Status of Superconducting Magnet Projects and R&D at KEK

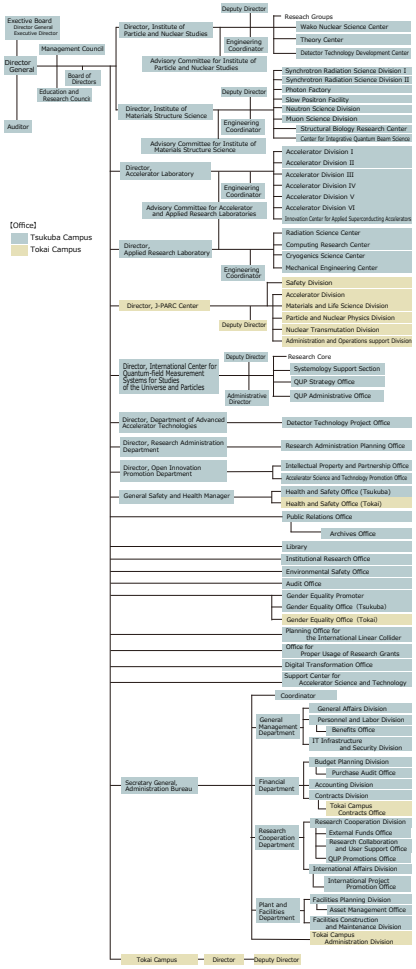
Toru Ogitsu

On be half of KEK Cryogenics Science Center

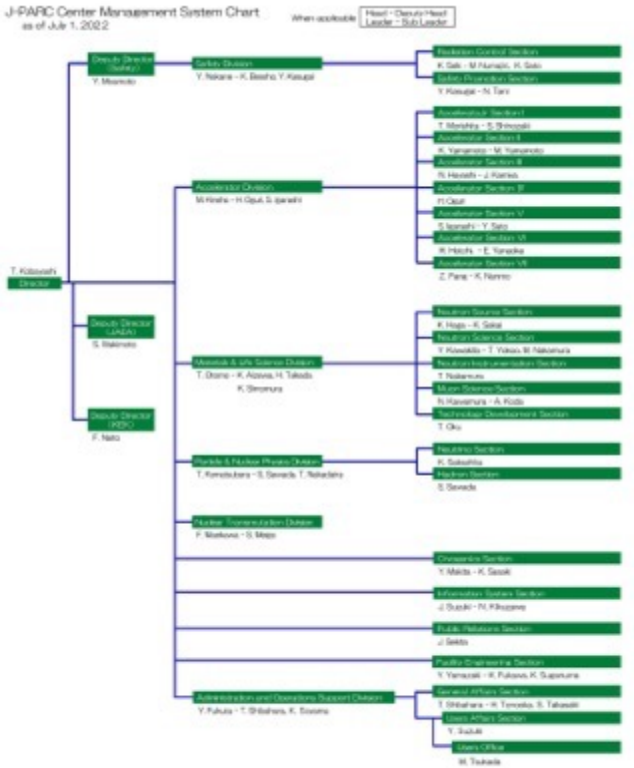
and

J-PARC Center Cryogenics Section

KEK Cryogenics Science Center and J-PARC Center Cryogenics Section



Scientists
Cryogenics Science Center
Toru Ogitsu(Head)
Tatsushi Nakamoto(D1)
Ken-ichi Sasaki(J-PARC)*
Michinaka Sugano(D1)
Masami Iio(J-PARC)*
Kento Suzuki(D1)
Naoyuki Sumi(J-PARC)*



J-PARC Cryogenics Section
Yasuhiro Makida(IPNS)
Ken-ichi Sasaki(CSC)*
Takahiro Okamura(IPNS)
Masami Iio(CSC)*
Makoto Yoshida(IPNS)
Naoyuki Sumi(CSC)*

Contents

- On going Projects
  - HL-LHC D1
  - COMET
  - g-2/EDM
- Future R&D
  - High Field Magnet
  - Radiation Hard Magnet
- Summary

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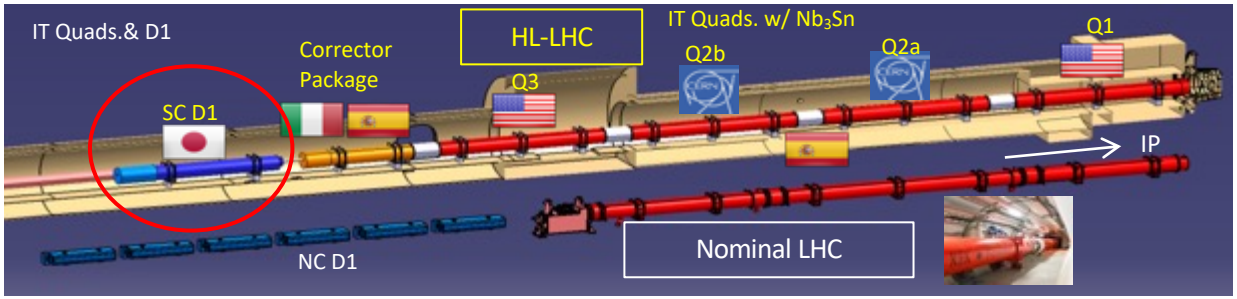
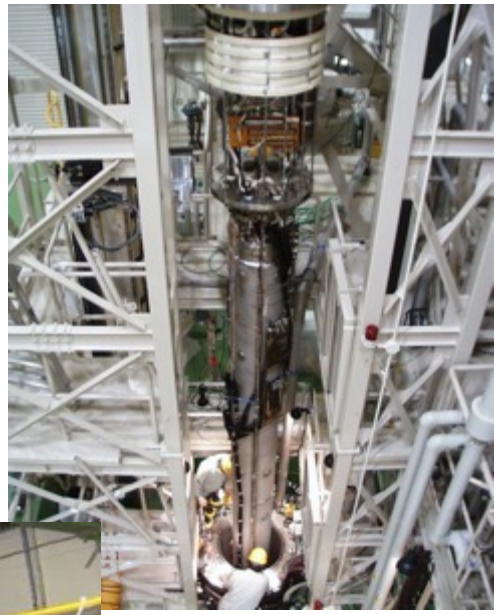
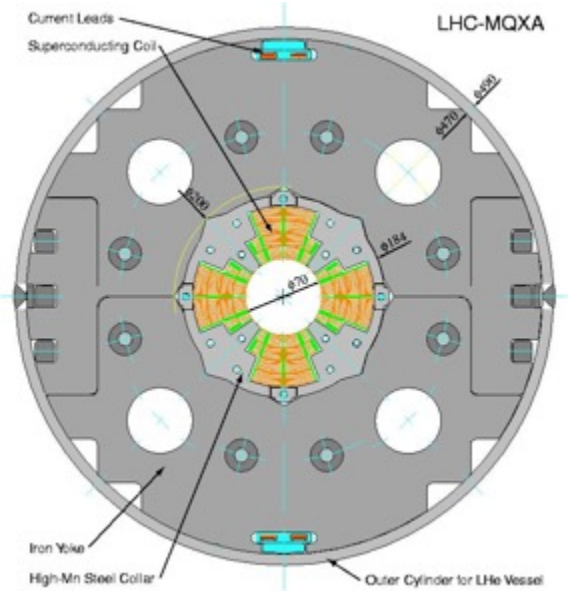
HL-LHC D1 Magnet

