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Design Status of the HL-LHC WP3 Splices

EDMS 2779604

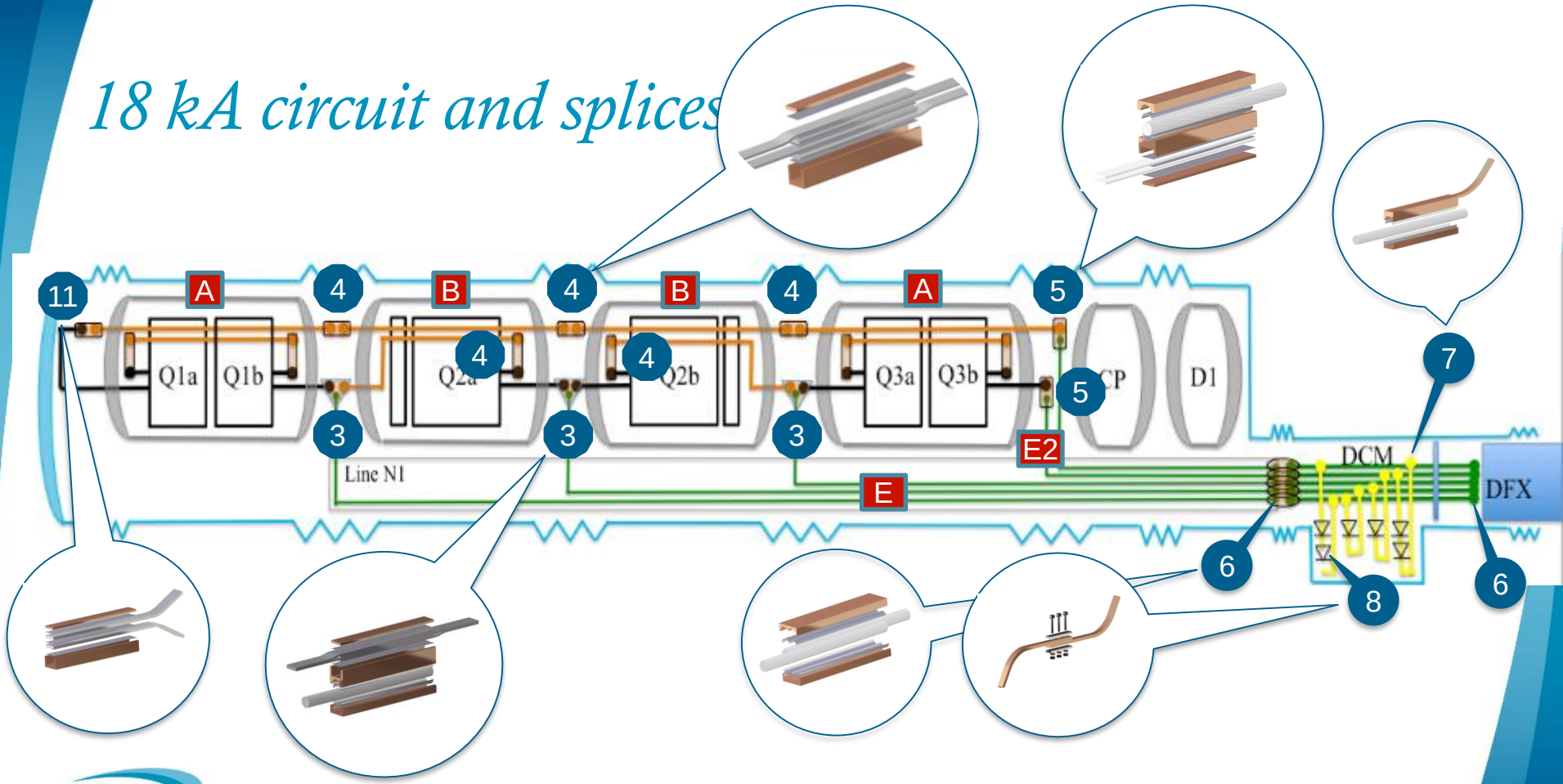
12th HL-LHC Collaboration Meeting, Sept 22, 2022

TE-MSC, R. PRINCIPE

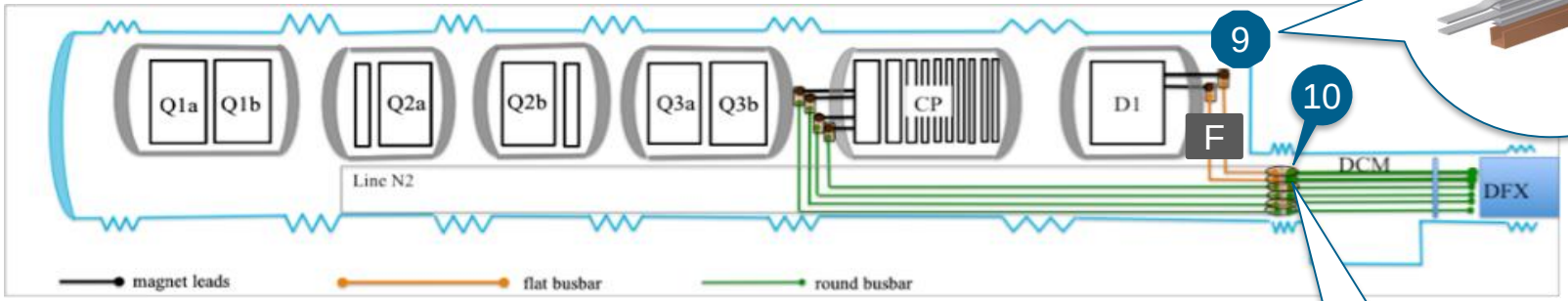
Summary

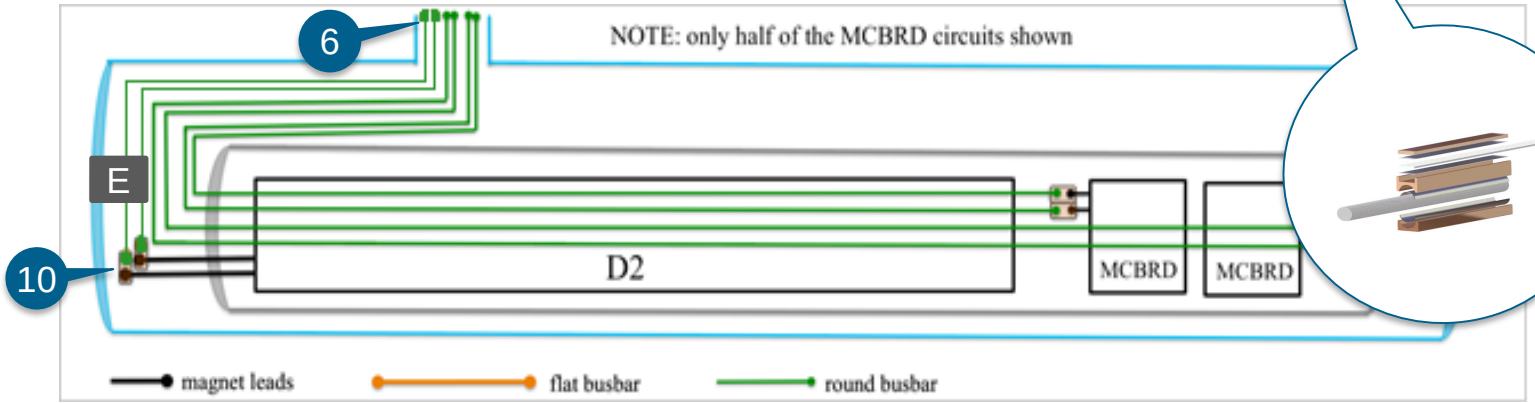
- Introduction;
- The splice qualification process and some test results;
- Integration and construction :
  - Shuffling module;
  - Interconnections;
  - 18 kA cable twisting system;
  - DCM design and construction;
- Conclusion.

18 kA circuit and splices

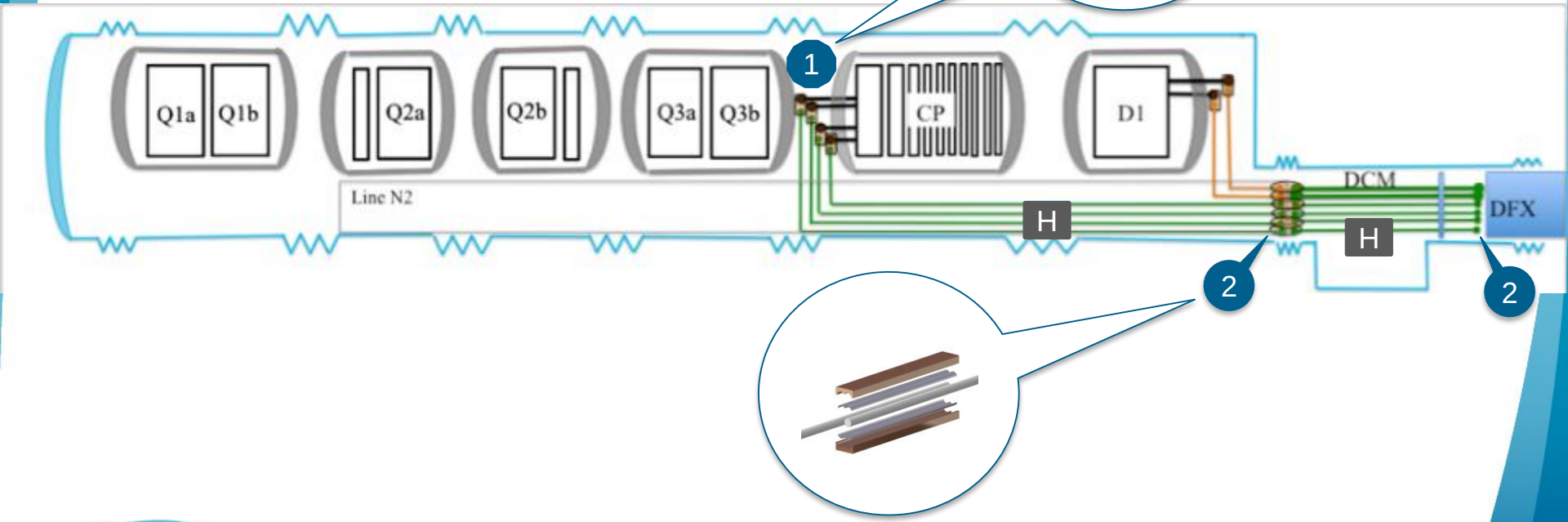


13 kA circuit and splices





2 kA circuit to Orbit Corrector



Ref. documents

- *HL-LHC WP3 Bus Bars technical specification and conceptual lay out* by E. Todesco et al. (EDMS 2029211);
- *HL-LHC Circuits Table V.9.2*, M. Zerlauth et al. (MCF Meeting #79, Jan-2021);

- *WP3 busbars and splices catalogue* in EDMS 2492410 v.27.

