KCS Review and R&D

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First, I'd like to offer congratulations to our KEK colleagues on their DRFS development and successful S1-Global work (which I hope we'll get to hear more about soon), and our prayers for a swift recovery from the impact of recent events.

Ganbatte, Nihon!

Review

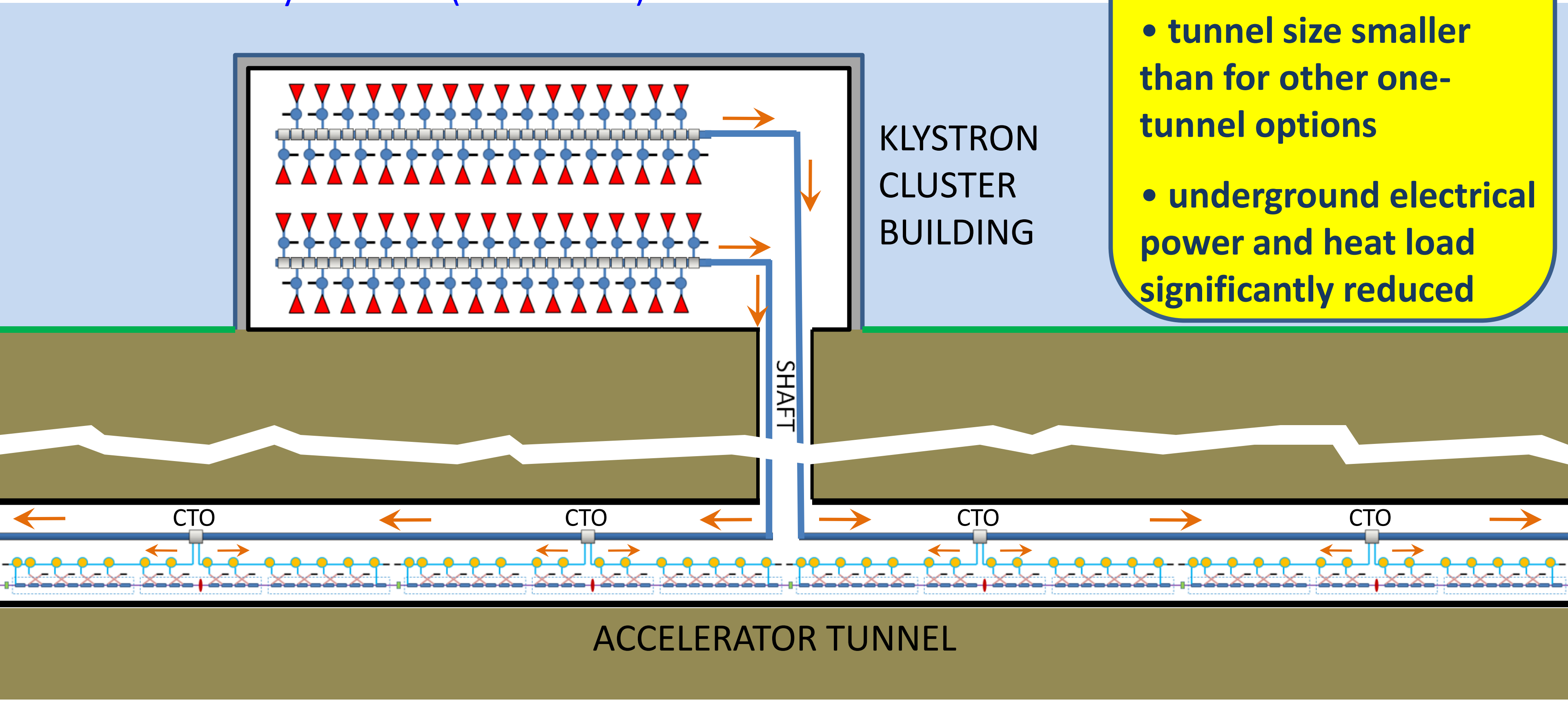
and Developments

Klystron Cluster Scheme

- Main linac rf power is produced in surface buildings and brought down to and along the tunnel in low-loss circular waveguide.
- Many modulators and klystrons are "clustered" to minimize surface presence and number of required shafts.
- Power from a cluster is combined and then tapped off in equal amounts at 3-cryomodule (RDR rf unit) intervals.

ADVANTAGES

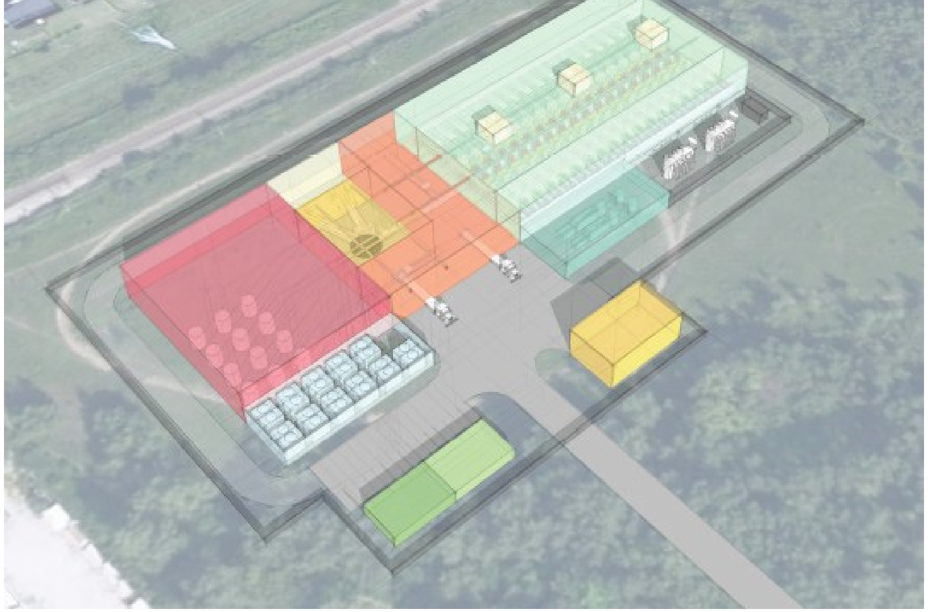
- **equipment accessible for maintenance**
- **tunnel size smaller than for other one-tunnel options**
- **underground electrical power and heat load significantly reduced**



2.05 km of linac powered per 2-cluster shaft. 12 shafts total for both linacs.

KCS Surface Buildings

Concepts by
Holabird/Root



Two clusters can be housed in one building (feeding upstream and downstream).

10 MW, 1.6 ms MBK's (multi-beam klystrons) powered by 120 kV RDR or Marx modulators.

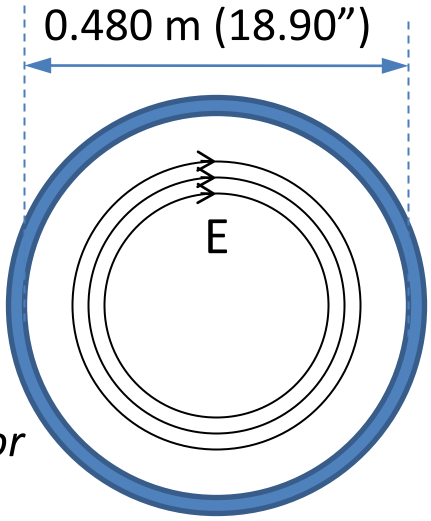
An initial *low power* (bunch number) installation, should include klystrons furthest from the shaft, allowing their combining waveguide circuit to remain intact when more sources are added. This likely requires *full size building* construction.

from Vic Kuchler

KCS Main Waveguide

For long distance, high-power rf transmission, use the TE$_{01}$ mode in *circular* waveguide.

- No surface electric field → high power handling capacity
- Attenuation falls quickly with radius → low loss achievable
- Extensive experience from NLC pulse compression, power distribution R&D

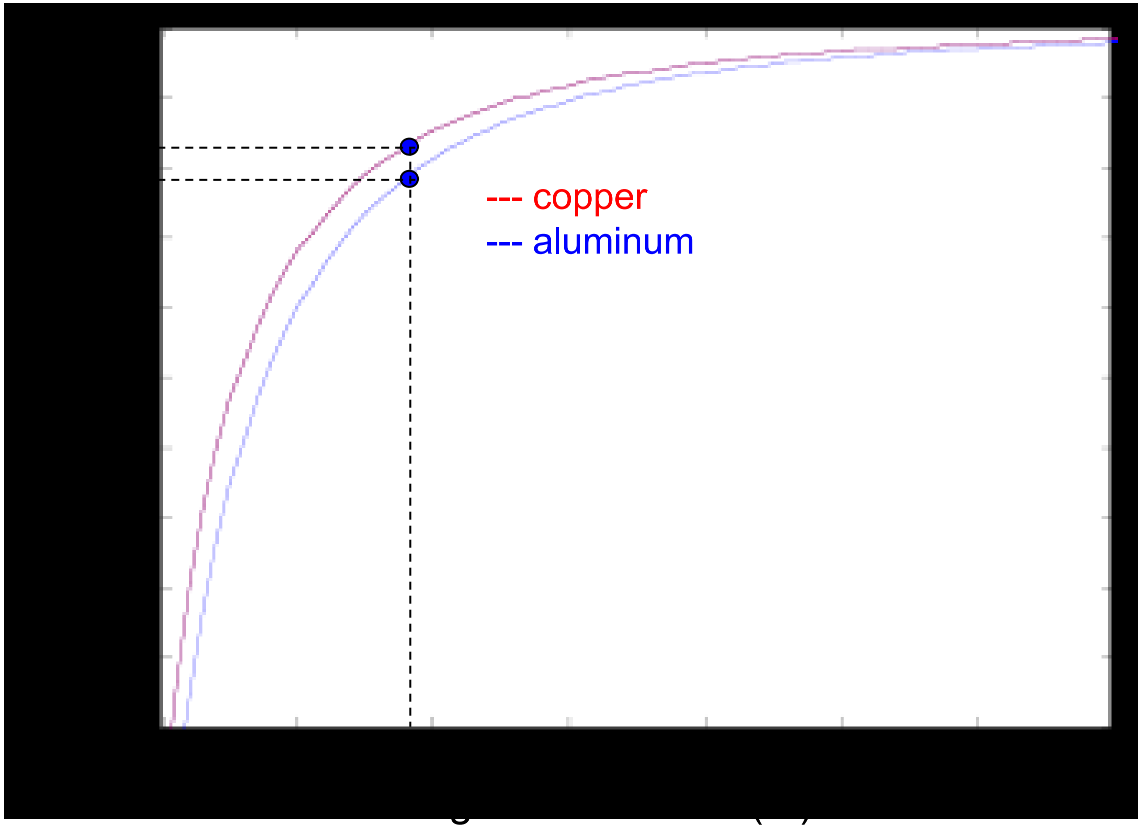


WC1890

evacuated *or* pressurized

TE$_{01}$ mode

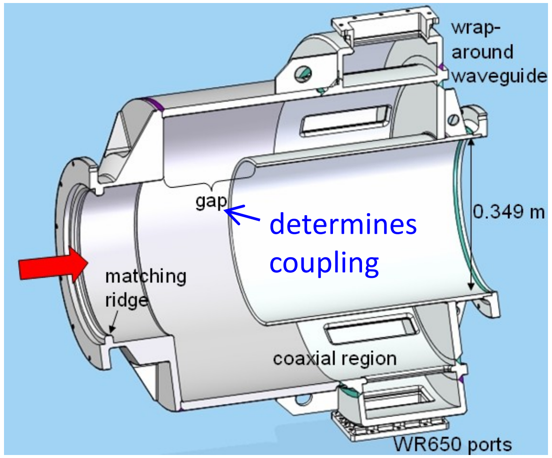
$$\alpha = \frac{R_s}{Z_0}\frac{1}{\sqrt{k_0^2-(\chi_{01}/a)^2}}\frac{\chi_{01}^2}{k_0 a^3}$$

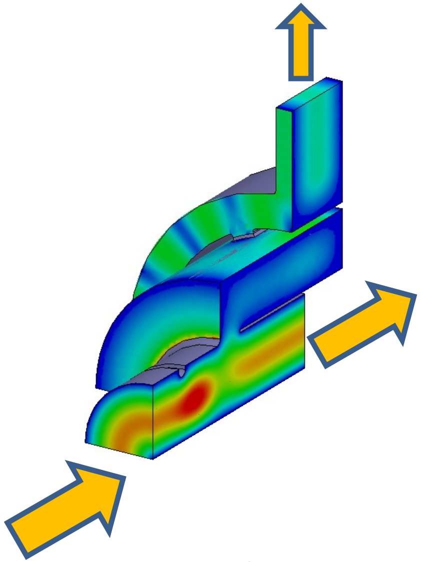


Combining and Distributing Power

A novel waveguide device was developed for coupling into and out of the circular TE_{01} mode waveguide without creating large surface fields.

CTO (Coaxial Tap-Off)



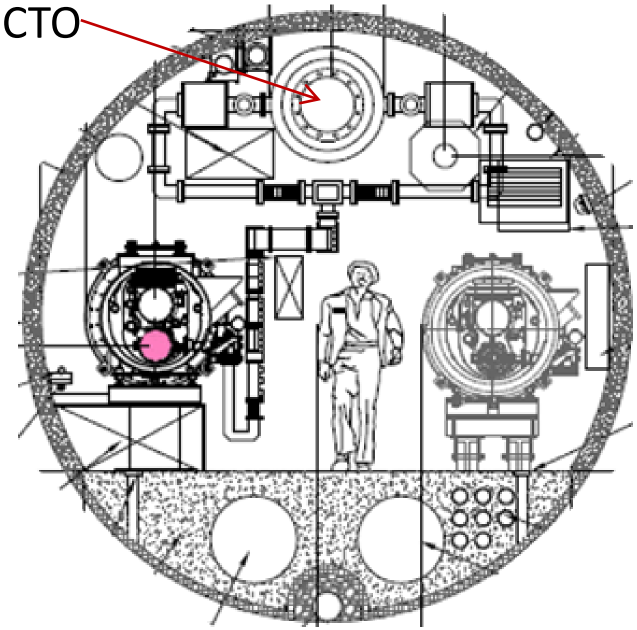


Couplings ranging from ~1 to 1/33 are required.

