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Designing Magnetic Coils From the Inside Out

Daniel Wagner, Dr. Christopher Crawford
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Conventional Method to Design a Magnetic Coil

1. Design geometry
2. Choose reasonable conductor and material configuration
3. Choose reasonable winding pattern
4. Simulate resulting field
5. Compare result with requirements
6. Adjust windings and repeat if necessary

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New Method (from the inside out)

1. Specify geometry (usually given and constraint by the experiment)
2. Specify magnetic field (by invoking boundary conditions in the region of interest)
3. Solve Laplace Equation (to determine the field at the other regions)
4. Extract the winding pattern from the magnetic scalar potential

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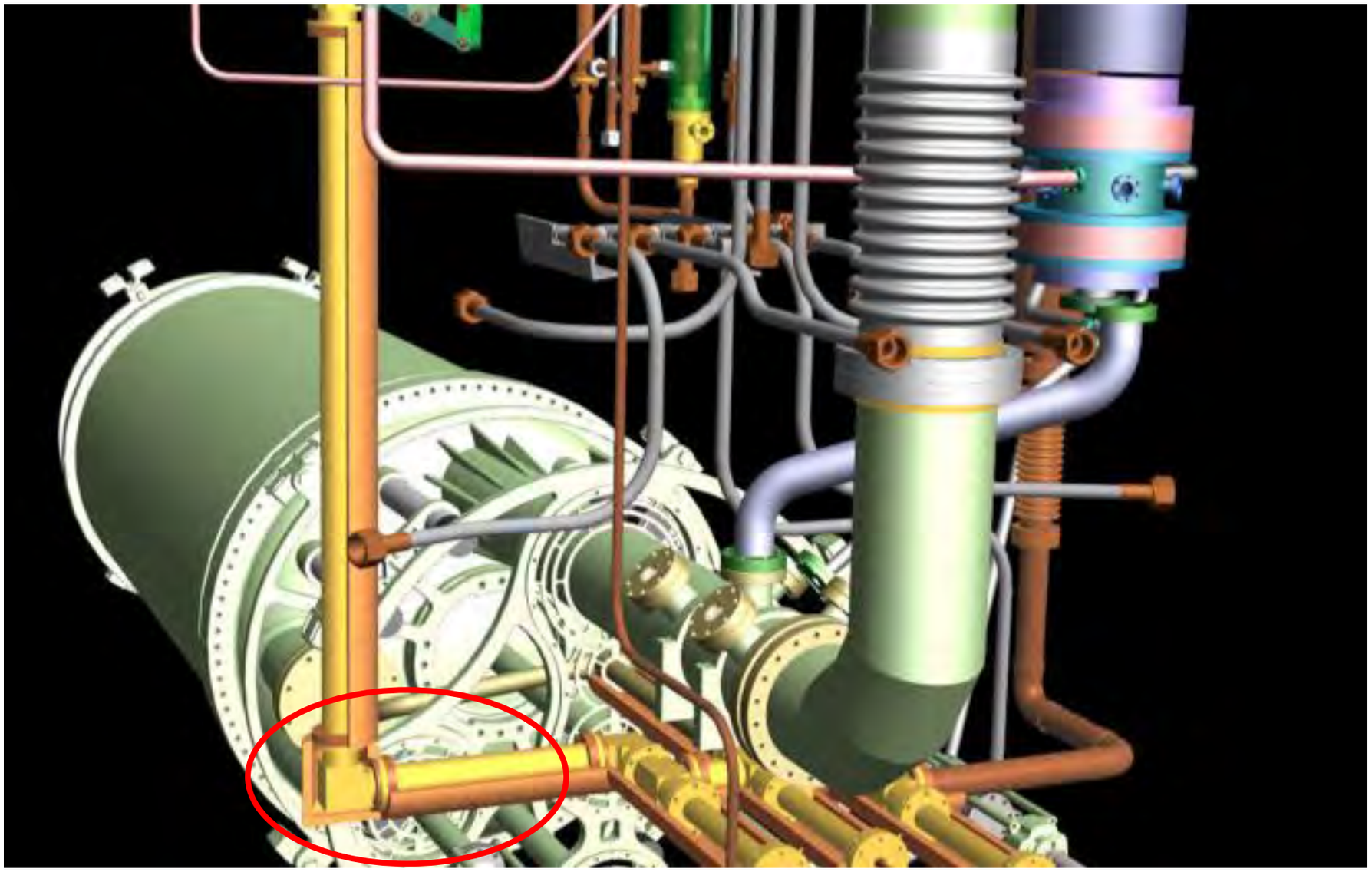


