FCC Synergy with Industry and the Impact on the Future Superconducting Magnet Technologies

Antoine DAËL

Ad hoc Working Group

Future Superconducting Magnet Technology

FuSuMaTech

FCC week Rome Wednesday the 13th of April 2016

HL-LHC and FCC context

- The CERN HL-LHC project and the Future Circular Collider (FCC) will result in a big push in the state of the art of High-Field Superconducting magnets.
- Industry is presently experiencing a renewed interest in the field of industrial applications of superconductivity
- HEP has always greatly contributed to Superconducting magnet technology
- In that context , CERN and CEA have created an ad hoc Working Group to explore the synergies with Industrial Companies
- The talk summarizes the first year of activity of the WG,

The FuSuMaTech Working Group , Other Contributors and International experts

I like to warmly thank:

- The working group :T. Schild (CEA Saclay),C. Porcheray (CEA Saclay),G. Kirby (CERN),D. Mazur (CERN)
- Other contributors : Amalia Ballarino (CERN), Pierre Vedrine et Philippe Fazilleau (CEA) , Michael Benedikt ,Gijs De Rijk , Svetlomir Starev and Pablo Garcia Tello from CERN.
- International experts
  - Yuki IWASA : meeting in last June
  - Akira YAMAMOTO : meeting in October 2015
  - Denis LE BIHAN (CEA) : meeting on July 9 2015
  - Martin WILSON : February 25 2016 at CERN
  - Graham GILGRASS (Siemens): meeting in May 2015

MANDATE of the ad-hoc Working Group (WG) on Future Superconducting Magnet Technology

Considering the high impact potential of the technology R&D within the efforts on HL-LHC and FCC, the mandate of the ad-hoc WG is:

1) to examine the synergies between on the one hand the **industrial areas of MRI, NMR as well as other relevant applications** and on the other hand the **FCC investments in the technology domains of superconducting magnets**;

2) to demonstrate the benefits of these investments to society;

3) to develop relationships with the European industries concerned;

4) **to propose practical joint R&D actions** to be implemented before the end of the decade.

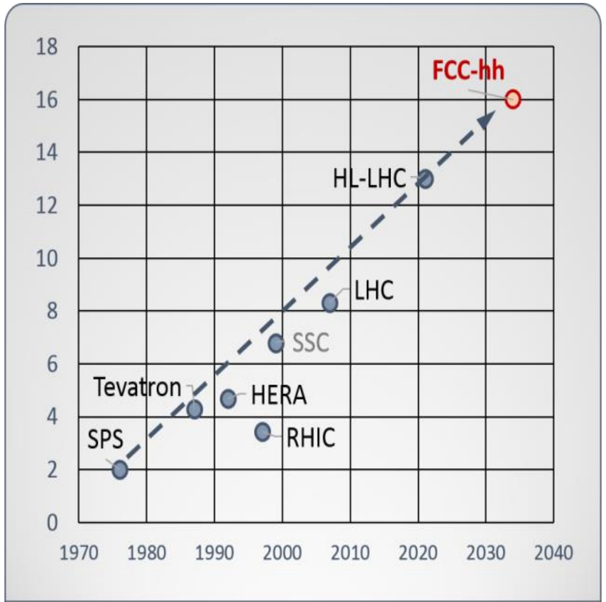
Working Group **on Future Superconducting Magnet Technology**

FuSuMaTech

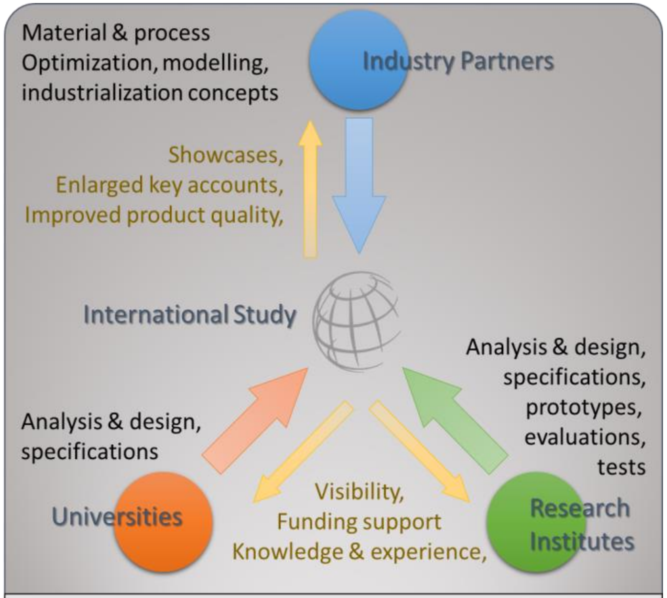
In Japanese traditional architecture , *fusuma* (襖) are vertical rectangular panels which can slide from side to side and act as doors.

So let's open the doors and have the communities working together!

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



Nominal accelerator magnet field [Tesla] vs. time [Year]

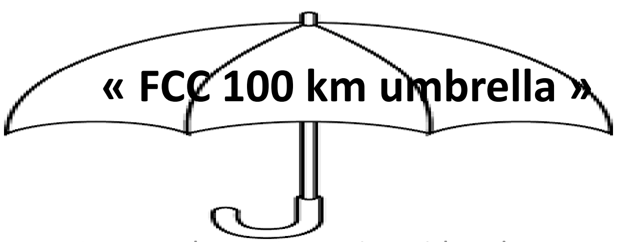


Implementing the Knowledge Triangle

Approach: The primary goal of the 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. A secondary goal aims at mastering the technological challenges inherent to the use of High Temperature Superconductors (HTS) for accelerator magnets up to the 20 T range.

