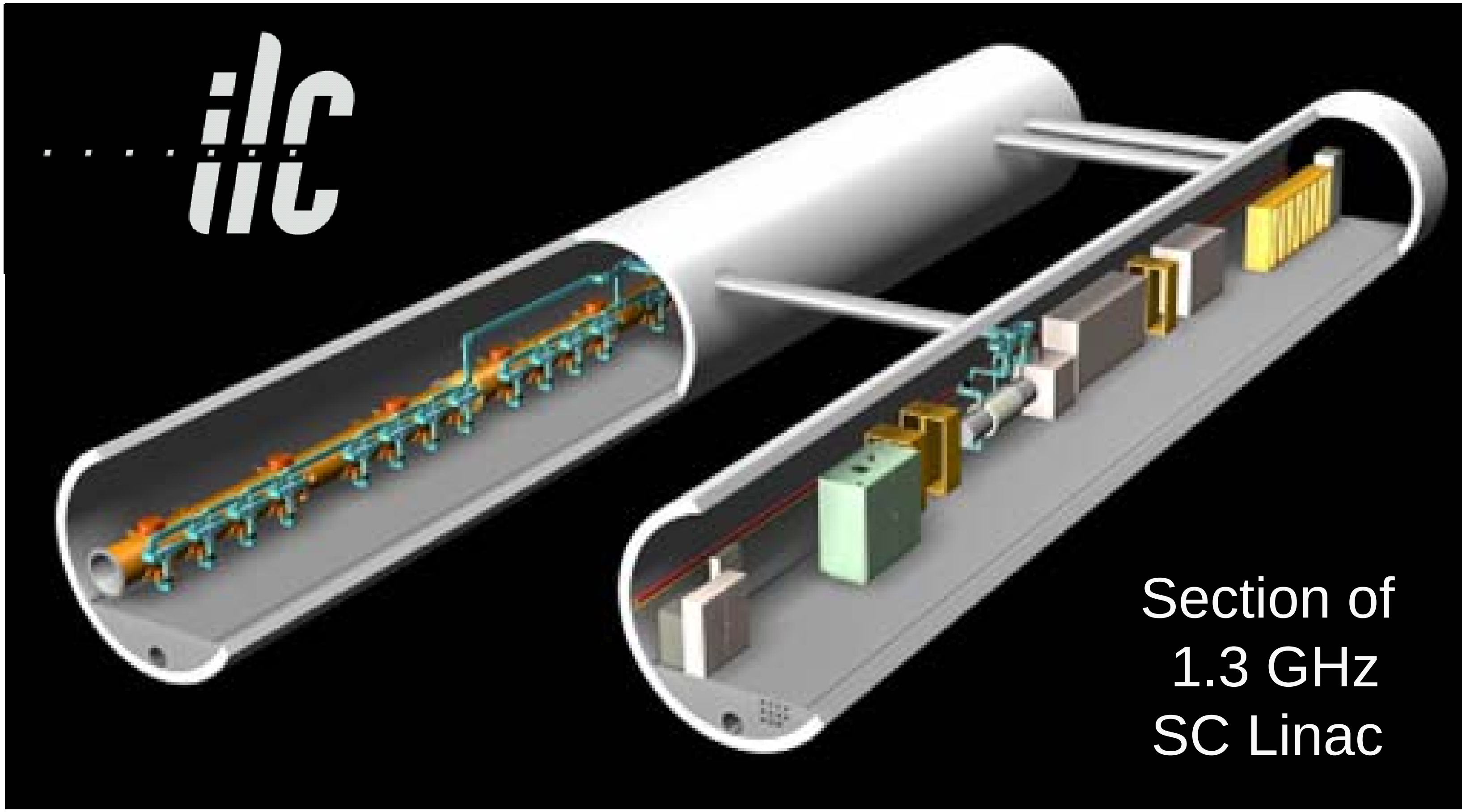
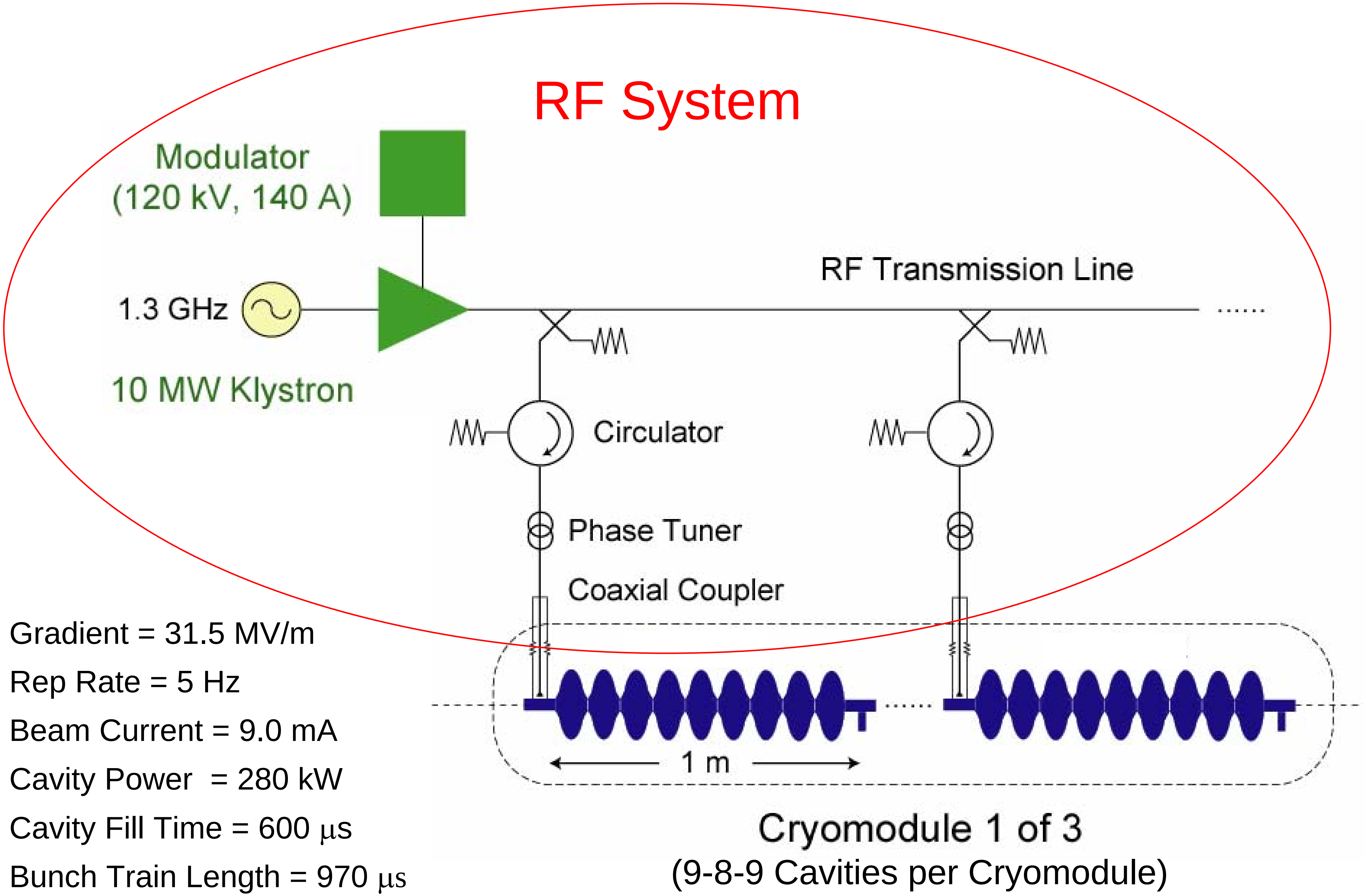
ILC RF System R&D



Chris Adolphsen, SLAC

June 29, 2007 – PAC07 Talk FRYC01

ILC Main Linac RF Unit (1 of 560)



Gradient = 31.5 MV/m

Rep Rate = 5 Hz

Beam Current = 9.0 mA

Cavity Power = 280 kW

Cavity Fill Time = 600 μs

Bunch Train Length = 970 μs

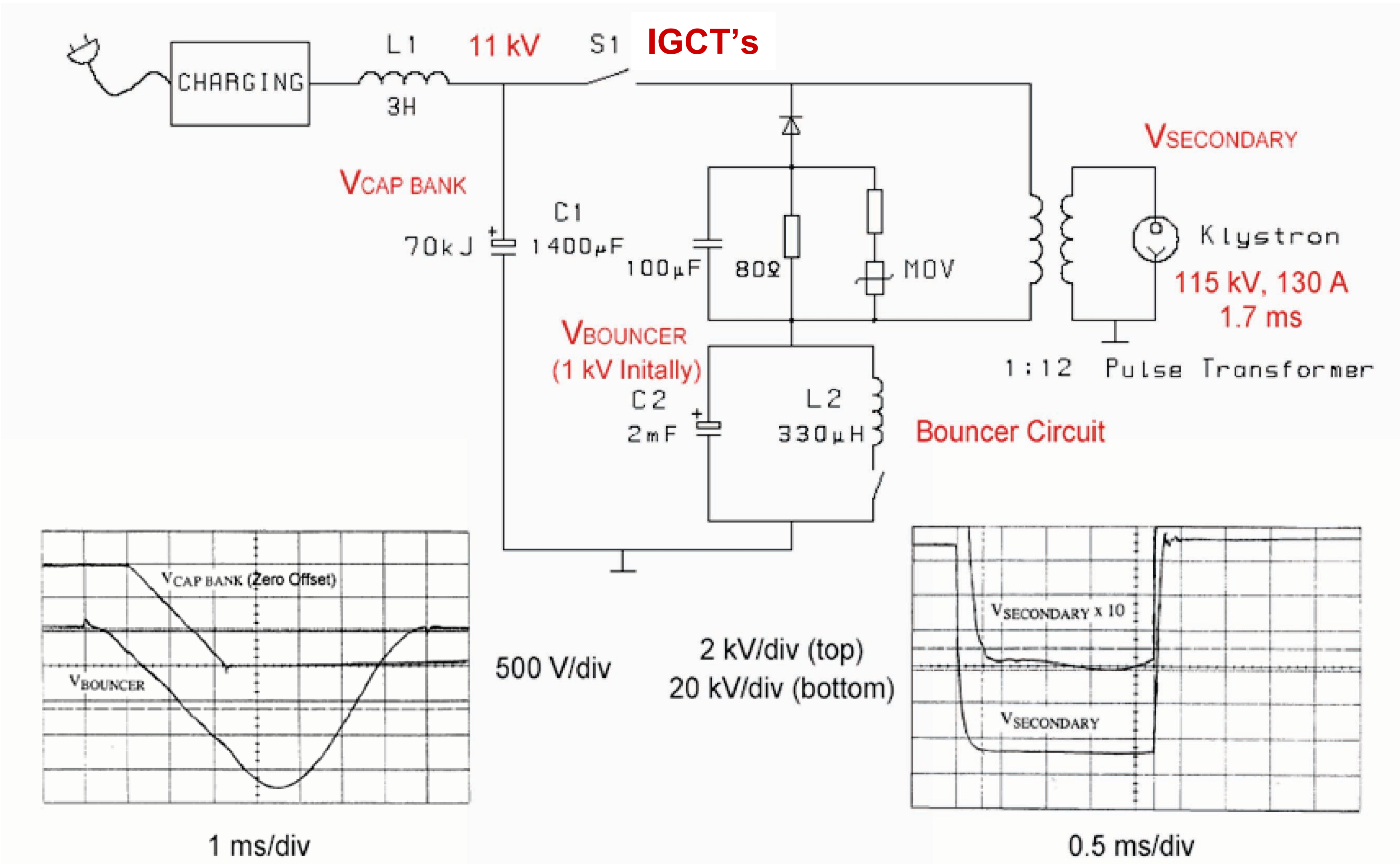
Many ILC/XFEL Presentations

Modulators		
	TUXC03	Design and Status of the XFEL RF System
	WEPMS044	High Power Switch for the SMTF Modulator
	THIBKI04	Developments of Long-pulse Klystron Modulator for the STF
	TUOAC02	Development and Testing of the ILC Marx Modulator
	THOBKI02	Marx Bank Technology for the ILC
	WEPMN113	A High Voltage Hard Switch for the ILC
	WEPMN073	A New Klystron Modulator for XFEL based on PSM Technology
	WEPMS028	Converter-Modulator Design and Operations
Klystrons		
	WEPMN013	Testing of 10 MW MBKs for the European X-ray FEL at DESY
	THIBKI03	Klystron Development by TETD
	WEPMS093	Grid-less IOT for Accelerator Applications
	THIBKI01	RF Sources for the ILC

ILC/XFEL Presentations (Cont.)

Klystrons (cont)		
	WEPMN054	Electron Gun and Cavity Designs for High Power Gridded Tube
	THPAS063	Second Order Ruled Surfaces in Design of Sheet Beam Guns
	WEPMN119	High-Power Ribbon-Beam Klystron
RF Distribution		
	WEPMS043	An RF Waveguide Distribution System for the ILC Test Accelerator at Fermilab's NML
	MOPAN015	Compact Waveguide Distribution with Asymmetric Shunt Tees for the European XFEL
Power Couplers		
	WEPMN032	R&D Status of KEK High Gradient Cavity Package
	WEPMN027	Construction of the Baseline SC Cavity System for STF at KEK
	WEPMS017	High-Power Coupler Component Test Stand Status and Results
	WEPMS041	Multipacting Simulations of TTF-III Coupler Components
	WEPMS049	A Coaxial Coupling Scheme for the ILC SRF Cavity

Pulse Transformer Modulator (ILC Baseline)



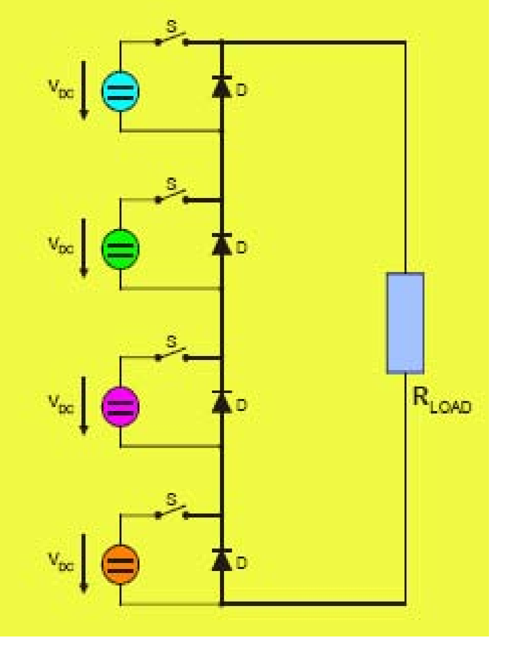
TESLA/XFEL Modulator Development at DESY

- 11 units have been built during past 10 years, 3 by FNAL and 8 by industry (PPT with components from ABB, FUG, Poynting) thru DESY funding.

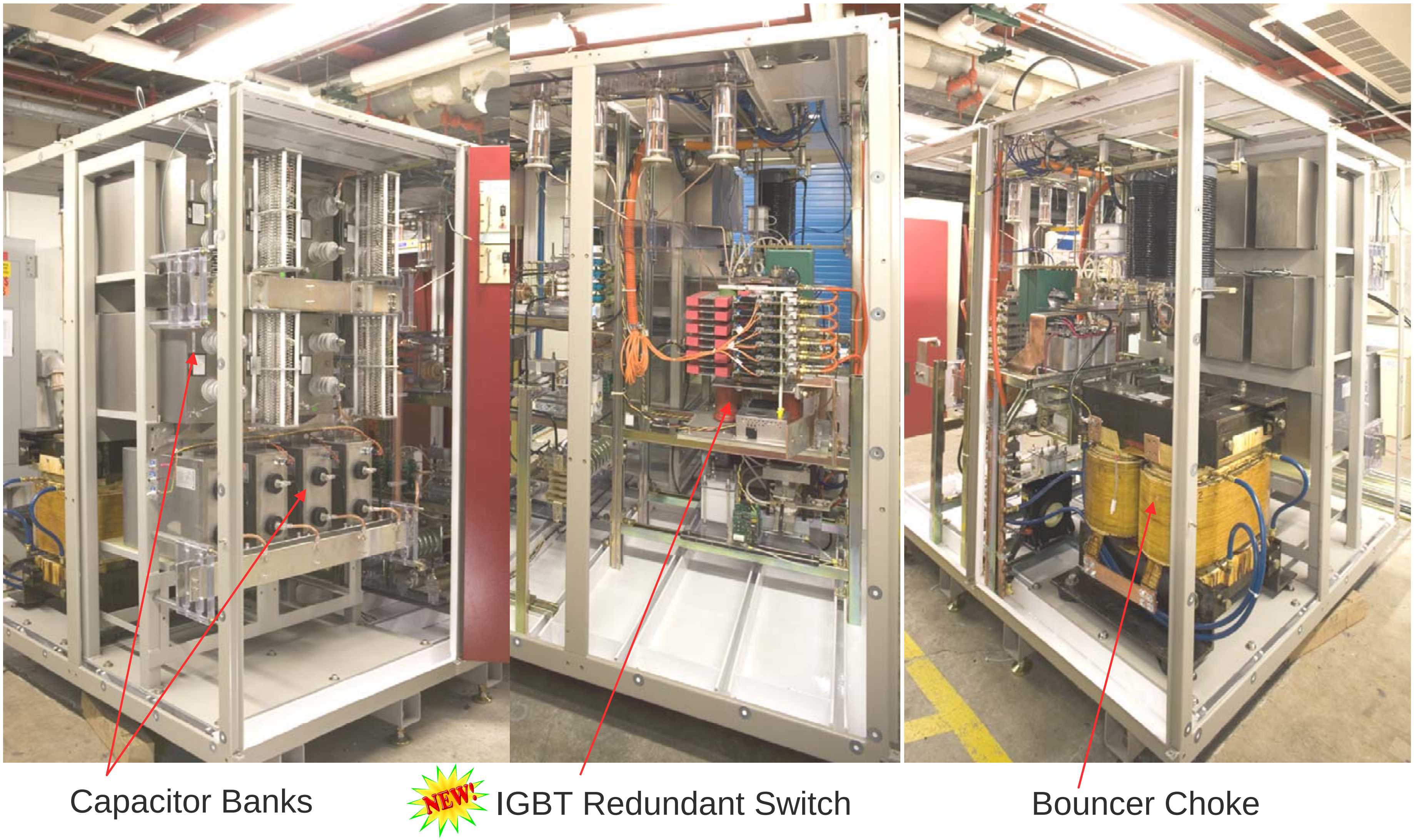
- Expanding vendor base for XFEL
  - Ordered prototypes from two vendors
    - Imtech-Vonk (Baseline Pulse Transformer)
    - Thompson (Pulse Step Modulator)
  - Test in new facility in Zuethen that includes the modulator, cable, pulse transformer, klystron, interlocks and controls
- Expect delivery of ~ 30 modulators in 2009-2011
- For ILC, compliments Marx and other alternative designs

Pulse Step Modulator

- Features
  - 24, ~ 0.5 kV, Marx-like cells are summed to drive a 12:1 transformer
  - Bouncer circuit eliminated
  - FPGA based control
  - 2 stages for redundancy
  - Pulse width modulation for fine control
- Slew rate and pulse shape controllable
- Concept used in PS's Thompson built for the W7-X experimental fusion reactor



New Pulse Transformer Modulator at FNAL with SLAC-Supplied Switch



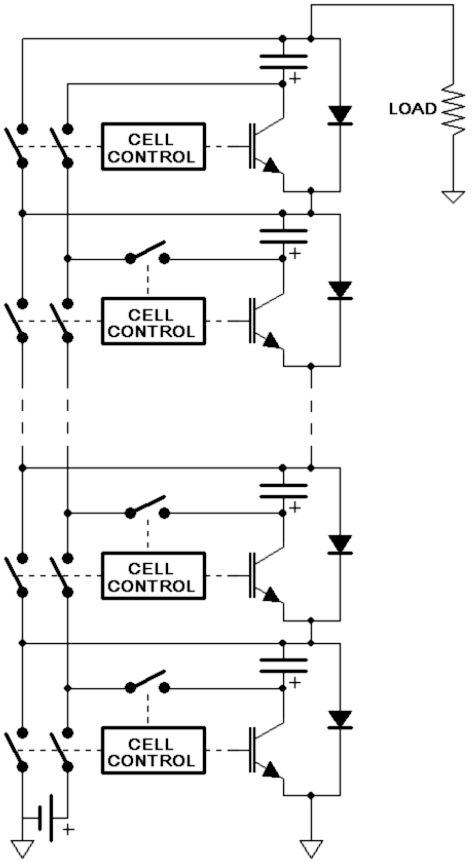
New Pulse Transformer Modulator at KEK

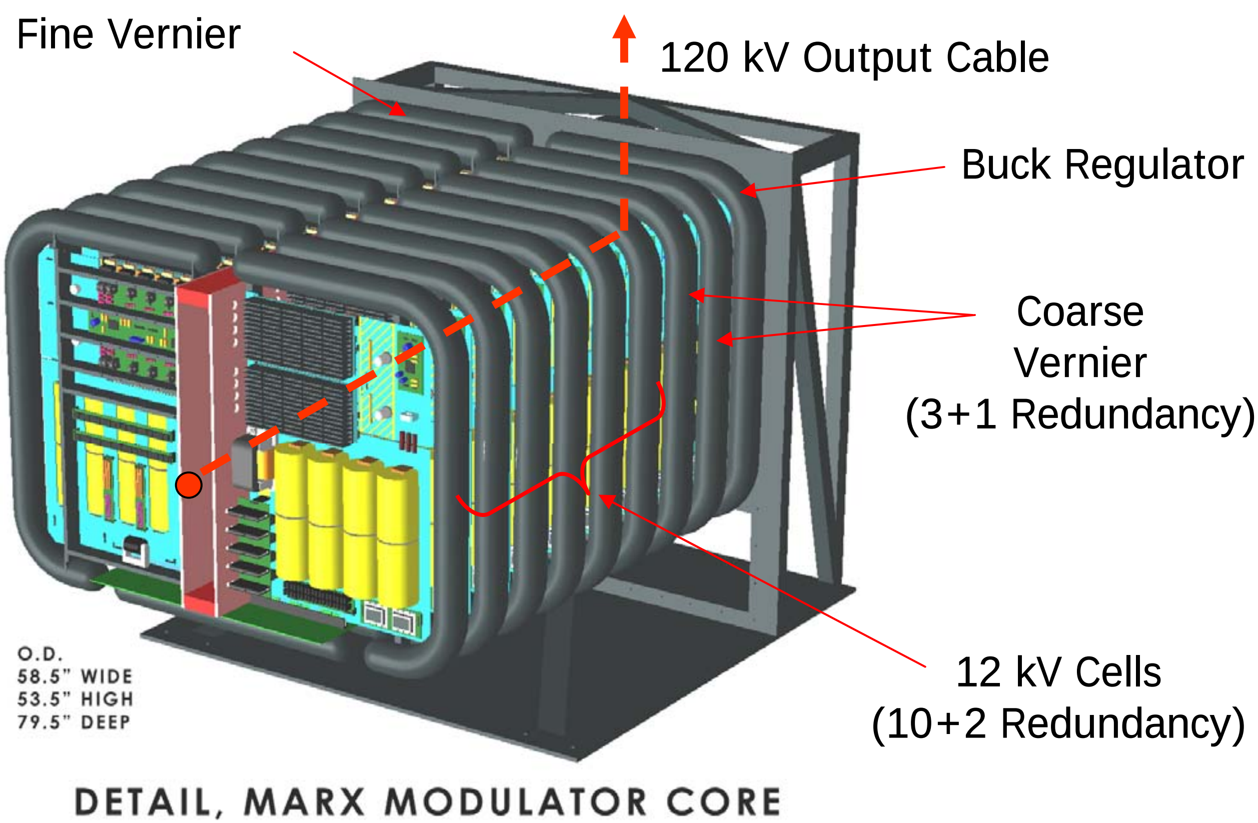
Nichicon (Kusatsu) Corporation and KEK Collaboration

Features crowbar-less system with optimized IGBT snubber circuit, compact and highly reliable self-healing capacitors, HV & LV twin pulse transformers of laminated steel core for reduced tank volume

SLAC Marx Modulator

Develop alternative Marx approach to reduce the cost, size and weight of the modulator (no oil-filled transformers) and to improve its efficiency, reliability and manufacturability.

