Superconducting Combined Function Magnet System for the J-PARC Neutrino Beam Line

~ Status of Magnets ~

Ken-ichi SASAKI
KEK

1. **Introduction**
2. **System Overview & Design**
3. **Development of Quench Protection Scheme**
4. **Tests for Production Magnets**
5. **Summary and Schedule**

Collaborators

KEK

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T. Obana

Mitsubishi Electric.

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BNL (Corrector magnet)

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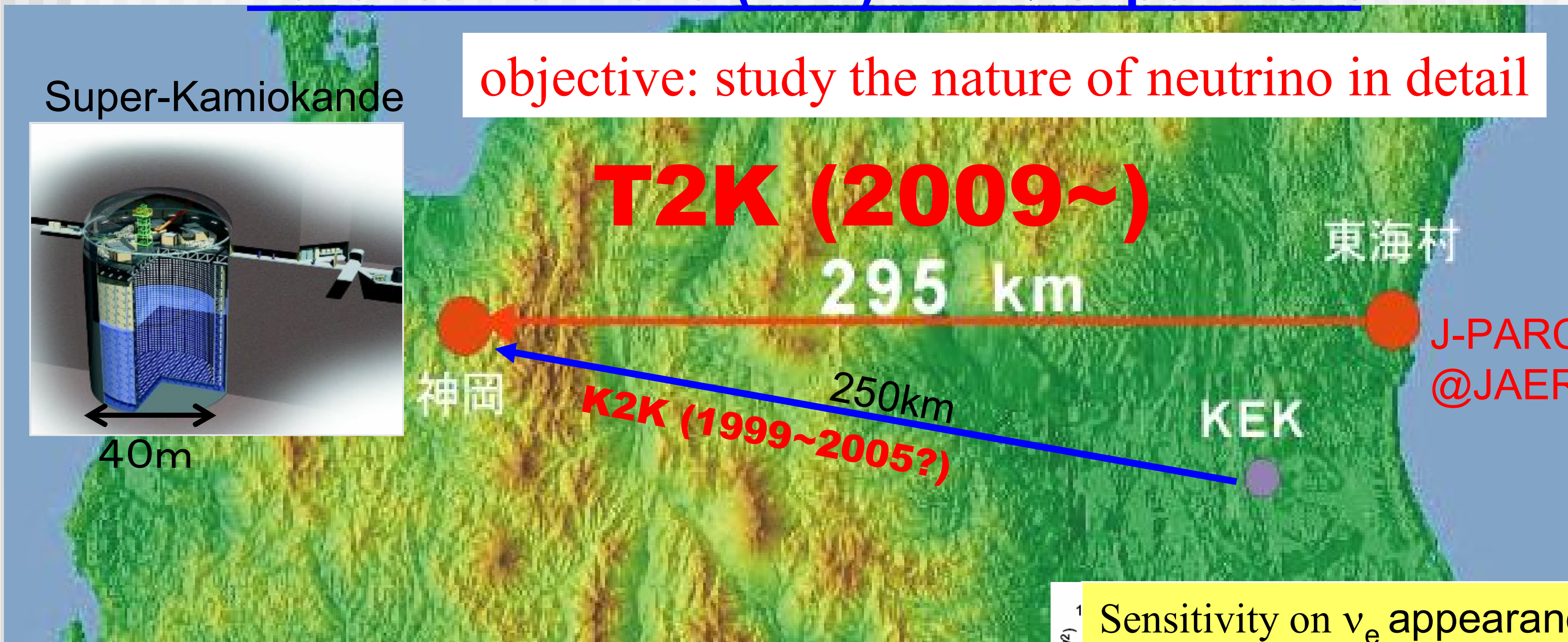
CEA/SACLAY (Quench Detection & Acquisition System)

J. P. Charrier, A. Bouty

Contents

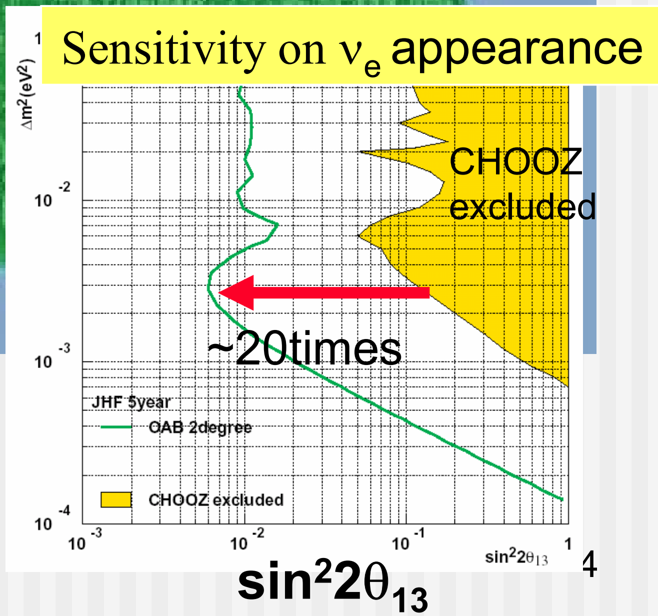
Neutrino physics at J-PARC
Tokai-to-Kamioka (T2K) LBL ν experiment

objective: study the nature of neutrino in detail



- Off-axis sub-GeV ν_μ beam from J-PARC 50GeV-PS
- ~3000 ν_μ CC int./yr (w/o osc.)
  - ν_e appearance discovery
  - ν_μ disapp. presice meas.
- 5 year const. Start exp. in 2009

Sensitivity on ν_e appearance

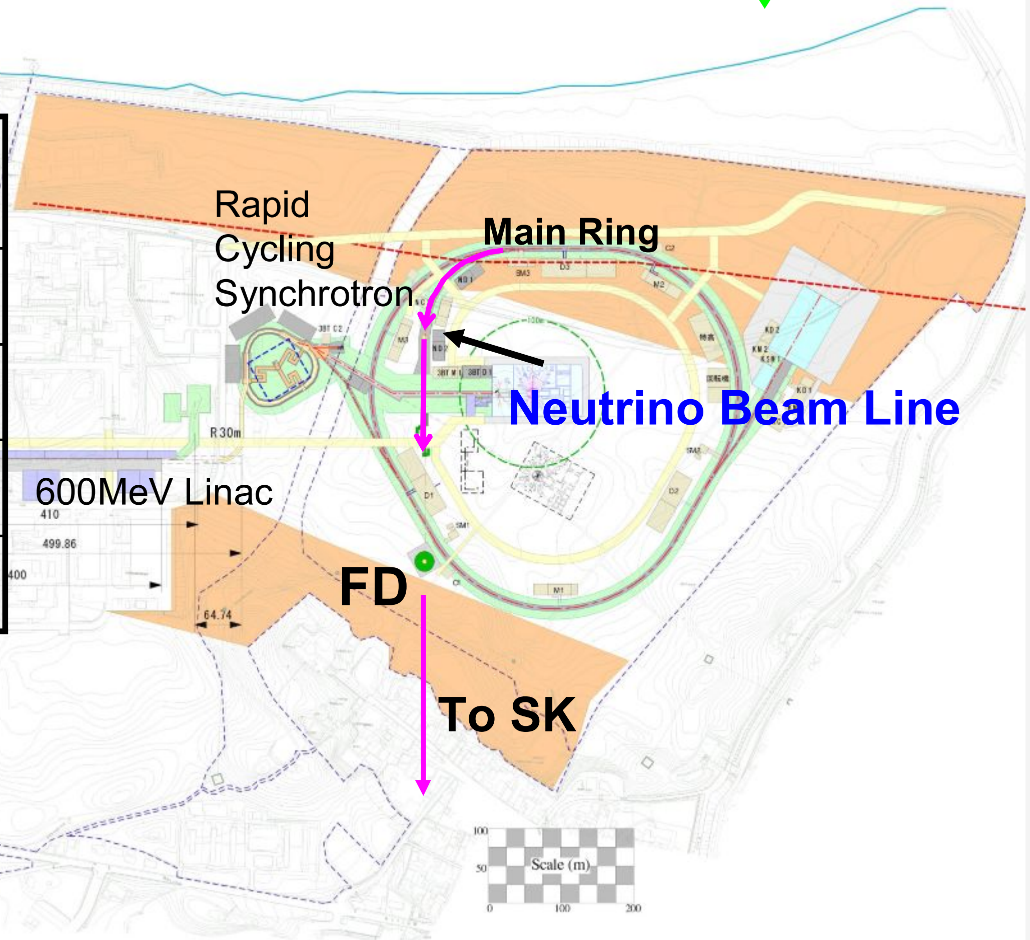


JPARC project and neutrino beam line

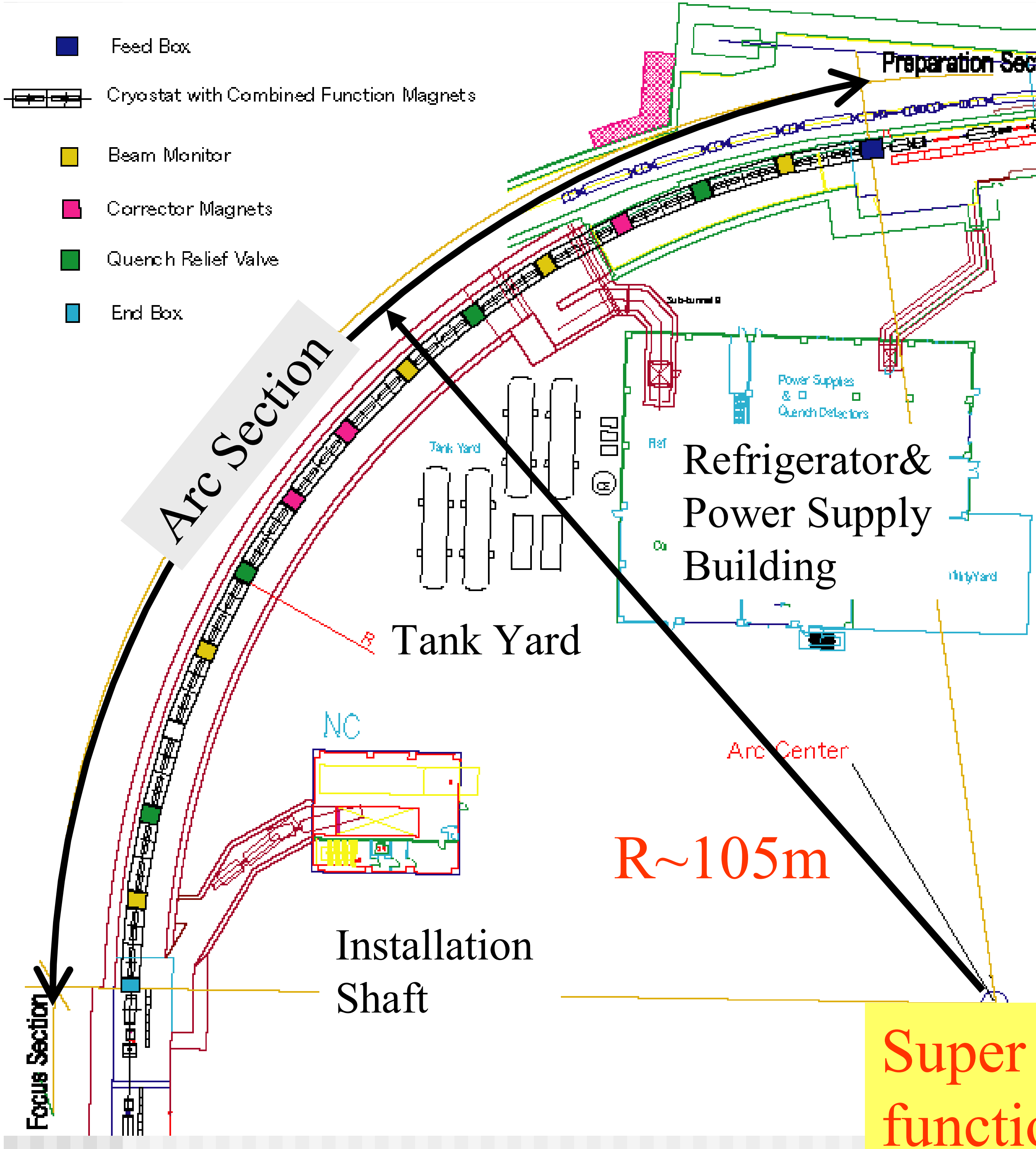
JAERI@Tokai-mura
(60km N.E. of KEK)

	JPARC	NuMI (FNAL)	K2K
E(GeV)	**50**	120	12
Int.(10^{12}ppp)	**330**	40	6
Rate(Hz)	**0.275**	0.53	0.45
Power(MW)	**0.75**	0.41	0.0052

10^{21}POT(130day)≡ “1 year”



System Overview



- about 90° bending
- R~105 m
  - Dipole : 2.6 T
  - Quad : 18.6 T/m

Super conducting combined function magnet system

Combined Function –Merit & Demerit?-

Merit

Reduce ...

- No. of components

  40 ⇨ ***28***
- Cost

  >~10% *cost reduction*

  (separate function)
- Time & Manpower for Development

  single magnet design

Increase ...

- Beam acceptance

  59π ⇨ ***69π*** **(**:Increase Q magnet)
- Space between magnets

  Beam monitor can be installed

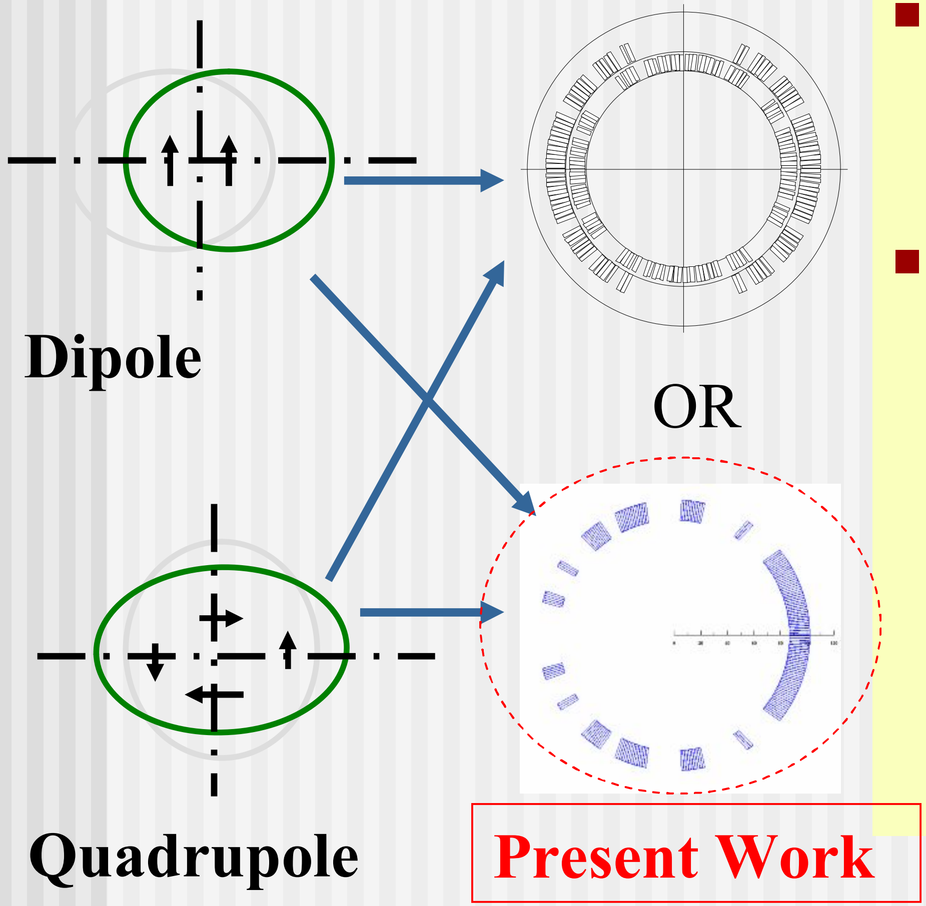
Demerit

- No example in the world
- Tunnability is restricted

⇩

need corrector magnets

Dipole and Quadrupole Field Superimposed in a single coil



- Conventional Magnet
  - **Inclined iron pole gap**
    - KEK-PS Booster
    - BNL AGS
- Superconducting Magnet
  - **Dipole and Quadrupole coils assembled in multi-layer coils:**
    - KEK-B insertion corrector
    - DESY HERA insertion,
  - **D & Q current distribution superimposed in single layer coil**
    - **New Proposal** for J-PARC neutrino beam line magnet,

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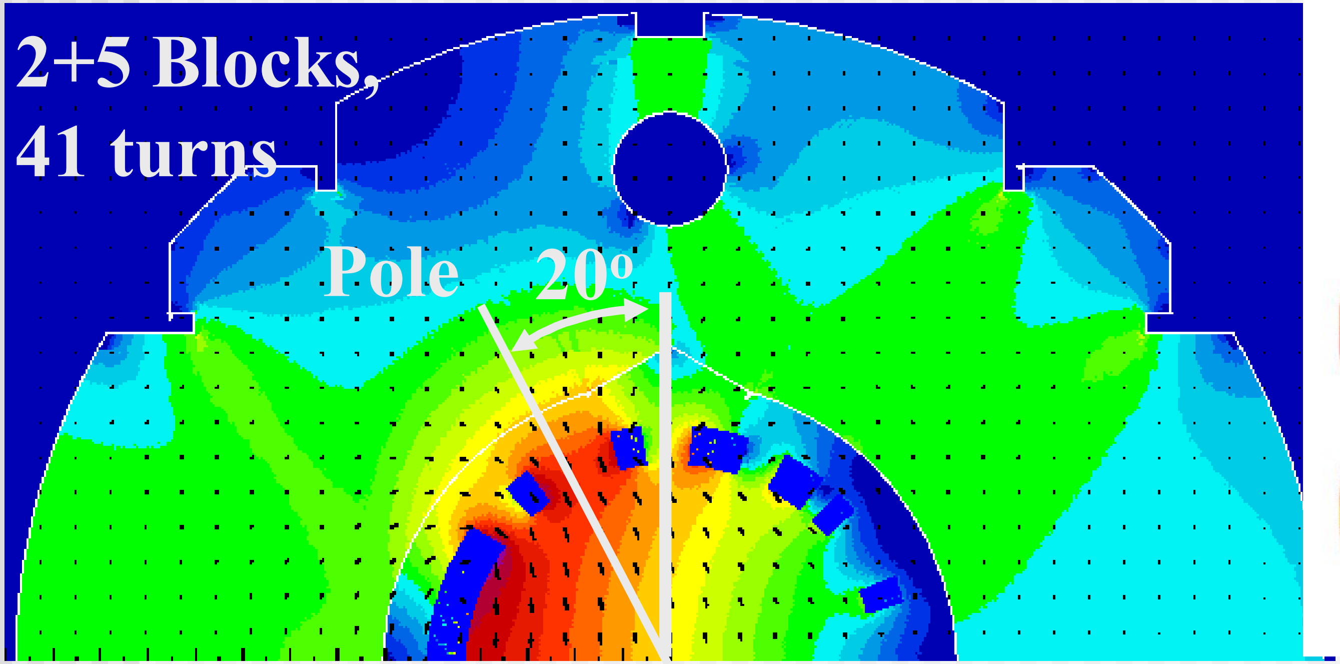
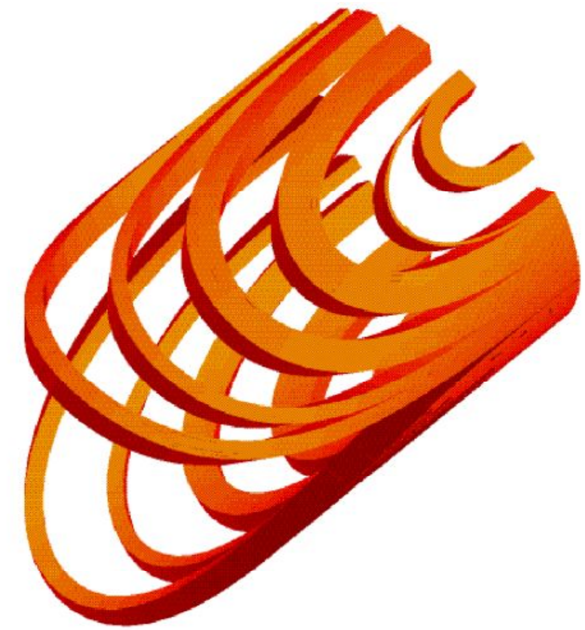
Specification

