Jitter sources in the cryogenics system at IR

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Purpose

The limit on the vibration amplitudes of QD0 is given at 50 nm within the 1 ms long ILC bunch train.

- It is necessary to employ a lot of cryogenic equipment in the IR experimental hall because in the central region, there are not only detector solenoids for ILD and SiD but also two pairs final focusing magnets, QD0s. The cryogenic equipment can be considered to be a vibration source.
- In order to cool down the superconducting magnets, forced convection cooling , thermo syphon cooling or pool cooling should be employed.

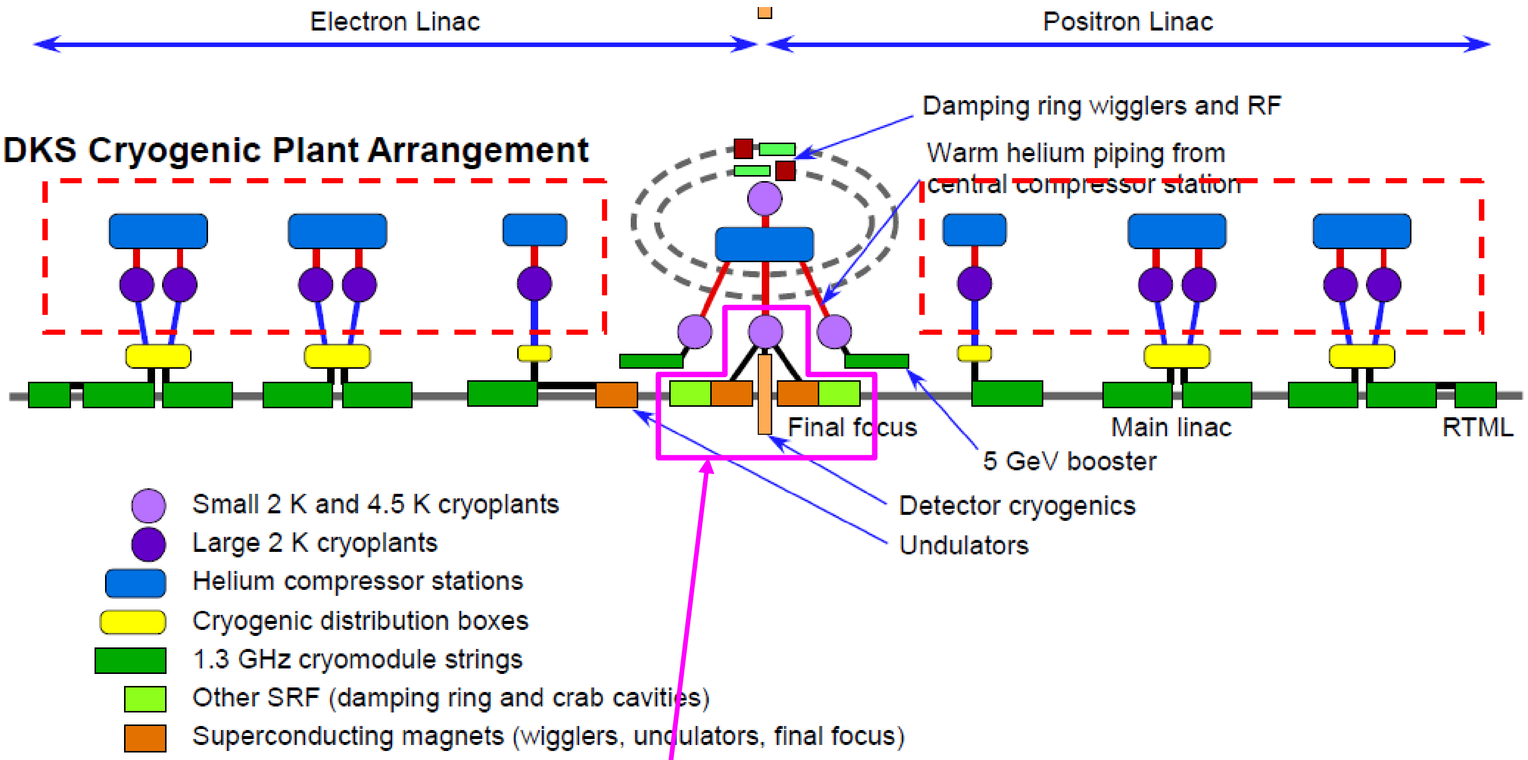
  Sometimes the cooling itself by the helium sometimes induces various kinds of vibration.
- There are a lot of vibration sources (mechanical vibration for infrastructure and fluid induced vibration) in the IR cryogenic system

- The assumed vibration source and its dumping methods for QD0 are discussed qualitatively in this presentation.

