



open EMS in open source EDA

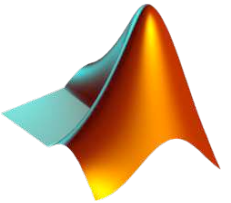
at OpenPDK Workshop 2023, Frankfurt (Oder), Germany

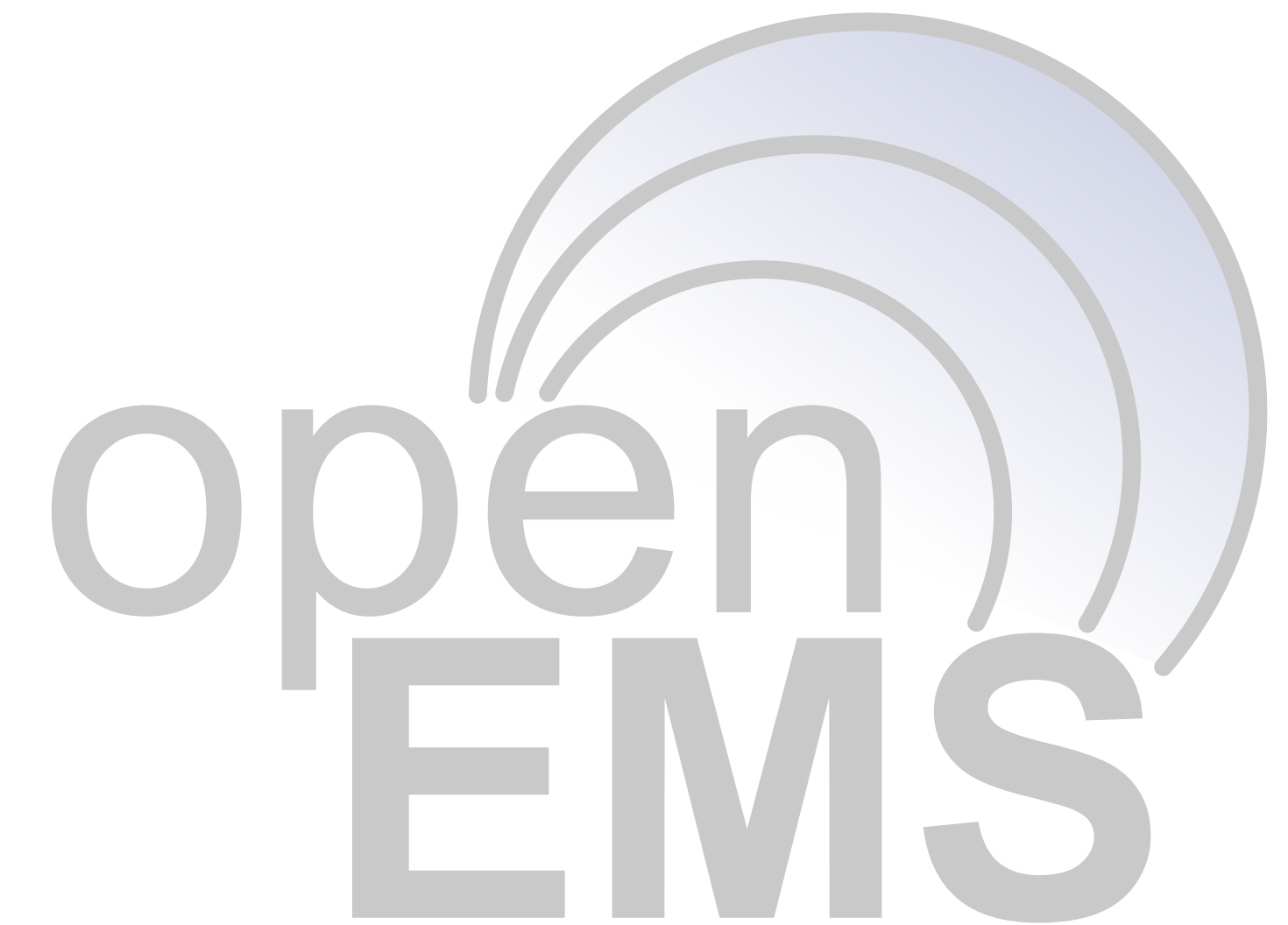
Jan Taro Svejda — jan.svejda@uni-due.de

General and Theoretical Electrical Engineering (ATE),
University of Duisburg-Essen,
CENIDE – Center for Nanointegration Duisburg-Essen,
D-47048 Duisburg, Germany

What is openEMS ?

an open source electromagnetic field solver

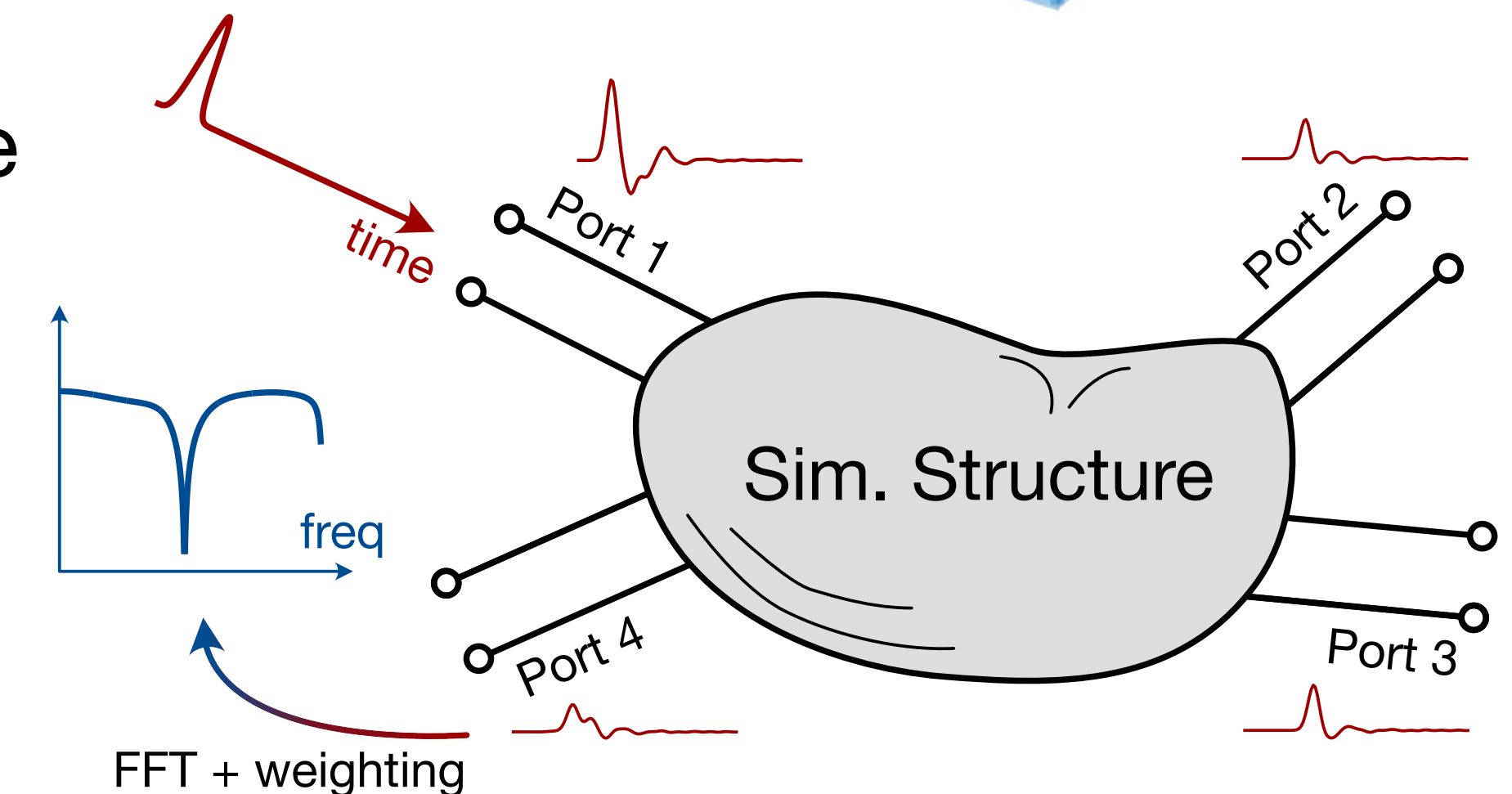
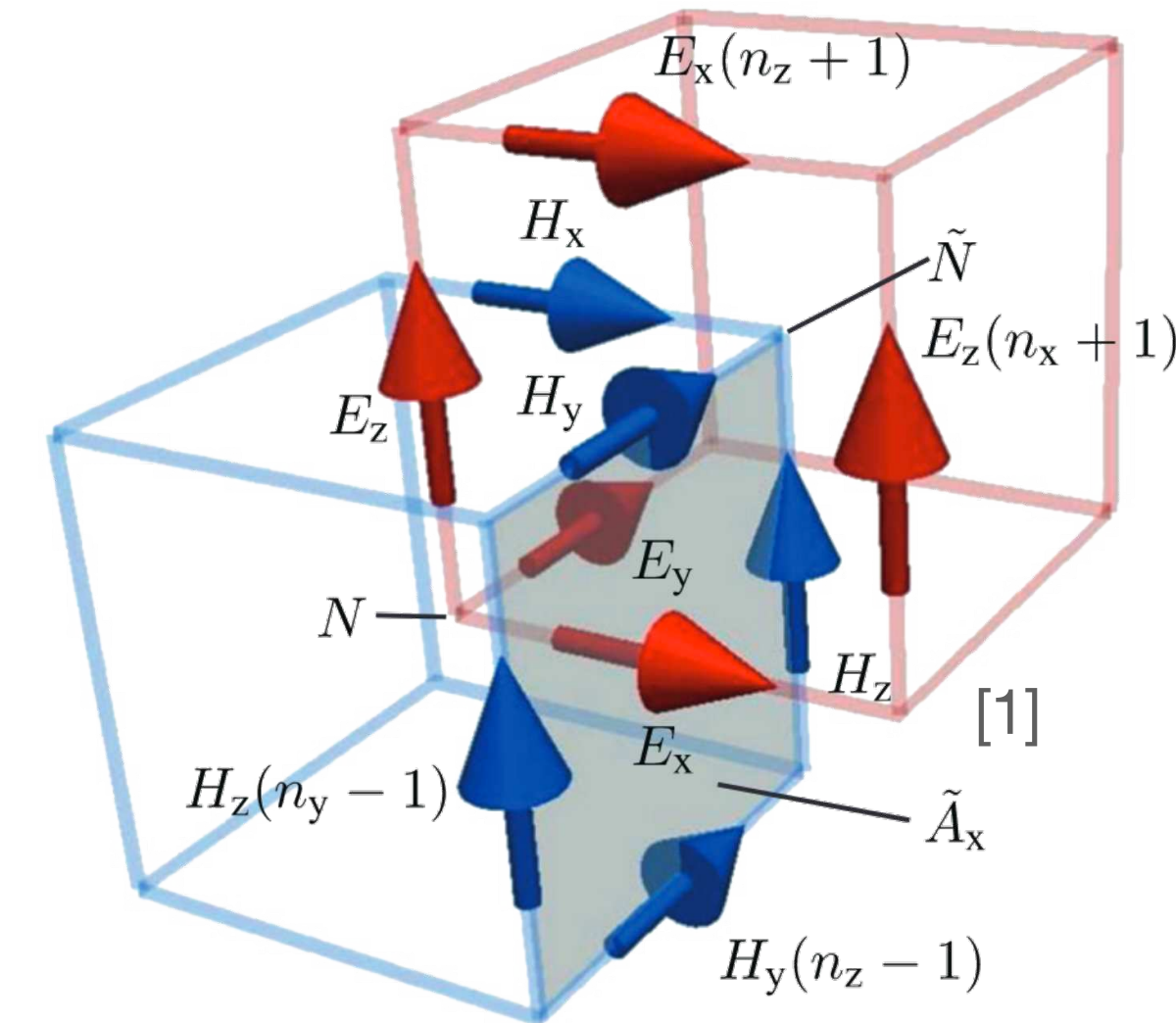
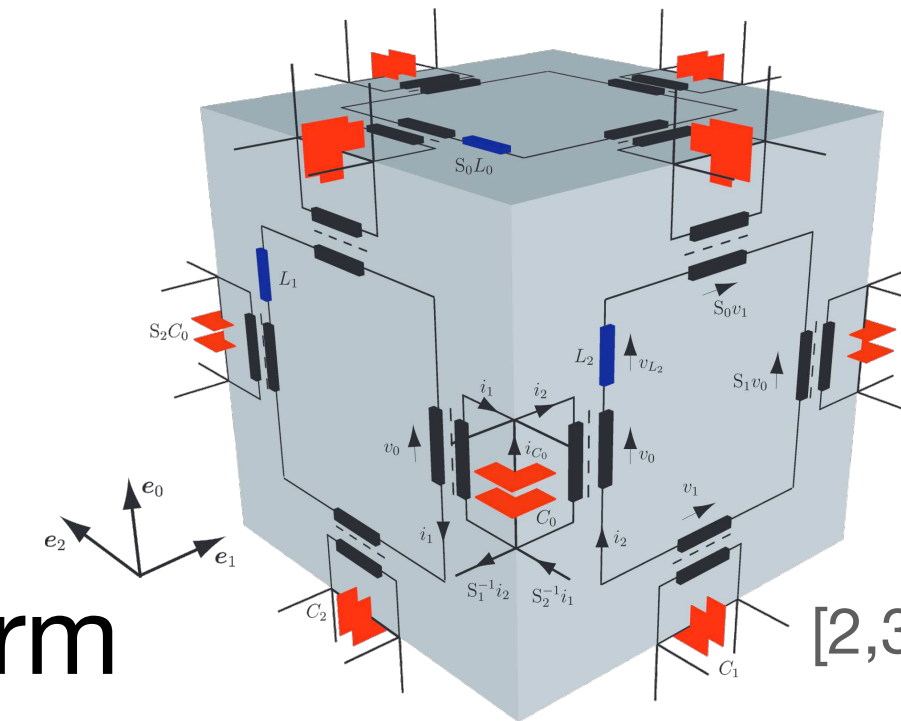
- Filed calculations with EC-FDTD [1,2] scheme
- Supported coordinate systems: cartesian and cylindrical
- Controlled by powerful scripting interface in
 - Matlab  | Octave 
 - Python 
- Result evaluation directly within scripting language or e.g. with  **ParaView**
- Support for remote and cluster simulation using MPI
- Software available for Linux, MacOS and Windows



