First experimental demonstration of the **ESC** quench protection method

Emmanuele Ravaioli (CERN, TE-MPE-PE, HFM WP4.5-T4-D9)

J. Bauche, M. Dumas, J. Feuvrier, I. Garcia-Aguirrebeitia Sanchez, M.M. Gawedzki, J-L. Guyon, F. Mangiarotti, M. Masci, J.C. Perez, P.A. Thonet, A. Verweij, P. Wachal, G. Willering, M. Wozniak (CERN),

HFM Forum
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High-field accelerator magnet designs are often limited by

**Critical
current density**

**Stress
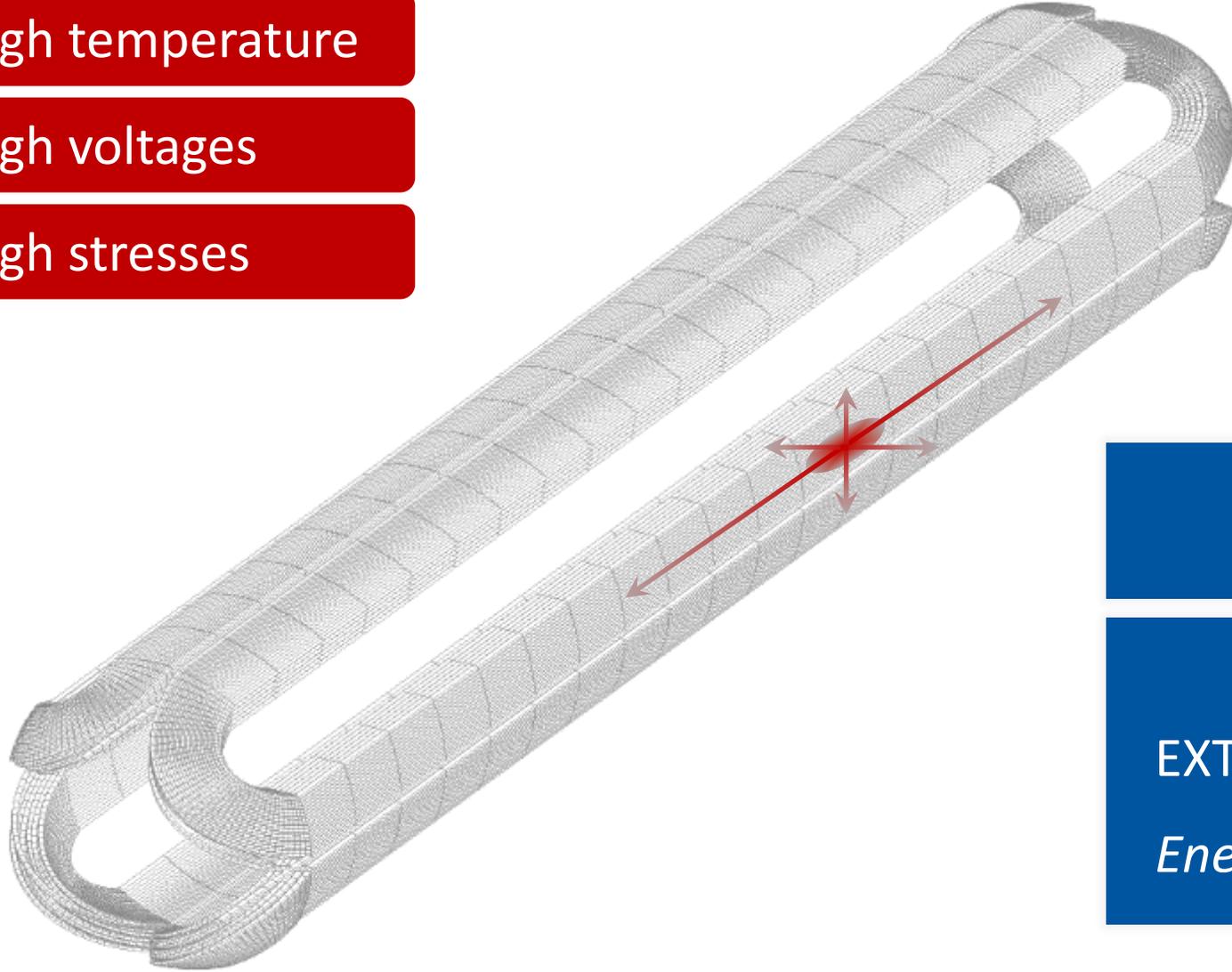in the conductor**

**Quench protection
performance**

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Quench protection in a high-magnetic field magnet

High temperature

High voltages

High stresses

DETECT QUENCH

ACTIVELY EXTRACT ENERGY

Energy extraction

ACTIVELY SPREAD ENERGY

Heaters, CLIQ

Energy Extraction

Extracts part of the magnet energy

CLIQ

Achieves very fast quench initiation

Quench Heaters

Make it easy to add redundancy

Energy Extraction

It requires high voltage across the magnet coil

CLIQ

It requires direct electrical connection to the magnet circuit

Quench Heaters

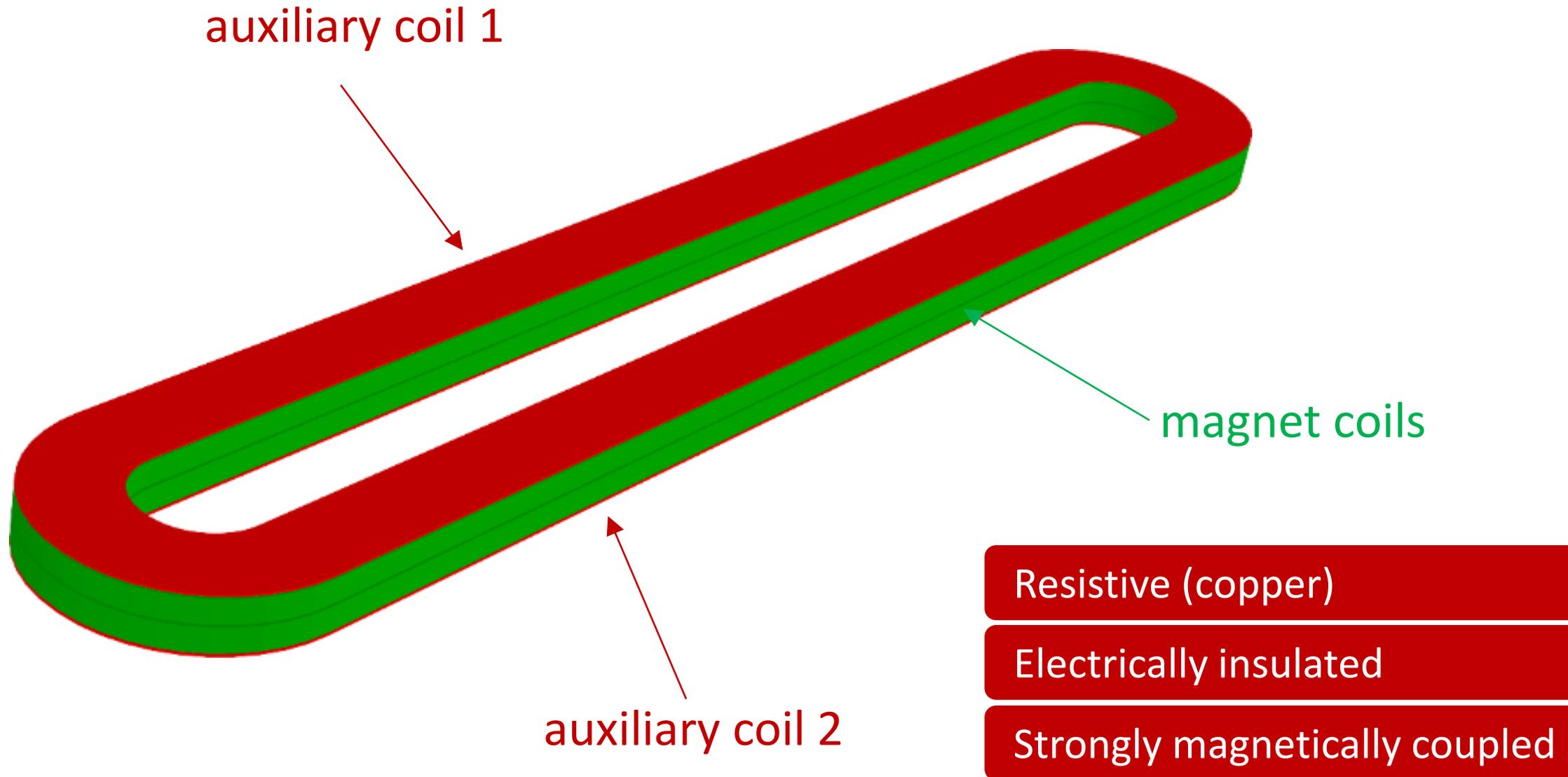They require thin insulation between protection elements and magnet coil

