Cryogenic System of the ILC Central Region in a Japanese Mountain Site

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Central Region

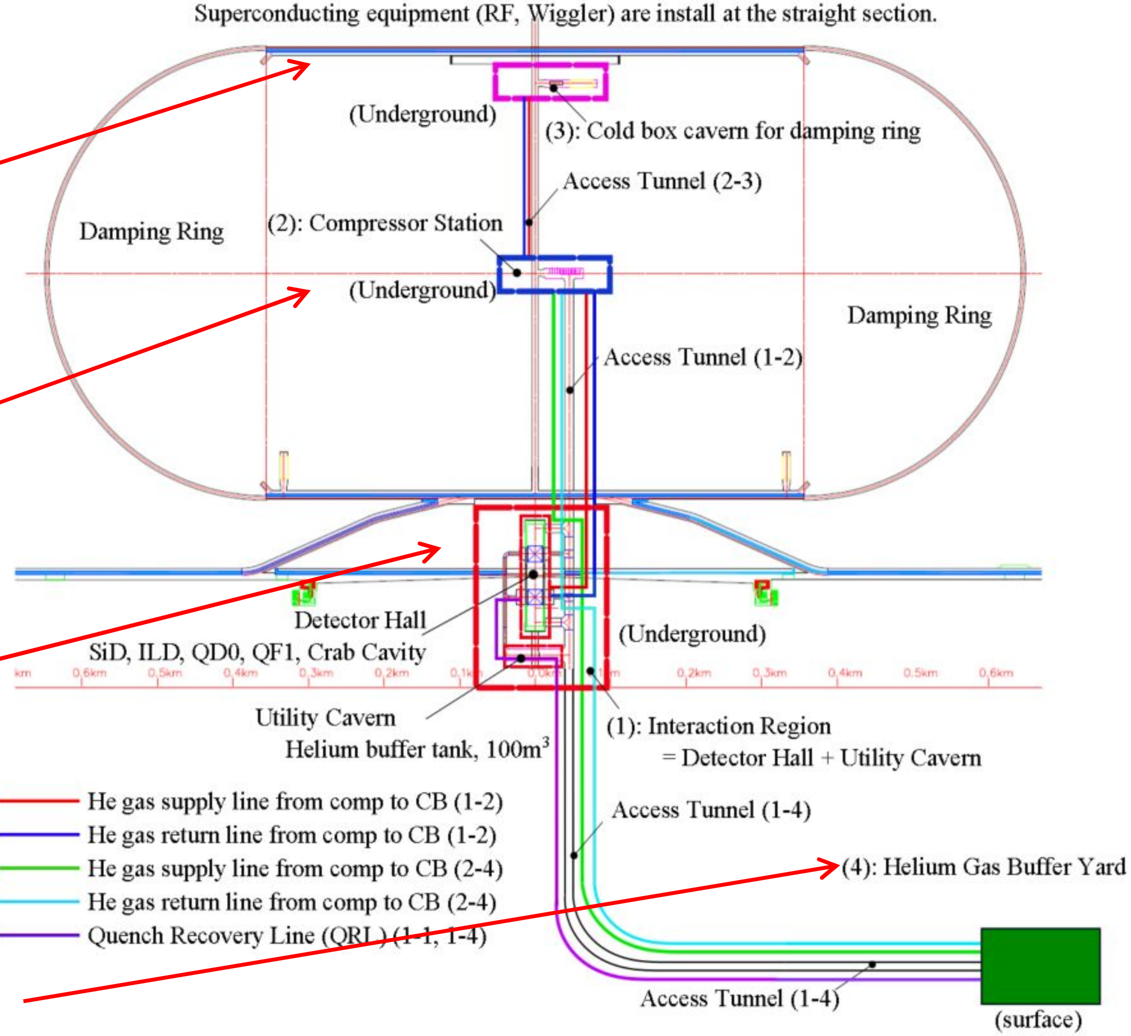
Central region is mainly composed of four sections from the cryogenics point of view.

3. Damping ring section (underground)

2. Compressor station (underground)

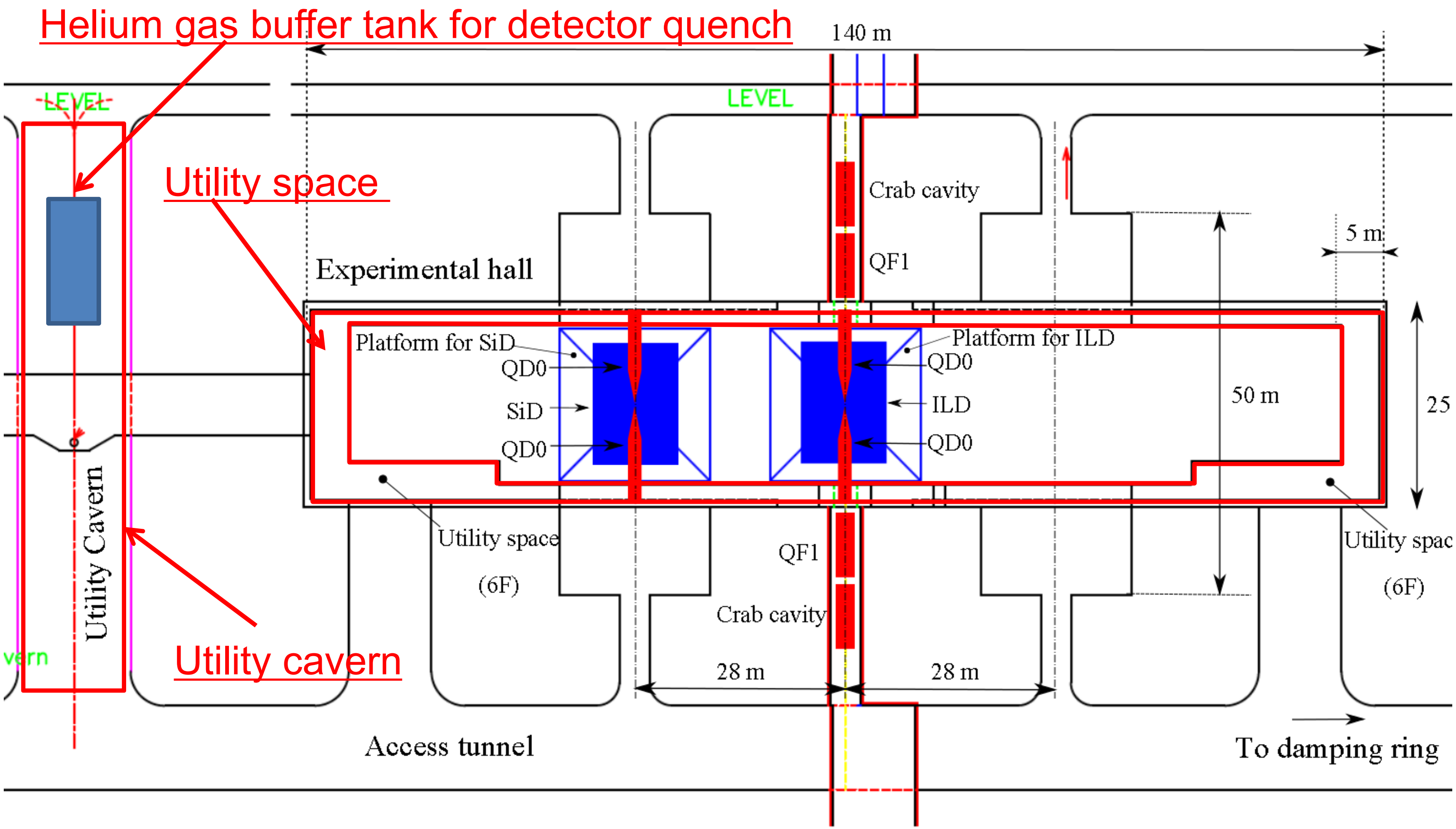
1. IR region (underground)

4. Helium gas storage yard (surface or underground)



Baby sitter type helium storage (Liquid heium storage method) is now considered.

Cryogenic Equipment in IR



- Push-pull operation will be applied to two detectors (SiD, ILD)
- QD0s are installed in both detectors. (move with detector)
- QF1 and CC are installed in the accelerator tunnel (do not move with detector)

Cooling conditions

Todays presentation is focused on cryogenics for detectors and QD0.

Equipment	T_{cool}	T_{shield}	Coolant	P_{inlet}
SiD	4.5 K	70 K	2pHe (Two phase cooling)	150 kPa-abs
ILD	4.5 K	70 K	2pHe (Two phase cooling)	150 kPa-abs
QD0	1.8-1.9 K	4K &70 K	pressurized HeII (105 kPa)	110 kPa-abs
QF1	1.8-1.9 K	4K &70 K	pressurized HeII (105 kPa)	110 kPa-abs
Crab cavity	1.8-1.9 K	4K &70 K	saturated HeII	1.68 kPa-abs
Damping ring	4.5 K	4K, 70 K	supercritical He (400 kPa)	

equipment	heat Load / cold mass
SiD	800 W / 130 ton at 4.5 K
ILD	800 W / 165 ton at 4.5 K
QD0	15 W / * ton at 1.8 K,
QF1	15 W / * ton at 1.8 K,
Crab cavity	20 W / * ton
Damping ring	

How to cool down ?

•**Three cold boxes** will be installed in experimental hall to cool down all superconducting equipment (detectors, QD0, QF1, CC).

–**One for CC + QF1 → Conventional Cryogenics**
CC and QF1 don't move with detectors.

–**One for ILD + QD0**
–**One for SiD + QD0**

→ Some technical difficulties because of following two reasons.

1. Push-pull Operation
2. Vibration problem for final focusing magnet,QD0.

Allowable vibration level is 50 nm within the 1 msec long ILC bunch train

Todays Talk is about cryogenic system for Detectors and QD0.

