Simulation packages and Review of Codes

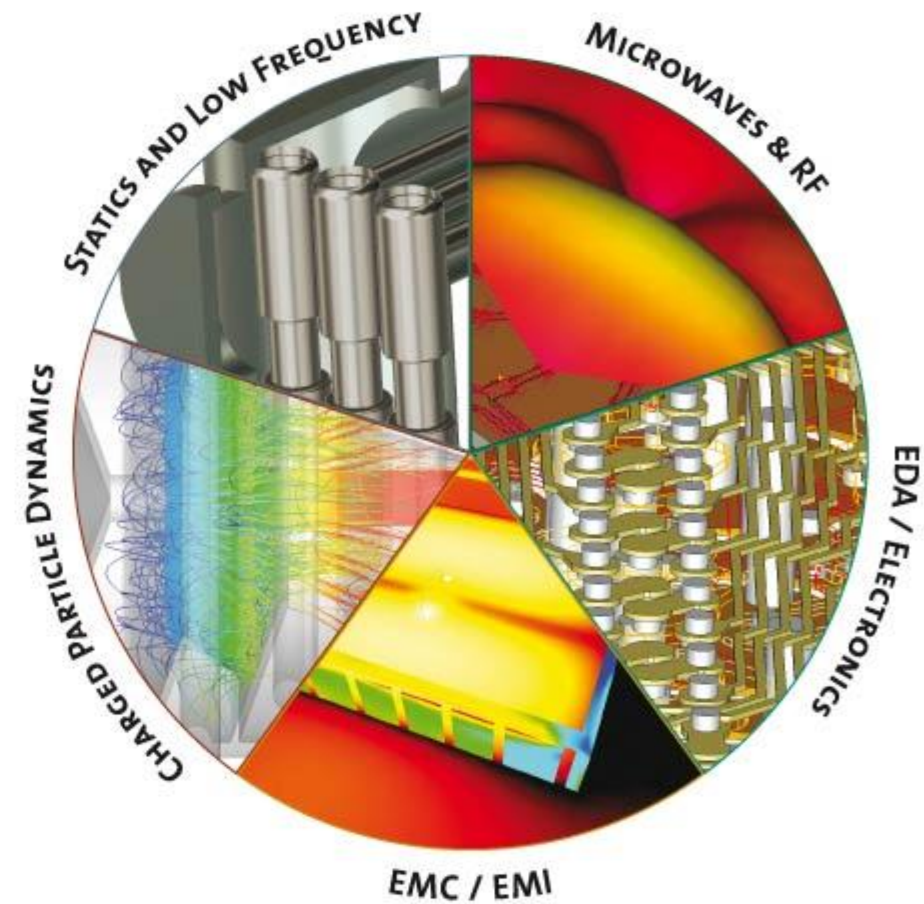
Alexej Grudiev

CERN, BE-RF

Packages for computer simulations of electromagnetic EM fields and more

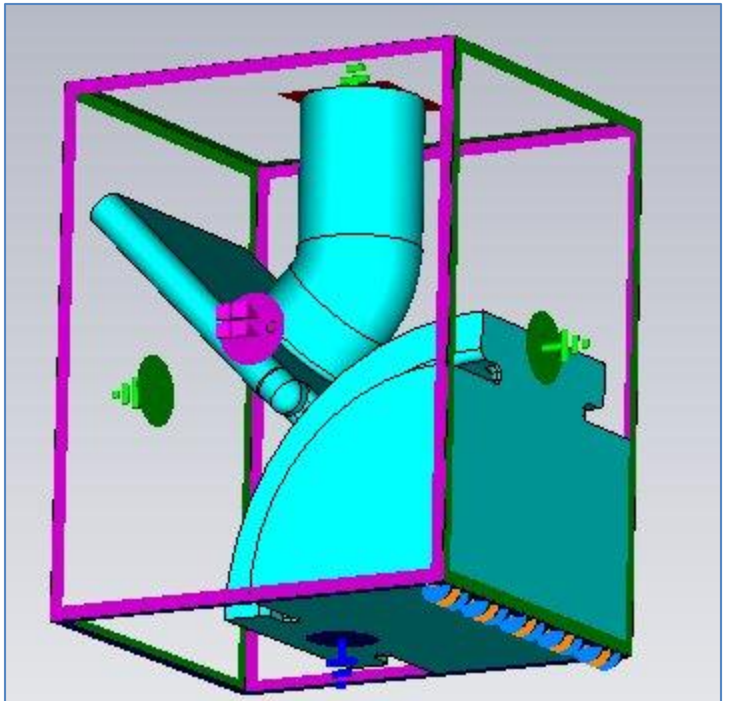
CST Studio Suite

CST STUDIO SUITE:
- **CST MWS**
- CST DS
- CST EMS
- **CST PS**
- CST MPS
- CST PCBS
- CST CS
- CST MICROSTRIPES
- Antenna Magus



CST: All(?) you need in one package

- •Powerful and user-friendly Input:
- •Probably the best time domain (TD) solver for wakefields or beam coupling impedance calculations (MAFIA)
    - •Beta < 1
    - •Finite Conductivity walls
- •Once geometry input is done it can be used both for TD and FD simulations
- •Moreover using Design Studio (DS) it can be combined with the other studios for multiphysics and integrated electronincs simulation, but this is relatively fresh fields of expertise for CST
- •Accelerator physics oriented post processor, especially in MWS and PS
- •Enormous progress over the last few years compared to the competitors.

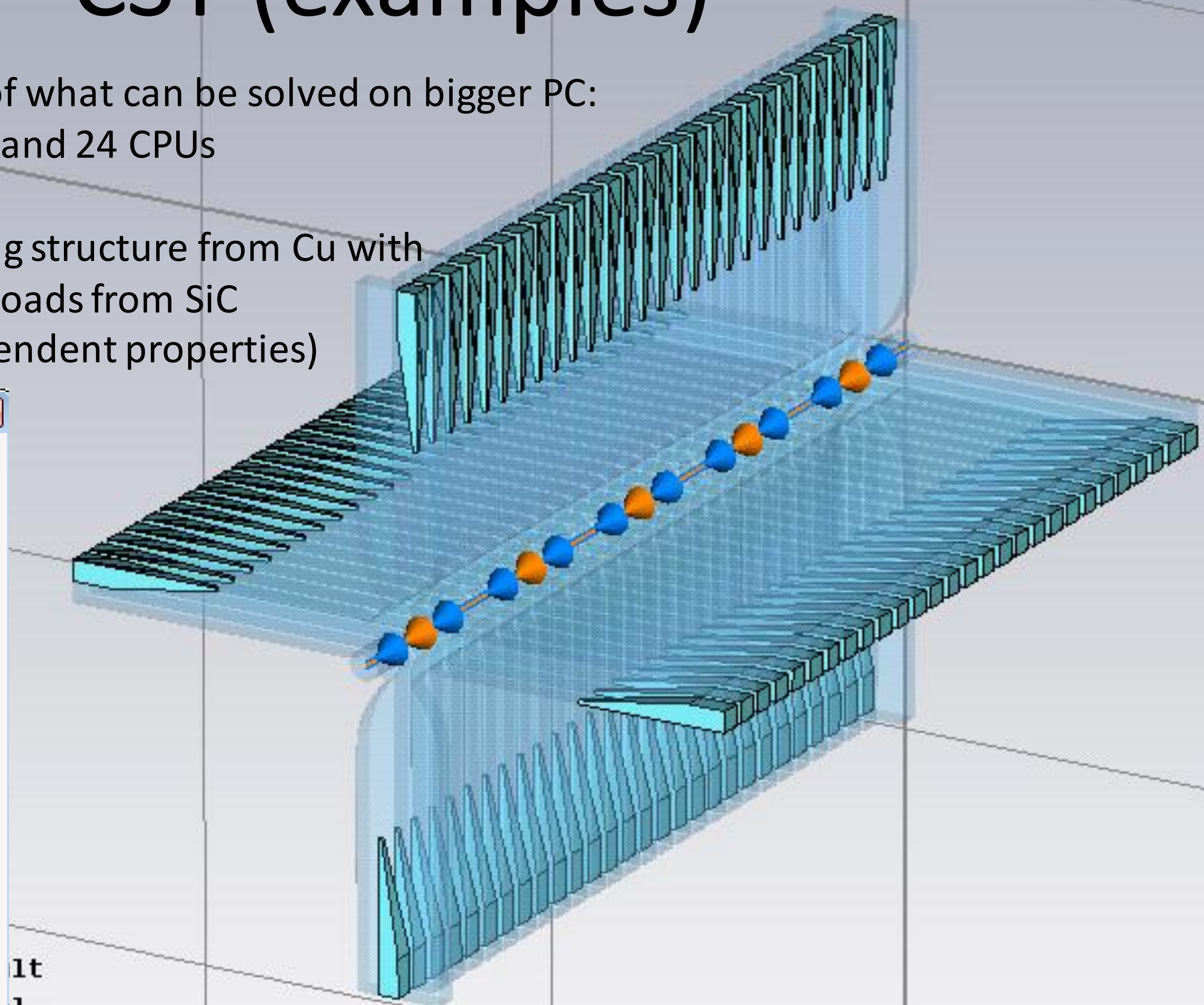

Courtesy of Igor Syratchev

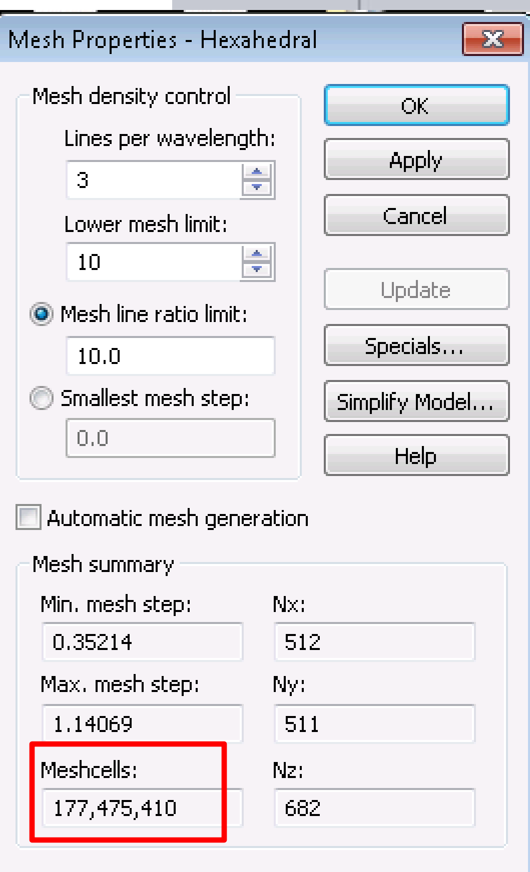
An example of what can be solved easily on a standard PC