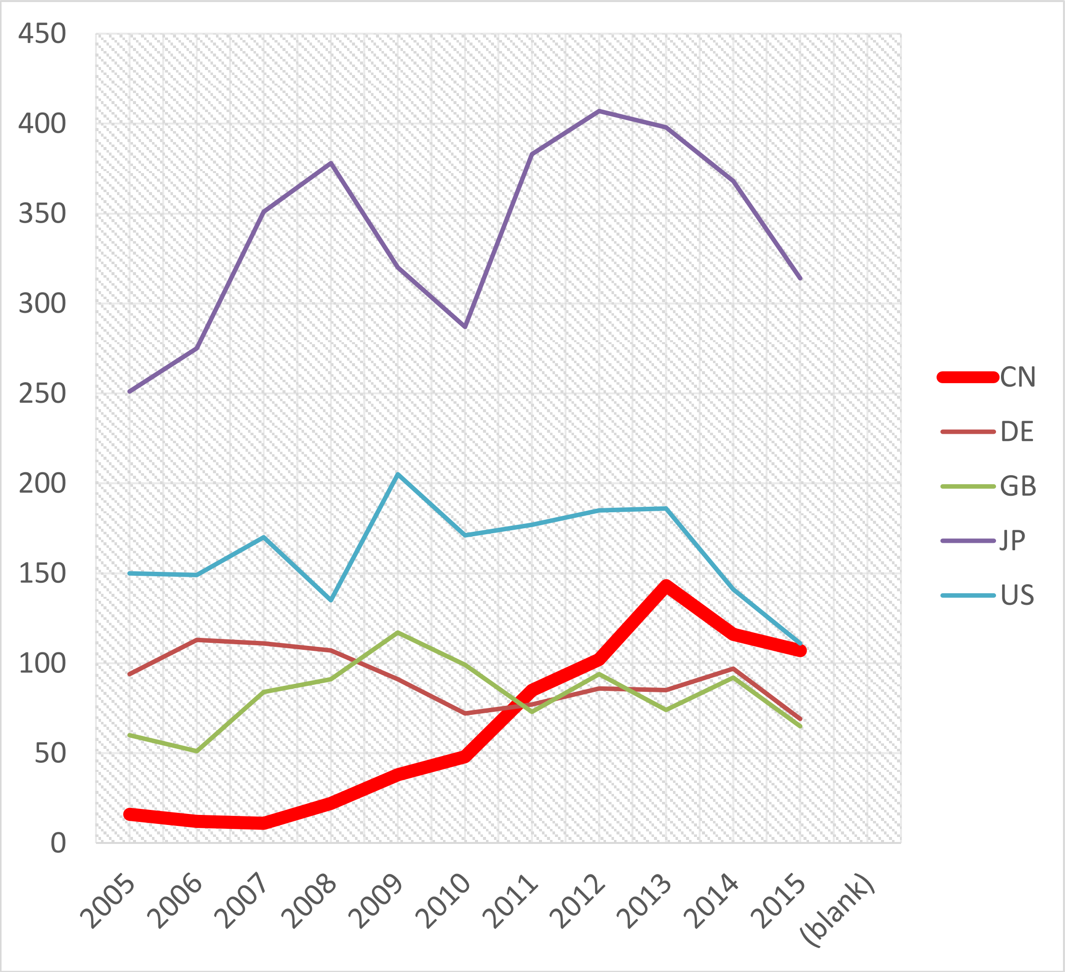
Methodology of FuSuMaTech

1. LOOK at the outside LANDSCAPES with a medium term perspective **of 5 to 7 years**:
   - Patent landscape
   - MRI market landscape
   - NMR landscape
   - Conductor landscape
2. HAVE Industrial contacts and expert interviews
3. DEFINE a set of realistic R&D common actions
4. DEFINE the frame for funding these actions under the



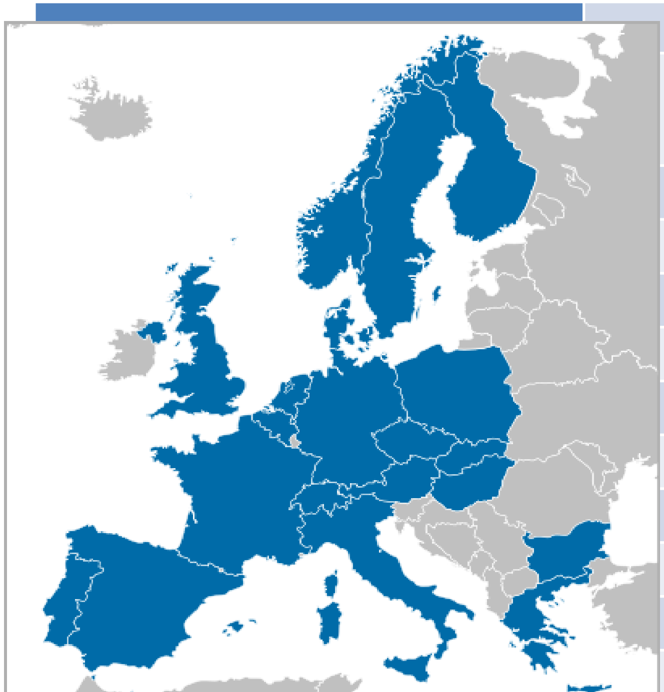
Patent Landscape

- Superconductivity is still a growing field in terms of patenting activity.
- Major increase in patents by Chinese entities
- EU Industry is in good position but should not get asleep



