Cryomodule design and construction at KEK

LCWS2024
10/Jul/2024

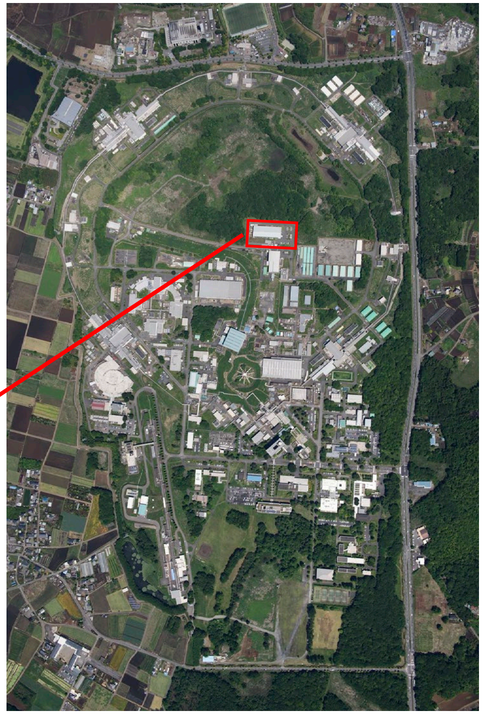
Takeshi DOHMAE
on be half of KEK SRF CM group

Contents

Introduction

- KEK SRF group is now constructing a cryo-module with ILC design under the program "MEXT-ATD". (Details of "MEXT-ATD" was presented by Takayuki Saeki)
- It is expected that cavities produced in other regions (ex. EU) will be employed into this CM.
- Completed cryo-module will be tested at COI in 2027.
- New CM test stand and cryogenic system is also under construction. (Details was presented by Kota Nakanishi "Cryomodule Test Bunker for ITN" on 10/July)

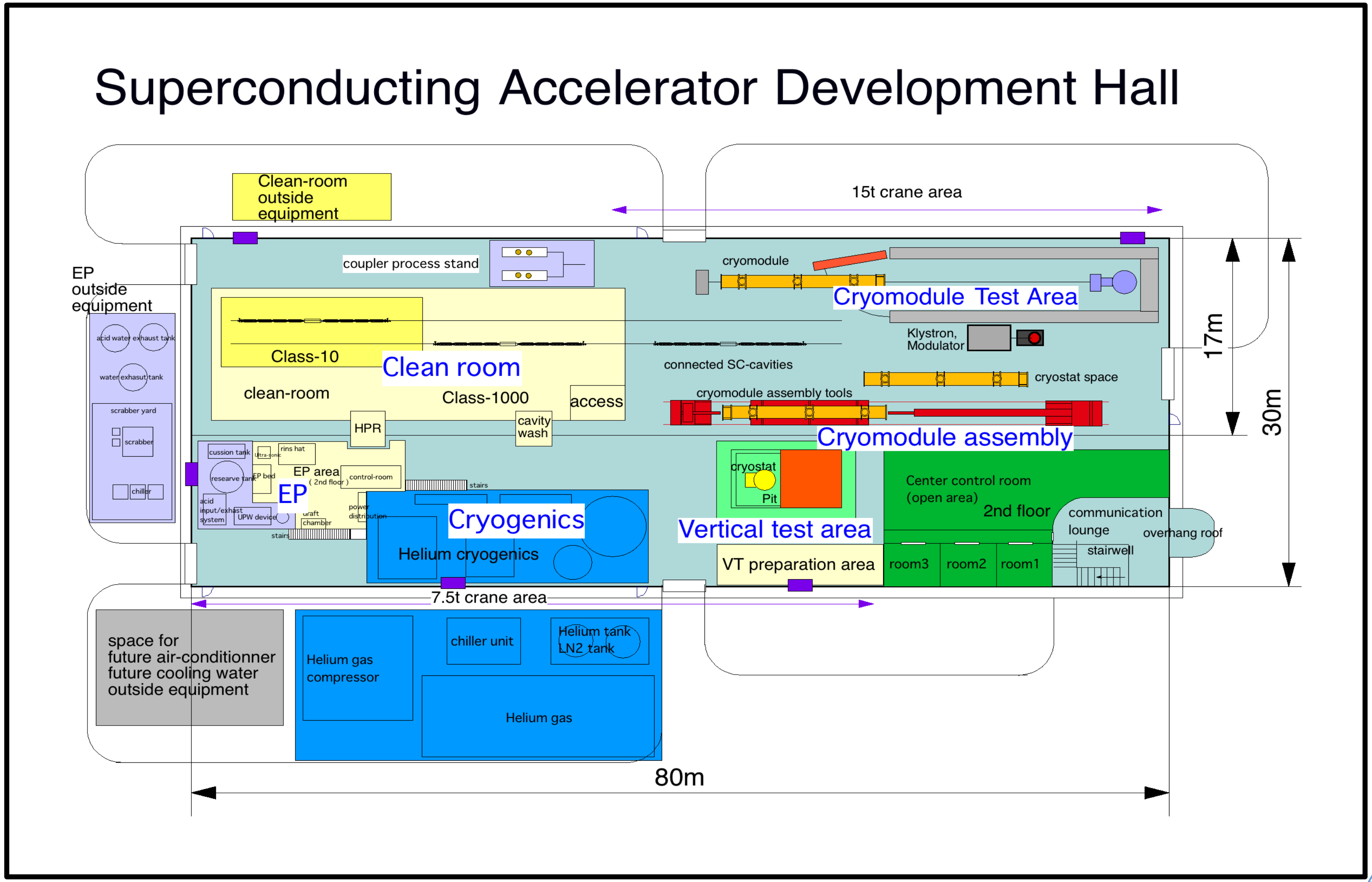
COI building at KEK



Layout of COI

Most facilities to construct CM will be prepared at COI building.

