UNIVERSITÀ DEGLI STUDI DI MILANO

Istituto Nazionale di Fisica Nucleare

Study and optimization of a magnetic field quality measurement system for the characterization of superconducting accelerator magnets

Analysis of Critical Aspects

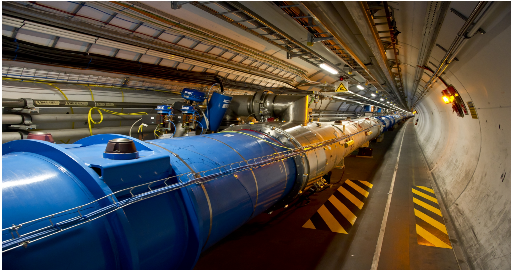
Samuele Mariotto

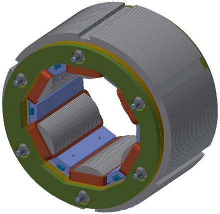
Physics Department

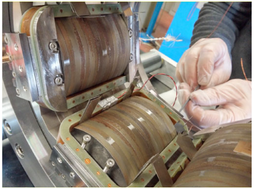
First Year PhD Workshop Presentation

9 October 2018, Milan

Outline



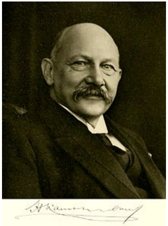


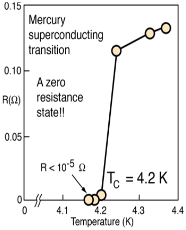


Superconductivity

Heike Kamerlingh Onnes

- 1908: He reaches $4.2\ K$ and lowered at $1.8\ K$
- 1911: Discovery of Superconductivity in Mercury
- 1913: **Nobel Prize in Physics** "for his investigations on the properties of matter at low temperatures which led, inter alia, to the production of liquid helium".





Theory

- *Ginzburg-Landau Theory:* Describe **properties of superconductors**. Derived from thermodynamics.
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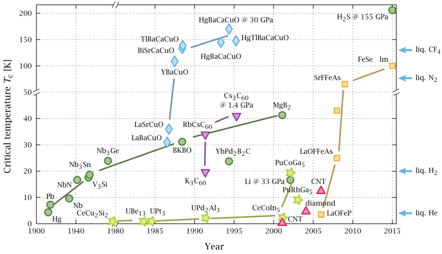
New superconducting materials: LTS, HTS, Fe-based, Cuprated ecc...



NbTi: $T_c = 9.2\ K$, Nb_3Sn: $T_c = 18.3\ K$
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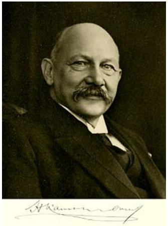

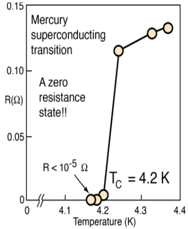

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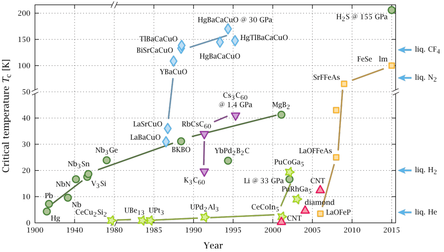

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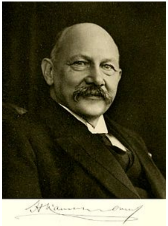

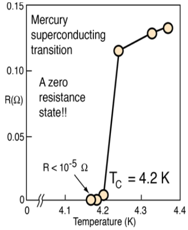

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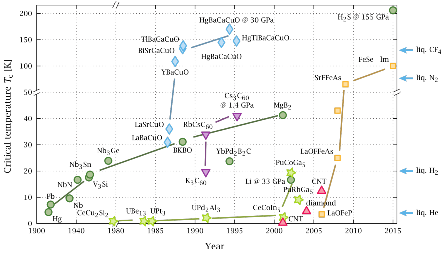

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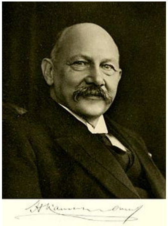

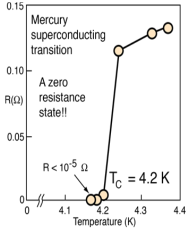

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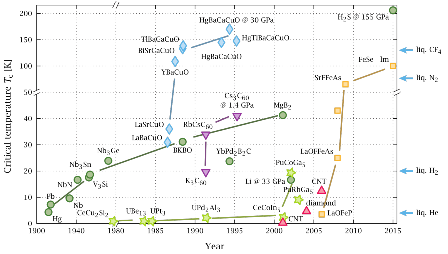

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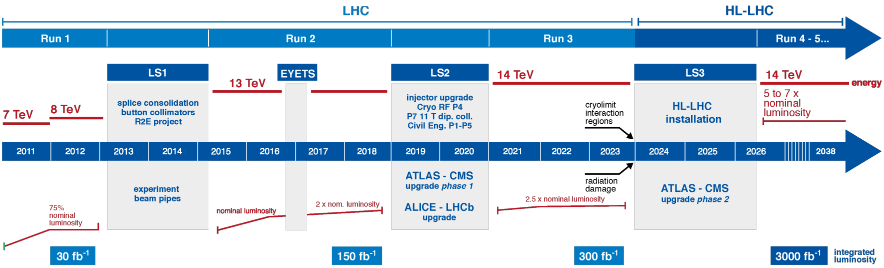
HL-LHC project



- † 10 times the nominal value of Luminosity (up to $\Longrightarrow$ 3000 fb^{-1} over 12 years)
- † New Low-β insertion region
- † Cryogenics and Collimation
- † Superconductive Links and Crab Cavities

