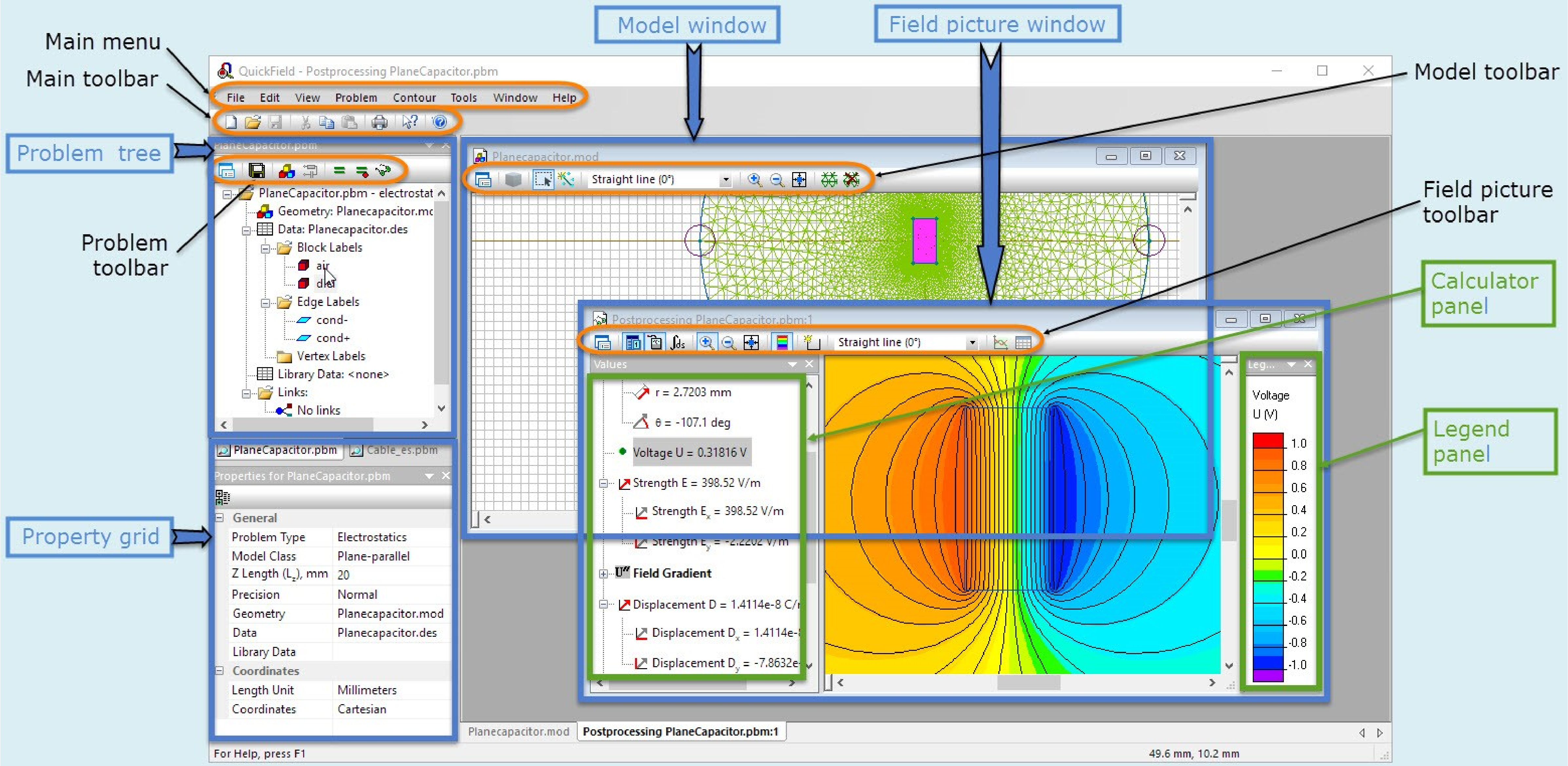
Week 2: QuickField Fundamentals

How to start QuickField and solve a simple problem of electrostatics.

1. Create the problem. Choosing the formulation
2. Draw the geometry by vertices, segments and arcs. Make the problem closed, when needed
3. Assign names to geometry shapes: all blocks, some edges, some vertices
4. Set up the material property, boundary conditions, field sources
5. Achieving optimal accuracy: control the mesh density (manually or automatically)
6. Analyzing the solution: field picture, local values, integral values, XY-plots, tables
7. Remember the field theory: how to calculate the capacitance

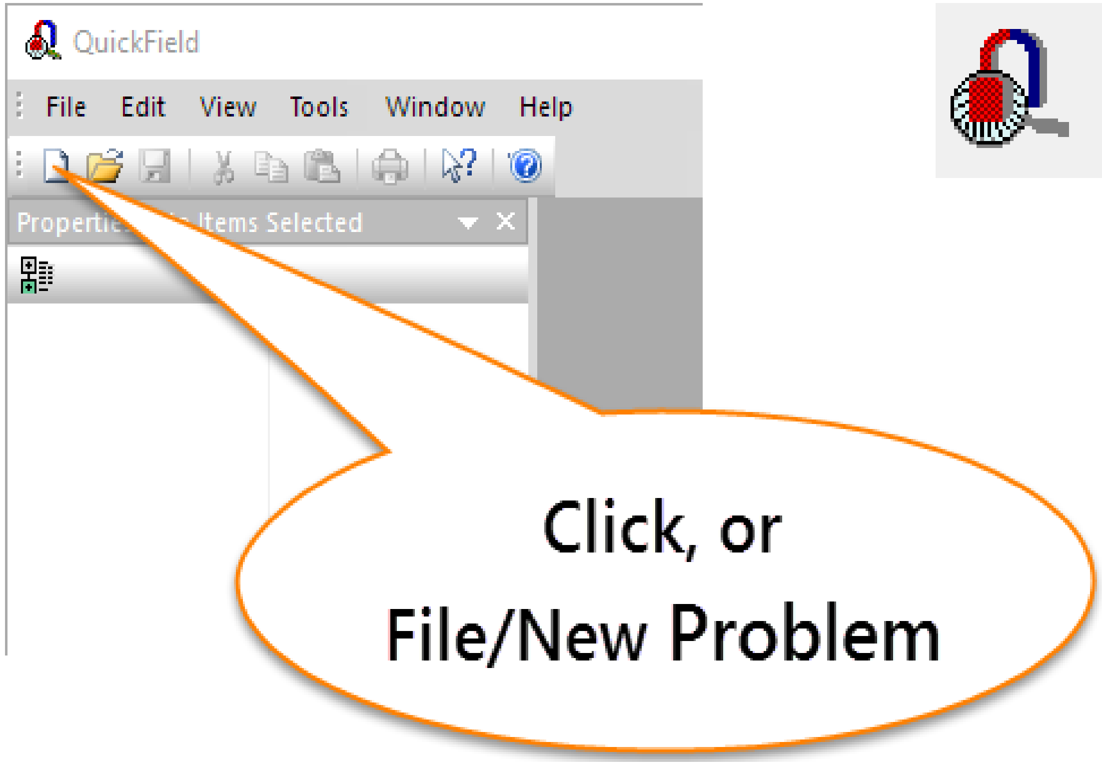
Getting started: the QuickField windows



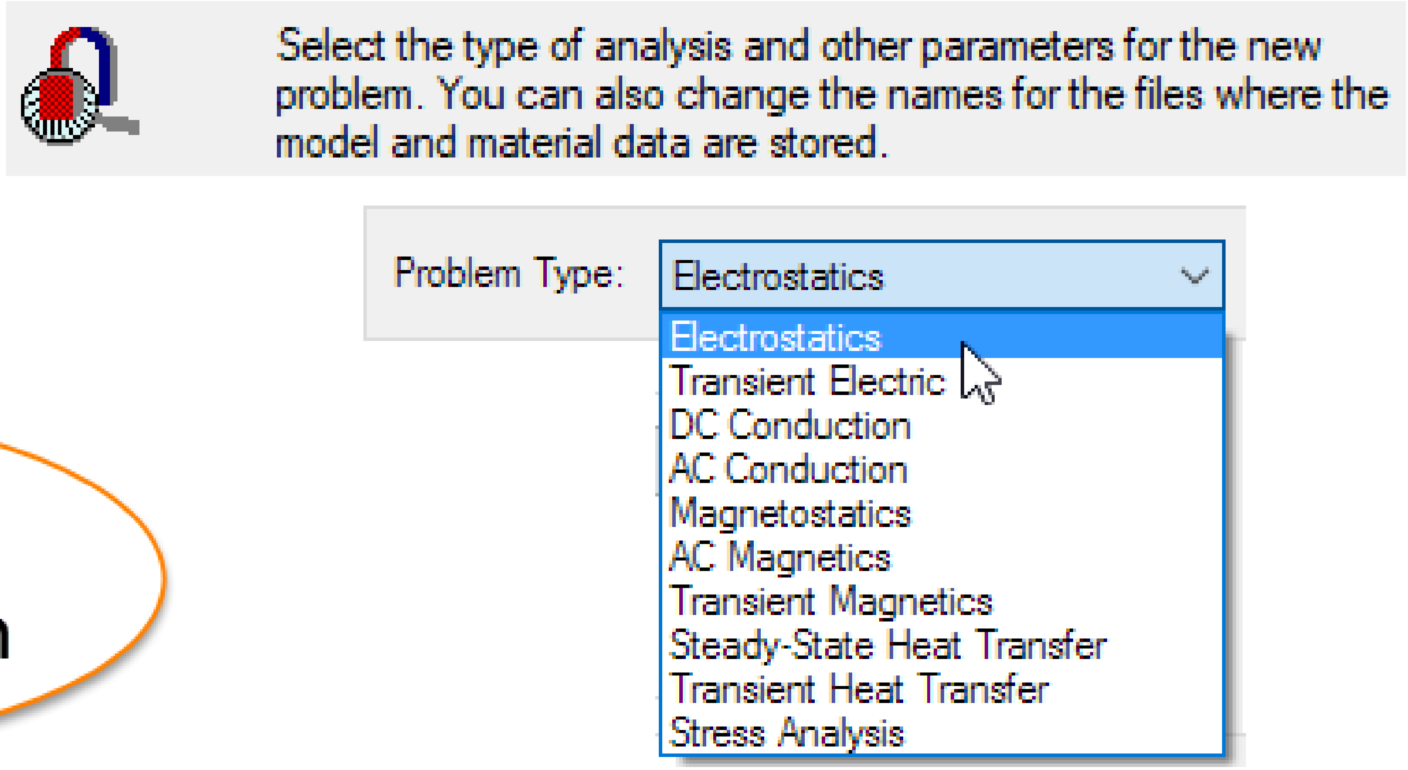
Getting started: Create a new problem

Think twice: Choose the proper problem formulation
(a subset of Maxwell equations)

1. Create the new problem and name it



2. Select the problem formulation

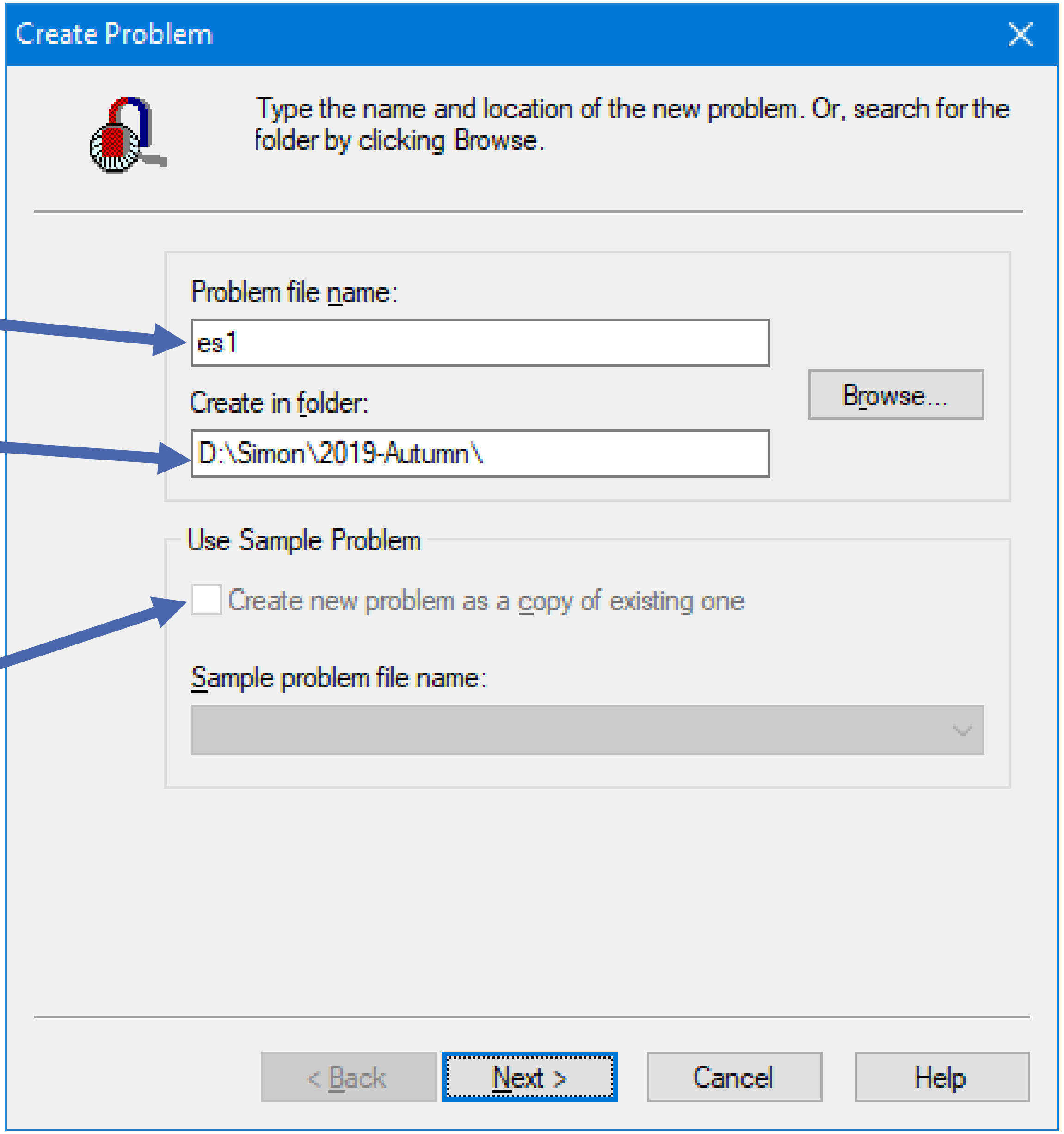


The Problem

Problem name

Location

Make a copy?



