Proposal of Distributed RF-source Scheme (DRFS)

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- Introduction
- Consideration of the cost
- Possible RF-source
- Comparison with other configurations
- LLRF Issues
- Cooling Issues
- Summary

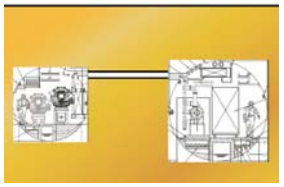
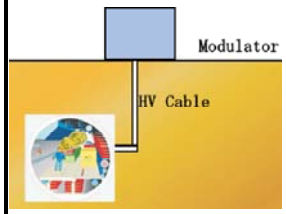
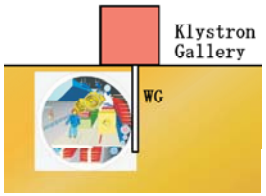
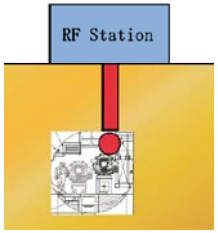
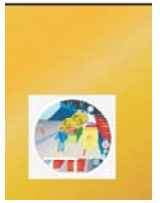
Currently proposed schemes and discussion

- BCD-2-tunnel scheme
  - Well accepted plan which has been discussed in GDE and basically good plan for Questionnaire
  - Cost cut-down is required
- Alternative scheme plan (at DUBNA)-Single tunnel
  - DESY type single tunnel scheme
  - Shallow tunnel scheme (DUBNA)
  - RF Cluster scheme

Proposal of Distributed RF-source Scheme (DRFS): an RF source feeds power to a cavity (Single cavity driver)

- Motivation
  - Currently various single tunnel schemes are discussed to cut down the cost of ILC and new scheme has another possible scheme.
  - Very simple configuration
  - Cost cut-down is expected for the large scale system such as ILC by the mass production.
  - Pros and cons should be discussed for making clear the feasibility of this plan.
- This scheme was discussed at Snowmass before but not adopted to ILC RF scheme.

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					

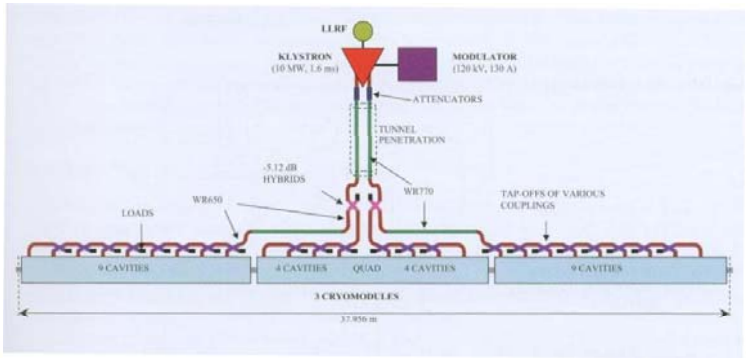
Cost(1): Cost balance between BCD and DRFS

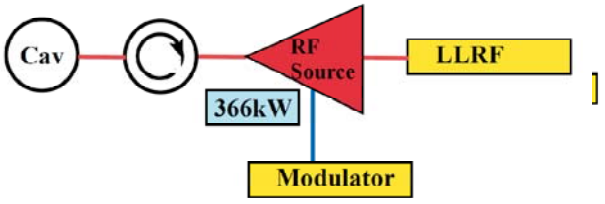
- Equivalent cost of 1 RF unit of DRFS against BCD
  1 Unit=26 cavities (of 650 Units)

RF Source	XXXk$
Modulator	XXXk$
PDS	XXXk$
Total	X,XXXk$

1 Cavity required power
=31.5MV/m*1.03m*9mA=293kW
Operation at 80% Saturation=366kW

→ 44.6k$/1 RF cavity





Total amount

X 26 X 650 =16900

RF Source Candidates

Candidate	Unit	IOT		Klystron	
Output Power	kW	366	△	366	◎
Current State of art		Max. pulsed IOT is 90kW.	△	Basically no technoligy limit.	◎
		Required the R&D/new technology		350 kW MBK	
		Harmonics IOT		--> Smaller, lower vaoltage and	
		Multi-beam IOT		higher efficiency	
Gain	dB	20 – 25	△	40 – 50	○
		Relatively hiigh drive power		Cheap driver	
Efficiency	%	70 – 80 (high)	◎	60 – 65 (high but less than IOT)	○
Focusing Solenoid		no	◎	required	△
Size		small		small but not less than IOT	
other remarks				possible to start immediately	◎

So far klystron is suitable for the RF source of DRFS. IOT's R&D are preferable.
Possible way to avoid using focusing solenoid is too use the permanent magnet.
It is necessary to consider the whole RF system to reduce the HLRF cost.