2D & 3D Model by ROXIE

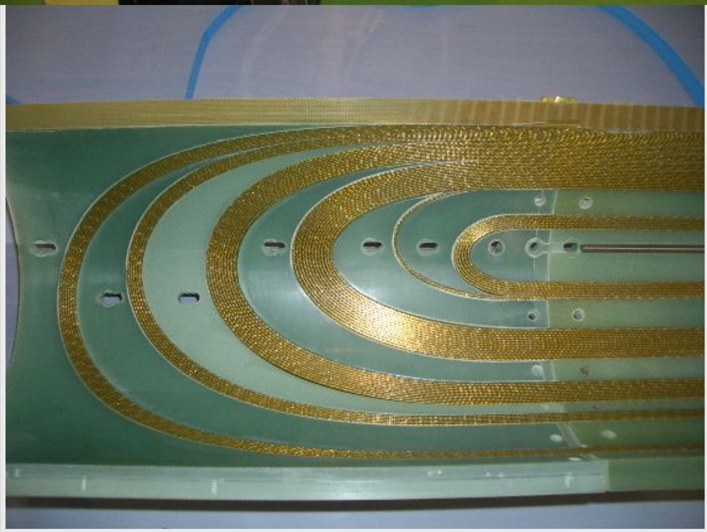


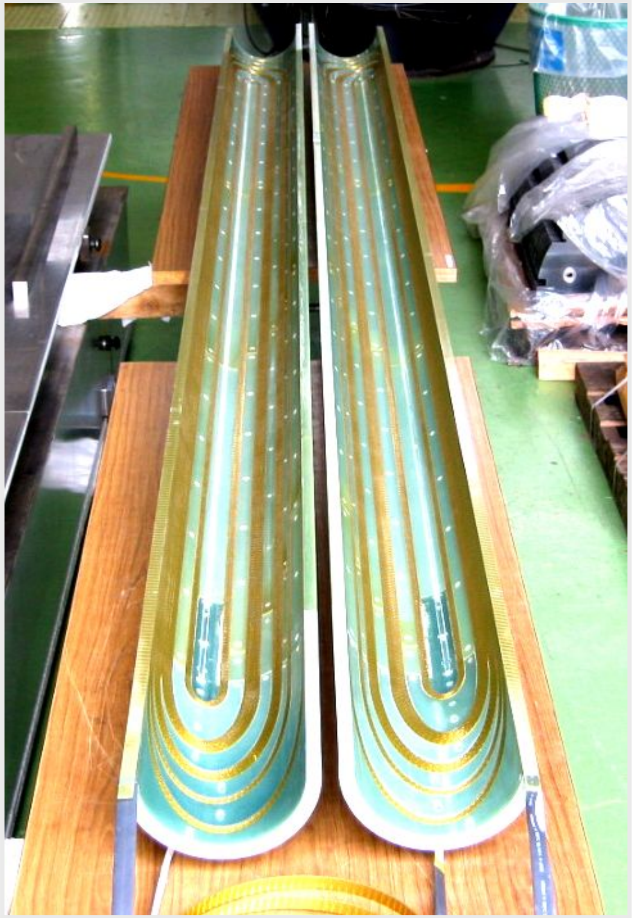


Coil ID.: 173.4mm		**Op. Current:**	**7345 A**
Mag. Length:	**3300 mm**	**Op. Margin:**	**72%**
Mech. Length:	**3630 mm @RT**	**Inductance:**	**14.3 mH**
Tmax:	**< 5.0K (Supercritical Helium)**	**Stored Energy:**	**386 kJ**
		# of Magnet:	**28**
Dipole Field:	**2.59 T**	**SC Cable:**	**NbTi/Cu for LHC arc Dipole Outer-L**
Quad. Field:	**18.6 T/m**		
Field Error:	**$< 10^{-3}$**		

- 50 GeV

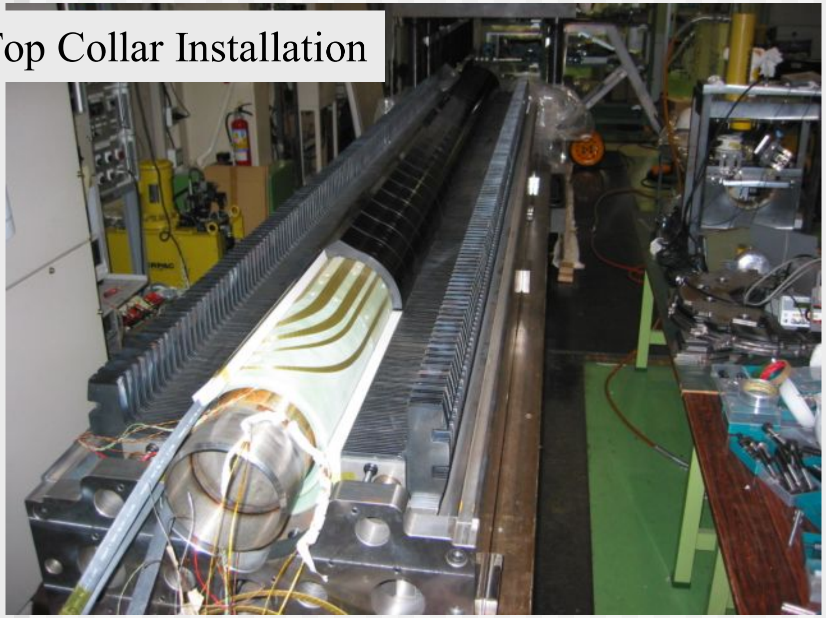
Coil Winding for Prototype Magnet





Mirror-symmetry Top & Bottom coils of the prototype

Yoking


Top Collar Installation


Top Yoke Installation


Key pushing

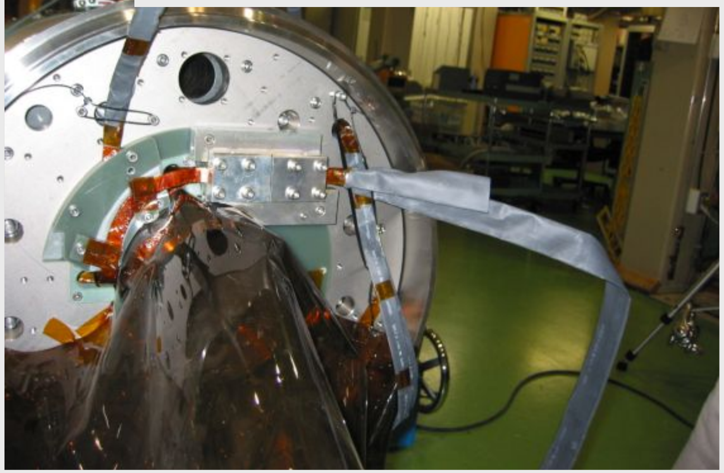

Yoking complete

Shell Welding, Ends Works

Longitudinal shell welding by two automatic welding machines.

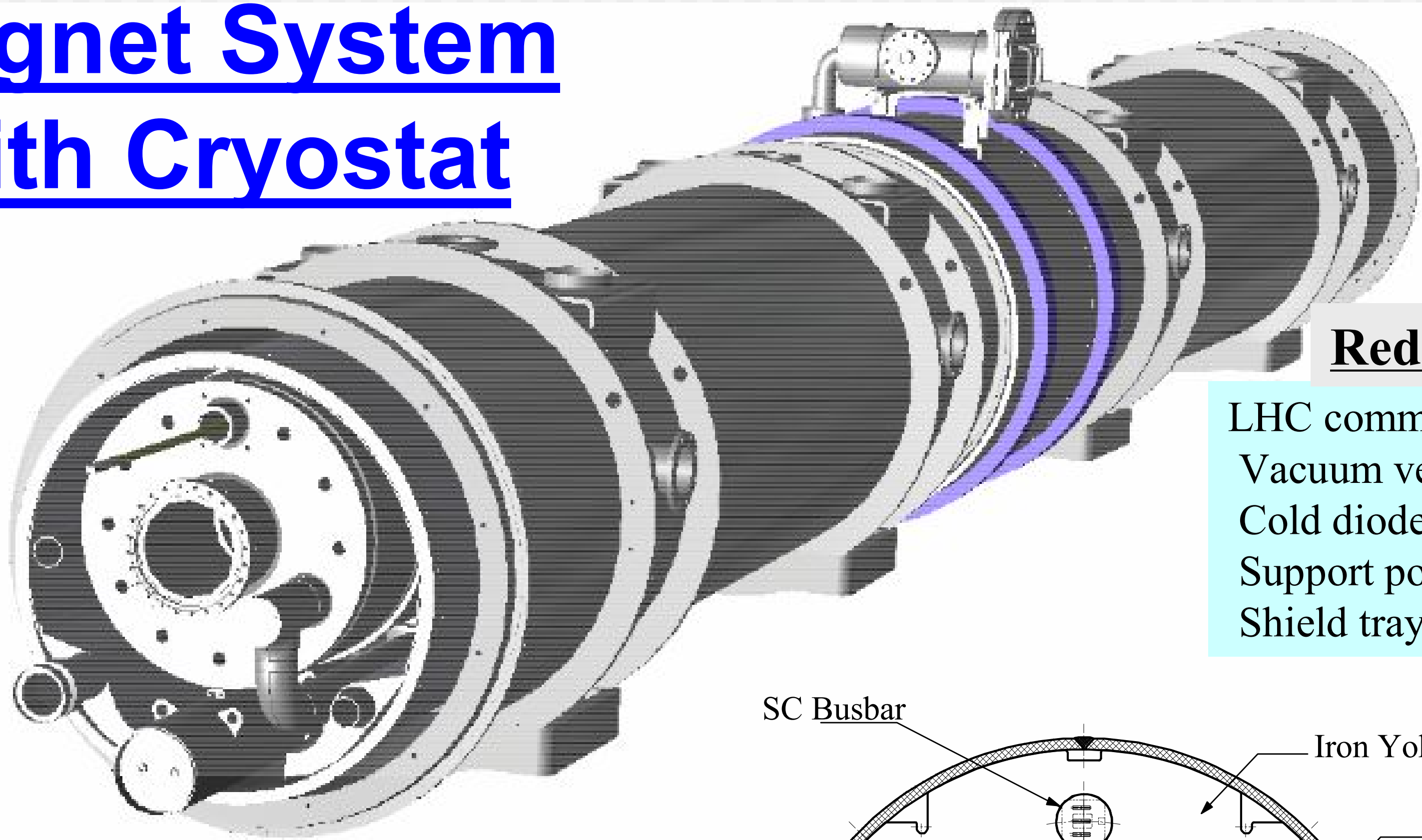
End-ring welding

Leads connection by soldering.



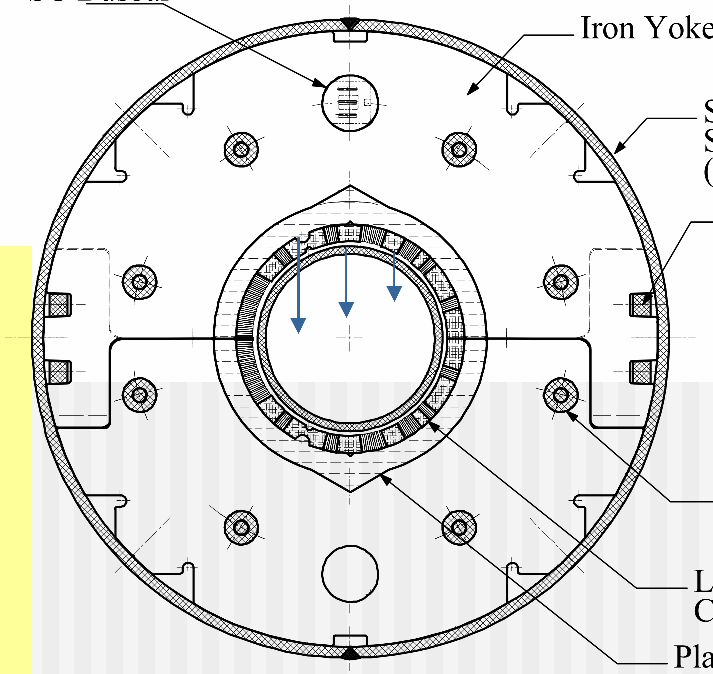
Complete

Magnet System with Cryostat



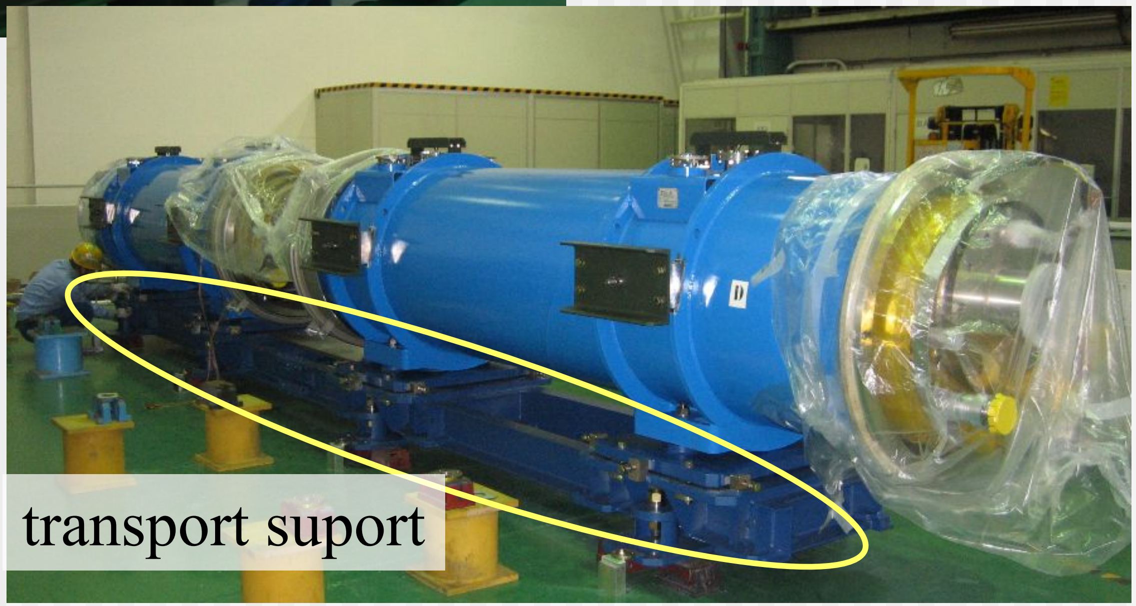
Reduce cost

LHC common parts
- Vacuum vessel
- Cold diode
- Support post
- Shield tray

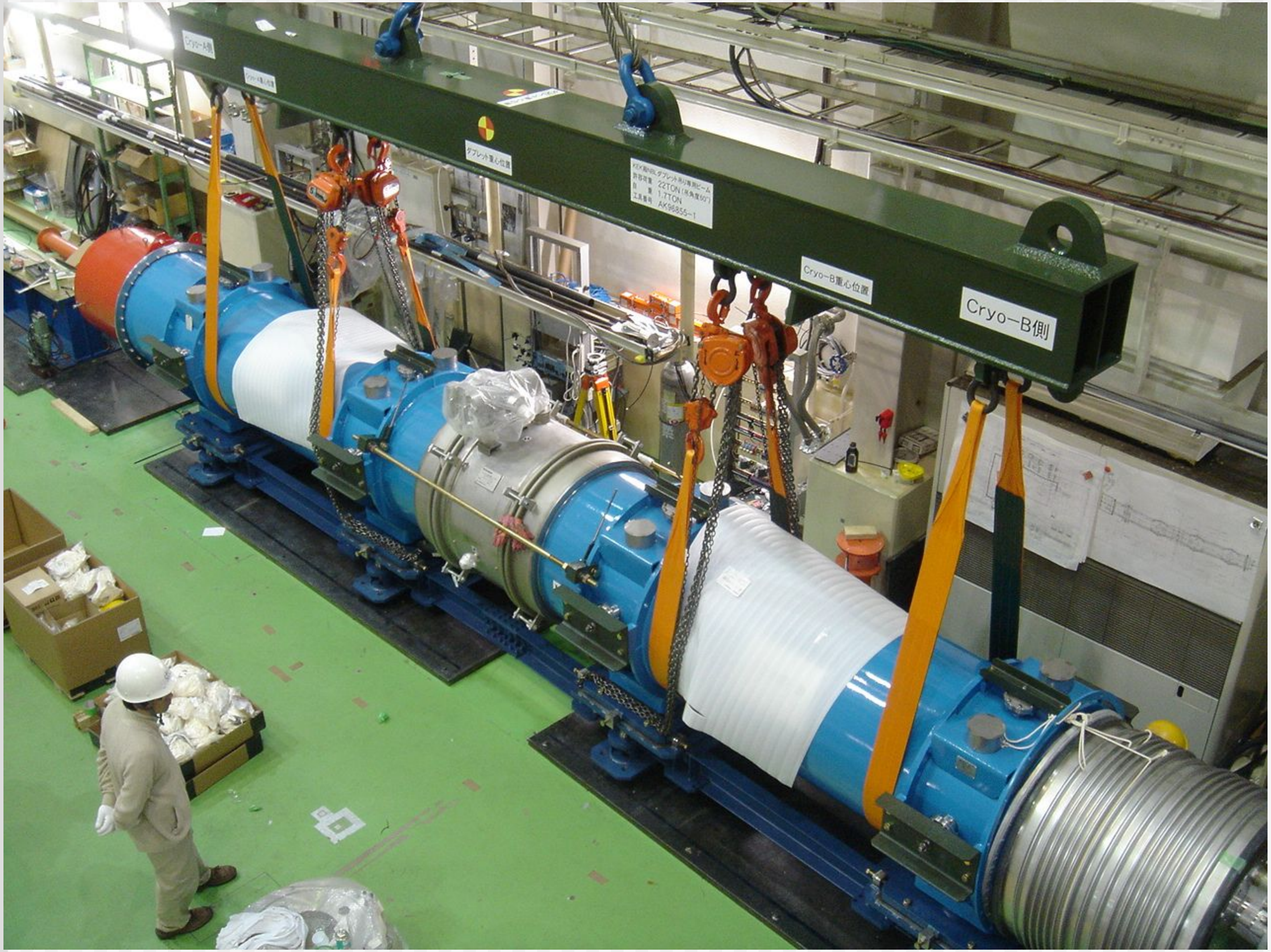


- Combined Function Magnet
  - Dipole 2.6 T
  - Quad 18.6 T/m
  - Produced by single layer coil
- 2 magnets assemble with 1 cryostat
  - F & D magnets (doublet optics)

