Study of superconducting solenoids for high intensity muon beam lines

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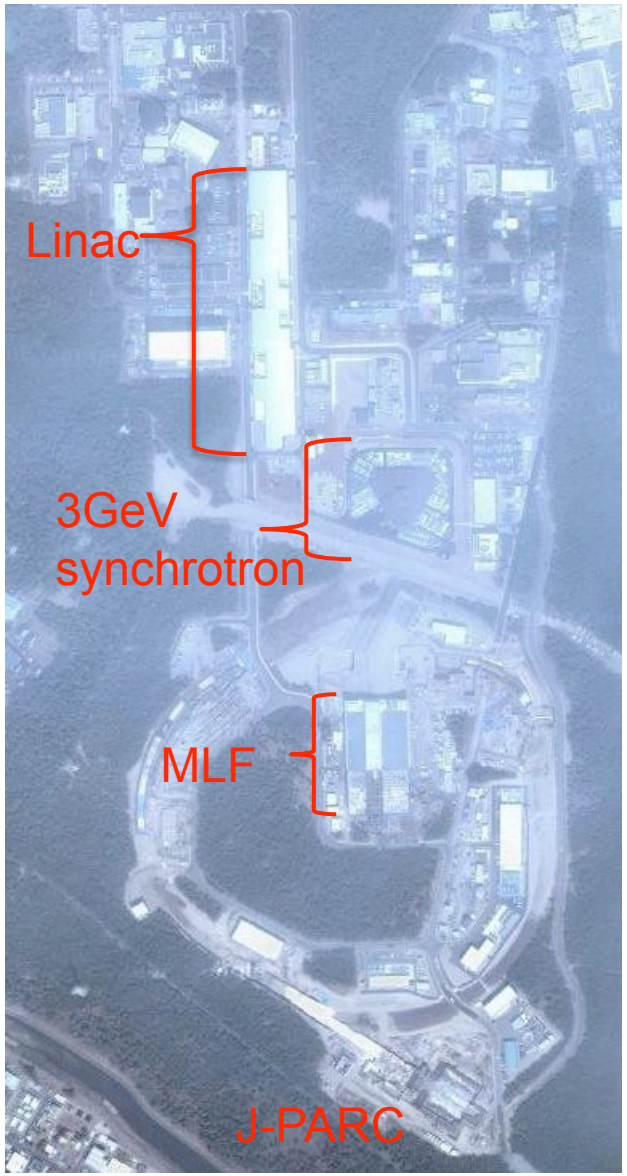
Abstract



- We designed "curved solenoids" for new muon beam line at J-PARC "Materials and Life Science Facility (MLF)".
- It can achieve transport efficiency of 94%.
- We made a part of the solenoid, tested it excited, and got good results.
- The curved solenoid seems to be able to manufactured.

Contents

1. Outline of our beam line
2. Design of transport solenoids
3. Tests and results
4. Conclusion

1. Outline of our beam line

1-1. Over view

1-2. Muon production target

1-3. Capture solenoids

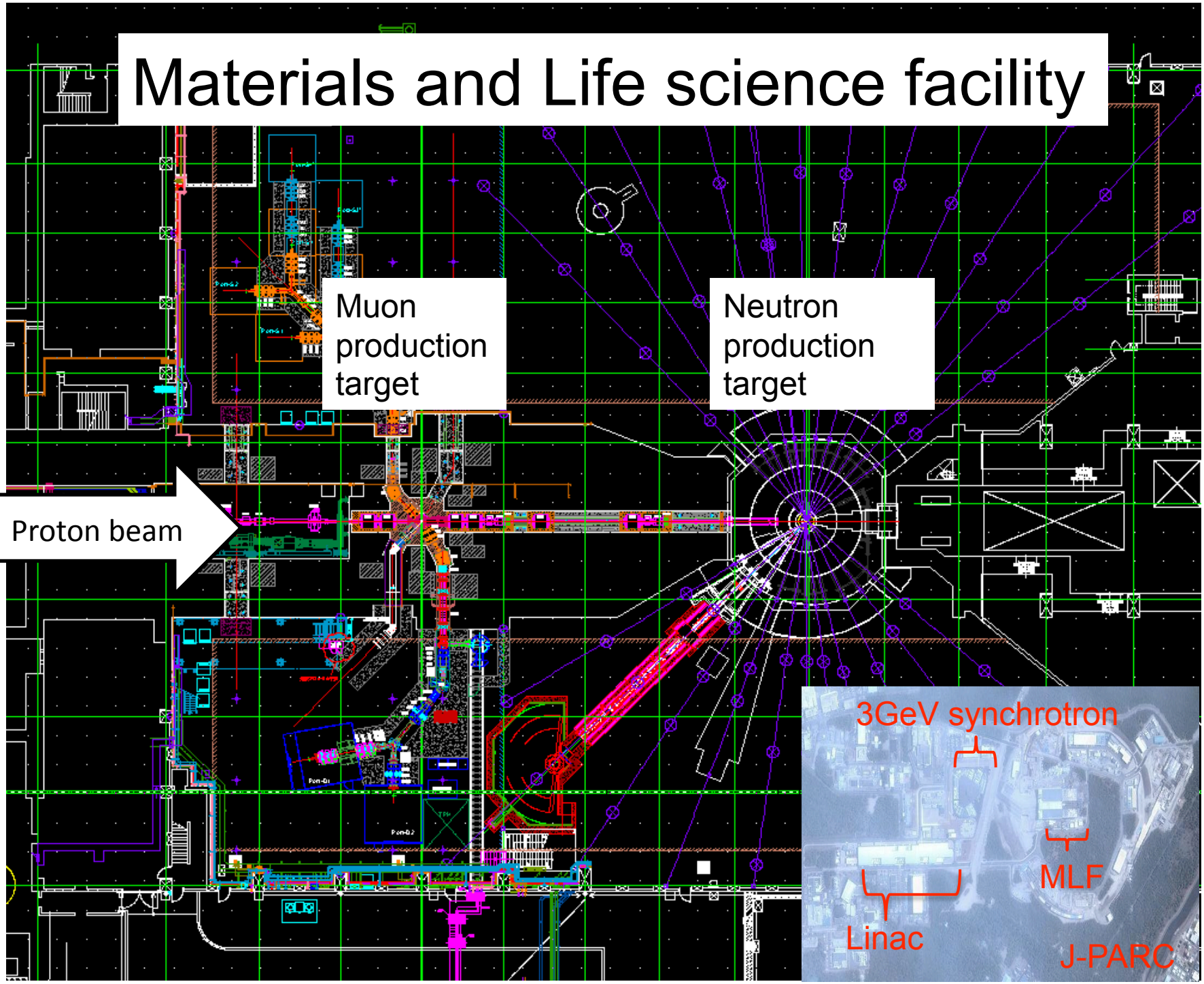
1-4. Transport solenoids

1-5. Focusing solenoids

1-1. Over view (1)

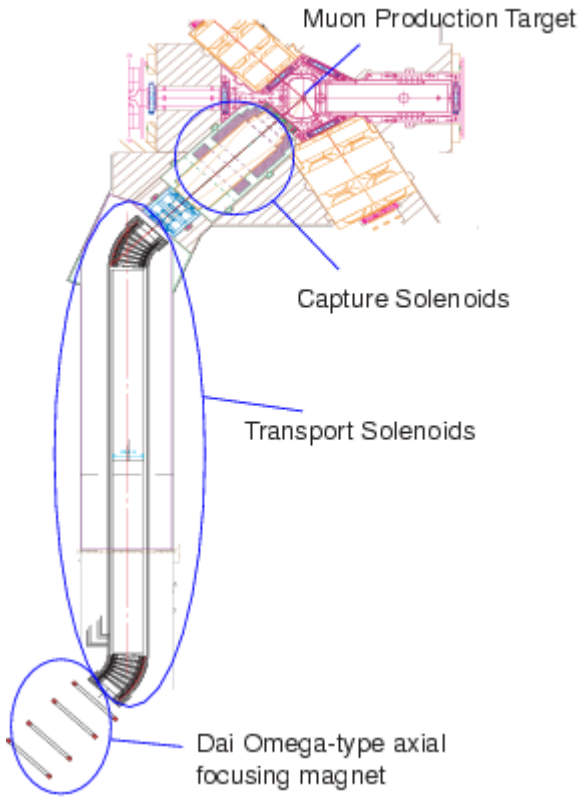
- Beam line called “Ultra slow muon port” or “Super Omega muon port”
- Under constructing at MLF in J-PARC
- Aiming the world’s highest intensity pulsed muon beam
  - 4×10^{8} μ^{+}/s (30MeV/c)
  - 10^{7} μ^{-}/s (30MeV/c)
- Decelerate μ^{+} to produce ultra slow muon

