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Metal-as-Insulation (MI) HTS Insert for Very High Field Magnet

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Collaboration

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PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR

The Grenoble High Field Facility

- to generate the highest field possible
- to welcome worldwide users
- to develop in-house R&D

- 24 MW power supply (36 MW upgrade)
- 300 l/s water cooling

10 T in 376 mm bore ➔ 17 T in 2020
20 T in 170 mm bore ➔ 27 T
31 T in 50 mm bore ➔ 38 T
37 T in 34 mm bore ➔ 43 T

- Part of the European Magnetic Field Laboratory (EMFL)

P. Pugnat, **Thu-Mo-Or17-06**: From Manufacture to Assembly of the 43 T Grenoble Hybrid Magnet
A. den Ouden, **Thu-Mo-Or17-05**: Progress in the construction of the Nijmegen 45T hybrid magnet system

About producing DC magnetic field

Today

In the future

2010
23.5 T
1 GHz
Bruker

Energy dissipation

0 5 10 15 20 25 30 35 40 45 Tesla

LowTc … NbTi, Nb3Sn … « commercial products»

41 T = 33 MW
37 T = 24 MW
Resistive magnet

45 T = 20 MW
Hybrid magnet

Superconductors = zero resistance
☞ Current transport without Joule heating

High Tc … Bi2212, TRBaCuO

24 T
Tohoku Univ.
Sendaï
User magnet

26.4 T
Sunam
NI demo
magnet

32 T
NHMFL
User
magnet

1.2 GHz Bruker

40 T
Projects

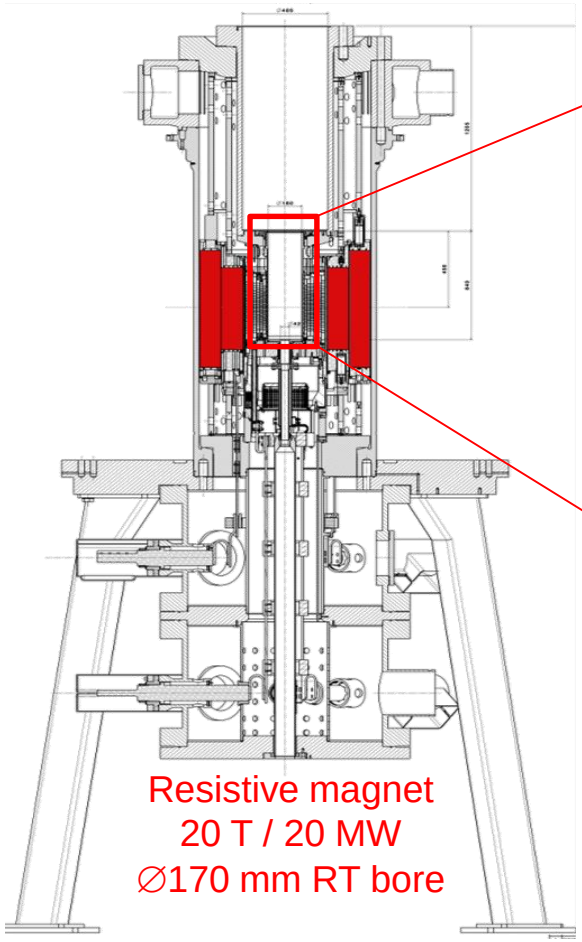
45 T
NHMFL
NI demo
magnet

Low Tc : operation in liquid helium
High Tc: operation in liquid nitrogen

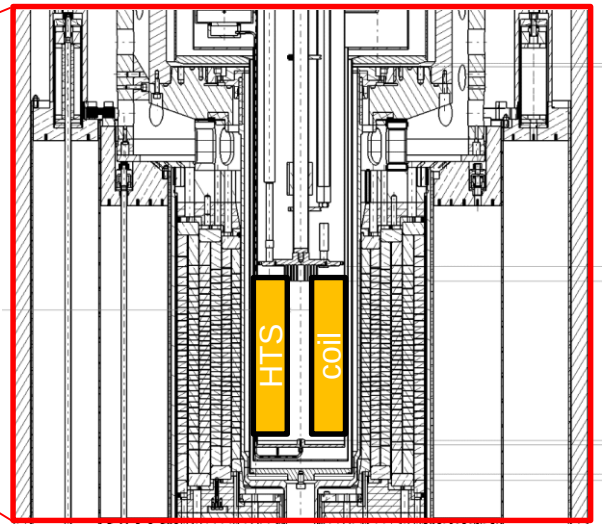
Operation at lower temperature enables **higher irreversibility field and Jc**

ANR NOUGAT 2014-2018

New generation of superconducting magnet for producing Tesla with a reduced energy consumption



Resistive magnet
20 T / 20 MW
∅170 mm RT bore



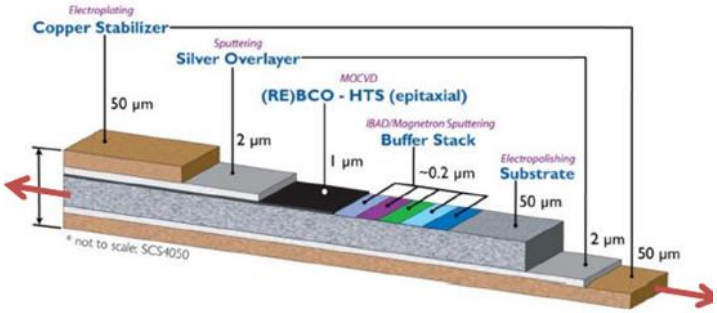
HTS insert in a **4.2 K liquid helium bath**:
Fixed dimensions :

$\varnothing_{int}$	50 mm
$\varnothing_{ext}$	115 mm
Height	220 mm

- build and test a 10 T HTS insert in the 20 T background field of a resistive magnet (central field of 30 T)
- pave the way to a **30 T+ all superconducting magnet**