Cryostat Assembly

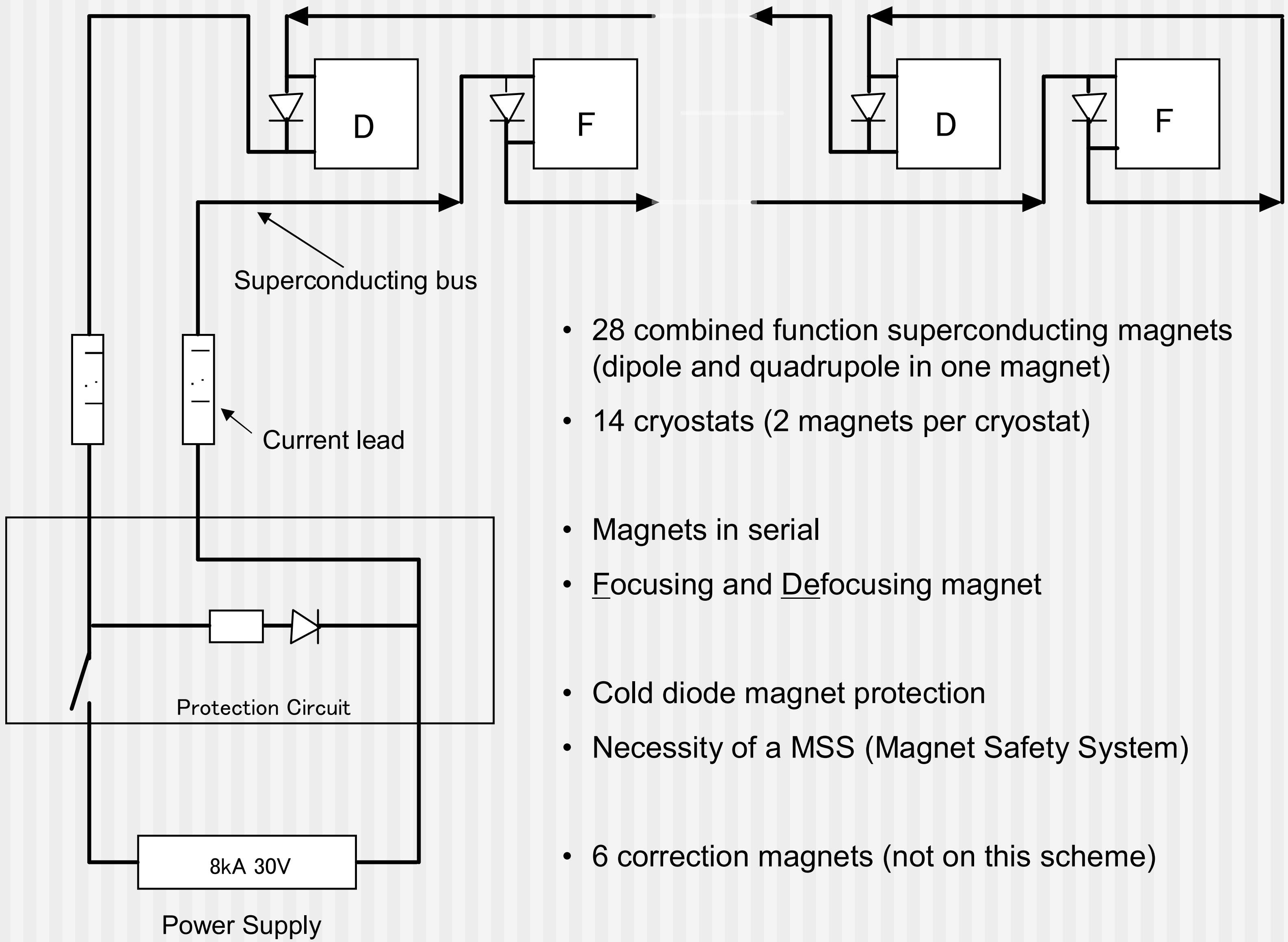


Complete



Cryo−A側
ダブレット重心位置
許容荷重 22TON
自重 1.7TON
AK96855−1
Cryo−B重心位置
Cryo−B側

Powering Scheme



- 28 combined function superconducting magnets (dipole and quadrupole in one magnet)
- 14 cryostats (2 magnets per cryostat)

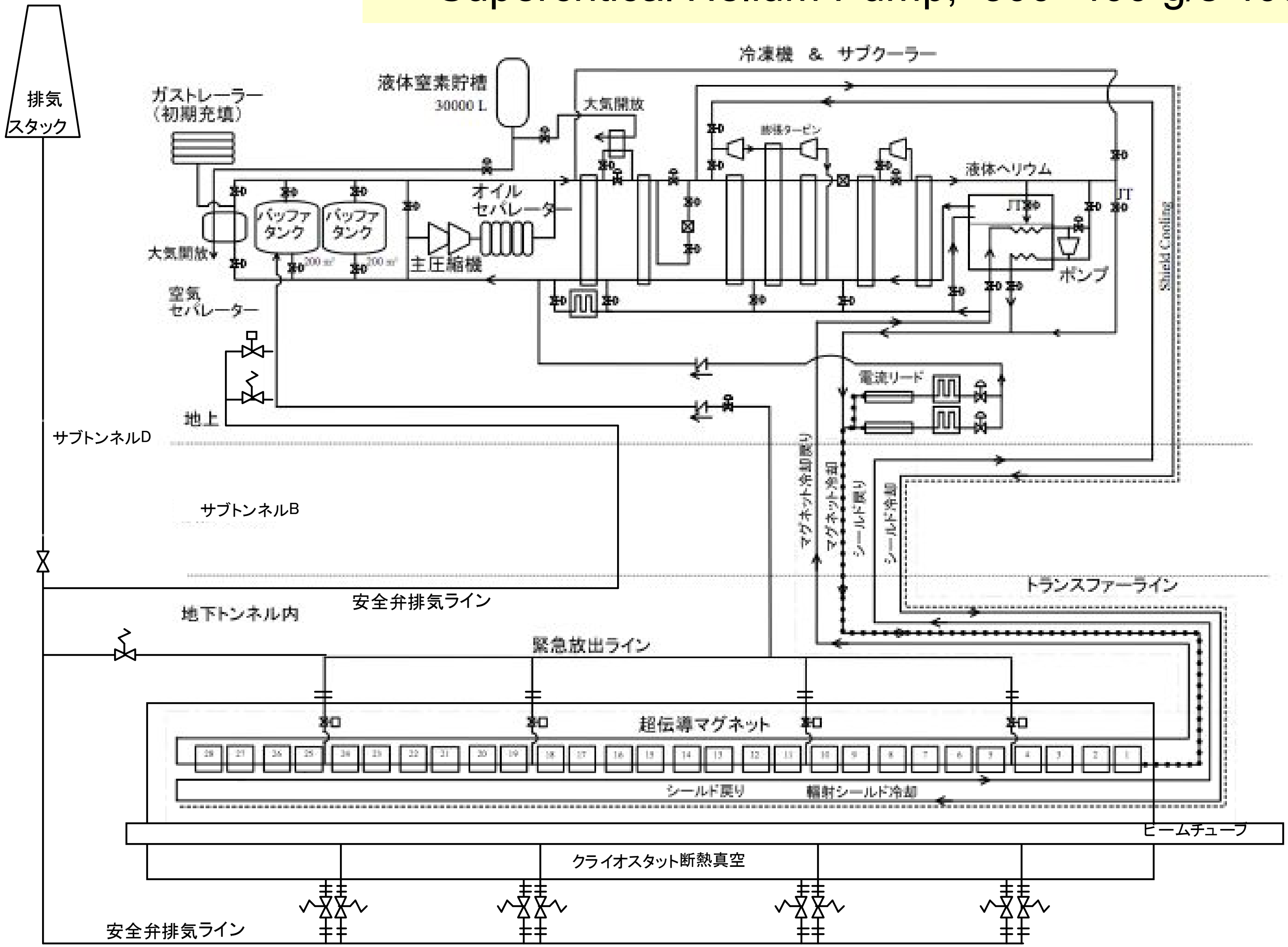
- Magnets in serial
- Focusing and Defocusing magnet

- Cold diode magnet protection
- Necessity of a MSS (Magnet Safety System)

- 6 correction magnets (not on this scheme)

Cryogenic

- Refrigerator Power； 1.2kW@4.5K、 2.5kW@80K
- Supercritical Helium Pump, 300~400 g/s 400kPa



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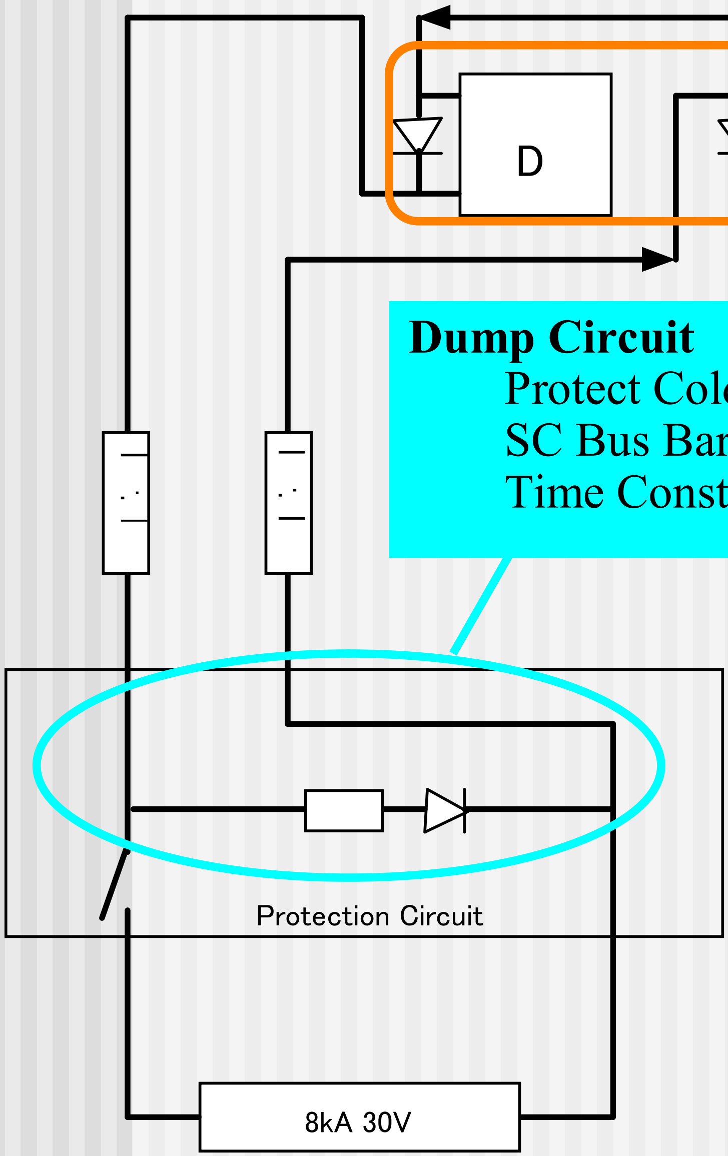
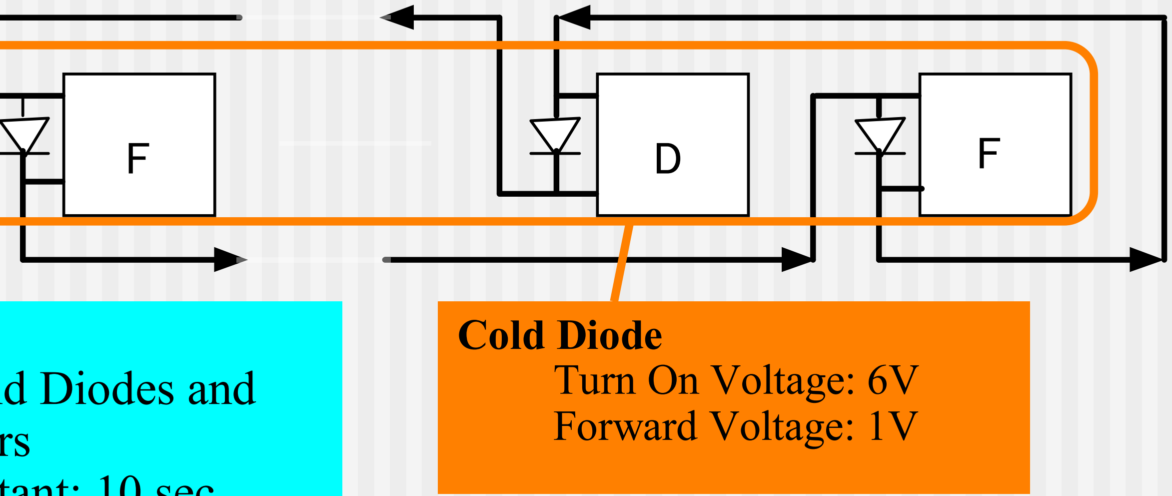


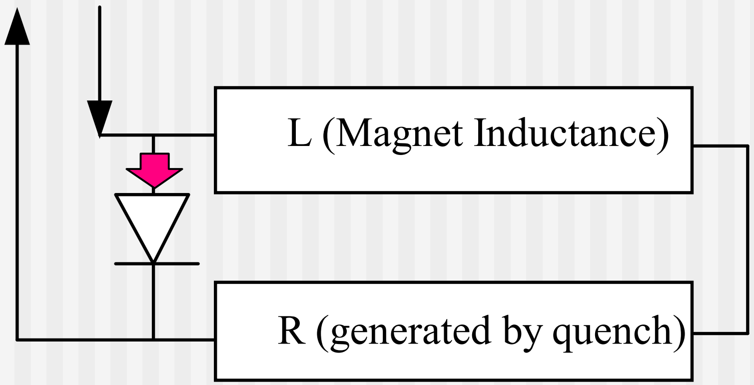


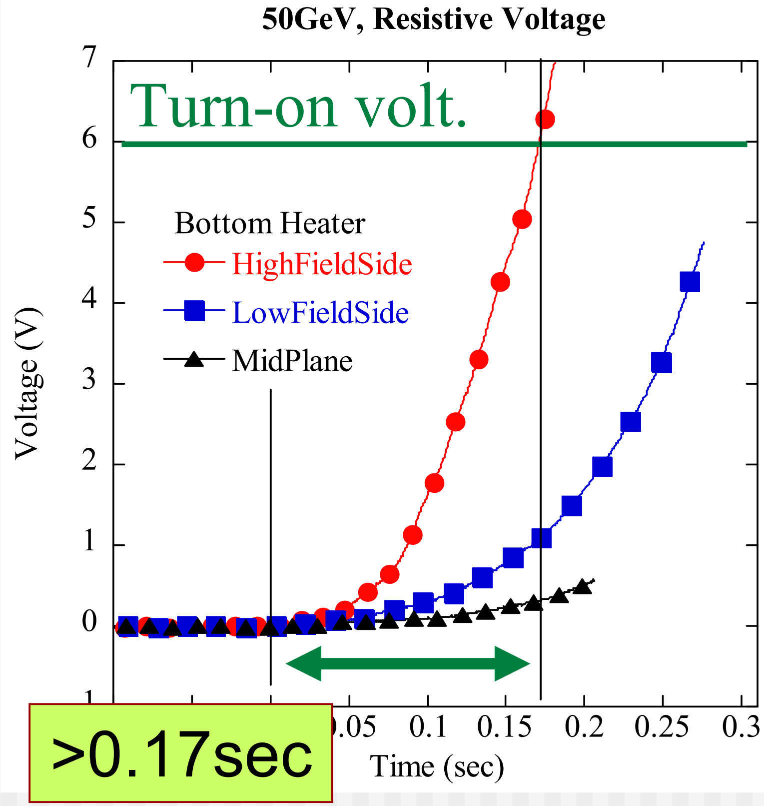
Powering Scheme

- Series Excitation of all magnets (~ 0.4 H)
- In the previous protection scheme, magnet is mainly protected by the cold diode.

Protection System

- **mainly protected by Cold diode**
  1. Once quench starts
  2. Exceed turn-on voltage
  3. Current bypasses to cold diode





Test results:

voltage rise was much slower than we expected

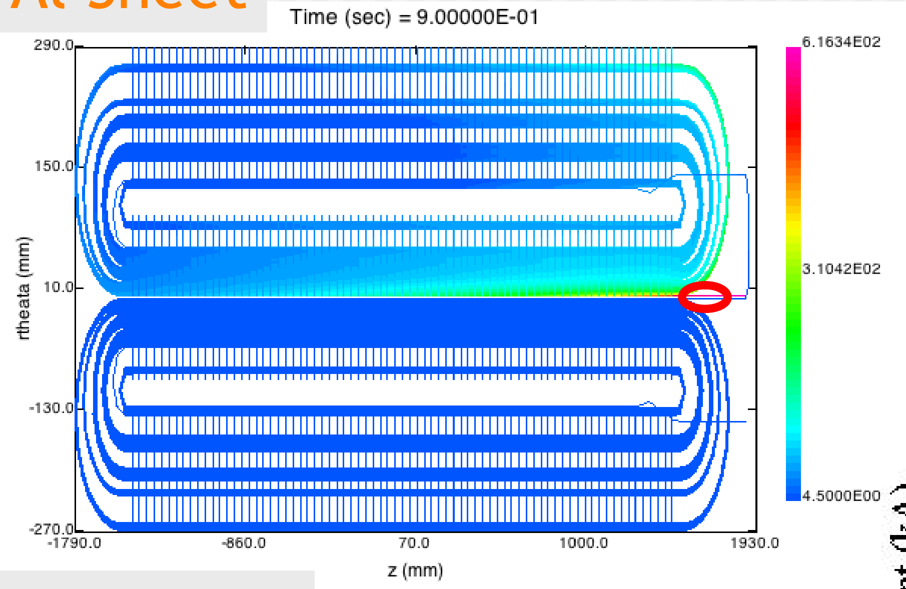
Peak Temp. > 500 K from numerical simulation

Discussion of Quench Protection Scheme

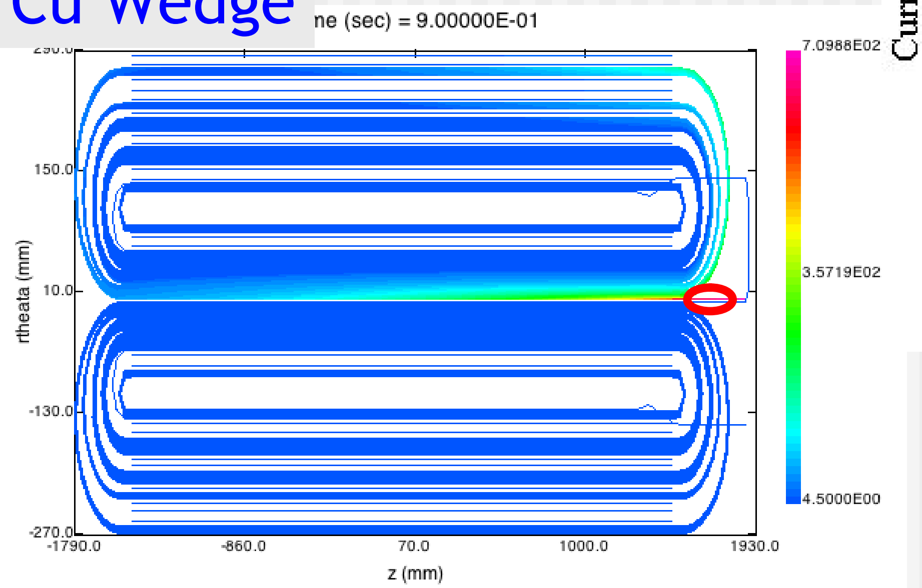
- Al sheet (t=0.1mm, RRR=2000)
  - cover the outside of the coil straight section
- Cu wedge (RRR=200)
  - use copper wedges in the straight section instead of G11 wedges
- Quench protection heater (QPH)
  - attach small sheet heaters

