RF fields simulations

Alexej Grudiev, BE-RF

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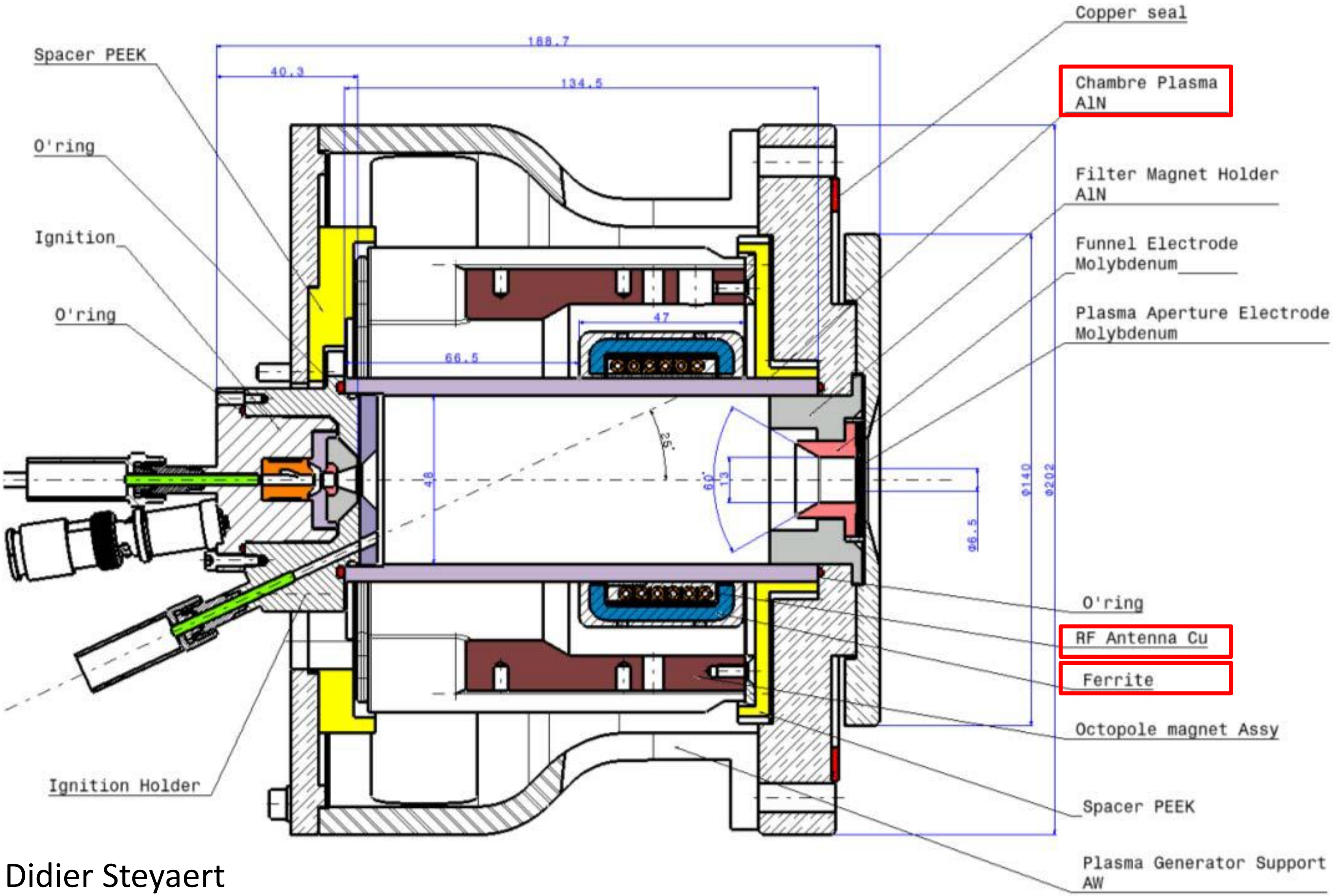
Linac4 Ion Source Review, CERN

Outline

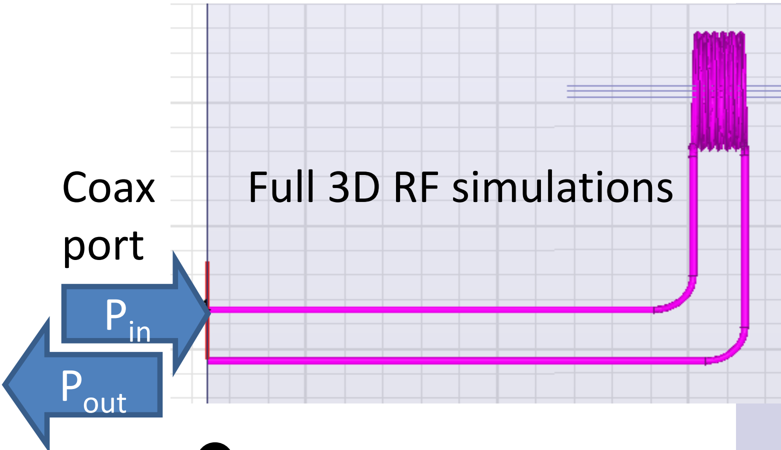
- RF field simulations setup
- Plasma model as a conductor
- Surface electric field enhancement
- EM field distribution in plasma chamber
- Ion source Impedance
- Comparison with measurements
- Variation of the ion source geometry
- Conclusions

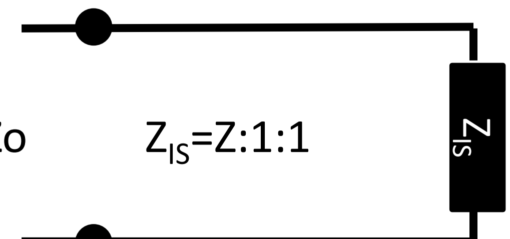
CAD 3D model of IS-01



Didier Steyaert

RF simulation setup (HFSS)



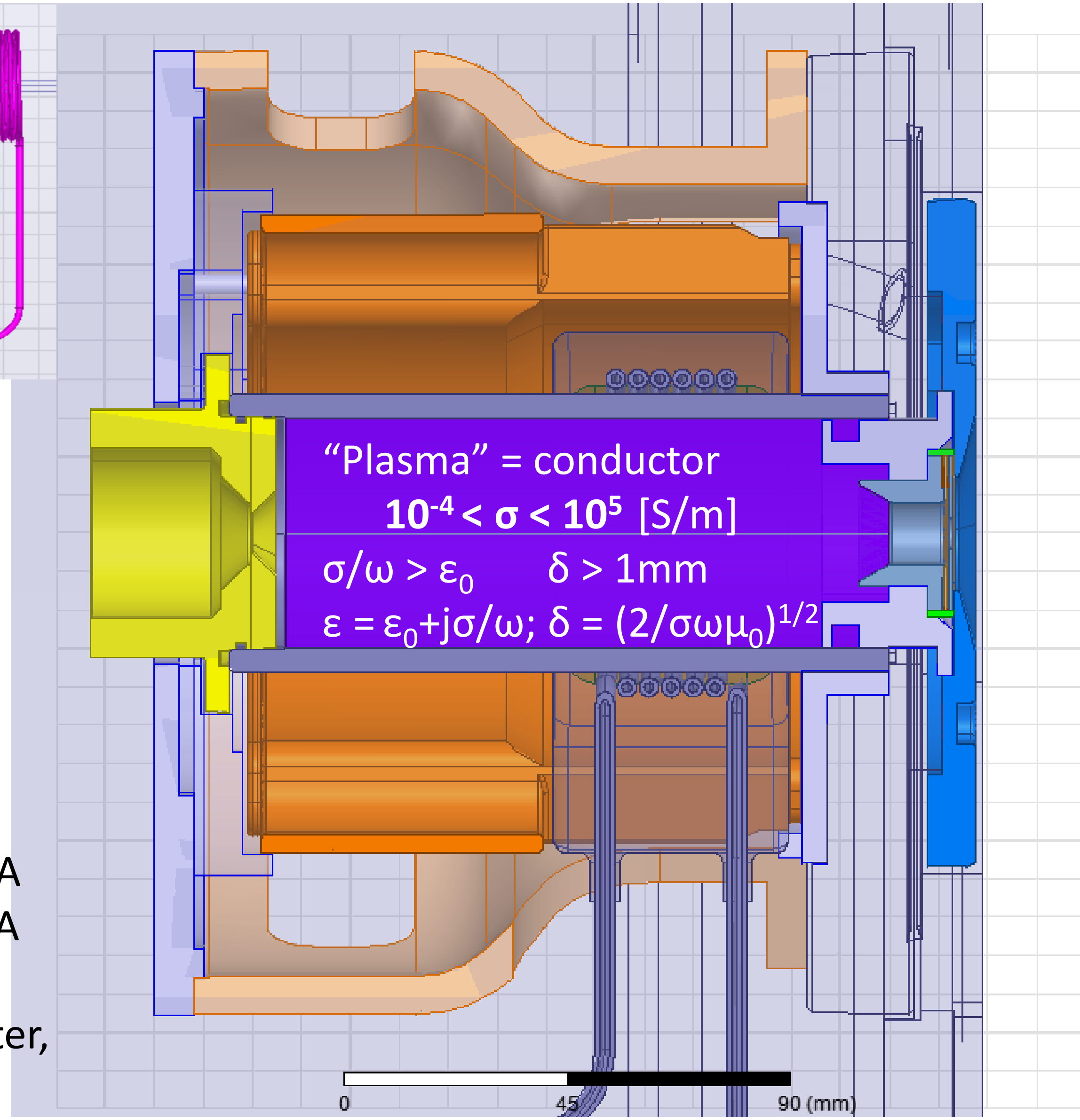


Port Zo	Z:1:1	Freq	
(158.65, -0.39477)	(0.1206, 33.427	2 [MHz]	1:1

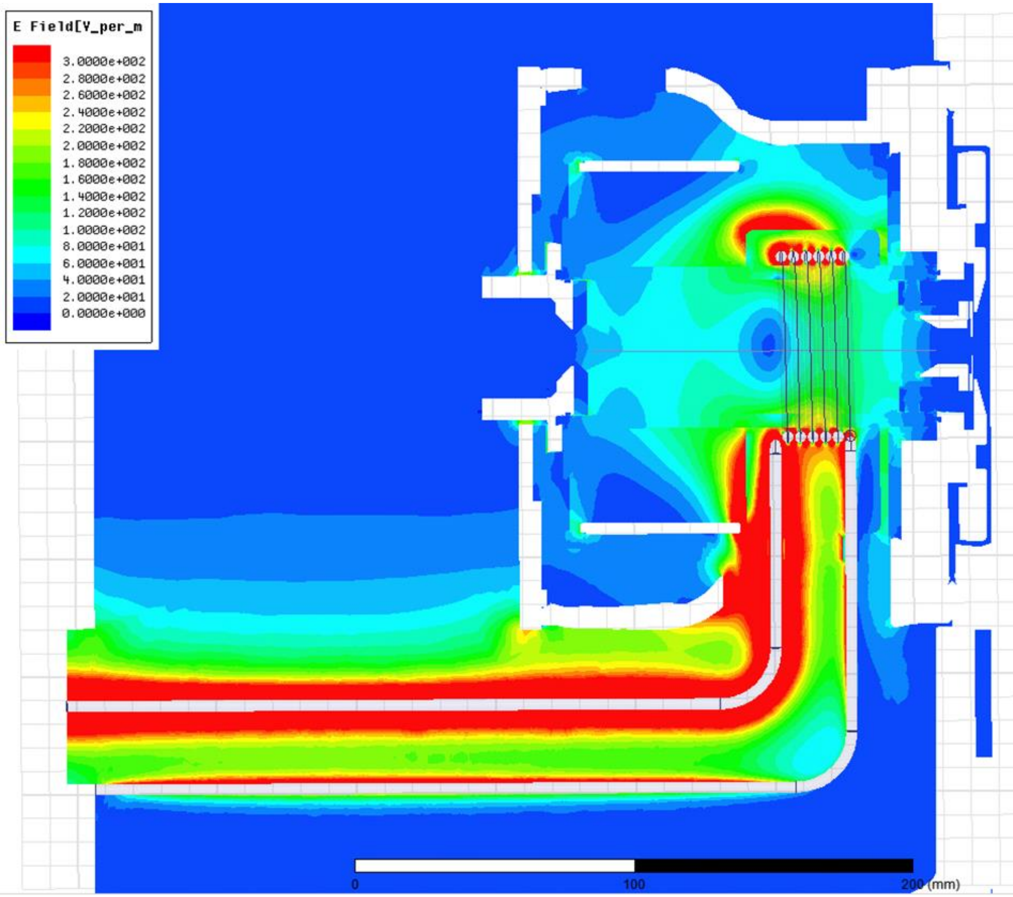
P_{in} = 1W => $I_{in} = \mathrm{sqrt}(2P_{in}/Z_c)$ = 0.11A

