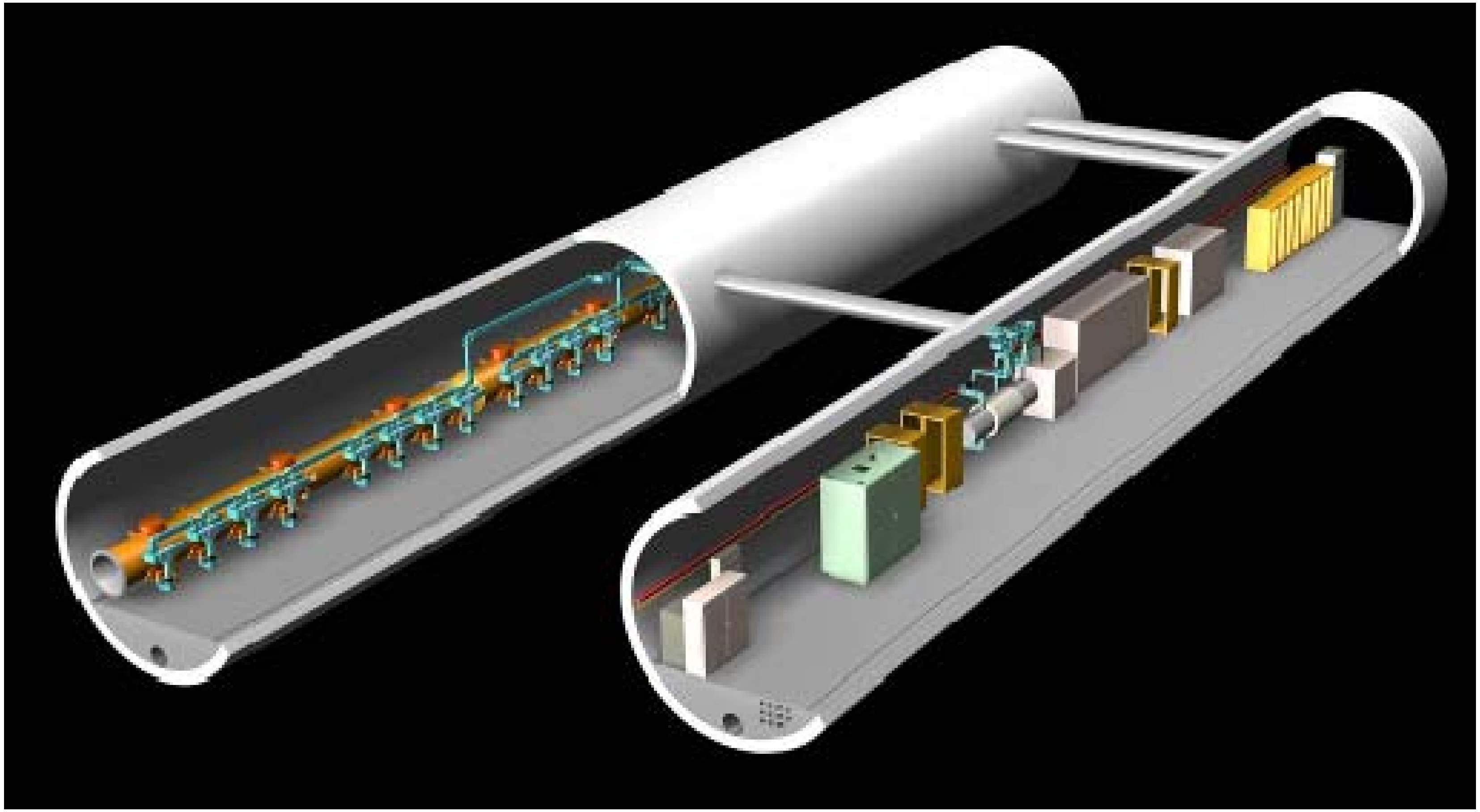
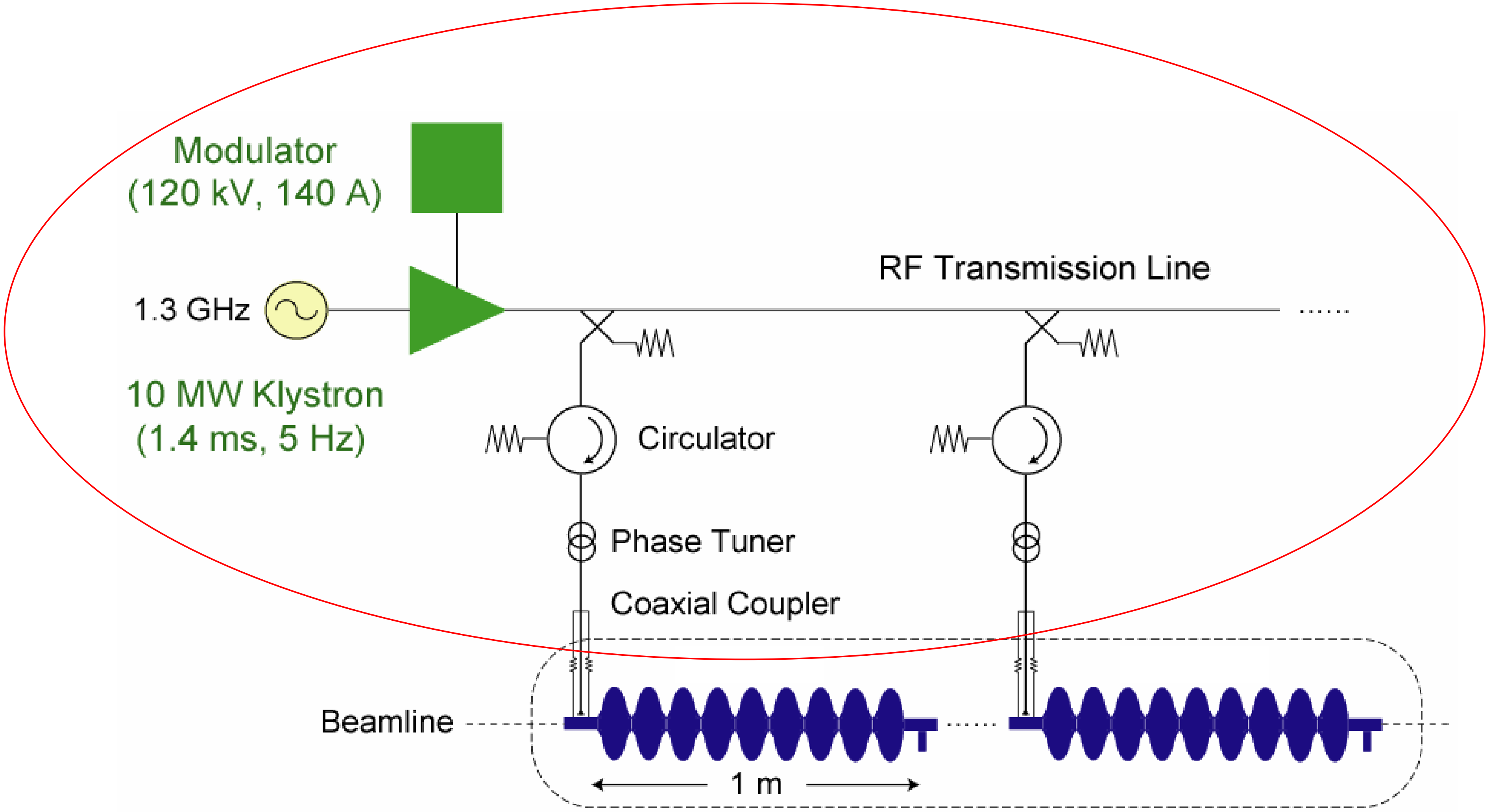
Main Linac Power
and Quad / BPM / Wakes



Chris Adolphsen

July 19-22, 2006 – Vancouver GDE Meeting

ILC Linac RF Unit (1 of ~ 600)

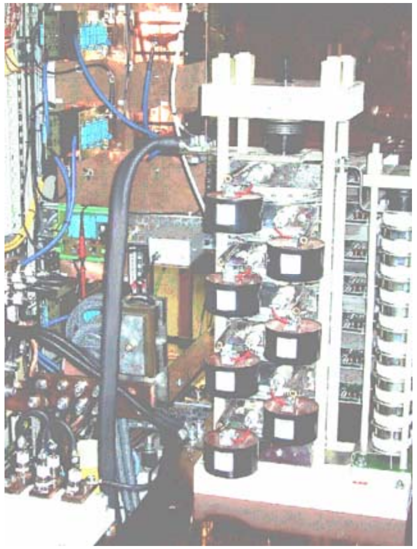


Cryomodule 1 of 3
(8 Cavities per Cryomodule)

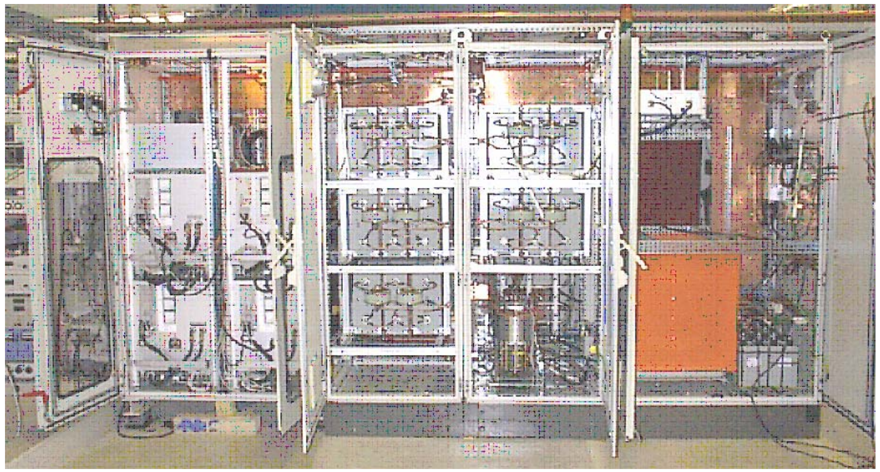
Pulse Transformer Modulator Status

- 10 units have been built, 3 by FNAL and 7 by industry (PPT with components from ABB, FUG, Poynting).
- 8 modulators are in operation.
- 10 years operation experience.
- Working towards a more cost efficient and compact design.
- FNAL building two more, one each for ILC and HINS programs – SLAC has bulit switching circuits.

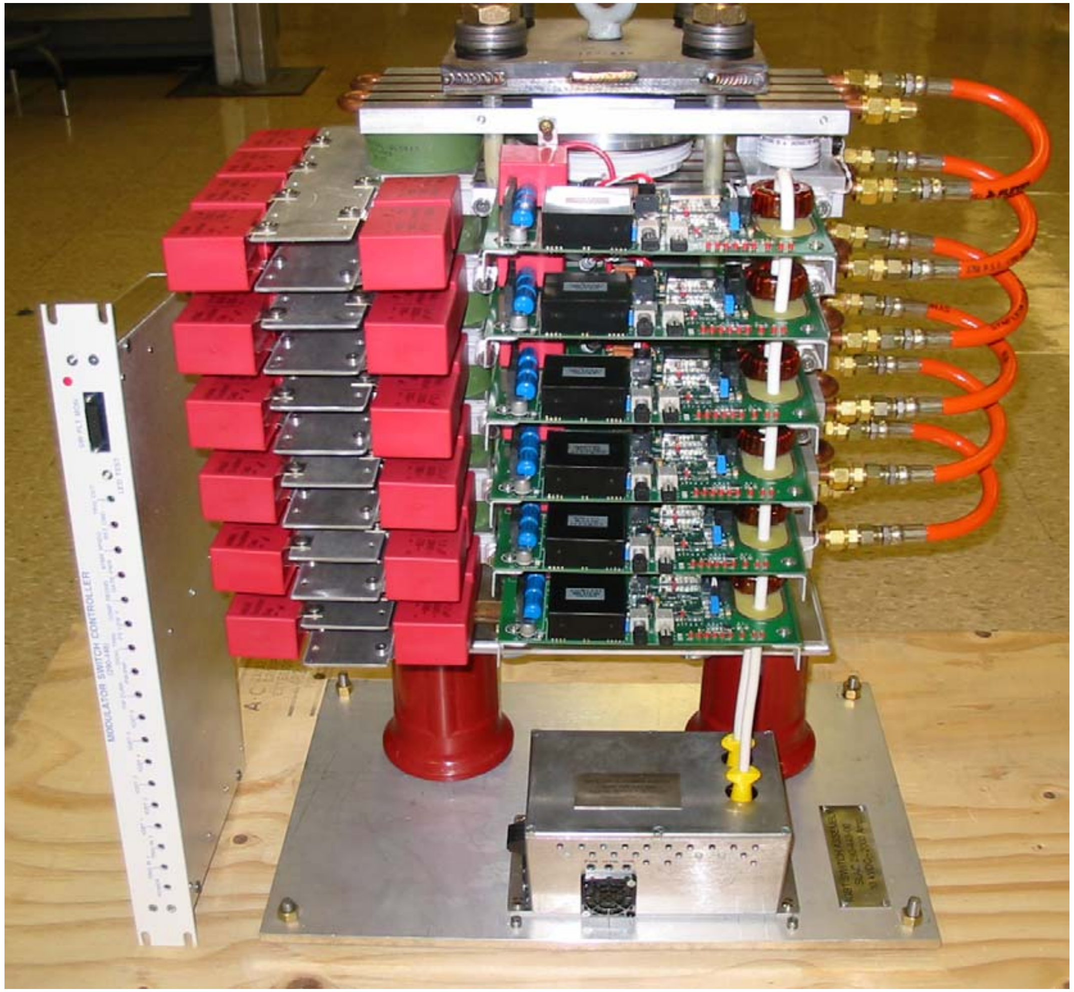
IGCT Stack

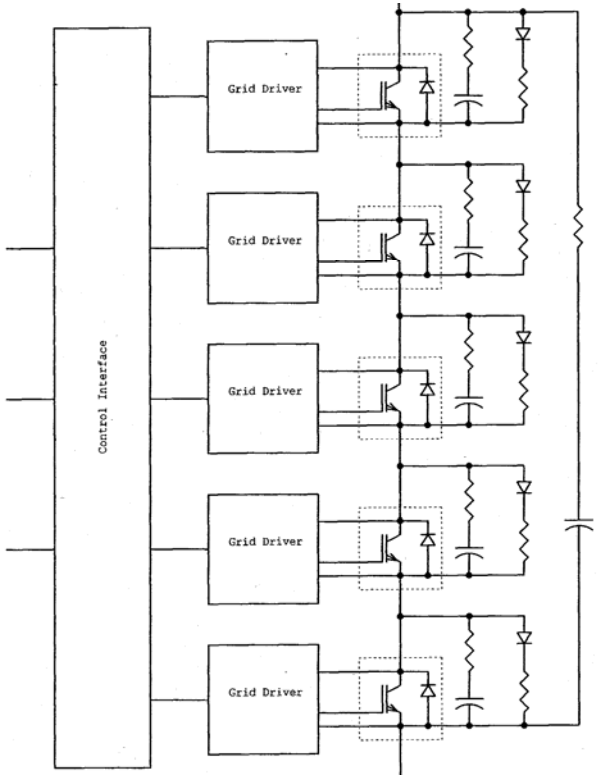


HVPS and Pulse Forming Unit



New Switch Design Provided by SLAC





Switch Schematic

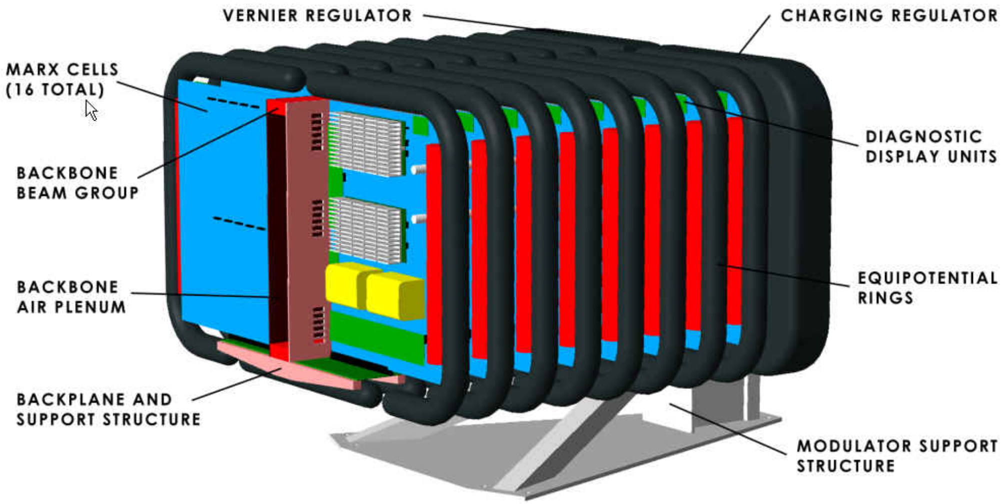
- 10 kV nominal operation
- Redundant drive
- Independent snubbers

BCD and ACD Modulators

(120 kV, 130 A, 1.6 ms, 5 Hz)

Baseline: Pulse Transformer Style Modulator

Alternative: Marx Generator Modulator



(~ 2 m Long)

Motivation: Reduce cost, size and weight, improve efficiency and eliminate large oil-filled transformer from tunnel.

