 FuSuMaTech	Deliverable 6.6 – FINAL FuSuMaTech PHASE 1 WORKSHOP
	FuSuMaTech-6.2-DE-22-V1.0






Future Superconducting Magnet Technology


H2020-FETOPEN-2016-2017/H2020-FETOPEN-3-2017

Grant Agreement Number n° 766974

DELIVERABLE D 6.6

FINAL FuSuMaTech PHASE 1 WORKSHOP

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<i>Date and visas</i>	5/04/2019 	15/04/2019 		15/04/2019 

 FuSuMaTech	Deliverable 6.6 – FINAL FuSuMaTech PHASE 1 WORKSHOP
	FuSuMaTech-6.2-DE-22-V1.0

HISTORY OF CHANGES					
Version	Publication date	Change	Edited by	Reviewed by	Approved by
1.0	05/04/2019	Final version	Han Dols	Sylvain Roux	Antoine Daël

PROJECT DELIVERABLE INFORMATION SHEET		
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	EC Project Officer	Adriana GODEANU-METZ

TABLE OF CONTENTS

Table of contents.....3

1. INTRODUCTION.....4

2. FINAL WORKSHOP.....4

 2.1 INVITATION.....4

 2.2 ORGANISING COMMITTEE5

 2.3 AGENDA.....5

 2.4 SPEAKERS & TOPICS.....6

 2.5 PARTICIPANTS.....8

 2.6 PICTURES10


 2.7 POSTER SESSION PRESENTATION12

3. CONCLUSION.....23

ANNEX 1 SOMES SLIDES FROM PARTICIPANTS PRESENTATIONS24

ANNEX 2 FUTURE FuSuMaTech COLLABORATION REQUEST FOR INFORMATION.....31

ANNEX 3 SIGNED PARTICIPANTS LIST.....33

 FuSuMaTech	Deliverable 6.6 – FINAL FuSuMaTech PHASE 1 WORKSHOP
	FuSuMaTech-6.2-DE-22-V1.0

1. INTRODUCTION

The final event for the Phase 1 FuSuMaTech project has been successfully executed on April 1, 2019 in the CERN Globe. In this document, we will provide the necessary evidence and summary of this deliverable 6.6. In chapter 2, the workshop elements and setup will be explained. In the annex 1, some slides from the presentations are included – to the extent these can be publically shared and not covered in the other WP reports.

2. FINAL WORKSHOP

2.1 INVITATION



The poster features the FuSuMaTech logo at the top, followed by the text 'SAVE THE DATE' in orange. Below this, a white banner contains the date '1st April 2019 - CERN, Geneva'. The main title 'FuSuMaTech Phase 1 Final Workshop' is displayed in large white font. The background shows a night view of the CERN Globe with its illuminated orange panels. At the bottom, contact information for the FuSuMaTech Secretariat is provided, along with logos of various partner organizations including the European Union, CERN, ASG, KIT, and Tesla.

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SAVE THE DATE

1st April 2019 - CERN, Geneva

FuSuMaTech
Phase 1 Final Workshop

For more information, please contact FuSuMaTech Secretariat through
Sylvain ROUX (s.roux@cea.fr) or Antoine DAËL (antoine.dael@cea.fr)

Logos: European Union, CERN, ASG, KIT, Science & Technology Facilities Council, gtmkAthena, tesla



2.2 ORGANISING COMMITTEE

CERN:

Anais Rassat

Bettina Hamoudi

Daniela Antonio

Gijs De Rijk

Han Dols

CEA:

Antoine Dael

Sophie Cavata

Sylvain Roux

2.3 AGENDA

10:00	Welcome coffee	
	<i>80-1-001 - Globe of Science and Innovation - 1st Floor, CERN</i>	10:00 - 10:30
	1 - Welcome Address, overview of CERN strategy and role of the FuSuMaTech Initiative	<i>Frederick Bordry</i>
	2 - Overview status of FuSuMaTech Initiative	<i>Antoine Dael</i>
11:00	4 - WP4 overview – Setting up Generic R&D&I actions	<i>Ziad Melhem</i>
	3 - WP5 overview – Setting up Technology Pilots	<i>Antoine Dael</i>
	6 - Report of the Scientific and technical committee	<i>Thierry Schild</i>
12:00	7 - Funding Strategy for FuSuMaTech Phase 2 - Presentation of MoU and ceremony of Signature	<i>Thierry Lagrange</i>
	<i>80-1-001 - Globe of Science and Innovation - 1st Floor, CERN</i>	12:05 - 12:30
	Lunch buffet	
13:00	<i>80-1-001 - Globe of Science and Innovation - 1st Floor, CERN</i>	12:30 - 13:30

14:00	8 - POSTER SESSION (10 R&D&I / Technology demonstrator Subjects)	
	<i>80-1-001 - Globe of Science and Innovation - 1st Floor, CERN</i>	13:30 - 14:30
	9 - High Field Magnet Development at CERN and potential role of FuSuMaTech <i>Luca Bottura</i>	
	12 - MRI in the Era of Future's Medicine and Status of ISEULT Project <i>Denis Le Bihan</i>	
15:00	<i>80-1-001 - Globe of Science and Innovation - 1st Floor, CERN</i>	
	15 - Applied Superconductivity in Europe (a retired spectator's view) <i>Martin Wilson</i>	
	10 - Message of the ESAS chair <i>Bernhard Holzapfel</i>	
	13 - Conclusion and Final Address <i>Philippe CHOMAZ</i>	
16:00	14 - COCKTAIL AND CELEBRATION	
17:00		


2.4 SPEAKERS & TOPICS

Frederick Bordry: Is CERN Director for Accelerators and Technology at CERN, where he is responsible for the operation and exploitation of the entire CERN accelerator complex, with particular emphasis on the LHC and the development of new projects and technologies. Fredrick Bordry will present about CERN Strategy and the role of the FuSuMaTech Initiative.

Antoine Dael: Has been head of the accelerator, cryogenics and magnet department at CEA Saclay, and currently is ILO for CERN and ESS. But more important for today: Antoine has been – absolutely- the driving force behind this FuSuMaTech initiative. As CEA is formally the FuSuMaTech project coordinator, Antoine Dael has been leading not only the overall program, but also WP1, WP3 and supported WP5 and WP6. So for sure he is the best to provide us with an overview of FuSuMaTech Phase 1 Project.

Ziad Melhem: Is Strategic Business Development Manager at Oxford Instruments Nanoscience, responsible for managing collaborative R&D and strategic projects on nanotechnology applications including Quantum Technologies. Ziad has over 26 years' of experience in applied superconductivity and many LTS and HTS applications. For FuSuMaTech, Ziad has been passionately leading WP4 and has been a big driving force in the FuSuMaTech program. He will provide an overview of the R&D&I tasks.

Thierry Schild: Is a senior, very experienced magnet engineer at ITER, and one of the fathers of Fusumatech concept. Thierry has an impressive background in the field of Fusion Technology and

 FuSuMaTech	Deliverable 6.6 – FINAL FuSuMaTech PHASE 1 WORKSHOP
	FuSuMaTech-6.2-DE-22-V1.0

large magnet engineering. He has been one of the key designers of the high field MRI magnet at CEA and will present to us a report of the scientific and technical committee.

Thierry Lagrange: The head of the Industry, Procurement & Knowledge Transfer Department. Thierry graduated in economics and financial management in Belgium, and joined CERN in 1985. He was appointed Head of Procurement when the major procurement contracts for the LHC machine and experiments were put in place. Thierry will address the funding strategy for FuSuMaTech phase 2 and present the FuSuMaTech Memorandum of Understanding.

Luca Bottura: Luca is by origin a nuclear engineer with a PhD in modelling of physical systems, and till 1995 he worked on SC magnet technology for fusion reactors. After that, he started to work at CERN in the broad field of SC materials, magnets, superconductors, magnet testing, field measurement methods and field mapping for the LHC. Today he is heading the CERN Magnet group, and in his presentation he will show the link between the science at CERN and the FuSuMaTech initiative.

Denis Le Bihan: Has achieved international recognition for his impressive contributions to the development of new imaging methods, in particular to study the human brain. His work in the field of MRI has had great impact on in the field of modern radiology and neuroscience. Denis Le Bihan is a doctor in medicin as well as physics, and father of the neurospin laboratory in France. In this talk, he will provide you with a look into the future of MRI and its role in medicine.

Martin Wilson: Some call him the father of applied superconductivity, and Martin Wilson is author of the famous book ‘Superconducting Magnets’ which I am sure is read many of the experts in this room. He has a world renowned reputation, and worked in this field from the 60s. He has seen and experienced how applied superconductivity has developed over the last decades, and is in a unique position to share with us his reflections about the status of superconductivity today.

Bernhard Holzapfel: Professor at the Karlsruhe Institute of Technology and director of the Superconductive Materials Institute. He has an impressive trackrecord related to the science and application of high temperature superconductive materials, and their use cases in the field of energy and transportation. Further, he is president of the European society for applied superconductivity (ESAS) – and will address us from this perspective.