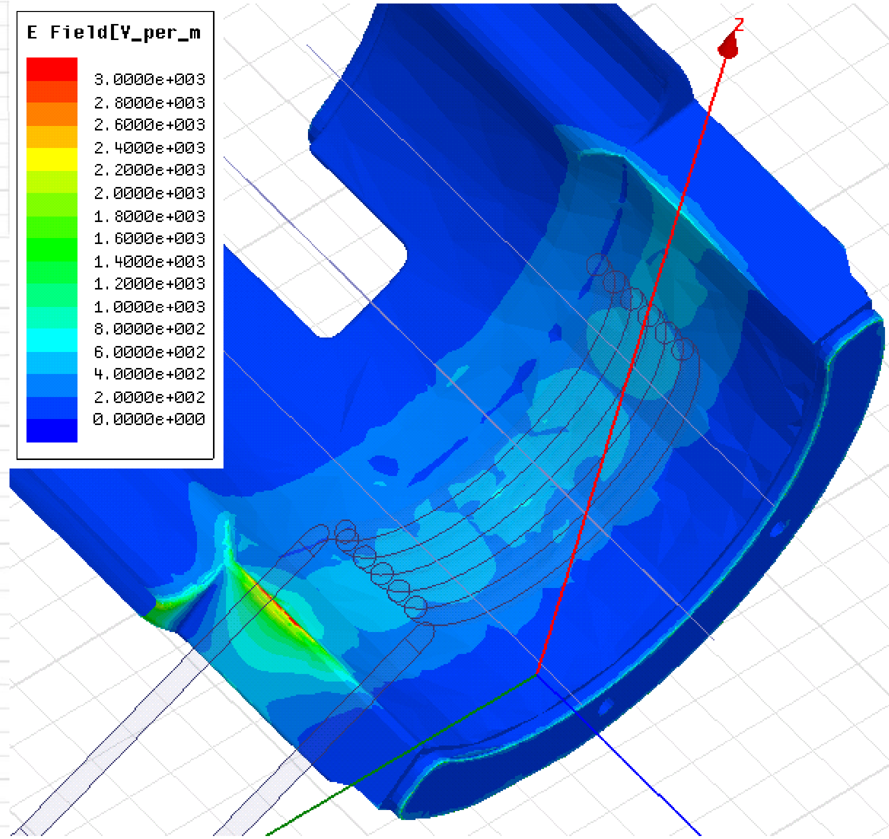
$I = 2I_{in}$ = 2*0.11A = 0.22 A

To scale the EM fields presented later, multiply by the current ratio



Surface electric field enhancement

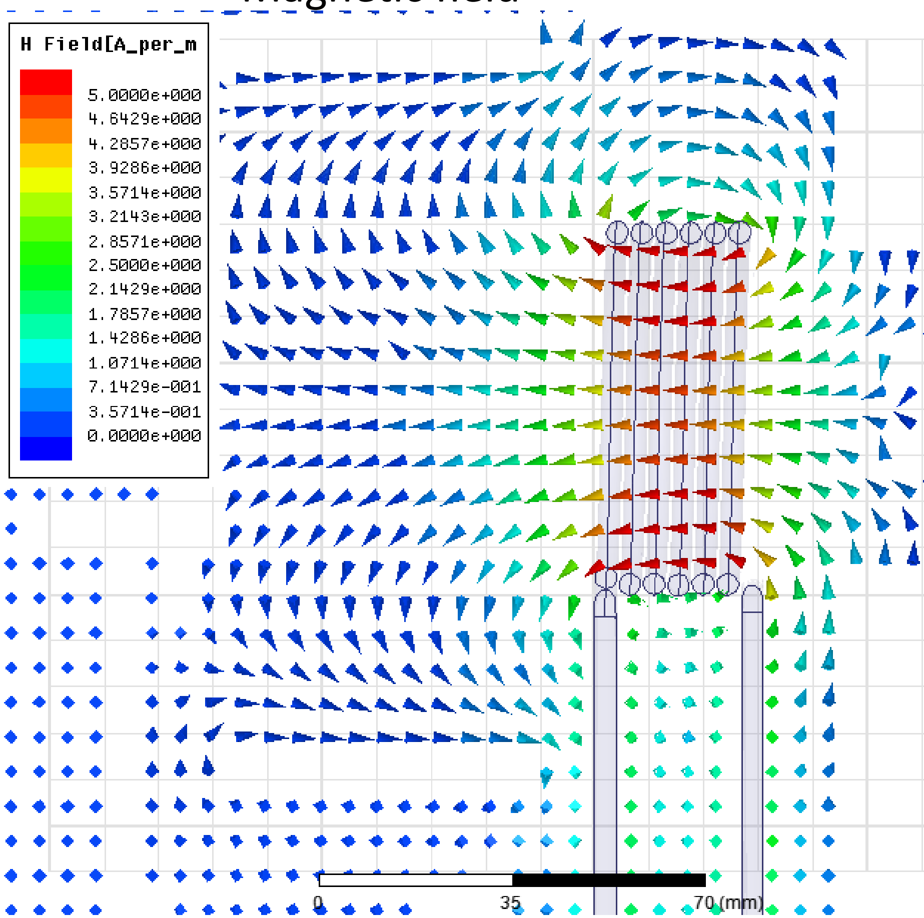




Max E-field on the surface of the Cu octupole envelop for 220 A coil current is about 3 MV/m, same as air discharge threshold. This due to sharp edge close to the coil.

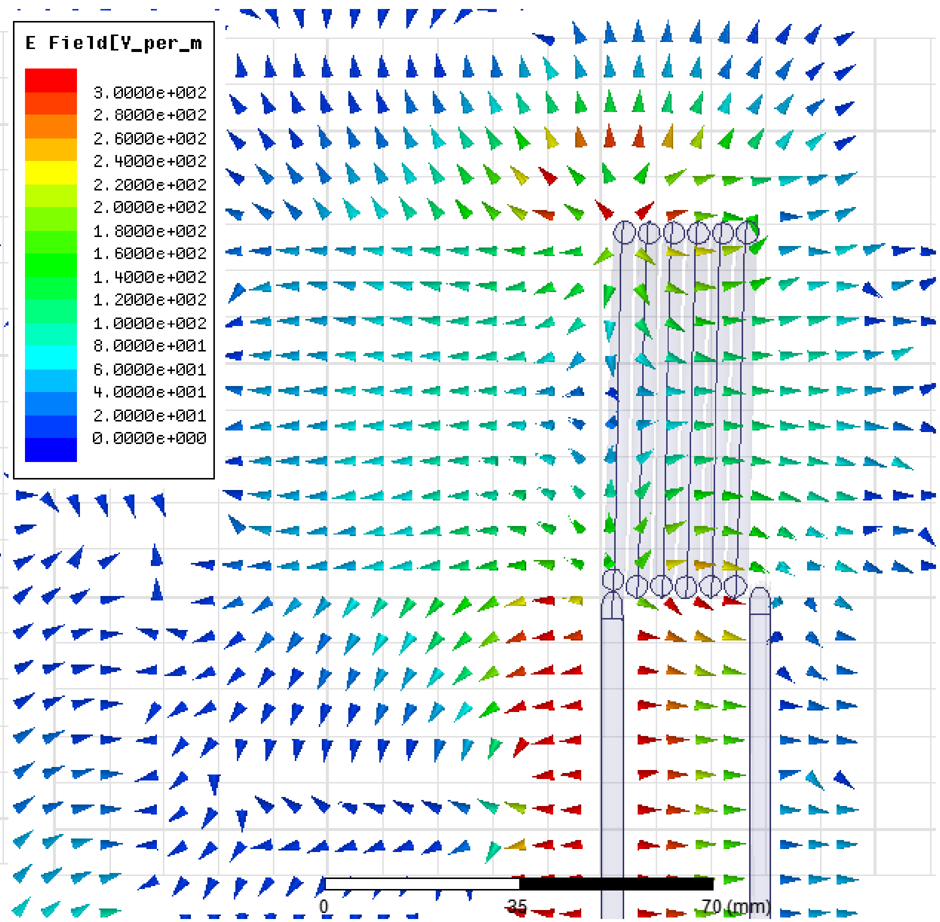
EM field distribution in plasma chamber region, σ=0

Magnetic field



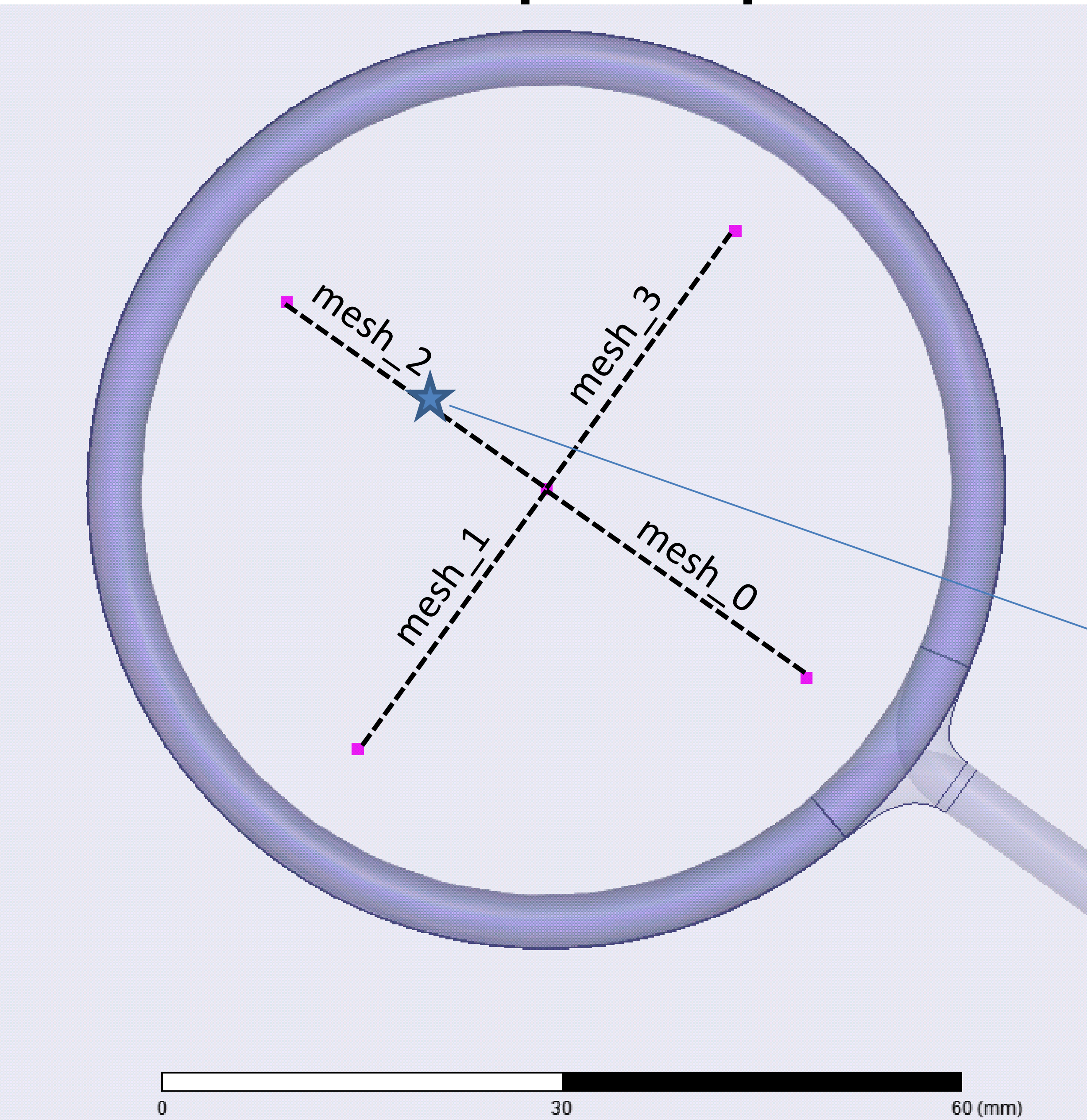
H-field is similar to the one of a solenoid