Luminosity: $L = \frac{N_1 N_2 f N_b}{4\pi \sigma_x \sigma_y}$

- † New and more powerful Superconductive magnets for bending and focusing of the beam

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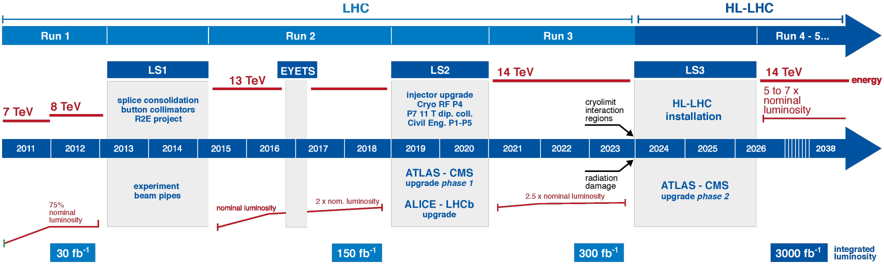

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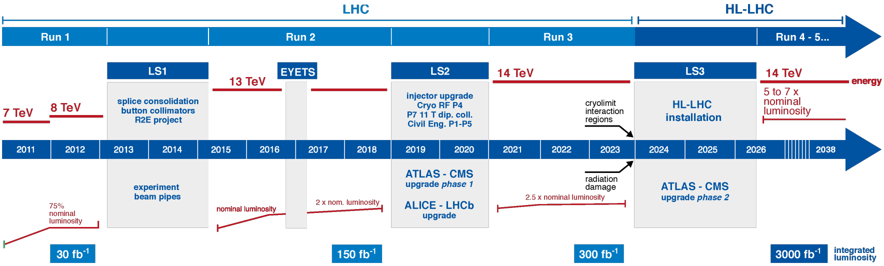

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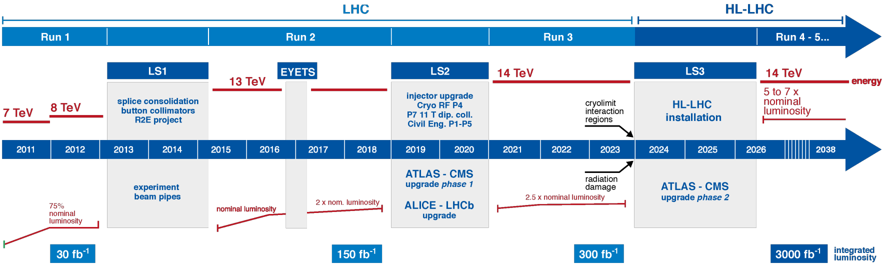

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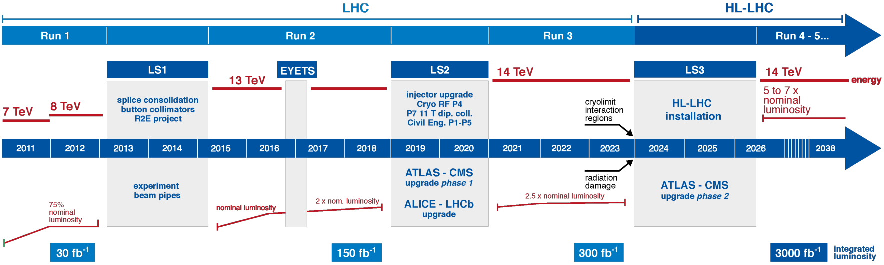

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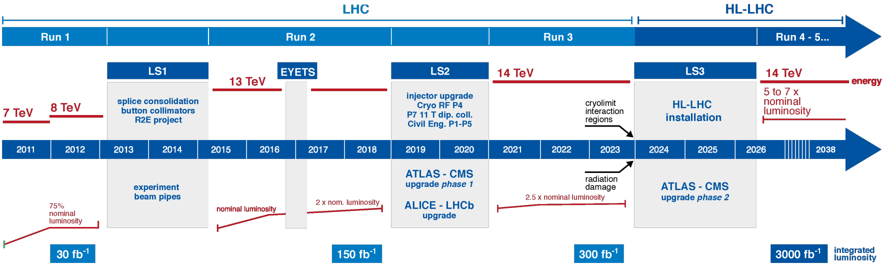

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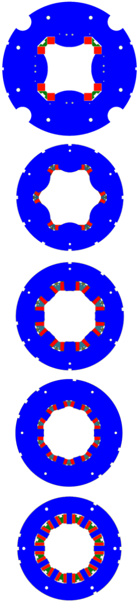
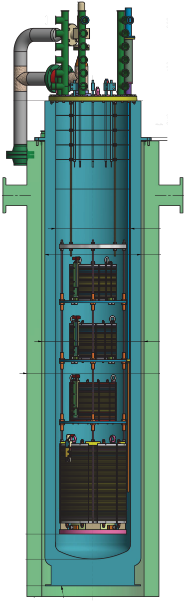
MAGIX project

- 54 High Order Corrector Magnets
- 1 MgB_2 magnet

- 2 New Test Station ⇒ Multiple Magnetic Field Measurement

Correlation between Field Quality at room and cryogenic temprreratures





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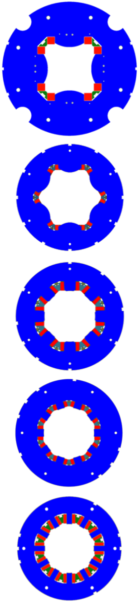
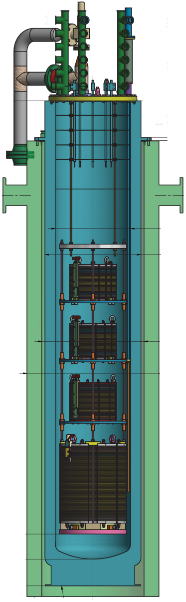
- Few Test Sessions
- Unique design of measurement's shaft
- Unique Data Acquisition setup





