SC Magnet Test Stand at KEK

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On behalf of Cryogenics Science Center, KEK

HL LHC SC Magnets Test Stand (SMT) Workshop, 13-14 June 2016, CERN

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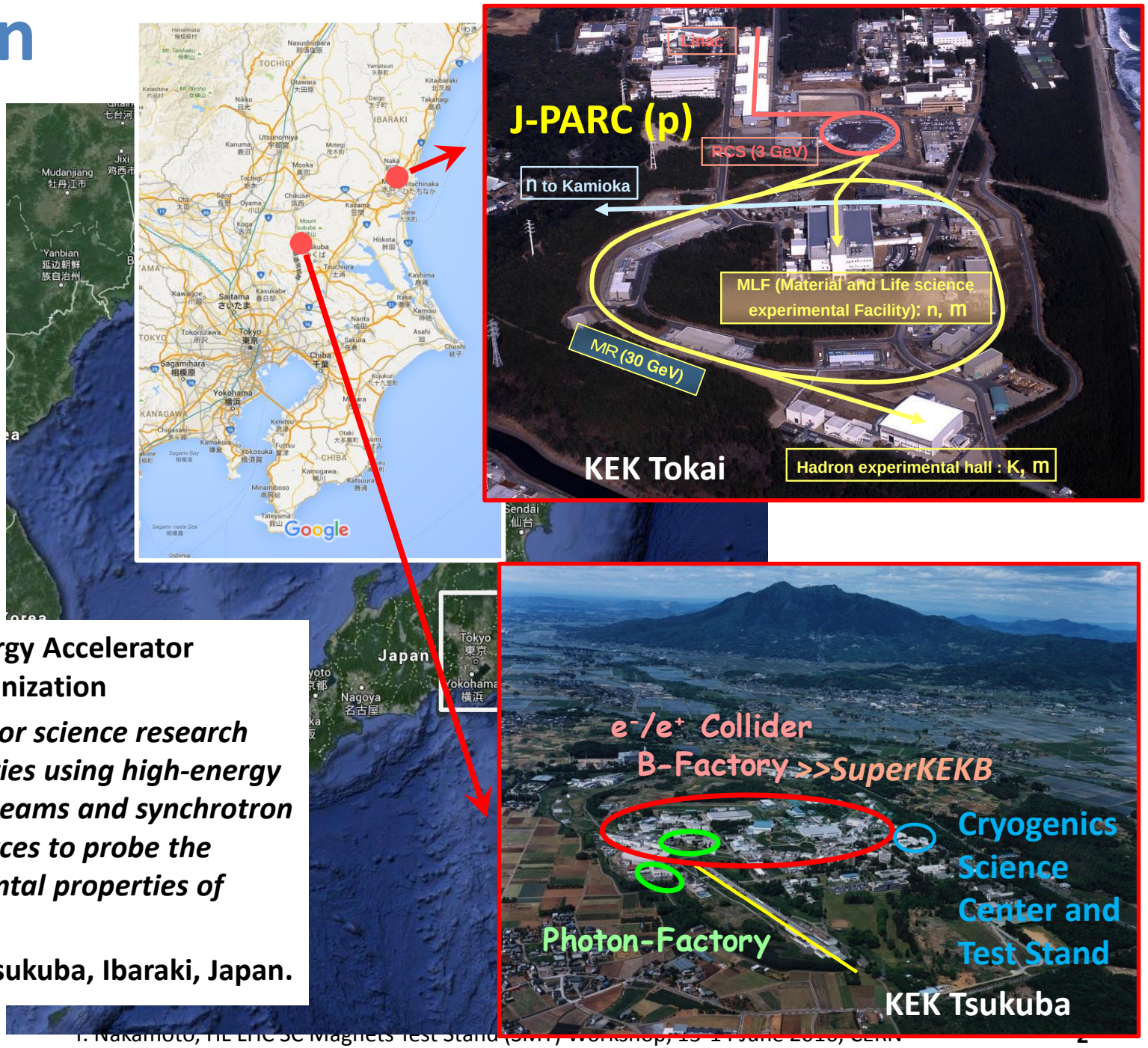
Location