COI building at KEK



Construction Schedule

Production Schedule of Cavity and Ancillaries for 5-year Plan (FY starts from April in Japan)

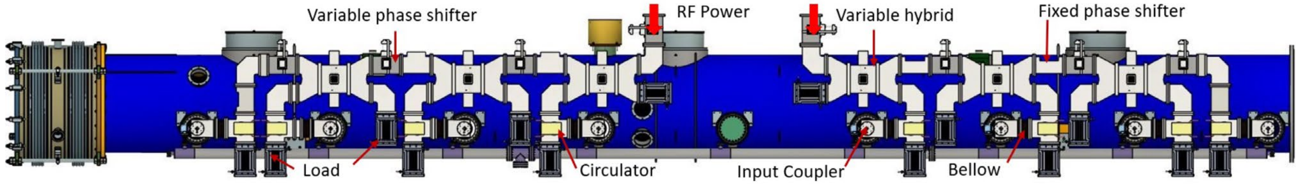
	Calender year	2023			2024				2025				2026				2027				2028
	Japanese fiscal year	JFY2023				JFY2024				JFY2025				JFY2026				JFY2027			
	Period	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Cavity	9-cell FG	1 (prototype)				2				1											
	9-cell MG				1 (prototype) + 1					1											
	9-cell MG (oversea)			press test						2											
	VT for recipe establishment																				
	VT for success yield																				
	Welding helium tank																				
Ancillaries	Power coupler					4				4											
	Frequency tuner					1				8											
	SCQ magnet+BPM					1															
	Magnetic shield					1				2				6							
Cryomodule	CM production																				
	CM assembly																				
	CM test ① w/ low power																				
	CM test ② w/ high power																				

now

Schedule by Kirk

Cryo-module design

- **Cryo-module (CM) design is based on T4CM v29 (ILC type-B).**
- CM also has to pass High Pressure Gas Safety Regulation. KEK will apply "Regulation on Safety of Refrigeration" same as cavity. (Also same as IFMIF)
- Waveguide will be attached on CM. (Details were presented by Prakash Joshi "Development of the RF power distribution System for the ILC Prototype Cryomodule" on 9/July.)



Specification	
Number of cavities	8
Magnet	SC magnets and BPM
Vacuum vessel length	12,652 m
Vacuum vessel diameter	OD965mm, ID946mm
Coupler pitch distance	1326.7 mm
Cavity length	1247.4 mm

Table 3.4
Installation alignment errors (rms) of the linac beam-line elements. BPM specifications are also included.

Error	with respect to	value	
Cavity offset	module	300	μm
Cavity tilt	module	300	μrad
BPM offset	module	300	μm
BPM resolution		5	μm
BPM calibration		≤10	%
Quadrupole offset	module	300	μm
Quadrupole roll	module	300	μrad
Module offset	beamline reference	200	μm
Module tilt	beamline reference	20	μrad

Alignment errors have to be within the definition of TDR.

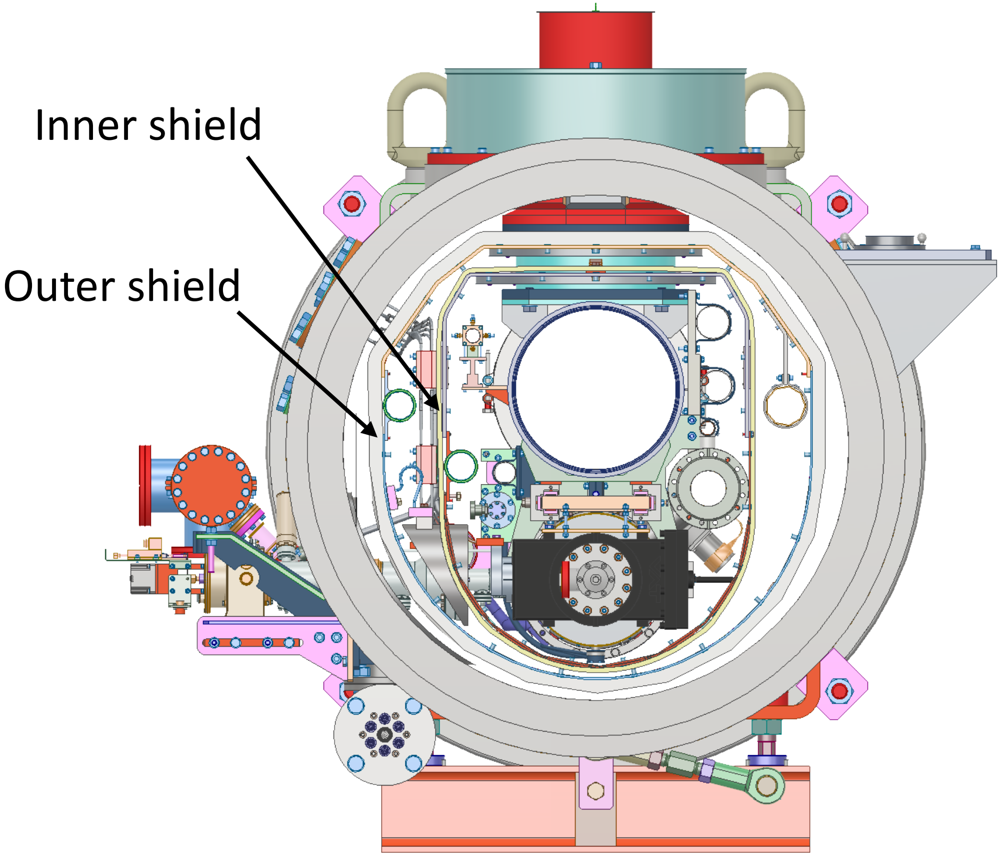
Change requests

- Followings are change requests from TDR.