Electric field



E-field is dominated by R,Z components.
It is mainly capacitive

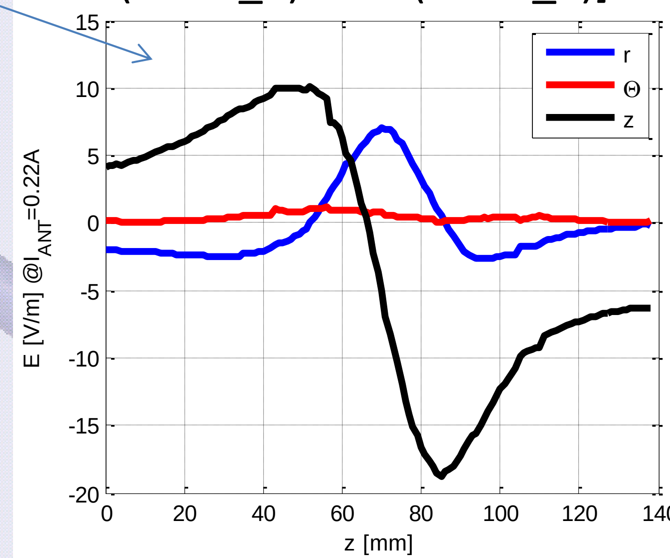
Field map for plasma simulations



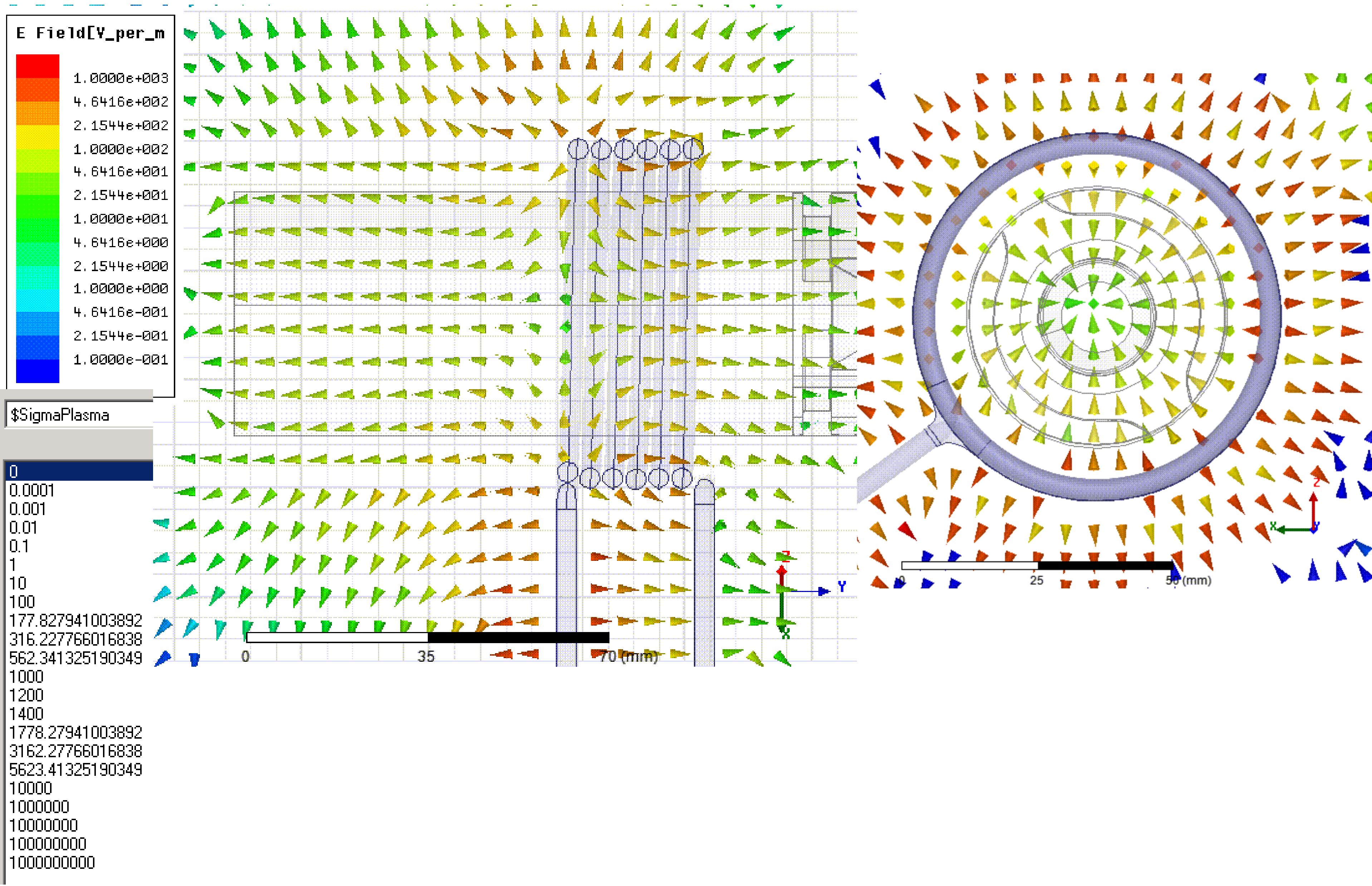
Averaging the field over 4 meshes remove radial and azimuthal components on axis r=0 and make the distribution quasi 2D.

To be used in the plasma simulation code with 2D field representation.

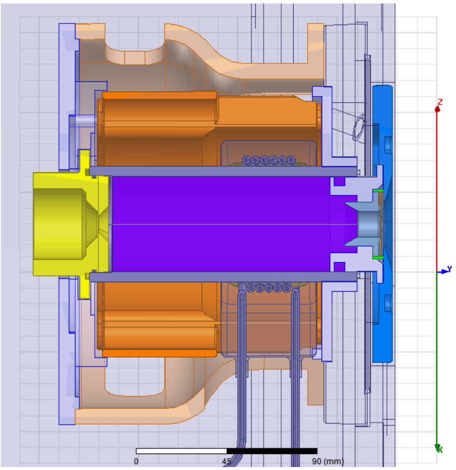
Field = 1/4*[
field(mesh_0)+field(mesh_1)+
field(mesh_2)+field(mesh_3)]

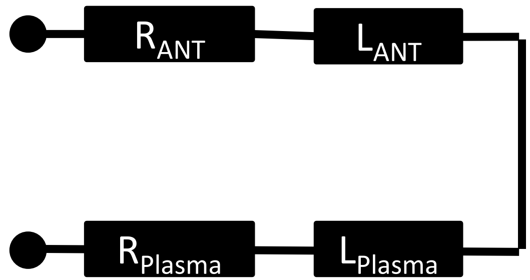


E-field distribution in plasma chamber. σ > 0



Ion source impedance



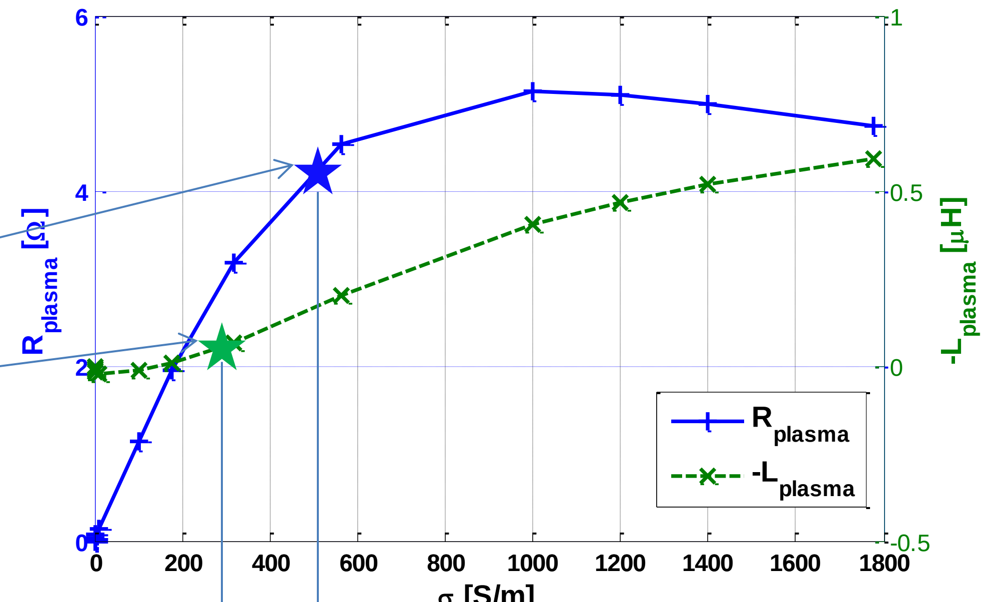


Model used in the RF measurements

$$Z_{Plasma} = Z_{Ant+Plasma}(\sigma>0) - Z_{Ant}(\sigma=0)$$
$$Z_{Ant} = R_{Ant} + j\omega_0 L_{Ant}$$
$$Z_{Plasma} = R_{Plasma} + j\omega_0 L_{Plasma}$$

RF Measurements IS-01:
R_{Ant} = 0.4 Ω
L_{Ant} = 3.2 µH
R_{plasma} = 4.3 Ω
L_{plasma} = -0.05 µH
M. Paoluzzi