Materials and Life science facility



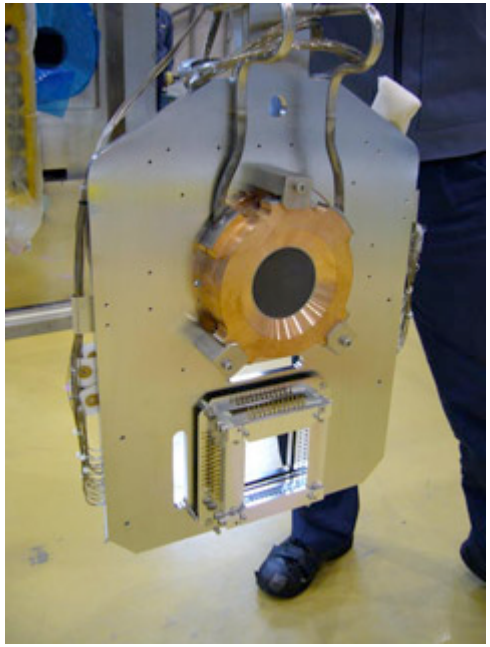
1-1. Over view (3)

- Solenoids capture particles from production target.
- Transport them efficiently.
- Curvature reduces background such as neutrons.
- Solenoids called “Super Omega” focus beam.
- Mainly surface muons, but decay muons also (if we could)



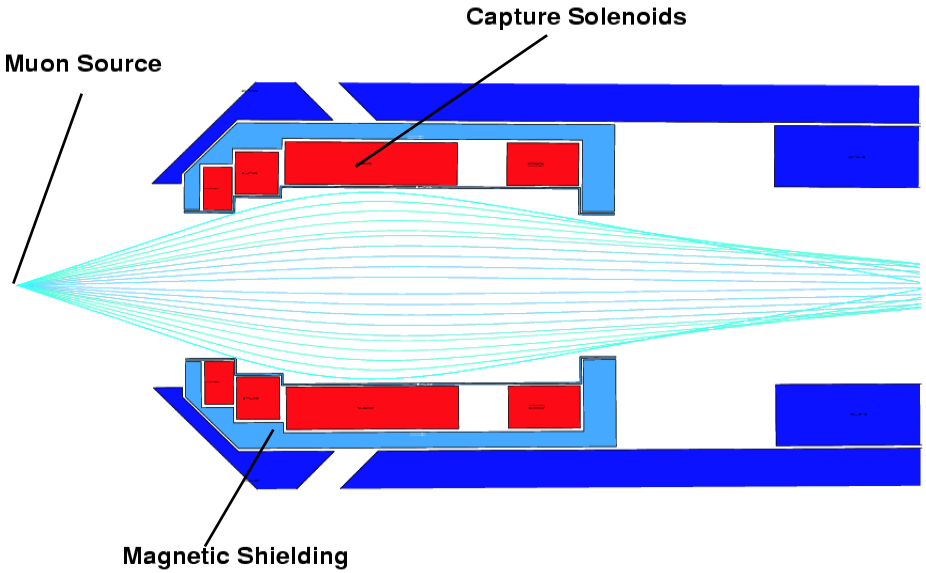
1-2. Muon production target

- Produce muons for four ports.
- 3GeV Proton beam hits graphite target.
- Pions and muons are produced.
- Neutrons, positrons and electrons are also produced.
- Already operating.



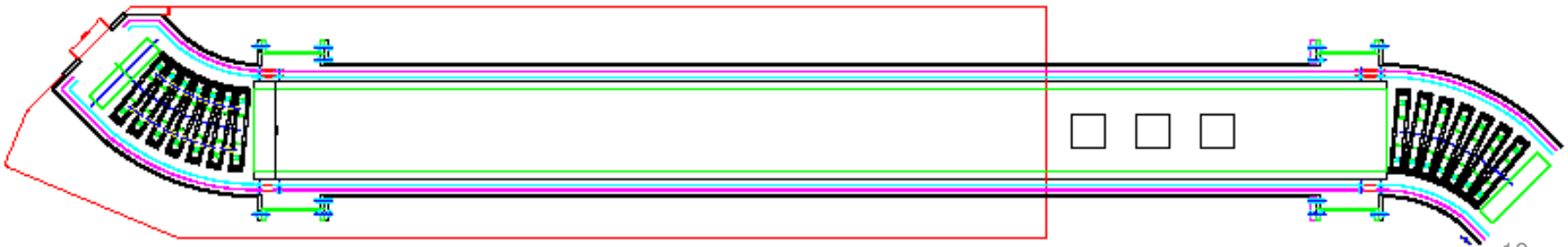
1-3. Capture solenoids

- Radiation-resistant normal conducting solenoids.
- Acceptance is 400mSr.
- Capture μ^+,μ^-,π^+,π^-



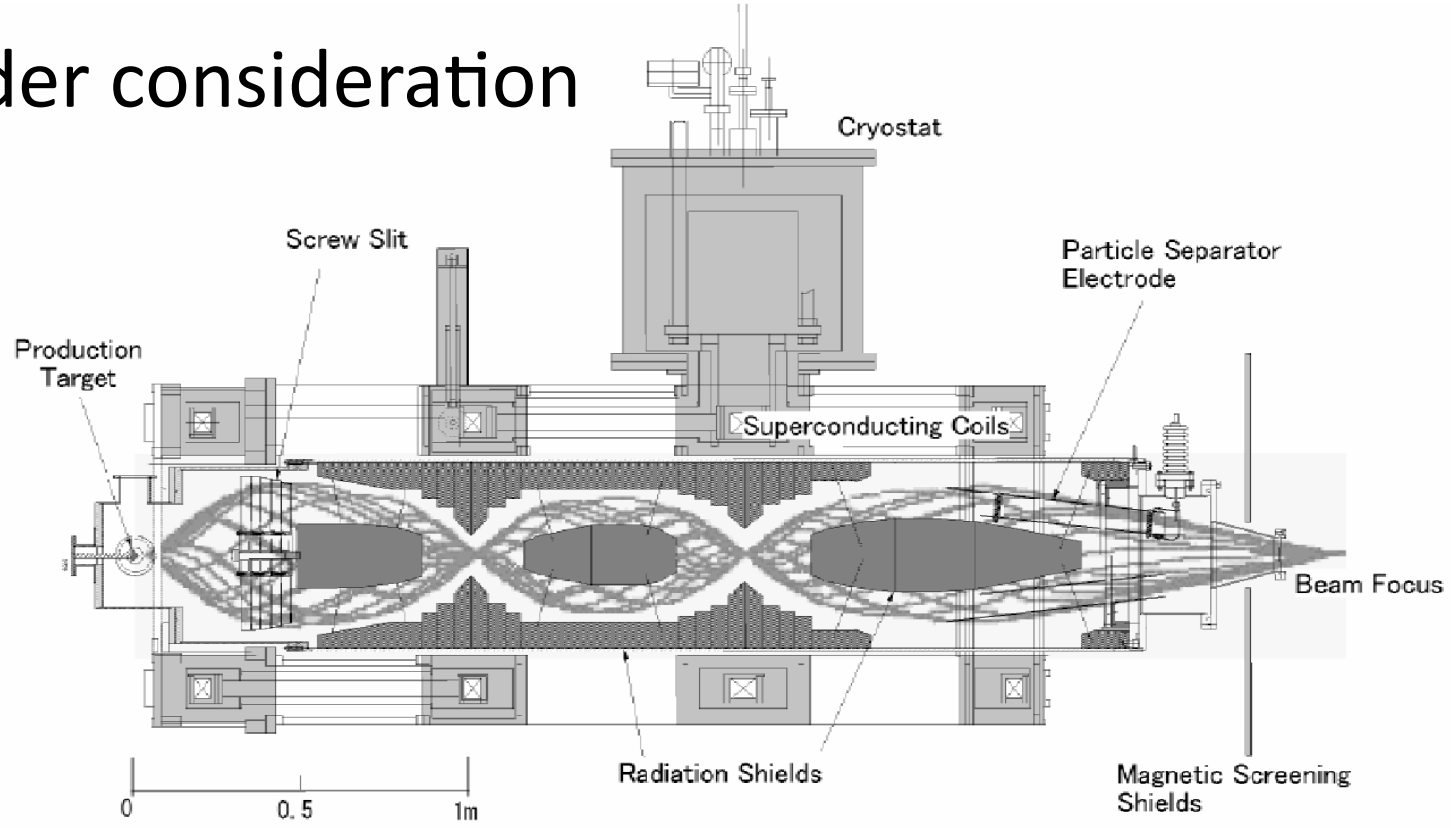
1-4. Transport solenoids

- Transport μ^+/μ^- together
- 6m straight section and two 45° curved section at each end
- Efficiency > 90% at 30MeV/c (surface muons, with 1.4T)
- Pions completely decay into muons in this section. (If we achieve 3.0T, we can transport decay muons)