Detailed description

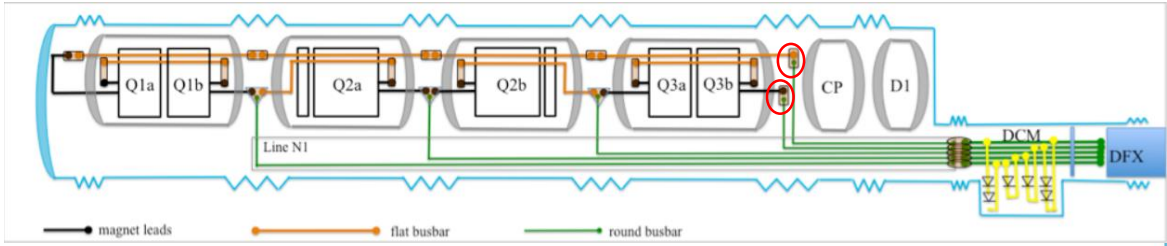
WP3 splice catalogue EDMS@2492410.

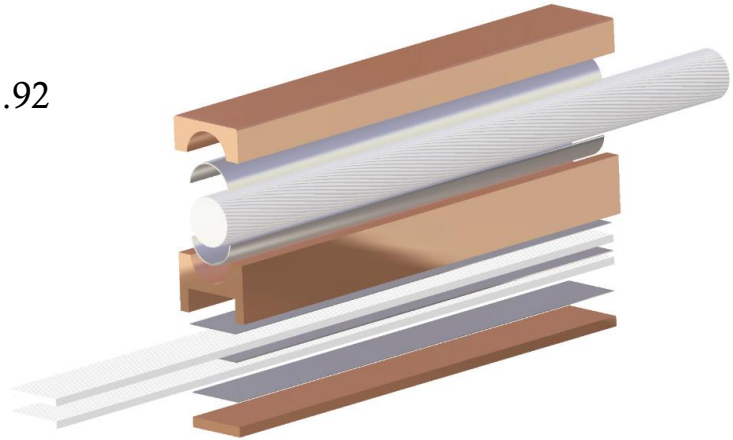
Splice file: a detailed description of the adopted technical solution for any single splice type including :

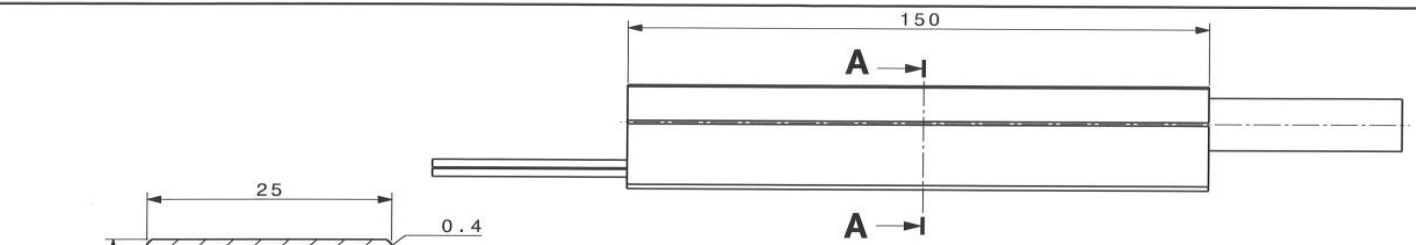
- Technology (soft/hard soldering, SnAg, SilFos),
- Materials (Cu OFE annealed, PEEK or ULTEM insulation box, et.),
- Drawings,
- 3D views,
- Test reports ref.,
- Fabrication procedures and follow up files,
- Controls to be performed.

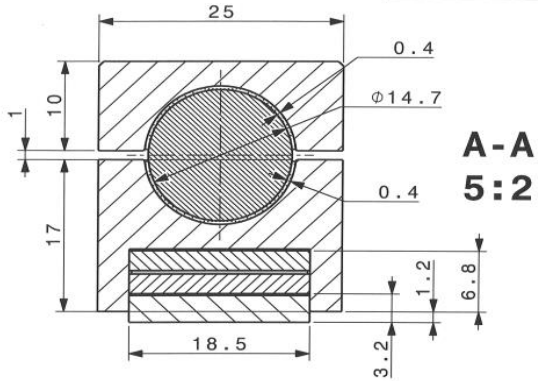
Ex. splice 5

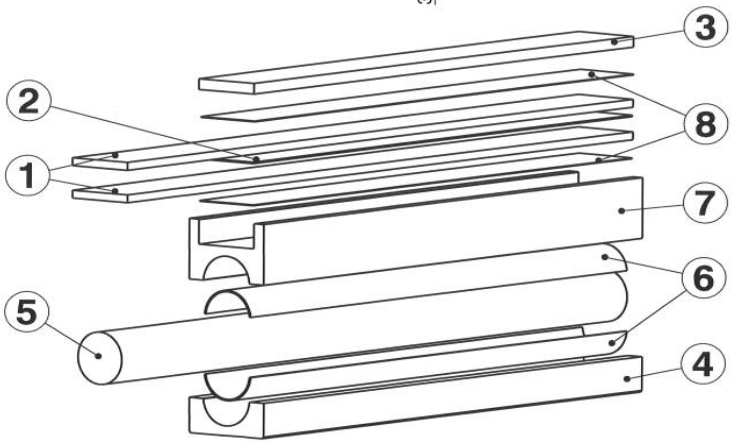
- Circuit 18 kA
- Splice Flat to Round (FR)
- Round cable 18kA diam. 13.3
  - Pre-tinning Sn96Ag4
  - Add 2 x 0.4 Sn96Ag4 foils
- Flat cable Nb-Ti 18 kA HL-LHC 2 x 18.15 x 1.92
  - Add 2 x 0.4 Sn96Ag4 foils
- Copper Wedges OFE annealed (RRR>100)
- Overlap 150 mm
- Soldering alloy Sn96Ag4
- Eutectic 221°C
- Flux MOB39











BILL OF MATERIALS

POS	QUANT	DESIGNATION	REFERENCE	MATERIAL	EDH SCEM
01	2	18kA Flat cable 18.15x1.92 straight	ST1410270		
02	1	18kA Flat Cable Solder Tape 0.4mm	ST1410286		
03	1	Splice 4 18kA Upper wedge Flat Cable 18.15x1.92	ST1410313	Cu ETP C11000 (H02)	
04	1	Splice 3 18kA Cover Round Cable Ø13.3	ST1410390		
05	1	Splice 3 18kA O Cable Ø13.3	ST1410417		
06	2	Ø13.3 Cable Solder Tape Sn96Ag4 0.4mm Thick.	ST1410864		
07	1	Splice 5 18kA U+O Profile 18.15x1.92/Ø13.3	ST1413126	Cu ETP C11000 (H02)	
08	2	18kA Flat Cable Solder Tape 0.2mm	ST1412433		

WHERE USED Not Applicable [Last checked at 2021-02-23 13:06]

DESIGNATION
Splice 5 Assy
18kA 2x Flat + Ø13.3 cables

DESIGNED	J.RAKOTOARISON	FORMAT A3
CHECKED		
RELEASED		SCALE 1:1
APPROVED		

DESIGNED 2021-02-23

EQUIPMENT CODE

REFERENCES Doc No: ST1410903_02 | INDEX | LABEL NOT VALID FOR EXECUTION | QAC | SHEET 1/1

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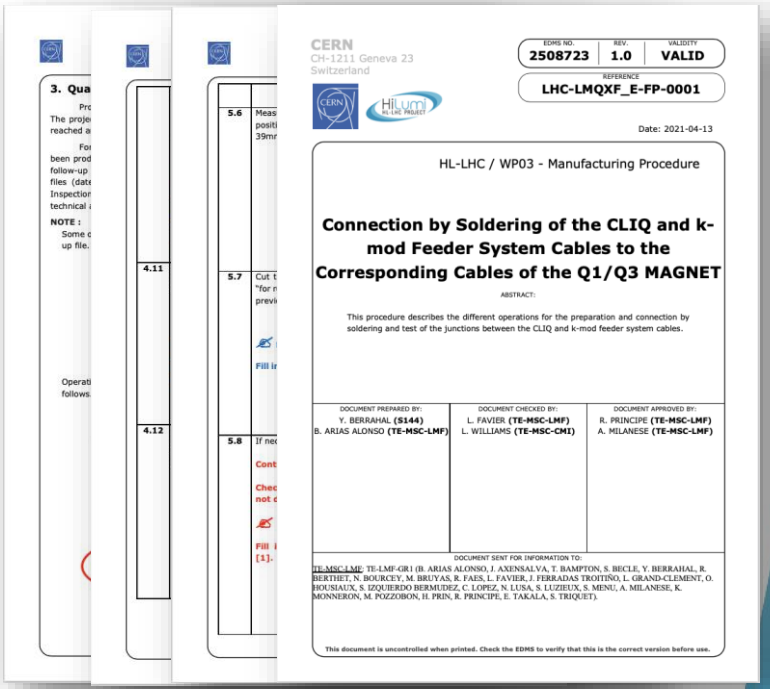
TD v2.2 A3/Landscape

7 6 5 4 3 2 1

e d c b a

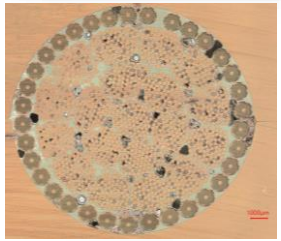
Fabrication procedure

- Reference to the drawing ;
- Reference to the test reports (EDMS);
- Includes the controls steps:
  - Visual inspections;
  - EL resistance test at RT;
  - Other if needed.
- Includes the ref. to the follow up file
- ***Ex. electric joint 14***
  - Fabrication procedure EDMS@2508723
  - Follow up file EDMS@2513665



Splice qualification process

1. Drawings (CDD and EDMS)
2. Test protocol including:
   - Step1: resistance @ RT by TE-MSC-LMF El team :
     - Resistance measurement at room temperature after sample production;
     - **Thermal cycling**: immersion in Nitrogen (repeated 10 times, Temperature 77K);
     - Resistance measurement at room temperature after cold cycling.
   - Step 2: mechanical test by EN-MME :
     - **First tensile testing at break;**
     - **Fatigue** (cycling process: 30 hysteresis loops at 50% of average ultimate force);
     - **Second tensile testing** at break after cycling;
     - Metallographic examination (EN-MME, samples by LMF).
   - Step 3: resistance test @ LT by TE-MSC-TM :
     - LT: max resistance **as per EDMS@2029211.**
3. Fabrication procedure (EDMS approval circuit as per TE-MSC QP (cfr. EDMS@1970009).

