10 kA joints for Multi-Tape HTS Cables

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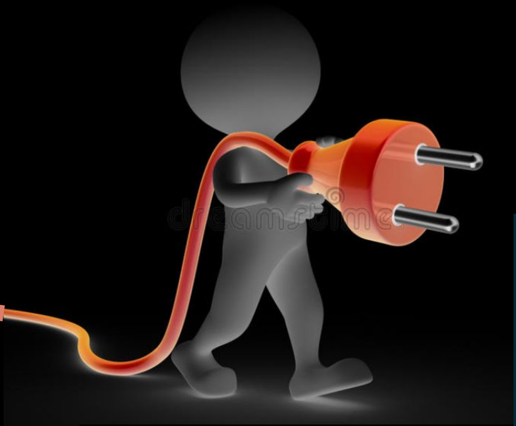
Magnet Technology 2017, Amsterdam, NL



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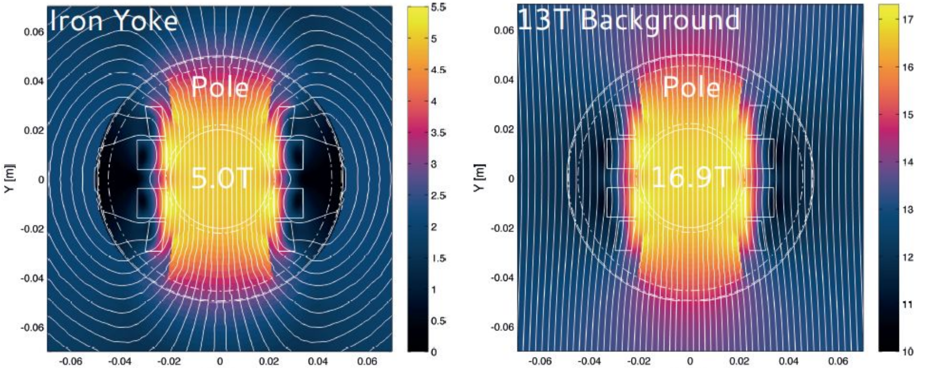
TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

EuCARD²

CERN

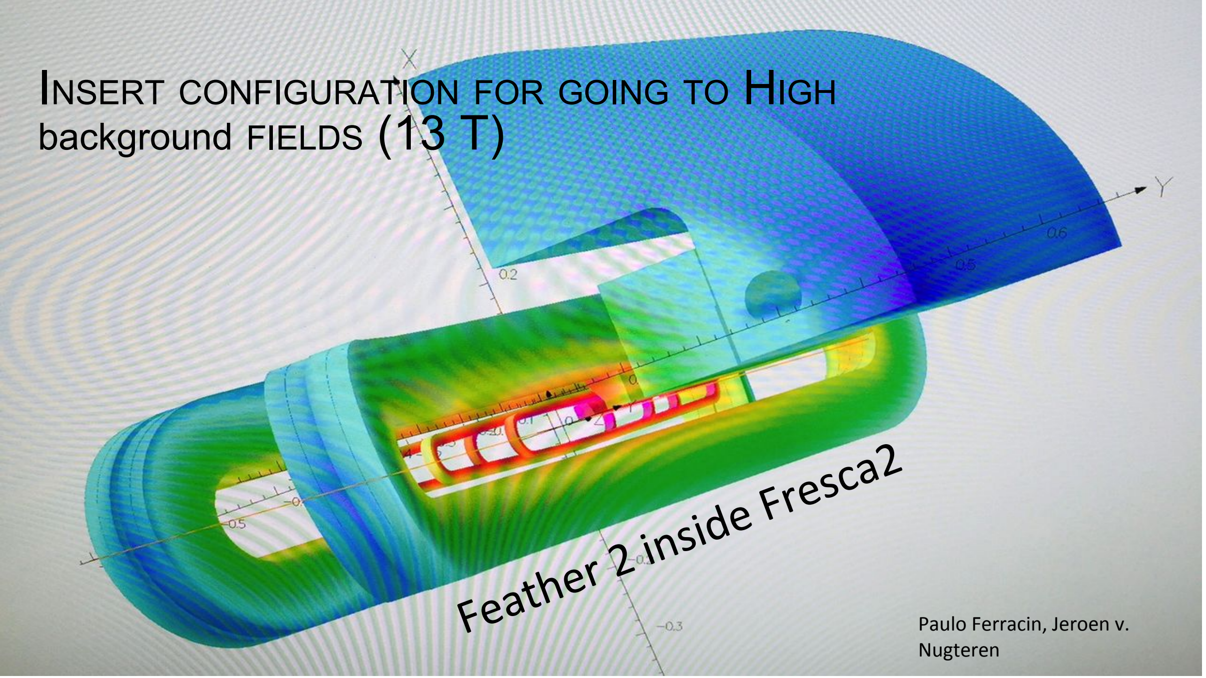
EuCARD-2 High Temperature Superconductor (HTS) Project

- **WP10 Magnet design: 40 mm Clear-Aperture Accelerator Dipole Demonstrator**
  - **Cable: so-called “Roebel” wound from REBCO tapes**

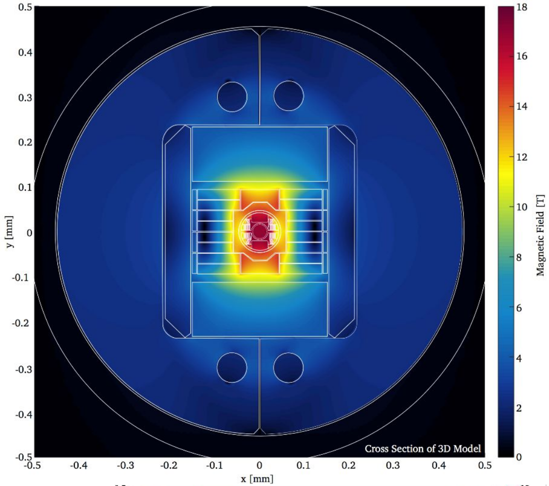


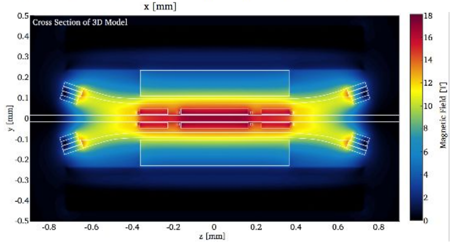
Side View of the Two Assembled and Impregnated Feather-M2 Poles

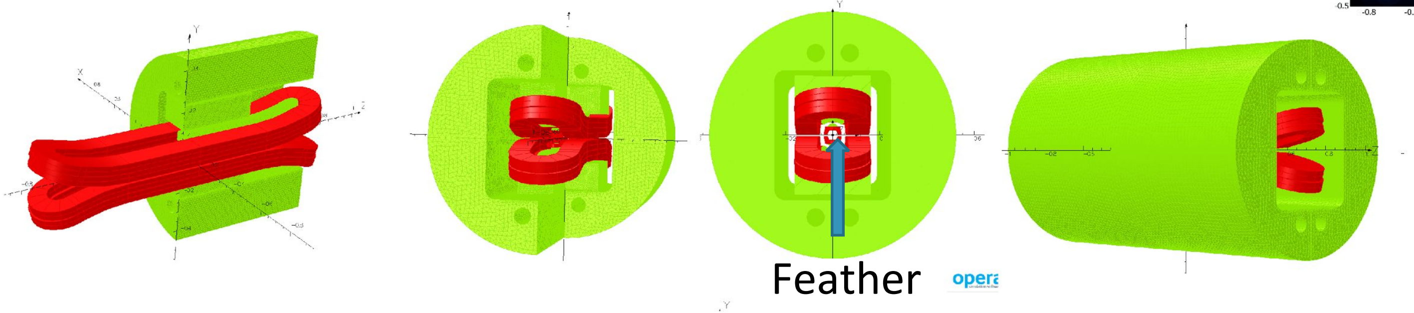
Insert configuration for going to High background fields (13 T)