1-5. Focusing solenoids

- Axial focusing magnets
- Developed for the KEK muon beam line
- Under consideration



2. Design of transport solenoids

especially curved solenoids

2-1. Structure and efficiency

2-2. Superconductor

2-3. Specification and stability

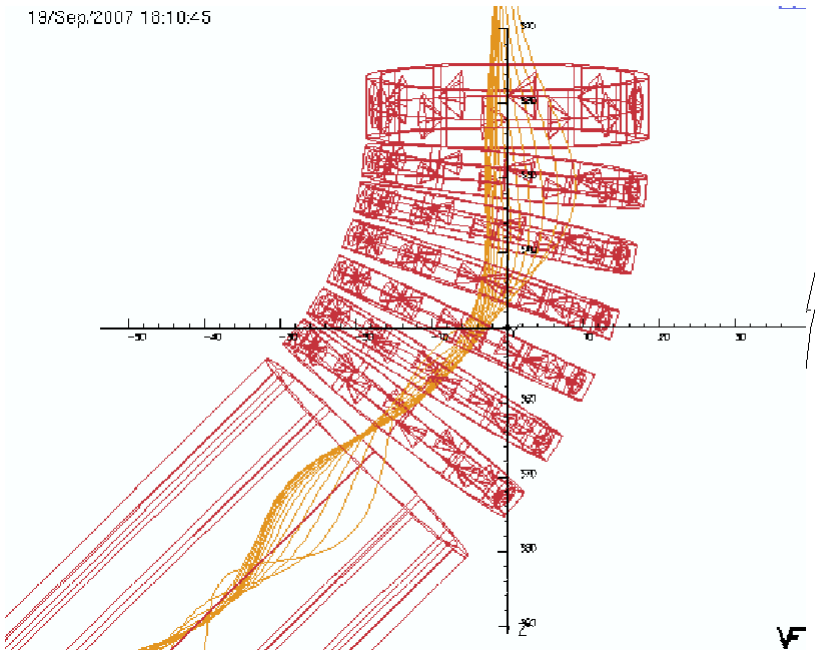
2-4. Cross-section of coil

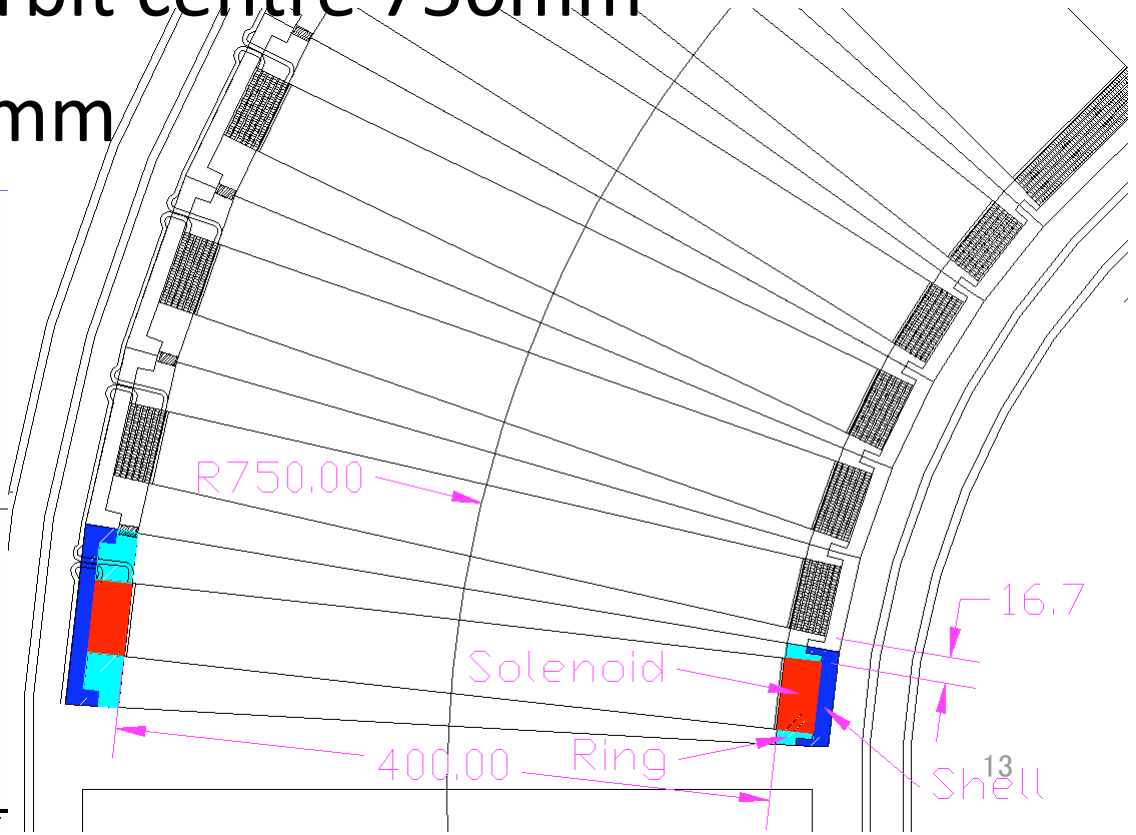
2-5. Support structure

2-6. Cooling

2-1. Structure and efficiency

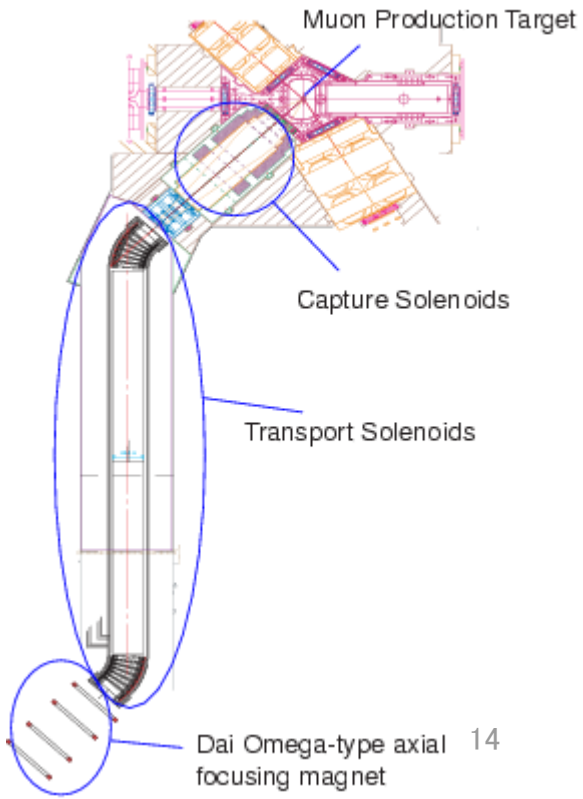
- Segmented Curved Solenoids
- Central Magnetic field 1.4T(peak field 2T)
- Bending radius of Orbit centre 750mm
- Inner diameter 400mm





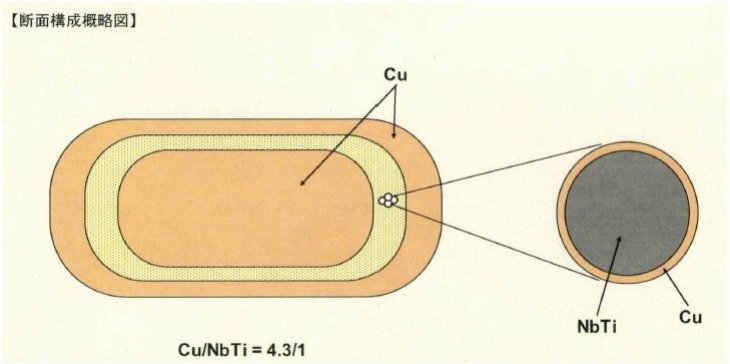
2-1. Structure and efficiency

- Efficiency of transport solenoids is 94% at 30MeV/c
- Rate of muons at the end of transport solenoids
  - 4×10^8 μ^+/s at 30MeV/c
  - 1×10^7 μ^-/s at 30MeV/c
- Calculated by G4beamline



