Cryogenic System for IR

KEK/IPNS

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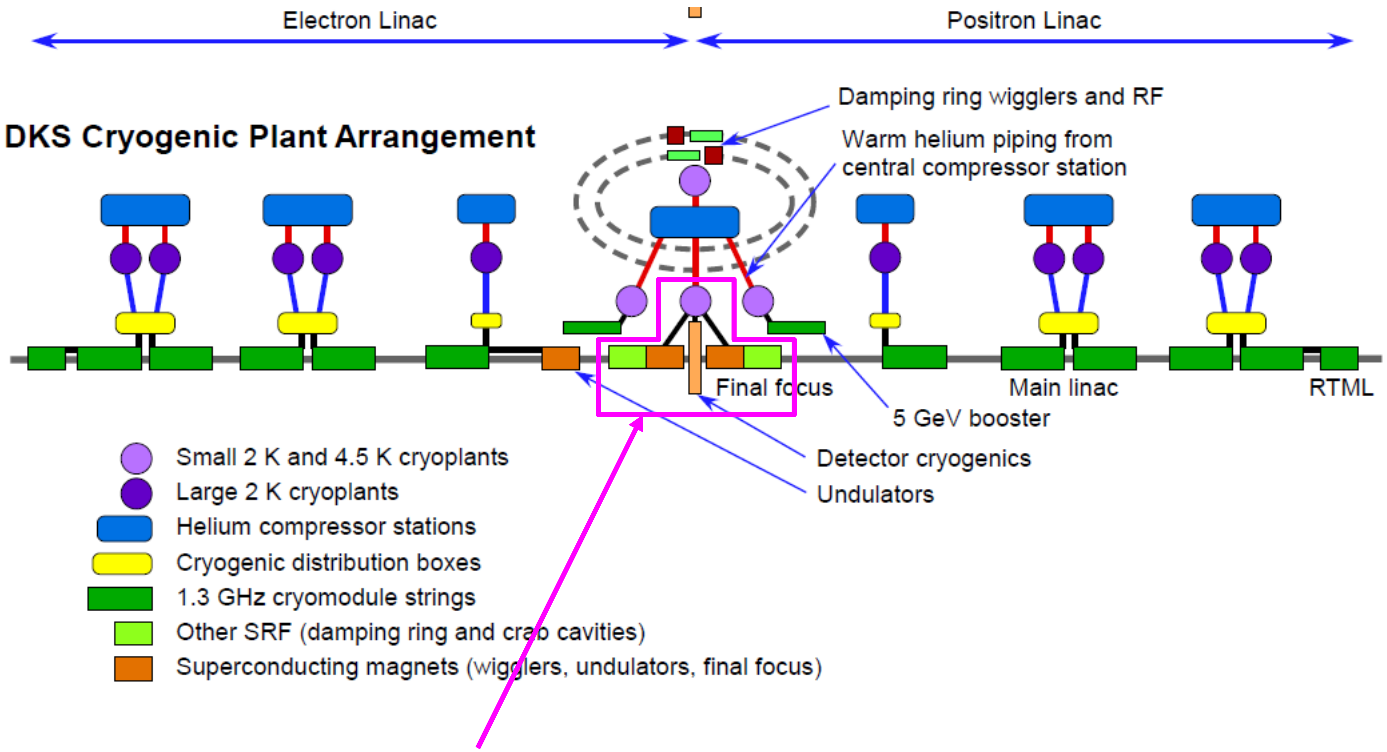
Configuration of Cryogenic System for ILC

Brief Decision of ILC cryogenics in mountain site

- Four small cryo-plants for detector, final focus, crab cavity, damping ring.
- 10 large cryo-plants for electron positron Linac



Today's talk is about cryogenics at IP (detector + Final focus + Crab cavity)

Cooling Strategy of IP cryo system

Definition : IP cryo system → cryo system for “Detector”, “QD0”, “QF1”, “CC”

- Three cold boxes are installed in the experimental hall (Utility Space).
- Two kinds of 2K refrigerator should be prepared.
  - One for QD0, the other for QF1 and CC

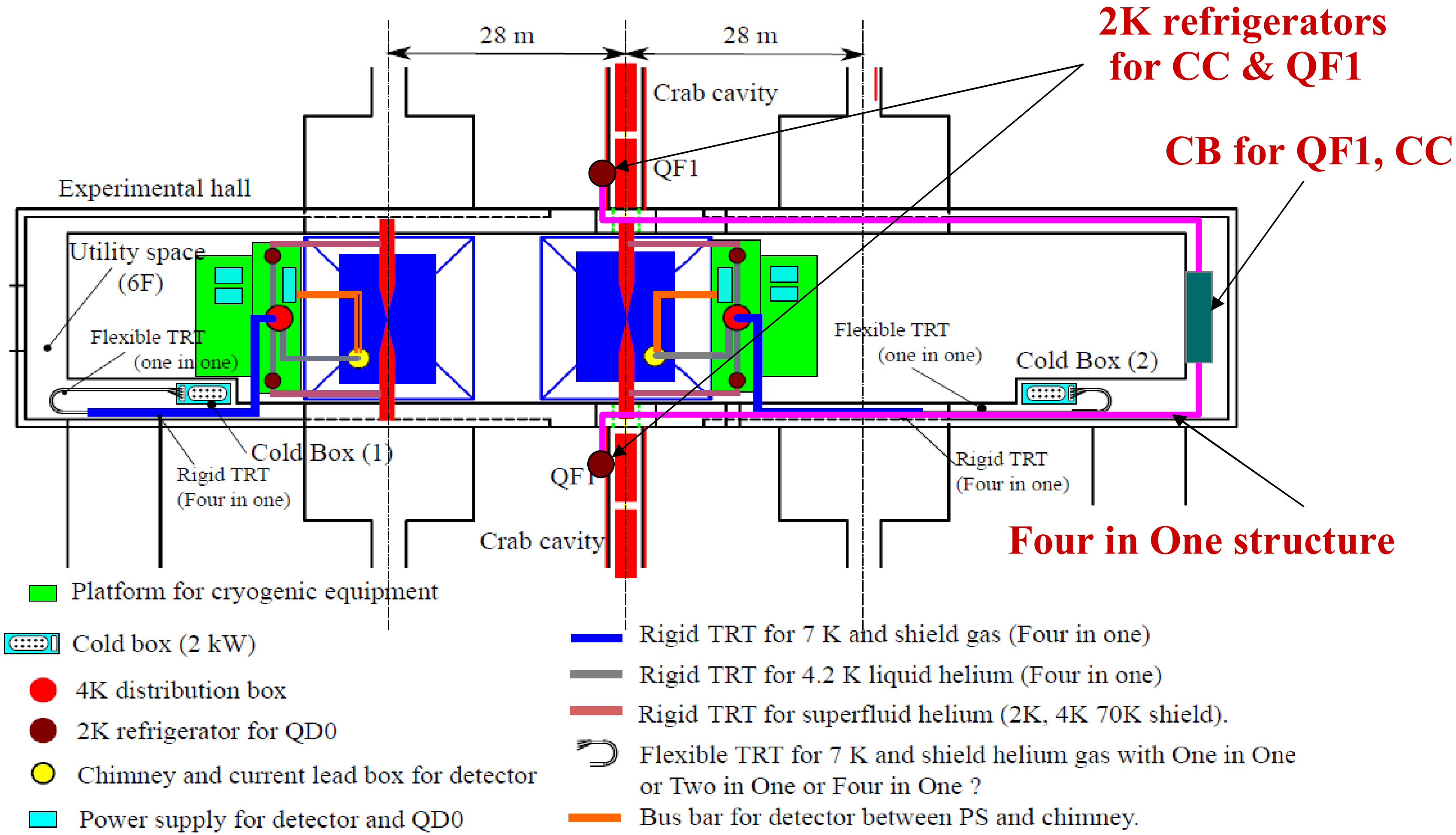
Table1 : Summary of cryogenic system for each superconducting equipment of IR