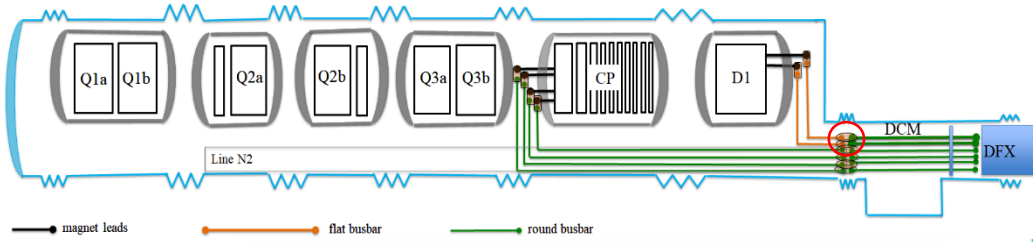


Test status

ID	POSITION	Tooling	EL@RT	EL @RT after thermal cycling	MECA test	Metallography	EL @LT
Splice 1	MCBXFB ; MCBXFA	OK	OK	OK	OK	OK	OK
Splice 2	DCM	OK	OK	OK	OK	OK	OK
Splice 3	Q1b to Q2a and Q2b to Q3a	OK	OK	OK	OK	OK	OK
Splice 4	Q2a and Q2b	OK	OK	OK	OK	OK	OK
Splice 5	Q3b to DCM	OK	OK	OK	OK	OK	OK
Splice 6	N to DCM	OK	OK	OK	OK	OK	Ok
El joint 7	DCM to Diode	OK	OK	OK	OK	OK	NA
EL joint 8	Diode	OK	OK	OK	OK	OK	NA
Splice 9	D1	OK	OK	OK	OK	OK	OK
Splice 10	D2	OK	OK	OK	OK	OK	NOK
Splice 11	Q1a	OK	OK	OK	OK	OK	OK
Splice 12	MCBRD	OK	OK	OK	OK	OK	Ongoing
Splice 13	D2	OK	Standard LHC	Standard LHC	OK	OK	Ongoing
EL joint 14	K-mode to CLIQ	OK	OK	OK	OK	OK	NA

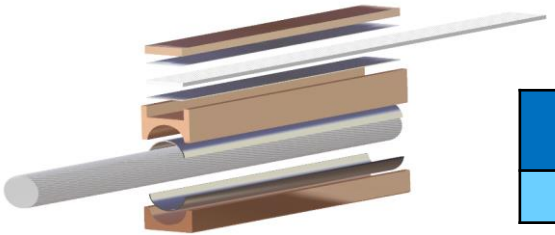
Splice 10

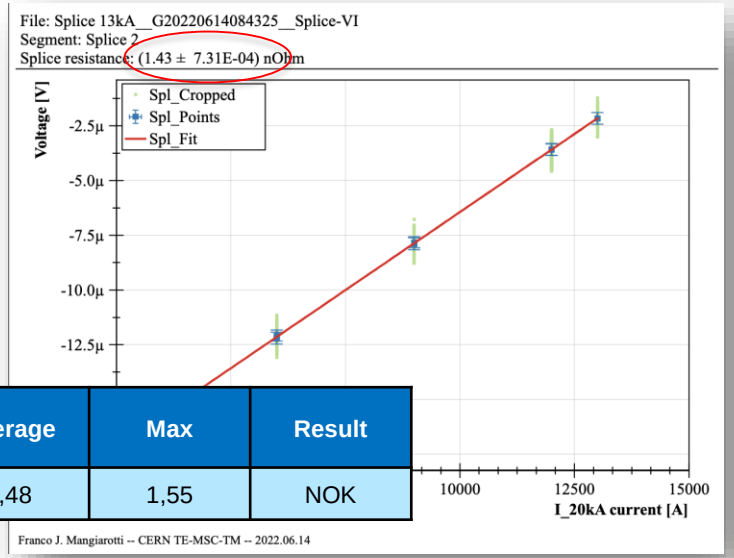
- Circuit 13 kA
- Splice Flat (13kA) to Round (18kA)
- Flat cable Nb-Ti 13 kA LHC type 2 dim 15 mm
- Overlap 120m



ACTION PLAN:

1. Modification of the soldering tool (reduction in length) in order to :
   - provide a better access to the splice during soldering;
   - improve the SnAg feeding.
2. Check of the pre-tinning of the cables;
3. The SnAg foils thickness unchanged;
4. Repeat the test @LT





Splice	Ref.	Average	Max	Result
10	< 1nΩ	1,48	1,55	NOK

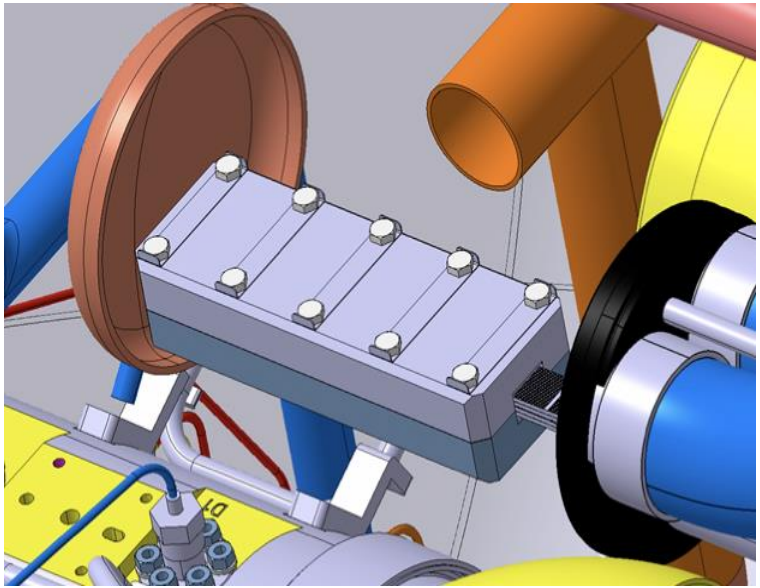
Mechanical test results

ID	Tensile at break (kN)	Average displacement (mm)	Tensile after cycling (kN)	Average displacement (mm)	Result
Splice 1	2.34 ± 0.03	3.17 ± 0.15	2.24 ± 0.09	3.17 ± 0.15	Ok
Splice 1 PH	0,544 ± 0,138	24.95 ± 9.65	0,545 ± 0,065	29.12 ± 1.02	Ok (transversal no box)
Splice 2	7.48 ± 1.11	6.84 ± 0.6	6.85 ± 0.24	5.91 ± 0.71	Ok
Splice 3	27.13 ± 0.5	6.28 ± 0.21	28.95 ± 1.14	7.24 ± 0.4	Ok
Splice 4	31.96 ± 6.6	10.87 ± 2.82	36.00 ± 1.53	10.54 ± 0.97	Ok
Splice 5	15.53 ± 3.0	7.99 ± 1.43	17.45 ± 0.5	8.53 ± 1.67	Ok
Splice 6	28.54 ± 1.98	8.22 ± 0.83	30.68 ± 0.42	8.5 ± 0.88	Ok
Splice 7	10.22 ± 0.22	21.98 ± 5.61	10.62 ± 0.06	32.89 ± 2.15	Ok
Electrical joint 8 V1	7,667 ± 1,501	0.60 ± 0.21	7,057 ± 0,465	0.50 ± 0.34	Ok
Electrical joint 8 V2	11,412 ± 0.064	6.95 ± 3.08	11,534 ± 0.077	15.25 ± 4.44	Ok
Electrical joint 8 V3	6,299 ± 0.045	2.38 ± 0.40	6,294 ± 0.096	2.57 ± 0.30	Ok
Splice 9	21.31 ± 0.67	15.41 ± 1.34	24.46 ± 0.67	16.16 ± 1.27	Ok
Splice 10	18.35 ± 1.81	3.1 ± 0.4	18.56 ± 1.78	2.78 ± 0.49	Ok
Splice 11 PH	1.98 ± 0.04	75.9 ± 6.8	2.38 ± 0.51	83.3 ± 3.7	Ok (transversal no box)
Splice 12	0,386 ± 0,00082	1,66 ± 0,04	0,385 ± 0,00059	1,82 ± 0,15	Ok (0.825 mm diam)
Splice 13	0.652 ± 0.00185	5.16 ± 1.01	0.65128 ± 0.00175	5.23 ± 0.36	Ok (1.6 mm diam)
El joint 14	1.82 ± 0.63	2.19 ± 1.75	1.47 ± 0.35	0.82 ± 0.5	Ok

The insulation of the WP3 splices

Design of insulation, installation sequence and testing:

- In the Fabrication Procedure;
- Adapted to the splice type;
- Inspired to the busbar insulation (polyimide foils, no Eccobond);
- Always protected with robust insulation boxes (PEEK, ULTEM);
- Testing @RT to be defined (extremities).

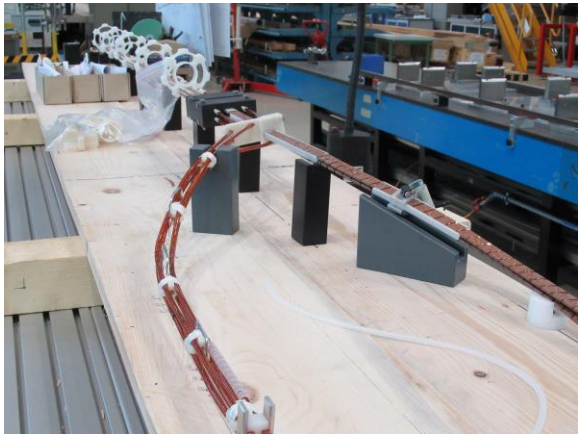


To do list

- Splice 10 redo with new tooling (ongoing, not critical).
- Fabrication procedures.
  - Integration design of interconnections, DCM, et.
  - Assembly test on realistic mock-up.
- To be completed by end 2022.
- NB: Iterative process.

