HLRF

KEK
Convener S. Fukuda

Content

- Status of BCD
- Various ACD Scheme
- RF Cluster Scheme
- DRFS (Distributed RF Scheme)
- LLRF Comparison among RF Cluster Scheme and DRFS

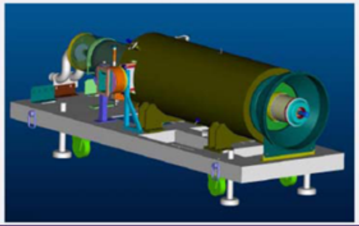
XFEL High Power RF Status

RF High Power Source

Horizontal MBK prototypes

•Horizontal versions of MBKs by all 3 vendors are under construction (THALES, TOSHIBA, CPI)
•First klystron has been tested at DESY (Toshiba, December 07 to February 08)

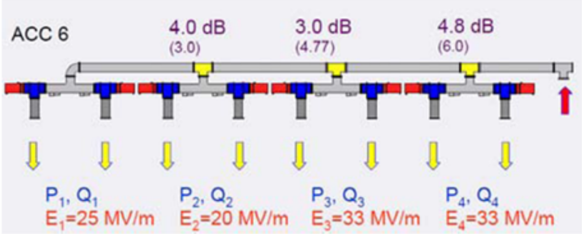
THALES TH1802



TOSHIBA E3736H

- #6 passed acceptance test at Thales, passed acceptance test at DESY (10MW, η=61%)
- #7 passed acceptance test at Thales, passed acceptance test at DESY (10.5MW on matched load, η=62%)

- 1 TOSHIBA E3736 at DESY
  - 10.4MW, 1.5ms, 10Hz, 66%
  - 750h, ~80% at full power
  - will be used at the modulator test stand in Zeuthen

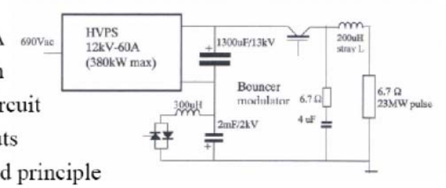


Modulator

Qualification of additional vendors

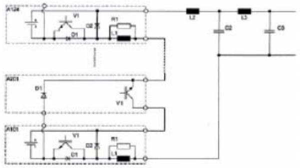
Bouncer Modulator by Imtech/Vonk

- Bouncer Type, as specified by DESY
  - 12kV HVPS
  - Bouncer 300uH/4.6kA
- 7st IGCT main switch
- Digital Regulation Circuit
- Analog In- and Outputs
- Well known and tested principle
- delivery time: 12 month



PSM Modulator by Thomson BM

- Different Type:
  - 12kV/2kA w. transformer
  - Pulse Width Modulation
  - 24 switching stages in series
  - FPGA based control
  - 2 stages for redundancy
- Slew rate and pulse shape controllable
- detailed description available, principle already successfully tested (worldwide, i.e. W7/X)
- delivery time: 14 month

