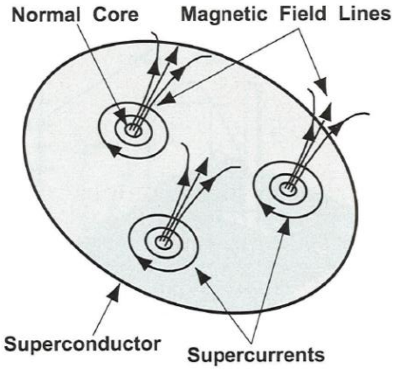
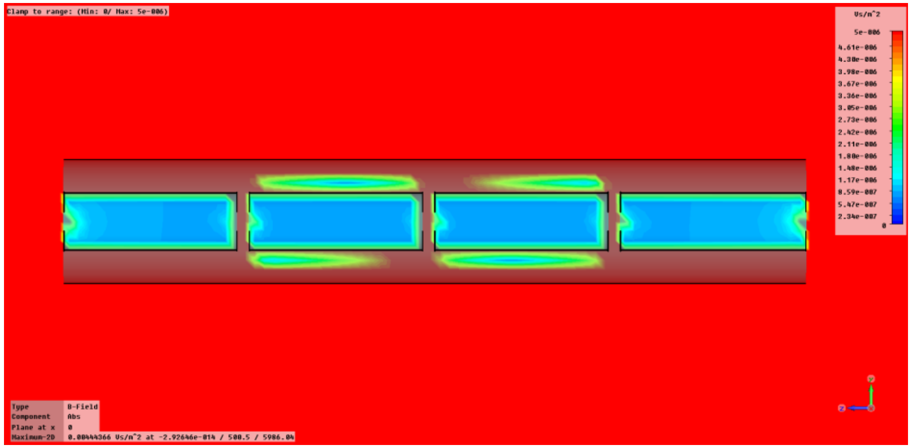
Magnetic shielding for SPL cavities Electromagnetic Simulations




Clamp to range: (Min: 0/ Max: 5e-006)

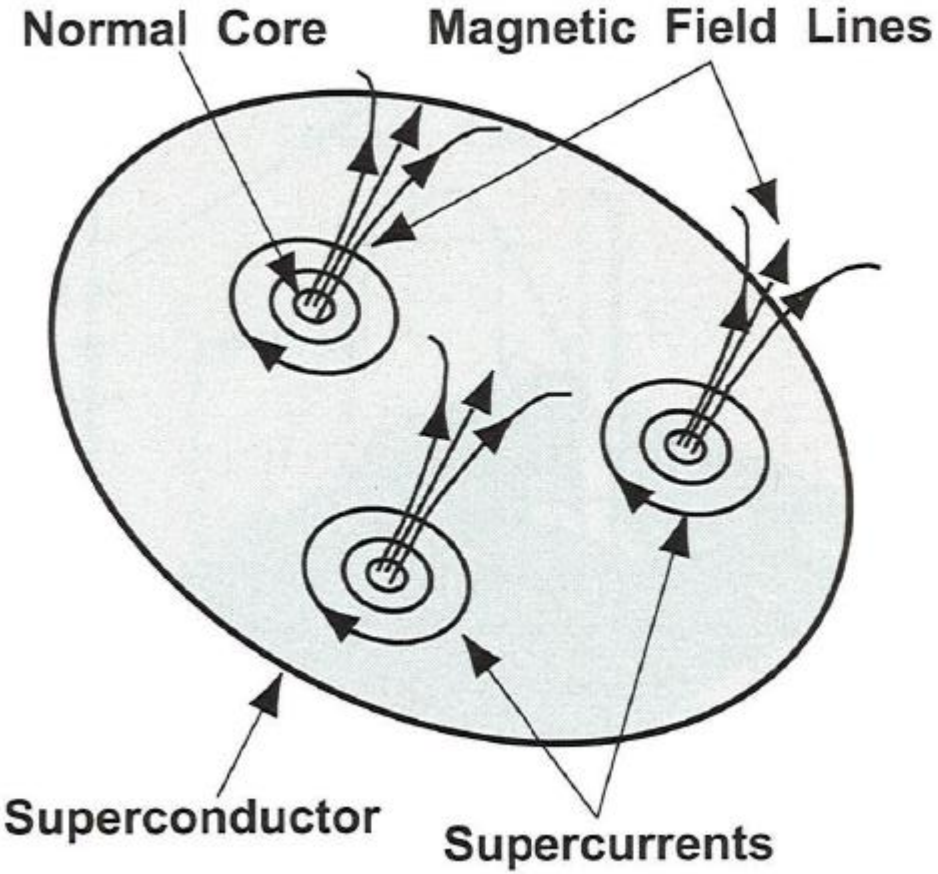
Type B-Field
Component Abs
Plane at x 0
Maximum-2D 0.00444366 Us/m^2 at -2.92646e-014 / 500.5 / 5986.04

Tobias Junginger

Tobias.Junginger@quasar-group.org

8th SPL cavities working group video conference meeting
15.11.2010

Why do we need a Magnetic Shield?



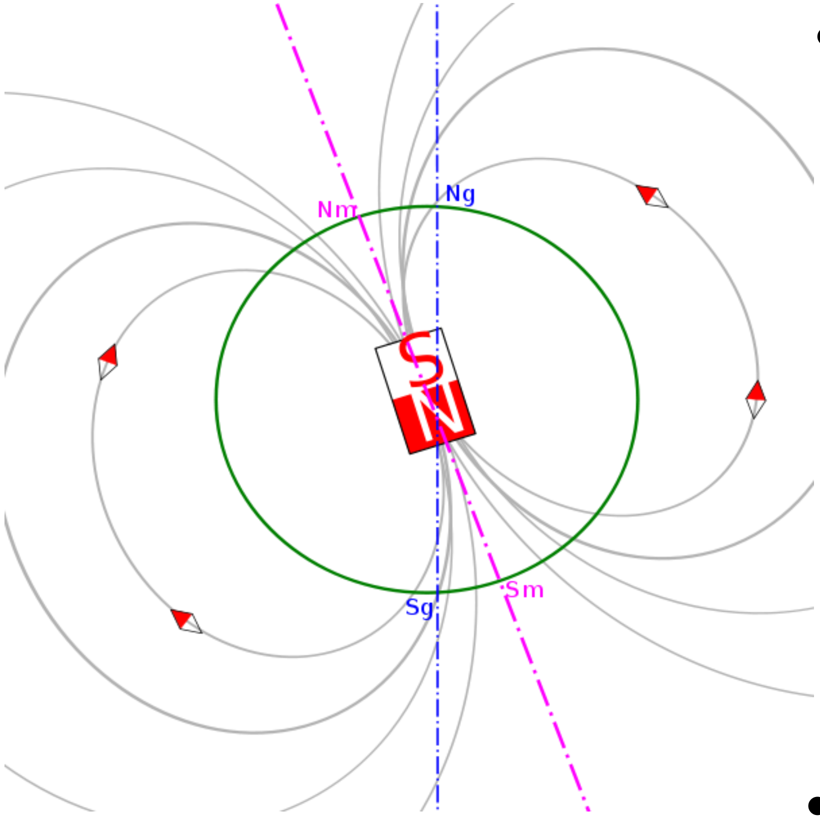
H. Padamsee et al. RF Superconductivity for Accelerators