Simulations IS-01:
R_{Ant} = 0.263 Ω
L_{Ant} = 3.02 µH

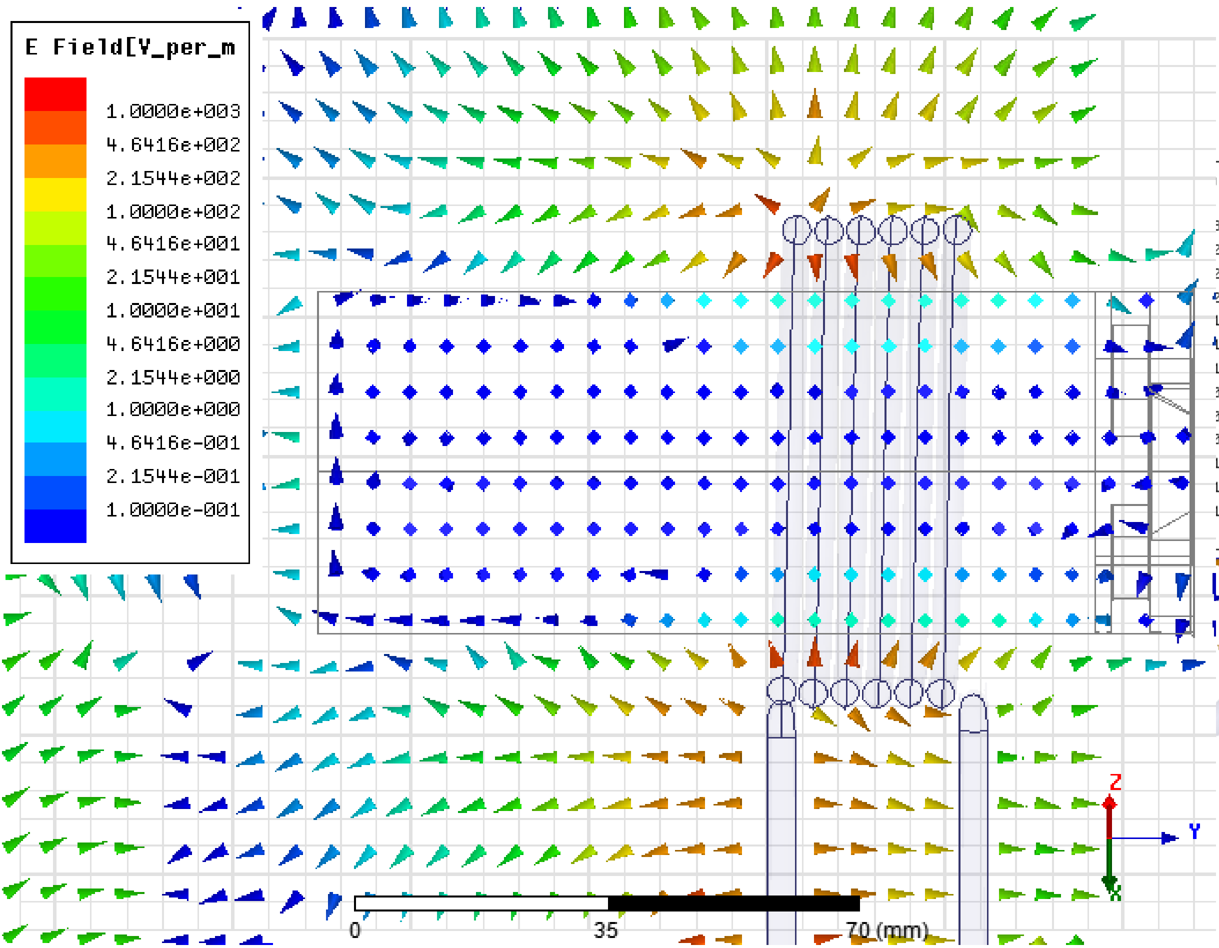


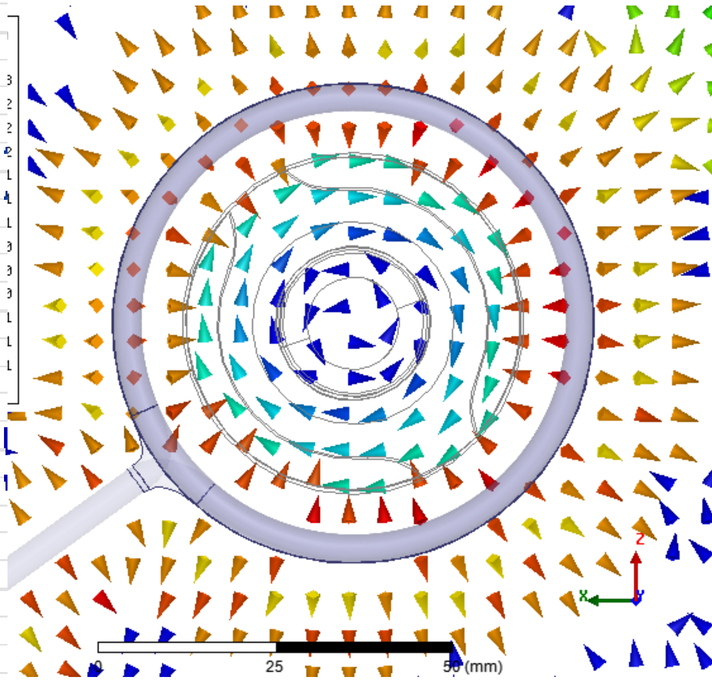
σ = **300 - 500** [S/m]

$$\sigma = \frac{n_e e^2}{m(\gamma_0 + j\omega)} \approx \frac{n_e e^2}{m\left(1.9\times10^{9} P + 1.5\times10^{-11} n_e T_e^{-3/2}\right)}$$

Plasma measurements (**SPL-IS**): H_2 pressure ~ 20 mTorr, n_e ~ 10^{18} - 10^{19} m^{-3} and T_e ~ 10 eV. => It gives an estimate of the conductivity of **730 - 6600** S/m for the above given density range
R. Scrivens

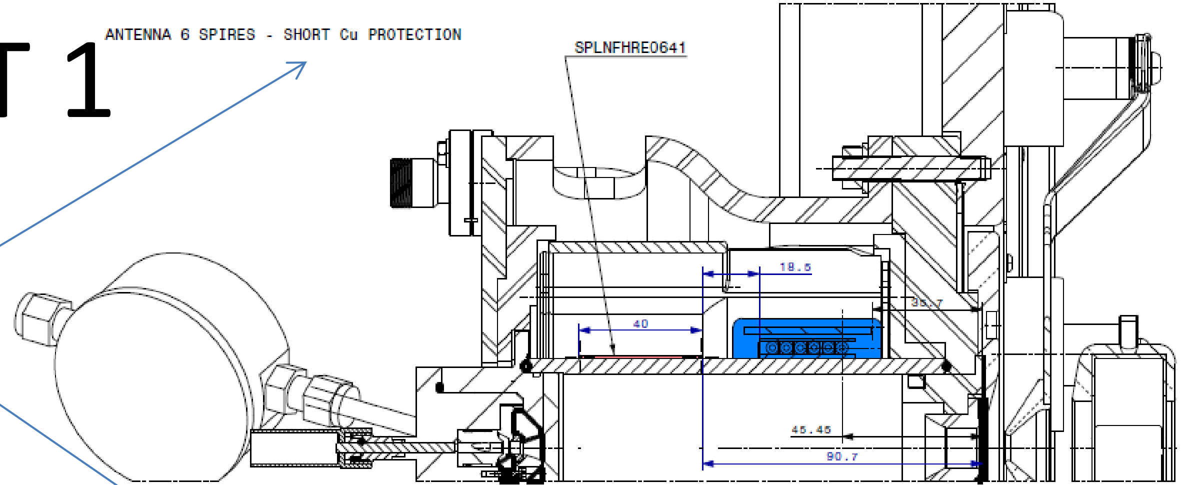
E-field distribution in plasma chamber, σ = 1000 S/m

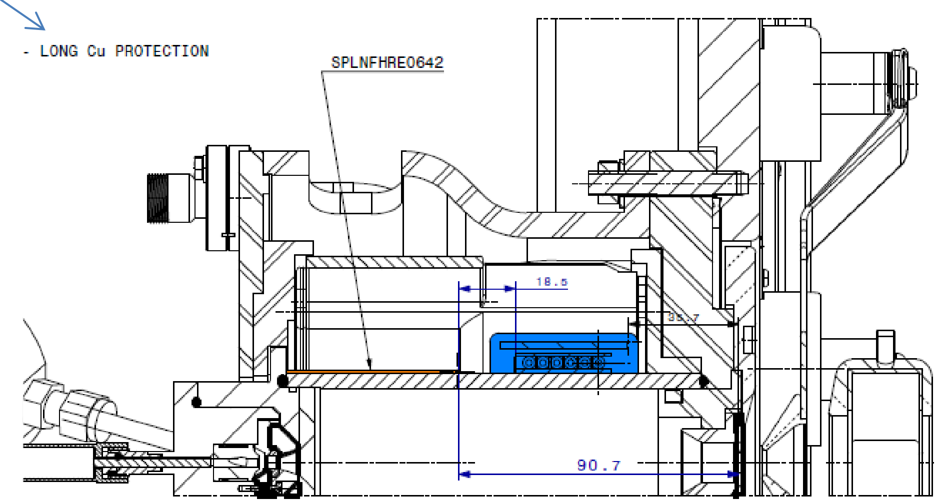


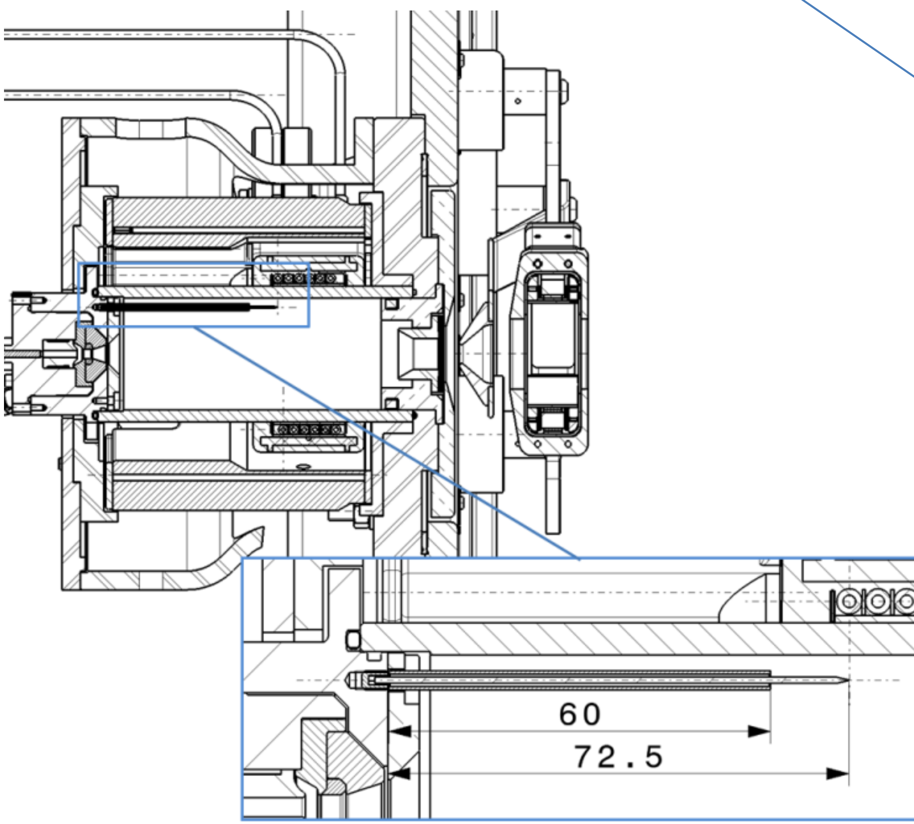


Variations: SET 1

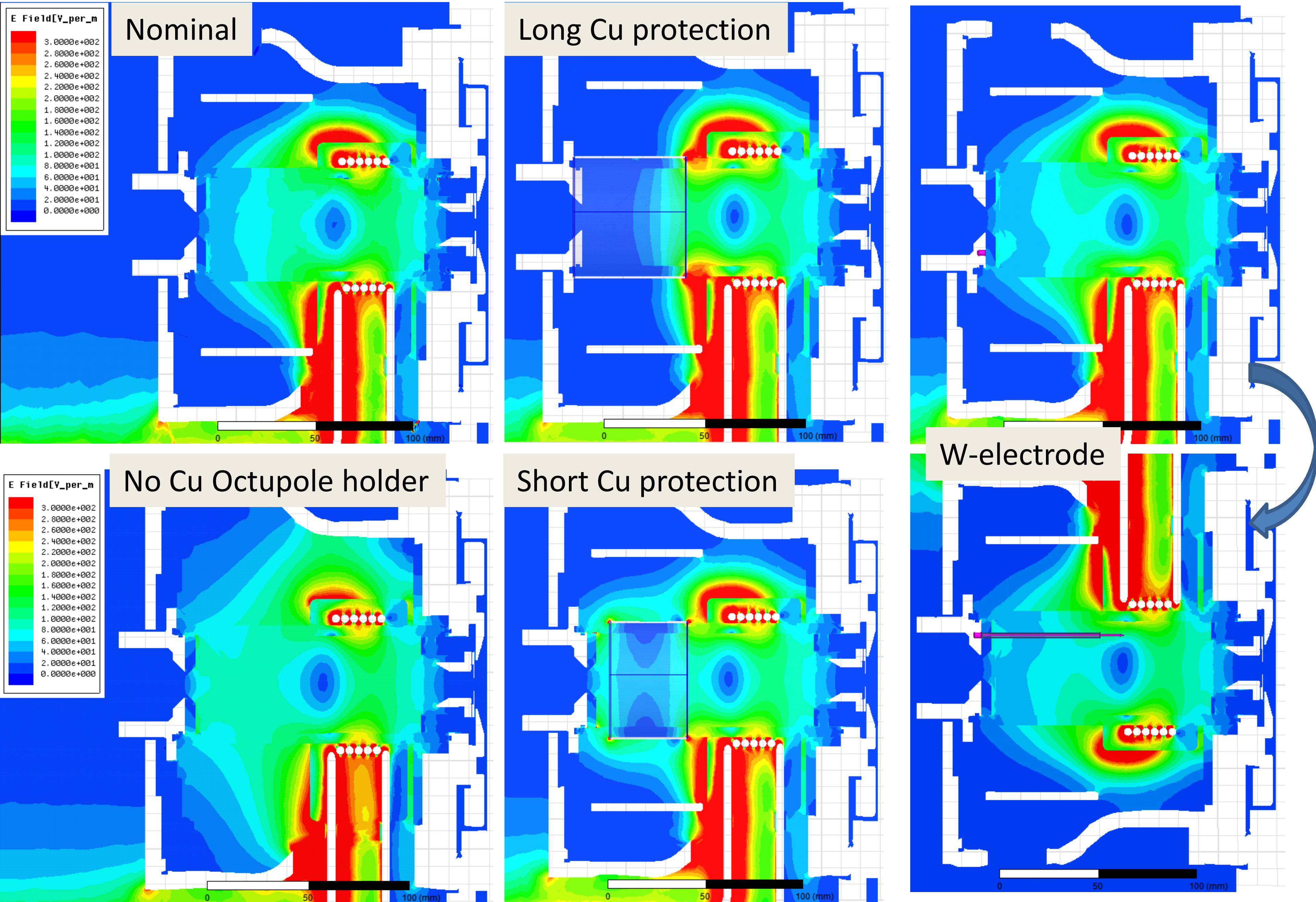
1. No Cu octupole holder
2. Long Cu protection
3. Short Cu protection
4. W-electrode







