Status Report on D1 Magnets

Tatsushi NAKAMOTO, KEK

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

CERN-KEK Committee, 16th Meeting, Oct. 7, 2021

Acknowledgement

- KEK (in particular)

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- Fusac Technologies

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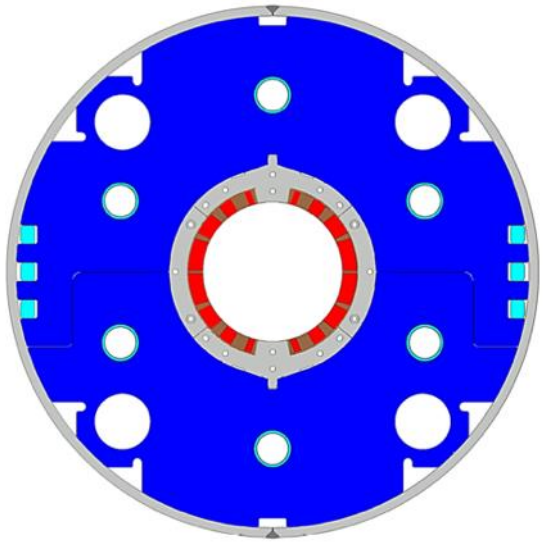
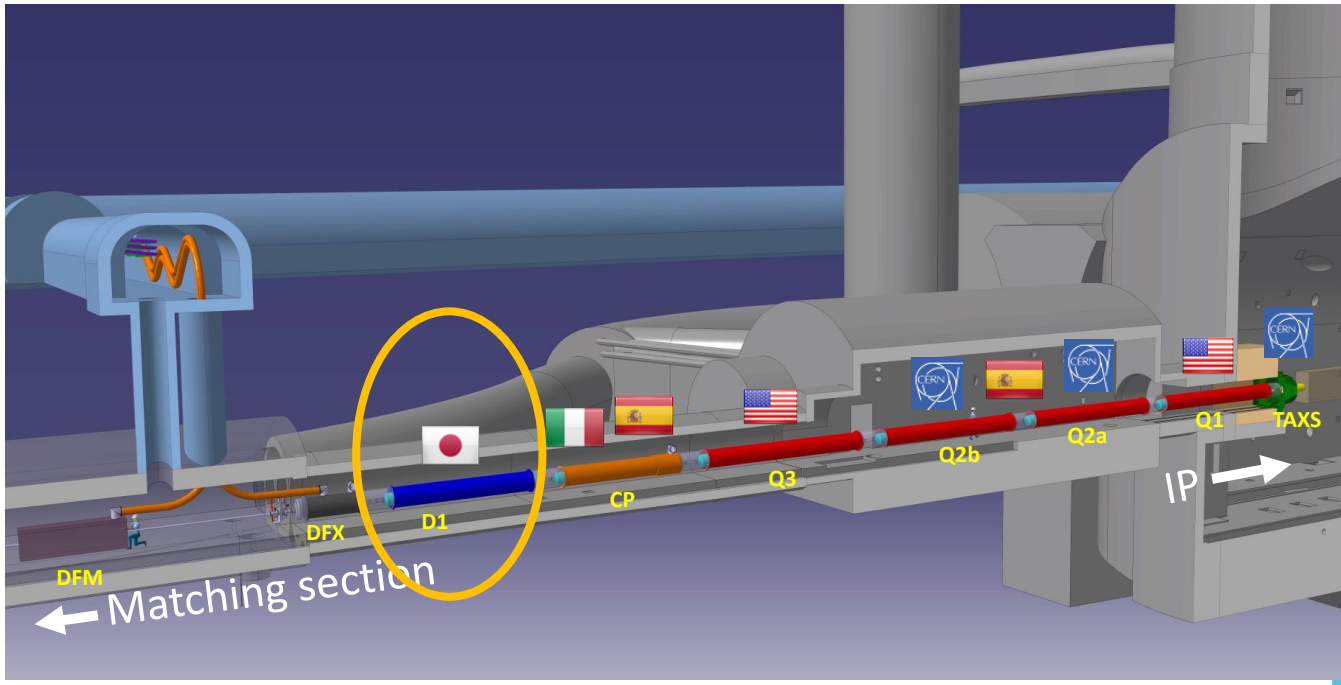
Japanese Contribution to HL-LHC: D1 magnets





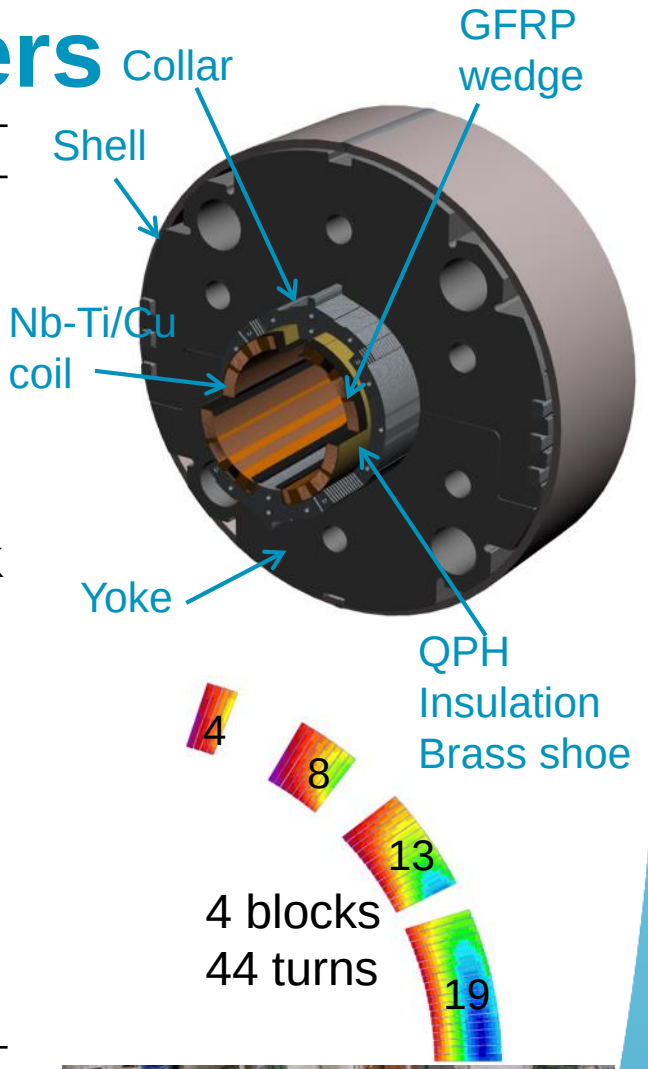
- Beam separation dipole (D1) by KEK
  - Design study of D1 for HL-LHC within the framework of the CERN-KEK collaboration since 2011.
  - 150 mm single aperture, 35 Tm (5.6 T x 6.3 m), Nb-Ti technology.
  - Development 2-m long model magnets (3 units) at KEK
- Deliverables for HL-LHC
  - *1 full-scale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

