TEM3P - Multi-Physics

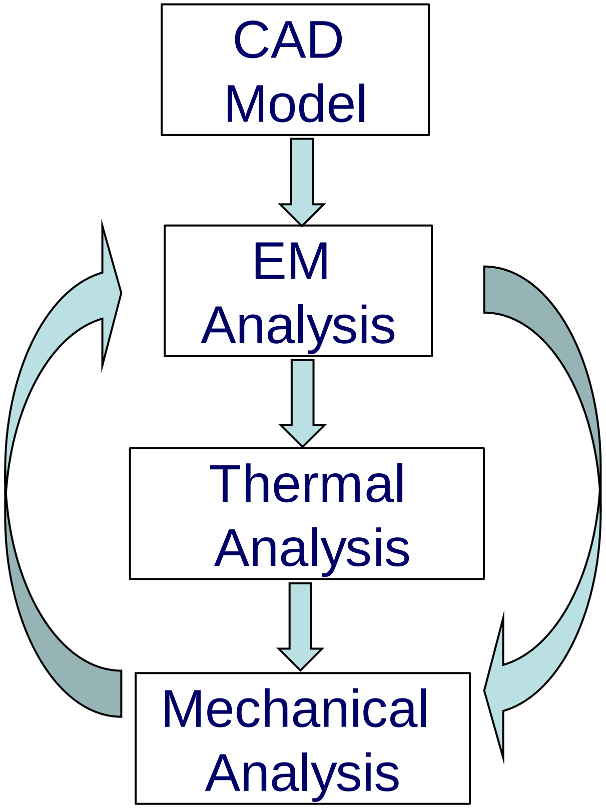
Advanced Computations

SLAC National Accelerator Laboratory

CW10, Stanford, September 20, 2010

TEM3P Multi-physics

TEM3P (**T**hermal – **E**lectromagnetic - Mechanical) Solver



TEM3P -Thermal Analysis

Equation for heat distribution

$$\nabla \cdot k(T)\nabla T = 0 \text{ in } \Omega$$

subject to boundary conditions:

- Prescribed temperature $T = T(x)$
- Heat input $k\frac{\partial T}{\partial n} = q$
- Insulated surface $\frac{\partial T}{\partial n} = 0$
- Convection $k\frac{\partial T}{\partial n} = h(T_0 - T)$

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TEM3P -Thermal Solver Capability

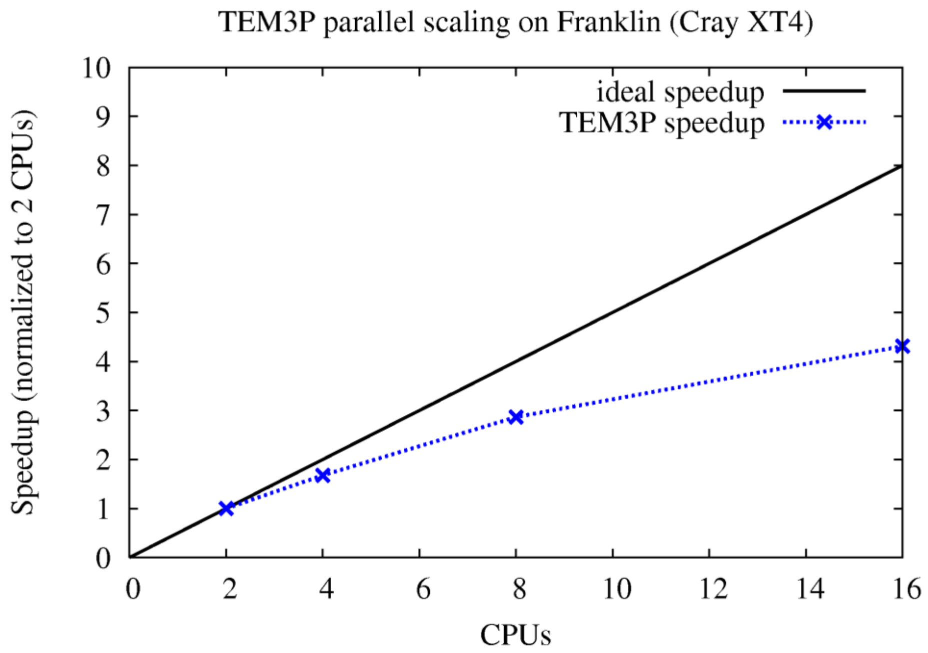
- Solver - Combine Picard with Newton method
  - Use Picard at the beginning
  - Switch to Newton when close to solution
- Capabilities
  - EM heating
  - Nonlinear thermal conductivity in near superconductivity condition - for example, Nb
  - Fluid-Solid interface - nonlinear Neumann boundary condition (Helium-Nb interface)
  - Shell elements for surface coating -

