Klystron Cluster RF Distribution Scheme

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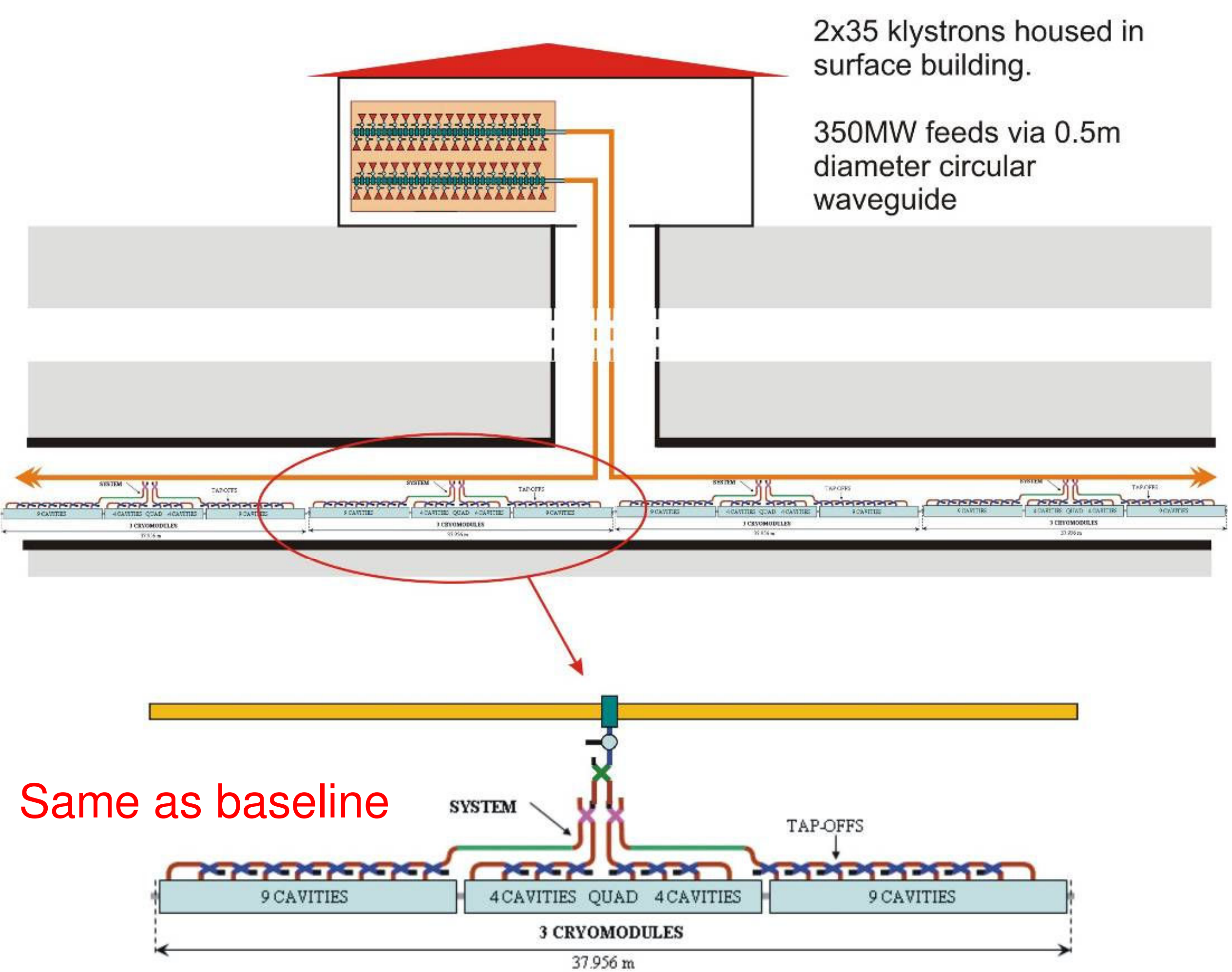
Klystron Cluster Concept