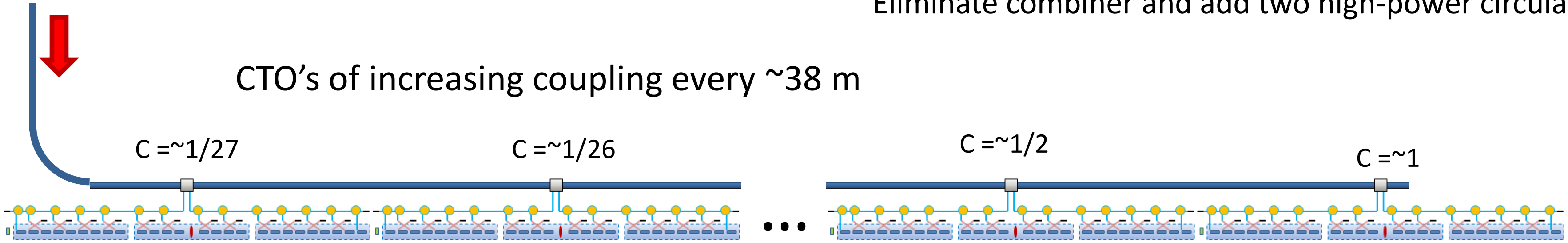
For *combining*, the tap-offs are used in reverse.

Proper phase and relative amplitude needed for match (mismatched power goes to circulators).

Tunnel Cross-Section



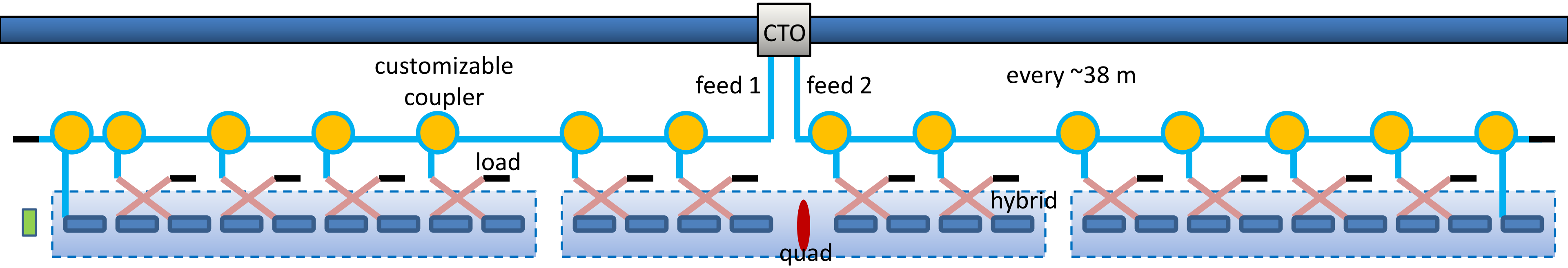
Replace vacuum windows w/ smaller pressure windows.
Eliminate combiner and add two high-power circulators.



CTO's of increasing coupling every ~38 m

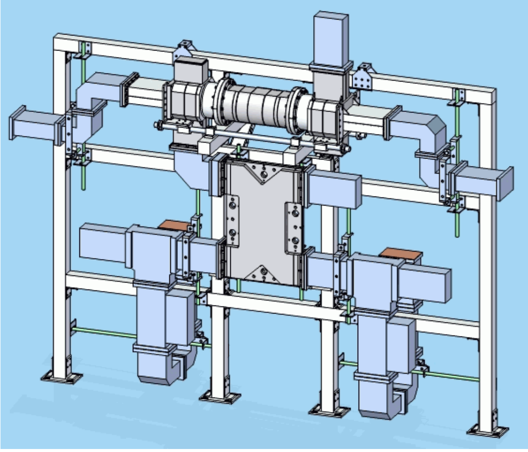
Local RF Power Distribution Scheme

Power from each CTO is distributed along a 3-CM, 26 cavity rf unit through a local PDS. Distribution is tailored to accommodate *gradient limits* of cavities.



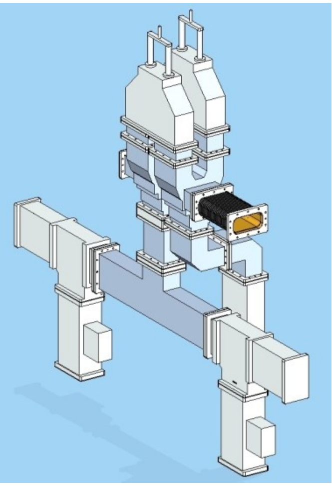
Original VTO (Variable Tap-Off) Pair-Feeding Concept

- manually adjustable by pairs
- requires pair sorting
- circulators can be eliminated



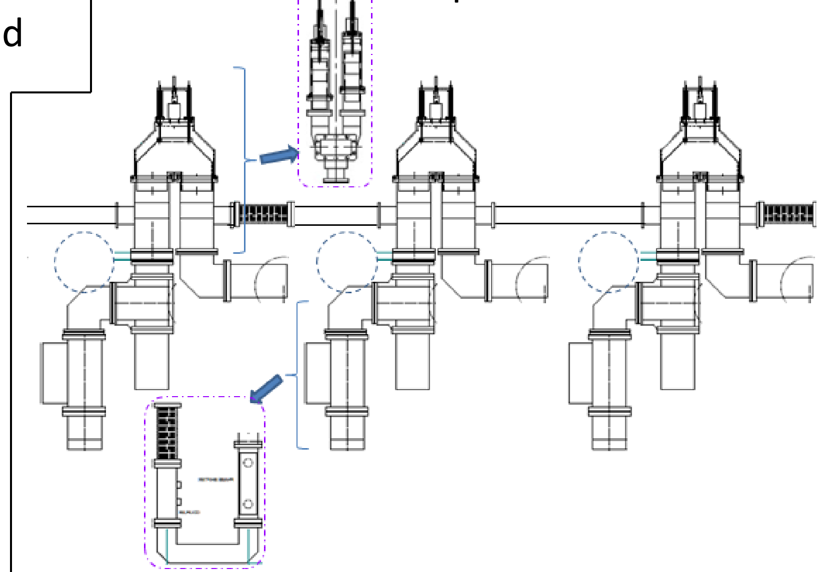
Alternate Scheme w/ Folded Magic-T's and Motorized U-Bend Phase Shifters

- *remotely* adjustable by pairs
- requires pair sorting
- circulators can be eliminated



Folded Magic-T's and Motorized U-Bend s for Each Cavity

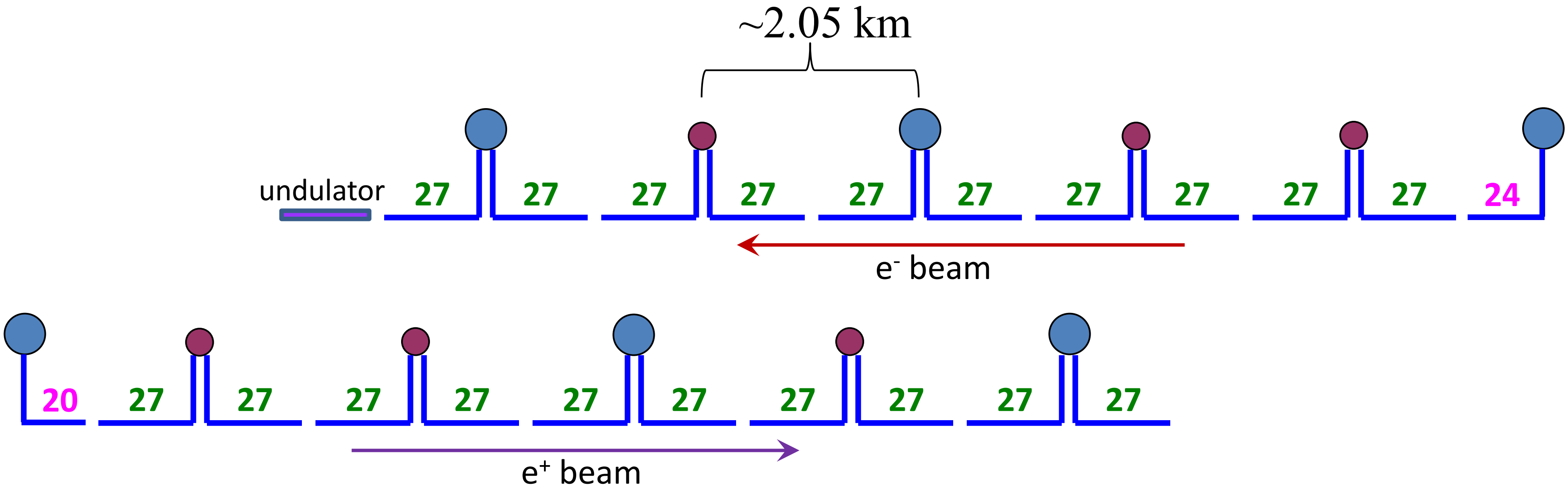
- *remotely* adjustable by cavity
- *no* pair sorting required
- circulators required



Shafts and RF Units* per KCS

With 12 rf units* moved from the RTML to each of the main linacs and 4 more in the e^- linac to compensate for *undulator* losses, they have **294** and **290** rf units, respectively.

The following would seem to be a reasonable modified KCS layout.



● -- main facilities shaft

● -- additional KCS shaft

*rf unit ≡ 3 cryomodules = 26 cavities

Peak RF Power Required from Klystrons per 27 RF Unit KCS (full current)

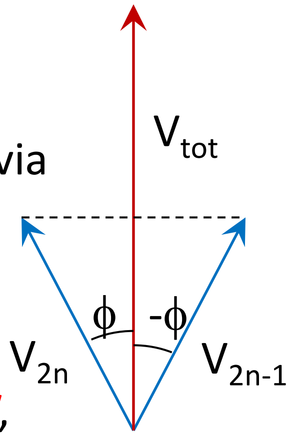
294.3 kW	(nominal to beam per cavity = 31.5 MV/m ×1.038m × 9 mA)	
× 1.059	(for flat gradient w/ cavity gradient spread and common timing)	
× 1.062	(for statistical spread in feed/rf unit requirements w/ fixed couplings)	
× 26	(cavities/rf unit)	
÷ 0.95	(~5% local distribution losses) = 9.06 MW/rf unit @ CTO	
× 27	(rf units)	
÷ 0.935	(6.5% main waveguide losses) = 271.3 MW @ beginning of linac run	
÷ 0.983	(shaft and bends)	~8% klystron-to-tunnel
÷ 0.993	(combining CTO circular waveguide losses)	
÷ 0.965	(input circulator and WR650 losses)	
÷ 0.977	(CTO coupling/klystron amplitude mismatches)	
284.2 MW	from klystrons	

Klystrons Needed per 27 Unit KCS (full current)

The calculation/estimate suggests we need 284.2 MW worth of klystron power.
At 10 MW each, 29 klystrons would give us 290 MW (2.0% to spare).

However, we want to be robust against a single klystron failure per system. With N sources combined in a passive network, failure of one source leaves combined the equivalent of $(N-1)^2/N$ sources.

With 31 klystrons and 30 on, we have 290.3 MW available (2.2% to spare).



However, we also need 7% (5% usable) overhead for LLRF to be harnessed via phase control of the rf drives, oppositely dephased in pairs, such that the combined power is reduced as $P = P_{max} \cos^2 \phi$, with ϕ nominally 15˚.

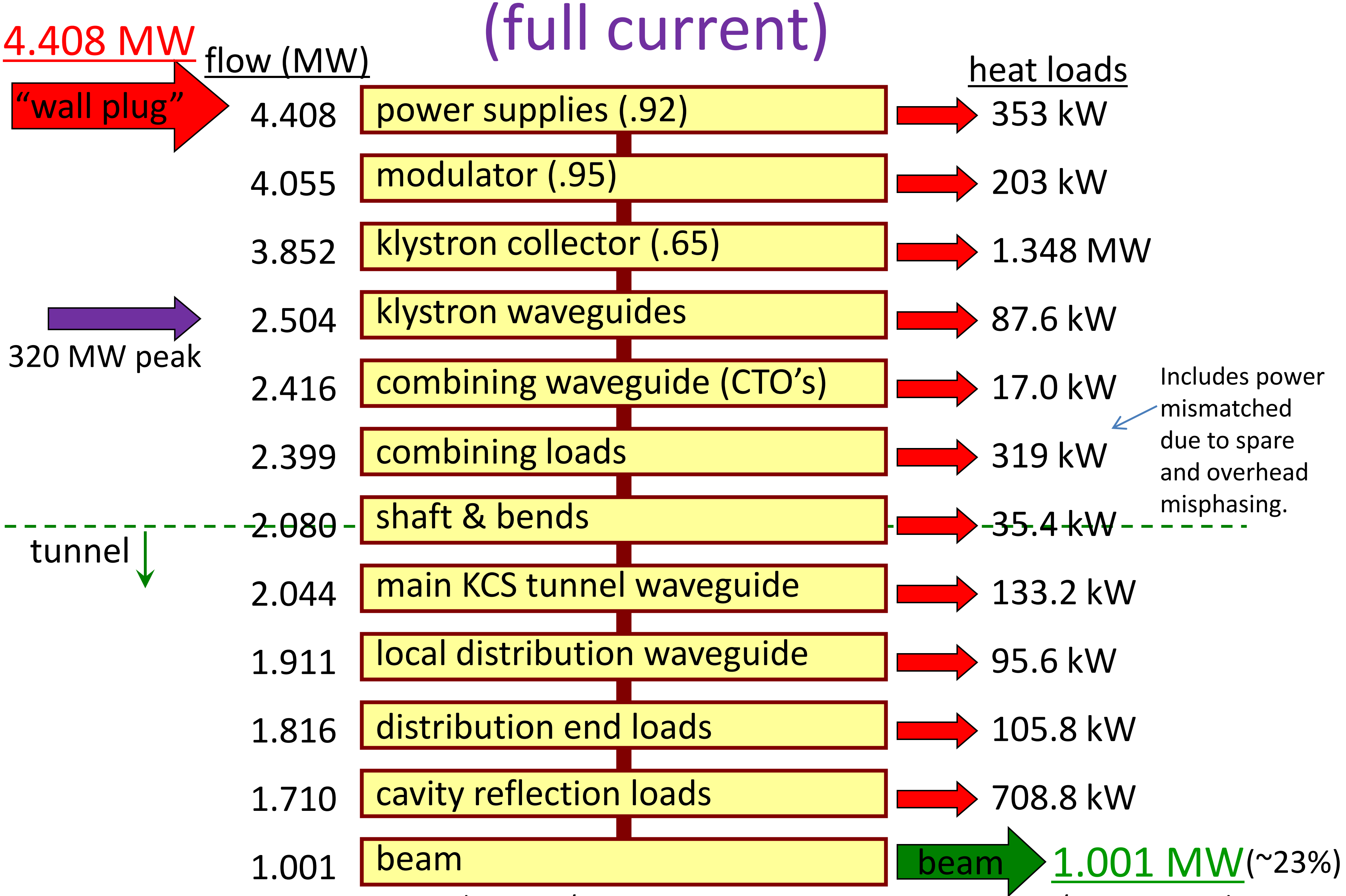
The maximum power requirement rises to 284.2 MW ÷ 0.933 = 304.6 MW,

With **33 klystrons** and one off, we have 310.3 MW (1.9% to spare).