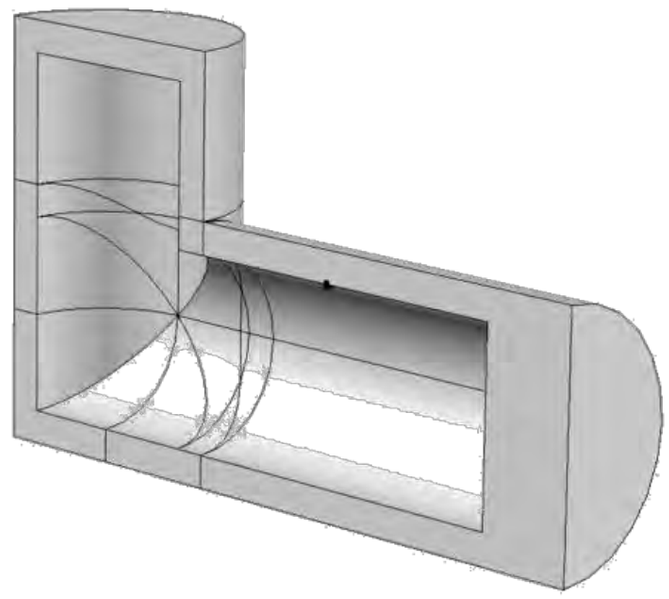
nEDM Experiment

Goal: Measure the neutron electric dipole moment and decrease it's upper limit to $<10^{-28}$

Design Requirements/ Constraints for Magnetic Coils of nEDM exp.

- Geometry is given / can't be changed
- will be used for spin-polarized ^{3}He transportation

  ➡ Extreme uniform field necessary!
- Field cancellation at the outside!
- Combination of solenoid and cosΘ-coil
- Design as a clamshell for assembly (using symmetries for the design process)



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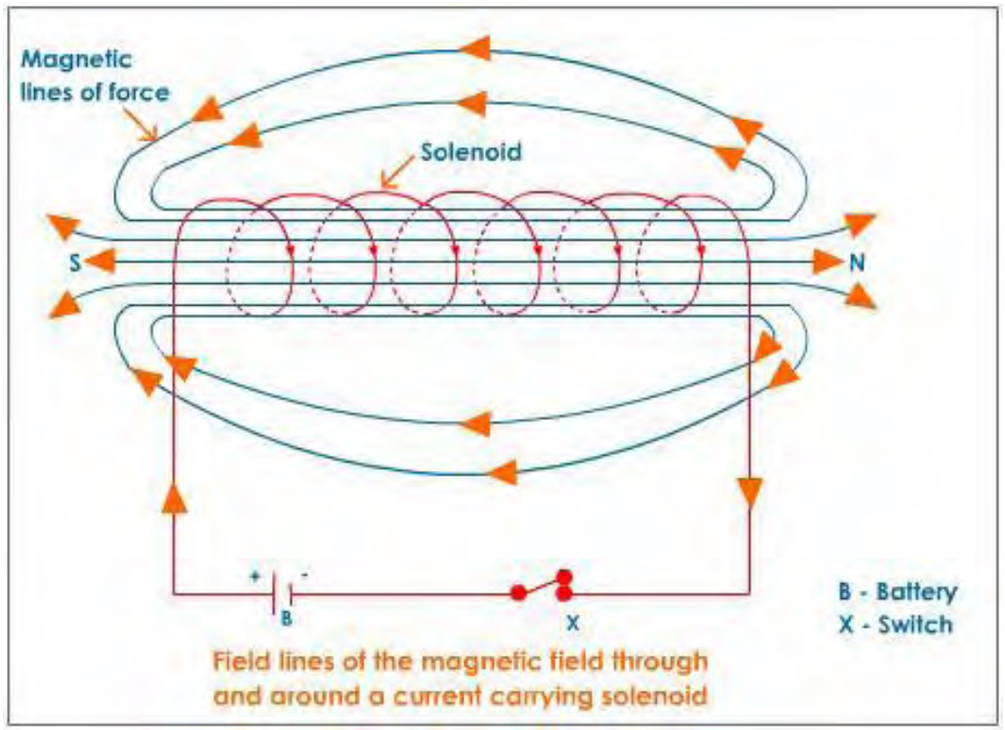
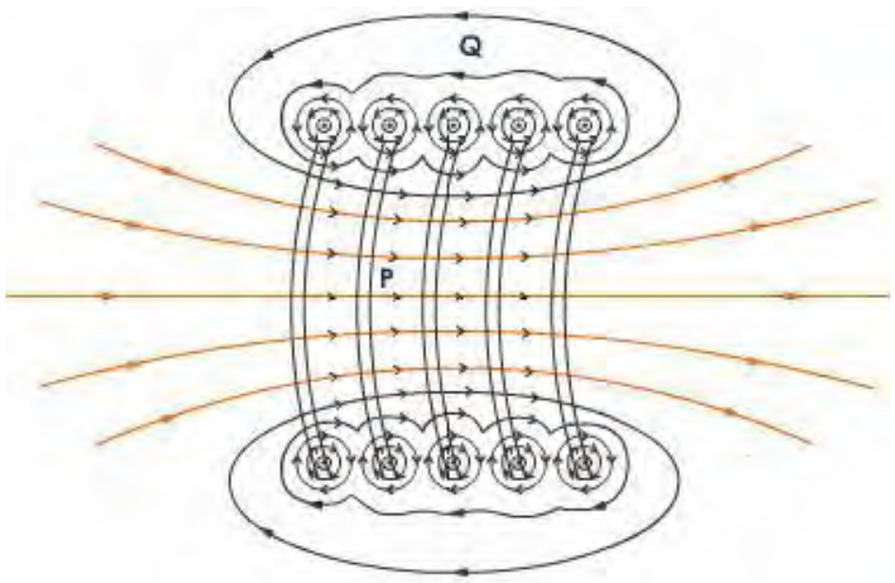
Magnetic Field in a Solenoid

