Cryomodule

Norihito Ohuchi
ILC Cryomodule Gp

Cryomodule development status

Basic design of the ILC cryomodule ;

9 cavities in the 11830 mm cryomodule

8 cavities and 1 quadrupole package in the module center

DESY and INFN

- 8 cavities in 11385 mm cryomodule and 8 cavities + 1 quadrupole package in the module end.
- 8 cryomodules have been constructed in FLASH.

FNAL

- CM1 has been assembled, and wait for cold test.
- CM2 will be completed in FY09 for S1 cryomodule.
- CM3 cryomodule in FY10.

KEK

- The 6 m cryomodule with 4 cavities was completed and cold-tested in FY08.
- The 6 m cryomodule will be modified and new 5 cavities are being constructed for S1-Global .
- The module-C of 6 m long is now being constructed under research collaboration with INFN.
- S1-Global will be completed in FY10.

ILC Cryomodule Developments-1

Cryomodule Design Optimization

Plug-compatible and Cost reduction

Thermal design (based on TTF-type III)

- Thermal performance of the components
  - Thermal intercepts
  - RF cables
  - Input couplers (Tesla type, KEK type)
  - Quadrupole package and BPM
- Evaluation of heat loads at 31.5 MV/m
- Temperature profile in the module
  - Module design with or without 5K shield
  - Cooling scheme in the cryomodule

Mechanical design

- Assembly process and tooling
- Alignment method

Tests and measurements

Cold test of cryomodule with or without 5K shield at KEK-STF

CM1 at FNAL-NML
S1-Global at KEK-STF

Design of ILC proto-type
Type IV or V at FNAL
STF2 module at KEK

ILC Cryomodule Developments-2

Mass Production Study (Industrialization)

Assembly for 1815 modules (605 modules in each area) for ML

- Procedures of assembly and test while construction
- Man power evaluation
- Production lines and tools
- Alignment method
  - Cavities, Quarupole and BPM
- Clean room size, assembly area and stock area

Acceptance tests

- Test scheme, required test stands and size.

High pressure gas regulation

- Pressure design of the components
- Material study for cold components

Learn the industrialization from XFEL, Project-X and LHC dipole construction

Study of material properties for the regulation by KEK

S1-Global cryomodule

The main target of the S1-Global;

Operating a cryomodule with an average accelerating gradient of 31.5 MV/m

Included research subjects;

1. Experience the design, assembly and the alignment procedures for cavity packages from participating parties.
2. Measure the heat loads for the cavity packages and the cryomodule for the static and the 31.5 MV/m dynamic conditions.
3. Conduct the comparative studies of performance of cavities from the participating institutes.
4. Attempt to attain an average accelerating gradient of 31.5 MV/m in a pulsed RF operation at 5Hz with 1ms flat-top length, 0.07% rms amplitude variation and 0.35 degree rms phase variation.
5. Advance implementation of the 'plug-compatibility concept'

S1-Global collaborative profile

INFN: Design and construction of the 6m Module-C for DESY and FNAL cavities

DESY: Two TESLA type cavities with Saclay tuner

FNAL: Two TESLA type cavities with blade tuner

SLAC: Power distribution system for Module-C

KEK: 6m Module-A for KEK cavities, four TESLA-like cavities and infrastructure for completing the module tests

Asian institutes: IHEP and RRCAT

Activities for S1-G

Bi-weekly S1-G meeting;

INFN: Carlo Pagani, Paolo Pierini, Serena Barbanotti
FNAL: Jim Kerby, Tom Peterson, Mark Champion, Tug Arkan, Don Mitchell, Harry Carter
KEK: Akira Yamamoto, Hitoshi Hayano, Hirotaka Nakai, Tetsuo Shidara, Norihito Ohuchi
RRCAT: Prashant Khare

Works;

- Design and construction of the cryomodule and the components
- Planning thermal load measurements and methods
- Design and preparation of assembly and alignment procedures
- Planning the cavity performance tests
- Control of the schedule of construction of the S1-G cryomodule system

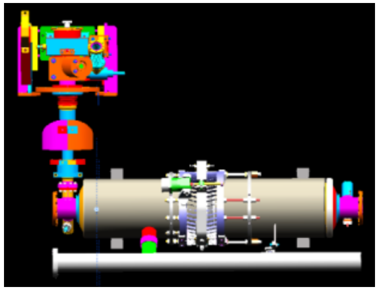
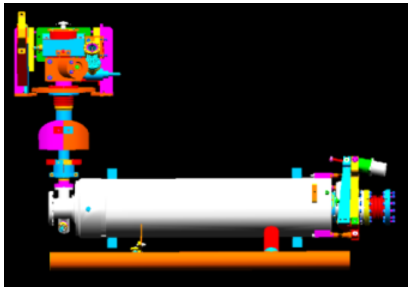
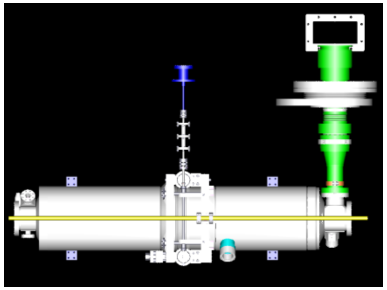
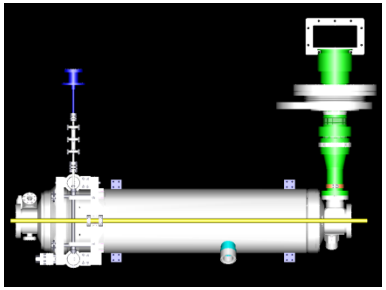
Preparation of cavities

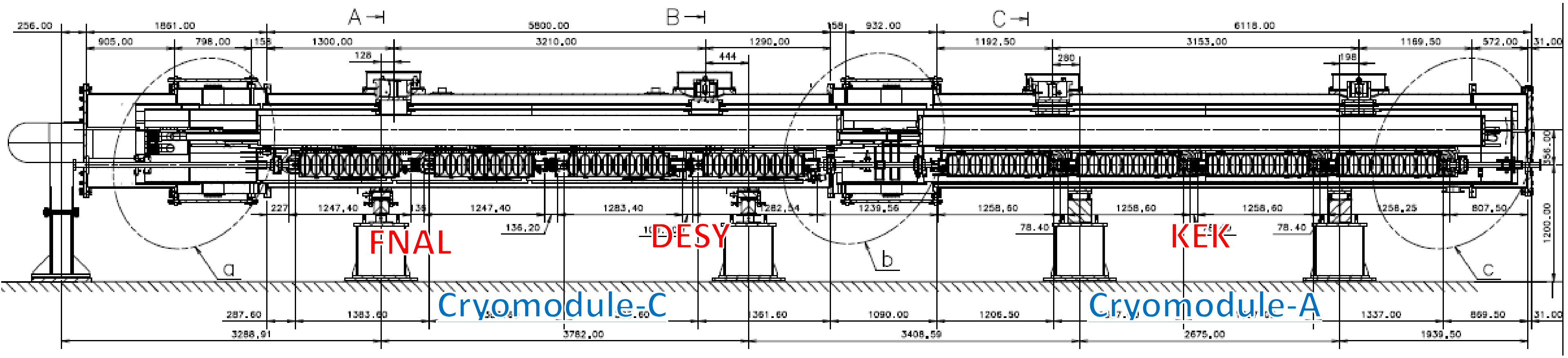
DESY:

FNAL:

KEK: Five Tesla-like cavities are now being constructed. Two cavities have been tested in the vertical stand, and the further surface process and the vertical test are scheduled

Status of design works of S1-G cryomodules-1

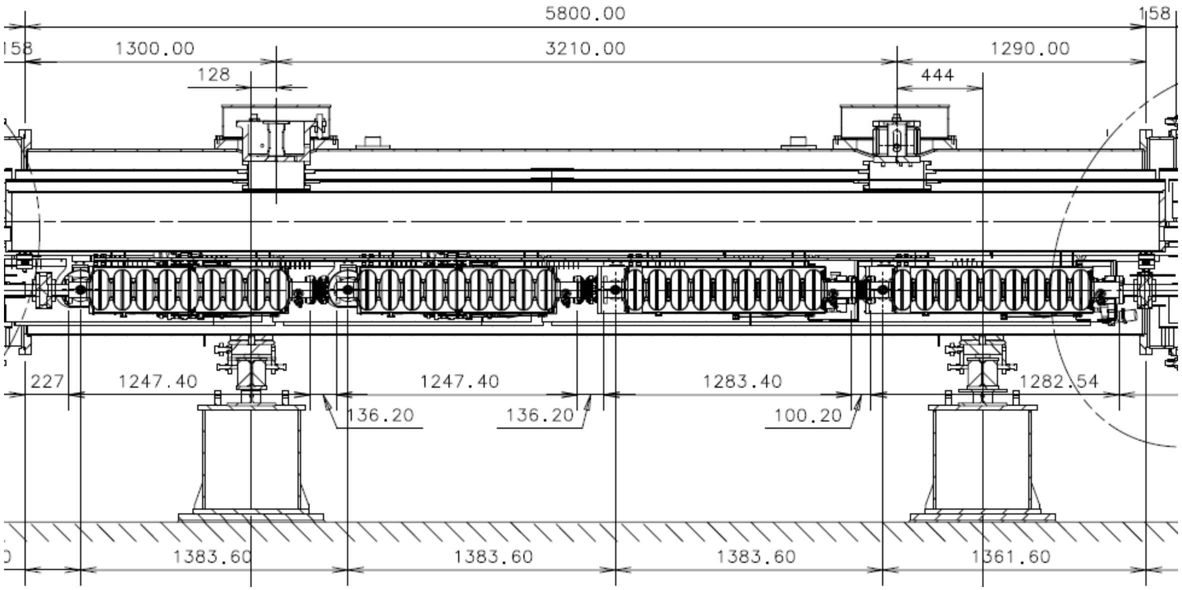





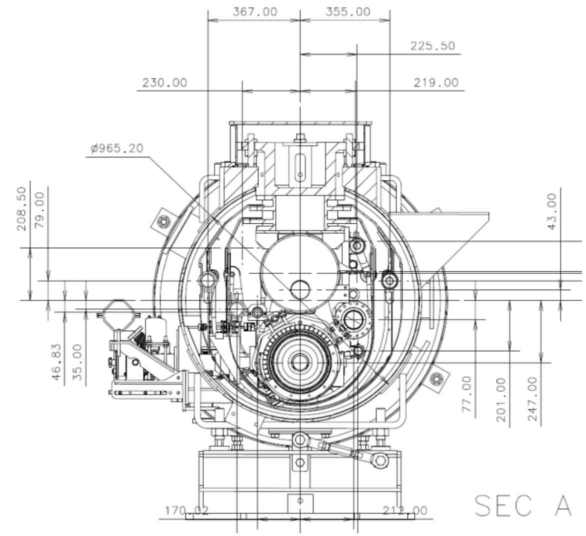


1. Design of the Module-C and -A for S1-G started at May 2008.
2. Module-C has two FNAL cavities and two DESY cavities, and Module-A has four KEK cavities.
3. Two vacuum vessels are connected with a vacuum bellows.
4. The total length of the S1-G modules including end cans is designed to be 14900 mm.

