Status Report on D1 Magnets

Tatsushi NAKAMOTO, KEK

On behalf of CERN-KEK Collaboration for D1 Construction for HL-LHC

CERN-KEK Committee, 18th Meeting, Dec. 7, 2023

Acknowledgement

- KEK (in particular)

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- Fusac Technologies

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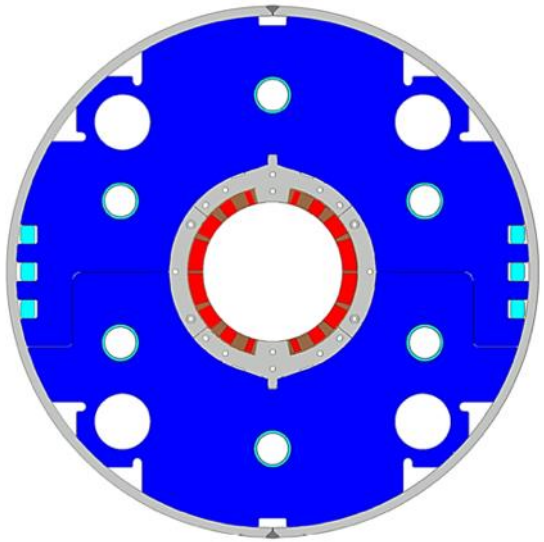
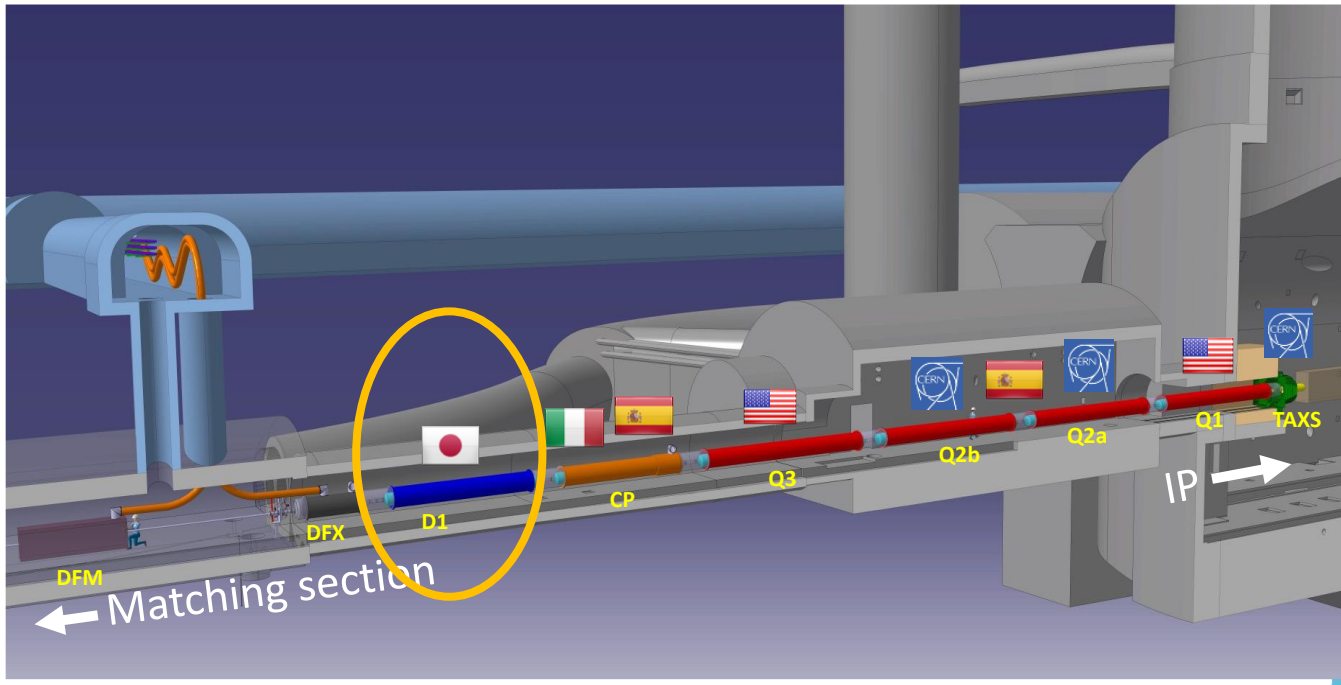
Japanese Contribution to HL-LHC: D1 magnets