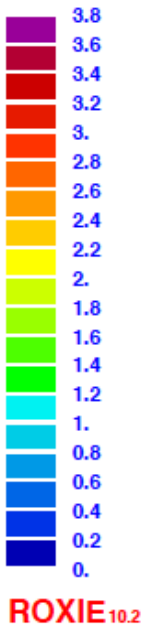


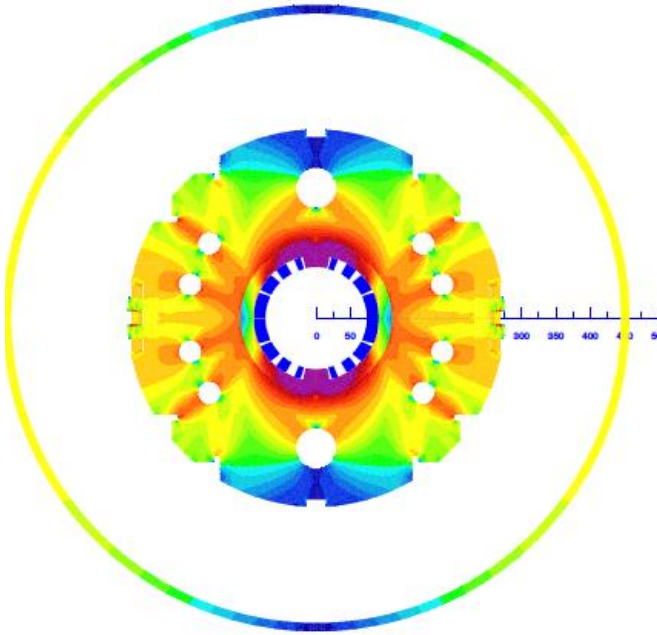
- **KEK, High Energy Accelerator Research Organization**
  - ***Accelerator science research laboratories using high-energy particle beams and synchrotron light sources to probe the fundamental properties of matter.***
- **Main office: Tsukuba, Ibaraki, Japan.**

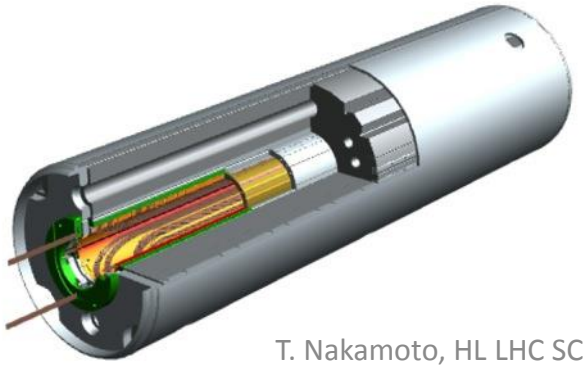
Design Parameters of D1, MBXF, for HL-LHC

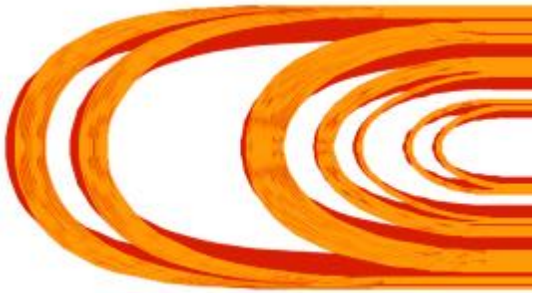
- *Coil ID:* ***150 mm***
- *Integrated field:* ***35 Tm*** *(26 Tm at present LHC)*
  - ***5.59 T at 12 kA. L_{coil}=6.6 m***
- *T_{op}:* *1.9 K by HeII cooling*
- *Op. point (2D coil):* ***75 %***
- *Coil layout:* *1 layer of 15.1 mm cable*
  - *Better cooling. Saving space for iron yoke.*
- *Conductor:* ***Nb-Ti LHC MB outer cable***
- *Structure:* *Collared yoke structure by keying*
- *Field quality:* *< 10^{-4} at R_{ref} = 50 mm*
- *Cold mass OD:* *550 +10 x 2 = 570 mm*
- *Cryostat OD:* *914 mm, same as MB cryostat (*TBD)*
- *Radiation, energy deposition:*

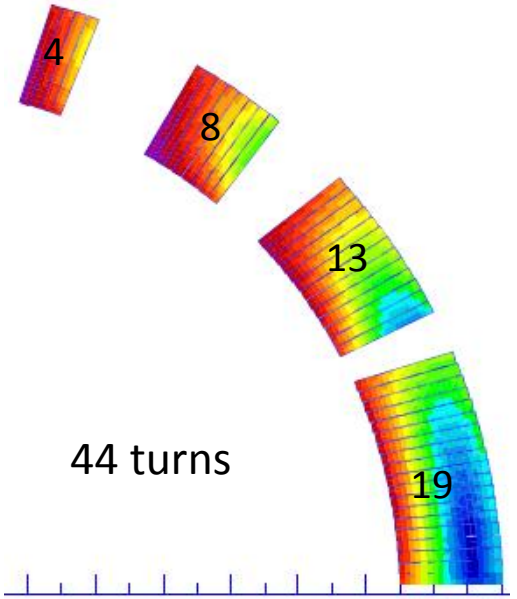
135 W in total, 2 mW/cm³ at local peak, Radiation dose >25 MGy