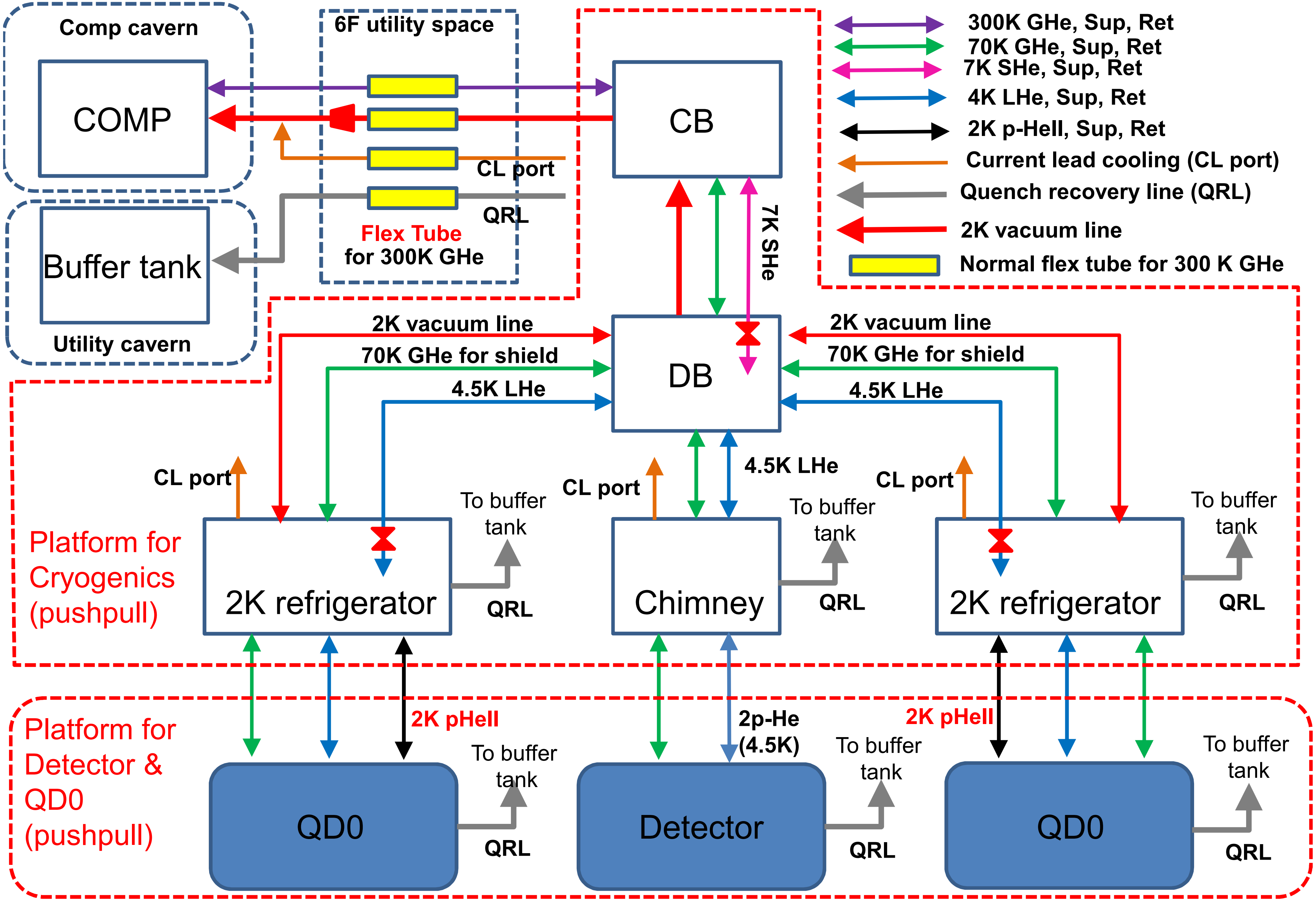
Cryogenic System for push-pull

- Two cryogenic options for cooling down the detector and QD0 are proposed.

  – Option A : Cold box moves with detector.

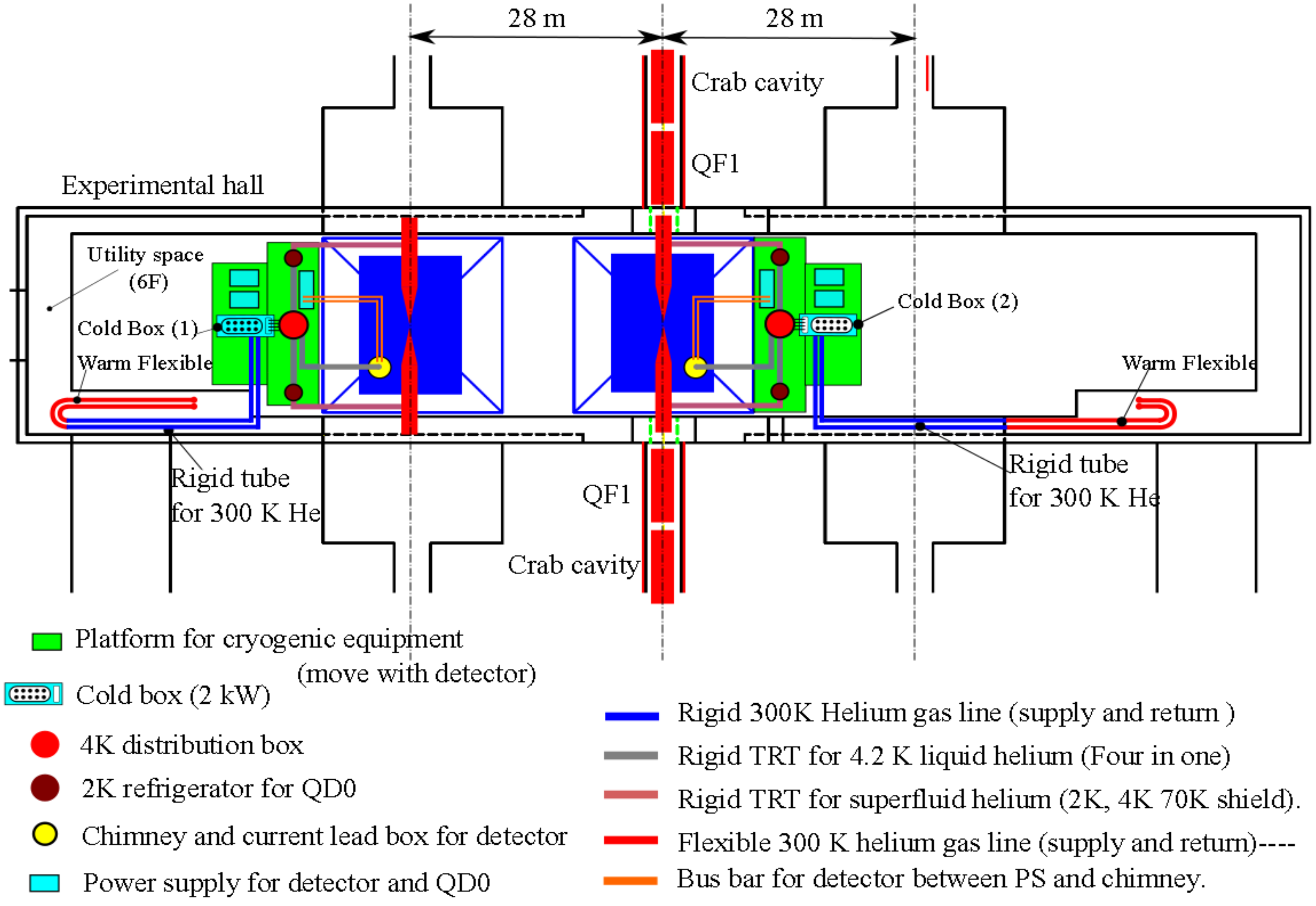
  – Option B : Cold box doesn' t move with detector.

Cryo & vacuum Block Diagram of Option A

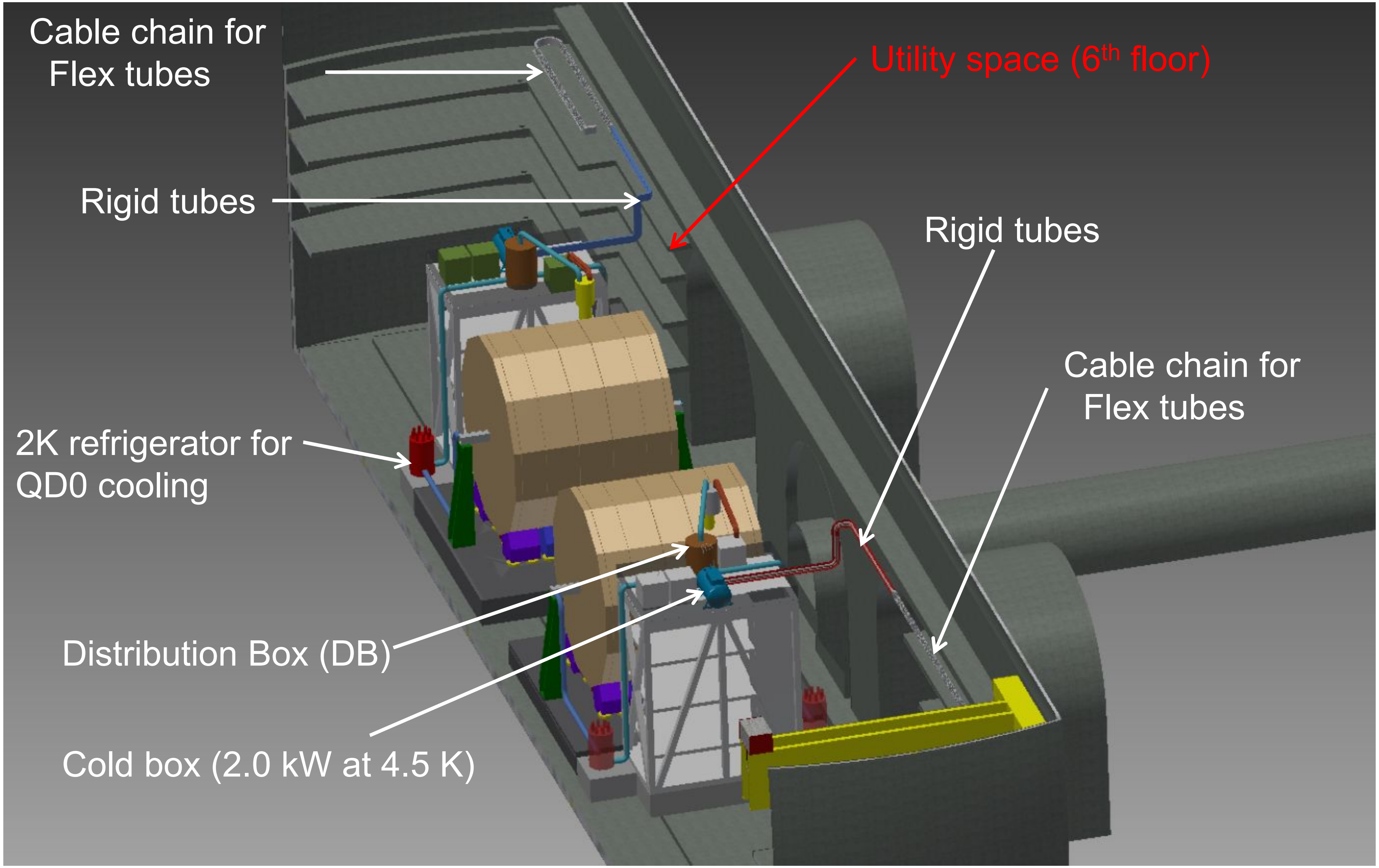


Option A (2D top-view)