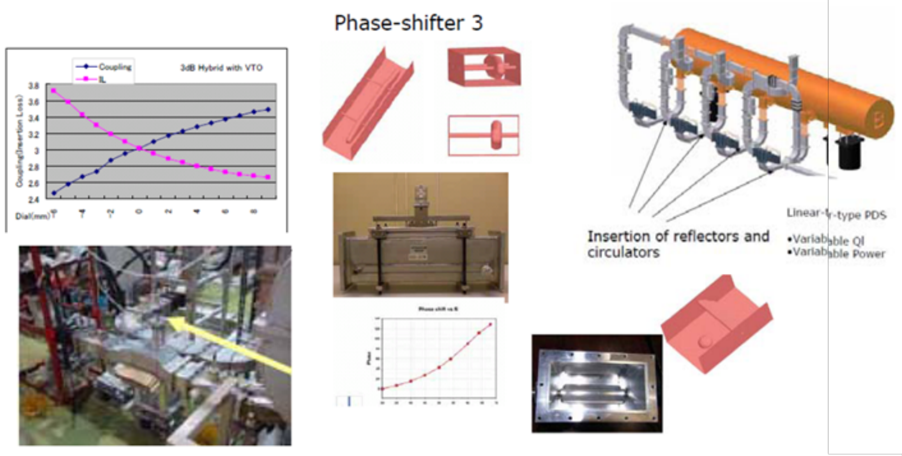


KEK HLRF Status and S1 Global

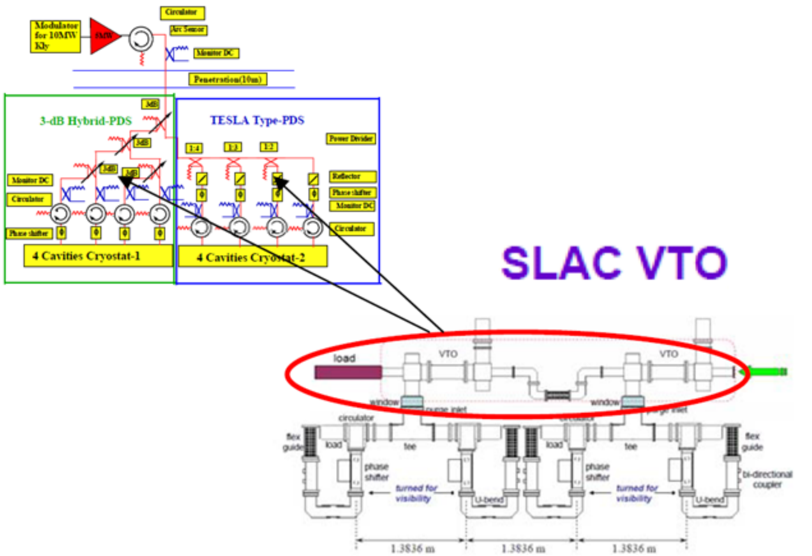
STF-1 is now under testing

Up to the end of November
- Coupler test and cavity test are performed
- 3 cavities go to 22MV/m
- 1 cavity goes to 32.9MV/m

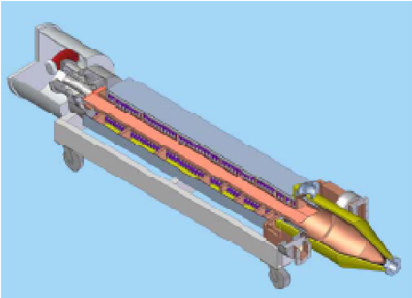
HLRF Own Program from December
- Evaluation of Tree-type PDS with 3dB VTO
  - With Circulators
  - Without Circulators---LLRF vector sum control
    ---investigation changing the hybrid isolation
- Evaluation of Linear-type PDS
  - Optimization of Ql by Adopting Reflector and Phase-shifter



- Expecting Cavities for S1-global
  - 2 Cryomodules with 8 Cavities
    - 4 from Asia including Ichiro Cavity(?)
    -> No coupler tuner (Fixed coupler), Power divider with VTO (+-10%?)
    - 2 from EU
      2 from US
    -> With coupler tuner, Power divider (SLAC VTO)

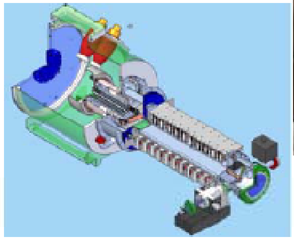


Development of Sheet Beam Klystron



LSBK Program Plan

- Build a flexible beam test diode to verify 3-D gun simulations.
  - Beam profile measurement capability for electrostatic and magnetic focusing cases
  - Modular design to allow quick modifications and component changes
- In parallel develop a klystron to be fabricated immediately after the beam test diode.



Beam, RF and Interaction Status

- Electron gun:
  - Simulations complete
- Beam Transport:
  - 3D magnetics design complete for diode
  - Klystron magnetics in progress
- RF circuit:
  - Cavity loading design complete
- RF-Beam Interaction:
  - TE mode discovered, studies underway for suppression

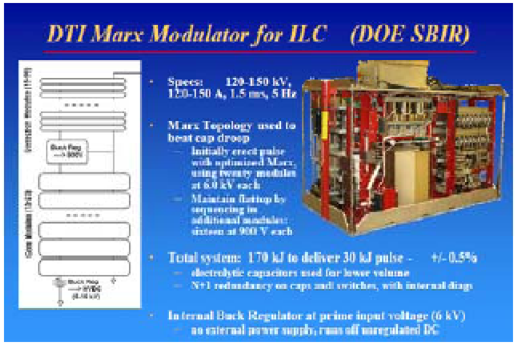
Mechanical Design Status

- Electron gun:
  - Three cathodes in house
  - FE machining in progress
  - Assembly beginning
- Anode assembly:
  - Brazed assemblies in final machining
- Beam diagnostic:
  - Sub assembly brazing complete
  - Assembly of vacuum chamber beginning
- Klystron design on hold for TE mode resolution

