HTS Aluminum Stabilized Conductor

For J-PARC MLF second target

Muon capture solenoid

J-PARC Future Muon Source

J-PARC MLF 2nd Target station

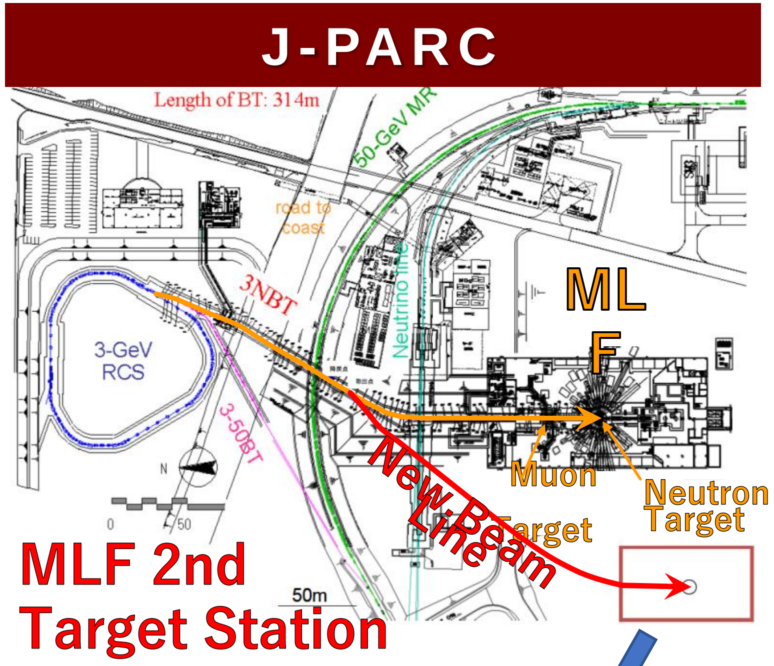
- Solenoid covering production target

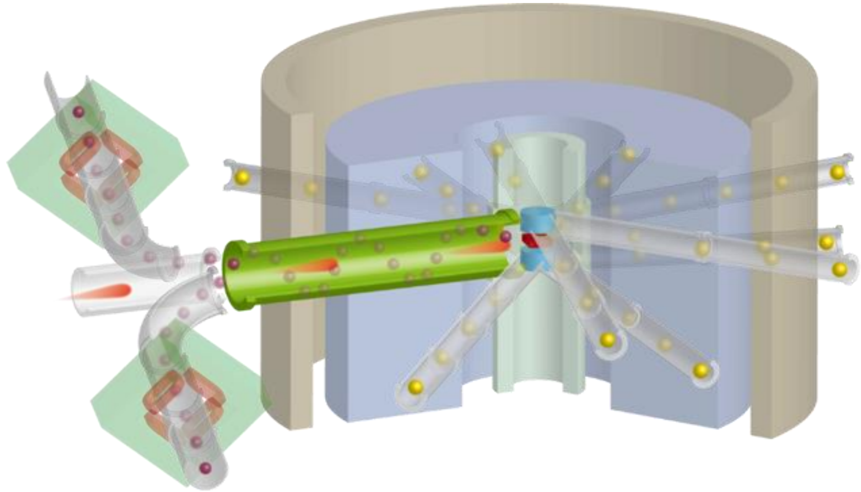
→ Absorbed Dose: 130 MGy???

Conventional Magnet Technology

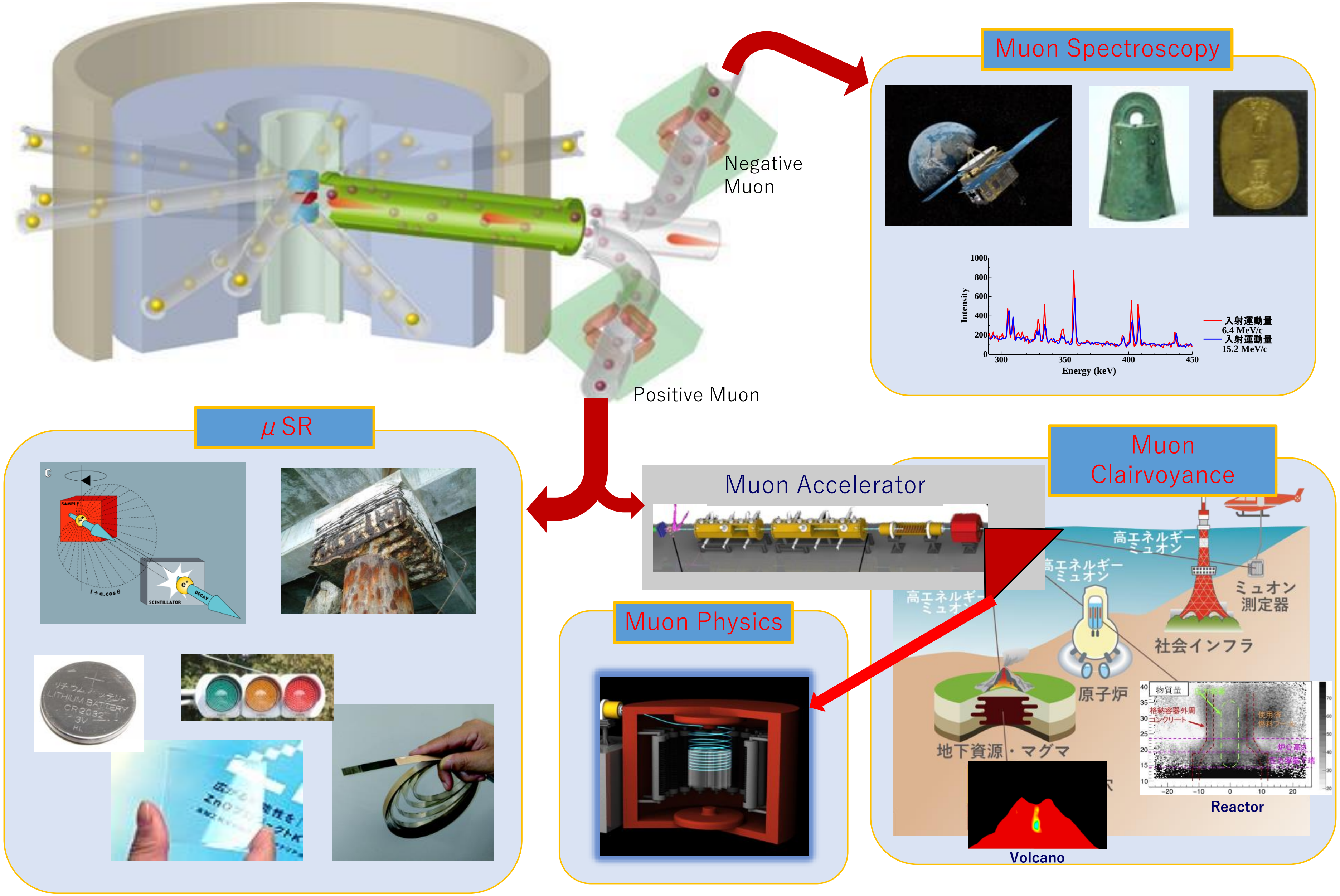
- **NbTi Cable**
  → T=5 K with heat load reaching 650 W? due to nuclear heating
- **Organic Material for Insulation**
  → Degradation of the machine strength from 10 MGy