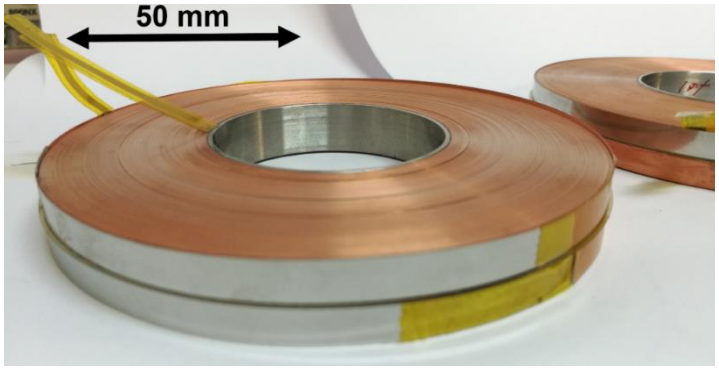
REBaCuO tapes at 4.2 K best candidate for high field magnet

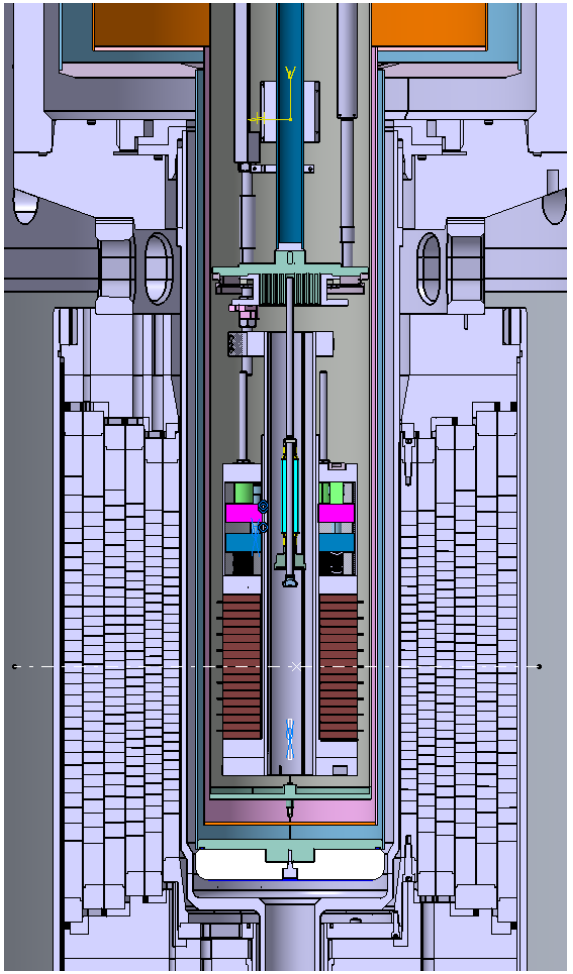
☺ High transport current under high magnetic field
☺ High mechanical strength due to Hastelloy



SP® 2G HTS Wire Type - SCS6050-AP 20µm Cu 180 A min

☺ Affordable for 100-200 m pieces ☞ pancake coils

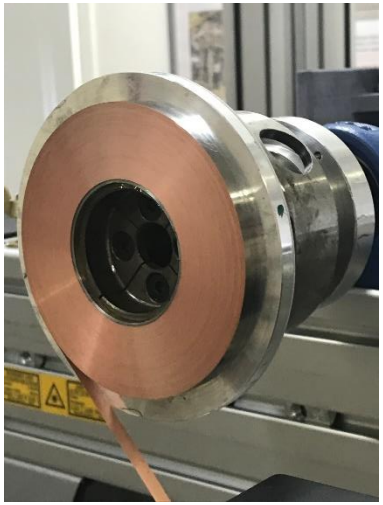


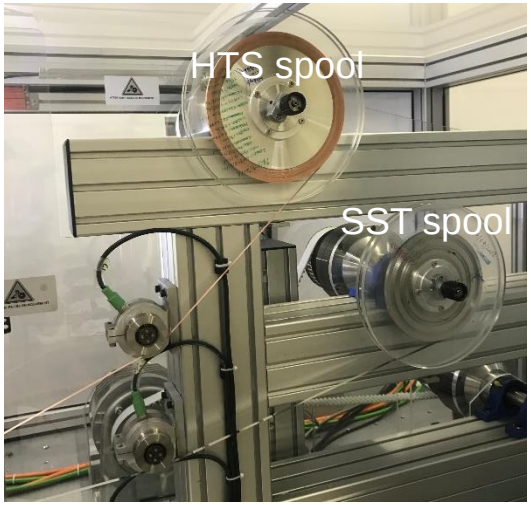


Mechanical design to limit the conductor strain to 0.4% max
With winding tension (100 MPa), overbanding, and uniaxial load prior to cooling

Metal-as-Insulation Technology

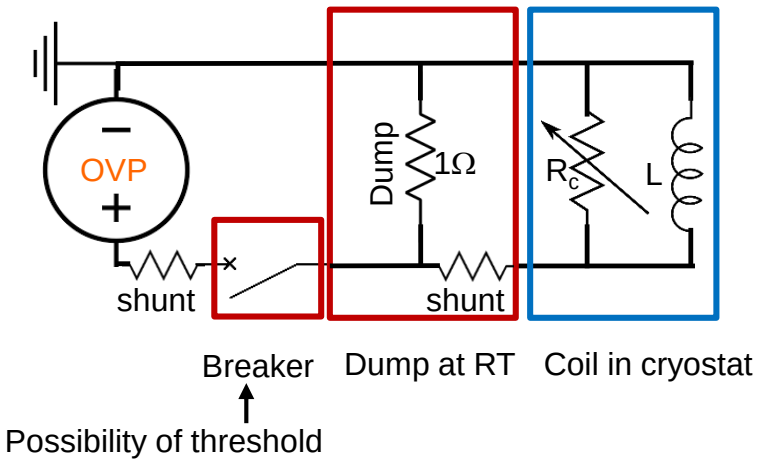
Bare HTS tape (75 µm) + SST Durnomag ribbon (30 µm)