- Infinite long solenoid creates uniform magnetic
- Finite solenoid creates causes magnetic field lines



Infinite Solenoid



Finite Solenoid

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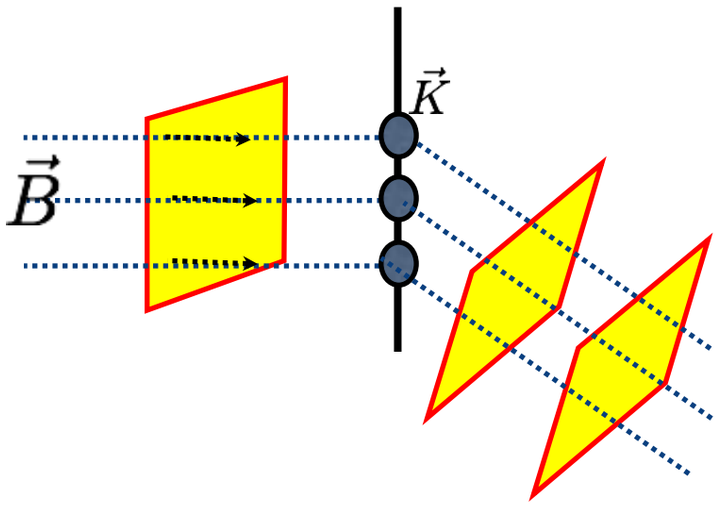
Invoking Boundary Conditions

$$\nabla \cdot B = 0 \longrightarrow \hat{n} \cdot \Delta \vec{B} = 0$$

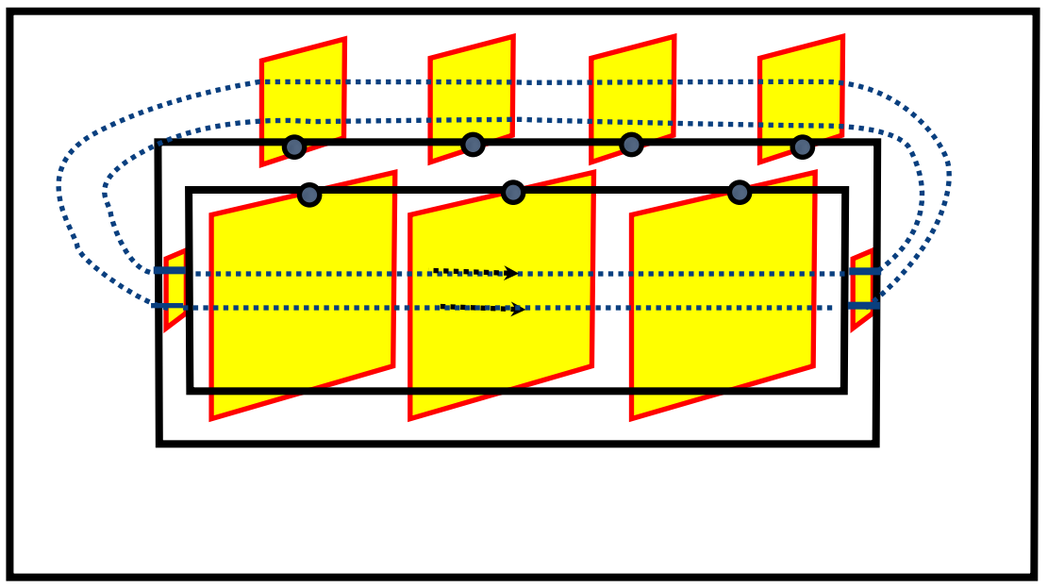
$$\nabla \times \vec{H} = J \longrightarrow \hat{n} \times \Delta \vec{H} = \vec{K}$$



Current kinks field lines!

Magnetic Scalar Potential U

Using the magn. scalar potential to create uniform field



- Current
- Magnetic Scalar Potential (U)
- Magnetic field line

- Perpendicular field lines on U
- Flux B. C.’s define Boundary Value Problem (B. V. P)
- Solution of B. V. P yields flow B. C.’s