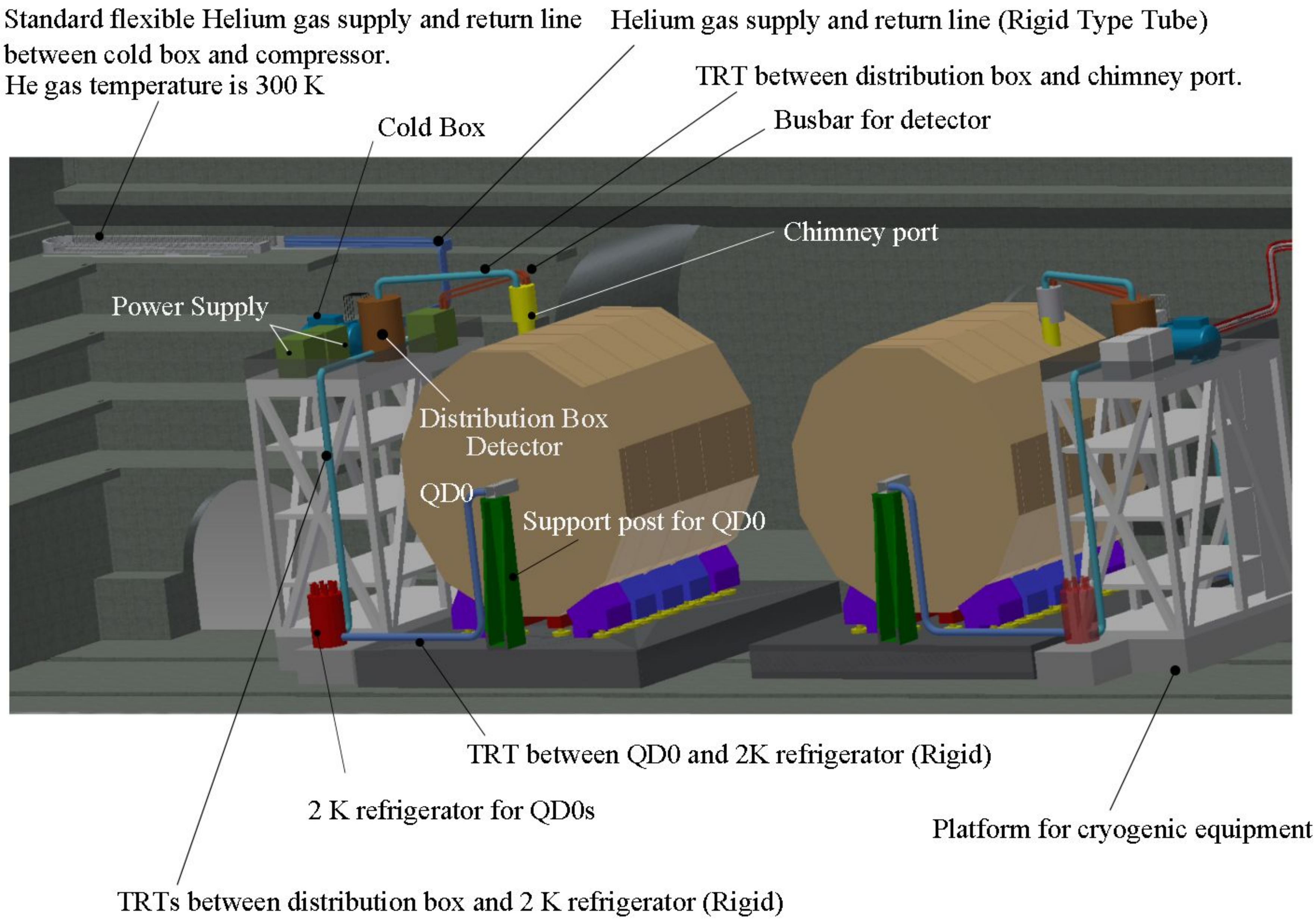
- **CBs are installed on a platform for cryogenic equipment (green area).**
- **Standard Flexible tubes for helium gas line, CL cooling line, 2K vacuum line and quench recovery line should be employed for push-pull.**



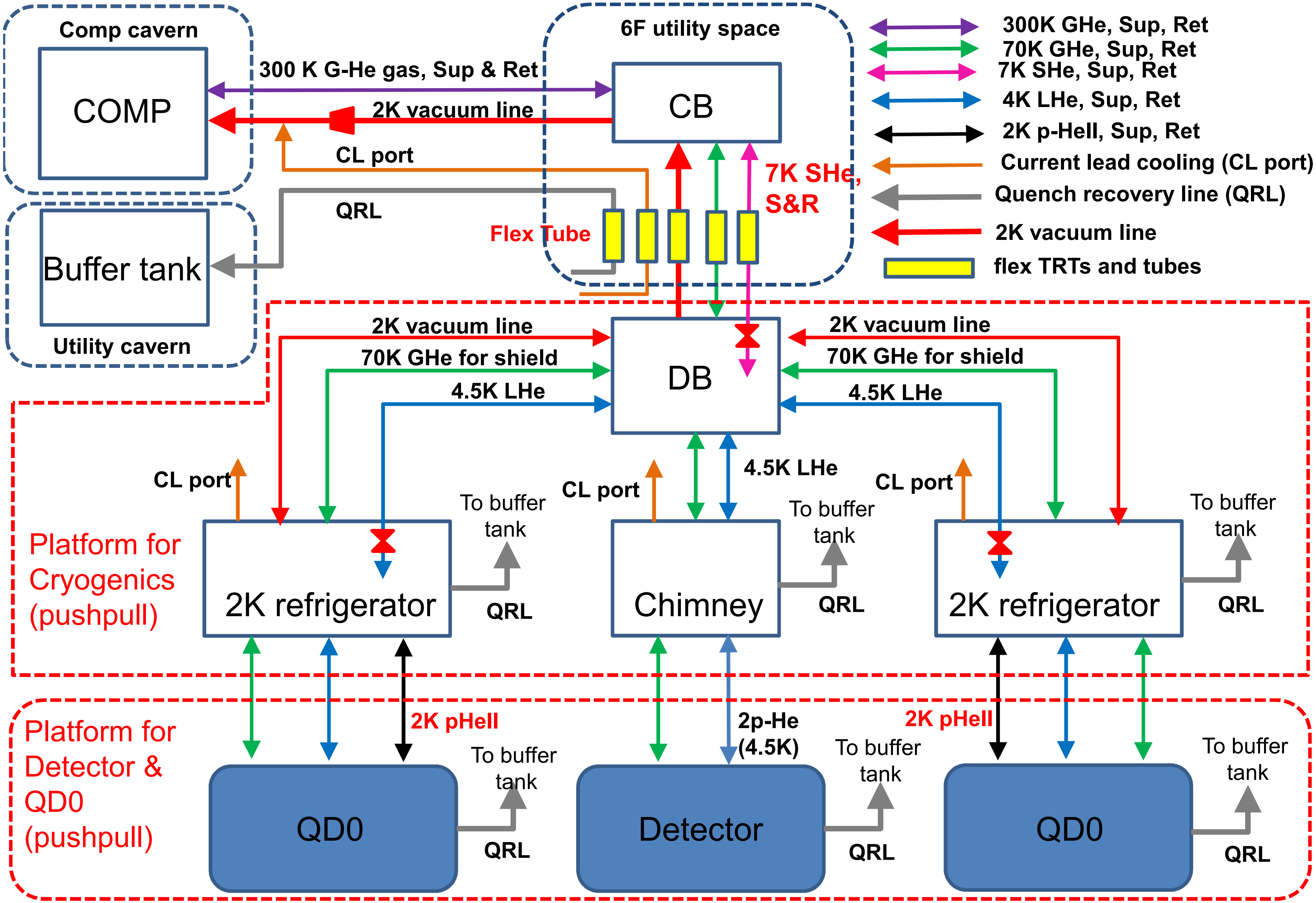
Option A (3D view of experimental hall)



Option A (Side view)