CST (examples)

Two examples of what can be solved on bigger PC:
128 GB of RAM and 24 CPUs

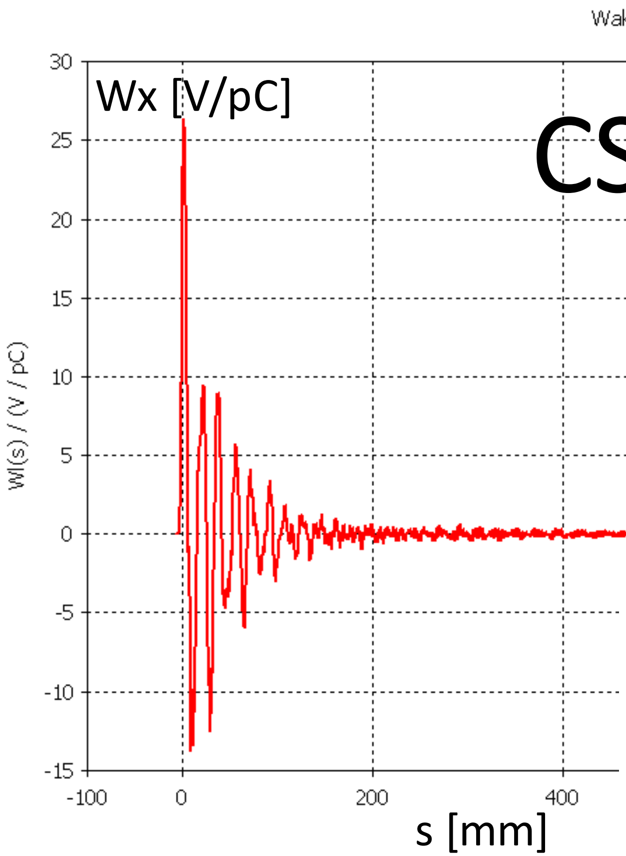
CLIC accelerating structure from Cu with
HOM damping loads from SiC
(frequency dependent properties)



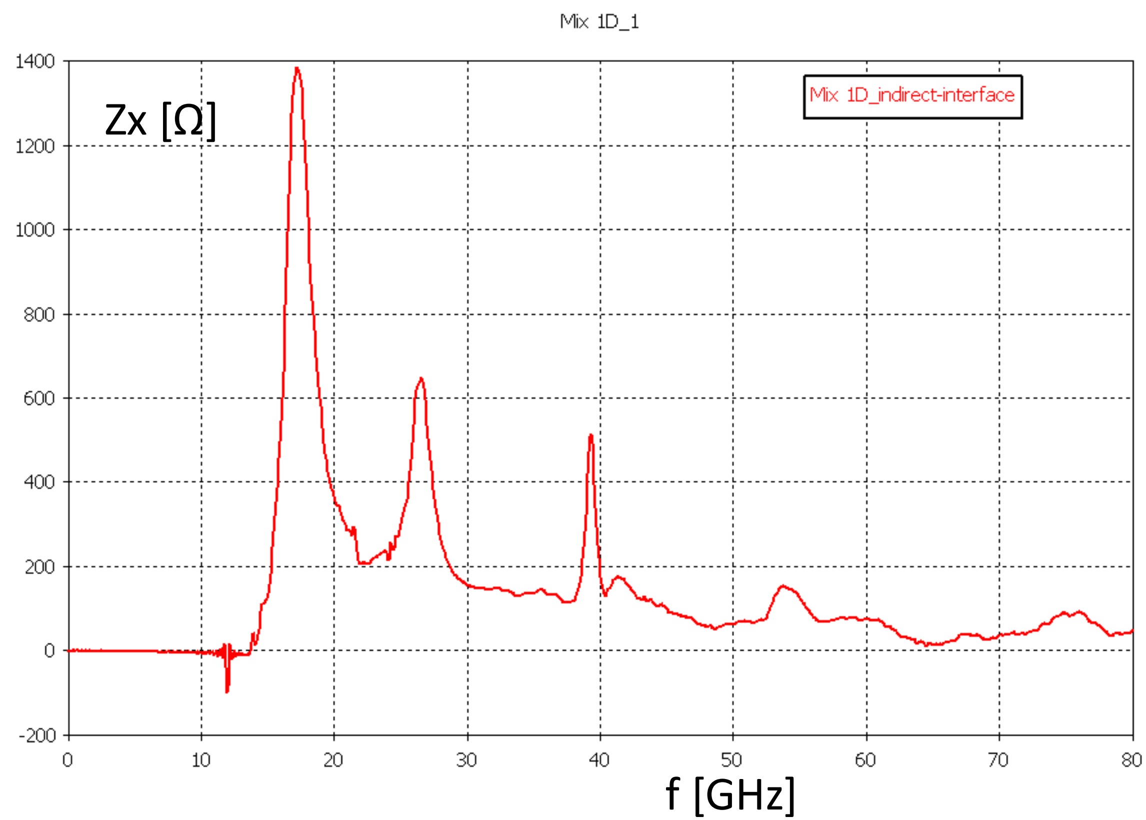


Giovanni De Michele

CST (examples)