Change requests from ILC TDR (TBD)	
Magnet	Conduction cooling Vertical split type
Thermal shield	Outer shield (80K) only*1
Pipe diameter	According to JIS
Usage of 40K forward line	Cool down outer shield*2
Tuner type	Double lever arm type
Current read port	Coupler port side
Cavity specification (VT)	$Q_0 > 1.0 \times 10^{10}$ @ 35MV/m

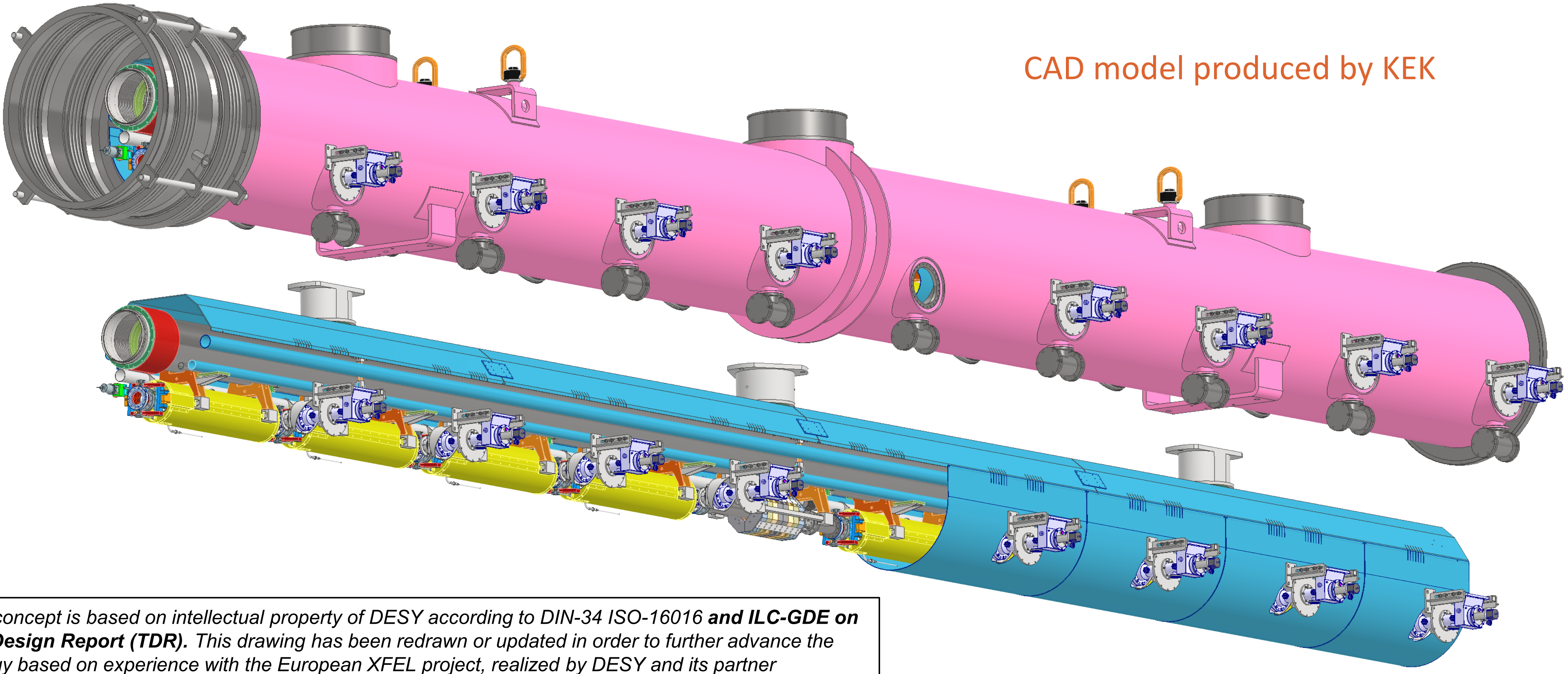
*1 No inner (5K) shield and only Multi-layer insulation (MLI) will be put inside of 80K shield
*2 Details will be explained in the following page

T4CM v29



CM CAD model

- KEK original CM CAD models are now under preparation.



CAD model produced by KEK

*The original design concept is based on intellectual property of DESY according to DIN-34 ISO-16016 **and ILC-GDE on the ILC Technical Design Report (TDR).** This drawing has been redrawn or updated in order to further advance the underlying technology based on experience with the European XFEL project, realized by DESY and its partner laboratories, and the LCLS-II project hosted at SLAC, in cooperation with Fermilab and JLab under supervision of the US/DOE. The design has been re-optimized by KEK, under the **agreement with** DESY, he SLAC/LCLS-II project office, and ILC-IDT Collaboration, exclusively for fabrication within the ILC Technology Network (ITN) program, hosted at KEK".*

