SLAC Power Distribution System R&D

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SLAC

Main Linac – KOM
SLAC
October 2, 2007

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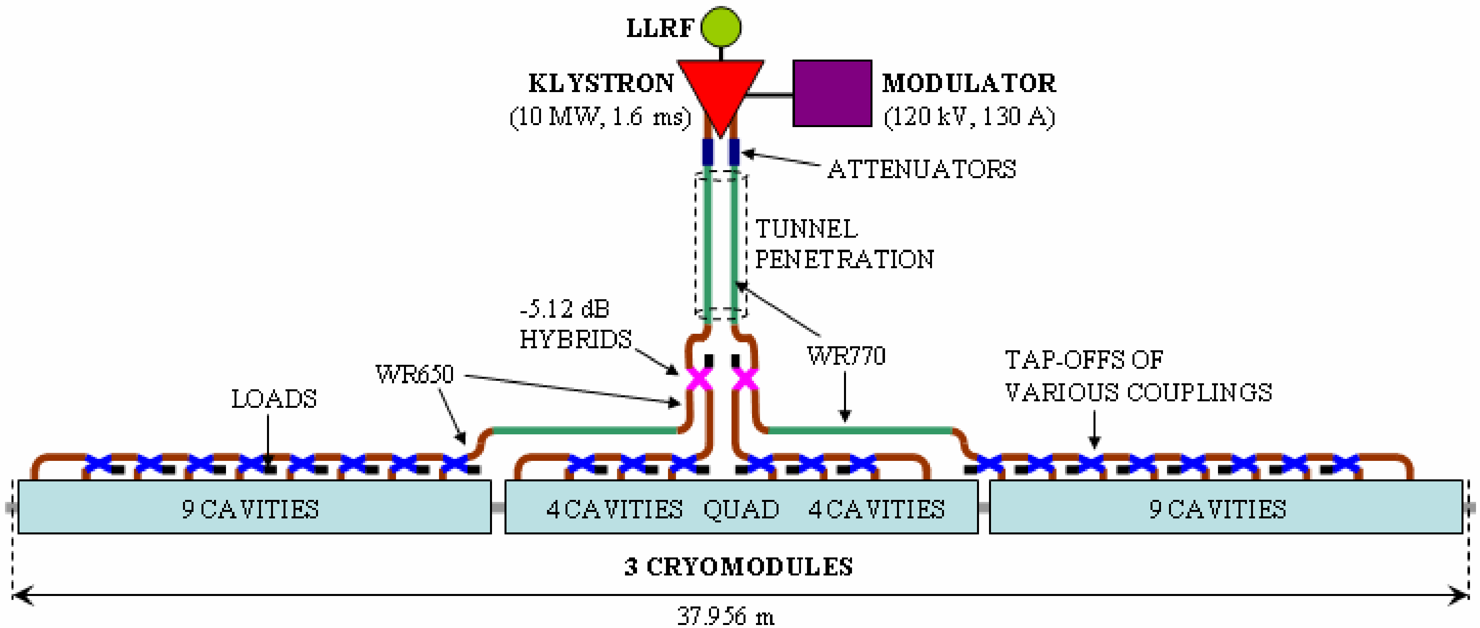
1919 - 2007

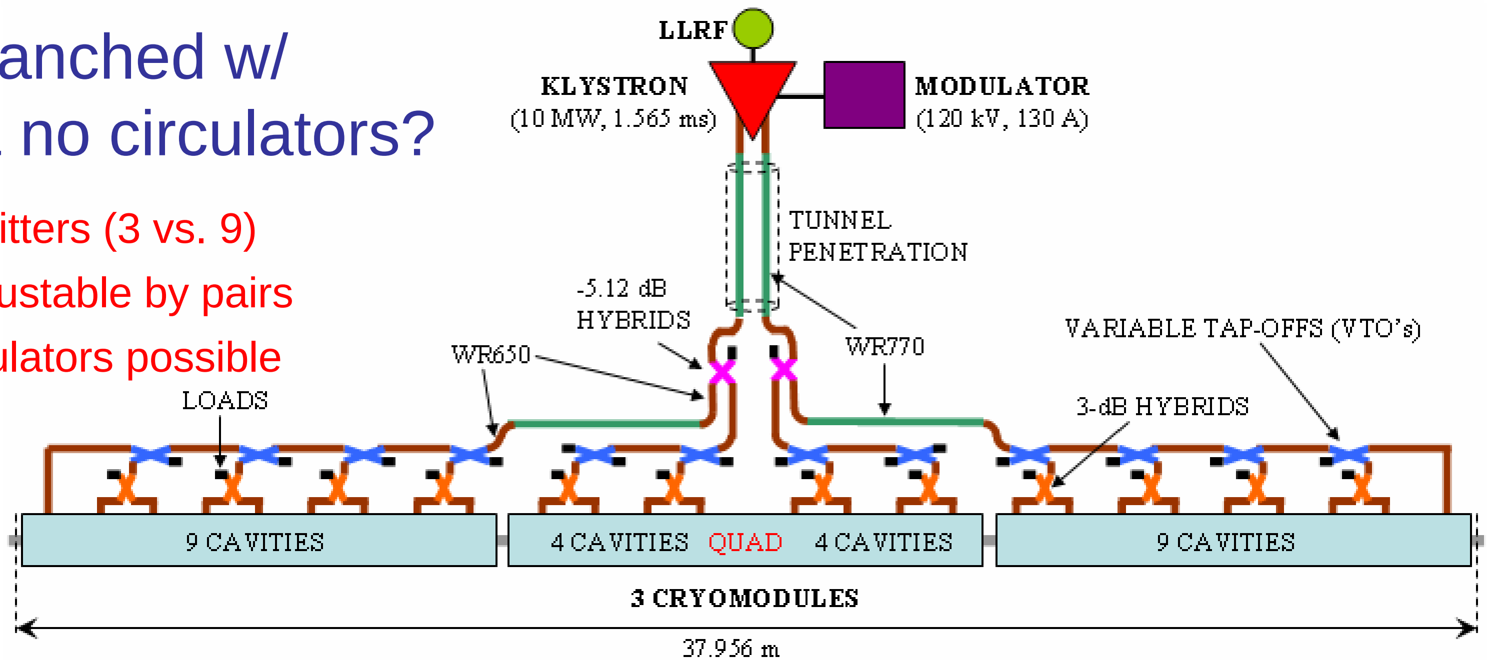
Basic Distribution Scheme

BCD: linear



ACD: semi-branched w/
VTO's & no circulators?