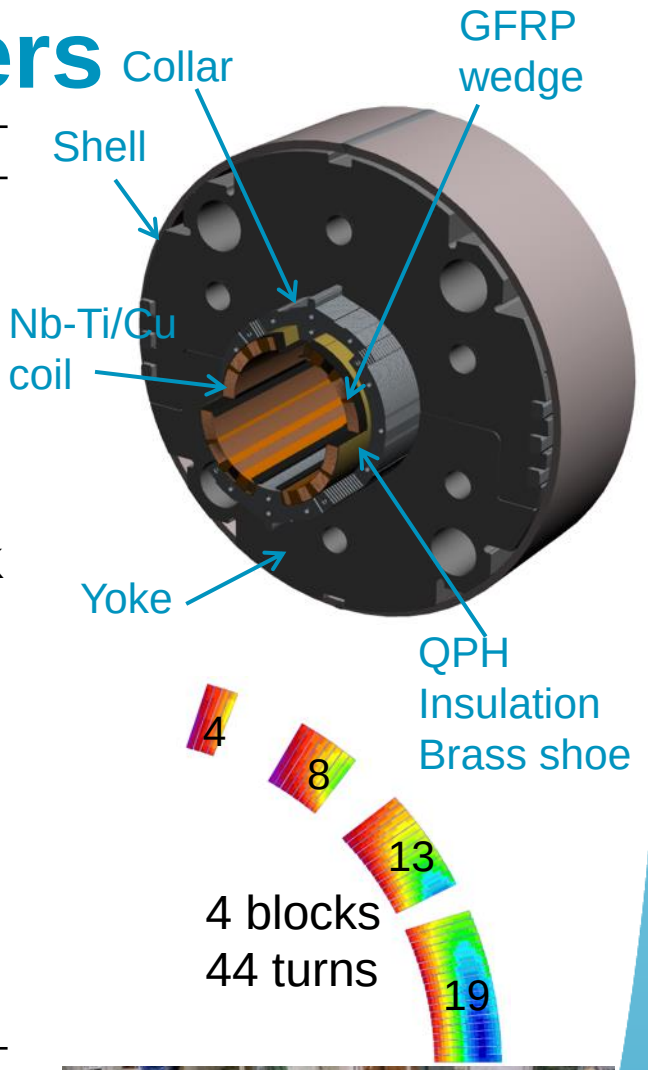


- Beam separation dipole (D1) by KEK
  - Design study of D1 for HL-LHC within the framework of the CERN-KEK collaboration since 2011.
  - 150 mm single aperture, 35 Tm (5.6 T x 6.3 m), Nb-Ti technology.
  - Development 2-m long model magnets (3 units) at KEK
- Deliverables for HL-LHC
  - *1 full-scale prototype cold mass (LMBXFP)*
  - *6 series cold masses (LMBXF1-6)*

7 units x 7-m long cold masses

Design parameters

	prototype, series production (7m)
Coil aperture	**150 mm**
Field integral	**35 T m**
Field (3D)	Nominal: 5.60 T, Ultimate: 6.04 T
Peak field (3D)	Nominal: 6.58 T, Ultimate: 7.14 T
Current	Nominal : 12.11 kA, Ultimate 13.23 kA
Operating temperature	1.9 K
Field quality	$<10^{-4}$ w.r.t B_1 (R_{ref}=50 mm)
Load line ratio (3D)	Nominal: 76.5%, Ultimate: 83.1% at 1.9 K
Differential inductance	Nominal: 4.0 mH/m
Conductor	Nb-Ti: LHC-MB outer cable
Stored energy	Nominal: 340 kJ/m
Magnetic length	6.26 m
Coil mech. length	6.58 m
Magnet mech. length	6.73 m 12 ton
Heat load	**135 W (Magnet total)** **2 mW/cm^3 (Coil peak)**
Radiation dose	**> 25 MGy**



Large-aperture single layer coil →
Mechanical support of a coil is challenging

Three 2 m model magnets were developed at KEK.