Development of Marx Generators

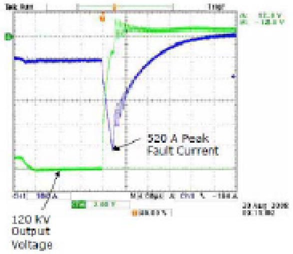
P1-Marx Status

- Developmental Testing in B015 Completed
  - Operational Testing
    - Full voltage (120 kV), current (140 A) and pulse length (1.6 mS) witl coarse flattening
    - Full PRF (5 Hz)
    - Near full power (135 kW), load limit ~100 kW, HVPS limit ~120 kW
    - Several shifts without intervention
  - Arc-down Testing (Simulated Klystron Arc)
  - Integrated into "Sealed" Enclosure
- Install in L-Band Test Station in ESB for Extended Life Tests
  - Marx Control System Upgrades: EPICS interface
  - L-band Test Stand Interlocks and Control
- Improve Output Voltage Regulation to $\pm 0.5\%$
  - Vernier Regulator



Normal Operational Testing

Fault Testing: Load Arc



- Coarse Pulse Flattening
  - 16 Cells: 11 prompt, 5 delayed
  - 0.86 kΩ water load
- Efficiency Measurement
  - Total power efficiency: 97%
  - Usable (RF) efficiency: 92%

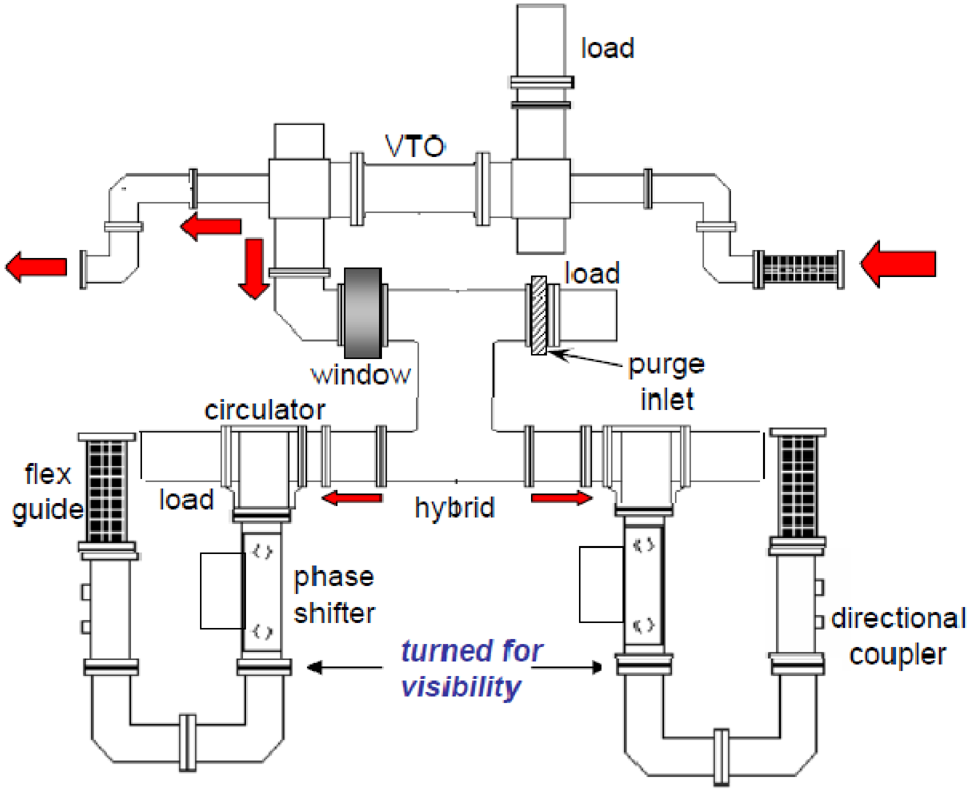
Marx Program Status Summary

- SLAC P1-Marx
  - Developmental Testing: Complete
  - Initial ESB Operation: 11/08
  - Integration into L-Band Station: Early '09
  - Output Regulation ($\pm 0.5\%$): 3/09
- SBIRs
  - Complete '09
  - Hardware to SLAC: FY10
- SLAC P2-Marx
  - Initial Design/Components Ordered: 12/09
  - 1st Cell Assembly & Testing: FY09-Q2&3
  - Multi-Cell Testing: FY09-Q4
  - Final Design/Components Ordered: FY10-Q1
  - Cell Assembly: FY10-Q2
  - Modulator Testing: FY10-Q3&Q4

