# Advances in Electromagnetic Modeling though High Performance Computing

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*SRF 2005, Cornell University*

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# What is SciDAC?

- *Scientific Discovery through Advanced Computing*
- *DOE Office of Science (SC) Simulation Initiative*
- *Phase I 5-yr program ending FY06, Phase II follow-on*
- *Orchestrated by ASCR to promote HPC across SC*
- *Supports AM and CS to work with the applications*
- *Total about 20 plus SciDAC projects*
- *HEP Accelerator Simulation Project has 3 components:*

*Electromagnetics (SLAC), Beam Dynamics (LBL), Advanced Accelerators (UCLA)*

# DOE/SciDAC Accelerator Simulation Project

*SLAC leads the <u>Electromagnetic Modeling</u> component*

***High Performance Computing** (NERSC IBM SP, ORNL Cray X1)*

**Simulation and Modeling** | **Parallel Code Development** | **Computational Science**

***<u>Accelerators</u>***

**SLAC**
**DESY**
**KEK**
**FNAL**
**Jlab**
**ANL**
**MIT**
**PSI**

***<u>SLAC</u>***

**Accelerator Modeling**

***<u>SciDAC</u>***

**Computational Mathematics**

**Computing Technologies**

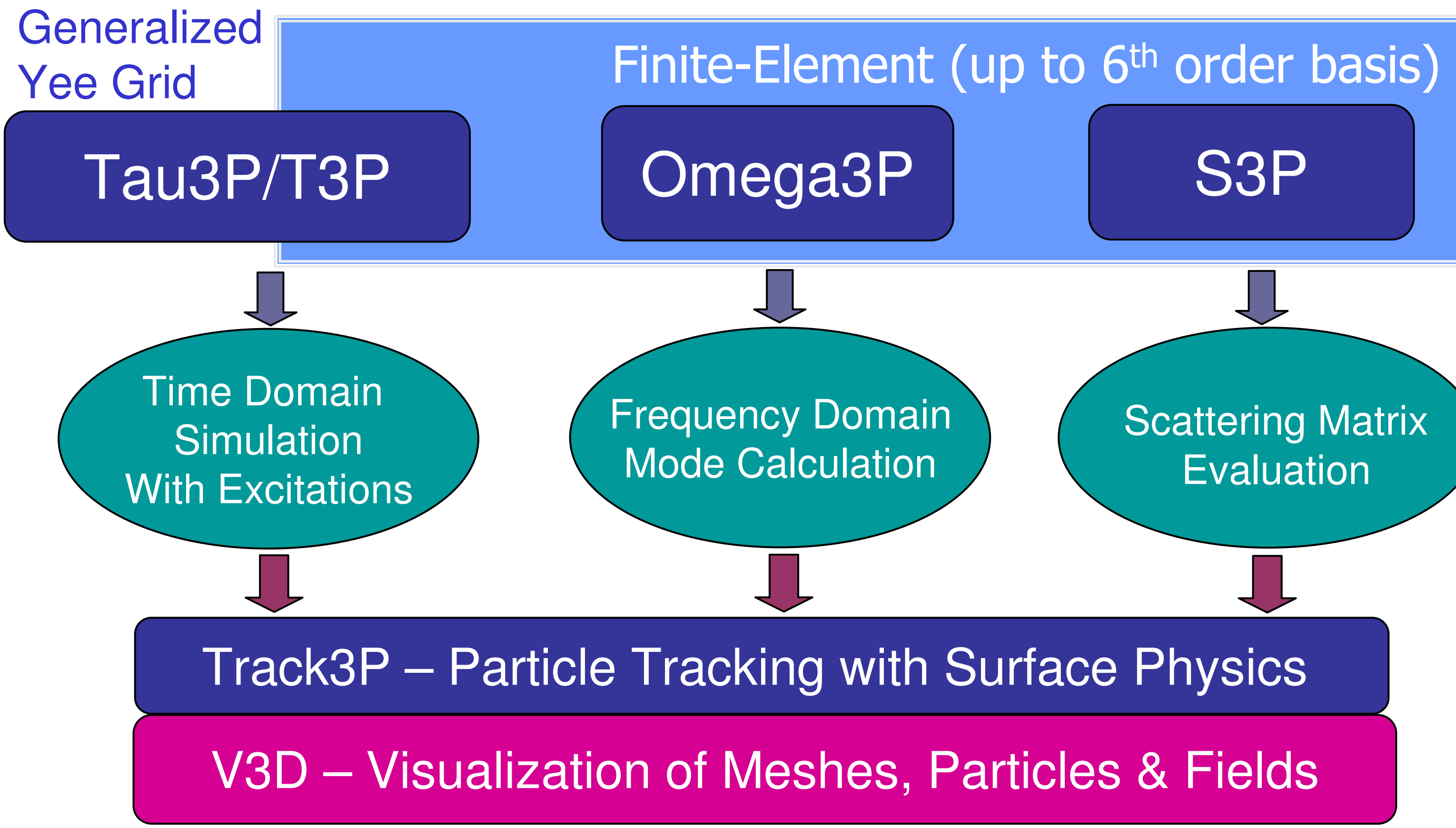
***<u>ISICs/SAPP</u>***

**LBNL**
**LLNL**
**SNL**
**Stanford, UCD**
**RPI, CMU**
**Columbia**
**UWisconsin**

*"DOE Grand Challenge prior to SciDAC"*

# Parallel EM Code Development

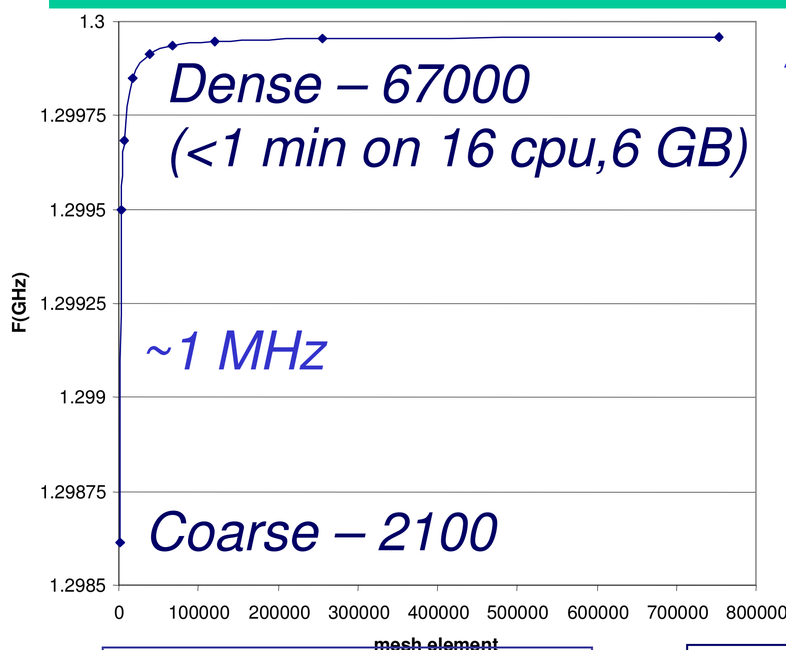
*Solve Maxwell's equations (with particles) in time & frequency domains using **unstructured grid** and **parallel processing** to target High Resolution Modeling and End-to-end Simulation.*



