Overview of RF Distribution System and Cost Drivers

For Snowmass 2005 WG 2

Brian Rusnak
Lawrence Livermore National Laboratory

This work was performed under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

The RF System is a Dominant Cost Driver - As Indicated in the TTF Technical Design Report

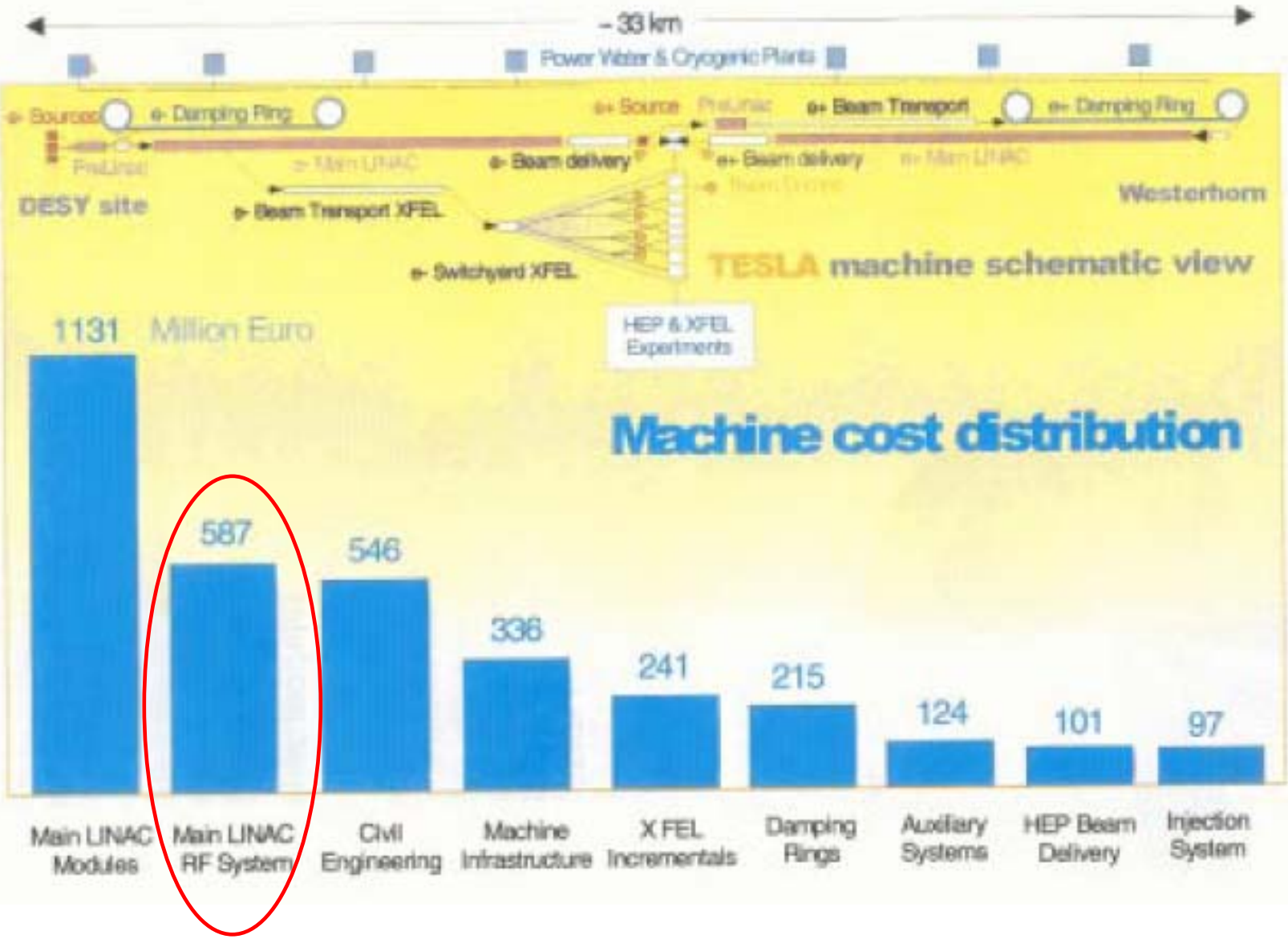
10.2.2 Main linac RF system

The RF system (chapter 3.4) is the second largest cost item with 587 million EUR. The most relevant parts with respect to cost are: klystrons; modulators and pulse transformers; wave guide distribution system; interlock and controls; low level RF system; HV cables. The cost estimates are based either on industrial studies or established costing procedures.

