Klystron Cluster System Development

Christopher Nantista

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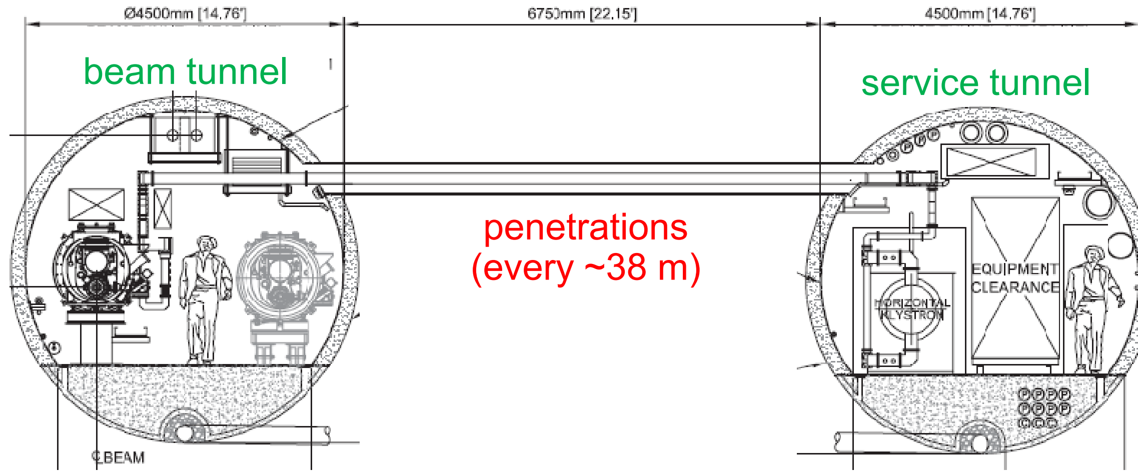
Two Tunnels to One Tunnel

RDR BASELINE: dual tunnels

RF power production is distributed along the length of the linac in a separate service tunnel.

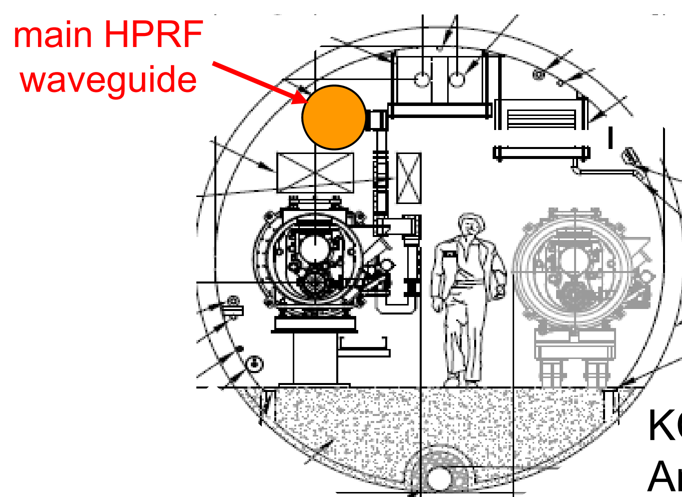


STRAWMAN BASELINE: single tunnel

(KCS or DRFS)

Klystron Cluster Scheme option moves high power rf production from underground to surface. It is brought through shafts into the main feed waveguides at intervals of approximately 2.4 km.

Additional equipment from service tunnel should fit, with appropriate radiation shielding, beneath the cryomodule support.