Philippe Chomaz: is executive scientific director at CEA, responsible for the fundamental research activities. Before that, he was leading the Institute for Research into the Fundamental Laws of the Universe, with world class research related to astrophysics, nuclear physics and particle physics. He studied at the Ecole Normale Superieur in Paris, and worked in the field of nuclear experimental and theoretical physics. Philippe Chomaz will share with us his view and conclusion related to the FuSuMaTech initiative.



2.5 PARTICIPANTS

ID	Full name	Affiliation	ID	Full name	Affiliation
#15	Graham Gilgrass	Aimant Ltd	#35	Cécile Lerman	CEA Saclay
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#66	Francois Debray	CNRS -LNCMI	#11	Xavier CHAUD	Laboratoire National des Champs Magnétiques...
#68	Chris Riley	Dassault Systemes UK Ltd	#9	Martin Wilson	MNW Consulting
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#70	Julio Lucas	ELYTT Energy	#23	Michael Cuthbert	Oxford Instruments
#93	Serdar Atamert	Epoch Wires	#37	Ziad Melhem	Oxford Instruments
#36	Patrick McCutcheon	European Commission	#10	stephane sanfilippo	Paul Scherrer Institut
#74	Thibault Genestier	General Electric	#43	Lenny Rvkin	Paul Scherrer Institut (CH)
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FuSuMaTech-6.2-DE-22-V1.0

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	#51	Carmine Senatore	University of Geneva
	#56	Susie Speller	University of Oxford
	#54	Massimo Sorbi	Università degli Studi e INFN-LASA Milano (IT)
	#95	Pierre-André Vuissoz	Université de Lorraine
	#28	Thibault LECREVISSE	Université Paris-Saclay (FR)
	#58	Angele Sene	Université Paris-Saclay (FR)
	#82	Pierre Vedrine	Université Paris-Saclay (FR)
	#64	Tord Johan Carl Ekelof	Uppsala University (SE)
	#94	Kevin Pepitone	Uppsala University (SE)
	#57	Linn Kretschmar	WU Vienna



2.6 PICTURES





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FuSuMaTech-6.2-DE-22-V1.0





2.7 POSTER SESSION PRESENTATION

T4.1 Transient-Effects Modelling of Superconducting Applications.

Description

- R&D&I in HTS technology crucially requires new and improved models to reliably and efficiently predict transient behavior such as quench propagation and -mitigation.
- Future systems are complex: hybrid LTS + HTS systems, strong magnetic coupling, insulation-free coils, tightly integrated systems (controls, power electronics).
- SC applications are too small a niche to be covered by commercial tools. Recent developments by the HEP community serve as a proof-of-concept for a radically new approach.

Architecture

Objectives

We build an R&D&I roadmap based on innovation in three areas:

- a novel architecture for transient-event analysis in complex systems;
- new and adapted numerical techniques to boost efficiency and accuracy;
- building a vibrant validation community to guide progress and disseminate knowledge.

The task does not intend to develop one all-encompassing new software. Rather, it proposes a flexible and light-weight architecture, allowing for optimized workflows, with dedicated GUIs.

Subtasks

Cost

Task	Start	End	Resources	Cost
HTS magnet modelling	2022-01	2022-12	10 FTE	100k
HTS magnet simulation	2022-01	2022-12	10 FTE	100k
HTS magnet testing	2022-01	2022-12	10 FTE	100k
HTS magnet validation	2022-01	2022-12	10 FTE	100k

Main Risks

Risk	Impact	Probability	Severity	Mitigation
HTS magnet modelling	High	Medium	High	Regular communication
HTS magnet simulation	High	Medium	High	Regular communication
HTS magnet testing	High	Medium	High	Regular communication
HTS magnet validation	High	Medium	High	Regular communication

Timeline

Applications

Stage 1 (3 years) focuses on the design and protection of a hybrid LTS + HTS magnet; see WP 5.4. Strong mag. coupling, non-insulated HTS coils, and the high R&D cost require new approaches to modeling.

Stage 2 (3 more years) will focus on novel HTS applications such as transmission lines, motors for transport systems, and generators for energy applications.

Proof-of-Concept

STEAM (Simulation of Transient Effects in Accelerator Magnets) is a proof-of-concept implementation of the proposed architecture for and by the HEP community (specifically LHC, HL-LHC and FCC-hh). It includes Model-Generator APIs for electric circuits (supporting two solvers) and 2D accelerator-magnet models (supporting eight tools, two of which commercial), three on-site GUIs for magnet testing and a co-simulation Meta-Method API based on waveform relaxation. The Model-Generator API was recently extended towards models of HTS accelerator magnets of the future. For more info, consult <http://cern.ch/steam>

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T4.2 Materials e-infrastructure

A new database of materials properties at cryogenic temperatures

Partners: STFC, KIT, CERN, TUM (associate member of Fusumatech)

We aim to enable safe and confident design of superconducting systems, by providing validated materials solutions: suggesting suitable materials with supporting data for design and simulation.

Phase 1 Creates an e-infrastructure, collects, reviews existing data; builds and commissions a sustainable, cryocooled test station to demonstrate multiphysical testing (e.g. thermal conductivity under stress at relevant temperatures)

Phase 2 Data Production, with test station as a user facility

Objectives

- To link to and support other tasks in Fusumatech, particularly by providing reliable data for the quench modelling task and materials testing of the high strength materials task
- To form a panel of expert reviewers who specialise in materials and/or measurement areas
- To identify which data sets can be used with regards to IP
- To critically review the existing data sets, identifying gaps
- To prioritise which measurements need to be performed
- To plan and demonstrate multiphysical testing infrastructure
- To develop an e-infrastructure that includes a materials database, linked to simulation software and machine learning frameworks such as "matminer"

Key Milestones

- M2.1 Review of existing cryogenic materials testing data, standards and standard reference materials M12 (type: report)
- M2.2 Review of multiphysical materials testing M18 (report)
- M3.1 Concept design report on cryogen-free environment (type: report)
- M3.2 Results of SRM cryo-mechanical tests M24 (report)
- M4.2 ML&AI concept M12 (report)
- M5.1 IPR guide to report data from external sources M18 (report)
- M5.2 IPR concept of e-infrastructure for new data M24 (report)
- M5.3 Sustainability model for the e-infrastructure M36 (report)
- M5.4 User access model for the new characterization station M36 (report)

Deliverables

- D1.1 Final report M36 (report)
- D2.1 Final Report M36 (report)
- D3.1 Commissioning of testing system M36 (testing machine)
- D4.5 Commissioned e-Infrastructure M36 (type: software)

Estimated costs (over 6 years) Total 3.1MEu
 WP1 160kEu, WP2 150kEu, WP3 870kEu, WP4 908kEu, WP5 300kEu, WP6 735kEu

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T4.3 Smart Wireless Diagnostics.

What if ... ?
we treat a superconducting magnet as an IoT device.

Medical MRI

CERN LHC Dipole

low temperature : in the order of the thermal shield levels, 50 K to 70 K, or below

What if ... ?
we **confine** the embedded electronics and sensors for the instrumentation inside the cryogenic vessel with **wireless** transmission for **data and power**.

The main challenges in front of us are:

- to develop a working electronic data acquisition system of high precision at low temperature
- to develop a working wireless electronic communication link at low temperature
- to develop a working wireless powering system at low temperature
- to develop a radio frequency transparent material to build a "window" or an antenna, at the wall of the cryogenic vessel, for the wireless communication link and for the wireless powering system
- to develop materials and assembly technologies to build flexible PCBs (printed circuit boards) for the confined electronics at low temperature

The main objectives are:

- to **confine the electronics** for monitoring, diagnostics, control and protection functionalities inside the superconducting magnet. This reduces the complexity of mechanical and thermal design eliminating the need of inserts for the instrumentation
- to **have more and different types of sensors** that are **better and faster** in collecting abundant high precision **real-time data**
- to "virtualise" the highly complex instrumentation and **profit from the new Big Data technologies and Artificial Intelligence**. This will reduce significantly the required time to gain "expert experience" from the superconducting magnets and will allow us to understand **and solve the problems** we are facing at the technology edge of superconductors
- to **access** a superconducting magnet **efficiently and conveniently** from remote devices (like smart phones, tablets or intelligent screens).

	DESIGN	SIMULATION	PROTOTYPING	PRODUCTION	INTEGRATION
START DATE	15/06/2022	15/06/2022	15/06/2022	15/06/2022	15/06/2022
END DATE	30/09/2022	30/09/2022	30/09/2022	30/09/2022	30/09/2022
STATUS	Completed	In Progress	Not Started	Not Started	Not Started

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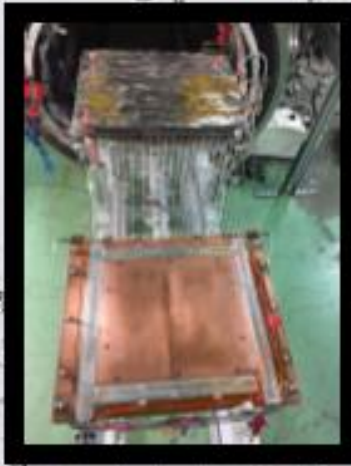
T4.4 Novel cryogenic solutions for next generation of superconducting applications.

