Electromagnetic Simulation Tools: from Accelerators to Detectors

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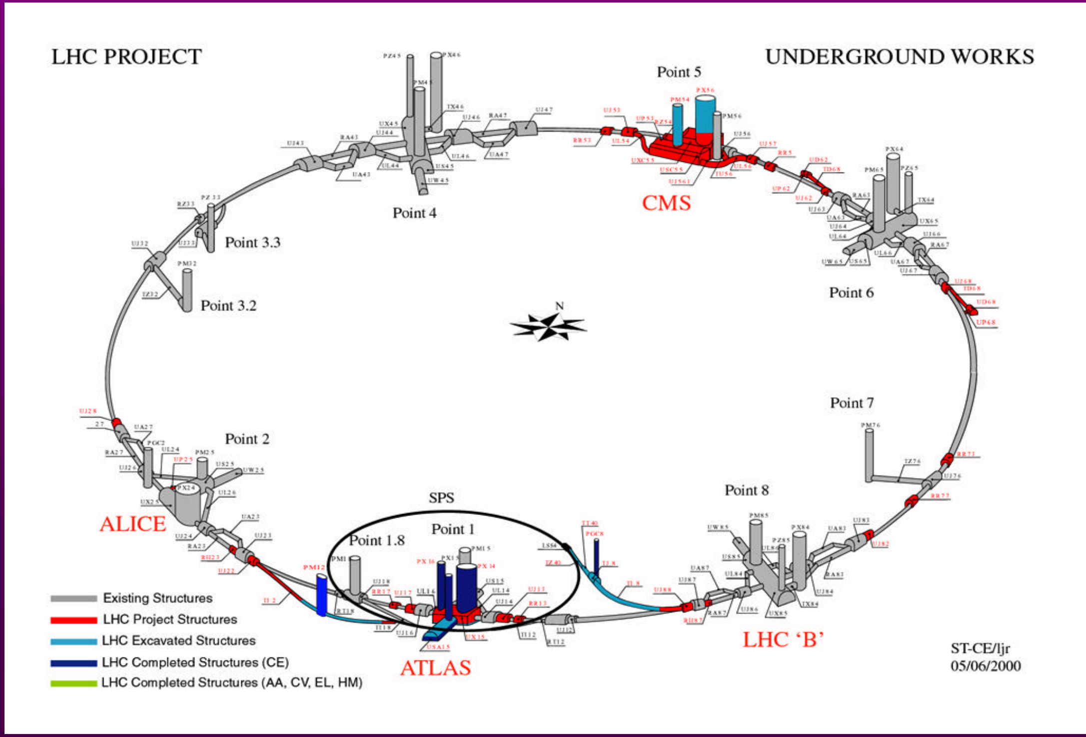
Need for electromagnetic simulation

- CERN is involved with ever more complex systems...
  - Detectors
  - Accelerators
  - Electronics



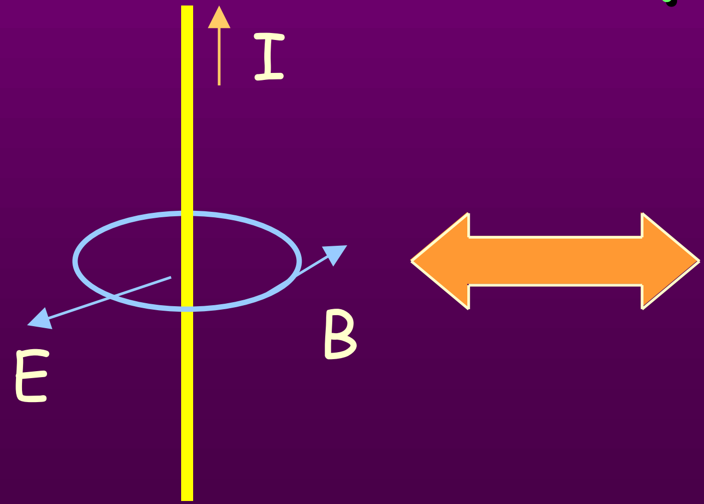
Need for electromagnetic simulation

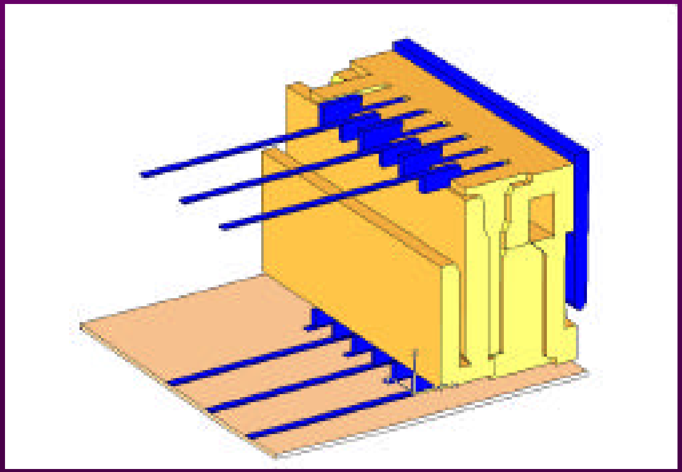
Complex designs

Design time

Arbitrary geometries

Optimization





What is electromagnetic simulation ?

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \cdot \mathbf{D} = \rho$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

Full wave solvers:

solve for any frequency

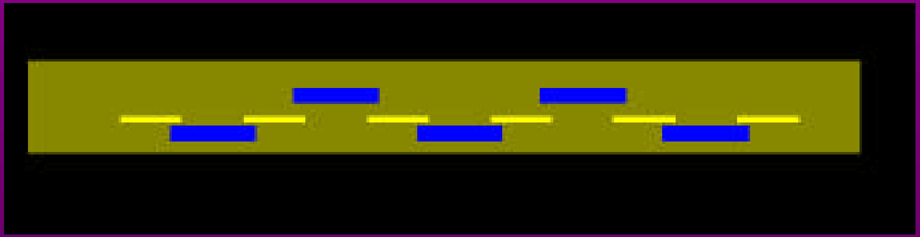
Static solvers: no time dependent variations

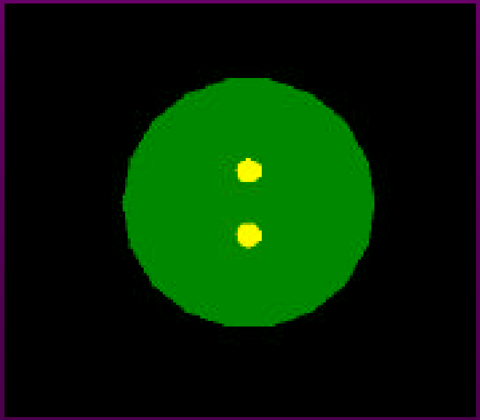
electrostatic & magnetostatic

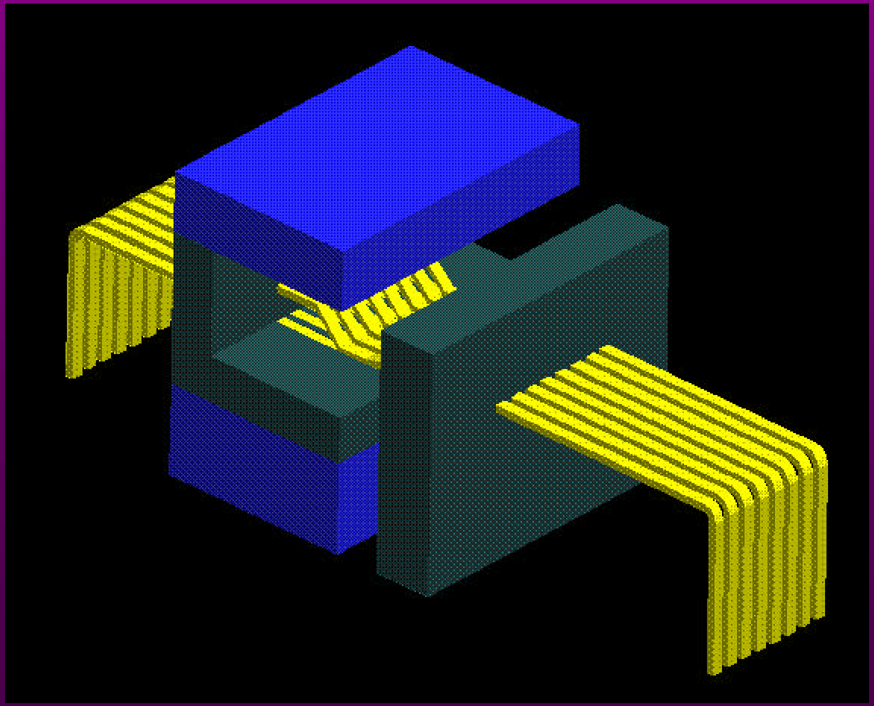
Simulation time

What can we solve ?