Will test full prototype in 2006

Marx Modulator Status

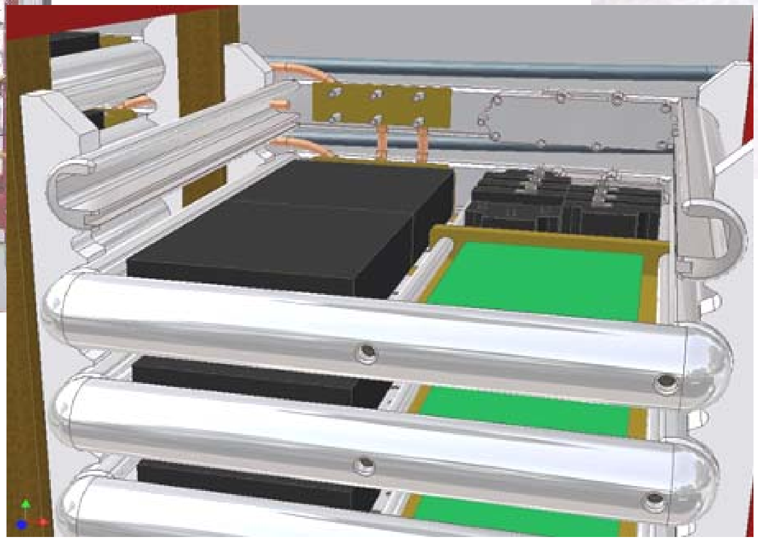
- Modulator support structure, backbone, complete.
- First 12 kV prototype Marx cell tested at full voltage and current
  - Survives ‘spark-down’ tests to simulate shorted load
- Equipotential rings, connection planes complete.
- PCB fabrication 50% complete
- Air cooled 150 kW test load 50% complete

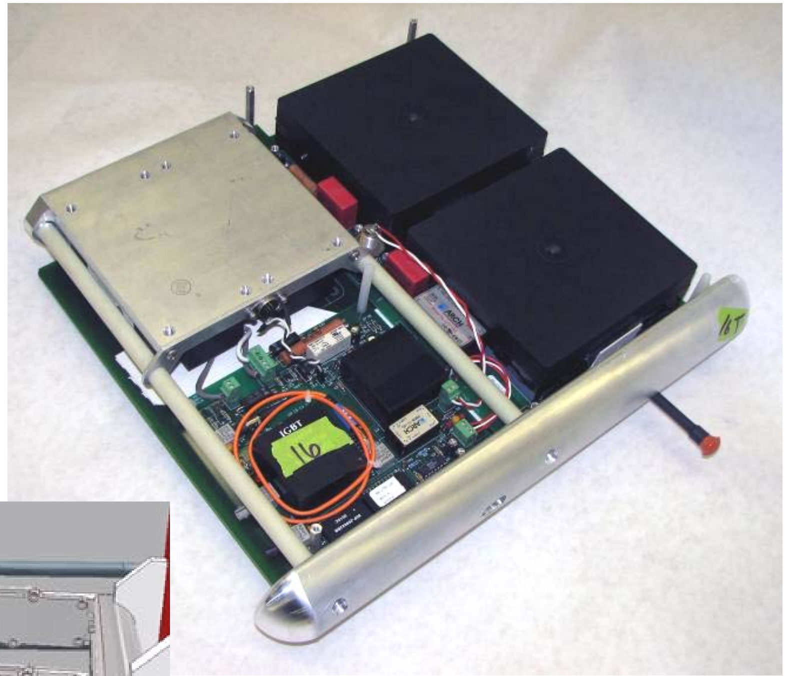
Stangenes Marx Generator for NATO Radar Systems

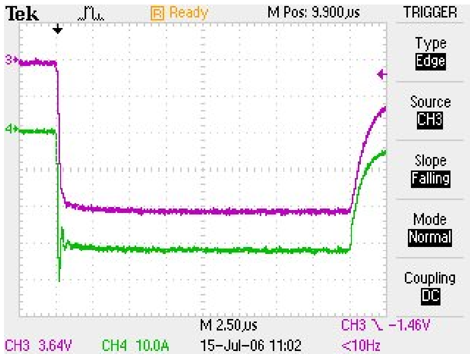
- Peak Operating Voltage: 90 kV
- Peak Operating Current: 50-150 A
- Pulse Width: 110 microseconds
- Duty Cycle: 4.8% (Short Burst)
- Continuous Duty Cycle: 2.5%
- Pulse Droop: 3% max, 1.5% desirable
- Input power: 120 kW
- Input voltage: 416 volts AC 60 Hz

Stangenes Marx Generator

(Produced 30*3 = 90 kV, 50A, 100 μsec Pulses)



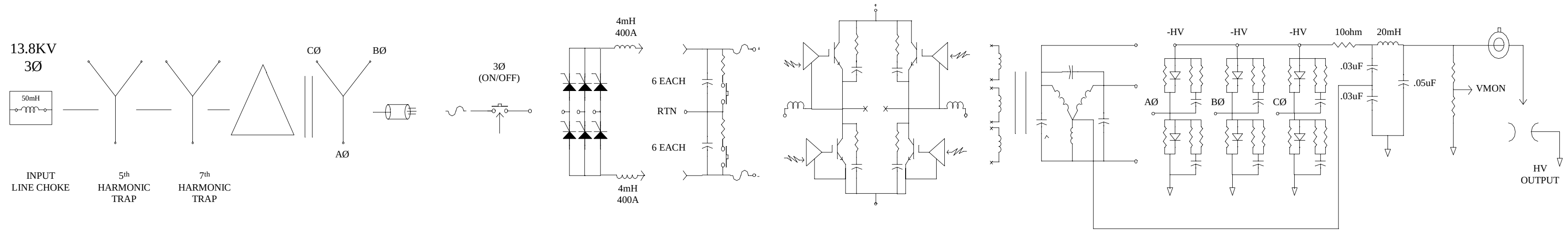




Other Alternative Modulators

SNS High Voltage Converter Modulator (Unit installed at SLAC)

RECTIFIER TRANSFORMER AND FILTERS | SCR REGULATOR | ENERGY STORAGE | SWITCHING | BOOST TRANS-FORMER | HV RECTIFIER AND FILTER NETWORK



RECTIFIER TRANSFORMER AND FILTERS

SCR REGULATOR

HVCM

EQUIPMENT CONTROL RACK

Series Switch Modulator
(Diversified Technologies, Inc.)

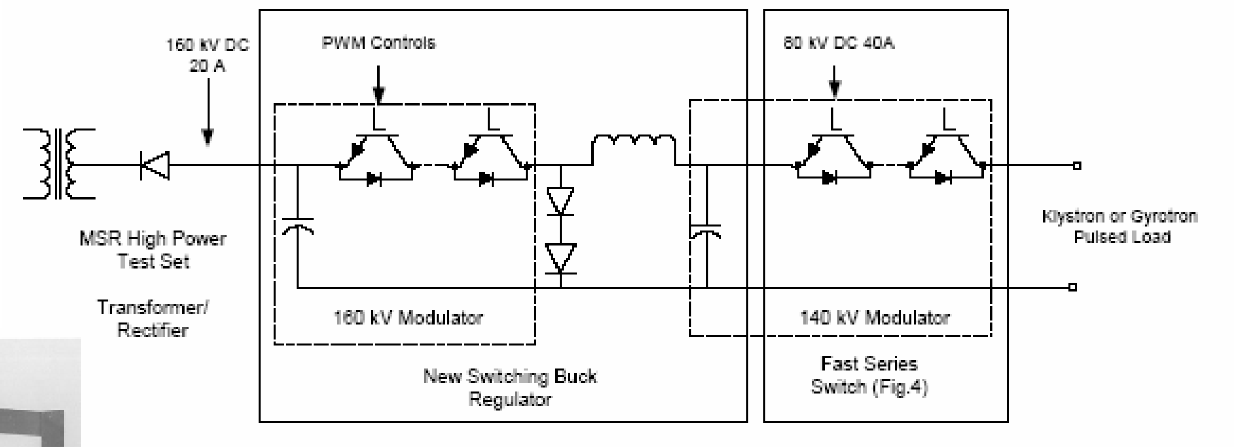


Figure 2. 140kV, 500A solid-state switch

IGBT Series Switch

140kV, 500A switch shown at left in use at CPI

As a Phase II SBIR, DTI is building a 120 kV, 130 A version with a bouncer to be delivered to SLAC at the end of 2006

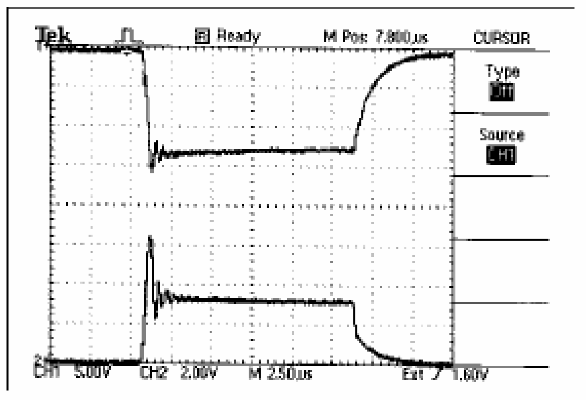


Figure 3: Test pulse (140 kV, 160 A, 13 μsec) of solid-state modulator. Upper trace is voltage at 63 kV/division. Lower trace is current at 100 A/division

SLAC FY07 Modulator Program

- Continue evaluation of SNS modulator (recently upgraded in a collaboration with LANL to allow 10 MW klystron operation).
- Establish two new test stands in ESB for DTI and Marx Modulators (start in FY06).
- Install and evaluate first prototype Marx modulator (run > 2000 hours).
- Install and evaluate DTI modulator (run > 2000 hours).
- Develop a Design-for-Manufacture (DFM) Marx Modulator in collaboration with LLNL - order parts for two units to be assembled in house in FY08, but with the circuit board subassemblies and loading let to commercial vendors.

Klystrons

Baseline: 10 MW Multi-Beam Klystrons (MBKs) with ~ 65% Efficiency: Being Developed by Three Tube Companies in Collaboration with DESY

Thales

CPI

Toshiba

Status of the 10 MW MBKs

- Thales: Four tubes produced, gun arcing problem occured and seemed to be corrected in last two tubes after fixes applied (met spec). However, tubes recently developed other arcing problems above 8 MW. Thales to build two more without changes and two with changes after problem is better diagnosed.
- CPI: One tube built and factory tested to 10 MW at short pulse. At DESY with full pulse testing, it developed vacuum leak after 8.3 MW achieved – has been repaired and has been tested again.
- Toshiba: One tube built, and after vacuum problem fixed, ran at full spec for one day – was then shipped to DESY where it has run at full power for 200 hours with good efficiency (66%).
- These are vertically mounted tubes – DESY recently asked for bids on horizontally mounted tubes for XFEL (also needed for ILC).

CPI 10 MW MKB Test at DESY in 6/06

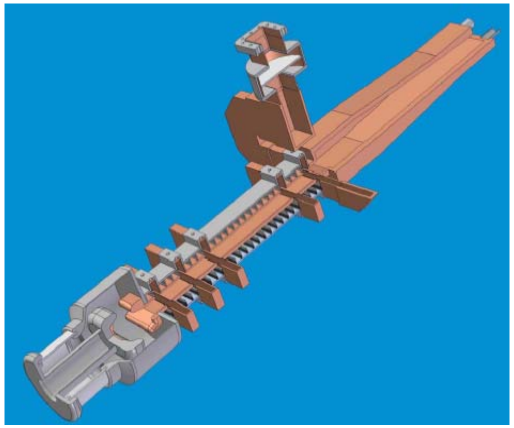
- Achieved ~ 8 MW with 1.5 ms pulses after vacuum fix.
- Limited by low efficiency (53%) – modulator voltage max'ed.
- During second week of testing, efficiency dropped to 48%.
- Cause not understood – tube will be used for component testing.

D. Sprehn

Alternative Tube Designs

10 MW Sheet Beam Klystron (SBK)

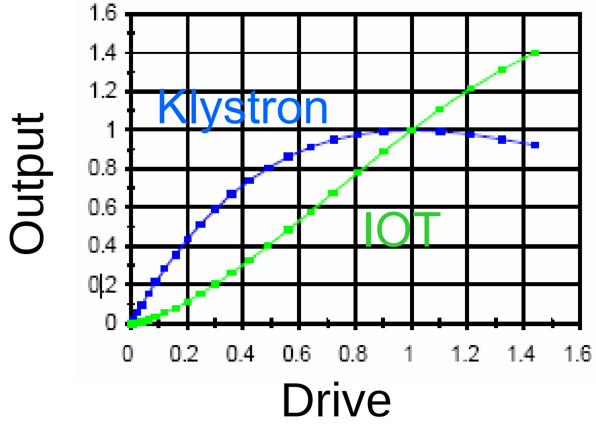
Parameters similar to 10 MW MBK



SLAC

5 MW Inductive Output Tube (IOT)

Peak Output Power	5	MW (min)
Average Output Power	75	kW (min)
Beam Voltage	115	kV (nom)
Beam Current	62	A (nom)
Current per Beam	5.17	A (nom)
Number of Beams	12	---
Frequency	1300	MHz
1dB Bandwidth	4	MHz (min)
Gain	22	dB (min)
Efficiency	70	% (nom)



CPI

Low Voltage 10 MW MBK

Voltage 65 kV
Current 238A
More beams

Perhaps use a Direct Switch Modulator

KEK

SLAC FY07 Klystron Program

- Three-prong approach to producing a robust ILC tube
  - Order second-generation 10 MW klystrons from CPI and Toshiba.
    - Most believe these tubes will work and have long cathode lifetimes (~ 100 khours). However, this forces a larger, more complex design,
  - Develop a 10 MW sheet-beam klystron at SLAC
    - Considered most risky approach but has the largest potential for cost savings.
  - Contract industry to build a higher efficiency, 5 MW, single-beam tube
    - Commercial 5 MW tubes are reliable, but have low efficiency (42%).
    - Considered a conservative approach, however, will likely require higher voltage modulator, which may decrease reliability of both the tube and modulator.
    - CPI and L3 Communications expressed interest in developing this tube.