Introduction of the configuration of ILC-IR cryogenics

ILC Cryogenic Strategy

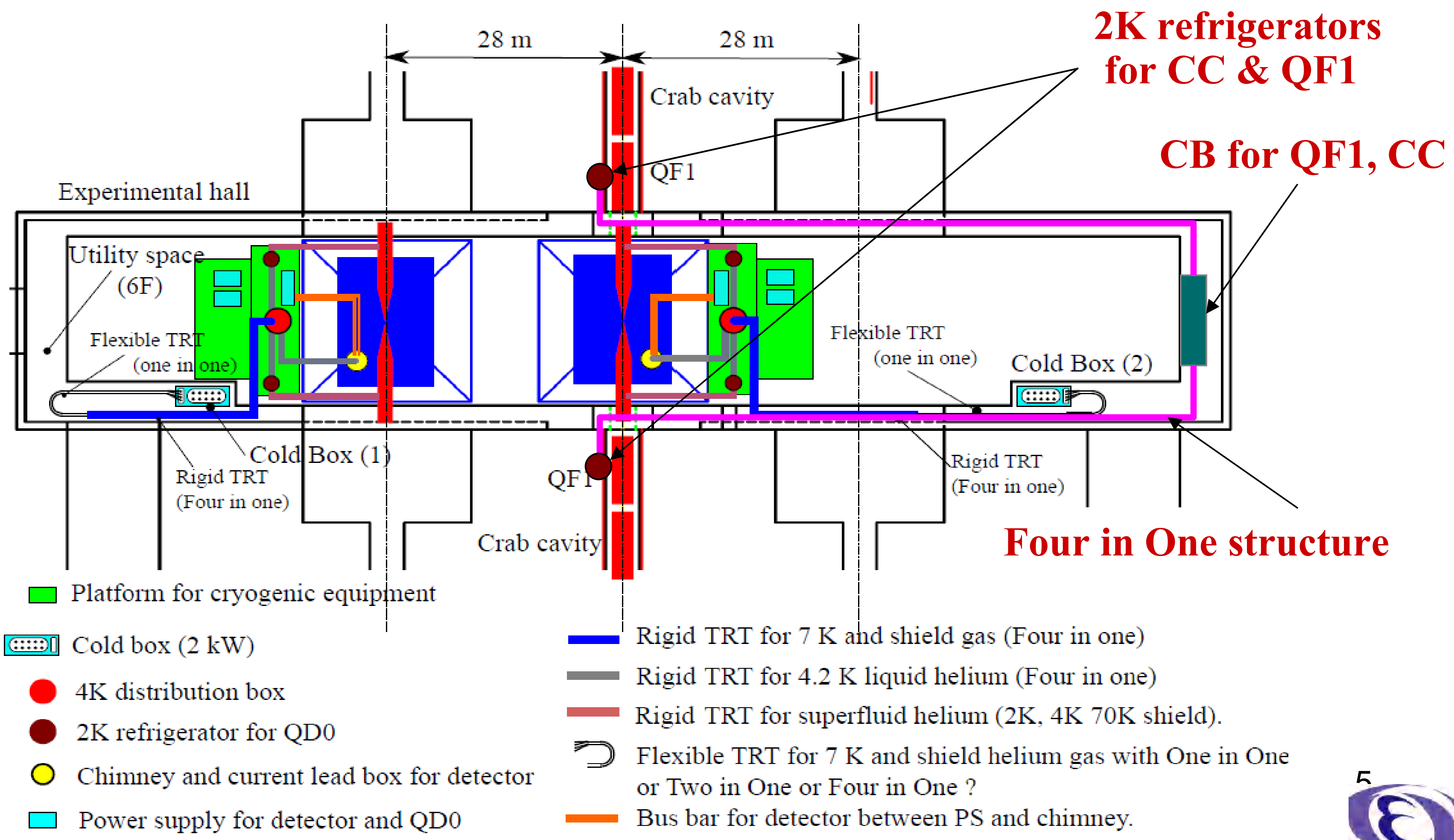
- Four small cryo-plants for detector, final focus, crab cavity, damping ring.
- 10 large cryo-plants for electron positron Linac



- Goal is to establish optimal configuration for IR cryogenics (Detector, Final focus).

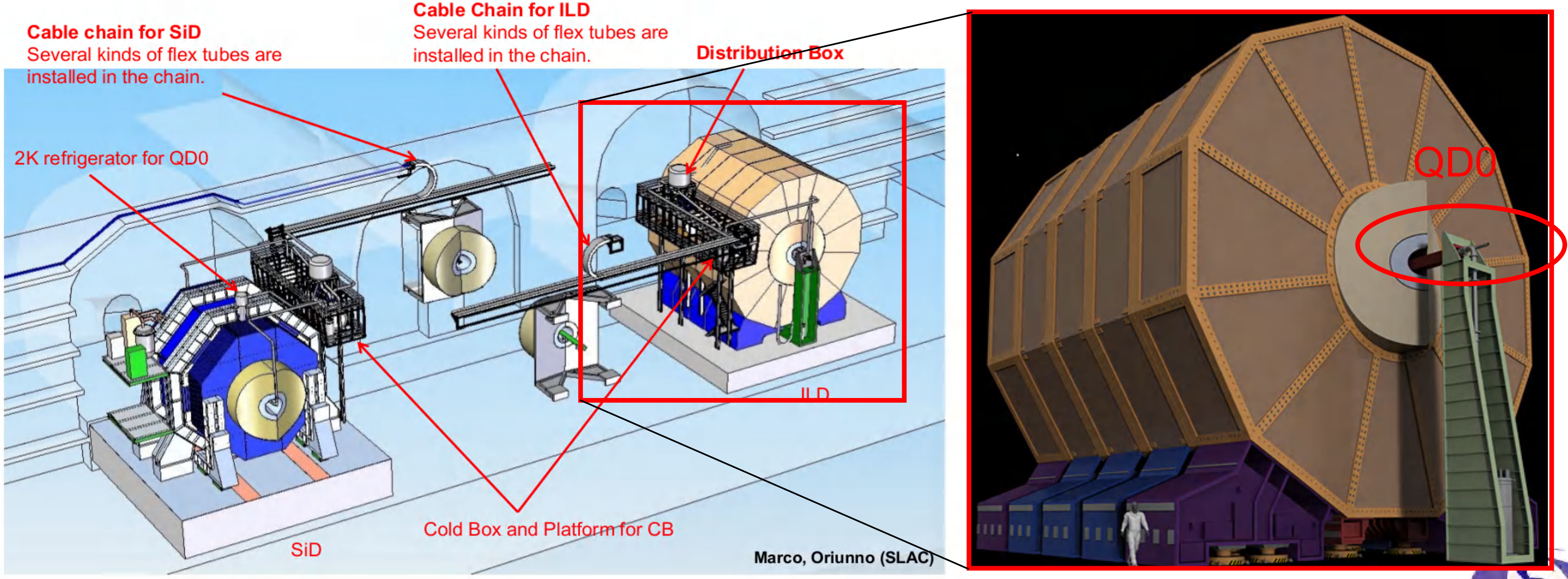
Central Region

- Superconducting magnets : detector solenoids(SiD,ILD), final focus(QD0, QF1) and CC
- Refrigerator : Cold box , 2K refrigerators



Layout example for Push-Pull Operation

- Two detectors (SiD & ILD) will be employed in the central region to allow for independent cross-check of the measurement.
- ILC design foresees to have two detectors that share one interaction region in a push-pull operation scheme.
- In that scheme, one detector would take data, while the other one is waiting in the close-by maintenance position.