- Arbitrary 2D/3D Structures





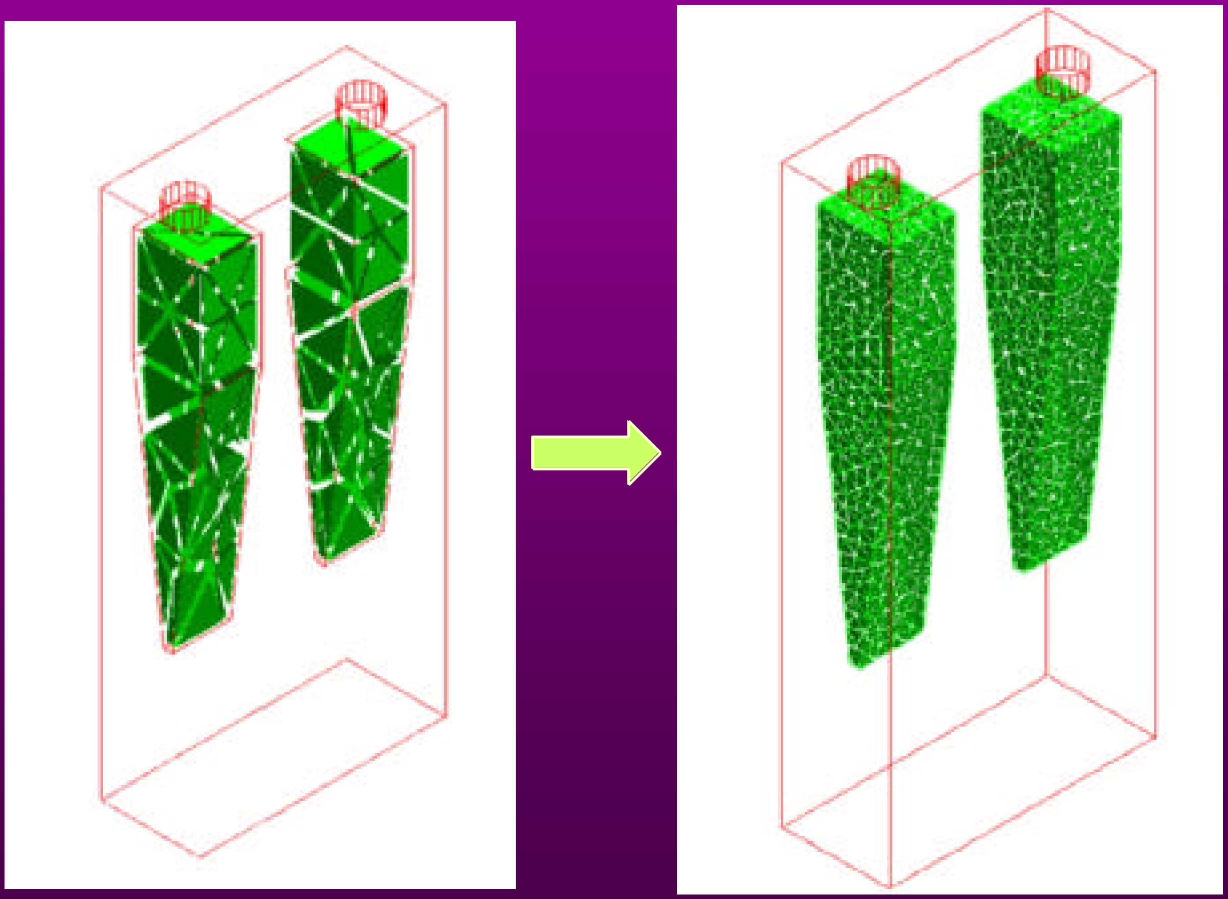


How does it work ?

- Finite Element Methods
  - General method to solve differential equations
  - Breaks the space into elements (mesh)
    - 2D: triangles
    - 3D: tetrahedra
  - Uses a polynomial function to describe the solution inside each element
  - Adaptive mesh refinement: no user intervention

- **Frequency Domain Solvers**

How does it work ?

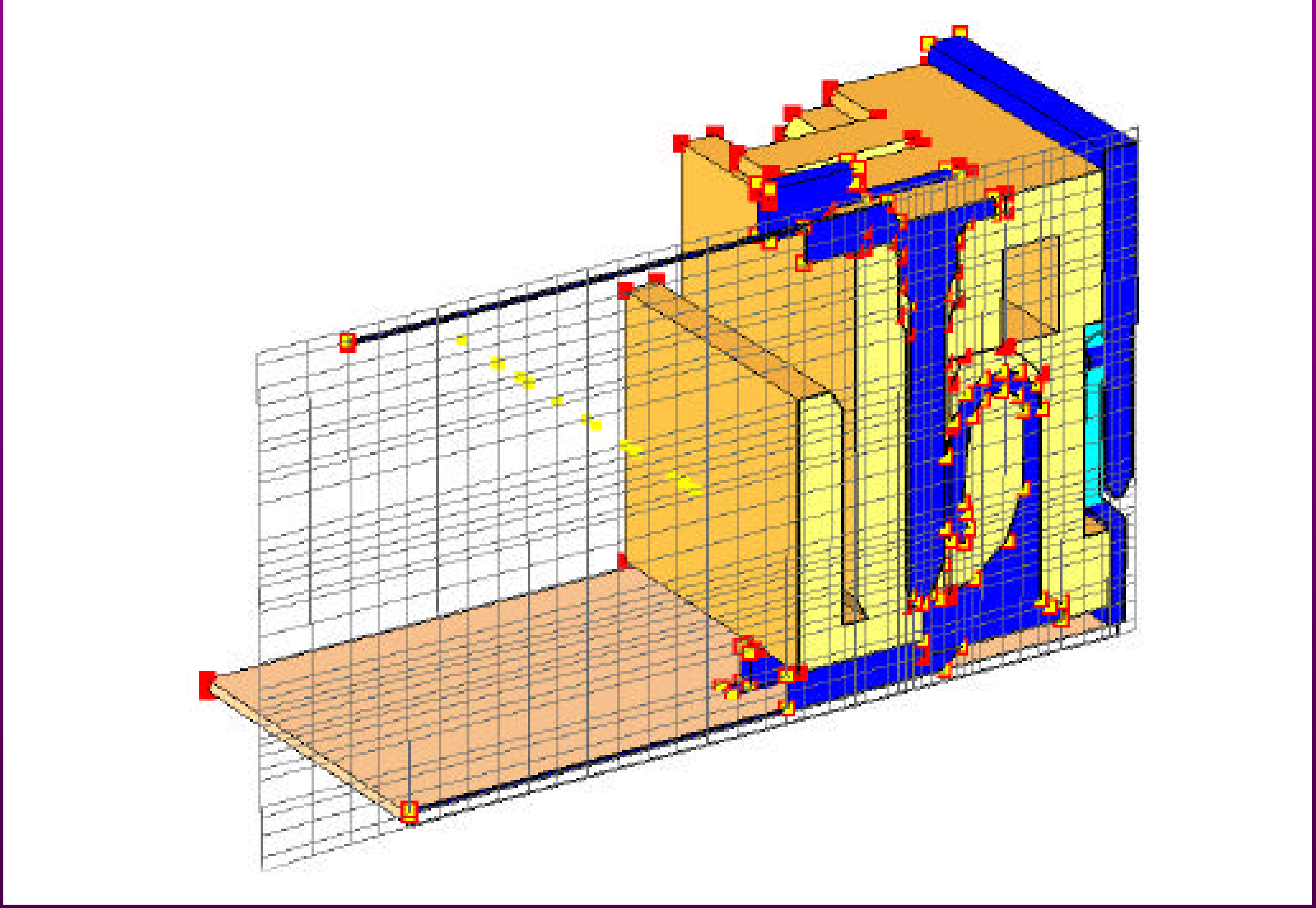


How does it work ?

