PAUL SCHERRER INSTITUT

PSI

CHART

Swiss Accelerator Research and Technology

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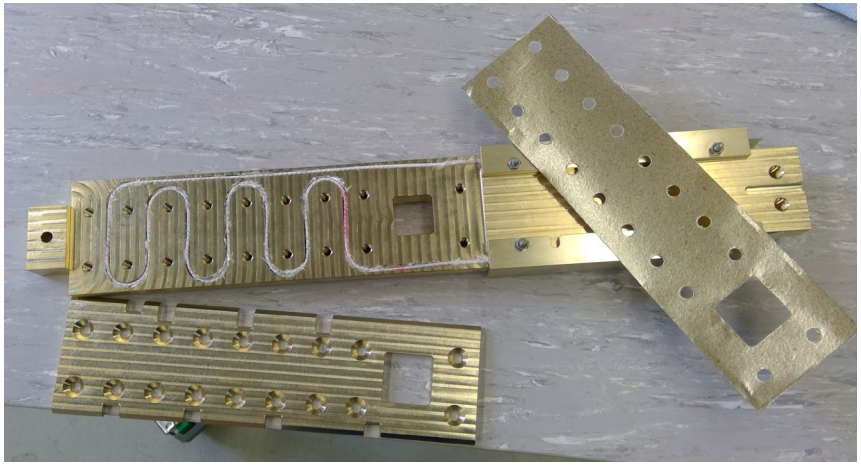
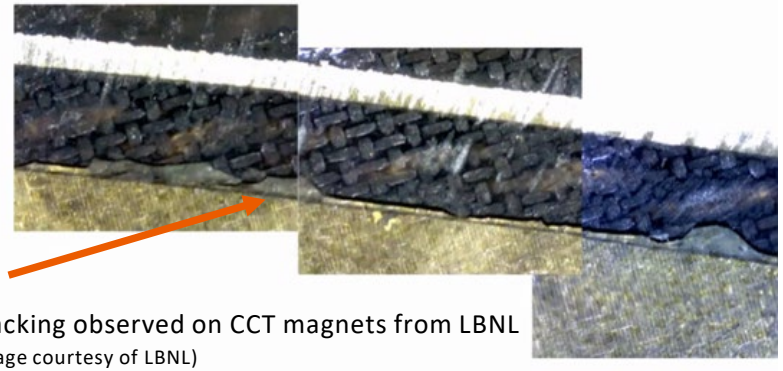
BOX Experiments and Material Assessment

Third KE4738 Technical Meeting, 24/03/2021

Overview

- Quick overview of BOX samples.
  - BOX Sample
  - Experimental Setup
  - Instrumentation
- Typical results from BOXs:
  - Training behavior
  - Data acquisition
  - Post mortem analysis
- Future Plans
- PART 2: presented by André Brem

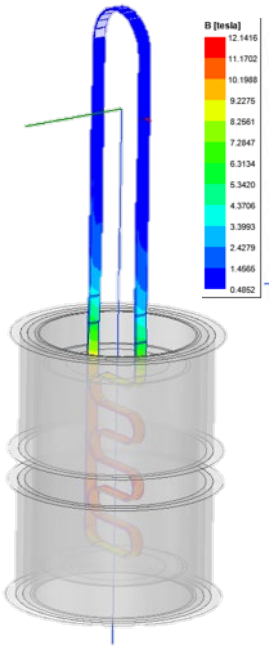


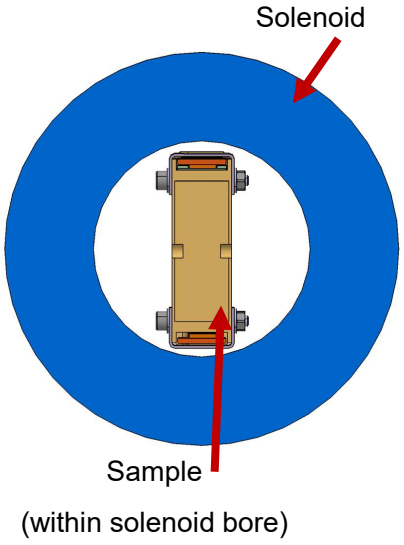


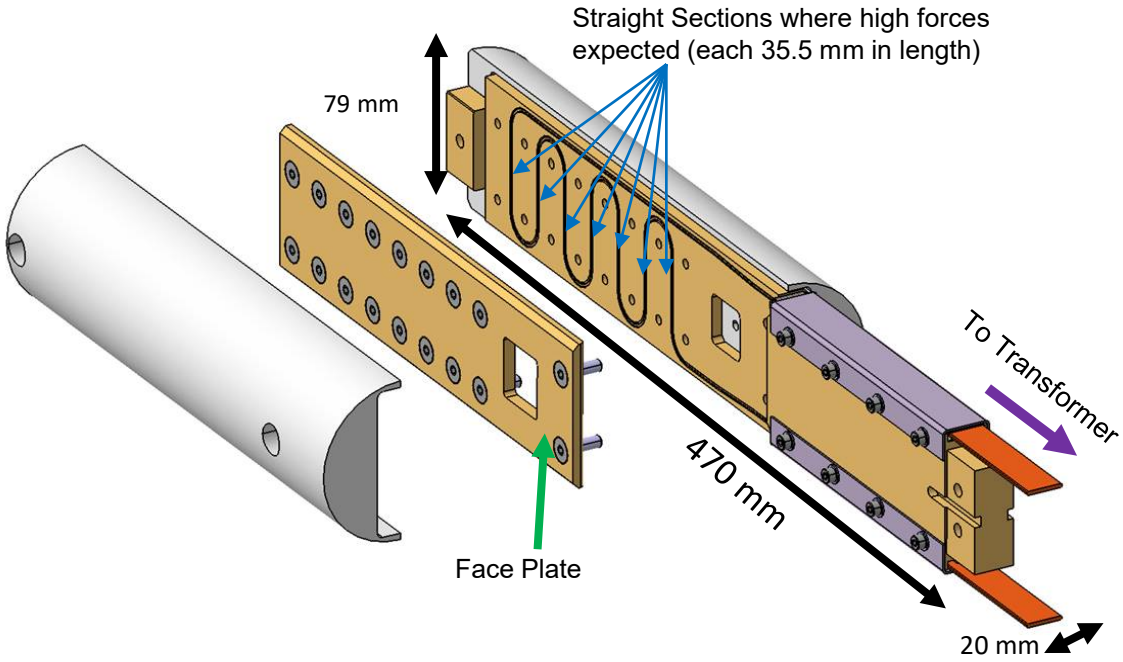
Cracking observed on CCT magnets from LBNL
(image courtesy of LBNL)

BOX Samples

- **BO**nding e**X**periment (BOX) to test technological solutions to the channel-bonding problem.
- University of Twente testing the BOX samples in up to 11 T background field, powered by a superconducting transformer.
- Results from BOX experiments will be used to decide the future steps for PSI CCT and assess alternative technologies.

