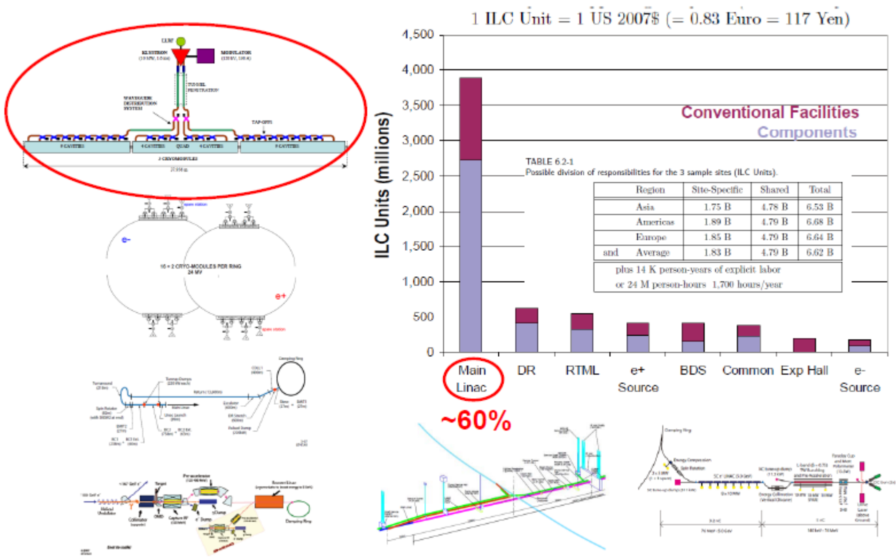
General HLRF Design in SB2009

S. Fukuda/KEK

SB2009 and HLRF

Construction Cost Profile



	Region	Site-Specific	Shared	Total
	Asia	1.75 B	4.78 B	6.53 B
	Americas	1.89 B	4.79 B	6.68 B
	Europe	1.85 B	4.79 B	6.64 B
and	Average	1.83 B	4.79 B	6.62 B

plus 14 K person-years of explicit labor
or 24 M person-hours 1,700 hours/year

RDR(2007) to TDR(2012)

- Cost Containment -

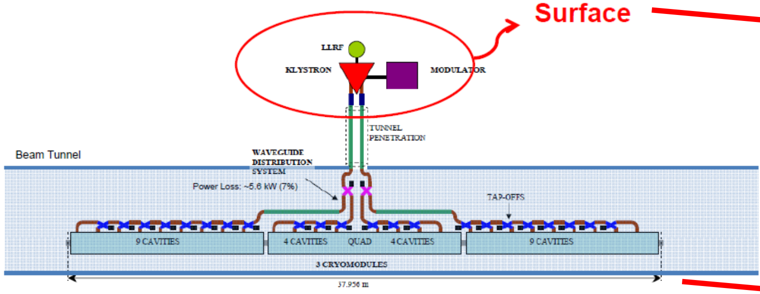
- RDR: 6.62 BILCU (4.80 Shared + 1.82 Site Specific) + 14.1 kPerson
- SB2009: 7 working assumptions with ~13% cost reduction
- One of the most cost-effective assumptions is:

2. **A single-tunnel solution for the Main Linacs and RTML, with two possible variants for the High-Level RF (HLRF):**
   - Klystron cluster scheme (KCS);
   - Distributed RF Source scheme (DRFS).

Single tunnel configuration

ML Single-Tunnel Configuration

- Klystron Cluster System (KCS)-



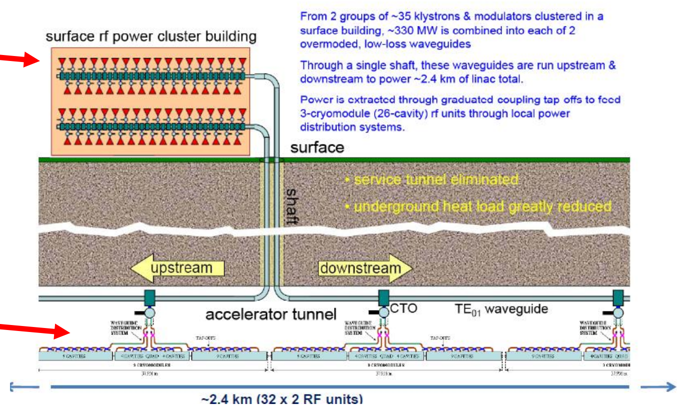
e- ML	282 RF units
e+ ML	278 RF units
Total	560 RF units

Field gradient	31.5 MV/m
Energy gain per RF unit	850 MeV

(with 22% tuning overhead)

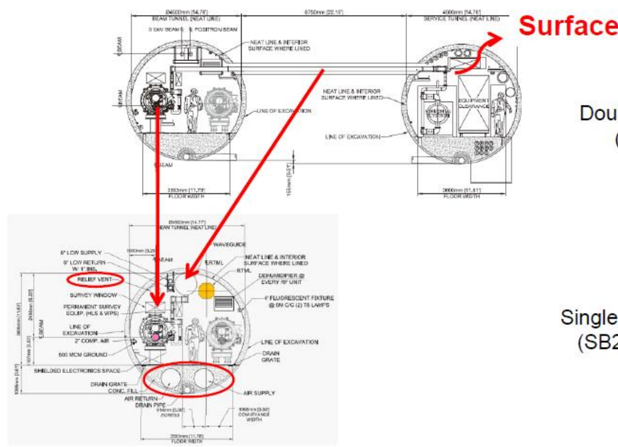
ML RF Units

- Klystron Cluster System (KCS) -



ML Civil Engineering

- Klystron Cluster System (KCS) -



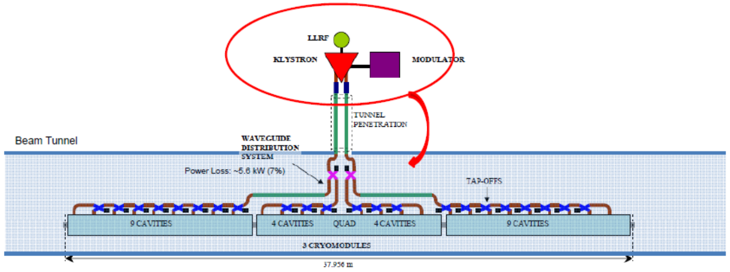
Double-tunnel (RDR)

Single-tunnel (SB2009)

Single Tunnel Configuration

ML Single-Tunnel Configuration

- Distribute RF System (DRFS) -

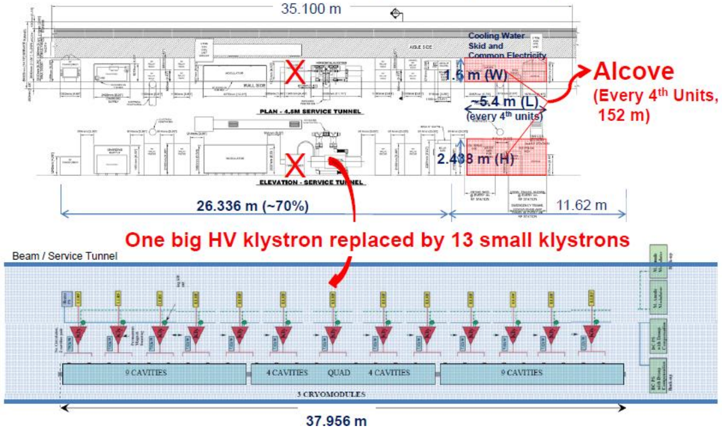


e- ML	282 RF units
e+ ML	278 RF units
Total	560 RF units

Field gradient	31.5 MV/m
Energy gain per RF unit	850 MeV
(with 22% tuning overhead)	

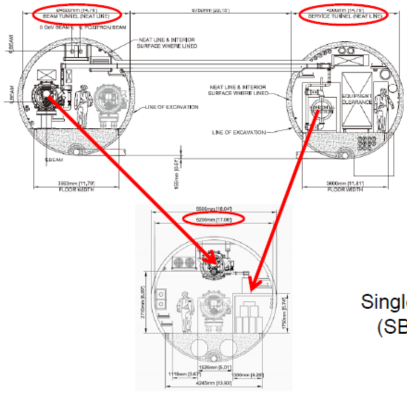
ML RF Unit

- Distributed RF System (DRFS) -



ML Civil Engineering

(DRFS)