- Finite Integration - Finite Differences
  - General method to solve differential equations
  - Breaks the space into cubic elements
  - Non adaptive mesh

  - **Time Domain Solvers**

How does it work ?



How do we define a problem ?

Draw the geometric structure

↓

Define materials

↓

Define boundary conditions (and excitations)

↓

Specify frequency ranges

↓

SOLVE

What tools do we have at CERN ?

Maxwell 2D/3D Field Simulator

Maxwell 2D/3D Extractor

HFSS

Microwave Studio

LC

What tools do we have at CERN ?

Detector Design

Maxwell 2D/3D Field Simulator

High Speed Electronics

Maxwell 2D/3D Extractor   Microwave Studio   LC

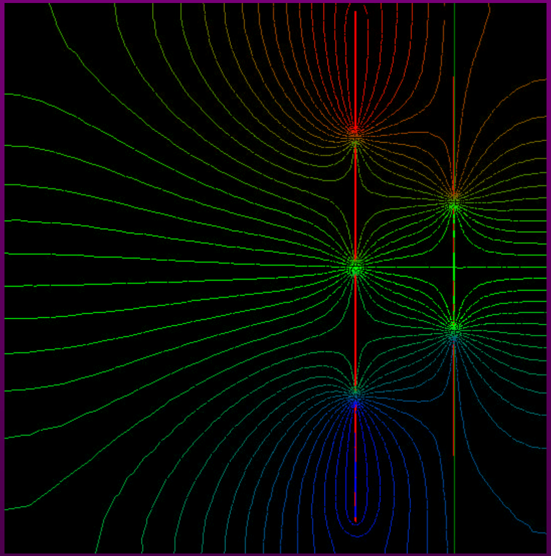
Radio Frequency Engineering

Microwave Studio   HFSS

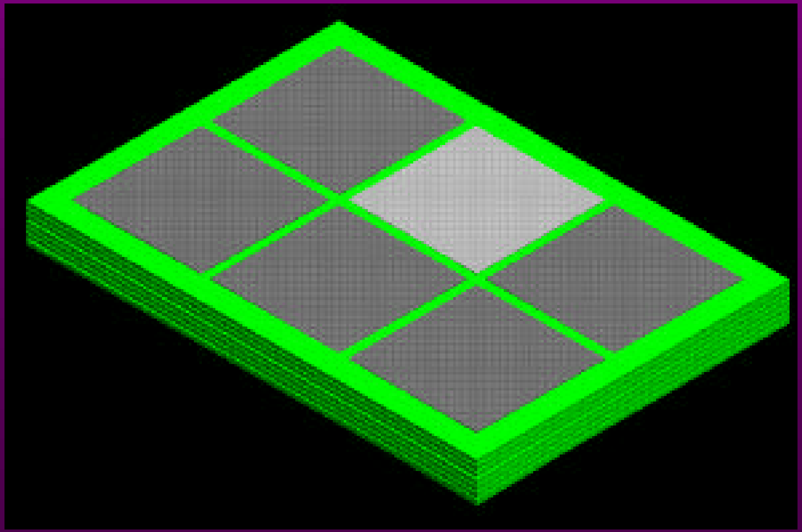
Electric Field maps

Particle drift

Design options



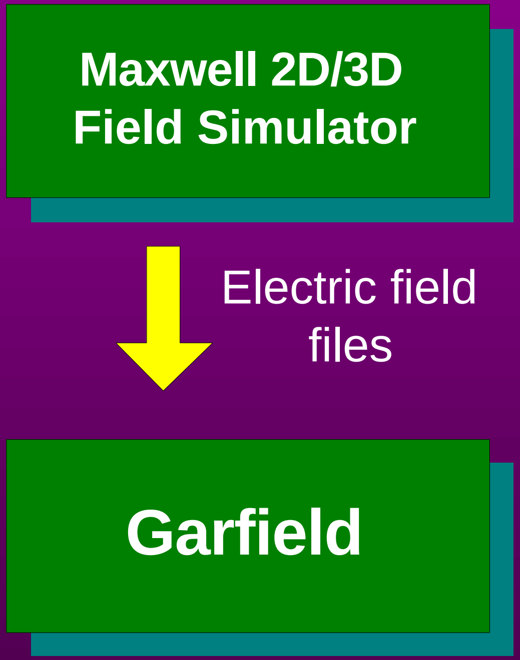
Maxwell 2D Field Simulator



Maxwell 3D Field Simulator

Detector Design

- Maxwell 2D/3D Field Simulators
  - Static solvers (no time dependence)
    - Electrostatic
    - Magnetostatic
  - Computationally 'simple'
  - Interface to Garfield



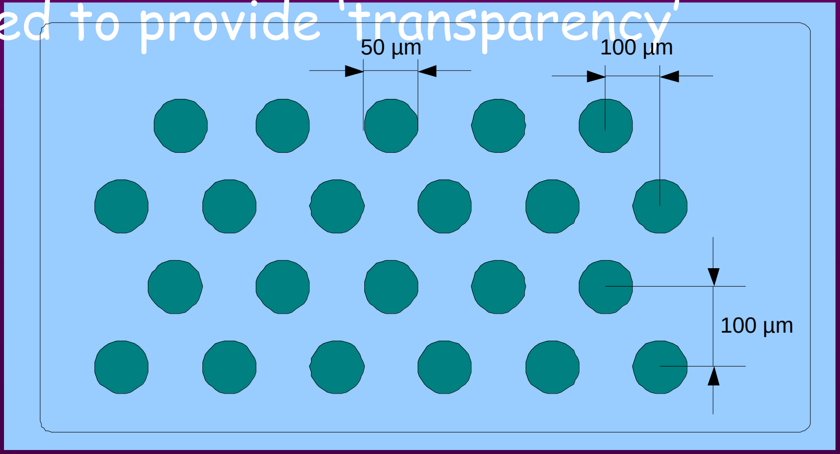
Detector Design Example

- Gas Electron Multiplier (GEM)
  - GEM amplifies electrons released in a gas by ionizing radiation
  - Two metal planes at different potentials create the accelerating field gradient
  - The planes are perforated to provide 'transparency'

