Advanced Electromagnetic Modeling for BES Accelerators with ACE3P*

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Accelerator Modeling with EM Code Suite **ACE3P**

*Electromagnetic Code Suite **ACE3P***

- Supported by DOE's HPC initiatives Grand Challenge, SciDAC-1 (2001-2007), and SciDAC-2 (2007-2012), SLAC has developed ACE3P, a comprehensive set of parallel electromagnetic codes based on the conformal, high-order finite-element method

ACE3P (Advanced Computational Electromagnetics 3D Parallel)

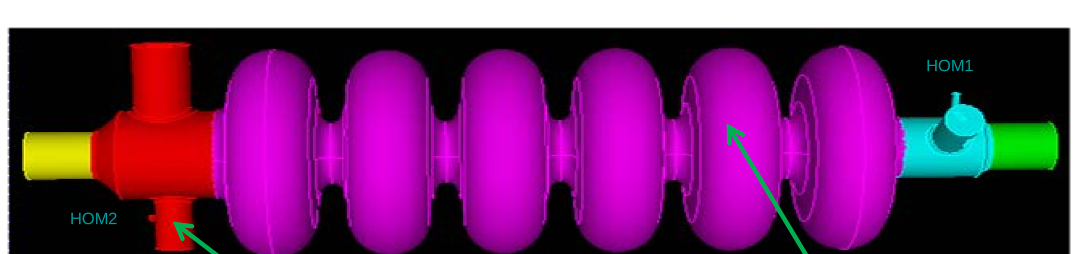
Frequency Domain:	**Omega3P**	**– Eigensolver (damping)**
	S3P	**– S-Parameter**
Time Domain:	**T3P**	**– Wakefields and Transients**
Particle Tracking:	**Track3P**	**– Multipacting and Dark Current**
EM Particle-in-cell:	**Pic3P**	**– RF guns & klystrons**
Multi-physics:	**TEM3P**	**– EM, Thermal & Structural effects**

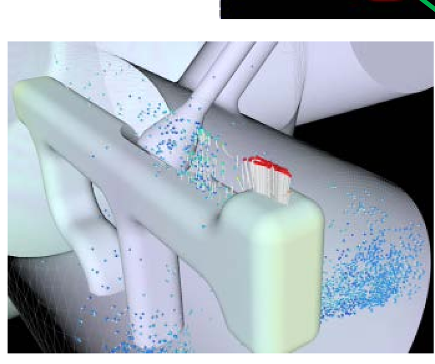
Challenges for Accelerator Modeling

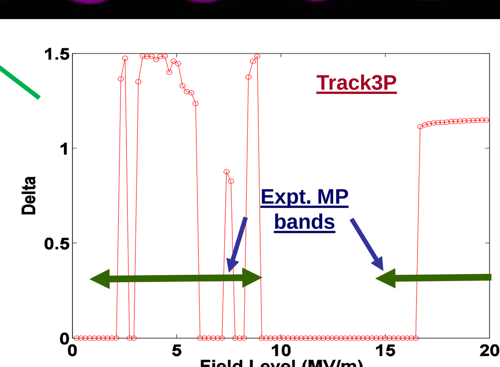
- Future light sources will employ high currents and short bunches to achieve machine requirements such as high brightness.
- Accelerating cavities need to be optimized to satisfy both rf and beam characteristics.
- Accurate calculation of wakefield is essential to determine the current threshold for beam breakup, which requires substantial computational resources especially for short bunches.
- Development of new capabilities in **ACE3P** will address modeling needs of these accelerators, and its use of high performance computing will facilitate the design and optimization process.