	Total num	ILD + QD0 (pushpull)	SiD + QD0 (pushpull)	CCs + QF1s (fix)
4K Cold BOX (W, location)	3	2.0 kW platform or hall space	2.0 kW platform or hall space	~1.0 kW hall space
2 K refrigerator (location)	6	P-He II Platform	P-He II Platform	S-He II & P-He II Accelerator tunnel
TRT from CB (length)		rigid or flexible (5m or 30m)	rigid or flexible (5m or 30m)	Rigid (40m)
Compressor	3	700 kW	700 kW	350 kW

* 1.8 K refrigerator : 850 W / W, 4.5 K refrigerator : 350 W / W

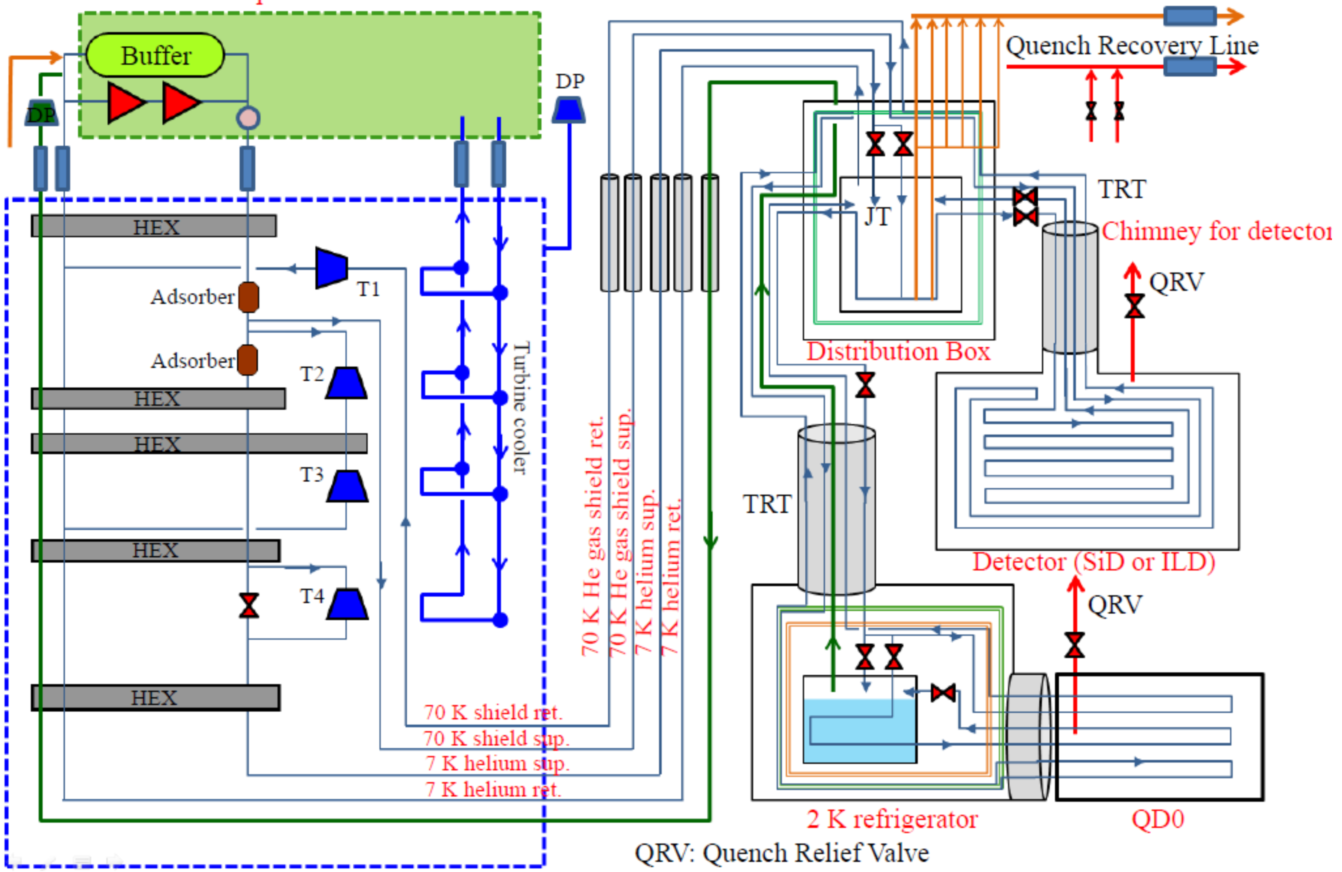
Installation Location of CB

- A cold box for CC and QF1 will be installed in the IR hall (utility space)
- Two 2K refrigerators are installed adjacent to the both side of the QF1 (in the accelerator tunnel)



Cryogenic Configuration for ILD (SiD)

