Advanced Electromagnetic Modeling for BES Accelerators with ACE3P

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Advanced Computations at SLAC & Collaborations

SLAC Team

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Accelerator Collaborators

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Computational Science Collaborators (SciDAC 1 + 2: 2001-2012)

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Parallel EM Code Development at SLAC

DOE's High Performance Computing Initiatives and SLAC support

- **1998–2001 HPC Accelerator Grand Challenge**
- **2001-07 Scientific Discovery through Advanced Computation (SciDAC-1) -** Accelerator Science and Technology (AST)
- **2007-12 Scientific Discovery through Advanced Computation (SciDAC-2) -** Community Petascale Project for Accelerator Science and Simulation (ComPASS)

PhD Research:

1998 *- Xiaowei Zhan, Parallel electromagnetic field solvers using finite element methods with adaptive refinement and their application to wakefield computation of axisymmetric accelerator structure, Stanford University*

2003 *- Greg Schussman, Interactive and perceptually enhanced visualization of large, complex line-based datasets, UC Davis*

2003 *- Yong Sun, The filter algorithm for solving large-scale eigenproblems from accelerator simulations, Stanford University*

2005 *- Lukas Stingelin, Beam-cavity interactions in high power cyclotrons, PSI, Switzerland*

2009 *- Sheng Chen, Adaptive error estimators for electromagnetic field solvers, Stanford University*

Parallel EM Code Suite ACE3P and User Community

ACE3P (Advanced Computational Electromagnetics 3P) Code Suite

https://slacportal.slac.stanford.edu/sites/ard_public/bpd/acd/Pages/Default.aspx

- conformal, higher-order, C++/MPI parallel finite-element based electromagnetic codes
- supported by SLAC and DOE HPC Grand Challenge (1998-2001), SciDAC1 (2001-06), SciDAC2 (2007-12)

Modules include

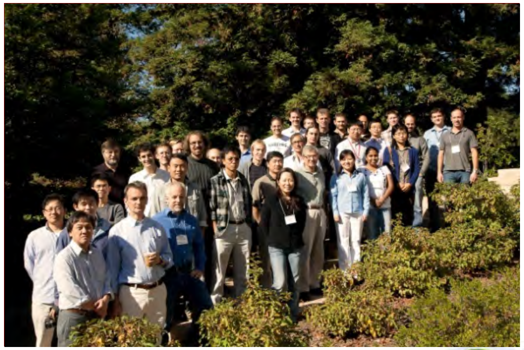
Frequency Domain:	**Omega3P**	**– Eigensolver (damping)**
	S3P	**– S-Parameter**
Time Domain:	**T3P**	**– Wakefields,Transients**
Particle Tracking:	**Track3P**	**– Multipacting, Dark Current**
EM Particle-in-cell:	**Pic3P**	**– RF Gun, Klystrons**
Multi-Physics:	**TEM3P**	**– EM, Thermal & Structural Analysis**

ACE3P Code Workshop

CW09 (15 attendees from 13 institutions) – 1 day

CW10 (36 attendees from 16 institutions) – 2.5 days

CW11 planned for 5 days



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SciDAC Scientific Discovery through Advanced Computing

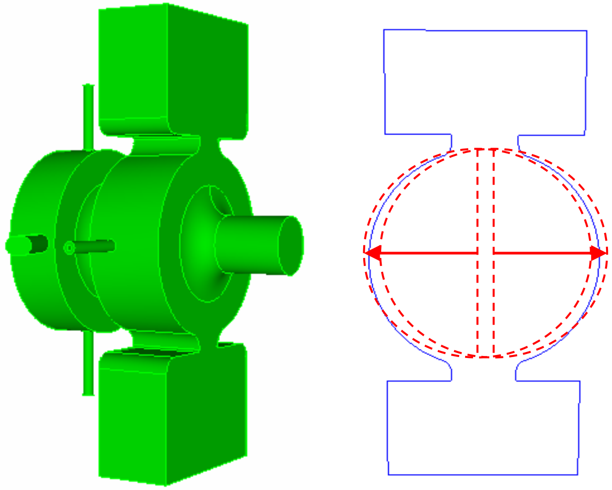
Achievements with ACE3P Beneficial to BES

