Developing SC magnet activity
Objectives, difficulties and benefits

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EUCAS 2017

- Sigmaphi presentation
  - General
  - Sigmaphi SC magnets
- Why making this development/Difficulties/Key factors
- Impact on Sigmaphi and its stakeholders
- Conclusion

Sigmaphi presentation

- Sigmaphi is focused on Particle Accelerator Technologies and Superconducting Magnets
- Founded in 1981, Sigmaphi group has sales of 32 M€ and employs 200 highly qualified people, of which 6 physicists, 70 engineers and managers, and many talented workers
- We have 4 companies: Sigmaphi Magnets in Brittany, Sigmaphi Electronics in Alsace, Sigmaphi China in Beijing, Sigmaphi Japan in Tokyo

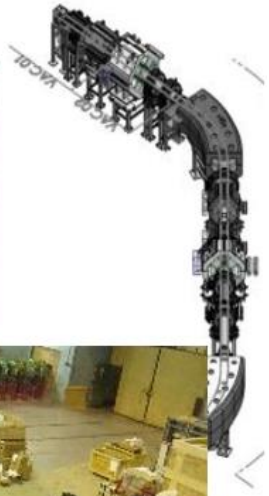
Turnkey systems for particle accelerators

- Particle beamlines and components
  (from optics to installation and alignment)

Magnets

from small to very large

PM/resistive/SC/AC



High stability power supplies

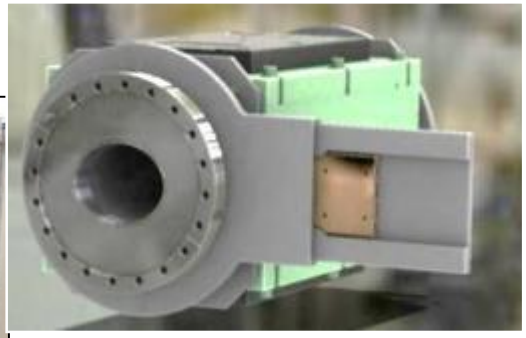
Vacuum

Diagnostics

Installation

Acculina 70m heavy ion beamline

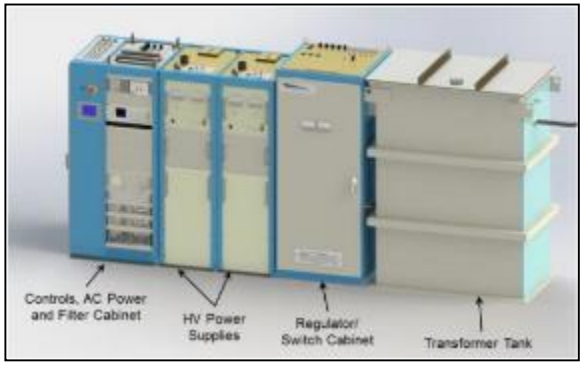
- Injection/extraction systems



FAIR/CRYRING Kicker
magnet and pulser
3500A / 280ns

- RF sources solutions (solid state amplifiers, Klystron modulators)

FZD
10kW @1.3 GHz



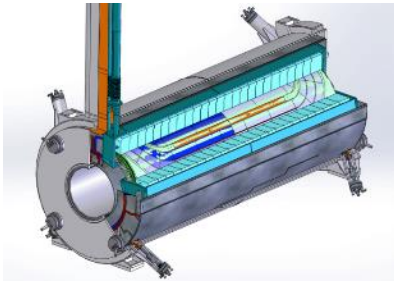
Klystron modulator for
IPN Orsay 115kV / 50A

Fermilab –
75 kW @ 162 MHz

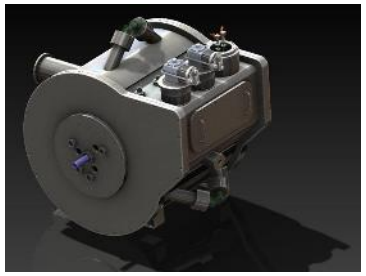
Superconducting magnets quench detection/CC/power supplies

- NbTi

33 correction dipôles for LHC (CERN)



Dipôle for JLAB (4,2T, 4m)