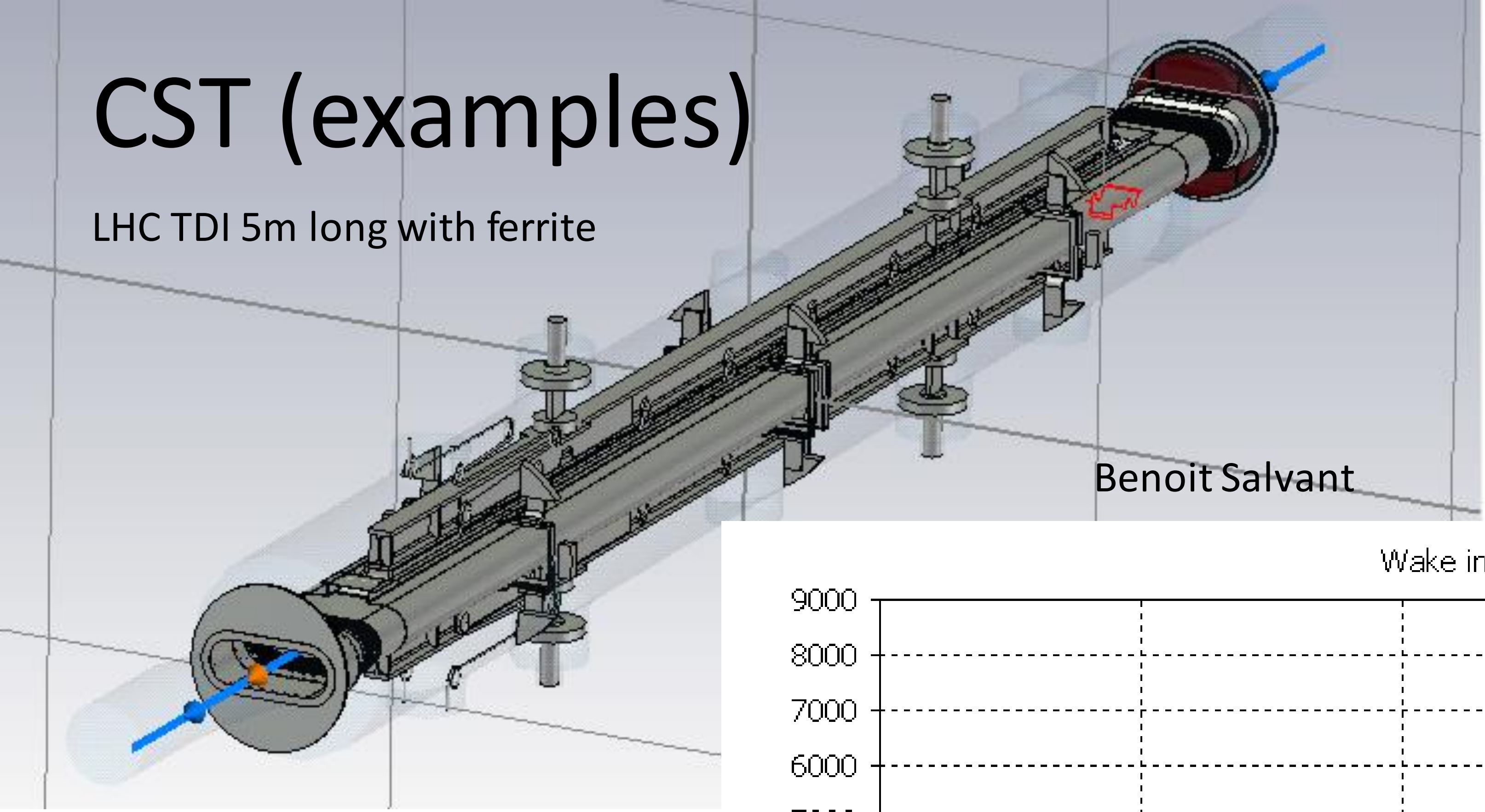
Transverse wake at offset of 0.5 mm



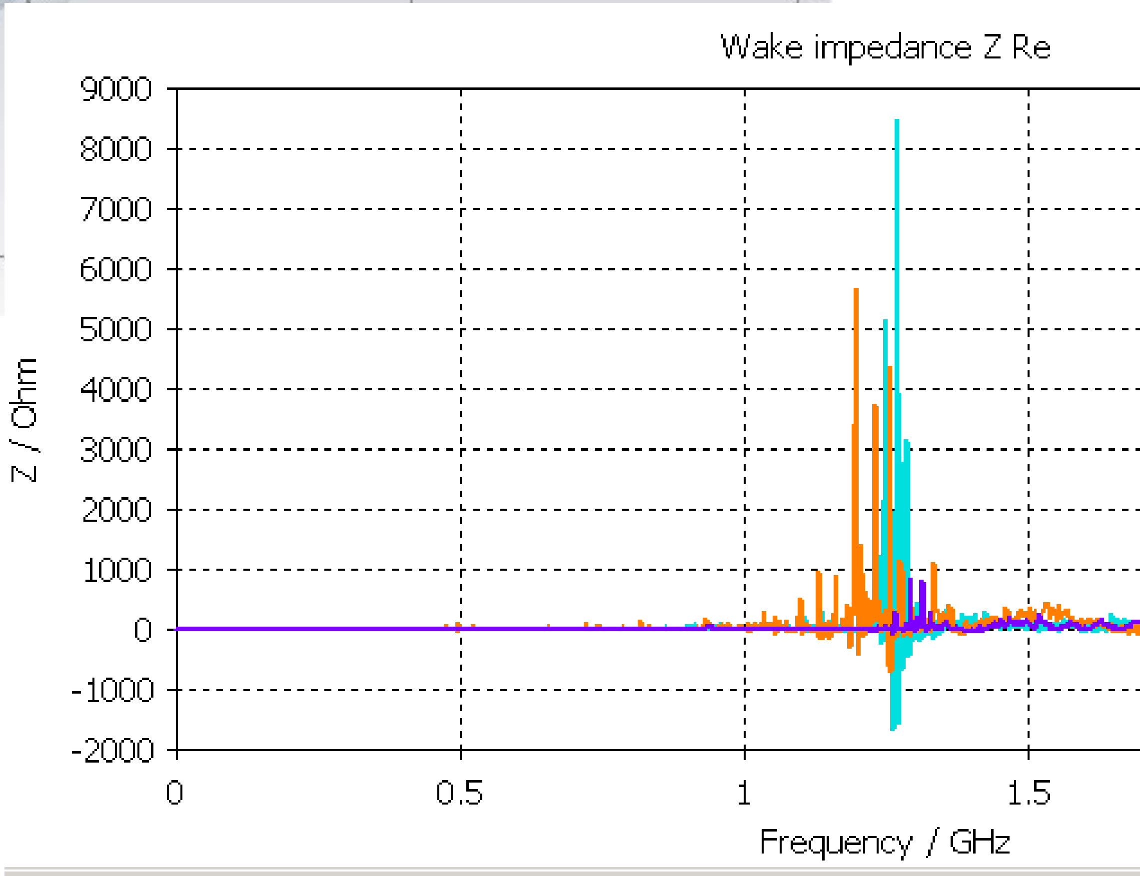
Transverse beam couping impedance at offset of 0.5 mm

CST (examples)

LHC TDI 5m long with ferrite



Benoit Salvant

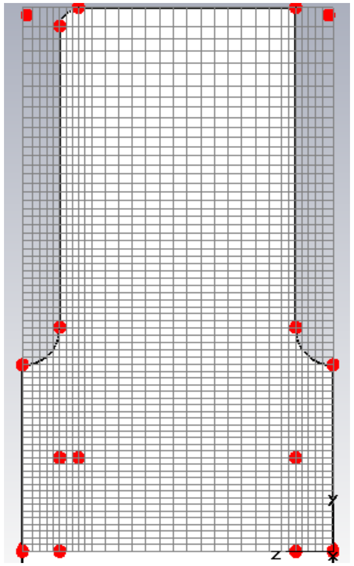


CST MWS: Comparison with HFSS

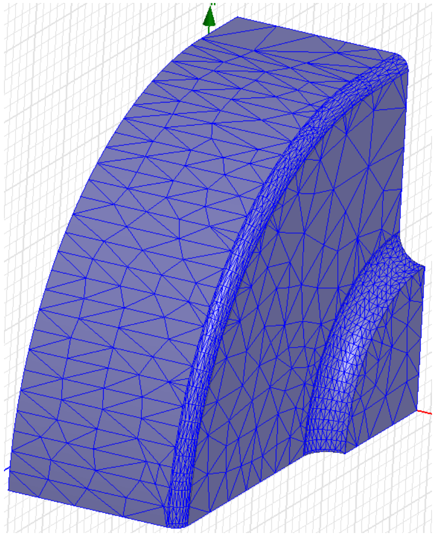
(Praveen Ambattu, Vasim F. Khan)

Property	MWS (PEC)	HFSS (Cu)
Freq, GHz	11.9941	11.9959
Q_{Cu}	6395	6106
R_t/Q, Ohm	54.65	53.78
E_{surf}/E_t	3.43	3.28
H_{surf}/E_t	0.0114	0.0106

Mesh view



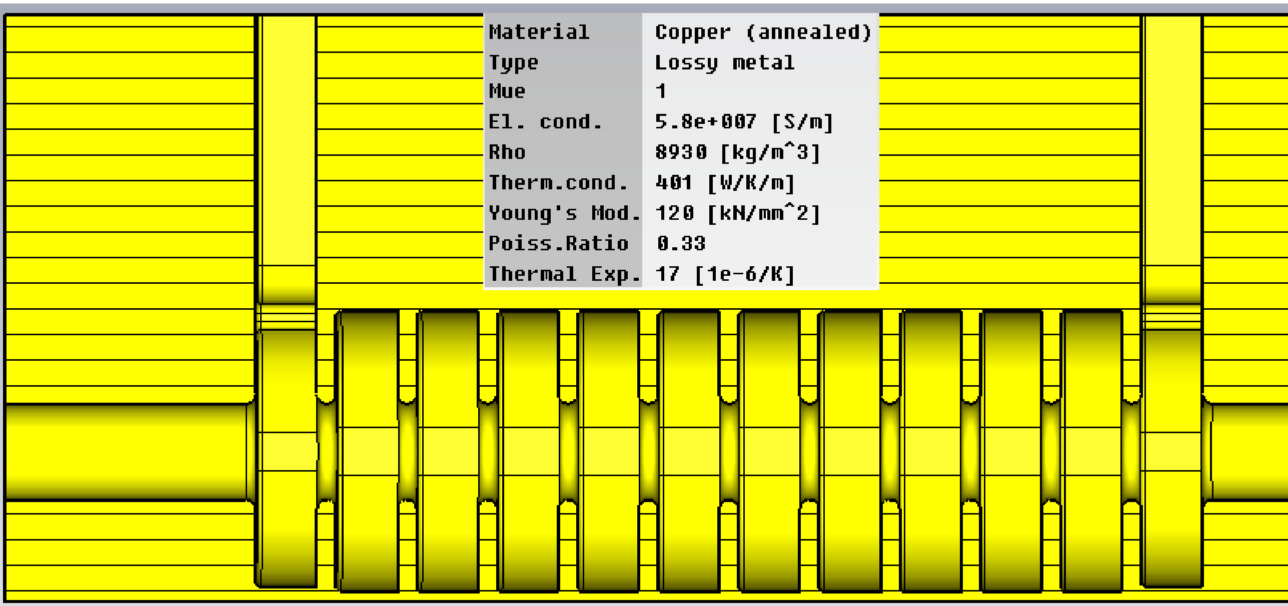
MWS

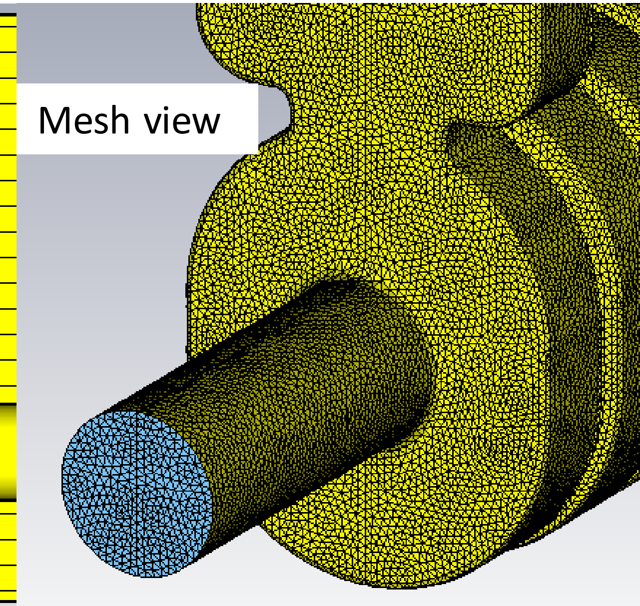


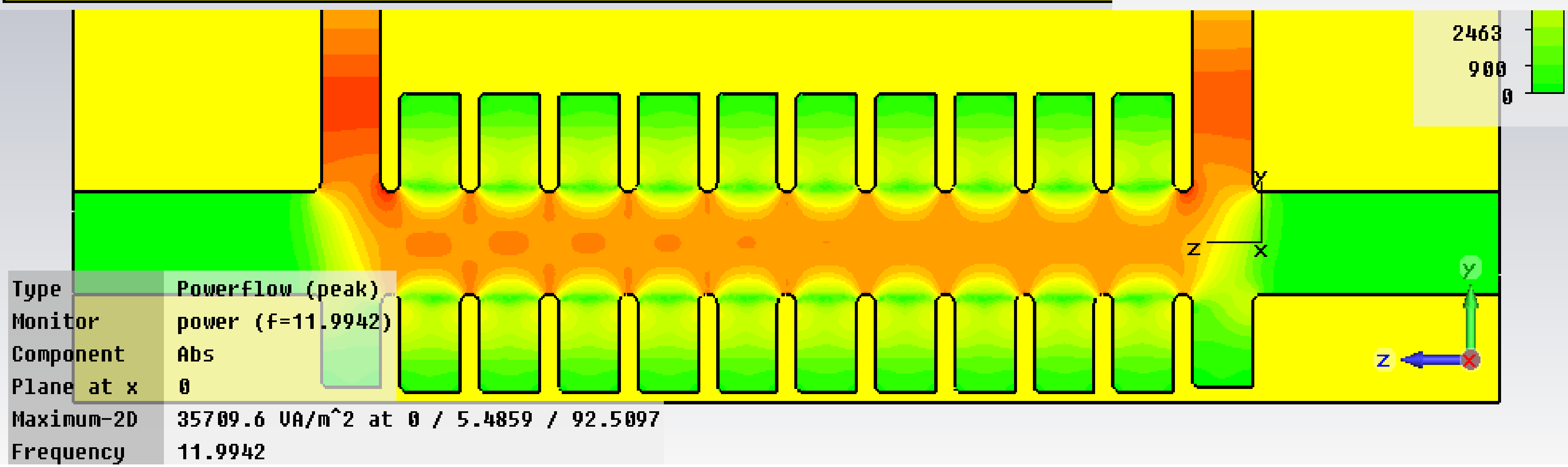
HFSS

- MWS used Perfect Boundary Approximation, 134,912 hexahedra per quarter (lines/lamda=40, lower mesh limit=40, mesh line ratio limit=40)
- HFSS used 8,223 tetrahedra per quarter (surface approximation= 5μm, aspect ratio=5)

CST MWS: Example. S-parameters in CLIC Crab cavity







(Praveen Ambattu)

CST: Shortcomings

1. **Cartesian mesh**: Especially in FD can results to less accurate calculations of **frequency, Q-factor, surface fields** compared to tetrahedral mesh (HFSS, COMSOL, ACE3P). Tetrahedral mesh became available only recently but it is improving very rapidly.
2. Boundary conditions can be set only in Cartesian planes
3. No Field Calculator (HFSS)
4. From three eigenmode solvers only one takes into account losses but it is iterative and very slow
5. ...

