High-gradient proton accelerating structure developments at CERN

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CLIC14 Workshop

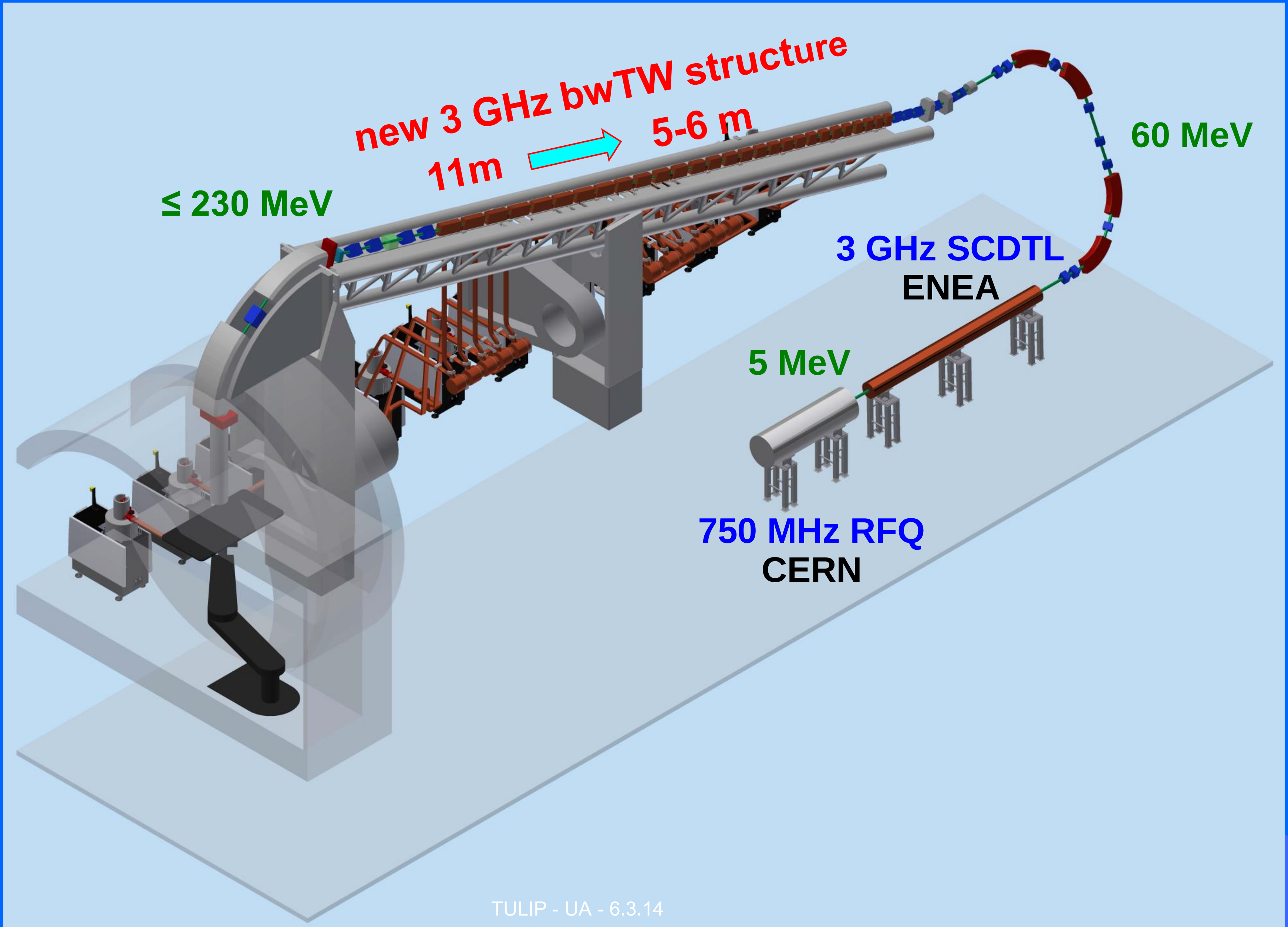
Acknowledgements

- This work is done in close collaboration between CERN (M. Garlasche, A. Grudiev, I. Syratchev, M. Timmins, W. Wuensch) and TERA foundation (U. Amaldi , S. Benedetti, A. Degiovanni, P. Magagnin, G. Porcellana) in the frame work of the CERN Knowledge Transfer (KT) Fund project: “High-gradient Accelerating Structure for Proton Therapy Linacs”

Outline

- *Introduction*
  - *RF cavities constraints for hadrontherapy*
- *Backward travelling wave* ***cell design*** *and* ***optimization*** *for high gradient operations*
  - *Nose cone study*
  - *Tapering*
  - *Couplers*
- ***Comparison*** *of different structure designs*
  - *SW SCL design*
  - *backward TW*
- ***Engenearing design***
- *Conclusions*

TULIP 2.0 at 3 GHz with E_0 ≅ 50 MV/m



Linac layout and BDR requirements

- Quasi-periodic **PMQ FODO lattice** sets a limit to the length of each structure and determines the group velocity range.

- The cells in each structure (**tank**) have the same length, while from one tank to the next, the cell length increases:

β tapering in the range 0.22-0.60

- Trade-off between transverse acceptance and RF efficiency:

bore aperture = 5 mm

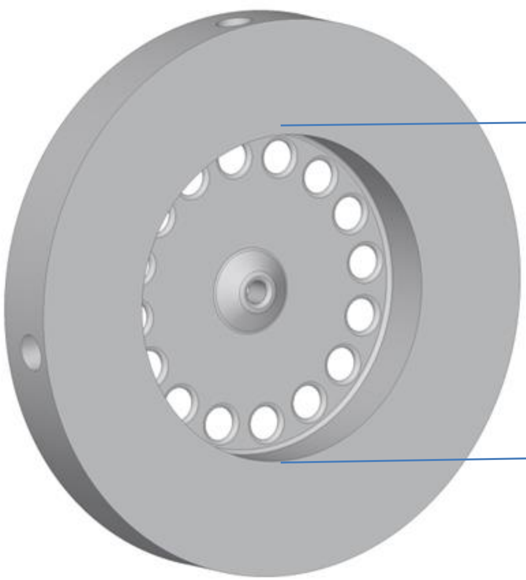
- **Max BDR:** 1 BD per treatment session (~ 5 min) on the whole linac length (~ 10 m).