Al sheet & Cu wedges

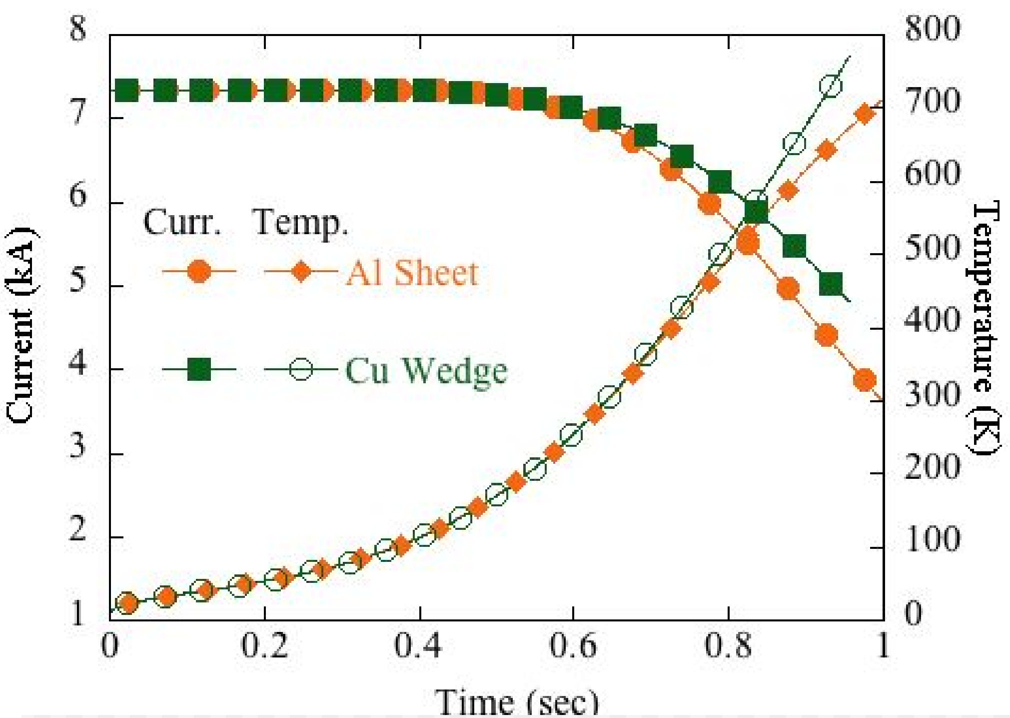
Al Sheet



Cu Wedge



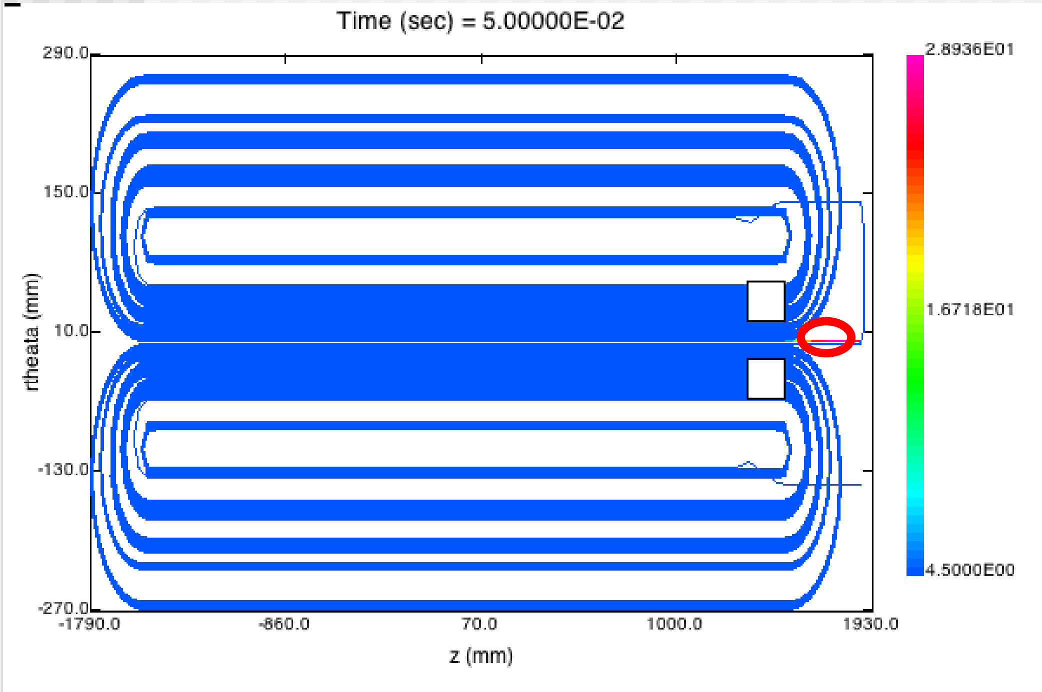
- Temp. distribution in 0.9 sec after quench

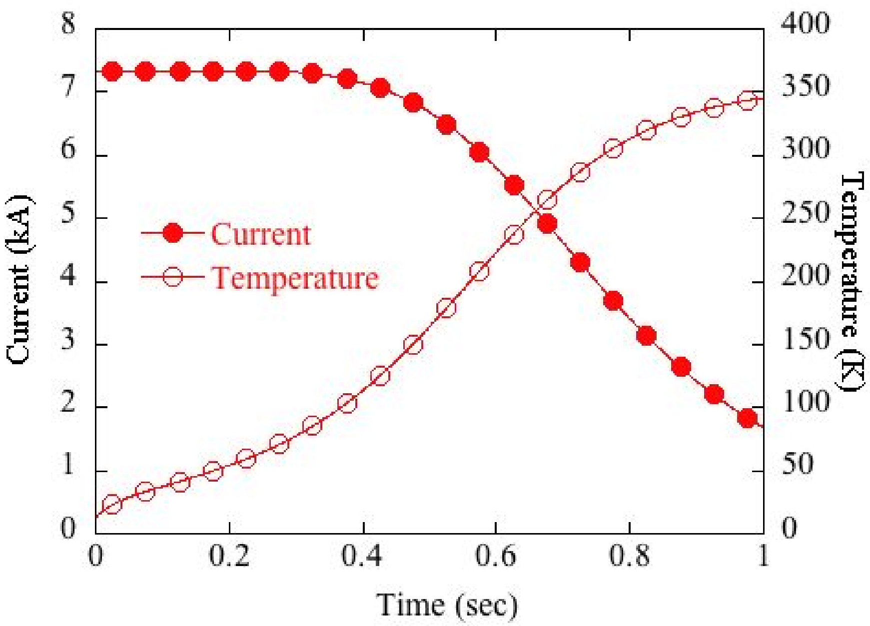


Peak Temp. >700 K !

Quench Protection Heater

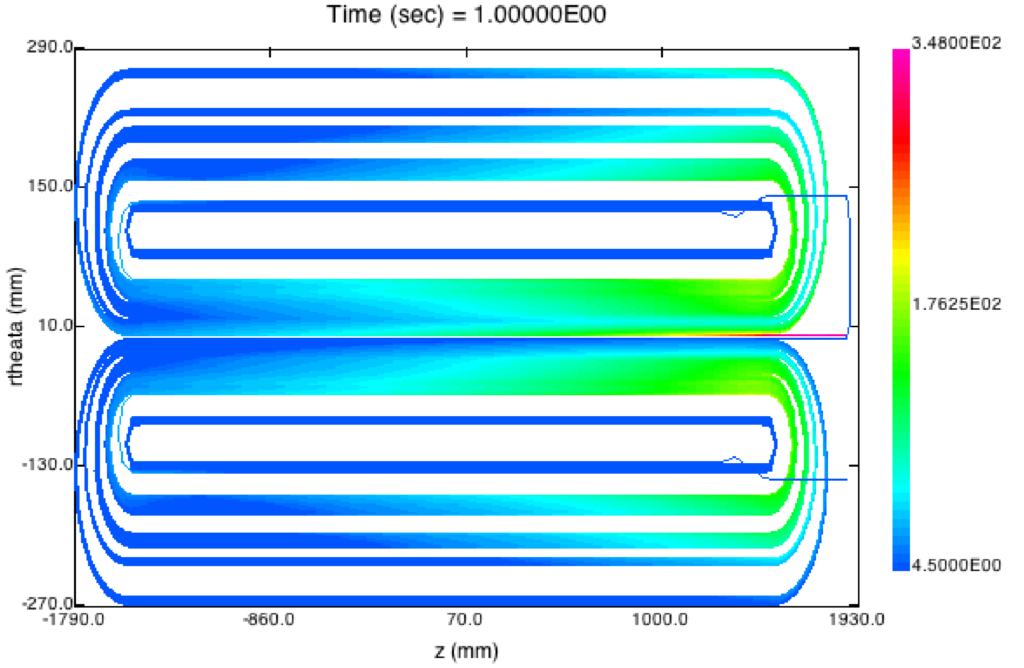
- Heater size : width 40 mm × height 61 mm
  - Quench Detector : 0.1V, 20ms

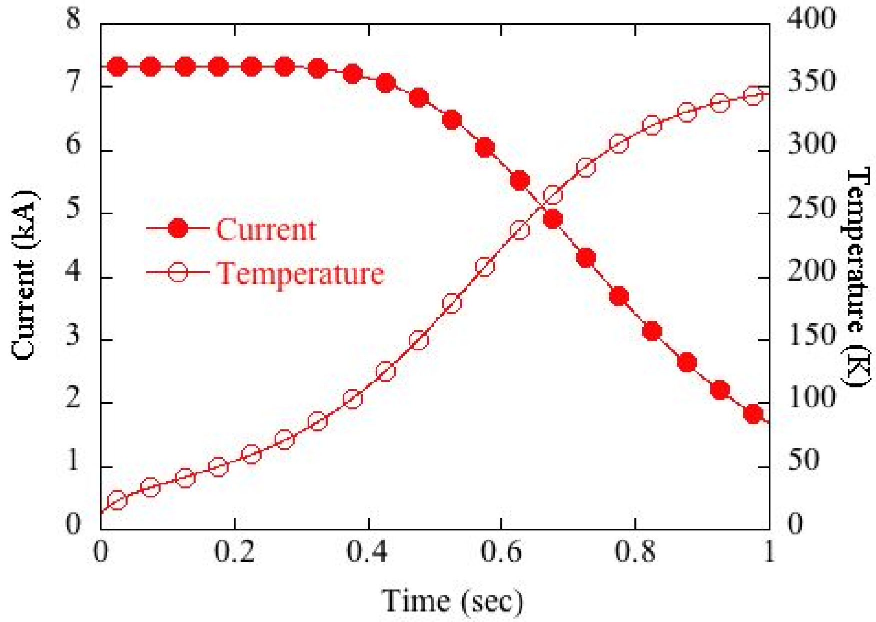




Quench Protection Heater

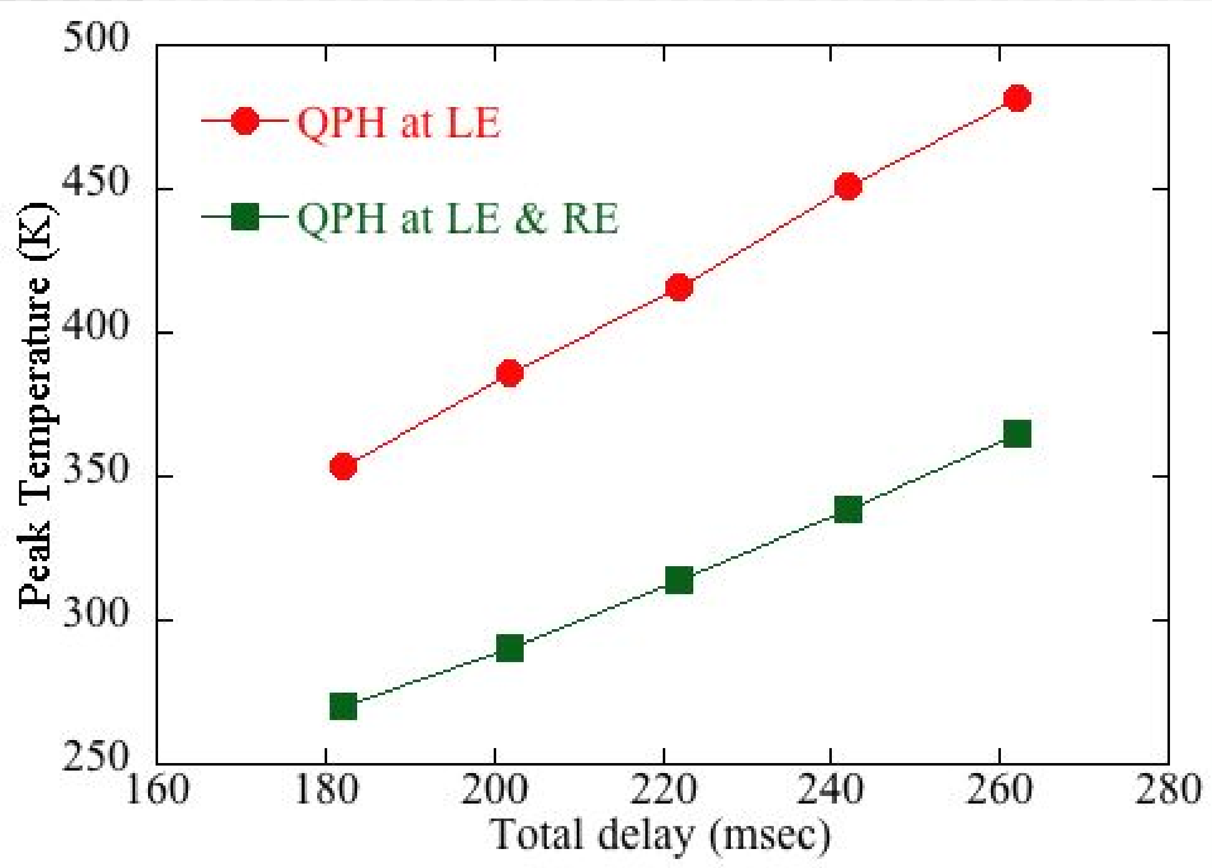
- Heater size : width 40 mm × height 61 mm
  - Quench Detector : 0.1V, 20ms

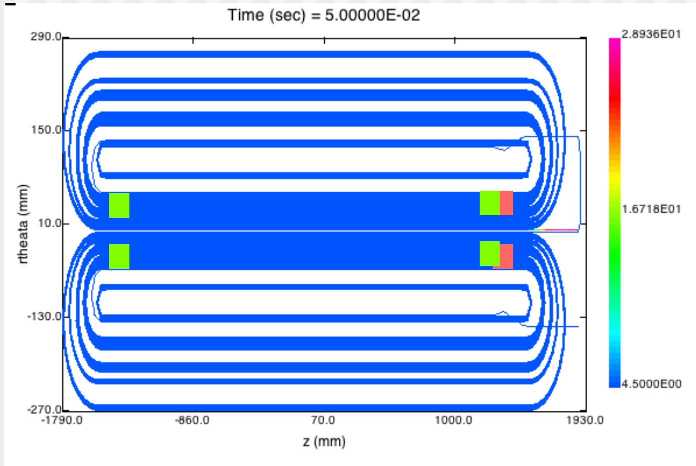




QPH is adequate for the conservative quench protection

QPH ~ number of QPH

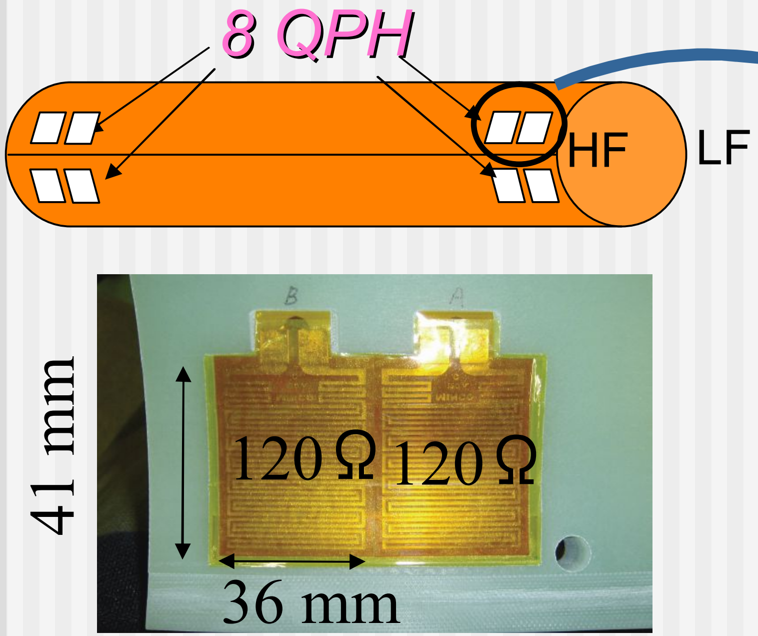


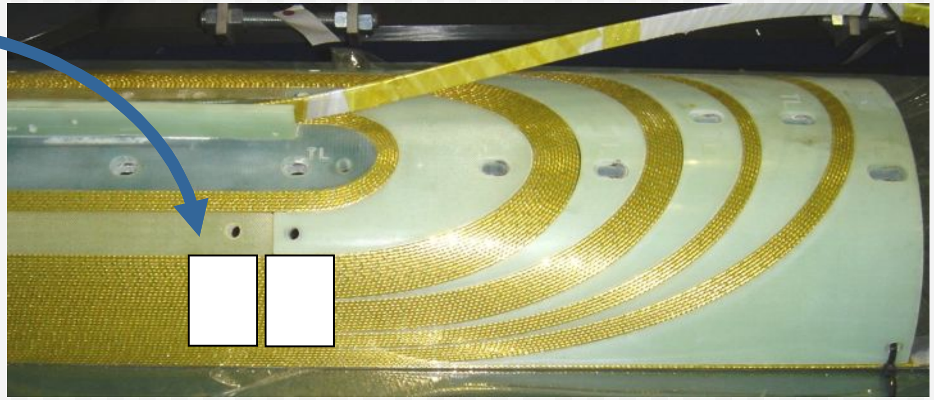


Total delay :
Quench detection delay
+ Thermal diffusion delay

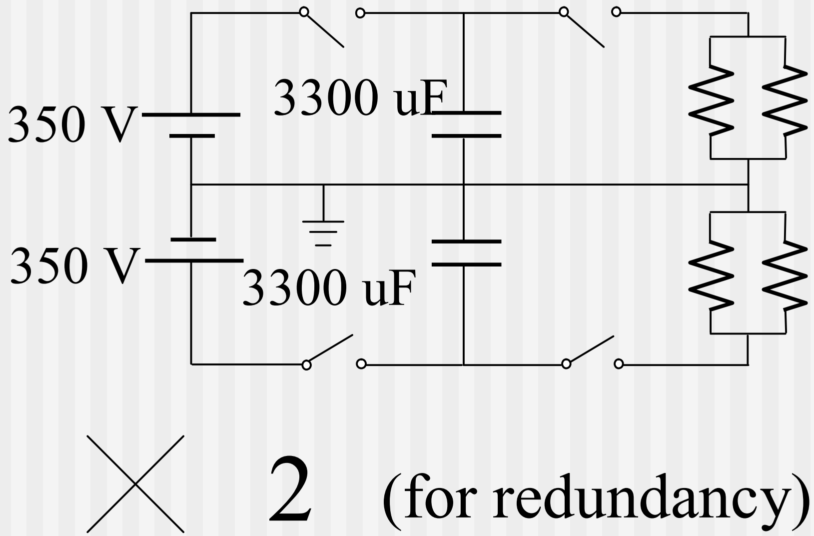
- ***4 QPHs are preferable for the safe protection***

Quench Protection Heaters

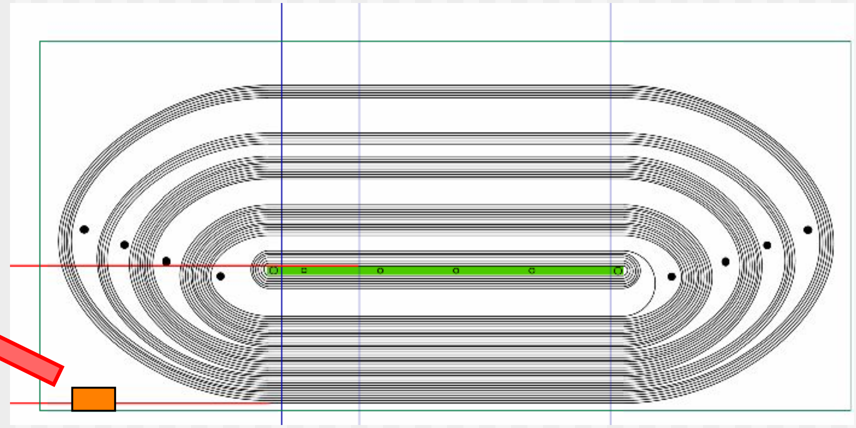


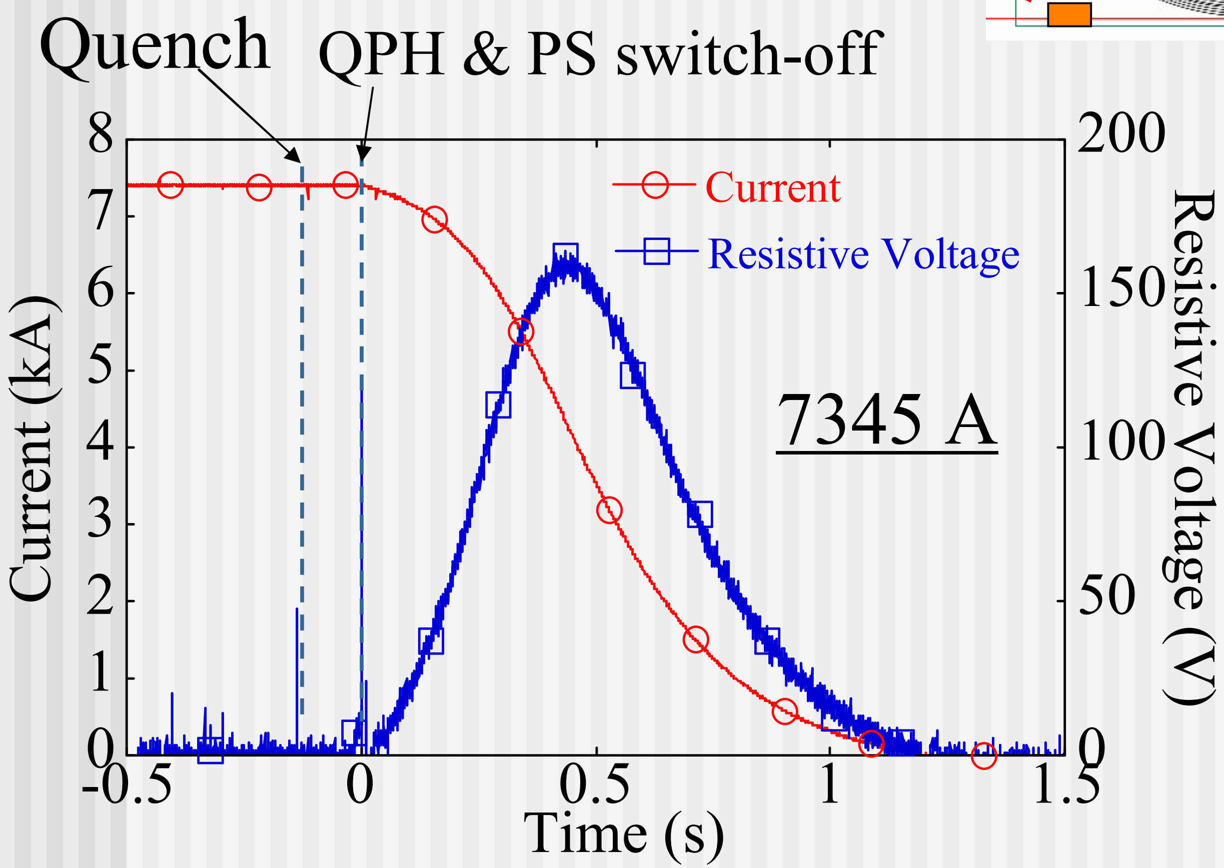


- *Power supply for QPH*
  - Capacitor Discharge Circuit
  - Energy : 100 J /1 element