- Fewer types of splitters (3 vs. 9)
- Power division adjustable by pairs
- Elimination of circulators possible



Gradient Optimization

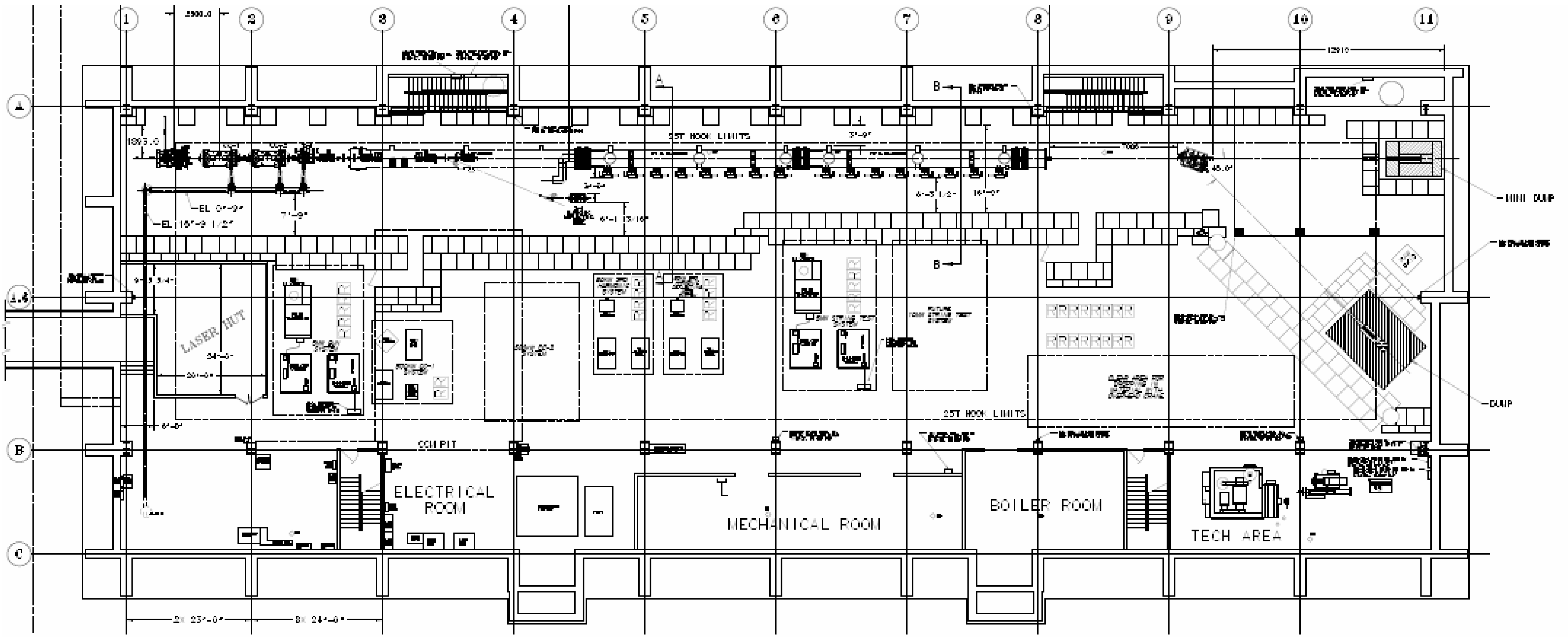
Case	Not Sorted	Sorted
Individual p's and q's	0.0	0.0
p's in pairs, individual q's (VTO's and circulators)	2.5 ± 0.4	0.8 ± 0.2
1 p, individual q's (needs circulators)	BCD 2.7 ± 0.4	2.7 ± 0.4
p's in pairs, q's in pairs (needs VTO's)	7.2 ± 1.4	ACD 0.8 ± 0.2
1 p, q's in pairs	8.8 ± 1.3	3.3 ± 0.5
g_i set to lowest $(g_{lim})_i$	19.8 ± 2.0	19.8 ± 2.0

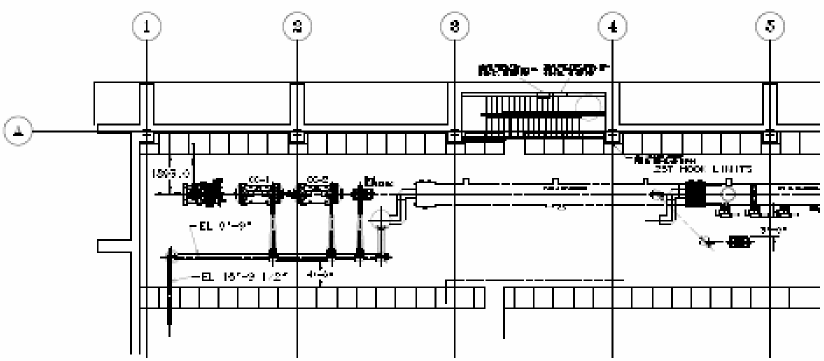
Also more efficient power usage

Optimized gradient loss, δ_{loss} in percent for various scenarios of p's and q's, where the overall beam time parameter τ_b is also adjusted. For 100 ensembles of 26 cavities, given are the average result and the rms deviation (the number after the $\pm$ sign).

