Gun 5 cavity -physics design review for X-FEL specification.

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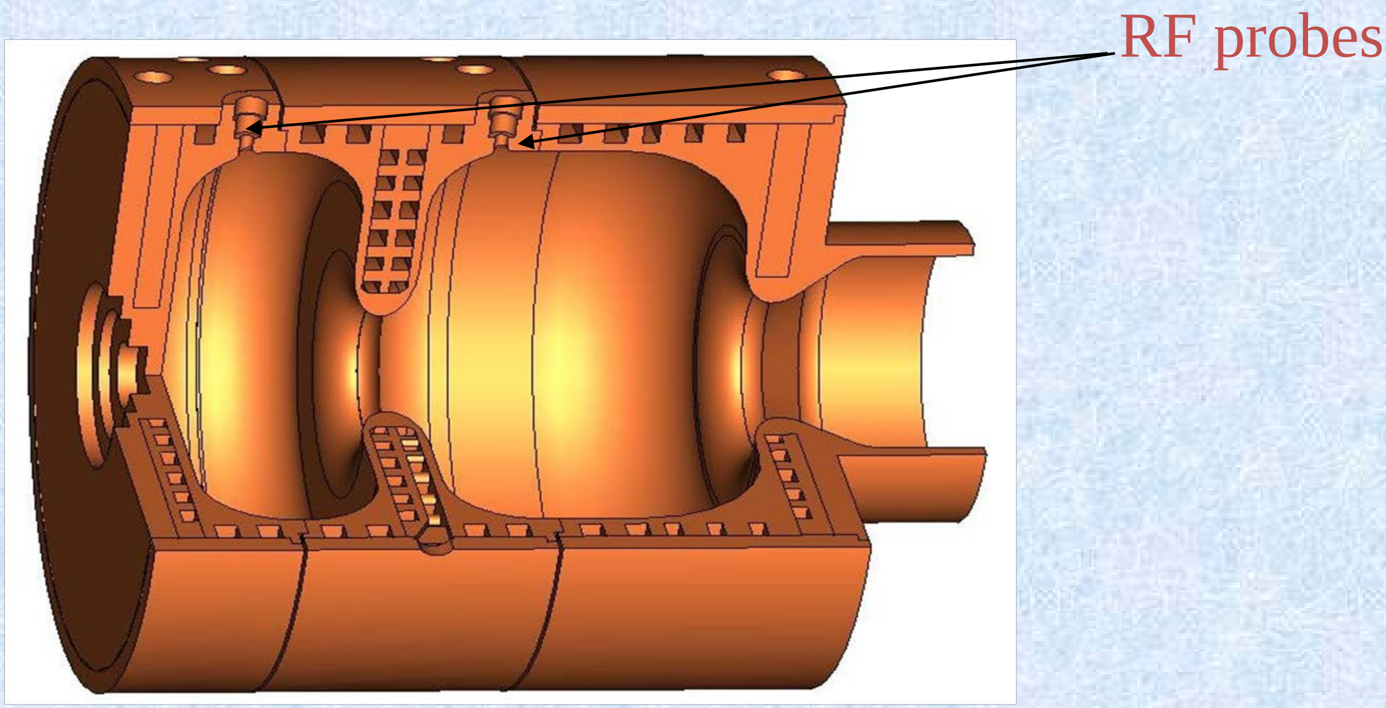
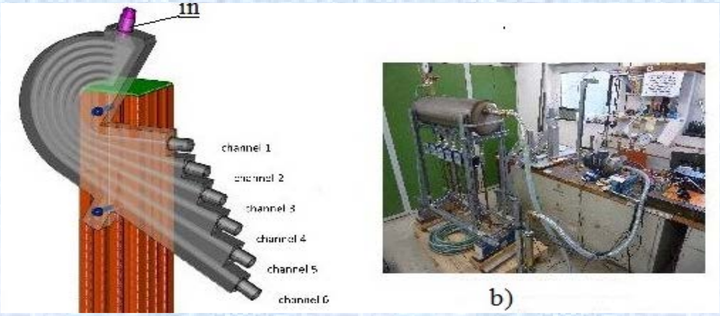
9. **Summary.**

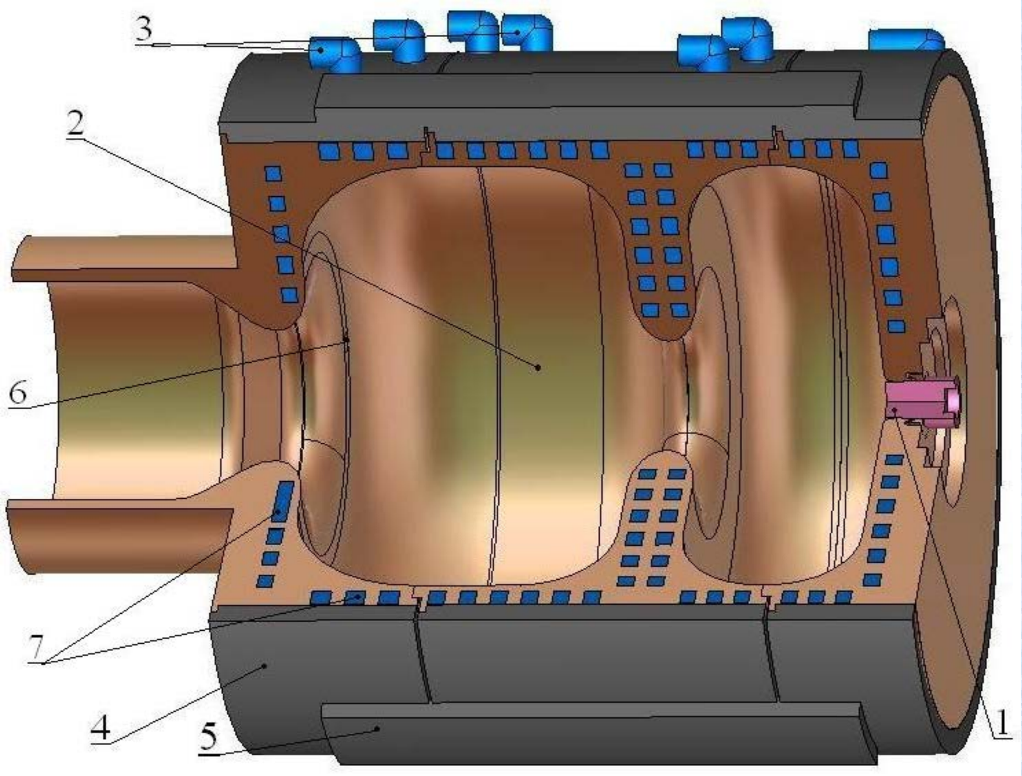
The Gun 5 cavity was developed as the continuation in the line of DESY L-band Gun cavities, basing on proven technology, experience of previous Gun cavities and involving some additional elements and new proposals, such as RF probes in cavity cells, optimized RF shape and improved cooling circuit.



The key point in the improved cooling circuit is in internal flow distribution between small and more effective channels.

Since initial proposal the key points for flow distributions were tested in experiments

