Multiphysics Design of ESS-Bilbao Linac Accelerating Cavities Using COMSOL

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Outline

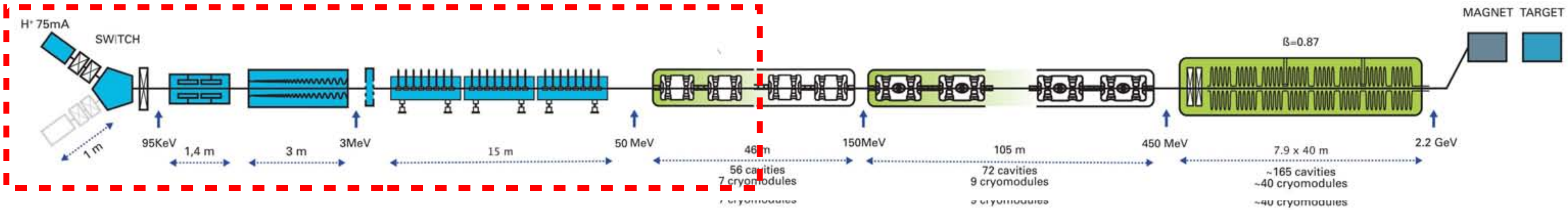
- ESS-Bilbao project description
- Accelerating cavities
- Buncher cavity design and optimization using multiphysics software
  - Geometry optimization
  - Thermo-mechanical studies
- Conclusions

ESS-Bilbao linac

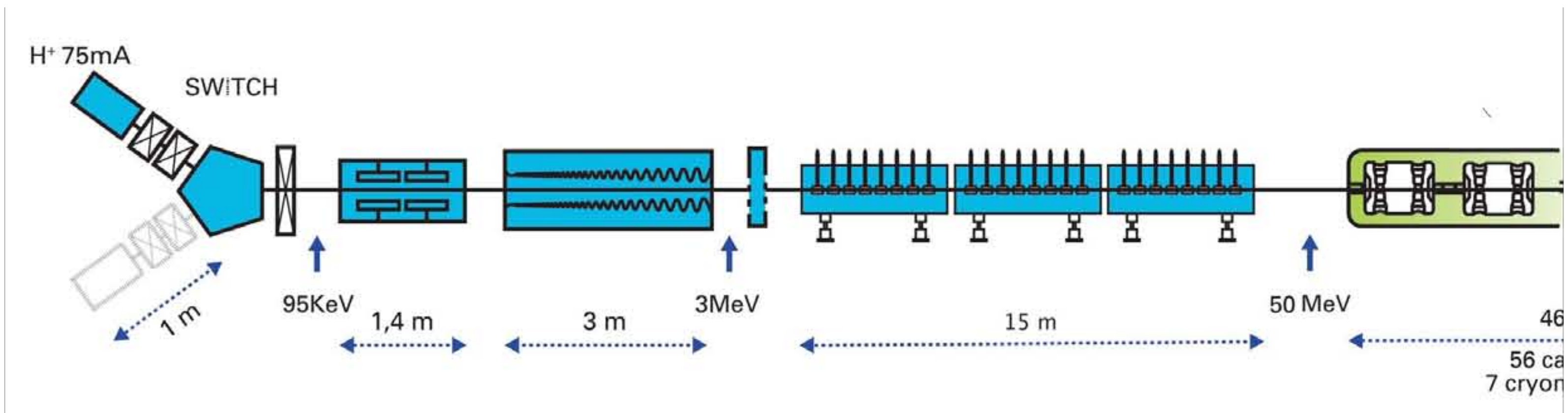
- **ESS-Bilbao** is a research center devoted to accelerators science and technology, whose main facility is a proton linac currently under development (http://www.essbilbao.org)

- ESS-Bilbao building and accelerator tunnel will be built in the Scientific Park of the U.P.V/E.H.U. besides Leioa Campus

ESS-Bilbao linac



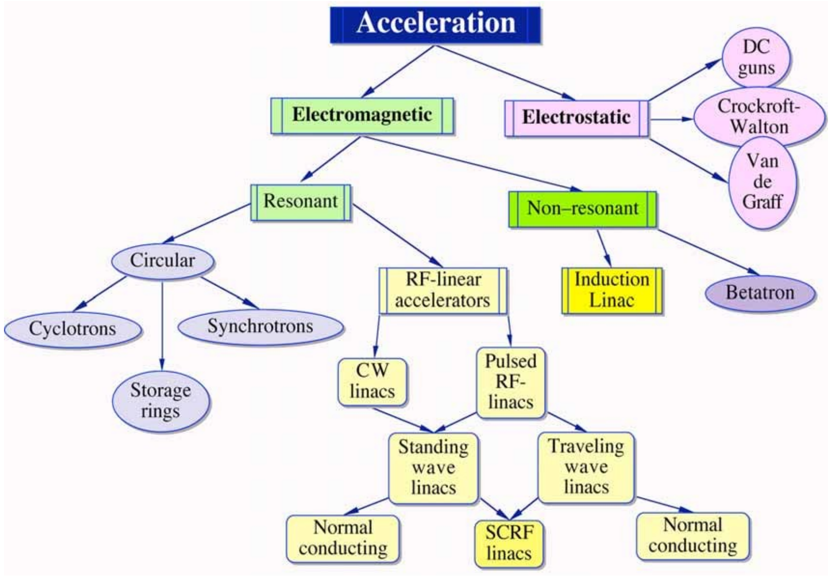
Stage 1:



	Ion sources (H^-,H^+)	LEBT	RFQ	MEBT	DTL	Spoke demonstrator
Kinetic energy:	75 keV	75 keV	3 MeV	3 MeV	50 MeV	

Accelerating cavities

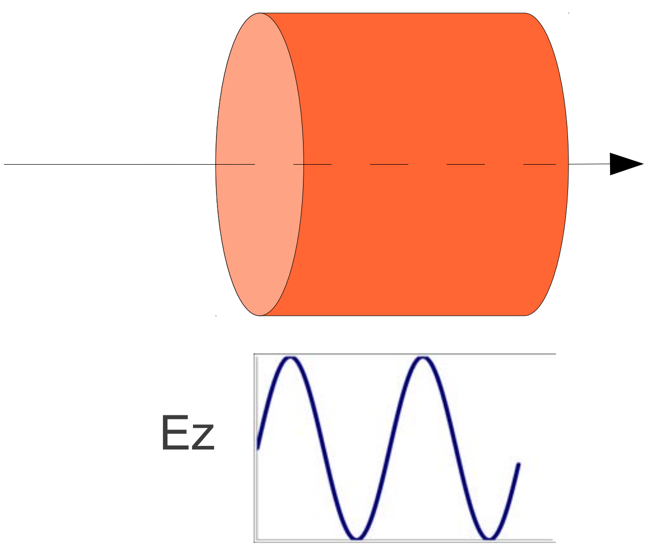
- An electric field is needed to change a charged particle kinetic energy:
  - Lorentz force: $\vec{F} = q(\vec{E} + \vec{v} \, x \, \vec{B})$
  - Change of kinetic energy... $\frac{dW_k}{dt} = \frac{c^2}{W_k} \vec{p} . \vec{F} = q \vec{v} \cdot \vec{E}$
- Electric field can be provided by different means...

