Development status of a NbTi conduction-cooled superconducting quadrupole magnet combined with dipole correctors for the ILC main linac

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Abstract

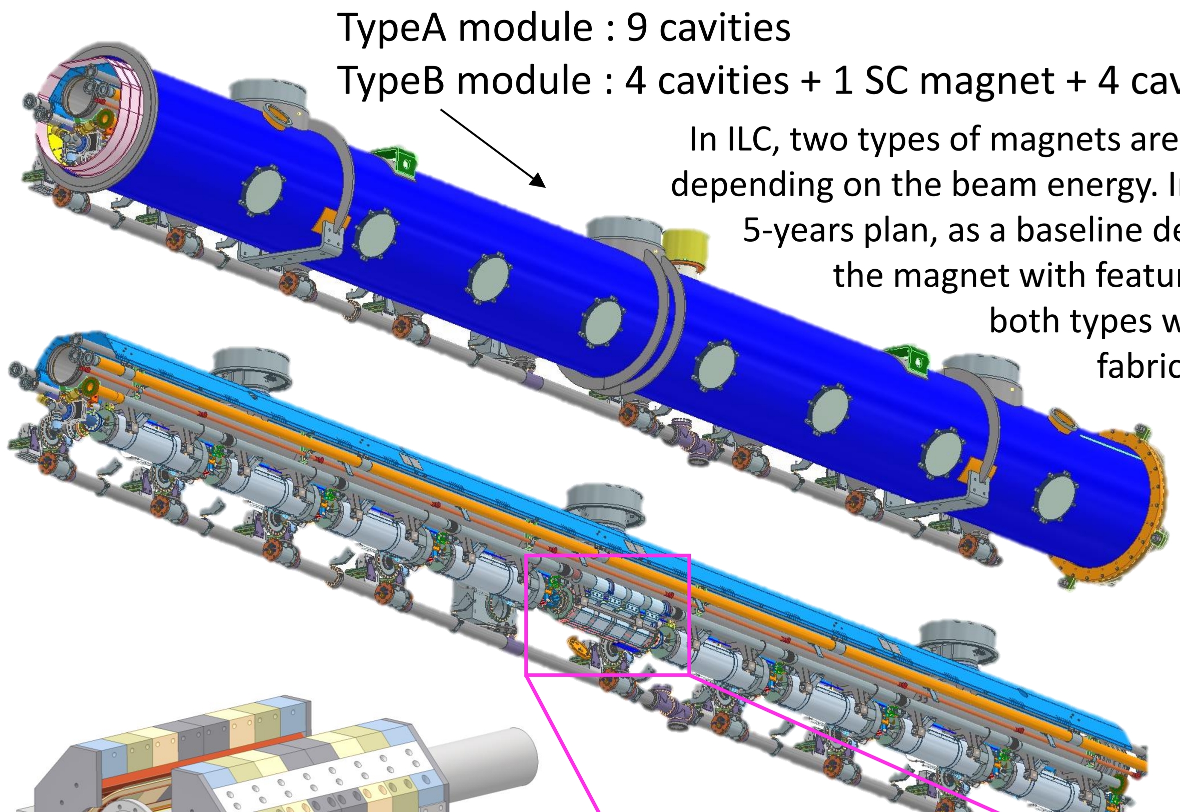
In International Linear Collider (ILC) main linac (ML), superconducting quadrupole (SCQ) magnets combined with dipole correctors, together with superconducting radio frequency (SRF) cavities, will be used to transport and accelerate electron and positron beams to the interaction point. The SRF cavity accelerates the e-beam up to 125 GeV per side, the SCQ focuses the beam, and the dipole collectors steer the beam and transport it along with the geoid. Two key features in the ILC-ML SC magnet are **vertical split design** and **conduction cooling**. This allows the SC magnet to be assembled after the string-assembly of SRF cavities in the clean room and the simplification of the cryomodule structure.

