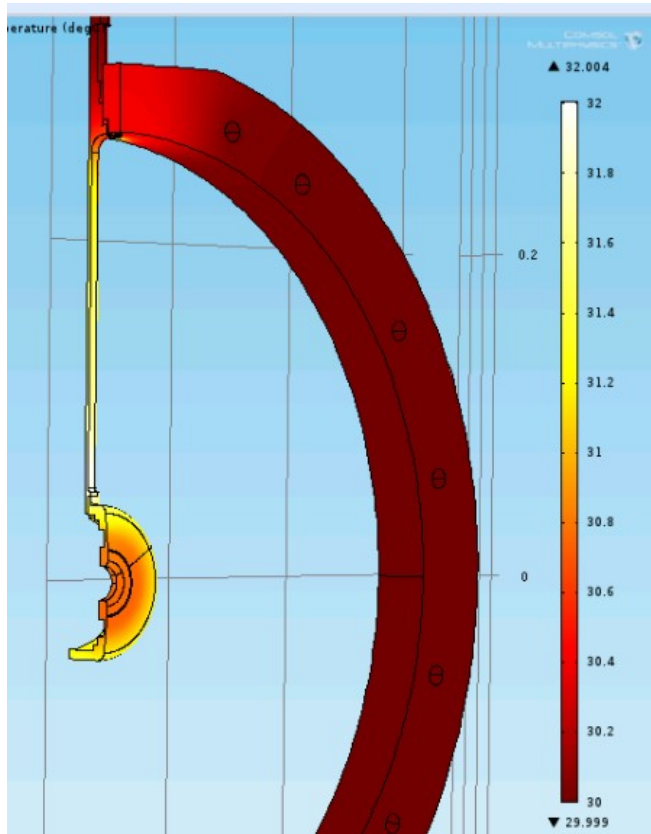
- ESS DTL analysis



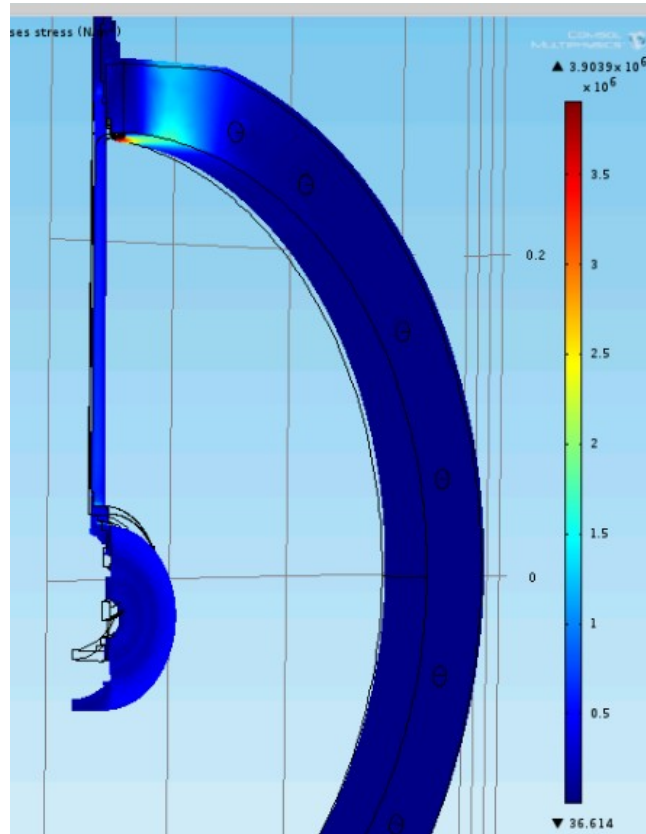
Half DT (101):
- detuning effects

ESSnuSB+ WP4 ESS-Bilbao