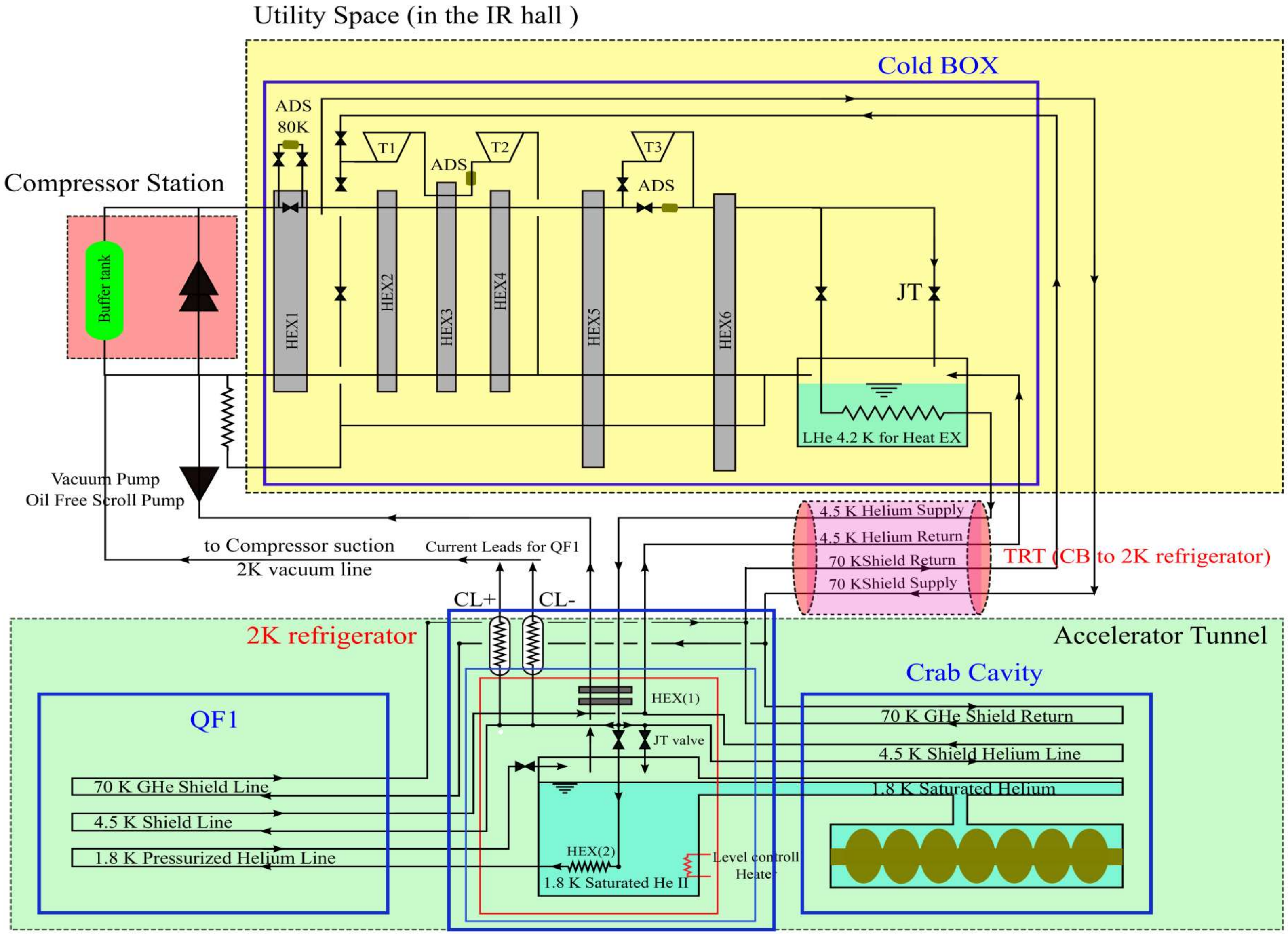
• The configuration for detector parts was already introduced in the previous workshop.
• Installation location of CB is quite important from the viewpoint of vibration of QD0.
• In the future, CB location will be determined by discussing SLAC and by performing fundamental studies (dynamic simulation and vibration measurement).



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

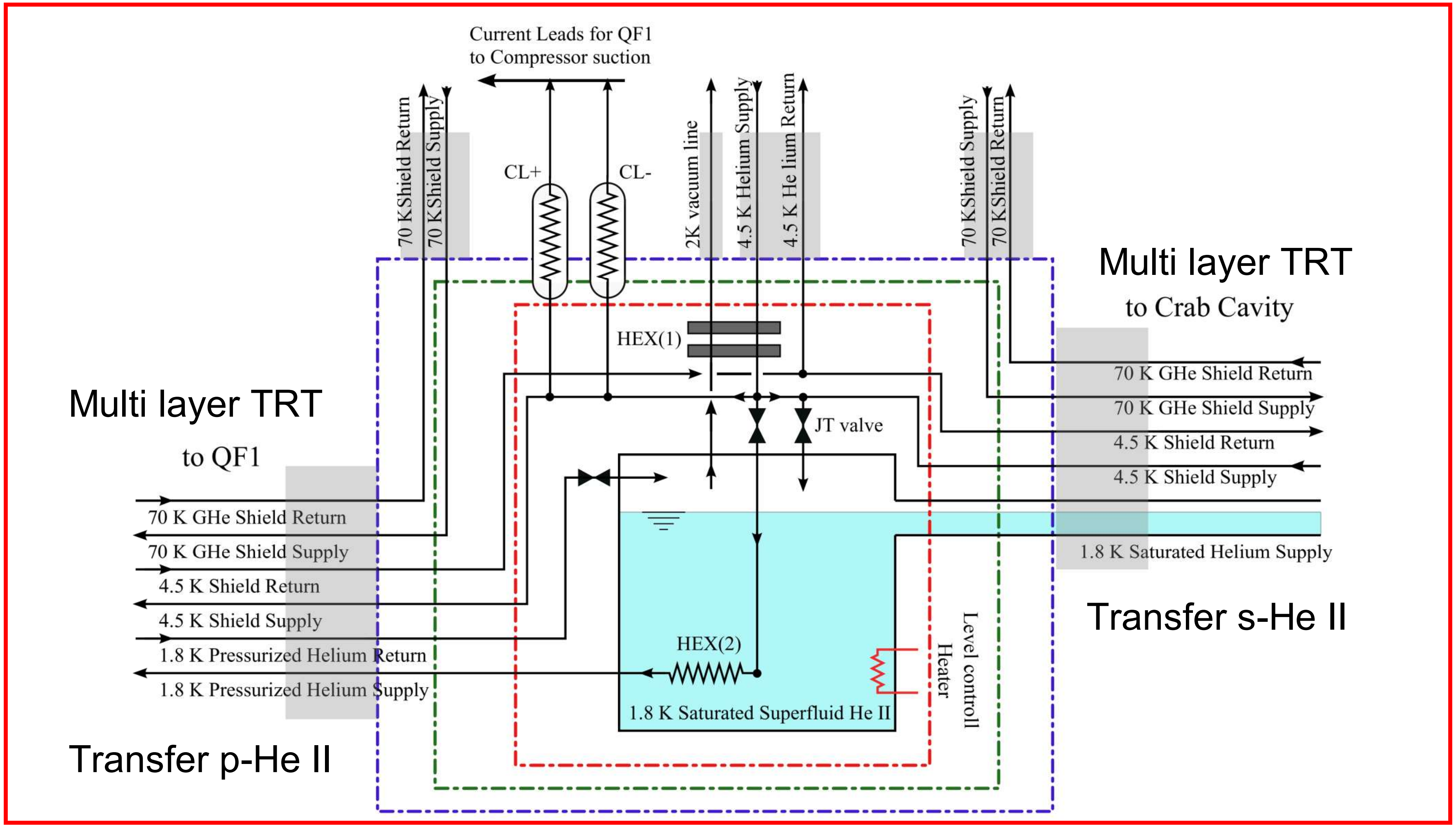
Cryogenic System for QF1 and CC

- Saturated and Pressurized He II are generated by a 2K refrigerator.
- Kernel of this system is clearly structure of 2K refrigerator.



