Status Report of D1 Magnets

Tatsushi NAKAMOTO, KEK

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

CERN-KEK Committee, 15th Meeting. Nov. 2, 2020.

Acknowledgement

- KEK (in particular)

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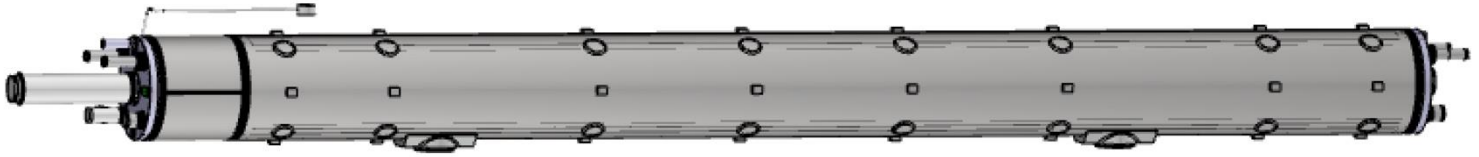
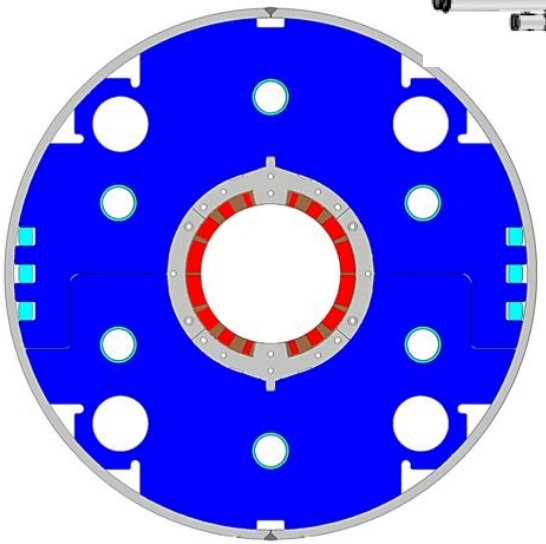
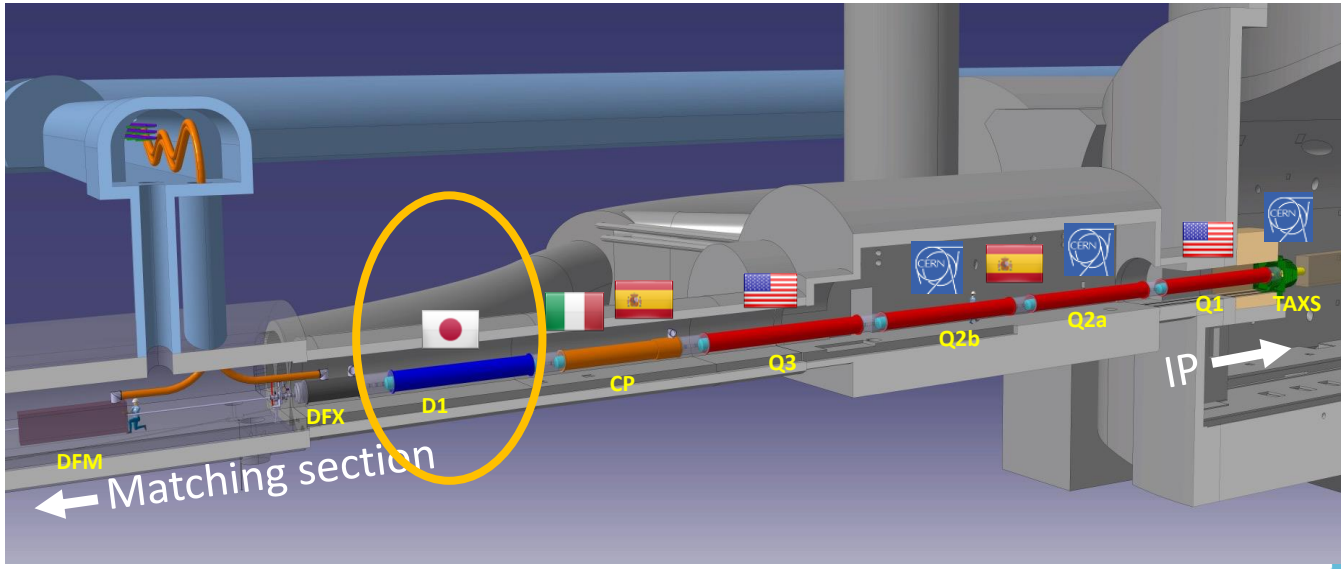
T. Ichihara.

