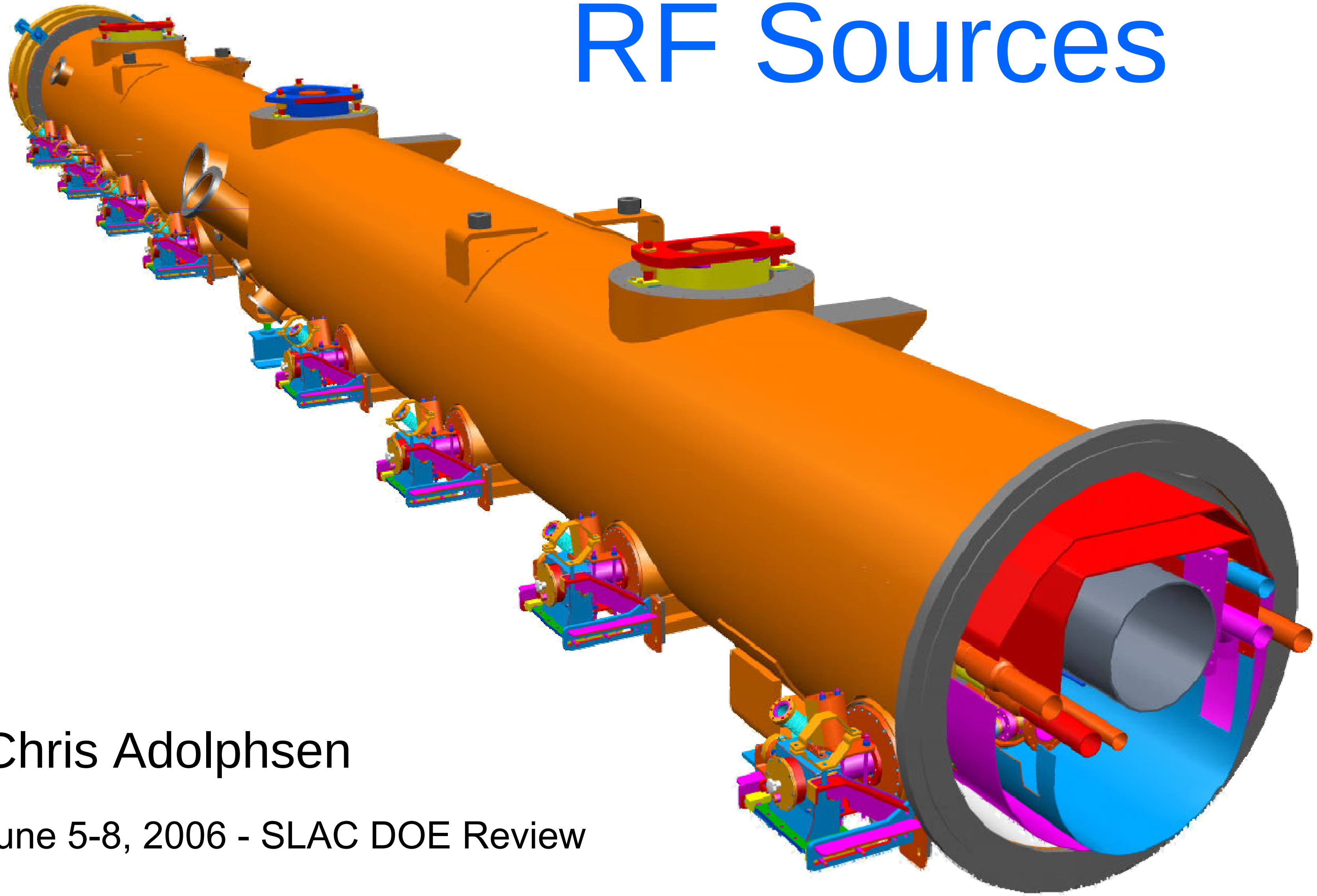
Main Linac and RF Sources



Chris Adolphsen

June 5-8, 2006 - SLAC DOE Review

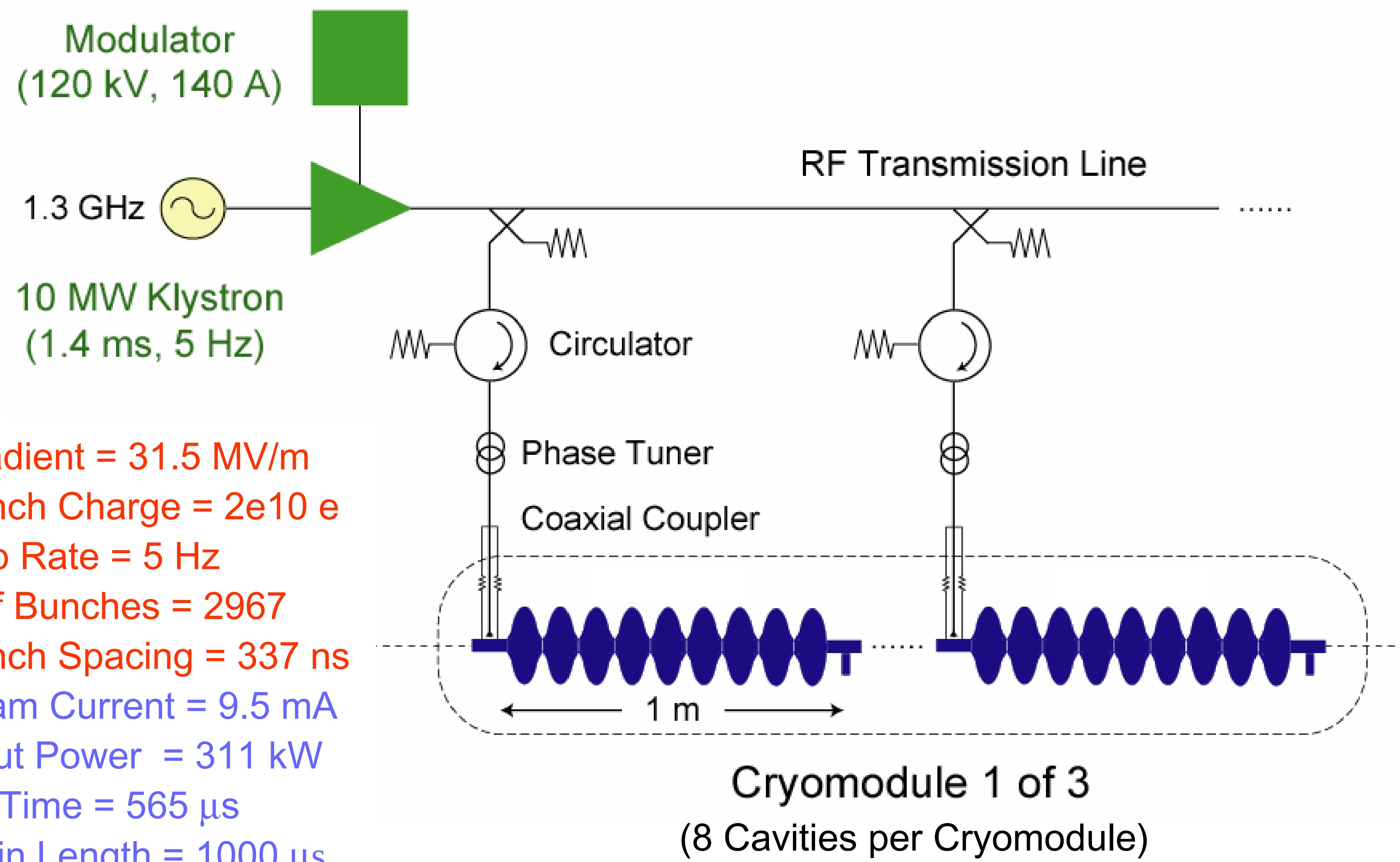
Linac Baseline Design

- August 05 Snowmass
  - Two weeks of talks/discussions on linac design, from which distilled recommendations for the Baseline Configuration Document (BCD), including alternatives, in the following few months.
  - Organized around working groups started after ITRP (WG2 + WG5 cover the linac)
  - GDE organization kick-off, one year after ITRP decision.
- December 05 – Frascati
  - Major design decisions finalized (further changes under Change Control Board). Linac design very similar to that in 2001 TESLA TDR.
  - RDR (Reference Design Report) effort started – this is a more detailed design including costs, to be completed by end of 06.
  - Reorganize around Area Systems (e.g., Main Linac), Technical Groups (e.g., RF Power) and Global Groups (e.g., Control System)

Toward the RDR

- Jan 06 KEK
  - Meeting of Area Systems Leaders – review status of Main Linac rf unit design.
- February 06 FNAL
  - RDR Meeting - Technical and Global Groups present plans.
- March 06 Bangalore
  - GDE meeting - begin costing discussions, organized by Design and Cost Engineering group
- May 06 DESY
  - Meeting on Linac costing progress – SLAC focusing on rf system costs for the linac.
- July 06 Vancouver
  - First pass at rolling up the ILC cost

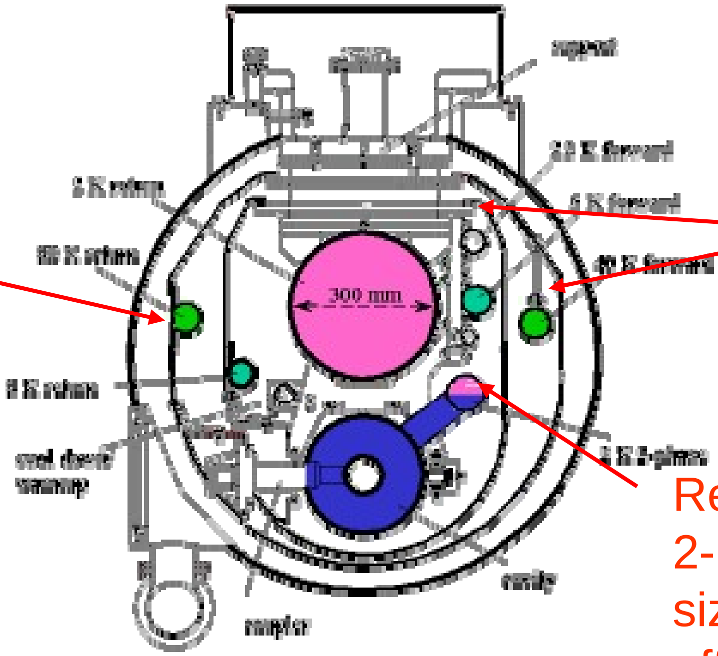
ILC Linac RF Unit (1 of ~ 600)



Gradient = 31.5 MV/m
Bunch Charge = 2e10 e
Rep Rate = 5 Hz
# of Bunches = 2967
Bunch Spacing = 337 ns
Beam Current = 9.5 mA
Input Power = 311 kW
Fill Time = 565 μs
Train Length = 1000 μs