Flow diagram of 2K refrigerator for CC &QF1

- Two Heat exchangers, HEX1 and HEX2
- JT valve to obtain s-HeII, flow control valves
- Current leads for QF1 are equipped (but the other solution is to install CL at Cryostat of QF1)



Action Item

1. Two phase flow simulation in the cooling channel of detector.

2. Thermo-fluid simulation of saturated and pressurized superfluid helium for QD0, QF1 and CC

3. Dynamic simulation of 2K and 4K combined cryo plants as introduced above.

Solenoid Cooling

- Large scale of superconducting solenoid as ILD and SiD is cooled by forced convective or natural convective cooling by means of two phase flow LHe.
- Cooling design of CMS is good bible. Both cooling can be performed and they can obtain successful results of cooling down of solenoid.
  - Parallel channel induces flow instability which means that two phase flow occurs only in one channel, the flow does not occur in other channel.
  - Voild fraction induces vibration in the cooling channel.
- Flow condition of two phase in the cooling channel should be clarified in order to make cryo system optimal design from various view point such as flow instability, vibration and so on.
- We will perform two phase flow simulation on the ILD cooling system.

Simulation method

- Calculation load becomes large in case of two or three dimensional simulation.
- To reduce the load, simulation is performed by MPI.
- Following two fluid equation (mass, momentum, energy conservation) defined by generalized coordinate system is solved numerically by means of FVM.

$$\frac{\partial}{\partial t}(\alpha\rho_g) + \nabla \cdot (\alpha\rho_g \mathbf{u}_g) = \Gamma_{gi}$$

$$\frac{\partial}{\partial t}[(1-\alpha)\rho_l)] + \nabla \cdot [(1-\alpha)\rho_l \mathbf{u}_l] = \Gamma_{li}, \qquad \Gamma_{gi} + \Gamma_{li} = 0$$

$$\frac{\partial}{\partial t}(\alpha\rho_g \mathbf{u}_g) + \nabla \cdot (\alpha\rho_g \mathbf{u}_g \mathbf{u}_g) = -\alpha\nabla p - \mathbf{F}_{wg} + \alpha\rho_g \mathbf{g} - \mathbf{F}_{lg} - \mathbf{F}_{\mathrm{VM}}$$

$$\frac{\partial}{\partial t}[(1-\alpha)\rho_l \mathbf{u}_l] + \nabla \cdot [(1-\alpha)\rho_l \mathbf{u}_l \mathbf{u}_l] = -(1-\alpha)\nabla p - \mathbf{F}_{wl} + (1-\alpha)\rho_l \mathbf{g} + \mathbf{F}_{lg} + \mathbf{F}_{\mathrm{VM}}$$

$$\frac{\partial}{\partial t}(\alpha\rho_g e_g) + \nabla \cdot (\alpha\rho_g e_g \mathbf{u}_g) = -p\nabla \cdot (\alpha \mathbf{u}_g) - p\frac{\partial \alpha}{\partial t} + Q_{wg} + Q_i - Q_{tg}$$

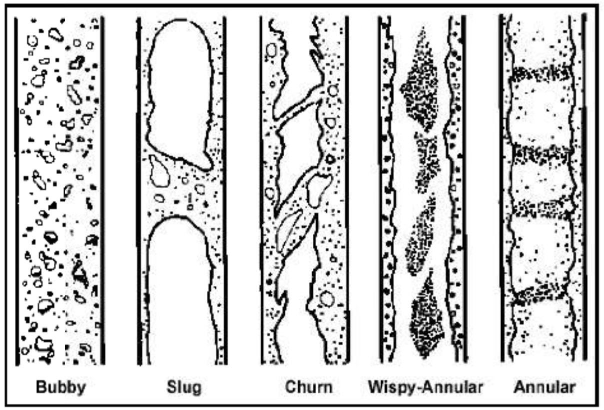
$$\frac{\partial}{\partial t}[(1-\alpha)\rho_l e_l] + \nabla \cdot [(1-\alpha)\rho_l e_l \mathbf{u}_l] = -p\nabla \cdot [(1-\alpha)\mathbf{u}_l] + p\frac{\partial \alpha}{\partial t} + Q_{wl} - Q_i - Q_{tl}$$

Test Run Results

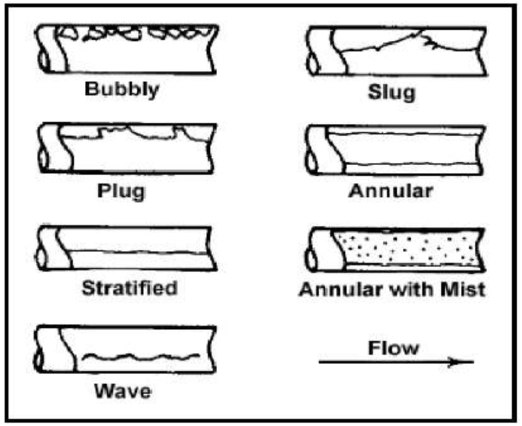
- We performed two phase flow simulation on the very simple test channel.
  (So far, we don't perform actual case.)

  Mass flow rate : 20 g/sec
  Inlet quality, x=0.45
  isothermal system,
  Cooling channel diameter : d=20mm
  Total cooling channel length : L=9 m

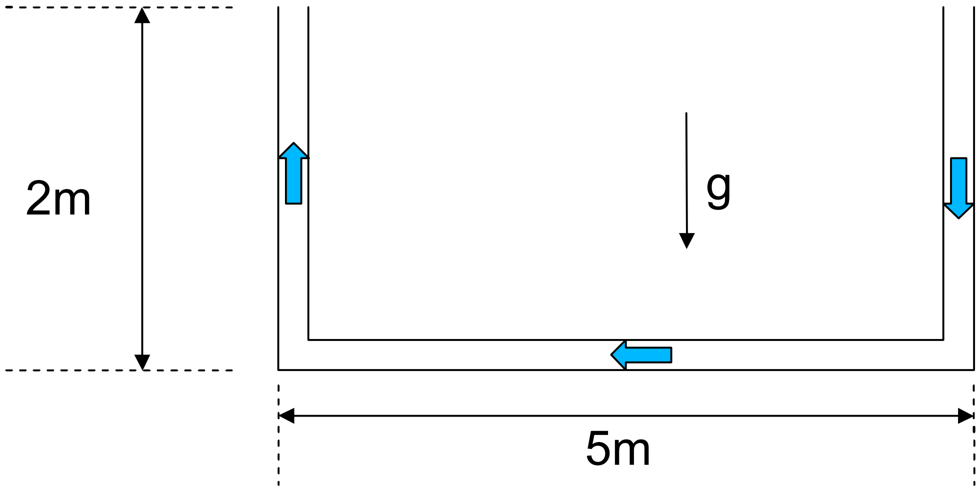
- The purpose is to confirm the simulation code and flow pattern induced in the horizontal and vertical channel under the gravitational field .