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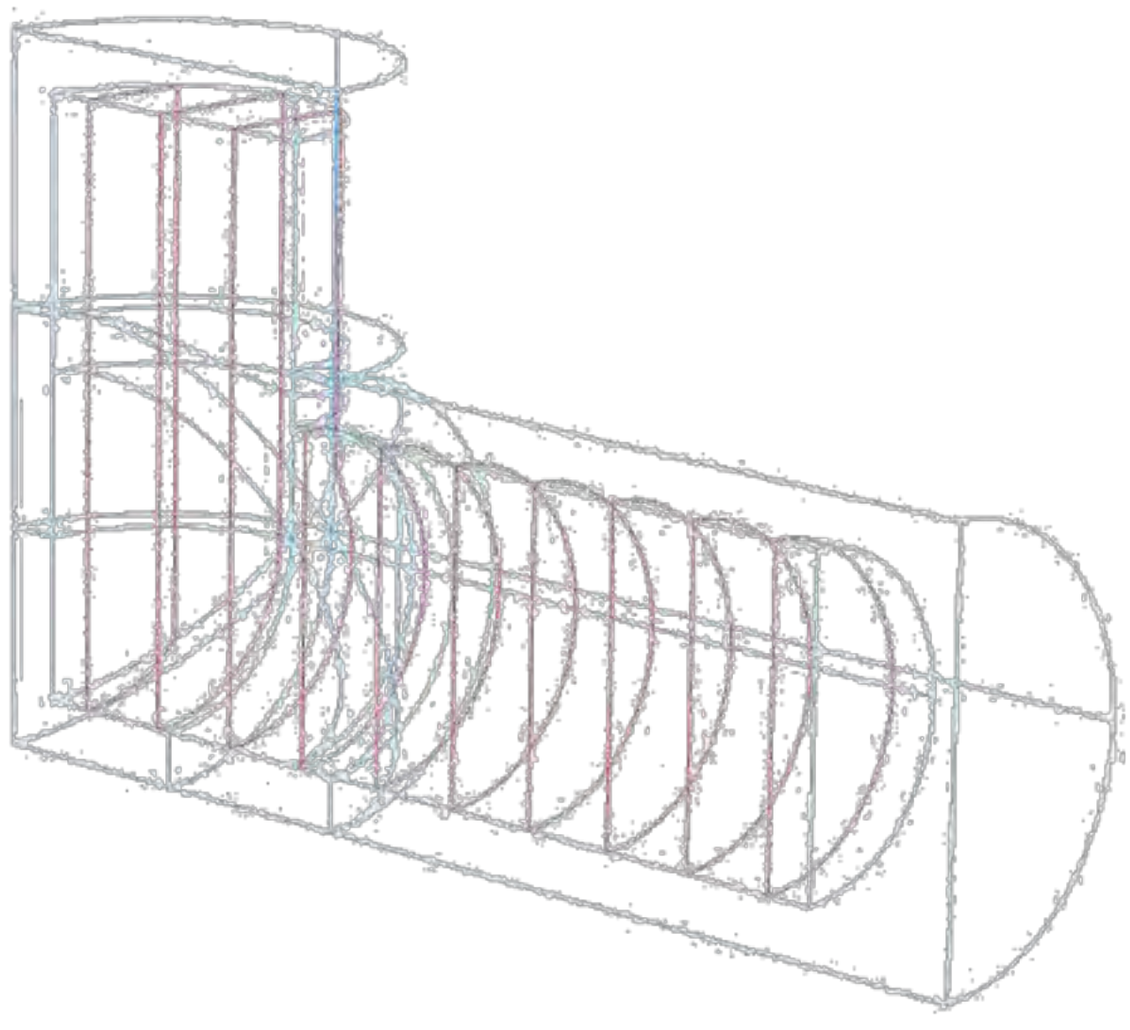
Trivial Inside Potential

- Uniformity in H gives planar equipotentials (U_1)
- Contours yields windings for each region!



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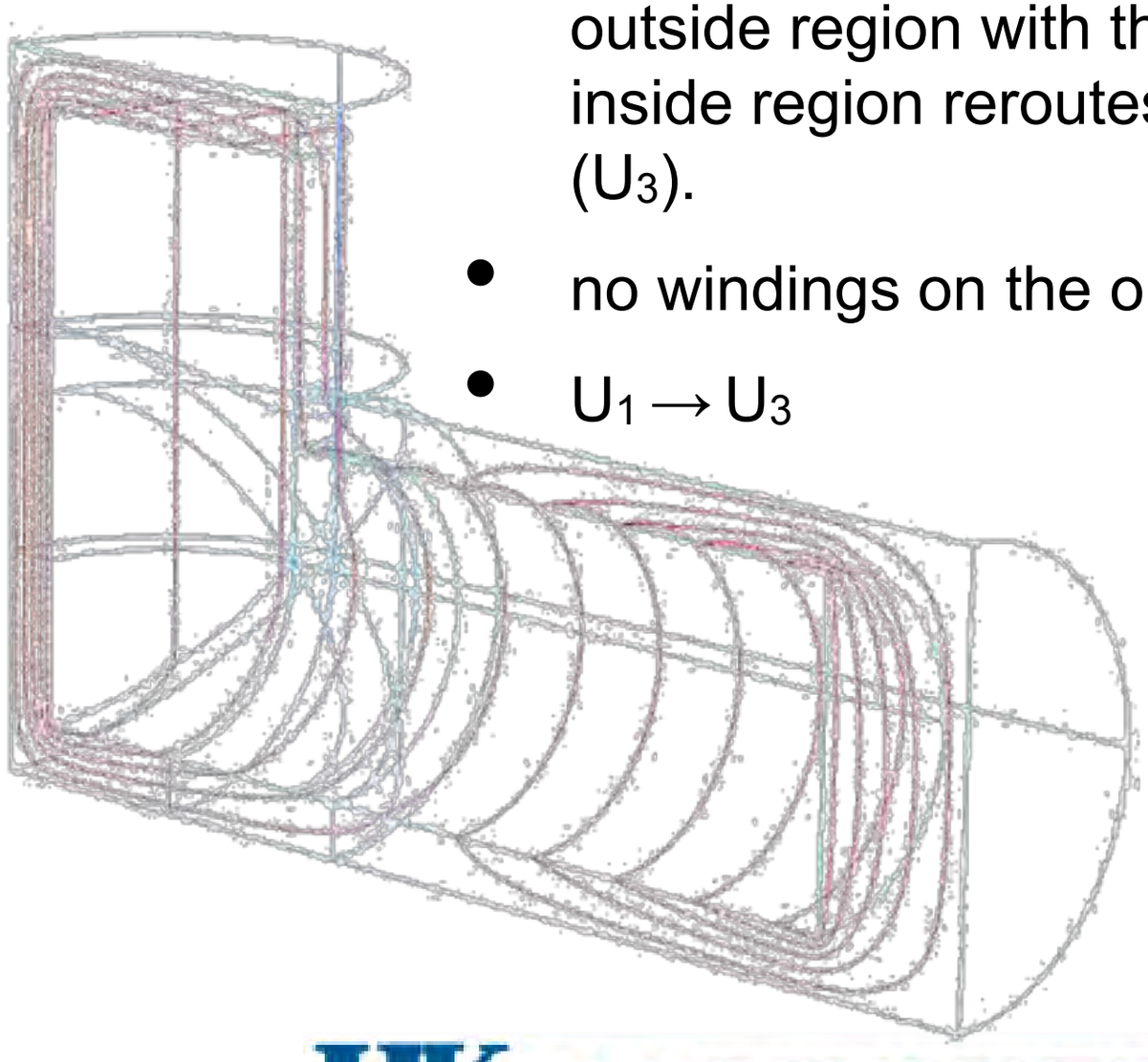
Inner coil after rerouting



