# 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.

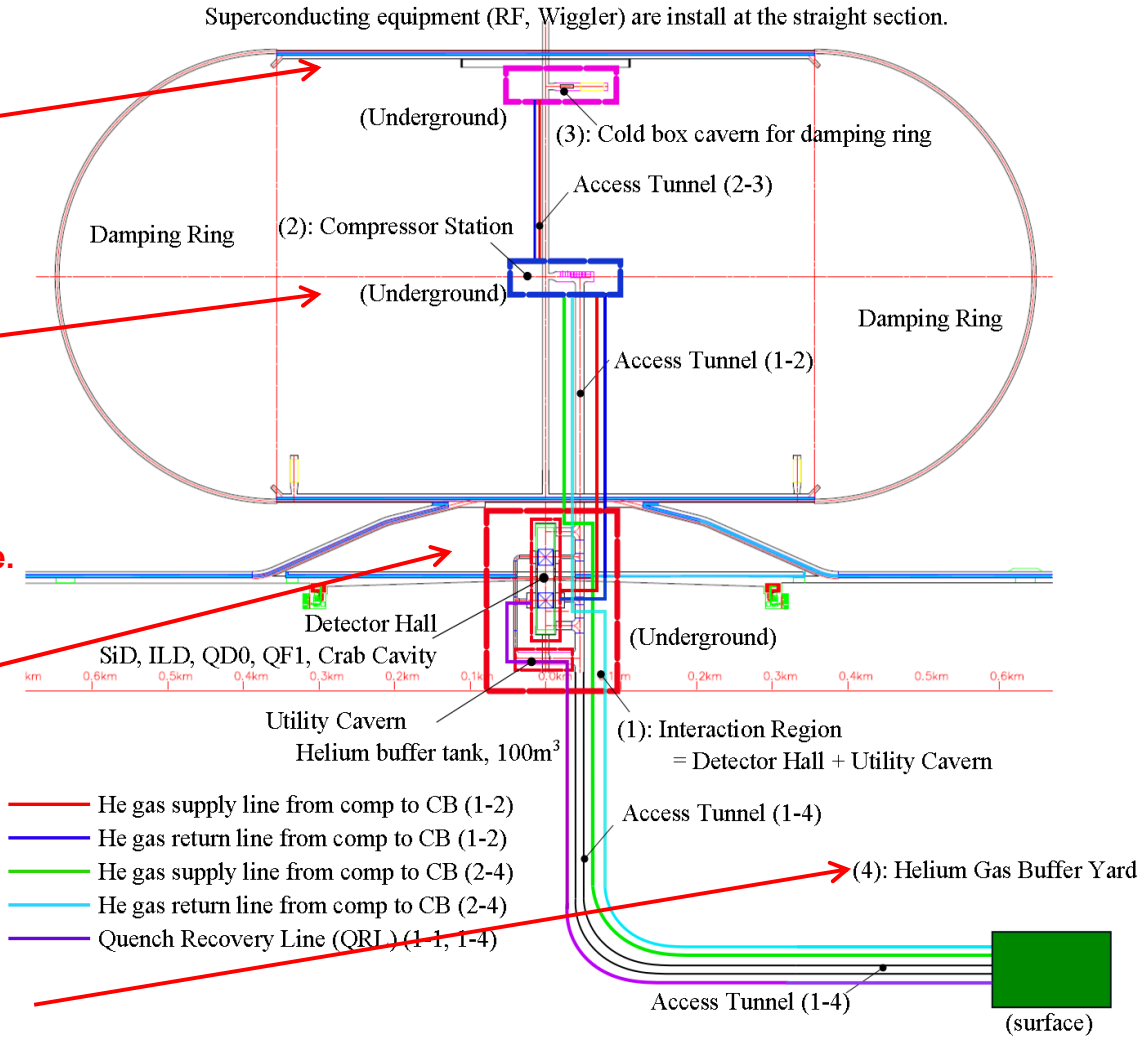
3. Damping ring section (underground)

2. Compressor station (underground)

**All compressors for SiD, ILD, QD0, QF1, CC and dumping ring will be installed so that continuous operation will be carried out even if one of the compressor is broke.**

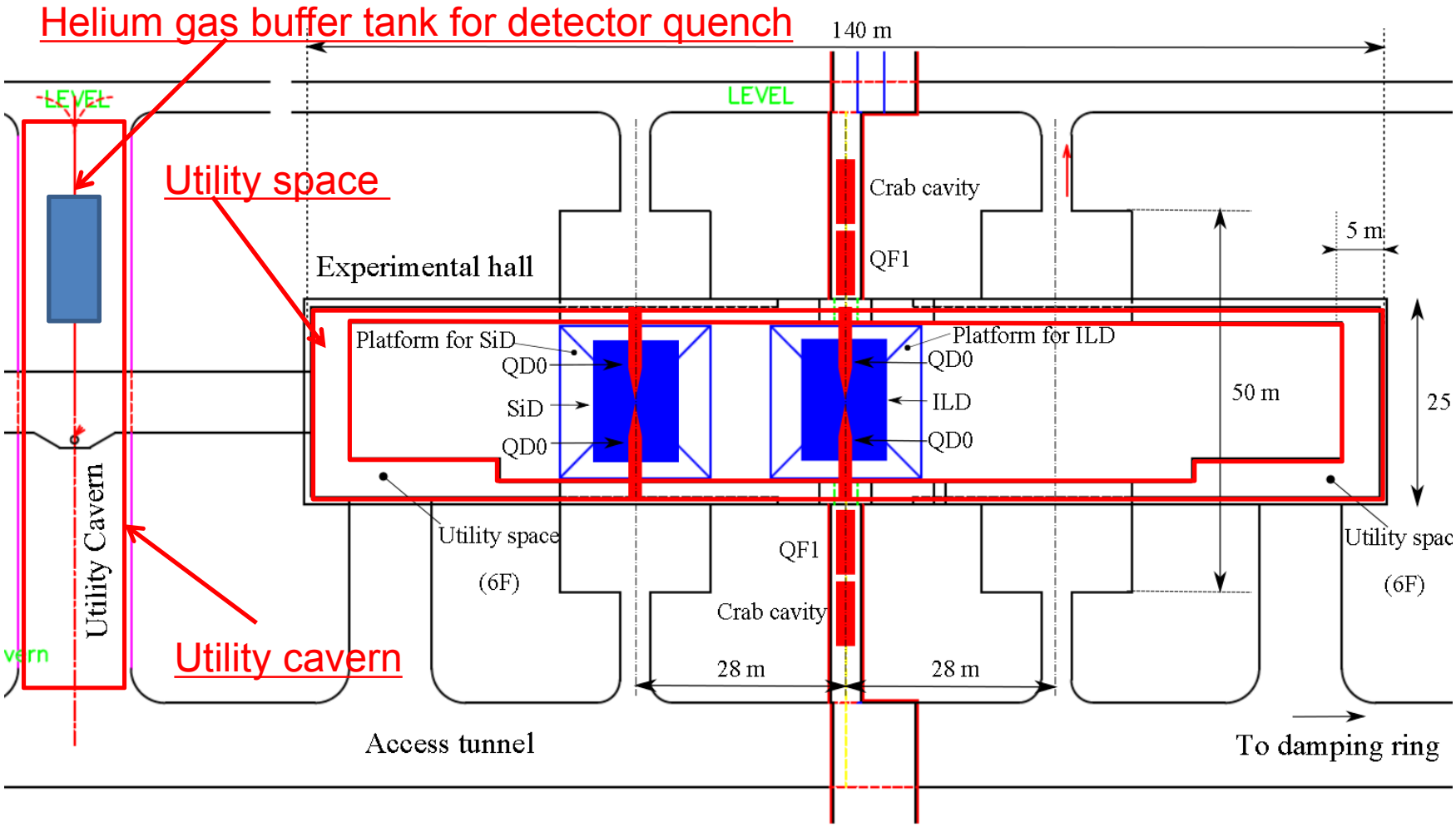
1. IR region (underground)

4. Helium gas storage yard (surface or underground)




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

# Cryogenic Equipment installed in Experimental Hall




- 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.

