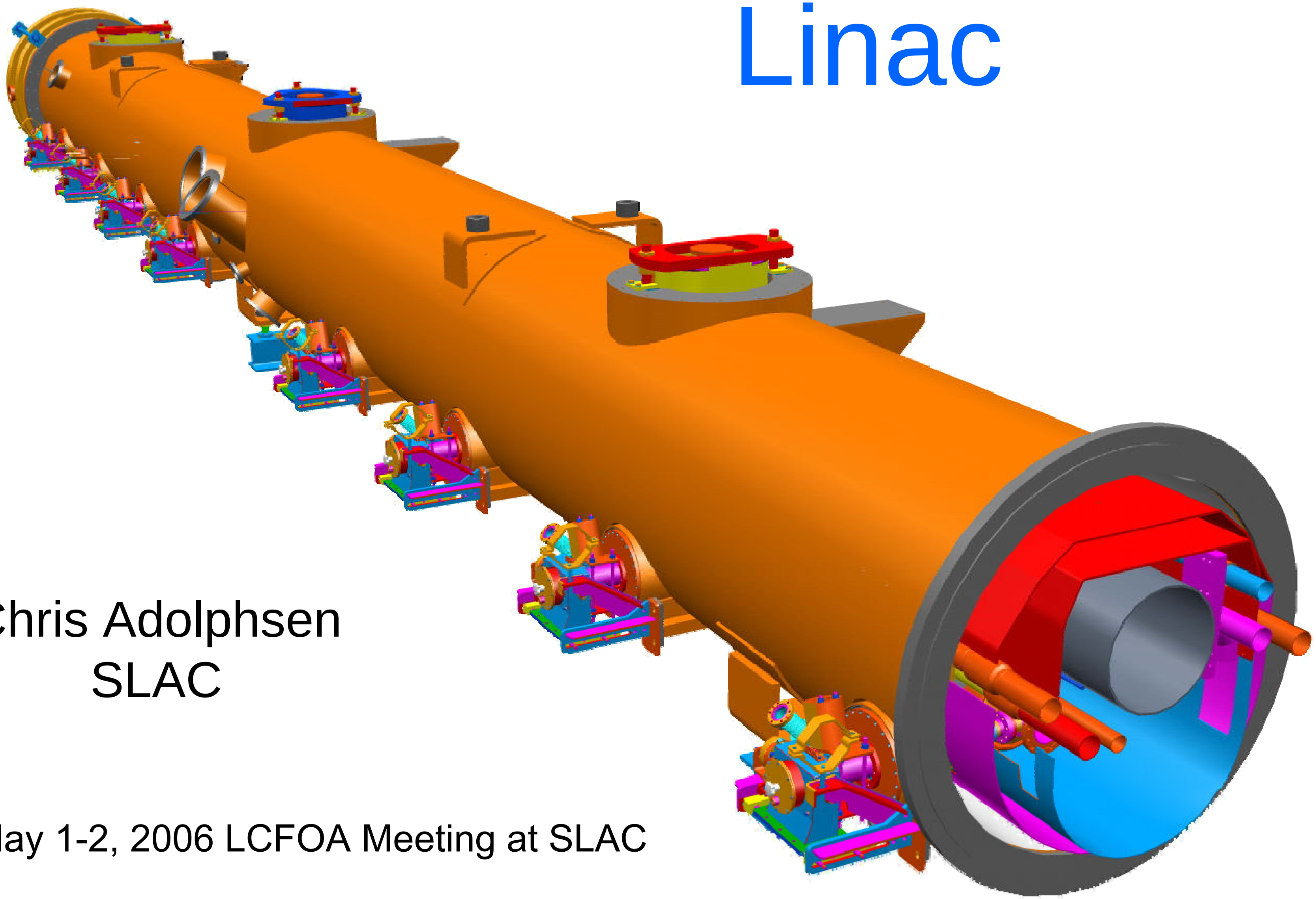
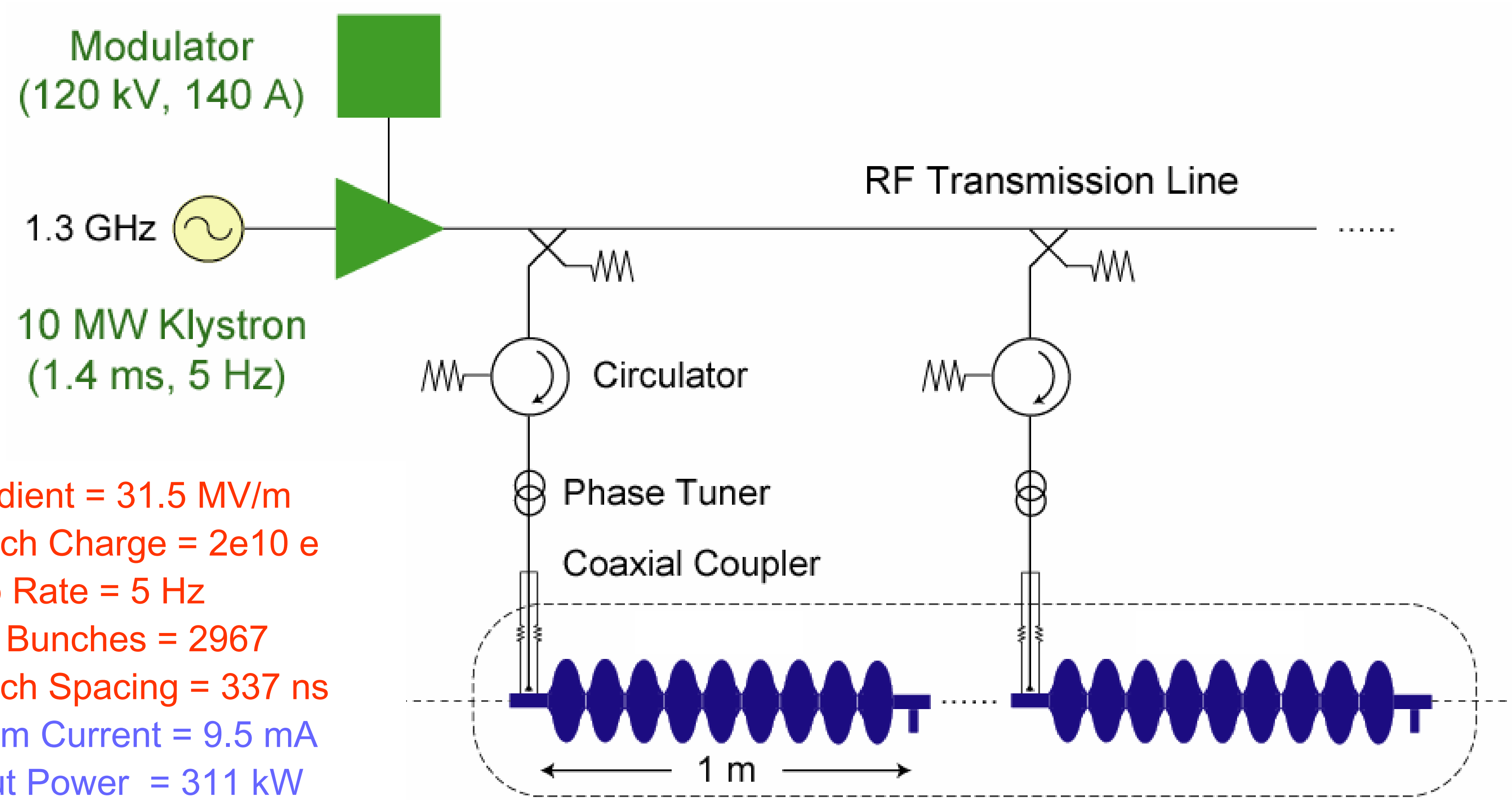
ILC Main Linac



Chris Adolphsen
SLAC

May 1-2, 2006 LCFOA Meeting at SLAC

ILC Linac RF Unit (1 of ~ 600)



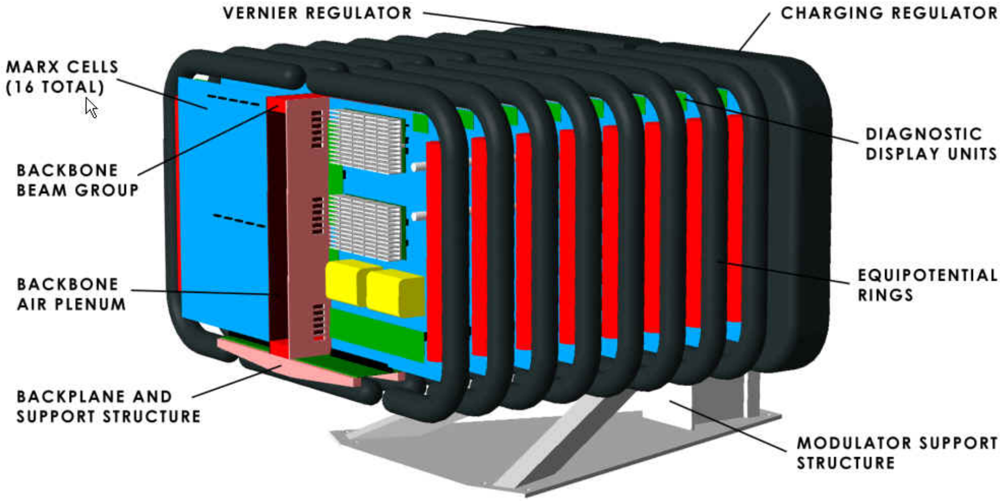
Gradient = 31.5 MV/m
Bunch Charge = 2e10 e
Rep Rate = 5 Hz
# of Bunches = 2967
Bunch Spacing = 337 ns
Beam Current = 9.5 mA
Input Power = 311 kW
Fill Time = 565 μs
Train Length = 1000 μs

Cryomodule 1 of 3
(8 Cavities per Cryomodule)

Modulators (115 kV, 135 A, 1.5 ms, 5 Hz)

Baseline: Pulse Transformer Style Modulator

Alternative: Marx Generator Modulator



(~ 2 m Long)

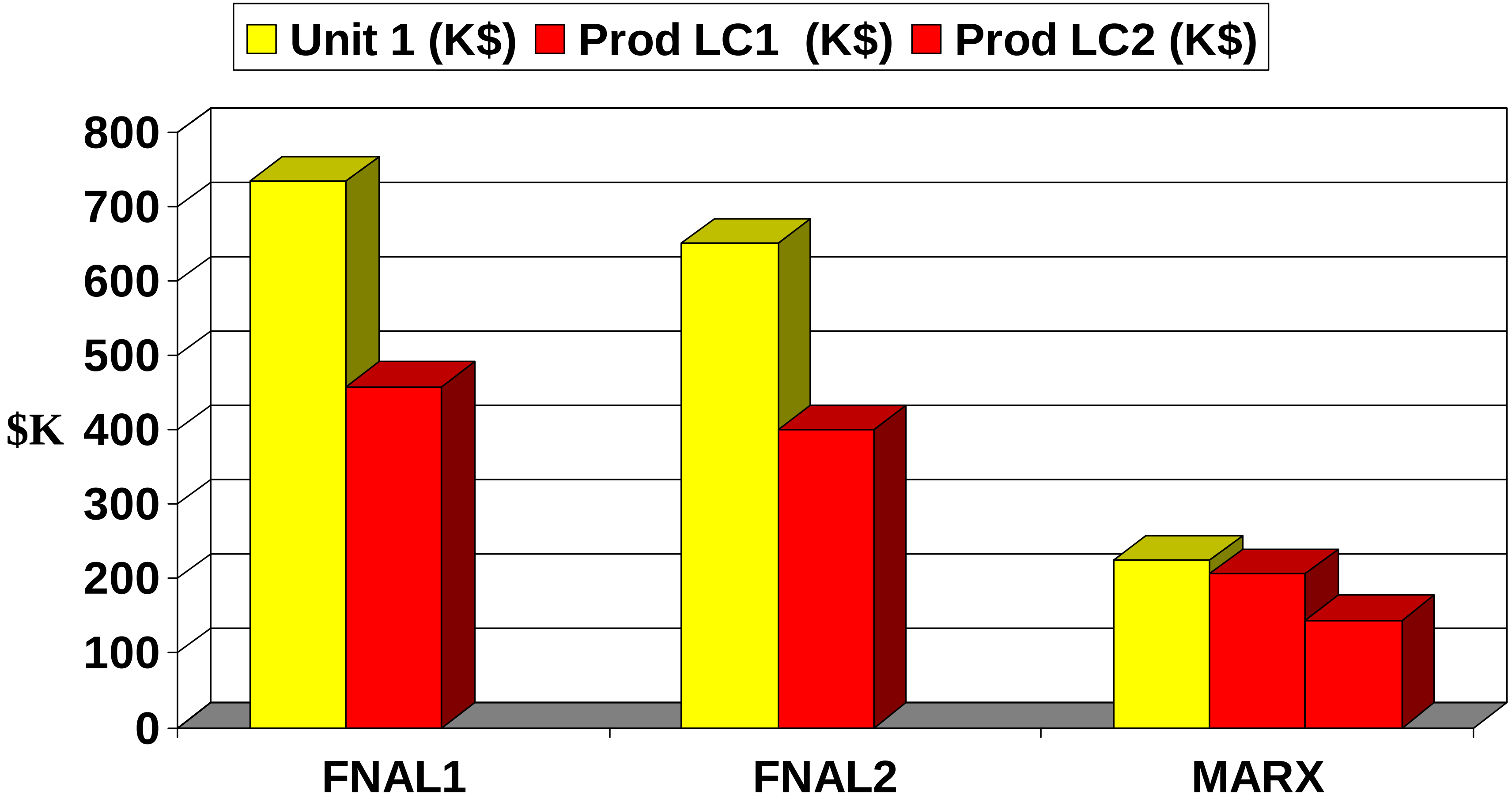
To generate pulse, an array of capacitors is slowly charged in parallel and then discharged in series using IGBT switches.