D1 Prototype Cold Mass: MBXFP1

Delivery of MBXFP1 to CERN

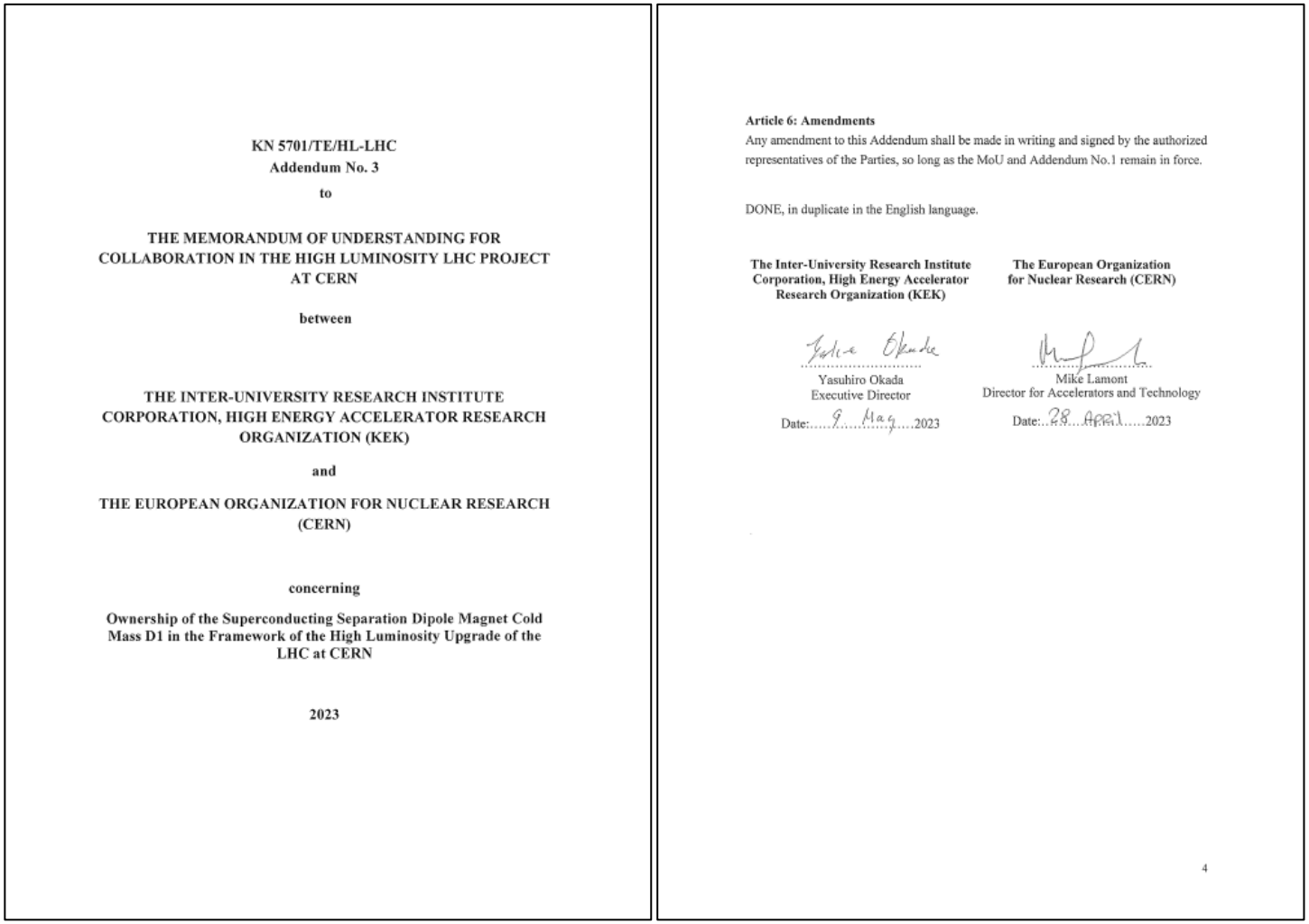
- The first D1 prototype cold mass was shipped from KEK on Jan. 25.
- The containership departed at Yokohama (Feb. 12) and arrived at Rotterdam (March 27). Delivery to CERN on April 4.
- The wooden box was totally covered by “mold”. Very kind support of TE-MSC-LMF and EN-HE-HH teams to pull out the cold mass under unpleasant condition. Material of shipping structure shall be modified at the next shipping for series cold masses.
- Data loggers were set on the cold mass. Thanks to barrier films with desiccant agents, the cold mass was kept in dry condition during the whole transportation. Measured acceleration was within $\pm$2G all the time except the loading onto the ship (-2.4 G and -2.8G).

Cryostatting of MBXFP1 at CERN

Courtesy of Delio Duarte Ramos, Franco Julio Mangiarotti

- Many thanks to H. Prin, D. Duarte Ramos for completing the cold mass and for cryostatting.
- Cryostatting report at WP3 meeting can be found at https://indico.cern.ch/event/1296834/ .
- Cooling of the magnet at SM18 was started in November and the powering test will be started soon.

New MoU Addendum



KN 5701/TE/HL-LHC
Addendum No. 3
to

THE MEMORANDUM OF UNDERSTANDING FOR COLLABORATION IN THE HIGH LUMINOSITY LHC PROJECT AT CERN

between

THE INTER-UNIVERSITY RESEARCH INSTITUTE CORPORATION, HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION (KEK)

and

THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

concerning

Ownership of the Superconducting Separation Dipole Magnet Cold Mass D1 in the Framework of the High Luminosity Upgrade of the LHC at CERN

2023

Article 6: Amendments

Any amendment to this Addendum shall be made in writing and signed by the authorized representatives of the Parties, so long as the MoU and Addendum No.1 remain in force.

DONE, in duplicate in the English language.