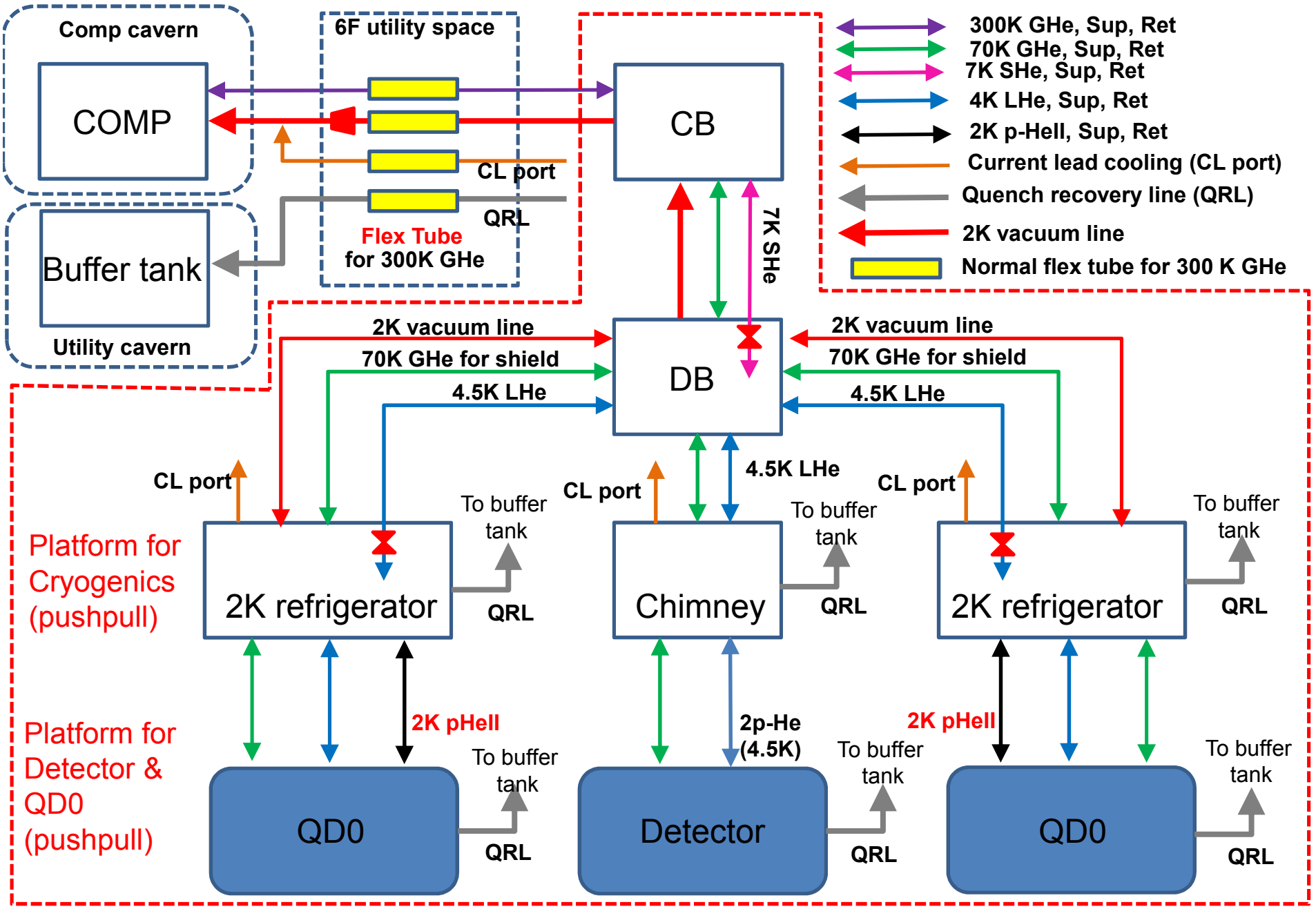
    Cold boxes for ILD and SiD are installed on the platform for detector.

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

    Cold boxes are installed on the utility space located in the hall.

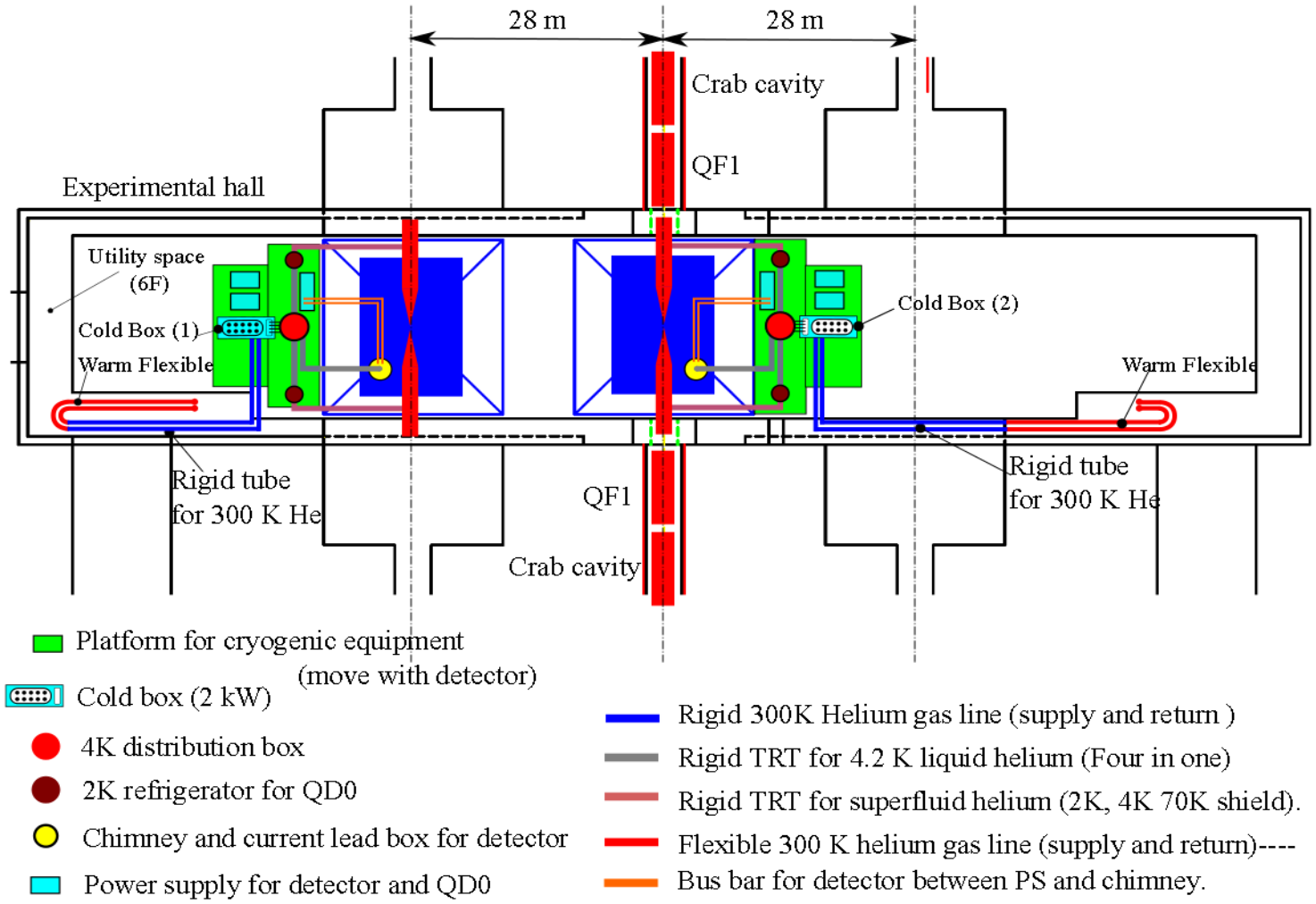
**Todays Talk is about Option A cryo scenario.**