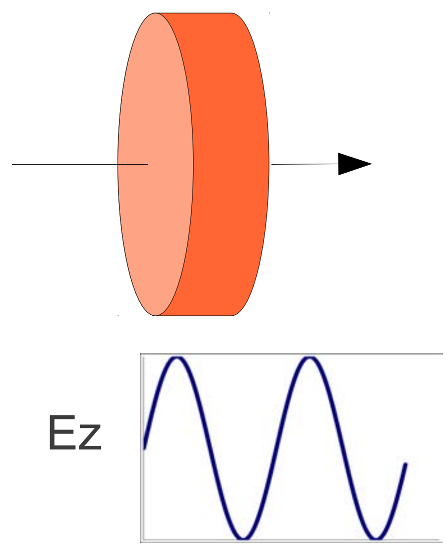


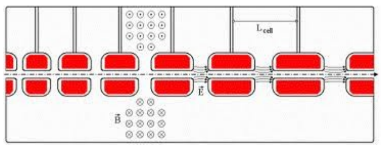
* (From W. A. Barletta, "Introduction to accelerators" U.S. Particle Accelerator School)

Accelerating cavities

- An accelerating cavity is a vacuum chamber with an AC (RF) electric field in resonance
- Synchronization between electric field and particles velocity is needed to have net acceleration -> λ~cm

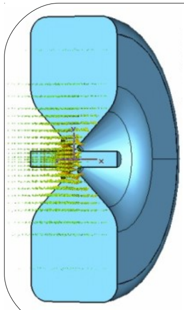






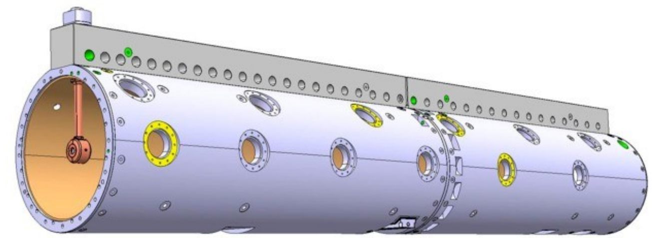
Components

- Examples of linac components showing typical design issues:

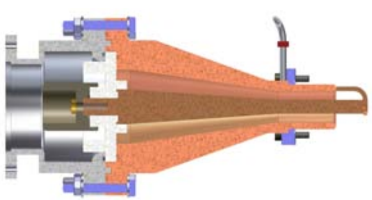


“Bunching” cavity:
•Axysimetric
•2D geometry optimization
•3D EM, Thermal, Mech
•Tuners, couplers...

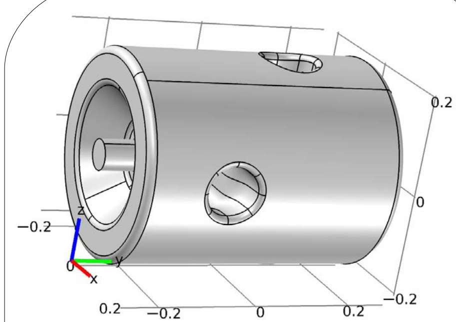
Accelerating cavities



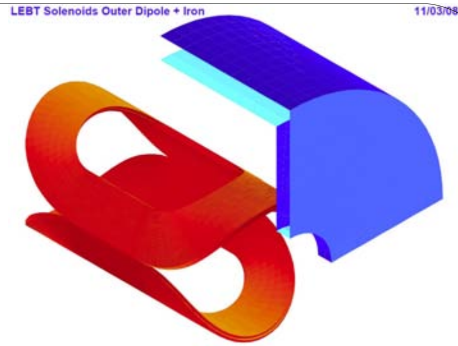
·Different feature sizes
·Very big models
·Complex EM behavior



Power couplers:
·EM optimization
·Thermal, mech,
·Ceramic windows...



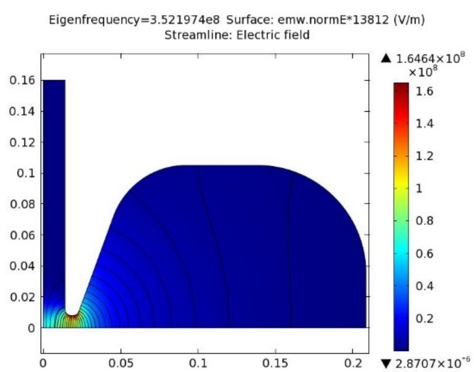
SC cavities:
·Surface fields
·Thermal...

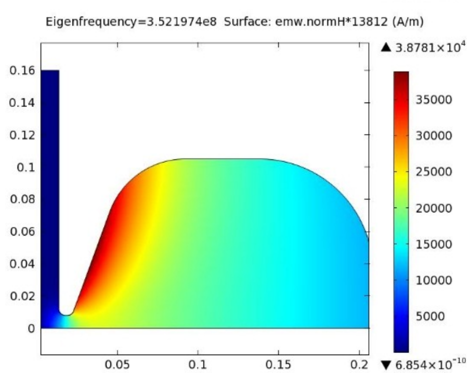


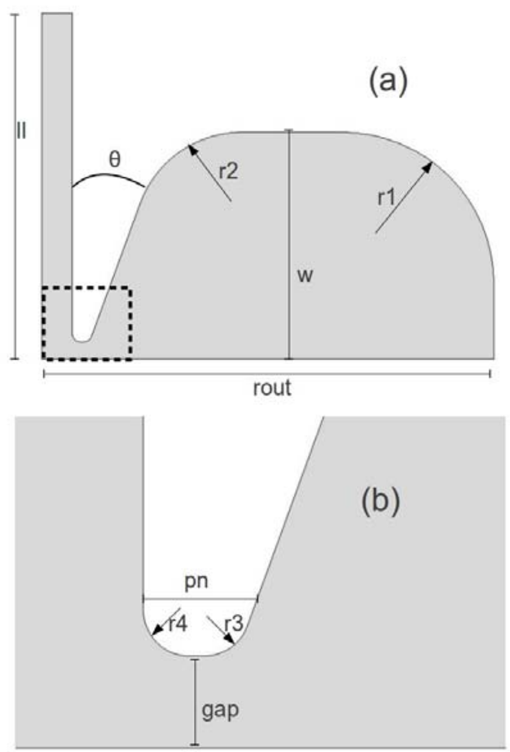
Magnets
·Complex coil geometries
·Non-linear materials

Buncher cavity

- 2D geometric optimization
  - Maximize figures of merit (Q, ZTT, ...) with restriction f=352.2 MHz