(30 klystrons for the 24 unit KCS and
25 klystrons for the 20 unit KCS)

TOTAL: $20 \times 33 + 30 + 25 =$ 715 klystrons installed (693 on)

27 Unit KCS Average Power Diagram (full current)



4.408 MW

“wall plug”

320 MW peak

tunnel

flow (MW)		heat loads
4.408	power supplies (.92)	353 kW
4.055	modulator (.95)	203 kW
3.852	klystron collector (.65)	1.348 MW
2.504	klystron waveguides	87.6 kW
2.416	combining waveguide (CTO’s)	17.0 kW
2.399	combining loads	319 kW
2.080	shaft & bends	35.4 kW
2.044	main KCS tunnel waveguide	133.2 kW
1.911	local distribution waveguide	95.6 kW
1.816	distribution end loads	105.8 kW
1.710	cavity reflection loads	708.8 kW
1.001	beam	beam 1.001 MW(~23%)

Includes power mismatched due to spare and overhead misphasing.

(31.5MV/m×1.038m×9mA×0.969ms×5Hz×26cav/unit×27units)

Reduced Beam Current

Halving the number of bunches in the ILC beam pulse is adopted as a way to reduce the initial cost of the machine. The direct impact on the luminosity is ameliorated by introduction of a traveling focus scheme. In this reduced beam current "low power" scenario, **site power** is reduced, along with **water cooling** requirements.

Additionally, for the high-power rf system, the amount of **installed rf** production equipment can be significantly **reduced**.

The impact depends on the bunch frequency, f_B, which affects:

beam pulse current: $I_b = N_e e\, f_B$

beam pulse duration: $t_b = (n_B - 1)\, f_B^{-1}$

and thus

rf power per cavity: $P_{rf} = I_b V_c = N_e e V_c f_B$

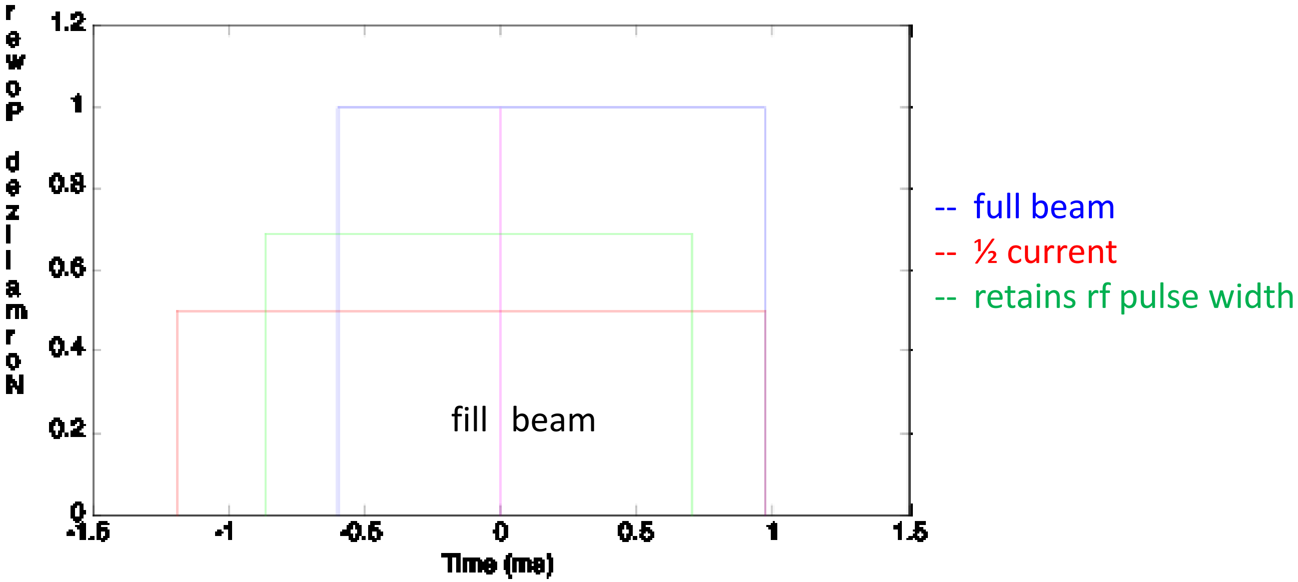
rf pulse duration: $t_{rf} = t_i + t_b = \left[\dfrac{2\ln 2}{\omega N_e e R/Q} V_c + (n_B - 1)\right] f_B^{-1}$

KCS Low Power

KCS is very *flexible*. Combining tens of klystrons allows us to adjust installed power with relatively fine granularity.

Fixed t_b: Simply eliminating every other bunch (**halving f_B**) maintains the beam duration and halves the *current*, cutting in **half** the required ***peak power***. *<u>However</u>*, it also *doubles* the cavity *fill time*. , thereby **increasing** the required **rf pulse width** at full gradient by **38%**. ($P_{rf} \rightarrow \frac{1}{2} P_{rf0}$, $t_{rf} \rightarrow 1.38\, t_{rf0}$)

Fixed t_{rf}: It's preferable to adopt parameters which allow use of the modulators and klystrons developed for full RDR beam specifications, i.e. to stay within the ~1.6 ms pulse width. This can be achieved by reducing the bunch spacing to increase the current to **0.69 I_0**. The rf peak power required at the cavities is reduced from that for the full beam by this factor. ($P_{rf} \rightarrow 0.69\, P_{rf0}$, $t_{rf} \rightarrow t_{rf0}$)

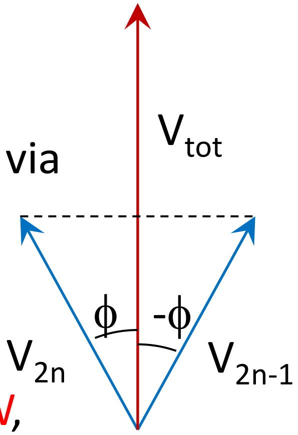


Klystrons Needed per 27 Unit KCS (1/2 bunches)

Scaling from the full current case, we need (**0.69** × 284.2=) 196.1 MW worth of klystron power. At 10 MW each, 20 klystrons would give us 200 MW (2.0% to spare).

However, we want to be robust against a single klystron failure per system. With N sources combined in a passive network, failure of one source leaves combined the equivalent of $(N-1)^2/N$ sources.

With 22 klystrons and 21 on, we have 200.5 MW available (2.2% to spare).



However, we also need 7% (5% usable) overhead for LLRF to be harnessed via phase control of the rf drives, oppositely dephased in pairs, such that the combined power is reduced as $P = P_{max} \cos^2 \phi$, with ϕ nominally 15˚.

The maximum power requirement rises to 196.1 MW ÷ 0.933 = 210.2 MW,

With **23 klystrons** and one off, we have 210.4 MW (0.12% to spare).

(21 klystrons for the 24 unit KCS and
18 klystrons for the 20 unit KCS)

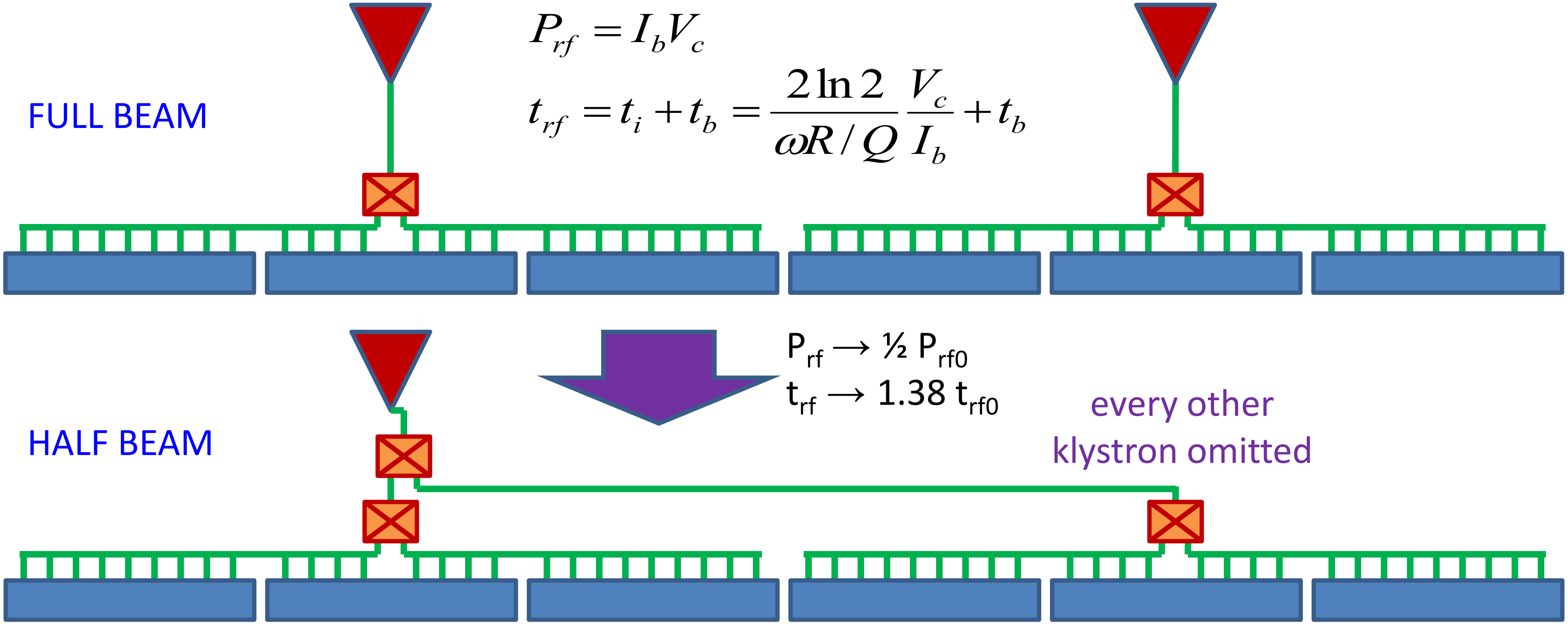
TOTAL: 20 × 23 + 21 + 18 = 499 klystrons installed (477 on)

30.2% reduced from full current

RDR-Like Fallback Low Power

With the KCS and DRFS schemes in development, an RDR-like layout w/ **10 MW klystrons, modulators, etc. in the (enlarged) single tunnel** is considered the fallback plan.

For half bunches operation, one could double the bunch spacing and install half the modulators and klystrons, each feeding 6 CM's, rather than 3.



FULL BEAM

$$P_{rf} = I_b V_c$$

$$t_{rf} = t_i + t_b = \frac{2\ln 2}{\omega R/Q}\frac{V_c}{I_b} + t_b$$

HALF BEAM

$P_{rf} \rightarrow \frac{1}{2} P_{rf0}$

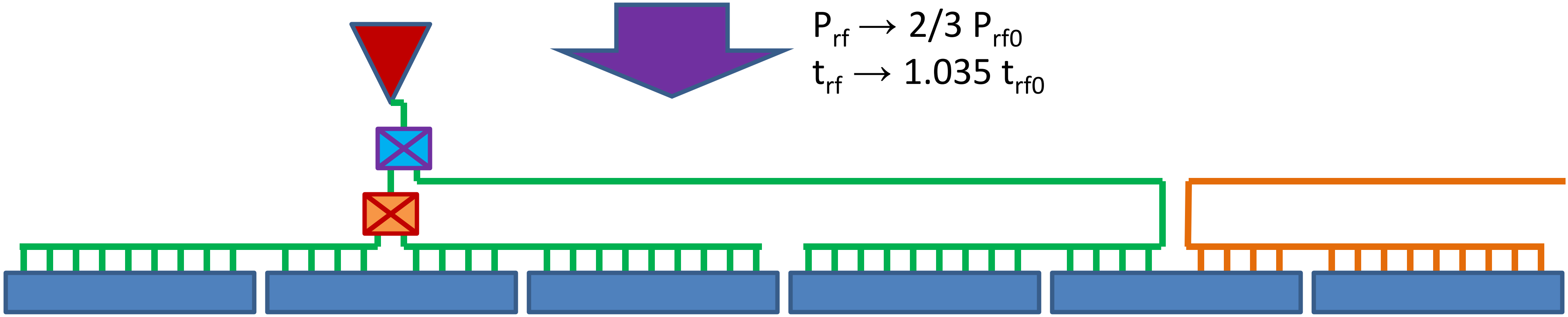
$t_{rf} \rightarrow 1.38\, t_{rf0}$

every other klystron omitted

This would double the fill time, **increasing** the required **rf pulse** width by 38%.
The installed modulators and klystrons would then be overspec.ed for the upgrade.

Alternatively, one could install 2/3 of the rf production equipment, with each klystron feeding 4 ½ CM’s.

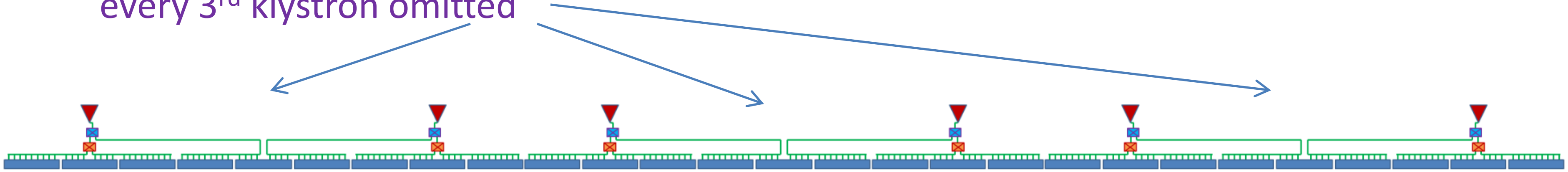
This would reduce the available power per cavity, and thus the acceleratable beam current or bunch frequency, by a factor of ~2/3 vs. RDR.



