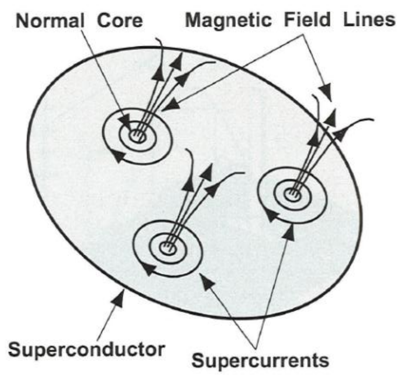
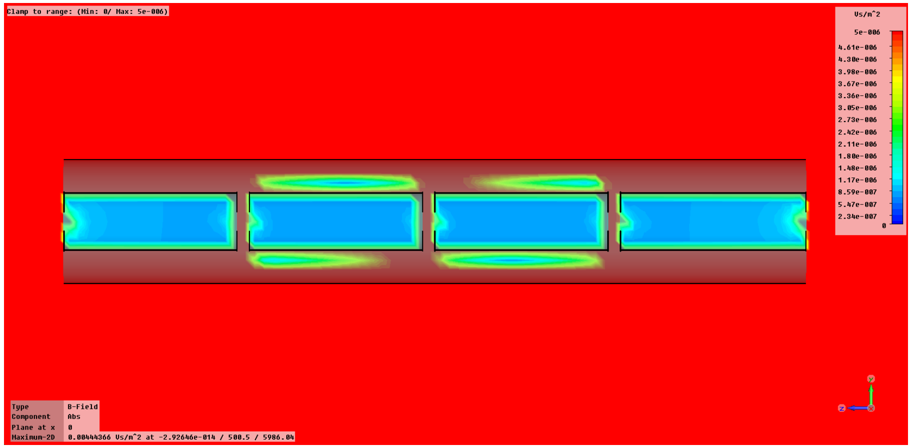
Magnetic shielding for SPL cavities
Electromagnetic Simulations





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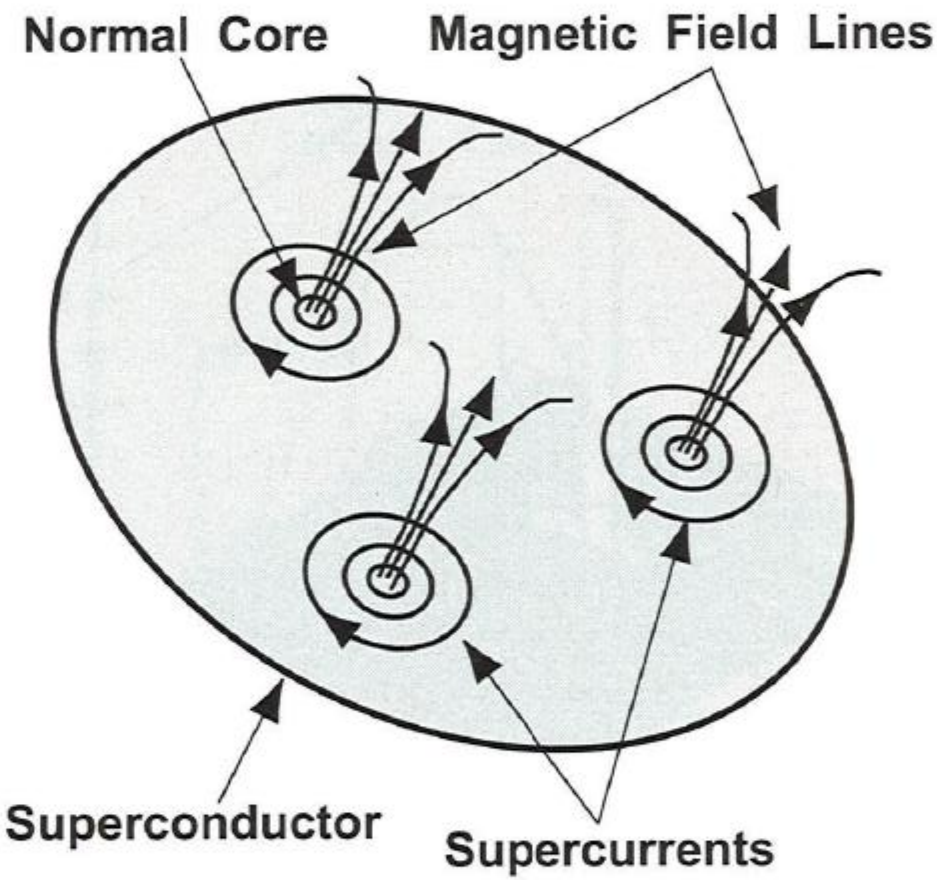

H. Padamsee et al. RF Superconductivity for Accelerators

$$R_{mag} = \frac{H_{ext}}{2H_{c2}} R_n$$

$$R_{mag}[n\Omega] = 3H_{ext}[\mu T]\sqrt{f[GHz]}$$

for RRR=300

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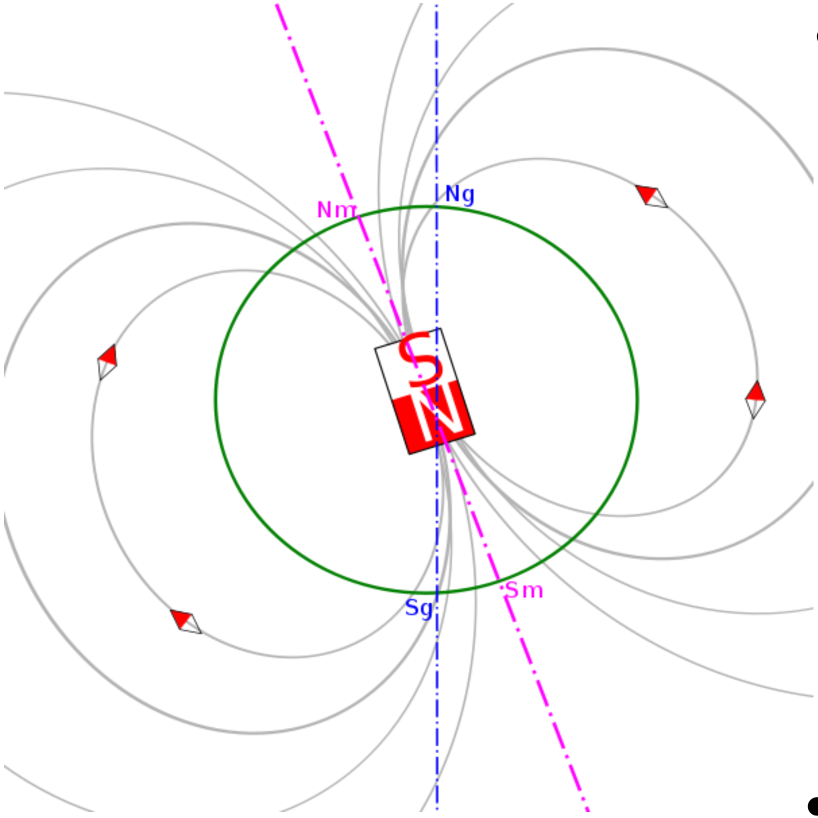

http://nl.wikipedia.org/wiki/Gebruiker:JrPol

- Assumptions
  - SPL goes straight from the South to the North (worst case)
  - Magnetic field 48 µT
    - Vertical 44 µT
    - Horizontal 20 µT