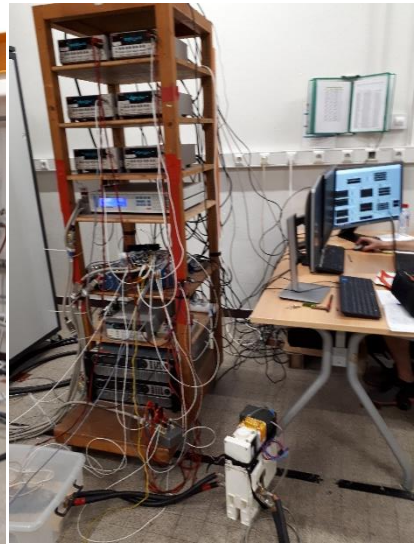




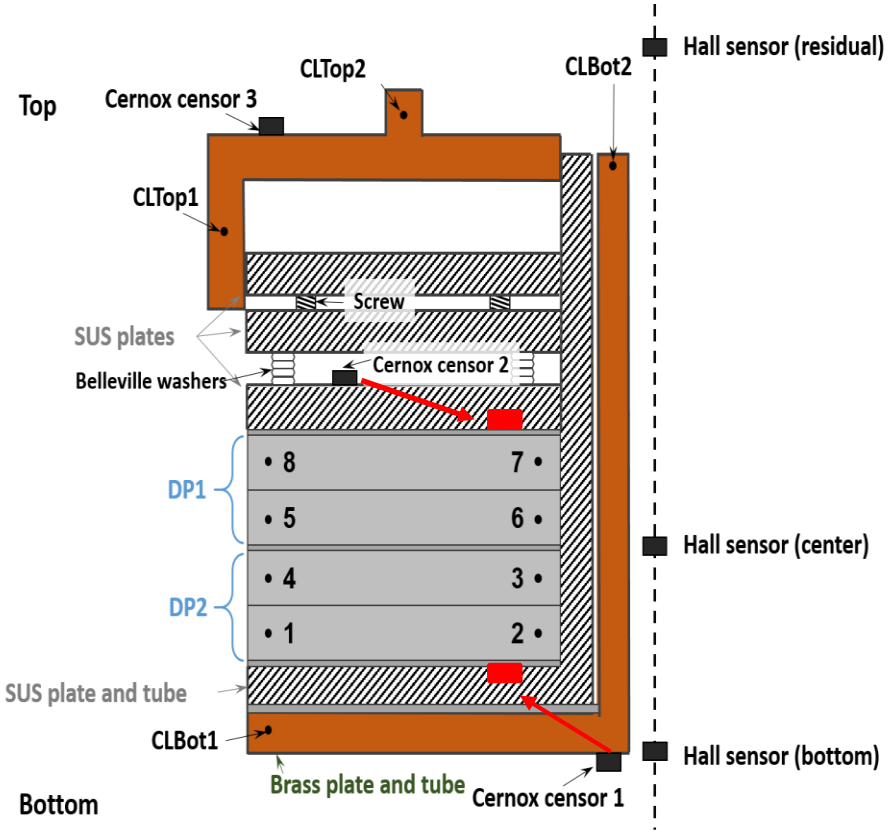
- Local shunt of degraded part (similar to NI)
- Additional Rc (lower time constant)
- Mechanical reinforcement
- Simple protection scheme