✓ Company Visits in 2015

European Superconducting Magnet Initiative

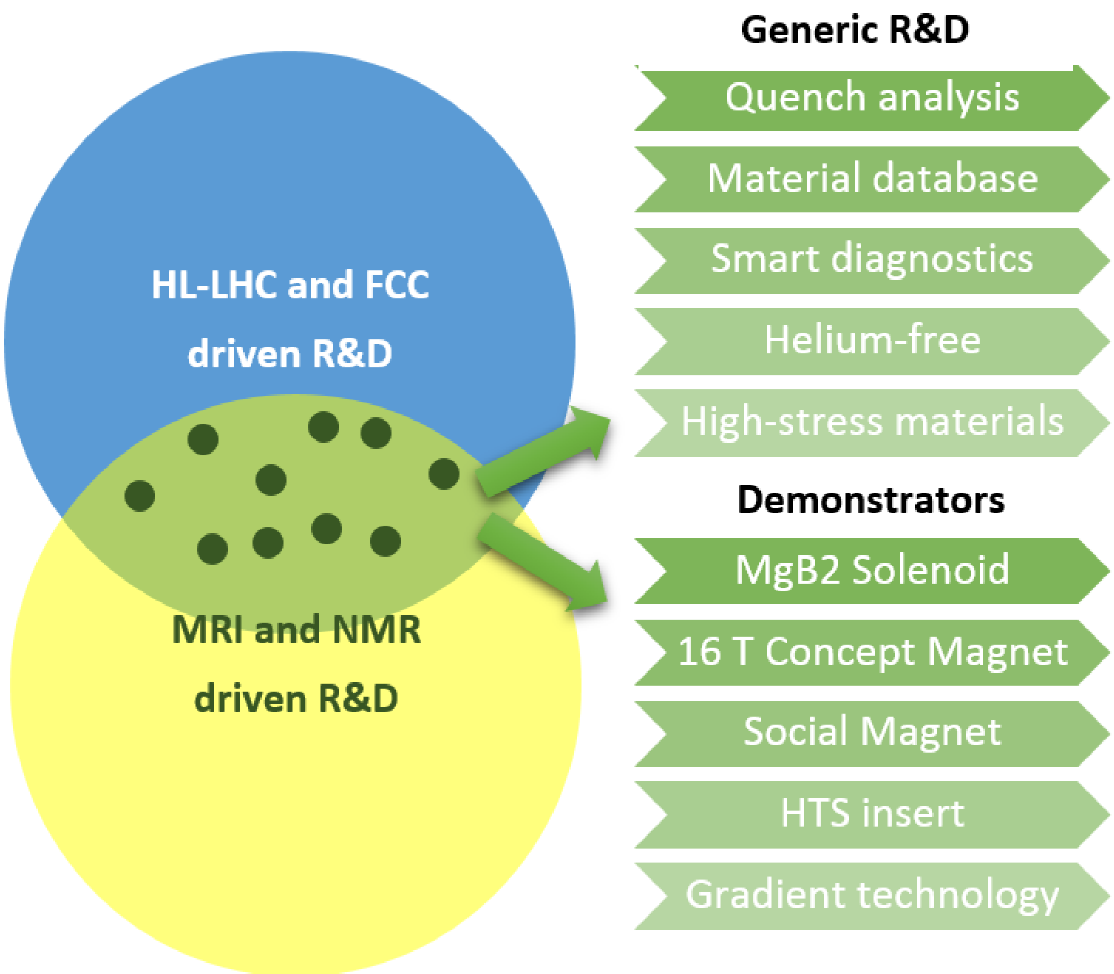


- ✓ Oxford Instruments (UK)
- ✓ Siemens Magnet Technology (UK)
- ✓ Tesla Engineering (UK)
- ✓ Bruker (CH)
- ✓ Alstom (FR) General Electric
- ✓ Columbus (IT)
- ✓ ASG (IT)
- ✓ Sigmaphi (FR)
- ✓ Danfysik (DK)
- Babcock Noell (DE) Planned in Q2 2016
- ✓ Elytt (ES)
- ANTEC (ES) Planned in Q2 2016

What we have asked to companies in year 1

- Welcome an open discussion with the FuSuMaTech WG and offer a visit of their facility.
- Express their interest by writing.
- Fill the Guidelines document which covers :
  - R&D strategy
  - Collaboration Strategy
  - Intellectual Property strategy
  - Open comments

Outcome of the discussions : common actions



WP3. Road mapping

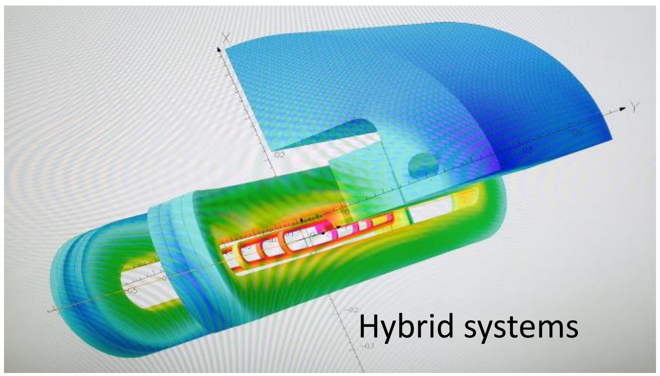
- **TASK 3.1** Elaboration of an R&D&I roadmap with different methodologies (Delphi, scenario analysis, forecasting, etc). The roadmap will take into account scientific, technological and applicability aspects as well as connections of those with societal challenges. Some of the foreseen areas of road mapping are:
- **TASK 3.2** Quench analysis new approach based on new computing capabilities and on multi-physics.
- **TASK 3.3** Large material properties database at Cryogenic temperature.
- **TASK 3.4** Smart diagnostics, Cold wireless instrumentation, and «embedded intelligence» for Quench detection and quench management.
- **TASK 3.5** Heat extraction and helium free cryogenics.
- **TASK 3.6** New high stress materials at cryogenic temperature.

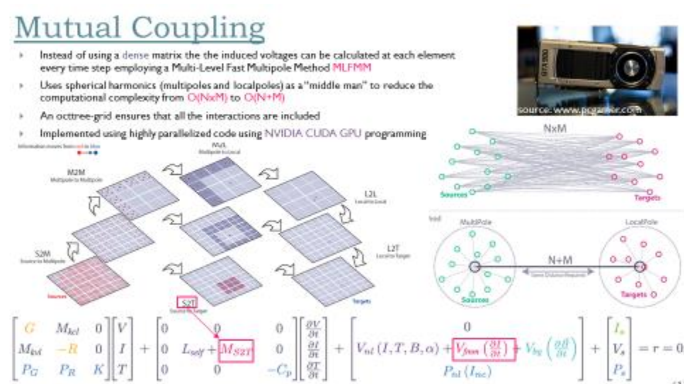
TASK 3.2: QUENCH ANALYSIS NEW APPROACH BASED ON NEW COMPUTING CAPABILITIES AND ON MULTIPHYSICS.

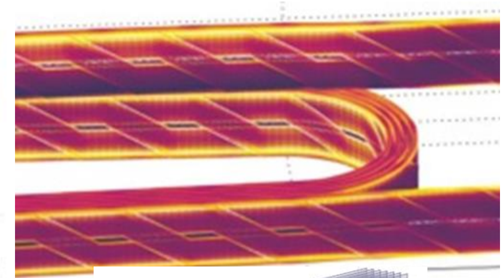
New generation of high field magnets either in LTS or HTS is using superconductors in stringent operational conditions. As a consequence, the quench management needs to be predicted with more accuracy and more reliability. Moreover, LTS and HTS quench behaviors are basically different and have to be simulated according to their own precise physical data.