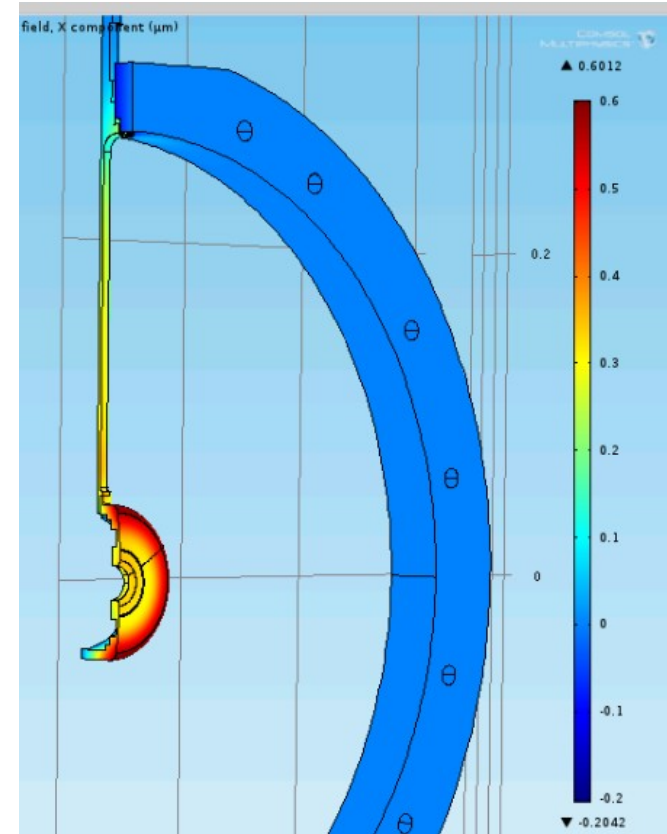
- ESS DTL analysis



Temperature



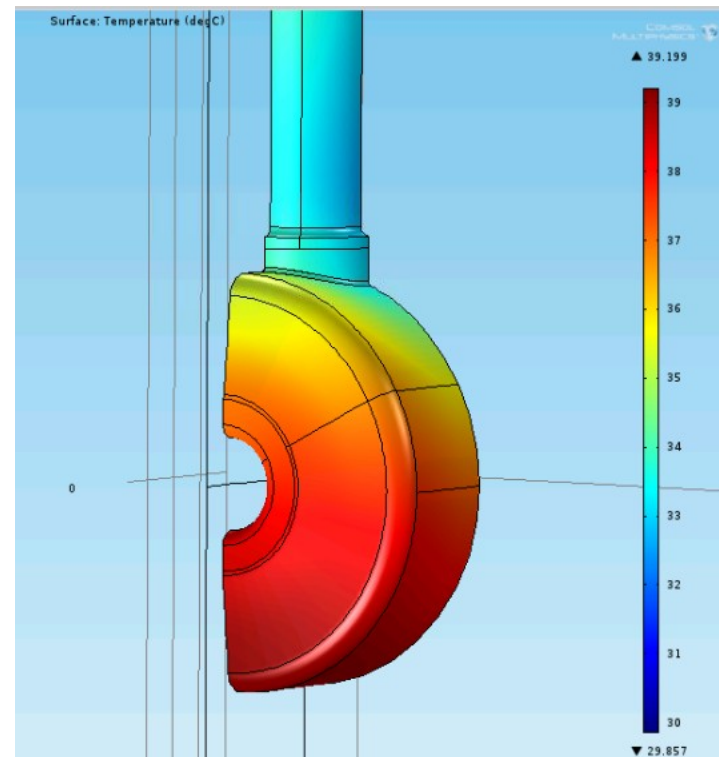
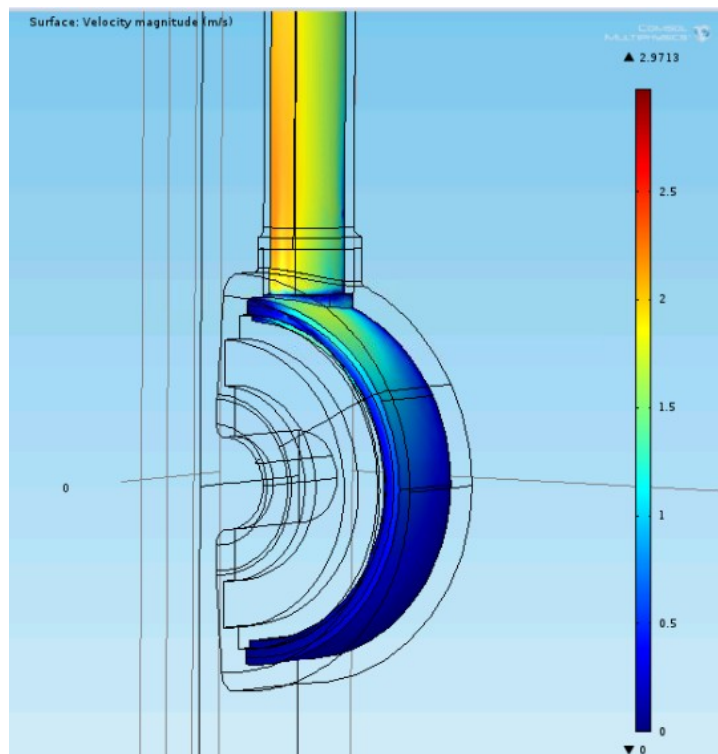
Stress