Will test full prototype in 2006

Modulators

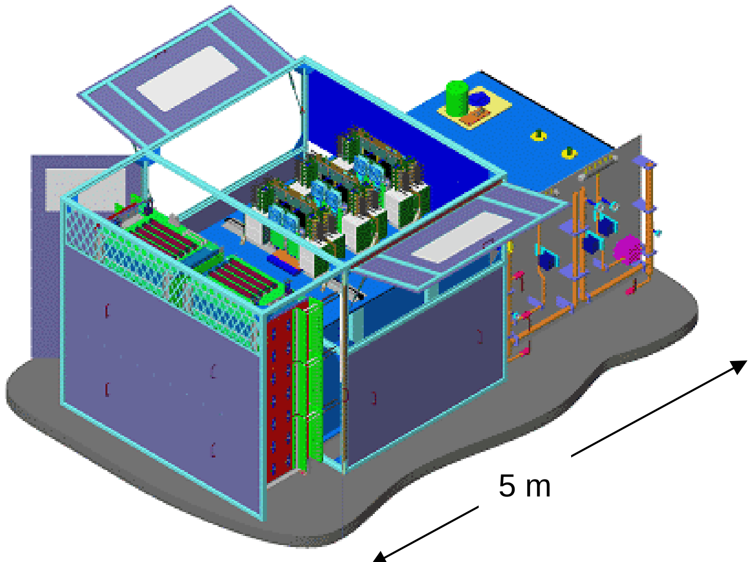
- Baseline: Pulse Transformer
  - 10 units have been built over 10 years, 3 by FNAL and 7 by industry.
  - 8 modulators in operation – no major reliability problems (DESY continuing to work with industry on improvements).
  - FNAL working on a more cost efficient and compact design, SLAC building new dual IGBT switch.
- Alternative: Marx Generator
  - Solid state, 1/n redundant modular design for inherent high availability, reliability.
  - Highly repetitive IGBT modules (90,000) cheap to manufacture.
  - Eliminating transformer saves size, weight and cost, improves energy efficiency.

Modulator Unit 1 vs. 600 Unit Avg. Production Cost Estimates

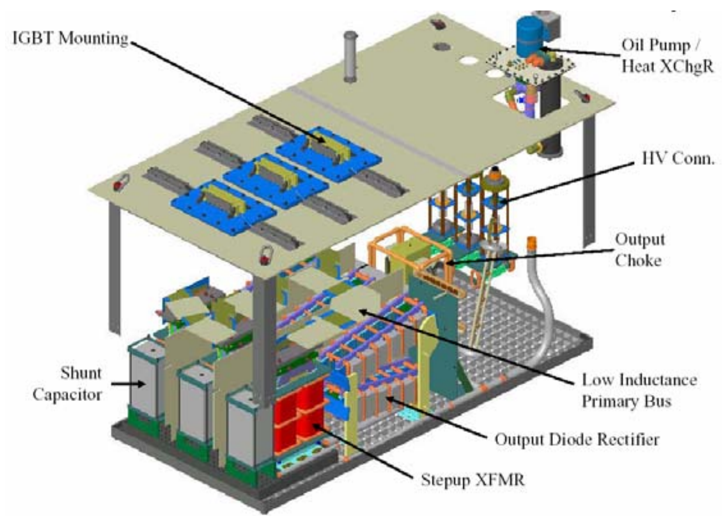


Other Modulator R&D

- Three Marx SBIR Phase I proposals awarded in US.
- DTI Direct Switch due at end of 2006 for evaluation at SLAC.
- SNS High Voltage Converter Modulator being operated, optimized, evaluated at SLAC L-Band Test Facility.



SNS High voltage power conditioning converter/modulator assembly



Klystrons

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

Thales

CPI

Toshiba

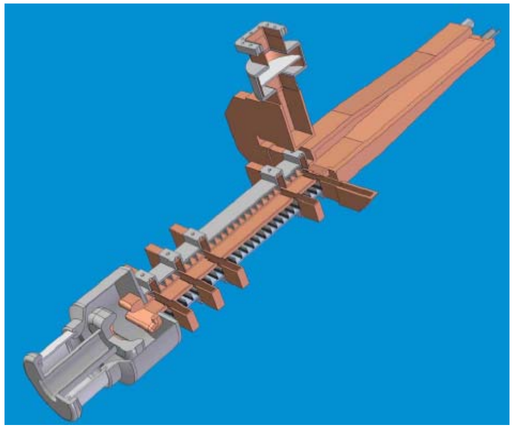
Status of the 10 MW MBKs

- 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, has run 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)

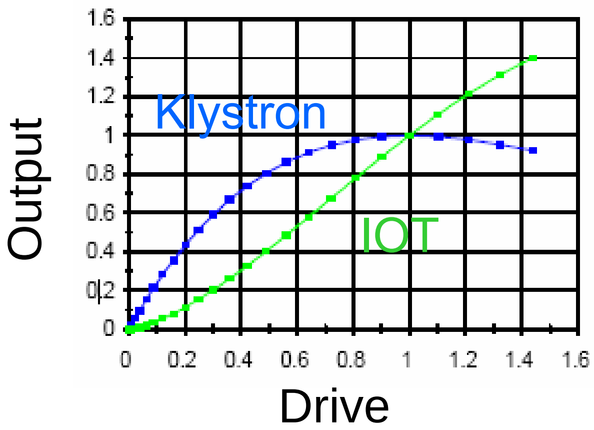
Parameters similar to 10 MW MBK



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

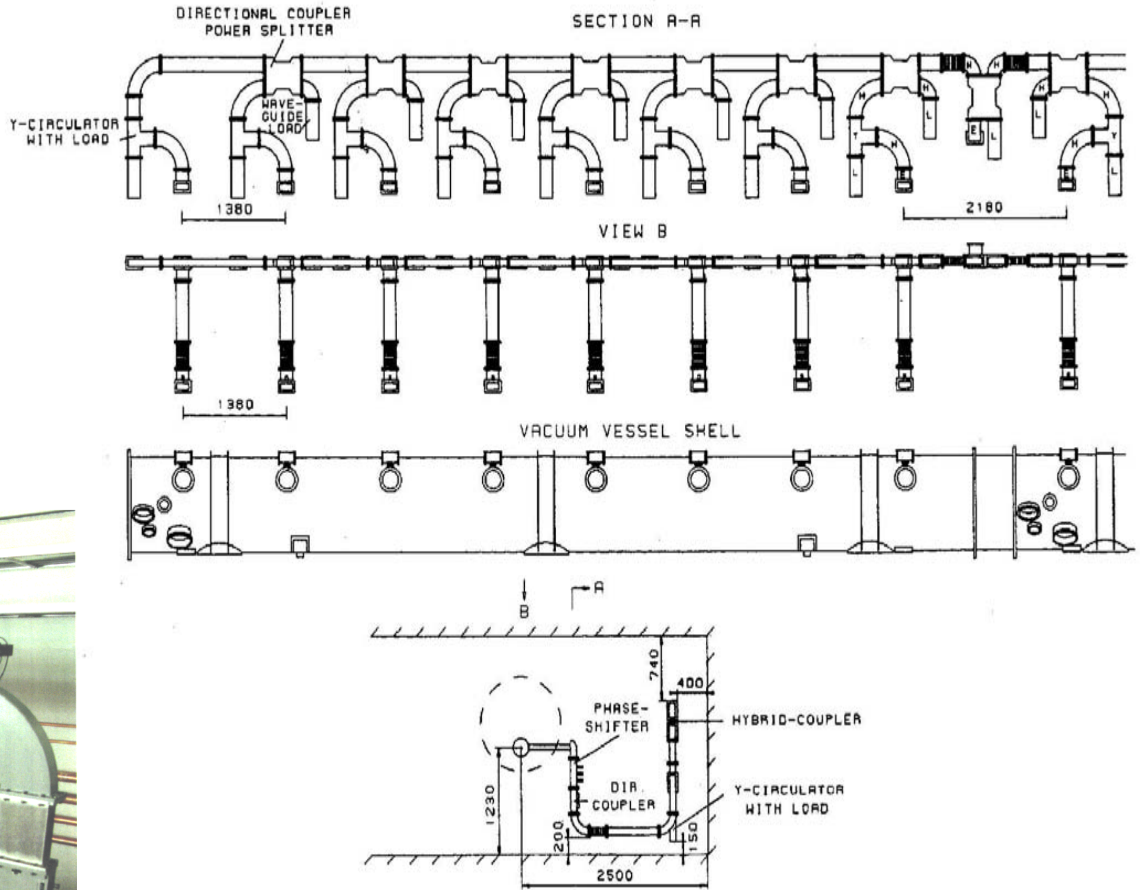
KEK

Klystron Summary

- The 10 MW MBK is the baseline choice – continue to support tube companies to make them robust (DESY needs 35 for XFEL although will run at 5 MW).
- SLAC funding design of a 10 MW sheet-beam klystron (will take several years to develop).
- Backup 1: Thales 2104C 5 MW tube used at DESY and FNAL for testing – it appear reliable (in service for 30 years) but has lower effiency compared to MBKs (42% vs 65%).
- Backup 2: With increased DOE funding next year, propose to contract tube companies to develop high efficiency, single-beam, 5 MW klystron.

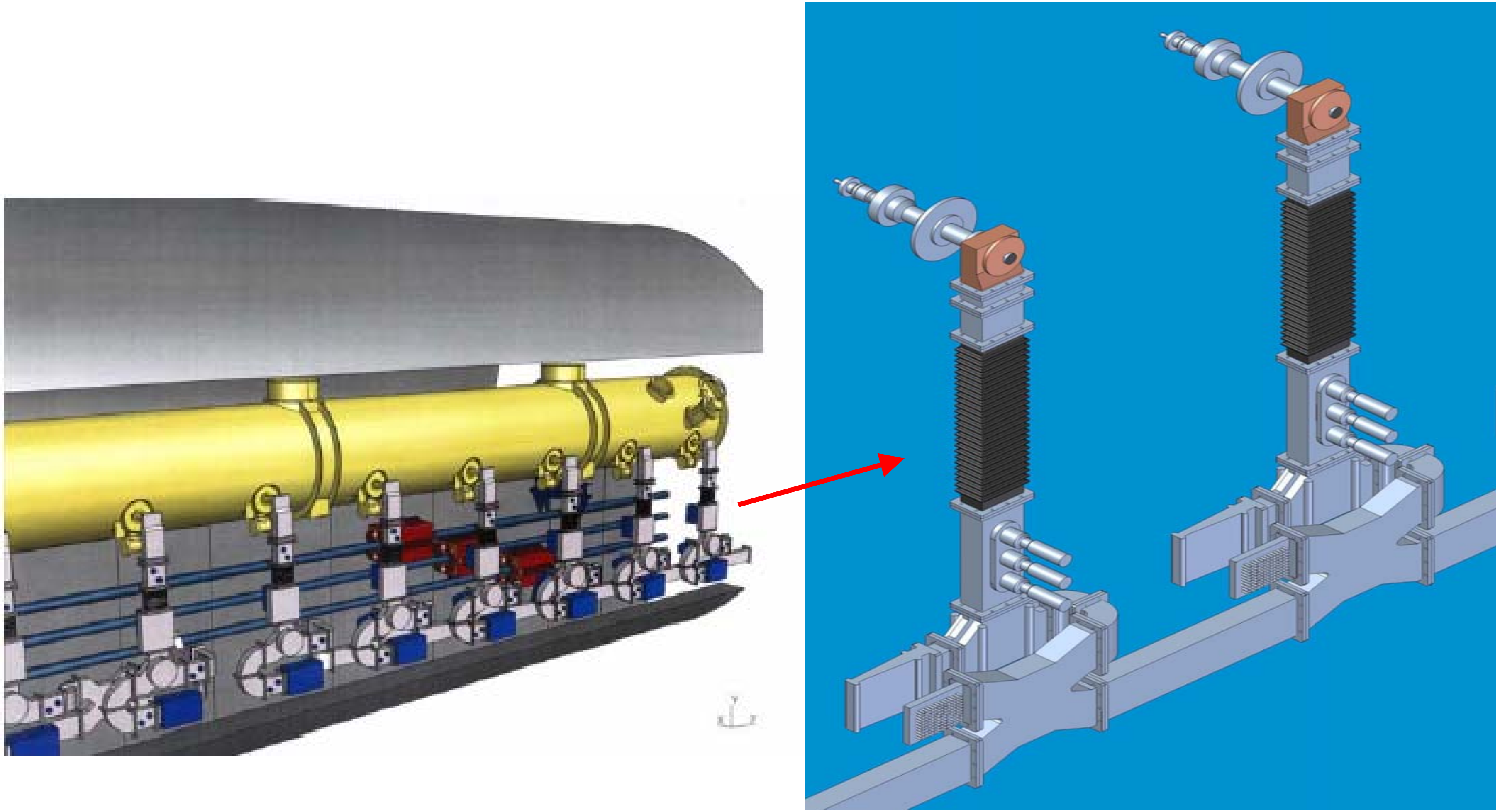
RF Distribution

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



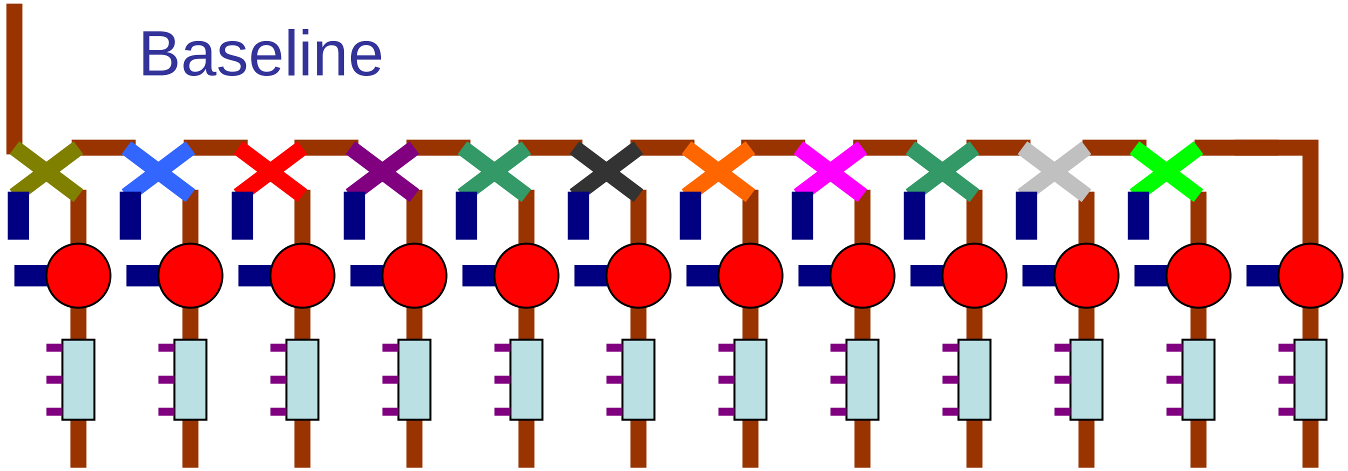
Need more compact design
(Each Cavity Fed 350 kW, 1.5 msec Pulses at 5 Hz)