Summary Status & Plans

- VME Interlock System
  - F3 FPGA based test stand interlock system in test, hardware installation continuing, interlock software nearing completion
- VME-ATCA Adapter
  - Board loading underway; will need IPMI, driver software development to complete
  - Reference design for future AMC carrier board
  - Future: Implement ATCA adapter version of test stand interlocks
- AMC's in MicroTCA promising for future controls upgrade
  - Commercial AMC, IP products can perform most SLAC linac controls functions
  - Collaborating with DESY to get fast ADC Firmware
  - Plan initial experimental tests in FY 09
- *Future:*
  - *Port controls designs directly to generic AMC FPGA modules with front-end plug-in options*
  - *optimize use of xTCA infrastructure over more payload modules*

Modular 2-Cavity PDS Unit for 1at FNAL CM



BENEFITS OVER LINEAR BCD:

- fewer types of splitters (2 vs. 9)
- power division adjustable by pairs (VTO)
- permits elimination of circulators (hybrid)

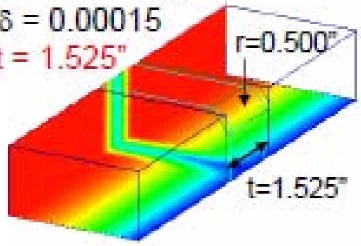
First (of 4) 2-cavity unit for ILCTA@NML CM-1 tested and delivered to Fermilab. The other three are about to be high-power tested and shipped.

Dielectric Plug Pressure Windows

shorter, simpler, cheaper replacement for pillbox window

RF DESIGN

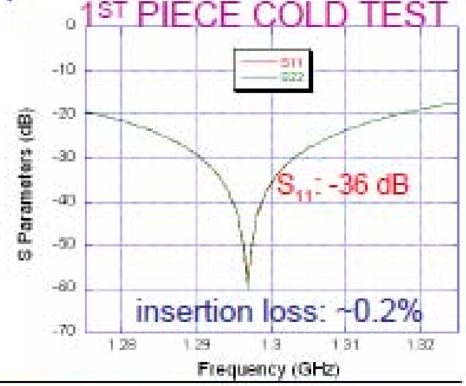
Alumina: ε = 9.37
tanδ = 0.00015
→ t = 1.525"



MECHANICAL DESIGN

(Andy Haase)

1ST PIECE COLD TEST



Achieving VTO Function w/ 3dB hybrids, Magic T's, U-bends & Spacers

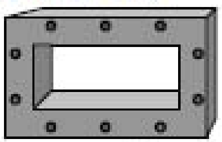
$$C = \cos^2(\beta\Delta T + \pi/4)$$

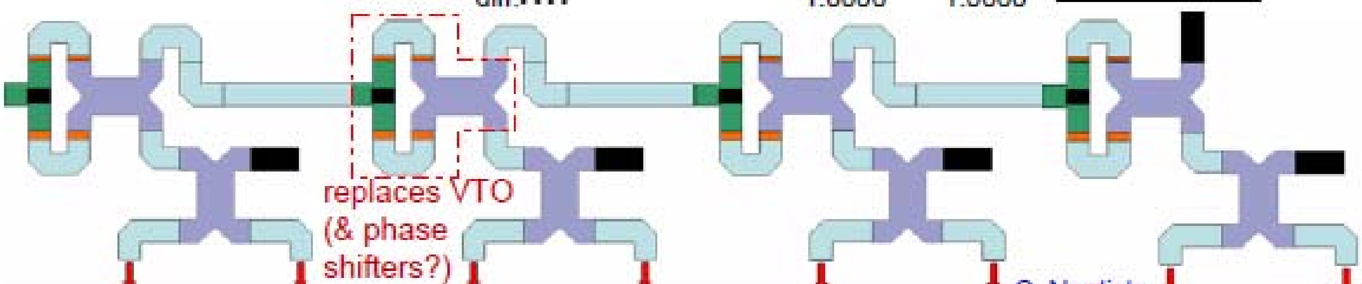
coupling (tap-off fraction)

spacer thickness diff.