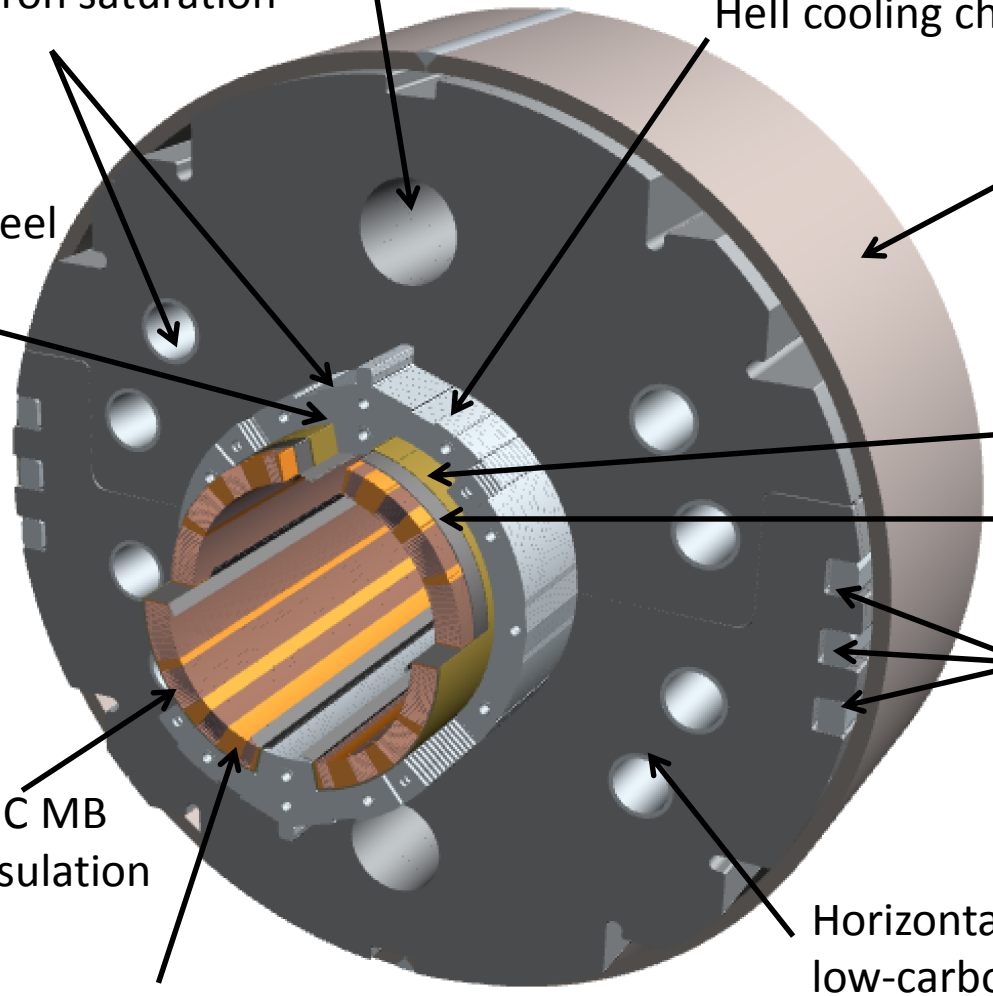






2m-long Model Magnet - Overview

Single-layer coil, 4-split spacer collars, collared yoke by keying



Notches and ϕ 34 mm holes for iron saturation effects

ϕ60 mm HX hole

HeII cooling channel

Shell: SUS304L

4 split stainless steel spacer collars: NSSC130S

Brass shoes

QPH+Insulations

Collaring keys

NbTi SC cable (LHC MB outer) + Apical insulation

Radiation resistant GFRP (S2 glass + BT resin) wedges

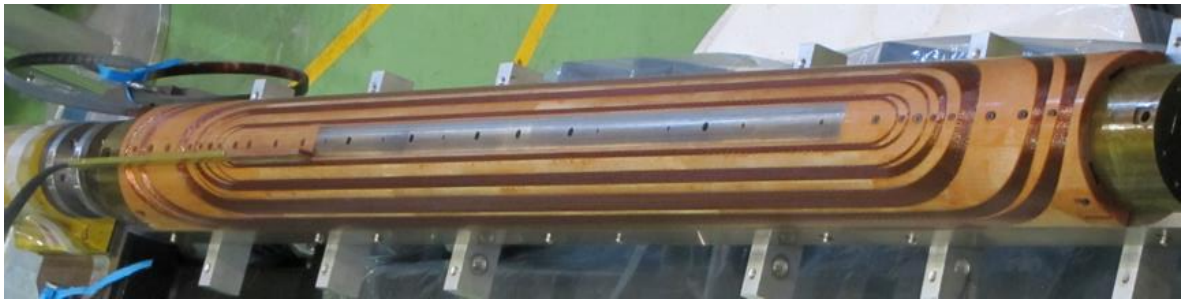
Horizontal split iron yoke: low-carbon steel (EFE by JFE steel)