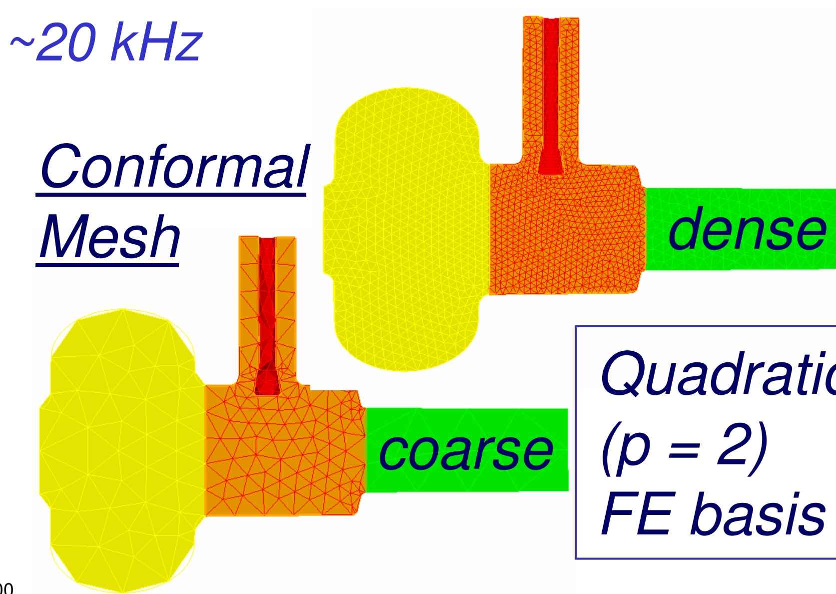

*C++/MPI*

# Finite Element + Parallel Processing

## *Combined features for Accuracy,Speed and Memory*




~20 kHz



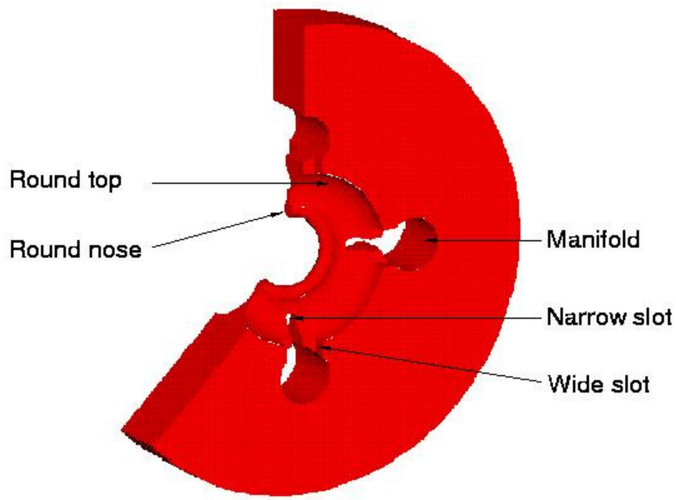

*Quadratic*
*(p = 2)*
*FE basis*

*Moore's Law*
*1 CPU ~10's GB*

*Linear Speedup = 1/N*
*6080 CPU ~1-4 GB each > TB total*

# Parallel Electromagnetic Modeling

*CAD/Meshing* → *Partitioning* → *Solvers* → *Analysis*




*NLC Cell Design*

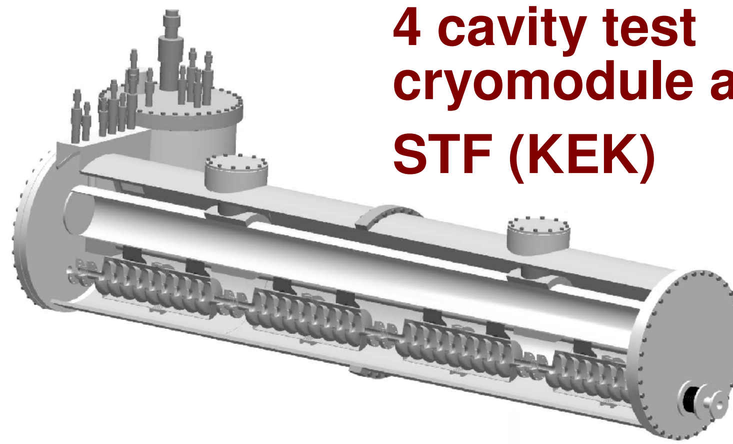
*Refinement* | *Performance* | *Optimization* | *Visualization*

***SciDAC*** *supports collaborations in applied mathematics and computer science (computational science) to enable new advances in electromagnetic modeling through HPC*

# Advances in Parallel Meshing

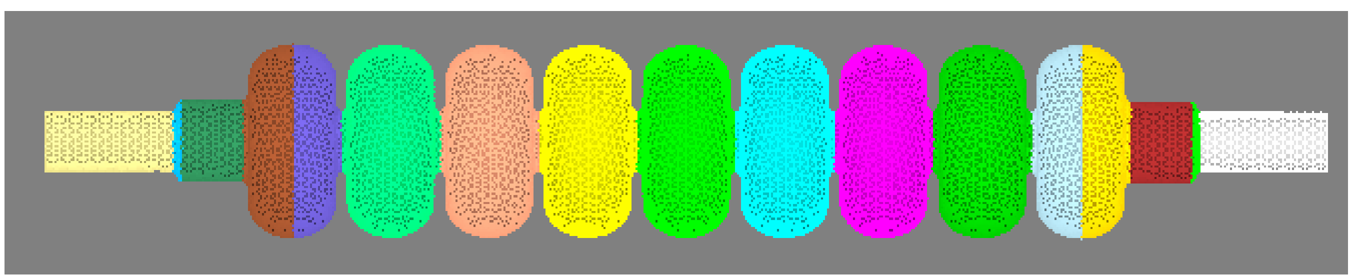
*(SLAC – U Wisconsin, SNL)*

*To model a chain of cavities within a cryomodule a parallel meshing capability has been developed to overcome the single CPU memory limitation of standard meshing software.*

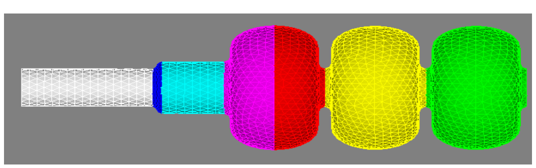


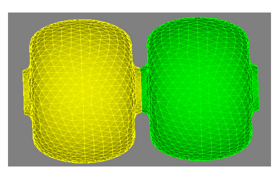
**4 cavity test cryomodule at STF (KEK)**

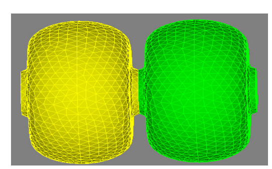
**CAD-based Partitioning for Parallel Meshing**