New method of piping

- For cost reduction and to simplify the structure, the inner (5K) shield is removed in case of the ILC CM.
- Thus, the outer (80K) thermal shield has to be cooled sufficiently.
- 40K supply line is used to cool down the outer shield. 80K return line is used to cool down input couplers.
- Simulation was done by N. Ouchi *et al.* in "Study of thermal radiation shields for the ILC cryomodule", doi: 10.1063/1.4707009

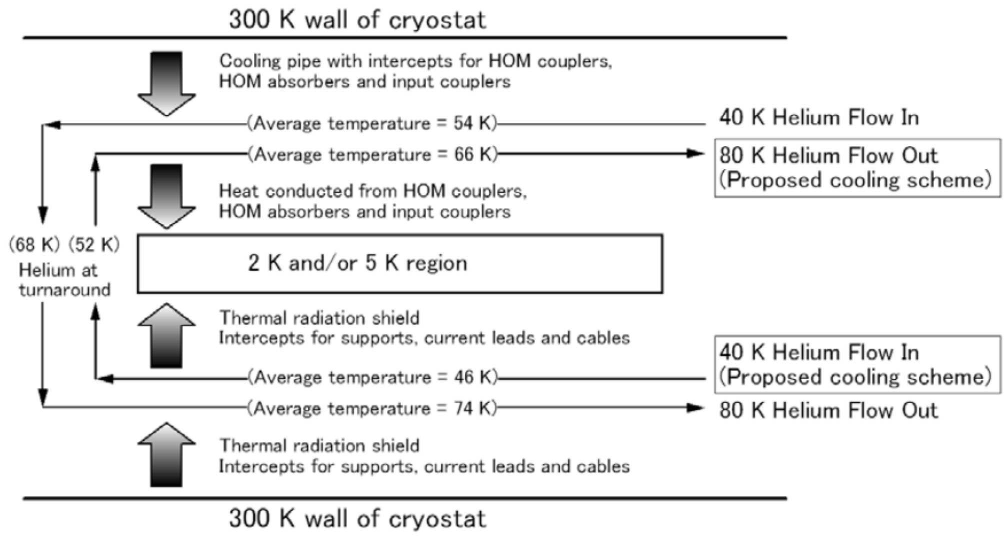
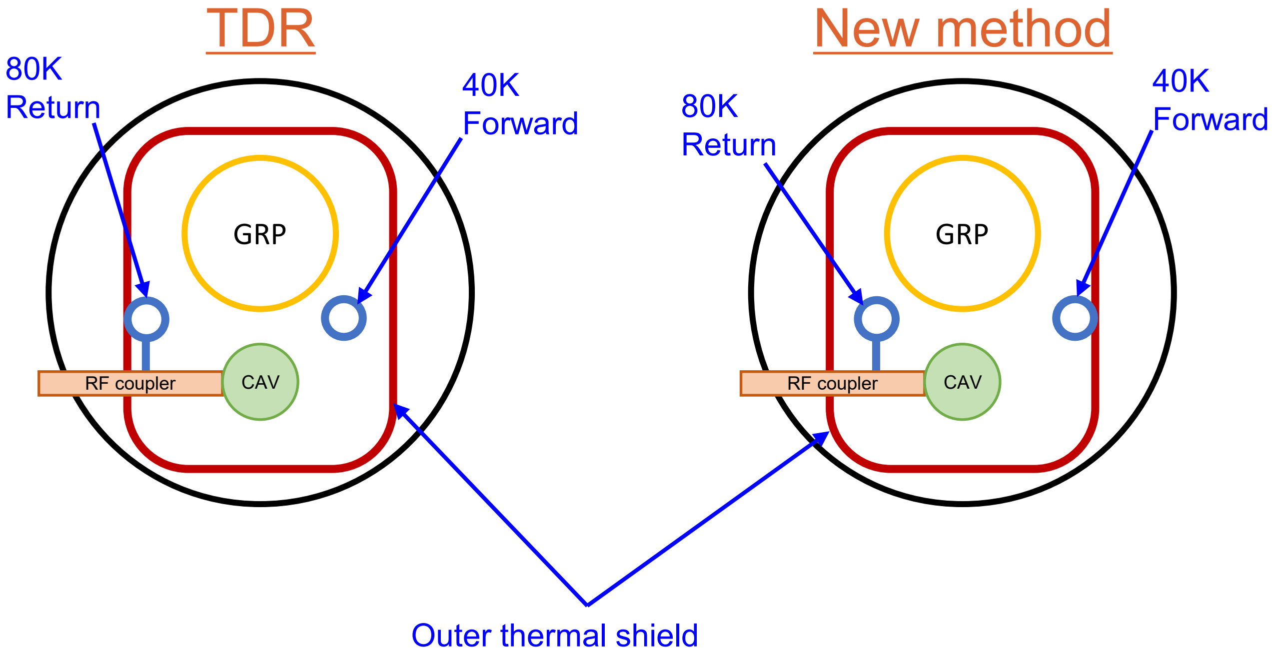


FIGURE 5. Allocation of thermal loads to 40 K－80 K circuit.