# Cryo & vacuum Block Diagram of Option A

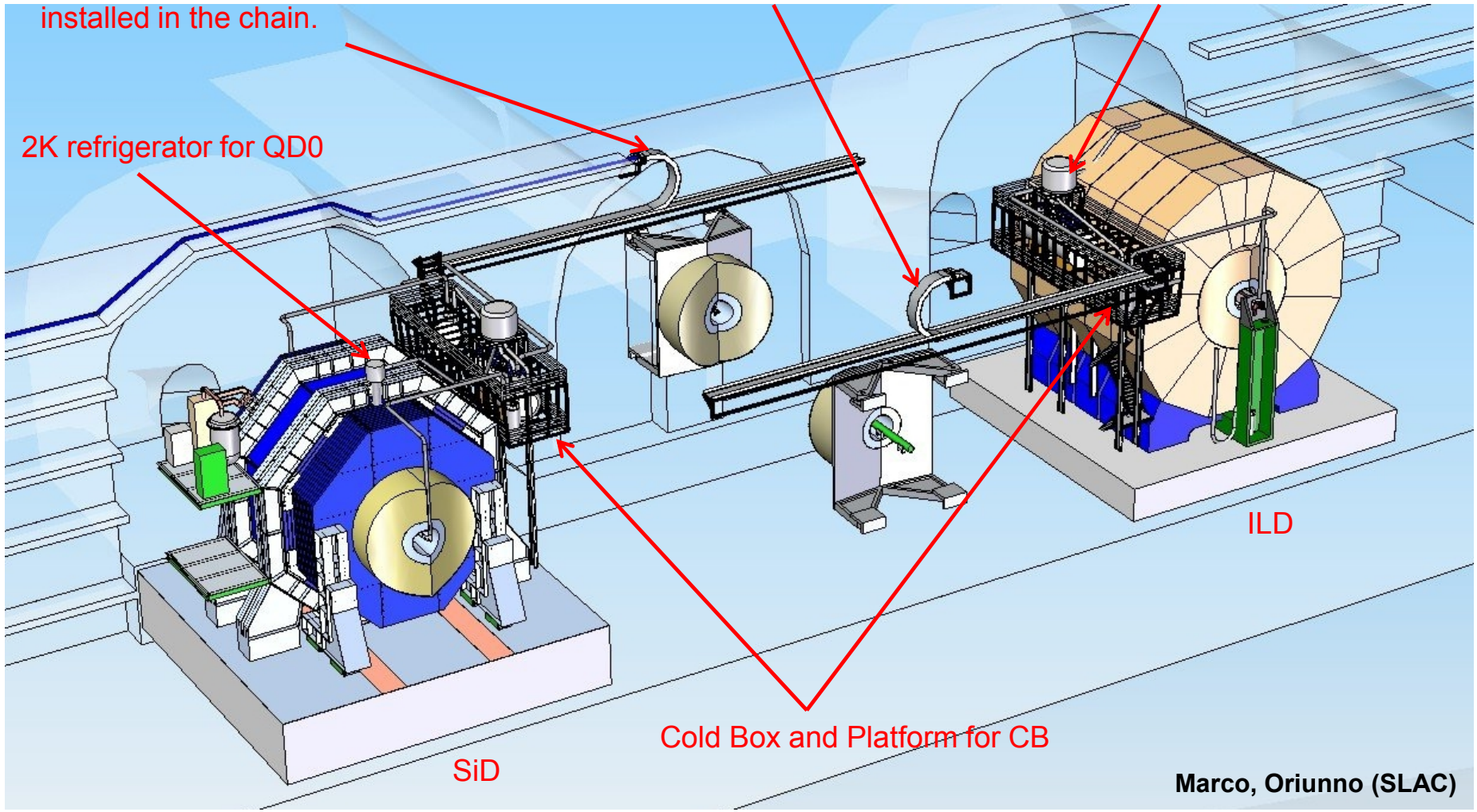


# Option A (2D top-view)

- **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.**



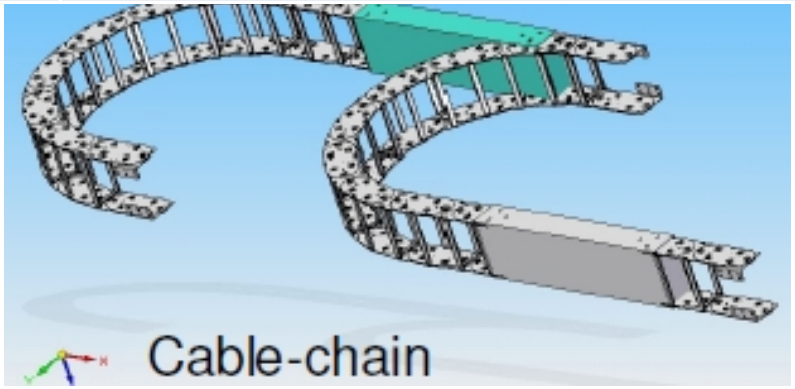
# Option A (3D view)



# 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 |
| 6 | Cooling water supply and return lines for turbines | Single | 25 mm | 2 |




Total number of Flex tube = 7 ~ 8

# 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.

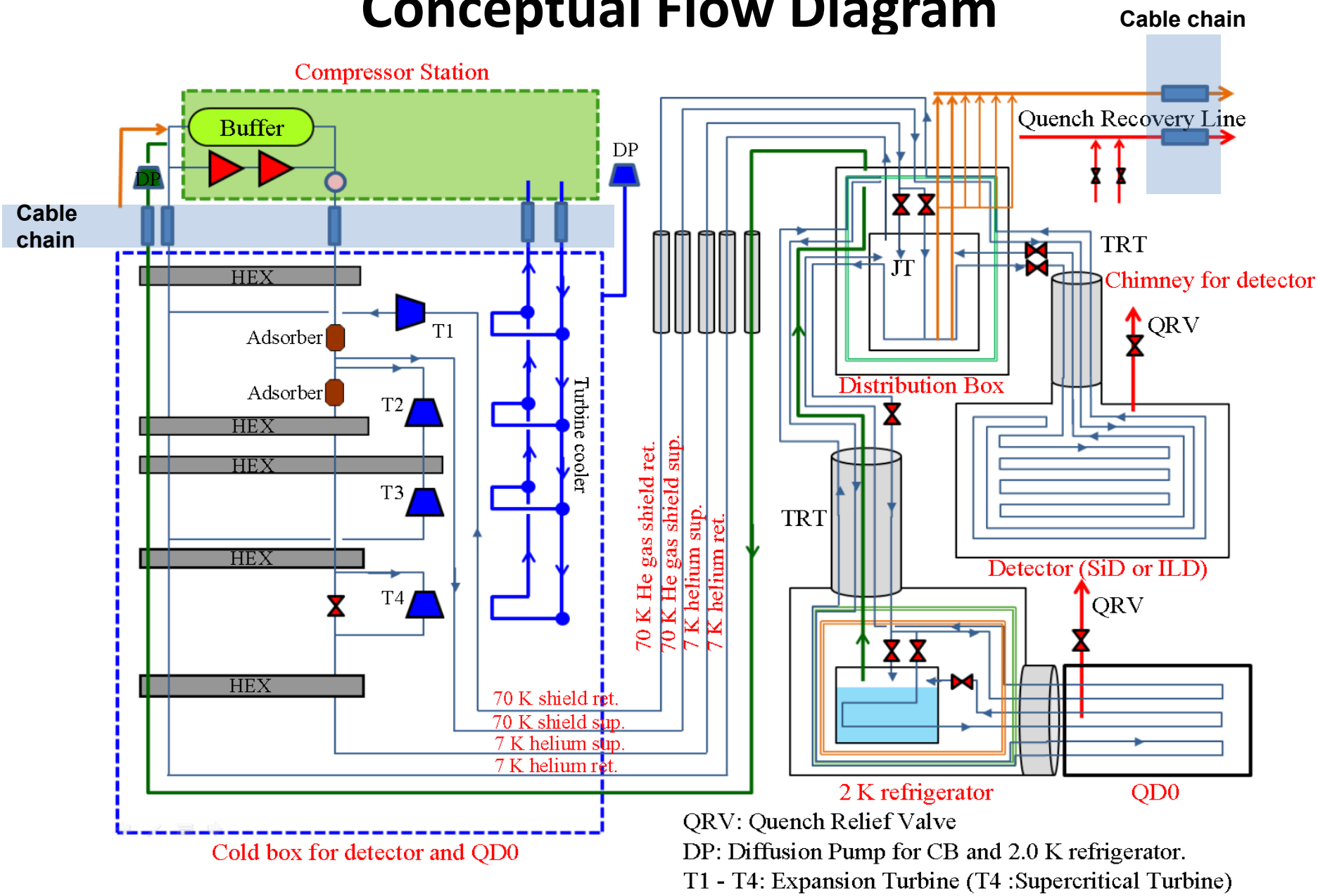
- **Vacuum pump for 2K refrigerator ( to obtain saturated superfluid helium)**

  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.)