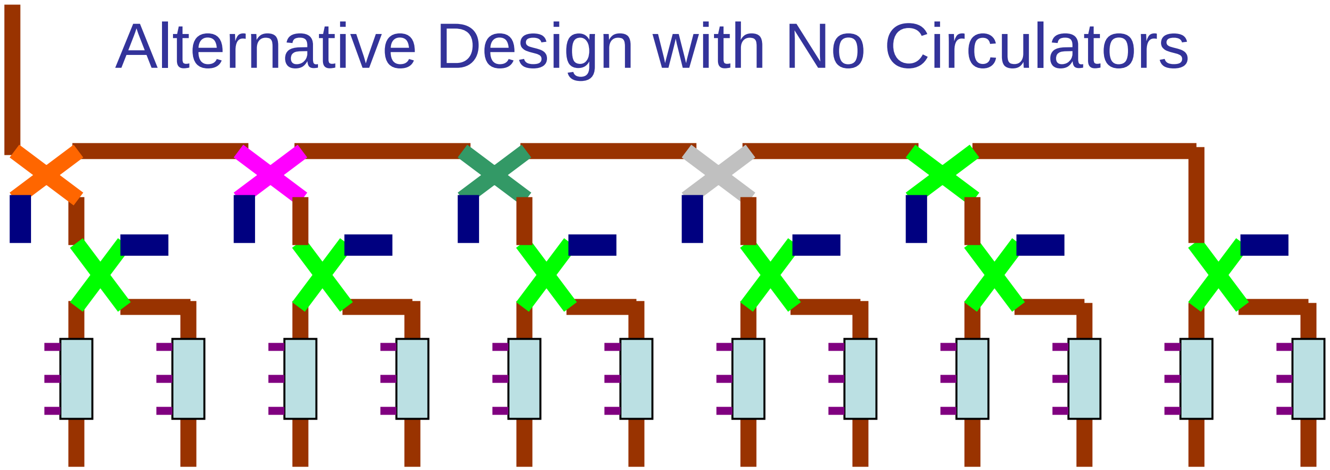
Two of ~ 16,000 Feeds



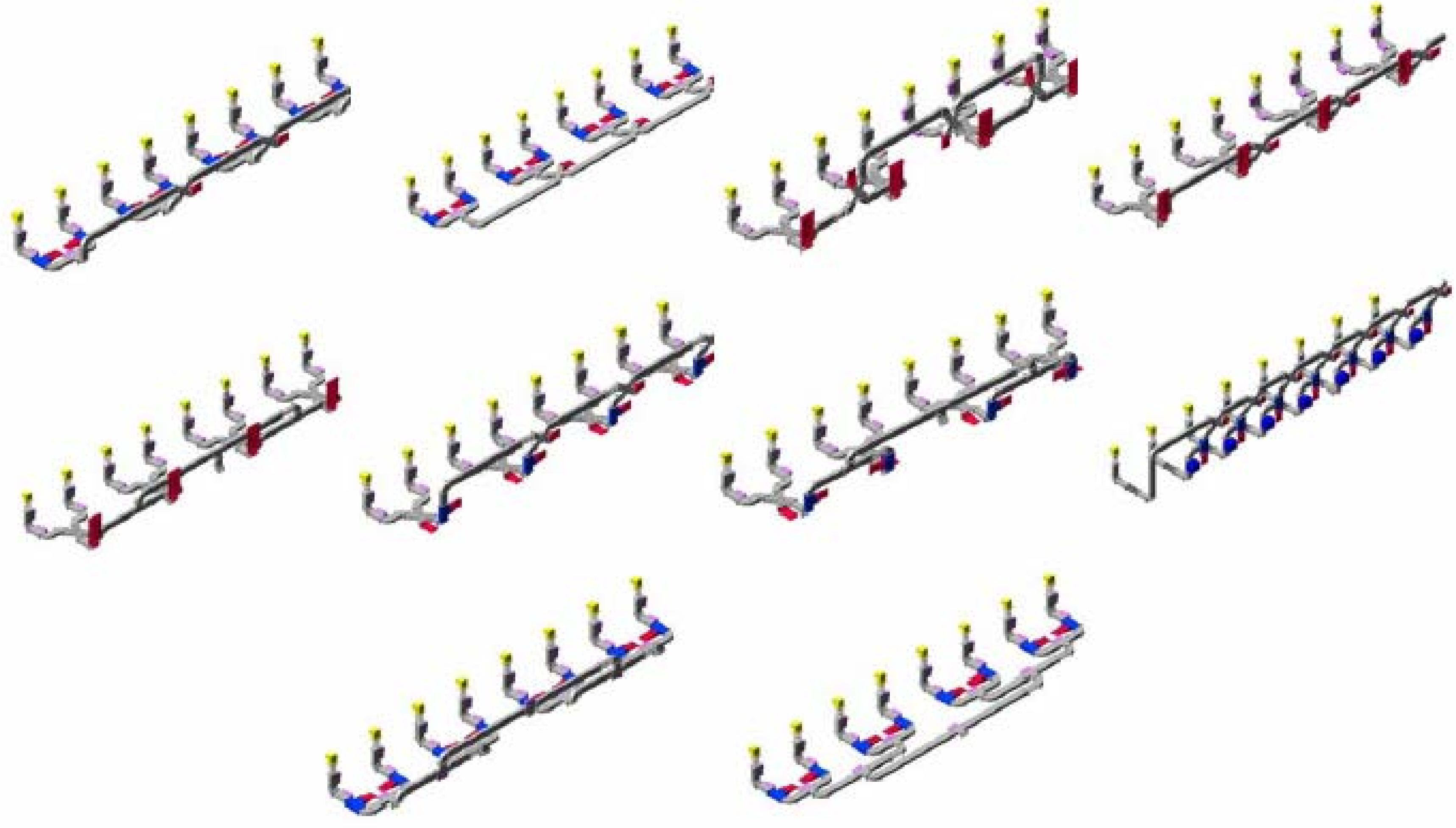
And should consider simplifications

(circulators are ~ 1/3 of cost)

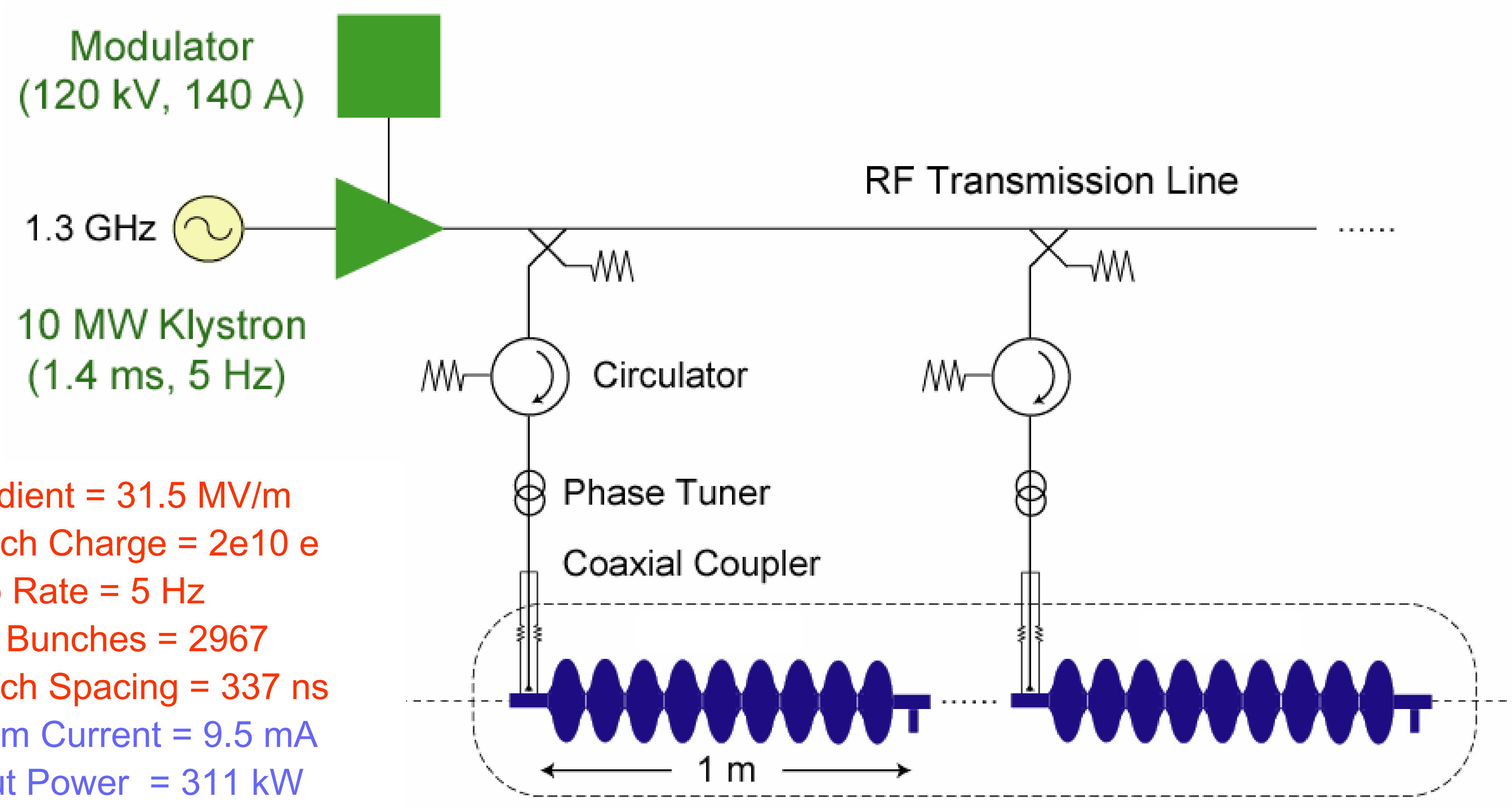




Alternative Waveguide Distribution Schemes Being Considered by DESY



ILC Linac RF Unit (1 of ~ 600)