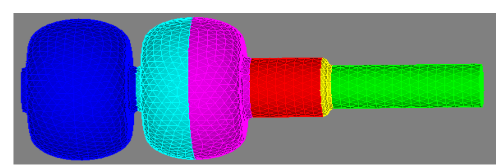


Processor: 1 2 3 4



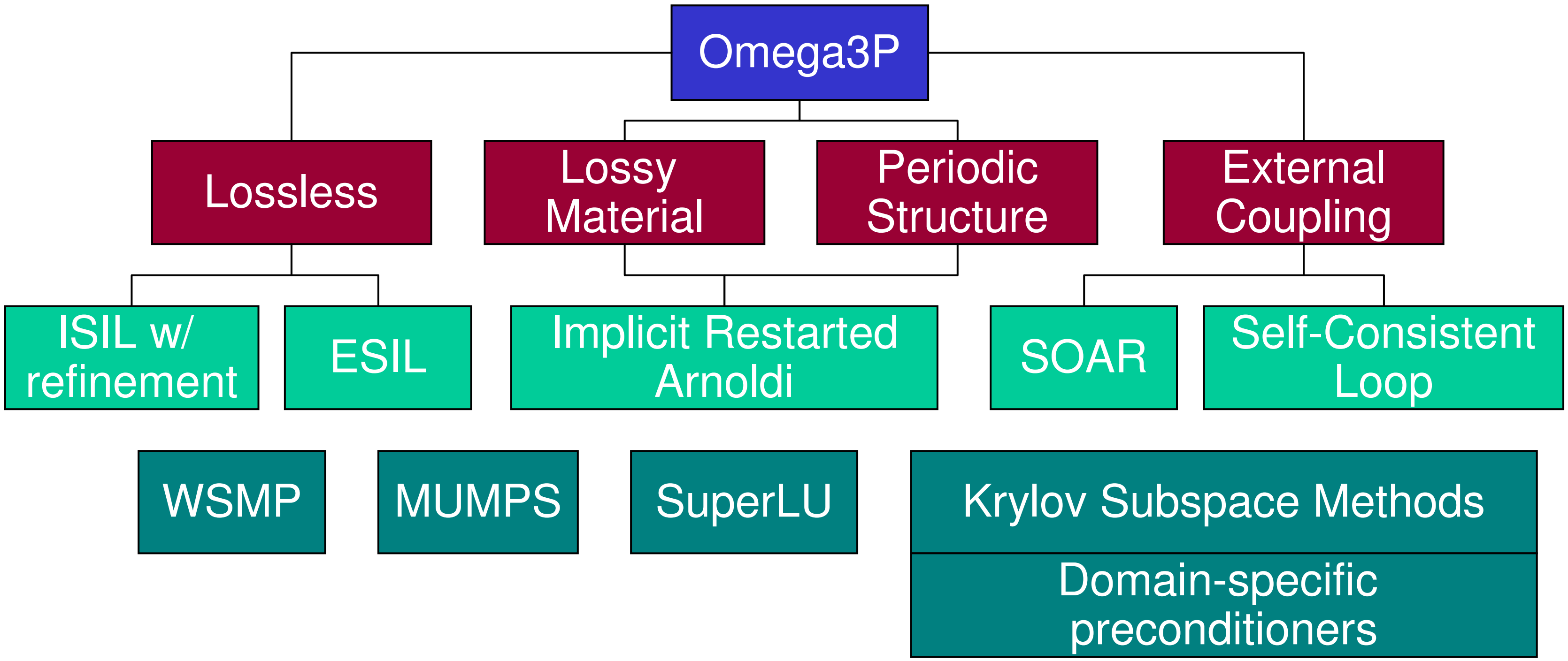






# Advances in Parallel Eigensolvers

*(SLAC - LBL, Stanford, UC Davis)*

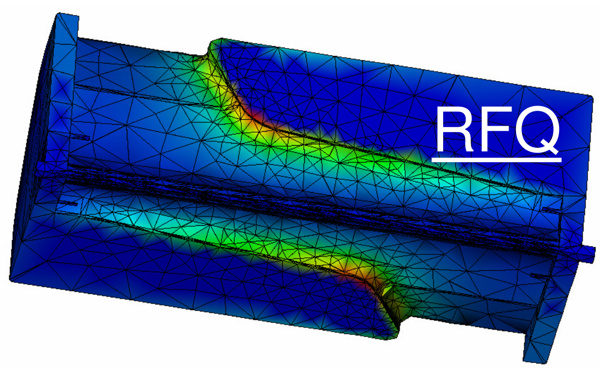



*<u>Modeling cavities with coupling to external waveguides</u> requires solutions to a nonlinear eigenvalue problem as the boundary conditions now also depend on the eigenvalue as matched waveguide terminations.*

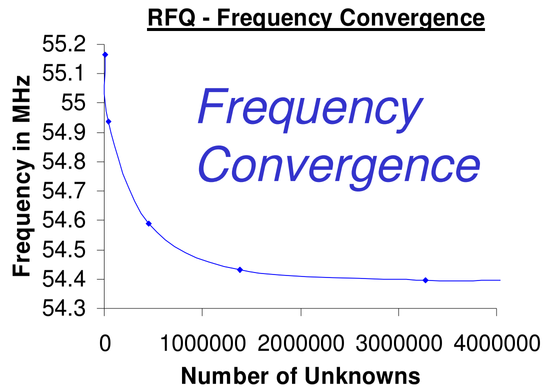
# Advances in Adaptive Mesh Refinement

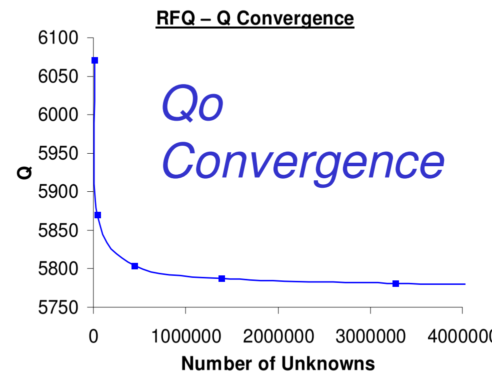
*(SLAC – RPI)*

***A**daptive **M**esh **R**efinement improves the accuracy in frequency and wall loss calculations at a fraction of resources by speeding up convergence.*