Parameters

	2m Model	Production Magnet
General		
Field integral	9.8 T·m	35 T·m
Coil aperture	150 mm	
Nominal dipole field	5.57 T	
Coil peak field	6.44 T at center, 6.59 T at coil end	
Load-line ratio	75.4 % at center, 76.6 % at coil end	
Nominal & ultimate current	12.0 kA & 13.0 kA (~108% nominal)	
Operation temperature	1.9 K	
Magnetic length	1.73 m	6.27 m
Stored energy	340 kJ/m	
Differential Inductance	4.0 mH/m	
Number of turns in quadrant	44 (4+8+13+19) turns in a single layer coil	
Superconducting Cable		
Superconductor	Nb-Ti	
Cable type	LHC MB outer cable	
Strand diameter	0.825 mm	
Coating	Sn5wt%Ag	
Copper to SC ratio	1.95	
Filament diameter	6 μm	
Number of filament	6500	
RRR	> 150	
Critical current (9 T, 1.9 K)	> 380 A	
Number of strand	36	
Cable bare width & mid-thickness	15.1 mm & 1.480 mm	
Insulation 1st & 2nd layer	APICAL (0.05 mm thick, 11 mm wide), 1/2 overwrap	
3rd layer	PIXEO (0.069 mm thick, 9 mm wide), adhesive, 2 mm gap wrap	

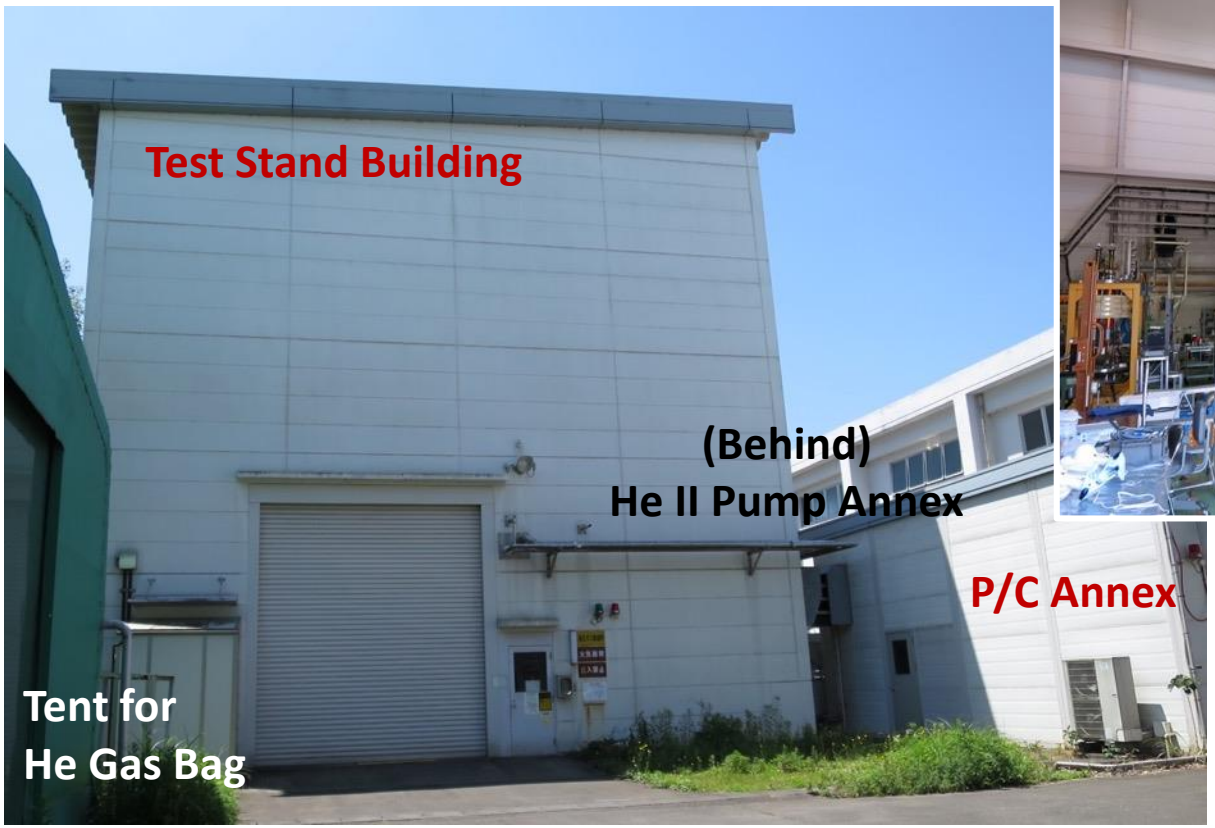
2 x 2m models & 7 x 7m magnets to be tested in KEK for HL-LHC.