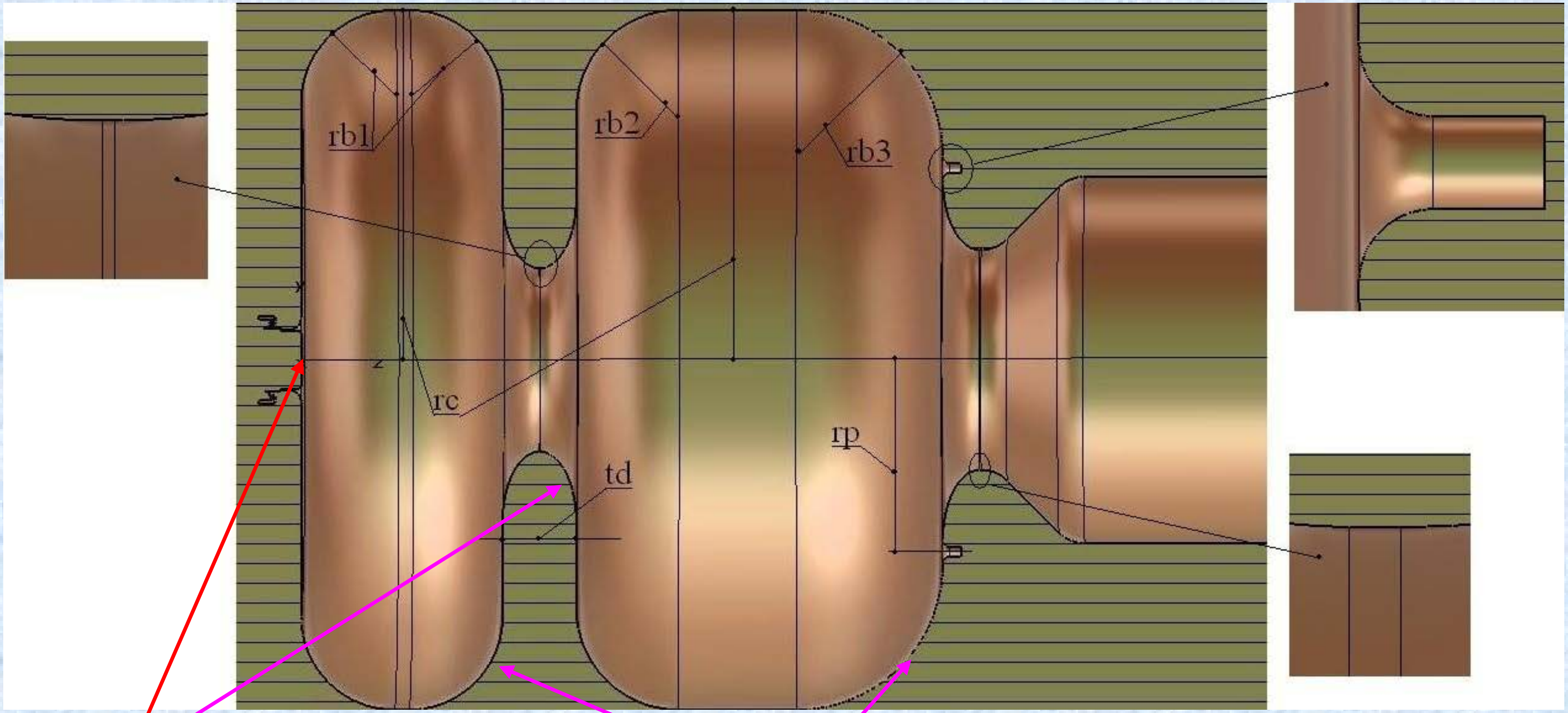




1. Cathode;
2. Cavity body, Cu;
3. Input/output, cooling water;
4. SS jacket;
5. Stiffening ribs,
6. RF probe;
7.Cooling channels.

Now re-optimized Gun 5 cavity is presented with mutually fitted physical and mechanical design.
This talk is mainly related to physical aspects.

RF parameters.

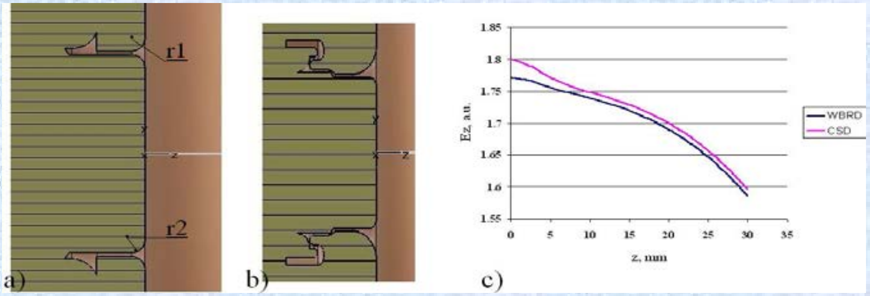


Elliptical shape for iris tip and rounded shape for cells.

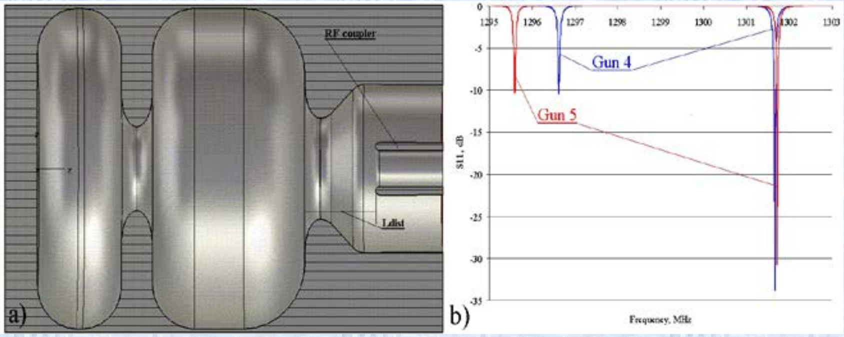
For E_c=60 MV/m – (as compared to Gun 4):

- reduced maximal electric field at the iris surface, $E_{smax}=1.01\ E_c$;
- slightly reduced required RF power,
- improved separations in frequency with 0-mode.

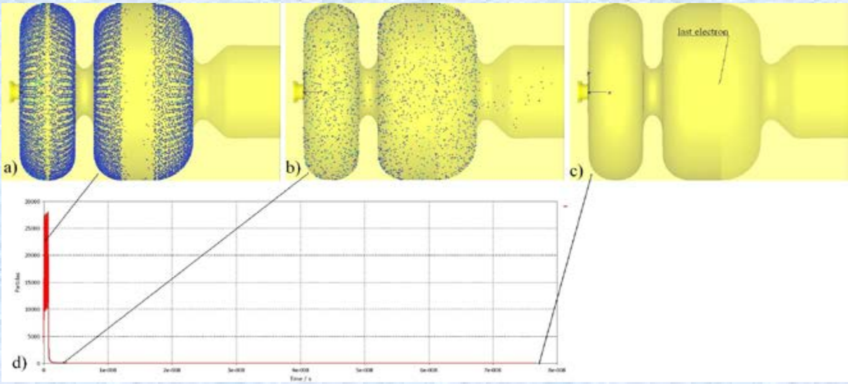
1. Cathode – the same, no difference.



2. RF coupler – the same, shift 1.7 mm.



3. Multipacting – not worse as compared to Gun 4,



…

For another details see, please, our report.

RF probe(s)

For RF phase measurements directly from the cavity. Now it are usual in another Gun"s.

The tight combination of contradictory effects and requirements:

- the field enhancement in the probe hole vicinity;

- pulsed RF heating in the probe hole vicinity;

- possible perturbation of the field distribution with quadrupole addition;

- compatibility with cavity cooling circuit;

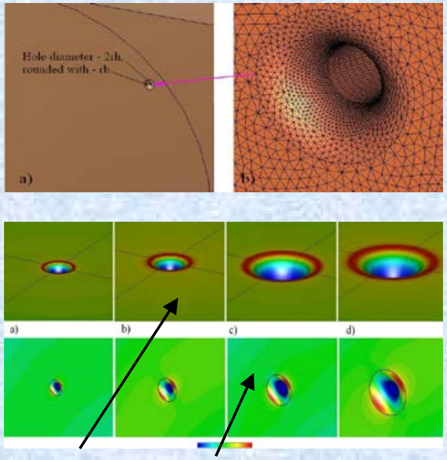
- compatibility with the external equipment of the cavity in photo injector;

- probes matching; - mechanical treatment.

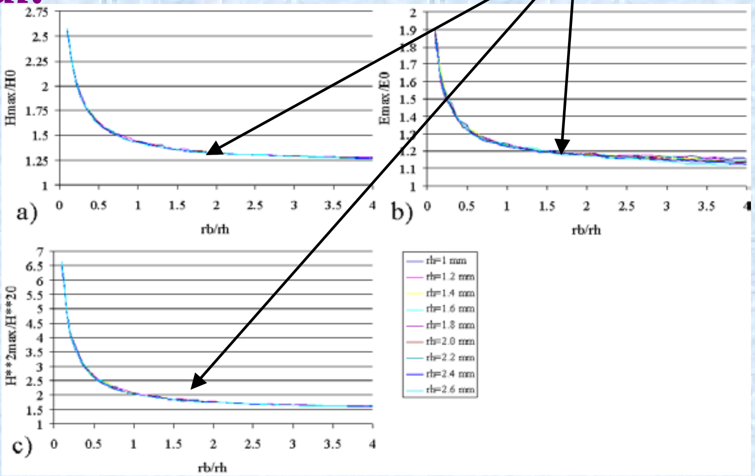
Due to this set of reasons, studied deeply.

Field enhancement – reasonably minimal:

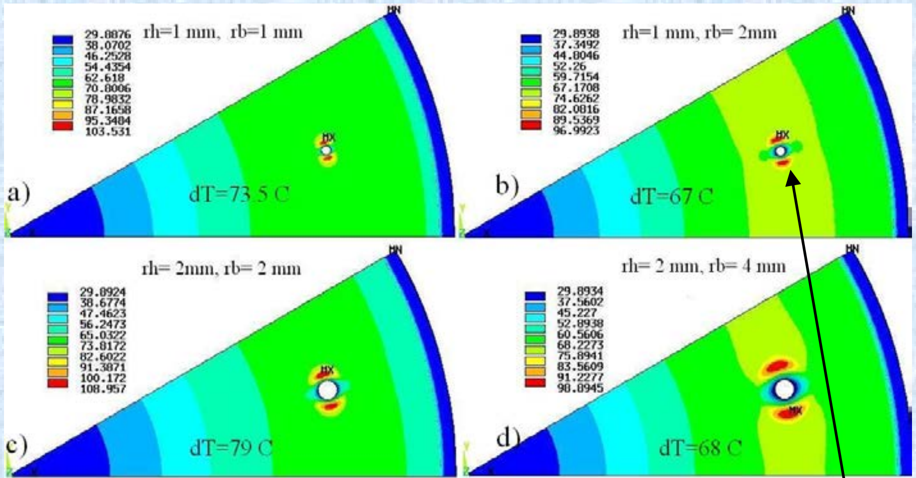
Selection $r_b=1.6r_h$

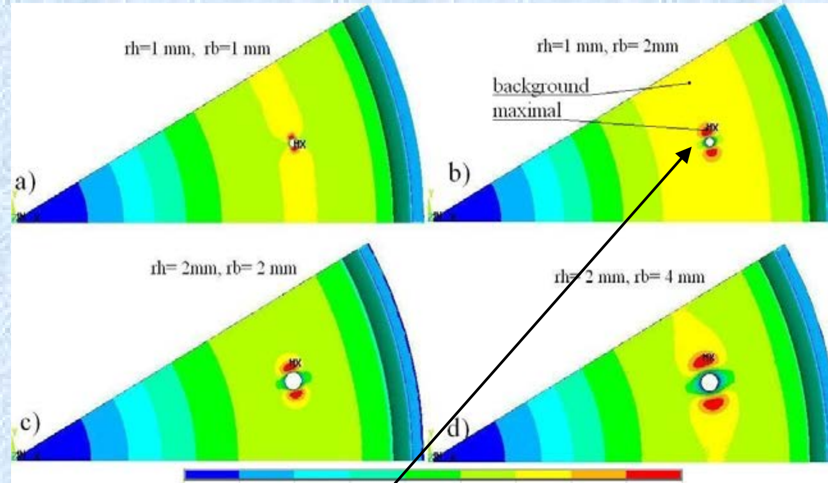


E^2 H^2



Pulsed RF heating.