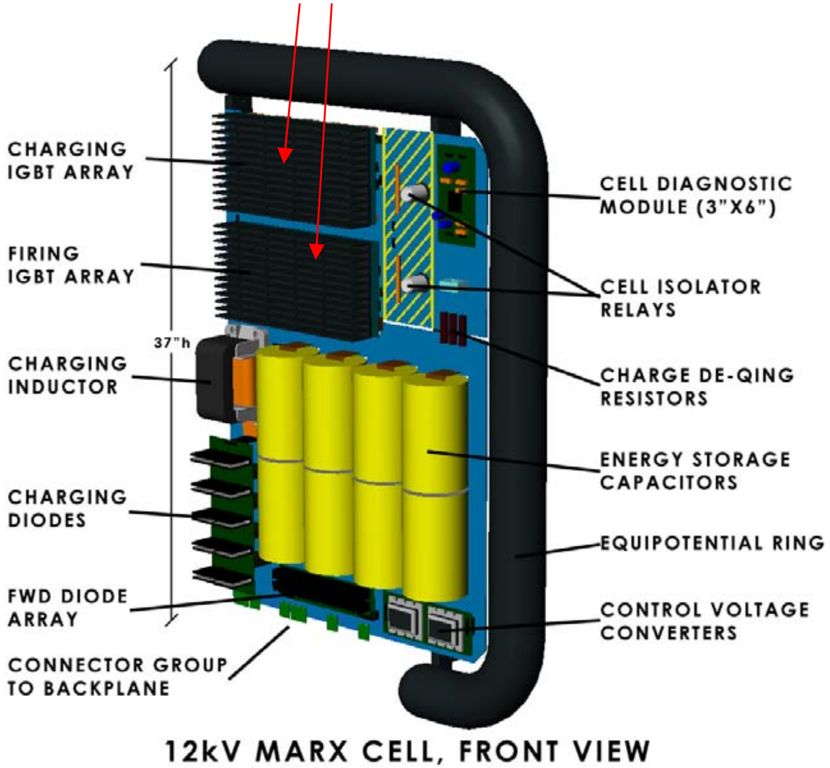


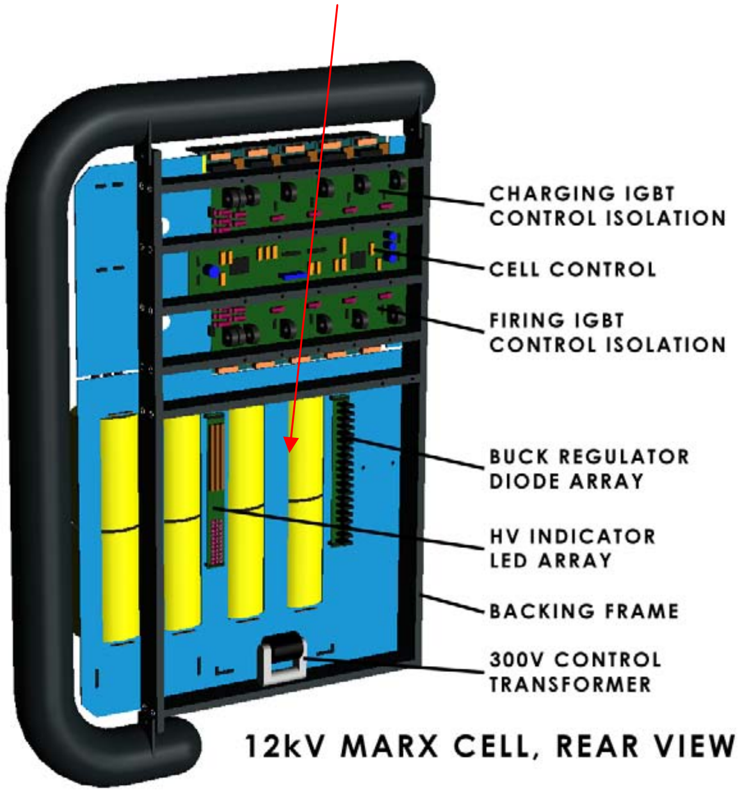


12 kV Cell Detail

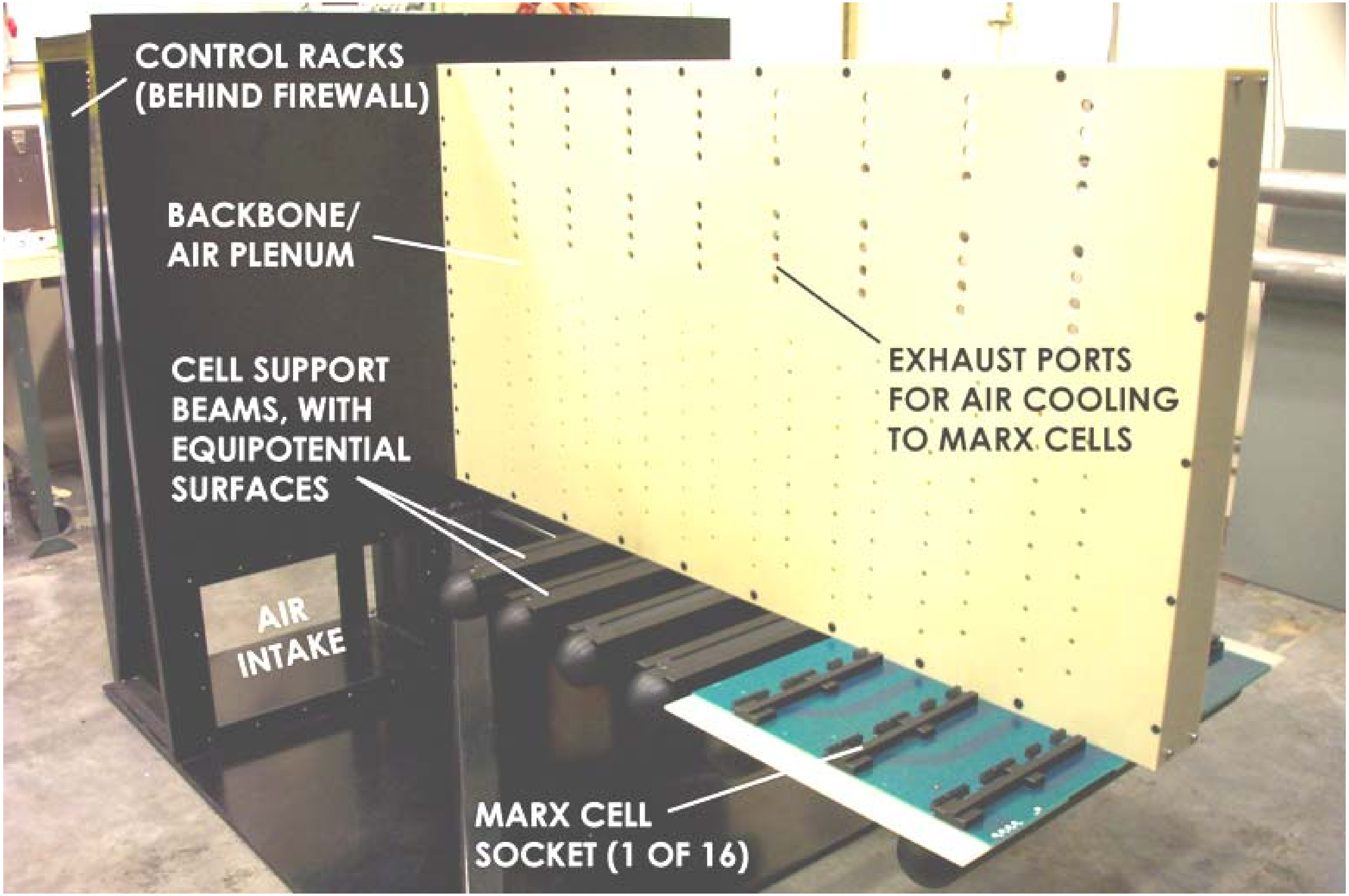
4+1 Redundant Switch Arrays for charge, discharge

6+2 Redundant Capacitors





Cantilever Backbone

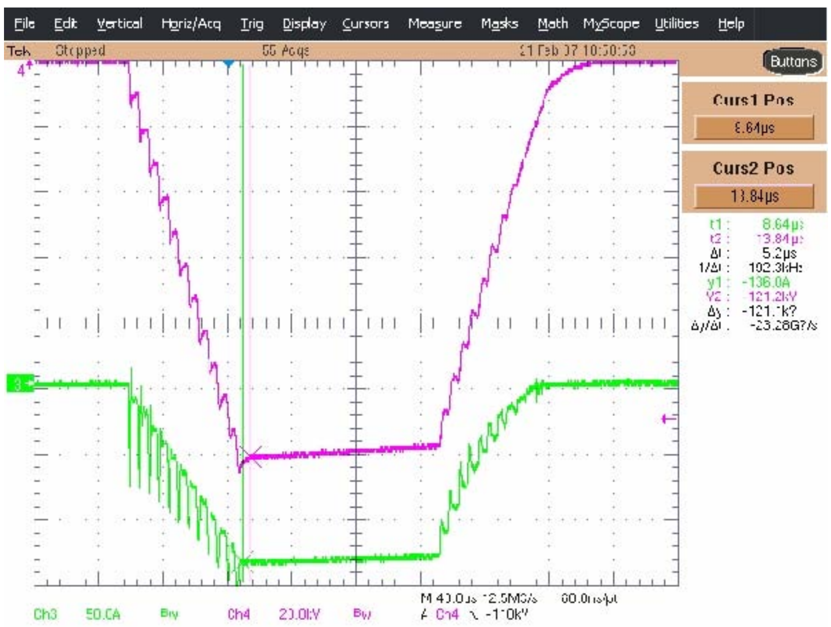


MARX Prototype

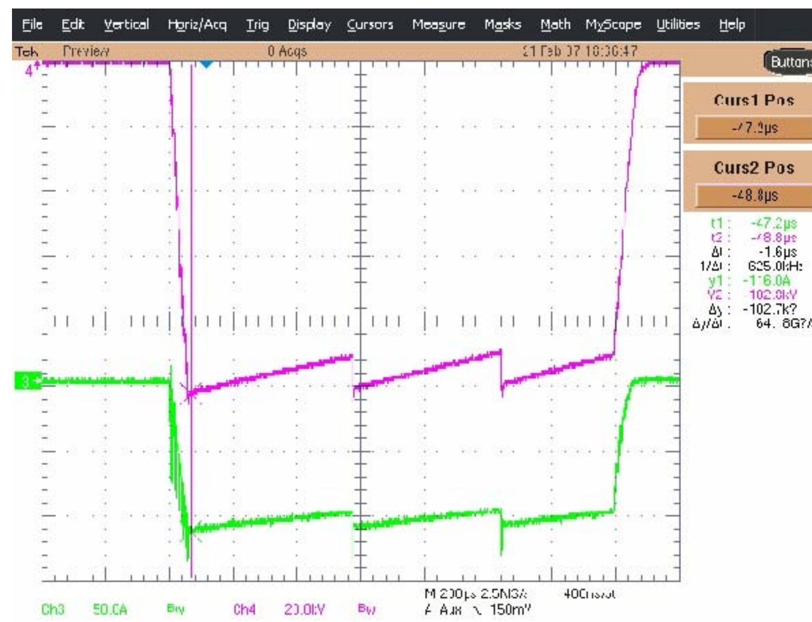
MARX Waveforms

With 10 cards but w/o Vernier,
which will be ready this Summer

120kV, 120 μsec Pulse



100kV, 1.4 ms ‘Leveled’ Pulse

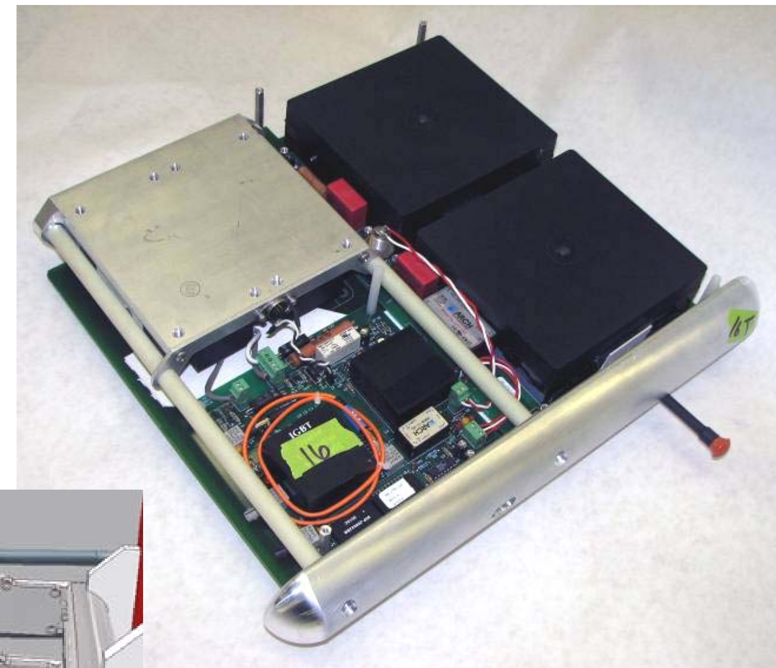


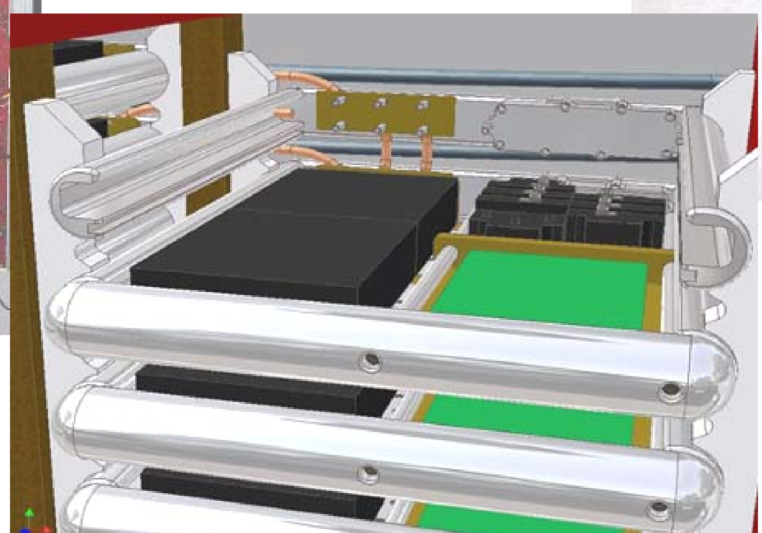
Marx Status & Plans

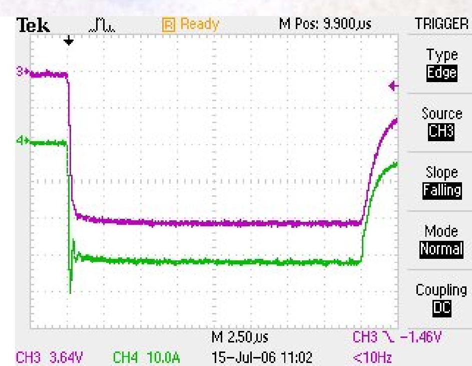
- Prototype built that has achieved peak power goals.
- Currently sorting IGBTs and improving protection circuits (run at low rep rate).
- Will then do 100 h full average power test and modify design to include new capacitor discharge switches, begin 2000 h test.
- In parallel, complete Vernier, Buck Regulator Boards.
- Complete full power 2000 h test with resistive load.
- Install unit in air-water cooled enclosure and move to SLAC ESB to operate Toshiba 10 MW Multi-Beam Klystron

Stangenes Marx Generator
(for NATO Radar Systems)

Produces 90 kV, 50A, 100 μsec Pulses



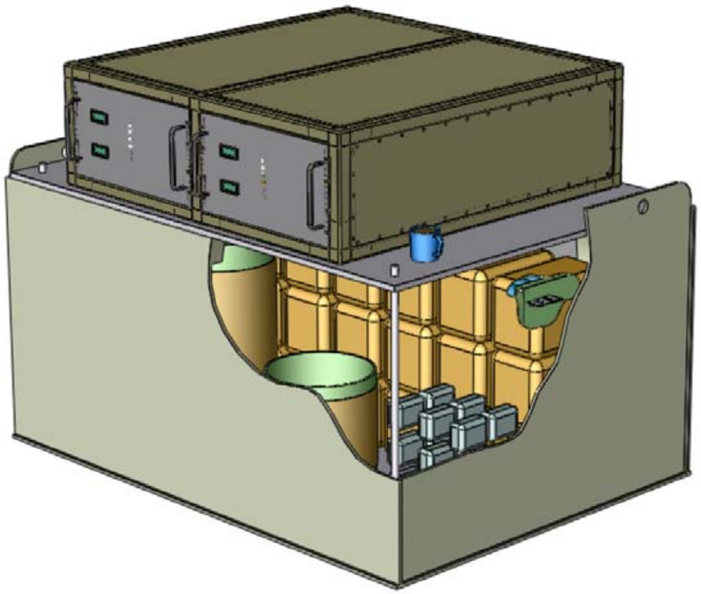




DTI Marx Under Construction
(Phase II SBIR)

DIVERSIFIED TECHNOLOGIES, INC.®

- ILC Modulator
  - 120-150 kV, 120-150 A, 1.5 ms, 5 Hz Klystron Pulses
  - ~ 750 Modulators Required
- Use Marx topology to beat the long pulse problem
  - Switch additional stages as pulse droops, maintain flattop with affordable size capacitor bank
  - Minimize Overall Size and Cost
- SBIR Goal
  - Design, build, deliver a fully functioning first article for evaluation & tube testing

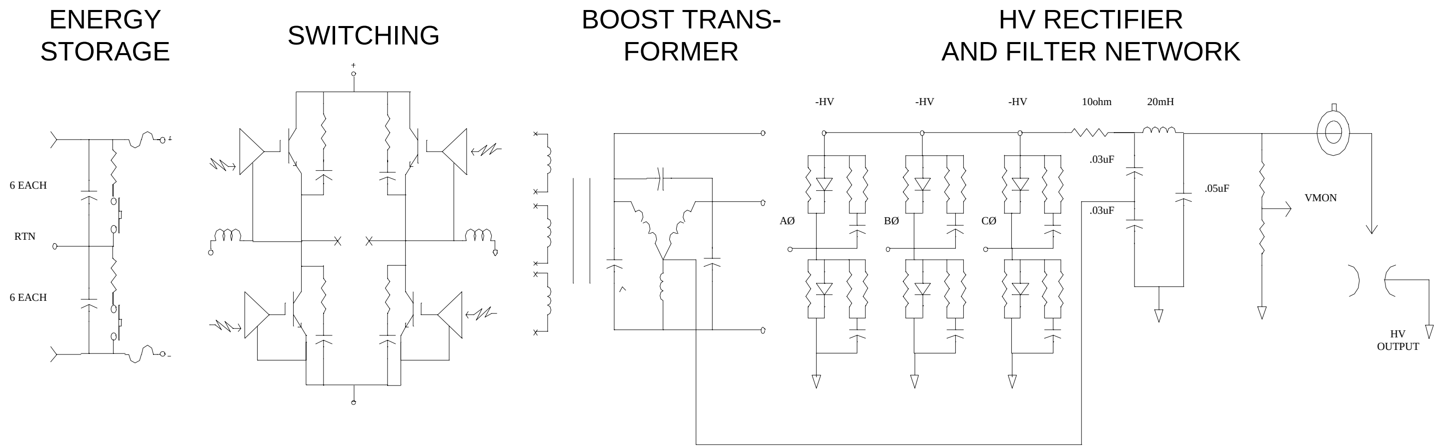


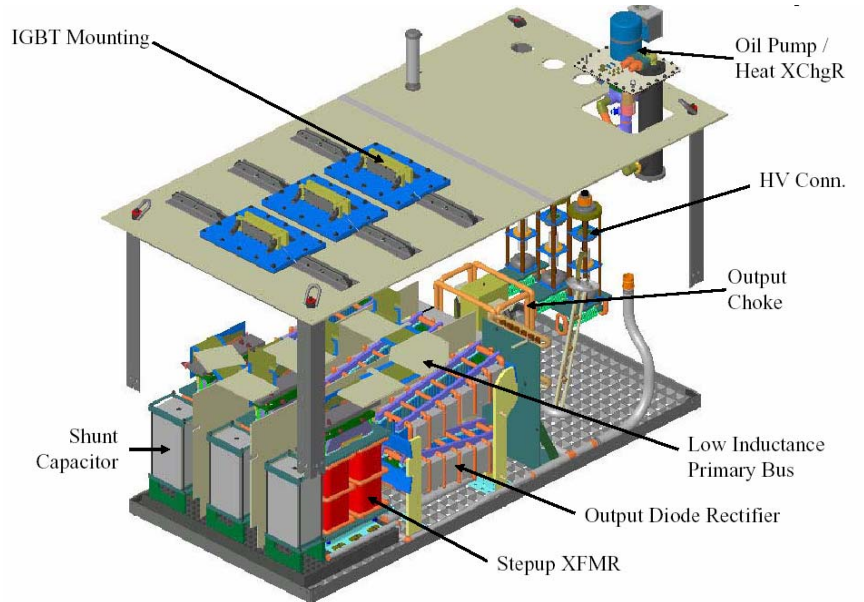
Advantage of Marx for ILC ...
... *COMPACT !!!*
... *LOW COST !!!*