Underlying EC-FDTD Engine

Equivalent Circuit — Finite Differences in Time Domain

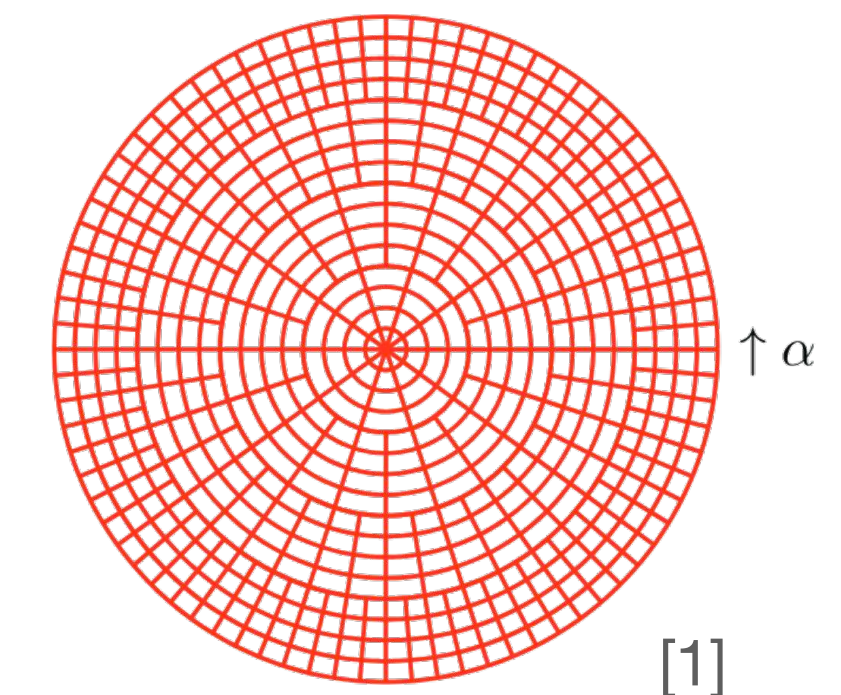
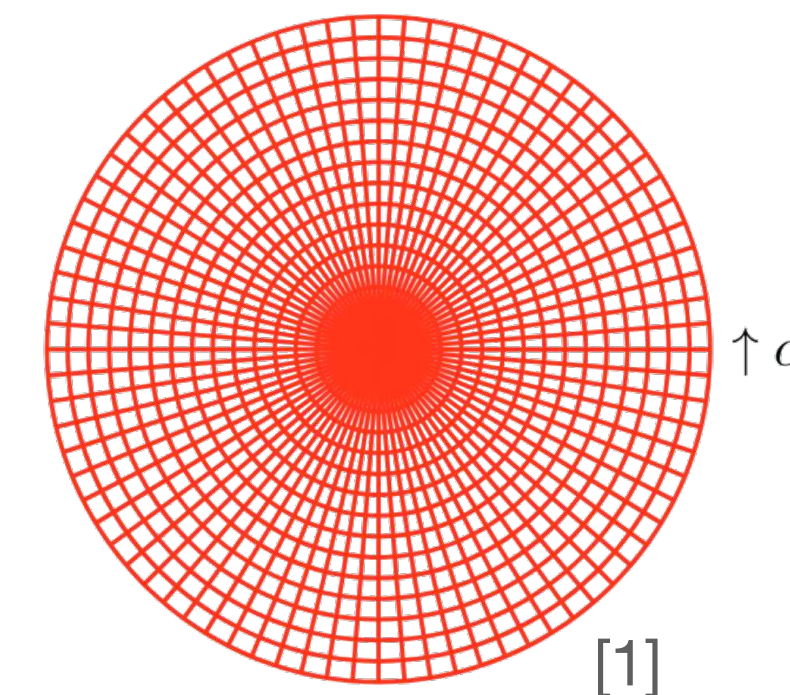
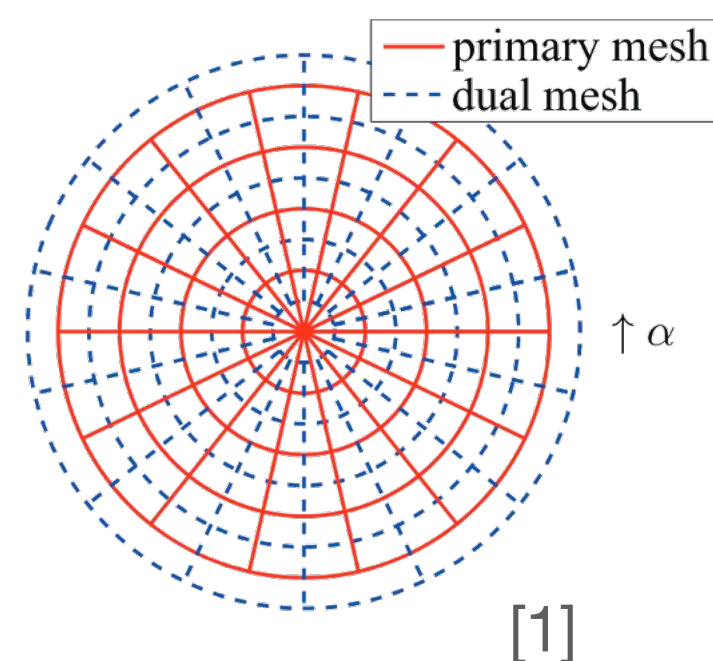
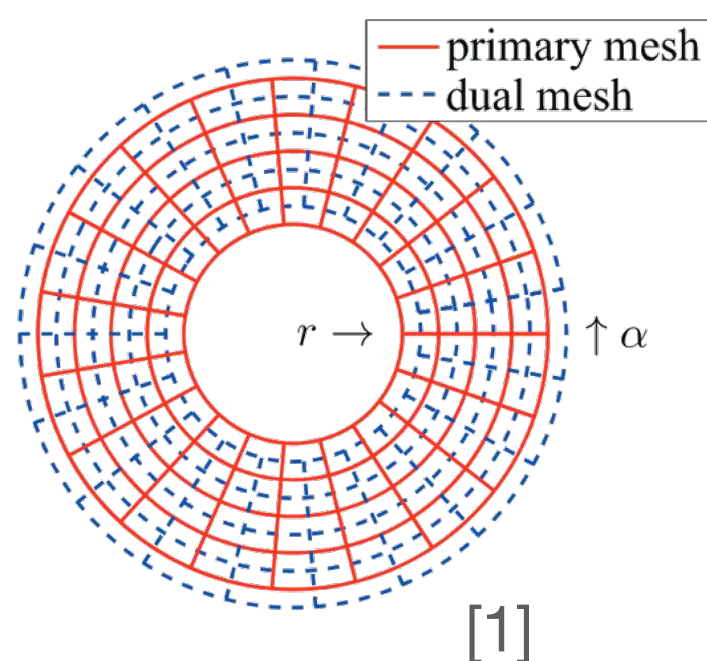
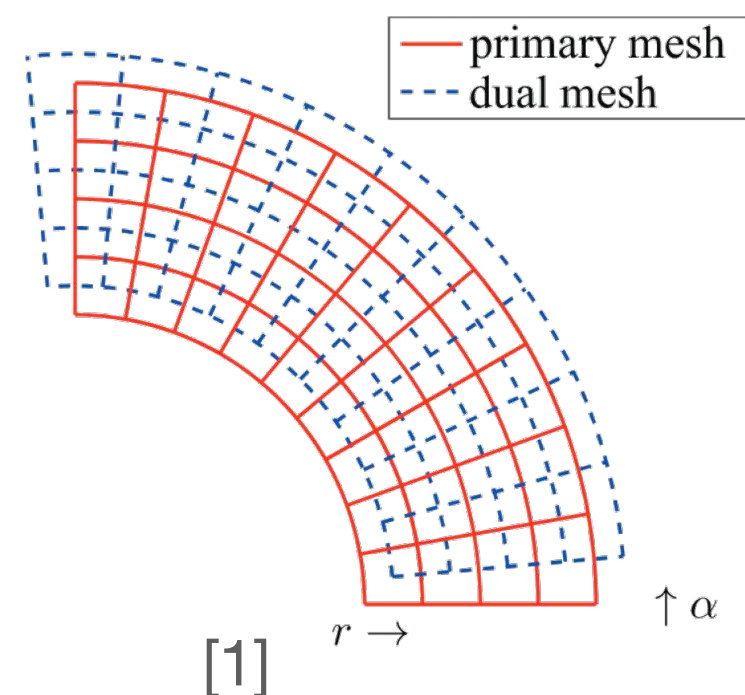
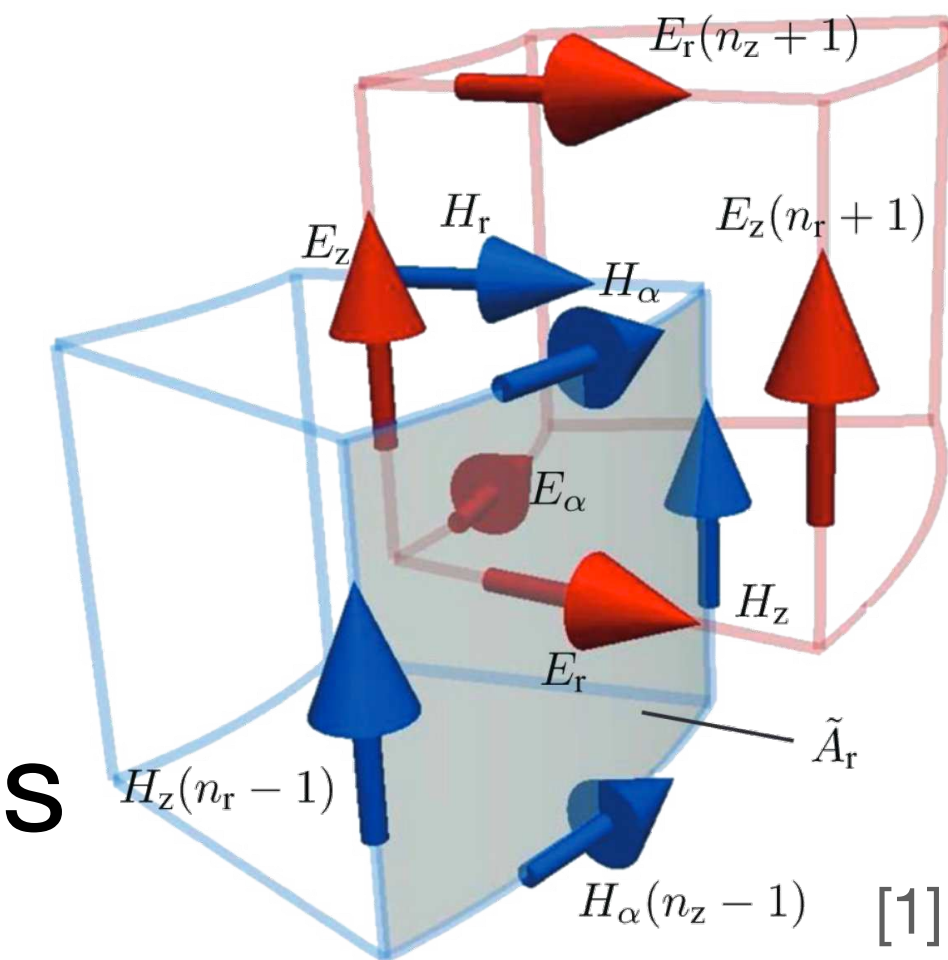
- Numerical equivalent to 'conventional' FDTD with all corresponding (dis)advantages
- Current and Voltages along with circuit elements form update equations
- Time domain method > broad band with one simulation (net response to gaussian pulse and FFT for freq. dom.)
- Computational resources scale linearly with problem size
- Integration of dispersive media via filter circuit (by e.g. multi-polar Drude-Lorentz model)
- Rigorous energy-based stability proof possible [2]



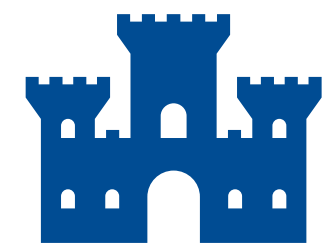
Cylindrical Coordinate System

a few words

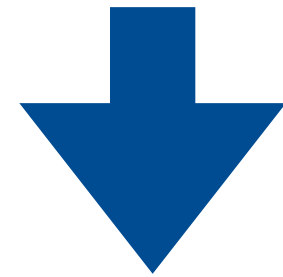
- *Identical* update equations (layout), coefficient format, calculation of EC parameters, support for e.g. dispersive materials
- Sole *difference* in calculation of edge length and surface areas
- Special boundary conditions needed: whole circle, origin
- Sub division of mesh grid (necessarily) useful