7 units x 7-m long cold masses

Design parameters

	A series production (7m)	MBXFS3 (2 m)
Coil aperture	**150 mm**	
Field integral	**35 T m**	9.5 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	1.67 m
Coil mech. length	6.58 m	2.00 m
Magnet mech. length	6.73 m	2.15 m
Heat load	**135 W (Magnet total)**	
	2 mW/cm³ (Coil peak)	
Radiation dose	**> 25 MGy**	

12 ton



Large-aperture single layer coil →

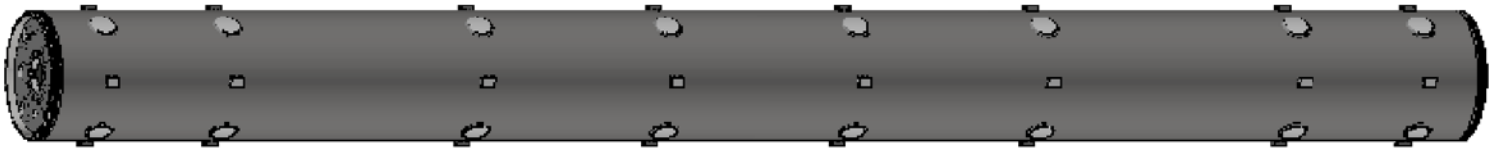
Mechanical support of a coil is challenging

Production magnet: 7 m-long

Three 2 m model magnets was developed at KEK.

Full-scale D1 Prototype

- Magnet technology developed through 2m-long model magnet program (2011-2019) by KEK has been transferred to Hitachi.
- **Objective:** *Validation of design, manufacturing procedure and performance of a full-scale magnet constructed by Hitachi.*
- Cold test of the D1 prototype magnet at 1.9 K at the 9-m deep vertical cryostat at KEK is underway.



D1 magnet for vertical cold test (Yoked magnet w/ shell, end-ring)

D1 cold mass to be delivered to CERN

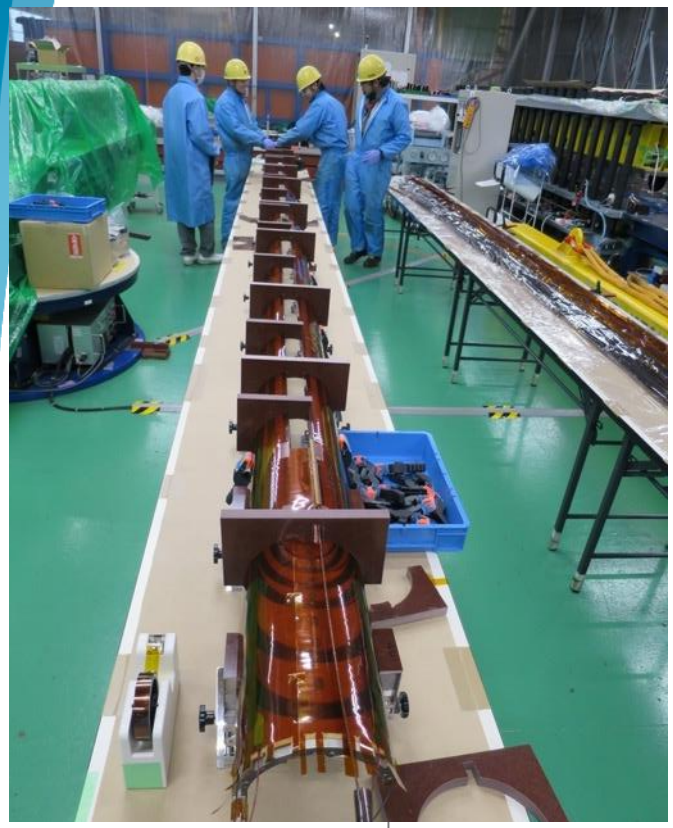
Manufacturing of D1 Prototype

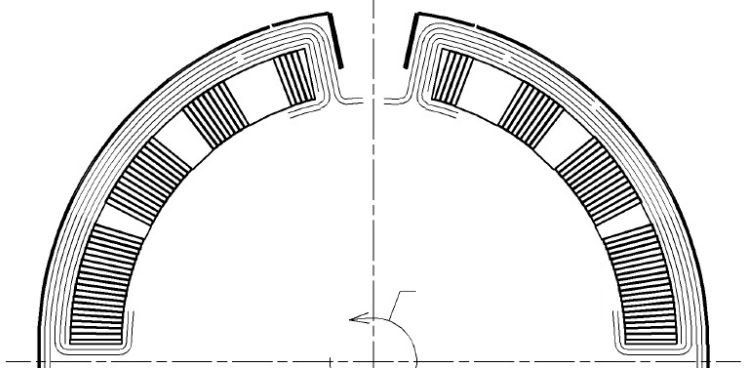
- Coil fabrication (LPT-1 and LPB-1 coils) started October 2.

- Azimuthal coil size measurement (evaluated as σ_{pole})
  - Top: L 113 MPa, R 112 MPa
  - Bottom: L 109 MPa, R 111 MPa
- The prototype coils achieved the coil size consistent with the model magnets and the sufficient pre-stress at the assembly can be expected.
- Dimension check: OK
- Electrical test: OK

Manufacturing of D1 Prototype

- QPH and 1L & 2L insulations covered on the Top Coil.
- The Top Coil set on the collaring mandrel.





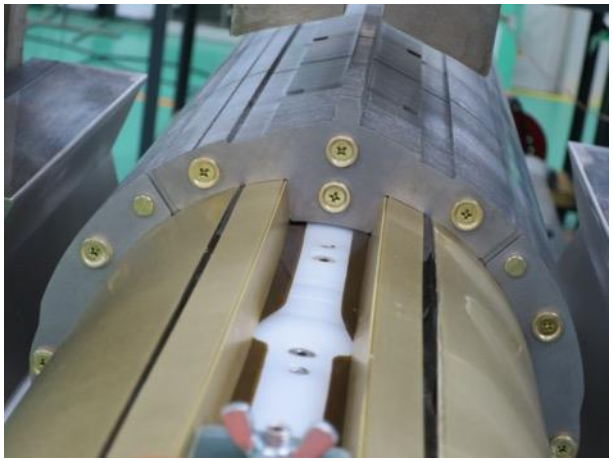
Manufacturing of D1 Prototype

- Collaring mandrel with Top Coil set on insulated Bottom Coil.