With a great help of Andrei Lunin

HFSS: Still an excellent tool for FD

High-Performance Electronic Design

- Ansoft Designer
- **ANSYS HFSS**
- ANSYS Q3D Extractor
- ANSYS SIwave
- ANSYS TPA

Electromechanical Design

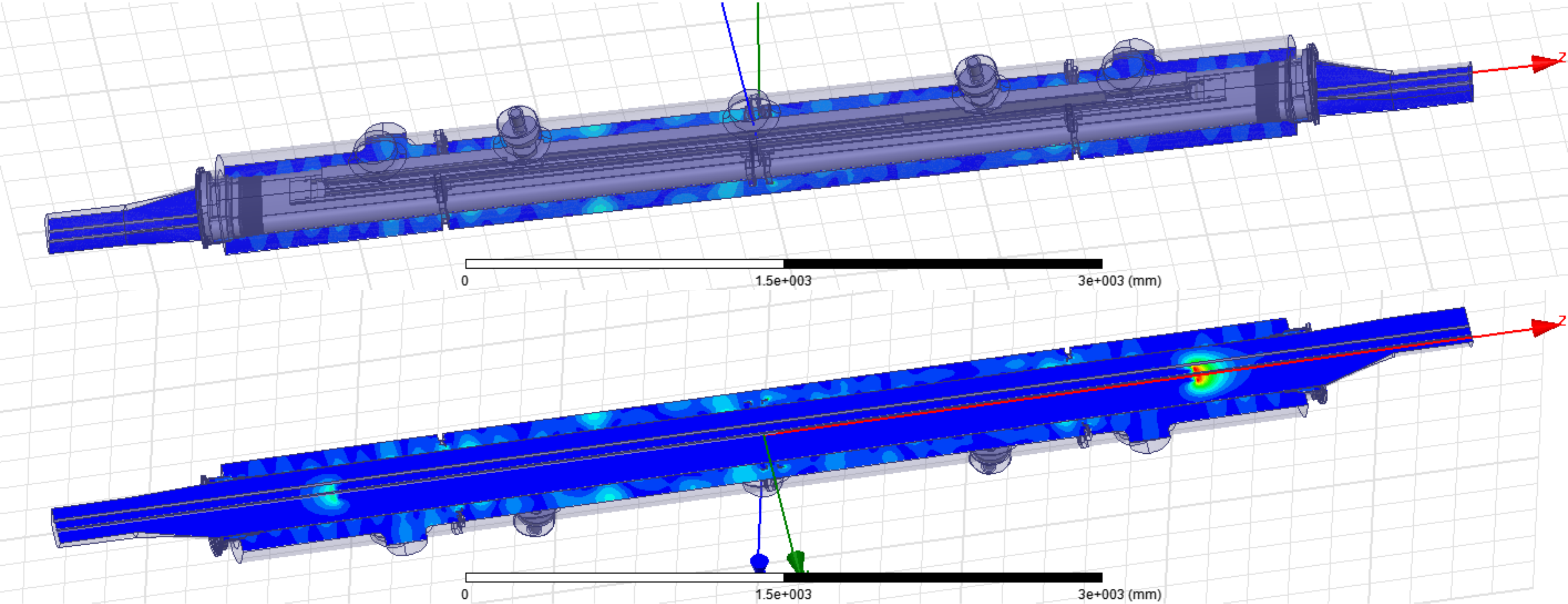
- ANSYS Multiphysics
- ANSYS Maxwell
- ANSYS Simplorer
- ANSYS PExprt
- ANSYS RMxprt

Product options

- AnsoftLinks for ECAD
- AnsoftLinks for MCAD
- ANSYS Distributed Solve
- ANSYS Full-Wave SPICE
- ANSYS Optimetrics
- ANSYS ParICs

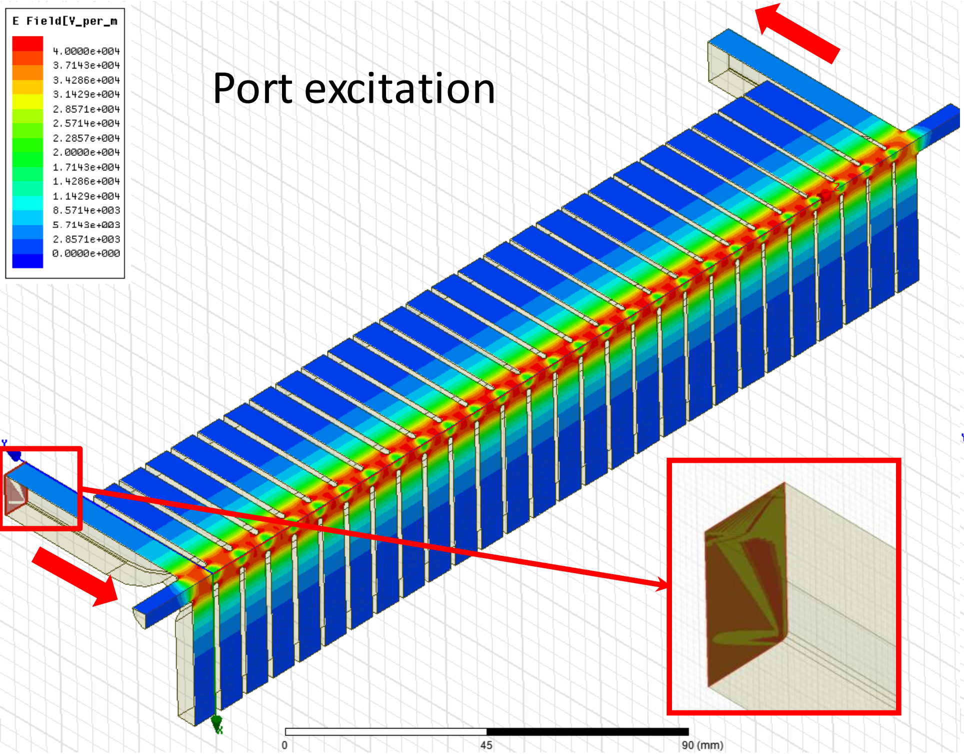
- HFSS was and I think still is superior tool for FD simulations both S-pars and eigenmode, though CST shows significant progress in the recent years
- Automatic generation and refinement of tetrahedral mesh
- Most complete list of boundary conditions which can be applied on any surface
- Ansoft Designer allows to co-simulate the pick-up (antenna), cables plus electronics and together with versatile Optimetrics optimise the design of the whole device
- Last year HFSS become a integral part of ANSYS – reference tool for thermo-mechanical simulations -> multiphysics
- Last year time-dependent solver has been released

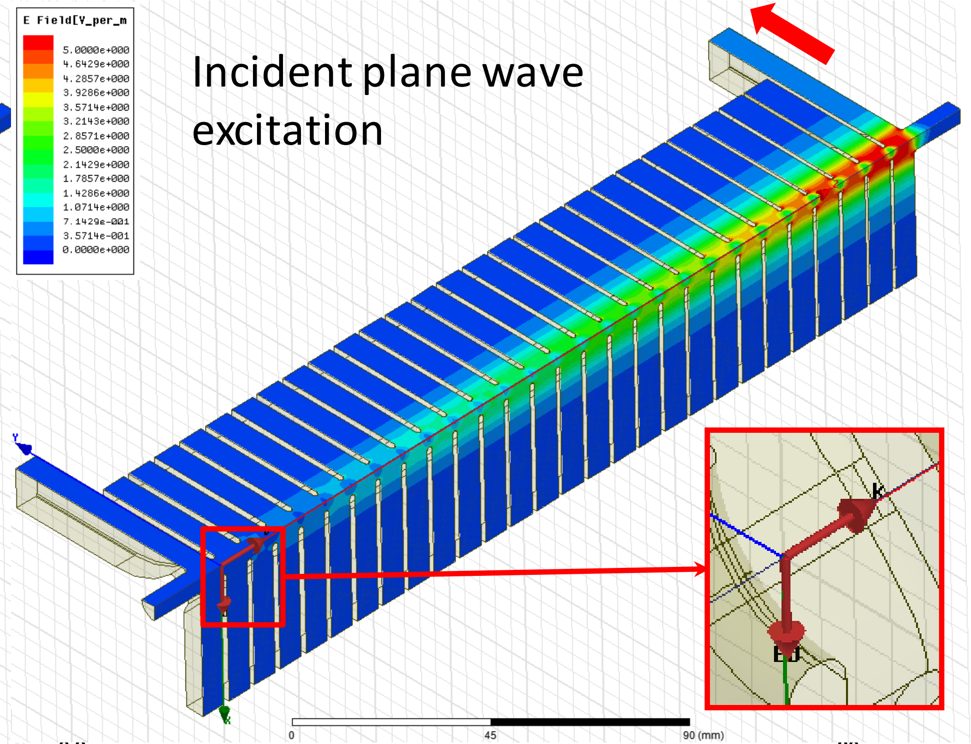
HFSS (examples, eigenmode)

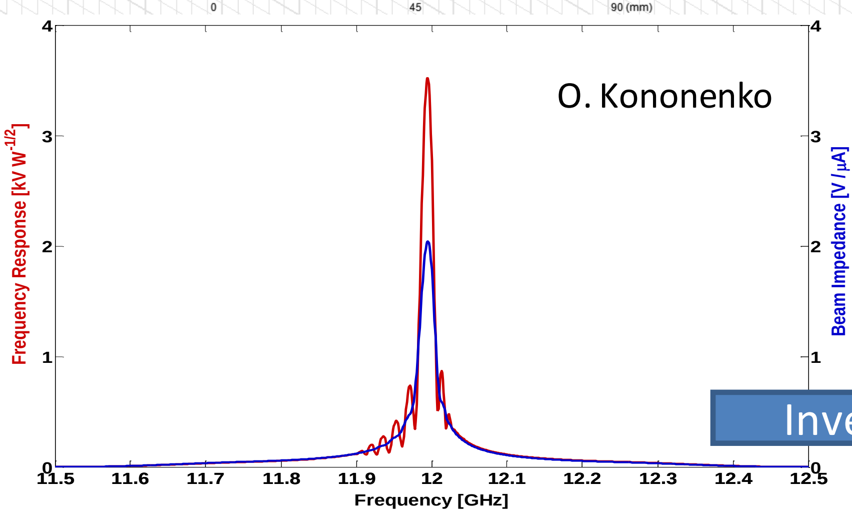


LHC TDI 5m long beam dump:
One of the most dangerous eigenmodes at 1.227 GHz, Q = 873,
Tetrahedral mesh with mixed order (0^{th} , 1^{st} , 2^{nd}) elements: Ntetr = 1404891
Solution obtained on a workstation with 128 GB of RAM,