Double-tunnel (RDR)

Single-tunnel (SB2009)

Key Features of Two Systems Comparison Table (KCS&DRFS)

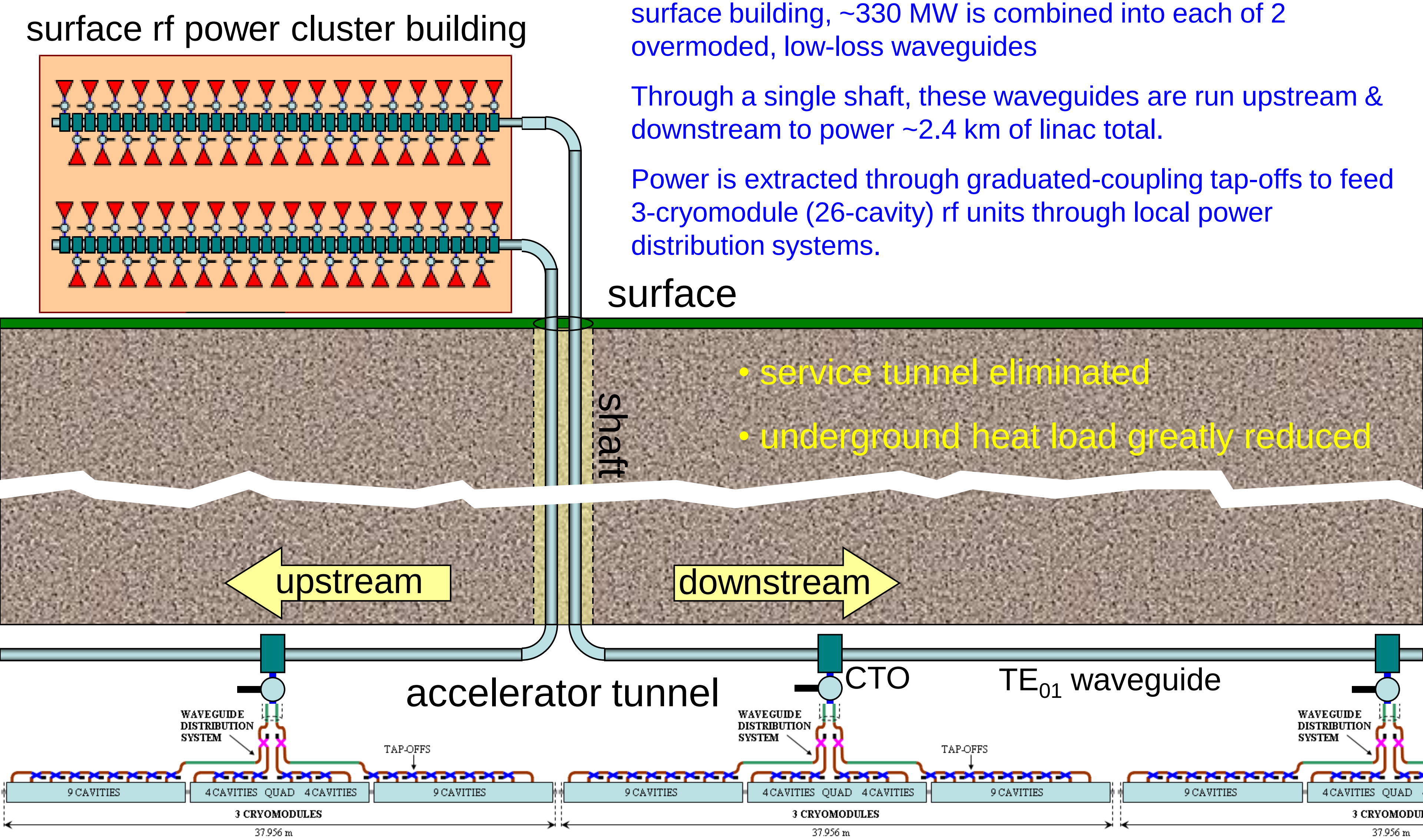
	Klystron Cluster System	Distributed RF System
Klystrons / Modulators	RDR-like 10MW klystrons + modulators on surface	Smaller ~750kW klystrons + modulators in tunnel
Surface Buildings	Surface building & shafts every ~2 km, each housing 2 clusters of 35 klystrons	-
RF power delivery	From surface building into the tunnels via circular TE01 waveguide (0.48m ϕ); After power splitting at circular tap-offs (CTO), RDR-like power distribution with revised design.	Waveguide system inside the tunnel local to each of the klystrons and the cavities associated with them.
Cavity / Klystron population ratio	832 cavities to be driven by RF power combined from 19 units of 10MW klystrons.	4 cavities to be driven by one unit of ~750kW klystron

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.



KCS: Concept & Layout (SB2009)

- Multiple sources are clustered together and their power combined into a single overmoded waveguide with very low loss circular TE01 mode, and power is then tapped off in equal portions at the same interval along the RDR linac.

- Elimination of service tunnel enables us to bring much of the heat load associated with rf generation to the surface.

- Long distance between the power sources and the accelerator gives flexibility for the rf source positioning. And it makes the KCS ideal for relatively open site topography.

- There is an intrinsic simplicity of the accelerator tunnel: no active electrical components and reduced water cooling

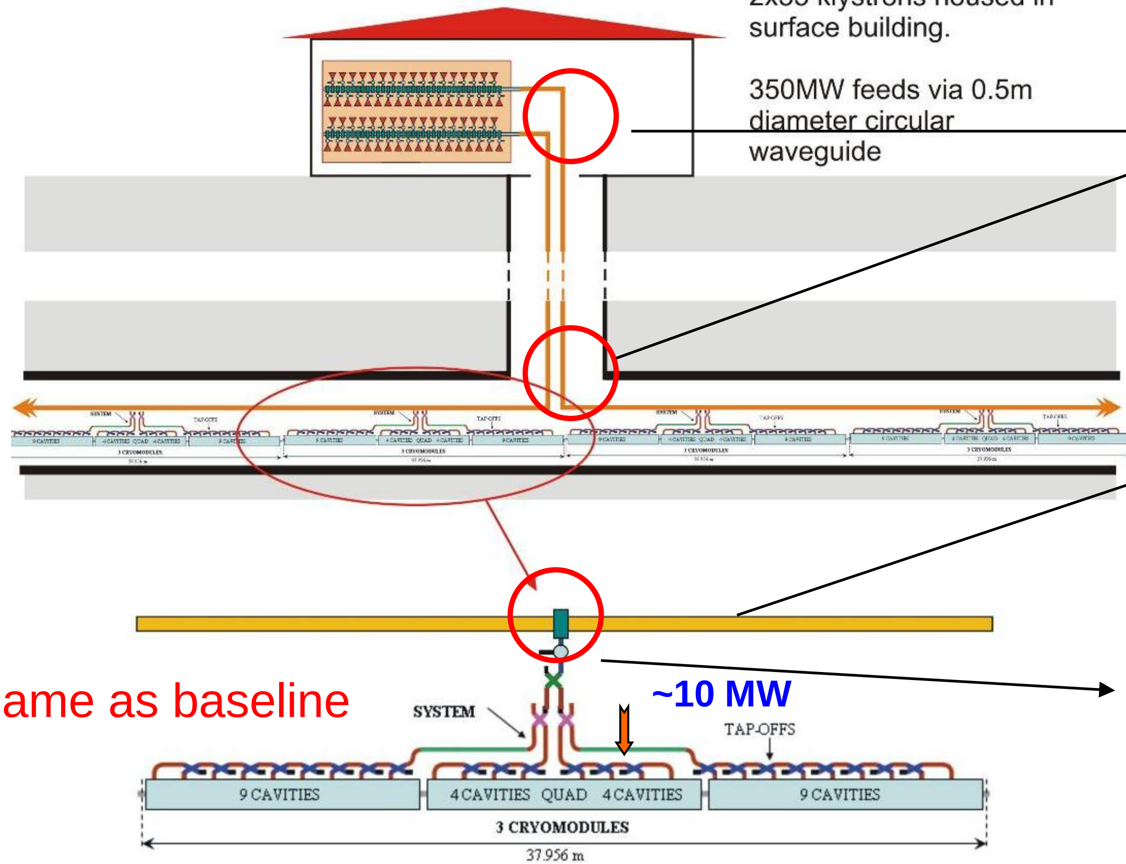
Waveguide into Tunnel

2x35 klystrons housed in surface building.