- 3L & 4L insulations and brass-shoe covered on the coils.

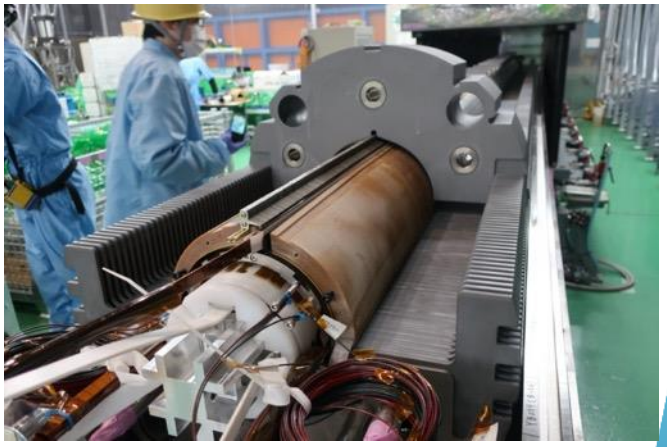
Manufacturing of D1 Prototype

- Collaring process

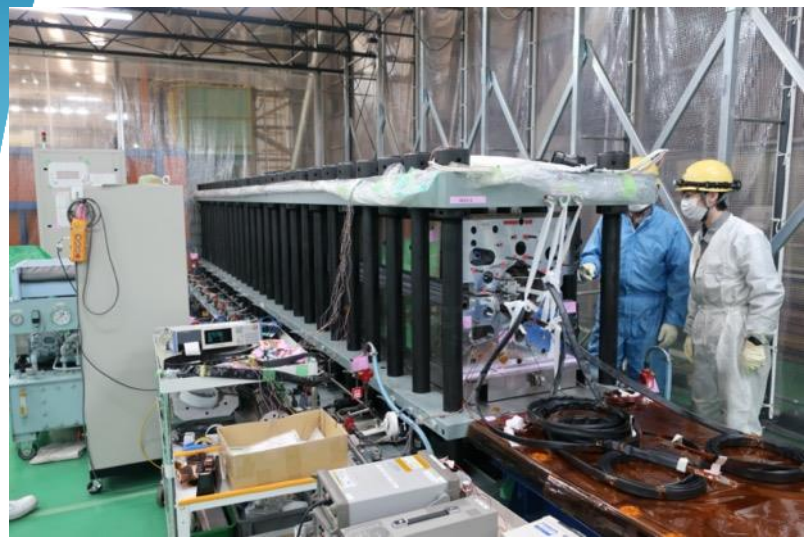

- Collared coil set on Bottom Yoke



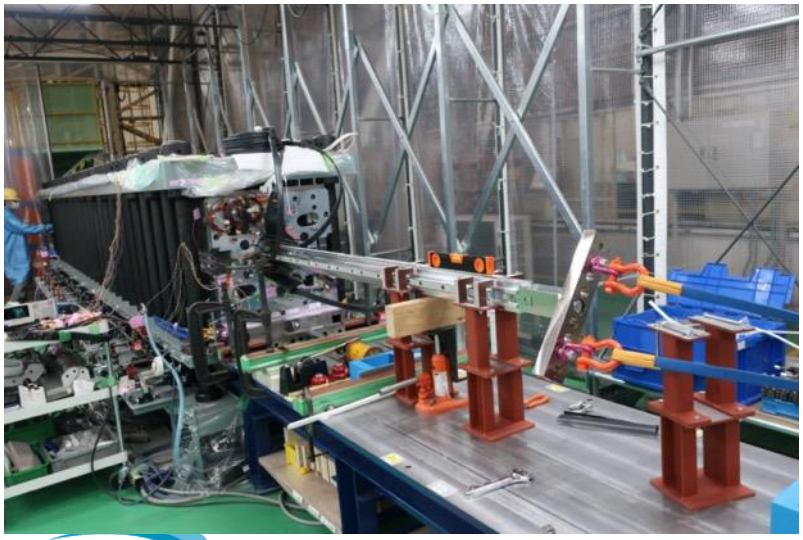


Manufacturing of D1 Prototype

- Yoking process

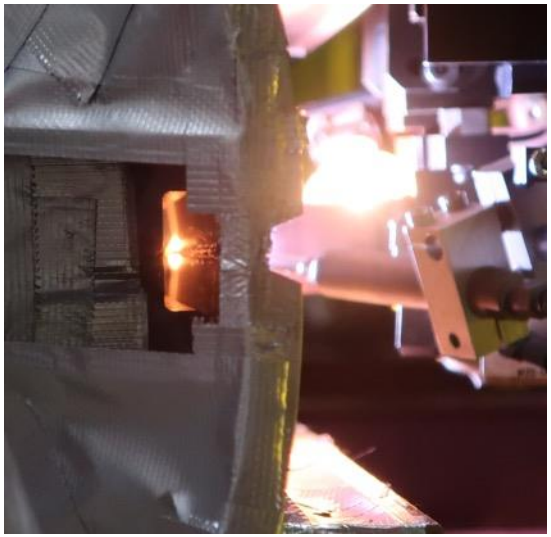


- Removal of collar-mandrel from the yoked magnet

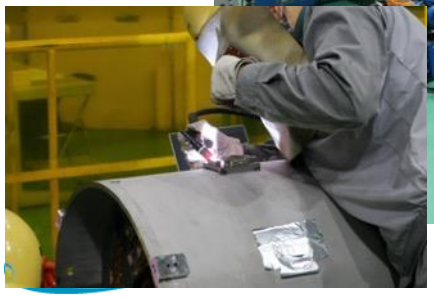


Manufacturing of D1 Prototype

- Shell welding

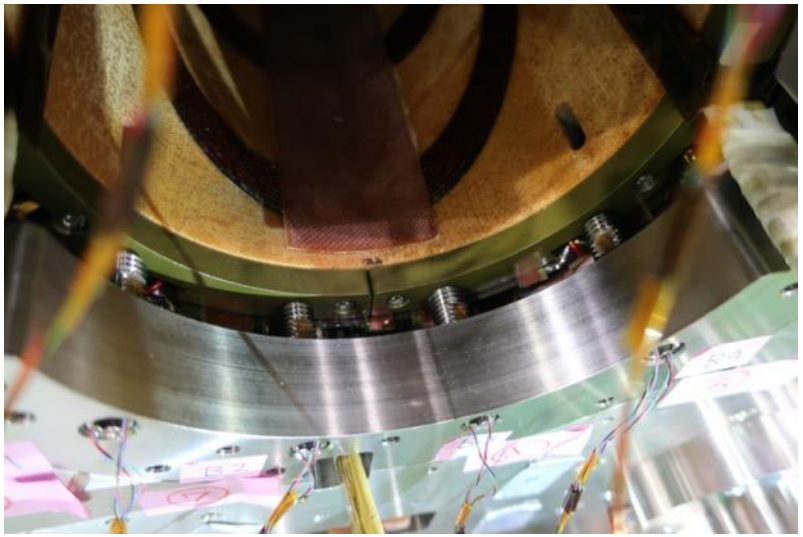


- Welding of alignment markers, end-ring

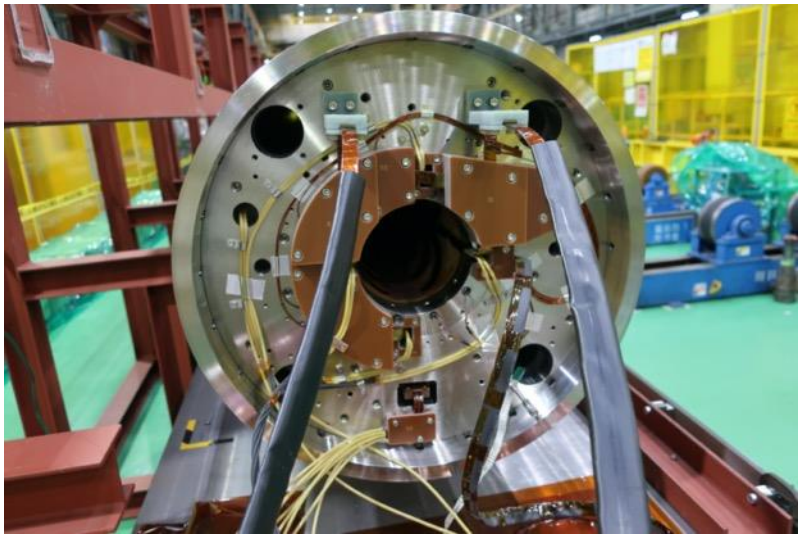


Manufacturing of D1 Prototype