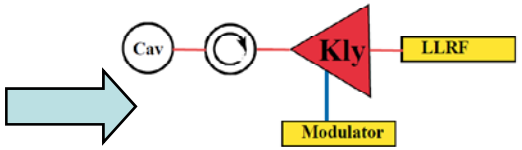
Cost(2): Possible variation and rough estimation

Cost balance between BCD and DRFS

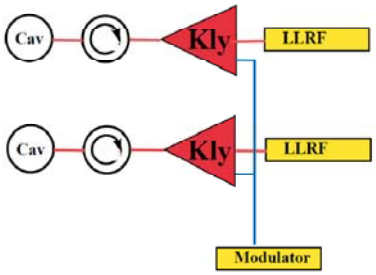
■ Equivalent cost of 1 Rf unit of DRFS against BCD

■For 1 RF unit of DRFS

RF Source 21.5k$
Kly solenoid 4.3k$
Circulator 3.4k$
Modulator 15.4k$(Too Cheap?)
Total 44.6k$

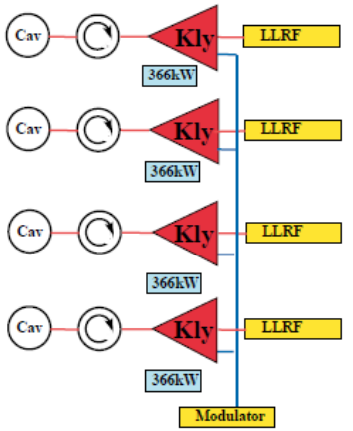


For 1 Modulator for 2 RF source
Modulator 30.8k$



For 1 Modulator for 4 RF source
Modulator 61.6k$

Smaller redundancy



Cost(3):

Unit Cost by the Mass Production of 16700 pieces.

- Model calculation using production learning curve
  - 366 kW MB Klystron :V=30kV, 4 beam klystron,60% efficiency
    Average rf power=3.1kW
  - 366 kW Single-bema klystron: V=47.3kV, uP=1.37, 55% efficeincy

R&D price 170k$, 1st Production 100k$
→ product of 16700, A=0.87 then 20.0k$ <21.5k$

- Modulator: Average power 4.4kVA, V out=30kV

R&D price 170k$, 1st Production 100k$
→ product of 22000, A=0.87 then 20.0k$ >15.4k$
2 klystron drive or 3 klystron drive is required if other module such as interlock, kly. Solenoid PS are included.

From this estimation, it is possible to manufacture the required devices in cheap price shown in the previous slide.

Criticism: Reliability for the learning curve. Is it OK to use learning curve from the 1st production? At least we need the actual price of manufactured device.
Use MBK results in higher cost and we should use a single beam klystron.
(certain tube vendor's cost estimation is conservative and tentative but 4 time's higher than our value.)

Cost(4):

Variation (I)

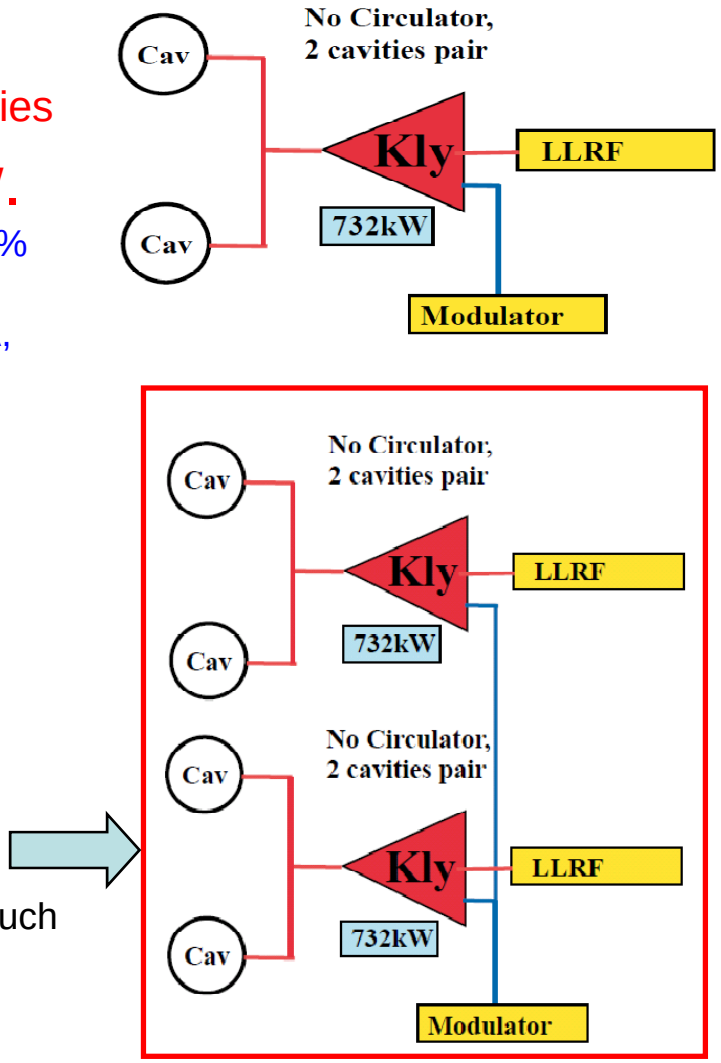
- Circulator elimination by power feeding to 2 cavities from one klystron. Output power is 732kW.
  - 732 kW MB Klystron :V=30kV, 8 beam klystron,60% efficiency.
  - 732 kW Single beam Klystron : V=62.4kV, I=21.3A, uP=1.37, 55% efficiency (Similar with J-Parc Kly).