- Solving Laplace's equation on the outside region with the B.C.'s from the inside region reroutes the windings (U_3).
- no windings on the outside surface
- $U_1 \rightarrow U_3$

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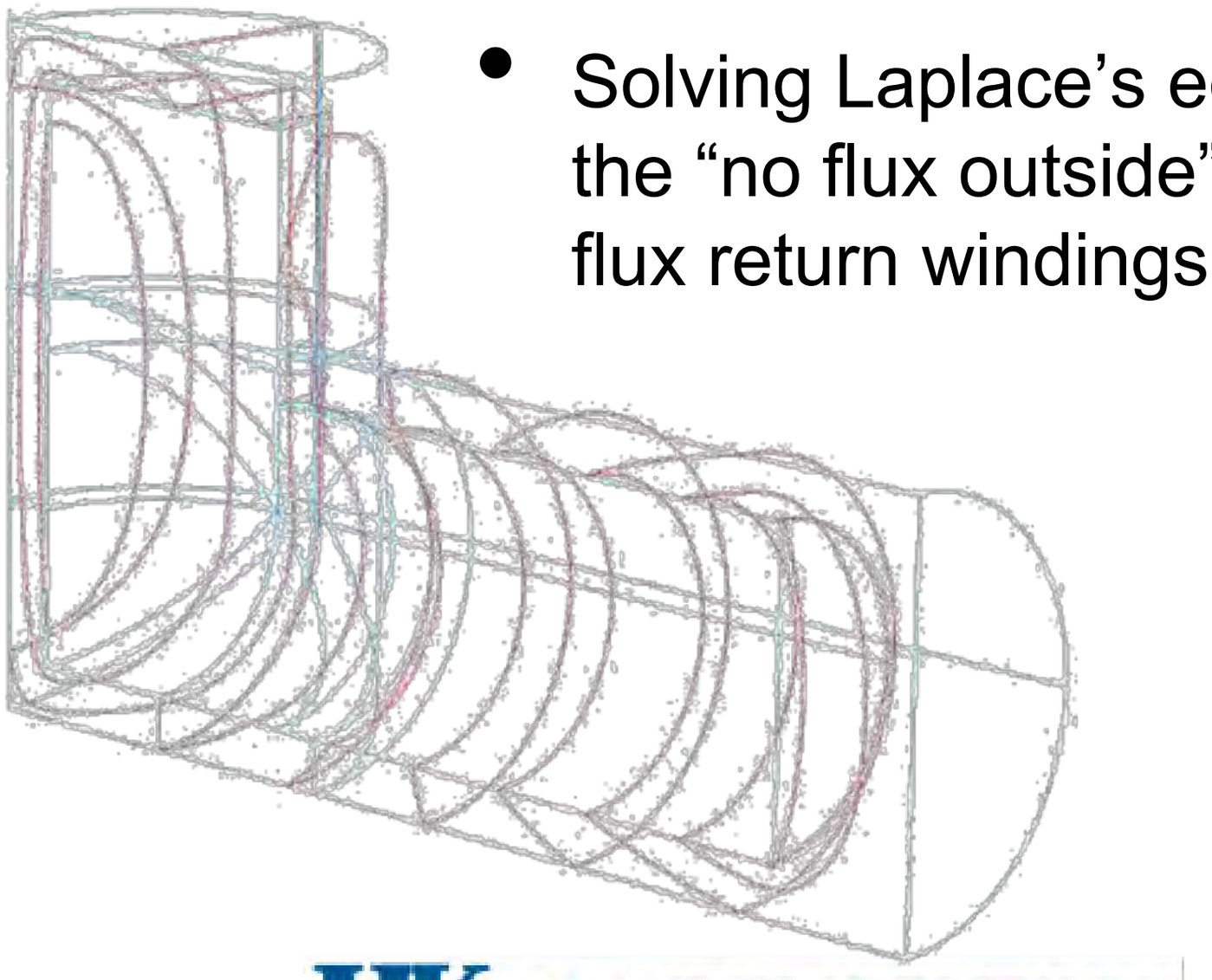
Outside windings (flux return)



- Solving Laplace's equation for the "no flux outside" B.C. yields flux return windings (U_2).