- Axial compression on SC coils



- Splice work and bus-leads



Manufacturing of D1 Prototype

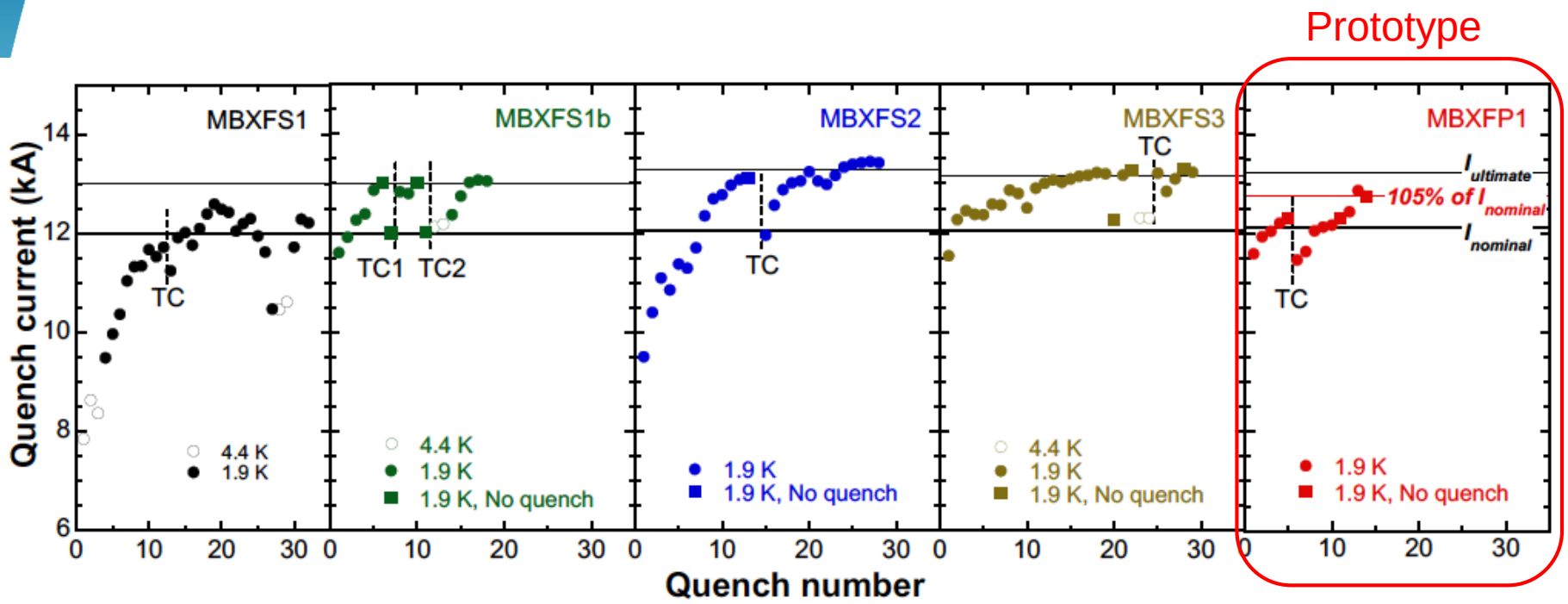
- Completed D1 prototype magnet

Testing of D1 Prototype at KEK

- Lifting up the D1 magnet

- Insertion into vertical cryostat

Training Performance

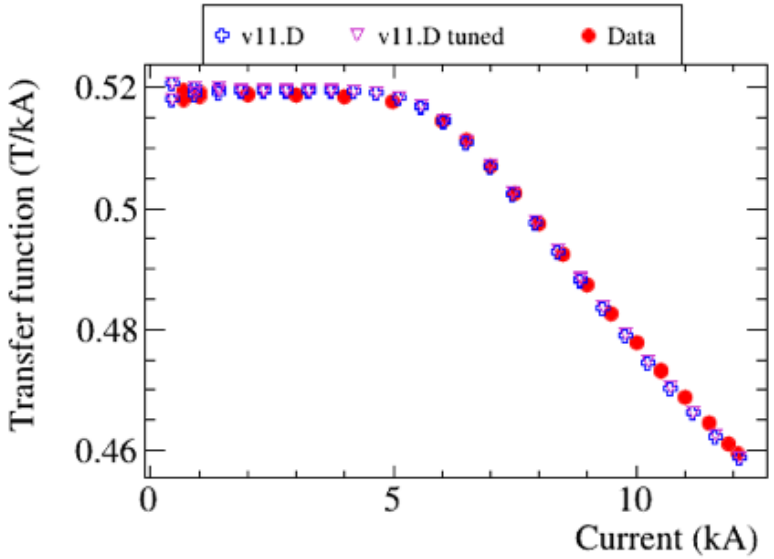


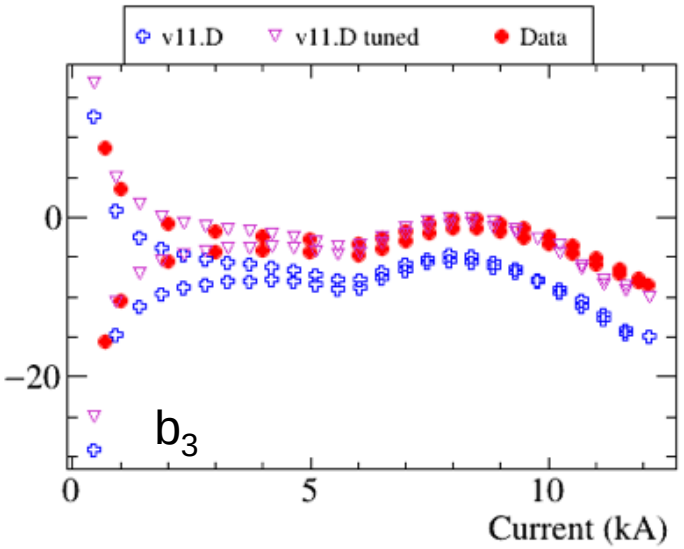
- The magnet needed 3 training quenches to reach the nominal (12.11 kA).
- The maximum current was 12.87 kA which was limited by allowable terminal voltage of DCCB.
- The magnet safely operated at 12.75 kA (105% nominal) for 4 hours.

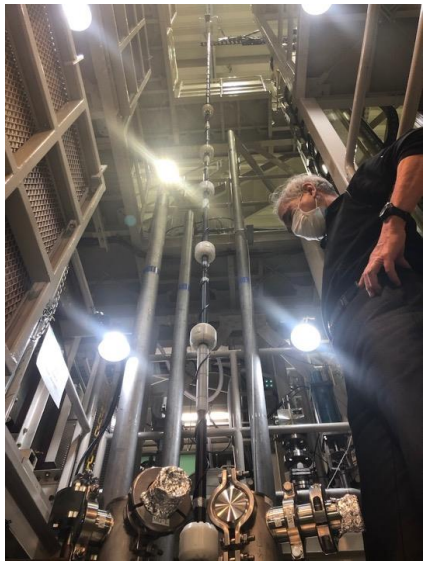
Good performance in training behavior.