350MW feeds via 0.5m diameter circular waveguide

High power TE01 bend

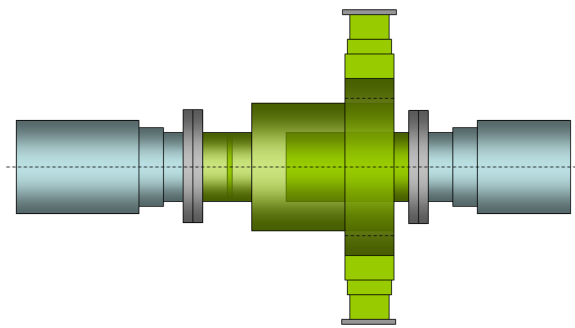
0.48m diameter circular Waveguide with TE01



Same as baseline

~10 MW

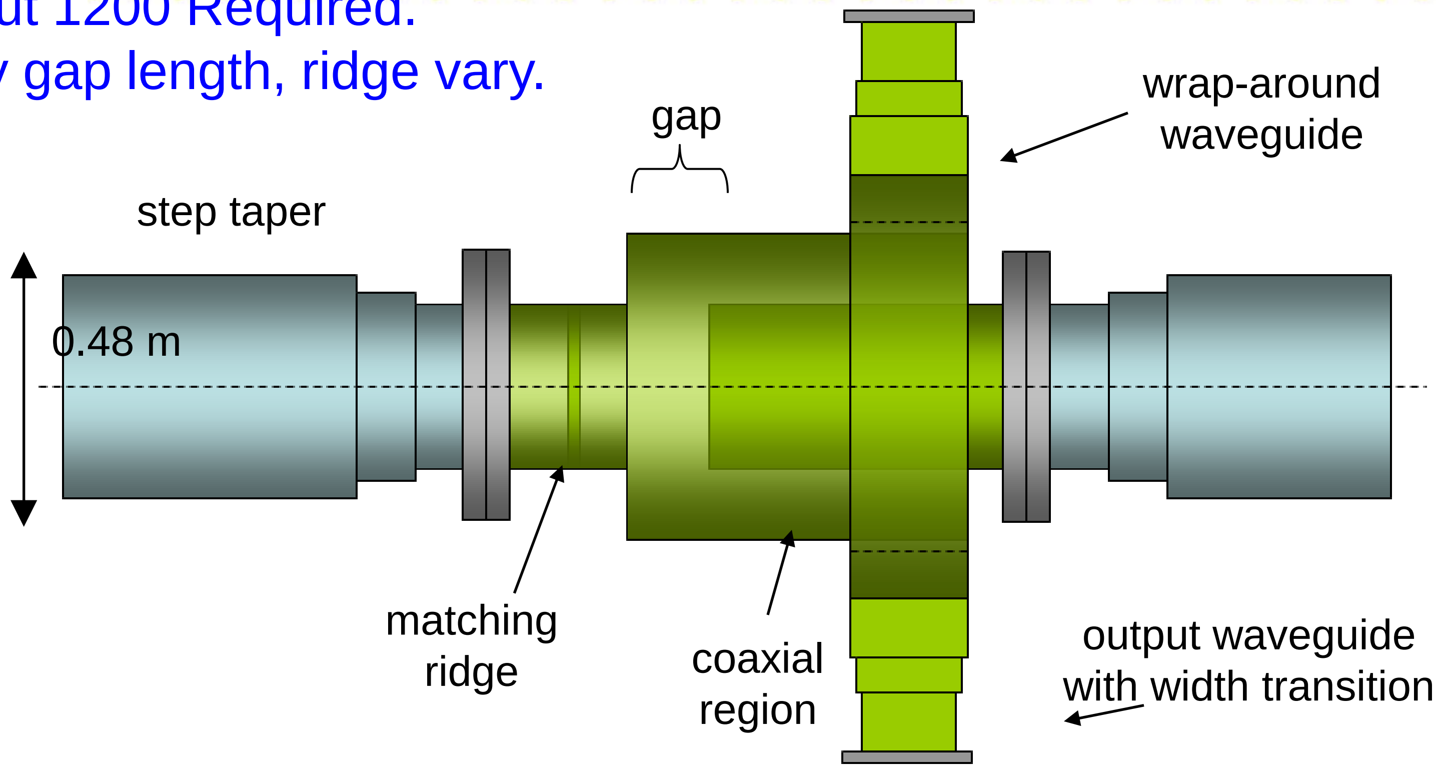
Each tap-off from the main waveguide feeds 10 MW through a high power window and probably a circulator or switch to a local PDS for a 3 cryomodule, 26 cavity RF unit (RDR baseline).



Coaxial Tap-off (CTO)

Coaxial Tap Off (CTO)

About 1200 Required.
Only gap length, ridge vary.



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

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	straw man 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.

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

Test CTO at ~45% full power level to be seen by rectangular ports (klystron limited).

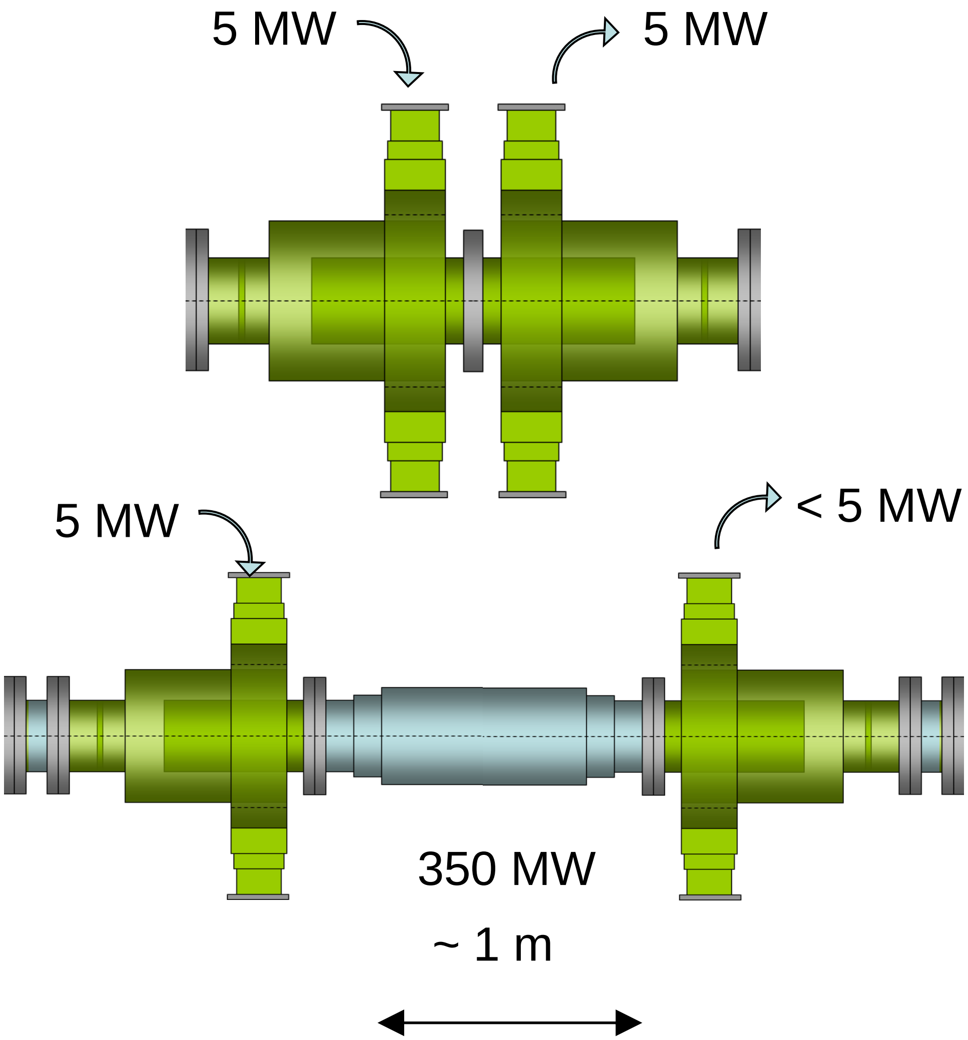
Test waveguide as a resonant line up to maximum field levels to be seen.