Cooling Strategy of IP cryogenic system

- 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

Jitter sources in the cryogenics system

Flexible TRT

- **In the case that cold boxes for each detector aren't installed on the platform (cold box for ILD is installed in a utility space in the IR hall)**

Multilayer flex tubes have to be employed.

- bending frequency : twice a month
- bending diameter : 2-3m
- reliability ?
- bending occurs

We have to develop the TRT satisfying above requirement.

It has large degree of freedom to reduce vibration of QD0 due to the cold box oscillation.

Flex TRT with multi structure for insulation

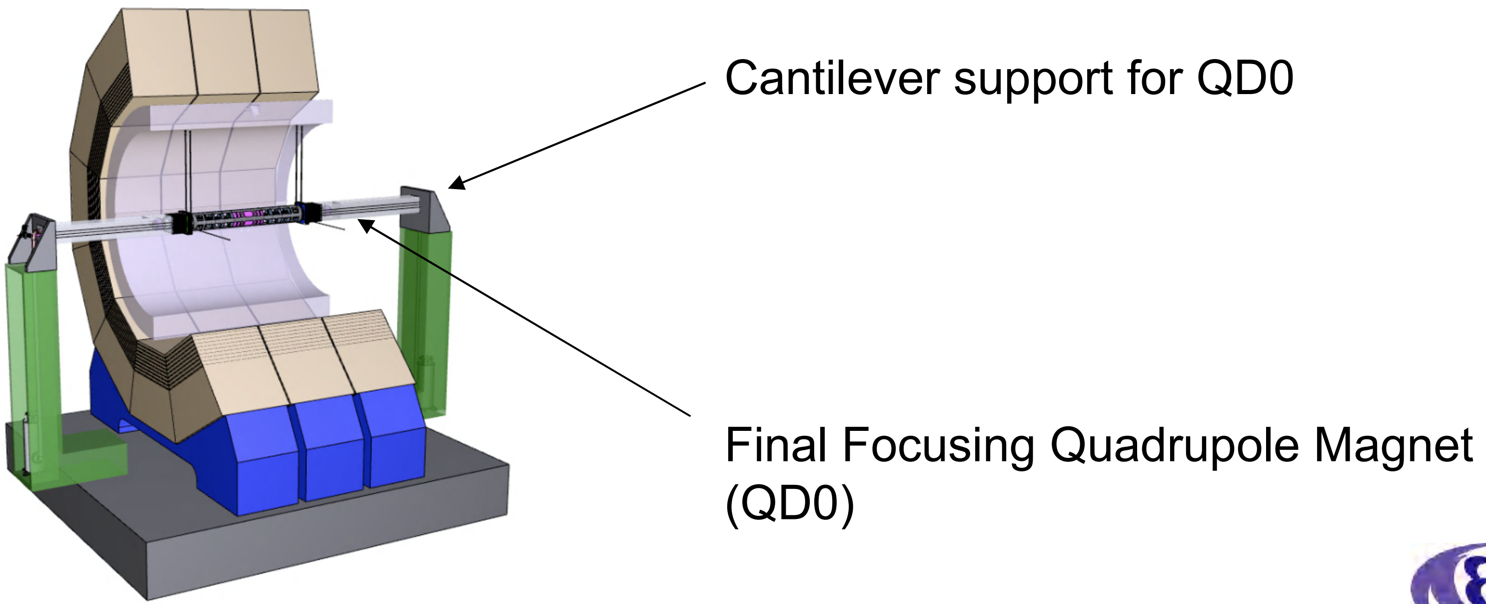
- **In the case that cold boxes are installed on the platform for push-pull.**

Single layer flex tubes can be employed for push-pull.

In this case, we have to build a optimal configuration to dump vibration efficiency within the limited length.

Integration with Final Focus Magnets

- Due to the pushpull operation, SiD and ILD will have their own pair of QD0 magnets that move together with the detector during push-pull.
- Cantilever support system for QD0 will be employed so far.
- The biggest concerns for the QD0 support system are the alignment and the protection against various vibration sources.
- In order to reduce the vibration of QD0, QD0 will employ superconducting magnet rather than normal one and the magnets will be cooled by pressurized superfluid helium so far.



Assumed vibration sources

- **ground vibration**
- **Mechanical vibrations**
  - cold box
    - Vibration source : turbine, vacuum pump for adiabatic vacuum layer
  - compressor
    - Vibration source : Fluid motion, screw compressor itself, cooling water
  - 2K refrigerator
    - Vibration source : vacuum pump for AVL and saturated He II bath
  - power supply for excitation of magnets.
    - Vibration source : Cooling water, transformer with 50Hz , IGBT, thirstier with high frequency
- **Fluid induced vibrations**
  - Single phase
    bending tube, bellows oscillation.

  - Two phase flow (is applied to cool down detector solenoid)
    various kinds of instability sometimes occurs due to the fluid condition.
    These kinds of instability induces vibration in the cooling channel.

  - Superfluid: (is employed to cool down QD0s)
    Nucleate boiling is not generated in the pressurized superfluid helium.

Vibration reduction method?

■ Compressor (screw compressor)

reduction of the shaft power of compressor

→ reduction of the rotational speed of the screw

→ mechanical vibration from motor may be reduced.

In order to perform this, compressor with the specifications that are higher than a required value should be chosen.

reduction of the mass flow rate by performing the low energy operation

→ fluid induced vibration may be reduced

■ Mechanical vibration from other equipment (Cold box, vacuum pump)

employment of flexible tubes

→ Acoustic impedance mismatch is generated spontaneously at the interface between SUS rigid tube and flex tube.

→ the material of flexible tube should be intentionally changed from the material of rigid tube.

→ the flex material satisfying the law of high pressure regulation should be chosen

■ Fluid induced vibrations

Bellows oscillation due to Single phase forced convection

→ A technique of employment of flexible tube with inner sleeve has been established.

Two phase flow (is applied to cool down detector solenoid)

two phase flow induces various kinds of instability or small fluid induced vibration.