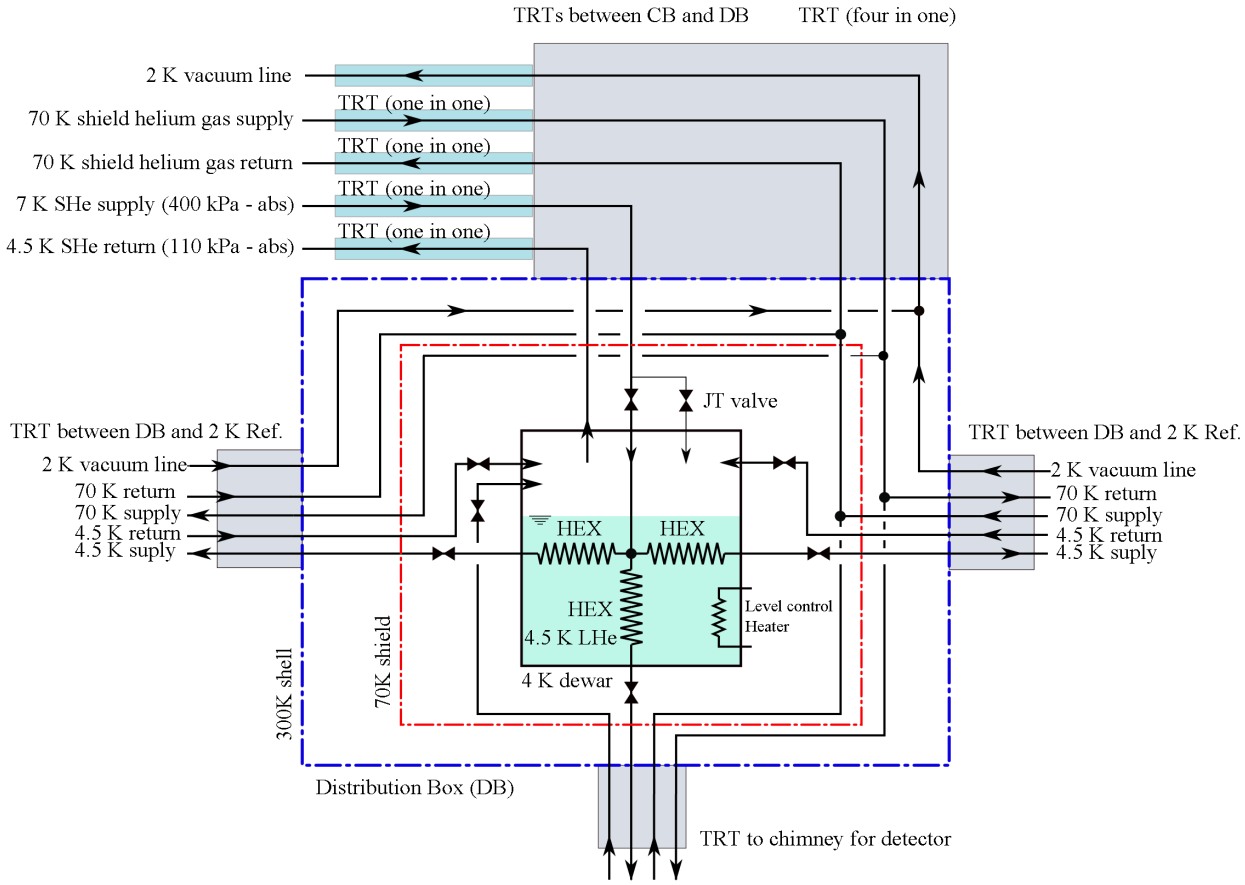
  *Appendix*: Heat load of QD0 is relatively small, 15 W at 1.8 K,
  therefore we don't have to employ cold compressor.

# Conceptual Flow Diagram



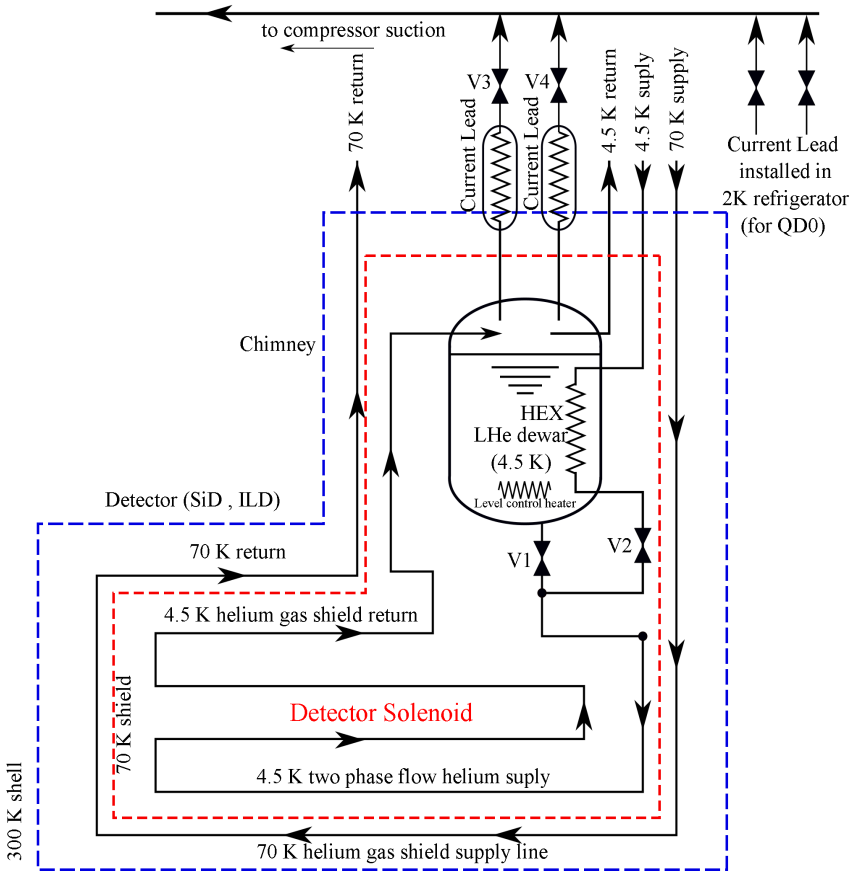

QRV: Quench Relief Valve
DP: Diffusion Pump for CB and 2.0 K refrigerator.
T1 - T4: Expansion Turbine (T4 :Supercritical Turbine)

# Flow Diagram of Distribution Box




- 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
- There is one JT valve (isenthalpic expansion valve) to obtain saturated liquid helium of 4.5 K filled in the dewar. (Helium dewar is regarded as heat exchanger.)
- There are three HEXes (heat exchangers) in the liquid helium dewar.