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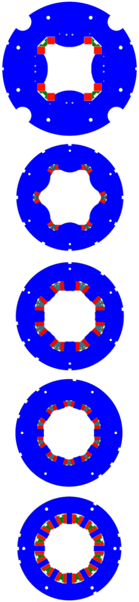
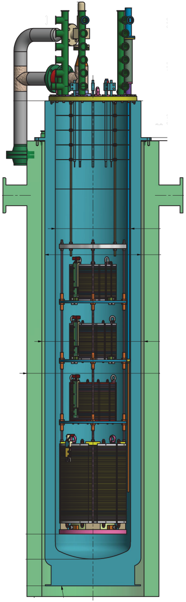
- Residual Magnetization effect
- More Time required for Cool Down





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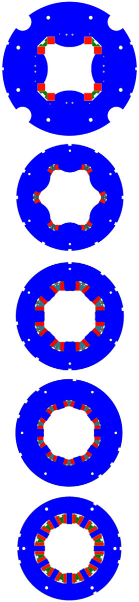

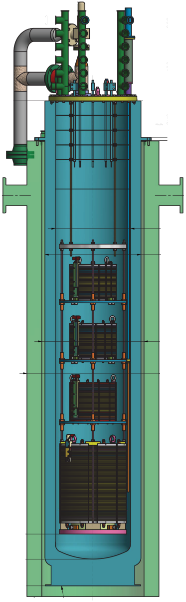

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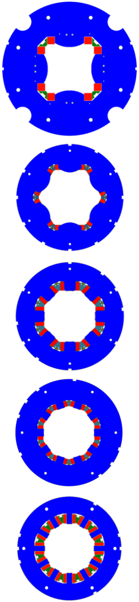
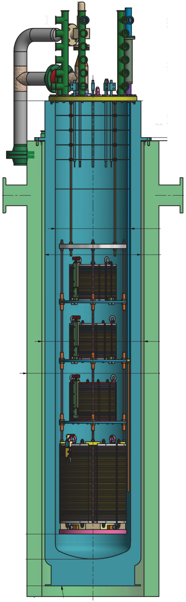
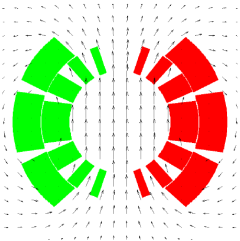
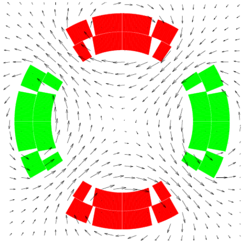




2D Magnetic Field Map





$$\nabla \times \mathbf{H} = 0 \Rightarrow \nabla \times \mathbf{B} = 0 \Rightarrow \mathbf{B} = -\nabla \Phi_m$$

$$\nabla \cdot \mathbf{B} = 0 \Rightarrow \nabla^2 \Phi_m = 0$$

- † Invariant longitudinal magnetic field
- † Null integrated B_z component along the rotational axis.

Defining: $\mathbf{B(z)} = B_y(x,y) + iBx(x,y)$

Analytic Function

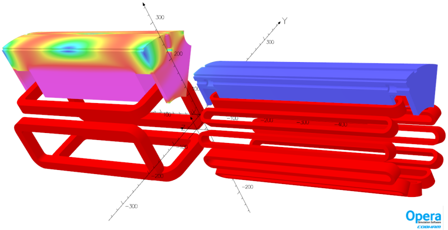
$$\mathbf{B(z)} = \sum_{n=1}^{\infty} C_n \left(\frac{z}{R_{ref}}\right)^{n-1}$$

$$\mathbf{B(z)} = \sum_{n=1}^{\infty} [B_n + iA_n] \left(\frac{z}{R_{ref}}\right)^{n-1}$$

$$b_n = Re\left[\frac{C_n}{B_{ref}}\right] = \frac{B_n}{B_{ref}}$$

$$a_n = Im\left[\frac{C_n}{B_{ref}}\right] = \frac{A_n}{B_{ref}}$$

Data Acquisition Issues

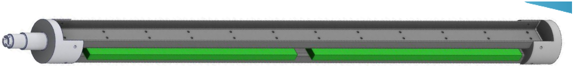


Magnets Fringe Field

† Magnets Cross Talking ⇒ d_{min}

1^{st} Magnet's Order	2^{nd} Magnet's Order	Distance [cm]
6^{th} order	6^{th} order	50
4^{th} order	12^{th} order	125

† Shaft Alignment



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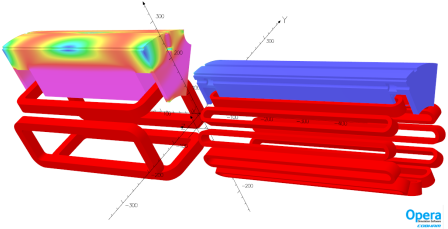

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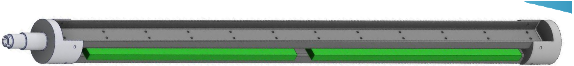

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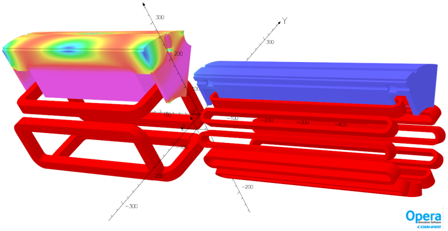