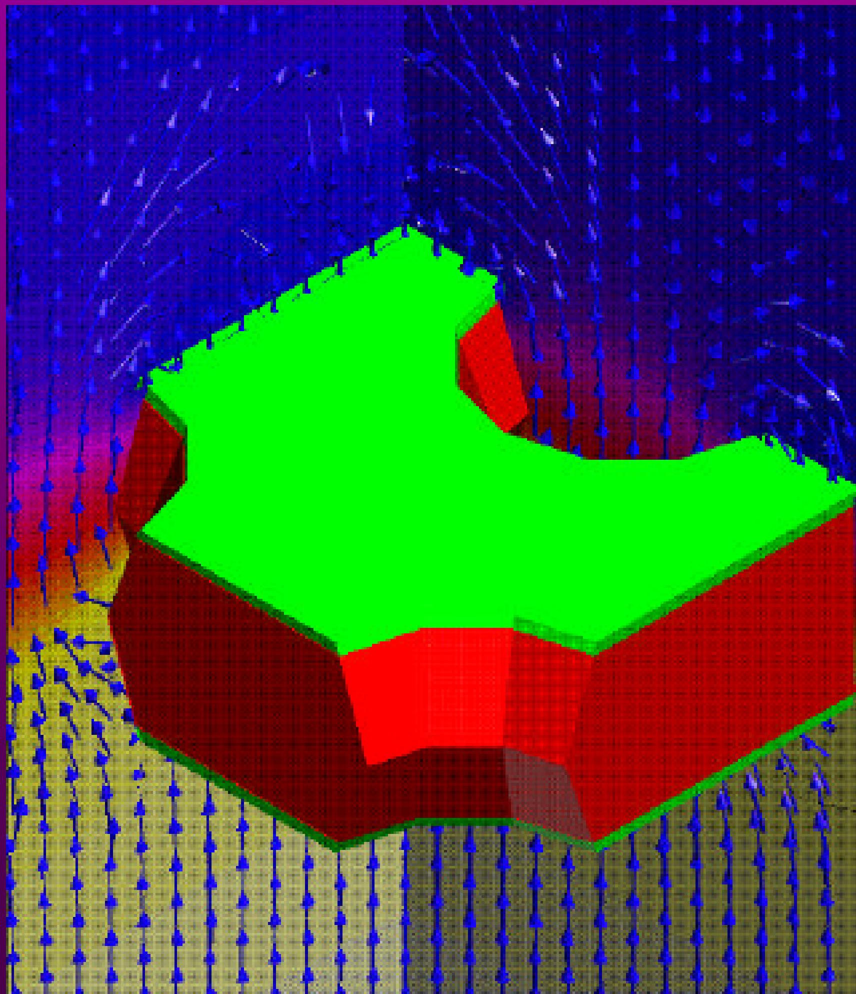
A 3D simulation

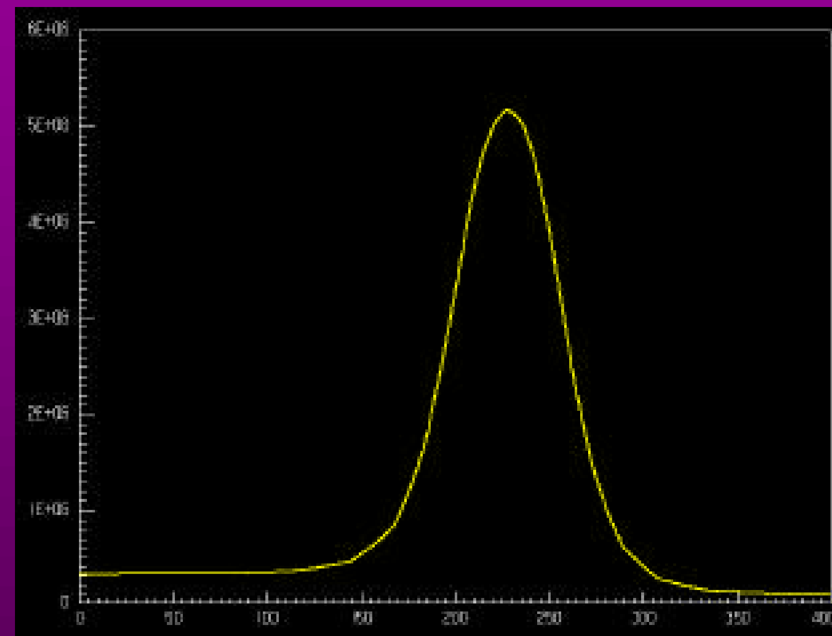
is needed to find

the electric field



Detector Design Example





Electric field magnitude

through the GEM hole

Detector Design Example

A valid model of the GEM was developed in Ansoft's Maxwell 3D Field Simulator !

Complete information: IT Report 1999-05

http://wwwinfo.cern.ch/ce/ae/Maxwell/documents.html

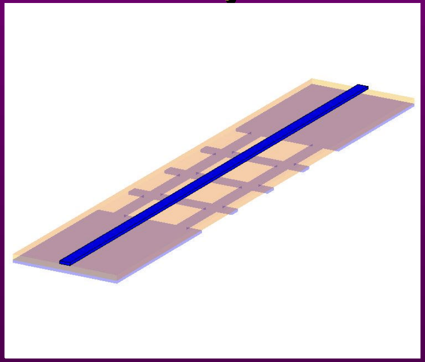
High Speed Electronics

Crosstalk

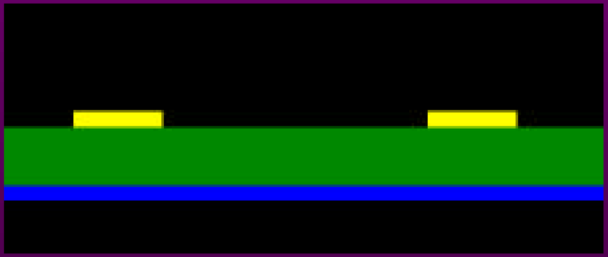
Ground bounce

Impedance mismatch

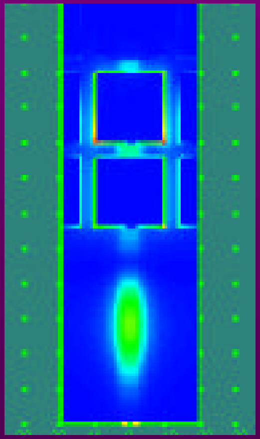
Lossy transmission lines



Microwave Studio



Maxwell 2D Extractor

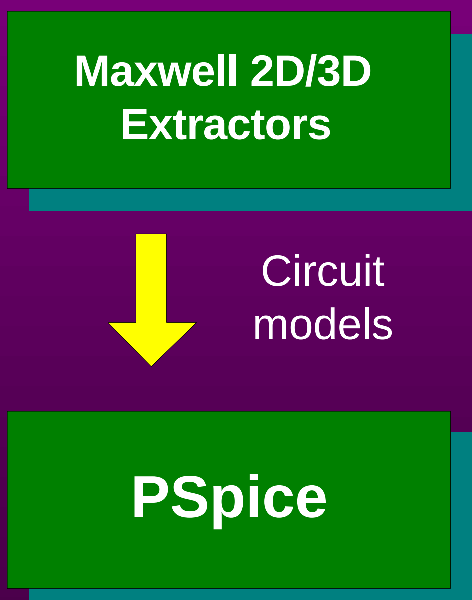


LC

PSpice

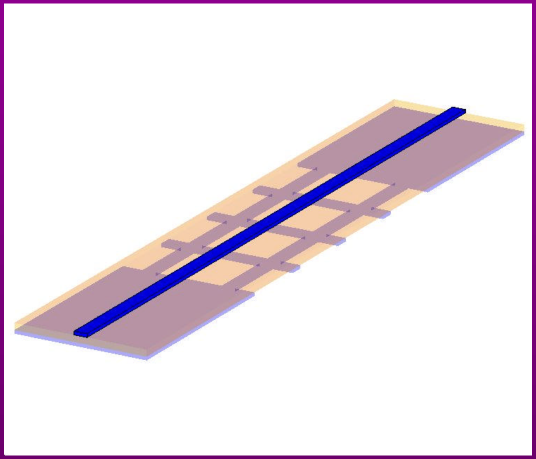
High Speed Electronics

- Mawxell 2D/3D Extractors
  - Create an equivalent model
  - Static solvers: L, C, R
  - The equivalent model is used in PSpice with other circuit components



  - Valid up to λ/10

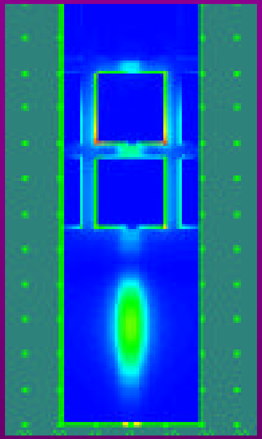
High Speed Electronics



- Microwave Studio
  - Nominally for RF engineering...
  - ...it can be used for digital applications !
  - PC environment and user friendly

