Cavity detuning due to power dissipation : a new numerical approach combining the thermo-mechanical and the e.m. codes

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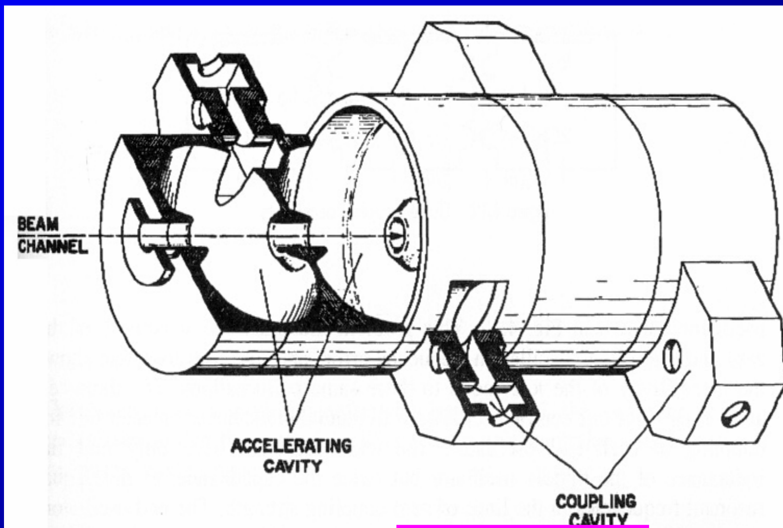
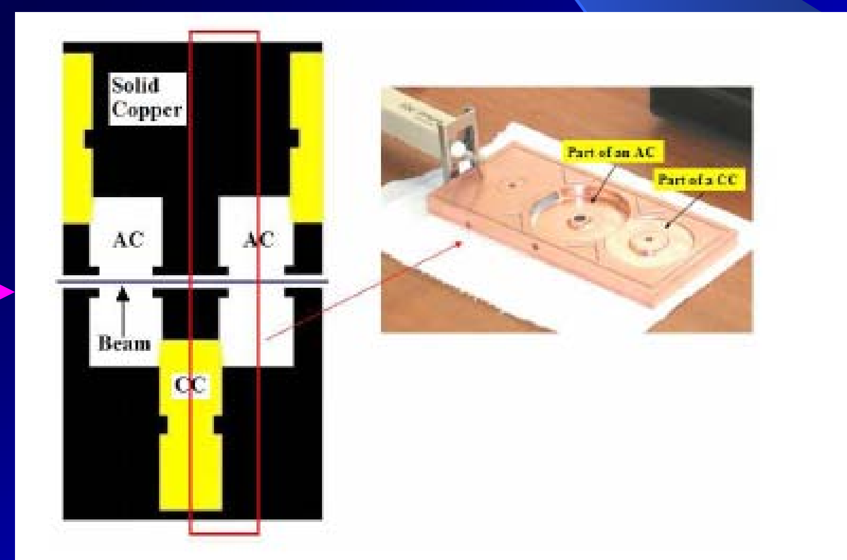
SIDE COUPLED LINAC (SCL)

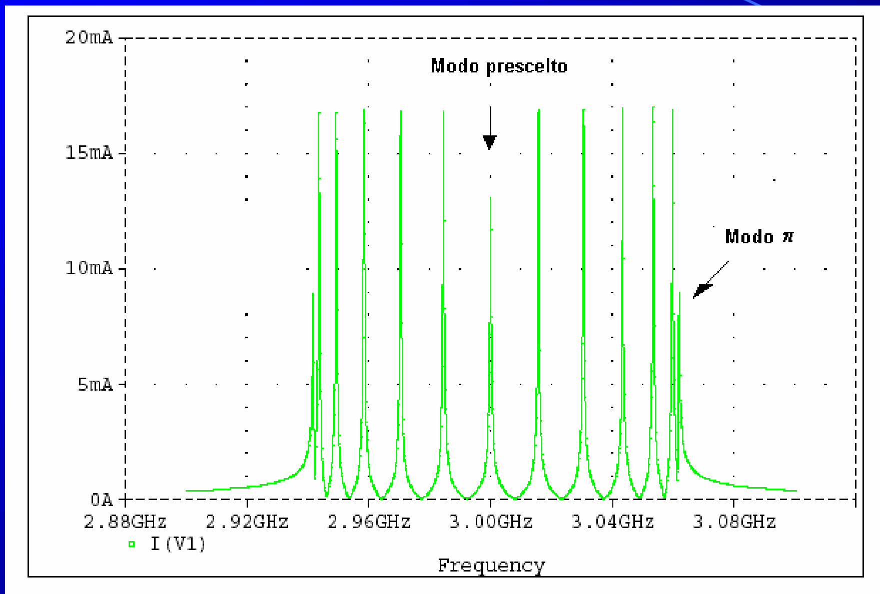


- Coupled Cavity Biperiodical System
- π/2 MODE

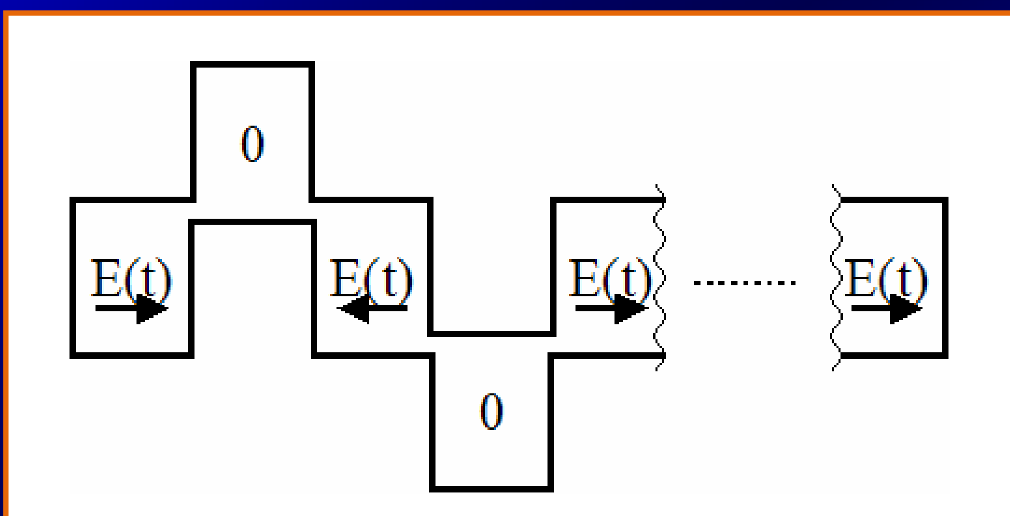


In the Fifties this Configuration was First Introduced at LANL

The π/2 MODE



Largest separation in frequency from adjacent frequencies.