Japanese Contribution to HL-LHC: D1 magnets





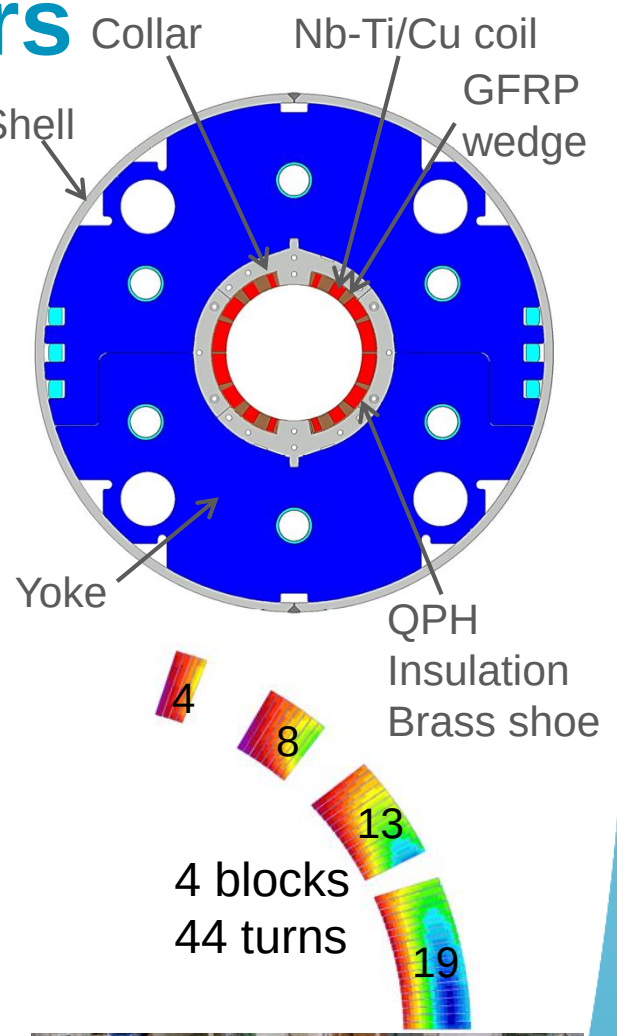


- Beam separation dipole (D1) by KEK
  - Design study of D1 for HL-LHC within the framework of the CERN-KEK collaboration since 2011.
  - 150 mm single aperture, 35 Tm (5.6 T x 6.3 m), Nb-Ti technology.
  - Development 2-m long model magnets (3 units) at KEK
- Deliverables for HL-LHC
  - *1 full-scale 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 : 12.05 kA, Ultimate 13.14 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/cm^3 (Coil peak)	
Radiation dose	**> 25 MGy**	



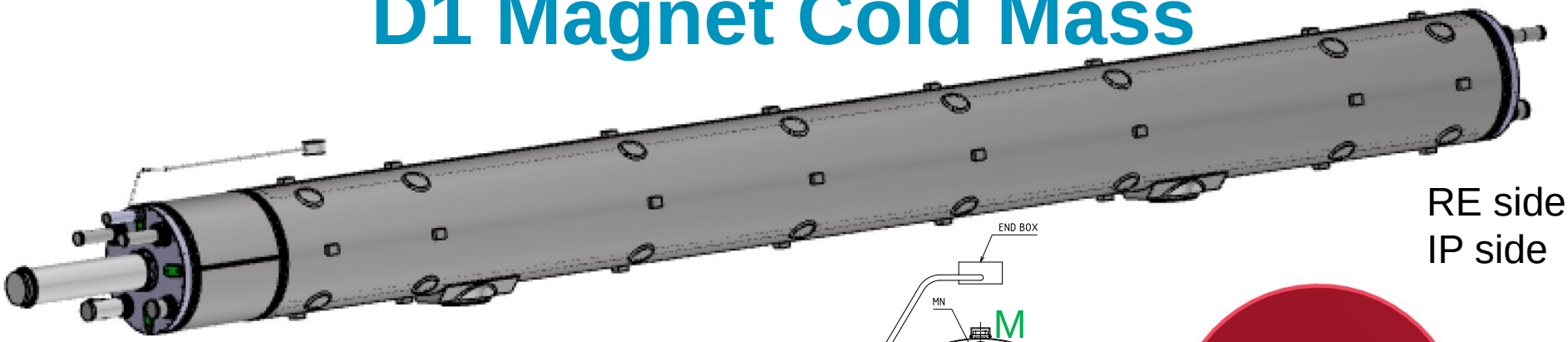
Large-aperture single layer coil →

Mechanical support of a coil is challenging

Production magnet: 7 m-long

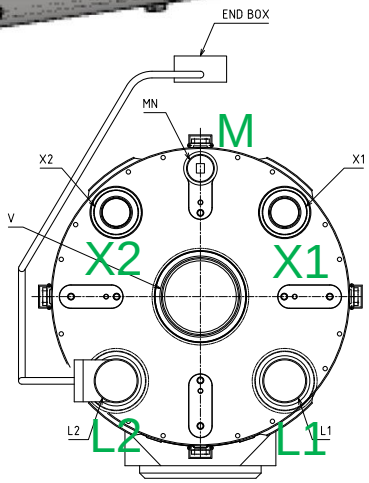
Three 2 m model magnets was developed at KEK.