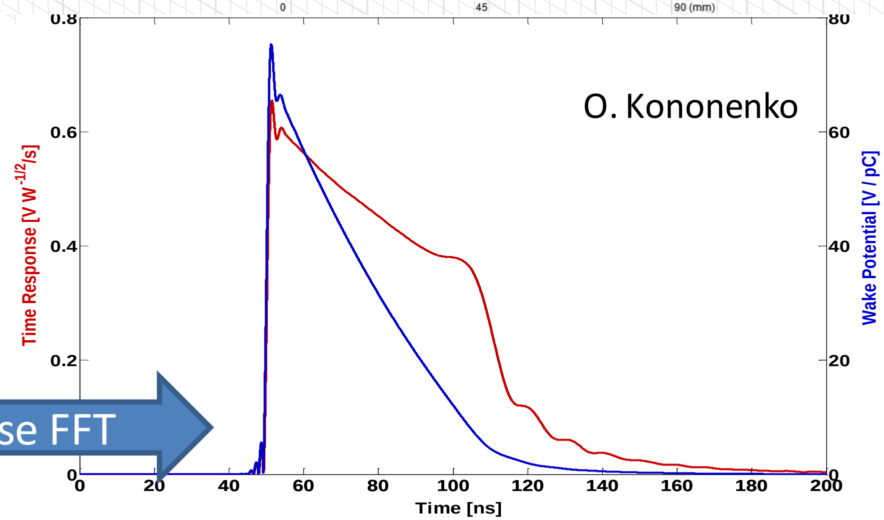
HFSS (example, S-parameters)







Inverse FFT



HFSS example

Example
Antenna with matching circuitry

Nominal Requirements

Create matching circuitry between RF PA and antenna

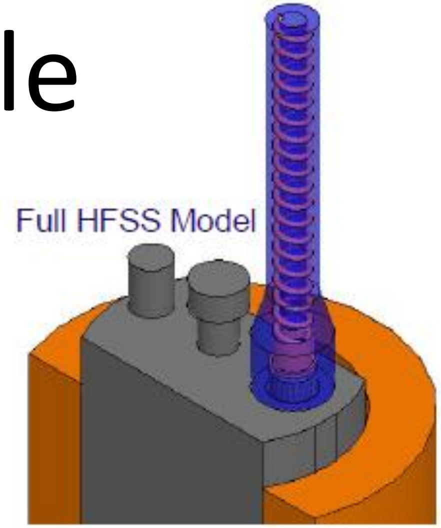
Procedure

1. Analyze Antenna in HFSS
2. HFSS model can be parameterized needed
3. Dynamically link HFSS sub-model results into Designer
4. Create general matching and driving circuitry in Designer
5. Tune/optimize matching circuitry.

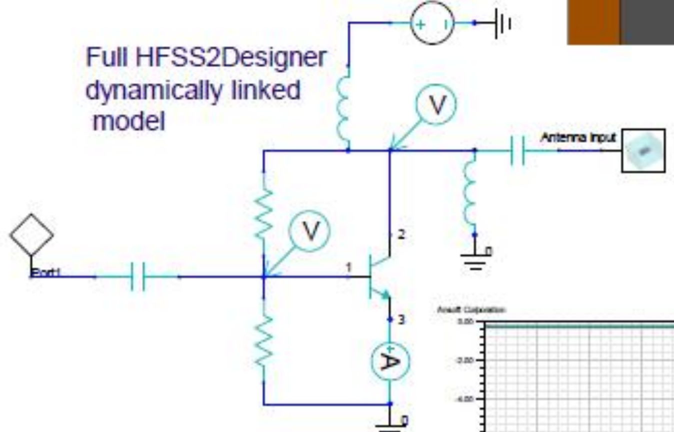
Benefit

1. Matching network can be designed schematic with realistic frequency varying load attached (active model)
2. Model is tunable.
3. Engineer has visual indication of performance while tuning/optimizing it.
4. Design is ready for harmonic balance analysis in Nexxim.

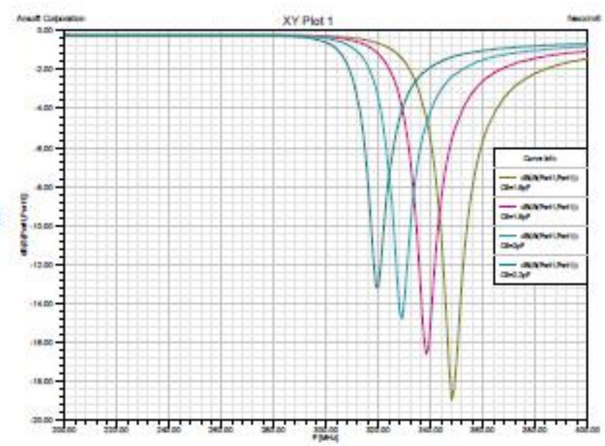
Full HFSS Model



Full HFSS2Designer dynamically linked model



Response of system with HFSS antenna and driving circuitry



HFSS: shortcomings

1. No possibility to simulate particles
2. Automatic mesh is not always perfect, but it has improved after adoption by ANSYS
3. TD and multiphysics are only recently implemented, but thermo-mechanics from ANSYS is a reference by itself
4. ...

GdfidL: Parallel and easy to use tool

bruns@gdfidl.de

The GdfidL Electromagnetic Field simulator

GdfidL computes electromagnetic fields in 3D-structures using **parallel** or scalar computers.

GdfidL computes

- Time dependent fields in lossfree or **lossy** structures. The fields may be excited by
  - port modes,
  - relativistic line charges.
- Resonant fields in lossfree or lossy structures.
- The postprocessor computes from these results eg. Scattering parameters, wake potentials, Q-values and shunt impedances.

Features

- GdfidL computes only in the field carrying parts of the computational volume. For eg. waveguide systems, this makes GdfidL about three to ten times faster than other Finite Difference based programs.
- GdfidL uses generalised diagonal fillings to approximate the material distribution. This reduces eg. the frequency error by about a factor of ten.
- For eigenvalue computations, GdfidL allows periodic boundary conditions in all three cartesian directions simultaneously.
- GdfidL runs on **parallel** and serial computers. GdfidL also runs on clusters of workstations.

Availability

- GdfidL only runs on **UNIX-like** operating systems.

