SLAC Parallel EM Codes for MI-Cavity Simulations

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Outline

- **SLAC Parallel EM Codes**
  - *parallel finite-element EM suite ACE3P*
- **ACE3P Tools for Cavity Simulations**
  - *development of Omega3P*
  - *benchmark for cavities with lossy materials*
  - *multipacting simulation using Track3P*
  - *thermal & mechanical analysis using TEM3P*
- **Project-X MI Cavity**
  - *simulation model for Omega3P run*
- **Summary**

1. Parallel Finite Element EM Code Suite ACE3P

SLAC has developed the conformal, higher-order, C++/MPI-based parallel EM code suite ACE3P for high-fidelity modeling of large, complex accelerator structures.

ACE3P: Parallel Finite Element EM Code Suite

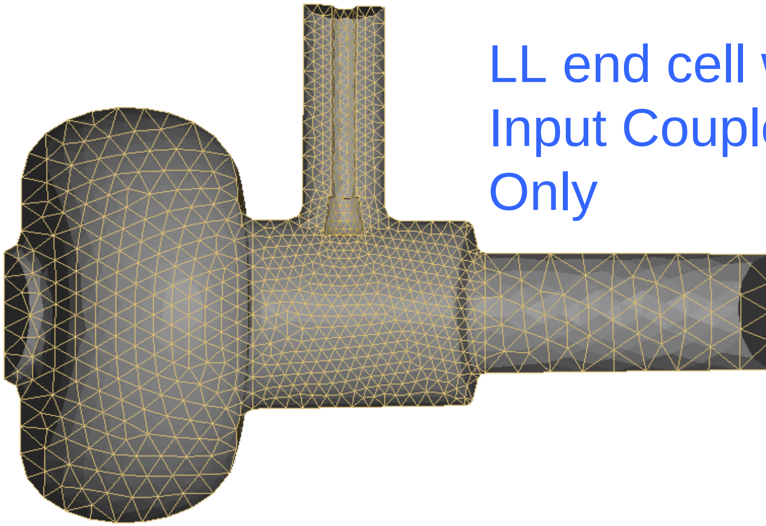
(Advanced Computational Electromagnetics, 3D, Parallel)

	ACE3P Modules	Accelerator Physics Application
Frequency Domain:	Omega3P	Eigensolver (nonlinear, damping)
	S3P	S-Parameter
Time Domain:	T3P	Transients & Wakefields
	Pic3P	EM Particle-In-Cell (self-consistent)
Particle Tracking:	Track3P	Dark Current and Multipacting
	Gun3P	Space-Charge Beam Optics
Multi-Physics:	TEM3P	EM-Thermal-Mechanical

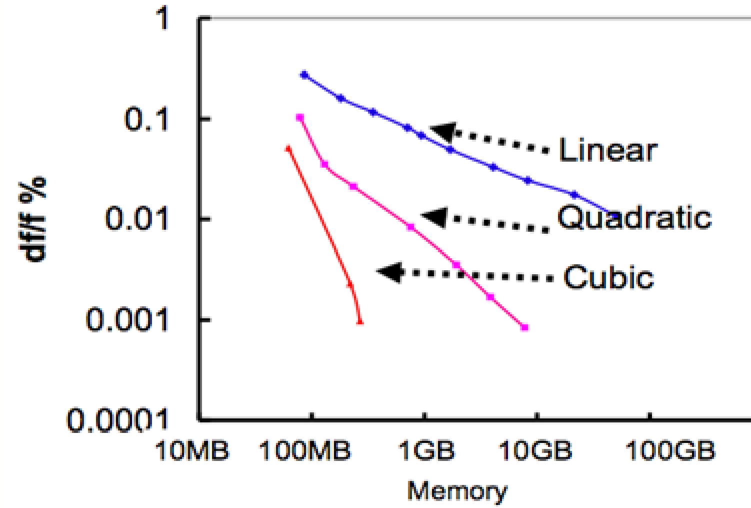
Visualization: ParaView – Meshes, Fields and Particles