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

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

for RRR=300

Tobias.Junginger@quasar-group.org



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

Tobias.Junginger@quasar-group.org

Shielding Factors of an Open Cylinder

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

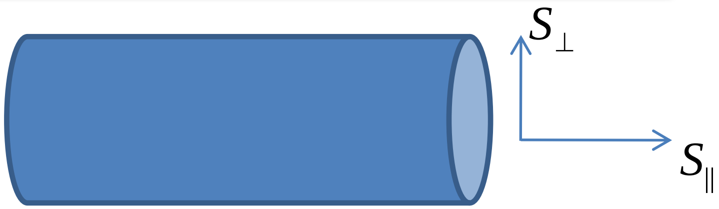
$$S_{\perp} \cong \frac{\mu d}{D} + 1$$

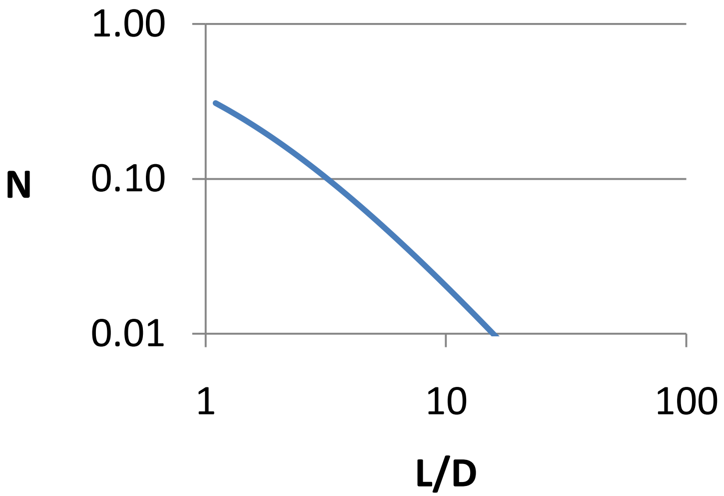
Bigger cavities need thicker shields for same field!

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

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

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

Solutions found by other labs

- 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?

Tobias.Junginger@quasar-group.org

Solutions found by other labs

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

- **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

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

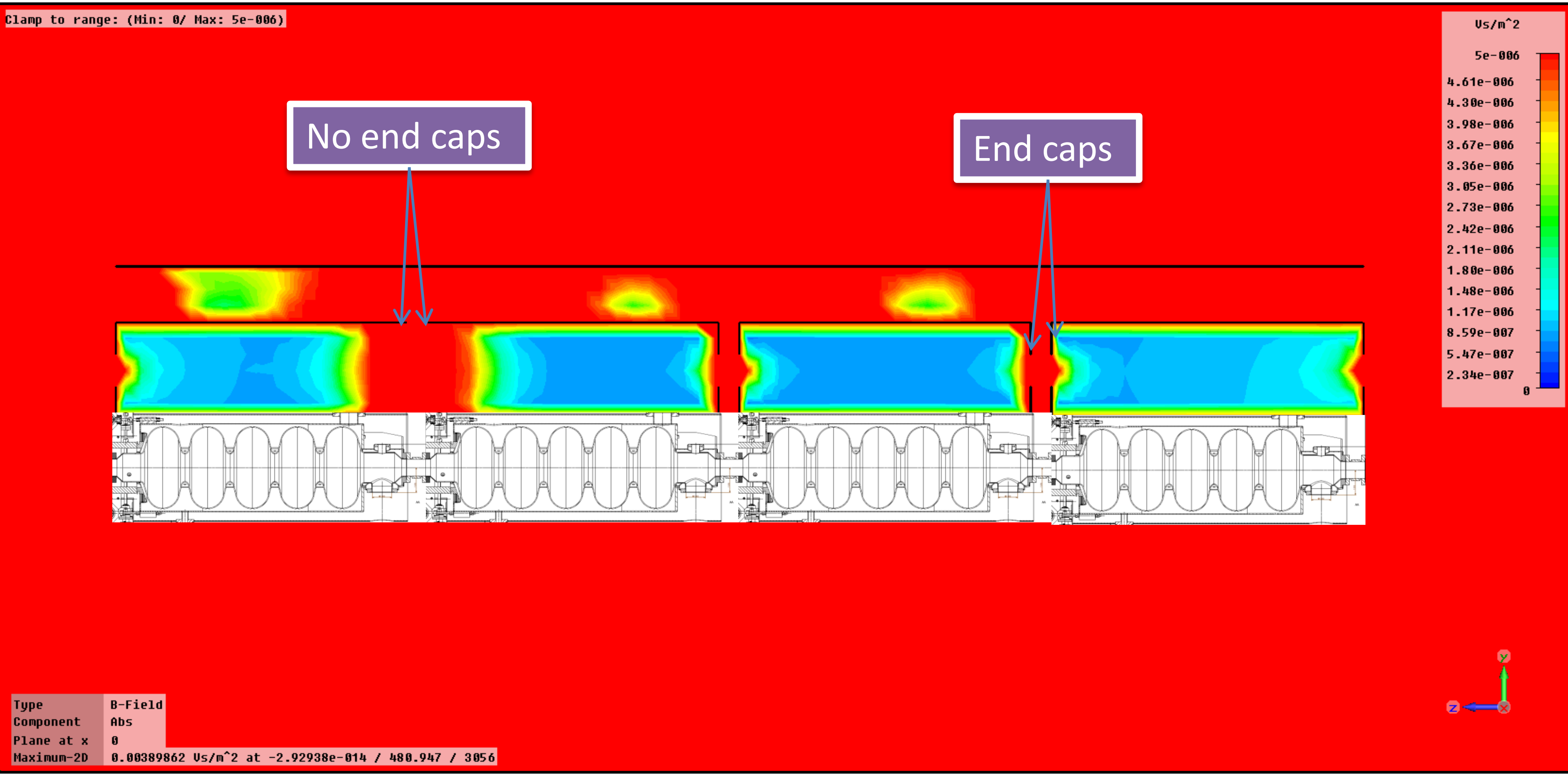
$$N \approx \frac{D^2}{2L^2}$$

Longer cylinders shield the longitudinal field less effective

Tobias.Junginger@quasar-group.org

Solutions found by other labs

End caps necessary between every cavity!