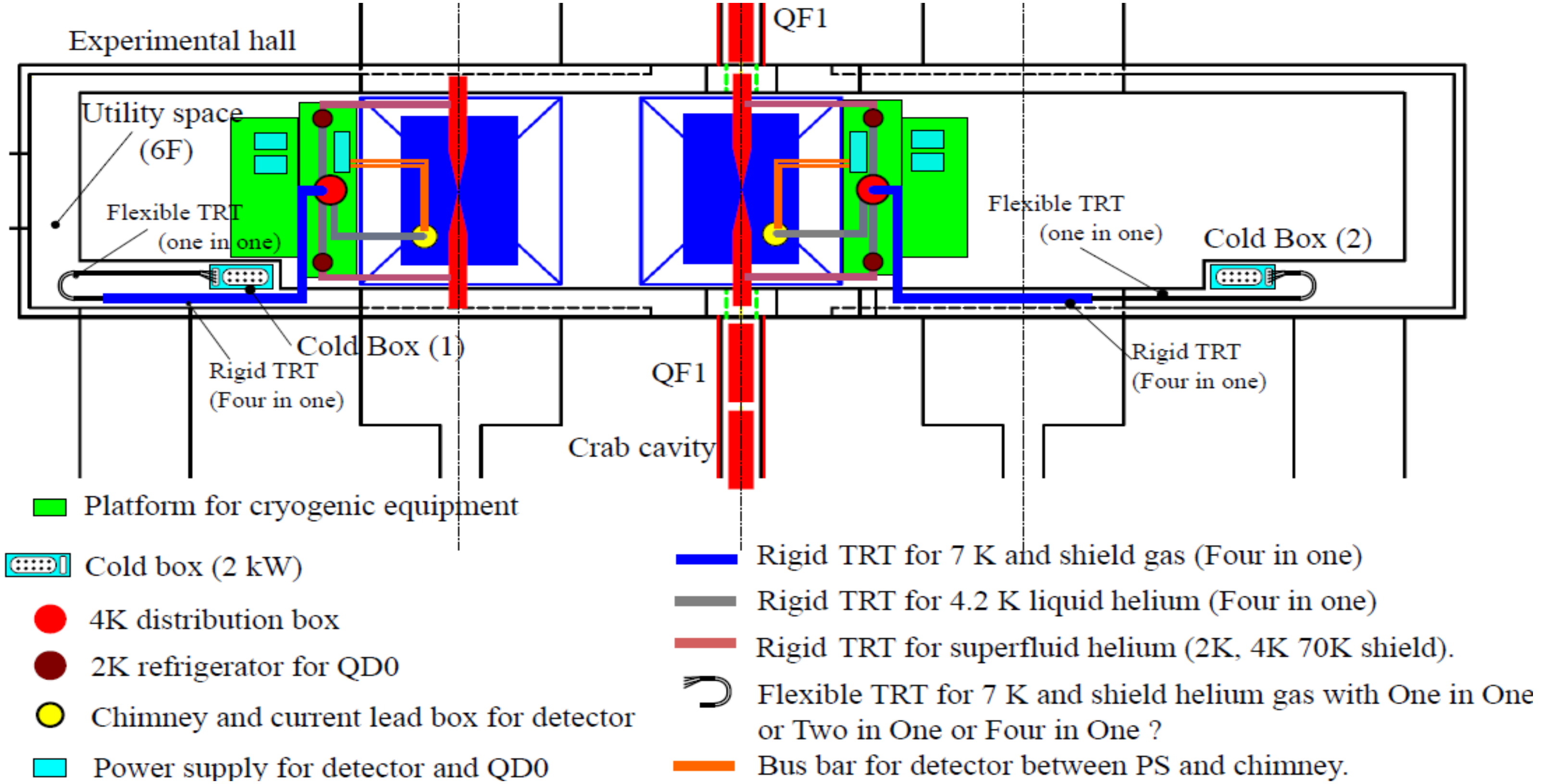


Cryo & Vacuum Block Diagram of Option B

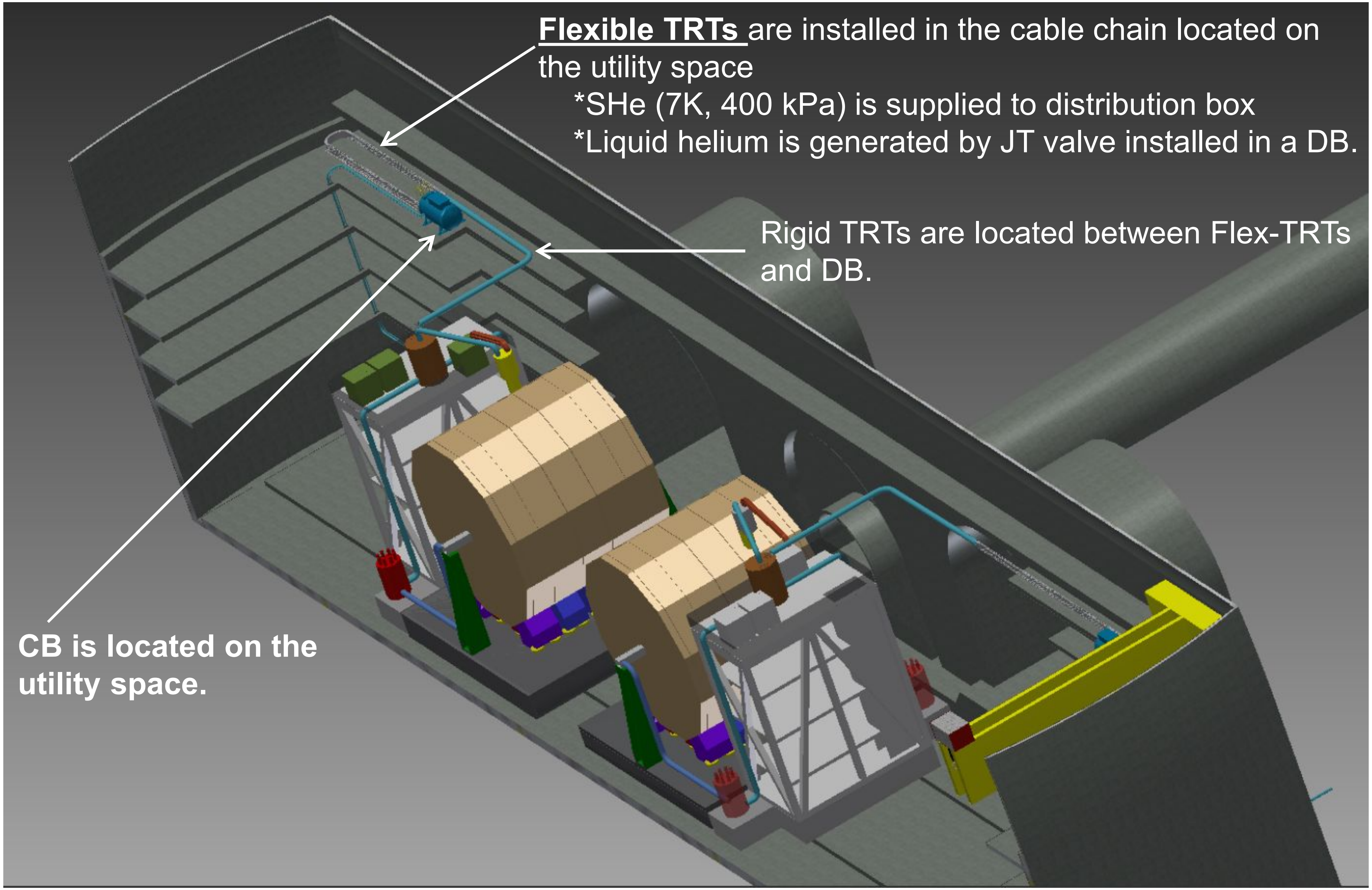


Option B (2D Top view)

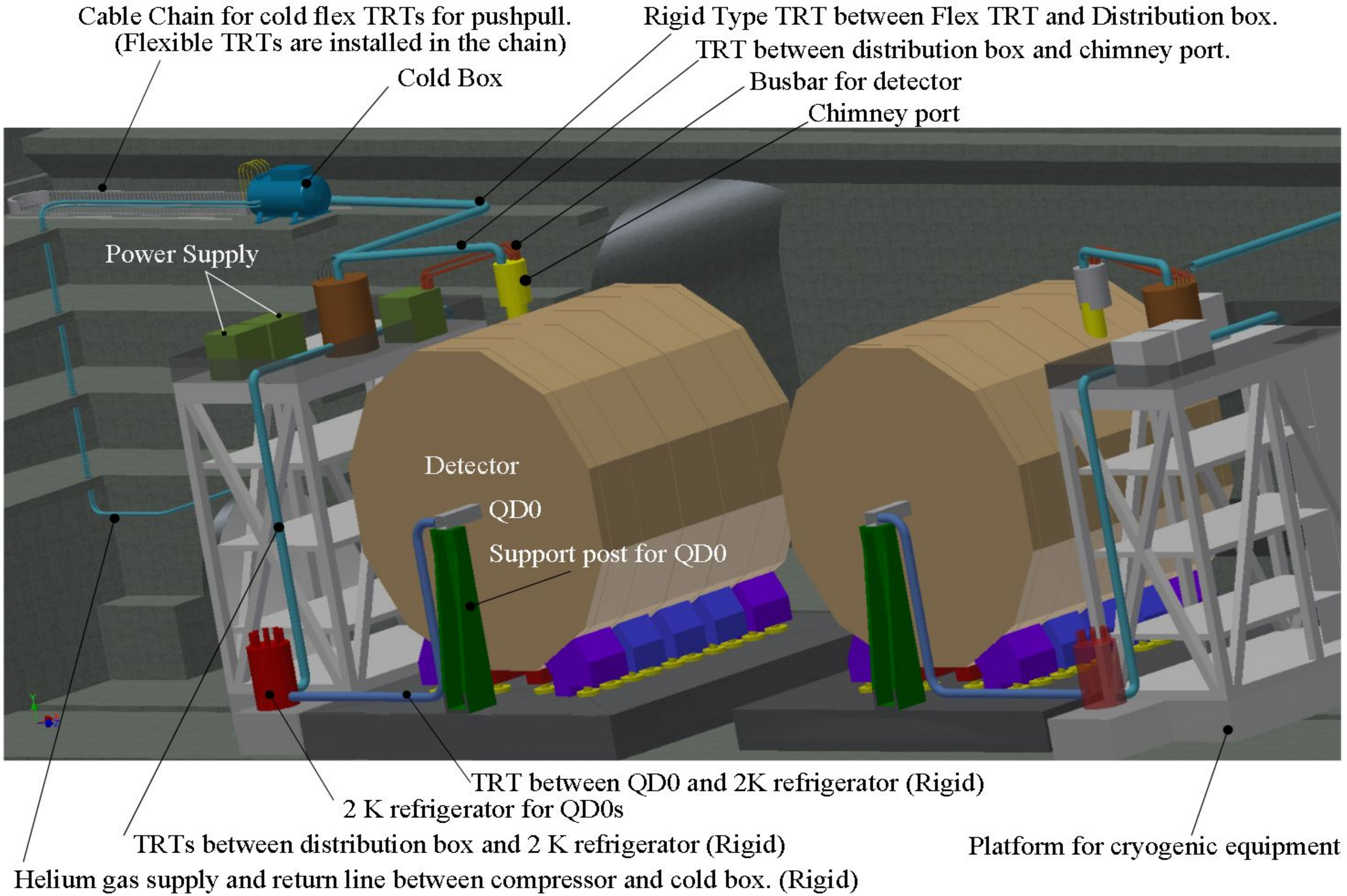
- CBs are installed on a utility space.
- On the contrary, DB is located on the platform for cryogenic equipment (Green area).
- In this case, helium condition in the TRT between CB and DB is not liquid but supercritical (7K, 400 kPa-abs).
- By doing so, cold flexible TRTs with one in one structures (without 70 K shield) can be employed because phase transition from liquid to gas does not occur
- As a result, bending diameter of flexible one in one TRT becomes small.