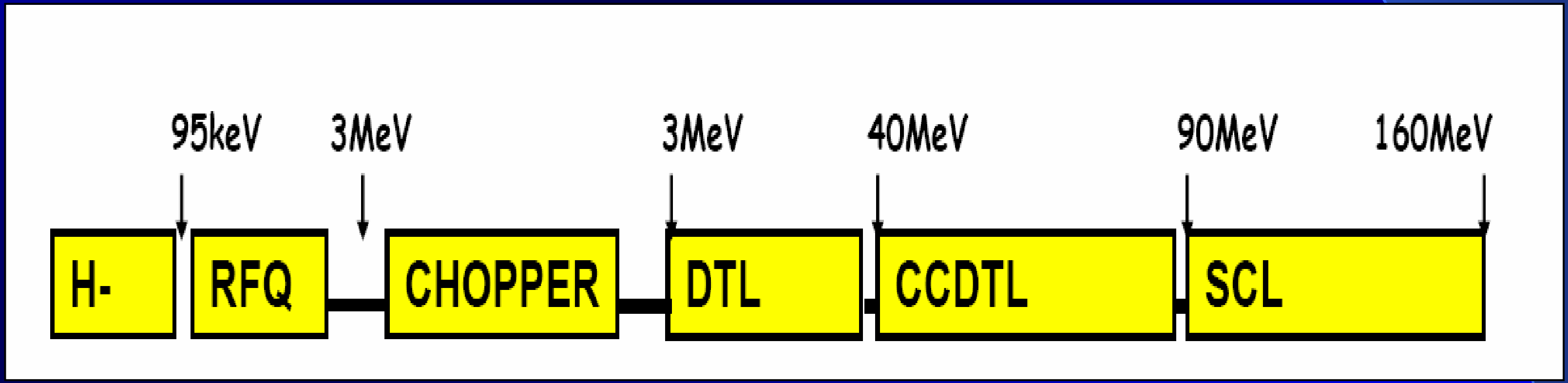
Zero field along axial direction in coupling cells.

Synchronization

LINAC4

LINAC4 is designed for doubling the beam “luminosity” and intensity at the exit *of PS Booster* thanks to use of H^- ions and to obtain a higher beam injection energy (160MeV).

Block diagram of linear accelerator



ELECTROMAGNETIC AND TERMOMECHANICAL BEHAVIOUR

The heating produced by electromagnetic power dissipated on the walls, produces a deformation of the cavity geometry which depends on the termomechanical boundary conditions. Tha effect is a variation of resonant frequency.

Not taking adeguated precautions, may produce to a discord between the feeder and the cavities: the final result can be a accelerating field reduction and so a mismatch of the particle pace from gap to gap accelerating field period.

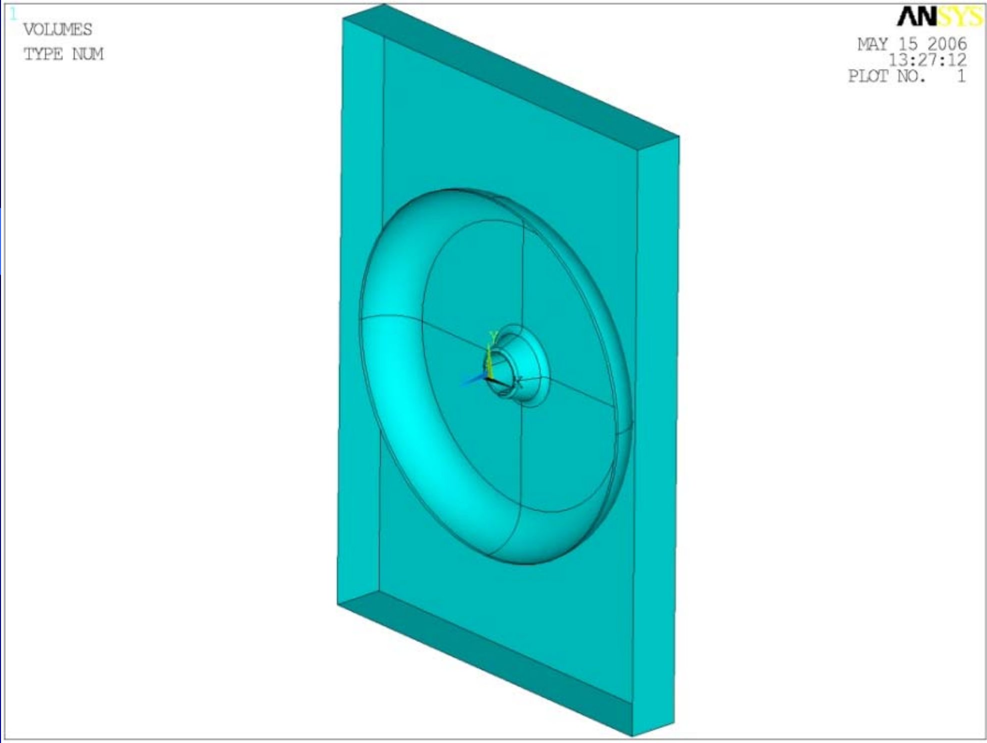
An accurate evaluation of the resonance frequency variation is a must.

THE ACCELERATING CAVITY

The model consists in an accelerating cavity of the ***Side Coupled Linac*** that is the last accelerating phase of ***LINAC4*** . This was analysed by means of the code ANSYS.

The choice of the subset to be analyzed must take into account the simmetries:

- Mechanical
- Thermal
- Geometrical
- Electromagnetis

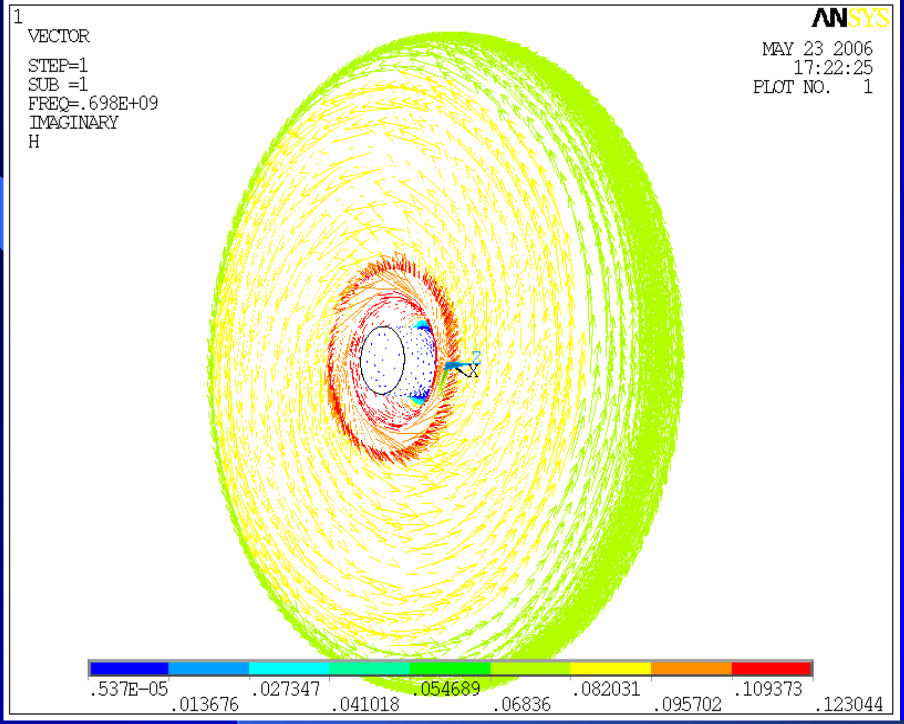


ELECTROMAGNETIC ANALYSIS

Frequency Form Amplitude of resonant field in the cavity are determined

- ✓ Mode TM_{01}
- ✓ $f_0 = 697.821$ MHz

Magnetic Field Representation in the cavity

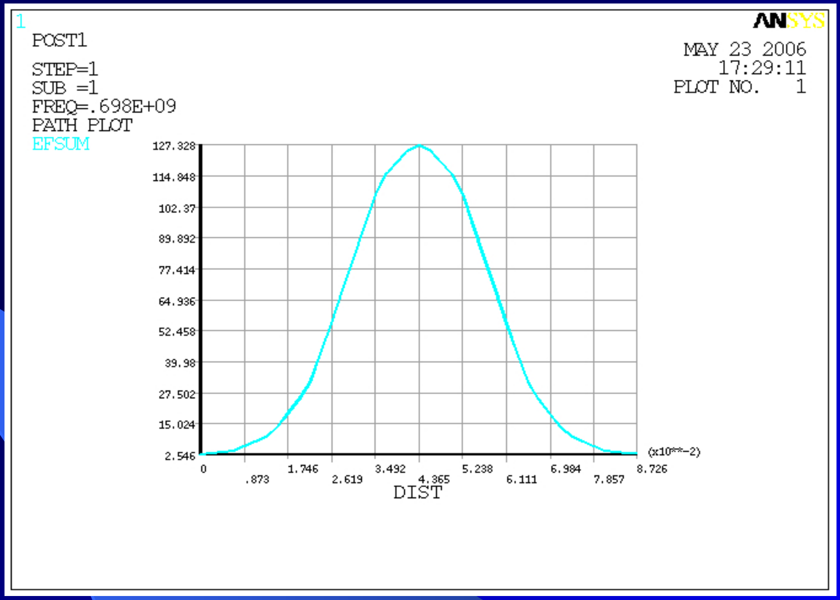


SCALING FACTORS

Reference Parameters:

- $E_0 = 4$ MV/m
- Duty Cycle = 1.5%

Electric Field Pattern given by ANSYS

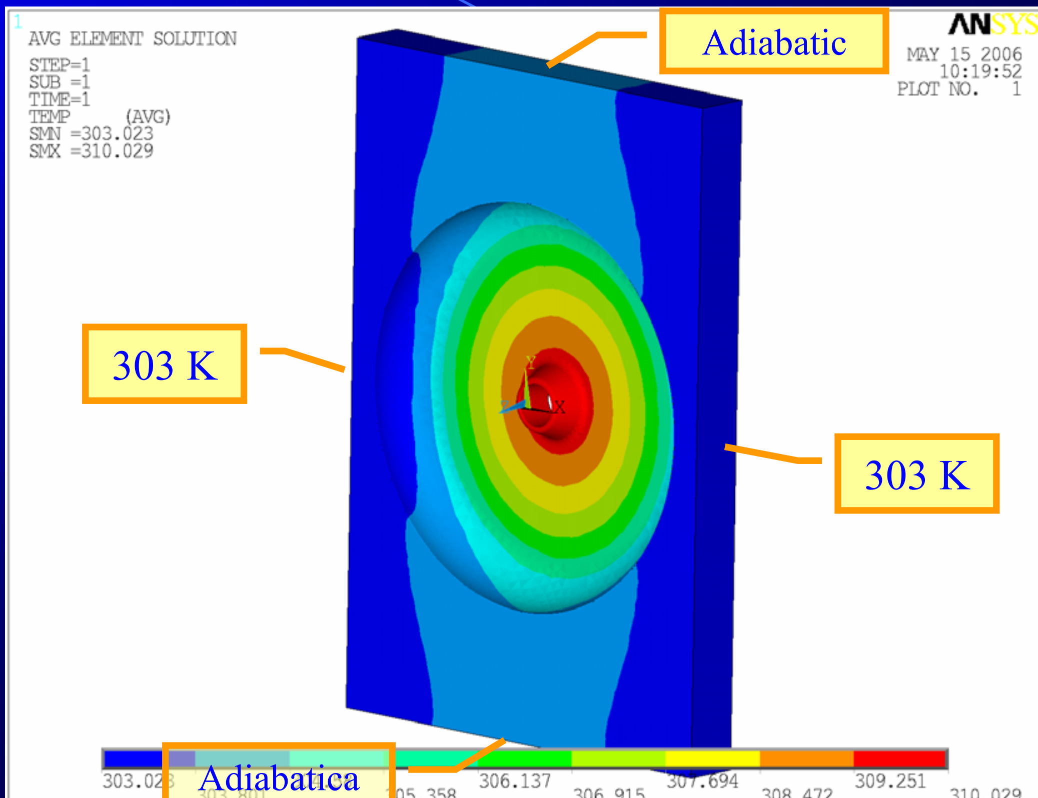


Field Pattern given by ANSYS → Scaling Factors →
→ Design Nominal Value of E.M. Fields

THERMAL ANALYSIS

By imposing as a “load” the e.m. power density dissipated on the cavity surface, it is possible to evaluate the heating induced in the subset

Temperature Pattern



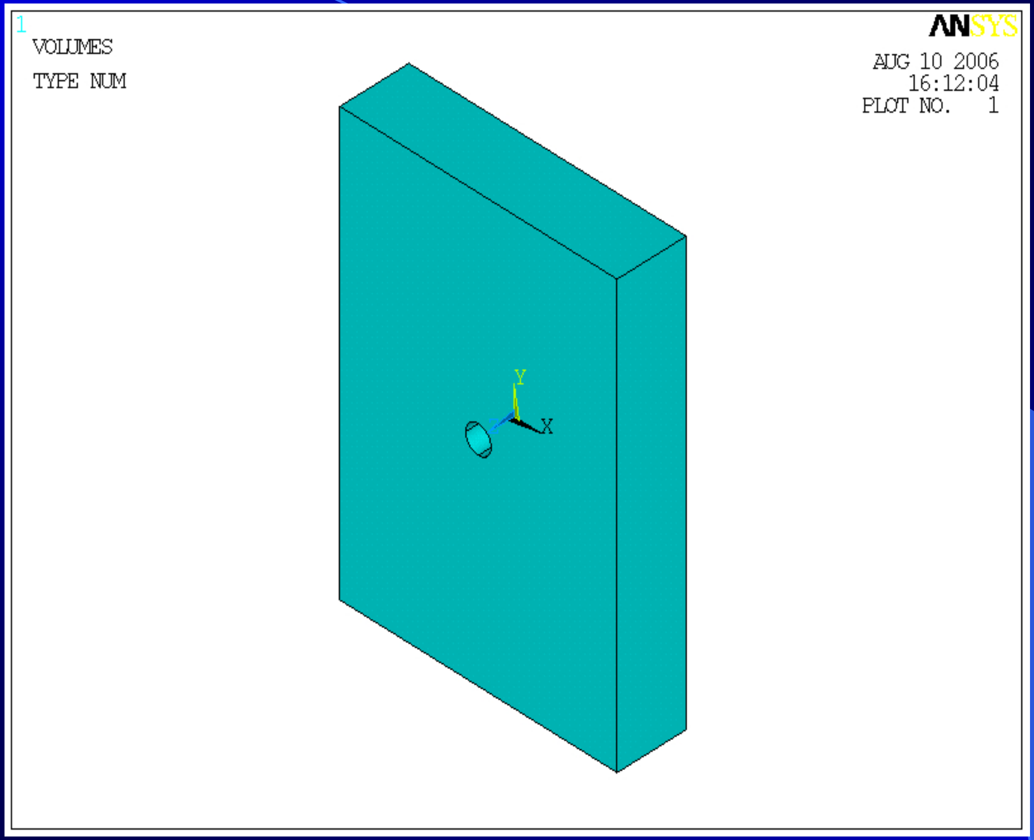
BOUNDARY CONDITIONS

- Chiller Temperature: **303 K**

- Because of thermal symmetry conditions rear and front surfaces are: **Adiabatic**

STRUCTURAL ANALYSIS

By imposing as a "load" the temperature pattern obtained by thermal analysis, it is possible to evaluate the stress and the strain in the structures



