FuSuMaTech

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

	Edited by	***Reviewed by***		***Approved by***
Name	Han Dols	Sylvain Roux		Antoine Daël
Functions	WP6 Leader (CERN)	Project Manager (CEA)		Project Coordinator (CEA)
Date and visas	5/04/2019	15/04/2019		15/04/2019

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		
FuSuMaTech Project	Project Reference	N° 766974
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	EC Project Officer	Adriana GODEANU-METZ

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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 extend these can be publically shared and not covered in the other WP reports.

2. FINAL WORKSHOP

2.1 INVITATION

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

	8 - POSTER SESSION (10 R&D&I / Technology demonstrator Subjects)		
14:00		*80-1-001 - Globe of Science and Innovation - 1st Floor, CERN*	13:30 - 14:30
	9 - High Field Magnet Development at CERN and potential role of FuSuMaTech	*Luca Bottura*	
	12 - MRI in the Era of Future's Medicine and Status of ISEULT Project	*Denis Le Bihan*	
15:00		*80-1-001 - Globe of Science and Innovation - 1st Floor, CERN*	14:45 - 15:15
	15 - Applied Superconductivity in Europe (a retired spectator's view)	*Martin Wilson*	
	10 - Message of the ESAS chair	*Bernhard Holzapfel*	
	13 - Conclusion and Final Address	*Philippe CHOMAZ*	
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 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
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#65	Cristian Boffo	Bilfinger Noell GmbH
#63	Michael Gehring	Bilfinger Noell GmbH
#79	Friedrich Haug	BMBF Germany, ILO at CERN
#4	Matteo Alessandrini	Bruker BioSpin AG
#76	Klaus Schlenga	Bruker EST
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#87	Amalia Ballarino	CERN
#88	Michael Benedikt	CERN
#30	Frédérick Bordry	CERN
#59	Luca Bottura	CERN
#78	Daniel Calcoen	CERN
#32	Manuela Cirilli	CERN
#13	Gijs De Rijk	CERN
#33	Han Hubert Dols	CERN
#20	Alexey Dudarev	CERN
#52	Johannes Gutleber	CERN
#1	Bettina Hamoudi	CERN
#8	Jose Miguel Jimenez	CERN
#7	Glyn Kirby	CERN
#16	Thierry Lagrange	CERN
#46	Florence Olivia Pesce	CERN
#22	Lucio Rossi	CERN
#69	Barbara Rusconi	CERN
#44	Andrzej Siemko	CERN
#38	Svetlomir Stavrev	CERN
#5	Herman Ten Kate	CERN
#96	Elisa Delphine Thielland	CERN
#90	Jeroen Van Nugteren	CERN
#26	Maurizio Vretenar	CERN
#55	Bernhard Auchmann	CERN/PSI
#14	Geert Rikken	CNRS
#99	Charles Simon	CNRS
#66	Francois Debray	CNRS -LNCMI
#68	Chris Riley	Dassault Systemes UK Ltd
#41	Angel Garcia	ELYTT ENERGY
#70	Julio Lucas	ELYTT Energy
#93	Serdar Atamert	Epoch Wires
#36	Patrick McCutcheon	European Commission
#74	Thibault Genestier	General Electric
#81	Mark Ladd	German Cancer Research Center (DKFZ)
#61	Pascal Tixador	Grenoble-INP
#34	Pietari Kauttu	Helsinki Institute of Physics (FI)
#18	Pasquale Fabbricatore	INFN e Universita Genova (IT)
#97	Jacques FELBLINGER	INSERM - Université de Lorraine
#6	Dariusz Bocian	Institute of Nuclear Physics Polish Academy of…
#62	Anne-Isabelle Etienvre	IRFU
#29	Thierry Schild	Iter
#49	Francesco Grilli	Karlsruhe Institute of Technology
#24	Bernhard Holzapfel	KIT
#71	Klaus-Peter Weiss	KIT, Institute for Technical Physics
#86	Pierre Pugnat	Lab. des Champs Magnet. Intenses (FR)
#11	Xavier CHAUD	Laboratoire National des Champs Magnétiques…
#9	Martin Wilson	MNW Consulting
#53	Denis Le Bihan	NeuroSpin/CEA
#23	Michael Cuthbert	Oxford Instruments
#37	Ziad Melhem	Oxford Instruments
#10	stephane sanfilippo	Paul Scherrer Institut
#43	Lenny Rivkin	Paul Scherrer Institut (CH)
#73	Mikael Vieweg	Scanditronix Magnet AB
#72	Simon Canfer	Science and Technology Facilities Council STF…

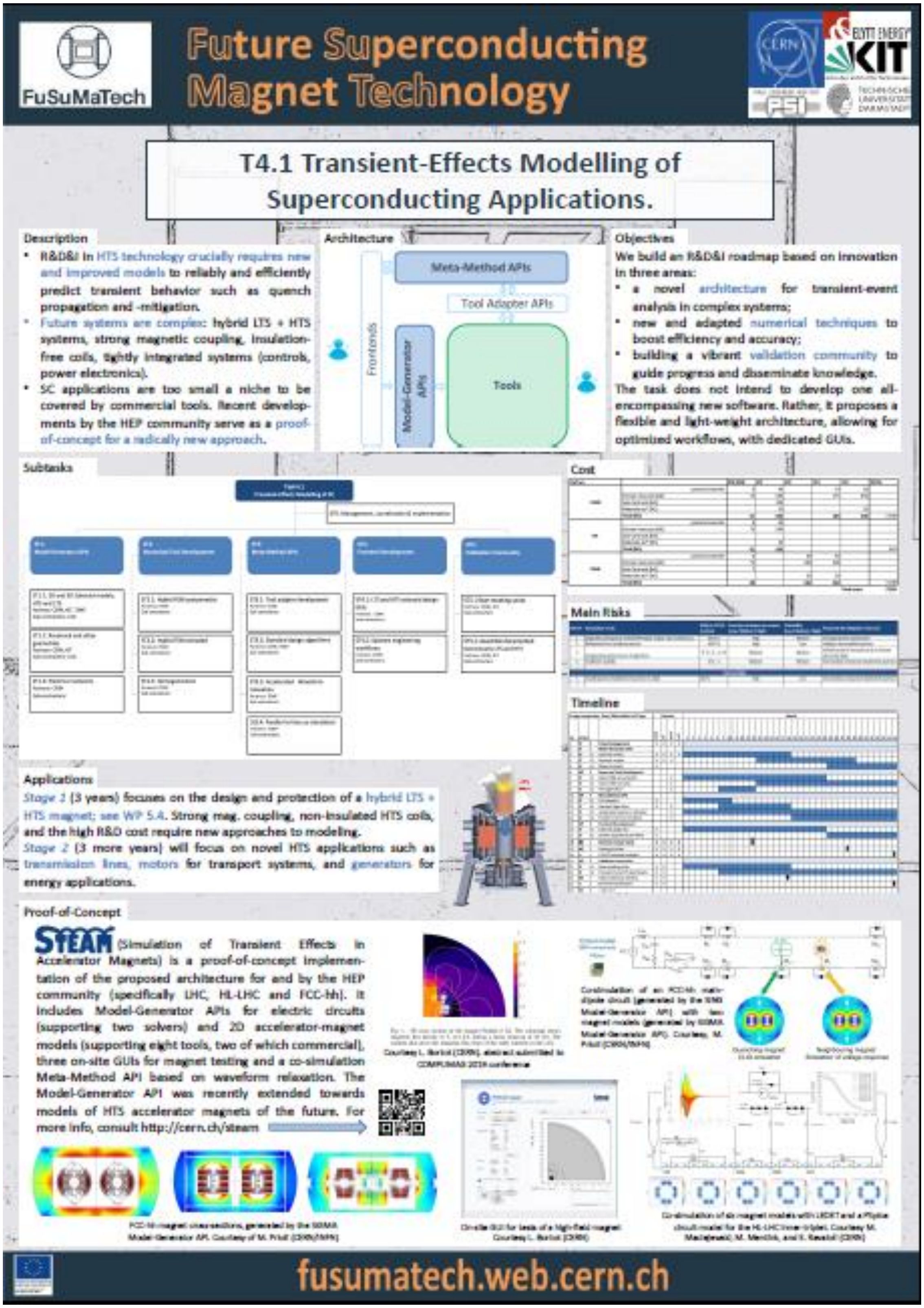
	#12	Frederick Forest	SIGMAPHI
	#48	Jean luc Lancelot	Sigmaphi
	#42	Antti Aleksis Stenvall	Tampere University of Technology
	#77	Ben Leigh	Tesla Engineering Ltd
	#40	Steve Bates	Tesla Engineering Ltd.
	#80	Markus Bauer	THEVA Dünnschichttechnik GmbH
	#83	Maria Luisa Polo Rubiales	Universite de Geneve (CH)
	#98	Marco Breschi	University of Bologna
	#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 Kretzschmar	WU Vienna