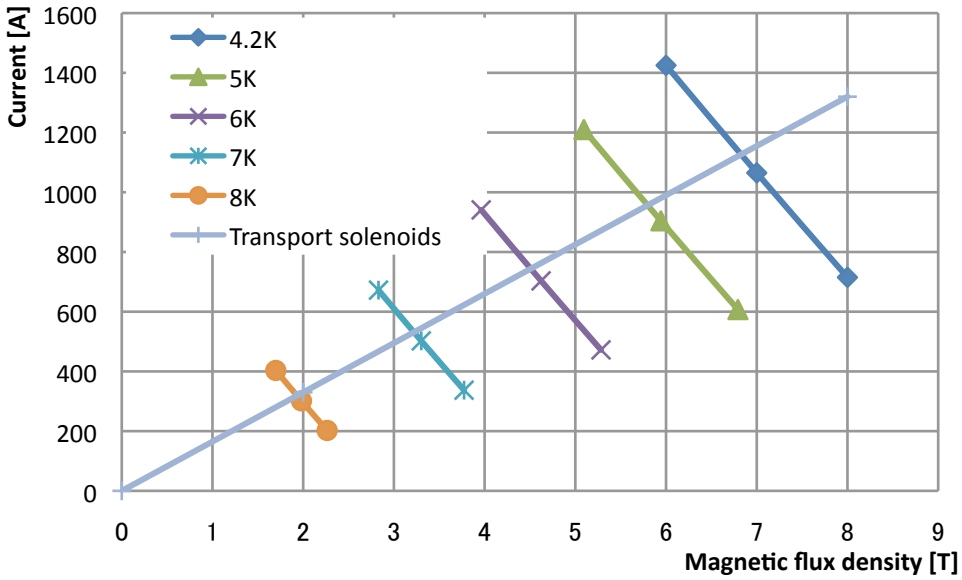
2-2. Superconductor

- NbTi
- Rectangular wire
- Cupper stabilized
- PVF insulation



Specification of superconductor	
Conductor	Nb-47wt%Ti
Width	1.67±0.04mm
Height	2.70±0.04mm
Cupper ratio	4.3±0.4
Ic(at 4.2K)	
-at 6T	≥1,425A
-at 7T	≥1,065A
-at 8T	≥715A
RRR (cupper)	≥100

2-3. Operational condition



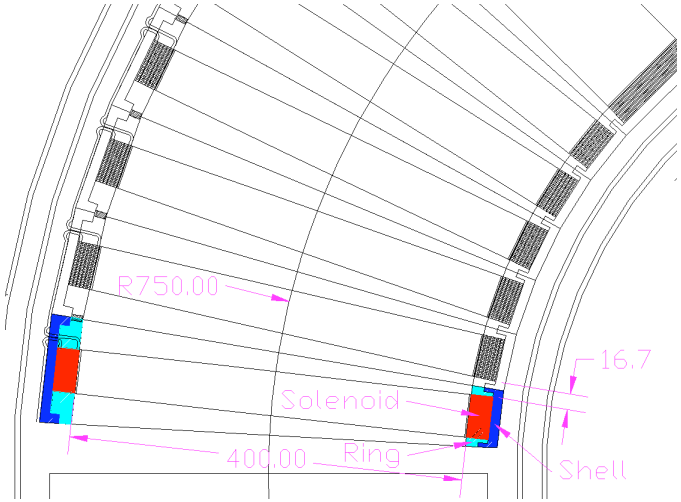
Load line of transport solenoids and Ic of wire

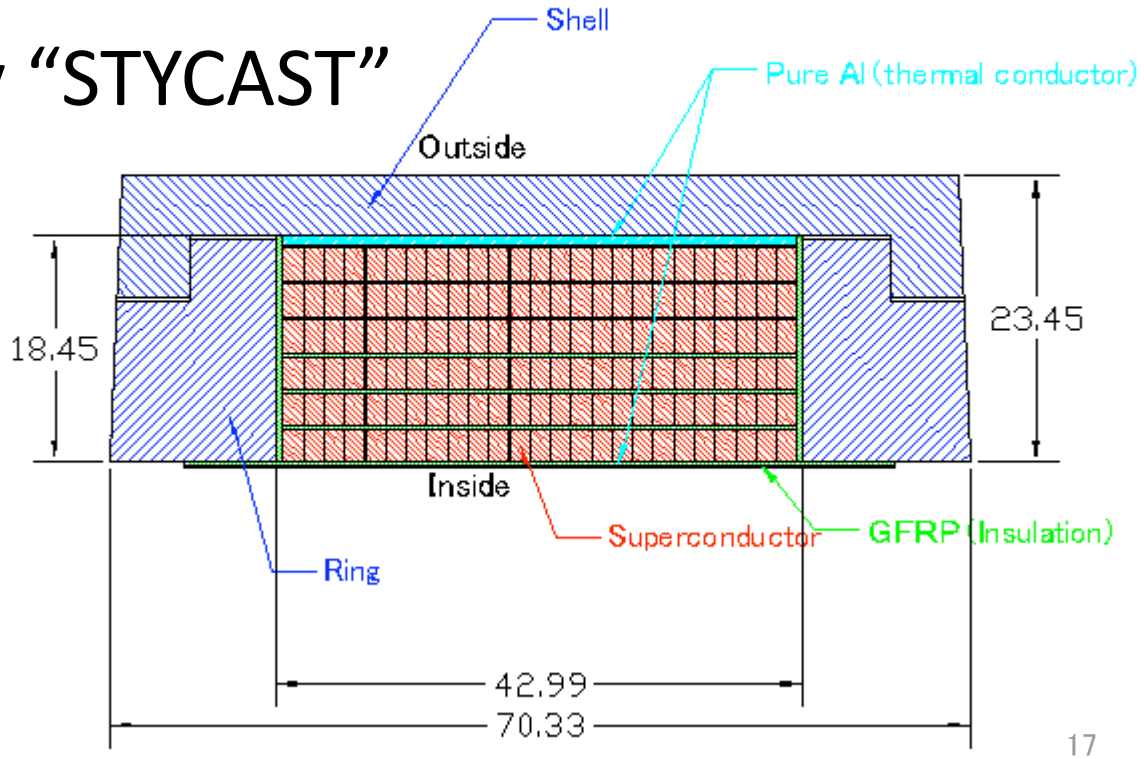
Specification of transport solenoids	
Operating temperature	6K
Current	330A
Central magnetic field	1.4T
Maximum magnetic field	2.0T
Inductance	~1H
Stored energy	100kJ
Inner diameter	400mm
Length	~7m

1.4T(peak field 2.0T) and 330A is secure.
For decay muons, 3T(peak field 4T) and 660A are required.

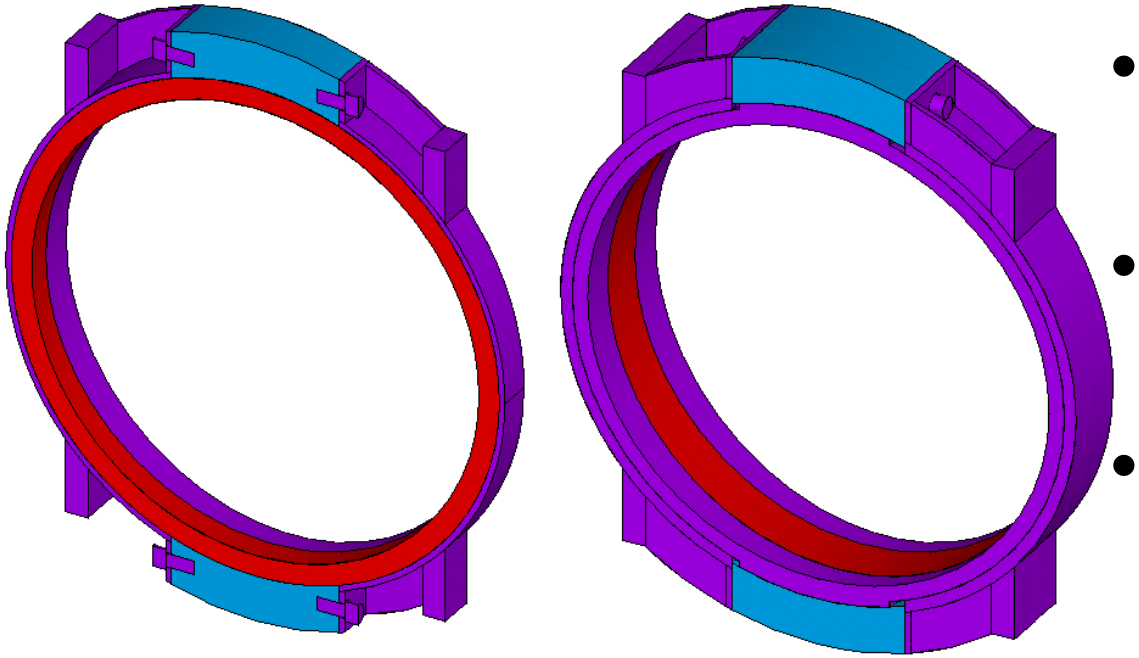
2-3. Cross-section of coil

- Solenoid winding
- Edgewise
- Pure Al support thermal conduction
- Glued by epoxy “STYCAST”