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

Concept Development R&D Steps

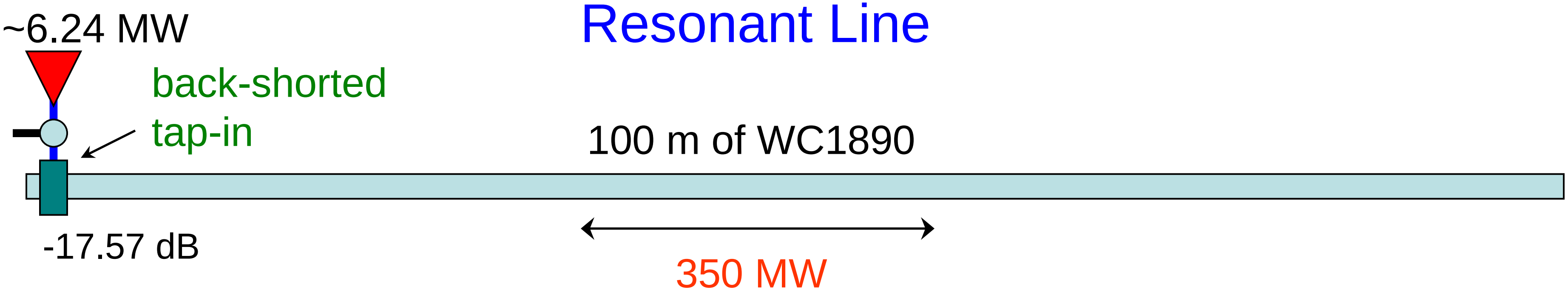
Step 1: Run 10 MW through back-to-back, blanked-off CTOs w/o pipe step up: no resonant rf build up

Step 2: Add pipe step up, adjust shorts (and thus coupling) to resonantly produce 350 MW SW



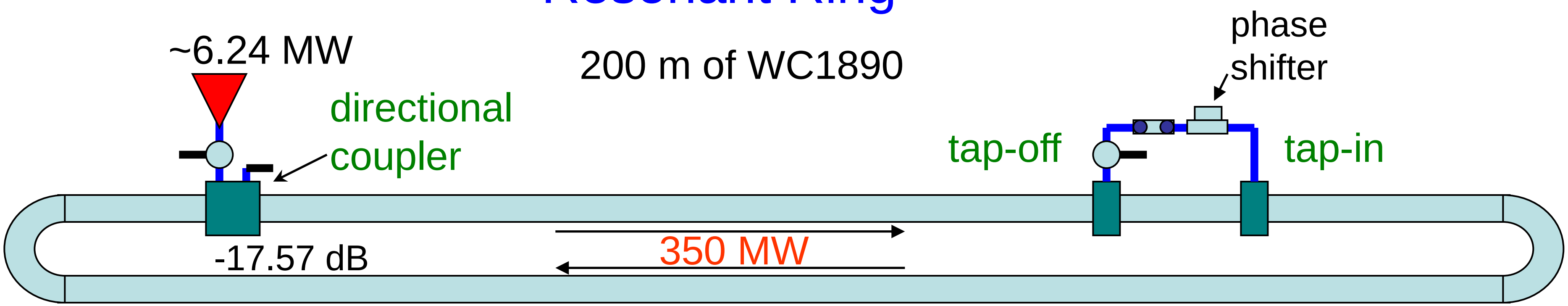
Step 3: Use resonant waveguide to build up the stored energy equivalent to 350 MW traveling waves - provides more realistic rf turn-off time if a breakdown occurs

Resonant Line



Step 4: Use resonant ring to test bends and 'final design' tap-in/off

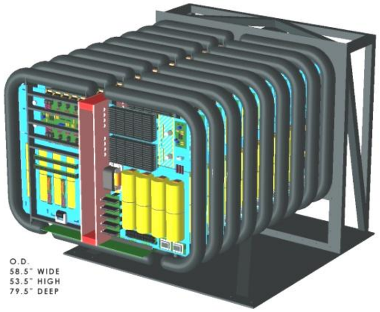
Resonant Ring



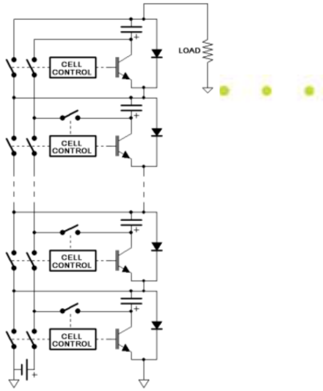
Klystron and Modulator

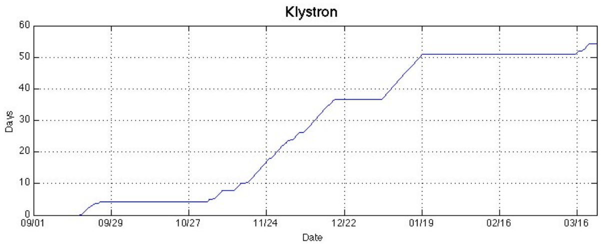
Testing continues of:

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

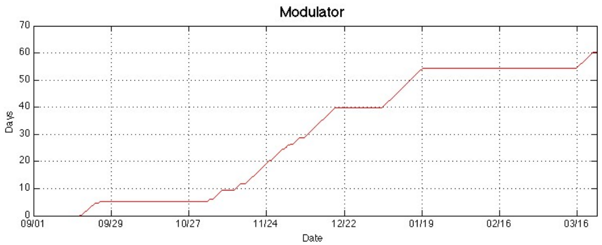


DETAIL, MARX MODULATOR CORE

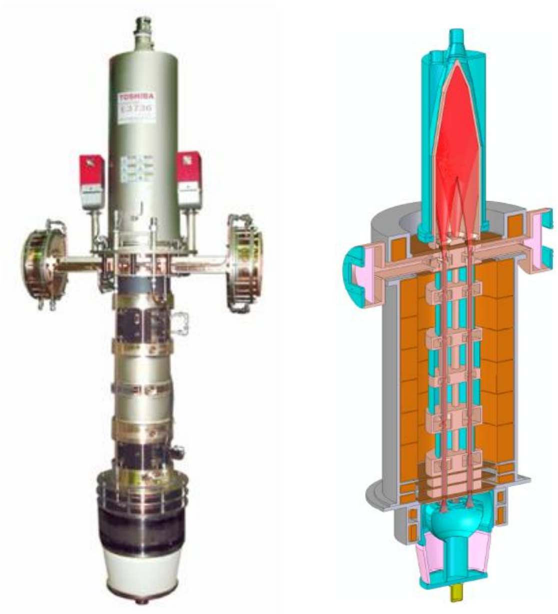




Klystron: 1301.0 hours (54.21 days) integrated operation; 191.0 hours (7.96 days) uninterrupted operation



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



Integrated uptimes, to date:

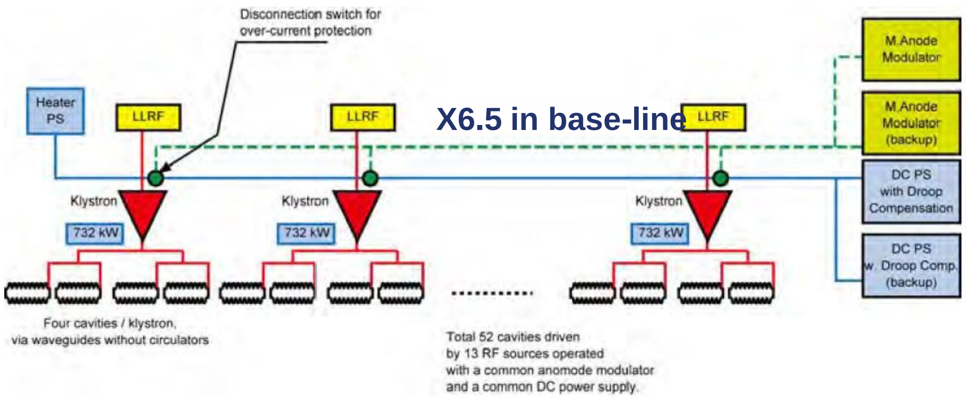
Month	Klys.	Mod.
Total Hrs	1301.1	1449.8
Total Days	54.21	60.41

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

Concept of DRFS

- The Distributed RF System (DRFS) is another possibility for a cost-effective solution in support of a single Main Linac tunnel design.