$P_{rf} \longrightarrow 2/3\ P_{rf0}$

$t_{rf} \longrightarrow 1.035\ t_{rf0}$

every 3rd klystron omitted

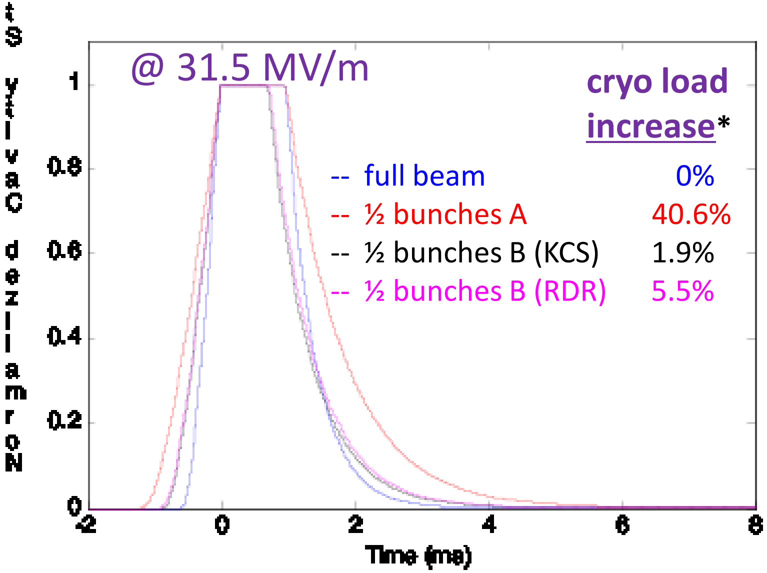


The beam pulse duration ($\propto n_B/I_b \longrightarrow$ ½ / 2/3) is then shortened by a factor of ¾, and the fill time increased by a factor of 3/2, yielding an rf pulse width increase of only ~3.5%.

Parameter Summary

250 GeV/beam	# of bunches	bunch spacing	beam current	beam duration	rf peak power	fill time, t_i	rf pulse duration
full beam	2625	369.2 ns	9 mA	0.969 ms	294.2 kW	0.595 ms	1.564 ms
½ bunches A	1313	738.5 ns	4.5 mA	0.969 ms	147.1 kW	1.190 ms	2.159 ms (up 38%)
½ bunches B KCS	1313	535.1 ns	6.21 mA	0.702 ms	203.0 kW	0.862 ms	1.564 ms
½ bunches B RDR	1313	553.8 ns	6 mA	0.727 ms	196.1 kW	0.893 ms	1.619 ms (up 3.5%)

Parameter choice also impacts cryogenic load.



* Only includes dynamic load of fundamental rf in cavity. Additional contributions come from coupler (linear w/ power and time) and HOM (current dependent).

Installation for Reduced Bunches

KCS:

- Everything in the tunnel is installed.
- 69.8 % (499/715) of high power rf production equipment (klystrons, modulators, power supplies, etc.) in KCS surface buildings, *upstream* from shaft, with main waveguide runs traversing the region where the rest will go.

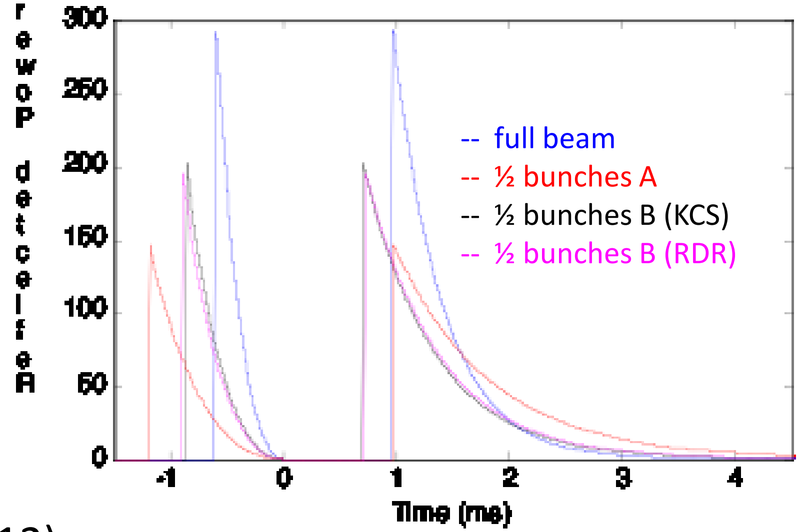
- 68.8% (477/693) of “wall plug” power for main linac high power rf.
- 75%* of water cooling capacity for heat load from high power rf.

RDR-Like Fallback:

- 66.7 % of high power rf production equipment in the linac tunnels, with *additional* power dividers and waveguide.
- 69% (1.035 × 2/3) of “wall plug” power for main linac high power rf.
- ~ 75%* of water cooling capacity for high power rf heat load.

Heat Load Breakdown for KCS

The rf energy deposited per pulse into the cavity **reflection loads** (circulator loads), being the product of P_{rf} ($\propto I_b$) and t_i ($\propto I_b^{-1}$), is, for a given gradient, **constant** across the parameter sets.



HPRF heat load distribution (from slide 12):
above ground – 68.3%
below ground – 31.2% (65.7% fixed, 34.3% power dependent)

HPRF heat load reduction factor:
above ground – 0.69
below ground – (0.657 + 0.343 × 0.69) = 0.894
Total – (0.683 × 0.69 + 0.312 × 0.894) = 0.750

For the RDR-like layout the total reduction is the same, **0.75**, all below ground.

Transition to Full Beam Current

KCS:

- Upgrade is all above ground.
- Install remaining 31% of “wall plug” power capacity.
- Install remaining 25% of cooling capacity.
- Install remaining 30.2% of high-power rf hardware in the *KCS buildings*.

Most, up to the point of connecting the sources into the main waveguide, can be done while *running*.

RDR-Like Fallback:

- Install remaining 31% of “wall plug” power capacity.
- Install remaining 25% of cooling capacity.
- Install remaining 33.3 % of high-power rf hardware in the *linac tunnels*.

ILC is *shut down* during installation.

Low E_{CM} Operation

Another design change was the relocation of the undulator for e^+ production from the middle to the end of the e^- linac, closer to the damping rings. This poses a **problem**.

For sufficient positron production, the e^- beam needs to be @ ≥150 GeV.

The physics specifications for the ILC call for running at various center-of-mass energies:

500 GeV, 350 GeV, 250 GeV, 230 GeV, and 200 GeV.

Previously, for the operation points < 300 GeV c.o.m., the e^- beam could be decelerated from 150 GeV after the undulator; with the undulator at the end, it can't be.

Solution:

For 250 GeV c.o.m. and below, run e- linac at double rep. rate, **10 Hz**, alternating between 150 GeV pulses for e+ production and half the desired E_{CM} for collisions.

10 Hz Running Considerations

To retain luminosity for $E_{CM} \leq 250$ GeV ($\leq$125 GeV/beam), run e^- linac (*only*) @ 10Hz, alternating between 150 GeV for e^+ production and the desired collision energy.

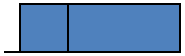
In this scheme, because the cavity couplers are mechanical, ***Q_L*** *cannot be optimized* for both gradients, but is set for the 150 GeV gradient (150/250 × 31.5 MV/m = **18.9 MV/m**).

For flat gradient during the alternating lower cavity voltage (V_L) pulses the needed input power and the residual cavity *reflection* (during the beam) are given by:

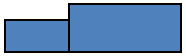
$P_L = \frac{1}{4}(1 + V_L/V_{150})^2 P_{150}$ $= 0.8403,\ 0.7803,\ 0.6944\ P_{150}$ @ 125, 115, 100 GeV

$P_r = \frac{1}{4}(1 - V_L/V_{150})^2 P_{150}$ $= 0.694\%,\ 1.36\%,\ 2.78\%\ P_{150}$ @ 125, 115, 100 GeV

To fill the cavity by beam arrival, one must also either toggle the timing or *step* the power level during the pulse (between fill and beam).



or



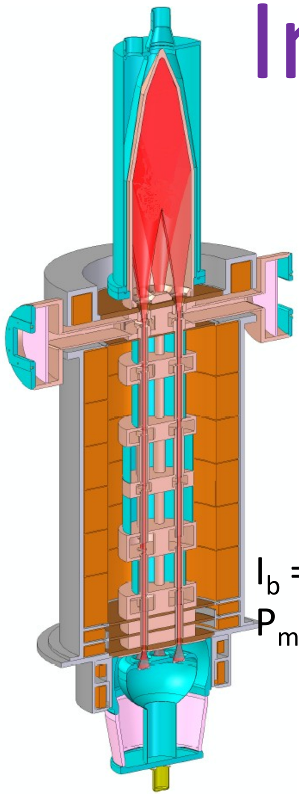
Fill:

const. power, P_L, → $t_{iL} = \frac{\ln(1+V_L/V_{150})}{\ln 2} t_i$ $= 0.8745,\ 0.8210,\ 0.7370\ t_{i150}$ @ 125, 115, 100 GeV

OR

const. fill time, t_i, → $P_{Li} = (V_L/V_{150})^2 P_{150}$ $= 0.6944,\ 0.5878,\ 0.4444\ P_{150}$ @ 125, 115, 100 GeV

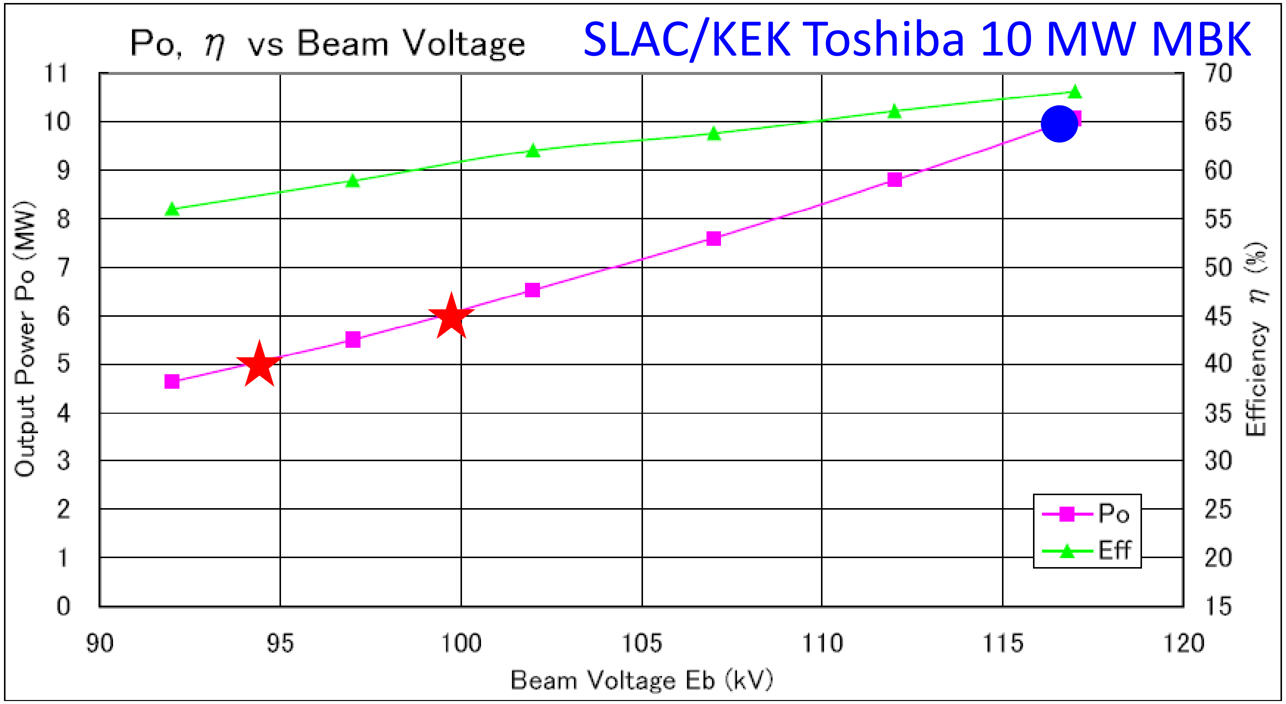
Impact on Power Requirements



$I_b = KV_a^{3/2}$,

$P_{mod} = I_bV_a$

$= KV_a^{5/2}$



For **125 GeV** beam, one needs 5 MW per tube (vs. 10 MW for 250 GeV),

→ V_{mod} can be lowered from 117 kV to 94 kV, reducing modulator *peak power* to $(94/117)^{5/2}$ = 0.579 × the nominal value.

Also, *pulse width* is reduced by a factor of [(125/250) × .595ms + .969ms]/1.564 ms = 0.810

(e⁺ linac) (e⁻ linac)

→ pulse energy reduced by factor of ~0.469.

For the **150 GeV** pulses, V_{mod} = 99.5kV, and this factor becomes .667 × .848 = 0.565, and for the alternate 125 GeV pulse .579 × .819 = 0.474

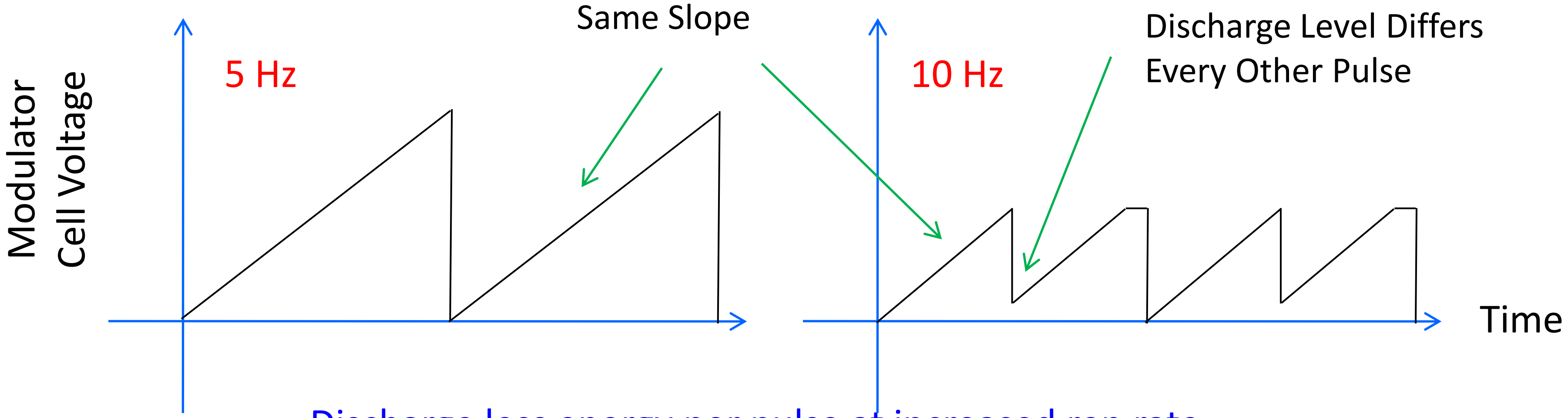
So the power load factor for the e- linac running at 10 Hz is about 0.565 + 0.474 = 1.039, a slightly increased demand. This can be avoided by running at 9.6 Hz, instead.

For **both linacs** combined, the HLRF power load is downby (1.039 + 0.469)/2 = **0.754**.

Effect on Modulator Charging

At lower gradients, reduce modulator voltage and increase pulse rate so that nominal average modulator input power not exceeded.

