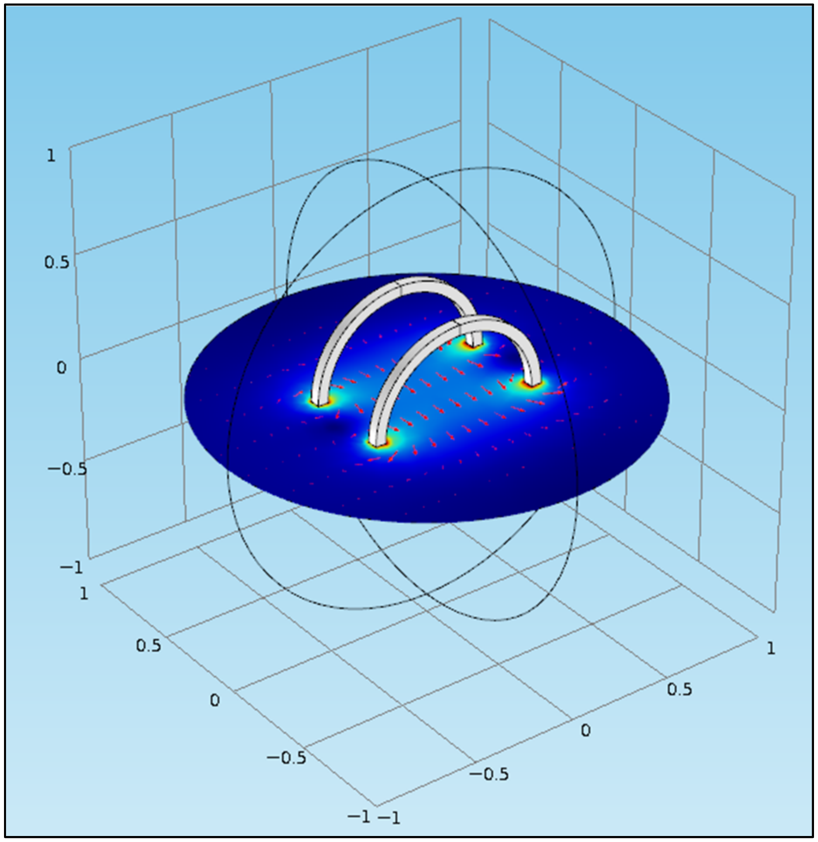
How to plot the gradients of magnetic field



COMSOL

Background

- 3D magnetic problems are solved in COMSOL using vector (curl) elements.

- The solution to these problems is the magnetic vector potential (***A***).

- The magnetic flux density (***B***) involves the 1st derivative of ***A*** and is given by the following equation.

$$B = \nabla \times A$$

- The second derivative is not defined on vector elements and hence we cannot visualize spatial gradients of ***B*** directly in COMSOL.

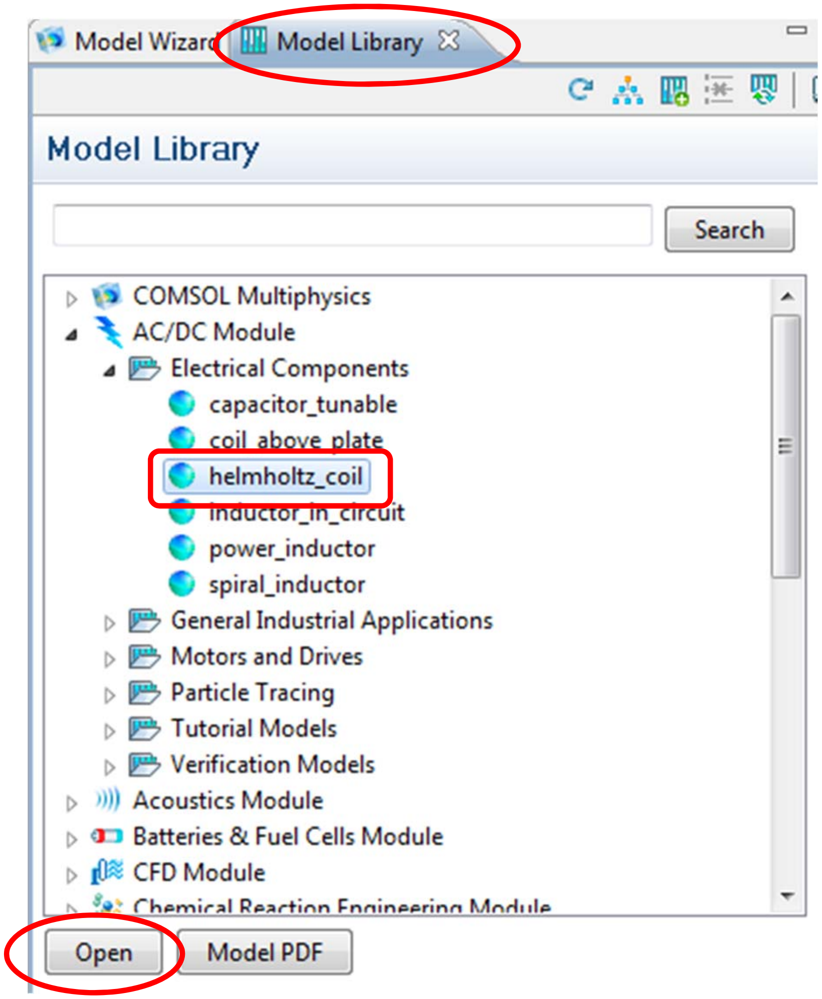
Objective

- This tutorial shows how to visualize the spatial derivatives of ***B***.
- The technique demonstrated here shows how each component of ***B*** = [B_x, B_y, B_z] can mapped to a separate variable say *u*, *u2*, *u3* respectively.
- These new variables would be defined on Lagrange elements.
- Since both 1st and 2nd order derivatives are defined on Lagrange elements, we would be able to obtain spatial derivatives of each component of ***B***.
- The mapping on Lagrange elements will also allow the use of polynomial patch recovery to get smooth values of derivatives.