- Base line of proposed DRFS
  - ➢ **one unit of 750kW Modulating Anode (MA) klystron would drive four cavities (in high current scheme (HCS), two cavities) .**
  - ➢ **totally about 4000 (8000 in HCS) MA klystrons would be used.**
  - ➢ **It is based on much simpler and more compact HLRF and LLRF units than the RDR baseline or KCS.**



RF unit for 3 cryomodules

  - ➢ **It offers a good operational flexibility in coupling with performance variations of individual cavities.**
  - ➢ **By employing suitable back-up modules for key component, high availability would be expected.**
  - ➢ **Complete single tunnel model, no facility in the surface**

Parameters in DRFS

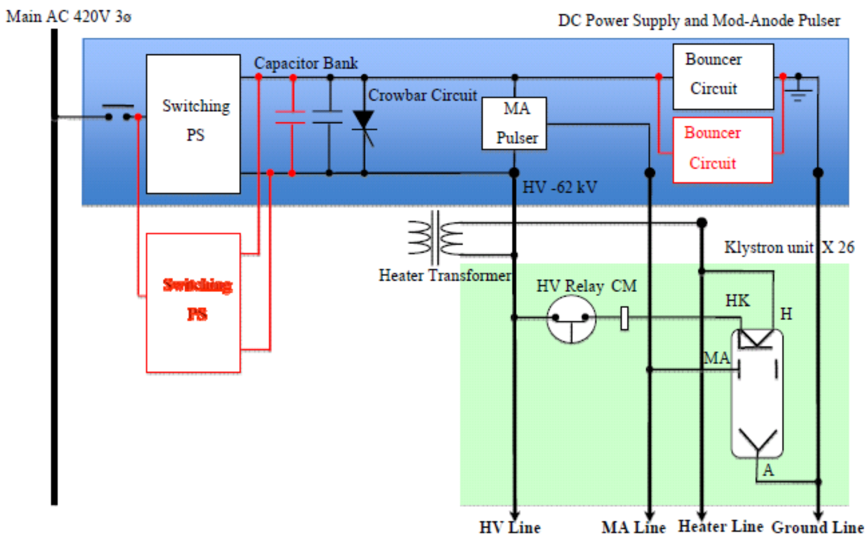
In the RDR scheme, three units of ILC cryomodules, containing 26 cavities in Total, are driven by the RF power from one unit of 10MW L-band klystron.

In the proposed new scheme of DRFS, four cavities are driven by one unit of 750kW L-band MA klystron. Therefore, one would see that three cryomodules with 26 cavities will be driven by six and a half units of MA klystrons.

In a practical implementation, the proposed scheme of DRFS is to use 13 units of MA klystrons to drive six cryomodules, containing 52 cavities.

Klystron		
	Frequency	1.3 GHz
	Peak Power	750 kW
	Average Power Output	7.50 kW
	RF pulse width	2 ms
	Repitition Rate	5 Hz
	Efficiency	60 %
	Saturated Gain	
	Cathode voltage	62.7 kV
	Cathode current	18.8 A
	Perveance(Beam@62.5kV)	1.2 μPerv
	(Gun@53kV)	1.53 μPerv
	Life Time	110,000 hours
	# in 3 cryomodule	6.5
	Focusing	Permanent magnet focusing
	Type of Klystron	Modulated Anode Type
DC Power supply per 6 cryomodules		
	# of klystron (6 cryomodule)	13
	Max Voltage	71.5 kV
	Peak Pulse Current	244 A
	Average Current	2.47 A
	Output Power	177 kW
	Pulse width	2.2 ms
	Repitition Rate	5 Hz
	Voltage Sag	<1 %
Bouncer Circuit		
	Capacitor	26 μF
	Capacitance	260 μF
	Inductance	4.9 mH
M. Anode Modulator		
	Anode Voltage	53 kV
	Anode Bias Voltage	−2 kV

Modulator Scheme/Base Line DRFS



- The DC power and anode modulation for a group of 13 units of klystrons are provided by one common DC power supply and one common anode modulator (MA modulator).
- In order to realize high reliability, each of the DC power supplies and MA modulators is associated with one backup units, which will be designed and implemented to be "hot-swappable".
- Each of the power and voltage distribution circuits will have a high-voltage SW, which switches off the line when over current failures are detected.
- A DC power supplies has a bouncer circuit for compensation of the pulse flat droop. (This leads to a relatively small condenser bank)
- The charger of a DC power supply comprises of a bundle of several units of identical switching PS. This allows us to increase its electrical power with ease, simply by adding more switching PS.
- Common heater power supply and permanent magnet focusing to eliminating magnet power supply.

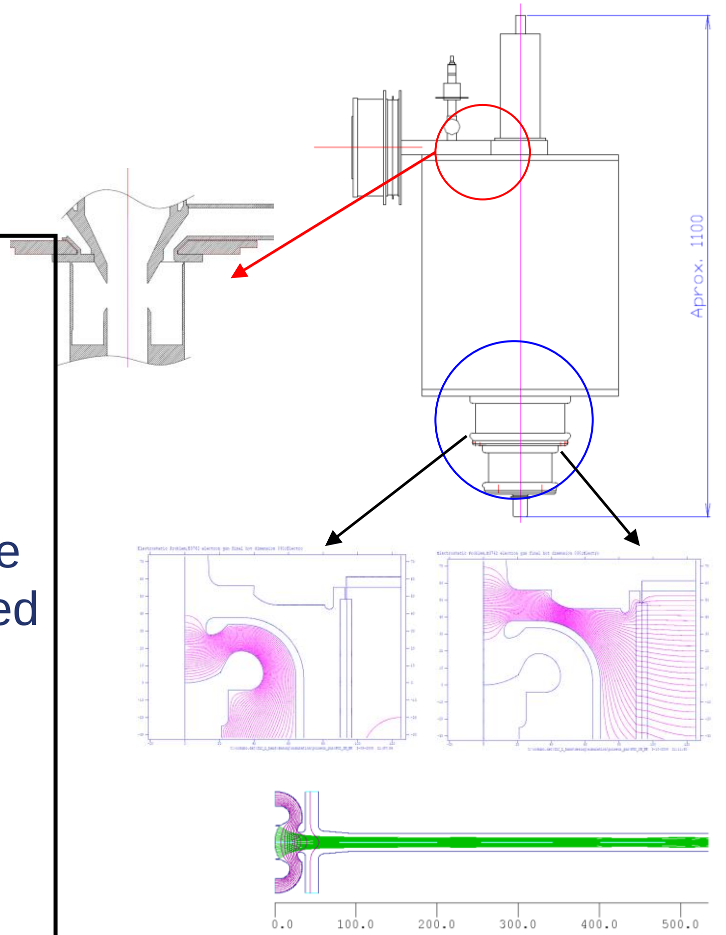
Klystron for DRFS

Parameters of MA klystron is summarized
In the previous table.