→ charging power supplies would see the same or smaller load (which is roughly constant), and the AC power capacity would not have to be increased.



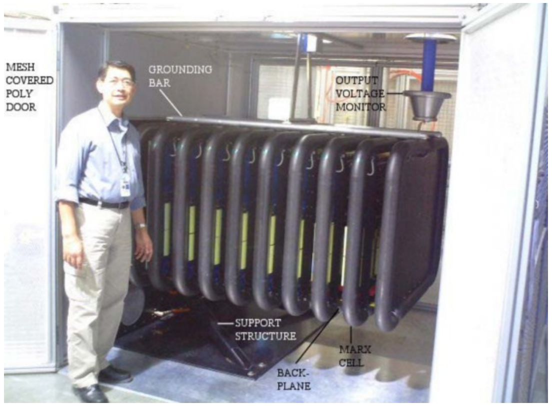
Discharge less energy per pulse at increased rep rate.

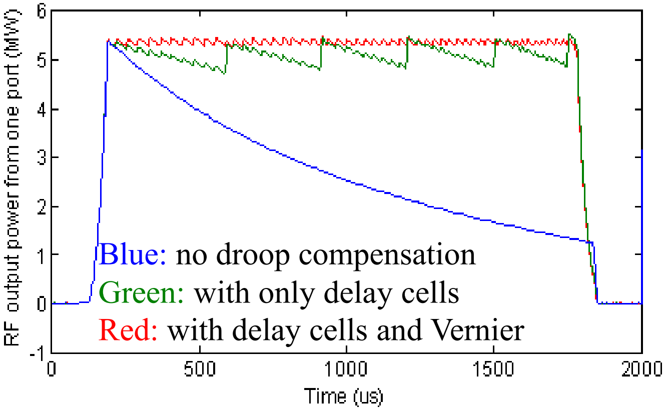
Additional line ripple introduced by alternating discharge levels would need to be reduced in the site electrical distribution system.

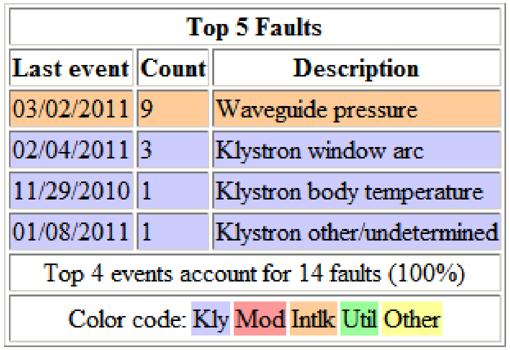
R & D

Marx Modulator and Toshiba MBK Operation

The Toshiba 10 MW MBK is being run into loads for lifetime testing while itself providing a load for testing of SLAC's 120kV, 140A, 1.6 ms, 5Hz Marx modulator.

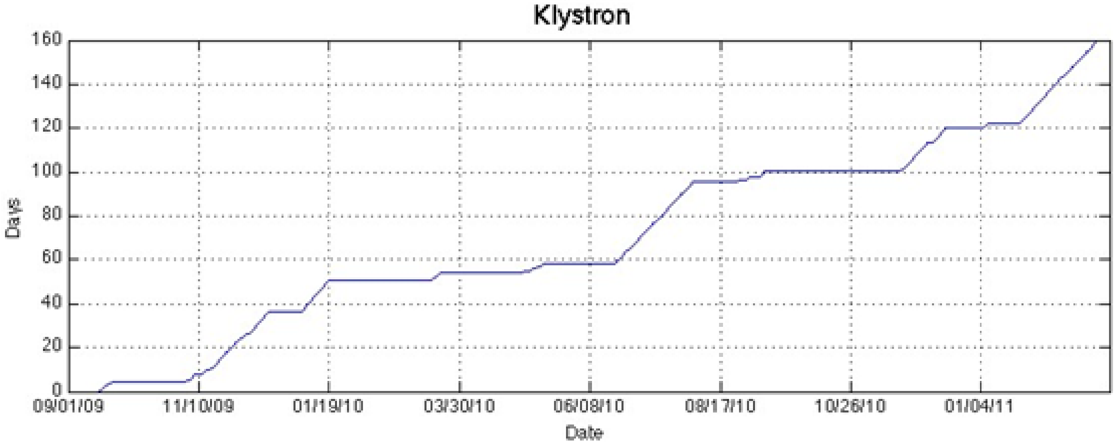




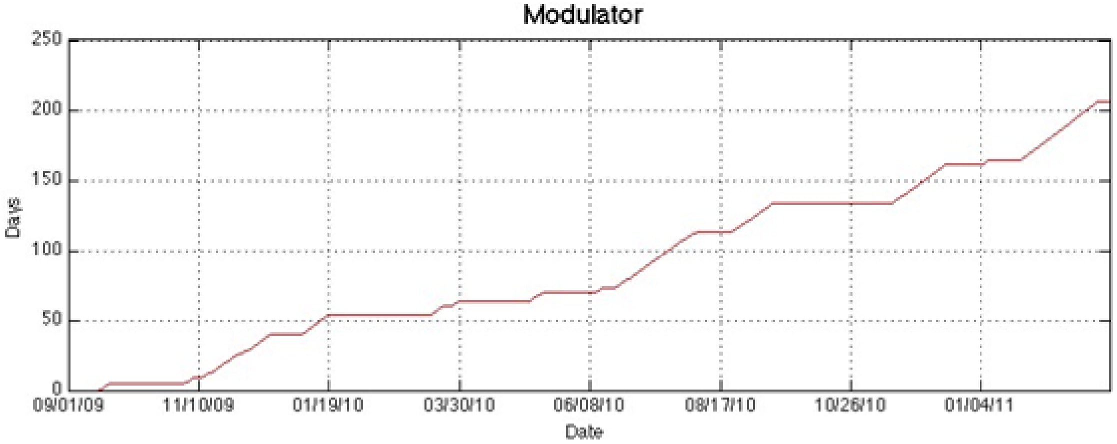


Top 5 Faults		
Last event	**Count**	**Description**
03/02/2011	9	Waveguide pressure
02/04/2011	3	Klystron window arc
11/29/2010	1	Klystron body temperature
01/08/2011	1	Klystron other/undetermined
Top 4 events account for 14 faults (100%)		
Color code: Kly Mod Intlk Util Other		

Marx Integrated Uptime from 09/01/2009 - 03/13/2011



Klystron: 3839.1 hours (159.96 days) integrated operation; 191.0 hours (7.96 days) uninterrupted operation

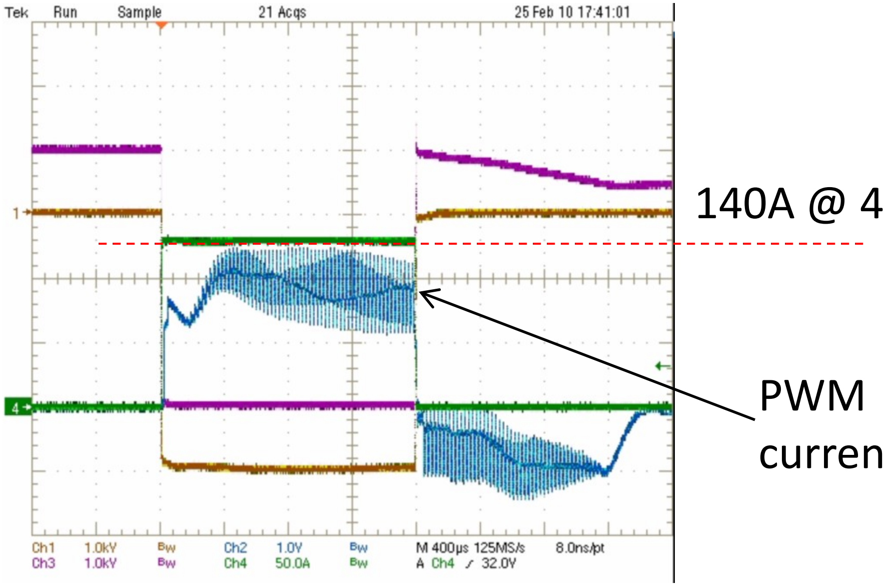


Modulator: 4931.3 hours (205.47 days) integrated operation; 625.9 hours (26.08 days) uninterrupted operation

SLAC P2 Marx: Progress Highlights[*]

A second generation Marx modulator is in development at SLAC.

Demonstrated
Active Droop Compensation Scheme

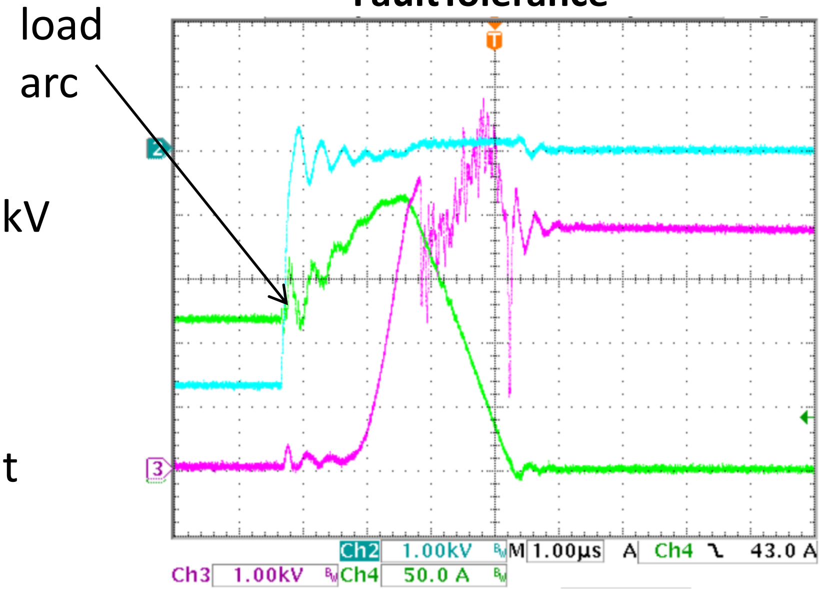


140A @ 4kV

PWM current

Cell Output Current
Cell Output Voltage
Main IGBT V_{ce}
PWM Inductor Current

Demonstrated
FaultTolerance

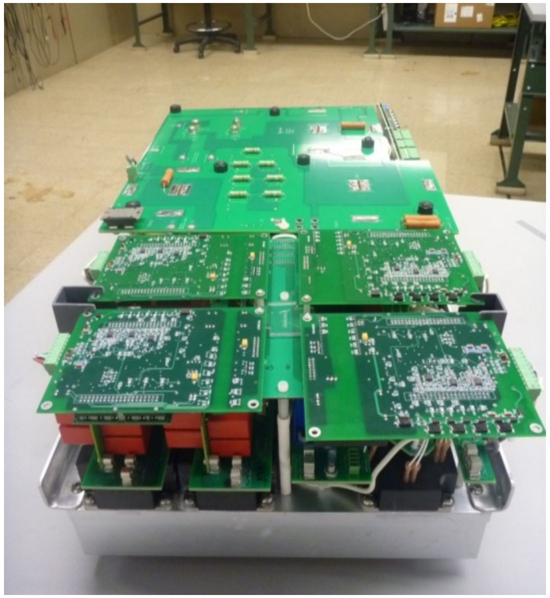


load arc

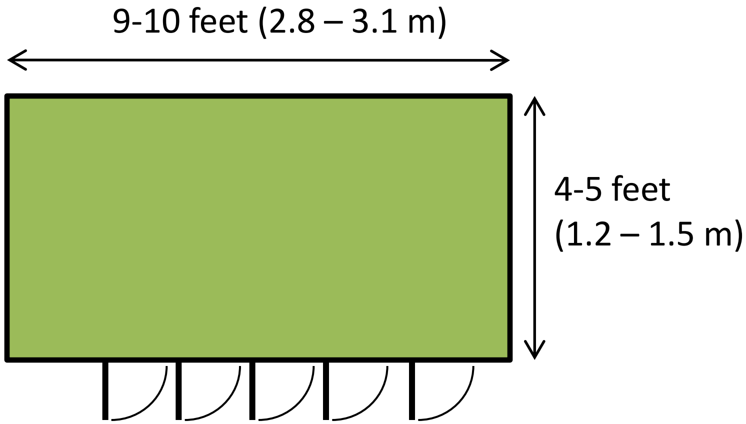
Load Current
Main IGBT V_{ce}
Load Voltage

* from Mark Kemp

SLAC P2 Marx: Progress Highlights



- Primary progress to-date at cell level
  - All hardware has been prototyped
  - Controls firmware has been written, but is not in final form
  - All cell fabrication drawings have been finalized
  - Cell has been tested in (nearly) all anticipated operating scenarios (nominal, fault, peak power, peak cell voltage, peak output average power, operation into stiff current source)
- Full modulator quantities of cells are currently being fabricated
  - >95% farmed out to industry
  - All in-house by end of April
  - Final assembly at SLAC



- Modulator Height: 7-8 feet (2.1 – 2.4 m)
- Located separately is double-bay power supply rack
- Cells are air cooled. Heat is removed via air/water heat exchanger.

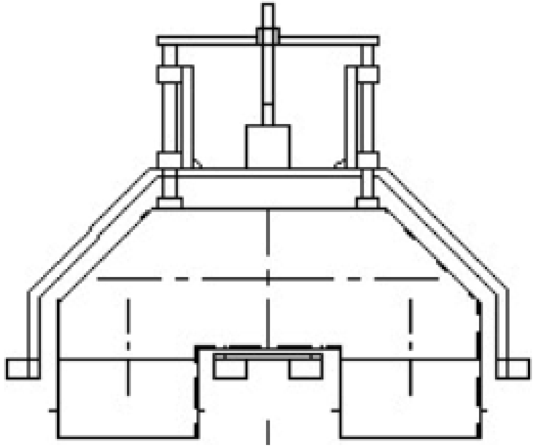
- Overall modulator status
  - Modulator being assembled
  - Able to hold cells mid-April
  - Start of full modulator testing by June.
  - Application manager software undergoing updates with final implementation to be in EPICS.
- Design aspects
  - Single side access
  - No oil
  - No transformer
  - N+2 redundancy /w automatic reconfiguration
  - Active correction scheme
  - Cell diagnostic and prognostic capability

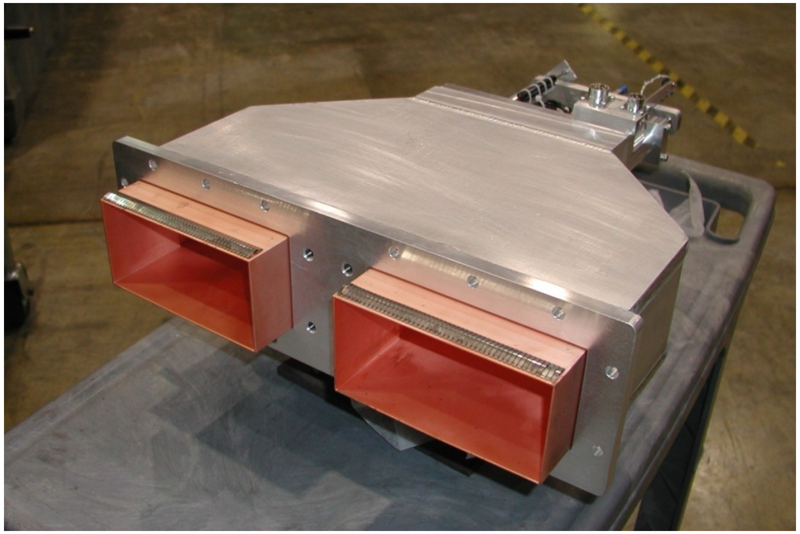
U-bend Phase Shifter for Local Power Tailoring in PDS

Cavity-to-cavity spread in sustainable gradient make it desirable to be able to tailor the local power distribution along the cryomodules.