Deformation

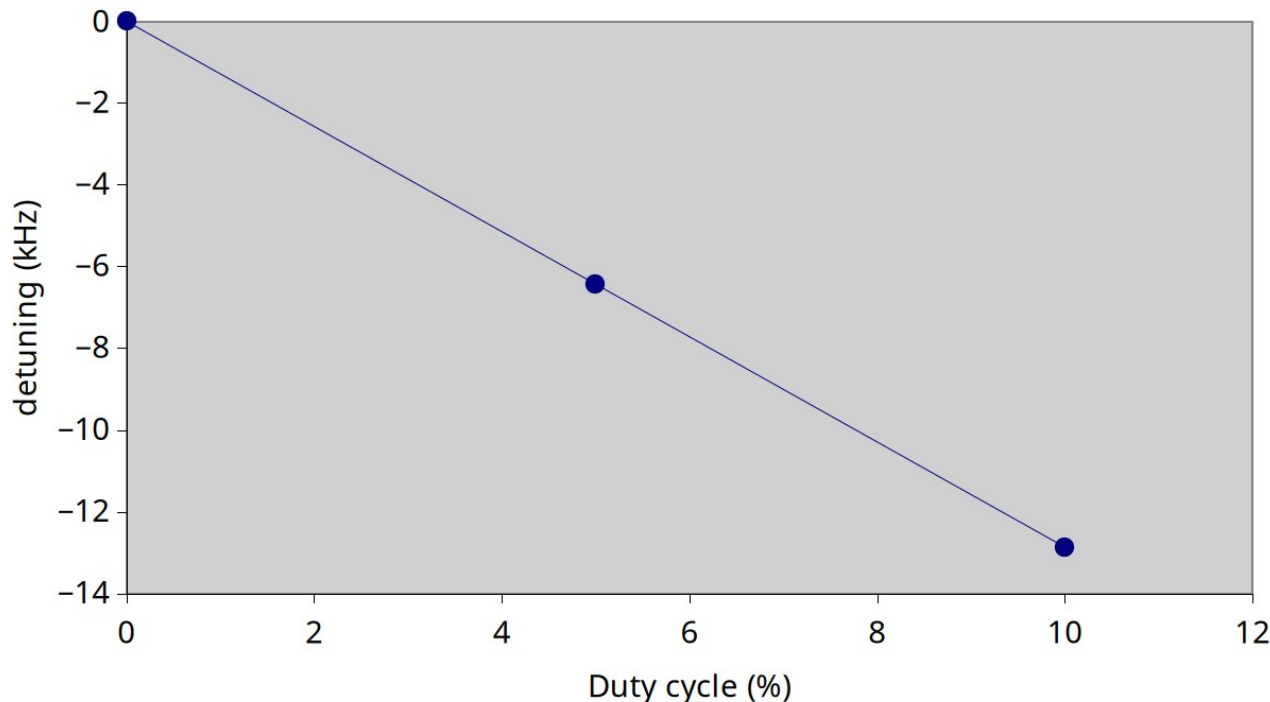
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- ESS DTL analysis using CHT (CFD+HT) for thermo-mechanical instead of a constant Heat Transfer coefficient