Tobias.Junginger@quasar-group.org

Solutions found by other labs

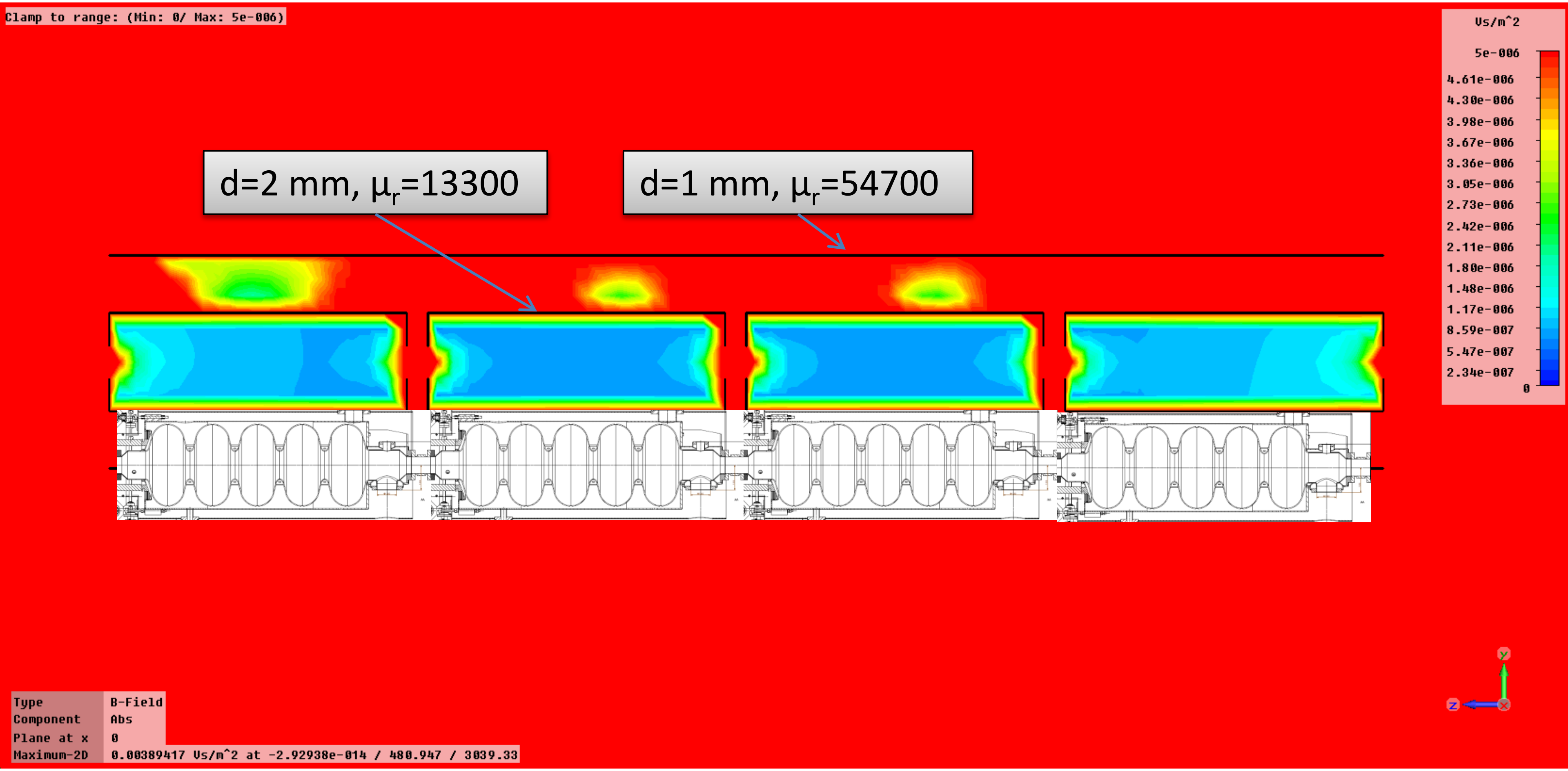
Four questions:
- Active or passive shield?
- One or two shields?
- Where to put the shield?
- Which material and thickness?

- **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

Tobias.Junginger@quasar-group.org

Solutions found by other labs

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



Clamp to range: (Min: 0/ Max: 5e-006)

d=2 mm, μ_r=13300

d=1 mm, μ_r=54700

Type	B-Field
Component	Abs
Plane at x	0
Maximum-2D	0.00389417 Vs/m^2 at -2.92938e-014 / 480.947 / 3039.33

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

Tobias.Junginger@quasar-group.org

Solutions found by other labs

Four questions:

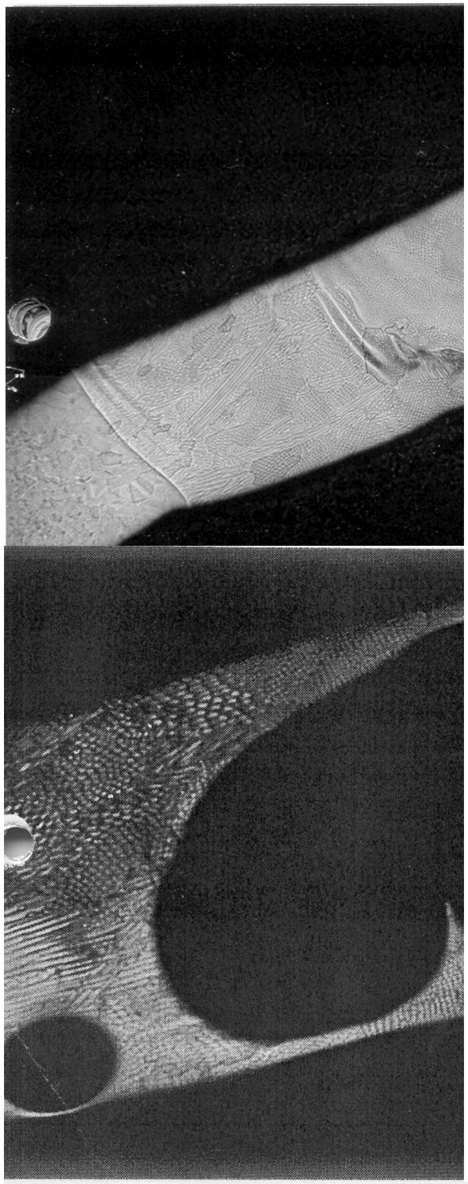
- Active or passive shield?
- One or two shields?
- Where to put the shield?
- Which material and thickness?

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

Tobias.Junginger@quasar-group.org

Application of mumetal: LHC septa chambers

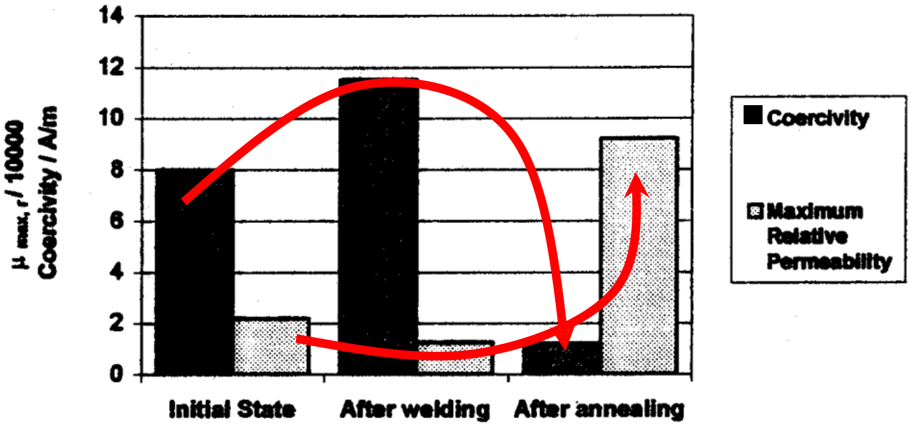


EST/SM Study of the influence of TIG welding and subsequent annealing on a Mumetal tube