Status of design works of S1-G cryomodules-2

Module-C



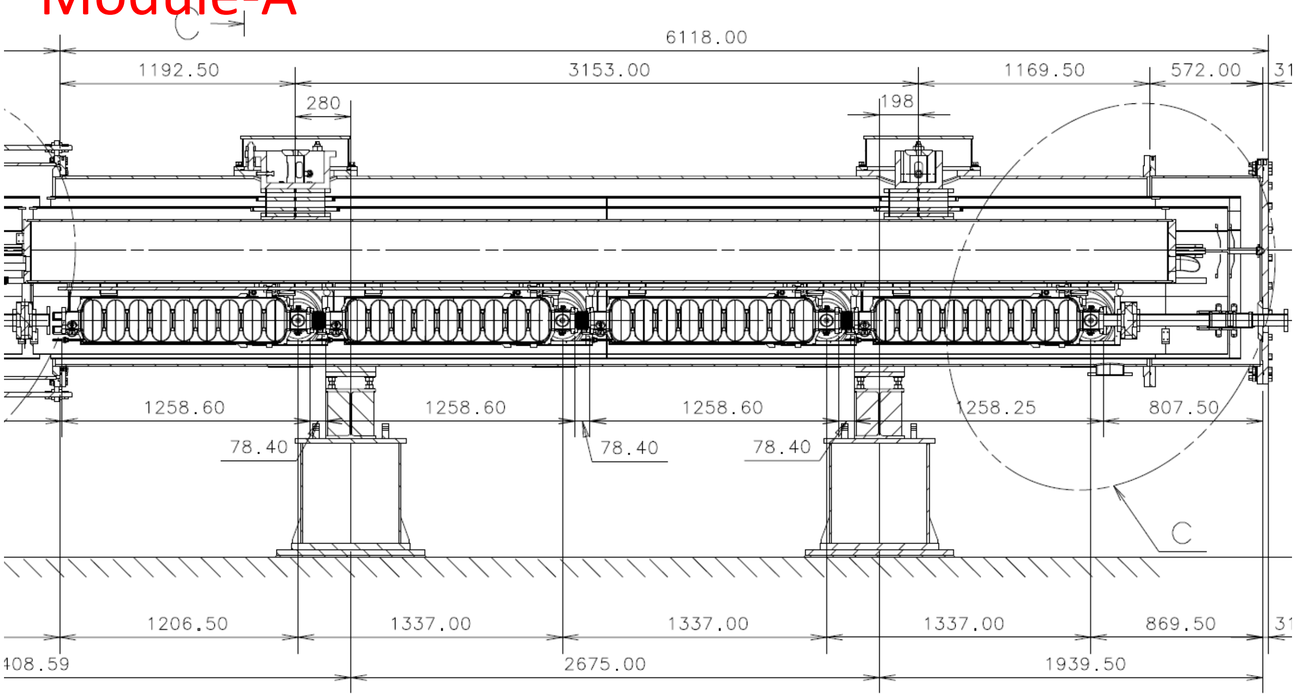


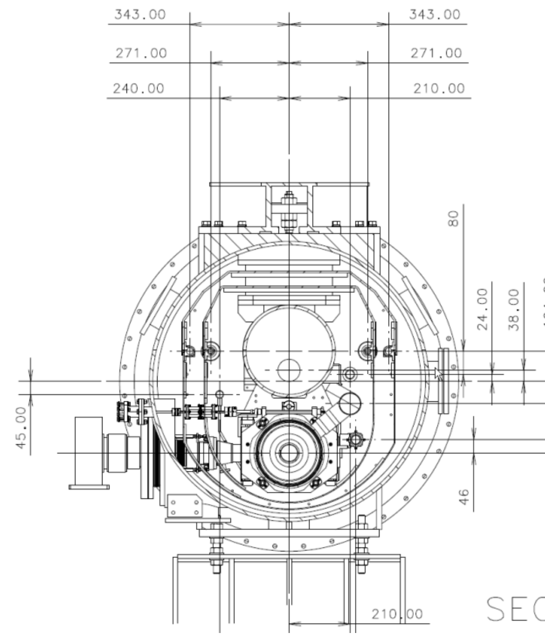
Cross section of Module-C

1. Main parameters of the Module-C were confirmed at January 2009, and Zanon started to produce the manufacturing drawings.
   - The whole set of drawings has been completed, and they are reviewed with the concerned peoples.
2. CAD-work and construction process of the Module-C by Zanon are controlled by INFN.
3. Design features of Module-C;
   - Design is based on the TTF Type-III cryomodule, and the vacuum vessel length is 5800 mm.
   - The cold mass is designed to be supported with two support posts from the vacuum vessel.
   - The components, like connection bellows between cavities and gate valves, will be designed from now.
   - Design difference of cavity packages are included;
     DESY cavity: Saclay tuner, outer magnetic shield and package length=1283.4mm
     FNAL cavity: Blade tuner, outer magnetic shield and package length=1247.6mm

Status of design works of S1-G cryomodules-3

Module-A



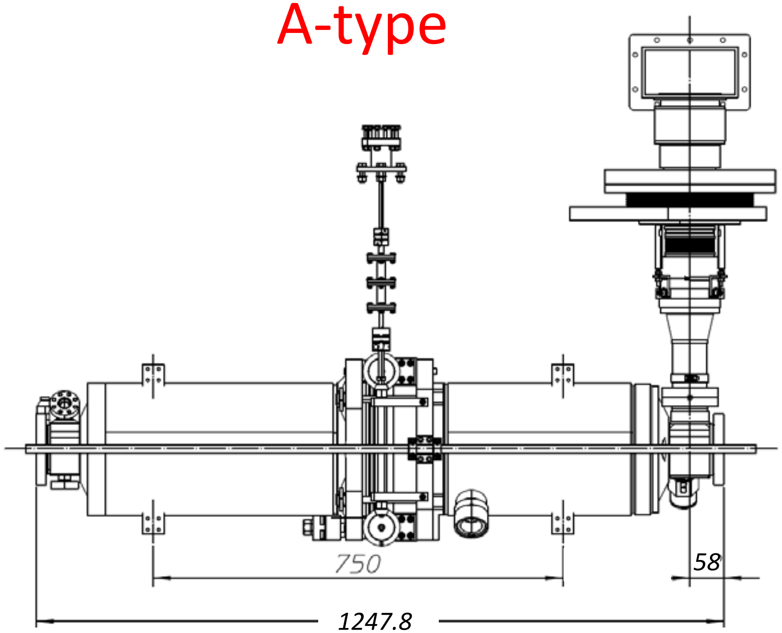


Cross section of Module-A

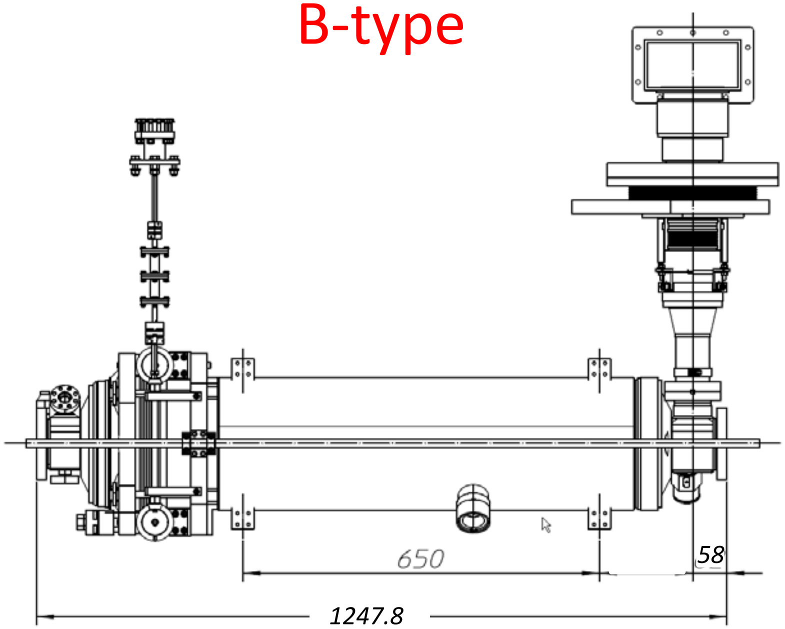
1. Module-A cryostat and cold mass components are those for STF Tesla-like cavities; re-used.
2. KEK has responsibilities on the design and CAD work of Module-A, and the data are reviewed in the S1-G cryomodule/cryogenics group.
3. Design features of Module-C;
   - Thermal and mechanical designs are based on the TTF Type-III cryomodule, and the length of the vacuum vessel is 5515 mm.
   - Module-A is connected to Module-C with a big vacuum bellows and reduced cooling pipes.
   - Cooling pipe sizes are different from those of Module-C.

KEK cavities of S1-G cryomodule

A-type



B-type



- The tuner locates in the middle of He jacket.
- The support lag distance is 750 mm.
- The plug compatible standard design

- The tuner locates out side of support lags and on the opposite side of input coupler.
- The support lag distance is 650 mm.

KEK is constructing five Tesla-like cavities for S1-G.

- A-type: 3 cavities, B-type: 2 cavities, and choosing the better four cavities in the five cavities.
- The distance between cavity flanges is designed to be 1247.8 mm while 1258.6 mm for the old design.