Modeling steps

- The next few slides illustrate the steps involved in mapping the solution from an existing 3D magnetic model.
- The detailed steps are available in the file: *helmholtz_coil_field_gradient_42a*

Open the Helmholtz Coil example



- Click on the **Model Library** tab
- AC/DC Module > Electrical Components > helmholtz_coil
- Click on the **Open** button

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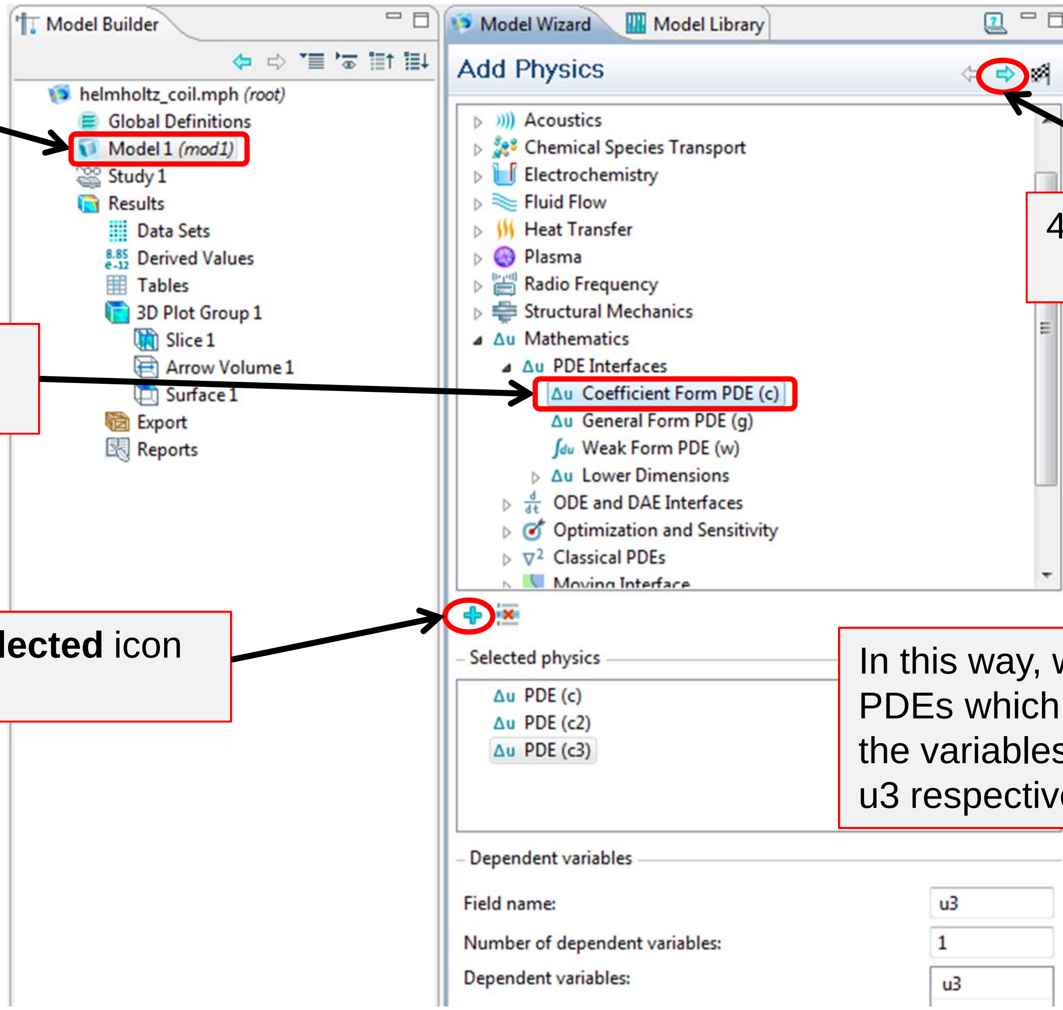
Add three PDEs