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



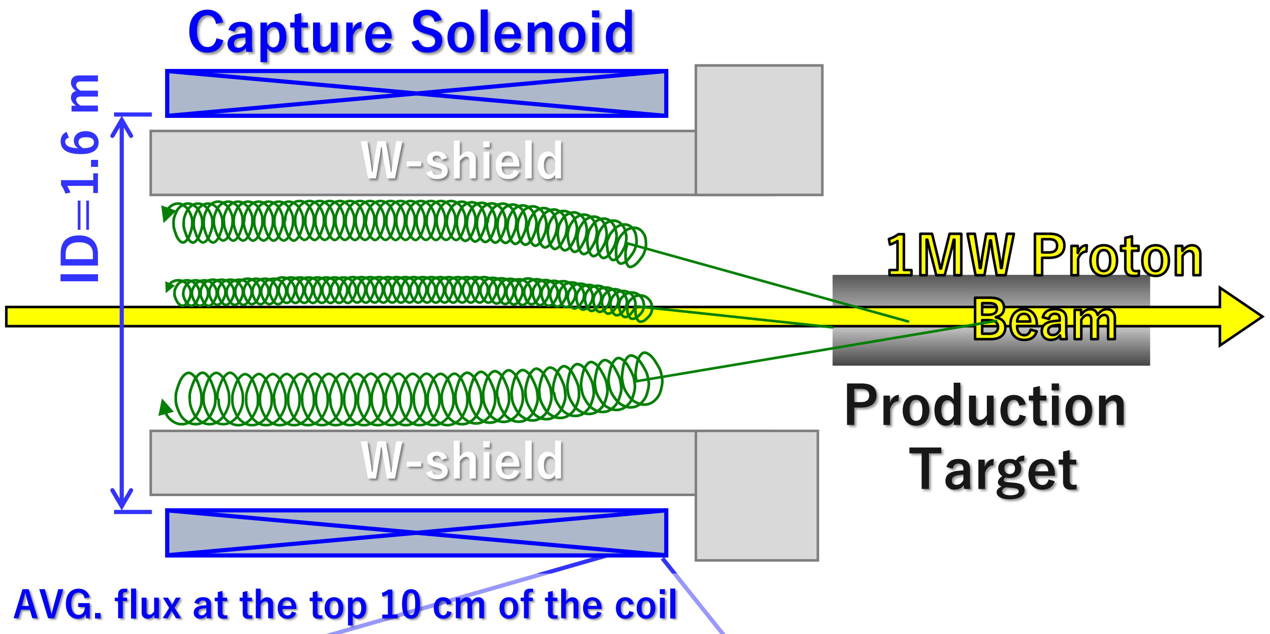


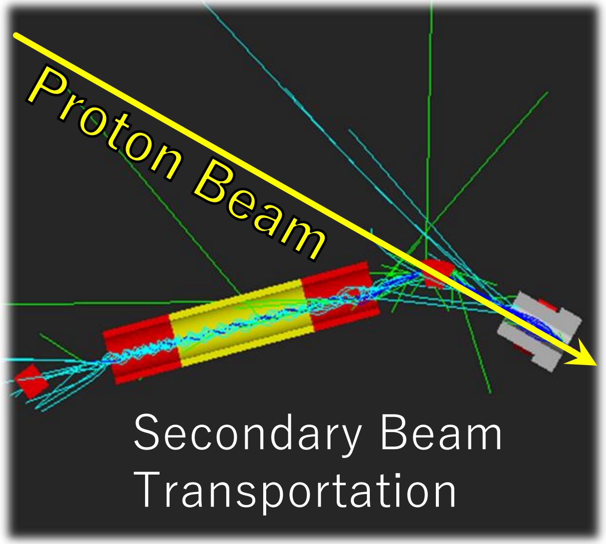
Muon Beam Usage

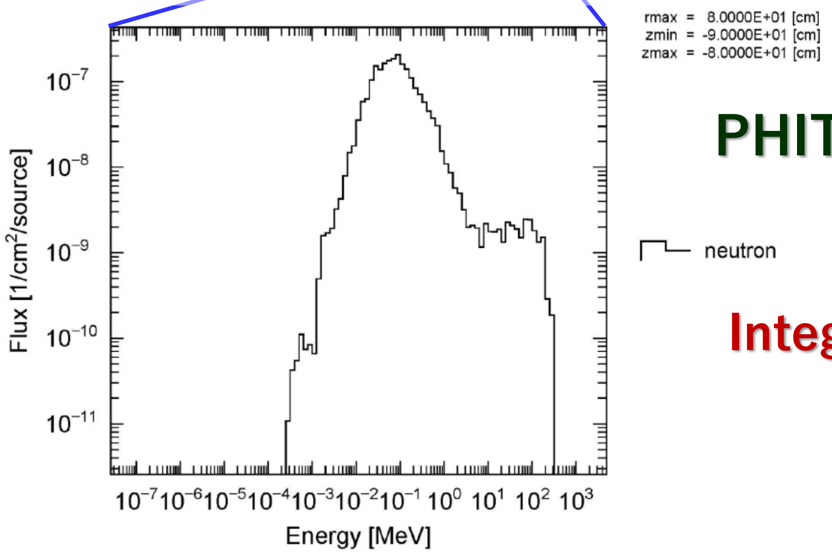


Capture Solenoid for MLF 2nd Target Station

- Conceptual design of capture solenoid is ongoing

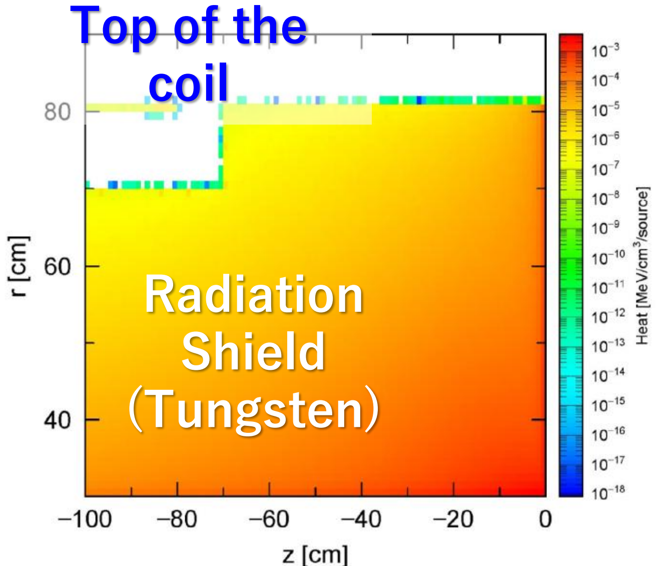






PHITS Code