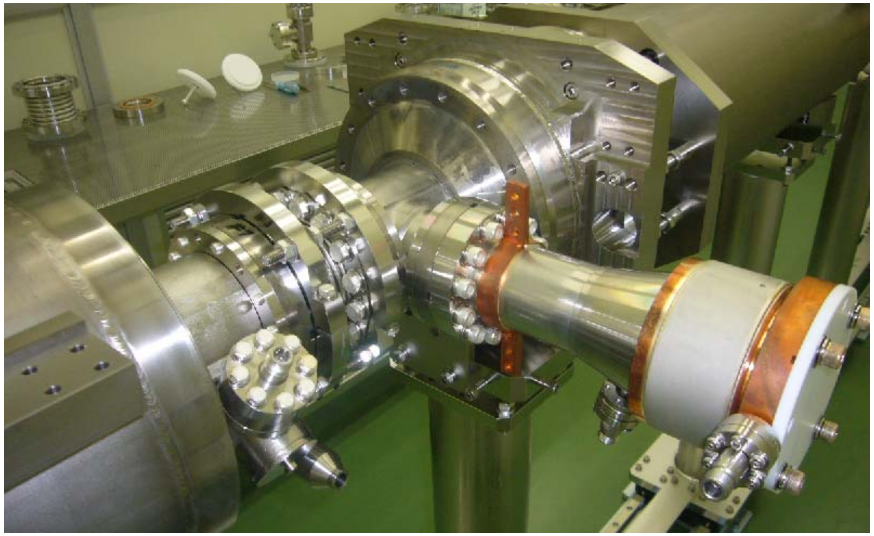
Assembly processes of cavities and cryomodules in S1-G (in the clean room)

The following points are different between the FNAL/DESY module and the KEK module, and the items in S1-G will be incorporated in the plug-compatible ILC-prototype design.

Assembly works in the clean room

– Making a string of cavity packages and assembly of input couplers to beam pipe.

DESY cavity and input coupler

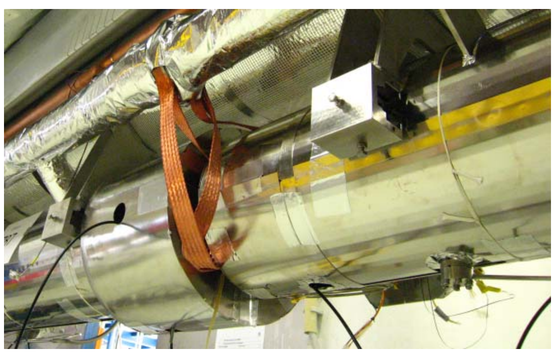


KEK cavity and input coupler

Assembly processes of cavities and cryomodules in S1-G (in the assembly area)

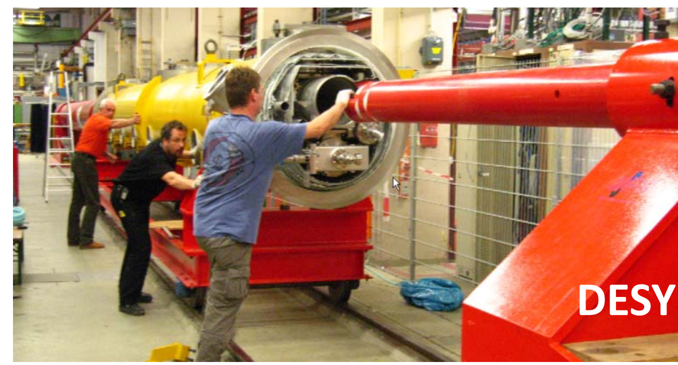
Assembly works out of the clean room

- Assembling different type of tuners and cavity packages including magnetic shields
- Aligning cavity-package with respect to the fiducials on the cryomodule
- Supporting a cavity package string to the Gas Return Pipe
- Assembling the thermal radiation shields, thermal intercepts and SI on the shields
- Test schemes against the vacuum leak of the cooling pipes
- Inserting the cold mass into the vacuum vessel



Outer magnetic shields for DESY/FNAL cavities

Magnetic shields inside KEK cavity jackets



Cold test of S1-G cryomodule

- Realization of average accelerating gradient at 31.5 MV/m with 8 cavities
- Study of performances of modules and components under 31.5 MV/m and 2K
  - Comparative studies of performance of DESY/FNAL/KEK cavities.
  - Operation of 31.5 MV/m in a pulsed RF operation at 5Hz with 1ms flat-top length, 0.07% rms amplitude variation and 0.35 degree rms phase variation.
  - Heat loads of the DESY/FNAL/KEK components at Static and dynamic conditions.
    - Input coupler, HOM coupler, RF cable and thermal intercepts
  - Thermal analysis of the modules with ANSYS by the INFN group, compared with the experimental data.

Cold test of S1-G cryomodule (Thermal sensors)

Thermal sensors to be installed in the module-A

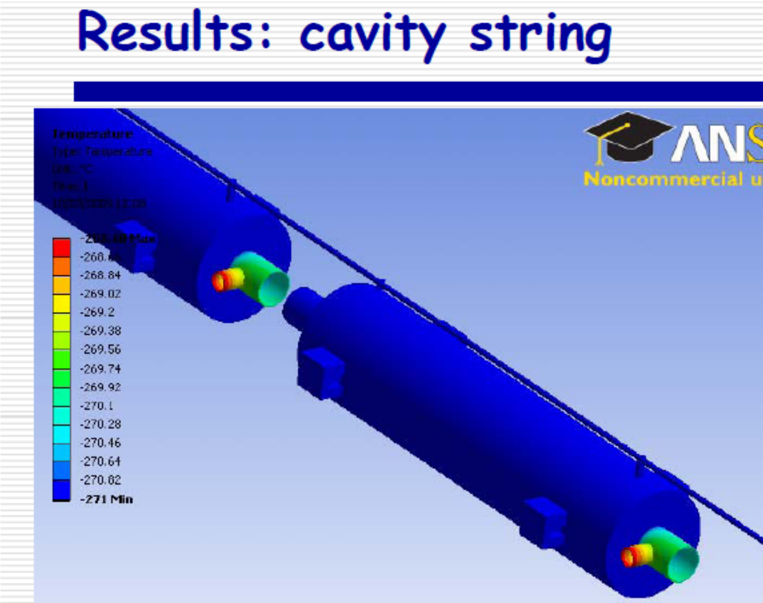
Cernox	(calibrated from 1.4K to 100K)	PtCo	(from 4K to 300K)	CC thermocouples	(from 70K to 300K)
#1Cavity	Helium Vessel	#1Cavity	Helium Vessel	#1 Cavity	80K thermal anchor of input coupler
	Connection area of input coupler with beam pipe	#2 Cavity	Helium Vessel		80K thermal anchor of input coupler close to cooling pipe
	5K thermal anchor of input coupler	#3 Cavity	Helium Vessel		Warm input coupler connection flange
	HOM coupler in the input coupler side-top	#4 Cavity	Helium Vessel	#2 Cavity	80K thermal anchor of input coupler
	HOM coupler in the input coupler side-bottom	5K Shield	0 degree in the side of mocule-C		80K thermal anchor of input coupler close to cooling pipe
	HOM coupler in the non-input coupler side-top		90 degree in the side of mocule-C		Warm input coupler connection flange
	HOM coupler in the non-input coupler side-bottom		180 degree in the side of mocule-C	#3 Cavity	80K thermal anchor of input coupler
	Piezo		270 degree in the side of mocule-C		80K thermal anchor of input coupler close to cooling pipe
#2 Cavity	Helium Vessel		90 degree at fixed support post		Warm input coupler connection flange
	Connection area of input coupler with beam pipe		180 degree at fixed support post	#4 Cavity	80K thermal anchor of input coupler
	5K thermal anchor of input coupler		270 degree at fixed support post		80K thermal anchor of input coupler close to cooling pipe
	HOM coupler in the input coupler side-top		0 degree at shield center		Warm input coupler connection flange
	HOM coupler in the input coupler side-bottom		90 degree at shield center	Fixed support post	80K anchor at the 0 degree
	HOM coupler in the non-input coupler side-top		180 degree at shield center		80K anchor at the 180 degree
	HOM coupler in the non-input coupler side-bottom		270 degree at shield center		Room temp. area
	Piezo		90 degree at movable support post	Movable support post	80K anchor at the 0 degree
#3 Cavity	Helium Vessel		180 degree at movable support post		80K anchor at the 180 degree
	Connection area of input coupler with beam pipe		270 degree at movable support post		Room temp. area
	5K thermal anchor of input coupler		0 degree in the side of end flange	80K Shield	0 degree in the side of mocule-C
	HOM coupler in the input coupler side-top		90 degree in the side of end flange		90 degree in the side of mocule-C
	HOM coupler in the input coupler side-bottom		180 degree in the side of end flange		180 degree in the side of mocule-C
	HOM coupler in the non-input coupler side-top		270 degree in the side of end flange		270 degree in the side of mocule-C
	HOM coupler in the non-input coupler side-bottom	Fixed support post	5K anchor at the 0 degree		0 degree in the center
	Piezo		5K anchor at the 180 degree		90 degree in the center
#4 Cavity	Helium Vessel	Movable support post	5K anchor at the 0 degree		180 degree in the center
	Connection area of input coupler with beam pipe		5K anchor at the 180 degree		270 degree in the center
	5K thermal anchor of input coupler	GRP	Connection area to the fixed support post		0 degree in the side of end flange
	HOM coupler in the input coupler side-top		Connection area to the movable support post		90 degree in the side of end flange
	HOM coupler in the input coupler side-bottom				180 degree in the side of end flange
	HOM coupler in the non-input coupler side-top				270 degree in the side of end flange
	HOM coupler in the non-input coupler side-bottom			Beam pipe	Position inside of 80K thermal anchor
	Piezo			GRP	Upstream-top (Module-C connection side)
GRP	Upstream-top (Module-C connection side)				Upstream-bottom (Module-C connection side)
	Upstream-bottom (Module-C connection side)				Center-top
	Center-top				Center-bottom
	Center-bottom				Downstream-top (end flange side)
	Downstream-top (end flange side)				Downstream-bottom (end flange side)
	Downstream-bottom (end flange side)				
Beam Pipe	Position inside of 5K thermal anchor				