Option B (3D view of experimental hall)



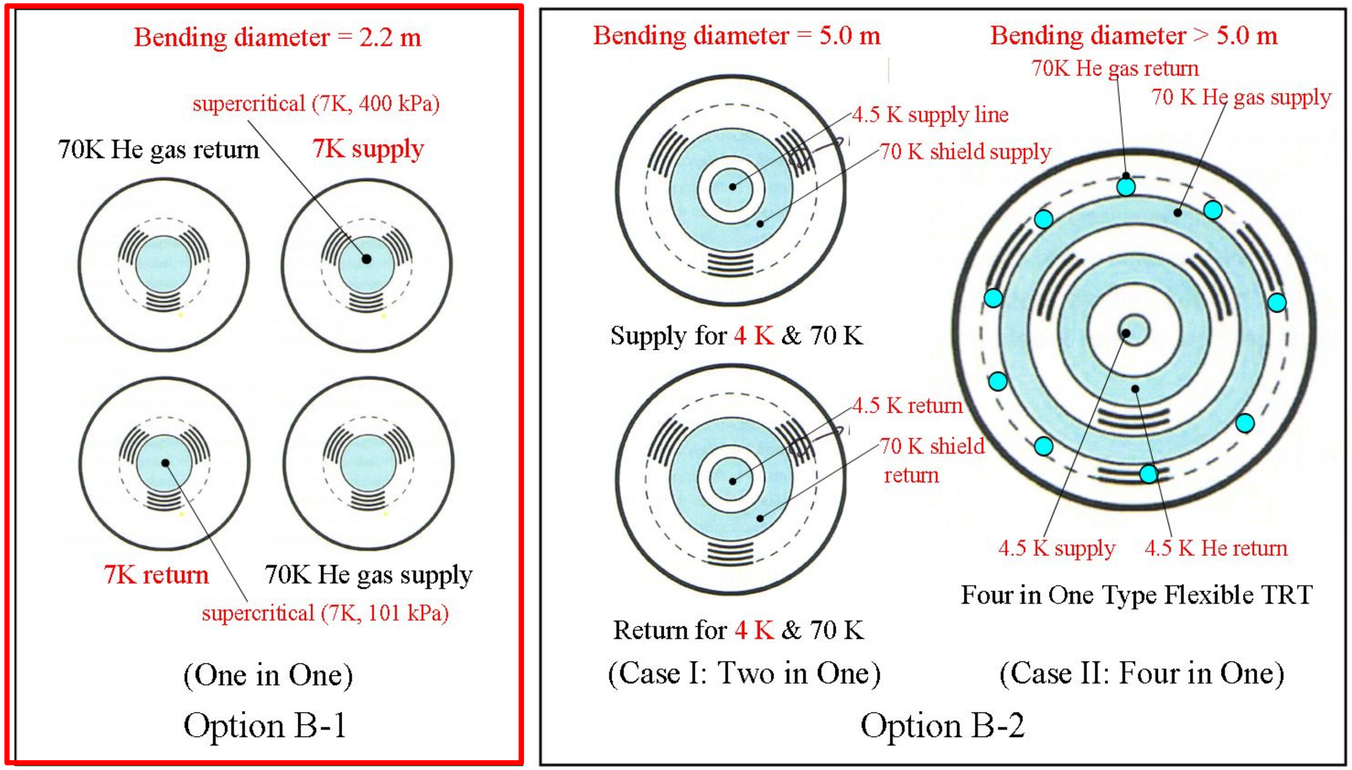
Option B (Side View)



Flexible TRT for Option B

Practical structure of flex-TRT | Impracticable structure of Flex-TRT

Bending Dia.= 2.2 m | **Bending Dia> 5 m**

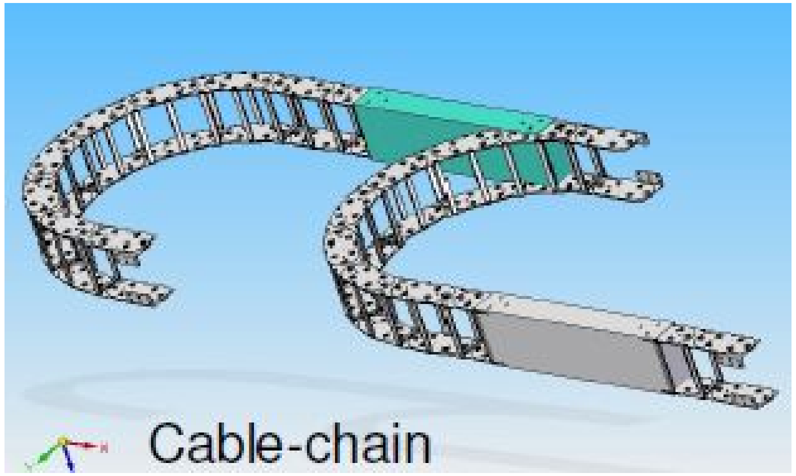


- Helium condition between CB and DB should be 7 K supercritical helium (not 4 K Liquid helium).
- By doing so, one in one type Flex TRT for supercritical He (SHe) can be applied between CB and DB.
- If DB is installed next to the CB (utility space), helium condition in flex TRT is 4K Liquid helium
  - → In this case, not one in one but multi layer Flex TRT (above) should be employed.
  - → Bending Dia. of multi-layer TRT is at least 5m.
- Therefore liquid helium Dewar (Distribution Box, DB) should be installed on the platform

Flex Tubes installed in a Cable Chain in the case of "Option A"

- All flex. Tube (TRT) are installed in the following cable chain.
- All flex tubes are single (standard flexible tube)

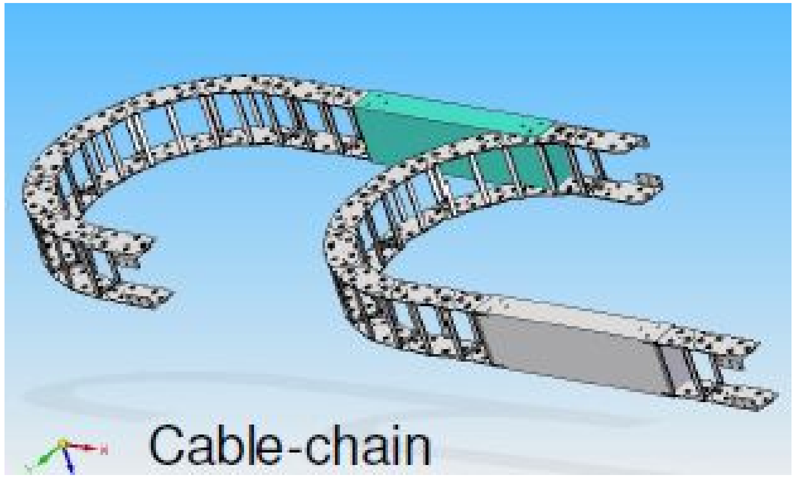
No	Tube installed in the cable chain	Structure	Tube Dia. (mm)	Num
1	300 K helium gas supply line between CB and COMP	Single	60.5 mm	1
2	300 K helium gas return line between CB and COMP	Single	200 mm	1
3	Helium gas vacuum line for 2 K refrigerator (for saturated He II)	Single	150 mm	1
4	Quench recovery line	Single	150 mm	1~2
5	Current lead cooling line	Single	30 mm	1



Total number of Flex tube = 5 ~ 6

Flex Tube installed in a Cable Chain in the case of "Option B"

	Tube name installed in the cable chain	Structure	Tube Dia. (mm)	Num
1	7 K supercritical helium supply line	One in One	OD~70 mm	1
2	4 K – 7 K helium gas return line	One in One	OD~70 mm	1
3	70 K shield helium supply line	One in One	OD~70 mm	1
4	70 K shield helium return line	One in One	OD~70 mm	1
5	Helium gas vacuum line for 2 K refrigerator (for saturated He II)	One in One	OD~70 mm	2
6	Quench recovery line	Single	150 mm	1~2
7	Current lead cooling line	Single	60.5 mm	1



Total number of Flex tube = 8 ~ 9

To determine the actual number of quench recovery line, we have to perform simulation of thermo fluid dynamics during the detector quench.

Vacuum pump operation strategy

- **Vacuum pumps for adiabatic vacuum layer**

  Vacuum pumps have only to be operated during precooling operation.
  Once temperature is less than around 70 K, vacuum pumps should be stopped because cryo-sorption effect occurs under the condition.

  Therefore vacuum pumps for adiabatic vacuum layer is not regarded as vibration source of QD0.

- **Vacuum pump for 2K refrigerator (to obtain saturated superfluid helium)**

  Vacuum pump to obtain saturated superfluid helium has to be operated continuously during steady state operation.

  From the view point of vibration, vacuum pump for 2 K refrigerator should be located on the utility space. (Detail research on vibration should be performed.)

  Appendix: Heat load of QD0 is relatively small, 15 W at 1.8 K,
  therefore we don't have to employ cold compressor.

Vibration Source

We have to consider various kinds of vibration described below.