Cyclotron magnet (He free)

- MgB2

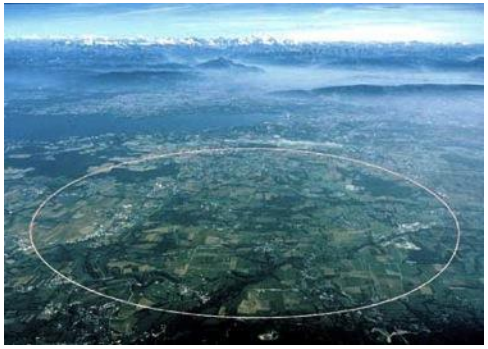
MgB2 coil tested at 460 A

Power supply for SC magnets

- HTS: program starting for a SMES and a dipole

2 main sectors

- Physics research labs



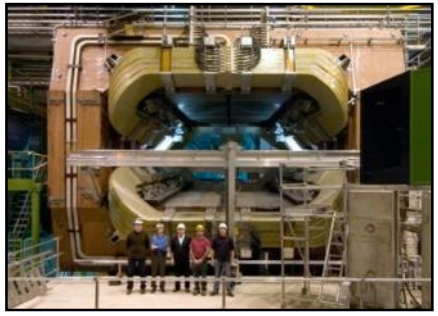
CERN-LHC

ESRF

Jefferson Lab

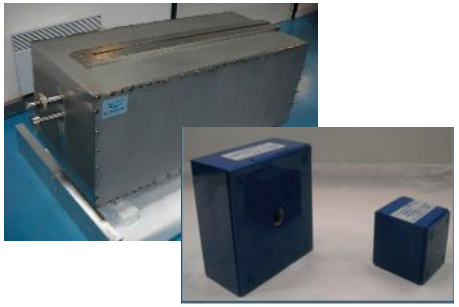
- Hadrontherapy centers manufacturers

Some examples - research labs



CERN-LHC-LHCb detector coils

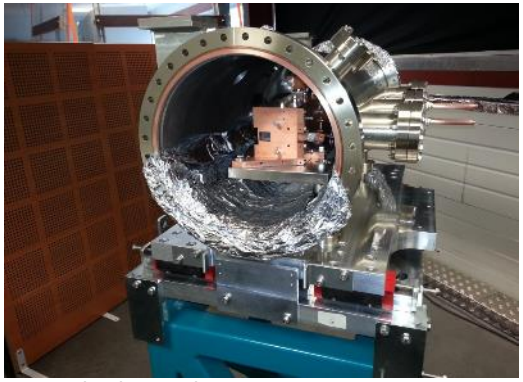
Soleil-124 sextupoles



LOA – PM quad and PM 1,4T in vacuum dipole

ALBA Barcelona Dipoles PS

Dubna-70m heavy ion beamline



Soleil under vacuum septum

CERN-LHC- 33 superconducting x-y dipoles

RF SSPA at HZD

10 kW CW / Pulse at 1.3GHz

- Europe: GSI, Bessy, Desy, Anka, LMUM, Stuttgart, CERN, PSI, INFN, Trieste, CEA, IN2P3, Ganil, Soleil, ESRF, Diamond, CCLRC, Alba, UCL…
- North America: BNL, ORNL, ANL, Fermilab, SLAC, MIT, JLAB, Triumf, CLS…
- Asia: KEK (Japan), Tohoku (Japan), CIAE (China), NSRL (China), CAEP (China), Barc (India), VECC (India)…