Full Energy Dump Test
~Reassembled 1st prototype

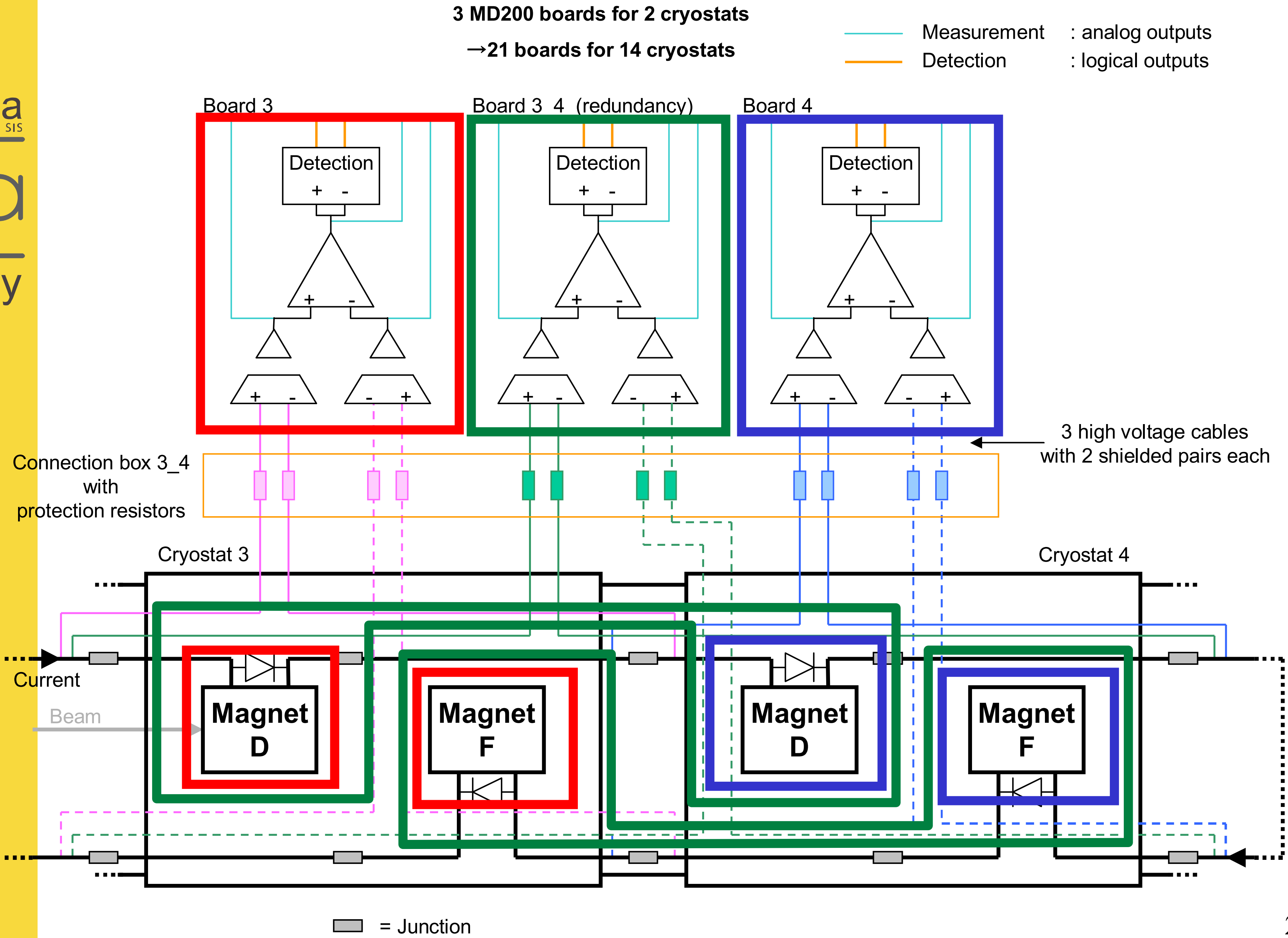




- Estimated Peak Temp.
  - ~170 K

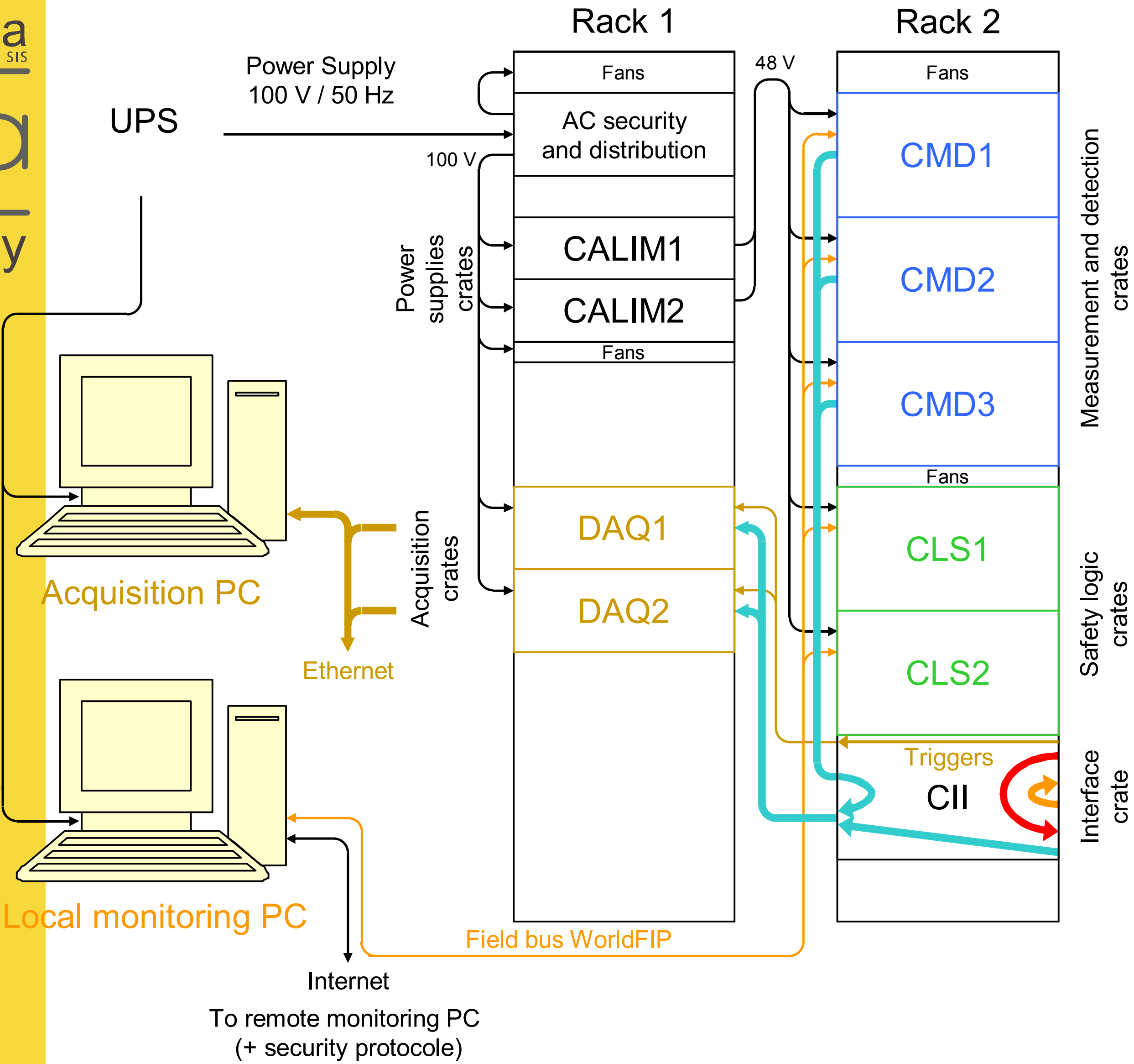
Acceptable value !

T2K MSS : Principle of quench detection



T2K MSS :MSS architecture

MSS: Magnet Safety System



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Magnet Production

- Three prototype magnets
  - **Verification of the magnet design, fabrication tools and assembly procedure.**
  - **Evaluation of magnet performance such as quench behaviors and magnetic field.**

Bidding won by Mitsubishi Electric

- **As of February 15, 2007**

  12 Production Magnets

  4 Magnet System with Cryostat including prototype

Performance Tests of Production Magnets

- Quench Tests
  - in vertical cryostat <- all the magnets
  - in horizontal cryostat <- 2 or 3 magnet system

- Magnetic Field Measurement (MFM)
  - at Room Temperature <- all the magnets
  - in LHe <- all the magnets
  - in SHe <- 2 or 3 magnet system

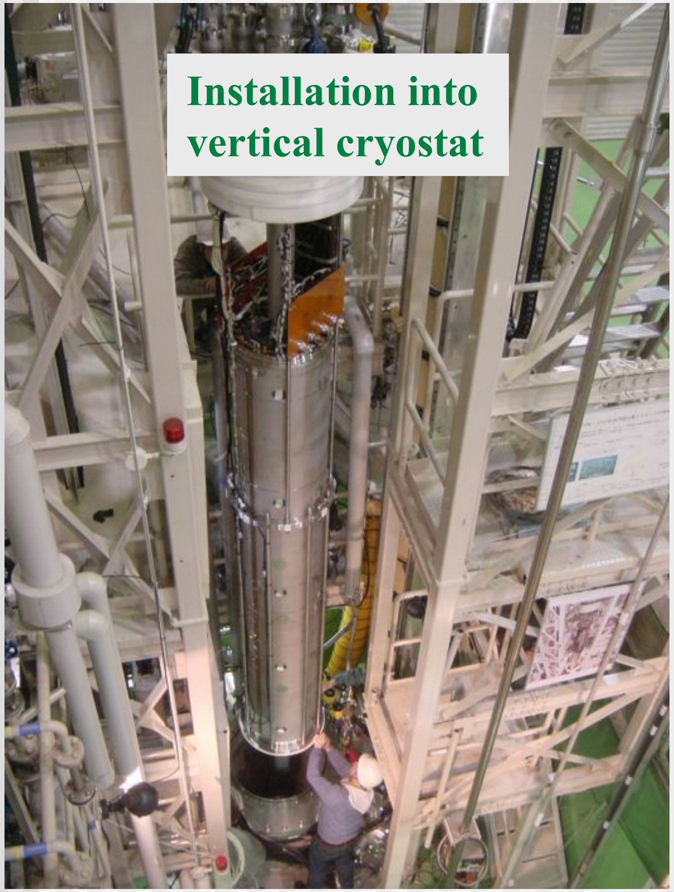
Quench Tests

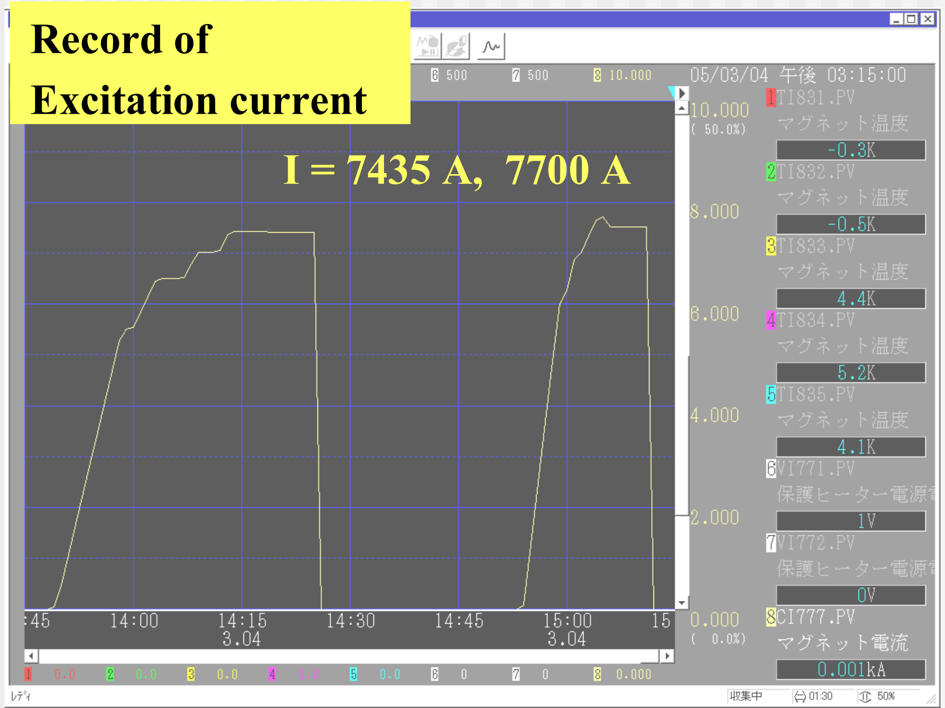
1. **Excitation Tests**
2. **Quench Protection Heater Check**
3. **Full Energy Dump Tests**
4. **Current Bypass Test** **<- in horizontal cryostat**

Up to now

- in vertical cryostat
  - SCFM-01 ~ SCFM-12 (12 magnets)
    - Analyze : SCFM-01~11
- in horizontal cryostat
  - CCFM-00, (CCFM-01 to be tested)

1. Excitation Test at 4.2 K





- I_{op} = **7345 A @ 50 GeV (and I_{max} = 7,700 A)** with no quench.
- Fast ramping up to 7345A: No quench at **500 A/s**

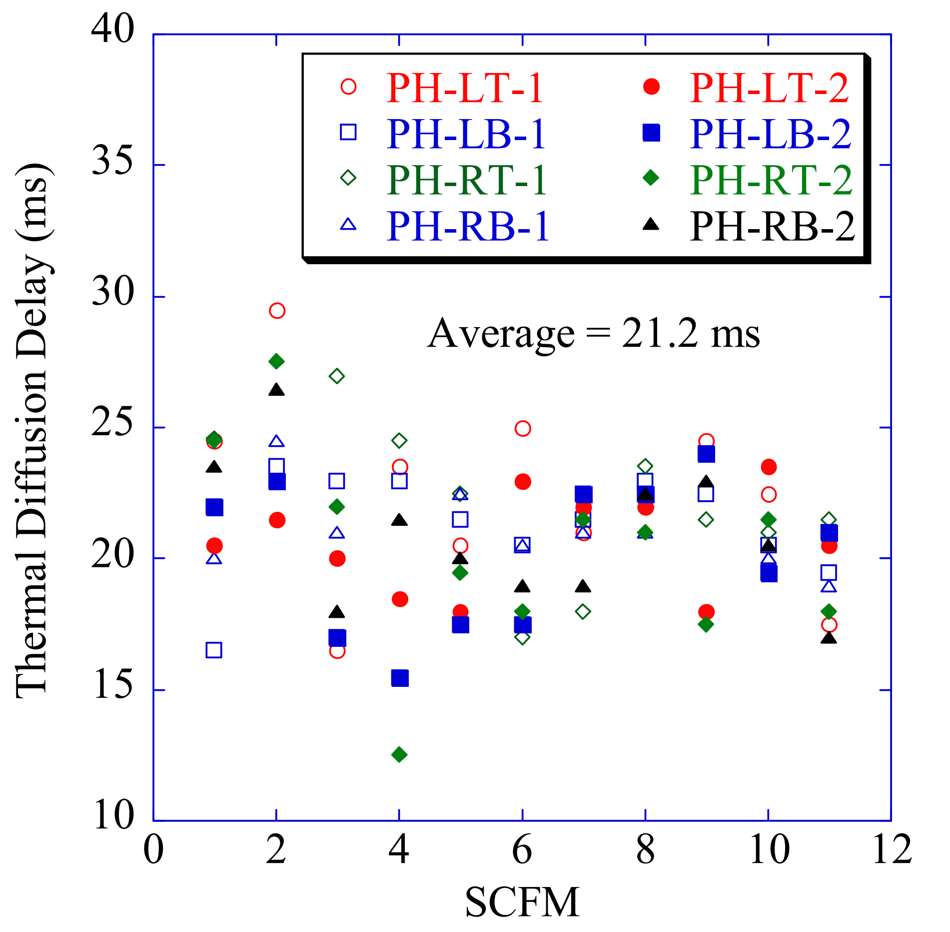
No training quench

2. QPH check

Quench Detection Delay (from prototype tests)