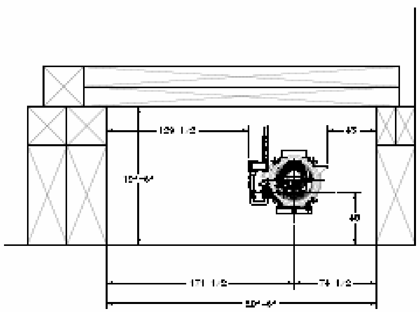
K. Bane

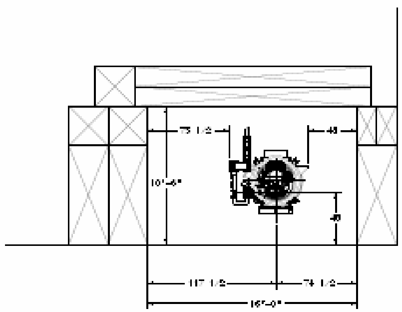
ILCTA in NML at Fermilab





SLAC will provide RF distribution at cryomodules

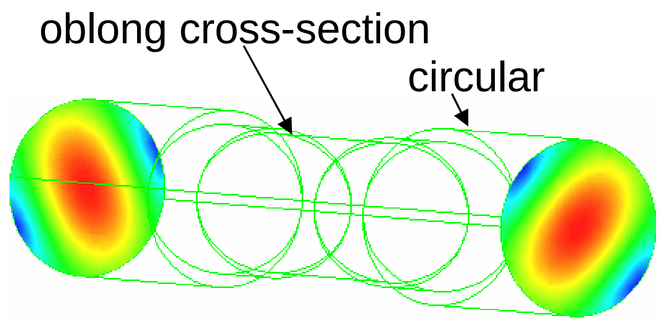




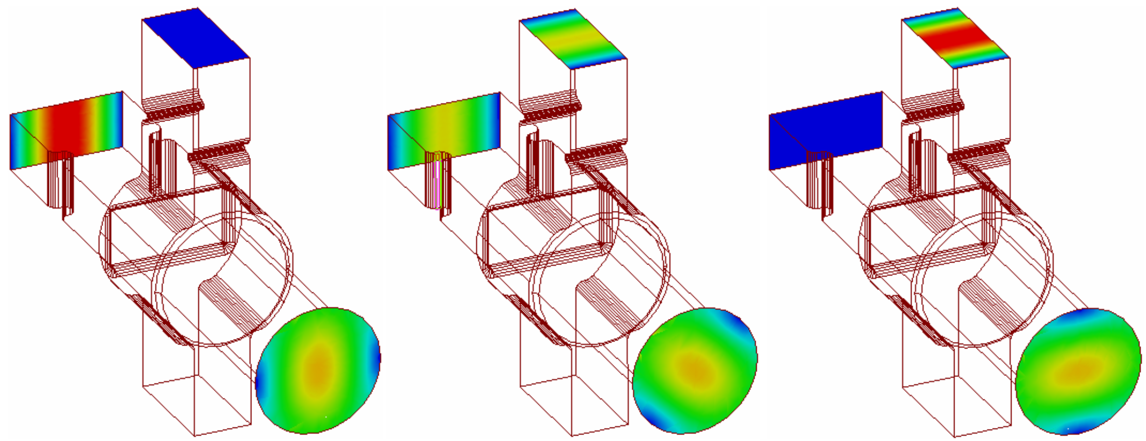
courtesy of Jerry Leibfritz – not final

Variable Tap-Off (VTO) Design

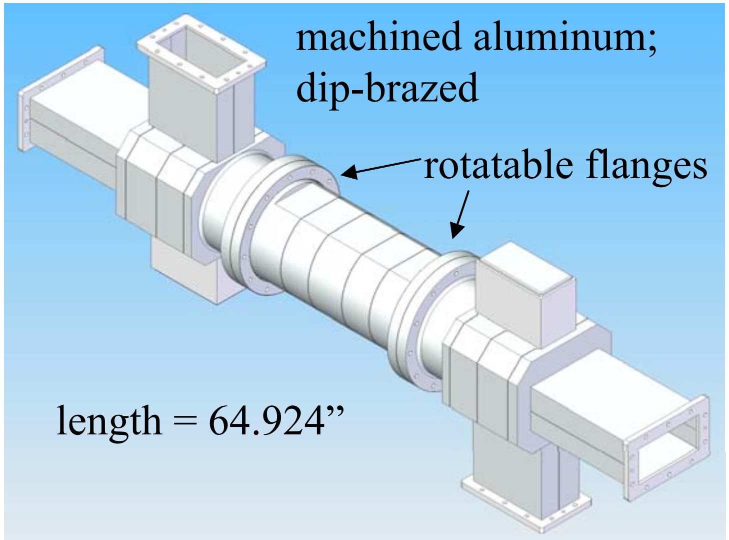
Mode Rotator:



Polarization Selecting 3-Port Junction:



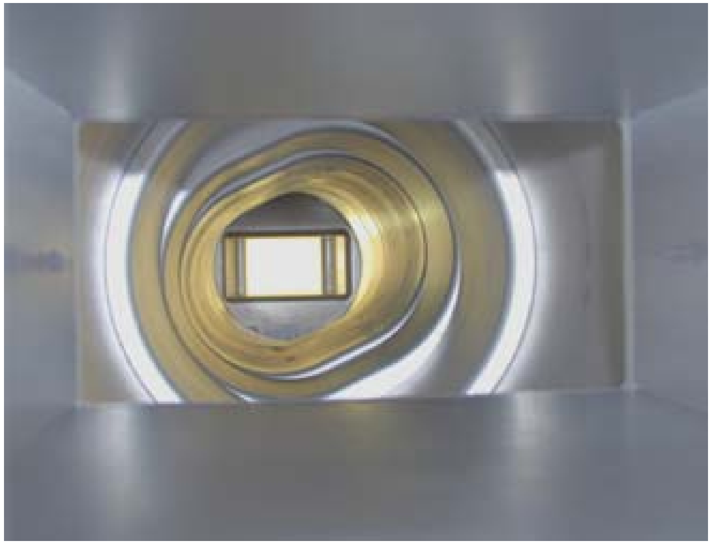
Full 4-Port Assembly:



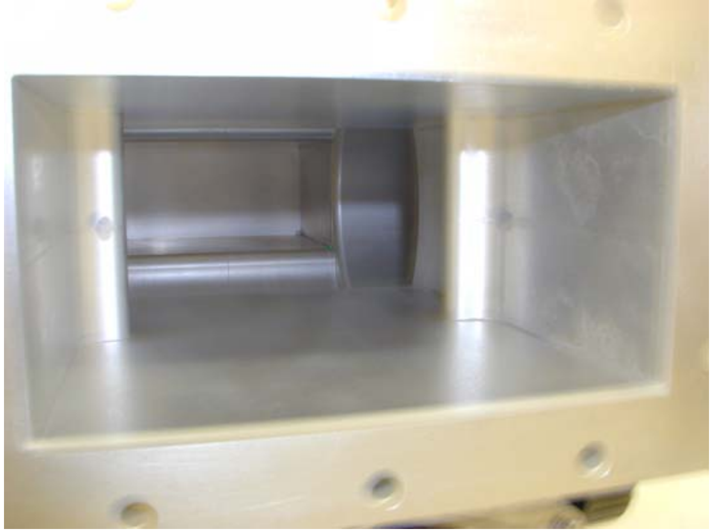
Coupling is a function of center rotation angle α.

$C = P_c / P_i$	$\alpha = 1/2 \sin^{-1}\sqrt{C}$
0	0.00°
1/4	15.00°
1/3	17.63°
1/2	22.50°
1	45.00°