Some expressions:

Q_0: $\omega W / P$

P: $\frac{1}{2} R_s \iint H^2 dS$

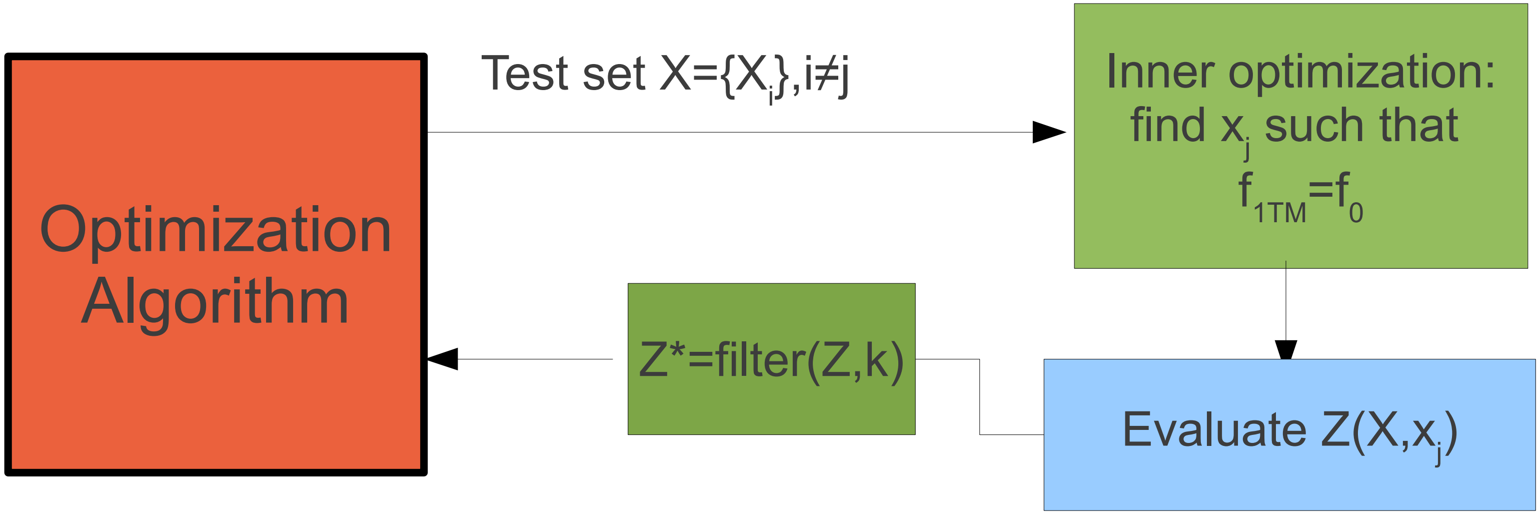
V_s: $\int_{-L/2}^{+L/2} E_{0z} dz$

T: $\frac{1}{L} \int_{-L/2}^{+L/2} E_{0z} \cos\left(\frac{\omega z}{\beta c}\right) dz$

Z_sTT: $\frac{V_s^2}{P} T^2$

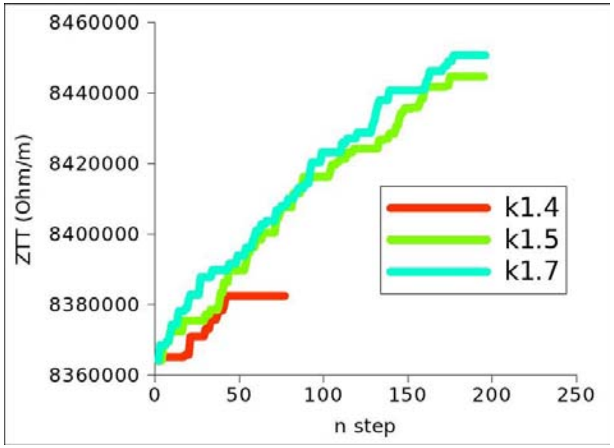
Cavity optimization

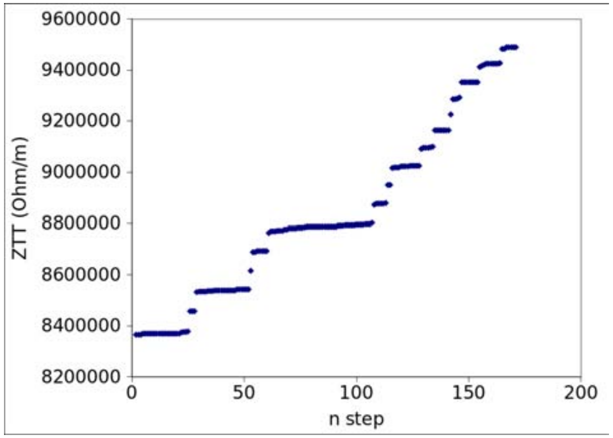
- Problem: Given a set of parameters $X=\{x_0,..,x_n\}$, maximize function Z(X)=ZTT(X) with the restrictions $f_{1TM}=f_0$ and $k(E_{s,max})<k_0$
- The restriction for $f=f_0$ is very strong. This is solved in two steps:

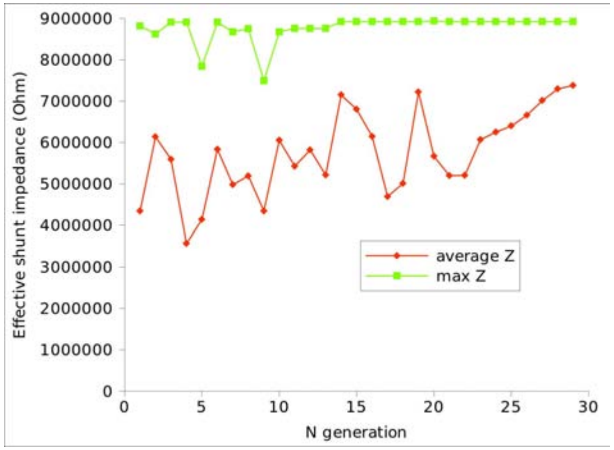


Cavity optimization

- Optimization using different algorythms (stochastic hill climbing, genetic, ...) coded in Matlab.