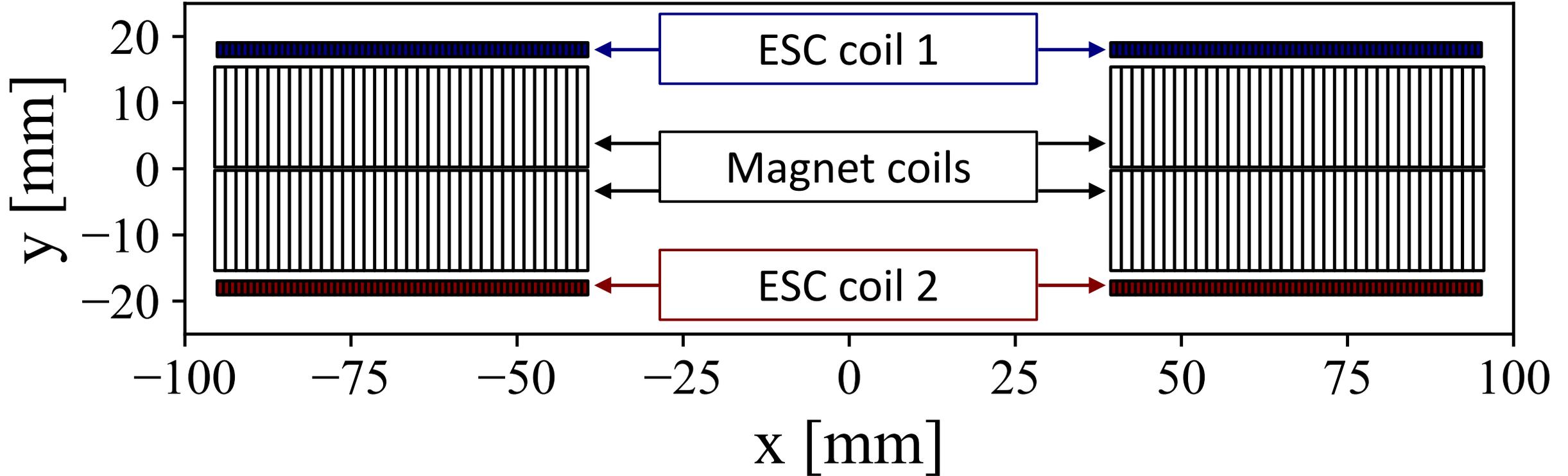# ESC
Energy Shift with Coupling

ESC auxiliary coils

auxiliary coil 1

magnet coils

auxiliary coil 2

Resistive (copper)

Electrically insulated

Strongly magnetically coupled

Short Model Coil (SMC) cross-section including two ESC auxiliary coils

Magnetic field of 12.5 T at 1.9 K

ESC coils made of 0.8x2 mm Cu single wire

Cable made of 40 Nb_3Sn 0.7 mm strands

Thick insulation between ESC and magnet coils

Design of the Short Model Coil (SMC) magnet by J.C. Perez and team (CERN).
Design of the ESC coils for SMC: E. Ravaioli, J. Bauche, M. Dumas, I. Garcia-Aguirrebeitia Sanchez, M. Masci, J.C. Perez, P. Wachal, M. Wozniak (CERN).

ESC working principle

1 Immediate reduction of the magnet current reduces ohmic loss and magneto-resistance	**2** Very high dB/dt (~1E2-1E3 T/s) transfers most/all turns to the normal state due to transient losses	**3** Energy transfer from magnet coils to auxiliary coils induced by ESC unit and coil resistance increase

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Energy Shift with Coupling (ESC) simplified schematic