M. Kempkes

Other Alternative Modulators

SNS High Voltage Converter Modulator at SLAC

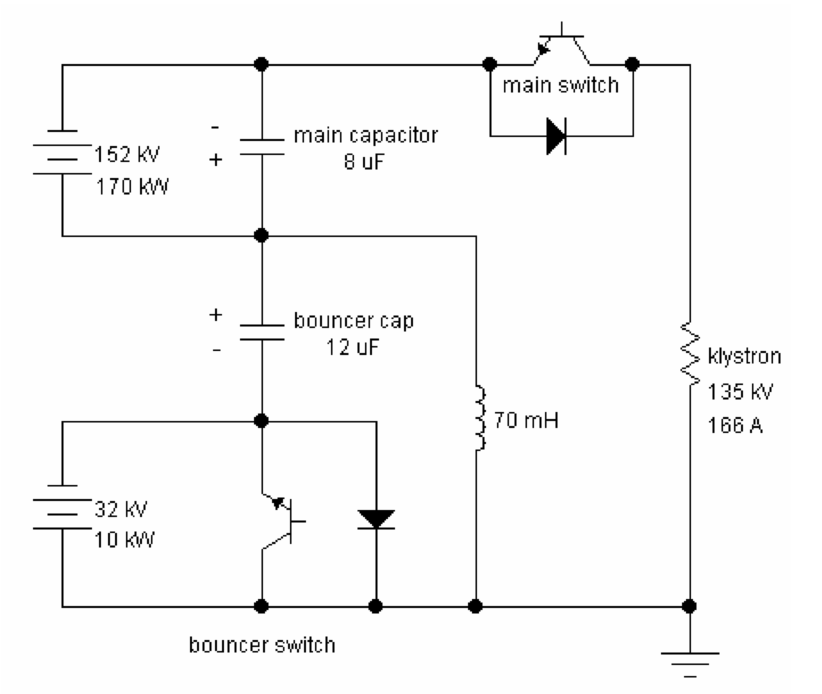


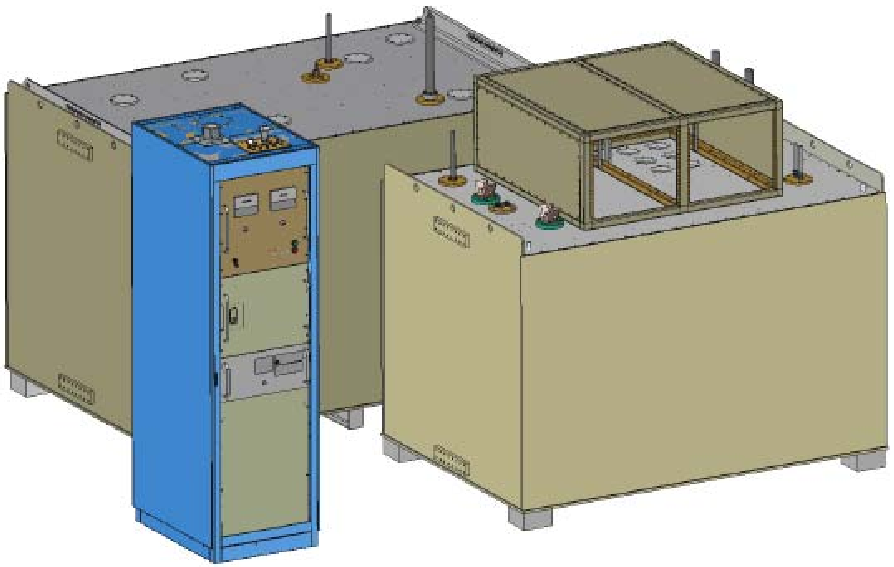


DTI Series Switch Modulator
(Phase II SBIR)

DIVERSIFIED TECHNOLOGIES, INC.®

DTI is building a 120 kV, 130 A IGBT Series Switch with a bouncer to be delivered to SLAC by the end of 2007





L-Band Klystrons

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

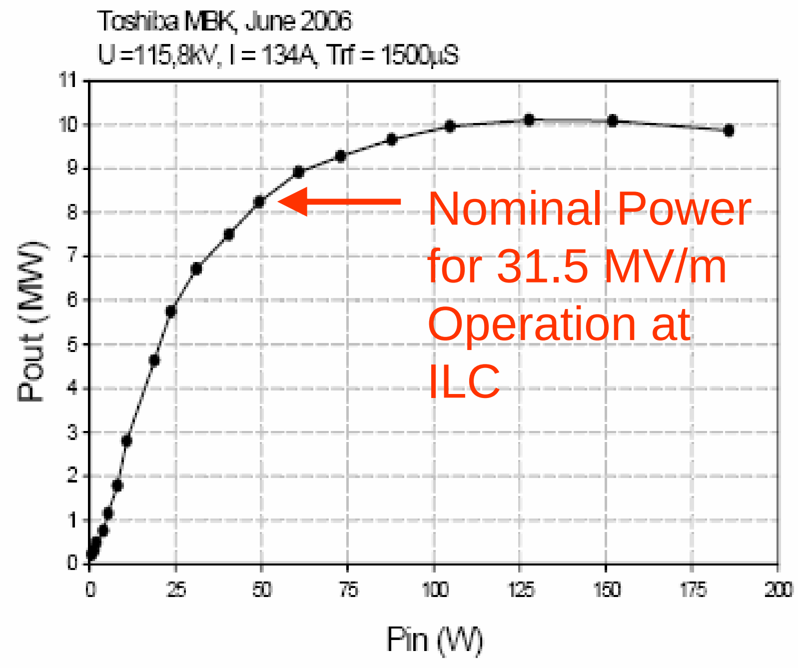
Thales (6 built)

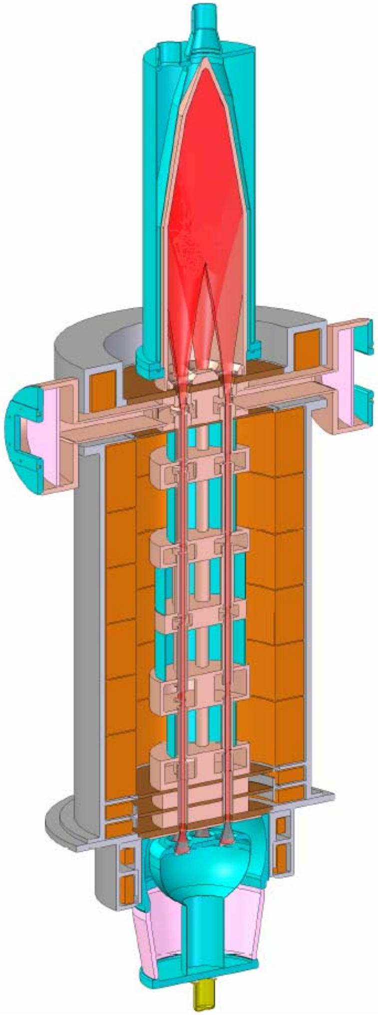
CPI (1)

Toshiba (1)

Test of First Toshiba MBK at DESY

- Operated 750 hours, 80 % at full power
- Efficiency = 65 %, which meets design goal

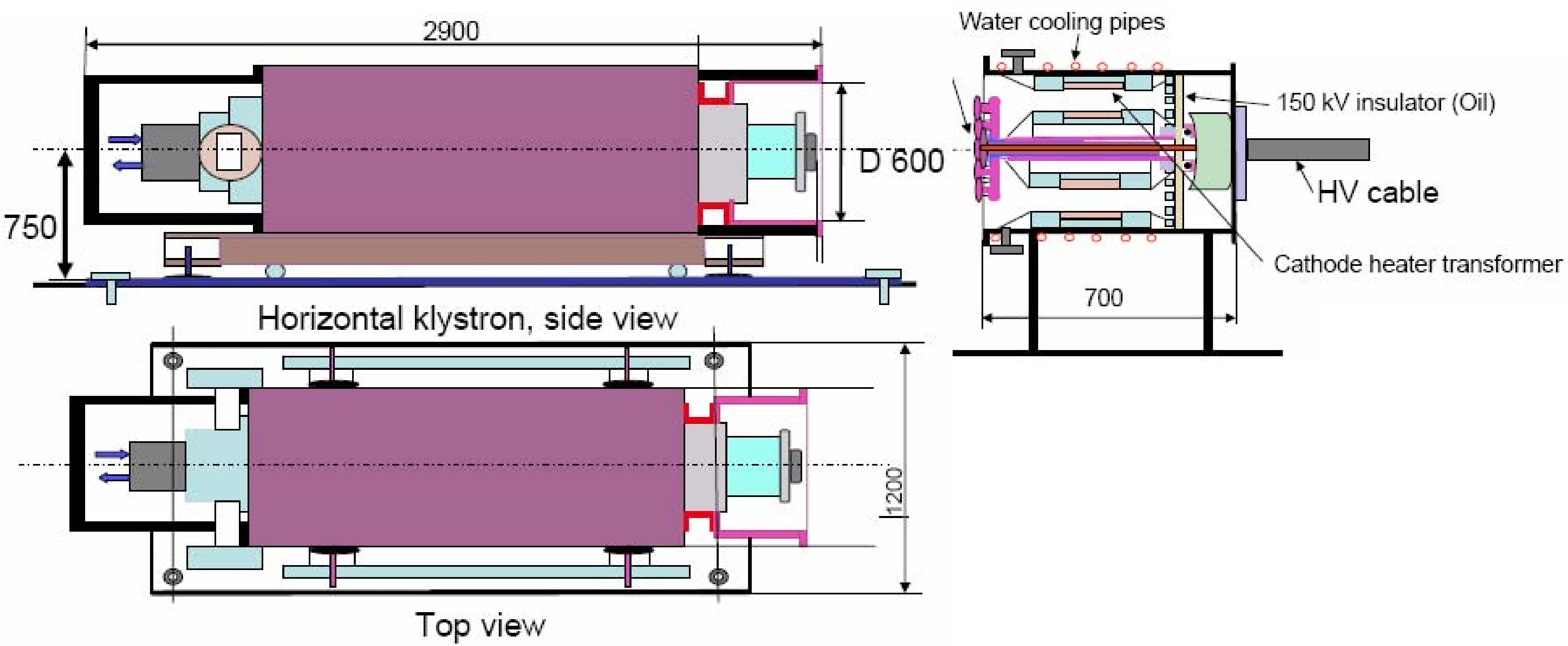




6-Beam Gun

Horizontal MBKs for XFEL

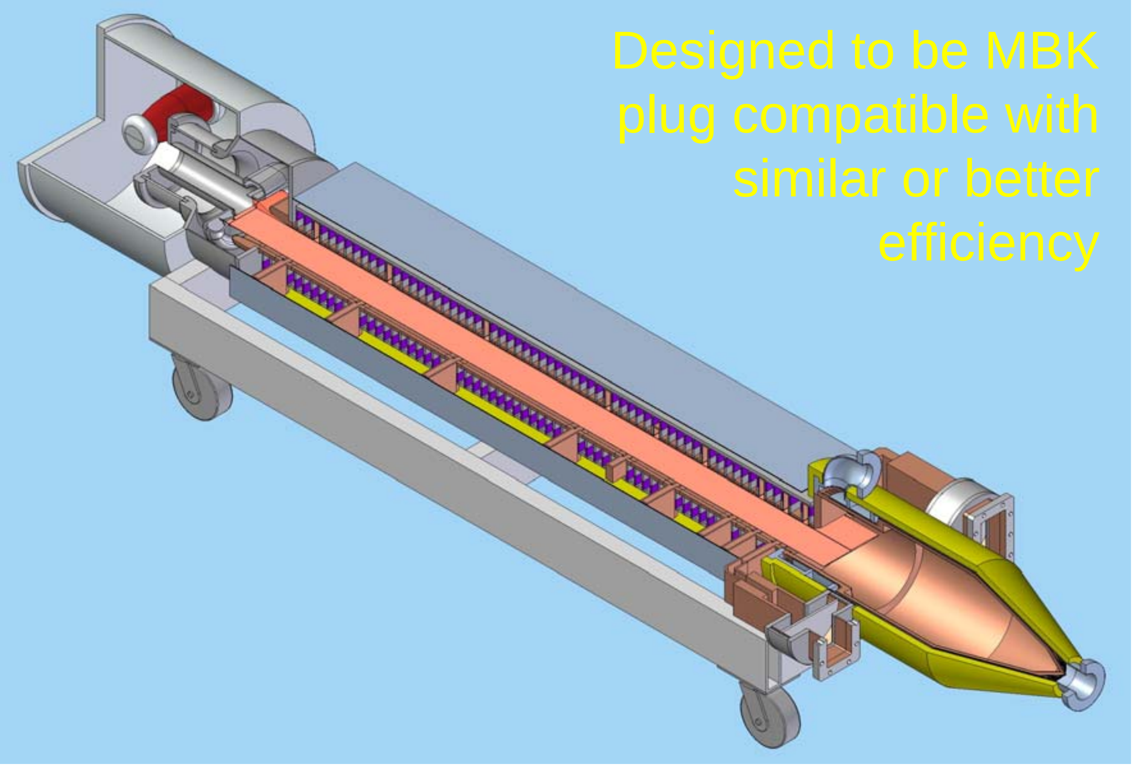
Expect the first of three horizontal MBKs this Fall. DESY is currently working with three companies to design the klystron interface to the transformer tank



Sheet Beam Klystron Development at SLAC

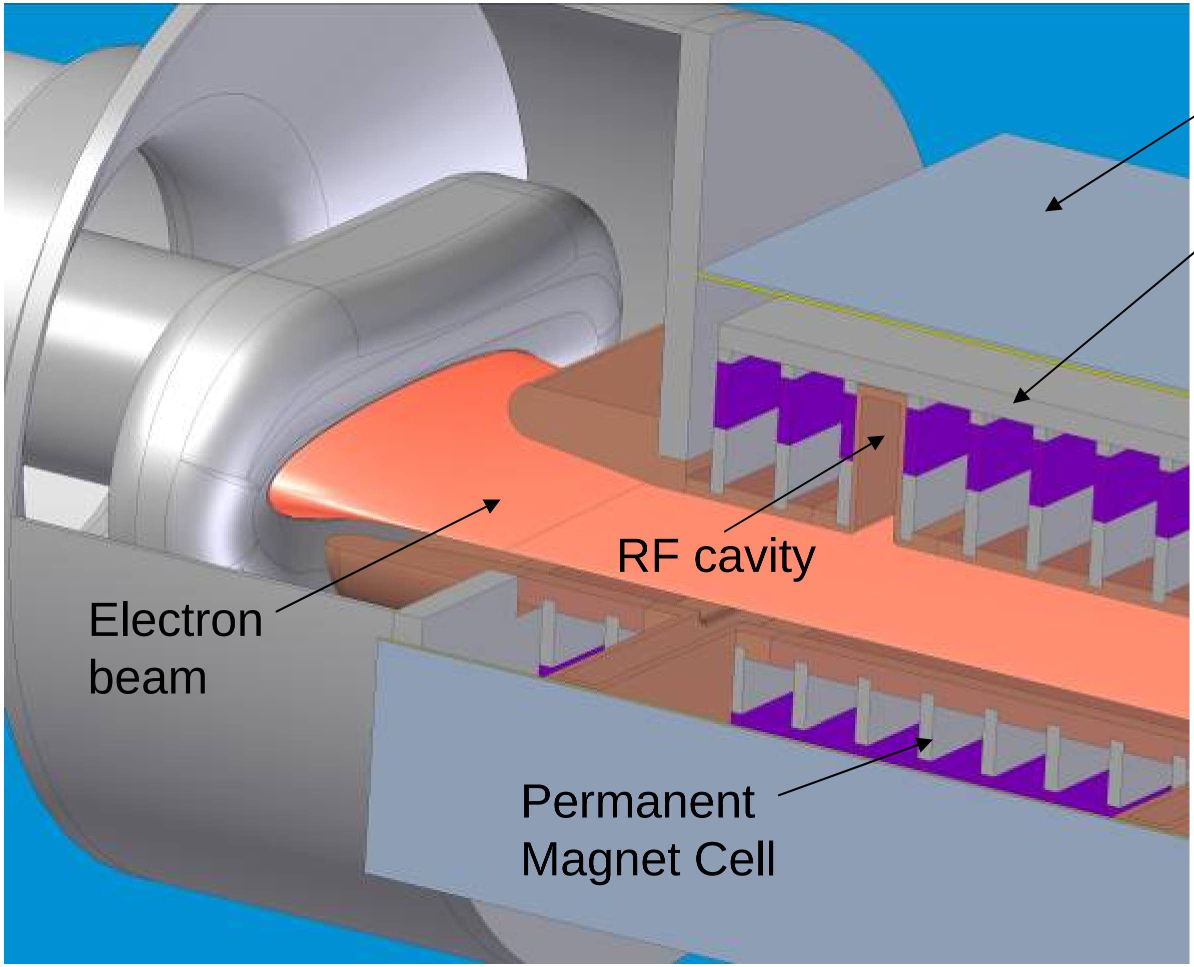
Why Sheet Beam ?

- Allows higher beam current (at a given beam voltage) while still maintaining low current density for efficiency
- Will be smaller and lighter than other options
- PPM focusing eliminates power required for solenoid



Beam Transport and RF

The elliptical beam is focused in a periodic permanent magnet stack that is interspersed with rf cavities



Lead shielding

Magnetically shielded from outside world

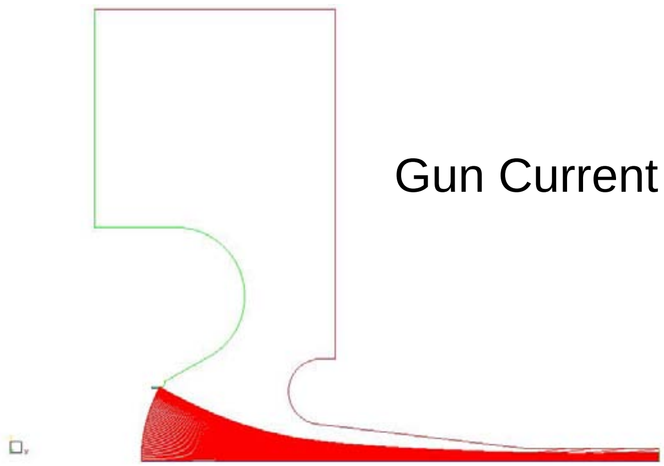
Have done:

3D Gun simulations of a 130 A, 40:1 aspect ratio elliptical beam traversing 30 period structures.

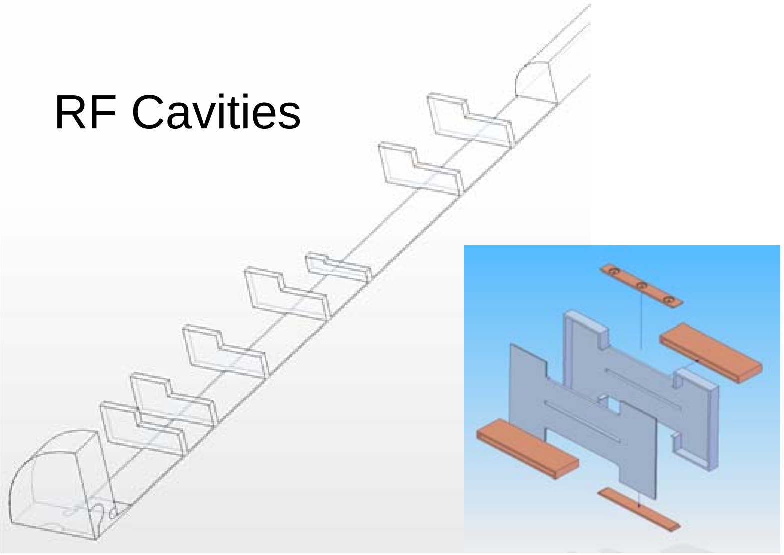
3D PIC Code simulations of rf interaction with the beam.

