Omega3P - Eigensolver

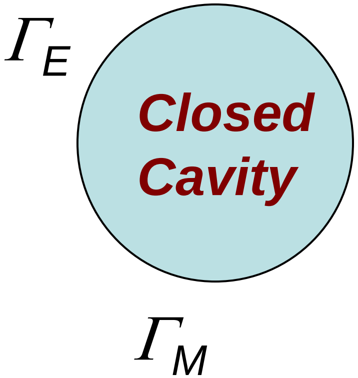
Advanced Computations

SLAC National Accelerator Laboratory

CW10, Stanford, September 20, 2010

Omega3P - Formulation of Closed Cavity

"Maxwell's Eqns in Frequency Domain"



$$\nabla \times \left(\frac{1}{\mu}\nabla \times \vec{\mathbf{E}}\right) - k^2\epsilon\vec{\mathbf{E}} = 0 \;\; on \;\; \Omega$$

$$\vec{\mathbf{n}} \times \vec{\mathbf{E}} = 0 \;\; on \;\; \Gamma_E$$

$$\vec{\mathbf{n}} \times \frac{1}{\mu}\nabla \times \vec{\mathbf{E}} = 0 \;\; on \;\; \Gamma_M$$

Discretization with Nedelec-type elements

$$\mathbf{E} = \textstyle\sum_i x_i \mathbf{N}_i$$

Eigenvalue Problem for Eigenvalue k2 and Eigenvector **X**

$$\mathbf{Kx} = k^2\mathbf{Mx}$$

Where

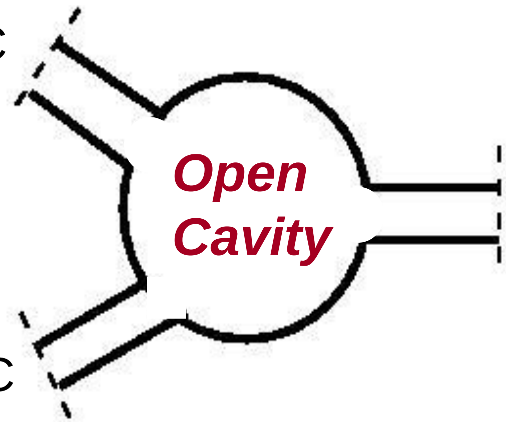
$$\mathbf{K}_{ij} = \textstyle\int_\Omega (\nabla \times \mathbf{N}_i) \cdot \frac{1}{\mu}(\nabla \times \mathbf{N}_j)\, d\Omega$$

$$\mathbf{M}_{ij} = \textstyle\int_\Omega \mathbf{N}_i \cdot \epsilon \mathbf{N}_j \, d\Omega$$

are M by N large sparse matrices

SLAC NATIONAL ACCELERATOR LABORATORY

Omega3P - Cavity with Waveguide Coupling



For waveguide loaded cavity with p number of ports:

$$\vec{\mathbf{n}} \times \frac{1}{\mu} \nabla \times \vec{\mathbf{E}} + P(\vec{\mathbf{E}}) = 0 \text{ where}$$

$$P(\vec{\mathbf{E}}) = \sum_{m}^{\infty} \sum_{n}^{\infty} \frac{k^2}{i\sqrt{k^2 - k_{mn}^2}} \vec{\mathbf{e}}_{tmn}^{TM} \int_{\Gamma} \vec{\mathbf{e}}_{tmn}^{TM} \cdot \vec{\mathbf{E}}\, d\Gamma - \sum_{m}^{\infty} \sum_{n}^{\infty} i\sqrt{k^2 - k_{mn}^2} \vec{\mathbf{e}}_{mn}^{TE} \int_{\Gamma} \vec{\mathbf{e}}_{mn}^{TE} \cdot \vec{\mathbf{E}}\, d\Gamma$$

Non-linear eigenvalue problem with complex eigenvalues (damping)