Field Quality

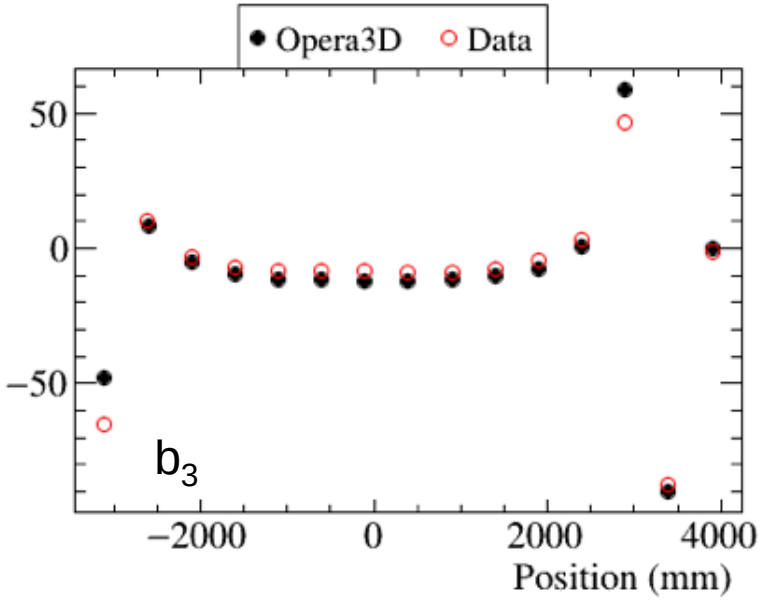
DC loop at magnet center







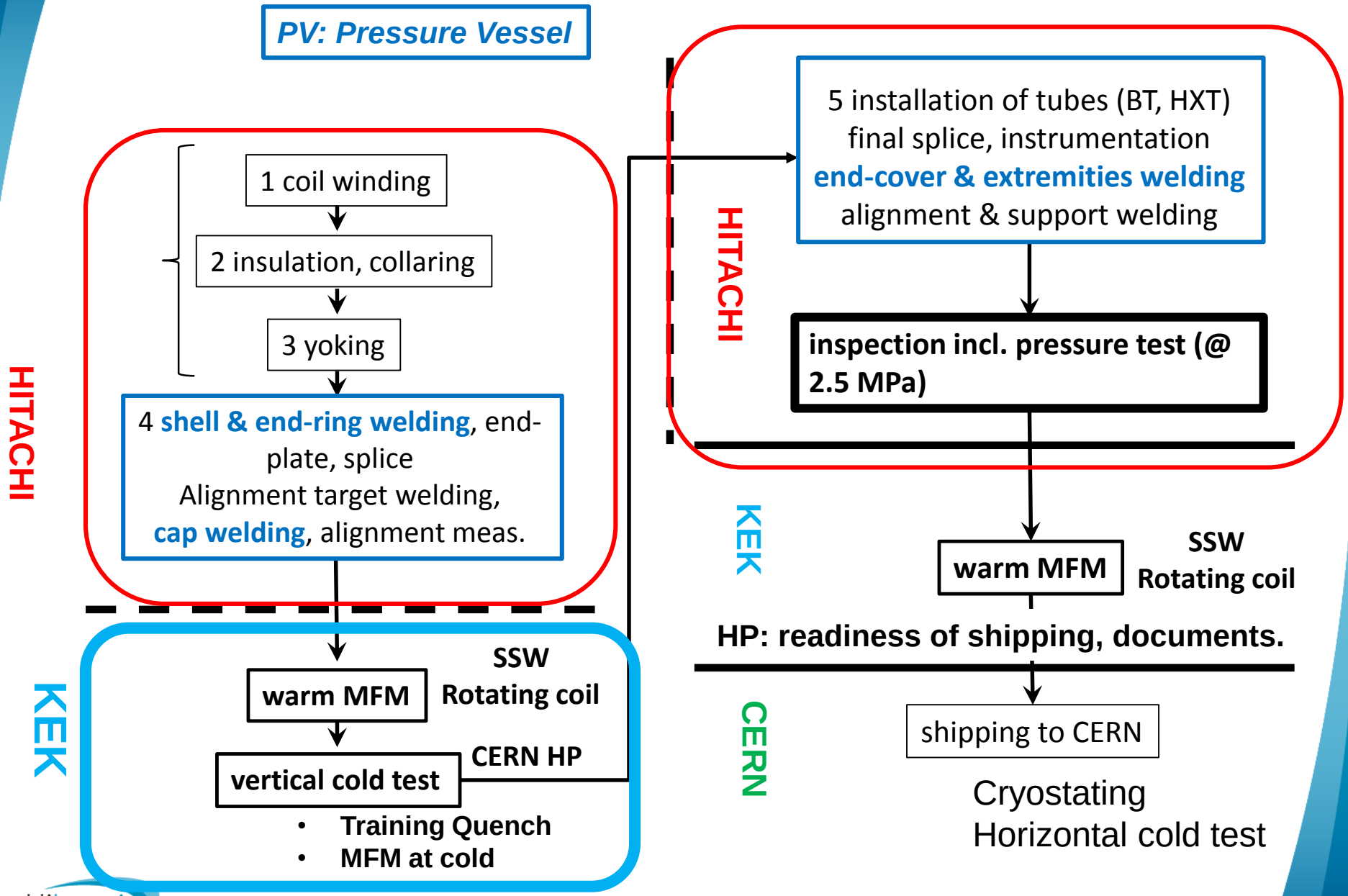
Z-scan at I=12.11 kA



- A large offset in b_3 (~40 unit) was observed in 2-m D1 models, but significant improvement was confirmed in the prototype.
- Based on the field measurement results of the prototype, fine tuning of the coil cross section has been applied to a series production magnets to achieve much better field quality.

Flow of D1 Cold Mass Production

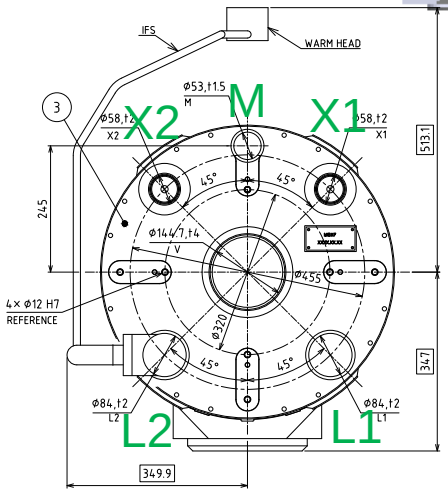
PV: Pressure Vessel

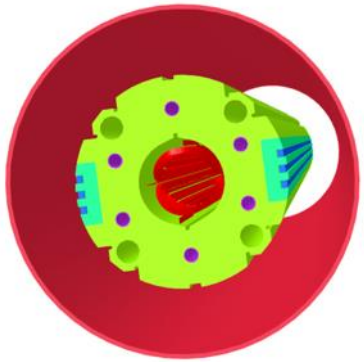


D1 Magnet Cold Mass

RE side
IP side

LE side
NIP side

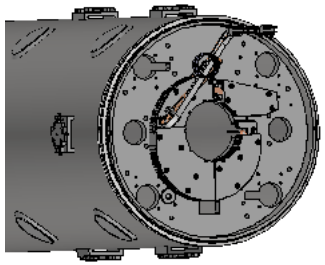




Design Parameters

- Nominal current and field, field integral: **12110 A, 5.58T, 35 Tm**
- Pressure vessel in accordance with PED Safety Requirement
- Design pressure and operating temperature: 2.0 MPa, 1.9 K
- Pressure test at 2.5 MPa
- He leak rate below 1 x 10^{-10} Pa m^3/s
- Cold mass length and distance between saddles: 7370 mm and 3900 mm
- Outer diameter: < 630 mm ➡ Shell OD: 570 mm ~~+ markers~~
- The detail of extremities given by CERN
  - Two HeII HX pipes in line with MQXF (X1, X2)
  - Two HeII conduction lines (L1, L2)
  - Bus bars interconnection line (M)