SBK Simulations

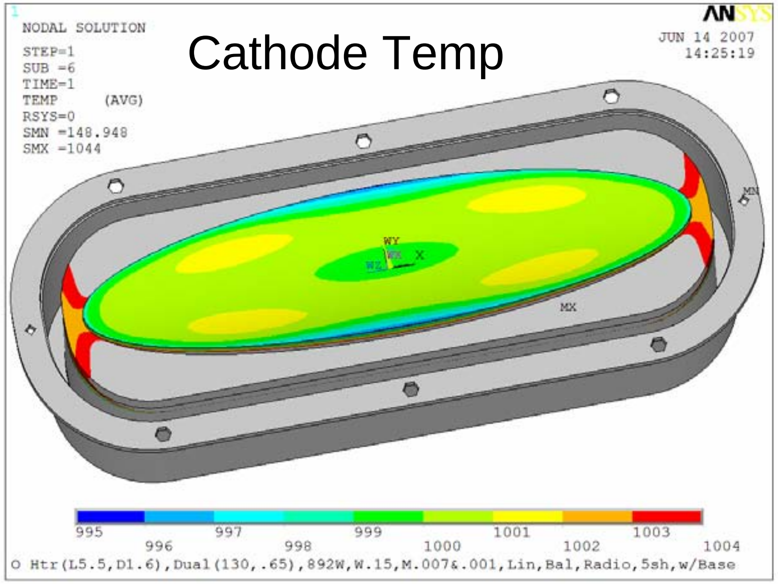
Gun Current



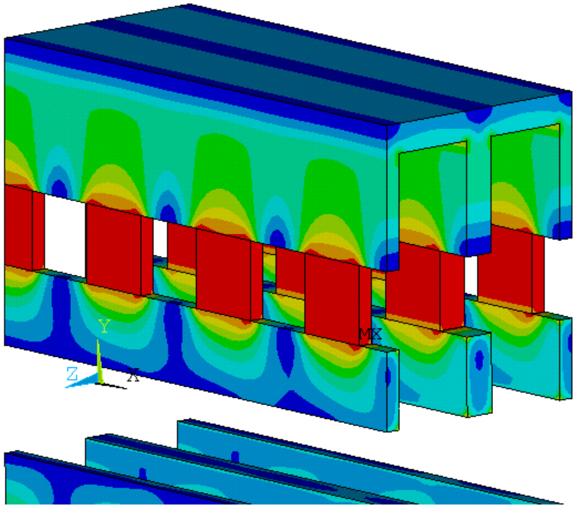
RF Cavities



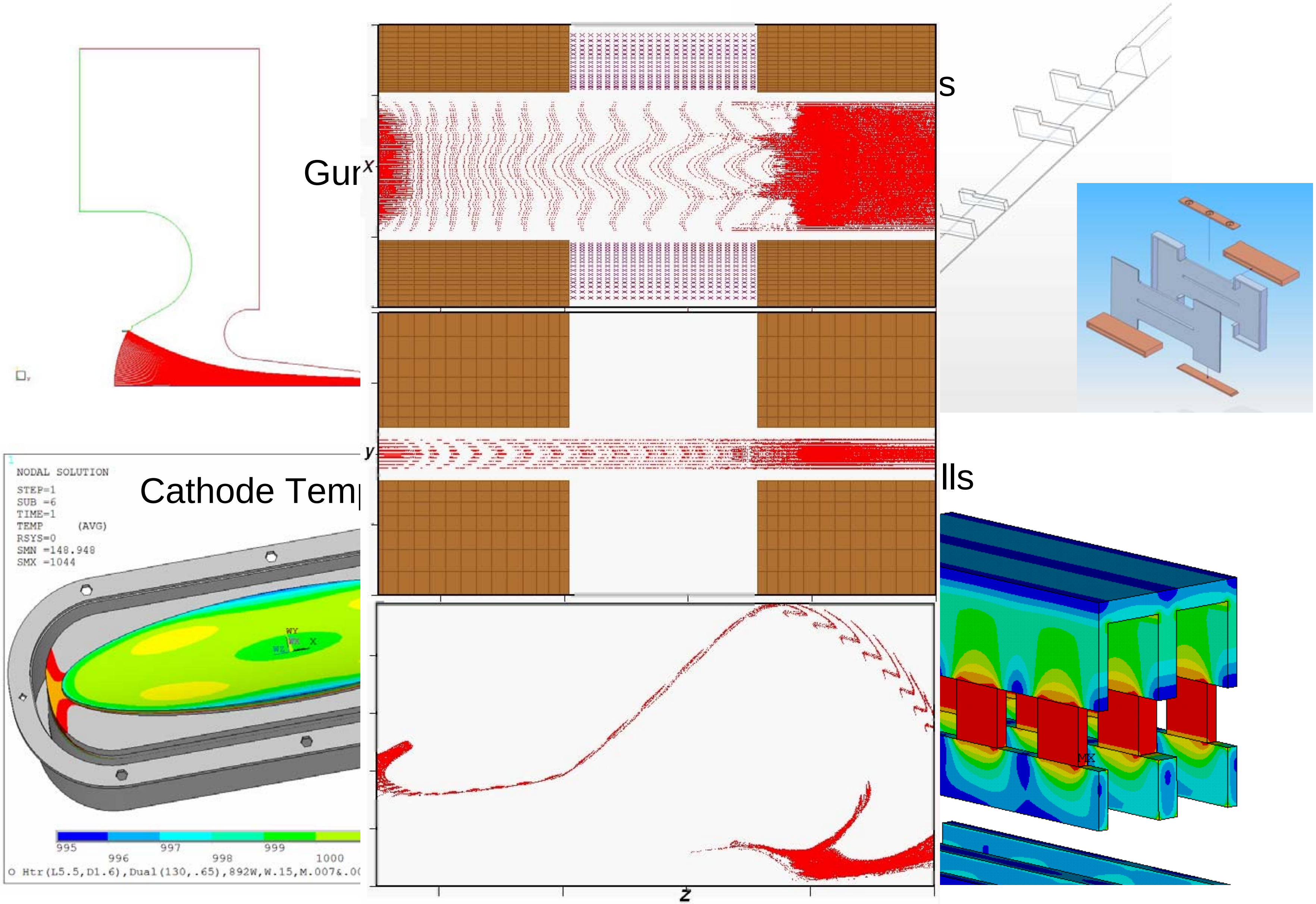
Cathode Temp



Magnetic Cells

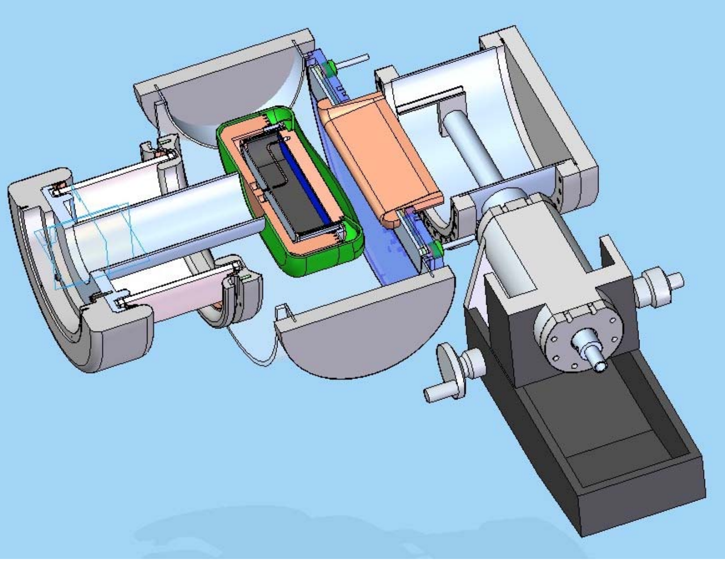


SBK Simulations

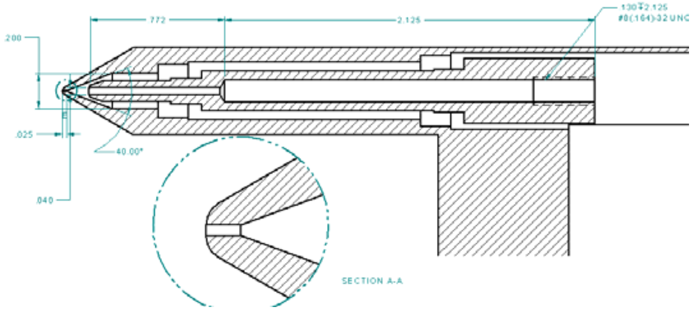


Sheet Beam Program

- Build beam tester and klystron by Summer 2008.
- The beam tester will validate 3-D beam transport simulations and allow a more rapid turnaround for electron gun changes.
- The klystron will be developed in parallel with little feedback from the beam tester. A rebuild of the klystron can incorporate design changes motivated by the beam tester.

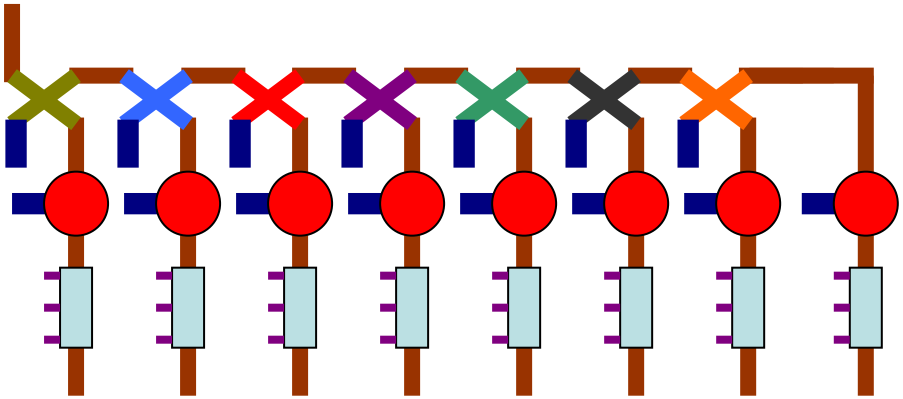


Gun and Beam Profile Monitor



Carbon beam probe assembly

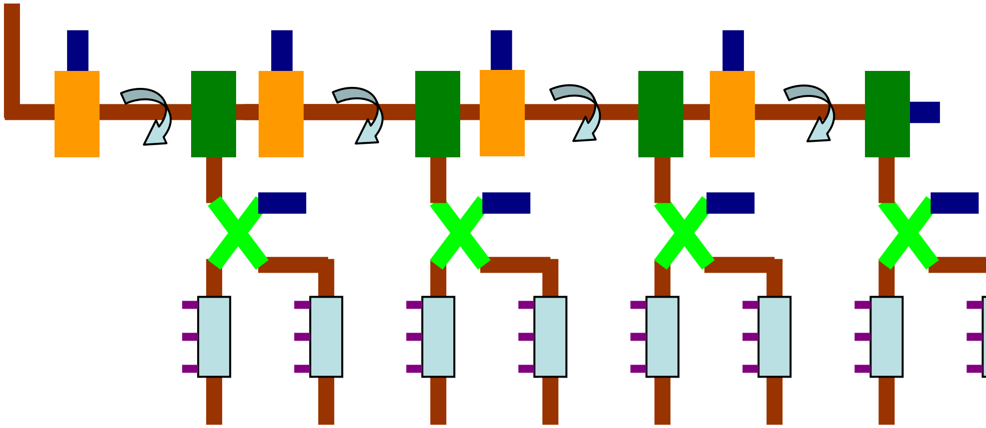
Baseline RF Distribution System



Fixed Tap-offs

Circulators

Alternative RF Distribution System

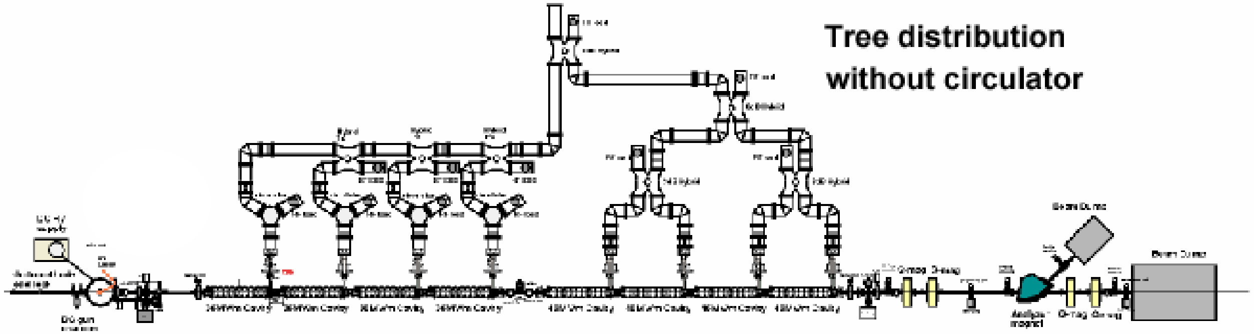


Variable Tap-offs (VTOs)

3 dB Hybrids

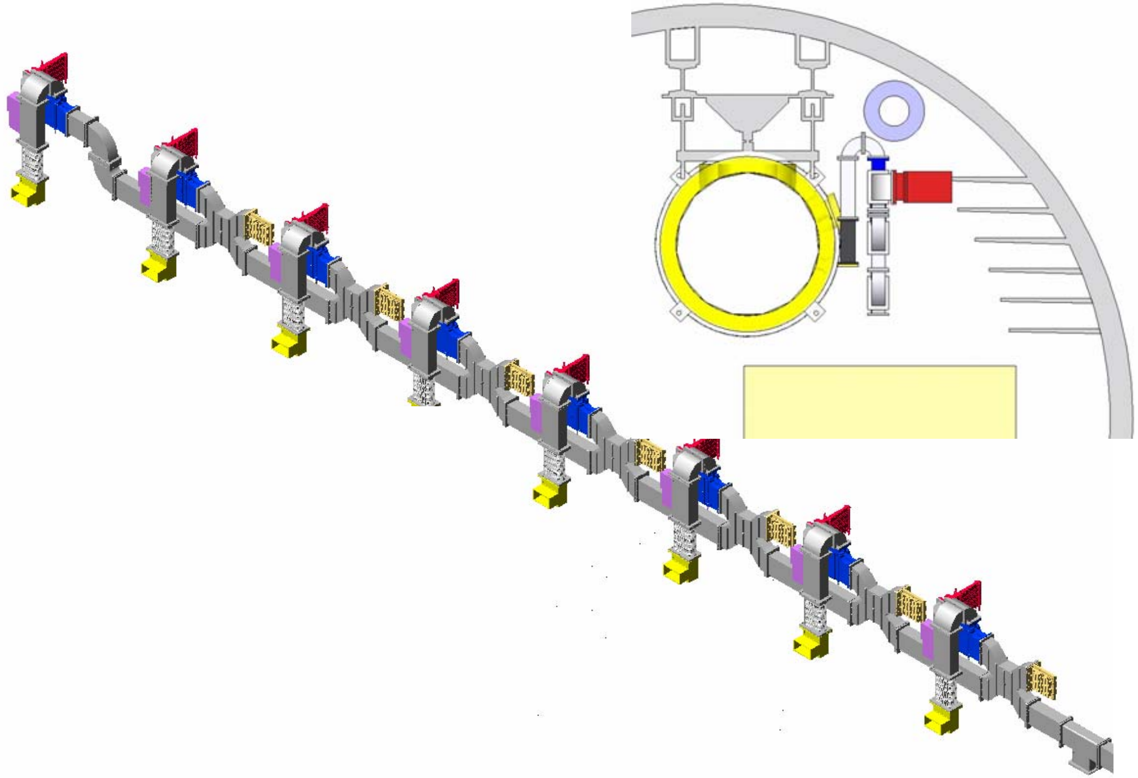
The KEK Superconducting Test Facility (STF) Will Use Both Individual and Tree-Like Feeds

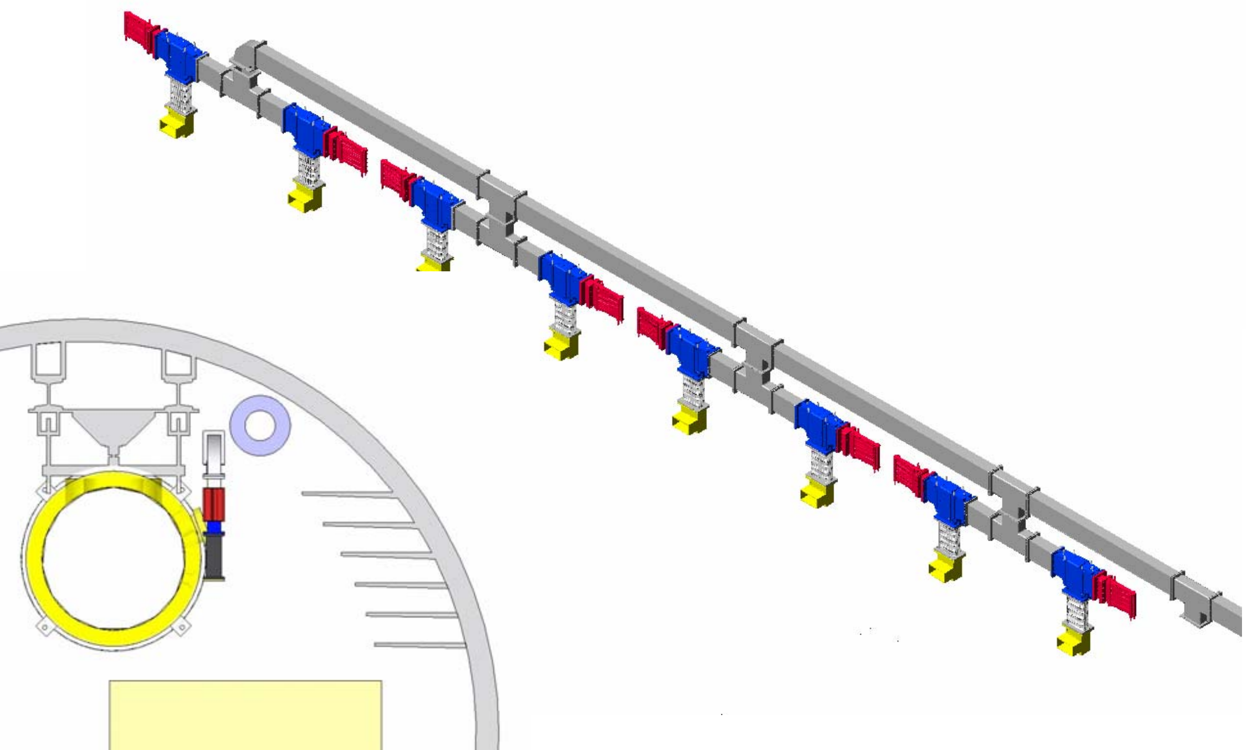
STF Phase 1: Two Cryomodules of Four Cavities Each



