Magnetic Shielding and Creation of homogeneous magnetic field for RF cavity

Research student: Gustavo A. Gandara Montano
Supervisor: Bertalan Juhasz

ASACUSA Collaboration

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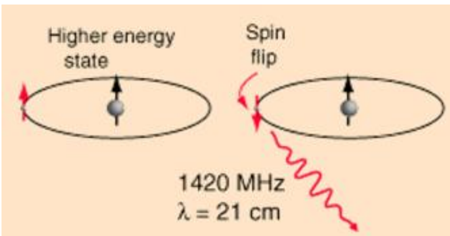
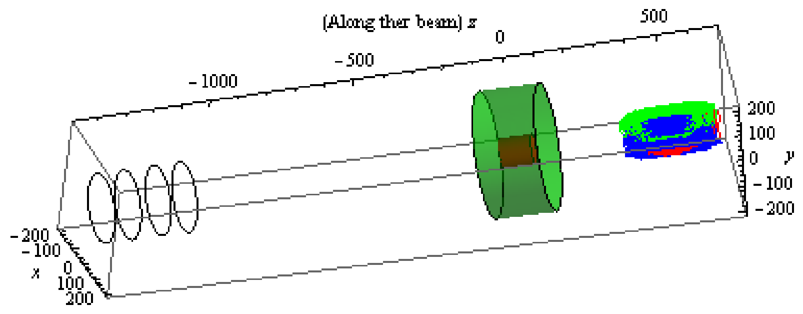
Rm 160-1-009 at CERN. Geneva, Switzerland

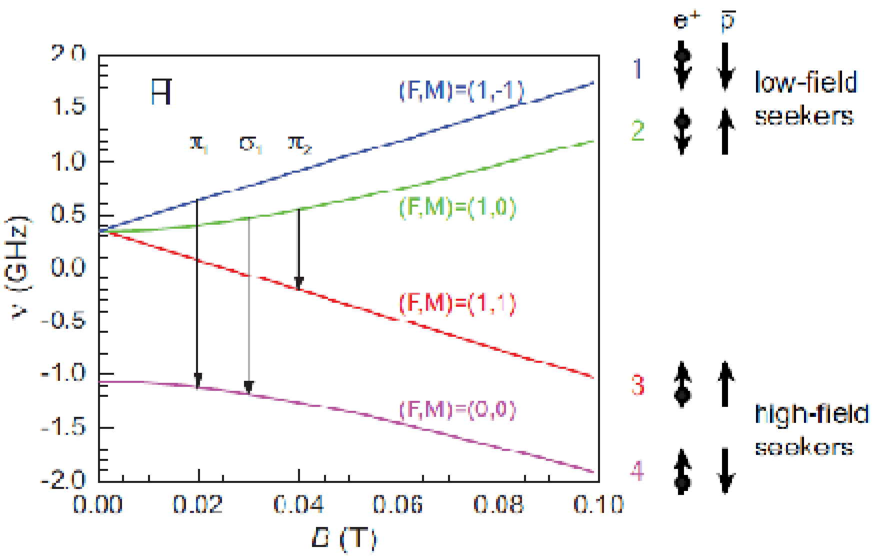
The Big Picture (1)

- The ASACUSA Collaboration is trying to measure hyperfine splitting of Antihydrogen



*HyperPhysics





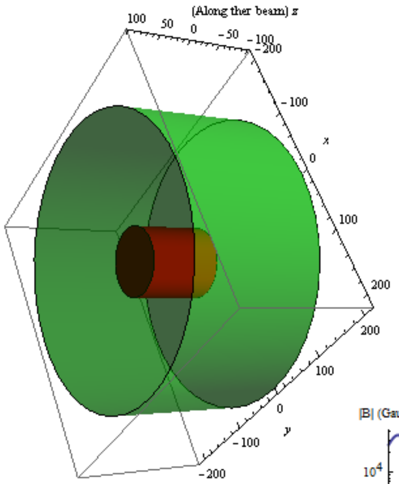
Inhomogeneity requirement of 2%

What can you get from this experiment?

CPT test and antiproton magnetic moment measurement

* B. Juahasz, E. Widmann

What I am trying to do:

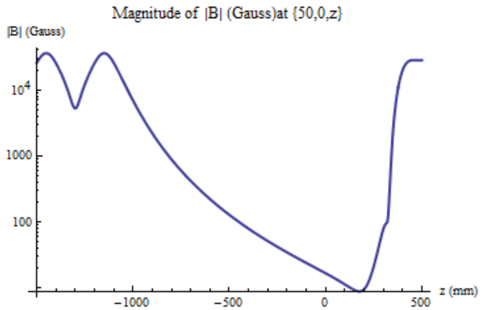


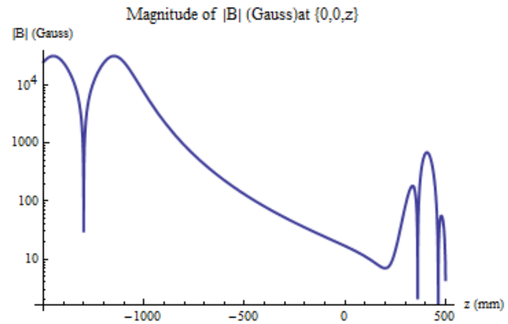
RF cavity: Radius of 210 mm

Length 100 cm

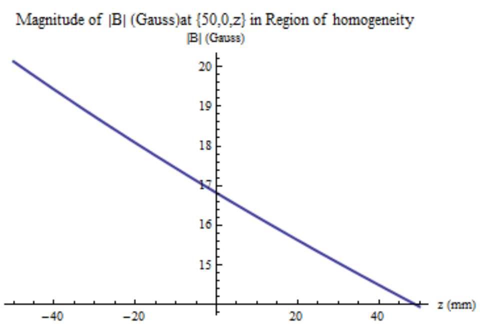
Region of Homogeneity: Radius: 100 mm

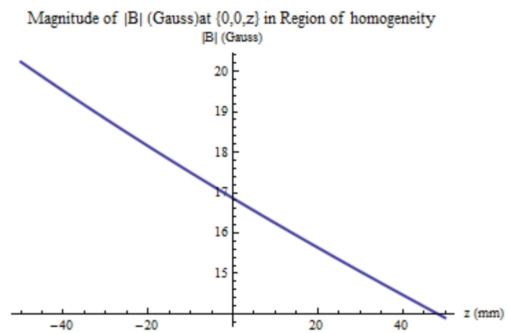
Length: 105 mm (HAW)