It is necessary to build a cryogenic design such that two phase flow instabilities are never generated.

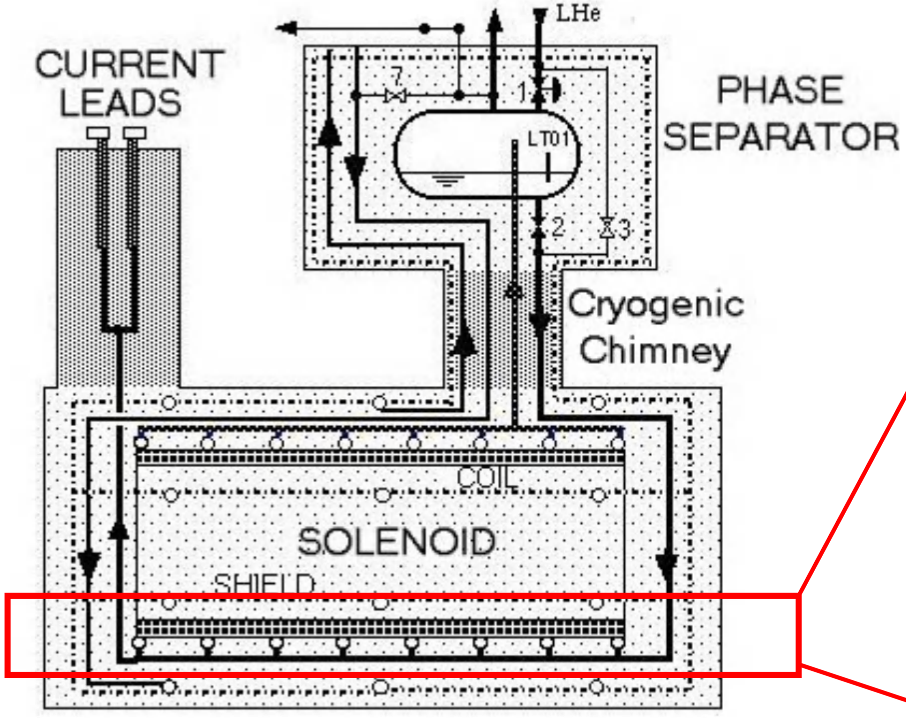
Superfluid: (is employed to cool down QD0s)

Nucleate boiling is not generated in the pressurized superfluid helium.

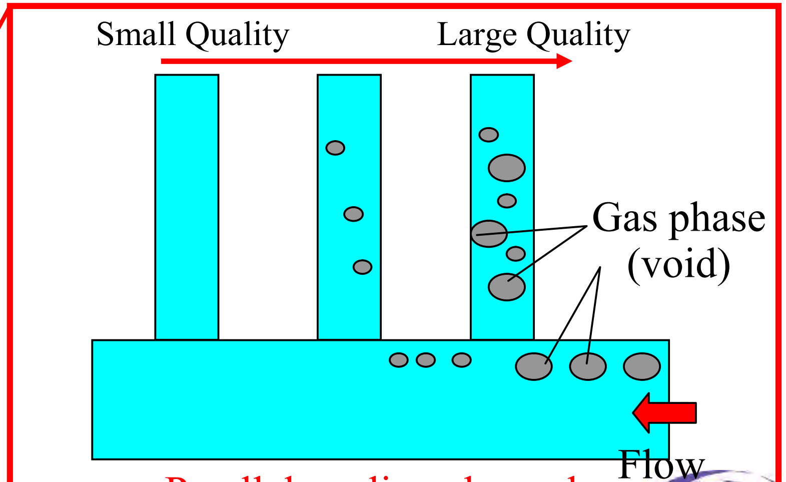
It is necessary to build a cryogenic design such that film boiling (lambda transition) is never generated.

Study on Two Phase Flow Cooling

- We investigate the especially following two phase flow characteristics for thermosyphon and forced convection.
  - mass flow intermittency
  - Optimal configuration of cooling channel.
  - relation between vibration and two phase flow instability.



Due to the buoyancy acted on gas phase in the horizontal channel,
Mass flow intermittency sometimes occurs.
It strongly depends on the flow condition.