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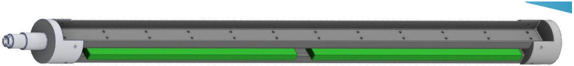
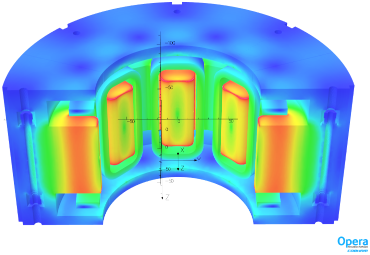
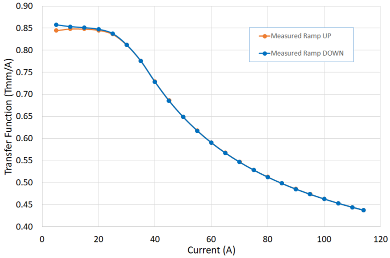
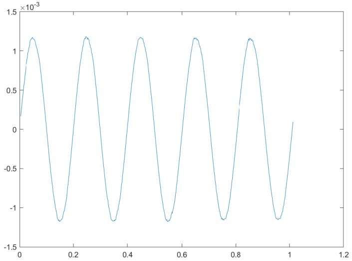


Experimental Signals





- † Shaft Calibration Signals
- † Transfer Function
- † Magnetization Effects



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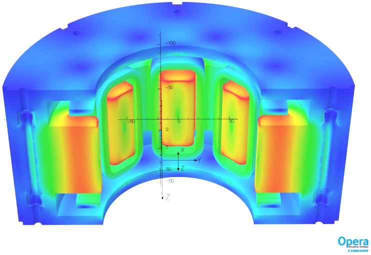

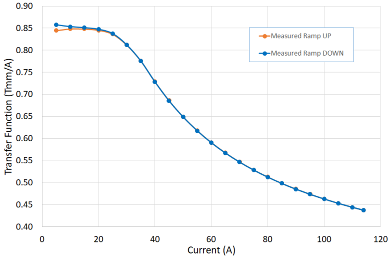

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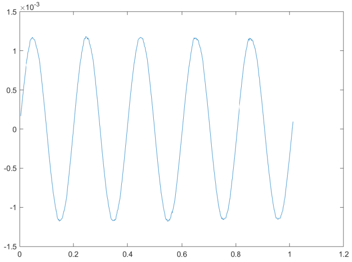
Discrete Fourier transform (DFT)

$$\Psi_n = \sum_{k=1}^{N} \psi_k e^{-2\pi i (n-1)\frac{(k-1)}{N}}$$



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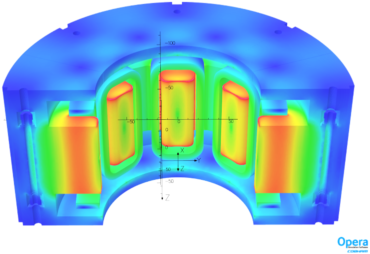

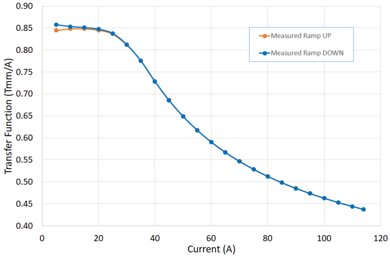

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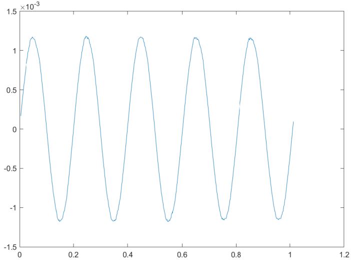
Requirements:

- † $|b_n| \leq 10$ units



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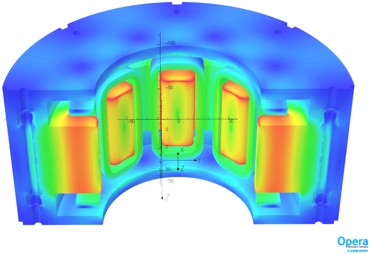

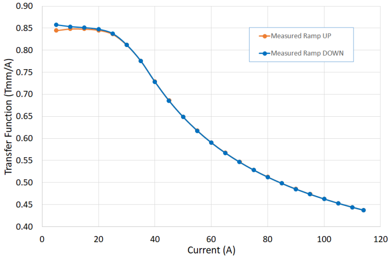

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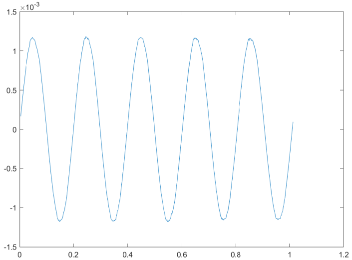
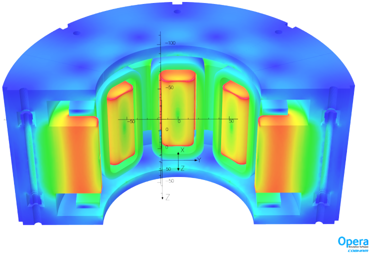
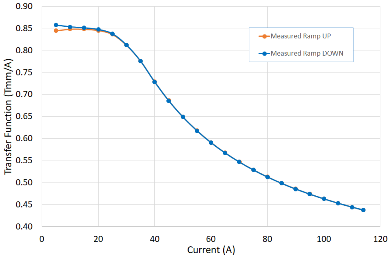


Requirements:

- $|b_n| \leq 10$ units

Experimental Signals





- Shaft Calibration Signals
- Transfer Function
- Magnetization Effects

Discrete Fourier transform (DFT)

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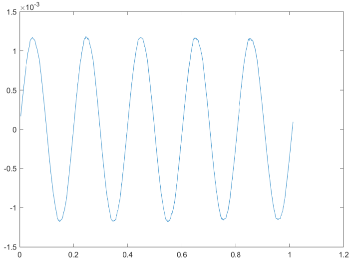