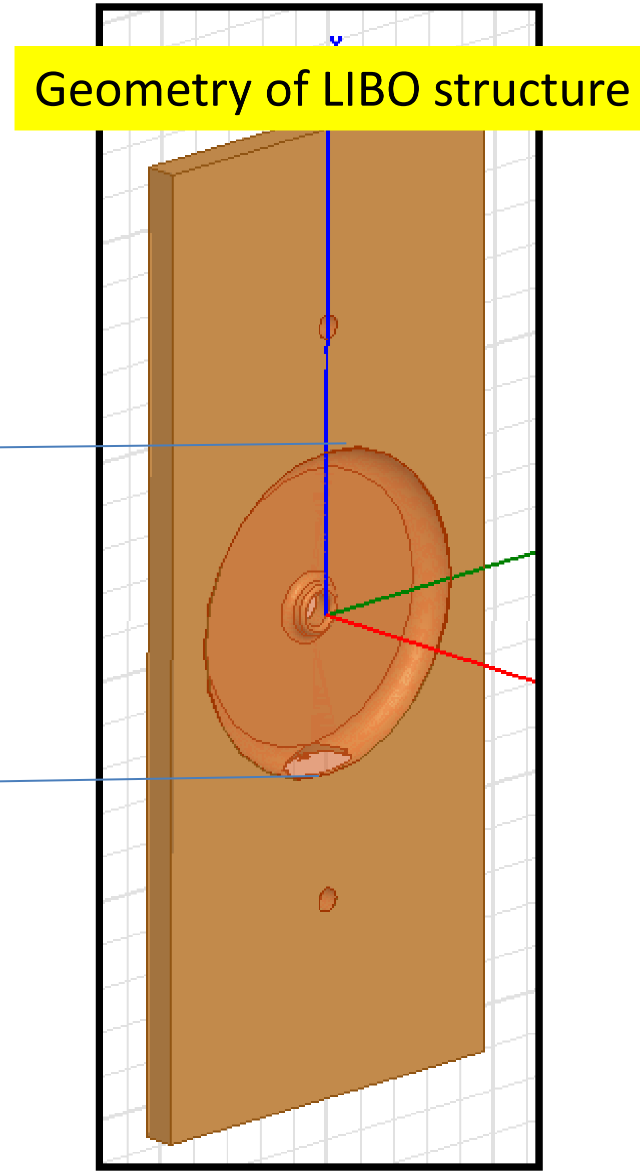
→ BDR ~ 10^{-6} bpp/m

COMPARISON BETWEEN TW AND SW STRUCTURES

Comparison between TW structure and SCL

Tapered structures:
the coupling holes are smaller
along the structure

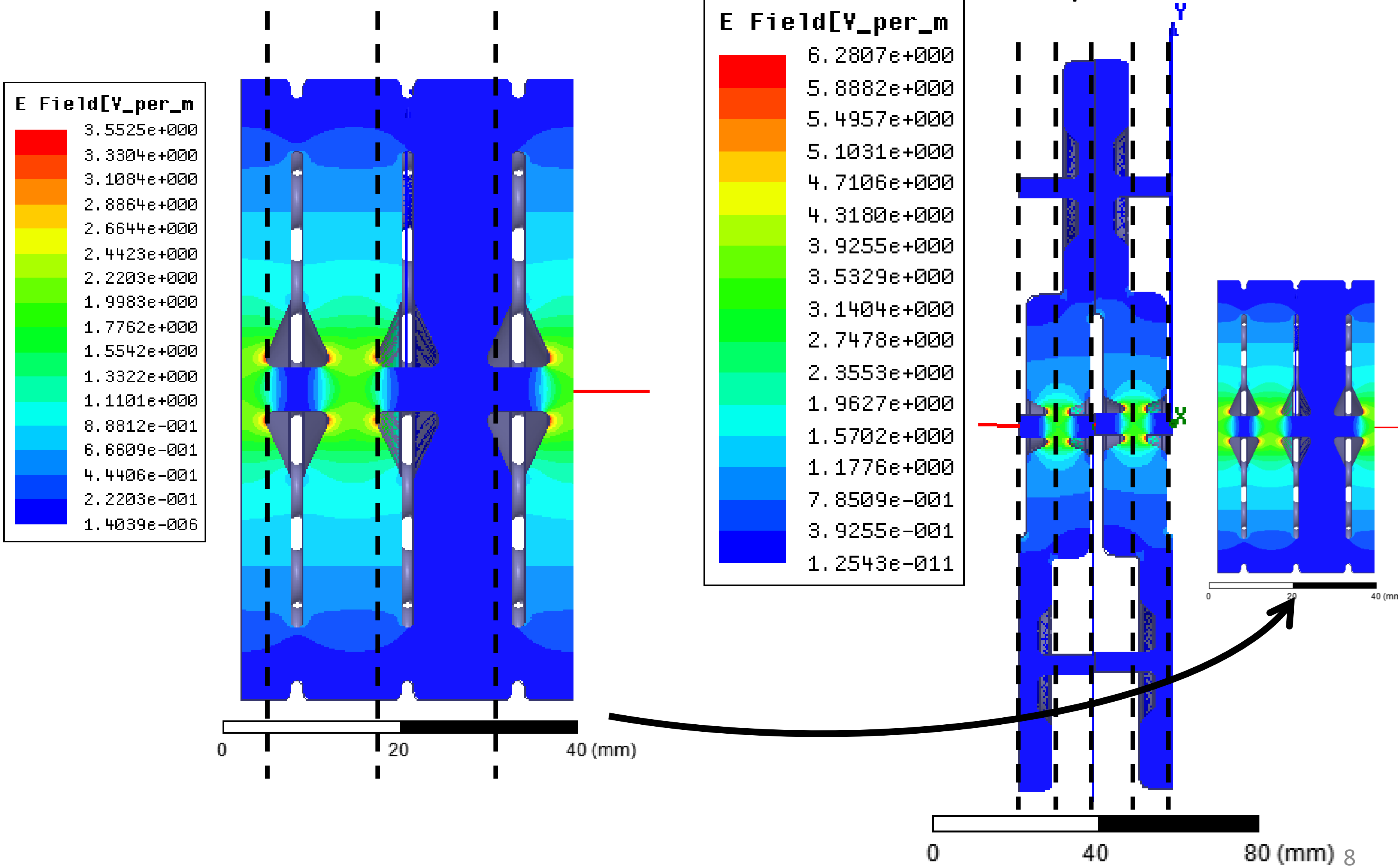




Comparison of E-field in TW and SW

2/3 π phase advance

π/2 phase advance

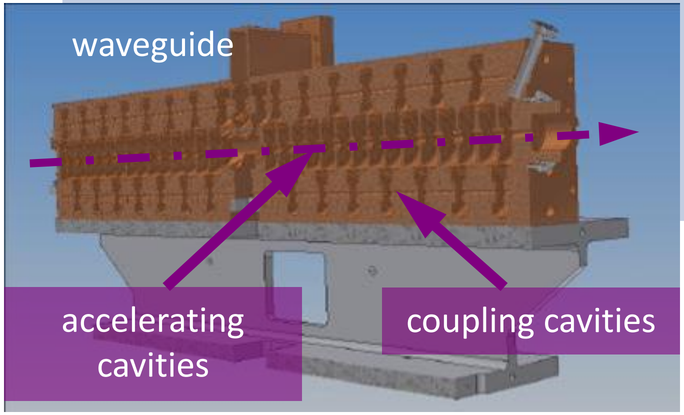


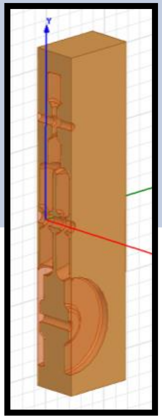
PROs and CONs
of bTW compared to standard SCL design

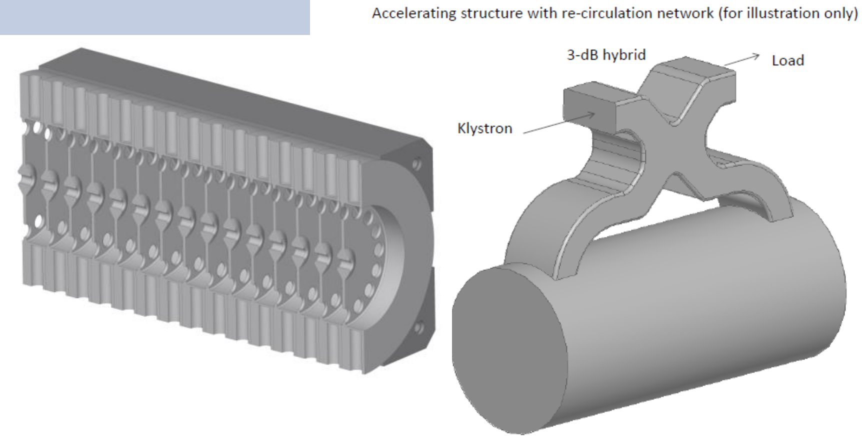
+ simpler mechanically
+ less material and brazing needed (lower number of cells)
+ tuning is easier for TW
+ shorter filling time
+ no bridge couplers

- small wall thickness
- material properties change during brazing
- Dissipated power is higher (half power goes to the load)

→ **Recirculation loop** (power for TW 10-20% higher than SW)

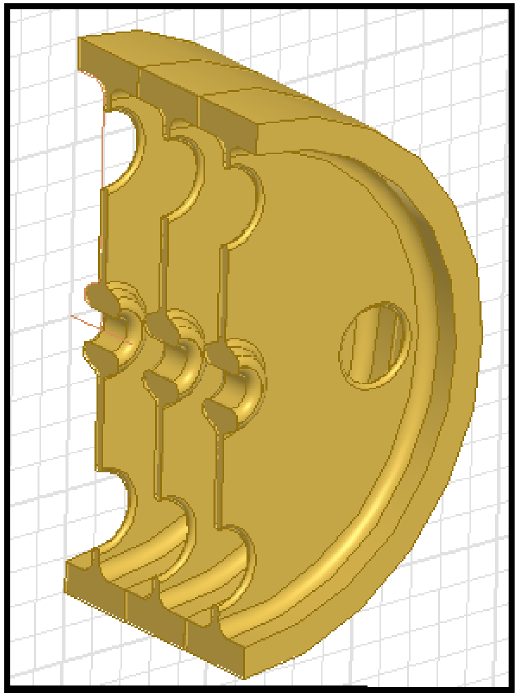






NOVEL DESIGN FOR HIGH GRADIENT OPERATION

Proposal for bTW design for hadrontherapy



Proposed by A. Grudiev

DESIGN GOAL and CONSTRAINTS

$$E_a := E_0 T \geq 50 \text{ MV/m}$$

$$S_c / E_a^2 < 7\ 10^{-4} \text{ A/V}$$

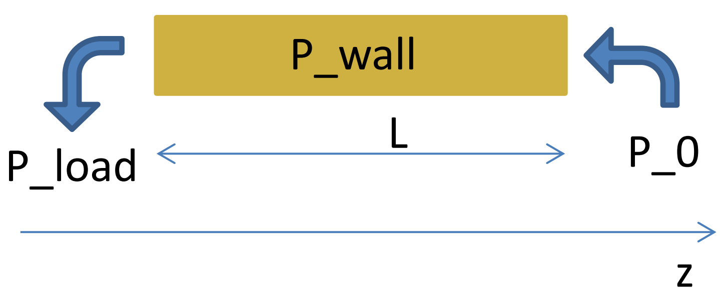
$$\frac{S_c^{15} \cdot t_{pulse}^{5}}{BDR} = const.$$

with: $S_c < 4$ **MW/mm²**

t_{TERA} **= 2500 ns**

t_{CLIC} **= 200 ns**

$BDR_{TERA} = BDR_{CLIC} = 10^{-6}$ **bpp/m**



vg_in ~ 0.4% c

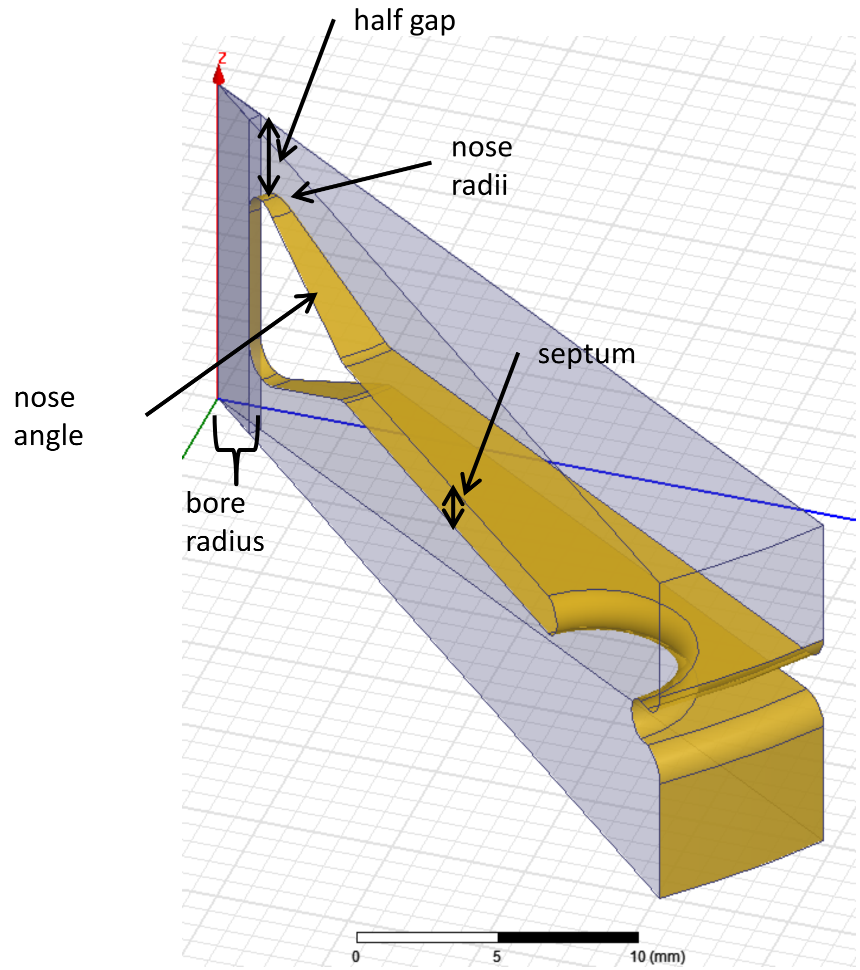
vg_out ~ 0.2% c

filling time ~ 0.3 μs

Nose geometry optimization

- Scan on:
  - Nose cone angle
  - Gap
  - Nose cone radius(*)
  - Phase advance (120°-150°)
  - coupling hole radius