Sheet Beam Klystron Motivation

Plug-compatible ILC RF Source replacement

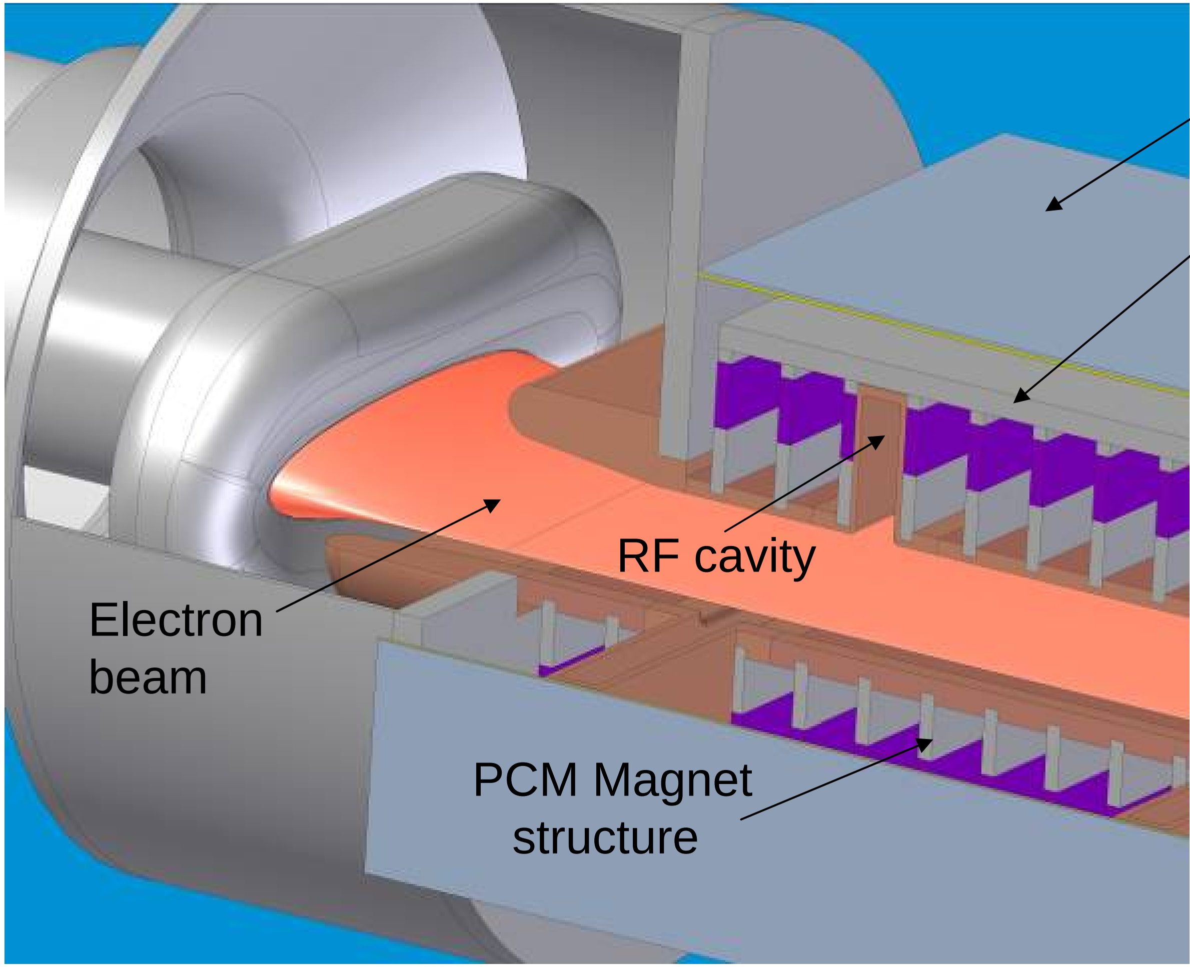
Large internal surface areas – low cathode current and power densities, low temperatures ⟶ ***very robust***

No solenoid power required - lighter, and simpler than MBK devices ⟶ ***lower costs***

Fewer parts than MBK devices – higher yields ⟶ ***lower costs***

Beam Transport and RF

130 A elliptical beam enters a PCM magnet stack with cavities inserted between magnets



Lead shielding

Magnetically shielded from outside world

3D Gun simulations give 130 A 40:1 aspect ratio elliptical beam

3D magnet simulations of 30 period structure

3D PIC Code for RF

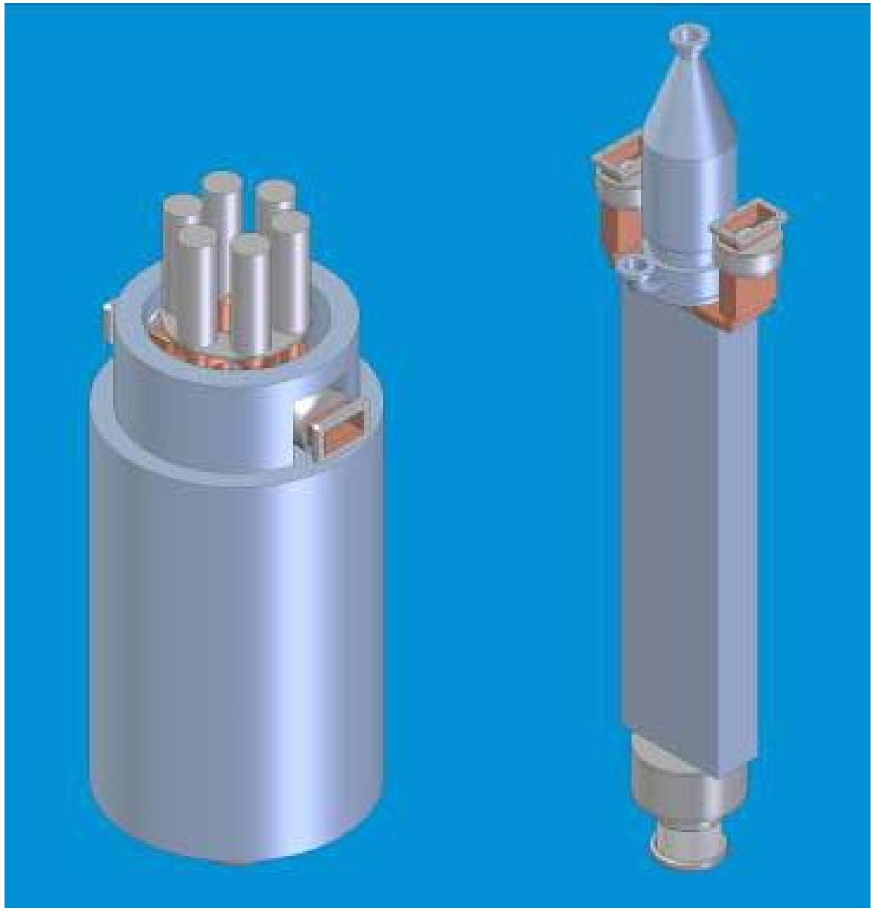
Size and Beam Focusing

ILC MBK vs. SBK

MBK's:

~5000 lbs.
91" - 98" long
35"- 45" wide

Solenoid power
4-8 kW



SLAC SBK:

921 lbs.
122" long
28" wide

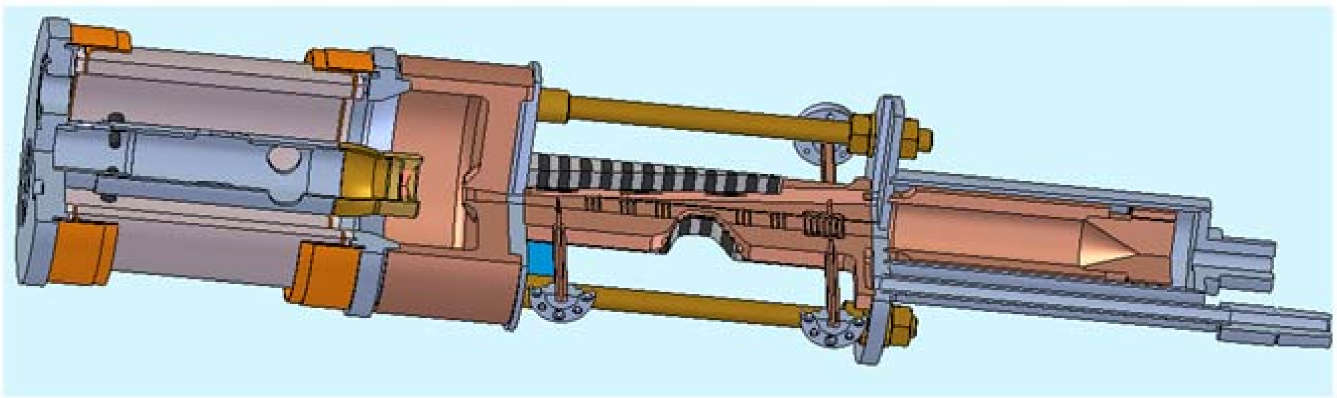
No solenoid
power required!

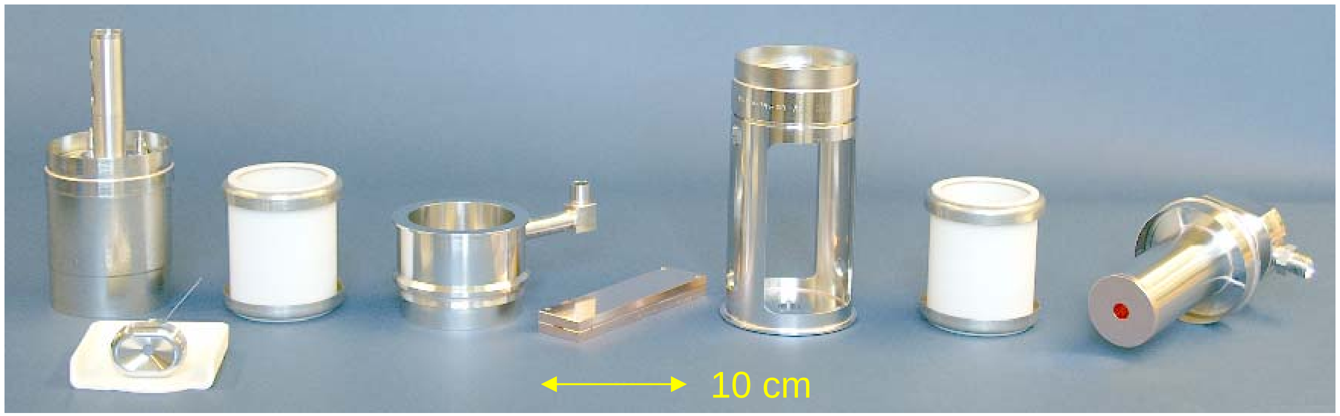
Sheet Beam Schedule
(FY06 Work Funded by SLAC)

Jun '06	Complete rf beam transport design
Jul '06	Complete gun electrode design
Aug '06	Complete electrical design
Aug '06	Complete mechanical layout
Mar '07	Mechanical drawings
Aug '07	Bake-out of first prototype
Jan '08	Bake-out of second prototype

W-Band Sheet Beam Klystron Program
(Not ILC funded)

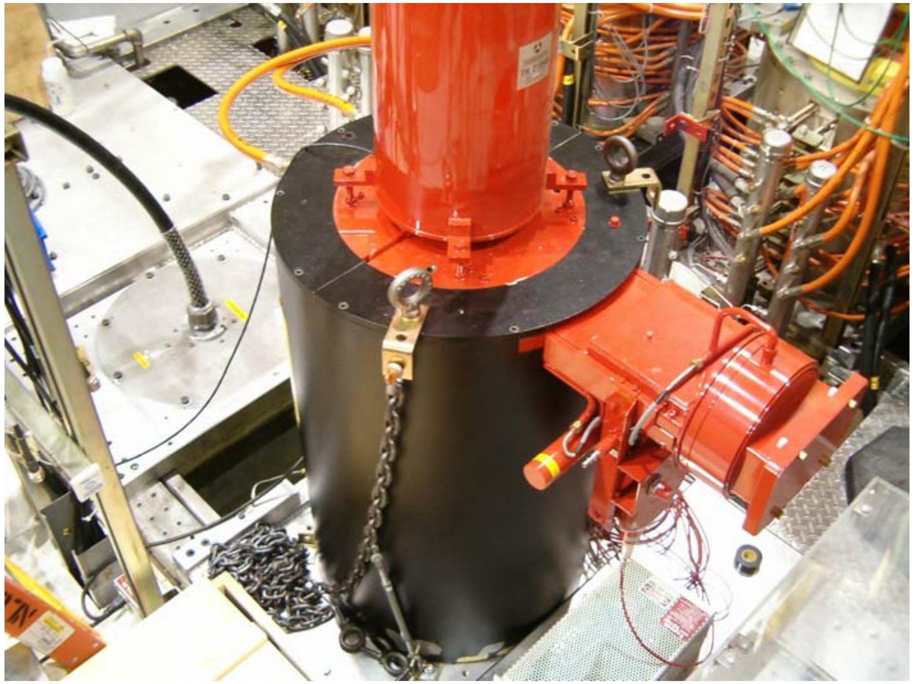
A 91 GHz Sheet-Beam Klystron (74 kV, 3.6 A beam) was built and successfully operated last year with low rf gain.





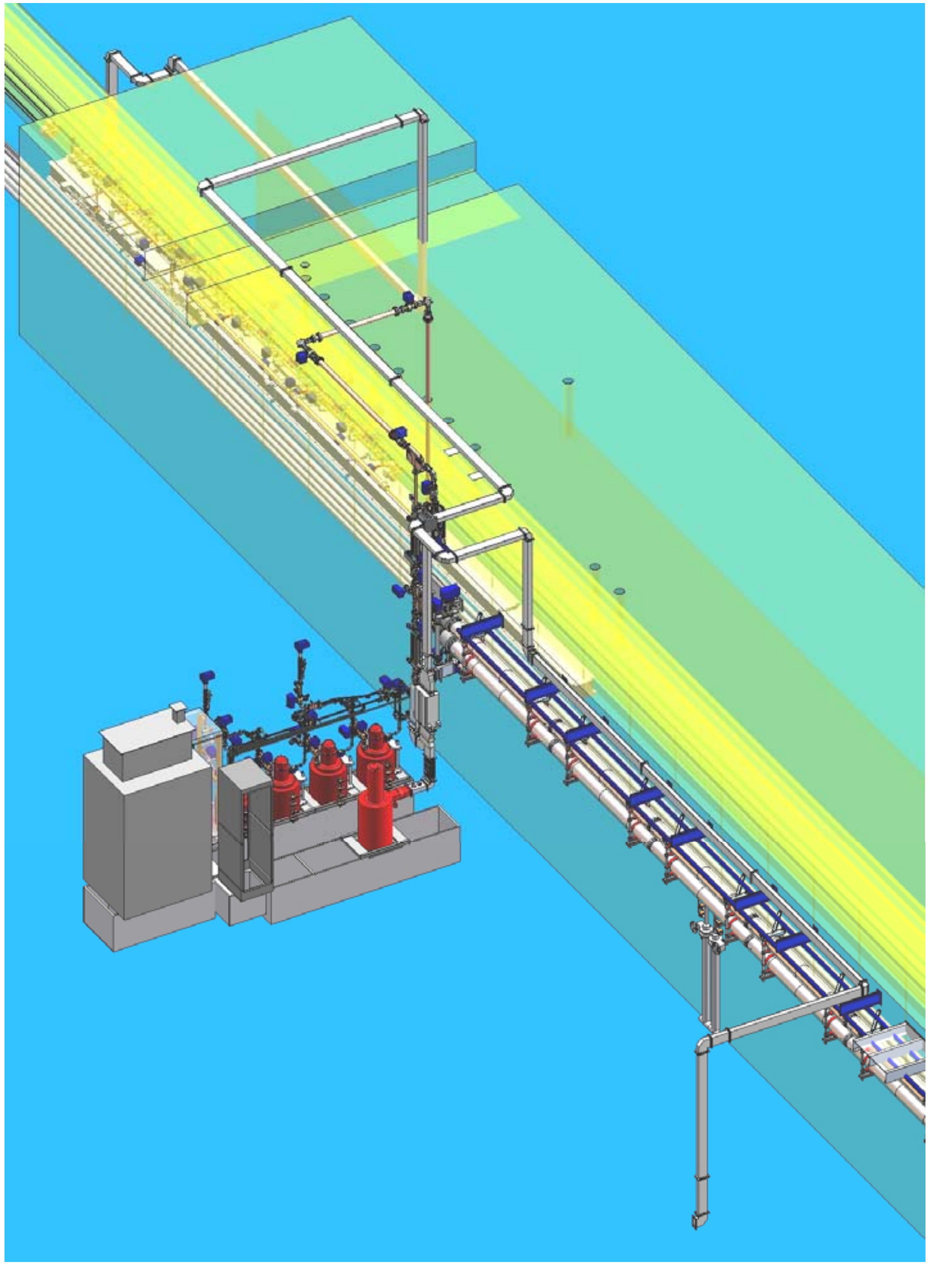
SLAC L-Band Test Stand

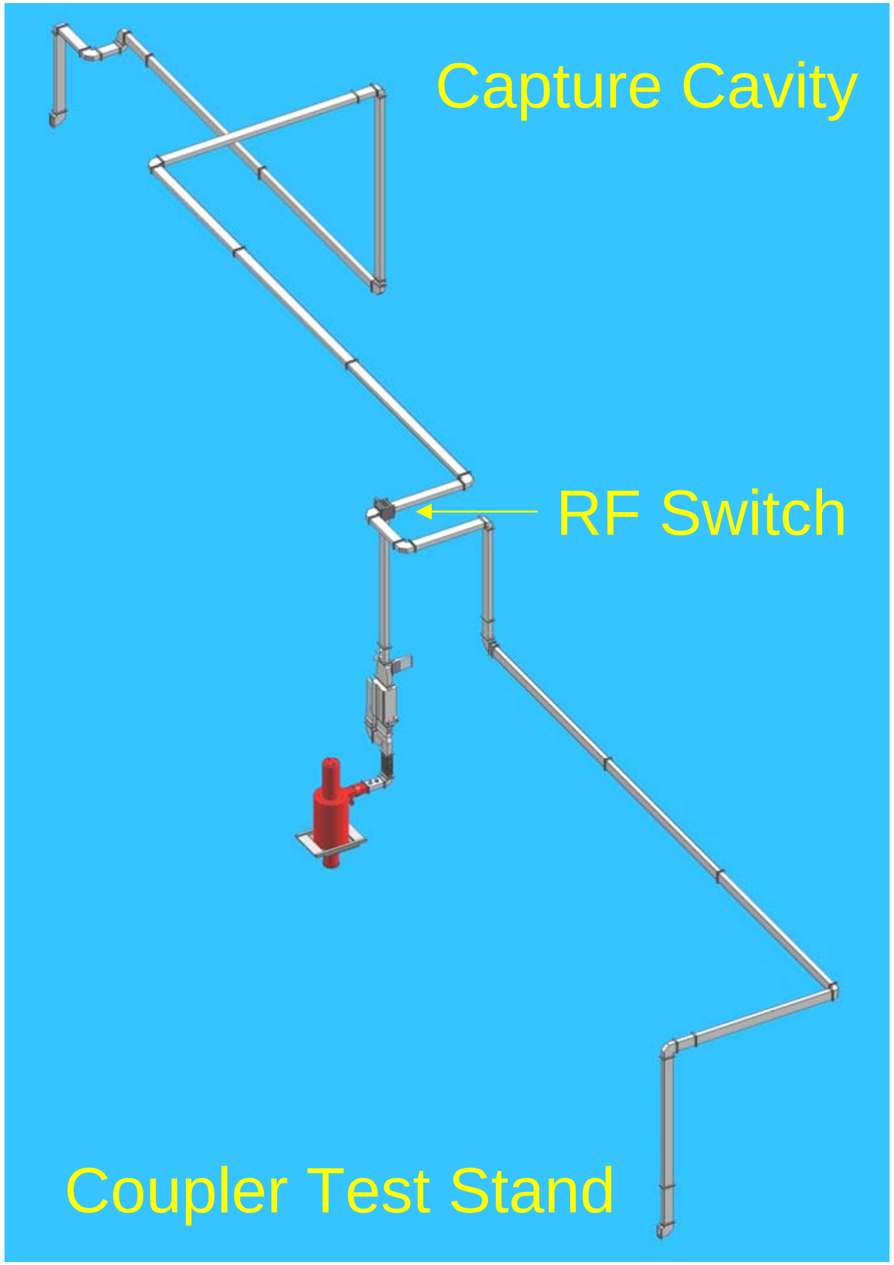
- Commercial Thales tubes powered with SNS Modulator
  - Have produced 3.3 MW, 1 msec pulses at 5 Hz with a SDI legacy TH2104U klystron powered with the SNS modulator.
  - Recently installed 5 MW TH2104C klystron (DESY testing workhorse).
  - Use these tubes to power a coupler test stand and a prototype normal-conducting ILC positron capture cavity.