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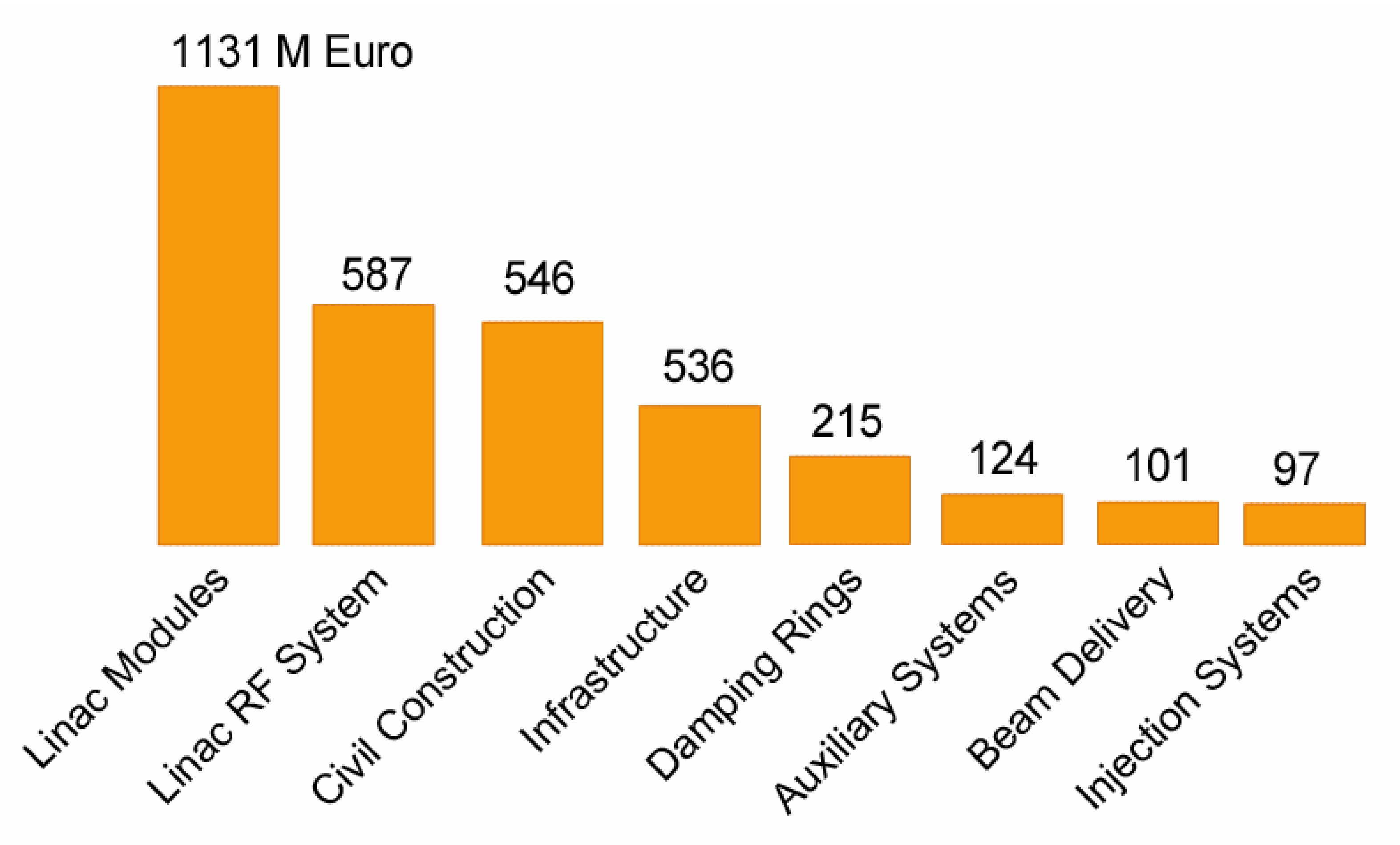
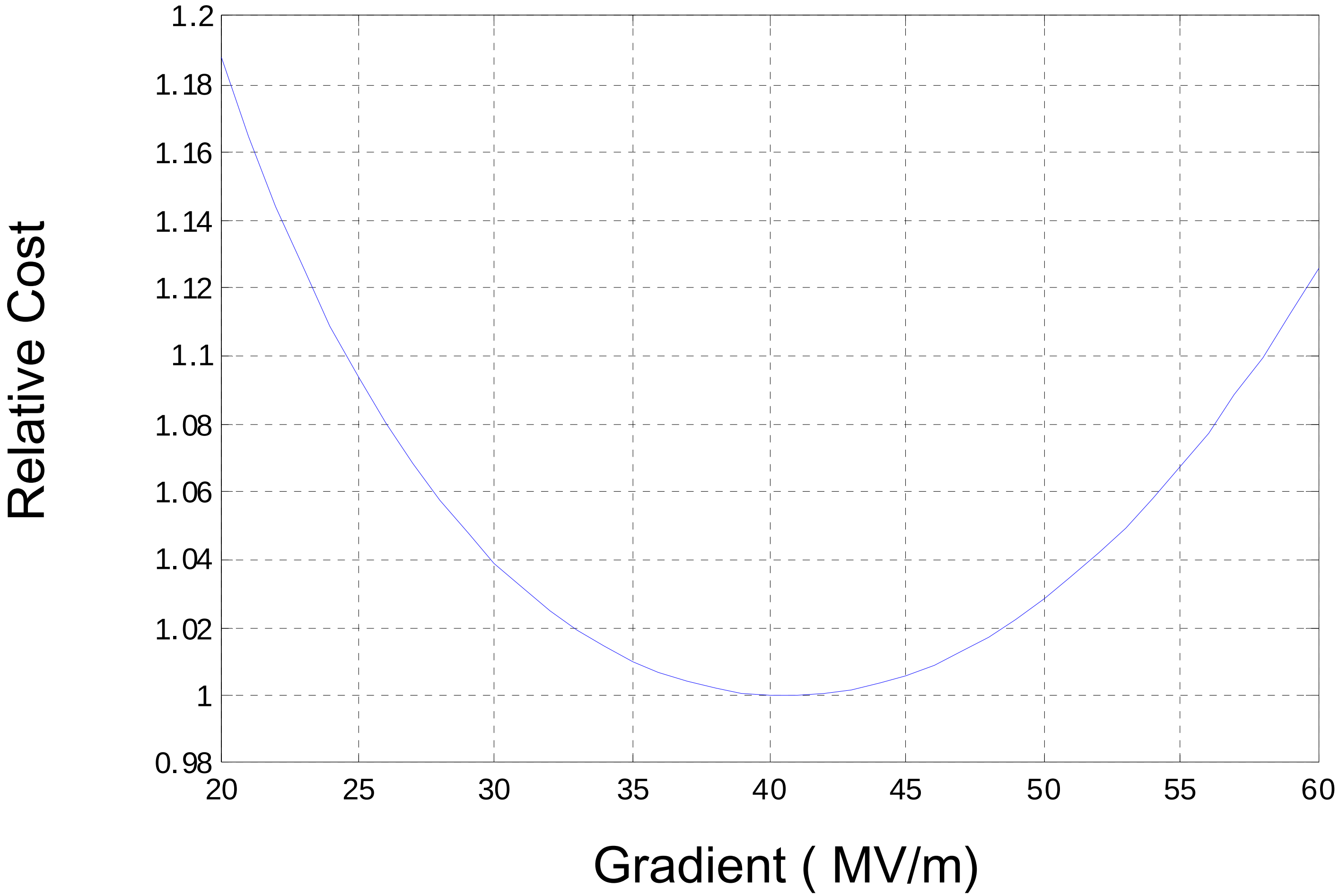
Cryomodule 1 of 3
(8 Cavities per Cryomodule)

TESLA TDR Cost Estimates
(Main Linacs ~ 2/3 Total Cost)

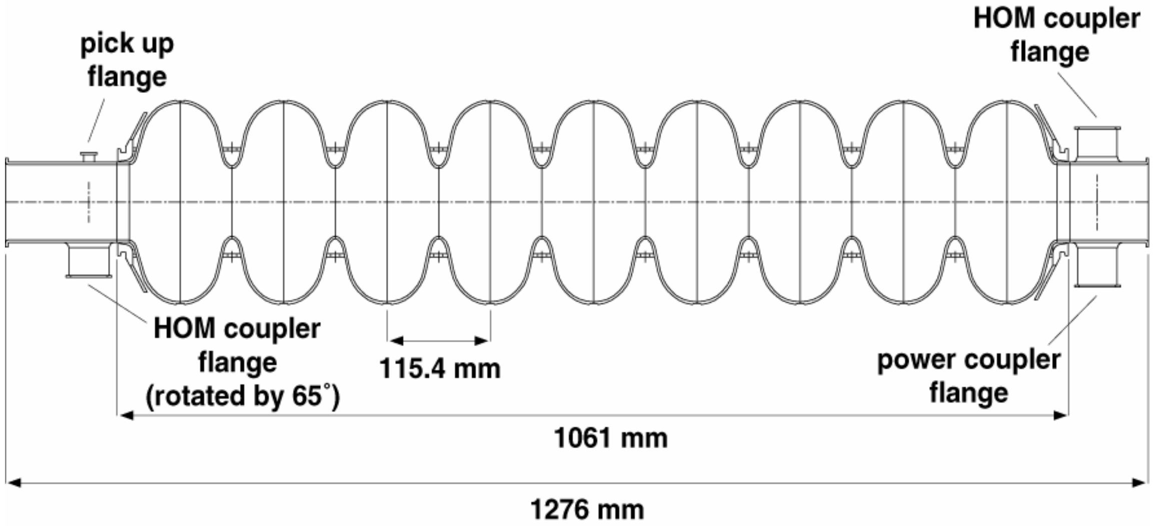


Relative Total Project Cost* (TPC)
-vs-
Linac Gradient



* TPC is for 500 GeV machine in US Options Study.

1.3 GHz TESLA Cavities

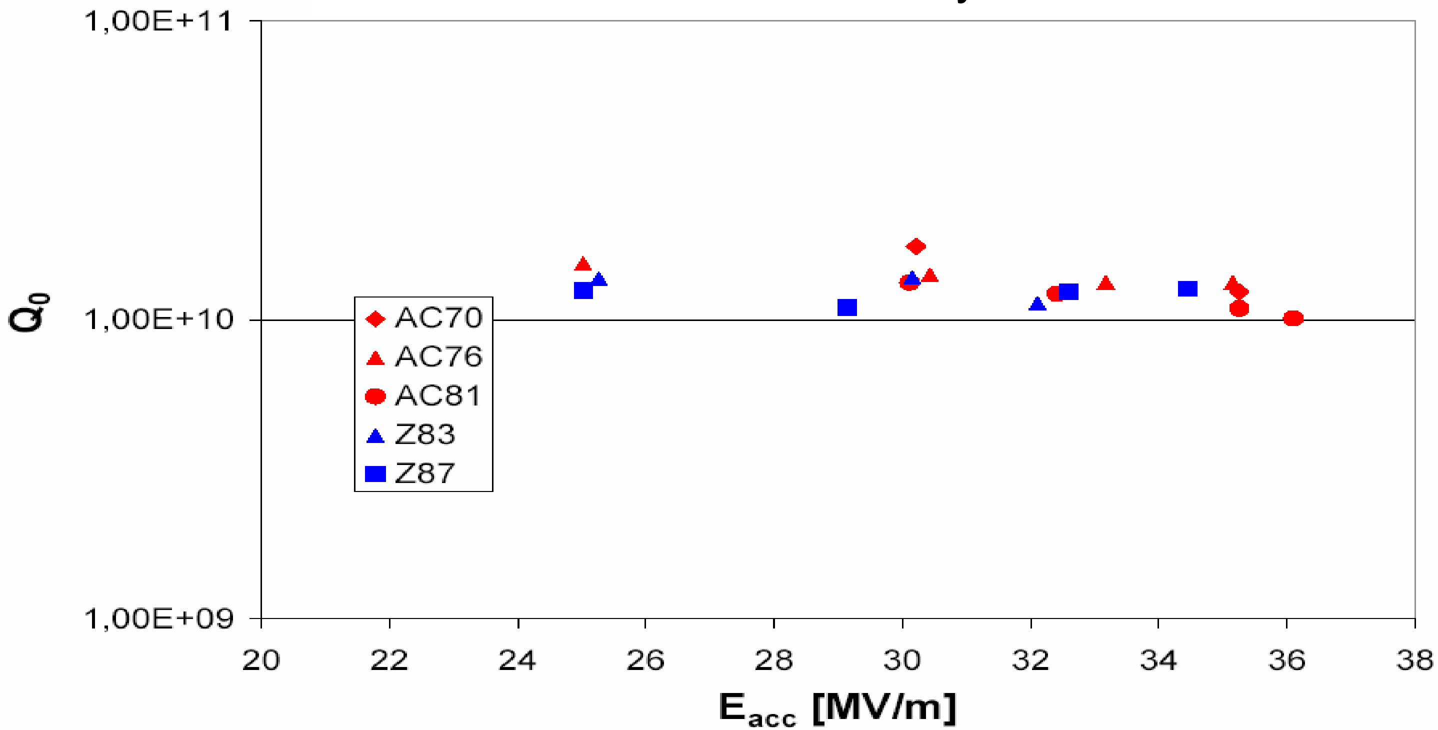


- For ILC, would accept only ‘vertically’ tested cavities (using CW rf without high power couplers) that achieve gradients > 35 MV/m and Q > 8e9 (discard or reprocess rejects). About 16,000 required.
- When installed in 8 cavity cryomodules, expect stable operation at an average gradient of 31.5 MV/m and Q = 1e10 (rf system designed for 35 MV/m).
- Derating due to desire for overhead from quench limit, lower installed performance and limitations from using a common rf source.
- For a 1 TeV upgrade, expect average gradient = 36 MV/m, Q = 1e10 for new cavities (the TDR 800 GeV design assumed 35 MV/m and Q > 5e9).

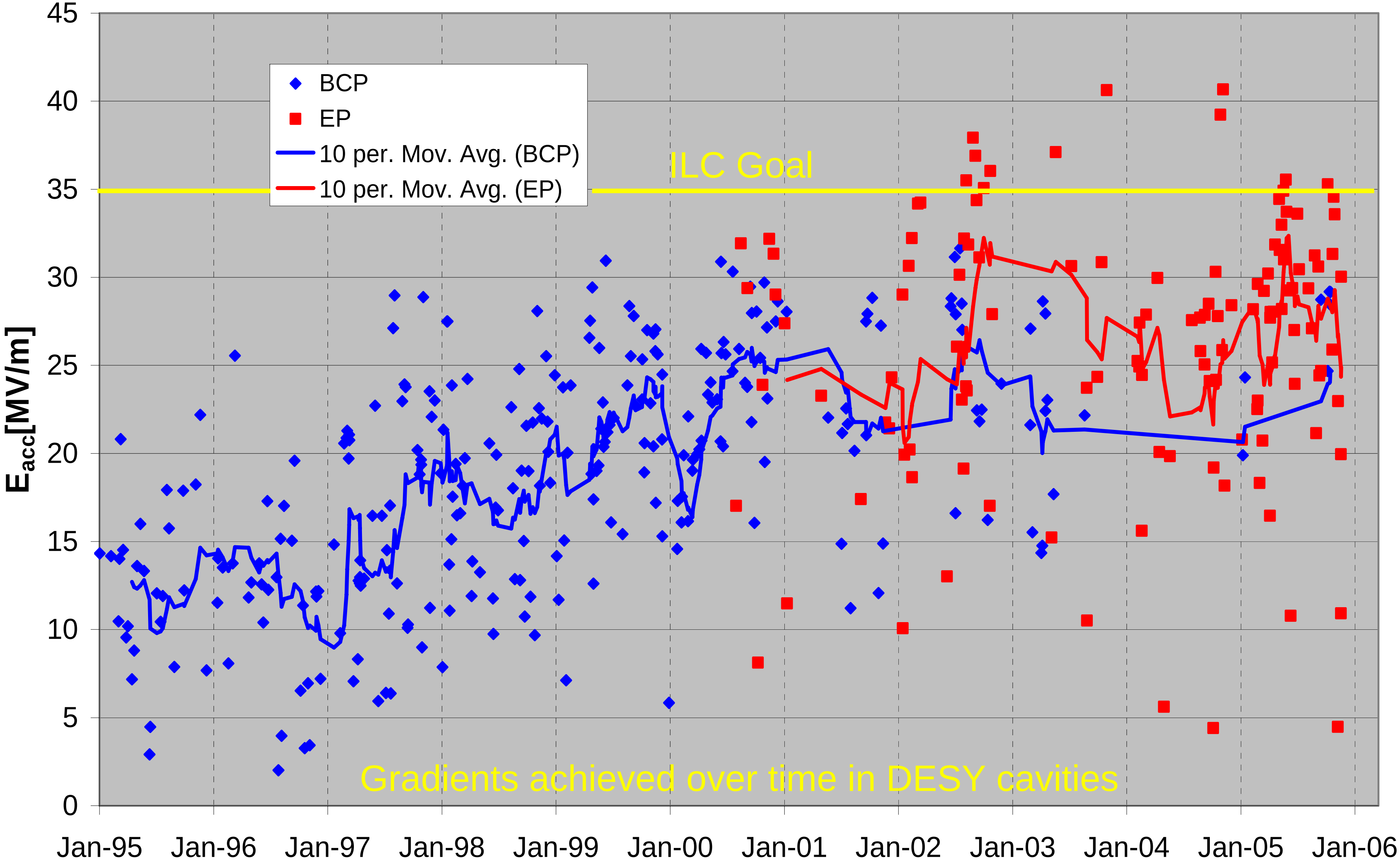
Achieved Gradients in Single and 9-Cell Cavities

- In recent years, single-cell cavity gradients approached fundamental limit: Bc * (Grad / B surface) ~ 1800/41.5 ~ 43 MV/m for Tesla-shape cavities.
- During past 2.5 years, DESY has produced 6 fully-dressed cavities with Gradients > 35 MV/m and Q > 8e9. Yield for such cavities < 30%.