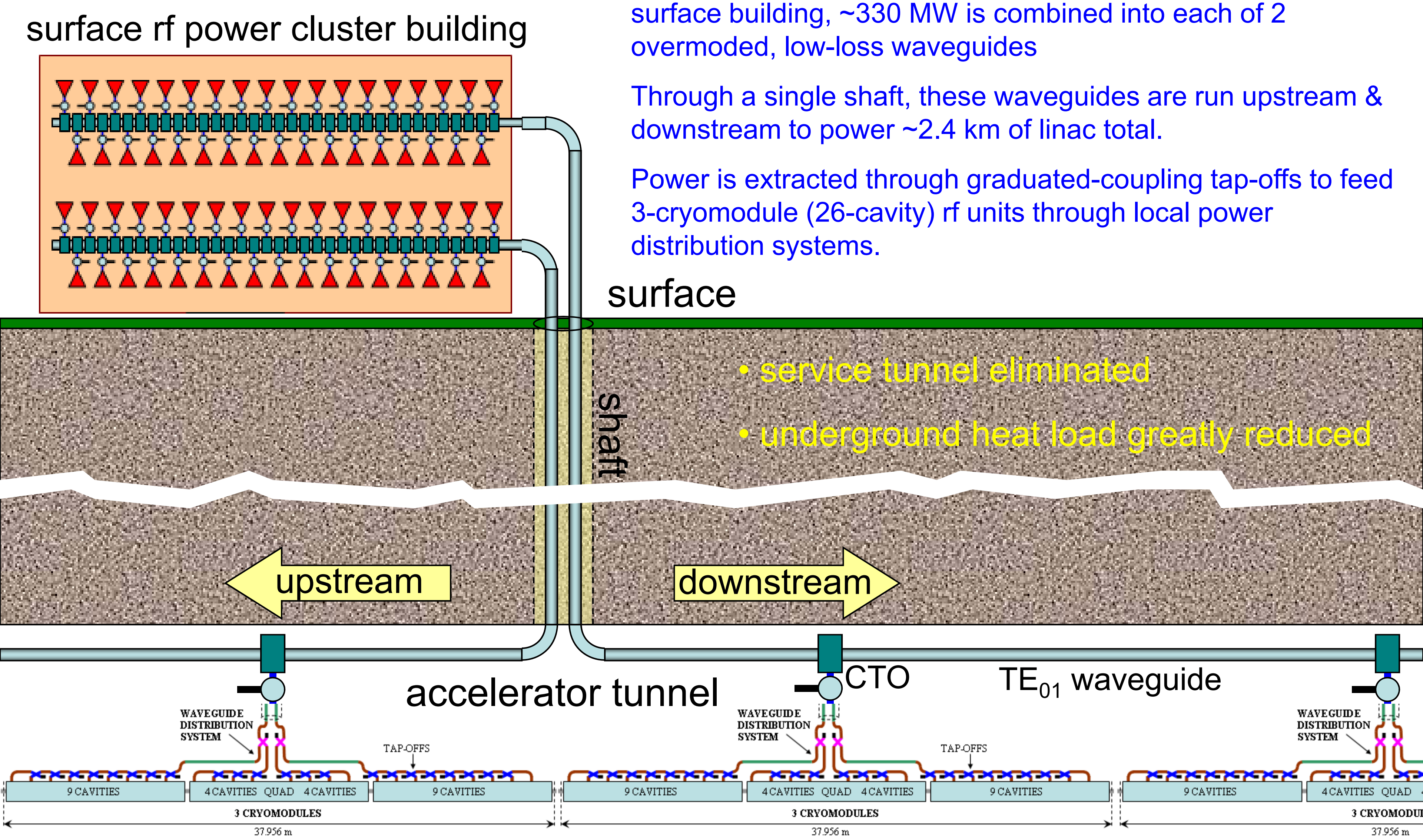
KCS option,
American version

Klystron Cluster Layout

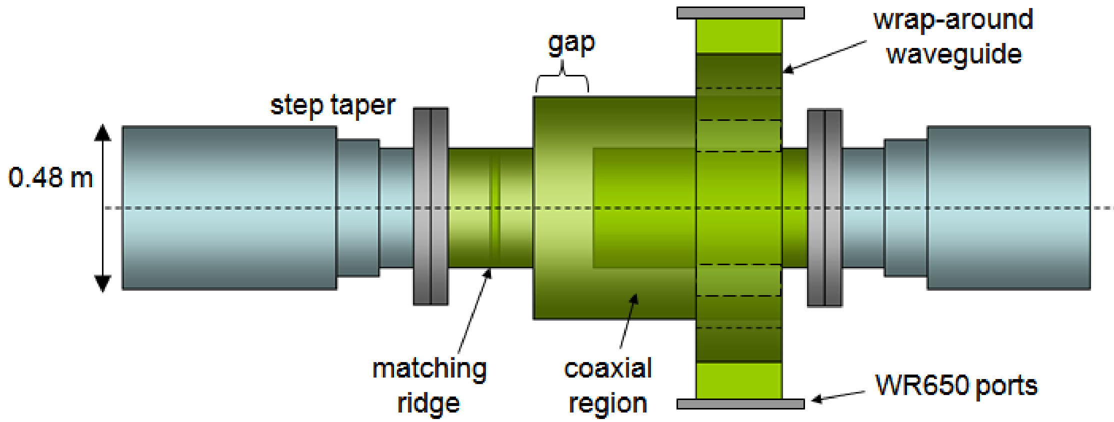
From 2 groups of ~35 klystrons & modulators clustered in a surface building, ~330 MW is combined into each of 2 overmoded, low-loss waveguides

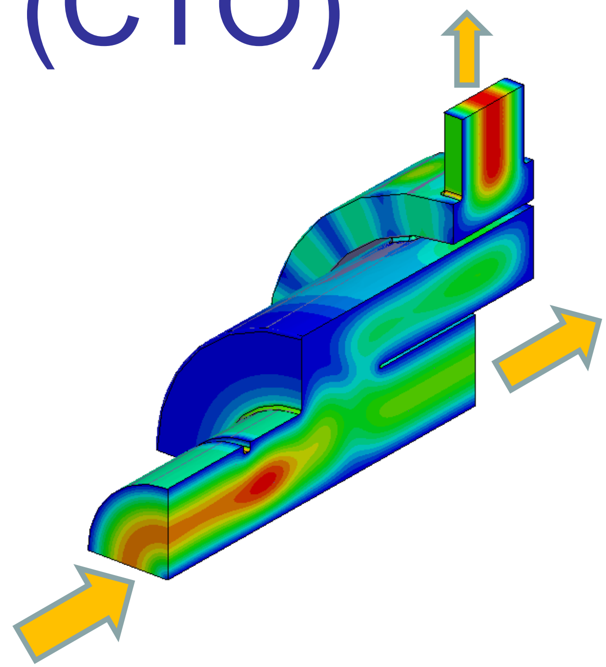
Through a single shaft, these waveguides are run upstream & downstream to power ~2.4 km of linac total.

Power is extracted through graduated-coupling tap-offs to feed 3-cryomodule (26-cavity) rf units through local power distribution systems.



Coaxial Tap Off (CTO)





•Power is tapped off from the circular TE$_{01}$ mode, in 10MW 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 (5MW each), analogous to 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 combining power into the pipe.

•Appropriately shorting the left port creates a mode launcher (or any coupling).

Nominal Parameters

# of KCS per main linac	9	
# of rf units/tap-offs per system	32	
# of cryomodules per system	96	
# of cavities per system	832	strawman half current option
# of klystrons/modulators per system	36 (one off)*	19
peak rf power per system (MW)	340	170

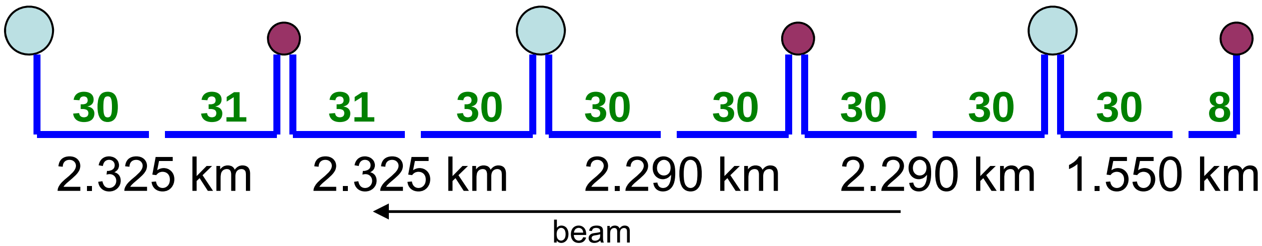
* To feed ~32 rf units, 2 extra units of power ($\rightarrow$ 340 MW) cover extra transmission loss and 2 more, with one off, provide redundancy for a single unit failure per cluster.

Shaft Location

560 3-CM rf units, 280 per linac
31 per cluster → 9.03 clusters, 5 shafts per linac

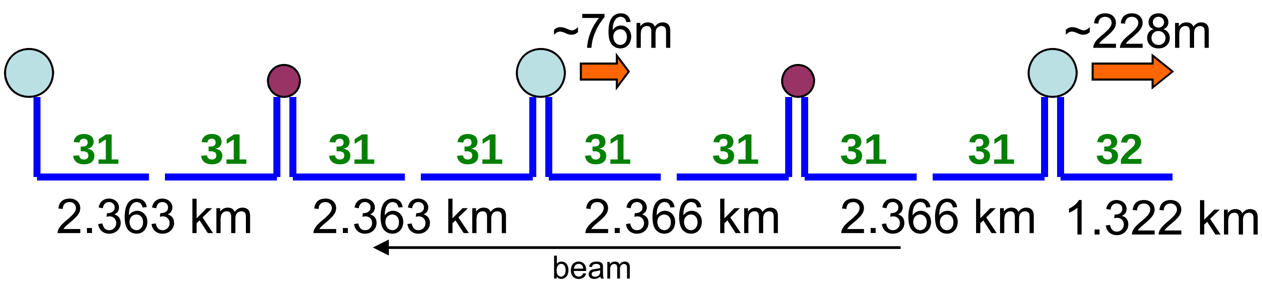
-- main shaft
-- additional KCS shaft

The RDR shaft location would require three additional shafts, for a total of 6, for the KCS.

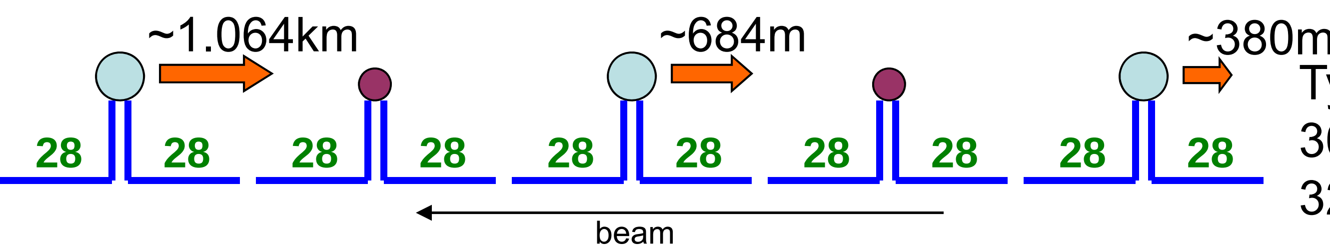


Typical KCS: 30 rf units, 32 klystrons worth of power, 34 klystrons/cluster

Shifting the main shafts would accommodate KCS implementation with only two additional shafts per main linac.