1. Right-click on **Model 1** and select **Add Physics**

2. Select **Coefficient Form PDE**

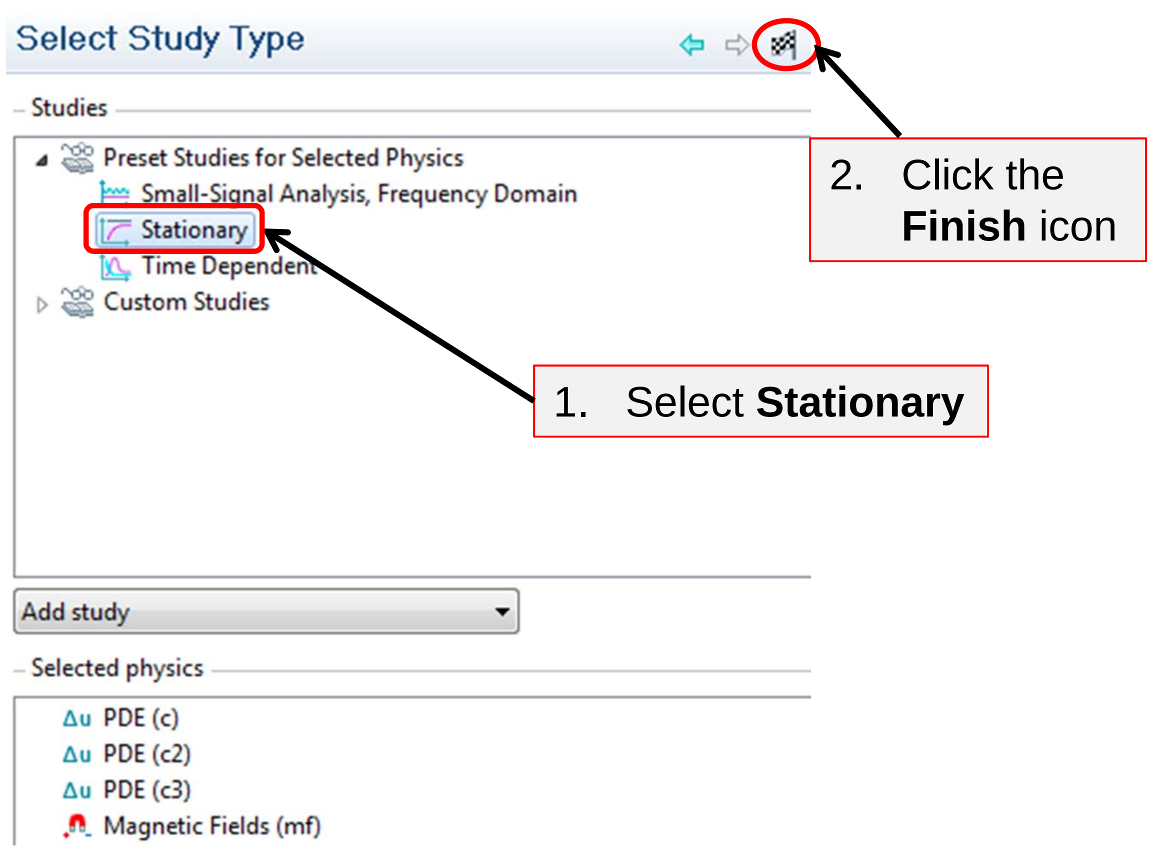
3. Click the **Add Selected** icon three times

4. Click on the **Next** icon

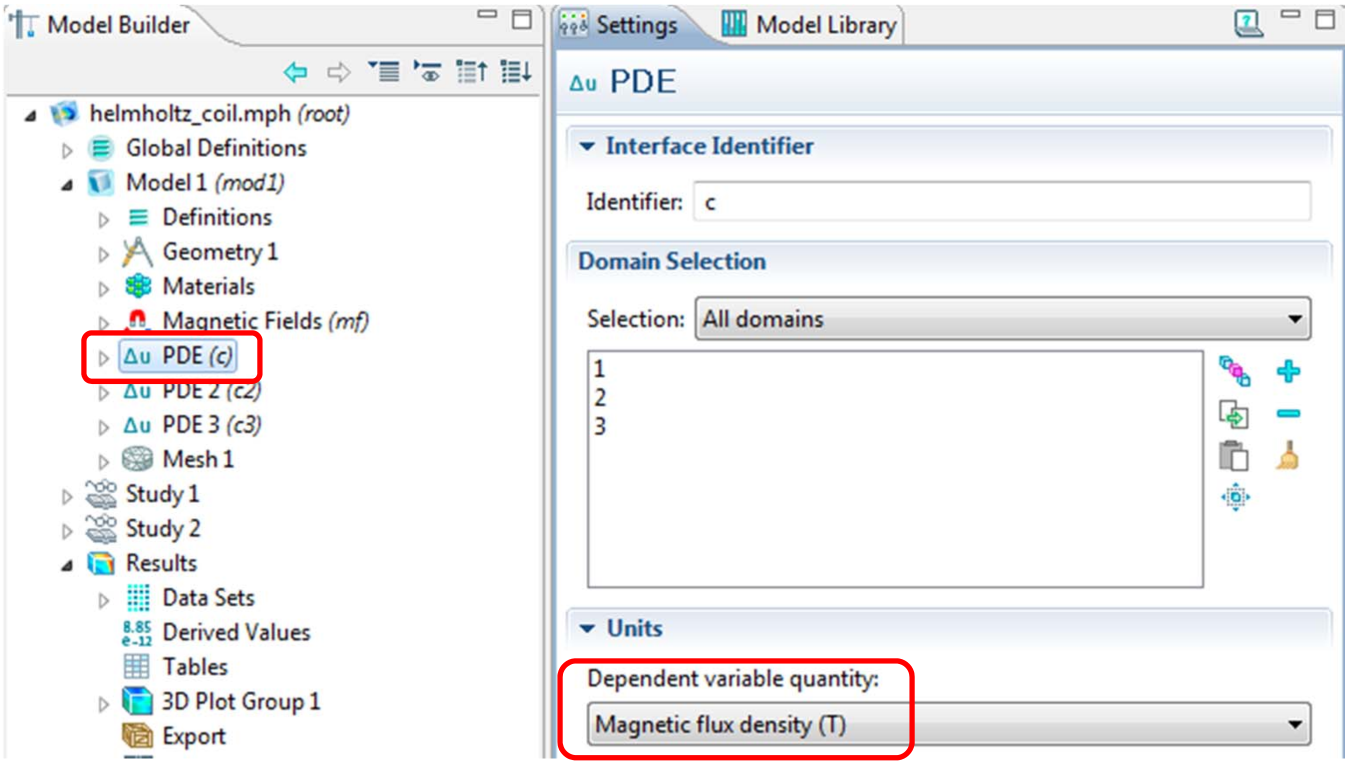


In this way, we add three PDEs which will solve for the variables u, u2 and u3 respectively

Choose a stationary study



Specify the unit



- This imparts the unit of magnetic flux density to the dependent variable **u** for this PDE interface.
- Repeat the same for the other two PDE interfaces as well.