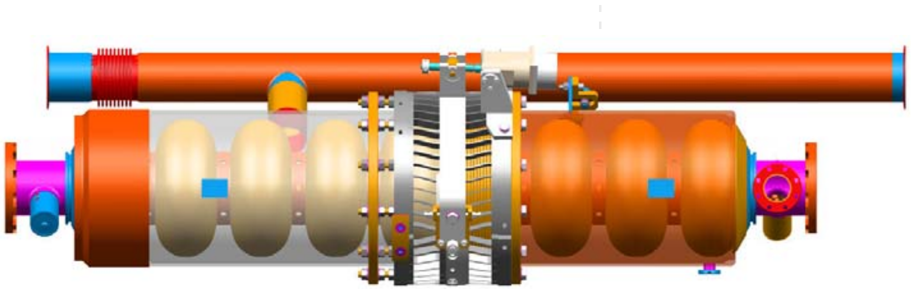
Cryomodule Design

Increase diameter beyond XFEL

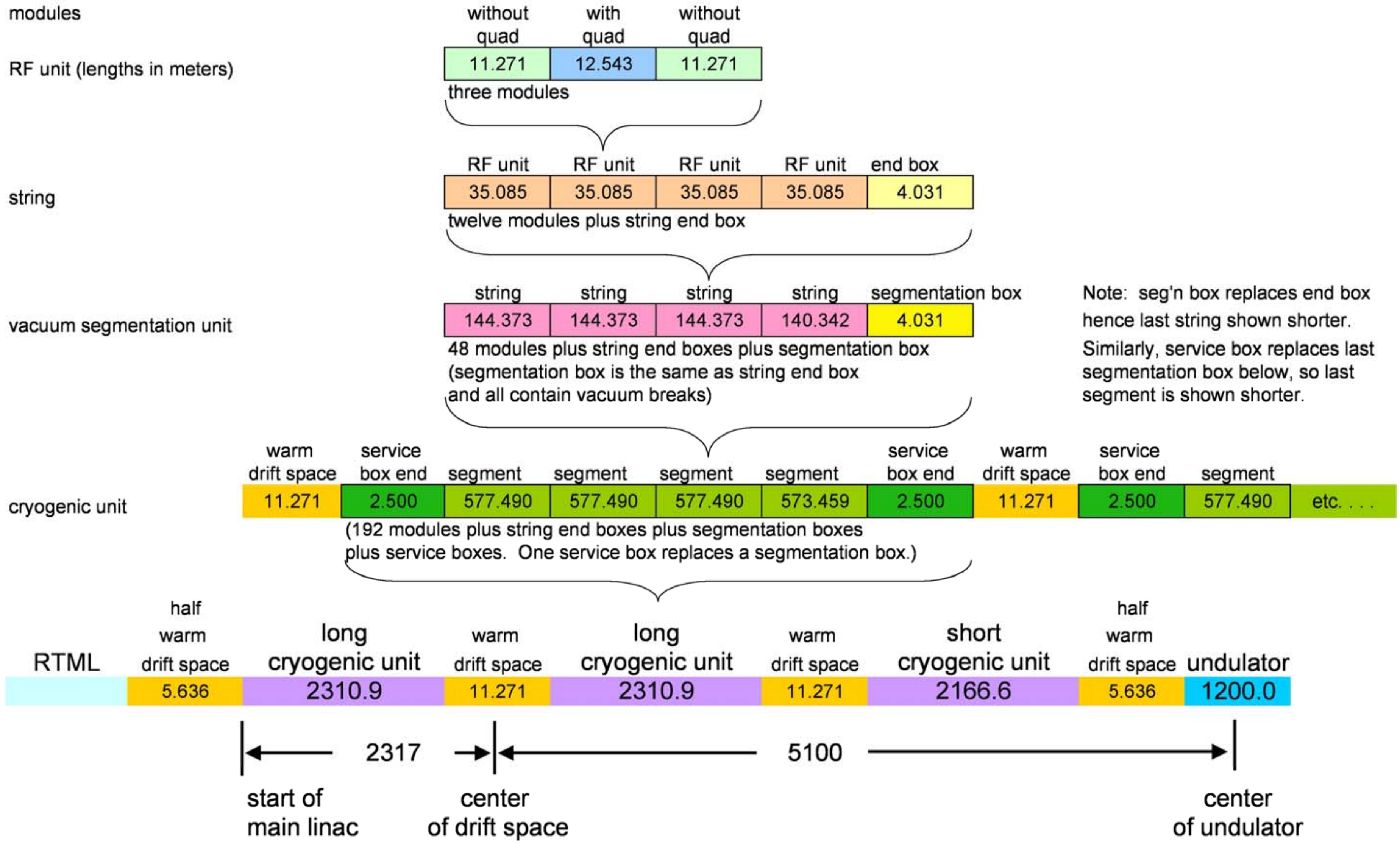


Increase diameter beyond XFEL

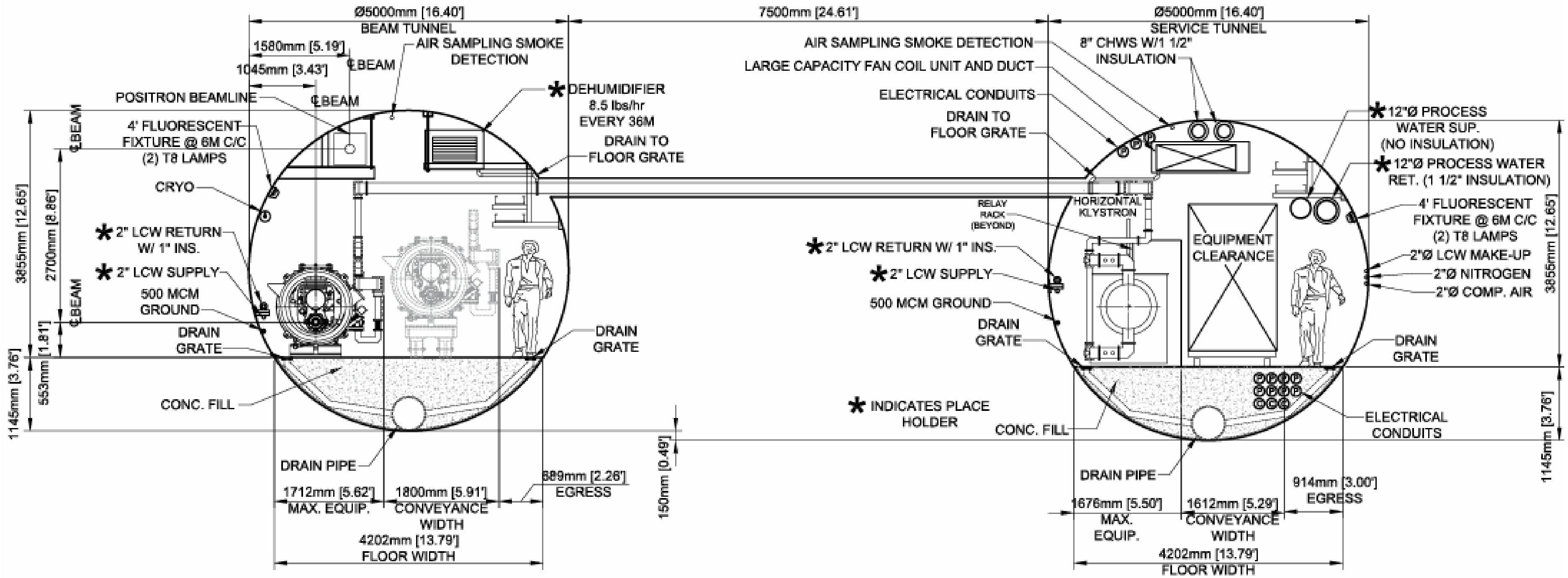
Review 2-phase pipe size and effect of slope

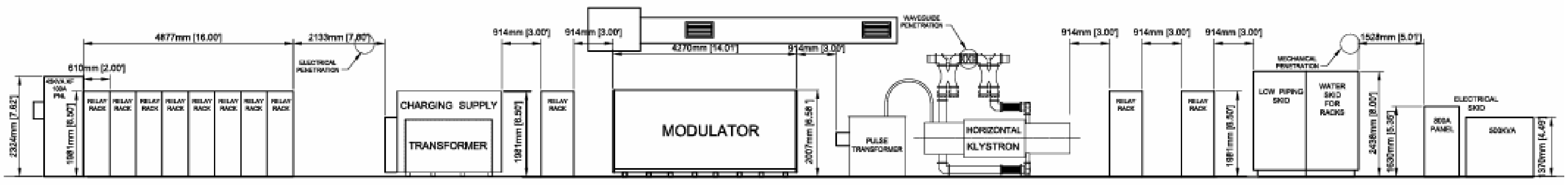


Cryomodule Layout



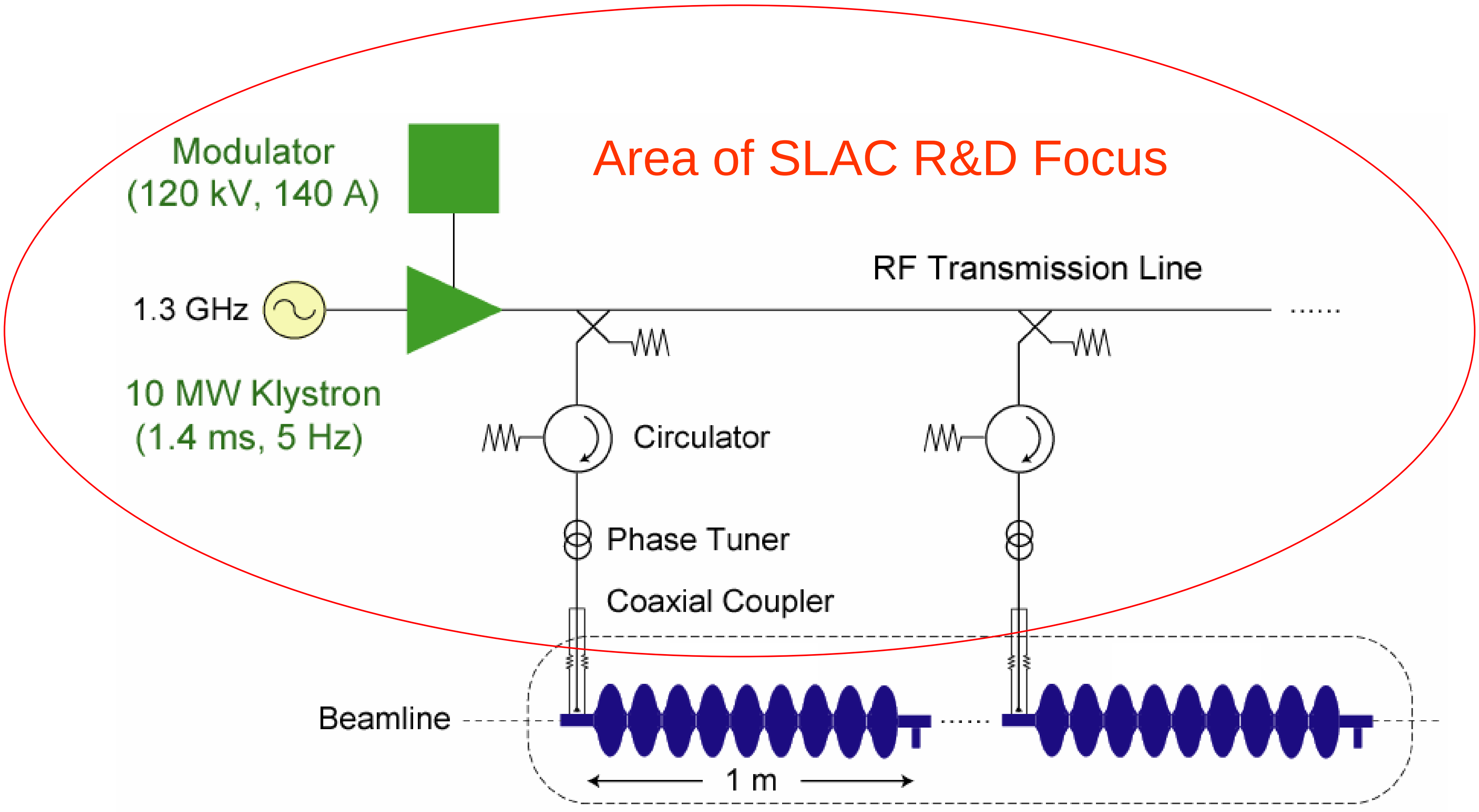
Tunnel Layout
(5 m Diameter)





Service Tunnel Elevation View – One RF Unit (36 m)

ILC Linac RF Unit (1 of ~ 600)

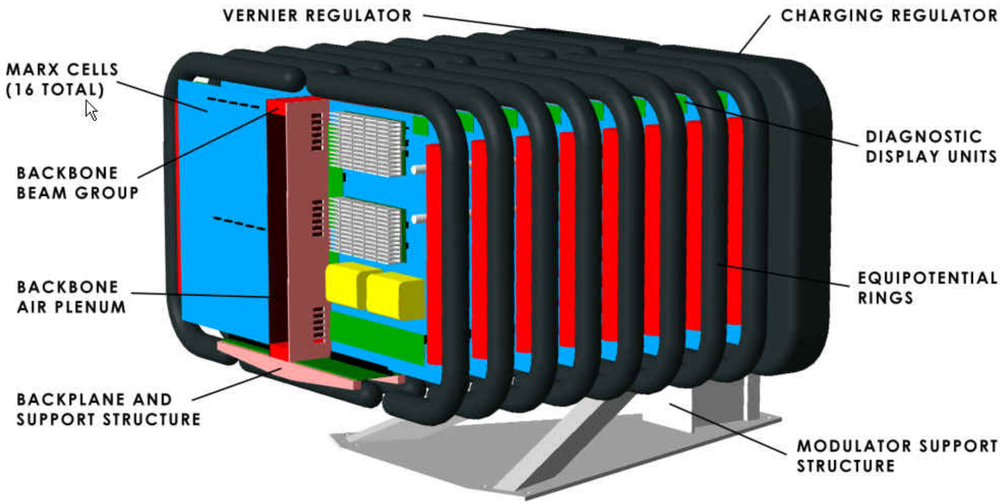


Cryomodule 1 of 3
(8 Cavities per Cryomodule)

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 Features

- Direct-coupled voltage stack of ten 12-kV cells producing 140A pk @ 1.6 msec.
- Cell can operate with failed components.
  - 4/5 redundant solid state output, re-charging switch banks.
- Modulator functions with up to 2 failed drivers
  - 10 needed, 12 available
- Vernier cells correct flat top to +/-0.5%.
  - Second stage correction also being studied to approach +/-0.1% if possible.
- Buck regulators (2) have 4/5 switch redundancy

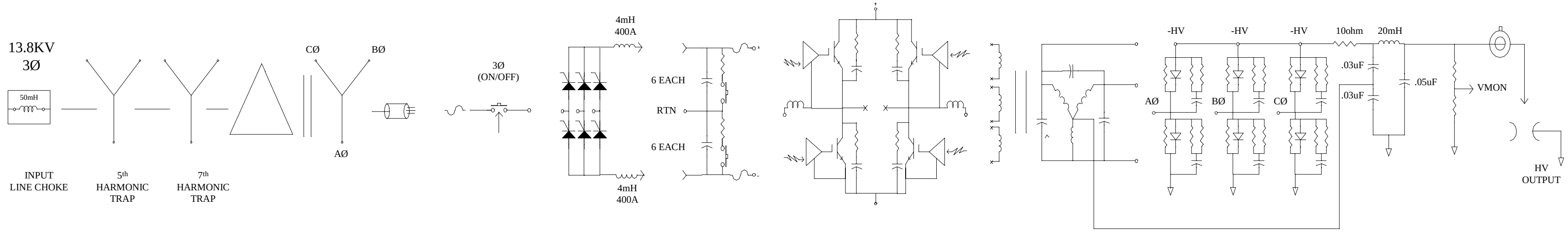
Marx Modulator Status

- 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.
- PPS system for modulator 30% complete
- Air cooled 150 kW test load 50% complete

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



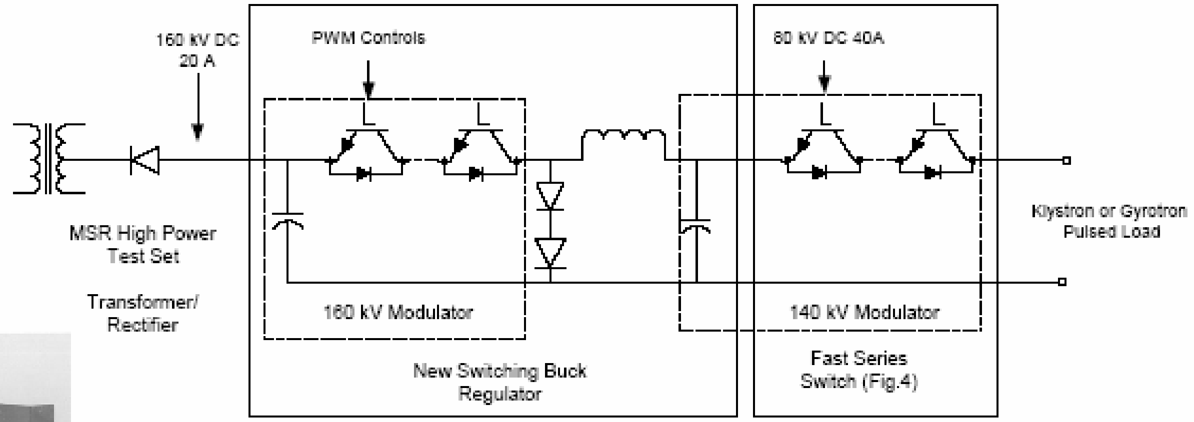
RECTIFIER TRANSFORMER AND FILTERS

SCR REGULATOR

HVCM

EQUIPMENT CONTROL RACK

Series Switch Modulator
(Diversified Technologies, Inc.)