Cryogenics for HTc superconducting applications = Cryocooling

- Cryocooling needs development of passive thermal links
- Actual thermal link = solid materials (copper straps)
 - Heavy
 - Slow thermal response
 - Low conductivity



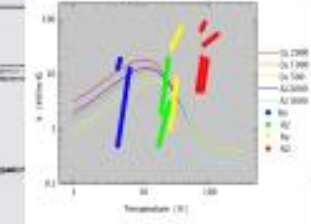
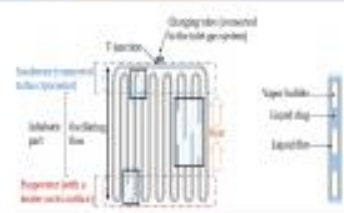
Fermilab's cavity cooled by a cryocooler



Flat horizontal 1 m long PHP @ CEA Saclay

Novel passive thermal link = Pulsating Heat Pipes

- Very high heat transfer (Two-phase heat exchange)
- Easy to construct : 1 single capillary tube
- Very light compared to thermal conductive link
- Versatile geometry



Objectives

- Develop an experimental program to characterize PHP
- Develop a predictive numerical code for designing
- Develop specific prototypes for different applications
- Implement a PHP system in a real cryo-magnetic device

Project

- 3 phases (7 years)
 - Test facility
 - Demonstrators
 - Real PHP system
- Manpower = 2185
- Materials = 580 k€

Numerous applications

- High temperature superconducting magnet cooled with hydrogen (20 K) or neon (27 K) PHP
- Superconducting magnet cooled with helium (4 K) (MgB2, MRI, rotating, ...)
- Nitrogen radiation thermal shield for a large helium temperature superconducting magnet
- Portable cooling system for HTc coil antenna for skin cancer detection
- Superconducting magnet for space application (spectrometer, radiation shields)
- Cryo-magnetism portable system (portable MRI system for field medicine, ...)





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T4.5 New high stress materials for next generation of superconducting applications.

year	1	2	3	4	5

New Cryo Materials

- widened design space for magnets (WPS)
- providing data via e-infrastructure (T4.2)
- network of application industry, material suppliers and test-labs (WPS, T4.2)

Application Industry

Project Coordinator Participating Labs

Material Supplier

High strength material selection and cryogenic characterization:

- processing (e.g. grain refinement, additive manufacture)
- fiber reinforced metal matrix (e.g. MMC)
- fiber reinforced polymers (e.g. prepreg, pultruded, additive)

Need for Applications

- high Lorentz forces of s.c. magnets
- this limits system size and geometry (e.g. open or high sensitive MRI)

Materials Potential

- cryo environment limits available material
- higher stress/fracture performance favorable

resource

traveling publication 30 k€

for 5 years

materials 350 k€

cryo-tests 1.300k€

scientist 1.5 FTE per year

technician 1 FTE per year

resource

References:

[1] Dine et al. JCP Conf. Ser. Mater. Sci. Eng. 102 02005 (2016)

[2] Sarason et al. Adv. Eng. Mater. 18, No. 7, 2708017 (2017)

[3] https://fhs.science.eu/information/interactions/interact+0342 (2017)

[4] FuSuMaTech WP6 Technology Plans (2018)

[5] Sarason et al. JCP Conference Proceedings 1676, 889 (2014)

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page 16/36

DE6.6- FINAL FuSuMaTech PHASE 1 WORKSHOP V1.0





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T5.1 MgB2 Demonstrator



Smaller
Cost
effective

New
Industrial &
Scientific
markets

Technology pilot parameters	MgB2 technology pilot
Operating field	3T and Field ramp up to 1T/s at 10K 5T in DC mode at 10K 1T in DC mode at 20K
Geometry	Curved Cos Canted Theta Dipole magnet 
Deviation angle	Between 10° and 30° for limited cost (90° expected for full scale application)
Deviation radius	2120 mm (in order to fit with ion carbon magnetic rigidity for hadron therapy)
Useful bore diameter	Between 100 mm and 200 mm (in order to fit with a gantry optic for ion carbon hadron therapy, a smaller aperture can be considered depending on the gantry optic and layout)
Operating temperature	10K to 20 K
Cooling mode	Conduction cooled or Helium gas cooled with zero boil off closed loop with thermosiphon

MgB2 – Potential markets

MgB2 technical critical objectives	Superconducting MRI magnets	Superconducting Accelerators magnets High Energy physics	Superconducting Accelerators magnets Hadron therapy gantry magnets or cyclotron magnets
Operating field full spectrum over the application range	1.5T - 3T - 7 T - 12T	0.5T - 5T - 8T - 12T - 16T	1.5 - 3T - 5T - 8T
Operating field spectrum compatible with future MgB2 technology	1.5T - 3T	0.5T - 5T	1.5 - 3T - 5T
Operating mode of main interest	DC	DC	DC (cyclotron) Slow ramp 1T/s - 3T/s - 6T/s (gantry)
Operating mode compatible with future MgB2 technology	DC	DC	DC Slow ramp 1T/s
Shape of main interest	solenoid	Cos n theta Racetrack (super ferric) Cos Canted Theta Solenoid	Cos Canted Theta Cos theta Race track (super ferric)
Typical useful bore diameter of interest	300 - 600 mm - 1000 mm	30 mm - 100 mm (accelerators) 0.5m to several meters (detectors)	30 - 50 - 200 mm
Key Success factor for MgB2 technology	Easy operating without helium & Competitive price compared to NbTi magnets	Cryogenic plant electrical consumption saving by operating the magnets between 10K and 20K	Ramping mode Compact magnet size & Competitive price compared to resistive magnets


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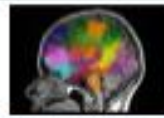


T5.2: FRONTIER EDGE HIGH-FIELD MRI 16T CONCEPT MAGNET

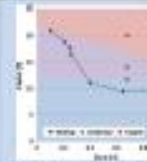
Partners: Lionel Quetier, Cécile Lerman, Thibault Lecroix, Nicolas Boulart

1. Introduction

- Magnetic Resonance Imaging (MRI) is an extremely powerful and versatile imaging technique, allowing to acquire images of the human tissue on-scales compatible with clinical exams and in a totally non-invasive way.
- The main source of MR signal is the protons of water molecules but other nuclei of interest are also detectable. MRI acquisitions can be parametrized to perform high spatial resolution anatomical imaging, but also diffusion and connectivity imaging, vascular imaging and metabolic imaging.
- The performance of MRI scanners has greatly improved in the last decades, thanks to technical progress in hardware and acquisition methods. Nevertheless, image quality is intrinsically restricted by the limited sensitivity of the technique.
- The sensitivity of an MRI scanner increases with its static magnetic field. Several research sites worldwide are already equipped with 9.4T clinical MRI scanners, while the first 33.5T MRI scanner is in operation at the OMMR (Minneapolis, USA) since 2017.



View of a subject's brain showing white matter tracts... (Caption text continues)

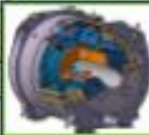


Scaling ultra high-field magnets and projects presented with the required sensitive... (Caption text continues)

2. Objectives

- In terms of scientific and medical applications, 16T will be the next relevant milestone after the successful exploitation of the generation of 11.7T MRI scanners. In particular, the sensitivity increase resulting from working at 16 T will allow to further explore the brain structure by thanks to a multi-scale analysis.
- EU has a leadership in very high-field MRI: industry has developed commercial 7T MRI magnets (Siemens, GE) and both Research Institutions (CNRS) and industries (AGS Superconductors) are now developing 11.7T projects.
- The aim of this task is to develop a coarse conceptual design study of a whole-body 16 T magnet that will require the use of NbTi-wires. Such a conceptual design study may be used by public research institutes to launch new projects and also by magnet manufacturers (AGS, Jeol) to propose innovative MRI designs (possibly also at lower field intensities) based on the same basic technology.

3. Description



3D model and real picture of the 16.7T NbTi magnet from OMA (France). Illustration courtesy from CERN.

The design of Frontier Edge MRI at 16T magnet includes a number of challenges that set it apart. These are the main technological problems to be overcome before such a magnet can be designed:

- Development of a super-conducting conductor suitable, due to the field level (>10T locally), NbTi-wire will have to be used, at least partially.
- Temporal stability, with variations in the magnetic field of less than 10⁻⁴ T over a period of ten minutes.
- A magnetic field that is homogeneous to within 1.10⁻⁴ T throughout the volume of interest corresponding to the brain of the patient.
- Containment of the stray field inside the experiment room.
- Management of considerable magnetic forces in the range of twice the forces of the 6.35T Magnet (at the conductor scale, and at the structural level).