R&D price 170k$, 1st Production 100k$
→ product of 8350, A=0.87
then 17.4k$ <21.5k$*2=43k$

- Modulator: Average power 4.4kVA, V out=30kV

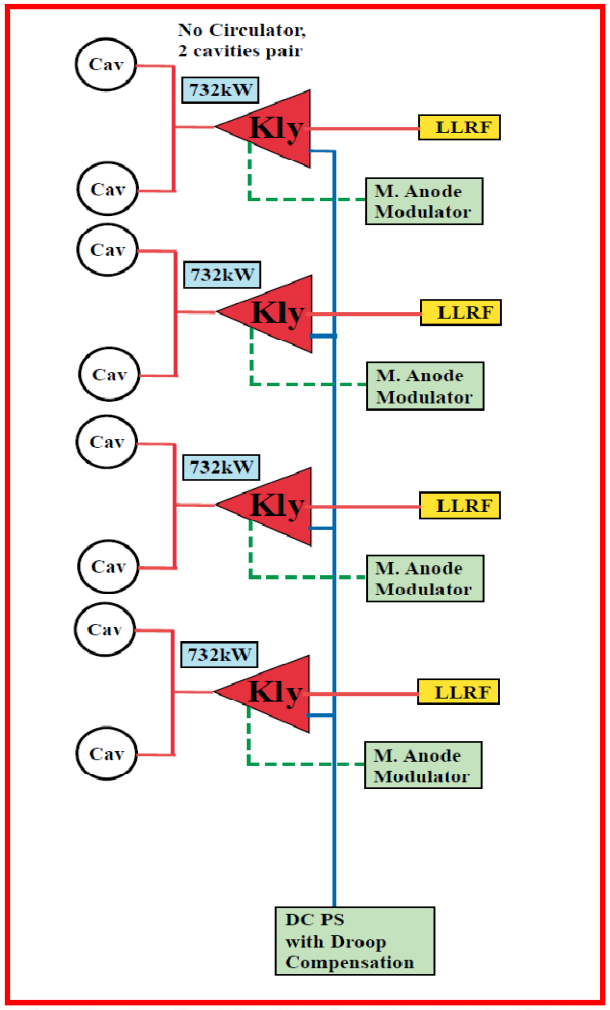
R&D price 170k$, 1st Production 100k$
→ product of 8350, A=0.87
then 17.4k$ >15.4k$*2=43k$

2 klystron drive to 4 klystron drive by a single modulator is more cheaper and other modules such as interlock, kly. solenoid PS are affordable.