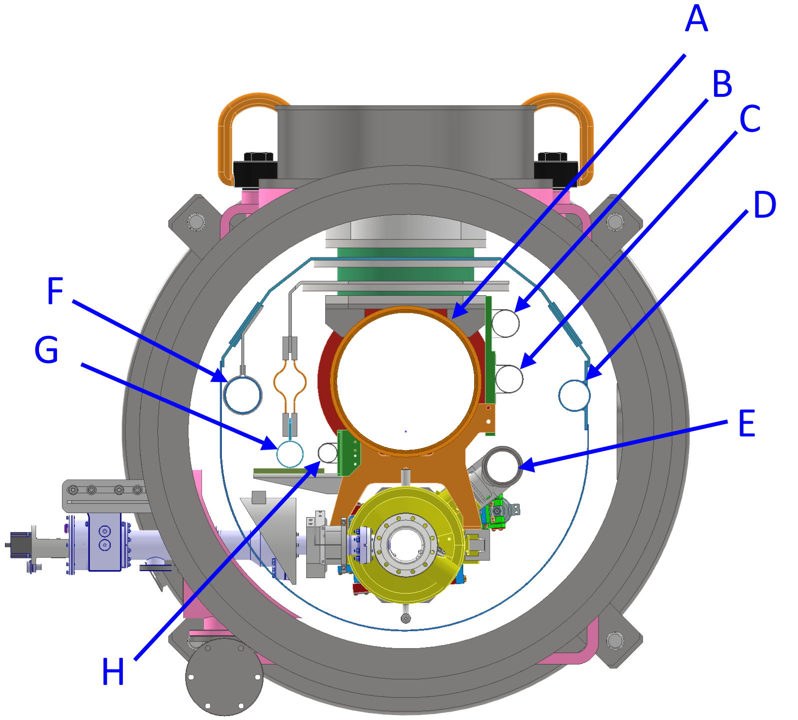
"Study of thermal radiation shields for the ILC cryomodule", N. Ouchi *et al.*, AIP Conference Proceedings **1434**, 929 (2012); doi: 10.1063/1.4707009



Pipe diameter (TBD)

- The size of each pipe will be changed according to JIS. (Japanese Industrial Standard)

		T4CM (ILC)	CM KEK	JIS #	Material
A	Gas return	OD312 × t6	OD312 × t6	N/A	SUS316L
B	2.2K supply	OD63.5 × t1.65	OD60.5 × t1.65	JIS G3459	SUS316L
C	5K supply	OD60.3 × t2.11	OD60.5 × t1.65	JIS G3459	SUS316L
D	40K supply	OD76.2 × t2.11	OD60 × t3	JIS H4080	Aluminum*2
E	2-phase	OD73 × t2.11	OD76.3 × t2.1	JIS G3459	SUS316L
F	80K return	OD60.3 × t2.77	OD70 × t2*1	JIS H4080	Aluminum
G	8K return	OD60.3 × t2.77	OD60 × t3	JIS H4080	Aluminum
H	Warm up/cool down	OD42.2 × t1.65	OD42.7 × t1.65	JIS G3459	SUS316L



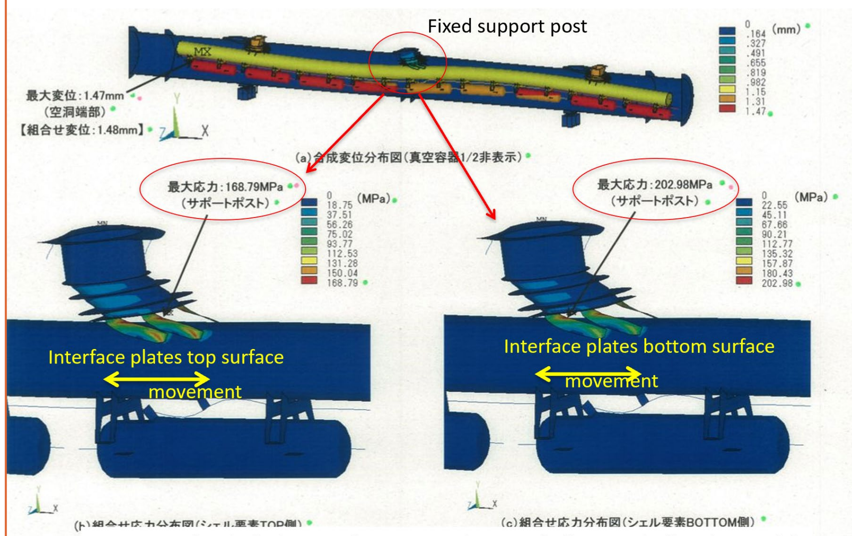
*1: OD80 × t2.5 (JIS H4080) alternative choice (TBD)
*2: In case of reversed cooling method (see the previous page)

CM: earthquake simulation

- Since Japan is the earthquake-prone country, we need to consider about earthquake proof for CM.
- Simulations were done by Hitoshi Hayano and presented on LCWS2013.
- This simulation should be updated with the new CM design.

Example of simulation

More detail explanation of max stress: (3) Interface plates between GRP and support post



Max. stress for shell-elements by 10.76Hz Eigen-mode (beam axis direction mode)

Summary slide from H. Hayaho

Summary of Analysis

ILC cryomodule based on T4CM(FNAL) was modeled for FEM analysis.
The Eigen-modes are;
10.76 Hz for X axis (electron beam direction)
19.75 Hz for Y axis (vertical direction)
6.67 Hz for Z axis (horizontal direction)

Earthquake spectrum based on ISO-3010 was assumed for;
100 years recurrence, 200 gal acceleration at Tsukuba area rigidity.
(It corresponds to 150 gal at Kitakami area, smaller than Tsukuba)