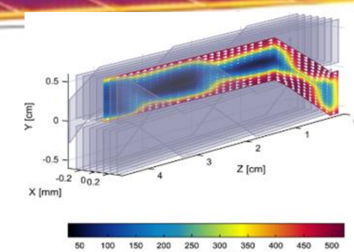
Many existing tools have been developed in the last decades and are well performing, having been benchmarked on many magnets. Numerous computing developments are also presently launched. Nevertheless, the huge step foreseen for HL-LHC and FCC requires considerable progress in the prediction. Fortunately, the tremendous progress in computing capabilities should make possible to support a new approach with the following guidelines and targets;

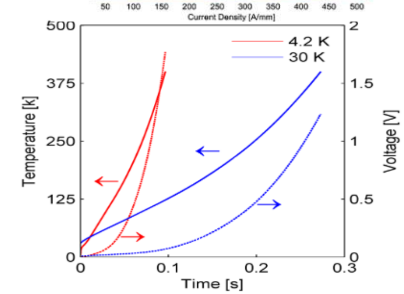
WP1: Quench analysis new approach based on new computing capabilities and on multiphysics (prepared by Glyn Kirby)

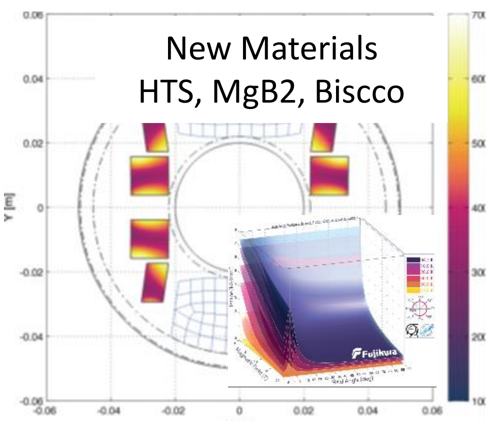




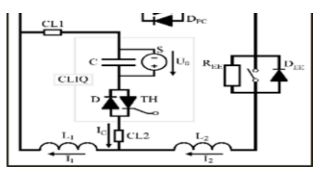


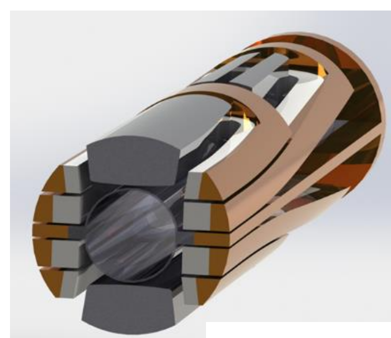






New active protection systems CLIQ





New passive energy extraction systems ICED.

TASK 3.3 : LARGE MATERIAL PROPERTIES DATABASE ASSOCIATED WITH PROPERTIES MEASUREMENTS AT CRYOGENIC TEMPERATURE.

To be able to accurately model and predict the performance of advanced superconducting magnet systems, an accurate materials data base is obligatory.

We have to provide an open access to this important information.

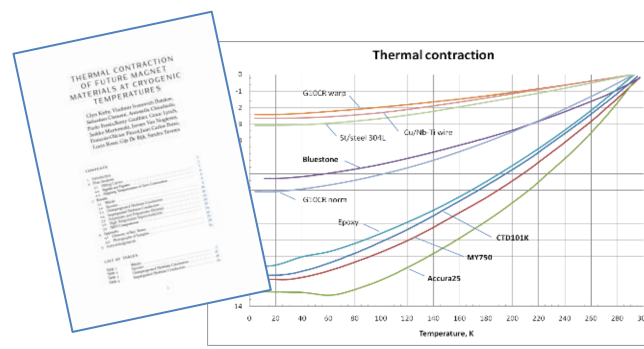
Covering the operating temperature range of the materials from cryogenic to above room temperature, however some materials will need measurements up to very high-temperatures to accurately model the components present during the high temperature reaction process of Nb3Sn and BSCCO. 750°C, 900°C respectively.

TASK 3.3: Large material properties database associated with properties measurements at Cryogenic temperature.

Measure properties of all materials used to build magnets plus the new materials over full operating temp range

Metals , Plastics, Composites, Assemblies …..

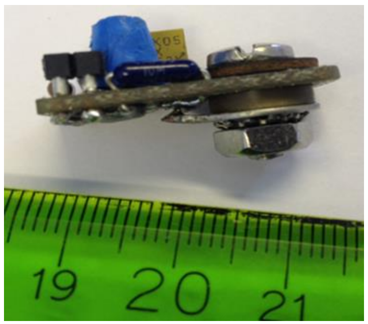
- Thermal contraction
- Thermal conductivity
- Magneto resistance
- Specific heat Cp.
- Resistivity
- Mechanical ….

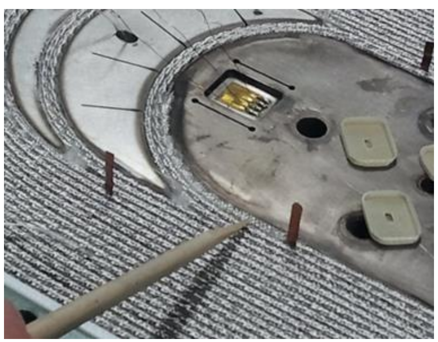


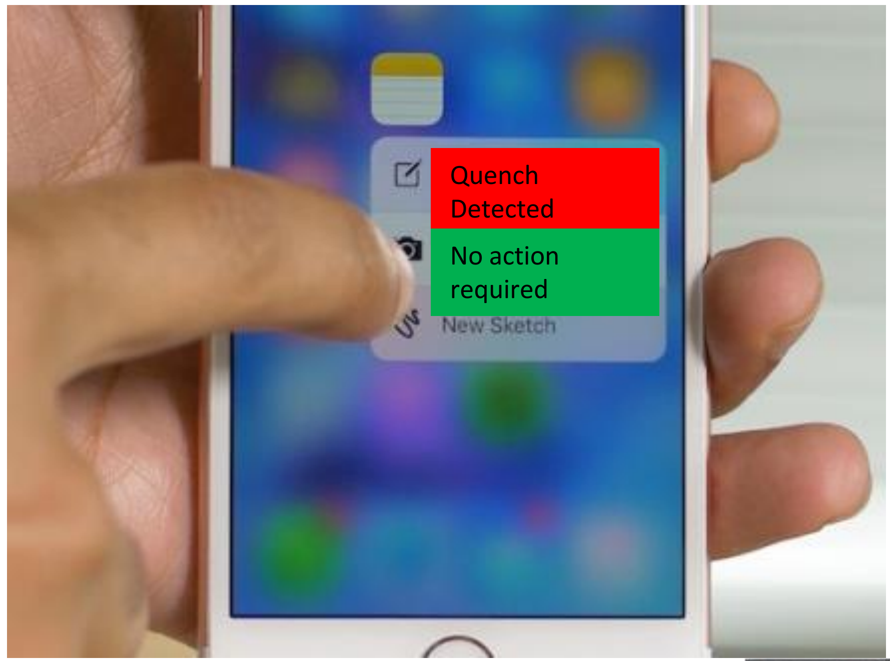
TASK3.4: SMART DIAGNOSTICS, COLD WIRELESS INSTRUMENTATION, « EMBEDDED INTELLIGENCE » FOR QUENCH DETECTION AND QUENCH MANAGEMENT.