XFEL RF Distribution System

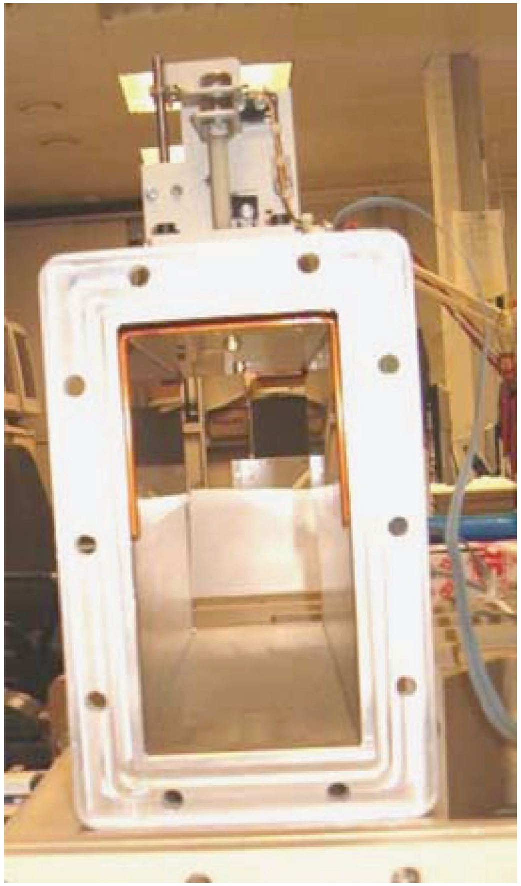
Switched from a Individual Feed System



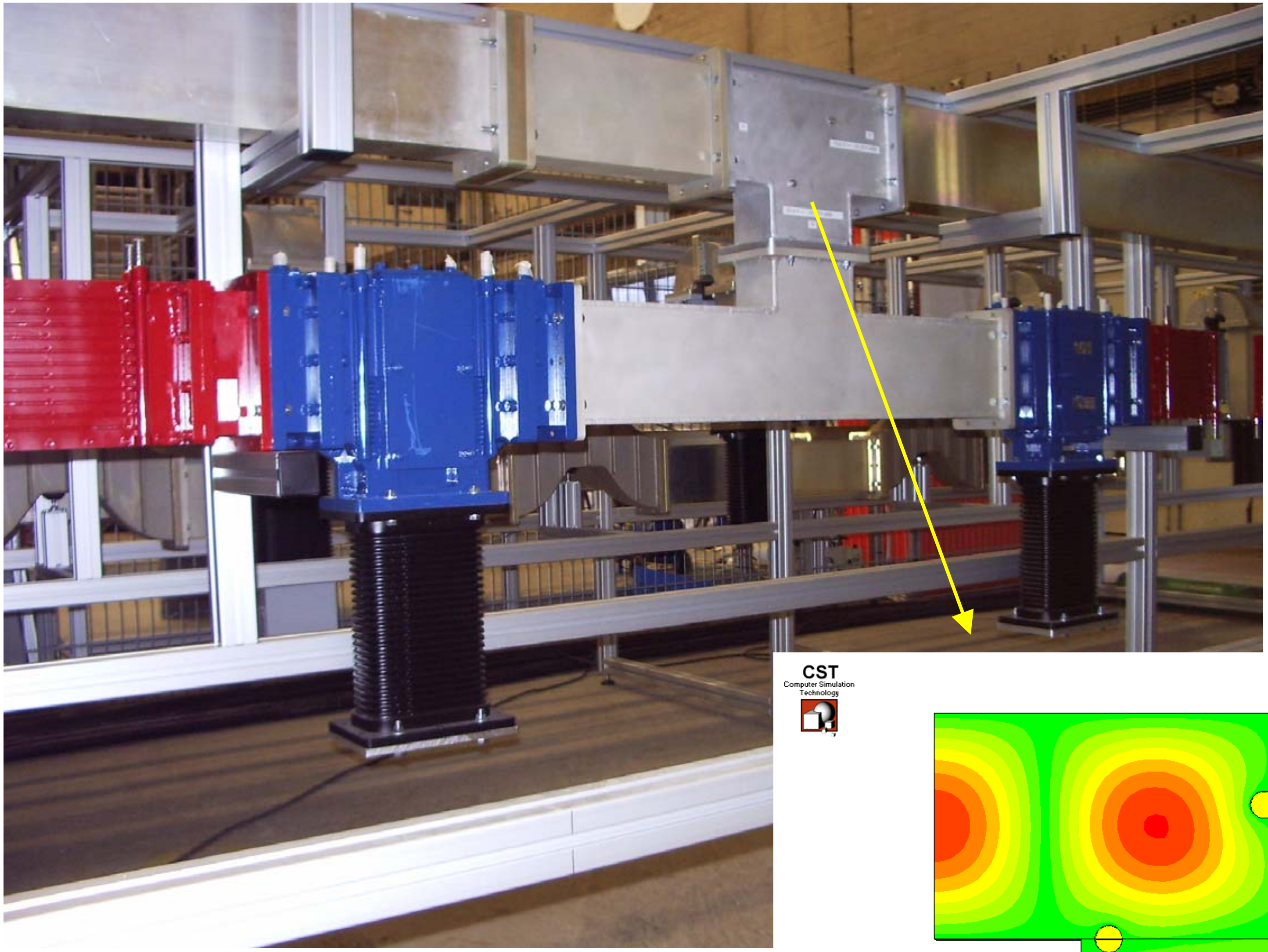


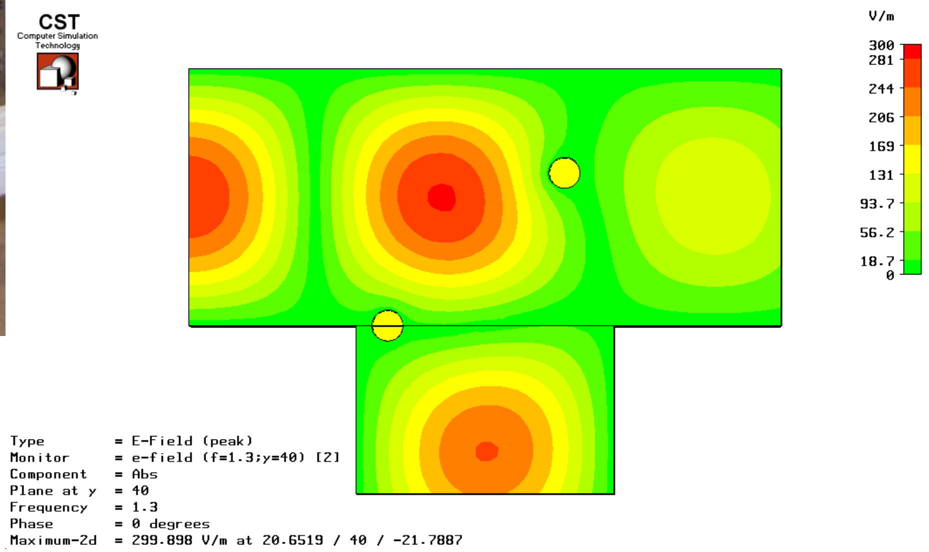
To a Tree-Like (2D) System

Replaced 3-Stub Tuner with Phase Shifter

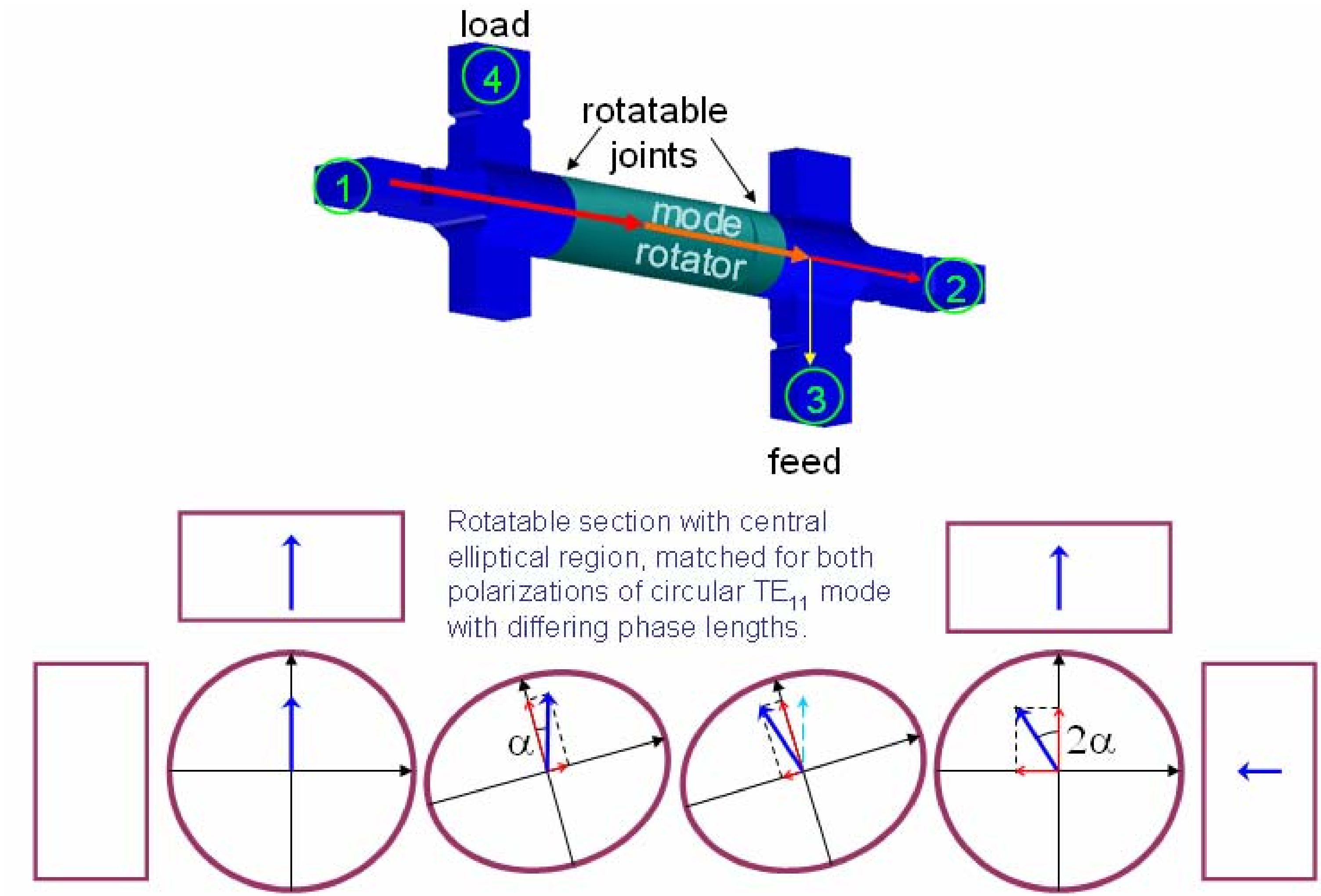


Feed Cavities In Pairs

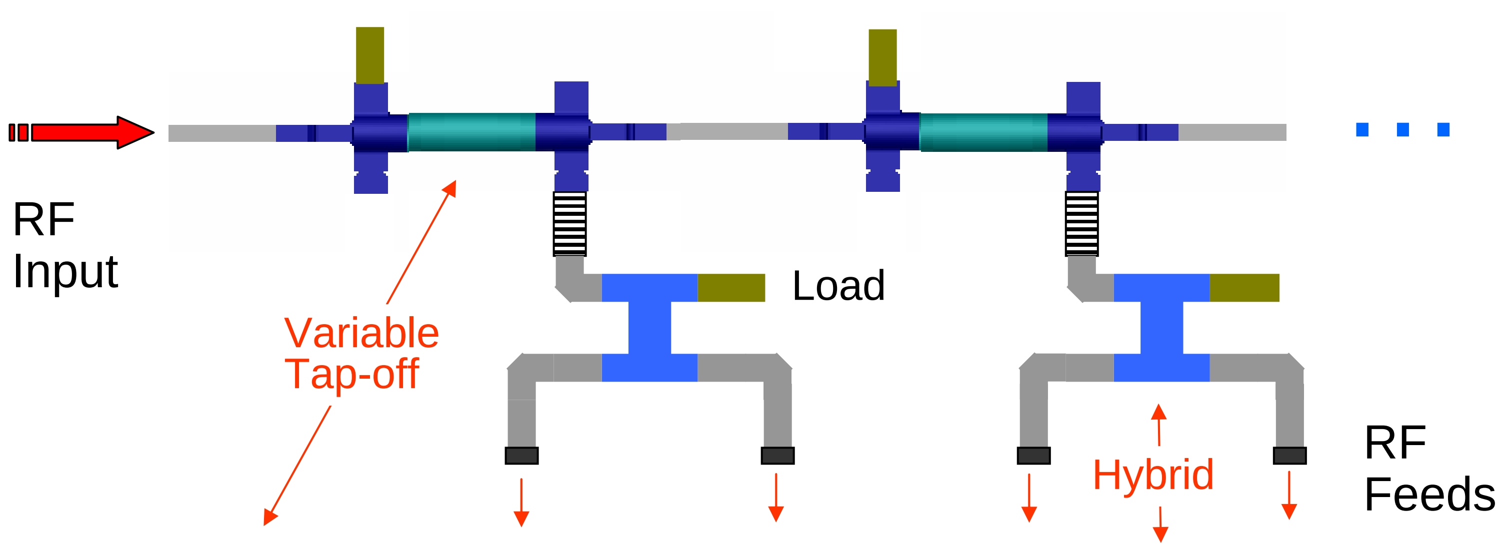


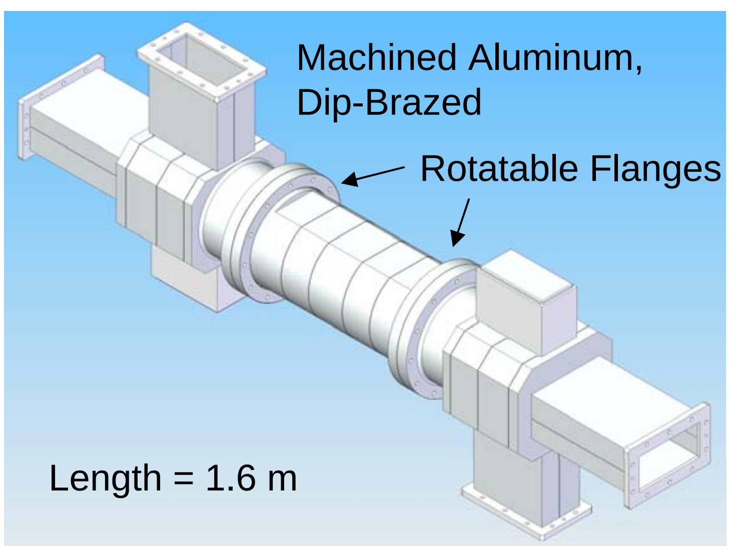


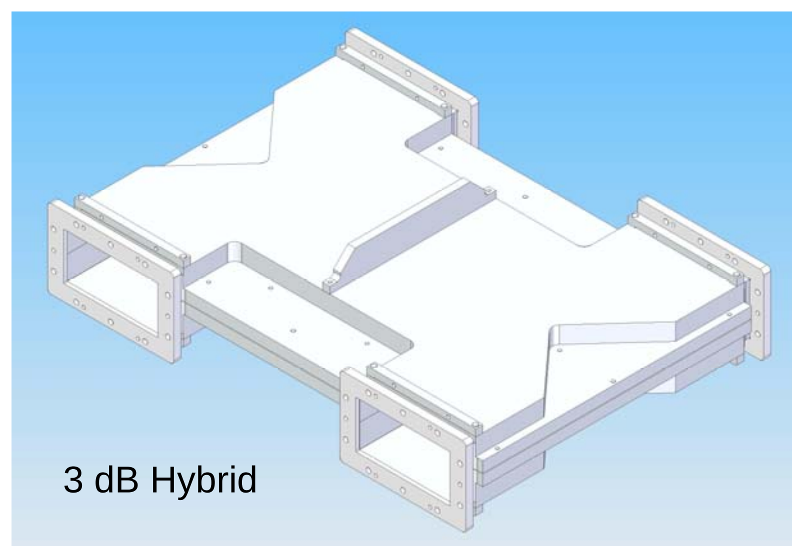
At SLAC, Developing Variable Tap-Offs Using Mode Rotation



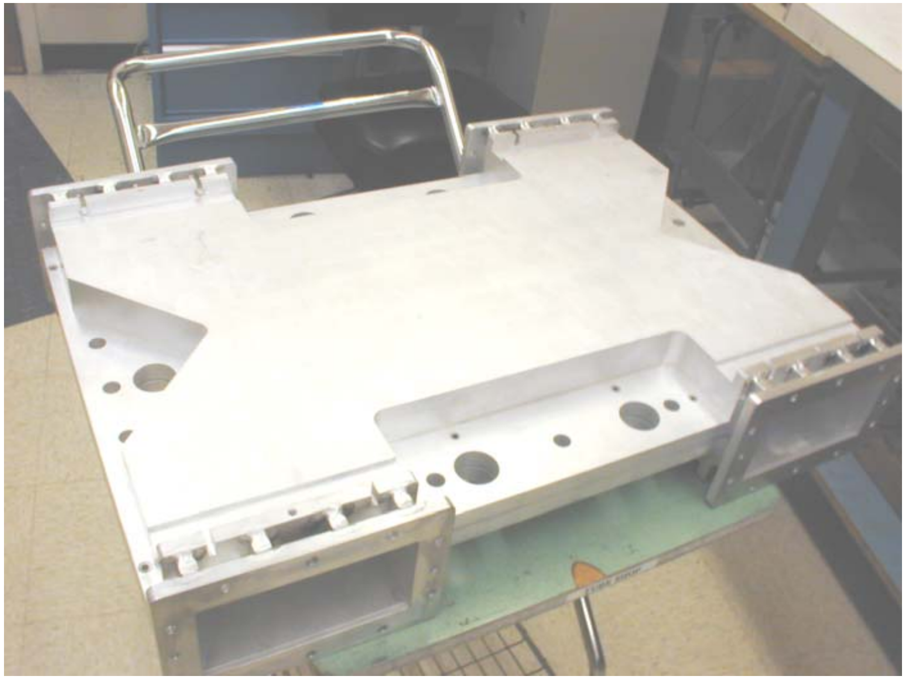
RF Distribution System without Circulators but with Variable Tap-offs (VTOs)

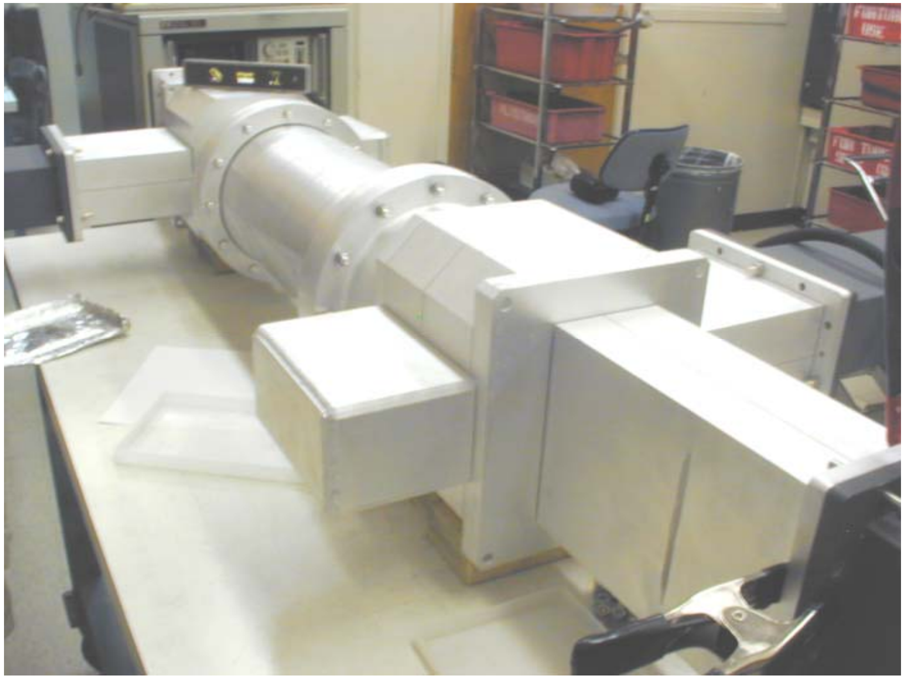


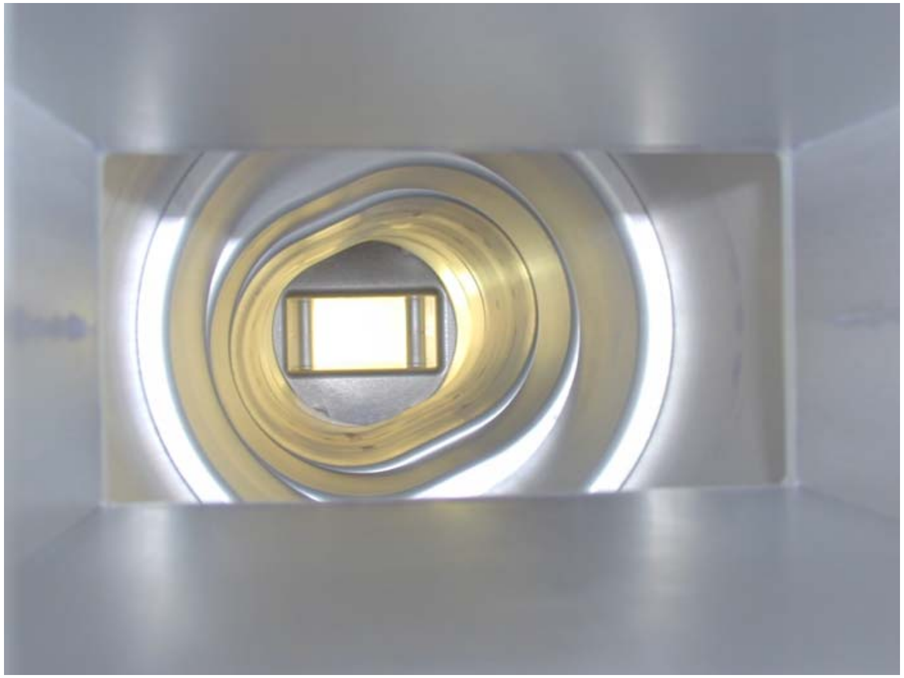




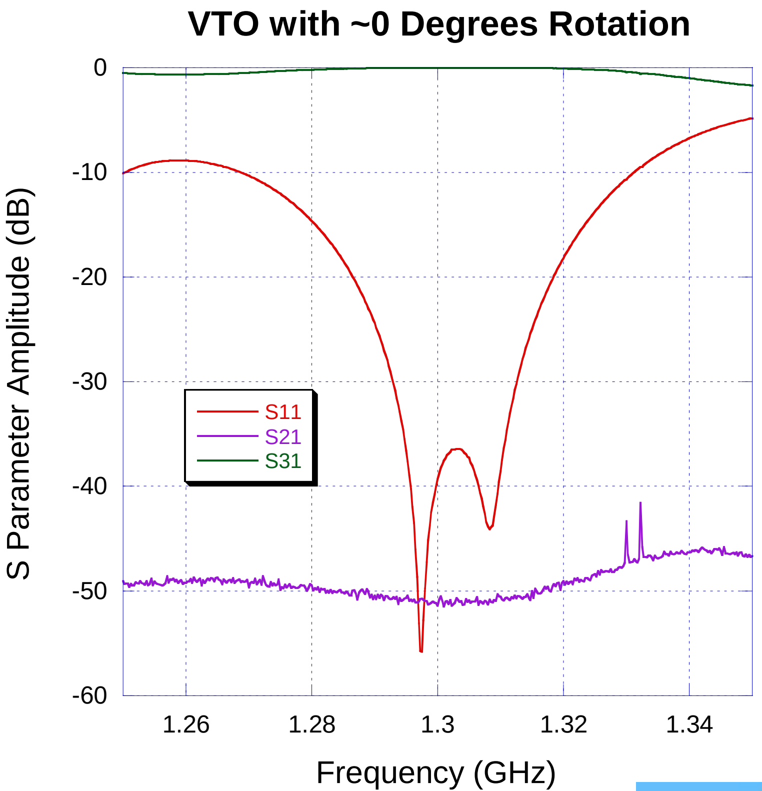
SLAC is building VTOs and custom hybrids and acquiring parts to assemble rf distribution systems for FNAL cryomodules