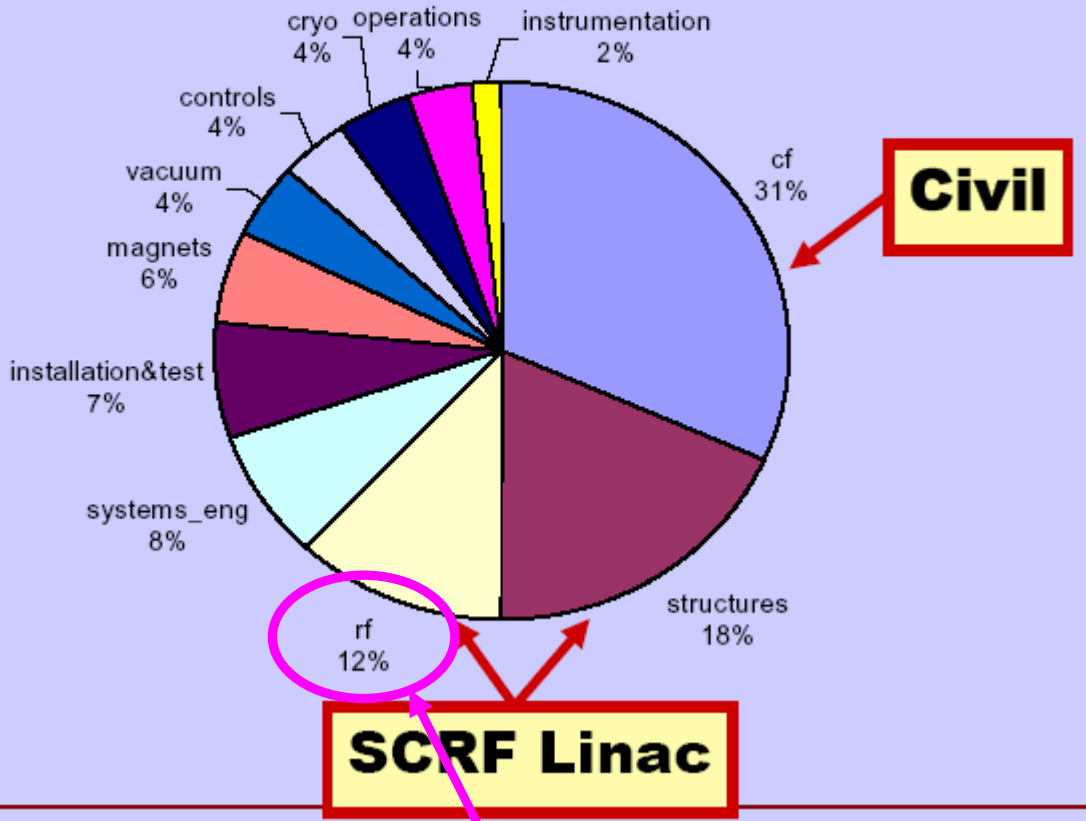
Klystron

The cost estimate is based on the production of the total number of klystrons by one manufacturer. A mass production study was made by the present prototype manufacturer (Thomson Tubes Electroniques, Velizy, France).

Prices for auxiliary power supplies (solenoid, filament, core bias, vacuum pump, electronics racks) were scaled from TTF costs using a standard industrial mass production costing rule, which states that a price reduction of 5% is achieved for each factor of two in production number (95% learning curve). The cost estimate for the racks is based on an estimate by a manufacturer.


~ 33 km
Power Water & Cryogenic Plants
e- Damping Ring
e+ Source
e+ Beam Transport
e+ Damping Ring
e- Beam delivery
e+ Beam delivery
DESY site
Beam Transport XFEL
Switchyard XFEL
Westerhorn
TESLA machine schematic view
HEP & XFEL Experiments
1131 Million Euro
Machine cost distribution
587
546
336
241
215
124
101
97
Main LINAC Modules
Main LINAC RF System
Civil Engineering
Machine Infrastructure
X FEL Incrementals
Damping Rings
Auxiliary Systems
HEP Beam Delivery
Injection System