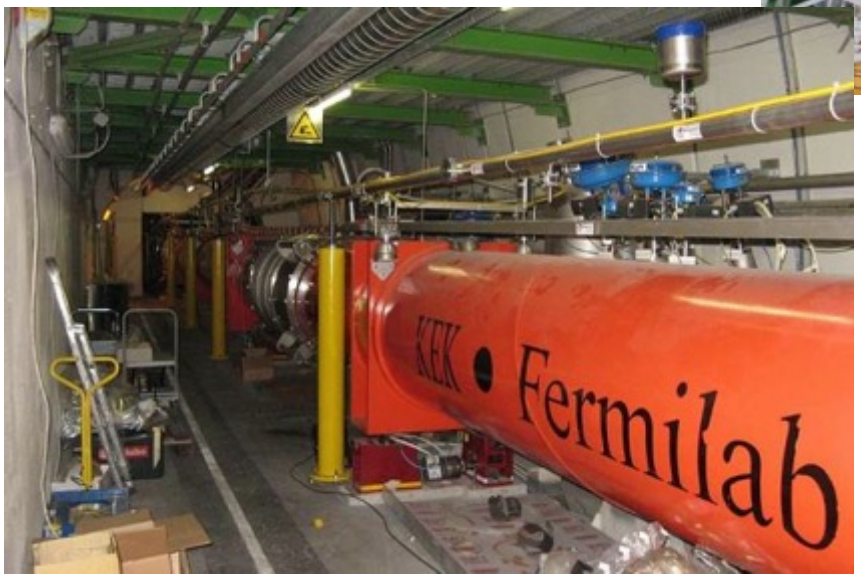


Japanese Contribution to LHC MQXA: Interaction Quadrupole

- **Focus Beam at Interaction Region (Increase Luminosity)**
  - Field Gradient 280T/m, Maximum Field 8.7 T