- LCLS – RF gun cavity design (*Omega3P* & *S3P*); emittance calculation (*Pic3P*)
- SNS – Multipacting in SNS cell & HOM coupler of SCRF cavity (*Track3P*)
- PEP-X – Impedance calculation of beamline components (*T3P*)
- ERL – Imperfection studies for SRF cavity (*Omega3P*)
- APS – Cavity design for SPX (*Omega3P*)

Omega3P – LCLS RF Gun Cavity Design

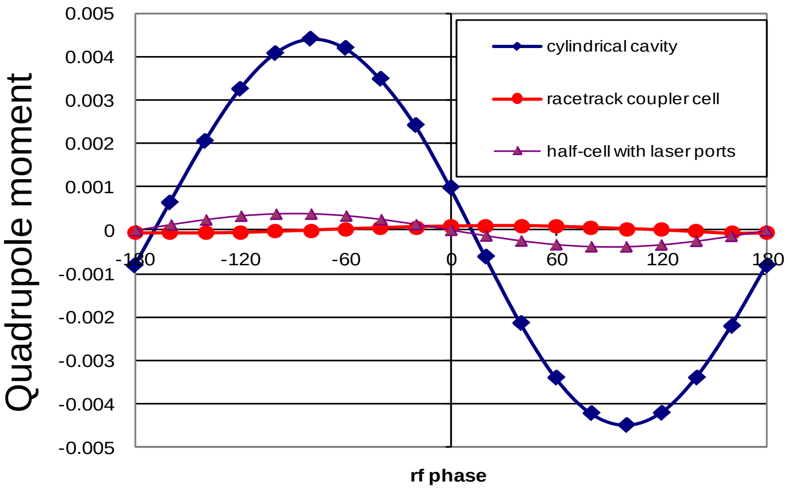
Provided dimensions for LCLS RF gun cavity to meet design requirements:

- *Reduce pulse heating by rounding of the z-coupling iris*
- *Minimize dipole and quadrupole fields via a racetrack dual-feed coupler design*