2.6 PICTURES


FuSuMaTech
ASG SUPERCONDUCTORS SPA

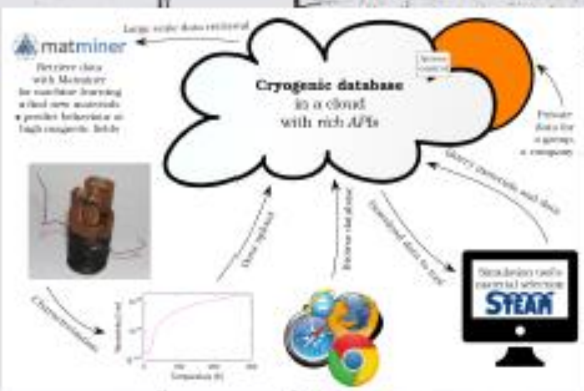

FuSuMaTech
CERN

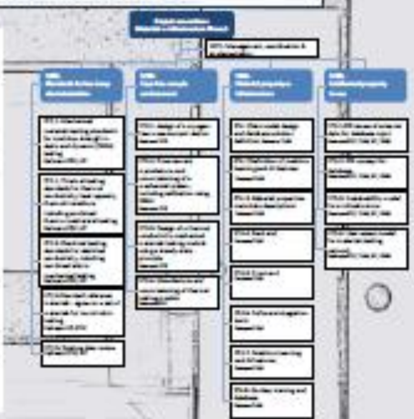
2.7 POSTER SESSION PRESENTATION



Future Superconducting Magnet Technology

T4.2 Materials e-infrastructure





A new database of materials properties at cryogenic temperature

Partners: STFC, KIT, CERN, TUNI (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 import 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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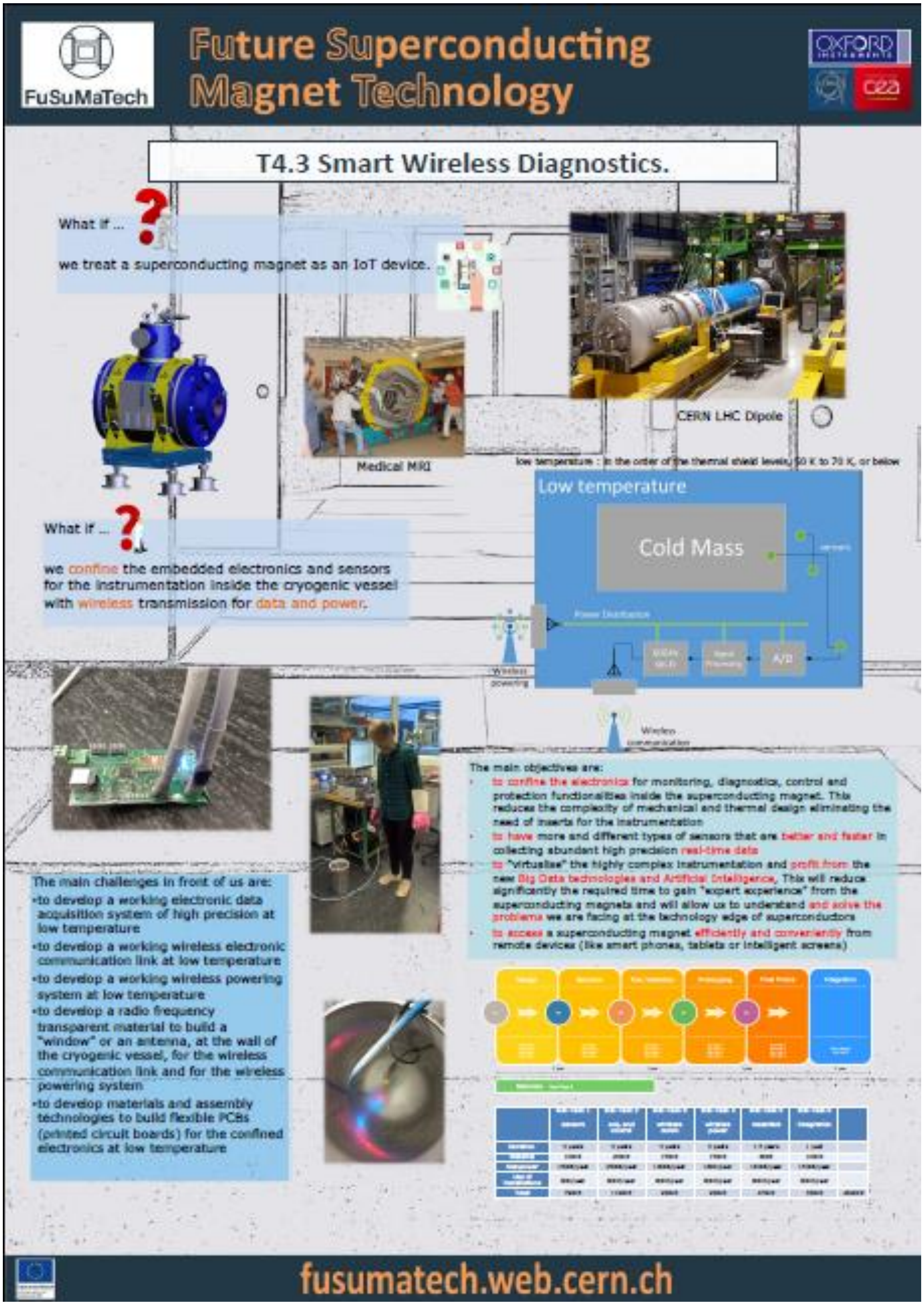
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OXFORD INSTRUMENTS
cea
T4.3 Smart Wireless Diagnostics.
What if ...
we treat a superconducting magnet as an IoT device.
Medical MRI
CERN LHC Dipole
What if ...
we confine the embedded electronics and sensors for the instrumentation inside the cryogenic vessel with wireless transmission for data and power.
Low temperature
Cold Mass
A/D
Wireless powering
Wireless communication
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)
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
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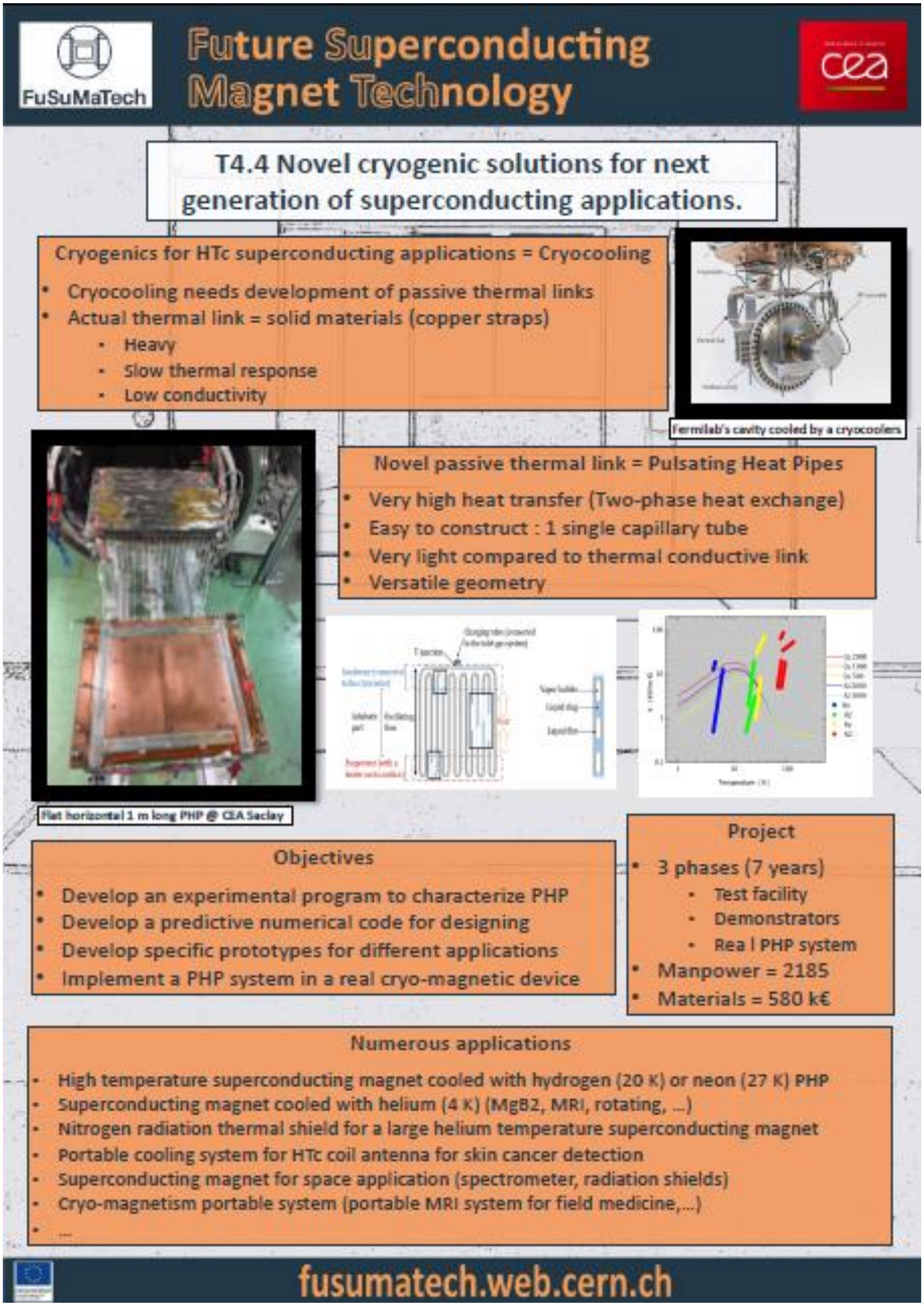
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T4.4 Novel cryogenic solutions for next generation of superconducting applications.