Test Results for Dressed-Cavities that will be used in a '35 MV/m' Cryomodule



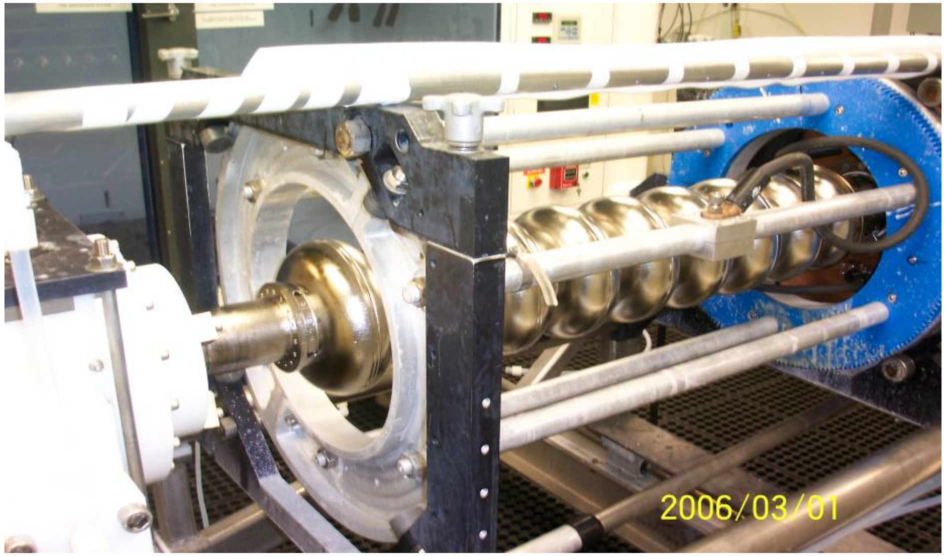
Main Production Problem Has Been Poor Reproducibility



Electro-Polishing (EP) Studies

EP System Alignment
Frame and Cathode with
ILC Cavity at JLAB.

Remove ~ 100 micron of Nb
Using a H_2SO_4, HF Mixture
Under Current Flow



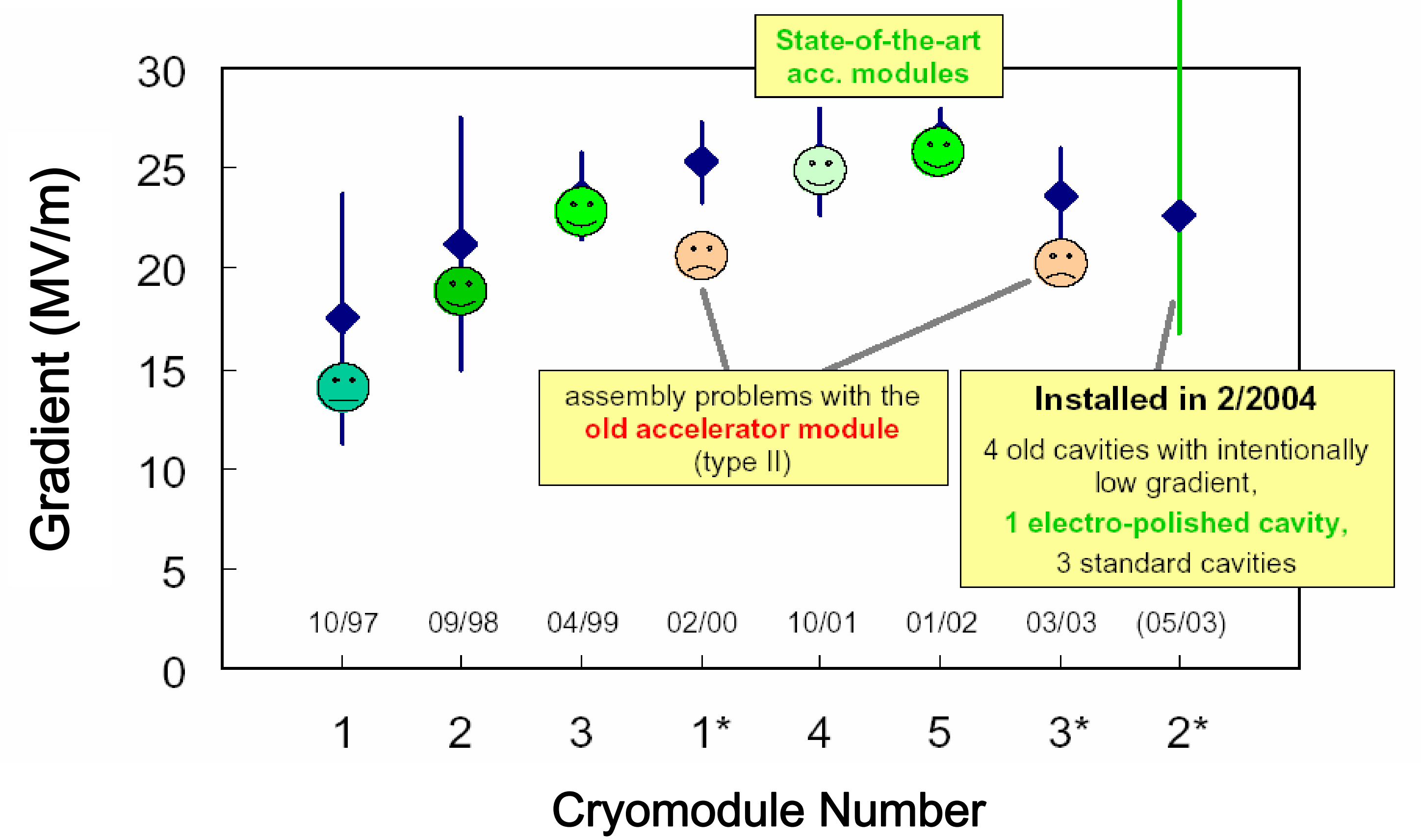
- Observe that field emission onset levels vary strongly
  - Sulfur contamination of EP ?
  - Efforts on better contamination control (e.g. H2O2 rinse, better filtering acids, cleanliness for EP)
  - Measure Nb, F, S contents of acids during EP
  - Control EP parameters, V, I, acid temp…
- Control studies on EP underway at DESY, KEK, JLab, and other places.

Achieved Gradients in Tesla Test Facility (TTF) 8-Cavity Cryomodules

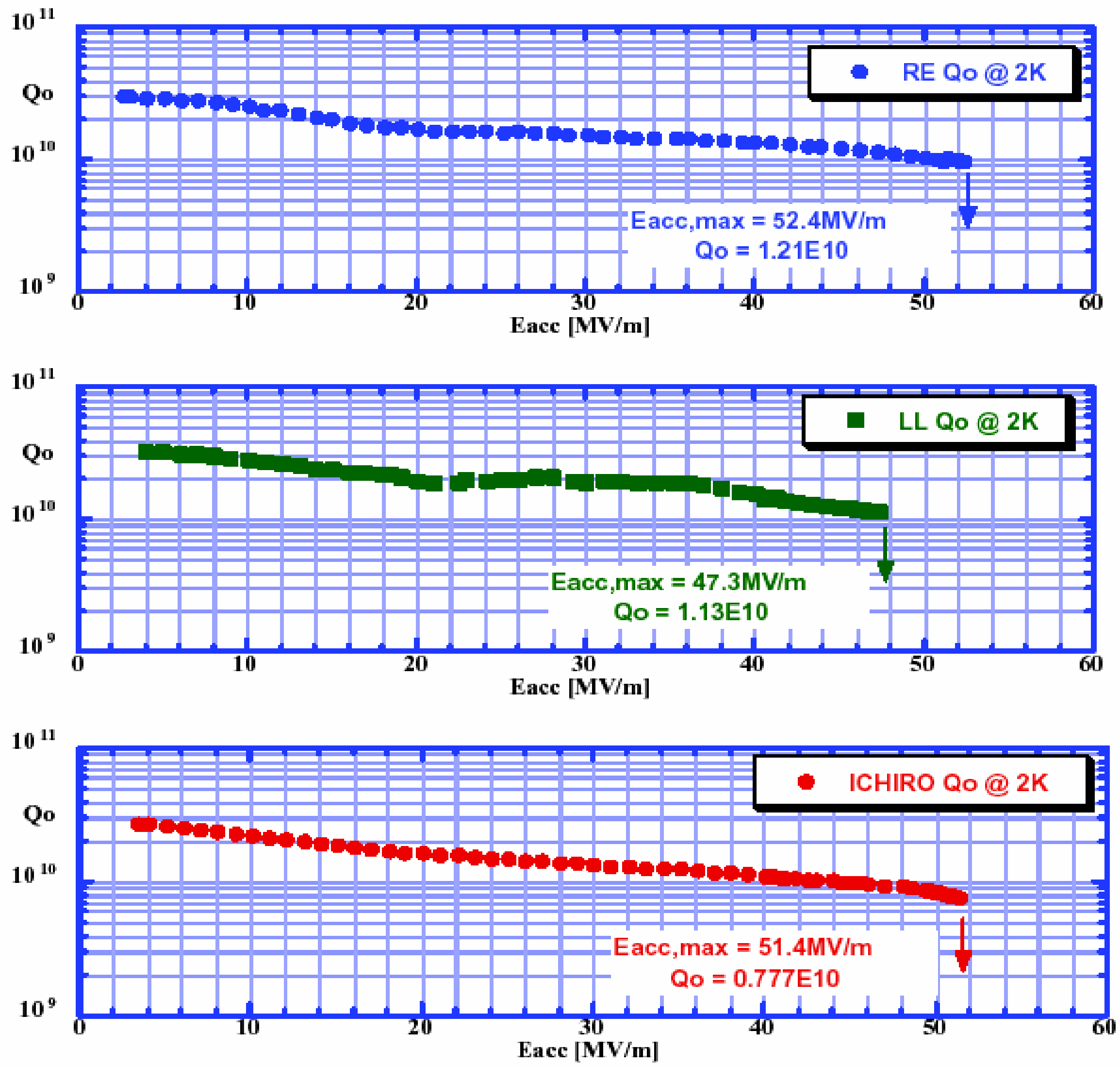
(Cavities not Electro-Polished)

Diamonds and Error Bars = Range of Gradients Achieved in Individual CW Cavity Tests.

☺ = Average Gradient Achieved in Cryomodule



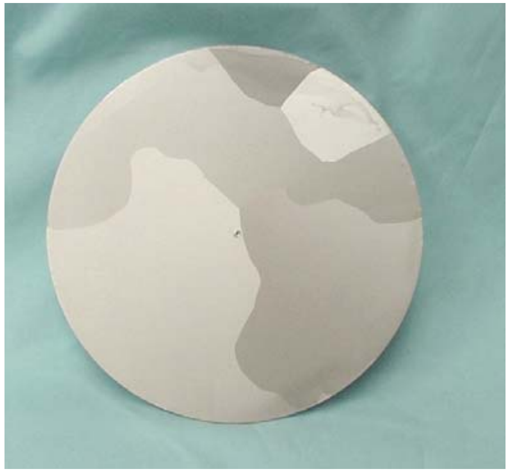
Advanced Cavities: Shape Cell for Lower B Field but Higher E Field – Achieved ~ 50 MV/m in Single Cells.



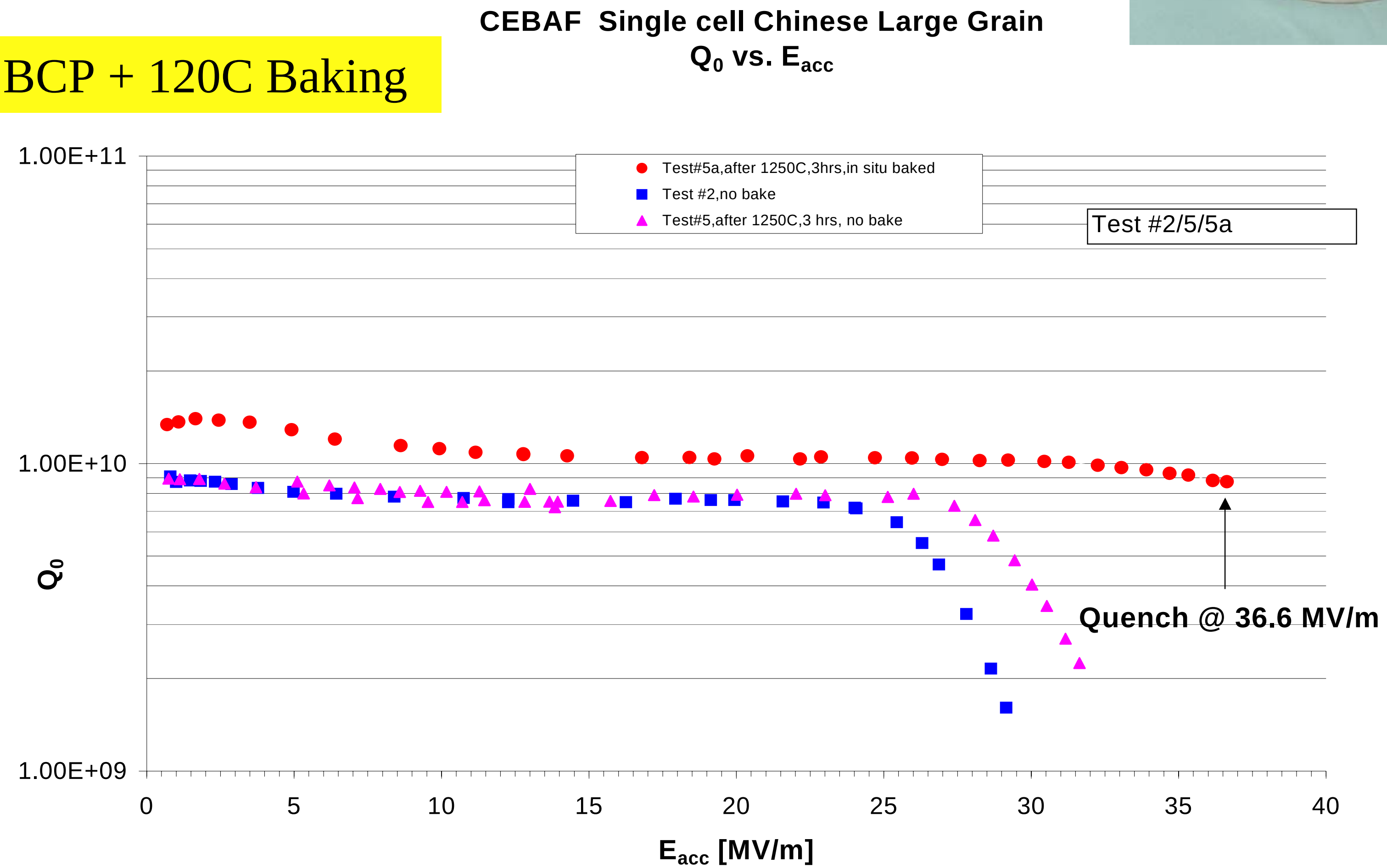
Re-entrant

Low-Loss

Tests also underway using single crystal or large grain Nb – could eliminate need for Electro-Polishing (EP)