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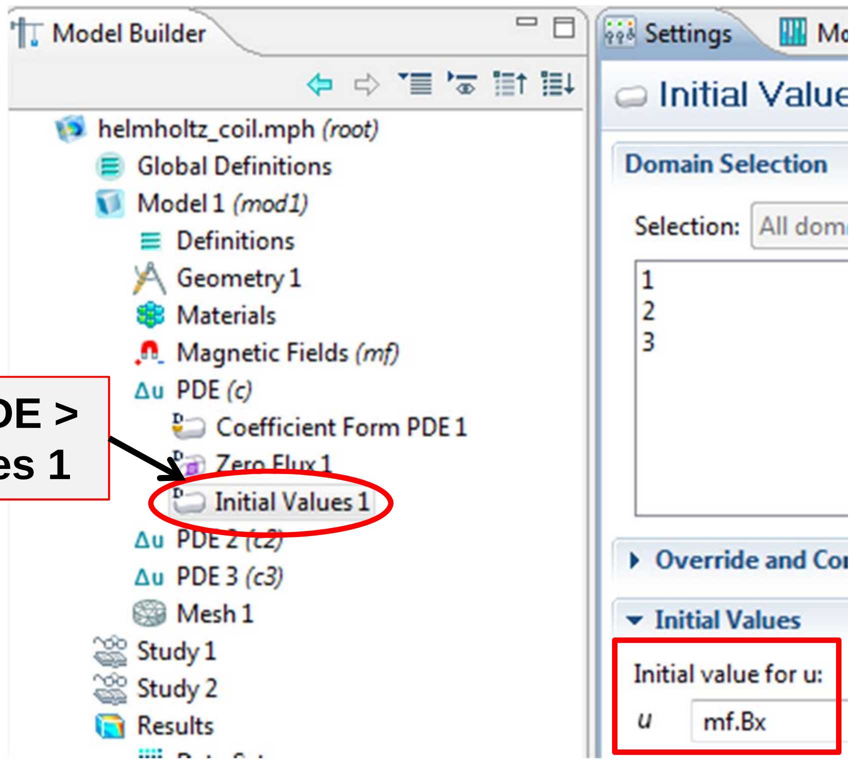
Map the solution



1. Select **PDE > Initial Values 1**

2. Set the value of **u** to be **mf.Bx**.
This is the value of the x-component of the B-field which was solved in the **Magnetic Fields** problem

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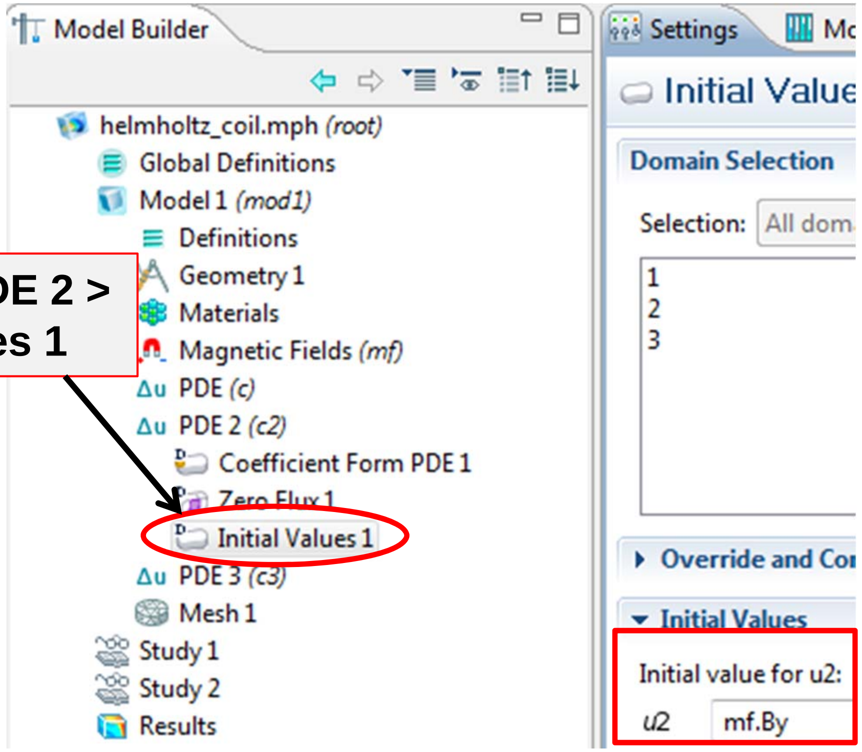
Repeat the step to map mf.By onto u2