  - Full wave solver
  - Time Domain Solver

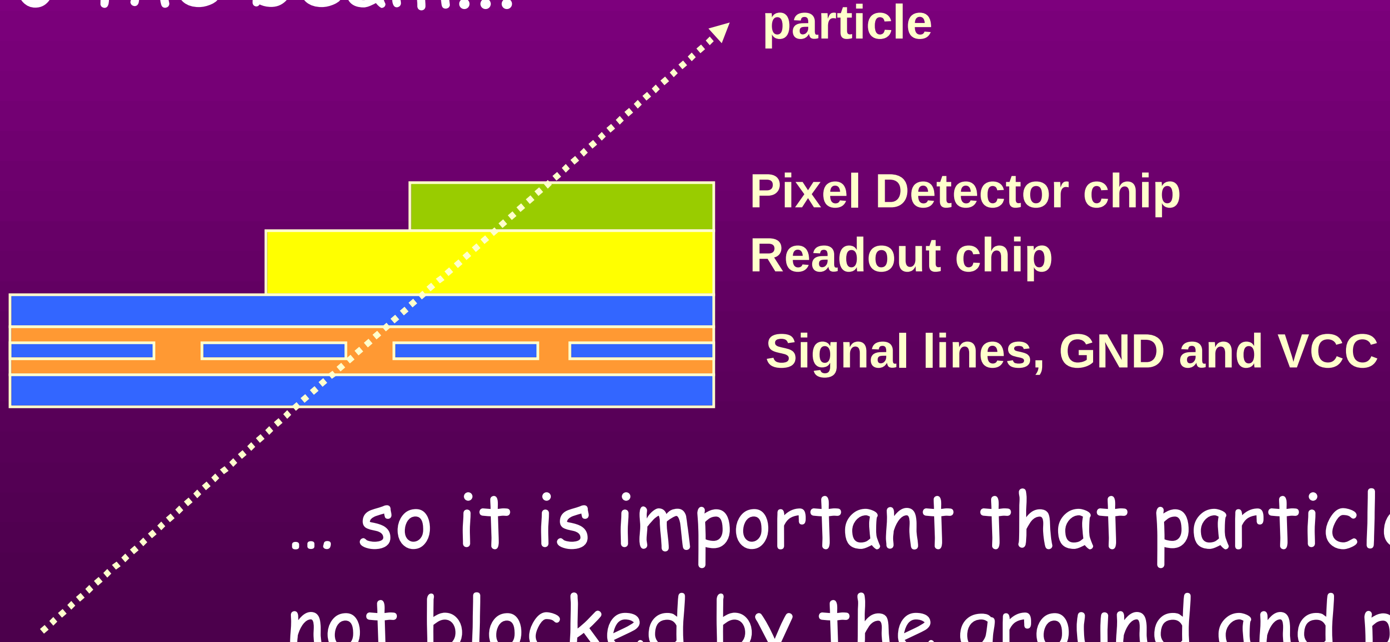
High Speed Electronics



- LC
  - Finite Difference Time Domain
  - Compute E and H   x   t
  - Computationally expensive
    - but now runs in PaRC (512 Mb RAM)
  - Animations of ground plane currents
  - Unlimited licenses

High Speed Electronics Example

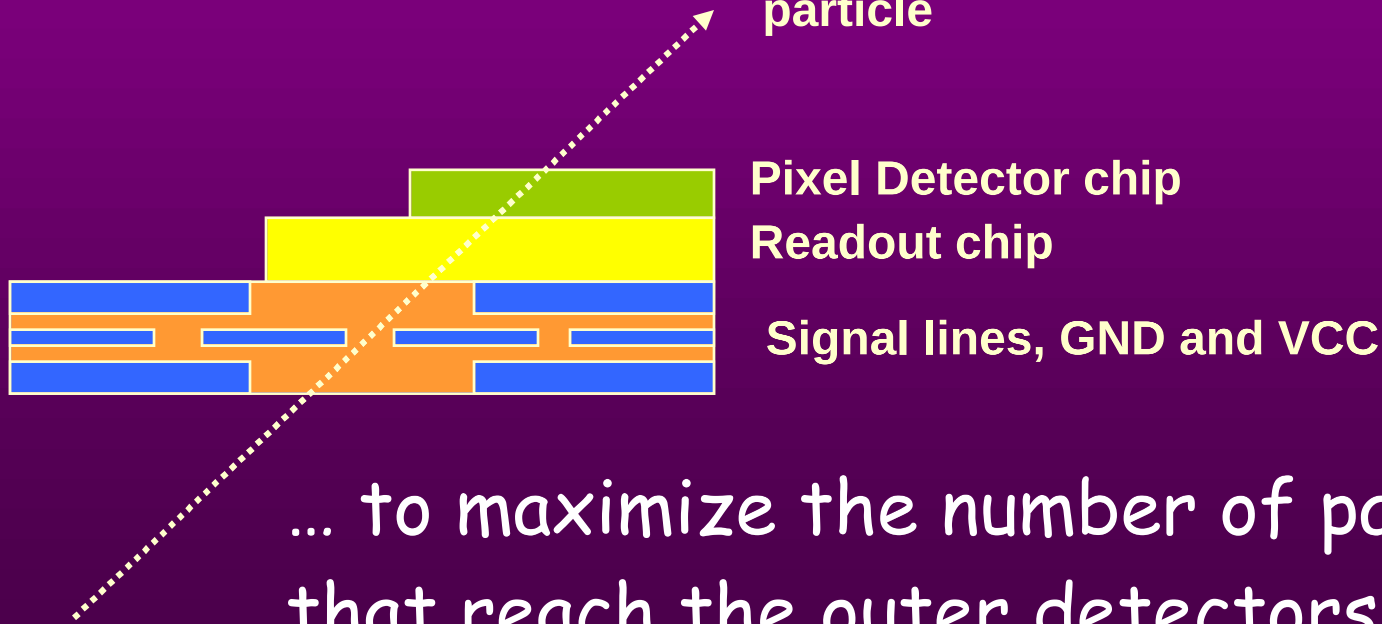
- ALICE Pixel Detector sits very close to the beam…



… so it is important that particles are not blocked by the ground and power metal planes.

High Speed Electronics Example

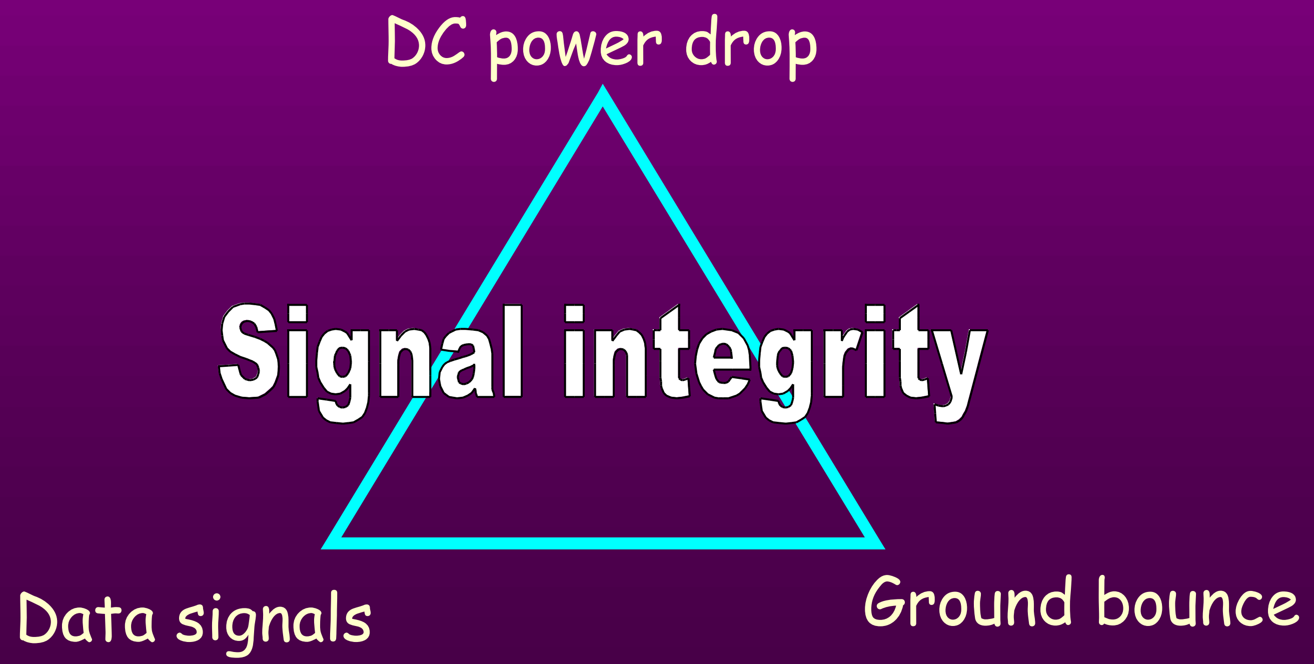
- Could we use a meshed power plane...