ESSnuSB+ WP4 ESS-Bilbao

- ESS DTL detuning
- Computed for duty 5% and 10%. Estimated $Q_0=43700$
- With these considerations, in principle no problem in increasing power (wrt detuning)
- But power losses in the ceramic window, and other components (like PCs) should also be studied



doi: 10.18429/JACoW-LINAC2024-TUPB068
Table 4: DTL RF Parameters (VNA Measurements)

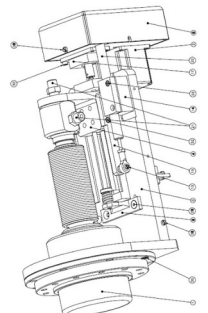
	Parameters	Design	Measured
DTL5	Freq. [MHz]	352.21	352.266 (in vacuum, no RF power, 18°C)
	Coupl. factor [β]	1.84	1.95
	Q_0 (SFish/1.25)	43415	43307
	E0 flatness [%]	± 2	± 1.15
	Tilt.Sens.	N.A.	± 4.5 %/MHz



Frequency tuning in operation

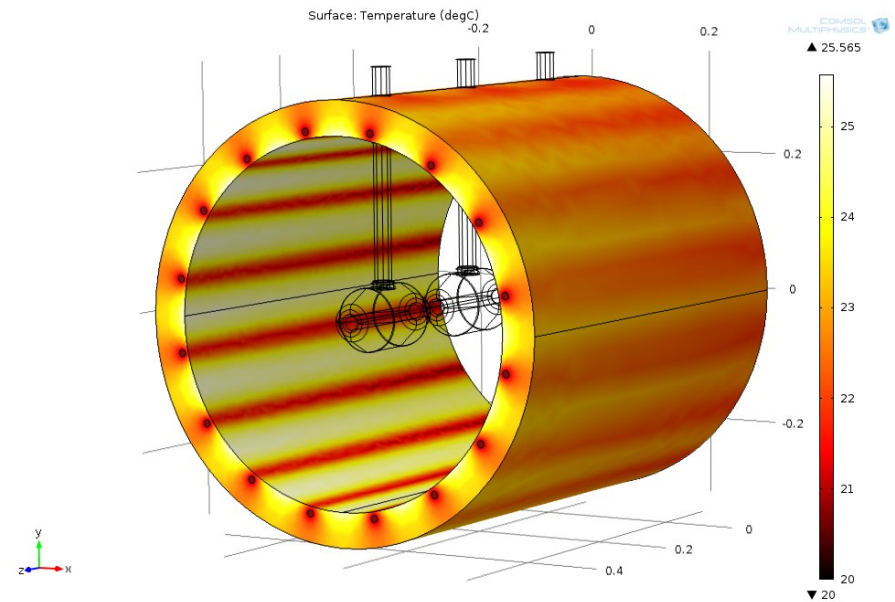
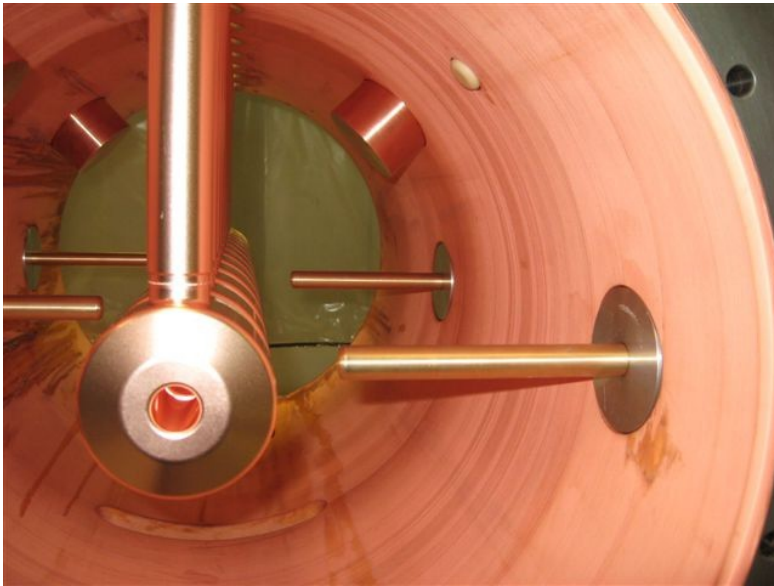