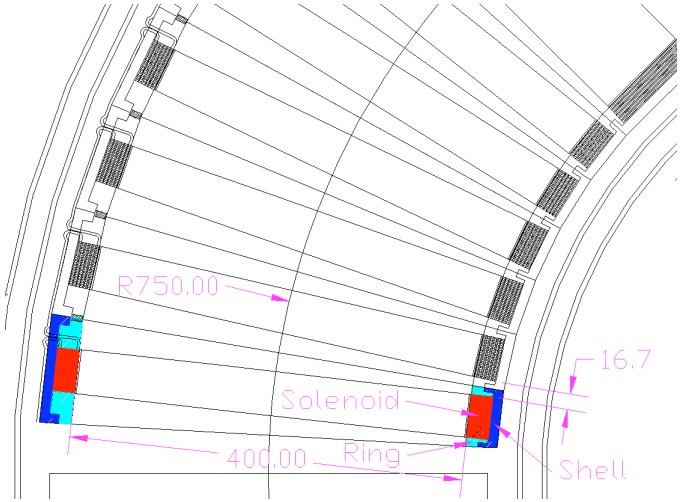


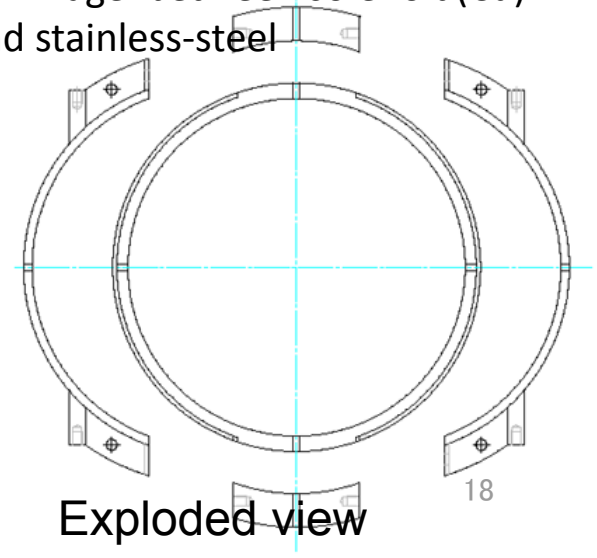


2-4. Support structure



- Stainless-steel ring
  - Hold axial direction stress
- Stainless-steel shell
  - Hold hoop stress
- Aluminum block
  - Cancel difference of thermal shrinkage between solenoid(Cu) and stainless-steel

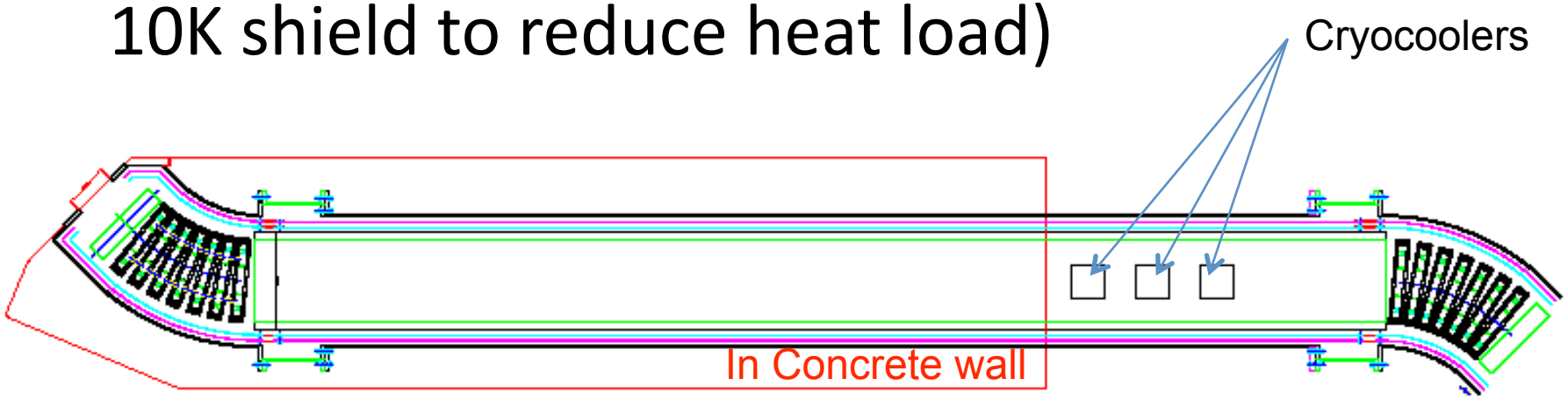




Exploded view

2-3. Cooling

- Conduction cooling by G-M cryocoolers
- ~10W heat load, mostly structural
- Radiation from production target is 1-2W
- 70K thermal shield (considering additional 10K shield to reduce heat load)