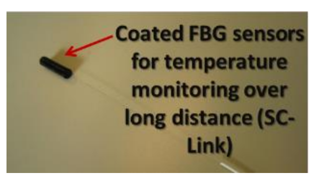
- The tremendous progress of computer capability is making nowadays possible to imbed a large amount of “intelligence” inside any equipment and in particular the cryostat of a superconducting magnet. In particular quench detection and quench management methods could be completely renewed by using either wireless instrumentation or cold sensors without any outside connection.

TASK 3.4: Smart diagnostics, Cold wireless instrumentation, « embedded intelligence » for Quench detection and quench management.





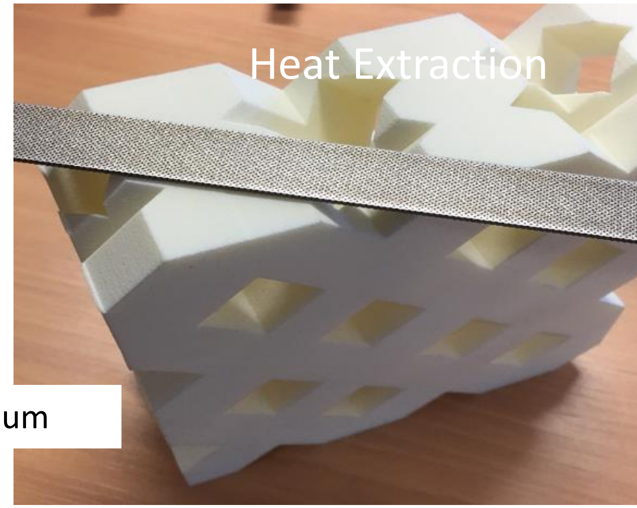




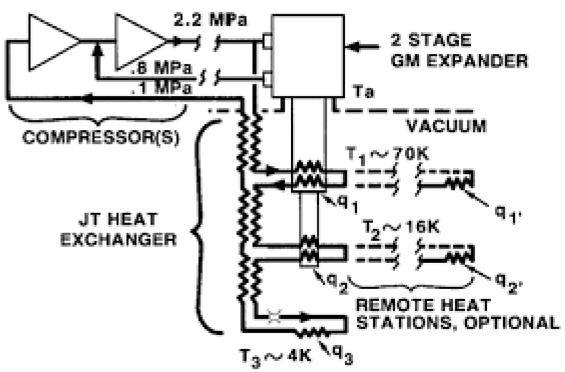
TASK 3.5: Heat extraction and Helium-Free magnets

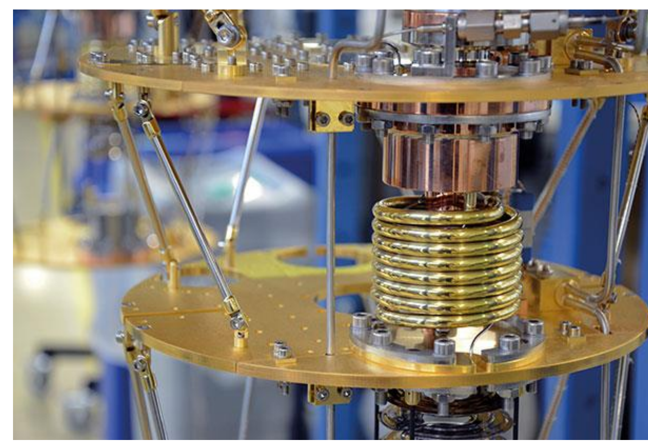
- The way in which heat is extracted from future superconducting magnets will need to be optimised depending on many operating constraints (helium availability, power requirements, reliability, cost, heat flux,….)
- Outside of the large national labs and MRI centers, helium supply is limited. But this may not always be the case, helium is a rare earth resource and is limited. This pushes the development of Helium free systems and the use of closed cycle refrigerators. Of particular interest to industry will be the development of closed cycle refrigerators

TASK3.5: R&D on Heat Extraction and Helium Free Cryogenics.



Transparent titanium





WP5: NEW HIGH STRESS MATERIALS AT CRYOGENIC TEMPERATURE

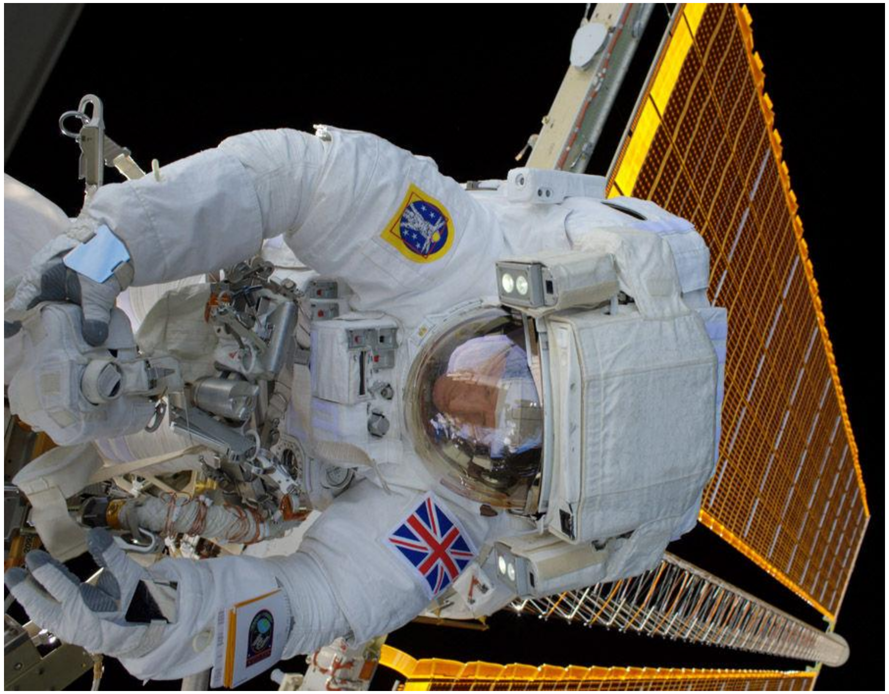
- Development of high field magnets will require the use of high strength materials. The characterisation of materials at low temperature will be critical for optimisation and cost reduction. Materials can be categorised into these main areas:

1. Superconductors, may have additional strengthening elements.
2. Coil support, high-strength materials are often bristle at low temperatures
3. Composite's, are an area of magnets design and development which have not been fully taken advantage of yet.
4. Radiation hard development of composite's

TAK 3.6: R&D on new high stress materials at cryogenic temperature

(prepared by Glyn Kirby)

- Learn from Aerospace …..