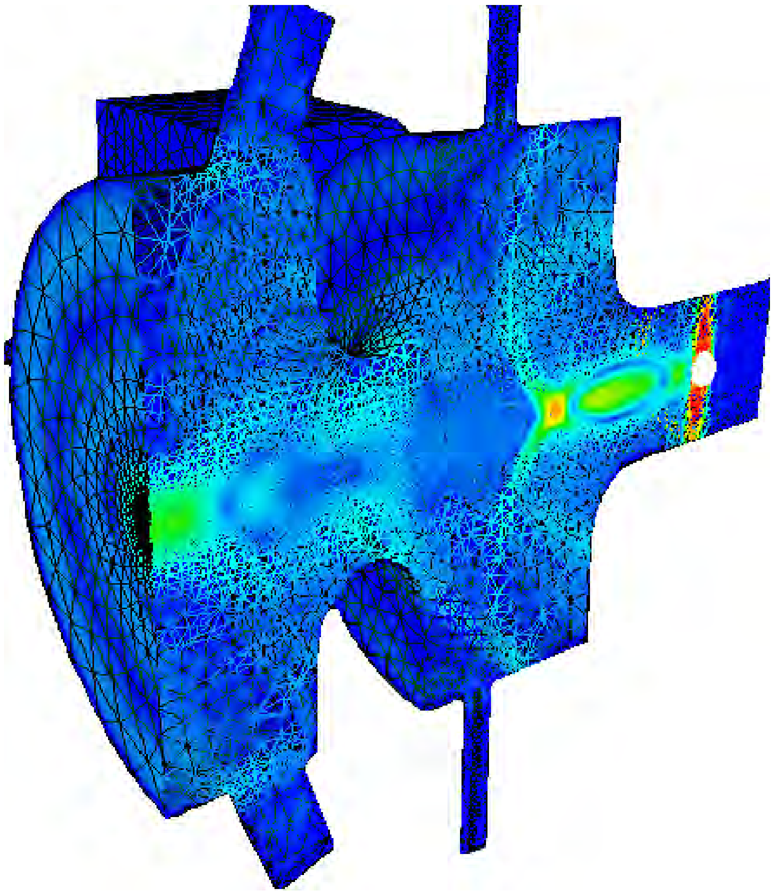


Code validated by Measurement

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

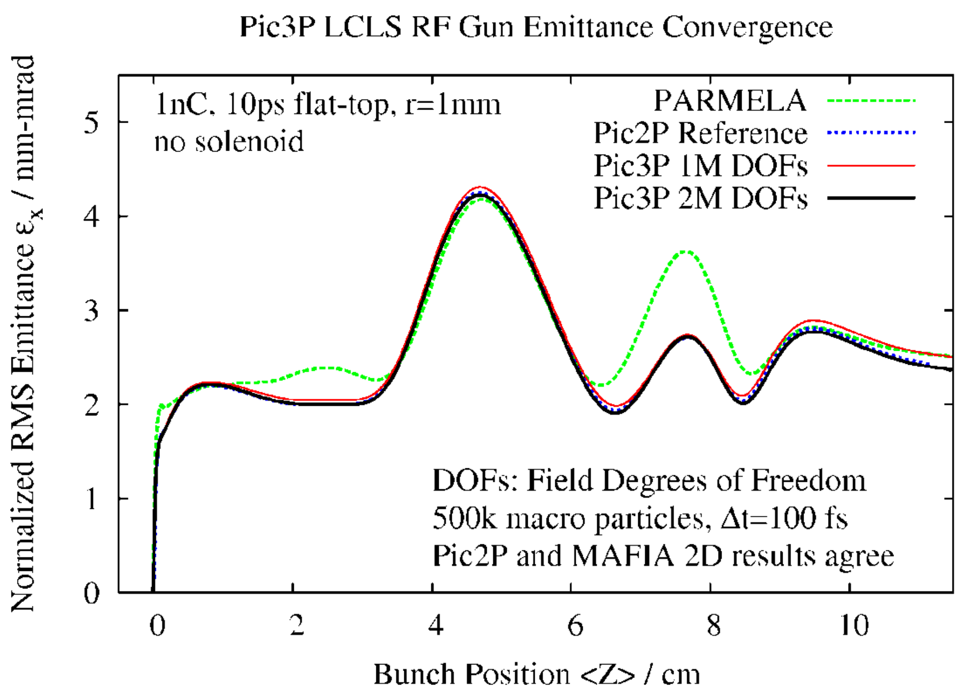


Pic3P – LCLS RF Gun Emittance



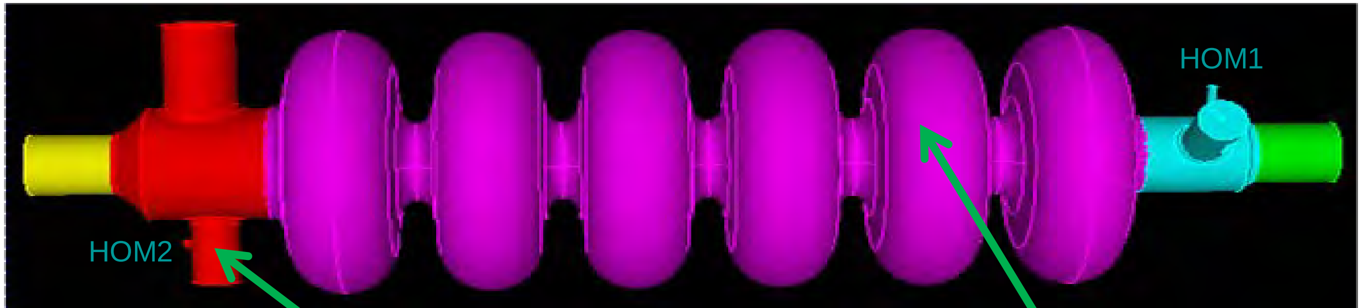
Snapshot of electron bunch and scattered self-fields