Report n. 98/10/06 **Att. 4, page 1 of 1**

Testing of magnetic properties and relative results

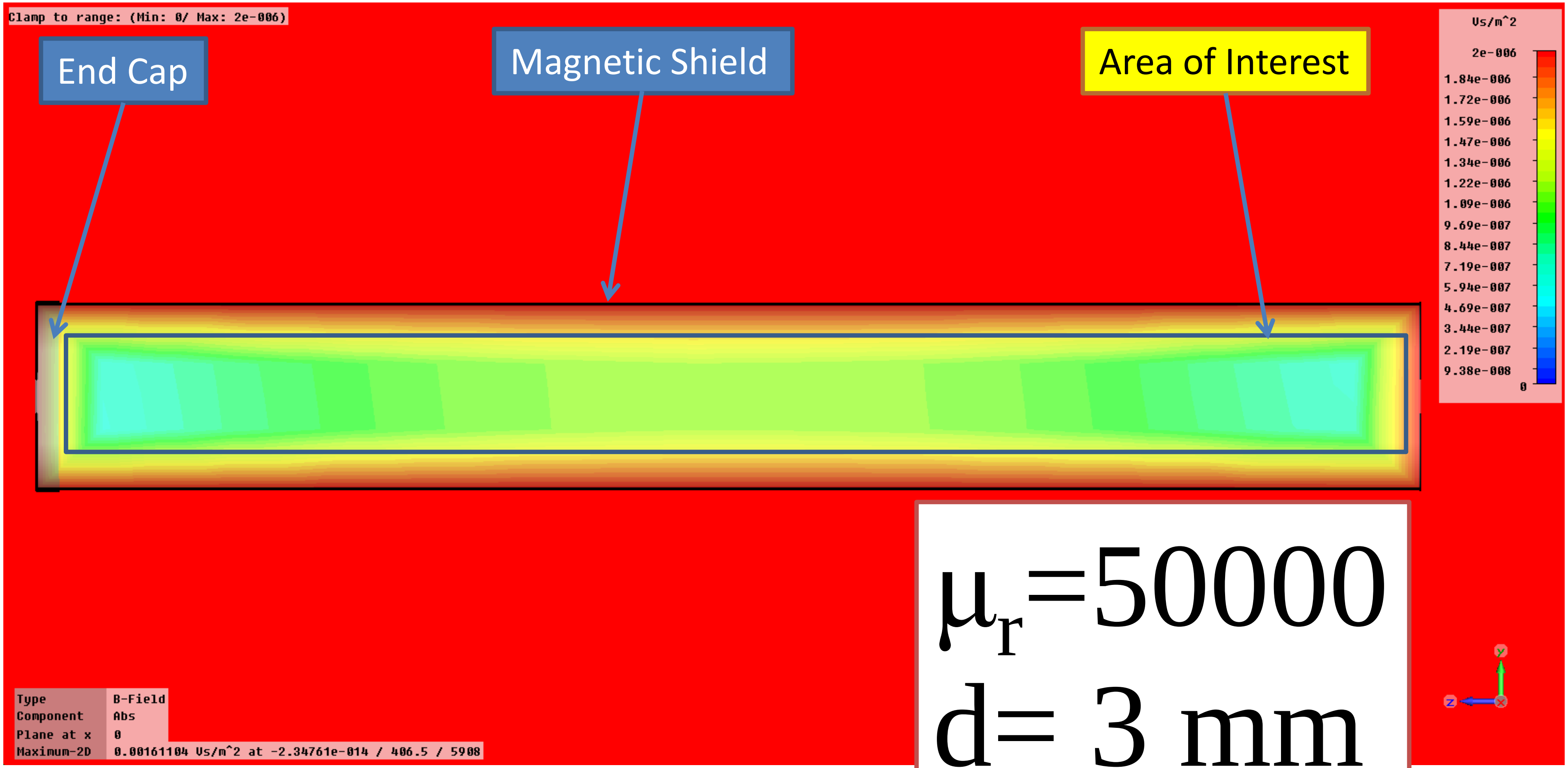
Graph, Table:	**Summary of the evolution of the measured magnetic properties on the Mumetal rings.**
Material:	**Mumetal**
Samples ID:	**ring 1, ring 2**
Density:	**8.6**
Weight before welding:	**ring (1&2) – 28.98 g**
Weight after welding:	**ring 1 – 14.47 g** **ring 2 – 14.42 g**
Permeameter:	**90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

Microwave Studio simulation – Whole Module

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



End Cap

Magnetic Shield

Area of Interest

Type	B-Field
Component	Abs
Plane at x	0
Maximum-2D	0.00161104 Vs/m^2 at -2.34761e-014 / 406.5 / 5908