Concept of Cold Mass Assembly (Non-IP Side)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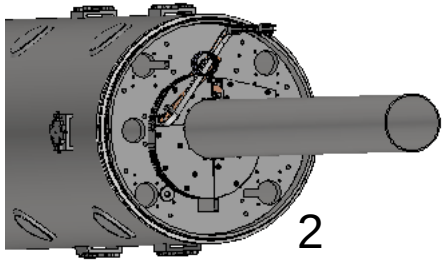
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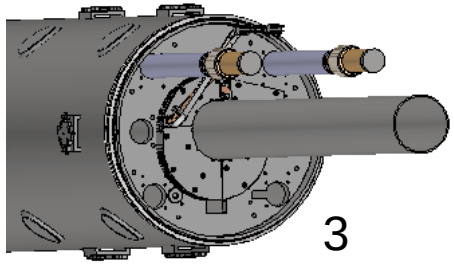
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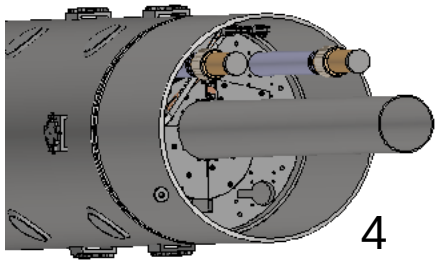
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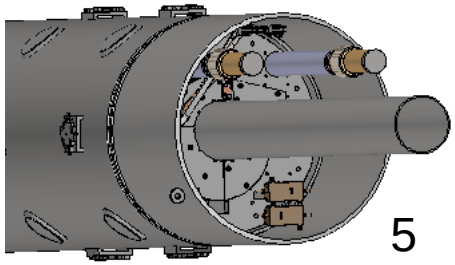
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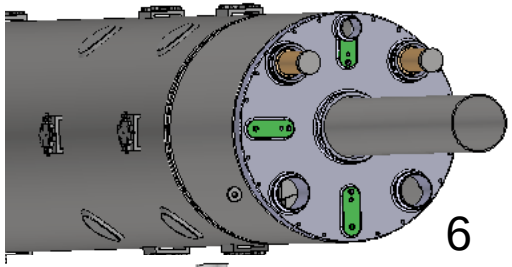
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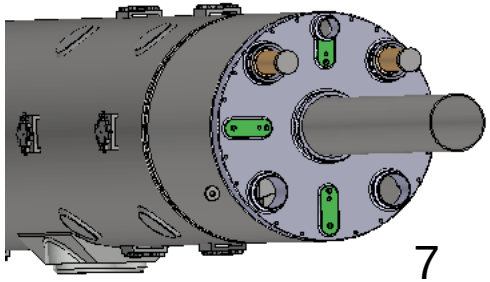