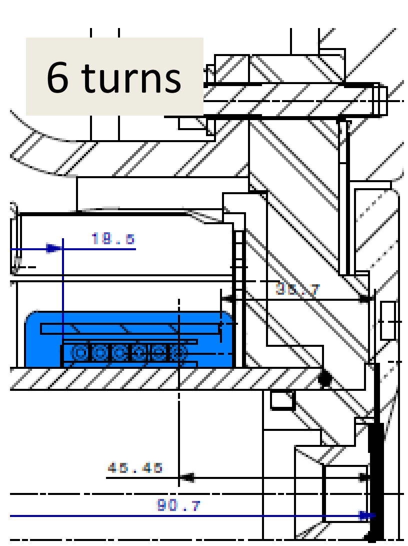
Variations SET 1: E-field distribution

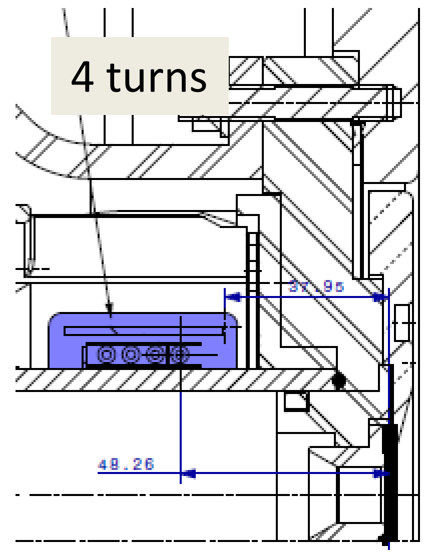


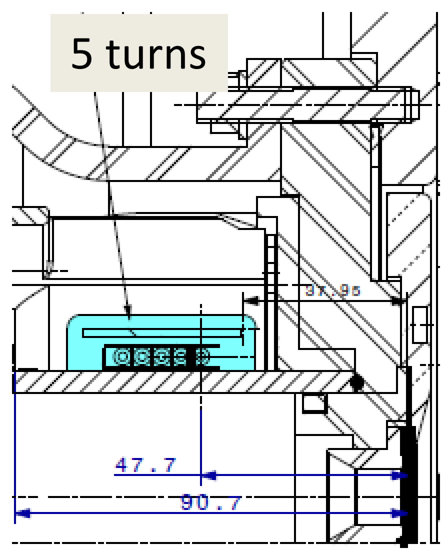
Variation of number of antenna turns

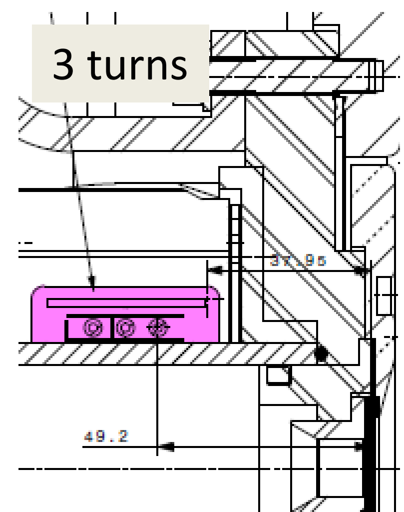
1. Nominal, 6 turns
2. 5 turns
3. 4 turns
4. 3 turns

N.B. for 5,4,3 turns the size of epoxy and ferrites are a bit smaller. The same materials are used