Funded by SciDAC1 (2001-2006) and continuing under SciDAC2 (in black)
Under development for ComPASS (2007-2011) (in blue)

1.1 Parallel Finite Element EM

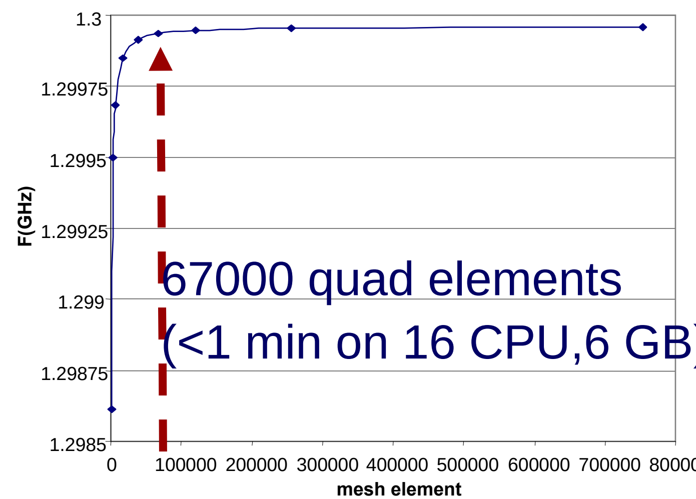


LL end cell with Input Coupler Only

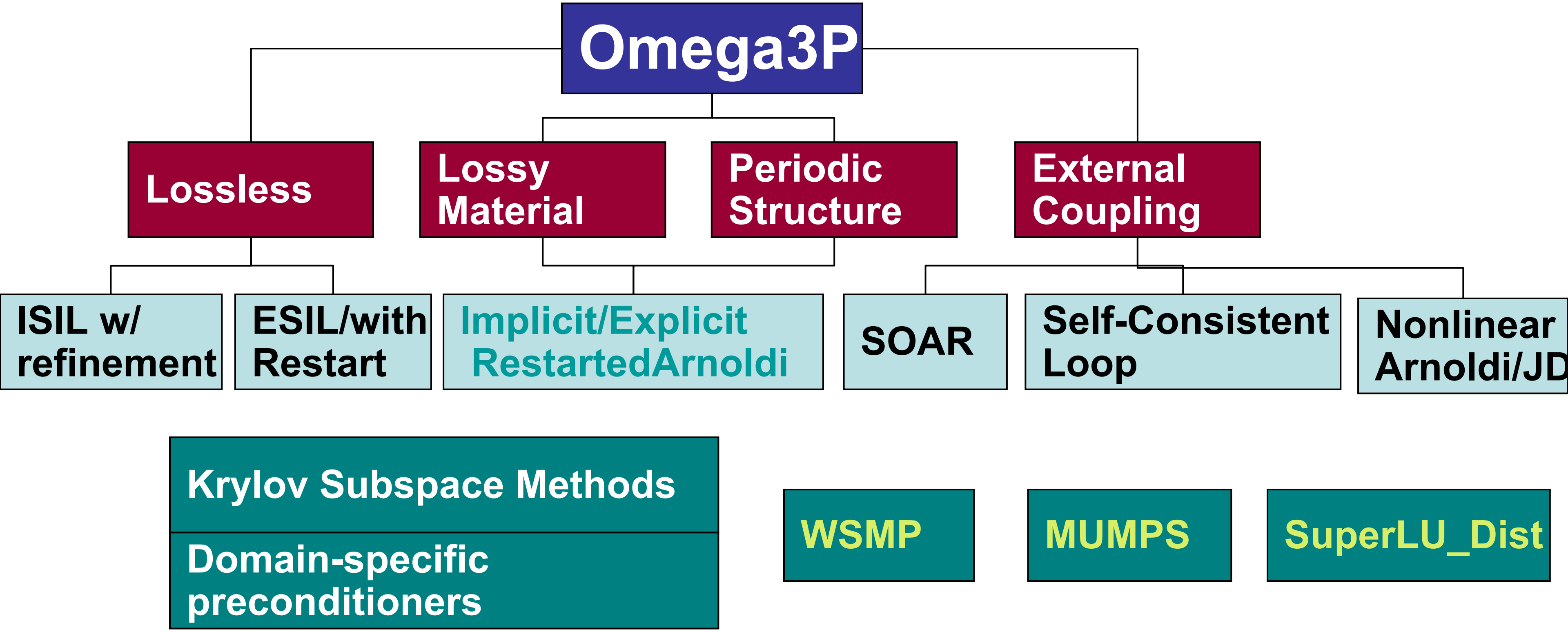


__Key Strengths__

- **Tetrahedral Conformal Mesh** w/ quadratic surface
- **Higher-order Finite Elements** p = 1-6
- **Parallel Computing** large memory & speedup



2. Omega3P for Cavity Simulations



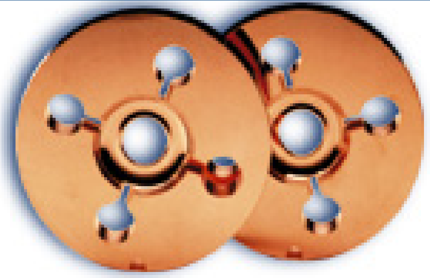
Different solver options have different performance dynamics