**Wall Loss on AMR Mesh**



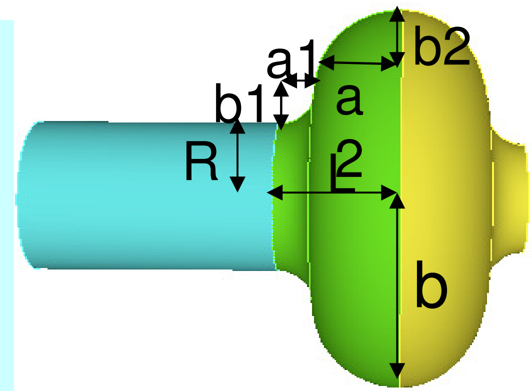



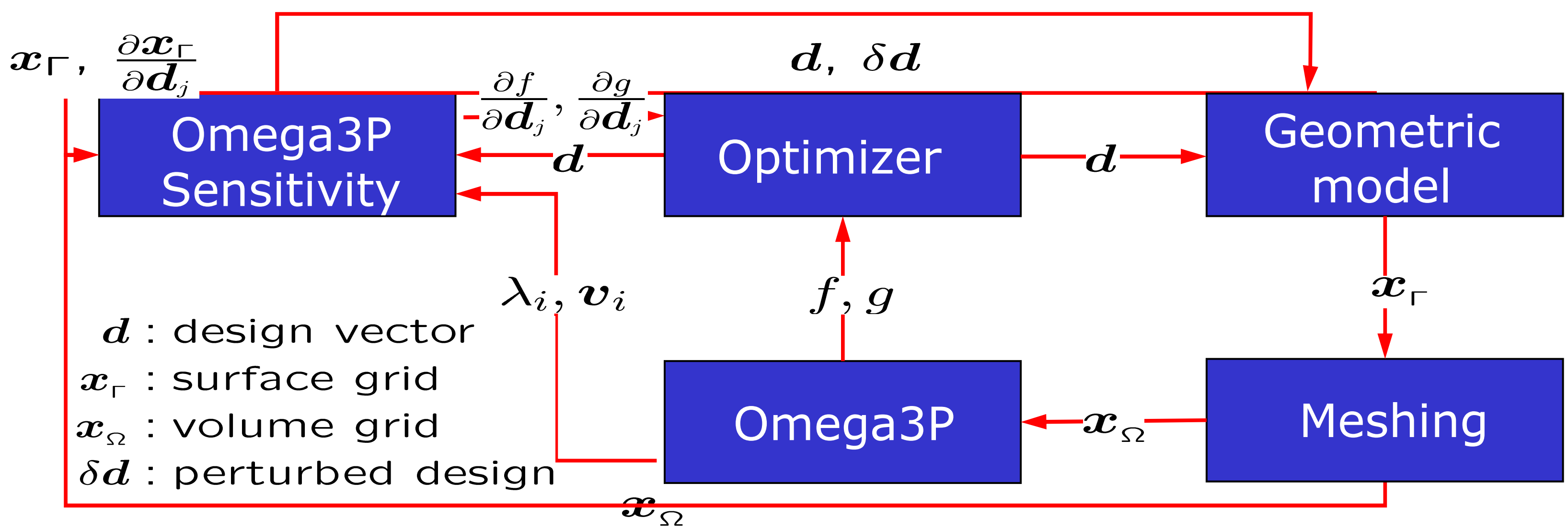

*For RIA's RFQ cavity, more accurate frequency and Qo predictions (factor of 10 and 2) reduce the number of tuners and ease tuning procedures, and improve cooling design (P, Ostroumov)*

# Advances in Parallel Shape Optimization

*(SLAC – CMU, LBL, Columbia, SNL, LLNL)*

*A **parallel shape optimization** capability is under development for **Omega3P** to replace existing manual iterative process. Primitive prototype being applied to the ILC cavity. (J. Sekutowicz)*



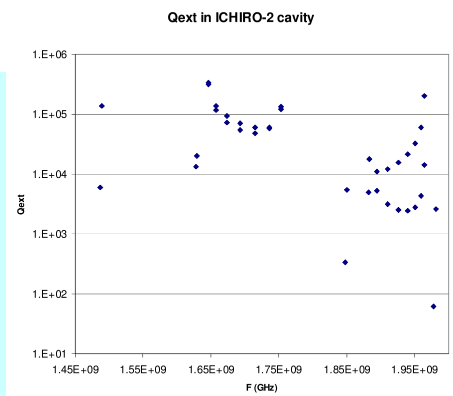

$\boldsymbol{d}$ : design vector
$\boldsymbol{x}_\Gamma$ : surface grid
$\boldsymbol{x}_\Omega$ : volume grid
$\delta\boldsymbol{d}$ : perturbed design

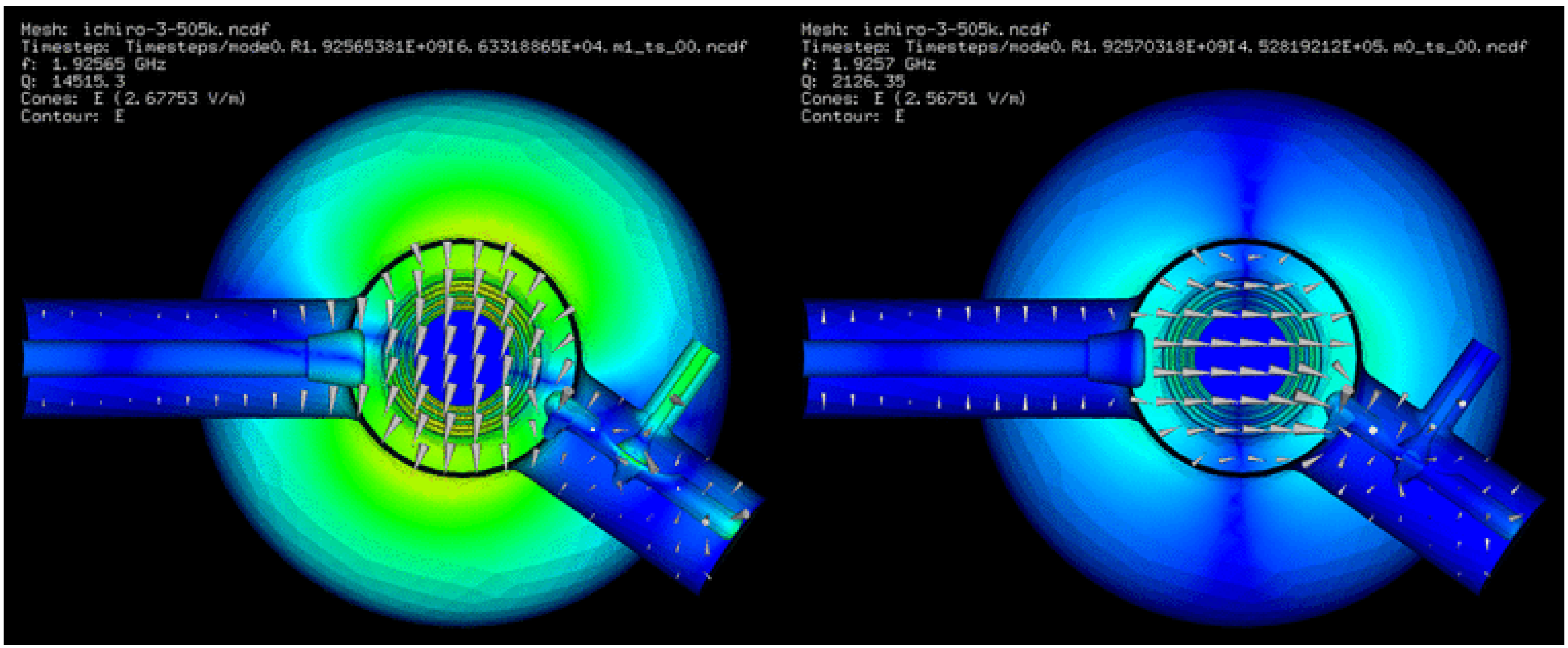
$\lambda_i, \boldsymbol{v}_i$ : design eigenpairs $f$ : objective $g$ : constraint

# Advances in Visualization

*(SLAC - UC Davis)*

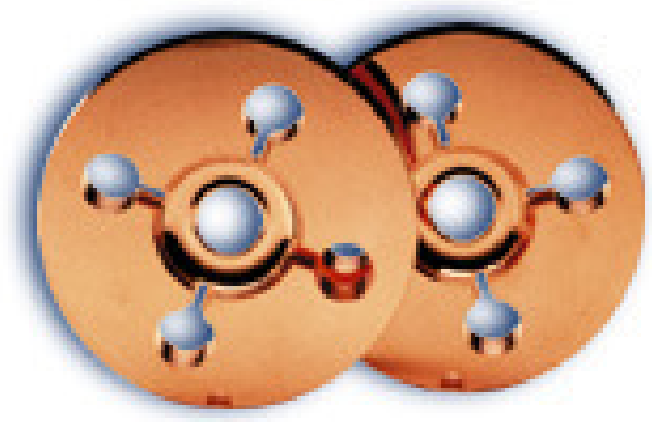
*Rendering* ***LARGE, 3D multi-stream, unstructured data*** *is essential for analysis, such as studying mode rotation in the ILC cavity (Vizualization Server).*