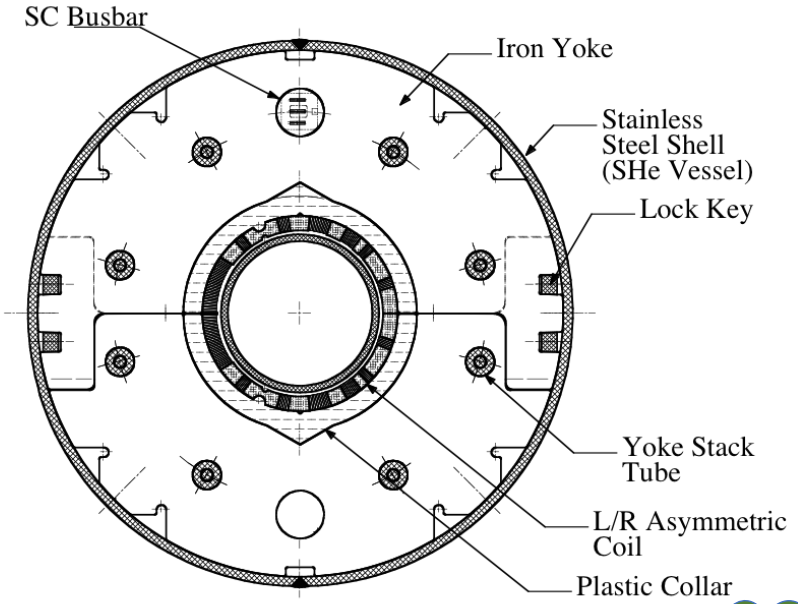


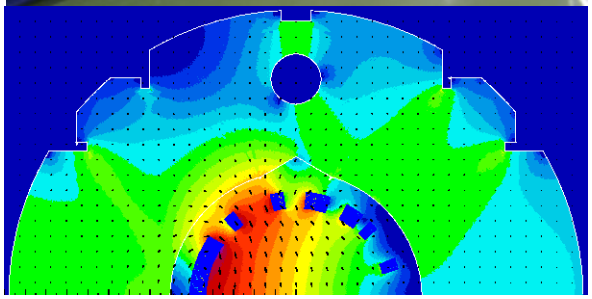


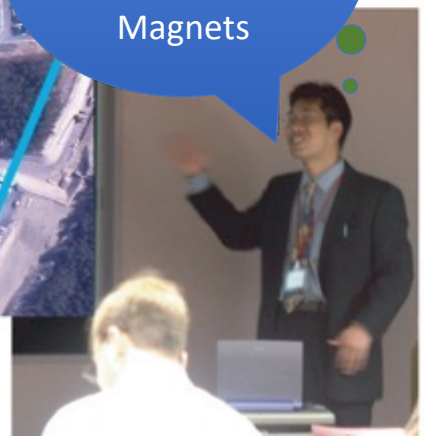


KEK SC Magnets
J-PARC Neutrino Facility

- Neutrino Facility needed SC magnets due to space limitation



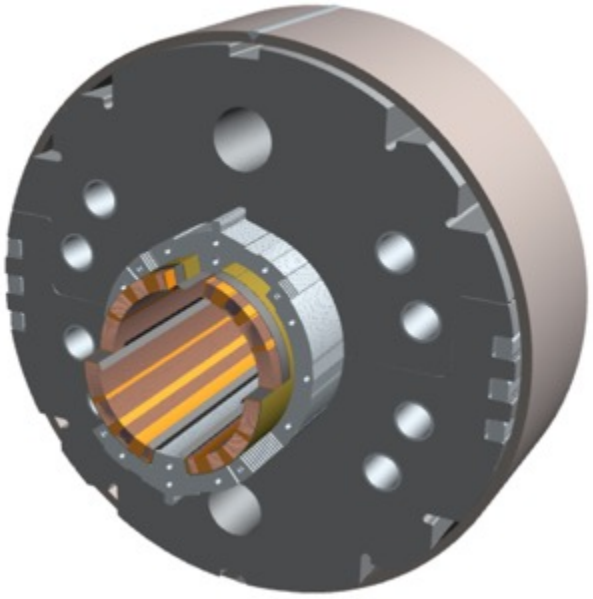




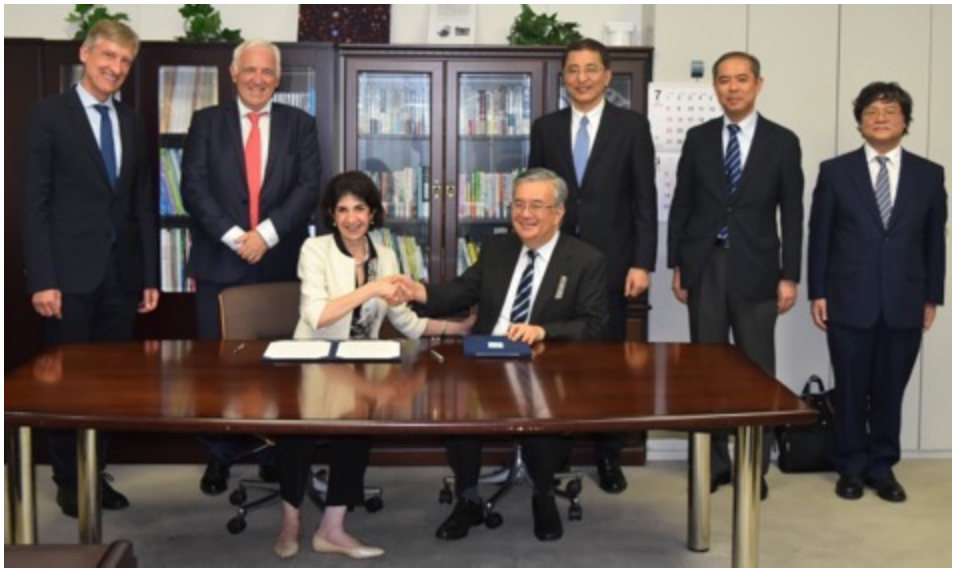
Combined Function MagnetS （2.6T+19T/m, 28 Magnets）
Optimize Cost and Schedule