Temperature

Stress

Field enhancement in the vicinity of RF probe hole.

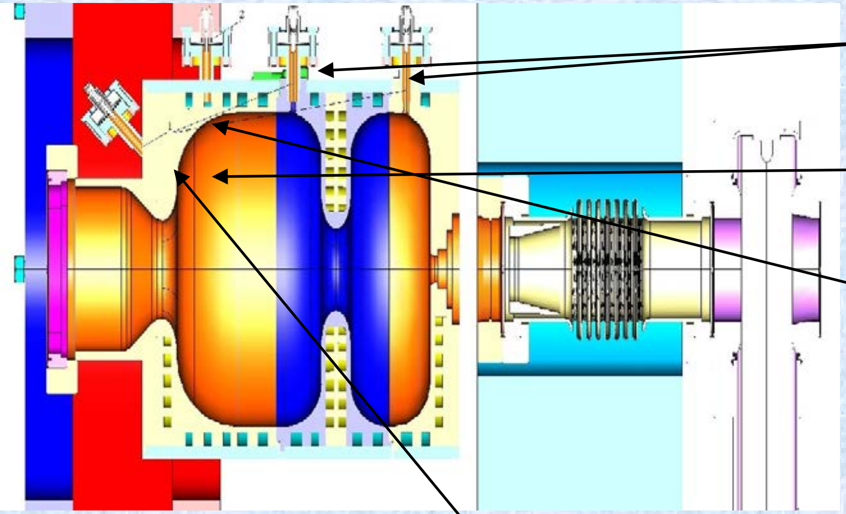
For τ=1 ms RF pulse the heat penetration depth D_h =337 μm,

requirement rb >> D_h,

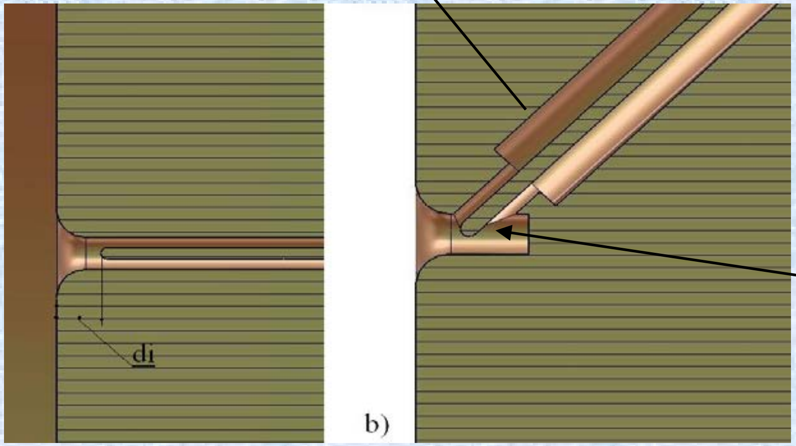
requirement – the probe hole vicinity should be hot spot in the sense of pulsed RF heating as compared to another parts of the cavity.

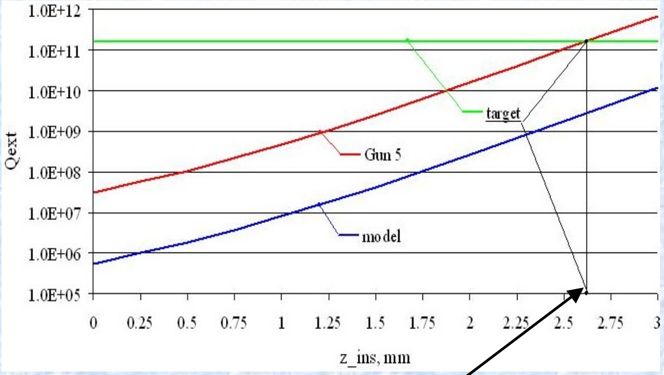
- selection r_h=1,25 mm, r_b=2 mm, closer to

Probe position and matching (in RF tuning).

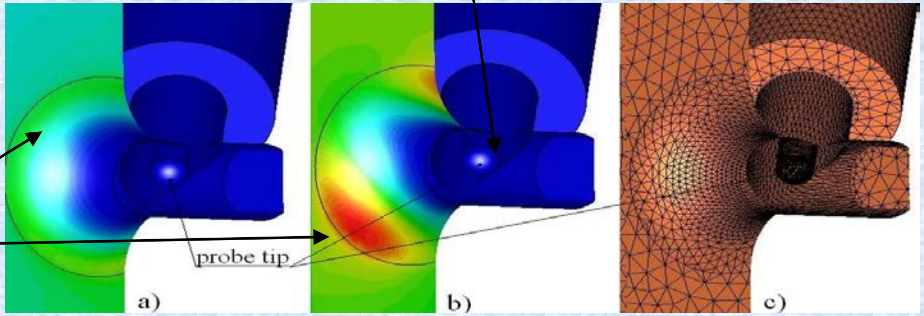


- *possible positions – not good due to high magnetic field;*
- *possible position with a tolerable magnetic field;*
- *not possible position.*





selection

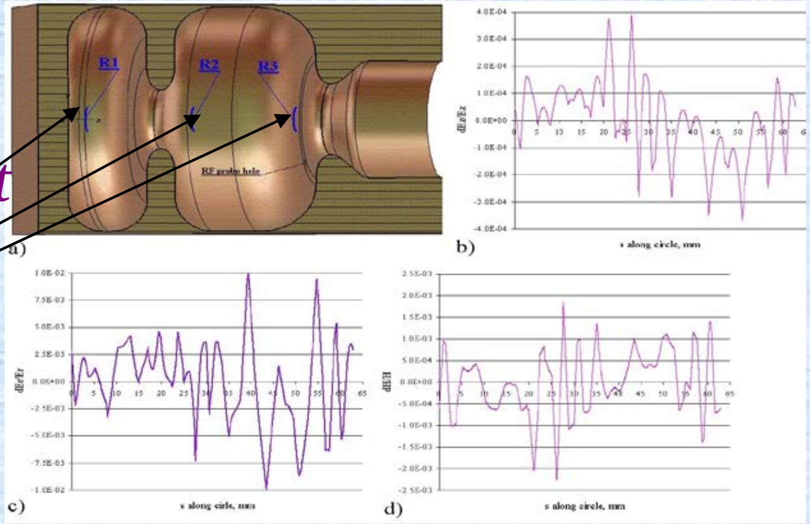


No field at the tip, V=10V, -65 dB.

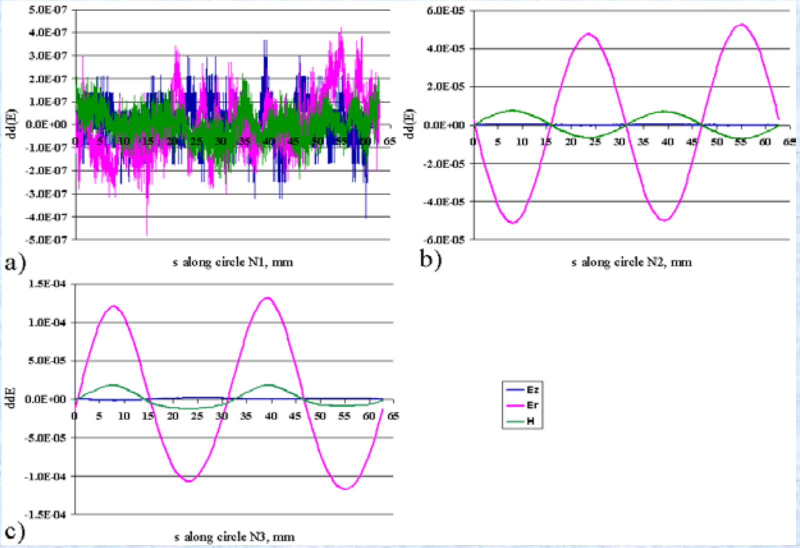
E^2, H^2

Field perturbation.

In ordinary careful simulations we do not see effect of hole at the standard background of numerical noises, ~10^{-3},10^{-2}, rings r=10 mm.



Just in special simulations and noises filtering we can detect the qyadrulope addition in the transverse components at the relative level ~10^{-4}, 10^{-5}.
It is far below the precisions both simulations and measurements both for fields and bunch dynamics.