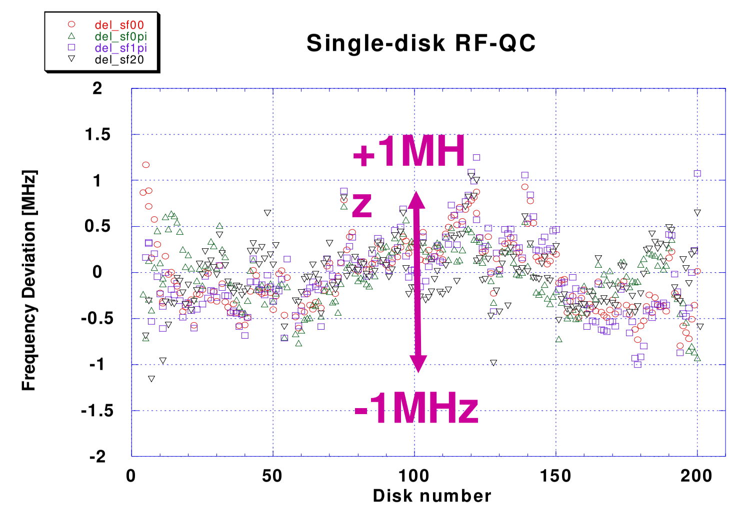


# NLC DDS Cell Design

***Omega3P*** *provided the dimensions for 206 NLC* ***D****amped* ***D****etuned* ***S****tructure cells. Microwave QC of cells verified frequency accuracy of 1 part in 10,000 as targeted.*





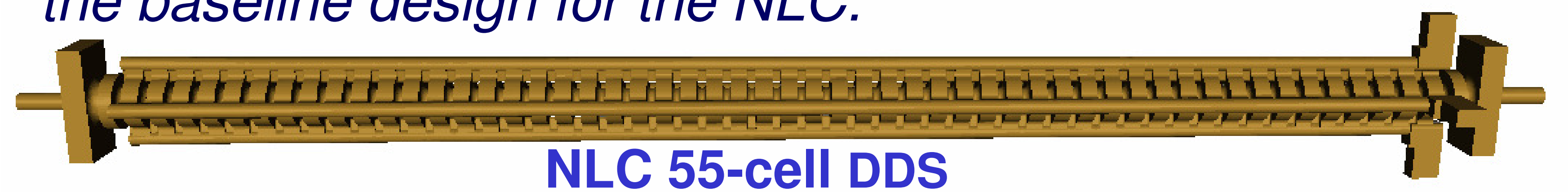

*Potential $100 million+ savings in NLC machine cost (DDS14% higher shunt impedance than standard design)*

*Omega3P - New core accelerator design capability*

*“High Resolution Modeling”*

# NLC DDS Wakefields

***Omega3P/Tau3P** computed the long-range transverse wakefields in an actual 55-cell DDS prototype which was the baseline design for the NLC.*

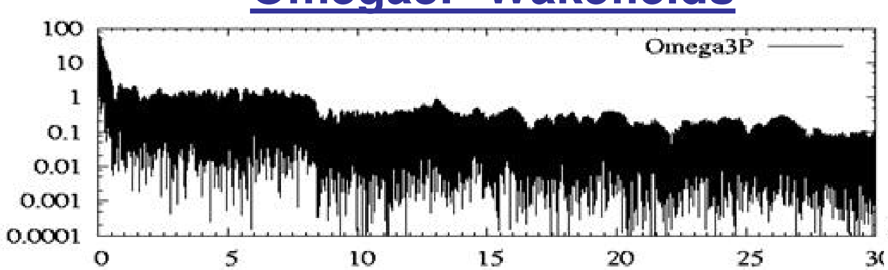


**NLC 55-cell DDS**

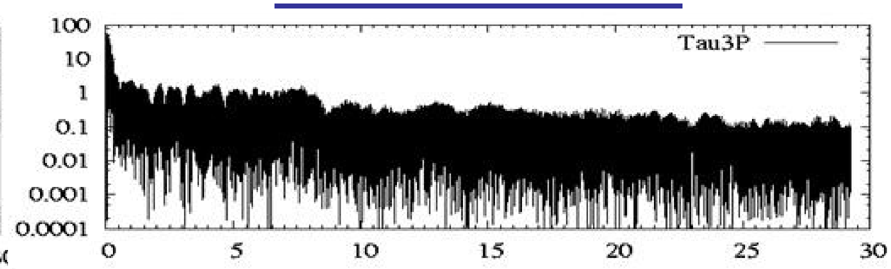
**Omega3P:** Sum over eigenmodes

**Tau3P:** Direct beam excitation

**Omega3P Wakefields**




**Tau3P Wakefields**




*"End-to-end Simulation"*

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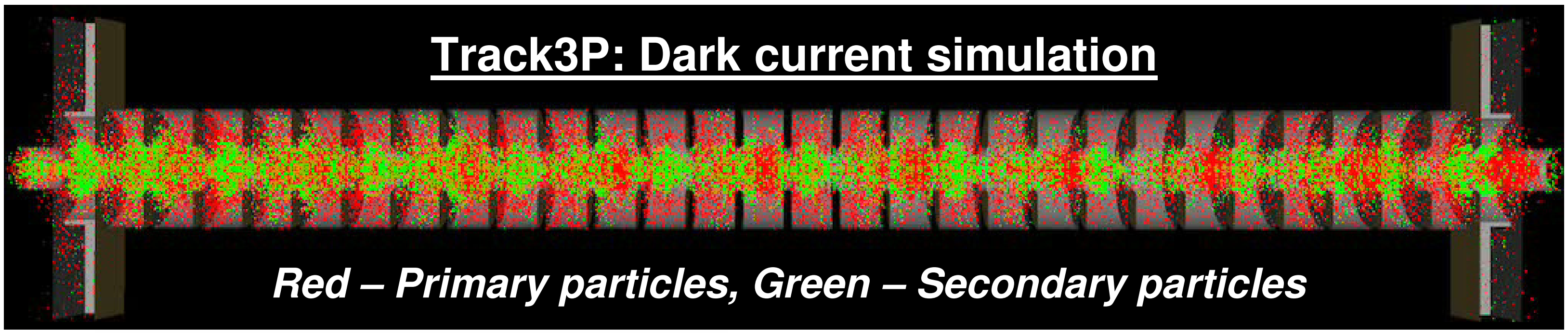
# NLC Dark Current Pulse

*Dark current pulse simulated for the **1st time** in an entire structure with **Track3P** and compared with data, showing agreement in dark current increase during pulse risetime.*