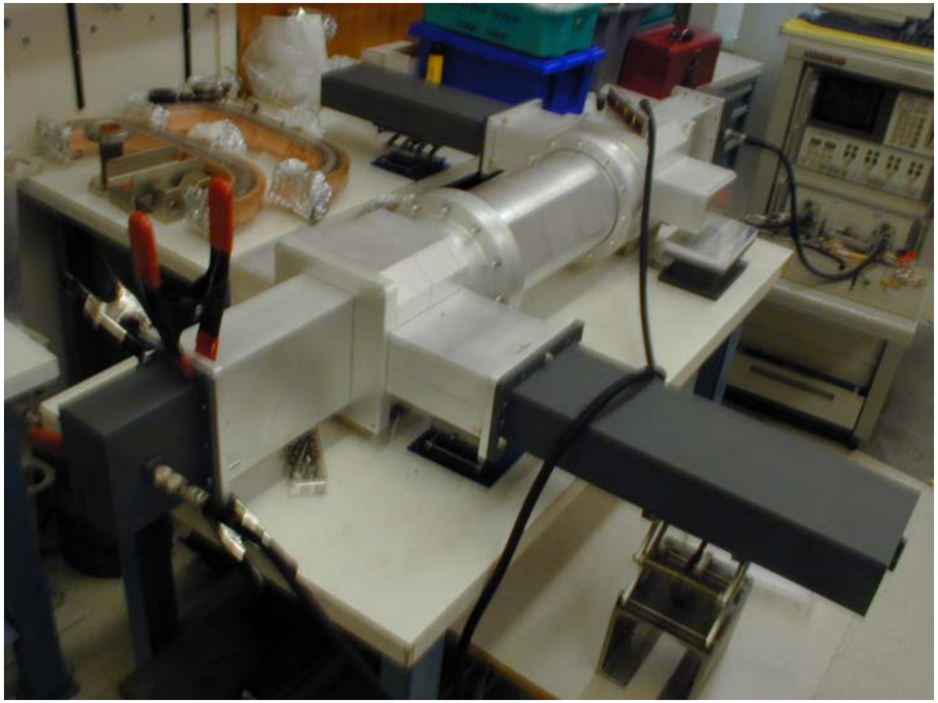
through port



coupled port

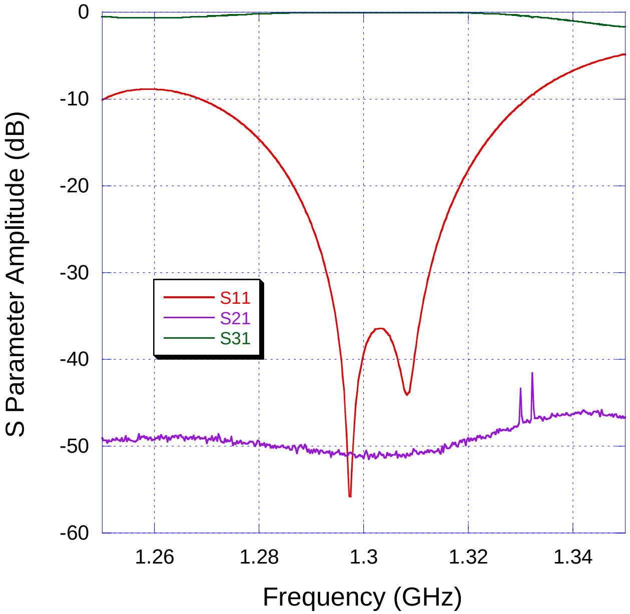


cold test setup

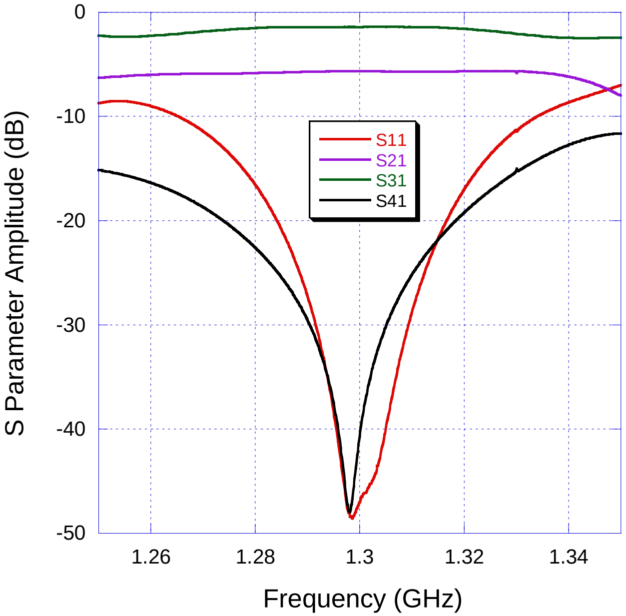


VTO Cold Test Results

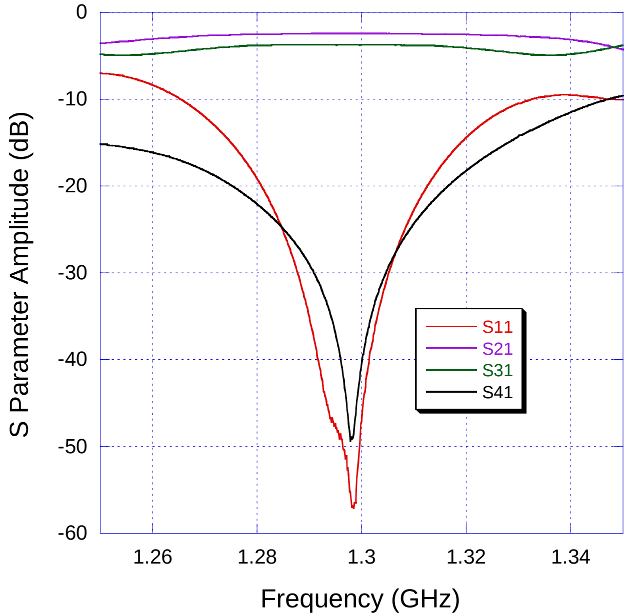
VTO with ~0 Degrees Rotation



VTO at Angle 1



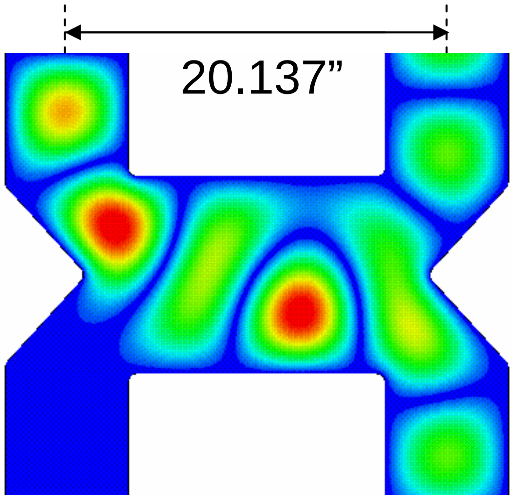
VTO at Angle 2



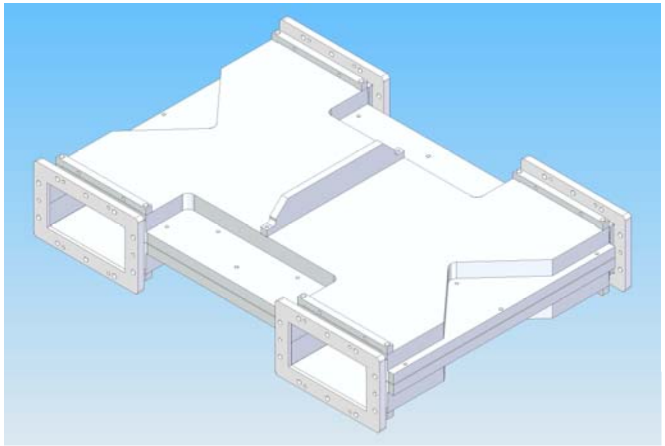
angle (degrees)	~0	angle 1	angle 2	~45
coupling (dB / %)	-51.4 / 0.0007	-5.67 / 27.10	-2.417 / 57.32	-0.004 / 99.9
coupled phase (degrees)	(57.496)	-81.581	-81.655	-81.508
through phase (degrees)	-22.165	-22.208	-21.547	(32.256)
reflection (dB / %)	-40.34 / 0.012	-48.39 / 0.001	-48.16 / 0.002	-36.84 / 0.02
loss (dB / %)	-0.033 / 0.77	-0.026 / 0.61	-0.028 / 0.65	-0.025 / 0.57

Average attenuation: -0.028 dB / 0.65%
Coupled phase variation: 0.15°
Through phase variation: 0.66°