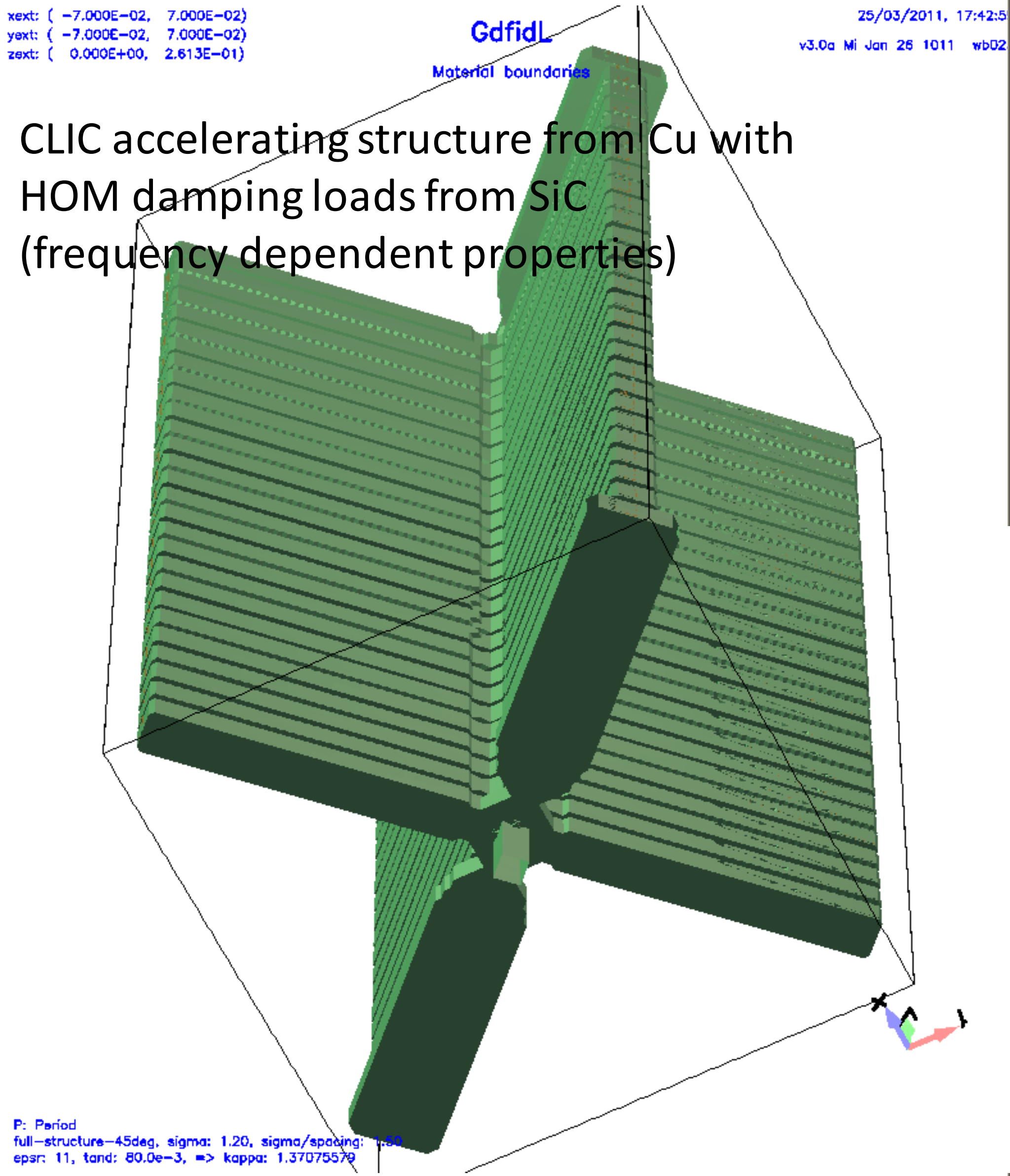
Price

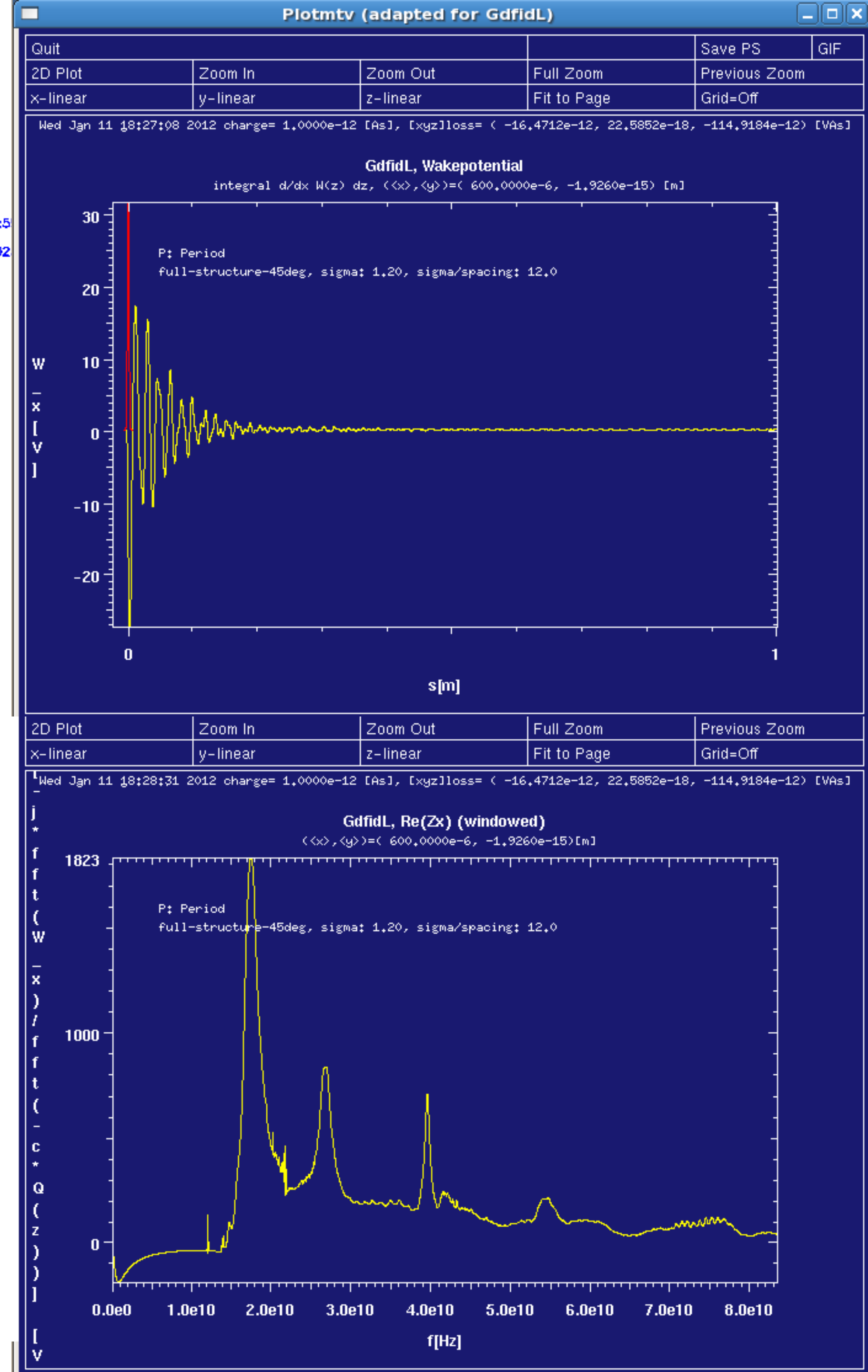
The price for a one year license for the serial version of GdfidL (including support) starts at 10.000 Euro .
The price for a one year license for the parallel versions starts at 20.000 Euro.
Access to a powerful cluster where GdfidL is installed on costs 9.000 Euro per year.

Powerful Syntax **Material Approximation** **Absorbing Boundary Conditions** **Periodic Boundary Conditions**

GdfidL (example)

CLIC accelerating structure from Cu with HOM damping loads from SiC (frequency dependent properties)





GdfidL: shortcomings

1. Available only under UNIX-like systems
2. Geometry input is limited
3. It is ‘one man show’
4. ...

COMSOL: pioneer in multiphysics

COMSOL Multiphysics®

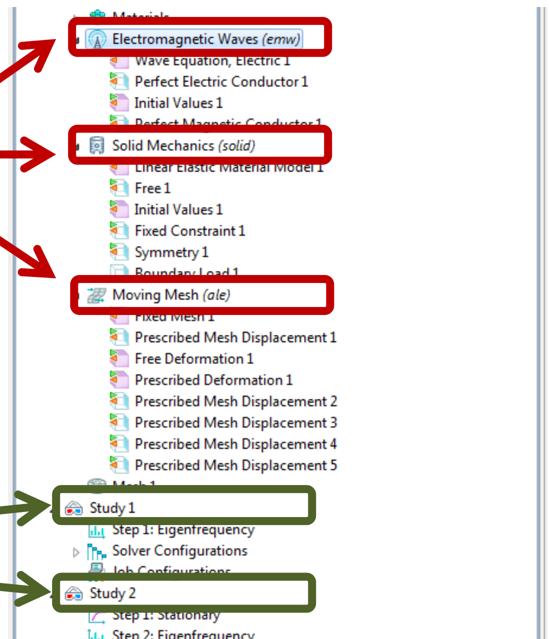
AC/DC Module	Heat Transfer Module	CFD Module	Chemical Reaction Engineering Module	Optimization Module®	LiveLink™ for MATLAB®	CAD Import Module
RF Module	Structural Mechanics Module	Microfluidics Module	Batteries & Fuel Cells Module	Material Library	LiveLink™ for SolidWorks®	LiveLink™ for SpaceClaim®
MEMS Module	Geomechanics Module	Subsurface Flow Module	Electrodepositi on Module	Particle Tracing Module	LiveLink™ for Pro/ENGINEER ®	LiveLink™ for Creo™ Parametric
Plasma Module	Acoustics Module				LiveLink™ for Inventor®	LiveLink™ for AutoCAD®

COMSOL: example df/dp Calculation

Mohamed Hassan

Electromagnetic Waves	Solid Mechanics	Moving Mesh
•Solving only for the RF domain •Applying the prober boundary conditions	•Solving only for the Cavity Vessel •Applying the proper fixed constraints, symmetries, displacements, and boundary load	•Solving for all domains •Applying the proper prescribed and free mesh deformation/displacement

Three Multiphysic Modules



Two Simulation Studies

$Study_1$	$Study_2$
• Eigen-frequency (to find f_0)	• Stationary (solving only for solid mechanics and moving mesh) • Eigen-frequency (to find f_p)

EM
- Eigen frequency simulation to find the resonant frequency (f_0)

Solid Mechanics
- Find the deformation under given pressure load (P_L)

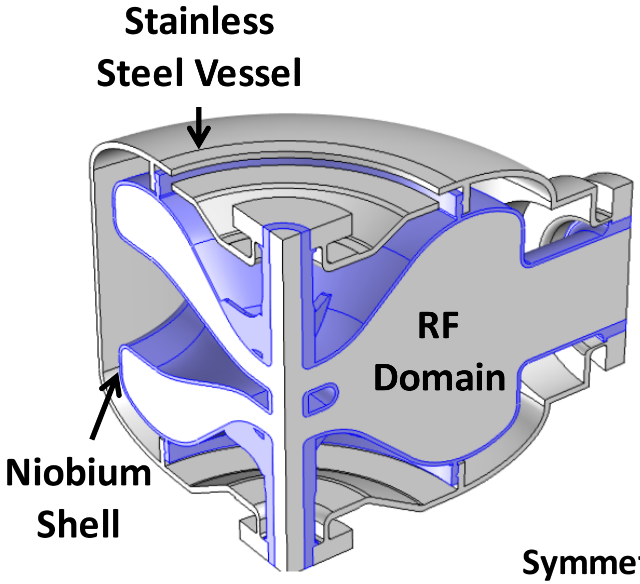
Moving Mesh
- Update the mesh after deformation

EM
- Eigen frequency simulation to find the resonant frequency after deformation (f_p)

$$\frac{df}{dp} = \frac{f_p - f_0}{P_L}$$

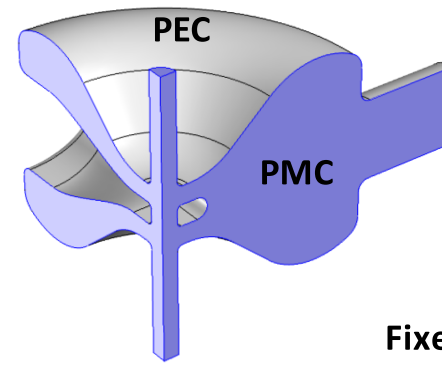
Example

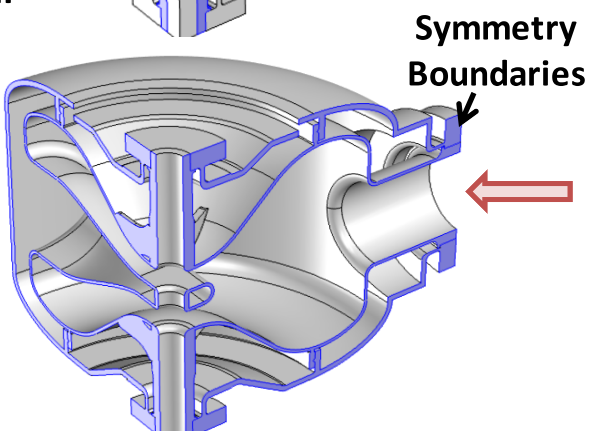
Mohamed Hassan



Electromagnetic Waves

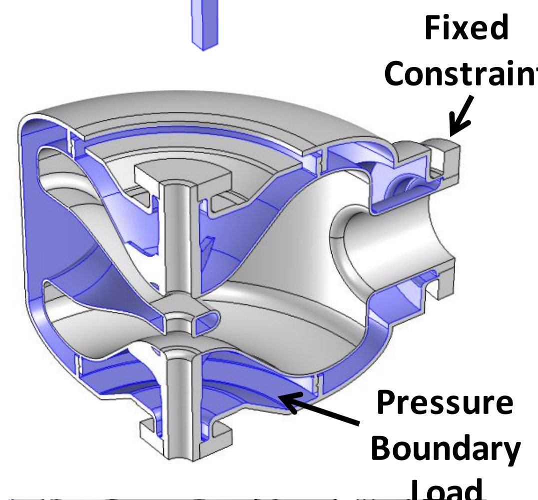
- Solving only for the RF domain
- Applying the prober boundary conditions