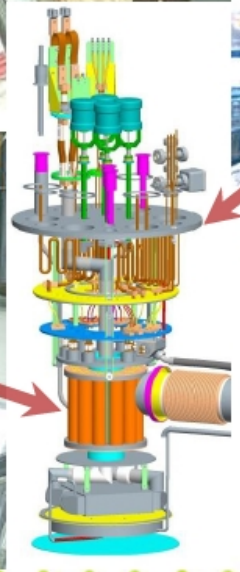
# Flow Diagram of Detector




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.
- ✓ Another 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.

# Structure of 2K refrigerator for QD0



- Work is on track to finish QD0 construction during FY2012.
- But we don't have adequate funds for cryogenic testing in FY2012....

# Conclusions and future plan

- Installation location of cold boxes for IR is quite important from the view point of pushpull and vibration of QD0.
- Option A that the cold boxes for detector are installed on the platform for each detector is introduced.
- So far, the cryogenics layout for IR is not determined.

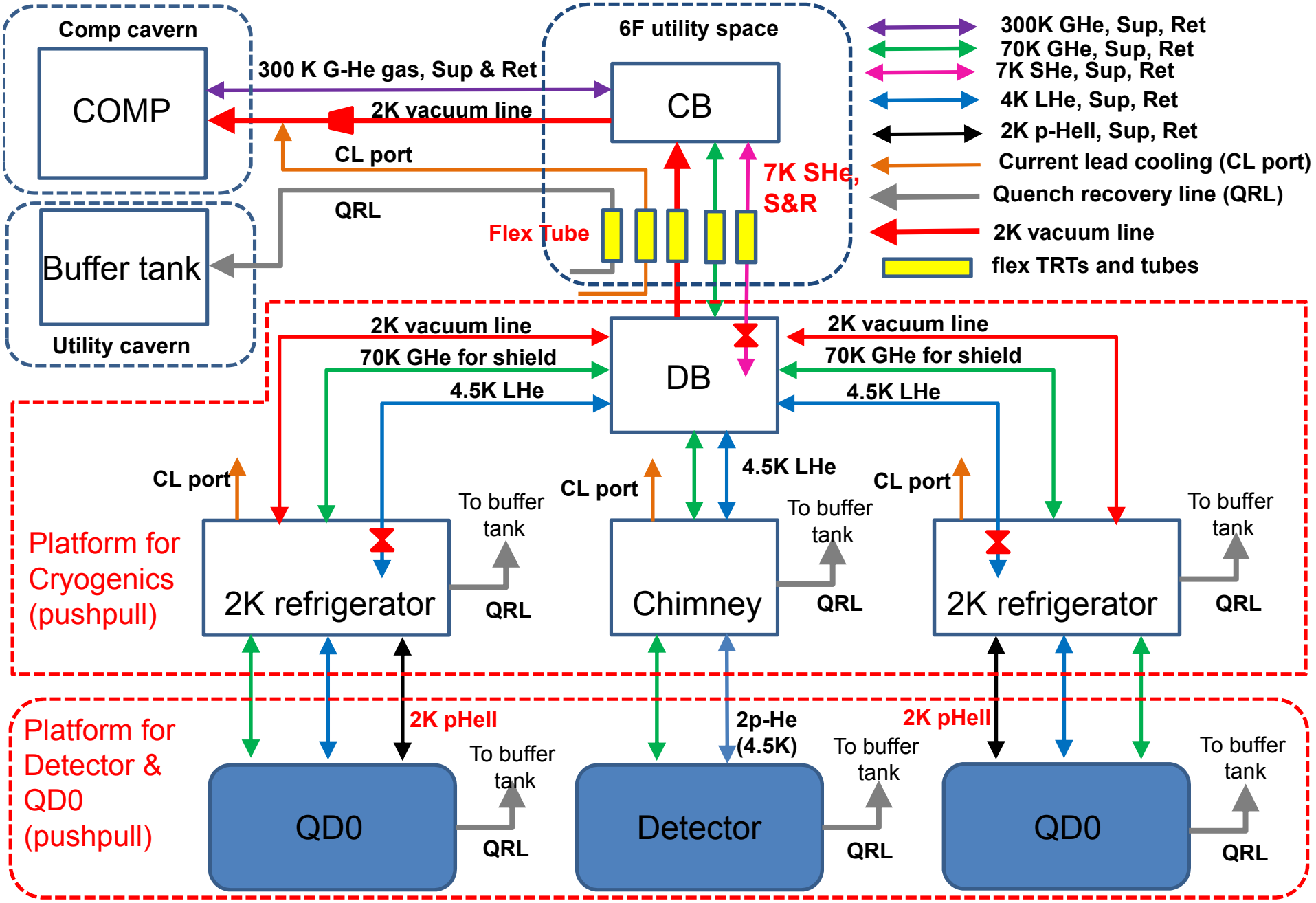
To determine the cryogenic system for IR, following additional researches will be performed.

- Study on superconducting magnet for detector
  - Development of superconducting solenoid (Design study)
  - Development of winding machine of superconductor and design on surface fabrication hall for detector
  - R&D of superconductor with aluminum stabilizer for Detector magnet

- Optimization of 2K+4K combined cryogenic system
  - Performing dynamics simulation to find optimal cryogenic scheme for IR at precooling mode, steady state mode, quench mode
  - Vibration studies of IR region in consideration of all kinds of vibration sources.