2m Model Development



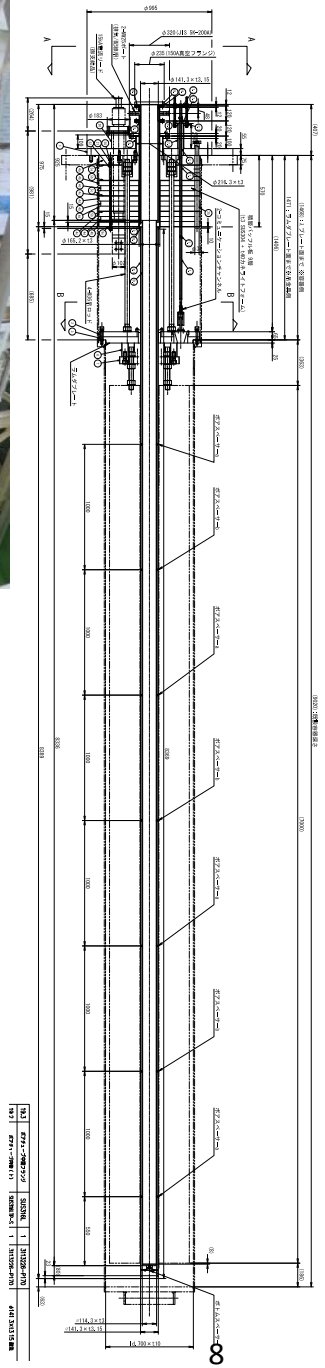
Test Stand - Buildings -

- Built in 2000 for vertical cold tests of LHC-MQXA magnets.
- Surface
  - Test Stand: 335 m^2 (20 m x 15 m + 7.9 m x 4.4 m)
    - Crane: 20 ton / 4.5 ton, 10.5 m in height
  - Power Converter: 50 m^2 (10 m x 5 m)
  - Pump for HeII: 40 m^2 (7.4 m x 5.4 m)



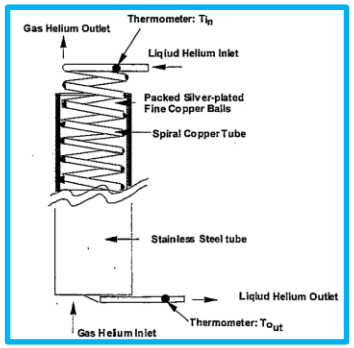
Cryostat

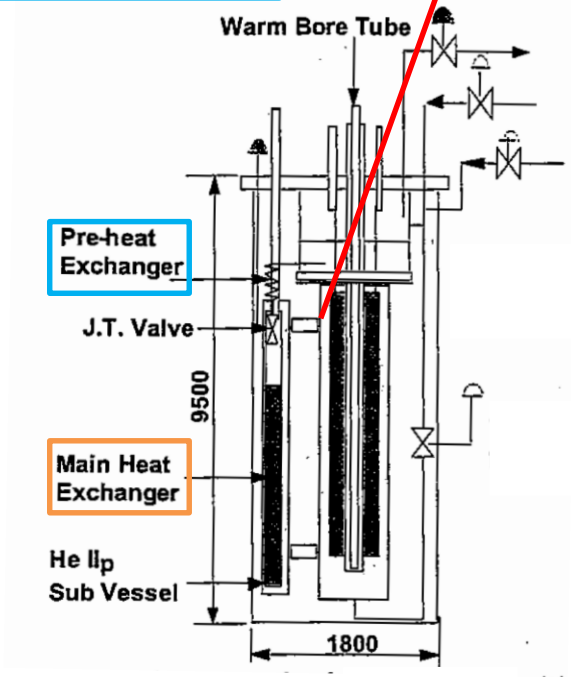
- Manufactured by Toshiba in 2000 for vertical cold tests of LHC-MQXA magnets.
  - 19 LHC-MQXA (7m), 32 J-PARC SCFM (4m)
- Applicable Law: Japanese High Pressure Gas Safety Act
  - Operation at 1.9 K is exceptional. Category of "Designated Equipment"
- Operating Temp.: 4.4K to 1.9K
- Cooling
  - 300K to 40K by GHe, 40K to 4.4 K by LHe
  - 4.4 K to 1.9K by HeII Sub-cooler (55W for MQXA)
- Capacity
  - whole bath: 9020 mm deep, 700 mm in a diameter.
  - 1.9 K bath: 7524 mm deep, 700 mm in a diameter.
  - Weight: 8.6 ton (MQXA). Need to check for D1.
- He Cryogenic Plants (see next slide in detail)
- New header for the D1 (MBXF)
  - Manufactured in 2014, approval of the JHPG Safety Act in 2015.
  - Anti-cryostat for field measurement: O.D. 141.3 mm
  - Quench antennas: 11 arrays for 7 m long magnet
  - Feedthrough: 48 poles x 10
  - HVWL: 1.5 kV (present limit 0.5 kV.)
  - 15 kA Current Leads
    - Manufactured by Fuji Electric in 2015. All copper base. (50L/h for a pair)



HeII Sub-Cooler

- Pre-heat exchanger
  - Copper spiral tube (I.D. 12mm, Spiral Dia. 42 mm)
  - Fine silver-plated copper balls
  - Efficiency 88%
- J-T expansion valve
- Main heat exchanger
  - Design: ΔT=30 mK at 80 W, 1.9 K.
  - Required surface area: > 3.0 m^2
  - 4.4 m long copper tubes: 3 x ϕ 76.2 mm, 10 x ϕ 12 mm.
- Pumping system
  - 4 parallel lines
    - 2 x Roots pumps: 2 x 900 m^3/h
      - SHIMADZU MB-1400
    - 1 x Oil free pump: 630 m^3/h
      - TAIKO MDP-1015
  - Note: Current performance is limited by cooling capacity of a water chiller (old!!).
    - Only 2 pumiping lines are operational.