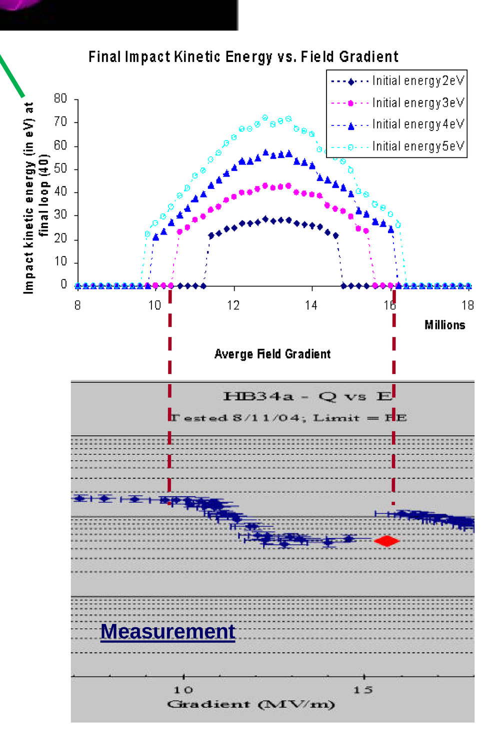
Multipacting Studies in SRF Cavity

SNS Superconducting RF Cavity







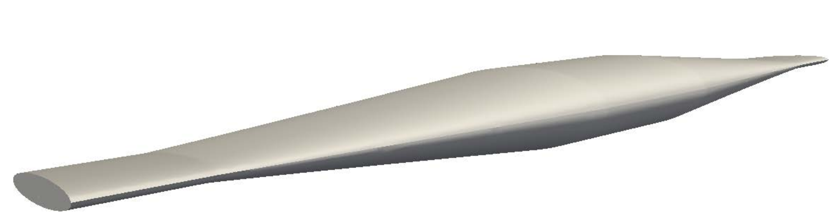


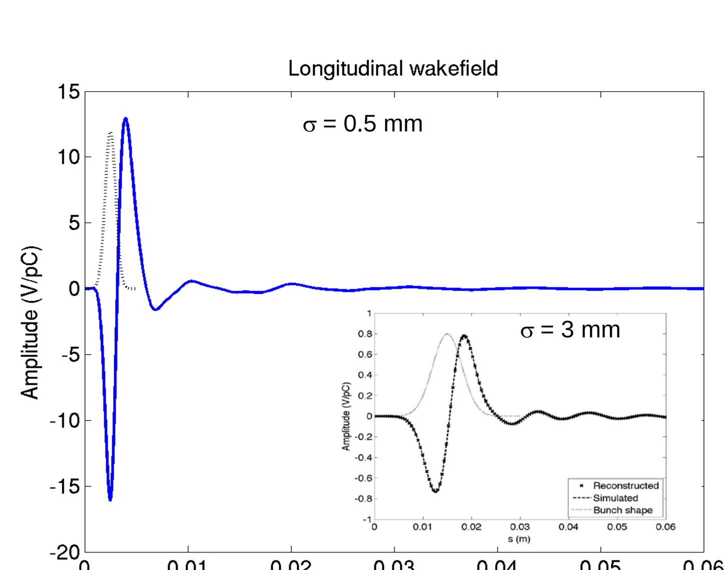
- SNS SCRF cavity experienced rf heating at HOM coupler
- **Cavity** - Both experiment and simulation showed same MP band: 11 MV/m ~ 15MV/m
- **Coupler** - Experienced rf heating at HOM coupler;3D simulations showed MP barriers close to measurements

Wakefield Computation for Short Bunches

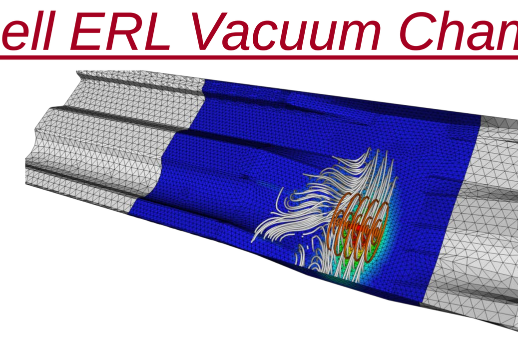
- **Next generation light sources** plan to operate with ultra-short bunches and their wakefield effects are important to the design of these facilities.
- Accurate wakefield simulation for very long 3D structures is extremely challenging due to the huge computation resources needed.
- A moving window technique in **T3P** localizes the calculation to within the bunch region, thus reducing the computation resources by several orders of magnitude.
- This capability has been applied with success to the PEP-X storage ring beamline components and the Cornell ERL vacuum chamber transition.