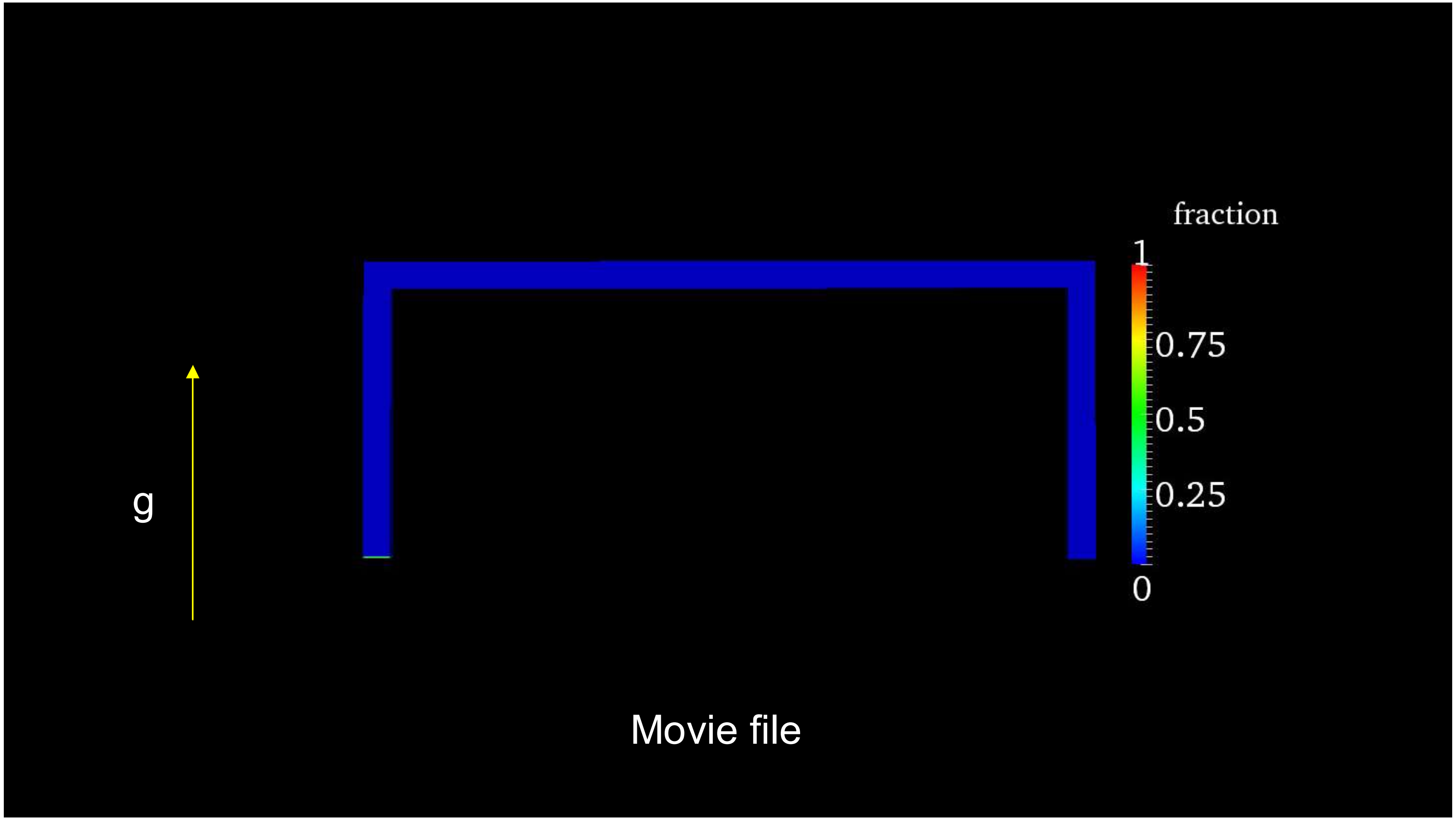
Flow patterns of Vertical channel



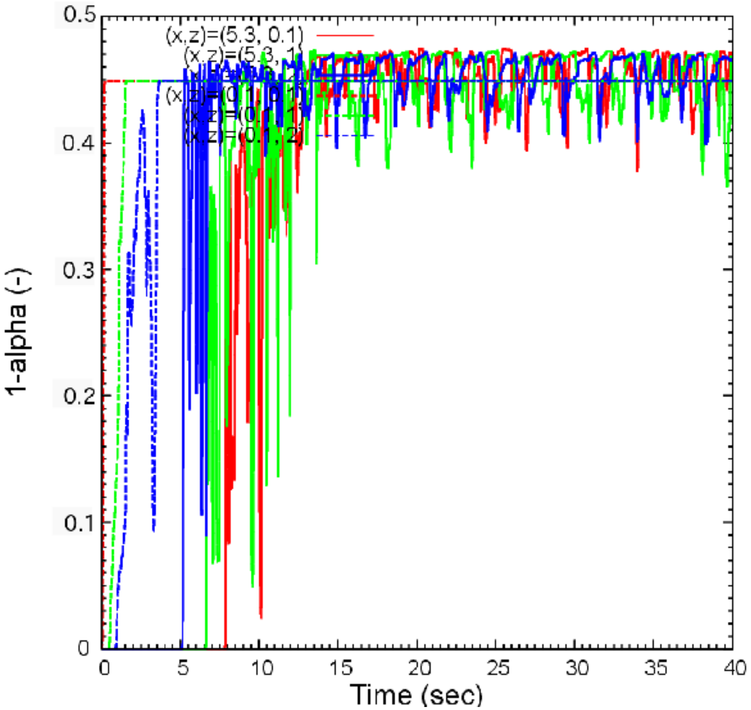
Flow patterns of horizontal channel

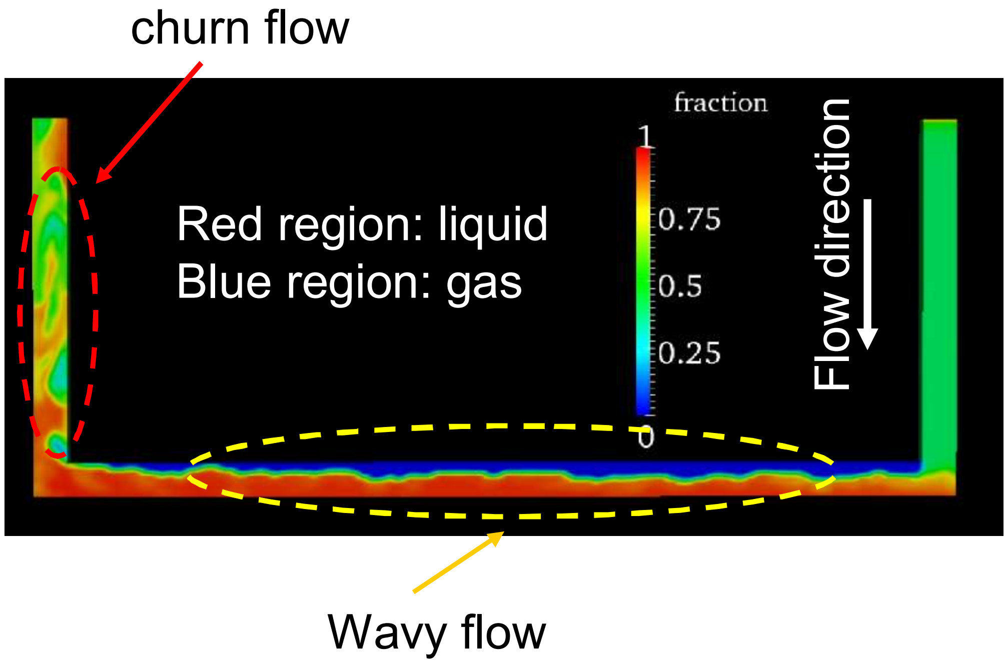


Time evolution of void fraction in the case of simple channel.



Time dependent of void fraction





In the transient state, fluctuation of fraction becomes large compared to the steady state.

Flow pattern in the horizontal channel regime is wavy like flow.
Flow pattern in the vertical channel regime is like churn flow.

Cooling condition of QD0, QF1 and CC

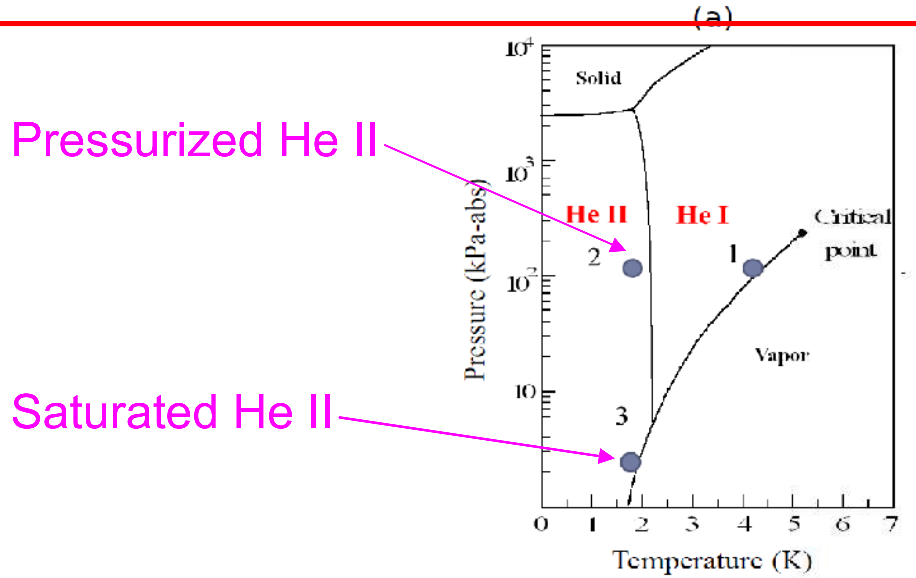
QF1, QD0

- Coolant = Pressurized He II (1.8 K ~ 2.0 K)
- Heat Load = 15 W@1.8 K
- Inventory = ?

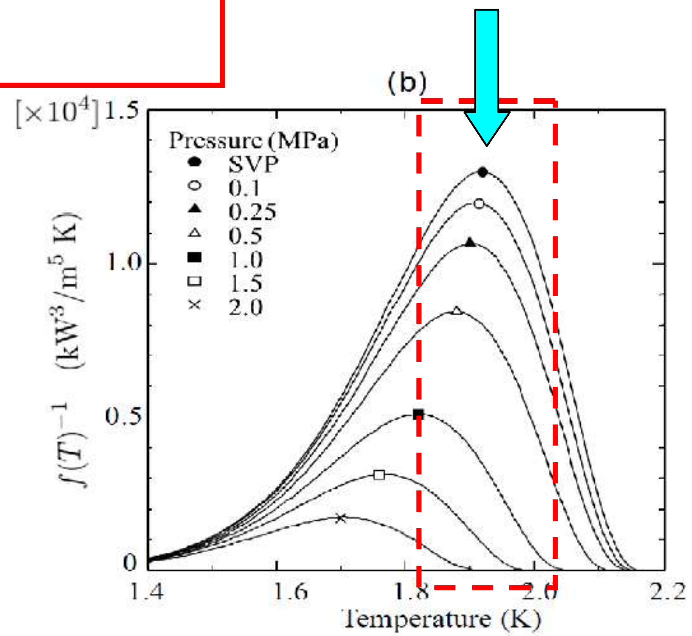
Crab Cavity

- Coolant = Saturated He II (1.8 K ~ 2.0 K)
- Heat Load = 10 W@ 1.8 K
- Inventory = ?

- Non nucleate boiling in the case of He II
- It is suitable to reduce vibration of final focus magnet



Large heat transfer function
Around 1.8K