Beam Separation Dipole
KEK Contribution to HL-LHC

- Large Aperture 150mm, 6T Dipole



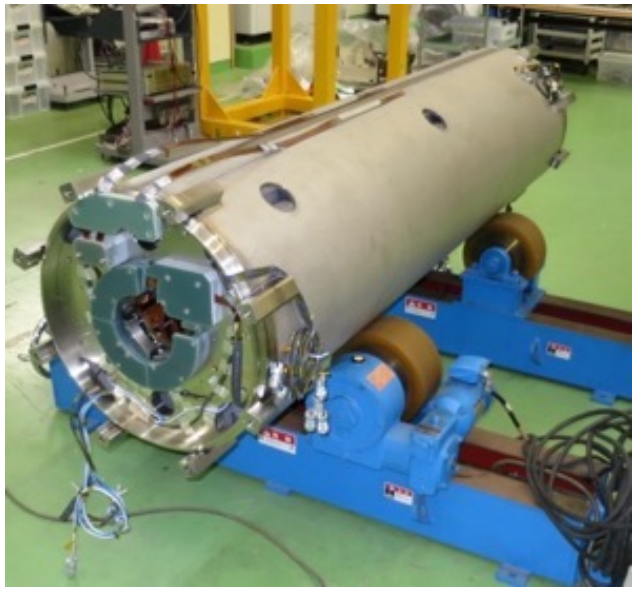
HL-LHC D1 Magnet



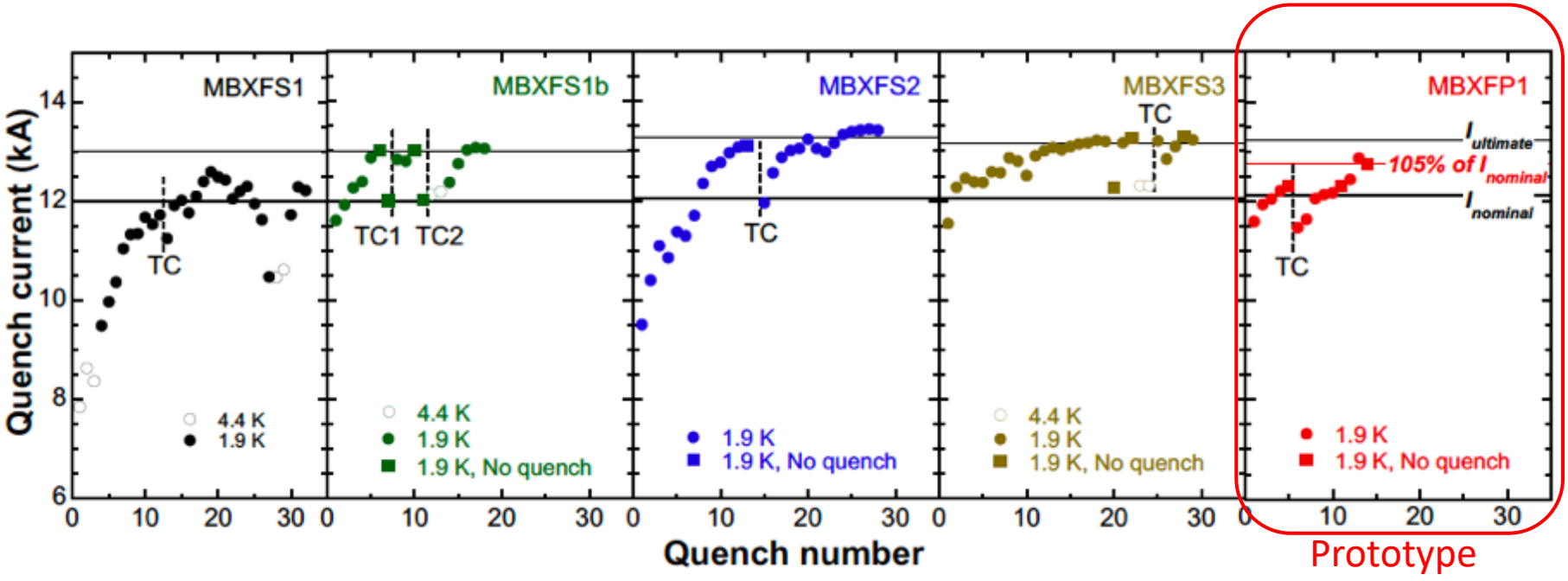
Sigh of MOU between CERN and KEK

Development of D1 Magnet

- D1 model magnet developed by KEK



- D1 prototype magnet produced by Company



Summary

- Accelerator Magnet Development
  - LHC MQXA
  - J-PARC Beam Line Magnet System for Neutrino Experiment
- D1 development
  - Model Magnet (since early 2010s)
    - 3 Model Magnets
      - 1st model rebuilt due to insufficient preload
      - 1st rebuilt and 2nd,3rd showed good training performance
      - Field qualities are not good > modified for Prototype
  - Prototype Magnet (since 2018)
    - Quench performance were good enough
    - Field quality needed to be optimized for production
  - Production Magnet (since 2021)
    - 5 production started to be built
    - 1st one come next spring

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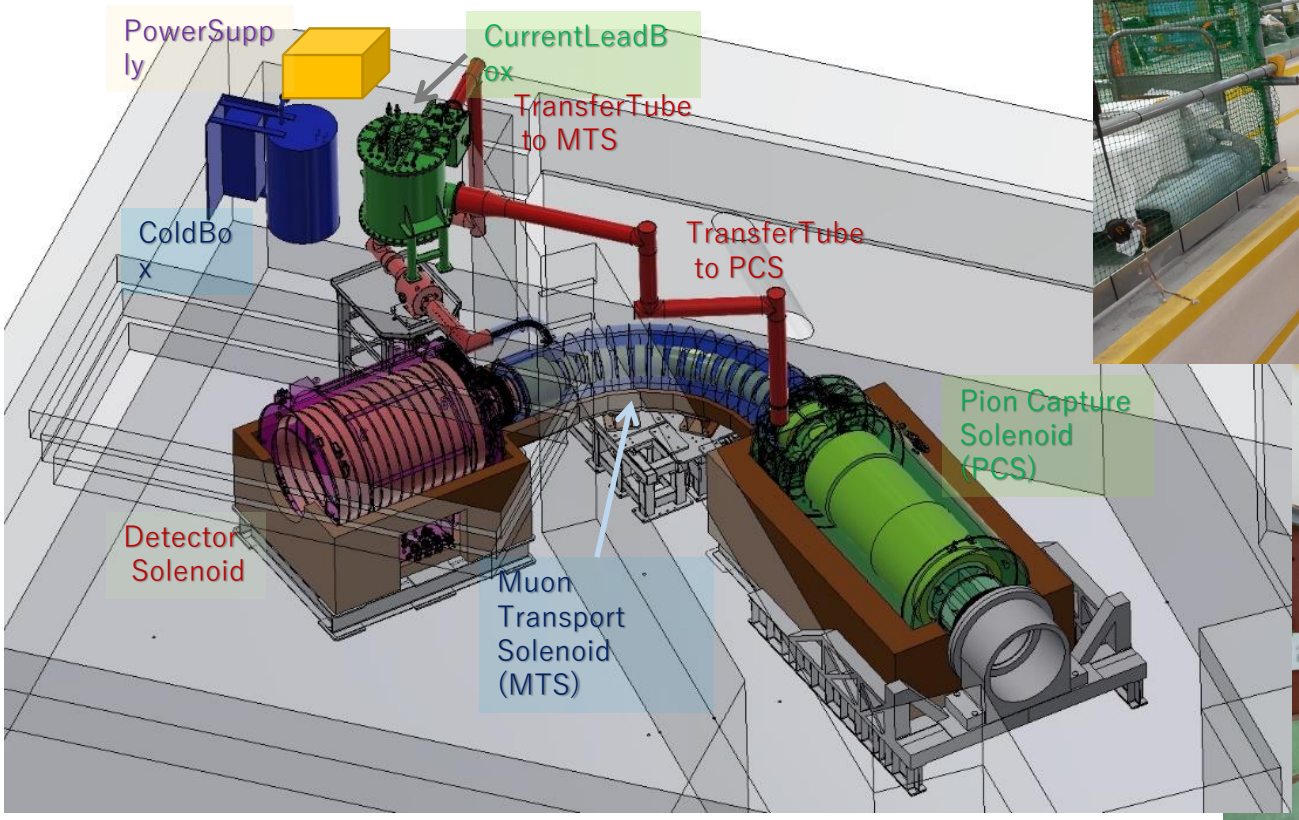
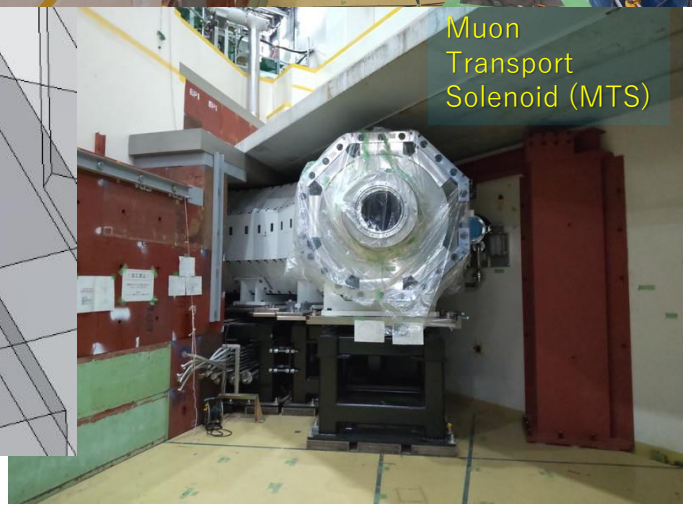
Superconducting Magnet System (COMET Phase-1)





Transport solenoid is installed and cold tested

Status of PCS Main Unit

- **PCS main unit has been in production since 2020 at the factory of Mitsubishi Electric in Kobe.**

Annual milestones

- FY2020: CS & TS1 cold masses: Completed
- **FY2021: Cooling objects conforming to High Pressure Gas Safety Act**
- FY2022: Main unit (cold masses, thermal shields, Part of vacuum vessel)

Summary

- The production of PCS main unit is underway at Mitsubishi Electric's factory .
- The production of cooling objects conforming to High Pressure Gas Safety Act is in progress. The production of built-in radiation shield and vacuum vessel parts is also progress in parallel.
- The PCS main unit will be delivered at the end of September 2023. And it will be installed in the beam room in Phase-I construction after temporary storage at the J-PARC site.
- Construction of a return yoke is in progress with the strong contribution of the Hadron Beamline Group.
- All parts of the return yoke will be delivered by mid-March 2022.