Initial Situation →



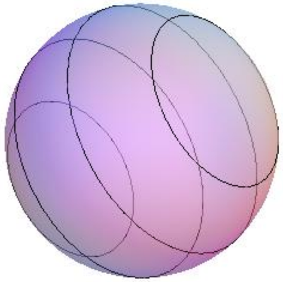


Inhomogeneity of 44.28%

How to produce the homogeneous Field? Garrett Coils

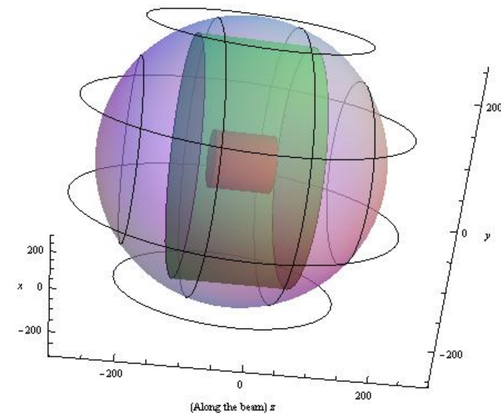
Garret Coils * M. Garrett

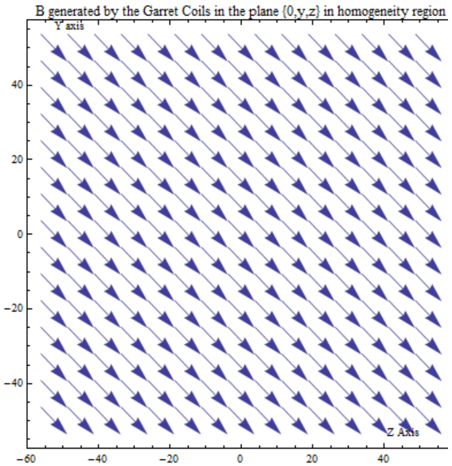
	Radius of Sphere	Radius of loop	Distance from center of sphere to center of loop	Current
Equatorial Pair	R	0.95845856R	0.2852315R	A
Paraxial Pair	R	0.64396446R	0.7650553R	0.682111A

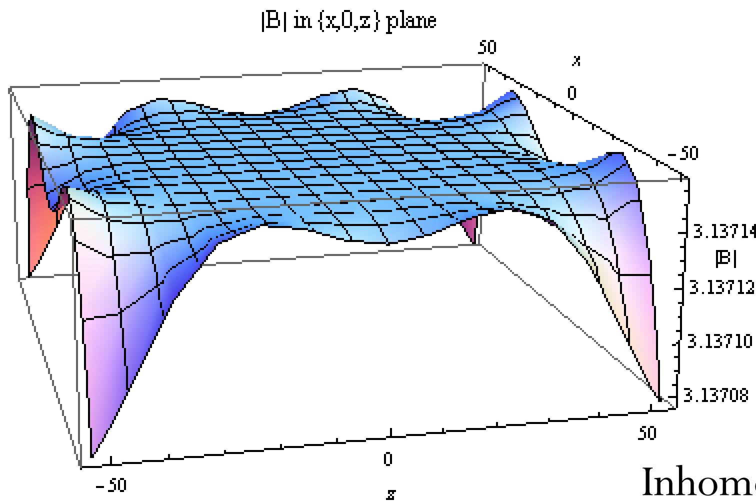


Smaller Garrett Coil: Laying along Z axis, it exists inside a sphere of 250 mm

Larger Garrett Coil: Laying along Y axis, it exists inside a sphere of 300 mm







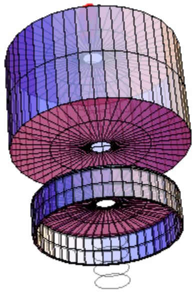
Inhomogeneity well below 0.01%

For both Garret Coils to produce the same magnetic field at the center.

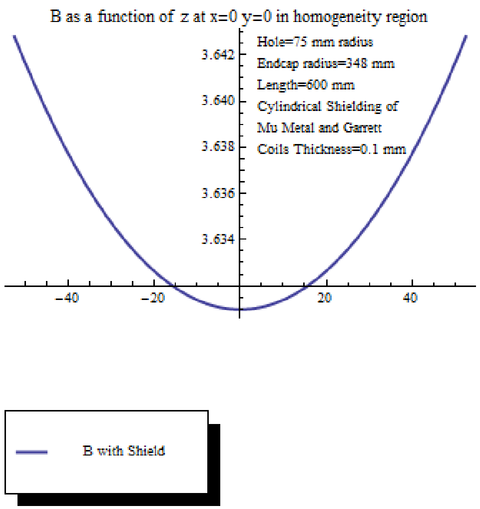
The external Coil must have a current larger by a factor of 1.2

An inherent problem with the shielding

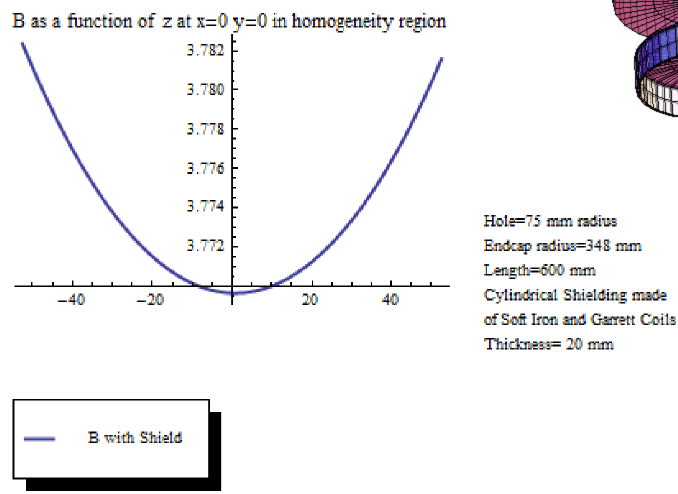
Graphs created by the Garret Coils and cylinders laying along Z-axis <u>ONLY</u>