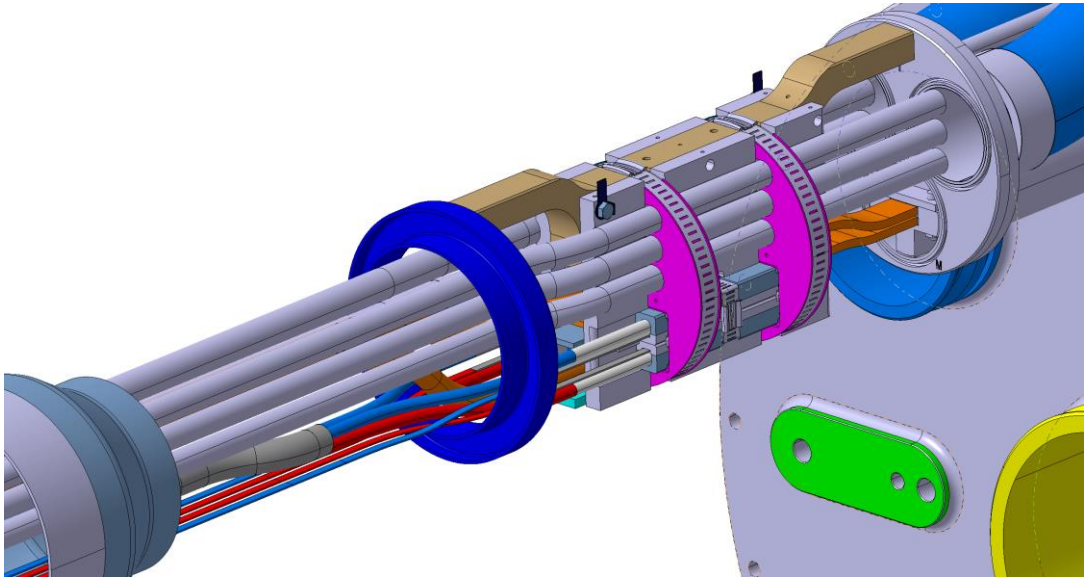
Shuffling module construction

- First set completed end of April 2022.
- Ready to be installed in SMI2.
- Positioning parts by Polymer LAB.

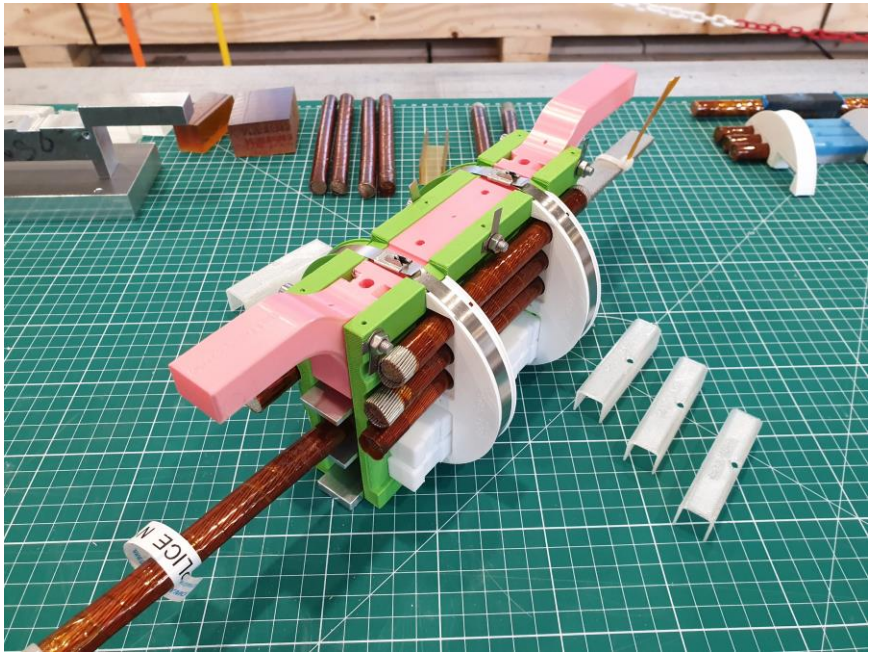


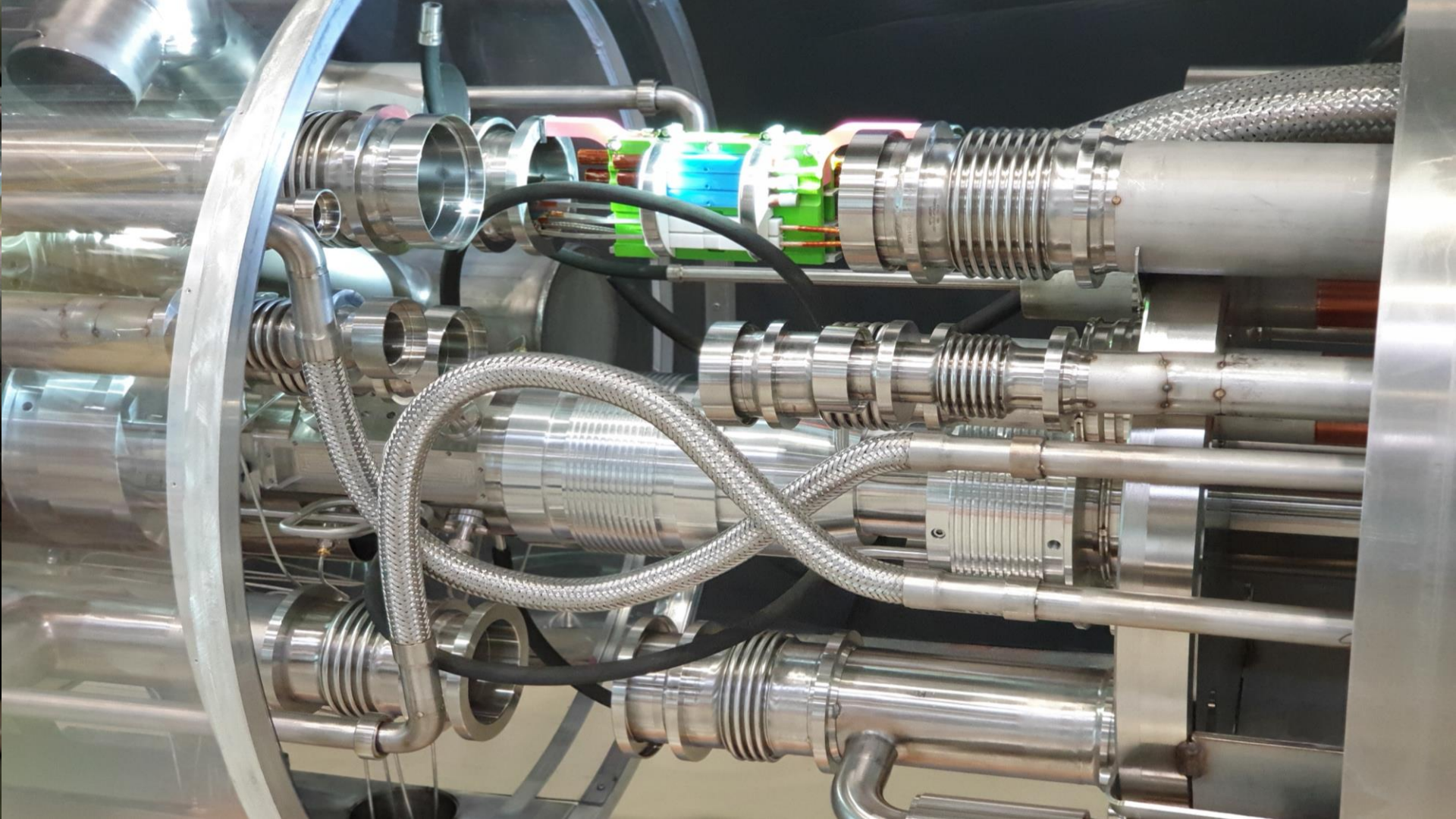
Interconnections

- Modular system
- Interconnections
  1. Q1 to Q2a
  2. Q2a to Q2b
  3. Q2b to Q3
  4. Q3 to CP
- Fix point