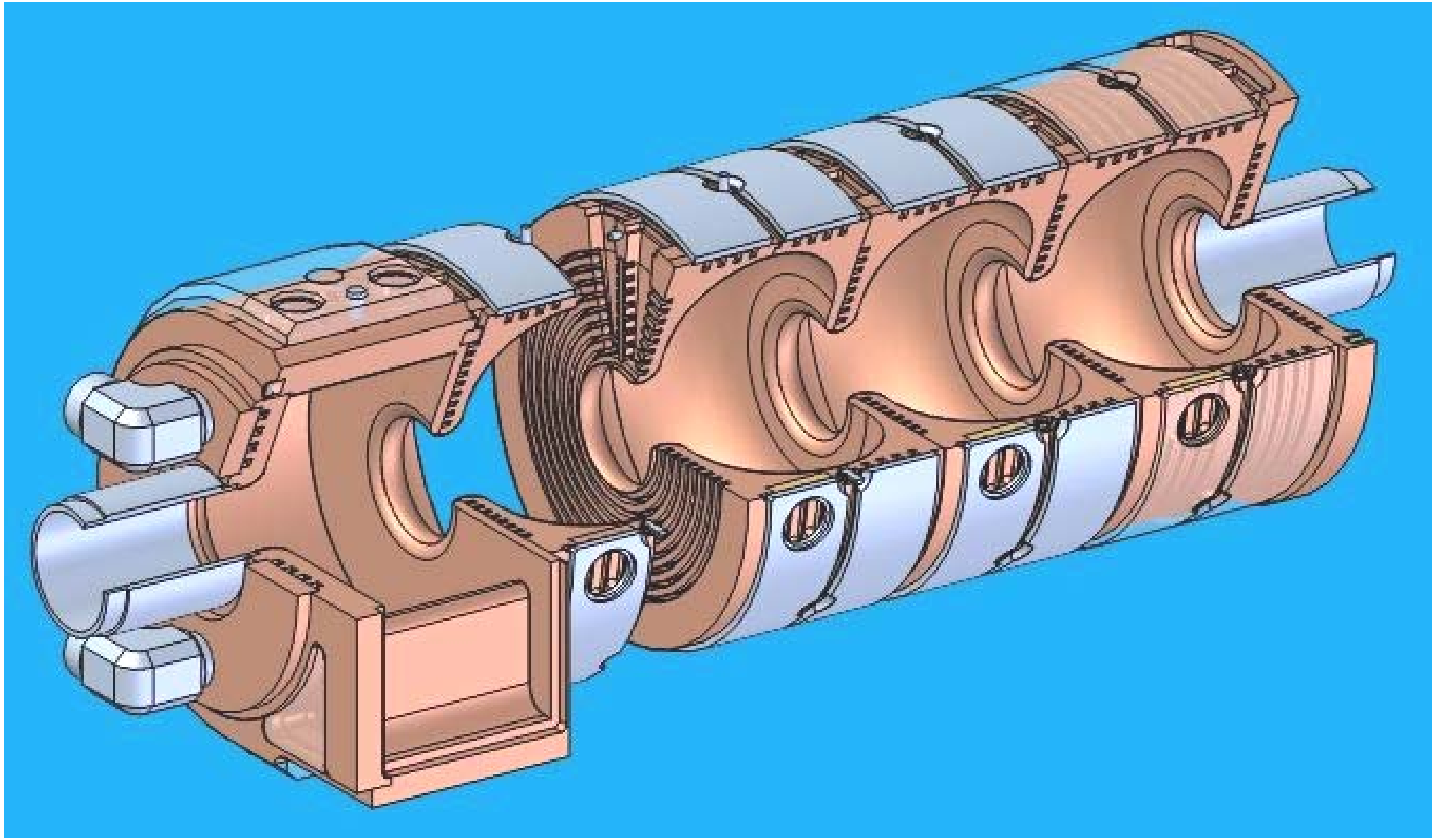
TH2104U Klystron (red) with Solenoid (black) Installed in an Oil Tank at ESB

Waveguide Distribution





ILC Positron Capture Cavity Prototype



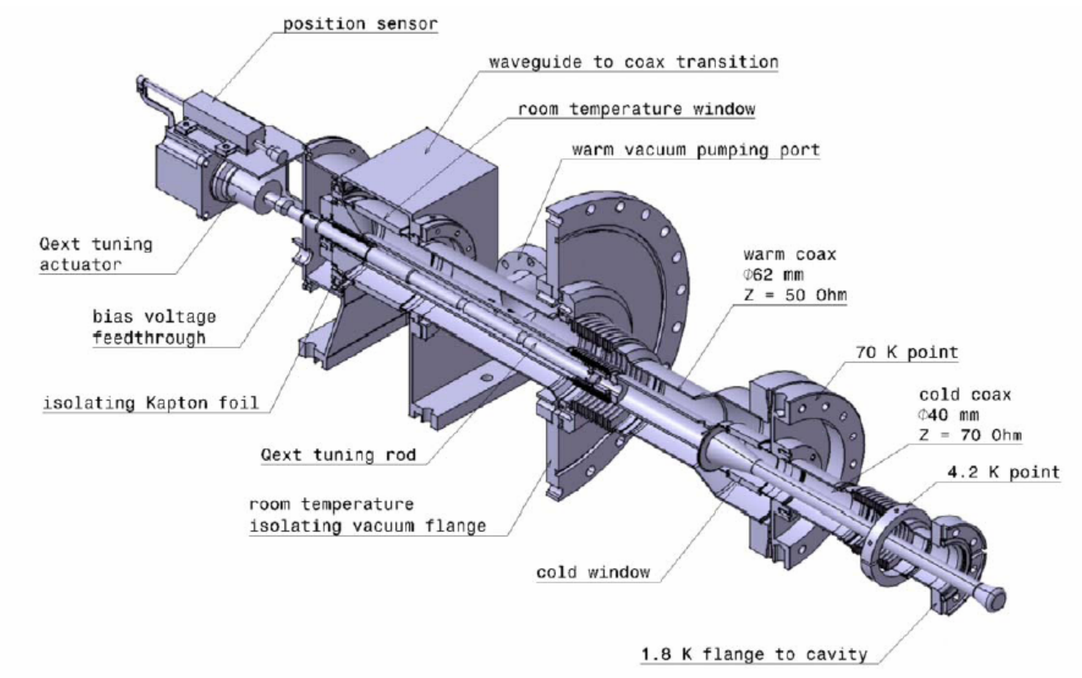
STF L-Band Source at KEK

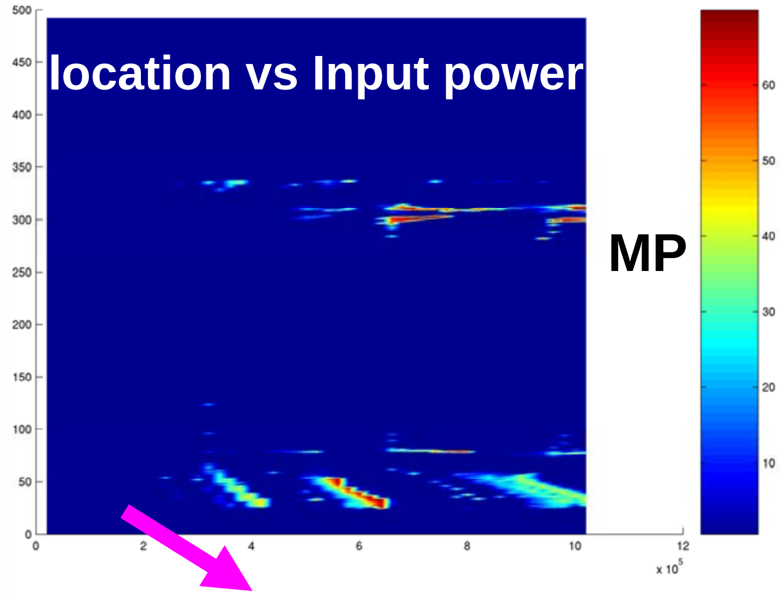
Waveguide to Distribute Power for Coupler Testing

Pulser Unit for a Pulse Transformer Modulator

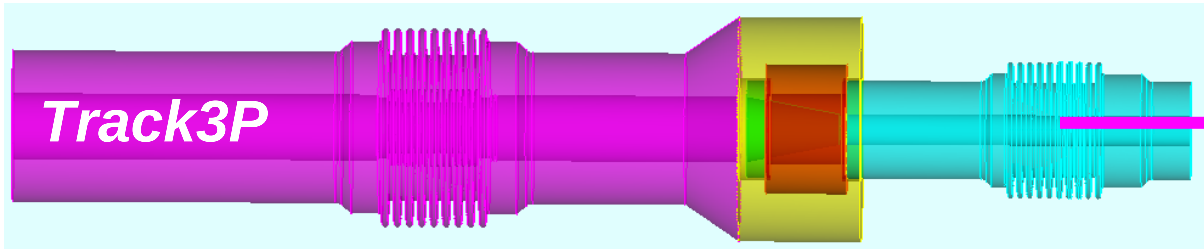
TTF3 Input Coupler - Multipacting

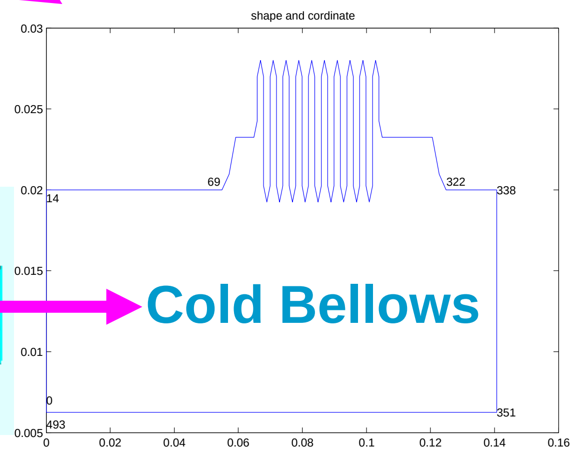
Simulation studies to understand long processing time





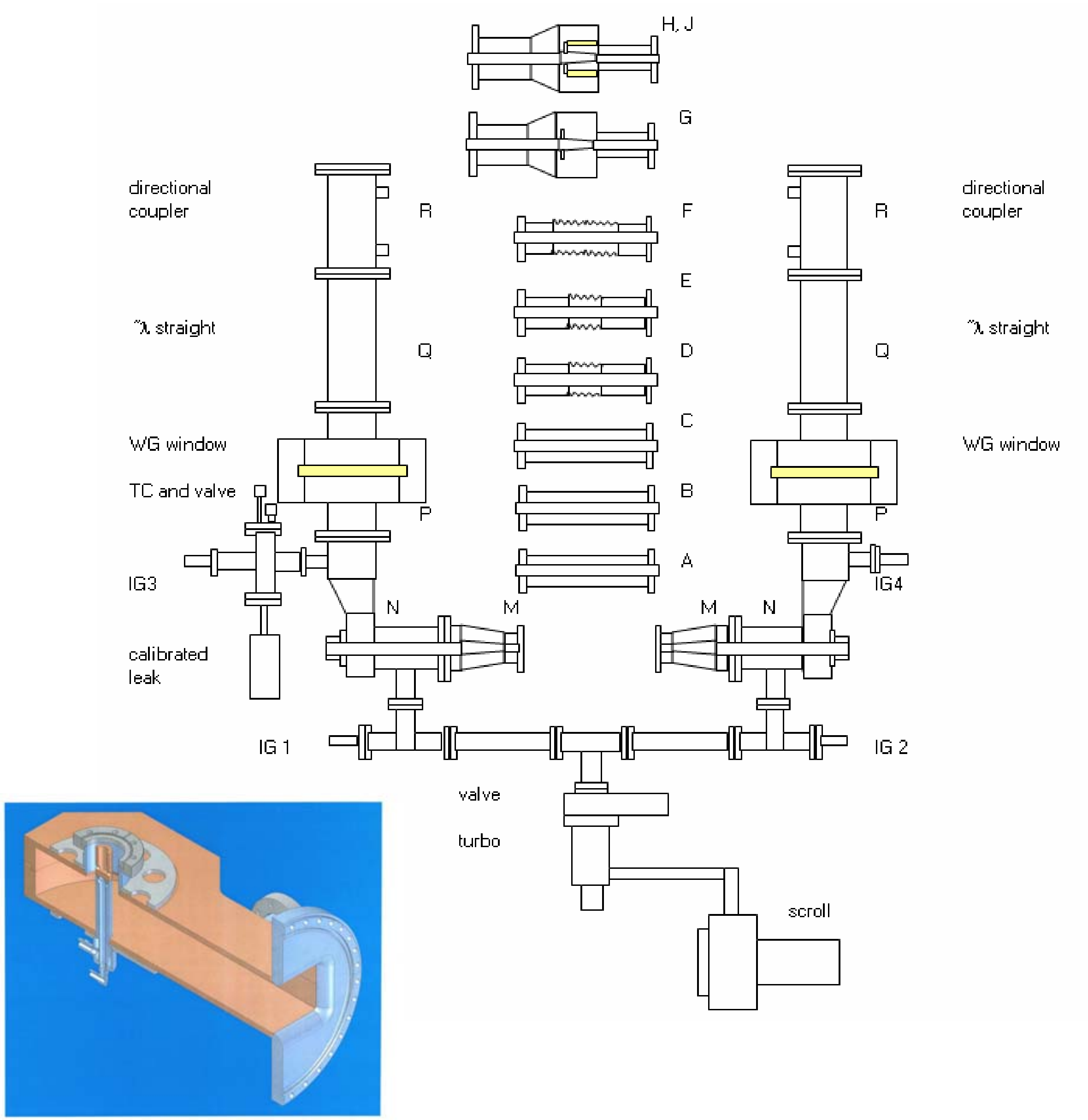
500 kW max input power





Coupler Processing Studies at SLAC

- Have chosen basic layout of system to test coupler parts
- Setup uses a detachable center conductor and 50 cm long test sections
- Currently building waveguide to coax adaptors