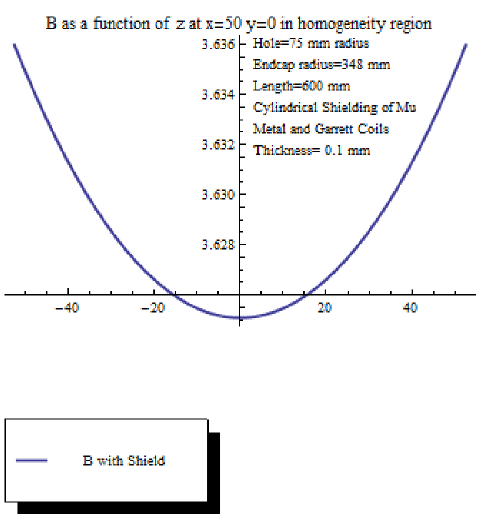


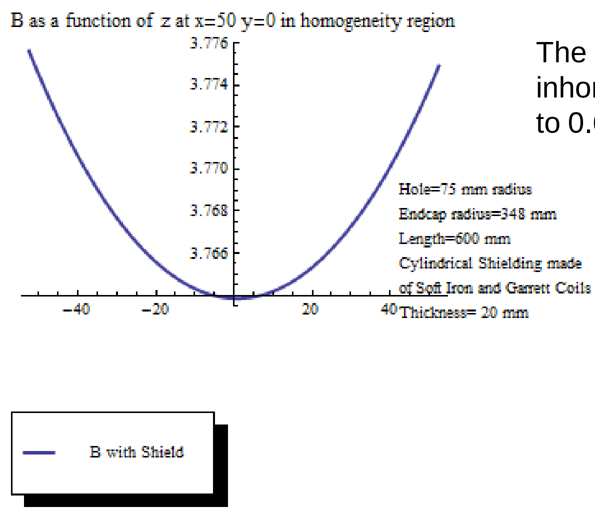
Mu metal



Soft Iron





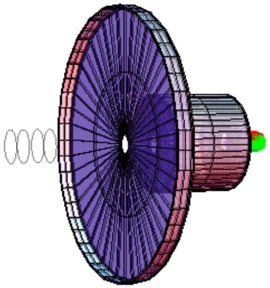


The induced field introduces inhomogeneity that can go from 0.2 % to 0.6 %

*The Garret Coils would create a field of 3.0 G in this set up

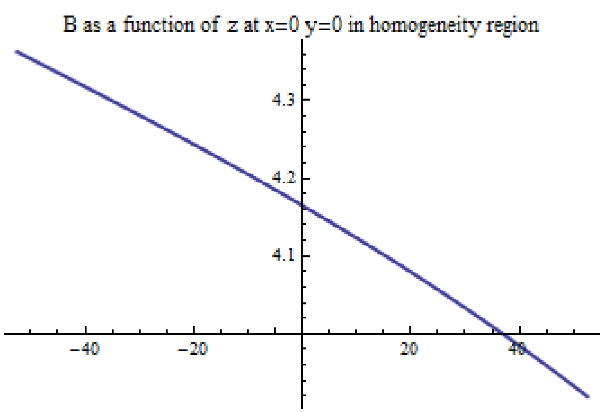
First geometry:

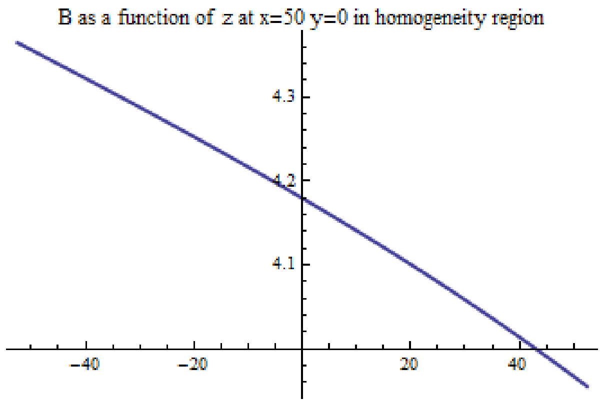
- Cusp Trap Shielding and cylinder laying along z-axis surrounding the cavity
- The parameters of the cusp trap shielding that gave the less external field in the region of homogeneity were:



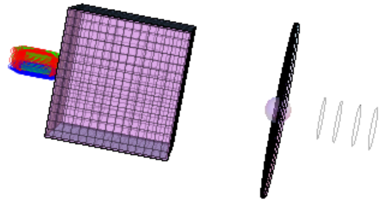
A length of 100 mm, a location of -550 mm and a Radius of 1000 mm. (This gave a |B| of 0.39697 G at {50,0,-53})

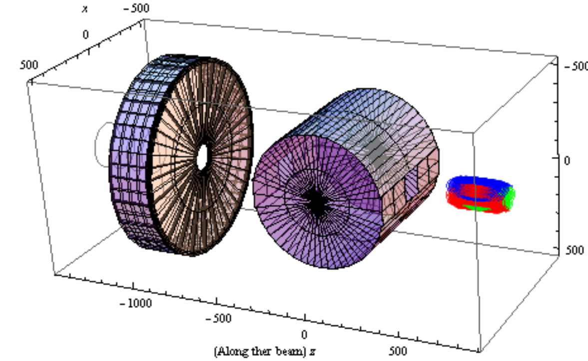
* You have to optimize the whole setup at the same time!!!