Paulo Ferracin, Jeroen v. Nugteren







Feather M2

Talk overview

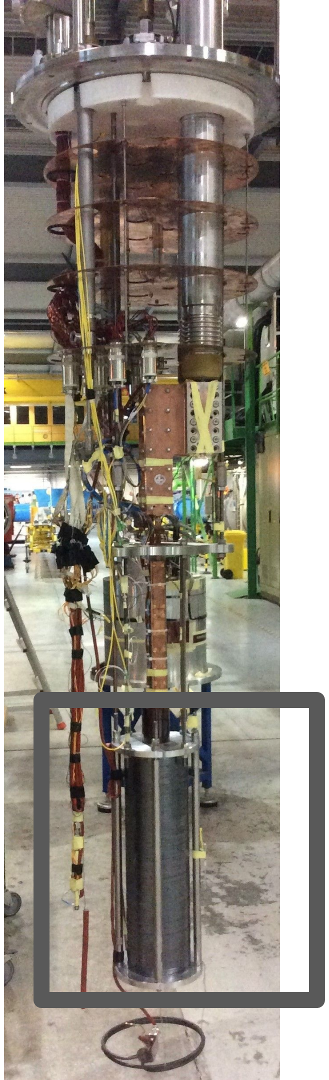
- Joint options for the FM2
- Requirements for a good joint
- Soldering process
- Testing results

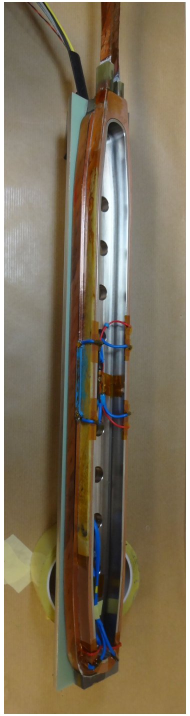
- Conclusion

Feather M0.4

"Inexpensive"
race track
Roebel test coil for
testing and solving
problems of FM2

Right: FM0.4
Ready to be
moved into
cryostat In a
test
insert

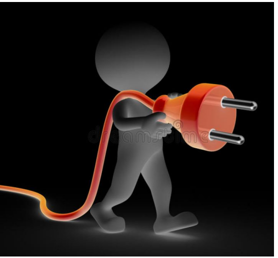




For testing, the FM2 magnet needed a connection to the cryostat leads and between the poles

Requirements for a good joint:

- **We have to be able to connect/disconnect from test site cryostat, or disconnect/exchange poles, no in situ soldering -> We need a "Roebel Plug"**
- **Soldering only to construct the "plugs" (connectors), ex-situ**
- **To do a safe soldered lap joint between tapes and the connector, we need large enough area**
- **We need to connect the connector into cryostat somehow**

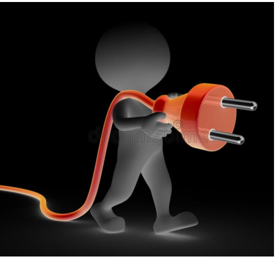


How?

For testing, the FM2 magnet needed a connection to the cryostat leads and between the poles

Requirements for a good joint:

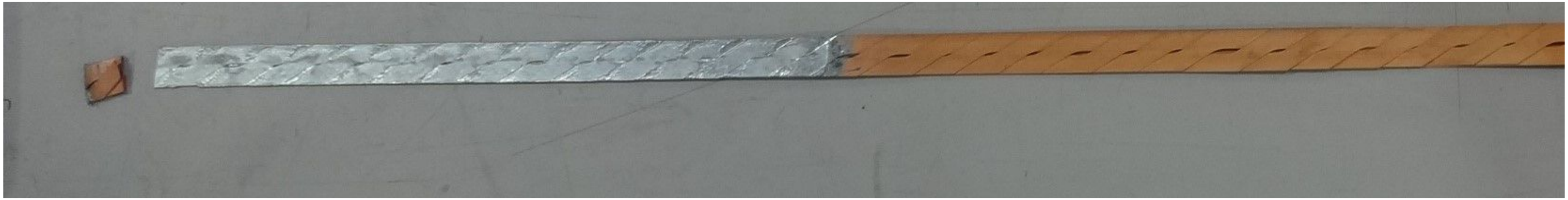
- **We don't want to focus on joint problems during the testing, but to test the magnet (quenches in the coil, not the joint)**



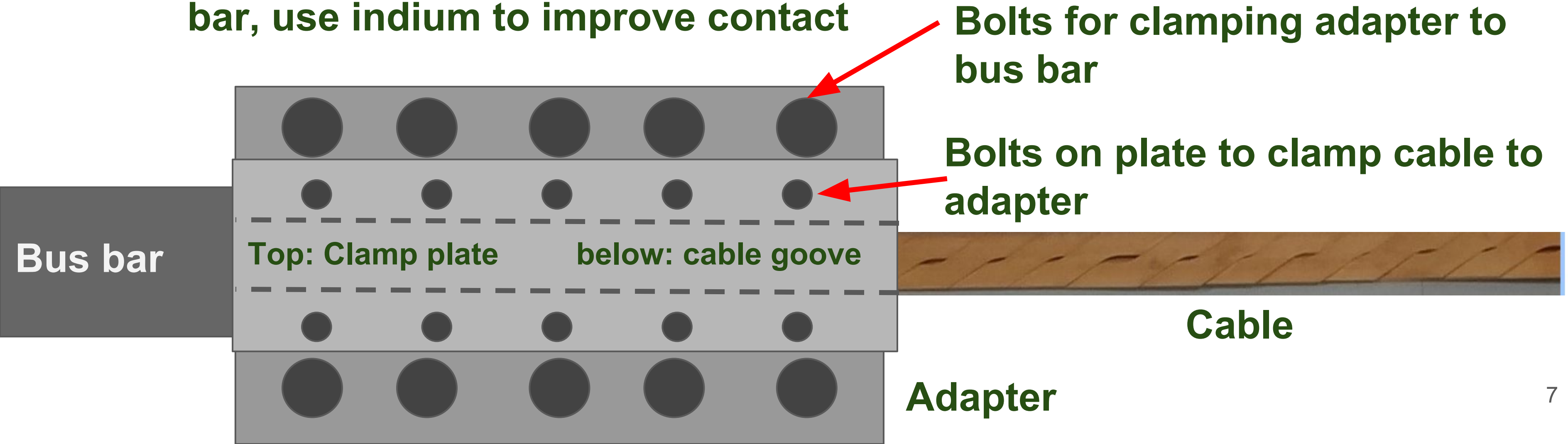
How?

Current leads: First thing to come in mind was to try

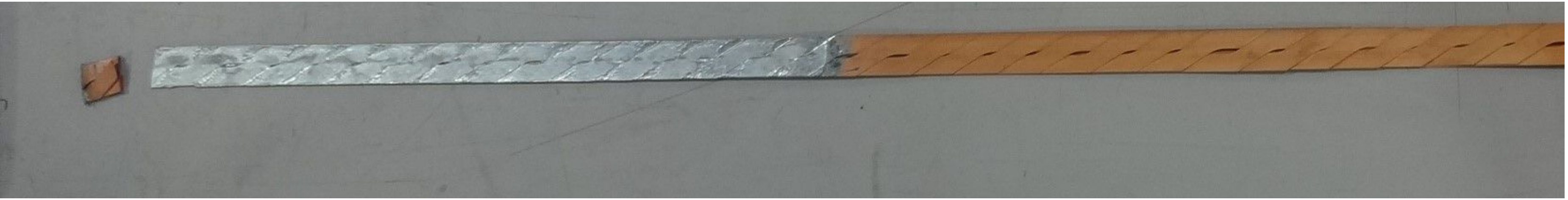
- “Conventional LTS type”
  Soldered block cable joint