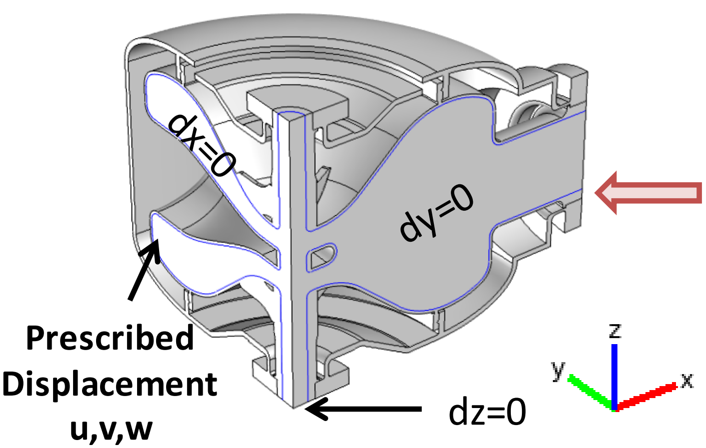




Solid Mechanics

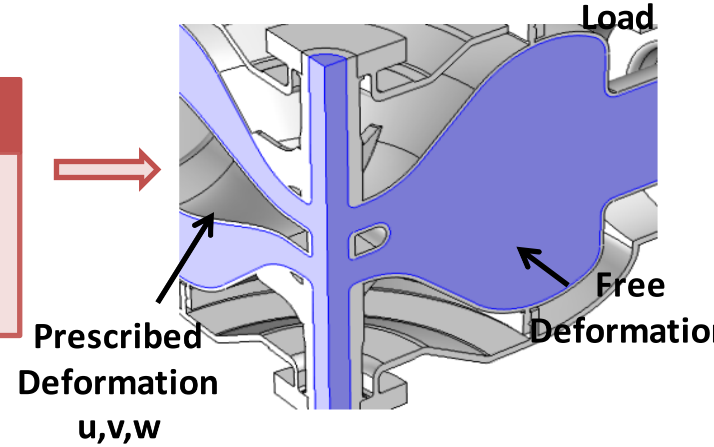
- Solving only for the Cavity Vessel
- Applying the proper fixed constraints, symmetries, displacements, and boundary load





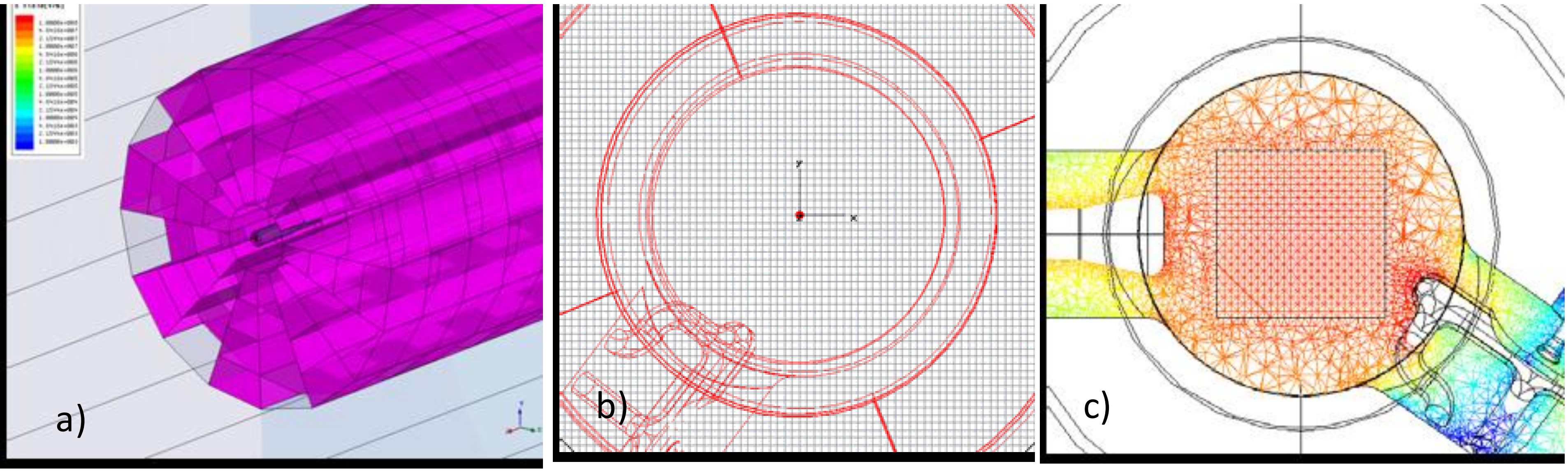
Moving Mesh

- Solving for all domains
- Applying the proper prescribed and free mesh deformation/displacement



COMSOL: example

Meshes used for RF kick simulations : a) HFSS , b) CST MWS, c) COMSOL



A. Lunin, et. al., FINAL RESULTS ON RF AND WAKE KICKS CAUSED BY THE COUPLERS FOR THE ILC CAVITY, IPAC10, Kyoto, Japan

- ‘Highly regularized tetrahedral mesh can be built by versatile COMSOL mesh generator’
- ‘Well parallelized, direct method for eigenmode calculations with losses and smooth surface fields’

Andrei Lunin

COMSOL: shortcomings

- Geometry input is limited
- Port excitation mode description is not convenient
- S-parameter solver is not convenient
- Postprocessing is not well developed at least for what concerns accelerator physicists and engineers

Andrei Lunin

Accelerator Modeling with EM Code Suite ACE3P

Meshing* - *CUBIT *for building CAD models and generating finite-element meshes*
http://cubit.sandia.gov

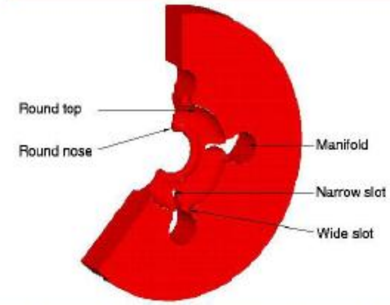
Modeling and Simulation – *SLAC's suite of conformal, higher-order, C++/MPI based parallel finite-element electromagnetic codes*
https://slacportal.slac.stanford.edu/sites/ard_public/bpd/acd/Pages/Default.aspx

ACE3P (Advanced Computational Electromagnetics 3P)

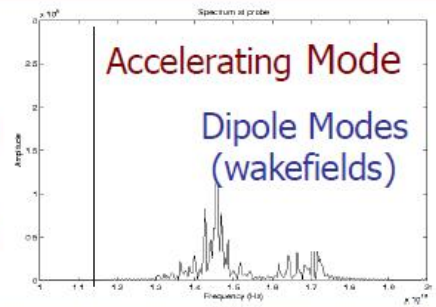
Frequency Domain:	**Omega3P**	– **Eigensolver (damping)**
	S3P	– **S-Parameter**
Time Domain:	**T3P**	– **Wakefields and Transients**
Particle Tracking:	**Track3P**	– **Multipacting and Dark Current**
EM Particle-in-cell:	**Pic3P**	– **RF guns & klystrons**
Multi-physics:	**TEM3P**	– **EM, Thermal & Structural effects**

Postprocessing* - *ParaView *to visualize unstructured meshes & particle/field data*
http://www.paraview.org/

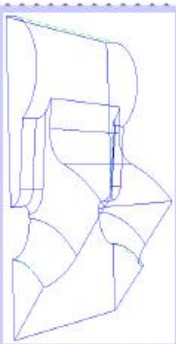
Accelerator Design and Analysis with ACE3P

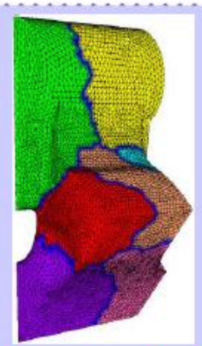


Constraint
$f = f_0$;
Maximize (R/Q , Q)
Minimize
(surface fields etc.)

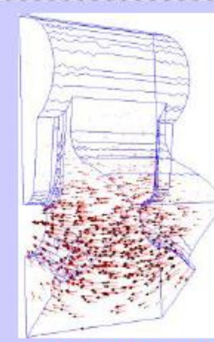


Minimize Wakefields





ACE3P

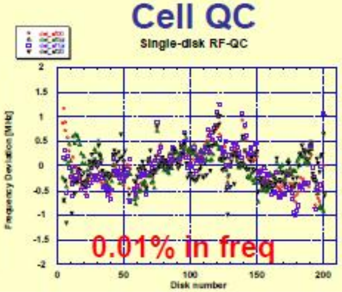


Model CAD → **Meshing Cubit** → **Partitioning ParMetis** → **Solvers** → **Visualization ParaView**

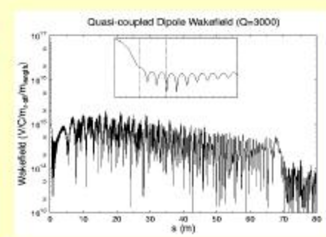
ACE3P EM Field Computations Determine Cavity Dimensions