- Terrible job. Inhomogeneity of 12%



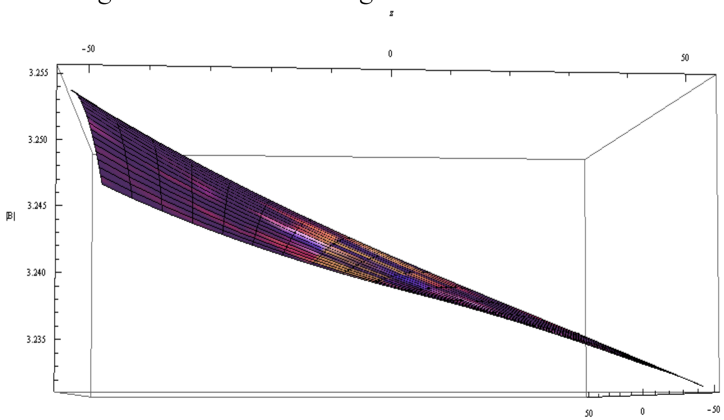


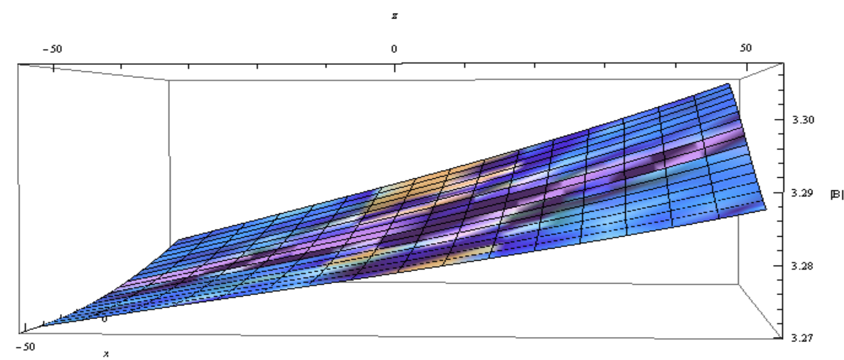
Best Optimizations:

Shielding along Z-axis
Cusp Shielding: Radius=500 Length=270 Location=-800
RF shielding: Radius 650 mm Length=776

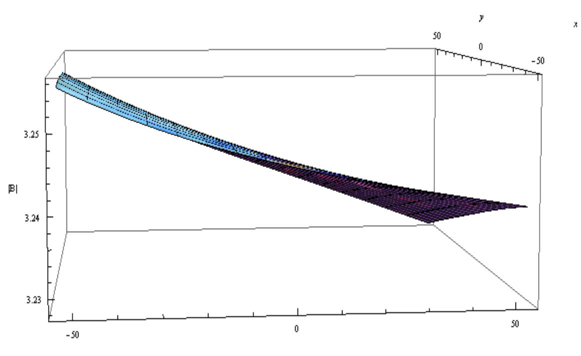
Shielding along X-axis
Cusp Shielding: Radius=500 Length=220 Location=-850
RF shielding: Radius 550 mm Length=776

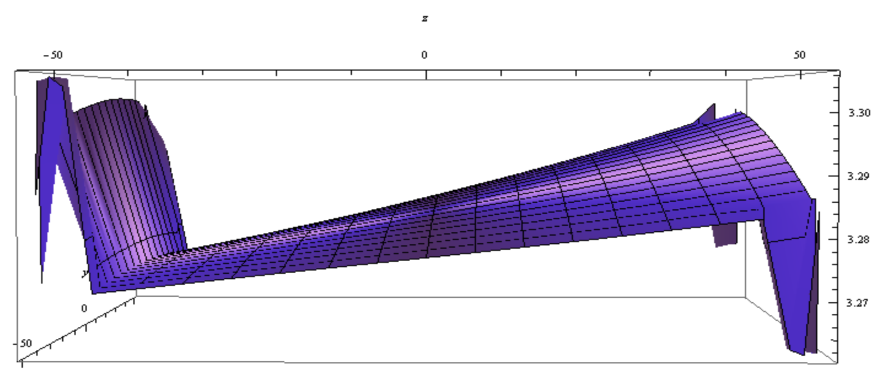
{x,0,z} plane





{0,y,z} plane

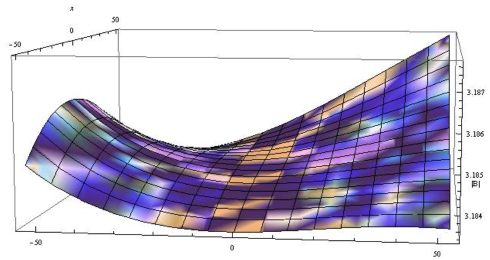
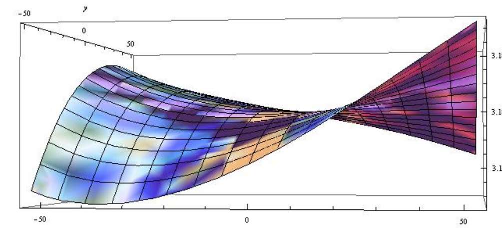
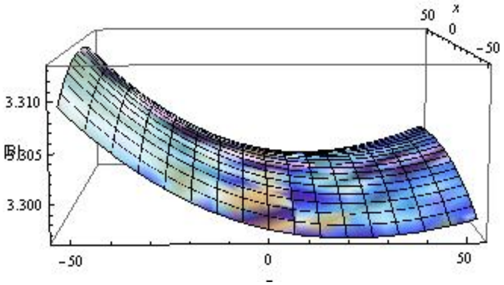
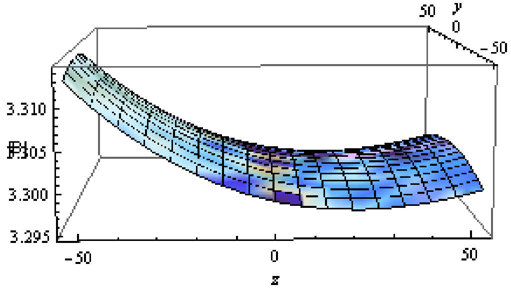
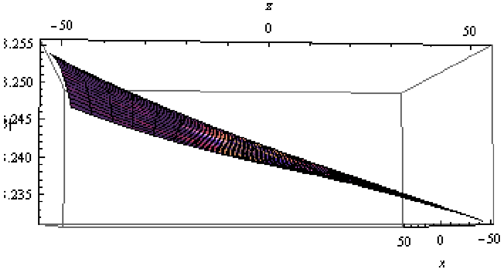
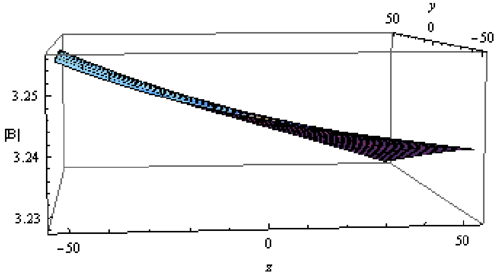