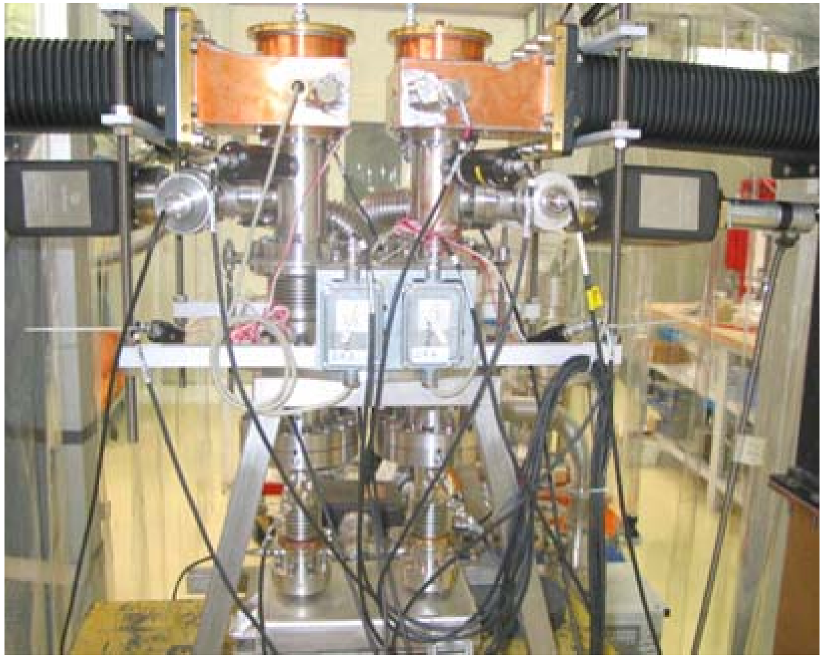


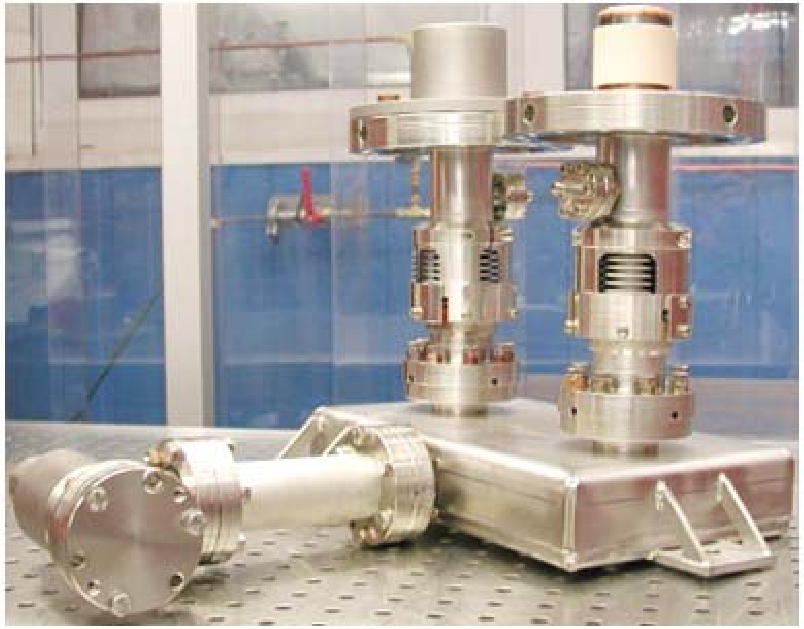
SLAC FY07 Coupler Program
(in collaboration with LLNL)

- Build improved version of TTF3 coupler based on
  - Results of FY06 tests of coupler components.
  - Evaluation of design by SLAC klystron engineers to improve reliability and reduce cost (they developed a new L-band window this year).
- Setup facility like that at Orsay to assemble and rf process couplers for the cavities being built for ILCTA
  - Use existing class 1000 clean room and water purification systems at SLAC (buy small class 100 clean room).
  - Use coupler test stand area in ESB to process couplers. EPICS based control system already developed.

Building Test Stand to RF Process Couplers for FNAL Cavities

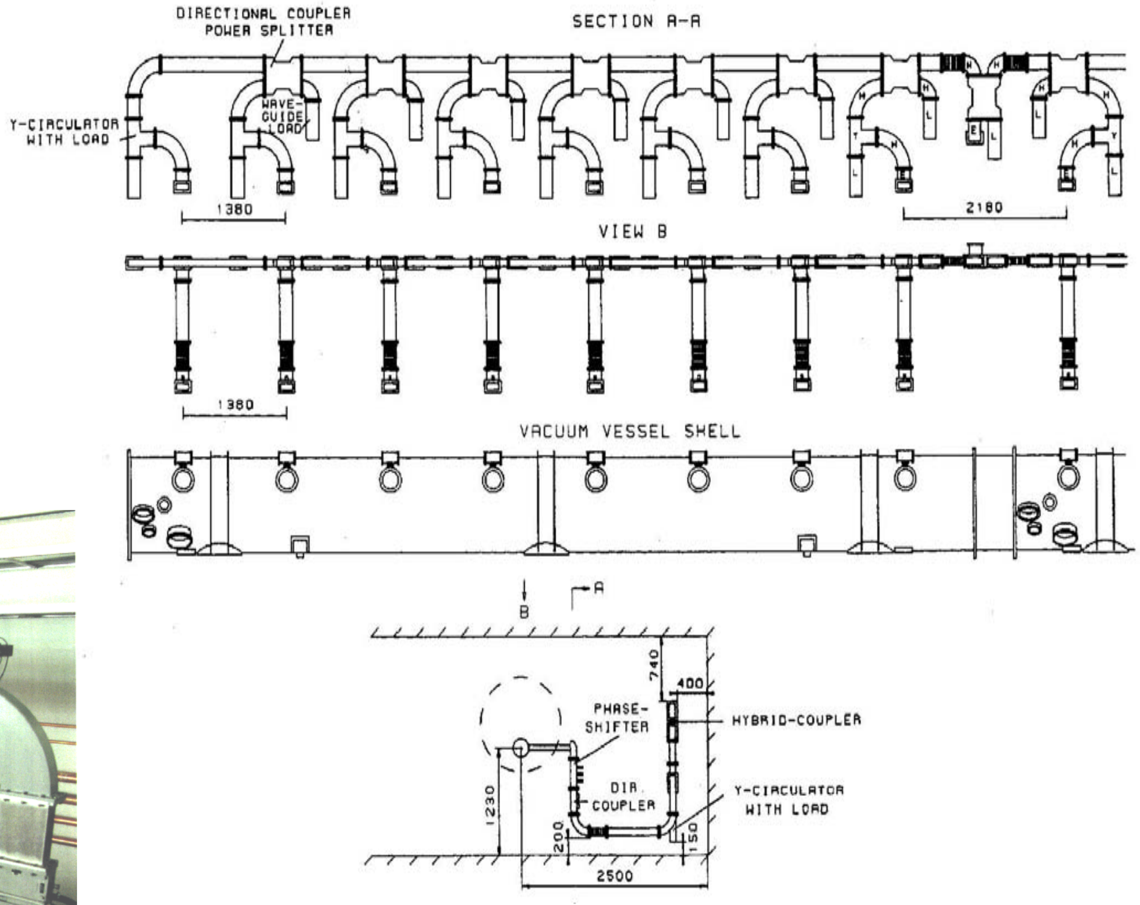
Instrumented Coupler Test Stand at Orsay





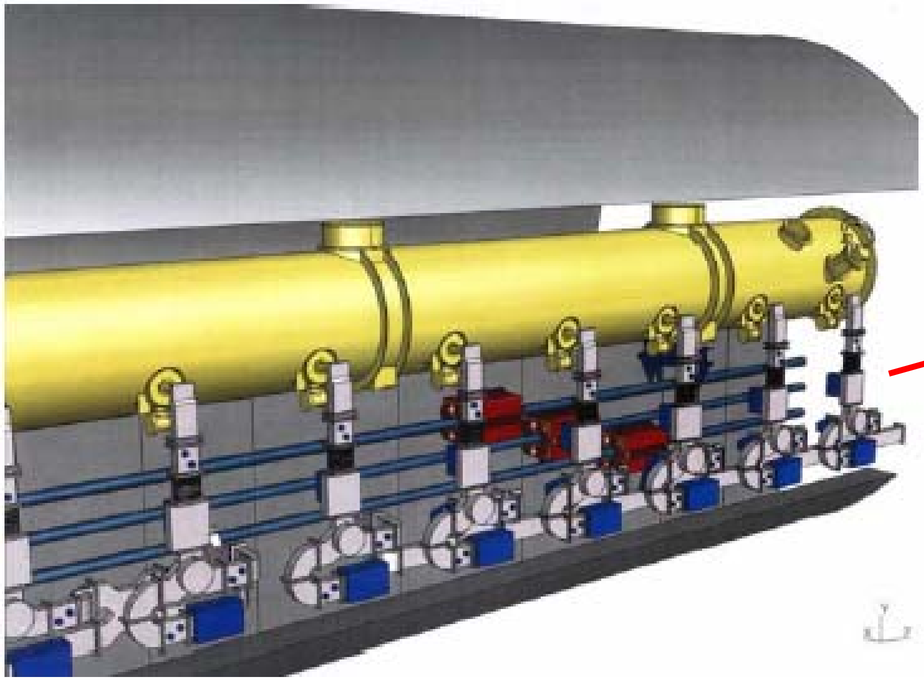
RF Distribution

Baseline choice is the waveguide system used at TTF, which includes off-the-shelf couplers, circulators and 3-stub tuners (phase control).

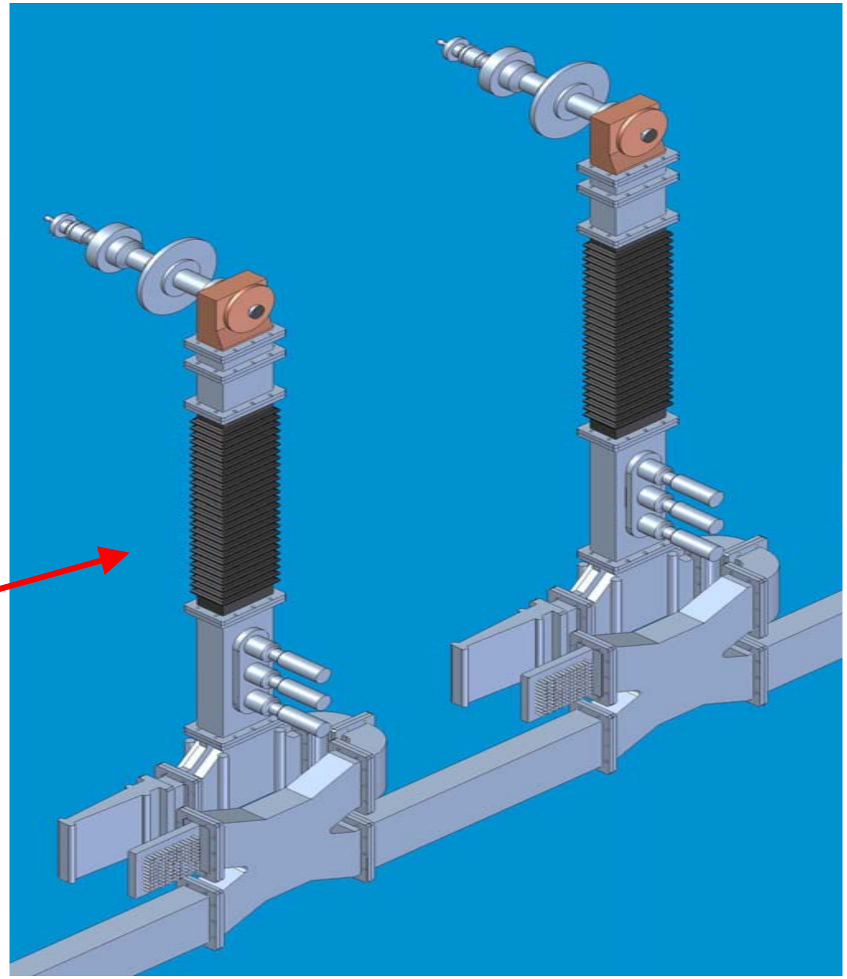


Need more compact design

(Each Cavity Fed 350 kW, 1.5 msec Pulses at 5 Hz)



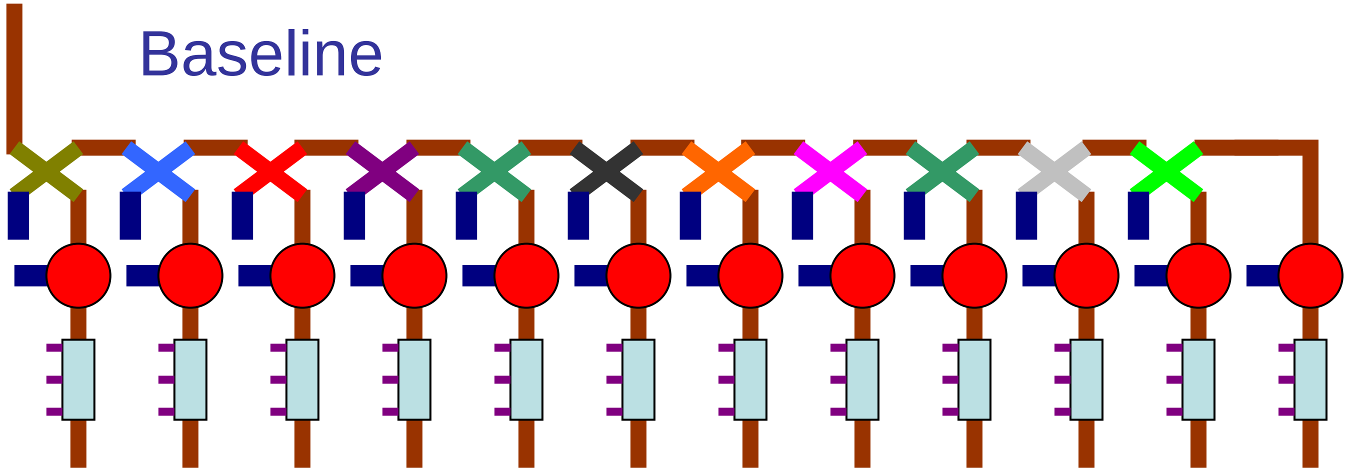
Two of ~ 16,000 Feeds



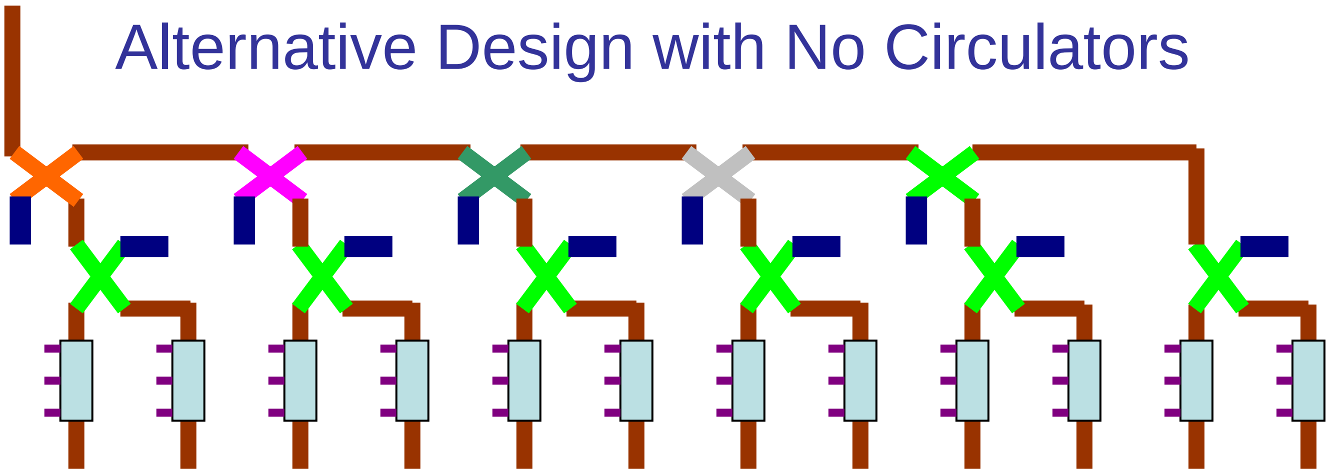
And should simplify system

(circulators are ~ 1/4 of rf distribution cost)

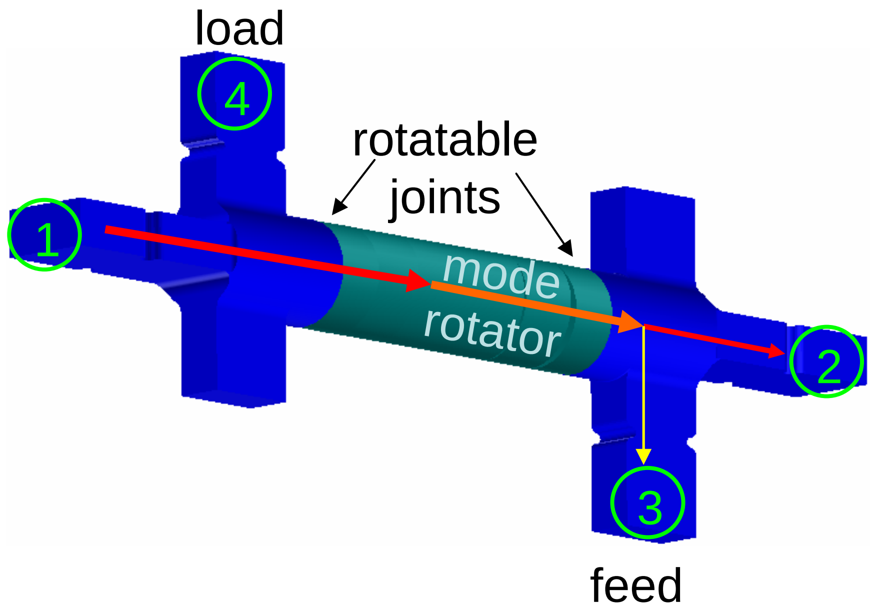
Baseline

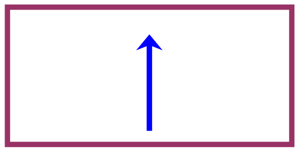


Alternative Design with No Circulators

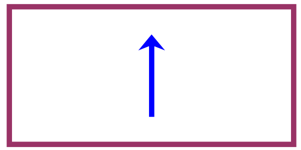


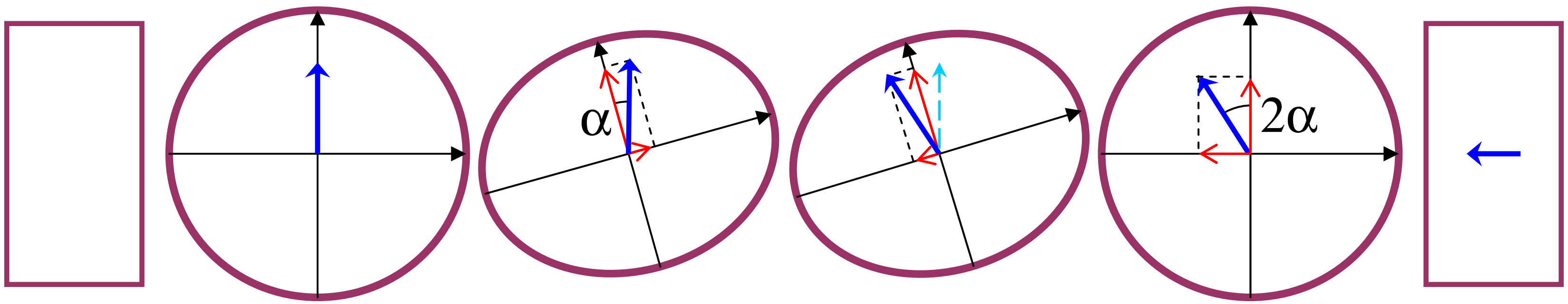
Adjustable Tap-Offs Using Mode Rotation





Rotatable section with central elliptical region, matched for both polarizations of circular TE_{11} mode with differing phase lengths.