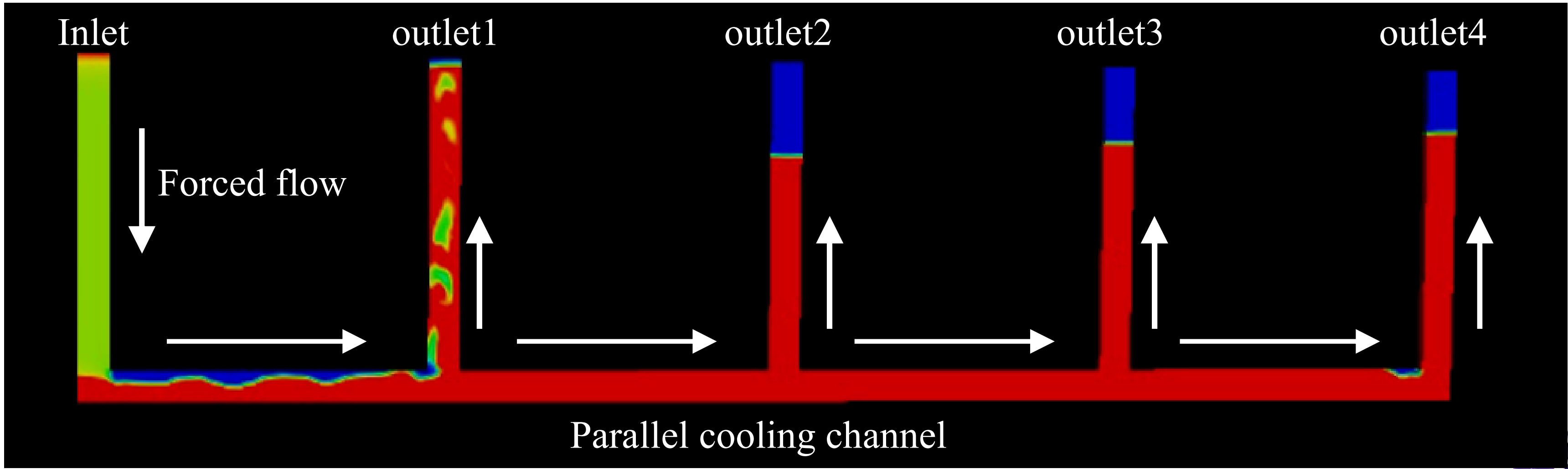


Parallel cooling channel

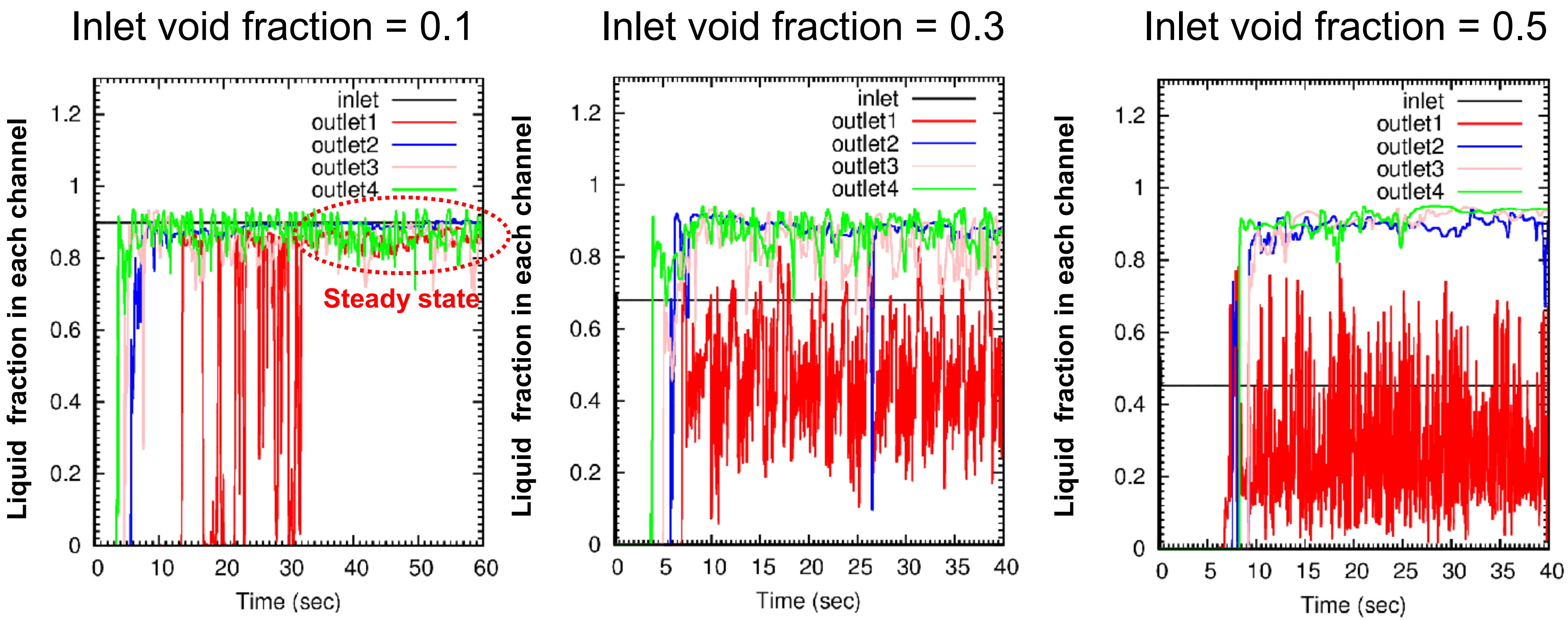
Present Studies

- Now we investigate mass flow instability generated in a parallel cooling channel system in the case of the two phase forced flow cooling by means of numerical simulation.

As a preliminary study, we investigate the relation between void fraction and mass flow intermittency generated in a parallel cooling channel system.

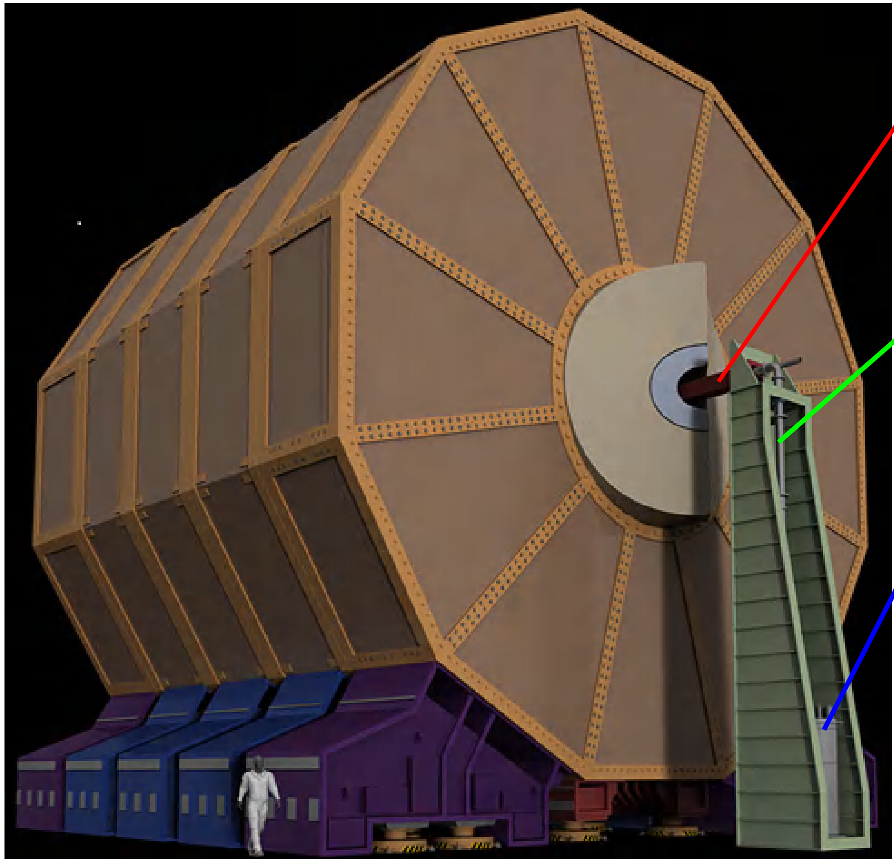


Simulation Results Example @ forced flow



- mass flow instability with void fraction fluctuation occurs in the case of the high void fraction flow.
- It is necessary to build a cryogenic design such that two phase flow instabilities are never generated.
- QD0 should not be supported from cryostat of detector solenoid because cryostat may have some kinds of vibration induced by two phase flow or mechanically induced oscillation.
- Is cantilever support by means of pillars that are standing directly on the transport platform best solution so far ?