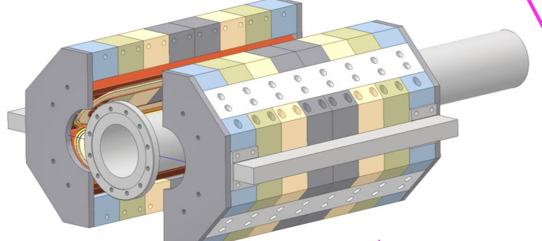
A 5-years plan to manufacture one ILC-type cryomodule began at KEK in 2023 with international collaboration. A prototype SCQ is being produced in JFY2024-2025, and a stand-alone performance evaluation test in a cryocooler-based cryostat is scheduled to be conducted in JFY2025.

Design of the ILC-ML SC magnet

TypeA module : 9 cavities
TypeB module : 4 cavities + 1 SC magnet + 4 cavities

In ILC, two types of magnets are used depending on the beam energy. In this 5-years plan, as a baseline design, the magnet with features of both types will be fabricated.

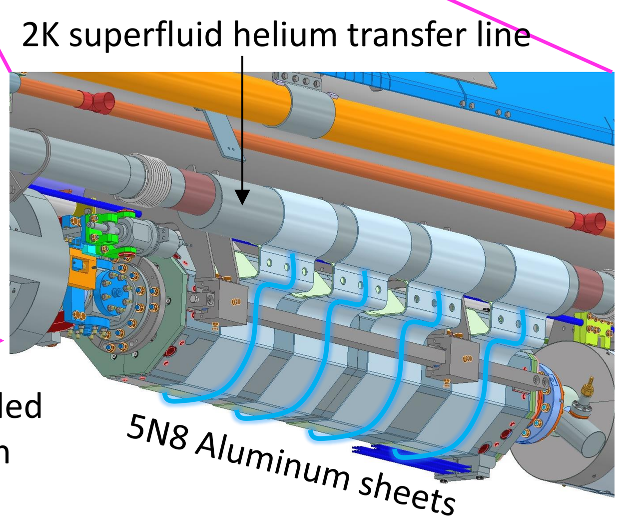




Key features

1. Split design*
2. Conduction cooling

*This allows the SC magnet to be assembled after the string-assembly of SRF cavities in the clean room.

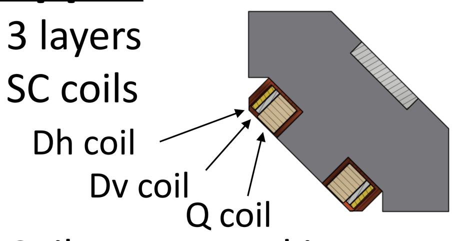


Parameters of the SC magnet and SC wire

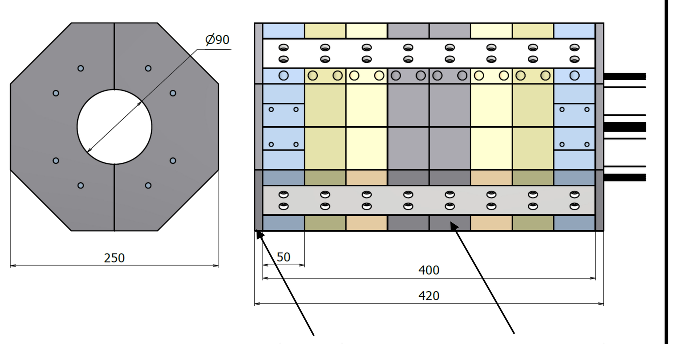
SC Magnet : Yoke		SC wire	
Pole length	300 mm	Superconductor	NbTi
Field length	~300 mm	Wire diameter	0.55 mm (Q)/0.50 mm (D)
Outer diameter	≦140 mm	Copper ratio	2.0 (TBD)
Inner diameter	45 mm	Electrical Insulation	Polyvinyl Formal
SC Magnet : Quadrupole		Wire dia. with insulation	0.60 mm (Q)/0.55 mm (D)
Field gradient	40 T/m	IC at 5 T	240 A (Q) / 197 A (D)
GL integral	~12 T	IC at 6 T	196 A (Q) / 161 A (D)
Current (Max)	52.4 A	IC at 7 T	150 A (Q) / 125 A (D)
SC Magnet : Dipole		Others	
Field	0.1 T	Max field in Q coils	2.6 T
B0L integral	~0.03 T	Operation temperature	2.0/4.5 K
Current (MAX)	37 A	Ground insulation of coil	200~500 V (TBD)