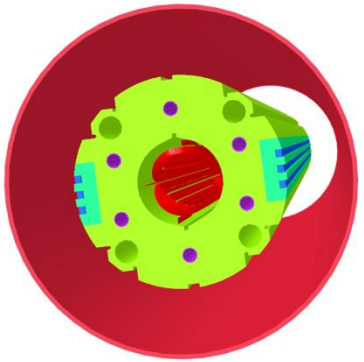
D1 Magnet Cold Mass



RE side
IP side

LE side
NIP side





Design Parameters

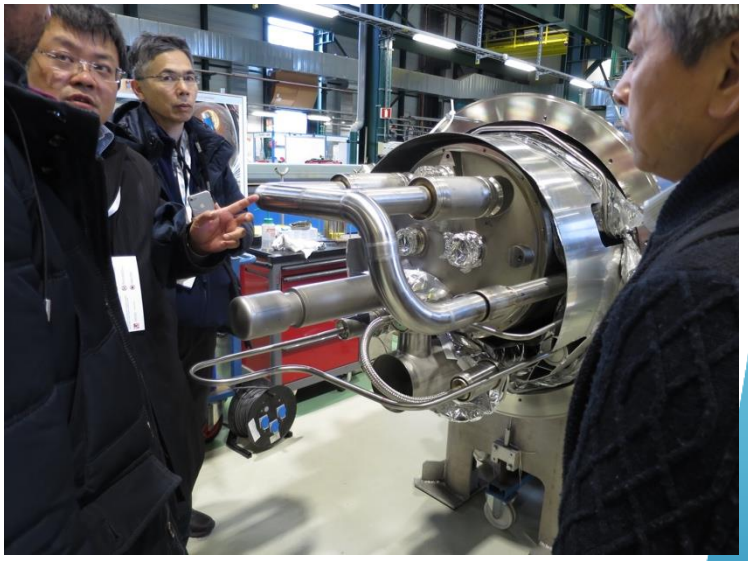
- Nominal current and field, field integral: **12070 A, 5.58T, 35 Tm**
- Pressure vessel in accordance with PED Safety Requirement
- Design pressure and operating temperature: 2.0 MPa, 1.9 K
- Pressure test at 2.5 MPa
- He leak rate below 1 x 10^{-10} Pa m^3/s
- Cold mass length and distance between 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)

1st Steering Committee Meeting for D1

- Held on Nov. 19, 2019 at KEK.
  - Technical visit to Hitachi Workshop.
- 2nd Steering Committee will be held on Dec. 4, 2020 (video).

Visit of Hitachi to CERN

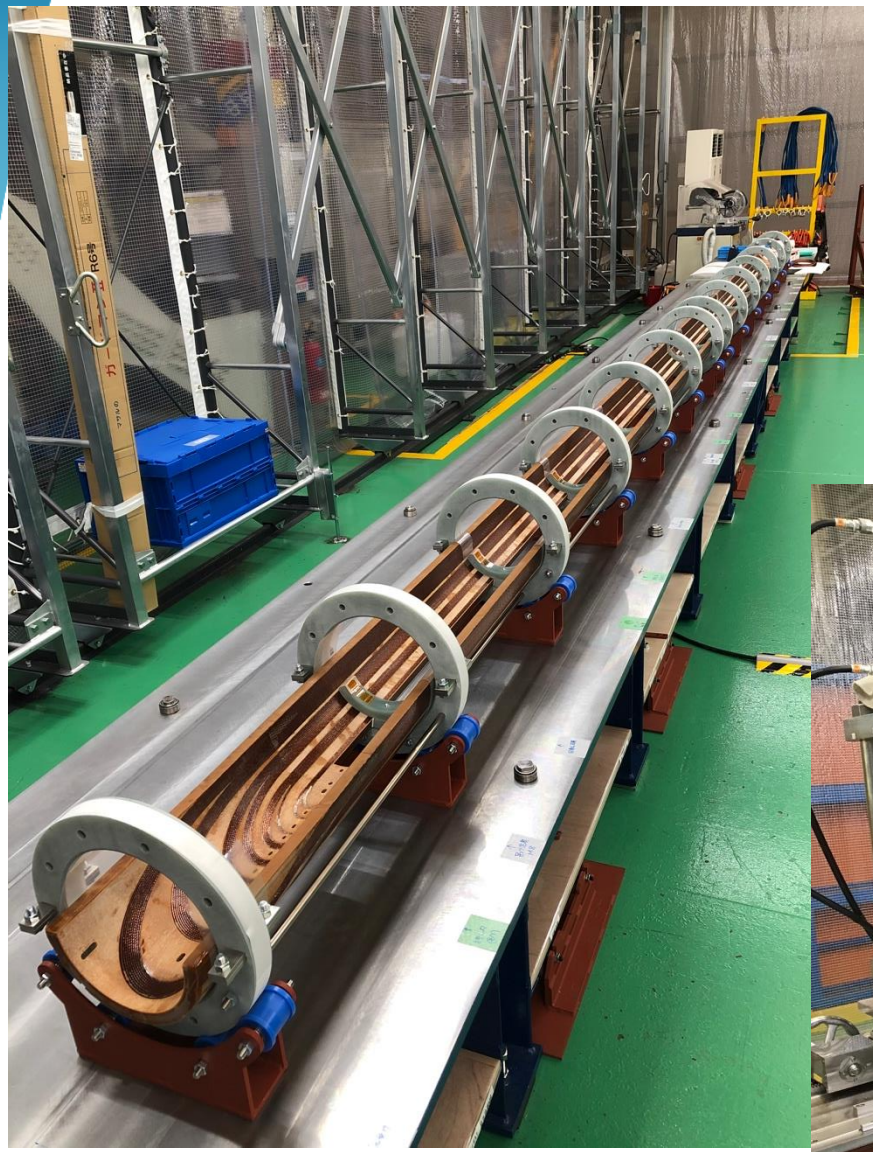
- To learn know-how of assembly, welding, alignment of cold mass, Hitachi and KEK visited CERN from Feb. 17-21, 2020.
  - *Right before entry restriction of CERN premise due to COVID-19…*
- Detailed discussions with H. Prin.
  - Implementation of “Guide Ring” for circumferential welding.
  - Welding procedure, NDT, etc
  - Extremity design
- Technical visits to Bld. 180 and SMI2.
- Meeting with HSE for discussion about welding qualification.
- Productive and informative visit to accelerate the cold mass engineering.