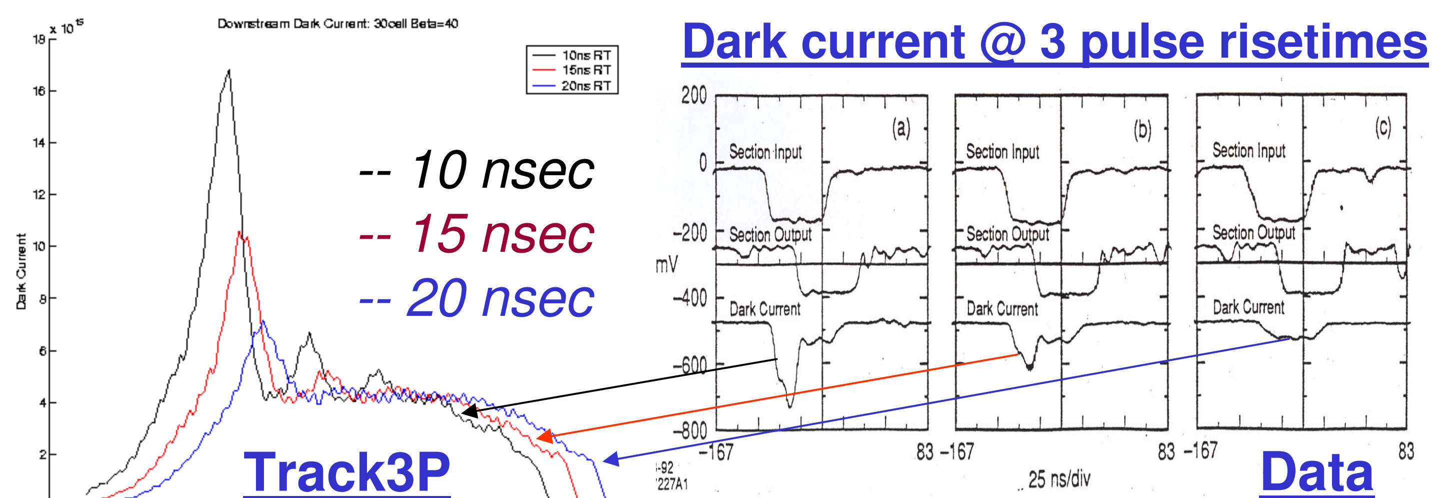
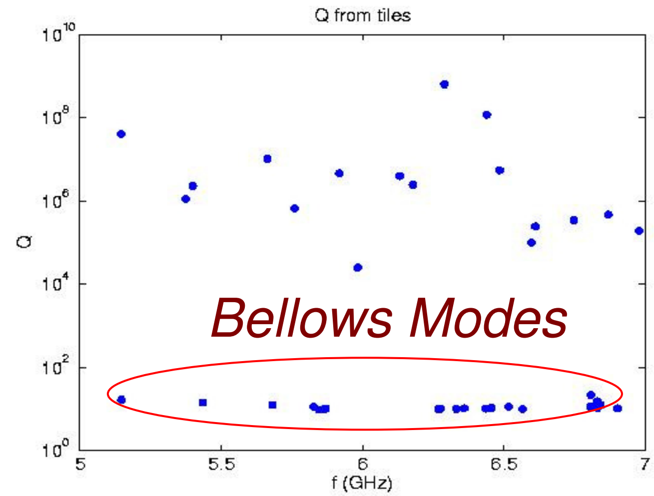



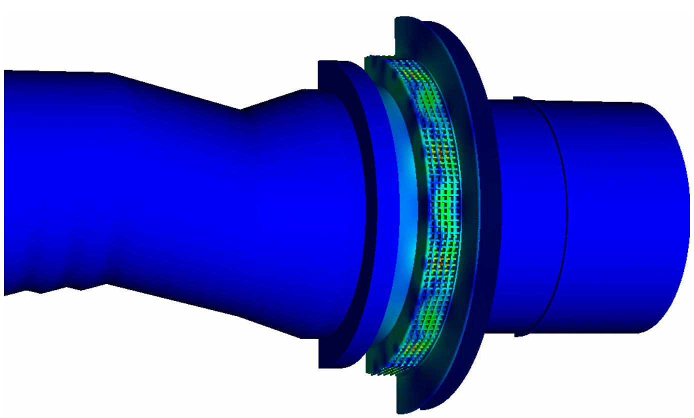

Fig. 7. Pulse shapes of section input, output and dark current for three different rise times of the RF pulse for 30-cavity TW section tests.

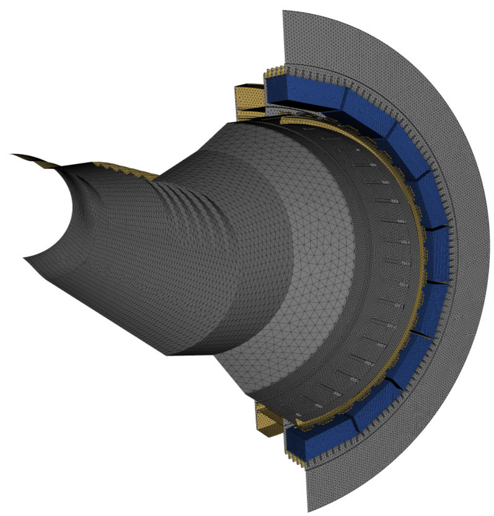
# PEP-II Vertex Bellows Heating

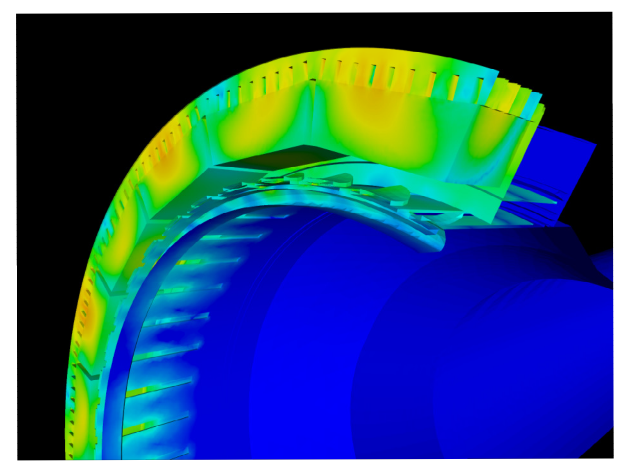
***Omega3P*** *was used to evaluate the damping of localized modes by mounting ceramic tiles on the bellows convolution. Bellows modes were found to be damped to very low Qs*