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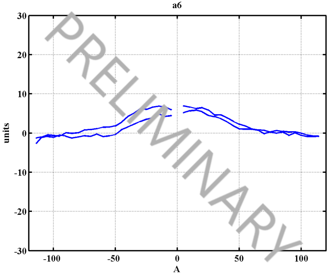
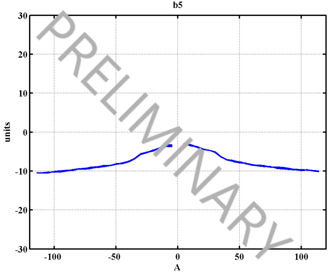
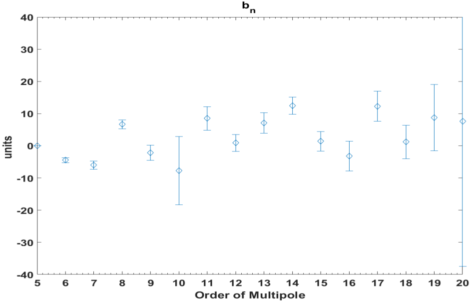
Analysis Results





Courtesy of Lucio Fiscarelli (CERN Magnetic Measurements Division)

Decapole's Multipoles



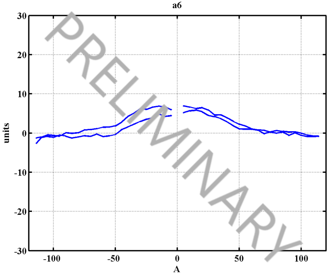
Octupole's Multipoles

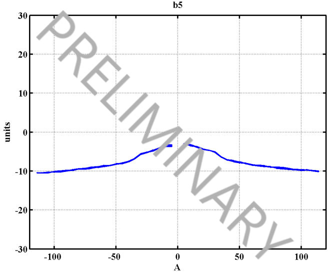
Order	5	6	7	8	9	10	11	12	13	14	15
b_n	3	-2	1	0	-1	-2	0	6	-8	4	0
a_n	-5	0	-1	0	0	-5	0	19	14	2	-1
σ_{b_n}	1	1	1	2	2	4	26	14	16	6	4
σ_{a_n}	0	0	1	1	1	3	27	15	11	5	3

Baseline features:

- † Iron Magnetization effect
- † n=12 Lost Sensibility

Analysis Results





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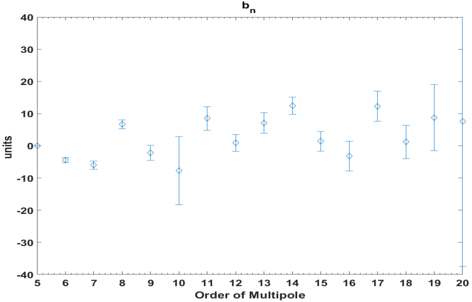

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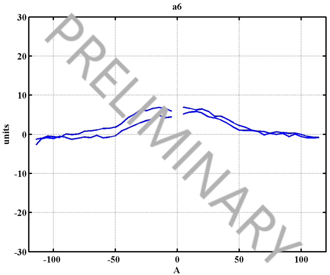

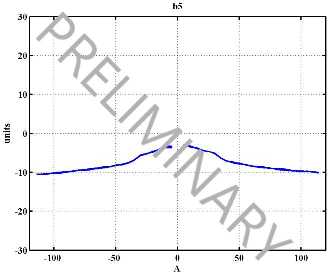

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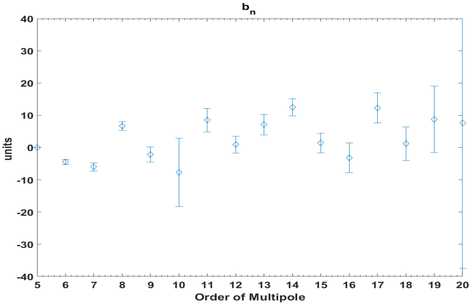

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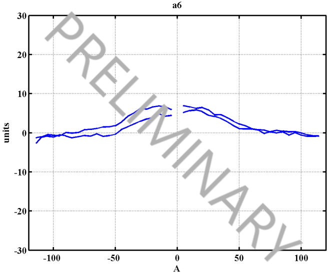

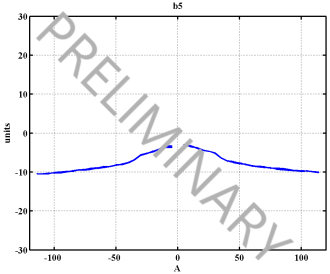

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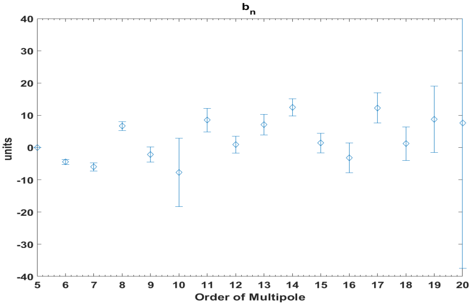

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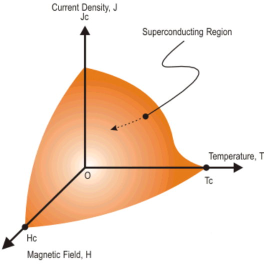
Superconductor's Quench

Definition: Fast transition to the resistive and normal conductive state



Solution:

† **FAST DISCHARGE**

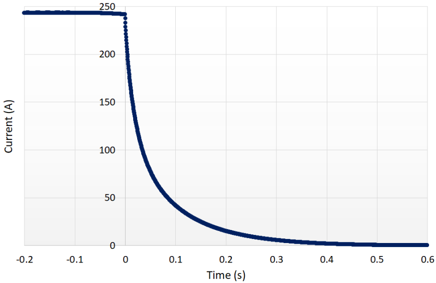
Quench Protection System (QPS)

† Quench Heaters

† Dumping Resistance

† CLIQ

LHC damage (2008)



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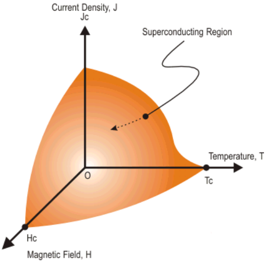

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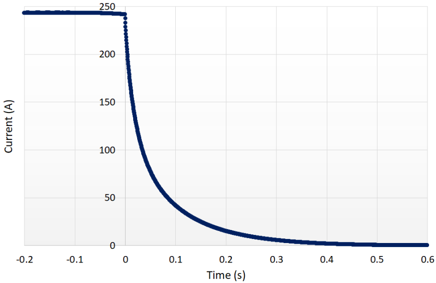

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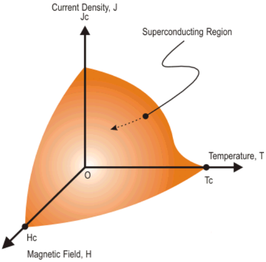

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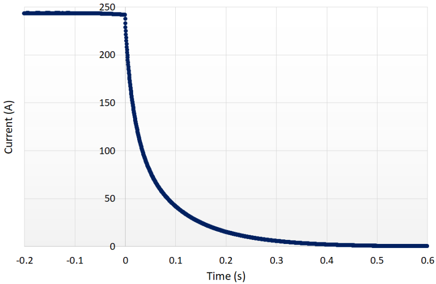

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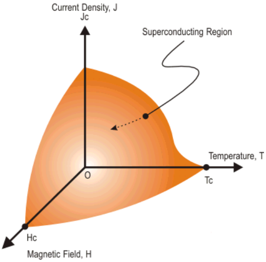

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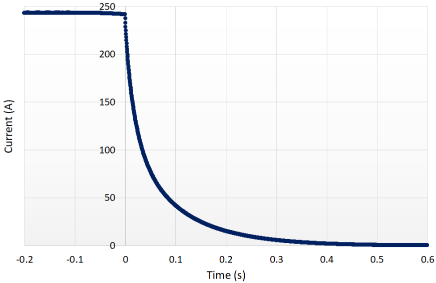

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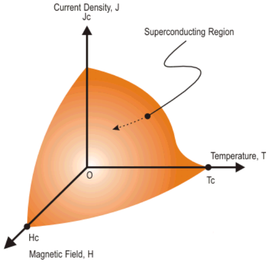

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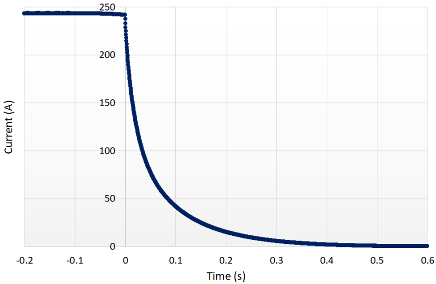
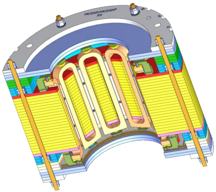
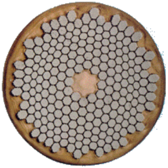
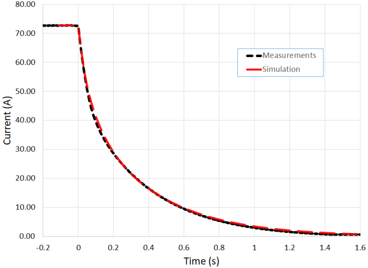


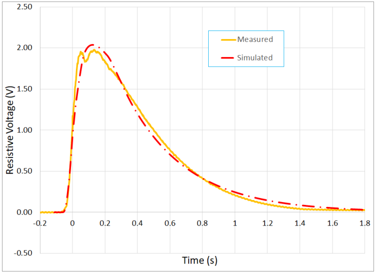
HO Corrector Magnets

Measured quench in Decapole's prototype









† Application to all multipole's orders

† No supposed degradation of the filaments

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All magnets can be safely protected

HO Corrector Magnets

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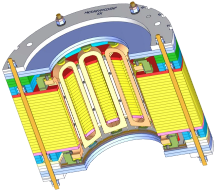

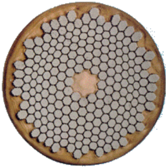

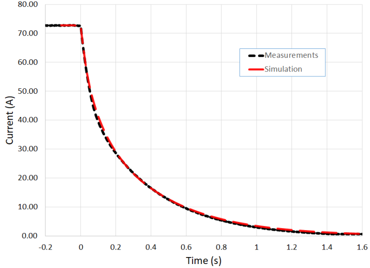

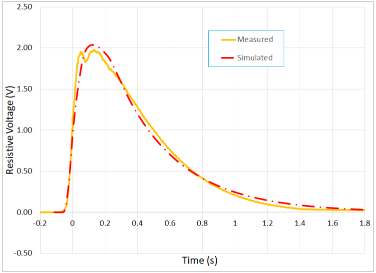

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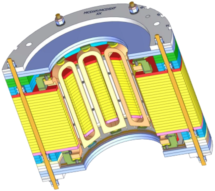