The Inter-University Research Institute Corporation, High Energy Accelerator Research Organization (KEK)	The European Organization for Nuclear Research (CERN)
Yasuhiro Okada Executive Director	Mike Lamont Director for Accelerators and Technology
Date: 9 May 2023	Date: 28 April 2023

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- Protocol of the ownership transfer of the D1 cold mass was NOT defined in the Addendum #1.
- Discussion was triggered by the delivery of the D1 prototype and the Addendum #3 was finally issued in May 2023.

Status of the series D1 Cold Masses

Flow of D1 Cold Mass Production

PV: Pressure Vessel

Magnet

HITACHI

1 coil winding

2 insulation, collaring

3 yoking

4 **shell & end-ring welding**, end-plate, splice. Alignment target welding, **cap welding for series**, alignment meas.

KEK

vertical cold test

CERN HP

- **Training Quench**
- **MFM at cold**

warm MFM

SSW
Rotating coil

Final assembly of cold mass

HITACHI

5 **cap welding for prototype**, installation of tubes (BT, HXT) final splice, instrumentation
end-cover & extremities welding
alignment & support welding

inspection incl. pressure test (@ 2.5 MPa)

KEK

warm MFM

SSW
Rotating coil

HP: readiness of shipping, documents.

CERN

shipping to CERN

Cryostating
Horizontal cold test

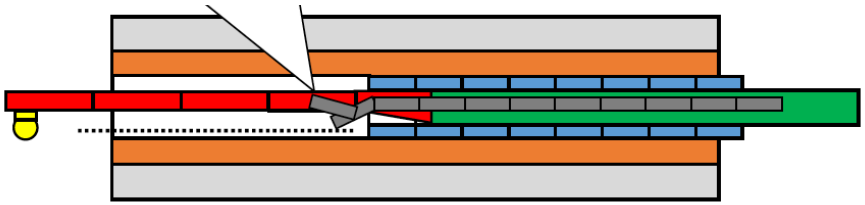
Status of Series Magnet Production

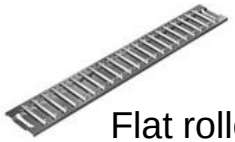
- MBXF5
  - NC: the coil insulation damages were found after removal of the collaring-mandrel after yoking process. EDMS 2753776. (Report at the last meeting.)

Recall Major NC in Manufacturing of MBXF5

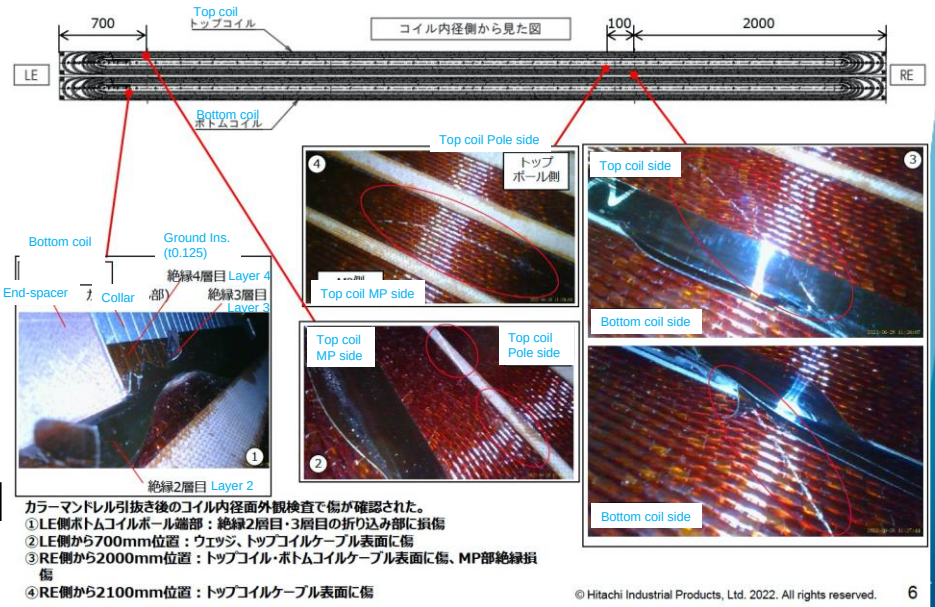
- LT-1 and LB-1 coils for MBXF5 were completed.
  - Estimated coil pre-stress: Good.
    - LB-1: L120.7 (L) & 122.9 (R), LT-1: 121.7 (L) & 122.2 (R) (unit: MPa).
    - EDMS 2724784
- All components for the magnet were already fabricated.
- Collaring and yoking processes were successfully done in June 2022.
- NC: potential coil insulation damage was found after removal of the collaring-mandrel. EDMS 2753776.
  - Investigation is underway.