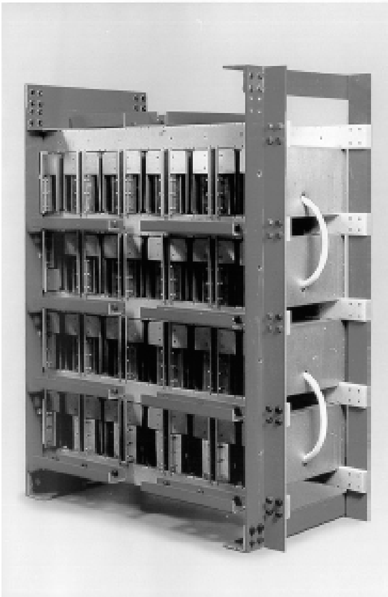


Figure 2. 140kV, 500A solid-state switch

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

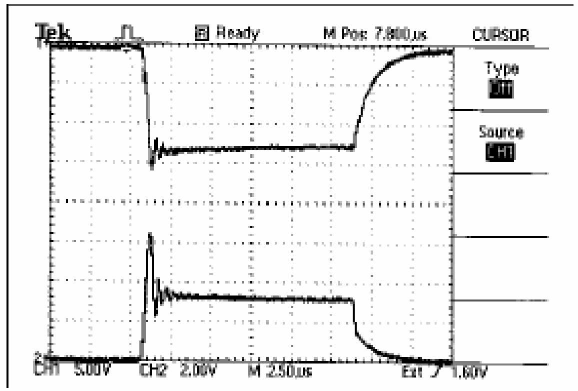


Figure 3: Test pulse (140 kV, 160 A, 13 µsec) of solid-state modulator. Upper trace is voltage at 63 kV/division. Lower trace is current at 100 A/division

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

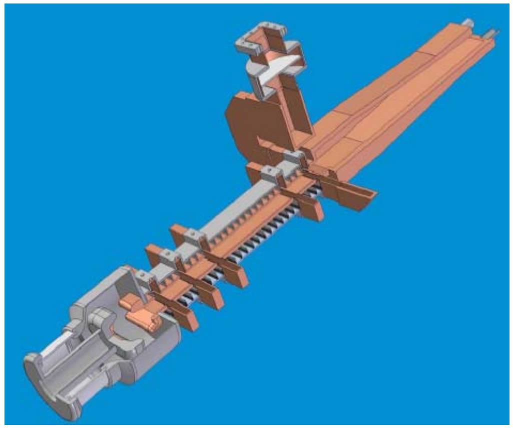
Status of the 10 MW MBKs

- 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 will be tested again.
- Toshiba: One tube built, and after vacuum problem fixed, ran at full spec for one day – has been shipped to DESY for further evaluation.
- These are vertically mounted tubes – DESY recently asked for bids on horizontally mounted tubes for XFEL (also needed for ILC).

Alternative Tube Designs

10 MW Sheet Beam Klystron (SBK)

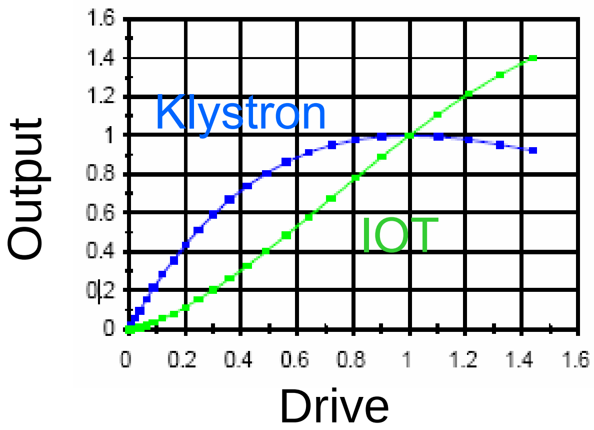
Parameters similar to 10 MW MBK



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

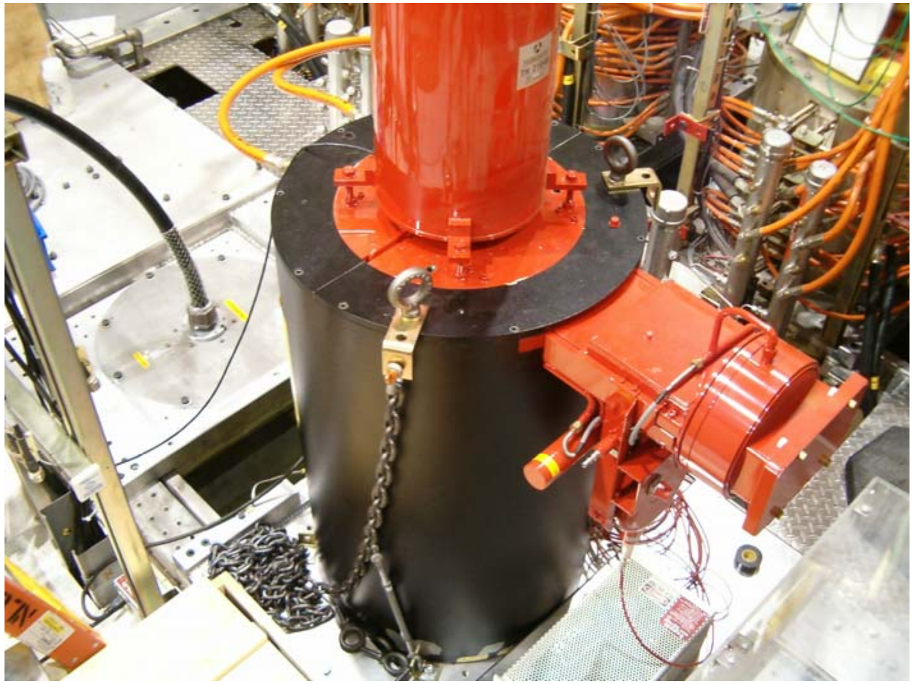
Voltage 65 kV
Current 238A
More beams

Perhaps use a Direct Switch Modulator

KEK

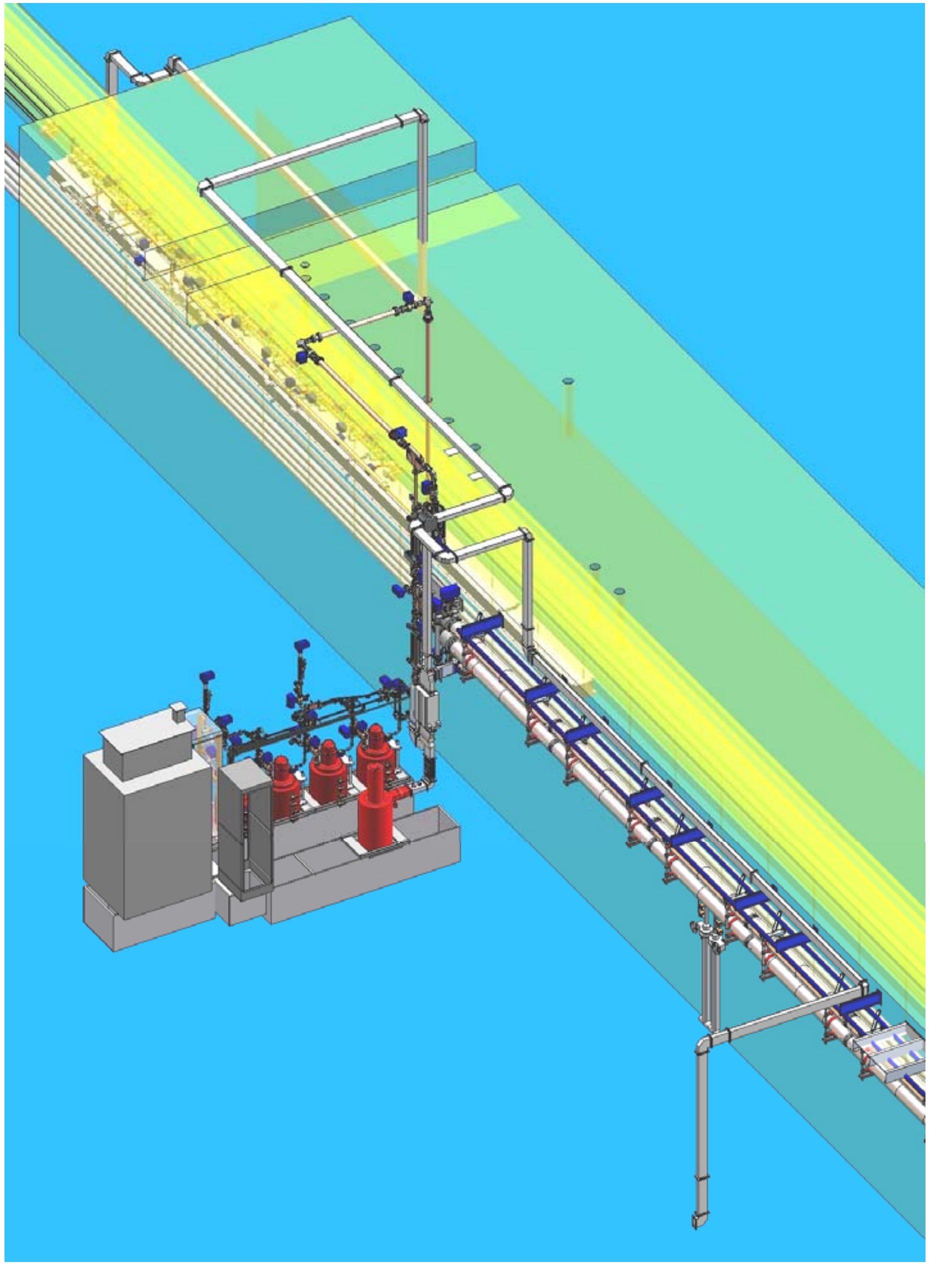
FY06 Klystron Program

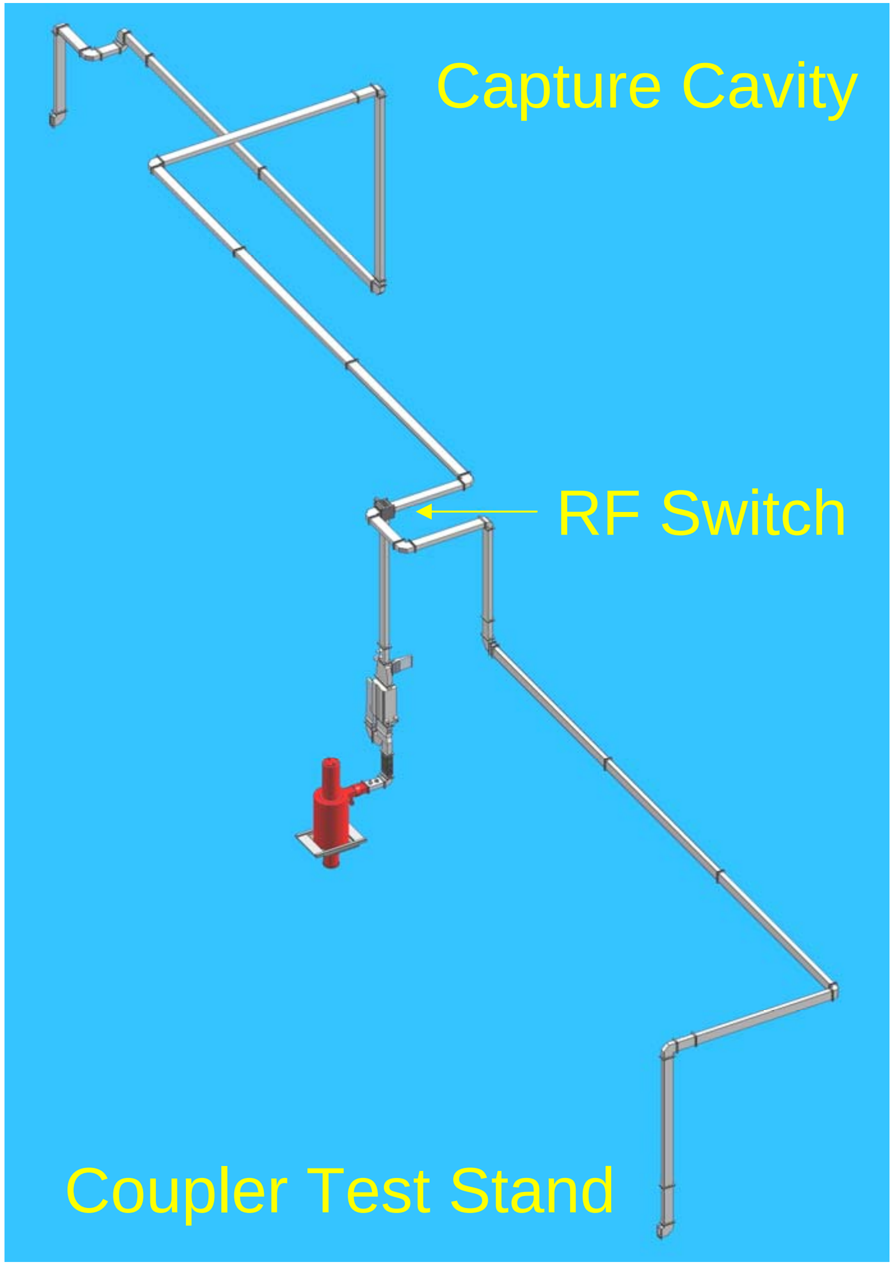
- Continue to gain experience with Commercial Thales tubes
  - Have produced 3.3 MW, 1 msec pulses at 5 Hz with a SDI legacy TH2104U klystron powered with the SNS modulator.
  - Expecting delivery of a 5 MW TH2104C klystron (DESY testing workhorse) this month.
  - Use these tubes to power a coupler test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