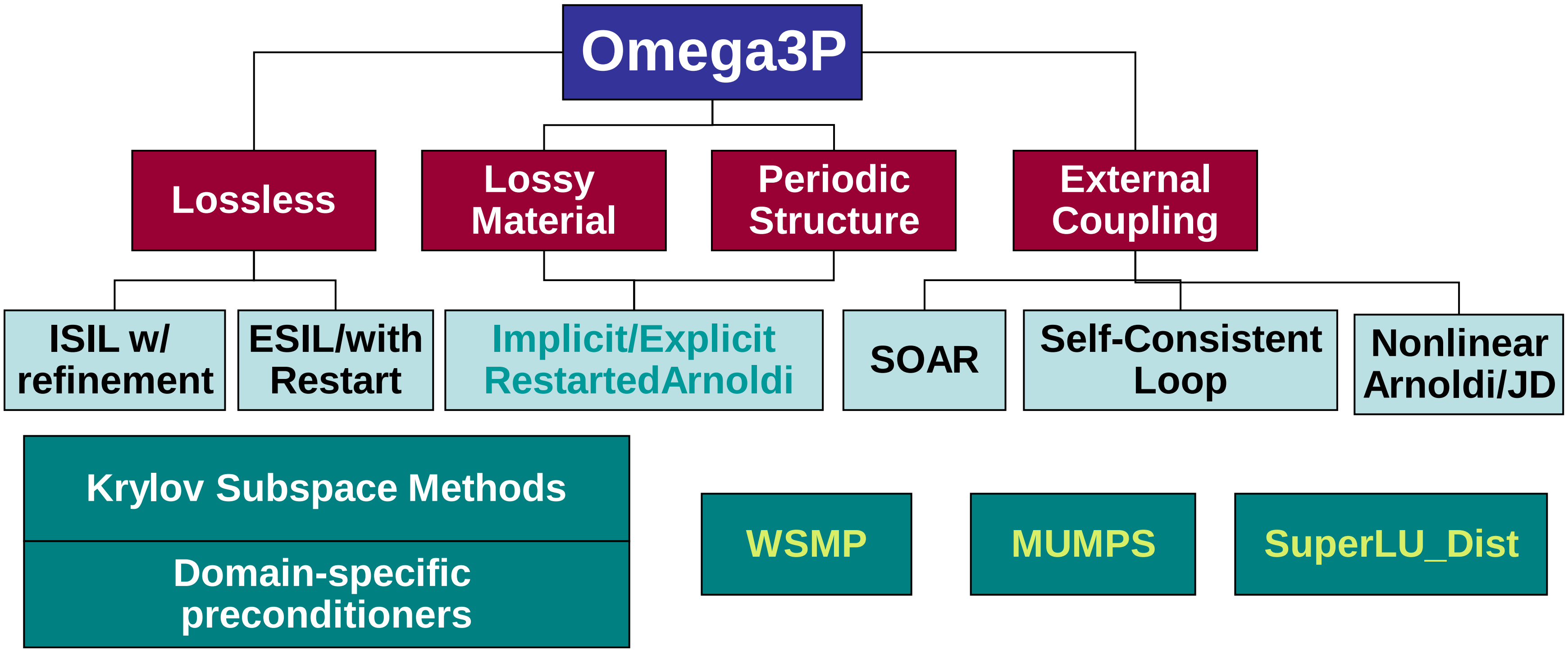
$$\mathbf{K}x + i \sum_{m,n} \sqrt{k^2 - k_{mn}^2}\, \mathbf{W}_{mn}^{TE} x + i \sum_{m,n} \frac{k^2}{\sqrt{k^2 - k_{mn}^2}} \mathbf{W}_{mn}^{TM} x = k^2 \mathbf{M} x$$

where

$$(\mathbf{W}_{mn}^{TE})_{ij} = \int_{\Gamma} \vec{\mathbf{e}}_{mn}^{TE} \cdot \mathbf{N}_i \, d\Gamma \int_{\Gamma} \vec{\mathbf{e}}_{mn}^{TE} \cdot \mathbf{N}_j \, d\Gamma$$

$$(\mathbf{W}_{mn}^{TM})_{ij} = \int_{\Gamma} \vec{\mathbf{e}}_{tmn}^{TM} \cdot \mathbf{N}_i \, d\Gamma \int_{\Gamma} \vec{\mathbf{e}}_{tmn}^{TM} \cdot \mathbf{N}_j \, d\Gamma$$