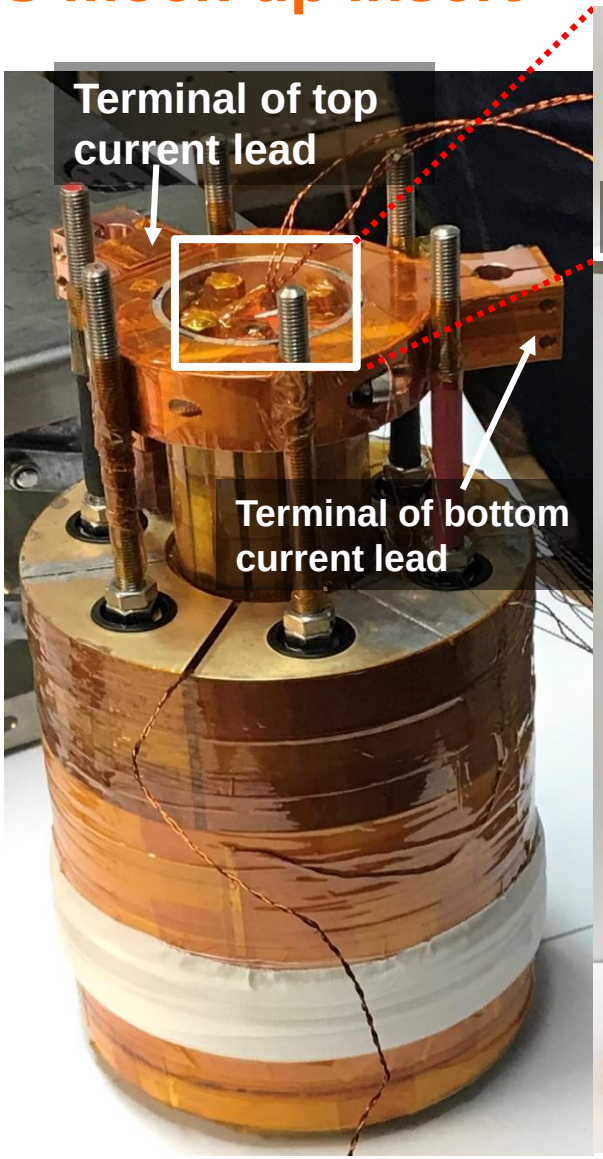
Circuit Breaker + OVP

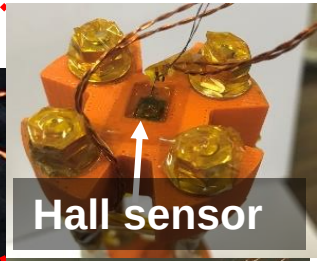




Instrumentation of NOUGAT HTS mock-up insert



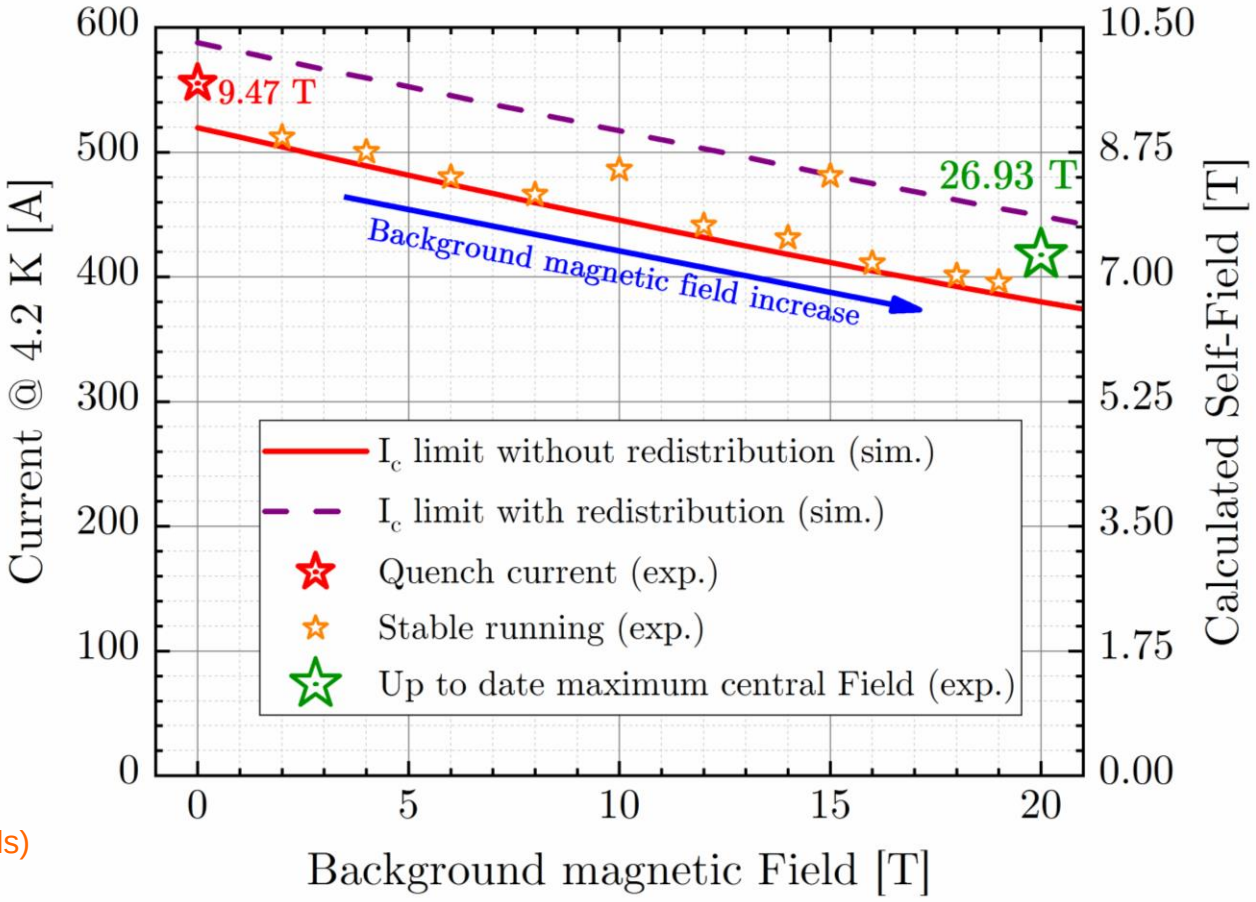




NOUGAT prototype: 2 DP coils mounted together 2017-2018

Parameter	Value
ID / OD_w/OD_{ob}	50 / 109,4 / 120 mm
# turns	279 / pancake
α_{DP} / α_{magnet}	9.1 / 17.4 mT/A
L_{DP} / L_{magnet}	24.5 / 83.0 mH
Winding tension	90-100 MPa
Min Ic,tape (77K, SF)	263 (DP1)/ 213 (DP2) A
Time constant	5.1 s
R_c	16.3 mΩ
Average R_{ct}	207 μΩ cm²

7 T reached in a 20 T background



Ramping rate 0.2 A/s
(2-3 order higher than reported for NI coils)

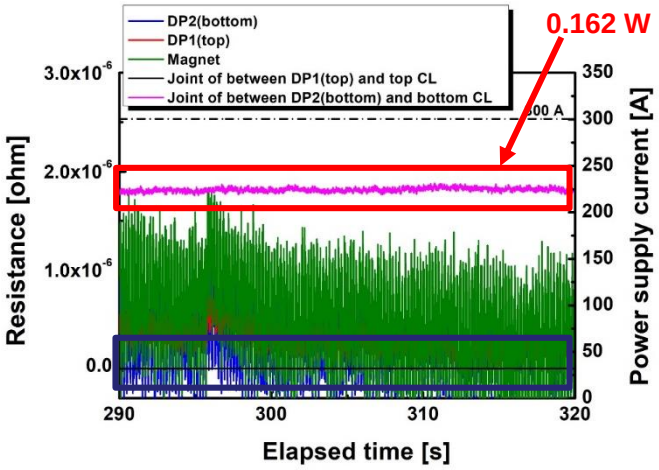
P. Fazilleau et al. **Supercond. Sci. Technol. 31** (2018) 095003

J. Song, **Mon-Af-Po1.20-01**: "Thermal, Electrical and Mechanical Behaviors of MI HTS Coils Wound with Commercial REBCO Tapes under High Background Magnetic Fields at 4.2 K "