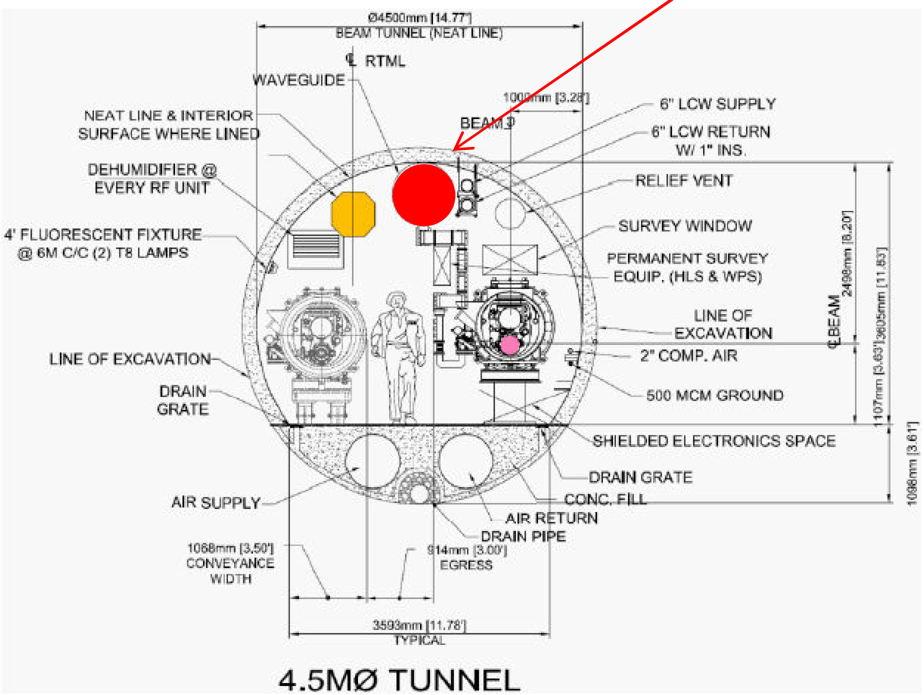


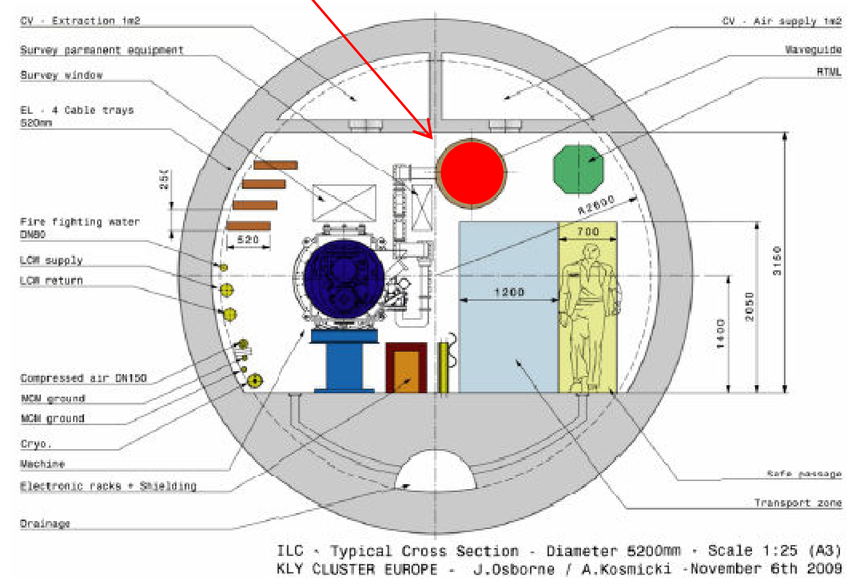
Each tap-off from the main waveguide feeds 10 MW through a high power window and probably a circulator or switch to a local PDS for a 3 cryomodule, 26 cavity RF unit (RDR baseline).

- RF power “piped” into accelerator tunnel every 2.5 km
- Service tunnel eliminated
- Electrical and cooling systems simplified
- Concerns: power handling, LLRF control coarseness