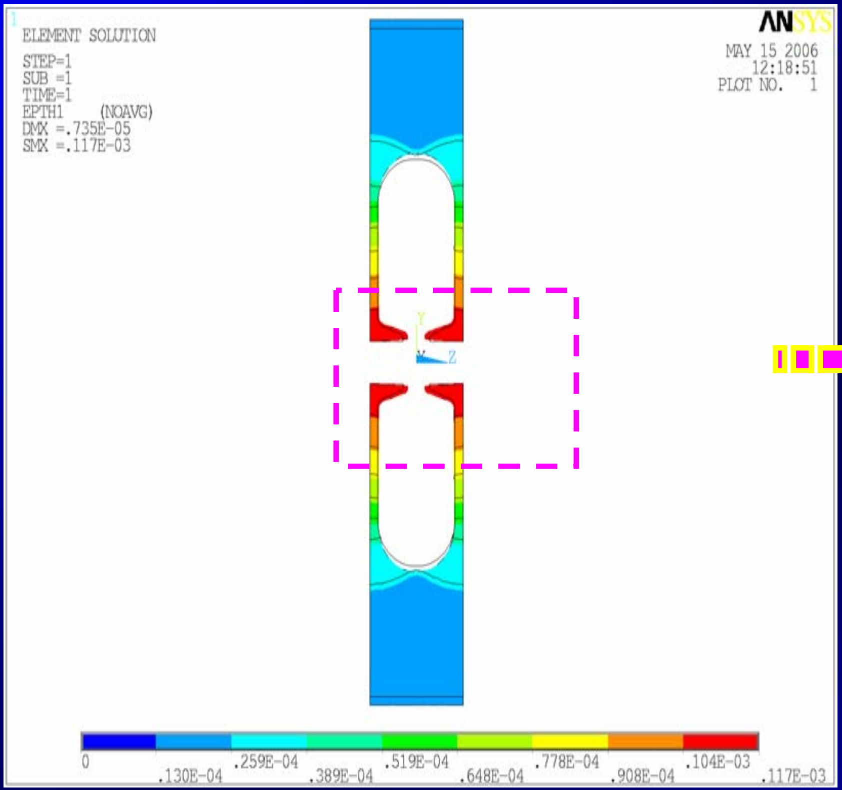
BOUNDARY CONDITIONS

- Rear and front surfaces:

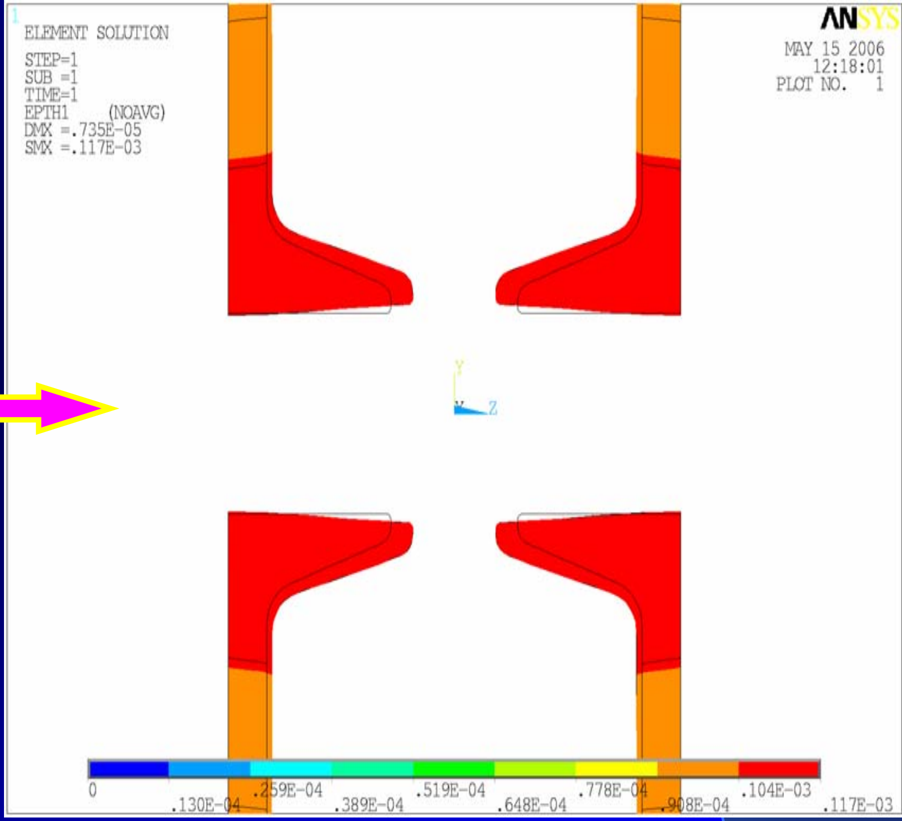
  ONLY SHIFTS IN THE PLANE

STRUCTURE DEFORMATION

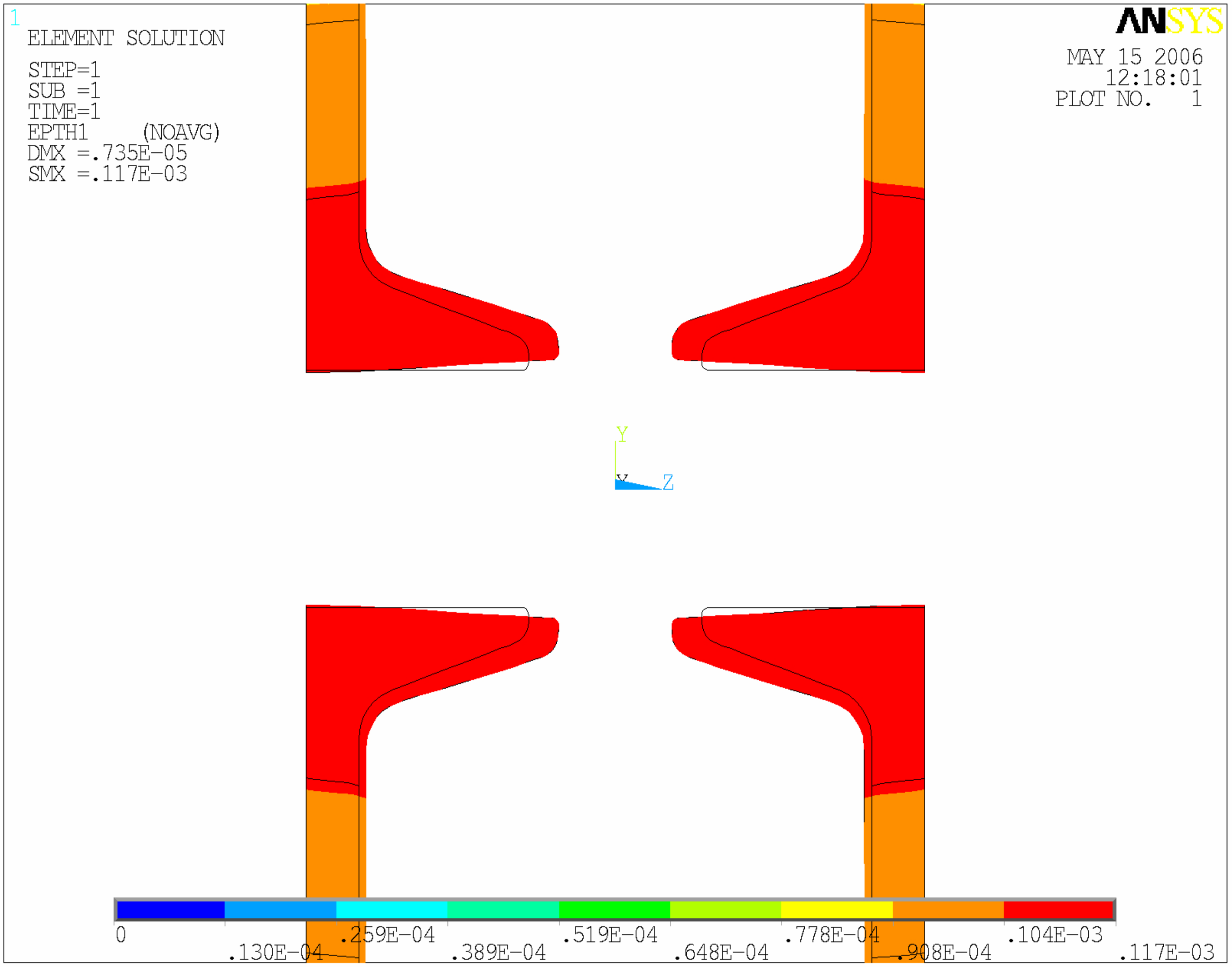
Subset Deformation



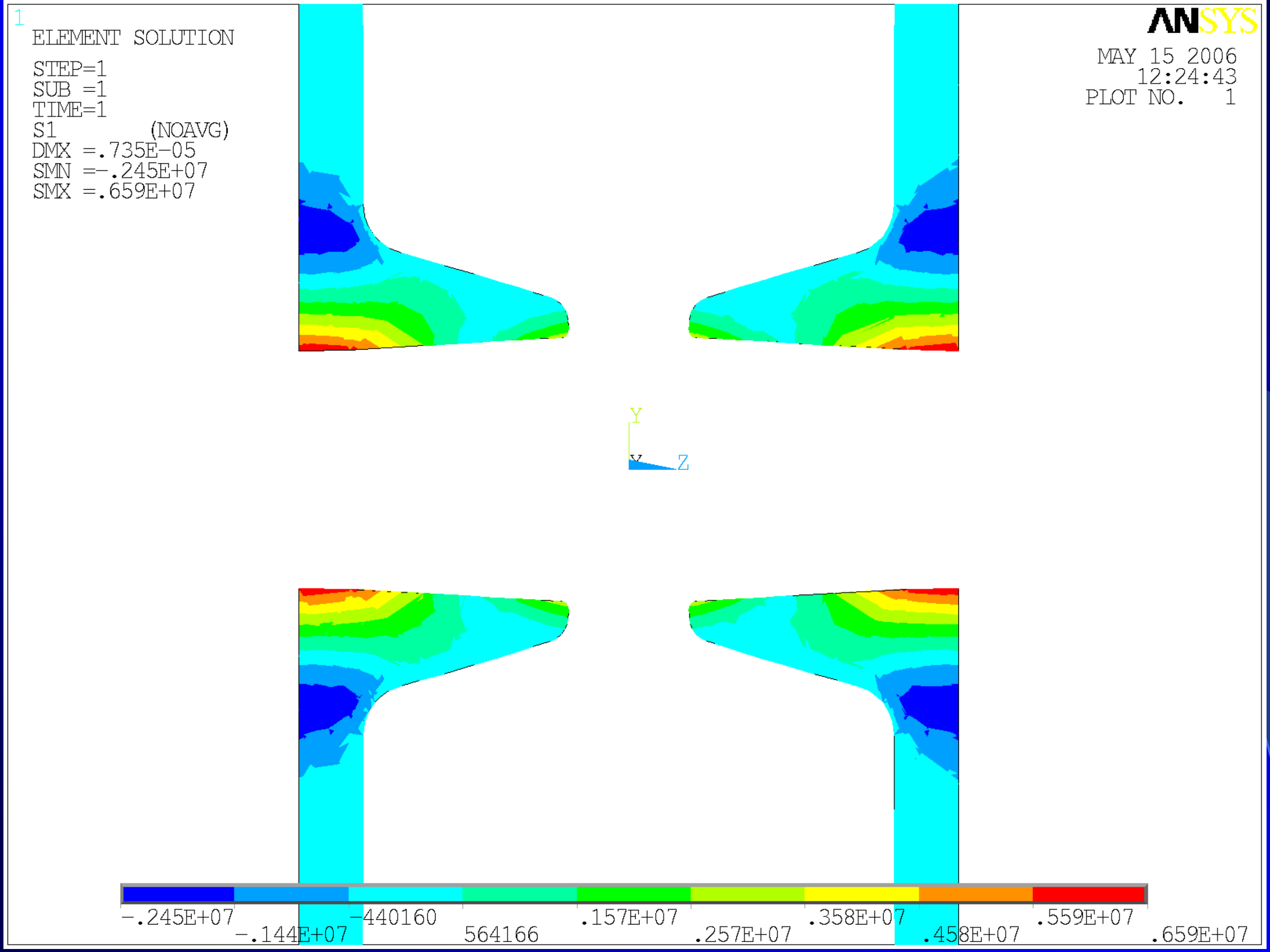
A Detail



Strain detail



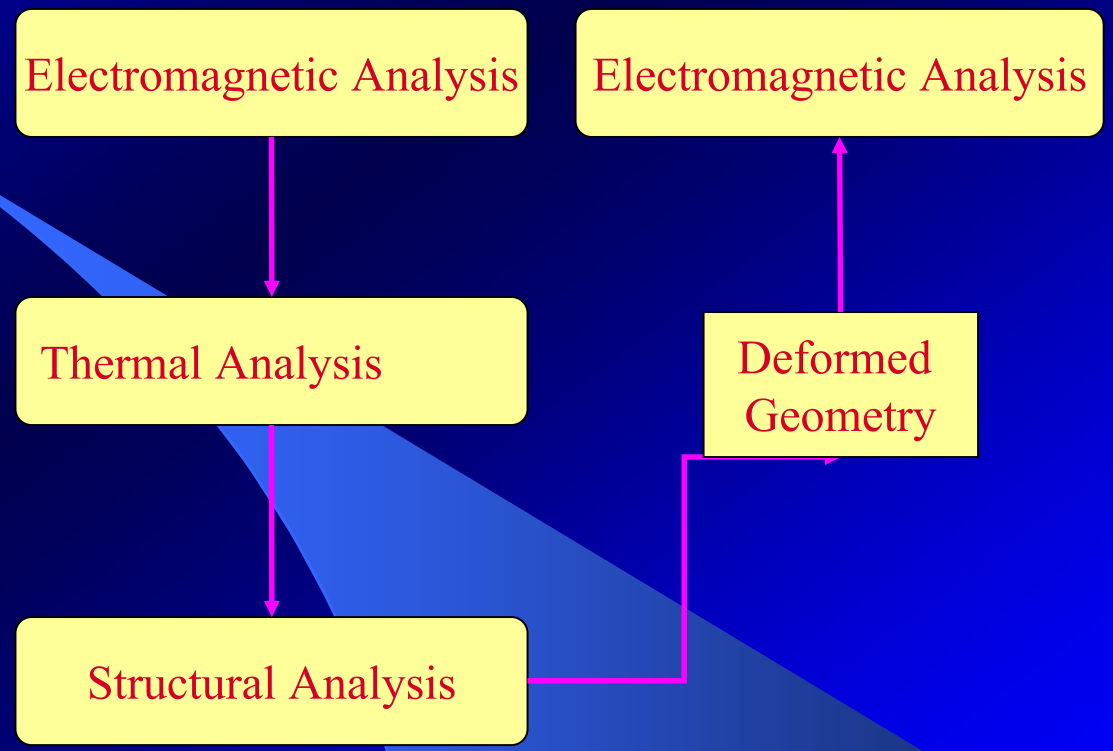
A detail of stress distribution



‘DETUNING’ CALCULATION

Classical Method

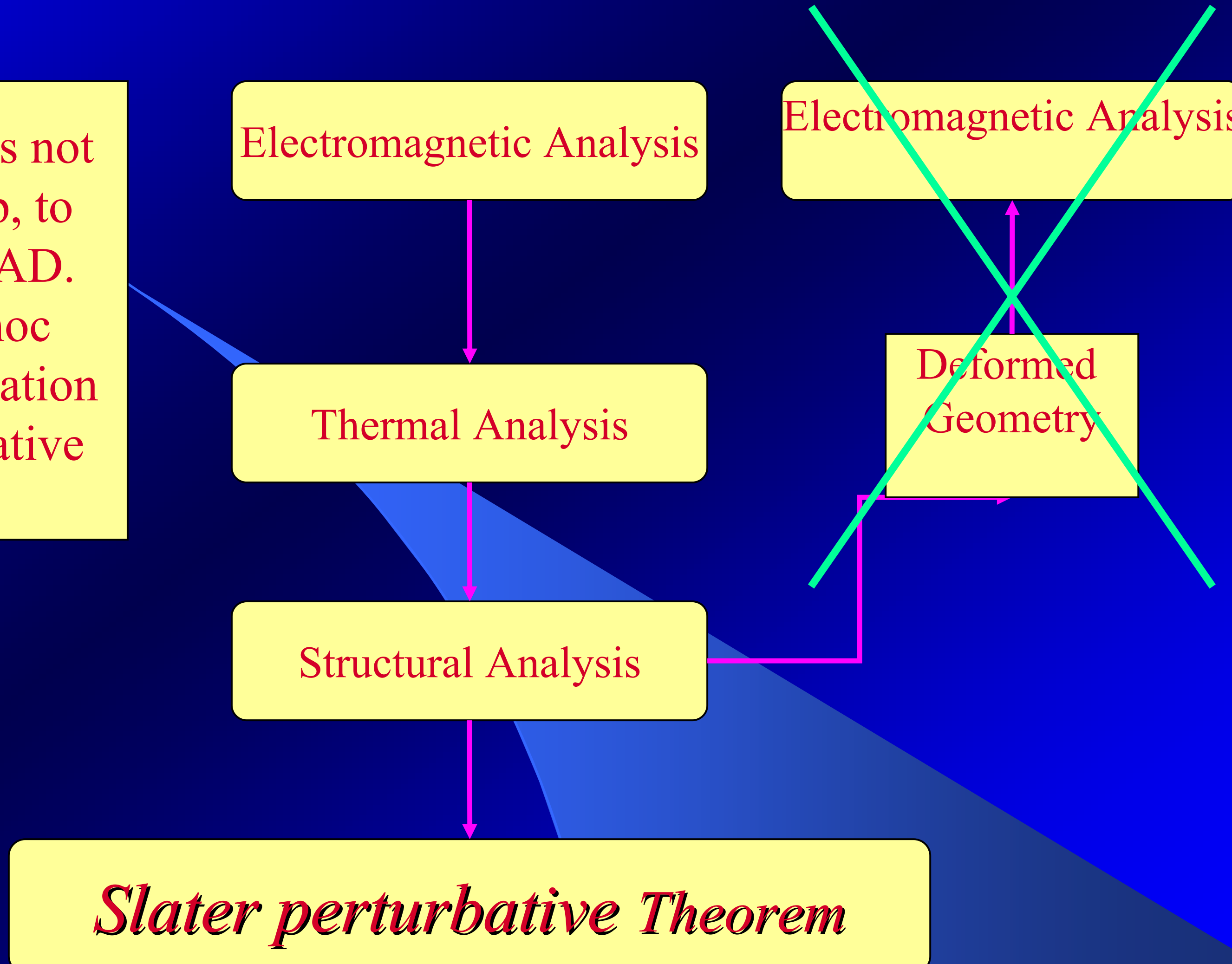
Classical Method used for detuning calculation foresees, starting from the result of the structure analysis ,the use of the finite element CAD



‘DETUNING’ CALCULATION

New Method

The new method does not resort, as a final step, to the finite element CAD. It resorts to an ad hoc numerical implementation of the Slater perturbative Theorem



SLATER PERTURBATIVE THEOREM

Slater Perturbative Theorem gives the resonance frequency variation for a small deformation in the cavity. The domain ΔV is the deformed volume.

$$\frac{\Delta f_0}{f_0} = \frac{\frac{1}{4}\iiint_{\Delta V}\left(\mu_0 H^2 - \varepsilon_0 E^2\right)dV}{\frac{1}{4}\iiint_{V}\left(\mu_0 H^2 + \varepsilon_0 E^2\right)dV} \cong \frac{\frac{1}{4}\iint_{\partial V}\left(\mu_0 H^2 - \varepsilon_0 E^2\right)*\left(\hat{n}\cdot\bar{v}\right)dS}{\frac{1}{4}\iiint_{V}\left(\mu_0 H^2 + \varepsilon_0 E^2\right)dV} = \frac{\Delta U_m - \Delta U_e}{U}$$

The vector $\hat{\boldsymbol{n}}$ is normal to the surface and $\bar{\mathbf{v}}$ is the strain vector on the surface

ANALYSIS AS A FUNCION OF THE 'MESHING'

An algorithm in Matlab workbench was implemented for numerical evaluation of Slater formula, using the field values, the strain vectors and the normal vectors on the surface.