4. Sub-Task / Deliverable / Resources

- Sub-task 1: Preliminary Magnet Design, and definition of the reinforced superconductor parameters.
- Sub-task 2: Development plan definition.
- Sub-task 3: R&D Conductor Development and performance validation.
- Sub-task 4: MRI System Design (magnet, and other accessories required for the image).



Stack of six prototype parallel coils. A temperature margin of 1K should be considered. A time level at least 100 Myrs is expected.

The first Challenge of the Frontier Edge MRI 16T concept magnet is the industrial development of a NbTi-wire conductor to be scaled with a factor of 1.46 in performance from the 10T 6.35T conductor.



Superconducting cable (6.2 mm x 4.8 mm) for the main coil in a trough, ten strands of composite NbTi-wire inserted in a copper trough and coated with solder.

Scaling up from 6.35T. The overall parameters of a 16T MRI magnet scaled up from 6.35T are summarized in the following table. In this table the dimensions are those of 6.35T magnet and the size of the conductor are kept (4.2*6.2). NbTi-wire is required.

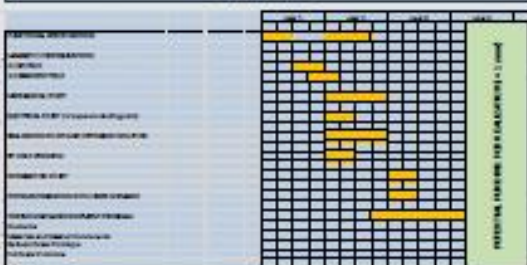
Parameter	6.35T	16T	16T
Central Bore	600	600	600
Magnet length	100	100	100
Operating current	1000	1000	1000
Operating voltage	100	100	100
Operating power	100	100	100
Operating temperature	4.2	4.2	4.2
Operating field	6.35	16	16
Operating current density	100	100	100
Operating field density	100	100	100

Manpower:
 Sub-task 1: 2.5 years 10 FTE Engineer
 Sub-task 2: 6 months 2 FTE Engineer
 Sub-task 3: 2.5 years 2 FTE technician 2 FTE Engineer
 Sub-task 4: 1 FTE Engineer
 Total: 2 FTE technician (200 k€), 15 FTE Engineer (2250 k€)
 Total for Manpower 2 450 k€

Materials:
 Using GRRN HL-LHC strand for 1 km conductor production 200 k€
 Conductor Production 800 k€
 Total for the materials 1 000 k€

TOTAL: 3 450 k€

5. Timeline





Future Superconducting Magnet Technology



T5.3: Preparation of a proposal for investigation of innovative magnetic configuration for emerging MRI applications.

Social Magnet, Open MRI Magnet, Mammo Magnet (Conceptual design)

Abstract:

The phase I of FuSuMaTech starts by describing the requirements of a MRI magnet devoted to breast scanning, making special emphasis in the medical advantages that such a device will have over more conventional diagnosis methods (conventional mammography). The medical use dictates the design parameters of the magnet.

A dedicated software for solenoid field quality optimization has been developed and tested.

A few results of the test runs were evaluated, although they are not intended at all as the proposed solutions. Nevertheless, the results already indicate the direction of further research in the domain of the open MRI system and the mammo-magnet. The latter application seems more feasible than the former for a project limited on time and budget.

The specifications of a small-scale and inexpensive breast MRI scanner should be the following:

- The apparatus must be small to be mobile and cheap.
- The field-of-view might be limited.
- The patient will be in a stand-up position.
- Field homogeneity must be <1ppm/20cm peak-to-peak (0.05ppm after shimming).
- Stability of the field must be better than 0.05ppm/h (10-4ppm/10minutes).
- Innovative radiofrequency systems will have to be designed.
- Field strength should be ideally 3T, but not be lower than 1.5T.
- Artificial intelligence algorithms designed for both signal acquisition and processing will help maintaining adequate signal: noise levels while reaching a spatial resolution better than 2mm.
- The foot print of the system must also be small in terms of the 5 gauss line.
- An open design will also allow image guided biopsy or therapy.

New Magnet Technology for a 1.5 T Open-MRI Breast Imager

Adilgün Sahar, Peter Mühlbauer, Jolf Bettschlag, David Chaves, James Gentry, and Joshua Kellum



Current Breast MRI Systems.

The Magnetom Espree Pink machine is the first MRI scanner by Siemens that was developed especially for breast exams.



The table below shows the resources required for detailed design of the mammo-magnet, indicating both the amount of person-power and budget for the fulfillment of a complete and functional design.

FuSuMaTech Phase 2 Prevision for Mammomagnet Wp5 Task S.L.	Year 1			Year 2			Year 3			Year 4		
	Months of engineer	Cost per month	Subtotal	Months of engineer	Cost per month	Subtotal	Months of engineer	Cost per month	Subtotal	Months of engineer	Cost per month	Subtotal
FUNCTIONAL SPECIFICATIONS	6	12,500,00 €	75,000,00 €	6	12,500,00 €	75,000,00 €						
MAGNET DEFINITION	12	12,500,00 €	150,000,00 €	6	12,500,00 €	75,000,00 €						
MAGNET DESIGN	6	12,500,00 €	75,000,00 €	12	12,500,00 €	150,000,00 €						
MECHANICAL STUDY				6	12,500,00 €	75,000,00 €						
SUPERCONDUCTING WIRE STUDY				6	12,500,00 €	75,000,00 €						
CRYOGENIC DESIGN STUDY				6	12,500,00 €	75,000,00 €						
THERMAL CALCULATION							6	12,500,00 €	75,000,00 €			
INTEGRATION STUDY							12	12,500,00 €	150,000,00 €			
MANUFACTURING STUDIES							18	12,500,00 €	225,000,00 €			
MANUFACTURING FINAL DESIGN										12	12,500,00 €	150,000,00 €
COST STUDY										12	12,500,00 €	150,000,00 €
TOTAL COST PER YEAR			300,000,00 €			525,000,00 €			450,000,00 €			300,000,00 €





Future Superconducting Magnet Technology



T5.3 The Social Magnet

E.R. Bielert, A. Dudarev, T. Mulder, A. Dael, S. Roux, C. Lerman, D. LeBihan, H. ten Kate

Description, context and objectives

The social magnet is presented here as an early stage conceptual design of a large superconducting magnet system, with a potential large impact on healthcare: specifically diagnostic equipment for functional MRI brain research, where several patients/subjects are tested and experimented on simultaneously in the same system, while they are socially interacting with each other. The conceptual designs should lead to generic R&D actions, that will be implemented over the next 5 years. Monitoring of brain activity in an MRI system, requires magnetic fields of at least 3T, with a high precision over a large volume. MRI has advantages over alternative techniques like post-mortem visual inspection of the brain, Functional Near Infrared Spectroscopy (fNIRS), Electroencephalography (EEG) and Magnetoencephalography (MEG). Therefore, the ambition is that the conceptual design of the magnet system for the social magnet allows for social interaction between two or more subjects that have a relative large degree of freedom concerning their position. Movement will still not be allowed and should be limited to a minimum. This implies that the volume where magnetic field needs to be generated is either very large or as open as possible (or both).

Present day "options"



Functional requirements and technical limitations

- To be able to host 2 or ideally 3 test-subjects *simultaneously*, the solenoidal main magnet should be about 3 m in diameter, leaving an effective free diameter of 2.4m.
- The main static homogeneous magnetic field needs to be at least 3 T strong and needs to have a stability in space of 0.05 ppm / 20 cm peak to peak over the total volume of a sweep spot where the subject's brain is positioned and a stability in time of 0.05 ppm / h over the long term and even 10^{-4} ppm / 10 min during an experiment.
- The most logical configuration for the gradient coils and RF transceiver implies a set of coils per sweep /sweep spot. An overall gradient coil will consume too much energy. A helmet / old fashioned hairdryer like construction for this purpose would offer the most logical solution.
- Magnetic shielding does not have priority, but should be taken into consideration at a later stage during the conceptual design. Nb-Ti would be the conductor of choice, where optimized pairs of Helmholtz like coils should be the basis of the overall design of the main coil.
- An alternative to a single large magnet, hosting all subjects, would be a combination of several smaller open systems in a smart configuration. However, for open systems, the 3 T minimum required magnetic field is simply not possible with Nb-Ti technology.

Challenges

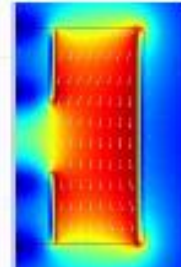
- Size of the system
- Magnetic field strength
- Homogeneity
- Size and shape gradient coils
- Flotation gradient coils
- Movement of patients/subjects

Basic concepts

Cylindrical systems generate magnetic field in a volume where it is not strictly necessary and the field is only homogeneous in the center, while for the social magnet, it needs to be meeting the strict requirements for MRI at a large radius away from the center. A more elegant solution would be to generate the magnetic field only where it is required: in a ring like shape, which can be generated by using a kind of "twin solenoid": an inner coil that generates a magnetic field in the opposite direction compared to the outer coil, such that in the middle part the magnetic fields cancel each other out, while the area in between the two coils contains the high magnetic field region. By using a Helmholtz like coil instead of a solenoid for the inner coil, an open window can be created, such that the subjects can see each other. End plates made of magnetic material at both the bottom and the top of the system drastically improve the homogeneity of the magnetic field.