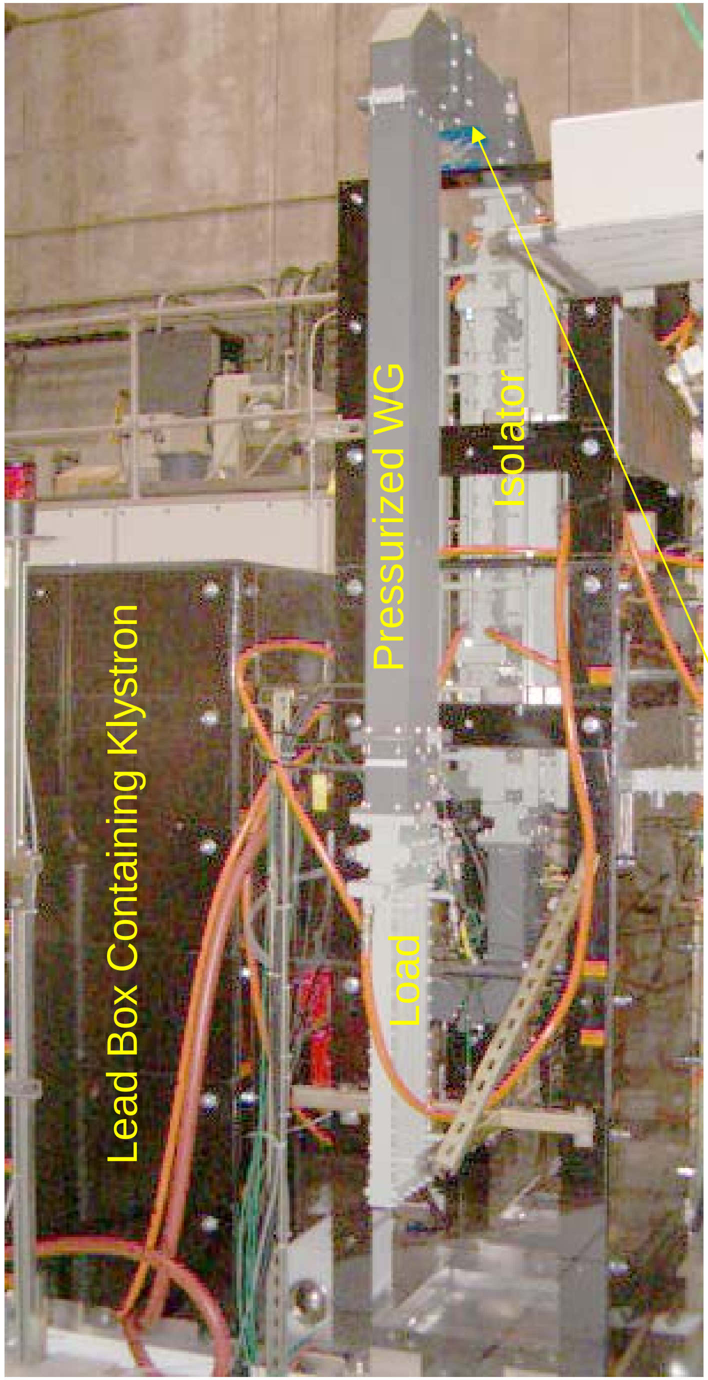


TH2104U Klystron (red) with Solenoid (black) Installed in an Oil Tank at ESB

Waveguide Distribution







Waveguide Test Setup

Observed some arcing at waveguide flanges when running with 3 bar N2 – have since improved the flange flatness and reduced volume of rubber seals to reduce flange gaps

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

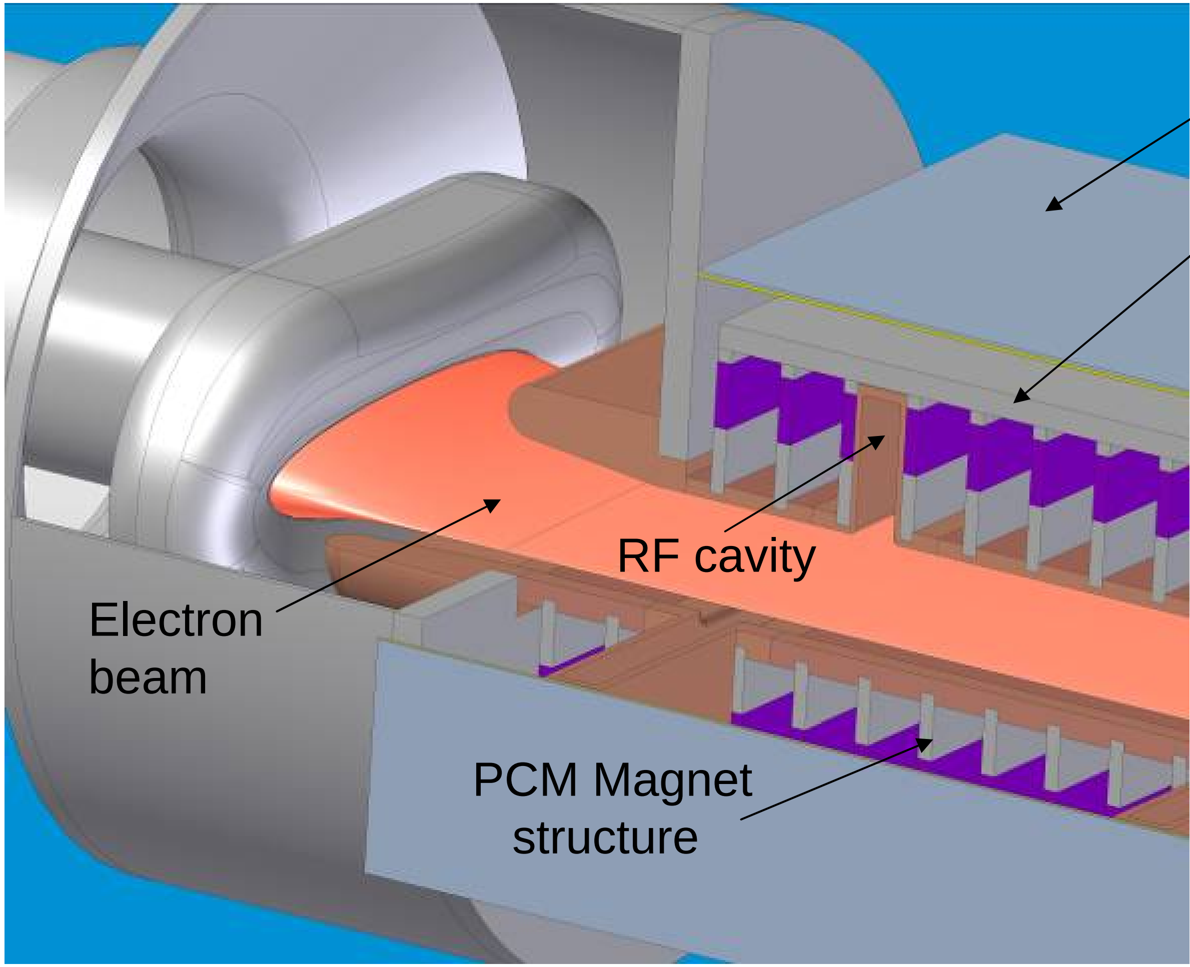
Large internal surface areas – low cathode current and power densities, low temperatures → ***very robust***

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

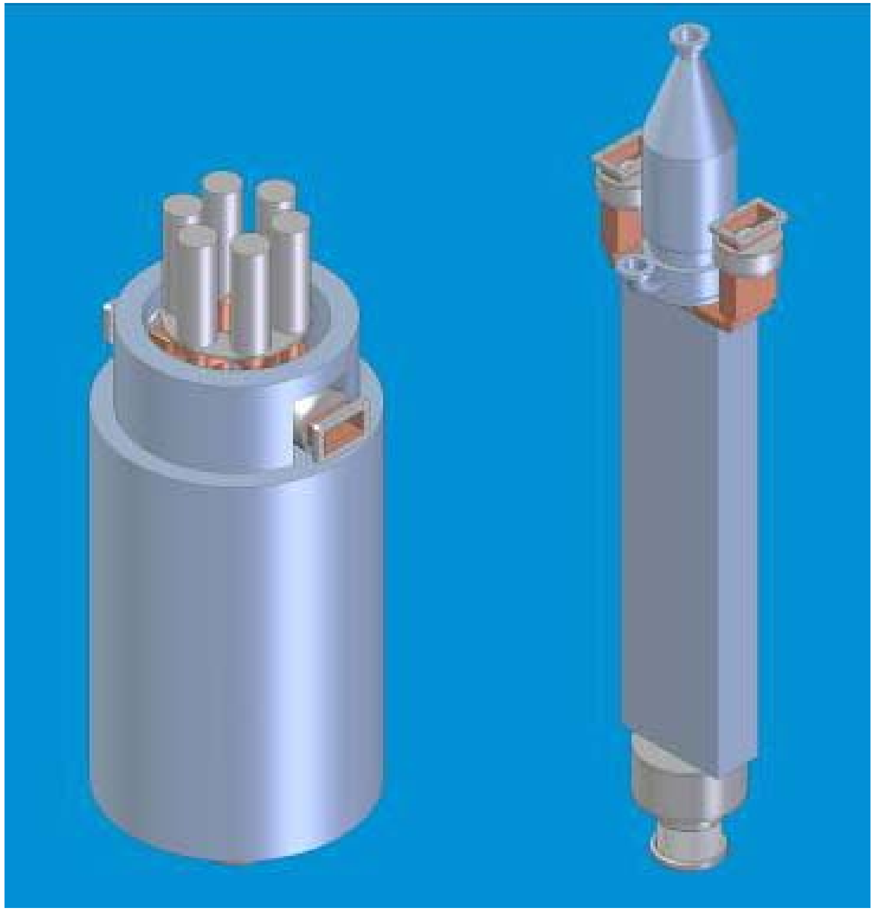
Size and Beam Focusing

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

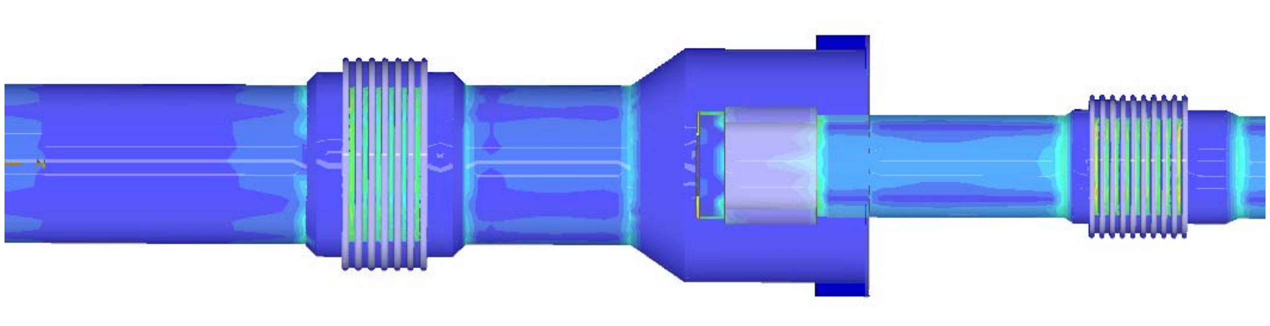
No solenoid
power required!

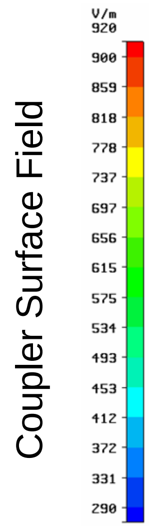
Sheet Beam Schedule
(FY06 Work Funded by SLAC)

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

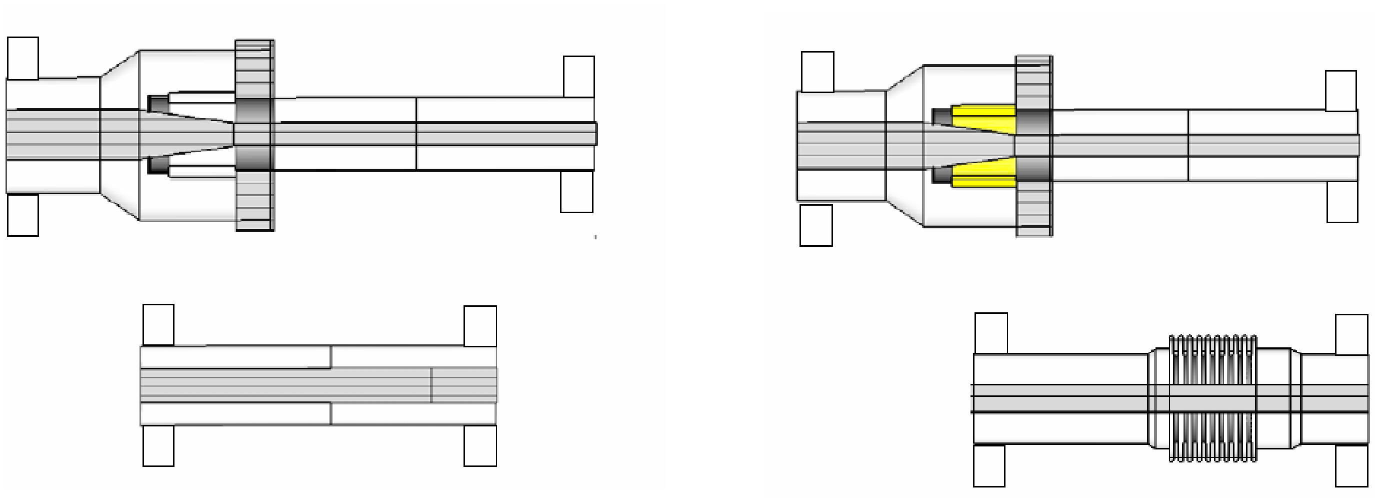
Coupler Processing Studies

Concern that the surface field variations in the bellows and near the windows may lead to excessive mulitpacting.