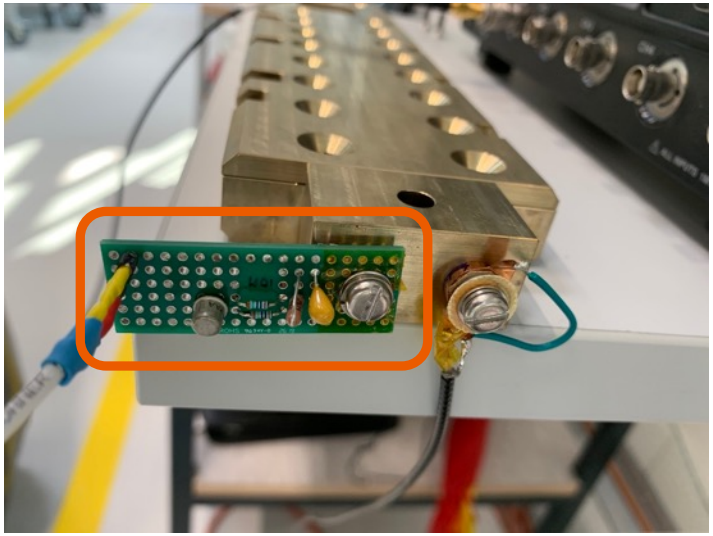




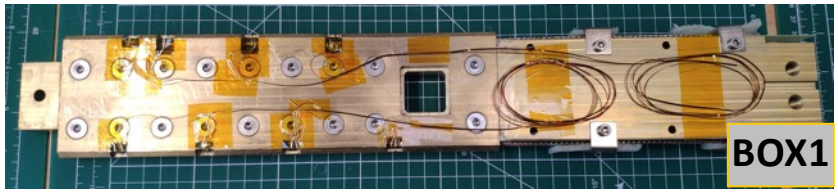


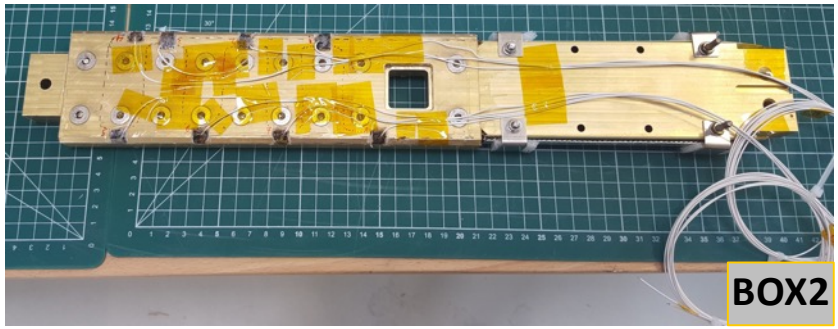
BOX Samples

- Five BOX samples tested until now (x4 Nb_3Sn and x1 NbTi)
- Some are representative of PSI's CD01 CCT magnet with some small variations:
  - With/without MICA, some cleaning of fibreglass sizing, sand blasting…
  - Alu-bronze, anodised aluminium, stainless steel.
  - Impregnations systems: CTD101K, Mix61, Wax…
- Intrumentation & Analytics:
  - Acoustic sensors similar to LBNL's – Maxim's design (1 to 2 sensors)
  - Vtaps to identify quenching segments
  - Wave analysis, V-I Measurements,
- Some compromises in dimensions required for winding sample.
  - Channel size



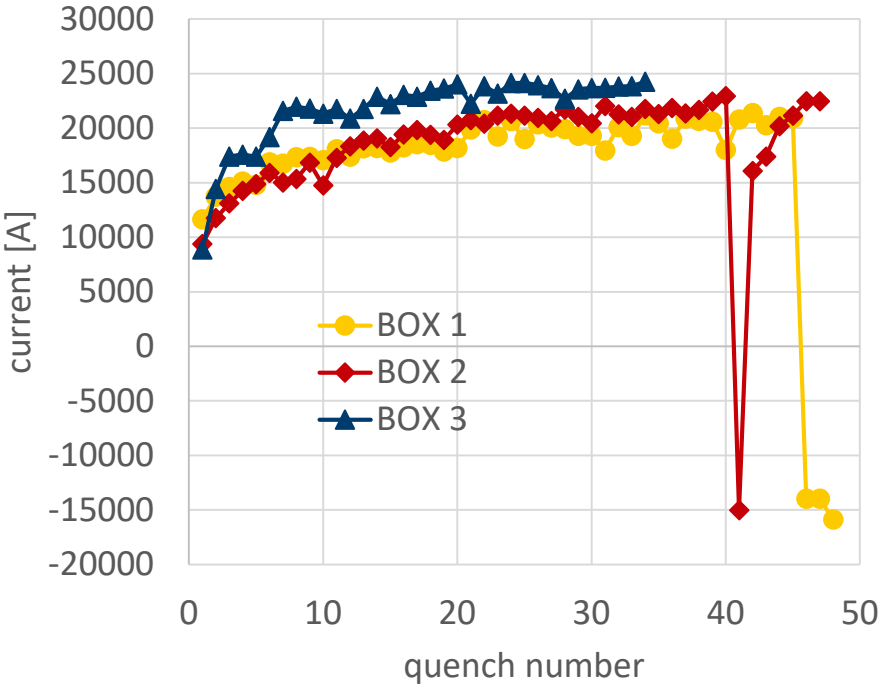
Piezo (right) and cryo-amp (left)

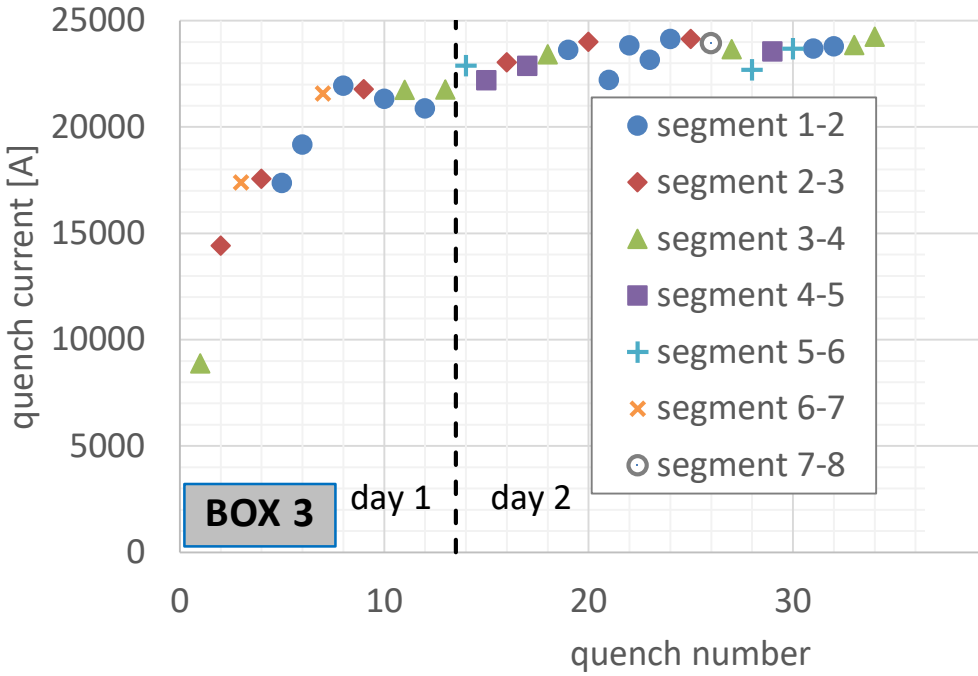




BOX1,2,3 Results - Training

- Target: 23 kA at 7,5 T solenoid field (6100 N on 36mm straight sections of Nb_3Sn)
- Ramp at 200 A/s (typical ramp for UTwente)
- Obtained training behavior, localization of quenches, acoustic & Vtap signals.
  - BOX 1 had a Mica Layer,
  - BOX 2 no Mica,
  - BOX 3 sand blasted and fibre glass braid cleaned (expected improvement)
- All impregnated using MIX 61