- Max simulated cell detuning in operation= -25kHz (tank 5)
- Water nominal temperature = 30deg
- Temp sensitivity= -10 kHz/deg
- water frequency range = +40 kHz (@26°C), -100 kHz (@40°C)
- Operating water temperature will be optimized in RF conditioning phase
- 3 movable tuners/tank, tuning range= +120 kHz (@ penetration=80mm), -90 kHz (@penetration=0mm)



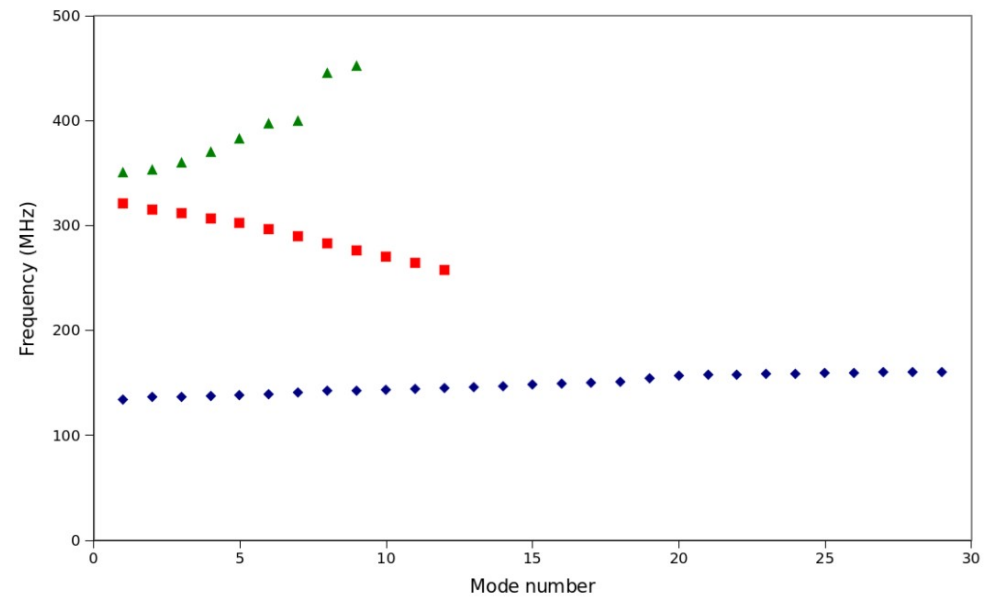
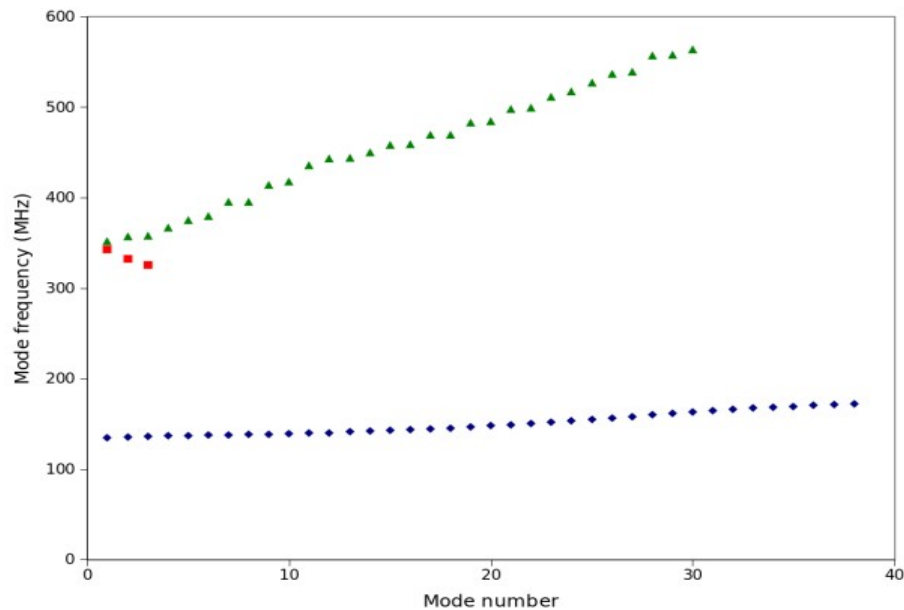
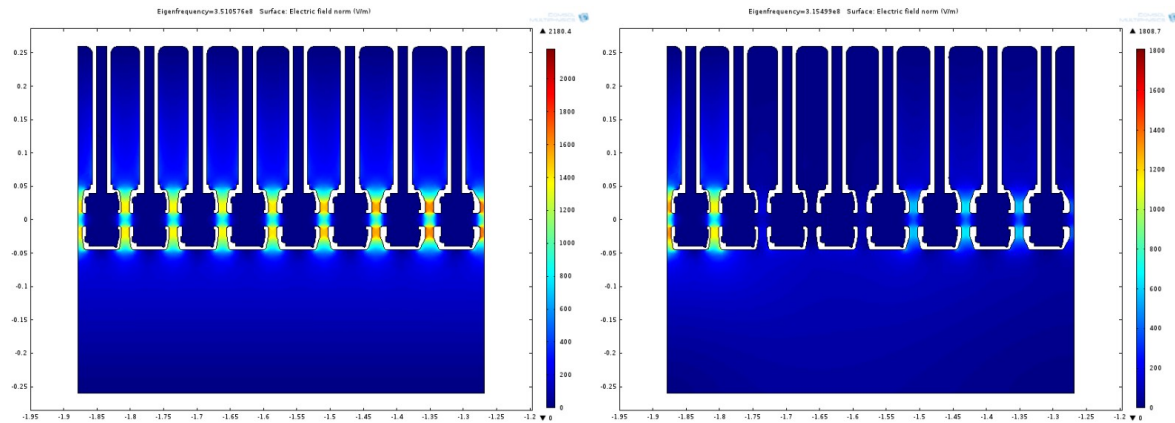
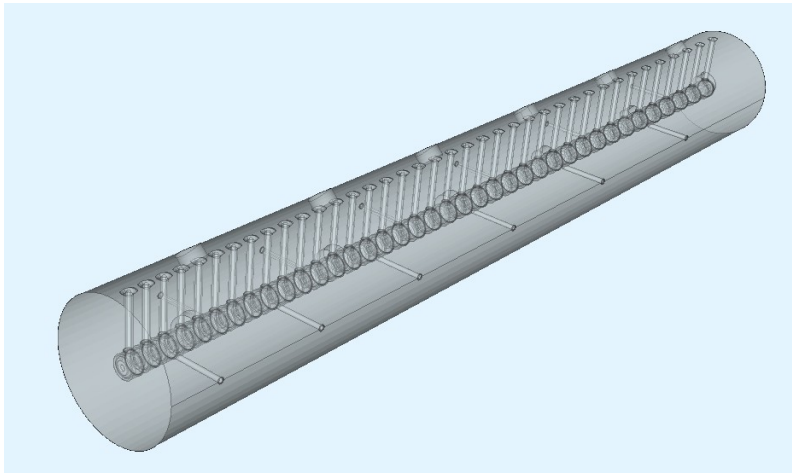
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- Next steps:
 - Post-couplers (play major role in stability) and whole cavity (tuner controlled)