Q.D. 0.1V, 10msec → *110 msec*@7345 A

Current : 4400A

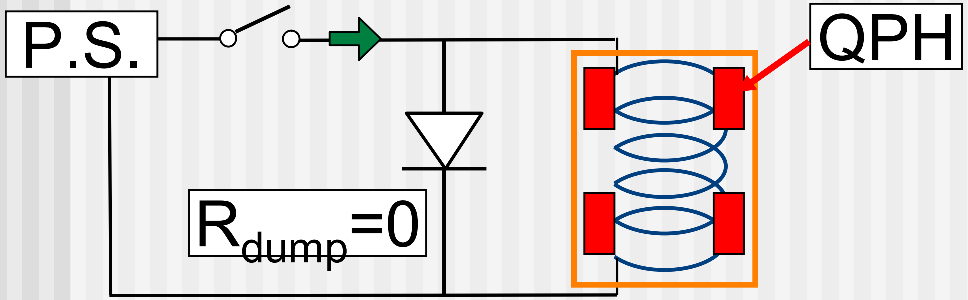


allowable delay → <150msec

- Meas. Average

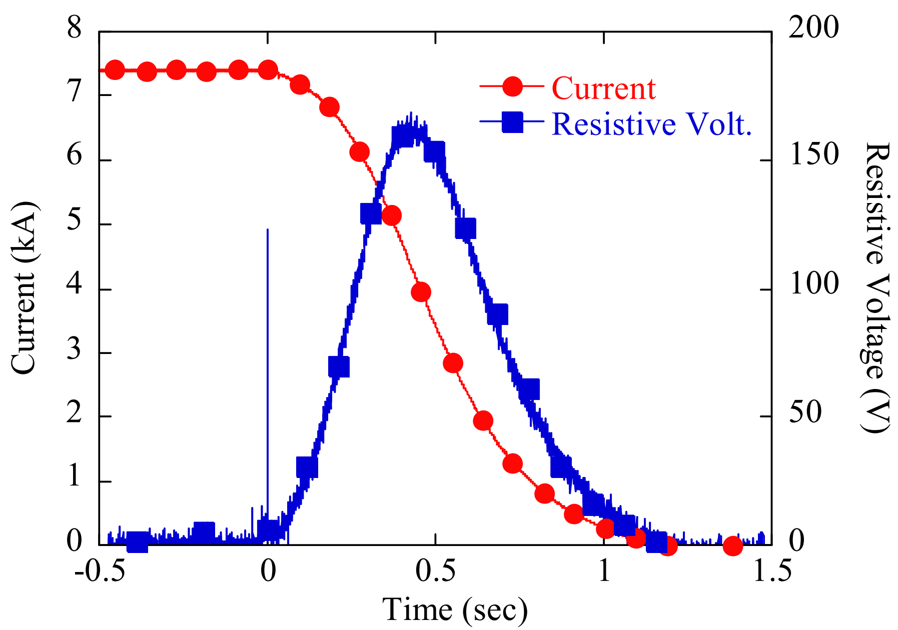
  ~21.2 ms

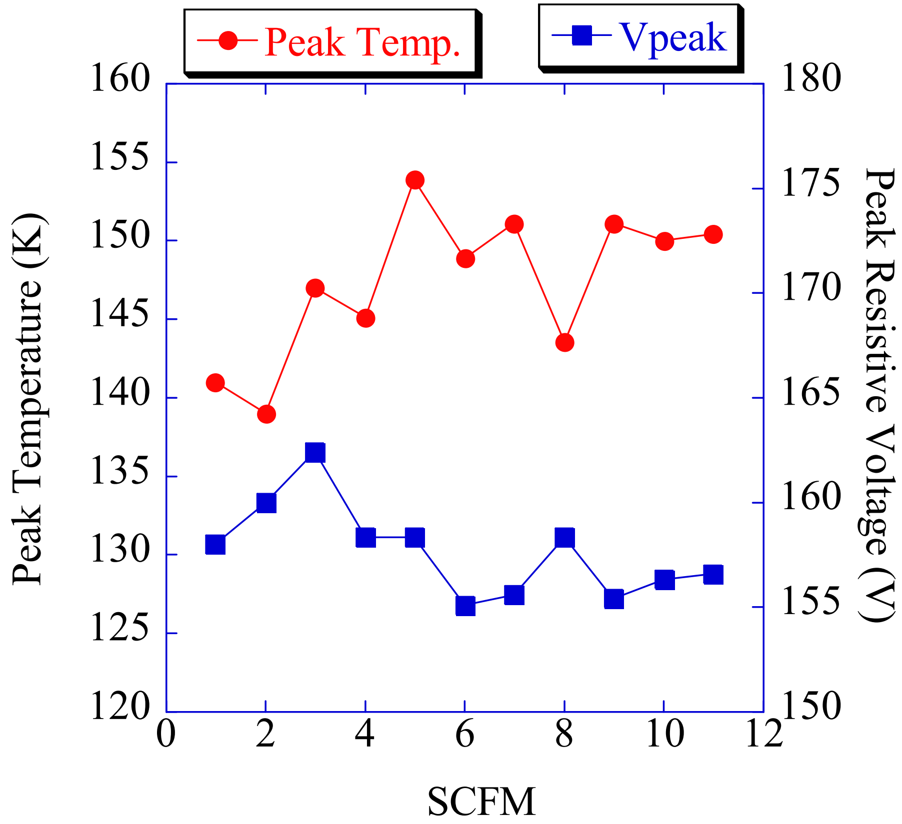
3. Full Energy Dump Tests



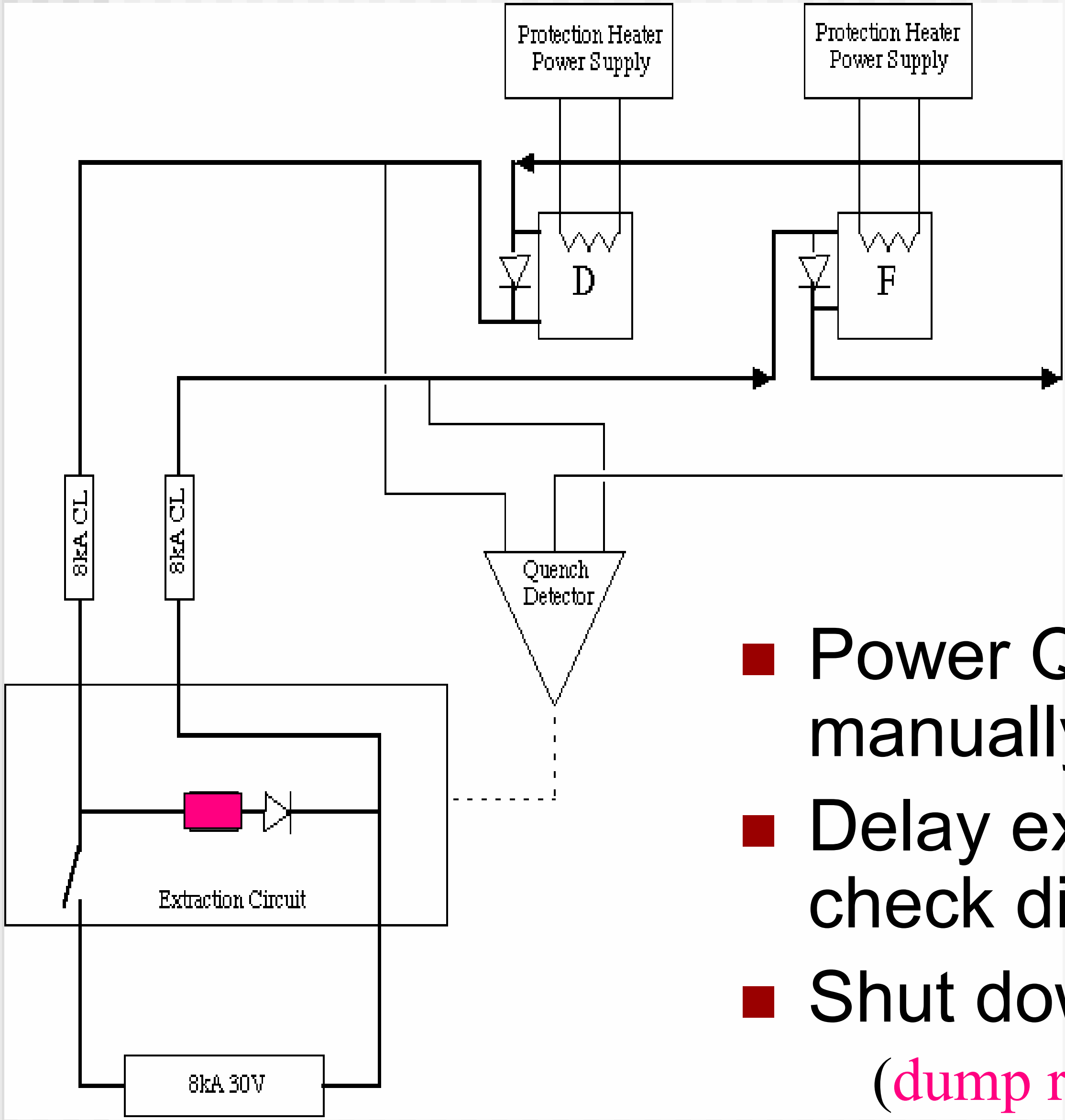
Peak Temp.
&
Peak Resistive Volt.
@ 7345 A

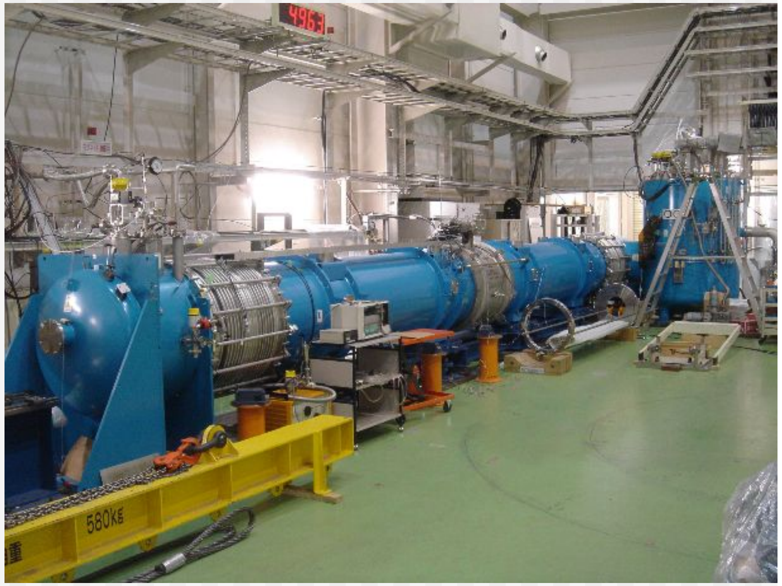
Example@7345 A





Quench Protection Test with Cold Diode



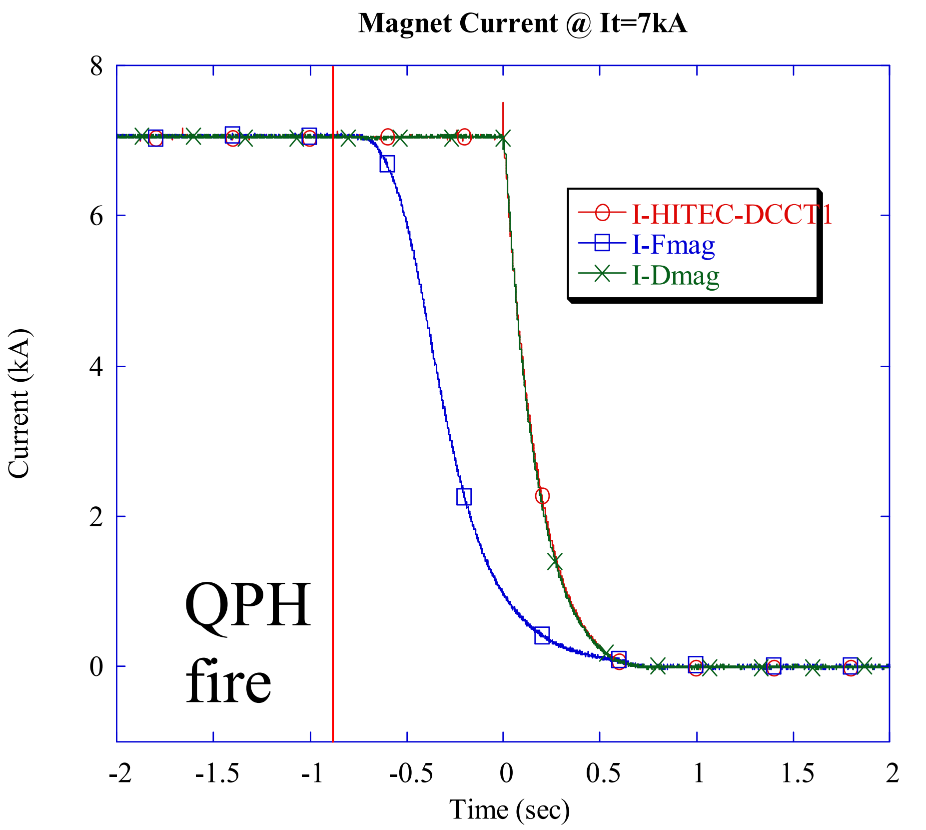


- Power QPH at F-magnet manually
- Delay extraction circuit to check diode bypass current
- Shut down power supply

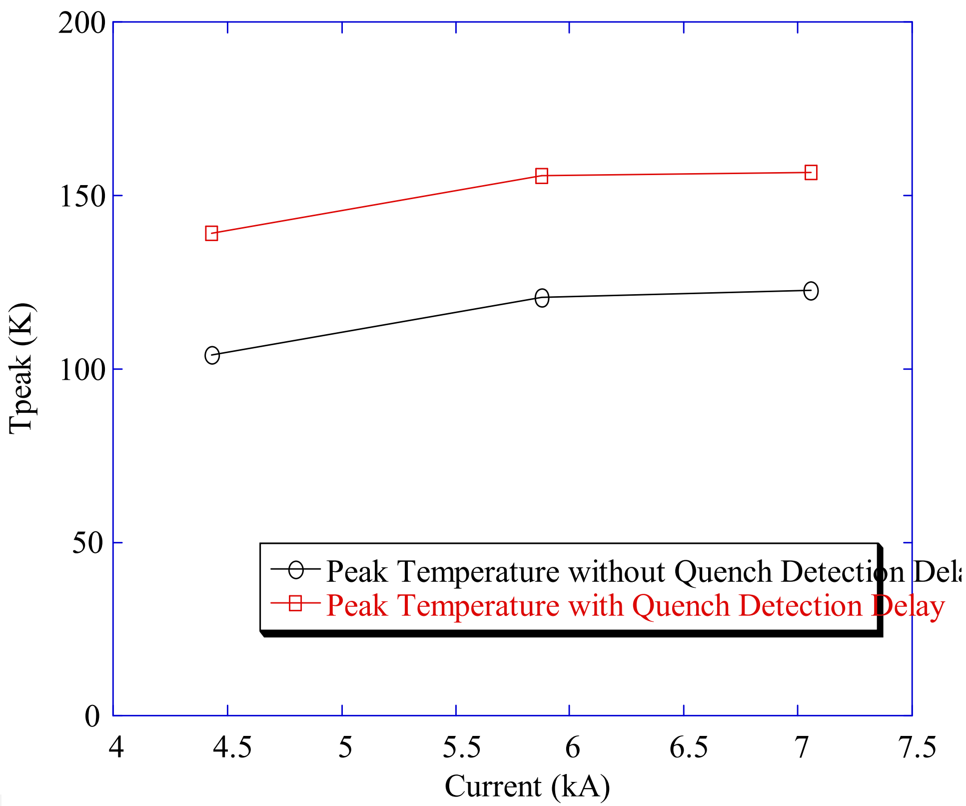
(dump resister = 75 m ohm)

Quench Protection Test

Current Bypass to Diode



Peak Temperature in Magnet



Current bypass to cold diode is observed as expected
Peak temperatures are well below 200K
→ Very comfortable margin

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    2. Magnetic Field Measurement
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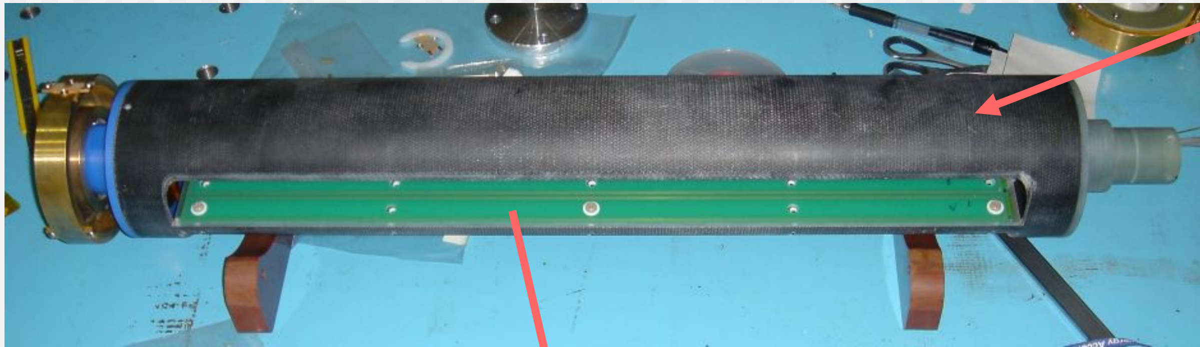
Magnetic Field Measurement

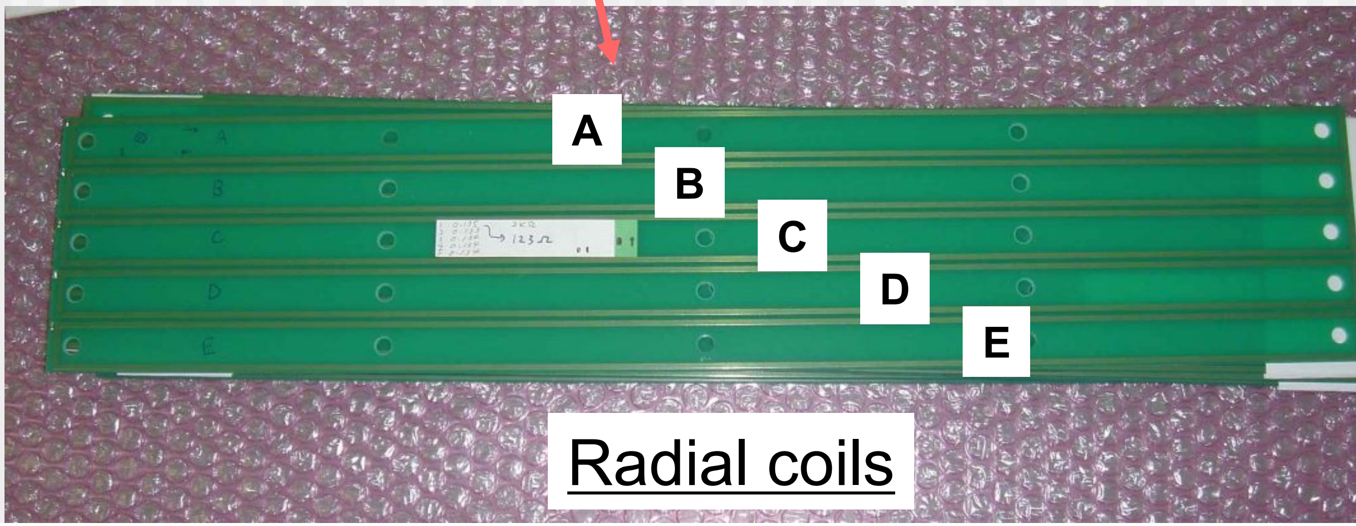
- at Room Temperature (all the magnet)
  - Check → Fabrication Process, Dipole field
- in LHe (all the magnet)
  - Check → Higher order harmonics
- in SHe (2 or 3 magnet system with cryostat)
  - Check → All multipole fields

Field Measurement ~ probe ~

- Use 500mm long rotating coil
- Scanning along magnet bore

GFRP case

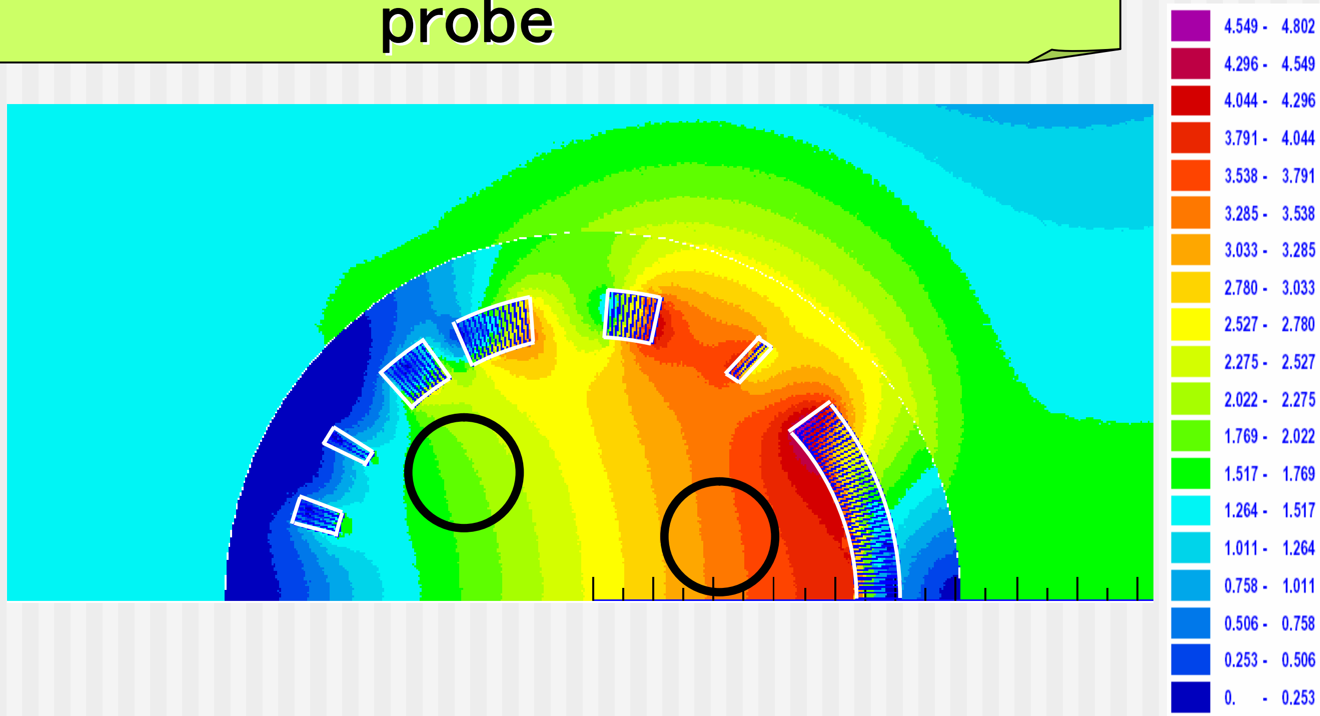




Measurement System @ R.T.