Superfluid helium is not perfect fluid (especially in the case of turbulent state).
Maximum temperature which strongly depends on cooling channnel shape should be less than lambda temp.

Numerical Simulation for cryo design of QD0

Behavior of superfluid helium can be described by Landau two fluid equation with Gorter-Mellink superfluid turbulent model.

Mass conservation

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}\left(\rho_{(s)} u_{(s)j} + \rho_{(n)} u_{(n)j}\right) = 0$$

Total fluid momentum equation

$$\frac{\partial}{\partial t}\left(\rho u_i\right) + \frac{\partial}{\partial x_j}\left(\rho_{(s)} u_{(s)i} u_{(s)j} + \rho_{(n)} u_{(n)i} u_{(n)j} - T_{ij}\right) = \rho f_i$$

Superfluid momentum equation

$$\frac{\partial u_{(s)i}}{\partial t} + u_{(s)j}\frac{\partial u_{(s)i}}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + s\frac{\partial T}{\partial x_i} + \frac{\rho_n}{2\rho}\frac{\partial}{\partial x_i}\left|u_{(n)j} - u_{(s)j}\right|^2 - A\rho_{(n)}\left|u_{(n)j} - u_{(s)j}\right|^2\left(u_{(n)i} - u_{(s)i}\right)$$