Cost Breakdown by Subsystem

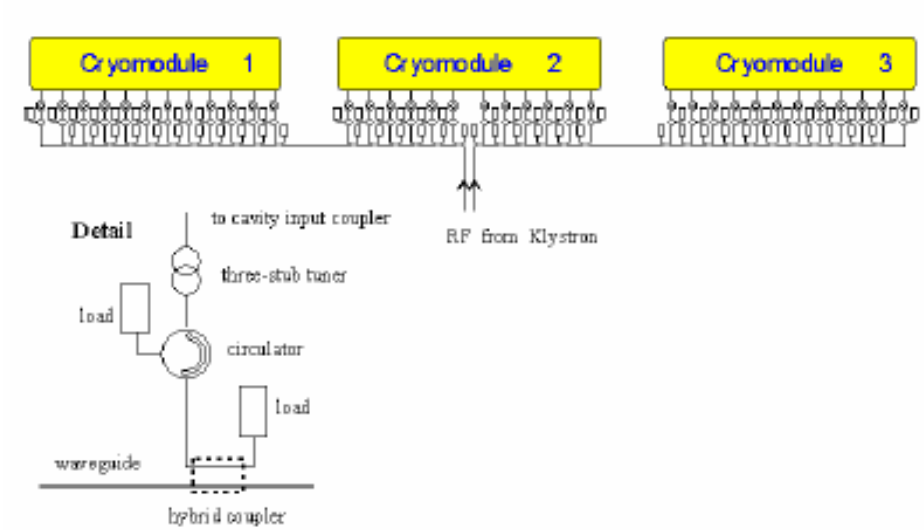


from Barish, Monday's GDE talk…

Depending on your favorite number for the total estimated cost of the ILC, this percentage gives a target value

So, Why Is It Expensive - It's Complex!

Waveguide type	WR650
Dimensions, mm	165.1 × 82.55
Material	A1
Flange type	PDR14
Max pulse power (theoretical for 30 kV/cm)	58 MW
Max pulse power (experience)	> 5 MW
Losses at 1.3 GHz (experience)	0.22%/m
Max waveguide losses (for 57 kW_{ave} 10 Hz)	125 W/m
Waveguide temperature (for 57 kW_{ave})	40 °C+$T_{ambient}$
Max thermal waveguide expansion	0.9 mm/m
Max phase-shift (over waveguide branch due to increasing waveguide width)	12 °
Total RF $power_{ave}$ for TESLA	36 MW
Total waveguide $losses_{ave}$	1.4 MW
Total circulator $losses_{ave}$	0.7 MW
Total length of waveguide system	85 km
Total length of circulator structure	10 km



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One Klystron is Split and Drives Between 16 and 32 Cavities Depending on Klystron Power