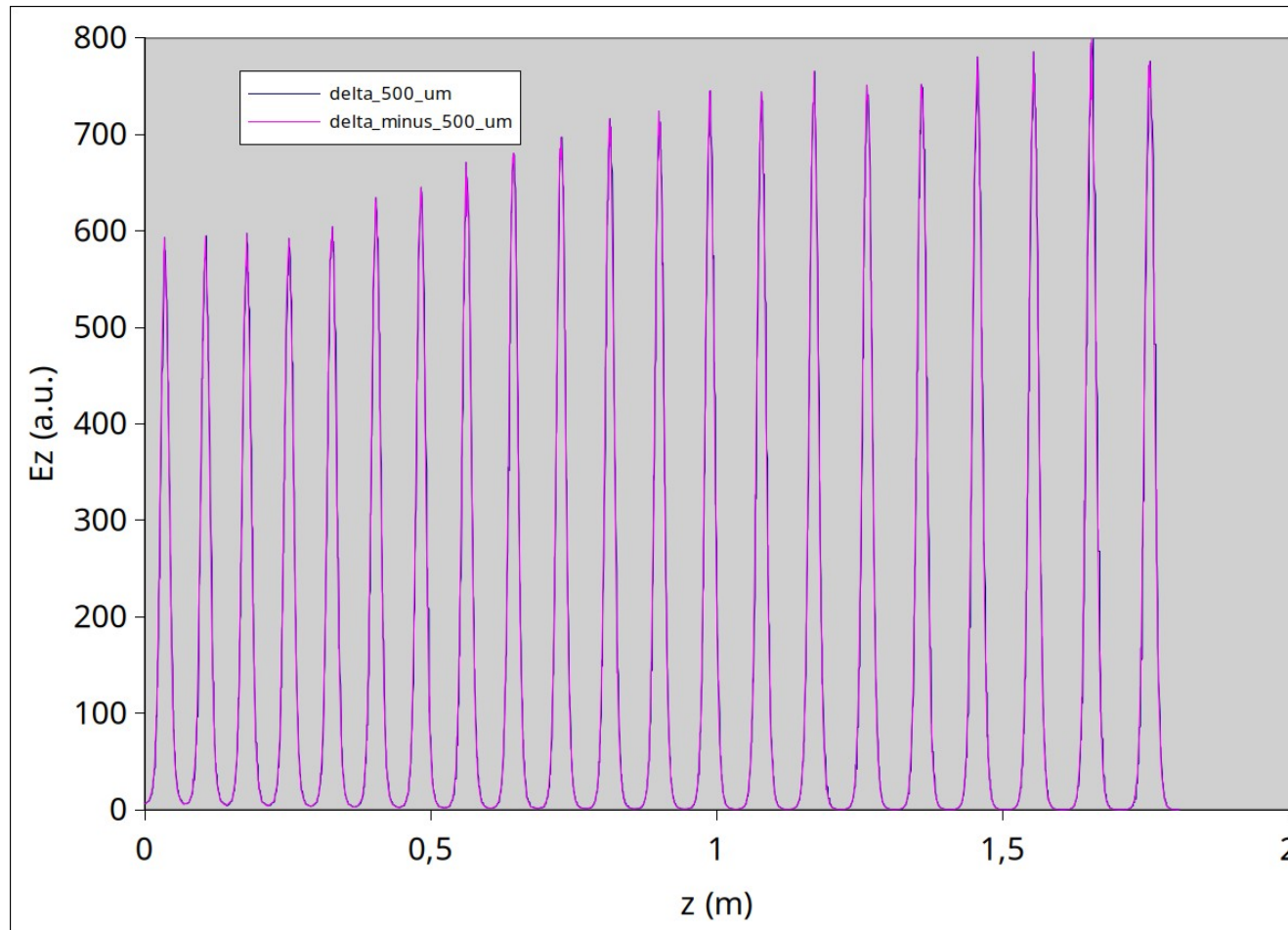
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- DTL post-couplers



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- There is not a noticeable effect in the thermal distortion of the PCs



ESSnuSB+ WP4 ESS-Bilbao

- Summary:
 - RFQ
 - Needs updated design for 10% operation
 - Suggestion of design changes presented for a new, more stable RFQ
 - DTL
 - Simulations do not detect noticeable variations in DTL operation at 10%, provided enough cooling water is supplied