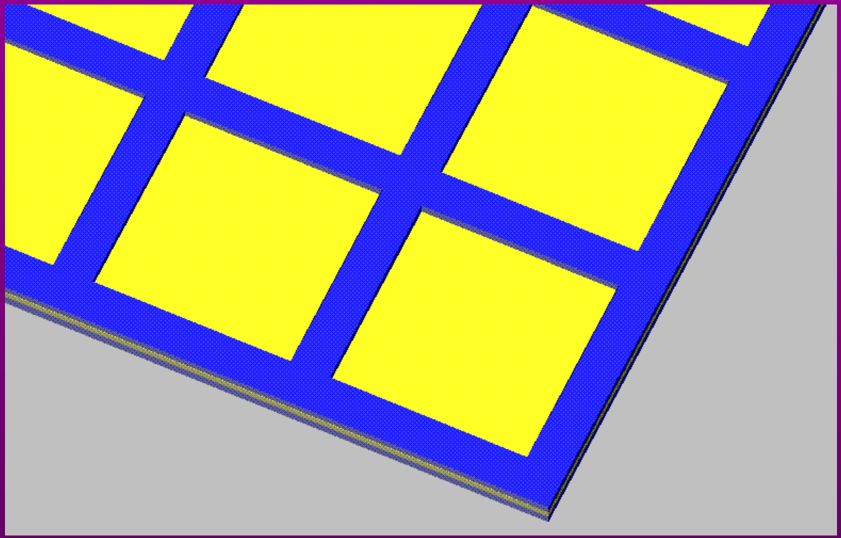
... to maximize the number of particle that reach the outer detectors !

High Speed Electronics Example

- Estimate how a meshed power plane could affect system behaviour:

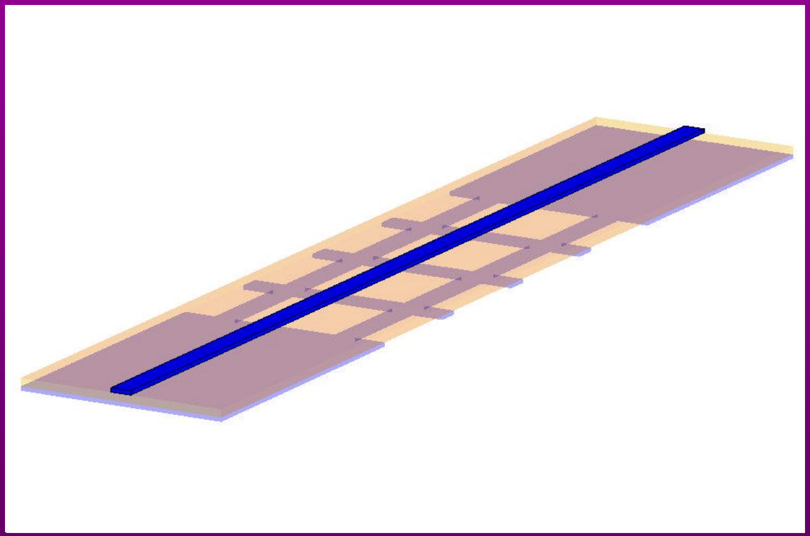


High Speed Electronics Example



Maxwell 3D Extractor

- Resistance
- Plane inductance
- Plane capacitance

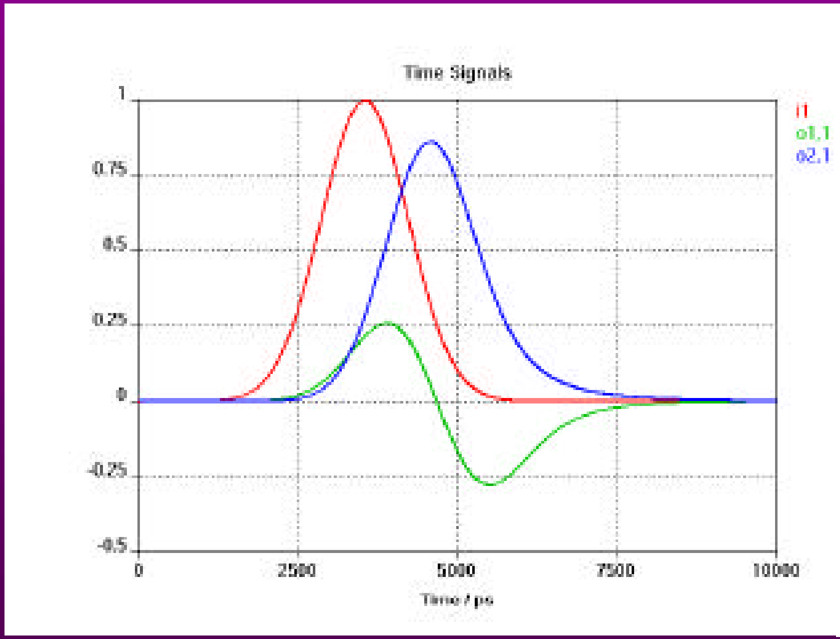


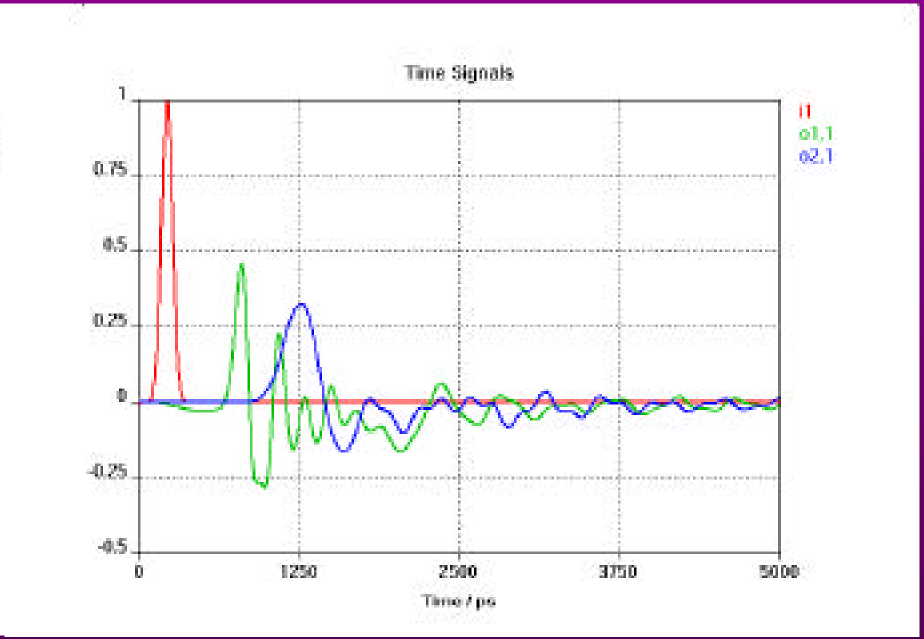
Microwave Studio

- Signal propagation

High Speed Electronics Example

- Is this mesh good enough for signal integrity ?