TEM3P -Thermo-Elasticity Analysis & Scaling

- Formulation

$$\nabla \cdot \left[\mu(\nabla \mathbf{u} + \nabla \mathbf{u}^T) + \lambda(\nabla \cdot \mathbf{u})\mathbf{I}\right] - (3\lambda + 2\mu)\alpha\nabla T = 0 \text{ in } \Omega$$
$$\mathbf{u} = \hat{\mathbf{u}} \text{ at } \Gamma_D$$
$$[\mu(\nabla \mathbf{u} + \nabla \mathbf{u}^T) + \lambda(\nabla \cdot \mathbf{u}) - (3\lambda + 2\mu)\alpha T\mathbf{I}]\mathbf{n} = 0 \text{ at } \Gamma_N$$

- TEM3P strong scaling



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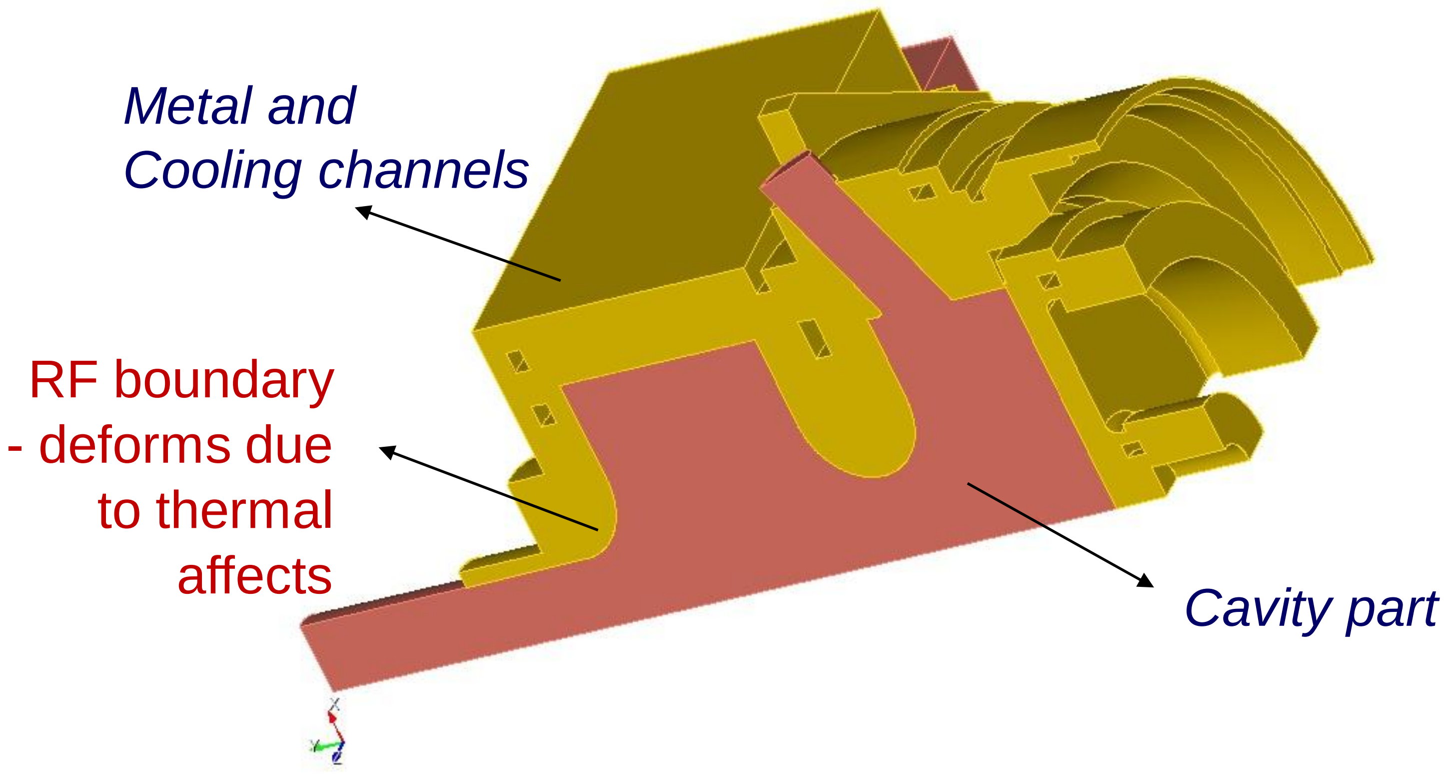
TEM3P Benchmark of RF Gun Cavity