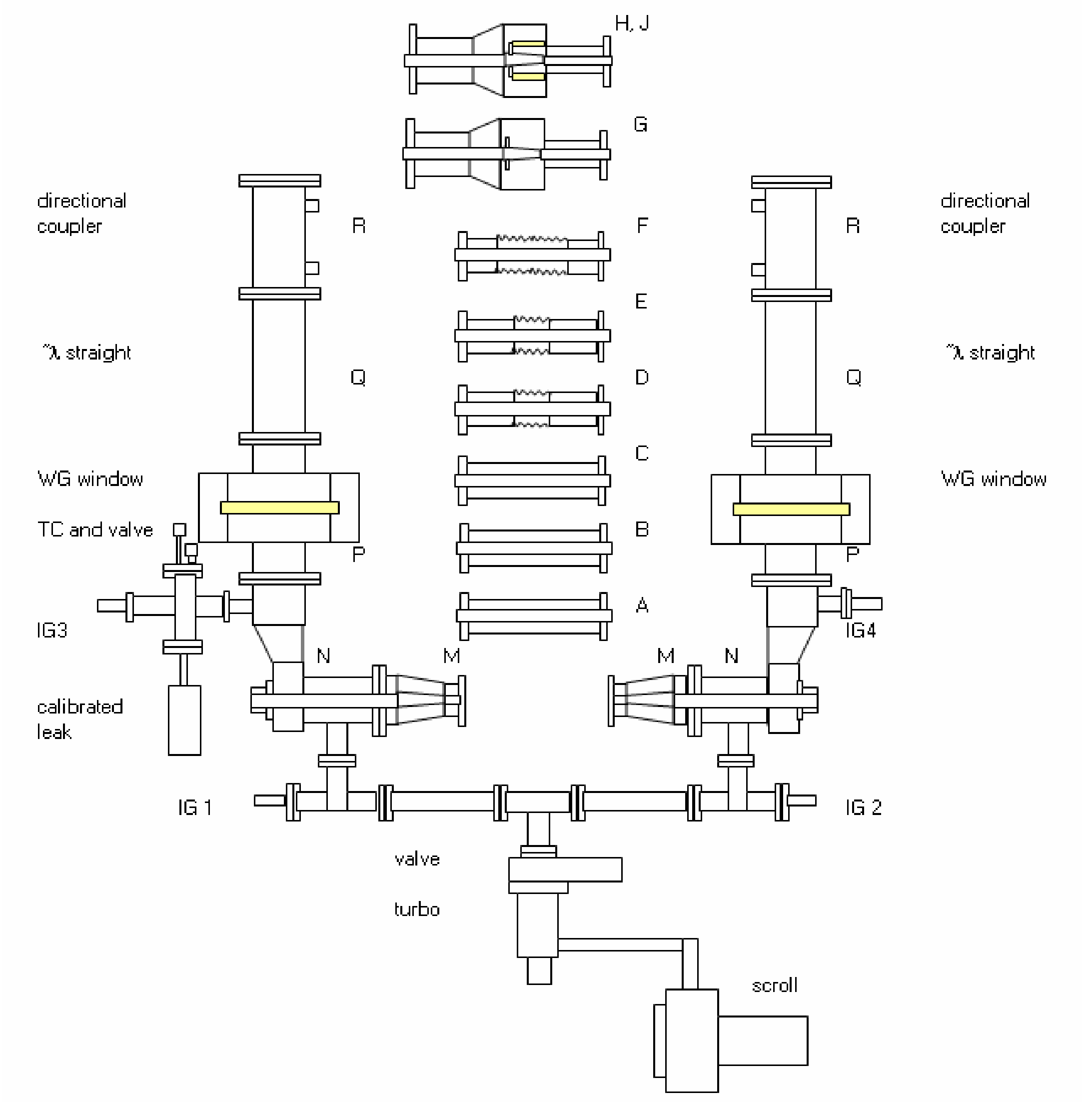


To understand processing limitations, plan to process coupler components individually. In particular, determine if bellows or the windows are the source of the long processing time.

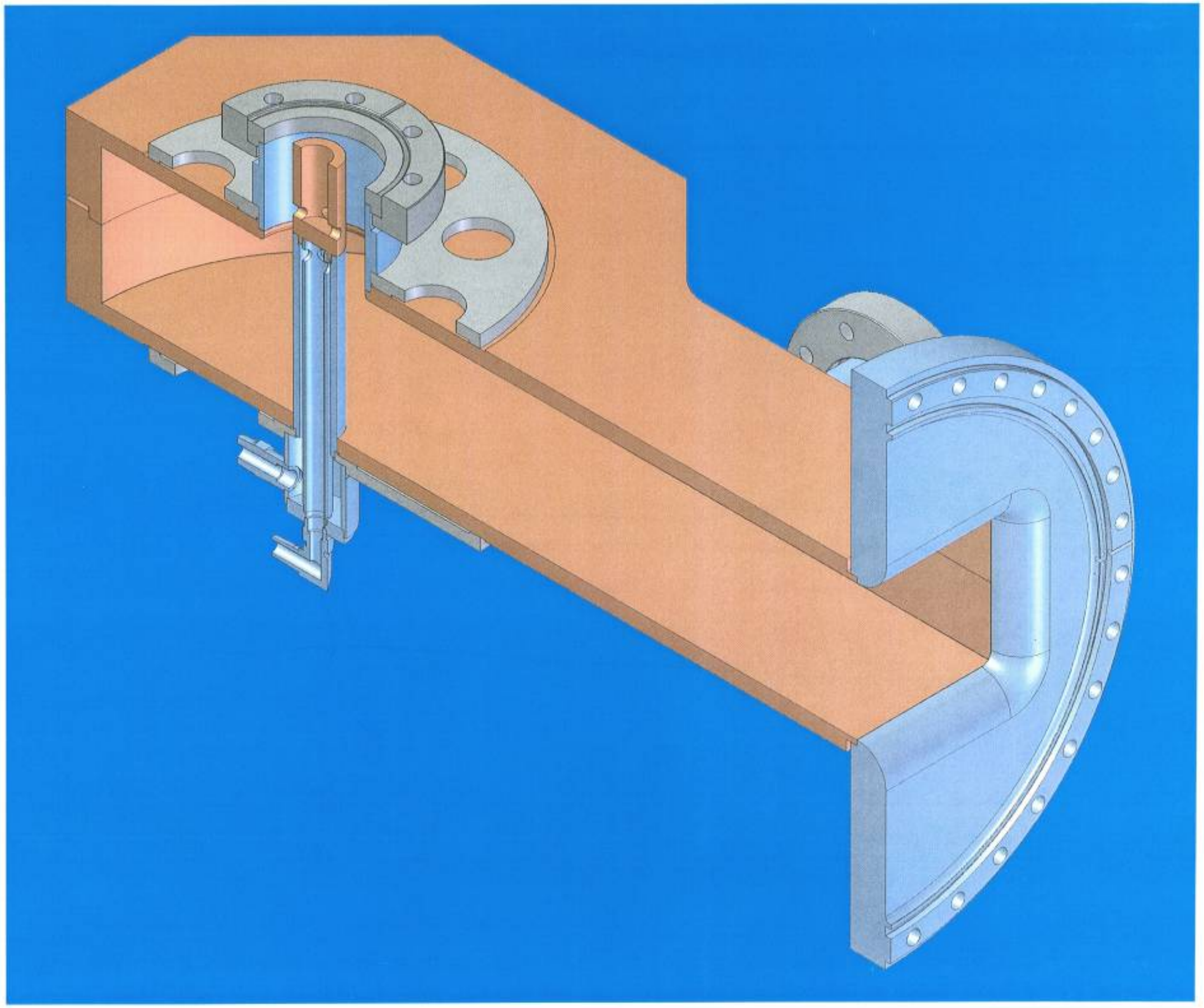


Coupler Development Status

- 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

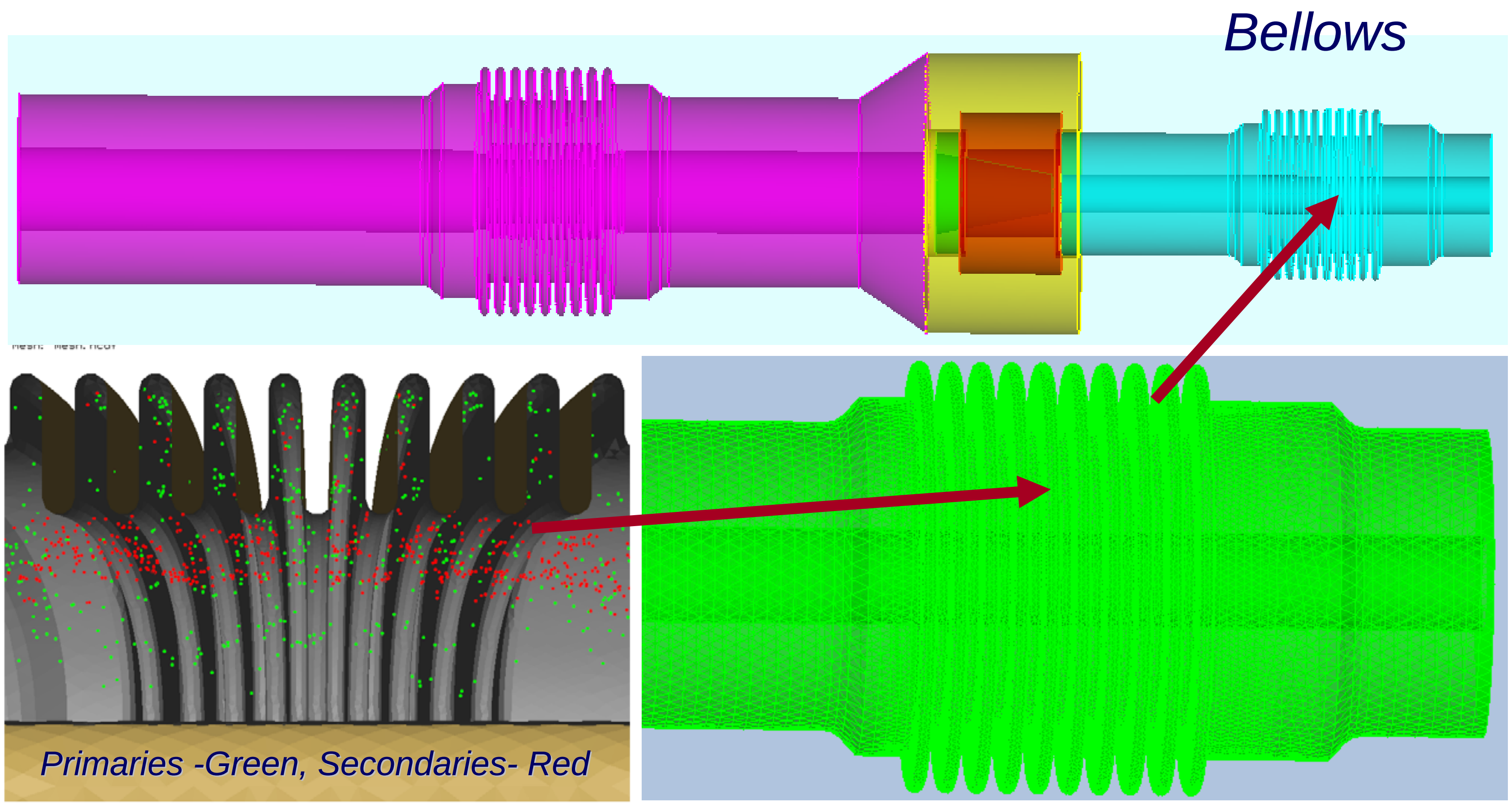


Design of WG-to-Coax Adaptor



Multipacting Simulation of TTF3 Coupler

"Cold Side"

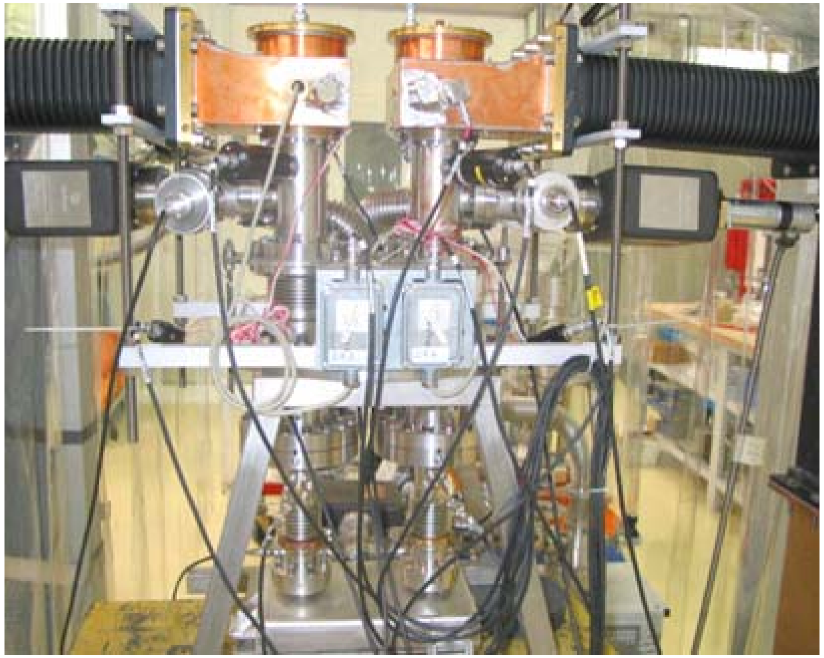


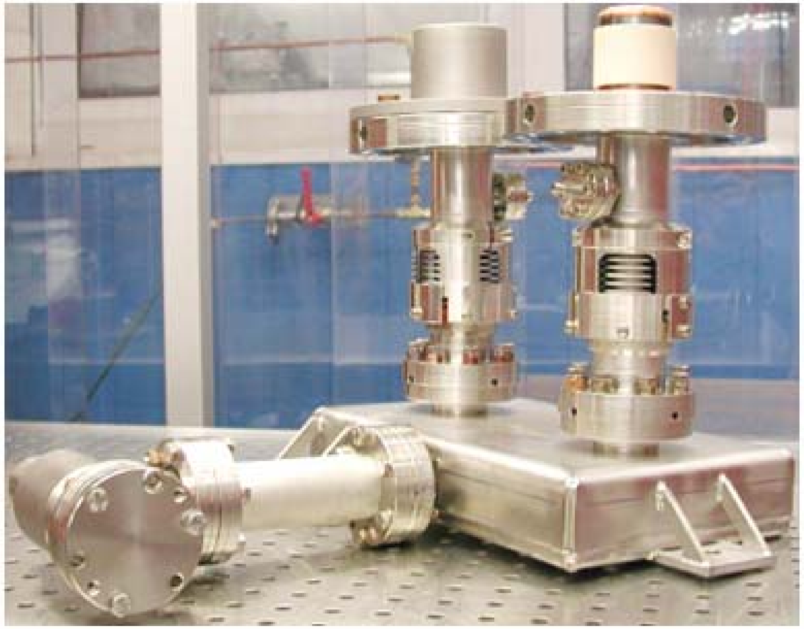
FY07 Coupler Program
(in collaboration with LLNL)

- 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.