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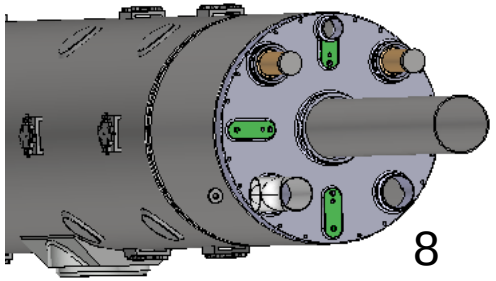
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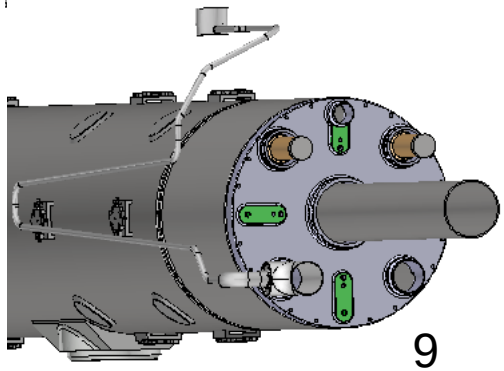
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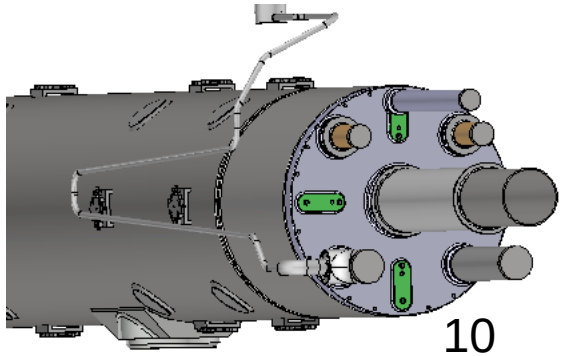
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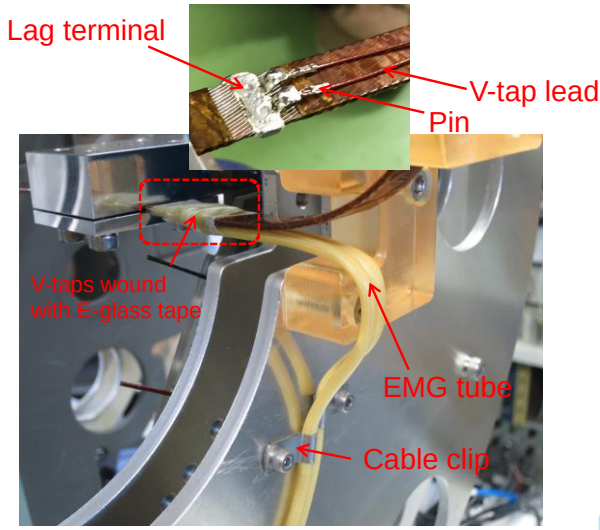
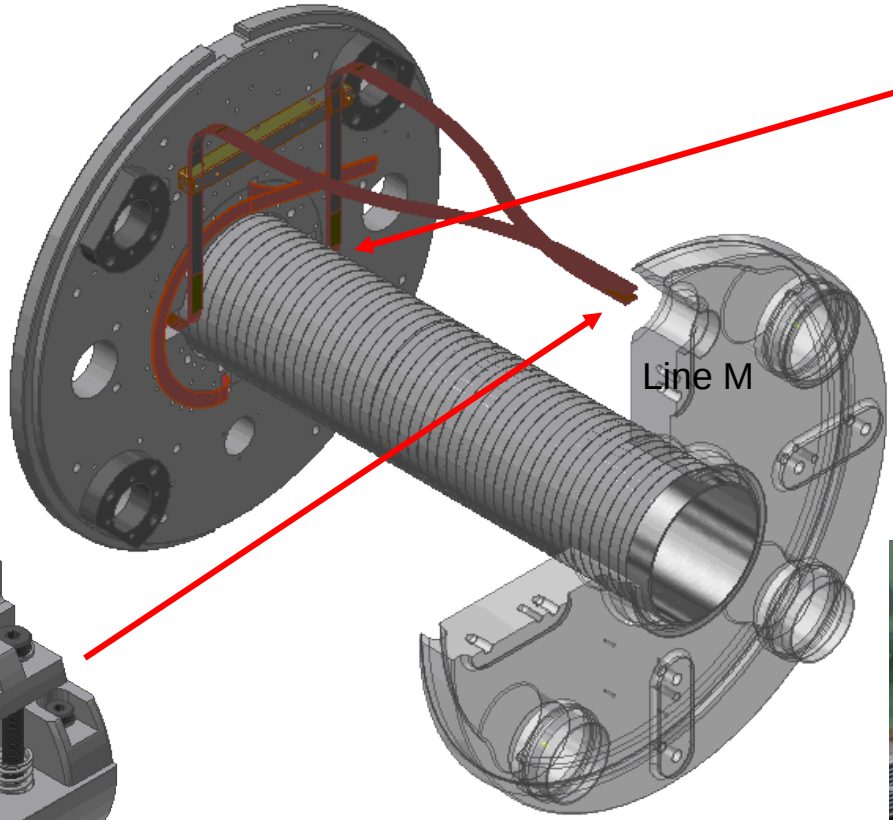
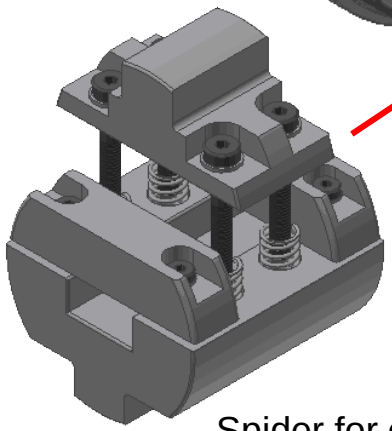
SC Bus Leads and “Spider”

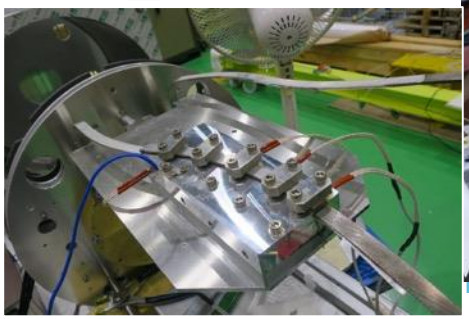
- Technical support by KEK for the D1 cold mass manufacturing at Hitachi.
- Design of SC bus leads and “Spider”.
- Vtap installation and wire routing.