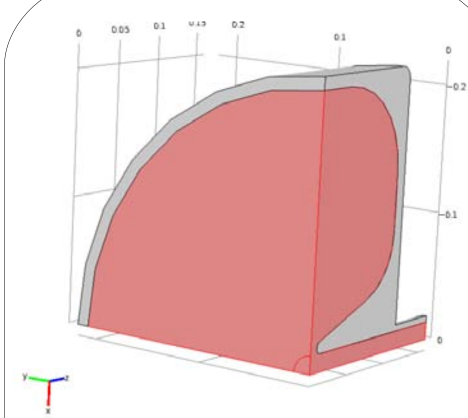






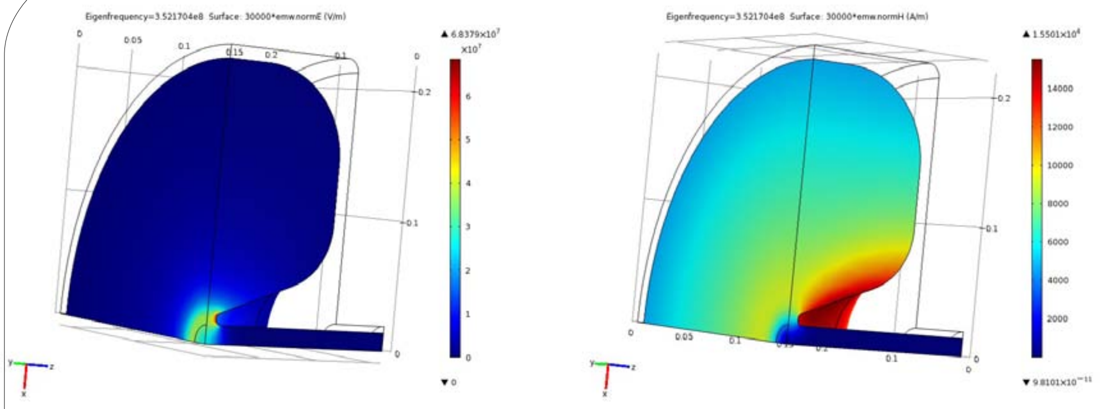
- Final design not yet decided as operational parameters and not yet frozen.

Buncher cavity



3D geometry

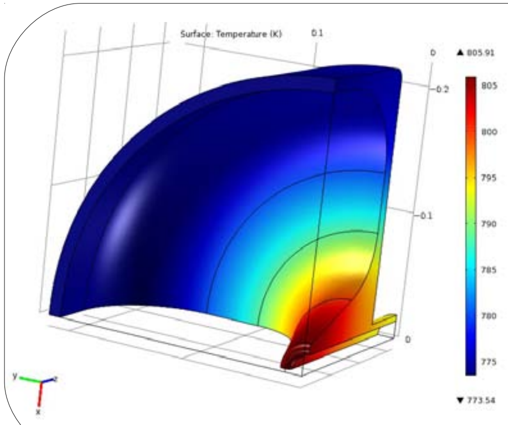
Eigenvalue solver



Electromagnetic fields

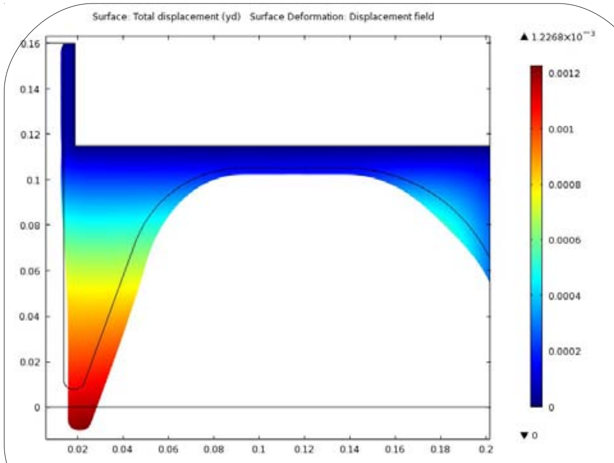
Heat transfer solver

$$P = \frac{1}{2}\eta R_s \iint_S H^2 dS$$



Temperature

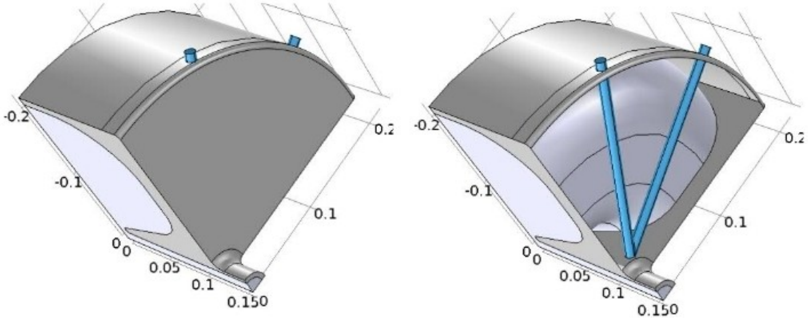
Mechanical solver

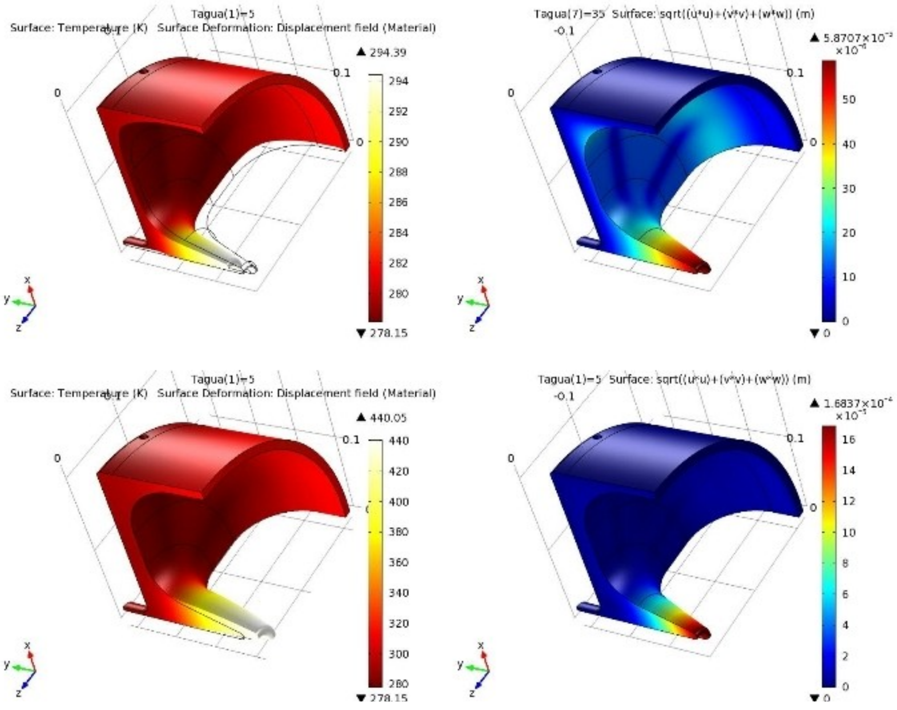


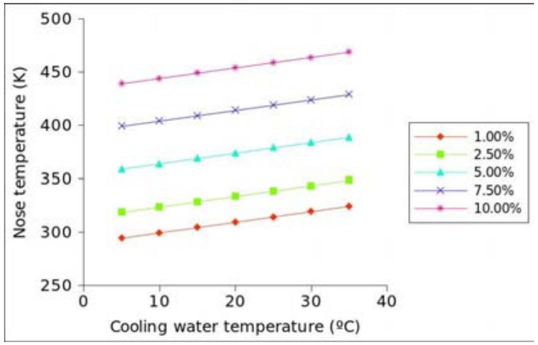
Deformation field

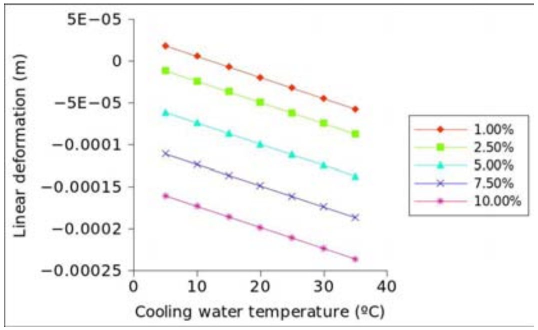
Buncher cavity thermal design

- Simulations coupled with cooling (with or without CFD simulation) help to design effective cooling systems