Nominal Spacer Set (2 each)

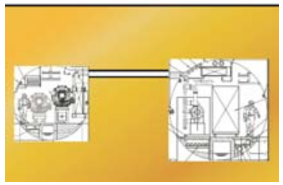
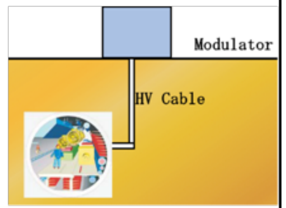
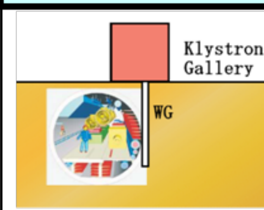
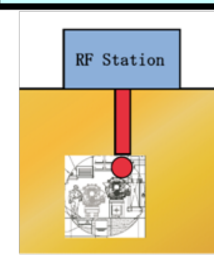
1.7928"	0.2072"
1.2643"	0.7357"
1.1715"	0.8285"
1.0000"	1.0000"





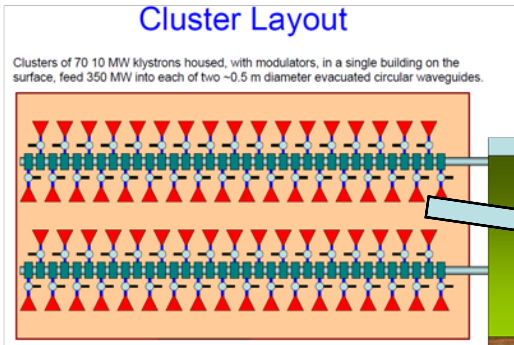
C. Nantista

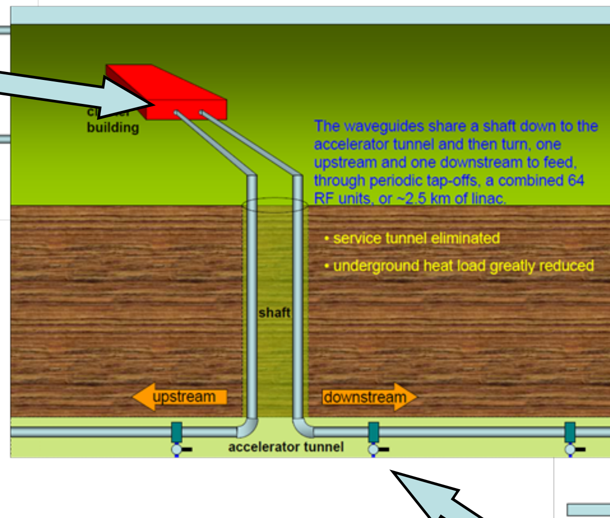
BCD and Alternative Scheme Proposed

	BCD	DESY	Shallow Tunnel	RF Cluster	DRFS
Scheme					
Deep/Shallow	Deep	Middle	Shallow	Middle	Deep
Civil Cost	High	Middle	Shallow tunnel cost	?	Cheep
Cooling Cost	○	◎	◎	◎	○
Heat source	Heat source of RF in the tunnel	Modulator on the surface	Heat source of RF on the surface	Heat source of RF on the surface	Heat source of RF in the tunnel
Site Dependence	OK	Japan Mountain Site	Dubna OK Japan ?	Japan -> longer WG	OK
LLRF handling	○	○	○	△	◎
Vector Sum	26 cav. Vector Sum	26 cav. Vector Sum	26 cav. Vector Sum	780 cav. Vector Sum	1 to 1
Redundancy	○	○	○	△	◎
Kly Failure Impact	26 Cavity Stop	26 Cavity Stop	26 Cavity Stop Easy Klystron Replace	Easy Klystron Replace	Scattered failure section
Other Issues		Long HV Cable		Long Vacuum WG System	Very Simple Configuration
R&D Cost	○	○	○	△	◎
Test Facility	3 Cryomodule/26 Cavity= 1 RF unit	3 Cryomodule/26 Cavity= 1 RF unit	3 Cryomodule/26 Cavity= 1 RF unit	Difficult to evaluate one minimum unit	Very small system
Total Cost					

RF-Cluster Scheme

- In order to cost down, klystrons and modulators are moved to surface.
- About 30 output powers from a klystron are summing up and transferred from the surface to a beam tunnel through 50 cm diameter's circular waveguide.
- Power distribution near to the cryomodule remains essentially the same configuration.