Single Tunnel Layout with KCS

RF Waveguide



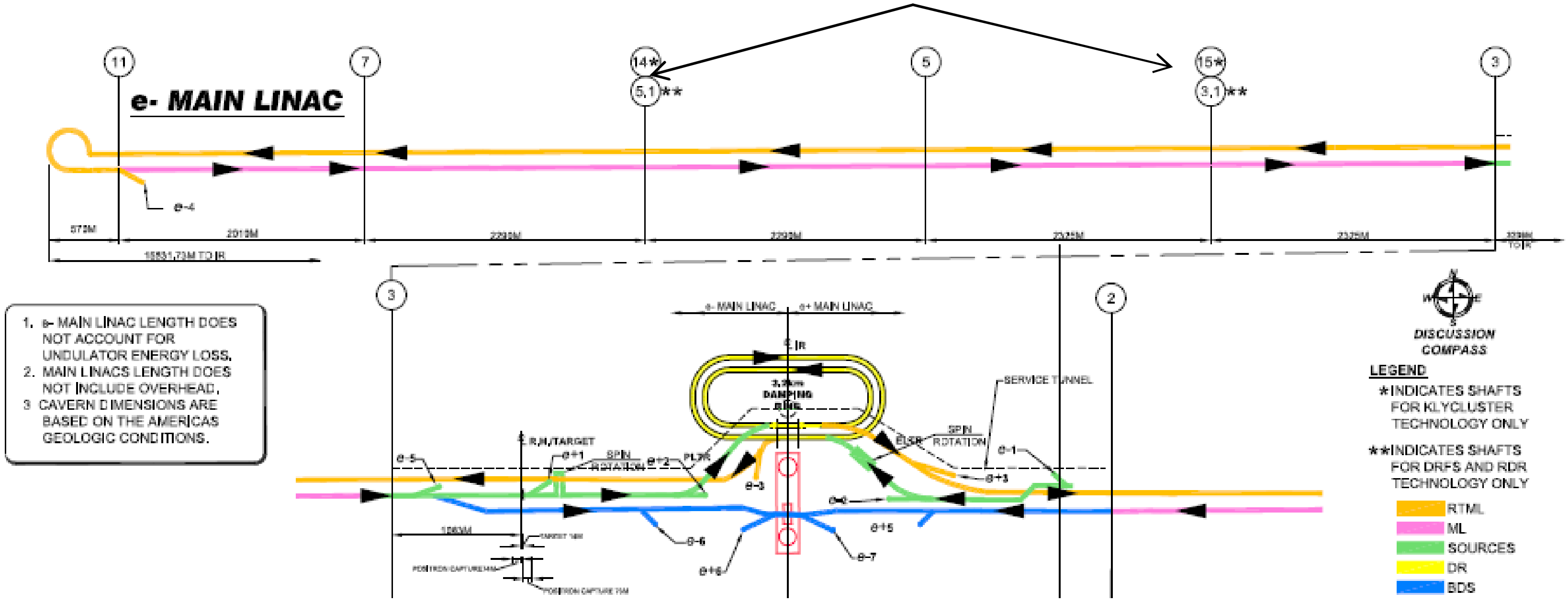


Americas Region

European Region

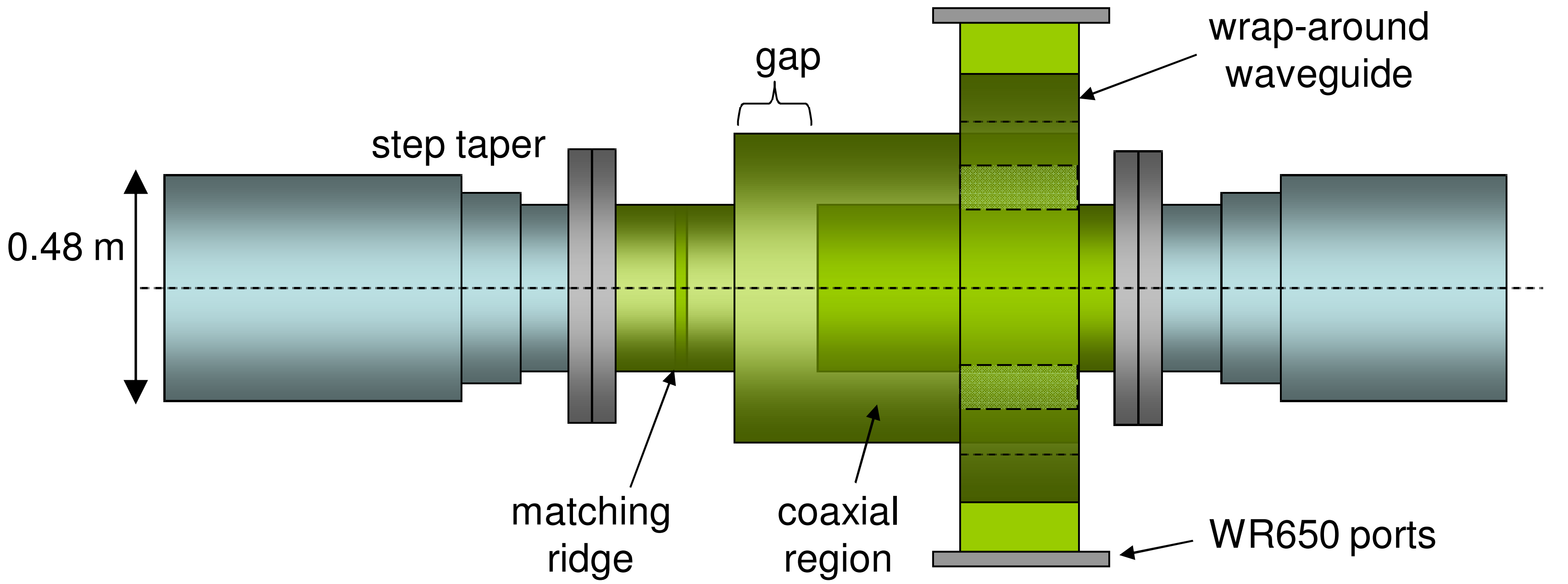
Layout

Requires Addition of Two 3 m Diameter Shafts per Linac



# of KCS per main linac	9
# of rf units per system	32
# of cryomodules per system	96
# of cavities per system	832
# of klystrons/modulators per system	19 (36)
peak rf power per system (MW)	170 (340)

Coaxial Tap Off (CTO)



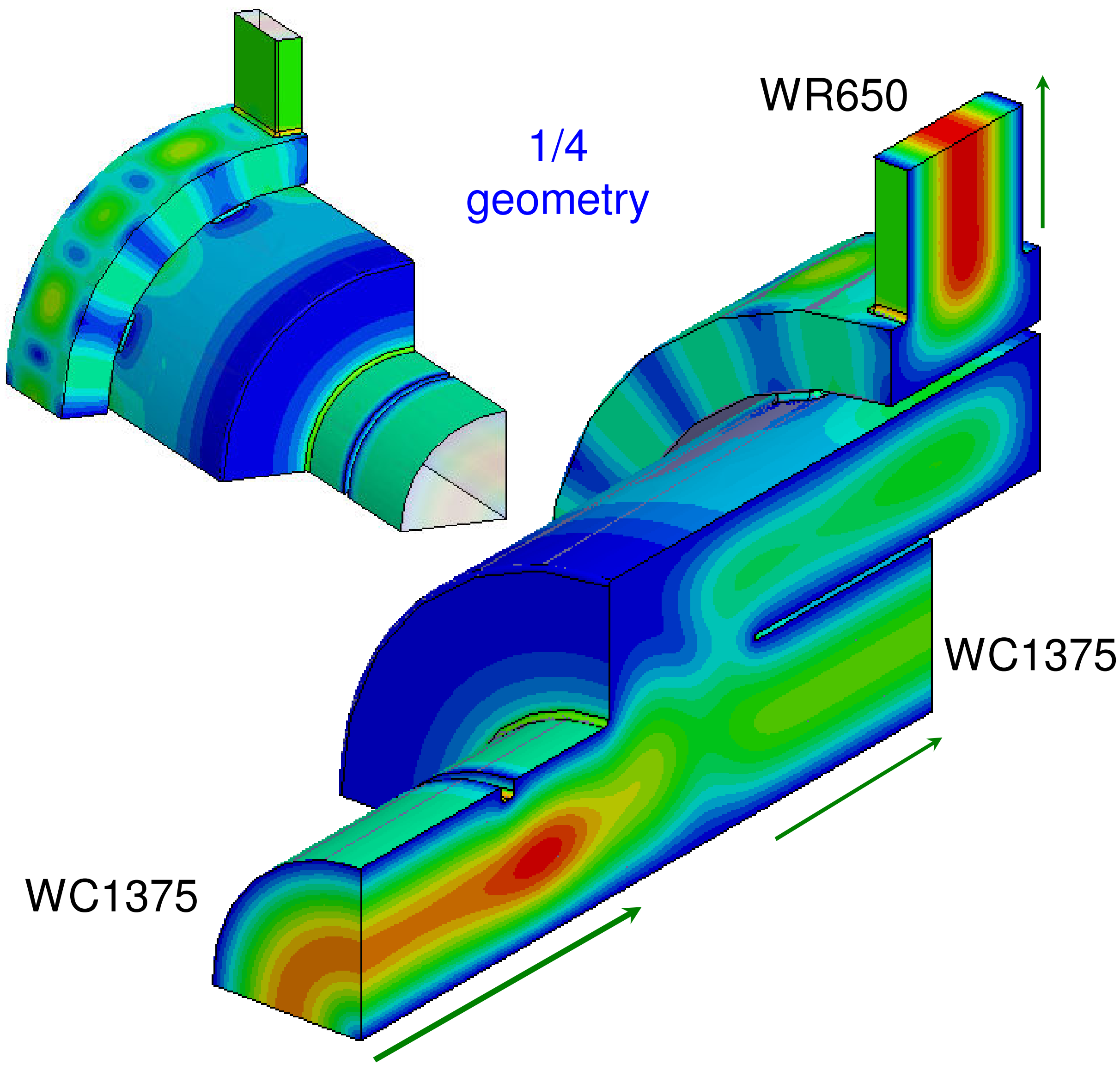
Power is tapped off from the circular TE_{01} mode, in 5 or 10 MW increments, into a coaxial region, without breaking azimuthal symmetry (*no surface E fields*).