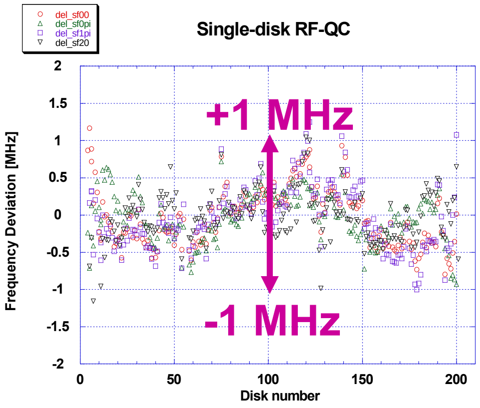
2.1 Advances of Omega3P

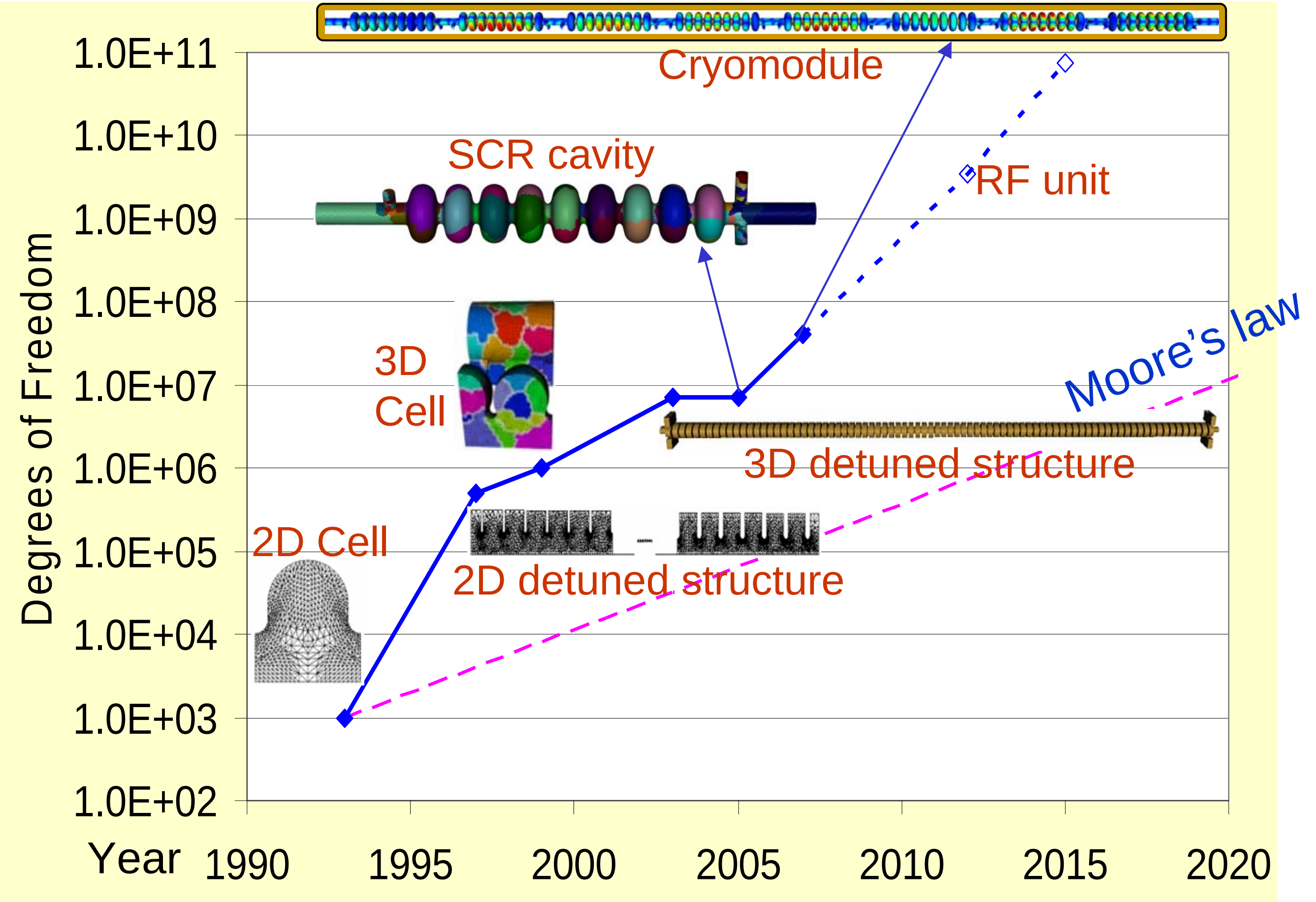
Goal: High Fidelity simulation -> CAD drawing -> hardware fabrication
- from single 2D cavity to a cryomodule of eight 3D ILC cavities

An increase of 10^5 in problem size with 10^{-5} accuracy over a decade

Code Validation *– Microwave QC of fabricated NLC cells verified frequency relative error to 0.01% which avoids tuning*