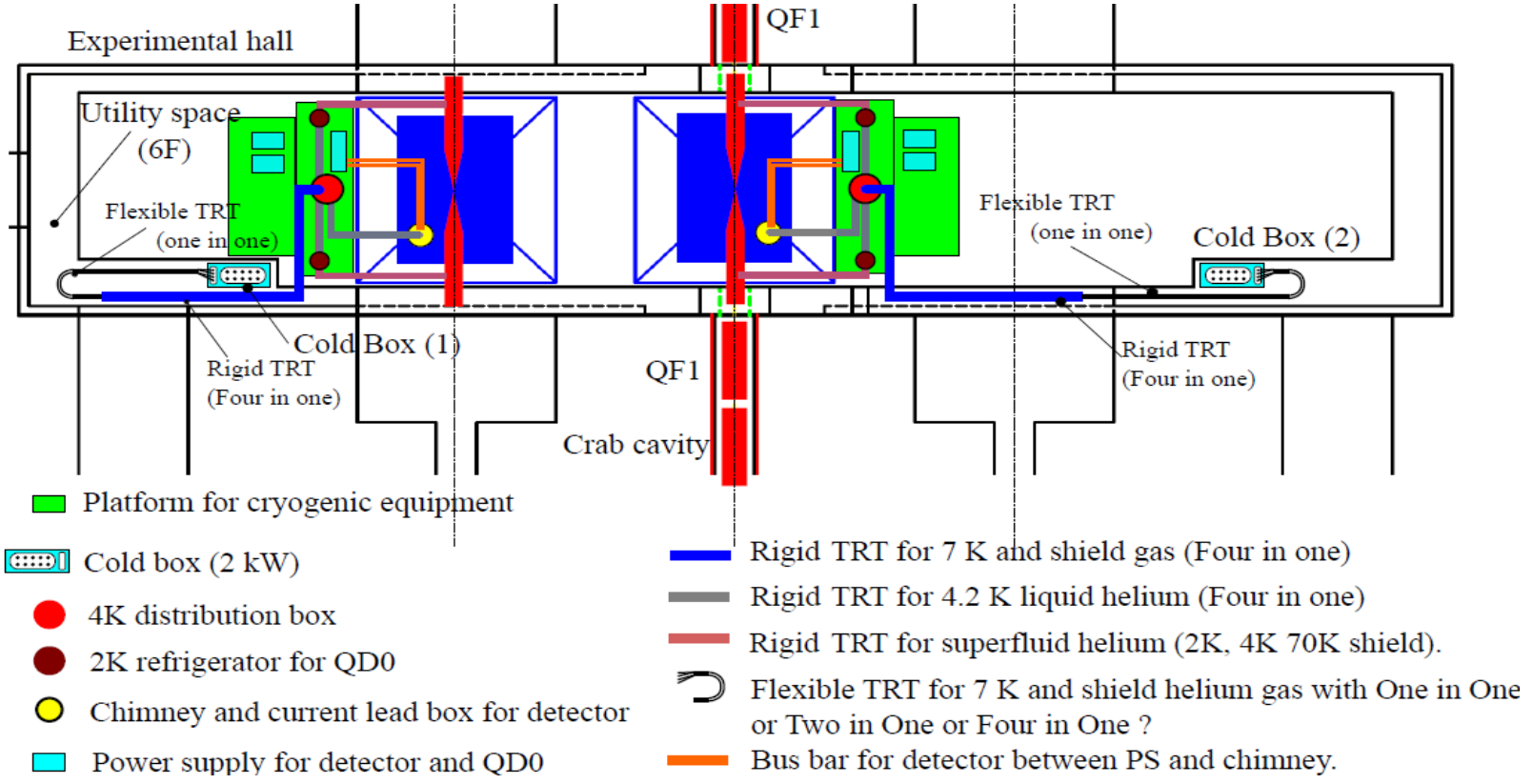
# APPENDIX

# Cryo & Vacuum Block Diagram of Option B

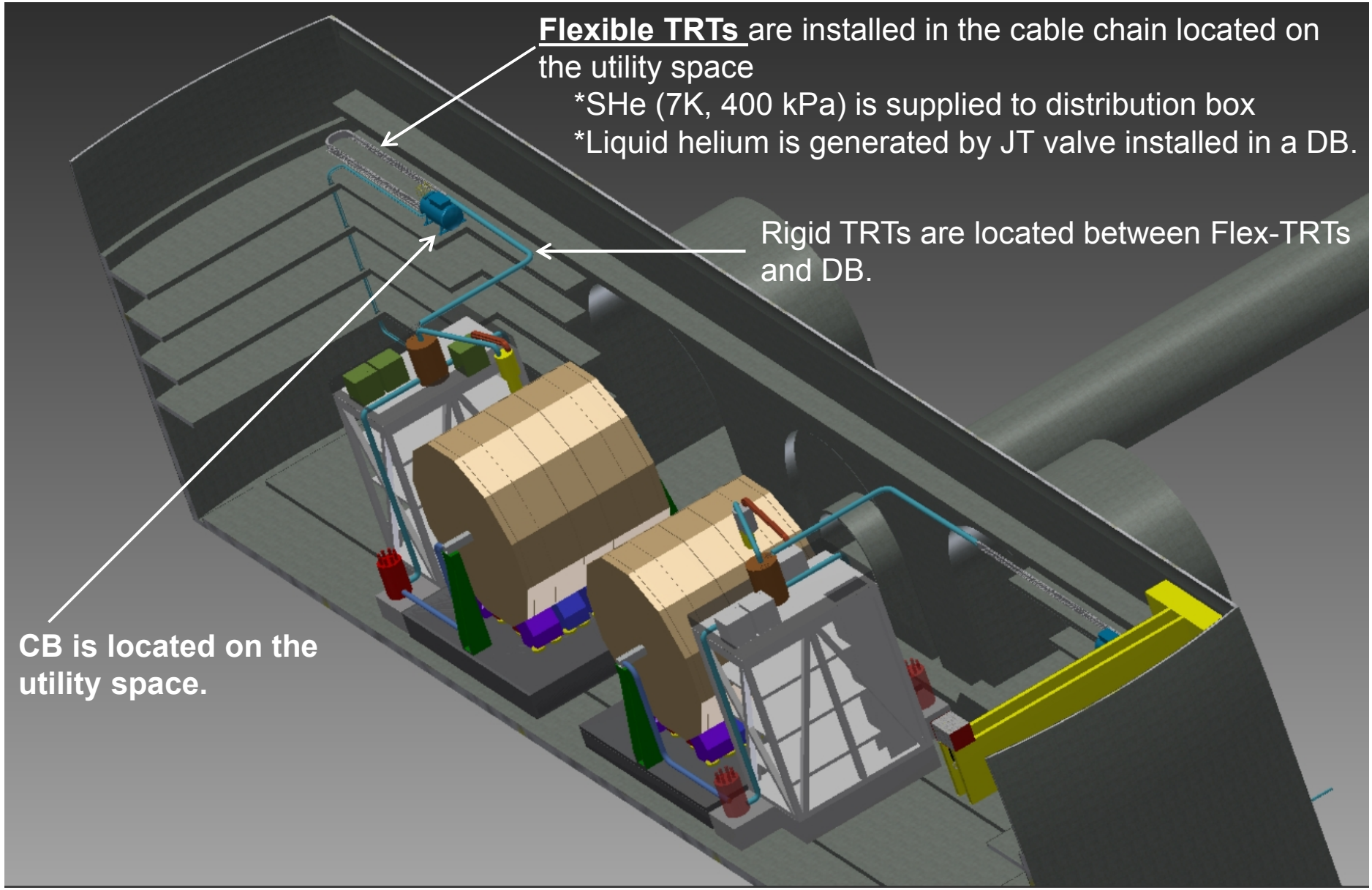


# Option B (2D Top view)

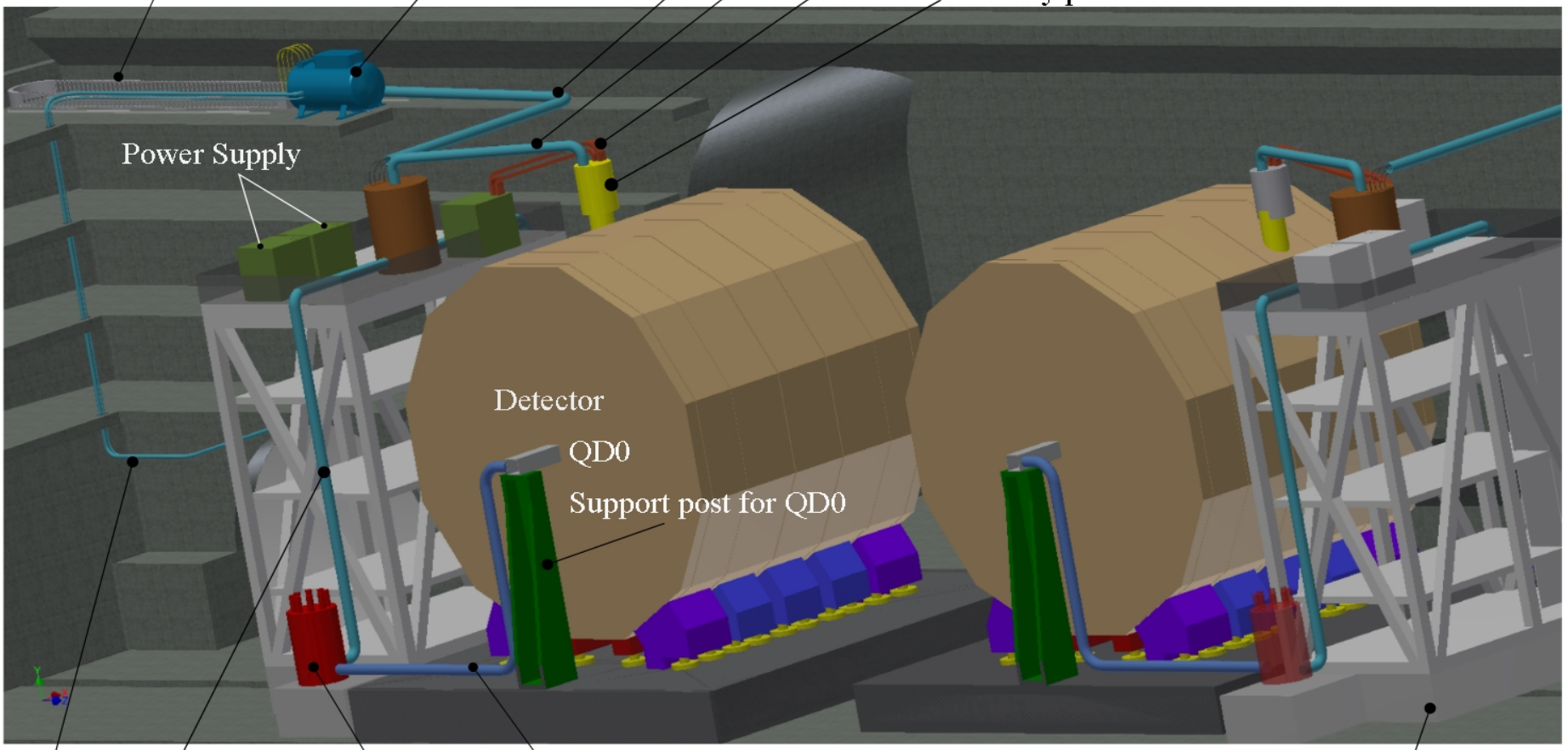
- **CBs are installed on a utility space.**
- **On the contrary, DB is located on the platform for cryogenic equipment (Green area).**
- **In this case, helium condition in the TRT between CB and DB is not liquid but supercritical (7K, 400 kPa-abs).**
- **By doing so, cold flexible TRTs with one in one 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)



