Distributed RF-source Scheme (DRFS) First Design

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- Introduction
- Possible RF-source
- General Cost Consideration
- Klystron Design Consideration
- Modulator Design Consideration
- Power Distribution
- Sketch of DRFS
- 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
  - Distributed RF Scheme (at LCWS08@Chicago)

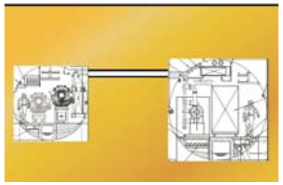
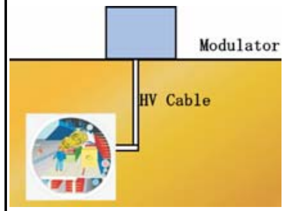
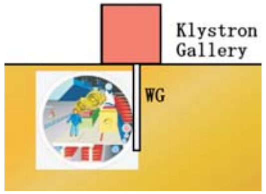
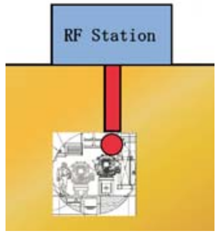
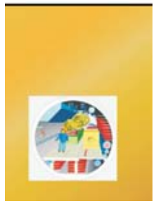
Distributed RF-source Scheme (DRFS):

an RF source feeds power to a few cavities

- 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 and simple control
  - Cost cut-down is expected for the large scale system such as ILC by the mass production.
  - Historically this scheme was discussed at Snowmass before but not adopted to ILC RF scheme.
  - After LCWS08, modeling of DRFS has been studied.

Comparison with other 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					

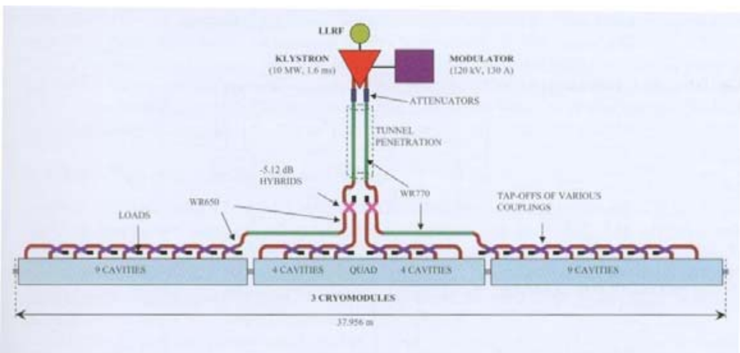
General Cost Consideration(1): Cost balance between BCD and DRFS

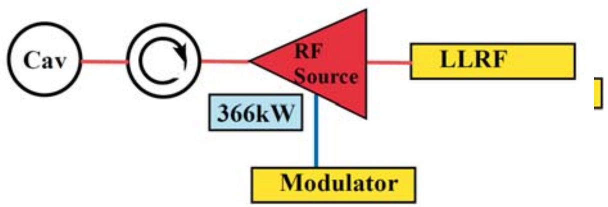
- Equivalent cost of 1 RF unit of DRFS against BCD
  1 Unit=26 cavities (of 650 Units)

RF Source	300k$
Modulator	515k$
PDS	345k$
Total	1,160k$

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

→ **44.6k$/1 RF cavity**



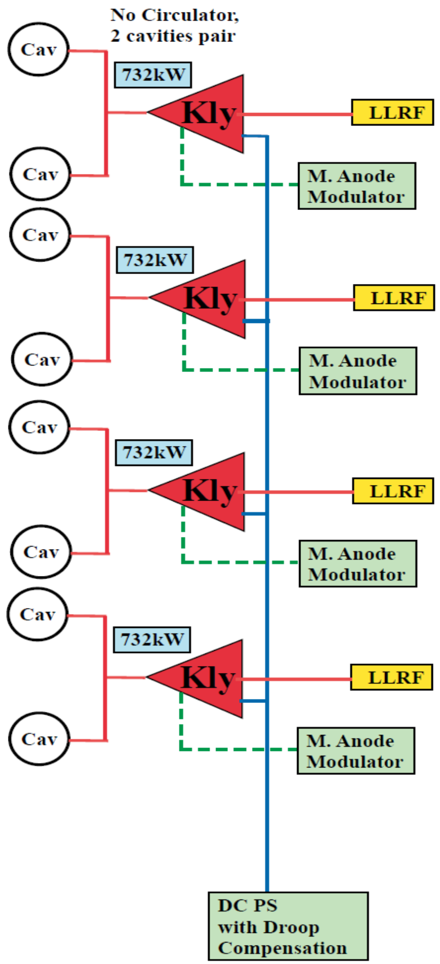


Total amount

X 26 X 650 =16900

General Cost Consideration(2): Most Likely Plan for DRFS

- 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.
- Total Number of MA-Klystron=8000
- Total Number of M. Anode Modulator=8000
- Total Number of DC PS =650