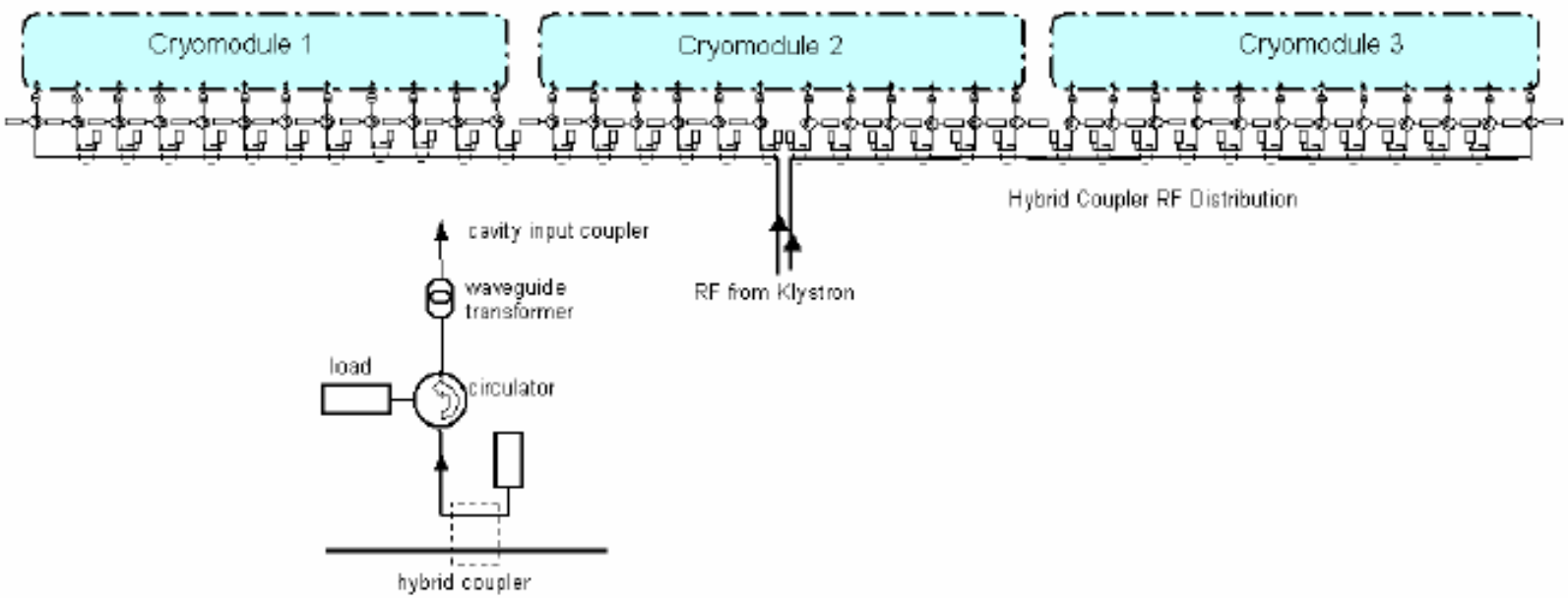
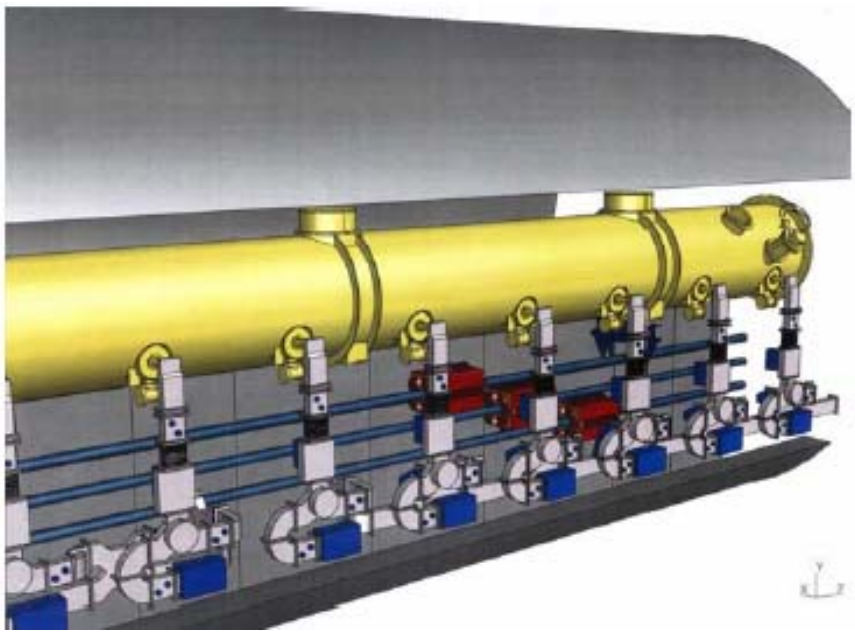