An example **Graphene**

WP4. Pilots identification

- **Task 4.1** Identification and description of R&D&I pilots. Some of the foreseen pilots could be:
- **Task 4.2** MgB2 Technology key-demonstrator: Solenoid 1m in diameter, 2m in length and 5 T.
- **Task 4.3** Frontier edge High Field MRI concept magnet: whole body 16 T.
- **Task 4.4** Open MRI magnet, interactive people magnetic chamber. Mammo-magnet (conceptual design).
- **Task 4.5** Technology key-demonstrator of an HTS insert for HFML.
- **Task 4.6** Gradient coils technology for high field MRI, over 10 T.

TASK 4.2 : MgB_2 TECHNOLOGY DEMONSTRATOR - SOLENOID 1M IN DIAMETER, 2M IN LENGTH AND 5 TESLA

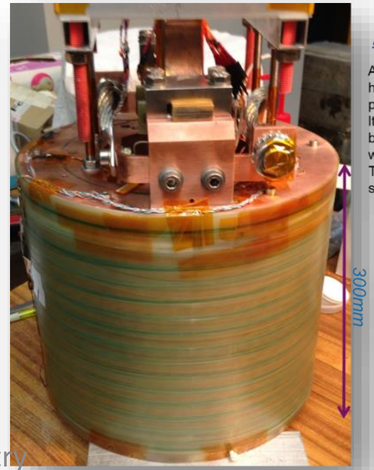
- Why MgB_2 Technology Demonstrator?
  - Columbus (IT) is proposing commercial tape/wire products with an official R&D road for high field MRI

Year	-> 2014	2015	2016	2017	2018	2019
MRI	*Dedicated & low field MRI*	1,5 Tesla	1,5 Tesla & 3 Tesla *dedicated*	3 Tesla *total body*	7 Tesla *total body*	9 Tesla +

Columbus, Presented at MT, Seoul, October 2015

  - An ambitious project will drive
    - Technological developments for FCC, High Field Lab (EMFLnet), etc…
    - Direct FCC application for FCC electron cooling lense is considered

2km wire solenoid at 4.1 teslas (CEA/Irfu)



SIGMAPHI bpifrance Columbus Superconductors

A MgB_2 solenoid of 2 km of tape provided by Columbus has been designed and manufactured by CEA/Irfu in partnership with SigmaPhi.
It has reached a central field of 1.1 T at 10K. It has then been submitted to a uniform background field of 3 T without experience any quench.
The temperature of current sharing is in agreement with short length data.

Coil Parameters	Value	Unit
Current	100	A
Inner winding diameter	200	mm
Outer winding diameter	280	mm
Central self field	1.09	T
Peak field	1.29	T
Number of Layers	44	
Number of Turns	60	
Tape length	2	km

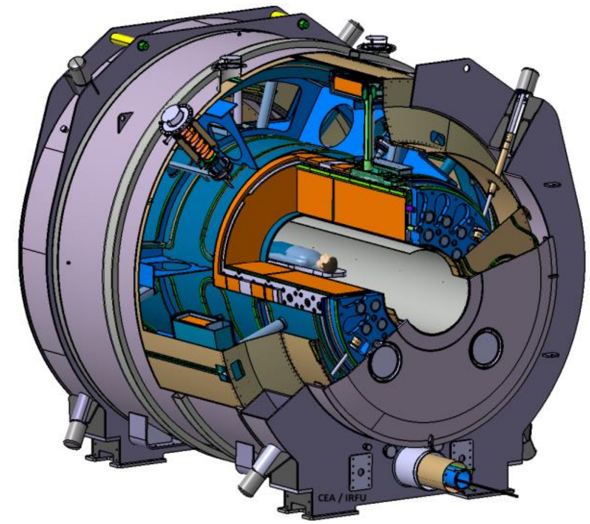
Contact: thierry.schild@cea.fr

TASK 4.2: MgB_2 TECHNOLOGY DEMONSTRATOR - SOLENOID 1M IN DIAMETER, 2M IN LENGTH AND 5 TESLA

- Why MgB_2 for MRI? Cryogen-Free, Improve stability
  - All MRI manufacturers have an R&D program on MgB_2
  - Practical synergy between High Energy Physics and Industry

TASK 4.3: CUTTING EDGE HIGH FIELD MRI CONCEPT MAGNET – WHOLE BODY 16 T

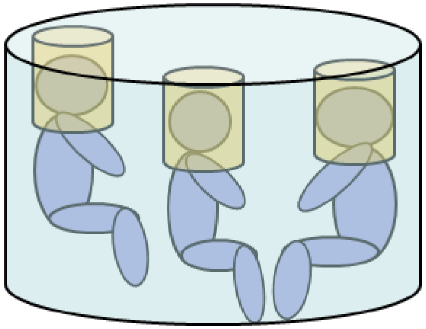
- In 2008, the Iseult was **the** only 11.7T/90cm/AS MRI project



- Now, one 11.7T/68cm/PS in NIH (damaged), one 10.5T/82cm/PS (on field), one 11.7-14T project in Corea, one 14T project in NHMFL
- In this context, a conceptual study of a whole body 16 Tesla magnet that will require the use of Nb3Sn wires foreseen for HiLumi or FCC, would give a long term perspective for new developments in this field. Such a design study may be used as well for public medical institutes to launch new project and as well for no conventional large magnet manufacturer (ASG, General Electric Alstom) to propose news MRI design maybe at lower fields.