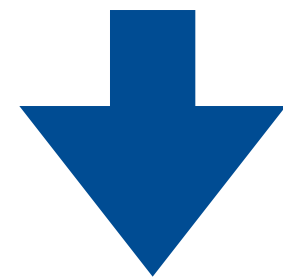
Structure of a Simulation



define simulation
structure

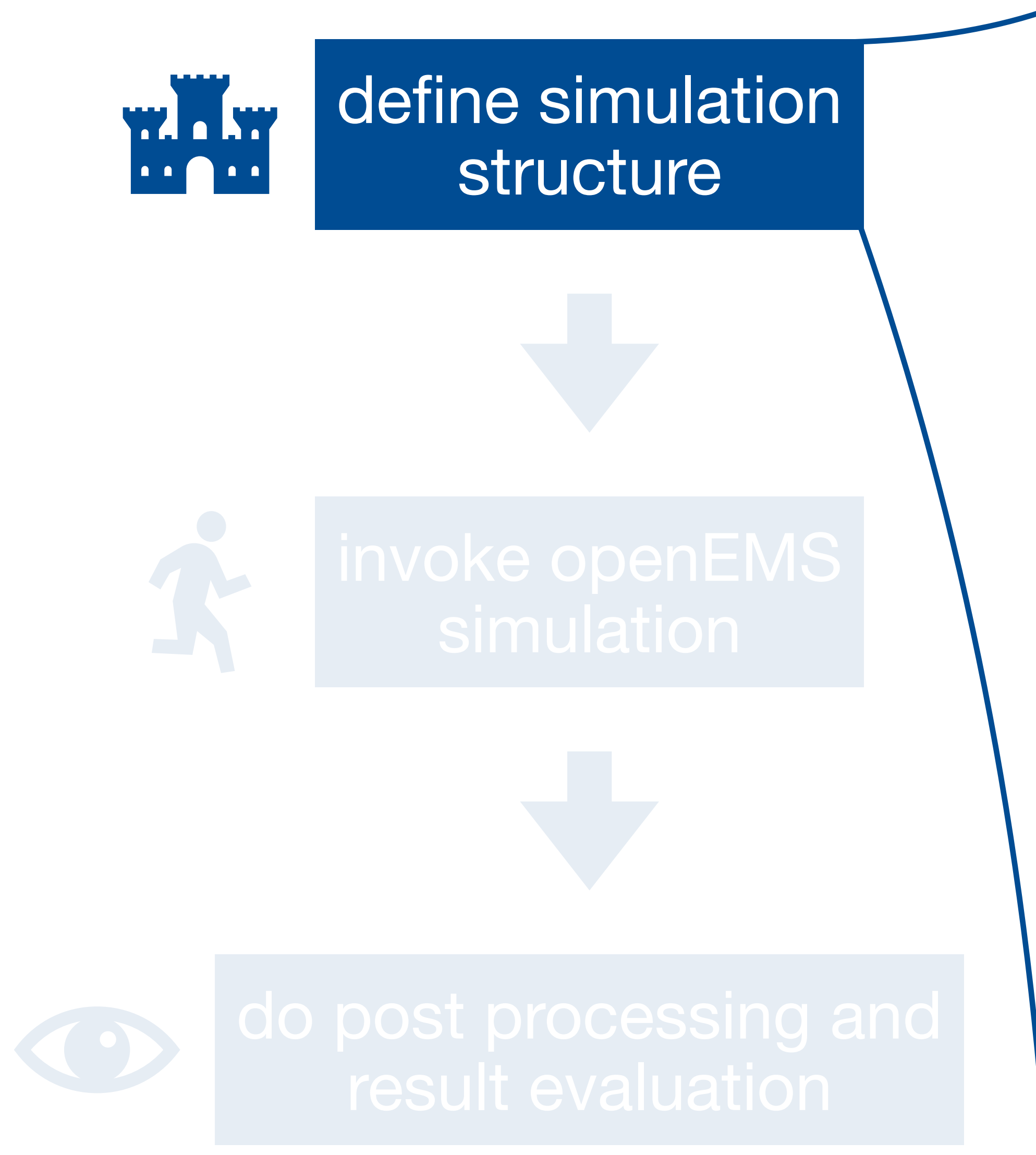


invoke openEMS
simulation



do post processing and
result evaluation

Structure of a Simulation

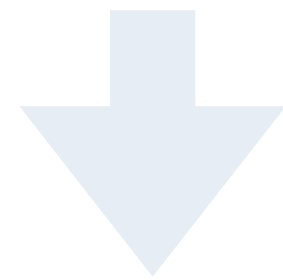


- Initialise CSXCAD
 - ➔ Continuous Structure XML CAD
 - open source library
 - description of geometrical objects along with physical properties
- Define parameters, functions, etc.
- Add material groups
- Add CSX specific primitive objects to material group
- (manually) define and smooth out mesh grid
- Inspect structure and mesh with AppCSXCAD

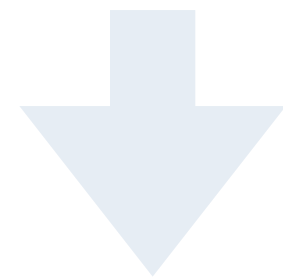
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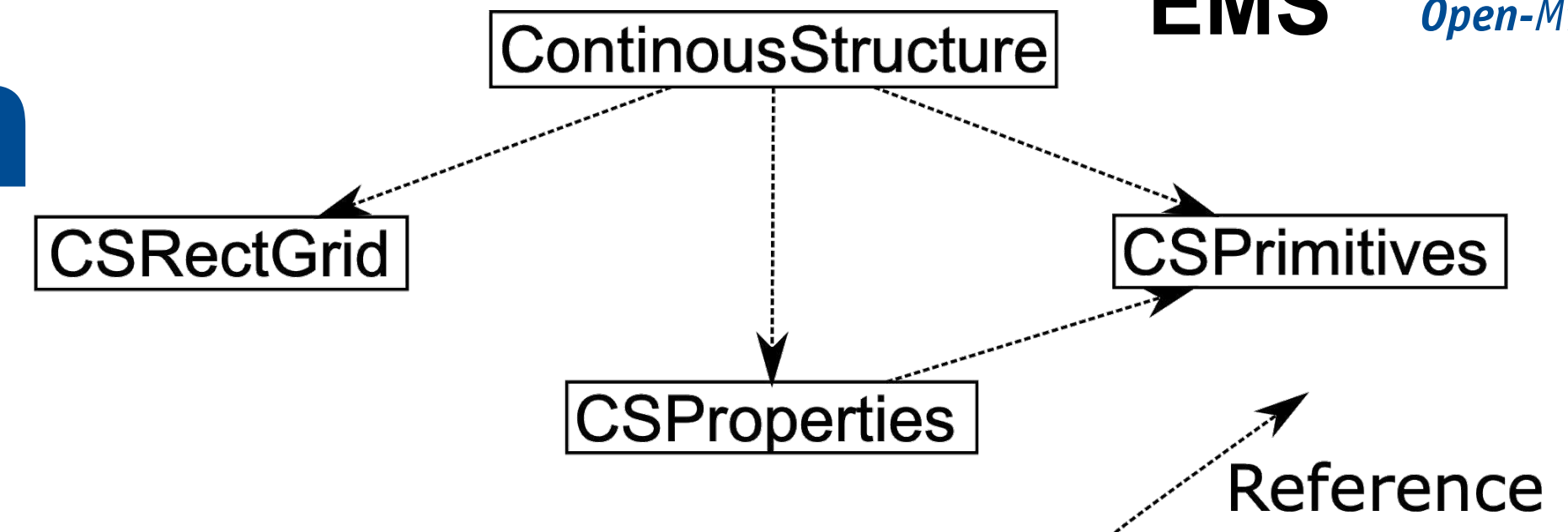
define simulation
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invoke openEMS
simulation



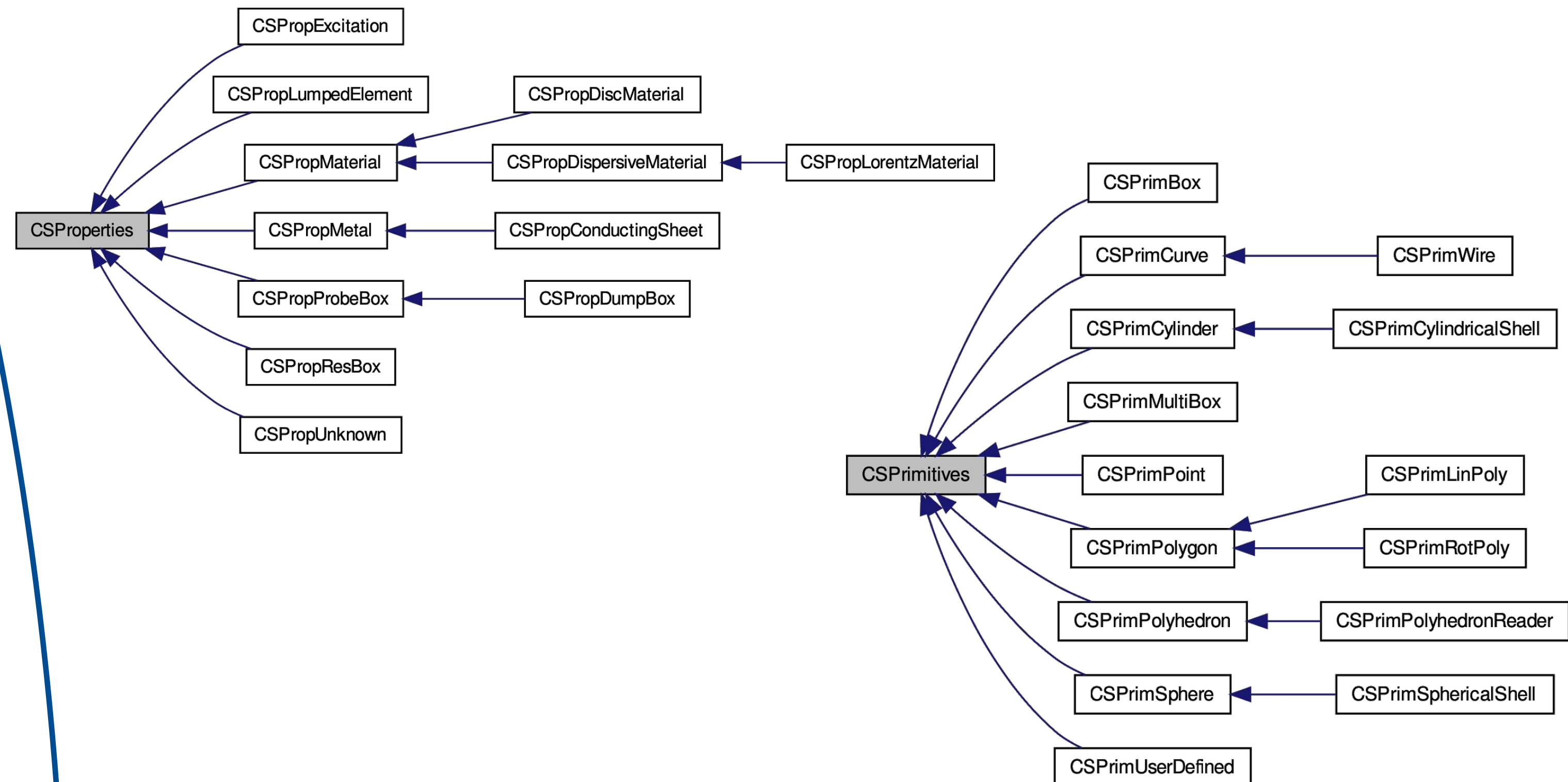
do post processing and
result evaluation



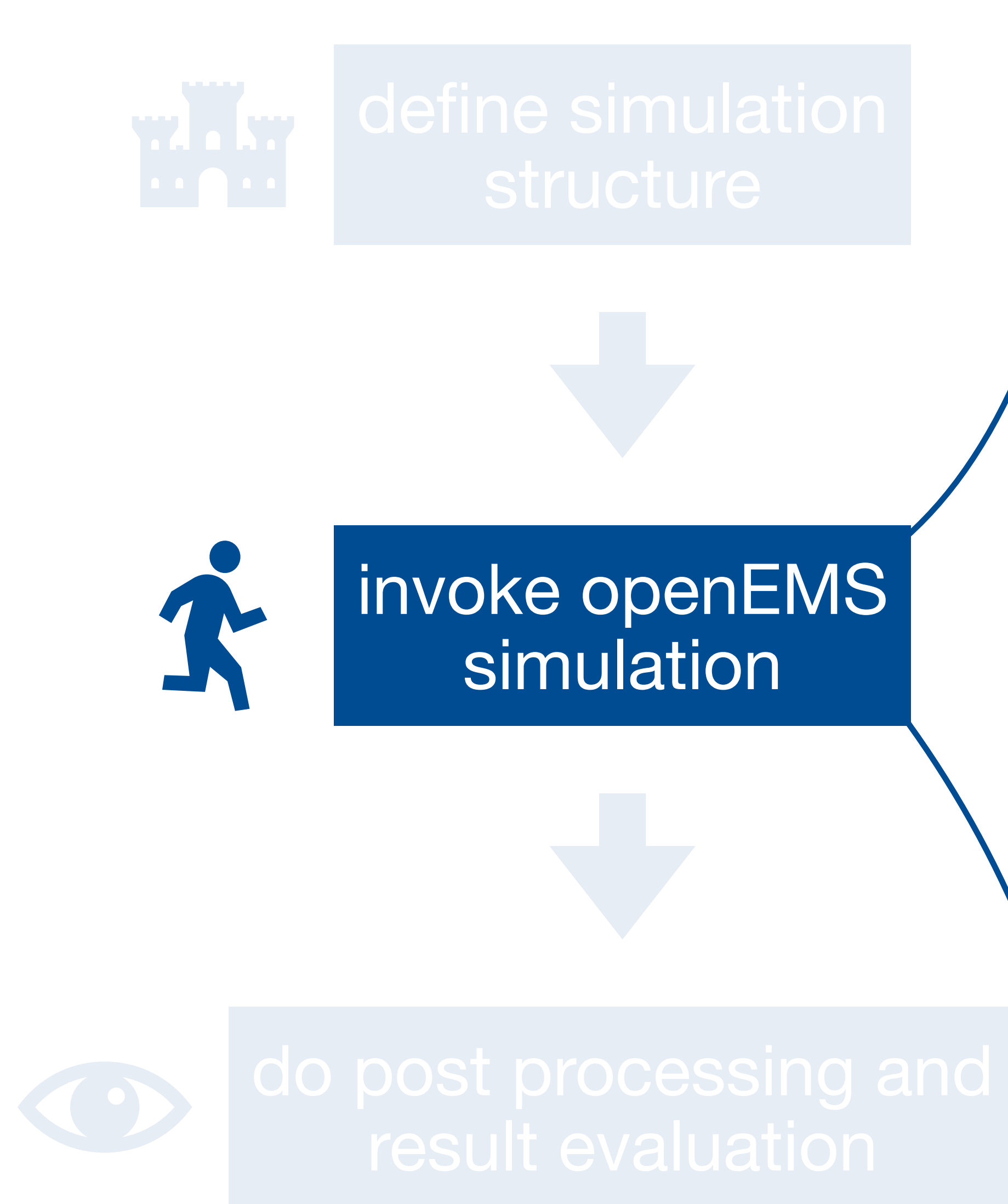
CSRectGrid: Class contains information for a (cartesian or cylindrical) mesh