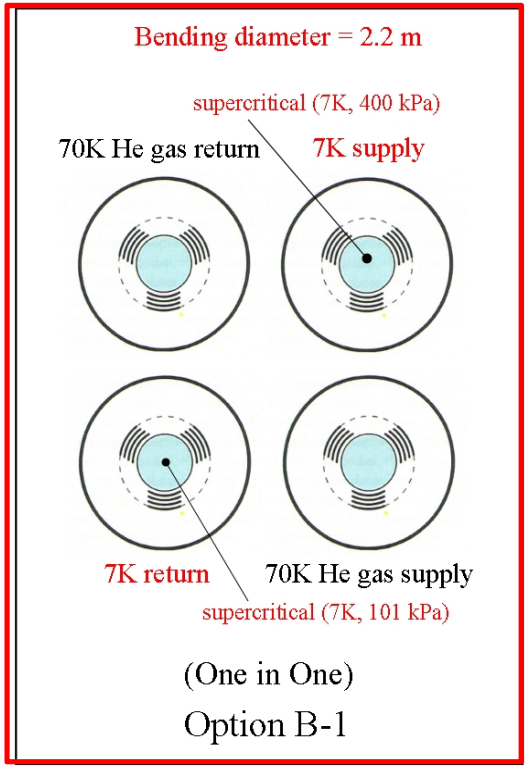
# Option B (Side View)



# Flexible TRT for Option B

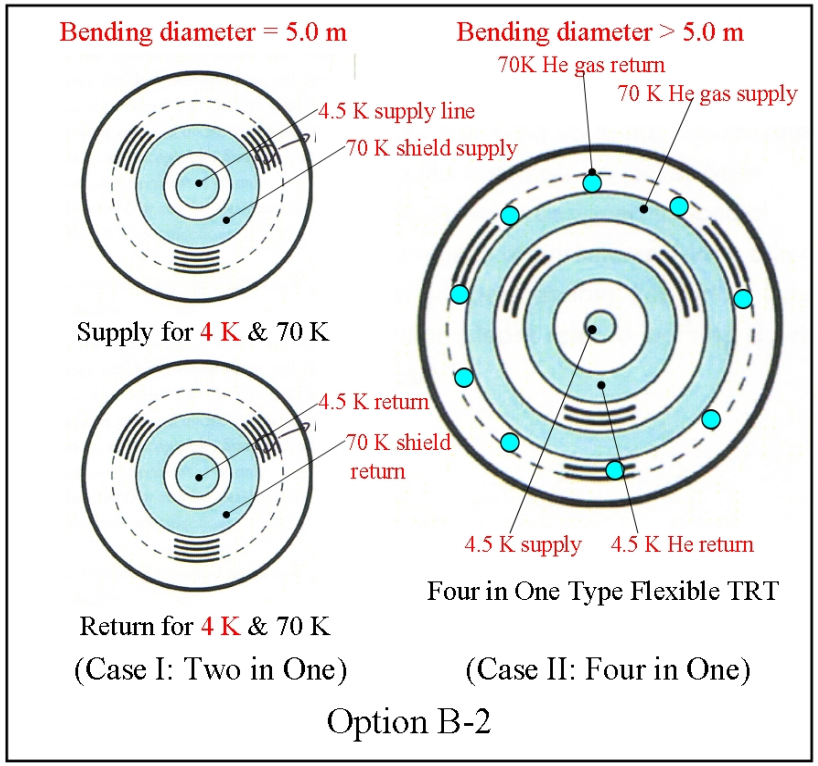
Practical structure of flex-TRT

**Bending Dia.= 2.2 m**




Impracticable structure of Flex-TRT

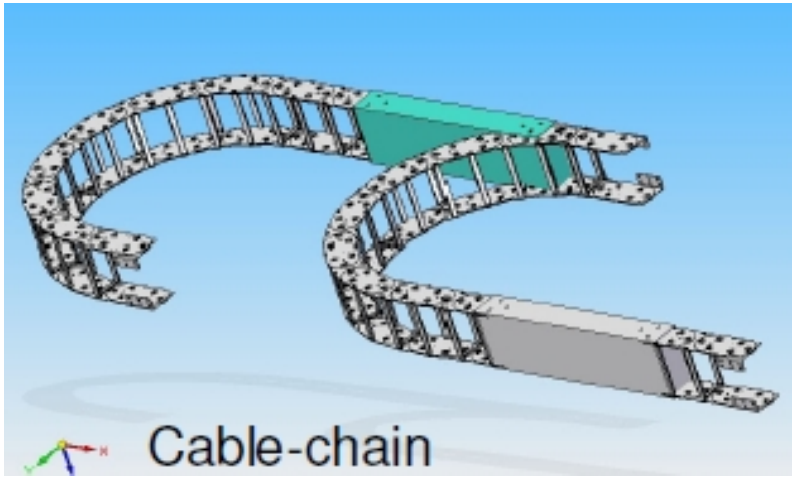
**Bending Dia> 5 m**




- 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 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.

# 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)

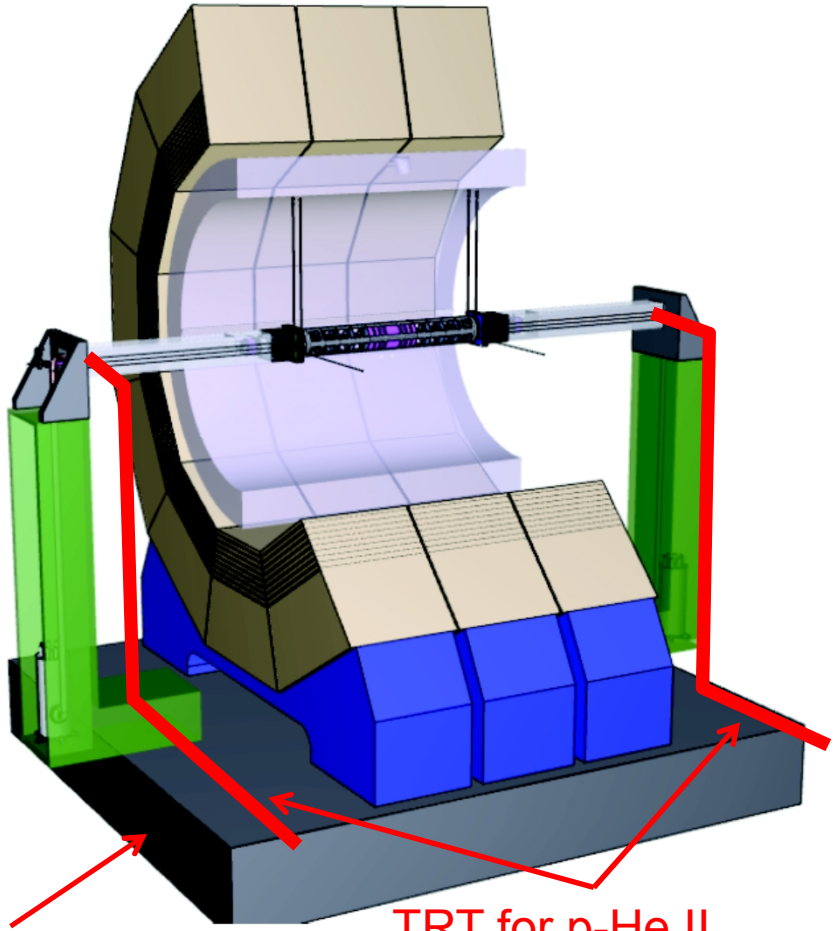
# QD0 vibration requirement

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.