The VTO allowed manually-set fixed tailoring to matched pairs of cavities.

As a more flexible alternative, a pressurizable U-bend phase shifter with motor-controlled feed through was developed, for use in pairs between folded magic-T's.

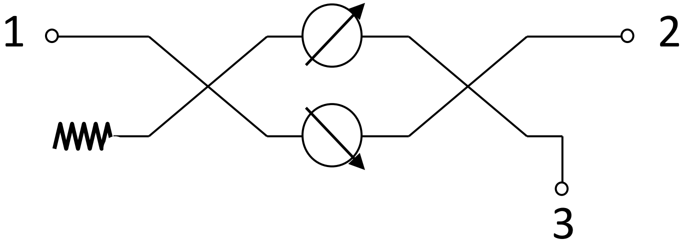




A folded magic-T provides convenient port orientations.

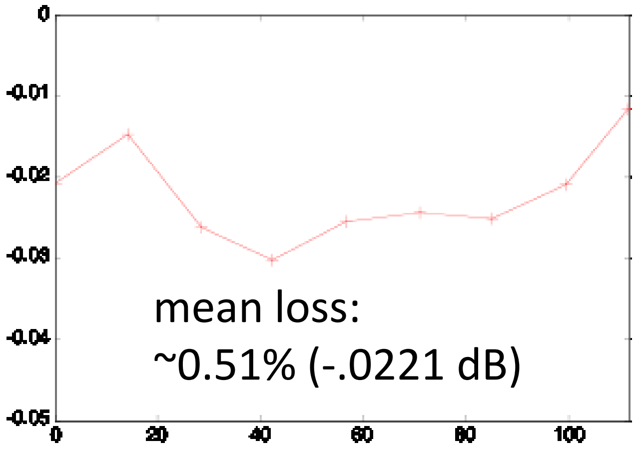
Opposite phase adjustment varies the split at ports 2&3, without changing the output phases.

(in-line phase shifters still used to adjust phase at cavity couplers)

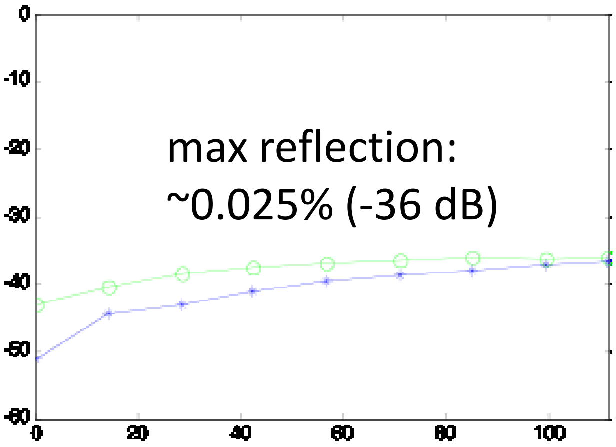


U-bend Phase Shifter Testing

Cold Test



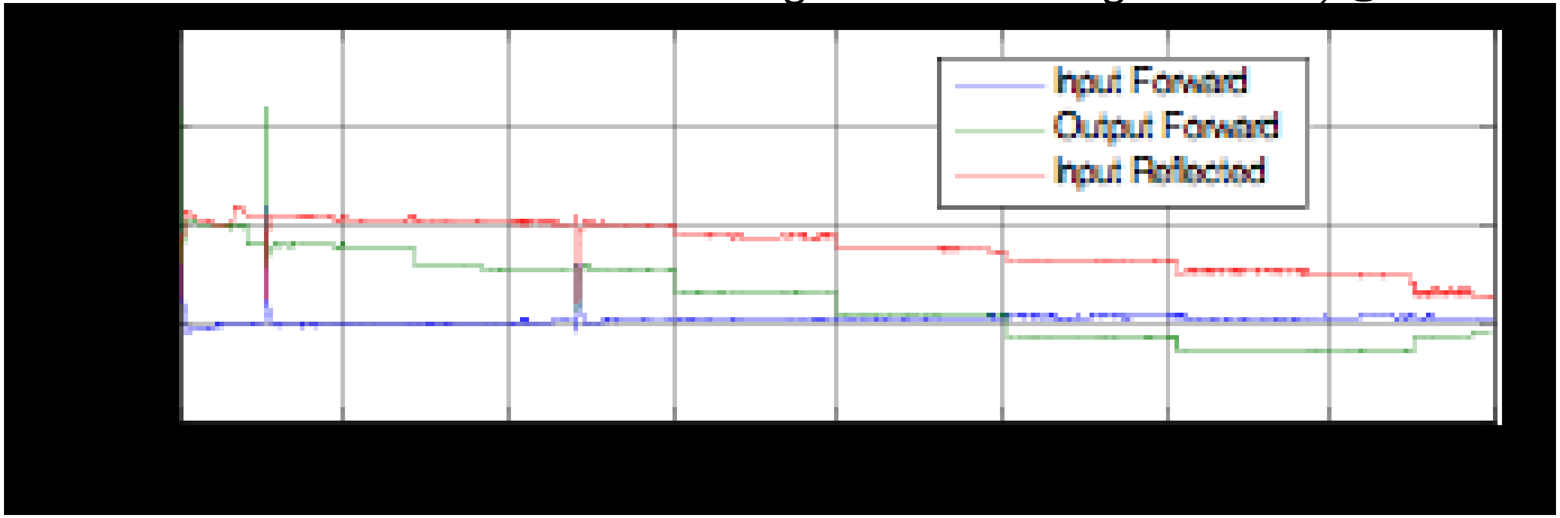
mean loss:
~0.51% (-.0221 dB)



max reflection:
~0.025% (-36 dB)

No breakdowns were detected during 8 hours running in 1bar N_2 @ 2MW.

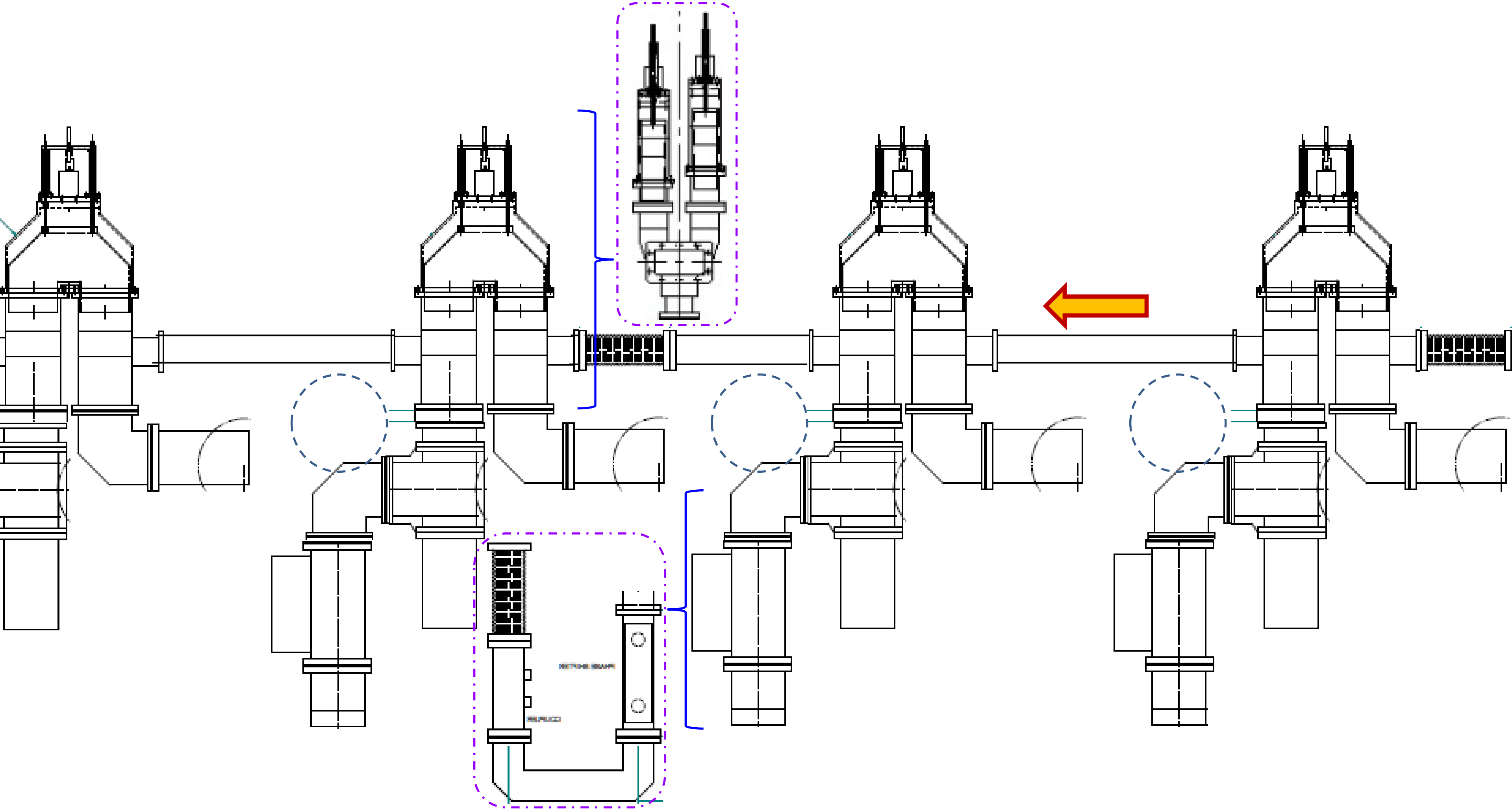
Hot Test



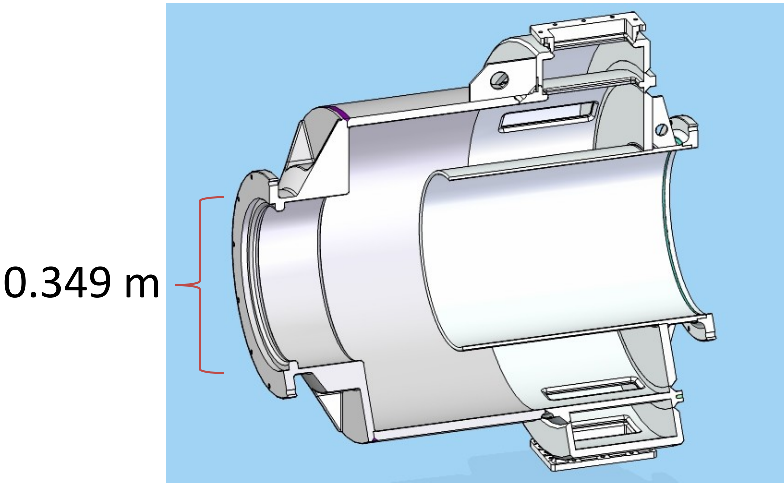
Eight such phase shifters have been fabricated for the second PDS for Fermilab's NML facility. The first 2-feed PDS module is ready for testing.

Fully Adjustable PDS

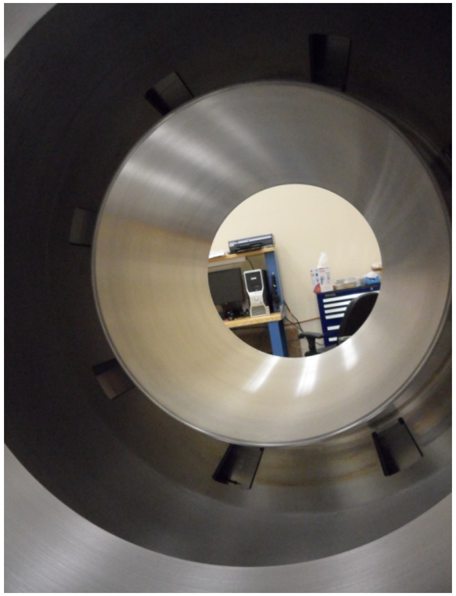
For ILC, w/ large (±20%) gradient limit spread, individual cavity adjustment of the power division can be achieved via the below PDS layout.
Cost and power losses will be increased, however, over pair-wise division due to doubling the number of power division units *and* including circulators.



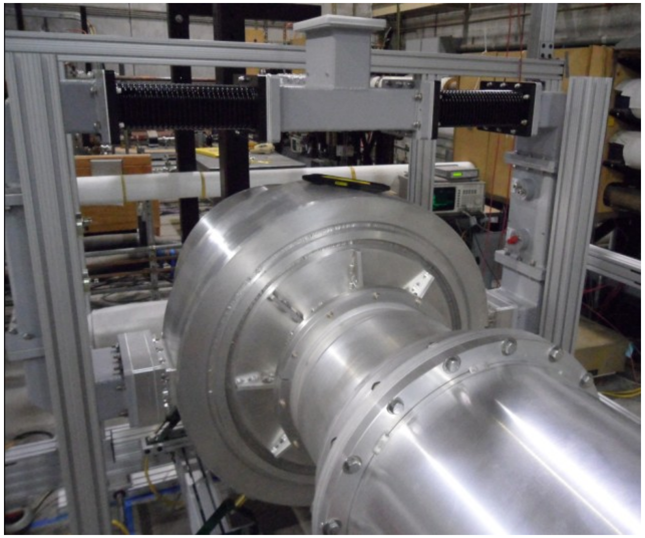
CTO (Coaxial Tap-Off)



A pair of 3-dB CTO's.