Spacers more than plan were removed from the RE side and the coil were exposed to the flat-rollers…

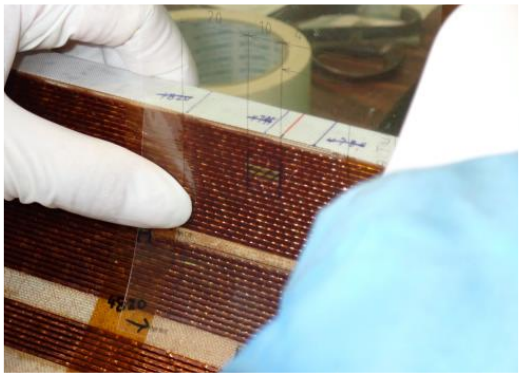


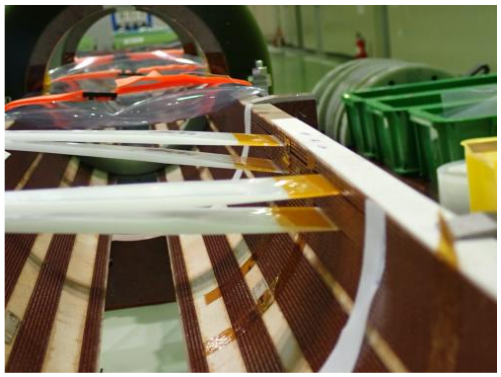


Flat rollers

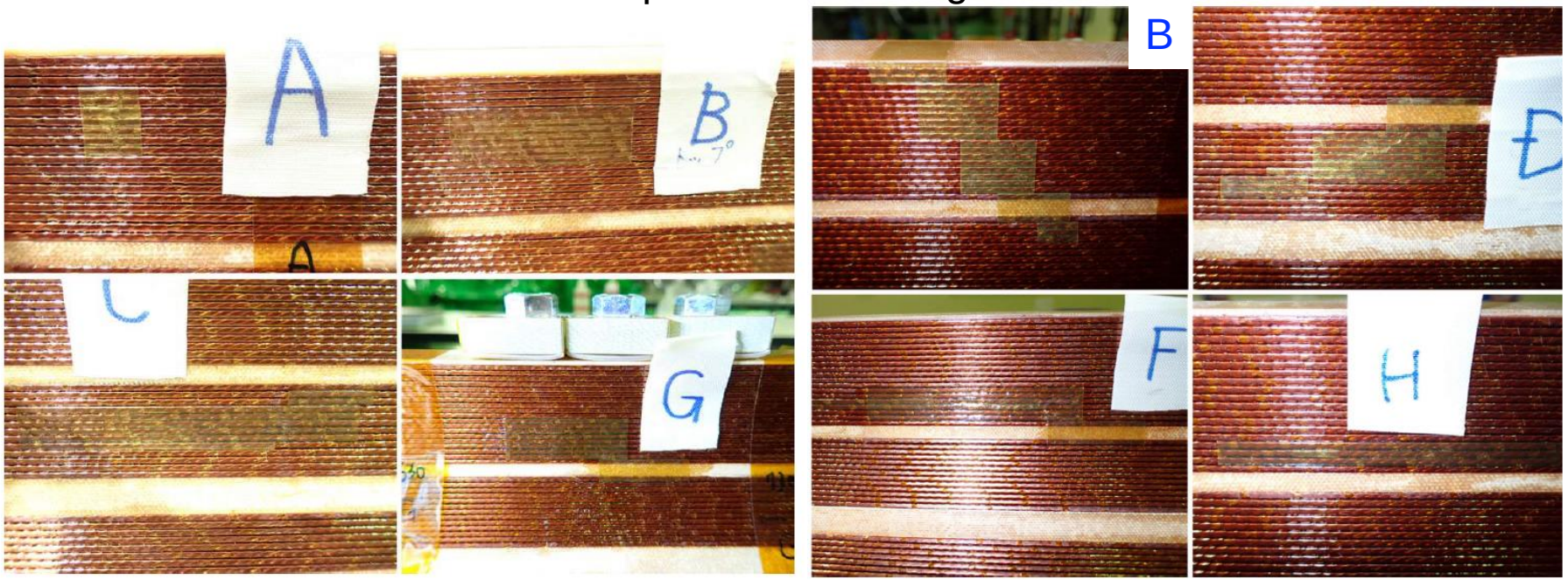


Repair of MBXF5 Coils





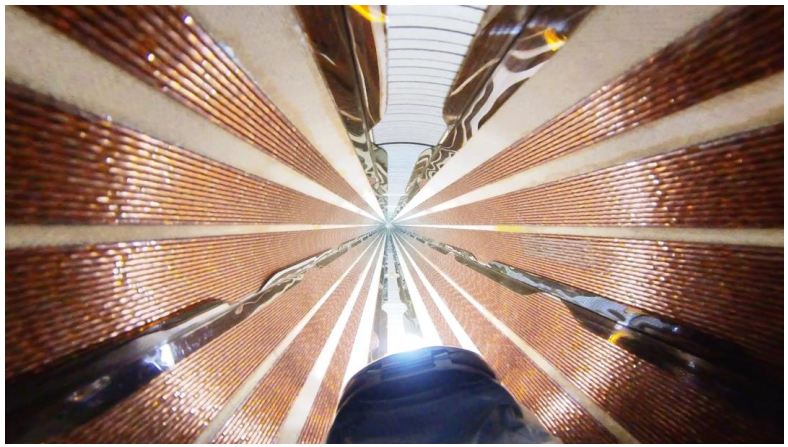
After repair of the damaged insulation



Electrical soundness of the repaired coils was validated by electrical test (coil resistance, inductance, impulse test at 1.3 kV).