2.2 Cavities with Lossy Materials

Cavity filled with lossless and lossy dielectric

- Solve for a transverse TE111-like hybridmode in a cavity partially filled with dielectric or magnetic material.
- Omega3P results agree very well with analytic solutions.

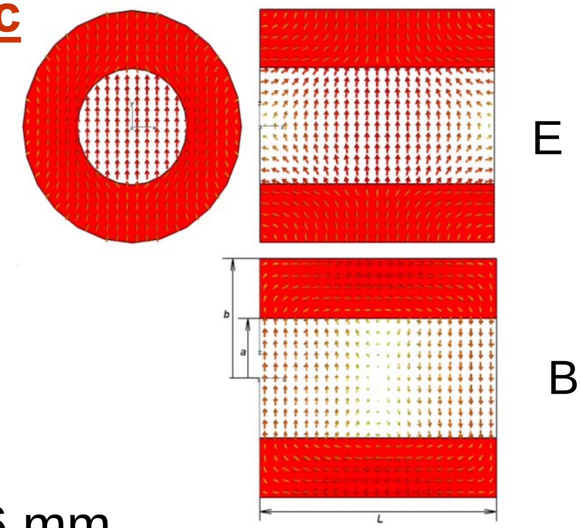


Table 1. Results for a = 55, b = 56 mm.