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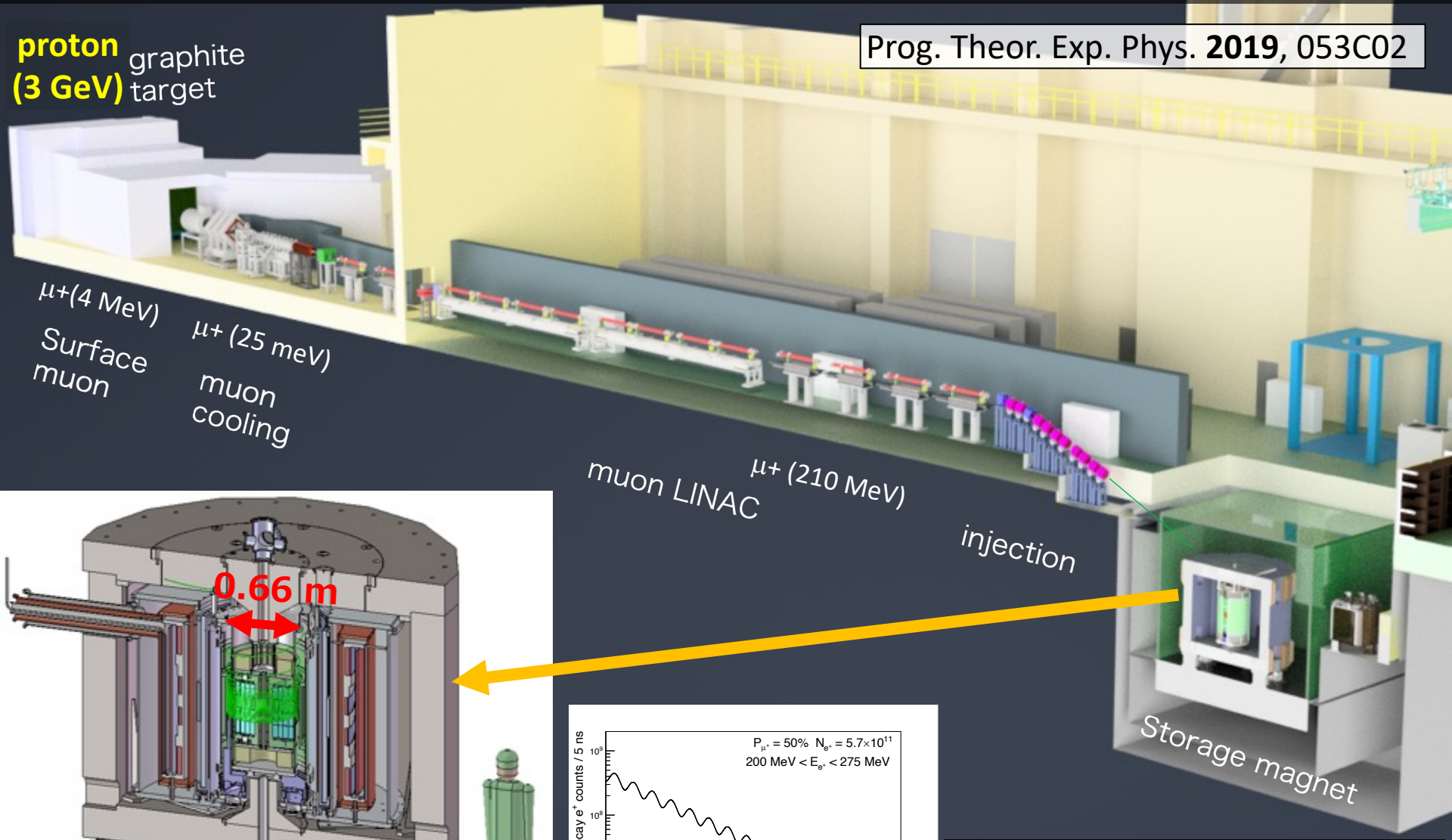
Muon g-2/EDM experiment at J-PARC



Prog. Theor. Exp. Phys. **2019**, 053C02

muon storage magnet

Goals:

g-2 450 ppb (~ BNL/FNAL run 1)

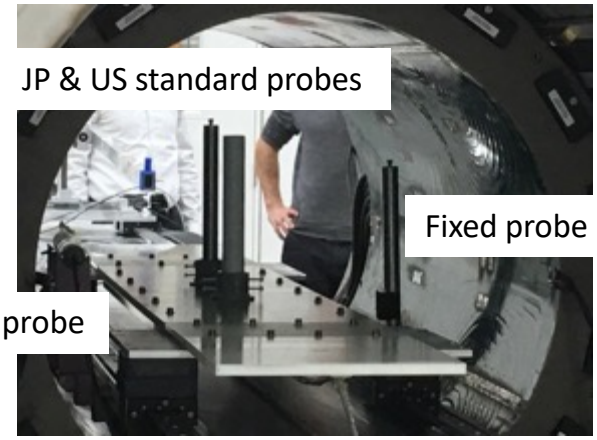
EDM 1.5 x 10^{-21} e・cm (x70 better)

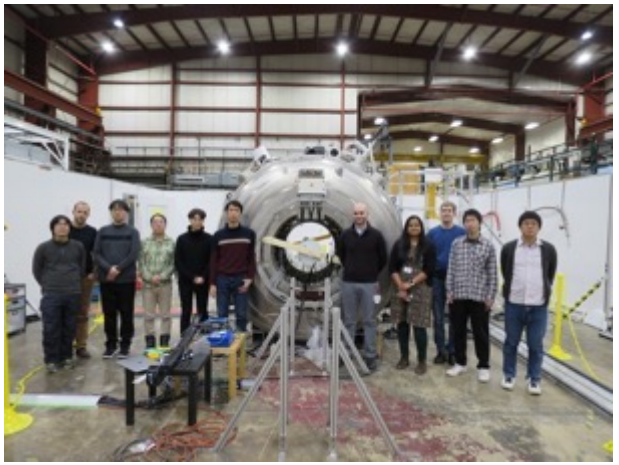
Cross calibration in US-JP collaborative framework