Connect the soldered part of cable with a clamp to cryostat bus bar, use indium to improve contact



Connect the soldered part of cable with a clamp directly to cryostat bus bar ---> NOT GOOD



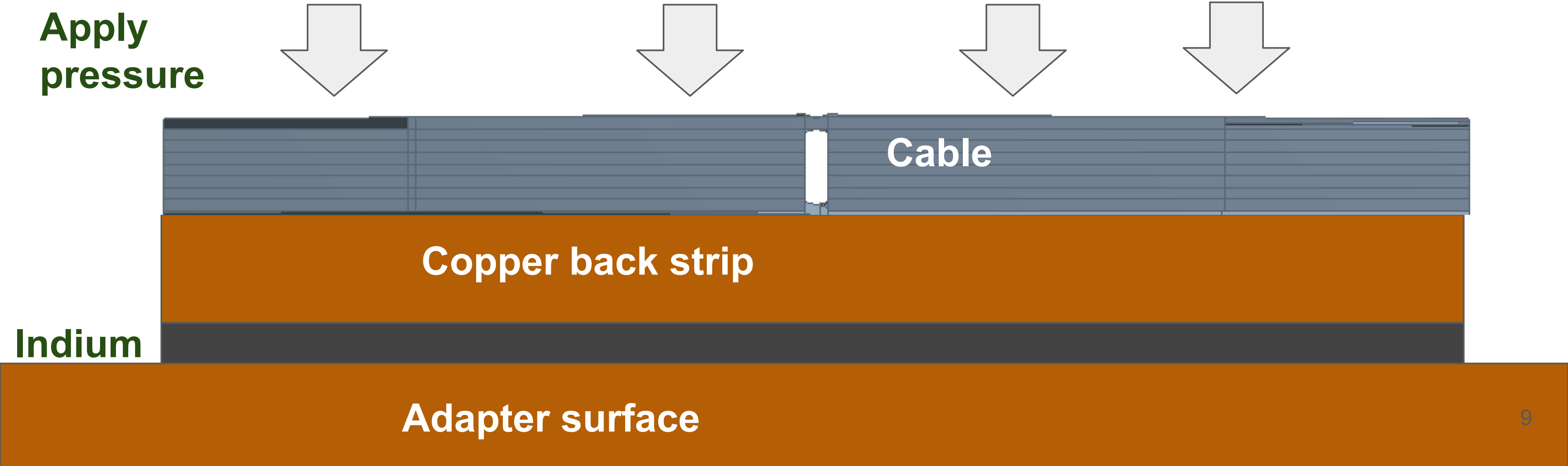
Cable delaminated, when disconnecting the cable from the clamp

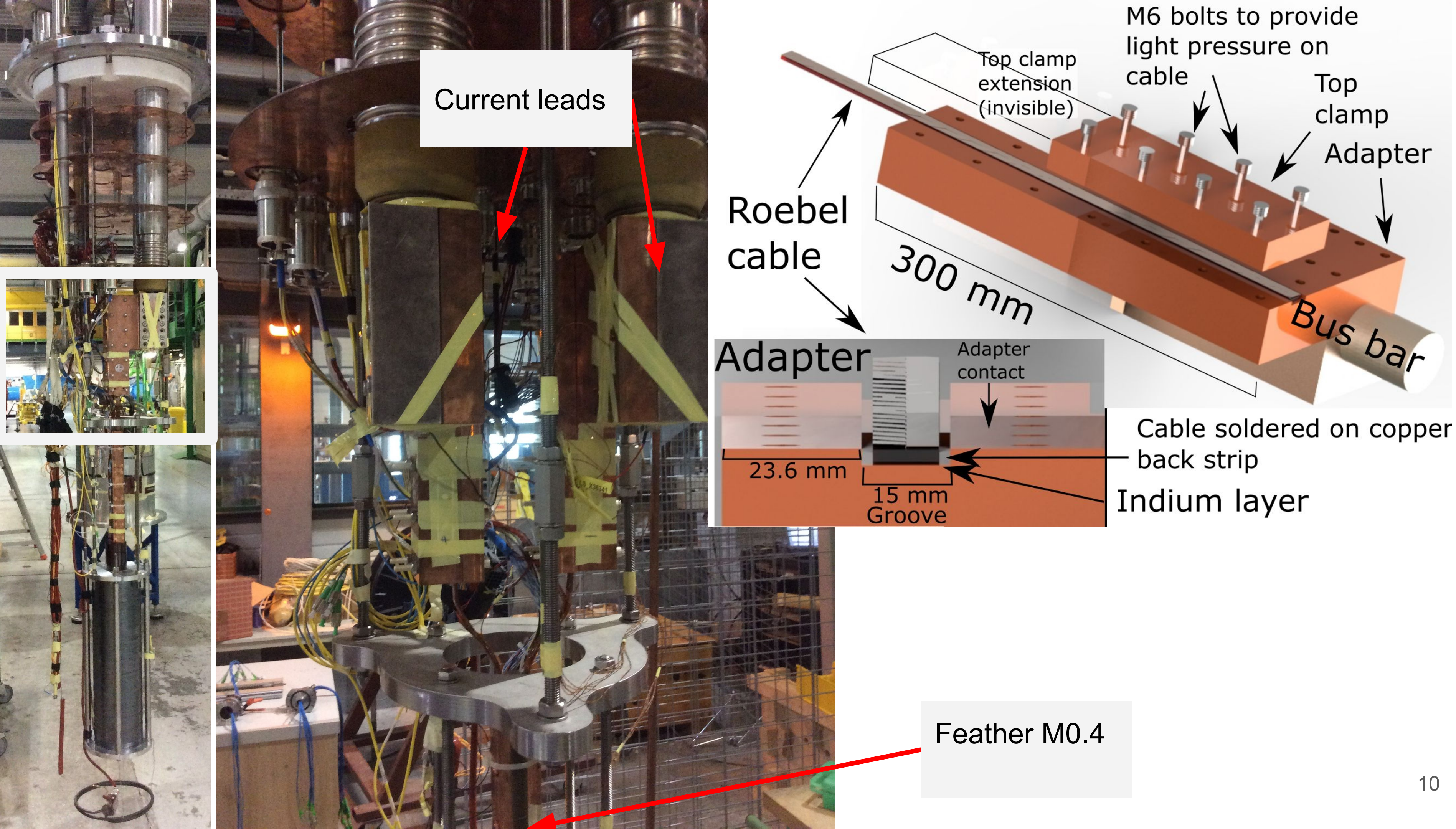
How to fix this??