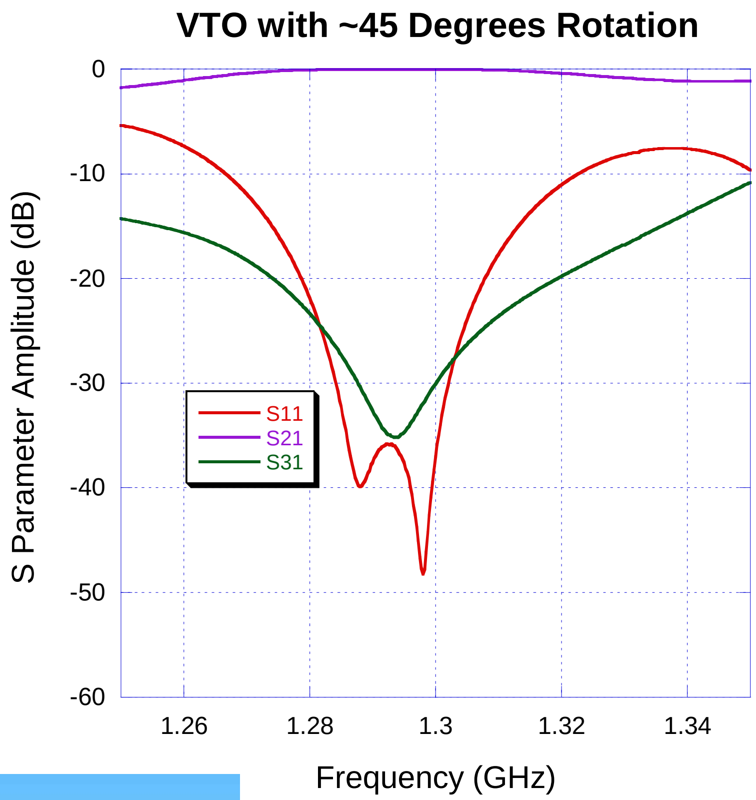


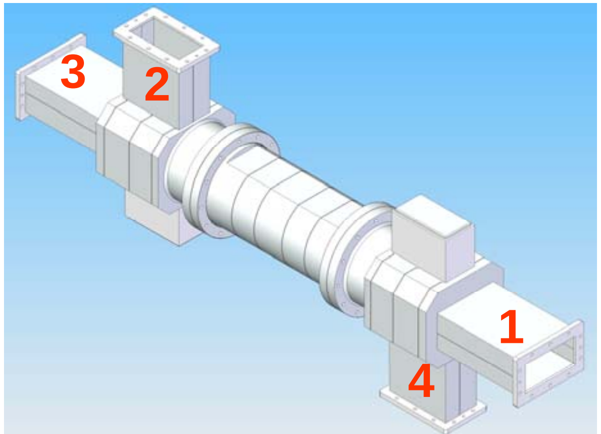




Variable Tap-Off (VTO) Low Power Test







S_{11} = -39.3 dB
S_{21} = -51.4 dB
S_{31} = -0.034 dB

S_{11} = -37.0 dB
S_{21} = -0.030 dB
S_{31} = -30.1 dB

Gradient Optimization with VTOs and Circulators

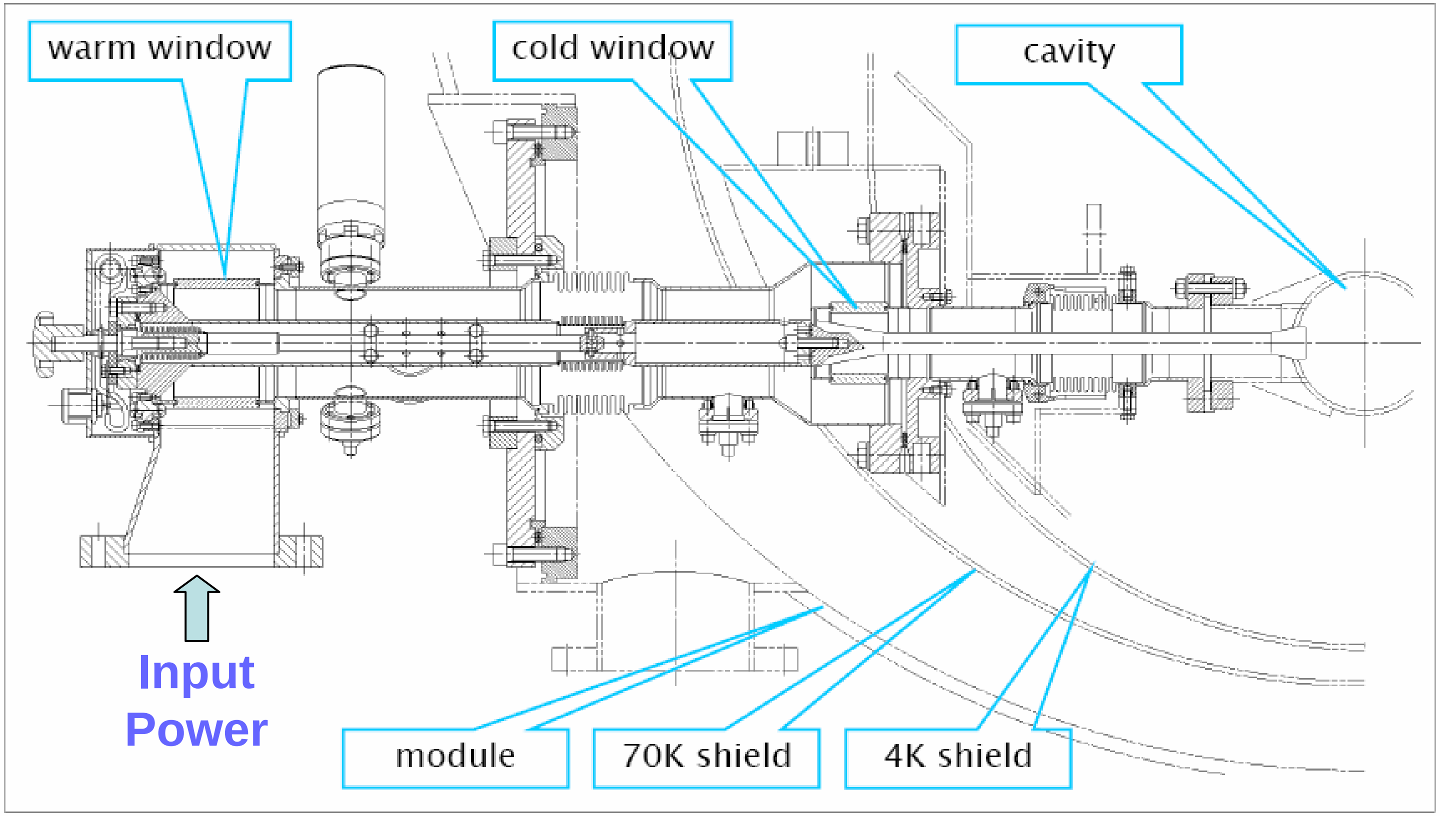
Consider uniform distribution of gradient limits $(G_{lim})_i$ from 22 to 34 MV/m in a 26 cavity rf unit - adjust cavity Q's and/not cavity power (P) to maximize overall gradient while keeping gradient uniform (< 1e-3 rms) during bunch train

Optimized $1 - \langle G \rangle / \langle G_{lim} \rangle$; results for 100 seeds

Case	Not Sorted [%]	Sorted [%]
Individual P's and Q's (VTO and Circ)	0.0	0.0
1 *P*, individual *Q*'s (Circ but no VTO)	2.7 ± 0.4	2.7 ± 0.4
P's in pairs, *Q*'s in pairs (VTO but no Circ)	7.2 ± 1.4	0.8 ± 0.2
1 *P*, *Q*'s in pairs (no VTO, no Circ)	8.8 ± 1.3	3.3 ± 0.5
G_i set to lowest G_{lim} (no VTO, no Circ)	19.8 ± 2.0	19.8 ± 2.0

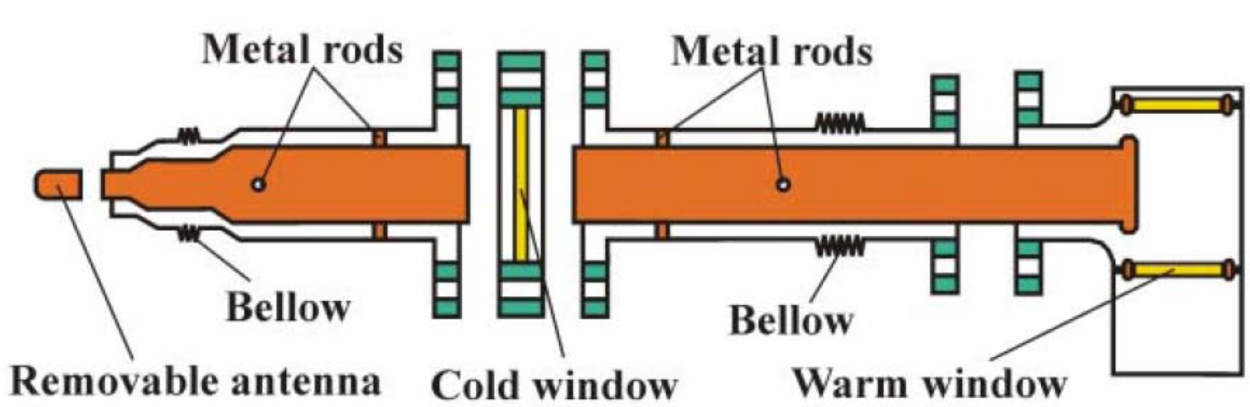
Baseline TTF-3 Coupler Design

Design complicated by need for tunablity (Qext), HV hold-off, dual vacuum windows and bellows for thermal expansion.



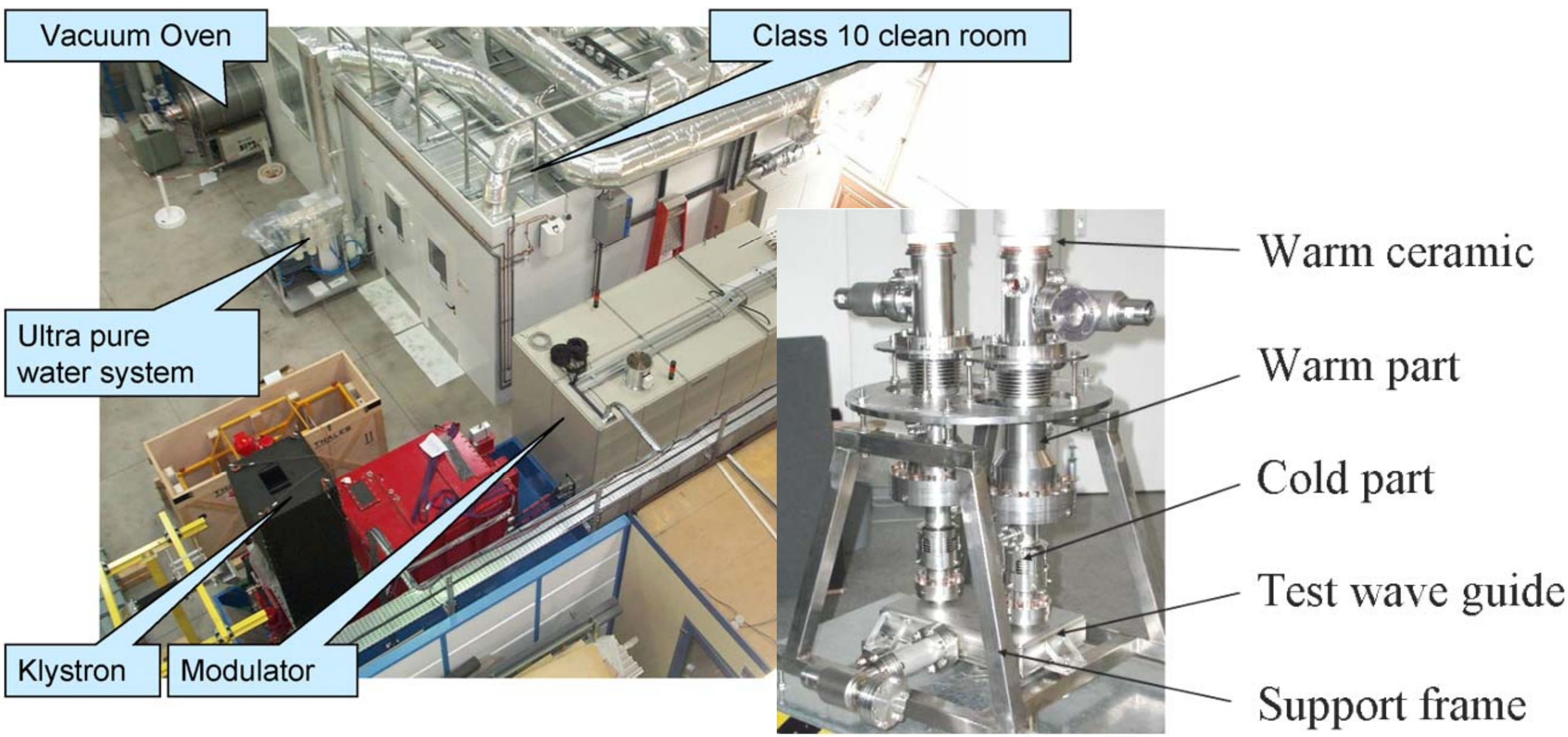
Baseline and Alternative Designs

	Cold Window	Bias-able	Variable Qext	Cold Coax Dia.	# Fabricated
TTF-3	Cylindrical	yes	yes	40 mm	62
KEK2	Capacitive Disk	no	no	40 mm	3
KEK1	Tristan Disk	no	no	60 mm	4
LAL TW60	Disk	possible	possible	62 mm	2
LAL TTF5	Cylindrical	possible	possible	62 mm	2

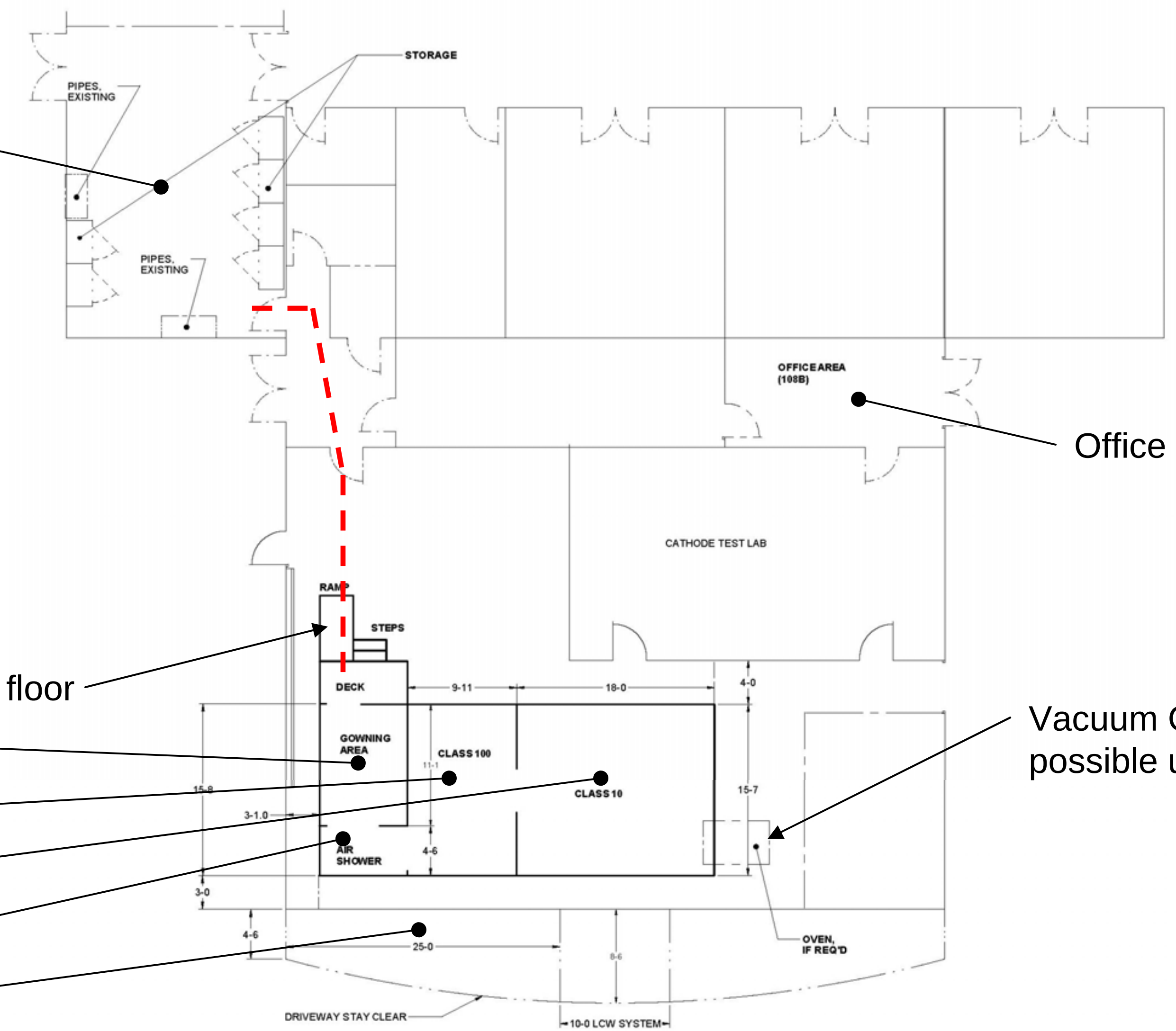


Coupler Assembly and Processing

- Orsay Facilities (shown below) - can process about 30 couplers / yr. Down to ~ 20 hours of rf processing time.
- SLAC building similar assembly facilities to provide FNAL with conditioned TTF-3 couplers.



SLAC Clean Room Layout



Storage Lockers

SLAC Modifications

Eliminate separate material pass-through

More class 10 area

Class 1000 => 100

Remote vacuum bake

Office Space

Ramp – if raised floor

Gowning Area

Class 100

Class 10

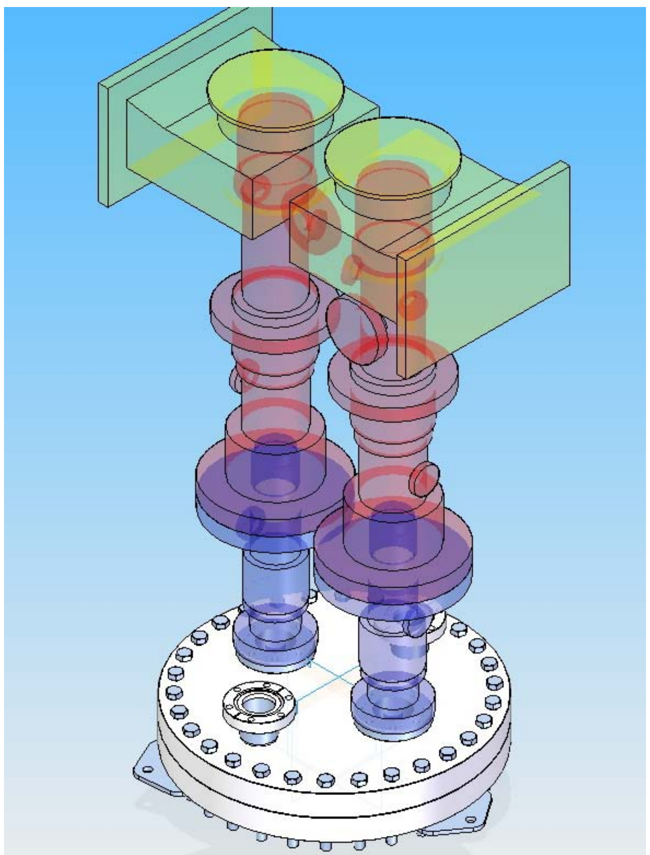
Air Shower

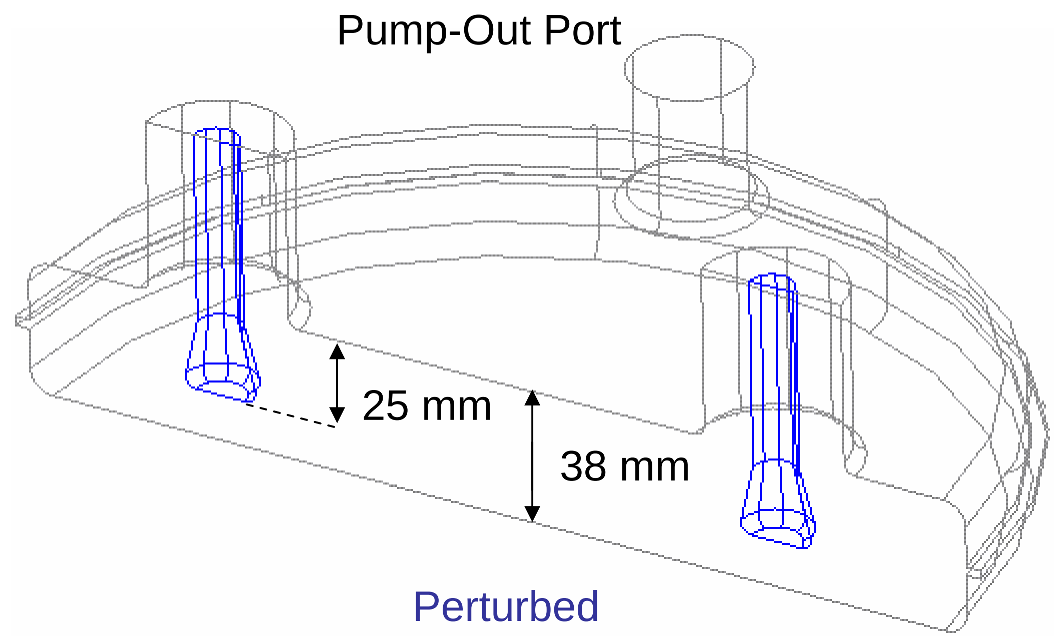
Air Handling System

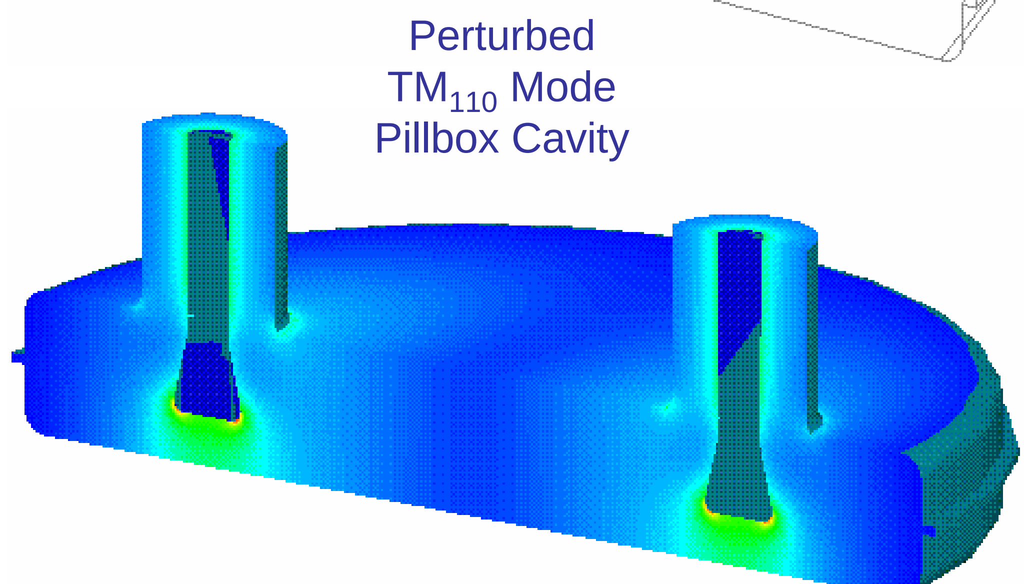
Vacuum Oven – possible upgrade

SLAC Coupler Connection Cavity

Opens fully for cleaning compared to enclosed Orsay design, and does not use indium seals as in KEK split-WG design