CSProperties: Class contains information about physical and non-physical properties

CSPrimitives: Class contains description for geometrical primitives



Structure of a Simulation



- Start openEMS by calling function within scripting interface
- Typical command line output:

```

-----
| openEMS 64bit -- version v0.0.35-110-g782a738
| (C) 2010-2023 Thorsten Liebig <thorsten.liebig@gmx.de> GPL license
-----

```

Used external libraries:

```

CSXCAD -- Version: v0.6.2-124-gb5919a6
hdf5 -- Version: 1.14.1
      compiled against: HDF5 library version: 1.14.1-2
tinyxml -- compiled against: 2.6.2
fparser
boost -- compiled against: 1_81
vtk -- Version: 9.2.6
      compiled against: 9.2.6

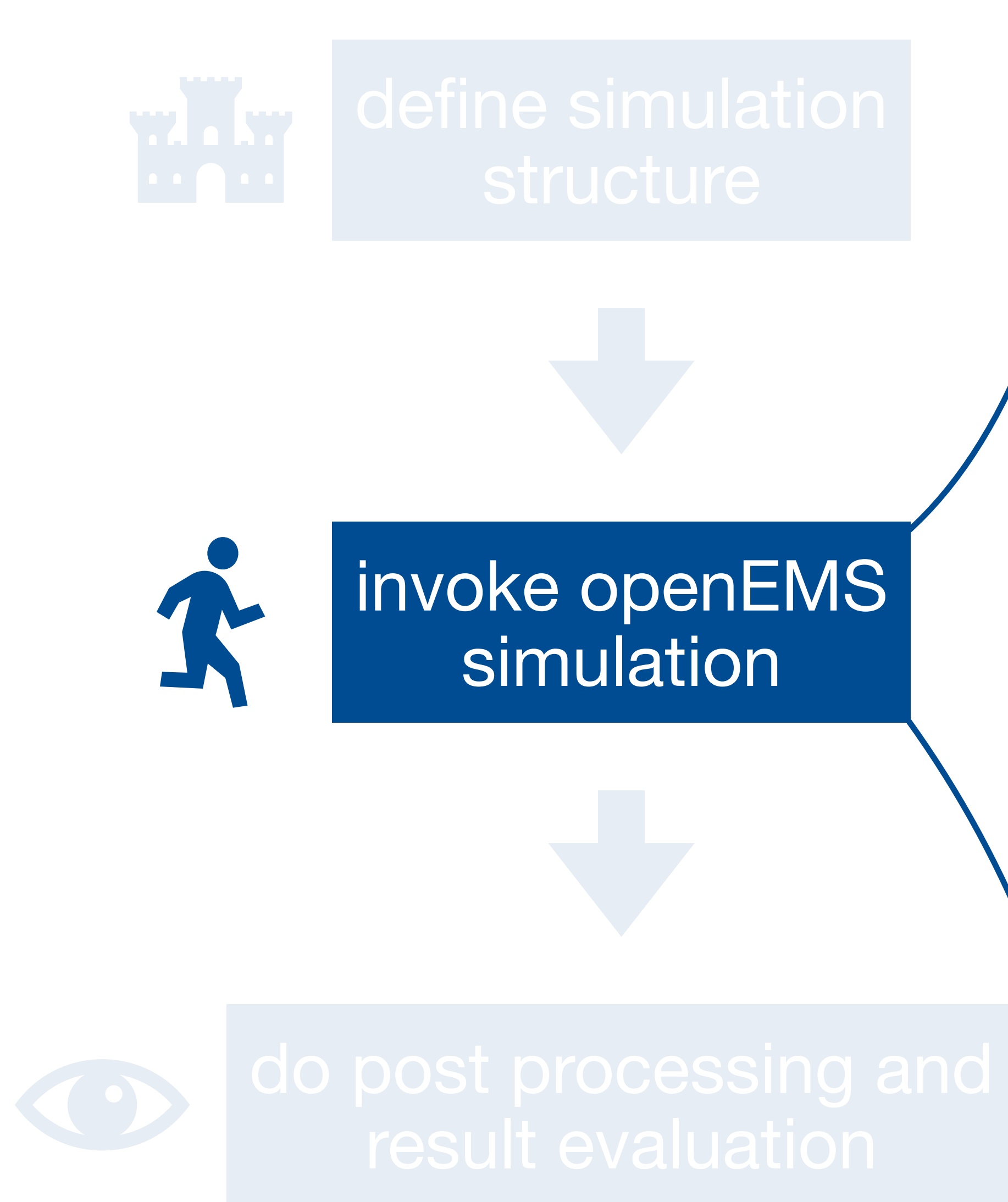
```

```

Create FDTD operator (compressed SSE + multi-threading)
FDTD simulation size: 83x83x178 --> 1.22624e+06 FDTD cells
FDTD timestep is: 5.58967e-12 s; Nyquist rate: 30 timesteps @2.98169e+09 Hz
Excitation signal length is: 1026 timesteps (5.73501e-09s)
Max. number of timesteps: 1000000000 ( --> 974659 * Excitation signal length)
Create FDTD engine (compressed SSE + multi-threading)
Running FDTD engine... this may take a while... grab a cup of coffee?!?
[@ 4s] Timestep: 203 || Speed: 61.8 MC/s (1.985e-02 s/TS) || Energy: ~1.03e-18 (- 0.00dB)
...
[@ 52s] Timestep: 3157 || Speed: 74.7 MC/s (1.641e-02 s/TS) || Energy: ~4.52e-20 (-52.49dB)
Time for 3157 iterations with 1226242.00 cells : 52.75 sec
Speed: 73.39 MCells/s

```

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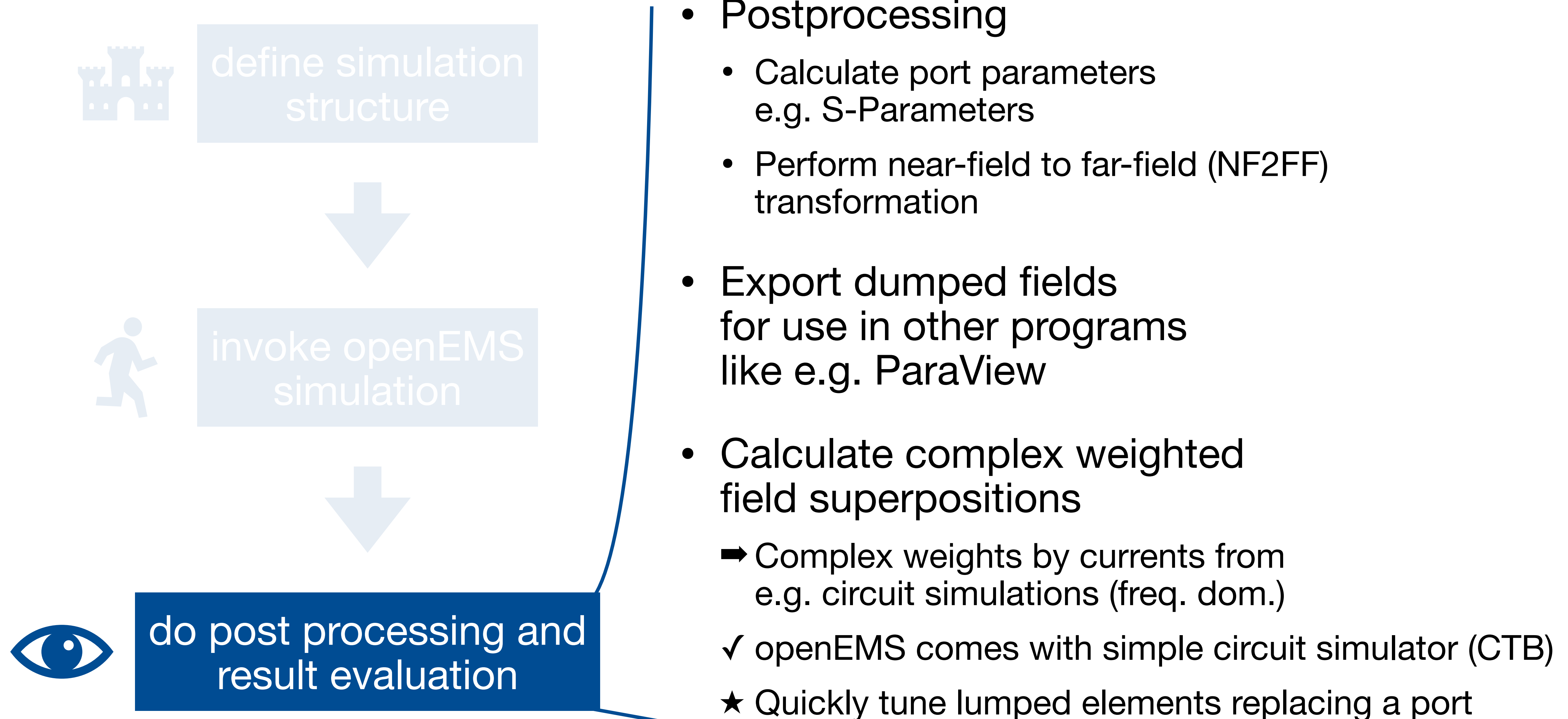
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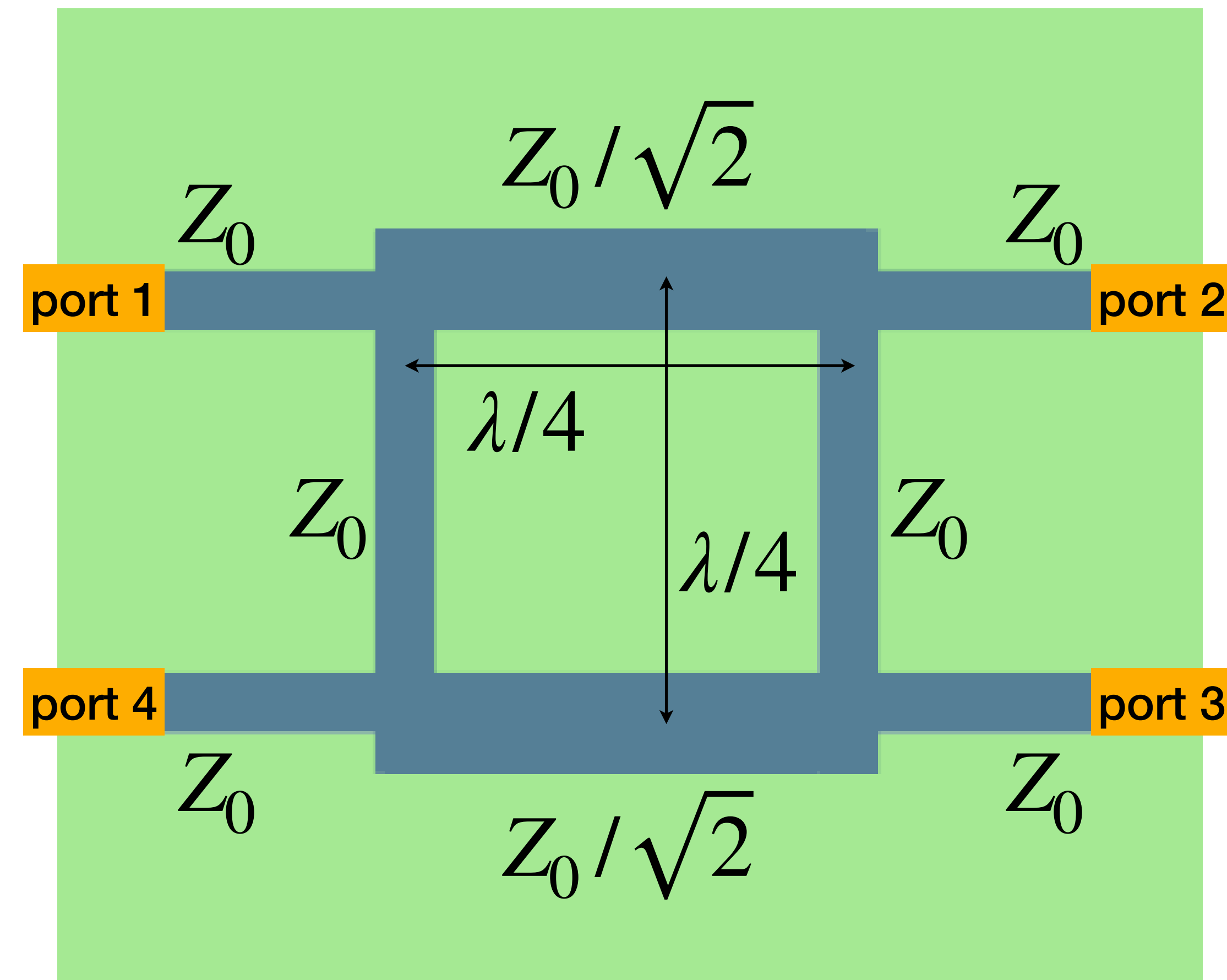
Structure of a Simulation



Simple Example Simulation

the problem

- Problem definition:
 - hybrid coupler (power split, 90° phase) in microstrip strip line technology
- Substrate:
Rogers RO4350B
1.5mm thickness
- Frequency range 0.0 ... 4.0 GHz
- Operating frequency 2.0 GHz