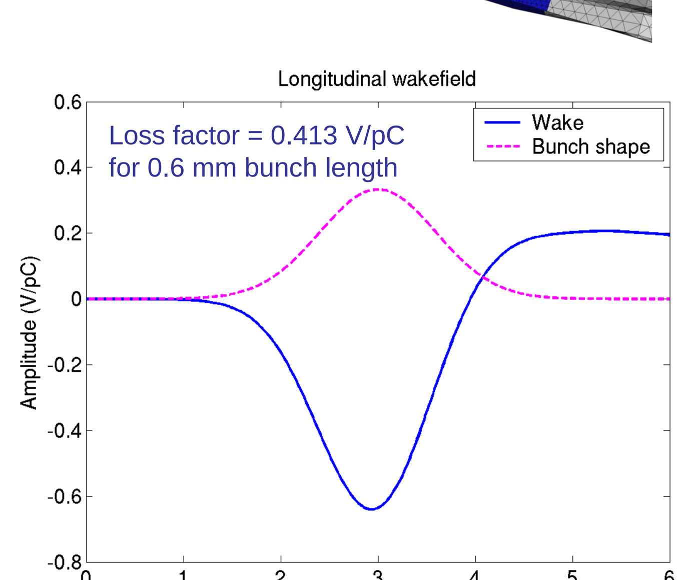
PEP-X Undulator Chamber





Cornell ERL Vacuum Chamber



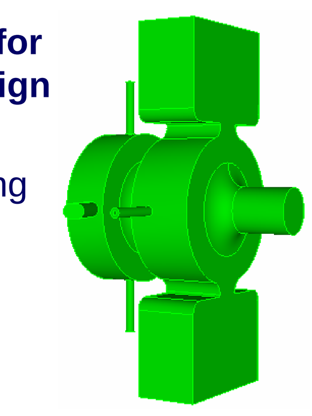


Design & Optimization of Accelerating Cavity

LCLS RF Gun

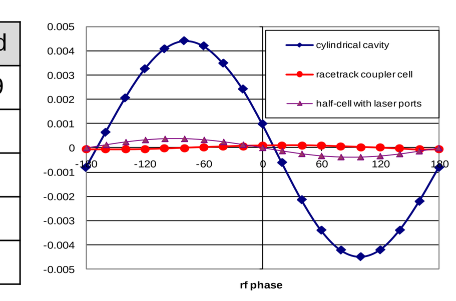
Omega3P provided dimensions for LCLS RF gun cavity to meet design requirements:

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



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

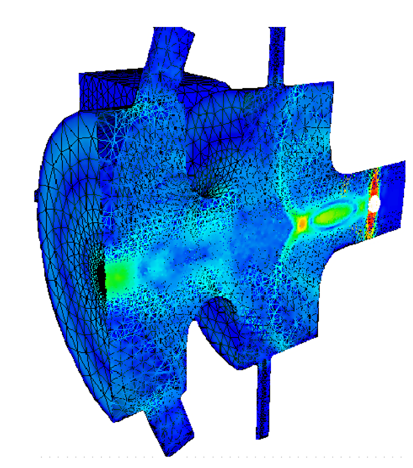
Code validated by measurement



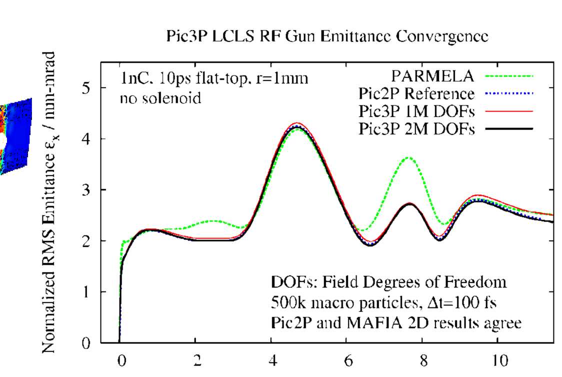
Quadrupole moment as a function of rf phase

Emittance calculation using Pic3P

- Racetrack cavity design: Almost 2D drive mode. Cylindrical bunch allows benchmarking of 3D code Pic3P against 2D codes Pic2P and MAFIA for emittance calculation.
- Unprecedented accuracy due to higher-order particle-field coupling and conformal boundaries