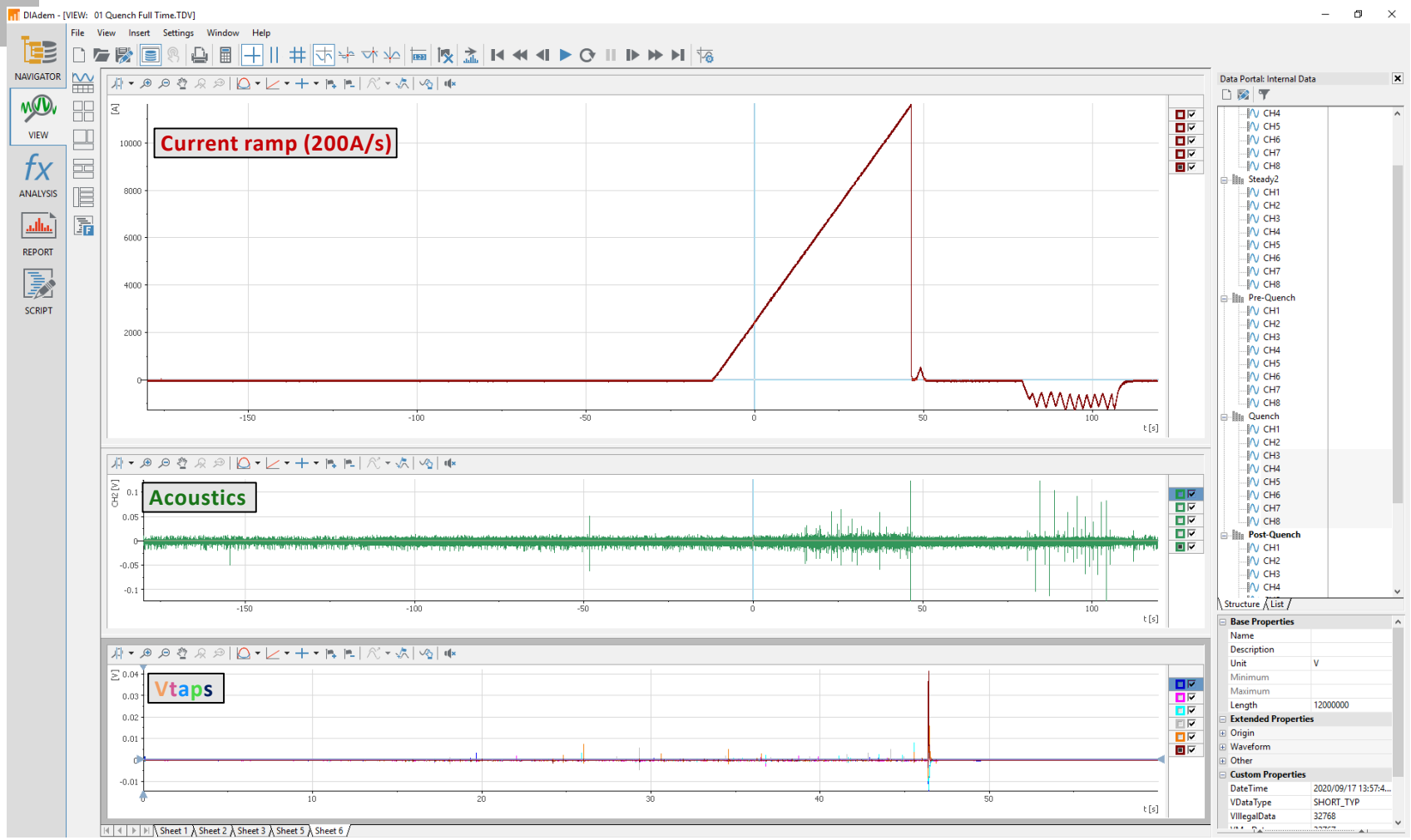




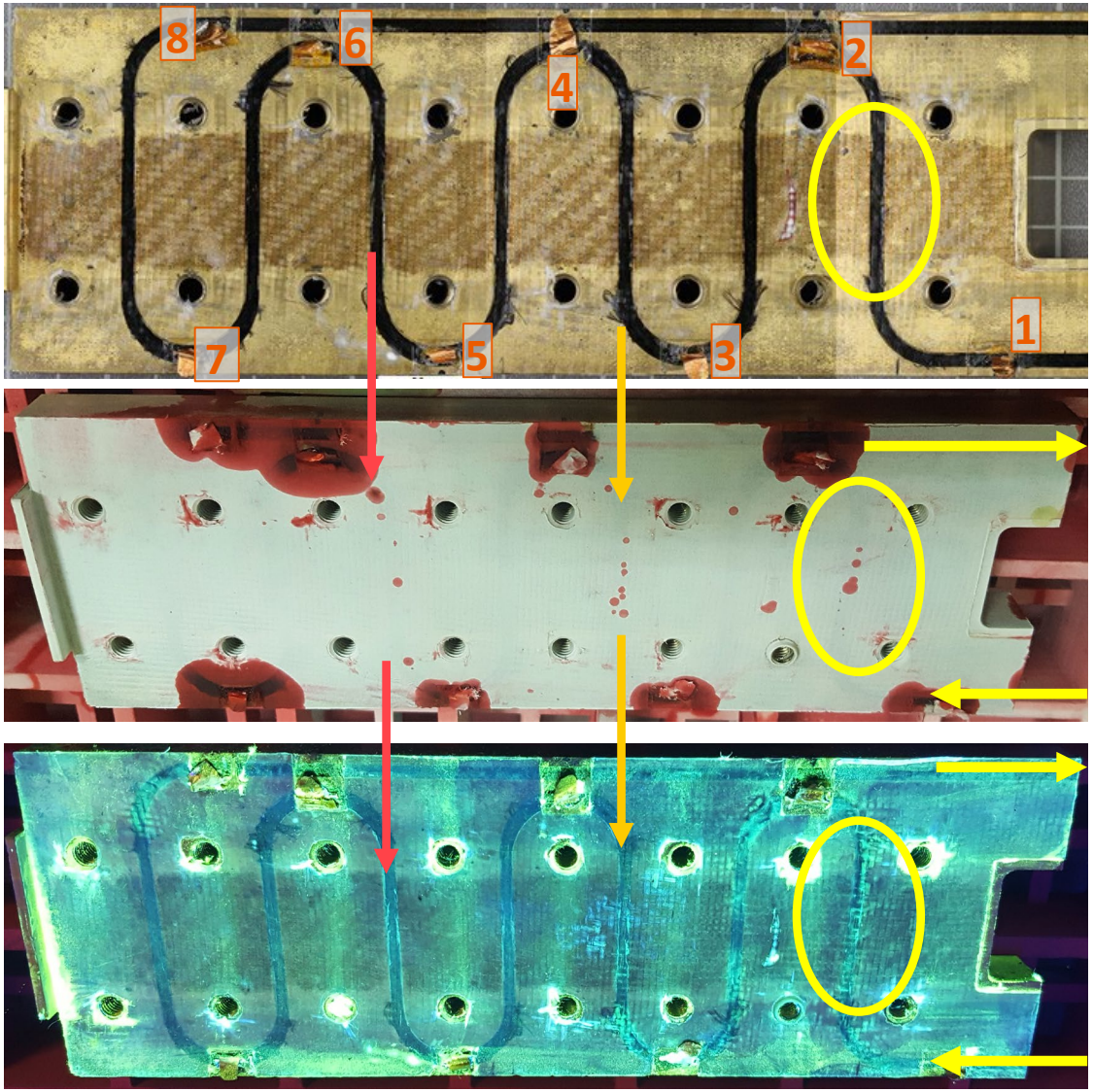
Courtesy S.Otten (Utwente)