Typical ESC transient – Phase 0 – Powering

Phase 0

Typical ESC transient – Phase 1 – Unit discharge
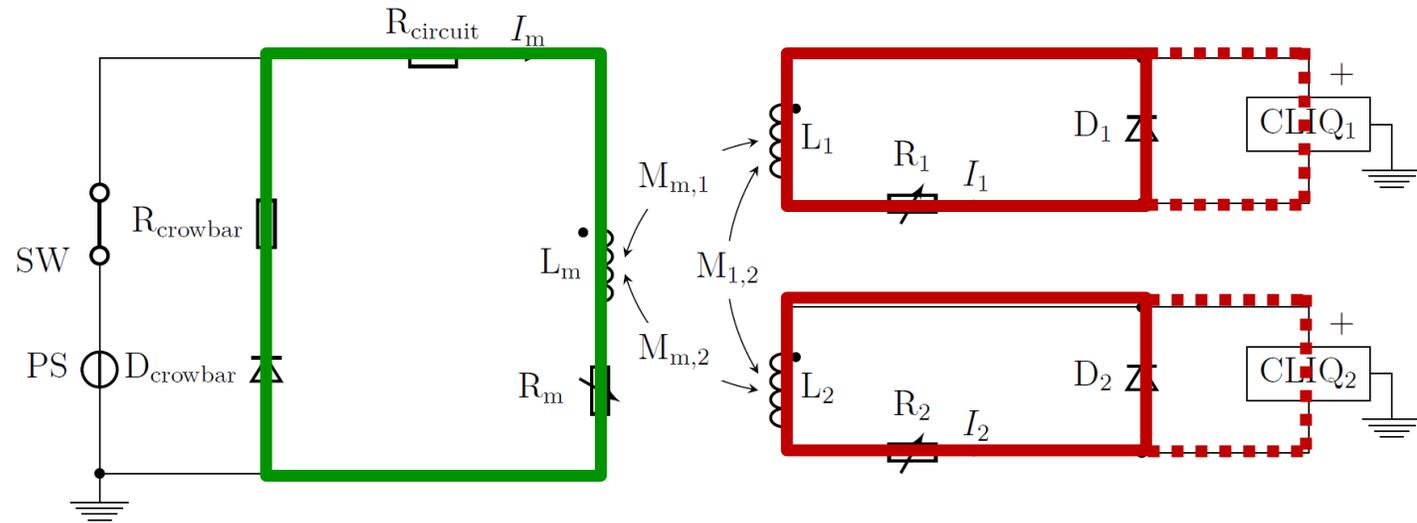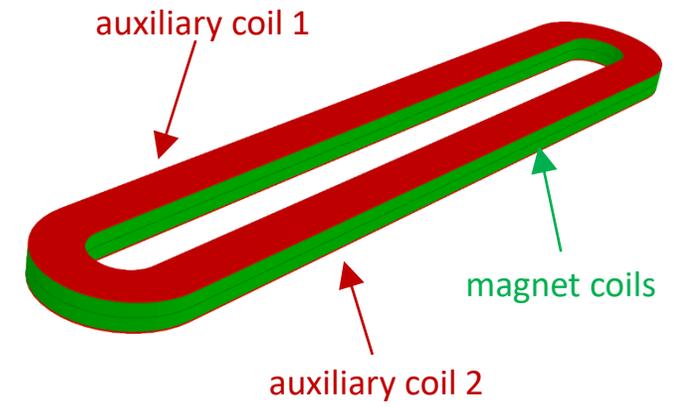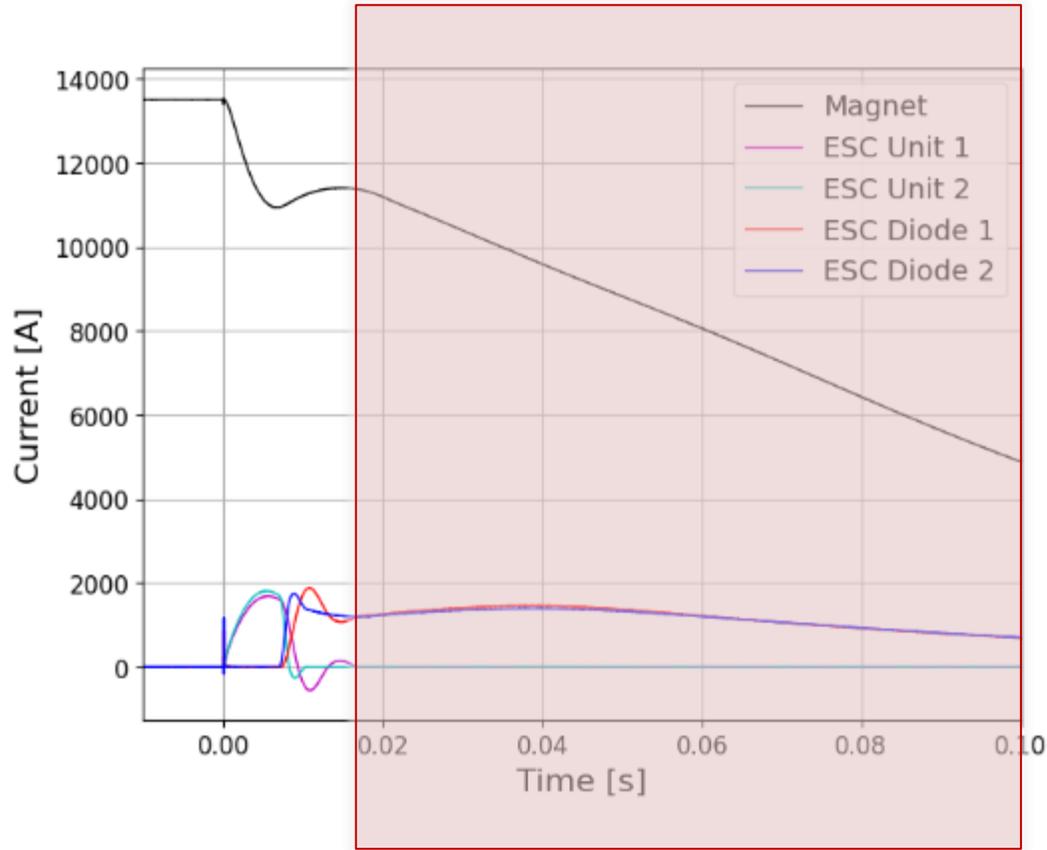
Typical ESC transient – Phase 2 – Diode conduction
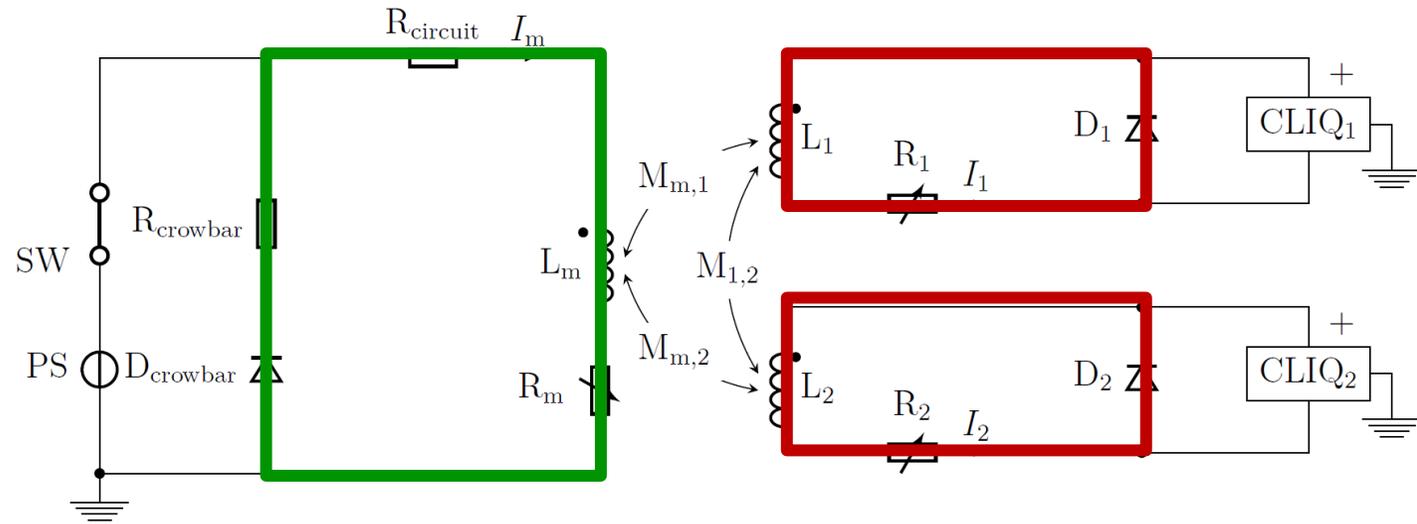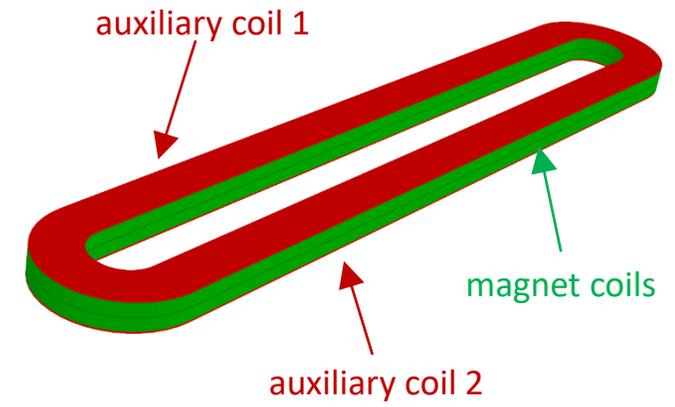