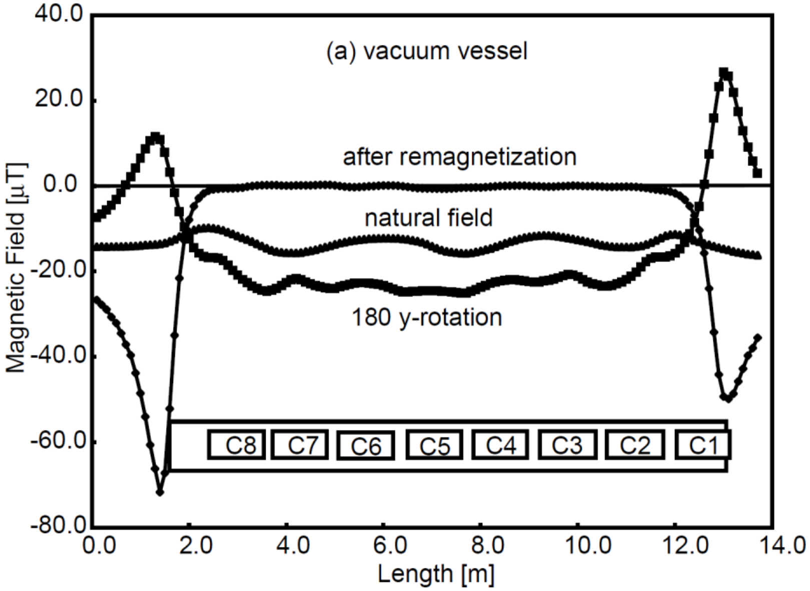
μ_r=50000

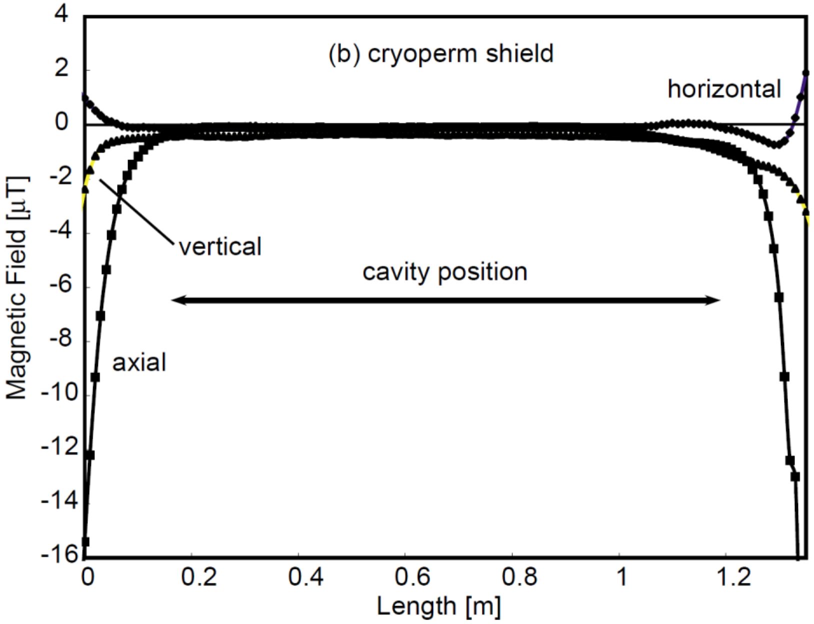
d= 3 mm

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

Tobias.Junginger@cern.ch

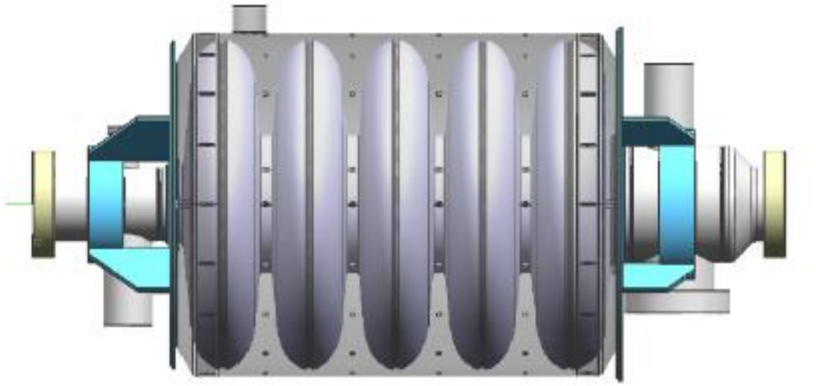
Solutions found by other labs - DESY



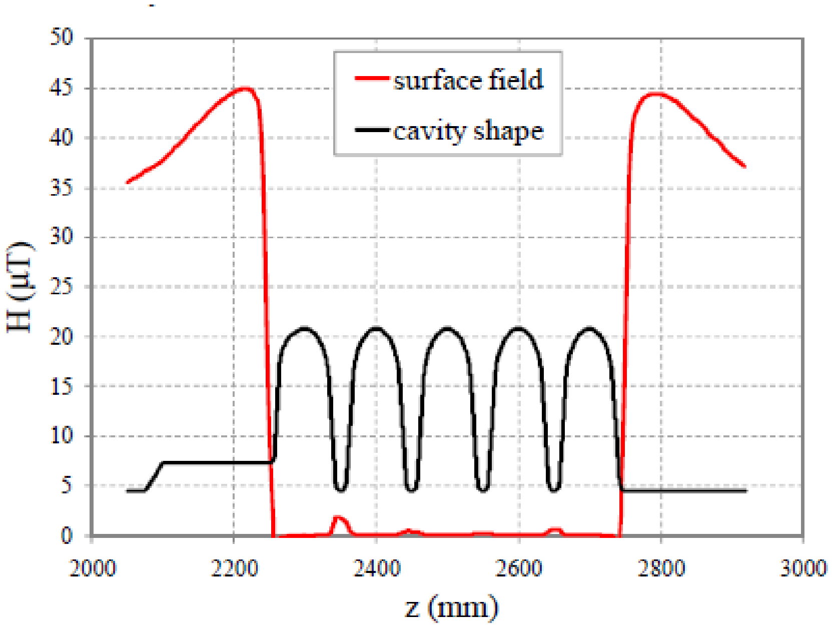


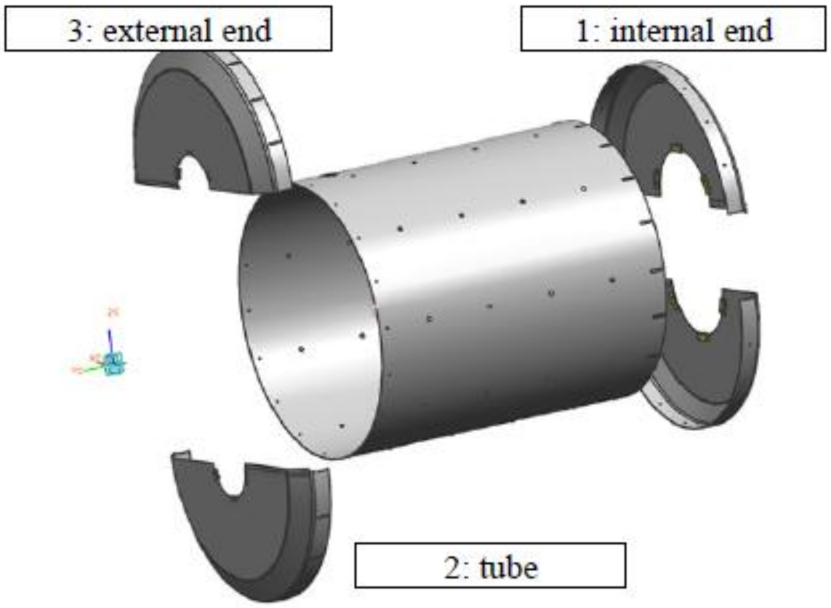
Tobias.Junginger@quasar-group.org

Solutions found by other labs - TRASCO



- 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

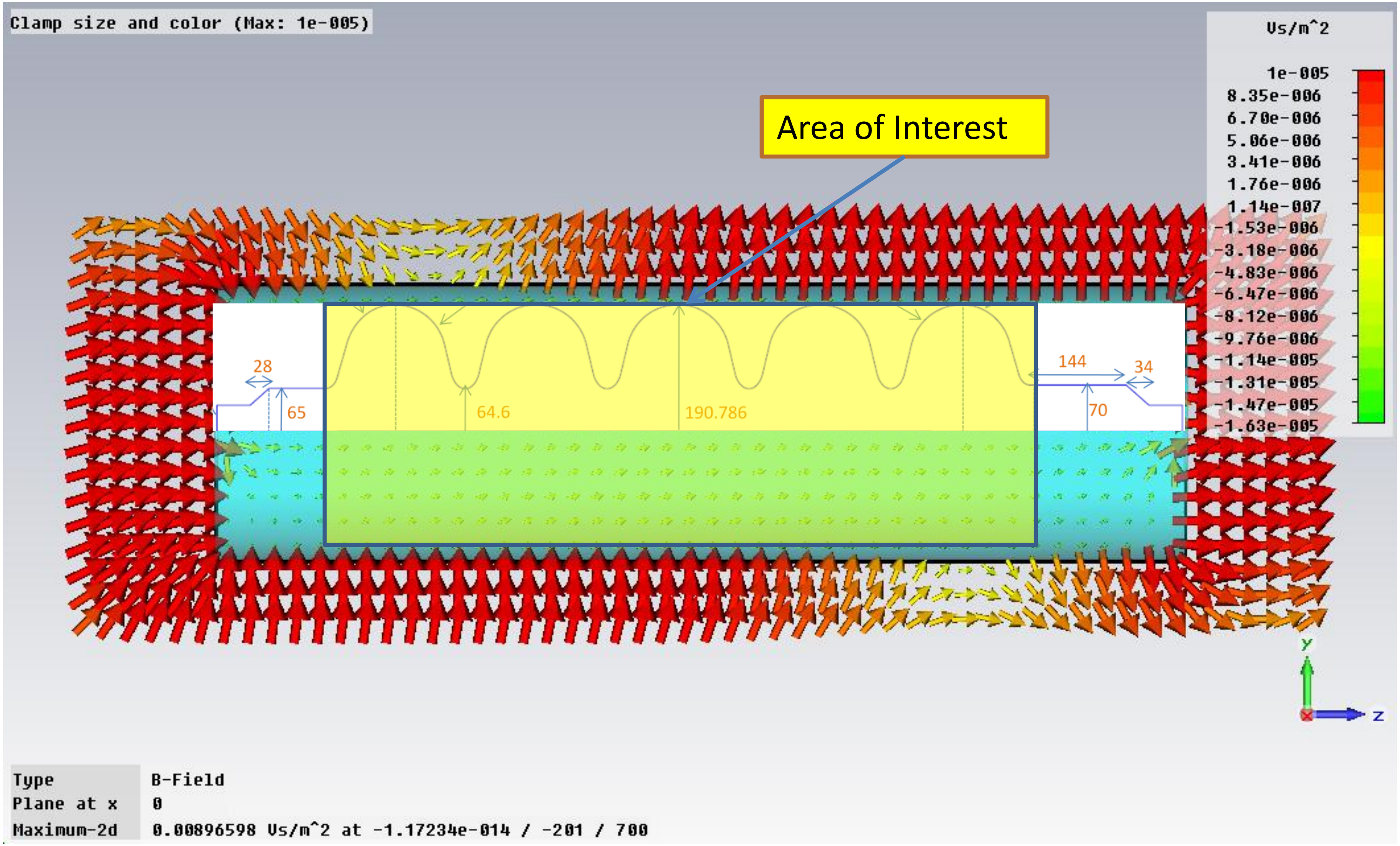
Tobias.Junginger@quasar-group.org

Needed Material

- 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)