- Check consistency btw J-PARC and FNAL probes
  - increase the robustness of magnetic field measurement
  - collaboration with ANL and UMass group
  - at 1.45, 1.7 and 3.0 T

✓ measure magnetic field of single magnet at the same location with different probes

- Performed tests at 1.45 and 1.7 T in 2019





- planned 3 T test in 2020 <- postponed
- Analyzed the data at 1.45 T and 1.7 T with blind offset

Summary

- Updates of magnet design
  - Optimized main coil size
  - Systematic and statistical study of manufacturing error on the magnetic field error -> on going
  - Study of shimming scheme -> on going
  - Study of magnet system vibration -> on going
- Field monitoring system
  - R&D of moving stage
    - material study of rotating bearing
  - Multi channel probe system
    - made 10 ch. prototype, checked cross-talk and meas. scheme
  - Cross calibration analysis
    - found the difference : 40 ~ 55 ppb -> further study is underway
  - He3 probe
    - made cells, checked discharge performance
    - preparing laser room to do the test in J-PARC

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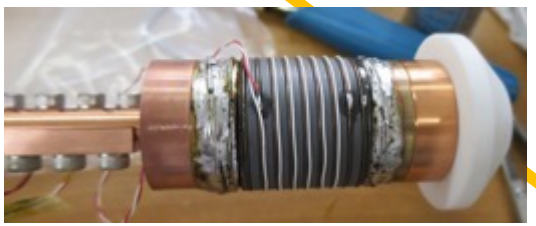
Nb3Sn conductor R&D structure

Design and Characterization

KEK

CERN

- In-depth characterization
  HT, J_c, composition, d_{eff} ...



- **Program coordination**
- **Defining specification**
- **Conceptual design**

- Evaluation of J_c, B_{c2}
- Mechanical property

Tokai University

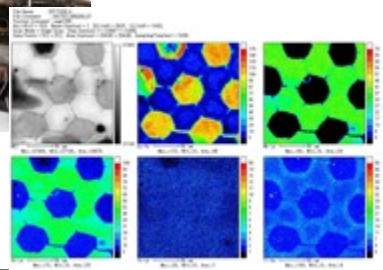
Tohoku University

- Optimization of HT condition
- Microstructure observation
- Compositional analysis

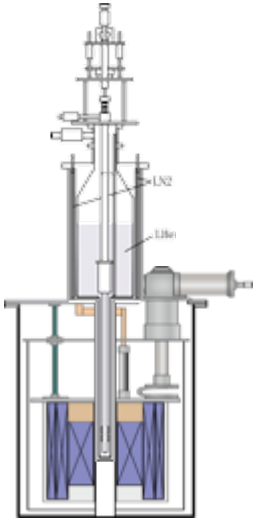
- High field magnet facility
- Evaluation of d_{eff}