1 ns ***100 ps***

It depends on the signal rise-time !!

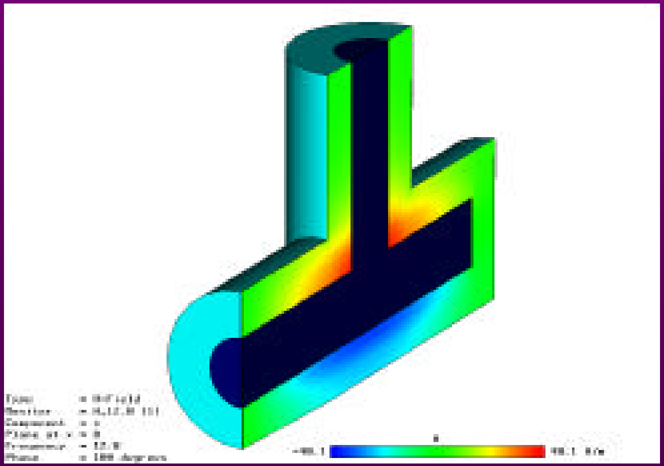
Accelerator Design: RF Engineering

S parameters

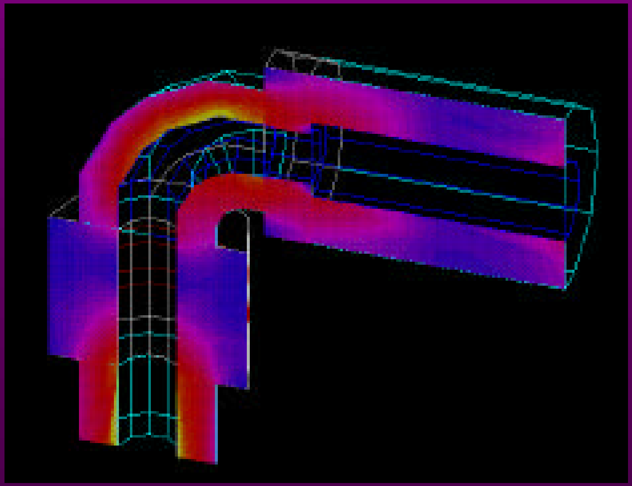
Q factors

Resonant cavities

Radiation

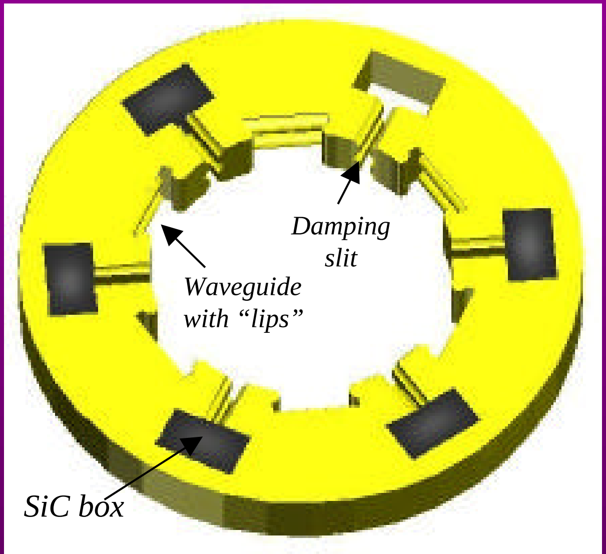


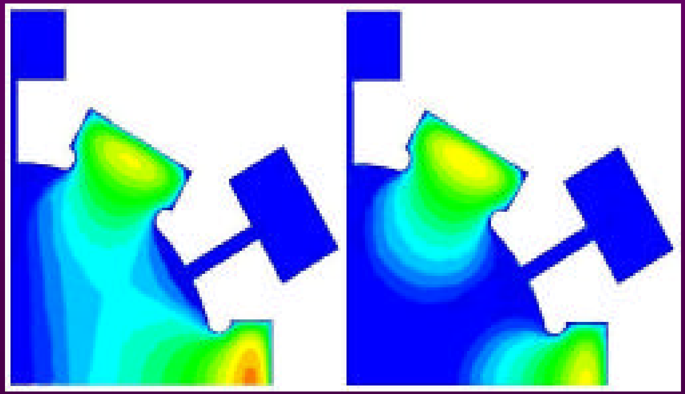
Microwave Studio



HFSS

Accelerator Design: RF Engineering

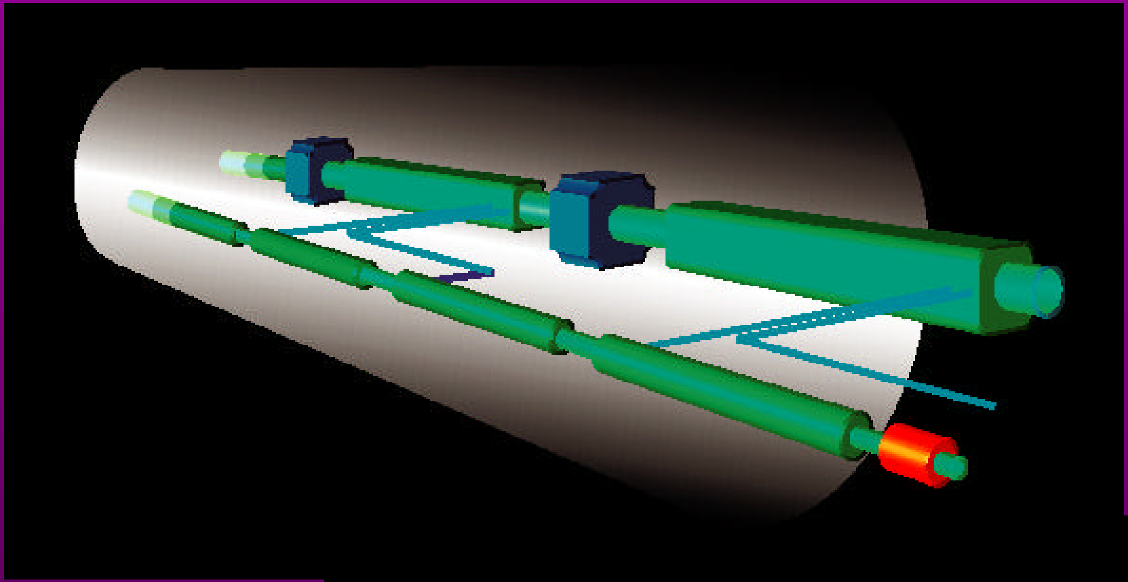




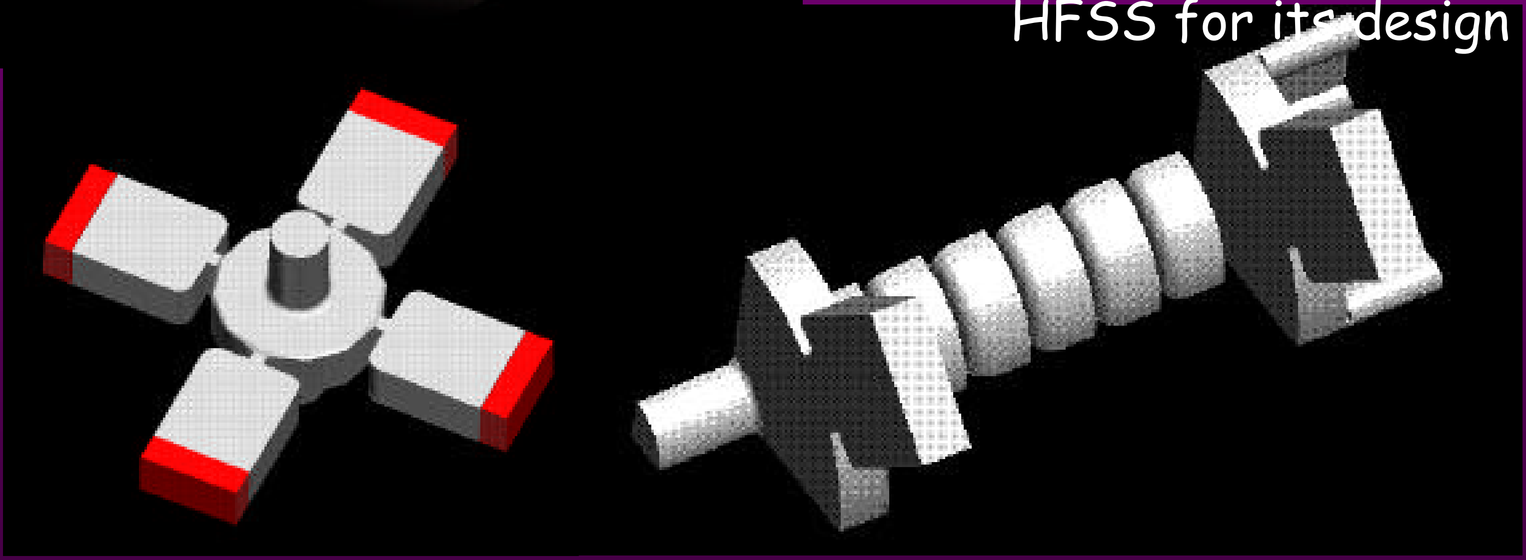
- HFSS
  - High Frequency Structure Simulator
  - Used in the accelerator divisions (PS, SL) to design accelerating systems
  - Powerful solver and post-processor
  - Intensive in computing resources

  - Full wave solver
  - Frequency Domain Solver

RF Engineering Example

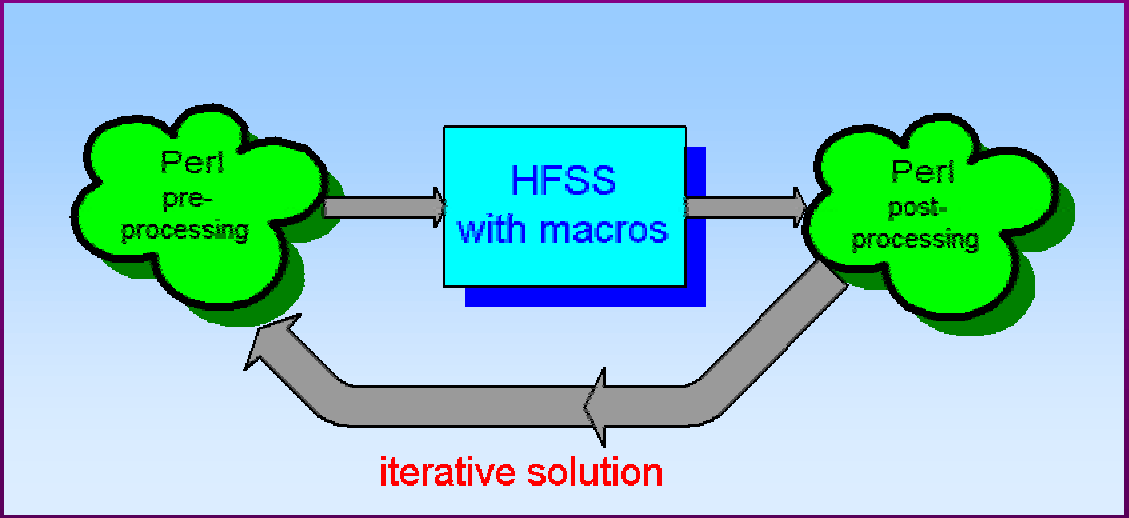


- CLIC
  - Compact Linear Collider