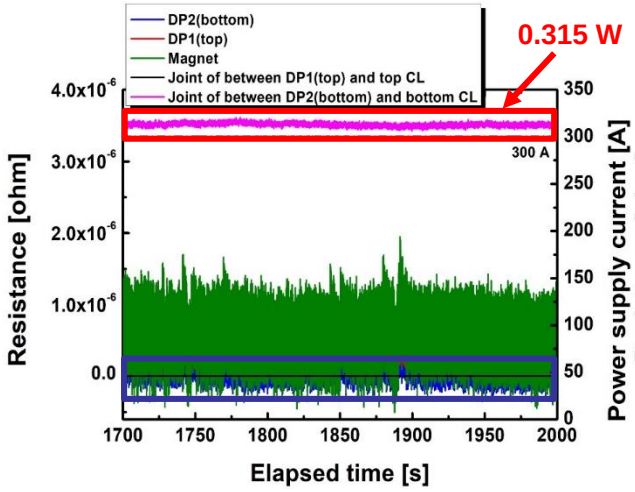
26.9 T @ 415 A (658 A/cm²)
BJR ~900 MPa

Damage check - R of DPs / magnet at 300 A in SF

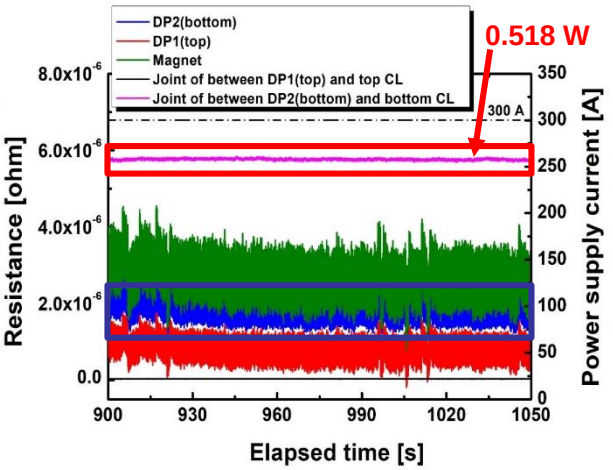
Test # 20 on 7th December 2017
-after 1st quench event



Test # 66 on 18th January 2018
-after 9th quench event



Test # 152 on 30th January 2018
after quench event under 20 T
- After 18th quench event*



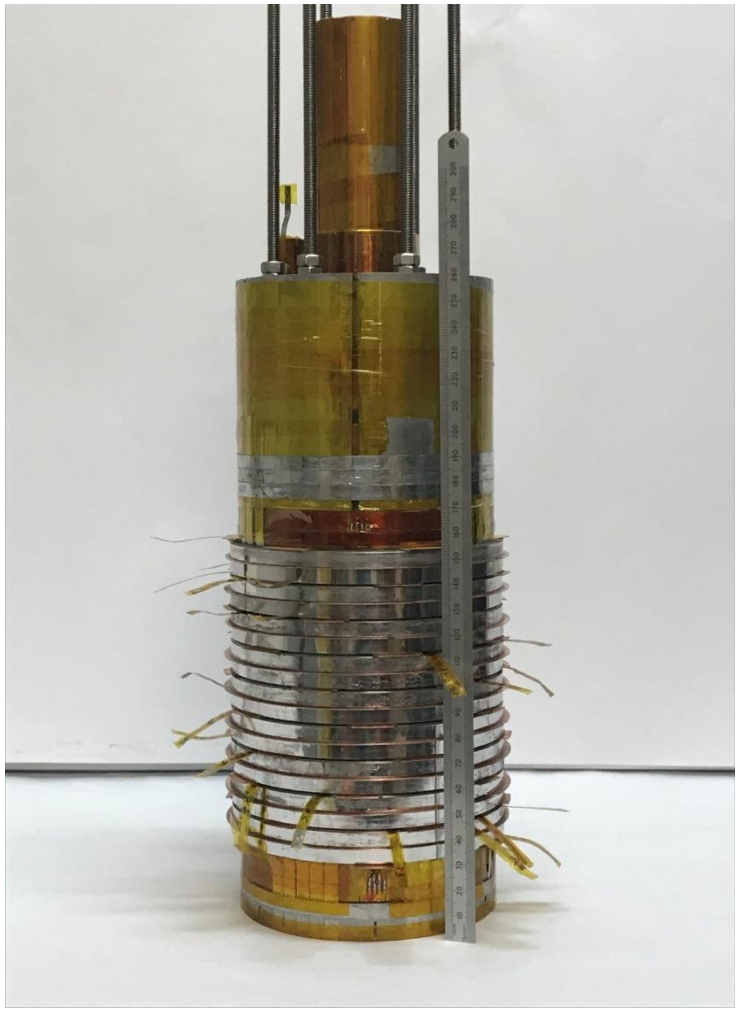
No I_c degradation of the magnet (operation at 550 A in SF)

8.1 % I_c degradation
(Quench at 510 A in SF)

*Insert and outsert !!
20 T B_{ext} drop

- **DP2(bottom)/bottom CL joint ☞higher resistance value with further quench**
- **Resistance of DP2 increased after the quench event under 20 T**