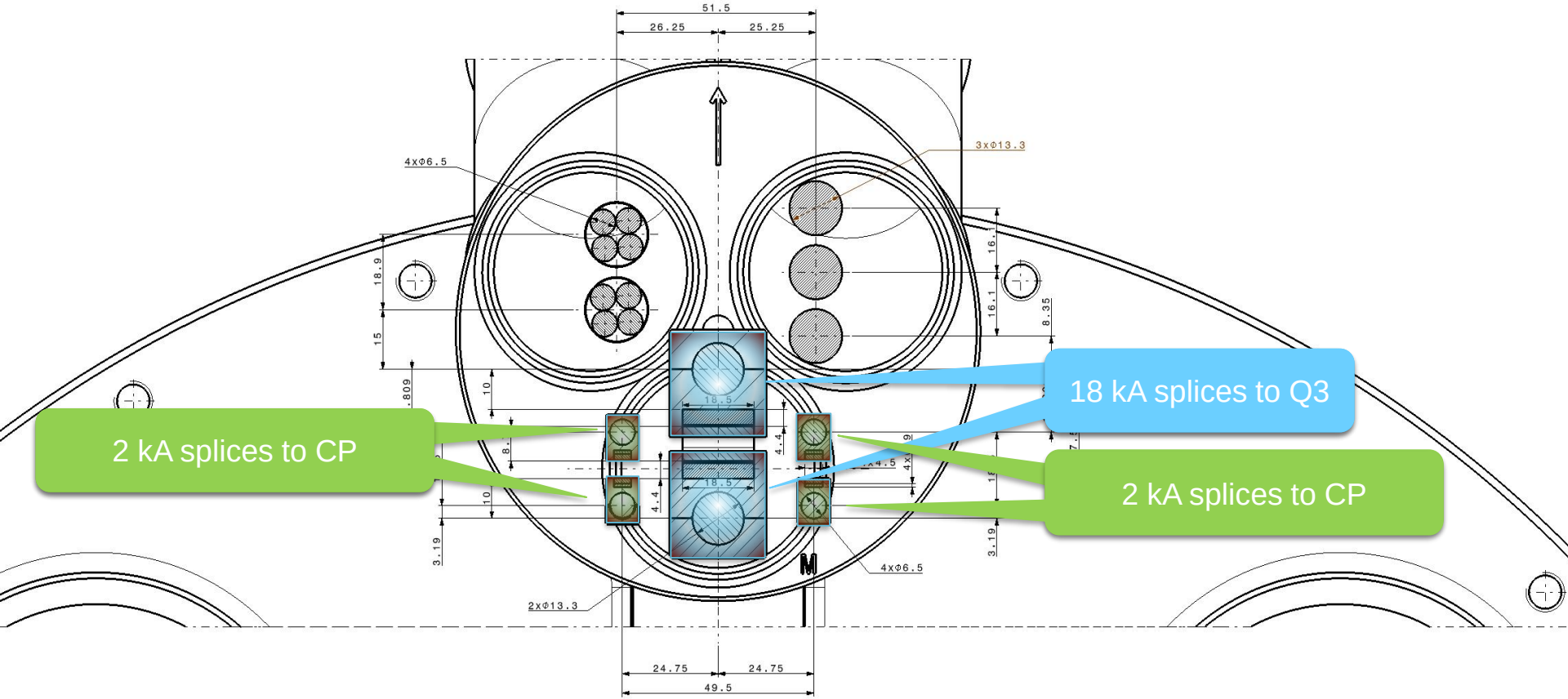


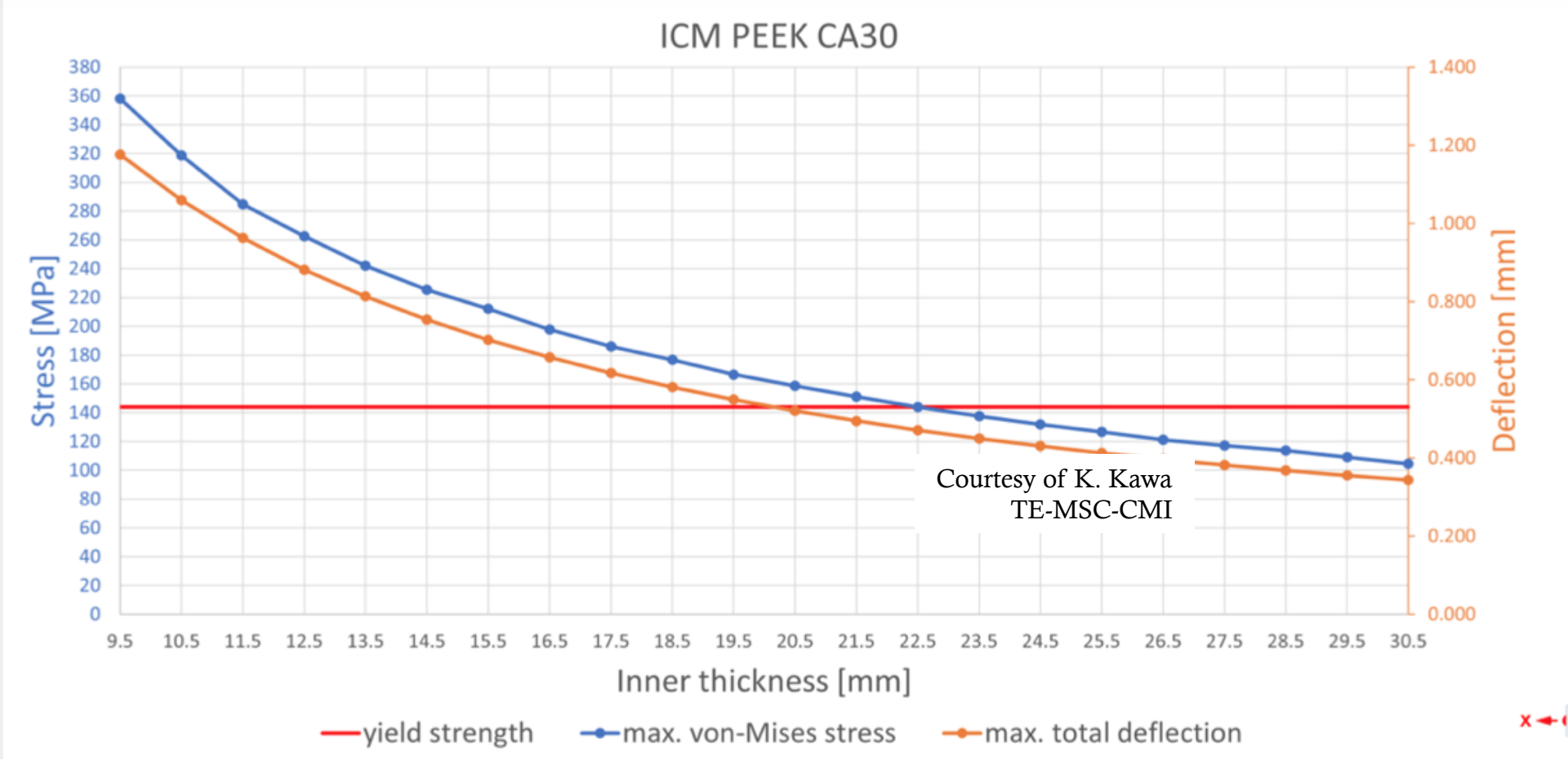
Q3 to CP fix point

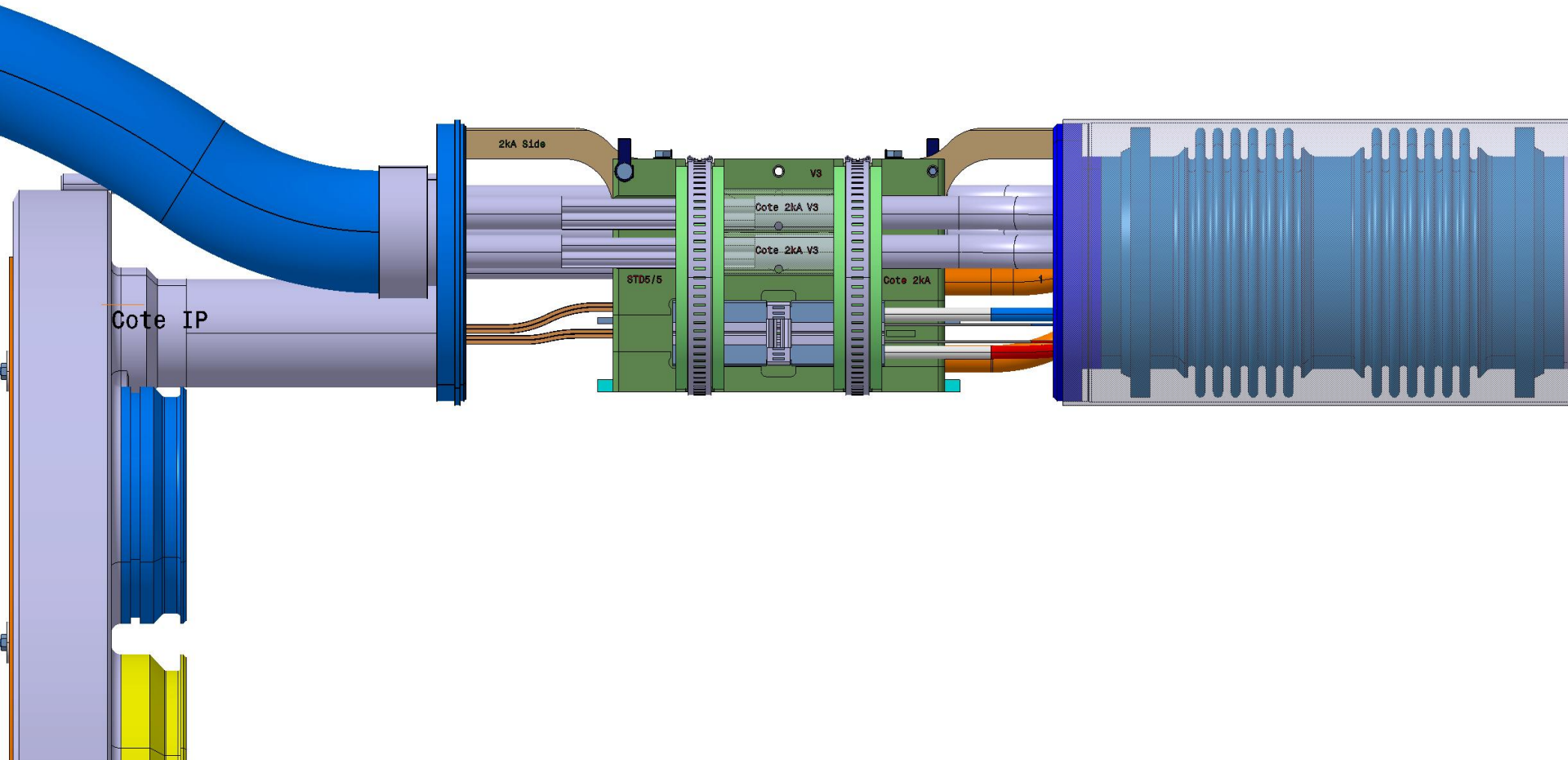




Splicing Cor.Pack/Q3




ICM PEEK CA30
Stress [MPa]
Deflection [mm]
Inner thickness [mm]
Courtesy of K. Kawa
TE-MSC-CMI
yield strength
max. von-Mises stress
max. total deflection


2kA Side
V3
Cote 2kA V3
Cote 2kA V3
STD5/5
Cote 2kA
Cote IP

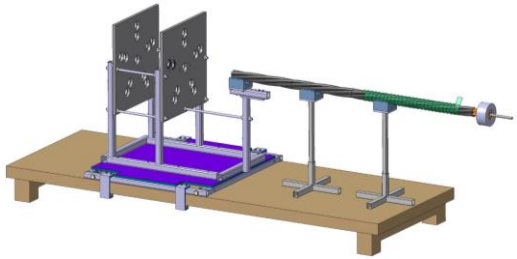
Interconnects to do list

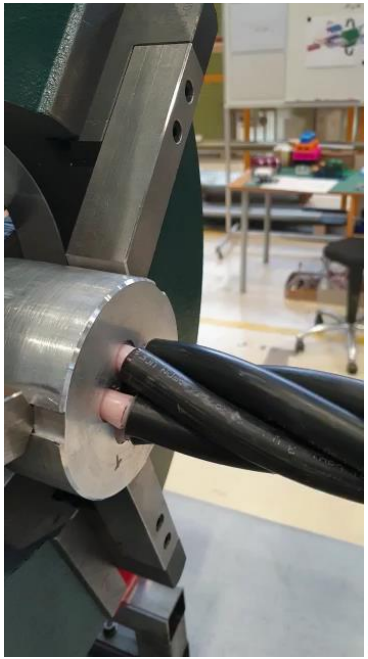
- Fix point mechanical tests, including fatigue, to be performed (EN-MME);
- Fix point assembly mock-up: assembly in a more realistic environment with **18 kA and 2 kA SC cable;**
- Finalize design and procedures.

- **Twisted cables in Line N1 (5x18 kA),** development ongoing;
  - 5x18 kA, 10 m long insertion test mock-up;
  - 5x18 kA, 54 m long insertion test mock-up;

Cable Twisting Machine

- Trials 10 m with Cu cables;
- Tape for the cable stabilization ;
- Considerable development work to be done.