*Bellows mode* | *Ceramic tile absorber* | *Dielectric loss*



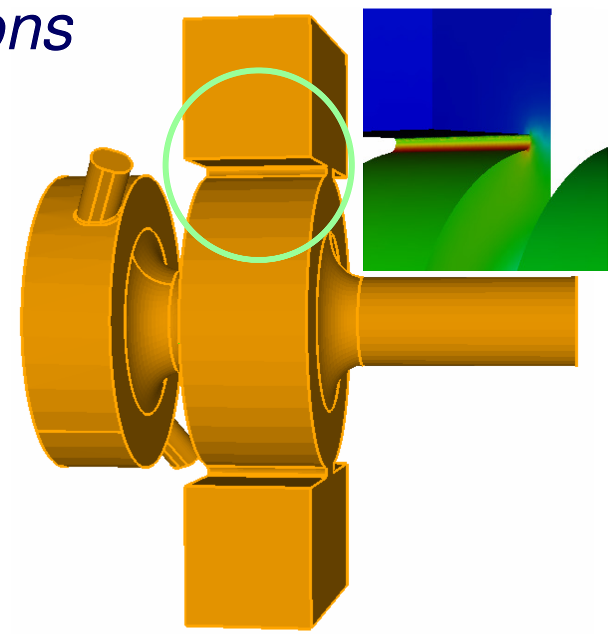




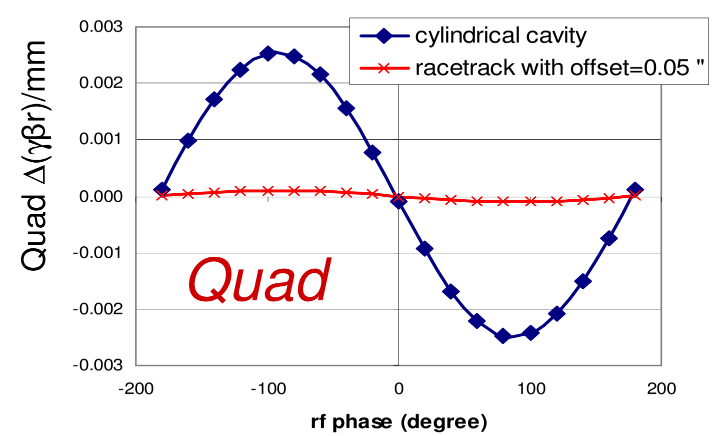
# LCLS RF Gun Cavity

***Omega3P/S3P*** *provided the dimensions for the LCLS RF Gun cavity that meet two important requirements:*

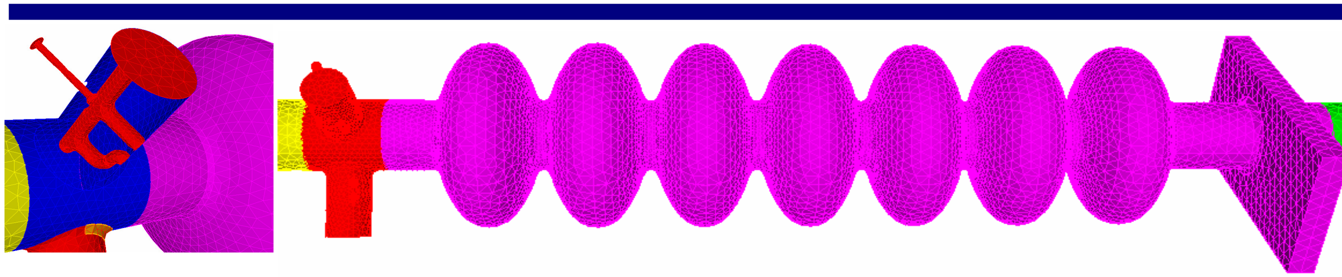
- *minimized dipole and quadrupole fields via a racetrack dual-feed coupler design,*
- *reduced pulse heating by rounding of the z coupling iris.*

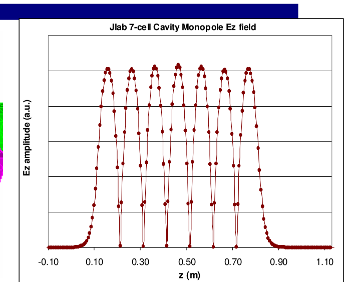


*A new parallel Particle-In-Cell (PIC) capability is being developed in* ***T3P*** *for self-consistent modeling of RF guns needed for the LCLS upgrade, future light sources and FELs.*

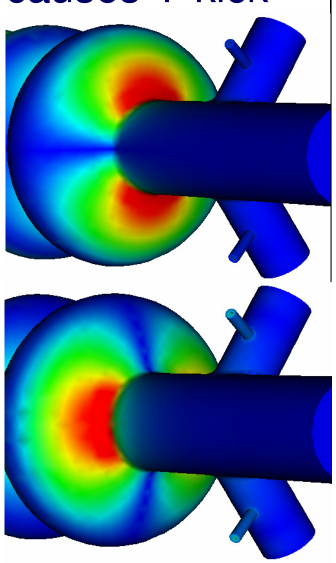


# JLab 7-cell SRF Cavity (Rimmer, Wang)

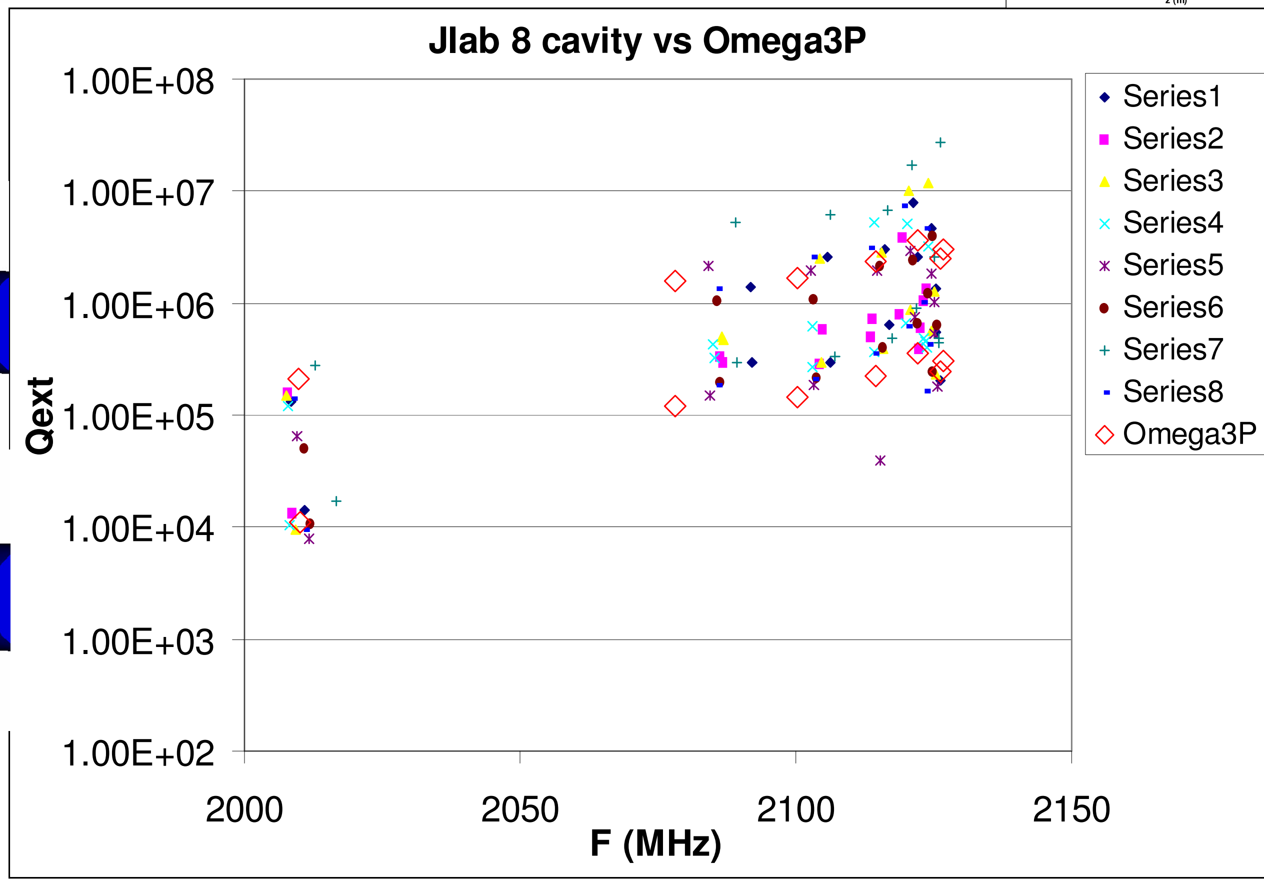





2.103654 GHz
high Q mode
causes Y-kick



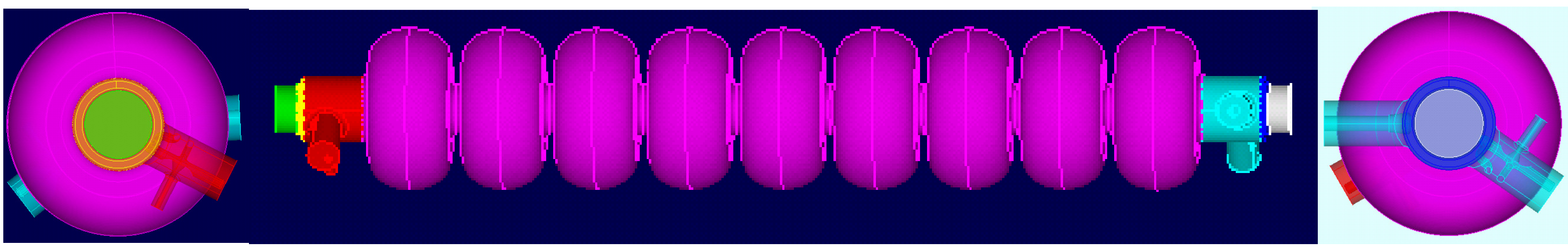
2.103666 GHz
Low Q mode
causes X-kick




*"Cavity for 12 GeV upgrade is in progress"*

# ILC Low-Loss Cavity Design

*An international collaboration comprising DESY, KEK, SLAC. JLab and FNAL is working on a Low-loss (LL) design for the ILC accelerating cavity. The **LL** cavity shape has 23% less cryogenic loss.*