Practice Coil Manufacturing

- Coil winding in the middle of April 2020.
- Curing in the middle of May.
- Attendance of KEK staff was not permitted by Hitachi due to **COVID-19**.
  - ➢ Several issues couldn‘t be detected before manufacturing…

Practice Coil Manufacturing

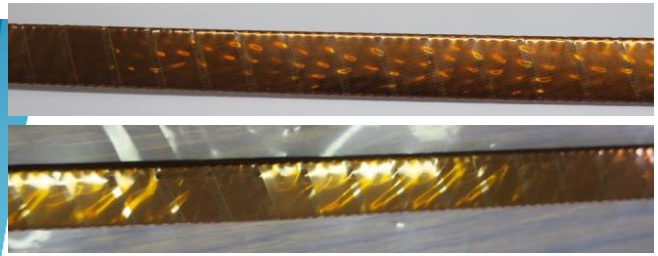


7m Long Shell Welding Mockup

- Objective
  - Handling of shell and tooling.
  - Practice of long. shell welding by automatic welding machine.
  - Practice of circumferential welding of end-ring, end-cover.
  - Survey of the structure by Laser Tracker.
  - Practice of lifting of the 7m magnet for vertical test.
- Contents: 2m MBXFS1b, dummy yoke & Mech. Short model.
- Welding was completed and mechanical deformation is being surveyed.

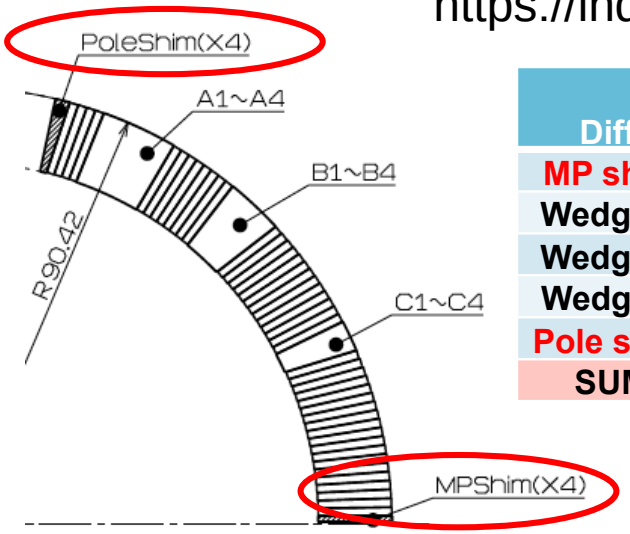
Issues: Change of SC Cable Thickness

https://indico.cern.ch/event/932218/



Cable insulation for LP-0

No.	Cable ID	Difference wrt S2-4 (mm, 44 turns)
1	3T50866B	+0.279
2	3T50866D	+0.313
3	3T80041A	+0.397
4	3T80041C	-0.019
5	3T50728A	+0.262
6	3T50833F	+0.403
7	3T50834A	+0.321
8	3T50871A	+0.297
9	3T50871B	+0.198
10	3T50871C	+0.407
11	3T50871D	+0.243
12	3T50878C	+0.254
13	3T50878D	+0.327
14	3T50883A	+0.418
15	3T50883B	+0.256
16	3T50883C	+0.422
17	3T50883D	+0.359
18	3T50891A	+0.363
19	3T50727B	+0.250
	Ave.	+0.320 (except No.4)



Diff.	DArc_L_in (mm)	DArc_L_out (mm)
MP shim	-0.178	-0.178
Wedge C	0.028	0.023
Wedge B	0.013	0.011
Wedge A	0.000	0.000
Pole shim	-0.303	-0.252
SUM	-0.440	-0.396

-0.42 mm

- SC cable (LHC-2) provided by CERN.
- Increase of the LP-0 coil size resulted from the insulated cable which was outsourced by CERN.
- KEK and CERN discussed this issue and concluded to modify the coil cross section of the prototype (and series) with the insulated cable as is.
  - **New coil design with "minimum" modification on existing wedges and shims was required to suppress the schedule delay.**