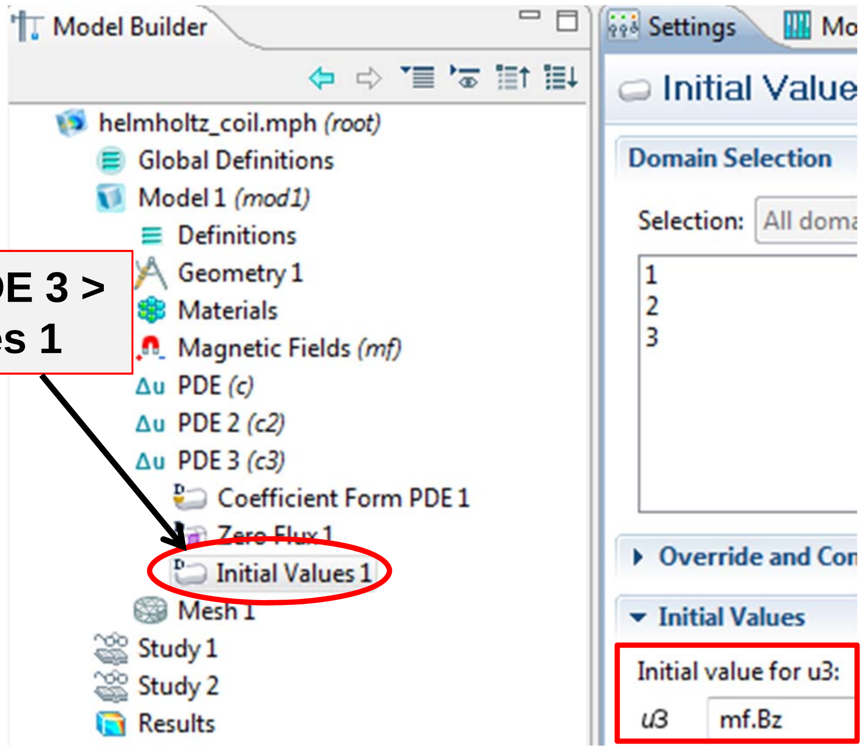
1. Select **PDE 2 > Initial Values 1**



2. Set the value of **u2** to be **mf.By**.
This is the value of the y-component of the B-field which was solved in the **Magnetic Fields** problem

Repeat the step to map mf.Bz onto u3

1. Select **PDE 3 > Initial Values 1**

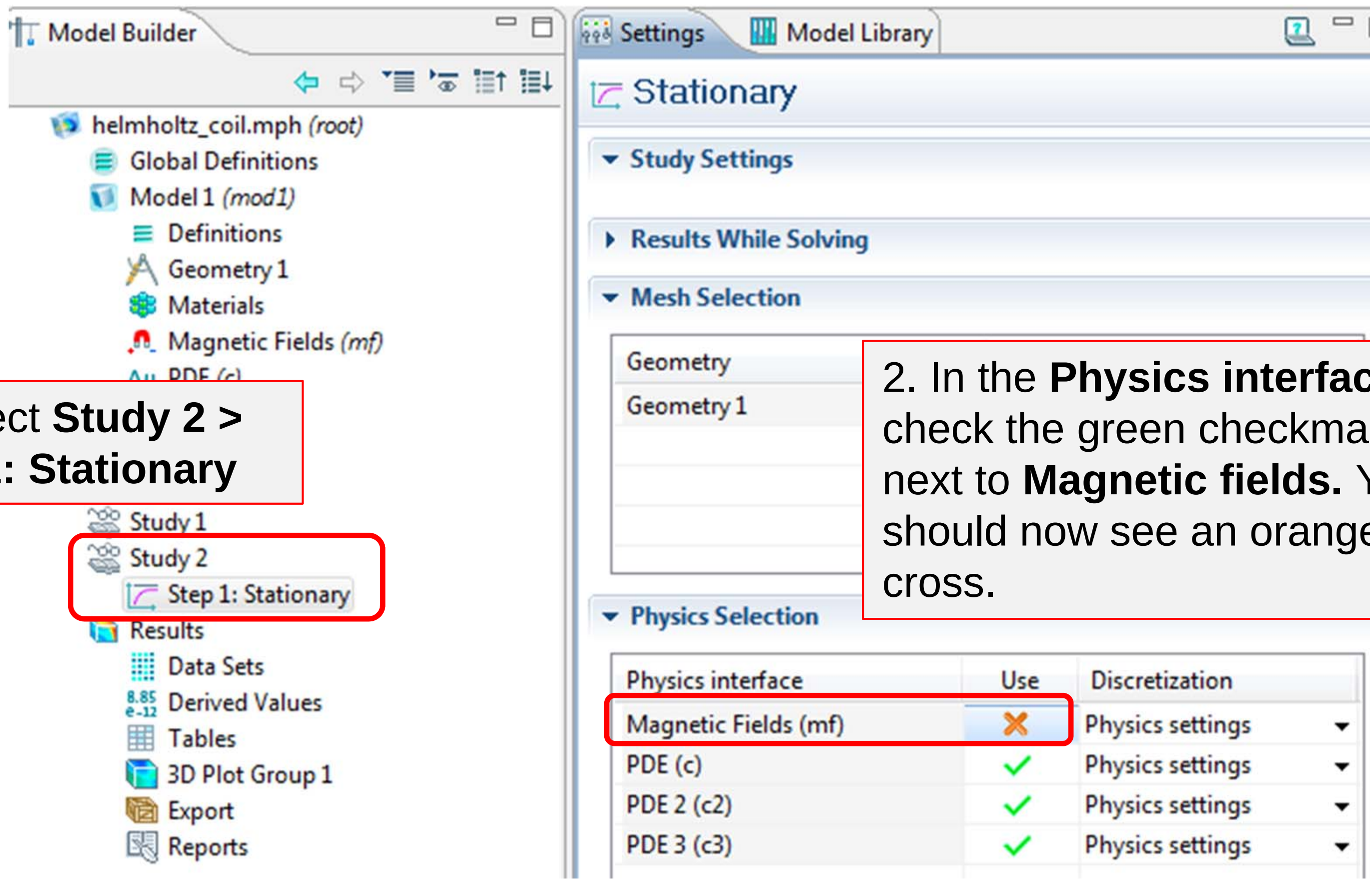


2. Set the value of **u3** to be **mf.Bz**.
This is the value of the z-component of the B-field which was solved in the **Magnetic Fields** problem

Deselect Magnetic Fields from Study 2

1. Select **Study 2 > Step 1: Stationary**

2. In the **Physics interface** list check the green checkmark next to **Magnetic fields.** You should now see an orange cross.