auxiliary coil 1

magnet coils

auxiliary coil 2

Phase 2

Typical ESC transient – Phase 3 – Magnet discharge

Phase 3

Typical ESC transient – Measured currents

Peak dI/dt ≈ 0.5 MA/s
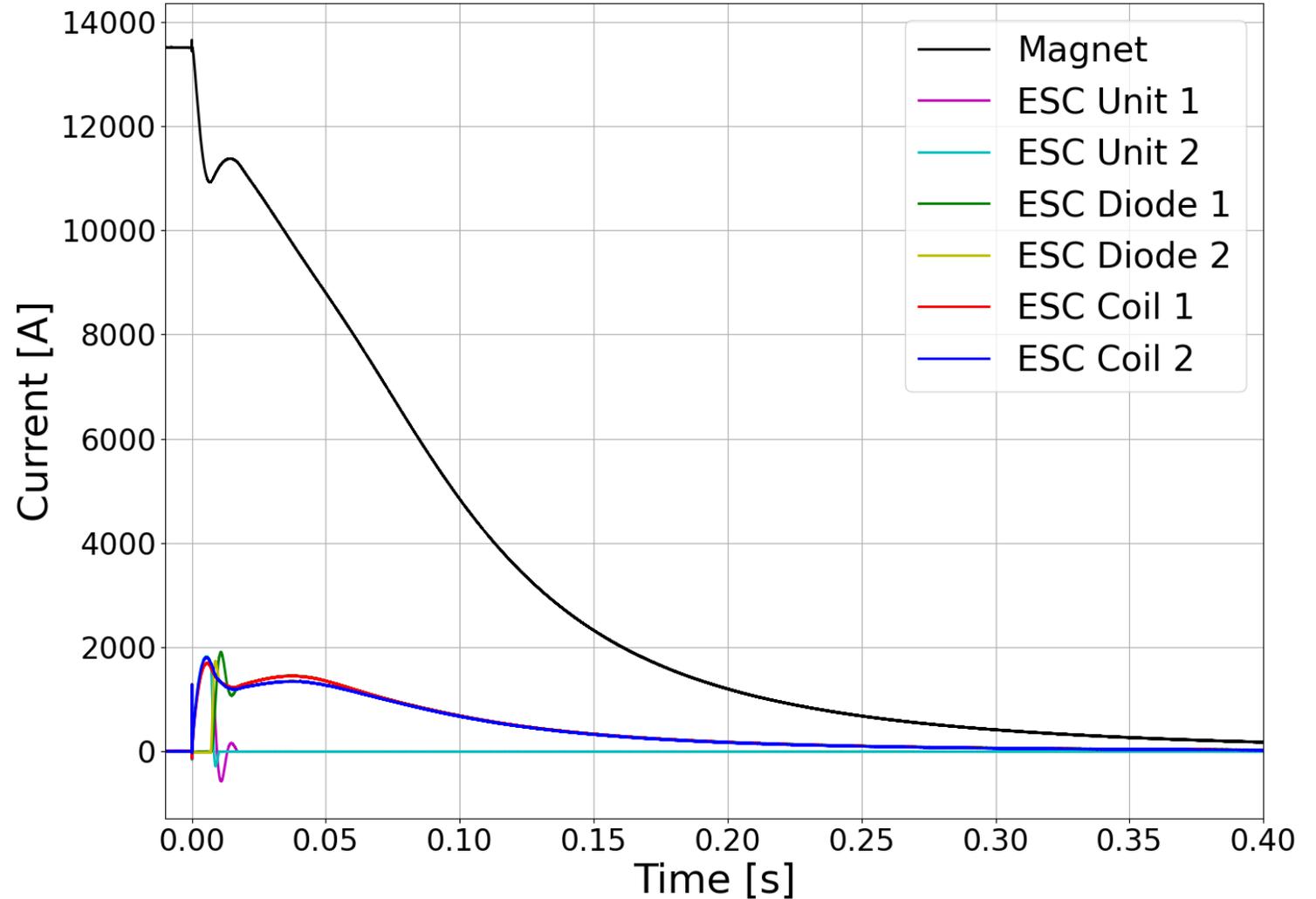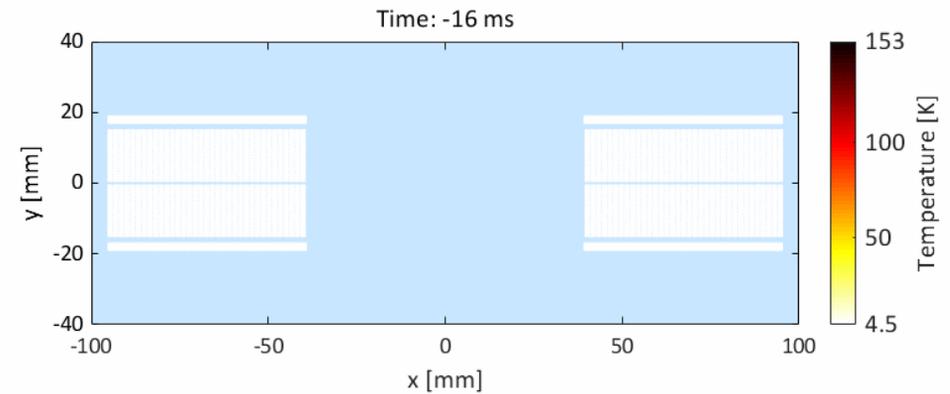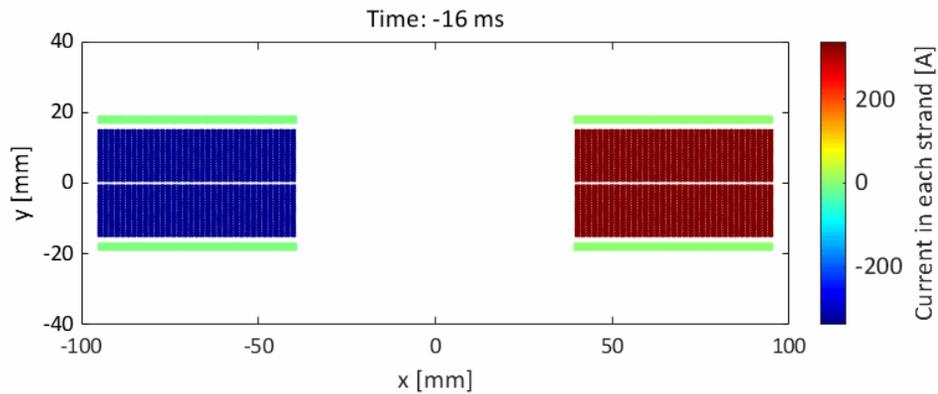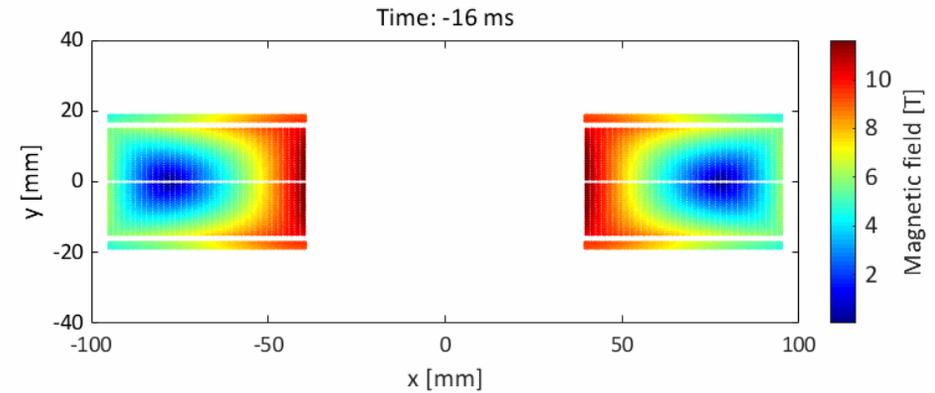
Peak dB/dt >1000 T/s

100% magnet coil quenched in <3 ms

Extracted >15% of the magnet's stored energy

Voltage across the magnet <30 V
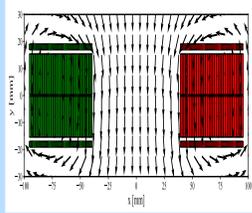
Simulation of a typical ESC transient

Simulations performed with STEAM-LEDET electro-magnetic and thermal magnet model
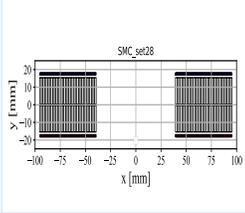
ESC technology development

ESC technology development

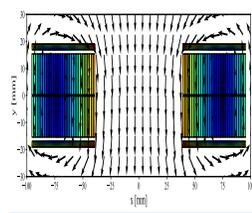| Conceptual design | Conductor selection | Magnetic design | Mechanical design | Integration study | ESC coil manufacture | ESC coil assembly | Test | Performance analysis |

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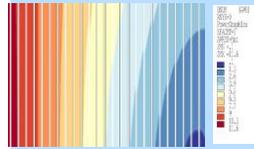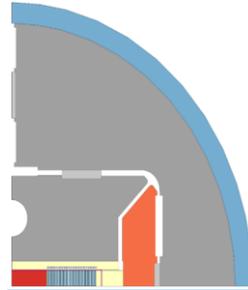
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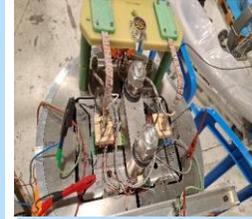
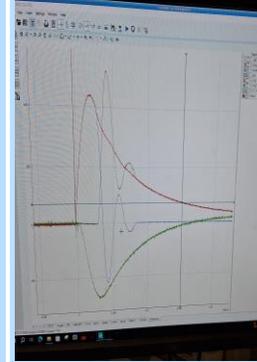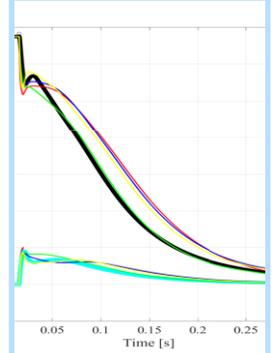Thanks to M. Dumas

Magnetic design

Mechanical design

Integration study

ESC coil manufacture

ESC coil assembly

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ESC technology development

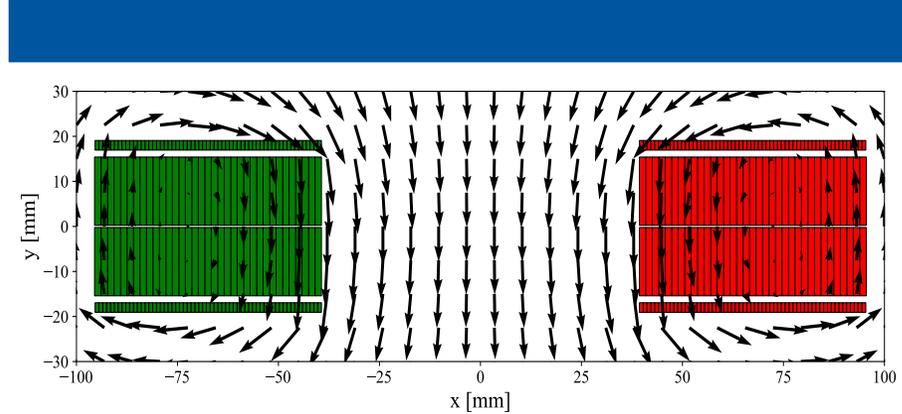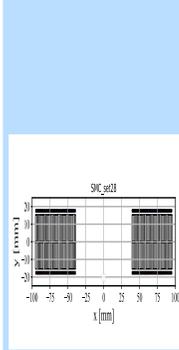Conceptual design · Conductor selection · **Magnetic design** · Mechanical design · Integration study · ESC coil manufacture · ESC coil assembly · Test · Performance analysis
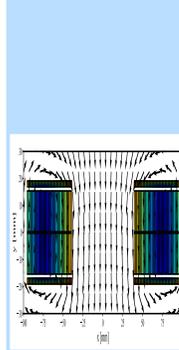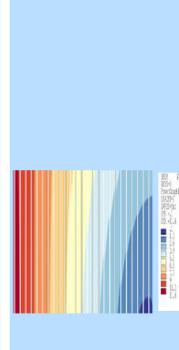
ESC technology development