Cryo-System of QD0



QD0

TRT for superfluid helium
Between QD0 and 2K refrigerator

2K refrigerator for QD0
Heat exchanger to obtain He II is installed

The distance between 2K and QD0 (TRT length) is about 4m

Advantage: large degree of freedom to reduce the vibration from the refrigerator.
Disadvantage: Large heat load from the TRT.

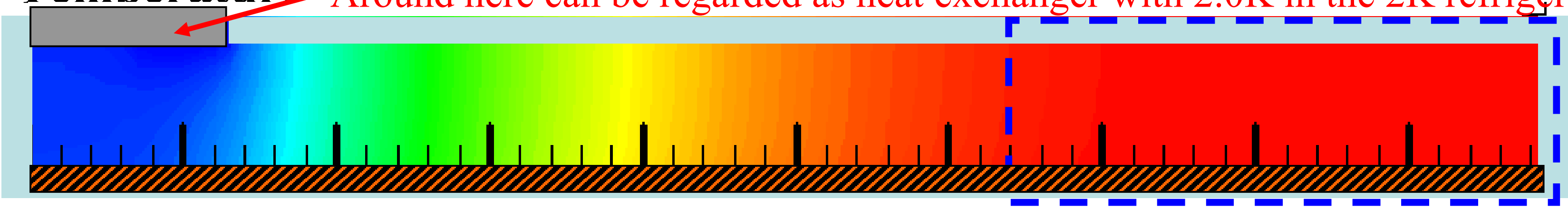
Temperature gradient is generated because of the existence of the heat load from TRT etc..
The norm of temperature gradient strongly depends on the size and shape of cooling channel.

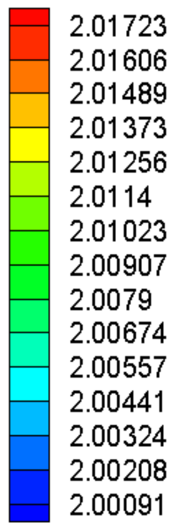
Therefore we have to investigate and confirm the design validity of final focus cryogenic system such that film boiling (lambda transition) does not occur in the cooling channel.

Numerical Results example

means heat load from TRT

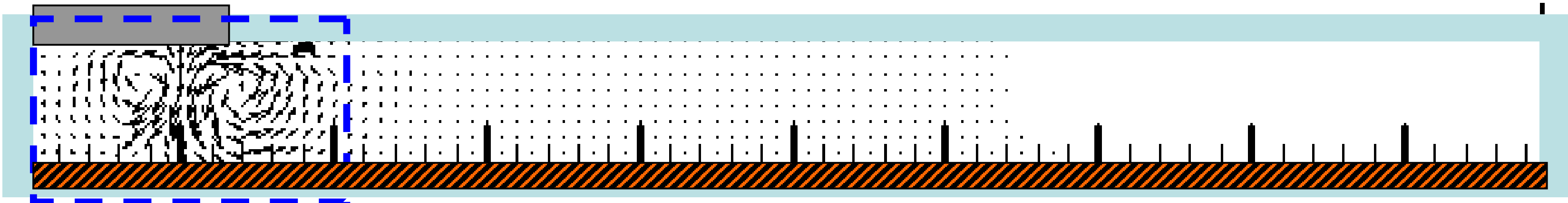
Temperature Around here can be regarded as heat exchanger with 2.0K in the 2K refrigerator.





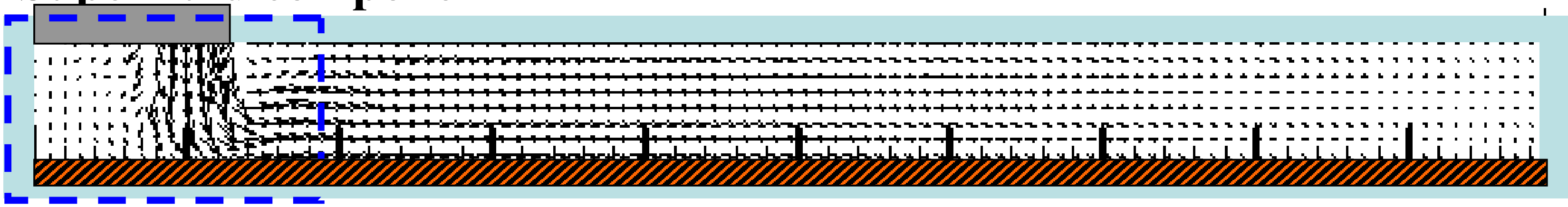
Far from the heat exchanger, superfluid temperature becomes large due to heat load of TRT

Total fluid

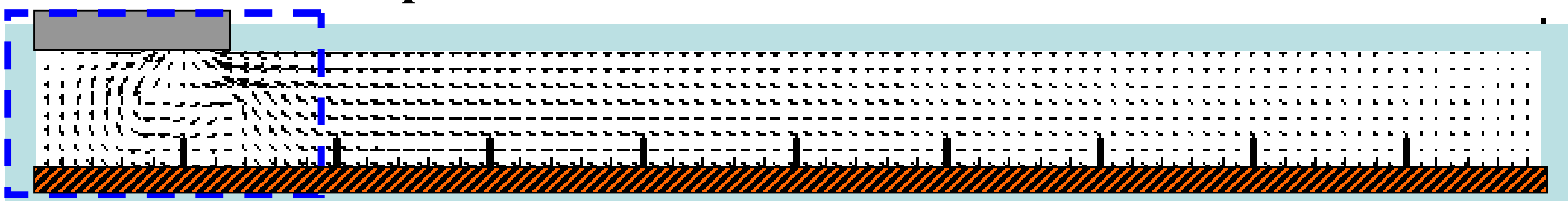


Total fluid is almost static except near the heat exchanger.