Simple Example Simulation



define simulation structure

% Parameteres

```
addpath('~\opt\openEMS_build\share\openEMS\matlab');
```

```
addpath('~\opt\openEMS_build\share\CSXCAD\matlab');
```

```
const_c0 = 299792458;    const_mue0 = 1.2566370621219e-6;    const_eps0 = 1/(const_c0^2*const_mue0);
```

```
unit_len = 1e-6; % Lengths in unit um
```

```
freq_0 = 2e9;    freq_range = [0.0, 4e9];
```

```
sub_h = 1524;    sub_epsr = 3.66;    sub_tand = 0.0037;
```

```
msl_Zc = [50, 50/sqrt(2)];
```

```
for n = 1:2    msl_w(n) = calc_msl_width_by_book_of_pozar(msl_Zc(n), sub_epsr, sub_h);    end
```

```
eps_eff = (sub_epsr+1)/2;
```

```
lambda_0 = const_c0/freq_0 /unit_len;    lambda_range = const_c0./freq_range /unit_len;
```

```
mesh_max_delta = min(lambda_range) /sqrt(sub_epsr) /20;
```

```
feed_l = lambda_0 / 2;
```

Simple Example Simulation



define simulation structure

% Init FDTD and CSX

```
FDTD = InitFDTD('EndCriteria', 1e-6, 'Oversampling', 6);
```

```
FDTD = SetGaussExcite(FDTD, 0, max(freq_range));
```

```
FDTD = SetBoundaryCond(FDTD, {'PML_8', 'PML_8', 'MUR', 'MUR', 'PEC', 'PML_8'});
```

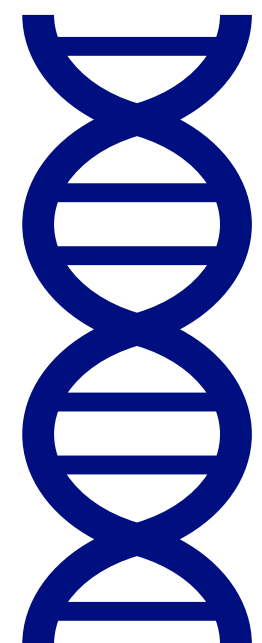
```
CSX = InitCSX();
```

% Define Structure

```
CSX = AddMetal(CSX, 'cond_top');
```

```
CSX = AddMaterial(CSX, 'R04350B');
```

```
CSX = SetMaterialProperty(CSX, 'R04350B', 'Epsilon', sub_epsr, 'Kappa', sub_tand*2*pi*10e9*sub_epsr*const_eps0);
```



(longer) code block not shown:

- calculating start and end points of boxes
- adding boxes to materials
- loop for similar parts
- add mesh lines of edges
- smooth mesh

```
start = [mesh.x(1), mesh.y(1), 0];
stop = [mesh.x(end), mesh.y(end), sub_h];
CSX = AddBox( CSX, 'R04350B', 0, start, stop );

mesh.x = AutoSmoothMeshLines(mesh.x, mesh_max_delta, 1.25);
```

Simple Example Simulation



invoke openEMS simulation

```
% Save, view and run simulation
```

```
Sim_Path = 'MSL_Quad_Hybrid';
```

```
Sim_CSX = 'MSL_Quad_Hybrid.xml';
```

```
[~] = rmdir(Sim_Path, 's'); % clear previous directory
```

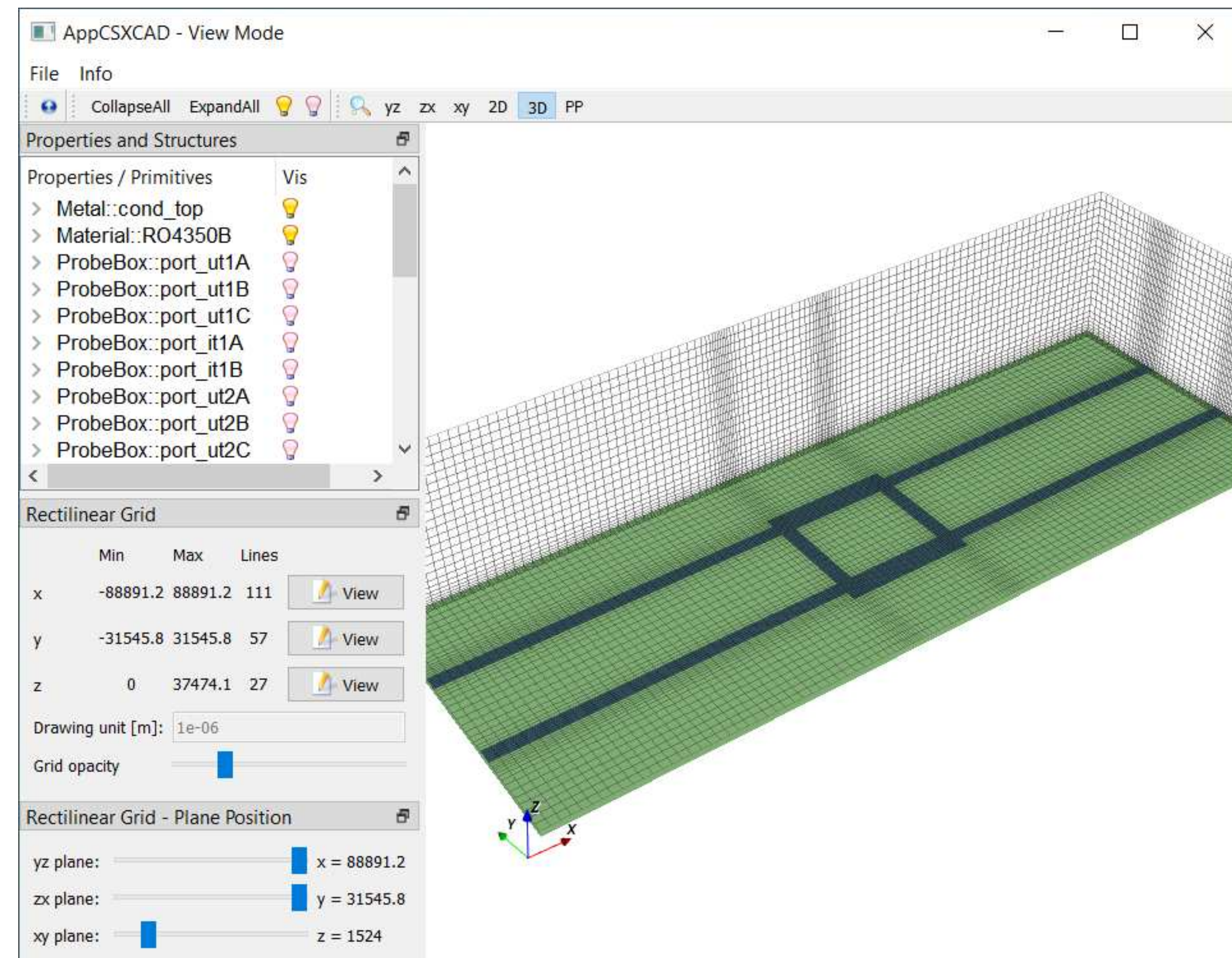
```
[~] = mkdir(Sim_Path); % create empty simulation folder
```

```
WriteOpenEMS(fullfile(Sim_Path, Sim_CSX), FDTD, CSX);
```

```
CSXGeomPlot(fullfile(Sim_Path, Sim_CSX));
```

```
Settings.LogFile = 'openEMS.log';
```

```
RunOpenEMS(Sim_Path, Sim_CSX, '', Settings)
```



Simple Example Simulation



invoke openEMS simulation

```
% Save, view and run simulation
```

```
Sim_Path = 'MSL_Quad_Hybrid';
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```
Sim_CSX = 'MSL_Quad_Hybrid.xml';
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[~] = rmdir(Sim_Path, 's'); % clear previous directory
```

```
[~] = mkdir(Sim_Path); % create empty simulation folder
```

```
WriteOpenEMS(fullfile(Sim_Path, Sim_CSX), FDTD, CSX);
```

```
CSXGeomPlot(fullfile(Sim_Path, Sim_CSX), ['--export-polydata-vtk=' Sim_Path]);
```

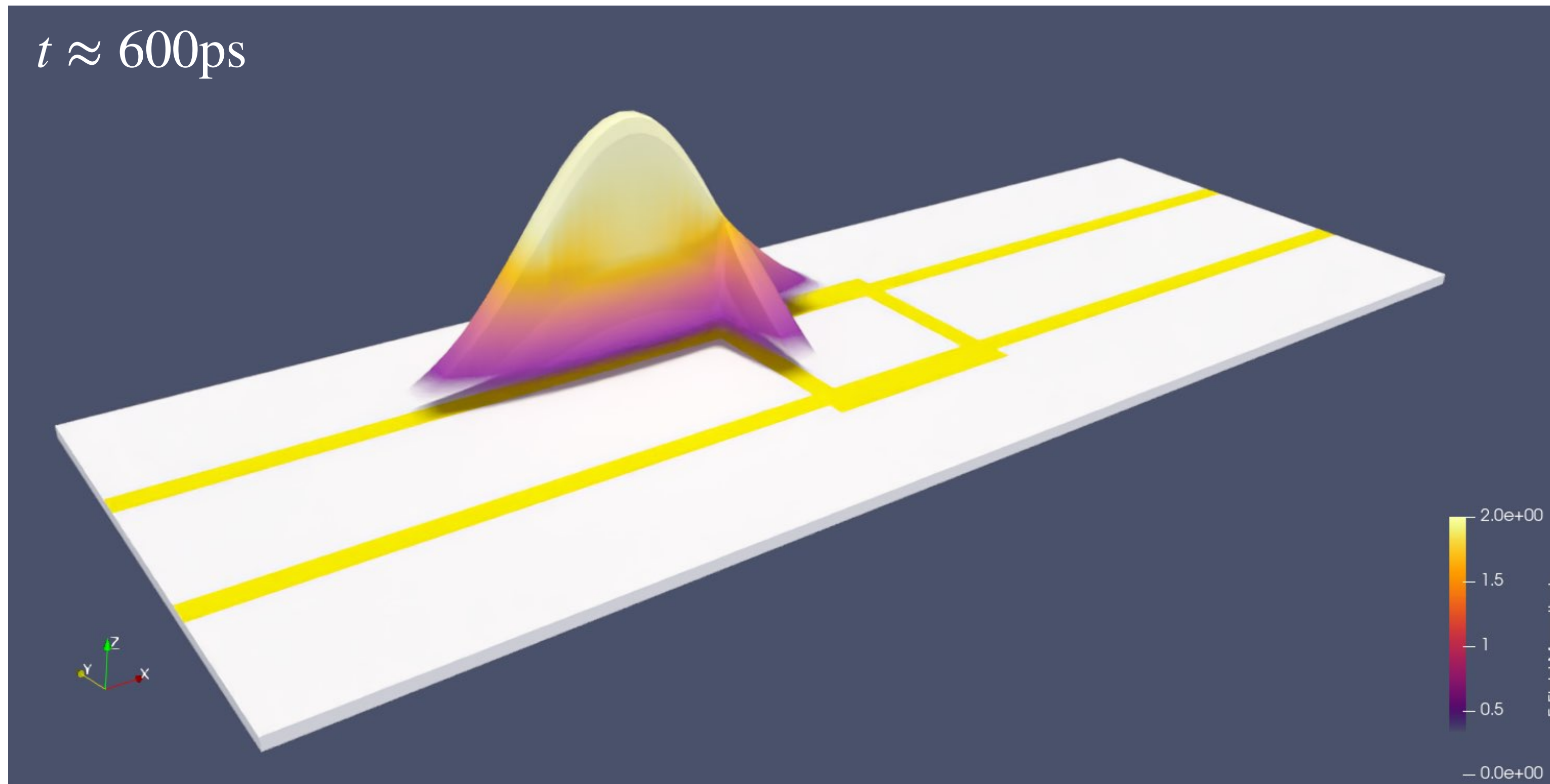
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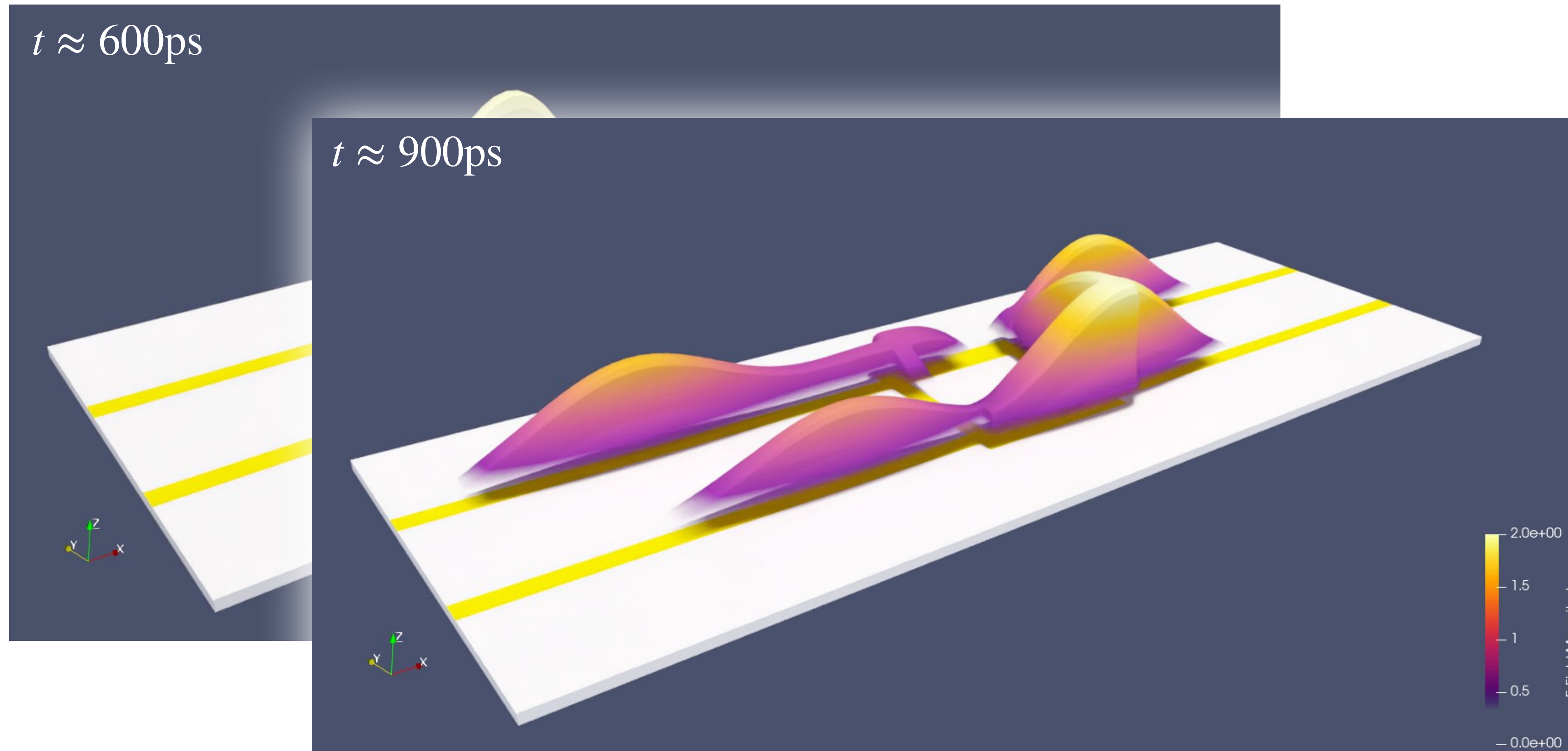
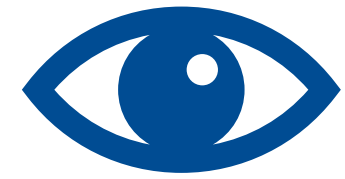
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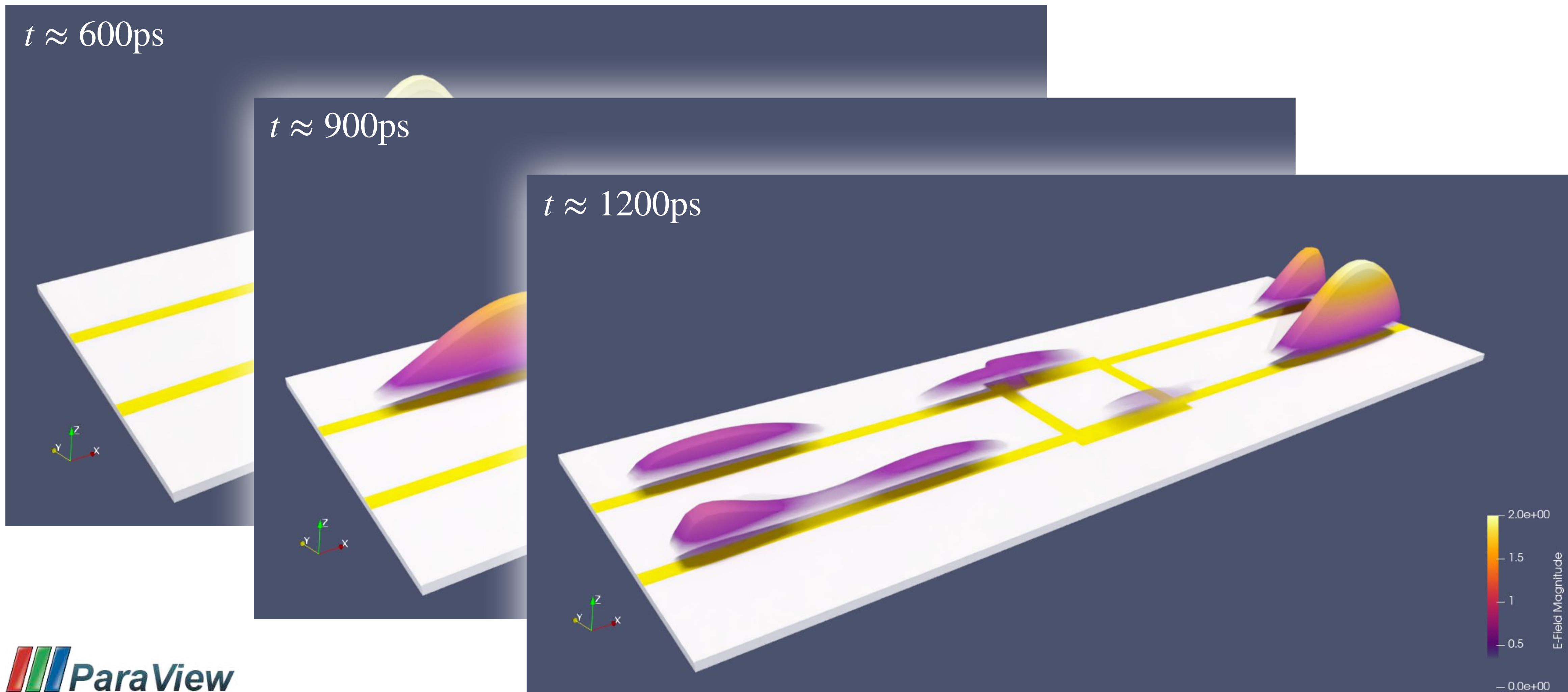
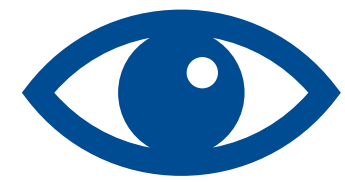
Magnitude of E-Field in Substrate