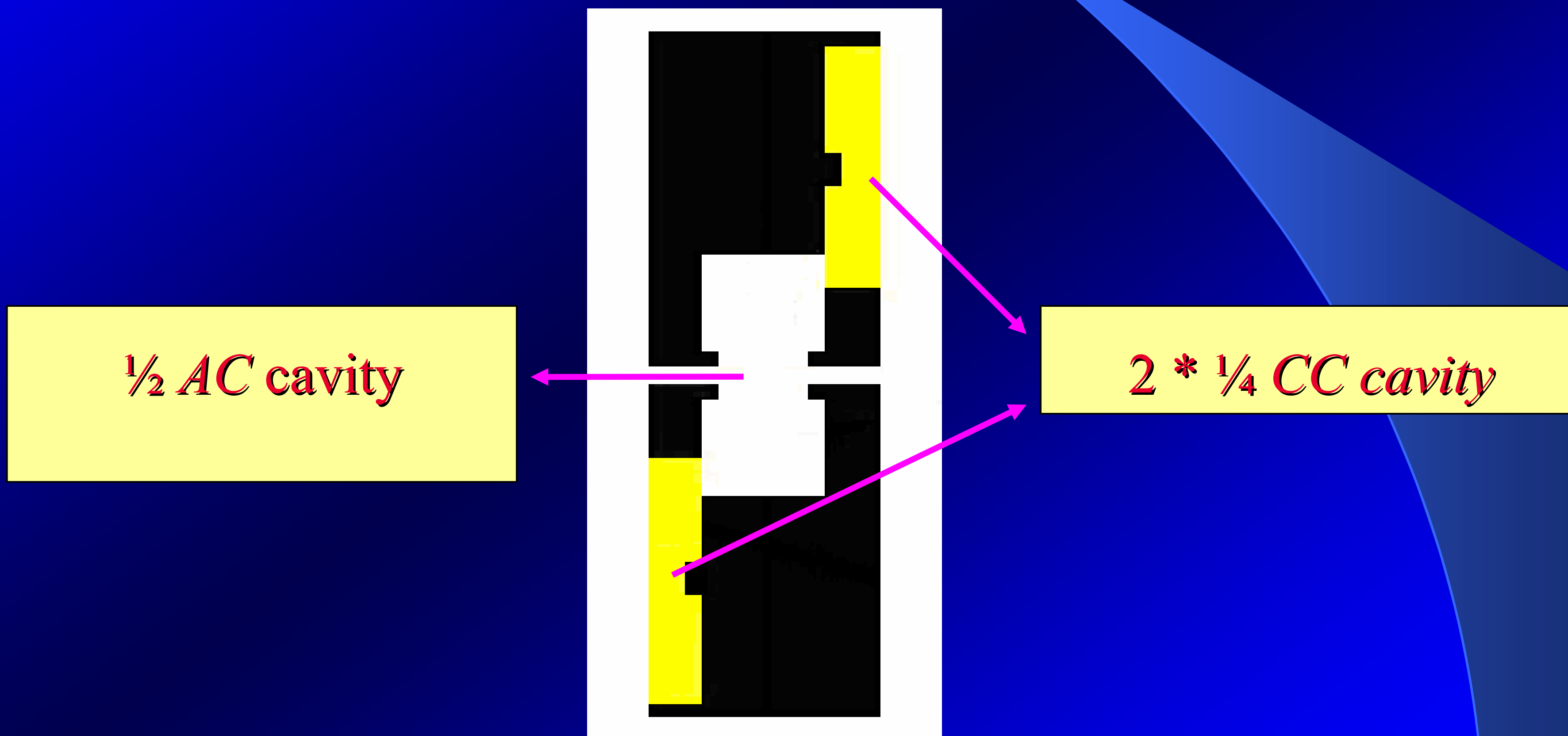
The accuracy of the new method was tested by means of the the implementation of simulations characterized by smaller and smaller amount of meshes.

Goals:

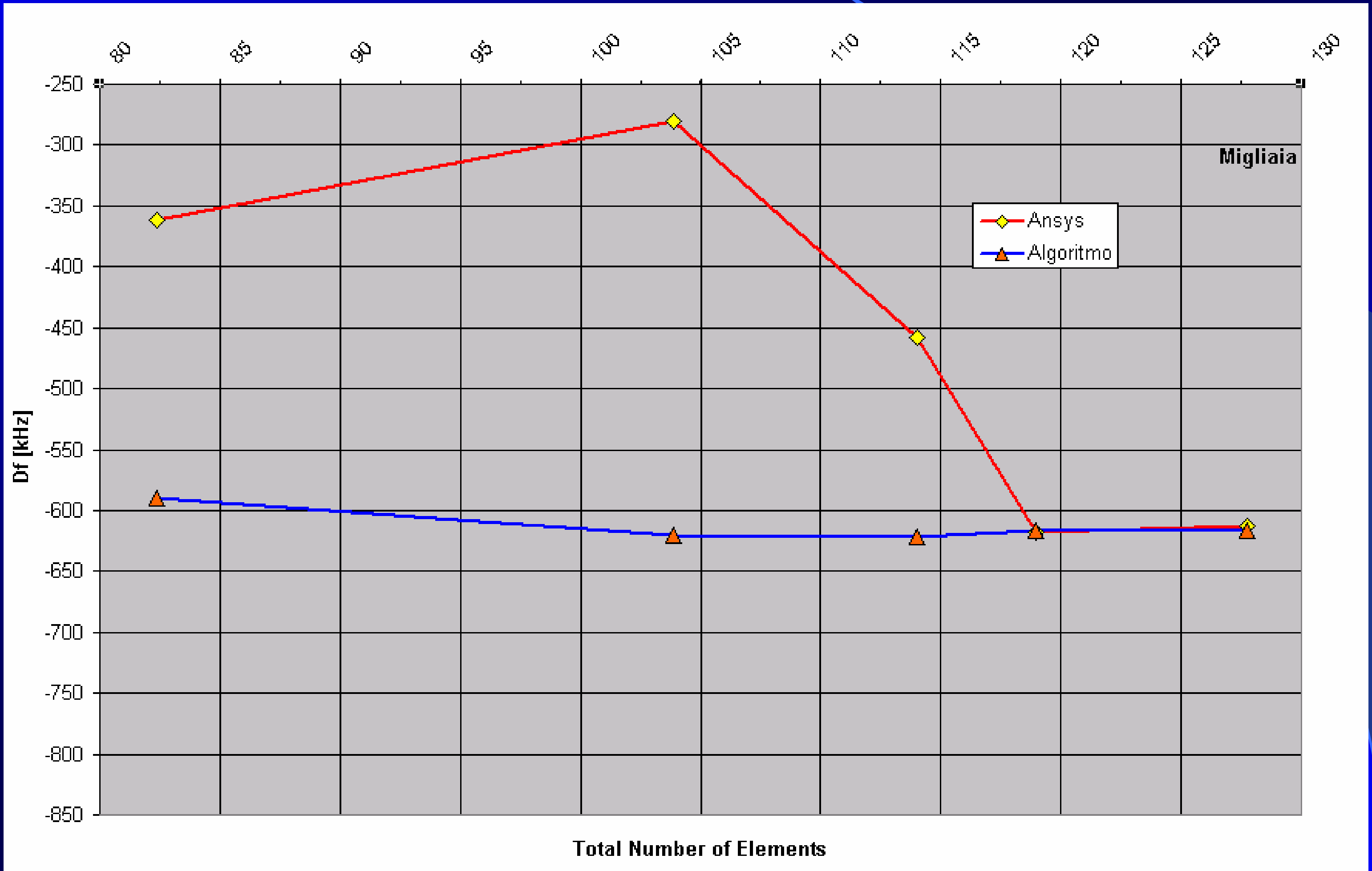
- ✓ Confrontation of the detuning values obtained with those of the standard method.
- ✓ Check the convergence velocity to the asintotic value as a function of the amount of meshes.

FURTHER ANALYSIS (closer to reality)

An interestintg test was the analysi of an *SCL* in its real shape:geometrical and electromagnetic. The subset, in spite of the seeming symmetries, is 8 times more complex than the previous one



Comparison between the frequency shifts calculated with the new algorithm (triangles) and the old procedure (circles) as a function of the mesh number.



REMARKS

CONVERGENCE OF THE STANDARD METHODS
TO THE ASYMPTOTIC VALUE

- FIRST CASE @ ~ 5.000 meshes

- SECOND CASE @ ~ 120.000 meshes

The complexity ratio is 8
The mesh number increases by a factor 24 !!

THE NEW METHOD IS ALREADY STABLE AT A MUCH SMALLER NUMBER OF MESHES !!