    (vg = 4 ‰ and 2 ‰)

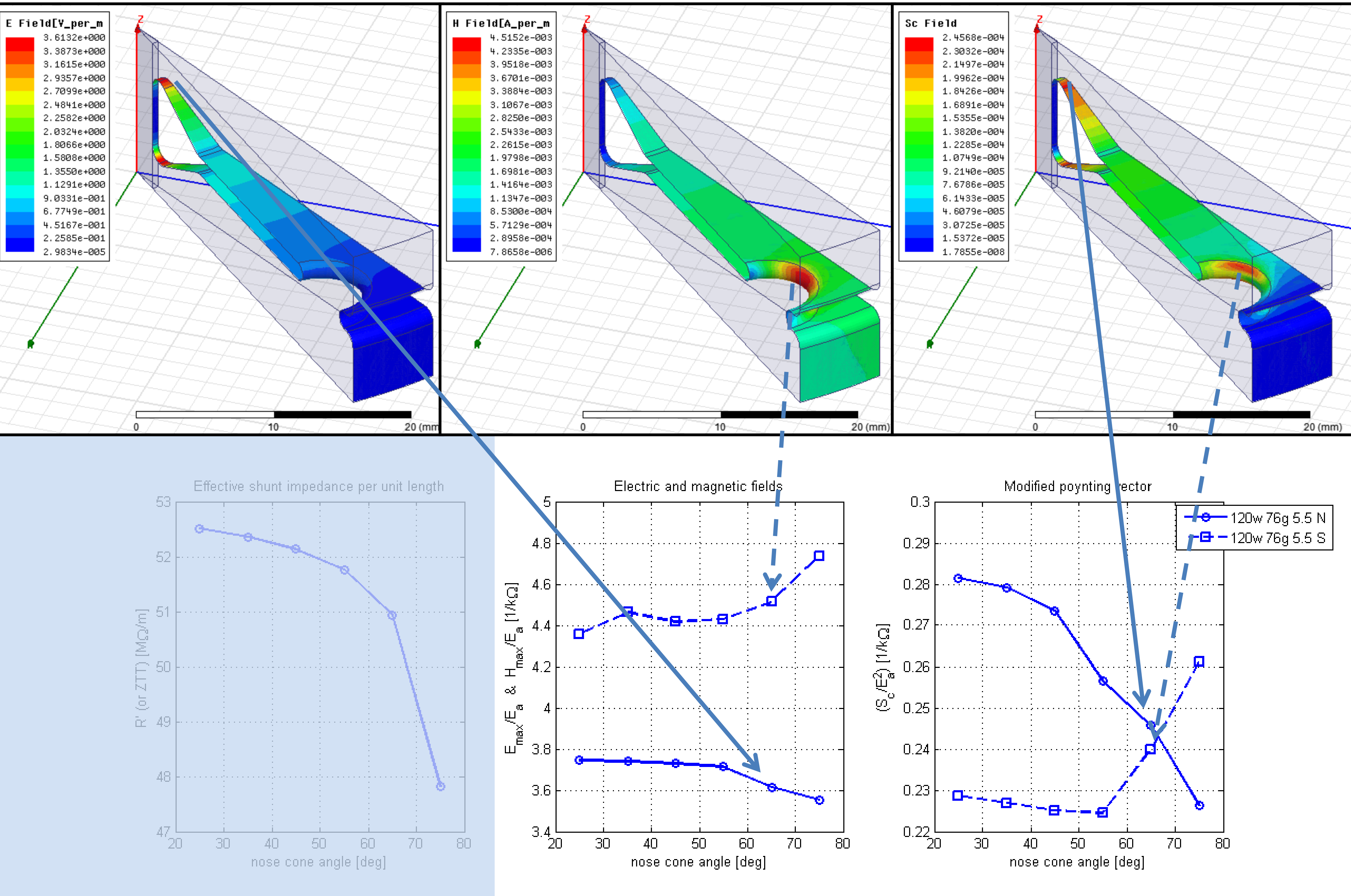


- **Optima:**
  - **Minimum of the quantity:**

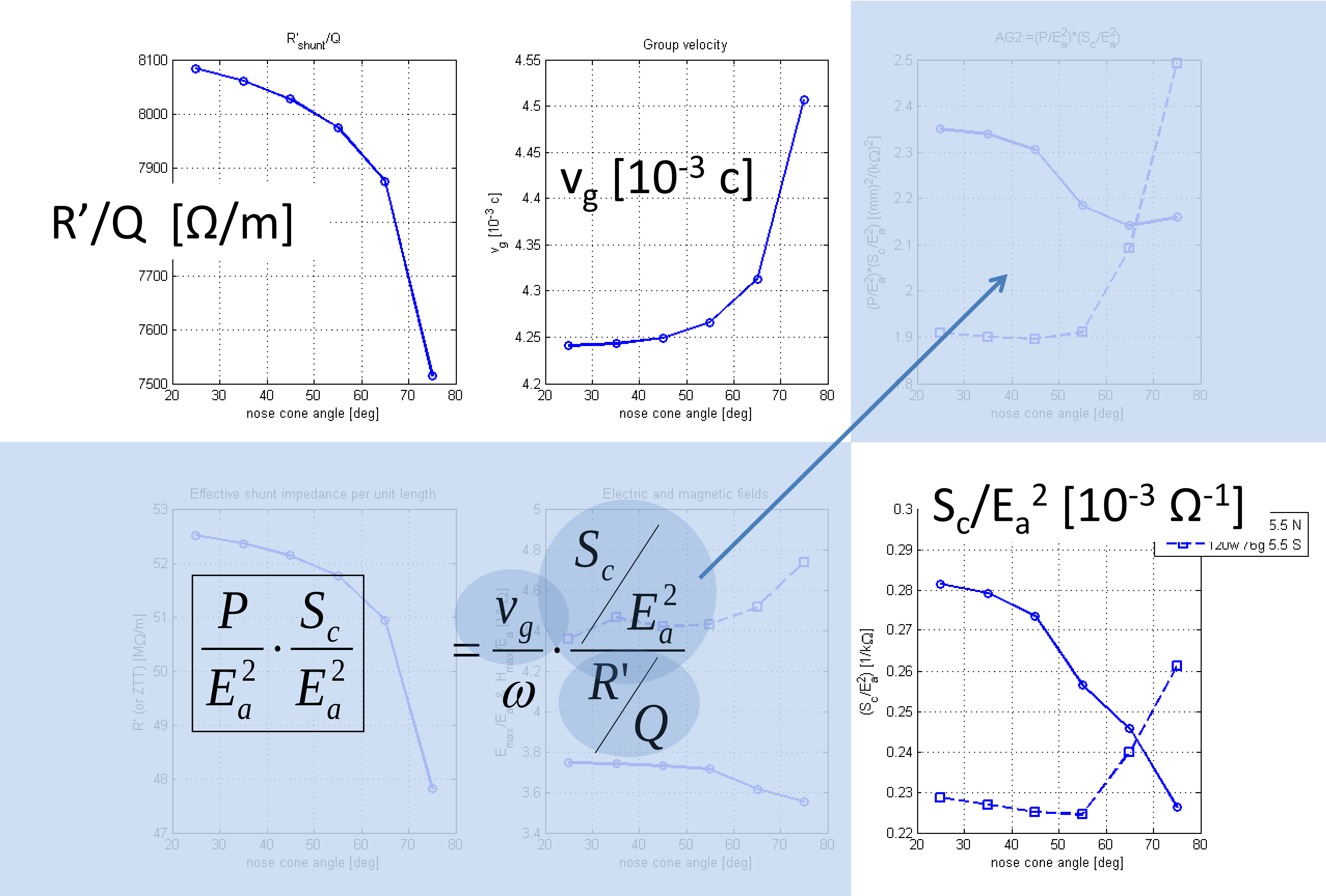
$$\boxed{\frac{P}{E_a^2}\cdot\frac{S_c}{E_a^2}} = \frac{v_g}{\omega}\cdot\frac{S_c / E_a^2}{R' / Q}$$