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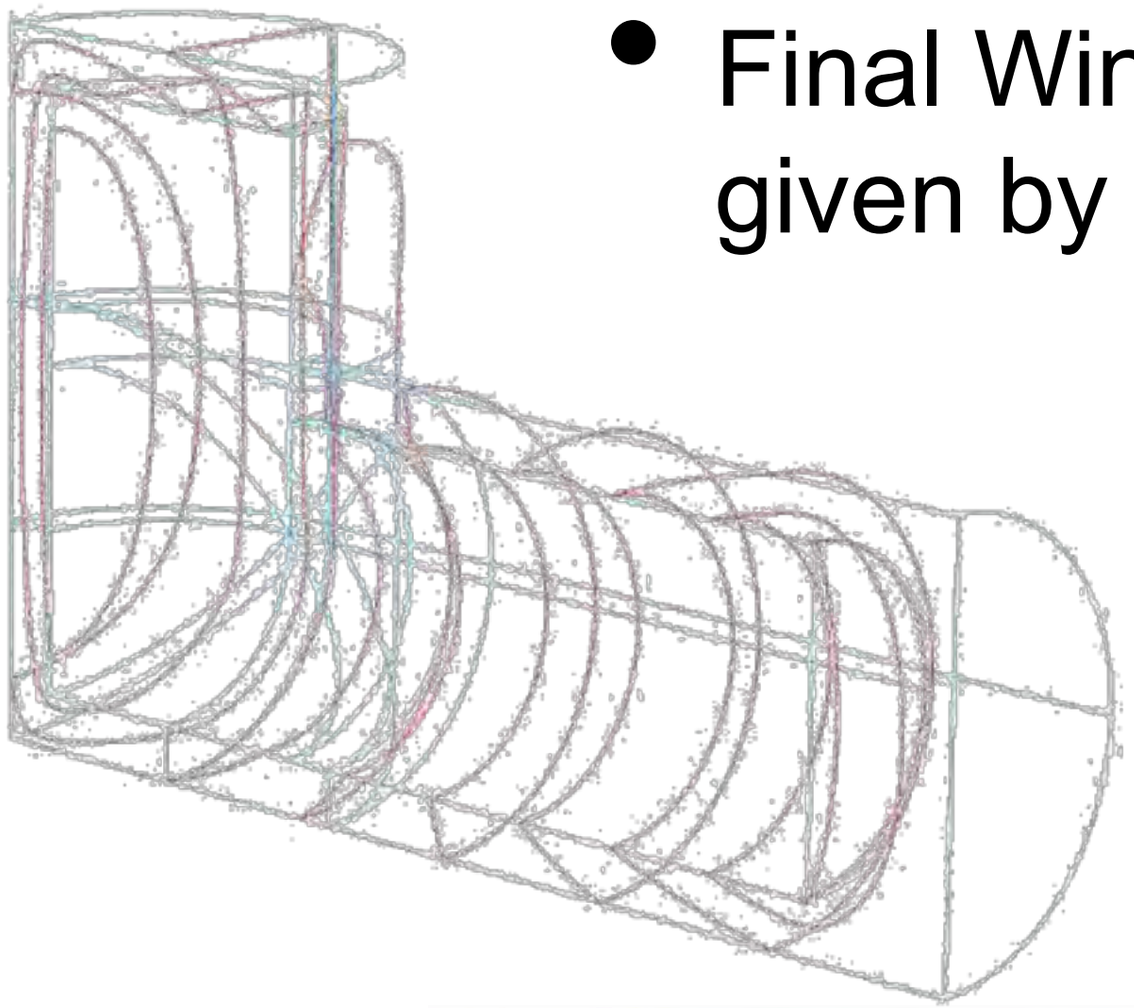
Combined Inner and Outside Windings