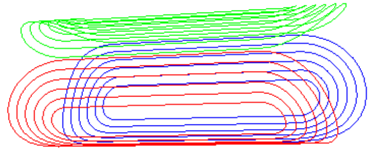
Inhomogeneity of 0.6 % in YZ plane

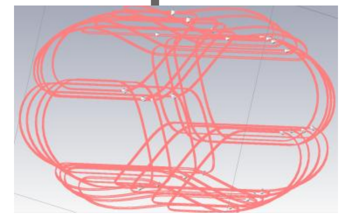
Inhomogeneity of 0.91 % in YZ plane.

An inconsistency with the software

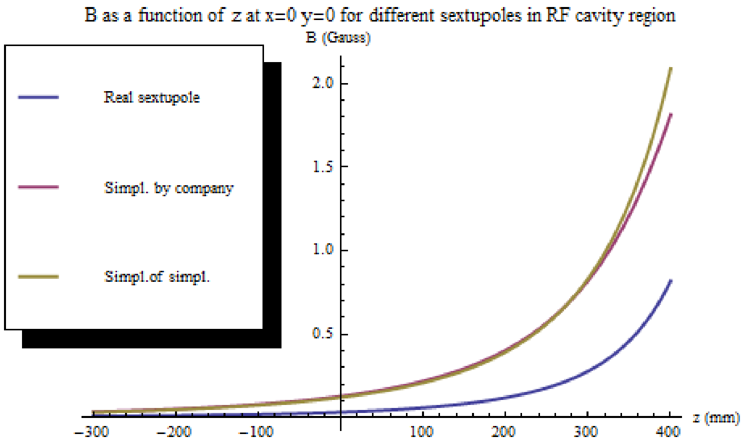
	XZ Plane	YZ Plane
2,2,2 divisions. B field goes from 3.182 to 3.186 in YZ Plane. Inhomogeneity: 0.12%		
3,3,3 divisions. B field goes from 3.310 to 3.295 in YZ Plane. Inhomogeneity: 0.45%		
2,2,4 divisions. B field goes from 3.23 to 3.25 in YZ Plane. Inhomogeneity: 0.61%		

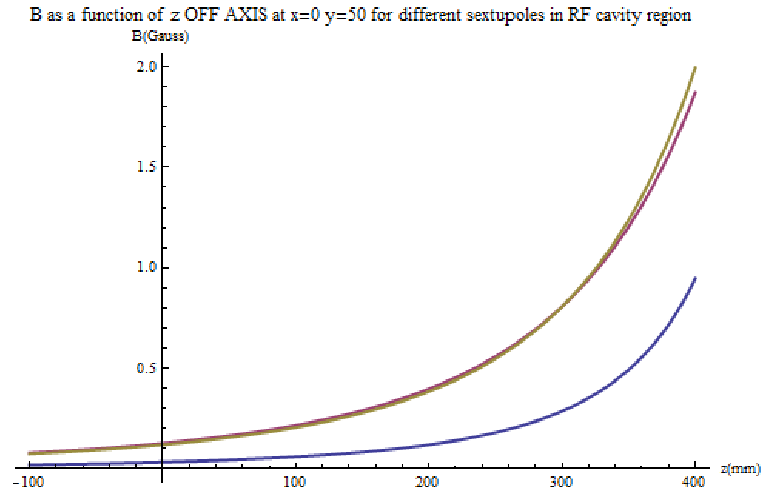
First task: Build the sextupole in CST



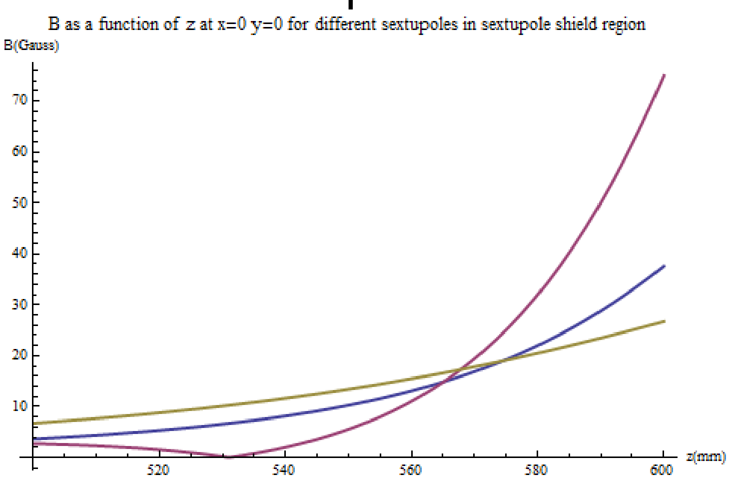


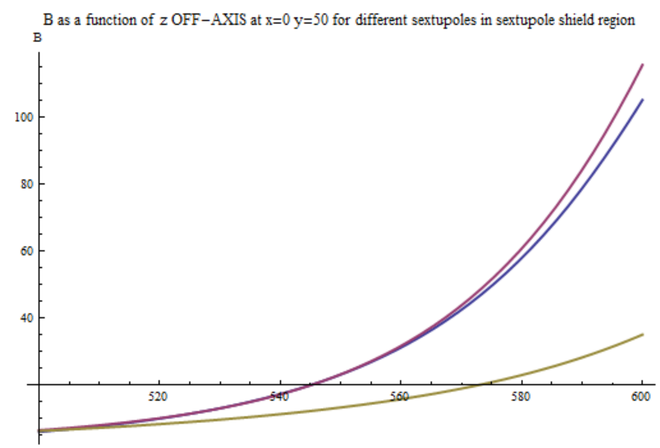
Cavity region





Close to the sextupole

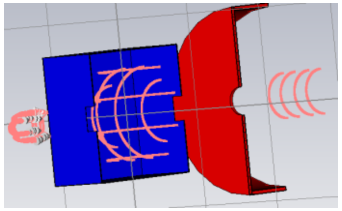




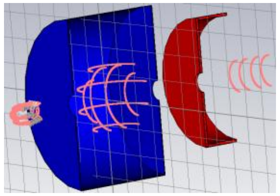
Some optimum configurations I tried with CST (I am showing some of many configurations)