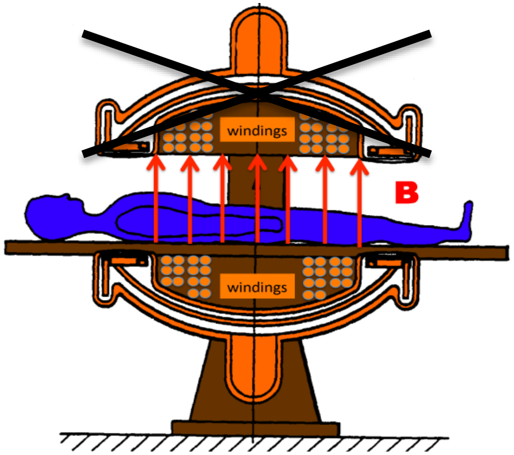
TASK 4.4: SOCIAL MAGNETS – OPEN MRI MAGNET, INTERACTIVE MAGNETIC CHAMBER, MAMMOMAGNET

- During the interview of Prof. Denis Le Bihan, three innovative designs were discussed:
  - The « Social Magnet »



3T, several « sweep spots » with high field homogeneity

  - One-side Magnet for clinical applications
  - Portable MammoMagnet



TASK 4.5 : TECHNOLOGY DEMONSTRATOR OF AN HTS INSERT FOR HFML

- To support HTS industry, demonstrator driven by academic institute is necessary (CEA, CERN, etc…)
- MRI industry has no R&D program with HTS
- NMR industry (Bruker) is supporting such development
- EMFL within EMFLnet (Joint Research Activity) is supporting such development

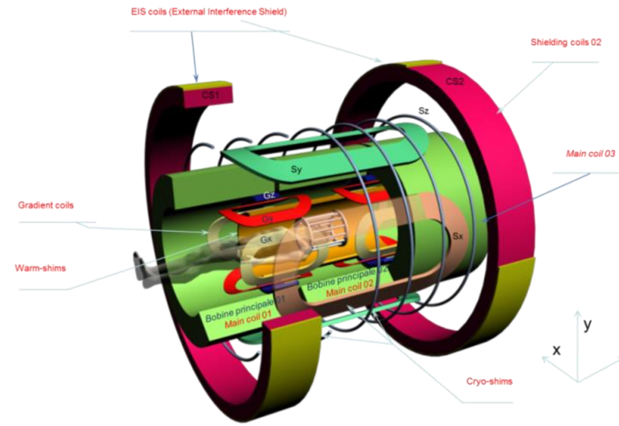
- In this context, we propose to join EMFL network in order to propose a common HTS insert, maybe a whole superconducting high field magnet

TASK 4.6 : GRADIENT TECHNOLOGY FOR HIGH FIELD MRI

- The gradient performance is as important as the magnet to improve image resolution and sampling time.

- The highest gradient strength reached at 3 T is a 300 mT/m gradient from Siemens, especially design for the Human Connectome Project funded by NIH (US).

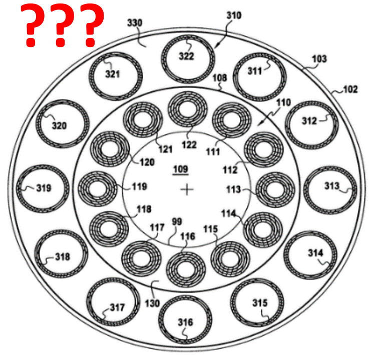
- An EU “Connectome-like” project is clearly required to push ahead gradient technology:
  - Develop a Multiphysics model
  - Test new kind of winding for gradient
  - Opportunity to use superconducting material



USA - $$$

HUMAN Connectome PROJECT

EU ???



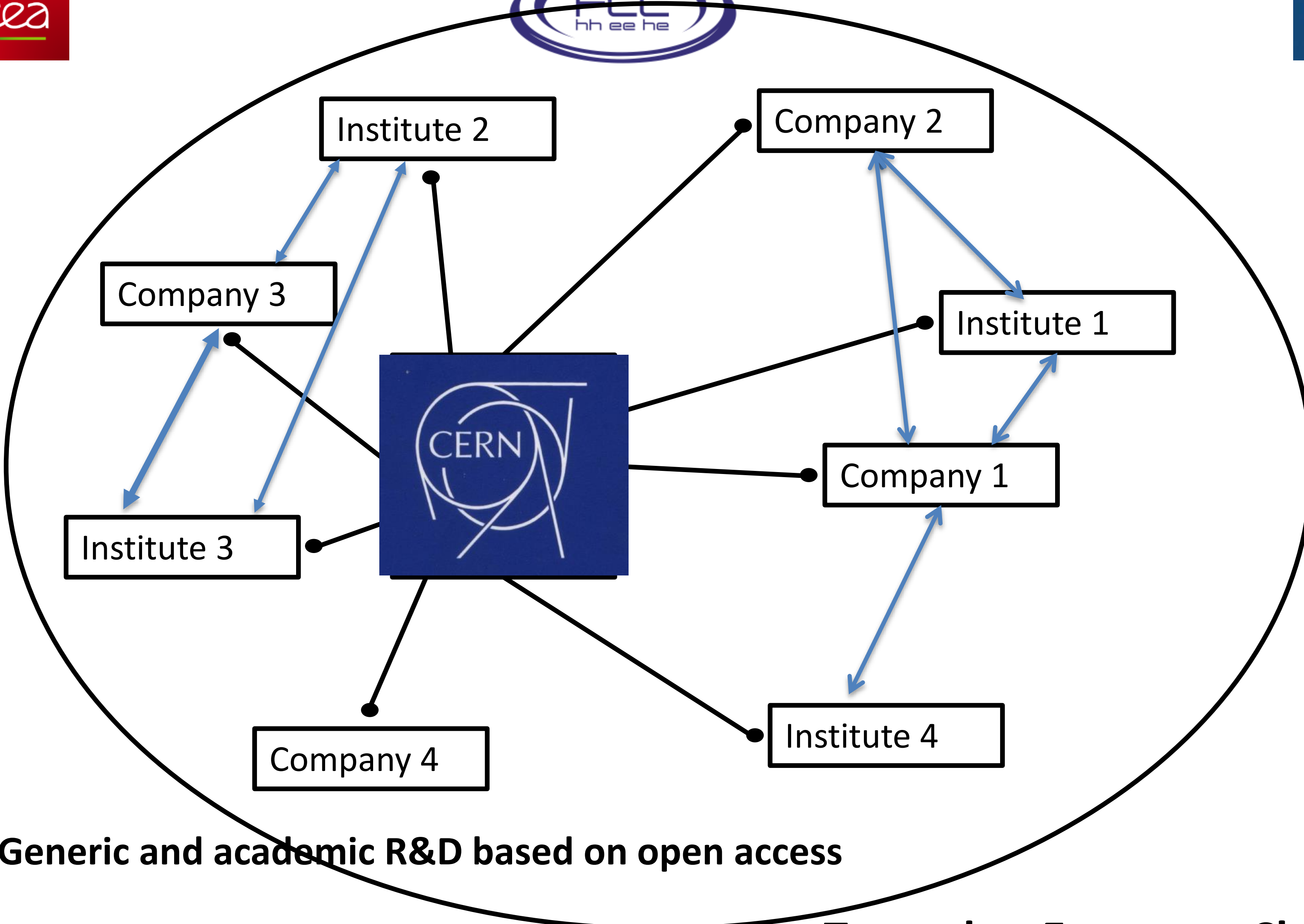
CEA Patent FR2892523

Liaising with conductor development

- Conductor R&D is mastered by companies under CERN leadership.
- We have established a close cooperation with Dr. Amalia Balarino (who has participated to the Neurospin visit).
- FuSuMaTech recommendations will not cover R&D on conductor but will focus on technology .