Omega3P Solvers



Each solver has its own features and performance depending on the application

Omega3P Capabilities

- Omega3P finds eigenmodes in

  lossless (real),

  periodic (real),

  lossy (complex),

  externally damped/loaded (complex) cavities

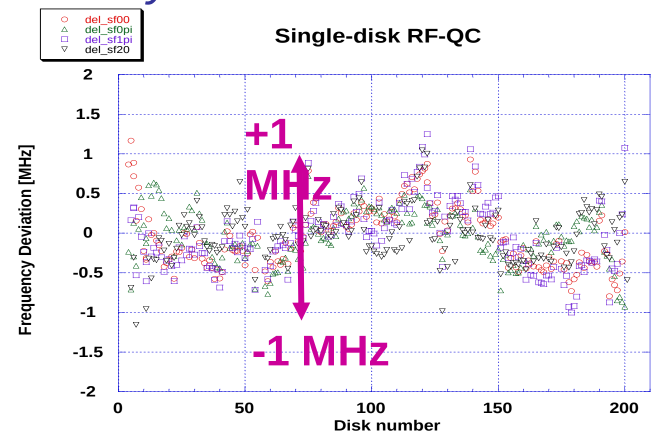
- Omega3P can be used to

  - optimize RF parameters,
  - reduce peak surface fields,
  - calculate HOM damping,
  - find trapped modes & their heating effects,
  - design dielectric & ferrite dampers, etc.

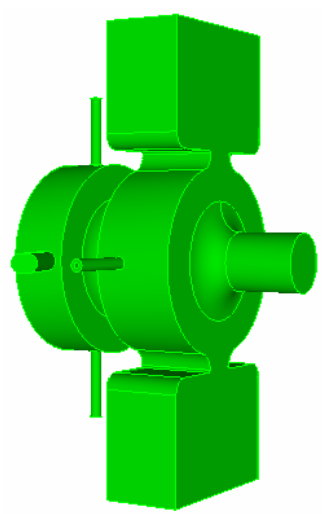
Omega3P Benchmarks - NLC Cell & LCLS Gun Cavity

Omega3P validated in 3D NLC Cell design in 2001

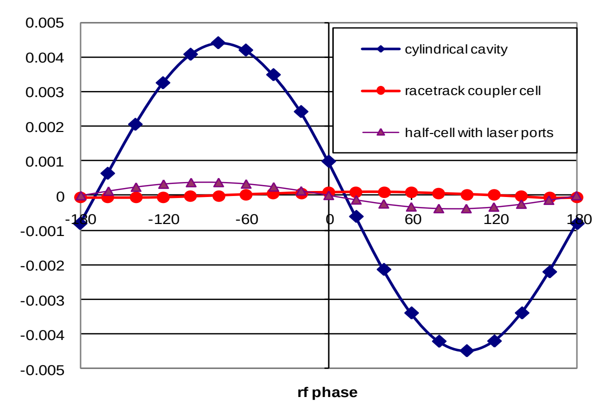
Microwave QC verified cavity frequency accuracy to 0.01% relative error (1MHz out of 11 GHz)



Omega3P compared with measurements in LCLS Gun Cavity Design

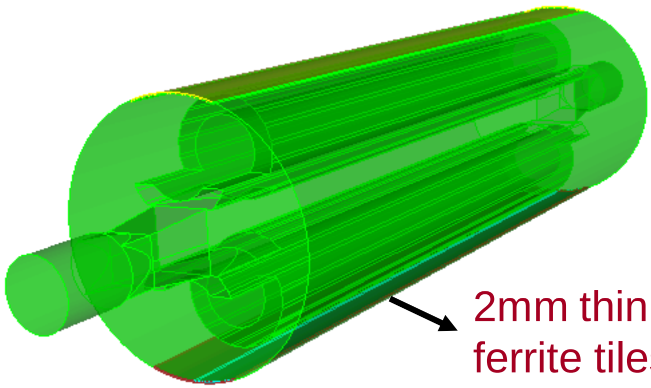


RF parameter	Design	Measured
fπ (GHz)	2.855987	2.855999
Qo	13960	14062
β	2.1	2.03
Mode Sep. Δf (MHz)	15	15.17
Field balance	1	1