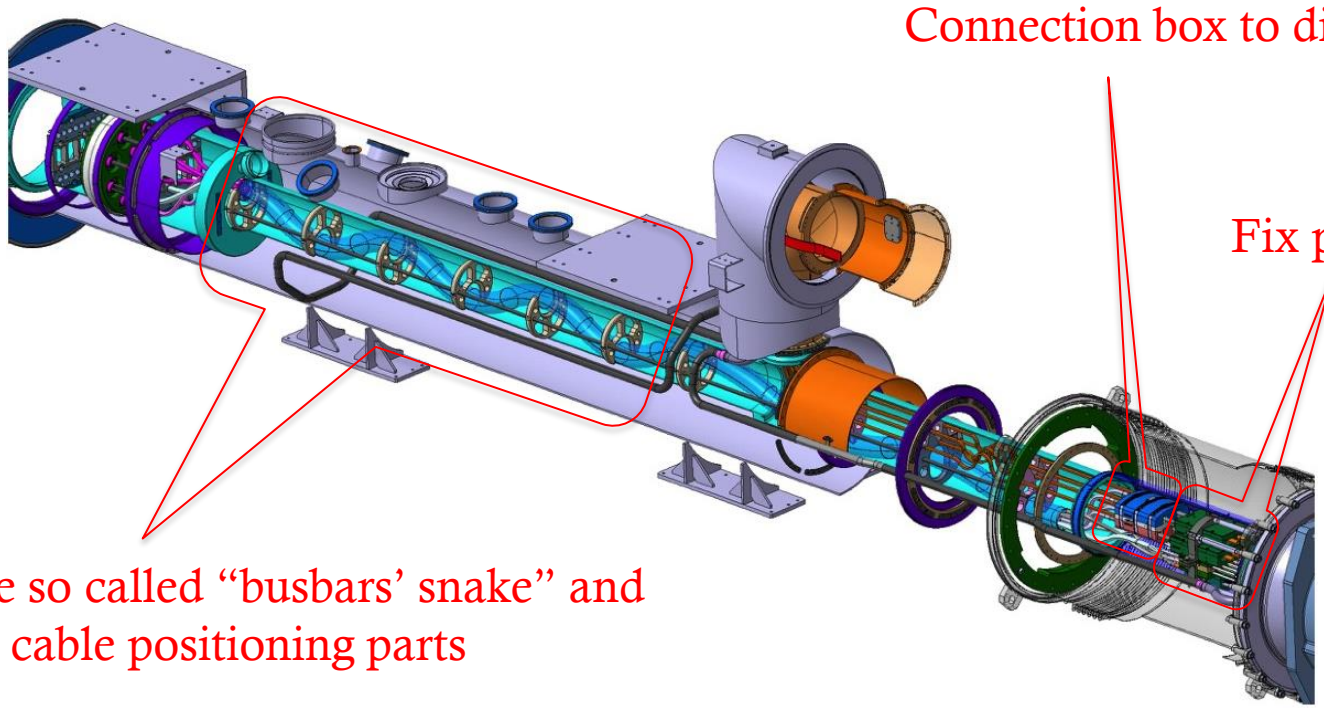
18 kA SC cable rigidity

- May 2022 received 18 kA and 2 kA round SC cable;
- High rigidity observed (qualitative) on the 18 kA insulated round SC cable (although bending radius 200 mm).

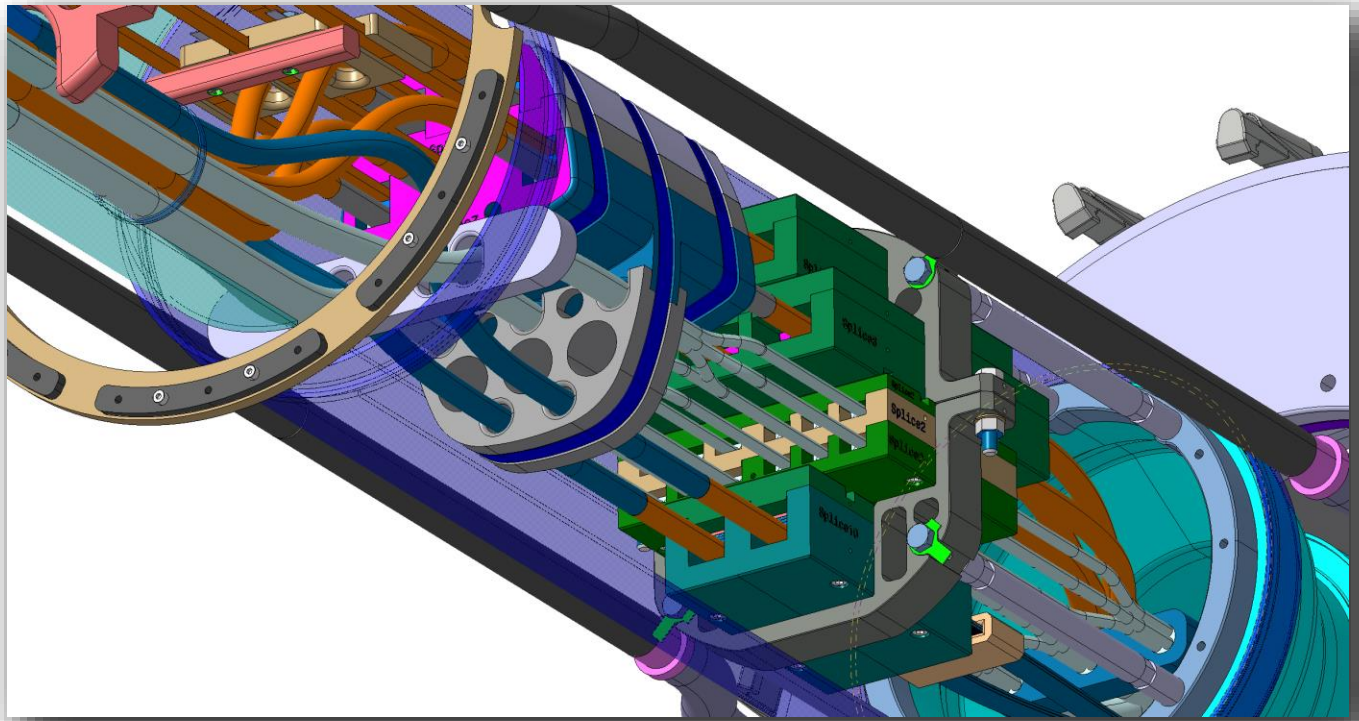
- Rigidity is a concern for the busbar routing, the interconnects design, DCM routing, et.
- Series of tests:
  - The bare cable results to be always very flexible. Twisting pitch checked: 90, 105, 113, 120, 135, 150, 165, 180 mm.
  - Rigidity due to polyimide insulation. Solutions checked: 49 % overlap, winding load 3, 3.5 and 4 kg.

- Request to reduce the winding load to 2 or 1.5 kg (2nd follow up review, July 14, 2022).

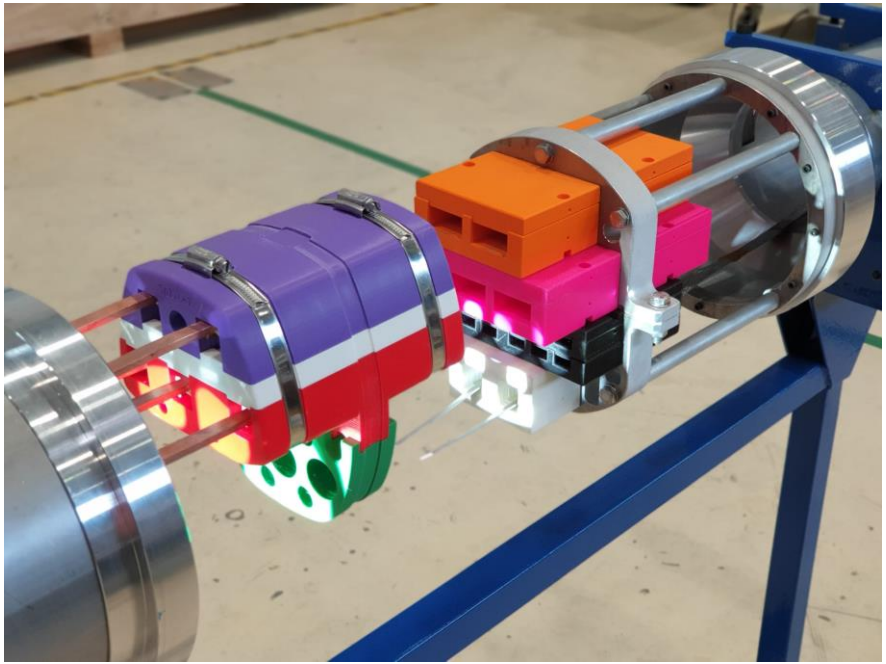
DCM busbars

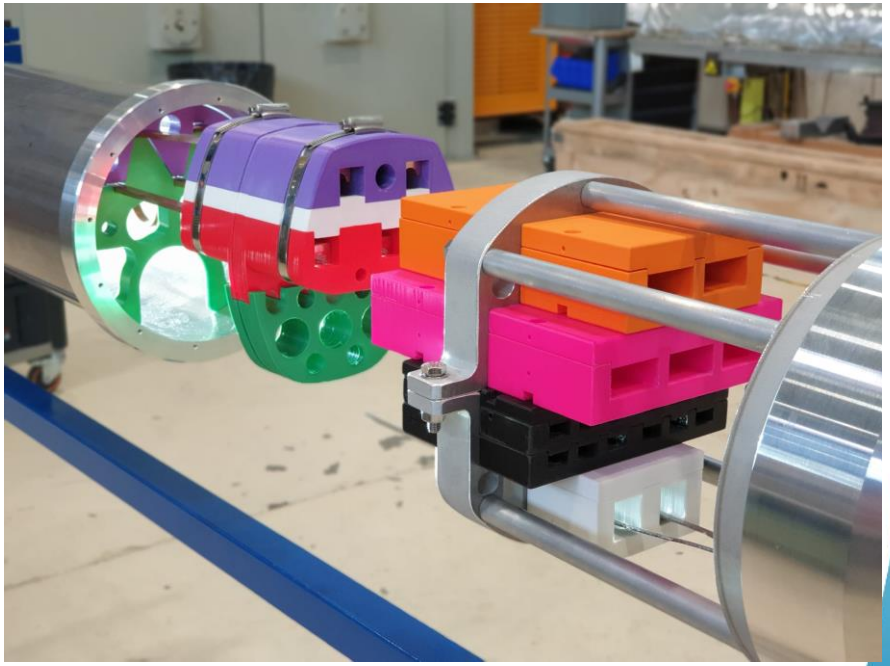

Connection box to diodes
Fix point
The so called “busbars’ snake” and
the cable positioning parts