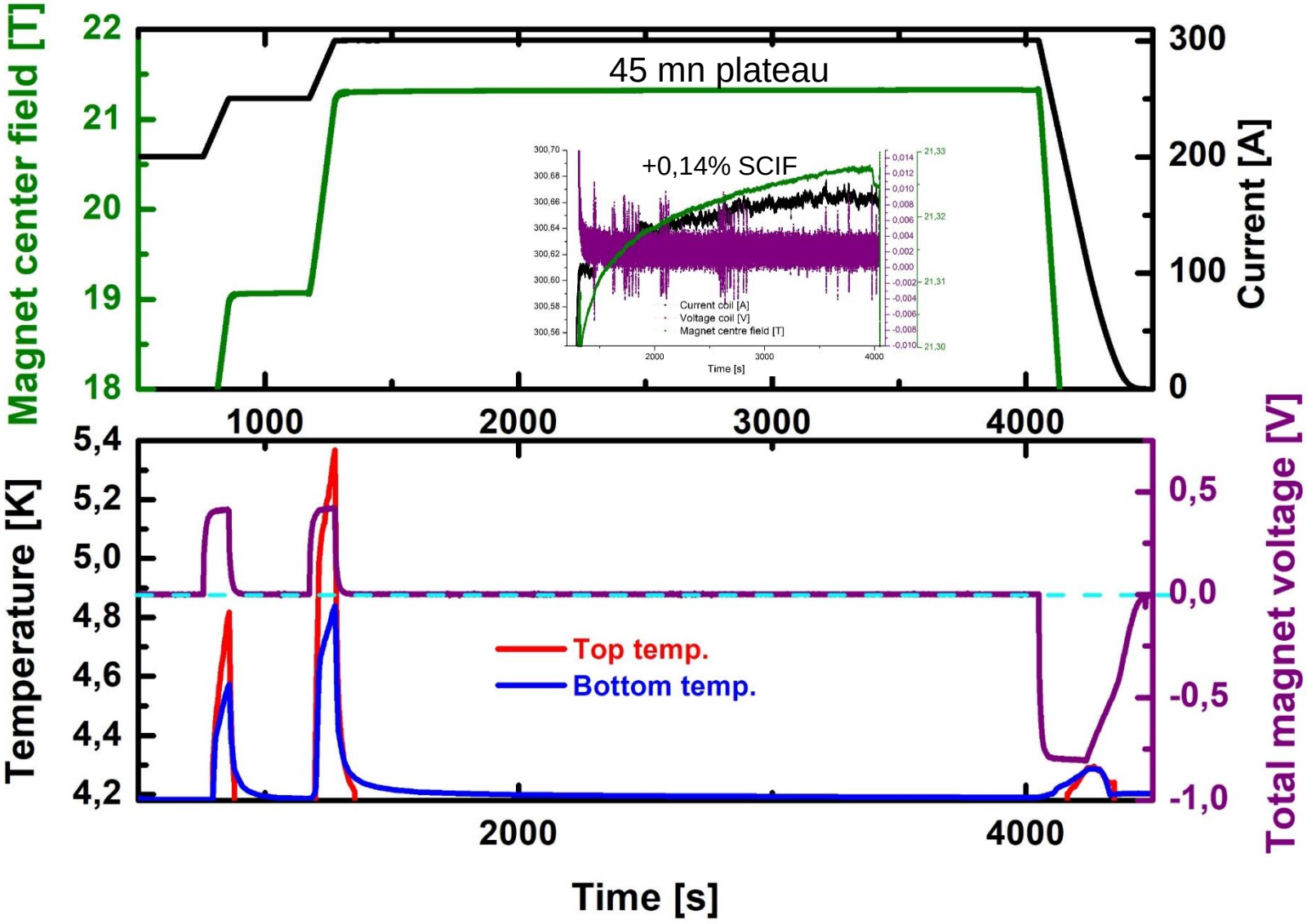
The 10 T NOUGAT HTS magnet 2018-2019



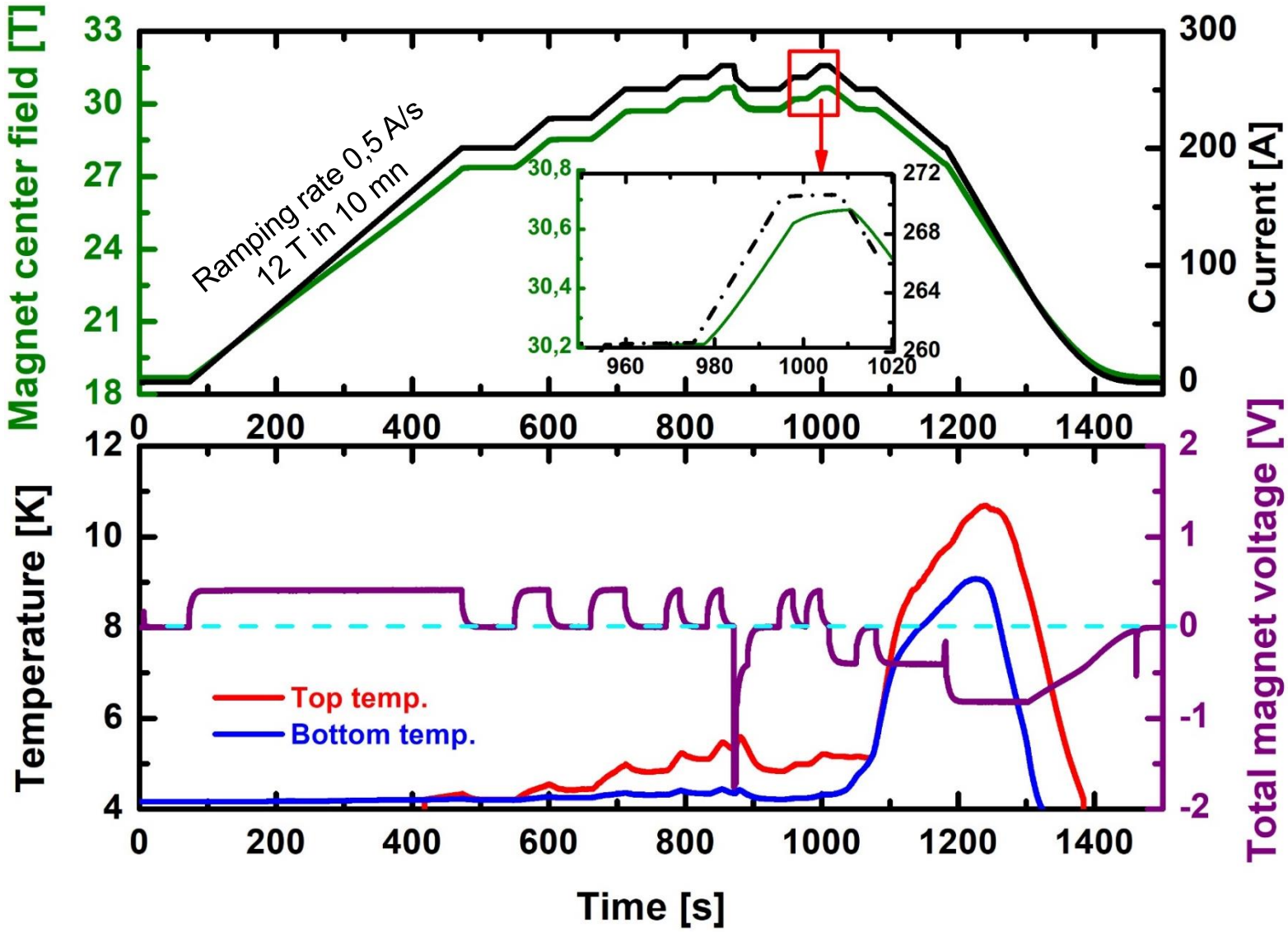
Specification of the 10 T NOUGAT HTS magnet