Cryogenic Plants

Refrigerator/Liquefier for Test Stand

- 160 L/h, 2400 L dewar
- Teisan / L'Air Liquide in 1987 for the TRISTAN-AMY detector
- New cold box in 2007
- Backup of the primary refrigerator for LHe supply.

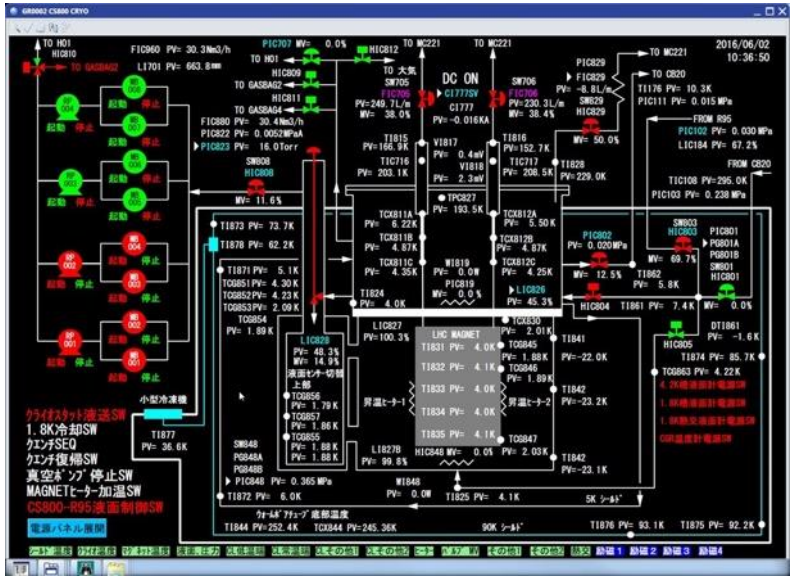
Neighbor refrigerator (Primary)

- 350 L/h, 5000 L dewar
- LINDE LR280 in 2014
- Mandatory to supply LHe to KEK users.
- 20 m long LHe transfer line to the test stand.
  - In linkage operation: 510 L/h max.

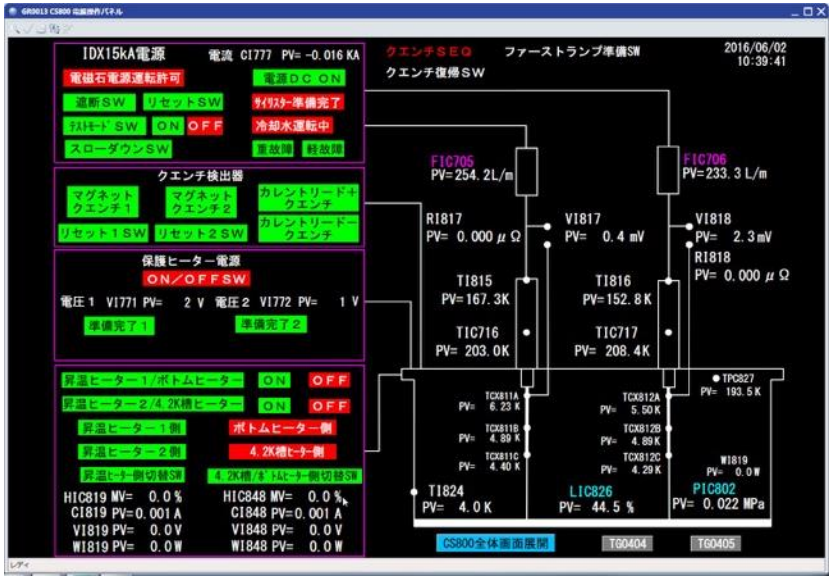
- Helium liquefying rate is sufficient to cover both supply for users and magnet testing.
- Attention to GHe handling
  - limitation in purification system
  - difficulty to predict GHe recovery from KEK sites

Control System

- CENTUM VP, Yokogawa Electric
  - A distributed control system (DCS) as a platform for automated control and operation of the cryogenic plant.
  - Programmed by KEK engineers.
  - Interlock for 15 kA P/C (slow down or shutoff)
    - Monitor: LHe level, CL status and refrigerator
  - Historical trend data