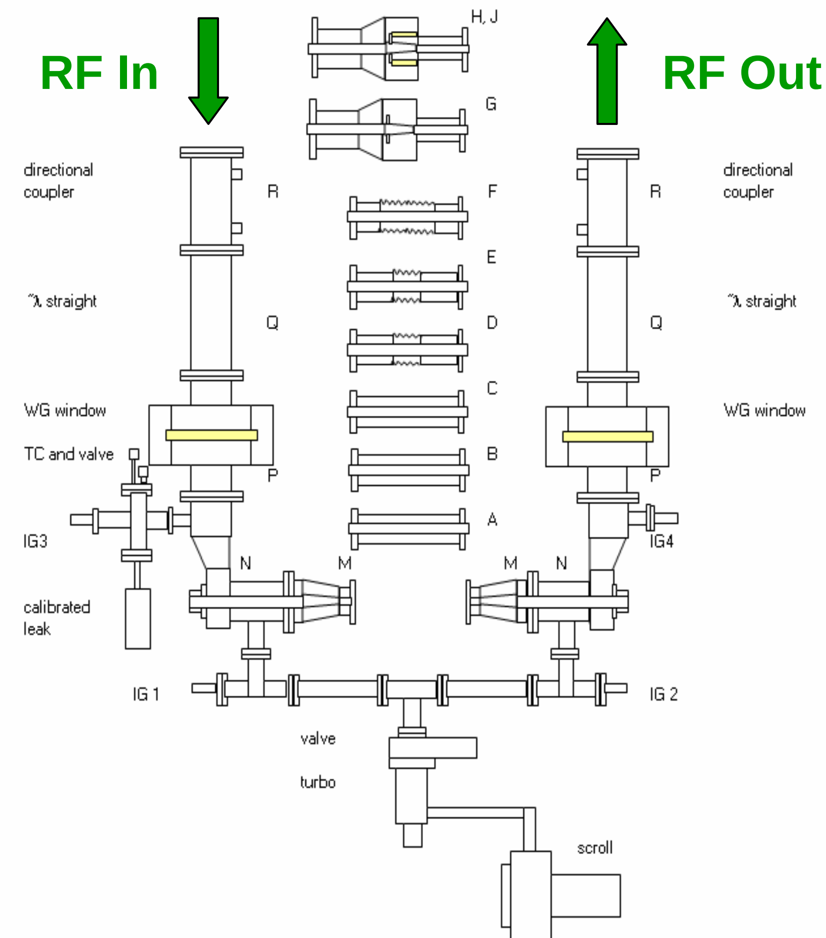


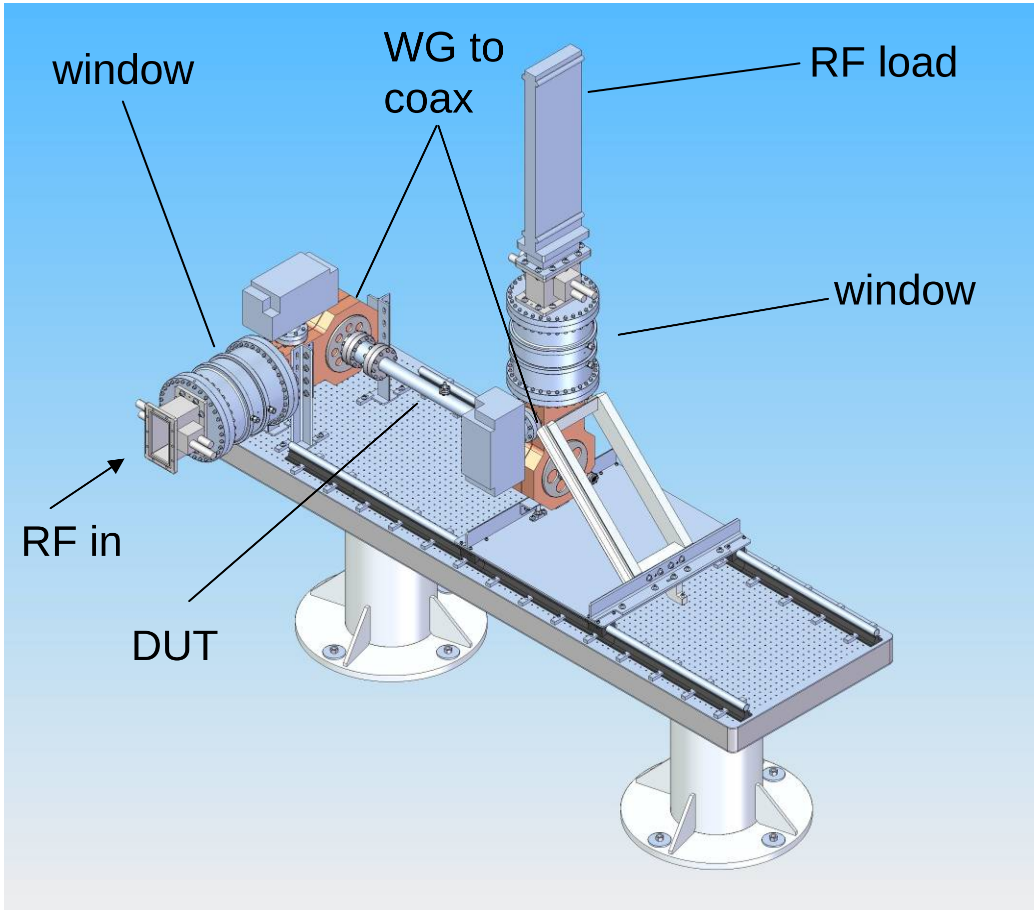




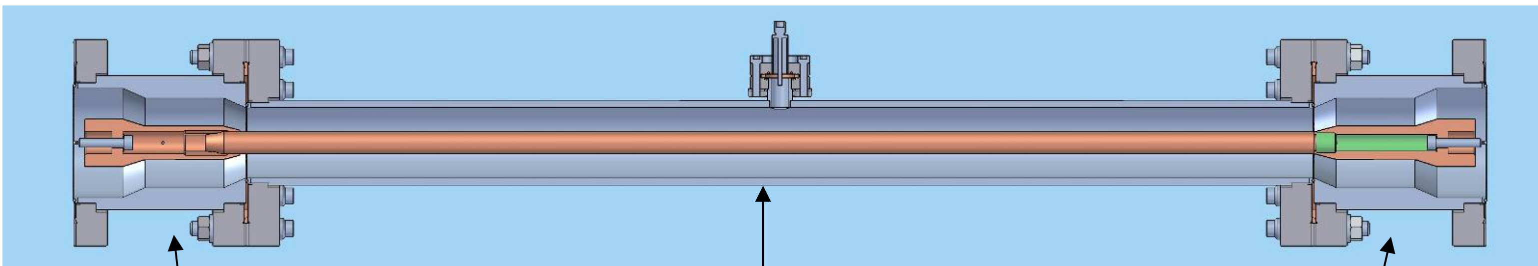
Coupler Component Test Stand
(SLAC / LLNL)

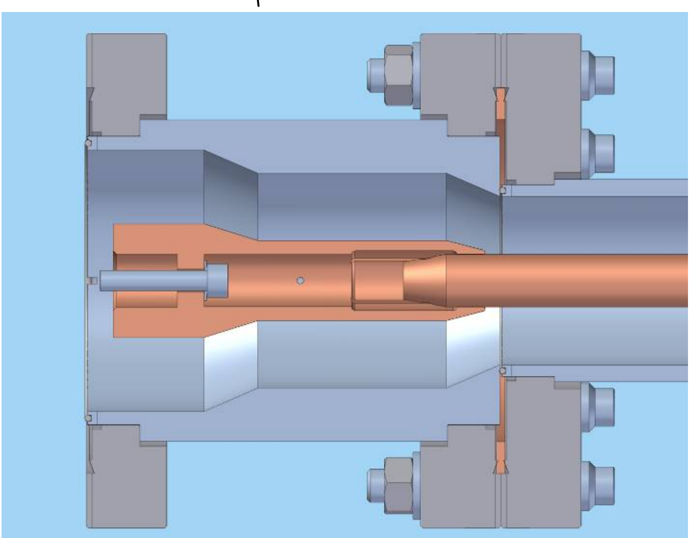
Facility assembled and operating – initially testing 600 mm long, 40 mm diameter stainless-steel coaxial section



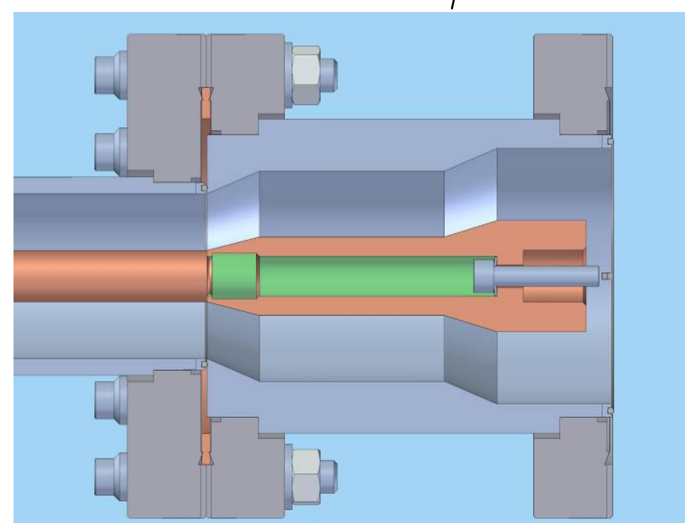


A Reliable Center Conductor Mating Scheme was Developed





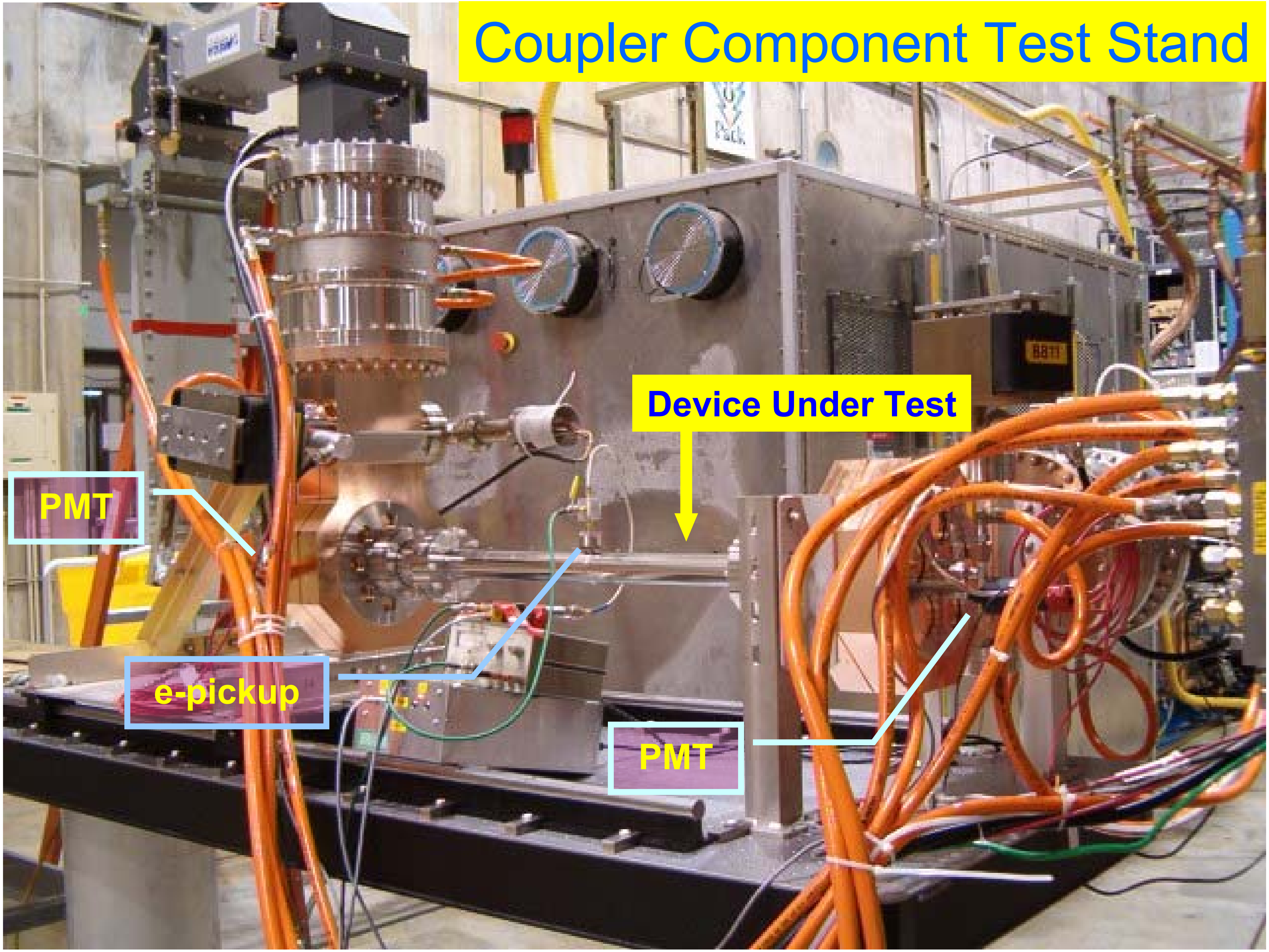
Outer conductor wall of the Device Under Test (DUT)



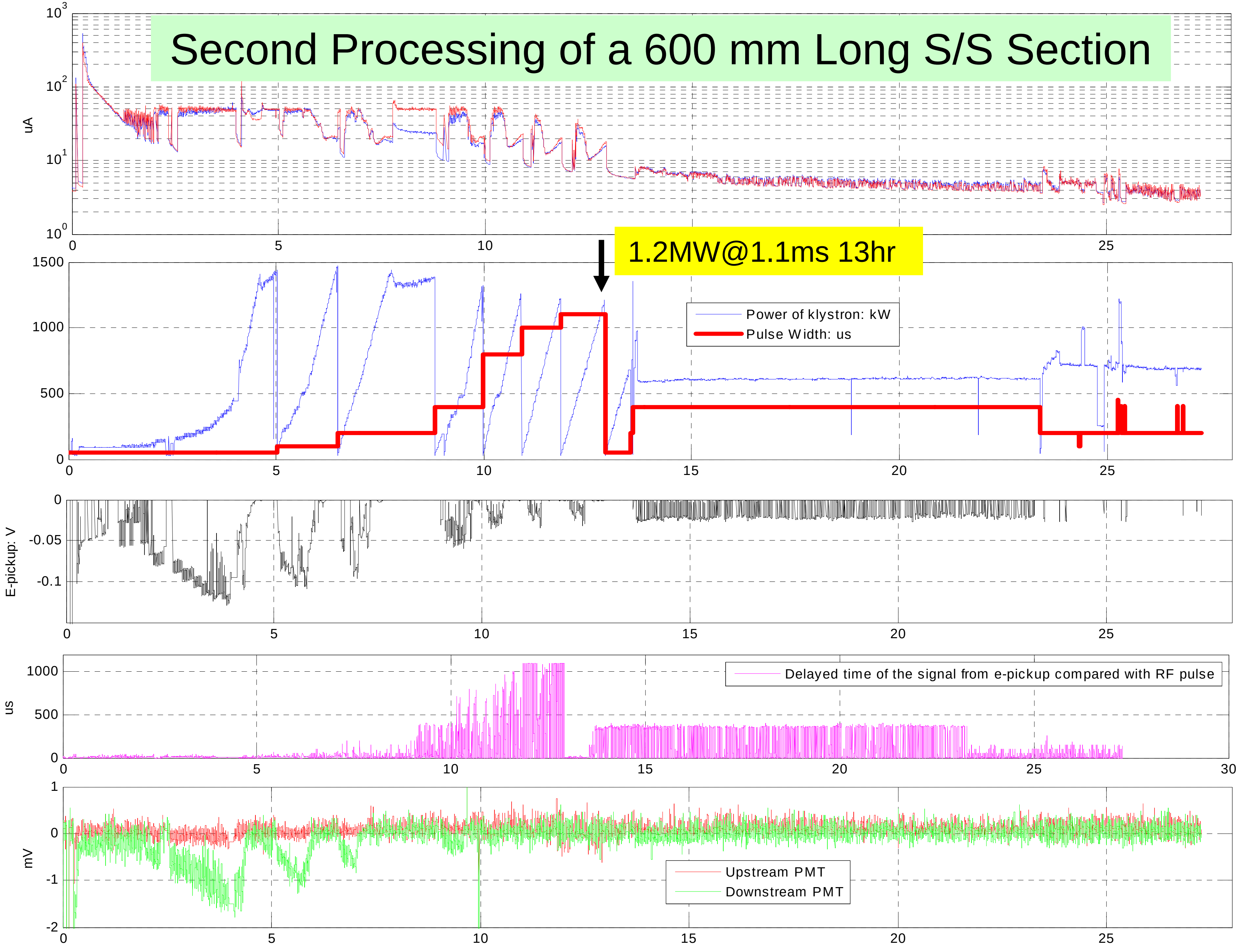
Slip-fit side to accommodate expansion

Threaded anchor side

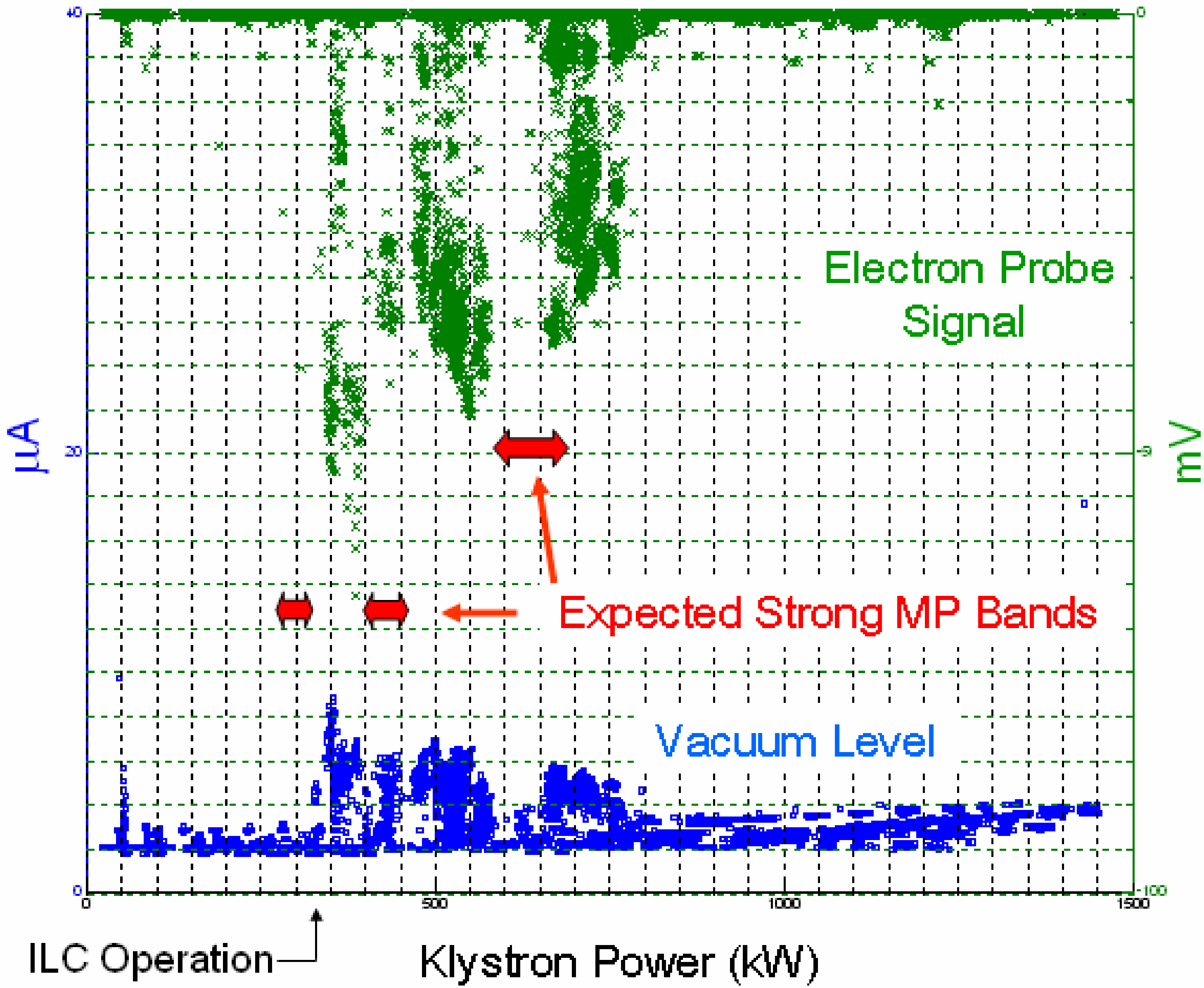
Coupler Component Test Stand



Second Processing of a 600 mm Long S/S Section



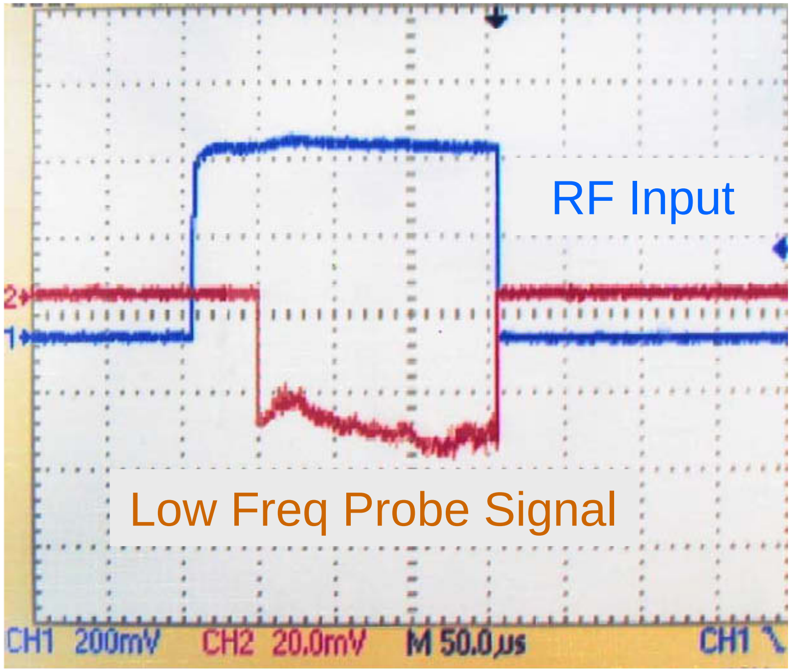
Evidence of Multipacting after Initial Processing



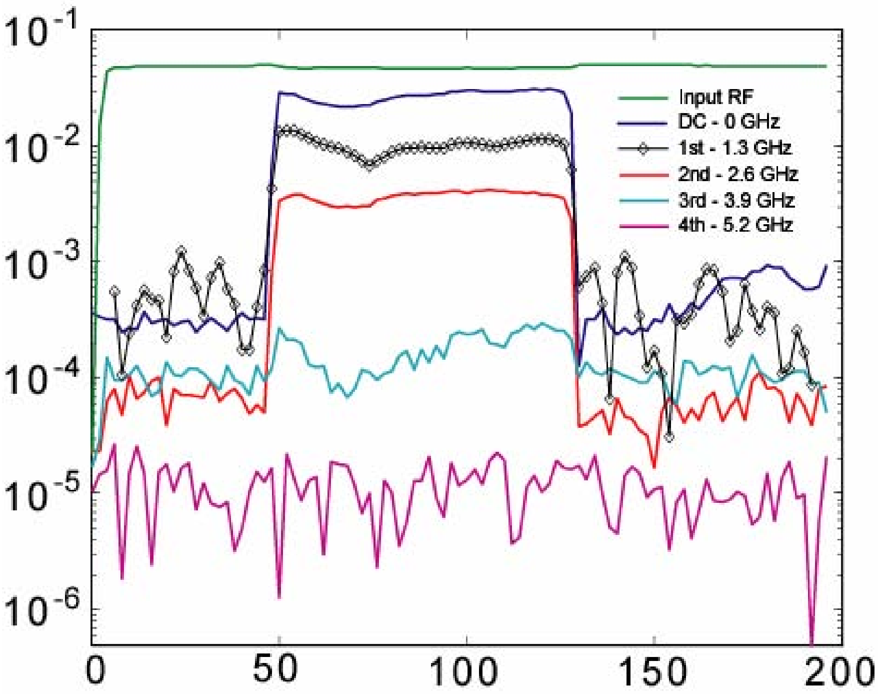
Electron Probe Signal

- Signal has delayed turn-on wrt to rf pulse that varies over time (delay time shortens in presence of magnetic field or high power spike).
- Shape changes with power, amplitude correlated with pressure level.
- After processing, signal becomes small and unstable, sometimes disappearing for long periods.