Integrated flux：
7.74×10^{20} n/m²/y
(@1 MW)

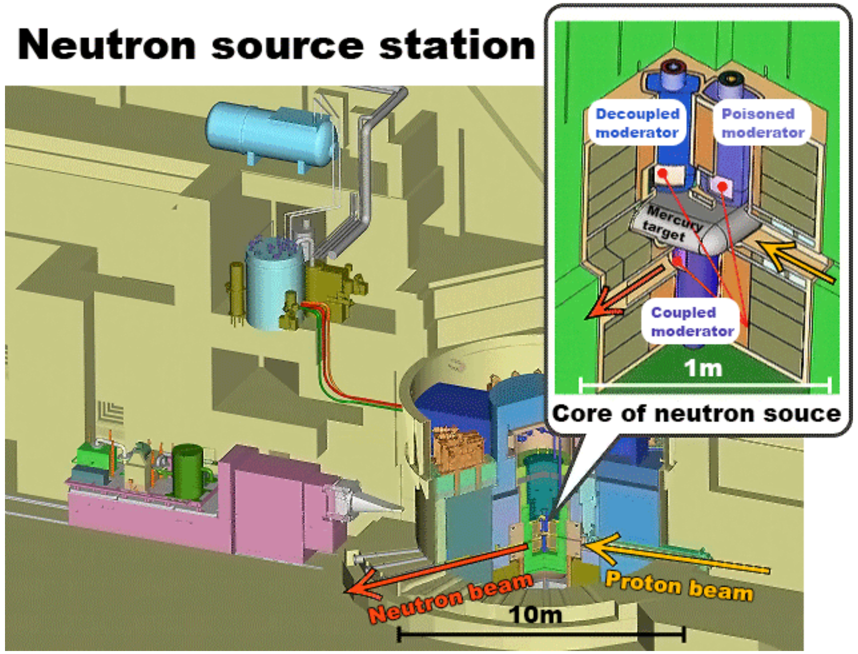


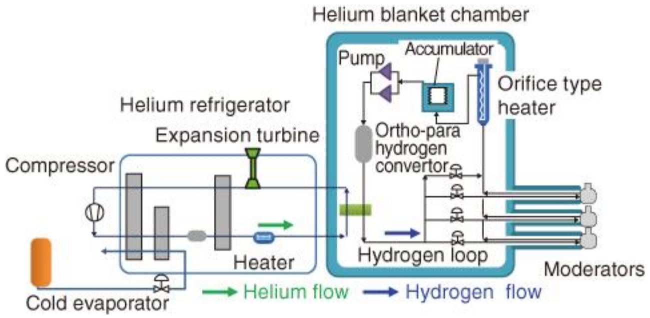
Heat Deposit to Coil: ~1kW
Overall Heat Load: ~1.5kW

REBCO coated conductor

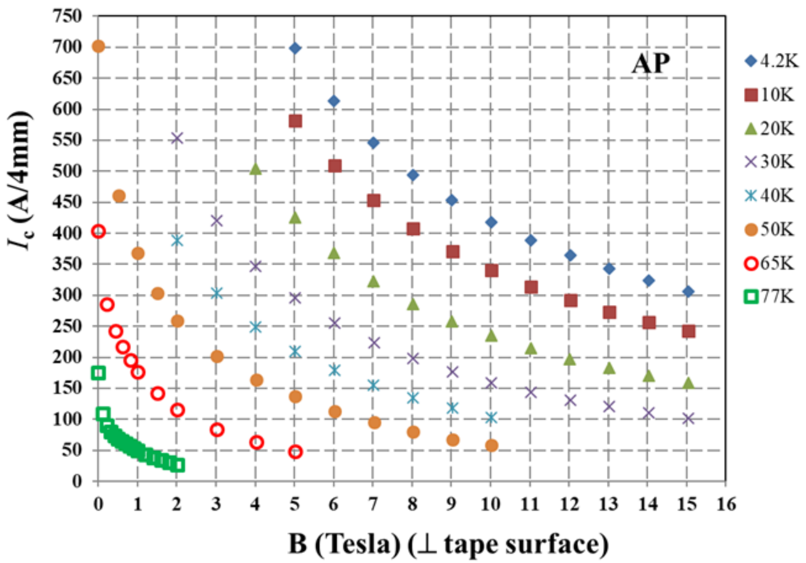
- **<u>High temperature margin</u> (T_C=93 K)**
  - Conduction cooling operation in the temperature range of 20 K