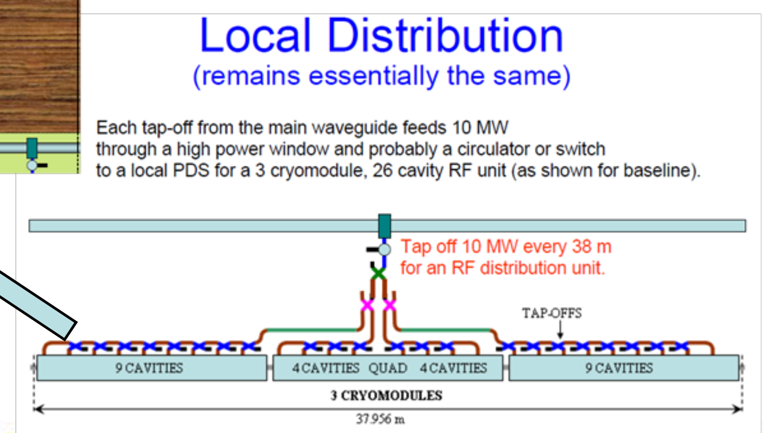




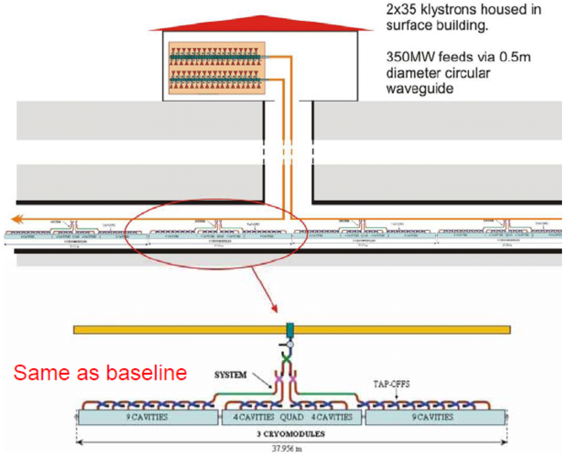
Difficulties

- Very High Transferred Power

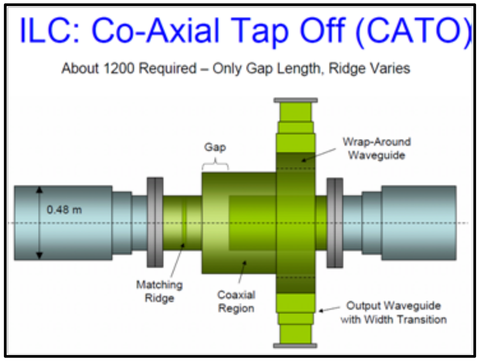
  (Circular Vacuum Pipe of 500 dia. and length of 1 k m)
- One unit to be examined is too large



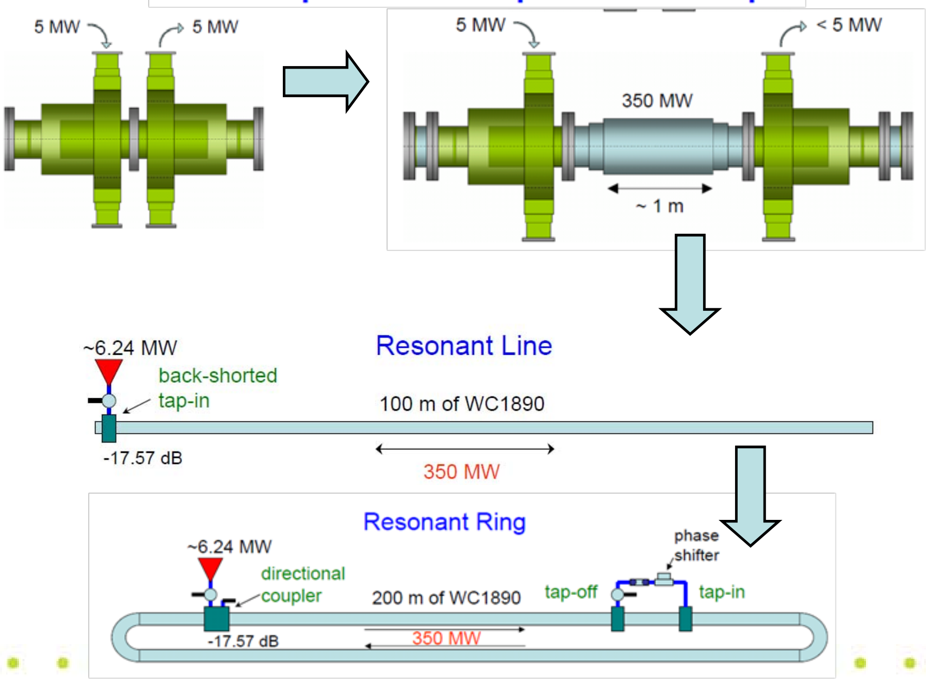
Klystron Cluster RF Distribution Scheme



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



Concept Development Steps



Summary

Surface klystron clusters can save ~ 300 M$ (~ 200 M$ from eliminating service tunnel and ~100 M$ from simpler power and cooling systems).