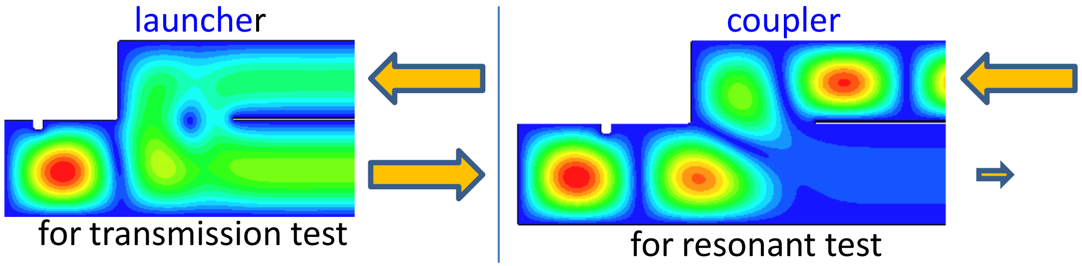
Inner view showing wrap-around slots.



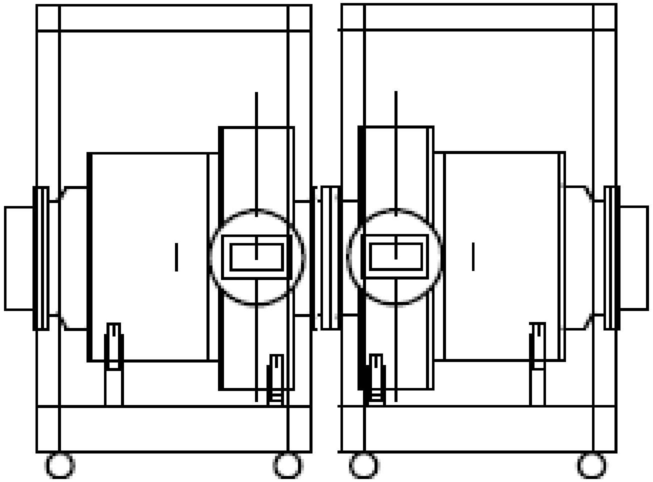
A CTO connecting WR650 waveguide to 0.48 m-diameter circular waveguide.

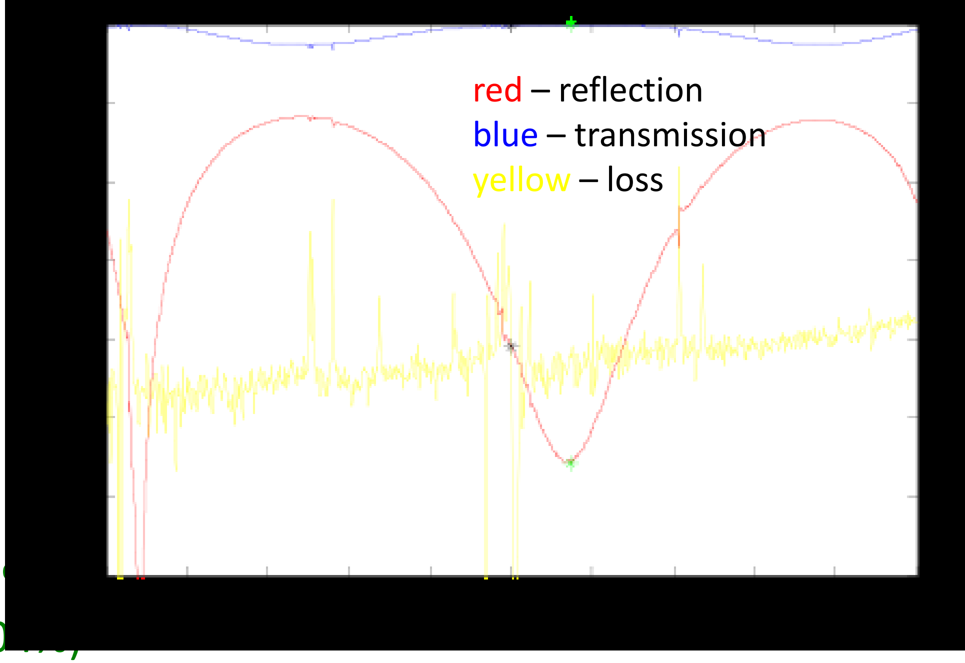
CTO Cold Test

Shorting one circular port of a 3dB CTO at the proper distance, converts it into a mode launcher (or partial coupler).



We tested our CTO’s as back-to-back launchers:





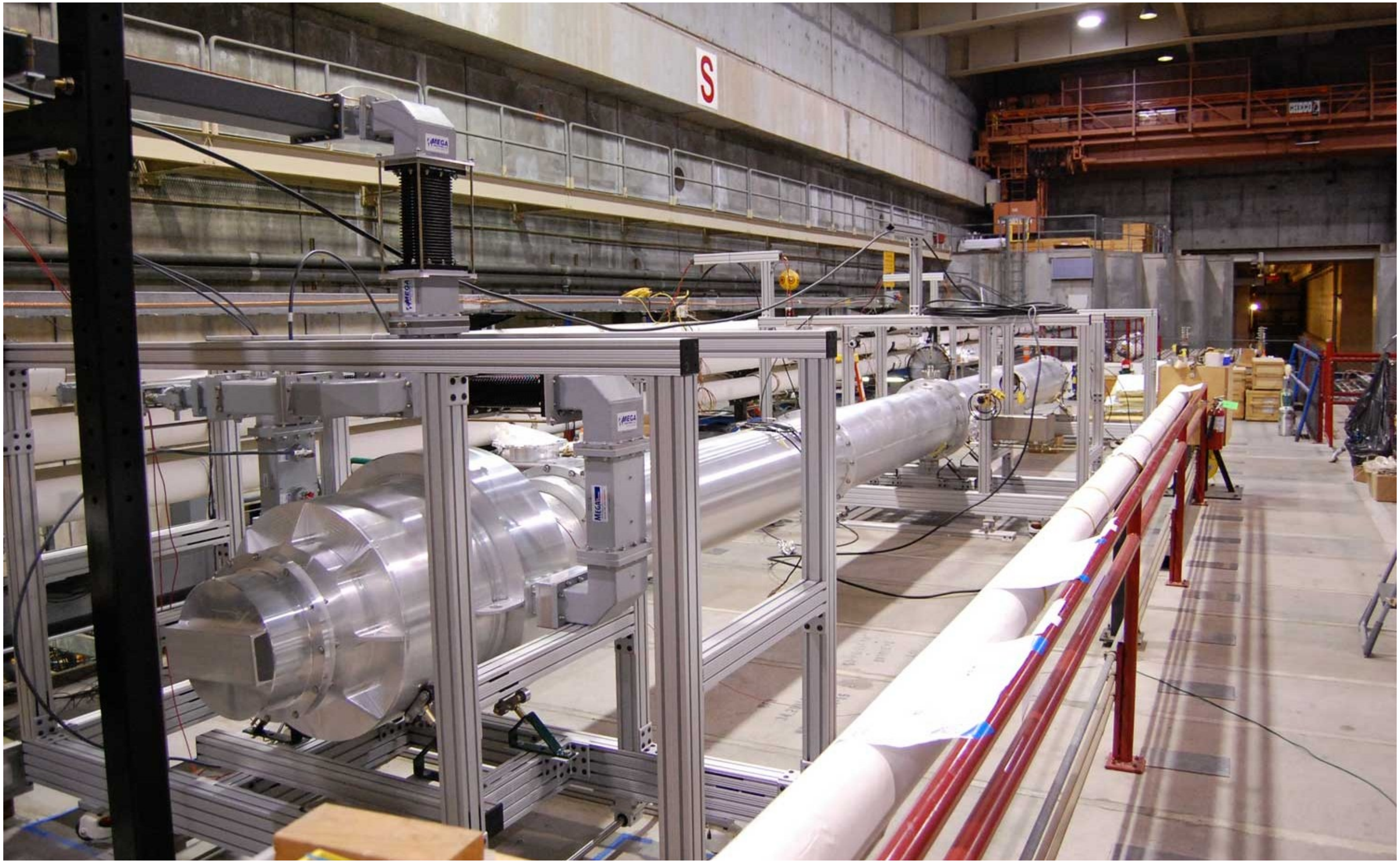
@1.300 GHz:
R = -20.43 dB (0.906%)
T = -0.0843 dB (98.08%)

@1.3036 GHz:
R = -27.84 dB (0.164
T = -0.0421 dB (99.0

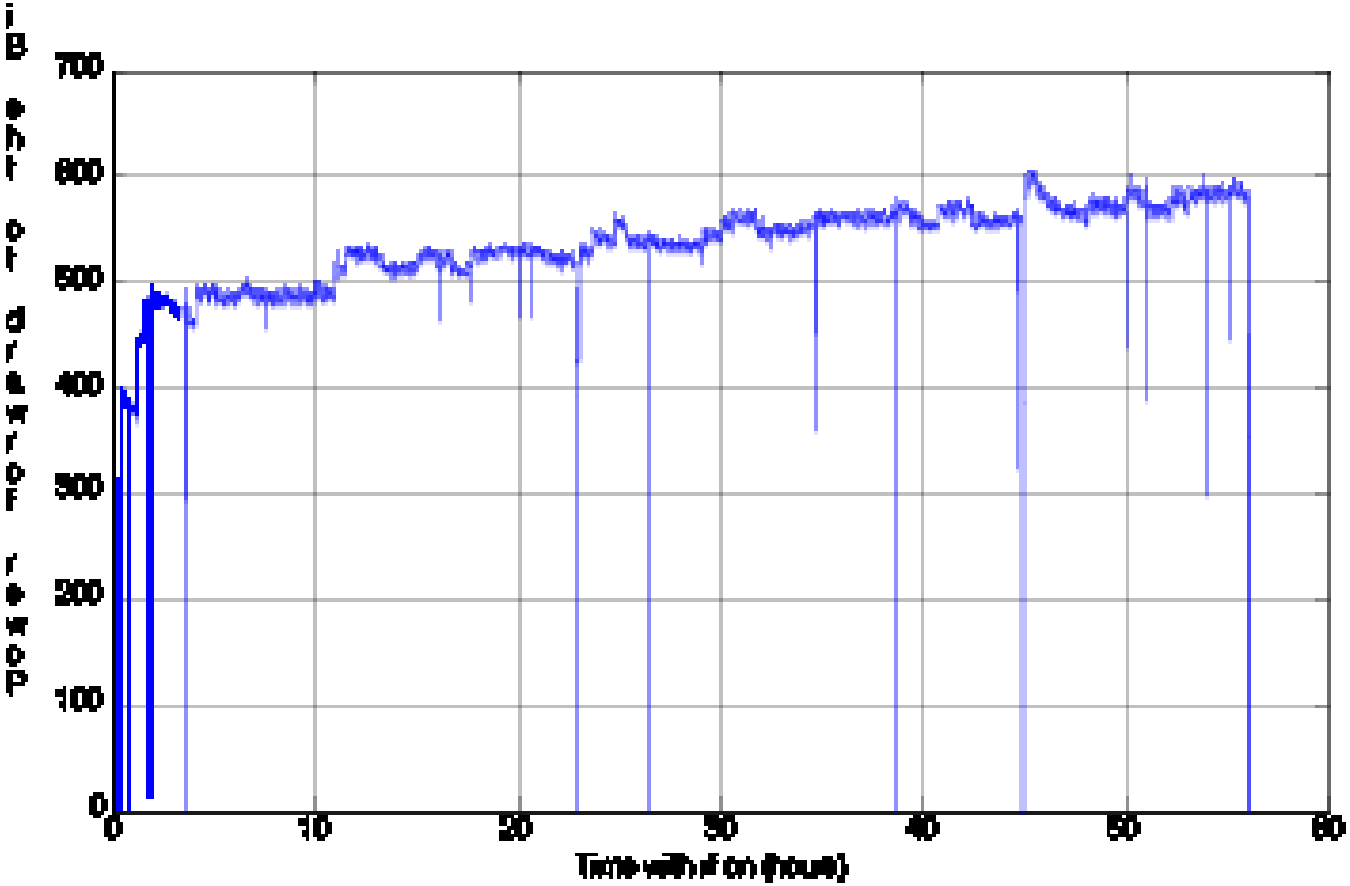
This initial test indicates good performance of the CTO’s, the 36 MHz offset of the optimum being attributable to deliberate endcap undermachining (for intended shim tuning and remachining).
Further tests with a ¼-wave spacer were deferred for schedule reasons.

Klystron Cluster Scheme Tests

Resonantly power a 10 m long 0.48 m diameter aluminum pipe, pressurized (1atm N_2), to 300 MW TE_{01} mode field equivalent, in 1 ms pulses.



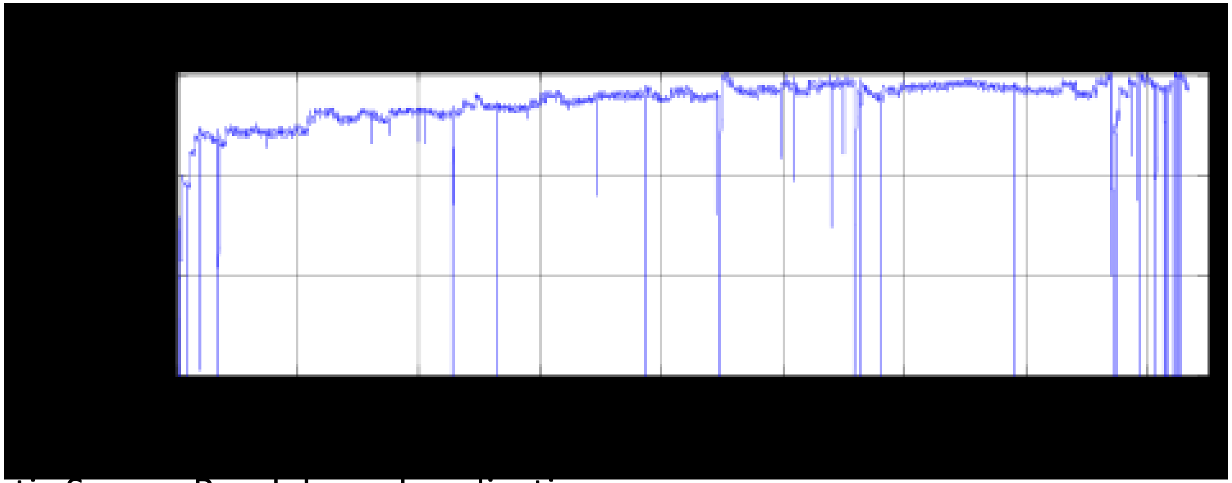
No Breakdown for more than 50 hours



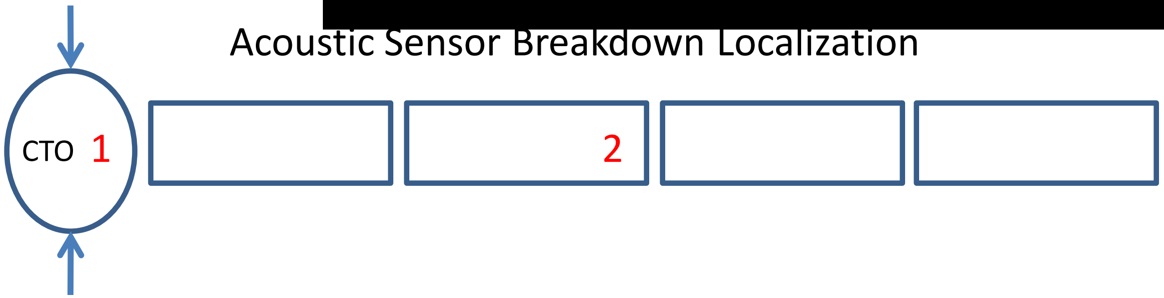
550 kW input corresponds to 75 MW traveling waves, creating a standing-wave pattern with peak fields equivalent to 300 MW one way.