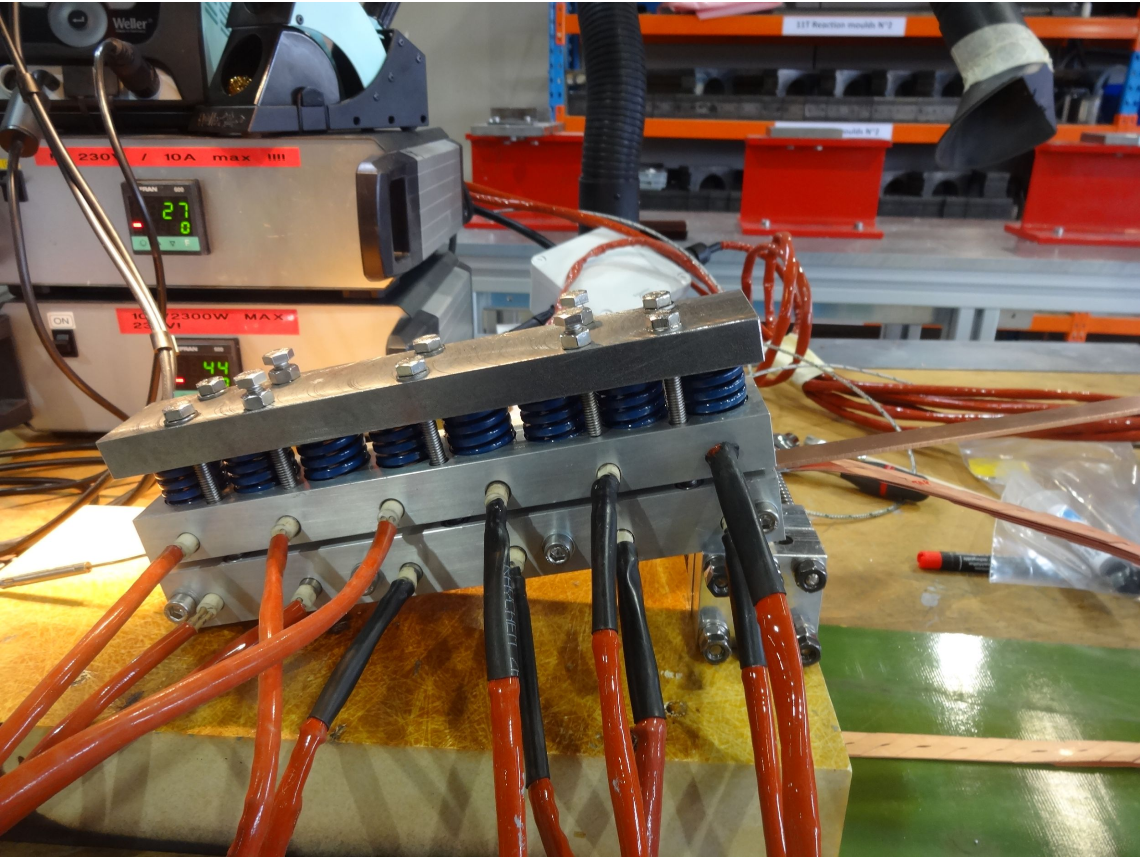
-> need more parts

Common sense: Avoid direct contact of the cable to sticky indium

->Solder Cable to back strip + indium

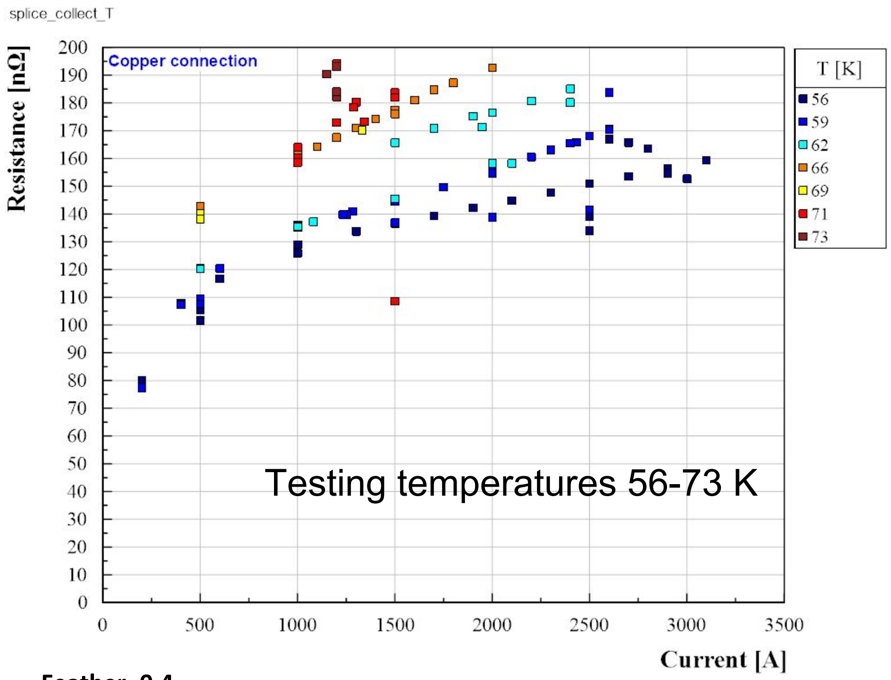


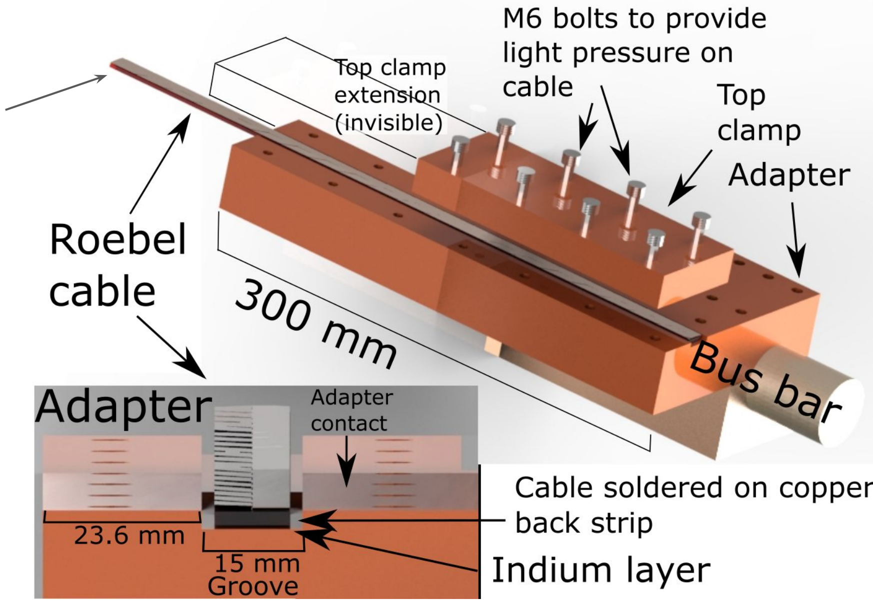

Current leads
Feather M0.4
Top clamp extension (invisible)
M6 bolts to provide light pressure on cable
Top clamp
Adapter
Roebel cable
300 mm
Bus bar
Adapter
Adapter contact
Cable soldered on copper back strip
23.6 mm
15 mm Groove
Indium layer



Constant compression provided during the soldering

+ temperature monitoring





- Run 2: Equivalent Resistance values measured before runaway of Splice 2 at 3200 A (not this joint, another internal splice between two Roebel block joints)
  - Splice 1 < 50 nΩ
  - Splice 2 < 150 nΩ
  - **Copper-clamp < 200 nΩ**
  - Coil < 70 nΩ

Feather_0.4
4-run test report

Hugo Bajas, Antonella Chiuchiolo, Alejandro Diaz Fontalva, Glyn Kirby, Francois Olivier Pincot

5th October 2016

In the Feather 0.4 coil, Bruker tapes were used, but the cable was first batches, “Frankenstein” cable.

After adding cooling to the internal extension of the Roebel, we continued testing with higher currents....

- Test stop at 9600 A due to quench in our joint

Later testing was continued..

finally FM0 went to 12kA at 20K but only for 5 min, due to temperature drifting

- Joint was not stable: eventually we didnt know if the temperature rose because of high resistivity of the joint, or bad conductor performance, or damaged conductor during soldering, because we didn’t know the tape Ic...

-> We had to solve all the joint problems regardless of not knowing why it didn’t work.