Omega3P – LARP Collimator & Project-X Injector

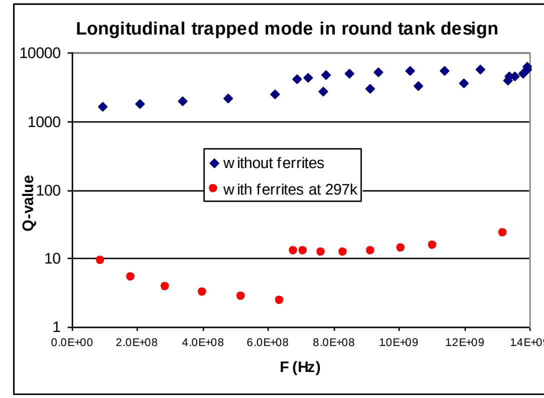
LHC / LARP Collimator



2mm thin ferrite tiles

- Trapped modes can cause excessive heating
- Adding ferrite tiles on circular vacuum chamber wall strongly damps trapped modes

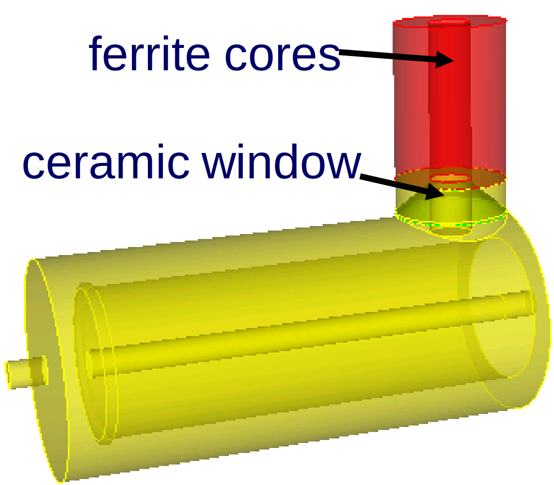
Q of resonant modes w/ and w/o ferrite



Project-X Main Injector Cavity

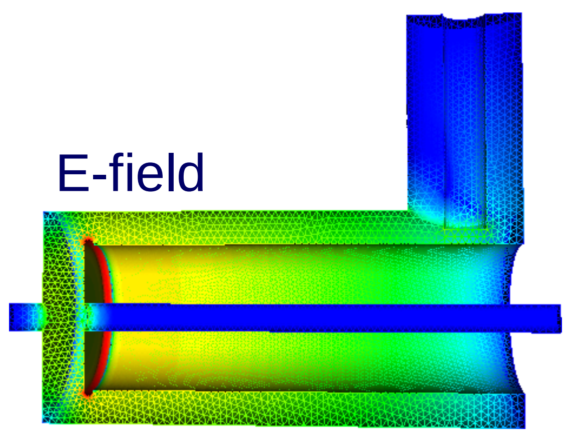
ferrite cores

ceramic window

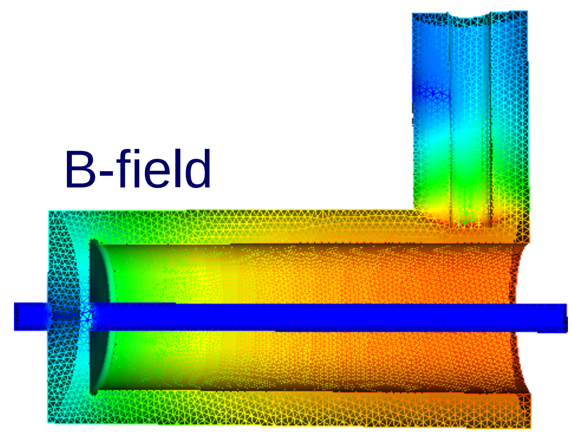