	Theory	MWS 2008	CLANS2 (H)	CLANS2 (E)	HFSS	Omega3P	MWS 2008	CLANS2 (H)	CLANS2 (E)	HFSS	Omega3P
ε	20						20				
μ	1						1				
tan(δ)	0						0.5				
F *MHz*	1990.307	1986.63	1990.31	1990.31	1990.69	1990.307	1986.63	1990.12	1990.15	1990.54	1990.155
Q		26244	42137	25968	26170	26112	957	224	1739	1745	1864

2.2 Cavities with Lossy Materials (cont'd)

Cavity filled with lossless magnetic material

Table 2. Results for a = 28, b = 56 mm (*Q* in parentheses, for Cu envelope).

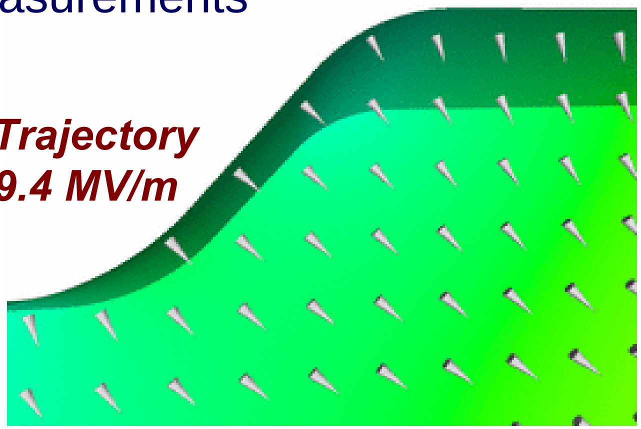
ε		1	2	10	1	2	10
μ		1	1	1	2	2	10
f, MHz, theory		**2005.311**	**1634.236**	**891.486**	**1507.439**	**1205.195**	**291.616**
f, MHz, SLANS2 (E)		**2005.311**	**1634.236**	**891.486**	1507.829	1205.347	291.614
f, MHz, SLANS2 (H)		**2005.311**	1634.154	891.288	**1507.439**	**1205.195**	291.612
f, MHz, CLANS2 (E)		**2005.311**	**1634.236** (20779)	**891.486** (11864)	1507.440	**1205.195** (41257)	**291.616** (176947)
f, MHz, CLANS2 (H)						**1205.195** (48914)	**291.616** (333744)
f, MHz, MWS 2008							291.396
Omega3P	All exterior Cu (E)	2005.311 (27235)	1634.236 (20900)	891.4850 (11932)		1205.1947 (31266)	291.6154 (60818)