Cost(5): Variation (II): Most cost effective method

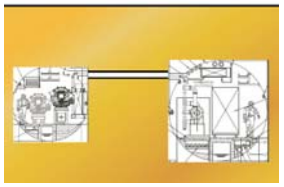
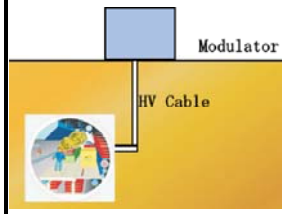
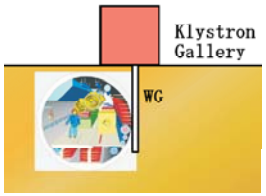
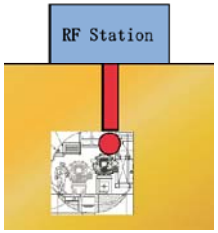
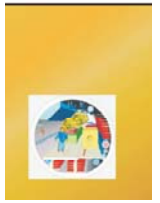
- Circulator elimination by power feeding to 2 cavities from one klystron. Output power is 732kW.
- Modulated Anode Klystron (MAK) is adopted.
- Anode modulation pulser does not need the high power and cost efficient pulser is manufactured.
- DC Power Supply is common for 26 cavities and voltage drop during the pulse is compensated with appropriate circuits at the level that LLRF can feed back.
  - It is easy to suppress the collector power dissipation without rf in MAK by adjusting the modulated anode voltage.
  - Are Disconnection SWs necessary?



Cost (6)
Total balance

- Previous slides present the cost balance of HLRF cost among the BCD/other schemes and DRFS.
- While, if the total ILC cost are reduced from BCD/other schemes, other cost saving fractions can be included to the HLRF cost.
  - **In DRFS, there are no HLRF facilities in the surface, and cost saving of them are expected.**
  - **CFS group may clarify the detailed cost saving among the various scheme.**

BCD and alternative scheme proposed

	BCD	DESY	Shallow Tunnel	RF Cluster	DRFS
Scheme					
Deep/Shallow					Deep
Civil Cost					Cheep
Cooling Cost					○
Heat source				f RF ce	Heat source of RF in the tunnel
Site Dependence				G	OK
LLRF handling					◎
Vector Sum	2			tor	1 to 1
Redundancy					◎
Kly Failure Impact				on	Scattered failure section
Other Issues				WG	Very Simple Configuration
R&D Cost					◎
Test Facility				luate unit	Very small system
Total Cost					

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.**

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

LLRF Summary (By Shin Michizono)

LLRF performance

- shorter latency results in higher FB gain (robustness)
- higher FB operation (aiming the FB gain of ~1000)

Operability

-simpler cavity control (flat field obtainable near below quench without worrying about Ql and P control scheme)

- LLRF diagnostics become possible even during luminosity operation.

HA/Robustness

- higher availability owing to the flexible selection of stand-by cavity

Exception handling

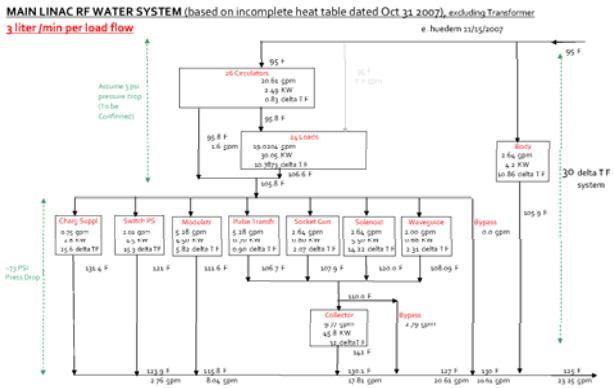
- No need for fast recovery (because each unit has small energy contribution)

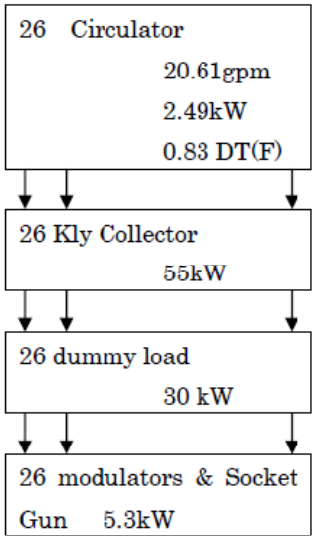
Other advantages/disadvantages

- Reduce the length of rf cables (less cost, less phase rotation)
- Omit fast optical link between llrf board (for vector sum)
- Omit phase-shifter, tunable coupler in waveguide and cavity
- Need IQ modulator (in each rf unit) (but the devise is cheap)