We decided to engineer a joint that would certainly solve every problem and take away all worries

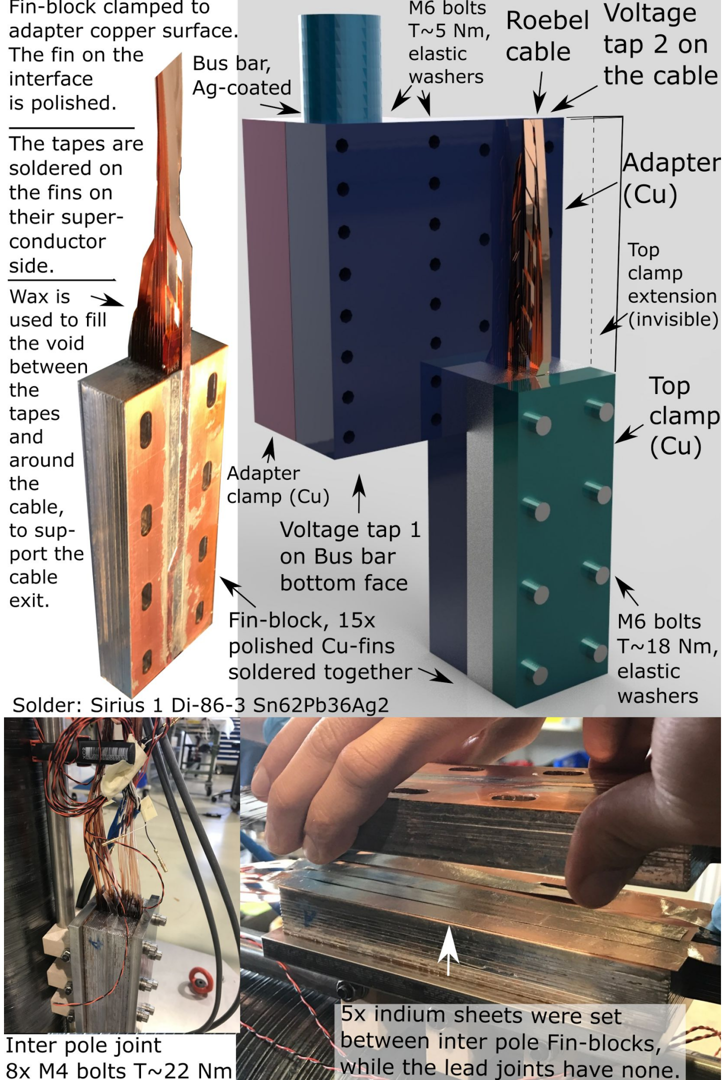
(Pressure with testing schedule of FM2)

Solution: Fin-block joint

- Solder all tapes to Cu-fins
- solder fins together
- polish the clamping interfaces
- clamp the block to adapter

inter pole joint:

- clamp two Fin-blocks together, we used indium to further improve the contact here



Performance comparison between the joints

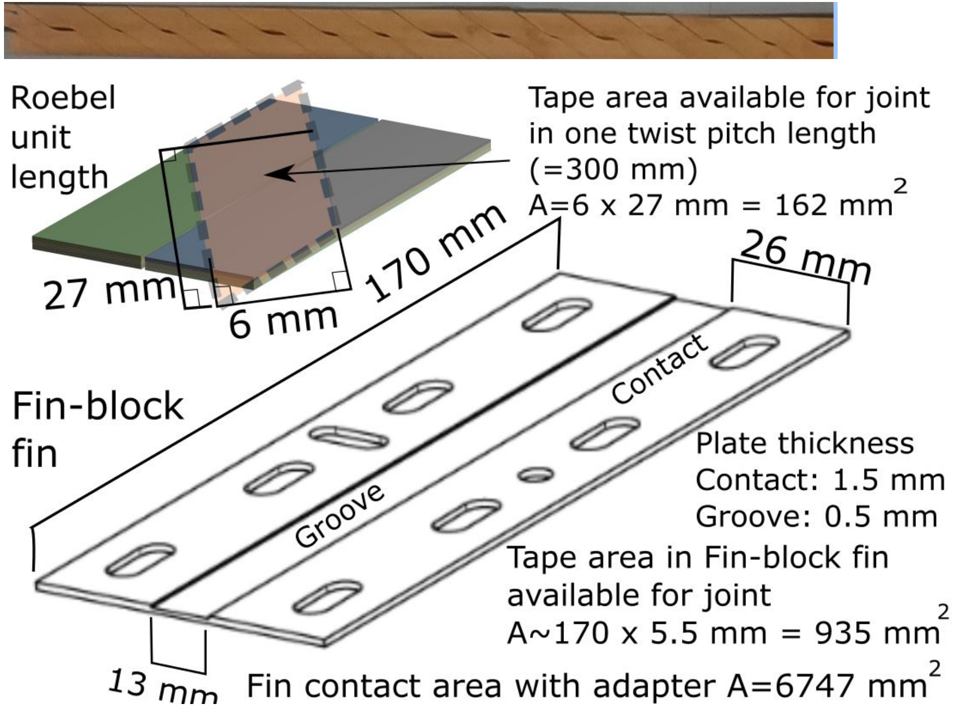


TABLE I
HEAT DISSIPATION RATE [W] OF JOINTS AT 4.2 K, 10 KA, DUE TO TAPE INTERNAL RESISTANCE

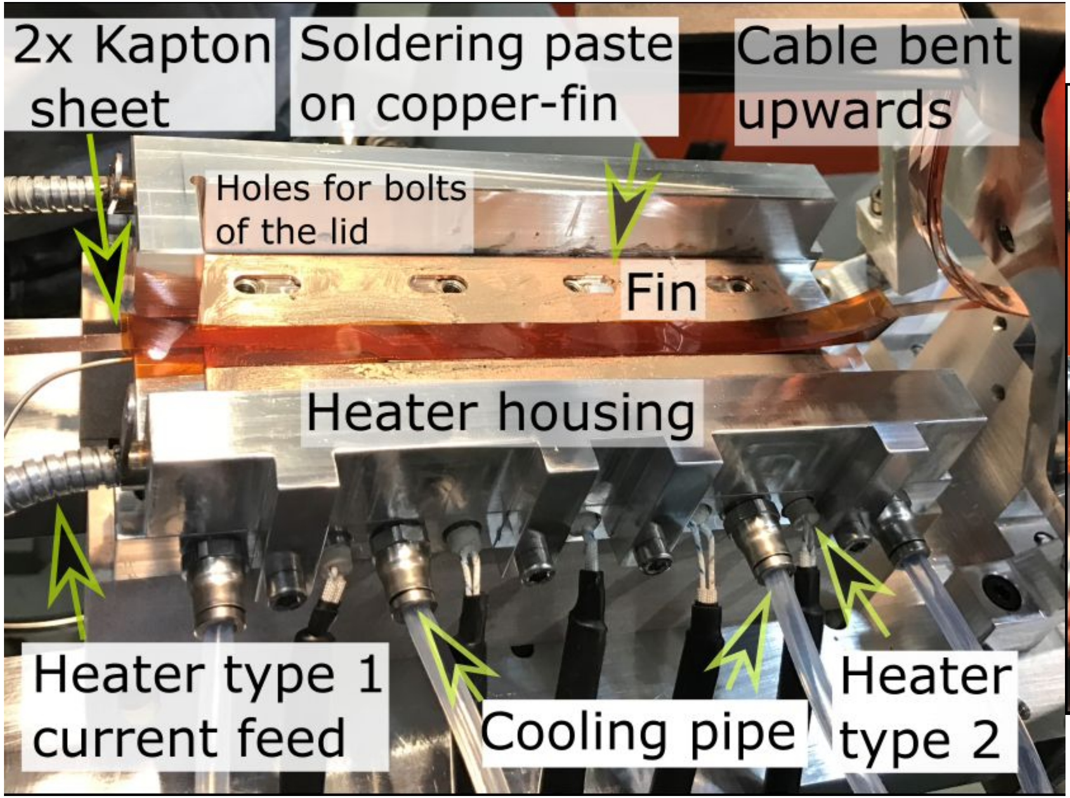
Joint	SuperPower	SuperOx	Bruker	Sunam	AMSC
Fin-block	1.3	1.3	0.4	29.4	5.4
Soldered block	7.4	7.4	2.5	169.8	31.3