FET-Open Exchange : FuSuMaTech

- Establishment of a strong and sustainable R&D&I European network for structuring and strengthening the field of superconductivity and associated industrial applications.
- FET-Open Coordination and Support Actions
- http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/2228-fetopen-02-2016.html(modality FET Exchange)
- deadline: 17 January 2017

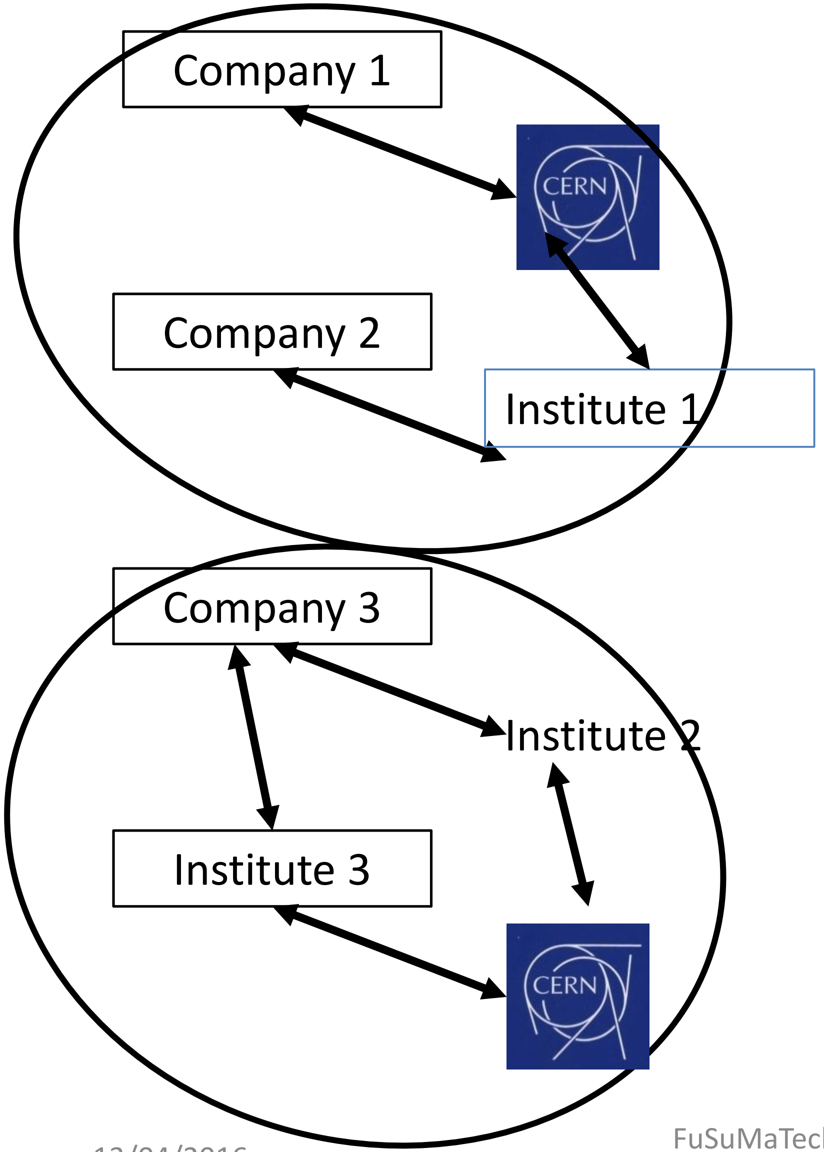


Generic and academic R&D based on open access

Towards a European Cluster

FuSuMaTech : Pilots or Technology demonstrators

The Heads of agreement for the Technology demonstrators area should be :

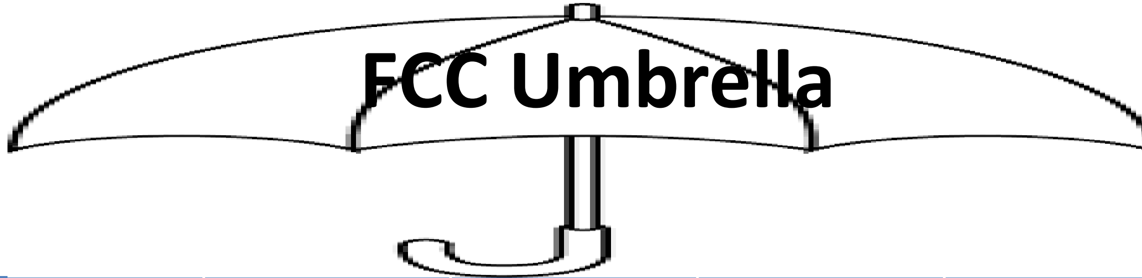


1. Purpose: *realisation of a pilot or technology demonstrator*
2. Organization: *specific collaboration agreement or consortium agreement*
3. Intellectual Property: *to be fully protected for Industrial partners*

What we will ask to companies in year 2

- Confirm their interest on the basis of the list of WP's and send letters of intent on specific ones.
- Review the draft FuSuMaTech MoU
- Contribute to the first European application FET open CSA and become partners
- Contribute to the specific task descriptions.
- Participate to the FuSuMaTech industrial meeting in early 2017 and approve the FuSuMaTech MoU

« FuSuMaTech » Overall roadmap



Working Group

2015	2016	2017	2018	2019	2020	2021

Short R&D programs (3 years)

Long R&D programs (5 years)

FET open

Other EU programs

Networking

Transnational Access

Joint Research Activities

Conclusion

- The FuSuMaTech working group has visited more than 10 companies in Europe and has been warmly welcomed
- Companies have a very positive attitude and see the HL-LHC and FCC huge effort as a real opportunity to strongly push the Superconducting Magnet Technology in the next decade
- European programmes appear as a unique tool to drive common work and to prepare efficient actions under the CERN umbrella.
- A promising set of WP and Tasks including generic R&D actions and technology pilots is under discussion between academic partners and high tech companies
- All of us are volunteers for this win-win strategy