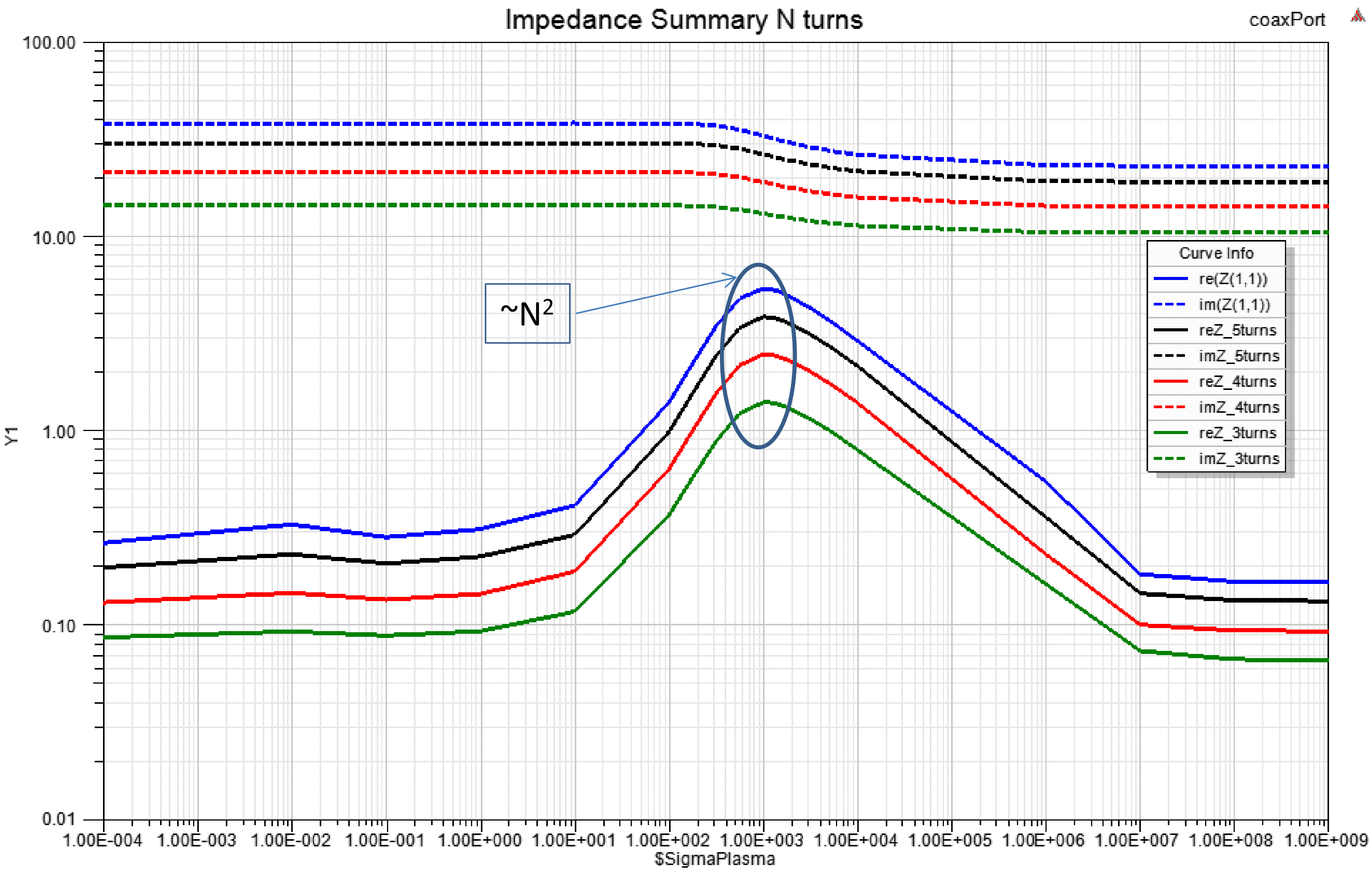




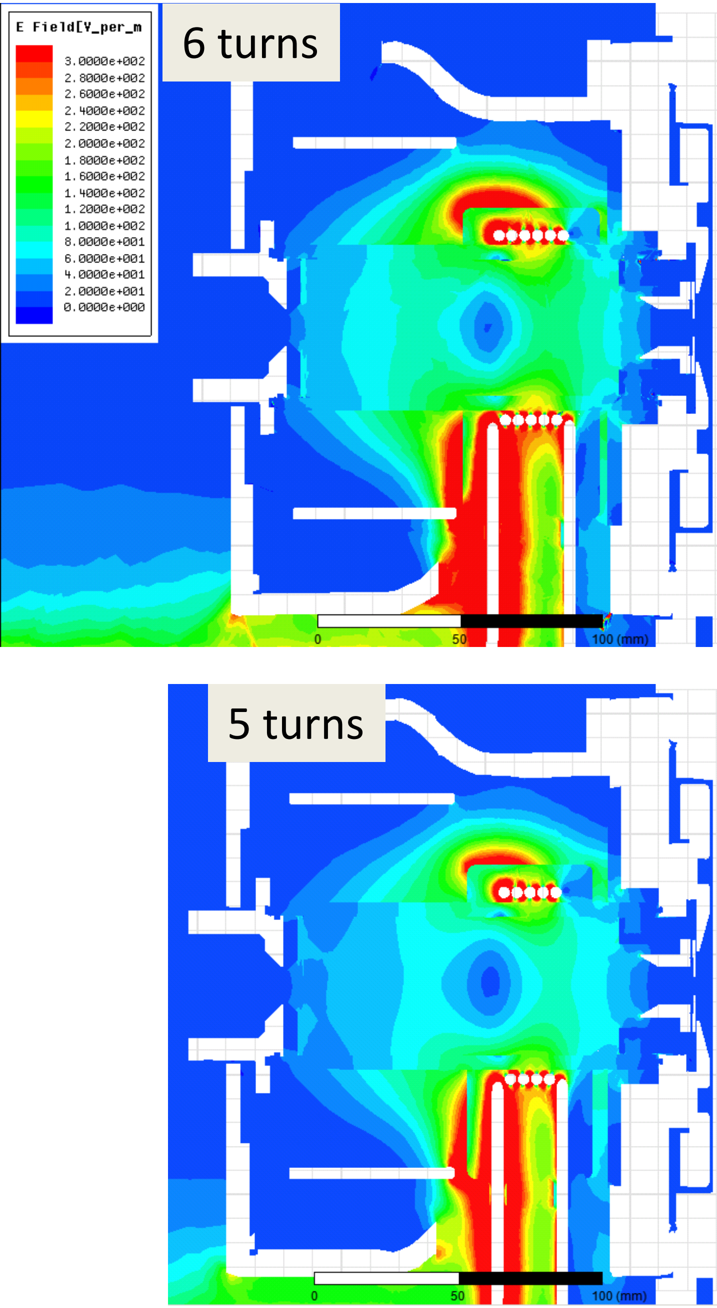




Variation of number of turns: impedance



Variation of N turns: E-field distribution



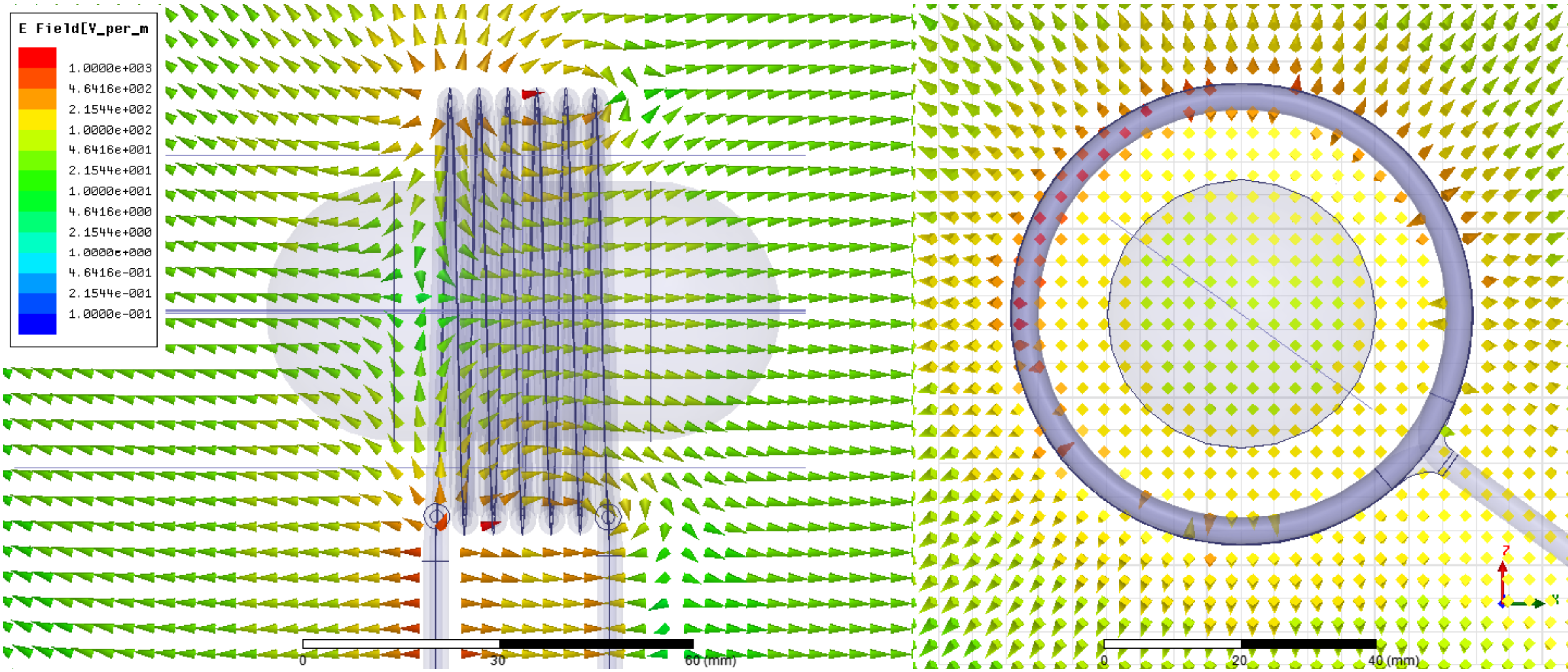
Plasma code

Conclusions

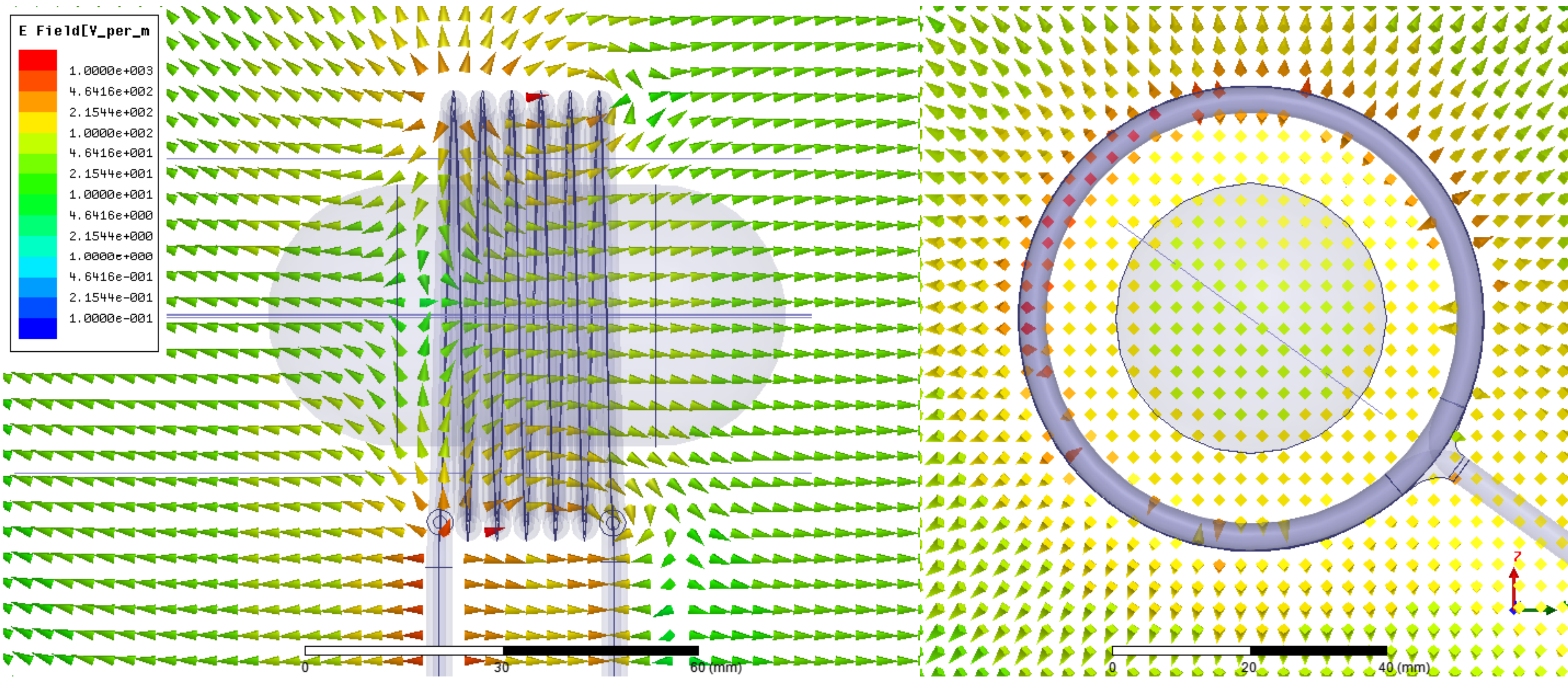
- Full 3D model with realistic material parameters is implemented and simulated using RF code HFSS
- Plasma is modelled as a conductor
- Surface electric field is calculated and compared to discharge limited values
- Without plasma electric field distribution in the plasma chamber is dominated by R,Z components, capacitive electric field
- EM field maps has been calculated for the plasma simulation code
- Impedance of the ion source as a function of “plasma” conductivity is calculated and compared to the RF measurements results
- Matching simulated and measured impedance values gives plasma conductivity which agrees with the one calculated from measured plasma parameters
- Several variations of the IS-01 has been simulated

Spare slides

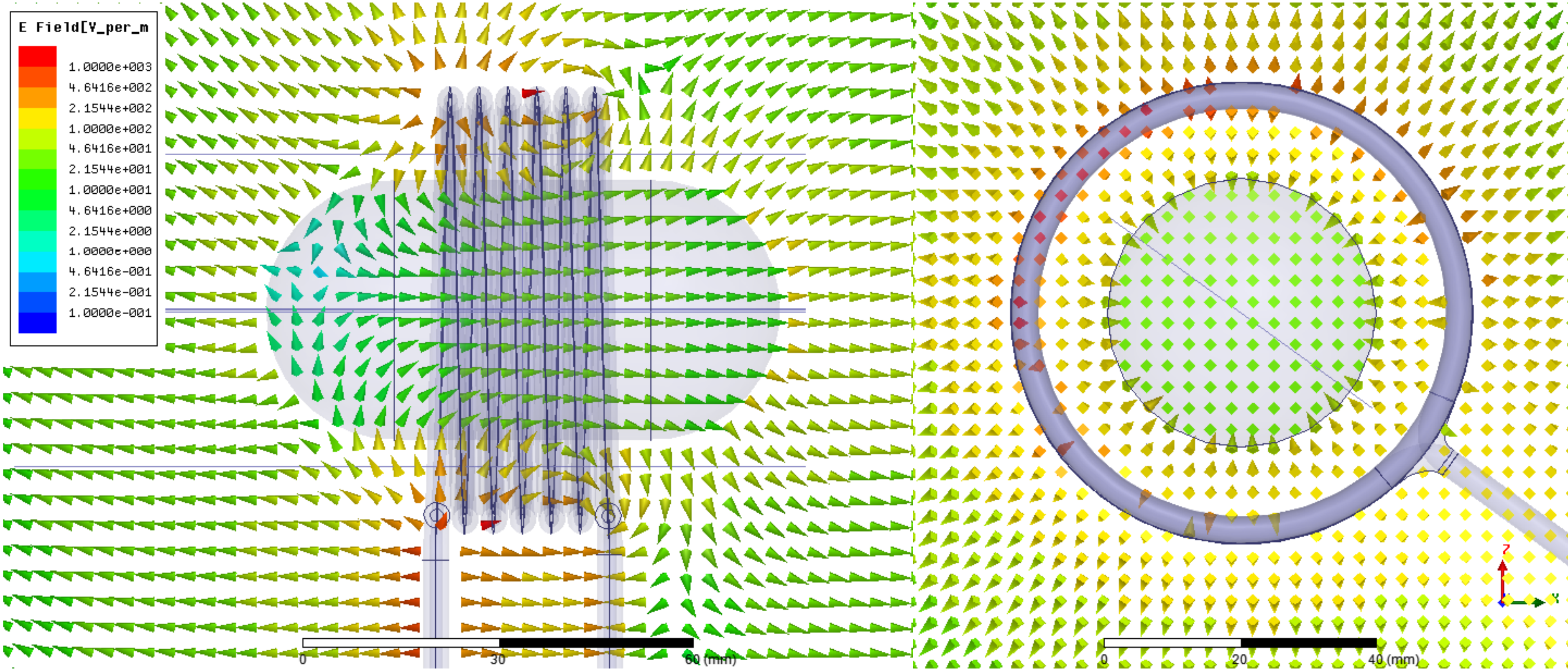
E-field: antenna + “plasma” (σ = 0 S/m)



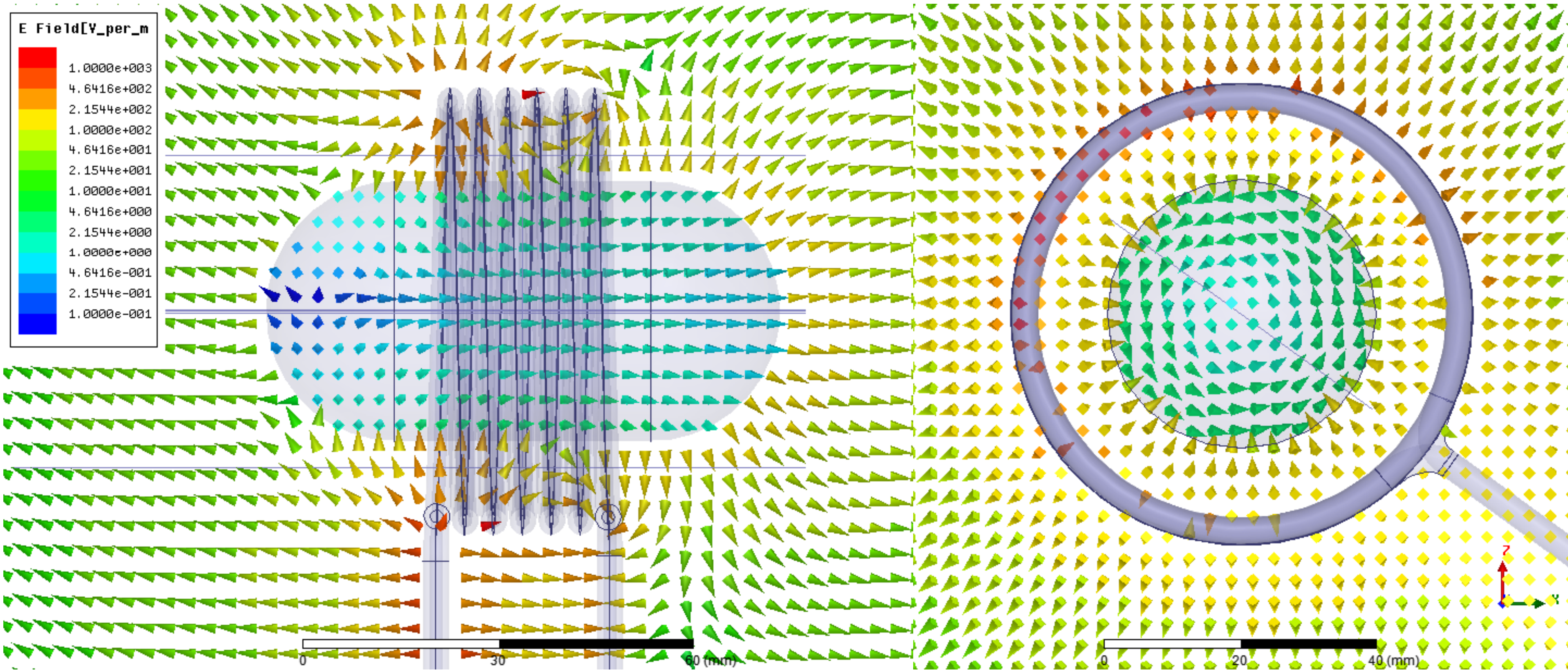
E-field: antenna + “plasma” (σ = 1e-4 S/m)