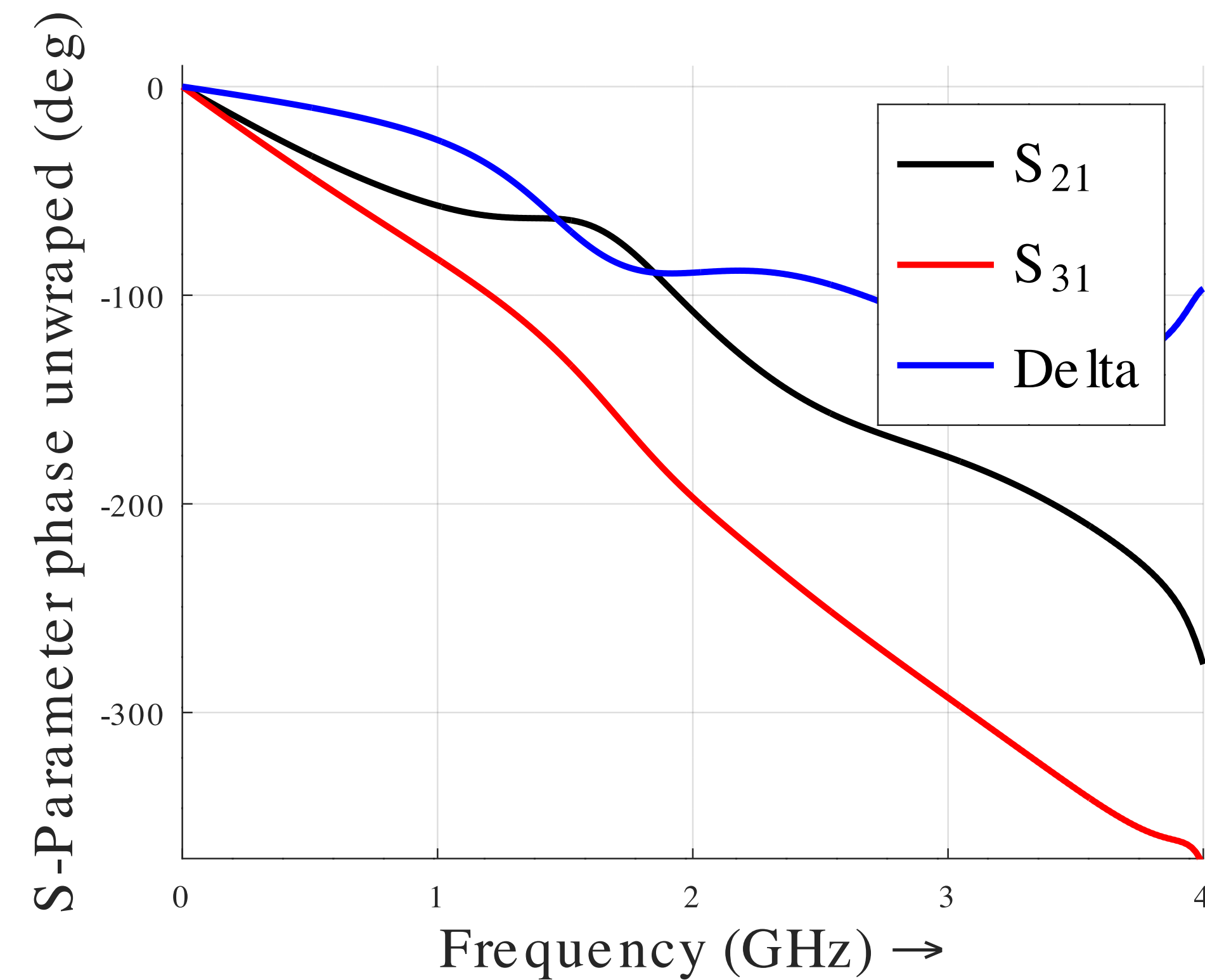
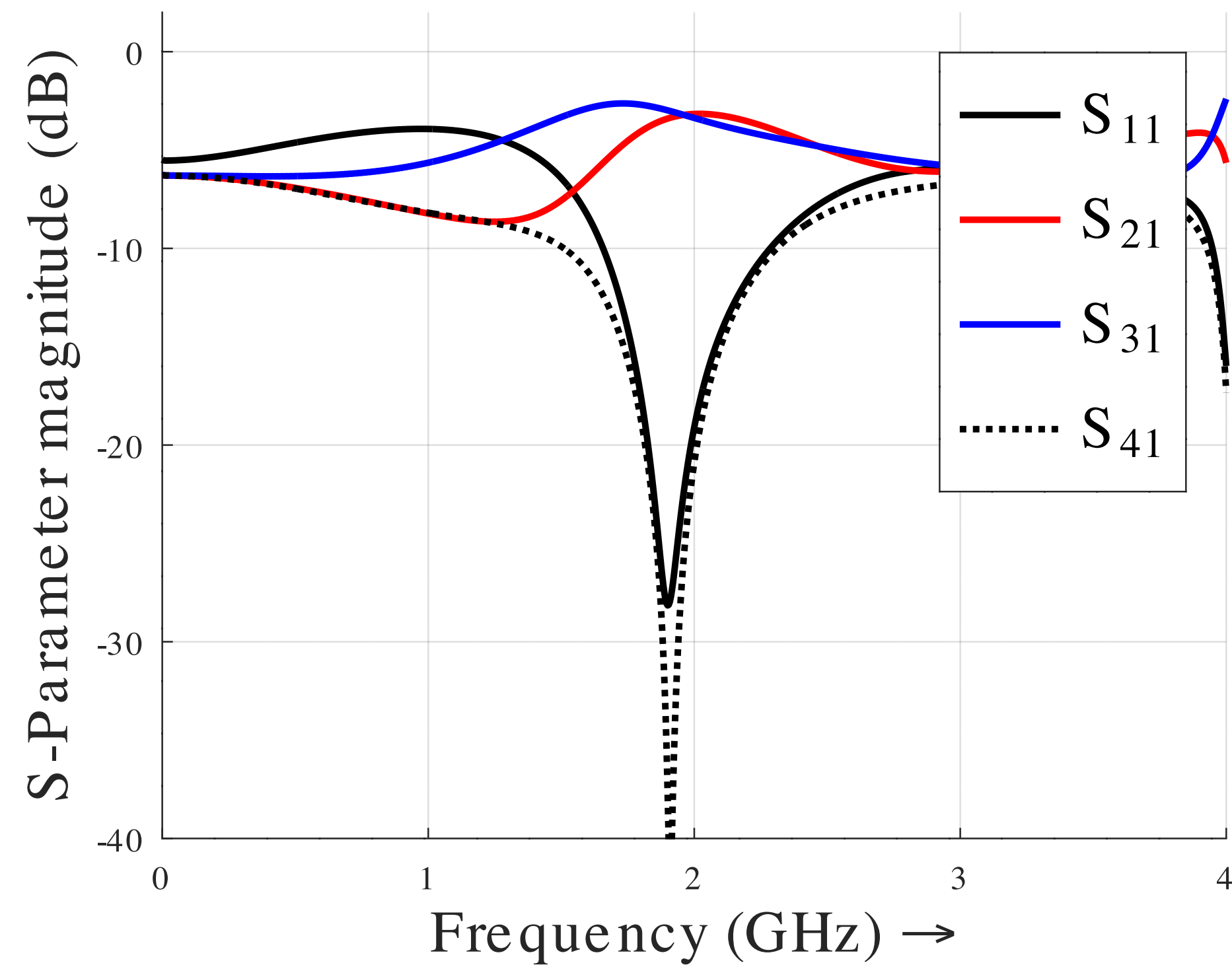
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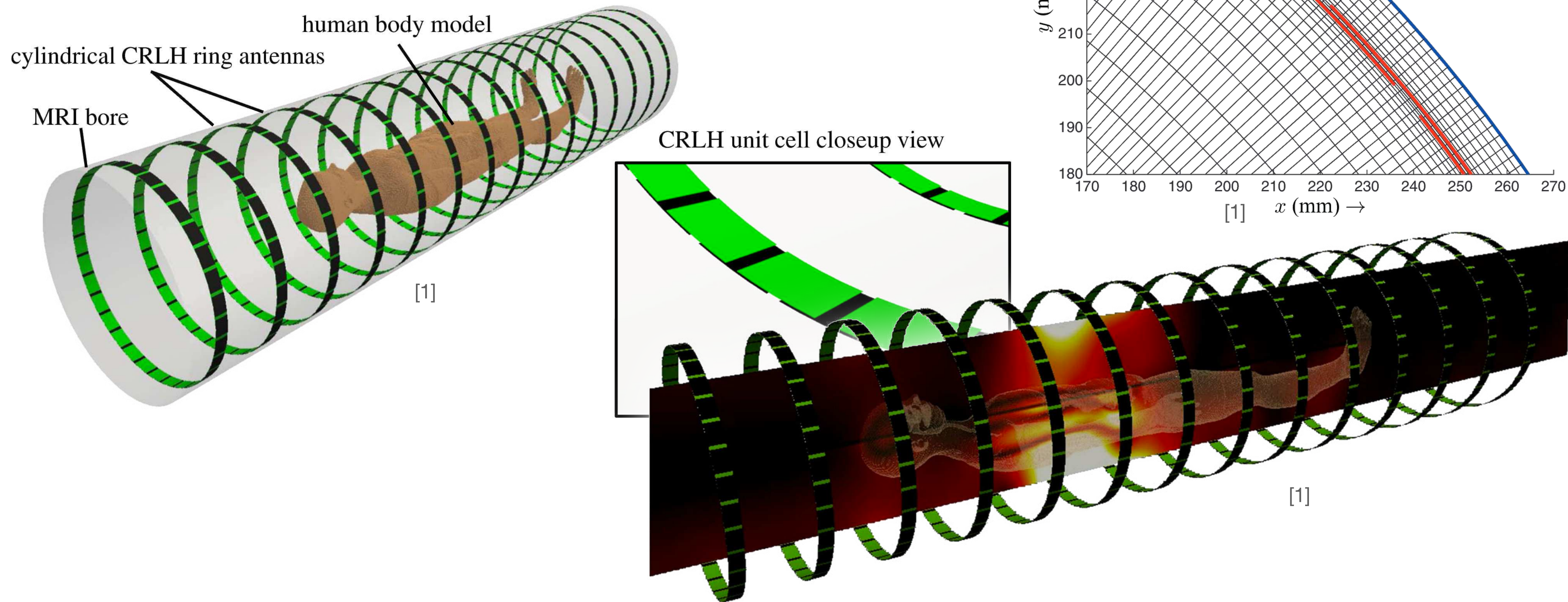