* based also on results of the SCL optimization

Optimization plots - fields

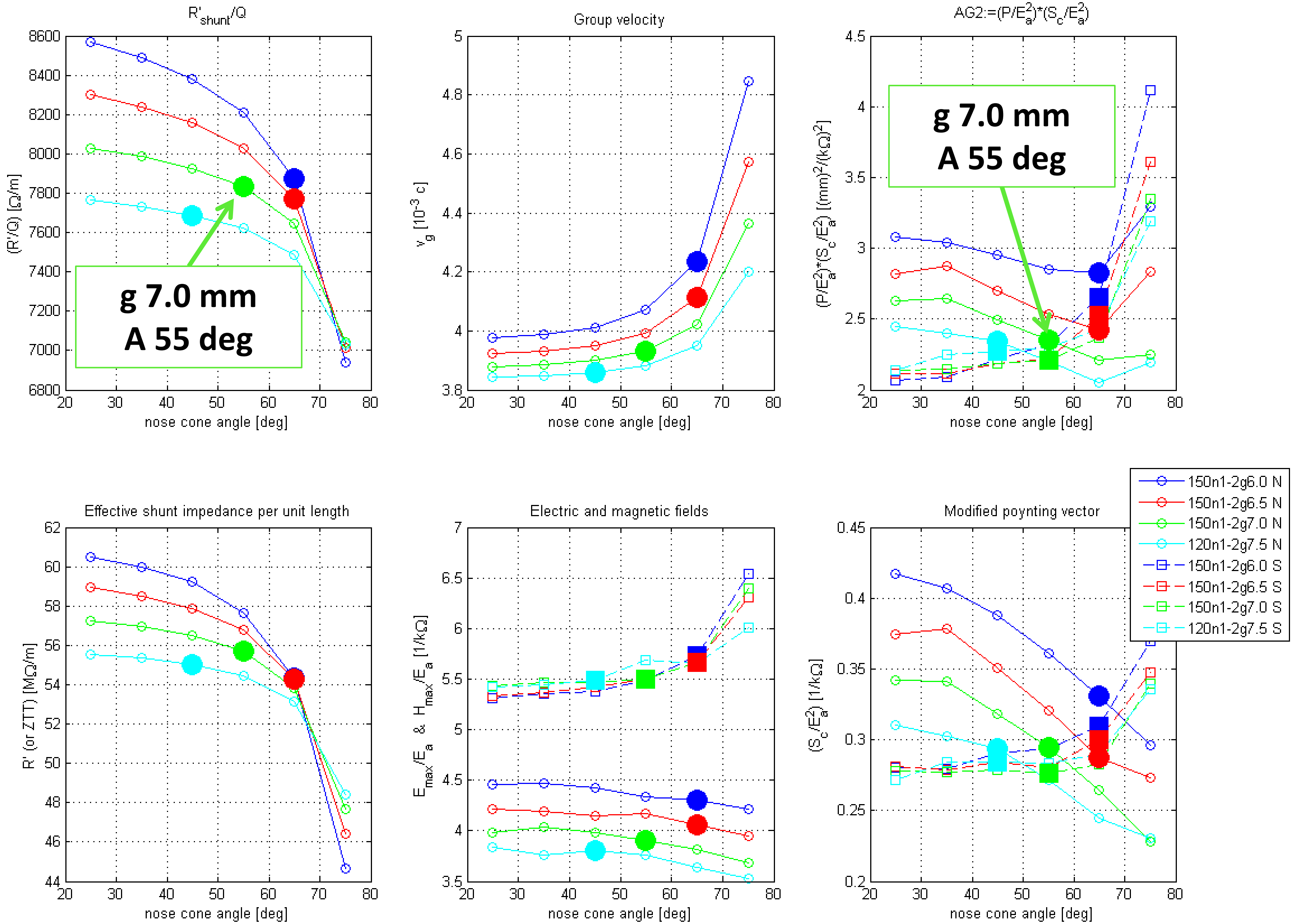


Optimization plots

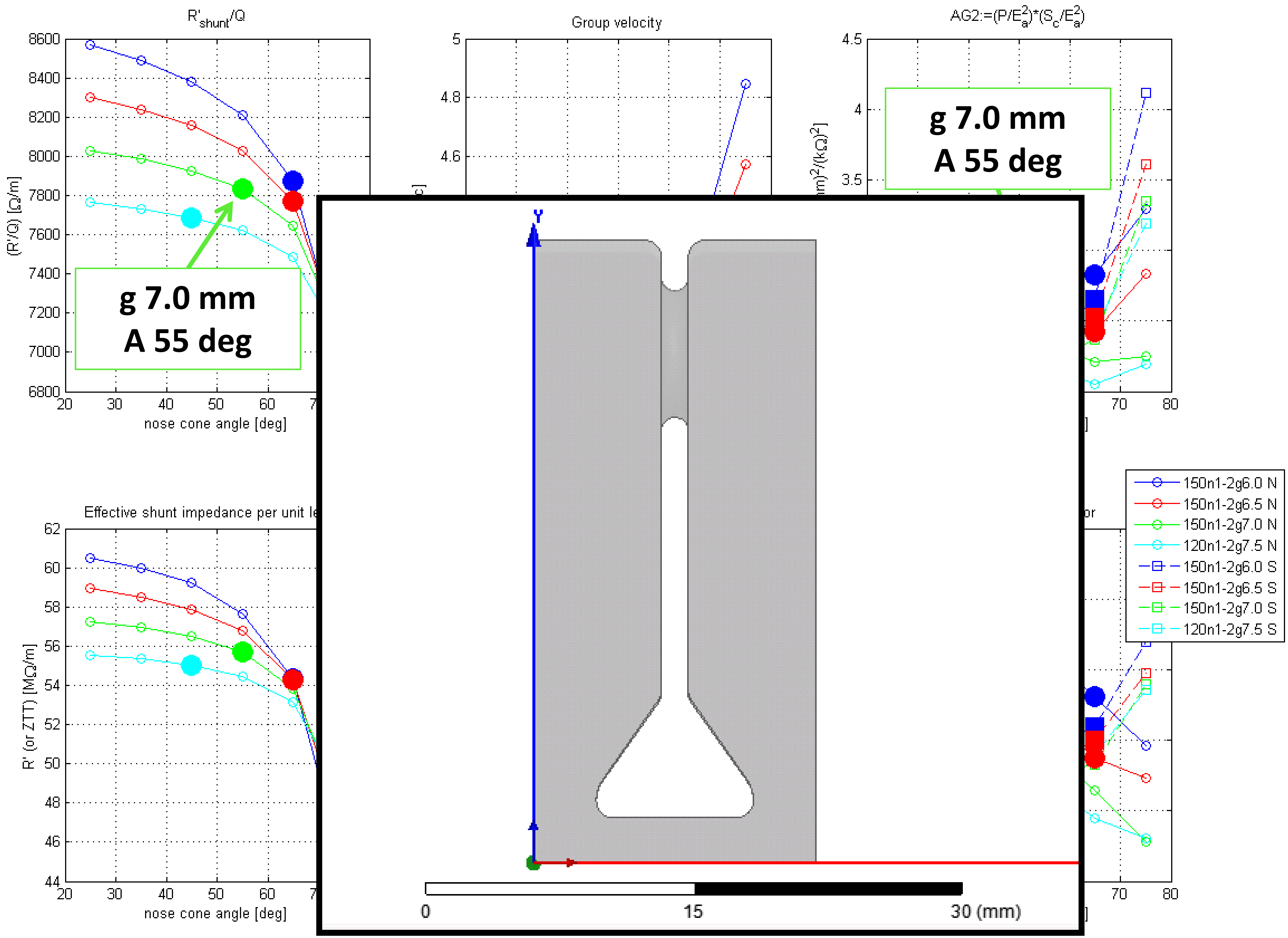


$$\frac{P}{E_a^2}\cdot\frac{S_c}{E_a^2} = \frac{v_g}{\omega}\cdot\frac{S_c/E_a^2}{R'/Q}$$

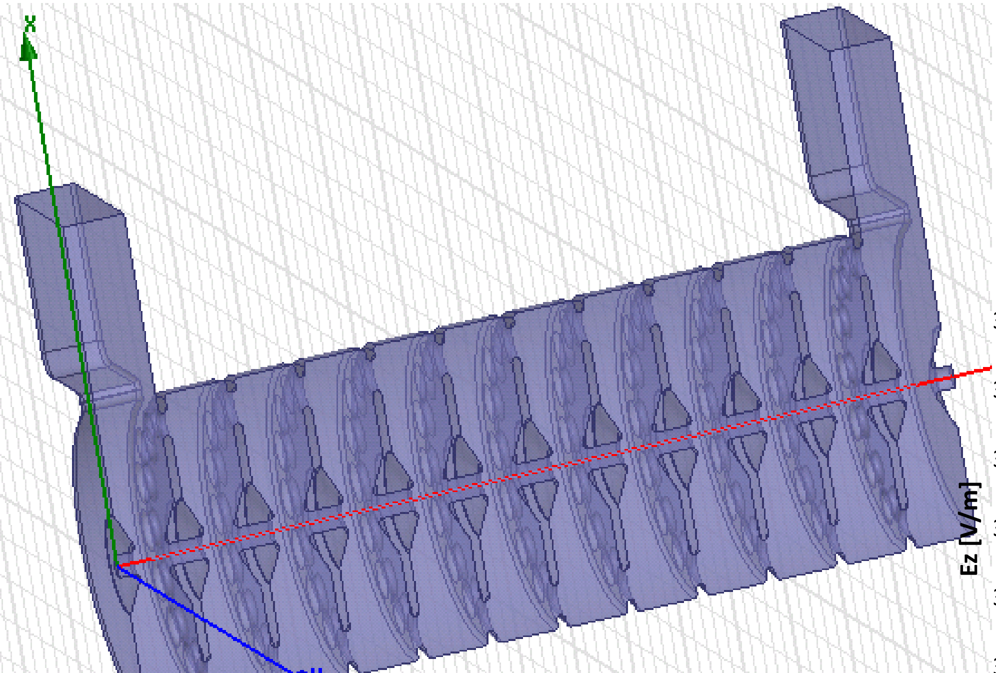
150° - 16 holes – nose 1 -2 mm – gap and angle scan



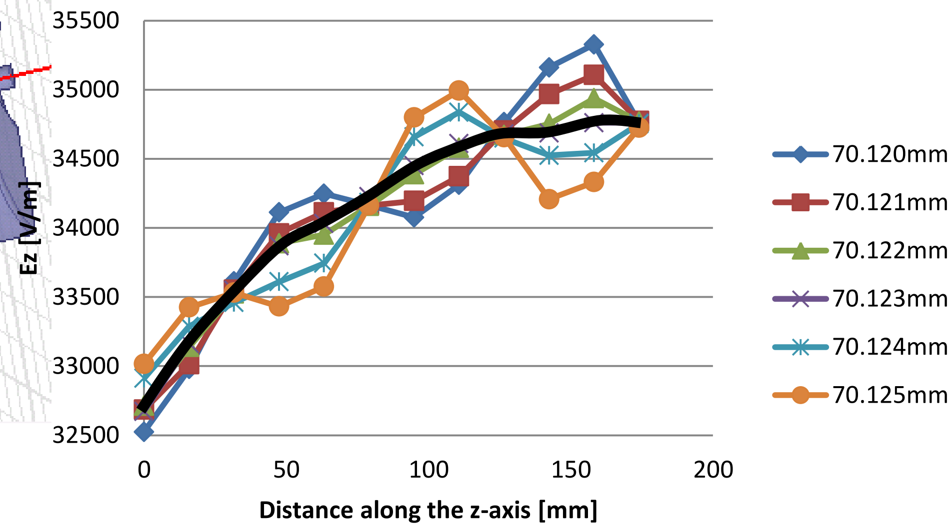
150° - 16 holes – nose 1 -2 mm – gap and angle scan