2.3 ***Track3P*** - Multipacting in SRF Cavities

Prediction of MP in Ichiro cavity

- Simulated MP barriers confirmed by measurements

MP Trajectory @ 29.4 MV/m

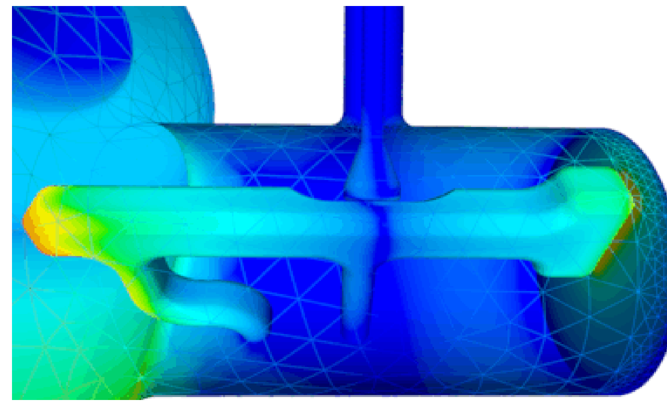


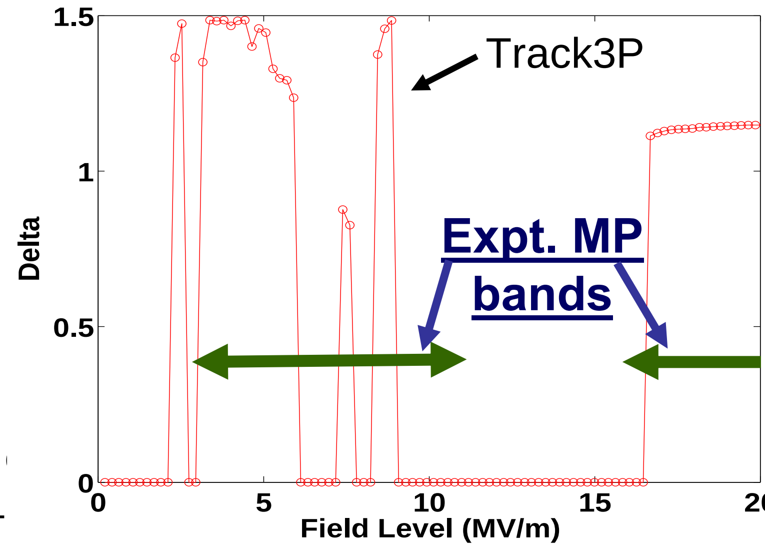
SLAC simulated MP levels [MV/m]	ICHIRO#0 X-ray barrier [MV/m]
	7.4, 9.0, 7-17
12.0	11-29.3, 12-18
13.9	13, 14, 14-18, 13-27, 13-27
16.8	(17, 18)
21.2	20.8
29.4	28.7, 29.0, 29.3, 29.4

In collaboration with KEK – K. Saito

SNS SRF cavity HOM coupler

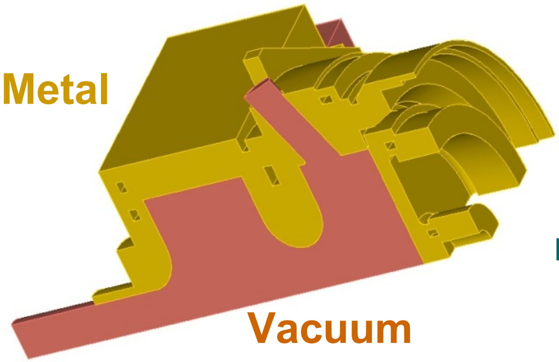
- RF heating observed at HOM coupler
- 3D simulations showed MP barriers close to measurements