- ♠ Mechanical vibration from compressor.
- ♠ Mechanical vibration from cold box.
- ♠ Mechanical vibration from vacuum pump.
- ♠ Mechanical vibration from power supply.
  - · Oscillation from electrical transformer
  - · Oscillation due to cooling water
- ♠ Vibration due to fluid motion.
  - · Bellows oscillation
  - · ~~Oscillation and instability due to two phase flow.~~
- ♠ ~~Vibration due to thermal instability~~
  - · ~~Taconis oscillation~~
- ♠ Vibration due to ground (seismic oscillation)

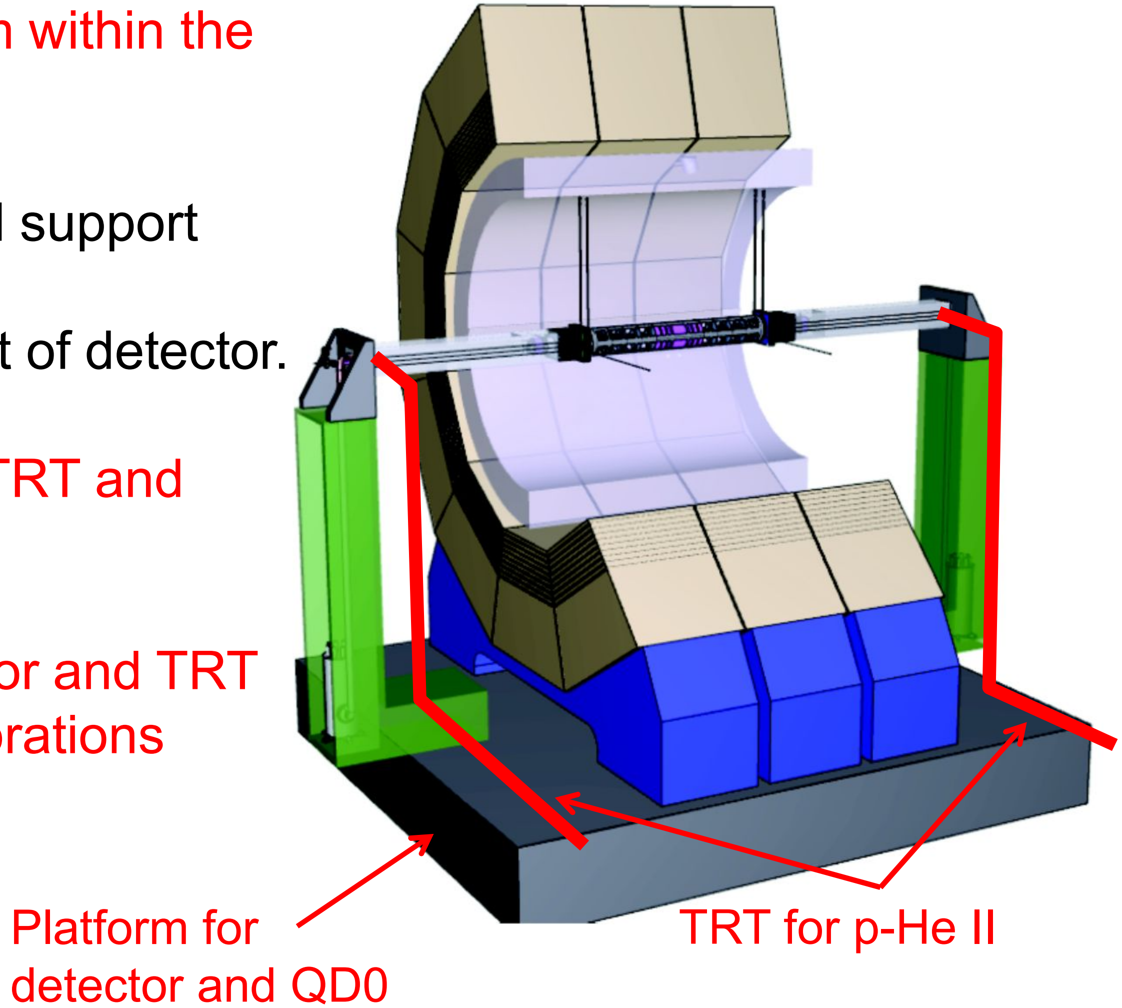
QD0 vibration requirement

Allowable vibration level is 50 nm within the 1 msec long ILC bunch train.

- QD0 is supported by pillar and support tube.
- QD0 is supported independent of detector.

Vibration is transmitted through TRT and platform.

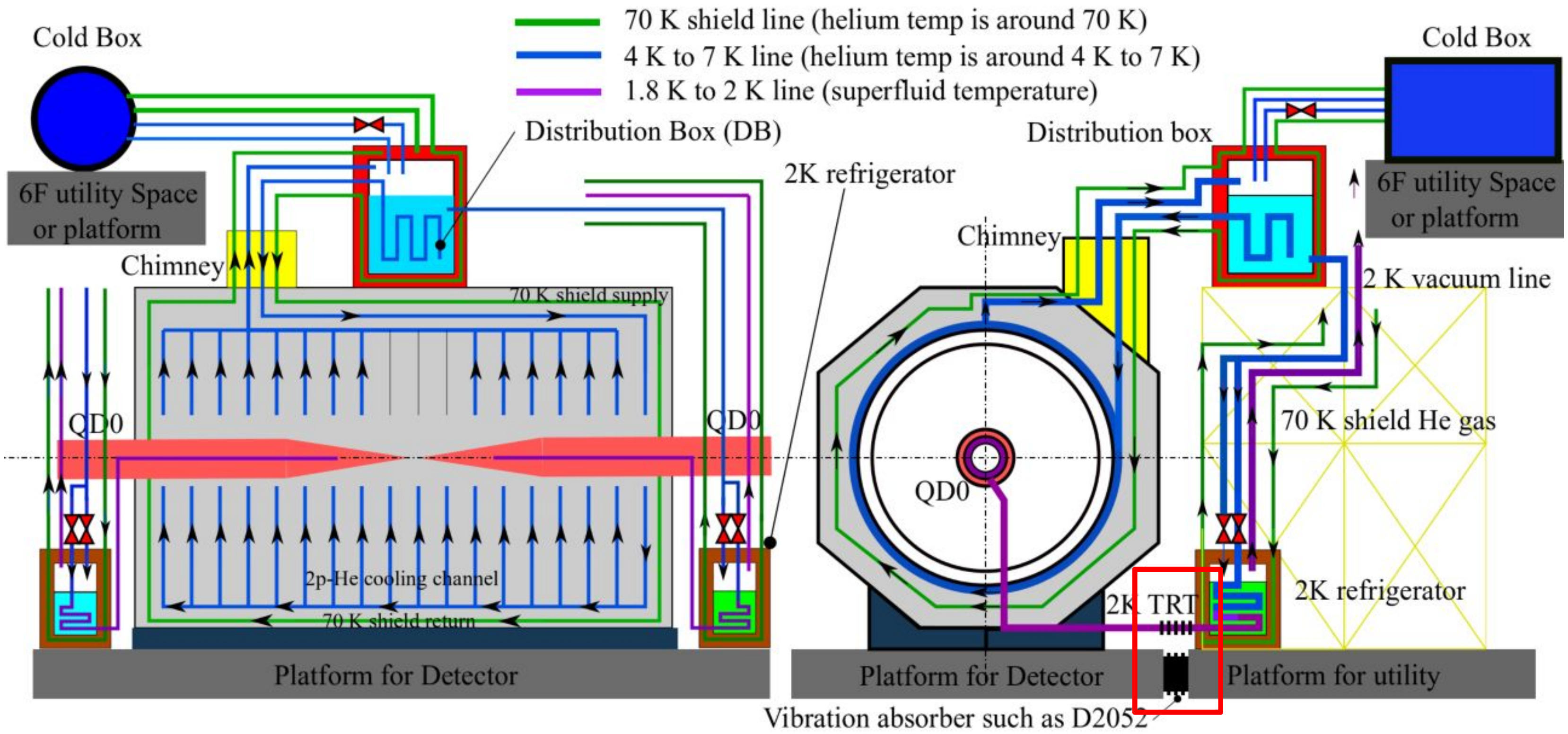
Therefore the platform for detector and TRT should be designed such that vibrations become minimum.



Vibration Reduction

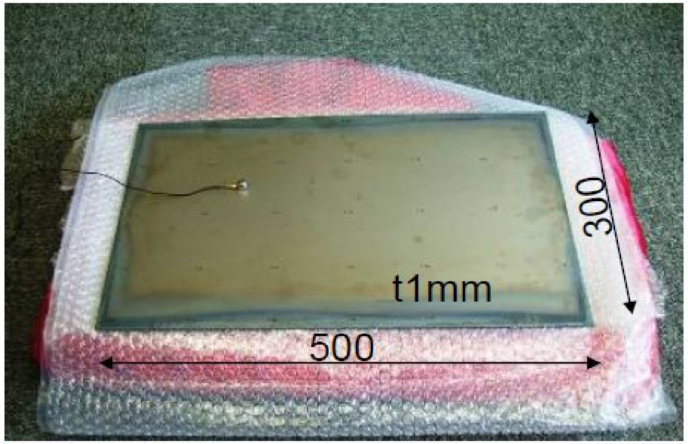
- Especially Option A is disadvantage from the view point of vibration.
- To reduce vibration of QD0, **platform for cryogenic equipment** should be prepared in addition to platform for detector. All equipment with vibration source should be installed on the platform for cryo-equipment.
- Vibration absorber such as D2052 should be employed between these two platforms.

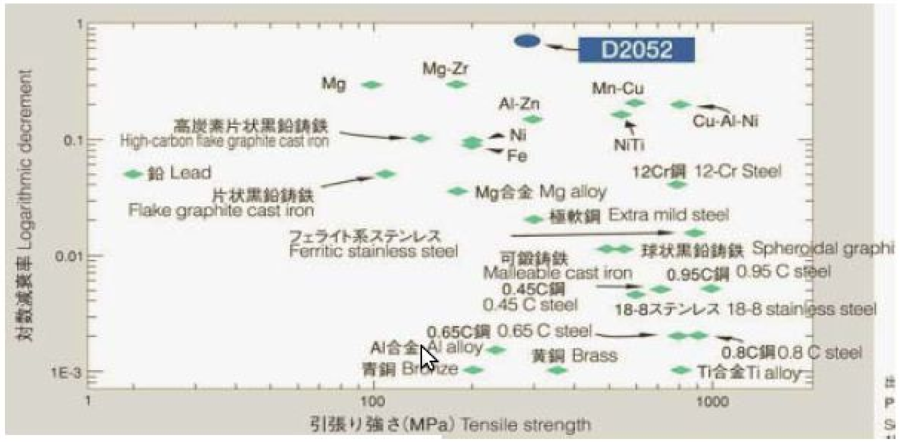
➔ **it is necessary to research vibration of QD0 (We have to do!)**



An example of vibration reduction method

- D2052 with Mn, Cu, Ni, Fe etc. has the high logarithmic decrement for vibration.
- As for one reduction method, D2052 is employed between each platform.