Problem Properties

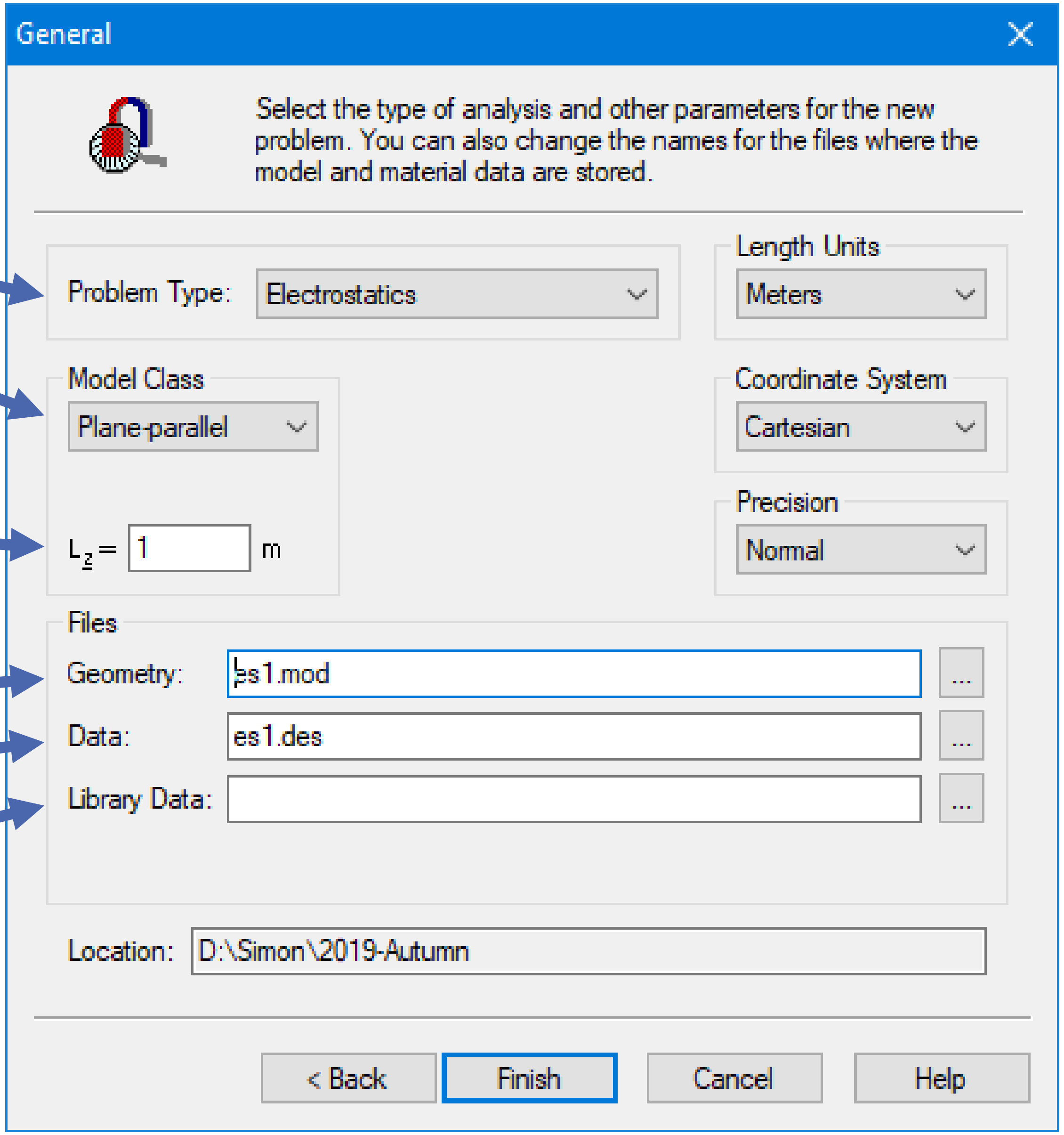
Formulation: Electrostatic field

Geometry class: Plane-parallel 2D problem

Length in the 3rd dimension (out of plane)

Links to referred files:

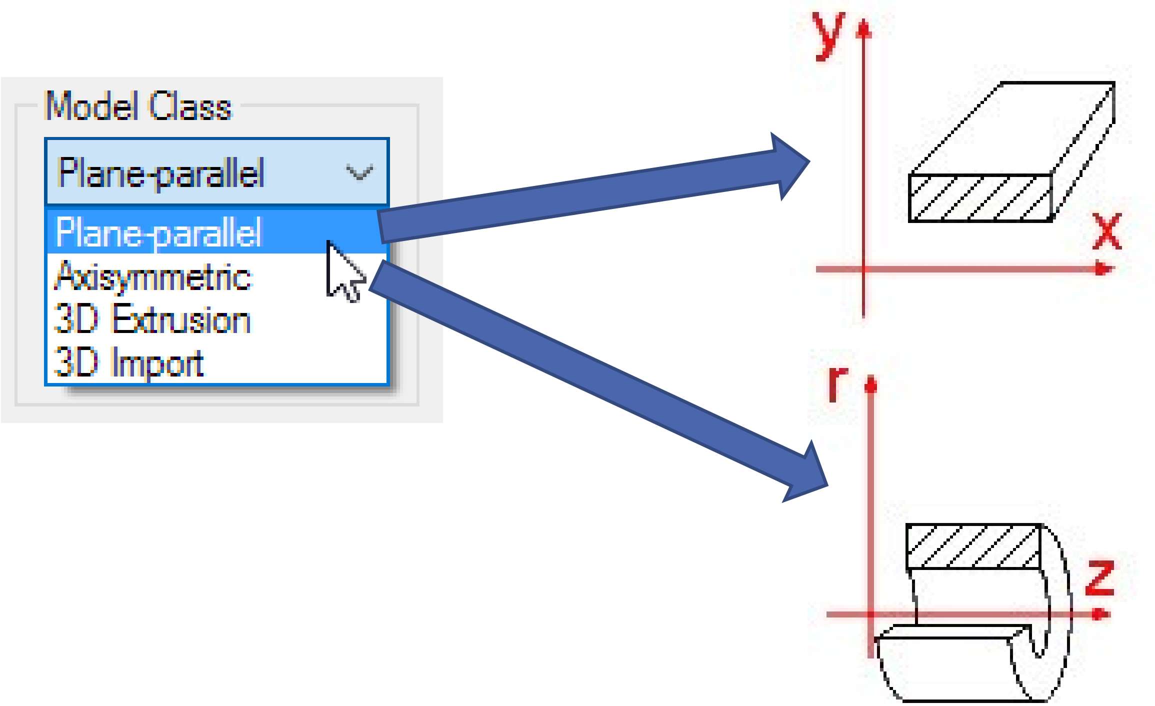
- Geometry
- Data
- Background data



Choosing the Model Class

How the 2D geometry extends in 3D world

3. Choose the Model Class: Plane-parallel or Axisymmetric



<u>Plane-parallel:</u>

1. Most of physical values are per 1 meter of axial length (in Z-direction)
2. You may define the axial length of the model. If you do that, QuickField calculates all integral quantities with respect to given Z-length

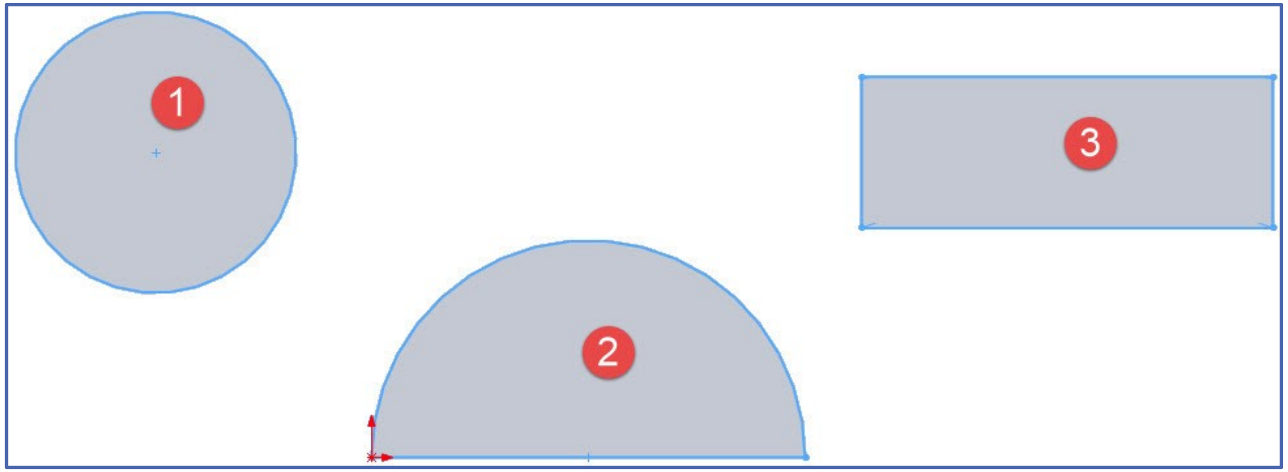
<u>Axisymmetric:</u>

1. With axisymmetric problems the rotation axis is always <u>horizontal</u> coordinate axis OZ
2. You only draw the cross-section of axisymmetric geometry <u>above</u> the rotation axis OZ

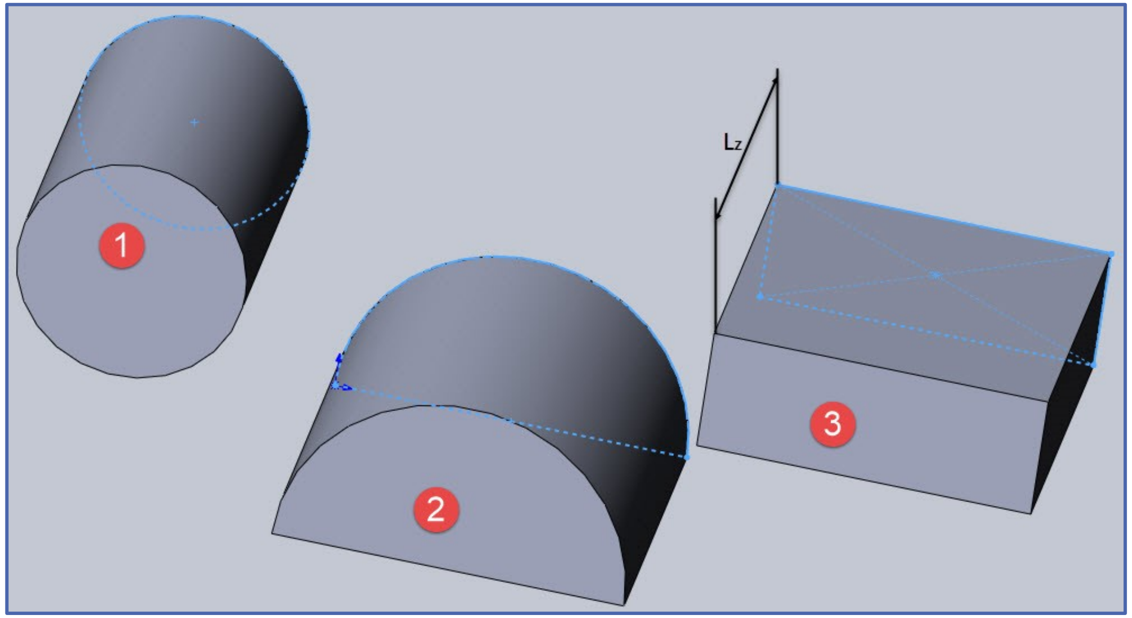
Getting started: Understand model classes

You draw:

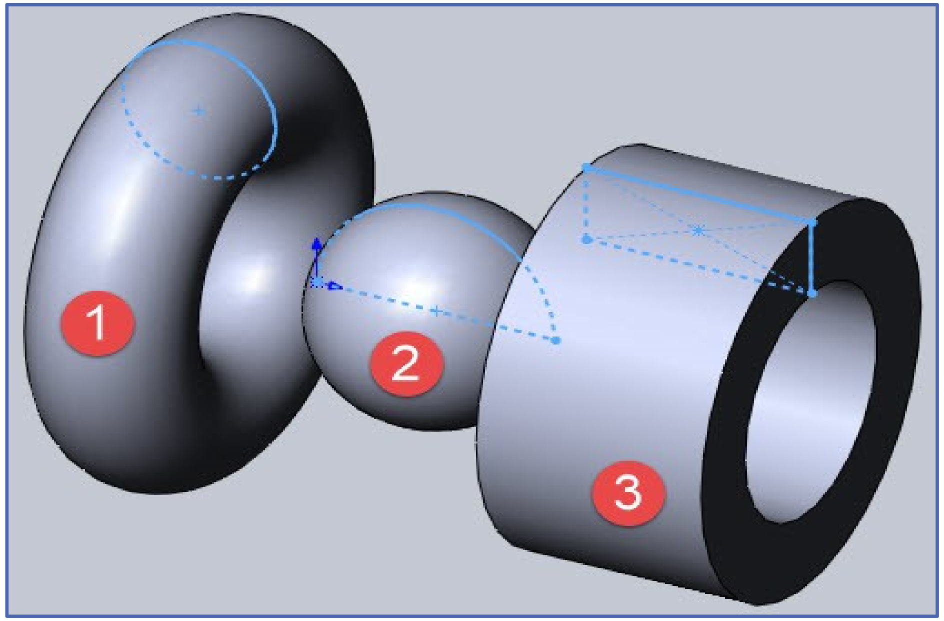
1. Circle
2. Semicircle
3. Rectangle



You get:



Or:



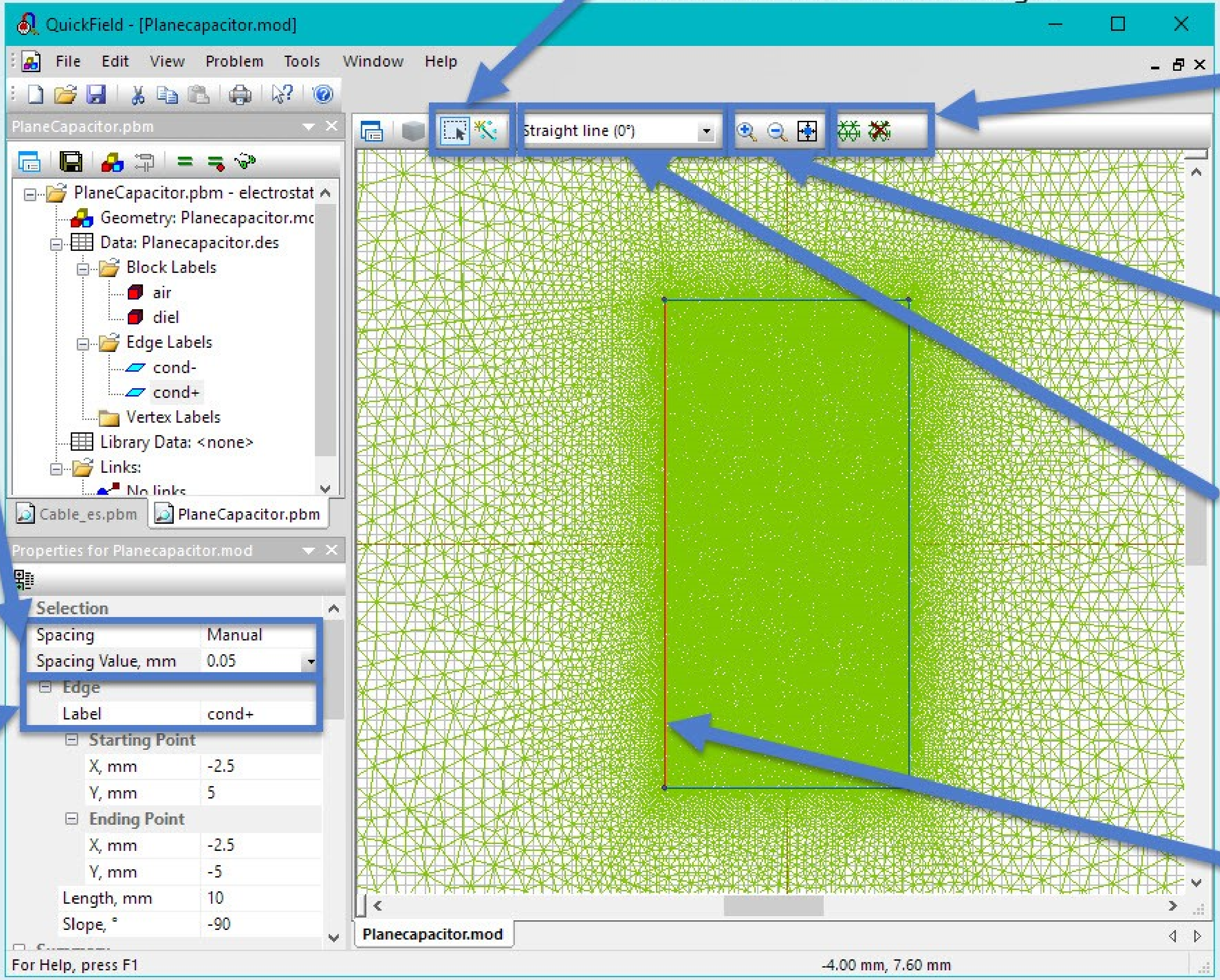
Working with the Model editor

Switch the operation mode:
Select shapes (left side), or
Insert new vertices and edges

Mesh controls:
build mesh
remove mesh
affects on selected blocks or on the whole model

Mesh spacing control:

Assign manual spacing to some vertices of your choise



Scale control:
+ zoom in
- zoom in
zoom to fit

Segment or Arc:
Choose 0 for segments or none-zero arc angle

Assing text label to all blocks, and edges and vertices with boundary condition

Selected shapes displayed in red color

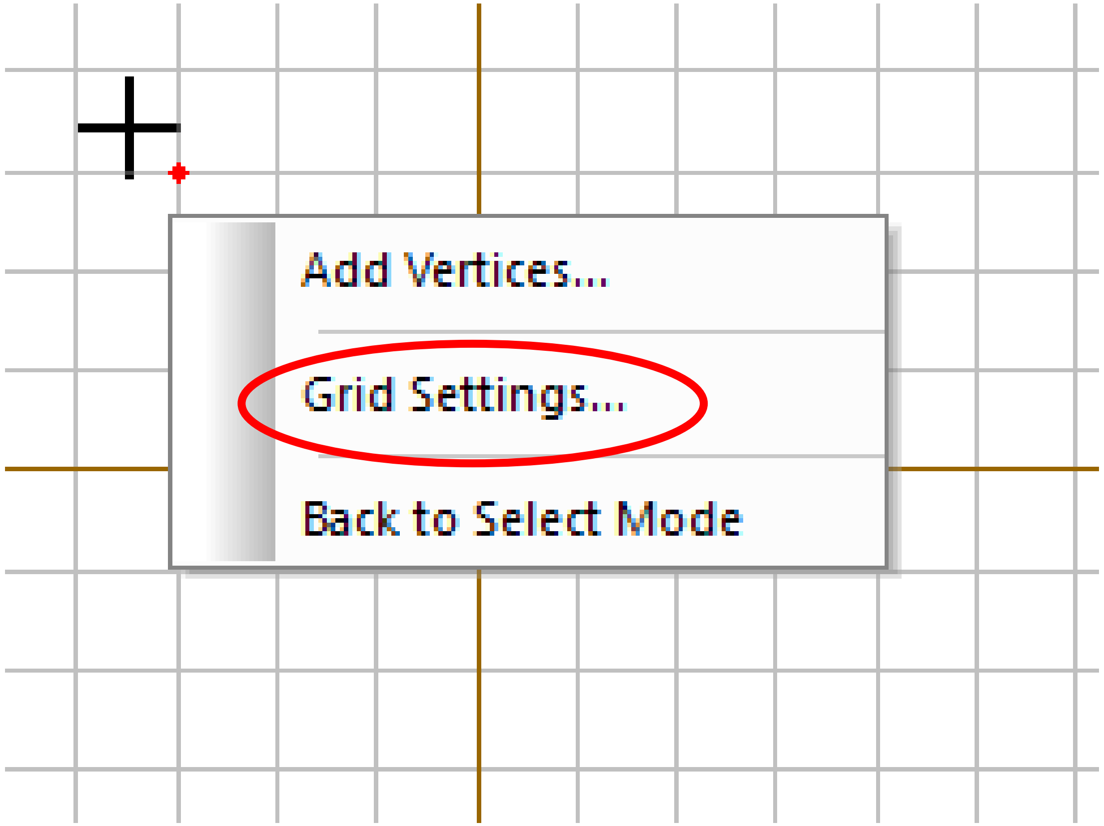
Working with the Model editor

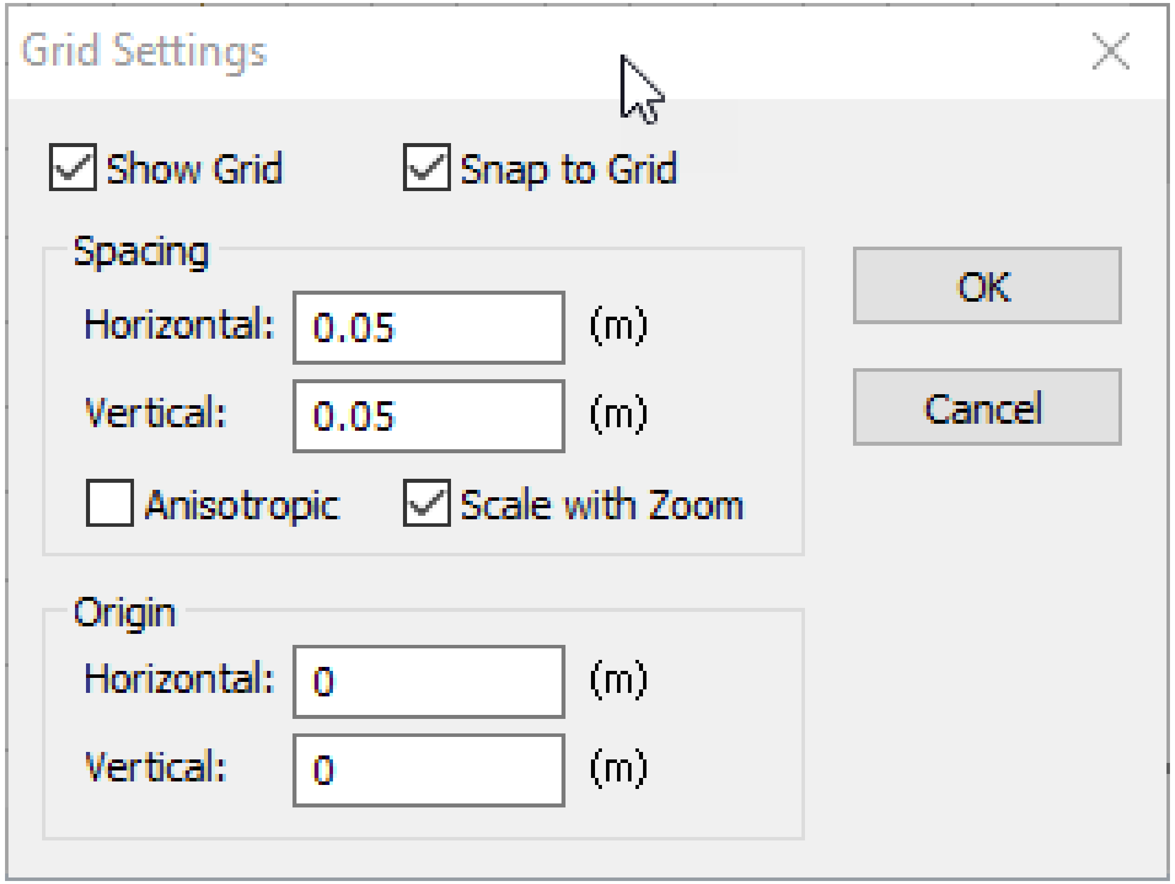
To add any geometry shape first switch to Insert mode:
use toolbar button or **INS** key

Primitive	***How to add***
Vertex	Left mouse button (LMB): double click
Line	LMB: Click – Drag – Release
Arc	Choose or enter the central angle, then LMB: Click – Drag – Release
Polygon	Detected automatically

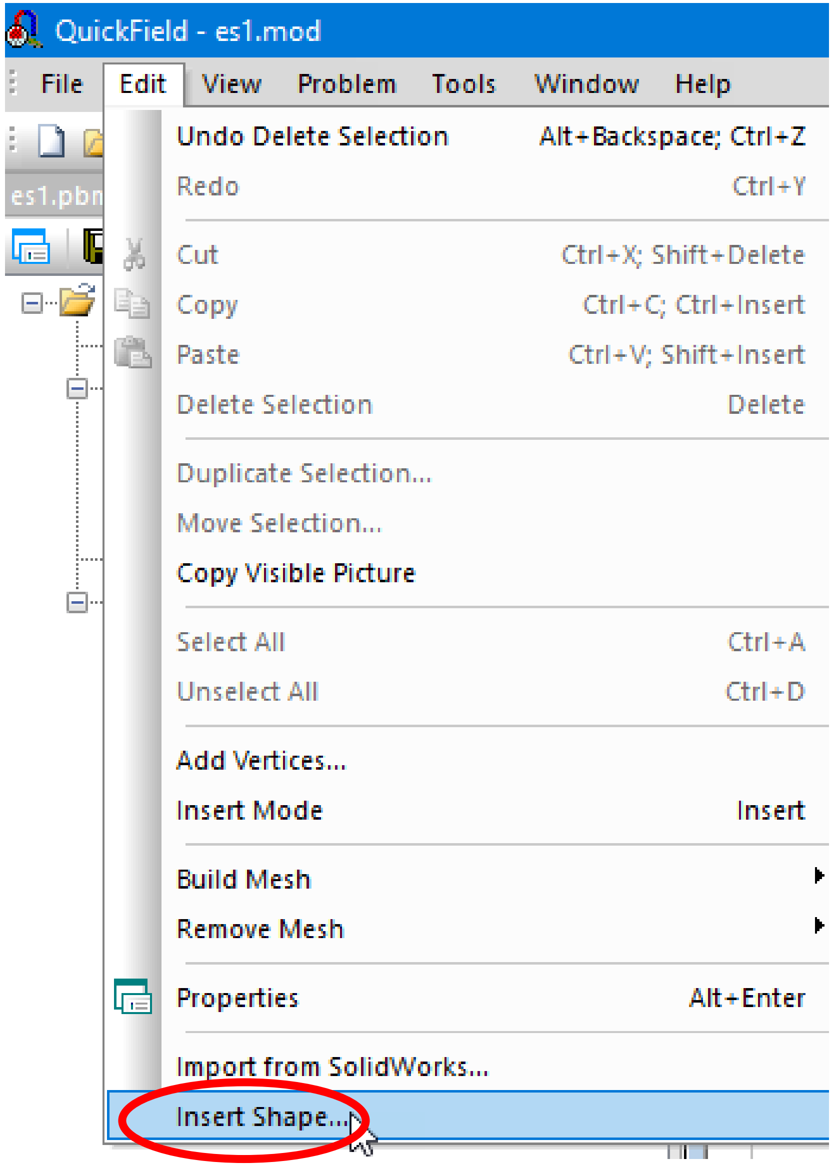
Working with the Model editor

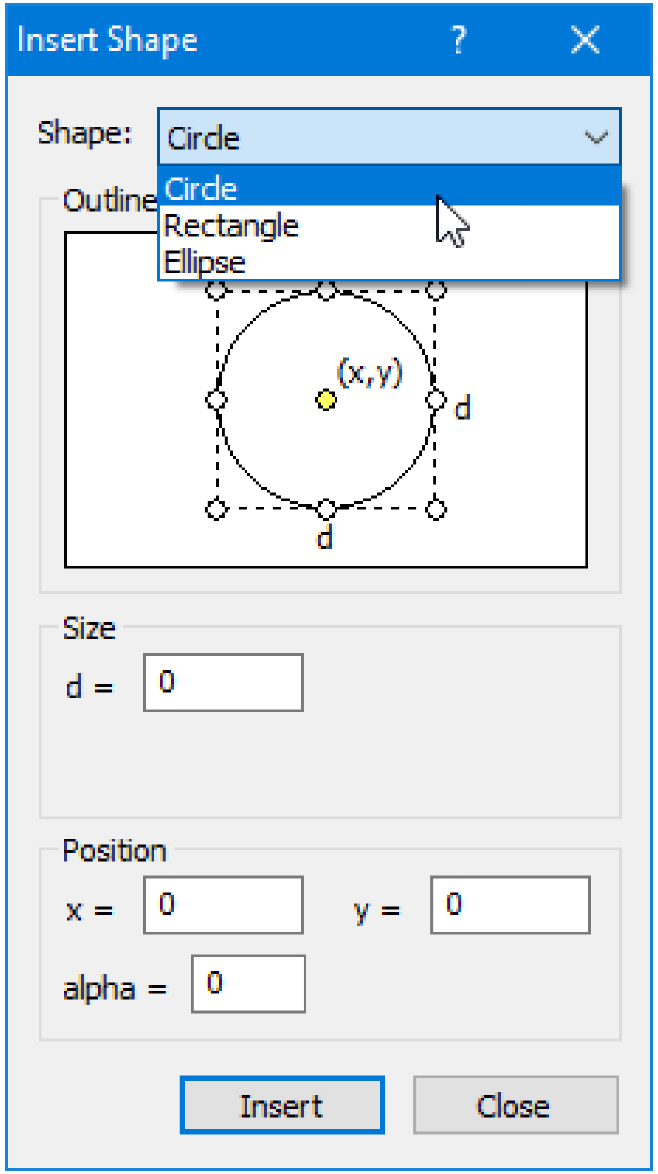
Snap to the background grid





Using the Shape Inserting Tool





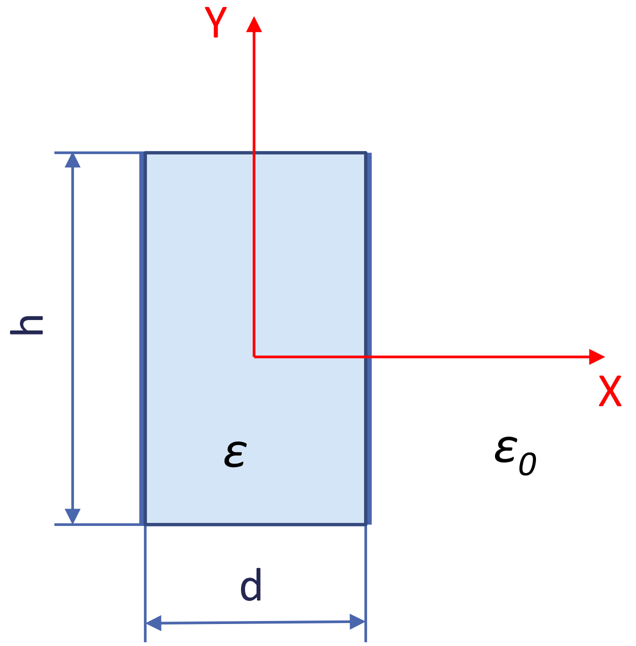
Shape

Sizing

Positioning

Draw the plane capacitor

Our first problem to solve is the plane capacitor.
We want to know its capacitance