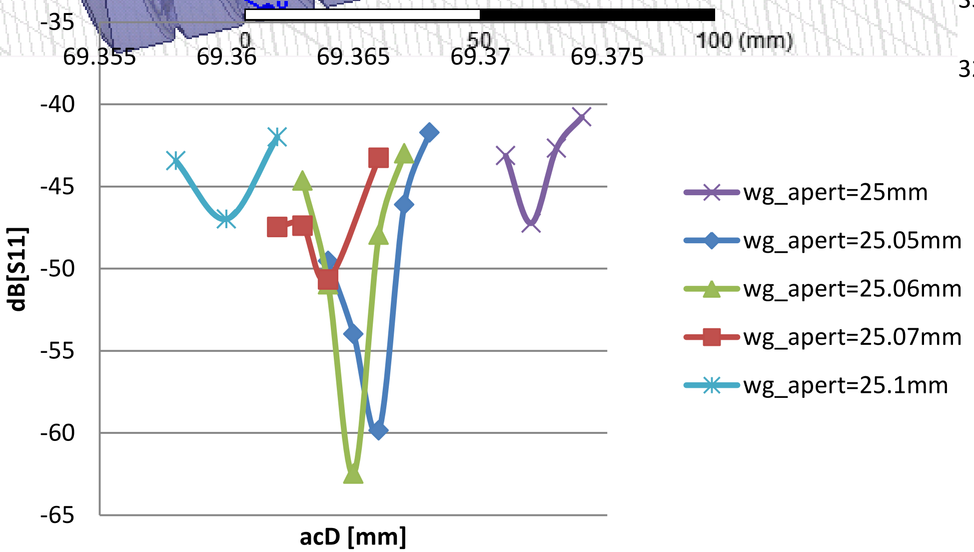


Tank optimization



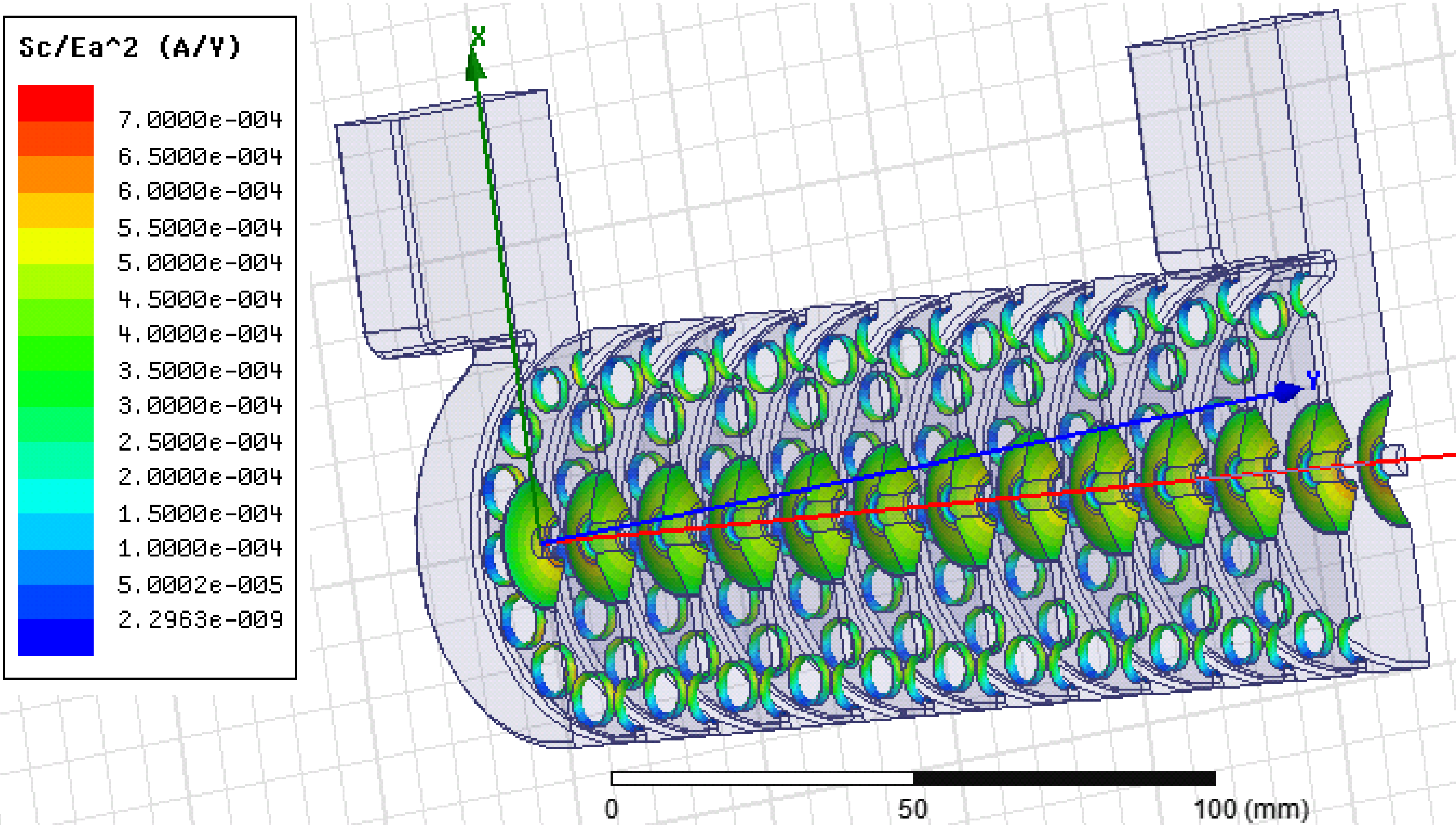
1. Minimization of the SW pattern by adjusting the out-coupler





2. Final optimization of the in-coupler to get the final design of the tank

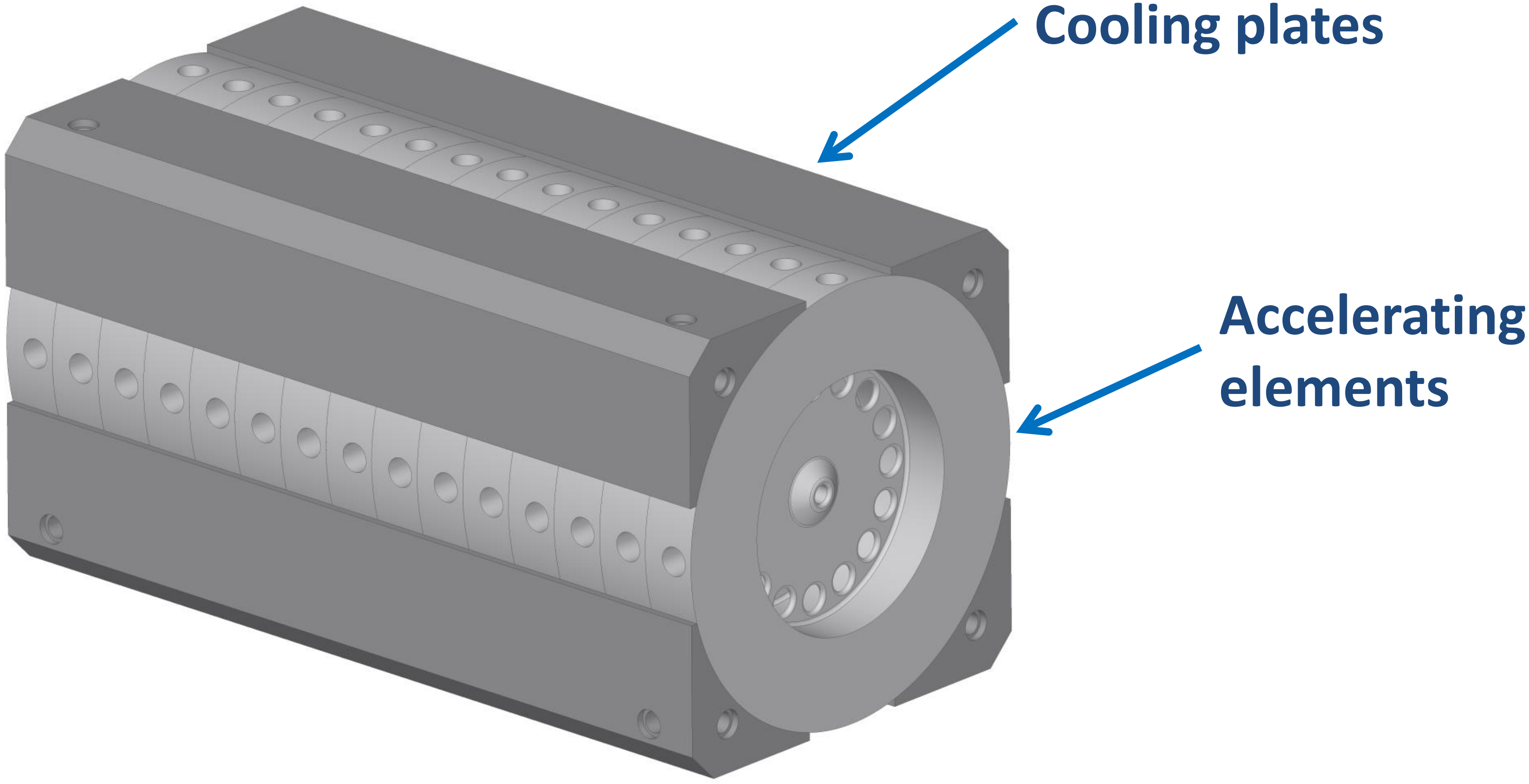
RF design of the full structure is done



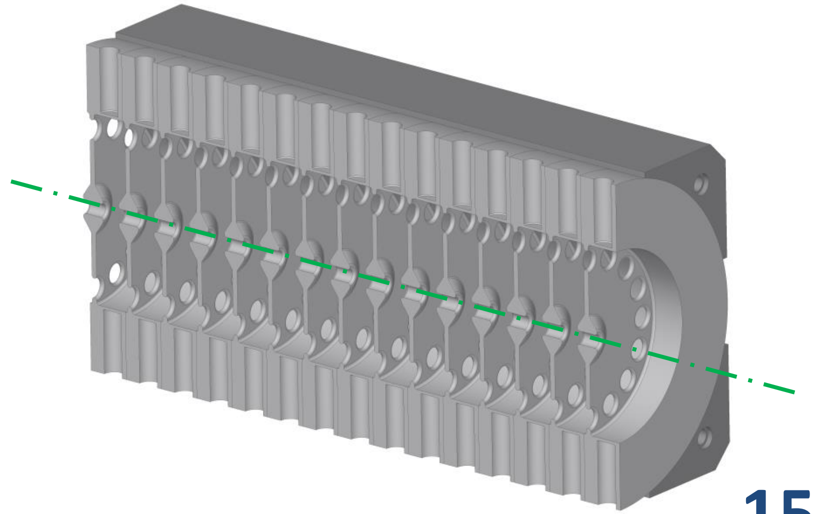
The Sc/Ea^2 < 7e-4 A/V constraint is respected