Superfluid component



Normal fluid component



The macroscopic flow as to super and normal fluid component exist near the heat exchanger.

→ Purpose is to build the cryo-design such that lambda transition does not occur.

Summary

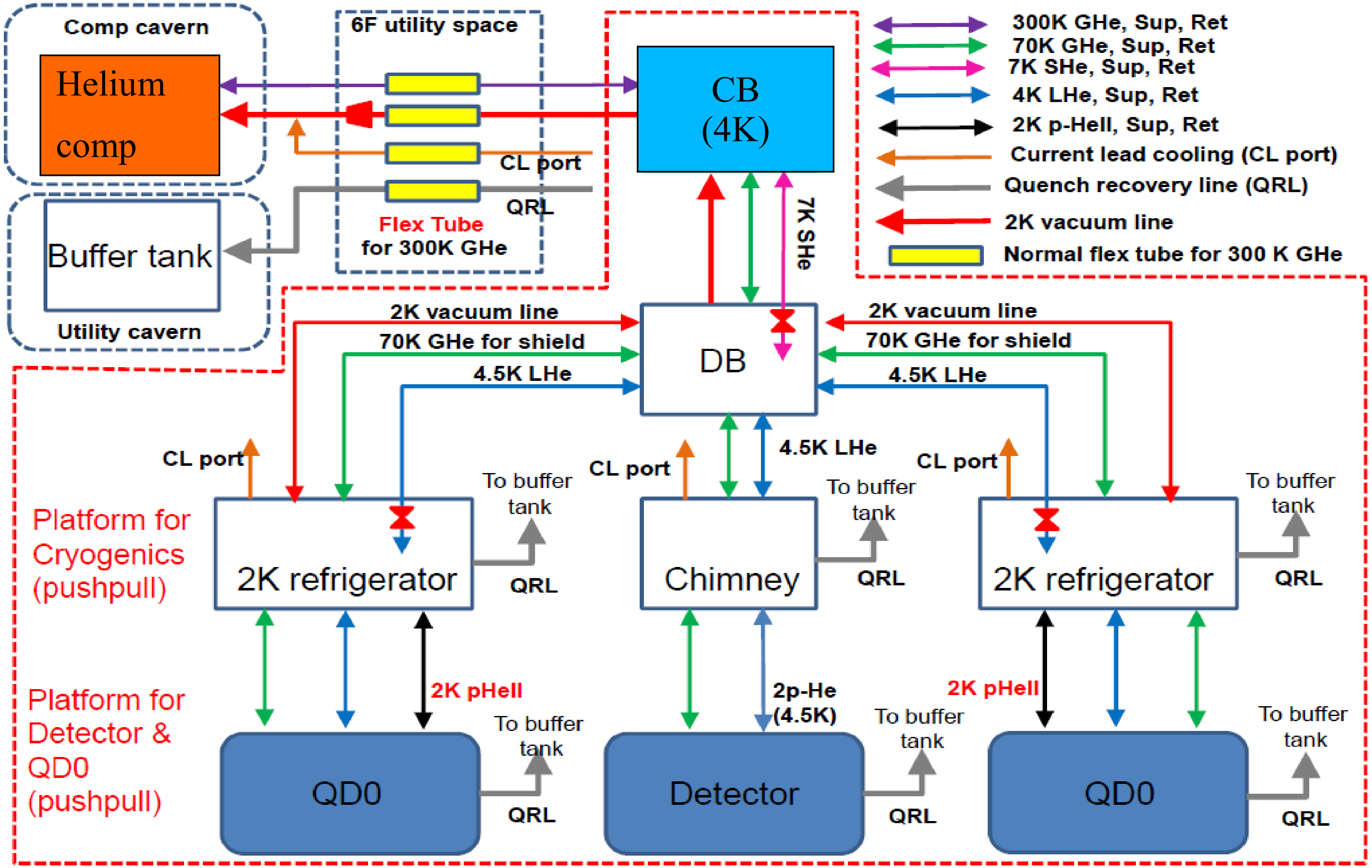
There are a lot of assumed vibration sources from not only cryogenic equipment but also various infrastructures in the central region.

1. Compressor will be installed far from the IR experimental hall. To reduce the vibration from screw compressor,
   - compressor with the high specifications compared with required one should be chosen.
   - Several flexible tubes with different mechanical characteristics should be employed between compressor and cold box in order to generate acoustic mismatching.
   - Even if the vibration from the compressor can not be dumped sufficiently by means of above mentioned methods, the cold box for detectors had better not be installed on the platform for push-pull.
2. We have to pay close attention to bellows oscillation due to the fluid motion to reduce mechanical vibration. But in this case, A bellows oscillation reduction technique has been already established. Bellows with inner sleeves should be employed to reduce the vibration.
3. We have to build a design such that two phase flow oscillation does not occur in the detector cooling channel.
4. Superfluid may be one of the best solution, but in this case we have to pay attention to the structure of the cryo-cooling line so that lambda transition (film boiling) does not occur.