Temperature sensors: 78 CERNOX thermometers for 2K-20K, 56 PtCo thermometers for 4K-300K,
74 CC thermocouples for 70K-300K

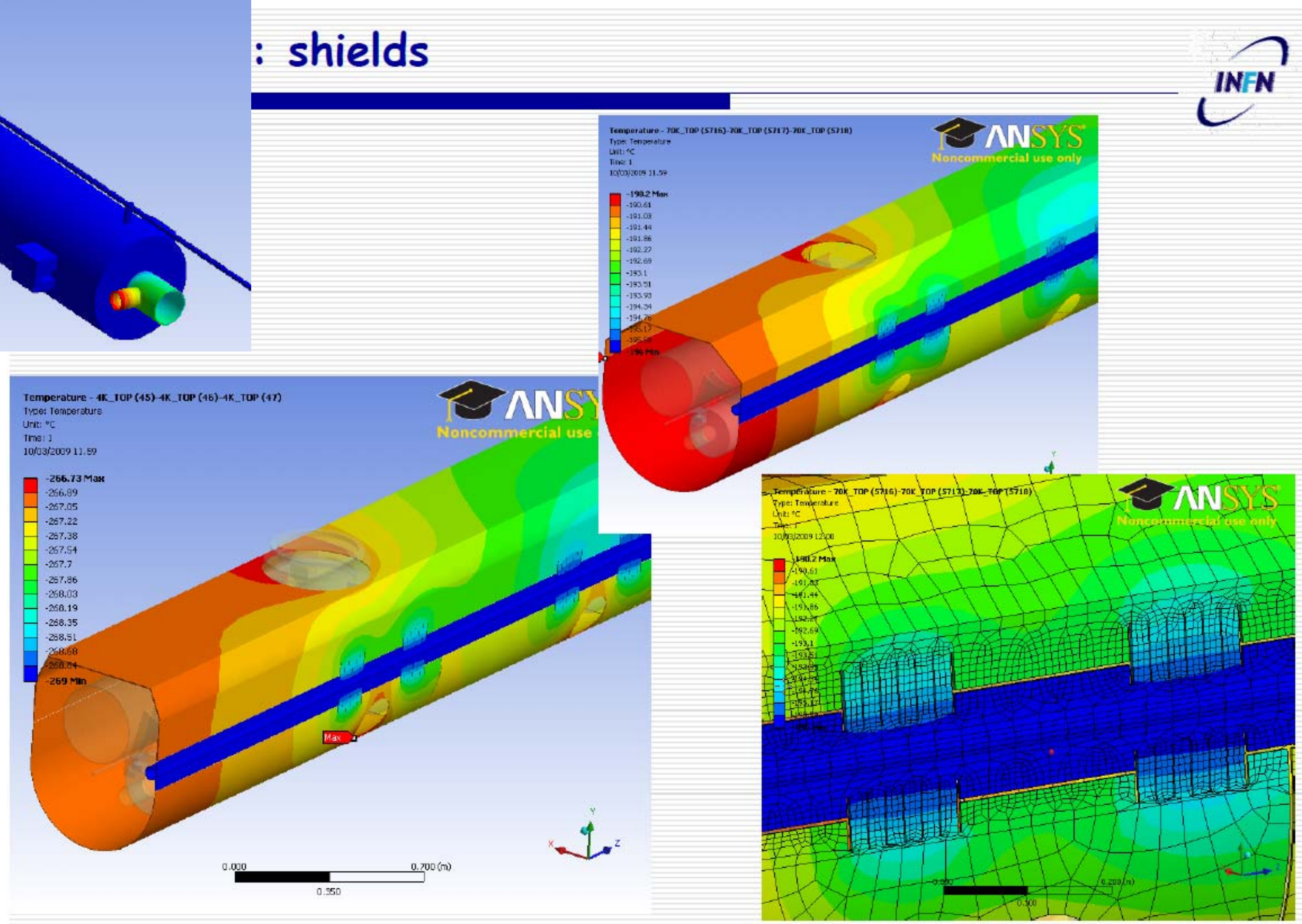
Pressure sensors: 4 absolute pressure sensors, 5 pressure sensors

Mass flow meters: 3 volume flow meters

Cold test of S1-G cryomodule (Thermal analysis)



Thermal calculation with ANSYS by the INFN group for the components in Module-C



5K shield study and test in STF

Original heat loads scaled from TESLA TDR by Tom Peterson (in RDR)

Heat Load @ 2 K

	Static	Dynamic
RF load	NA	7.46
Supports	0.6	NA
Input Coupler	0.55	0.16
Current Leads	0.28	0.28
Others	0.27	1.76
Total	1.70	9.66

Total : 11.36 W

Heat Load @ 5 K

	Static	Dynamic
Radiation	1.41	NA
Supports	2.40	NA
Input Coupler	1.48	1.32
HOM Coupler (cable)	0.29	1.82
HOM Absorber	3.13	0.76
Current Leads	0.47	0.47
Diagnostic Cable	1.39	NA
Total	10.56	4.37

Total : 14.9 W

Heat Load @ 40 K

	Static	Dynamic
Radiation	32.5	NA
Supports	6.0	NA
Input Coupler	15.5	60.1
Others	5.2	28.2
Total	59.2	94.3

Total : 153.5 W

It is assumed that in the cryomodule without the 5 K shield, the heat load of 1.41 W at 5 K by radiation in the table goes into the 2 K region.