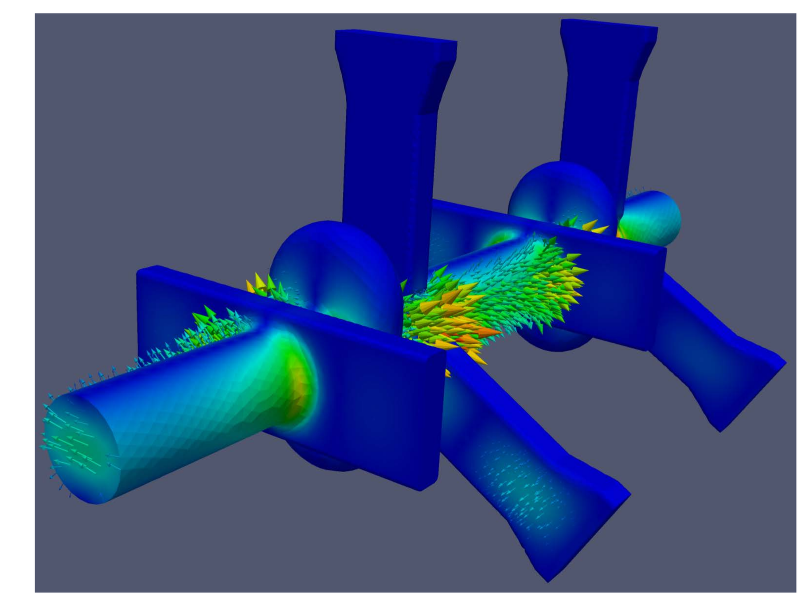


Snapshot of electron bunch and scattered self-fields

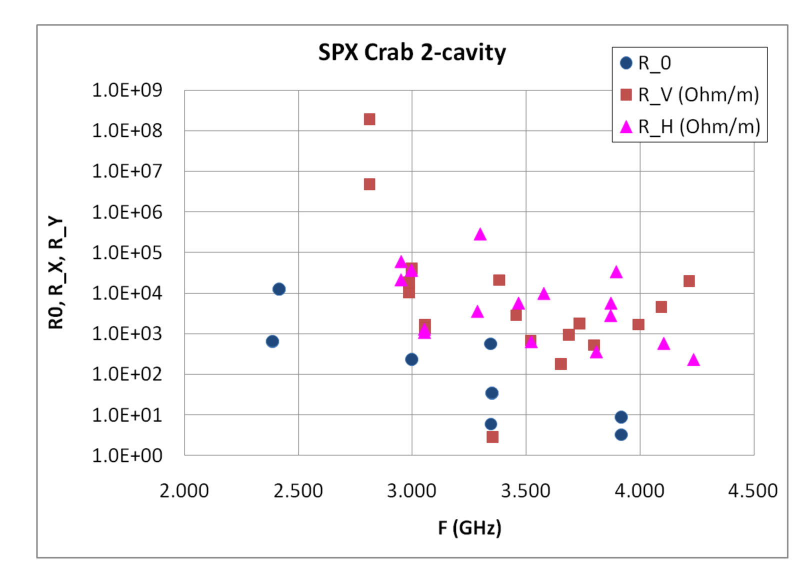


Deflecting Cavity for APS Upgrade

- **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

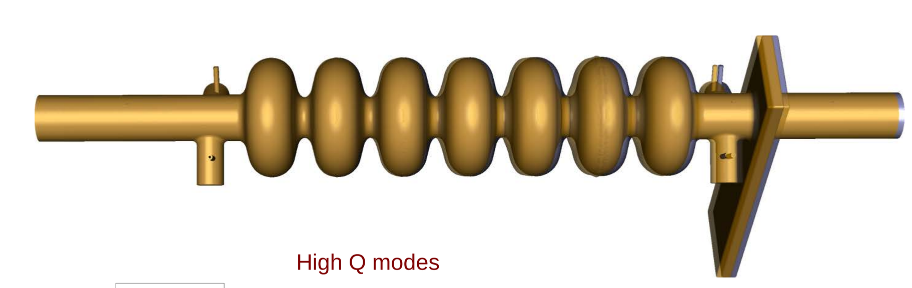


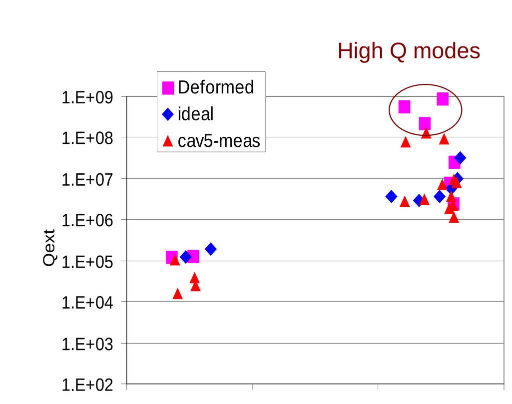
Monopole and dipole HOM impedance

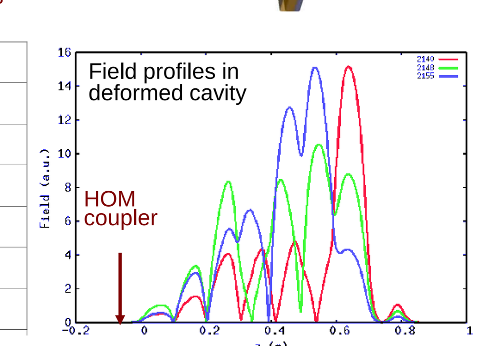
Wakefield and Beam Breakup in SRF Cavity

CEBAF 12-GeV Upgrade

- **Beam breakup (BBU)** observed at beam currents well below design threshold
- Using measured RF parameters such as f, Q_{ext}, and field profile as inputs, **solved the inverse problem** to find the deformed cavity shape.
- Found cavity is 8 mm short as predicted and confirmed by measurements (causing the fields of the 3 abnormally high Q modes shifted away from the coupler).
- **Experimental diagnosis, advanced computing and applied math** worked together to solve a real world problem as intended by **SciDAC**.