Fabrication

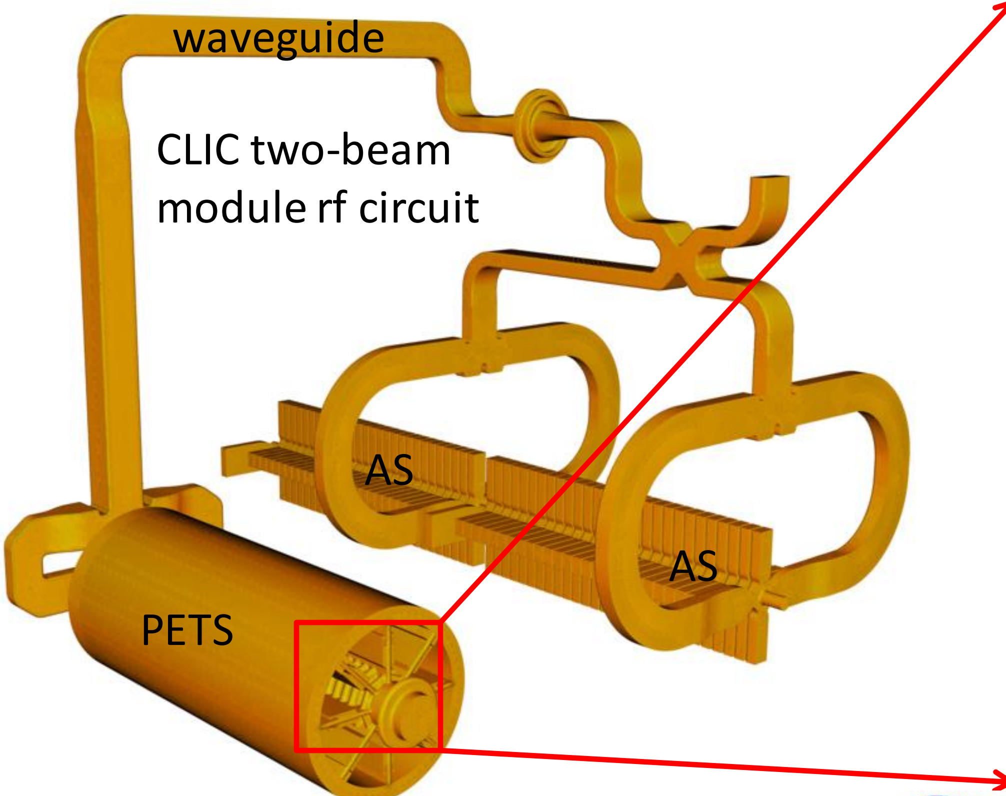
Cell QC

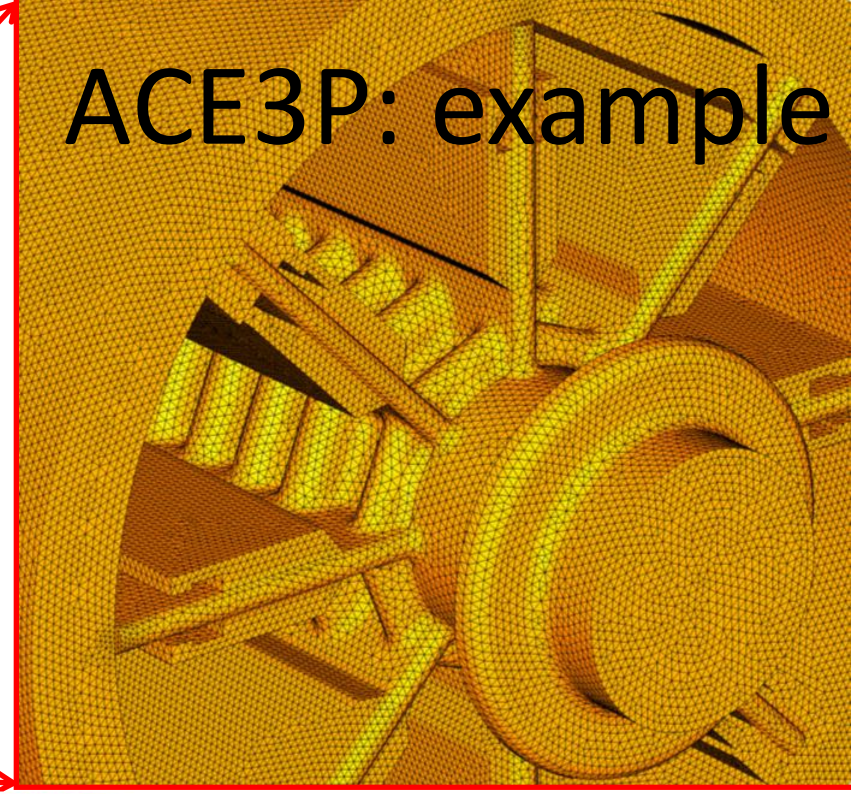


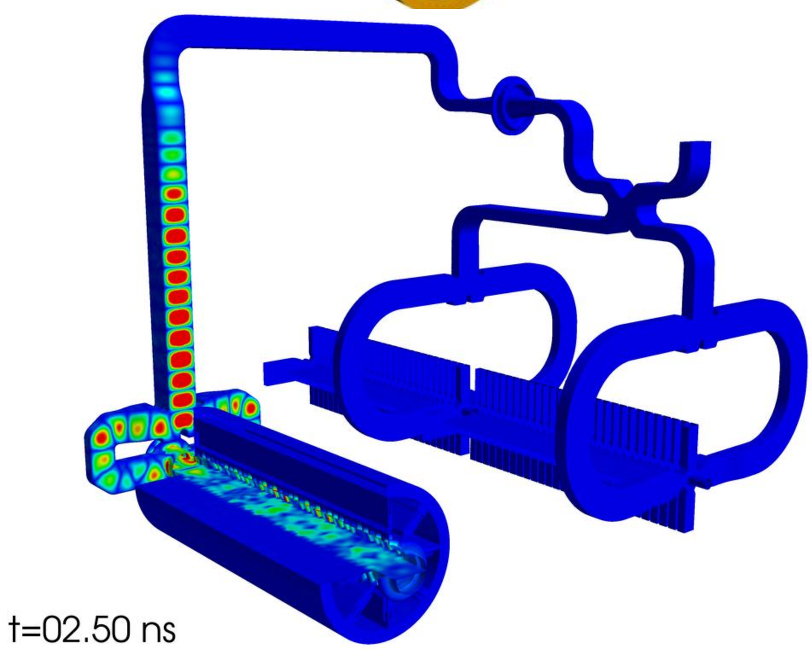
Wakefield Measurement

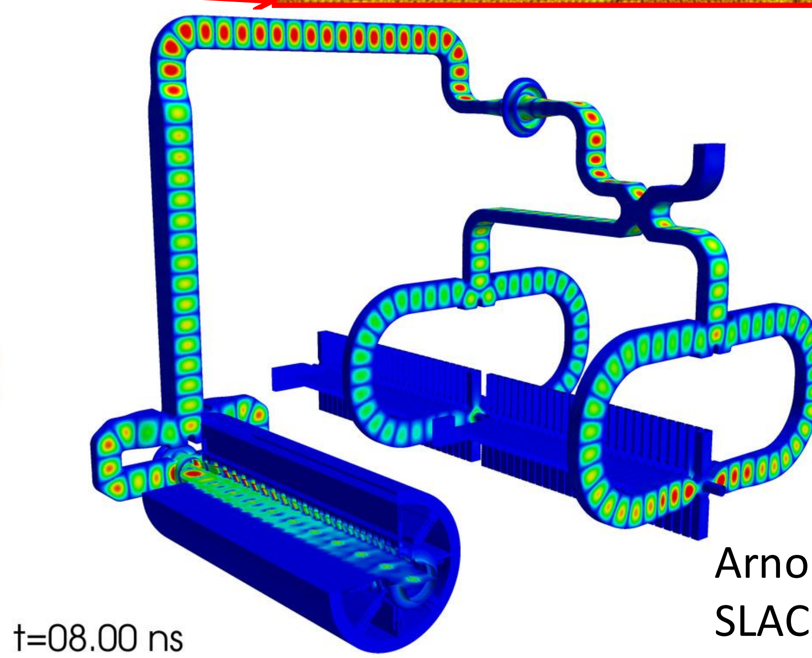


ACE3P: example







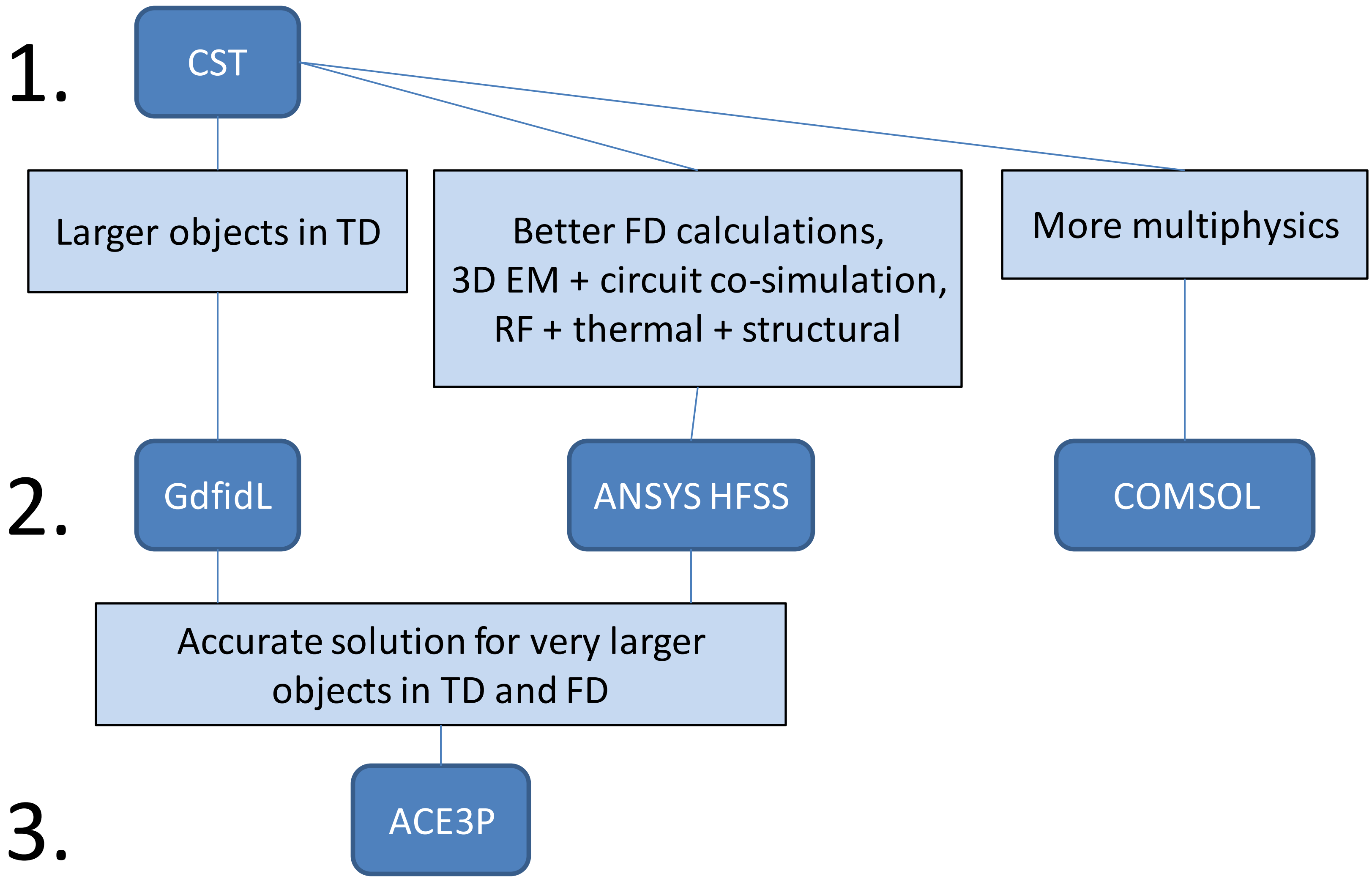


Arno Candel et. al.,
SLAC-PUB-14439

ACE3P: shortcomings

- Very complex package to use. It is not user-friendly at all and requires a lots of time to invest before it can be used efficiently
- It is not a commercial product -> no manual reference, limited tech support. No it is an open source.
- …

Summary



1.
CST
Larger objects in TD
Better FD calculations,
3D EM + circuit co-simulation,
RF + thermal + structural
More multiphysics
2.
GdfidL
ANSYS HFSS
COMSOL
Accurate solution for very larger
objects in TD and FD
3.
ACE3P