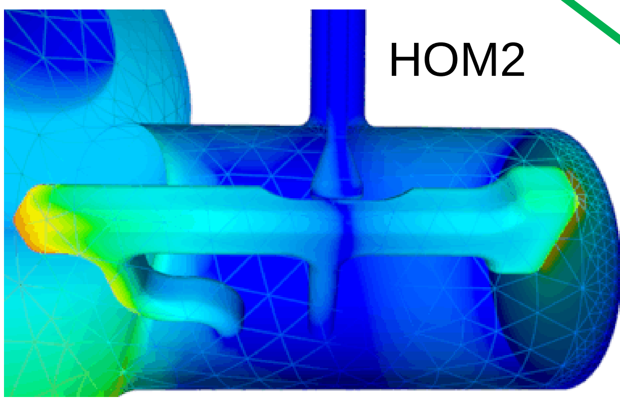
Racetrack cavity design: Almost 2D drive mode. Cylindrical bunch allows benchmarking of 3D code Pic3P against 2D codes Pic2P and MAFIA

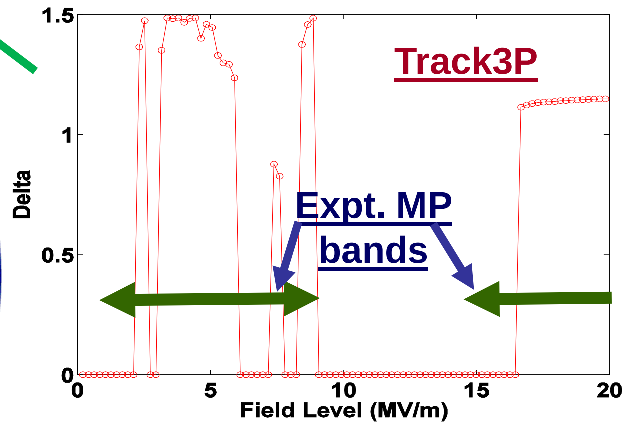


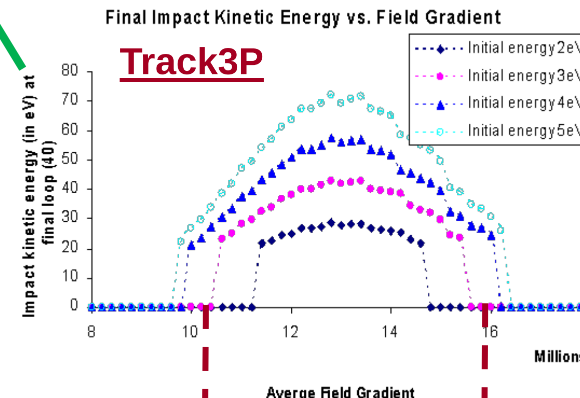
Unprecedented Accuracy due to Higher-Order Particle-Field Coupling and Conformal Boundaries

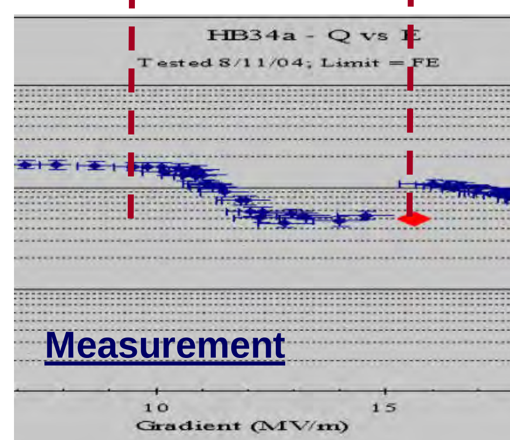
Track3P - Multipacting in SNS SRF Cavity











Cavity - Both experiment and simulation showed same MP band: 11 MV/m ~ 15MV/m

Coupler - Experienced rf heating at HOM coupler;3D simulations showed MP barriers close to measurements