ENGENERING DESIGN

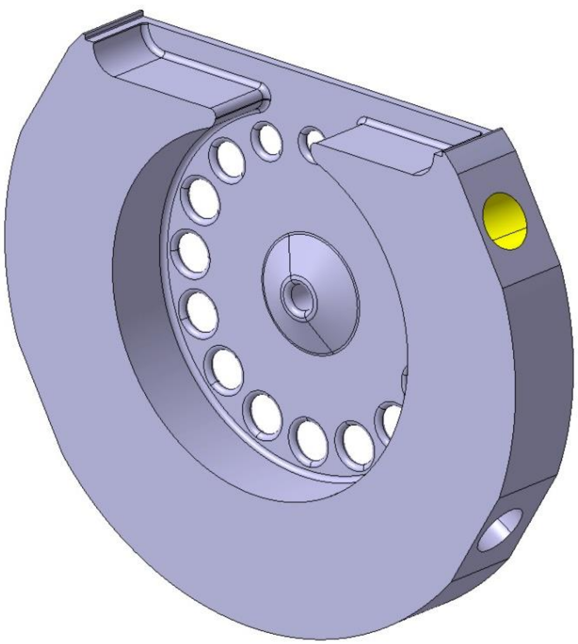
Backward travelling wave accelerating structure



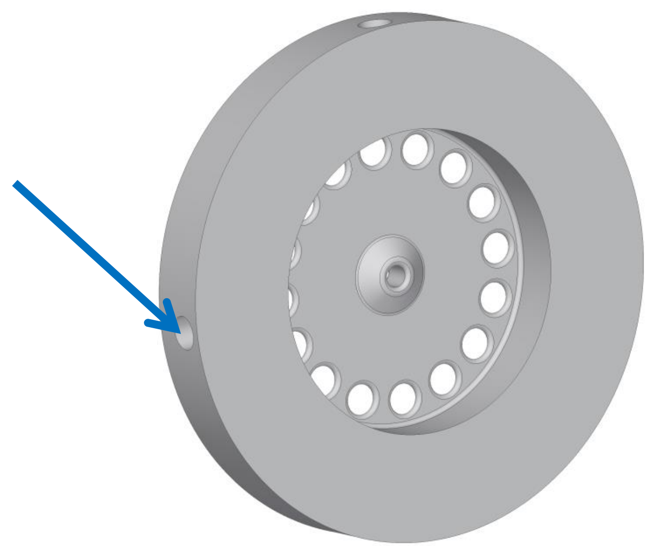
Accelerating structure



150° of phase advance

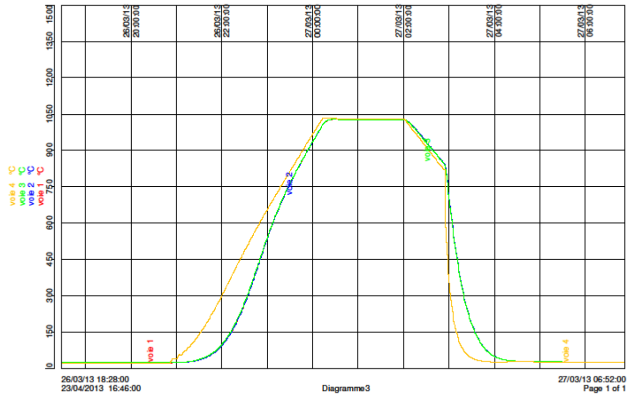


4 holes for dimpler tuners

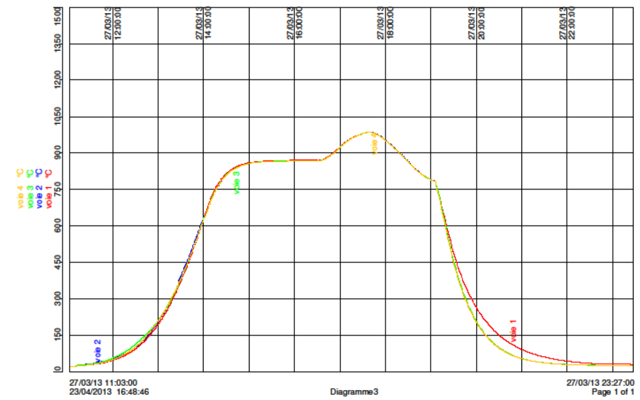


Joining procedures

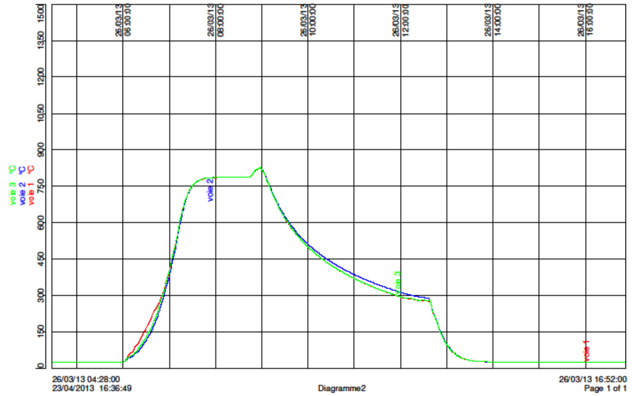
Hydrogen Bonding: T_{HB}=1050 °C



Gold Brazing: T_{GB}=950 °C



Silver Brazing: T_{SB}=820 °C



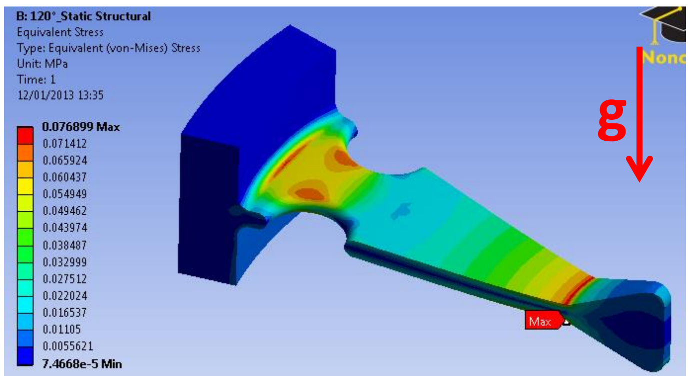
OFE Copper melting point

1083 °C

CREEP?