Tobias.Junginger@quasar-group.org

Microwave Studio simulation



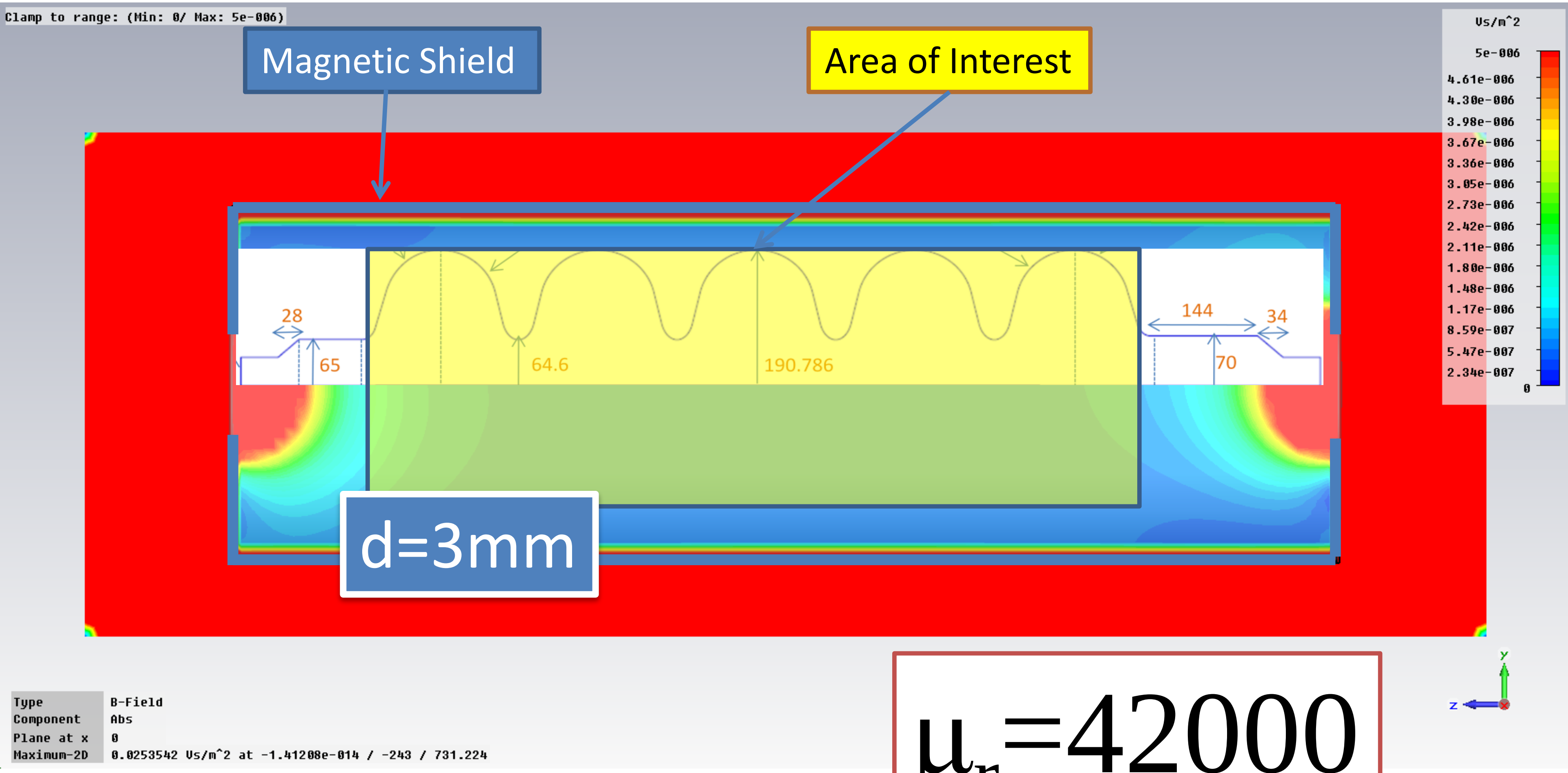
Clamp size and color (Max: 1e-005)

Area of Interest

Type B-Field
Plane at x 0
Maximum-2d 0.00896598 Vs/m^2 at -1.17234e-014 / -201 / 700

Tobias.Junginger@quasar-group.org

Microwave Studio simulation



```
Clamp to range: (Min: 0/ Max: 5e-006)
```

Magnetic Shield

Area of Interest

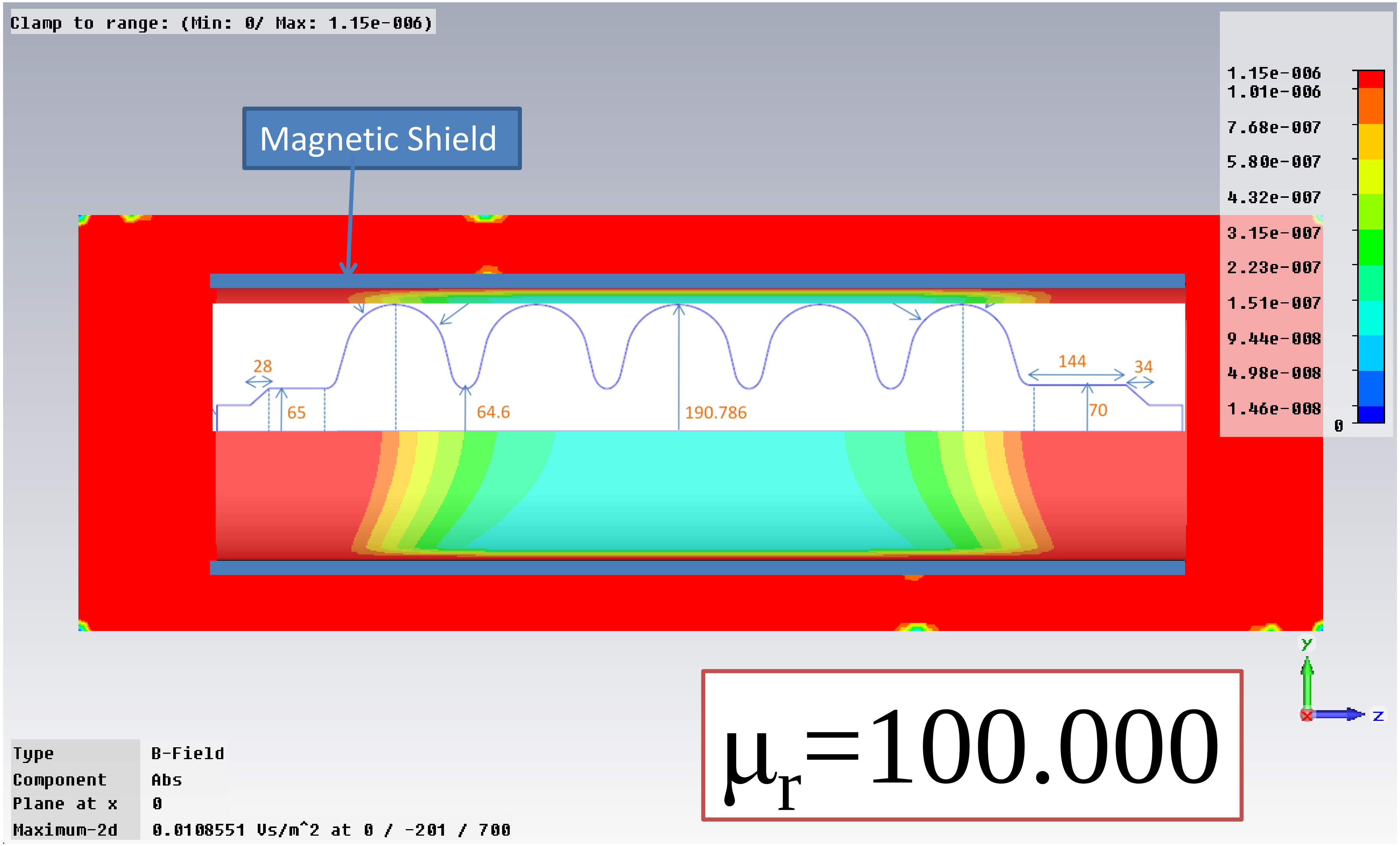
d=3mm

```
Type          B-Field
Component     Abs
Plane at x    0
Maximum-2D    0.0253542 Vs/m^2 at -1.41208e-014 / -243 / 731.224
```

μ_r=42000

Tobias.Junginger@quasar-group.org

Microwave Studio simulation



Clamp to range: (Min: 0/ Max: 1.15e-006)