SC MAGNETS

SIGMAPHI SUPERCONDUCTING MAGNETS

MCBX Correctors for CERN LHC

Dipole V ID90 mm - 3,26 T – Dipole H ID120,8 mm – 3,35T - 550 A

NbTi Liquid helium 1,9 K

2001

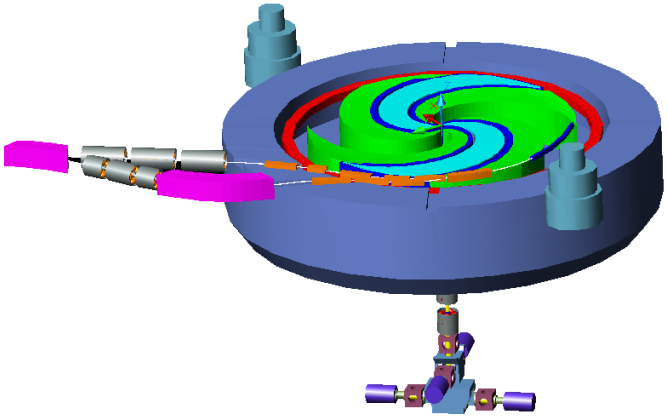
1st SC activity

Cold mass only

Built to print

Large SC cyclotron coil

4,6 m diameter, 1000 A with 2 currents per coil (C 6+ and H2+),
2 openings in cryostat
2008



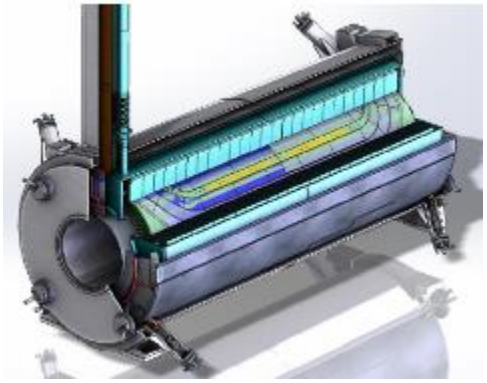
1st Sigmaphi design activity
project unfortunately stopped, might revive