General Cost Consideration(3): Balanced Cost between DRFS and BCD

BCD

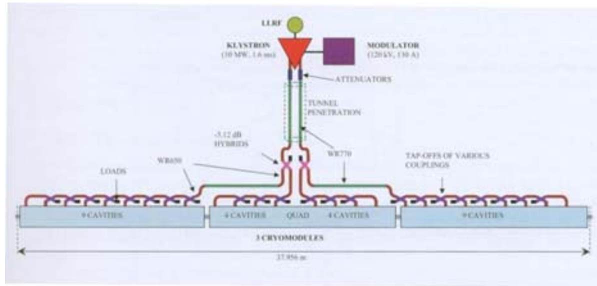
RF Source 300k$ (for 26Cavities)
Modulator 515k$
PDS 345k$
Total 1,160k$

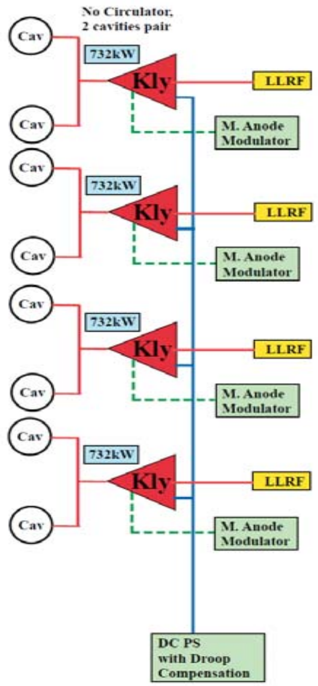
DRFS

Cost for 1 klystron unit =1,160/13 = 89.23k$

"Target Cost"

Since DRFS is a complete single tunnel plan and extra contribution to RF source is expected by a simple CFS.



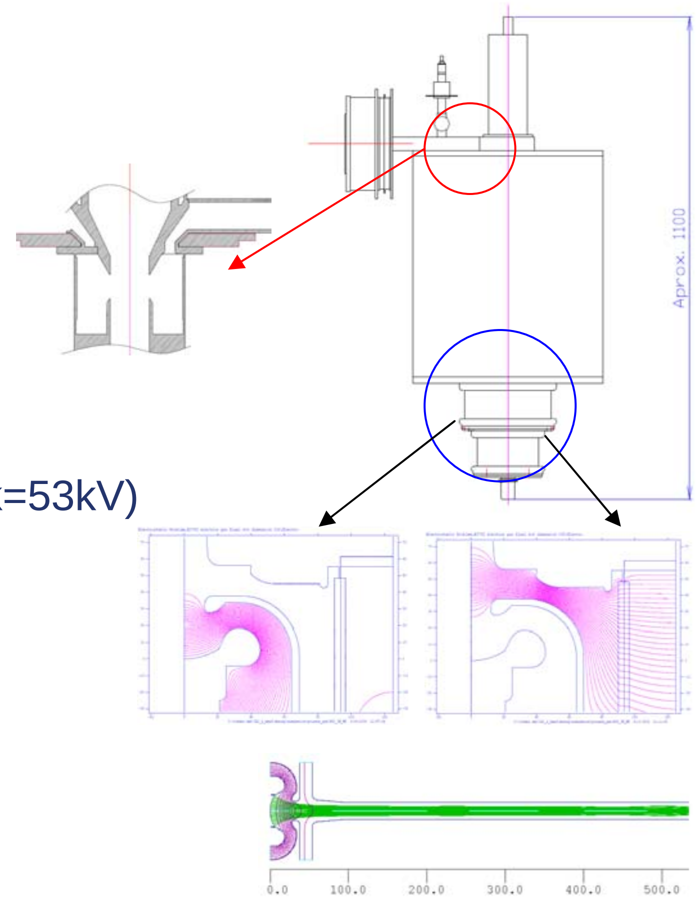


X 13

Klystron Design for DRFS

Design Parameters

• Frequency	1300MHz
• Output Power	750kW
• RF pulse width	1.565ms
• Beam pulse width	1.7ms
• Average RF power	6kW
• Peak beam voltage	62kV
• Peak beam current	21A
• Beam Perveance	1.36mP(@62kV)
• Gun Perveance	1.735mP (@Ea-k=53kV)
• DC Gun Voltage(A-B)	>64kV
• Tetrode MA-type	
• Electromagnetic Focusing	
• Water cooling	
• Total length	1.1m
• Weight	70kg