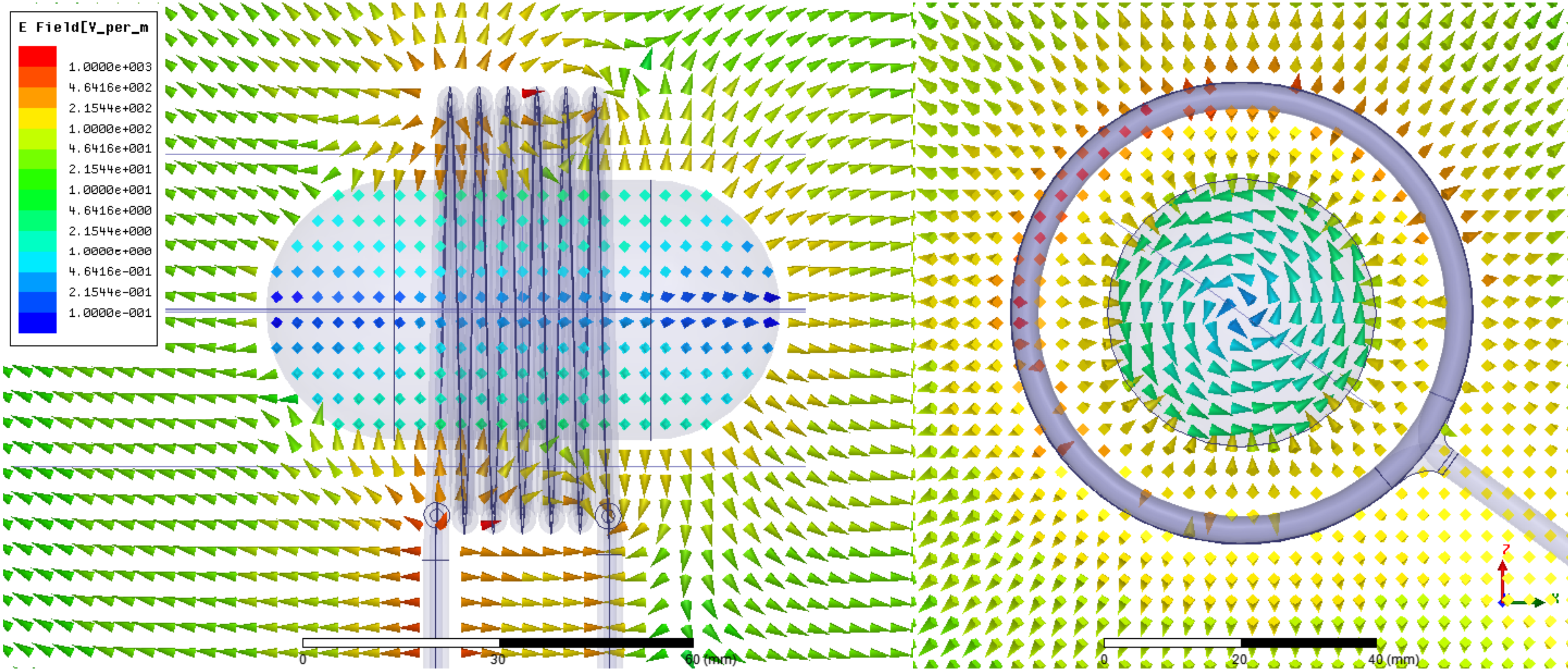
E-field: antenna + “plasma” (σ = 1e-3 S/m)



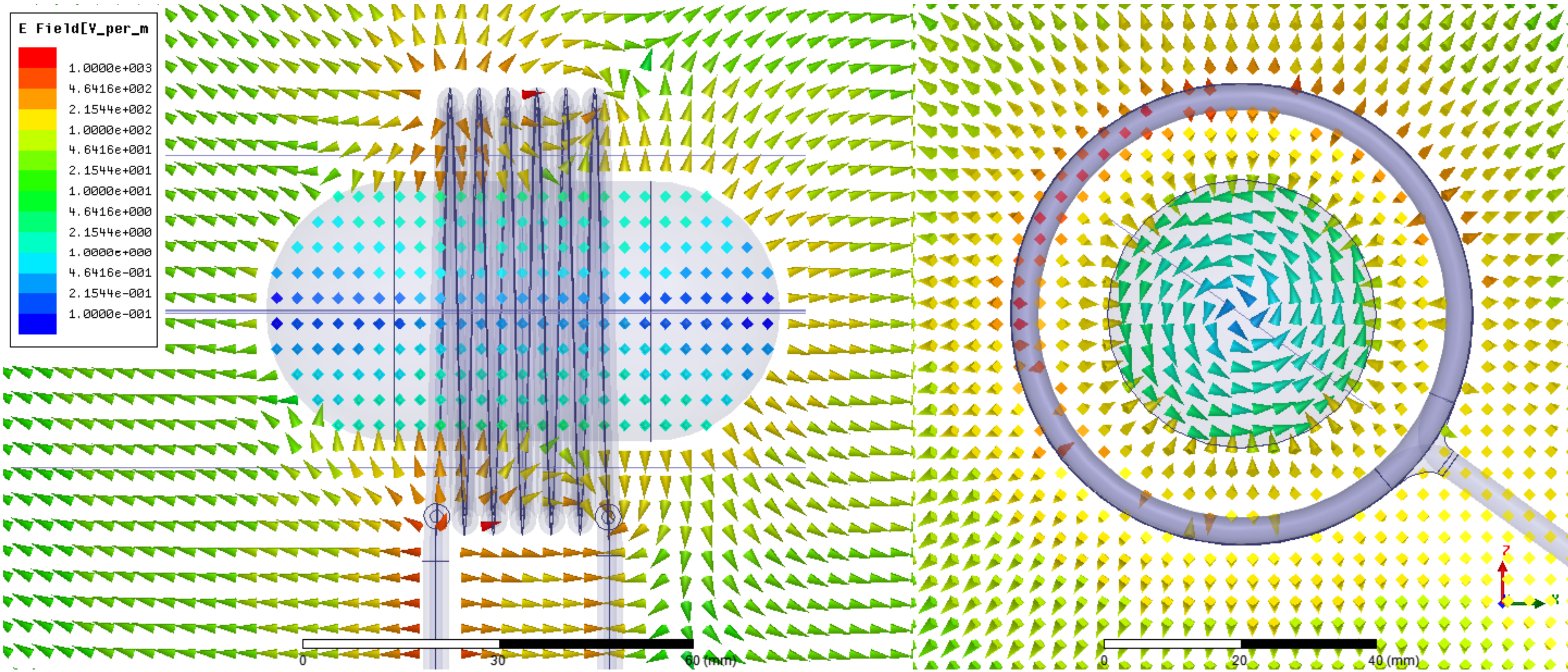
E-field: antenna + “plasma” (σ = 1e-2 S/m)



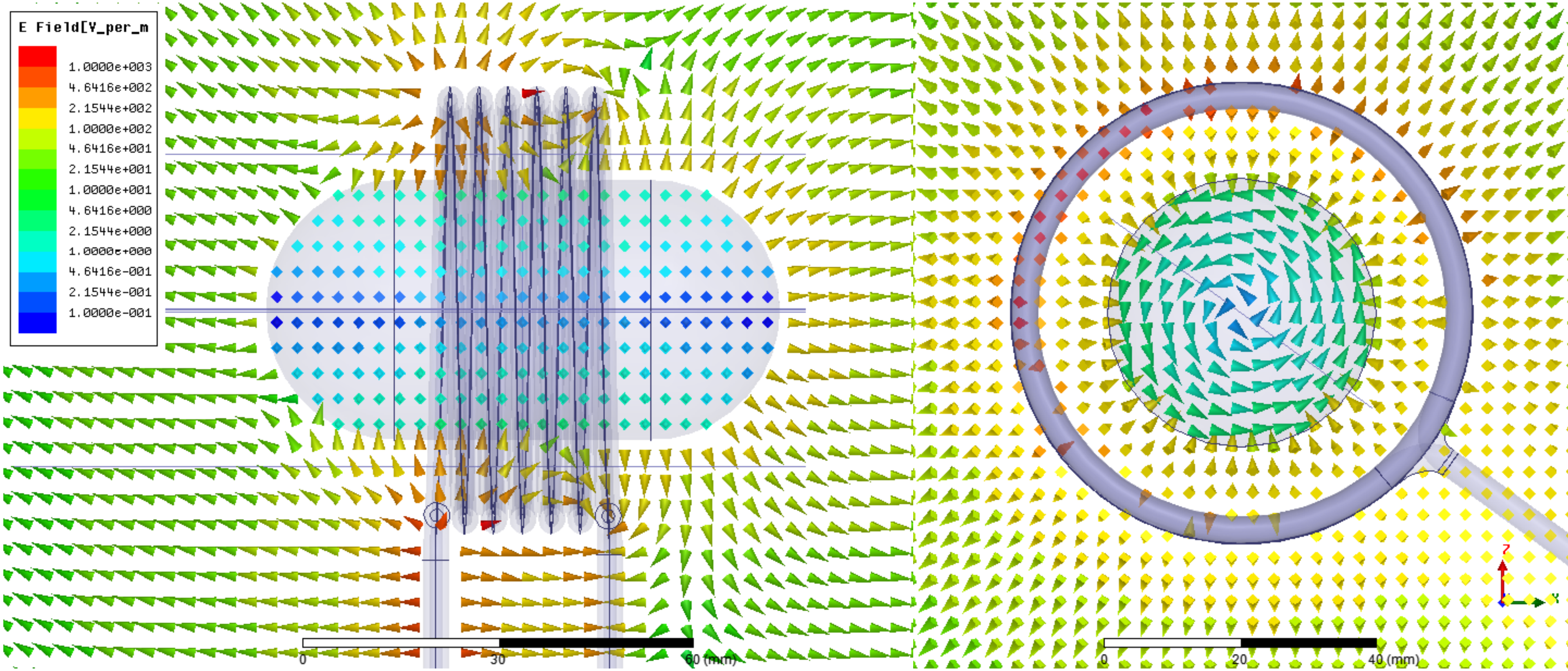
E-field: antenna + “plasma” (σ = 1e-1 S/m)



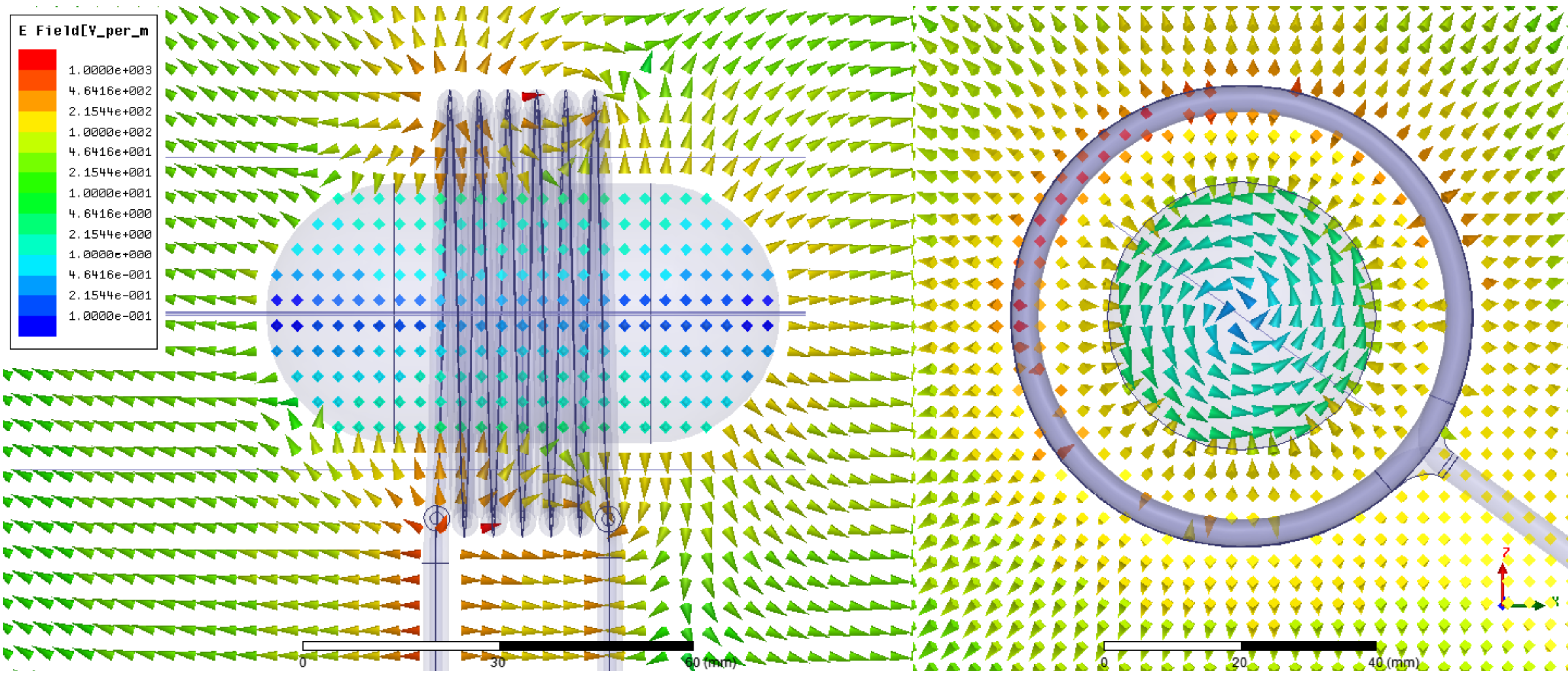
E-field: antenna + “plasma” (σ = 1e-0 S/m)