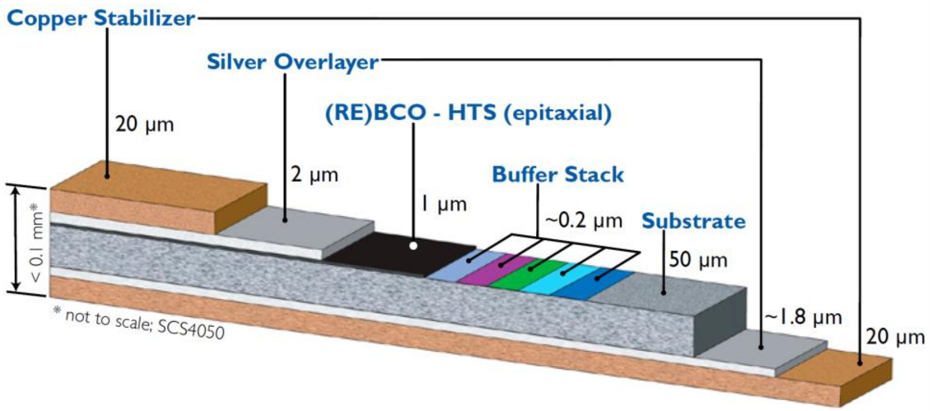
Share 20K refrigerator with Neutron Moderator