Energy conservation

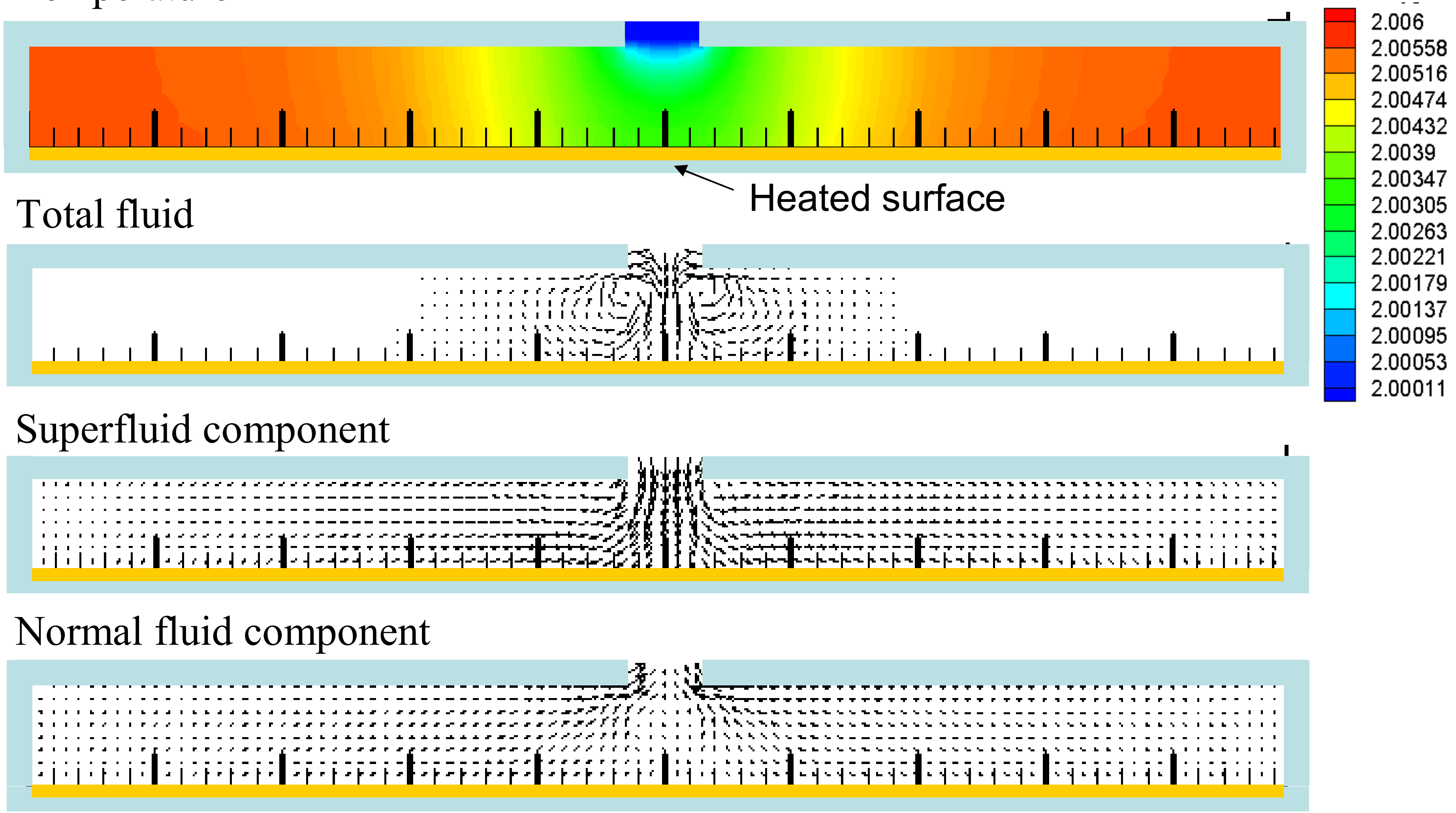
$$\frac{\partial}{\partial t}\left(\rho s\right) + \frac{\partial}{\partial x_j}\left(\rho_{(n)} s u_{(n)j}\right) = \frac{A\rho_{(n)}\rho_{(s)}\left|u_{(n)j} - u_{(s)j}\right|^4}{T}$$

Constitutive equation

$$T_{ij} = -p\delta_{ij} + 2\mu\left(D_{ij} - \frac{1}{3}\delta_{ij}\frac{\partial u_{(n)k}}{\partial x_k}\right), \qquad D_{ij} = \frac{1}{2}\left(\frac{\partial u_{(n)i}}{\partial x_j} + \frac{\partial u_{(n)j}}{\partial x_i}\right)$$

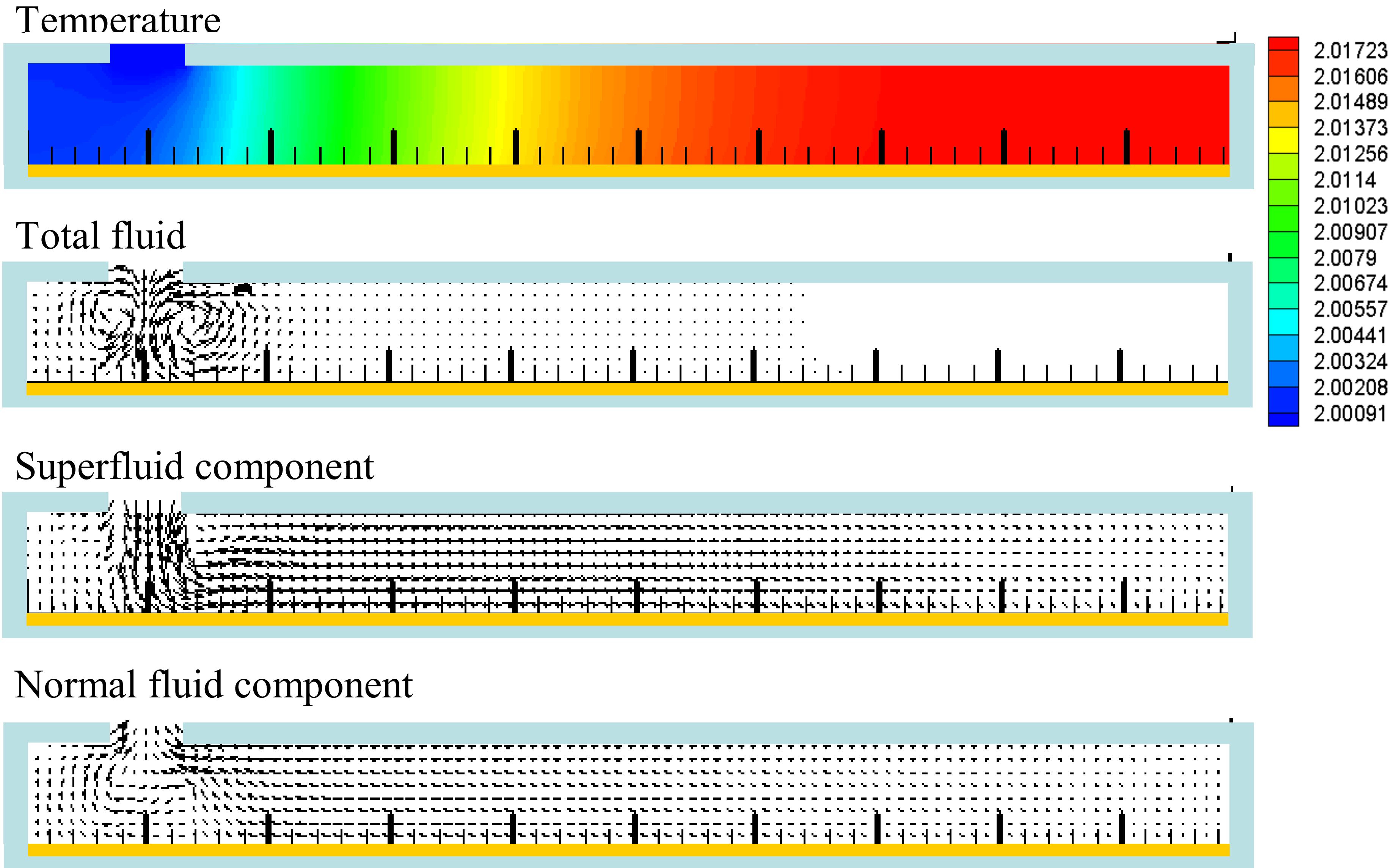
Numerical Results example1
In case that jacket tube is located at the center of the vessel.