Cooling scheme of components with 40K helium gas

In the original cooling condition

40K GHe at inlet

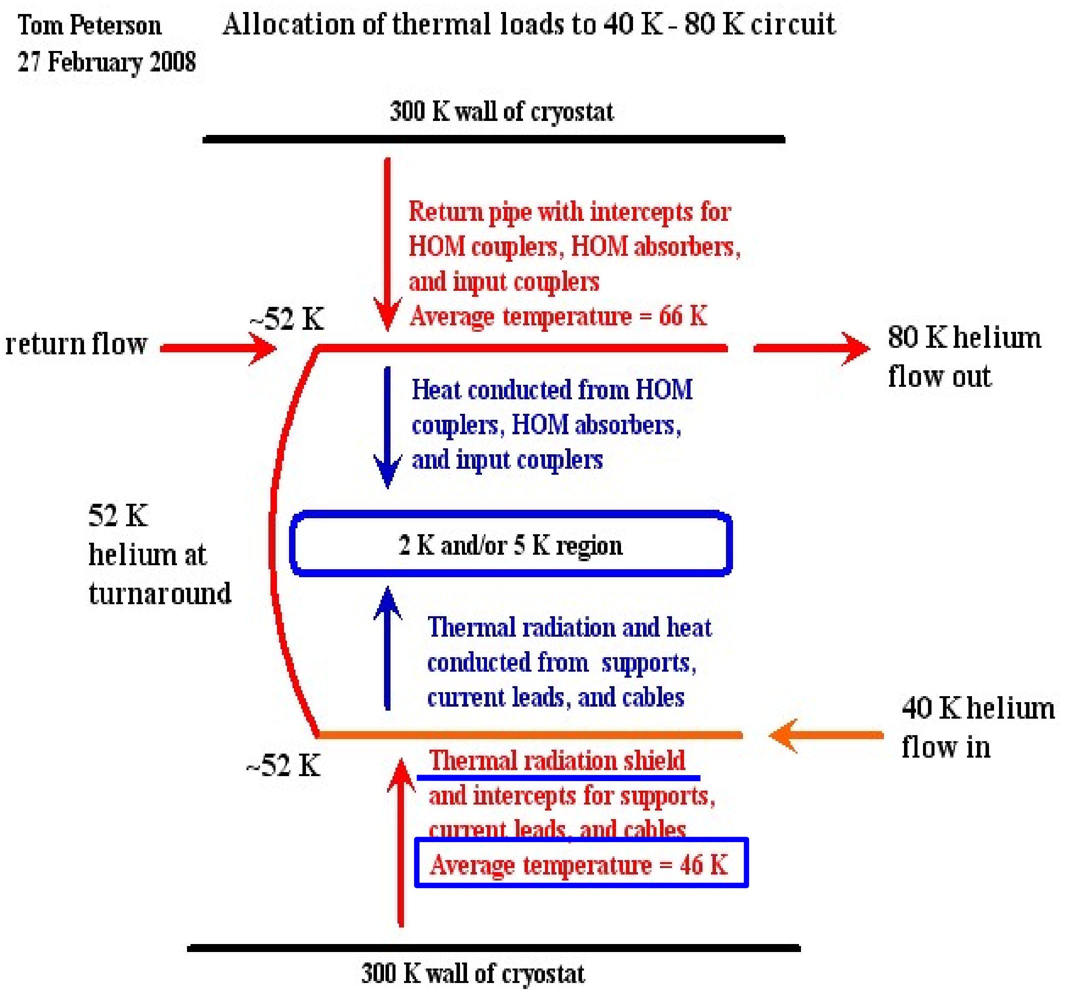
54K — Intercepts for HOM couplers, HOM absorbers, input couplers

54K Helium at turnaround

74K — Thermal radiation shield, intercepts for supports, current leads and cables

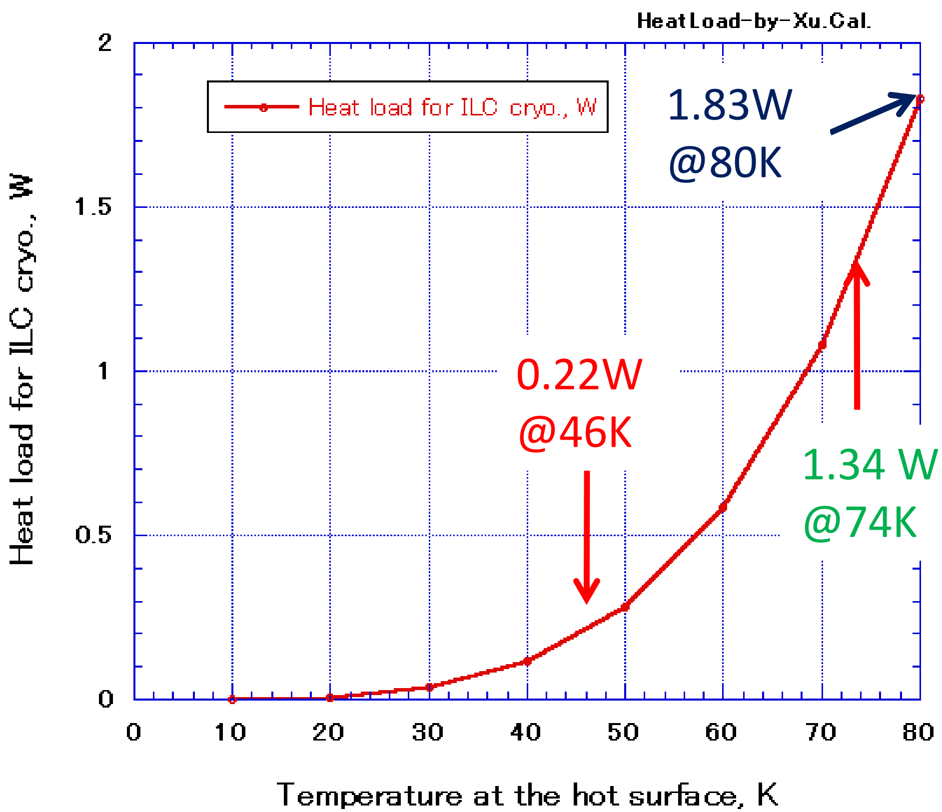
80K GHe at inlet

Cooling scheme of the 40K~80K level proposed by Tom Peterson



Heat load with the temperature distribution by T.P. model for STF cryomodule cross section

Heat load by thermal radiation as a function of outer shield temperature without 5K shield



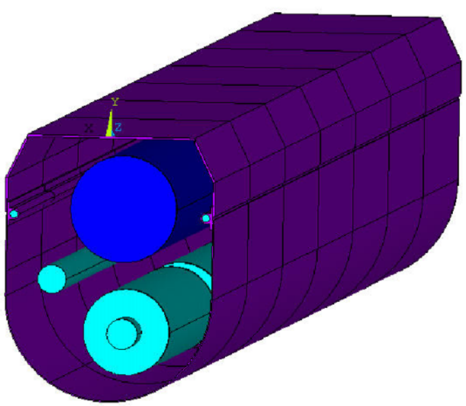
This calculation includes the geometrical factor of GRP, cavity vessel and LHe supply pipe.