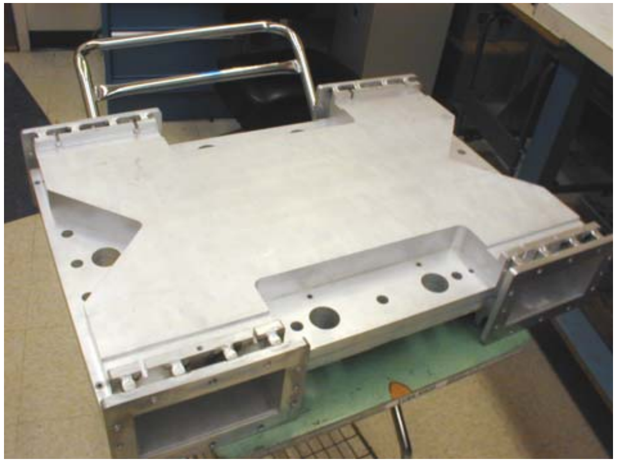
L-Band “Magic-H” 3-dB Hybrid



HFSS Design



Mechanical Design

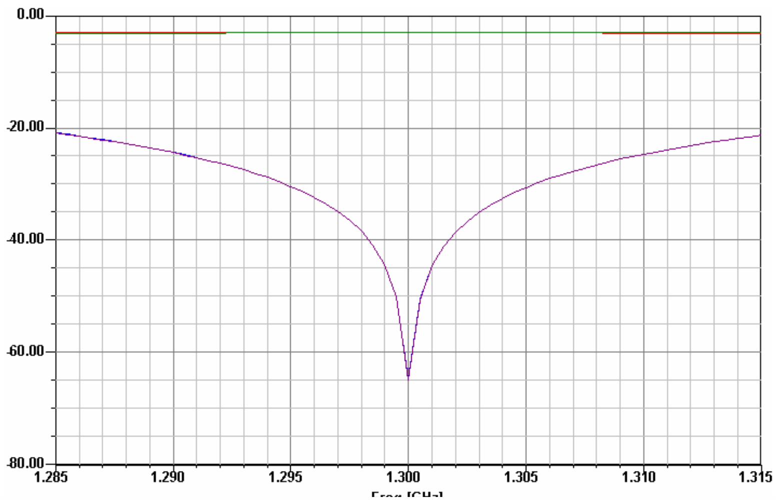


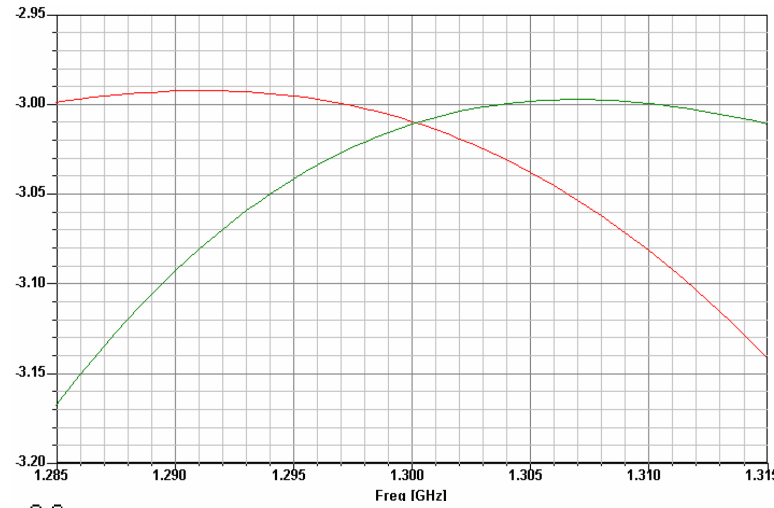
Aluminum Dip-Brazed Prototype

- Ports oriented for branching distribution (eliminate 2 bends)
- Design for high accuracy/isolation at 1.3 GHz. Don’t need broad bandwidth
- Fabricate by aluminum dip-brazing milled halves.

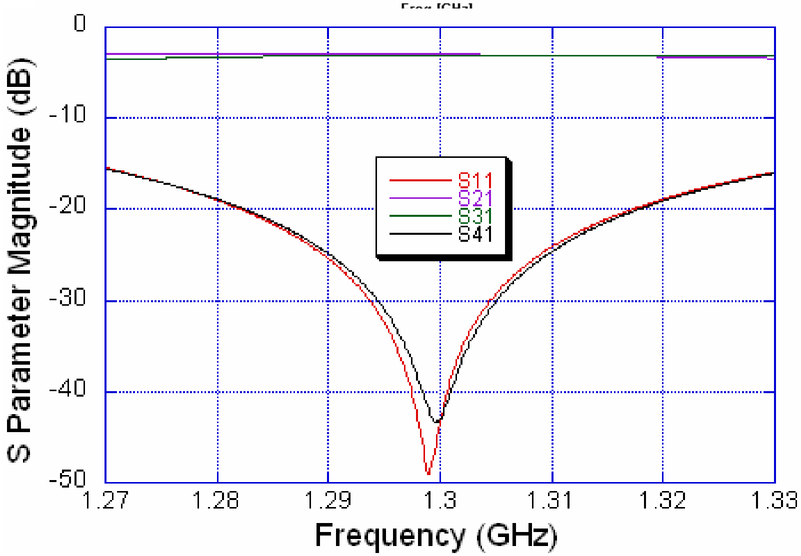
Hybrid Results

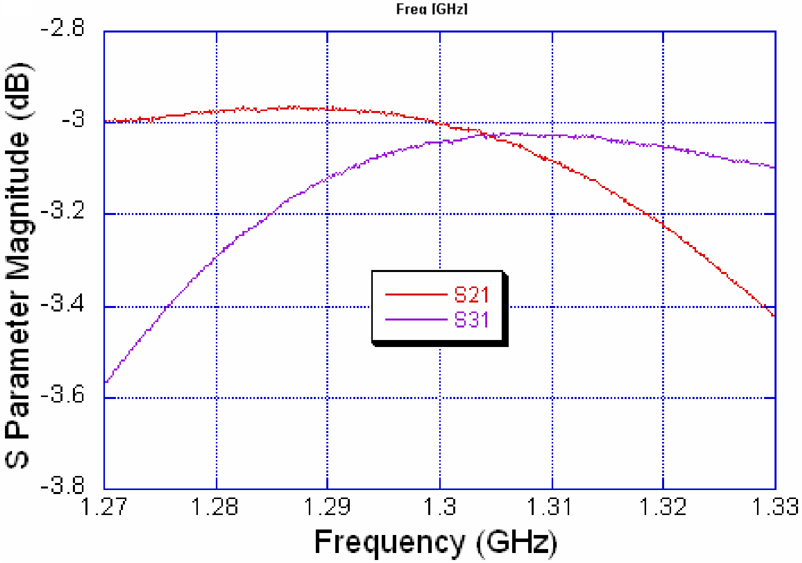
Design Simulation:





Cold Test Results:





Loss: 0.31%

Coupling: -3.031 dB (49.76%)

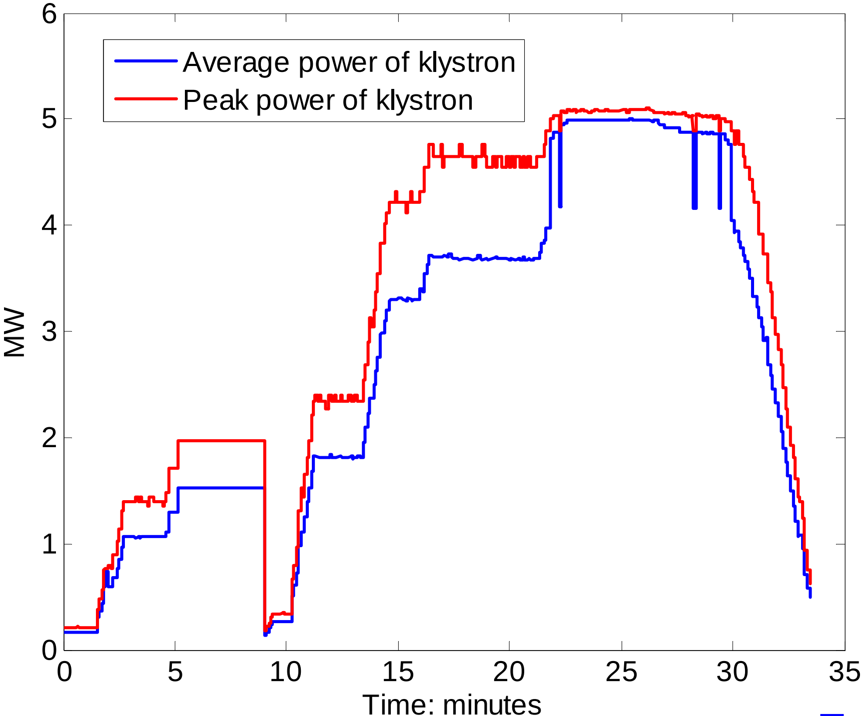
Coupling Error: -0.0207 dB or Frequency Error: 4.4 MHz