Status of Series Magnet Production

- MBXF5
  - NC: the coil insulation damages were found after removal of the collaring-mandrel after yoking process. EDMS 2753776. (Report at the last meeting.)
    - ✓ **The coils were successfully repaired and the NC was closed.**
  - The vertical cold test is being performed at KEK (Sep. 2023~).
- MBXF1
  - The vertical cold test was completed at April to June 2023.
  - The final assembly of the cold mass is currently underway at Hitachi.
  - Delivery to CERN is planned in June 2024 as the 1st series cold mass.
- MBXF2
  - The longitudinal shell welding was completed. The magnet will be delivered to KEK for the cold test in February 2024.
- MBXF3
  - Two coils were fabricated and the coil size measurement is ongoing.



MBXF5: Inside of coil bore after successful insulation repair.

Recall

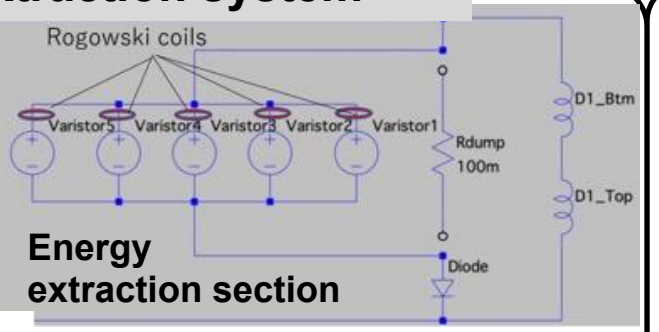
Remaining Issues in KEK Test Facility after MBXFP1 Powering Test

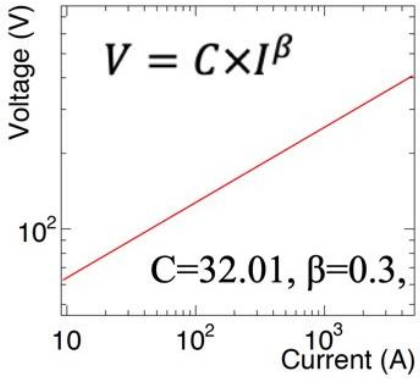
Training quench up to the ultimate current (13.2 kA) was NOT demonstrated in the powering test of MBXFP1 due to limitation of the test facility…

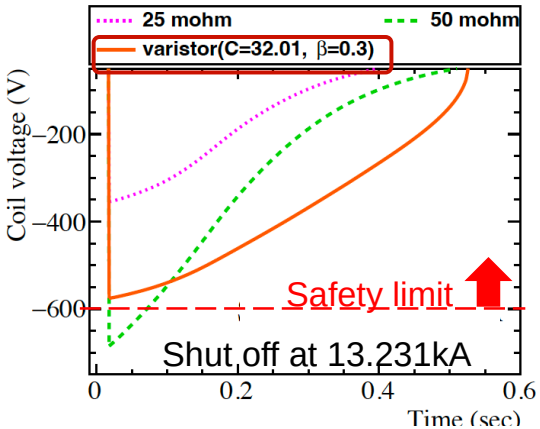
- **Target of Facility Upgrade**
  - Maximum voltage below 600 V at the ultimate current.
  - Magnet dissipation energy below the safety limit of 1.5 MJ.
  - Increase of helium gasbag capacity.
- To satisfy these targets, new energy extraction using **varistors** and **the additional helium gasbag** were implemented before the cold test of MBXF1.