An alternative modular open design.



A simplified 3D representation, field map and a top view.

Deliverables and main milestones





Future Superconducting Magnet Technology

T5.4 High temperature superconducting inserts for high field magnets.

Brief Description - extremely complementary and synergetic

FuSuMaTech Task 5.4 focuses on HTS coils to generate magnetic fields greater than 30 T. NOELL is focusing on medium diameter HTS coils, complementary to the CNRS-CEA focus on small diameter inserts. CNRS and Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA) have completed in 2018 a common program (ANR NOUSAT project) in which two inserts with an outer diameter of 120 mm were developed and manufactured. The magnets planned to be tested in a 20 T background field to reach a total of 30 T (March 2024).

NOELL High Flux Magnet (NOELL) is working on the development of high magnetic flux HTS coils with large inner diameter (up to 800 mm) and completed the manufacturing of eight 400 mm inner diameter coils that are undergoing qualification tests in conductor cooling environment.

COLLABORATION

CNRS is the largest governmental research organization in Europe. The Laboratoire National des Champs Magnétiques Intenses, **LNCMI**, was created on 7 January 2009. It has three main missions: to generate the highest possible magnetic fields for research purposes; to use these fields for in-house research and to develop the necessary scientific infrastructure to provide access to qualified French and European users to these high magnetic fields and the associated scientific infrastructures. **CEA**, the French Alternative Energies and Atomic Energy Commission (CEA) is dedicated to connecting the worlds of research and industry. The Fundamental Research Division of CEA (DRF) is dedicated to research, development and innovation in areas with major societal challenges: SPJ develops particle accelerators, cryogenic systems and superconducting magnets. As a result SPJ is the partner for the construction of superconducting magnets for the 42 T hybrid magnet in CERN LHCb, the NOELL whole body 11.7 T MRI magnet in MRUCORP. HTS activities are also being developed at DRFC, mainly in two fields: accelerators magnets and High-Field magnets. **NOELL** High Flux Magnet (NOELL) is a leading developer and manufacturer of superconducting magnets with over 30 years of experience in the field.

NOELL began developing tools and techniques for the production of HTS coils over 12 years ago. In addition to several small coils, NOELL produced a superconducting undulator prototype using 20 HTS in 2010. A few years ago, NOELL started manufacturing HTS coils of higher diameters as more conductor length was available. In addition, NOELL is manufacturing the ITS subcoil for the current 30 T High Field magnet at LNCMI.

Milestones

Milestone	Year											
	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
1. Finalize the design of the HTS insert												
2. Manufacture of the HTS insert												
3. Test of the HTS insert in a 20 T background field												
4. Manufacture of the HTS coil												
5. Test of the HTS coil in a 20 T background field												
6. Manufacture of the HTS coil assembly												
7. Test of the HTS coil assembly in a 20 T background field												

Application Oriented Objectives

- Develop and manufacture technology to reach 40 T by HTS insert
- Extend field of applications by demonstration of feasibility
- Enable and promote technology for HTS applications

Applications

Short term:

- Main target: Research facilities
- High Field Laboratories (Dresden, Toulouse, Chandra et al.)
- Neutron facilities (ILL, ISIS)
- Synchrotron facilities (SOLEIL, SCUBA)
- Free Electron Lasers (FEL)

Mid-term

Technologies of this project will enable and facilitate other applications by proving the reliability of these materials in very controlled environment:

- Commercial magnets up to 25 and possibly 30 T
- Compact HTS electric motor and transformers with application in wind turbine and naval vessels.
- Link with the 40 kV electric plane program.
- Fast current limiter on the electric network
- MRI and NMR

SUMMARY

FuSuMaTech Task 5.4 focuses on HTS coils to generate magnetic fields greater than 30 T. NOELL is focusing on medium diameter HTS coils, complementary to the CNRS-CEA focus on small diameter inserts.

The objective is the development of magnets made out of high temperature superconductors (HTS) of the second generation to be inserted in high field magnets in order to produce field in excess of 40 T.

The main goal is aiming at reducing energy consumption while boosting the performance of the superconducting magnet system.

The ultimate target of the project is the fabrication of a 40 T full-superconducting user magnet including both a low temperature superconductor (LTS) and a HTS part enabling ILL to become the leader in the high field magnet international community.

The partners propose a modular, 3-step approach with assessable progress and milestones.

CEA/CNRS ANR NOUSAT
Left: HTS-Insert Right: Double Pancake coil

NOELL High Flux Magnet
Left: Double Pancake coil Right: Coil assembly

fusumatech.web.cern.ch



Future Superconducting Magnet Technology



T5.5 GRADIENT COIL TECHNOLOGY FOR HIGH FIELD MRI, OVER 10 T

Partners: Steve Baker, Udoe Lemmen, Thibault LeClerc, Nicolas Roussel, Lionel Quetier, Paul Harvey, Peter Koenec, Xavier Mooney

1. Introduction

- The gradient coil is a key component of a Magnetic Resonance Imaging (MRI) system, since its performance constrains the maximal spatial resolution achievable with the MRI system.
- There are numerous LHF MRI laboratories around the world, with at least four 3T sites in the planning phase. It is envisaged FuSuMaTech must surpass the performance levels of the sites in order to stand out as a class leading project.
- The gradient coil has been given the project name **HyperGrad**. It is a completely new design, based on parametric inputs from academic and industrial contributors listed above.
- The creation of such a high performance gradient coil in this LHF MRI system should give researchers a very powerful tool for flow study of a variety of human brain disease and function, e.g. Parkinson's, Schizophrenia, Dementia, Cognitive, Multiple Sclerosis, Stroke.



Post-mortem reference of the human hippocampus connectivity and reconstruction using ultra-high field diffusion MRI at 32.7 T. Bernard, et al. Brain Structure and Function, 2020.

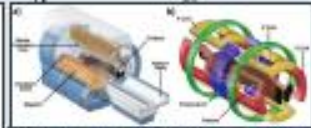


Diagram of a typical MRI system. Gradient Coils, a set of electromagnets embedded in the body of the Magnetic Resonance Imaging (MRI) system, normally on the bore surface of a cylindrical main field magnet, produce Gradient coils alter the main magnetic field in a predictable manner in the X, Y, and Z-directions and are used to spatially encode the MRI signal.

2. Objectives

- The gradient coil will need to be very high field strength and dew rate, in accordance with the desires of the research community.
- Additionally, it is certain that extremely demanding pulse sequences will be used, such as fMRI, DWI, therefore high duty cycle and resilience are prerequisites for such a coil.
- Ultra high field sites place additional requirements on the gradient coil design space, in particular: for high order shim (HOS) coils, often up to 4th order, but perhaps even higher or decs may be required here. The specification of HOS will be considered as part of the gradient coil in this case.

3. Description

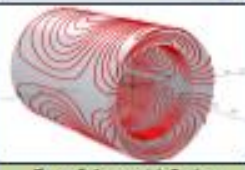


HyperGrad initial design, using symmetric coils.

HyperGrad Design parameters			
	1	2	3
Imaging parameters			
Strength per axis	120 T/m@1s	100 T/m@1s	100 T/m@1s
Current direction (T/m)	0, 0, 0.33	0.33, 0, 0	0.33, 0, 0
Volume	30cm x 30cm	30cm x 30cm	30cm x 30cm
Radial wire current	+40%	+40%	+40%
Phi current asymmetry	+40.2%	+40.2%	+40.2%
Z-Y orthogonality	97.45.1°		
Physical parameters			
Volume	30cm	30cm	30cm
Resistance @10K	10mΩ	10mΩ	10mΩ
Predicted performance when driven by a set of 1000A, 1000V amplifiers at 2.5-1000V impedance in all directions			
Gradient strength (T/m)	100 mT/m	100 mT/m	100 mT/m
Rise time (100%)	100µs	100µs	100µs
Dew rate	100 T/m/s	100 T/m/s	100 T/m/s
Dew rate (soft-start)	100 T/m/s	100 T/m/s	100 T/m/s
Predicted performance when driven by a set of 300A MRI			
Gradient strength (T/m)	30 mT/m	30 mT/m	30 mT/m

4. Deliverables / Main milestones

- Novel gradient architectures such as flange or asymmetric gradient coils may be used to maximise efficiency and eddy current shielding.
- Direct cooling for all three gradient sets to maximise steady state gradient strength, which is duty cycle.
- Ultra high dew rate for improved imaging performance and resolution for the most demanding pulse sequences, such as functional MRI (fMRI), and Diffusion Weighted Imaging (DWI)



Flange & Asymmetric Design Gradient Coil


6. Timeline / costs



5. Main Risks

Risk	Mitigation	Action Indicator
Accurate estimation between design and Gradient	Full study of fabrication, eddy currents, Lorentz forces, acoustic noise	Task and TDR
Temperature/force distribution	Simulation of heat pulse sequences and gradient field	TDR
Gradient coil mechanical integrity in high field, AC	AC/DC model	Task and TDR
Gradient coil space needed to service discharge and accurate detection (technology)	feasibility study and design	Task

Task	Duration (TDR max weeks)	Estimated Cost
Functional specification	2	€1.000
RF Technology Design	2	€1.000
AC/DC modelling	2	€1.000
Gradient/temperature simulation studies	10	€10.000
Thermal model	2	€1.000
RF Coil System Integration	10	€10.000
Acoustic noise study	10	€10.000
Gradient integration Post User Groups	4	€1.000
Technology development	10	€1.000
Functional model/prototype	10	€10.000 labour €1.000.000 materials/parts
Total		€1.422.000

 FuSuMaTech	Deliverable 6.6 – FINAL FuSuMaTech PHASE 1 WORKSHOP
	FuSuMaTech-6.2-DE-22-V1.0

3. CONCLUSION

The FuSuMaTech Phase 1 final workshop has been a real opportunity to bring together most of the major actors of Applied Superconductivity in Europe.(see the list of attendees).