- Requirement
  - Less than 1 µT on cavity surface

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$$R_{mag}[n\Omega] \propto \sqrt{f[GHz]}$$

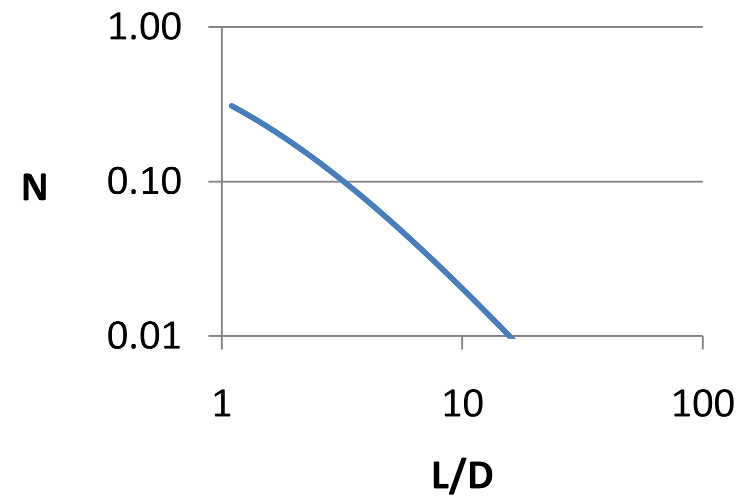
$$S_{\perp} \cong \frac{\mu d}{D} + 1$$

Bigger cavities need thicker shields for same field!

$$S_{\parallel} \cong 4NS_{\perp}$$

$$N \approx \frac{D^2}{2L^2}$$

Longer cylinders shield the longitudinal field less effective



Shielding of horizontal field is harder than of vertical

S: Shielding factors
μ: Permeability of material
d: Thickness of sheet
D: Diameter of cylinder
L: Length of cylinder
N: Demagnetization coefficient

- DESY (TTF)
  - 1 mm Cryoperm Shield attached to helium tank
  - Remagnetisation of soft iron vacuum vessel
- PEFP/SNS
  - Two amumetal magnetic shields
    - Inner shield attached to helium vessel
    - Outer shield attached to support structure
- TRASCO
  - 1 mm Cryoperm shield inside the helium tank
- S-DALINAC
  - Vertical - 0.1 mm sheets of cryoperm
  - Horizontal - Solenoid

Four questions:
- Active or passive shield?
- One or two shields?
- Where to put the shield?
- Which material?

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- **One inner shield per cavity**
  - Horizontal field is harder to shield
  - Demagnetization factor decreases quadratically with length
  - Around **inner thermal shield**
    - As close as possible to the cavity (more effective and less expensive)
    - End caps necessary between every cavity

$$S_{\parallel} \cong 4NS_{\perp} \qquad S_{\perp} \cong \frac{\mu d}{D} + 1$$

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Longer cylinders shield the longitudinal field less effective

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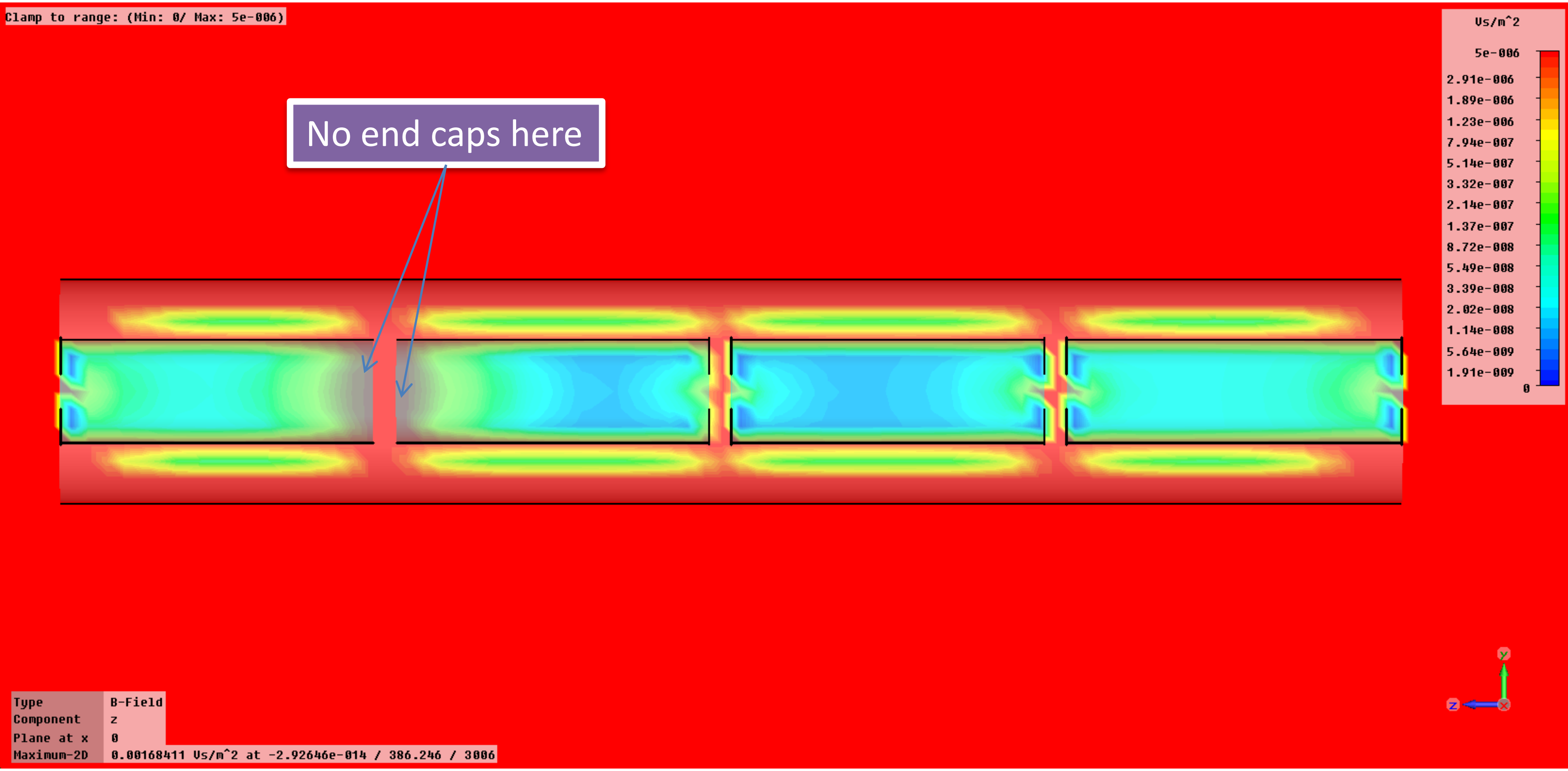
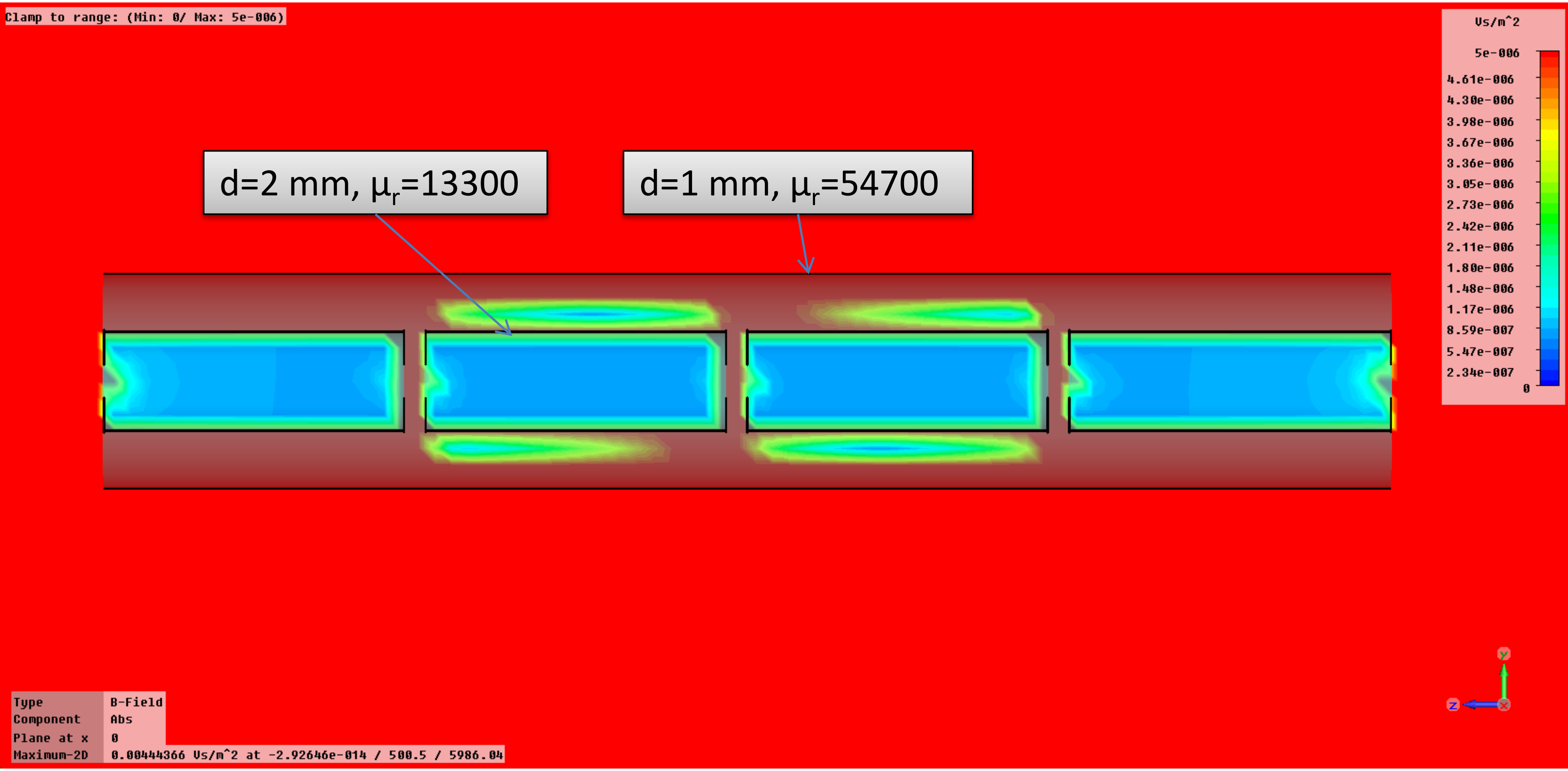
End caps necessary between every cavity!