DCM fix point and connection box to diodes



3D printed trials

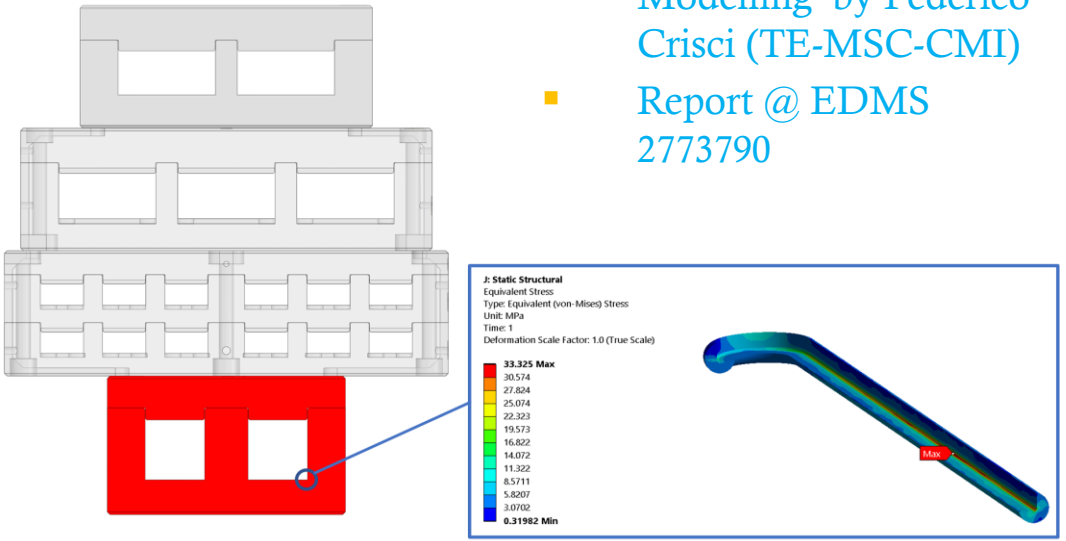




DCM fix point modelling

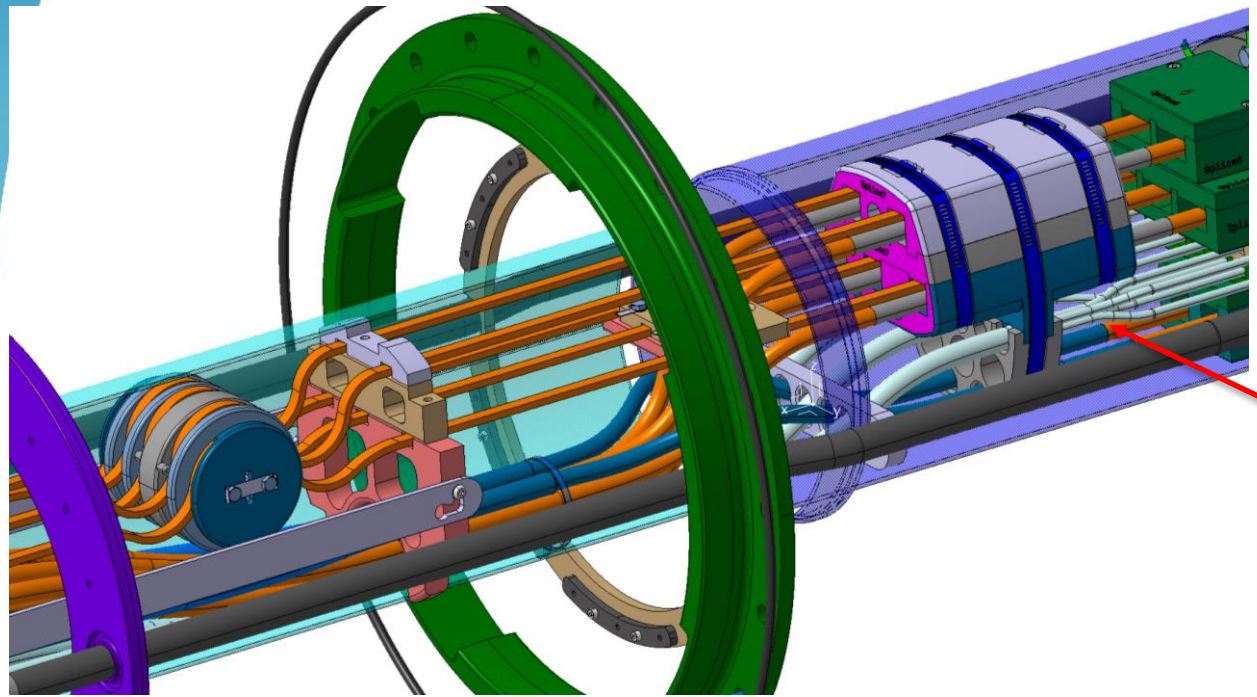
Mature design:

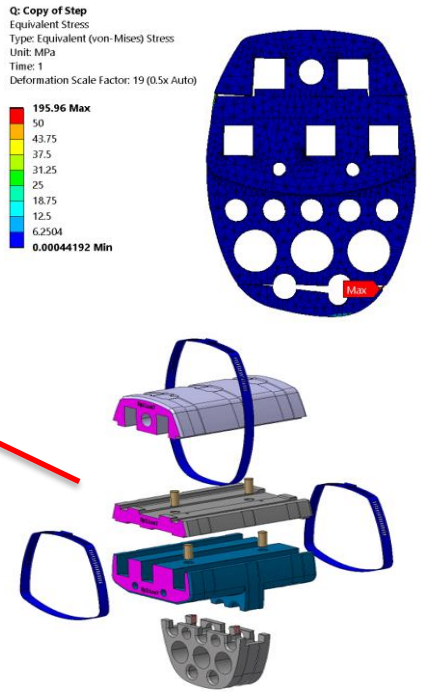
- The results of the stress analysis confirm the design assumptions;
- Highest stress level in the 13 kA box;
- Internal radius 0.2 mm;
- Max stress = 33.5 MPa



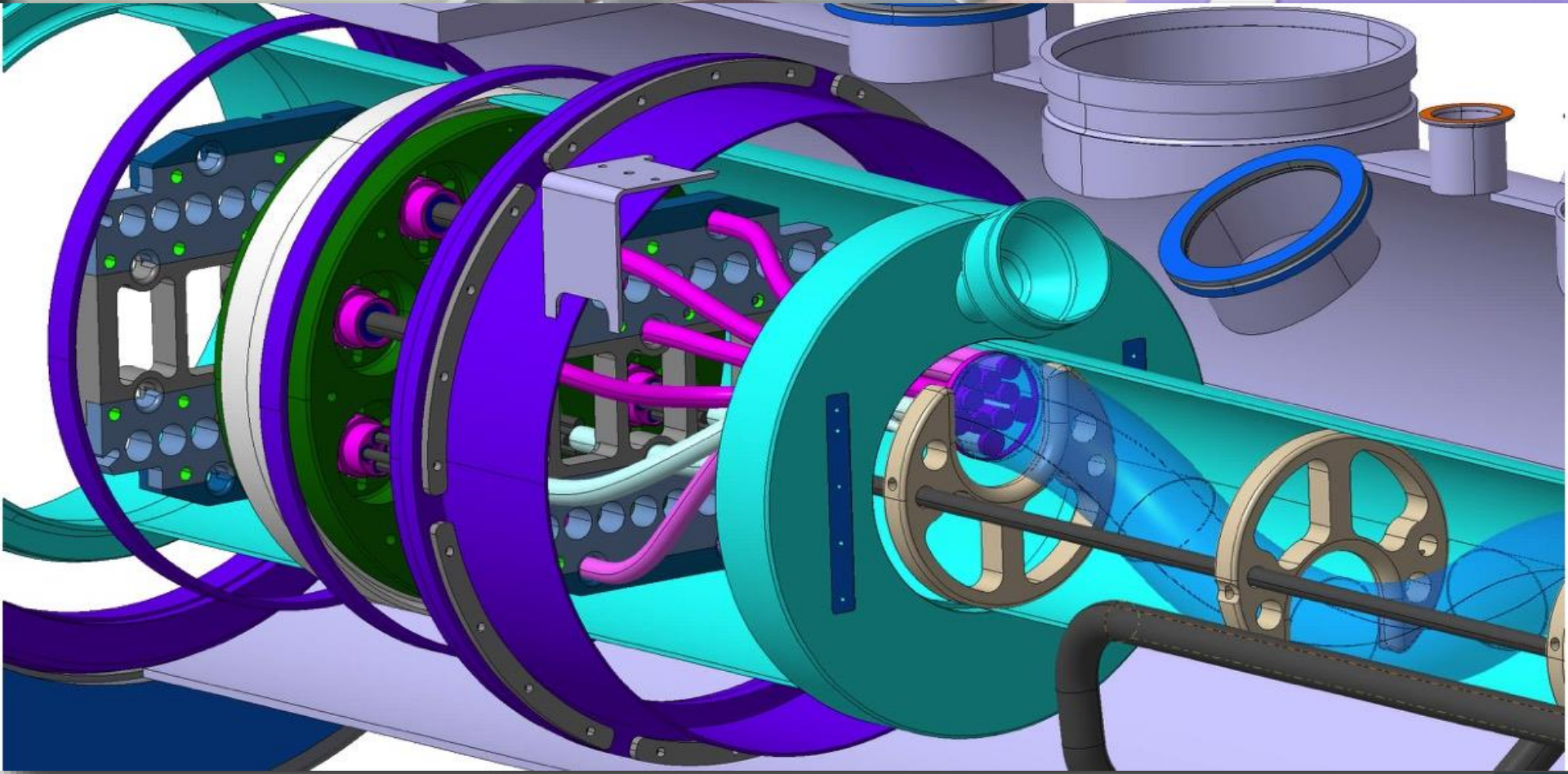
- Modelling by Federico Crisci (TE-MSC-CMI)
- Report @ EDMS 2773790