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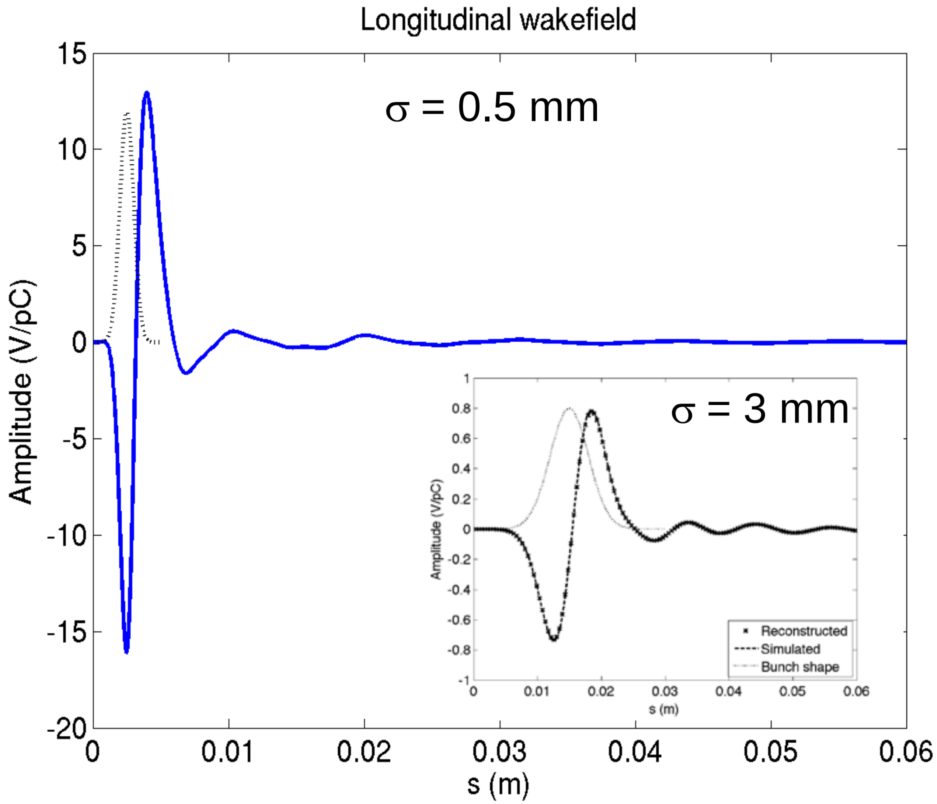
Scientific Discovery through Advanced Computing

T3P - Wakefield of PEP-X Undulator Chamber

- **Next generation light sources** plan to operate with ultra-short bunches and their wakefield effects are important to the design of these facilities.
- Accurate wakefield simulation for very long 3D structures is extremely challenging due to the huge computation resources needed.
- A moving window technique in **T3P** localizes the calculation to within the bunch region, thus reducing the computation resources by several orders of magnitude.
- Reconstructed wakefield from Green's function wakefield agrees excellently with direct calculation at σ = 3 mm for PEP-X undulator.



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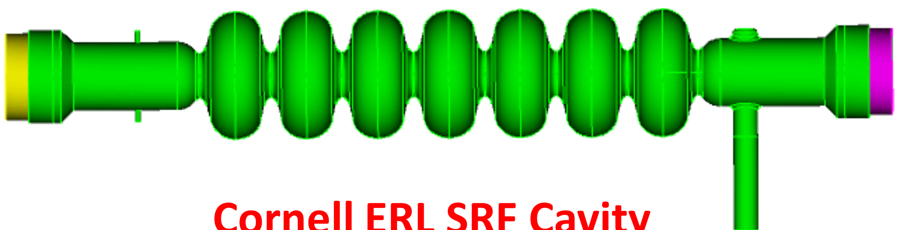
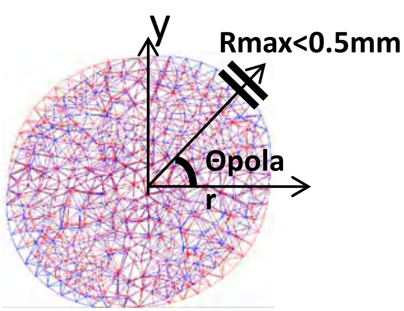
Omega3P - Imperfection Studies for ERL SRF Cavity