High Power Tests

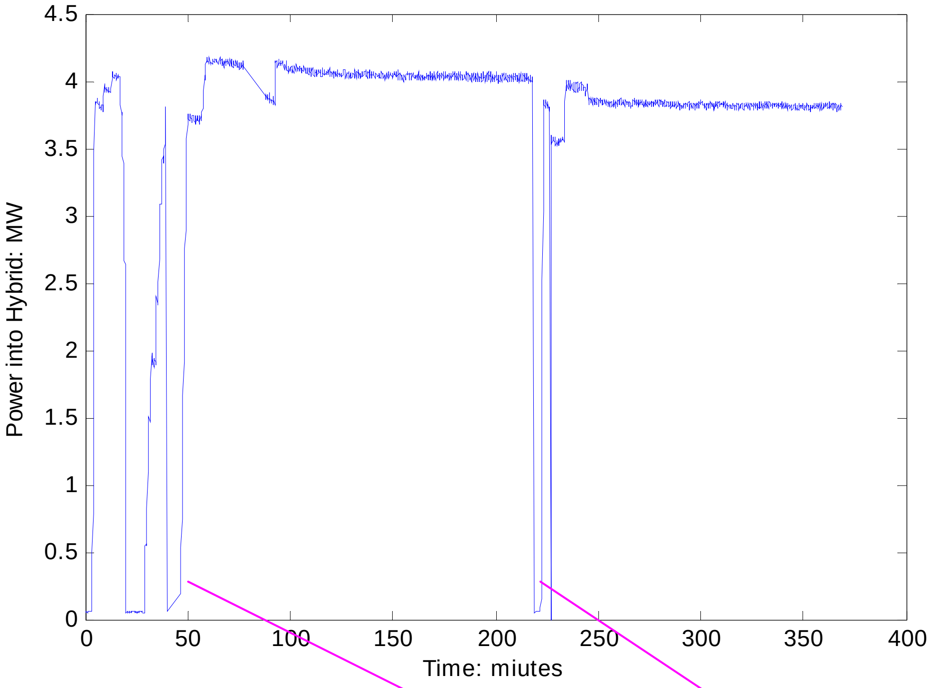
VTO

VTO -75Degrees test Jul-12-2007

The width of RF is 1ms and the repeat frequency is 1Hz



Hybrid



Modulator tripped off

Hybrid has been tested at 4MW for few hours at the pressure of 0psig. No breakdown during the test.

Faya Wang

Pressurization

We had planned to operate at 3 bar absolute (29 psig) pressure to avoid breakdown.

The cavity coupler input cannot be pressurized.

We’ve incorporated a pressure window into our system.

Both the VTO and Hybrid have been high power tested above 4 MW peak power ~1 ms and run stably without breakdowns - both pressurized and down to atmospheric pressure.

We’ve now relaxed our pressure to 2 bar absolute (14.5 psig) for the main distribution line up to the hybrid input, thus avoiding “pressure vessel” complications. From the hybrid on will be at atmosphere. Fermi will incorporate an additional window upstream to pressurize the klystron window to 3 bar as required by the manufacturer.

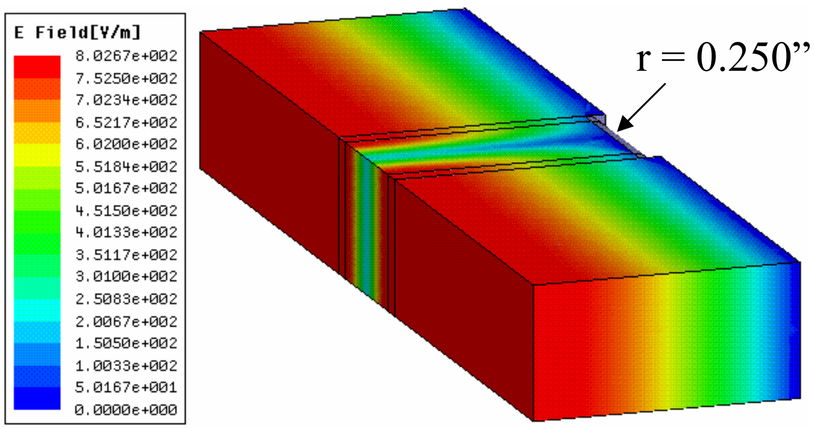
Half Wavelength Dielectric Plug Window

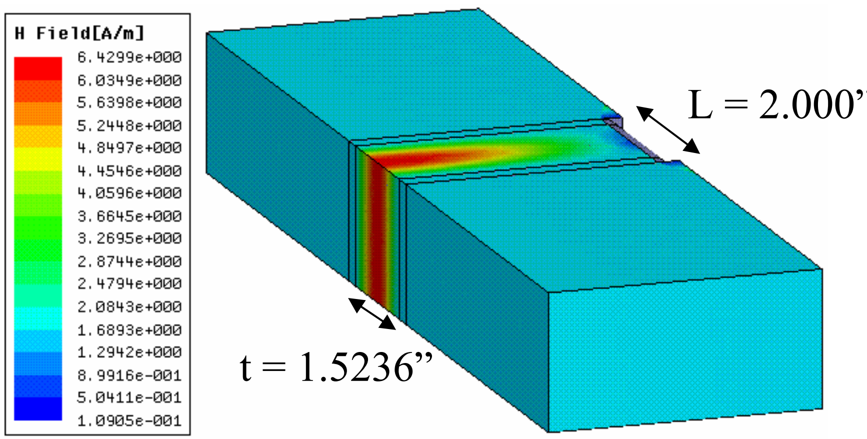
(in fabrication at SLAC)

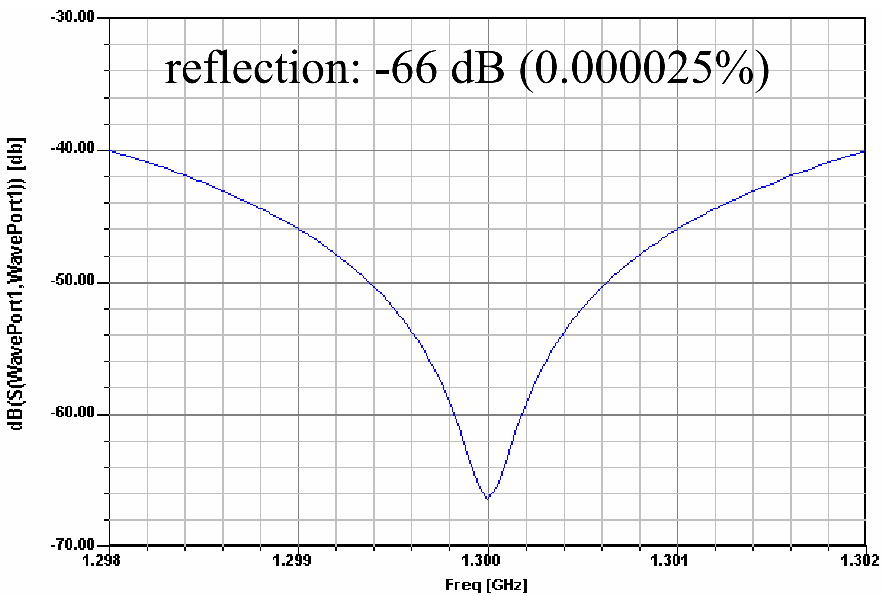
Alumina:

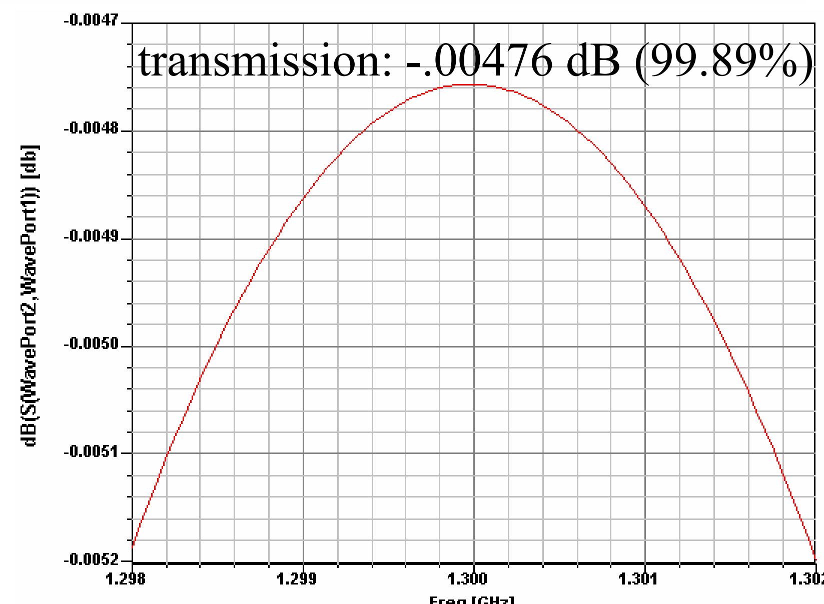
$\varepsilon = 9.37$, $\tan\delta = 0.00015$

$\rightarrow$ t = 1.5236”







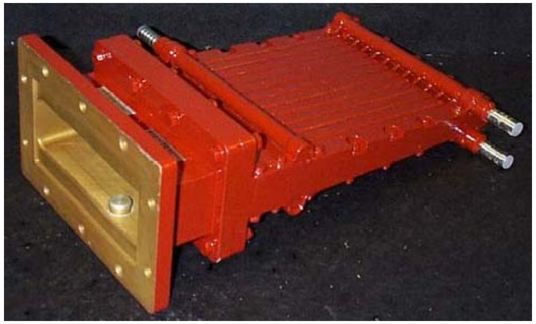


heating: 0.11%×650kW×1.6ms×5Hz = 5.72 W

Other Components

S.P.A. Ferrite, Ltd. (St. Petersburg)