Temperature



150ms時 maximum temp.=2.006K

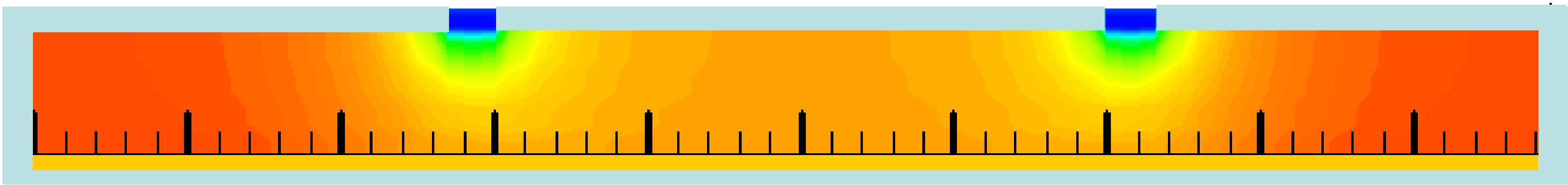
Numerical Results example2
In case that jacket tube is located at the end of the vessel.

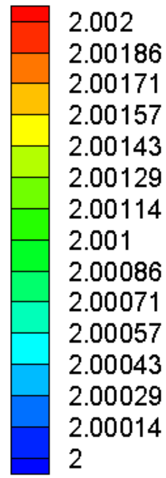


150ms時　maximum temp.=2.017 K

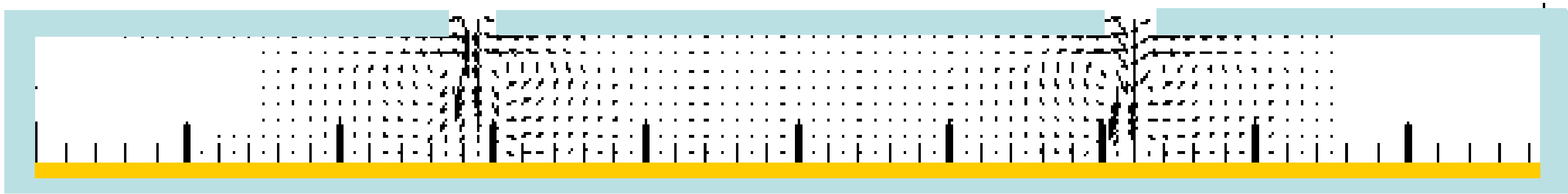
Numerical Results example 3
In case that two jaket tubes are installed as shown in followings.

Temperature

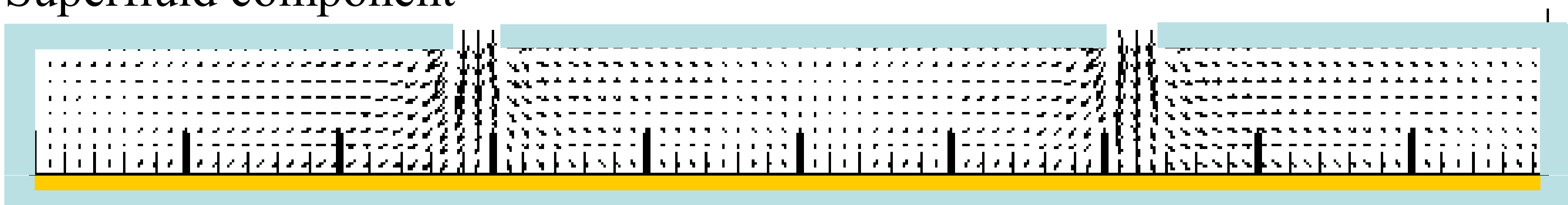




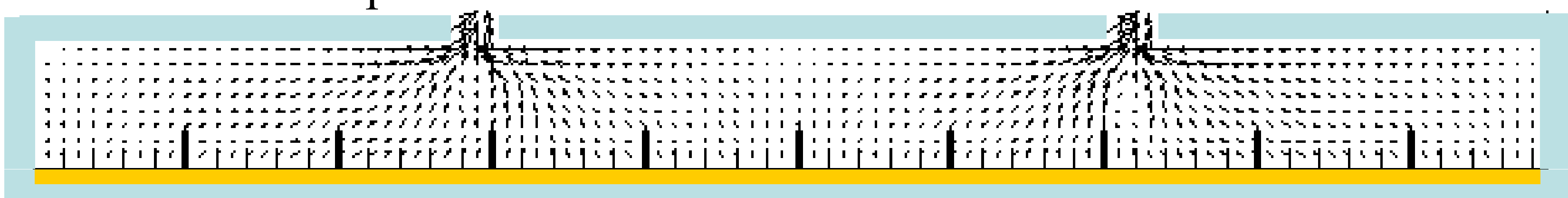
Total fluid



Superfluid component



Normal fluid component



150ms時　maximum temp.=2.002 K

Summary

Now we are preparing the numerical tools to establish optimal designs of cryogenic system of IP with 2K and 4K refrigerators.

1. Two phase flow simulation in the cooling channel of detector.

2. Thermo-fluid simulation of saturated and pressurized superfluid helium for QD0, QF1 and CC

3. Dynamic simulation of 2K and 4K combined cryo plants as introduced above.

- After validity confirmation, we will simulate actual superconducting system.
- To perform actual case, we have to input accurate condition….
    - Obtained results are fed back cryogenic configuration.