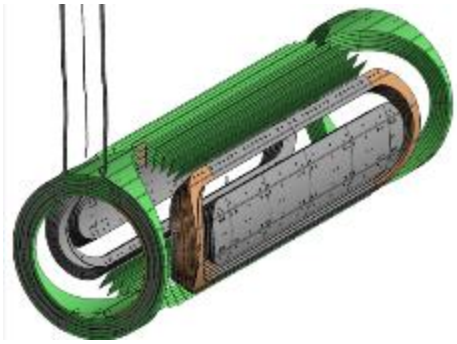
SIGMAPHI SUPERCONDUCTING MAGNETS

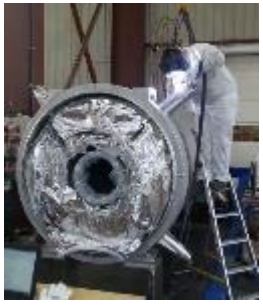
SHMS Dipole for JLAB

24 tons, warm bore 600 mm, 4,25 T, NbTi Liquid helium 4,2K – 3500 A

Delivery 2016







SIGMAPHI SUPERCONDUCTING MAGNETS

Q2 Q3 quadrupoles for JLAB

15 tons, warm bore 600 mm, 16T/m, NbTi Liquid helium 4,2K – 4250 A

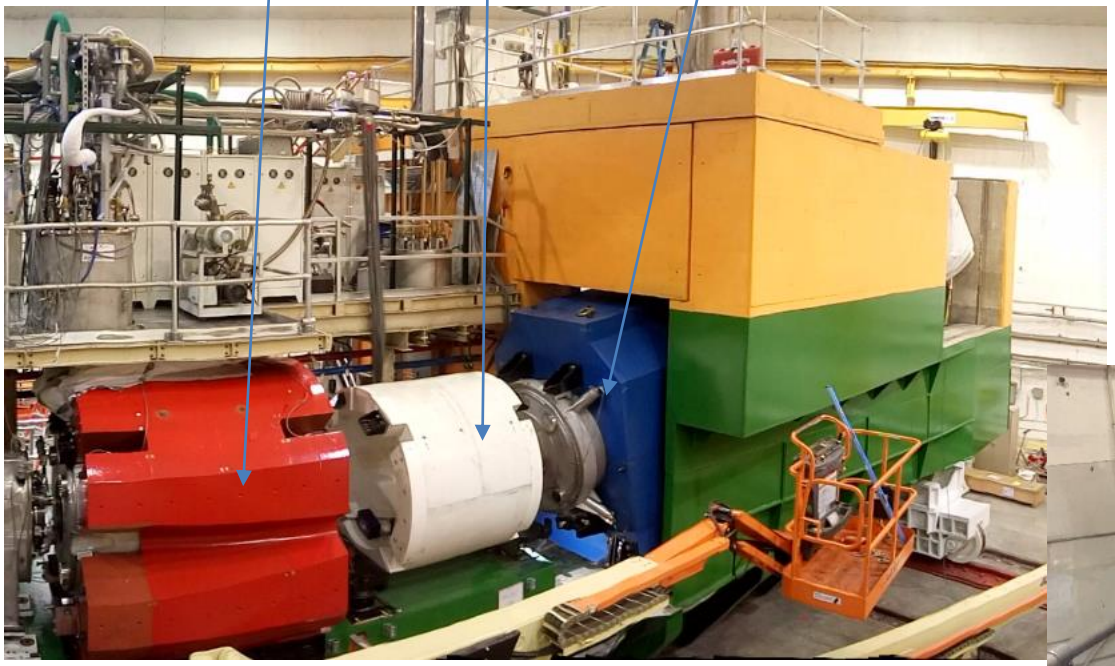
Delivery 2016

Jefferson Lab

SIGMAPHI SUPERCONDUCTING MAGNETS

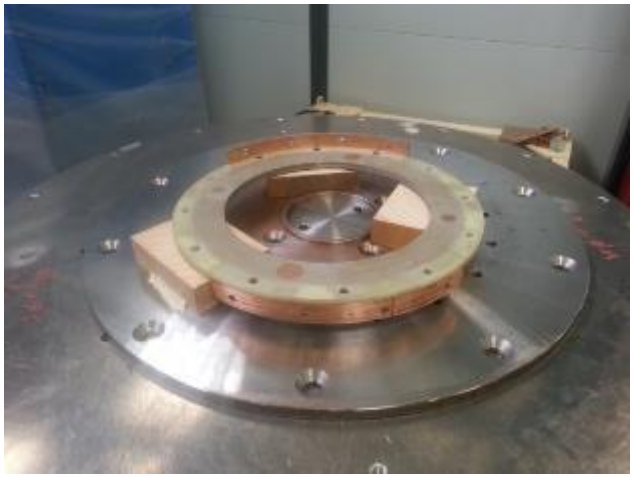
Magnets installed in Hall C at JLAB

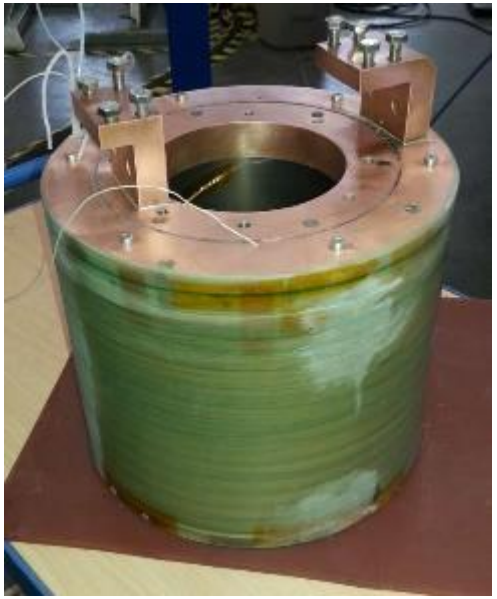
Jefferson Lab



MgB2 double pancake and solenoid R&D with CEA partnership

Double pancakes and Solenoid in MgB2 - 1T in 3T background field – 460 A conduction cooled 2015