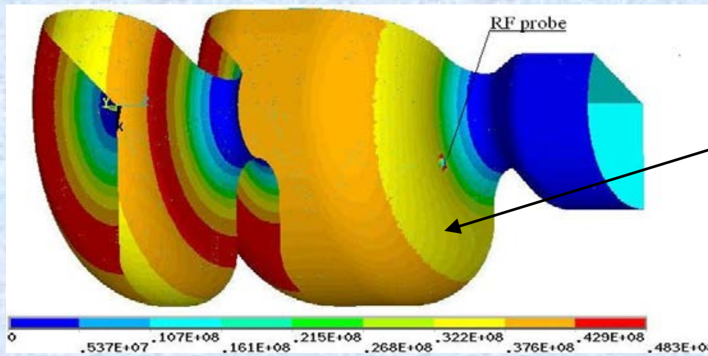


For RF probes in the Gun 5 cavity we propose solution, which is realistic and doesn't deteriorate anther cavity performances.

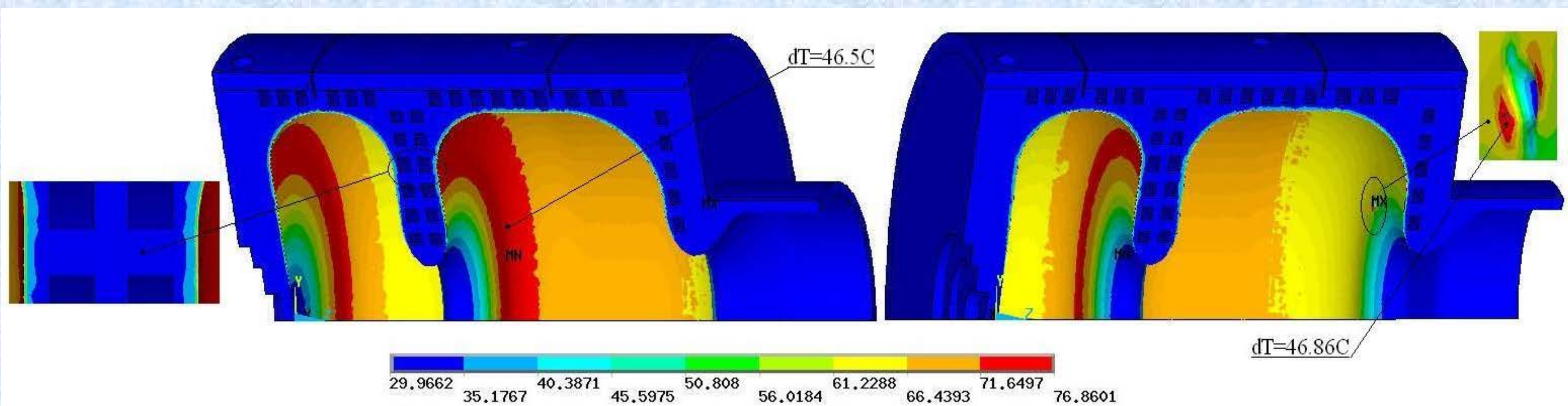
Pulsed RF heating in Gun 5 cavity

Both pulsed RF heating (during RF pulse) and average cavity heating are considered for τ=1 ms, E_c=60 MV/m RF pulse.

Due to practically the same maximal density of RF losses during RF pulse P_d=48 MW/m^2, the maximal temperature rise dT_s at the surface for Gun 4 and Gun 5 are similar.



P_d distribution

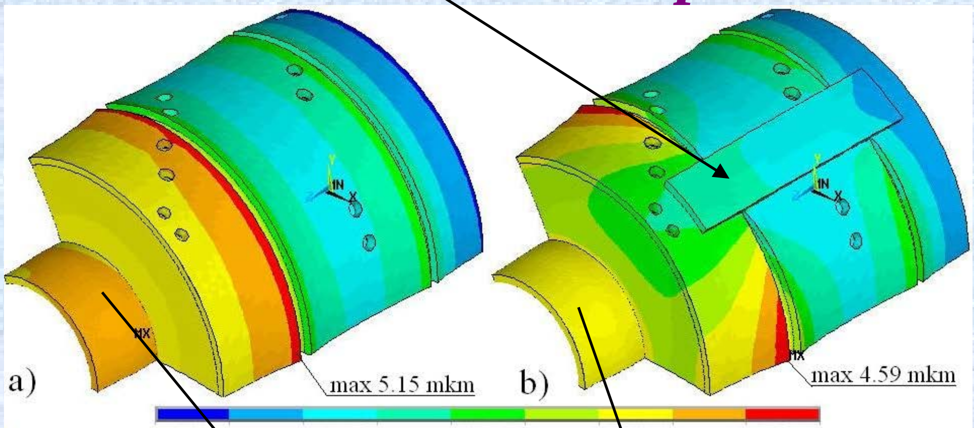


Temperature rise distribution.

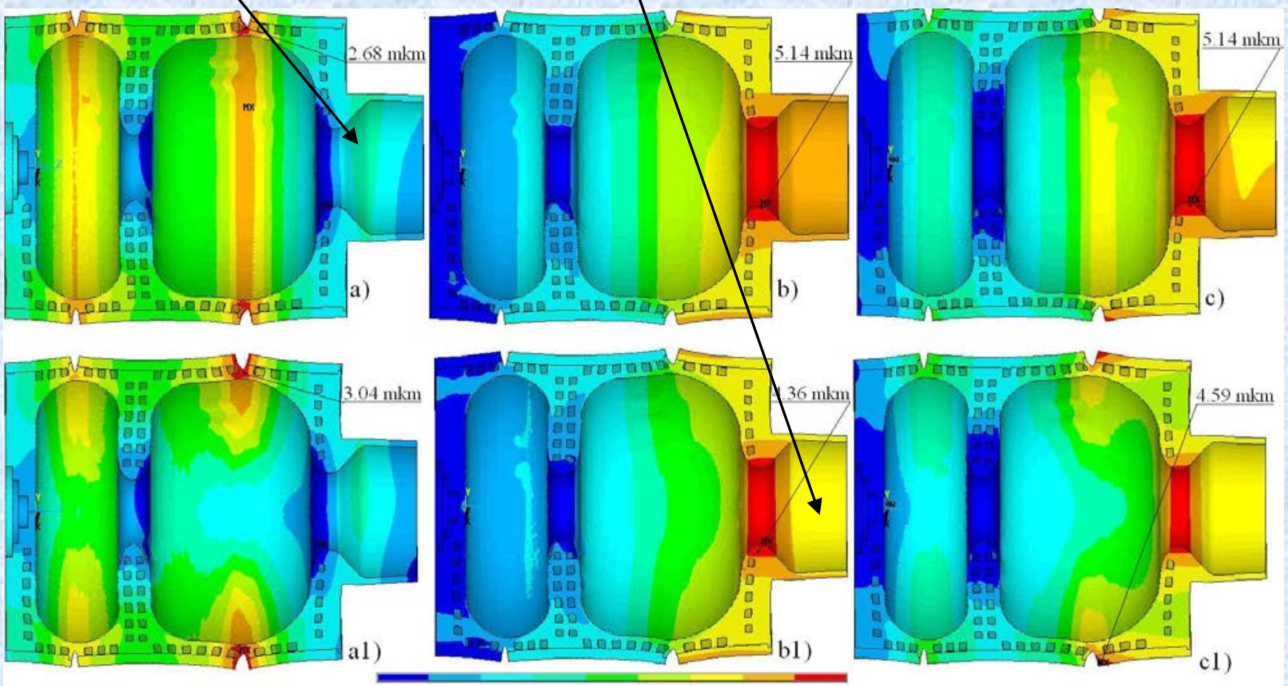
Probe hole vicinity is not a "hot spot",

Displacements

Stiffening rib



Stiffening ribs restrict cavity deformation due to pulsed heating, protect brazed surfaces, decrease frequency sensitivity and provide high order sextupole modulation in the cavity shape with ~µk scale.



u_r u_z u_{tot}

In the sense of pulsed RF heating Gun 5 is not worse as compared to Gun 4.

Cooling circuit.