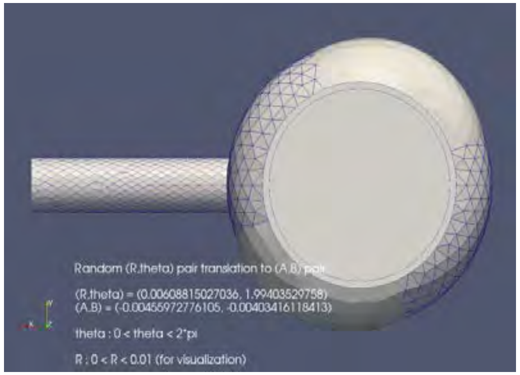
- ERL cavity shape is optimized to minimize the dipole mode BBU parameters;
- The actual ERL cavity cell shapes differ from the ideal one;
- Mesh distortion method is used to study the effects of elliptical cell shapes to the dipole modes.



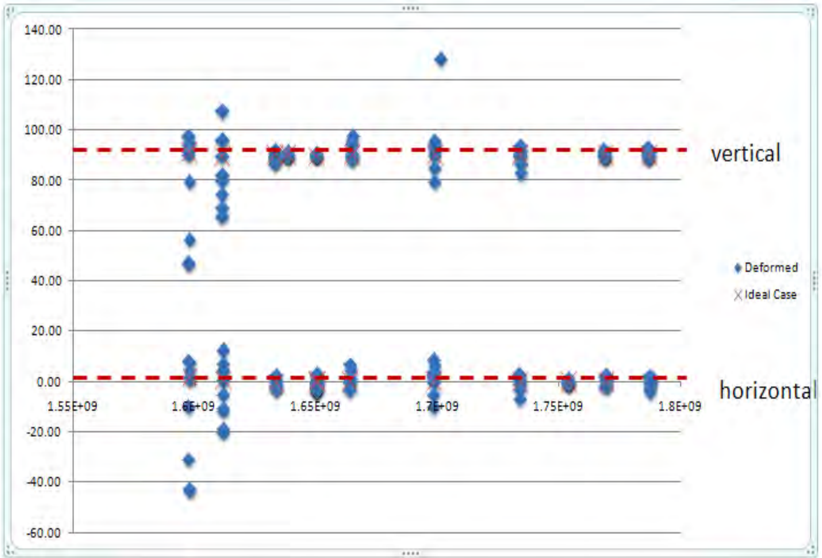
Cornell ERL SRF Cavity



Red: ideal cell mesh
Blue: deformed cell mesh



20 randomly elliptically deformed cell cavities



Dipole mode polarization angle

- x and y coupling of dipole modes results from the spread of polarization angles in deformed cavities.