First Quench BOX 1: seg 7-8 – overview of data

- First quench of sample at 11,6kA.
- Increasing AE signals during ramp up.
- Fairly distinct signals at Quench



Dye penetrant testing BOX 1

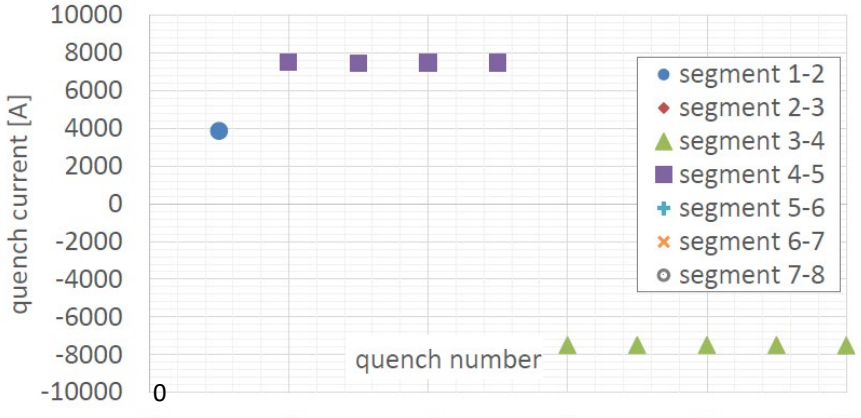


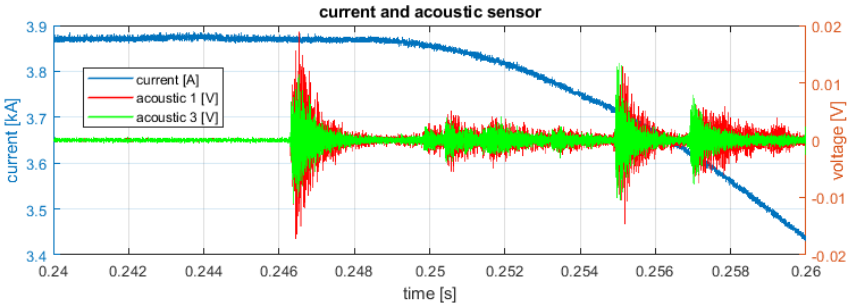
Channel	Segment	ID	Counts
1	Current		
2	Acoustic Signal		
3	1-2		14
4	2-3		7
5	3-4		8
6	4-5		8
7	5-7		8
8	7-8		3

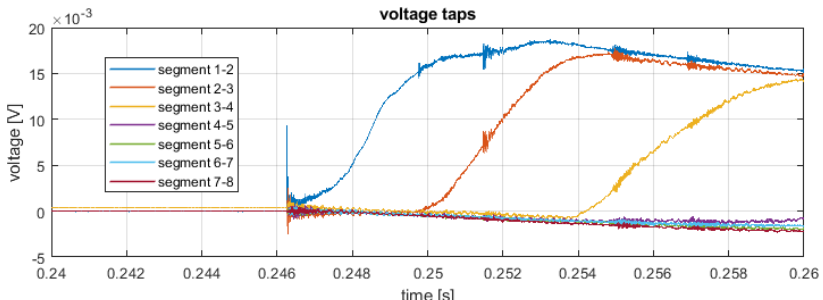
BOX 5: Results

- NbTi (MQM, Ref 0,825) at 4,5 T; Ic = 7,5 kA (1200 N)
- S2 fibreglass sleeve, heated to 300°C for >2hrs to remove some sizing
- Anodised Aluminium
- CTD101K