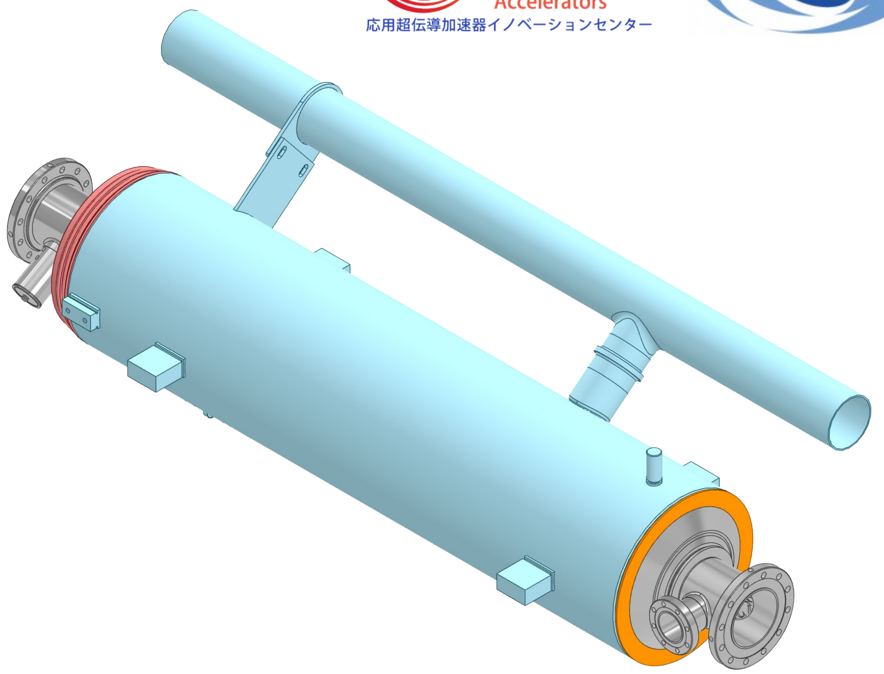
Components excessing max. allowable stress (200MPa) are;

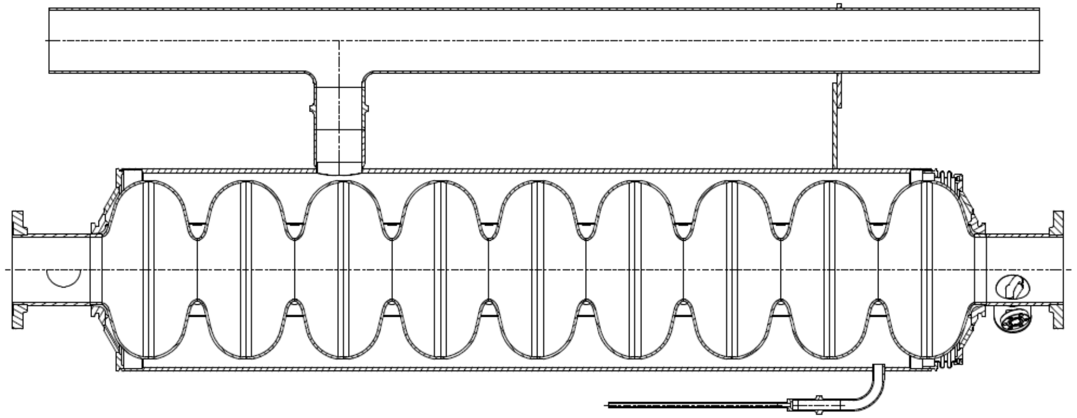
(1) M24 adjustable bolts of the support post (360MPa)
(2) M24 adjustable bolts of vacuum vessel basement (399MPa)
(3) Interface plates between GRP and support post (318MPa)

Need size-up of M24 bolts, additional support for the GRP-support post interface plate.
Their cost-up will not be so much.

Cavity design

- Cavity design is based on TESLA shape.
- Jacket design is based on LCLS-II.
- Both kind of cavities will be produced: fine grain and medium grain.
- Bellow design was slightly changed.
- Ti tubes based on JIS will be used for supply line and 2-phase line.
- Eddy current scanning will be performed to all sheets/discs.
- Need to pass high pressure gas safety. (HPGS)
- Details of HPGS and surface treatments were presented by Kensei Umemori “High pressure gas safety and cavity performance in MEXT-ATD/ITN” on 10/July)





E_{acc} (qualification)	35 MV/m ($\pm$20%)
Q_0 @35 MV/m (qualification)	1.0×10^{10}
E_{acc} (operation)	31.5 MV/m ($\pm$20%)
Q_0 @31.5 MV/m (operation)	1.0×10^{10}
Operation Frequency	1.3 GHz
# of Supply line	1
End tube	Short-short
Yield ratio	≧ 90%