Status of Welding Qualification

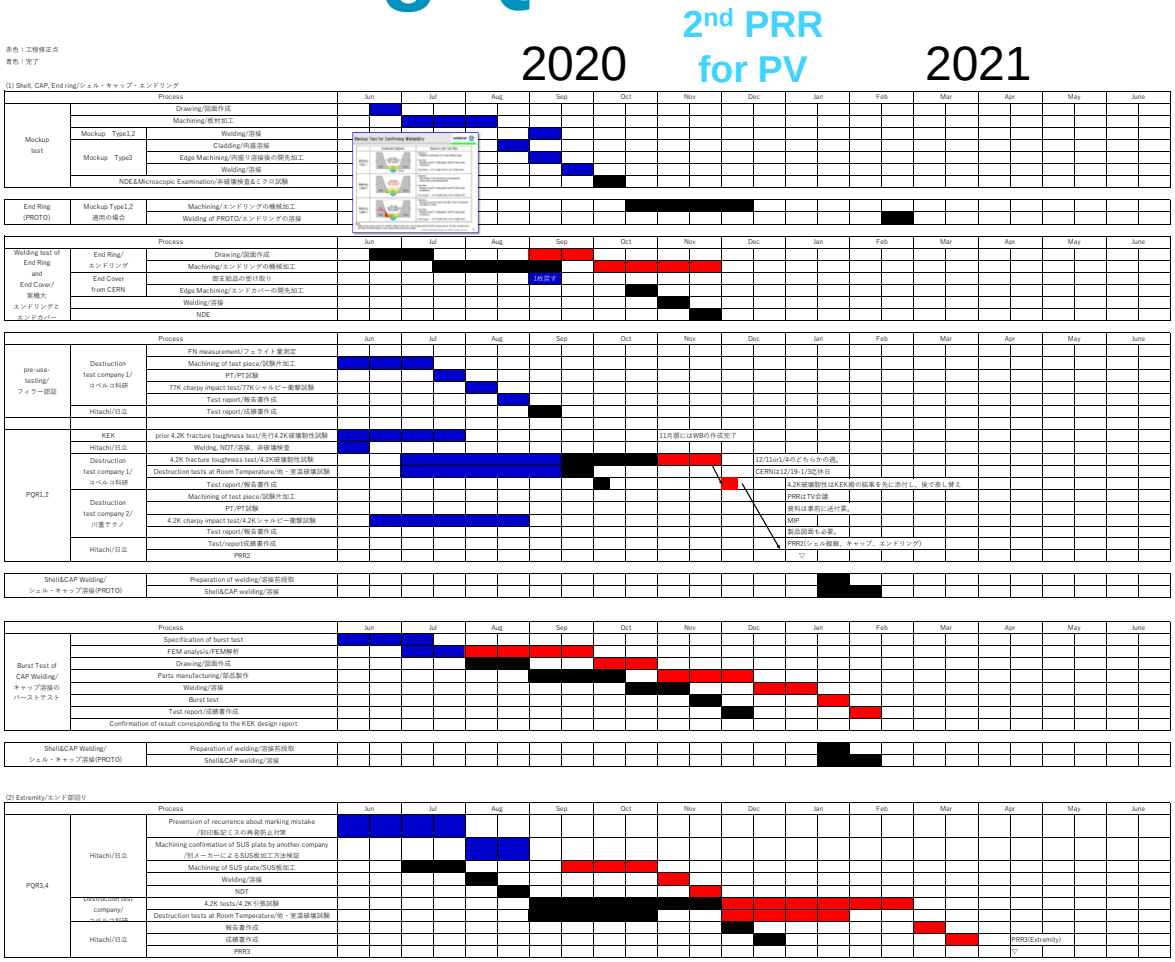
Mockup weld test for PMA- F304L

Filler 308L

PQR: Shell weld

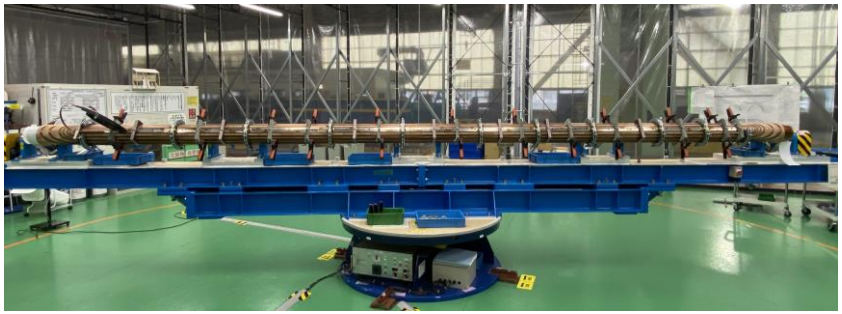
Burst test for design validation of shell cap