Cooling circuit is very essential particularity of Gun 5 cavity and realizes following ideas:

- several small channels, distributed in space, are more effective in cooling than one big channel with sum cross section. *Now there* ***are 10 channels, distributed inside cavity in 43 small channels;***

- simultaneously reduces distance for heat travel from cavity surface;

- fast "one turn" heat evacuation is realized;

- cooling capacity of small channels is fitted to RF loss profile;

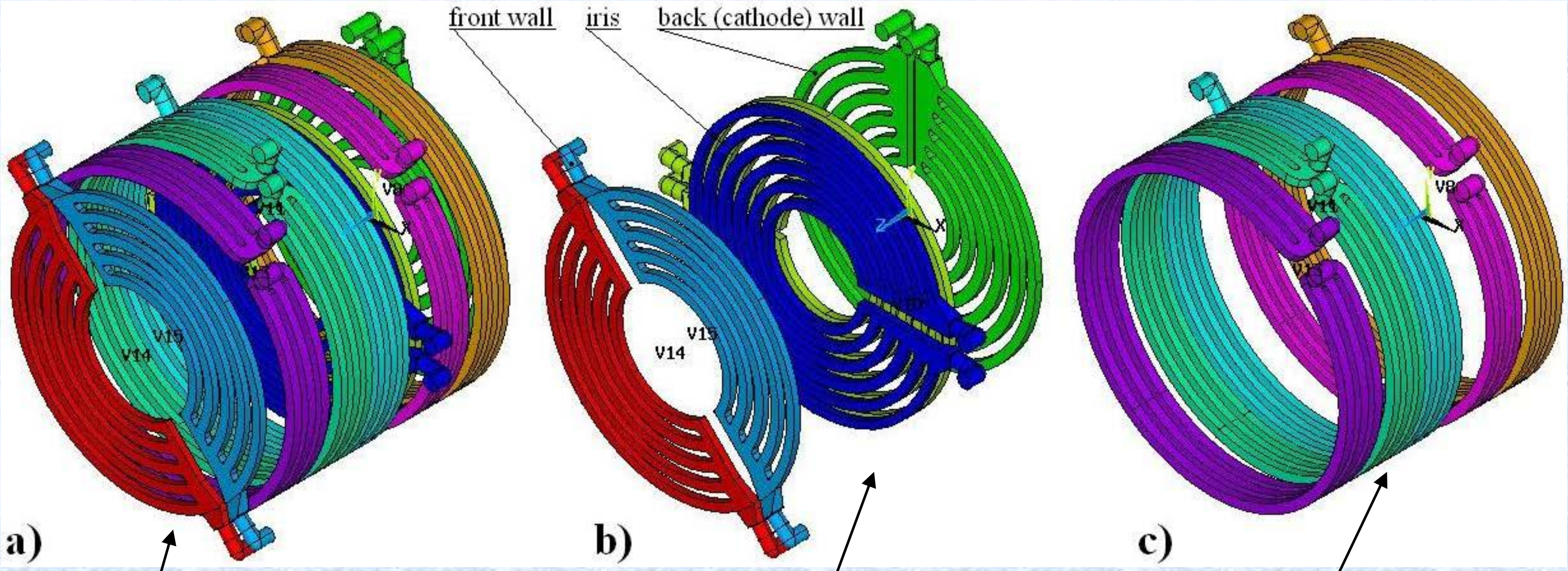
- the average flow velocity in channels is not more than 2 m/sec;

- the same pressure drop is assumed for all channels;

- flow distribution in channels is optimized to minimize velocity modulation and avoid possible whirling;

- fitted with mechanical design;

- for more flexibility all channels are developed symmetrical with respect input/output;

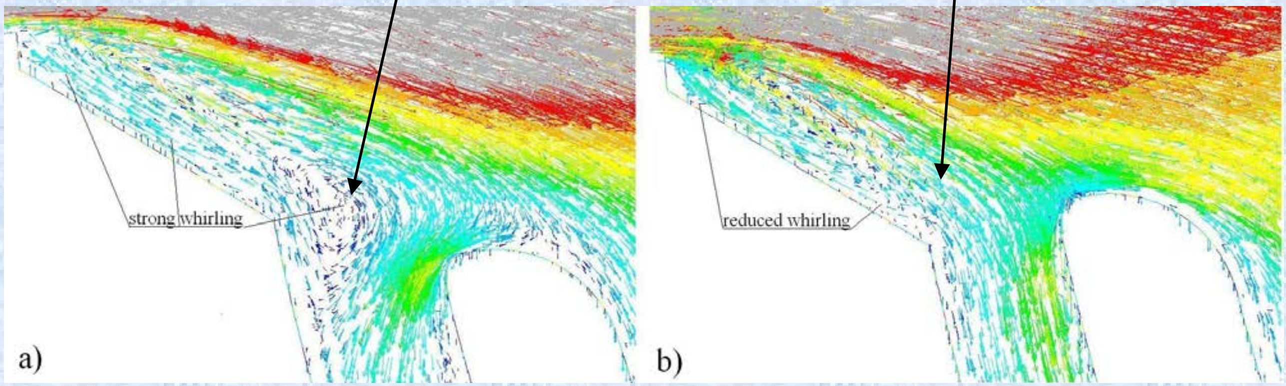


Total circuit
7444 l/h

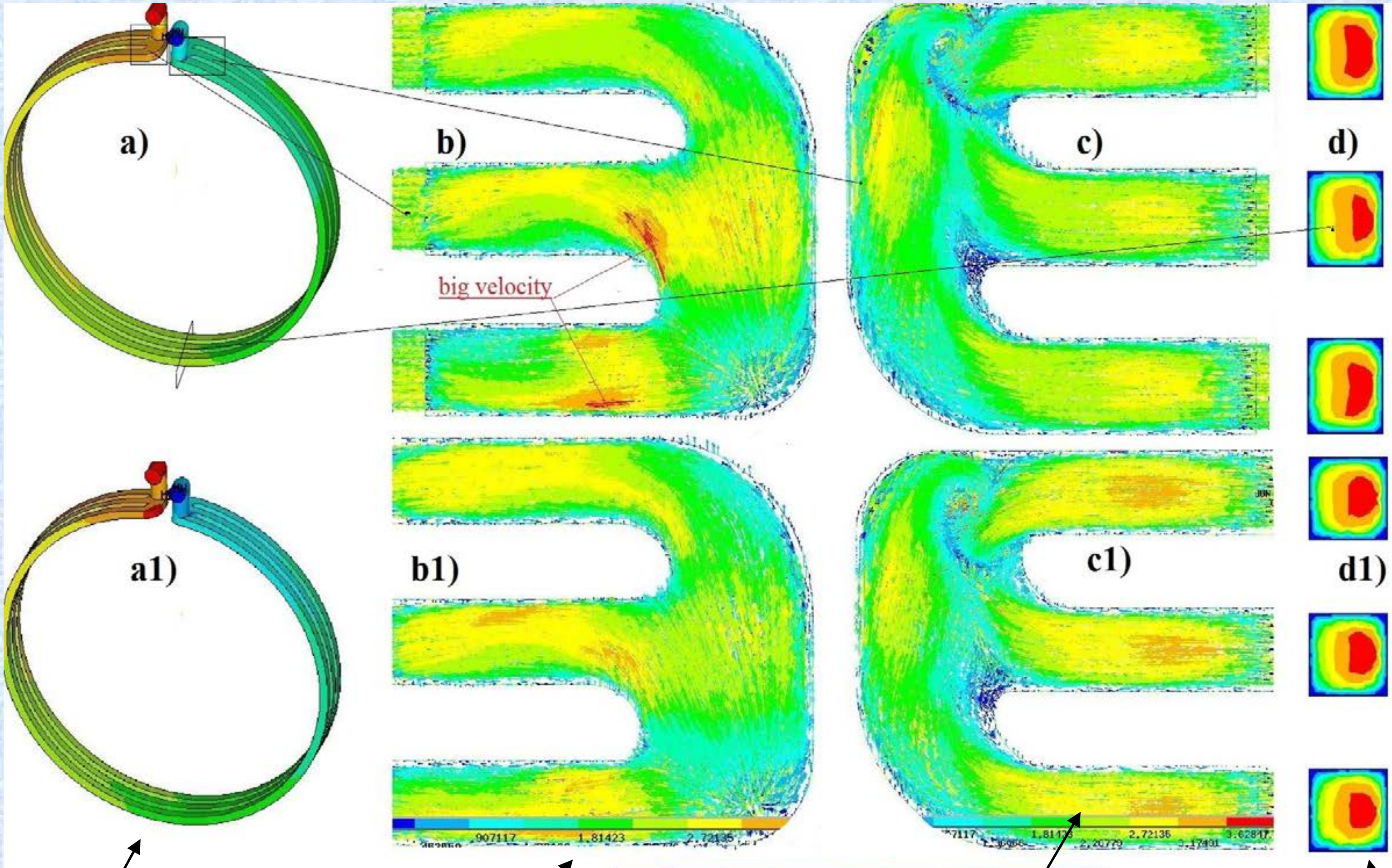
radial circuit
4118 l/h

outer circuit
3326 l/h

Physical design of cooling circuit is applied. The first step – flow optimization. ***before*** ***after***