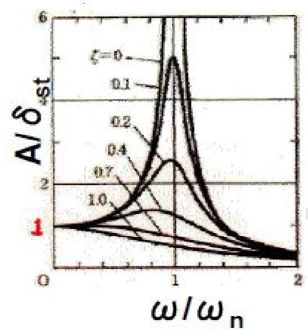


代表的な化学成分 Typical chemical composition

Mn	Cu	Ni	Fe	単位 Unit
Bal.	22.4	5.2	2.0	wt%
Bal.	20.0	5.0	2.0	at%

主な物性値 Typical properties

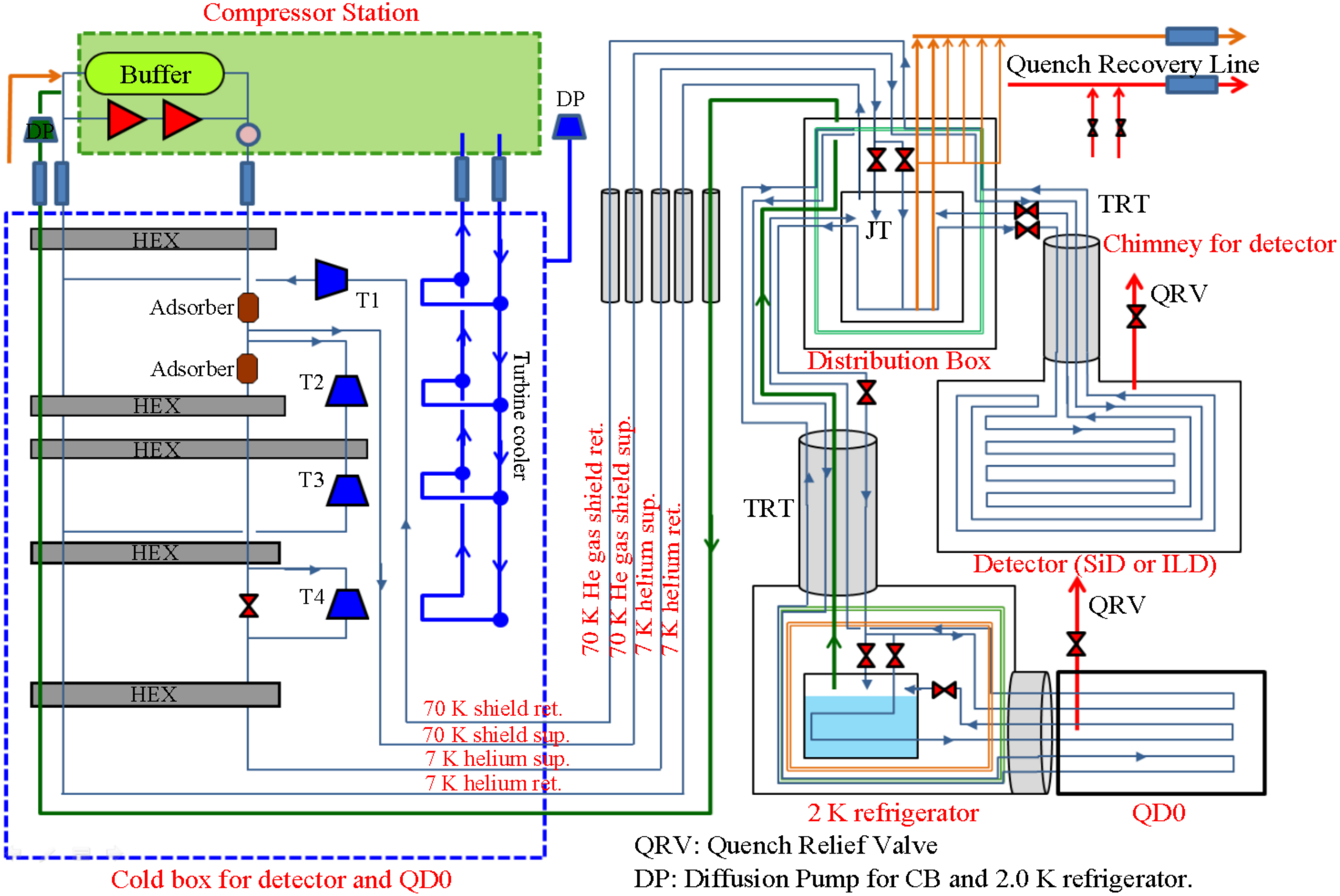
物性 Property		値 Value	近い元素 Approximate element
ヤング率	Young's modulus	80 GPa (300K)	Al、Ag、Cd
熱伝導率	Heat conductivity	10 W/(m·K) (300K)	Ti、Sb、Pb、Bi
比熱	Specific heat	512.7 J/(kg·K) (300K)	Ti、Fe、Cr
熱膨張率	Coeficient of thermal expansion	22.4 $\times 10^{-6}$/K (300K)	Al、Ag、Sn、Cu
密度	Density	7.25 $\times 10^{3}$kg/m^{3}	Fe、Mn
硬さ	Vicker's hardness	120~140	



機械的強度 Mechanical strength

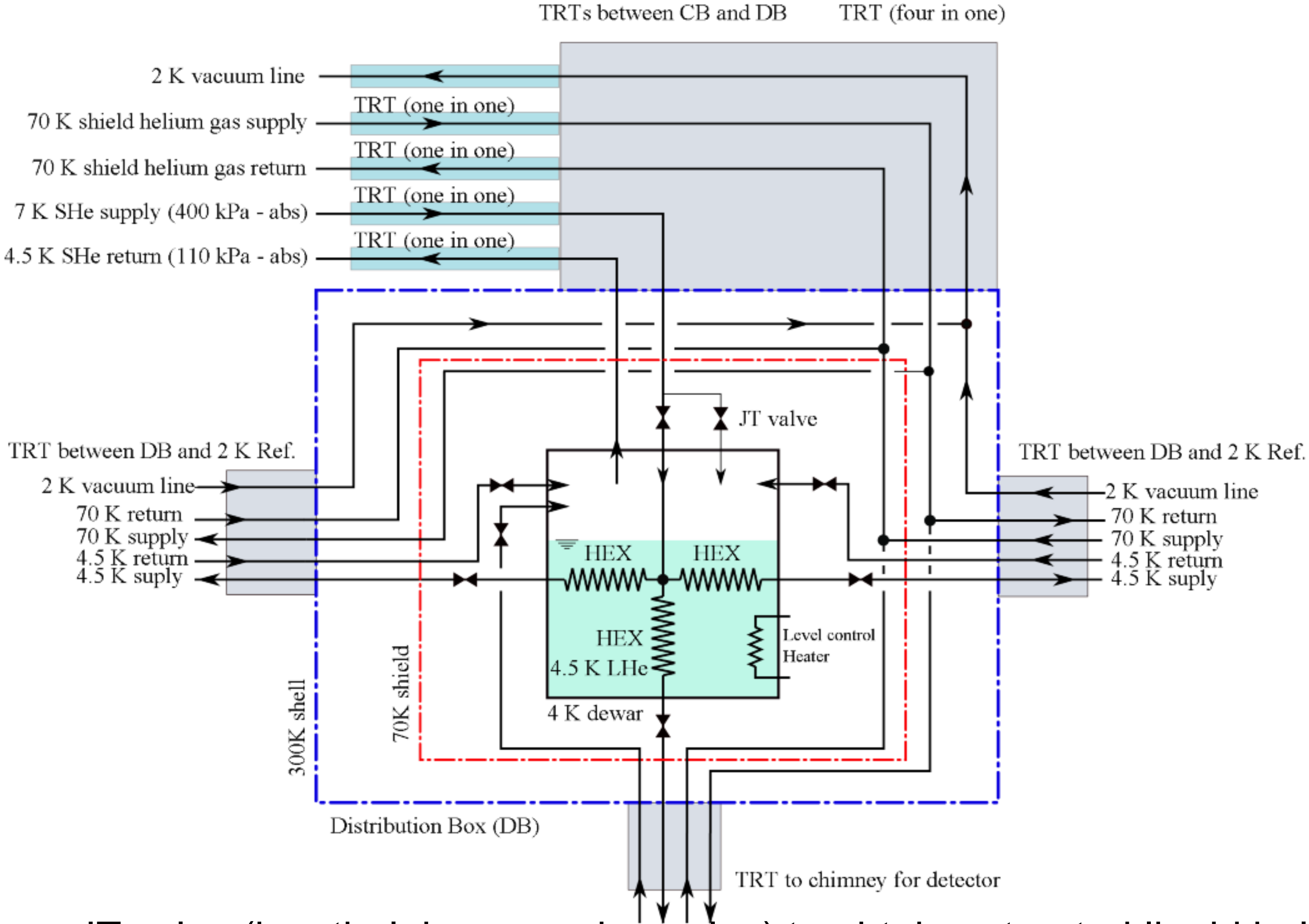
	引張強さ Tensile strength	耐力 (0.2%) Yield strength	伸び Elongation	絞り Reduction of area	疲労強度 ($\times 10^7$回) Fatigue strength($\times 10^7$times)
標準材 Standard material	530MPa	265MPa	40%	61%	125MPa