Cryogenics for HTc superconducting applications = Cryocooling
• Cryocooling needs development of passive thermal links
• Actual thermal link = solid materials (copper straps)
• Heavy
• Slow thermal response
• Low conductivity
Fermilab's cavity cooled by a cryocoolers
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
Flat horizontal 1 m long PHP @ CEA Saclay
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
• Rea l 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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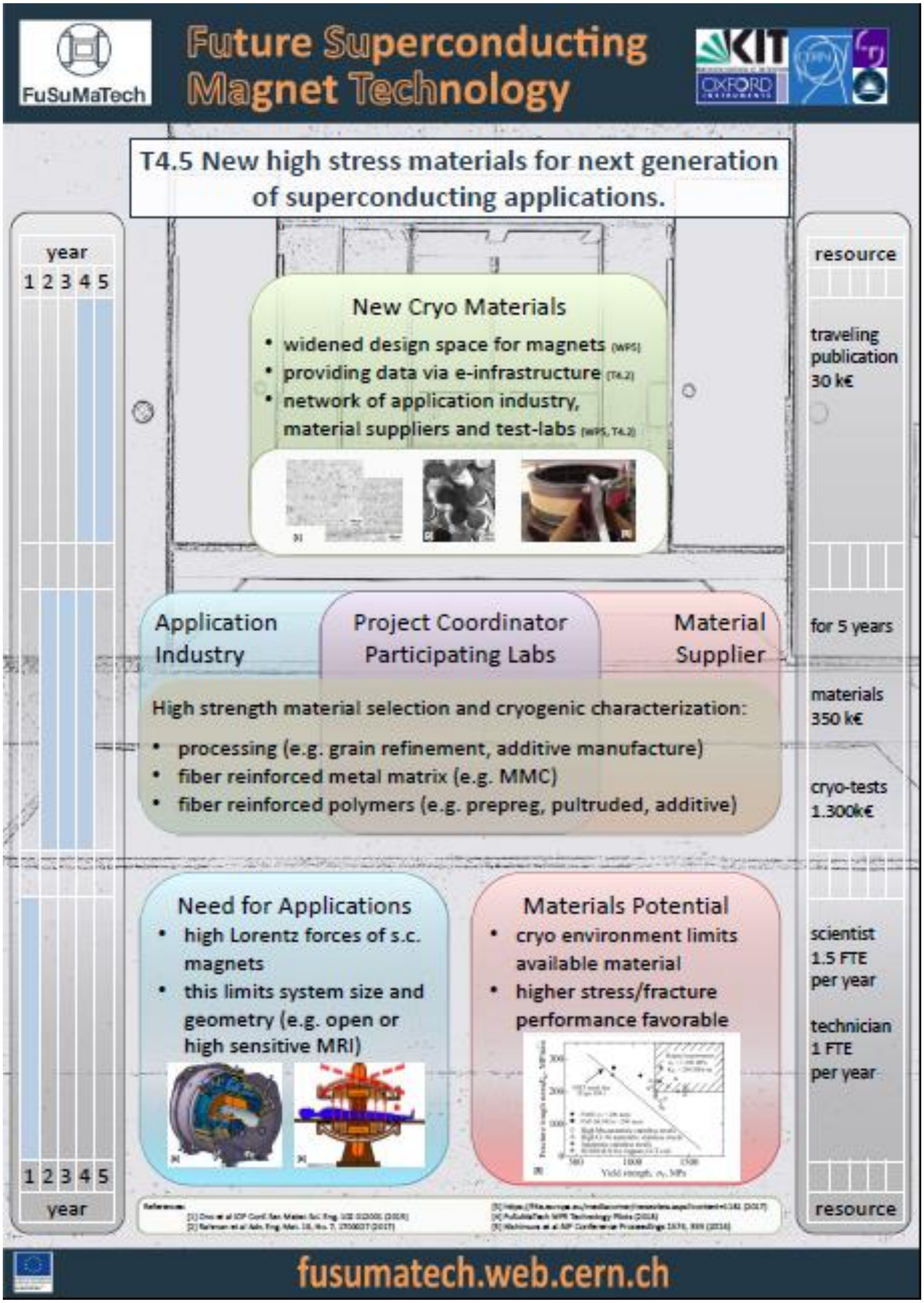
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KIT
OXFORD
T4.5 New high stress materials for next generation of superconducting applications.
year
1 2 3 4 5
New Cryo Materials
• widened design space for magnets (WP5)
• providing data via e-infrastructure (T4.2)
• network of application industry, material suppliers and test-labs (WP5, T4.2)
resource
traveling publication 30 k€
for 5 years
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)
materials 350 k€
cryo-tests 1.300k€
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
Yield strength, σ_y, MPa
scientist 1.5 FTE per year
technician 1 FTE per year
1 2 3 4 5
year
resource
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T5.1 MgB2 Demonstrator