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Thanks to M. Masci, P. Wachal

Integration study

ESC coil manufacture

ESC coil assembly

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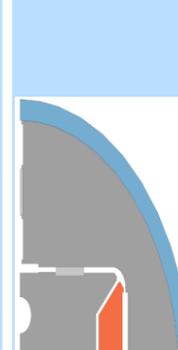# ESC technology development

Conceptual design

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Integration study

Thanks to J. Bauche, M. Dumas,
I. Garcia-Aguirrebeitia Sanchez, M. Masci,
J.C. Perez, P. Wachal, M. Wozniak

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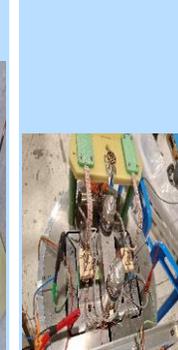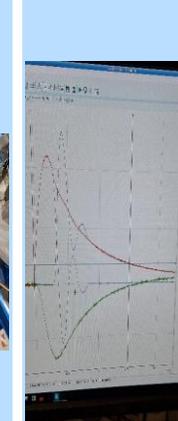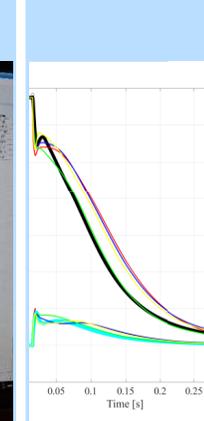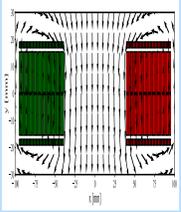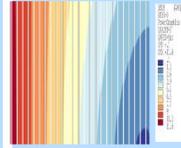

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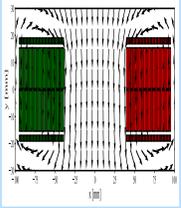
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Thanks to J. Feuvrier, J-L. Guyon,
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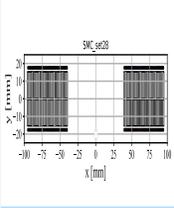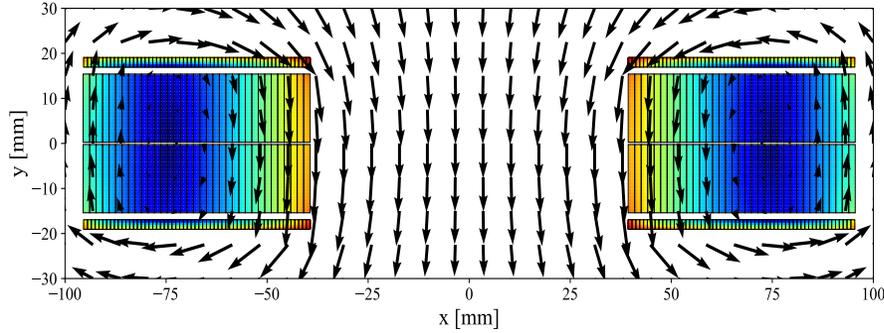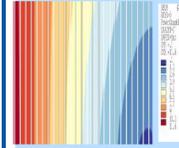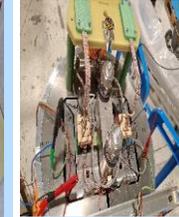
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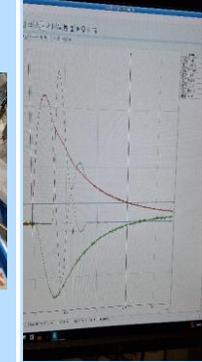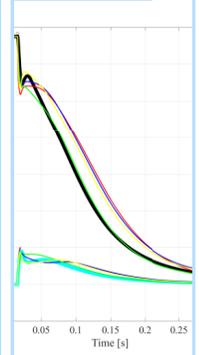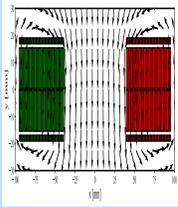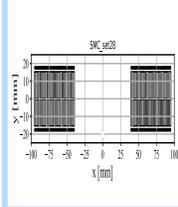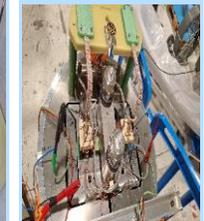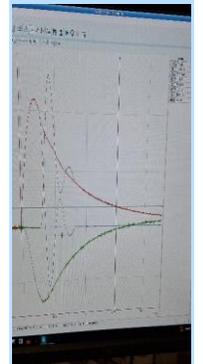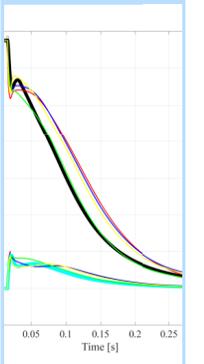| Conceptual design | Conductor selection | Magnetic design | Mechanical design | Integration study | ESC coil manufacture | ESC coil assembly | Test |

Performance analysis

Thanks to M. Wozniak

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A BIG **THANK YOU** TO ALL THE COLLEAGUES INVOLVED!

ESC technology tested on the CERN Short Model Coil (SMC)

- SMC magnet design and fabrication: J.C. Perez and team (CERN).

- ESC coil design: J. Bauche, M. Dumas, I. Garcia-Aguirrebeitia Sanchez, M. Masci, J.C. Perez, E. Ravaioli, P. Wachal, M. Wozniak (CERN).

- ESC coil fabrication: J. Bauche, M. Dumas, I. Garcia-Aguirrebeitia Sanchez (CERN).

- ESC coil impregnation: M. Gavedzki, P.A. Thonet (CERN).

- ESC coil integration in the SMC 107b magnet: J.C. Perez and team (CERN).

- SMC 107b magnet test: J. Feuvrier, J-L. Guyon, F. Mangiarotti, E. Ravaioli, G. Willering (CERN).

- Last minute current sensor loan: B. Panev, V. Vizziello (CERN).

- SMC 107b frequency transfer measurements: M. Bednarek, E. Ravaioli (CERN).

- SMC 107b ESC simulations: E. Ravaioli, M. Wozniak (CERN).

Highlights from ESC first experimental demonstration

Quench protection at all relevant current levels

Quench was certainly induced when the magnet current is in the range 3625-15000 A.
Analysis is still ongoing for the currents ≤2900 A.

Redundancy

Redundancy
When only 1 out of 2 units is used, the discharge is almost as fast

Failure cases successfully reproduced.
Redundancy demonstrated: performance was acceptable also when 1 out of 2 units was disconnected.

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Training quenches protected only by ESC [1 ESC active, 1 ESC passive]

The training quenches at T=1.9 K and T=4.5 K reached 12.1 and 11.1 MIIt, respectively.
The conservative limit of 12 MIIt written in the test plan corresponds to 200 K adiabatic hot-spot temperature.