Test Stand to RF Process Couplers

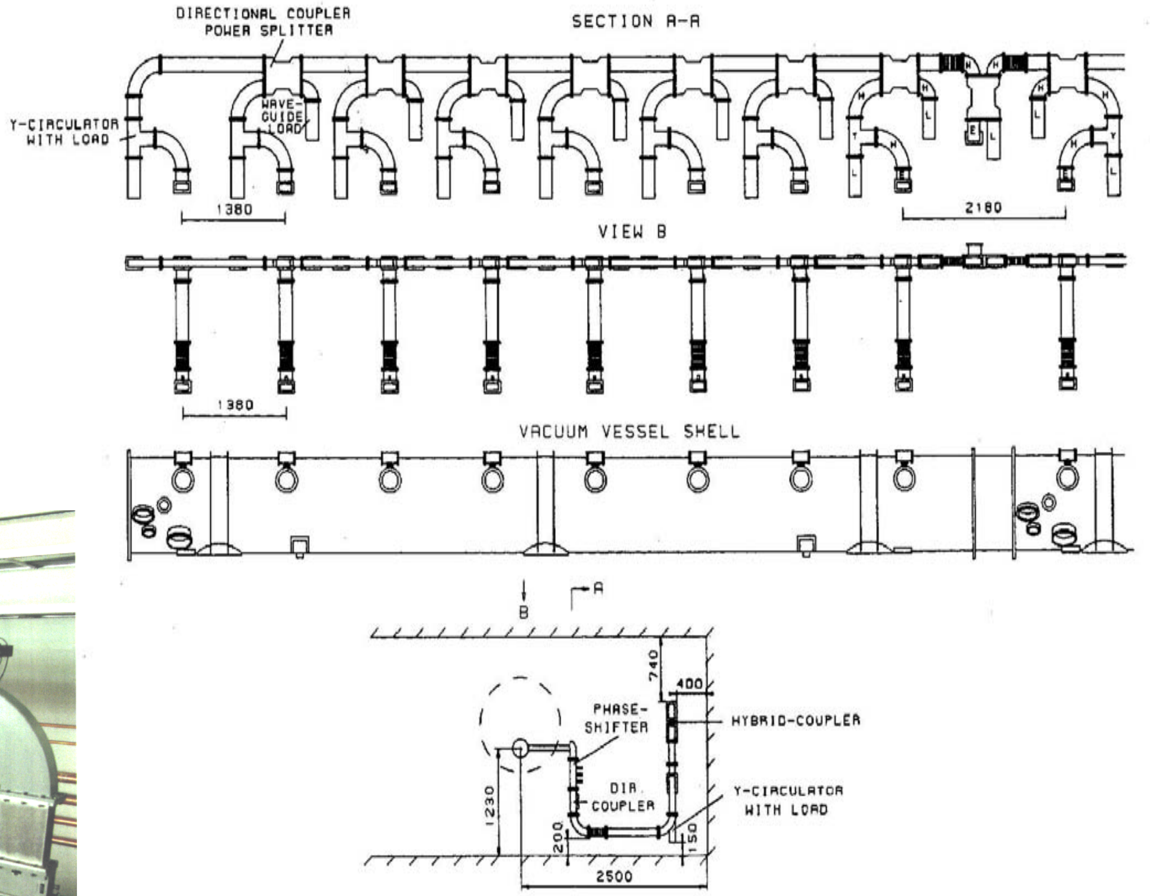
Instrumented Coupler Test Stand at Orsay





RF Distribution

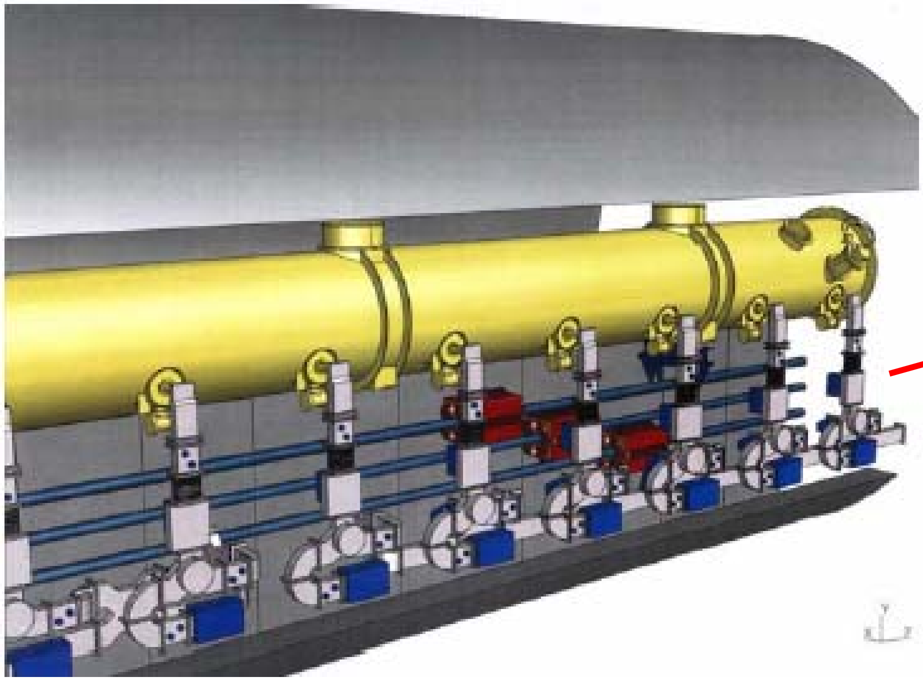
Baseline choice is the waveguide system used at TTF, which includes off-the-shelf couplers, circulators and 3-stub tuners (phase control).

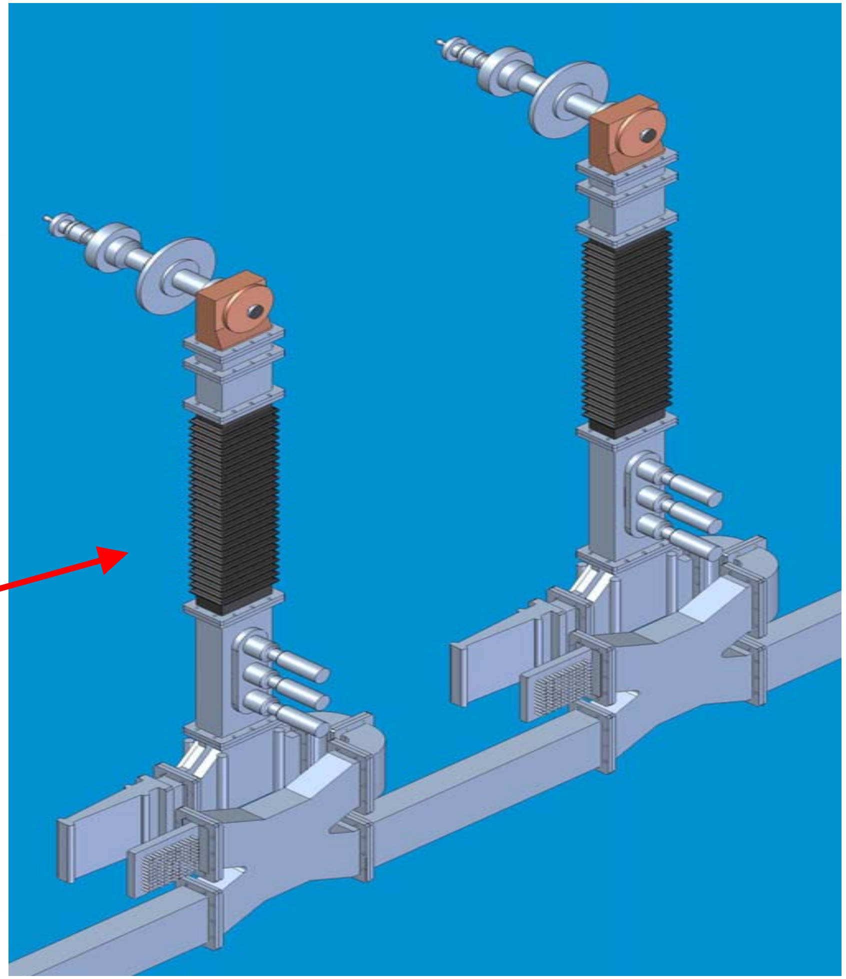


Need more compact design

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

Two of ~ 16,000 Feeds

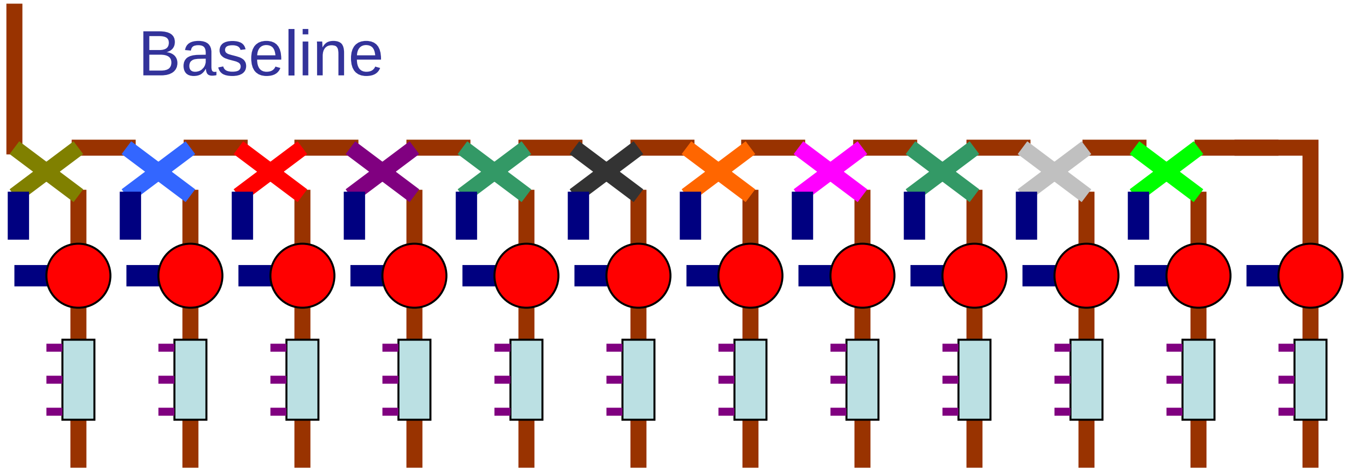




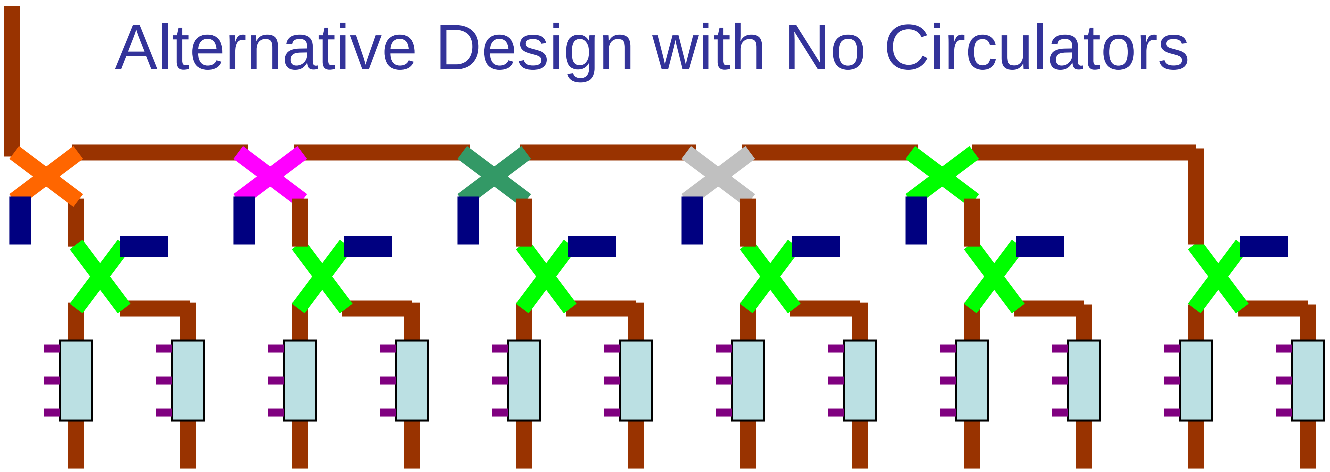
And should simplify system

(circulators are ~ 1/3 of rf distribution cost)