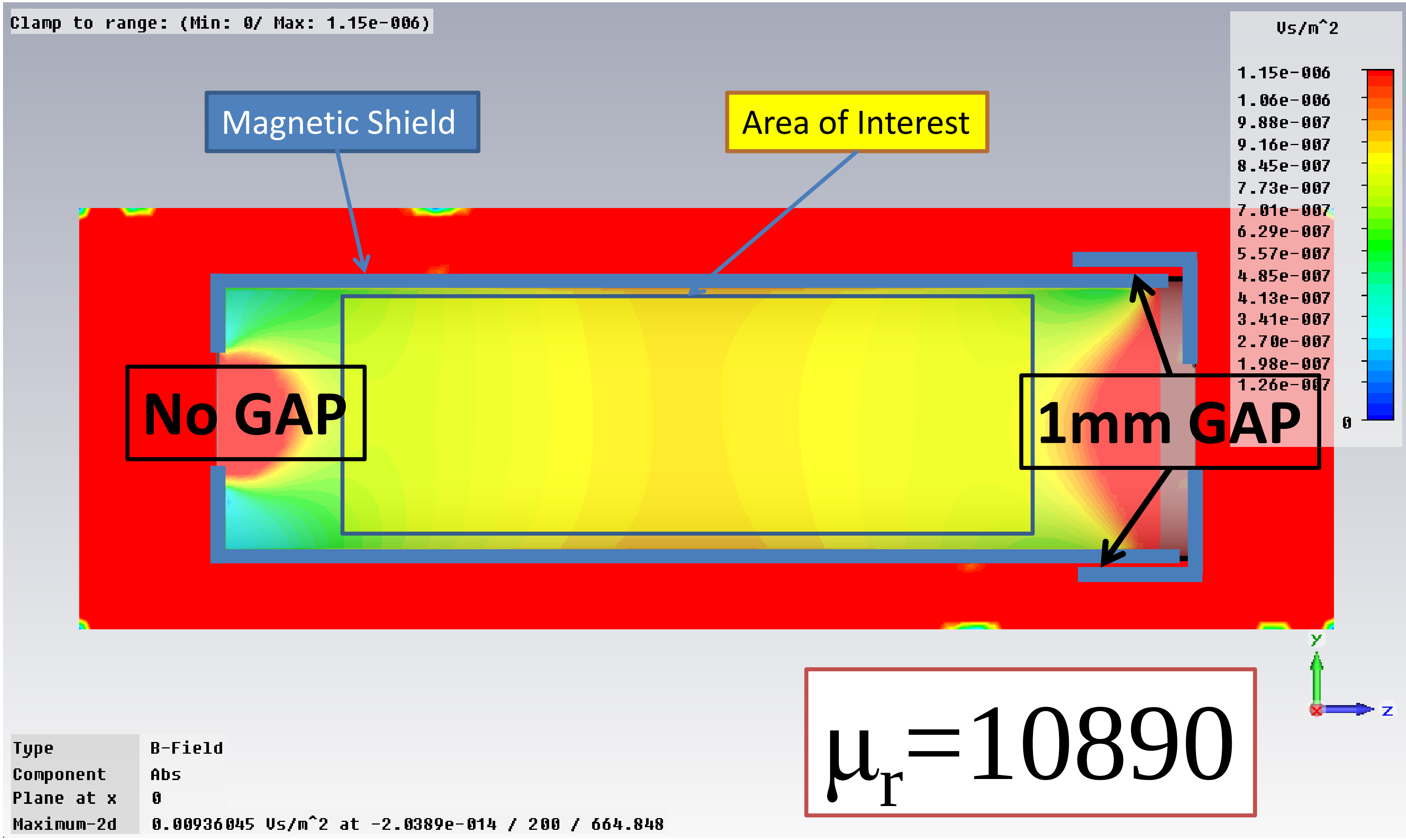
Magnetic Shield

Type	B-Field
Component	Abs
Plane at x	0
Maximum-2d	0.0108551 Vs/m^2 at 0 / -201 / 700

μ_r=100.000

Tobias.Junginger@quasar-group.org

Microwave Studio simulation

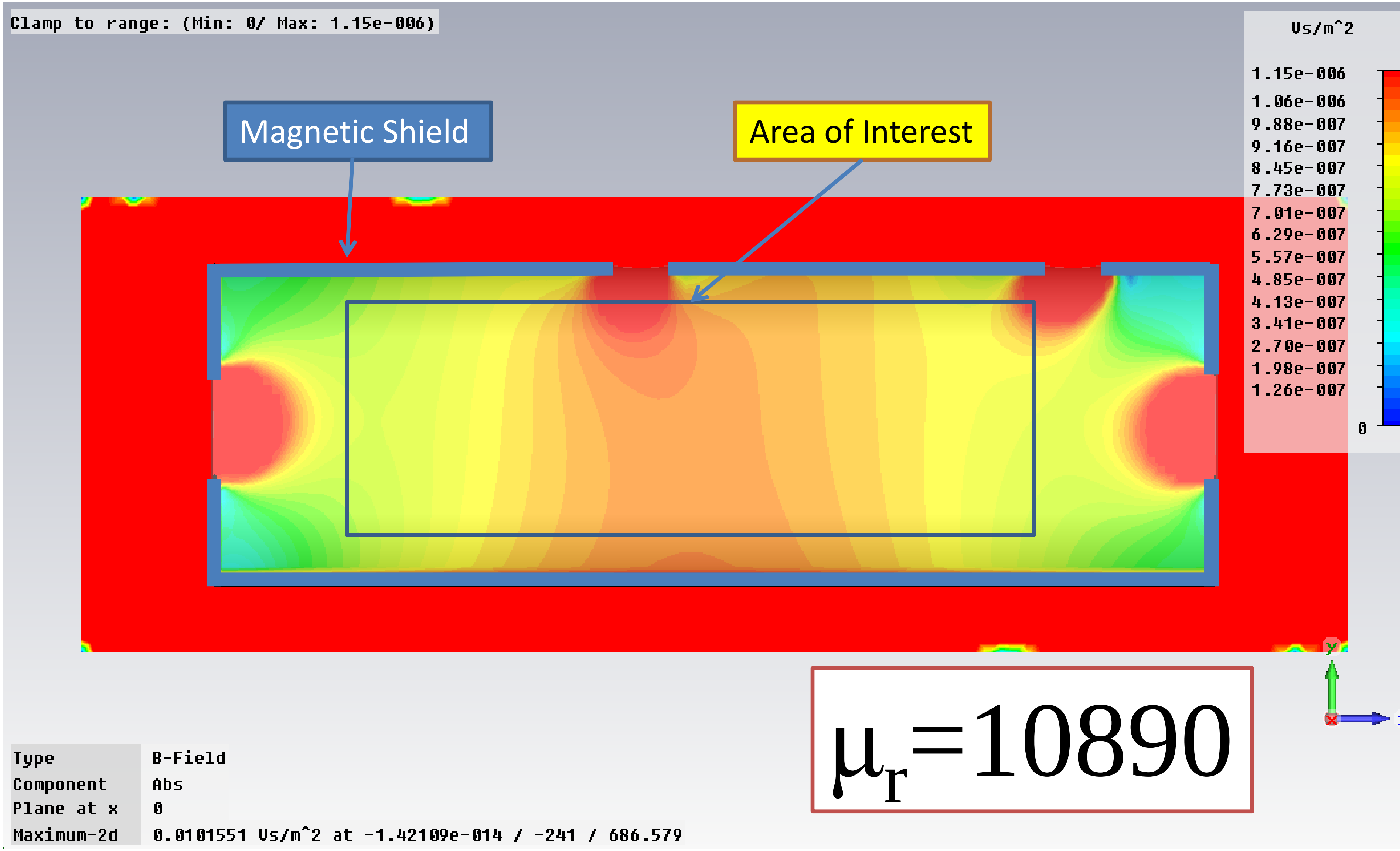


Type	B-Field
Component	Abs
Plane at x	0
Maximum-2d	0.00936045 Vs/m^2 at -2.0389e-014 / 200 / 664.848