Features of DRFS klystron

Applied voltage of less than 65kV
60% efficiency with 1.2 microperveance
Low field gradient in klystron gun —few arcing
Low cathode loading--- long cathode life
Low output power--- free from output window failure
⇨ Long life of klystron would be expected

Permanent magnet focusing--- free from magnet and power supply failure
Common heater power supply with back-up --- contribute to high availability



Power Distribution System (PDS) in Base line DRFS

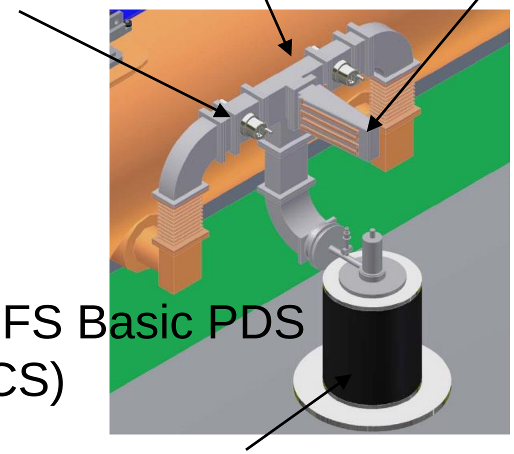
Very simple power distribution system

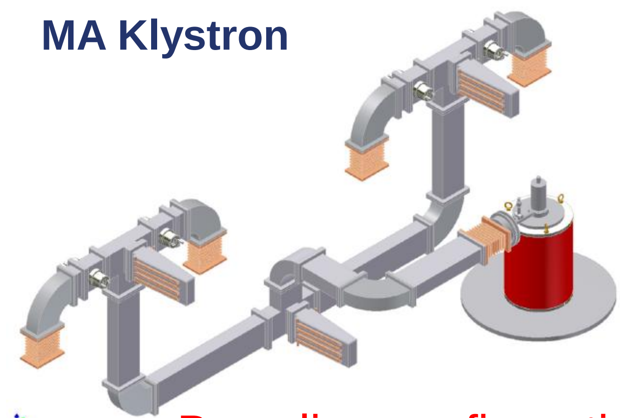
- No circulator
- Power divider employs magic tee with high isolation for space saving.
- One Phase-shifter with symmetric PDS between couplers or asymmetric PDS with a phase-fixed waveguide for cost saving

•Design of eliminating flange as possible

- 750kW RF is propagated in the dry air without any extra ceramic window

- In base line, an MA klystron feeds power to 4 cavities and additional PDS is required.





Base line configuration

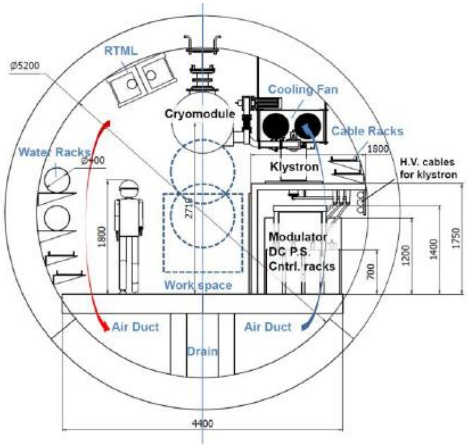
DRFS: Tunnel Layout

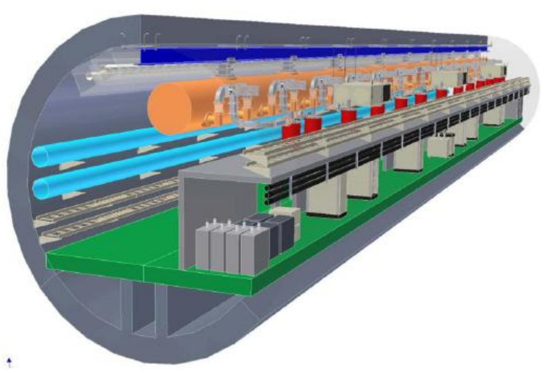
Tunnel Layout

Studies of hardware installation of DRFS in the single-tunnel scheme so far have been made, and so far it is known to be accommodated within a tunnel diameter of 5.2m. Figure 4.6.3.3 shows a cross sectional view of such an installation layout.

Cryomodule is hung down from the ceiling. The support structure with suitable vibration suppression needs to be worked out and this is an issue to pursue during TDP2.

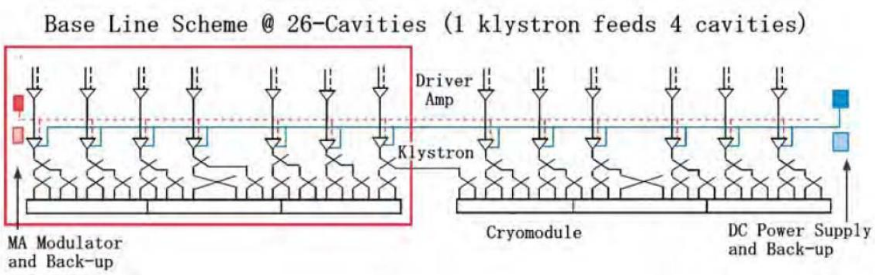
RF sources are nearly uniformly distributed the tunnel: the modulators, DC power supplies, LLRF rack units and other electrical devices are installed inside a shielded area for protection from the radiation exposure. Thickness of the shield structure and materials are currently considered as per similar implementation considered at EuroXFEL. They will be examined more closely during TDP2. Underneath the floor the air ducts will be deployed with a total cross section exceeding 1 m^2.





Base line DRFS and upgrade pass

Base Line Configuration



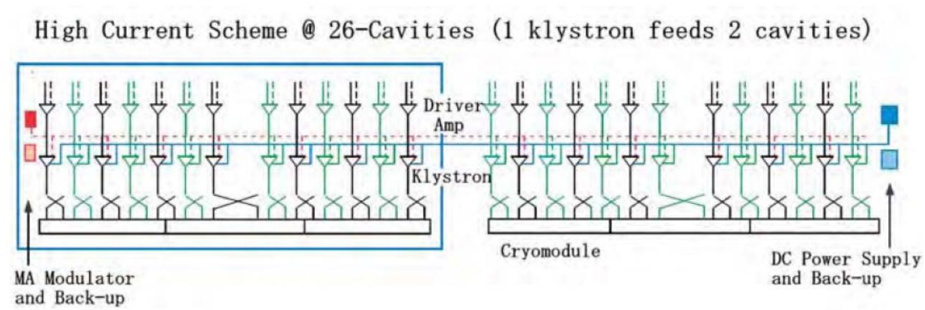
System configuration of DRFS in the baseline case.

Base Line Scheme (@ 3 Cryomodules)

Cavity	26
DC	26
Magic T	19.5
750kW Kly.	6.5
PM Focusing	6.5
Coil PS	0 PM focusing
Heater PS	0.5 (0.5 back-up)
Preamp	6.5
MA Pulser	0.5 (0.5 back-up)
LLRF &Intlk	6.5
DC P/S	0.5 (0.5 back-up)

The component count for the DRFS in the baseline case. For comparison with the RDR. The numbers are quoted for a group of three cryomodules.

High Current Scheme



High Current Scheme (@ 3 Cryomodules)

Cavity	26
DC	26
Magic T	13
750kW Kly.	13
PM Focusing	13
Coil PS	0 PM focusing
Heater PS	1 common (1 back-up)
Preamp	13
MA Pulser	1 (1 back-up)
LLRF &Intlk	13
DC P/S	1(1 back-up)

The component count for the DRFS in the high-current case. For comparison with the RDR, the numbers are quoted for a group of three cryomodules.

Klystrons are increased.
PDS are changed.
Charger of a DC power supplies are reinforced.

Heat Dissipation

One of the potential issues in hardware implementation of the DRFS is the heat dissipation by components in the single main linac tunnels.
Heat dissipation table is shown below.