87 persons have signed the presence list and have participated to the one day meeting

These people could obtain easily all the available information on the results of the Phase 1 through the oral contributions , the poster presentations and more over through a lot of "person to person" discussions during the all day.

The funding members of FuSuMaTech have signed the following Declaration of Intent :

The undersigned have reached an agreement in principle according to which they hereby state their intent to continue to be part of the FuSuMaTech collaboration, which aims at establishing a strong and sustainable European network for structuring and strengthening the field of superconductivity and associated industrial applications.

The terms and conditions of the FuSuMaTech collaboration are detailed in the proposed Memorandum of Understanding (MoU), which has been passed on to all the Parties for review.

The undersigned hereby express their genuine interest in reaching the signature of the MoU, provided that the text is consistent with all the Parties' expectations.

The undersigned acknowledge that on 1 June 2019, the MoU will enter into force between all the Parties having signed it by that date.

The other interested companies, research Institutes or unversities inrested to join the FuSuMaTech Scientific Collaboration have been invited to express this interest by sending a "REQUEST FOR INFORMATION". (See ANNEXE 2)

Twenty Five ad hoc forms have been distributed to possible new comers



ANNEX 1 SOMES SLIDES FROM PARTICIPANTS PRESENTATIONS

Some slides from presentation by Frederick Bordry:

CERN, European Organization for Nuclear Research
An Intergovernmental Organisation for the High Energy Physics Research
founded in 1954: "Science for Peace and Development"
Today: 22 Member States

- ~ 2'500 staff
- ~ 1'800 other paid personnel
- ~ 13'000 scientific users
- Budget (2018) ~ 1'100 MCHF

The Mission of CERN

- Push back the frontiers of knowledge**
 E.g. the secrets of the Big Bang ... what was the matter like within the first moments of the Universe's existence?
- Develop new technologies for accelerators and detectors**
 Information technology - the Web and the GRID
 Medicine - diagnosis and therapy

CERN 3 pillars: based on the 2013 European Strategy for Particle Physics

- Full exploitation of the LHC:**
 - successful operation of the nominal LHC
 - construction & installation of LHC upgrade (HL-LHC)
- Scientific diversity programme series**
 - ongoing experiments and facilities and their upgrades (HBE-ISOLDE, EIC)
 - participation in accelerator-based programmes (presently mainly LBNF in the US)
- Preparation of CERN's future:**
 - vibrant accelerator R&D programme (including **superconducting high energy** accelerators)
 - design studies for future high-energy accelerators

Important milestone: update of the European Strategy for Particle Physics (ESPP) Inputs in December 2018, Granada meeting in May 2019 and to be completed in May 2020

LHC (Large Hadron Collider)

1983	First studies for the LHC project	} ~ 25 years
1988	First magnet model (feasibility)	
1994	Approval of the LHC by the CERN Council	
1996-1999	Series production industrialisation	
1998	Declaration of Public Utility & Start of civil engineering	
1998-2000	Placement of the main production contracts	
2004	Start of the LHC installation	
2005-2007	Magnets installation in the tunnel	
2006-2008	Hardware commissioning	
2008-2009	Beam commissioning	
2010-2017...	Physics exploitation	} ~ 30 years
2010-2012	Run 1: 7 and 8 TeV	
2016-2018	Run 2: 13 TeV	
2021-2023	Run 3 (14 TeV)	
2024-2025	HL-LHC installation	
2026-2037...	HL-LHC operation	

A 27 km circumference collider...



Some slides from presentation by Antoine Dael:

1. History and Presentation of FuSuMaTech Initiative

HL-LHC and FCC Context : A win-win triangle for FuSuMaTech

The primary goal of the HL-LHC & FCC magnet R&D program is to extend the range of operation of accelerator magnets based on Low Temperature Superconductors (LTS), possibly operating at 4.2 K, up to 16 T.
The secondary goal of the FCC magnet R&D program aims at mastering the technological challenges inherent to the use of High Temperature Superconductors (HTS) for accelerator magnets up to the 20 T "range".

FuSuMaTech Phase 1 final workshop – session 02/09/2018 – 10 April 2017 – Antwerp, B.

1. History and Presentation of FuSuMaTech Initiative

- 6 companies (Oxford Inst., ASG, TESLA, Sigmaphi, ELYT& Babcock Noell) together with 6 academics (CERN, CEA, KIT, STFC, CNRS and PSI) had launched themselves into this initiative.

FuSuMaTech Phase 1 final workshop – session 02/09/2018 – 10 April 2017 – Antwerp, B.

1. History and Presentation of FuSuMaTech Initiative

- The European programs appeared as a unique toolbox to drive common work and to prepare efficient actions under the CERN umbrella.
- A proposal for FuSuMaTech Initiative Phase 1 was submitted the 17th January under a FET-Open Coordination and Support Actions Call and selected the 25th of June 2017 with a score of 14.25/15
- Industrial partners have the key role and all of us are volunteers for this win-win strategy.

FuSuMaTech Phase 1 final workshop – session 02/09/2018 – 10 April 2017 – Antwerp, B.

1. History and Presentation of FuSuMaTech Initiative

- The main objective, namely the creation of a sustainable European cluster in applied Superconductivity, is pertinent, timely, clearly addressed
- it will eventually structure a domain of major scientific and technological importance.
- The concept is eminently sound and the methodology described in the work-packages becomes remarkably clear after the relatively anephrastic first 5 pages.
- The participants clearly understand the need to engage in silo-breaking activities to rejuvenate the field and compete with Asia / USA.
- Risks are well identified in particular the possibility of seeing competing materials being developed elsewhere during the time frame of the project.
- This reinforces the need to support this project to maintain the technological leadership of EU industry.

FuSuMaTech Phase 1 final workshop – session 02/09/2018 – 10 April 2017 – Antwerp, B.



Some slides from presentation by Thierry Schild:

Task 4.1: Transient-Effects Modelling of Superconducting Applications

The objective is to build a powerful and versatile architecture for superconducting coil quench modeling. The community (especially HTS) needs have been identified through a survey and addressed. If the project succeeds it will have a big impact on the design of future superconducting magnets, particularly those which are pushing against the limits of what can be achieved. This task is well integrated inside the FuSuMaTech consortium.

STC strongly supports this task.

Final FuSuMaTech phase 1 Workshop, Geneva, 1st April 2019

Task 4.2: Materials e-infrastructure

STC supports the principle to make accessible verified materials data based a standardized procedure. The poor accessibility, relevance, quality, accuracy of existing data force very often teams in charge of new magnet development to perform characterization already existing. The first step is to dig into existing data, review them, and structure the information. The team should review the existing facilities within the FuSuMaTech consortium. Then, the need to develop a dedicated facility has to be demonstrated based on new data requirements.

STC supports strongly the principle of creating a common database, but the task content need to be reviewed for that purpose.

Final FuSuMaTech phase 1 Workshop, Geneva, 1st April 2019

Task 4.3: Smart Wireless Diagnostics for Superconducting and Cryogenic Applications

This task aims to develop a cryogenic instrumentations fully embedded in the magnet cryostat fully wireless (powering and communication). No survey has been done on developments done by the space industry. The need to develop new sensors is not supported. Even if the principle looks attractive, the benefit of such a development for the superconducting community is not demonstrated for the short term.

STC recommends to review the proposal and integrate space academic or industrial partners.

Final FuSuMaTech phase 1 Workshop, Geneva, 1st April 2019

Task 4.4: Novel cryogenic solutions for next generation of superconducting applications

The objective to develop the Pulsed Heat Pipe technology for cryogen free superconducting magnet is clearly very promising. The task describes a well balanced theoretical and experimental development. A successful development will have a real impact on European industry as the PHP technology can be applied to numerous superconducting and cryogenic domains. The only team member is CEA. Partners should be found within the consortium. A direct application of the developments to the Task 5.1 MgB2 would be very beneficial for both tasks. **STC supports this task but recommends a better integration in the FuSuMaTech consortium.**

Final FuSuMaTech phase 1 Workshop, Geneva, 1st April 2019



Some slides from presentation by Thierry Lagrange:

Why a MOU?