Spec, design

R&D billets



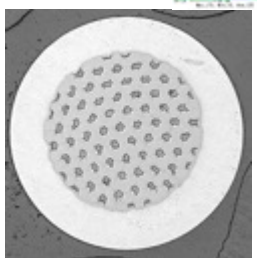
28 T HM



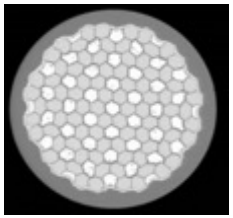
Fabrication

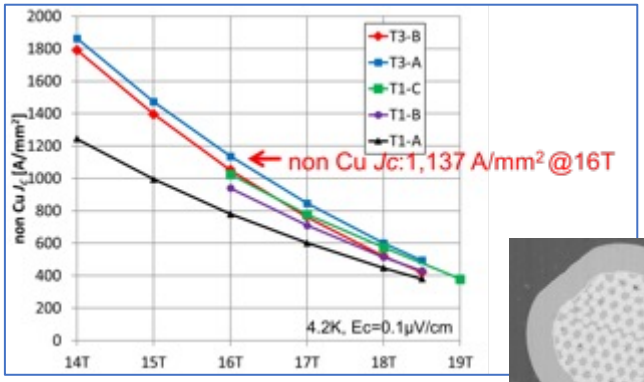
Kobe Steel / JASTEC

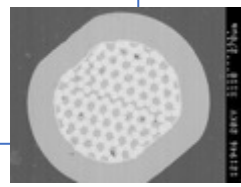
Furukawa Electric



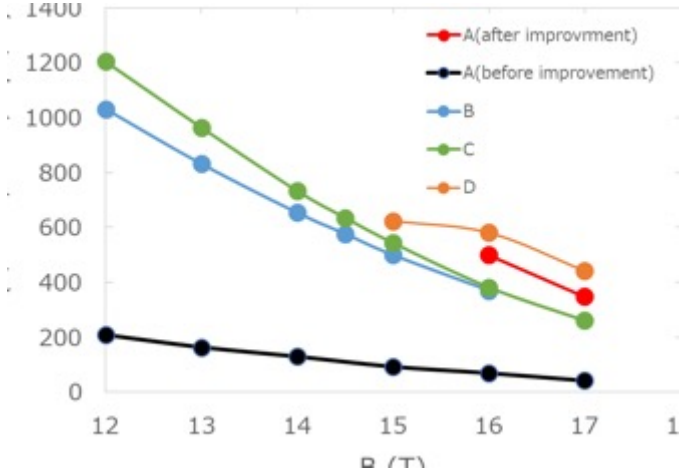
Status of Nb3Sn conductor R&D



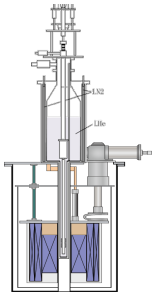


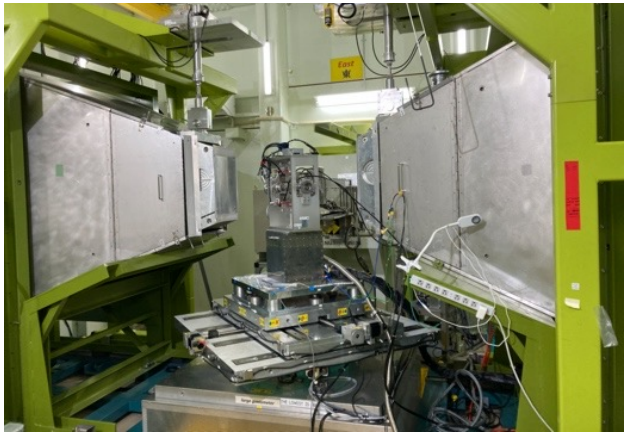


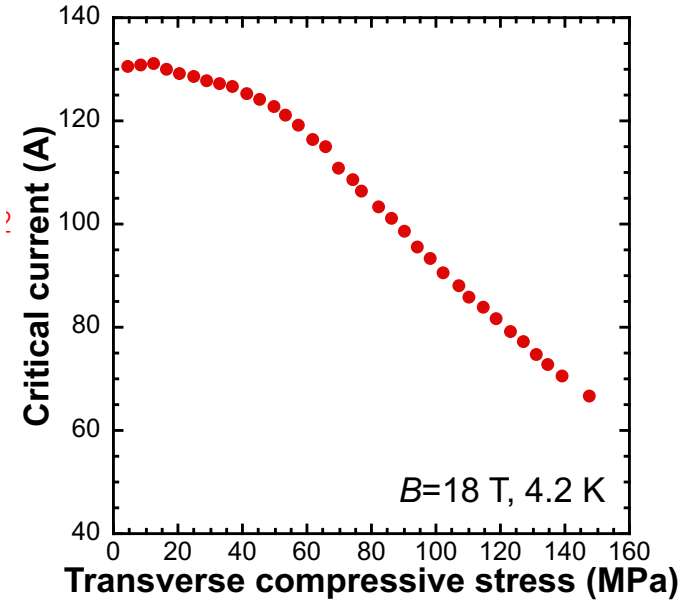
- DT wire
  - non Cu J_c @16T 1,100 A/mm^2
  - reasonable results in d_{eff} (~50μm)
  - and rolling test (Ic/Ic0>95%, RRR>100 @ 10% roll)
  - Production of 10km wire is on going.
- Nb tube wire
  - Non-Cu Jc of 580 A/mm^2 @16 T
  - Further improvement in progress



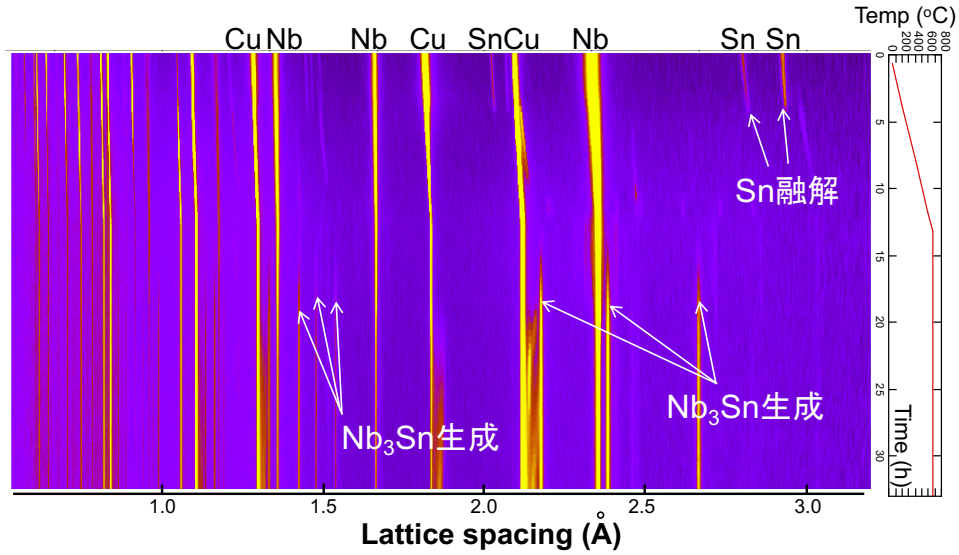
Nb_3Sn Recent Progress







Ic Measurement with
Transverse Stress at Tohoku U.



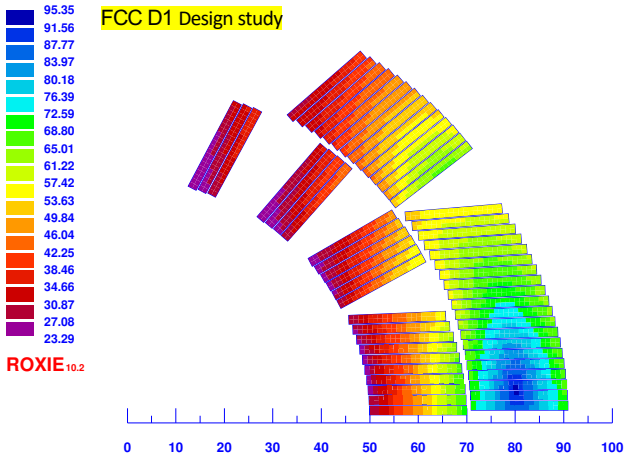
In-situ Material Analysis during Heat Treatment
at J-PARC Neutron Beam Line

Future Magnet Development with Large Funding (Budget Proposal being submitted)