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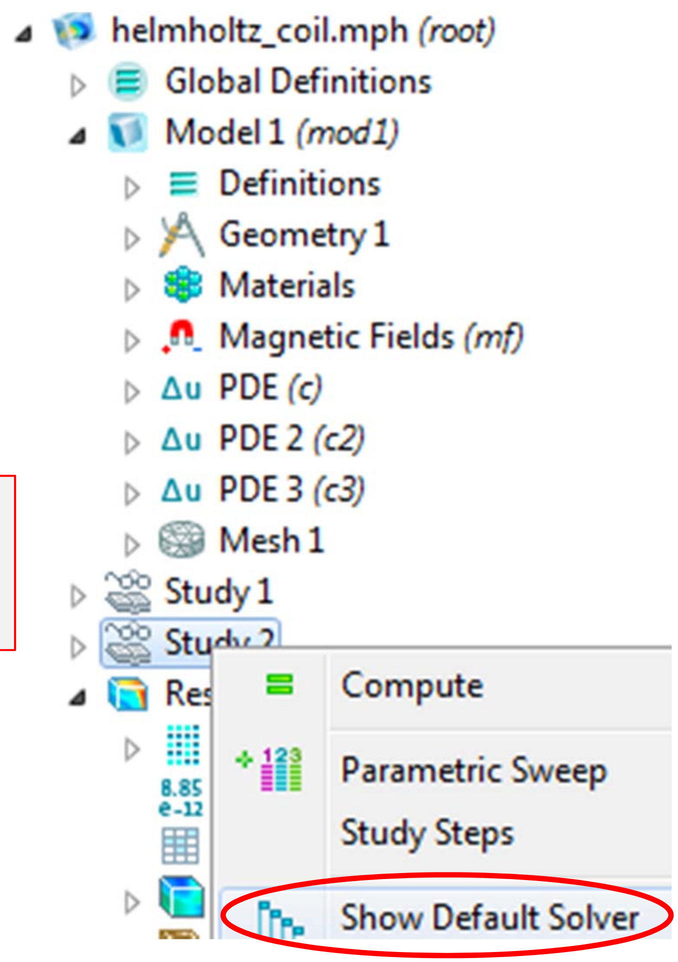
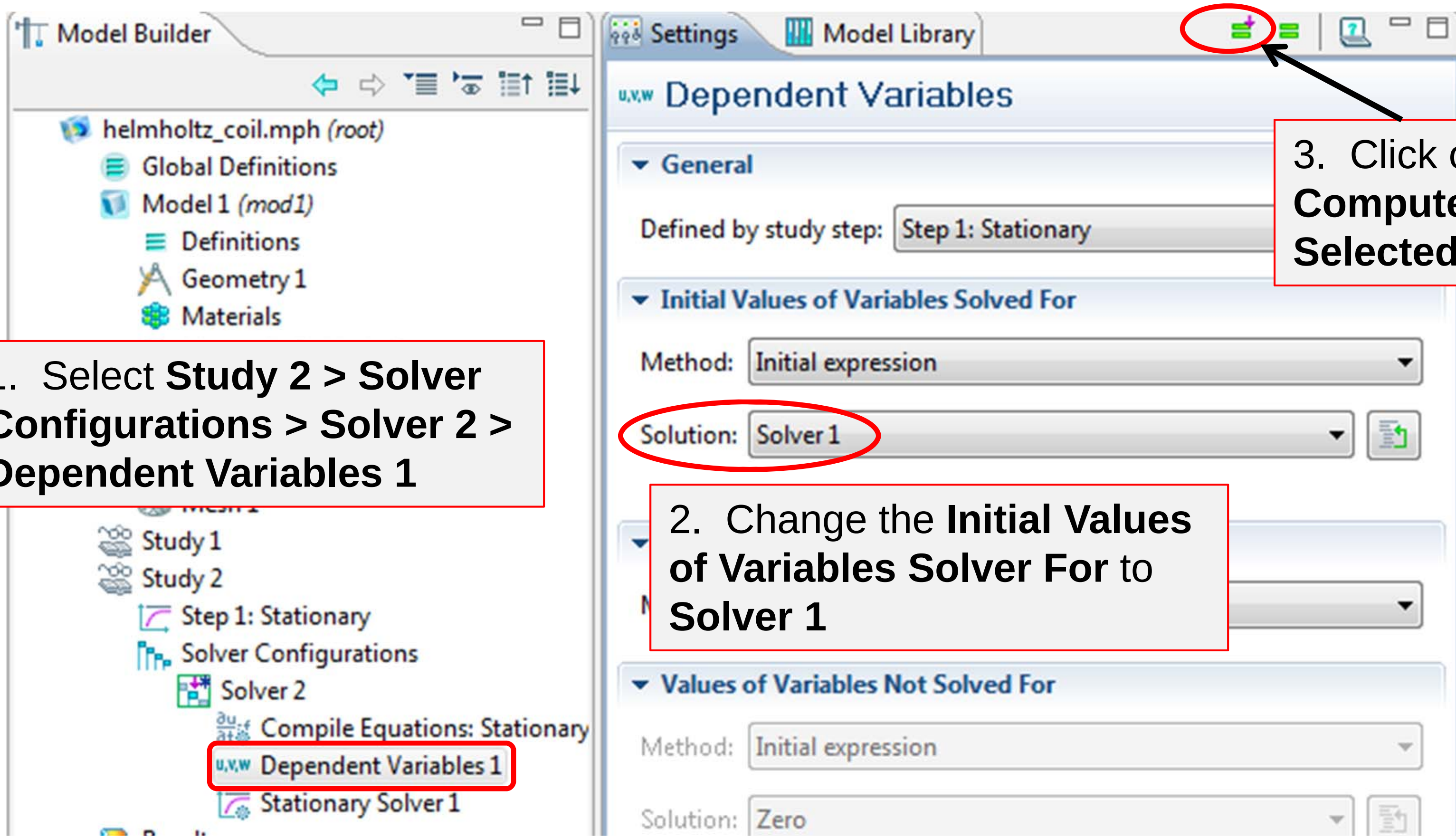
Find the default solver settings for Study 2