A wrap-around mode converter extracts this power from the coaxial TE_{01} mode into two output waveguides, analogous to the klystron output arms.

The various required coupling designs (~3-50%) differ only in a) gap width (~3-8”) and b) matching ridge.

The same devices are used in reverse for launching power into the pipe.

3dB CTO Design Simulation



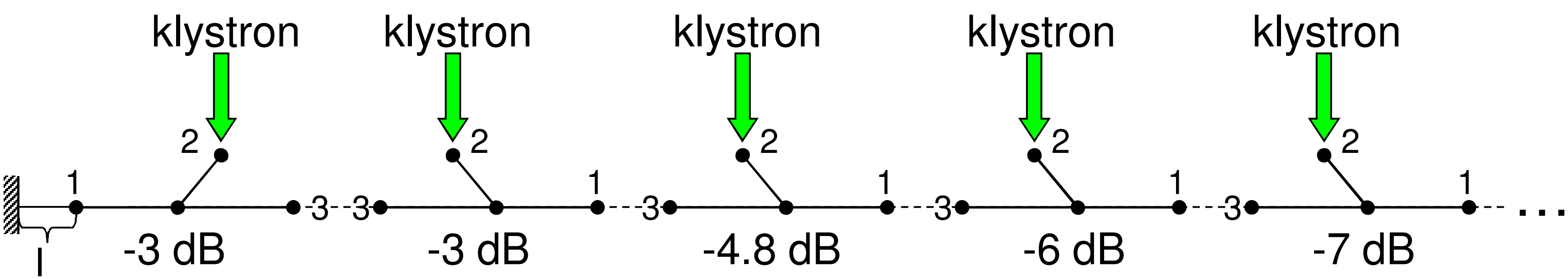
Arrangement of Couplers

As it runs along the tunnel, tap-offs of increasing coupling extract the same amount of power from the main waveguide every three cryomodules (rf unit).

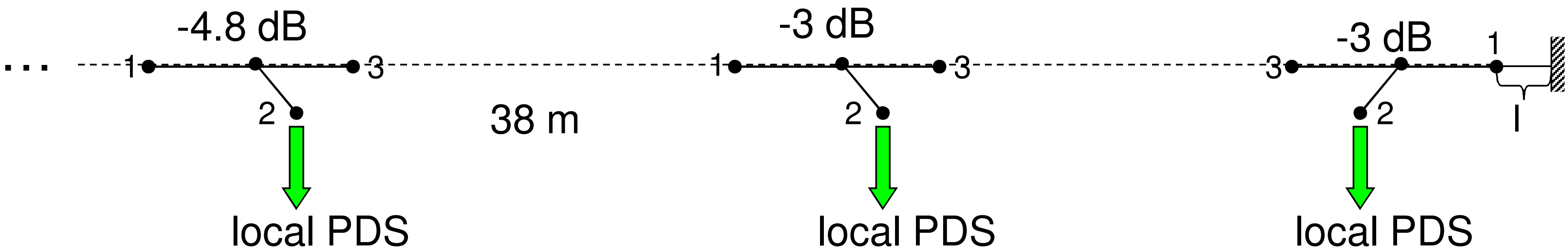
The same coupling devices are used in reverse to combine the power in the cluster building. Tap-ins depend on proper ratio and proper phase of power already in pipe.

First tap-in (launcher) and last tap-off (extractor) are 3 dB units reversed relative to the others and shorted (with proper phase length) at port 1.

Power Combining:

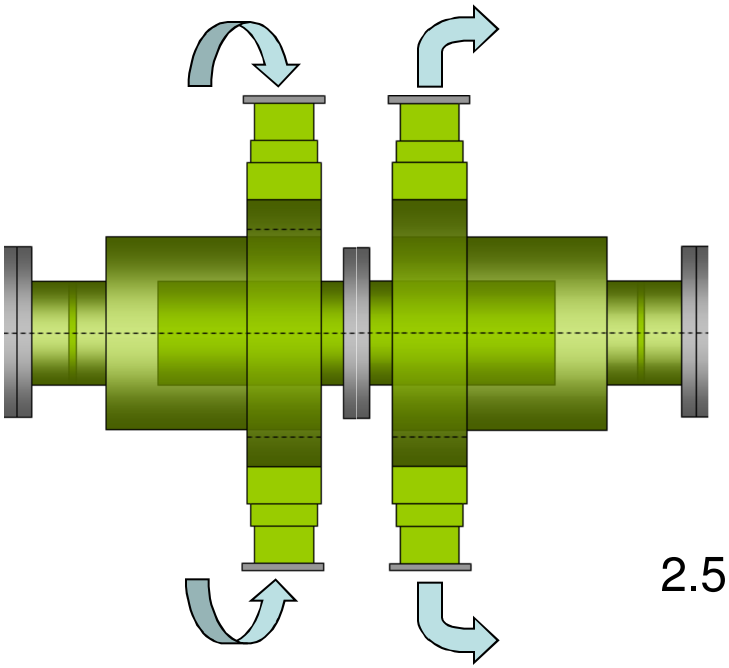


Power Dividing:



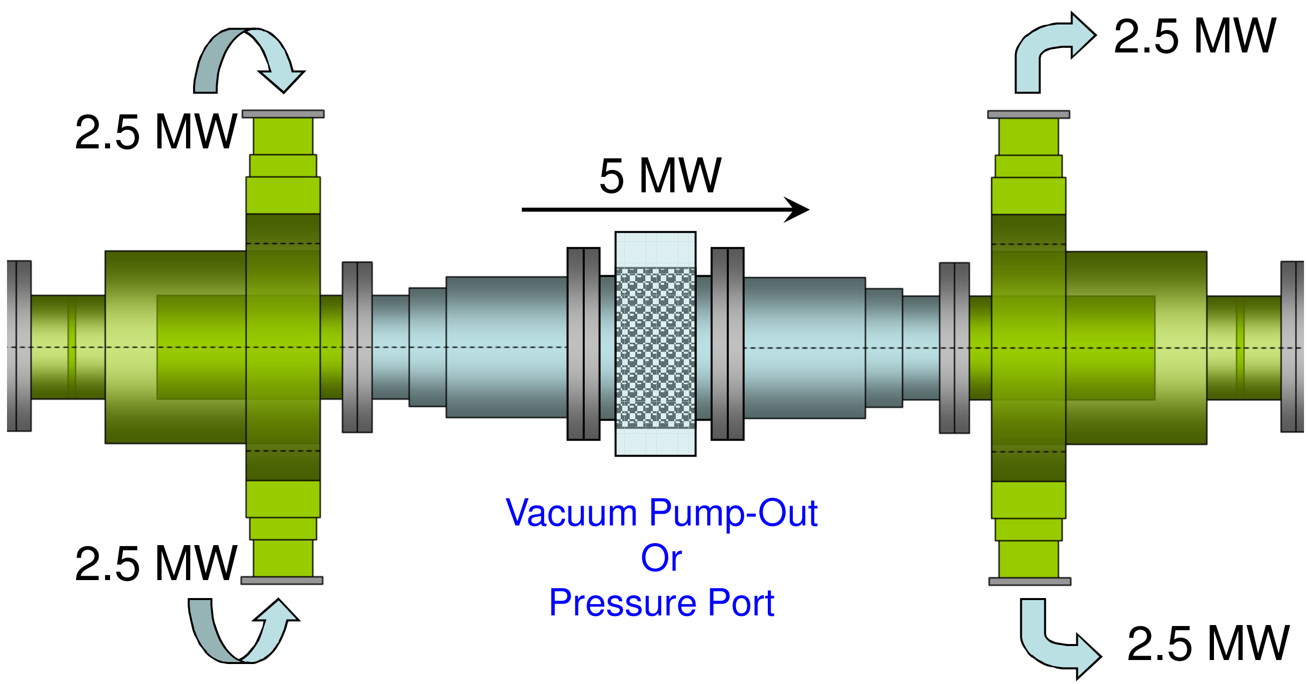
Phase I Demonstration Steps

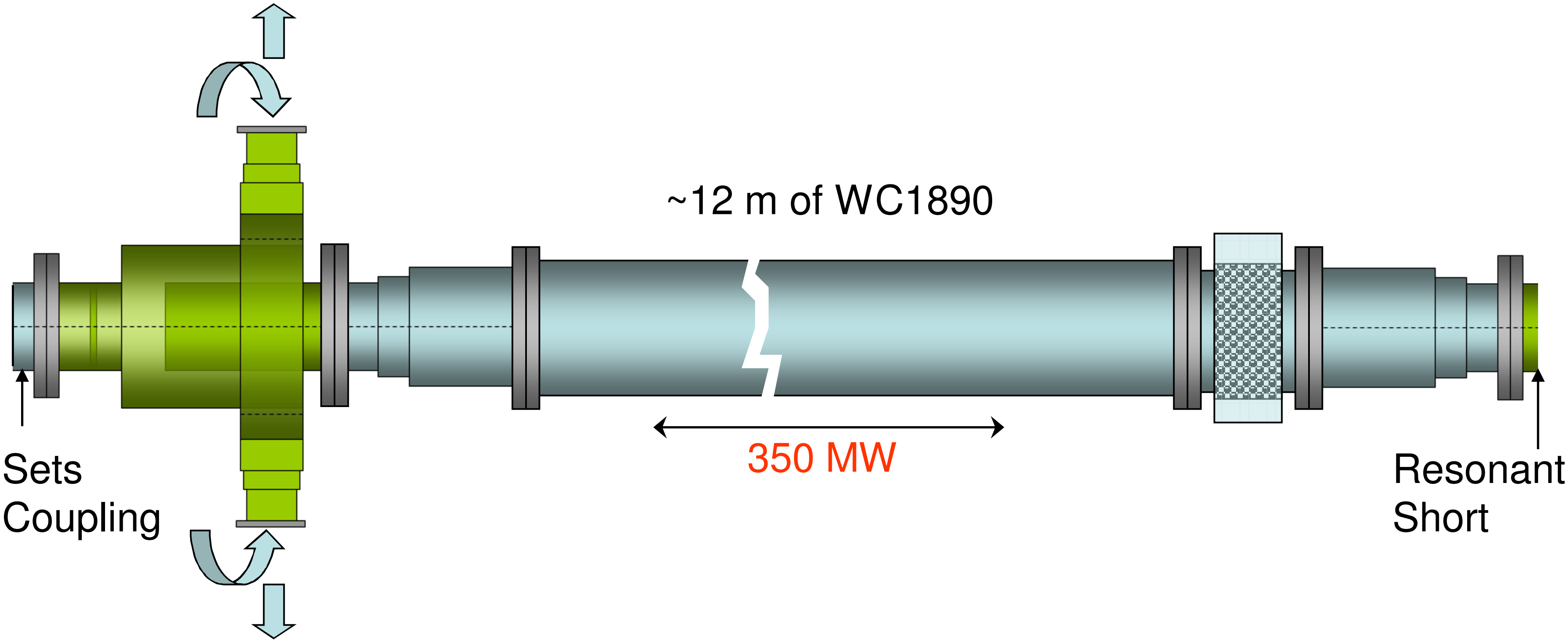
(To Be Completed in Next 6 Months)



Step 1: Build two 3dB CTO's, short port 1's to make launcher/extractors, and cold test back-to-back (verify w/ spacer).

Step 2: Build step tapers and pumpout, include in assembly, cold test again, and high power test up to 5 MW.