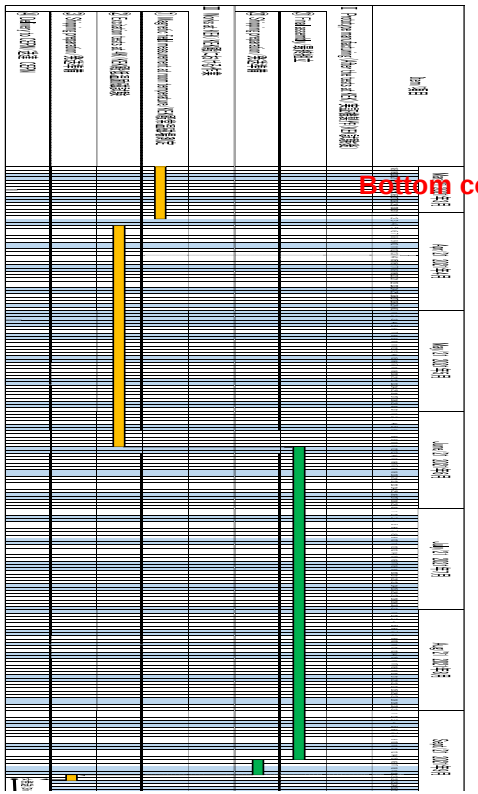
PQR: Extremity weld

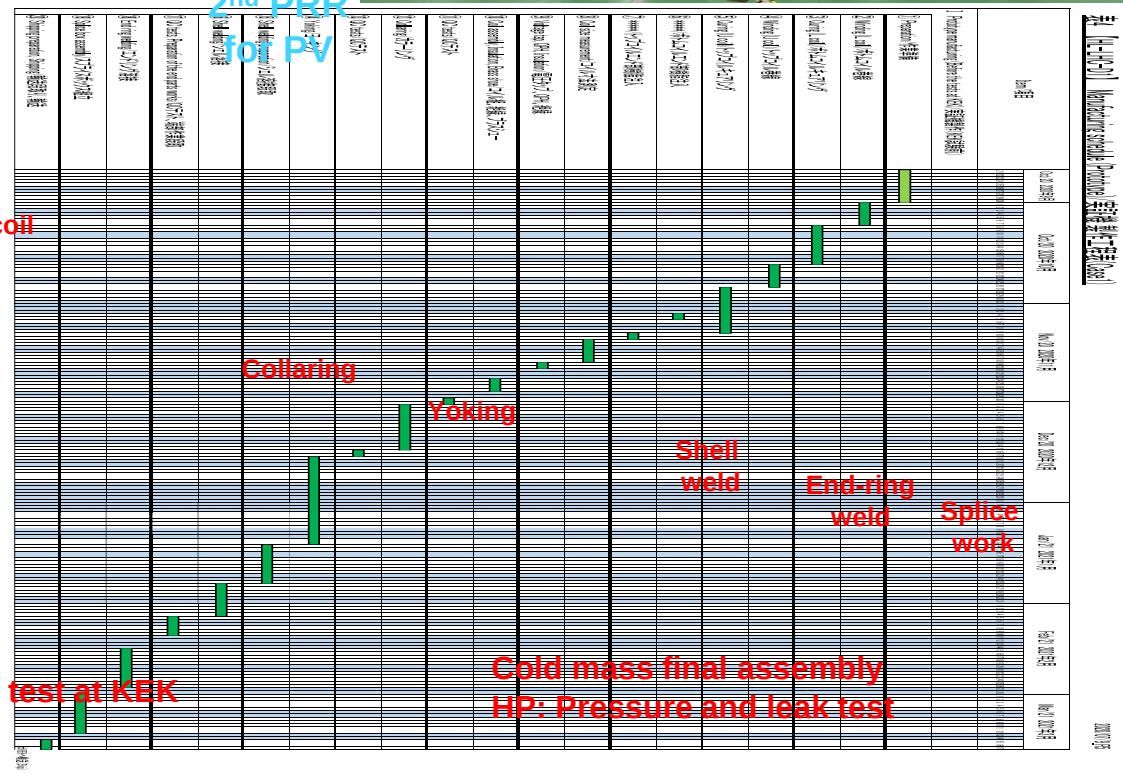


- Agreement: EDMS no.2052040 ver.1.0, EDMS no.1891856 ver.4.3
- Construction code for D1 PV: ASME BPVC Section VIII Div. 2
- Base metal of SUS304L with filler 308L.
  - ✓ PMAs have been submitted.
- Ad-hoc meetings with CERN-HSE and expert (Dr. Sgobba)
- Some delay in PQR for extremity weld but still fit to manufacturing schedule

Manufacturing of D1 Prototype



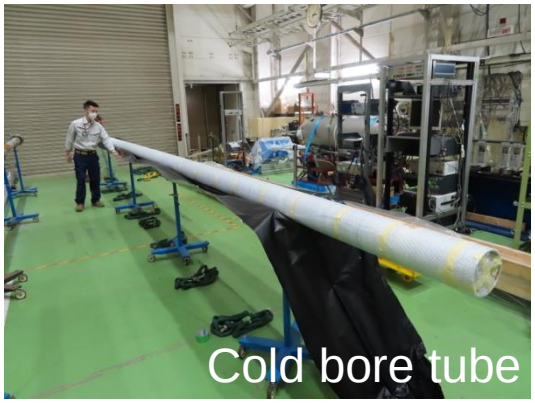




- Coil winding was already started on Oct. 2.
  - NC occurred at fabrication of the Bottom Coil. The measure was very quick and now it is closed.
  - Top Coil was cured last Saturday and looks very nice.
- 2nd Production Readiness Review for "Pressure Vessel of D1 cold mass" will be held at Dec. 2, 2020.
- Cold test at KEK in April 2021.
- Completion of D1 prototype cold mass at Sep. 2021 and shipped CERN for IT String Test.