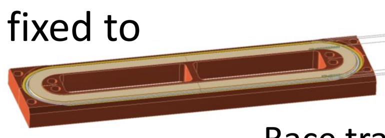
Copper coil case

- 3 layers SC coils
- Coils are wound in a winding die, impregnated with resin, and fixed to the case.



Magnet dimension





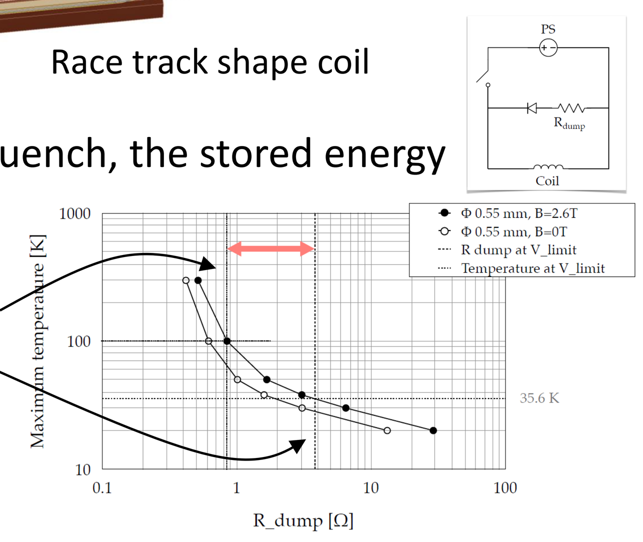
Race track shape coil

Quench protection

In a case of the SC magnet quench, the stored energy is extracted by an external electrical resistance.

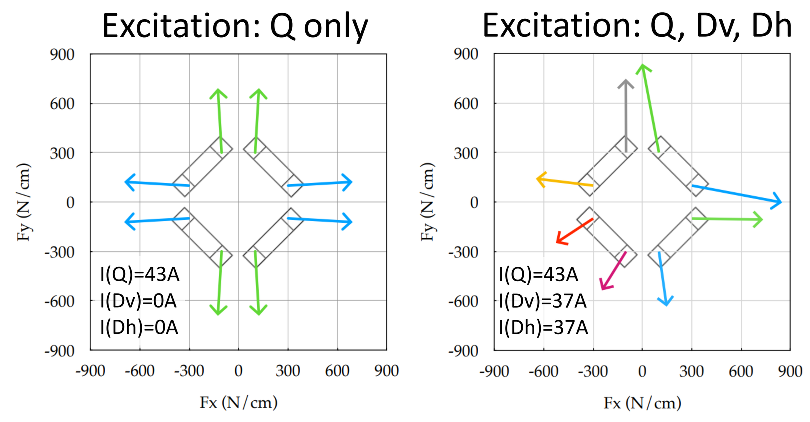
- Max temperature : 100 K
- Ground insul. limit: 200 V