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Extract part of the magnet energy

= Energy Extraction

Make it easy to add redundancy

= Quench Heaters

Achieve very fast quench initiation

= CLIQ

Without high voltage across magnet coil

≠ Energy Extraction

Without requiring thin insulation layers

≠ Quench Heaters

Without electrical contact to the coil

≠ CLIQ

Conclusion: Very successful first ESC test campaign

- ✓ Demonstrated that the ESC method works as expected
  - ✓ Fast dI/dt (≈0.5 MA/s) induced in the ESC and magnet coils
  - ✓ Little voltage (<30 V) induced across the magnet coils
  - ✓ Quench induced in the magnet conductor due to transient losses
  - ✓ ESC circuit current diverted from the units to the diodes
- ✓ Demonstrated quench protection at all relevant current levels
- ✓ Demonstrated quench protection during a training (detection → trigger → protection)
- ✓ Demonstrated the redundancy of the method when only one unit is triggered
- ✓ Demonstrated no magnet performance degradation after using ESC
- ✓ Demonstrated reproducibility
- ✓ Demonstrated that ESC transient introducing negative current in the magnet circuit is fine
- ✓ Collected data to validate simulations in a wide range of configurations & operating conditions

Further analysis is ongoing to fully understand the transients

ESC coil 1
(Cu)

Magnet coil
(Nb_3Sn)

ESC coil 2
(Cu)

Aluminium Shell
(eddy currents during
transients)

Iron Yoke and Pads
(nonlinear, shorter
than the magnet coil)

3D transient analysis performed by M. Wozniak (CERN) using STEAM-FiQuS

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The future of ESC technology

The future of ESC technology

Fast design/simulation tools to study different applications

Demonstrate ESC on insulated high temperature superconductor magnets

Focus on applications that remove technology bottlenecks and enable

Keep an open mind (and eyes) for other protection techniques

ESC studies for future magnets (not in scale)

1 - SMACC2 (D. Araujo, PSI),   2 - SMC (J.C. Perez, CERN),   3 - FCC MQ (M. Karppinen, CERN),
4 - BOND (A. Haziot, J.C. Perez, CERN), 5 - HFM 12 T (L. Fiscarelli, CERN),   6 - SMCC (D. Araujo, PSI),
7 - MQXF (P. Ferracin, S. Izquierdo Bermudez, et al., CERN, US HL-LHC AUP),
8 - US MDP 20 T cos-theta (M. D'Addazio (LBNL), V. Marinozzi (FNAL), E. Ravaioli (CERN), G. Vallone (LBNL))

Enabling a new design space for superconducting magnets?

Conventional high-field magnet designs are often limited by

- Critical current density
- Stress in the conductor
- Quench protection

Targets for Optimized ESC

- ✓ 90% magnet conductor quenched in 5 ms
- ✓ 90% magnet's stored energy extracted

Less stabilizer needed

- ✓ Lower Cu/Ag fraction
- ✓ Smaller conductor
- ✓ More compact magnet

Future R&D efforts

- ✓ Lower Cu/Ag fraction

- ✓ Use the extra space for strand reinforcement

- ✓ Use the extra space for stress-management elements

It's likely that past rules of thumb for designing quench protection will need to evolve. For ex:

- Current density J
- $J^2/f_{stabilizer}$
- "Time margin"

Challenges

- ✓ Integrate ESC coils
- ✓ Mechanical analysis including transients
- ✓ Identify most effective ESC coil concepts

- Cu/Ag can't be reduced at will (due to stability, mechanical strength)
- Current density can't be increased at will (stress in the conductor)

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Magnet quench protection

ESC (Energy Shift with Coupling)

ESC technology development

ESC first demonstration

Enabling a new design space?

We did it

Let's do it

together

Annex 1 – Additional measurements

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A few words on SMC 107b training performance

- 5 training quenches at T=4.5 K. Last quench at 13695 A

- V-I curve at T=4.5 K. Quench at 13640 A

- 9 training quenches at T=1.9 K . Last quench at 15136 A

- 2 training quenches at T=4.5 K. Last quench at 13625 A

- V-I curve at T=4.5 K. Quench at 14290 A

- >110 ESC discharges

- 1 training quench at T=1.9 K at 15045 A (protected by ESC)

- 1 training quench at T=4.5 K at 13563 A (protected by ESC)

- 1 training quench at T=4.5 K at 13567 A (protected by EE)

- V-I curve at T=4.5 K. Quench at 14203 A

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SMC 107b test campaign in a nutshell

Test type
Training at 4.5 K and 1.9 K using EE
V-I curve
ESC checkout
EE + ESC with 2 units
A. ESC with 2 units and 2 separate coils
B. ESC with 1 unit and 2 coils in series
C. ESC with 1 unit + 1 passive ESC coil
D. ESC with 1 unit (1 ESC coil disconnected)
EE with 2 passive ESC coils
ESC minimum energy to quench
Training at 4.5 K and 1.9 K using ESC
Training at 4.5 K using EE
V-I curve
Transfer Function Measurements

SMC 107b test campaign in a nutshell   -2

I [A]	A, T=1.9 K	B, T=1.9 K	C, T=1.9 K	A, T=4.5 K	A, 1/2 voltage, T=4.5 K	B, T=4.5 K	C, T=4.5 K	D, T=4.5 K
15000			50	-	-	-	-	-
13500	50	50		50	50	50	50	50
10875	50			50	50		50	50
7250	50	50		20-50	50	50	50	50
5800				20-50	50		50	50
4350	50	50		10-50	50	50		
3625	50	50		10-50	50	50	50	50
2900	50			50				
1450				50	50			
1000	50	50		50	50	50	50	50
0	50	50		50	50	50	50	50

The numbers indicate the ESC (CLIQ) unit capacitance values in [mF].
Green: Quench induced. Red: Quench not induced. Yellow: Analysis is ongoing.

Typical ESC transient – 2 ESC 50 mF 200 V – 2 ESC coils – T=1.9 K – I=13500 A

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Typical ESC transient – 2 ESC 50 mF 200 V – 2 ESC coils – T=1.9 K – I=13500 A

dI/dt ≈ 0.5 MA/s **(!!)**

When a positive dI/dt is imposed on the ESC coils, a negative dI/dt of 0.5 MA/s is imposed on the magnet coils. It is estimated that 100% of the magnet conductor is actively quenched within 1-3 ms by transient (AC) losses.

Typical ESC transient – 2 ESC 50 mF 200 V – 2 ESC coils – T=1.9 K – I=13500 A

The huge dI/dt was imposed to the magnet current with <30 V peak voltage across it.
The voltage is not exactly 0 V only because of the warm circuit. Its value doesn't scale up with the magnet length.

Typical ESC transient – 2 ESC 50 mF 200 V – 2 ESC coils – T=1.9 K – I=13500 A

The voltage across the ESC units is applied across the ESC coils.

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Different configurations – T=4.5 K – I=13500 A

Redundancy
When only 1 out of 2 units is used, the discharge is almost as fast

Failure cases successfully reproduced.
Redundancy demonstrated: performance was acceptable also when 1 out of 2 units was disconnected.

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Different configurations – T=4.5 K – I=7250 A

Failure cases successfully reproduced.
Redundancy demonstrated (50% nominal current).

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Different configurations – T=4.5 K – I=3625 A

Failure cases successfully reproduced.
Redundancy demonstrated also at 3625 A (20% nominal current).

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Different unit capacitance and charging voltage – T=1.9 and T=4.5 K – I=13500 A

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Different unit capacitance and charging voltage – T=1.9 and T=4.5 K – I=10875 A

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High Field Magnets

Different unit capacitance and charging voltage – T=1.9 and T=4.5 K – I=7250 A

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Different unit capacitance and charging voltage – T=4.5 K – I=5800 A

Different unit capacitance and charging voltage – T=1.9 and T=4.5 K – I=4350 A

Different unit capacitance and charging voltage – T=1.9 and T=4.5 K – I=3625 A

Different unit capacitance and charging voltage – T=1.9 and T=4.5 K – I=1000 A

Test with negative current in the main magnet circuit was successfully performed without issues.

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2 ESC 50 mF 200 V – 2 ESC coils – T=1.9 K – All current levels

1 ESC 50 mF 200 V – 2 ESC coils in series – T=1.9 K – All current levels

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High Field Magnets

2 ESC 50 mF 200 V – 2 ESC coils – T=4.5 K – All current levels

1 ESC 50 mF 200 V – 2 ESC coils in series – T=4.5 K – All current levels

2 ESC 50 mF 100 V – 2 ESC coils – T=4.5 K – All current levels

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High Field Magnets

1 ESC 50 mF 200 V – 1 active and 1 passive ESC coils – T=4.5 K – All current levels

1 ESC 50 mF 200 V – 1 active and 1 disconnected ESC coils – T=4.5 K – All current levels

Annex 2 – Additional information

Quench Protection in a Superconducting Magnet

High Current Density

$J \approx kA/mm^2$

High Magnetic Field

$B = 5\text{-}10 \text{ T}... 16\text{-}20 \text{ T}$ ↑

High Energy Density

$e = B^2/(2 \, \mu_0) \approx 10\text{-}40 \text{ MJ/m}^3$ ↑

Quench

If of a portion of cable suddenly becomes non-superconducting, it starts heating up

The energy stored in the magnet is usually sufficient to melt kilos of copper and permanently damage the magnet!