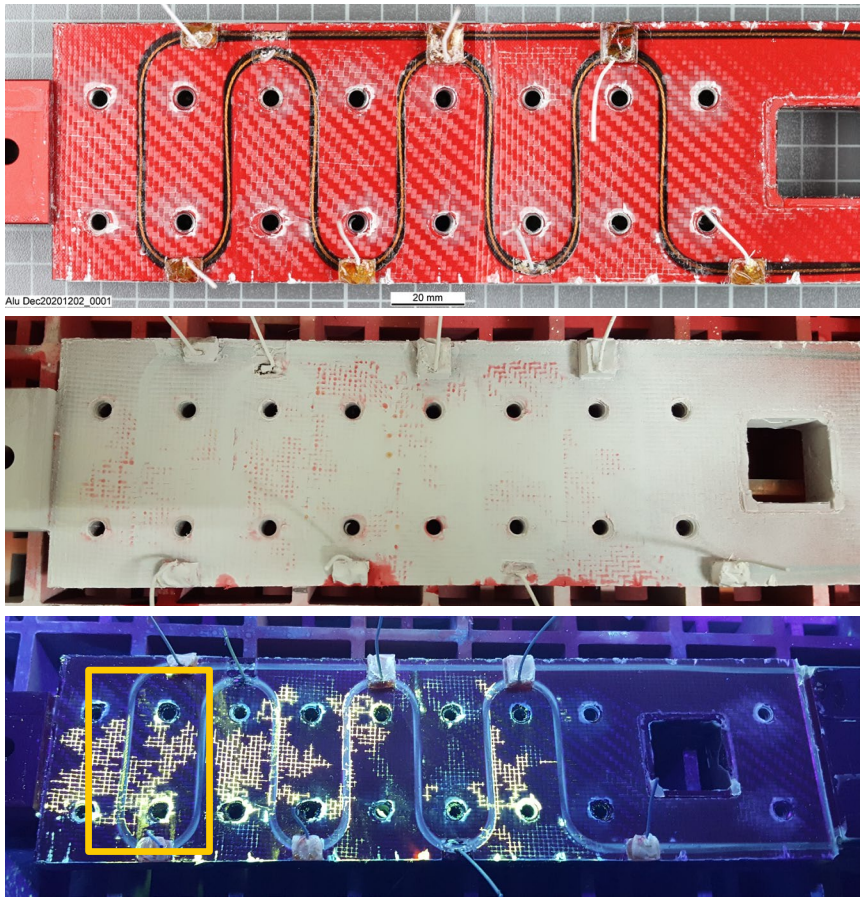
Quench #1





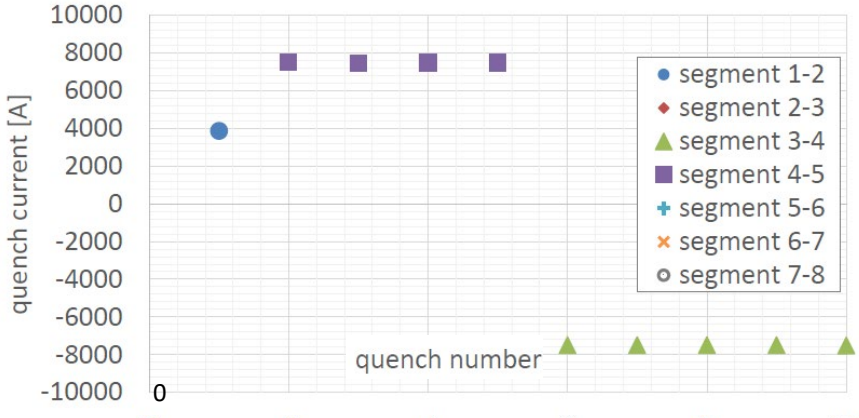


Observation prior to testing

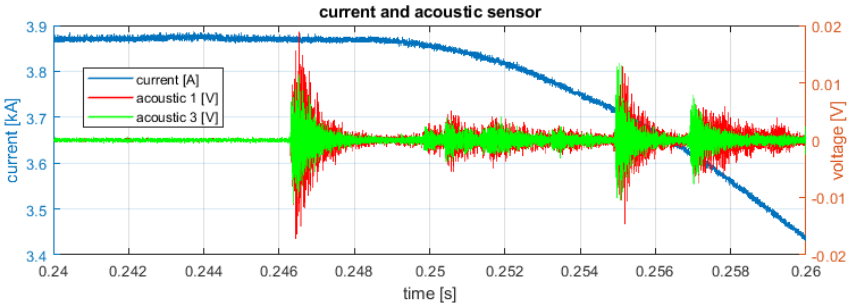


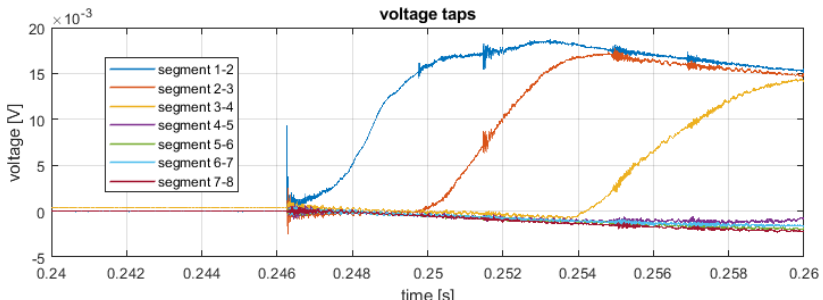
BOX 5: Results

- NbTi (MQM, Ref 0,825) at 4,5 T; Ic = 7,5 kA (1200 N)
- S2 fibreglass sleeve, heated to 300C for >2hrs to remove some sizing
- Anodised Aluminium
- CTD101K

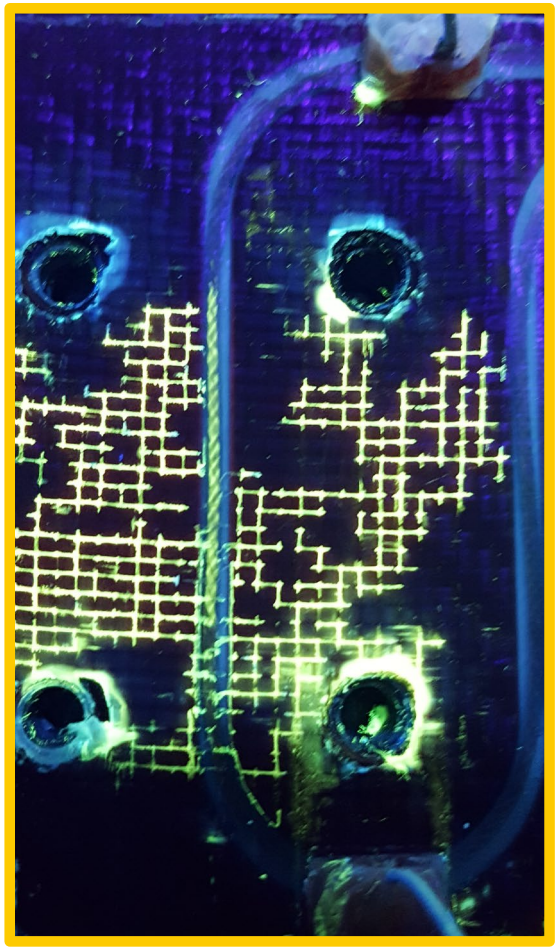


Quench #1





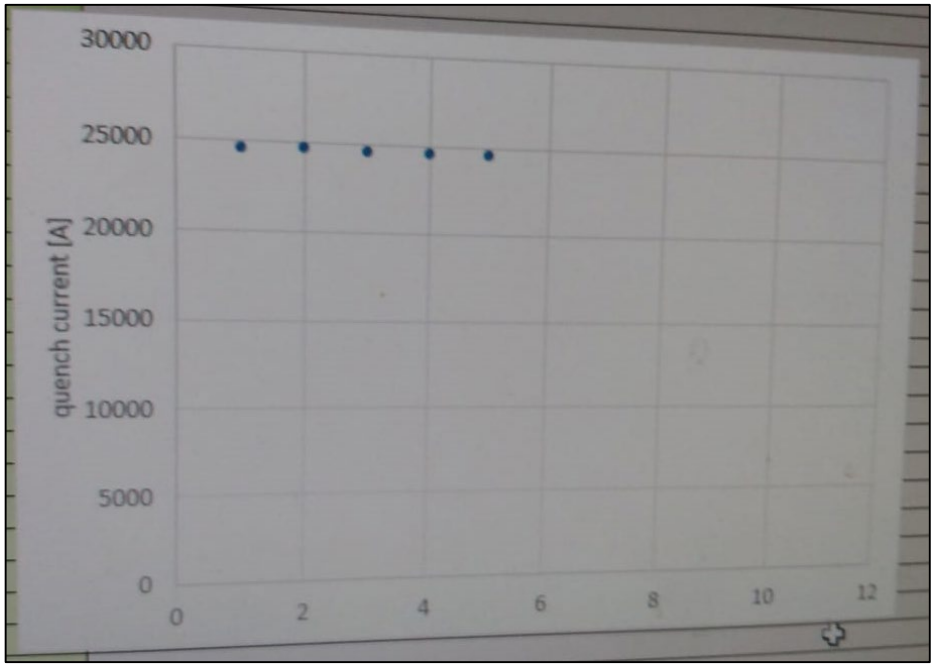
Observation prior to testing



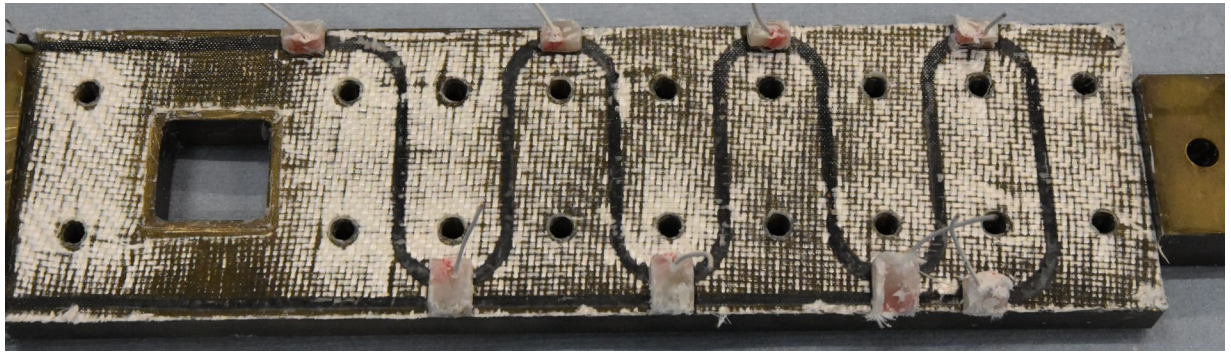
BOX 6: Paraffin Wax Impregnation

- Nb_3Sn conductor, similar to previous BOX samples.
- Cable insulated with S2 braid.
- Fibre glass sheet interlayer.
- Sand blasted alu-bronze former.
- Impregnated with paraffin.