Evaluation of different cells structural performance

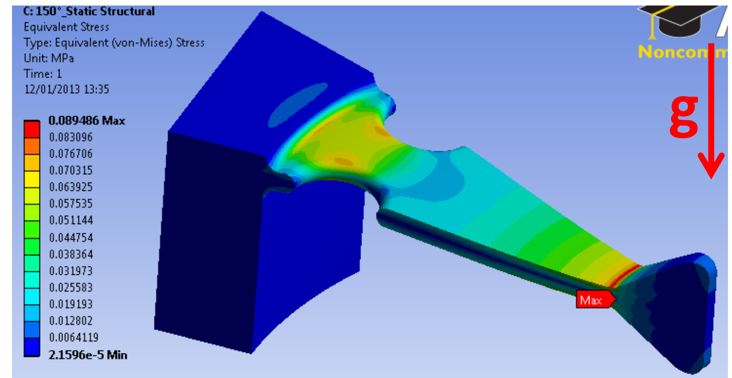
120° of phase advance



$$\sigma_{max} = 0.077\ [MPa]$$
$$f_{max} = 8.9 \cdot 10^{-5}\ [mm]$$

Load: gravitational force

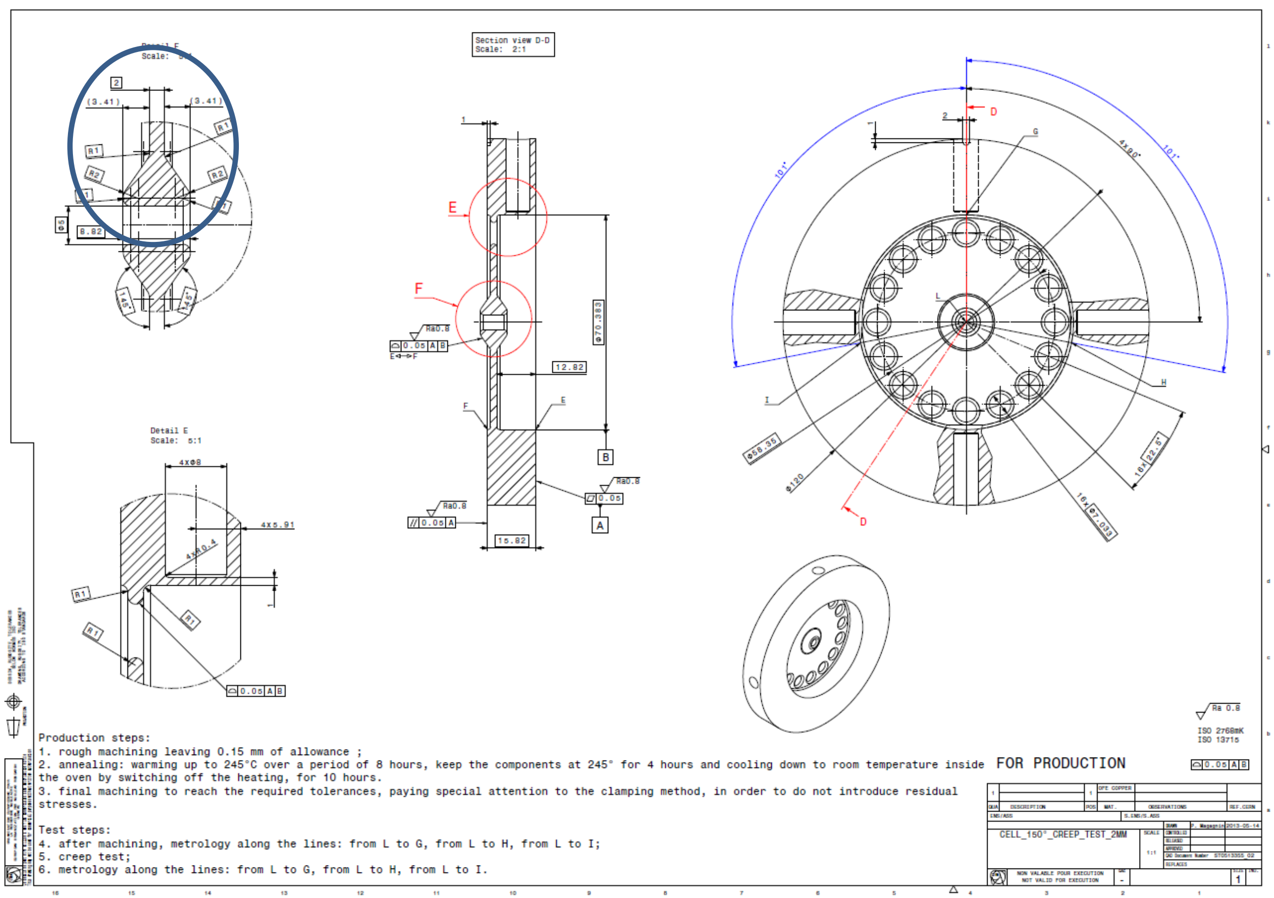
150° of phase advance



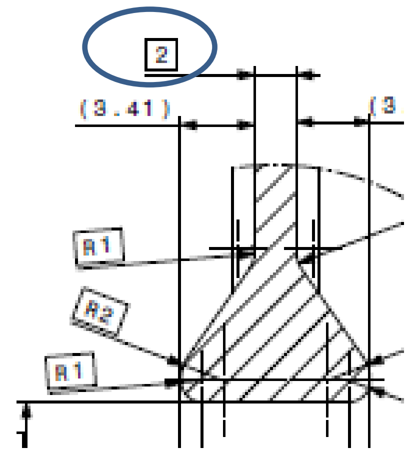
$$\sigma_{max} = 0.090\ [MPa]$$
$$f_{max} = 9.1 \cdot 10^{-5}\ [mm]$$

Creep tests

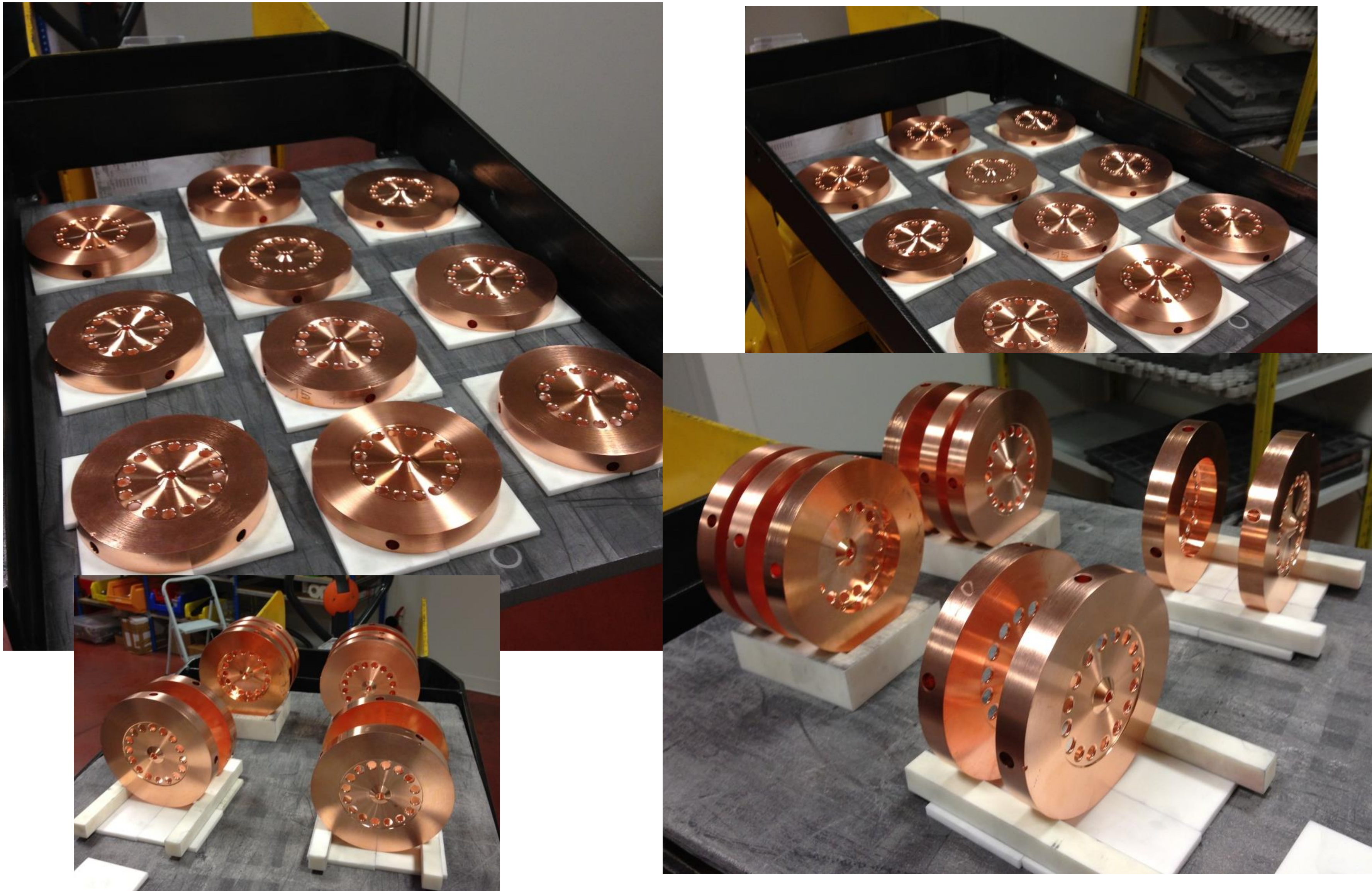
20 discs, to be tested at the 3 temperatures, in order to simulate vertical and horizontal bonding/brazing.



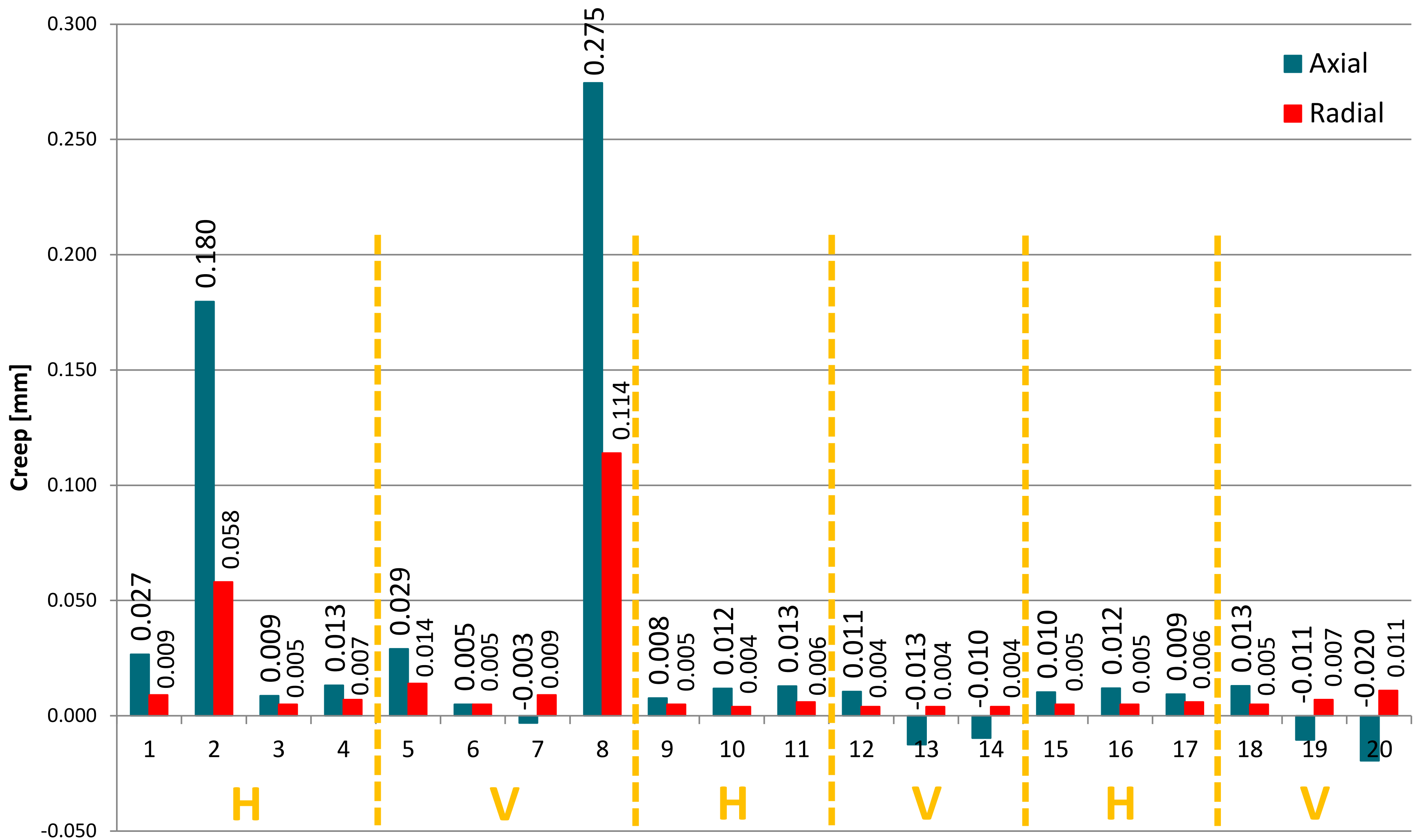
S = 2 mm



Thermal Test at Bodycote



Creep Results in general - Summary



Average Axial: 13 µm ; Average Radial: 6 µm

(without cells 2 and 8)