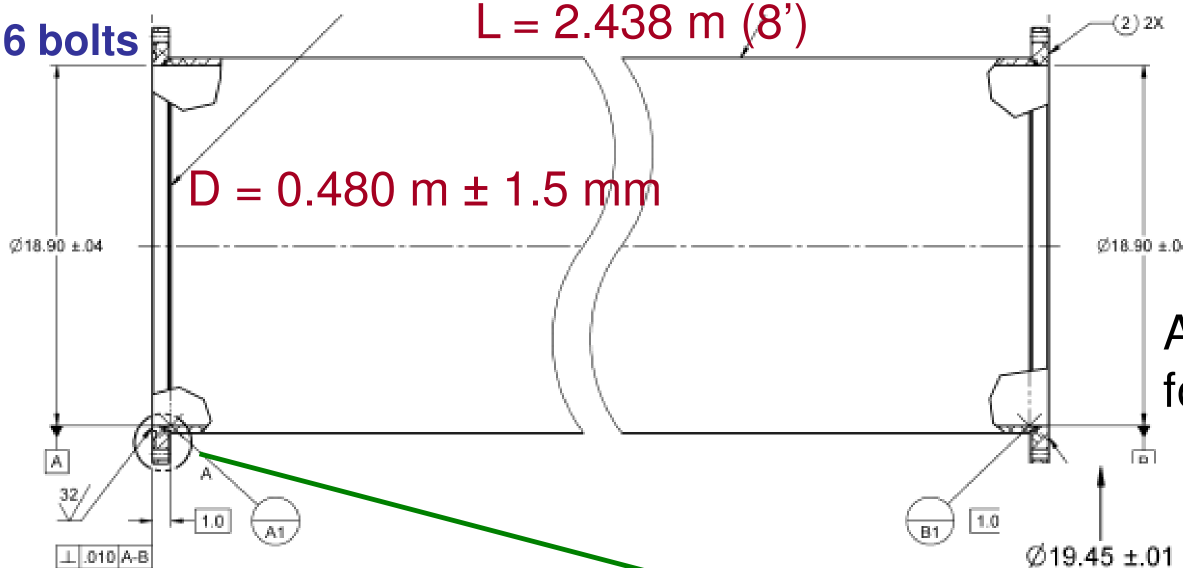
Step 3: Adjust input coupling (beta = 6) and resonantly charge line (tau = 8 us) to field levels equal to those for 350 MW transmission (requires only 2.5 MW of klystron power). Do this under pressure (2 bar absolute) and under vacuum (< 1e-6 Torr).

Main Waveguide

16 bolts

L = 2.438 m (8')

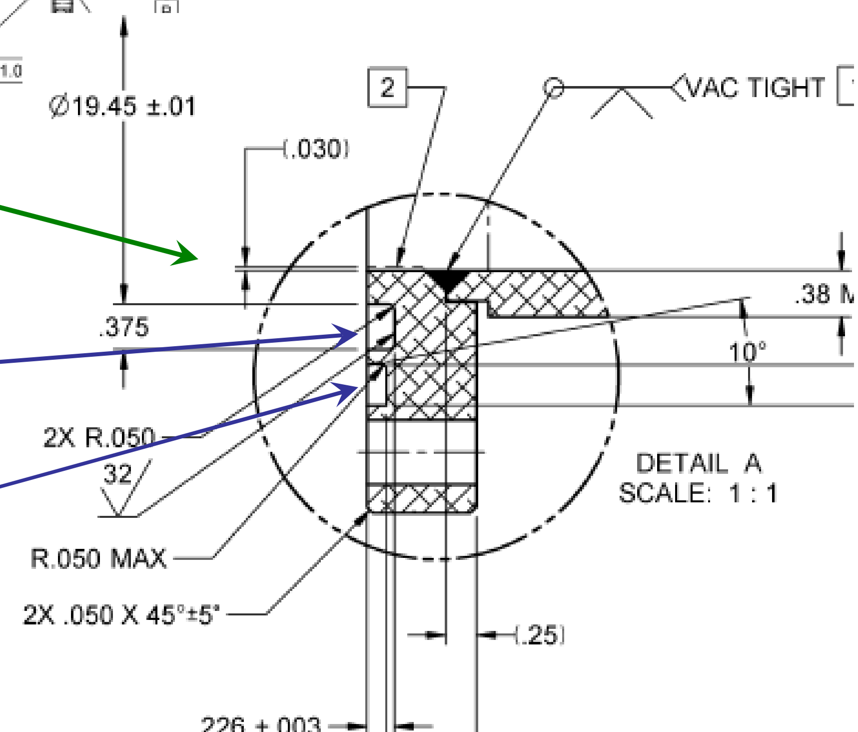
D = 0.480 m ± 1.5 mm



Order for 4 sections due in January 2010

(~ 1.5 mm tolerances)