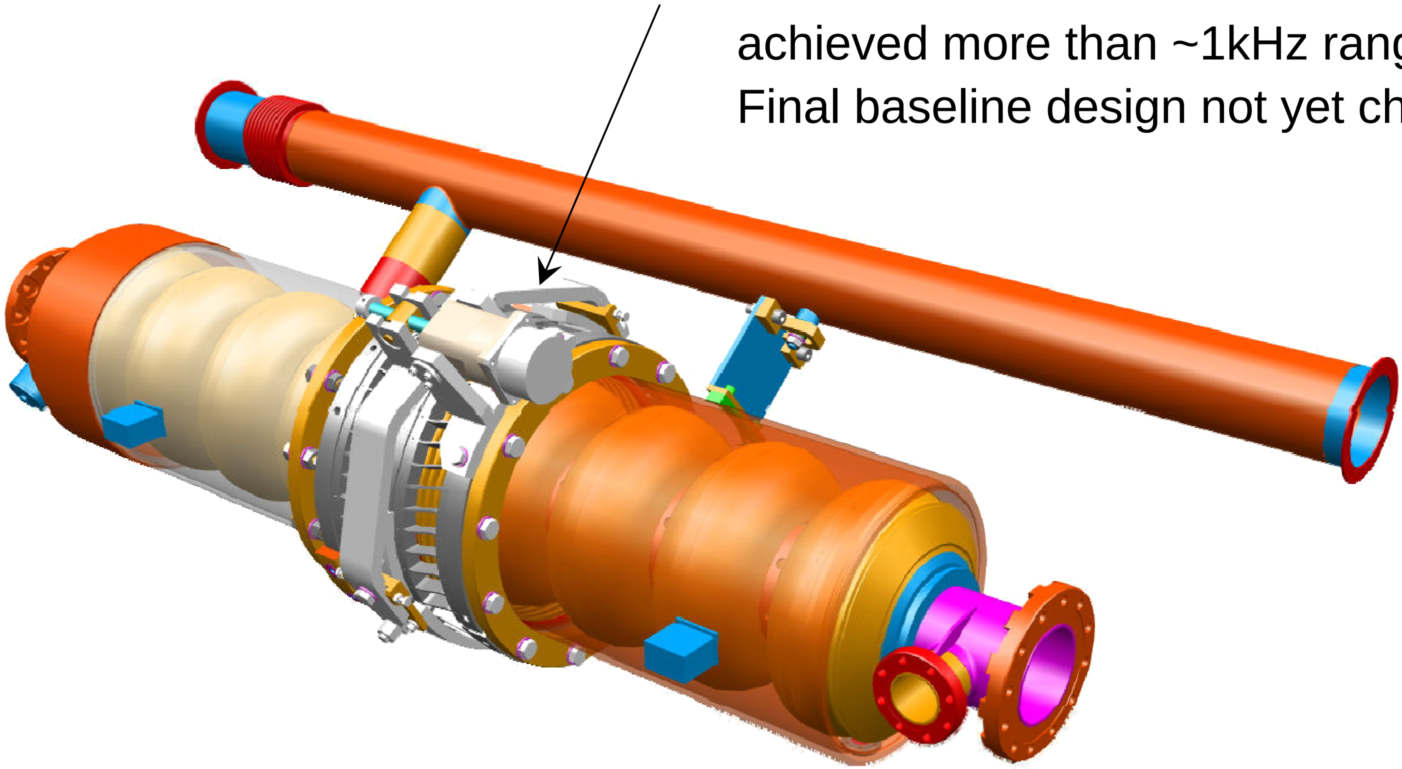


BCP + 120C Baking



Tuning the Cavities

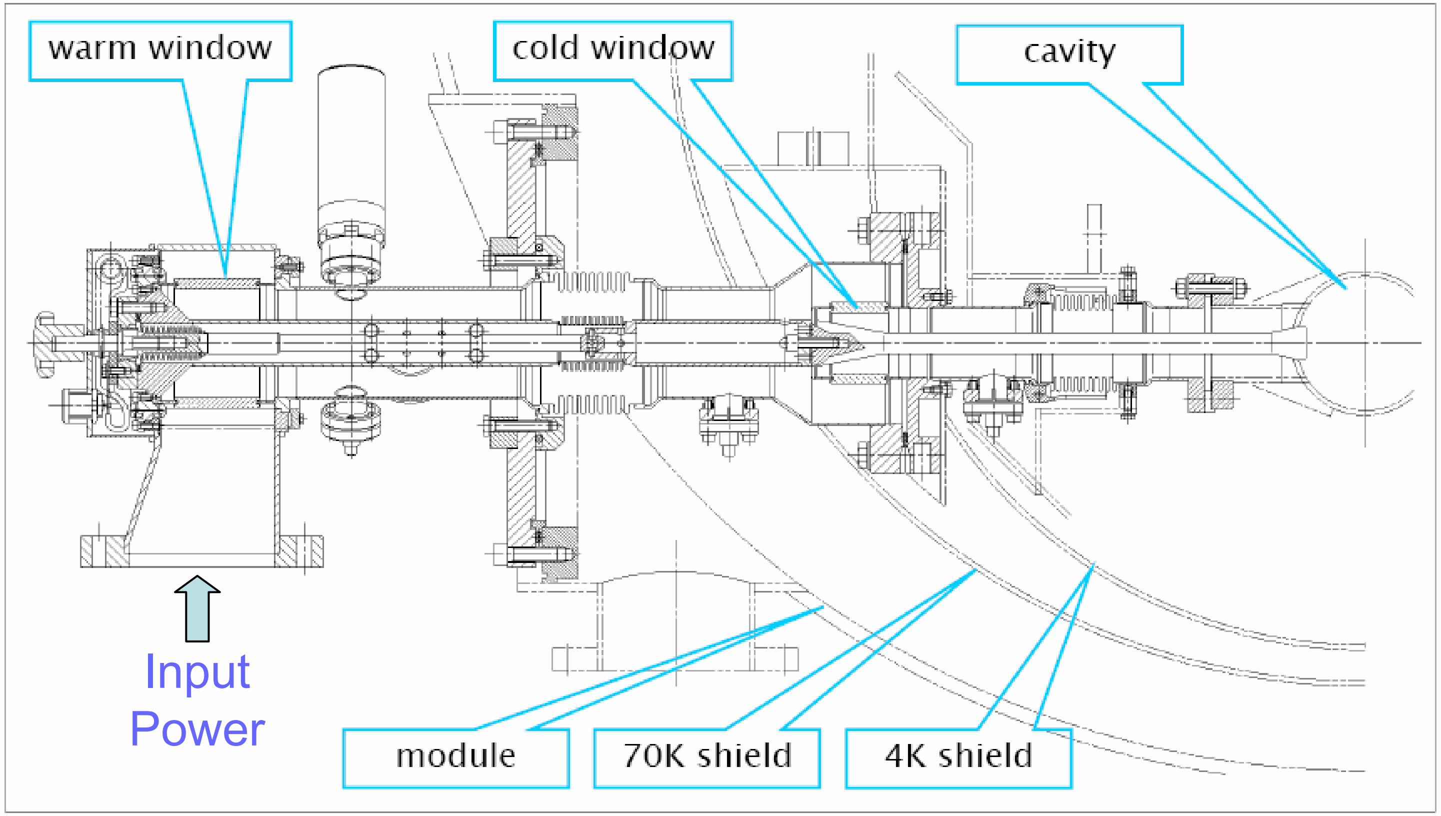
- Both slow (500 kHz over minutes) and fast (2.5 kHz during the 1.6 ms pulse) tuning required – achieve by compressing the cavity (~ 1 micron per 300 Hz).
- Want tuners located away from cavity ends to minimize cavity spacing.
- 'Blade Tuner' shown below. To date, have not achieved more than ~1kHz range of fast tuning. Final baseline design not yet chosen.



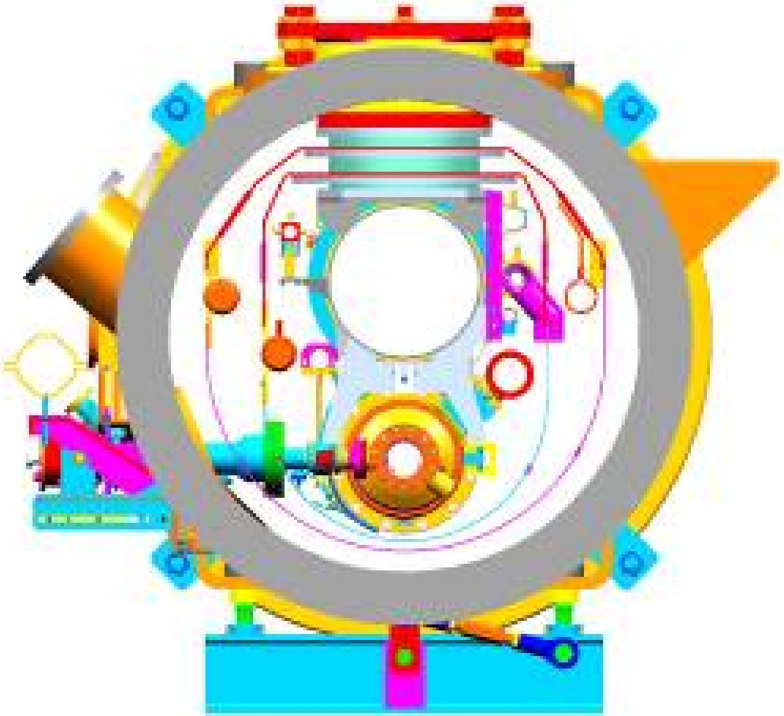
Powering the Cavities

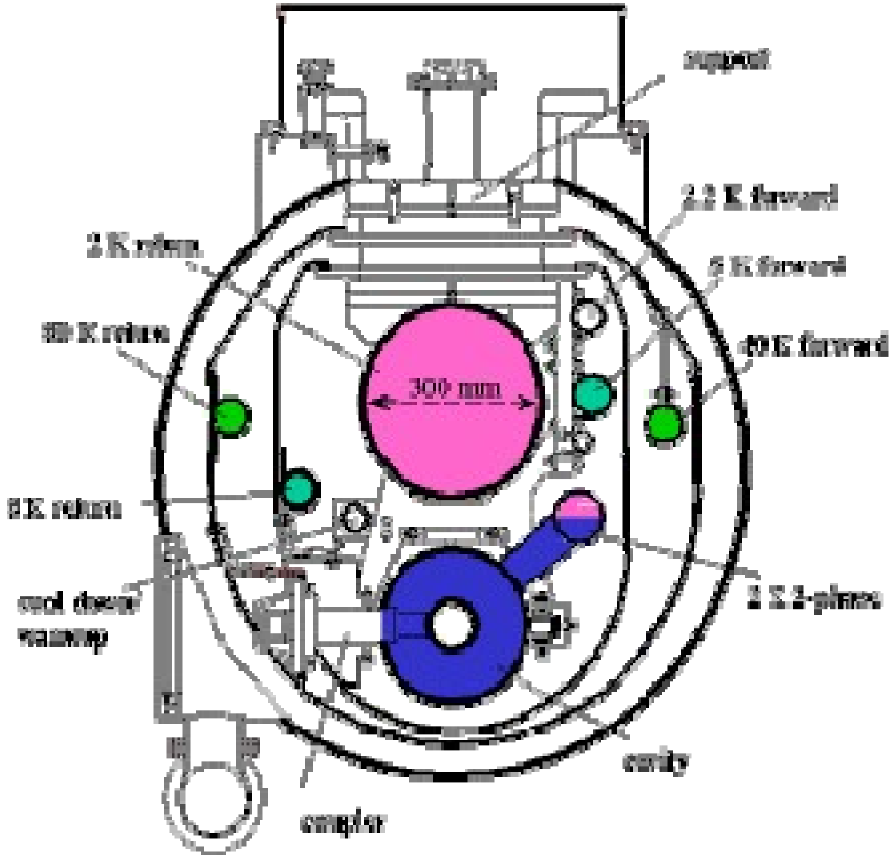
- Power coupler design complicated by need for tunablity (Qext), windows and bellows.
- Baseline TTF3 design processed to 1 MW and tested up to 600 kW for 35 MV/m operation (1000 hours): long term reliability for required operation at 350 kW not known.