Four questions:
- Active or passive shield?
- One or two shields?
- Where to put the shield?
- Which material and thickness?

- **One inner shield per cavity**
  - Horizontal field is harder to shield
  - Demagnetization factor decreases quadratically with length
  - Around **inner thermal shield**
    - As close as possible to the cavity (more effective and less expensive)
  - End caps necessary between every cavity
- **Two passive** shields
  - Outer shield helps to reduce the fields especially between two cavities
- **Amumetal or Cryoperm inside, Mumetal outside**
  - For realistic μ_r values a thickness of **1 mm outside** and **2 mm inside** sufficient

Numerical model has been crosschecked with simplified analytical expression
Numerical value for magnetic field in the middle of one cavity only 4 % higher



μ_r values taken from TESLA-Report 1994-23, measured on test cylinders

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Four answers:

- Passive shields
- Two shields
- One inner shield per cavity,
  one outer shield per module
- 2 mm Cryoperm or Amumetal inside
  1 mm Mumetal outside

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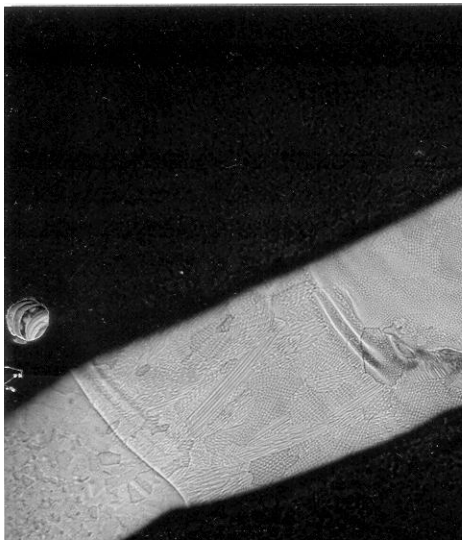
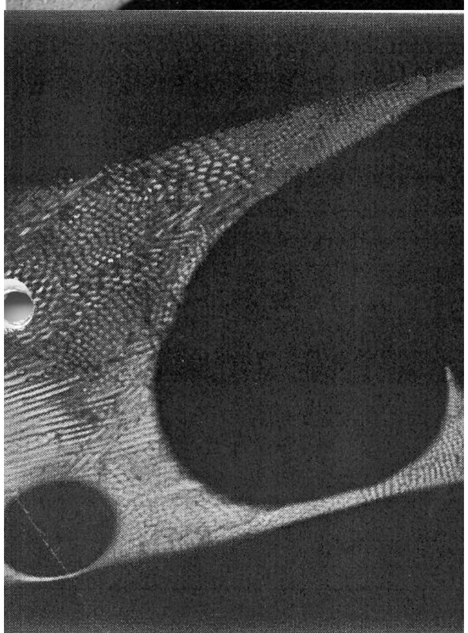
Application of mumetal: LHC septa chambers





EST/SM Study of the influence of TIG welding and subsequent annealing on a Mumetal tube