3. Tests and results

3-1. Winding

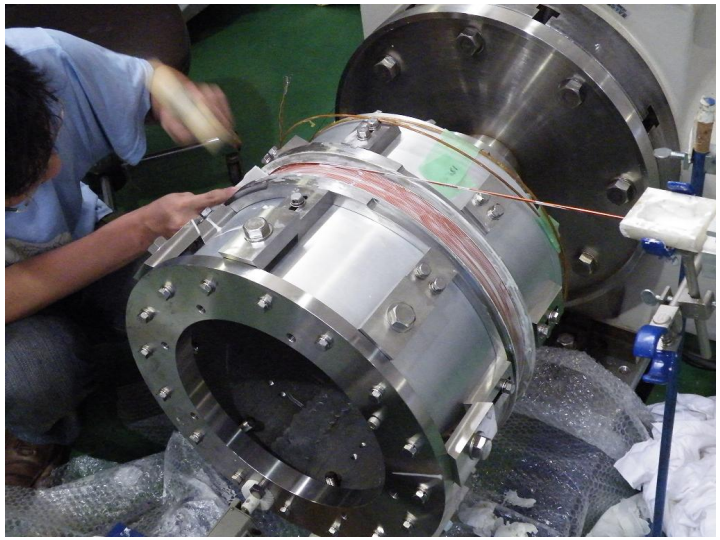
3-2. Cooling

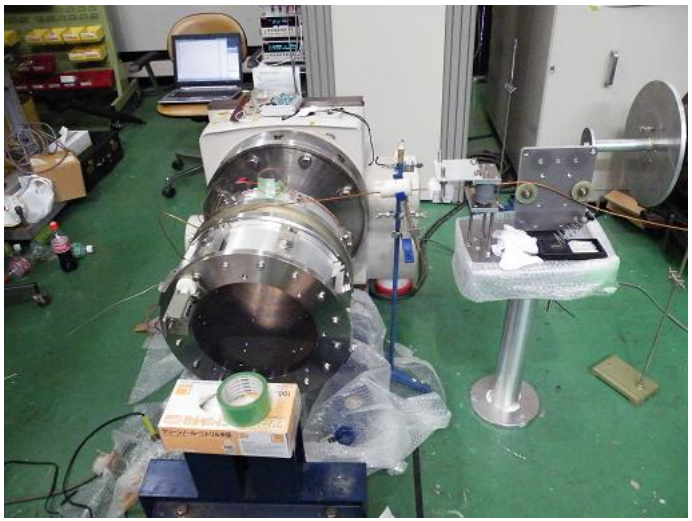
3-3. Excitation

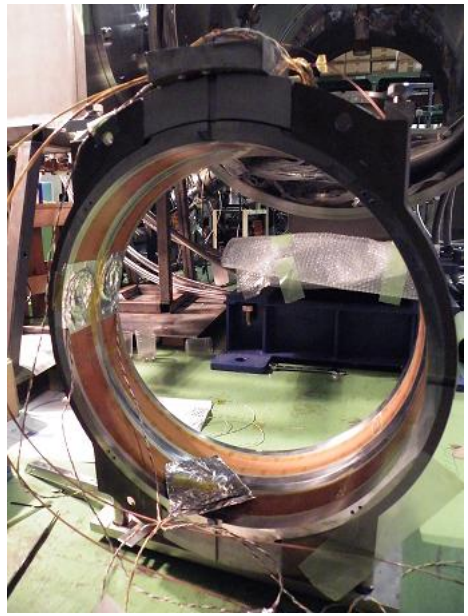
3-4. Results

3-1. Winding

- Wet-winding
- Finished winding 2 segments successfully

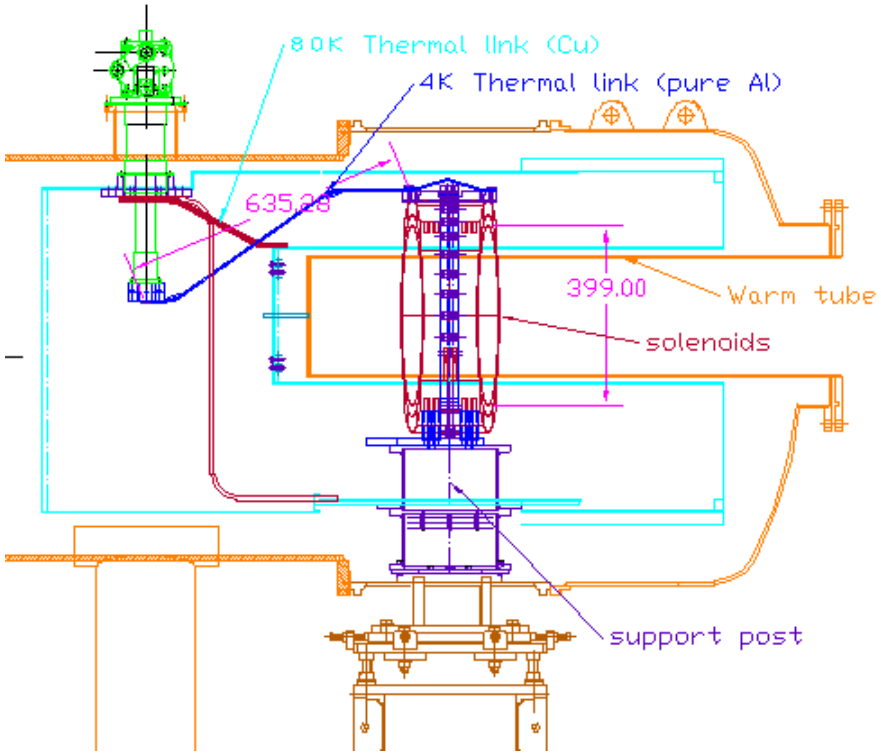


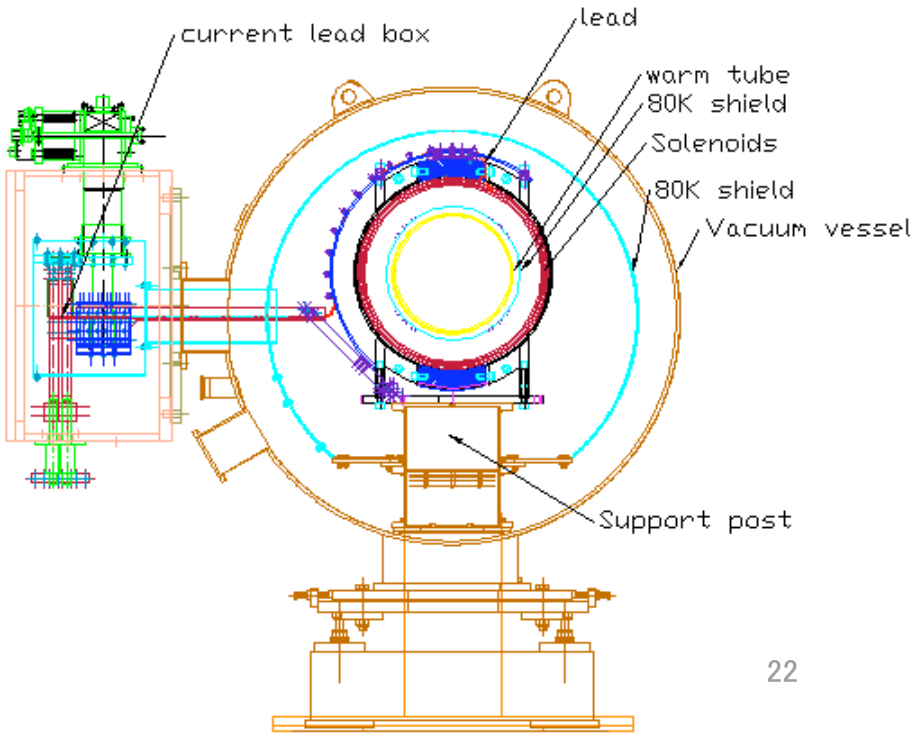




3-2. Cooling

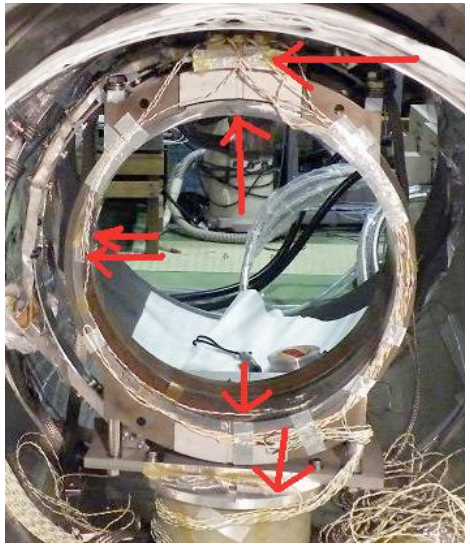
- Use 3 cryocoolers (1.5W@4K x 2units, 54W@40K x 1unit)
- Conduction cooling





3-2. Cooling

- Cool down under Tc
- Not 6K(operation temperature)



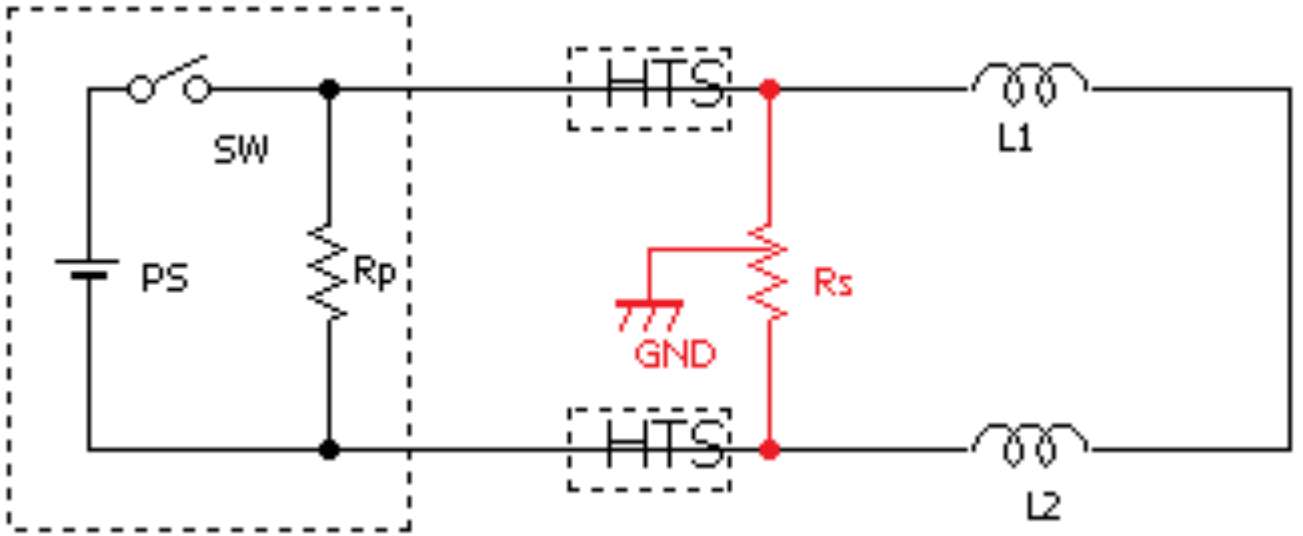
Temperature sensors

Achieved temperatures

	C14	C10	C9	C13	C11	C12
Position	Thermal anchor	Coil2 top	Coil2 side	Coil1 side	Coil1 bottom	Support base
Temp. [K]	4.8	6.5	6.6	7.1	7.4	29.8