S-Parameter Results



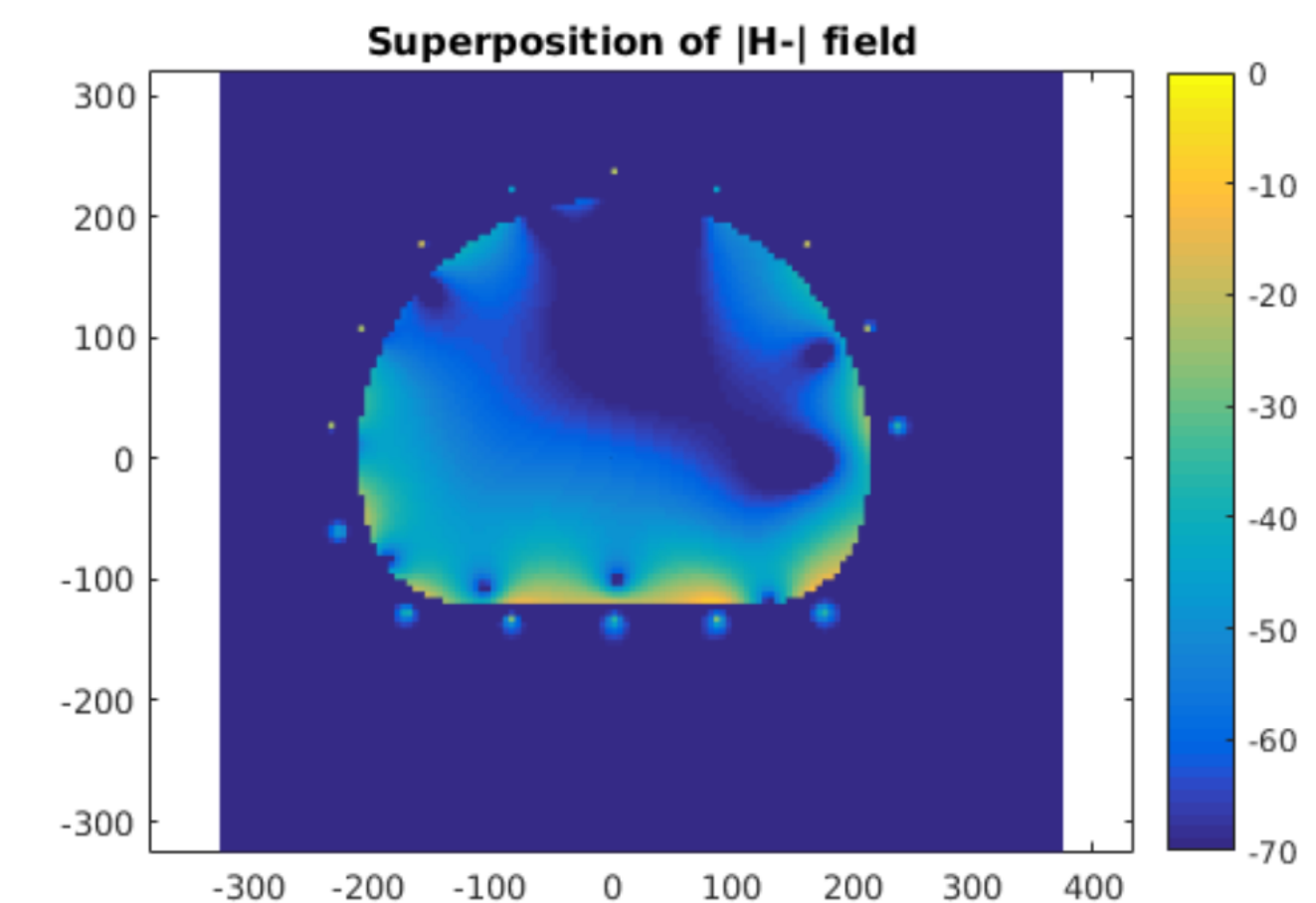
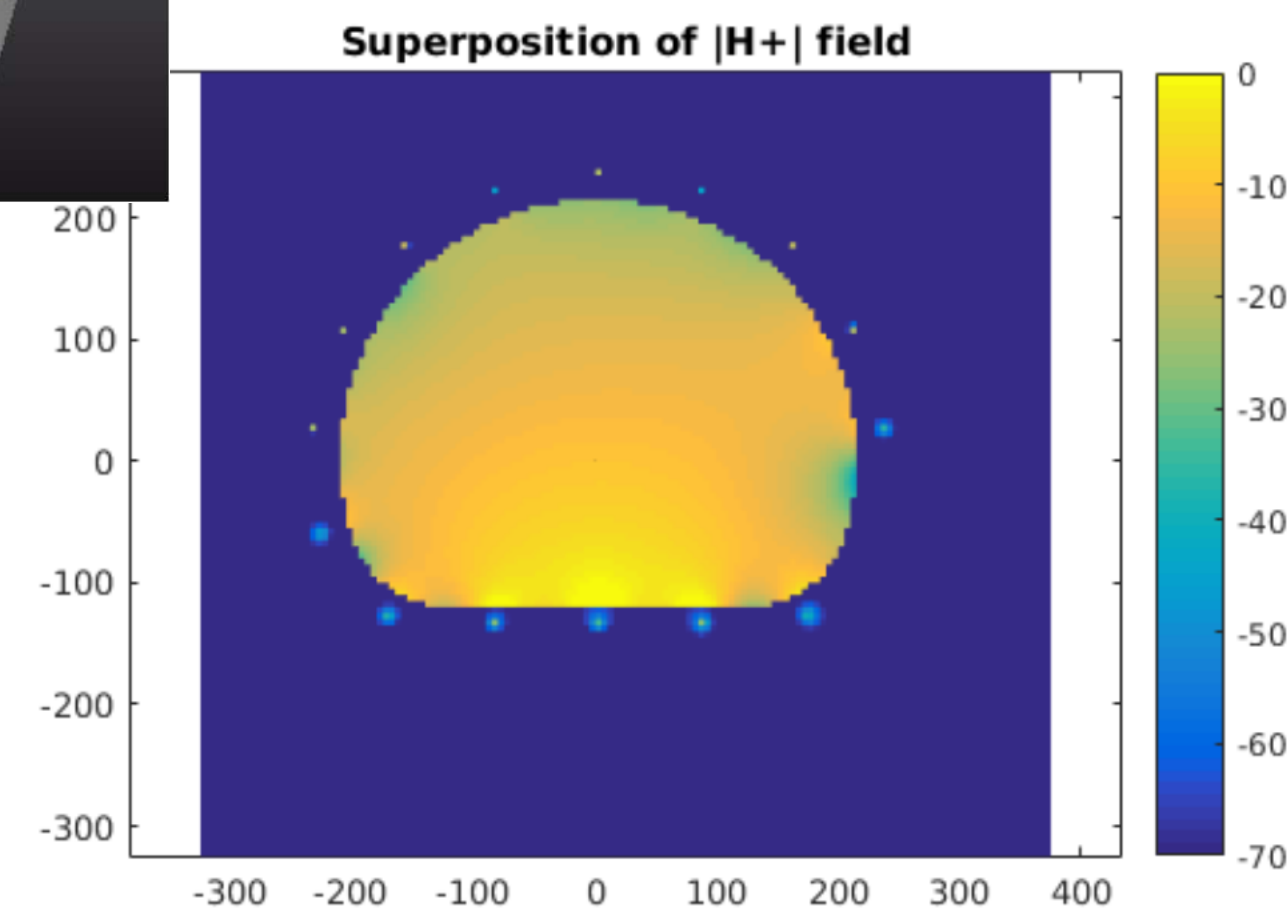
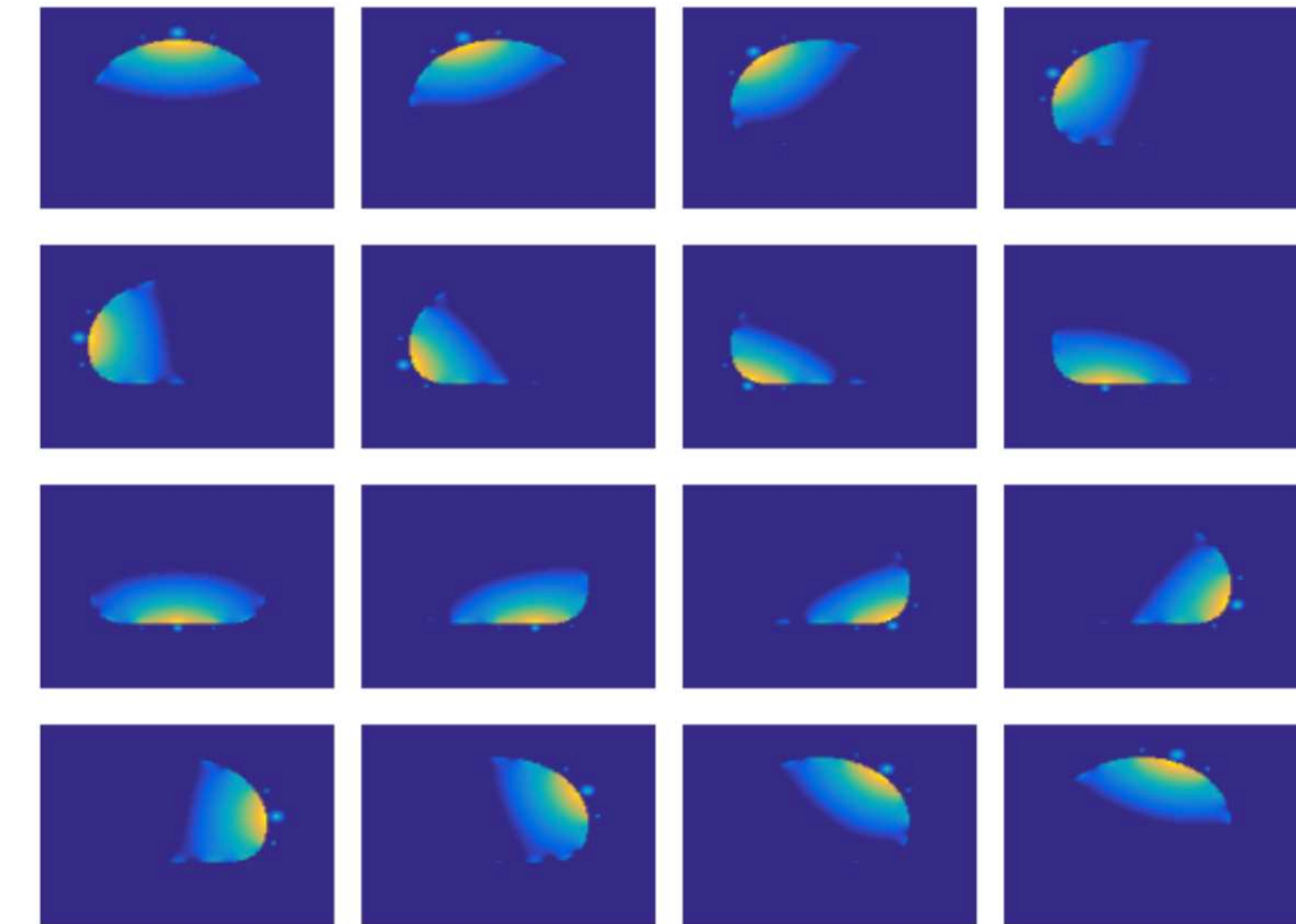
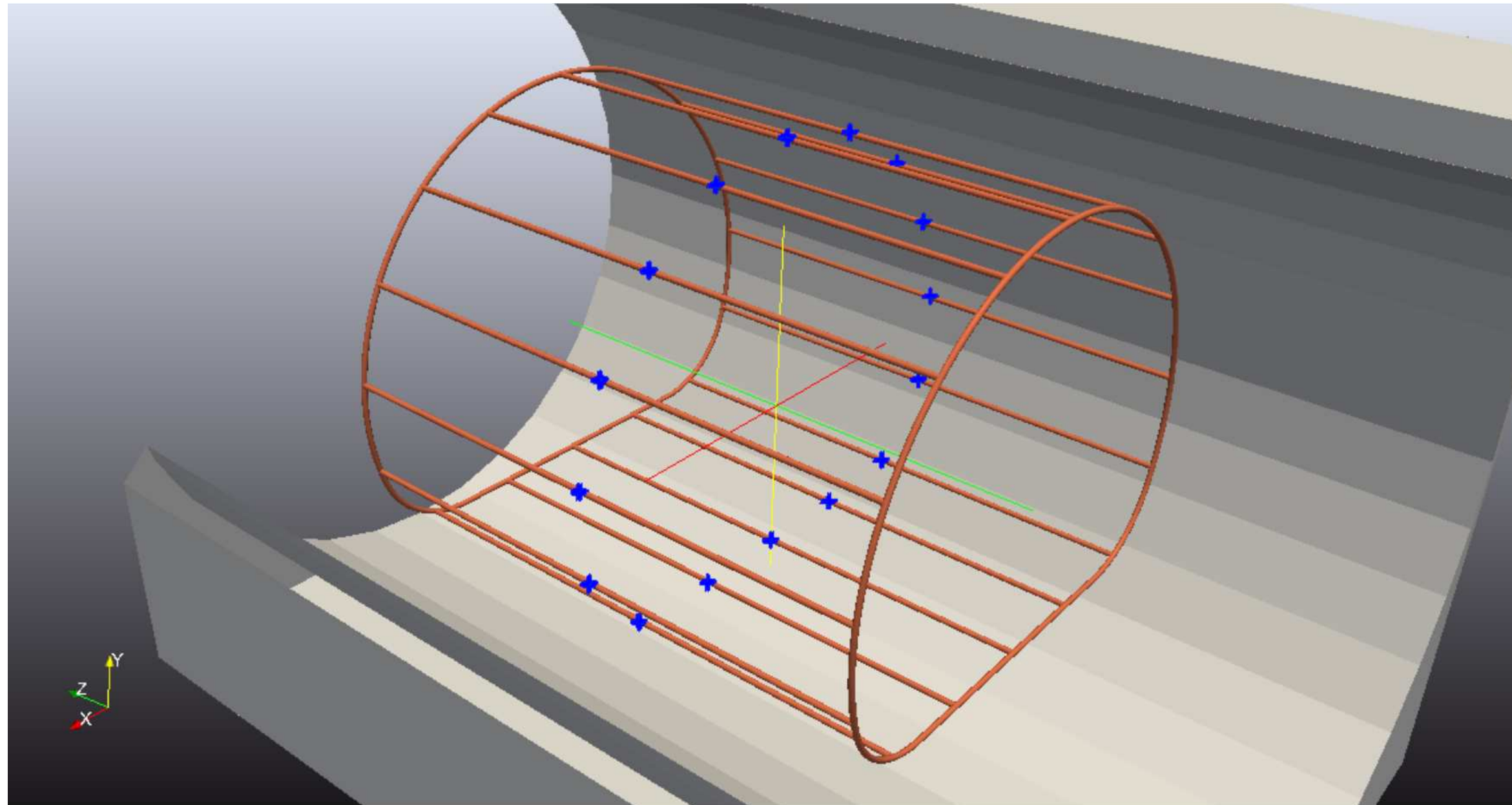
Showcases