Figure 3.3.5: *RF waveguide distribution of one RF station.*

With All the Splitting and Distributing, a Whole Lot of RF Hardware is Needed



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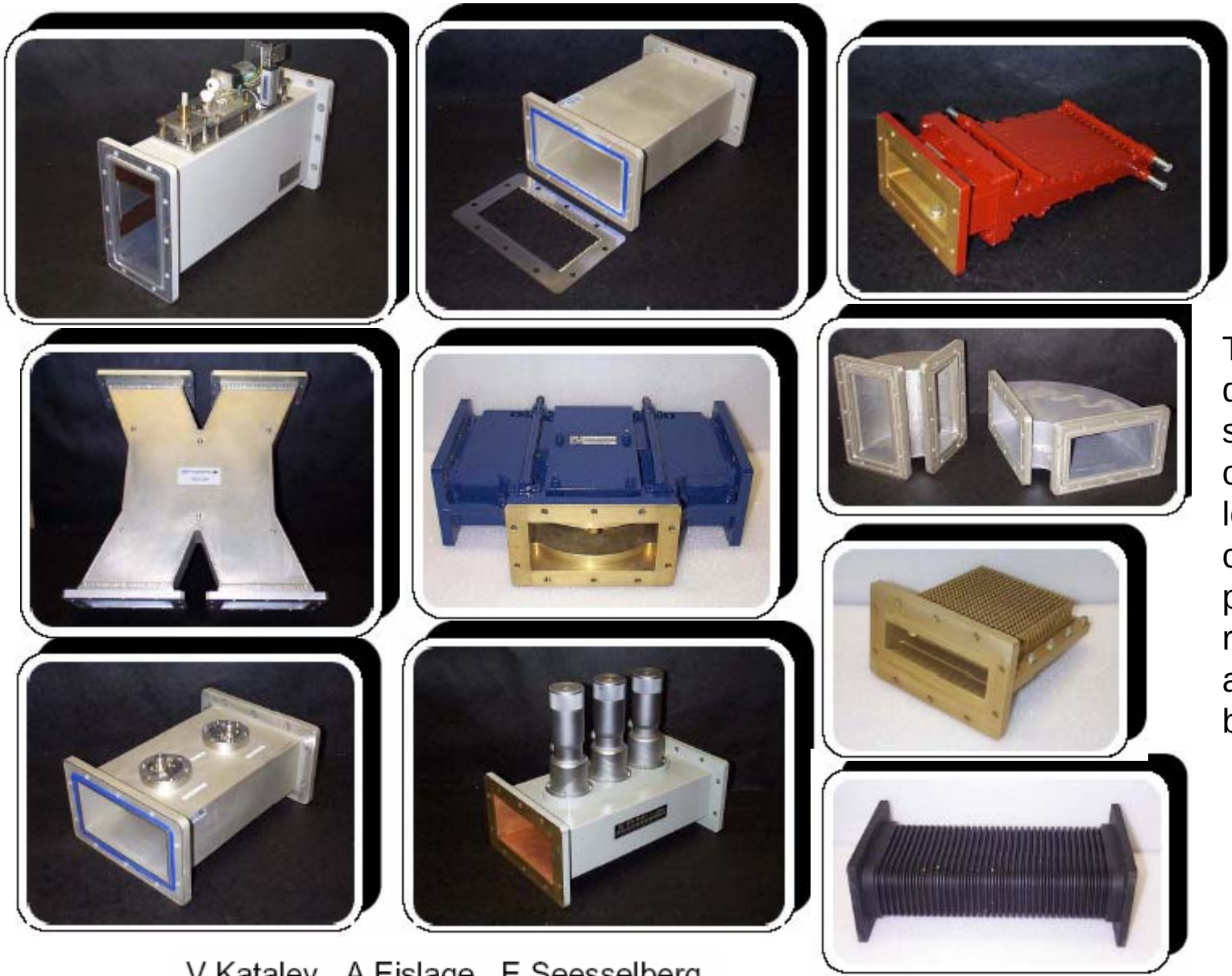

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The RF distribution system is comprised of lots of complex parts, requiring time and effort to build

To Try and Better Understand the Cost Drivers in the RF Distribution System, an Assessment was Done

- Some costs were obtained from the TESLA Technical Design Report, others from the FNAL assessment of the TDR (which were similar)
- Some costs were obtained from discussions with experts (though different people often had quite different experiences)
- Other costs were determined by project estimating the task of building the pieces of hardware, then adjusting numbers around for interconsistency
- In general, the approach was to assume that more complex pieces of hardware would be more costly that simple pieces.
  - complex: couplers, circulators, loads, hybrids, 3 stub tuners
  - simpler: straights, H bends, flex guides (?), directional couplers

- Overall, at this stage, the exact estimated numbers are not as crucial as the areas they identify as major cost drivers for the overall system

To Give Some Idea of Numbers…

1.1.2	Main Linac RF System			587
	1.1.2.1	RF Power Distribution & LLRF		
		1.1.2.1.1 RF Power Distribution	572	
		RF power circulators		
		RF power hybrid couplers		
		RF wave guides		
		RF transformers		
		RF bellows		
		RF signal couplers		
		1.1.2.1.2 Low Level RF Control	572	
		LLC digital feedback		
		LLC monitoring		
		LLC RF components		
		LLC miscellaneous		
		LLC master oscillator & distribution		
		1.1.2.1.3 (blank)		
	1.1.2.2	Klystrons & Interlocks		
		1.1.2.2.1 Klystron, solenoid & socket	572	
		1.1.2.2.2 Klystron interlocks	572	
		1.1.2.2.3 Klys, aux. PS Fil, Sol, Bias, Vac.	572	
		1.1.2.2.4 (blank)		