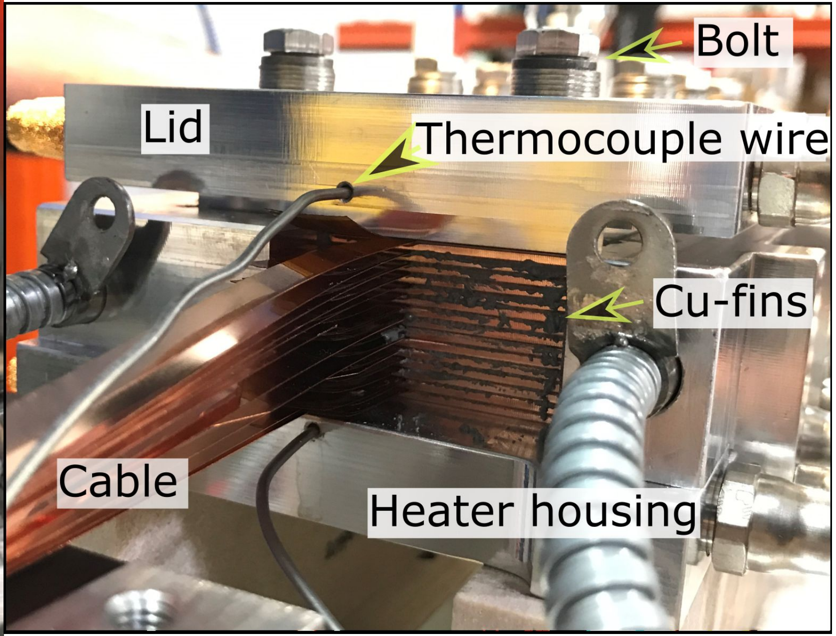
- We can estimate the resistance of the two joints by looking at the tape internal resistance only

  - We have at least factor 6 lower resistance in the Fin-block based on simple computation,

because the soldered tape area is simply much larger

Soldering equipment Fin-block





Soldering

- The preparation of the soldering configuration takes approximately 2 h for two technicians, if all the equipment is available.

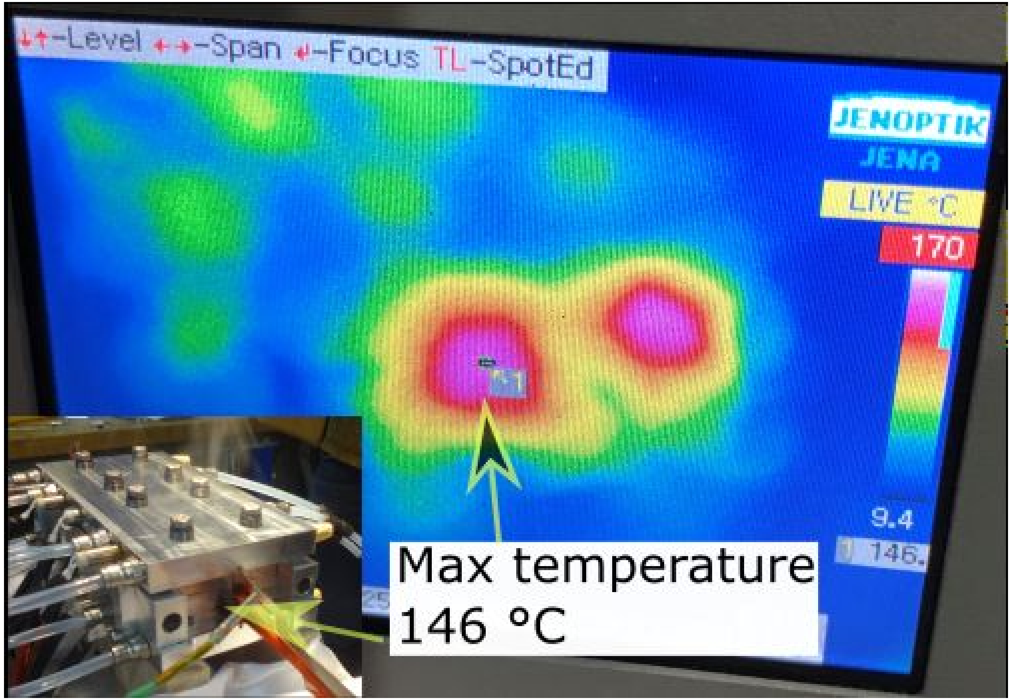
- Sirius 1 Di-86-3 Sn62-Pb36-Ag2 solder

- The solder flux requires 2 min activation time at 140 °C, and melting temperature of the solder is 190 °C.

- The soldering process lasted 40 s at melting temperature.

After that, the joint was rapidly cooled down by blowing ambient c air into the joint.

Thermal camera Image



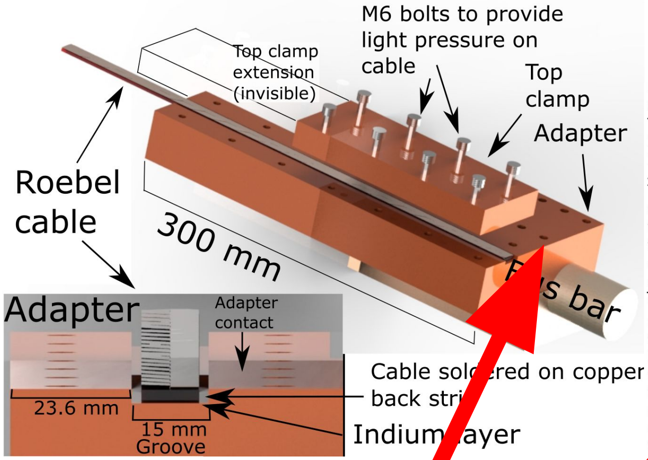
Camera not calibrated: hotter in reality??

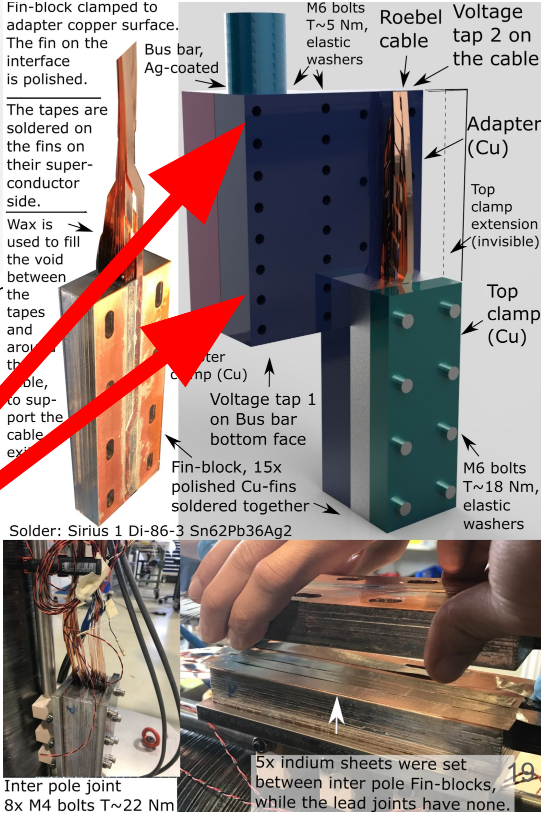
Large uncertainties in the measurement of joint resistance

- We measure the joint resistance over the Vtap on the bus bar and on one of the tapes

-> over 2 clamped interfaces, bus bar to adapter and adapter to Fin-block.