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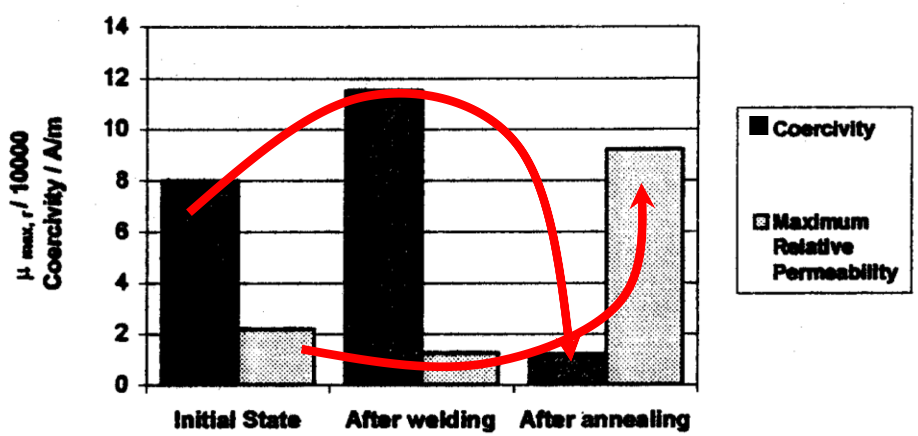
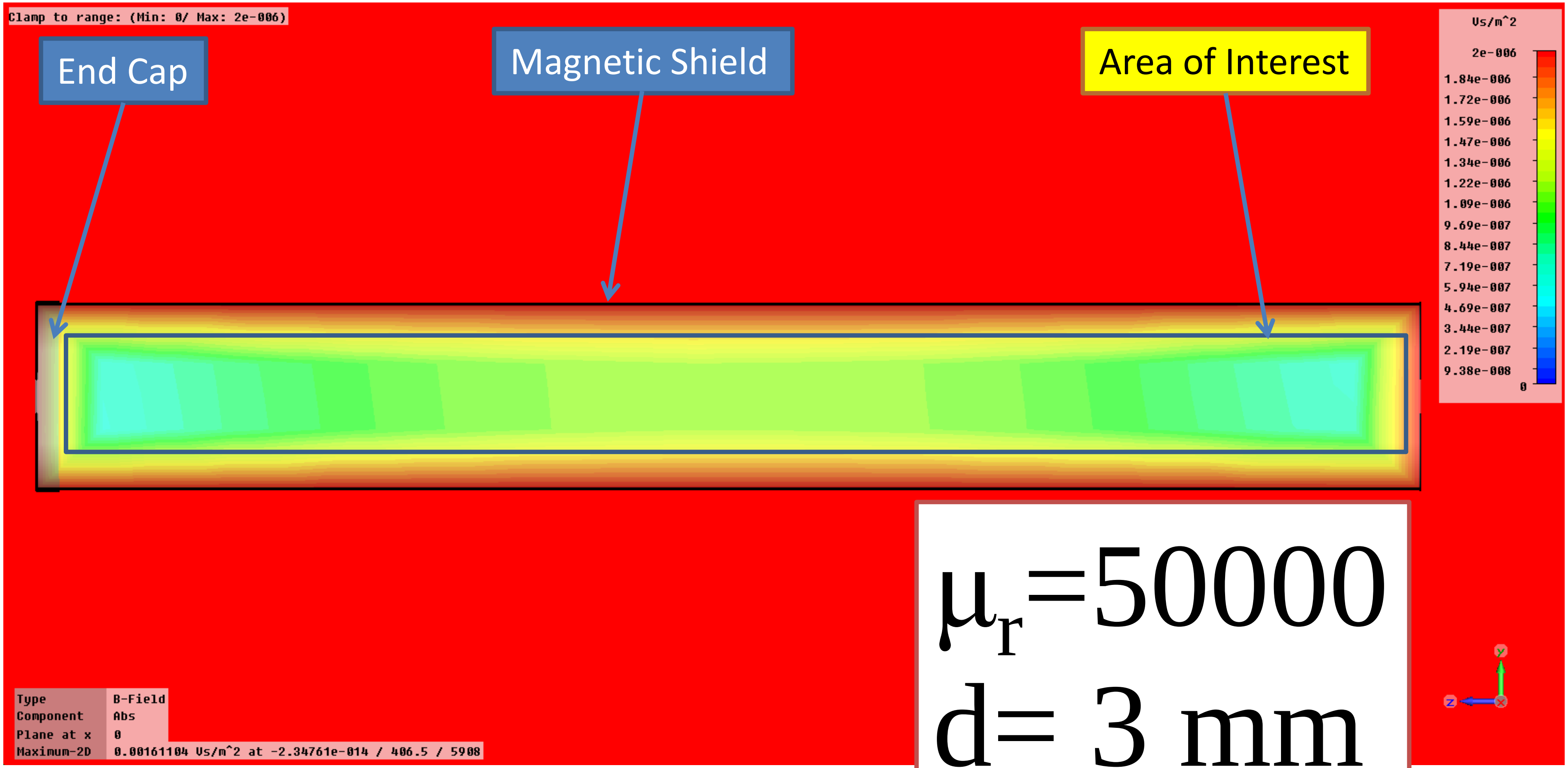
Testing of magnetic properties and relative results

Graph, Table:	**Summary of the evolution of the measured magnetic properties on the Mumetal rings.**
Material:	**Mumetal**
Samples ID:	**ring 1, ring 2**
Density:	**8.6**
Weight before welding:	**ring (1&2) – 28.98 g**
Weight after welding:	**ring 1 – 14.47 g** **ring 2 – 14.42 g**
Permeameter:	**90 turns used for excitation** **180 turns used for detection**



Note: The properties of the initial state were measured on the two rings coupled. After the TIG welding, they were measured on both rings together and on each one separately. Since the measured values of the magnetic properties were reproducible between ring 1 and ring 2, further operations and measurements were performed only on one ring (ring 1).

Numerical model has been crosschecked with simplified analytical expression
Numerical value for magnetic field in the middle only 4 % higher



μ_r=50000
d= 3 mm

If the whole cryomodule shares one shield a maximum field value of approximately 1 μT can be achieved for μ_r=50000 and d=3 mm

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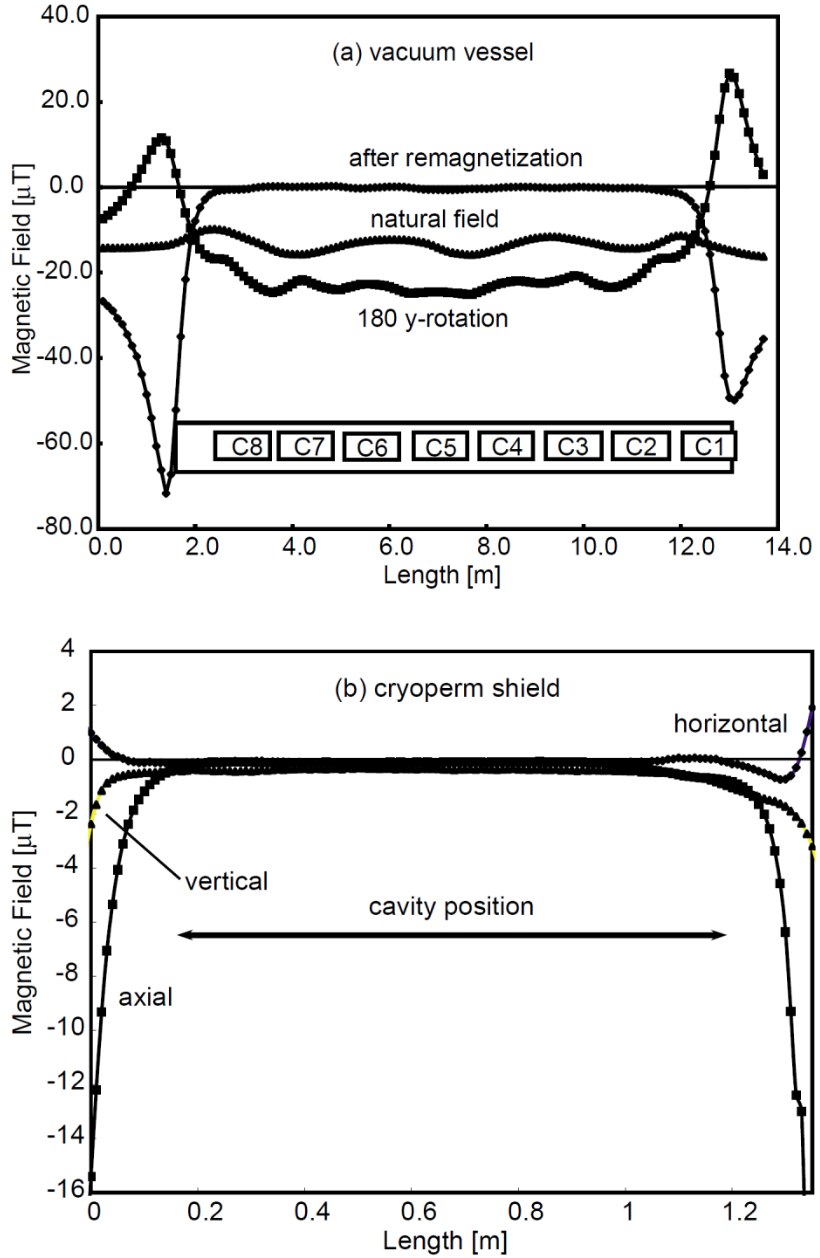
Solutions found by other labs - DESY