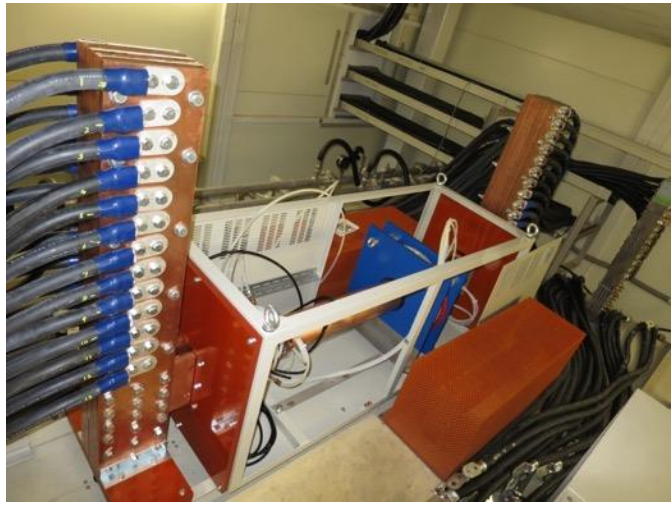
Ex) display for main cryostat control



Ex) display of interlock for 15 kA P/C

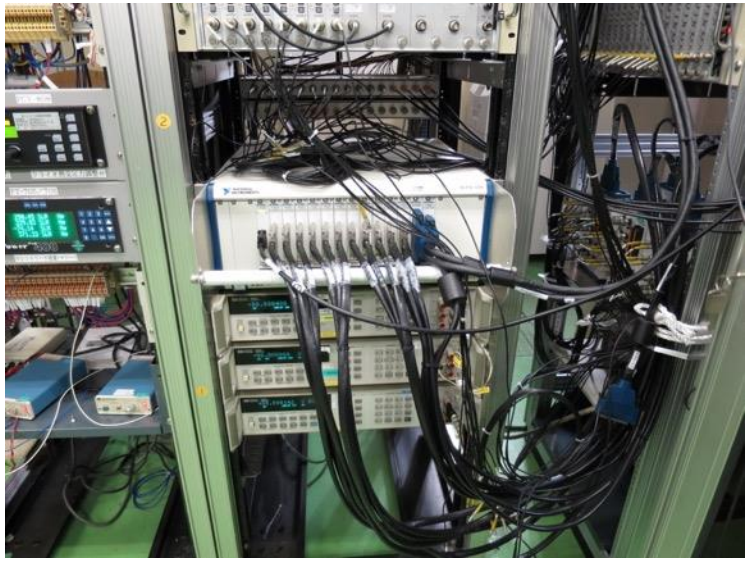
Power Converter

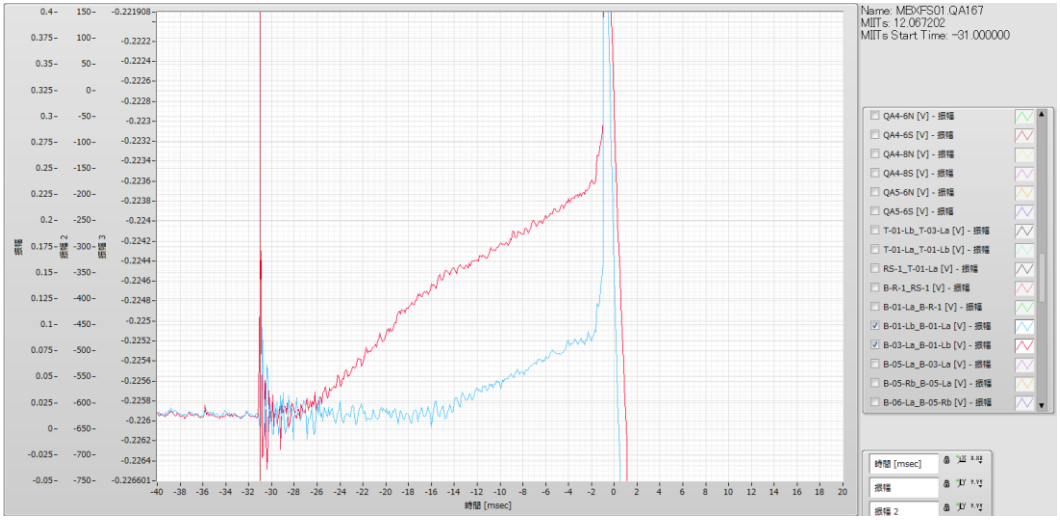
- Manufactured by IDX in 1993 for SSC-SDC magnet development.
- Nominal: 15 kA, 15V
- Thyristor switch for prompt shutoff.
- Dump resistor of 73 mΩ (grounding at middle point) for the D1
  - Available: 0, 12.5, 25, 50, 75 and 100 mΩ.
- Water cooling: 150 L/min, 10 kg/cm2
- Quench detectors
  - 2 x Balanced Voltage (Main)
  - 2 x Total Voltage
- External 15 kA DCCT (Zero-Flux Current Transformer)
  - Fully calibrated at CERN as a standardization of current.
  - But unwanted shutoff caused by vibration during the excitation in May 2016.
  - Performance degradation is concerned.
- Note: some contact failures found in relays through the D1 model magnet testing.
  - aged deterioration…
  - Overhaul must be done be as soon as we can.