Normal conducting gantry built at Heidelberg for cancer treatment with ion carbon

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 – 9T
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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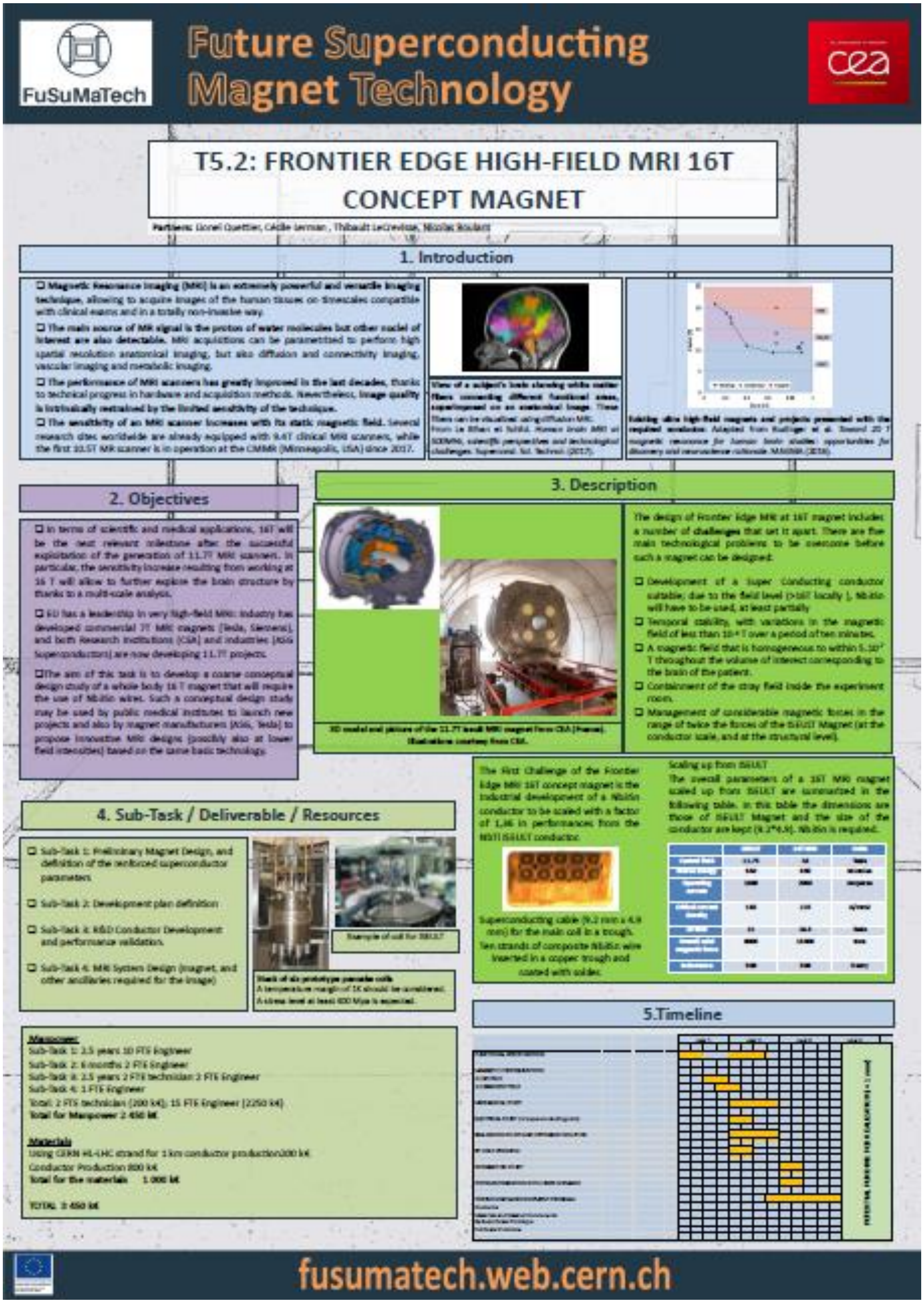
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T5.2: FRONTIER EDGE HIGH-FIELD MRI 16T CONCEPT MAGNET
1. Introduction
2. Objectives
3. Description
The design of Frontier Edge MRI at 16T magnet includes a number of challenges that set it apart. There are five main technological problems to be overcome before such a magnet can be designed.
Containment of the stray field inside the experiment room.
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 ancillaries required for the image)
Total for Manpower 2 450 k€
Total for the materials 1 000 k€
TOTAL 3 450 k€
5.Timeline
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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.

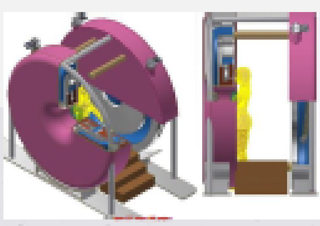
A dedicated software for solenoid field quality optimization has been developed and tested.

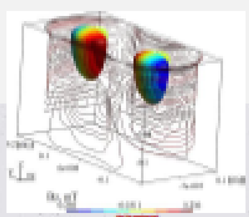
A few results of the test runs were evaluated, although they are not intended at all as the proposed solutions. Nevertheless, the results already indicate the direction of further research in the domain of the open MRI system and the mammo-magnet. The latter application seems more feasible than the former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

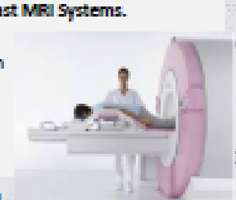
New Magnet Technology for a 1.5 T Open-MRI Breast Imager





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 5.3.	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 €