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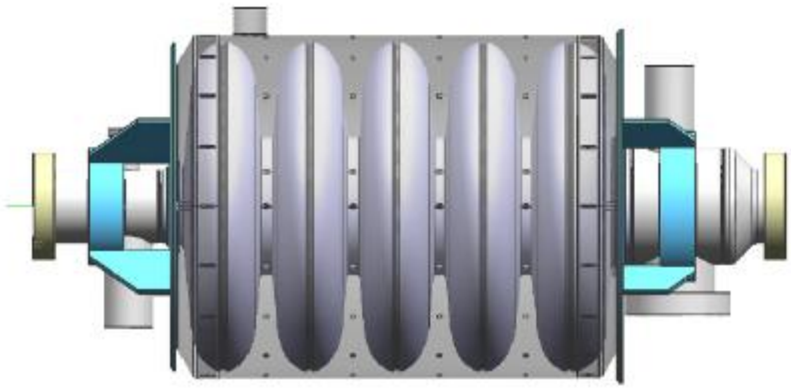
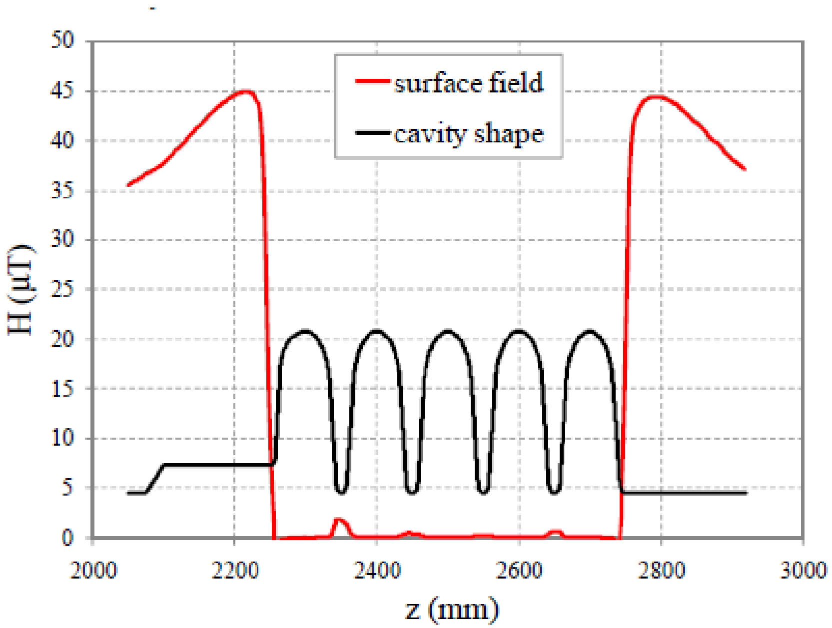
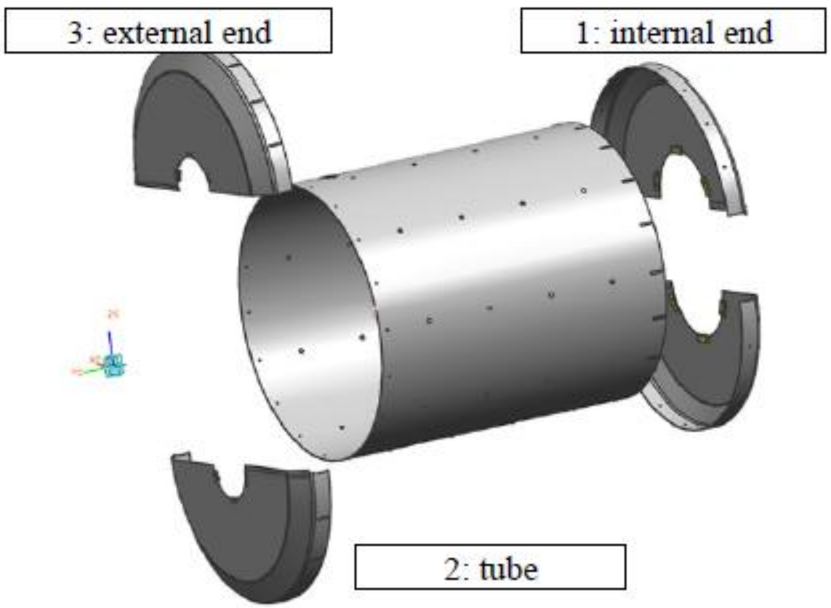


- 30 μT field parallel to beam axis
- 1 mm thick cryoperm 10 shield (μ_r=150000)
- Two shields have already been produced and their shielding performance will be measured





Case	<H> (μT)	Rs (nΩ)
Ideal: no gap	0.44	1.10
Not ideal: 0.1 mm gap at each end	2.08	5.23

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- Material: Cryoperm 10
- Thickness of sheet: 1 mm
- 206 Cavities
- 500 m^2 sheet
- 4.5 t of material (σ=9 kg/l)
- 450 kCHF (100 CHF/kg)