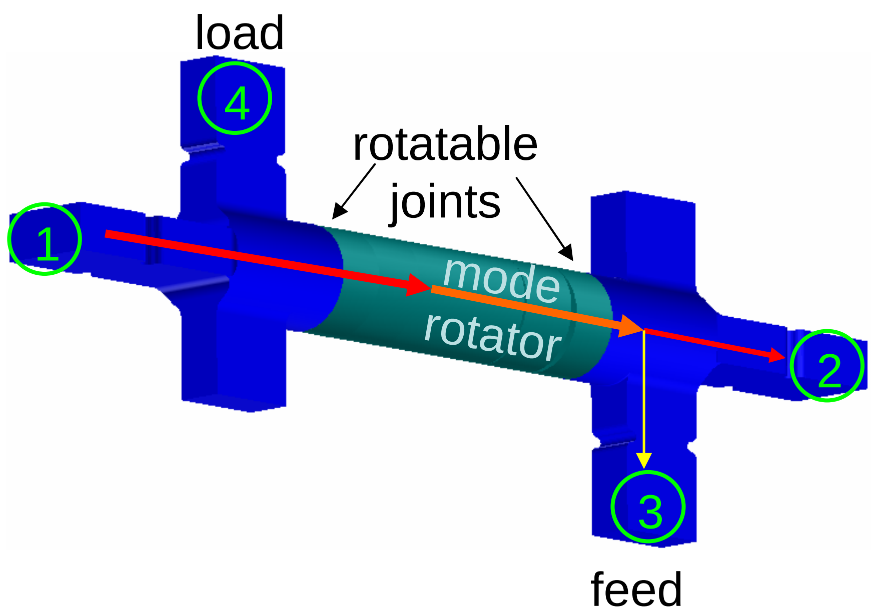
Baseline

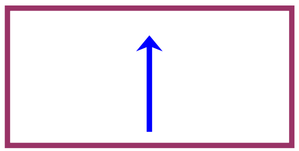


Alternative Design with No Circulators

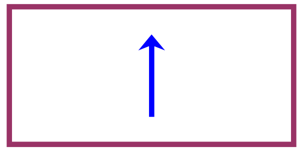


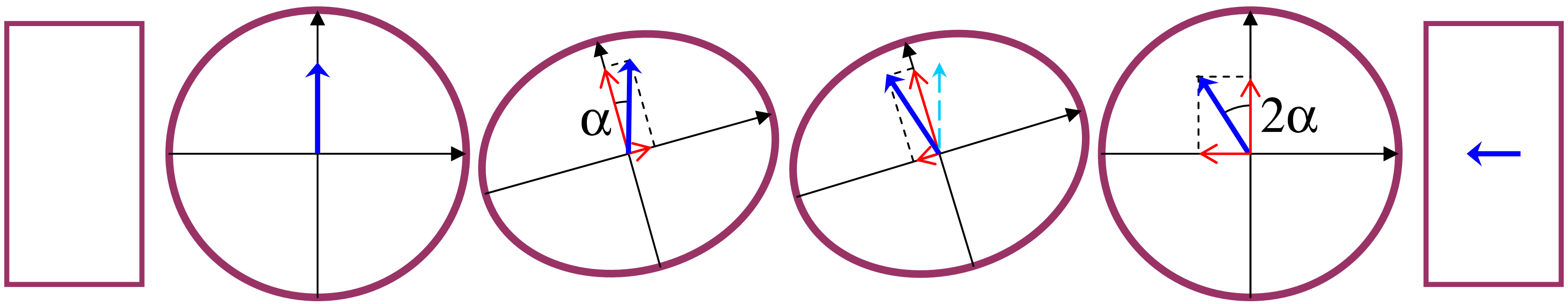
Adjustable Tap-Offs Using Mode Rotation





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

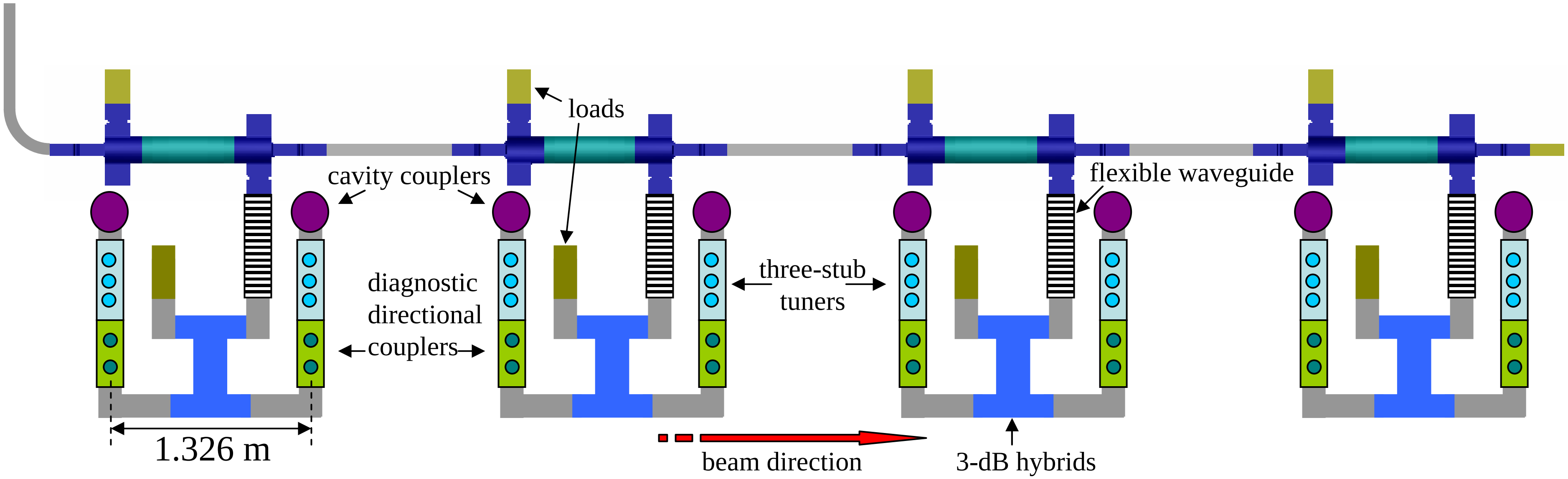




C. Nantista

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)

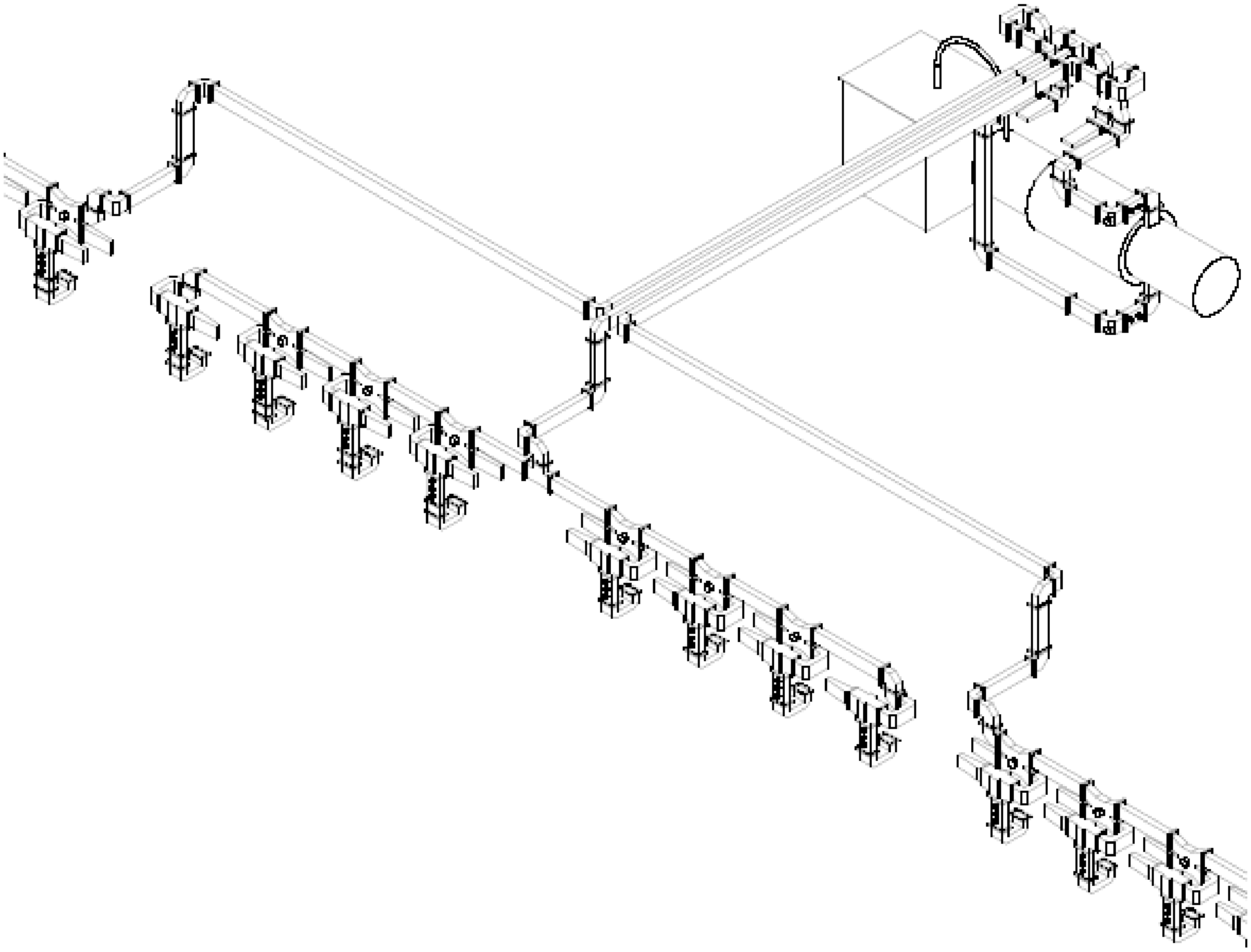


C. Nantista

FY07 RF Distribution Program

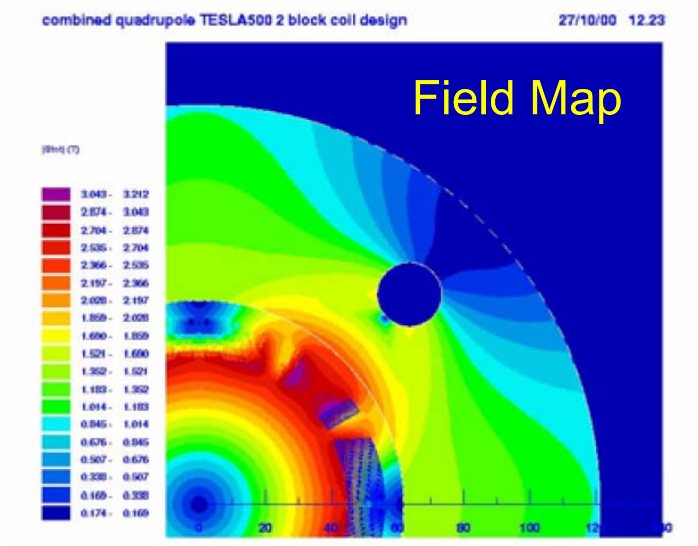
- Test both high and low power circulators.
- Develop adjustable tap-offs and simple phase shifter, and test at high power.
- Build rf distribution systems for the first two FNAL cryomodules (nλ cavity spacing).
  - Both would include circulators (needed for beam operation) that could be removed to test 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

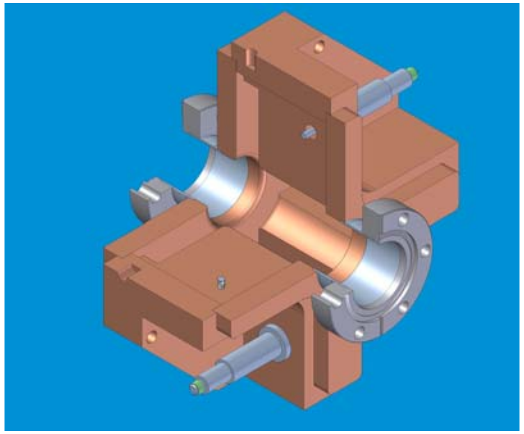


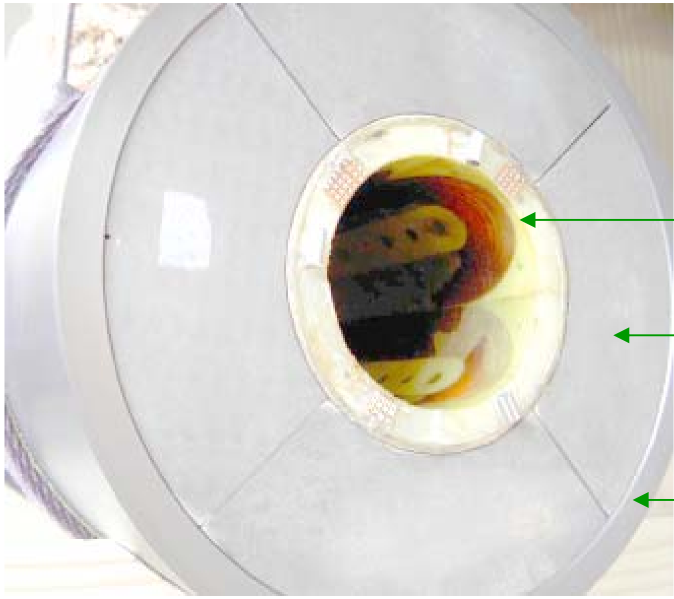
ILC Linac SC Quad/BPM Evaluation

Cos(2Φ) SC Quad
(~ 0.7 m long)



S-Band BPM Design
(36 mm ID, 126 mm OD)