Outer channels

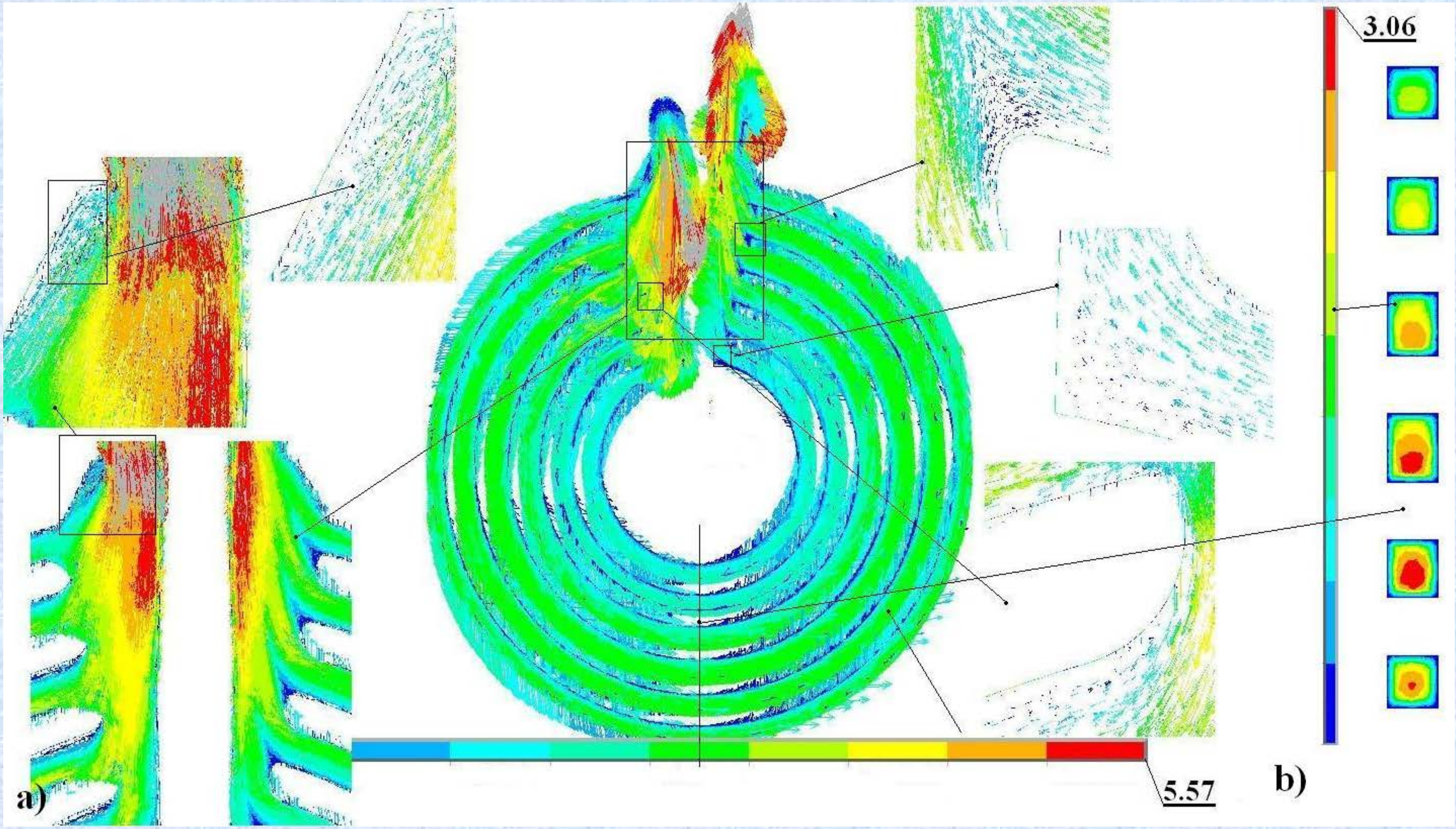


← **before**

← **after**

P **V input** **V output** **V cross**

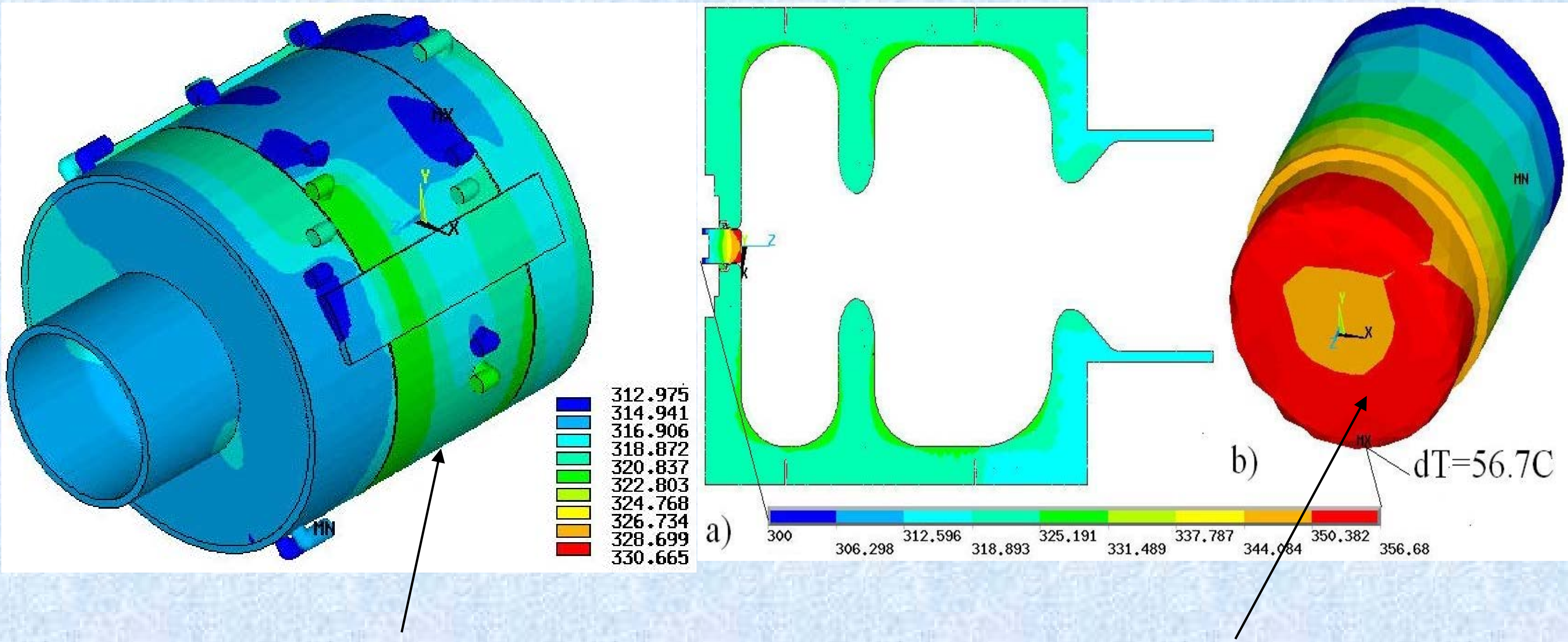
Radial channels



The channel for iris cooling with the space for thermo sensor placing

Expectations for cavity average cooling

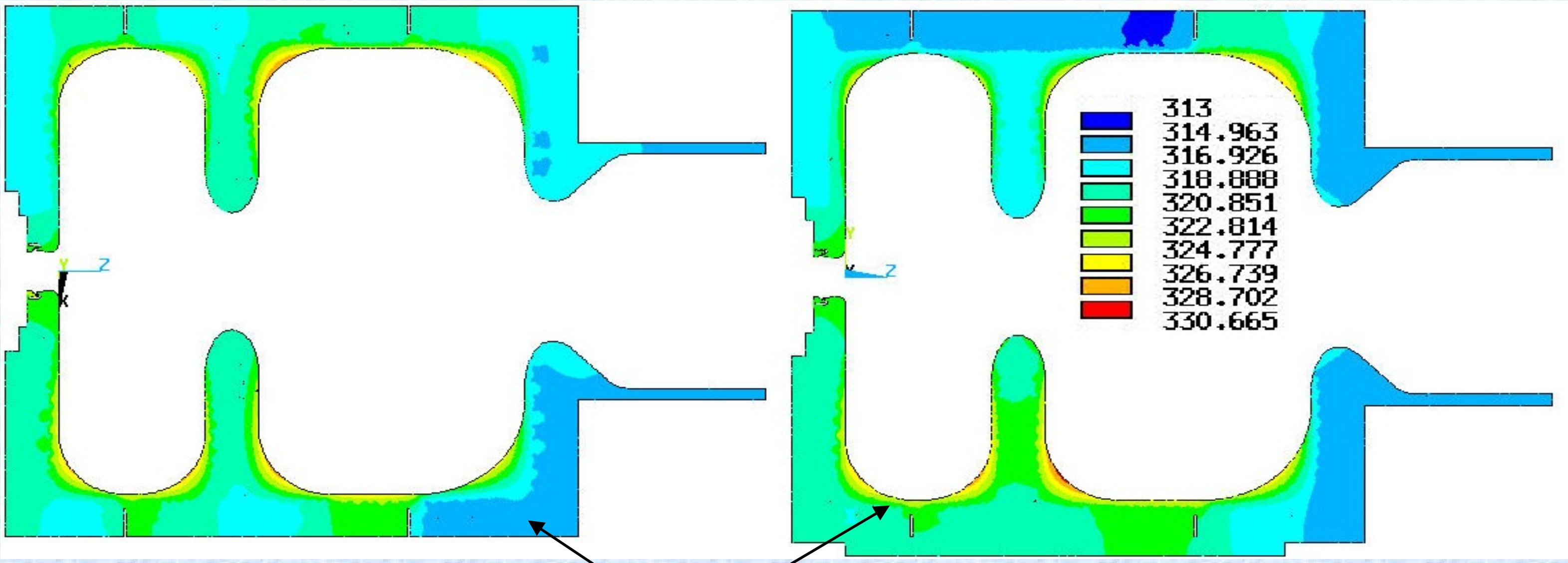
assuming τ=1 ms, Ec=60 MV/m, 10 Hz operation.