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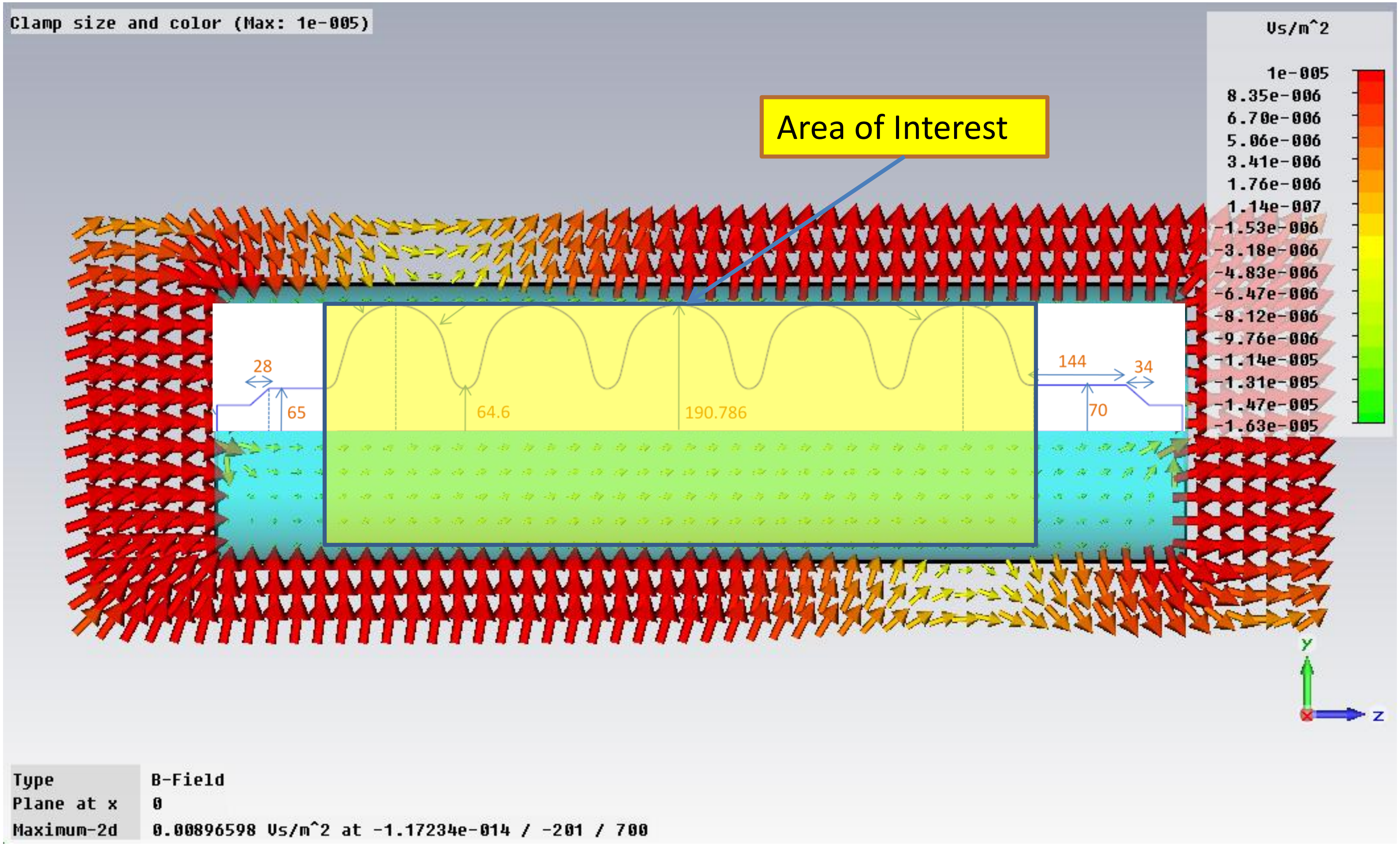
Microwave Studio simulation



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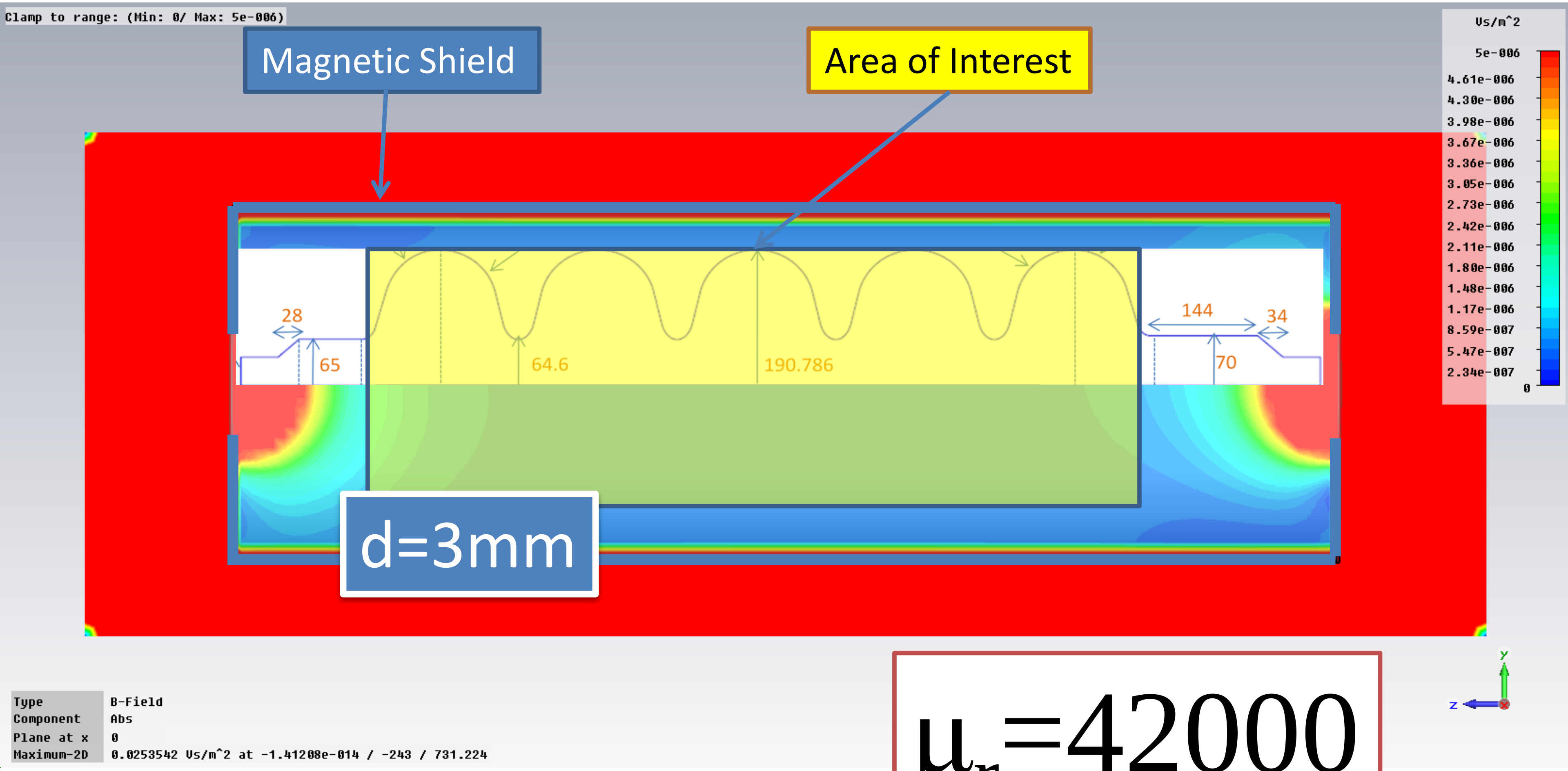
Microwave Studio simulation