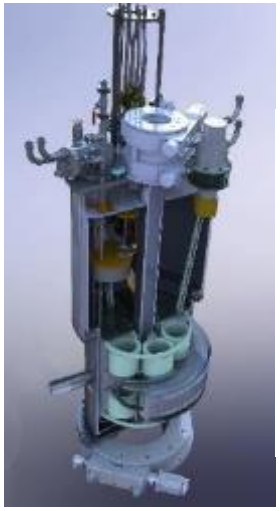
SIGMAPHI SUPERCONDUCTING MAGNETS

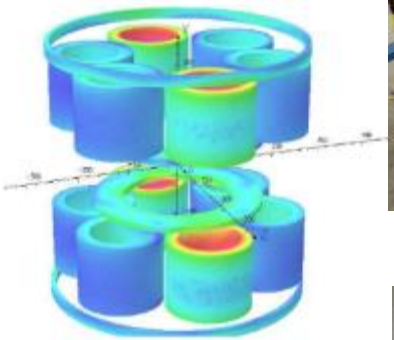
WAVE Vector Magnet for CEA

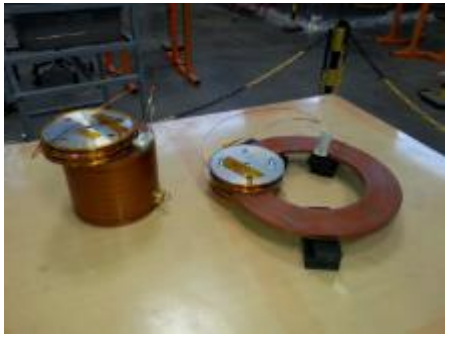
1T/1T/1T Bore diameter 100 mm - NbTi Liquid Helium Zero boil off – 200 A

High field homogeneity 50 ppm within R5mm – Turn key sytem delivered with 4 Sigmaphi power supplies and quench protection system

2017





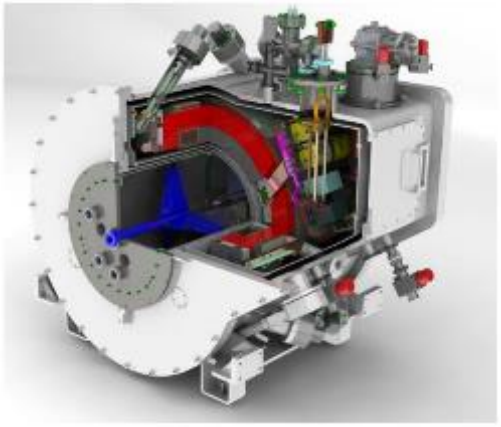


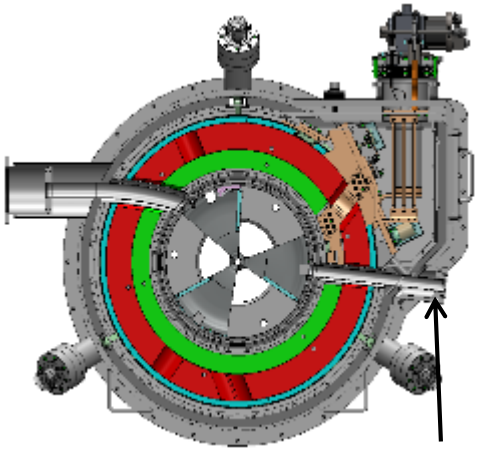
SIGMAPHI SUPERCONDUCTING MAGNETS

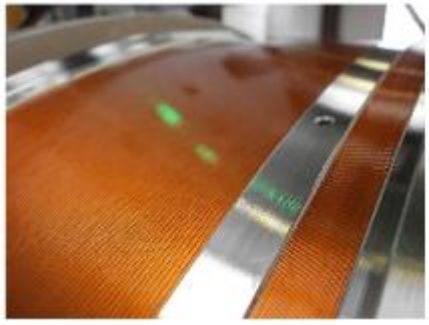
LOTUS Cyclotron magnet with CEA R&D partnership

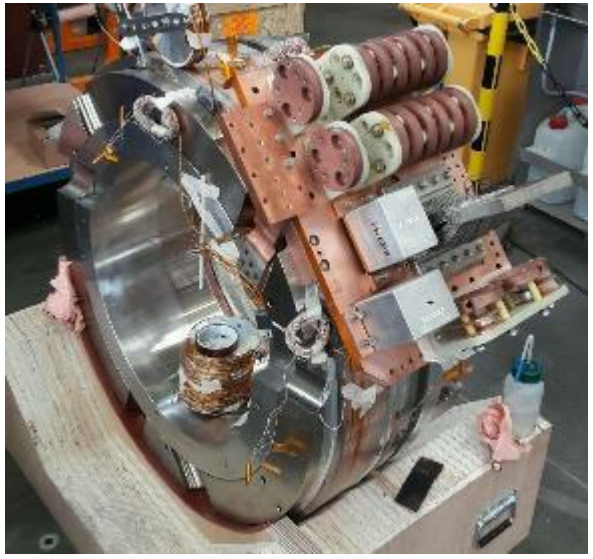
Solenoid warm bore 514 mm – 2,36 T – NbTi Helium Free – 100 A – Persistent