* Cusp shielding made of iron. Has radius=500 Length=270 Left side at=-800

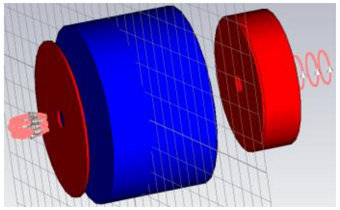
Box made with Mu metal*. 776 mm length
Inhomogeneity: 1.34%



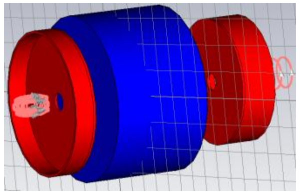
Cylinder across z axis with Length: 776 mm Radius: 650 mm
Mu metal*: 0.5523 Iron: 1.3314%



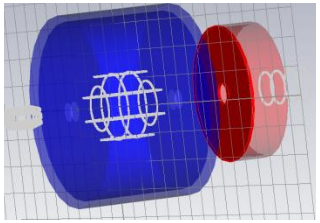
With a flat iron shielding acting as sextupole shielding.
Inhomogeneity: 1.0149%



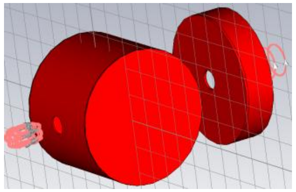
With whole sextupole shielding.
Mu metal*: 0.4268%
Iron: 0.6152



Double shielding with Mu metal: 0.9839



Cylindrical shielding perpendicular to beam
Mu metal*: 0.5952 %
Iron: 0.6844%

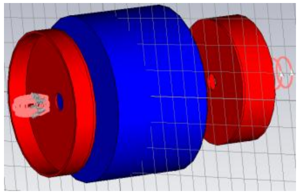


Initial results obtained in CST:

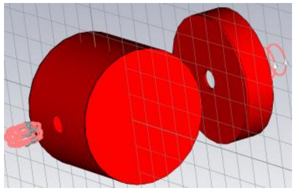
1) Box shielding is less efficient than cylindrical
2) A sextupole shielding (with a side) improves considerably the situation
3) Adding a second layer of shielding makes the situation worse. Just a single shielding produces a more homogeneous field.

Test of fire: Go to the lowest field (where the inhomogeneity is maximum)

With whole sextupole shielding, and cavity shielding made of Iron:
Inhomogeneity: 1.9711 %



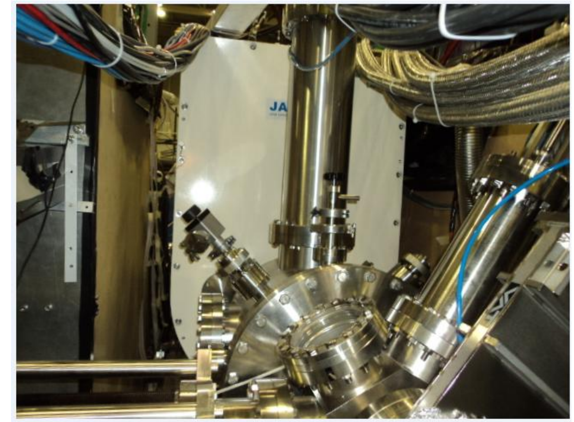
With Cylindrical shielding perpendicular to beam, and cavity shielding made of Iron:
Inhomogeneity: 2.0744 %



Mission accomplished?
Is it over?

New factors to consider

Cusp trap looks U-shaped

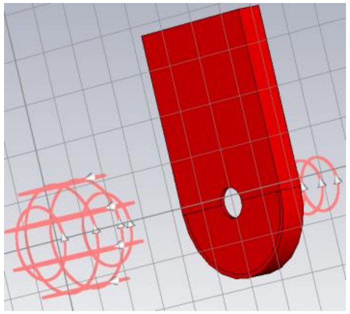


1) The Cusp Trap shielding is allowed to "be" in a very small 45 mm area->Bad :'(

2) There must be 890 mm of "empty space" in simulation between cusp trap shielding and RF shielding-> Good

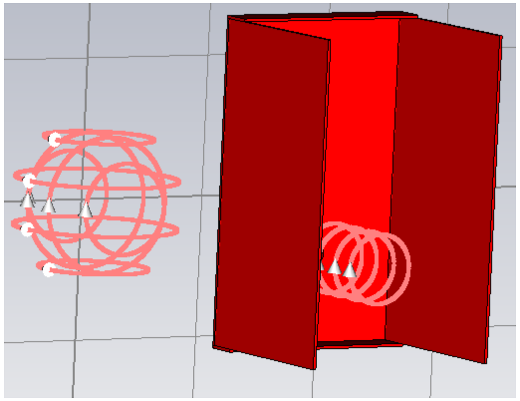
An idea too perfect to be real

- A shielding for Cusp Trap and a shielding for sextupole only



Length =100 mm Inhomogeneity=41.42%

Length =200 mm Inhomogeneity=52.02%

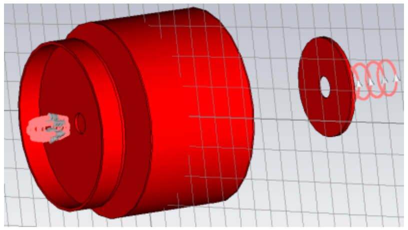


Length =325 mm Inhomogeneity=38.97%

Length =635 mm Inhomogeneity=38.37%

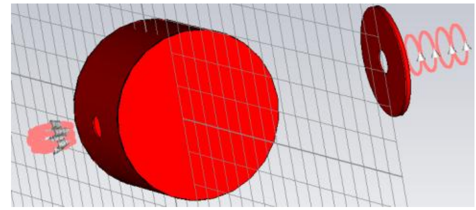
A *"Berti"* Shielding: Like a box shielding but the faces on the sides extends along the beam more than top and bottom faces