Recent evolution of the connection box to diodes





Tested 3D printed assemblies



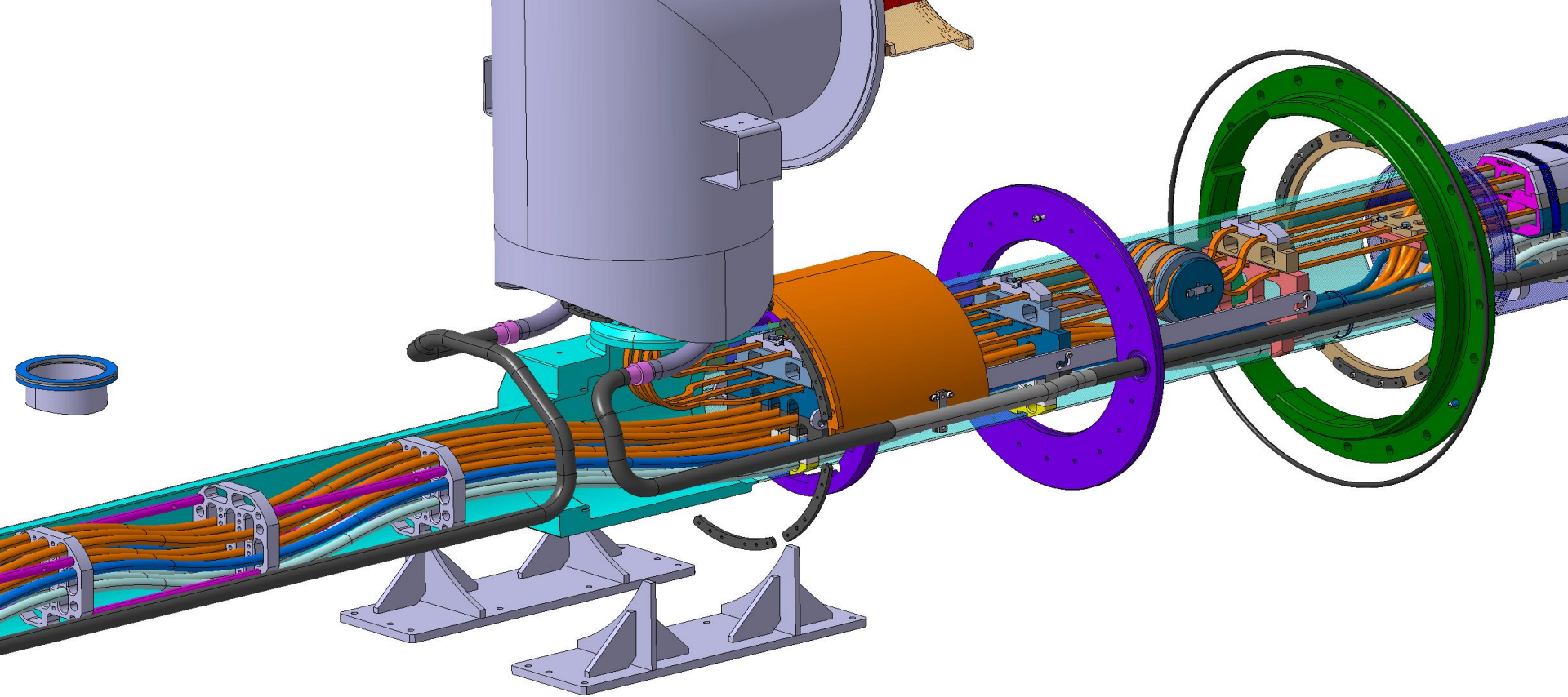
DCM to do list

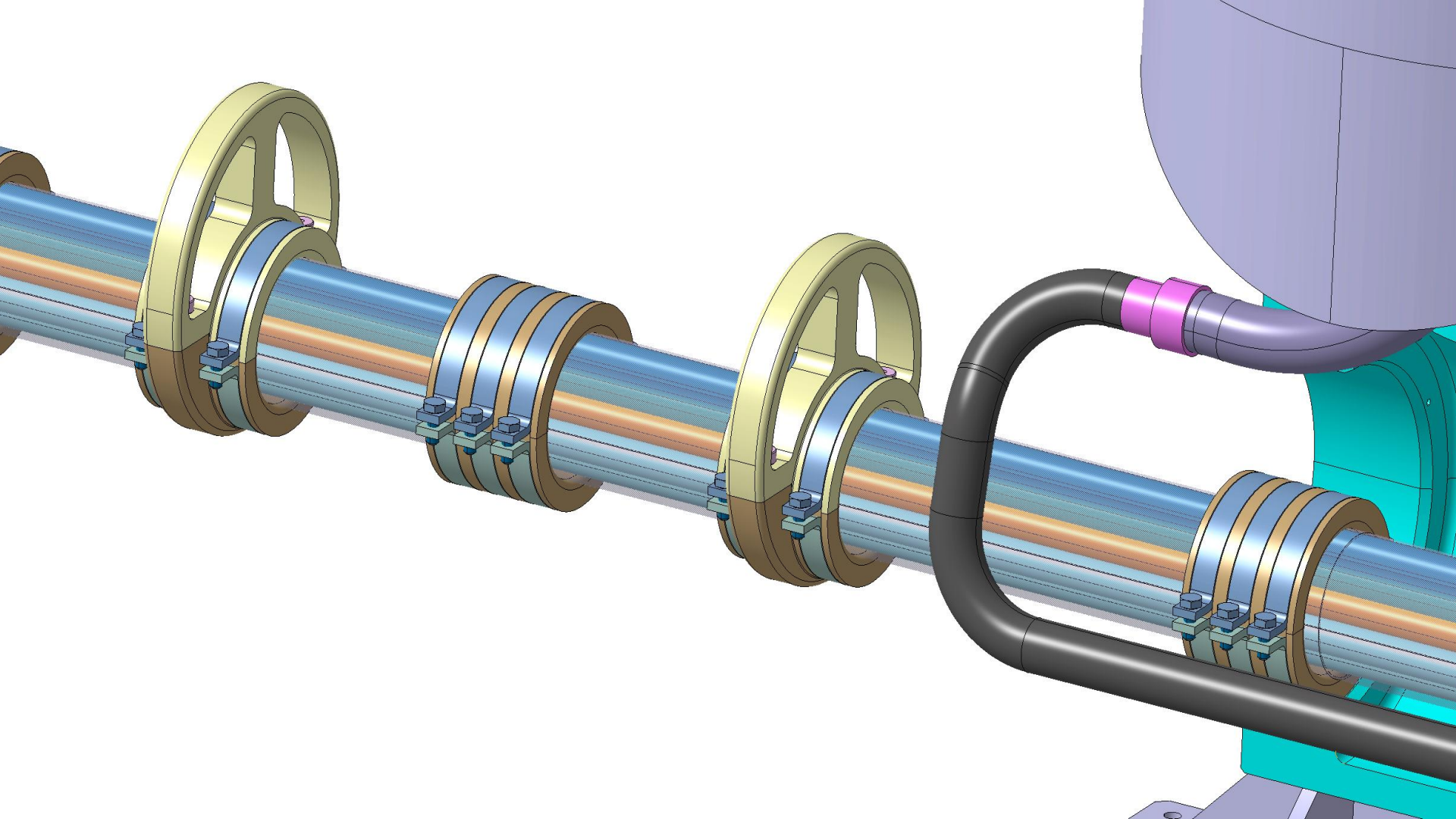
Recently :

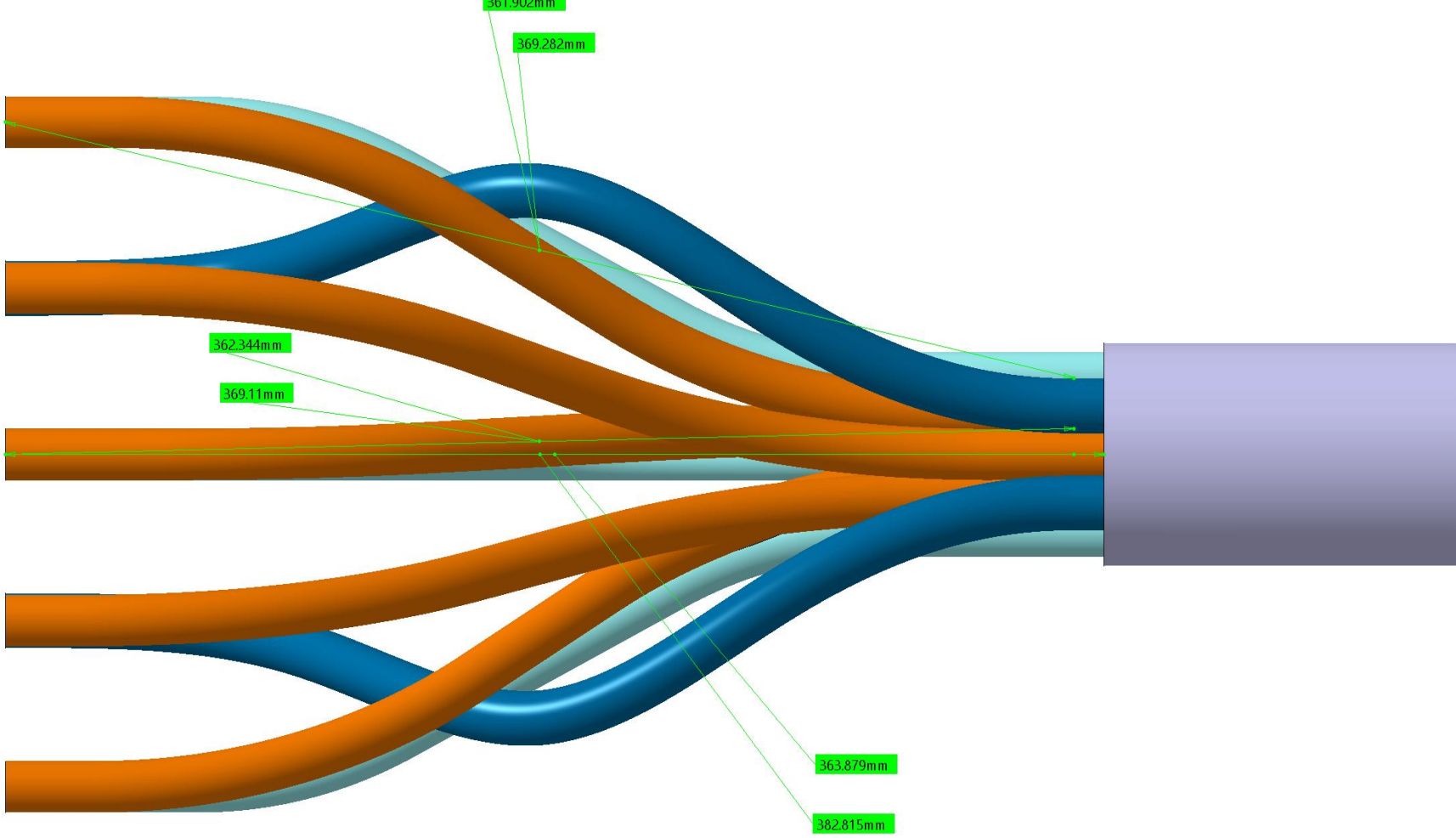
- DCM fix point and diode boxes design.
- First 3D printed assemblies tested. To be repeated with 18 kA cable.
- Modelling of the fix point and stress analysis completed.

Next step focusing on:

- The “busbars’ snake” in order to complete the design by ~~Sept 2022~~ Oct 2022 including guiding and supporting parts.
- Fix point and diode box assembly mock-up.
- Finalize design and procedures.






361.902mm
369.282mm
362.344mm
369.11mm
363.879mm
382.815mm

Conclusion

- **Splice 10 redo** and complete the WP3 splices test phase (Sept 2022, depends from cluster availability. Not critical);
- **Cable Twisting Machine** and 5x18 kA cable production development ongoing (restart with the delivery of the 18 kA round cable);
- **Interconnections :**
  - Fix point assembly **mock-up** ;
  - 5x18 kA, 10 m long insertion test **mock-up** ;
  - 5x18 kA, 54 m long insertion test **mock-up** ;
  - Finalize design and procedures ;
- **DCM busbar routing:**
  - Focusing on the "busbars' snake" in order to complete the design by Oct 2022 including guiding and supporting parts;
  - Fix point and diode box assembly **mock-up** ;
  - Finalize design and procedures.


many
Thanks!

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