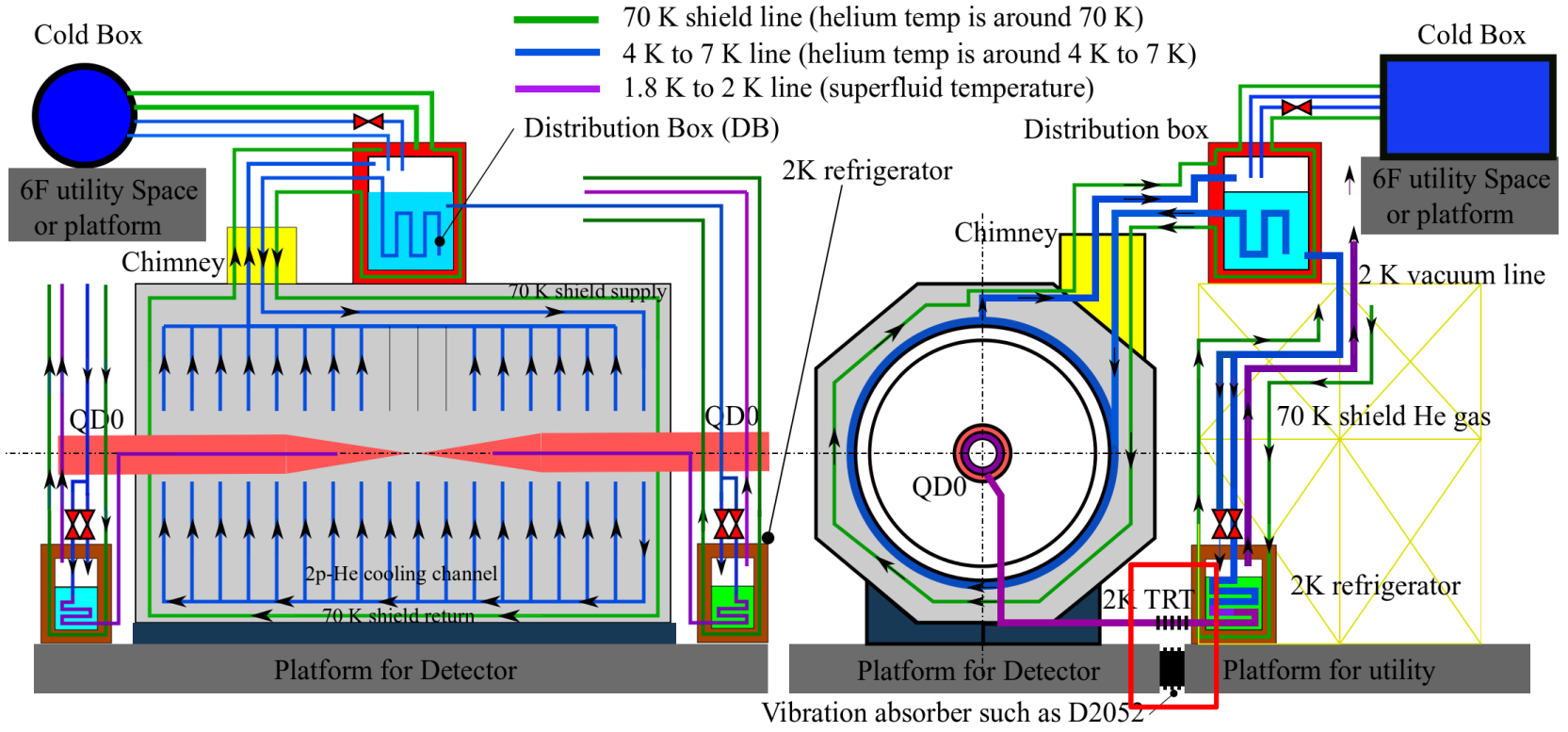
Therefore the platform for detector and TRT should be designed such that vibrations become minimum.



# Vibration Reduction

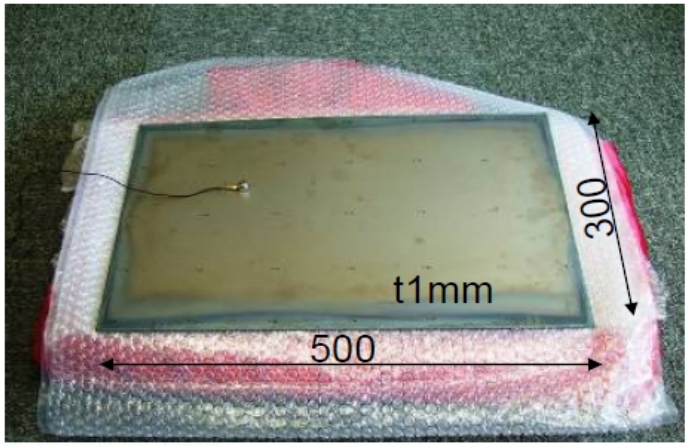
- Especially Option A is disadvantage from the view point of vibration.
- To reduce vibration of QD0, **platform for cryogenic equipment** should be prepared in addition to platform for detector. All equipment with vibration source should be installed on the platform for cryo-equipment.
- Vibration absorber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

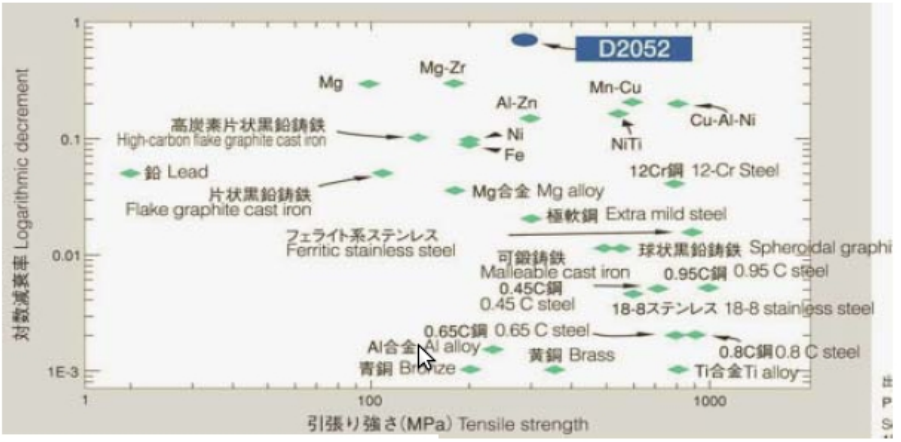
➔ **it is necessary to research vibration of QD0 (We have to do!)**



# 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

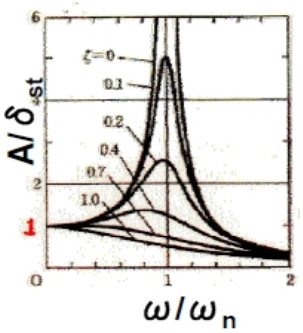
| Mn | Cu | Ni | Fe | 単位 Unit |
|---|---|---|---|---|
| Bal. | 22.4 | 5.2 | 2.0 | wt% |
| Bal. | 20.0 | 5.0 | 2.0 | at% |

## 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 (×10$^{7}$回) Fatigue strength(×10$^{7}$times) |
|---|---|---|---|---|---|
| 標準材 Standard material | 530MPa | 265MPa | 40% | 61% | 125MPa |



# 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** |