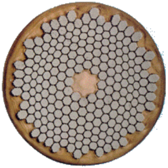

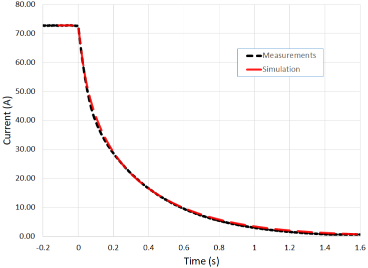

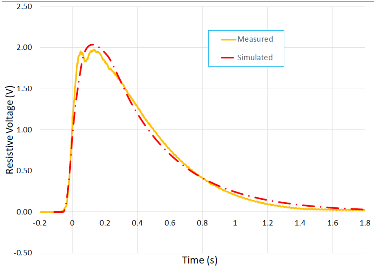

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Order	T_{max} [K]	V_{max} [V]	R_{dump}
4P	122	216	YES
6P	120	70	NO
8P	140	58	NO
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HO Corrector Magnets

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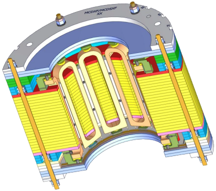

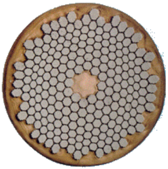

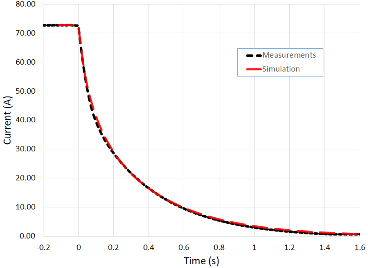

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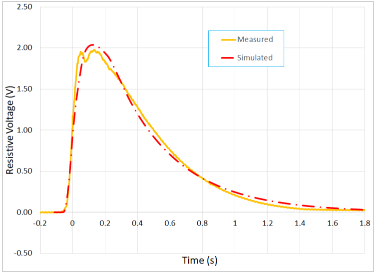

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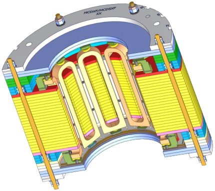
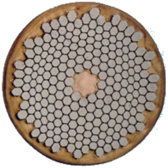

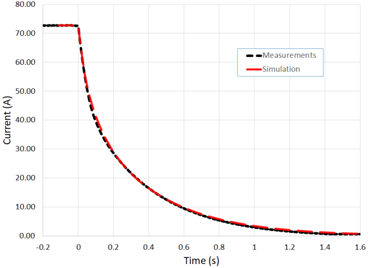

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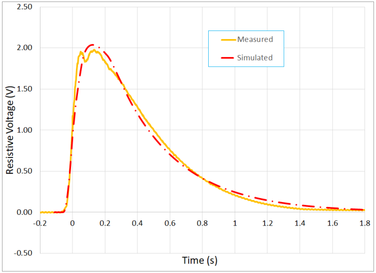

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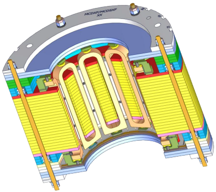

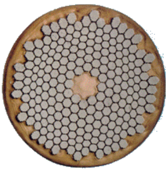

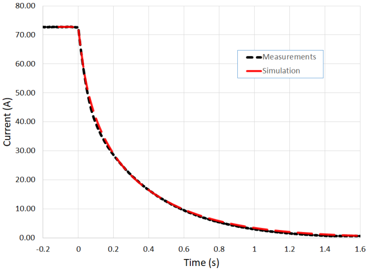

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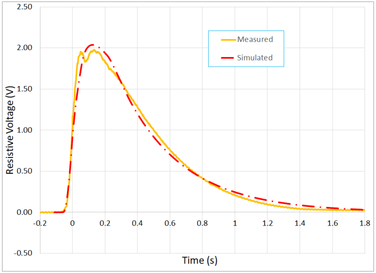

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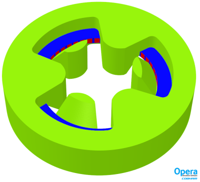
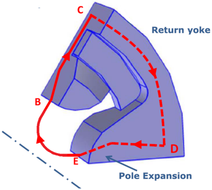
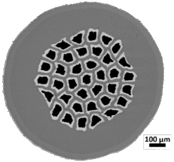
RCSM

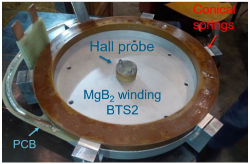
New type of Superferric Corrector Magnet



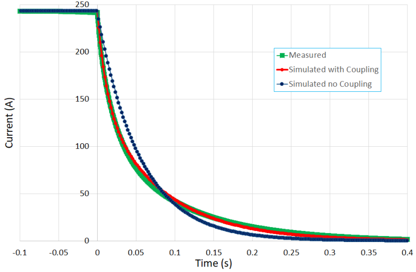


- Can create all multipole orders
- Suitable to strain sensitive SC





- 1^{st} Coil of the Demonstrator: Assembled and Tested



- Well described considering also Aluminum Coupling
- Next Step: build of Iron Yoke

[1] I. F. Malyshev. Patent for a multipole magnetic lens. 1973 Patent 1 689 890/26-25, Oct.12, n 41

[2] V. Kashikhin, "A novel design of iron dominated superconducting multipole magnets with circular coils," IEEE Trans. Appl. Supercond., vol. 20, no. 3, pp. 196–199, Jun. 2010

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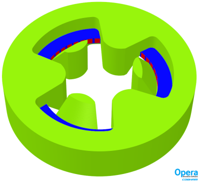