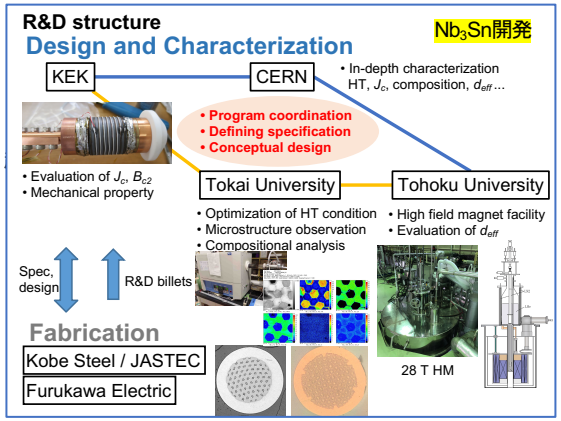
Magnet Manufacturing Experience

Infrastructure

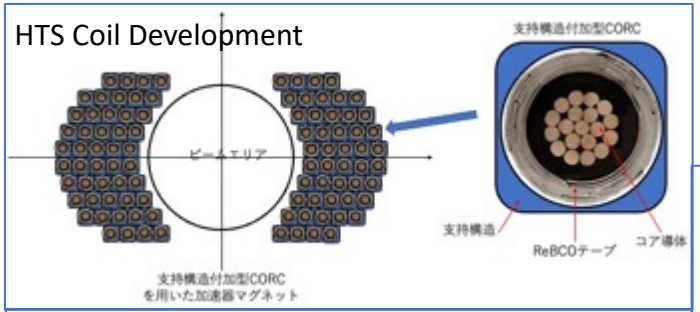
Magnet Design



Advanced Conductor Development



HTS Coil Development



New JSPS Funding with Tohoku and Kyoto

4-8T
Insert Coil

16-20T Magnet

Large Aperture
12T Magnet

Tohoku&KEK
Stress analysis on HTS cable
3D strain measurement on HTS tape
Kyoto&KEK
Quench stability and protection on HTS cable

High Field Magnet for
Future Accelerator

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J-PARC Future Muon Source

J-PARC MLF 2nd Target station

- Solenoid covering production target

→ Absorbed Dose: 130 MGy???

Conventional Magnet Technology

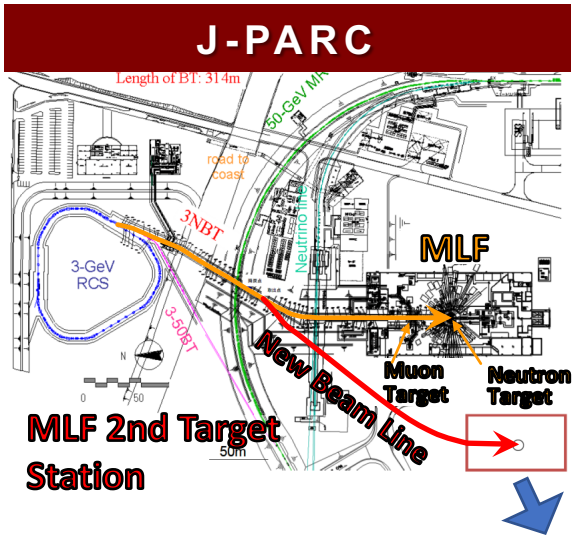
- **NbTi Cable**

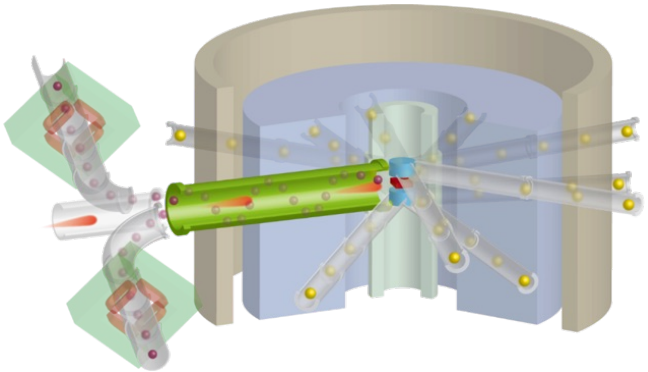
→ T=5 K with heat load reaching 650 W? due to nuclear heating

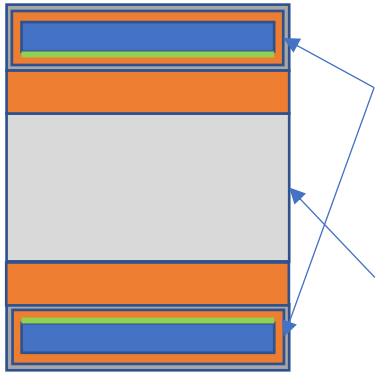
- **Organic Material for Insulation**

→ Degradation of the machine strength from 10 MGy

Development of next-generation radiation-resistant superconducting magnet has been awaited





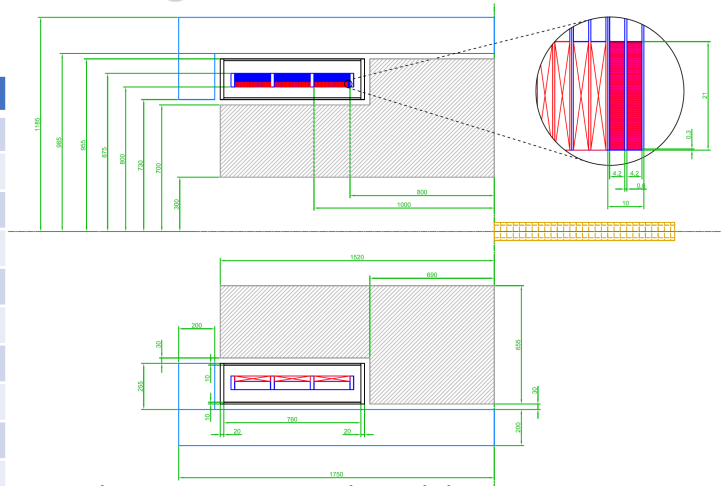


HTS Tape
12mm wide tape
30μm thick Hastelloy
5μm thick Copper Plating
4μm thick Solder Plating

Copper Clad Aluminum
Copper: 60μm thick each
Aluminum: 1.1 mm thick
Solder Plating: 4μm each

Preliminary conductor design

Parameter	Value
Coil Inner Diameter	1600 mm
Coil Thickness	55 mm
Coil Length	600 mm
Operation Current	1200 A
Peak Field @solenoid axis	1.12 T
Peak Field @coil	2.41 T
Peak Field B//ab	2.09 T
Peak Field B//c	2.25 T
Inductance	~4 H
Total conductor length	~7km



Preliminary capture solenoid design

Summary

- On going Project
  - HL-LHC D1
  - COMET
  - g-2/EDM
  - Also some user experiments at J-PARC
  - Too many projects for not enough resources
- For future projects
  - We still need R&D for new technologies (Nb3Sn, HTS…)
  - Can we make it?
    - Collaboration!: Universities (Tohoku, Kyoto, Berkeley), Laboratories (LBNL, CERN..)
  - Need Funding
    - Collaboration!: US-JP, CERN-KEK, Joint Proposal with Accelerator Dev. and/or Physics Groups and/or Universities
- For survival: widen collaborations and applications