Summary

- **Optimization** of TW structures for high gradient operations has been performed **for 120° and 150° phase advance**.
- **150° phase advance has been chosen**
- The **RF design of the input and output coupler** is finished.
- **Creep tests have been performed to validate H-bonding at 1050 ° C**
- The **Engenering design including thermo-mechnical simulation** is progressing well
- **The design and test of the novel bTW structures is boosting the TULIP project!**

High-Gradient RF Test Stand plans at IFIC

IFIC-IFIMED, Valencia

CLIC Workshop 2014
3-7 February 2013

GAP

A. Faus-Golfe on behalf of
IFIC, GAP (Group of Accelerator Physics)
http://gap.ific.uv.es
Valencia, Spain

IFIC
INSTITUT DE FÍSICA CORPUSCULAR

IFIMED

Framework

►**The IFIMED**: Research on Imaging and Accelerators applied to Medicine. As an R&D Institute on Medical Physics it is configured through two Research Groups:

- **Image Science:** New Imaging devices as Compton combined with Positron Emission (PET) in the context of the ENVISION project, as well as the development and design of the reconstruction algorithms

- **Accelerators:** Linacs for medical applications as cyclinacs (S and C-bands) in the context of PARTNER project in collaboration with TERA and Beam Instrumentation for hadrontherapy

Objectives

IFIMED

►**In the framework of the KT project:** **“High Gradient Accelerating Structures for proton therapy linacs”**, whose scope is the design, construction and high power test of two high-power prototype 3 GHz accelerating structures at 76 MeV (low energy) and 213 MeV (high energy) which corresponds to the to the lowest and highest energy of the proton linac.

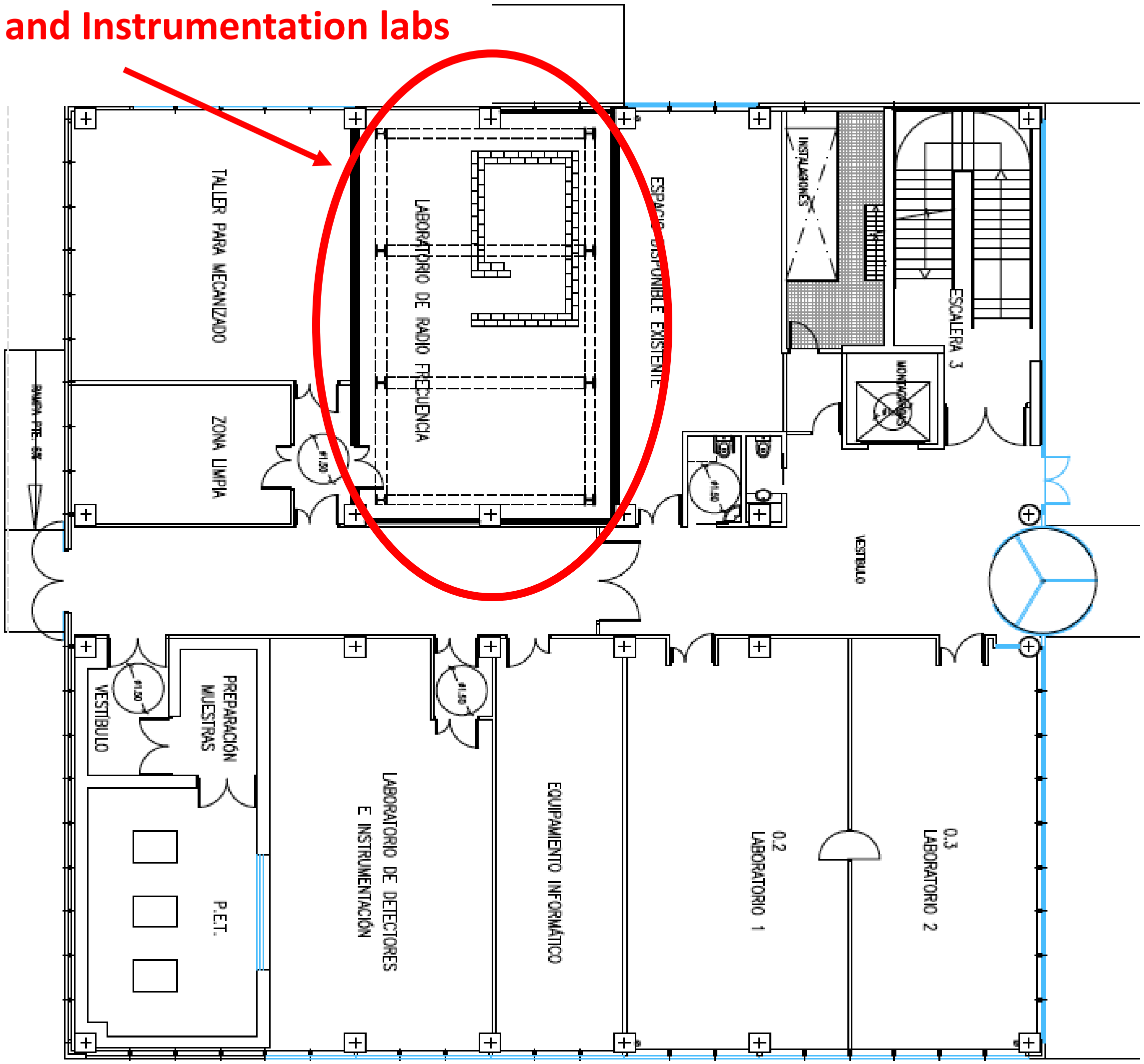
- The idea is to complement these studies with the **design and test of two intermediate** (2nd and 3rd) proton linac structures. This complementary study will give us the possibility to simulate the most realistic conditions and running operation conditions of this kind of linacs.

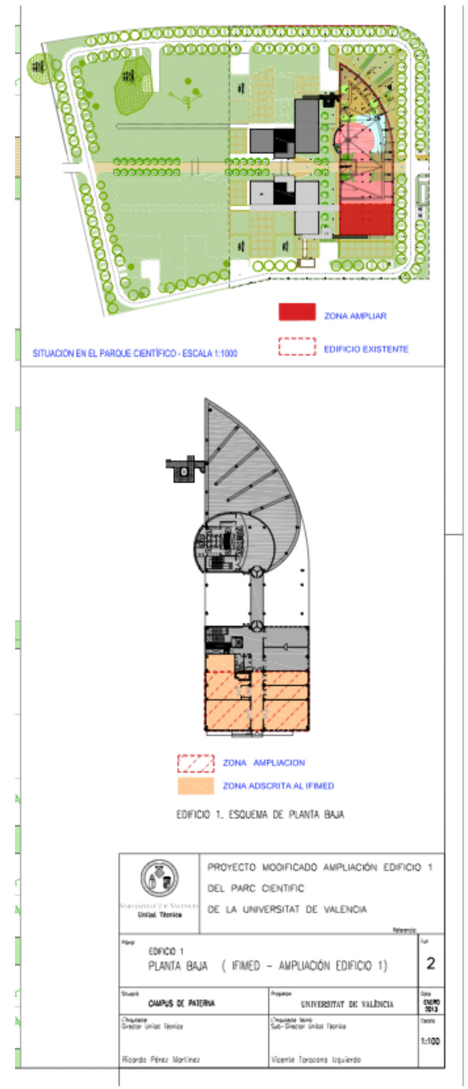
- Test stand with **two klystrons** (3GHz have 7.5 MW power each, 5 ms RF pulse duration and 400 Hz), the RF system becomes much more flexible allowing arbitrary phase and amplitude pulse shapes even when using a pulse compressor.

Location

IFIMED R&D labs integrated in the Scientific Park of the UV

RF and Instrumentation labs





BACK-UP slides

SUMMARY	120 deg		150 deg		SCL base	SCL – HG
wall thickness (mm)	1.5		1.5		3.0	3.0
gap (mm)	5.5		7.0		5.1	9.5
nose cone angle (deg)	65		55		25	55
length (mm)	189.9		189.9		189.9	189.9
ncell	15		12		10	10
Ea_avg (MV/m)	25		25		25	25
Sc_nose (MW/mm2)	0.149		0.185		0.486	0.188
t_pulse (ns) flat	2500		2500		2500	2500
expected BDR (at given Ea and t_pulse) (bpp/m) based on Sc limit	1.1 E-22		2.9 E-21		5.7 E-15	3.7 E-21
max Ea (for BDR of 10^{-6} bpp/m) (MV/m)	85.2		76.3		47.1	75.7
Pin (MW) (w/o recirculation)	2.70	5.19	2.49	5.10	1.75	2.26
Pout (MW) (w/o recirculation)	-	2.90	-	3.02	-	-
Q0 (first/last)	6482/6721		7088/7545		8291	8250
vg (first/last) [%c]	0.421/0.226		0.404/0.236		-	-
R'/Q (first/last) [Ohm/m]	7872/7847		7835/7794		8406	6355
time constant (ns)	320		340		440	440
field rise time (time to reach 99% field) (ns) (w/o recirculation)	750	204	800	204	1050	1050