Quick propagation of the normal zone needed

Homogeneous distribution of the magnet energy

Discharge of the magnet energy with coil resistance

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Examples of ESC coils applied to different magnet geometries

A good rule of thumb:
Build small copper coils around the magnet coils

Designs not really in scale

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The 5 concepts that inspired the development of ESC

1. Inducing a quench with inductive heating using insulated coils	2. Extract energy with a coupled secondary	3. Design auxiliary coupled coils to extract energy	4. Inducing a quench with transient losses using the magnet coils	5. Double-purpose auxiliary coils

More information and references in the Annex

1. Inducing a quench with inductive heating using insulated coils

[1] L. Bromberg, J.V. Minervini, L. Myatt, T. Antaya, J.H. Schultz, Inductive quench for magnet protection, WO 2008030911 A2, US 7701677 B2, EP 2064564 A2, priority date: 7 September 2006

[2] L. Bromberg, J.V. Minervini, J.H. Schultz, T. Antaya and L. Myatt, Use of inductive heating for superconducting magnet protection, PSFC/JA-11-26, 2011

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[5] E. Ravaioli, V.I. Datskov, A.V. Dudarev, G. Kirby, K.A. Sperin, H.H.J. ten Kate, and A.P. Verweij, First Experience with the New Coupling-Loss Induced Quench System, Cryogenics, 2014

[6] E. Ravaioli, "CLIQ", Chapter 6, PhD thesis, 2015

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2. Extract energy with a coupled secondary

Figure 5. Quench protection circuit for a simple coil with a coupled bore tube.

[8] M.A. Green, Large superconducting detector magnets with ultra thin coils for use in high energy accelerators and storage rings, 1977
[9] M.A. Green, Development of large high current density superconducting solenoid magnets for use in high energy physics experiments, [Thesis], 1977
[10] J.A. Taylor et al., Quench protection for a 2-MJ magnet, IEEE Transactions on Magnetics, 1979

3. Design auxiliary coupled coils to extract energy

$T_{min}(t = 0\ s) = 8\ K,\ T_{avg}(t = 1\ s) = 94\ K$

Blocking diode

Quench absorption coils (L_s)

Quenching dipole, primary coils (L_p)

Power supply

Non-quenching dipoles

M

Bypass diode

'Hotspot turn',
$T(0\ s) = 125\ K$,
$T(1\ s) = 259\ K$

$t = 1\ s$

Secondary 'Quench absorption' Cu coils
$T(t = 0\ s) = 4.2\ K,\ T(t = 1\ s) = 98\ K$

T [K]
260
220
180
140
100

Primary circuit
RQT circuit

[11] M. Mentink et al., "Quench protection of very large, 50-GJ-class and high-temperature-superconductor-based detector Magnets", IEEE Trans. Appl. Supercond., 2016
[12] M. Mentink and T. Salmi, "Quench absorption coils: a quench protection concept for high-field superconducting accelerator magnets", SuST, 2017

4. Inducing a quench with transient losses using the magnet coils

Fig. 6. Circuit schematic with protection by current pulse on center tap.

[10] J.A. Taylor et al., Quench protection for a 2-MJ magnet, IEEE Transactions on Magnetics, 1979
[13] R. M. Schöttler and H. W. Lorenzen , "Temperature and Pressure Rise in Supercritical Helium during the Quench of Indirectly Cooled SC Coils", Cryogenic Eng. Conference Publication, 1996
[6] E. Ravaioli, "CLIQ", PhD thesis, 2015
[14] E. Ravaioli et al., "New, Coupling Loss Induced, Quench Protection System for Superconducting Accelerator Magnets", IEEE Trans. on Appl. SC, 2014
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5. Double-purpose auxiliary coils

[16] M. Mentink and E. Ravaioli, "Secondary CLIQ, a robust, redundant, and cost-effective means of protecting high-field accelerator magnets," Supercond. Sci. Technol., vol. 33, no. 8, 2020
[17] E. Ravaioli, T. Mulder, A. Verweij and M. Wozniak, "Optimizing Secondary CLIQ for Protecting High-Field Accelerator Magnets," IEEE Transactions on Applied Superconductivity, 2023

Energy extraction system (EE)

Advantages
- Straightforward design and implementation
- Extracts energy from the cryostat

Disadvantages
- Can be large and expensive for high current magnets
- Impractically high voltage needed for high current density magnets
- **Can't be applied to a chain of high-field magnets**

Note: EE of LHC main dipole circuits doesn't protect magnets

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Quench Heaters (QH)

Courtesy of D. Cheng

Strip heating

Heat transfer to coil

Temperature increase

Coil SC→resistive

Magnet energy discharged

Reduced hot-spot temperature

Advantages
- Scales well with the magnet length
- Doesn't impose a voltage on the magnet coils
- Well known and established technology

Disadvantages
- Thin insulation between QH and conductor is risky
- Challenging to cover all turns and layers
- Challenging to cover all length (heating stations)

Coupling-Loss Induced Quench (CLIQ)

| Current change |
| Field change |
| **Transient losses** |
| Temperature increase |
| Coil SC→resistive |
| Magnet energy discharged |
| Reduced hot-spot temperature |

Advantages
- Fast and effective heat deposition
- Heat deposited simultaneously in most of the coil volume
- Electrically robust system

Disadvantages
- Direct electrical connection to the magnet circuit
- Challenging to make it redundant
- Additional asymmetric forces on the magnet coils

CLIQ (Coupling-Loss Induced Quench) technology

Current change

Magnetic field change

Coupling losses (Heat)

Temperature rise

Coil SC→resistive

Magnet current discharged

Reduced hot-spot temperature

[ref] V. Datskov, G. Kirby, E. Ravaioli,
Patent EP13174323.9, 2013
[ref] E. Ravaioli, "CLIQ", PhD thesis, 2015

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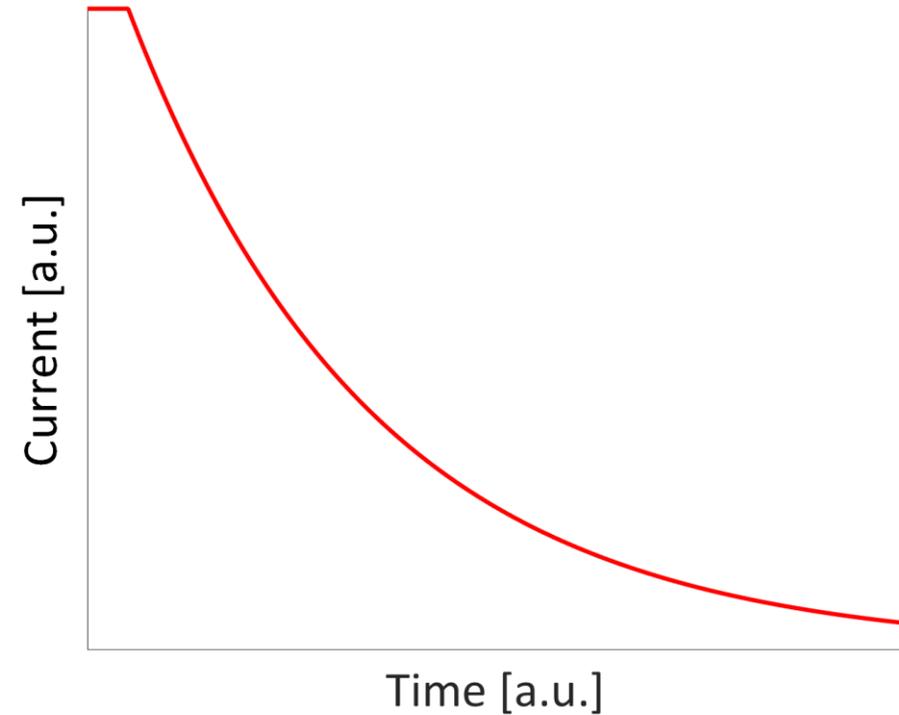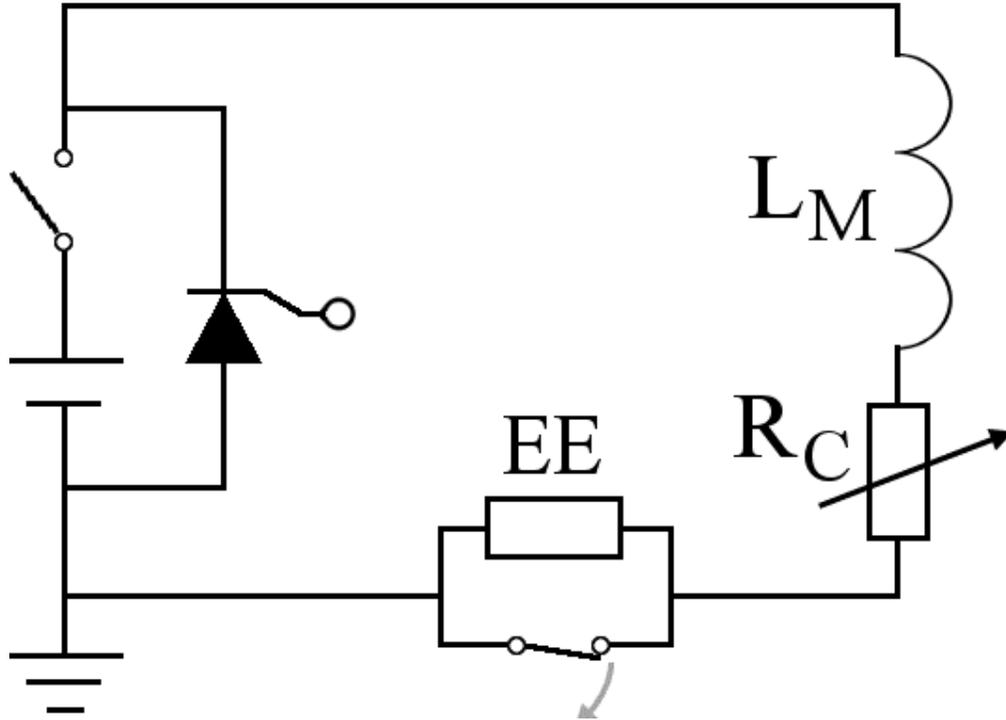High Field Magnets