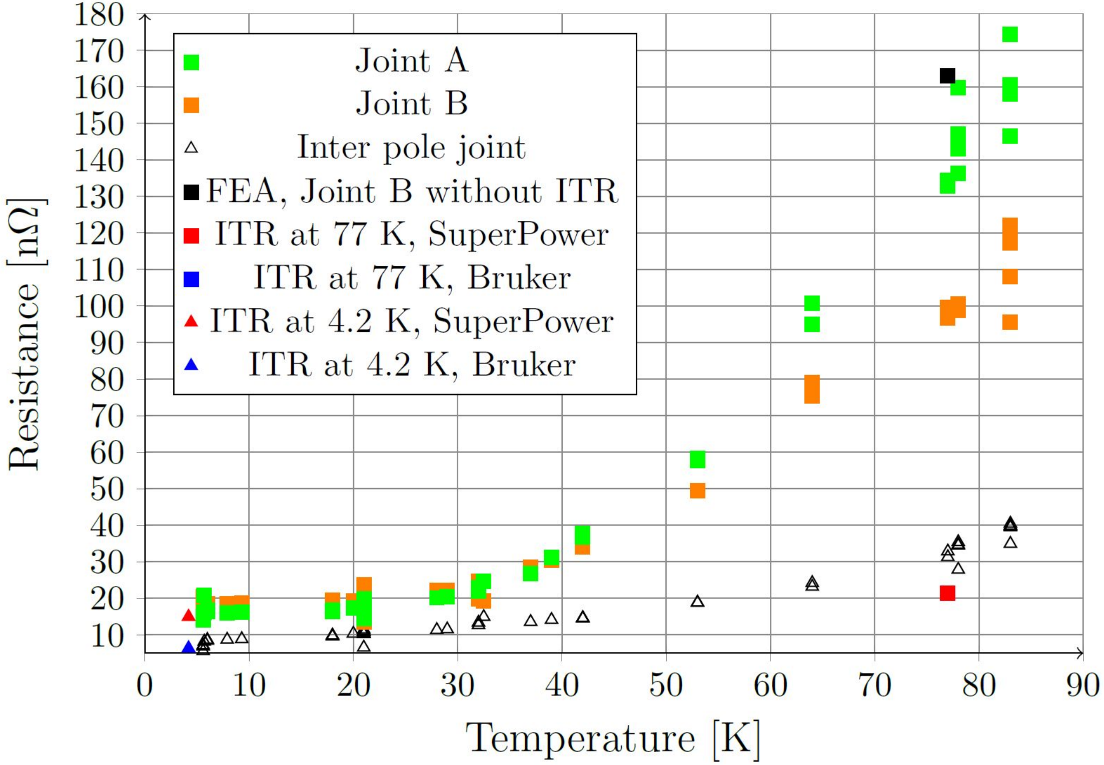
- We dont know the Ic of the cable -> we dont know if the tape reached it's Ic due to heating or if it reached the Ic due to current

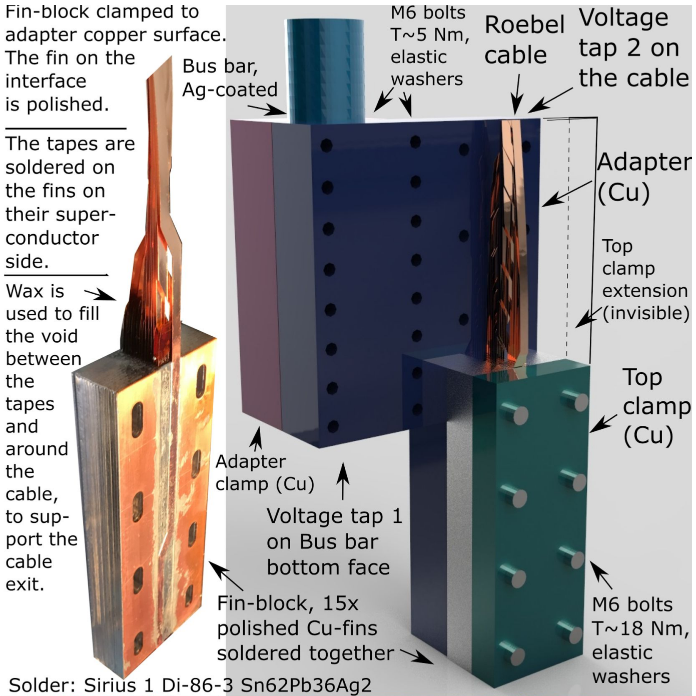


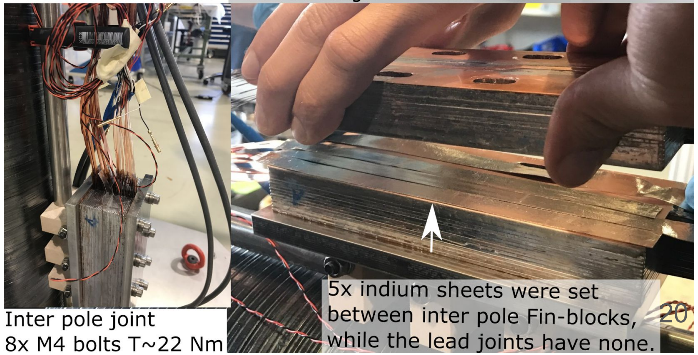


- We dont know the torque of the bolts in both tests connecting the busbar to the Adapter. - > significant impact on resistance

Comparable resistance between the Fin block and the soldered cable joint is close to the points for the inter pole joint since there is Indium to improve the contact