Coaxial Power Coupler



Cryomodule Cross Section





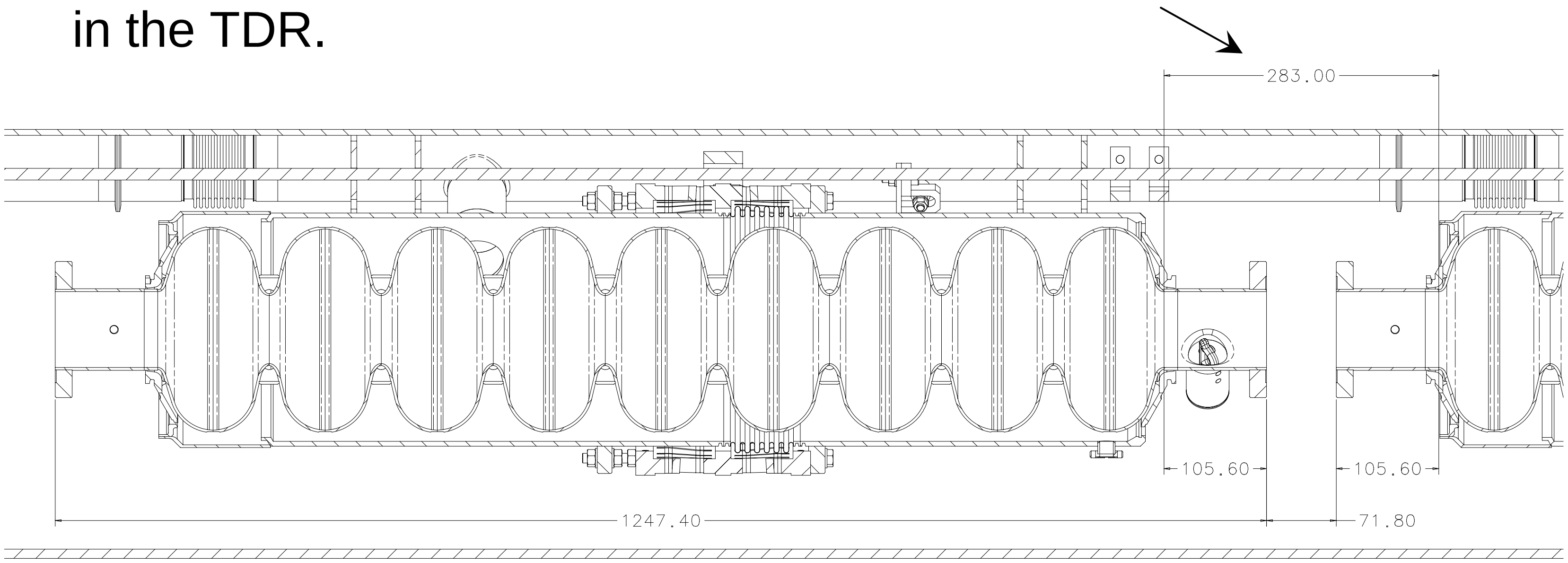
Cryomodules

TTF Module	Installation date	Cold time [months]
CryoCap	Oct 96	50
M1	Mar 97	5
M1 rep.	Jan 98	12
M2	Sep 98	44
M3	Jun 99	35
M1*	Jun 02	30
MSS		8
M3*	Apr 03	19
M4		19
M5		19
M2*	Feb 04	16

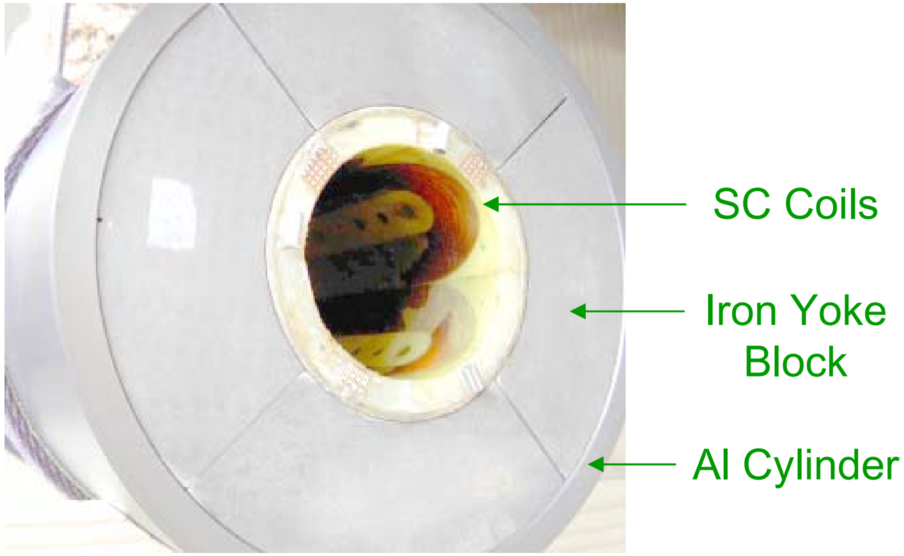
Cryomodule Design

Relative to the cryomodules at the TESLA Test Facility at DESY

- Continue with 8 cavities per cryomodule based on experience and minimal cost savings if number increased (12 in TDR).
- Move quad / corrector / bpm package to center (from end) to improve stability.
- Increase some of cryogenic pipe sizes (similar to that proposed for the XFEL).
- Decrease cavity separation from 344 mm to 283 mm as proposed in the TDR.

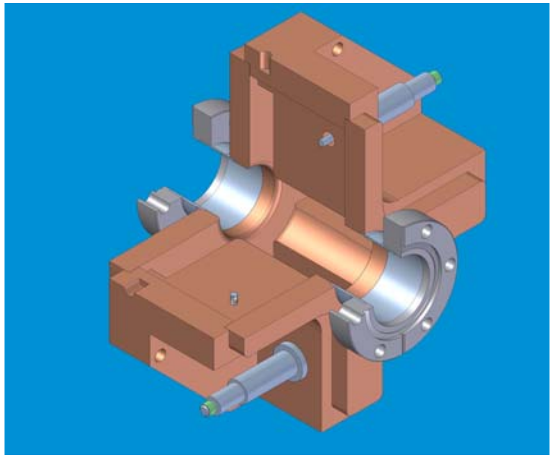


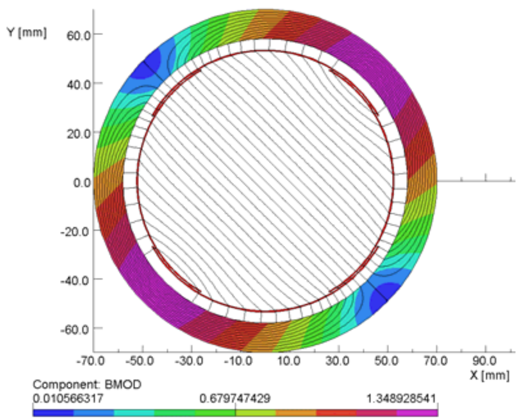
Quad / Corrector / BPM Package



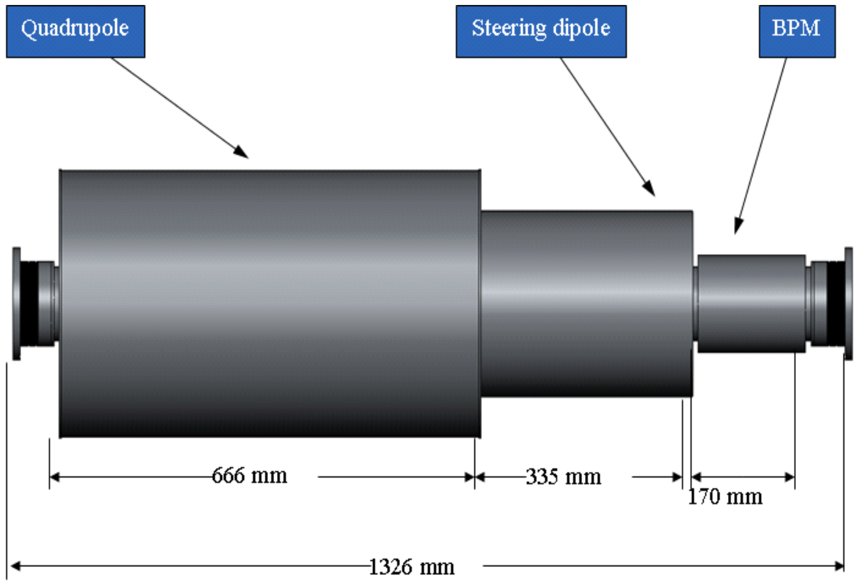
SC ‘Cos(2ϕ)’ Quadrupole Magnet

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





Dipole Design: Flux density and Flux Lines



Cryogenic System

Assume static heat leaks based on TTF measurements instead of the smaller values assumed in the TDR

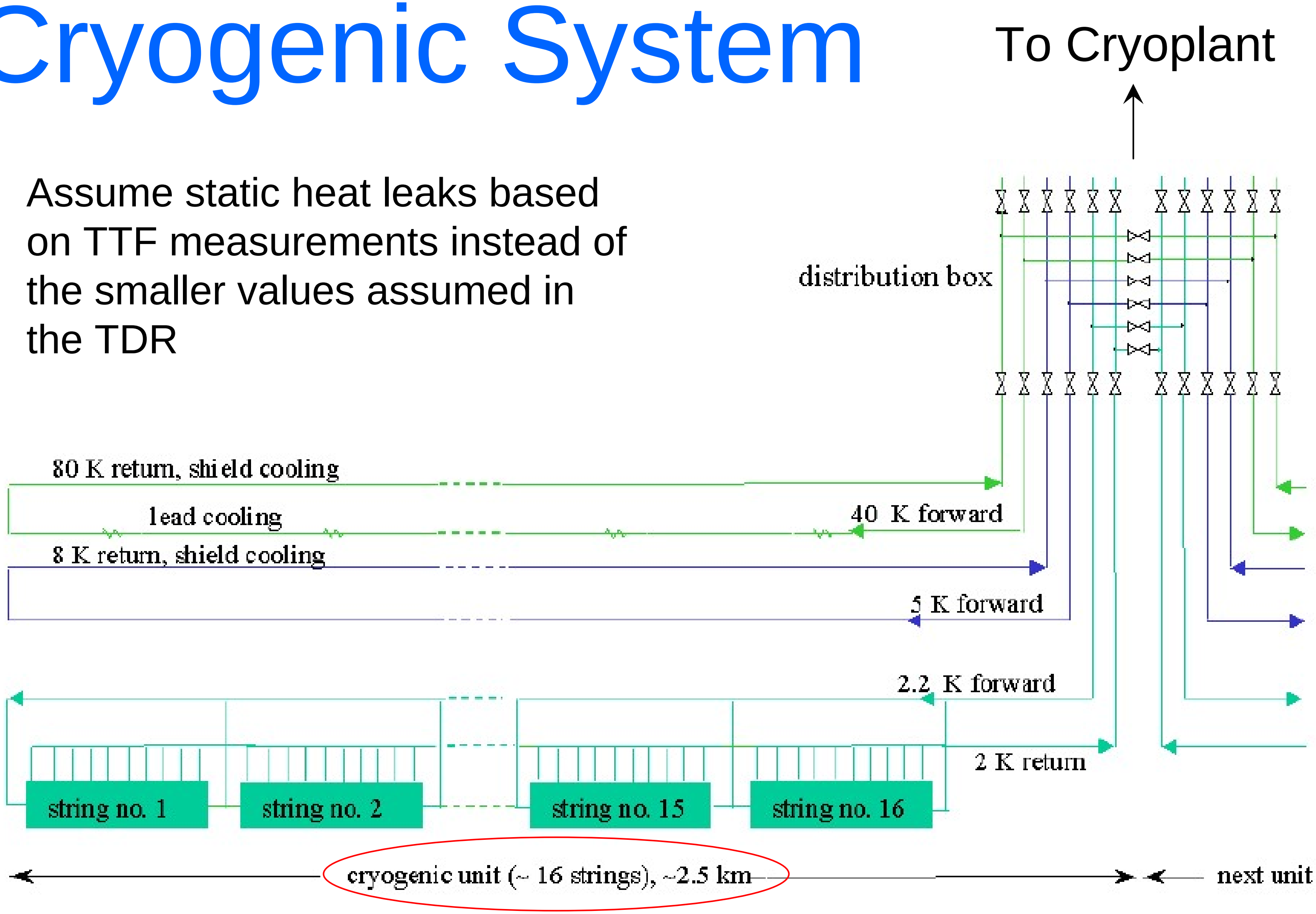
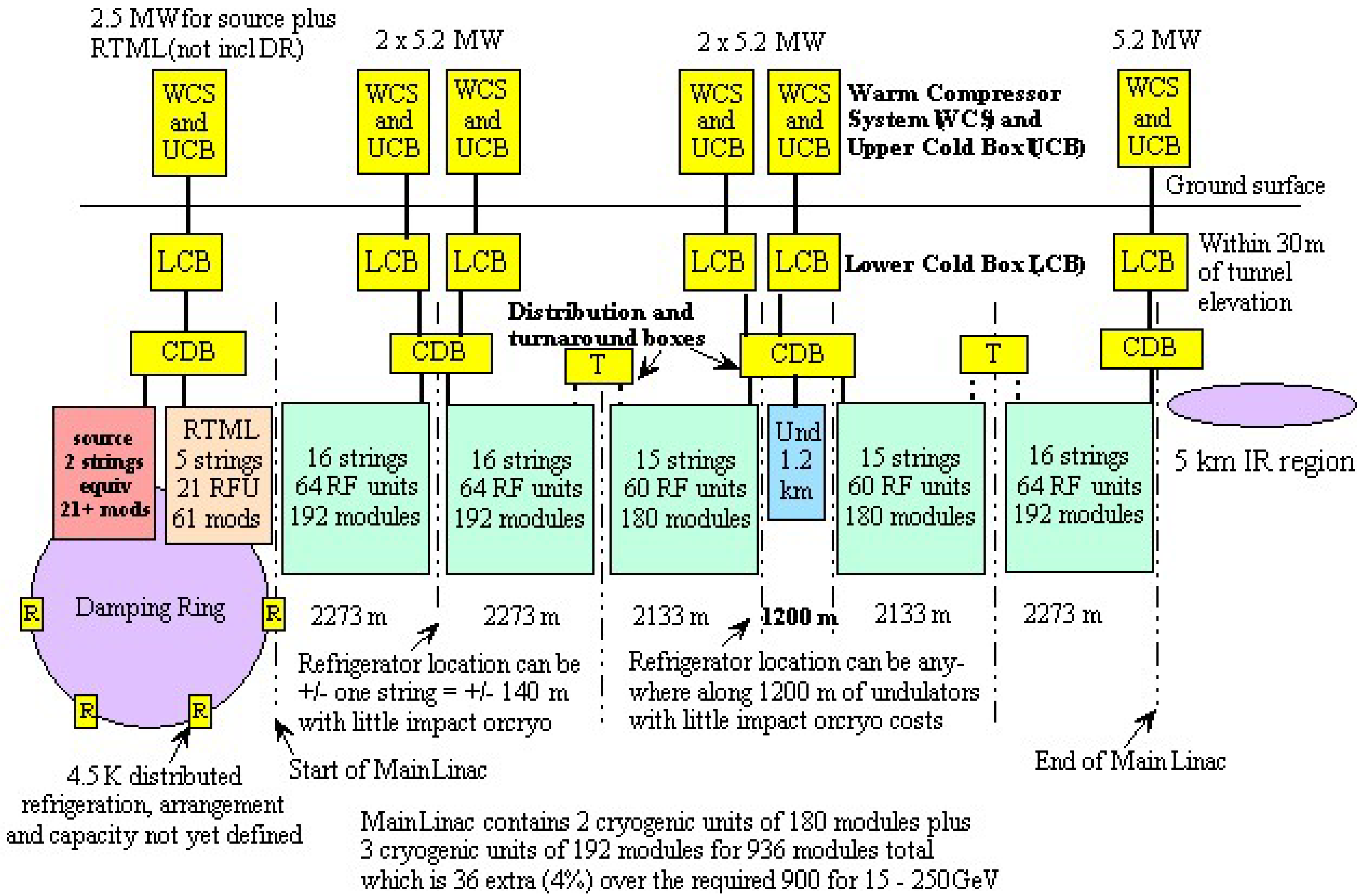