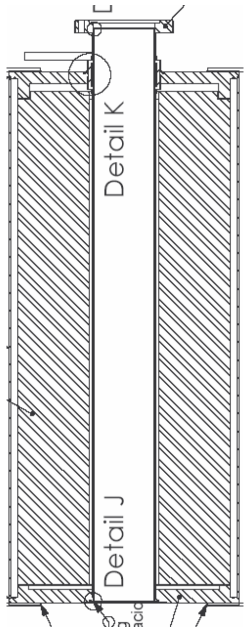


He Vessel →

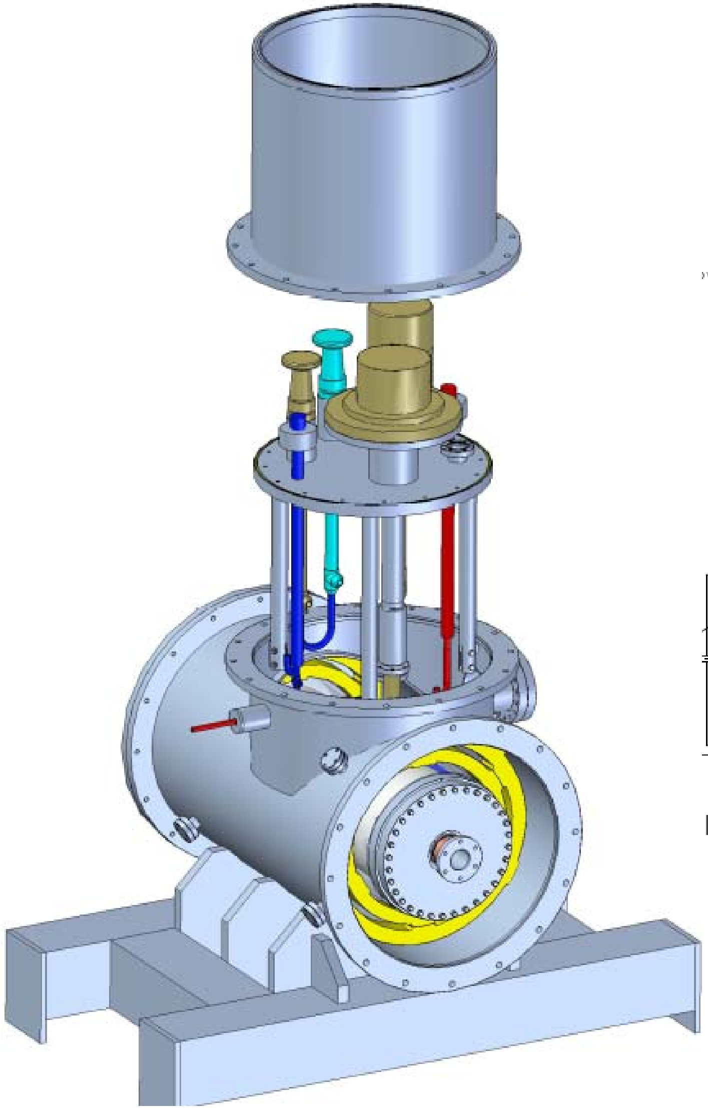
SC Coils

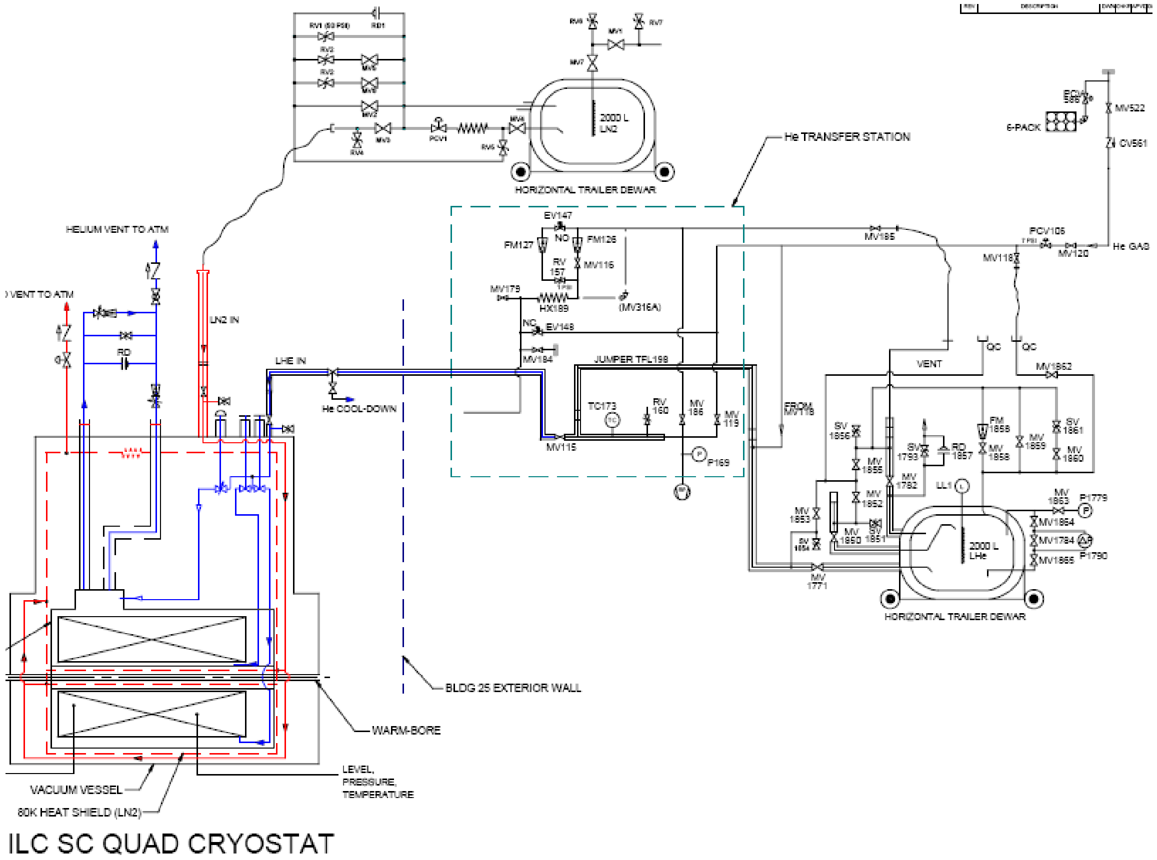
Iron Yoke Block

Al Cylinder



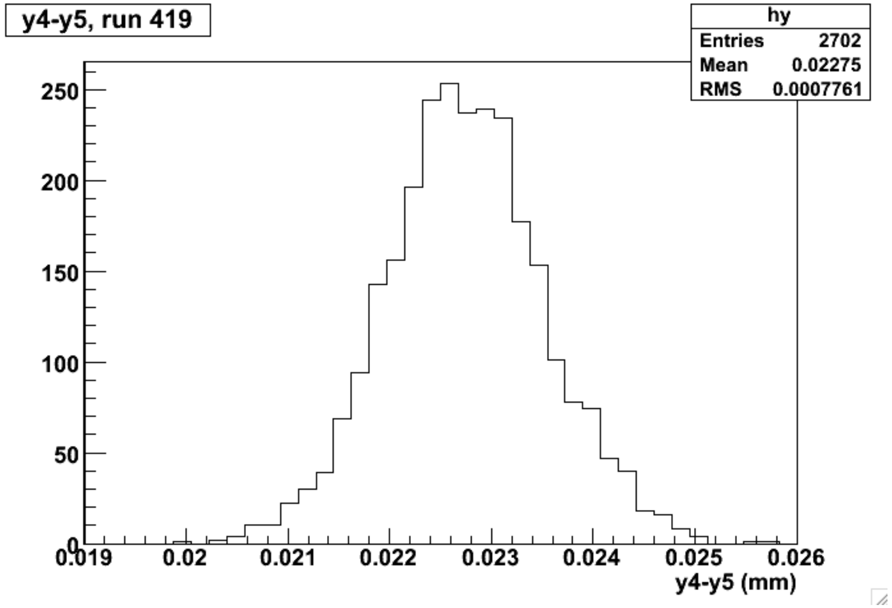
Cryostat and Cryogenic System

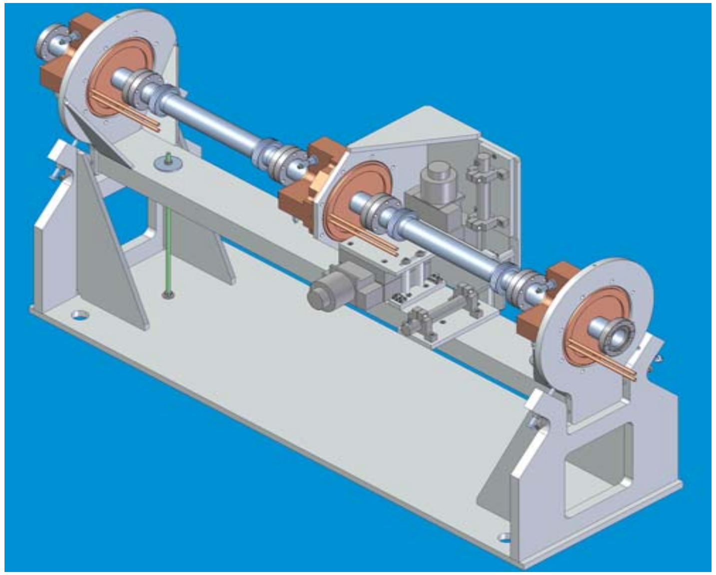


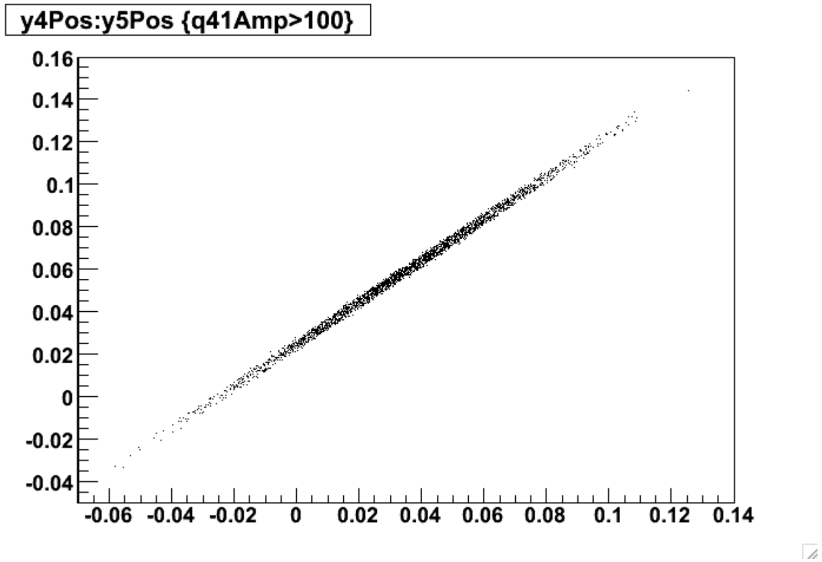


Recent BPM Triplet Results

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







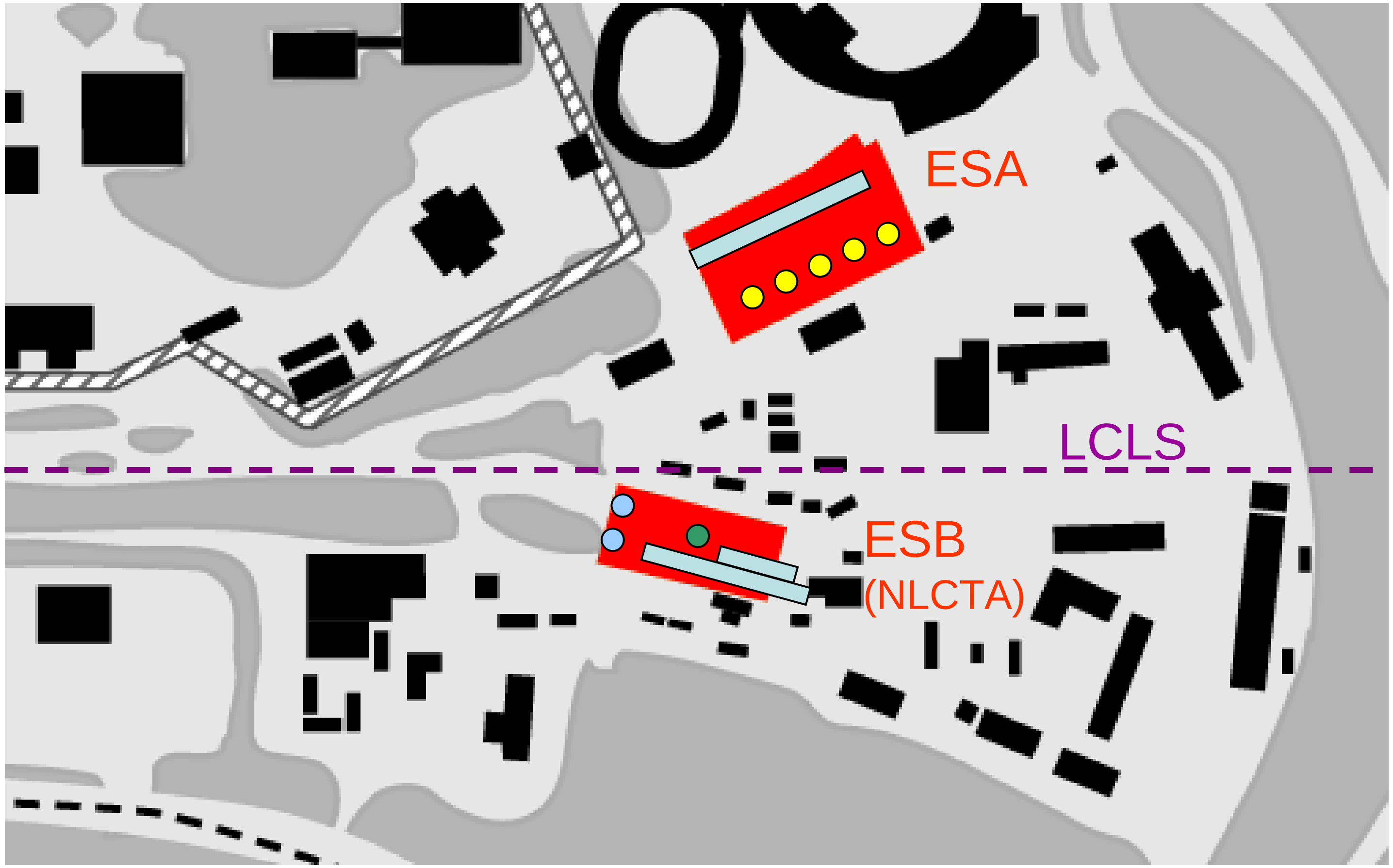
FY07-09 RF System Program

- Goal: demonstrate viable, cost-optimal rf source for ILC. Operate six ‘production’ sources from industrial vendors by FY10. Supply power source through couplers for RF unit tests at FNAL.
- SLAC has substantial expertise in this area and ILC Americas expects SLAC to lead this program. Would be responsible for all components from the AC power to the couplers.
- Program would be comparable in size to that during NLC rf development.
- Schedule meshes well with FNAL cryomodule program.
- Schedule allows for testing to establish > 2000 hour MTBF’s, which is minimum allowable in particular availability models.

	FY06			FY07				FY08				FY09			
	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Modulators															
Run SNS Modulator with 15 MW upgrade	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Fabricate three 150 kW resistive loads		•		•	•										
Install and evaluate DTI modulator				•	•	•									
Marx Prototype construction	•	•	•	•											
Marx Prototype testing				•	•	•									
Design Marx DFM			•	•	•										
Choose modulator for ILC						•									
Fabricate 2 DFM ILC modulators					•	•	•	•	•						
Two companies build 3 prod. units ea.									•	•	•	•	•	•	
Klystrons															
Contract Industry to build 1-beam, 5 MW tube				•	•	•	•	•	•						
Design/Build SBK prototype at SLAC	•	•	•	•	•	•	•								
Build 2nd gen. SBK at SLAC						•	•	•	•						
Contract CPI to build 2nd gen. MBK				•	•	•	•	•	•						
Contract Toshiba to build 2nd gen. MBK		•	•	•	•	•	•								
Test above 5 klystrons in separate test stands							•	•	•	•	•				
Choose klystron design for ILC											•				
Two companies build 3 prod. units ea.											•	•	•	•	

SLAC Research Yard

L-Band Test Stands: Existing (green), FY07 (blue), FY08-09 (yellow)



	FY06			FY07				FY08				FY09			
	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
RF Distribution															
Design low cost, adjustable dist system	•	•	•												
Build prototype for first FNAL cryomodule				•	•										
Build next generation for 2 FNAL modules								•	•						
Build production version for 3 FNAL modules											•	•	•		
Study coupler processing limits	•	•	•	•	•										
Build and test improved version of TTF3 coup					•	•	•								
Supply couplers for FNAL cryomodules						•	•	•	•	•	•	•	•	•	•
RF Source															
Develop interlock system for Marx + Klystron			•	•	•	•	•	•	•						
Assemble 6 production units											•	•	•	•	
Operate 6 ILC rf sources														•	•

Summary

- SLAC has leadership roles in ILC Linac design and RF source development.
- Have made good progress toward achieving FY06 goals.
- Gaining expertise in low-frequency, long-pulse rf sources required for ILC, and beam related issues with SC quads and ‘cold’ BPMs.
- Starting in FY07, will expand work toward producing a robust klystron and a lower cost rf distribution system.
- In a good position to ramp up program in the next few years to produce several prototype ILC rf sources.