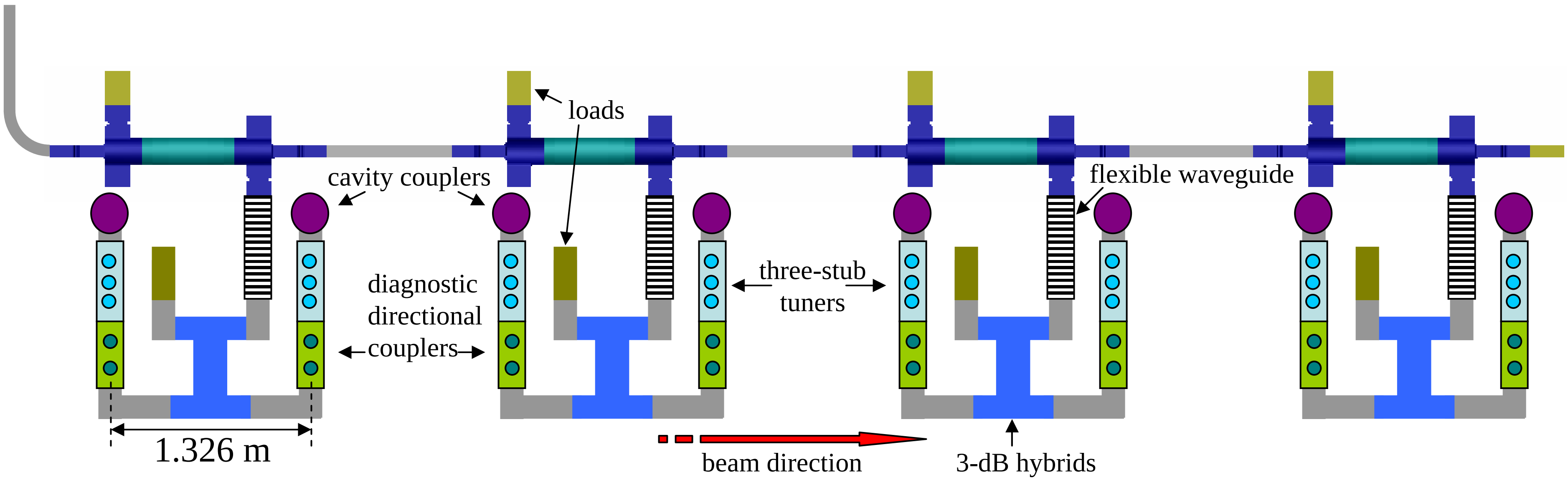




C. Nantista

Proposed RF Distribution Layout

- Adjustable power to pairs of cavities
- No circulators
- Pairs feed by 3 dB hybrids (requires nλ +/- 90 degree cavity spacing – only 7 mm longer than TDR/BCD spec)

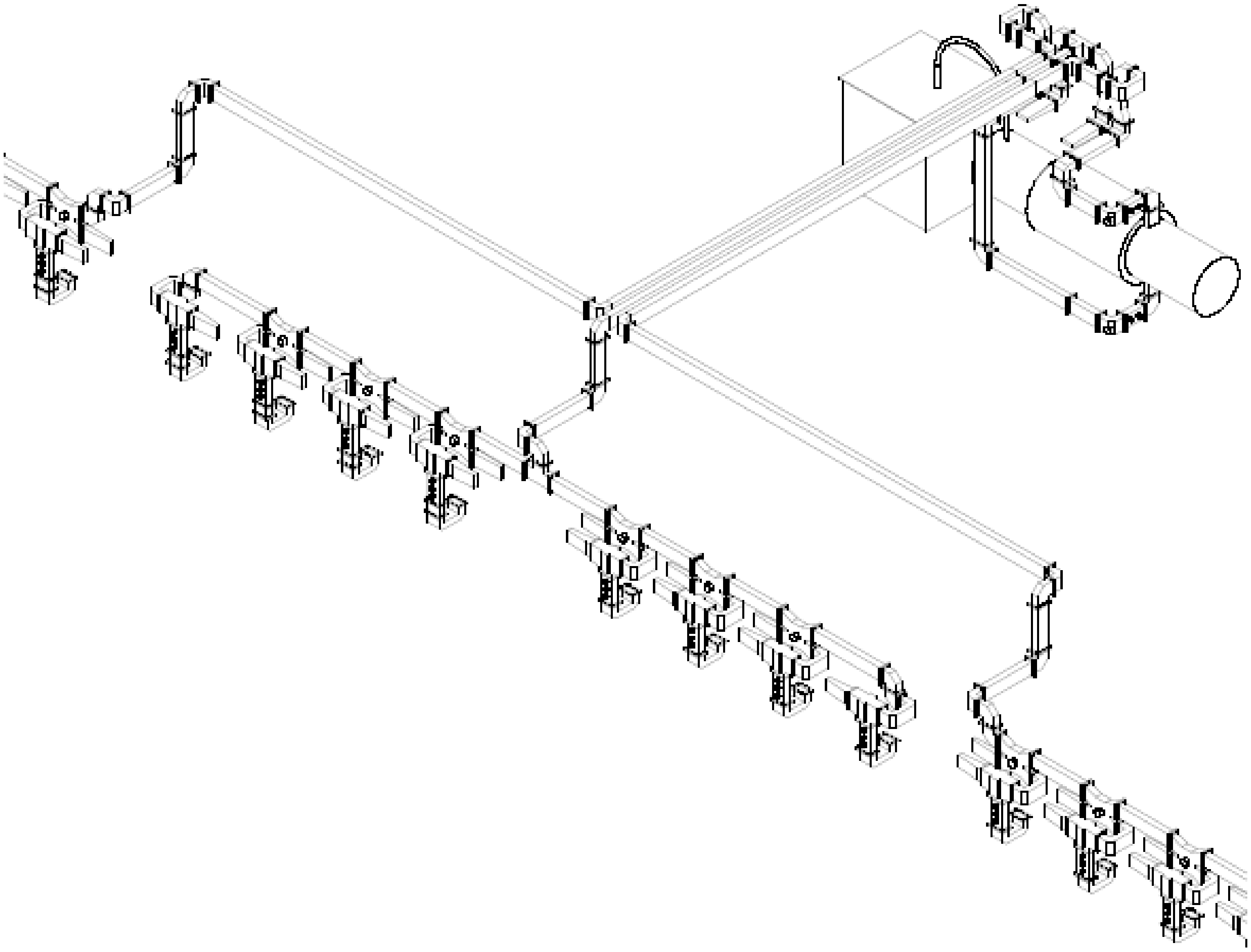


C. Nantista

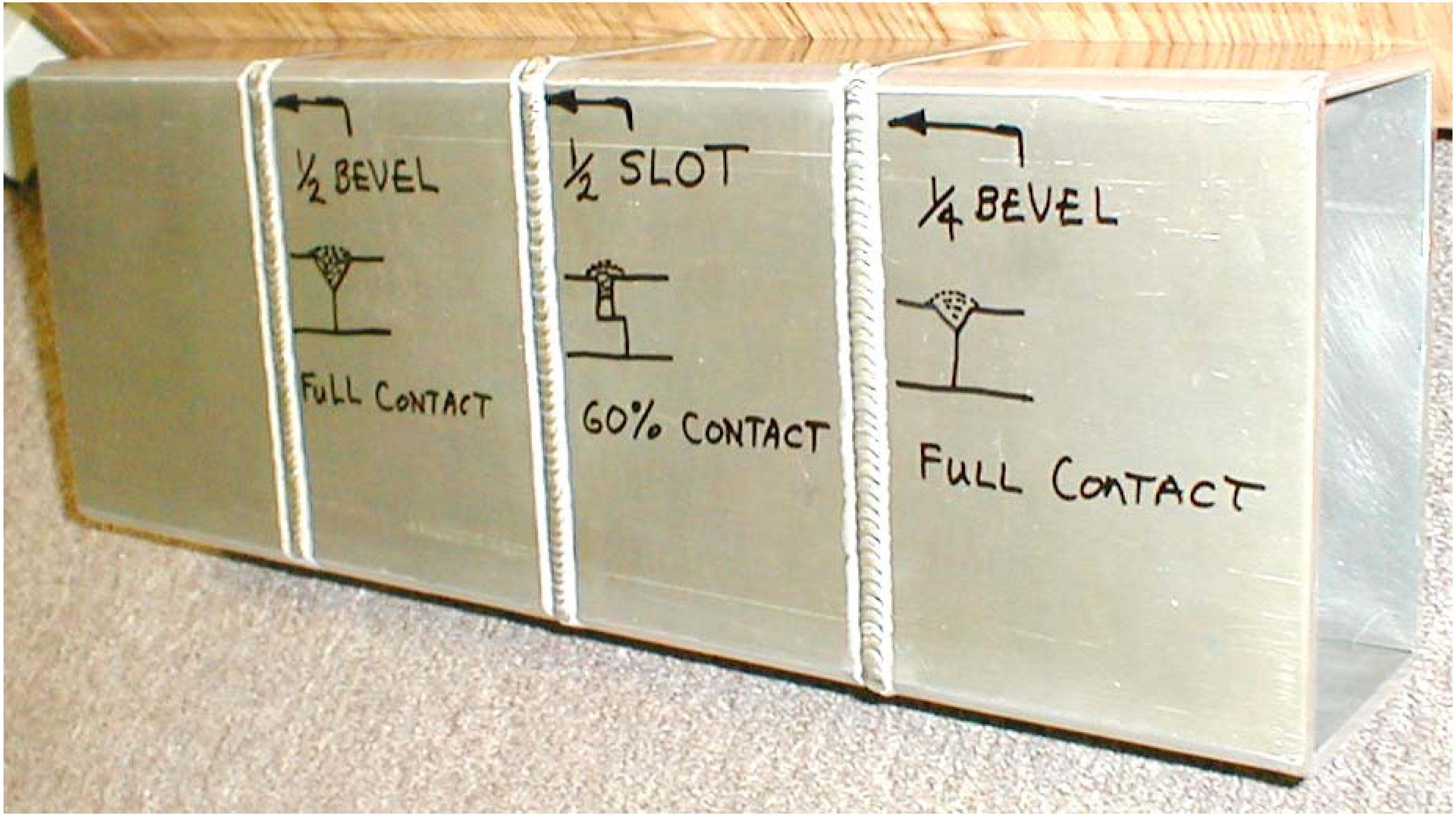
SLAC FY07 RF Distribution Program

- Test both high and low power circulators.
- Develop adjustable tap-offs and simple phase shifter, and test at high power.
- Build rf distribution systems for the first two FNAL cryomodules (nλ cavity spacing).
  - Both would include circulators (needed for beam operation) that could be removed to test cavity-to-cavity rf coupling without them.
  - Second would include a simpler phase shifter in place of 3-stub tuner.
  - The TTF4 cryomodules would hopefully not need circulators.
- Develop methods to weld waveguides together to avoid costly and unreliable flanges.

ILC RF Distribution System

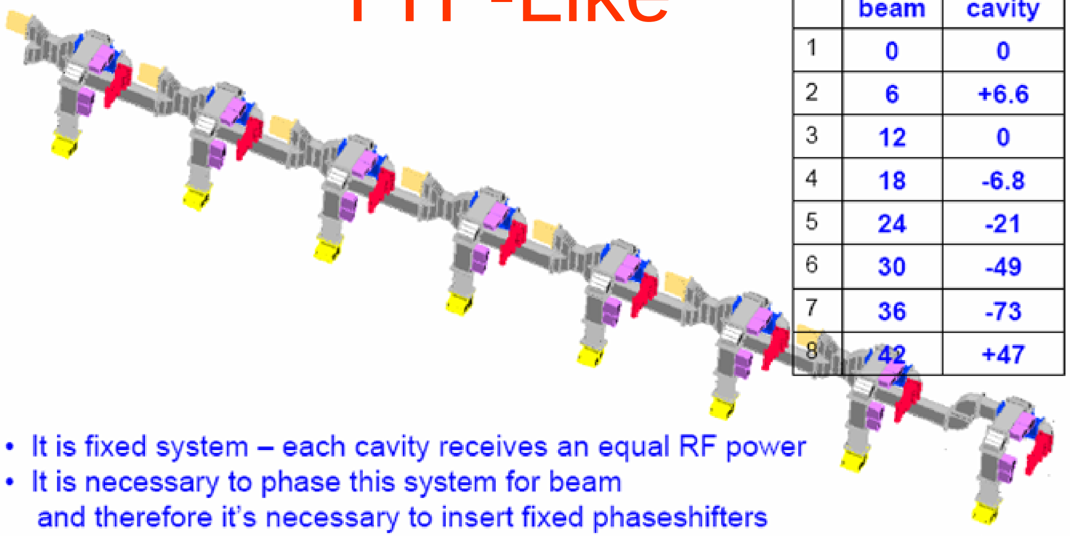


Al Waveguide Test Welds



XFEL Prototype Distribution Systems

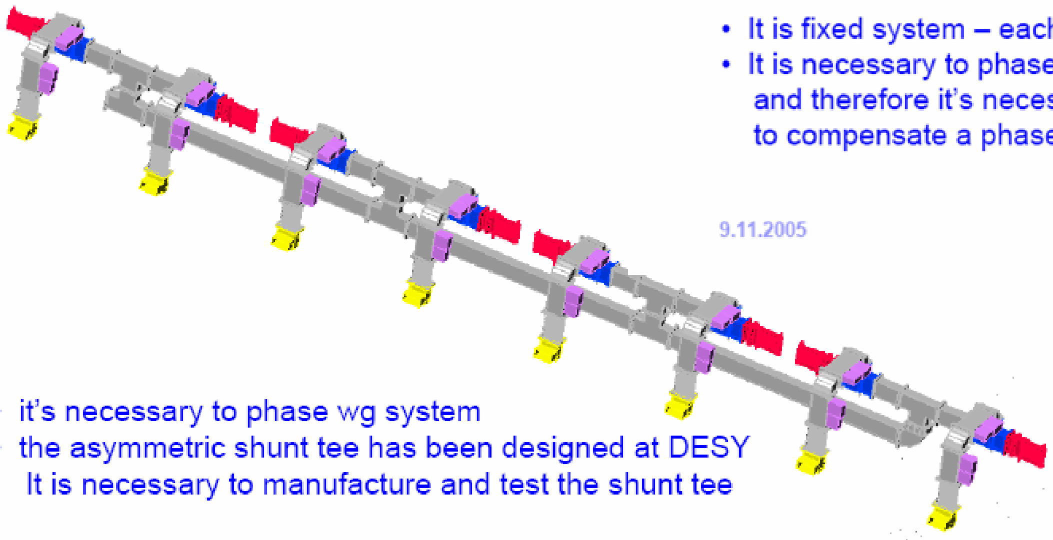
TTF-Like



№	phase	
	beam	cavity
1	0	0
2	6	+6.6
3	12	0
4	18	-6.8
5	24	-21
6	30	-49
7	36	-73
8	42	+47

- It is fixed system – each cavity receives an equal RF power
- It is necessary to phase this system for beam
  and therefore it's necessary to insert fixed phaseshifters
  to compensate a phase difference up to 110 degree