- Results:
  - No training…
  - … and reaches Ic 24,5 kA
  - Ramp rate 200 A/s
  - 7.5 T Sol field
  - …



Observations prior to testing



Future plans

		Identifying Feature	Conductor		
			Type	Insulation	Coating/treatment
Sep-20	BOX 1	Trial	Nb_3Sn	S2 braided + Mica	N/A
	BOX 2	Rep CD1 mag	Nb_3Sn	S2 braided	N/A
Dec-20	BOX 3	Rep CD1 improved adhesion	Nb_3Sn	S2 braided	wash off S2 sizing
	BOX 4	Schlomo: No impregnation	Nb_3Sn	S2 braided + sleeve	e heated to 300C for
	BOX 5	Kirby/CERN CCT	NbTi	S2 Sleeve	e heated to 300C for
	BOX 6	Bee's wax impregnation	Nb_3Sn	S2 braided	wash off S2 sizing
	BOX 7	Improve CD1 with MY750	Nb_3Sn	S2 braided	wash off S2 sizing
	BOX 8	Improve sliding	Nb_3Sn	S2 braided	wash off S2 sizing
	BOX 9	Liquid metal	Nb_3Sn	None	?????
	BOX 10	Stycast + dip-coating	Nb_3Sn	None	N/A
	BOX 11	New insulation scheme	Nb_3Sn	Mullite/Basalt	N/A
	BOX 12	PSI coating R&D	Nb_3Sn	glass glue	N/A
	BOX 13	Wind react Unwind/wind	Nb_3Sn	S2 braided	N/A
	BOX 14	CD1 + improvements + CTD101K	Nb_3Sn	S2 braided	wash off S2 sizing
	BOX 15	CD1 + improvements + MY750	Nb_3Sn	S2 braided	wash off S2 sizing
	BOX 16	3D printed	Nb_3Sn	S2 braided	wash off S2 sizing
	BOX 17	2 turn	Nb_3Sn	S2 braided	wash off S2 sizing
	BOX 18	Force cracking on surface	Nb_3Sn	S2 braided	N/A
	BOX 19	Solid N2 Impregnation	Nb_3Sn	S2 braided	wash off S2 sizing
	BOX 20	Sliding contacts	Nb_3Sn	S2 braided	improve sliding
	BOX 21	Improve heat capacity	Nb3Sn	S2 braided	Gd ribbon

		Identifying Feature	Conductor			Former		Reaction	Impregnation				Final assembly (interlayer)	Pre-tinning		Goals
			Type	Insulation	Coating/treatment	Material	Coating/treatment	Condition	Resin	Impregnation	curing	Conditioning		Solder	Quantity	
Sep-20	BOX 1	Trial	Nb_3Sn	S2 braided + Mica	N/A	Alu-bronze	As received/machined	210/400/665	Mix 61	vertical	horizontal	vacuum	Fibre glass sheet	SnAg	2 x double ribbon + addition wire	Represent as best CD1 magnet production and test BOX sample concept and fabrication
	BOX 2	Rep CD1 mag	Nb_3Sn	S2 braided	N/A	Alu-bronze	As received/machined	210/400/665	Mix 61	vertical	vertical	vacuum	Fibre glass sheet / fibre tape	SnAg	1 x double ribbon	Represent as best CD1 magnet production and improve BOX fabrication
Dec-20	BOX 3	Rep CD1 improved adhesion	Nb_3Sn	S2 braided	wash off S2 sizing	Alu-bronze	Sand blasted	210/400/665	Mix 61	vertical	vertical	vacuum	Fibre glass sheet	SnAg	2x double ribbon + Solder wire	Reproduces CD1 as best as possible with sand blasted grooves and hope for better adhesion.
	BOX 4	Schlomo: No impregnation	Nb_3Sn	S2 braided + sleeve	e heated to 300C fo	S-Steel	As received/machined	210/400/665	None	N/A	N/A	N/A	Fibre glass Sheet	SnAg	2x double ribbon + Solder wire	How far can the cable survive?; effects of stick slip and/or sliding; effects of micro-cracking;
	BOX 5	Kirby/CERN CCT	NbTi	S2 Sleeve	e heated to 300C fo	Aluminium	Anodised/Sand Blasted	N/A	CTD101K	vertical	vertical	vacuum	Fibre glass Sheet	SnAg	2x double ribbon + Solder wire	Emulate CERN CCT technology; See effects of non reaction residues/pollution on cable/wall/resin interface bond; Are there signs of cracking from micro we
	BOX 6	Bee's wax impregnation	Nb_3Sn	S2 braided	wash off S2 sizing	Alu-bronze	Sand blasted	210/400/665	Paraffin Wax	vertical	vertical	vacuum	Fibre glass Sheet	SnAg	2x double ribbon + Solder wire	Intermediate between no impregnation and fully impregnated. Softer release of energy? Can we have a low-friction contact on the channel walls?
	BOX 7	Improve CD1 with MY750	Nb_3Sn	S2 braided	wash off S2 sizing	Alu-bronze	Sand blasted	210/400/665	MY750	vertical	vertical	vacuum	Fibre glass sheet	SnAg	2 x double ribbon	Reproduces CD1 as best as possible with sand blasted grooves and MY750 (Better fracture toughness and thermal contraction)
	BOX 8	Improve sliding	Nb_3Sn	S2 braided	wash off S2 sizing	Alu-bronze	HND (Br Ni coating)	210/400/665	MY750/MIx61	vertical	vertical	vacuum	None	SnAg	2 x double ribbon	Avoid Stick slip
	BOX 9	Liquid metal	Nb_3Sn	None	?????	Alu-bronze	dip-coating insulator	210/400/665	Metal Solder	Horizontal	horizontal	ambient	Kapton Sheet	SnAg	2 x double ribbon	Martin Wilson previous studies; better cooling; better bonding?
	BOX 10	Stycast + dip-coating	Nb_3Sn	None	N/A	S-Steel	dip-coating insulator	210/400/665	Stycast	vertical	horizontal	pressure	Kapton Sheet	SnAg	2 x double ribbon	Improved electrical insulation, former can be stainless steel and better properties of stycast at cold.
	BOX 11	New insulation scheme	Nb_3Sn	Mullite/Basalt	N/A	Alu-bronze	Sand blasted	210/400/665	Mix 61	vertical	vertical	vacuum	Fibre glass sheet	SnAg	2 x double ribbon	Anna's and PSI's suggestions to avoid pollution and therefore improve adhesion.
	BOX 12	PSI coating R&D	Nb_3Sn	glass glue	N/A	Alu-bronze	Calcium oxide	210/400/665	Mix 61	vertical	vertical	vacuum	Fibre glass sheet	SnAg	2 x double ribbon	Assess other coatings to improve electrical insulation and adhesion and build upon PSI knowledge
	BOX 13	Wind react Unwind/wind	Nb_3Sn	S2 braided	N/A	Alu-br/S-Steel	As received/machined	210/400/665	Mix 61	N/A	N/A	N/A	Fibre glass sheet	SnAg	2 x double ribbon	Can it be done without compromising the conductor?
	BOX 14	CD1 + improvements + CTD101K	Nb_3Sn	S2 braided	wash off S2 sizing	Alu-bronze	Sand blasted	210/400/665	CTD101-K	vertical	vertical	vacuum	Fibre glass sheet	SnAg	2 x double ribbon	Make improvements to bonding and test new resin
	BOX 15	CD1 + improvements + MY750	Nb_3Sn	S2 braided	wash off S2 sizing	Alu-bronze	Sand blasted	210/400/665	MY750	vertical	vertical	vacuum	Fibre glass sheet	SnAg	2 x double ribbon	Make improvements to bonding and test new resin
	BOX 16	3D printed	Nb_3Sn	S2 braided	wash off S2 sizing	3D Printed	Scaffolds	210/400/665	Mix 61	vertical	vertical	vacuum	Fibre glass sheet	SnAg	2 x double ribbon	Encouraging results from ETHZ; Check improved bonding
	BOX 17	2 turn	Nb_3Sn	S2 braided	wash off S2 sizing	Alu-bronze	Sand blasted	210/400/665	Mix 61	vertical	vertical	vacuum	Fibre glass sheet	SnAg	2 x double ribbon	Can we wind two cables at the same time, connected in series at the splice; two cables are pushing out instead of one, required 2x the current.
	BOX 18	Force cracking on surface	Nb_3Sn	S2 braided	N/A	Alu-bronze	As received/machined	210/400/665	Mix 61	vertical	vertical	vacuum	No fibre/shim for a gap	SnAg	2 x double ribbon	Reproduce production and assembly of CCTs from LBNL
	BOX 19	Solid N2 Impregnation	Nb_3Sn	S2 braided	wash off S2 sizing	Alu-bronze	As received/machined	210/400/665	N2	In-situ test	N/A	In-situ test	Unknown	SnAg	2 x double ribbon	Can we freeze liquid Nitrogen to impregnate the cable inside the groove
	BOX 20	Sliding contacts	Nb_3Sn	S2 braided	improve sliding	Alu-bronze	Promote sliding	210/400/665	N/A	N/A	N/A	N/A	Unknown	SnAg	2 x double ribbon	Avoid stick slip motion
	BOX 21	Improve heat capacity	Nb3Sn	S2 braided	Gd ribbon	Alu-bronze	Sand blasted	210/400/665	Mix 61	vertical	vertical	vacuum	Fibre glass sheet	SnAg	2x double ribbon + Solder wire	Heat heat capacity for better recovery