- Final Winding pattern is given by U_2+U_3

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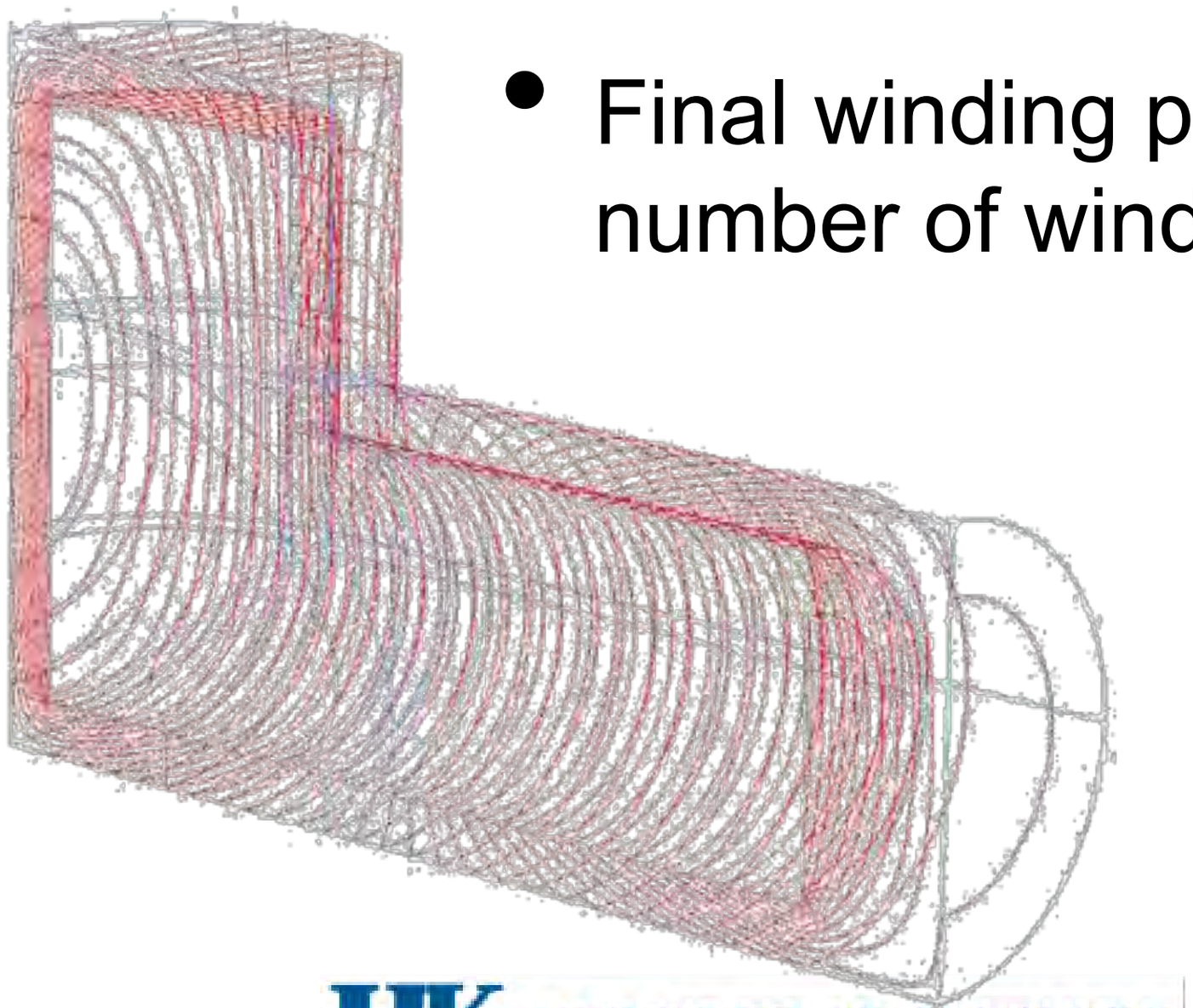
Final Winding Pattern



- Final winding pattern with number of windings N=50

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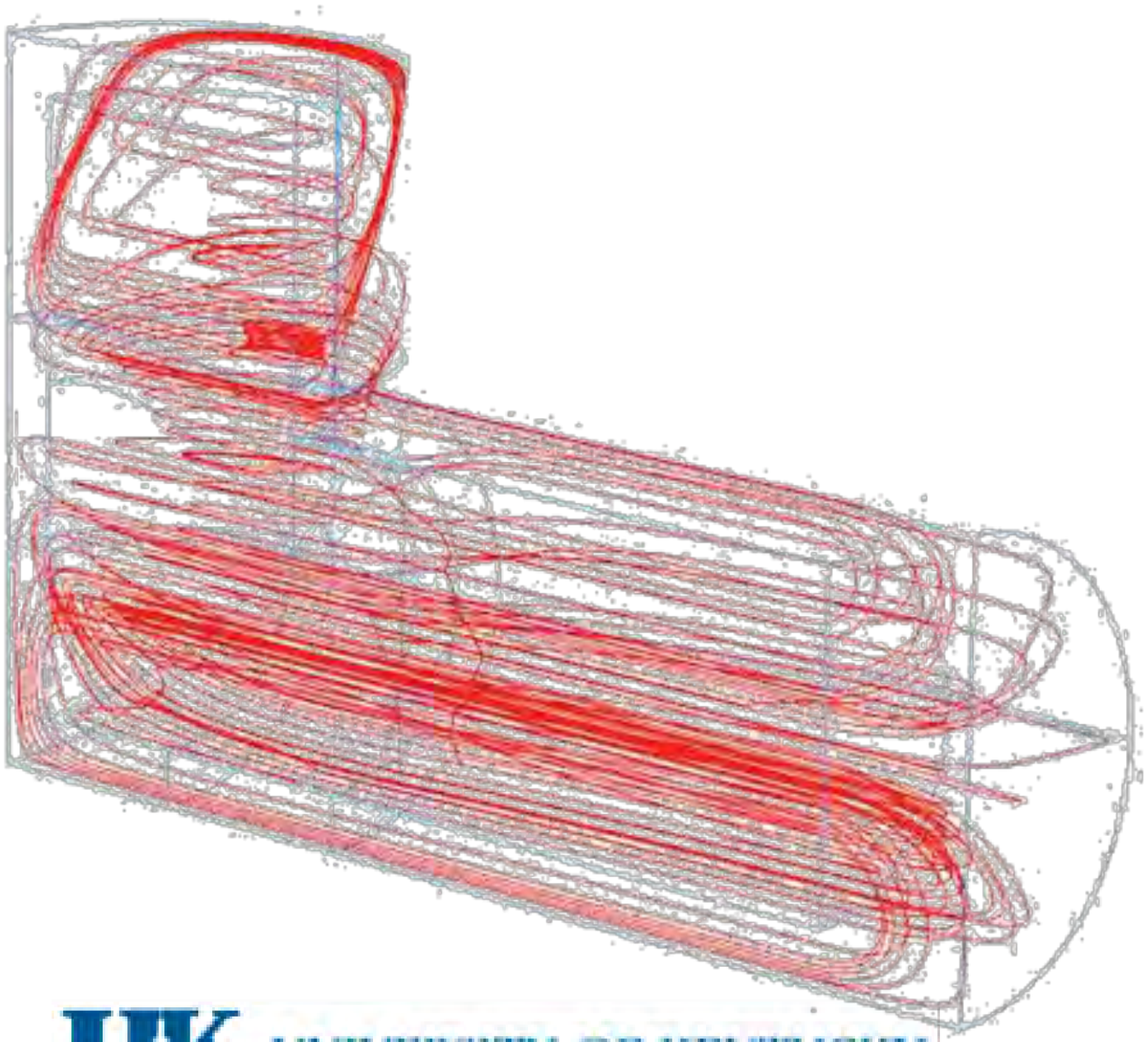
Calculated Flux