S-CLIQ (Secondary CLIQ)

auxiliary coil 1

auxiliary coil 2

magnet coils

[ref] M. Mentink and E. Ravaioli, "Secondary CLIQ, a robust, redundant, and cost-effective means of protecting high-field accelerator magnets", SuST 2020, https://cds.cern.ch/record/2724798?ln=en.

CLIQ using an external coil

Inter-filament coupling loss

$\dot{B}$

"Fast" loss:
Characteristic time constant in the order of **ms** or **tens of ms**

Deposited **power** density roughly proportional to **(dB/dt)²**

SC

Cu

100μm

SMC magnet and ESC coil parameters

SMC magnet parameters	
Nominal current, $I_{nominal}$	14500 A
Peak field on the conductor at $I_{nominal}$	12.5 T
Operating temperature	1.9 K
Differential inductance per unit length at $I_{nominal}$	3.8 mH/m
Magnetic length	0.38 m
Superconductor	Nb_3Sn
Number of strands	40
Strand diameter	0.7 mm
Cu/no-Cu ratio	1.19

ESC coil parameters	
Conductor material	Copper
Insulation material	Enamel
Wire cross-section	$2x0.8 mm^2$
Insulation thickness	60-65 µm
Number of turns	2x 60
Total cross-section	$2x 189 mm^2$
ESC coils cross-section / magnet coils cross-section	2x 7%
Distance between magnet and ESC conductors	1.775 mm

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ESC unit and coil design

ESC coil optimization

- ✓ Realistic conductor
- ✓ Magnetic design
- ✓ Quench protection performance
- ✓ Mechanical simulations
- ✓ Integration

Design of the SMC magnet by J.C. Perez and team (CERN).
Design of the ESC coils for SMC: E. Ravaioli, J. Bauche, M. Dumas, I. Garcia-Aguirrebeitia Sanchez, M. Masci, J.C. Perez, P. Wachal, M. Wozniak (CERN).

Mechanical analysis of ESC transient

Magnetic field in the magnet and ESC coils [T]

Equivalent stress in the ESC coil [MPa]

X stress in the cover plate [MPa]

ANSYS mechanical simulations by M. Masci, P. Wachal (CERN).

Cross-sections not in scale

Mechanical analysis of ESC transient – Bonded vs Frictional contact

Bonded

Frictional

ANSYS mechanical simulations by M. Masci, P. Wachal (CERN).   Cross-sections not in scale

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High Field Magnets

Original Design

Slide by M. Dumas, I. Garcia-Aguirrebeitia Sanchez

Original Design – G11 Plates

Slide by M. Dumas, I. Garcia-Aguirrebeitia Sanchez

Updated Design – G11 Plates + Coil

Updated Design – G11 Plates + Coil

Slide by M. Dumas, I. Garcia-Aguirrebeitia Sanchez

Updated Design – G11 Plates + Coil

Updated Design – G11 Plates + Coil

Slide by M. Dumas, I. Garcia-Aguirrebeitia Sanchez

ESC coil fabrication

Design of the ESC coils for SMC: E. Ravaioli, J. Bauche, M. Dumas, I. Garcia-Aguirrebeitia Sanchez, M. Masci, J.C. Perez, P. Wachal, M. Wozniak (CERN).
Fabrication of the ESC coils for SMC: J. Bauche, M. Dumas, I. Garcia-Aguirrebeitia Sanchez (CERN).

Deduced magnet and ESC test circuit

ESC technology development

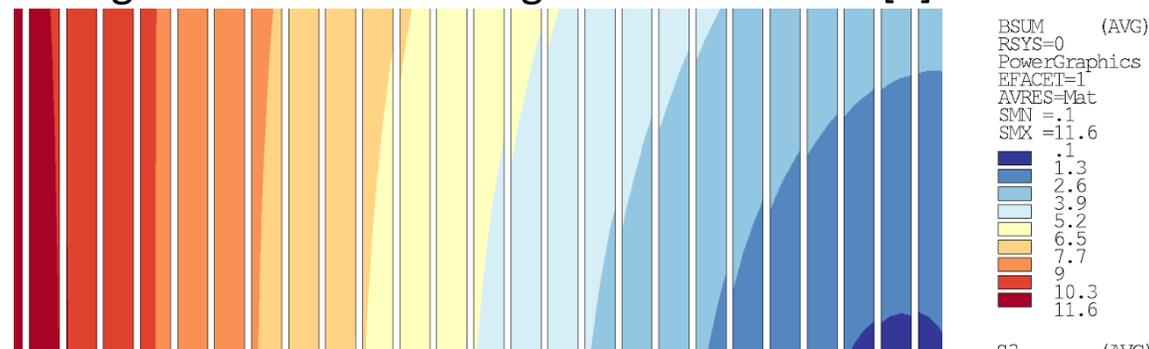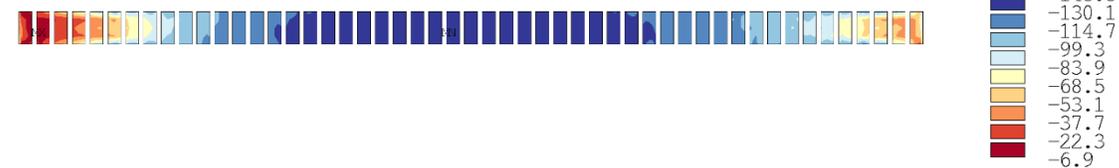| Magnet	Conceptual design	Conductor selection	Magnetic design	Mechanical design	Integration study	ESC coil manufacture	ESC coil assembly	Test	Performance analysis
SMC	done	done	done	done	done	done	done	done	ongoing
PSI subscale	done	done	done	done	done	ongoing			
MQXFS	done	done	done	ongoing	ongoing				
HFM 12 T	done								
HFM 12 T mirror	done								
BOND	done	ongoing	ongoing						
FCC MQ	done	done	done	ongoing	ongoing				
PSI 13 T SMACC	done	ongoing	ongoing	ongoing	ongoing				
PSI 14 T SMACC	done	ongoing	ongoing	ongoing	ongoing				
MDP 20 T dipole	done	ongoing	ongoing						

Many thanks to the designers who already considered using ESC.
It's relatively easy (and very interesting!) to study new cases, so you're very welcome to ask for a custom analysis.

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