Figure 8.7.2: *Cryogenic unit.*

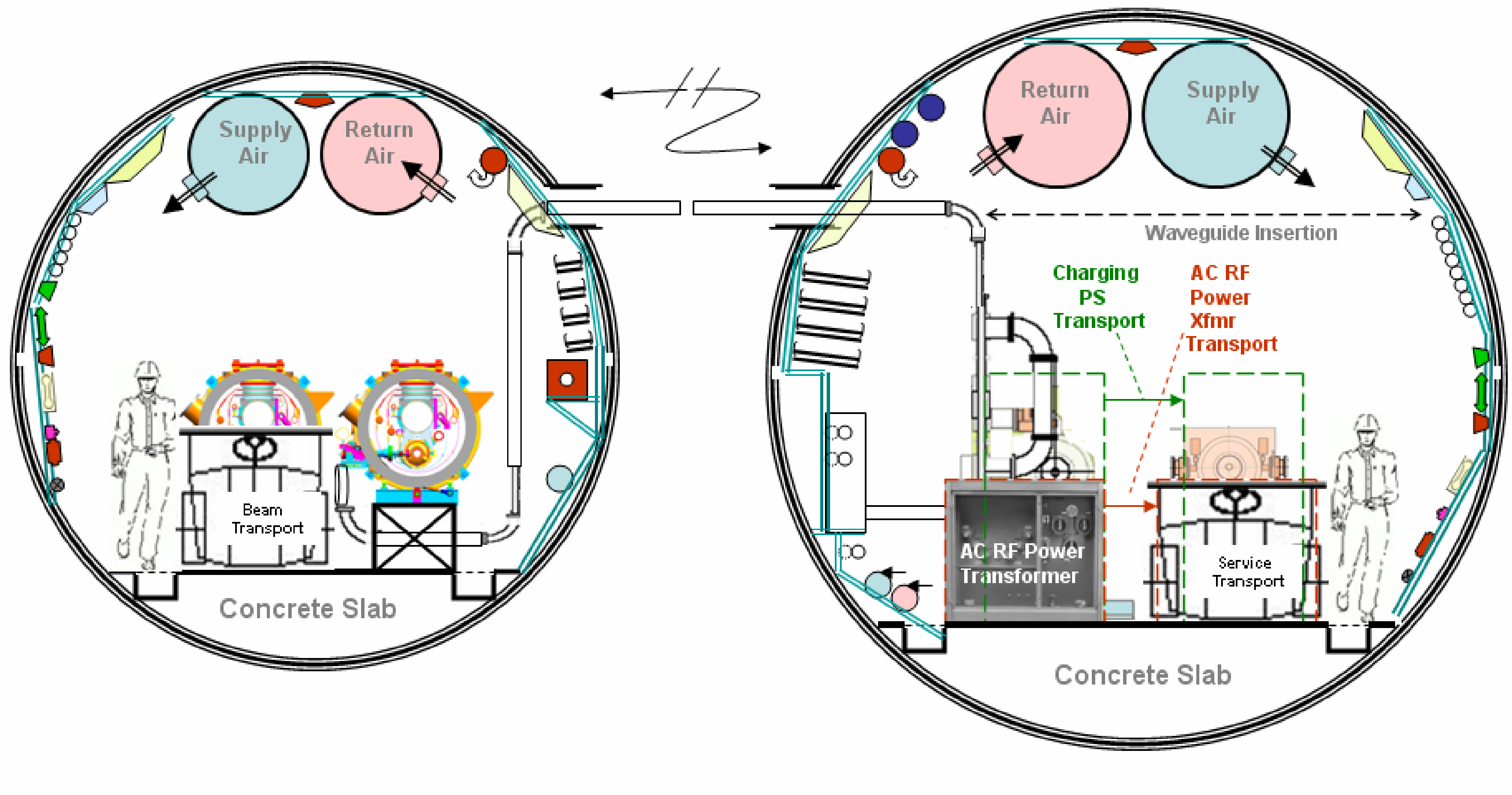
Cryoplant Layout

For ILC 500, require 57 MW of AC power for Cryoplants



Tunnel Layout

For baseline, developing deep underground (~100 m) layout with 4-5 m diameter tunnels spaced by 7 m.



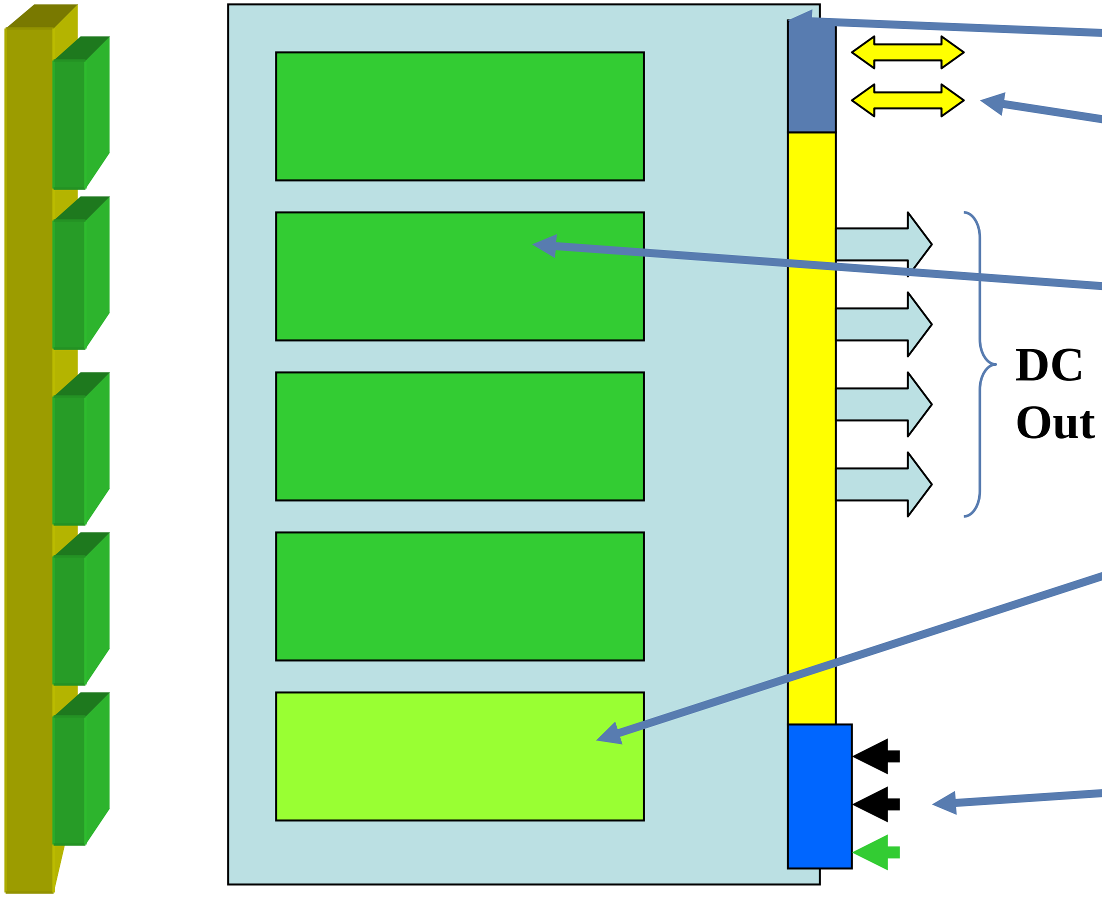
ILC Availability Challenge

- The ILC will be an order of magnitude more complex than any accelerator ever built.
- If it is built like present HEP accelerators, it will be down an order of magnitude more (essentially always down).
- For reasonable uptime, component availability must be much better than ever before. Must do R&D and budget for it up-front.

Lifetime Improvements

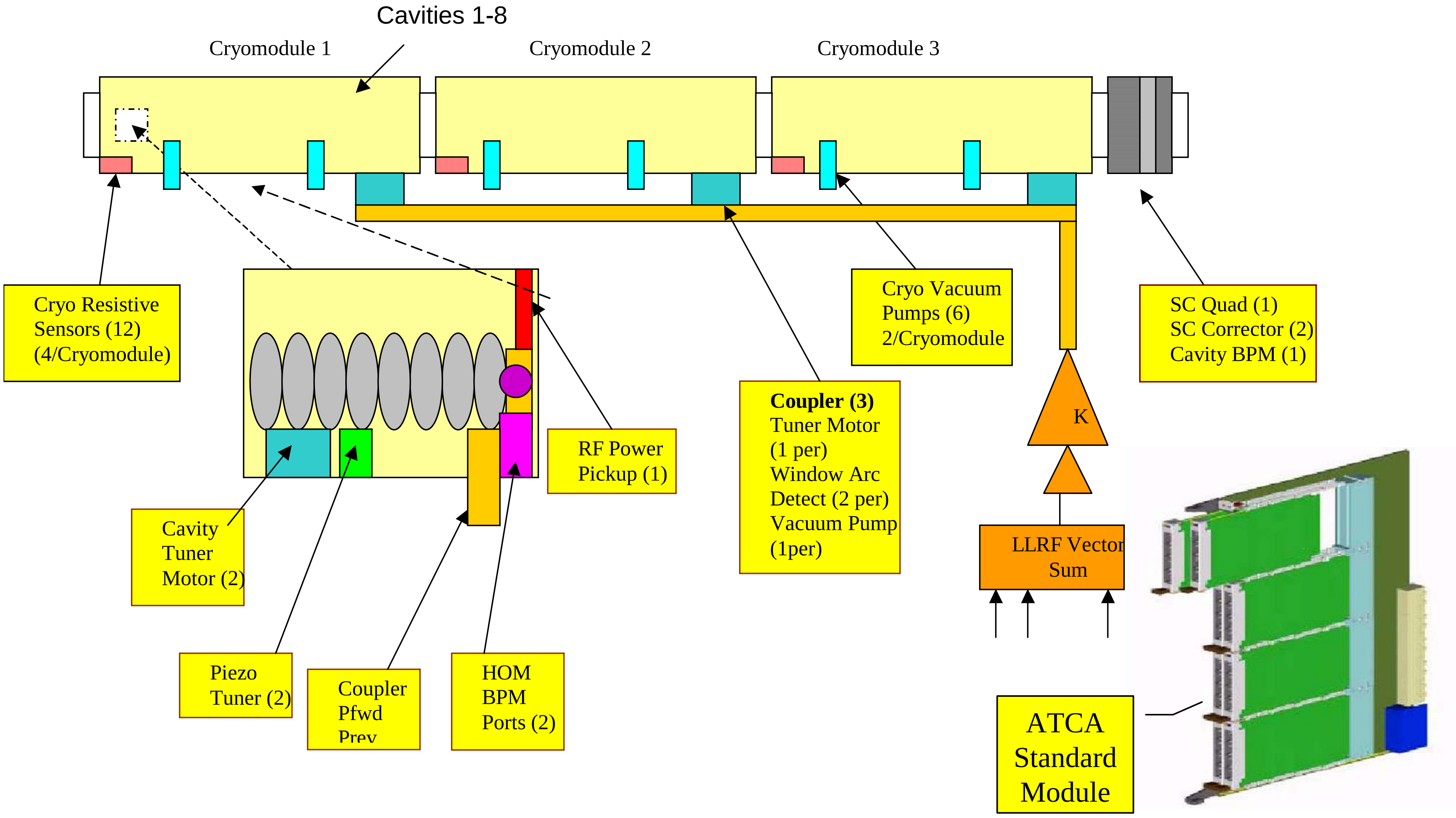
Device	Required MTBF Improvement Factor	MTBF from Present Experience (khours)
magnets - water cooled	20	1,000
power supply controllers	**50**	100
flow switches	10	250
water instrumention near pump	10	30
power supplies	5	200
kicker pulser	5	100
coupler interlock sensors	5	1,000
collimators and beam stoppers	5	100
all electronics modules	**10**	100
AC breakers < 500 kW	**10**	360
vacuum valve controllers	**5**	190
regional MPS system	**5**	5
power supply - corrector	**3**	400
vacuum valves	**3**	1,000
water pumps	**3**	120
modulator		50
klystron - linac		40
coupler interlock electronics		1,000

High Availability Power Supply Module (Low Power)



- Motherboard
- Dual Serial Control IO
- Independent Carriers Hot Swappable
- Optional: Redundant n/N w/ Switchover
- Dual Bulk 48V DC In

ILC Linac Instrumentation (One of 600 RF Units)



Summary

- Basic linac design complete: converging on details
  - Tradeoffs of operability, availability and cost.
- Major cost and technical risks
  - Producing cryomodules that meet design gradient at a reasonable cost (cost model still in development, XFEL will provide a reference, and will get new industry-based estimates).
  - Producing a robust 10 MW klystron.
- Potential Cost Savings
  - Adopt Marx Modulator
  - Use simpler rf distribution scheme
  - Have one tunnel although ‘the additional cost is marginal when considering the necessary overhead and equipment improvements to comply with reliability and safety issues.’
  - Reduce cavity aperture to 60 mm for 21% reduction in dynamic cryo-loading and 16% reduction in cavity fill time.