WATER AND AIR HEAT LOAD for SB2009 DRFS Base Line Scheme

MAIN LINAC - ELECTRON & POSITRON									
					To Low Conductivity Water	to Chilled Water	keith Jobe load to air Nov 22 06		To Fan Coil Chilled
Components		Quantity Per 36m	Total Heat Load (KW)	Average Heat Load (KW)	Heat Load to LCWater (KW)	Heat Load to Rack Chilled Water (KW)	Power fraction to Tunnel Air (0-1)	Power to Tunnel Air (KW)	Heat Load to Fan Coil Chilled Water (KW)
RF Components									
--- High Voltage Circuit Breaker (6.6 kV) ---		1/76 m							
DC Power Supply, 6.6 kV (I), 60 kV, 2 A (O), 125 kW, 90% eff.	Rack 1	1/76 m		12.50	7.50	0.00	0.40	5.00	5.00
Modulating Anode Modulator, 6.6 kV (Shunt 0.5A, then 3 kW heat load)	Rack 3	1/76 m		3.00	1.80	0.00	0.40	1.20	1.20
Heater P/S, 200V,18A, 4kW	Rack 3	1/76 m		0.50		0.50	0.00	0.00	0.00
Klystron Socket Tank / Gun 0.2 kW X 13		13/76 m		3.90	3.12	0.00	0.20	0.78	0.78
4.5 kW X 13		13/76 m		58.50	56.75	0.00	0.03	1.76	1.76
Klystron Body & Windows		13/76 m		3.76	3.76	0			
--- LLRF Racks ---		3Units/76m		0.91		0/91	0.00	0.00	0.00
--- Other Racks ---		8Units/76m		19.30		19.30	0.00	0.00	0.00
Waveguides in beam tunnel		13/76 m		0.80	0.00	0.00	1.00	0.80	0.80
RF Loads		13/76 m		22.80	22.12		0.03	0.68	0.68
Pulse motor for input coupler/tuner		(26+26)/76 m	1.79	0.00			1.00	0.00	0.00
Vacuum Pumps		(2+2)/76 m		1.26			1.00	1.26	1.26
Subtotal RF unit Only				*127.23*	*95.04*	*20.71*			*11.48*

Operability

- Only 4 cavities are driven by a klystron, and LLRF control is very easy. 4-vector sum enables us to have an easy Ql and distribution control, fast loop delay, and high FB gain.

  Cf. RDR baseline: 26 cavities are one set of vector sum

  For KCS, about 700 cavities are one set of vector sum.
- Each cavity field flatness is easy with suitable sorting of the cavity.
- With relatively unsophisticated sorting of the cavities, a high efficient operation is expected to achieve a high average accelerating gradient.
- In case of failures of cavities, the affected number of cavity units is limited and we can minimize the effect to the operation.
- High operation flexibility will be achieved.

MTBF of Important components in DRFS

Items	No	MTBF (hrs)
DC Power Supply	1	50,000
possibly having redundancy (Failure free/y)	+1(Back-up)	>100,000
Modulating Anode Modulator	1	70,000
possibly having redundancy (Failure free/y)	+1(Back-up)	>100,000
MA Klystron	6.5	110,000-120,000 (KEK's recent 10 years data)
Focusing Coil— Permanent Magnet	6.5	Degaussing by gamma ray???
Coil PS	0	-
Heater Power Supply	1+1(Back-up)	70,000 (Fan)
IP PS	0	-
Preamplifier (radiation?)	6.5	>100,000
Interlock module	6.5	
Bin module/PS	6.5	
Rack System with cooling	2	
Water flow SW	15	

Klystron: MTBF=110,000hr, ILC Op/year=5000hr, then 325 tubes are failured. Fraction=4.5%. Two scheduled long maintenance covers the 2,5% failures, and if overhead is more than 2.5%, klystron failures don't affect to the ILC operation.

DC Power supply: MTBF of 70000hr is assumed. Fraction=7.1%.

This fraction exceeds the allowable overhead. It is possible to introduce backup DC power supply as the redundancy as MA modulator. Then DC PS failures don't affect to the ILC operation. Cost impact is not large in DRFS.

MA Modulator: Assume MTBF=from 50,000 to 70,000 hr.

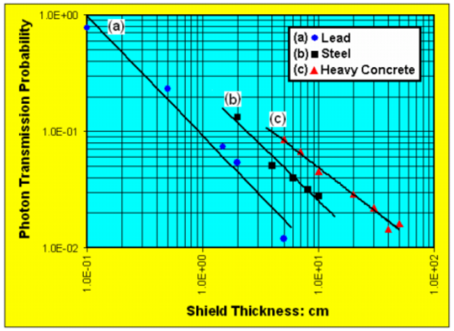
Back-up modulator covers the another modulator's failure. Since two modulators failures at the same time are very rare, we can expect no failure in a year operation. Failured MA modulator are repaired or exchanged in the scheduled shutdown.

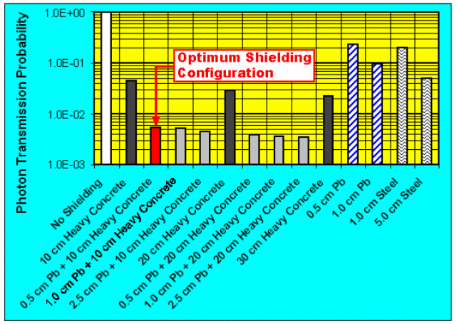
Concerns about the radiation effects against the electrical component in the tunnel

- **Since DRFS is a complete single tunnel plan, great concern of the radiation effect against the electrical components in the tunnel.**
- **Front ends of LLRF are required to be near to the cavities, RDR base line and KCS would face to the same problems.**
- **DRFS has a shielding structure which is assumed to be similar with FLASH and XFEL. All electronics would be installed in this shield.**
- **First study for the radiation effect is studied by FLASH facility in advance to construct XFEL. DRFS first insight for this problems is come from their study.**

Efficacy testing of shielding materials for XFEL using the radiation fields produced at FLASH

TESLA-FEL 2008-06



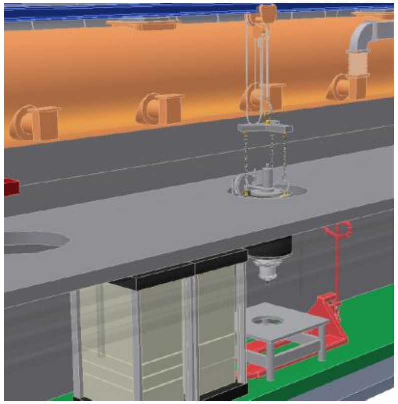


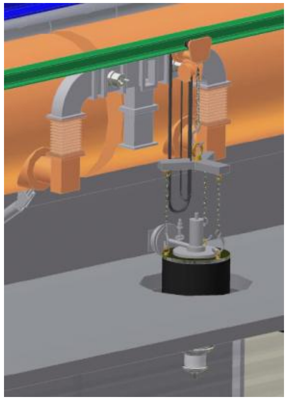
In SB2009 document, we assume the shield of 10 cm heavy concrete and 1cm lead.

DRFS Exchanging Working In Scheduled Shut down (in Baseline)

- **Maintenance model: 24 hours maintenance in every 2-weeks of continuous operation (312hrs)**
- **Numbers of replacement required**

Component	# of units requiring replacement or repair	MTBF assumed	Total # of units deployed at the ILC
DC power supply	2	50,000 hours	325
MA modulator	1.5	70,000 hours	325
MA klystron	12	110,000 hours	4225





Estimated times of the repair work of DRFS

Action	Time for unit piece of work	Rationale
Transportation of klystron	0.5 person-hours / tube	2 persons in 2 hours could bring 8 tubes on one carrier.
Removal of a failed klystron and installation of a replacement klystron	4 person-hours / tube	2 hours with 2 persons
Time for personnel to move from one point of repair to another	2/3 person-hours / tube	20 minutes with 2 persons
Replacement of a MA modulator	6.67 person-hours / modulator	
Replacement of a DC power supply	27 person-hours / DC power supply	

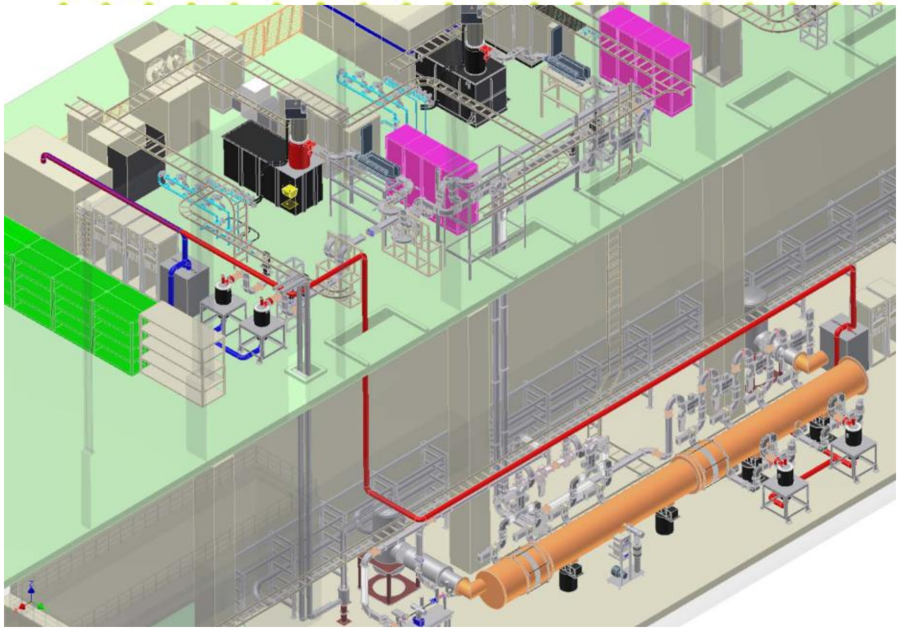
- **Then 62 person-hour for 12 MA klystron replacement.**
- ***10 person-h for 1.5 MA Mod.***
- ***54 person-h for 2 DC PS.***
- **→16 person-days**
- **→43 person for 9 hours/shift**

- **Backup for Mod. and DC PS enables us to employ less person.**

This is likely to be manageable!