⇨ R_{dump}~a few Ω



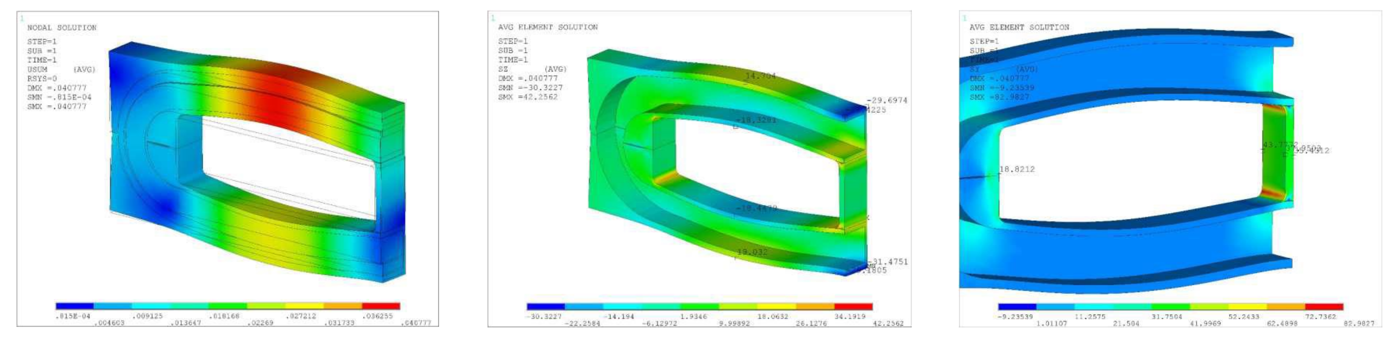
Lorentz force analysis

⇨ Direction: pressing against the iron yoke



Structural analysis

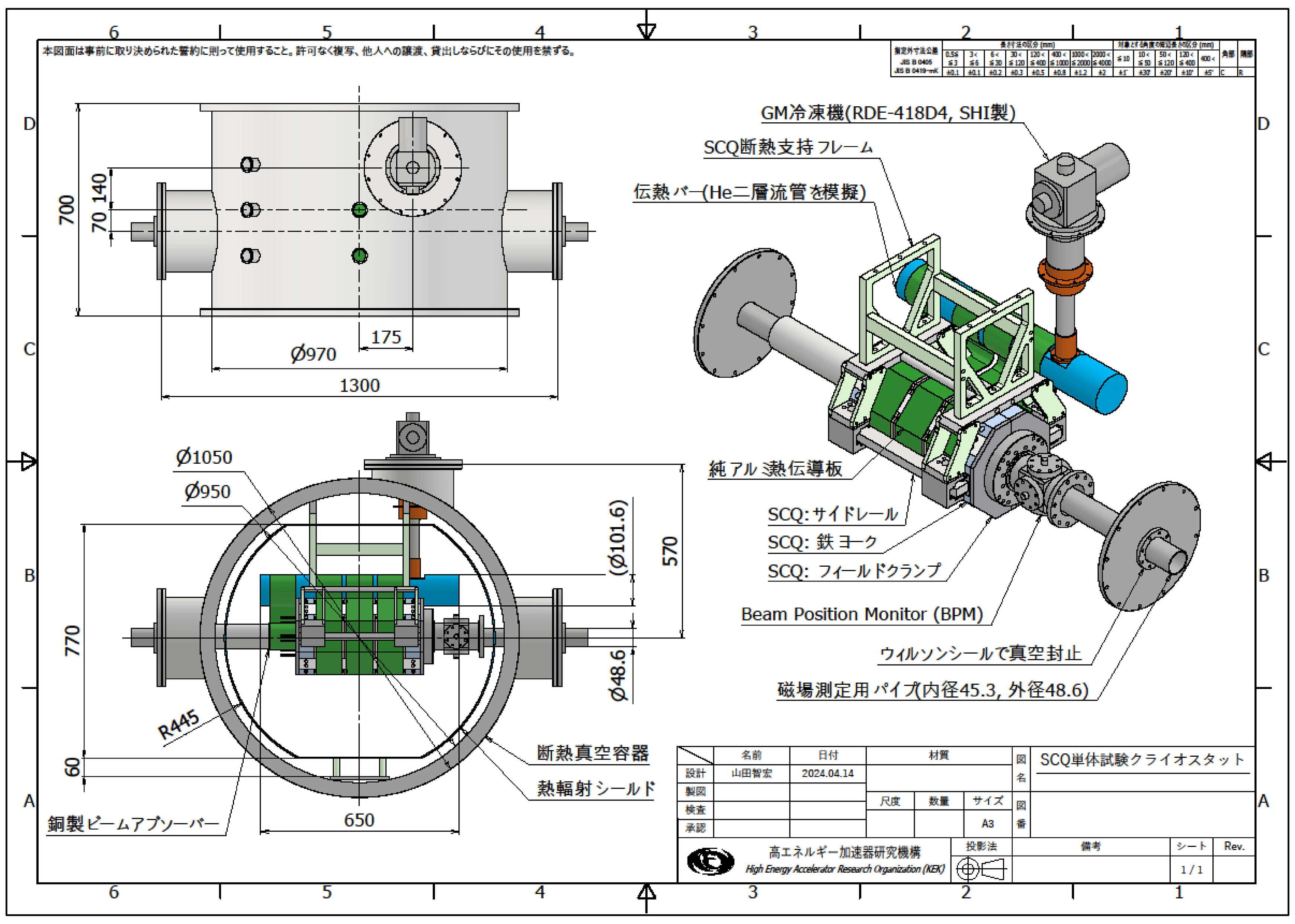
⇨ The outer wall of the coil case made of copper was thickened and ribs were placed in the center to withstand the Lorentz forces during excitation.