Test facility upgrades

New extraction system

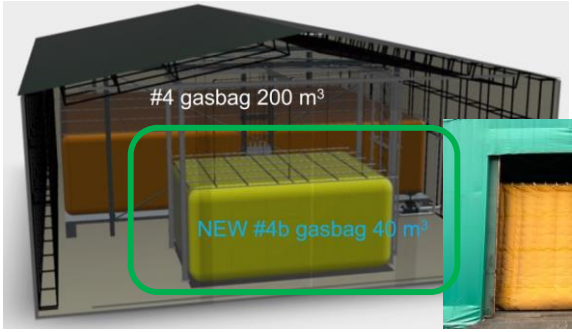






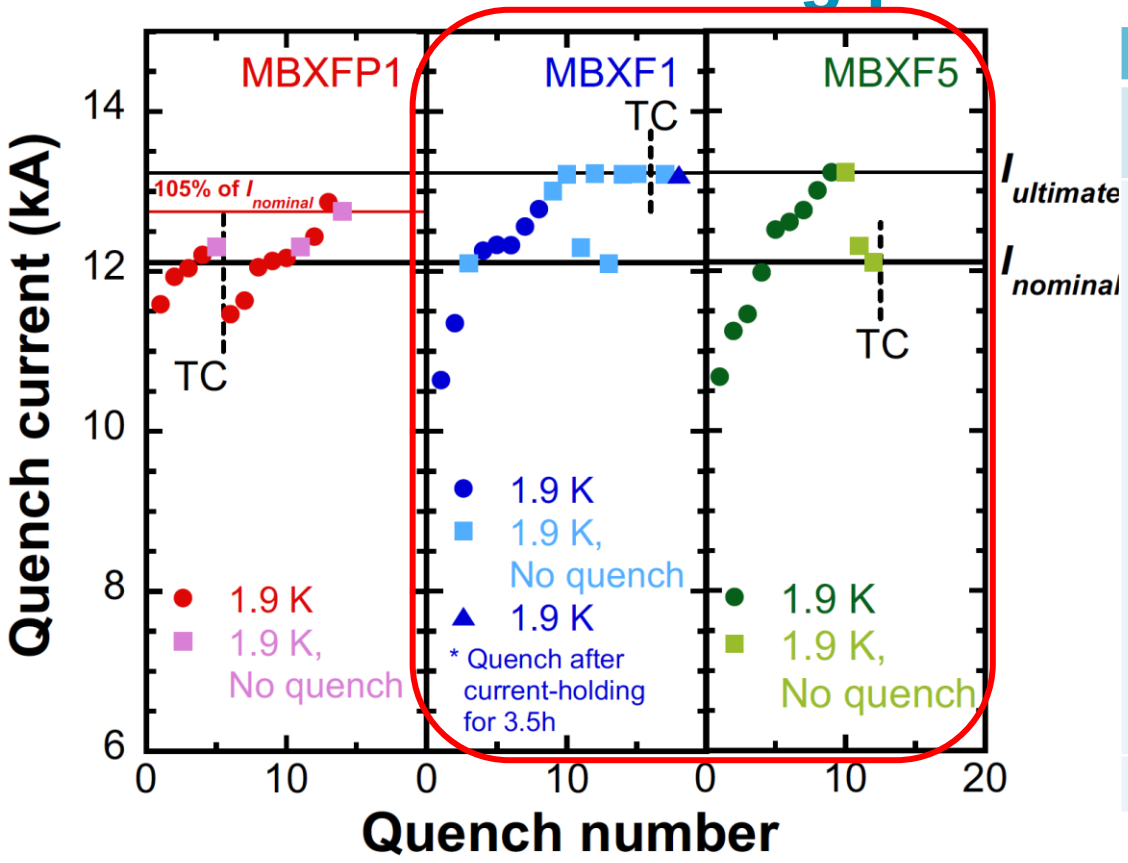
- Non-linear resistance, varistors (Metrosil®) was installed
- Can suppress the maximum voltage below 600 V
- Expect an excellent energy-extracting performance

Additional gas storage bag



- Helium gas at 13.23 kA w/ Varistors: 294 m^3 (prediction)
- New Helium gasbag was installed (#4b, 40 m^3)
  - Total capacity: 320 m^3 > 294 m^3
  - #4b Gasbag to be installed next to #4 Gasbag in the same tent warehouse