Right-click **Study 2** and select **Show Default Solver**



Get the initial values of the PDE variables

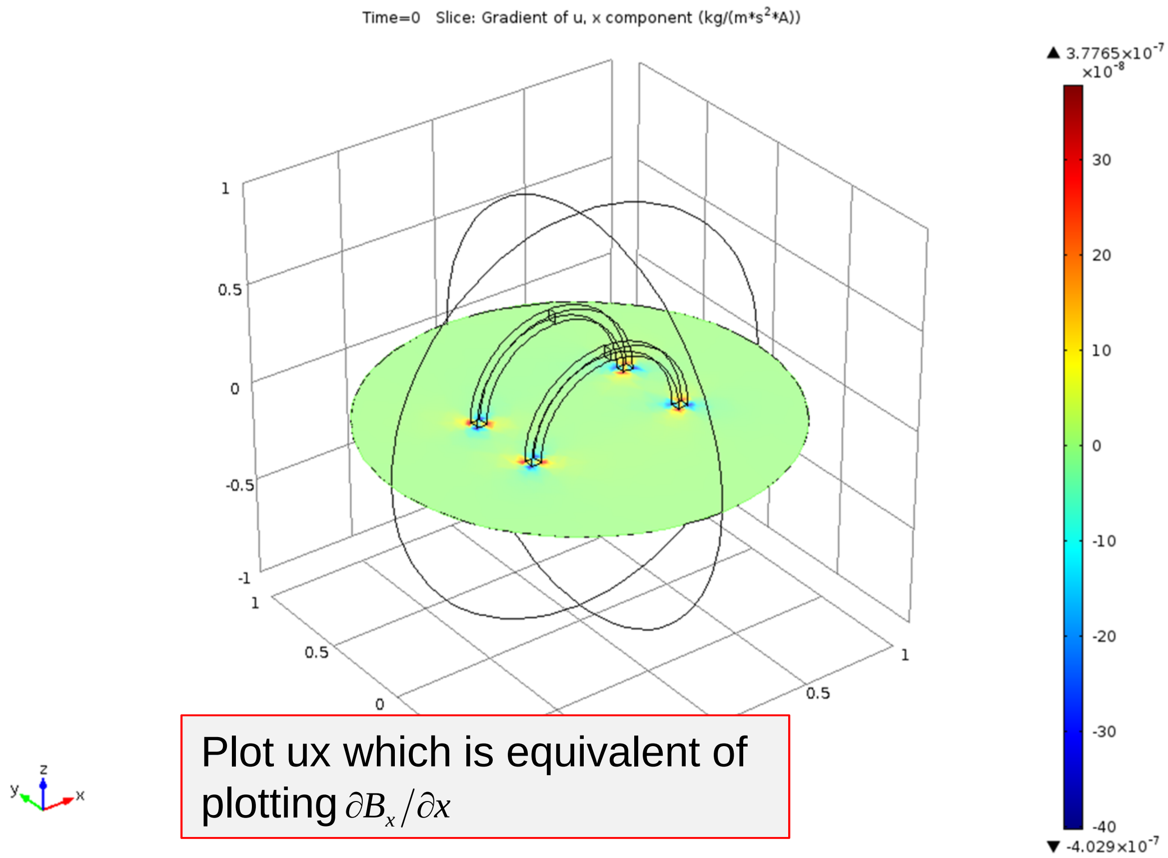


1. Select **Study 2 > Solver Configurations > Solver 2 > Dependent Variables 1**

2. Change the **Initial Values of Variables Solver For** to **Solver 1**

3. Click on the **Compute to Selected** icon

Results > 3D Plot Group 2



Plot ux which is equivalent of plotting $\partial B_x / \partial x$

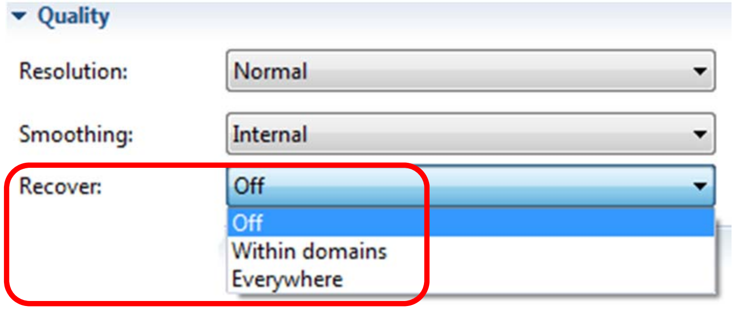
Note on polynomial patch recovery (ppr)

- The *polynomial patch recovery* feature allows you to obtain smoother derivatives.

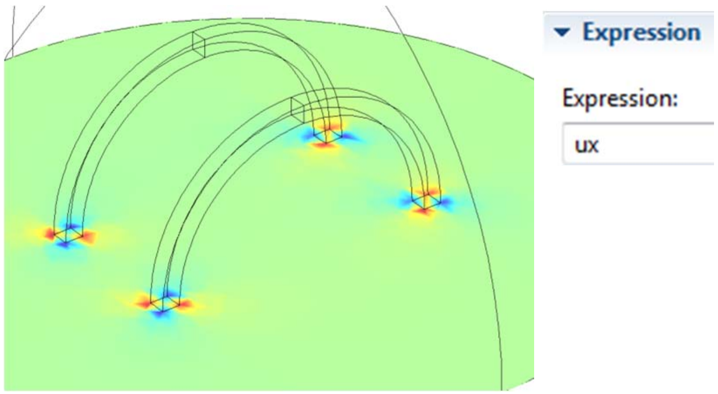
- How to use this feature?
  - You can either use the *ppr* or *pprint* function