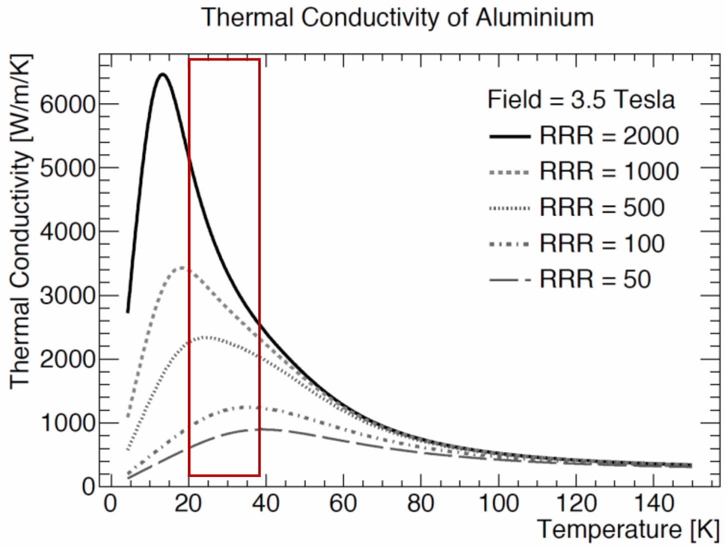




Helium Refrigerator for J-PARC MLF Neutron Moderator: 20K 6kW





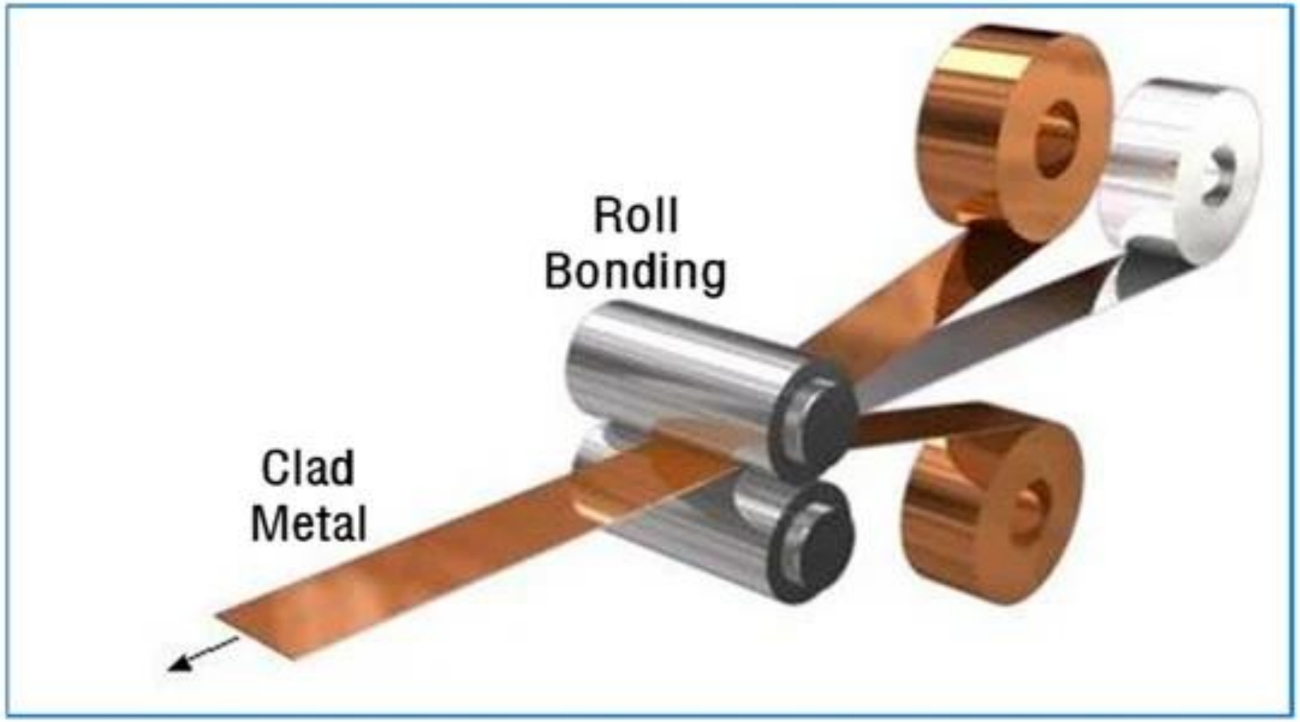


Aluminum Stabilized HTS conductor

- Add sufficient stabilizer for quench protection
  - Field shut down time constant may not be fast
    - There are sensitive machines such as target and moderators near by
  - Keep engineering current density low ~80 A/mm^2
    - Shutdown time constant ~10 sec
- Yet keep light weight to reduce radiation heat deposit
  - Aluminum as stabilizer

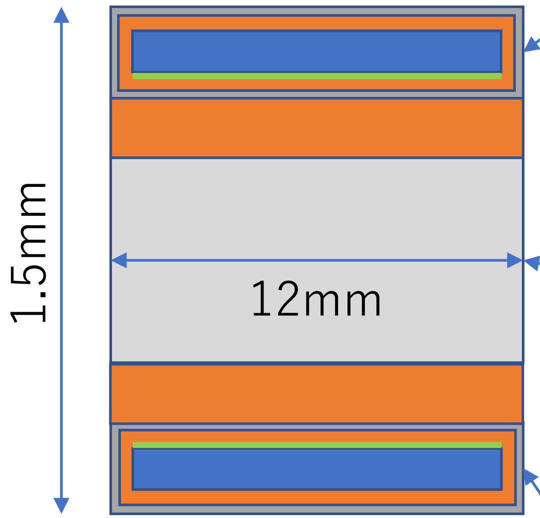
How to implement Aluminum Stabilizer

- Use Clad Metal technology
  - Copper Clad Aluminum



Examples of Clad Metal Usage

Al Stabilized HTS by Clad Metal



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

HTS Tape
12mm wide tape
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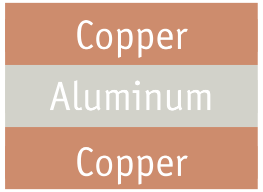
Copper Clad Aluminum



Width (in)	0.125 – 25.000
Thickness (in)	0.005 – 0.120
Outer layer ratio %	5% – 30%
Core material	Alum alloy
Layer material	Copper alloy

Engineered Materials Solutions
Wickeder Group

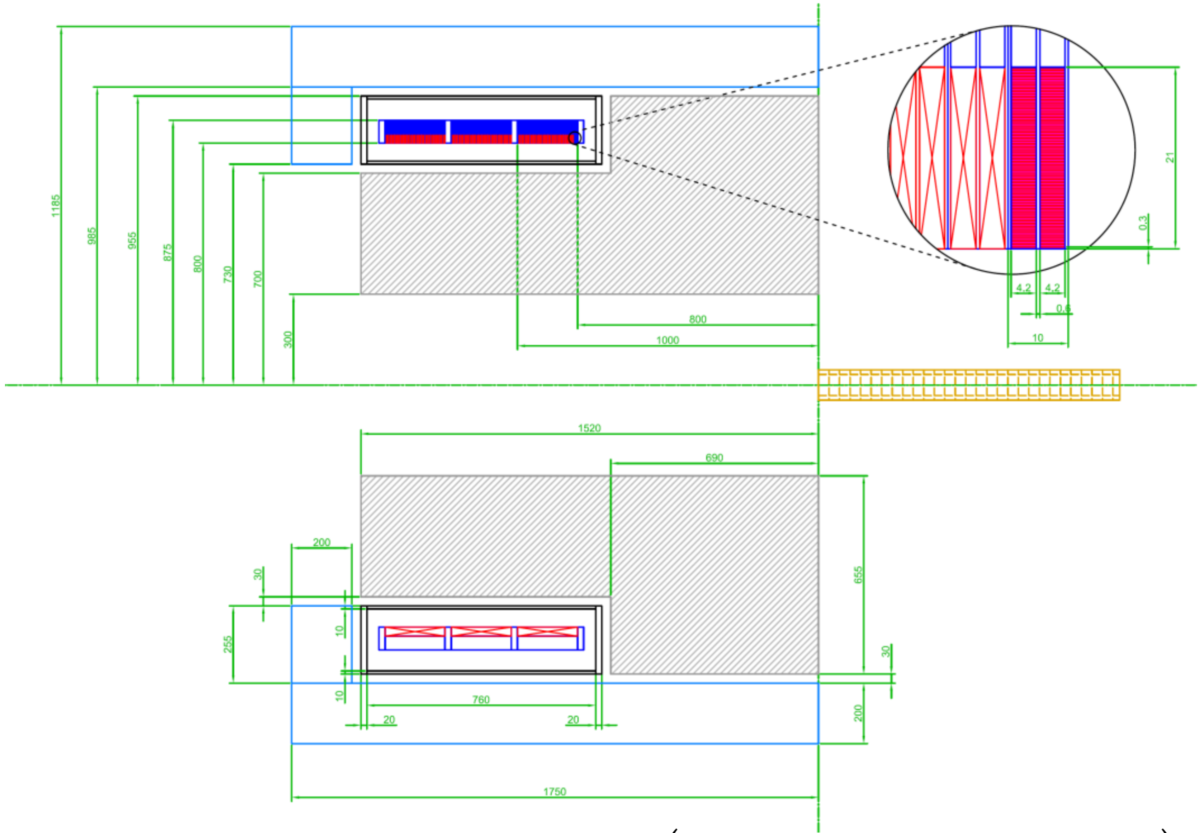
Material Ratio
Thickness: ~1.3mm
Aluminum: ~85% (2.7)
Copper: ~10% (8.9)
Hastelloy: ~5% (8.9)
Av. Density:= 3.6 g/cm^3