2.4 ***TEM3P*** - Parallel Multi-physics Simulation Tool

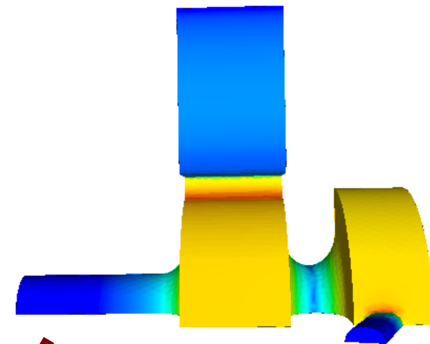
CAD model



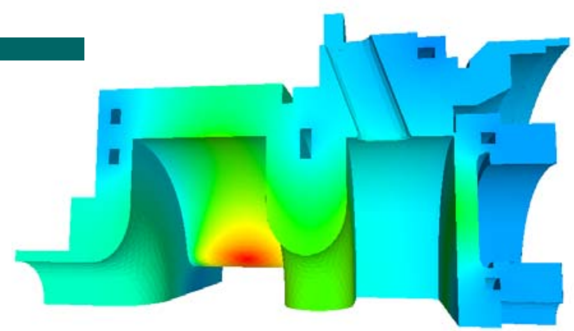
Courtesy E. Jongewaard

TEM3P for design and optimization

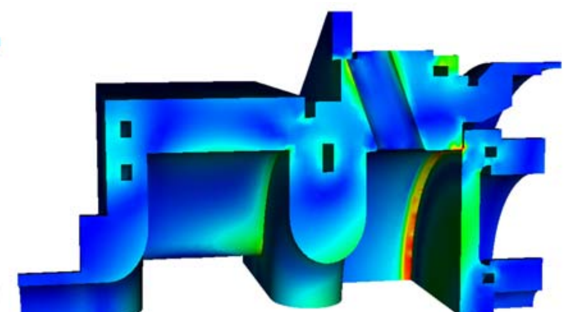
Electromagnetics



Thermal



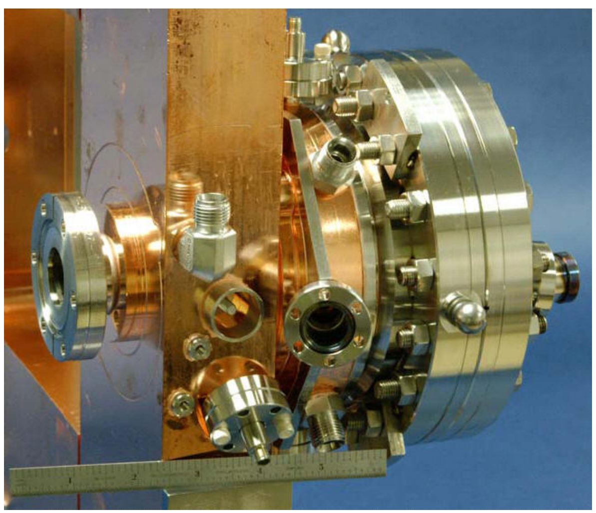
Mechanical



LCLS

***RF* Gun**

Engineering prototype

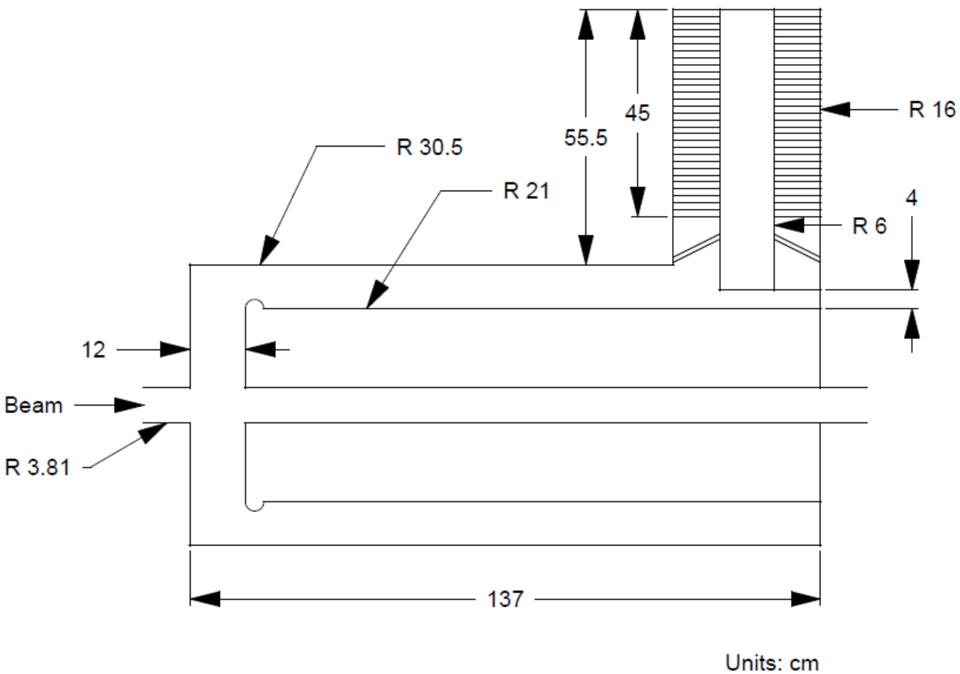


Courtesy D. Dowell

Benchmarked against ANSYS

3. MI Cavity for Project-X

Ioanis Kourbanis (FNAL)