meta material resonators for 7T-MRI



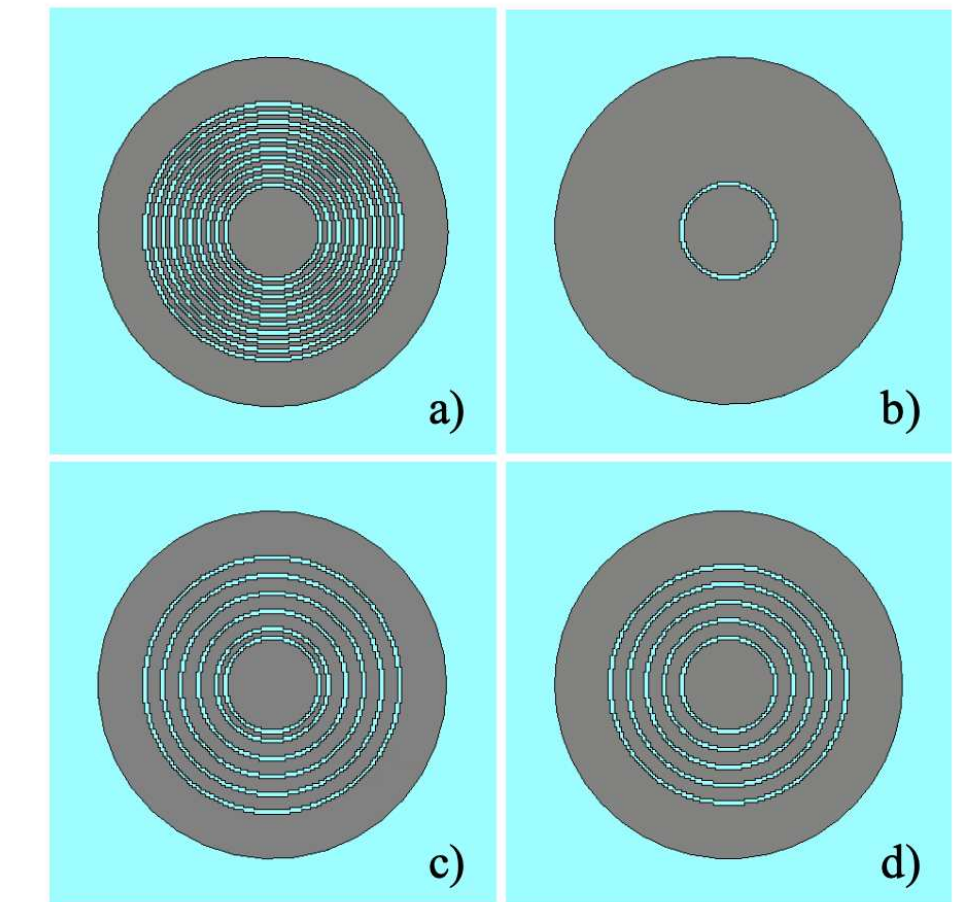
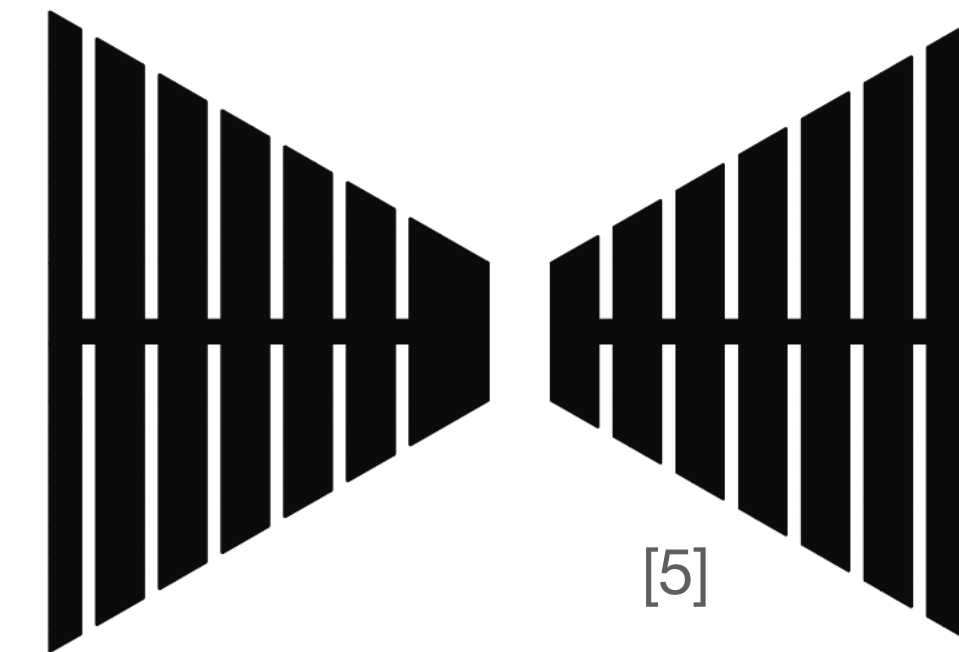
Showcases

flatened birdcage coil for 7T-MRI [4]

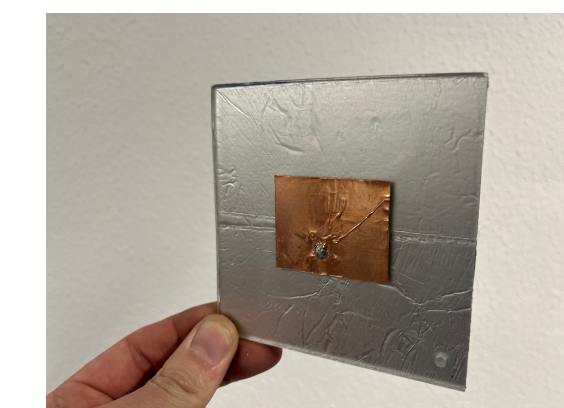
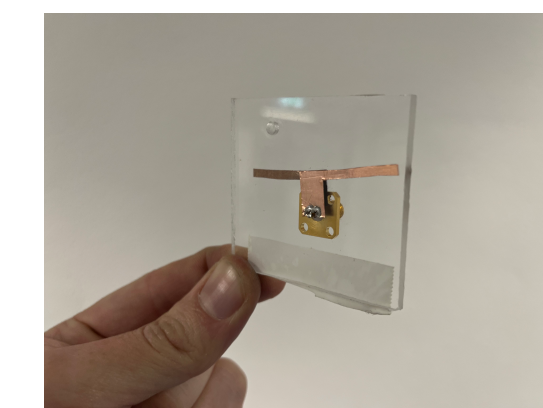
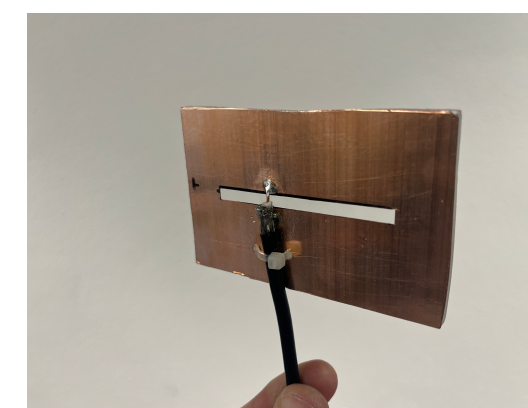


OpenEMS in Education at UDE

- Within remote Master degree program (*Hochfrequenz und Photonik Fernpraktikum*)
 - Students decide on Chipless RFID-Tag design from given list of papers
- Task is to show functionality of at least three 6-Bit tags with varying codes
- Simulations are done in openEMS (due to benefits of open-source)
- Included in Computational Electromagnetics course as an example FDTD solver
- Possible choice for antenna simulation during workshop part of Antennas for Communications course



[6]



Ways to Import | Export Structure

Export

- Structure is defined in CSXCAD
 - Export (currently) possible to
 - STL
 - Gerber (RS-274X)
 - KiCAD footprint
via open source tool
🔄 matthuszagh / pyems
- EM-Filed export to VTK, HDF5
- S-Parameter to e.g. touchstone

Import

- Inhomogenous materials
 - Import via CSXCAD as spacial
dependent disc material
 - HDF5 File
- PCB-Design from KiCAD
 - Import via open source tool
🔄 jcyrax / pcbmodelgen
- STL
- All imports need to fit CSXCAD

Summary

- Open EMS is a versatile EM solver
- Cartesian and cylindrical coordinate systems

➔ Advantageous:

- ✓ All benefits of open-source — freely available, no complicated licenses
- ✓ Several aspects of EM-simulations can be learned — meshing, boundary conditions, simulation domain
- ✓ Structure can easily be parameterised (
- ✓ FDTD enables broad band solutions with one simulation run

➔ Cons:

- Meshing is (for now?) to be done (primarily) by hand
- Single frequencies can not (easily) be simulated

★ Outlook

- Simulation speed improvement to more complex EC-FDTD implementation
- Interconnection with layout and circuit design tools



Thank you

Feel free to clone, fork
and contribute:

<https://www.openems.de>

Jan Taro Svejda — jan.svejda@uni-due.de

General and Theoretical Electrical Engineering (ATE),
University of Duisburg-Essen,
CENIDE – Center for Nanointegration Duisburg-Essen,
D-47048 Duisburg, Germany

- [1] Liebig Thorsten, Rennings Andreas, Held Sebastian, and Erni Daniel, “openEMS – a free and open source equivalent-circuit (EC) FDTD simulation platform supporting cylindrical coordinates suitable for the analysis of traveling wave MRI applications,” Int. J. Numer. Model., vol. 26, no. 6, pp. 680–696, 2013, doi: 10.1002/jnm.1875.
- [2] A. Rennings, “Elektromagnetische Zeitbereichssimulationen innovativer Antennen auf Basis von Metamaterialien,” Dr.-Ing. Dissertation, Universität Duisburg-Essen, Fak. IW / ATE, Duisburg, DE, 2008.
- [3] P. Russer, U. Siart, and W. J. R. Hoefer, Eds., Time domain methods in electrodynamics: a tribute to Wolfgang J.R. Hoefer. in Springer proceedings in physics, no. 121. Berlin: Springer, 2008.
- [4] Gregor Dziuk, Entwurf und Aufbau von nicht-kreisförmigen Birdcage-Resonatoren für die X-Kern MRT bei 7 Tesla. Master thesis, (Master Wilng), Fachgebiet Allgemeine und Theoretische Elektrotechnik (ATE), Universität Duisburg-Essen, Jan. 8, 2016.
- [5] L. Xu and K. Huang, “Design of Compact Trapezoidal Bow-Tie Chipless RFID Tag,” International Journal of Antennas and Propagation, vol. 2015, pp. 1–7, 2015, doi: 10.1155/2015/502938.
- [6] M. Martinez and D. Van Der Weide, “Compact slot-based chipless RFID tag,” in 2014 IEEE RFID Technology and Applications Conference (RFID-TA), Tampere, Finland: IEEE, Sep. 2014, pp. 233–236. doi: 10.1109/RFID-TA.2014.6934234.