With 5 K shield model:

Two shields at 80 K and 5 K are assumed to be parallel and same surface area.
Heat flux=0.05 W/m^2 (from 80K to 5K)
Surface area=30.9 m^2

Calculated heat load at 5K shield

74K→ 5K	1.32W
46K→ 5K	0.20W



Comparison of the costs for the 5K shield of STF cryomodule

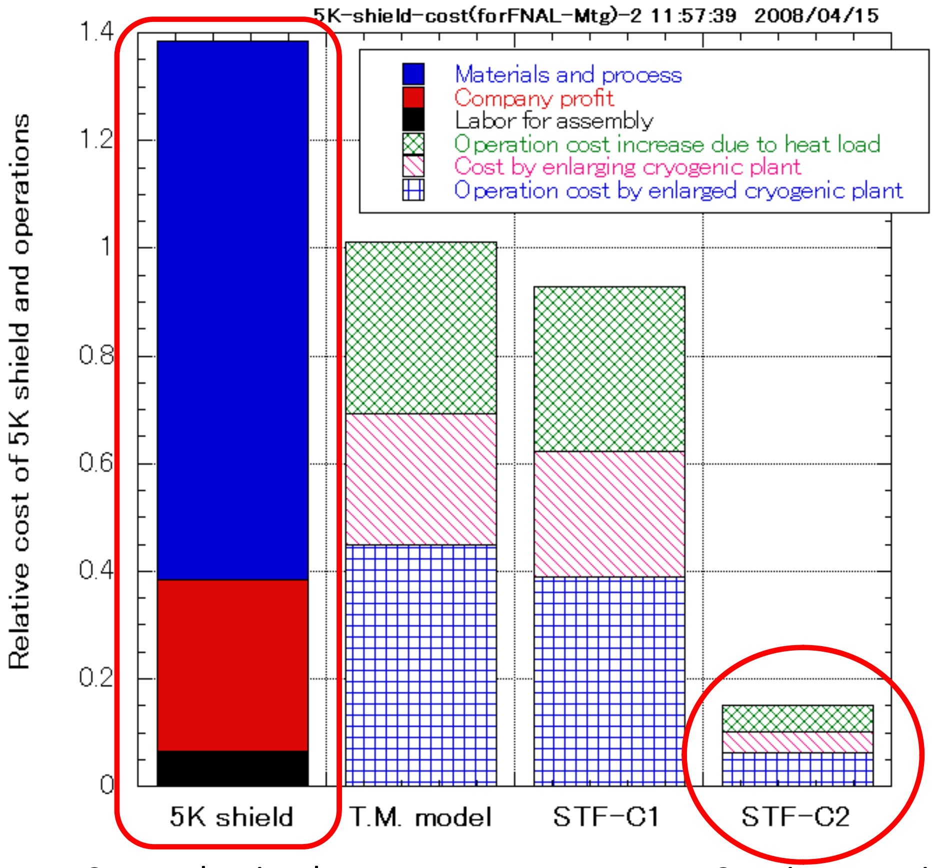
In case of removing 5 K shield;

<u>Cost increase items</u>

1. Operation cost by increasing heat load of cryomodule
2. Enlarging the cryogenic plant by increasing the heat load
3. Operation cost by the enlarged cryogenic plant

<u>Cost reduction items</u>

1. 5 K shield components
2. Labor cost for assembly
3. Company profit for 5 K shield and assembly