Parameter	Value	Units
R/Q	50	Ω
Q	10000	
Max. Voltage	240	KV
Harmonic number	588	
Frequency	52.8114-53.104	MHz
Number of Cavities	20	

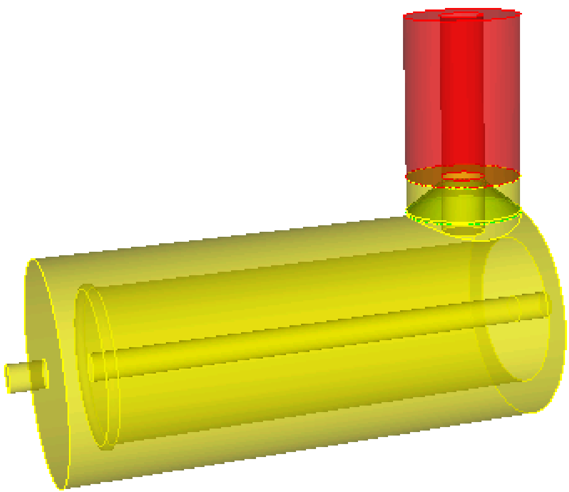
3.1 Simulation Model for the MI Cavity

Red: Ferrite

Green: Ceramic window

Yellow: Copper coated wall

& Vacuum part



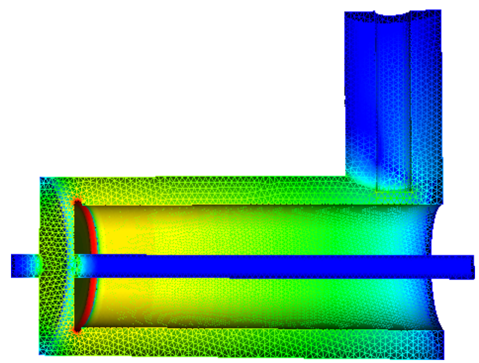
Model

Fundamental mode with the empty ferrite vessel

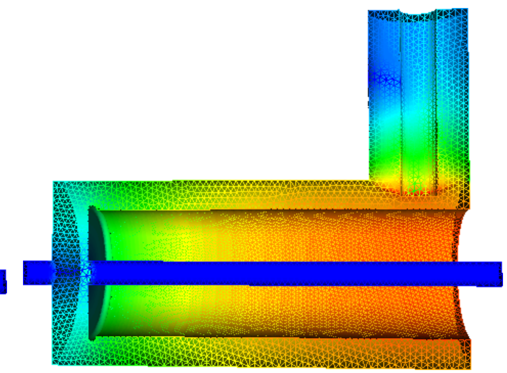
F = 53.701MHz

R/Q = 58.69 Ω (β=1)

Q0 = 9630 (σ=5.8e7 s/m)



E-field



B-field

3.2 Work Plan for MI Cavity Simulations

Modify the MI cavity model with realistic ferrite cores to simulate:

1. Fundamental mode's Q and Rs;
2. HOM parameters including frequency spectrum and their R/Q;
3. Fundamental mode's frequency tuning range with different tuner coupling;

   (FNAL will provide realistic ferrite and ceramic parameters)
4. Peak surface field and its location;
5. Power dissipation on cavity wall, in tuner and ceramic.

4. Summary

- SLAC has developed a comprehensive set of ***parallel* EM codes** that have been benchmarked and applied to R&D of major accelerator projects;
- ***Omega3P*** is an effective tool to simulate the MI cavity for Project-X;
- Close collaboration between FNAL and SLAC is required to define the scope of modeling for the MI cavity design.