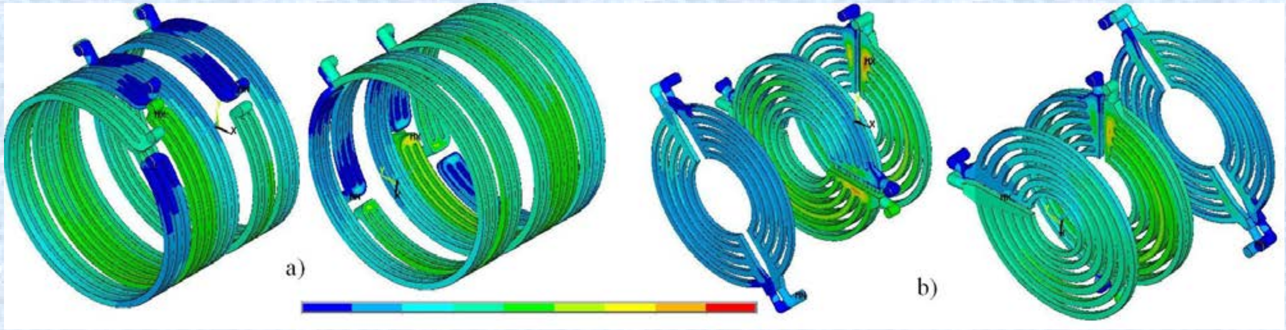
w/o cathode   outer surface   with cathode (or 38.6 C)

The cathode is a common problem for all Gun's. No essential effect thermal depending on contacts design.

As for the cavity itself…



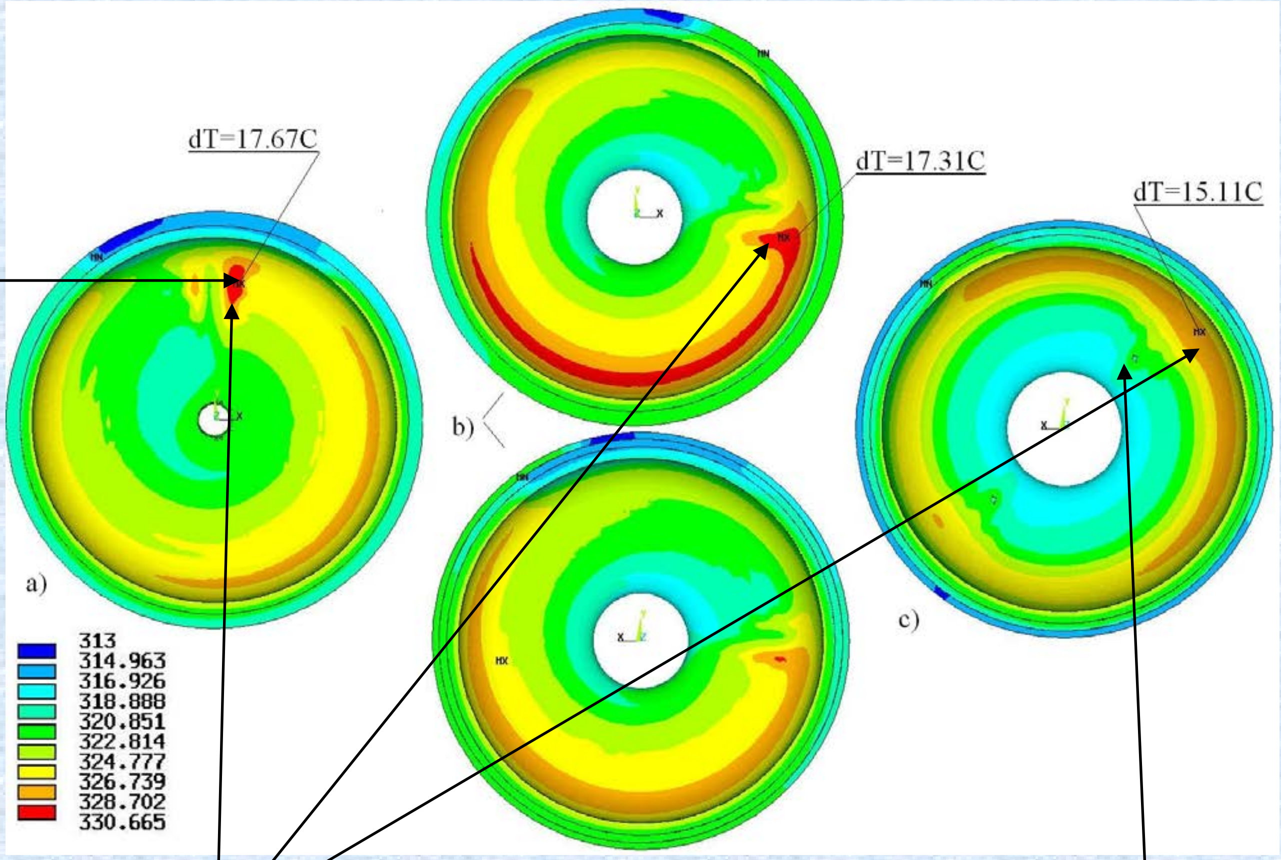
Temperature in two cross sections – rather uniform.



Temperature at the cooling channels (different projections).
Channels works uniform – spread in output temperature is inside 2 C.