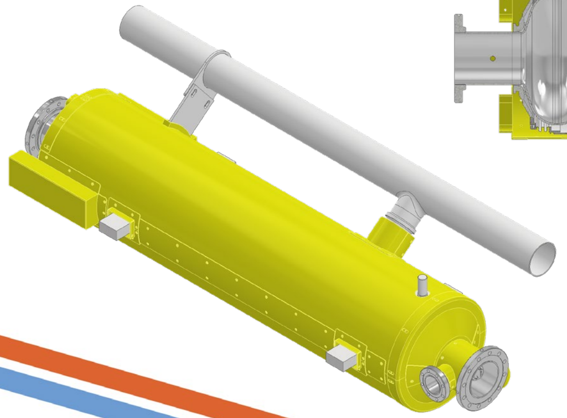
Magnetic shield and BPM/SCQ

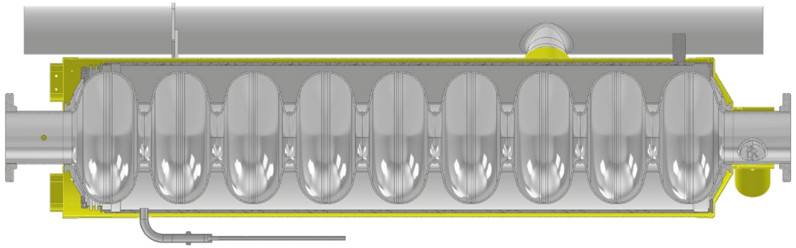
Magnetic shield

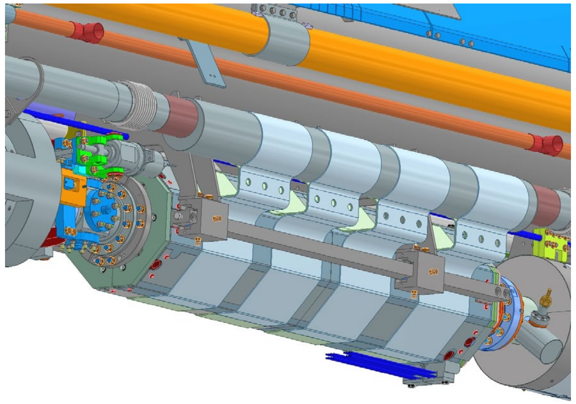
- A single layer magnetic shield will cover the cavity.
- Material of magnetic shield will be 1.5mm thickness of permalloy.
- No magnetic shielding between cavities.
- Magnetic field simulation of the new design is being performed. Depending on the results the design might be updated.

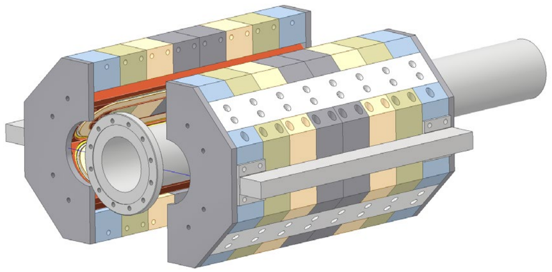
BPM and SCQ

- Conduction cooling from 2K line will be employed.
- SCQ can be divided into two part, hence SCQ can be assembled after cavity string assembly.
- Unit test of SCQ will be performed in the small cryo-stat and refrigerator.
- NbTi is used for coils.
- Dimension of magnet is about 420L × 250 × 250mm.





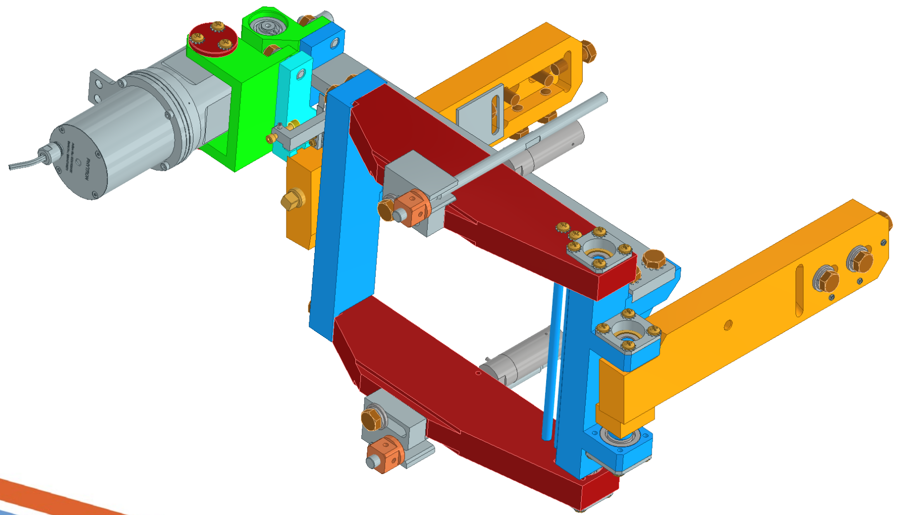




Tuner and Power Coupler

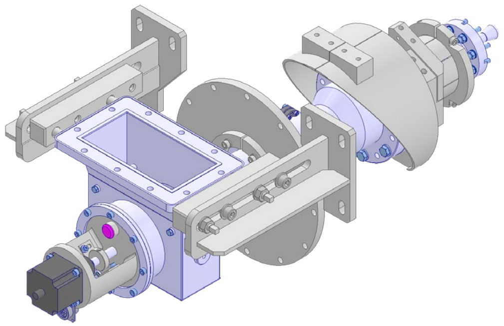
Tuner

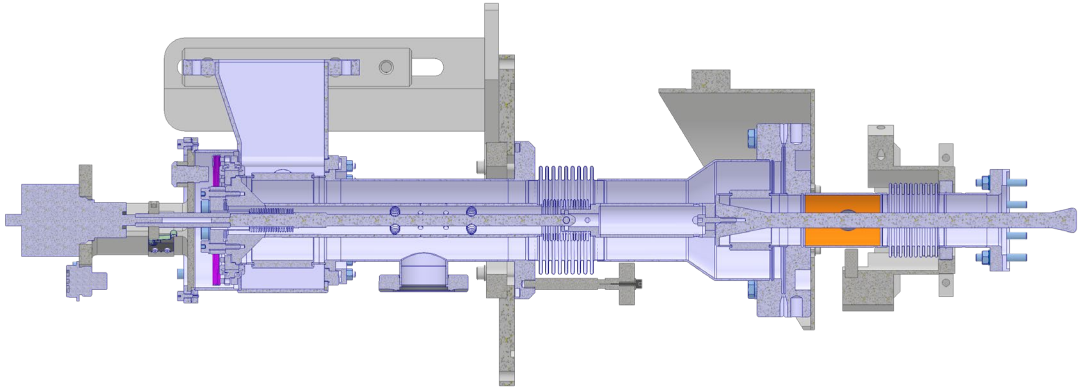
- Tuner design is based on double lever arm type tuner.
- Miner changes were added to the design.
- Slow tuning is done in compression direction.
- Operational displacement will be within 2mm. (max. 3mm from the view point of HPGS)
- Please refer the talk by Mathieu Omet "Cavity tuner development for the ITN cryomodule at KEK" on 9/Jul for more details.