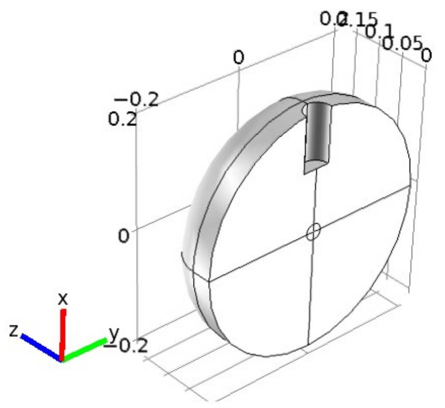


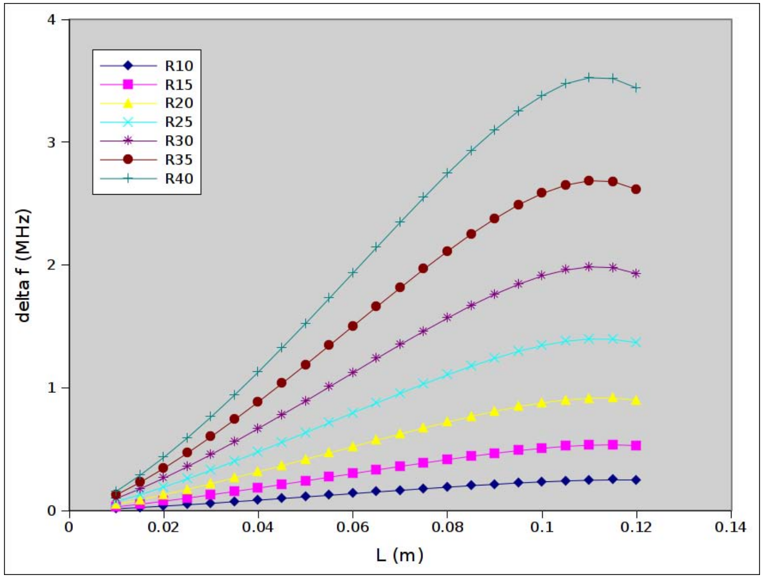


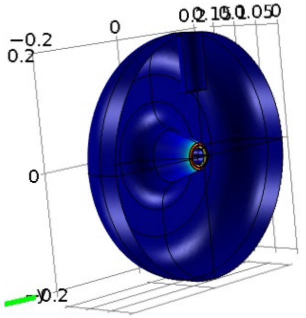


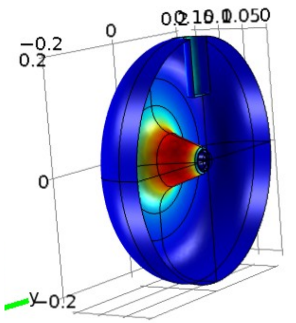
Buncher cavity tuning system

- To dinamically change cavity frequency during operation, a slug tuner is used:



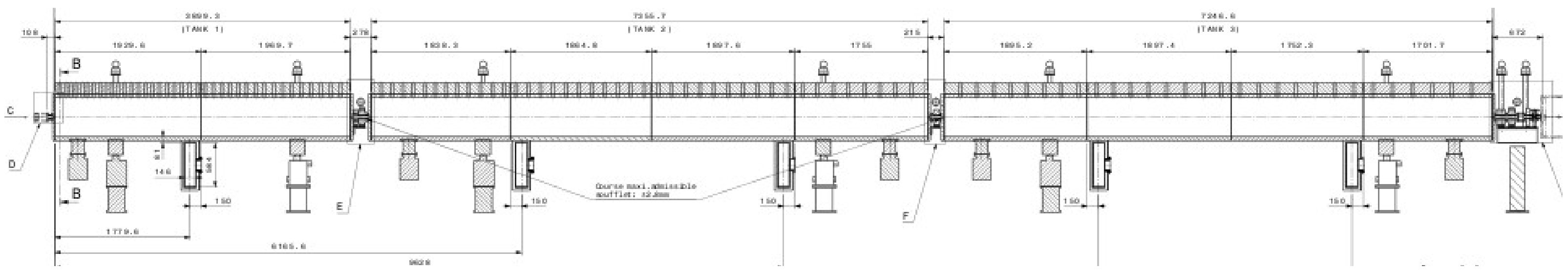


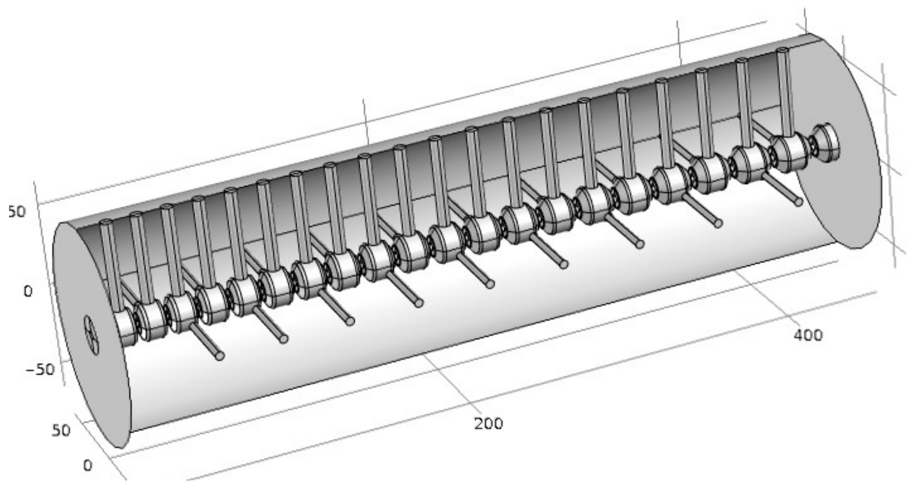


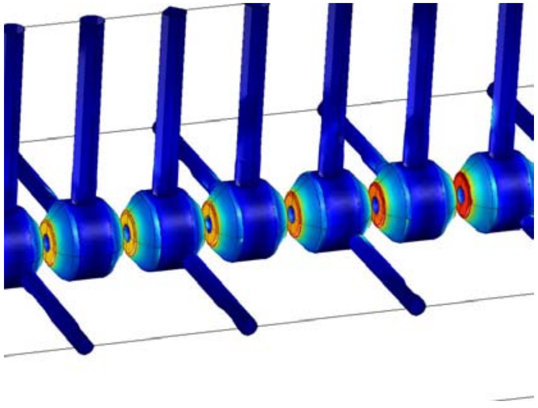


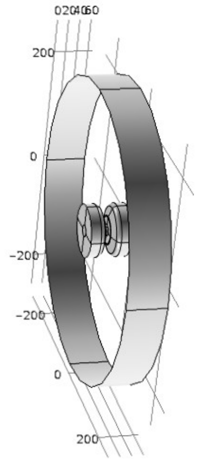
Other accelerating structures

- Drift Tube Linac: Tanks of about 4 and 8 m long, 520 mm diameter, with fine details and no simmetries:



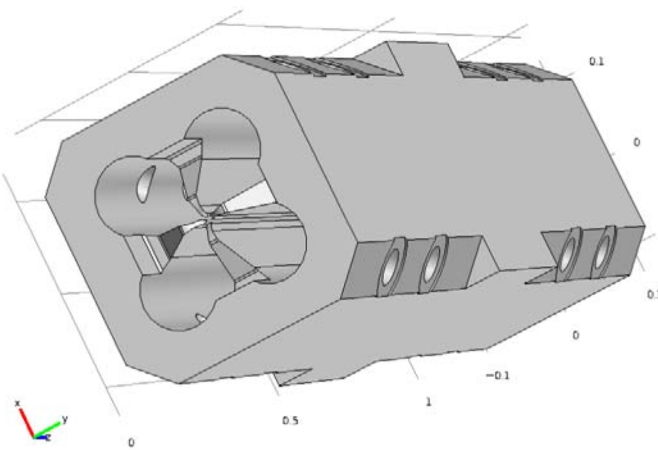


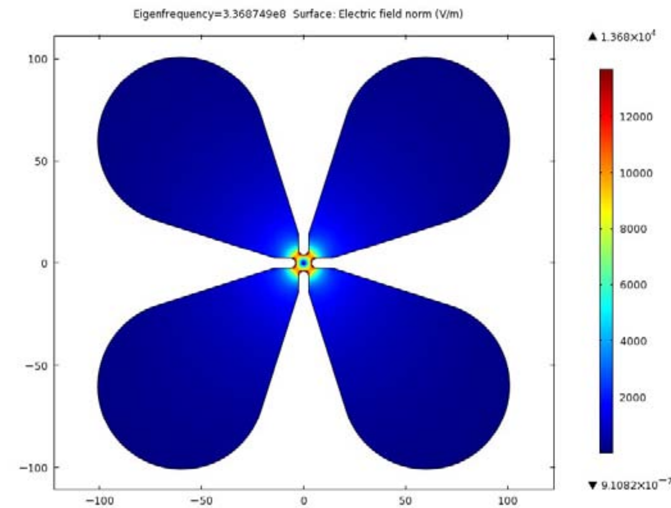




Other accelerating cavities

Radiofrequency quadrupole (RFQ) has about 4 meters long with very fine detail in vane modulation

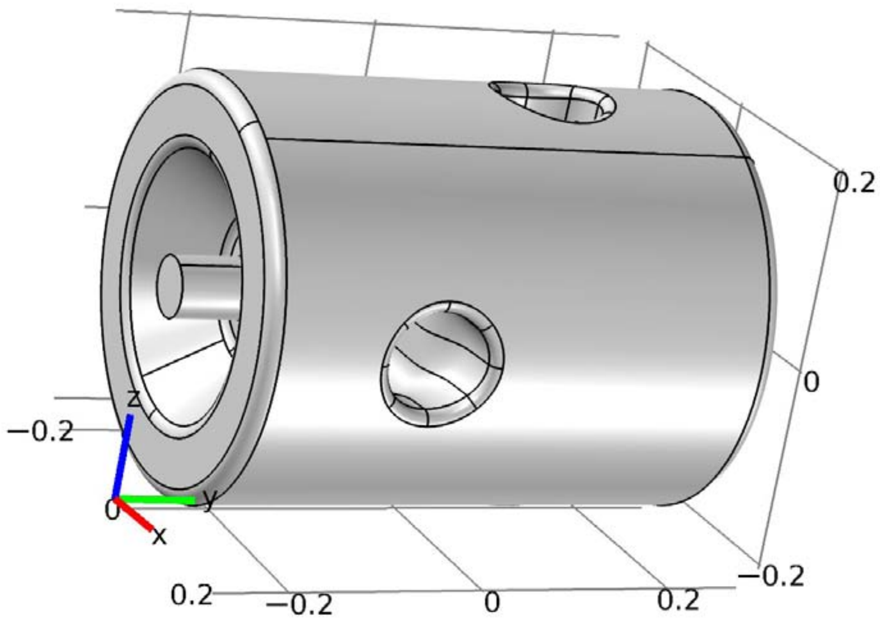


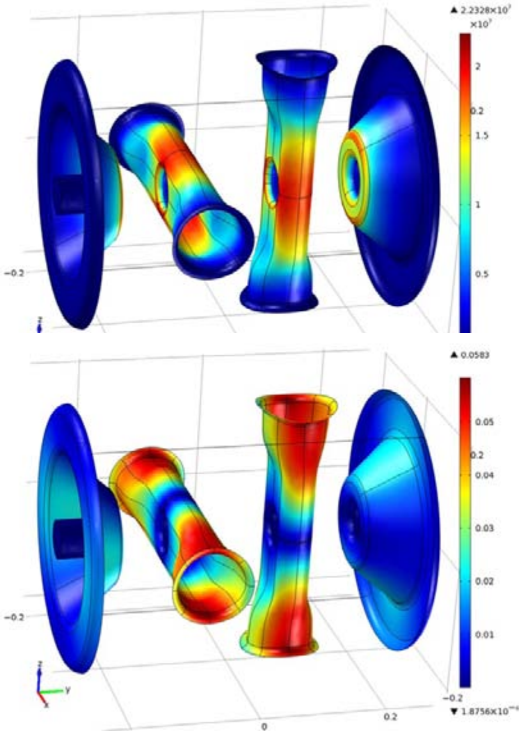


Resonant frequency and electric field profile are very sensitive to every feature of the geometry

Superconducting cavities

- The “spoke” cavities that will be built as prototypes at ESS-Bilbao have other additional difficulties:
  - Complex shapes, mechanical fabrication (in Nb),...