Deformation: 0.04 mm Bending stress: 31.5 MPa Tensile stress: 40.9 MPa

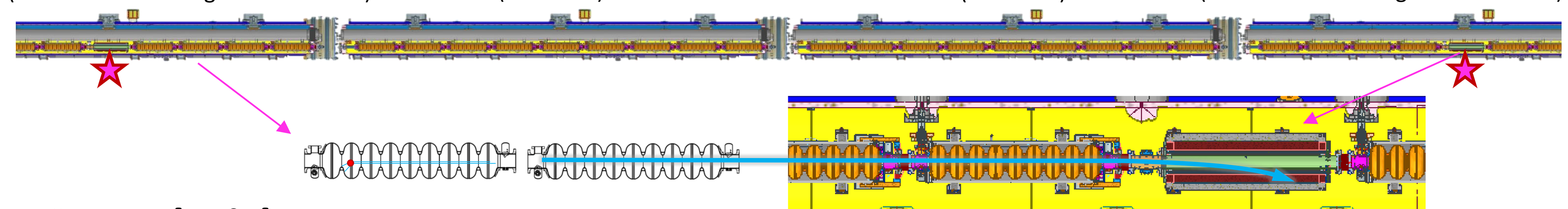
Stand-alone test cryostat

This cryostat was designed to conductively cool the SC magnet and conduct performance evaluation tests without liquid helium environment. Rotating coils can be inserted into the warm bore pipe to measure the magnetic field distribution (quality). The support structure of the SC magnet is the same as that in the ILC cryomodule and this cryostat is planned to be used in the practice of integrating the magnet into the cryomodule.



Quench risk & countermeasure for dark current

In ILC, the SC magnet is installed every 26 cavities.



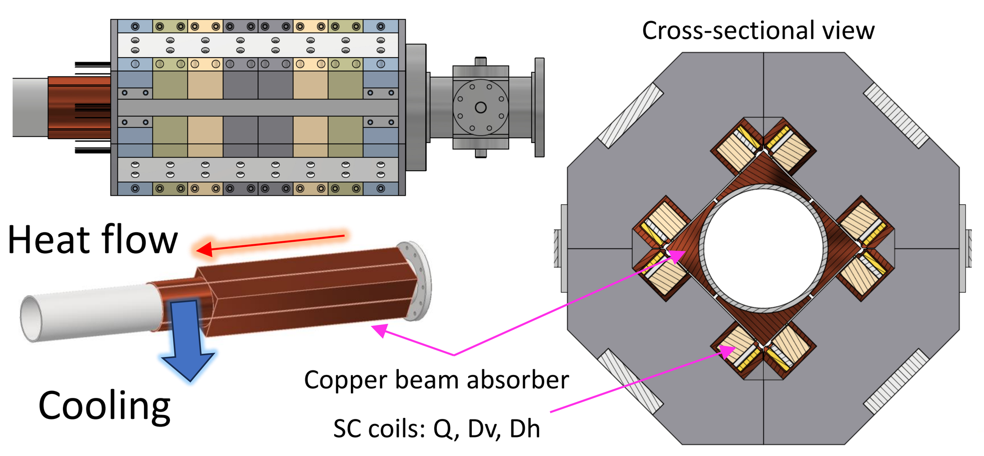
Quench risk

Field-emitted particles from the cavity inner surface are naturally accelerated along with the main beam by the accelerating electric field in the cavity cell. ⟶ **Dark current**