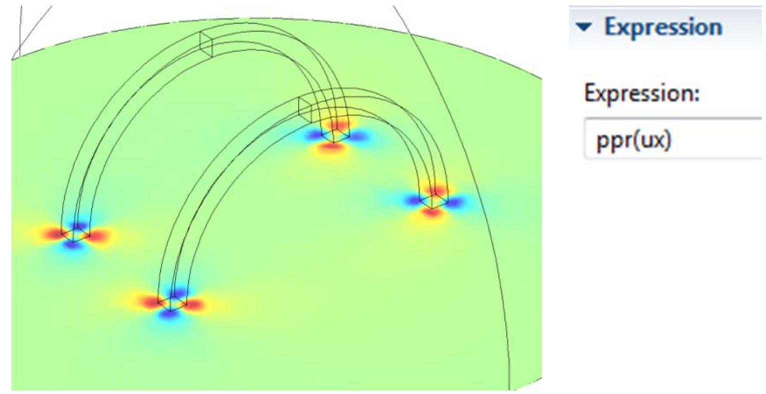
  OR…
  - Expand the **Quality** section of the plot settings and see the **Recover** list

- Refer to the COMSOL Multiphysics User's Guide for details.



Apply ppr to derivatives of B-field

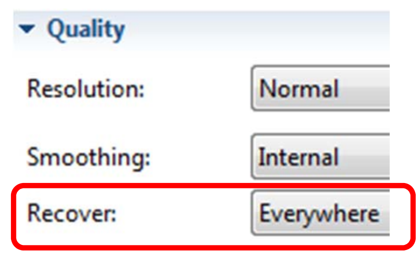




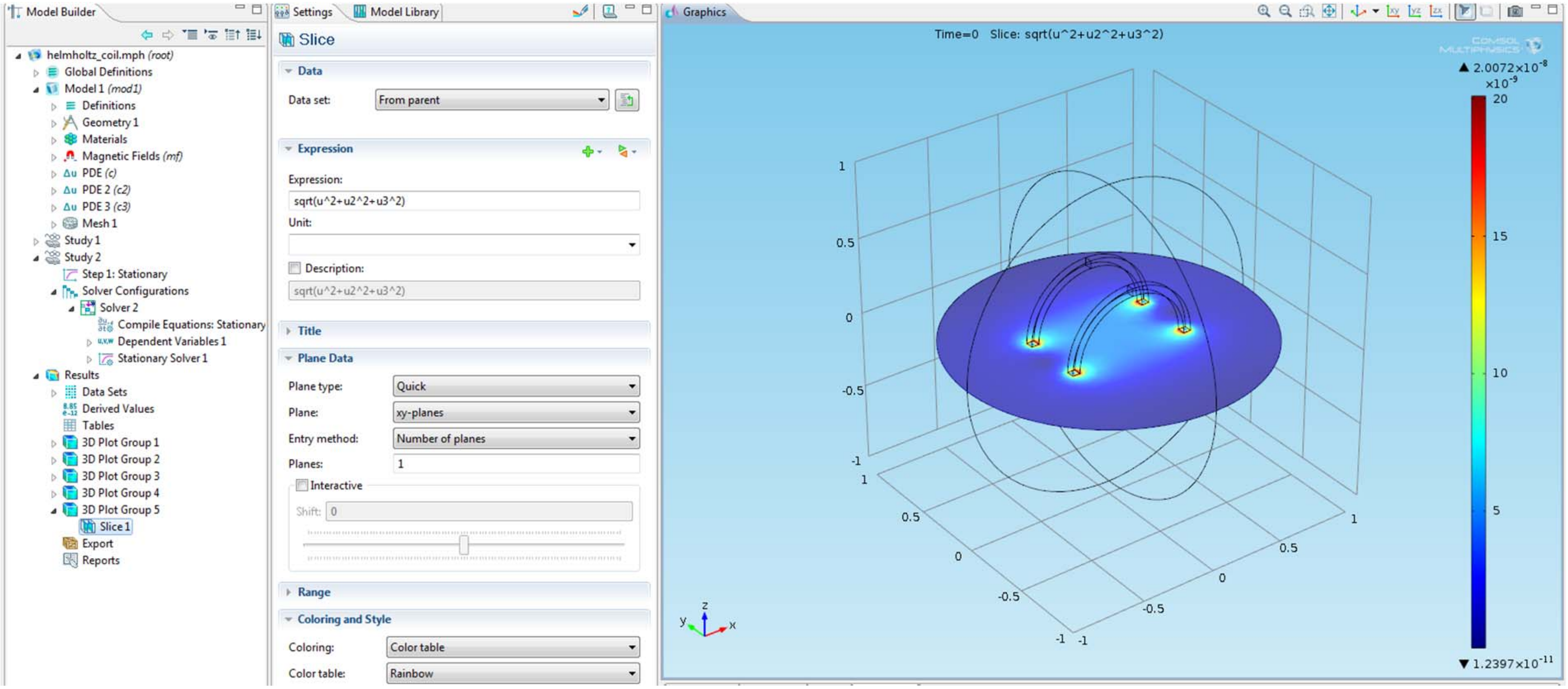
Plot of **ux** (notice the rough edges in the color pattern)

Plot of **ppr(ux)** (notice the smoothened color pattern)

You will get the same smoothing if you set the expression as **ux** and choose **Everywhere** for **Recover.**



Results > 3D Plot Group 5



- Create a slice plot of the magnitude of B-field using the variables u, u2 and u3 to verify the mapping.
- Compare this with the original solution in 3D Plot Group 1.

Summary

- This tutorial showed how to visualize the spatial gradient of magnetic field.
- The magnetic field solution was mapped from vector elements to Lagrange elements.
- The derivative operations could be performed on the solution on the Lagrange elements.
- Mapping the solution onto Lagrange elements also give us the advantage to get smooth derivatives by using the polynomial patch recovery feature.