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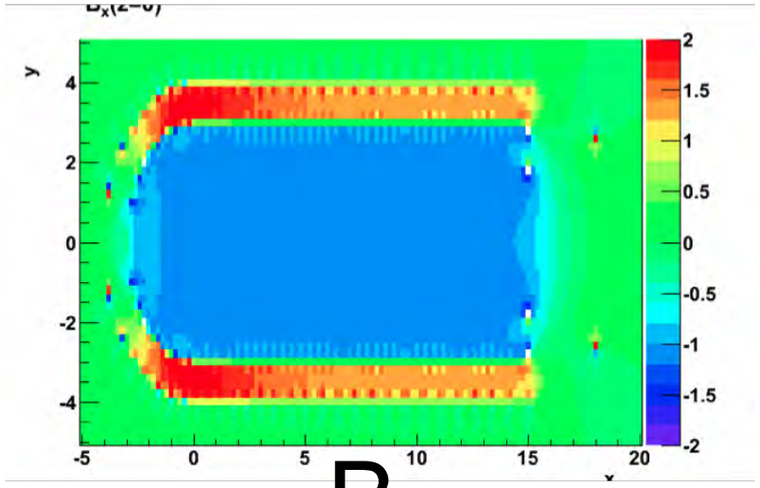
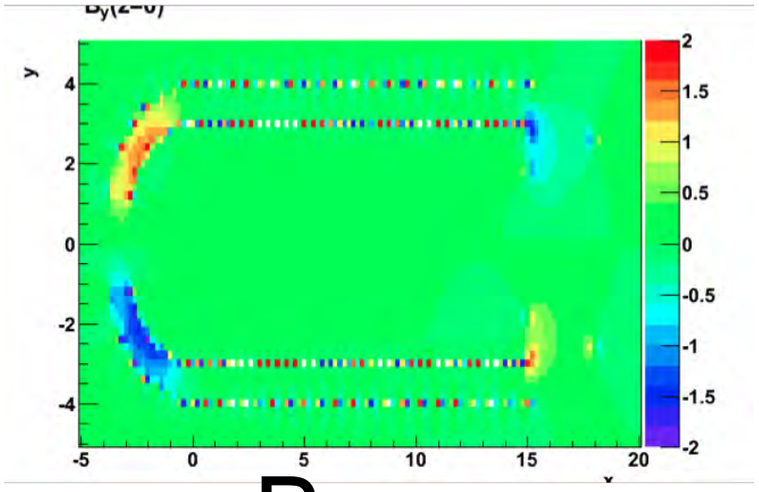
Simulated magnetic field

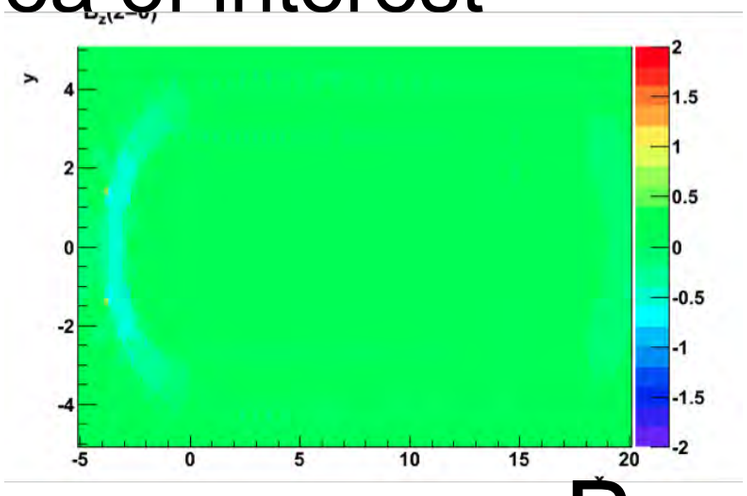


B_x

- Finally the resulting magnetic field is simulated by using Biot-Savart's Law
- No field outside
- Extreme uniform in the area of interest



B_y



B_z

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