μ_r=42000

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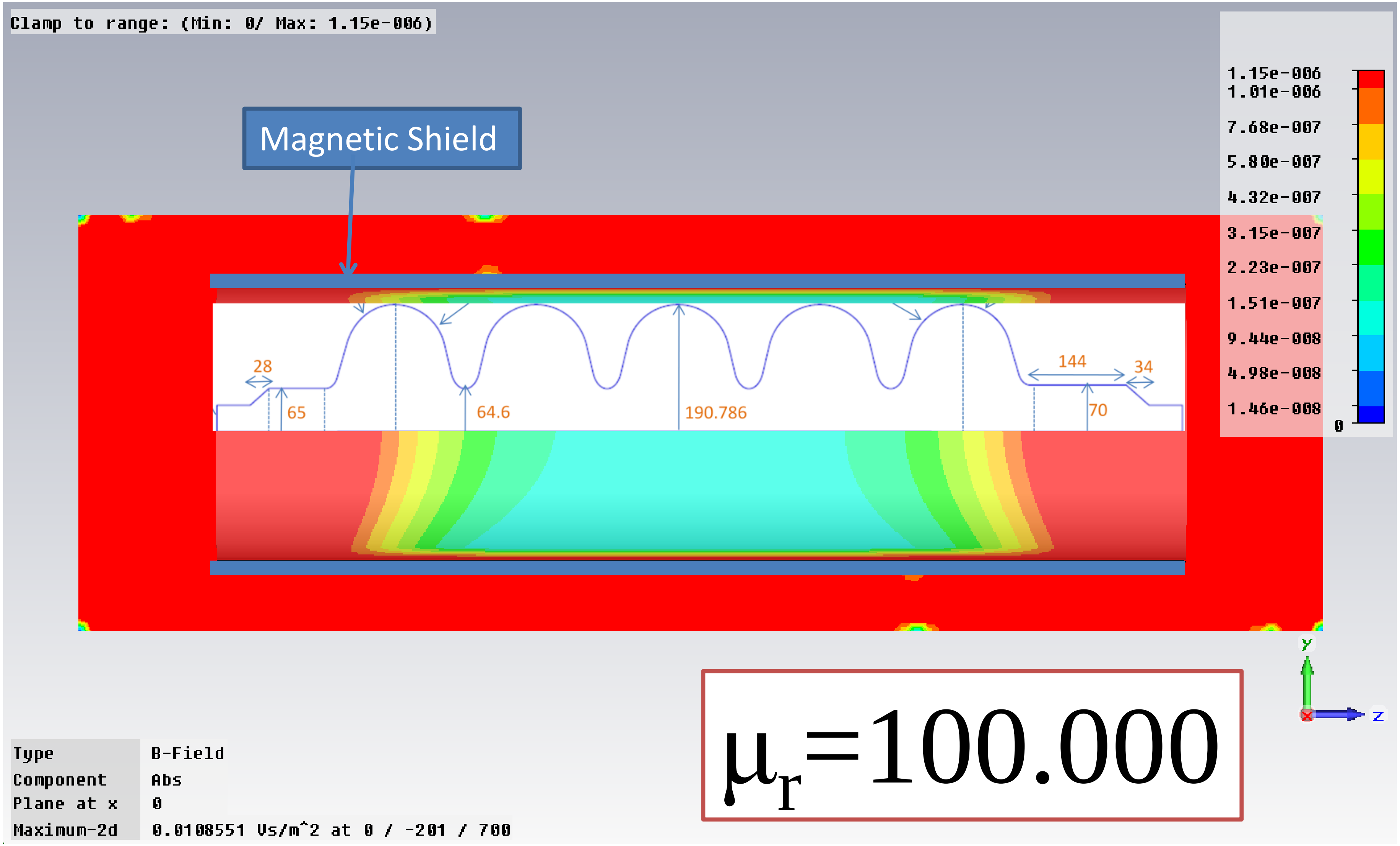
Microwave Studio simulation



μ_r=100.000

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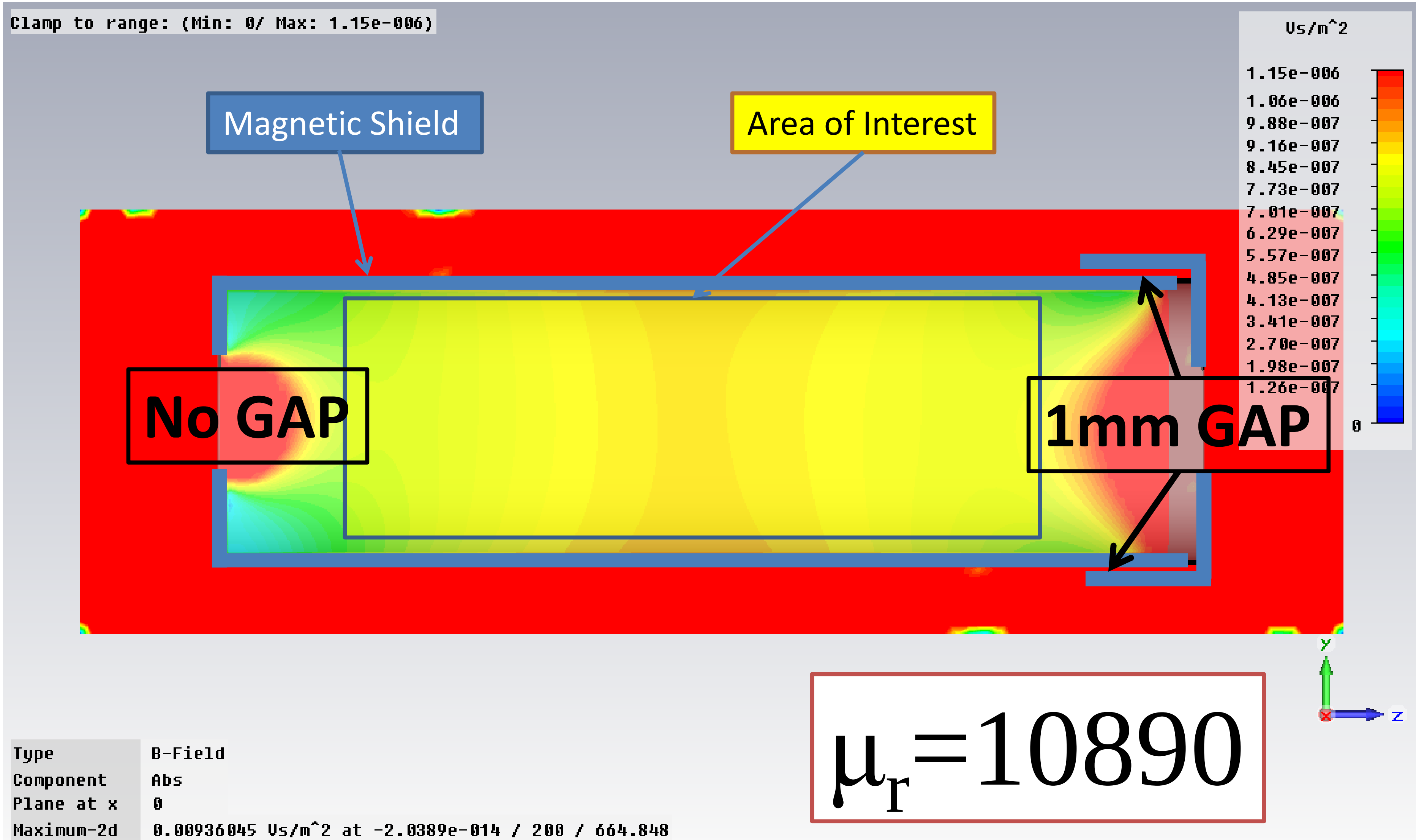
Microwave Studio simulation