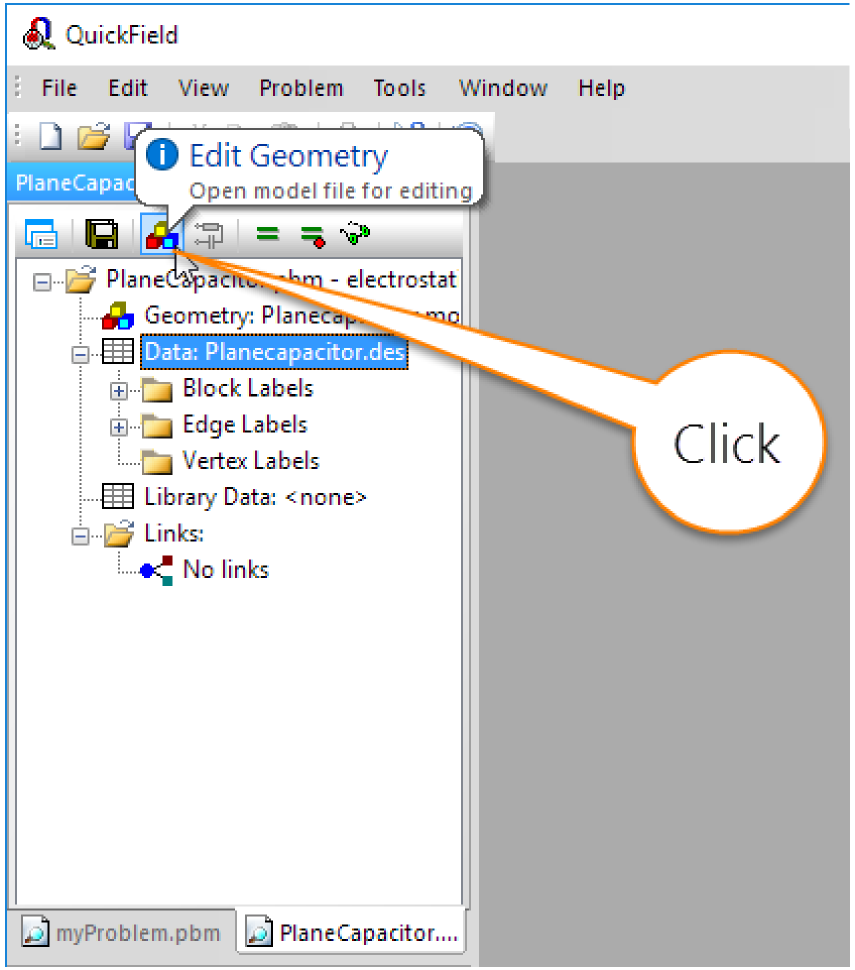
Formulation: Electrostatic field

Geometry class: Plane-parallel 2D problem

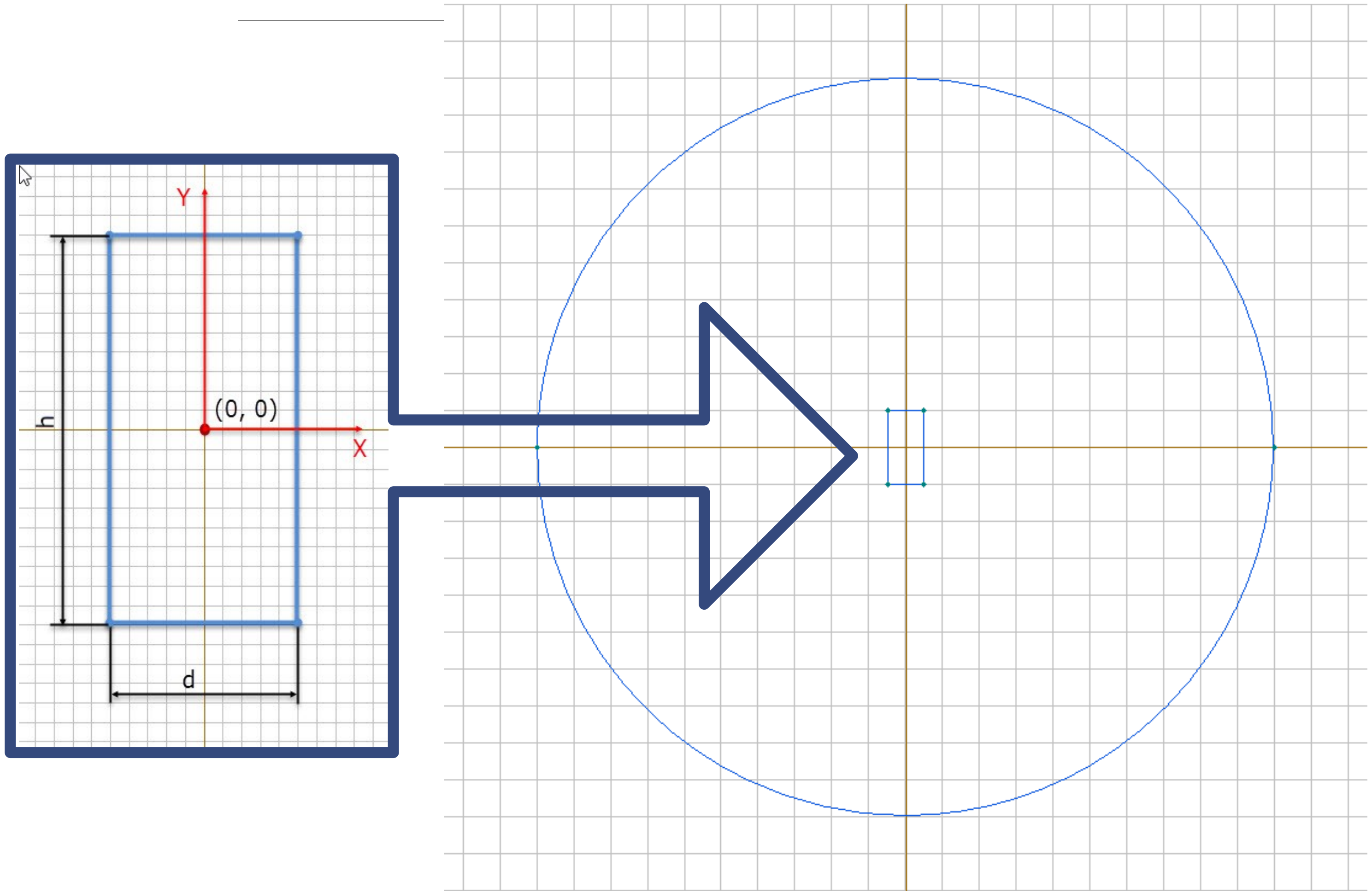
Parameter	**Notation**	**Value**
Distance between plates	d	5 mm
Height	h	10 mm
Axial length	Z_L	20 mm
Dielectric permittivity	ε	4

Draw the plane capacitor

1. Open the model editor



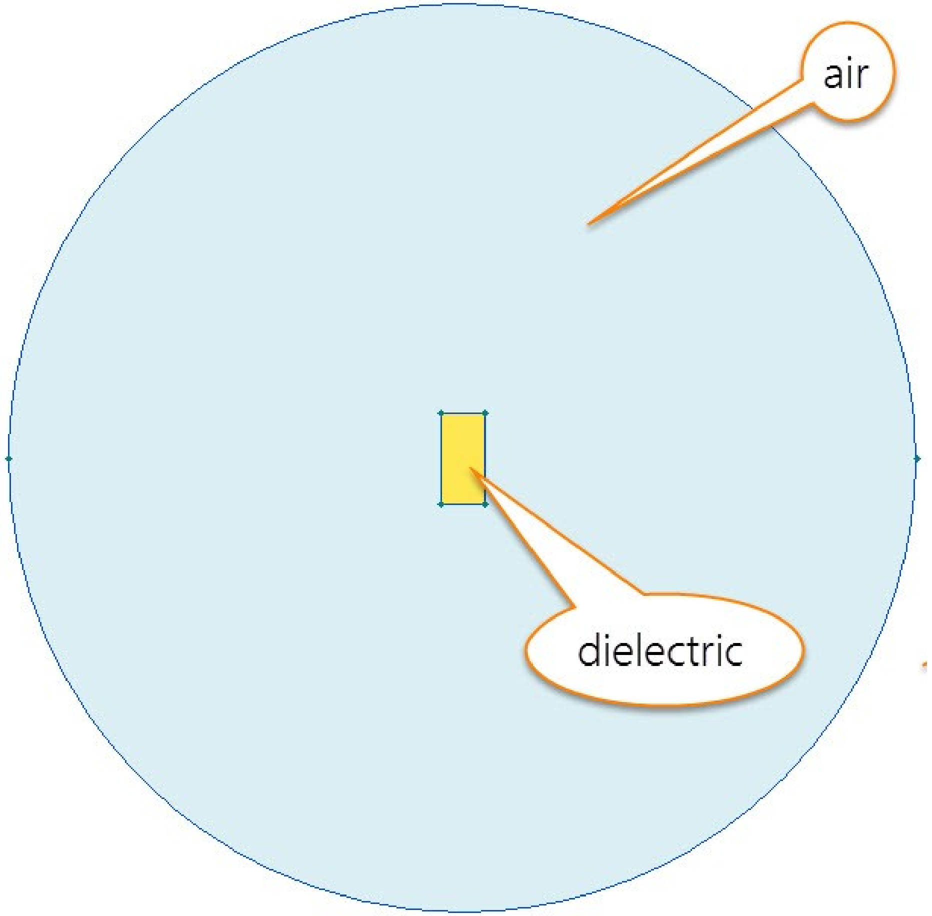
2. Draw the rectangle (capacitor), and the circle (artificial outer boundary)



Making the problem bounded

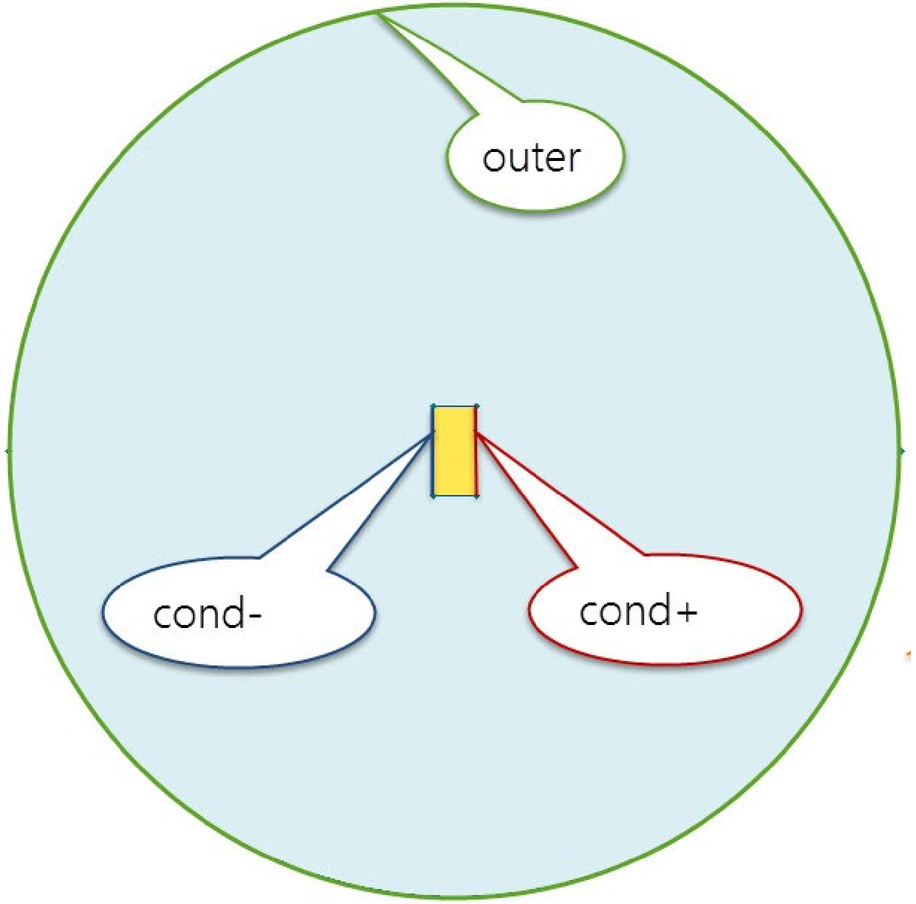
1. Add the artificial outer boundary

Material properties:



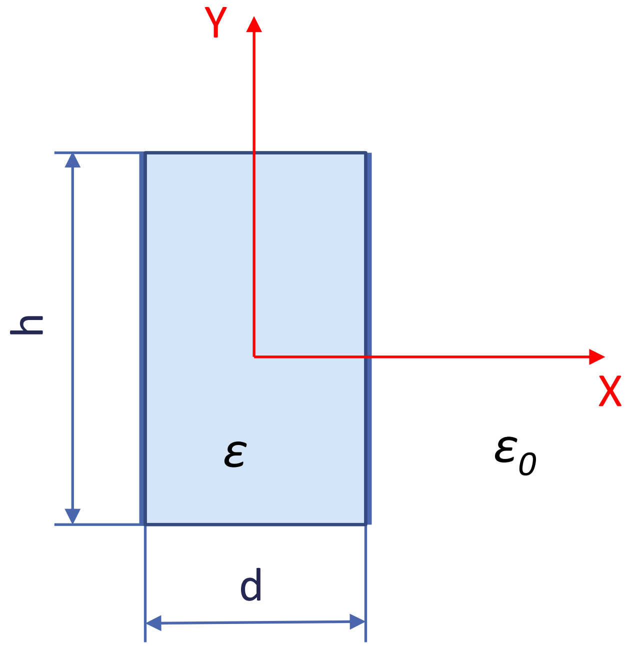
2. Replace the discarded part of the universe with the boundary condition

Boundary conditions:



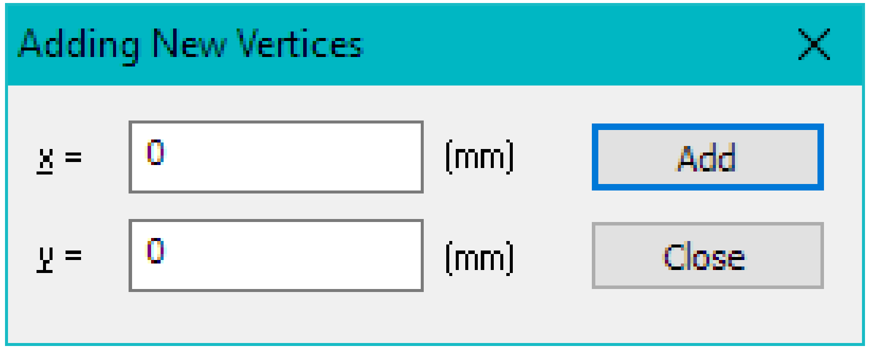
Draw the plane capacitor (cont.)

1. Draw the capacitor's cross-section



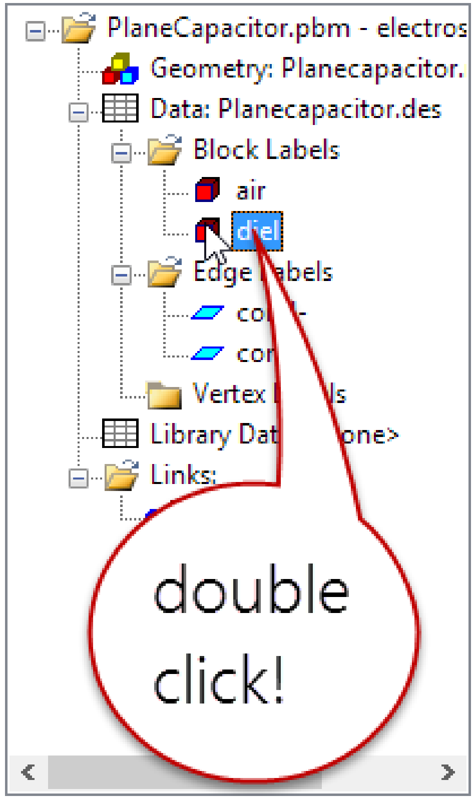
Parameter	Notation	Value
Distance between plates	d	5 mm
Height	h	10 mm
Axial length	Z_L	20 mm
Dielectric permittivity	ε	4

The simplest way is starting with creating 4 vertices using the **Edit / Add Vertices** command:

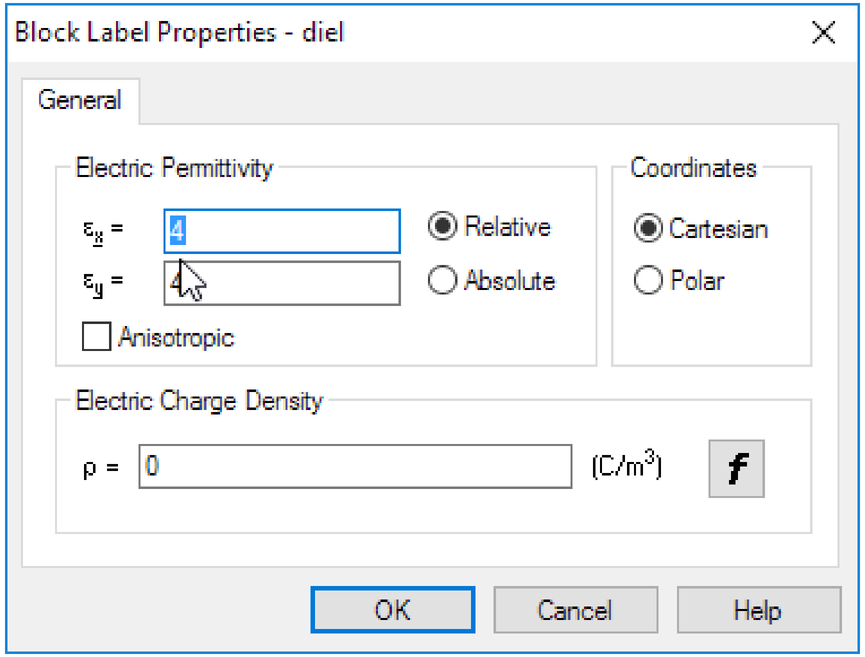


Now set up the physical data

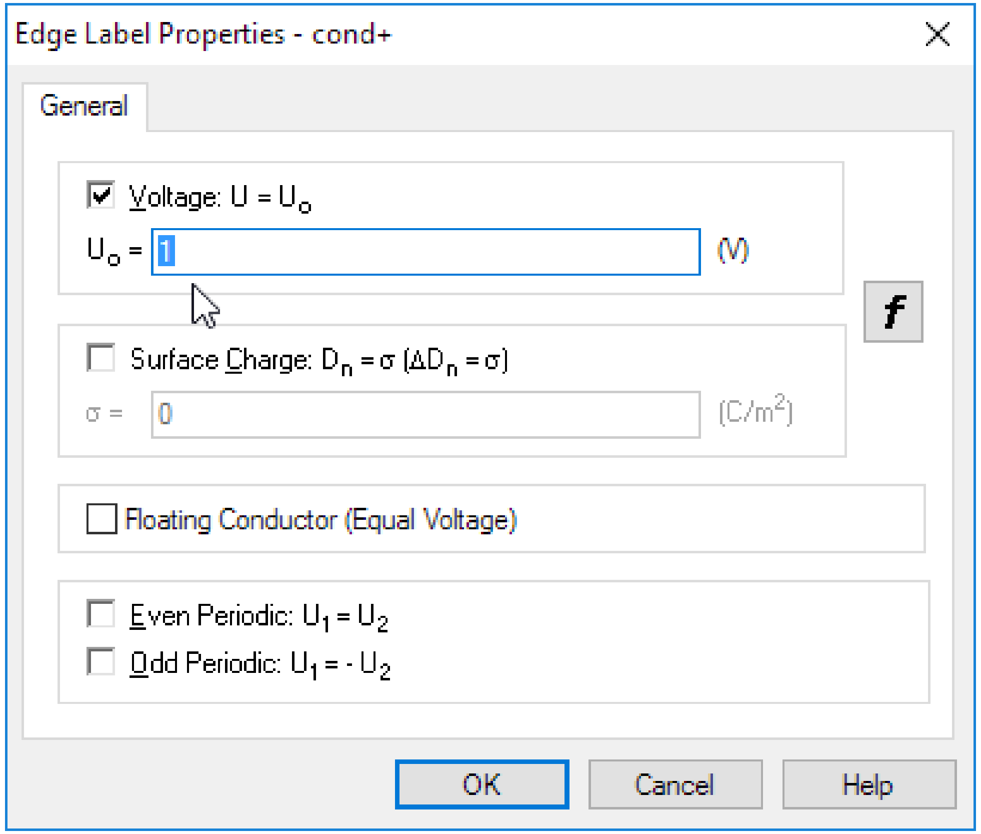
1. Activate label properties



2. Set material property for block labels



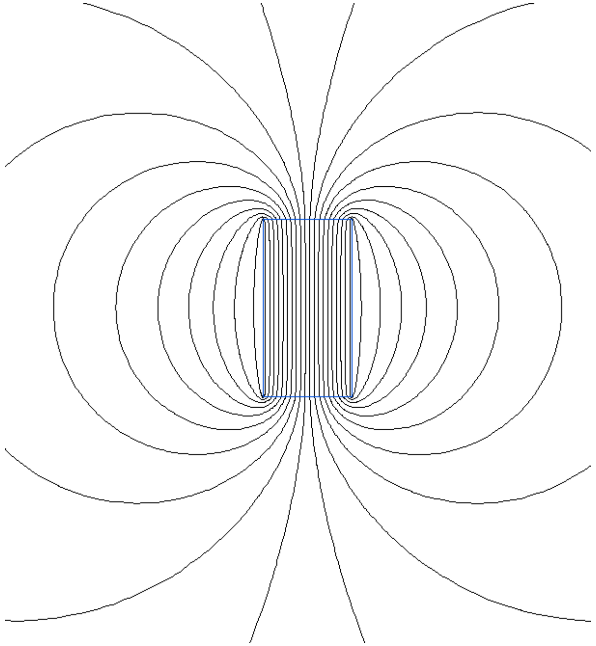
3. Set Dirichlet or Neumann boundary condition



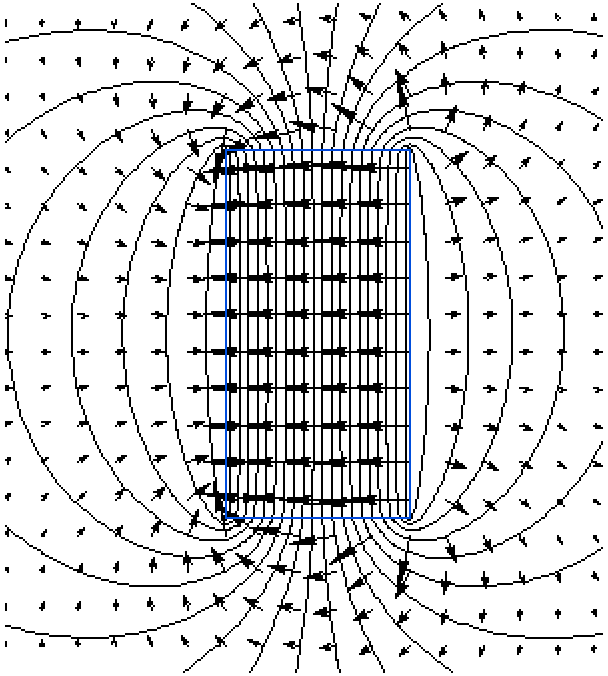
Working with the Field picture

The calculation results may be presented as:

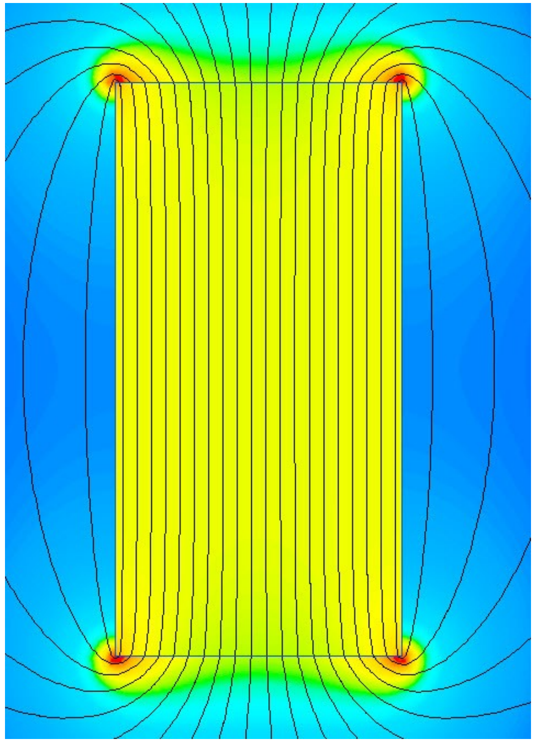
1. Field Lines



2. Vectors

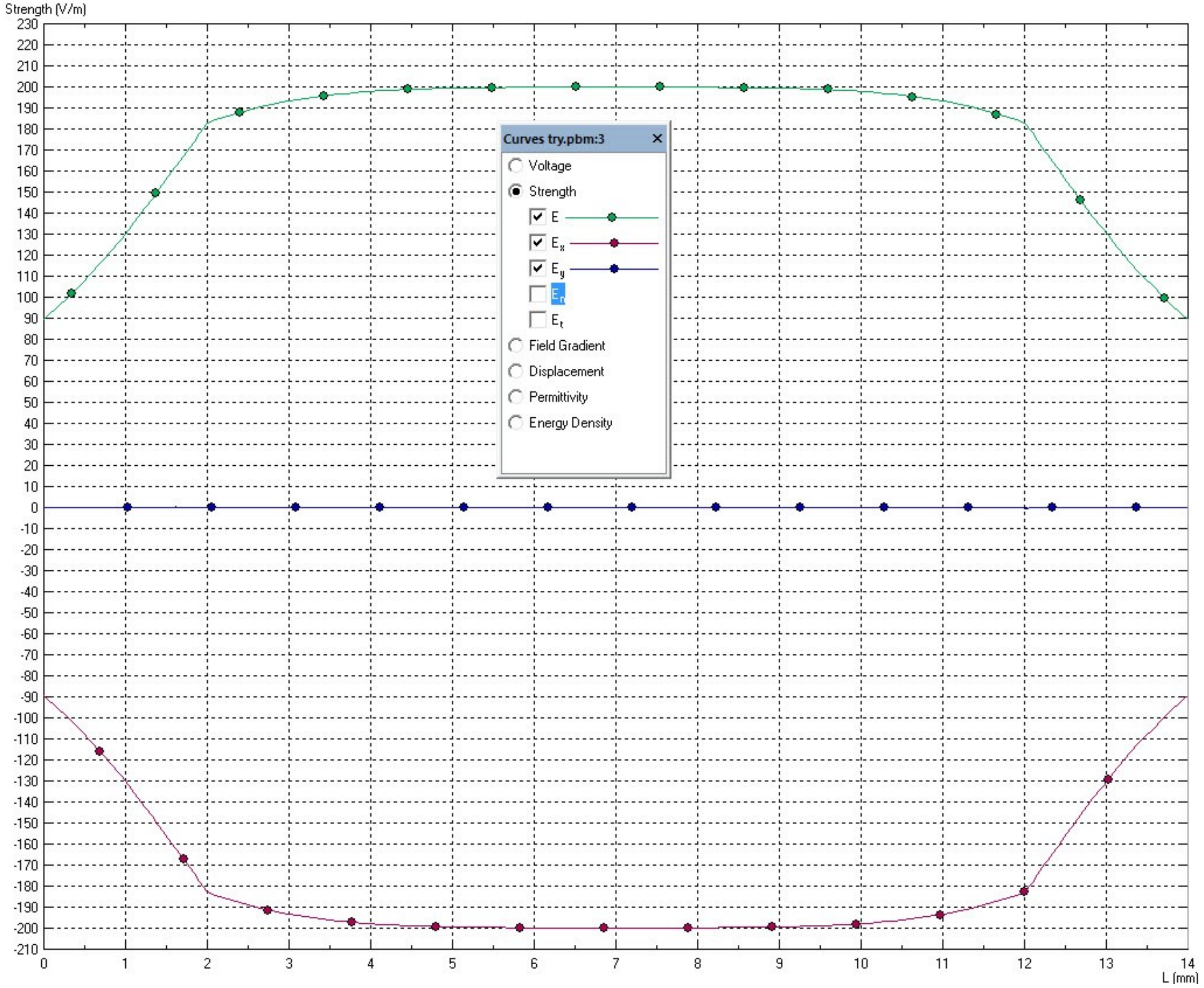


3. Color map



Field postprocessing

4. XY-Plot



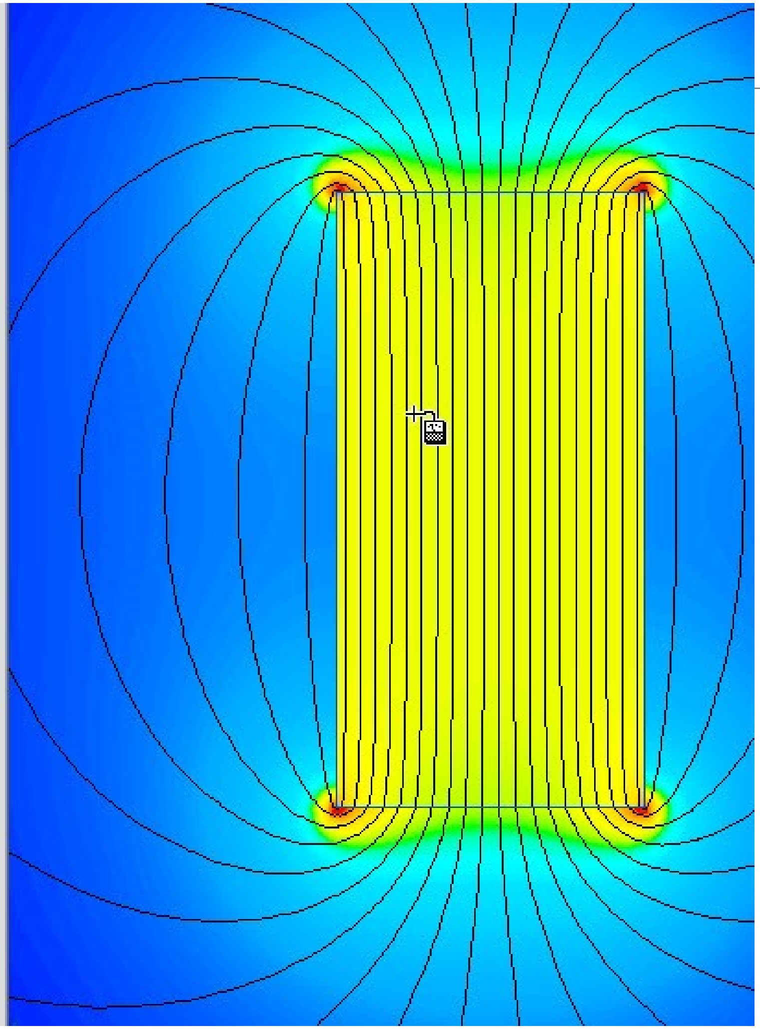
5. Table

L (mm)	x (mm)	y (mm)	N_x	N_y	U (V)	E (V/m)	E_x (V/m)	E_y (V/m)
0.00000	0.00000	-7.00000	1.00000	-0.00000	2.15068e-4	89.5768	-89.5768	0.0567527
0.700000	0.00000	-6.30000	1.00000	-0.00000	2.23998e-4	116.558	-116.558	-0.134715
1.40000	0.00000	-5.60000	1.00000	-0.00000	-2.86082e-6	150.659	-150.659	0.00779105
2.10000	-4.06576e-16	-4.90000	1.00000	-0.00000	3.42190e-5	184.201	-184.201	0.00230175
2.80000	-4.06576e-16	-4.20000	1.00000	-0.00000	2.76852e-5	191.776	-191.776	0.0111026
3.50000	-4.06576e-16	-3.50000	1.00000	-0.00000	2.01271e-5	196.137	-196.137	0.0101272
4.20000	-4.06576e-16	-2.80000	1.00000	-0.00000	1.38484e-5	198.308	-198.308	0.00771142
4.90000	-4.06576e-16	-2.10000	1.00000	-0.00000	9.36994e-6	199.279	-199.279	0.00197479
5.60000	-4.06576e-16	-1.40000	1.00000	-0.00000	6.25337e-6	199.690	-199.690	0.00353100
6.30000	-4.06576e-16	-0.700000	1.00000	-0.00000	4.31451e-6	199.853	-199.853	0.00233199
7.00000	-4.06576e-16	-9.40395e-33	1.00000	-0.00000	3.31278e-6	199.896	-199.896	9.78339e-4
7.70000	-4.06576e-16	0.700000	1.00000	-0.00000	2.90362e-6	199.853	-199.853	1.87734e-4
8.40000	-4.06576e-16	1.40000	1.00000	-0.00000	3.04931e-6	199.690	-199.690	-0.000603730
9.10000	-4.06576e-16	2.10000	1.00000	-0.00000	3.75649e-6	199.278	-199.278	-0.00144128
9.80000	-3.08998e-16	2.80000	1.00000	-0.00000	5.09622e-6	198.316	-198.316	-0.00238518
10.5000	-8.13152e-17	3.50000	1.00000	-0.00000	7.06330e-6	196.172	-196.172	-0.00316025
11.2000	1.46367e-16	4.20000	1.00000	-0.00000	9.29121e-6	191.784	-191.784	-0.00286609
11.9000	3.74050e-16	4.90000	1.00000	-0.00000	8.43755e-6	184.424	-184.424	0.0218234
12.6000	2.84603e-16	5.60000	1.00000	-0.00000	-1.02829e-4	150.703	-150.703	0.115639
13.3000	1.42302e-16	6.30000	1.00000	-0.00000	1.72624e-4	116.347	-116.347	0.0143037
14.0000	0.00000	7.00000	1.00000	-0.00000	1.23501e-4	89.3916	-89.3916	-0.0773936