DRFS R&D

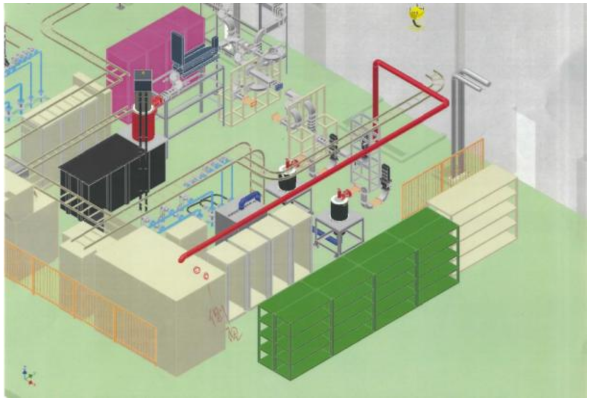
DRFS Demo in S1-Global



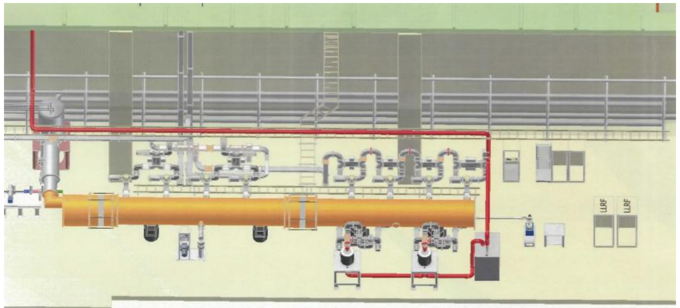
DRFS demonstration will be Prepared in the end of S1-global: December of 2010.

2 units DRFS

Birds eye view of STF site

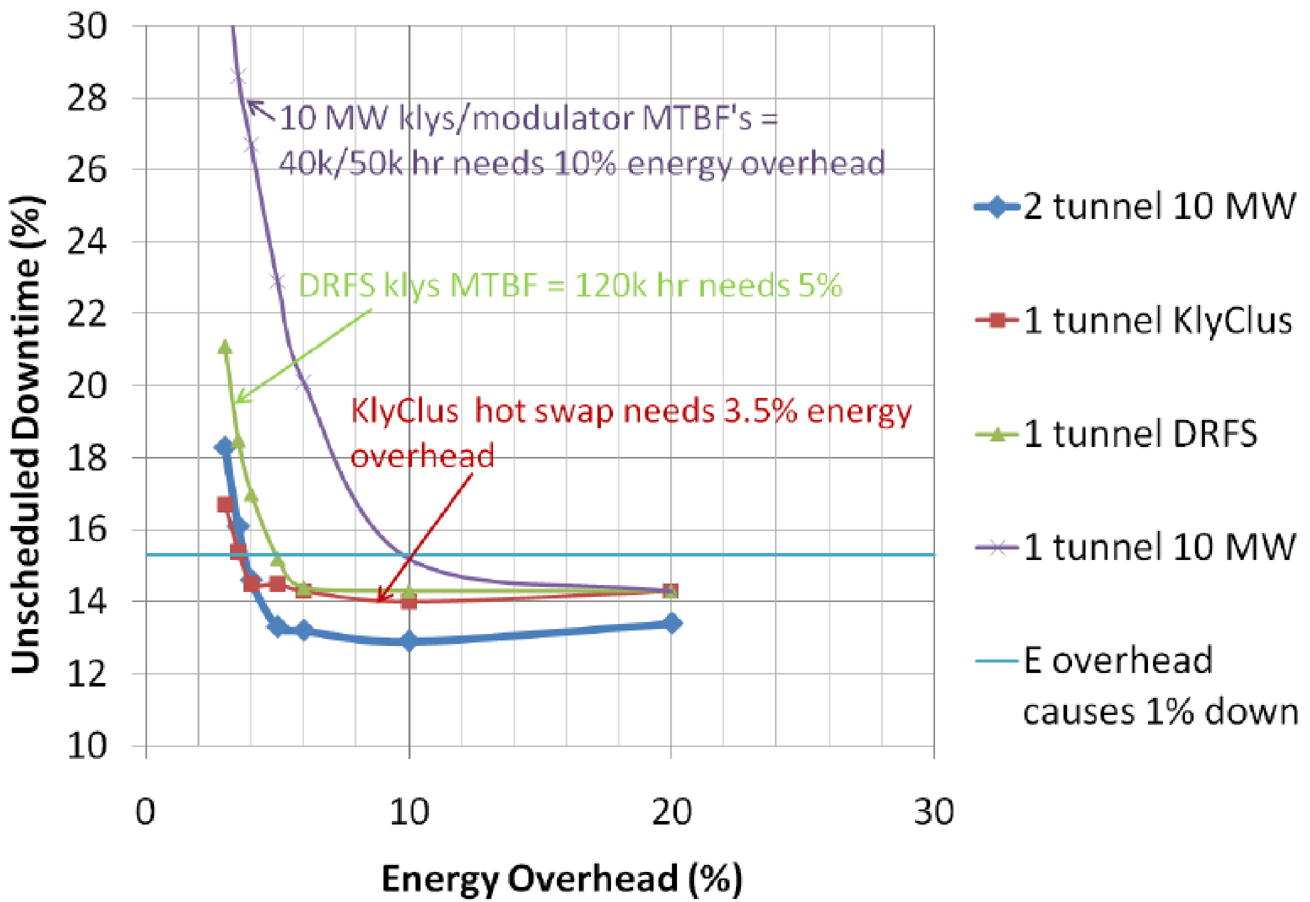


First evaluation test is done in klystron gallery



Then 2 DRFS units are connected to the four cavities in the cryomodule.

Availability Simulation



Pros and Cons for KCS

	Pros	Cons	Comments
Configuration	*Single tunnel	*Need Surface facility	
	*All heat dissipation on surface		
	*No radiation effect against HLRF	* Radiation effect for LLRF frontend	*Check XFEL data
Operability		*RF vector sum of 832 Caviies *Remote control of P&Q	
Availability	*High availability of HLRF Components *Easy maintenance during operatior	*Concern about the long WG trouble *Relaibilty for PDS(CTO etc)	*Reliability Study
Cost	*Kly same as RDR, For Mod.&PDS not clear		* Total cost evaluation
R&D		*Hard to one unit demonstration	*How to show the feasibility
ETC			*System difinition is not enough

Pros and Cons for DRFS

	Pros	Cons	Comments
Configuration	*Complete single tunnel ; very simple	*All heat dissipation in a tunnel *concern about radiation effect against the components	* Need more study *Check XFEL data
Operability	*Very good *RF Vector sum of only 2-4 cavities *Flexibility to cavity quench ets.		
Availability		*Concern about failures of components *Concern about maintenance	*Check for MTBF *Introduce redundancy *Reasonable scenario
Cost		*Concern about high cost	* Need total cost evaluation including HLRF and CFS
R&D	*Easy demonstration		*S1-global, STF-PhaseII

Summary

- Two proposed HLRF schemes in SB2009, Klystron Cluster Scheme (KCS) and Distributed RF Scheme (DRFS) are described.

- Both schemes have pros and cons and need more feasibility study.

- Both have a R&D plan in near future to show the basic feasibility.