Tree-Like

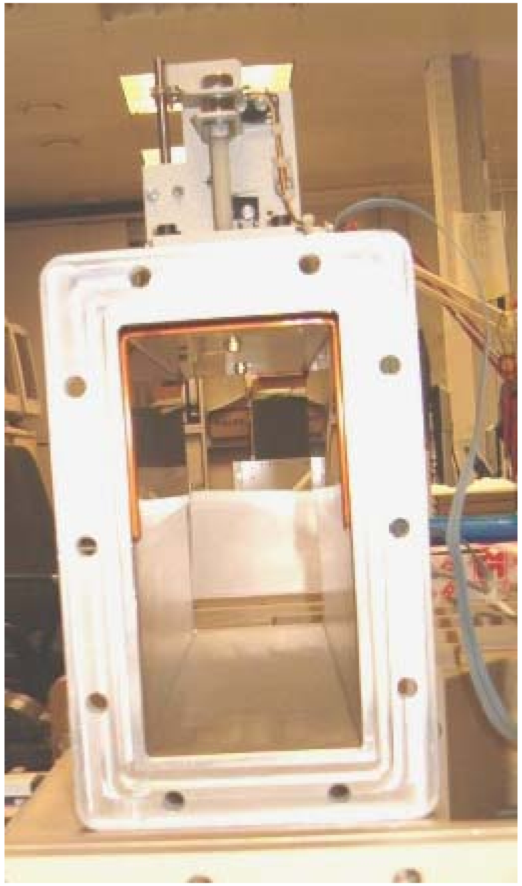


- it's necessary to phase wg system
- the asymmetric shunt tee has been designed at DESY
  It is necessary to manufacture and test the shunt tee

XFEL
X-Ray Free-Electron Laser

Treelike and TTFlike waveguide system in Halle II

Replace 3-Stub Tuner with Phase Shifter

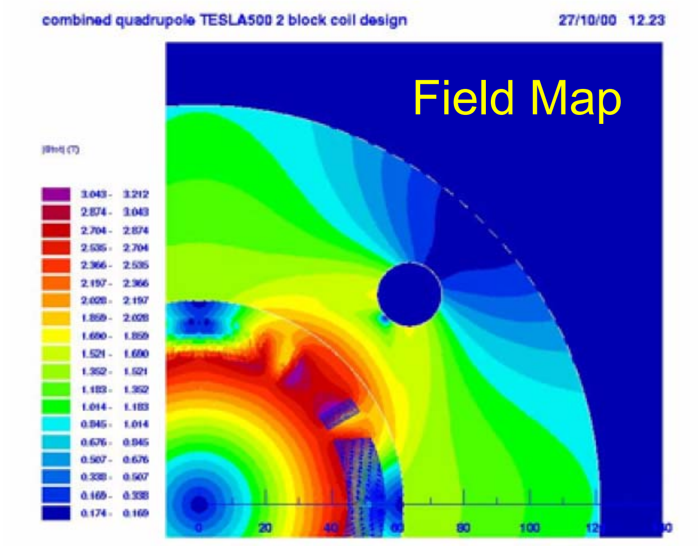


V. Katalev, S Choroba

ILC Linac SC Quad/BPM Evaluation

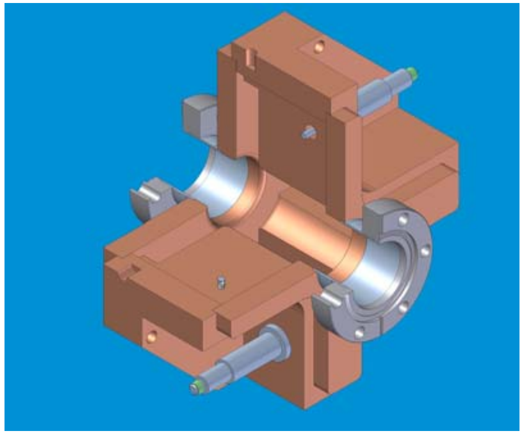
Cos(2Φ) SC Quad

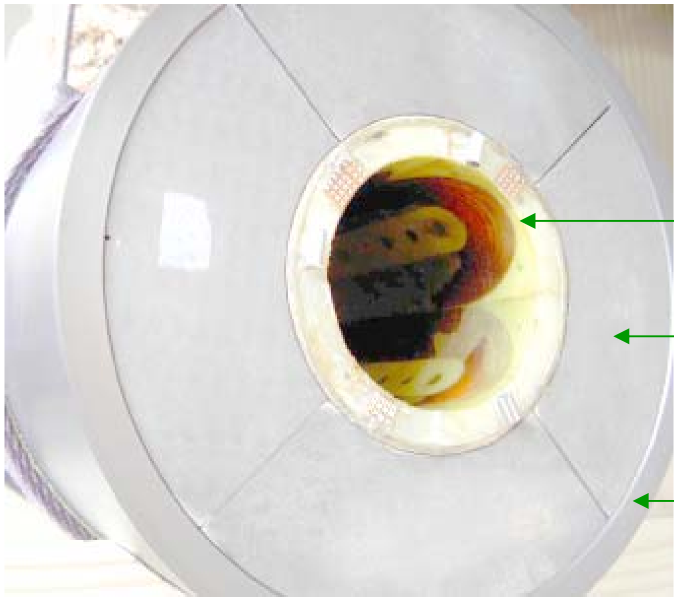
(~ 0.7 m long)



S-Band BPM Design

(36 mm ID, 126 mm OD)



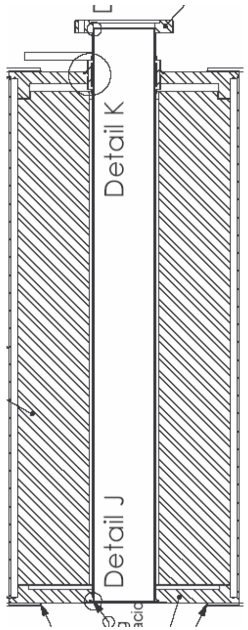


He Vessel

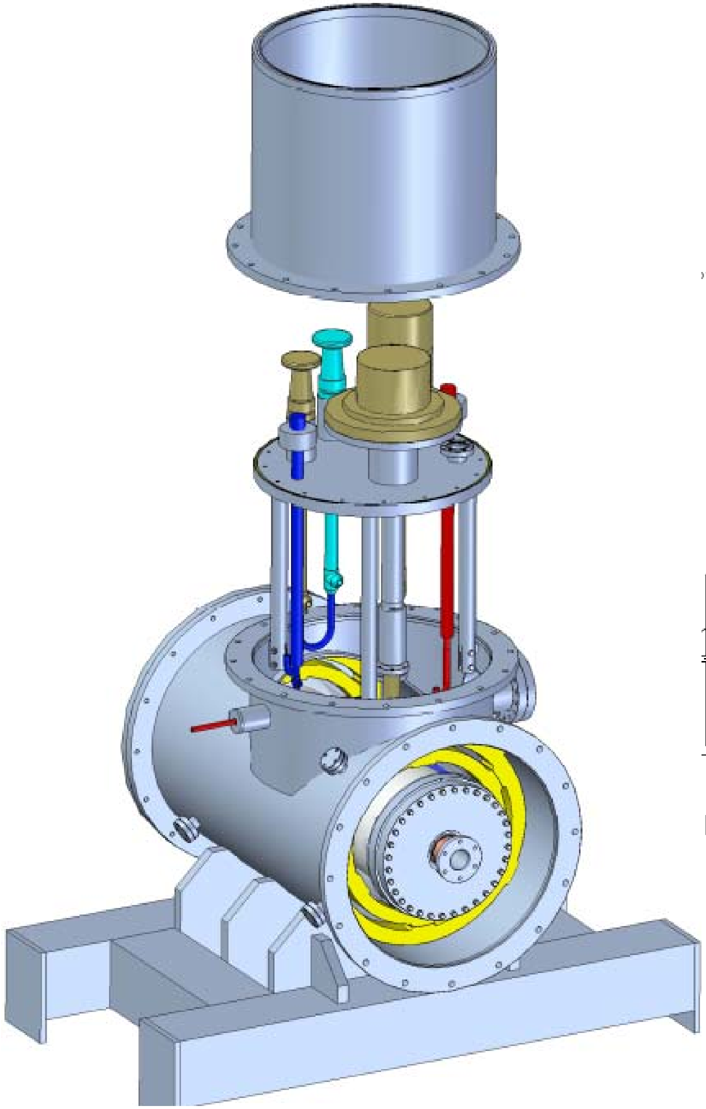
SC Coils

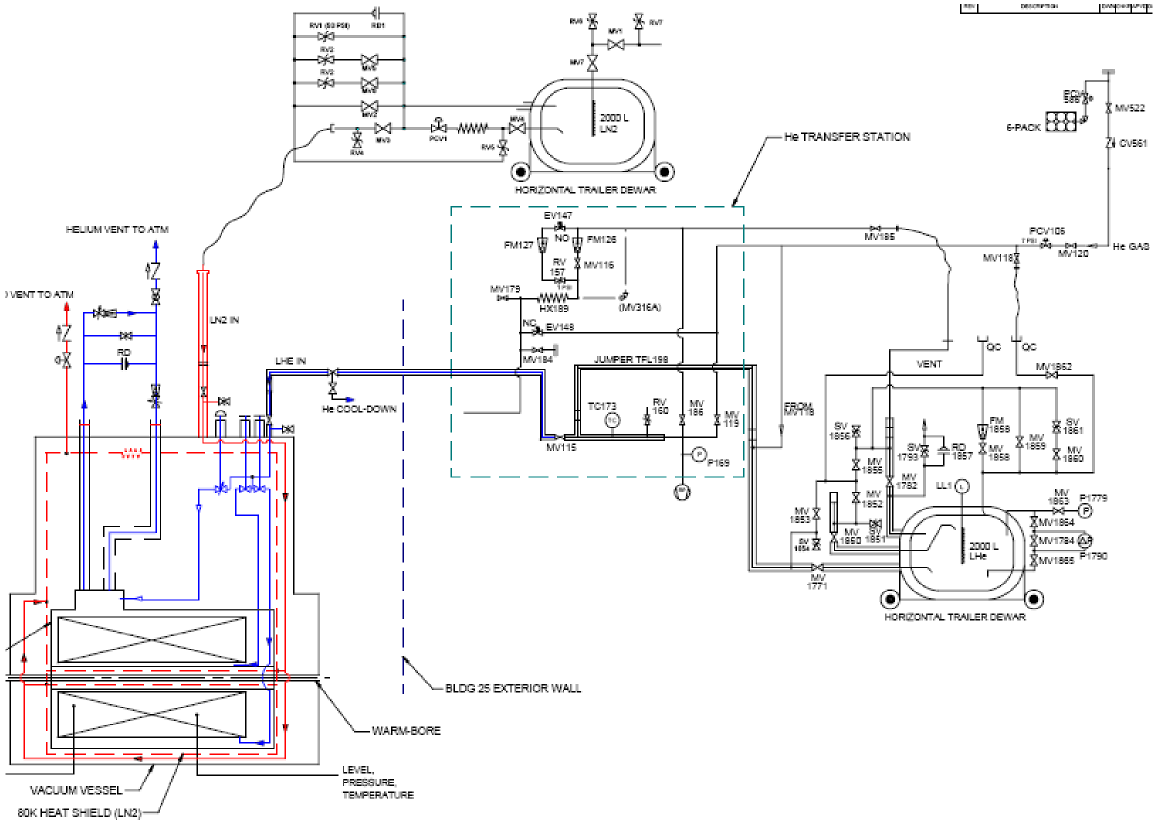
Iron Yoke Block

Al Cylinder



Cryostat and Cryogenic System

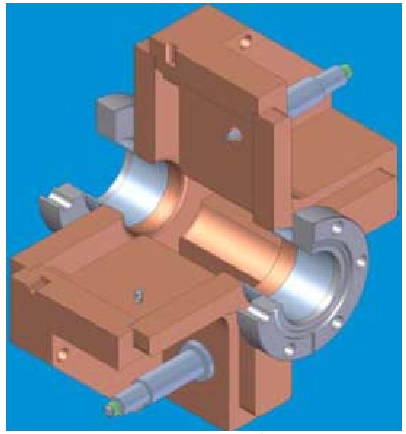


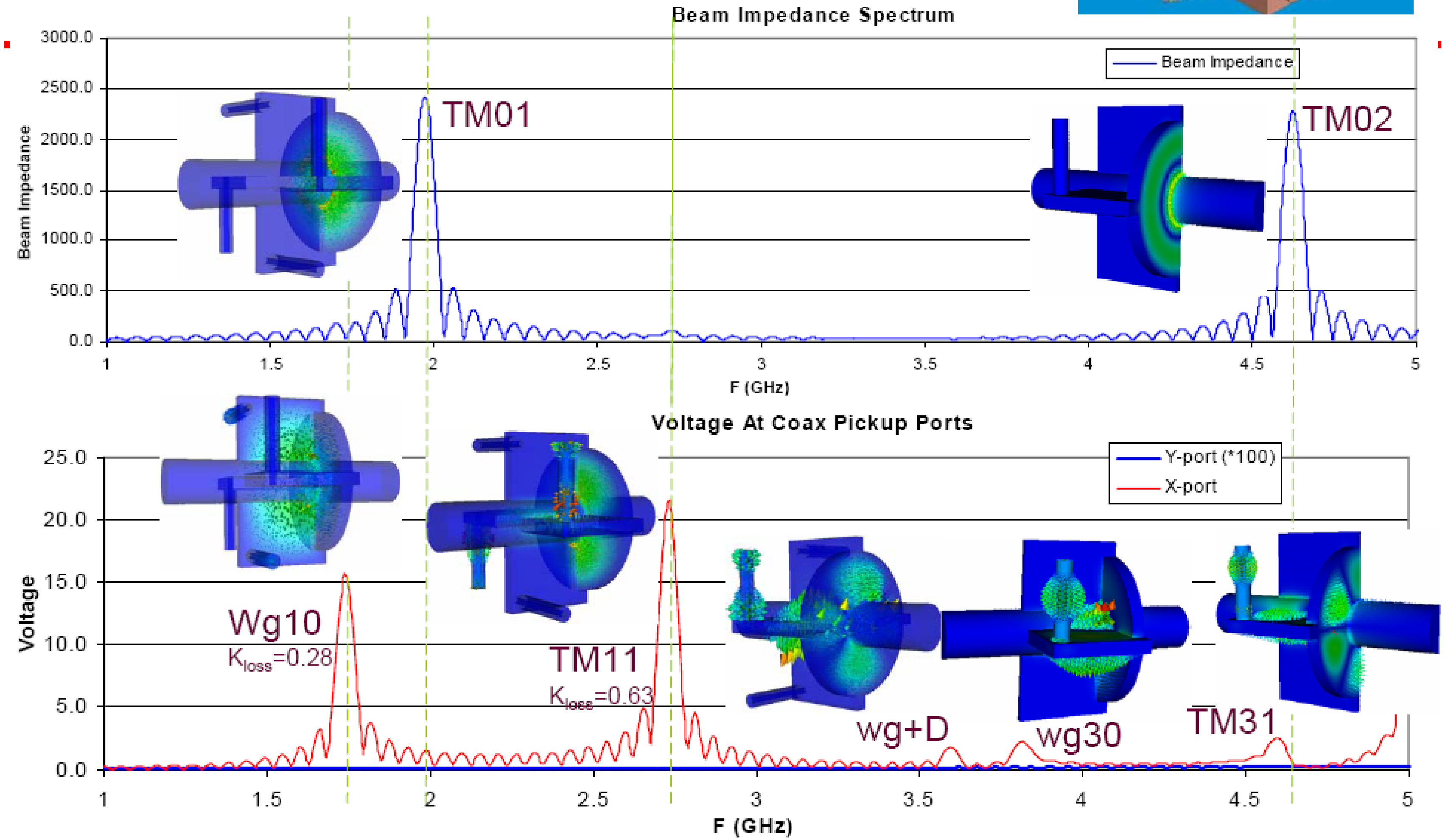


ILC SC QUAD CRYOSTAT

S-Band (2.86 GHz) BPM

Mode Spectrum (monopole mode signals suppressed geometrically)