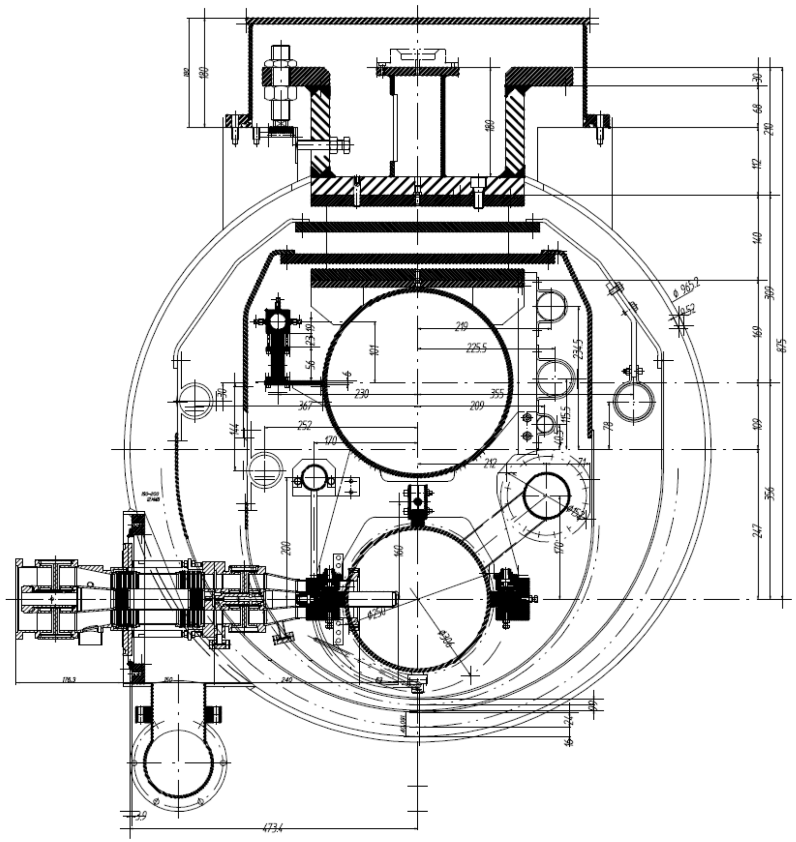


Cost reduction by removing 5K shield

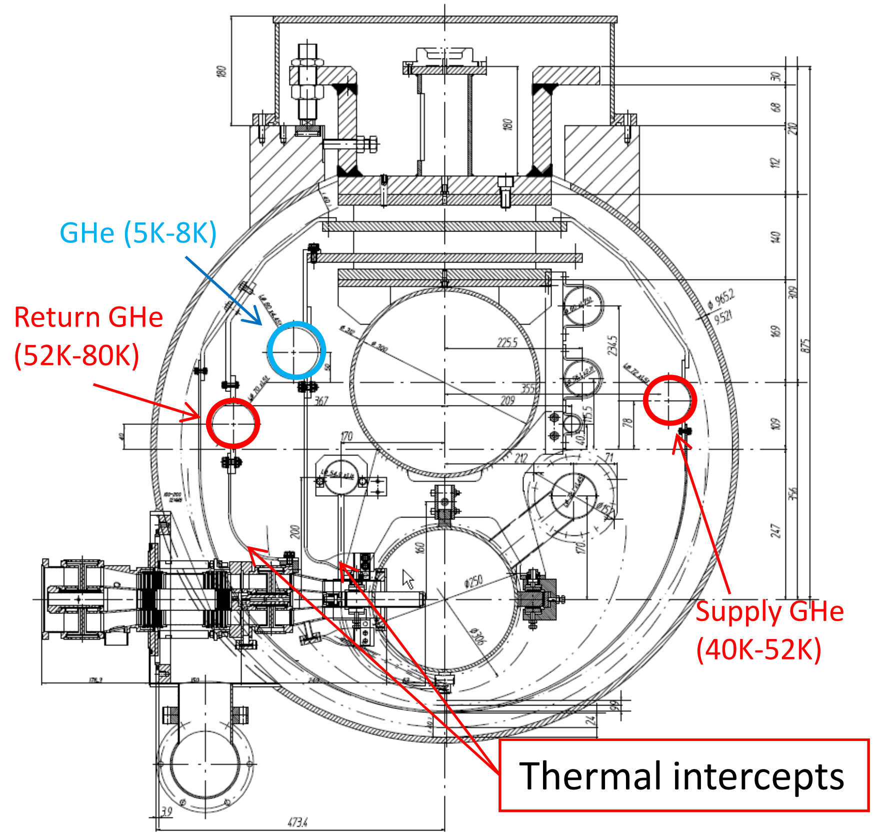
Cost increase in T.M. cooling scheme

With the model of STF cryomodule, the additional cost by removing the 5K shield (operation and enlarging cryogenics system) is ~ 10 % of the 5K shield cost (component and assembly).

Cryomodule cross section with/without 5K shield



Two shields model based on TTF-III with KEK input coupler



One shields model based

1. 5K shield bridge is removed.
2. 5K cooling line is left in the cryomodule.
3. Flow direction of 40K helium gas is opposite to the original model.
4. All thermal intercepts are assembled before completing outer shield.

Test plan of 5K shield performance in STF

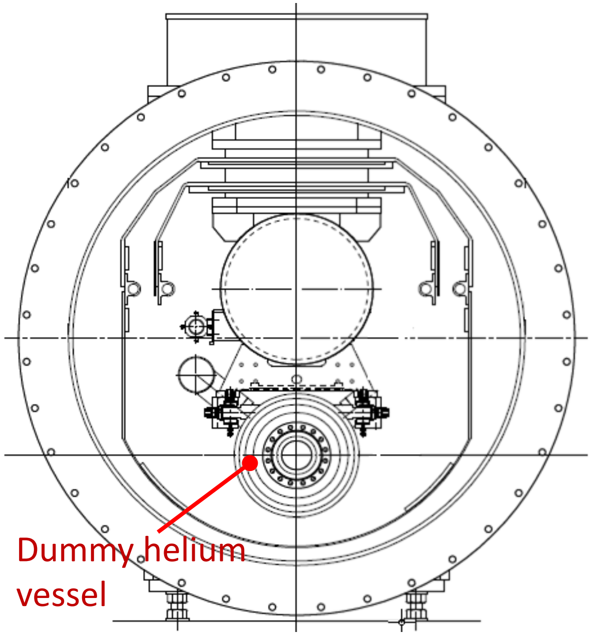
Target : making the effect of 5K shield on the heat load at 2K clear (heat load measurement at 2K with and without the 5K shield)

1. 4 dummy helium vessels as same size as the cavity jackets are installed in the STF-Module-B.
2. No input couplers.
3. The outer shield (80K) is cooled by LN_2, and the inner shield (5K) is cooled by LHe.
4. The average temperature of outer shield is estimated to be 86.5 K. At the temperature, the difference between the heat loads at 2K with and without 5K shield is calculated to be 1.14 W.

Test schedule of 5K shield

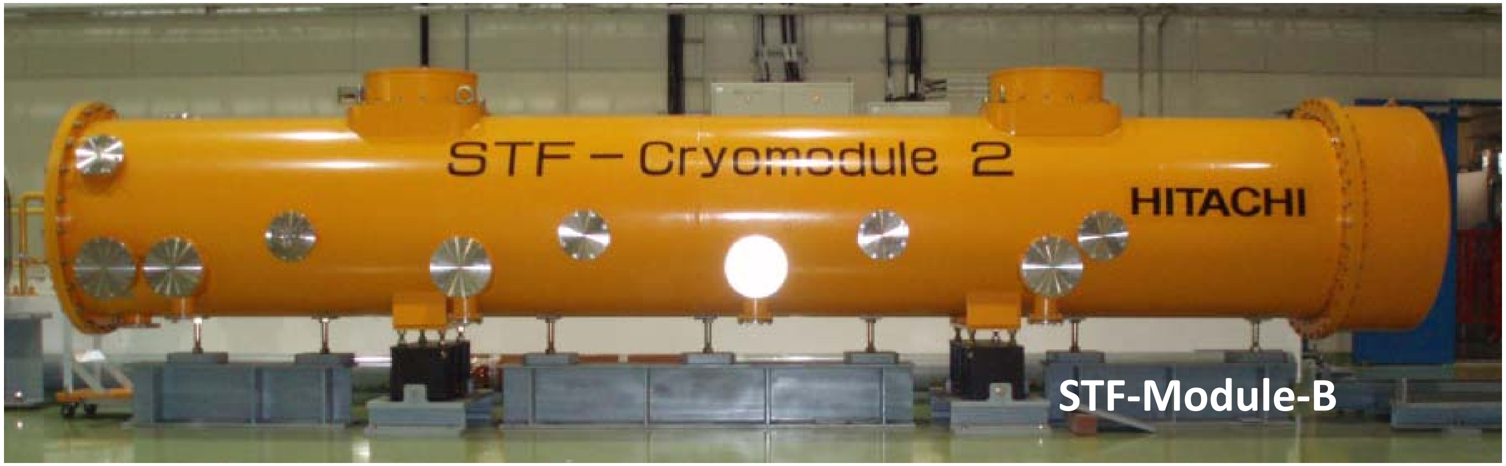
- 6/2009: heat load measurement of Module-B with 5K shield
- 7-8/2009: disassembling Module-B, removing 5K shield bridge and reassembling Module-B in the tunnel
- 9-10/2009: heat load measurement of Module-B without 5K shield

STF-Module B for 5K shield test



Length of the module-B= 5515 mm
(Module length in the spec. table=11829.6 mm)

Input couplers are not installed.



Schedule of the ILC prototype cryomodule development

	CY	2008			2009				2010				2011		
		4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9
S1-G	Cryomodule Design														
	Construction module-C components														
	DESY/FNAL cavities														
	Assembly of module-C														
	KEK cavities														
	Assembly of module-A														
	Installation modules in the tunnel														
	S1-G cryomodule cold test														
FNAL CM1 cold test															
FNAL CM2 const. as S1															
5K shield test at STF	Installation module-B in the tunnel														
	Cold test of module-B with 5K shield														
	Modifying module-B														
	Cold test of module-B without 5K shield														
	Deciding the 5K shield performance														
STF2 module	Cryomodule design														
(as the ILC prototype)	Construction of cryomodules														