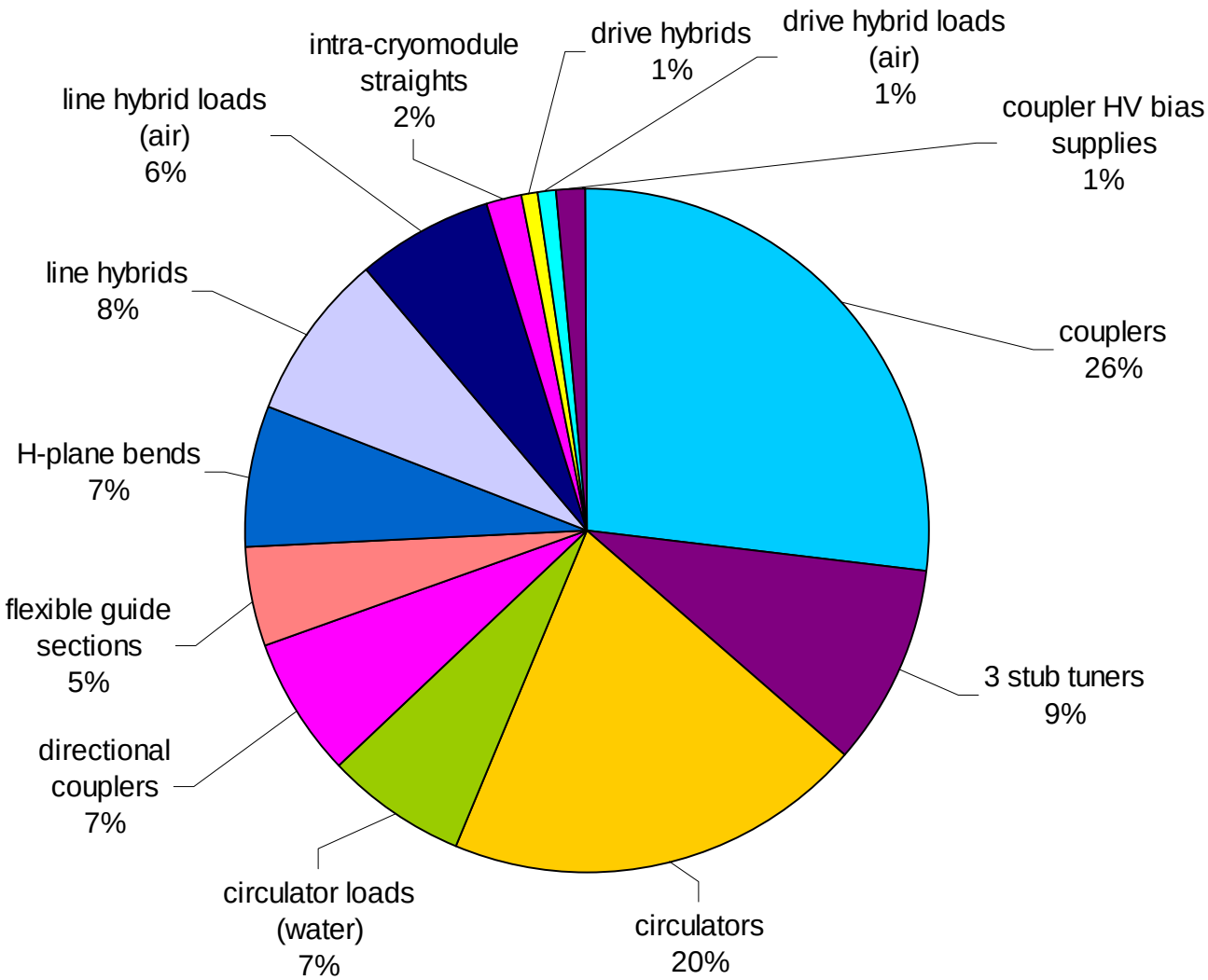
Some quantity numbers were taken from the FNAL Tesla Engineering Study Review

Approximate Present TTF RF System Costs

(K Euro, assuming $=Euro)	Fermi Modulator 1996 costs	TTF Costs	notes
Modulator	209		
IGBT switch	28		
Pulse Transformer	110		
Ignitron	8		
Interlocks and modulator controls	40		
Klystron auxiliary	6		
Modulator total	401		
(escalate * 1.16 for 2001 costs) ➔	465		
adding escalated labor (see below)	337		
less projected savings (see below	-157		
total Fermilab modulator cost	645	645	can drive 10 MW tube
Klystron, solenoid, socket (TH2104C) assumes a 10 MW tube costs same		180	5 MW - two 8 cavity modules 10 MW – four 8 cavity
Other			
Pulse power cables		-	not applicable at TTF
RF power distribution costs for 5 MW circulators and associated equipment has been subtracted because they will not be used in TESLA		280	for four 8 cavity modules
Interlocks (couplers 5.4 * 32)		162	
Tunnel cable connections		-	not applicable at TTF
LLRF		170	for 4 modules of 8 cavities
Driver		30	
TTF Total per system of four 8 cavity modules (32)		1467	+ ? for cables, connections
TESLA Total per four 9 cavity modules (36)		1028	(= 587 ME/572 klystrons)