‘Big Pipe’ Operation

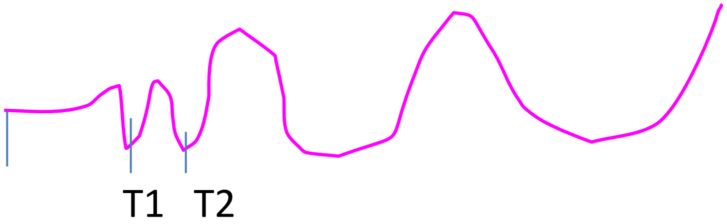
550 KW input power yields 300 MW equivalent surface fields in the pipe - see bkdn every ~ 15 hours, maybe from CTO or upstream – rate seems very pressure dependent



Acoustic Sensor Breakdown Localization

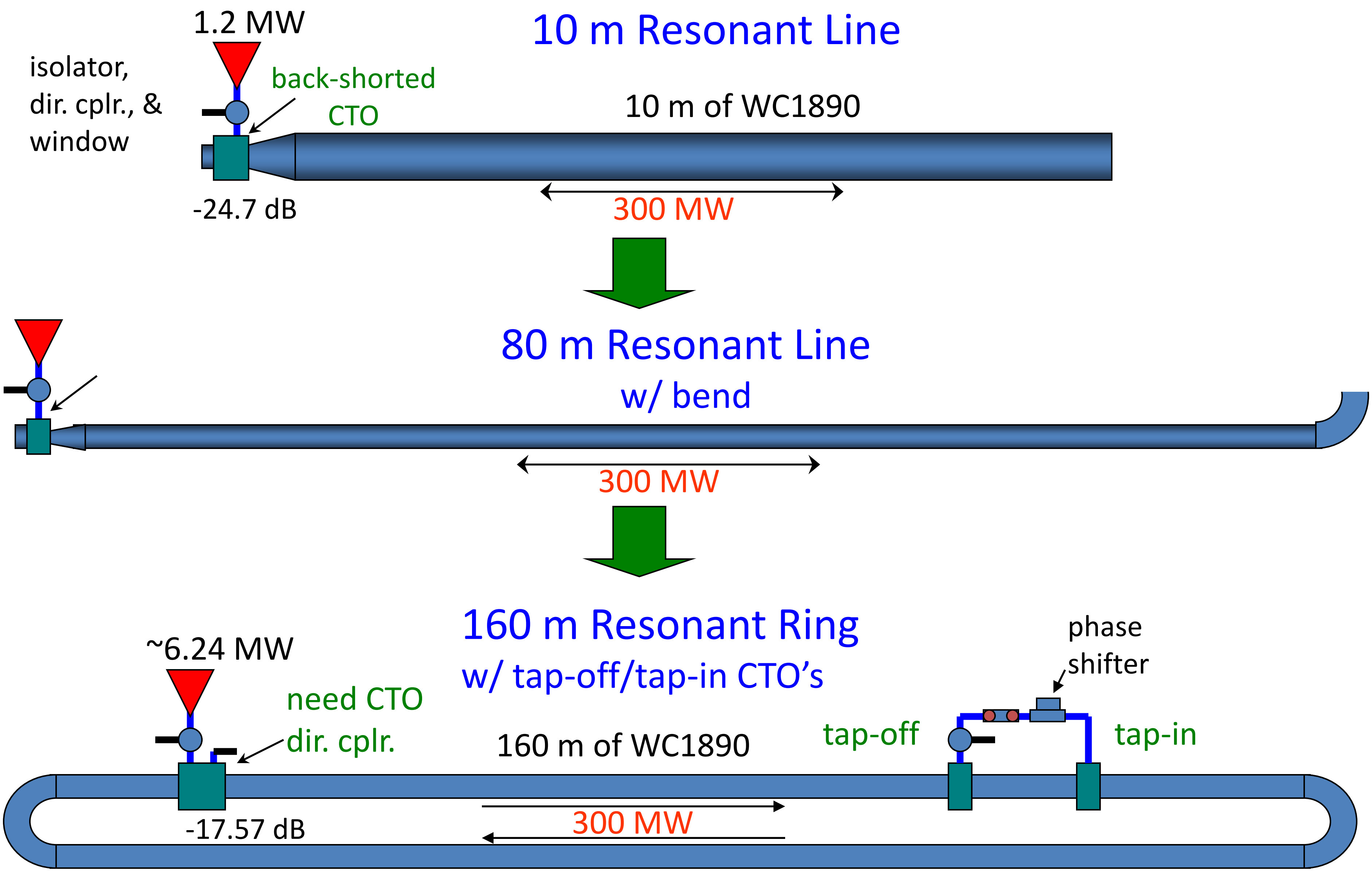


Time of Position 2 markers (T1,T2) are ~ 1 ms later than those from Position 1, which suggest events are much closer to Position 1 (5 m / 5100 m/s ~ 1 ms)



Problem believed to have been waveguide switch near klystron. Further testing is underway.

KCS “Big Pipe” High Power Test Plans



10 m Resonant Line

1.2 MW

isolator,
dir. cplr., &
window

back-shorted
CTO

10 m of WC1890

-24.7 dB

300 MW

80 m Resonant Line

w/ bend

300 MW

160 m Resonant Ring

w/ tap-off/tap-in CTO’s

~6.24 MW

need CTO
dir. cplr.

160 m of WC1890

-17.57 dB

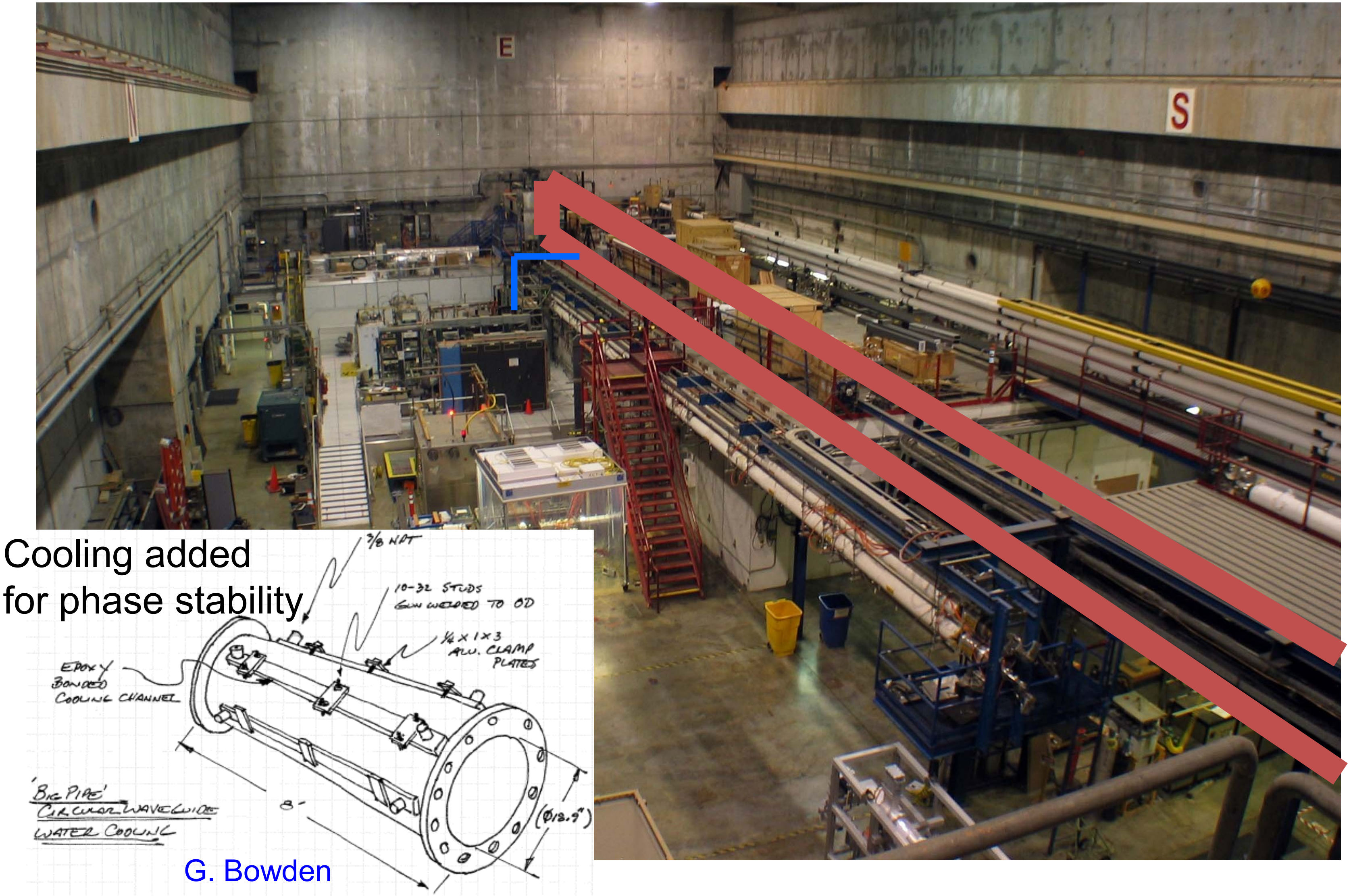
300 MW

phase
shifter

tap-off

tap-in

“Big Pipe” Resonant Ring Layout
In End Station B



Cooling added
for phase stability

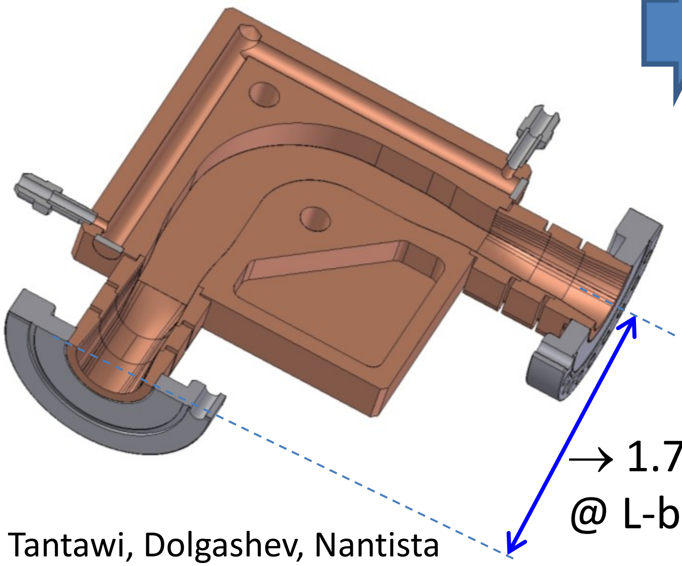
G. Bowden

90˚ Bend for KCS Main Waveguide

For KCS, we need to bend the main rf waveguide *at full power* through multiple 90˚ bends to bring it down to and along the linac tunnel. Demonstration of such a bend is crucial to establishing the feasibility of KCS.

Our best option seems to be a scaled, modified version of the current standard SLAC bend used in X-band work.   Multi-stage linear cross-section tapers convert the circular TE_{01} mode into the rectangular TE_{20} mode, which is preserved through a swept bend.

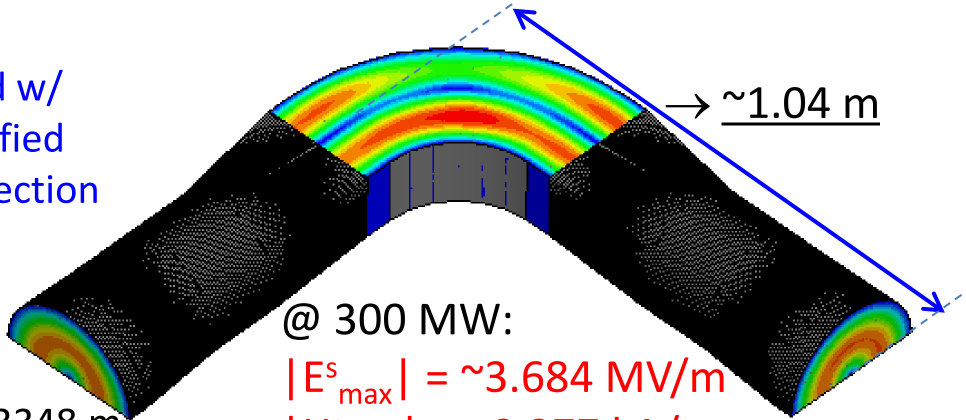
SLAC X-band TE°_{01} bend:



→ 1.73 m
@ L-band

Tantawi, Dolgashev, Nantista

Scaled w/
simplified
mid-section



→ ~1.04 m

D=0.3348 m

@ 300 MW:

$|E^{s}_{max}|$ = ~3.684 MV/m

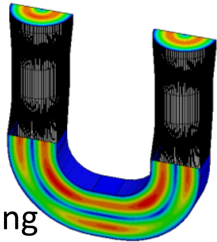
$|H^{s}_{max}|$ = ~8.377 kA/m

$|S_{21}|^2$ = 99.69% (w/o wall losses)

Highest parasitic excitation: -28.1 dB

Complicated taper requires wire e.d.m. of 10.4”-thick aluminum.

A mechanical design/fabrication plan for this bend is in underway.
Optimization of a *possible alternate design* is being simultaneously pursued.



Compact
U-bend
version for
resonant ring

Summary: Responses to Changes

(for KCS option)

Single Tunnel Main Linacs:

KCS - surface buildings, shafts, large waveguide, & CTO's

±20% Gradient Spread:

overhead for spread in PDS feed requirements

local power division (remotely) controllable by cavity?

Low Power (half bunches):

adjust bunch spacing to maintain rf pulse width

reduced initial installation of rf sources (same building size?)

reduced electrical and cooling requirements

Undulator Relocation:

10 Hz operation of e^- linac for low E_{CM} runs to maintain e^+ production