In collaboration with Cornell – M. Liepe

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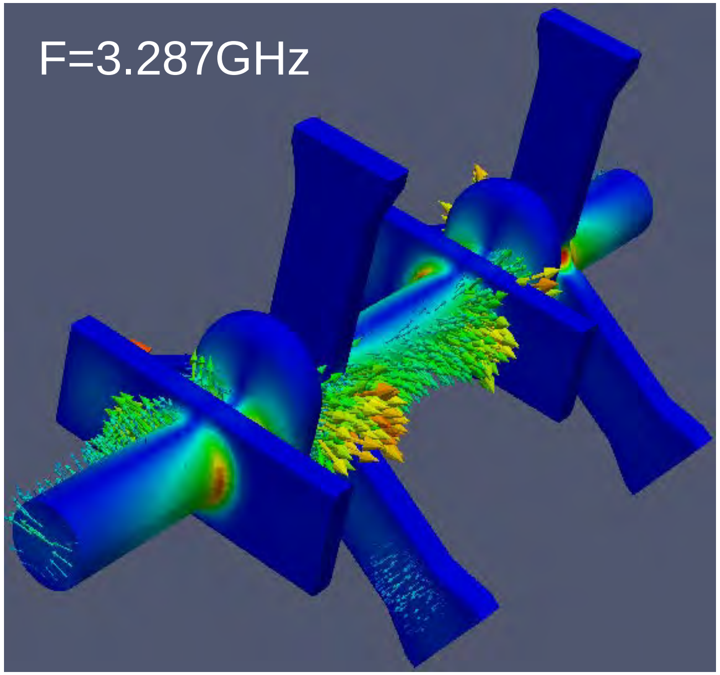
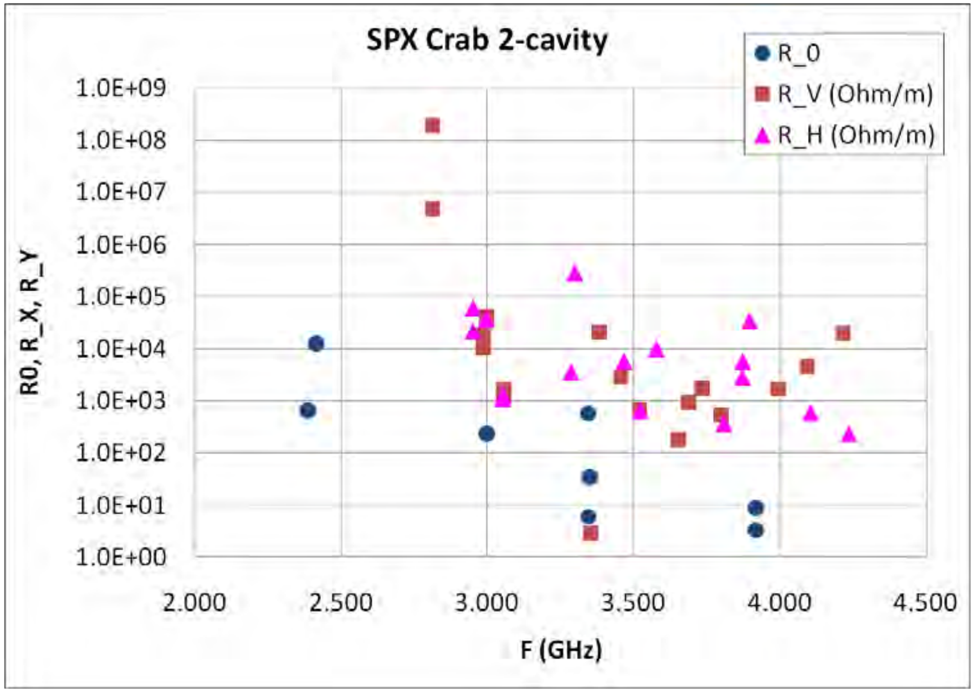
Omega3P - Cavity Design for SPX at APS

- **Short Pulse X-ray (SPX)** generation with new superconducting deflecting cavity R&D
- In collaboration with Argonne and Jlab, SLAC is modeling the design with the **ACE3P** code suite and will evaluate the wakefield effects in the coupled SPX 2-cavity system.
- The cavity will be built and tested at Jlab and delivered to Argonne for final installation.



Trapped mode in 2 SPX cavities



Monopole and dipole HOM impedance

In collaboration with Argonne & JLab

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Modeling & Simulation for Future BES Projects

- Crab cavity (SPX) for APS Upgrade
  - Trapped mode in cavities
  - Bellows impedance
  - Mulitpacting simulation
  - Cryomodule simulation including thermal effects
  - Multipole fields for beam dynamics studies
- NSLS-II
  - Multipacting simulation in SRF cavity
  - Impedance of beamline components
- ERL & NGLS design
  - Wakefield effects on beam breakup
  - Thermal analysis of couplers & HOM absorbers in SRF cavities

Long Term Goal for BES Accelerator Modeling

- Develop a fully integrated modeling capability in ACE3P that includes rf, thermal and mechanical effects as well as the engineering and beam aspects of the machine to enable simulation at the system level to reach the optimal design for performance and reliability.

Deflecting cavity cryomodule for APS Upgrade

Courtesy A. Nassiri