Aluminum, formed & welded



<u>One-side double grooved flanges:</u>

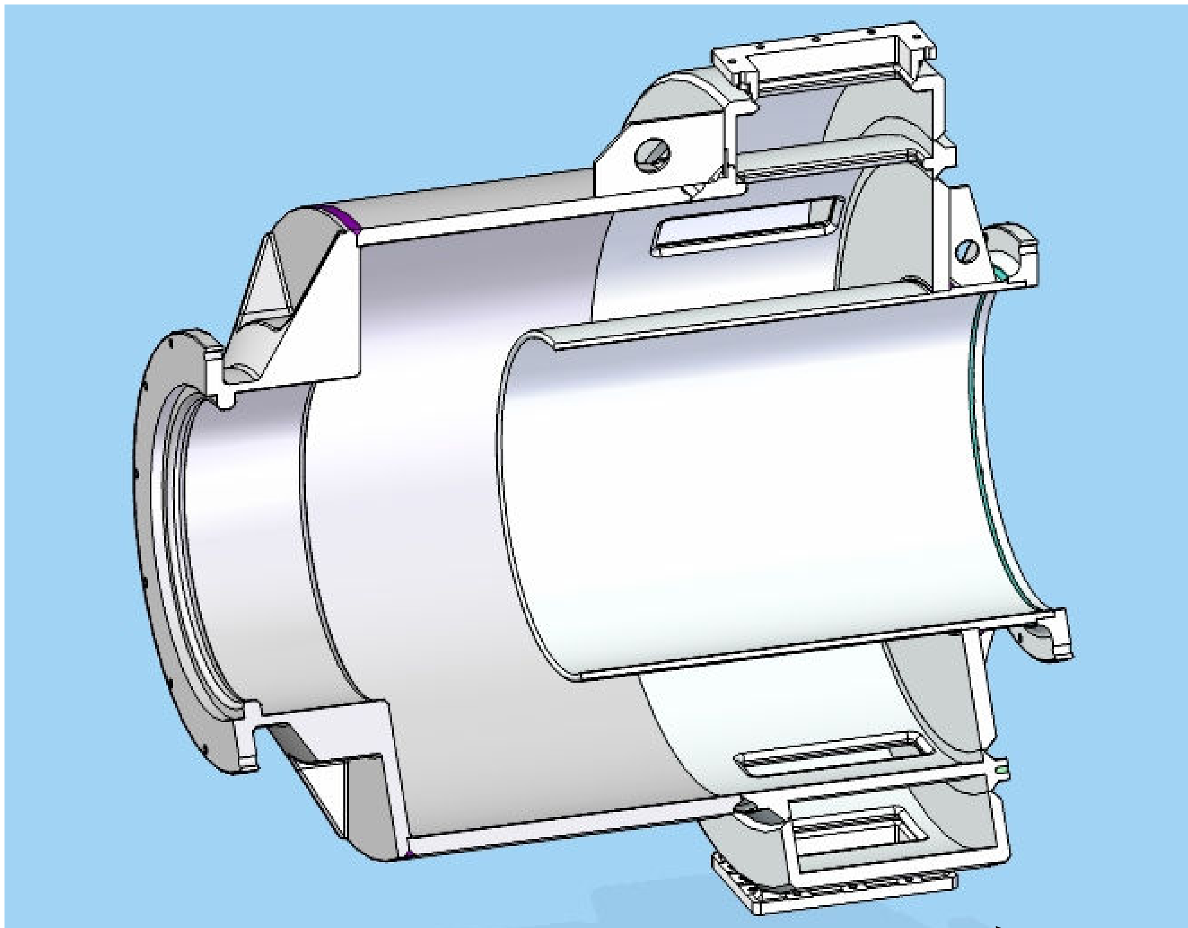
Vacuum seal – Viton® fluoroelastomer O-ring

RF back-up seal – Bal Seal® canted coil contact spring

Coaxial Tap-Off (CTO)

with wrap-around power extraction

Order for 2 CTOs due in March 2010



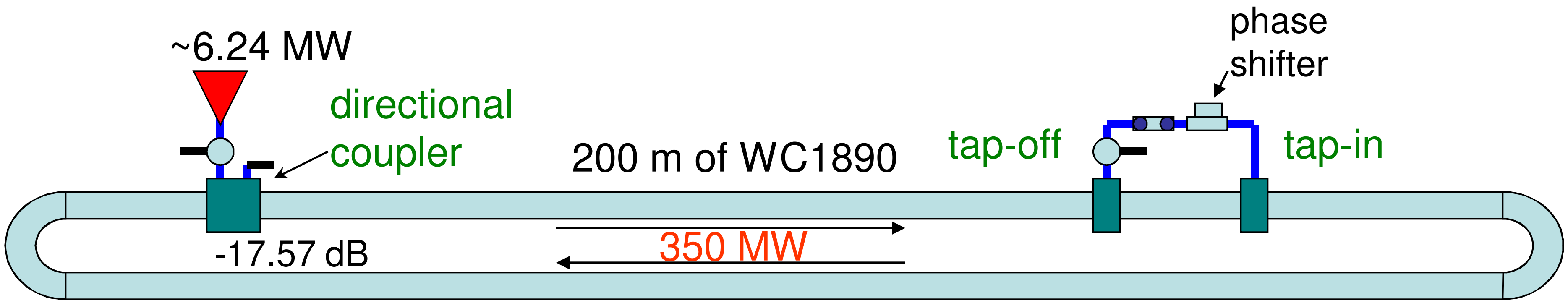
Aluminum, welded

35.51” (0.902 m)

Phase II Demonstration

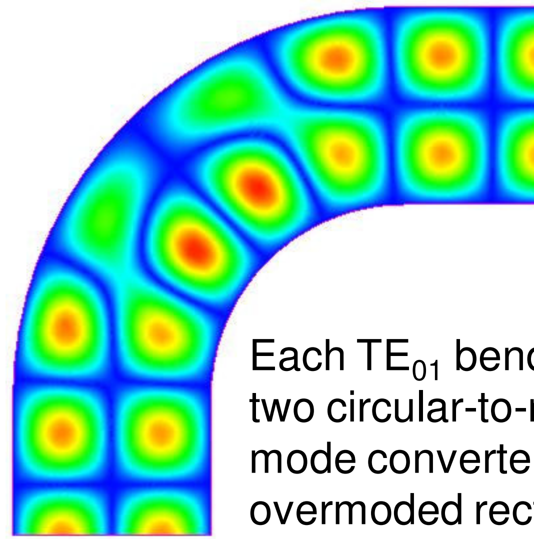
(To Be Completed in 2012)

Develop bends and configure a 200 m resonant ring to test them and a final design tap-in/off. Stored energy is about 1/5 of the worst case in the ILC with speed-of-light limited klystron shutoff times.