Goal: to compute the thermal drift in RF frequencies due to the mechanical deformations caused by EM heating



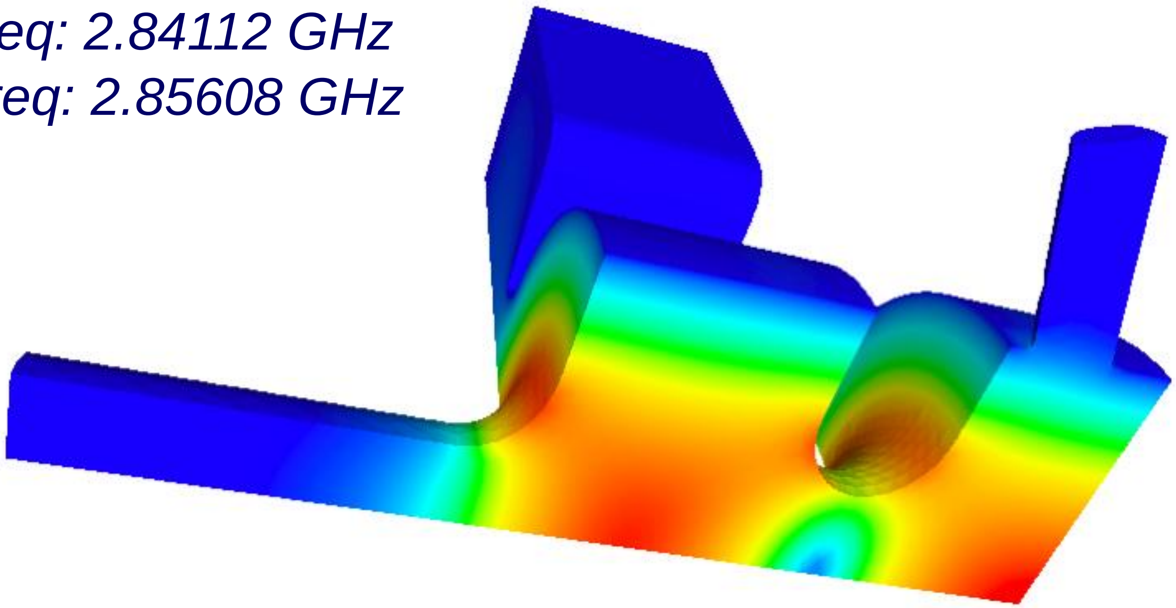
TEM3P - RF Gun Cavity EM Analysis

Power loss:

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

Two modes:

- *1st freq: 2.84112 GHz*
- *2nd freq: 2.85608 GHz*



Electric field distribution for the accelerating mode

TEM3P - RF Gun Cavity Thermal Analysis

- 7 cooling channels with bulk temperatures ch1: 25.21, ch2:25.85, ch3: 25.73, ch4: 25.9, ch5: 25.91, ch6: 26.05, ch7: 25.9, and film coefficients: ch1: 22409, ch2: 22584, ch3: 22272, ch4: 21542, ch5: 22320, ch6: 21447, ch7: 7000
- TEM3P: cooling channels are modeled as Robin (mixed) BC.
- Thermal load from EM power loss (4000 Watt), EM Heating BC.
- Thermal conductivity for copper 391
- Thermal conductivity for stainless steel 16.2