  - PS/RF group making extensive use of HFSS for its design



Interfacing with other tools

- We can use other tools to control HFSS or Maxwell 3D Field Simulator



Multiple simulation runs controlled by scripts

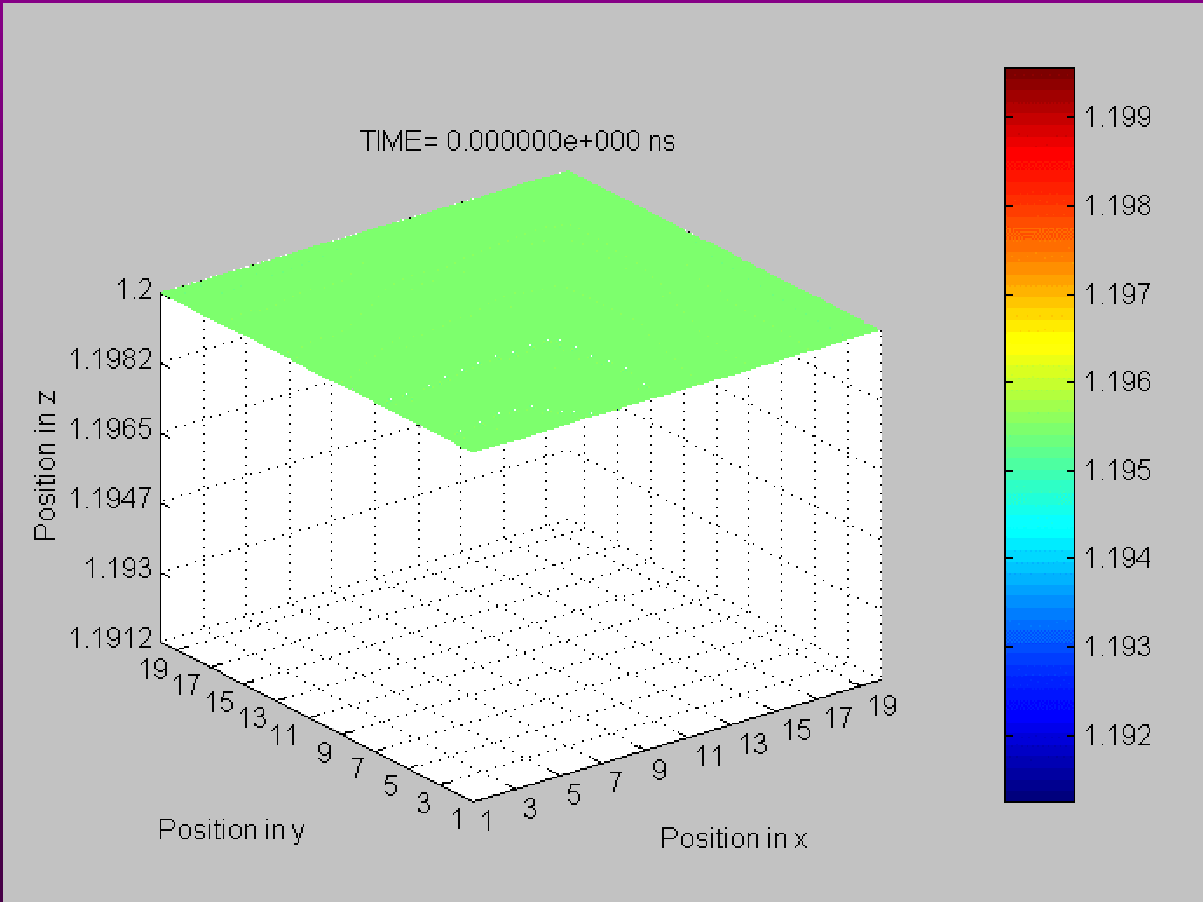
OPTIMIZATION

Interfacing with other tools

- Using Matlab to control PSpice

Matlab: numerical and plot capabilities

PSpice: circuit solving



Conclusions

- Electromagnetic simulation is crucial in today's design processes
- Different EDA tools for electromagnetic and signal integrity can help to design high-end systems
- They can be applied to many different problems: from accelerator to detectors.
- These tools are readily available at CERN and fully supported by IT/CE-AE

http://wwwinfo.cern.ch/ce/ae/Maxwell/Maxwell.html