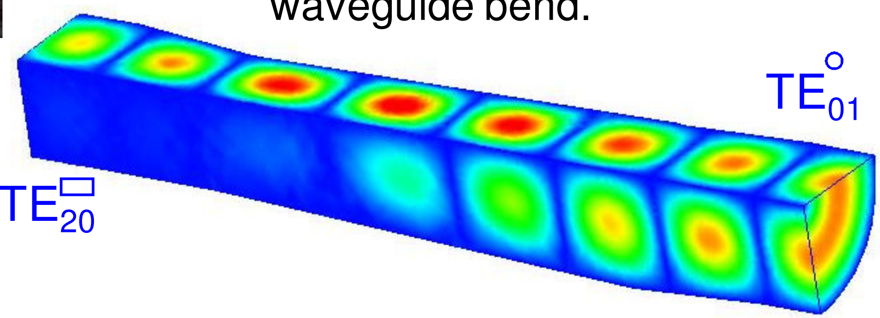


Overmoded Bend
(Two Approaches)

General Atomics high power 90° profiled curvature bend in 44.5 mm corrugated waveguide for TE_{01} mode at 11.424 GHz



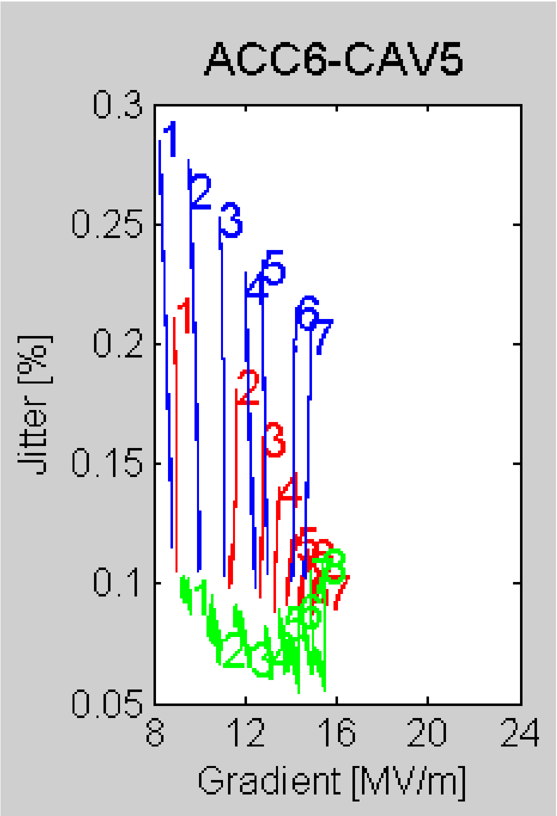
Each TE_{01} bend is composed of two circular-to-rectangular mode converters and an overmoded rectangular waveguide bend.



SLAC compact high power 90° bend in 40.6 mm circular waveguide tapered to overmoded rectangular waveguide for TE_{01} mode at 11.424 GHz

Beam Energy Variation

- The pulse to pulse cavity gradient jitter at FLASH is < 0.1% with appropriate initial detuning, and is not correlated cavity to cavity.
- Thus with FB control of the cluster, the pulse to pulse energy gain variation within a cluster would be < 0.5 * sqrt(832) * 0.1% = 1.4%
- Starting the KCS at 15 GeV, the largest beam energy variation would be < 1.4% at about 30 GeV, which is comparable the beam energy spread. It decreases as roughly 1/energy along the linac.



Blue: Nominal + 100Hz Initial Detuning;
Red: Nominal Initial Detuning;
Green: Nominal – 100Hz Initial Detuning.

Assumptions for Availability Study

- No downtime from rf breakdown in the main rf distribution waveguide – will gauge reliability during the R&D program.
- Include 2 spare klystrons – no downtime if any source fails (klystrons can be repaired/replaced while cluster operational).
- Can also quickly turn off power to individual cryomodules. Failures in local distribution system and cryomodules the same as for the RDR.
- Vector sum control system for each cluster would have redundancy so it would be rare to lose cluster control (OK if input from a few of the cryomodules are missing).

RF Breakdown

- The peak surface electric field in the CTO of 1.6 MV/m is lower than in the Aluminum VTO (variable tap-off) at 5 MW (1.9 MV/m), which has run for hours with 1ms pulses at 14 psig N2 with no rf breakdowns.
- Running the CTO under vacuum (< 1e-6 Torr) should be breakdown free based on operational experience with SS and copper (if Al worse, would Cu coat it). E.g., our 5-cell,1.3 GHz SW structure runs reliably with 20 MV/m surface fields with 1 ms pulses.
- The peak surface magnetic field for the maximum 340 MW (full current) flowing through a CTO is 15 kA/m on the edge of the tube defining the gap. The pulsed heating temperature rise of 3 degC in this case is considered negligible.
- In the tapers and main 0.48m waveguide, the surface electric fields are non-existent. SLAC has decades of experience running high power in overmoded X-band TE01 mode waveguide. The mode can basically only break down by gas ionization (Emax ~ 4 MV/m), so need to have a good vacuum or high gas pressure.
- The two bends required in each main waveguide may be the most risky part of the system, as they carry the maximum power and must depart from the pure TE01 field pattern.

LLRF Cluster Control

- Digitize and sum cryomodule (CM) probe signals locally and transmit in real time to the associated cluster building.
- Here the digital signals from each of the ~ 100 CMs are split three ways and sent to three identical Drive Processors
- The output rf from each of the klystrons are also digitized and split three ways, one going to each Drive Processor.
- Each Drive Processor uses the CM sum signals, the klystron output signals and dynamic FF tables to compute the digital drive signal to each of the klystrons (one digital output per klystron).
- At each klystron, the three digital signals from the Drive Processors go through 2-of-3 majority logic before being used to generate a klystron drive signal.
- The clock signals and LO for this system are provided by redundant sources so that if one source fails, the signals would still be provided by the others.
- With this scheme, individual CMs or klystrons may have to be turned off due to LLRF failures, just as in the baseline design, but rarely the entire cluster.

Summary

Surface klystron clusters reduce the ILC cost by a few 100 M$, eliminate the service tunnel and simplify the power and cooling systems.

Design builds on our 15 year experience with high power (up to 500 MW), over-moded, low loss X-band components, and 5 year experience developing L-band distribution systems and a SW accelerator.

Construction underway of a test system to evaluate the robustness of this approach – will be operated both under vacuum and under pressure. If successful, a larger scale system (200 m) would be built by 2012 that's includes bends.

Will continue to evaluate the effect on beam operation due to the more coarse energy control.