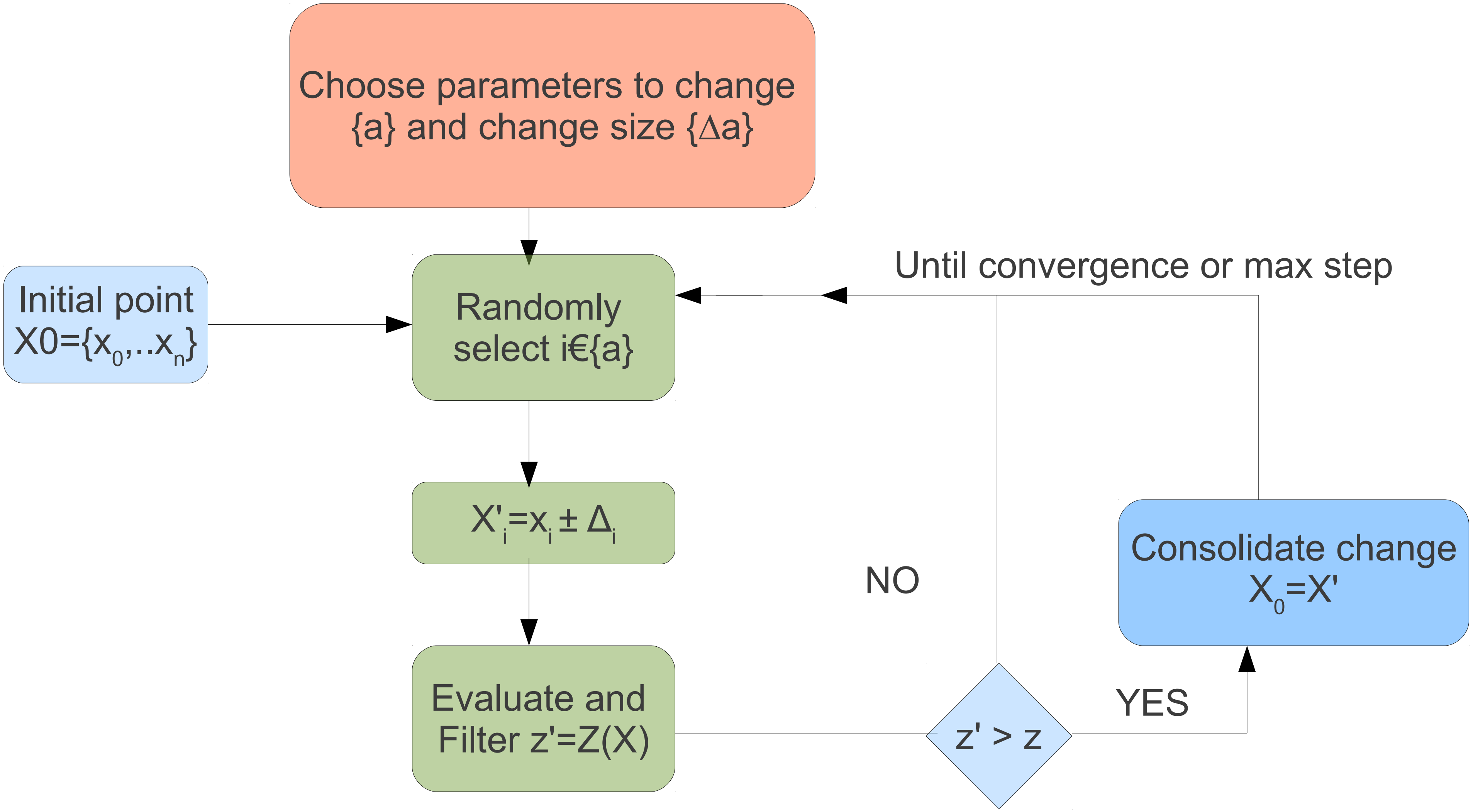
Conclusions

- The designs stage of a linear accelerator structures involves strong use of Multiphysics simulation tools. This is being done in ESS-Bilbao linac using COMSOL
- The main activities correspond to the RF design of the cavities, althouth thermal, mechanical and CFD are also used.
- Geometry optimization schemes (hill climbing, genetic) have been coded in Matlab and used with COMSOL to get optimum cavity shapes.

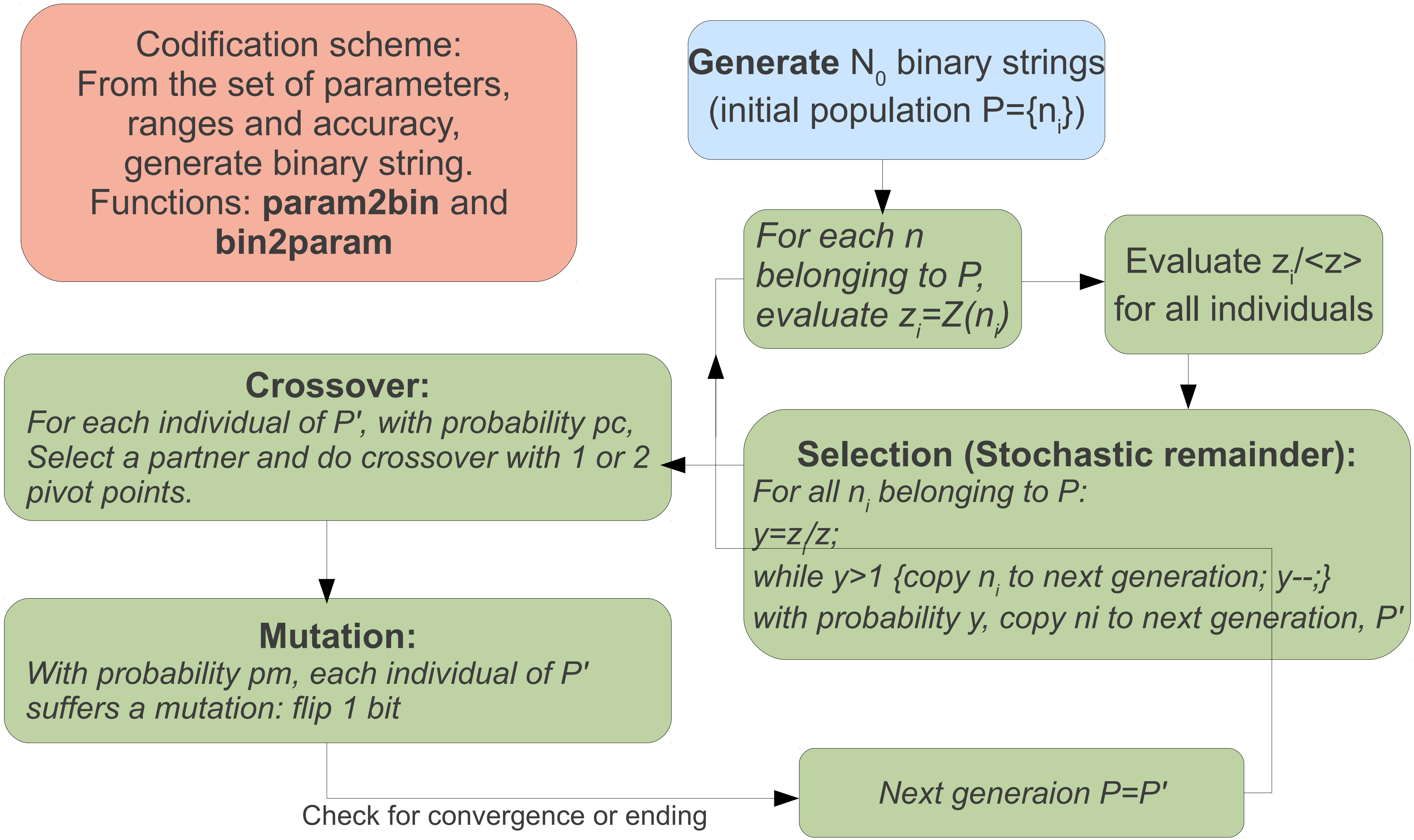
Thank you!