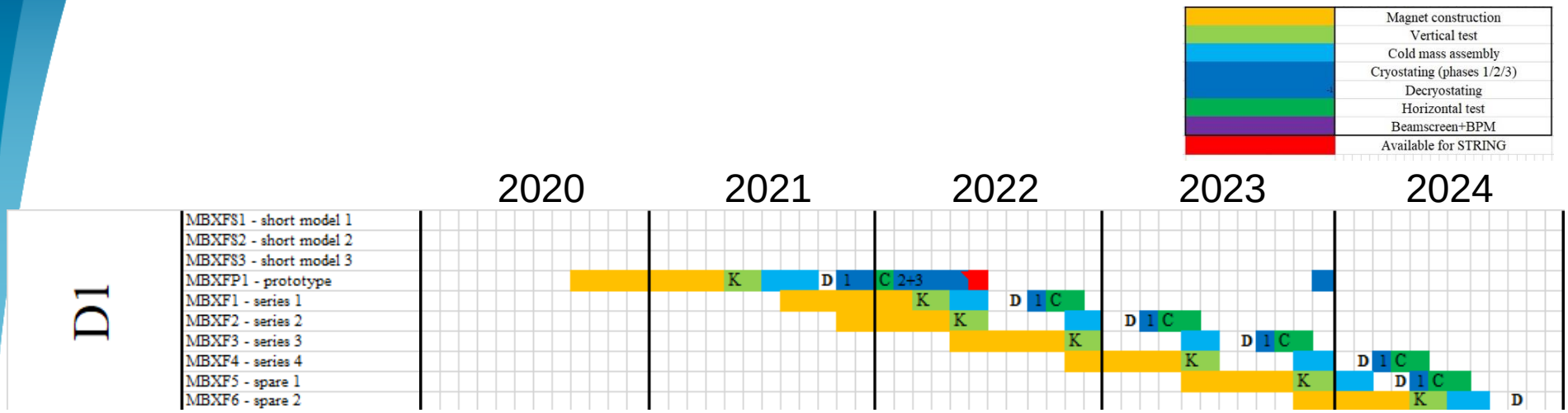
Components delivered from CERN

		0	1	2	3	4	5	6	7
		SC cables	QPH Laminate	Cold bore tube	End-cover	HX tube	Extremity parts	Cryo Heaters	Thermometers
By 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	0	0
April, 2020	ID 8302253, delivery on July 3	0	14	0	3	0	3	4	8
Oct., 2020	ID 8455728, delivery on Nov. 4	0	0	0	11	0	3	10	20
Dec. 2020		0	0	3	0	4	3	0	0
Nov., 2021		0	0	4	4	10	0	0	0
Total # (unit, set)		0	14	8	18	14	9	14	28



- EDMS 2326071 v.1.0, EDMS 2209761 v.1.0
- 19 spools of NbTi cables: completed in Dec. 2019.
- 14 Laminates for QPH production: once completed in Dec. 2019. But, …
  - Yield ratio and dimension control in Trackwise was not good...
  - Considering request of additional supply of the laminates.
- The 1st shipping of PV components was done in July and August.
  - Issues of qualification and quality document for “He Vessel Extension”.
- The next shipping including the 1st batch of HX tubes is planned very soon.