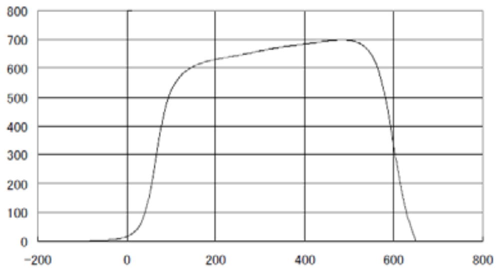


Design Results and Remarks

- Cavity Numbers 6
- Higher harmonics cavity yes
- Efficiency 60%
- Input power @ saturation <40W
- Electric field 54.7kV/m(A-K)
- Electric field 63.1kV/m(A-B)
- Cathode Loading 2.1A/cm^2
- Focusing Magnetic Field:

  Magnet is completely axial symmetric

20A, 80V



Cost Consideration for the MAK

In order to manufacture cheaply, cost cut-down efforts as follows are required.

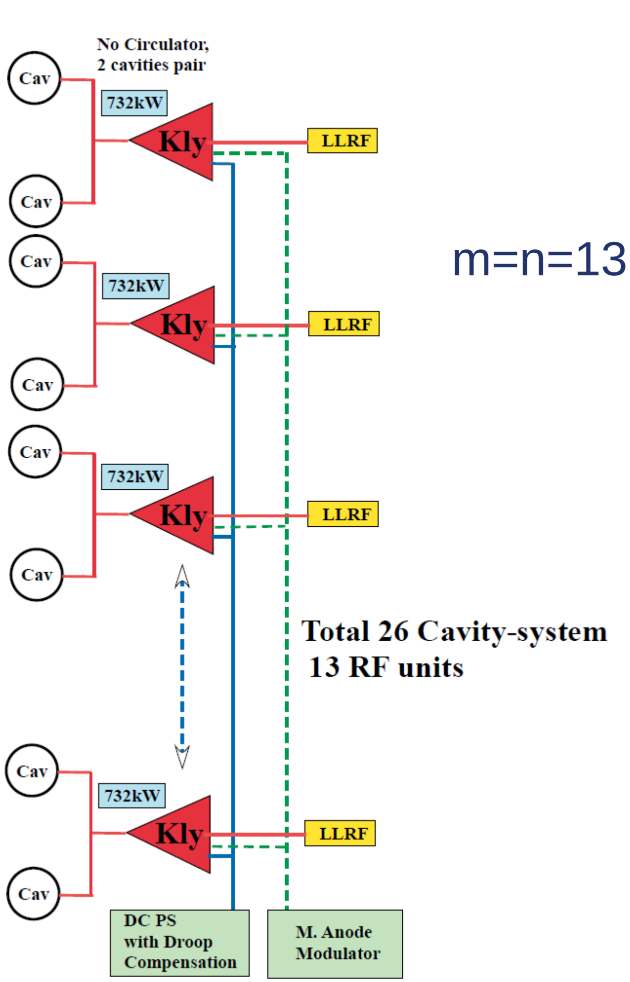
- 9000 tubes are manufactured during the 5 years (1,800/year) and 400/year manufacturing is follows as the maintenance.
- Company proceeds up to the tube baking. (Company needs to invest the baking and brazing furnaces)
- Tube processing is performed at the ILC site utilizing the ILC modulator.
- Common parts of the tube : employing hydro-forming
- Cavity tuning: auto tuning introducing the tuning machine
- No ion pump: getter in the tube
- No lead shield in the tunnel of the ILC
- Gun insulation ceramic is operated in the air. Corrugated ceramic to make a longer insulation length is considered.
- Focusing magnet is relatively high cost, and we need to look for the cheapest manufacturer in the world. Since it is completely axial –symmetric, lathe machine and auto winder in the simple manufacturing way is expected.