- During the 18 months of the FET CSA program , the 12 partners fruitfully worked together under the Consortium agreement.
- To build up on the present results, a « FuSuMaTech » scientific collaboration is required.
- The 6 Institutes and the 6 companies reviewed the DRAFT MoU proposal. Feedback was integrated in last version.
- This MoU is very light and expresses the wishes and intentions how to work together of the different partners for the future.
- The schedule is to sign the MoU not later than 1st of June 2019 between the founding members.

MoU basic Idea

- The FuSuMaTech will be a scientific Collaboration as of 1st June 2019 with 12 founding members.
- The members undertake to apply to European programs.
- New members are welcome to join, but under some conditions.
- Governance with a council , a coordinator and an annual meeting.
- THERE IS NO BUDGET : members are covering their travel expenses.

FuSuMaTech Collaboration Phase 2

The diagram shows a central 'Coordination' box connected to 'Acad' and 'Industry' boxes. Below, a large circle contains 12 'X' marks representing members, with lines connecting them to 'Acad' and 'Industry' nodes. Text on the right notes 'No set of members on the Superfederation' and 'Education meeting within 2019-20'. A legend at the bottom left identifies 'X' as 'Company/Institute' and 'X' as 'Acad/Industry'.

FuSuMaTech Collaboration

The diagram shows a large yellow circle labeled 'Scope of the Annual meeting' containing 12 'X' marks. To the right, two smaller circles represent 'Enterprise 1' and 'Company 1'. A legend at the bottom left identifies 'X' as 'Acad/Industry' and 'X' as 'Company'.

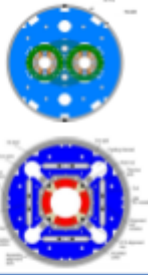


Some slides from presentation by Luca Bottura:

Courtesy of A. Bellarino, CERN

High field magnets for HL-LHC

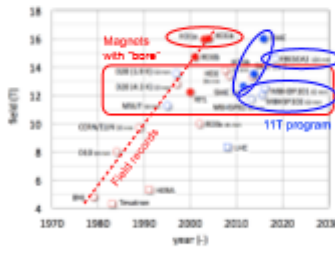
- HL-LHC high-field Nb₃Sn magnets are:
 - Arc dipole magnets (6):
 - 6.752 m length
 - 11.23 T bore field
 - 11.8 T peak field at nominal current of 11.85 kA
 - IR quadrupole magnets (10):
 - 7.15 m length
 - 132.6 T/m gradient
 - 11.4 peak field at nominal current of 16.47 kA
 - 20 IR quadrupole magnets identical to the above, but shorter length (4.2 m) are produced in the US



We have learnt a lot in the past 4 years – 1/2

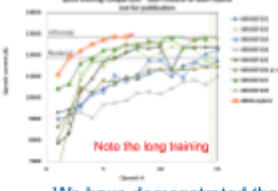
- Significant effort went into R&D on high field Nb₃Sn accelerator magnets since the mid 1990's
- Efforts at CERN have substantially accelerated in 2014 (end of LS1)
 - Personnel more than doubled, from 20 FTE (2014) to about 50 FTE (2019)
- Demonstrated stable industrial production and cabling of high-performance (HEP-class) Nb₃Sn wires (at a single producer)
- Achieved 16 T peak field in demonstration magnets (9 racetrack magnets built)
- Achieved 14.6 T bore field in a large aperture dipole (FRESCA2, in collaboration with CEA)

Highest "dipole" fields



The graph shows the evolution of dipole magnetic fields from 1970 to 2030. A red dashed line labeled 'Nb3Sn dipole' shows a steady increase from approximately 4 T in 1970 to 16 T in 2010. A red box highlights 'Magnets with bore' starting around 2000, with a peak at 16 T. A blue box highlights '11T program' around 2010-2015. Three photographs show physical magnets: 'LHC HCL', 'CERN RMC', and 'CERN/CEA FRESCA2'.

MBH (11T) dipole



The graph shows the field training for the MBH dipole, plotting field (T) against time (min). Multiple curves show the field increasing over time, with a red arrow pointing to the end of the training period. A photograph of the MBHDP101 magnet is shown with the following specifications:

- Aperture: 60 (mm)
- Field: 10.8 (T)
- Current: 11850 (kA)
- Peak field: 11.35 (T)

Note the long training


- We have demonstrated that a long accelerator magnet is feasible and can reach the desired performance
- This has taken years of sweat, and it is not over




Some slides from presentation by Martin Wilson:

LHC has brought us

- the experience of building and operating a really large superconducting magnet installation
 - operating very large scale 1.8K cryogenics over periods of years.
 - designing magnets to operate reliably close to their limits (stress, field, current density etc)
 - coping with accidents, designing better protection and control systems.
- the incentive to push for even higher performance
 - HiLumi High Luminosity Upgrade
 - FCC Future Circular Collider



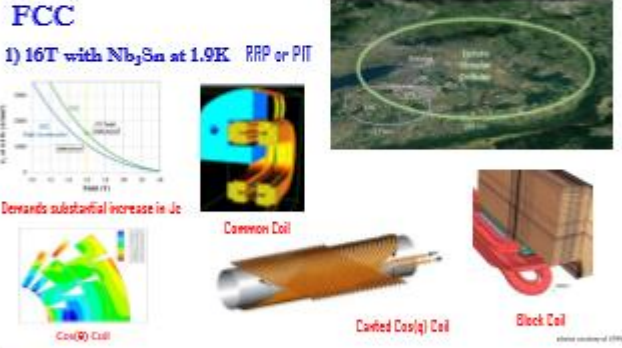
HiLumi High Luminosity LHC
Nb₃Sn at 1.9K



Dipole
11.2T in 60mm aperture

Quadrupole
13.3T/ro over 150mm aperture (11.6T peak)

FCC
1) 16T with Nb₃Sn at 1.9K RRP or PIT

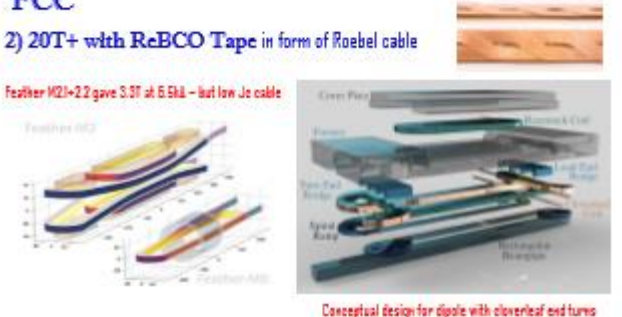


Demands substantial increase in J_c

Common Coil, Canted Cos(θ) Coil, Block Coil

FCC
2) 20T+ with ReBCO Tape in form of Roebel cable

Feasible M2I+2.2 gave 3.3T at 6.5kA – but low J_c cable



Conceptual design for dipole with cloverleaf end turns



Some slides from presentation by Bernard Holzapfel:

HTSC Application Areas

The slide shows various applications of HTSC technology, including Fusion, Magnets (NMR/MRI), Power Applications (AC/DC cables, Transformer, FCL), and Rotating Machines.

State-of-the-Art HTSC Technology Development

This slide features a Gantt chart showing the development timeline for various HTSC technologies from 2010 to 2025. The stages are Technology demonstration, Large scale prototypes in field, First commercial products, and Full market entry.

Technology	Technology demonstration	Large scale prototypes in field	First commercial products	Full market entry
DC Cable				
AC Cable				
SCFCL				
Transformer				
Rotating M.				
NMR				
MRI				
Research M.				
Acc. Mag.				
Fusion M.				

From SC Materials to Systems

It's a long way from a new SC to a magnet. The process is divided into three stages: Material, Conductor, and Application.

- Material:**
 - New materials
 - New properties
 - Economic wire synthesis
- Conductor:**
 - Quench characteristics
 - Low ac-loss conductor
 - Mechanical properties
 - Special coil designs
- Application:**
 - Coils for Power Applications
 - HTSC Magnets
 - Cryogenics
 - Modelling


Superconductivity based Research Topics at ITEP

The slide outlines research topics in three main areas: Superconducting and Cryo Materials, Energy Applications, and Superconducting Magnet Technology.