Power coupler

- Coupler design is based on E-XFEL type.
- Miner changes were added to the design. (new ceramic design)
- Please refer the talk by Ryo Katayama "Production status of power coupler in MEXT-ATD/ITN" on 9/Jul for more details.

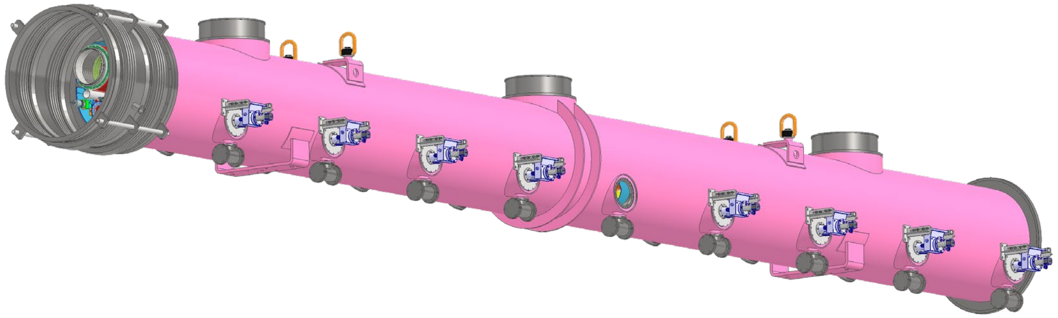




Summary

- KEK is constructing cryo-module which design is based on ILC CM.
- Some parts are changed from ILC TDR specifications.
- KEK is also constructing CM construction facilities and test stand.
- Completed CM will be test in JFY2027.

Acknowledgment
We appreciate DESY, FNAL and SLAC colleagues to share the experiences about CM.
This work was supported by 【MEXT Development of key element technologies to improve the performance of future accelerators Program】 Japan Grant Number **JPMXP1423812204**.



Discussion1

Cooling

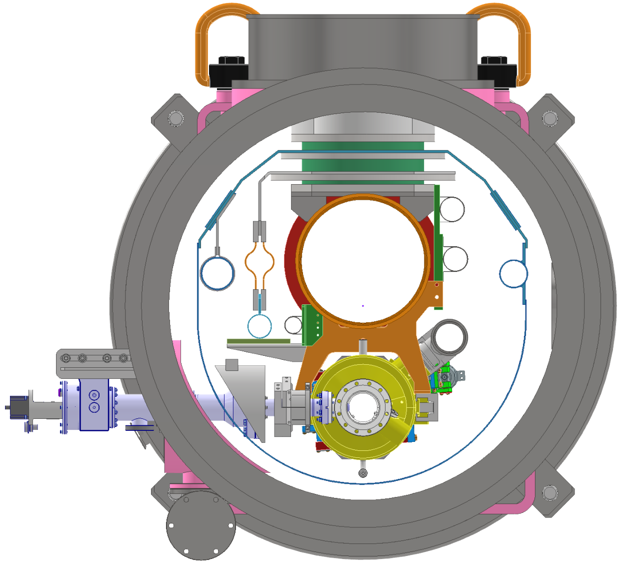
- Inner (5K) thermal shield and MLI necessary?

  Current KEK plan is:

  Cavity → MLI → Mag. Shield → MLI instead of inner shield (around Mag. shield?) → Outer shield → MLI

- How to cool down the magnetic shield? Or, do not need to cool down?

  If we did not cool down the magnetic shield, only 80K shield exists outside of cavity in case of 5K shield-less model.

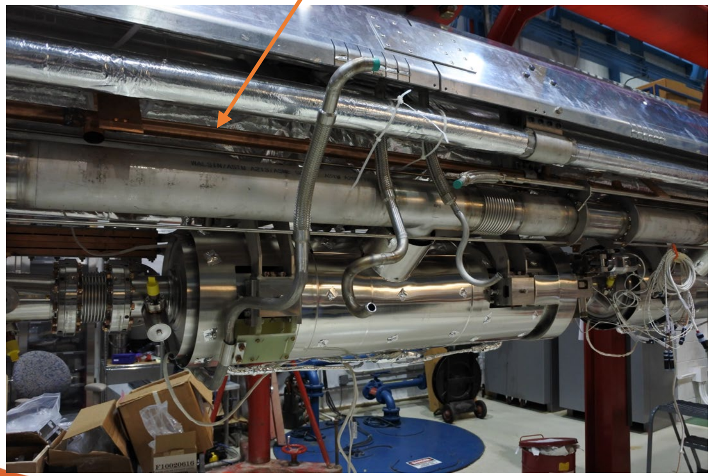


Discussion2

Others

- Is cabling pipe for stepping motor pipe necessary? What is the purpose?
- Structure of cryo-vessel bellows, single or double?
- Is there any meanings for strange shape coupler hole on thermal shield?

Stepping motor pipe



Cryo-vessel bellows

Double

Single (STF)