Lossy dielectric and ferrite calculation

E-field



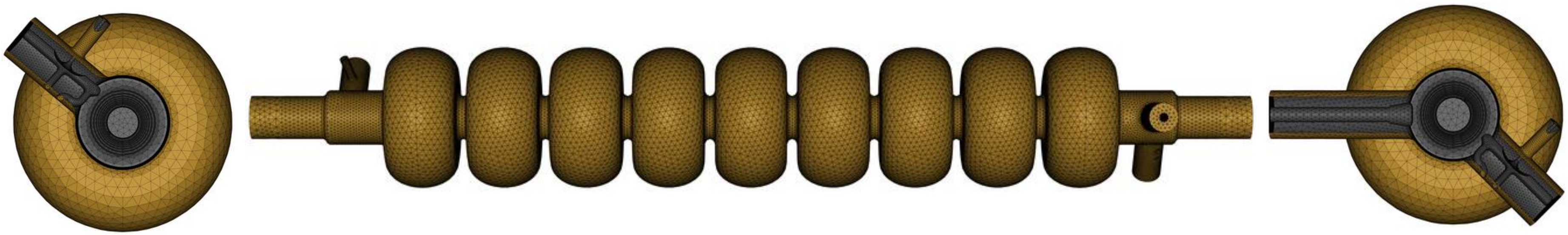
B-field



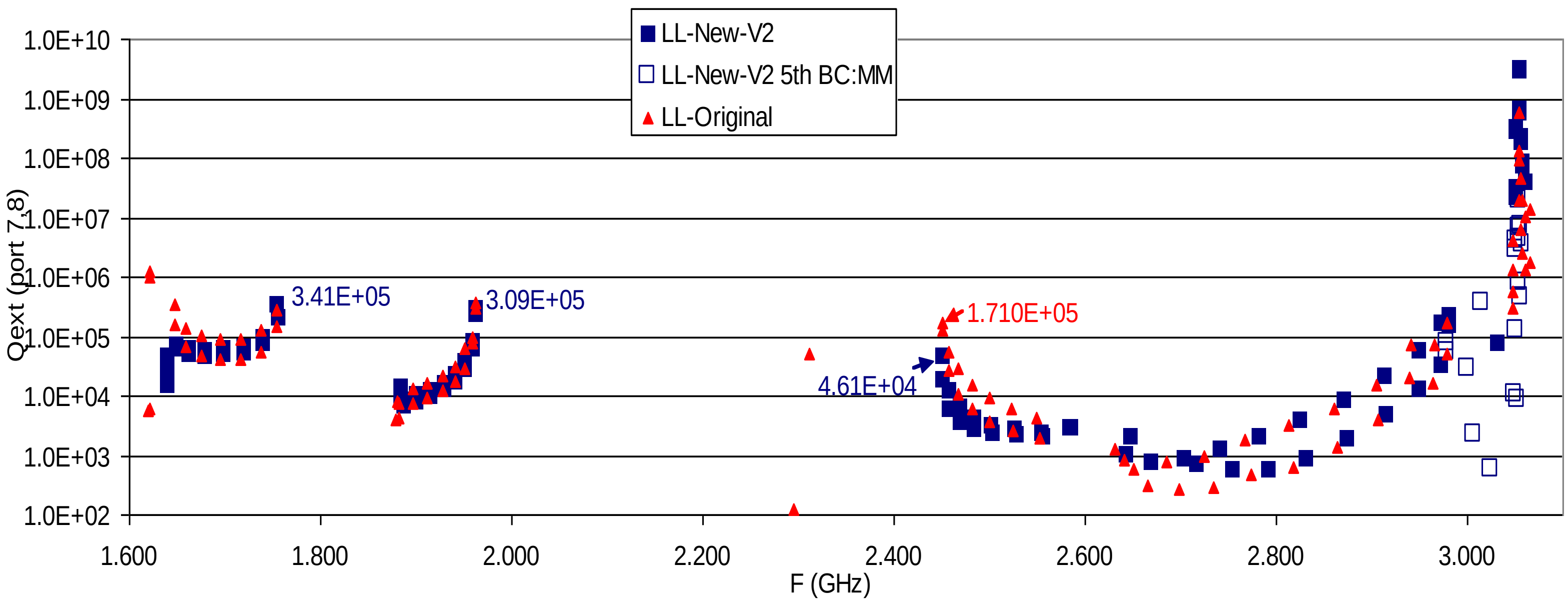
In collaboration with FNAL

Omega3P - HOM Damping in ILC Low-loss Cavity

- **SLAC** *design has 20% cryogenic loss and higher shunt impedance than TDR cavity,*
- *TDR HOM coupler provides inadequate damping - dangerous mode in 3rd dipole band,*
- *Optimization of end-groups* **SLAC design (blue) with lower Qext**



Qe



SLAC NATIONAL ACCELERATOR LABORATORY