Field postprocessing: Get Numbers

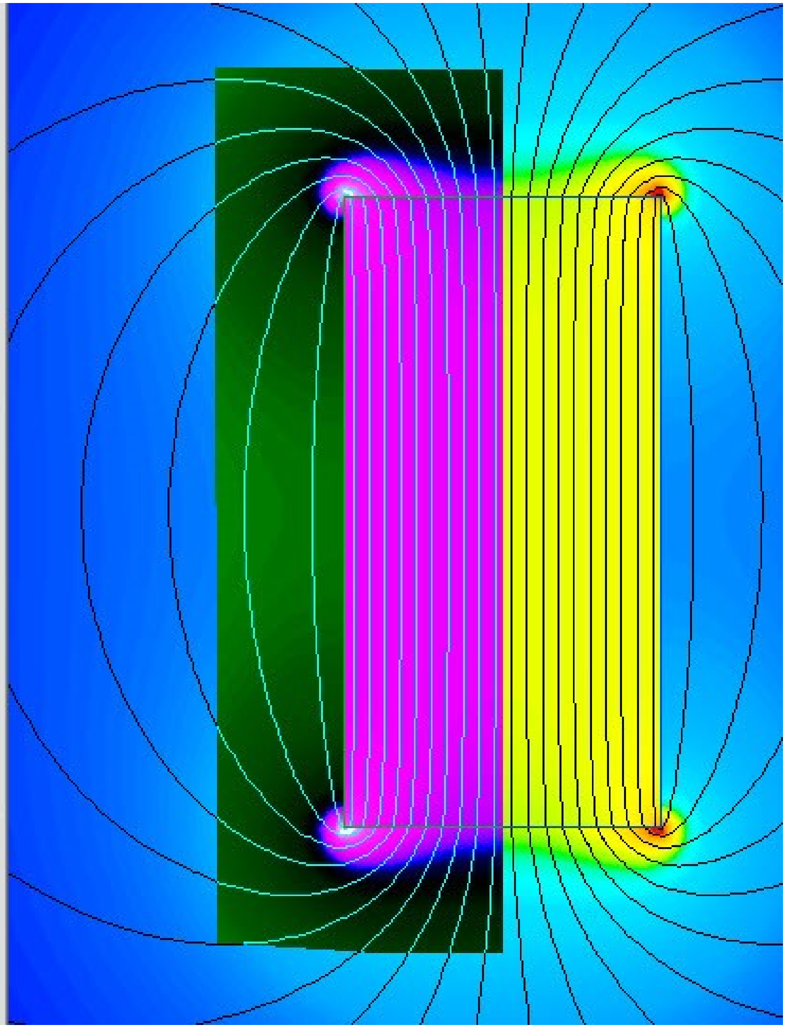
6. Local values

- **Local Values**
  - **Coordinates**
    - x = -1.26 mm
    - y = 1.4 mm
    - r = 1.8835 mm
    - θ = 131.99 deg
  - Voltage U = -0.25175 V
  - Strength E = 200 V/m
    - Strength E_x = -200 V/m
    - Strength E_y = -0.29369 V/m
  - **Field Gradient**
  - Displacement D = 7.0835e-9 C/m²
    - Displacement D_x = -7.0834e-9 C/m²
    - Displacement D_y = -1.0402e-11 C/m²
  - Permittivity ε = 4
  - Energy Density w = 7.0836e-7 J/m³
- **Integral Calculator**
- **Capacitance Wizard**



7. Integral values

- **Integral Calculator**
  - **Geometric Quantities**
    - Contour length
    - Cross section area
    - Surface area
    - Volume
  - **Physical Quantities**
    - Electrical charge
      - Q_s = -1.6498e-12 C
    - Mechanical force
      - f = 1.458e-10 N
      - φ = -0.0035824 °
      - f_x = 1.458e-10 N
      - f_y = -9.1161e-15 N
    - Mechanical torque
    - Stored energy
    - Surface energy
    - Potential difference



Calculation Capacitance

By Charge and Voltage

$$C = \frac{q}{U}$$

Where:
C is the capacitance,
q is the total charge of one conductor,
U is the potential difference between conductors

By Energy and Voltage

$$C = \frac{2W}{U^2}$$

Where:
C is the capacitance,
W is the total energy of electric field,
U is the potential difference between conductors

Calculation Capacitance

By Charge and Voltage

By Energy and Voltage

$$C = \varepsilon_0 \varepsilon \frac{S}{d}$$

$$C = \frac{q}{\Delta U}$$

$$C = \frac{2W}{U^2}$$

Theory

mm	1000	
ε_0	8.8542E-12	F/m
ε	4.0000	
d	5	mm
h	10	mm
L	20	mm
S	0.0002	m^2
C	1.4167E-12	F
	1.4167	pF

By Charge and Voltage

Qs	1.6499E-12	C
ΔU	1	V
C	1.6499E-12	F
	1.6499	pF

By Energy and Voltage

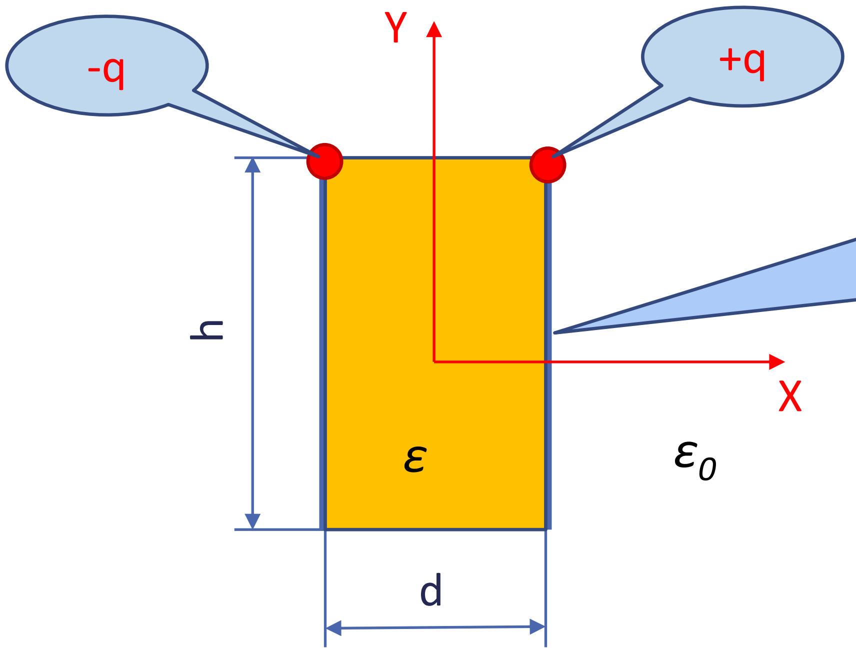
W	8.24E-13	J
C	1.6474E-12	F
	1.6474	pF

What Next?

1. Give the charge, measure the voltage (q -> U)
2. Benefit from problem symmetry.
   How to modify boundary conditions?
3. How to know the maximal electric field?
   Make the model a bit more realistic.
4. What if we have more than two conductors?
   Calculation of the capacitance matrix.
5. How to apply an external field?
   A trick with coordinate dependent Dirichlet boundary condition.
6. ELECTROSTATIC SUMMARY:
   Equation, boundary conditions, calculated field quantities

Calculation Capacitance

Give the charge, measure voltage



The conductor's potential is equal (as with any conductor), but its value is unknown

We **assign** the known **charge to any vertex**, belonging to the conductor.

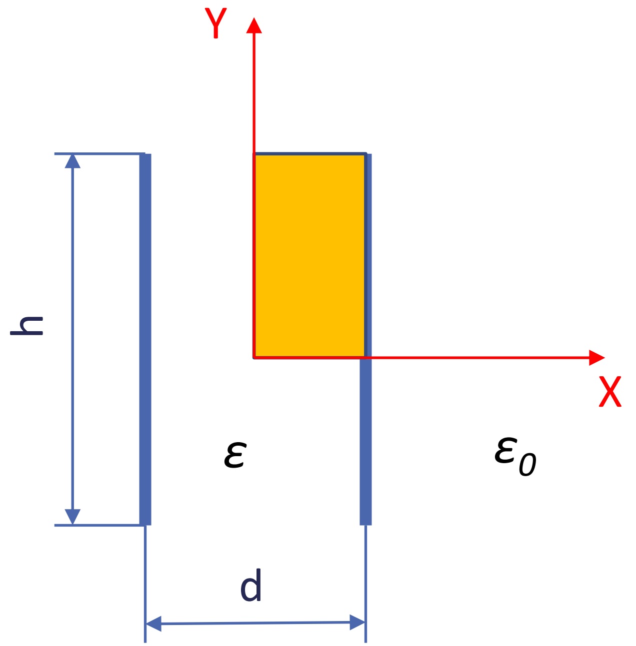
The conductor itself is describer as a **floating conductor.**

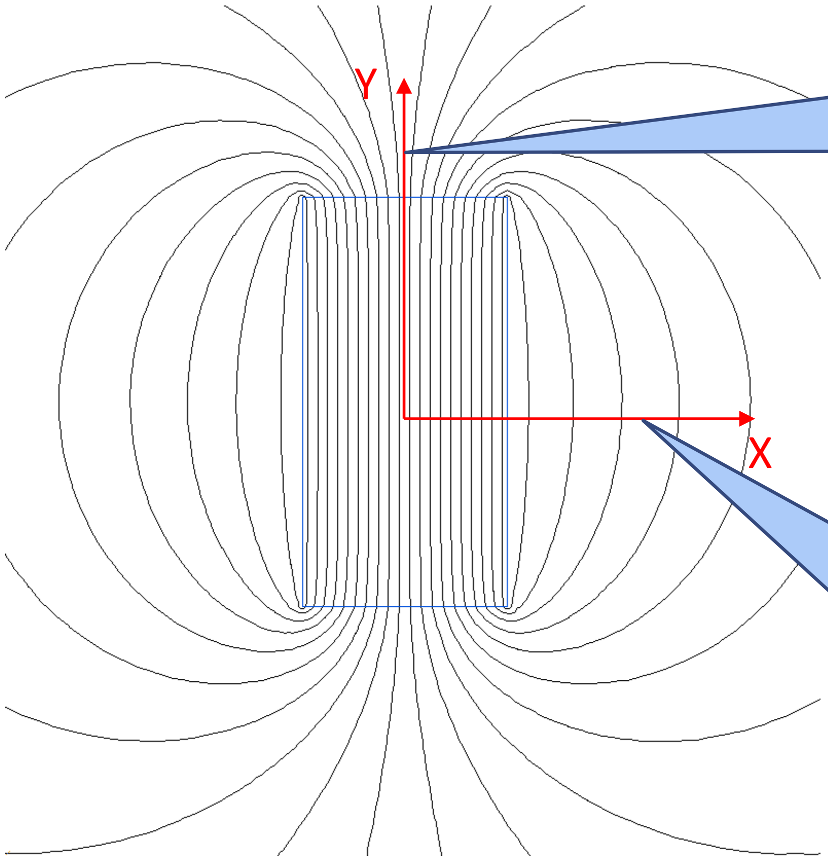
Its potential is subject to calculation

Assigning the charge we have to use the value per 1m of length, no regards of the actual model length Z_L

Calculation Capacitance

Employ the symmetry





Vertical wall is equipotential:
$U_{vert}=0$
(zero Dirichlet condition)

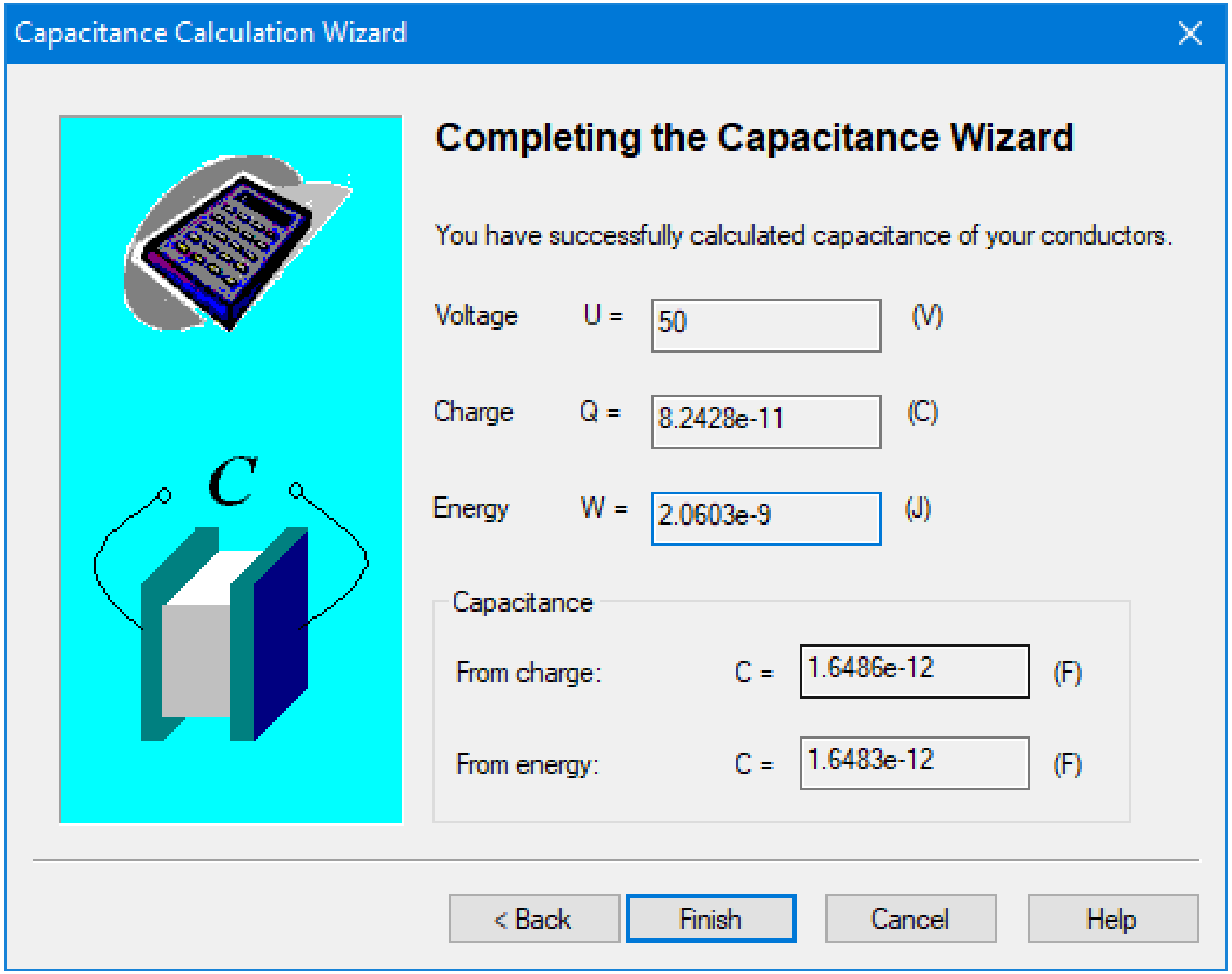
Horizontal wall is normal to the equipotential lines:

$$\frac{\partial U}{\partial n} = 0$$

(zero Neumann condition)

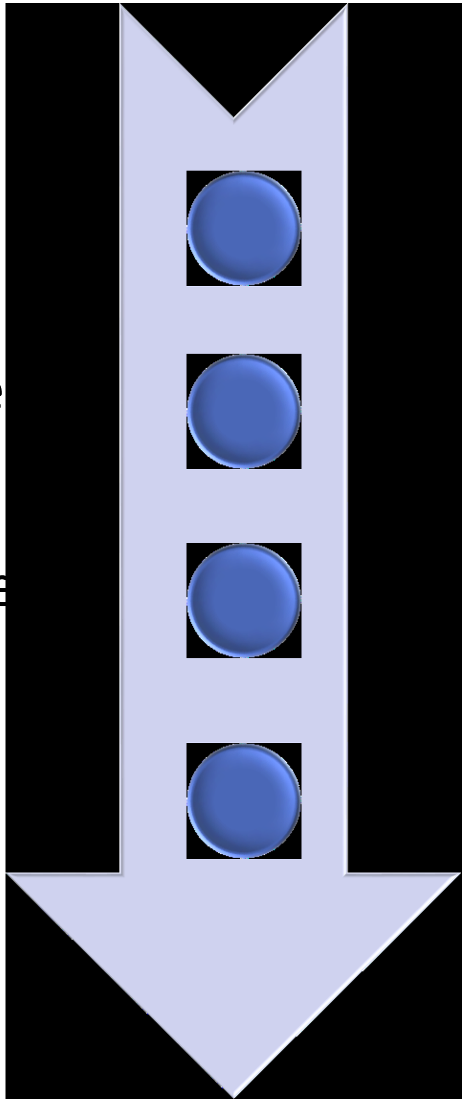
Removing a part of geometry,
we have to take into account the removed part by appropriate boundary condition