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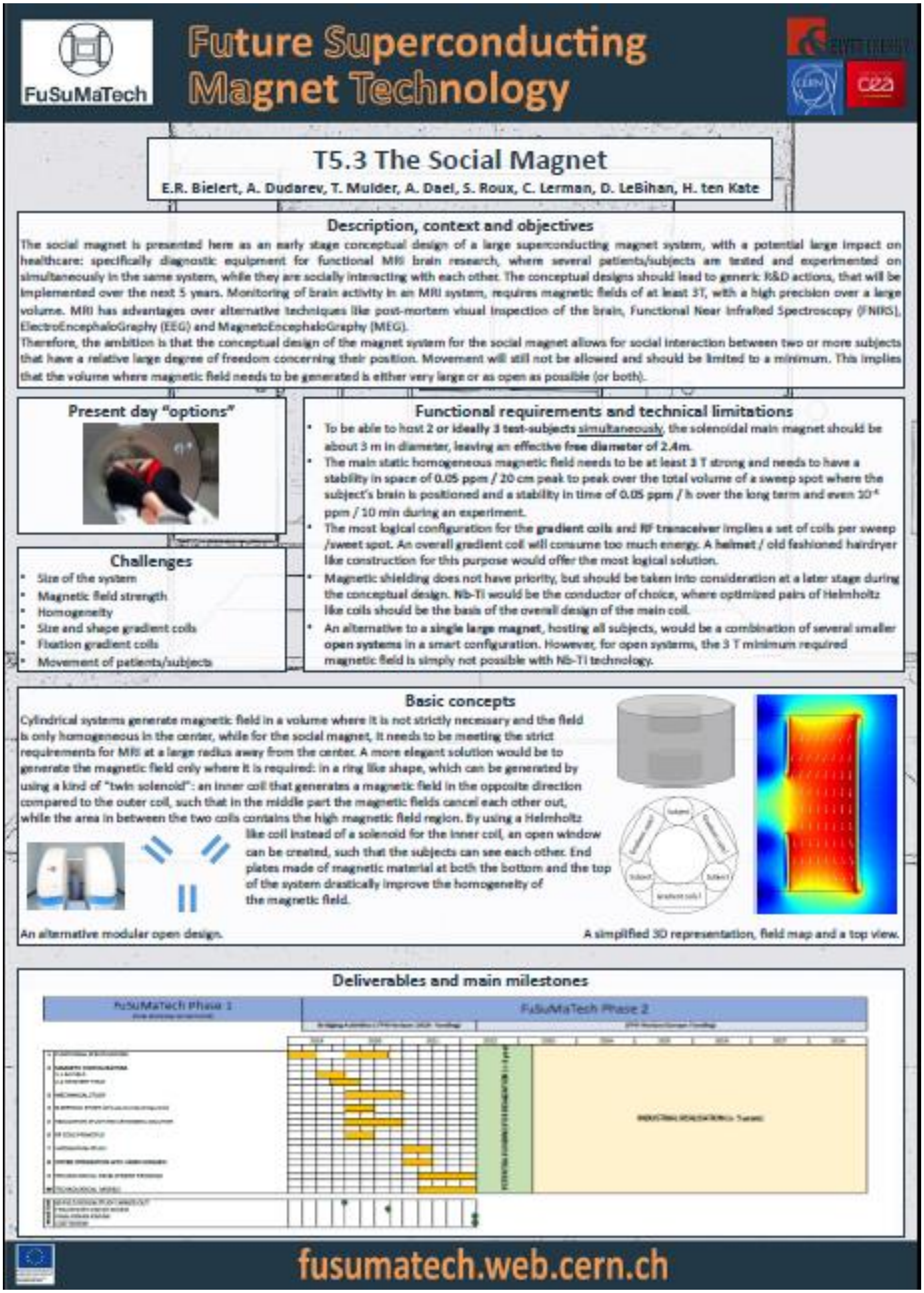
FuSuMaTech
Future Superconducting Magnet Technology
T5.3 The Social Magnet
E.R. Bielert, A. Dudarev, T. Mulder, A. Dael, S. Roux, C. Lerman, D. LeBihan, H. ten Kate
Description, context and objectives
The social magnet is presented here as an early stage conceptual design of a large superconducting magnet 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"
Challenges
Size of the system
Magnetic field strength
Homogeneity
Size and shape gradient coils
Fixation gradient coils
Movement of patients/subjects
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 /sweet 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.
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
FuSuMaTech Phase 1
FuSuMaTech Phase 2
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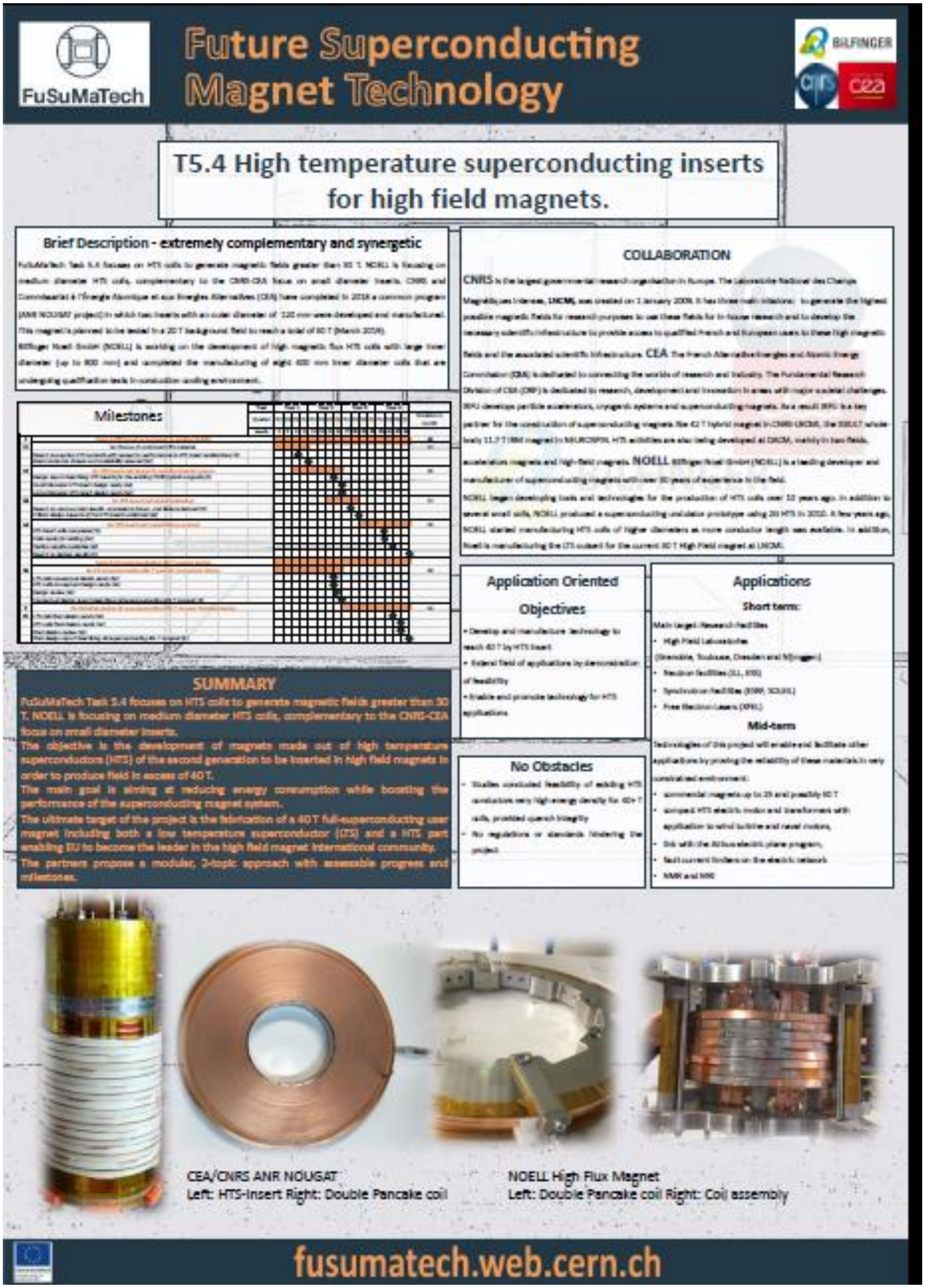
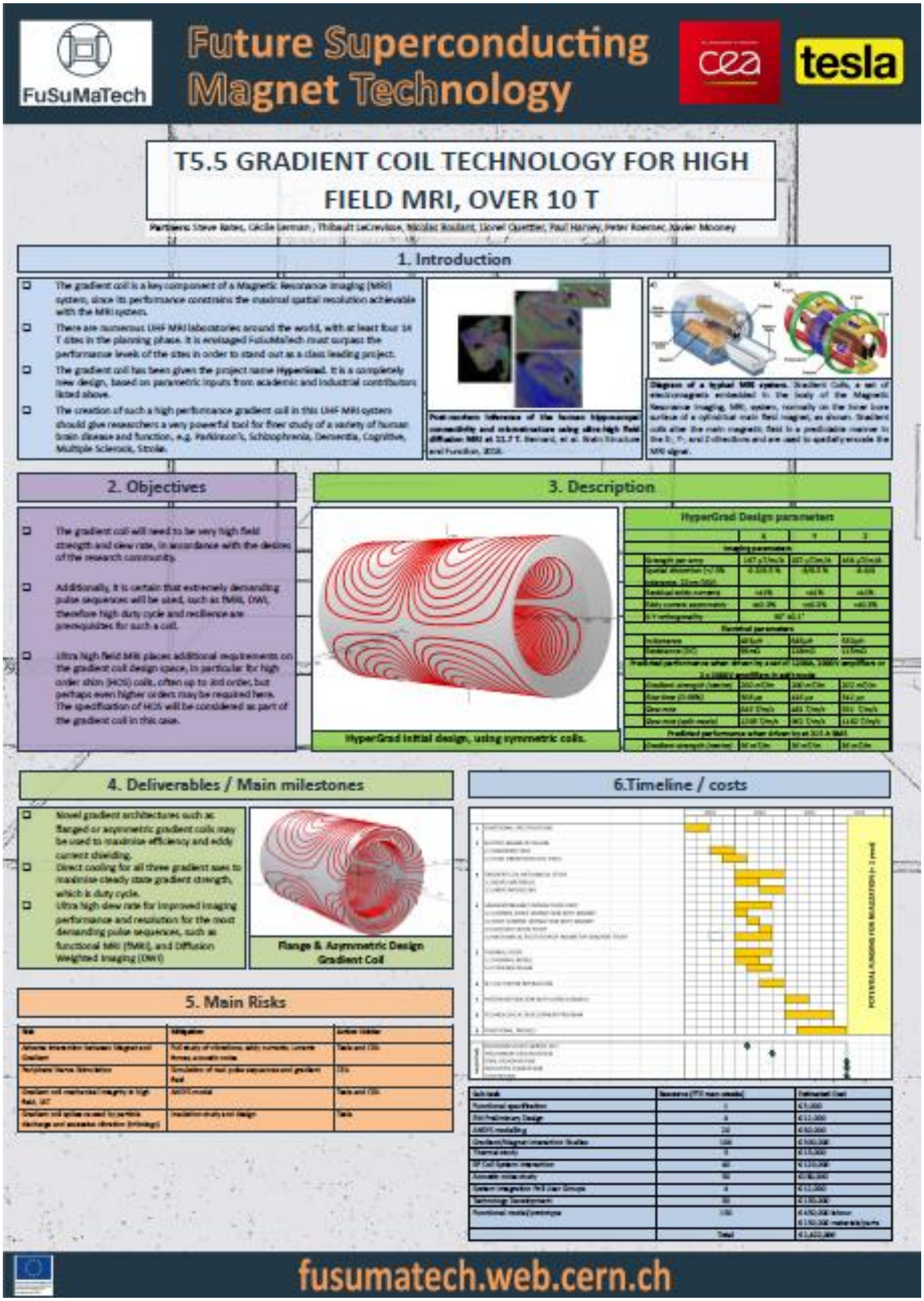