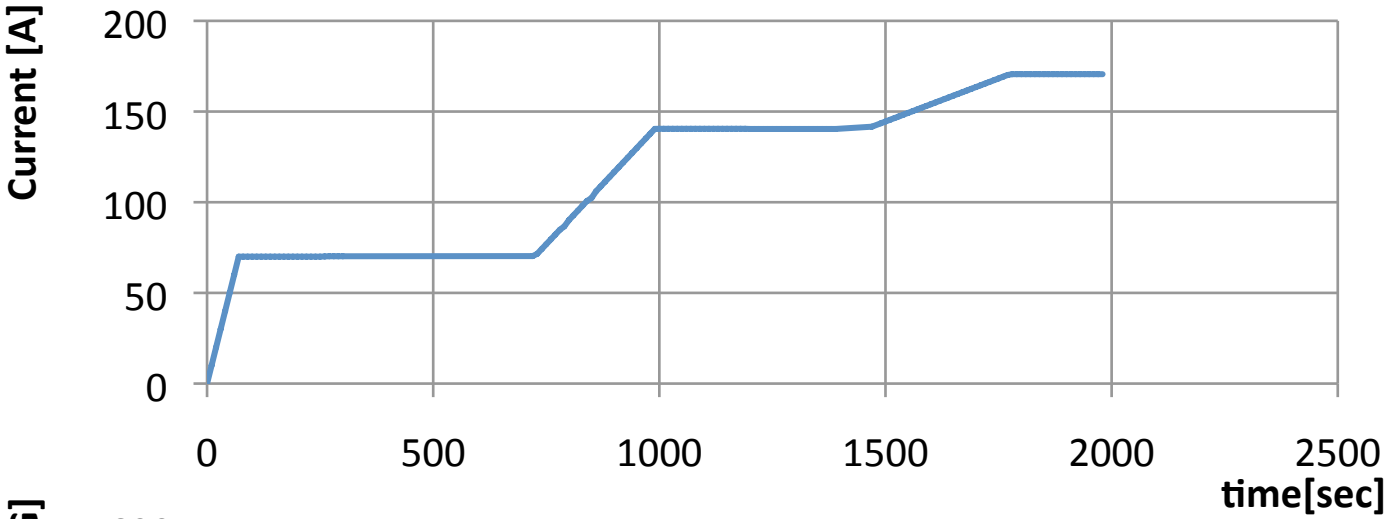
3-3. Excitation

- Short circuit has occurred
- It happened superconducting section



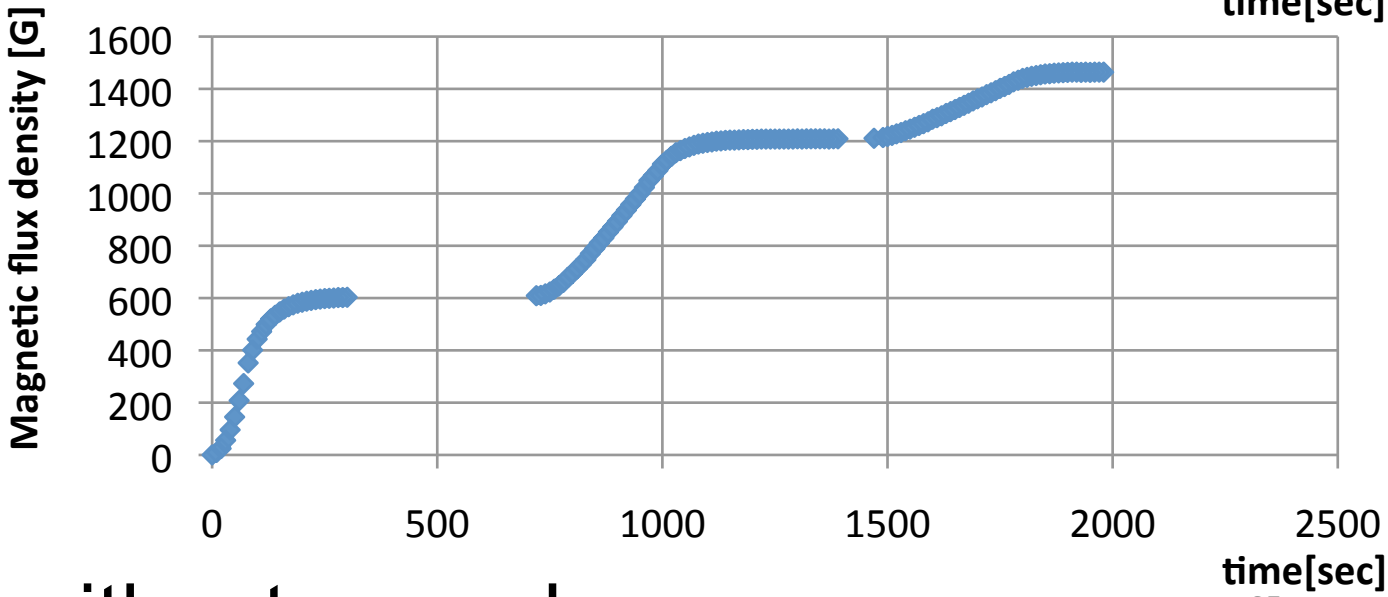
3-3. Excitation

Time dependence of Current at Power Supply



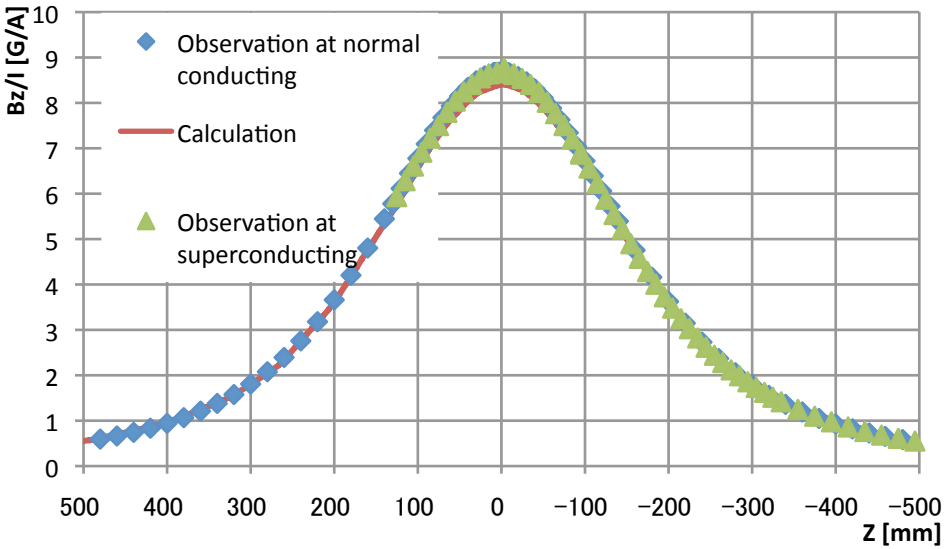
Time dependence of Central Magnetic Field