MEGA INDUSTRIES



1 MW load

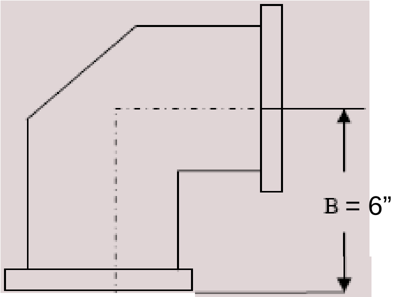
circulator

mitered E-plane bend

semi-flex waveguide

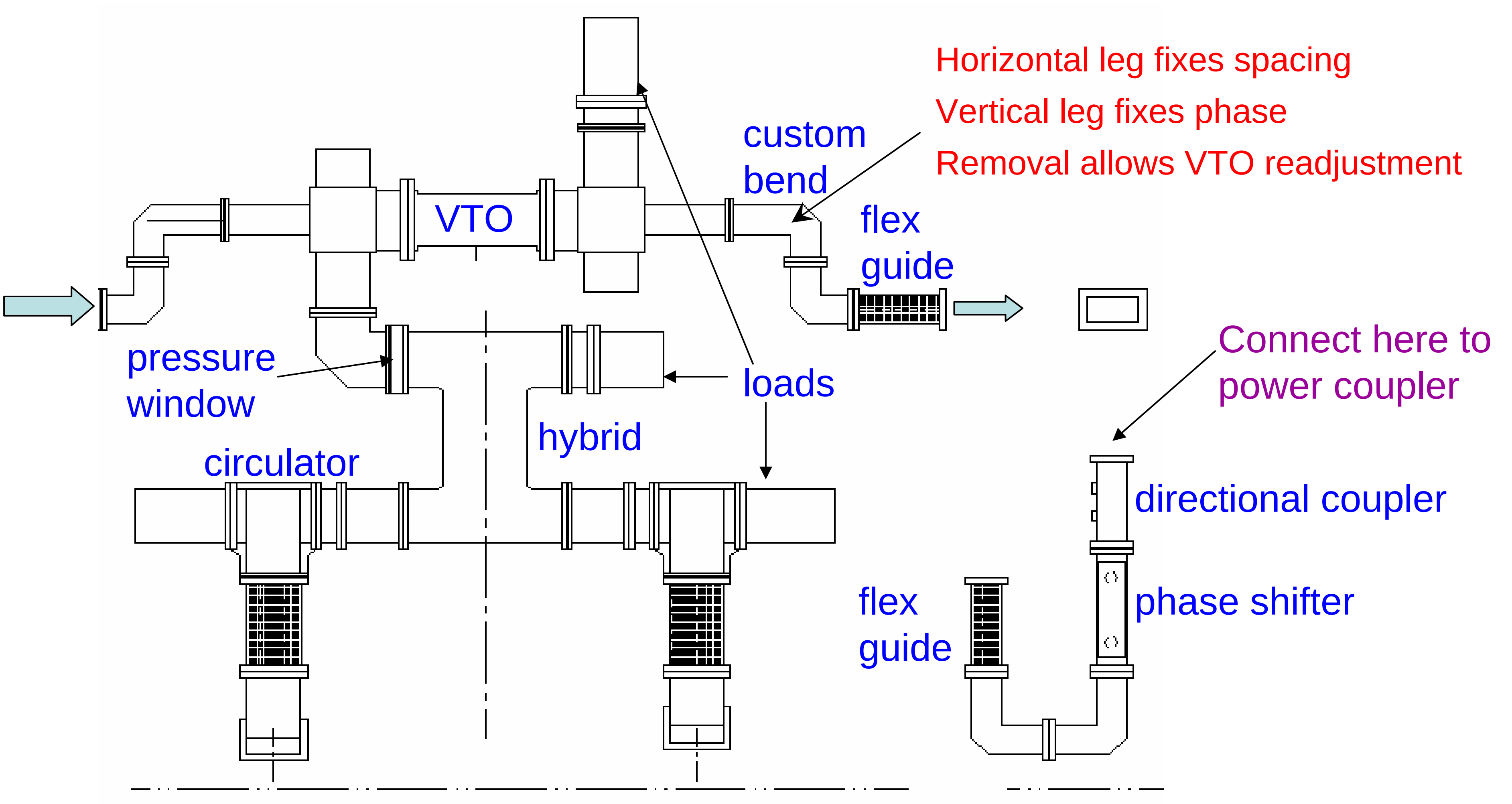
bidirectional coupler

DESY phase shifter

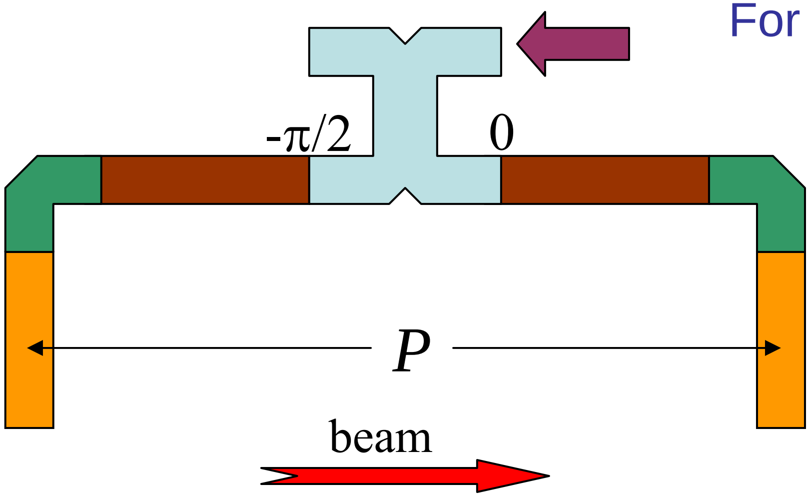


mitered H-plane bend

Modular 2-Cavity Sub-Assembly



Phasing Considerations



For cavity phasing: $\frac{\pi}{2} = -k_0 P + 2n\pi$

$$P = \frac{(2n - 1/2)\pi}{k_0} = (n - 1/4)\lambda_0$$

$$= (n - 1/4) \times 0.23061\text{m}$$

$n=6 : \rightarrow$ **P=1.3260m** = 52.205”

The centered hybrid must be fed opposite the beam direction to phase the RF for the beam with 1.3260m spacing.

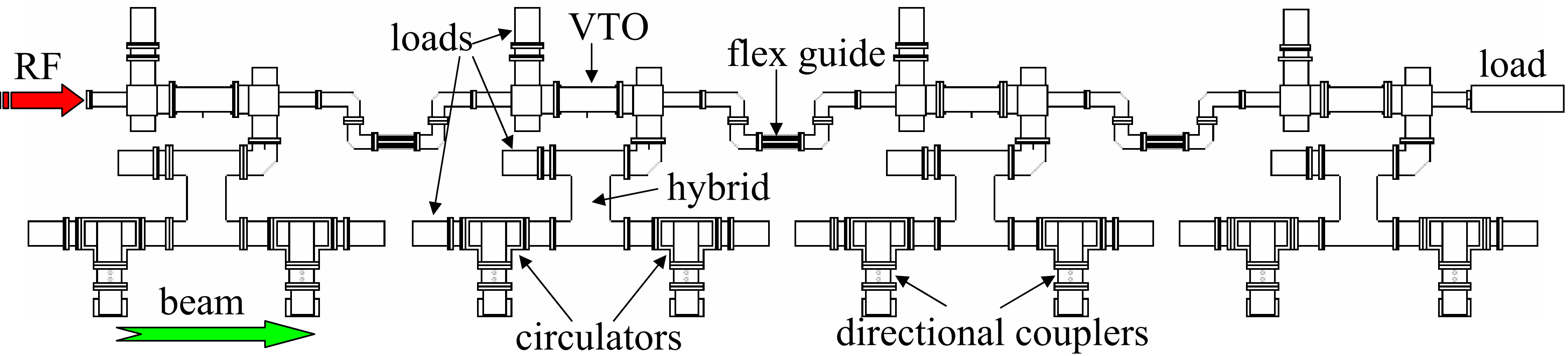
The first two cryomodules at NML will be Type 3+ with 1.3836m (= $6\lambda_0$) spacing, designed to allow energy recovery in X-FEL.

Type 4(+?) cryomodule will have correct spacing.

→ Operation without circulators will test reflection cancellation and cavity field stability (Is achievable isolation sufficient to avoid cavity beating problems?) , but configuration with circulators is required for beam running.

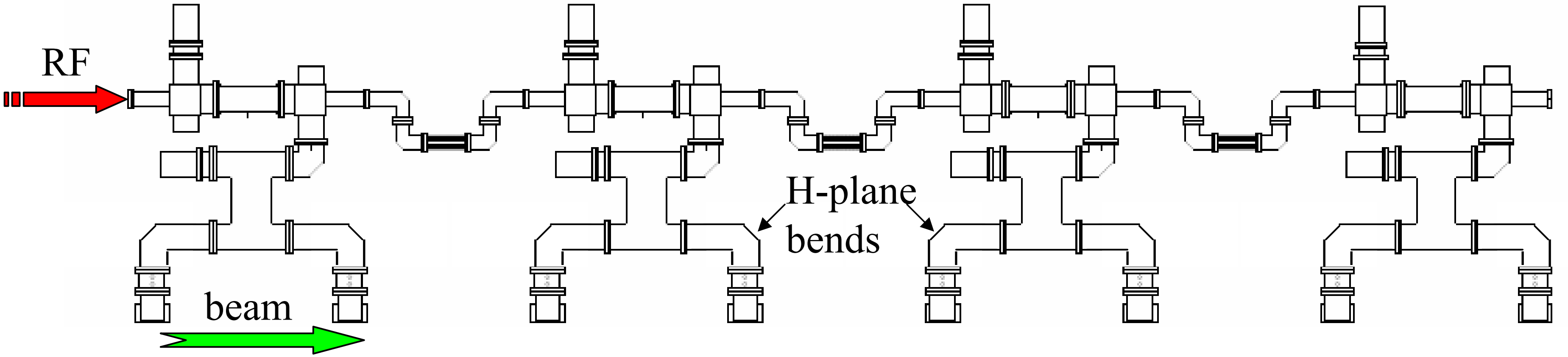
Alternative RF Distribution Layout

with circulators:



VTO's allow pair-wise adjustment of power distribution.

without circulators:



Hybrid feeding of equal-Q cavity pairs directs reflected power into hybrid loads.

Parts Cost Estimate for One Cryomodule of RF Distribution

VTO's	4 × $15,000	$60,000
Circulators	8 × $6,500	$52,000
Hybrids	4 × $8,000?	$32,000
Support frame	4 × $7,500	$30,000
Phase shifters	8 × $3,300	$26,400
E-plane bends (cust.)	22 × $925.12	$20,353
Loads (1 MW)	8 × $2,000	$16,000
Directional couplers	10 × $1,150	$11,500
Pressure windows	4 × $2,500?	$10,000
Gaskets	112 × $78.95	$8,842
E-plane bends (6"×6")	6 × $841.12	$5,047
H-plane bends	4 × $1,236.48	$4,946
Flex guide (atm.)	8 × $588	$4,704
Load (5 MW)	1 × $4,000	$4,000
Flex guide(press.)	4 × $756.75	$3,027
~8" spools	8 × $371	$2,968
Pressure section+inlet flange	1 × $1,000	$1,000
Nuts&bolts	4 × $250	$1,000
TOTAL		**$293,787**

Possible Changes for Next Cryomodule

- Explore cheaper VTO fabrication (casting?)
- Replace bottom double-bends with more compact U-bends (incorporate flex guide?)
- Eliminate thick walls (for pressurization) where not needed.
- Use shorter (5.906”) bidirectional couplers.
- Develop alternate or eliminate phase shifter?
- Develop cheaper low-power dummy load.
- Minimize number of flex guides in main line.