CONCLUSIONS: NEW METHOD A DVANTAGES

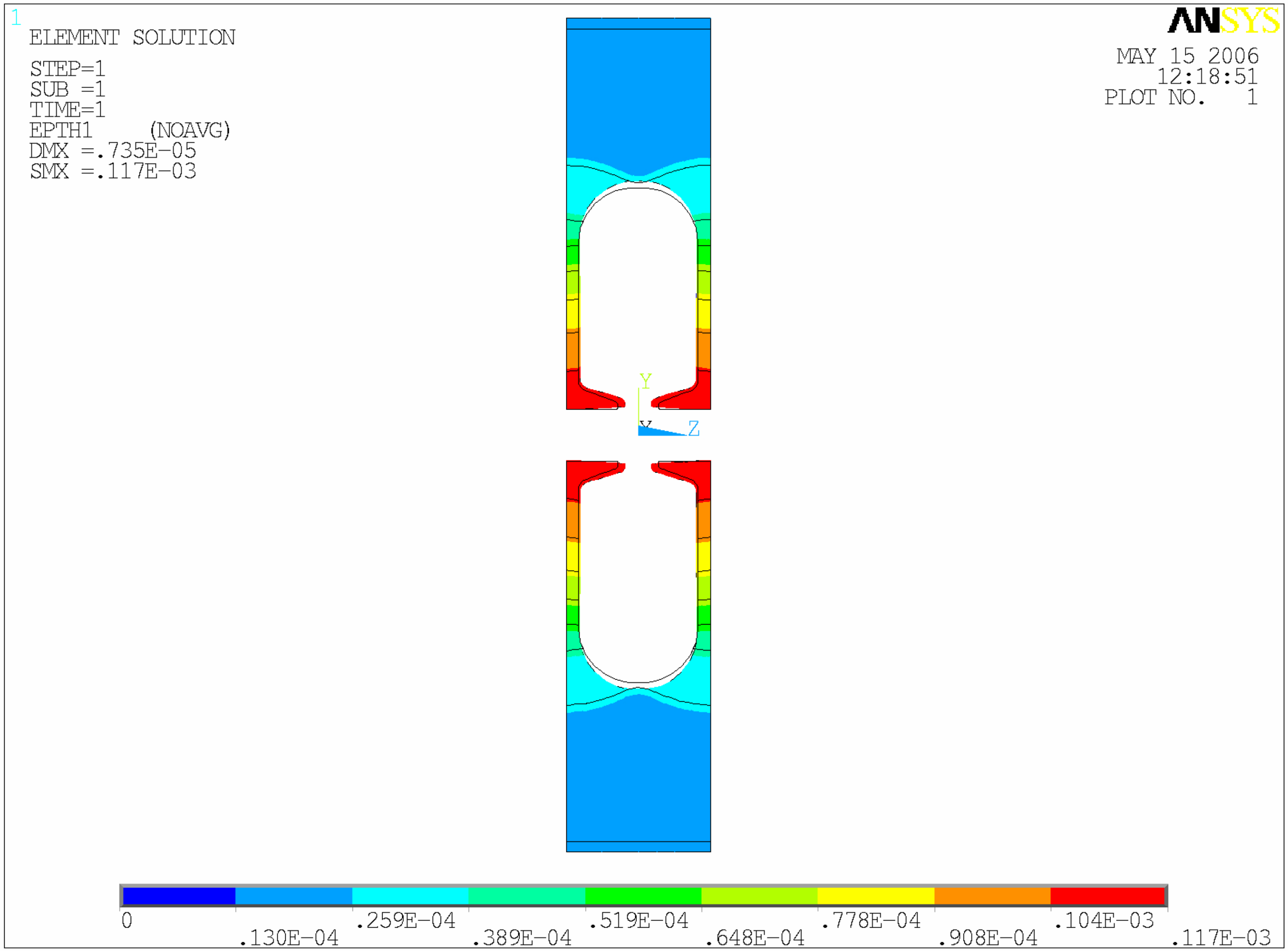
The accuracy of the results obtained with a small number of meshes gives :

✓The possibility to extend the analysis to more complex geometries

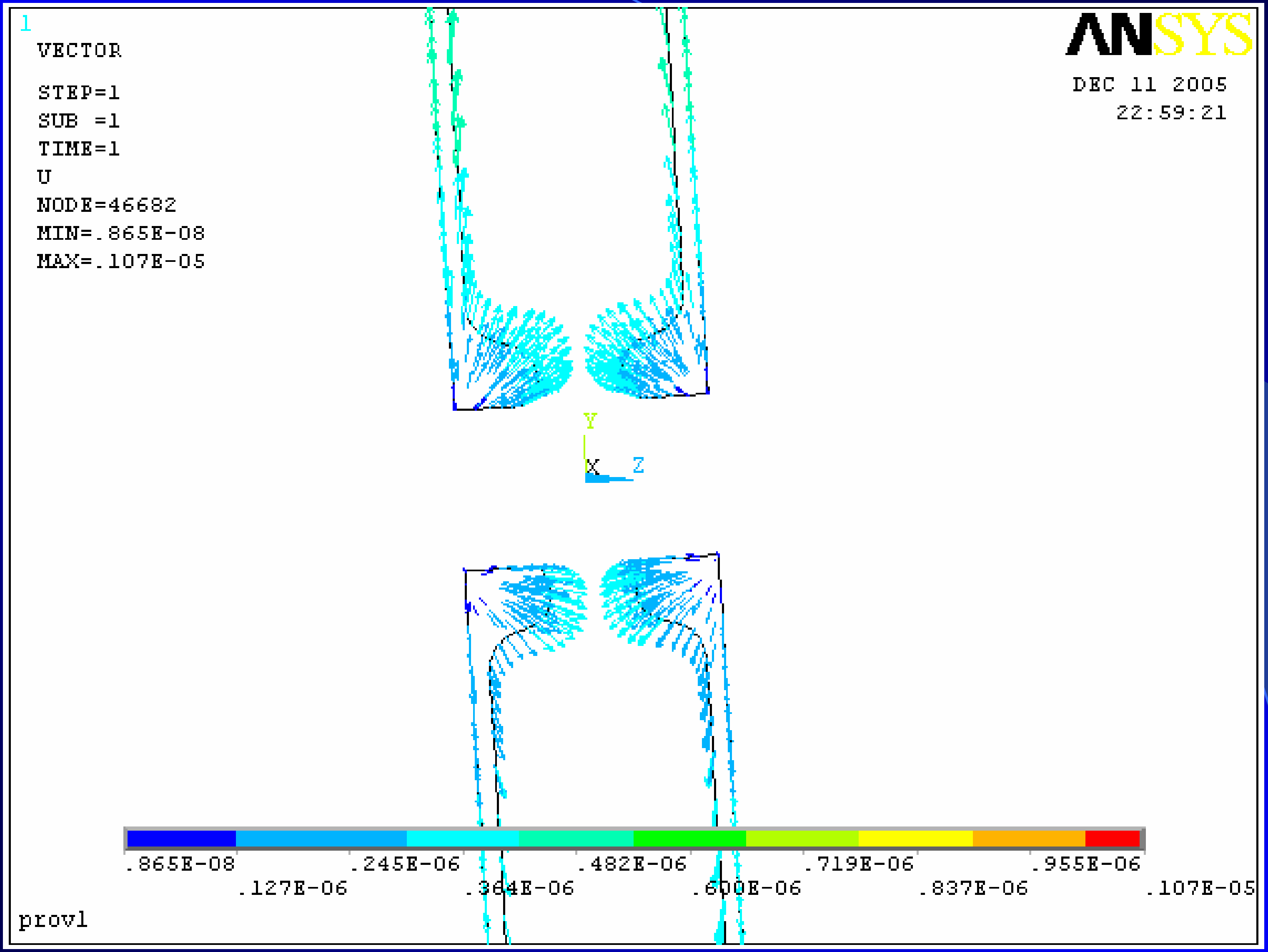
(ofte this is not allowed with the standard method because of the limited abailable hardware facility)

✓ To possibility to save computing time thanks to an inplementation of elettromagnetic e termo-mechanical analysis with a small number of elements

Strain total



Strain in the plane



CONFRONTATION OF THE RESULTS

The results are obtained by considering a reduced volume of the cavity