Temperature distributions at the inner surface

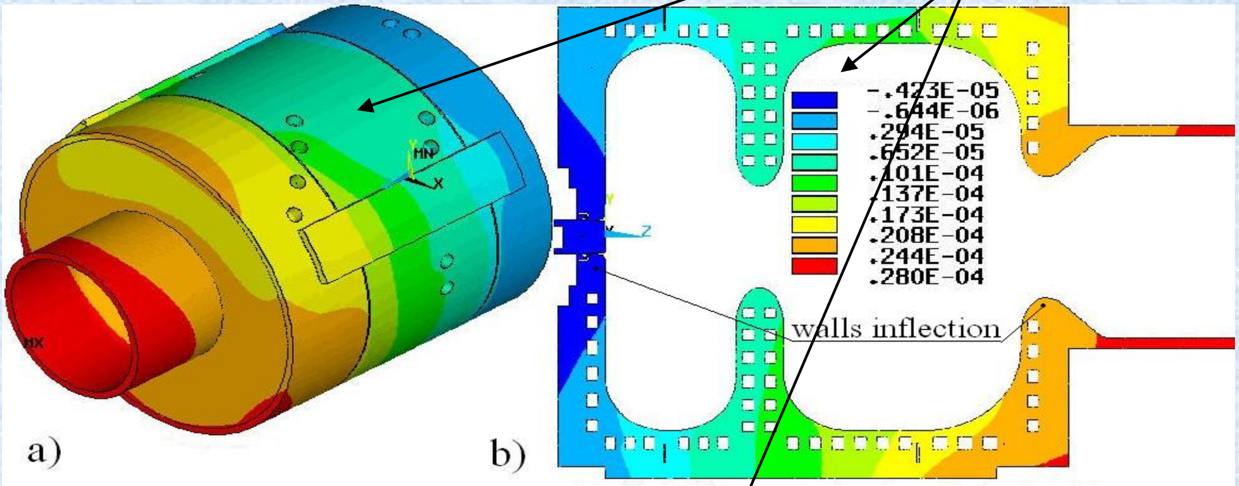
max

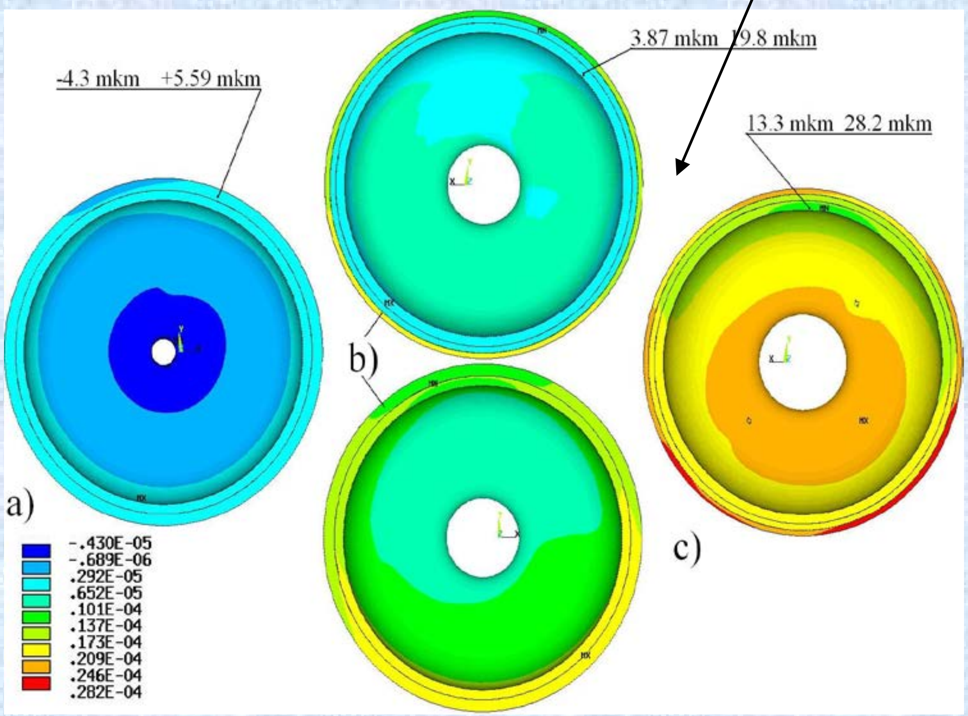


Narrow spread, ~2.5 C

Cold vicinity of RF probe

Displacements, *total,* u_z



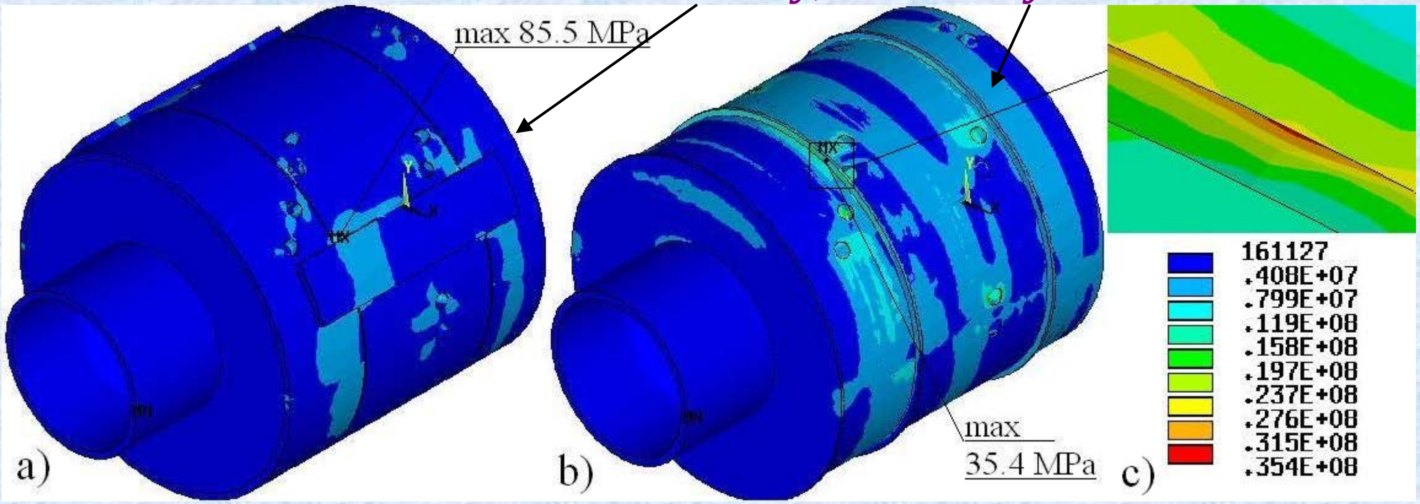


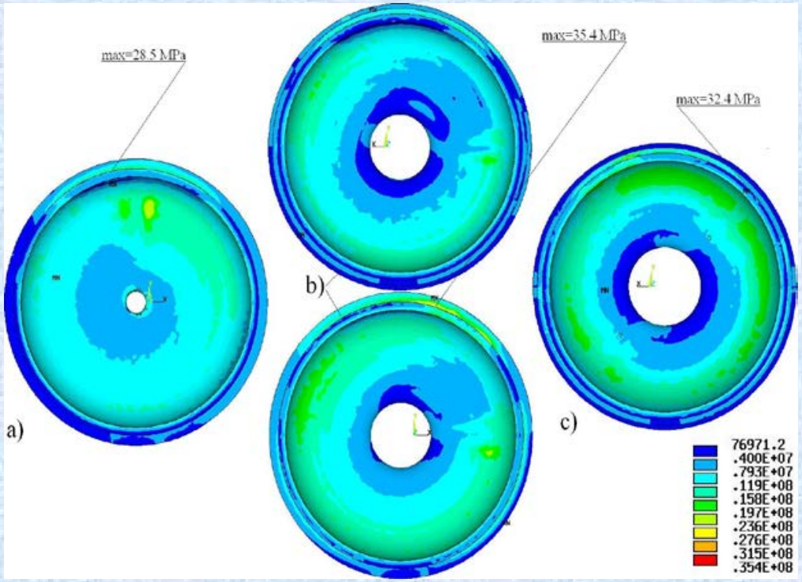
Uniform, in general. There are no bright points for dipole mode generation.

Calculated frequency shift df =-147 kHz, equivalent to uniform heating at 7 C ~17C/2

Thermal stress

total cavity, Cu body





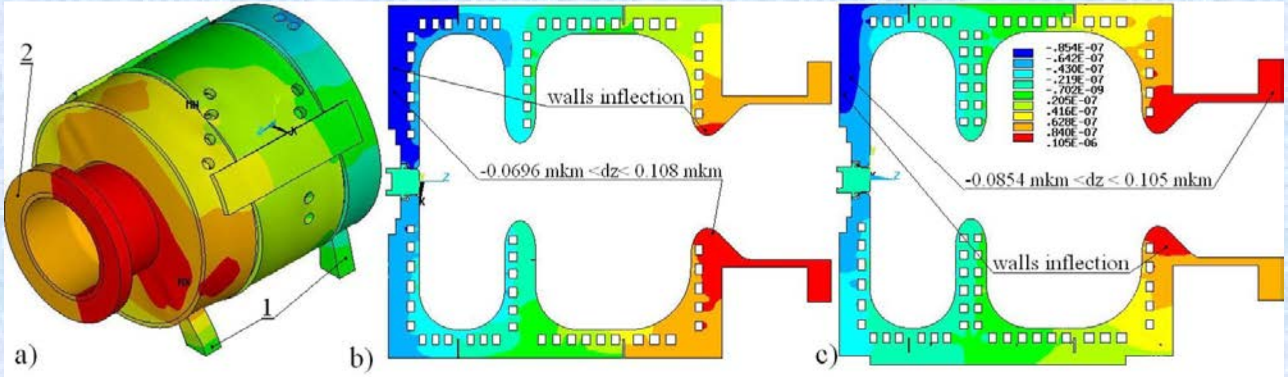
Gloomy (dark blue, green) picture for stress distribution at inner cavity surface. Very good – stress are low!

According simulations, due to elaborated cooling circuit, Gun 5 cavity has ~two times reserve in the tolerable dissipated power and can operate with higher duty factor.

Another parameters

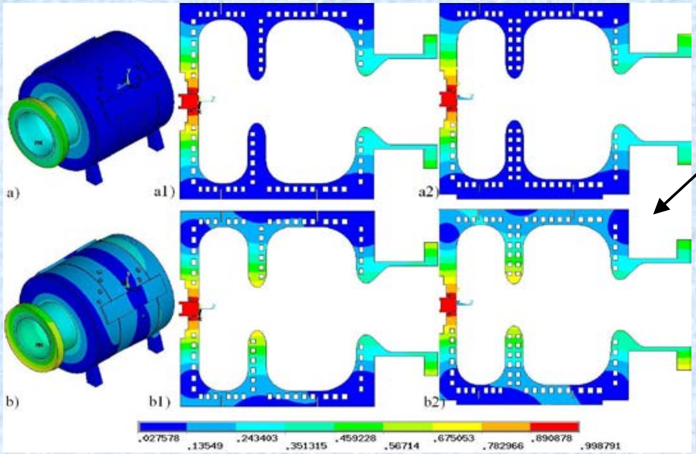
Cavity rigidity – similar to Gun 4.

Higher force is required for RF tuning (~25 %, S. Philipp).



Deformations due to 2bar pressure in channels , df~-82 Hz

Spectrum of acoustic modes   > 600 Hz



Important acoustic modes

f > 2800 Hz

Comparison with existing Gun cavities.

Table 9.2: The summary of expected parameters for Gun 5 cavity reference design. The value of percents in the column "Relation" is recalculated with respect to parameter value for Gun 4.

Parameter	Gun 5 reference	Gun 4	Relation
Cathode RF field, $\frac{MV}{m}$	60	60	=
Surface RF field, $\frac{MV}{m}$	60.6	72	$< 15.8\%$
Quality factor	25770	23400	$> 10.1\%$
Pulse RF power, MW	6.31	6.43	$< 1.8\%$
Modes separation, MHz	6.07	5.07	$> 19.7\%$
RF probes	Yes	No	
(2) Pulsed surf. temp. rise, C^o	46.86	45.2	$> 3.7\%$
(2) Pulsed deformation, μm	4.59	9.3	$< 50.6\%$
(2) Frequency shift, kHz	-16.89	-17.36	$< 2.7\%$
(3) Average RF power, kW	63.1	64.3	$< 1.8\%$
(3) Max. surf. temp. rise, max. C^o	17.67	32.5	$< 45.6\%$
(3) Frequency shift, kHz	-146	-226	$< 35.4\%$
(3) Power sensitivity, $\frac{kHz}{kW}$	-2.31	-3.52	$< 34.4\%$
(3) Maximal stress value, MPa	35.4		
Number of water I/O	9	14	
(4) Water consumption, $\frac{m^3}{h}$	7.44	10.5	$< 29.1\%$
Cavity diameter, mm	227	230	$< 3mm$

There is just one parameter, in which (according simulations), Gun 5 does not overlaps existing cavities. (But it depends on cavity tuning).

Conclusion.

1. **Gun 5 reference design realizes optimized, counterbalanced and mutually fitted physical solutions, fitted also with mechanical design.**
2. **In the total list of parameters Gun 5 reference design overlaps existing L-band Gun cavities.**
3. **In RF parameters Gun 5 cavity has a lower surface electric field, slightly lower required RF power and improved modes separation. It should improve stability of operation.**
4. **RF probes, foreseen in the design, do not deteriorate another cavity performances.**
5. **Gun 5 design is much more optimized for operation with high average RF power. It satisfies completely to the X-FEL start specification with the expectation of improvement in operational stability.**
6. **Existing reserve in the dissipated average RF power opens possibility of operation with τ=700 ms, E_c=60 MV/, 25 Hz regime.**

Thank you
for attention!