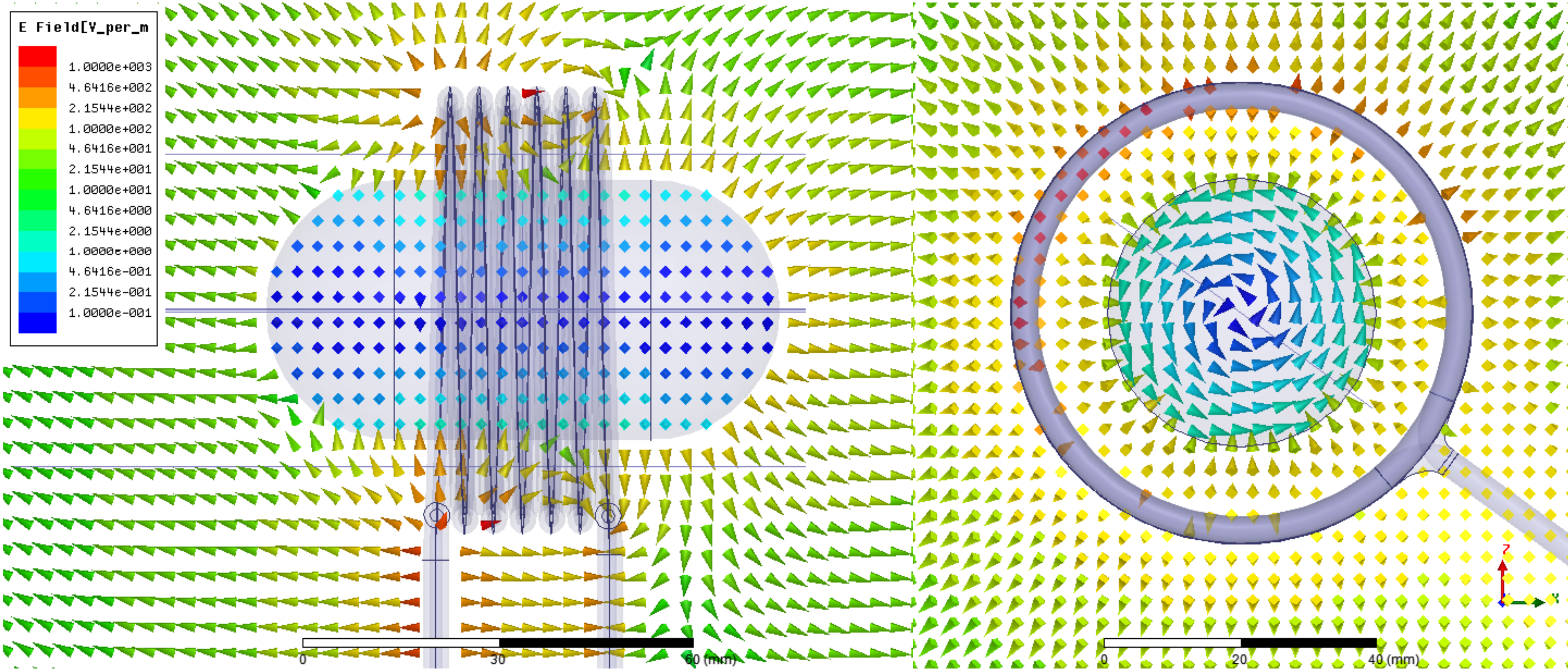
E-field: antenna + “plasma” (σ = 1e+1 S/m)



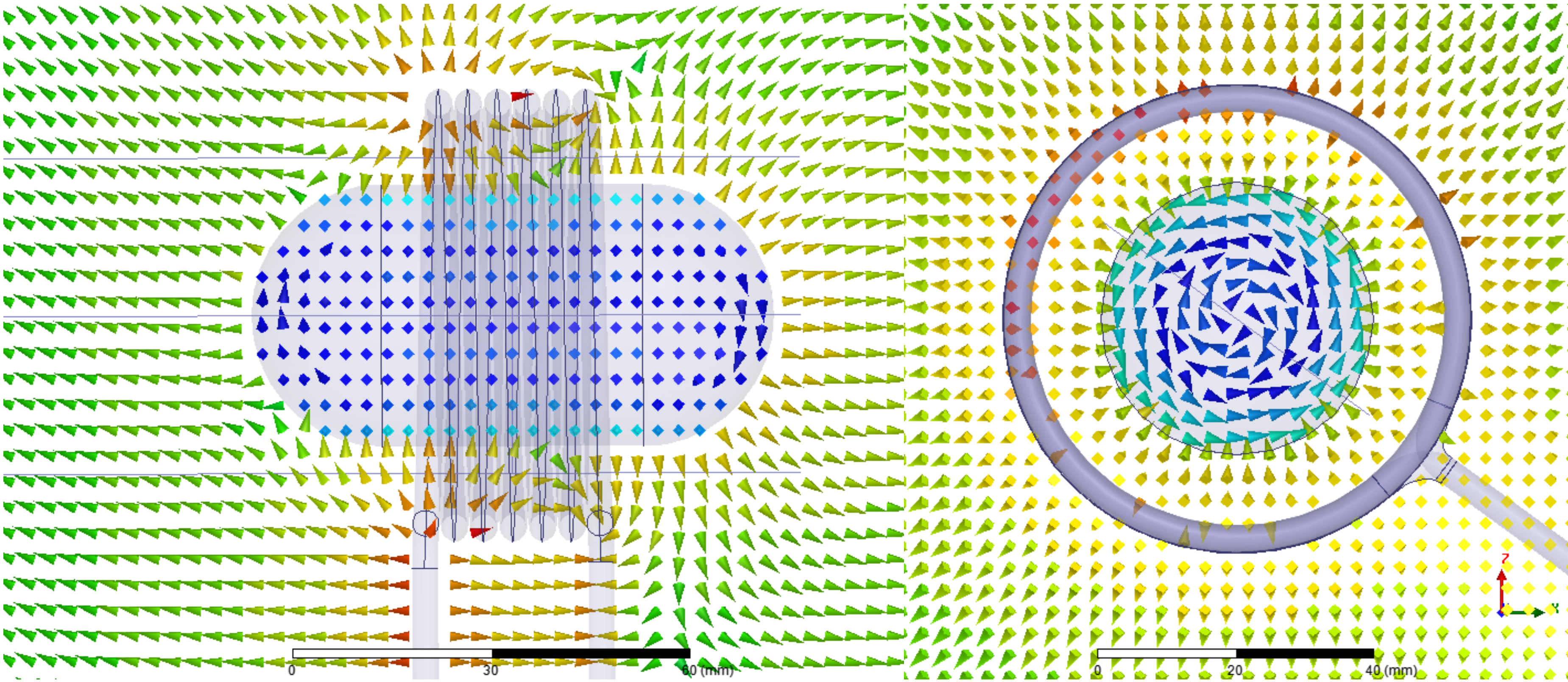
E-field: antenna + “plasma” (σ = 1e+2 S/m)



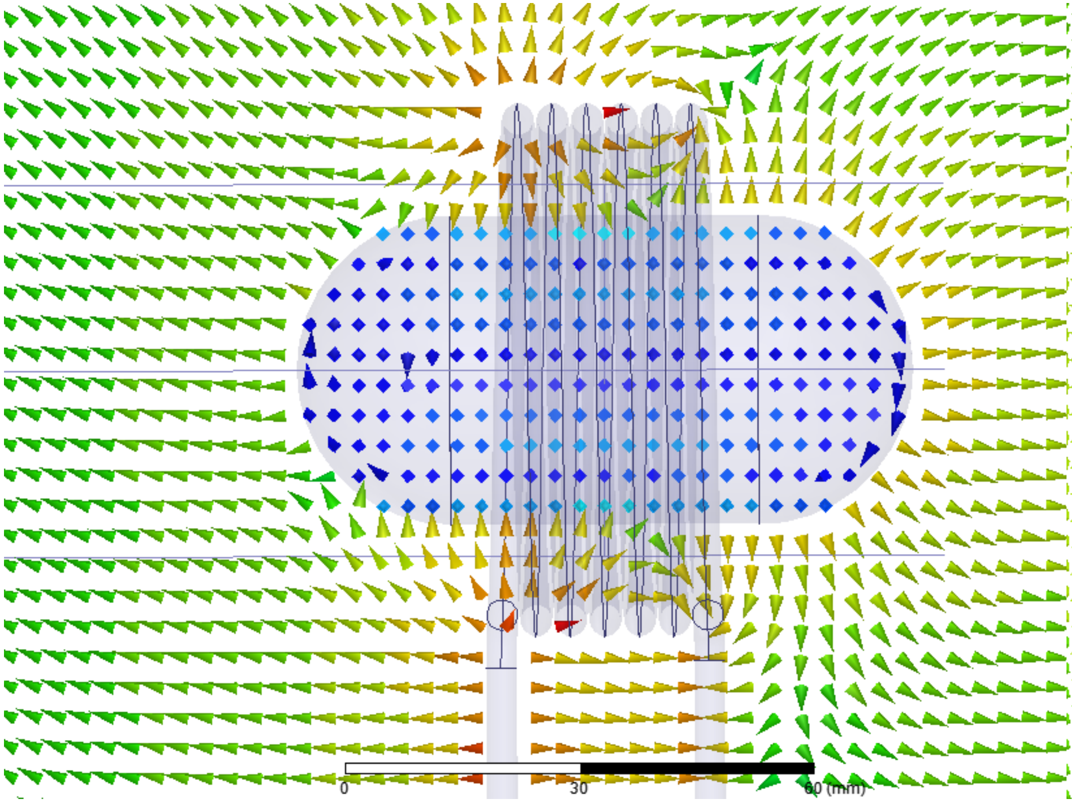
E-field: antenna + “plasma” (σ = 1e+3 S/m)

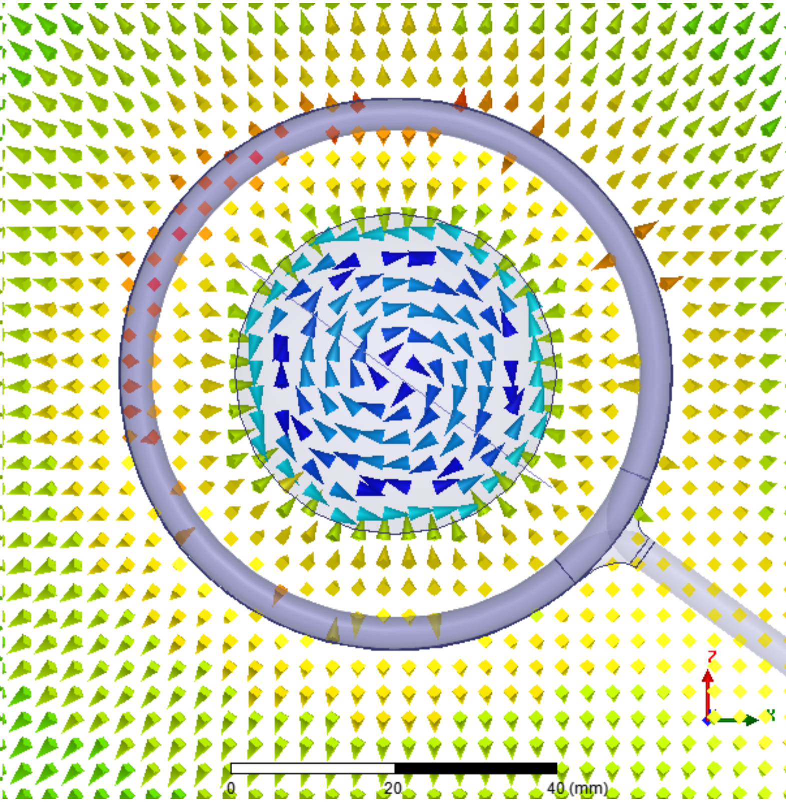


E-field: antenna + "plasma" (σ = 2e+3 S/m)



E-field: antenna + “plasma” (σ = 3e+3 S/m)





E-field: antenna + "plasma" (σ = 1e+4 S/m)