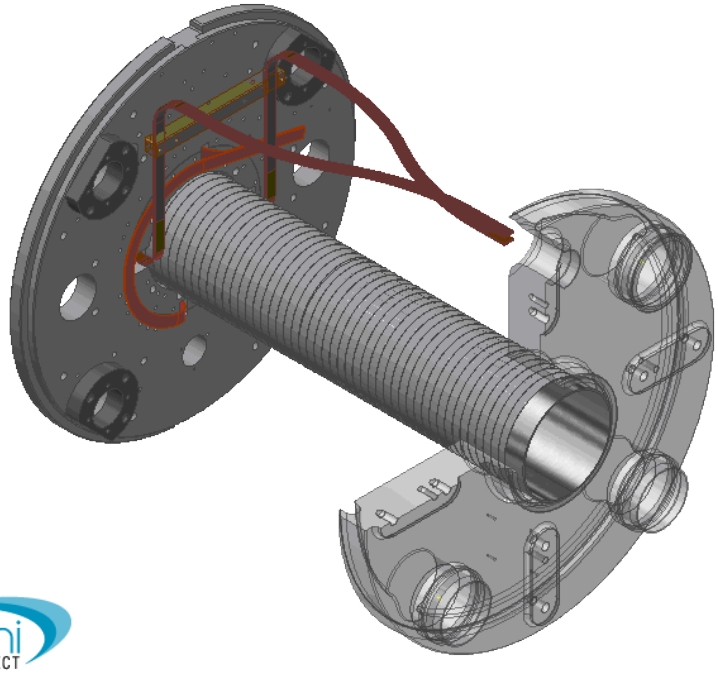
Schedule of D1 Production

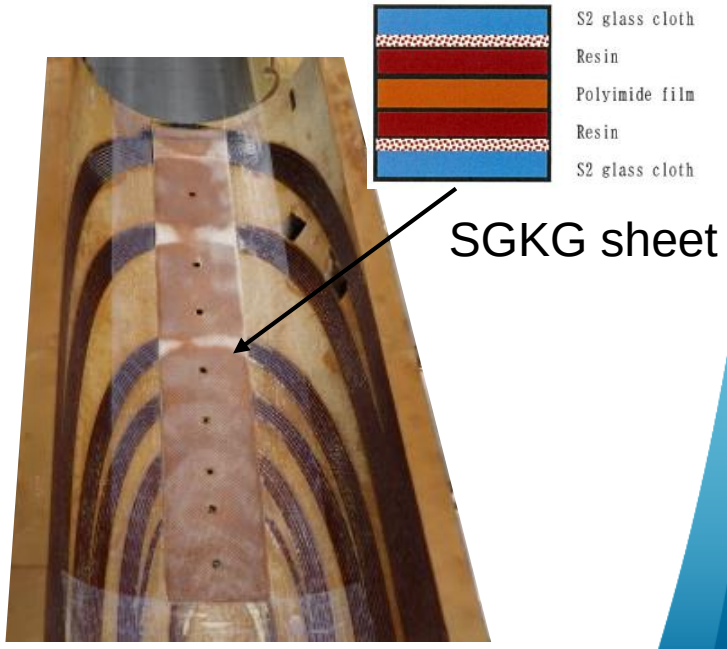


- Delivery of D1 Prototype is on the edge of schedule for IT-String Test.
- Optimization of coil cross section will be applied to the 1st series magnet and some time-gap is need to start the manufacturing.
- 4 units of series cold mass can be delivered by 2024.

KEK Status

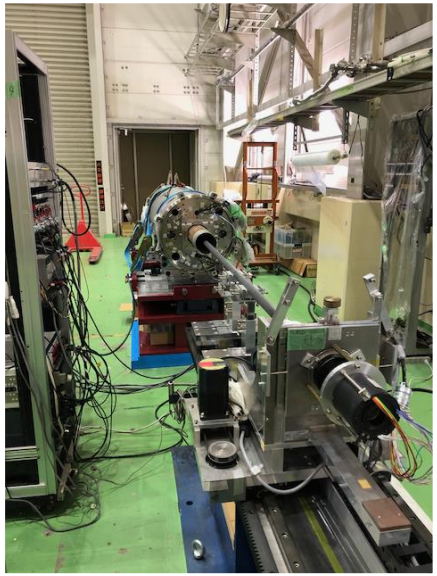
- Technical follow up of the D1 cold mass manufacturing by Hitachi.
  - Engineering of final cold mass assembly including extremities with a support pf CERN.
  - Design of SC bus leads.
  - Development of additional electrical insulation at coil end.
- Procurement of new facilities
  - 15 kA P/C & chiller
  - Hell pumping system: 5 units x Edwards GXS750/2600
  - Laser tracker and laser scanner for alignment and for support of cold mass assembly.

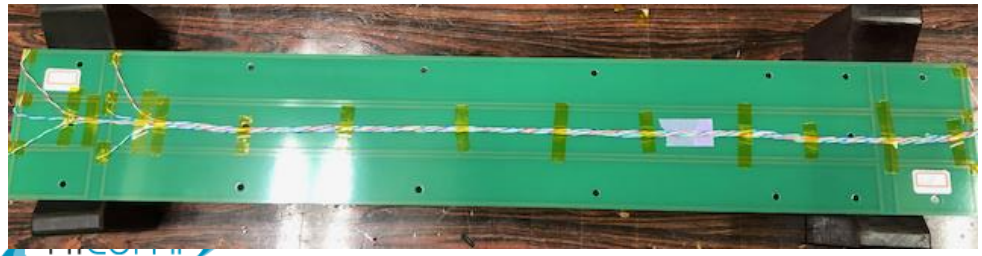




KEK Status

- **Preparation of test station at KEK**
  - **Vertical cold test station: Tooling for 7-m long magnet is being designed. Some update needed for MFM system and header for cryostat.**
  - **Horizontal bench: Commissioning of a new MFM system and an alignment methodology by using 3rd model magnet.**





Remarks, Summary

- Influence of COVID-19 on D1 construction.
  - We had difficulties to follow up the activities of Hitachi in March to May 2020 and this resulted in the some technical problems in the practice coil fabrication.
  - Since Feb. 2020, we have not been able to visit CERN. Technology transfer of cold mass assembly (technical details) has not been completed yet.
- Manufacturing of D1 prototype is underway at Hitachi.
  - There is NO restriction of technical visit to Hitachi premise.
- Vigorous preparatory work for D1 prototype test at KEK.
- D1 prototype is planned to be delivered to CERN by Dec. 2021.
  - Followed by individual horizontal cold test with a dedicated cryostat in 2022,
  - and IT String in 2023.
- Ownership of the D1 cold mass which has to be transferred from KEK to CERN immediately after provision will be discussed at the 2nd D1 Steering Committee in December.
- D1 model magnet #3 (MBXFS3) is planned to be shipped to CERN for inter-calibration of the field measurement systems.