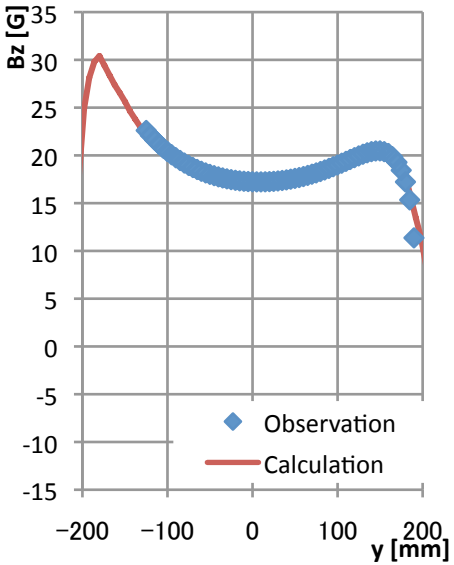
Short circuit caused delay

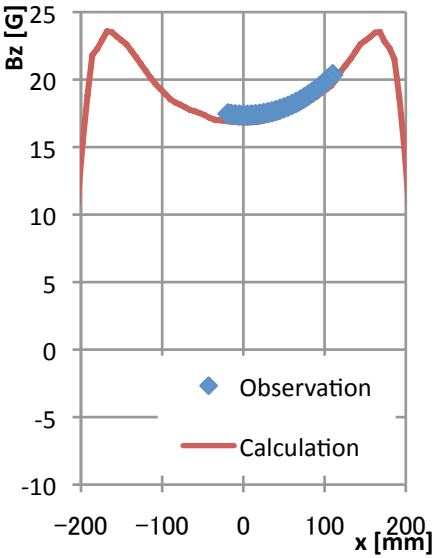


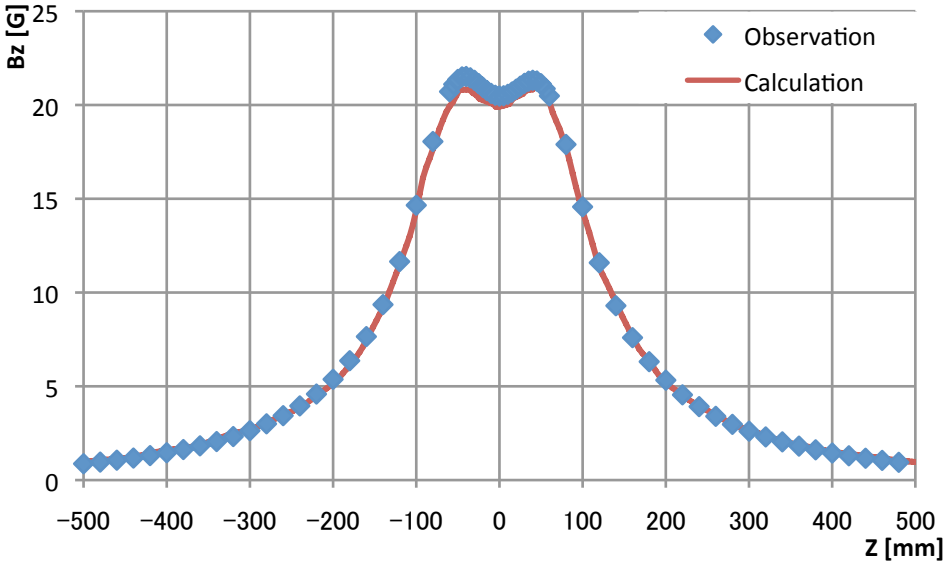
Achieve170A without quench and we stop exciting for safety

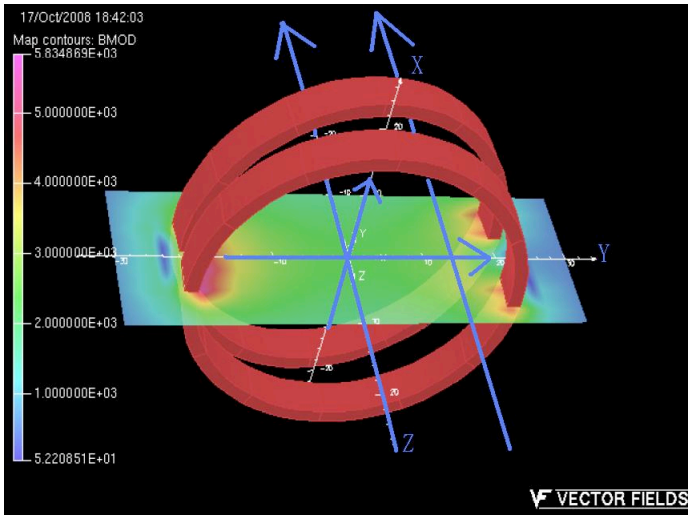
3-3 Excitation











3-4. Results

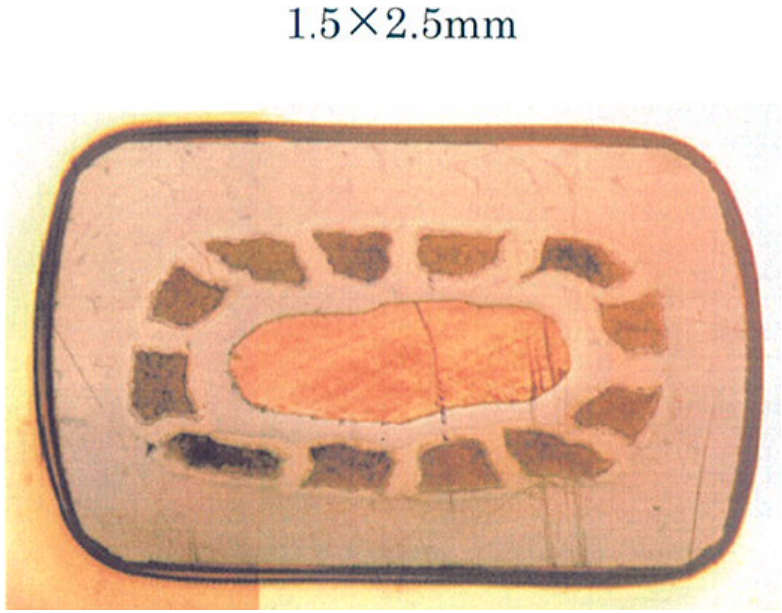
- Achieved 170A without quench
- 170A is 19% of Ic at 7.4K
- Generated magnetic force is 11% of Design
- Magnetic field conform to calculation within 4% error
- Tests are still running.

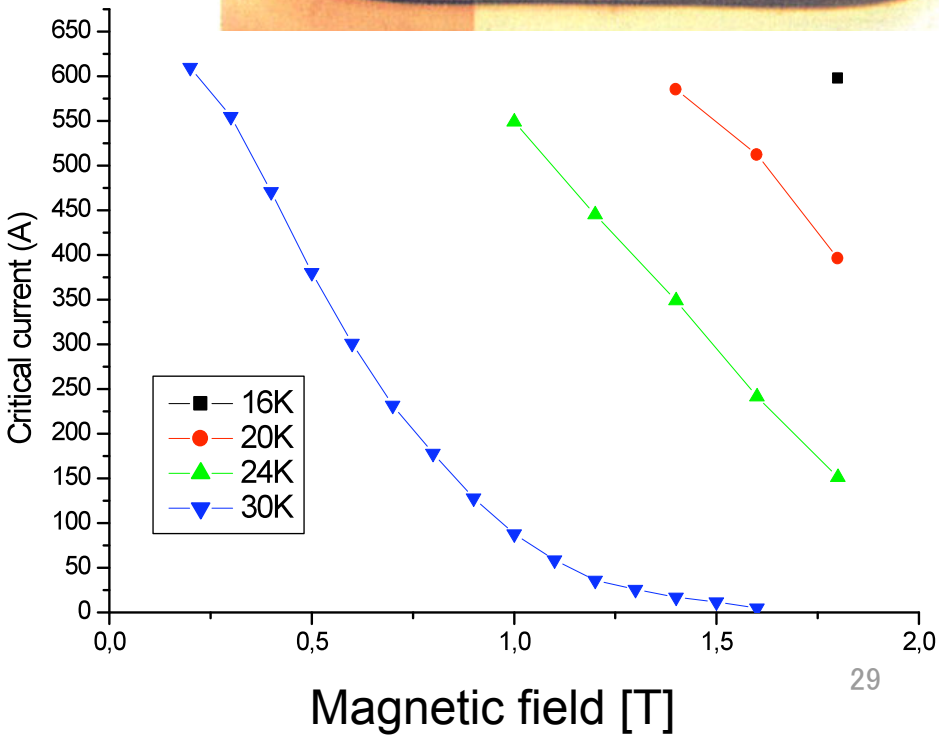
4. Conclusion

- We designed “curved solenoids” for super omega muon port at J-PARC
- The transport efficiency is to be 94%.
- We can fabricate curved solenoids.
- They are stable to at least 170A.
- Conduction cooling has succeed, but transport solenoids (7m) has difficulty.

MgB_2

- We are considering to use MgB2
- Aiming higher Tc (10~20K)
- Benefit
  - Efficiency of G-M cryocooler
  - Specific heat is higher
  - Thermal conductance is higher





Project with superconducting curved solenoids