＊to measure exact dipole field strength

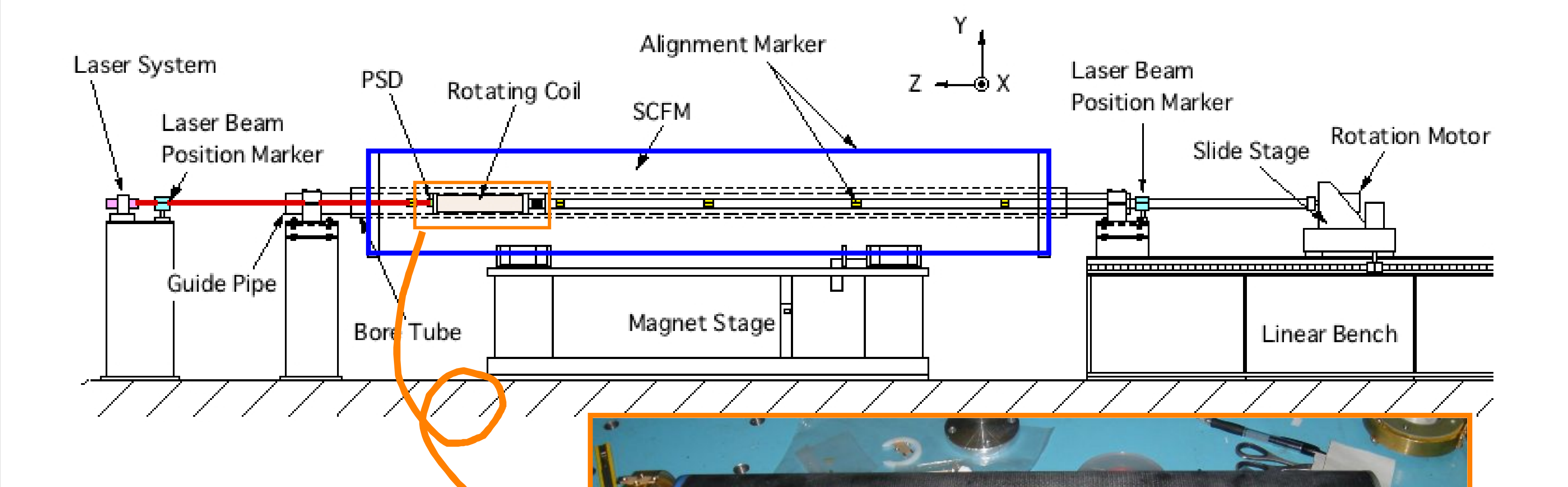
Need to measure the position of rotating probe



required precision ⇨ ＜±0.1mm

- Allowable alignment error of the magnet in the beam line : *<±0.3mm*

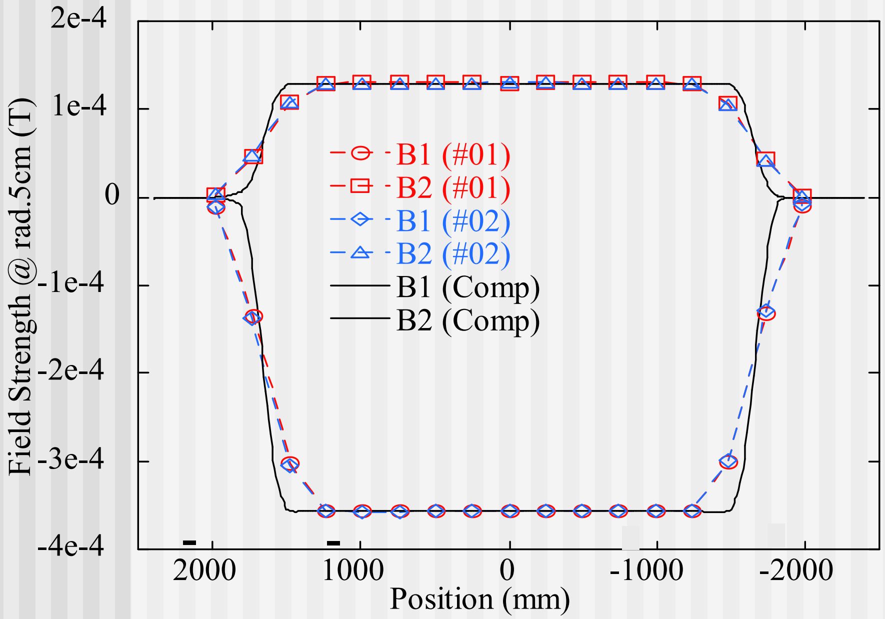
Magnetic Field Measurement @ R.T.
~ System ~

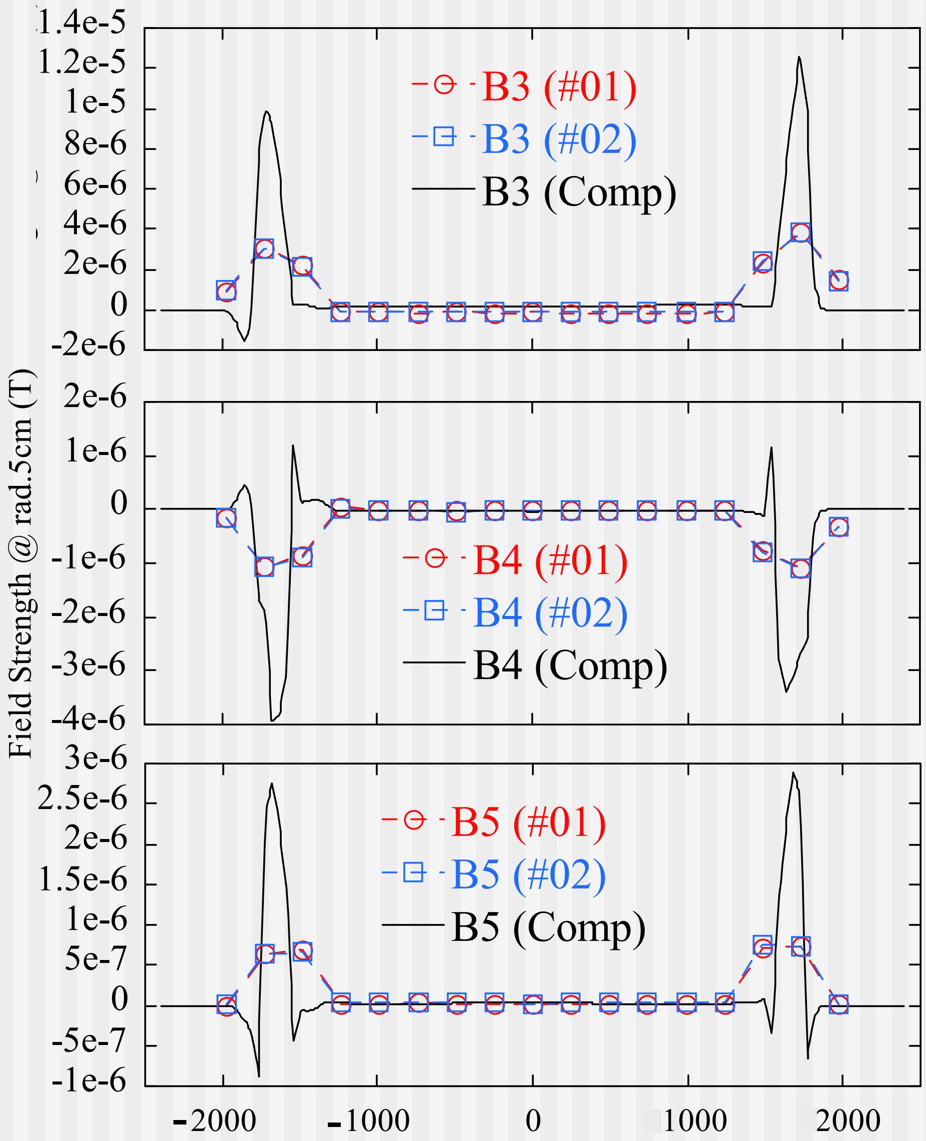


PSD
Position Sensitive Detector

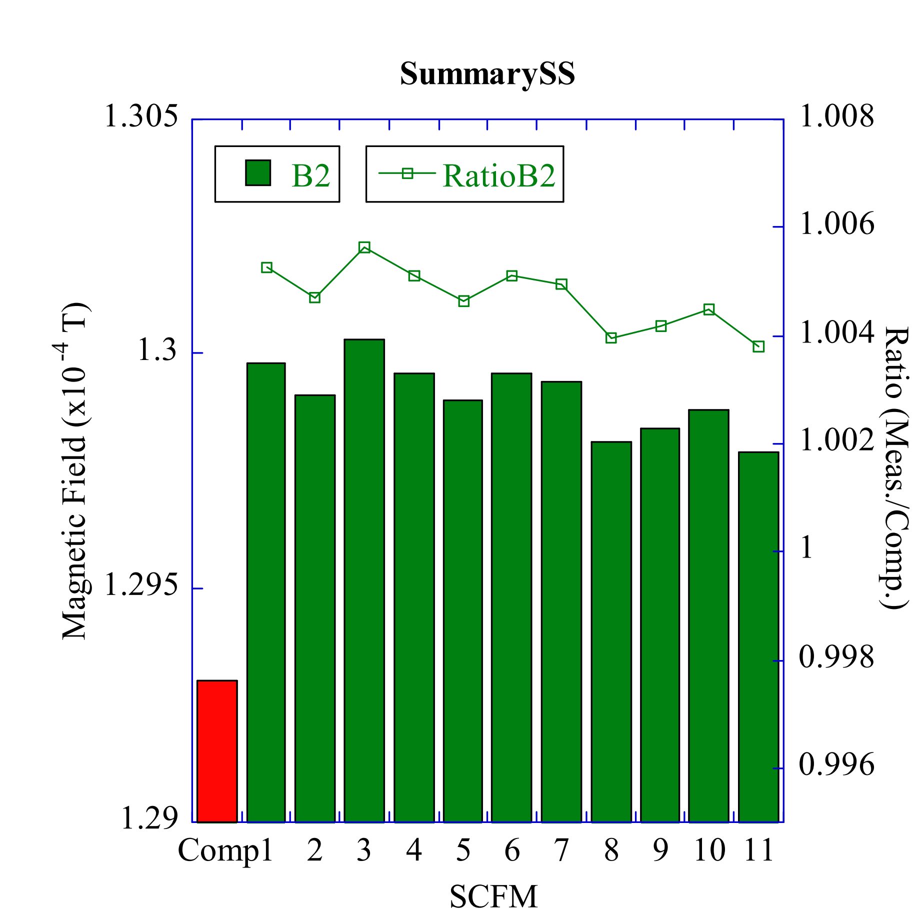
- Coincide the magnet central axis with the laser beam
- Measure displacement of the probe from laser beam by PSD

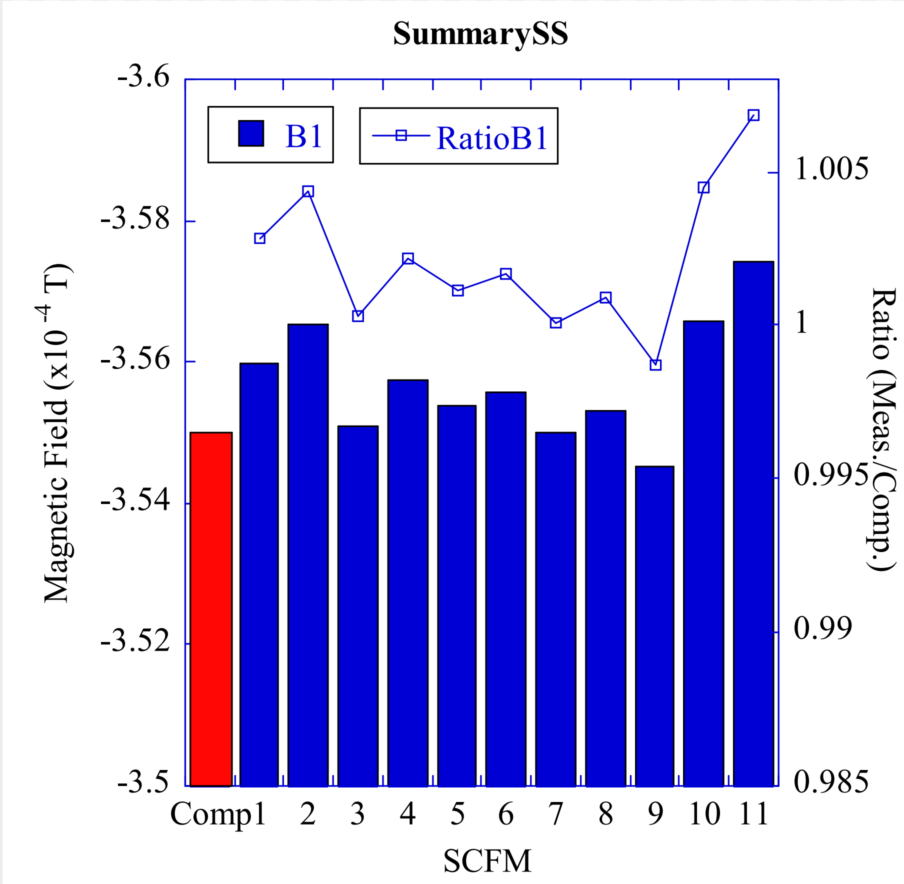
Field Distribution @ 1A, R.T.





Magnetic Field in Straight Section @ 1 A





- Good reproducibility
- Difference : larger than that in B2

⇓

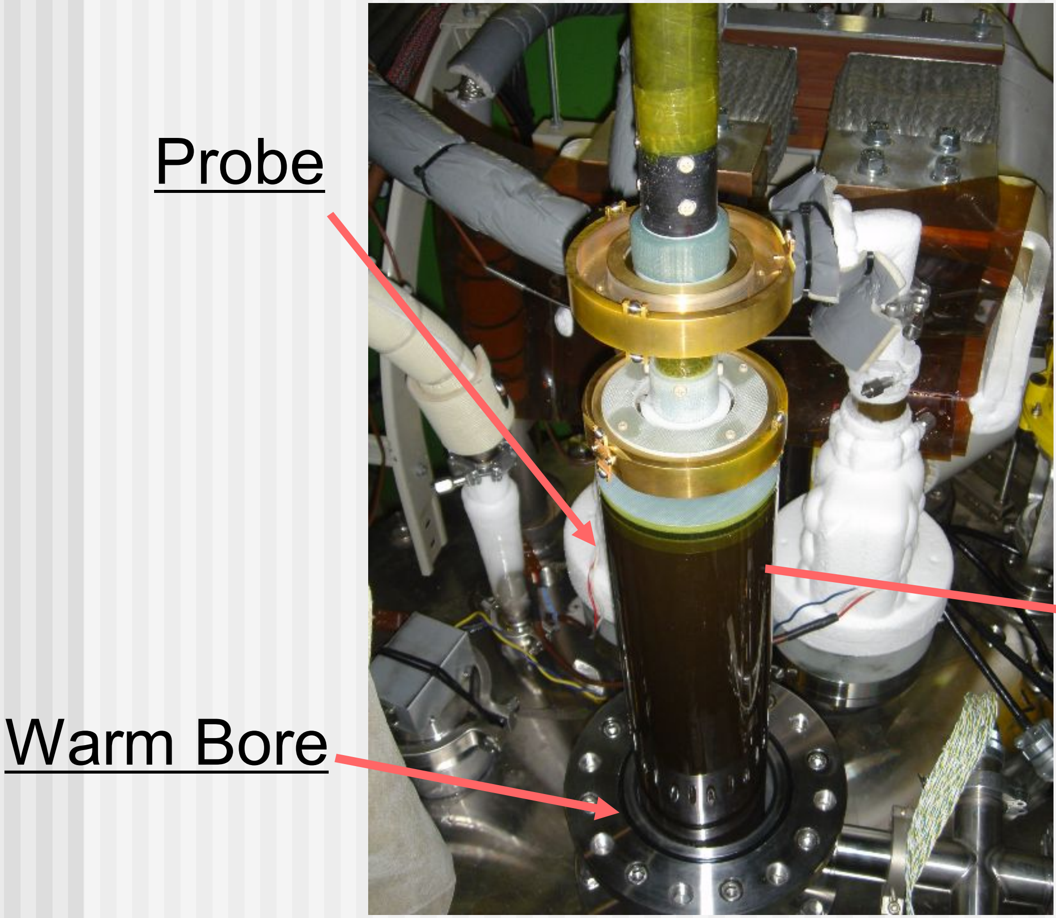
Further study is needed.

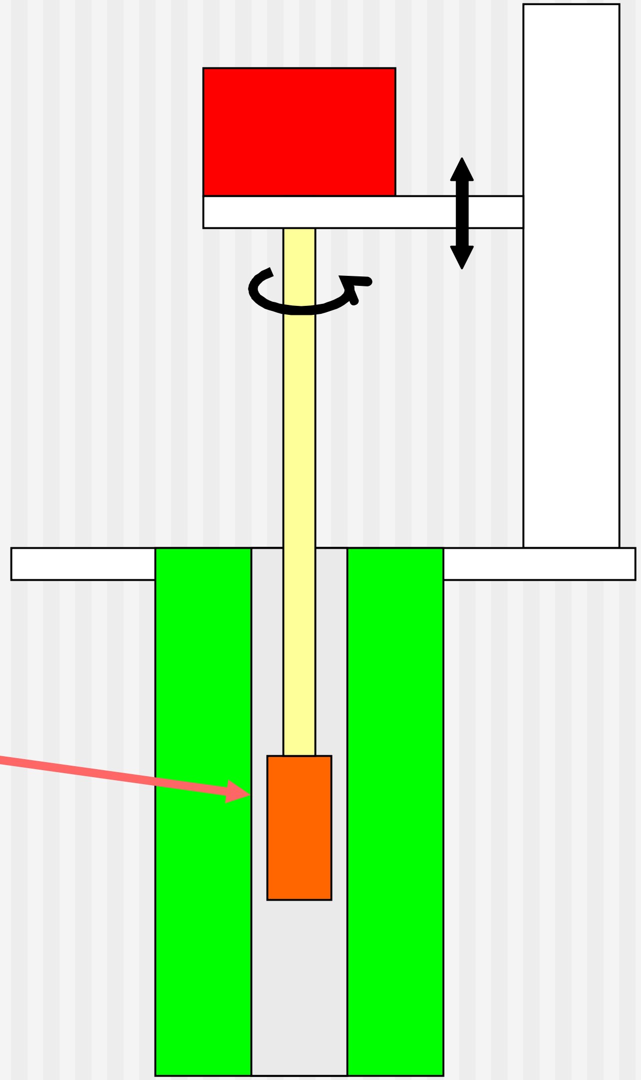
Magnetic Field Measurement

- at Room Temperature (all the magnet)
  - Check → Fabrication Process, Dipole field
- in LHe (all the magnet)
  - Check → Higher order harmonics
- in SHe (2 or 3 magnet system with cryostat)
  - Check → All multipole fields

Field Measurement in LHe

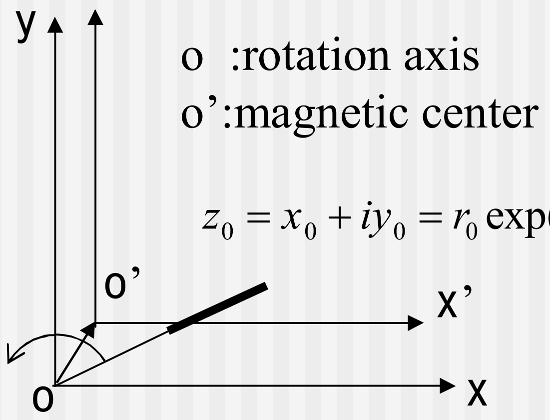
- Scanning along magnet bore





Field Measurement in LHe

- In the vertical cryostat
  - objective: check higher order harmonics
    - Difficult : measure dipole field with good accuracy
    - ↑
    - Difficult : measure the displacement of the probe from magnet axis
  - because of "feed down" from higher order harmonics.