Extra slides...

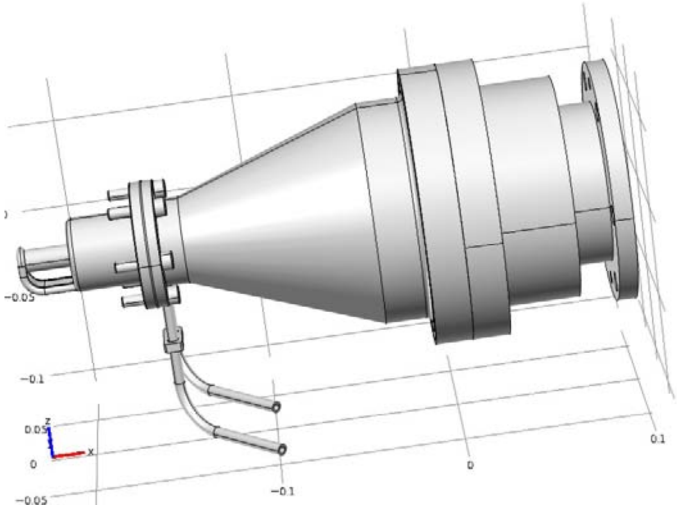
Hill climbing algorithm



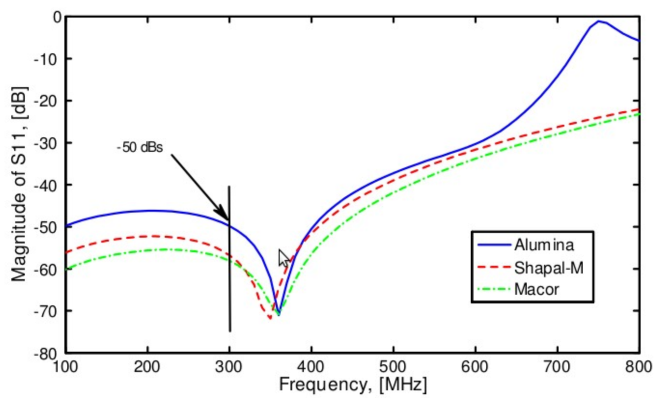
Genetic algorithm



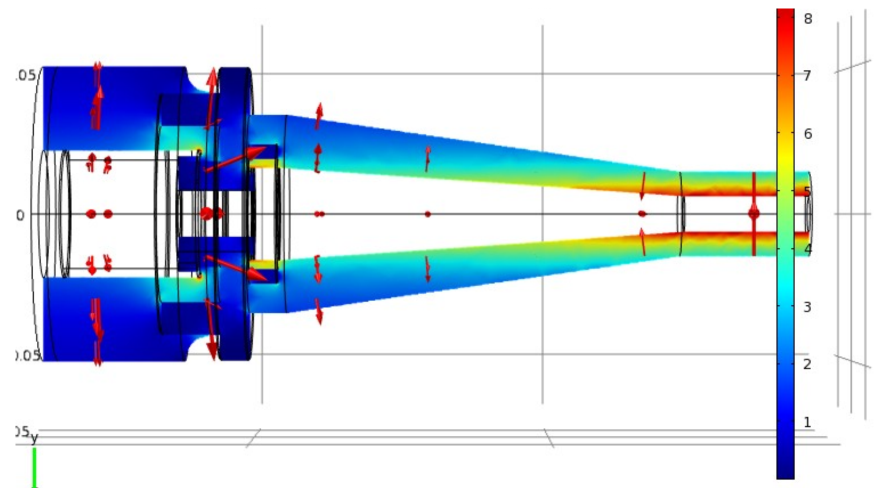
Power couplers



Model with loop, cooling,...



Impedance matching



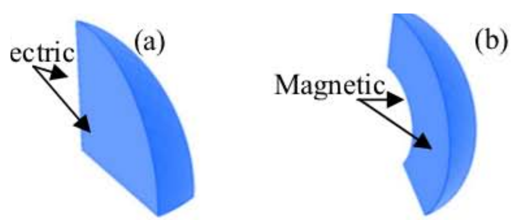
Electric field, power dissipation

Superconducting cavities

- SC cavities has an extra difficulty: determination of accurate surface field values.
- Solvers are accurate for frequency calculation but not very accurate with the values of surface E and H fields
- These values are used as critical values for maximum power input in the cavity, becaue field values above some limits can suppress superconductivity

Superconducting cavities

- Simple geometries with known analytic solution (pillboxes, spheres...) are used as benchmarks



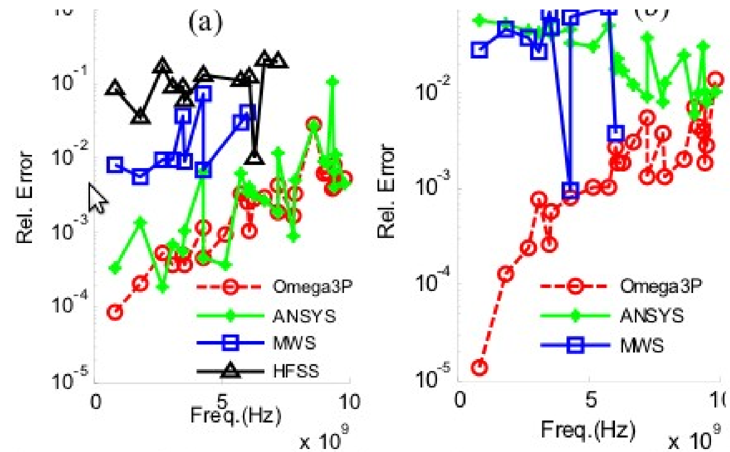


Figure 5: Relative errors of the maximum surface electric fields for the double sphere. (a) Inner surface; (b) outer

* (From K. Tian et al,
"Benchmark of different electromagnetic codes for the high frequency calculation"
Proceedings of PAC'09)

Magnets

- Different kind of magnets are used in accelerators (for beam focusing and bending)
- All of them suffer from numerical difficulties:

(non linear materials, coils with strange shapes, ...)