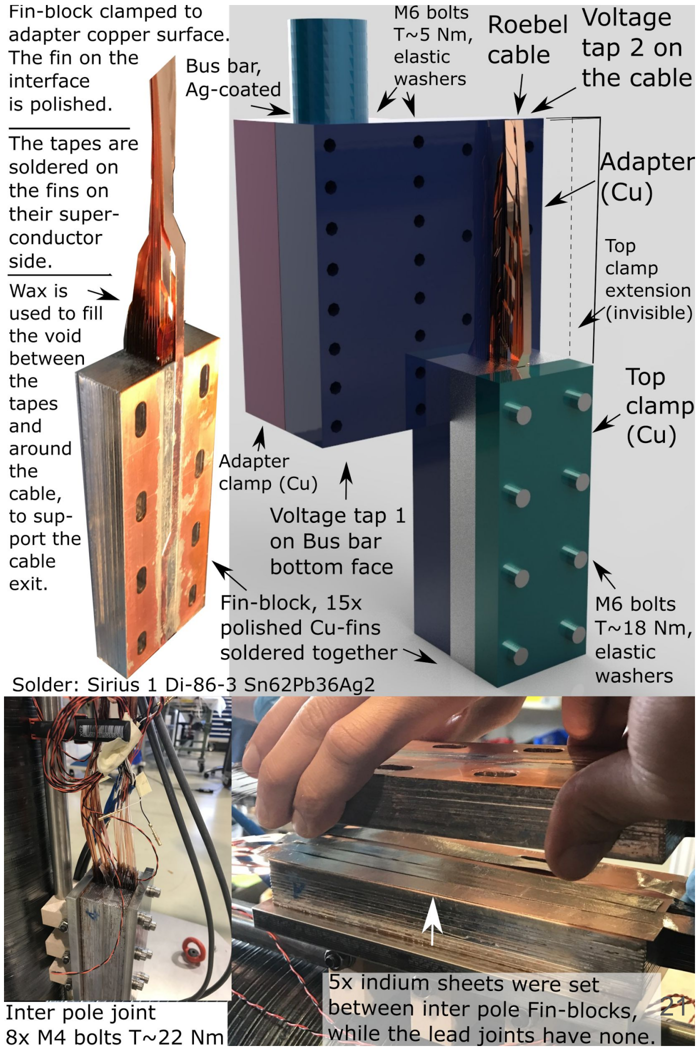


Inter pole joint
8x M4 bolts T~22 Nm

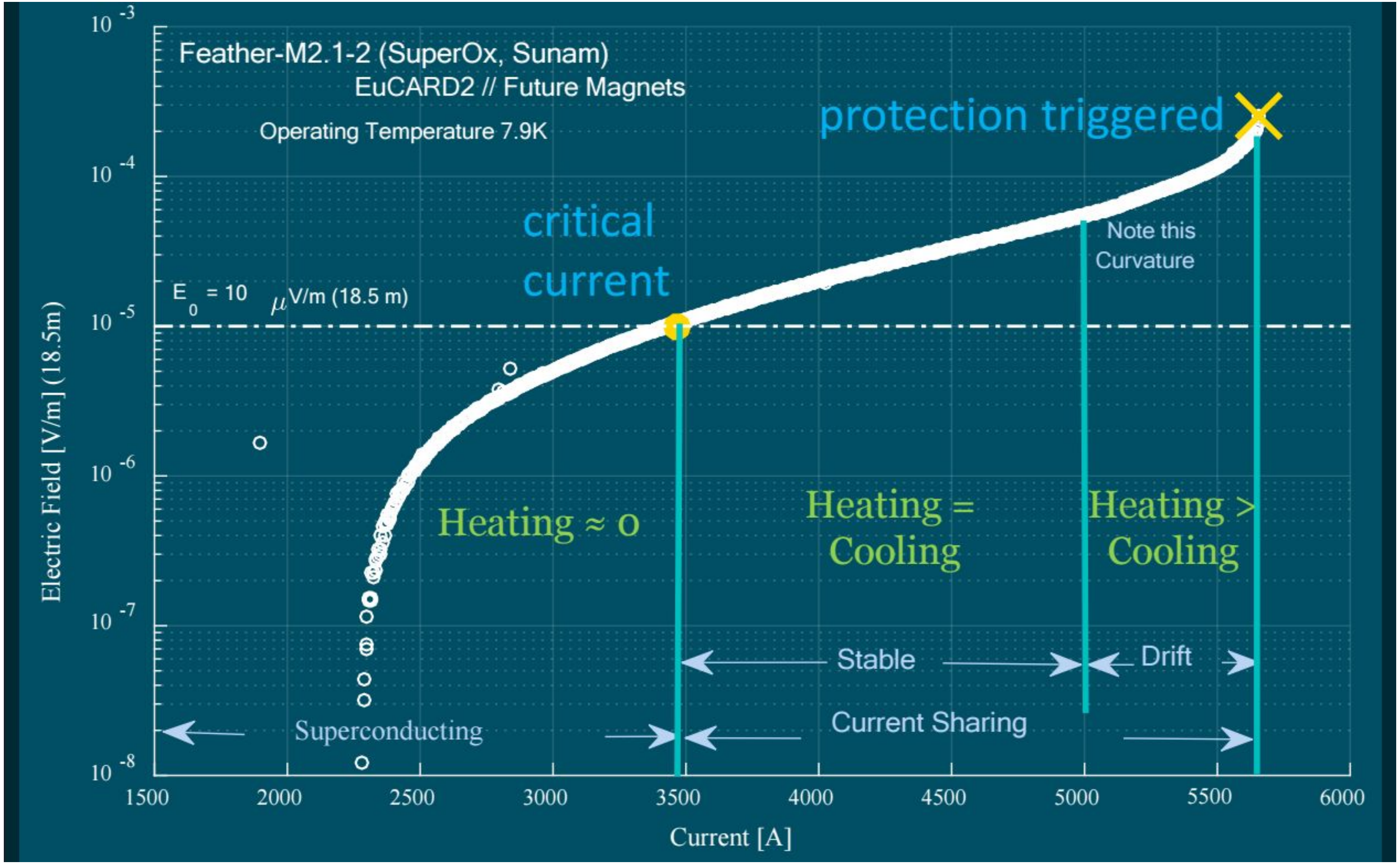
5x indium sheets were set between inter pole Fin-blocks, while the lead joints have none.

Conclusions

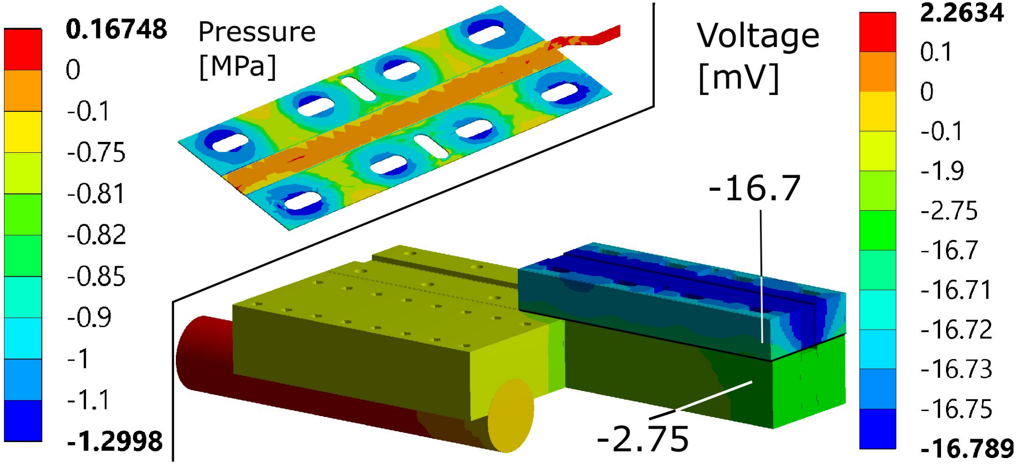
- We have a fully working joint, no issues thermally. We took the FM2 until 6.5 kA with Fin-block.
- We need to develop tape exit, to prevent the tapes to squeeze together due to electromagnetic forces. Maybe instead of wax filling use Stycast.
- Tape exit support need to be connected better to Fin-block



Extra slide FM2.1-2 Critical current



Electromechanical modelling of contact resistances



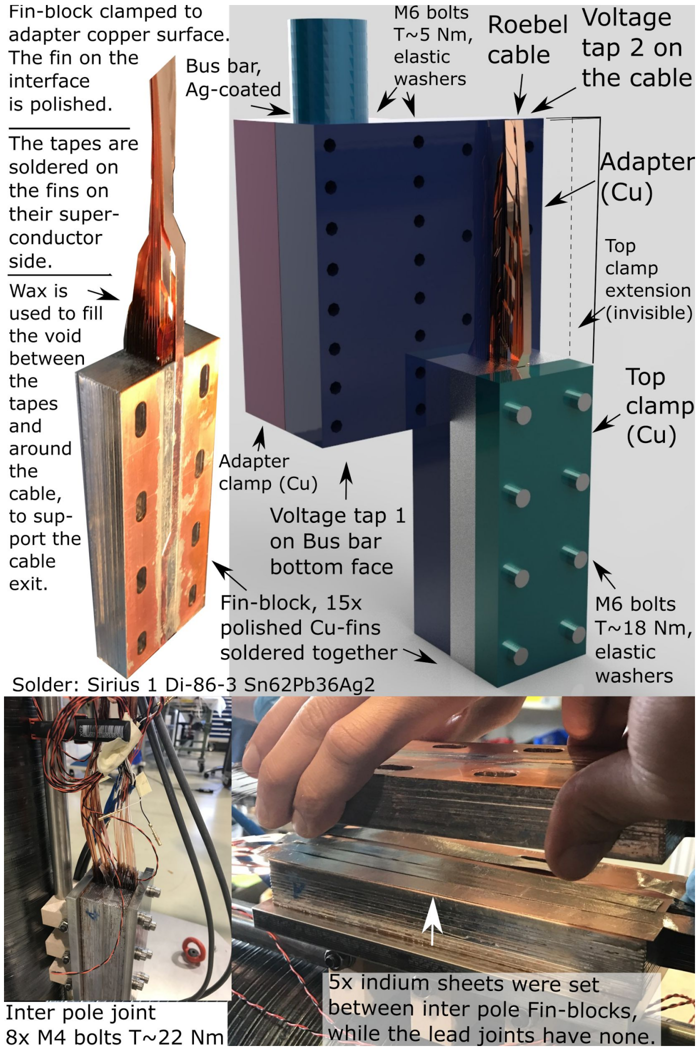


TABLE II
APPROXIMATE RESISTANCE INCREASE OVER THE JOINT B

Location: Interface (I) / Solid (S)	Value	Unit
Bus bar to Adapter (I)	4.4	nΩ
Adapter (S)	14.7	nΩ
Adapter to Fin-block (I)	143.0	nΩ
Fin-block (S)	0.4	nΩ
Total	163.2	nΩ

Extra slide

Testing scheme