2017



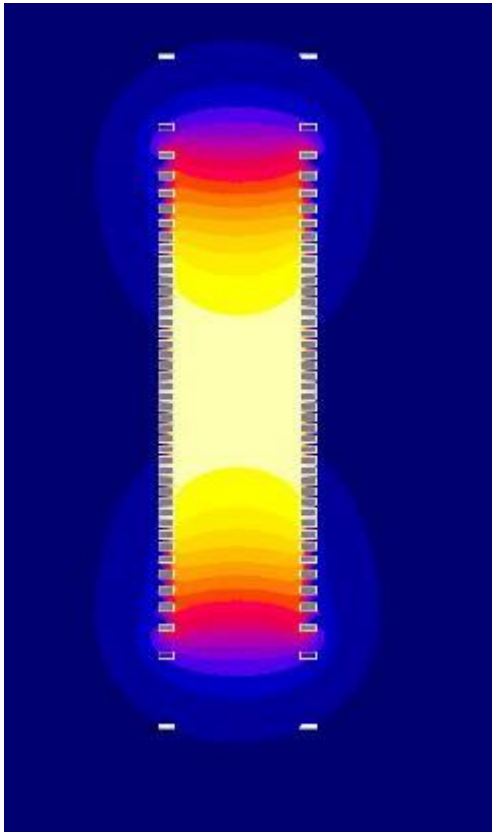


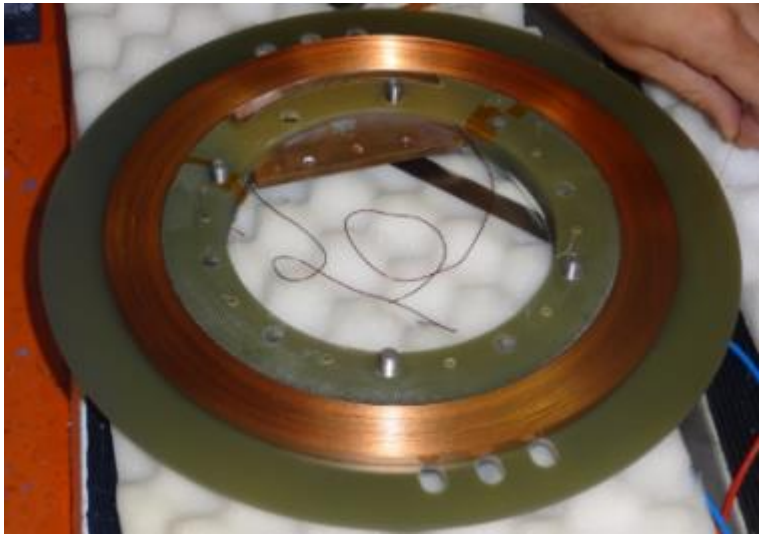


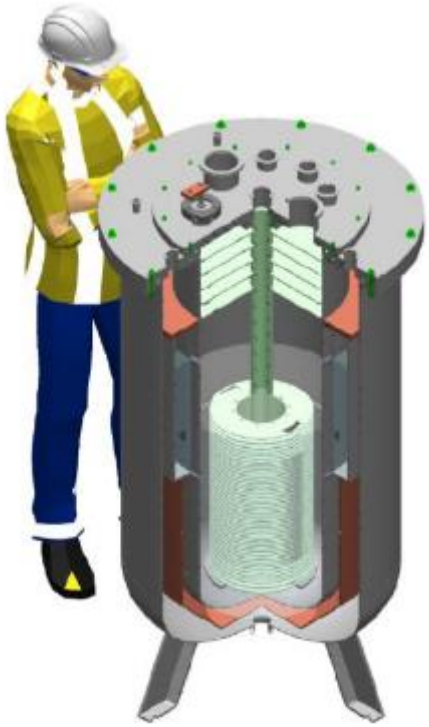


SIGMAPHI SUPERCONDUCTING MAGNETS

BOSSE Solenoid for energy storage in partnership with CNRS for DGA
YBaCuO solenoid – bore 180 mm – 13,1 T – 972A **- 1,3MJ**
2018