Parameters		Values
ID; OD	[mm]	50; 112
Height	[mm]	122.3
I_c values of DP coils at 77 K	[A]	54.5 ~ 67.3
Number of DP		9
Turn per pancake		290
Total conductor length	[Km]	~ 1.35
Stainless steel overband turns		44
OD after SUS overband	[mm]	118.8 ~ 119.0
Winding tension	[MPa]	92 ~100
Magnet inductance	[H]	0.825
Magnet constant	[mT/A]	44.5
Time constant (τ) at 4.2 K	[s]	23.06
Characteristics resistance (R_c)	[mΩ]	37
Contact surface resistance (R_{ct})	[μΩ·cm^2]	103

Long duration test - 8 T resistive ousert + 13.3 T HTS MI insert

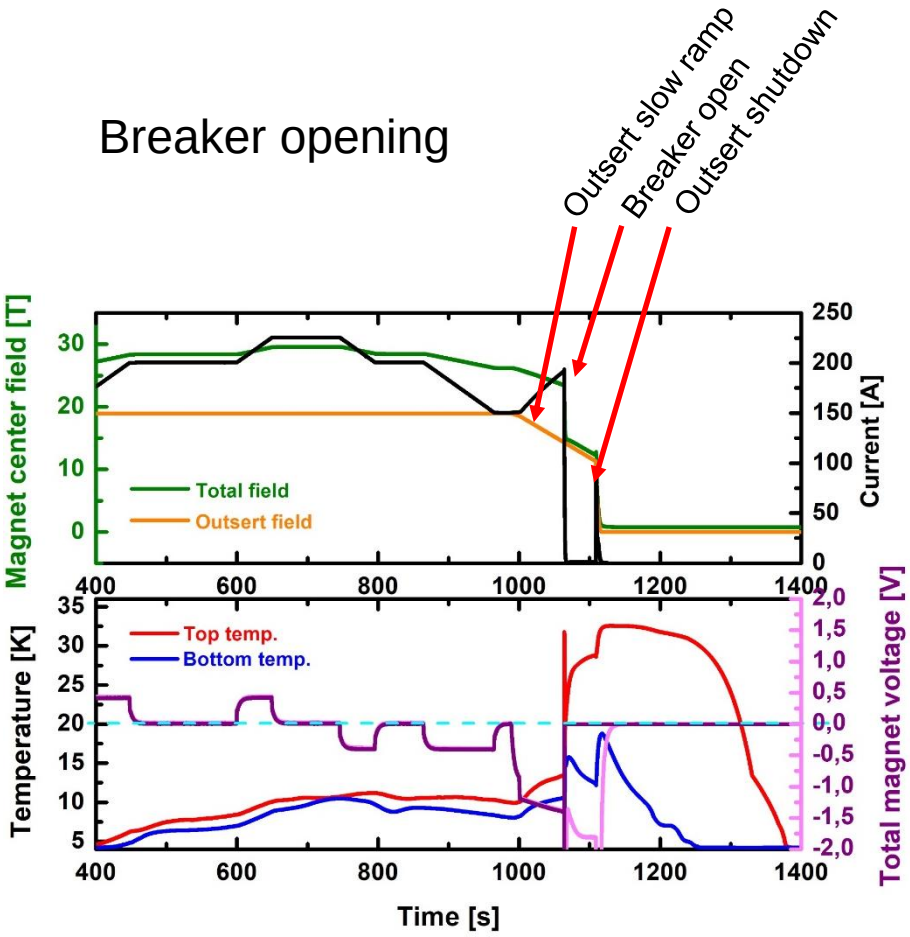


Test at 30 T - 18 T resistive magnet + 12 T HTS MI insert

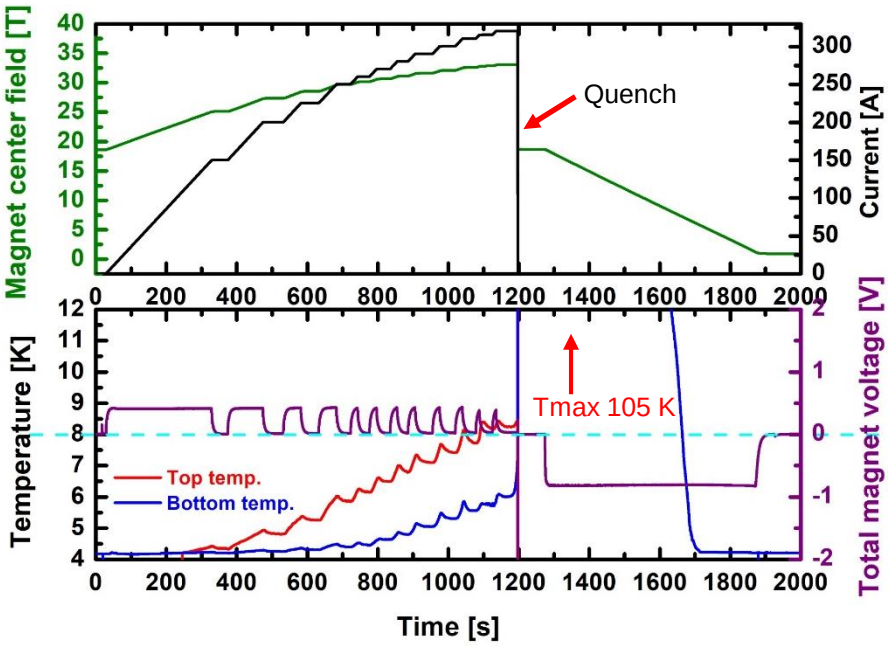


Unexpected events

Breaker opening



Temperature quench

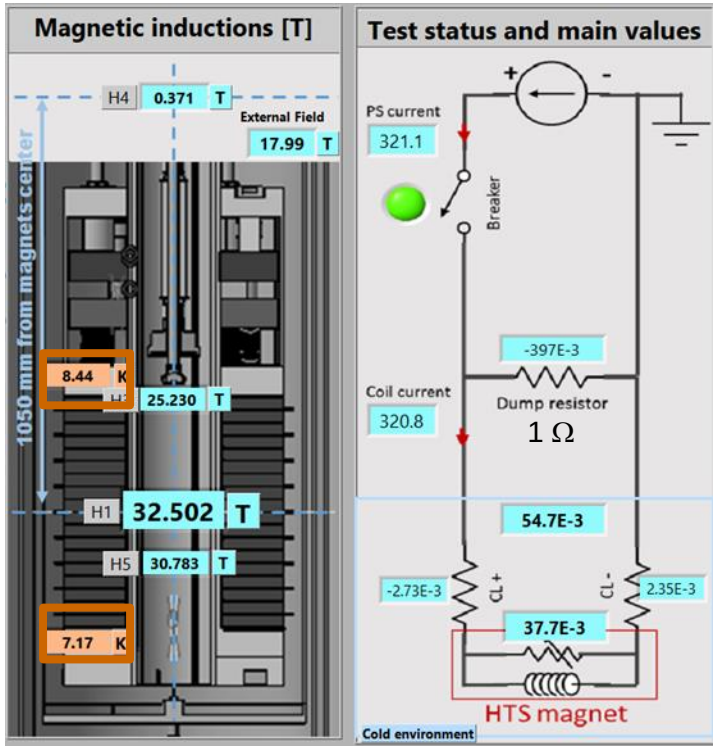


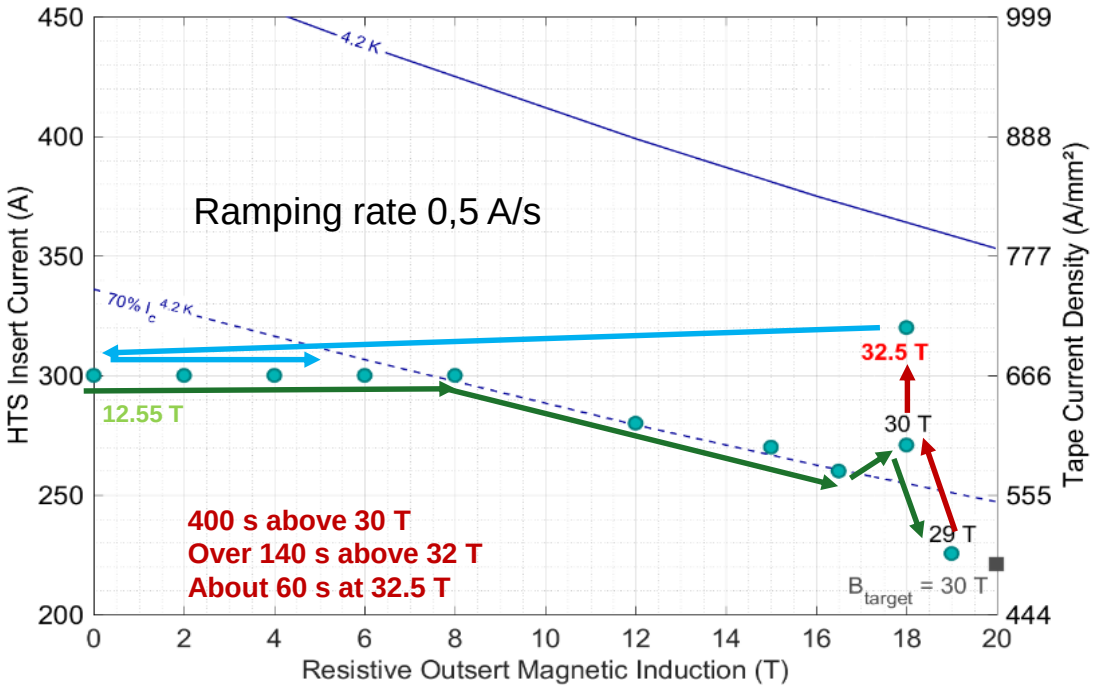
30 T –
19 T outsert + 11 T MI insert

32.5 T –
18 T outsert + 14.5 T MI insert

Final test of the 10 T NOUGAT HTS insert (assembly of 9 MI DP coils)

03/26/2019





Incident at 19 T background field
=> half of signals lost

321 A @ 0.5 A/s (~22.8 mT/s)
Je **717A/mm² in HTS tape**
Energy 44,3 kJ

Cooling issue

BdB/dz > 21 T^2/cm

McNiff et al., **Rev. Sci. Instrum. 59** (1988) 2474

Conclusions

Tests of MI coils under very high magnetic field (2 DP / 9 DP)

- ☺ 32.5 T reached
- ☺ A very simple protection scheme
- ☺ Survived to Self quench and outsert emergency shutdown

- ☹ Instrumentation damage
- ☹ Cooling issue
- ☹ Screening current

Let's make a full superconducting magnet

- ? Full coupling
- ? Mechanical analysis

P. Fazilleau, **Tue-Mo-Po2.05-01** : Analytical formulation of mechanical stresses in no-impregnated, multi-layer solenoids

Thank you for your attention !!