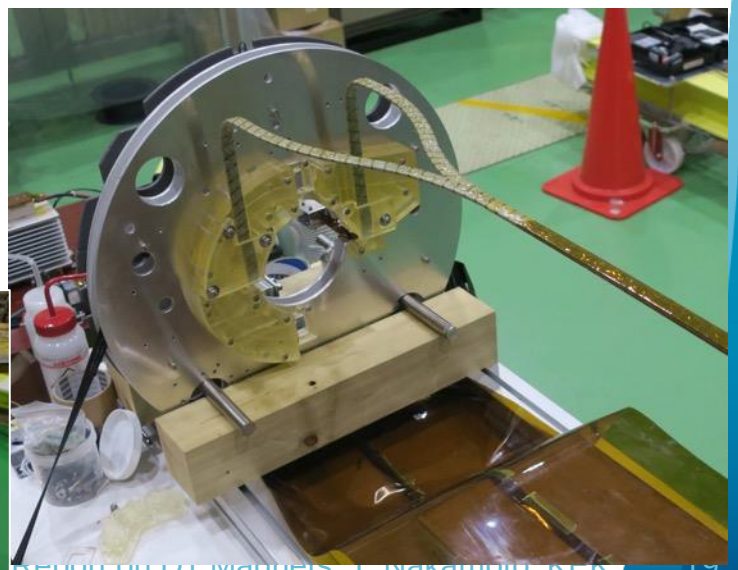






Spider for centering the bus-leads in Line M



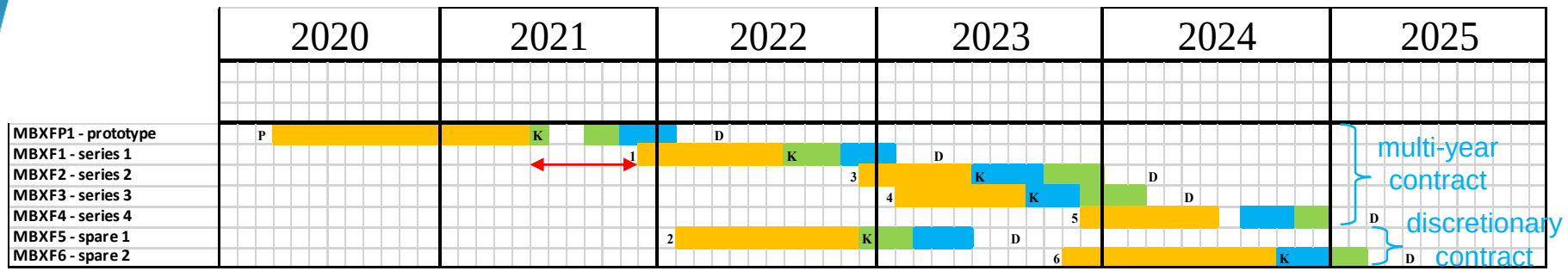


Components delivered from CERN

	Item Code	0	1	2	3	4	5	6	7
		SC cables	QPH Laminate	Cold bore tube	End-cover	HX tube	Extremity parts	Cryo Heaters	Thermometers
Until Dec. 2019		19	14	0	0	0	0	0	0
March, 2020	ID 8294098, delivery on August 18	0	0	1	0	0	9 IFS pipes (obsloleted)	0	0
April, 2020	ID 8302253, delivery on July 3	0	14	0	3	0	3	4 (obsloleted)	8
Oct., 2020	ID 8455728, delivery on Nov. 4	0	0	0	11	0	3	10 (obsloleted)	20
Dec., 2020	ID 8477112, delivery on Jan. 12, 2021	0	0	3	0	4	6 IFS pipes	0	0
Aug., 2021	ID 8842597, delivery on Aug. 6, 2021	0	4	0	4	0	3	2	
Dec., 2021		0	0	4	0	10	*	12	0
Total # (unit, set)		19	18	8	18	14	9	14	28

- EDMS 2326071 v.1.0, EDMS 2209761 v.1.0
- KEK already received 5 shipments from CERN.
  - New “conformed” HVEs (9 units) and QPH laminates (requested in July) were delivered in this August.
- The extremity parts list needs to be confirmed.(*)
  - KEK is preparing a new amendment of MOU Addendum #2: revision of extremity parts.

Procurement Schedule



Note: this schedule is based on the latest manufacturing plan of Hitachi (ES21-HL-LHC-0205) but still tentative. Further detailed planning with KEK be needed.

- A multi-year contract was given to Hitachi at May 2019 to the end of JFY2024 by an open-tender.
  - Covering 1 prototype & 4 series cold masses.
- For remaining 2 cold masses, **discretionary contracts** will be given to Hitachi as well.
- Optimization of coil cross section will be applied to the 1st series magnet and some time-gap is need to start the manufacturing.
- Production schedule is stretched due to a “flat” budget profile of KEK and limitation of tooling & HR availability at Hitachi.
- 4 units of series cold mass will be delivered by the end of 2024.

Summary

- The D1 prototype magnet (MBXFP1) was manufactured by Hitachi and delivered to KEK at the end of May 2021.
- The cold powering test of MBXFP1 at KEK vertical cryostat showed;
  - A good training behavior while the ultimate was not achieved due to limitation of the test facility,
  - Lack of training memory after thermal cycle that could be probably attributed insufficient training in the 1st test cycle,
  - a significant improvement of b_3.
- Horizontal warm field measurement and alignment study of MBXFP1 is being performed at KEK. After that, final assembly of D1 prototype cold mass will be started in November.
  - Detail of transportation is being discussed by the Technical Coordinators.
- A series production of D1 magnets will be started soon.
  - Based on the field measurement results of MBXFP1, fine tuning of the coil cross section has been applied to a series production magnets to achieve much better field quality.
- Ownership of the D1 cold mass was discussed at the 2nd D1 Steering Committee (EDMS 2564308). Some work still needs to be done to convince the government about ownership…
- D1 model magnet #3 (MBXFS3) was shipped to CERN in March for inter-calibration of the field measurement systems. The magnet is also planned to be used for the HTS coil development as generating backup field.