Typical KCS: 31 rf units, 33 klystrons worth of power, 35 klystrons/cluster



Typical KCS: 28 rf units, 30 klystrons worth of power, 32 klystrons/cluster

Current Test Program

Prototype CTO and main overmoded circular waveguide.

Cold test CTO in launching mode.

Test waveguide under vacuum.

Test transmission efficiency of waveguide between two CTO's

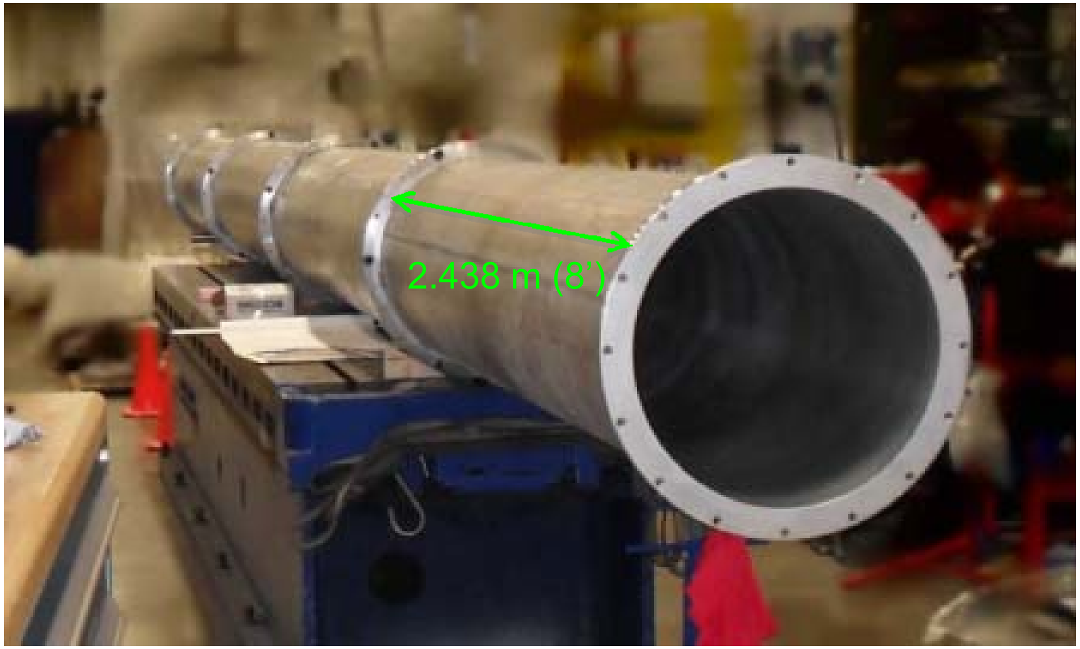
~45%

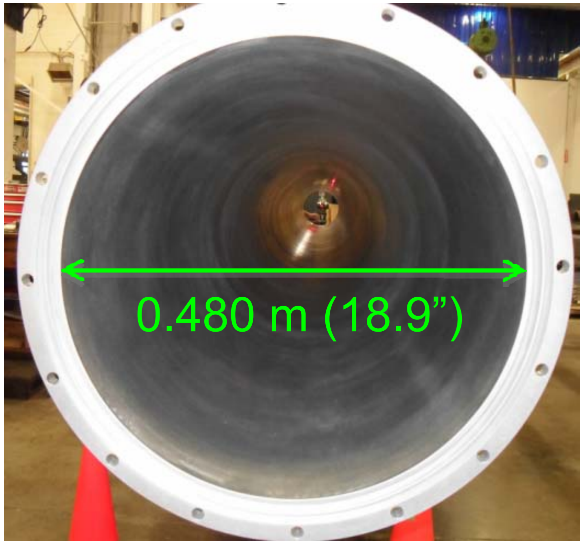
Test CTO at full power level to be seen by rectangular ports (klystron limited).

Test waveguide as a resonant line up to maximum field levels to be seen.

Redo tests under 14.5 psig pressure, as possible alternative to vacuum.

Prototype “Big Pipes” for KCS Tests





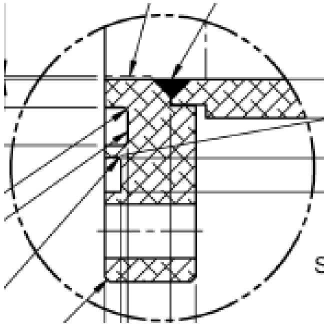
Four 8’ sections (9.75 m total) of 0.48 m-diameter waveguide (WC1890).

Fabricated from formed aluminum sheets, welded and machined.

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

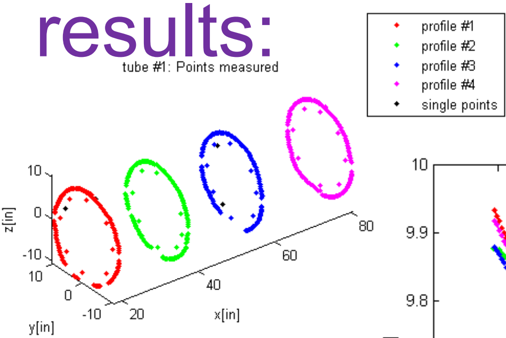
vacuum/pressure seal – Viton® O-rings

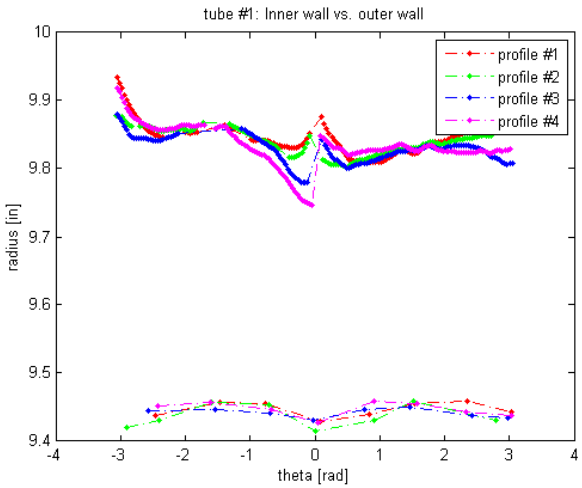
rf seal – Bal Seal® canted coil contact spring

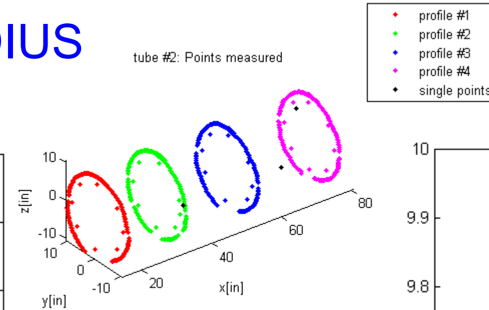


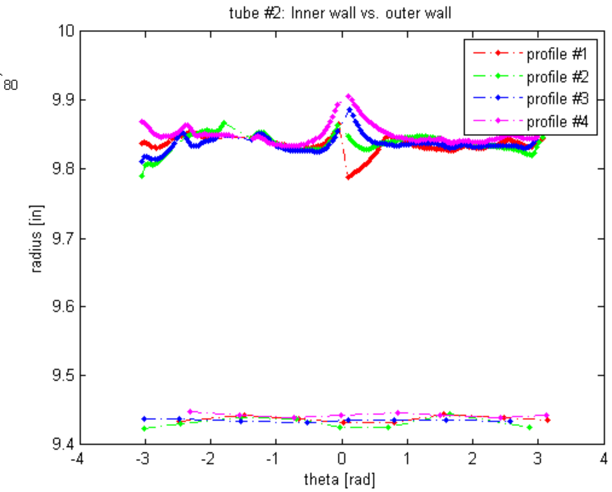
WC1890 Metrology QC results:

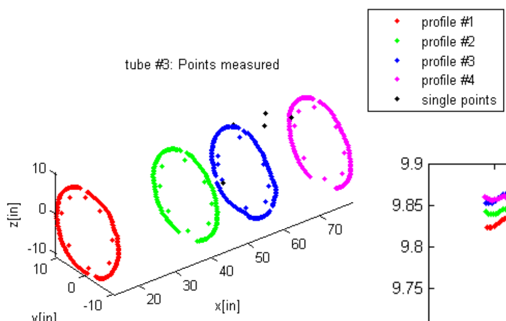
RADIUS

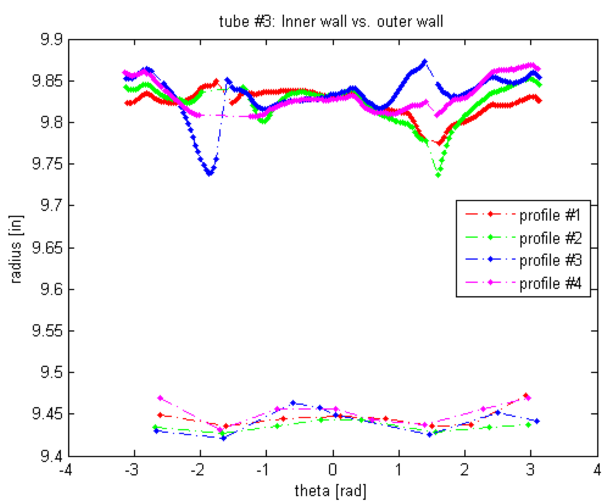


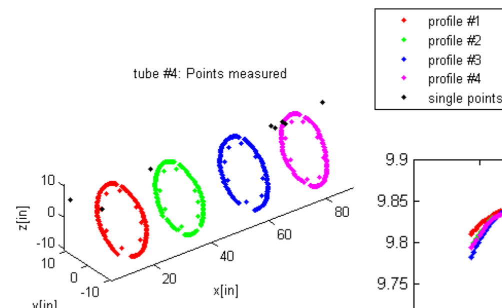


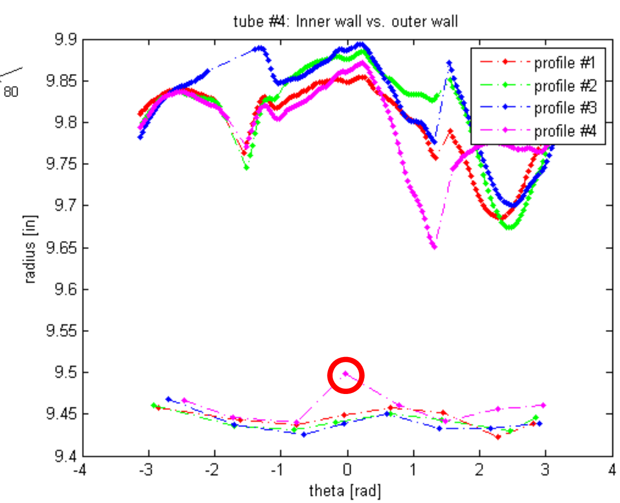




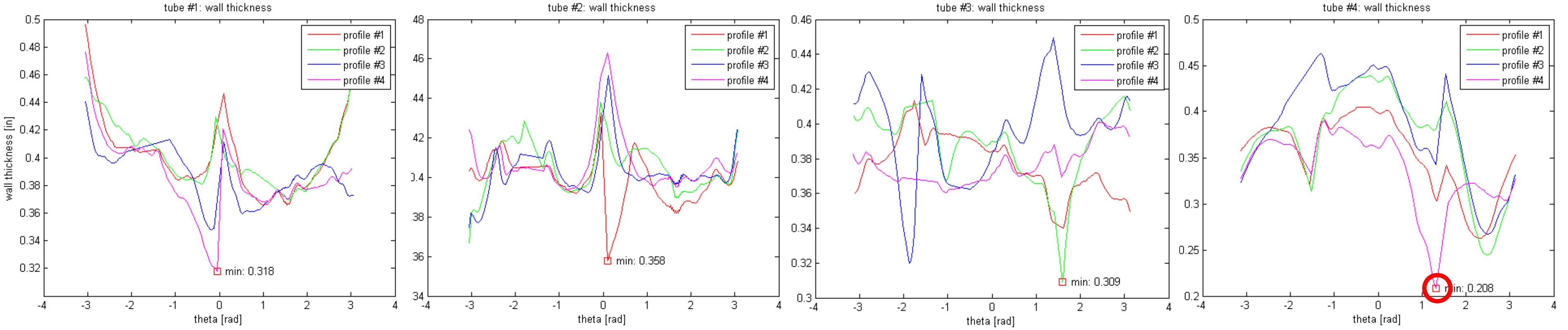








WALL THICKNESS



Inner radius variation basically met tolerance of ~1 mm.

Flange o.d.-i.d. concentricity within <~0.015”, well within tolerance.

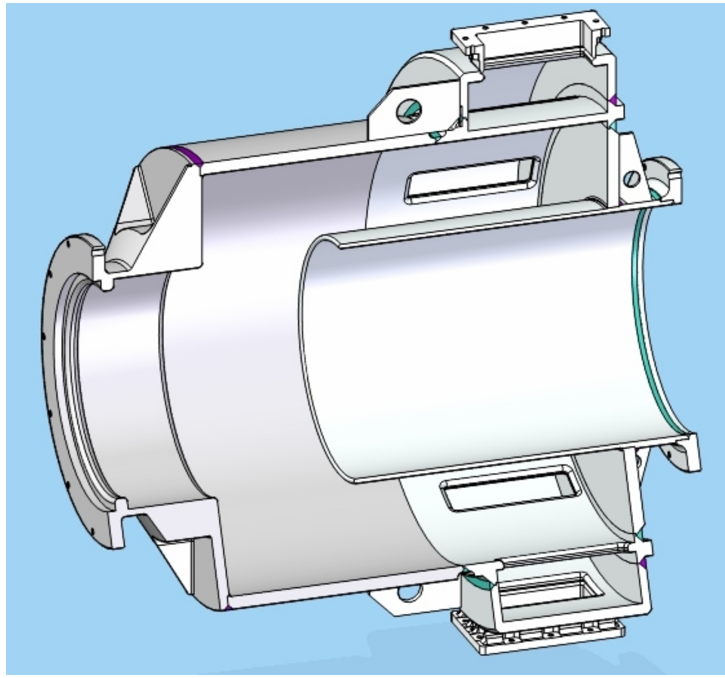
Wall thickness falls short in places of the 0.375” specification.
Some anomalous spots were found, going as low as 0.120” (tube #4).

Pipes are being hydrotested to 1.5 times operating pressure of 14.5 psig and cleaned for vacuum.