Operation Condition
Field: 3T
Temperature: 30K
Operation Current: 1200A
Margin: ~50%
Current Density: ~77 A/mm^2

Coil Configuration

Series of pancake coils

Parameter	Value
Coil Inner Diameter	1600 mm
Coil Thickness	55 mm
Double Pancake coil	
Number of Turns	70 (35 each)
Width	30 mm
Number of DP Coils	20
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



Schematic of capture coil (drawing is old version)

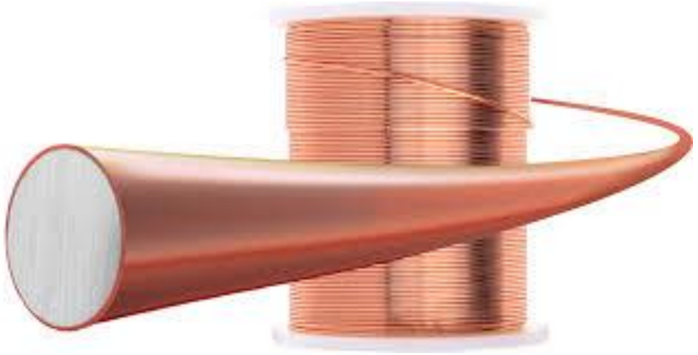
Quench protection by 0.4Ω dump resister
Shutdown time constant: 10sec
Magnet terminal voltage: 500V

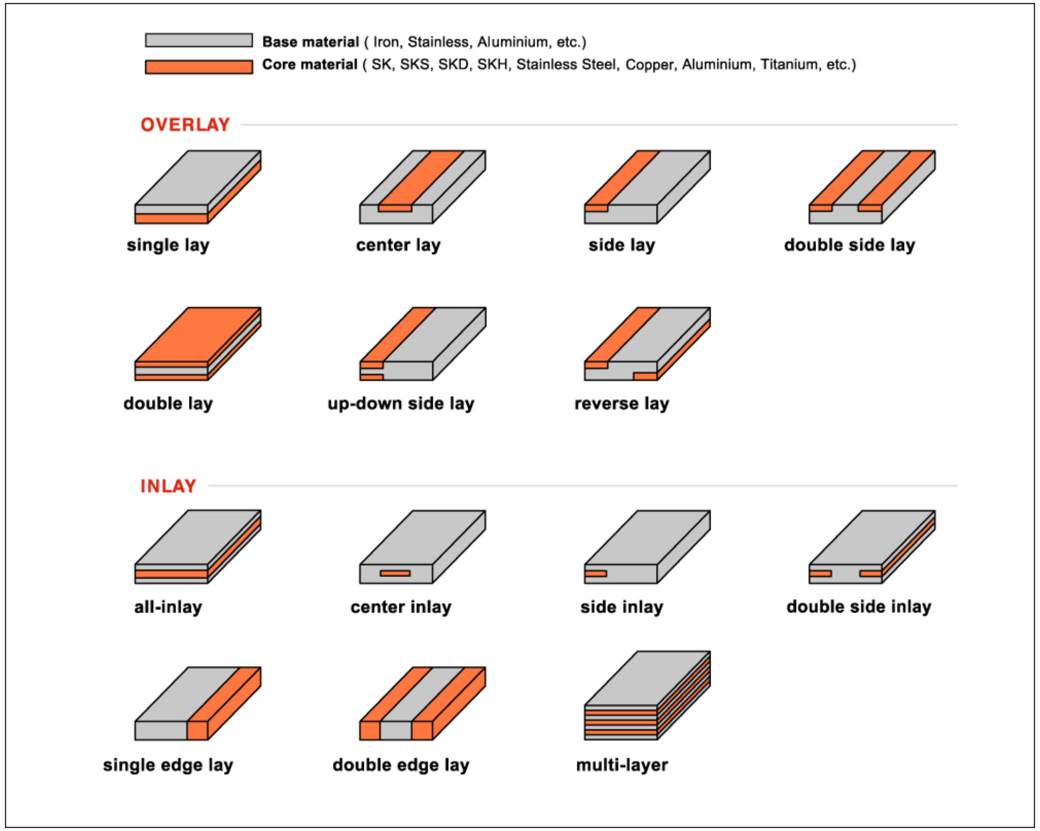
Conductor additional cost: ~ 2M$
Cost saving in refrigerator > 3M$

Cost saving only if coil survive more than 10 years

Clad Metals

- Various shapes available

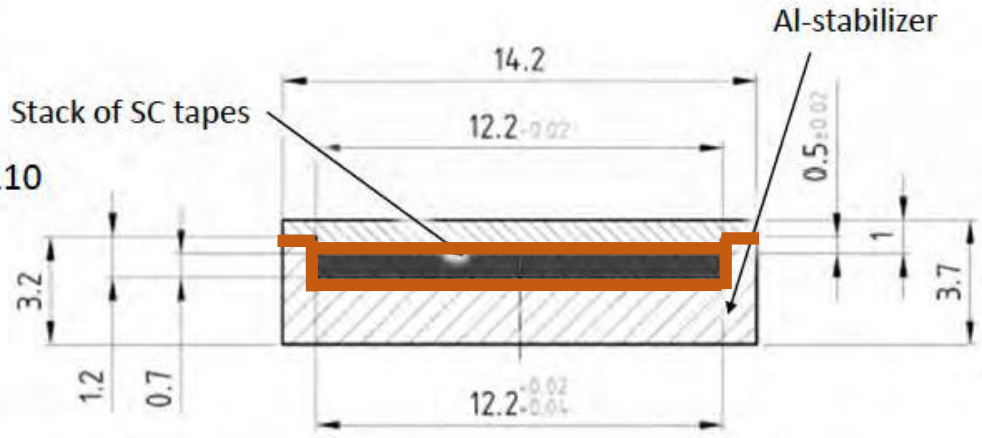


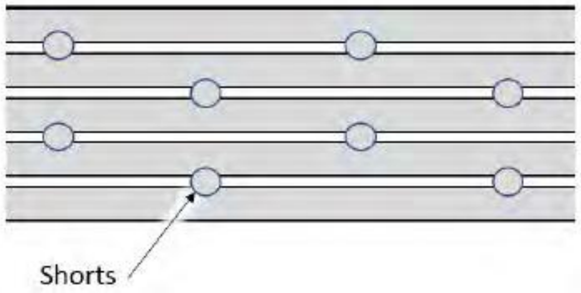


AMS-100

Current conductor layout:

- Stack of twenty 12 mm wide HTS tapes, 25 µm substrate of 5 µm of stabilizer.
- HTS stack is soldered to tin-coated aluminum (6110 series) conductor stabilizer.
- Conductor closed by welded cap.
- Conductor thickness of 3.7 mm.
- Outer surface anodized to provide turn-to-turn insulation.





Shorting turns by (EB / laser) point welding.

- 1 mm² weld provides a turn-to-turn resistance of about 3e-5 Ω.
- AMS-100 -> 1250 mm² per turn (10 % of the circumference) covered with point welds of 1 mm² -> τ = 10 hours.
- Provides mechanical strength and provides thermal/electrical path.
- Shorts are within the envelope of the conductor pack.
- To be tested and to be demonstrated.

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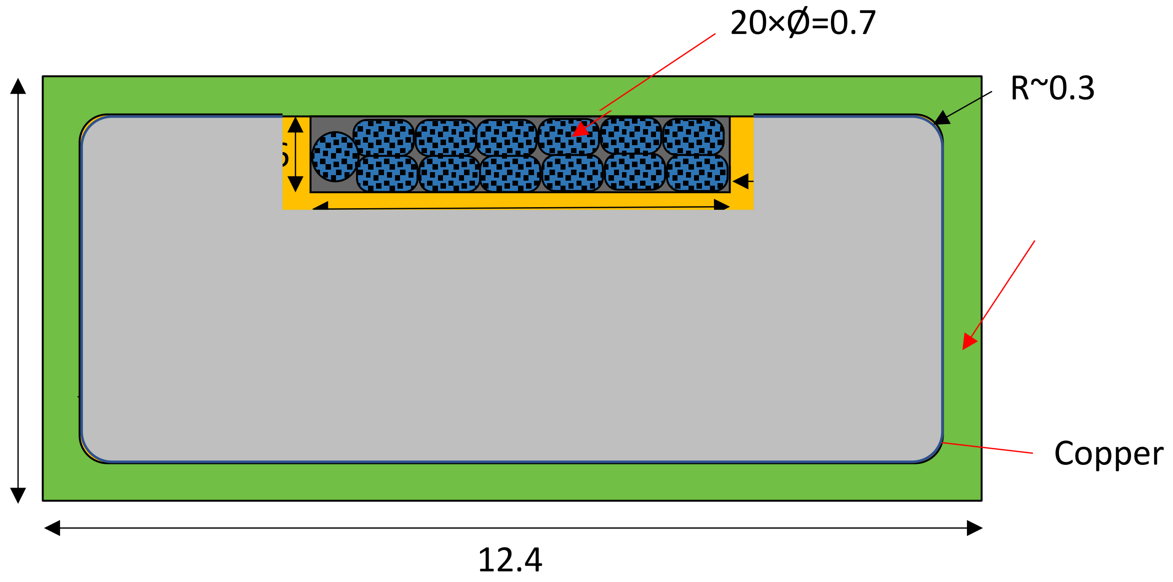
- It can be made with some compromise
    - Use copper clad (add some copper: increase density..)

Copper Clad Aluminum for EIC?

- Copper stabilizer can be converted to copper clad aluminum.
  - Can obtain desired shape CCA?
  - With enough size accuracy?
  - Within the schedule?
  - Manufacturer?

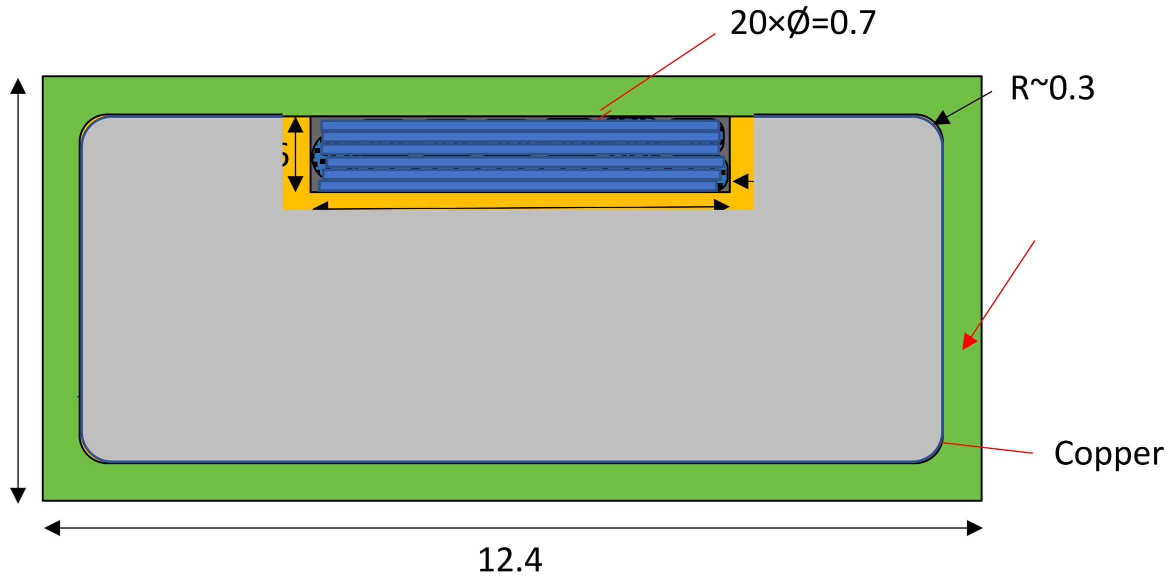


Dimensions are in mm

HTS EIC?