Test best configurations with new settings

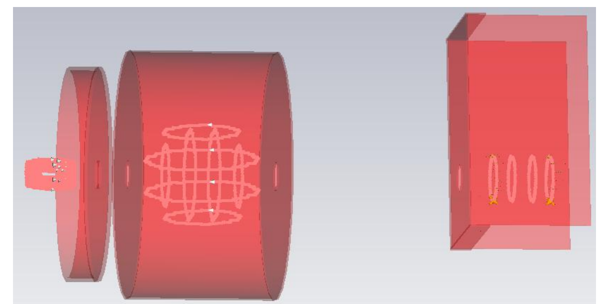


Inhomogeneity at high field: 0.6418%
Inhomogeneity at low field: 1.8562%

It works!



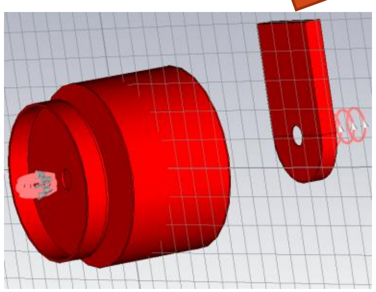
Inhomogeneity at high field: 0.7723 %
Inhomogeneity at low field: 2.7436 %



Inhomogeneity at low field: 1.8276%

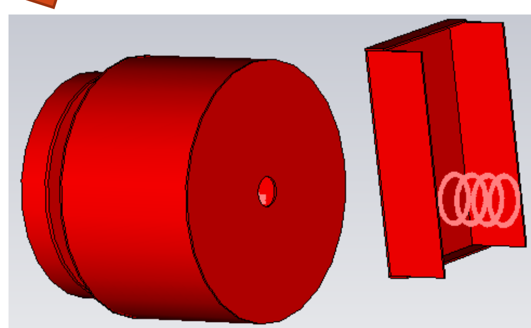
It works!

Extending the shielding proved to be very handy



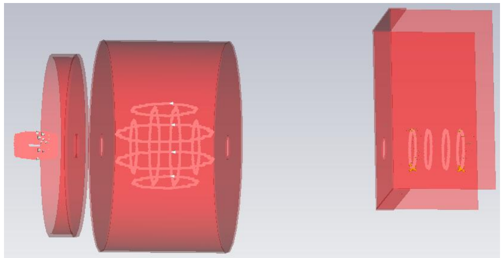
Inhomogeneity at high field: 0.8606%

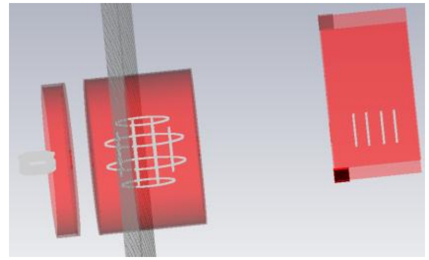
The U-shaped shielding does not give the desired inhomogeneity with all the set up

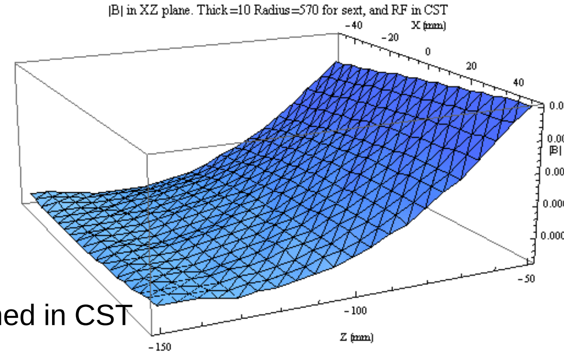


Inhomogeneity at low field: 2.3550 %

The Berti Shielding lets you go small



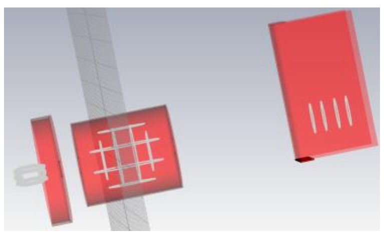


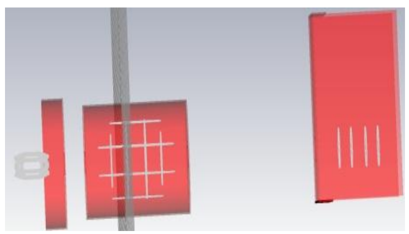


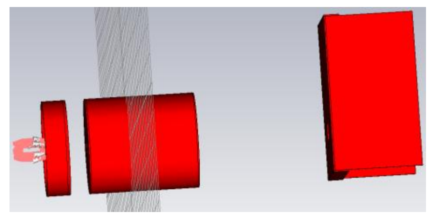
Original:
RF shielding radius: 650 mm
Sextupole shielding radius:570
Sextupole shielding thickness: 20 mm
Inhomogeneity: 1.8562 %

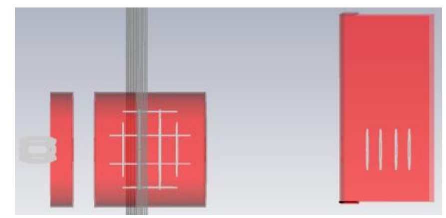
The most homogeneous configuration obtained in CST
RF shielding radius: 570 mm
Sextupole shielding radius:570 mm
Sextupole shielding thickness: 20 mm
Inhomogeneity: **0.84** %