Backup slides

Cryogenic block diagram example

It it necessary to use 4K refrigerator to obtain pressurized and saturated superfluid helium .
So, cold box which have cooling capacity with the heat load of detector and QD0



Simulation Model and Condition

■ Mass conservation of gas and liquid phase

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

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

■ Momentum conservation of gas and liquid phase

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

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

■ Energy conservation of gas and liquid phase

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

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

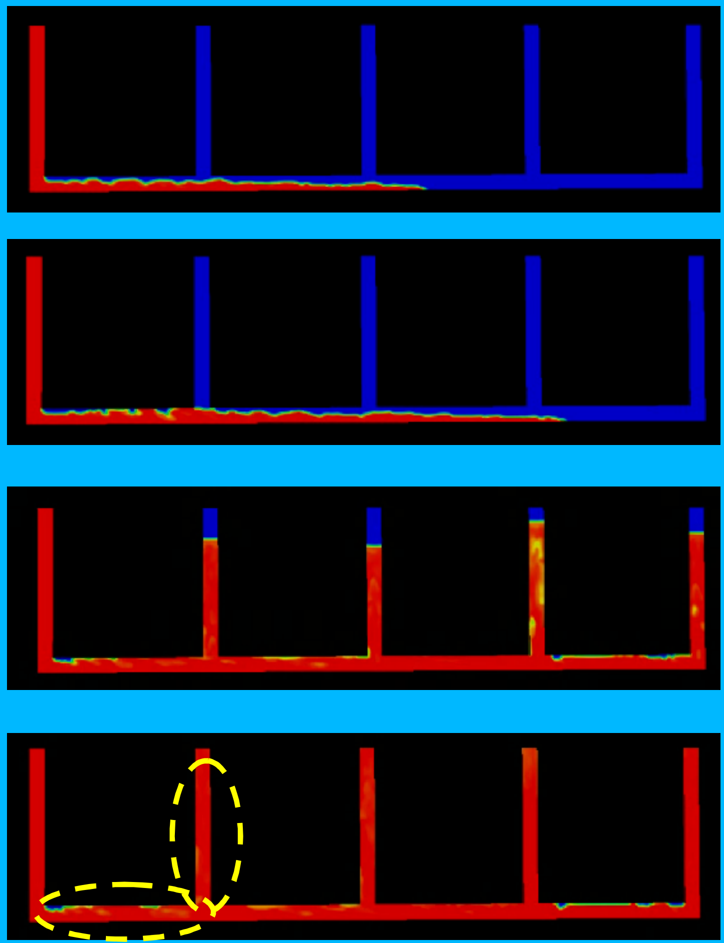
In this presentation, we focus on two phase forced convection cooling .

In this studies, we investigate the relation between void fraction and mass flow heterogeneity.

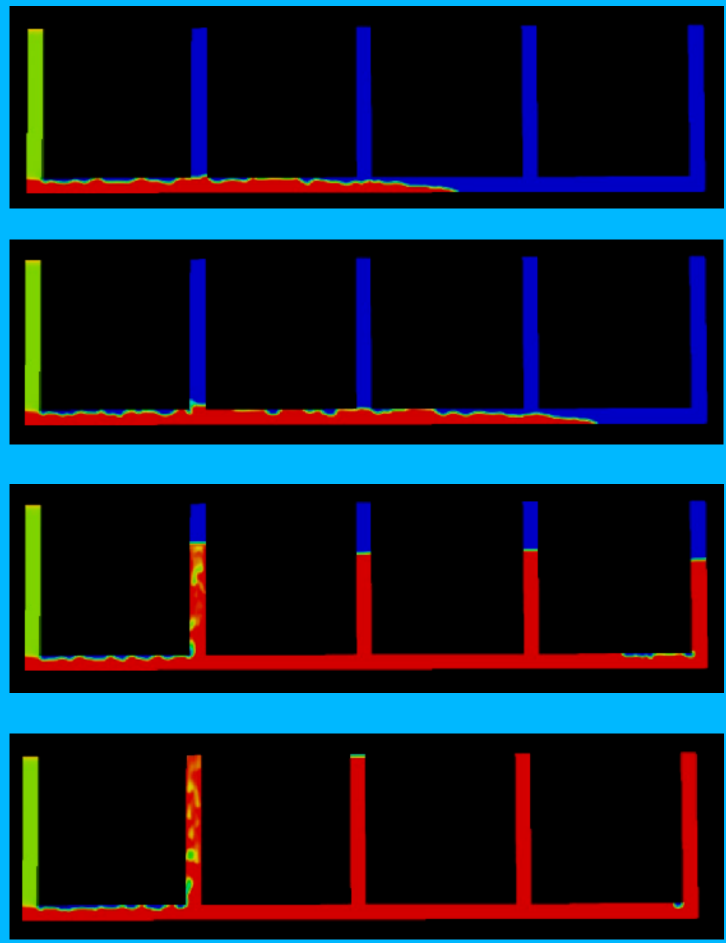
Case1) void fraction = 0.1 **Case2) void fraction = 0.3**
Case3) void fraction = 0.5
* Other flow conditions such as mass flow rate are completely same between two cases.

Mechanism of Mass Flow intermittency

In case of **void fraction=0~0.1**
(liquid fraction=1~0.9)



In case of **void fraction=0.3~0.5**
(liquid fraction=0.7 ~ 0.5)

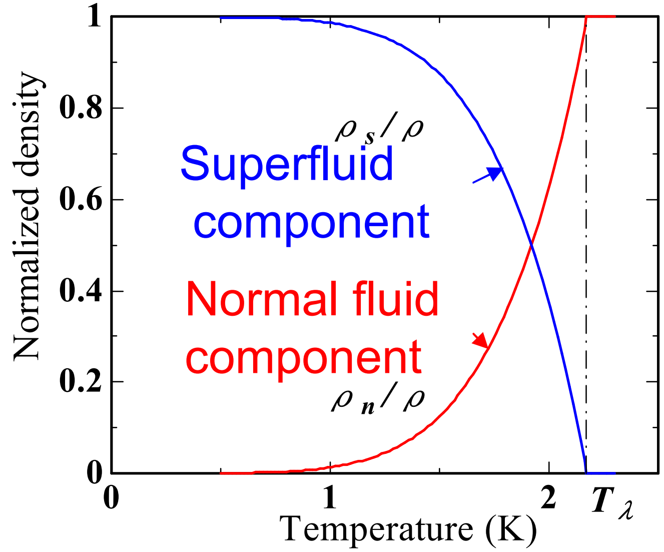


Red region : liquid phase (same as void fraction = 0) , blue region : gas phase (same as void fraction=1)

Analytical Model

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

Concept of Landau two fluid 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

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

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

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

Constitutive equation

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