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THANK YOU FOR LISTENING

PART2...

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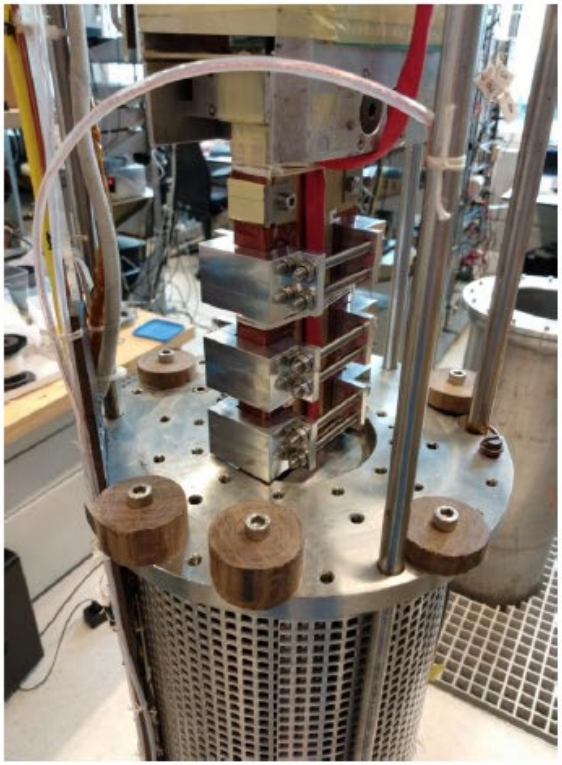
COMPLEMENTARY SLIDES