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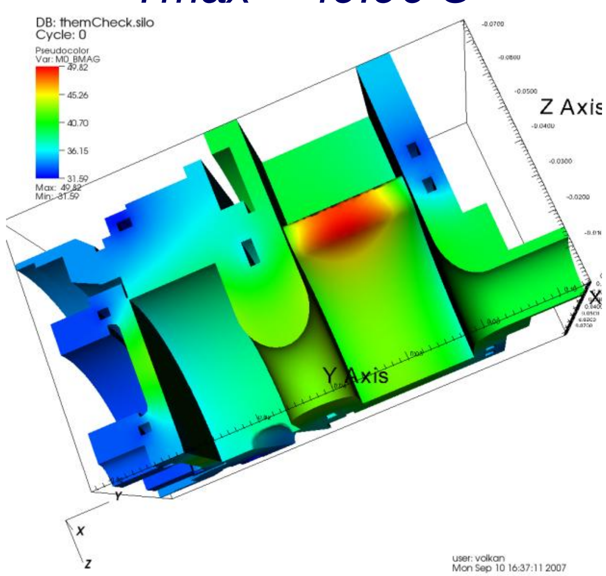
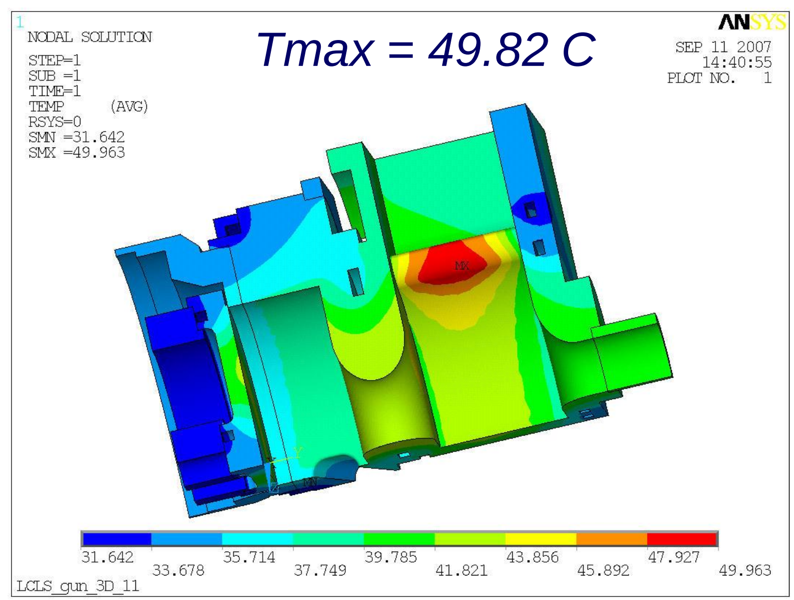
Tmax = 49.96 C



ANSYS



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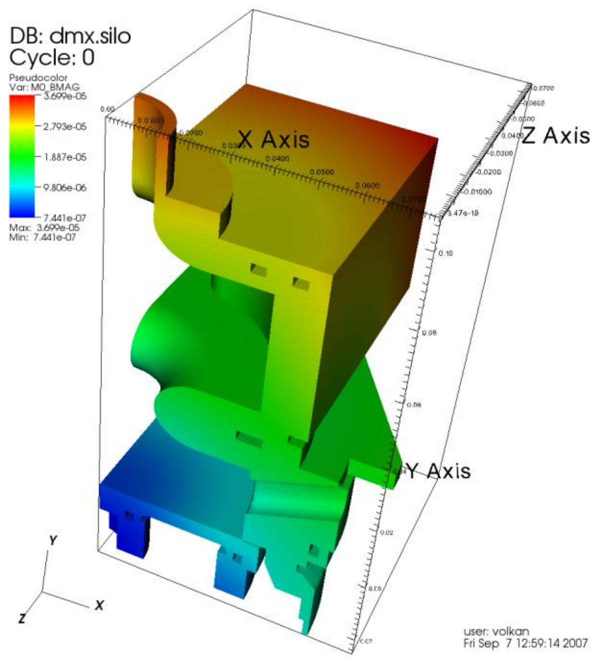
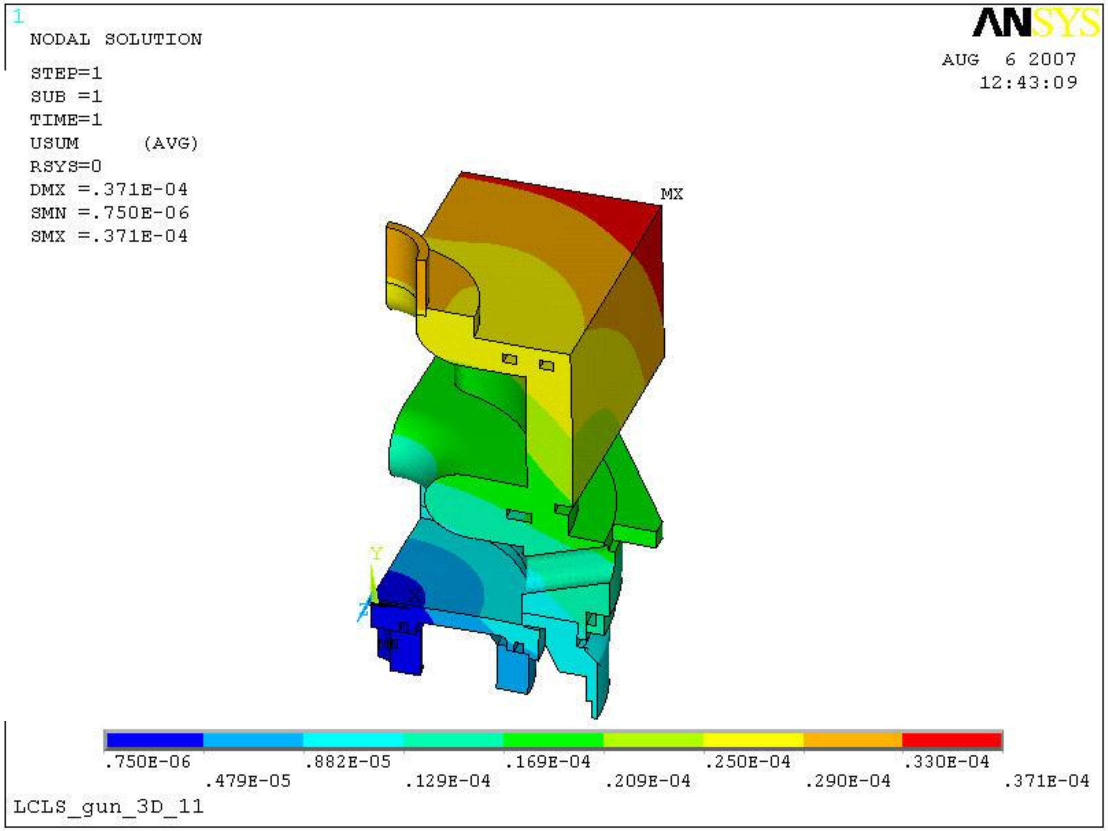
TEM3P - RF Gun Cavity Thermo-elastic Analysis