- 10 layer of 6mm wide HTS
  - Ic at 3T 30K: ~6000A
  - Additional cost ~8M$ total (16.2km)
    - Can refrigeration cost reduction compensate the above cost?

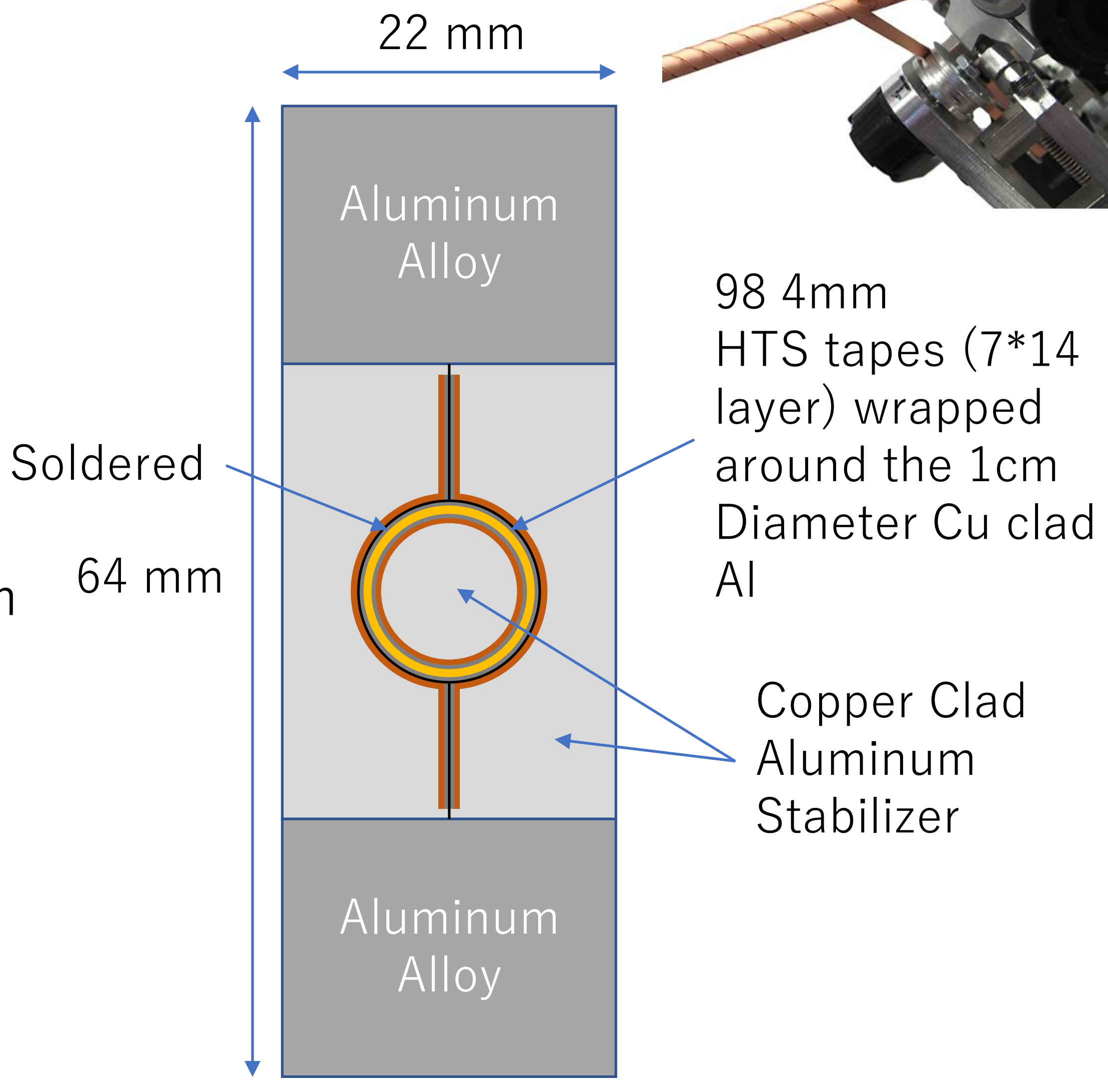
    → maybe not; need big discount on HTS

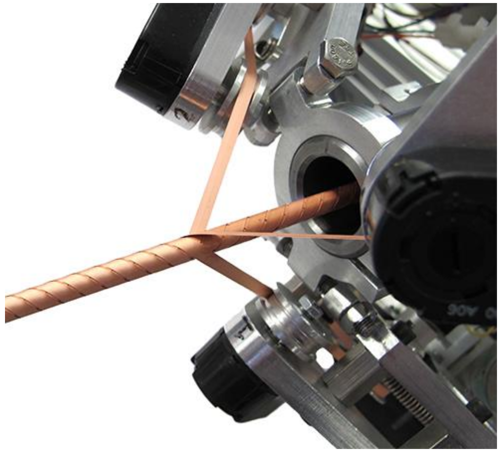


Dimensions are in mm

Can it be extended to CMS like solenoid?

- Critical Current @ 5 T, 30 K
  - Single tape(4mm wide): ~300 A
  - 98 tapes: ~ 98*300 ~ 29kA/(20kAop)
    - Additional cost ~3,000$/m ~150M$ for 50km
      - Too expensive for now





Summary

- Clad Metals
  - Now widely used
  - Various shapes available
  - Copper Clad Aluminum may solve soldering issue
  - It can be the solution for Aluminum stabilized conductor for both HTS and LTS
- HTS?
  - For now, HTS is maybe too expensive for detector magnets
    - But with optimum cost reduction it can be a good candidate in the future
  - It can be used for the special occasions for now
    - Large heat load such as secondary beam capture magnet
    - Need to avoid complicated refrigeration system such as space usage