Conceptual Flow Diagram



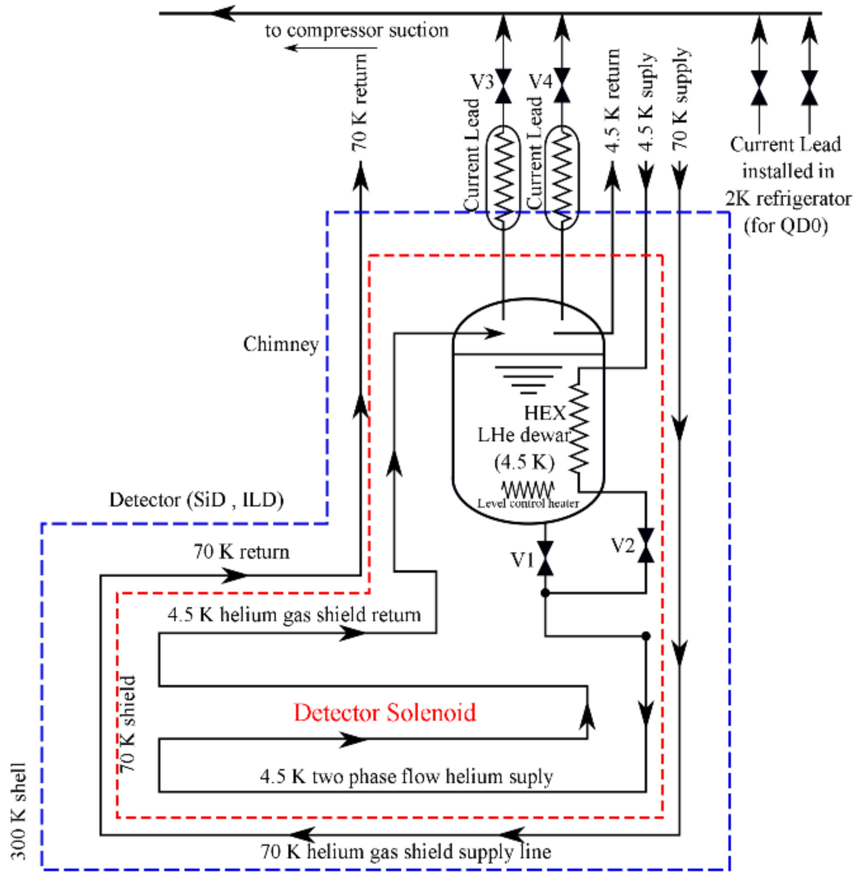
QRV: Quench Relief Valve
DP: Diffusion Pump for CB and 2.0 K refrigerator.
T1 - T4: Expansion Turbine (T4 :Supercritical Turbine)

Flow Diagram of Distribution Box



- There is one JT valve (isenthalpic expansion valve) to obtain saturated liquid helium of 4.5 K which is regarded as a heat exchanger.
- There are three HEXes (heat exchangers) in the liquid helium dewar.
- DB supplies coolant of 4.5 K helium to chimney and 2K refrigerator when 7 K supercritical helium from CB is directory passed through the HEXes
- The installation location of the distribution box should be same level as the top of the detector

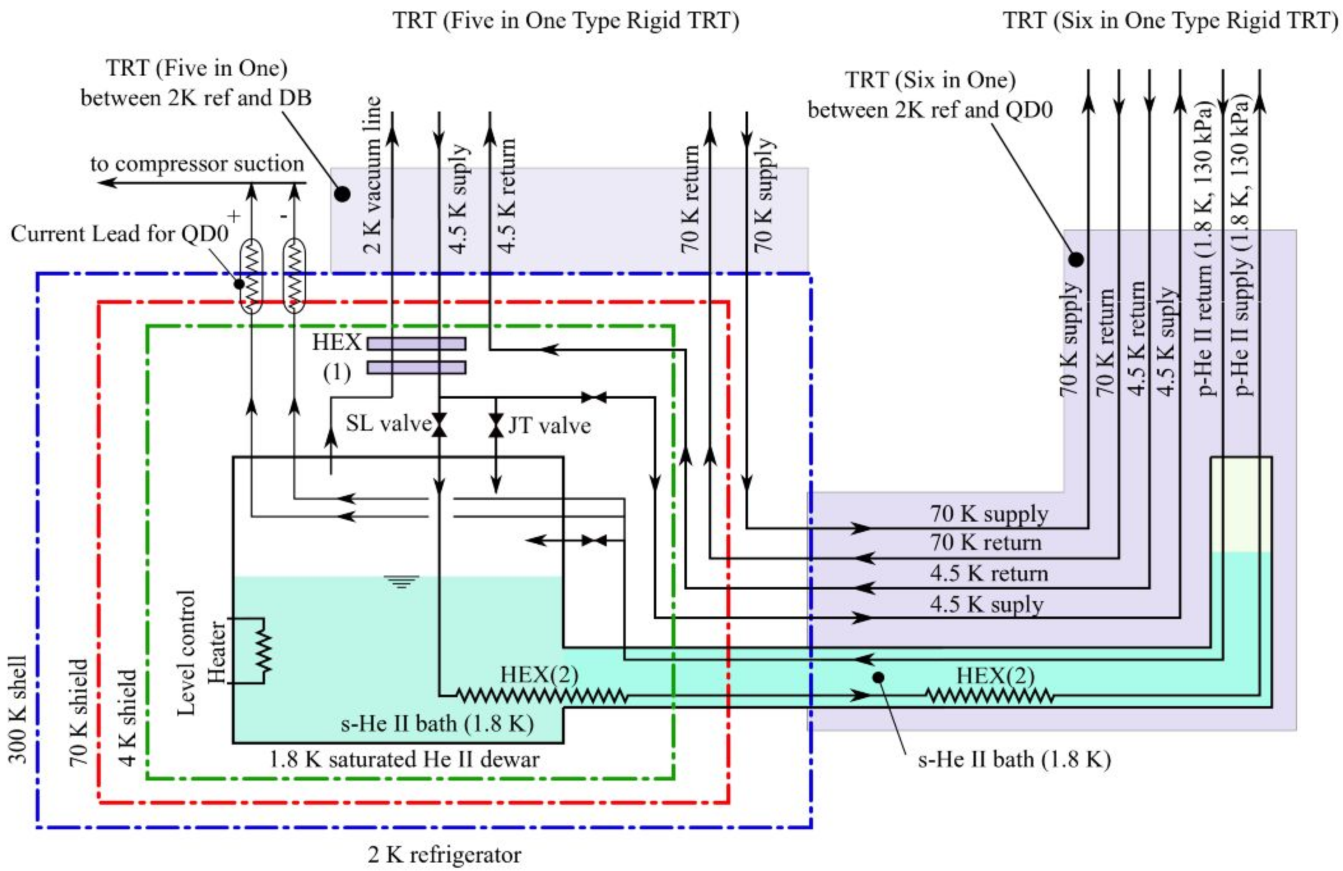
Flow Diagram of Detector



The chimney has mainly two functions.

- ✓ One is to cool down the current lead which is cooled by forced convection cooling.
  Required mass flow ~ 3 g/sec at 20 kA.
- ✓ The other is to supply the detector cooling channel with the two phase flow of HE.
  We can choose cooling scheme of thermo syphon cooling or forced convection by controlling the V1 and V2 valves.

Flow Diagram of 2 K refrigerator



- 2 K refrigerator has the dewar for saturated He II which is regarded as heat exchanger to perform transition from normal liquid helium (He I) to pressurized He II.

- Pressurized-He II can be obtained when the 4 K liquid helium from distribution box passes the heat exchangers HEX(2).
- The 2 K vacuum line also can be regarded as a kind of heat exchanger (HEX1). Therefore the temperature of liquid helium from distribution box becomes decreasing to around less than 3 K.

Which option is better ?

	Option A	Option B
< From the view point of Push-pull>		
Type of Flexible tube for push-pull	Warm (single)	Cold (one in one)
Bending Dia. of Flex TRT	~ 2.0 m	~ 2.2 m
Total number of Flex tube for push-pull	**5~6**	**8~9**
Heat Load between CB and DB	**1.25 W (L=5m)**	**20.5 W (L=50 m)**
Repair and Reliability of multiple TRT (Cold TRT)	Low broken rate	Easy to replace (by employing Bayonet joint)
< From the view point of Vibration>		
Cold box location	Platform	Utility space
Vibration of QD0	**Disadvantage ??**	**Advantage ??**
< From the view point of Cost >		
Production Cost of Flex line for push-pull	**1 (Flex tube + TRT from CB to DB)**	**4.2 (Flex and Rigid TRT from CB to DB)**
Total Production cost of cryogenic system (per 1 detector system)	**1**	**1.032**
Present Score	**1**	**1**

Conclusions

- Present score is almost same between Option A and Option B from the various viewpoint.
- Option A has high reliability for push-pull because multiple flexible TRT is not employed but has disadvantage from the view point of vibration.
- Option B has low reliability for push-pull compared with option A because a lot of flexible one in one TRT has to be employed but If one of the Flex TRT is broken we can easily replace back-up one by employing Flex TRT with bayonet joint. The degree of freedom to reduce vibration of QD0 becomes high compared with Option A because CB is installed on utility space which is independent of the detector platform.
- To determine the cryogenic system for push-pull, following additional researches has to be performed.
  - Studies on vibration reduction method
  - Quench simulation from the viewpoint of thermo-fluid dynamics.

How to obtain a cryogenic scenario ?

- **Experimental and numerical researches on vibration of QD0 should be performed.**

- **Experimental research**
  - The best way to clarify the vibration characteristics of QD0 is to fabricate prototype of QD0 with pillar and support tube and to measure the vibration.

- **Numerical research**
  - Eigen value problem with respect to large size of matrix has to be solved numerically,

$$\hat{A}\left|\phi\right\rangle = \lambda\left|\phi\right\rangle$$

  - Multi step mode superposition method developed by Kubo is good from the view point of parallel & high speed computing.
  - By solving inverse problem, we can obtain optimal solution to reduce vibration of QD0.

Vibration investigation procedure

(Numerical Approach)

1. PSD of vibration source (CB, vacuum pump, PS) are measured.
2. Seismic oscillation with respect to site is also measured.
3. Eigen value problem is solved numerically by means of measured PSD.
   Measured PSD is given as an input condition.
4. Response function, *G*, can be obtained from numerical simulation.

(Measurement)

1. Prototype QD0 with support post and pillar is fabricated.
2. Artificial vibration is given to prototype QD0.
3. Output vibration amplitude is measured by means of three laser displacement meter
4. We can obtain response function, *G,* from measurement result.
   G~PSD_OUT/PSD_IN
5. We can also evaluate the validity of numerical simulation by comparison with measured G

(Research vibration reduction method)

1. After the confirmation of validity of numerical simulation,
   inverse analysis is performed to find optimal vibration reduction method.