μ_r=10890

Tobias.Junginger@quasar-group.org

Microwave Studio simulation



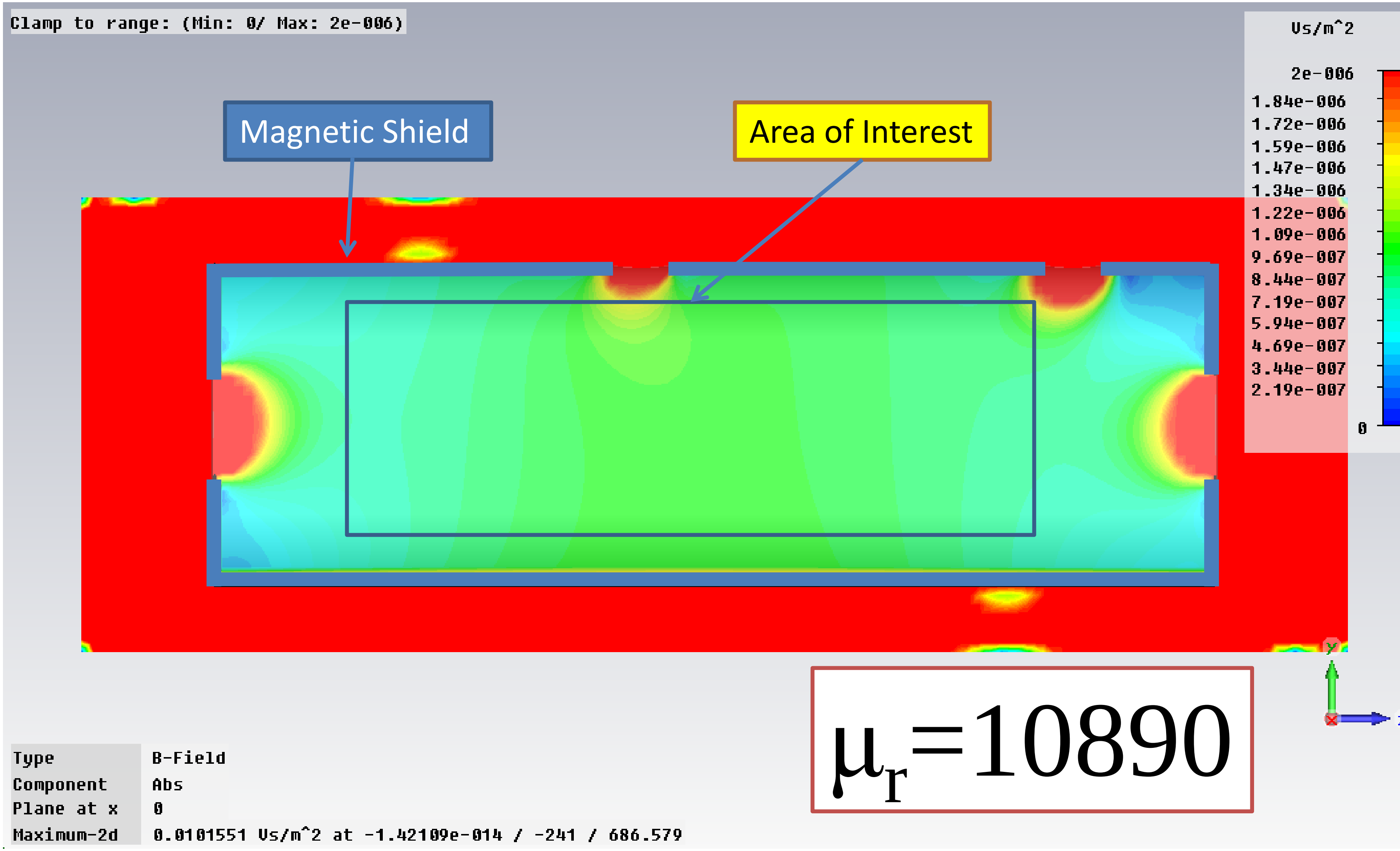
```
Clamp to range: (Min: 0/ Max: 1.15e-006)
```

```
Type          B-Field
Component     Abs
Plane at x    0
Maximum-2d    0.0101551 Vs/m^2 at -1.42109e-014 / -241 / 686.579
```

$$\mu_r=10890$$

Tobias.Junginger@quasar-group.org

Microwave Studio simulation


Clamp to range: (Min: 0/ Max: 2e-006)

Type	B-Field
Component	Abs
Plane at x	0
Maximum-2d	0.0101551 Vs/m^2 at -1.42109e-014 / -241 / 686.579

Magnetic Shield

Area of Interest

μ_r=10890

Tobias.Junginger@quasar-group.org

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

Tobias.Junginger@quasar-group.org

FLUXON INDUCED LOSSES

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

- Assumptions
  - Flux completely trapped

→ For fields in μT range usually the case

  - Fluxoids are static and RF currents flow through them

→ RF currents flowing around defect would yield different frequency dependency

  - All fluxoids are perpendicular to the cavity surface

→ Yields an overestimation of about 50 %

  - Losses are independent on RF field

→ In contradiction to experimental Results

For a 1.5 GHz Cavity (RRR=300)

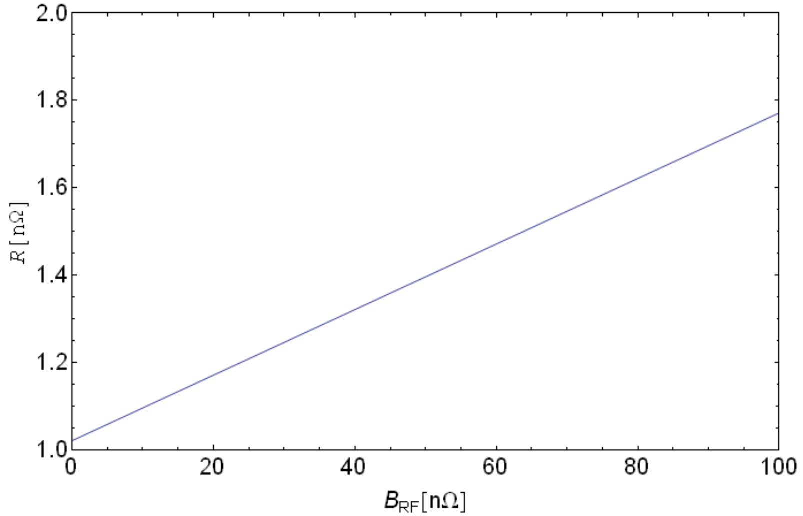
$$R_{mag}[n\Omega] = (1.022 +/- 0.011)H_{ext}[\mu T] + (0.0075 +/- 0.0040)H_{ext}[\mu T]H_{RF}[\mu T]$$

Tobias.Junginger@quasar-group.org

W. Weingarten / Physica C 339 (2000) 231-236 C. Benvenuti et al. / Physica C 316 (1999) 153-188

FLUXON INDUCED LOSSES

$$R_{mag}[n\Omega] = 1.022 + 0.0075\, H_{RF}[\mu T] \qquad H_{ext} = 1\mu T \qquad f = 1.5 Ghz$$



If the losses scale with √f we we would have

≈25 nΩ for B_{ext}=13.8 μT

$$R = R_{BCS} + R_{magn} + R_{\mathrm{Res}}$$
$$91.7 n\Omega = (65.4 + 25 + R_{\mathrm{Res}}) n\Omega$$

To achieve $Q0=3 \cdot 10^9$ R_{Res} may not be higher than 1.3 nΩ

Tobias.Junginger@quasar-group.org

C. Liebig Master-Thesis TU Darmstadt, September 2009