FuSuMaTech
Future Superconducting Magnet Technology
BILFINGER
cea
T5.4 High temperature superconducting inserts for high field magnets.
Brief Description - extremely complementary and synergetic
Milestones
COLLABORATION
Application Oriented Objectives
Applications
Short term:
Mid-term
No Obstacles
SUMMARY
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 EU to become the leader in the high field magnet international community.
The partners propose a modular, 2-topic approach with assessable progress and milestones.
CEA/CNRS ANR NOUGAT
Left: HTS-insert Right: Double Pancake coil
NOELL High Flux Magnet
Left: Double Pancake coil Right: Coil assembly
fusumatech.web.cern.ch


FuSuMaTech
Future Superconducting Magnet Technology
cea
tesla
T5.5 GRADIENT COIL TECHNOLOGY FOR HIGH FIELD MRI, OVER 10 T
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 UHF MRI laboratories around the world, with at least four 14 T 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 UHF MRI system should give researchers a very powerful tool for finer study of a variety of human brain disease and function, e.g. Parkinson's, Schizophrenia, Dementia, Cognitive, Multiple Sclerosis, Stroke.
2. Objectives
The gradient coil will need to be very high field strength and slew 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 MRI places additional requirements on the gradient coil design space, in particular for high order shim (HOS) coils, often up to 3rd order, but perhaps even higher orders may be required here. The specification of HOS will be considered as part of the gradient coil in this case.
3. Description
HyperGrad Design parameters
HyperGrad initial design, using symmetric coils.
4. Deliverables / Main milestones
Novel gradient architectures such as flanged or asymmetric gradient coils may be used to maximise efficiency and eddy current shielding.
Direct cooling for all three gradient axes to maximise steady state gradient strength, which is duty cycle.
Ultra high slew 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
5. Main Risks
6.Timeline / costs
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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 partcipated 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.

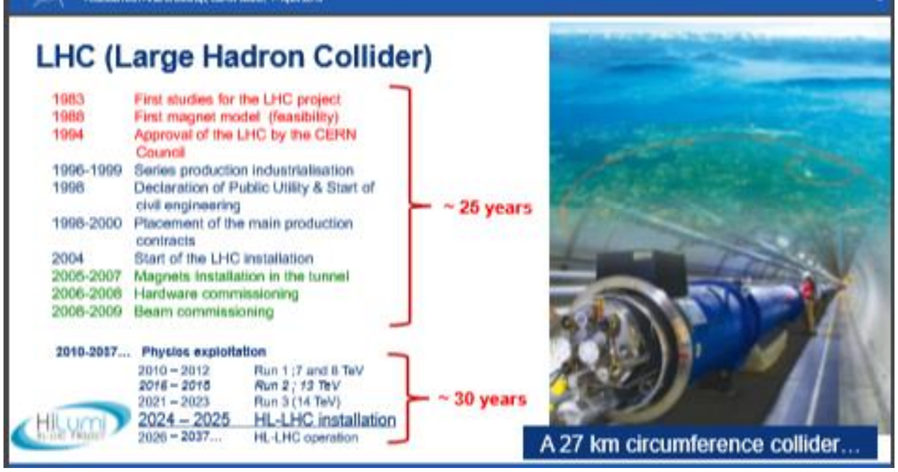
The undersigned hereby express their genuine interest in reaching the signature of the MoU, provided that the text is consistent with all the Parties' expectations.

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

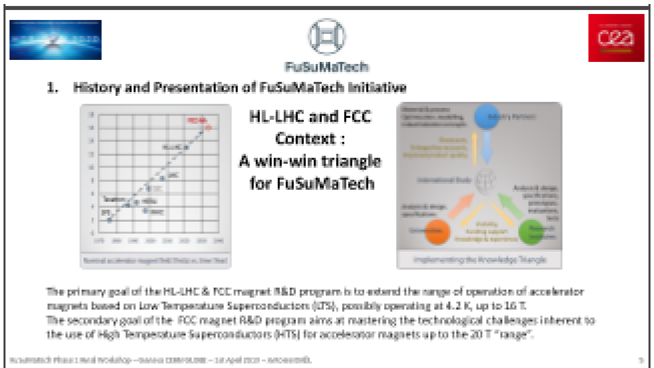
The other interested compagnies, research Institutes or unversities inrested to join the FuSuMaTech Scientific Collaboration have been invited to express this interest by sending a ”REQUEST FOR INFORMATION”. (See ANNEXE 2)
Twenty Five ad hoc forms have been distributed to possible new comers

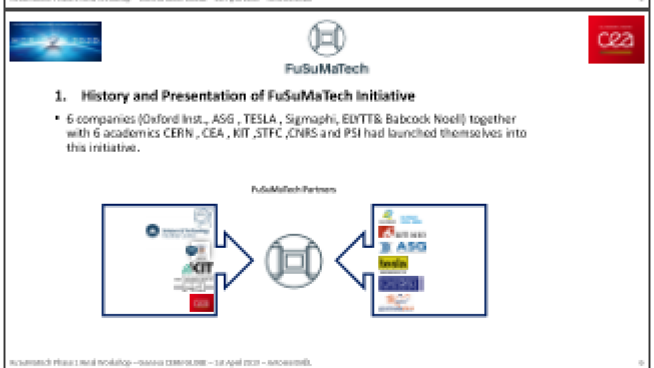
ANNEX 1 SOMES SLIDES FROM PARTICIPANTS PRESENTATIONS

Some slides from presentation by Frederick Bordry:

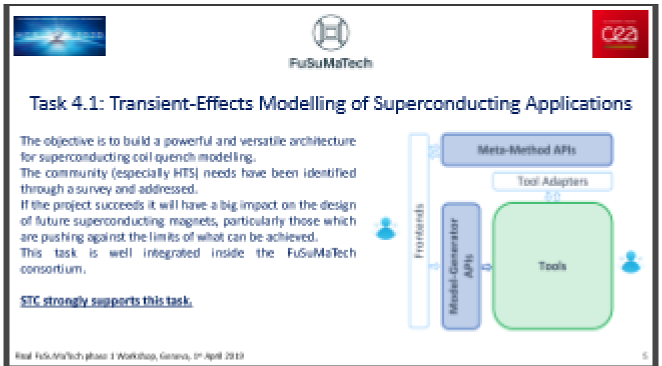


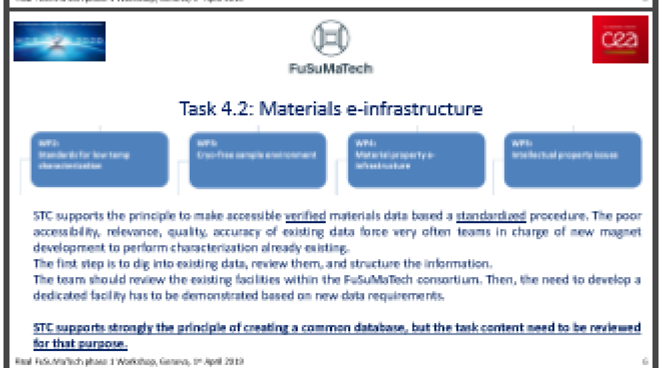
Some slides from presentation by Antoine Dael:

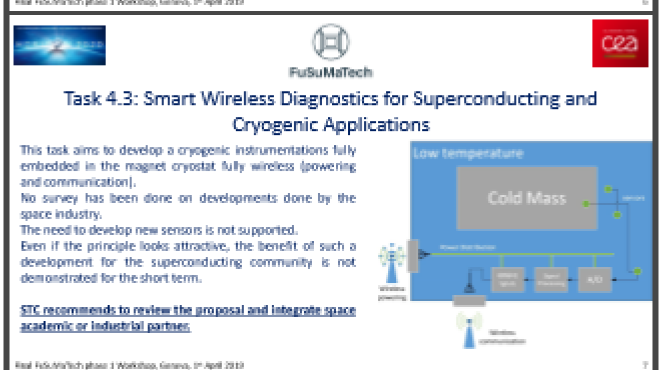


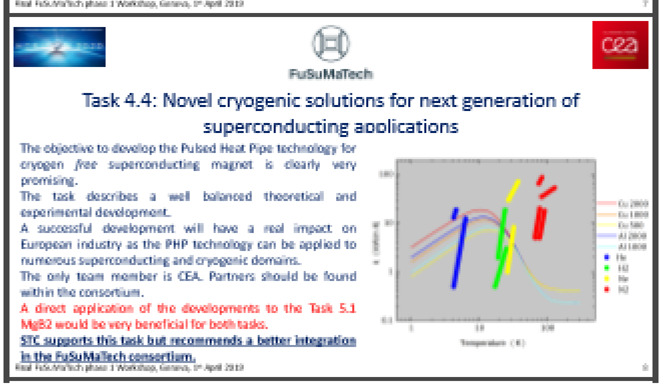


Some slides from presentation by Thierry Schild:

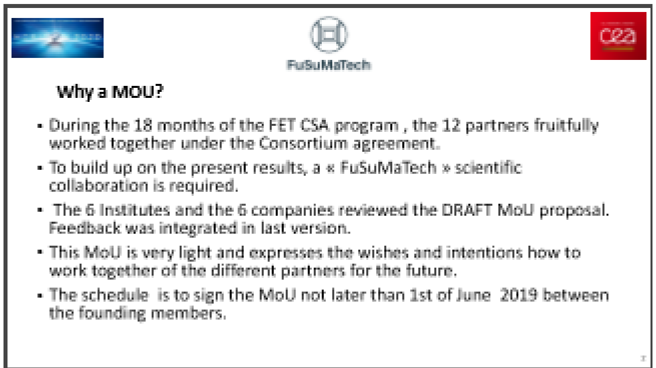


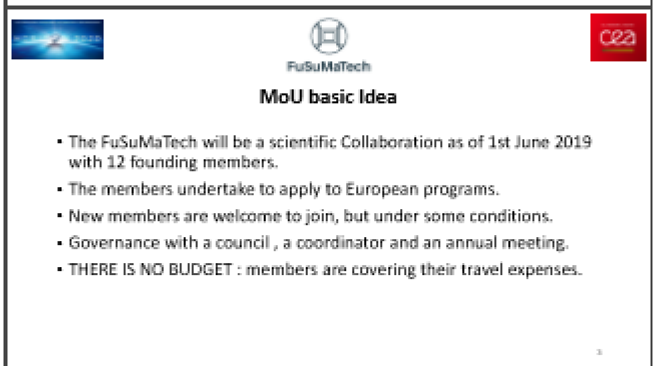


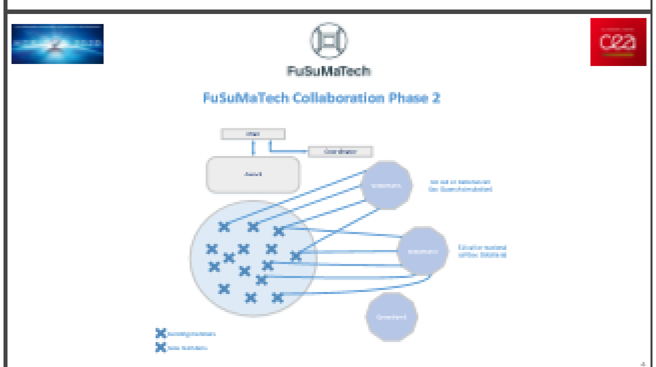


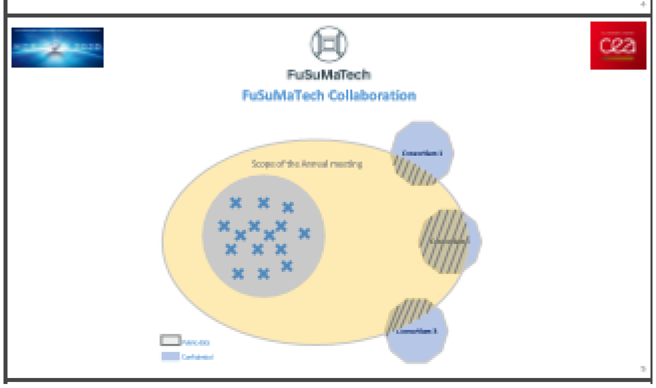


Some slides from presentation by Thierry Lagrange:

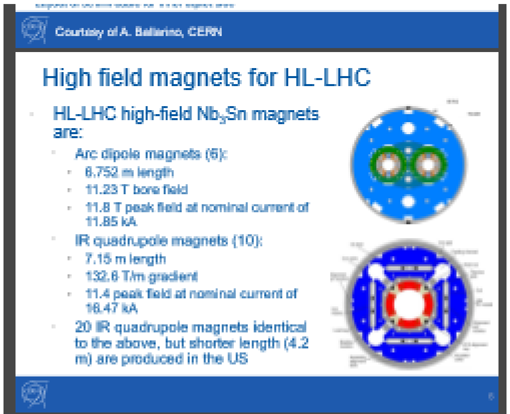


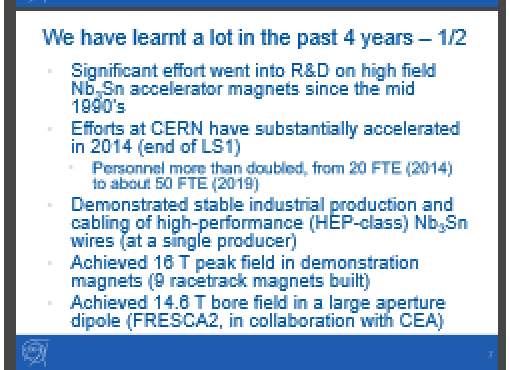


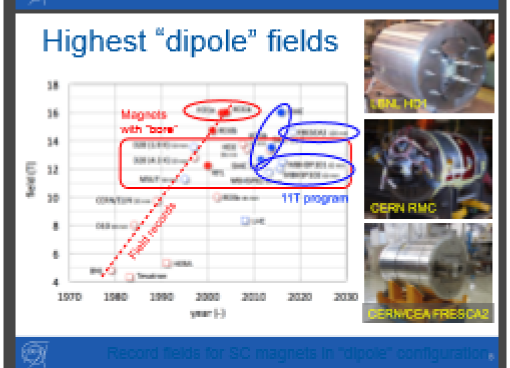


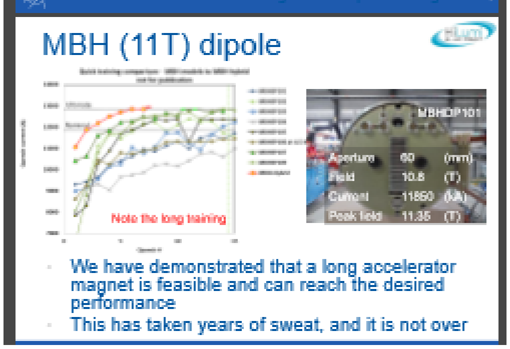


Some slides from presentation by Luca Bottura:

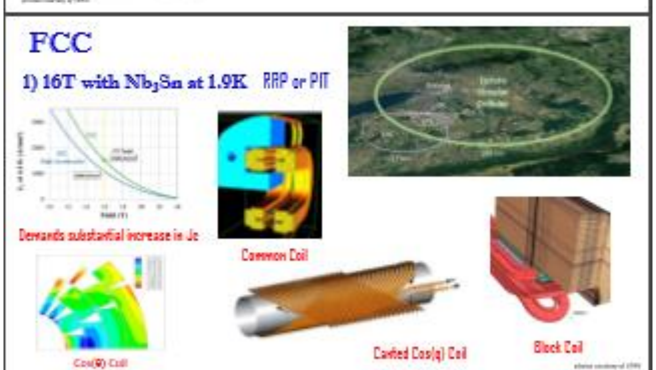


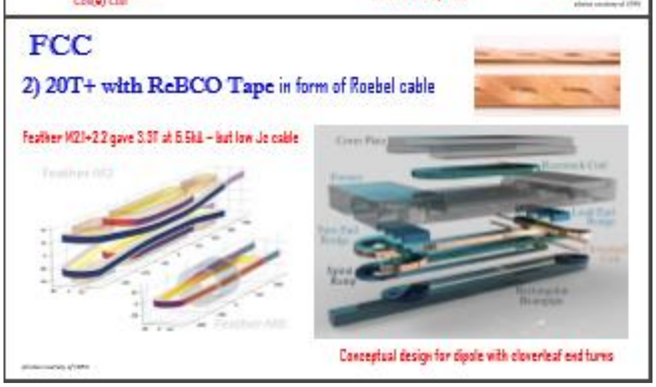




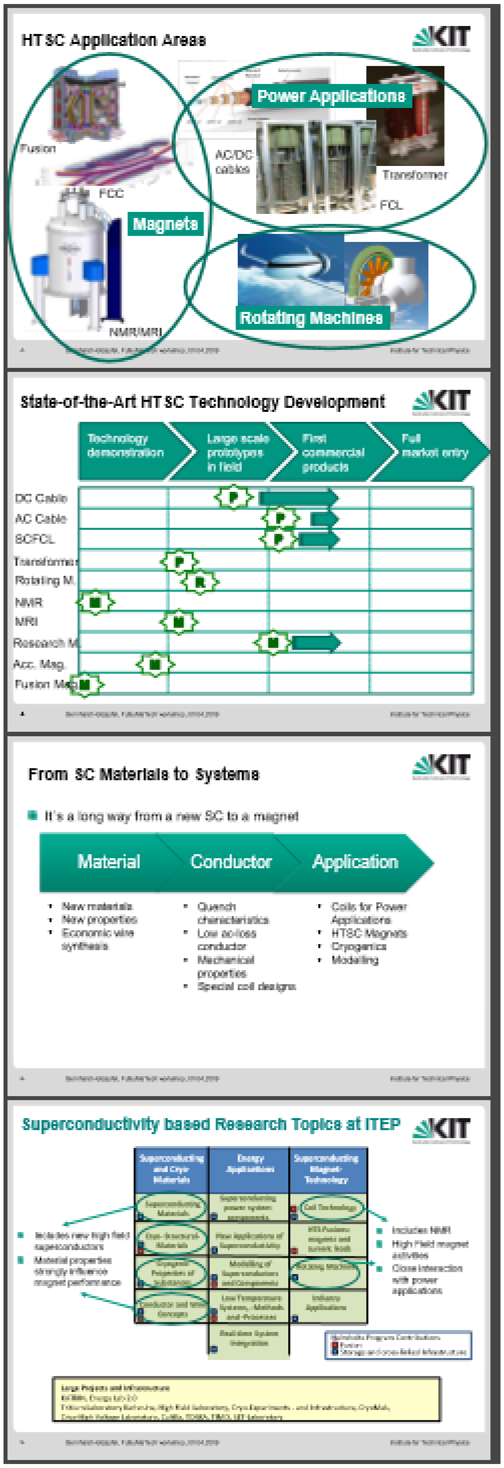


Some slides from presentation by Martin Wilson:





Some slides from presentation by Bernard Holzapfel:



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

CEA Saclay

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This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 766974.

ANNEX 3 SIGNED PARTICIPANTS LIST

FuSuMaTech

FuSuMaTech

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	

1

FuSuMaTech

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

No.	Last Name	First Name	Organisation	Signature
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	Franscesco	KIT	
44	GUTLEBER	Johannes	CERN	
45	HAMOUDI	Bettina	CERN	
46	HAUG	Friedrich	BMBF Germany, ILO at CERN	

3

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No.	Last Name	First Name	Organisation	Signature
47	HOLZAPFEL	Bernhard	KIT	
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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No.	Last Name	First Name	Organisation	Signature
81	SCHLENGA	Klaus	BRUKER EST	
82	SENATORE	Carmine	University of Geneva	
83	SENE	Angele	CEA	
84	SIEMKO	Andrzej	CERN	
85	SIMON	Charles	CNRS-LNCMI	
86	SORBI	Massimo	INFN-LASA Milano	
87	SPELLER	Susie	University of Oxford	
88	STAVREV	Svetlomir	CERN	
89	STENVALL	Antti Aleksis	Tampere University of Technology	
90	TEN KATE	Herman	CERN	
91	THIELLAND	Elisa Delphine	INP-Grenoble	
92	TIXADOR	Pascal	INP-Grenoble	
93	VAN NUGTEREN	Jeroen	CERN	
94	VEDRINE	Pierre	CEA	
95	VIEWEG	Mikael	SCANDITRONIX Magnet AB	
96	VRETENAR	Maurizio	CERN	
97	VUISSOZ	Pierre-André	University of Lorraine	

6

FuSuMaTech

No.	Last Name	First Name	Organisation	Signature
98	WEISS	Klaus-Peter	KIT	
99	WILSON	Martin	MNW Consulting	
100	BERRIAUD	christophe	CEA	
101	Ruber	Roger	Uppsala Univ	
102				
103				
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