- Superconducting and Cryo Materials:**
 - Superconducting Materials
 - High-Tc Research Materials
 - Cryogenic Properties of Superconductors
 - Conductor and Wire Systems
- Energy Applications:**
 - High-Temperature power system superconductors
 - New Applications of Superconducting
 - Modeling of Superconductors and Composites
 - Low Temperature Systems, Methods and Processes
 - Real-time System Integration
- Superconducting Magnet Technology:**
 - Cold Technology
 - HTS Systems, magnets and current leads
 - HTS Magnet Technology
 - HTS Applications

Large Projects and Infrastructure:

- ITER, Energy 10-150
- ITER-Related Activities: High-Field Laboratories, Cryo Experiments, and Infrastructure, CryoMag, European Fusion Laboratory, Fusion, ITER, ITER-Related Activities

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	FuSuMaTech-6.2-DE-22-V1.0

ANNEX 2 FUTURE FUSUMATECH COLLABORATION REQUEST FOR INFORMATION



FuSuMaTech

**Future FuSuMaTech Collaboration
REQUEST FOR INFORMATION**

Dear Antoine Daël, FuSuMaTech Coordinator,

We Company / Institute
Represented by Mr / Dr
E-mail

have expressed our interest to be invited to the FuSuMaTech Phase 1 Final Workshop. On the basis of the FuSuMaTech Phase 1 results presented at CERN the 1st of April 2019, we confirm our interest for this initiative and our intention to participate to the Phase 2. In that perspective we would like to receive the text of the MoU as soon as the agreement will enter in force.

We hereby acknowledge that we have taken note of the criteria considered for accepting new members.

An applicant to the FuSuMaTech Collaboration must:

- Enjoy a legal status whether as a research institute or a company;
- Be active in the field of superconducting magnet technology;
- Be established in a EU Member State or Horizon 2020 associated country, or in the territory of a CERN Member State or Associate Member State; and
- Express its commitment to join the FuSuMaTech Collaboration.

We indicate only for information our subjects of interest.

- TASK 4.1 *New tools in Quench Analysis*
- TASK 4.2 *New database of Material properties at Cryogenic temperature*
- TASK 4.3 *Smart Diagnostics*
- TASK 4.4 *Heat extraction and cryogen free cryogenics*
- TASK 4.5 *New high stress material at cryogenic temperature*
- TASK 5.1 *MgB2 Technology Demonstrator*
- TASK 5.2 *Frontier hedge High-field 14T/16T concept magnet*
- TASK 5.3 *Investigation of innovative magnetic configurations for emerging MRI applications*
- TASK 5.4 *Technology demonstrator of an HTS insert for HFML*
- TASK 5.5 *Gradient coils technology for High-field MRI, over 10T*

OTHER --

.....

Please return this letter as soon as possible and not later than June 1st 2019:

At The

Signature

Antoine Daël
FuSuMaTech Coordinator
Département des Accélérateurs, de Cryogénie et de Magnétisme



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 Research and Innovation programme under Grant Agreement no. 766974.



ANNEX 3 SIGNED PARTICIPANTS LIST



FuSuMaTech

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PARTICIPANTS LIST



Date of the meeting: 1th of April 2019
 Location of the meeting: CERN GLOBE GENEVA
 Purpose/Title of the Meeting: FuSuMaTech Final Workshop

No.	Last Name	First Name	Organisation	Signature
1	ALESSANDRINI	Matteo	BRUKER Biospin AG	
2	ANELLI	Giovanni	CERN	
3	ANTONIO	Daniela	CERN	
4	ARNDT	Tabea	SIEMENS AG	
5	ATAMERT	Serdar	EPOCH WIRES	
6	AUCHMANN	Bernhard	CERN / PSI	
7	AYASS	Myriam	CERN	
8	BALARINO	Amalia	CERN	
9	BATES	Steve	TESLA Engineering Ltd	
10	BAUDOUY	Bertrand	CEA	
11	BAUER	Markus	THEVA Dünnschichttechnik GmbH	
12	BENEDIKT	Michael	CERN	



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No.	Last Name	First Name	Organisation	Signature
13	BENHABILES	Nora	CEA	
14	BOCIAN	Dariusz	Institute of Nuclear Polish Academy of Science	
15	BOFFO	Christian	BILFINGER NOELL GmbH	
16	BORDRY	Frederick	CERN	
17	BOTTURA	Luca	CERN	
18	BOUNAB	Ayoub	CEA	
19	BRESCHI	Marco	University of Bologna	
20	BRIET	Philippe	CEA	
21	CALCOEN	Daniel	CERN	
22	CANFER	Simon	STFC	
23	CHAUD	Xavier	CNRS-LNCMI	
24	CHOMAZ	Philippe	CEA	
25	CIRILLI	Manuela	CERN	
26	CUTHBERT	Michael	Oxford Instruments	
27	DAËL	Antoine	CEA	
28	DE RIJK	Gijs	CERN	
29	DEBRAY	François	CNRS-LNCMI	

2

30	DECROIX	Gaëlle	CEA	
31	DHULST	Chris	BEKAERT	
32	DOLS	Han Hubert	CERN	
33	DUDAREV	Alexey	CERN	
34	EKELOF	Tord	Uppsala University (SE)	
35	ETIENVRE	Anne-Isabelle	CEA	
36	FABBRICATORE	Pasquale	INFN-Genova	
37	FELBLINGER	Jacques	INSERM-University of Lorraine	
38	FOREST	Frederick	SIGMAPHI	
39	GARCIA	Angel	ELYTT ENERGY	
40	GEHRING	Michael	BILFINGER NOELL GmbH	
41	GENESTIER	Thibault	General Electric	
42	GILGRASS	Graham	AIMANT Ltd	
43	GRILLI	Francesco	KIT	
44	GUTLEBER	Johannes	CERN	
45	HAMOUDI	Bettina	CERN	
46	HAUG	Friedrich	BMBF Germany, ILO at CERN	

3



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FuSuMaTech-6.2-DE-22-V1.0



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48	ITURBE	Rafael	ANTEC Magnets S.L.U	
49	JIMENEZ	Jose Miguel	CERN	
50	KAUTTU	Pietari	Helsinki Institute of Physics	
51	KIRBY	Glyn	CERN	
52	KRETSCHMAR	Linn	WU Vienna	
53	LADD	Mark	German Cancer Research Center (DKFZ)	
54	LAGRANGE	Thierry	CERN	
55	LANCELOT	Jean-Luc	SIGMAPHI	
56	LE BIHAN	Denis	CEA	
57	LECREVISSE	Thibault	CEA	
58	LEIGH	Ben	TESLA Engineering Ltd	
59	LEMAITRE	Estelle	CEA	
60	LERAY	Sylvie	CEA	
61	LERMAN	Cécile	CEA	
62	LUCAS	Julio	ELYTT ENERGY	
63	McCUTCHEON	Patrick	European Commission	

4



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No.	Last Name	First Name	Organisation	Signature
64	MELHEM	Ziad	Oxford Instruments	
65	MOLINIÉ	Frederic	CEA	
66	PELLECCHIA	Antonio	ASG Superconductors	
67	PEPITONE	Kevin	Uppsala University (SE)	
68	PEREZ-MORALES	Jose Manuel	CIEMAT	
69	PESCE	Florence Olivia	CERN	
70	POLO RUBIALES	Maria Luisa	CERN	
71	PUGNAT	Pierre	CNRS-LNCMI	
72	QUETTIER	Lionel	CEA	
73	RIKKEN	Geert	CNRS	
74	RILEY	Chris	DASSAULT Systemes UK Ltd	
75	RIVKIN	Lenny	PSI	
76	ROSSI	Lucio	CERN	
77	ROUX	Sylvain	CEA	
78	RUSCONI	Barbara	CERN	
79	SANFILIPPO	Stephane	PSI	
80	SCHILD	Thierry	ITER	

5



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FuSuMaTech-6.2-DE-22-V1.0



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83	SENE	Angele	CEA	<i>AS</i>
84	SIEMKO	Andrzej	CERN	<i>A. Siemko</i>
85	SIMON	Charles	CNRS-LNCMI	<i>Ch. Simon</i>
86	SORBI	Massimo	INFN-LASA Milano	<i>Massimo S.</i>
87	SPELLER	Susie	University of Oxford	<i>S. Speller</i>
88	STAVREV	Svetlomid	CERN	<i>S. Stavrev</i>
89	STENVALL	Antti Aleksis	Tampere University of Technology	<i>Antti Savol</i>
90	TEN KATE	Herman	CERN	
91	THIELLAND	Elisa Delphine	INP-Grenoble	<i>Thielland</i>
92	TIXADOR	Pascal	INP-Grenoble	<i>Tixador</i>
93	VAN NUGTEREN	Jeroen	CERN	
94	VEDRINE	Pierre	CEA	<i>Vedrine</i>
95	VIEWEG	Mikael	SCANDITRONIX Magnet AB	<i>Vieweg</i>
96	VRETENAR	Maurizio	CERN	<i>Vretenar</i>
97	VUISSOZ	Pierre-André	University of Lorraine	<i>Vuissouz</i>

6



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No.	Last Name	First Name	Organisation	Signature
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99	WILSON	Martin	MNW Consulting	<i>Wilson</i>
100	BERRIAUD	christophe	CEA	<i>Berriaud</i>
101	RUBER	Roger	Uppsala Univ	<i>Ruber</i>
102				
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