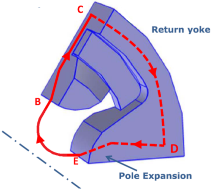

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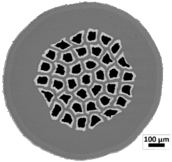
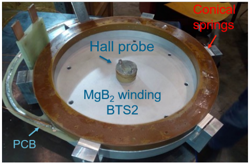
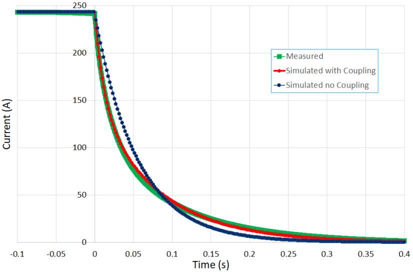




- 1^{st} Coil of the Demonstrator: Assembled and Tested



- Well described considering also Aluminum Coupling
- Next Step: build of Iron Yoke

[1] I. F. Malyshev. Patent for a multipole magnetic lens. 1973 Patent 1 689 890/26-25, Oct.12, n 41

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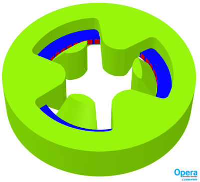
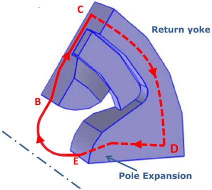
RCSM

New type of Superferric Corrector Magnet





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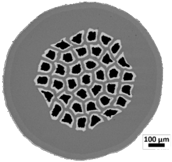

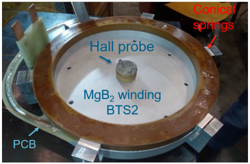

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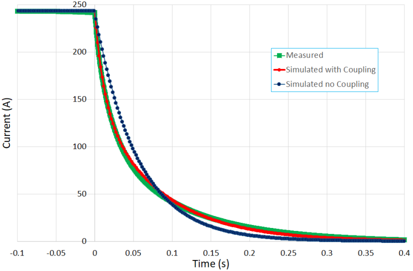

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Conclusions and Perspectives

- † Cryogenic Measurements of Sextupole, Octupole and Decapole: DONE.
- † Study of Cross Talking has been performed and will have impact on shaft design
- † Analysis of Iron and superconductr magnetization effects at cryogenic temperature

- † Dodecapole Prototype is being tested right now (8^{th} October - 12^{th} October 2018) Quadrupole Prototype's coils are being assembled.
- † Design of cryogenic test station is on going
- † Simulations of Magnets' deformations
- † Parametrization of the Field Quality as function of temperature

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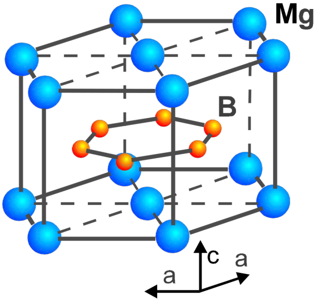
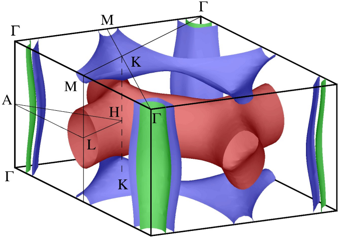
Superconducting MgB_2

Crystal Structure

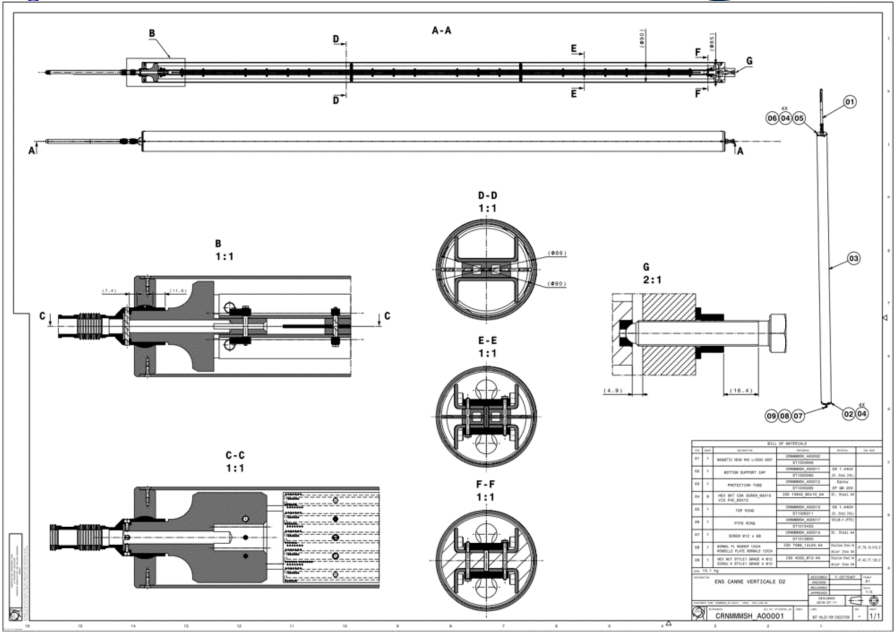




Features

- Discovered in 2001 by group of professor Akimitsu
- Critical Temperature of $39\ K$
- Two gap of energy: Band π and σ $\Delta_\pi = 2.2\ meV$ and $\Delta_\sigma = 1.7\ meV$
- Coherence lengths: $51\ nm$ and $13\ nm$
- London penetration depths: $33.6\ nm$ and $47.8\ nm$

Magnetic Measurements Shaft



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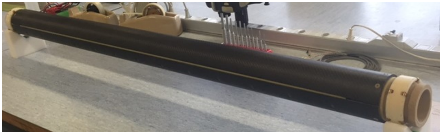

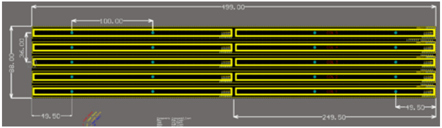

Courtesy of Lucio Fiscarelli (CERN Magnetic Measurements Division)