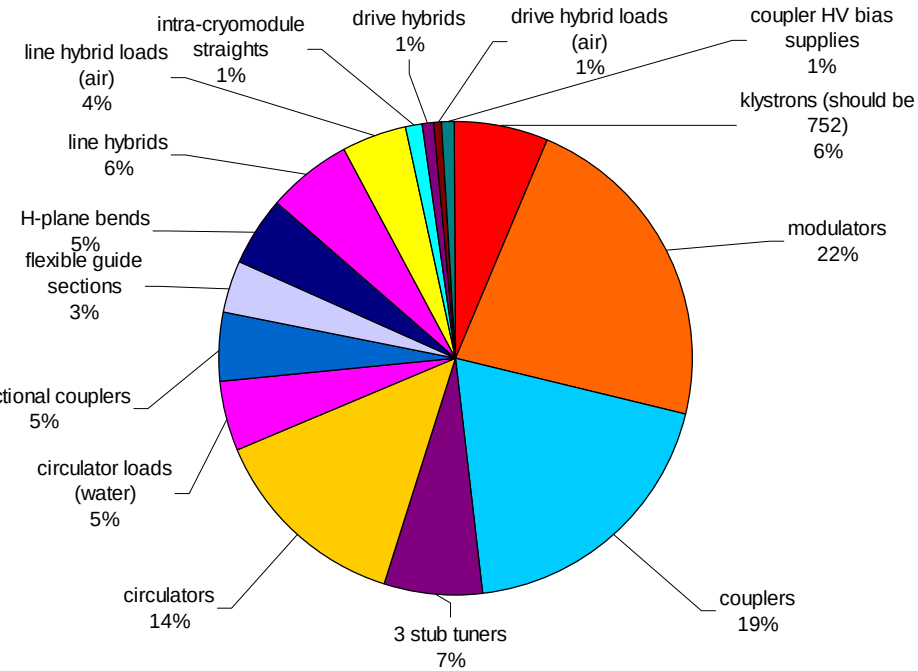
And costs as well…

An Assessment of Some Relative Costs - sans Klystron and Modulator



The assessment was done using a cost estimating exercise to determine what the relative costs of components were based on an independent evaluation of materials and effort to build components

An Estimate of Some Costs - Includes Klystron and Modulator



WR 650 waveguide

SRF cavities	24064	check	
cavities/cryomodule	8	check	
cavities/klystron	32	check	16 per 5 MW, 32 per 10 MW
klystron peak power (MW)	10	check	
cryomodules	3008		

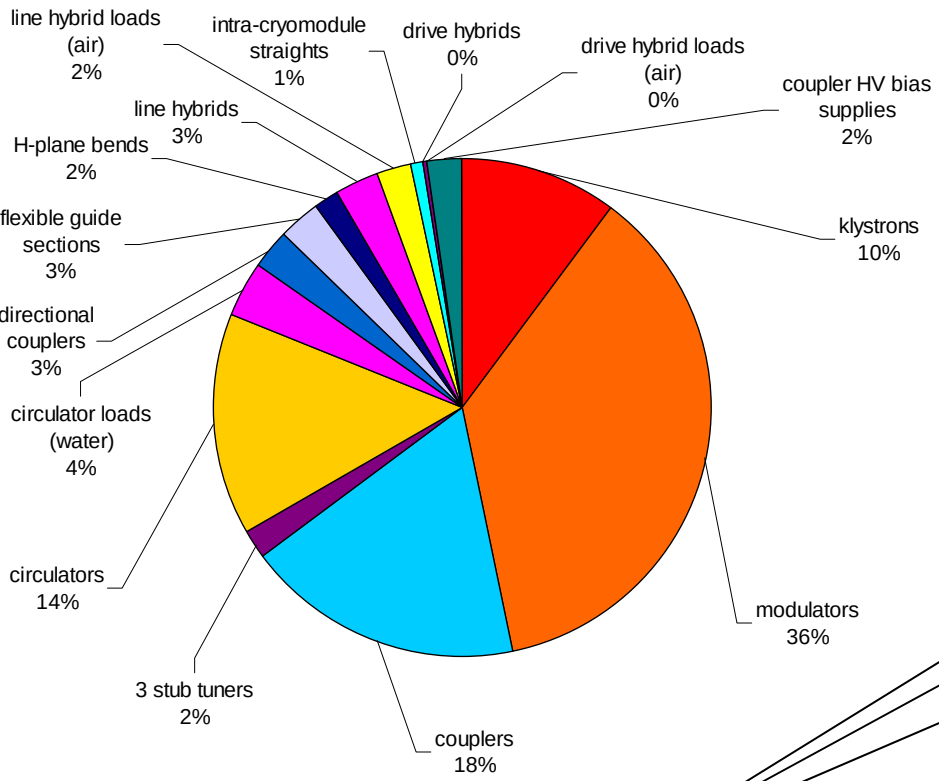
yikes! (recall the 12% number…)