➢ The dark current is bent by the magnetic field in the SC magnet aperture and injected into the SC coils.
➢ SC coils are heated up and under risk of quench.

Countermeasure: Beam absorber

Copper blocks are placed around the beam pipe to **shield** and **absorb** the dark current before it enters SC coils. Heat is extracted along the copper beam pipe combined with copper beam absorber.



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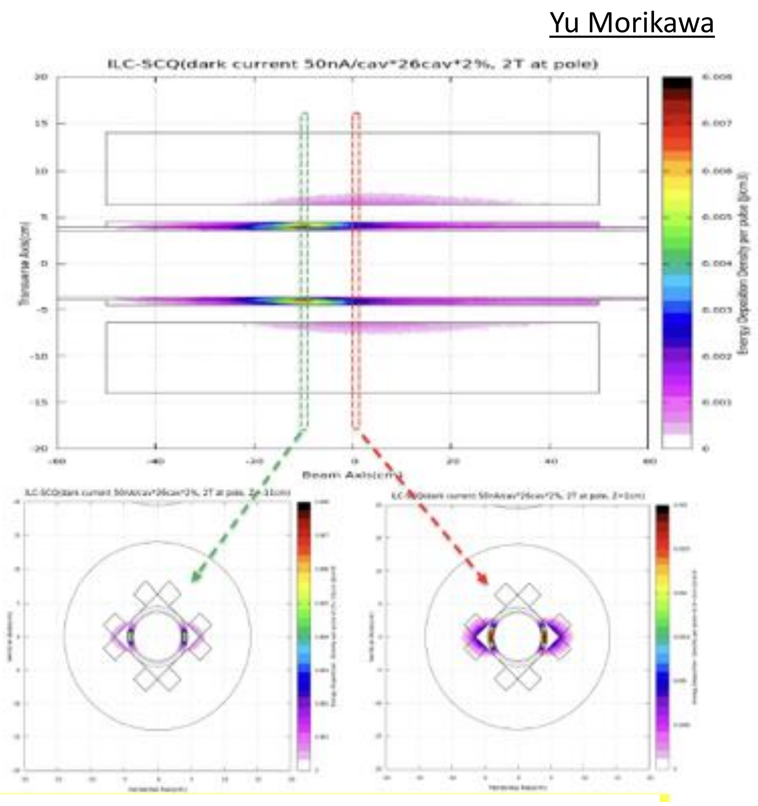

Summary and Schedule

- The superconducting magnets for ILC-ML have two key features: vertical split design and conduction cooling.
- The magnet design was completed in JFY2023. Production has already started and is scheduled to be completed by the end of next fiscal year.
- The design of the cryostat for stand-alone testing is also underway in parallel.
- The copper beam absorber is being considered as a countermeasure against quench risk due to the dark current, and a detailed analysis for its implementation will be performed soon.
- The development schedule is shown on the right. Stand-alone test of the magnet will be completed by JFY2025. The cryomodule assembly and test will be performed in JFY2027.

	JFY2023	JFY2024	JFY2025	JFY2026	JFY2027
SC magnet design	■				
SC magnet production		■	■		
Cryostat production		■	■		
Beam absorber production		■	■		
Stand-alone test of SC magnet			■		
Integration test of SC magnet and beam absorber				■	
Cryomodule assembly and test					■

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Reference

- Y. Arimoto et al., “Study of conduction-cooled superconducting quadrupole magnets combined with dipole correctors for the ILC main linac”, Proc. Of IPAC/2021, SP, Brazil, Jacow publishing (2021).
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