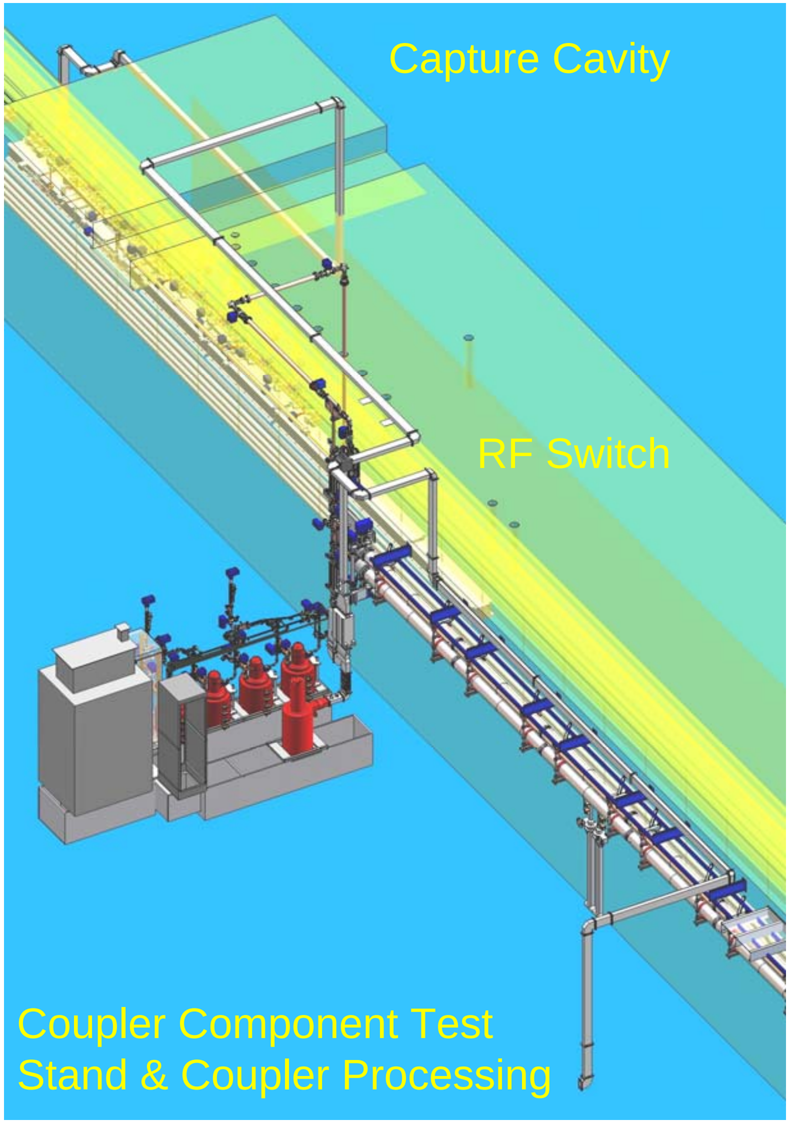
Waveforms
(50 μs / division)



Harmonic (1.3 GHz) Content
Relative Amp -vs- Time (μs)

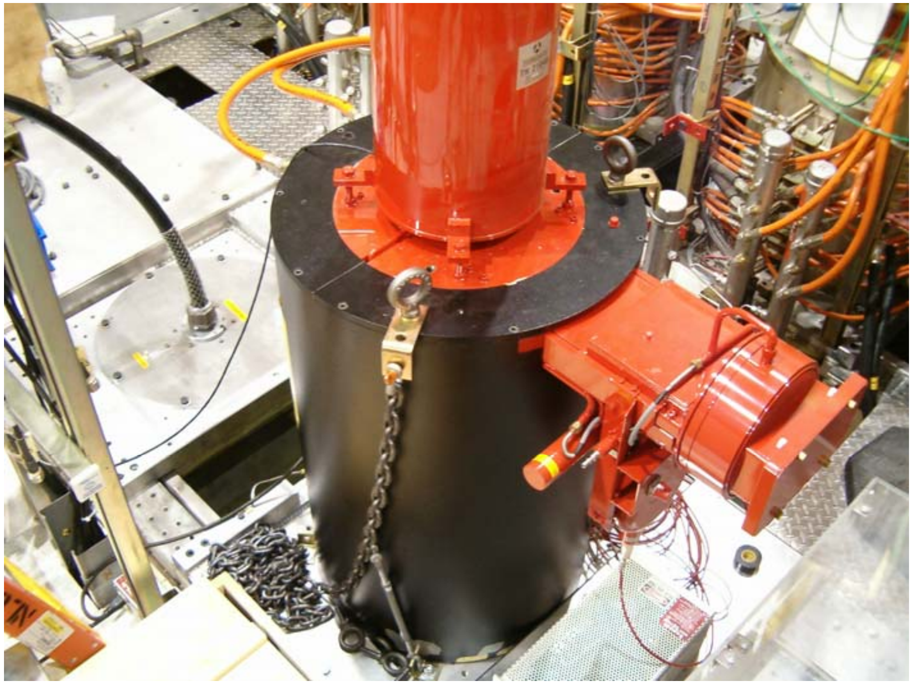


Current SLAC L-Band Test Stand



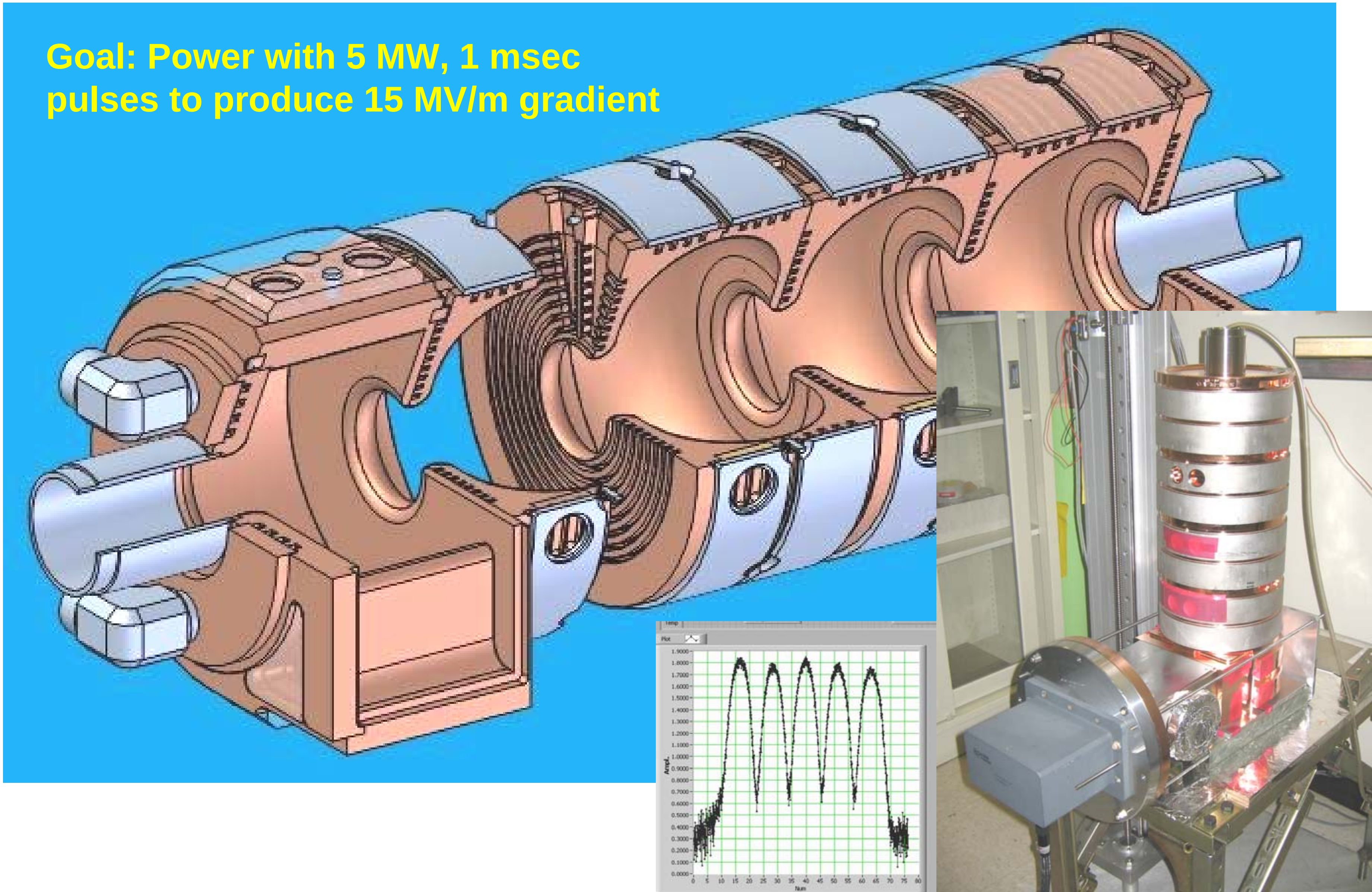
Produces 5 MW, 1.4 msec pulses at 5 Hz with a TH2104C klystron and a SNS-type modulator

Source powers a coupler test stand and a normal-conducting ILC e+ capture cavity

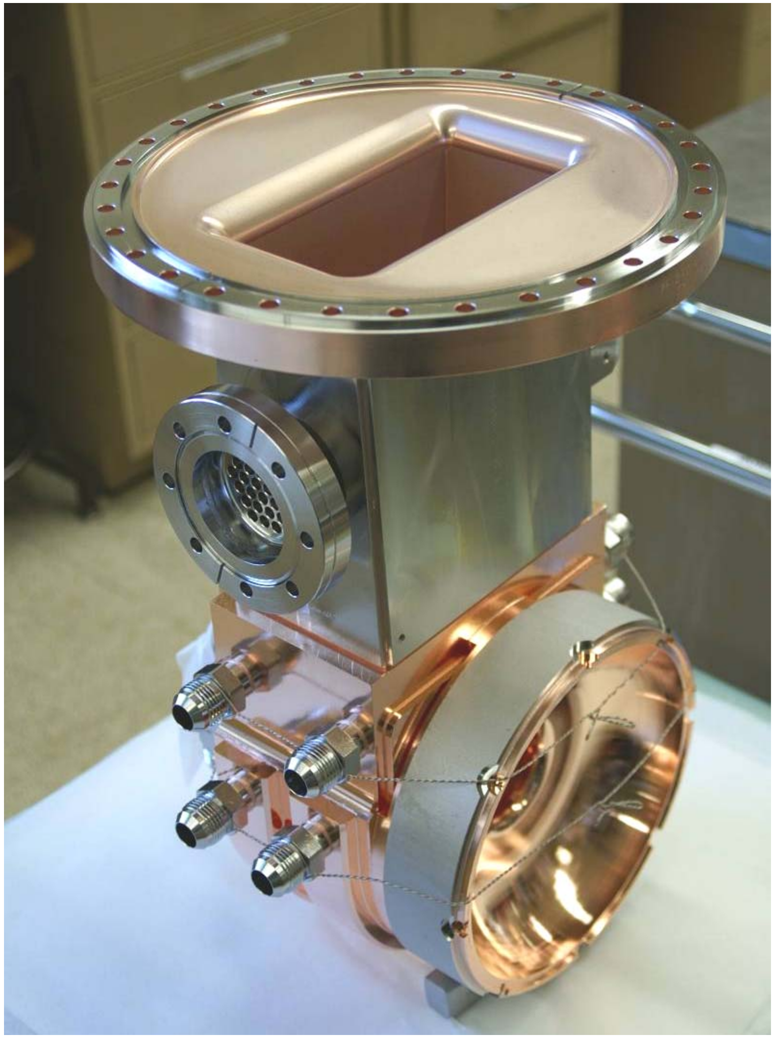


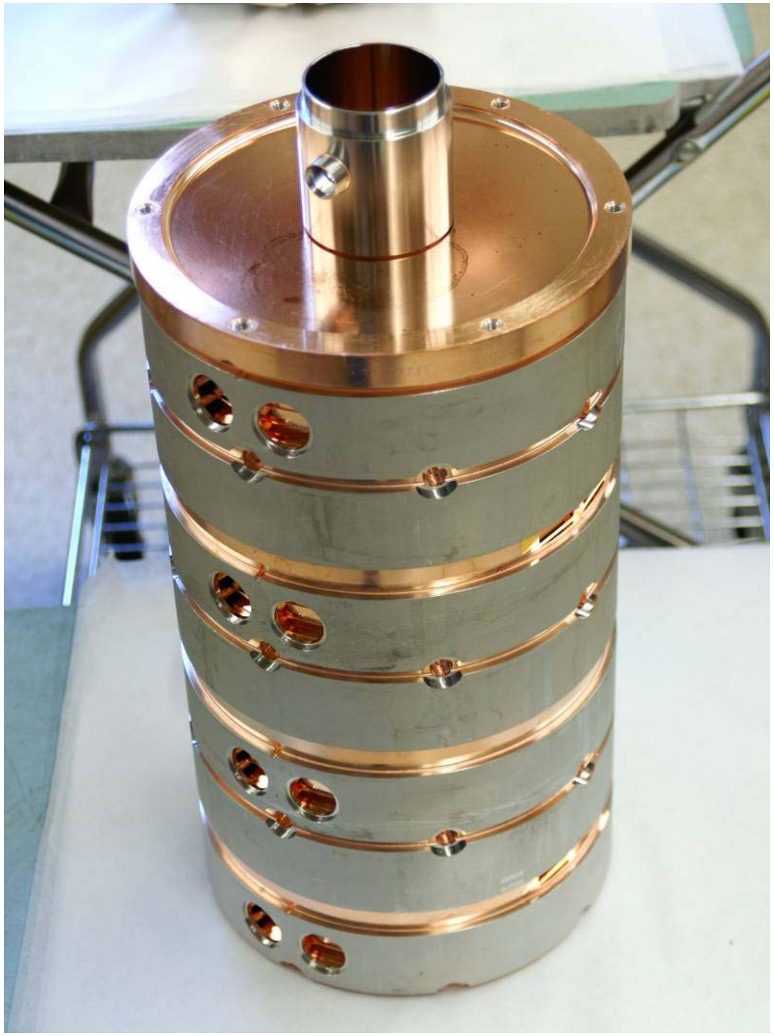
ILC Positron Capture Cavity Prototype

Goal: Power with 5 MW, 1 msec pulses to produce 15 MV/m gradient



Brazed Coupler and Body Subassemblies Ready for Final Brazing



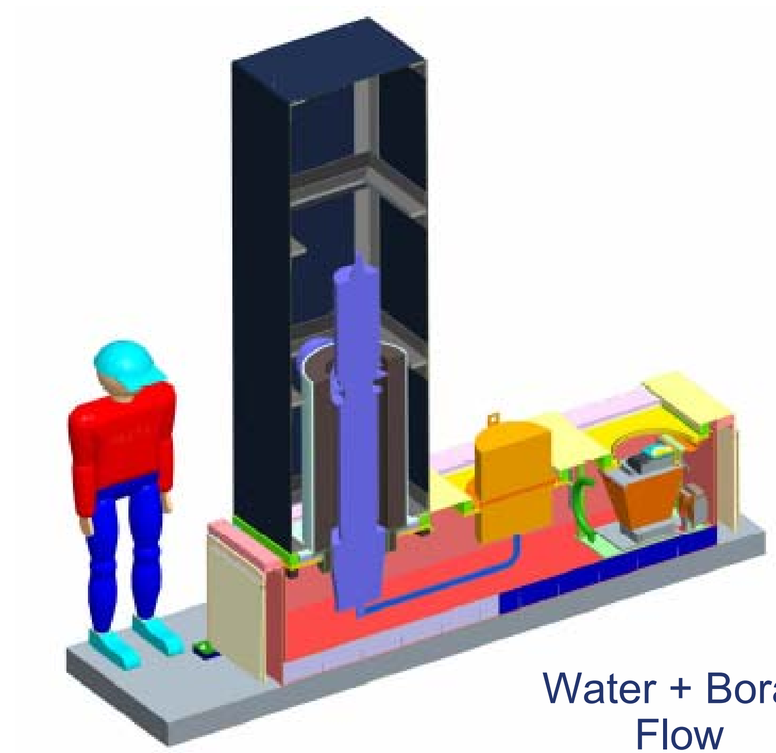


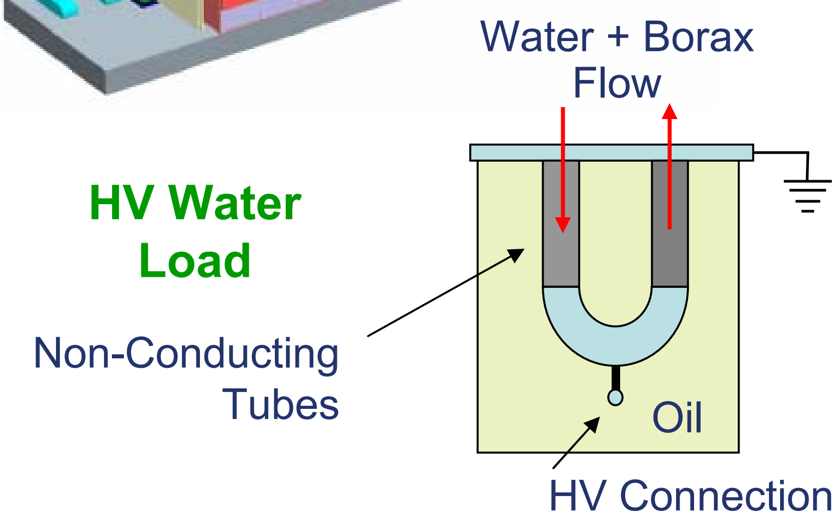
Two New L-Band Test Stands

Each new test stand will have

- Modulator with Charging Power Supply
- Oil Tank with
  - HV Water Load
  - Filament PS Transformer
  - Klystron Socket
- Instrumentation and Controls

Will run independently, 24/7, with summary data archived for trends, detailed data for faults.





FY08-09 SLAC Deliverables

- Design-for-Manufacturability Marx (start in FY07)
- 6 Modulator Production Units
- Toshiba10 MW MBKs (purchased in FY07)
- Sheet Beam Klystron (started in FY07)
- 6 Klystron Production Units
- 5 RF Distribution Systems to FNAL (1 in FY07)
- 60 Processed Couplers to FNAL (12 starting in FY07)
- Coupler Development and Prototypes
- 5 Production RF Sources Operating at SLAC (1 at FNAL)

RF System Summary

- SLAC pursuing alternate designs while XFEL concentrating more on baseline approaches.
- Marx Modulator approach looks promising.
- First Toshiba 10 MW MBK successful, Thales tubes have run tens of khour, design evolved to correct problems. Horizontal versions being developed.
- A sheet beam klystron is being built that is more compact, lighter and likely less expensive than the MBK.
- Evaluating various rf distribution approaches to lower system cost and maximize useable gradient.
- US program ramping up, includes coupler development.