THIS IS FOR THE ENTIRE ILC SYSTEM **total=** **$3,666,988,880**

	numbers	cost/unit	sub cost	% of total
klystrons	752	$180,000	$135,360,000	3.69
modulators	752	$645,000	$485,040,000	13.23
couplers	24064	$34,402	$827,849,728	22.58
3 stub tuners	24064	$12,103	$291,234,560	7.94
circulators	24064	$25,029	$602,297,856	16.42
circulator loads (water)	24064	$8,601	$206,962,432	5.64
directional couplers	24064	$8,498	$204,483,840	5.58
flexible guide sections	24064	$6,232	$149,954,816	4.09
H-plane bends	48128	$4,172	$200,765,952	5.47
line hybrids	24064	$10,455	$251,577,088	6.86
line hybrid loads (air)	24064	$7,931	$190,851,584	5.20
intra-cryomodule straights	24064	$2,163	$52,050,432	1.42
drive hybrids	1504	$10,455	$15,723,568	0.43
drive hybrid loads (air)	1504	$7,931	$11,928,224	0.33
coupler HV bias supplies	24064	$1,700	$40,908,800	1.12

As this was a first attempt, I assume I was being too conservative in my costing. I attempted to “shoot low” to hit closer to what I thought a good 12% number might be…

A Further Estimate of Some Costs - Includes Klystron and Modulator



SRF cavities	24064	check	
cavities/cryomodule	8	check	
cavities/klystron	32	check	16 per 5 MW, 32 per 10 MW
klystron peak power (MW)	10	check	
cryomodules	3008		

THIS IS TO TRY TO HIT THE 12% NUMBER
THIS IS FOR THE ENTIRE ILC SYSTEM

total= $1,329,987,200

	numbers	target! cost/unit	sub cost	% of total
klystrons	752	$180,000	$135,360,000	10.18
modulators	752	$645,000	$485,040,000	36.47
couplers	24064	$10,000	$240,640,000	18.09
3 stub tuners	24064	$1,000	$24,064,000	1.81
circulators	24064	$8,000	$192,512,000	14.47
circulator loads (water)	24064	$2,000	$48,128,000	3.62
directional couplers	24064	$1,500	$36,096,000	2.71
flexible guide sections	24064	$1,400	$33,689,600	2.53
H-plane bends	48128	$500	$24,064,000	1.81
line hybrids	24064	$1,500	$36,096,000	2.71
line hybrid loads (air)	24064	$1,250	$30,080,000	2.26
intra-cryomodule straights	24064	$500	$12,032,000	0.90
drive hybrids	1504	$1,000	$1,504,000	0.11
drive hybrid loads (air)	1504	$1,200	$1,804,800	0.14
coupler HV bias supplies	24064	$1,200	$28,876,800	2.17

Some of these costs appear very low to me

Even with drastic cost reductions, this does not appear consistent with 12% of accepted ILC TEC

Thoughts on Assessments and RF Distribution Costs So Far

- Costs on the ILC RF distribution system will be driven up by two main factors:
  - **Very big costs on smaller numbers of items, e.g., modulators - $645,000 x 752**
  - **Very big number of moderately expensive items, e.g., couplers - 24,000 x $10,000**
  - **For some perspective, in the analysis, ILC will need ~250,000 RF plumbing parts! At an *average* of $1000 each, that's $250,000,000.**
- This assessment is an attempt to start to look at high dollar items to help prioritize cost reduction efforts
- This also gives suggests (to me) that we had better realize some significant cost reductions due to quantity to meet some of the present cost estimates out there