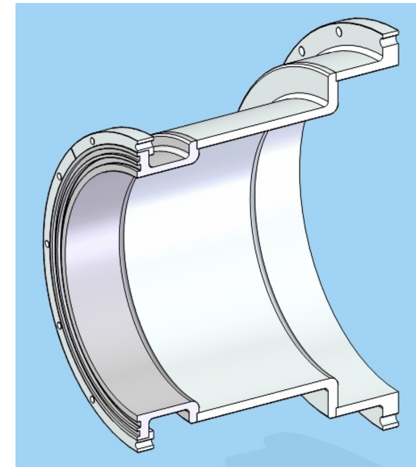
Anchored restraints are being designed to assure safety under vacuum.

A replacement is being made for tube #4.

CTO’s and Auxiliary Parts

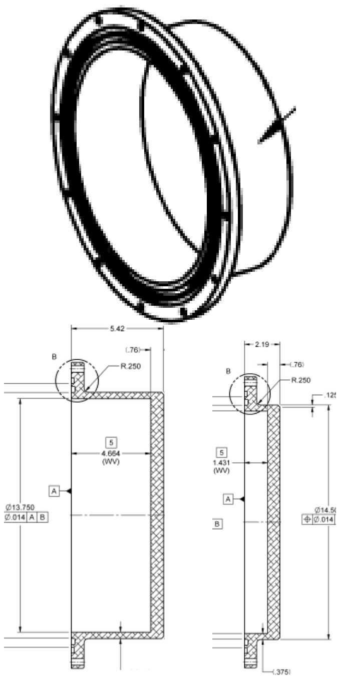


Two welded aluminum 3-dB CTO’s are being fabricated and expected to be shipped next month.



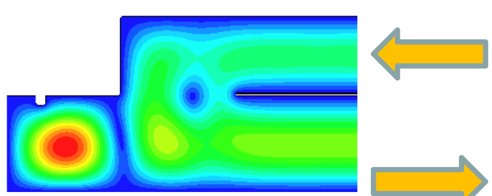
13.75” → 18.90”

Two circular step tapers to connect to main waveguide are in fabrication at SLAC.

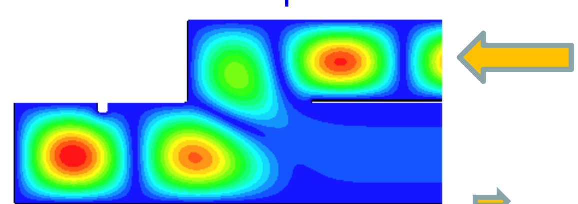


End caps for launching and resonant coupling. (to be final machined after cold-testing with shims)

launcher

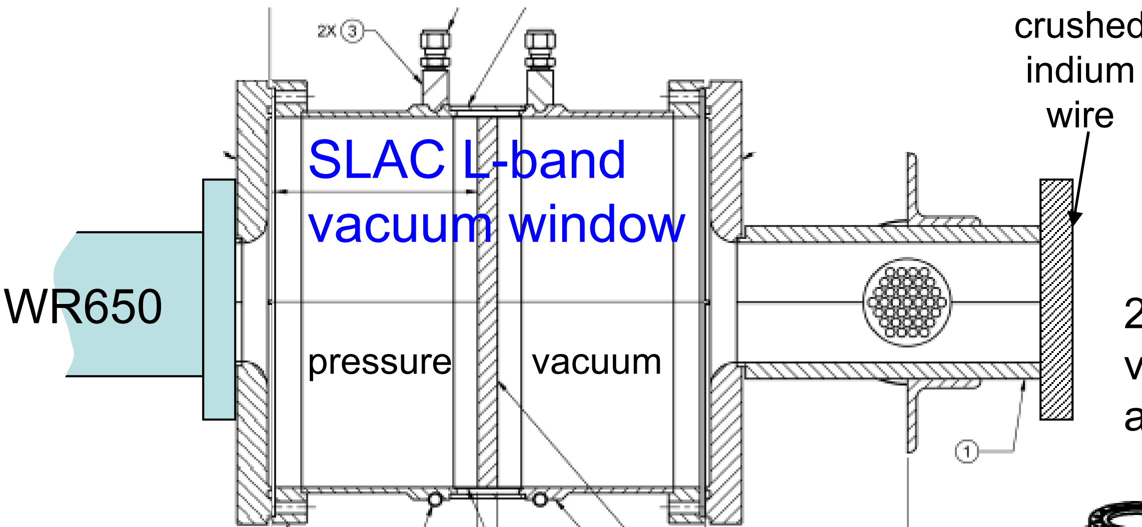


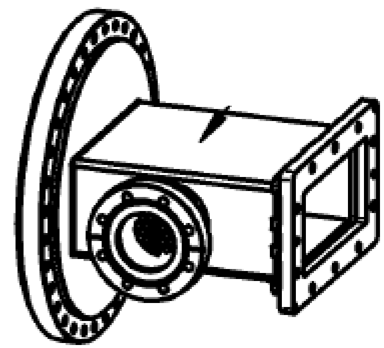
coupler



Vacuum Pumping

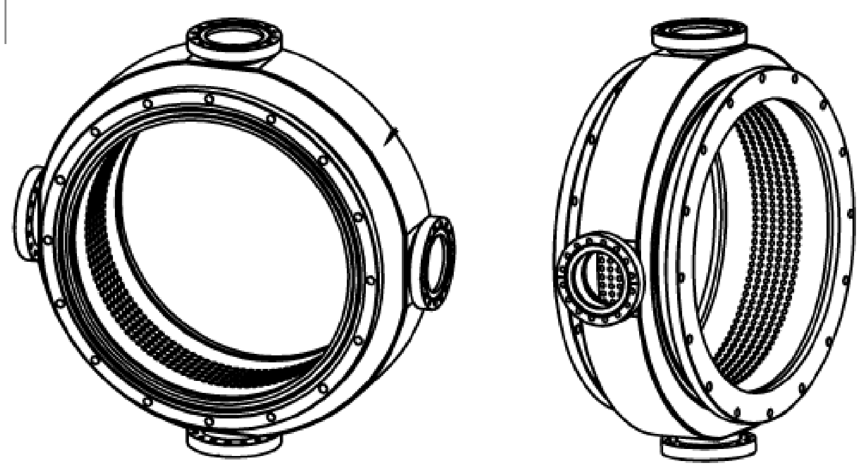
After UHV cleaning, the pipe sections will be connected and pre baked with heat tape and insulation with pumping through an end cap to outgas the surface.





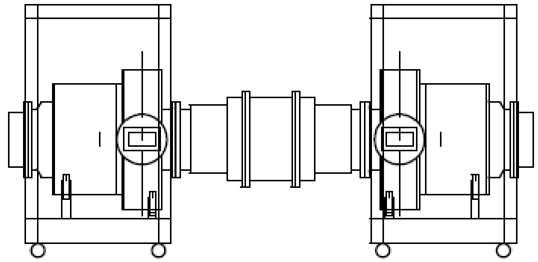
20 l/s ion pumps will be used on vacuum ports built into window adaptors on either side of each CTO.

Two 100 l/s ion pumps will pump through a special pump-out insert in the middle of the large circular waveguide run.