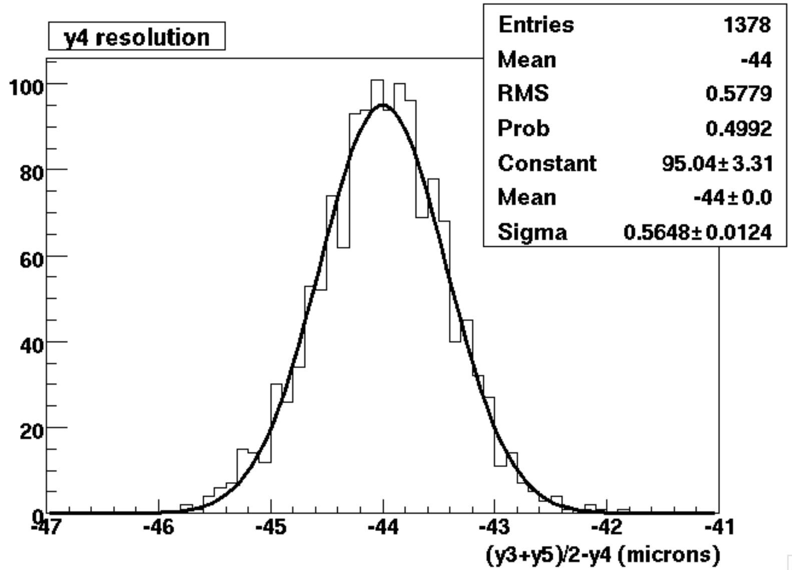


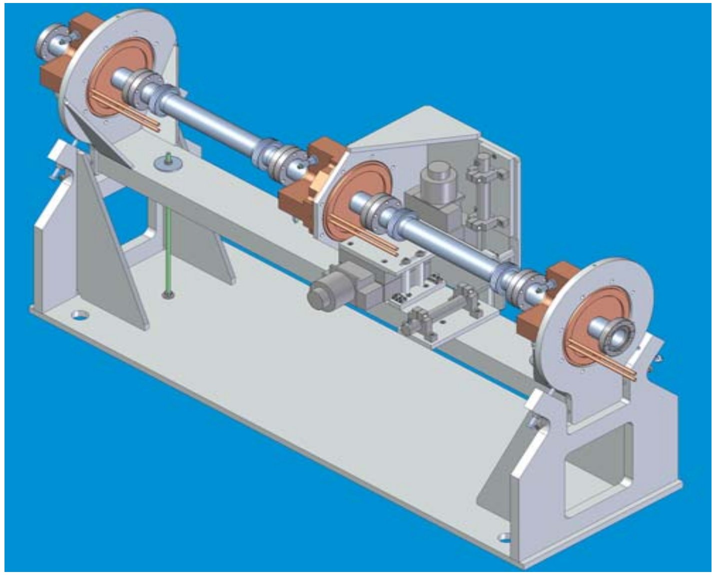


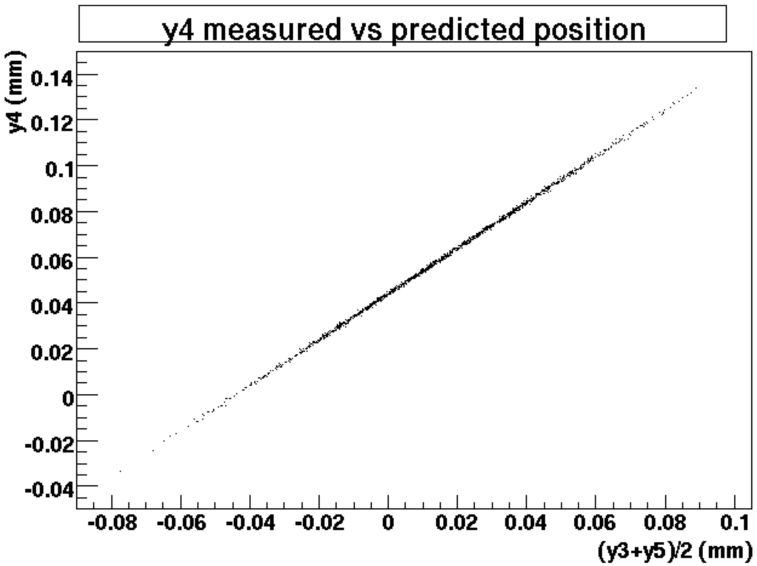
Z. Li

Recent BPM Triplet Results

(0.5 micron resolution, 1.4e10 electrons, Q of 500 for clean bunch separation)

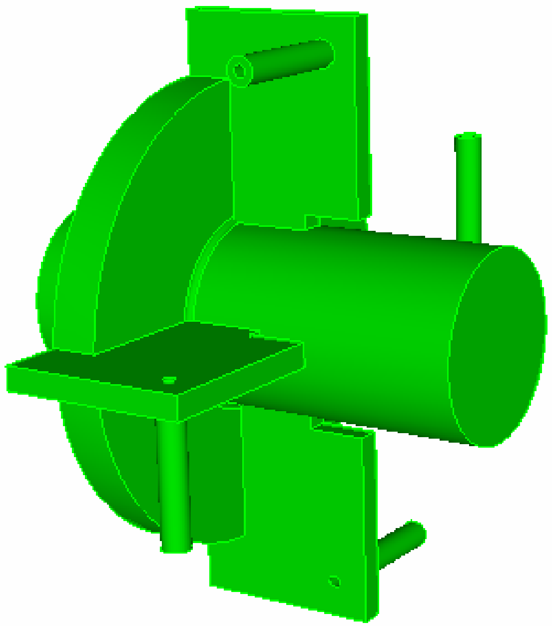






L-Band Preliminary Design

- Selective coupling scheme
- Hidden coax pickup from the beam
- Easily cleanable
- Preliminary parameters:
  - Beampipe radius: 39 mm
  - Radial dimension: ~ 250 mm
  - Longitudinal dimension: ~100 mm
  - Will fit into the present footprint
  - Thermal noise limited resolution: ~6 nm for a 20-mm cavity gap



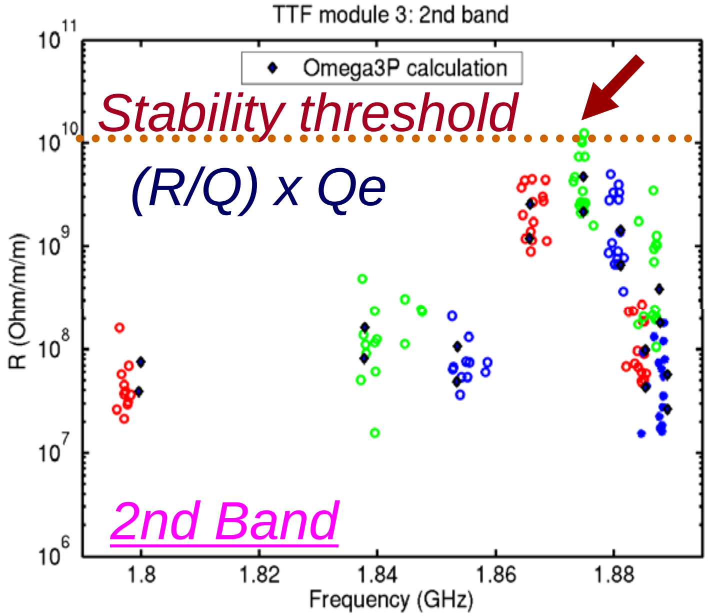
Cavity Dipole Mode Q and Frequency Spread

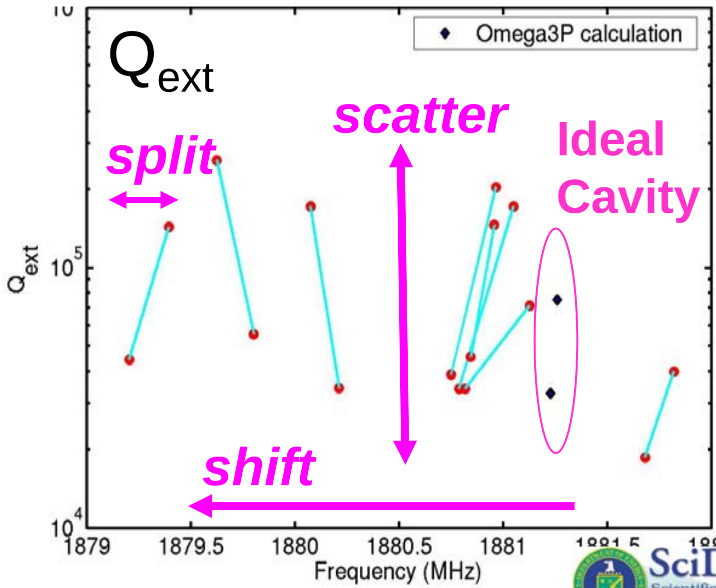
Effects of cavity deformations:

- *Mode splitting is 100s of kHz (10s of kHz in ideal cavity),*
- *Mode frequency is shifted by as much as few MHz,*
- *Qext scatter towards high side - may lead to dangerous modes.*

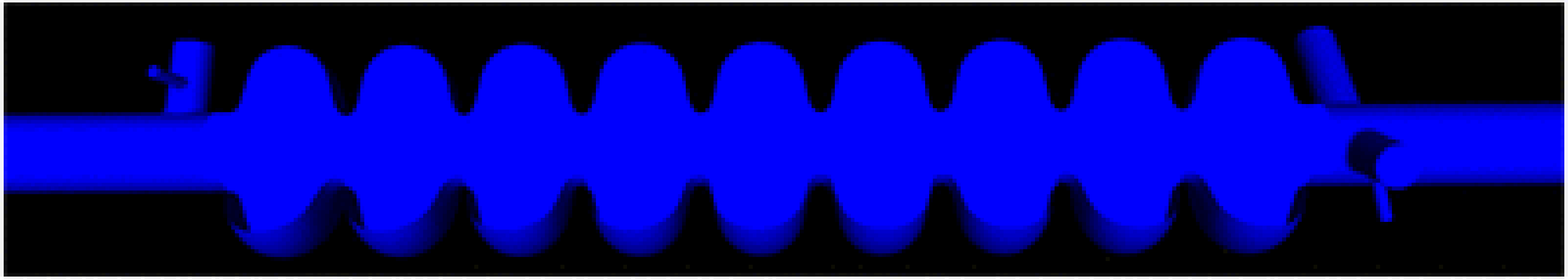
Shape determination:

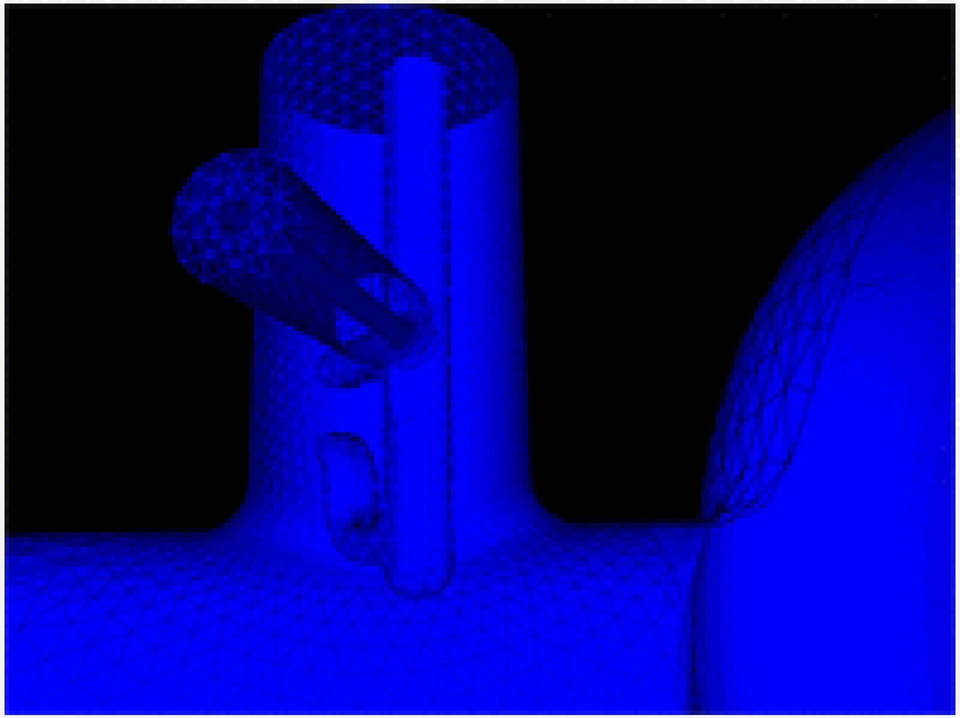
- *Solve an inverse problem to find cavity TRUE shape*
- *Use measurements from TESLA cavity data bank as input*
- *Goal to identify sensitivity of critical dimensions affecting Qe*

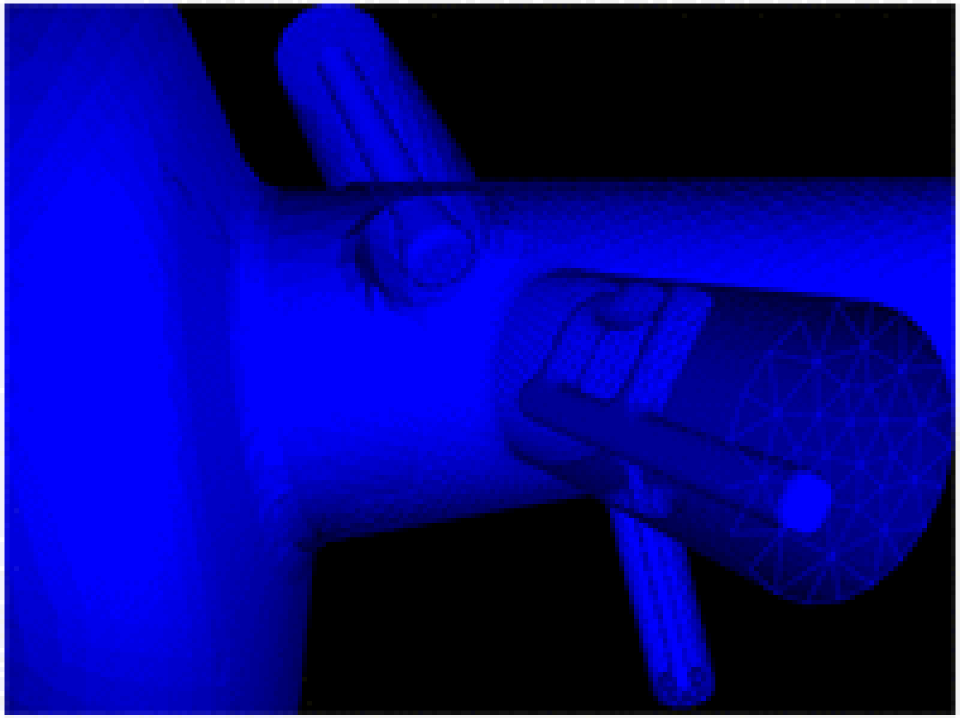




TESLA Cavity – Wakefields (T3P)





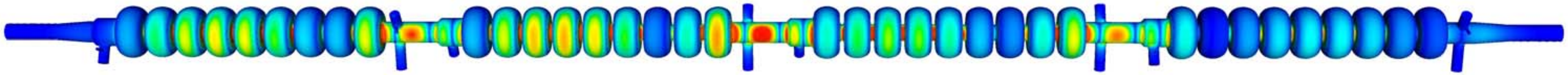


1.75 M quadratic elements, 10 M DOFs, 47 min per nsec on Seaborg 1024 CPU with 173 GB memory – CG and incomplete Cholesky preconditioner

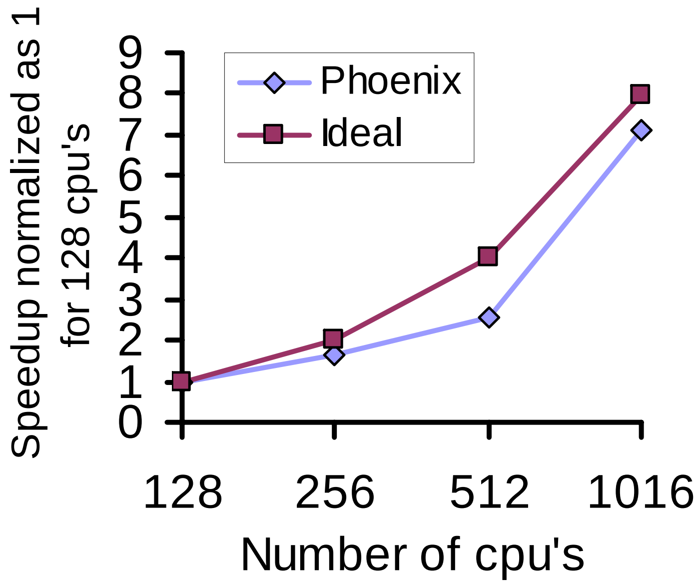
Towards Petascale Simulations

<u>Omega3P</u> - *A nonlinear eigensystem with > 15 million of DOFs was solved within 10 hours on 768 CPUs with 276 GB memory on NERSC's Seaborg as a 1st step towards modeling an entire cryomodule:*

4-cavity Structure



<u>T3P</u> – *Code has been improved to allow scalability to more than 1000 CPUs for a medium-size problem with close to linear speedup on NCCS's Phoenix*



RF Source Summary

- Marx Modulator approach looks very promising.
- Toshiba 10 MW klystron appears robust. Sheet-beam approach likely to reduce costs.
- Both SLAC and DESY working on lower cost rf distribution systems.
- SLAC and KEK now have working L-Band test stands.
- SLAC beginning program to understand TTF3 coupler processing limitations and improve design.