Using the Capacitance Wizard



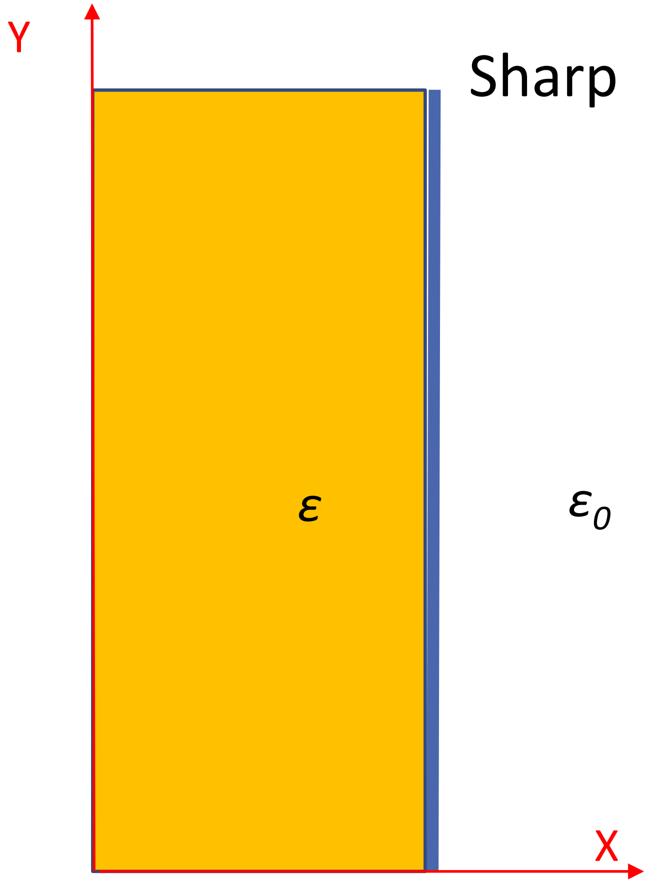
PAGES:

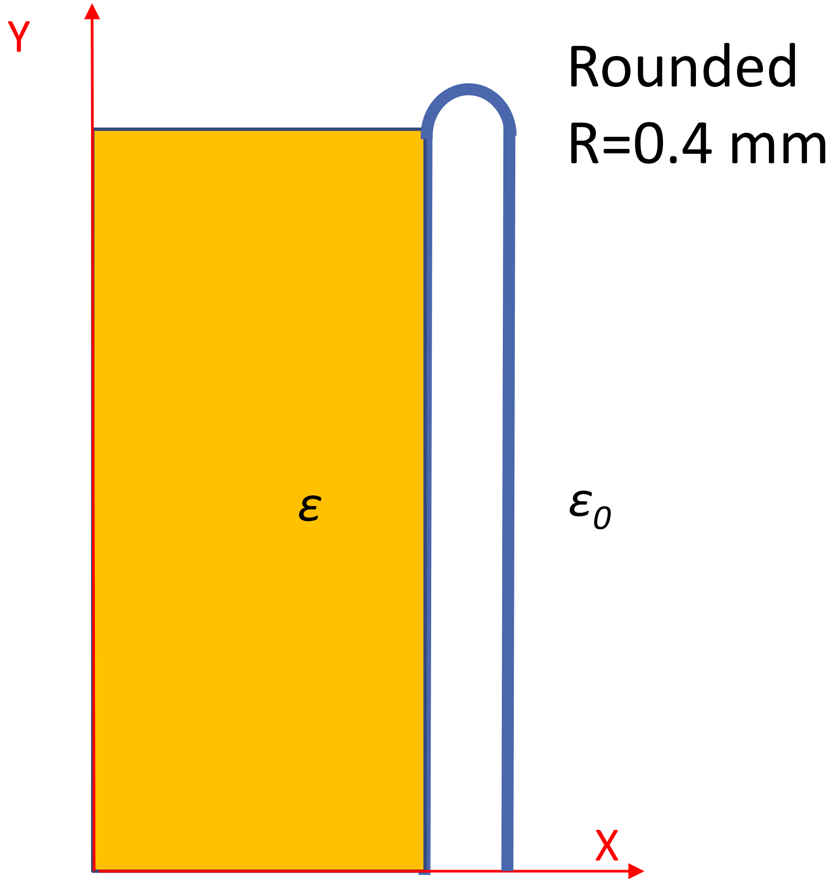
1. Welcome
2. Electrode
3. Charge/Ene
4. Results



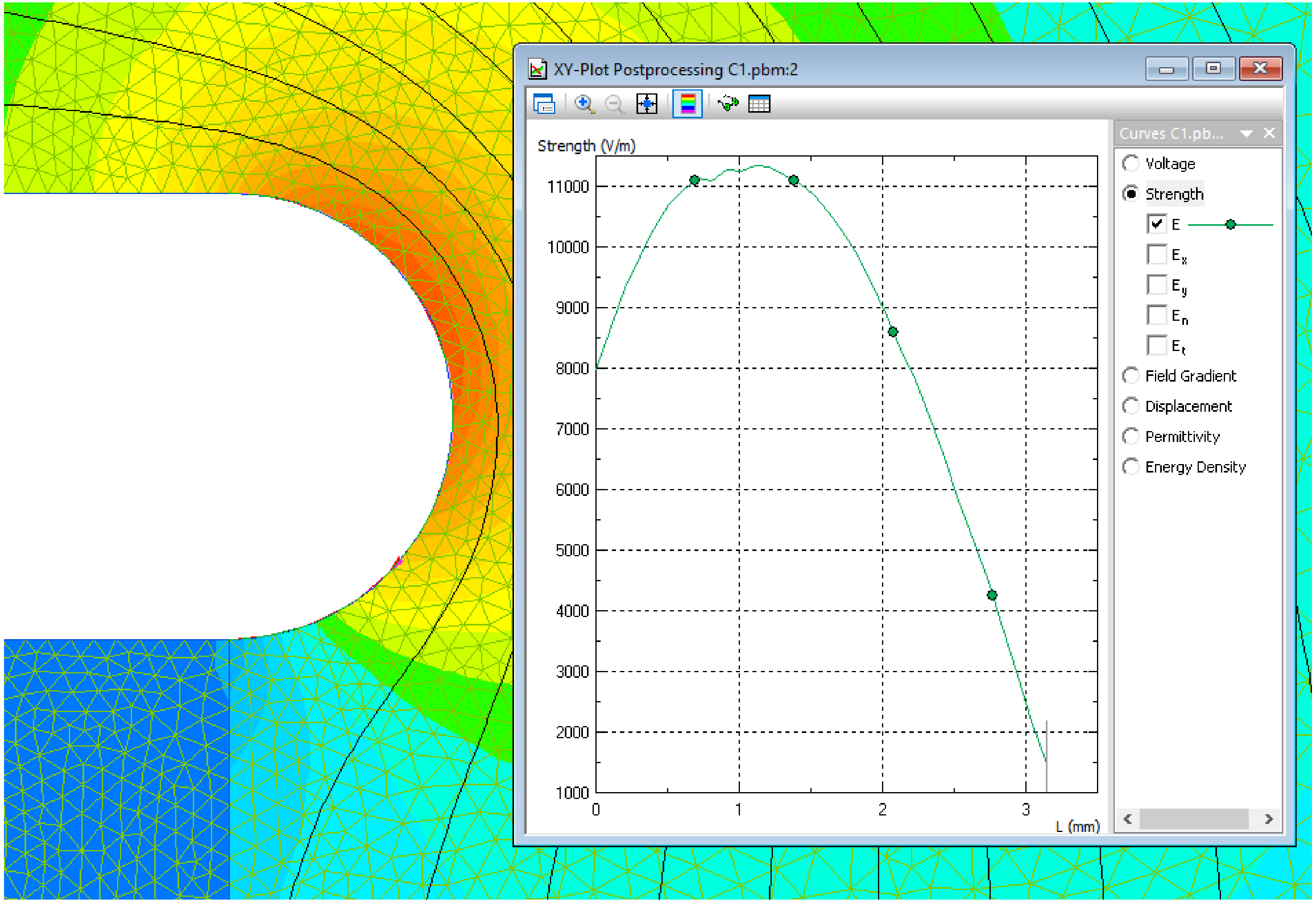
Maximal Electric Field

Field **E** near the sharp edge is theoretically infinite big





Maximal Electric Field

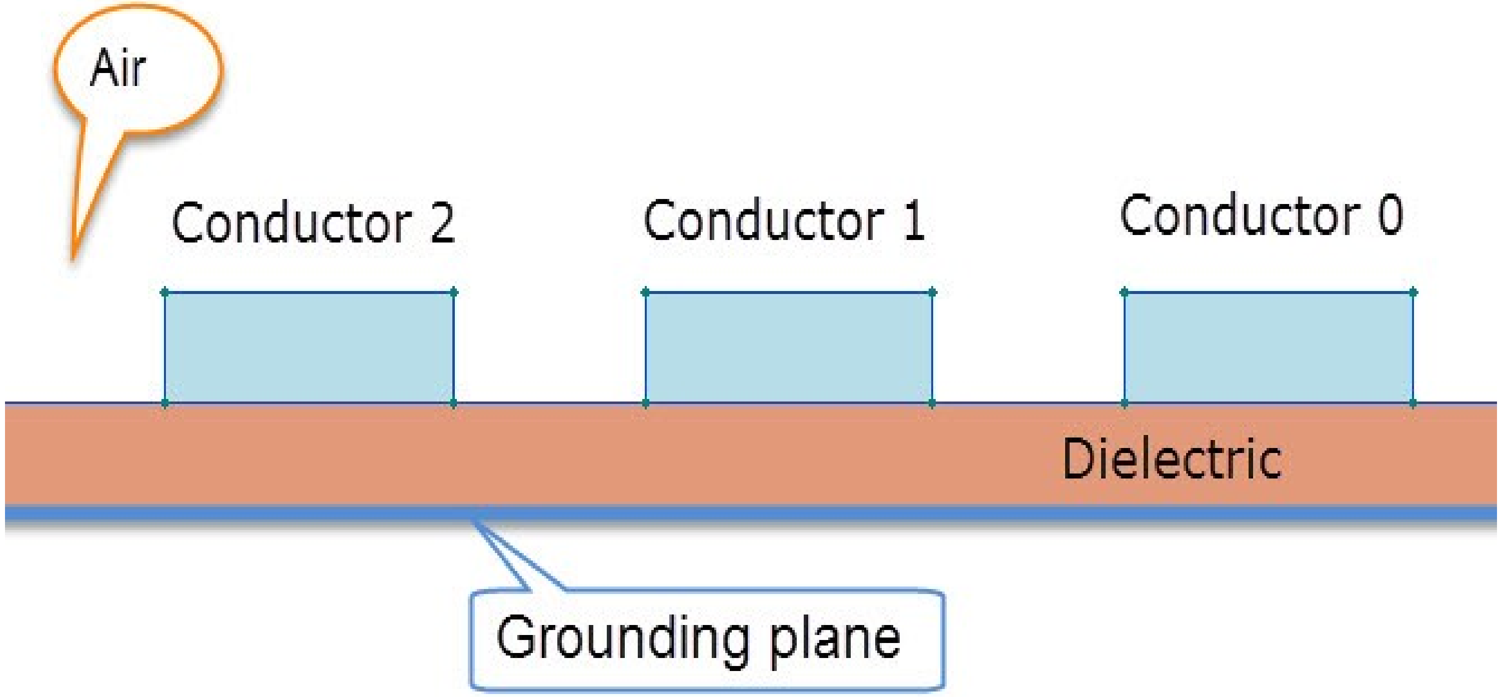


The mesh density near the rounded corner is vitally important for accuracy of **E**-field

Electrostatics: Summary

3. Calculated quantities: Capacitance matrix

What is the capacitance when we have more than one conductor?



Electrostatic induction coefficients

$$\begin{vmatrix} q_0 \\ q_1 \\ q_2 \end{vmatrix} = \begin{vmatrix} \beta_{00} & \beta_{01} & \beta_{02} \\ \beta_{10} & \beta_{11} & \beta_{12} \\ \beta_{20} & \beta_{21} & \beta_{22} \end{vmatrix} \cdot \begin{vmatrix} U_0 \\ U_1 \\ U_2 \end{vmatrix}$$

Electrostatics: Summary

3. Calculated quantities: Capacitance matrix

Two equivalent forms of the capacitance matrix

Electrostatic induction coefficients

$$\begin{vmatrix} q_0 \\ q_1 \\ q_2 \end{vmatrix} = \begin{vmatrix} \beta_{00} & \beta_{01} & \beta_{02} \\ \beta_{10} & \beta_{11} & \beta_{12} \\ \beta_{20} & \beta_{21} & \beta_{22} \end{vmatrix} \cdot \begin{vmatrix} U_0 \\ U_1 \\ U_2 \end{vmatrix}$$

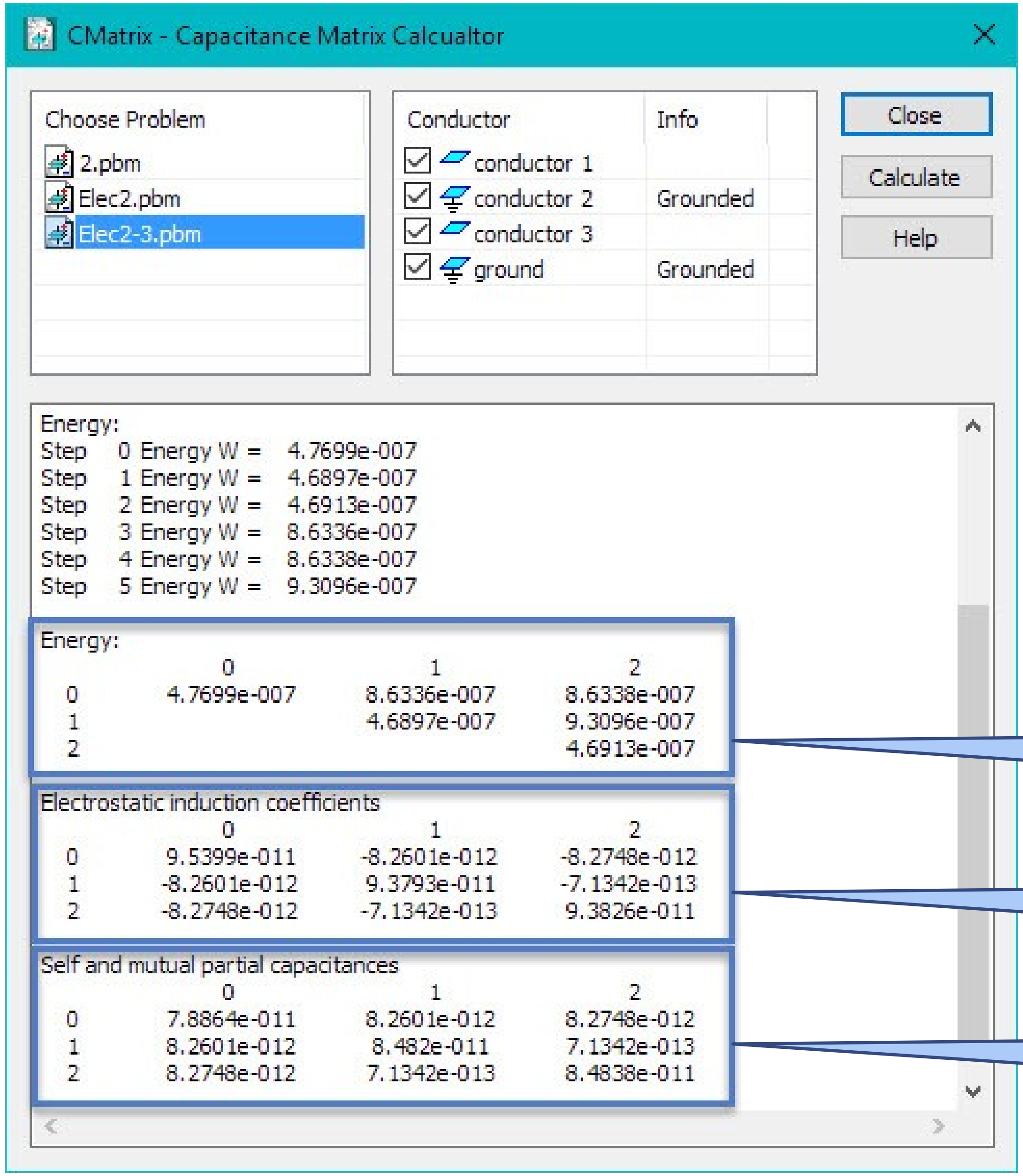
B_{nk} can be negative

Self- and mutual partial capacitances

$$\begin{vmatrix} q_0 \\ q_1 \\ q_2 \end{vmatrix} = \begin{vmatrix} C_{00} & C_{01} & C_{02} \\ C_{10} & C_{11} & C_{12} \\ C_{20} & C_{21} & C_{22} \end{vmatrix} \cdot \begin{vmatrix} U_0 & U_0 - U_1 & U_0 - U_2 \\ U_1 - U_0 & U_1 & U_1 - U_2 \\ U_2 - U_0 & U_2 - U_1 & U_2 \end{vmatrix}$$