The GDE Executive Committee encourages R&D to pursue this idea.

The proposed CATO tap in/off design is likely to be robust breakdown-wise. Have a plan to demonstrate its performance, although with only 1/5 of the worst case ILC stored energy after shutoff.

Need to better study:

Waveguide fabrication and tolerances – too large to be drawn, but don't want seams (KEK working with industry on this).

Bend design – mode preserving; low-loss; support 350 MW, 1.6 ms; compact enough for tunnel

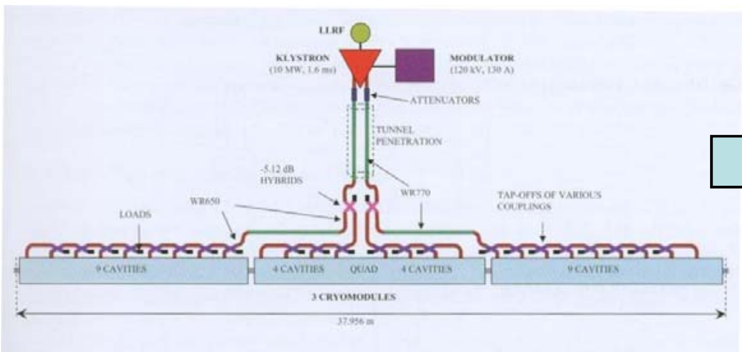
Impact on LLRF control, energy spread minimization, & efficiency.

Modifications to accelerator tunnel to accommodate waveguide plus other systems from tunnel systems.

DRFS and General Cost Consideration

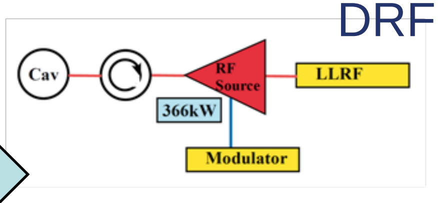
■**Distributed RF Scheme is a scheme that a klystron feeds power to small numbers of cavities. (one or two).**

If 1 RF Unit of BCD is replaced with a single cavity driver, 26 klystrons are required (totally 16900 tubes), and if a klystron drives two cavities, 13 klystrons are necessary (totally 8450 tubes). If cost of RF units are reduced significantly by mass production, there are lots of advantages comparing with the BCD.



BCD Scheme

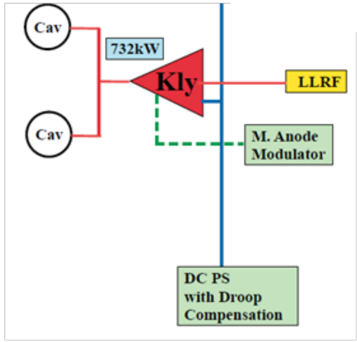
DRFS



One RF unit cost =

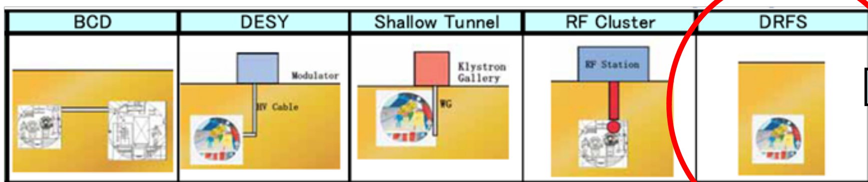
a BCD RF unit/26

= 45～50k$



One RF unit cost = a BCD RF unit /13
= 90 ～100k$
Two cavities feed -> no circulator
Modulating Anode Klystron makes Modulator cheaper.

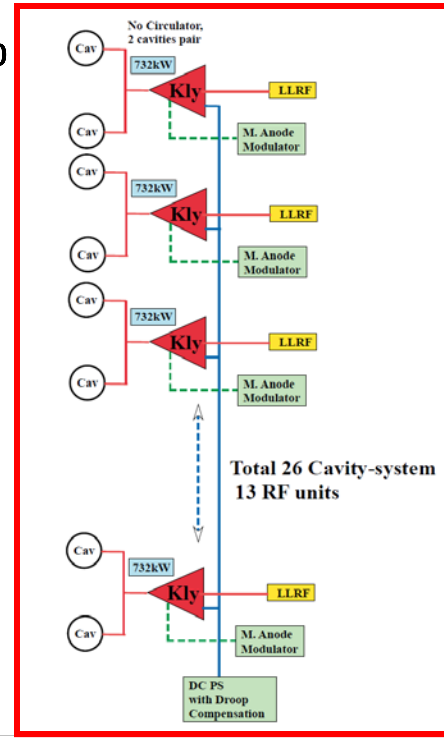
DRFS Current Design



One Klystron feeds power to two cavities.