UTwente solenoid overview

Entire set-up

Top of the magnet



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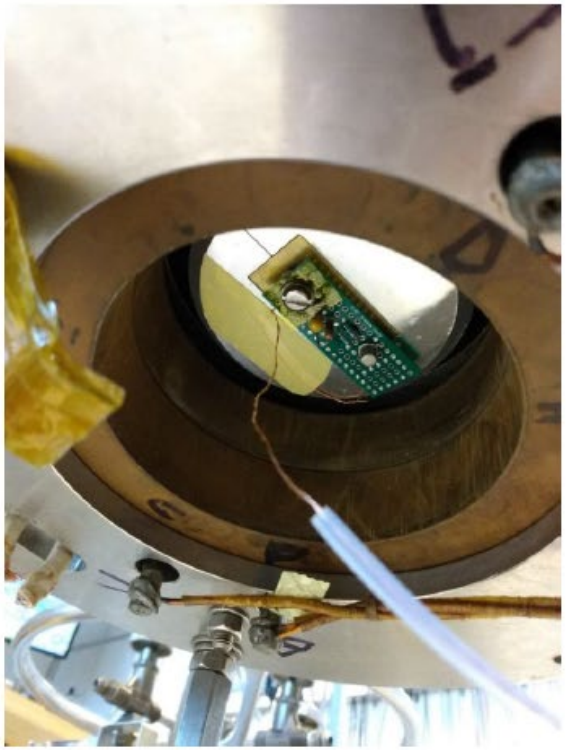
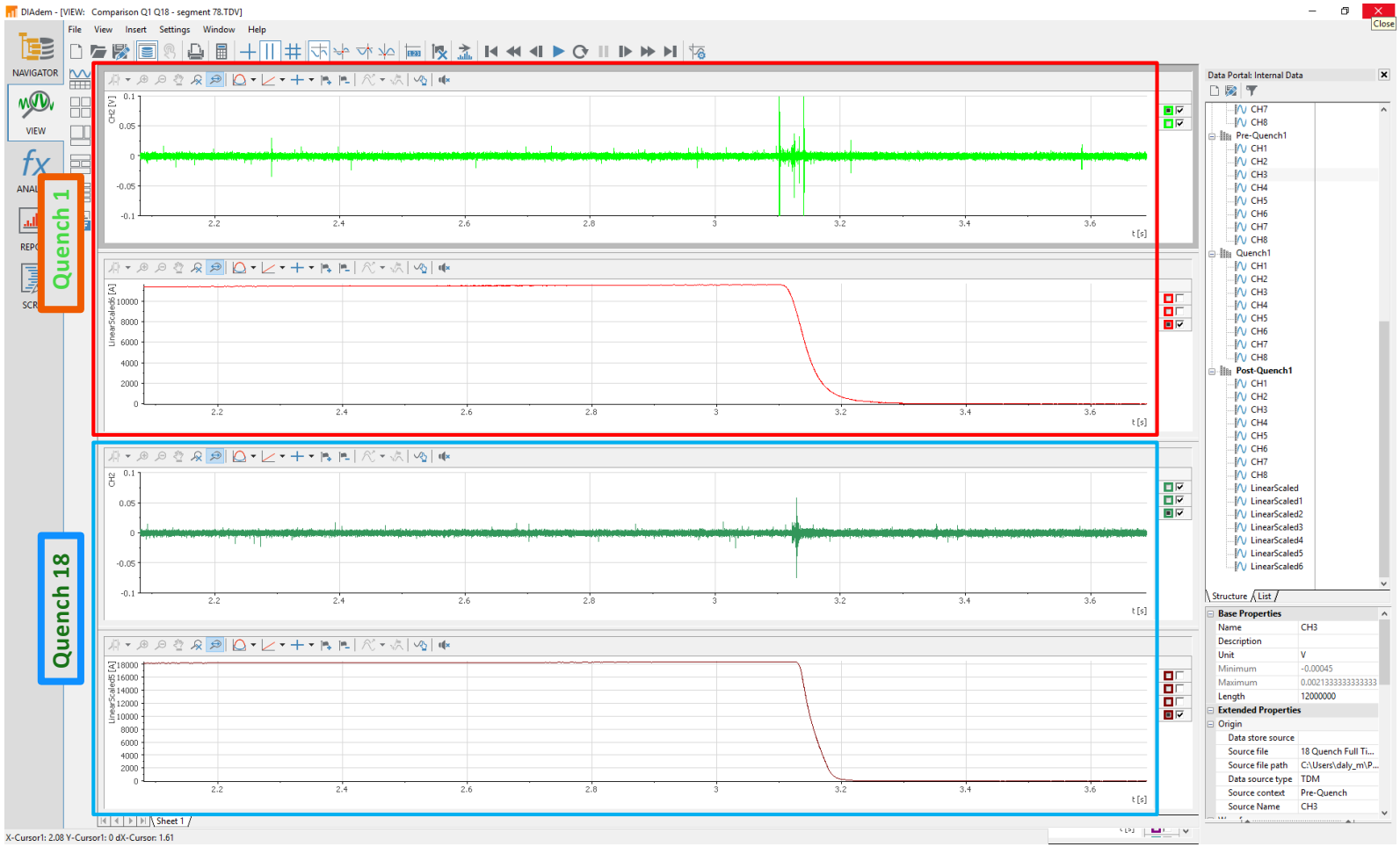


Courtesy S.Otten (Utwente)

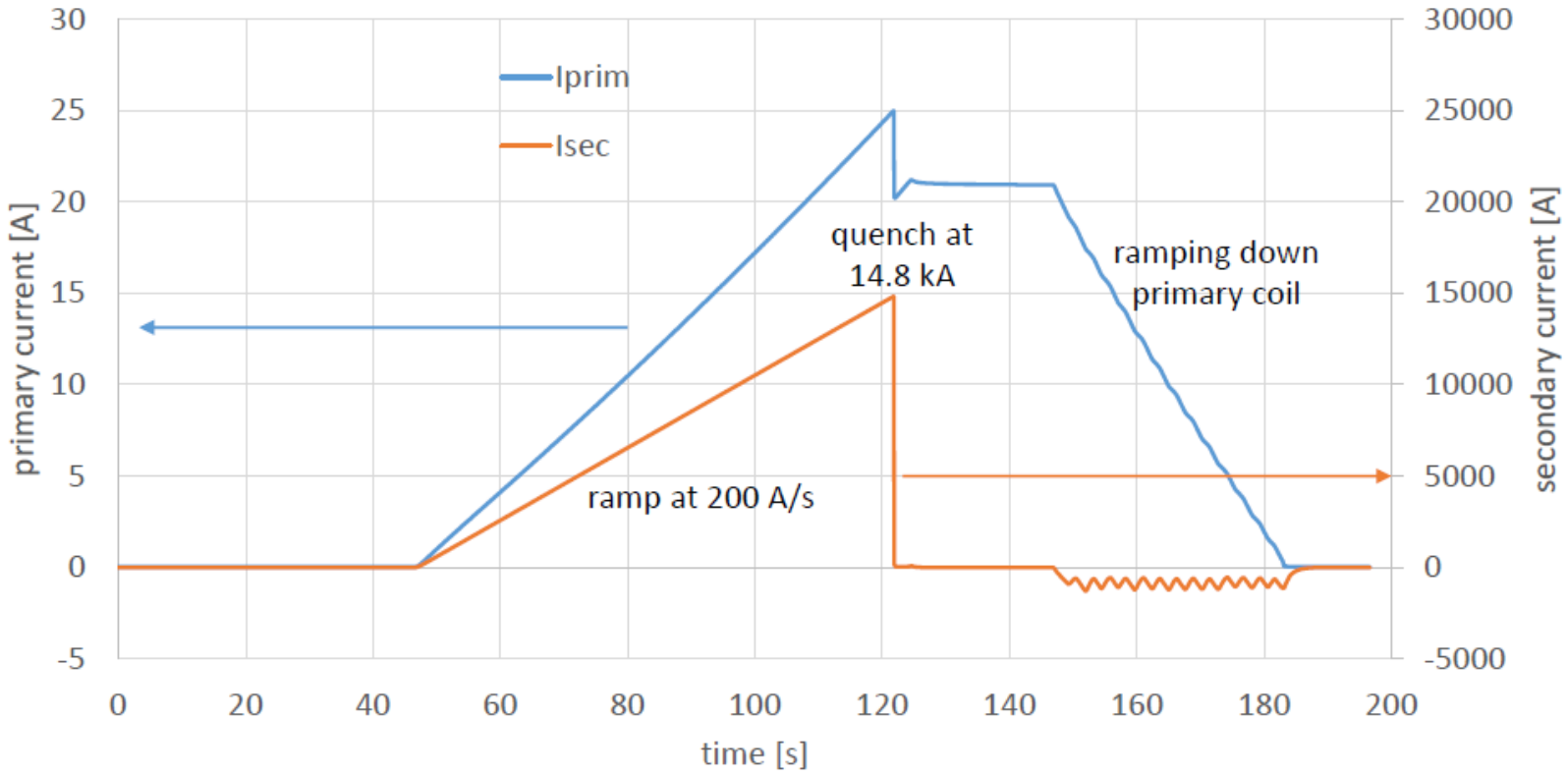
BOX 1 - Q1 vs Q18: seg 7-8

- Stark difference between the AE signal of the first and 18th quench occurring in the same segment.



Test protocol

- Target: 23 kA at 7,5 T solenoid field
- Ramp at 200 A/s (typical ramp for Utwente)
- If there is a limitation then reduce ramp rate (50 A/s) or change current direction.



Courtesy S.Otten (Utwente)