C_{nk} is always positive

Capacitance matrix



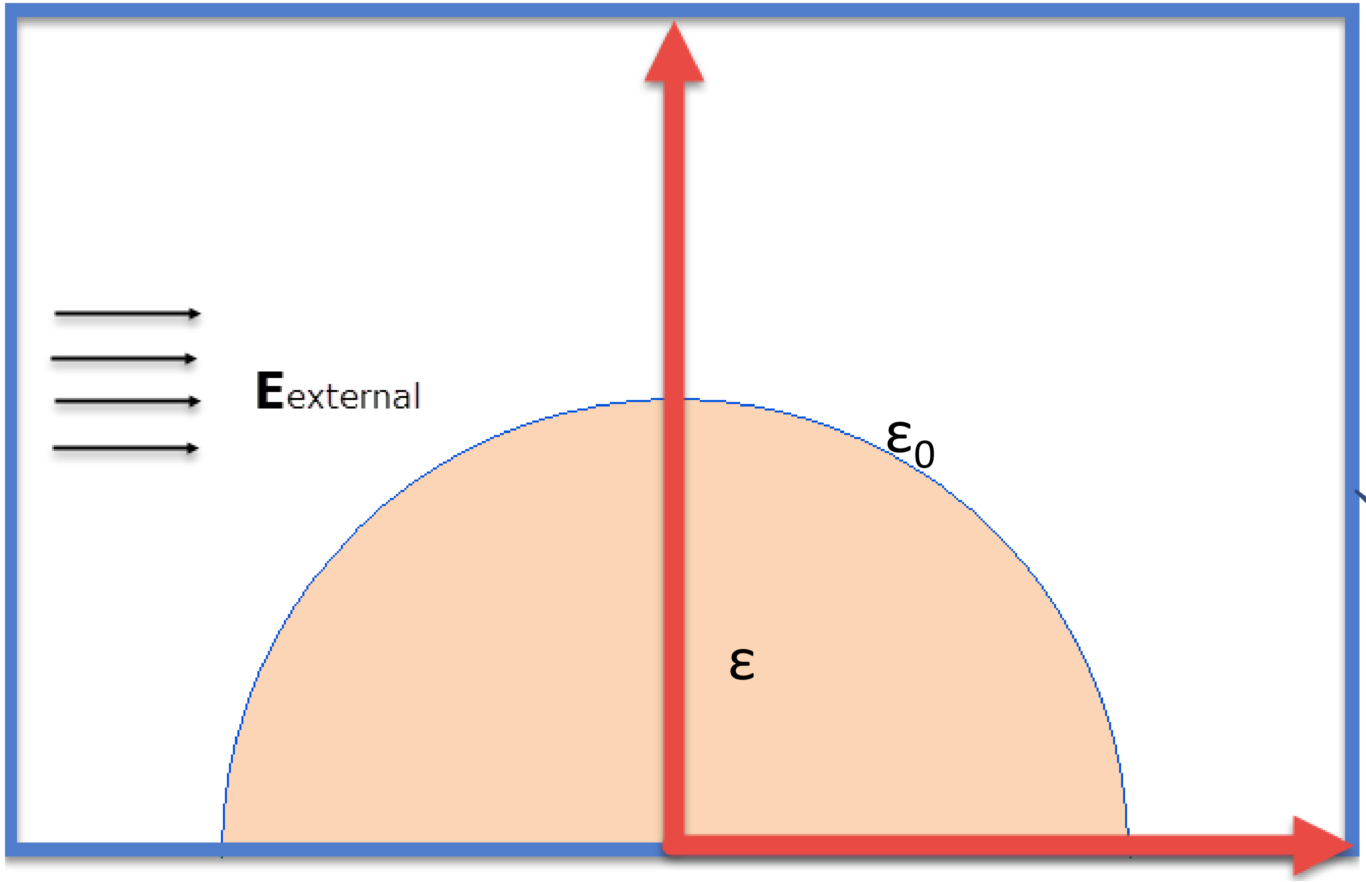
Energy

β_{ij}

C_{ij}

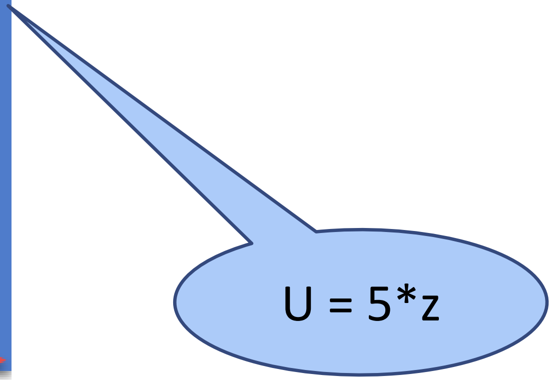
Applying external field by Dirichlet boundary condition

We want to model a dielectric sphere
in an uniform electric field **E** = 5 V/m



$$\mathbf{E} = \mathrm{grad}U \Rightarrow E_z = \frac{\partial U}{\partial z}$$

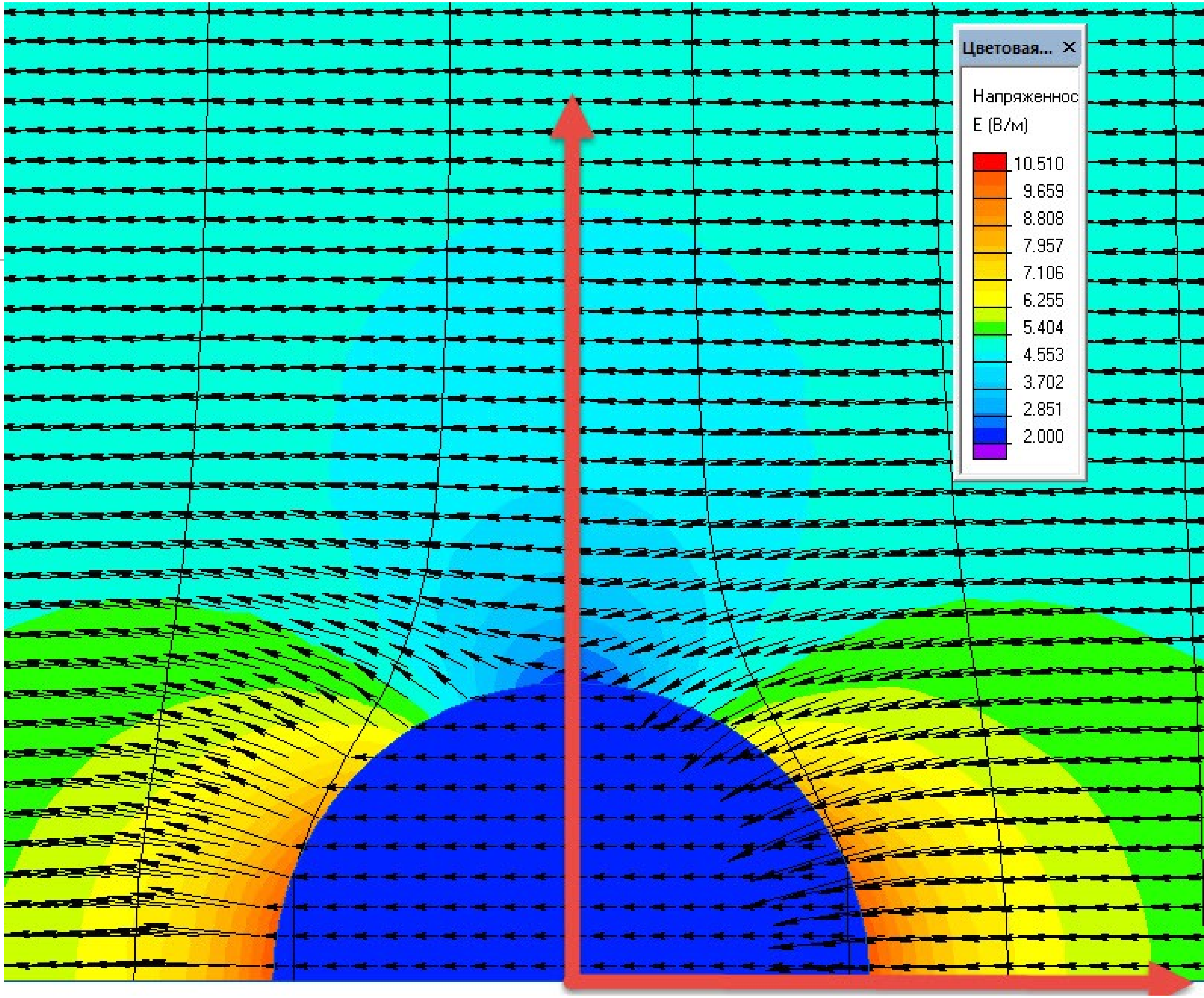
Setting U=5z on the all outer boundary,
we obtain **E_z = d(5z)/dz = 5** V/m



Electrostatics: Summary

Analytical solution for the **E**-field inside the sphere:

$$E_z = E_0 \frac{3\varepsilon_0}{2\varepsilon_0 + \varepsilon_{sphere}} = $$
$$= 5\frac{3}{2+4} = 2.5\frac{V}{m}$$



Electrostatics: Summary

1. The Poisson Equation

$$\mathrm{div}(\varepsilon \cdot \mathrm{grad}U) = -\rho$$

Poisson equation
(coordinate independent form)

$$\frac{\partial}{\partial x}\left(\varepsilon_x \frac{\partial U}{\partial x}\right) + \frac{\partial}{\partial y}\left(\varepsilon_y \frac{\partial U}{\partial y}\right) = -\rho$$

In Cartesian coordinates (x, y)

$$\frac{1}{r}\frac{\partial}{\partial r}\left(\varepsilon_r r \frac{\partial U}{\partial r}\right) + \frac{\partial}{\partial z}\left(\varepsilon_z \frac{\partial U}{\partial z}\right) = -\rho$$

In cylindrical coordinates (r, z)

Electrostatics: Summary

2. Boundary Conditions

$$U = U_0(x, y)$$

Dirichlet Condition: the known potential (may depend on coordinates)

$$D_n = \varepsilon \frac{\partial U}{\partial n} = \sigma(x, y)$$

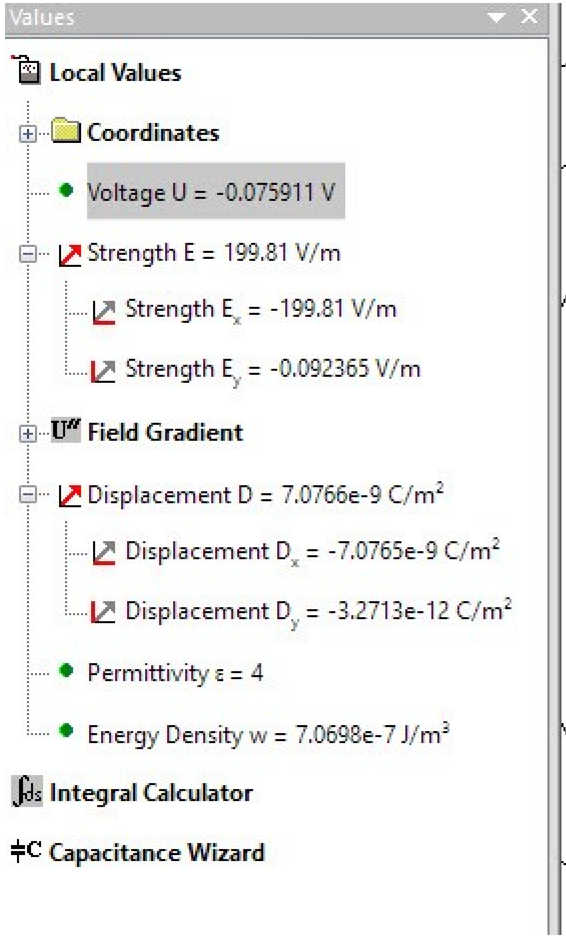
Neumann condition: the known value of normal potential gradient

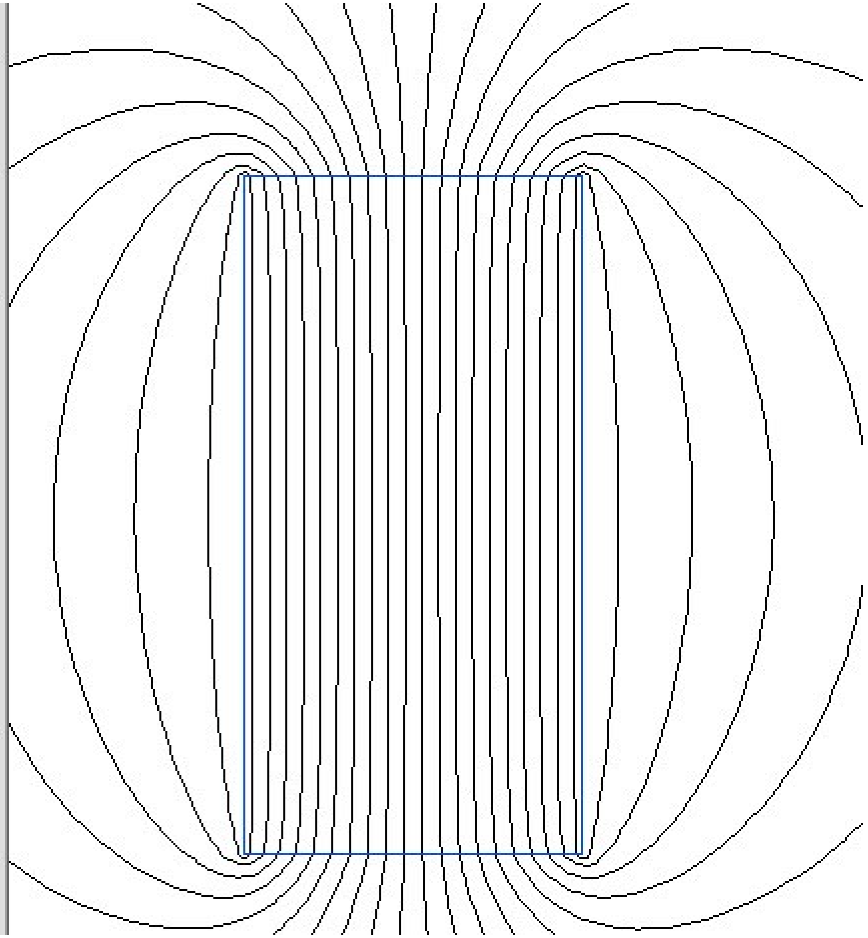
$$U = const = unknown$$

Floating conductor:
A special type of Dirichlet condition

Electrostatics: Summary

3. Calculated quantities: Locals





Strength $\mathbf{E} = -\mathrm{grad}U$

Displacement $\mathbf{D} = \varepsilon\mathbf{E}$

Energy density $w = \dfrac{\mathbf{D} \cdot \mathbf{E}}{2}$