TEM3P	ANSYS
Umax = 3.699e-5m	*Umax = 3.71e-5 m*





TEM3P - RF Gun Cavity Thermal Drift

- Ideal cavity
  - 1st freq: 2.84112 GHz
  - 2nd freq: 2.85608 GHz

- Deformed cavity
  - 1st freq: 2.84101 GHz
  - 2nd freq: 2.85593 GHz

For 2nd freq. $\Delta f = 1.5$ e5 Hz

TEM3P - Lorentz Force Detuning

- In superconducting cavities, high electromagnetic fields produce a Lorentz force acting as a pressure force perpendicular to the cavity walls.

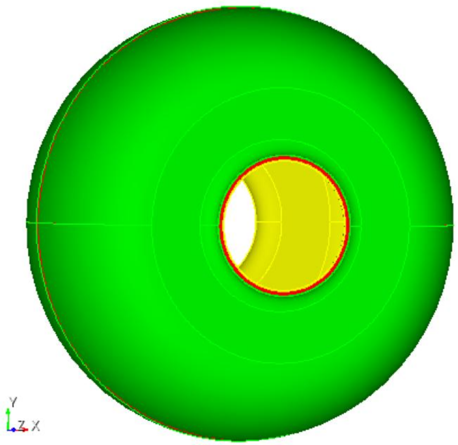
- The gradient dependent Lorentz force detunes the cavity and is proportional to the square of the electric field.

$$\mathbf{P} = \frac{1}{4}\left(\mu_0|\mathbf{H}|^2 - \epsilon_0|\mathbf{E}|^2\right)$$

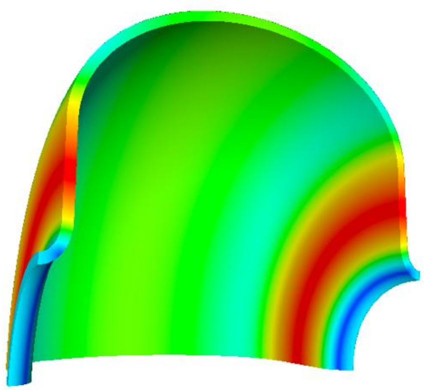
- Lorentz force detuning simulation has two steps:
  - Use Omega3P to solve for the accelerator field.
  - Use TEM3P to solve the for structural deformations

TEM3P - Lorentz Force Detuning in ICHIRO Cavity

The CAD model



Deformation



Parameters:

- Acceleration gradient: 26.5 MV/m
- Elastic property: 1.05×10^{11} N/m^2
- Wall thickness: 2.8 mm

Maximum displacements caused by Lorentz for using different meshes

Mesh layer	No. DOFs	order	Umaxz
1	116,025	2	4.653*e*-8 m
2	1,101,558	2	4.728*e*-8 m
4	4,764,993	2	4.735*e*-8 m