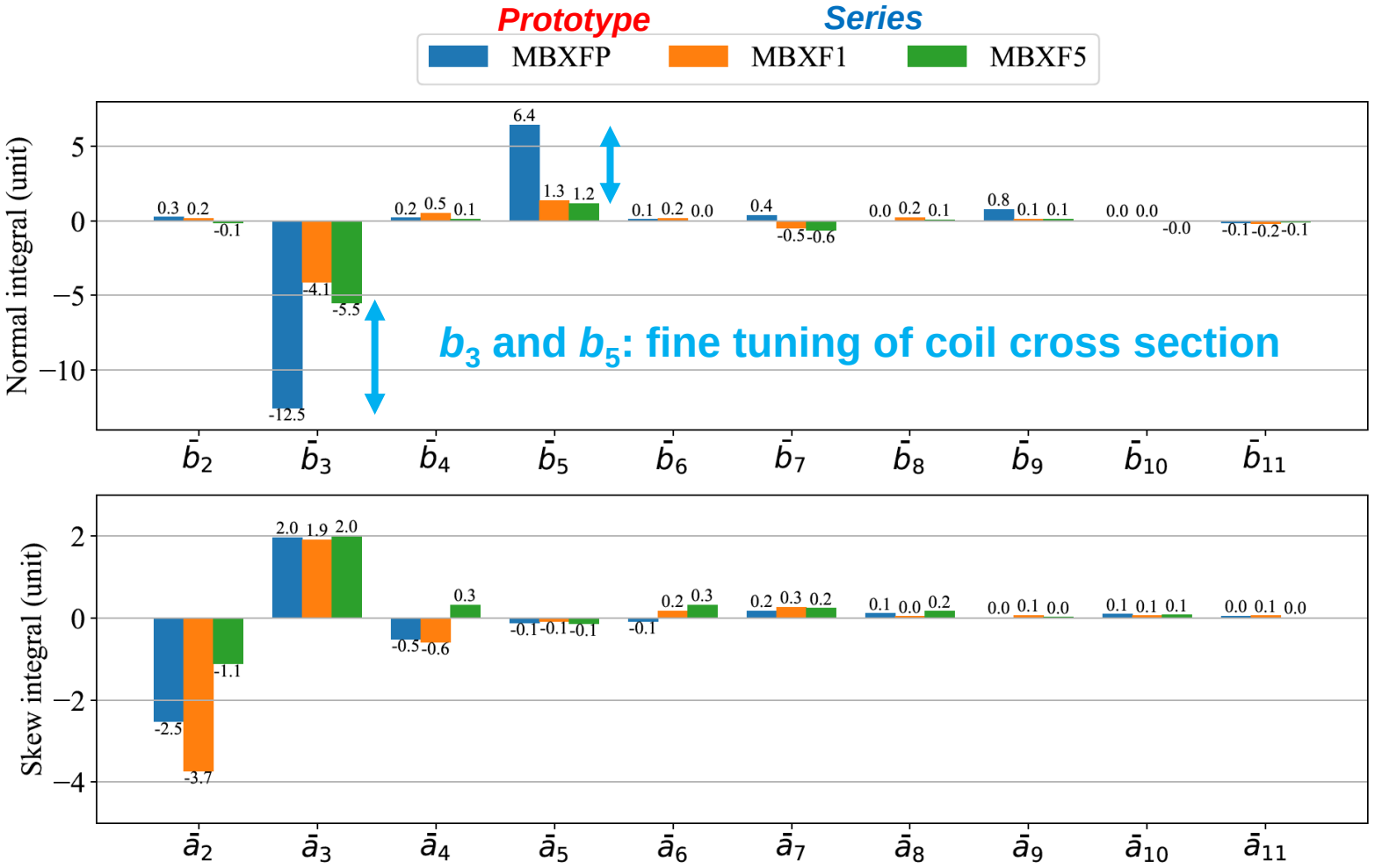
Training performance



	MBXF1		MBXF5	
Test Cycle	Quench #	Iq (A)	Quench #	Iq (A)
1st TC	1	10639	1	10673
	2	11353	2	11246
	3	12260	3	11461
	4	12331	4	11978
	5	12326	5	12514
	6	12559	6	12611
	7	12778	7	12778
	NQ	13214	8	13004
			9	13231
			NQ	13231
2nd TC	NQ	13213	TBD	TBD

- MBXF1 and MBXF5 successfully reached the ultimate current (108% of the nominal current for HL-LHC). Thanks to the upgrade of the test facility.
- Similar behavior of the training performance was observed.
- No quench was needed for MBXF1 to reach the ultimate current after the full thermal cycle. Good training memory was confirmed.
- The 2nd TC of MBXF5 is ongoing.
  - In the meantime, the test has been postponed due to a technical issue of the warm-turbine of the refrigerator.

Field Quality: Integral



- Fine tuning of coil cross section to improve b_3 and b_5 was implemented for the series and the effectiveness was demonstrated.
- The measured results were in good agreement with the calculation.
- Good reproducibility was confirmed in the series magnets.

Summary

- The D1 prototype cold mass was delivered to CERN in April 2023. Cold test at SM18 will be started TODAY (the 7th of Dec.).

- A series production of the D1 has been progressing.
  - MBXF5: NC of the insulation damage was closed. The 2nd TC of the cold test is underway at KEK.
  - MBXF1: Following the successful cold test, the final assembly of the cold mass is ongoing.
  - MBXF2 and 3: Magnet production is ongoing.
  - MBXF6: A contract to fabricate the magnet parts will be awarded to Hitachi soon.
  - MBXF4: Manufacturing will be started in JFY2024.

- Powering test of the series magnets (MBXF1 and 5) at KEK
  - 2 series magnets successfully reached the ultimate current.
  - Good training memory was demonstrated by MBXF1.
  - Multipole coefficients have been within the tolerance. Good reproducibility was confirmed.