*SLAC's ACD is calculating the HOM damping and optimizing the HOM couplers for the DESY LL cavity (J. Sekutowicz) and the KEK ICHIRO cavity (K. Saito)*

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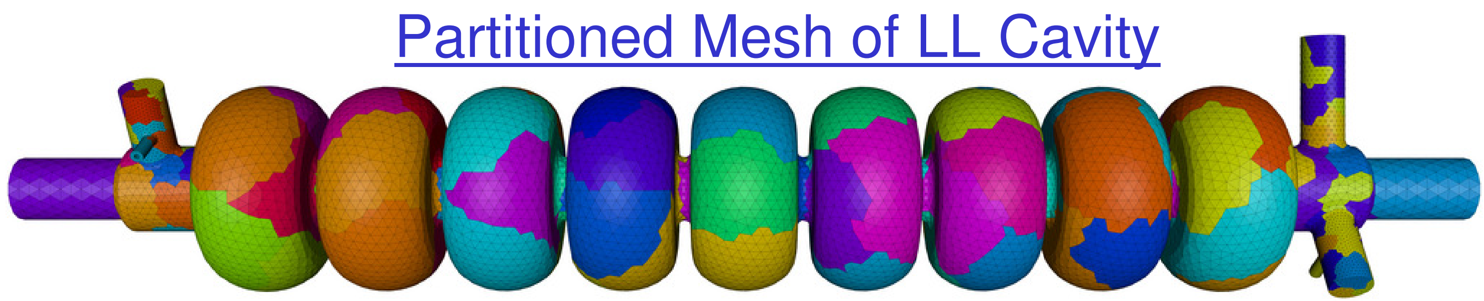
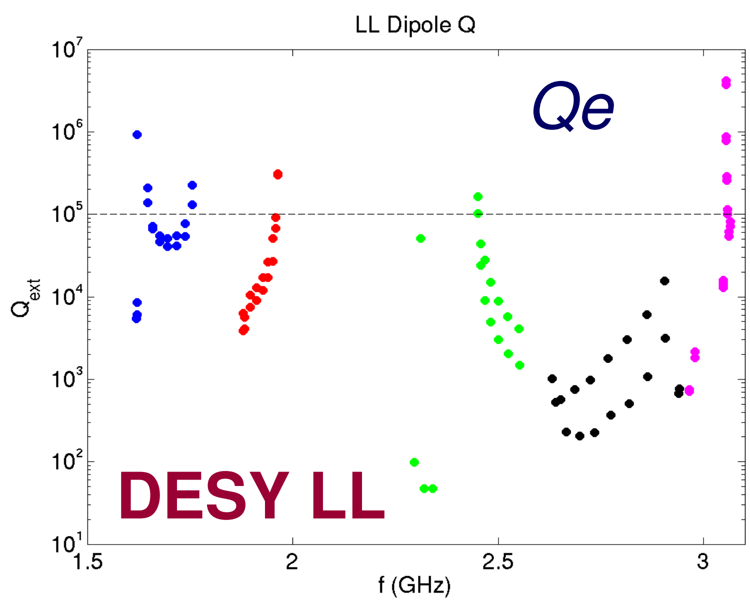
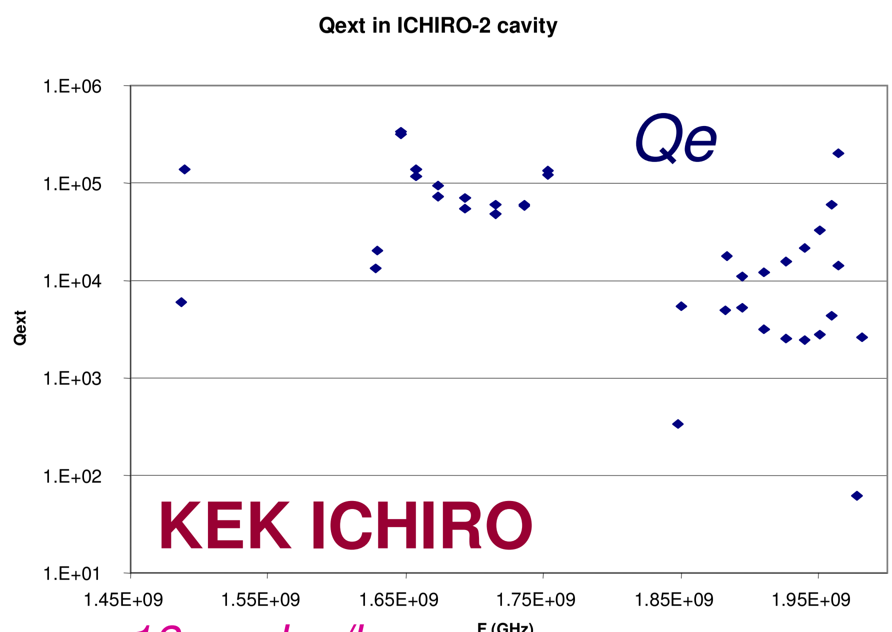
# ILC Cavity HOM Damping




***Omega3P*** *computes the complex frequency or Qe = $\omega_R/2\omega_I$ of HOMs due to damping by the HOM couplers*

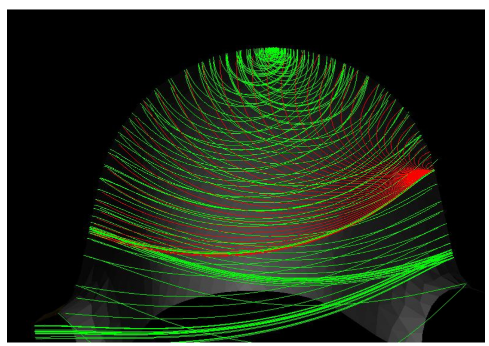


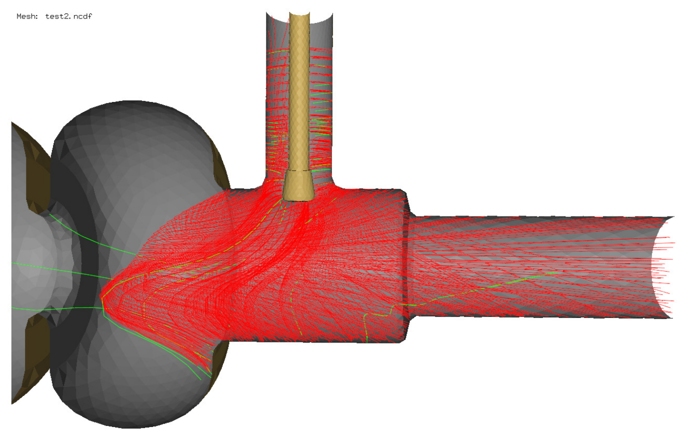




*18 modes/hour*
*768 cpu,300 GB*

# Work in Progress

- *ILC Cavity modeling – Optimize HOM damping*
  - *Effect of Imperfections*
  - *Multi-cavity interconnections*
- *Beam Dynamics – Wakefields effects (mode rotation)*
- *Multipacting –*






- *Code release – Single CPU version within a year (?)*

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