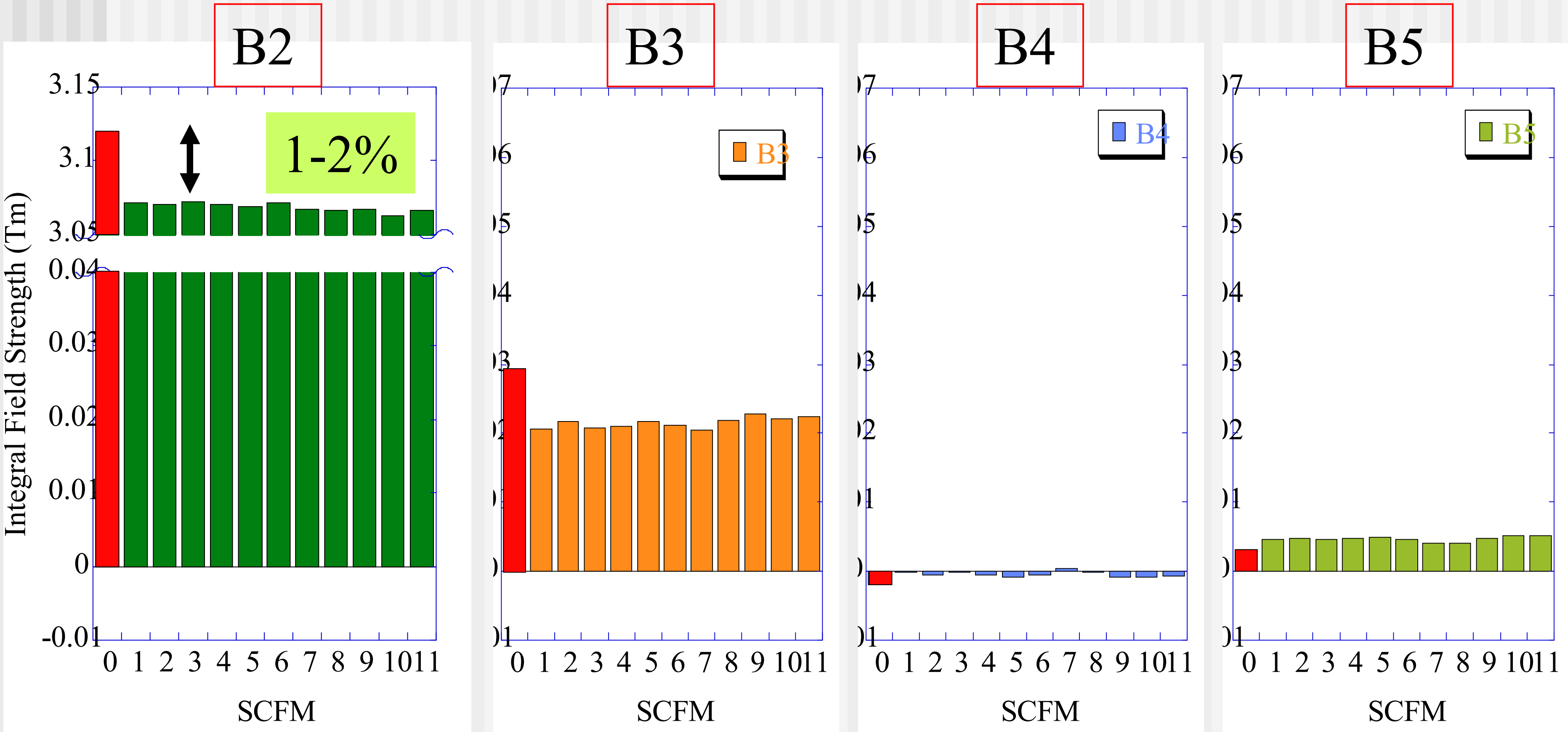
$$z_0 = x_0 + iy_0 = r_0 \exp(i\xi)$$

✦ feed down :

measurement error caused by offset in rotation axis from magnetic center.

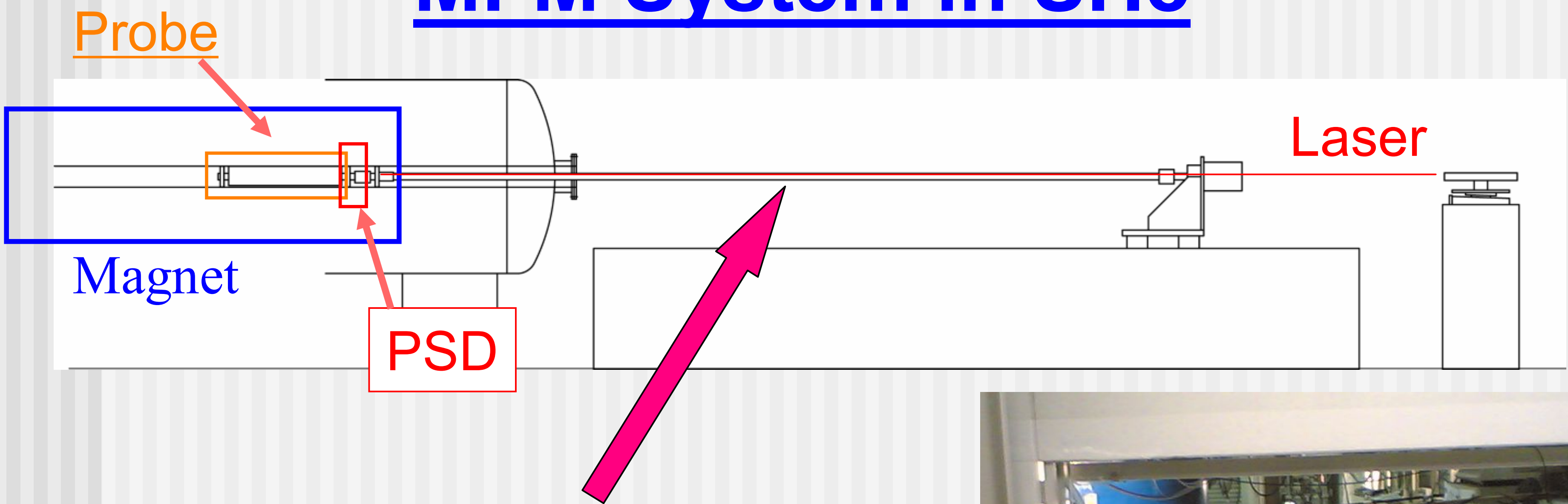
Average skew component of quadruple along straight section ⇨ 0

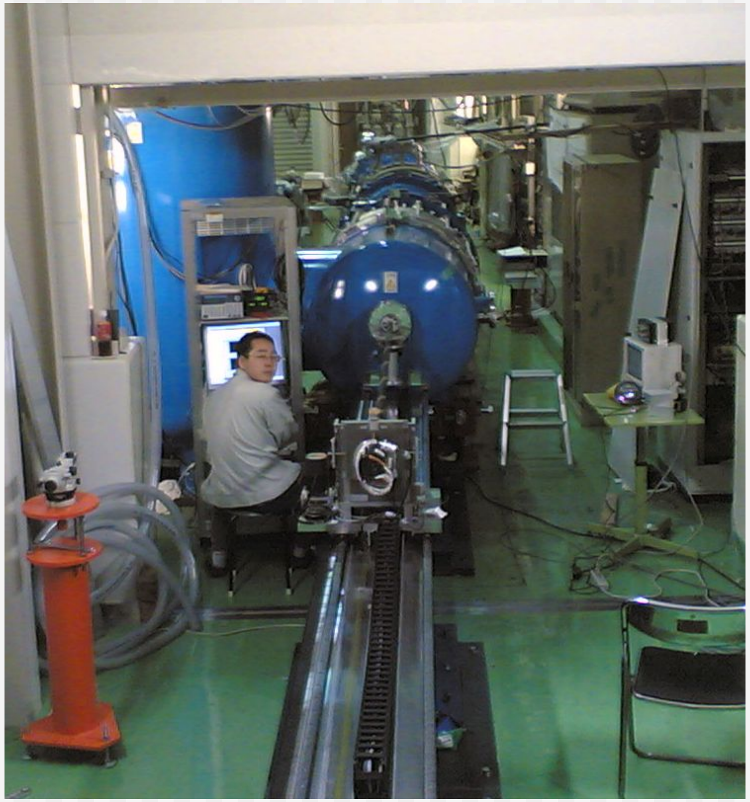
Integral Field Strength @ 7345 A



- Higher order hammonics -> small
- 1-2 % difference in B2 <- ??

MFM System in SHe





- *Laser passes through the shaft.*

to be tested next month

Summary

- The magnet and magnet system are successfully developed!
  - Quench Protection Scheme

- Magnet and Magnet System Production
  - Almost on schedule (12 magnets, 4 magnet system)
  - Performance -> sufficiently good
    - Field measurement system has to be improved.

Schedule

	2005	2006	2007	2008
Cryostat w/ 2-SCFMs	1 (proto)	6 (12 Mag.)	6 (12 Mag.)	2 & Install
Transfer Line				Install
Refrig.				Install
PS				Install
Corrector Magnet				Install
Quench Detector				Install

Dipole field measurement

Dipole strength will be measure in the horizontal test stand.

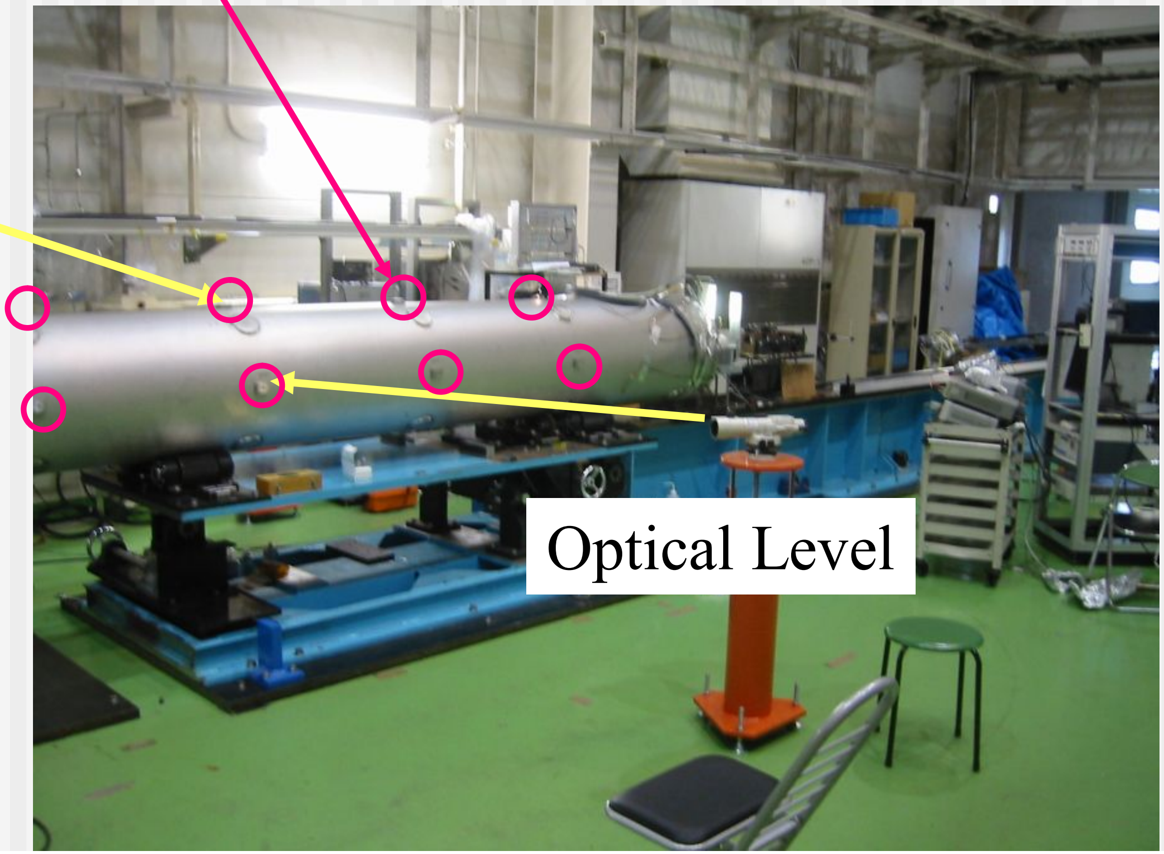
- In the horizontal cryostat:
  Several magnets will be measured in supercritical helium.

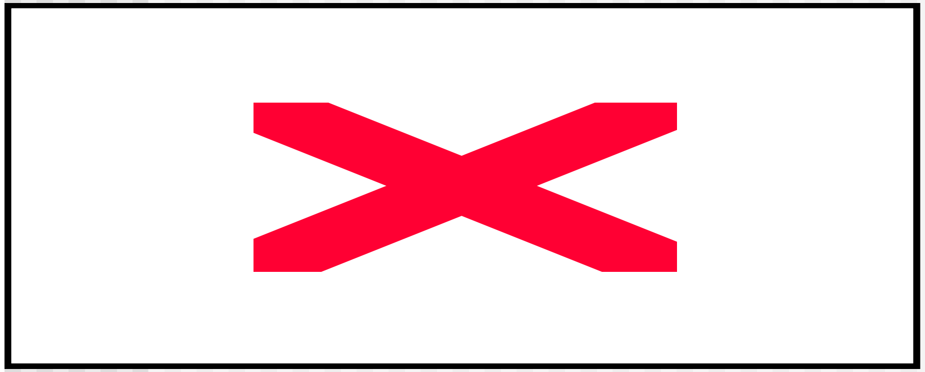
- At the room temperature
  All the magnets will be measured.

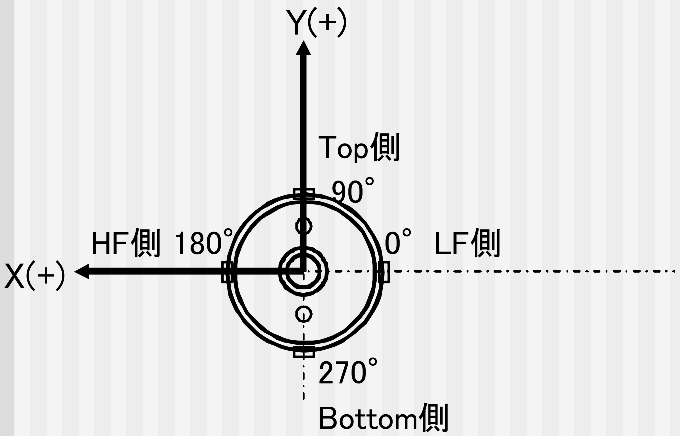
Field measurement system at R.T will be presented in the poster session, MOA08PO02

Alignment of Magnet

- Align the magnet by referring the alignment markers attached on the magnet

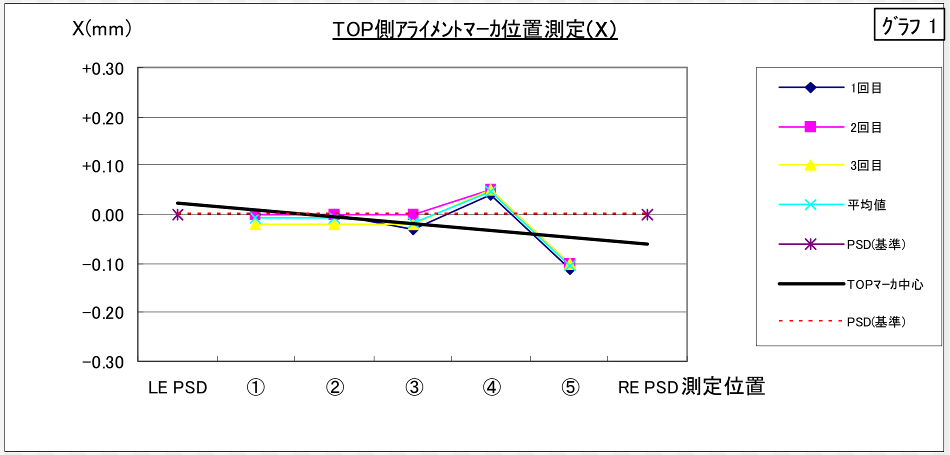




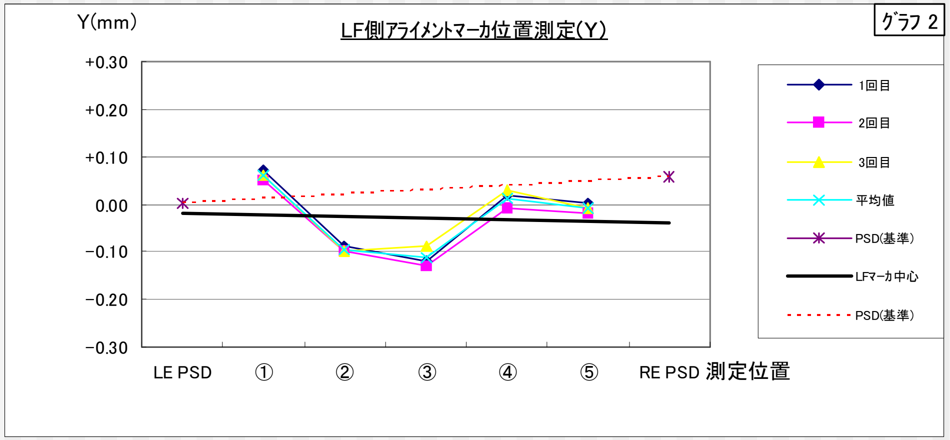


Y(+)
Top側
90°
HF側 180°
0° LF側
X(+)
270°
Bottom側

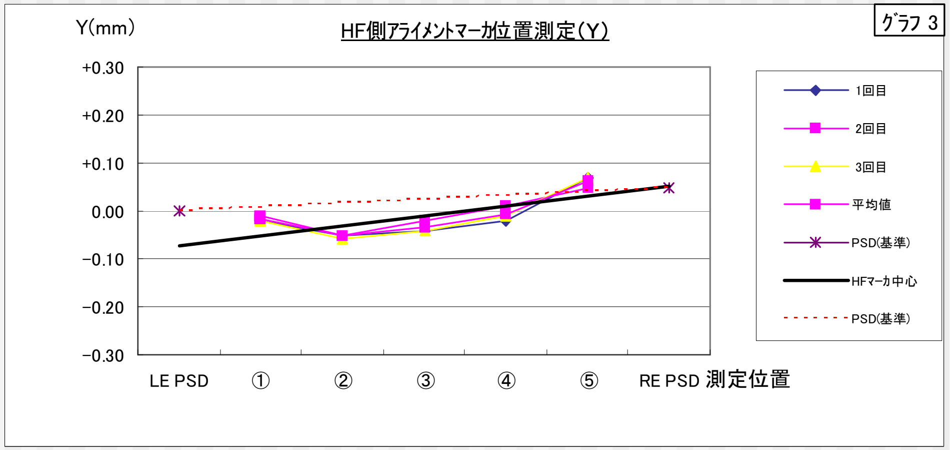
LE側から見て



X(mm)
TOP側ｱﾗｲﾒﾝﾄﾏｰｶ位置測定(X)
ｸﾞﾗﾌ 1
+0.30
+0.20
+0.10
0.00
−0.10
−0.20
−0.30
LE PSD
①
②
③
④
⑤
RE PSD
測定位置
1回目
2回目
3回目
平均値
PSD(基準)
TOPﾏｰｶ中心
PSD(基準)



Y(mm)
LF側ｱﾗｲﾒﾝﾄﾏｰｶ位置測定(Y)
ｸﾞﾗﾌ 2
+0.30
+0.20
+0.10
0.00
−0.10
−0.20
−0.30
LE PSD
①
②
③
④
⑤
RE PSD
測定位置
1回目
2回目
3回目
平均値
PSD(基準)
LFﾏｰｶ中心
PSD(基準)



Y(mm)
HF側ｱﾗｲﾒﾝﾄﾏｰｶ位置測定(Y)
ｸﾞﾗﾌ 3
+0.30
+0.20
+0.10
0.00
−0.10
−0.20
−0.30
LE PSD
①
②
③
④
⑤
RE PSD
測定位置
1回目
2回目
3回目
平均値
PSD(基準)
HFﾏｰｶ中心
PSD(基準)