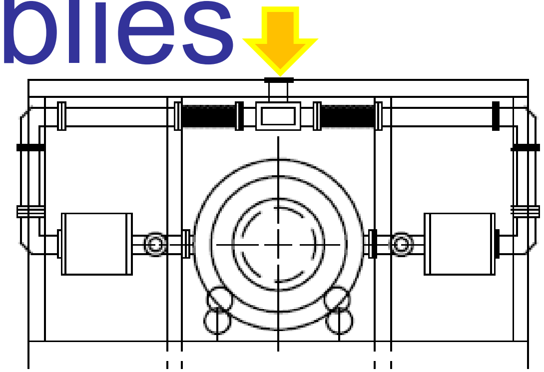


Experimental Assemblies

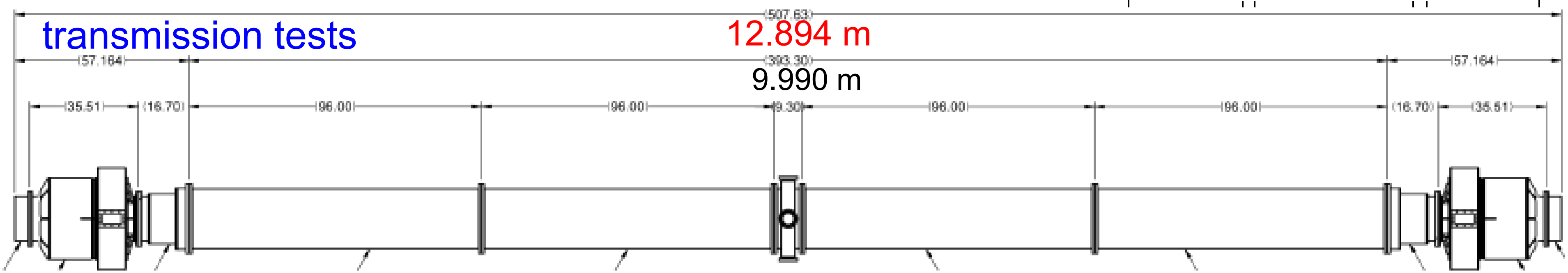
CTO cold tests



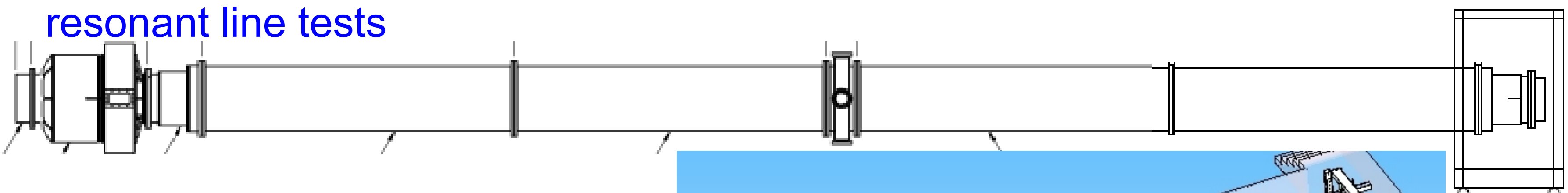
input assembly

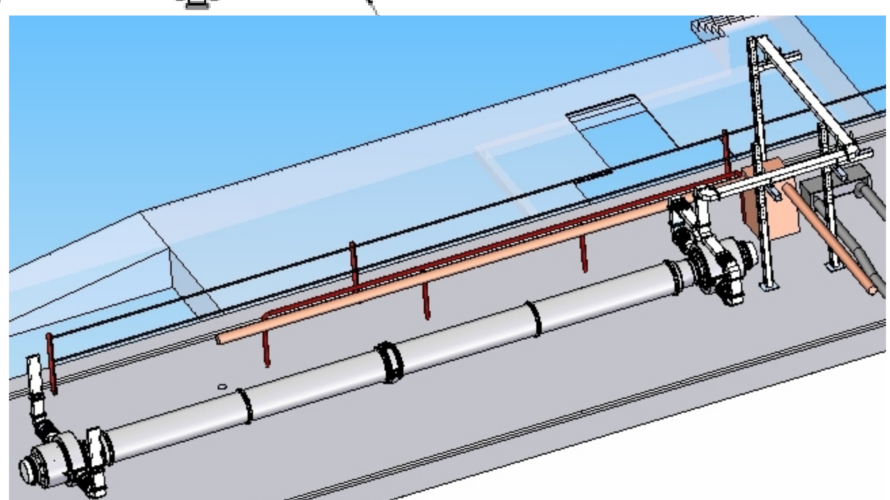


transmission tests



resonant line tests





Location:

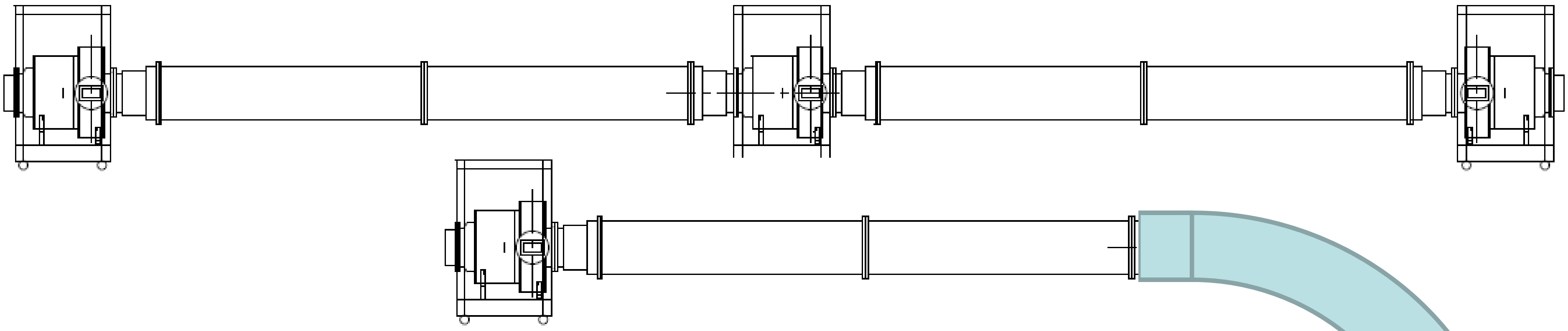
Roof of NLCTA bunker

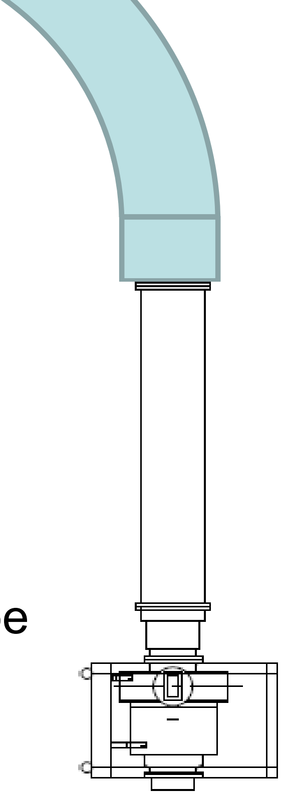
Power source:

SNS modulator and

Thales “5 MW” klystron

Further Work

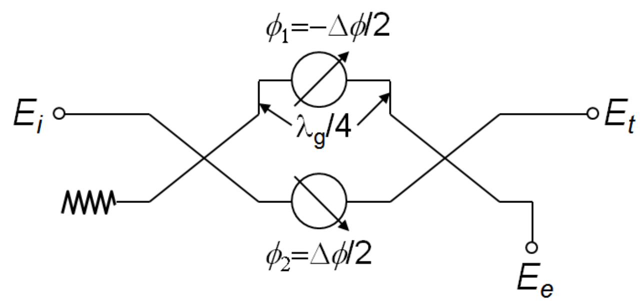




Further work can be done toward establishing the feasibility of the Klystron Cluster Scheme, including:

- demonstrating the matched tap-off function with a third CTO
- demonstrating power combining
- designing a very high-power TE_{01} mode bend
- demonstrating transmission efficiency of such a bend
- demonstrating power (field) handling of such a bend
- studying the effect of KCS granularity on emittance preservation
- developing a TE_{01} mode diagnostic directional coupler for the big pipe
- studying the combining scheme/efficiency
- studying coupling errors, mode conversion, line resonances…

Phase Shifter for Local Power Tailoring



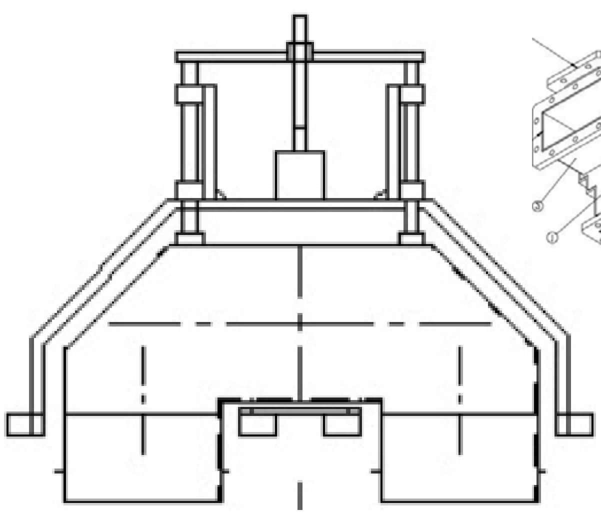
$$E_e = e^{i\left(\frac{\phi_1+\phi_2}{2}+\frac{\pi}{4}\right)}\sin\left(\frac{\Delta\phi}{2}+\frac{\pi}{4}\right)$$

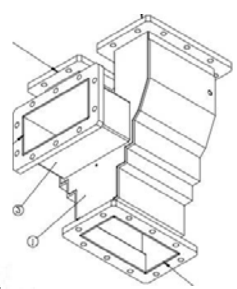
$$E_t = e^{i\left(\frac{\phi_1+\phi_2}{2}-\frac{\pi}{4}\right)}\cos\left(\frac{\Delta\phi}{2}+\frac{\pi}{4}\right)$$

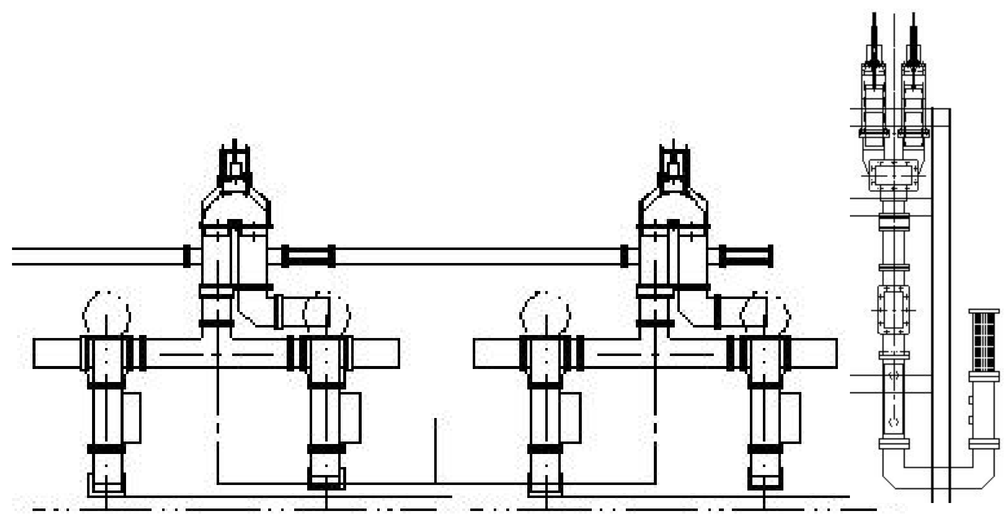
Phase shifter range of 0°–90°, the above arrangement allows full range power division.

If ϕ_1 and ϕ_2 are moved equally in opposite senses, the output phases are unaffected.

With a 20% spread in accepted cavity gradient capacity, efficiency could be increased by incorporating at least pairwise adjustability in the local PDS.

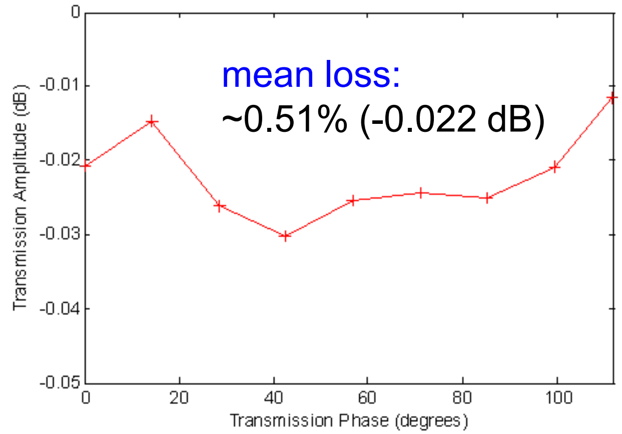


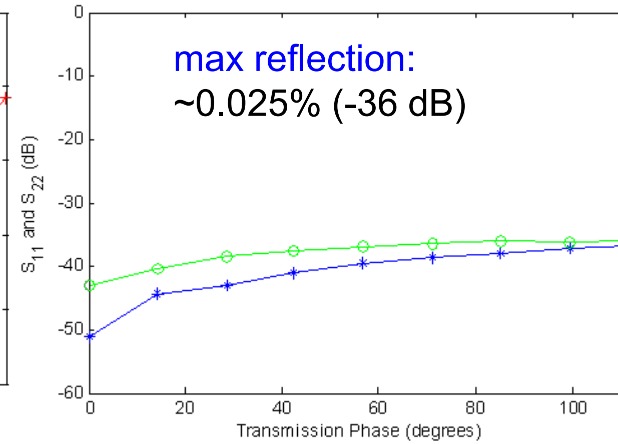




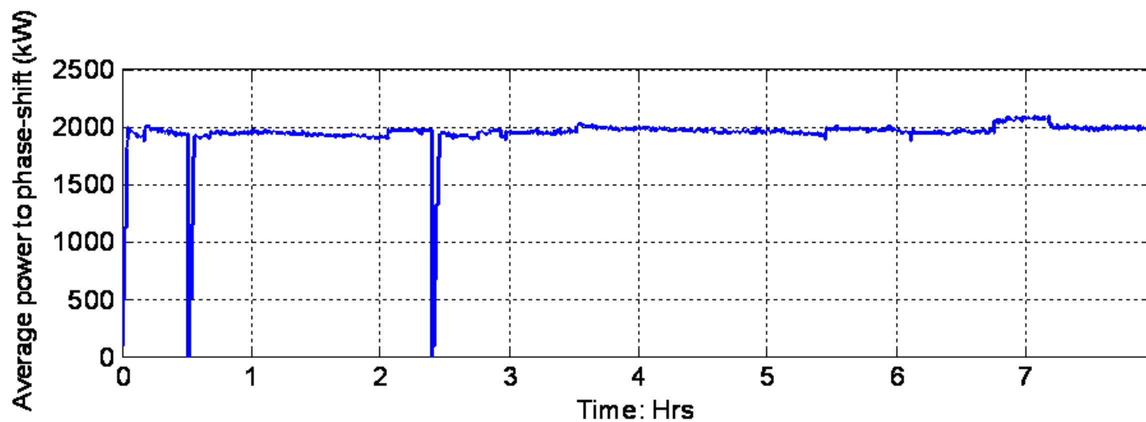
Phase Shifter Prototype

cold tests:

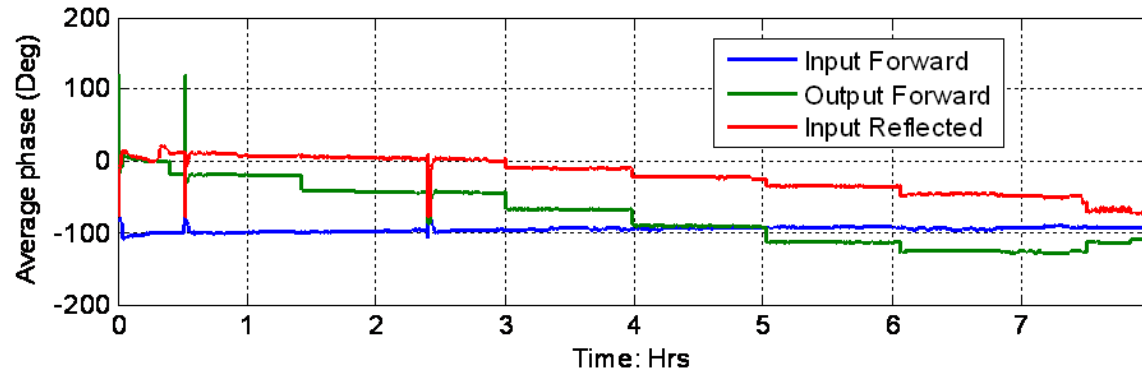




high-power test:



No breakdown detected during 8 hours running at 1bar N_2.



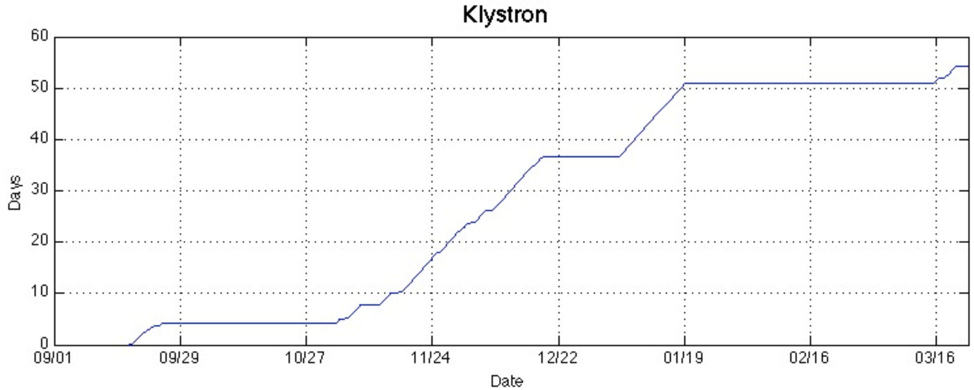
8 more are in fabrication for Fermilab NML CM2 PDS.

Teflon spacers will be replaced with s.s. and rad hard epoxy will be used to affix fingers.

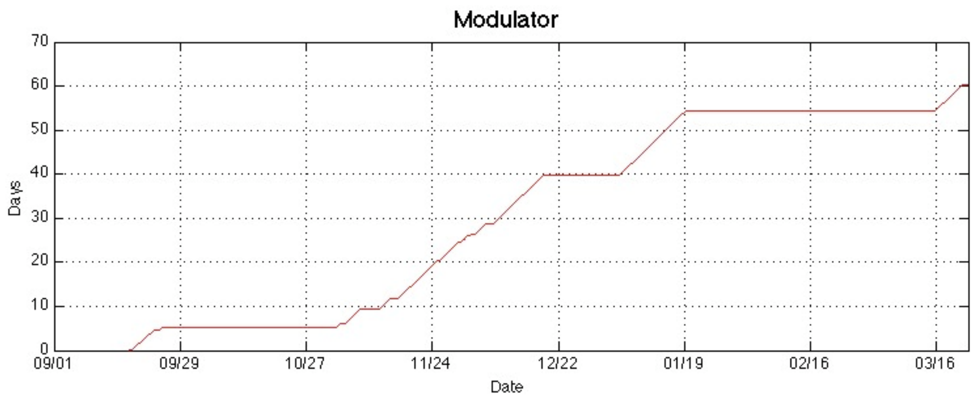
Klystron and Modulator

Testing continues of:

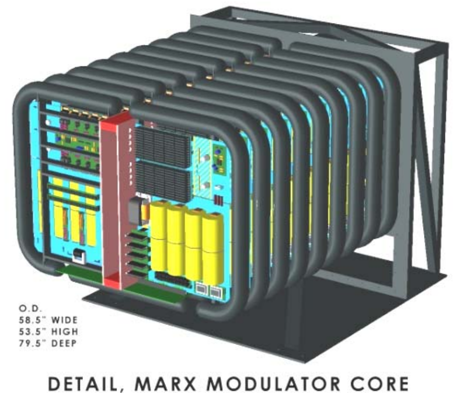
SLAC 120 kV Marx Modulator and
Toshiba 10 MW 6-beam MBK

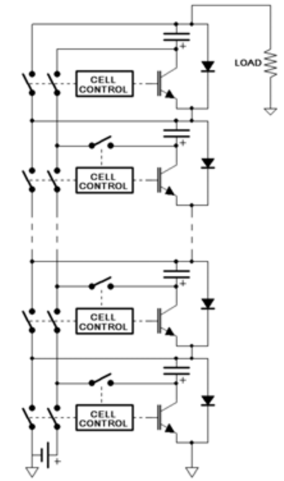


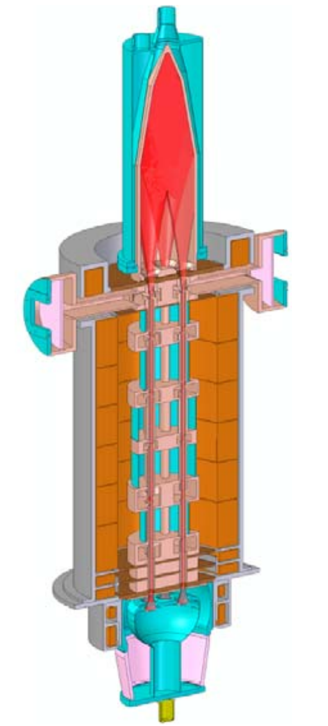
Klystron: 1301.0 hours (54.21 days) integrated operation; 191.0 hours (7.96 days) uninterrupted operation



Modulator: 1450.0 hours (60.42 days) integrated operation; 265.0 hours (11.04 days) uninterrupted operation







Integrated uptimes, to date:

Month	Klys.	Mod.
Total Hrs	1301.1	1449.8
Total Days	54.21	60.41

min. value to define kly "on": 1 MW
min. value to define mod "on": 100 kV