Measurement System - Present -

- Isolation Amp: NF P-62A, 76 ch
- Fast DAQ:
  - NI PXI 1643 (16bit, 250 kS/s/ch), 88 ch
    - Voltage taps, quench antennas, P/C, etc.
- Slow DAQ: GP-IB
  - KEYSIGHT 3458A multimeter (8.5 digit) x 3
  - Kyowa UCAM-60B for strain gauge measurement, currently 30 ch (80 ch max.)
- Software: Labview (& KEYSIGHT VEE only for field measurement)
- 3 PCs: Fast DAQ, Slow DAQ, MFM.





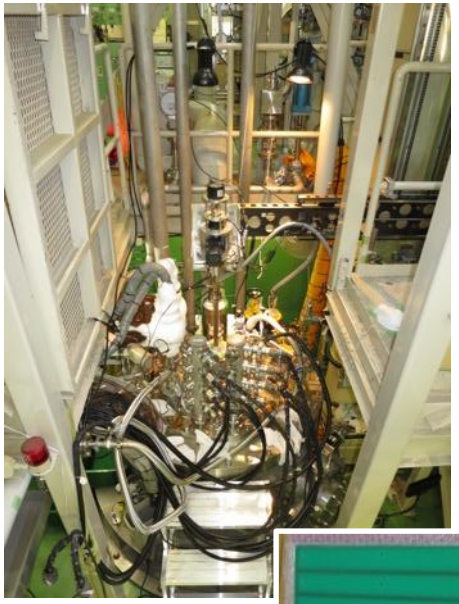
Field Measurement System

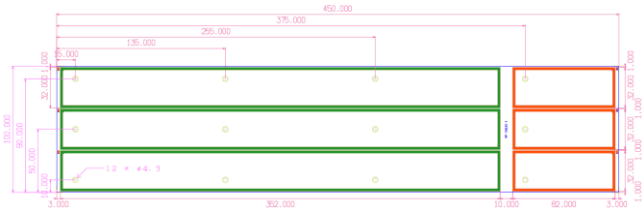
Vertical Measurement

- **Rotating coil in anti-cryostat (I.D. 108.3mm) at "warm" temperature.**
  - **Printed-circuit board**
  - **3 radial coils: B1 and analogue bucking**
  - **Long (350mm) and short (80mm) arrays**
  - **GN_2 flow from the end to suppress thermal shrinkage of the pipe**
- **7 m long GFRP shaft**
  - **not long enough for the 7 m magnet, but it can be extended.**
- **Encoder: HEIDENHAIN RON 255**
- **Integrator: MetroLAB PDI-5025 x 3**
- **Magnet scale: SONY LY51**

Horizontal Measurement

- **For warm measurements of LHC-MQXA and J-PARC-SCFM cold mass.**
- **But the system is dismantled for the time being…**
  - **The system will come back for the D1 magnets.**





Operating Personnel

- Operators for the cryogenic plant
  - 3 to 4 weeks for a test cycle.
  - 24 hours operation >> 3 shifts/day, 5 days/week.
  - 15 shifts/week: 1 shift for 8.75 hours
  - 10 shifts/week by outsourcing from 16:30 to 9:00 for safety reason.
  - 5 KEK staffs and 2 outsourcing workers
    - They must be holders of “a high pressure gas production safety management”.

- Operators for the magnet test
  - Quench Tests: from 9h to 19h (sometimes 20h)
  - Field measurement: mainly daytime, through nighttime if necessary.
  - 3 to 4 KEK staffs (not only dedicated to the test…)

*** Staff of Cryogenics Science Center: 17 in total.**

- **Tsukuba: Researchers 6, Post-doc 2, Engineers 4**
- **Tokai: Researchers 2, Post-doc 1, Engineers 2**
- **Mandatory: LHe supply for users**
- **Projects: J-PARC (T2K neutrino, COMET, g-2, muon beam lines, etc.), HL-LHC upgrade, KAGURA (gravitational telescope)**

Summary

- KEK has been engaged in the D1 magnet (MBXF) development for the HL-LHC design study. KEK is supposed to deliver 6 magnets with cryostats for the HL-LHC.
- The 9 m deep vertical test stand at KEK was originally built for the MQXA construction. The facility will be utilized for the cold tests of the D1 model and production magnets for HL-LHC.
  - 2 x 2 m model magnets
  - 7 x 7 m production magnets (incl. 2 spares and 1 prototype)

  *Horizontal cold test bench with SHe cooling (4.4K) was established for the J-PARC SCFM. But it is dismantled now.
- The first D1 model magnet was tested at 4.4 K and 1.9 K in the vertical cryostat in this April to May. The new header with 15 kA CLs and a large bore anti-cryostat successfully functioned for the cold test.
  - The original facility (cryogenic plant, HeII sub-cooler, power converter) has almost worked. But some malfunctions and performance limitation due to aged deterioration were found through the test …
  - Adequate refurbishment/replacement must be done well in advance of starting the D1 construction.