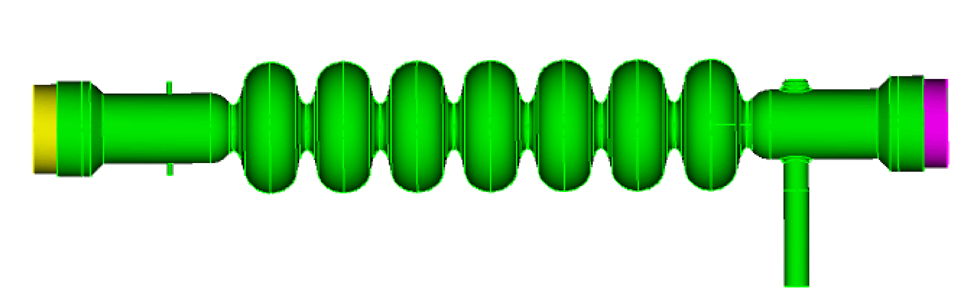




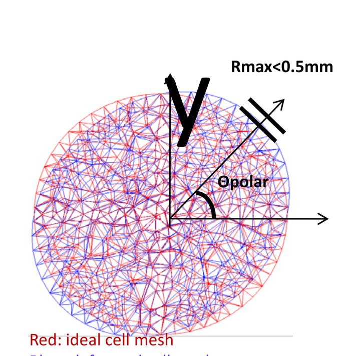


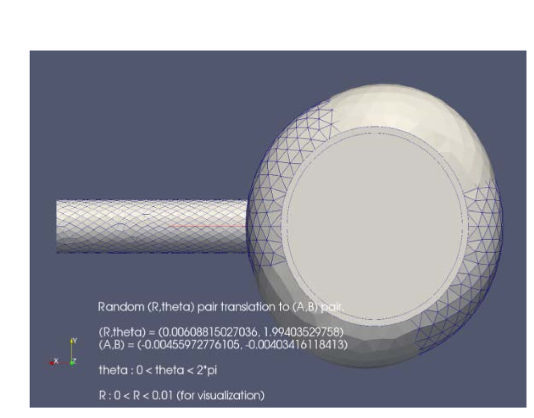
Effects of Cavity Deformation

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

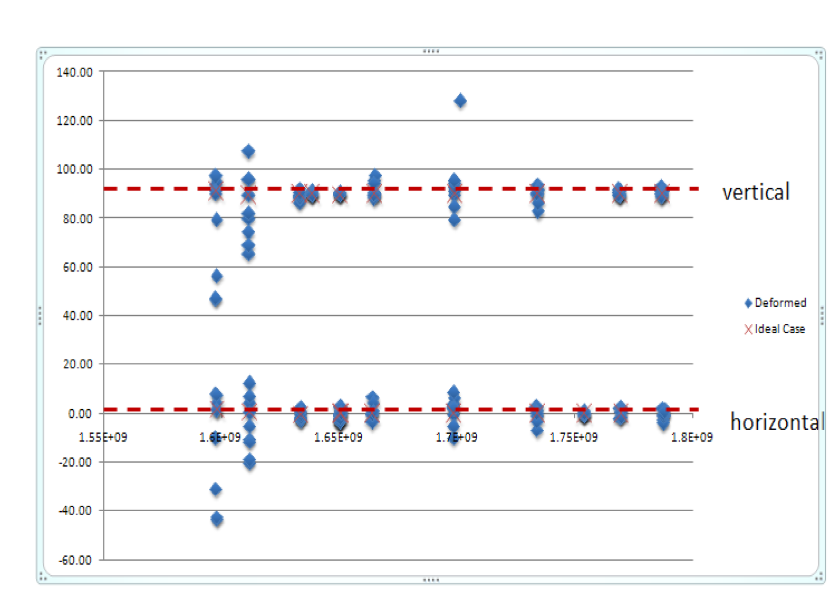


Cornell ERL SRF Cavity





20 randomly elliptically deformed cell cavitiy



Dipole mode polarization angle

Same techniques can be applied to study BBU for ERL light sources and NGLS.

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