Modulator Design

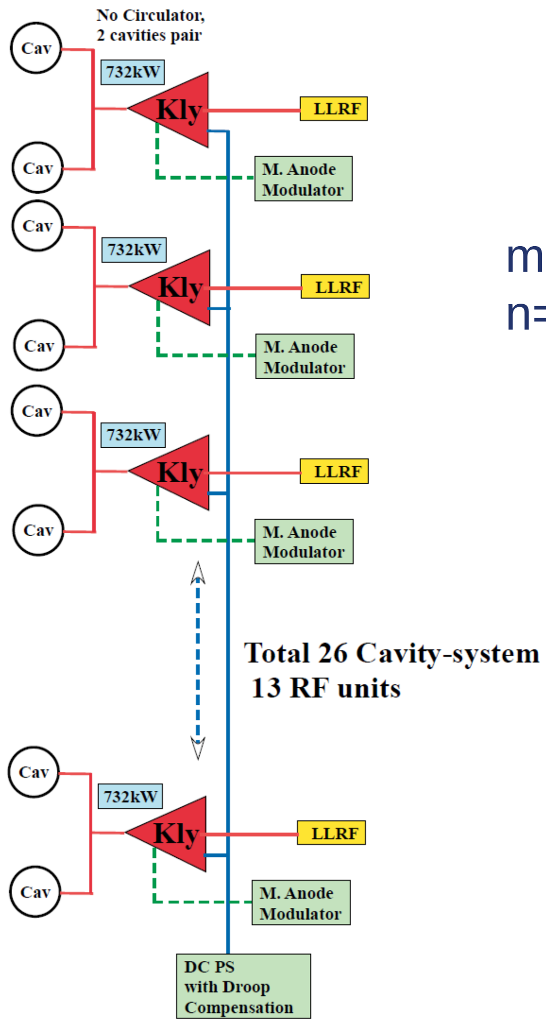
Key Features of Modulator Consideration in DRFS

- One RF unit feeds power to 2 cavities.
- Modulated Anode Klystron is driven by DC power supply and modulated anode pulser.
- DC power supply feeds the voltage and current to “m” RF units. If m=13, this scheme corresponds to BCD one unit.
- Modulated anode pulser gives the modulation pulse to “n” RF units. If n=1, an individual RF unit are driven by a M-A pulser. If n is not 1, it is necessary to check the total stray inductance and capacitance to affect the pulse trangent phenomena.
- Cost is strongly depended on the choice of m and n.

Modulator Design(2)



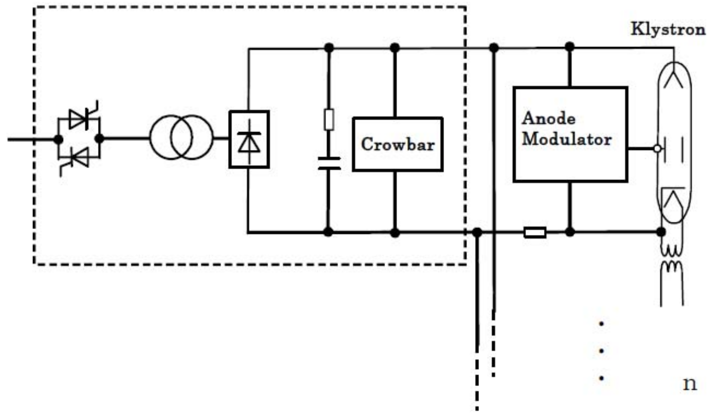
m=n=13



m=13
n=1

Tentative Cost Study

- Case of m=13, n=1



- DC Power supply comprises of AC thyristor, step-up transformer, rectifier diodes, capacitors and crowbar circuit. *(Is it possible to eliminate the crowbar?)*
- Each unit needs a disconnection switch, an M anode pulser, a filament power supply, a focusing magnet P/S and an IP P/S.
- Key points is how cheap the M anode pulser is designed and manufactured.
- Another issue is to eliminate IP power supply by employing the getter in the tube.
- Very simple filament power supplies. 13 tubes are driven by common filament P/S.
- *Focusing magnet P/S??*
- Eliminate the disconnection SW, which is related with the system redundancies.
- Very simple control system such as a PLC in one DC P/S.

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

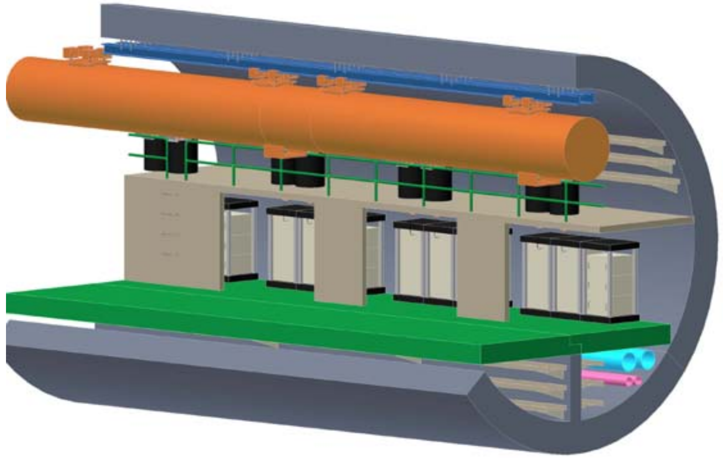
- No need for fast recovery (because each unit has small energy contribution)