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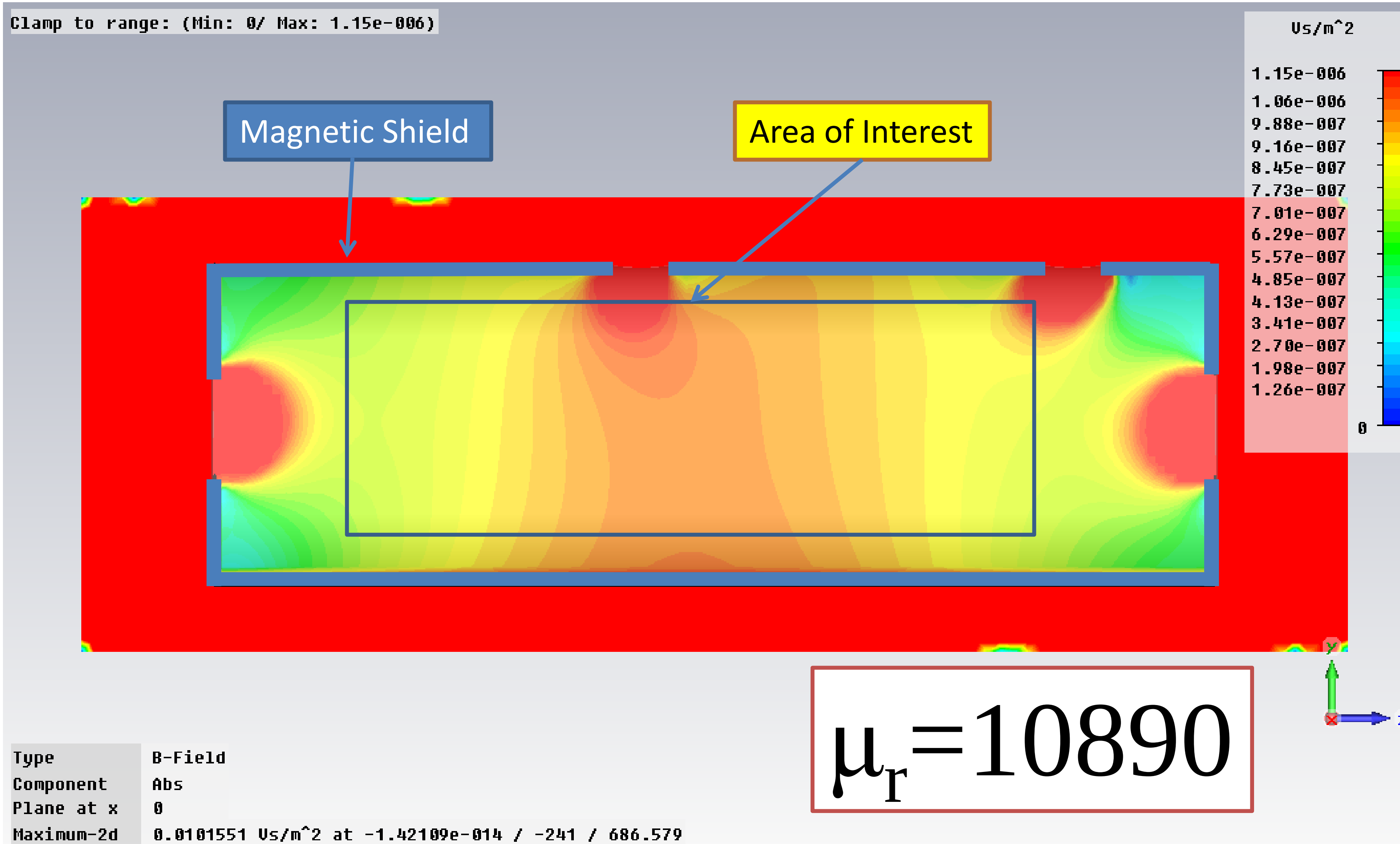

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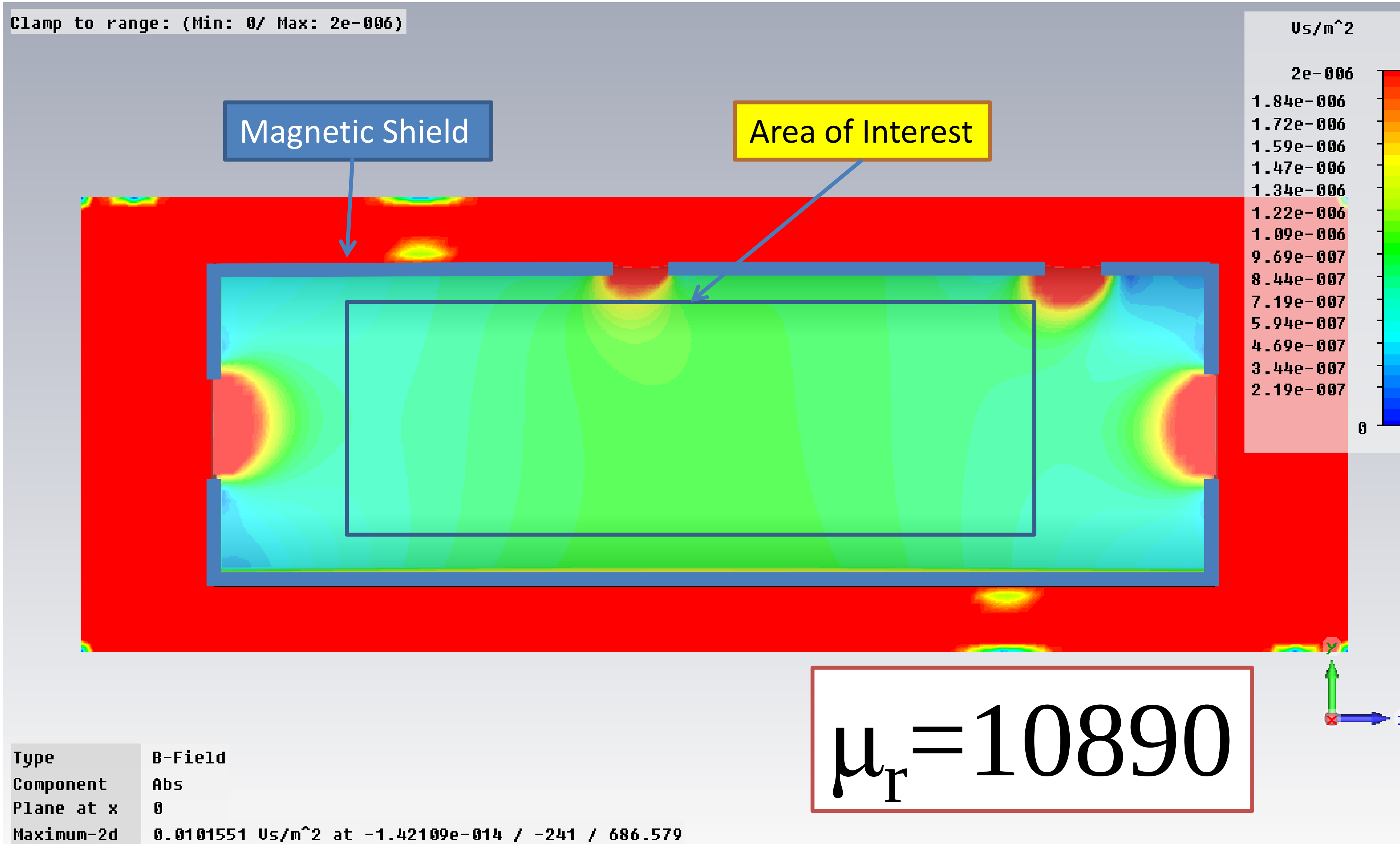
Microwave Studio simulation



$\mu_r = 10890$

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Conclusions

- μ_r = 42.000 needed for the whole temperature range for 3 mm sheet
- End caps are necessary
- A gap of a few millimetres between end caps and cylinder can be tolerated
- Holes lead to higher field values than 1μT in spots of approximately their size

My recommendations:

- External Shield of Cryoperm (3 mm)
- As close as possible to the helium tank
- Annealing of tubes and end caps

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