Cooling Issues and cost comparison between various schemes

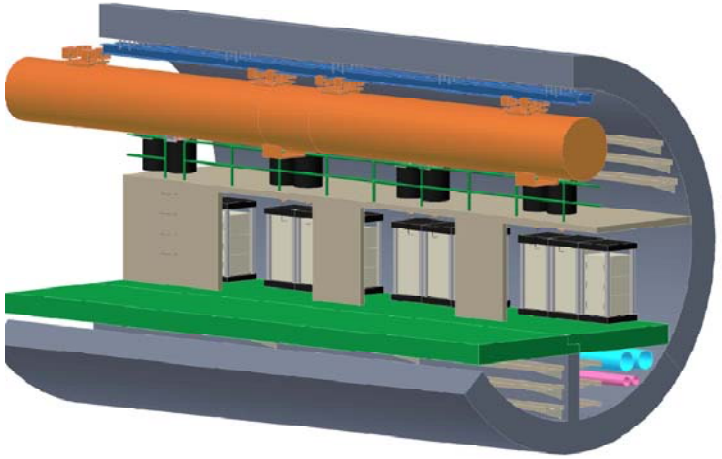
- From the comparison table, heat load of DRFS is equivalent with BCD, since all heat sources are in the tunnel. There are no advantages for cooling problem.
- Each klystron heat loss is small and system becomes very simple. No pulse transformer, simple waveguide system, solenoid is possibly eliminated. 26 tandem cooling channels are possible.

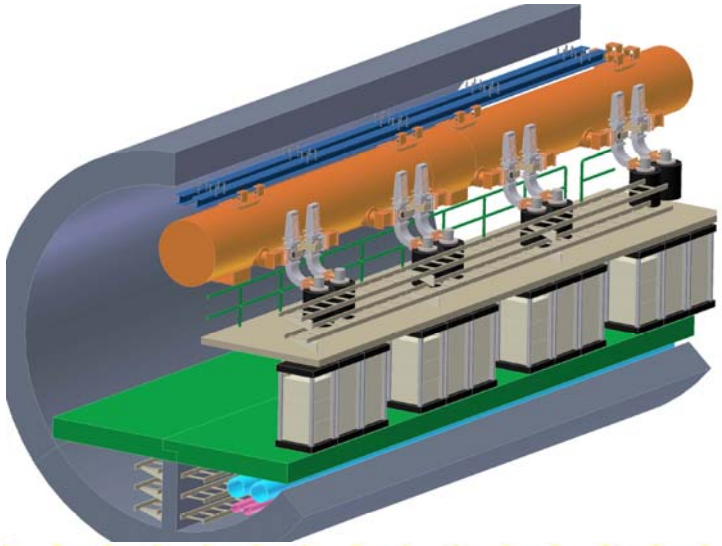


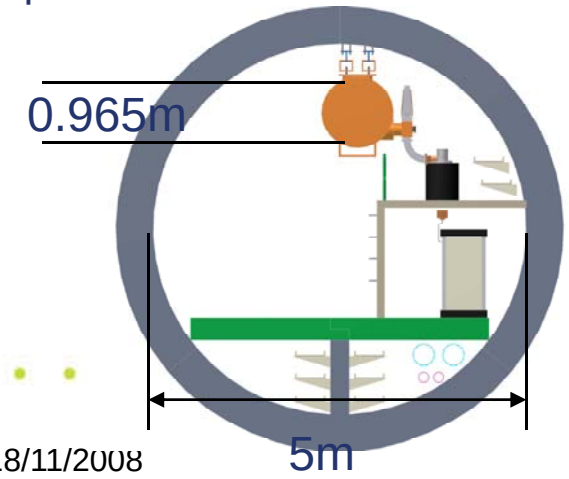


Rough Sketch for DRFS

- Single tunnel layout. 5m diameter (like DESY)
- Cryomodule is hanged down from the top of the tunnel.
- RF sources are connected thru circulator, but plan without circulator is possible and discussed.
- In this drawing, a modulator applies the voltage to two RF source. Working space are considered as shown in the drawing.
- Modulators, LLRF units and other electrical devices are installed in the shielding tunnel.
- There is a choice that the DC power supplies or chargers are concentrated for 4 or 8 units or more.
- Layout of using a modulated anode klystron is possible.







Is DRFS worth value to consider seriously?

- Scheme of distributed RF system (a single RF driver to a cavity) is shown and compared with the other schemes.
- Total cost of HLRF of DRFS is possibly set to be roughly equal to the cost of other schemes such as BCD, but saving the cost from other category like civil cost is expected.
- There are lot of advantages for DRFS. They are as follows;
  - **Single tunnel scheme**
  - **Very simple configuration**
  - **LLRF control is easy and operation with optimized cavity characteristics is available**
  - **HLRF failures or cavity quenching are not serious if their probability is usual level, and maintenance at the shut down period is enough to keep the accelerator in the good condition.**
- There is an ambiguity for the cost of cooling cost.
- Serious discussion and consideration are expected to be performed.
- Further detailed cost analysis will be provided.