And you keep going until…







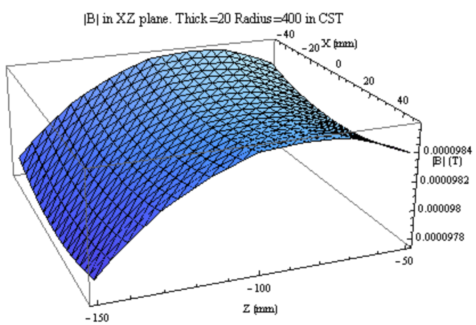


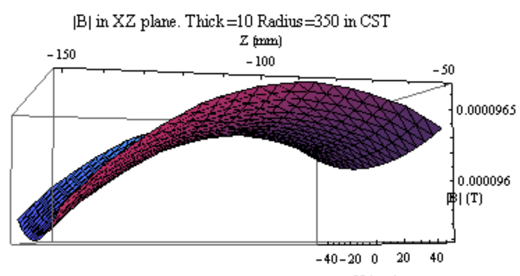
Units (mm)
RF shielding radius: 350
Sextupole shielding radius:350
Sextupole shielding thickness: 20
Inhomogeneity: **1.3887**%

Units (mm)
RF shielding radius: 350
Sextupole shielding radius:350
Sextupole shielding thickness: 20
Inhomogeneity: **1.6312**%

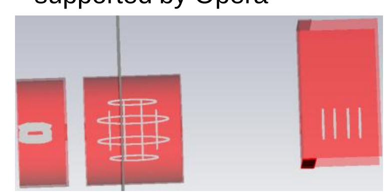
Units (mm)
RF shielding radius: 350
Sextupole shielding radius:350
Sextupole shielding thickness: 20
Inhomogeneity: **1.8344**%

Units (mm)
RF shielding radius: 350
Sextupole shielding radius:350
Sextupole shielding thickness: 20
Inhomogeneity: **1.9356**%

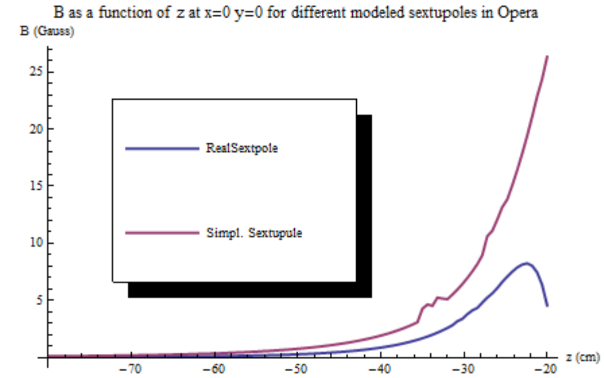


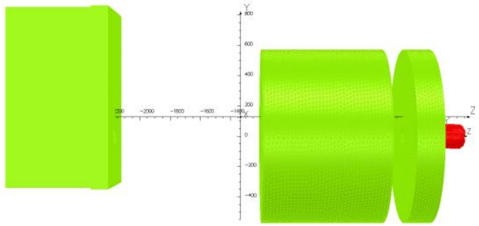


* Two interesting results supported by Opera

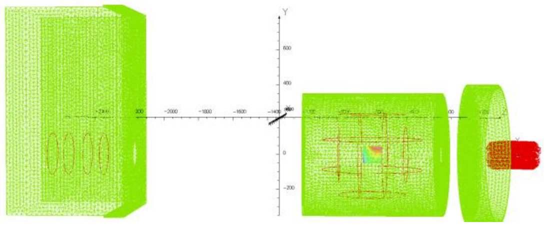


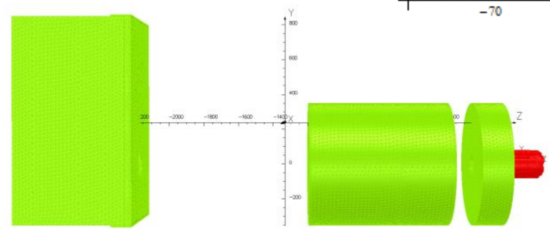
Studying the results using Opera





Units (mm)
RF shielding radius: 570
Sextupole shielding radius:570
Sextupole shielding thickness: 20
Inhomogeneity: **1.6893**%





Units (mm)
RF shielding radius: 400
Sextupole shielding radius:350
Sextupole shielding thickness: 20
Inhomogeneity: **1.3827**%

Units (mm)
RF shielding radius: 400
Sextupole shielding radius:350
Sextupole shielding thickness: 10
Inhomogeneity: **1.3728**%

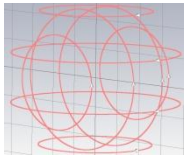
Units (mm)
RF shielding radius: 350
Sextupole shielding radius:350
Sextupole shielding thickness: 20
Inhomogeneity: **1.3893**%

Units (mm)
RF shielding radius: 350
Sextupole shielding radius:350
Sextupole shielding thickness: 10
Inhomogeneity: **1.2947**%

Opera shows:

1._ The configurations respect the 2 % inhomogeneity requirement

2._ Both programs agree in the field values to within 0.04 Gauss
3._Both programs disagree with respect to the particular inhomogeneity values assigned to each configuration. The average difference is 0.43%
4._Unlike CST, for the smallest configurations, Opera does not show strong dependence on the dimensions of the sextupole shielding



Possible reasons of points 3 & 4:

1._ An error factor of +-0.30 % appears in CST when calculating Garret Coil fields
2._ The sextupoles themselves: According to Opera, my sextupole overestimates the real field in the region of sextupole shielding
3._Meshing size (finer in different regions in different programs)
4._Pushing the software too much (asking for accuracy of a part in 10 million)

Final result: “Small” configurations which “do the job”

My advice for ASACUSA

Pick a design where CST and Opera agree. Don’t be too greedy with the size

Geneva

London

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Bibliography

- B. Juhasz. Radiofrequency Cavity for the Measurement of the Ground-State Hyperfine Splitting of Antihydrogen. Stefan Meyer Institute for Subatomic Physics. February 2009
- B. Juhasz, E. Widmann. Planned Measurement of the Ground-state Hyperfine Splitting of Antihydrogen. Stefan Meyer Institute for Subatomic Physics. Springer Science & Business Media. August 2009
- M. Garrett. Axially Symmetric Systems for Generating and Measuring Magnetic Fields. Journal of Applied Physics Vol:22 Number:9. September 1951
- The Hydrogen 21-cm Line. HyperPhysics. Department of Physics and Astronomy of GeorgiaState University

Thank you for your attention ☺
Any questions

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