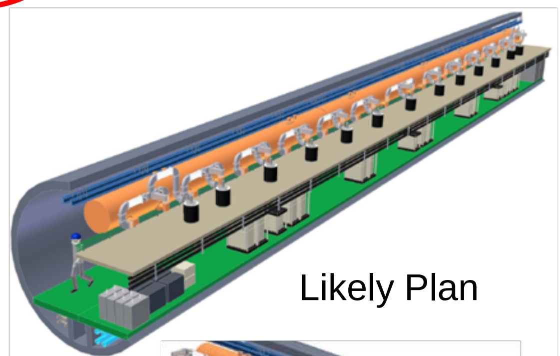
- MA Klystrons of 8450
- MA modulators of 8450
- DC P/Ss of 650

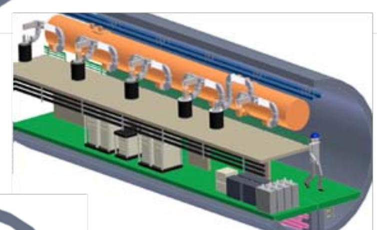
Cost estimates Under going

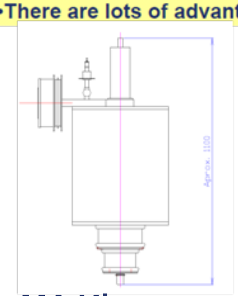


There are several merits in DRFS.

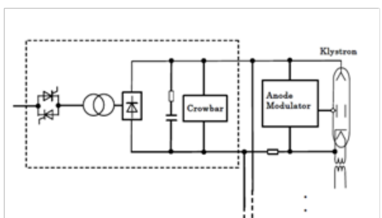
- Complete single tunnel scheme and simple configuration. (Cost benefit is expected)
- Klystron failure doesn't give a serious effect to beam operation since failures are scattered. (cf. BCD, RF Cluster)
- Adoption of MAK leads to the cheap HLRF system and introduction of power handling is possible for klystron.
- Direct connecting of about 60kV to klystron eliminates pulse transformer and use of huge insulation oil.
- LLRF control is easy and vector sum of 2 cavities are better than BCD plan.
- By coupling two cavities with same performance, circulators are possibly eliminated.
- There are lots of advantages for the operation and control.



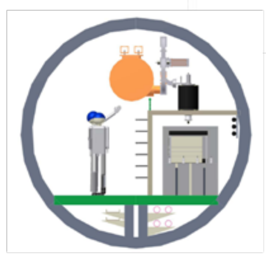


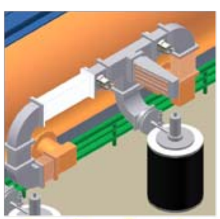


MA Klystron



Modulator Diagram





- Circulator elimination by power feeding to 2 cavities from one klystron. Output power is 732kW.
- Modulated Anode Klystron (MAK) is adopted.
- Anode modulation pulser does not need the high power and cost efficient pulser is manufactured.
- DC Power Supply is common for 26 cavities and voltage drop during the pulse is compensated with appropriate circuits at the level that LLRF can feed back.

Comparison of LLRF configurations

	Baseline	Single tunnel	Klystron cluster	Single driver
No. of tunnels	2	1	1	1
LLRF unit	Service tunnel	Beam tunnel	Beam tunnel	Beam tunnel
Cavity/ rf unit	26	26	780	1 or 2
No. of vector sum	26	26	780	1 or 2
Ql and power distribution control	Necessary	Necessary	Difficult	No need
No. of llrf cable /rf	~80	~80	~2,400	~3
Loop delay	~1 us	~1 us	~10 us	~0.3 us
Typical FB gain	~100	~100	~20	~1,000
Each cavity field flatness	Bad	Bad	Worse	Complete
Robustness	Good	Good	Not good	Better
Exception handling	Not easy	Not easy	Quite complicated	Easy

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Summary

- HLRF Status are summarized and reviewed.
- Solid Progress on all Fronts
  - New Modulator and RF Distribution Systems designs being tested
  - Good progress in 9mA FLASSH program and better understanding of cavity perturbations thought this results are not included in this presentation.

- There proposed a few single tunnel ADC in order to aim for the cost down.
  - Design effort for RF Cluster Scheme and DRFS are introduced in this presentation.