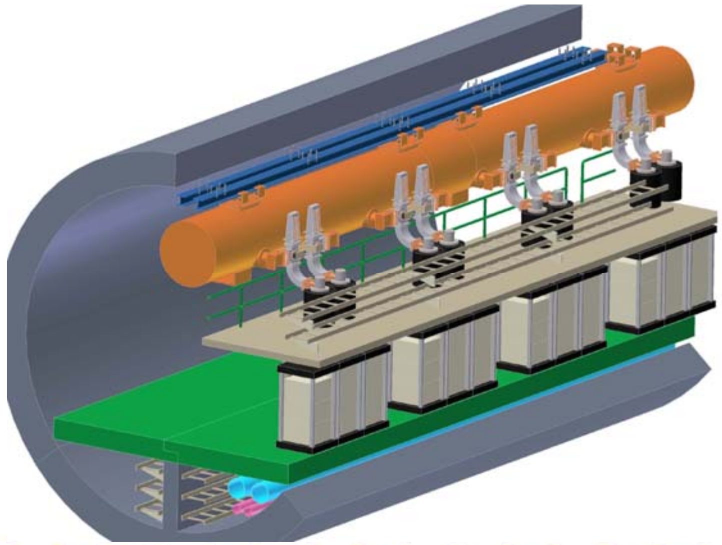
Other advantages/disadvantages

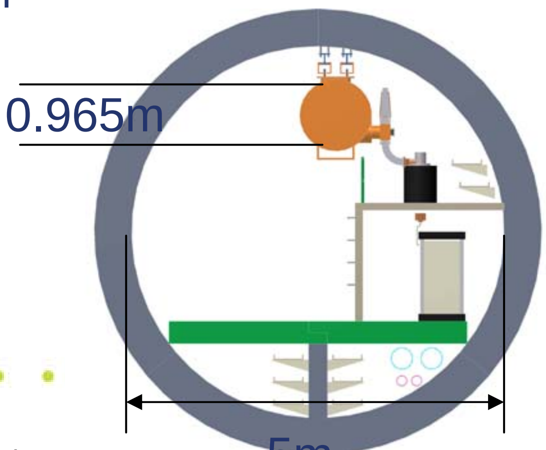
- Reduce the length of rf cables (less cost, less phase rotation)
- Omit fast optical link between llrf board (for vector sum)
- Omit phase-shifter, tunable coupler in waveguide and cavity
- Need IQ modulator (in each rf unit) (but the devise is cheap)

Rough Sketch for DRFS

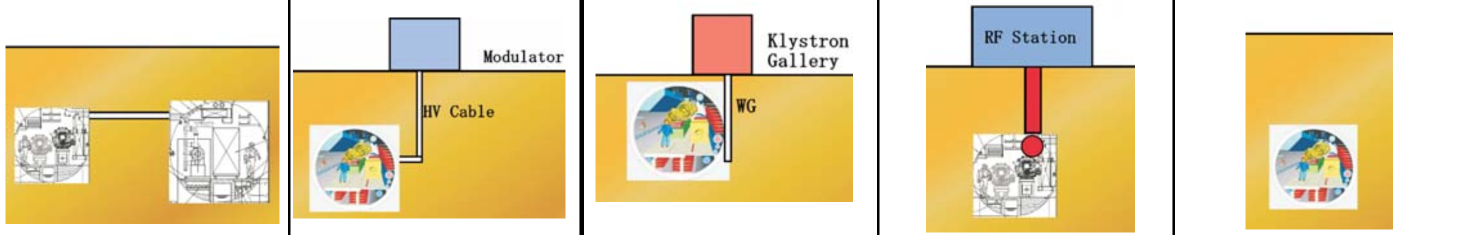
- Single tunnel layout. 5m diameter (like DESY)
- Cryomodule is hanged down from the top of the tunnel.
- RF sources are connected thru circulator, but plan without circulator is possible and discussed.
- In this drawing, a modulator applies the voltage to two RF source. Working space are considered 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.







BCD and alternative scheme proposed



	BCD	DESY	Shallow Tunnel	RF Cluster	DRFS
Scheme					
Deep/Shallow					Deep
Civil Cost					Cheep
Cooling Cost					○
Heat source	H			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.**

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.