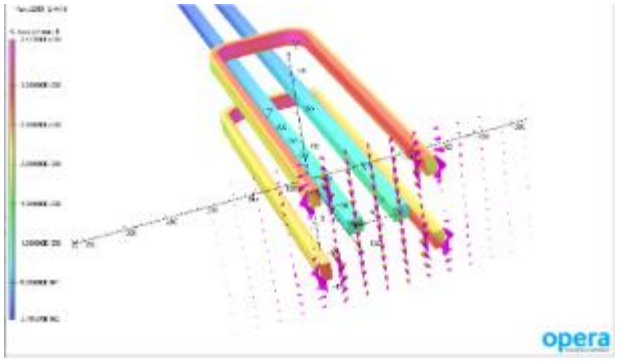


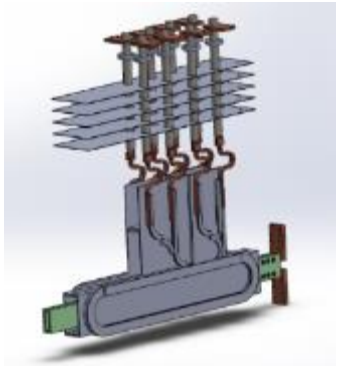


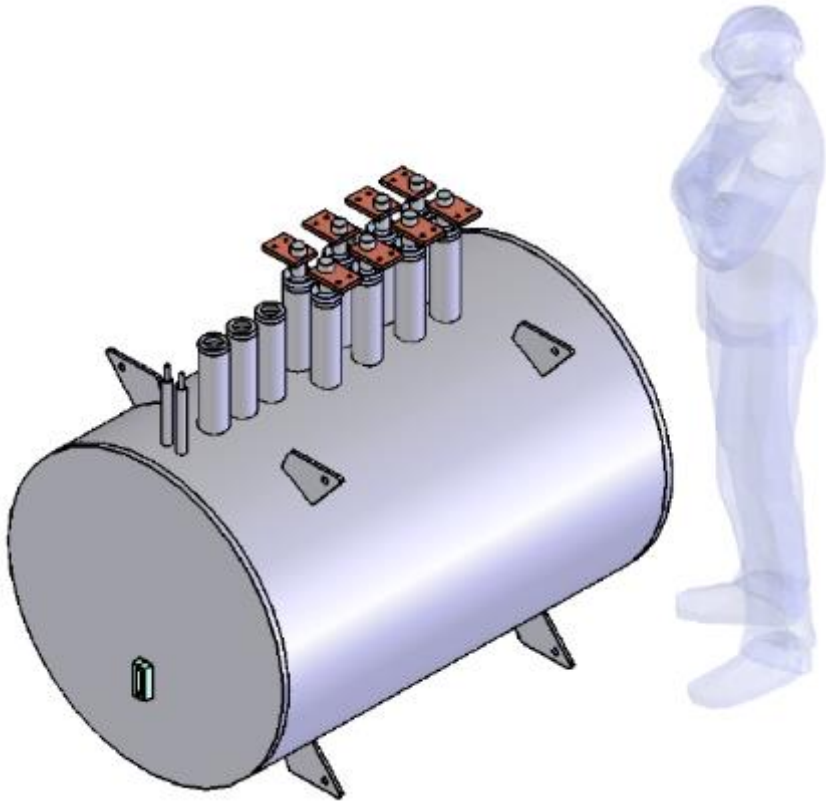
BOSSE Dipole for an electromagnetic launcher in partnership with CNRS for DGA

YBaCuO dipole – 20 kA – 1,2 T

2018

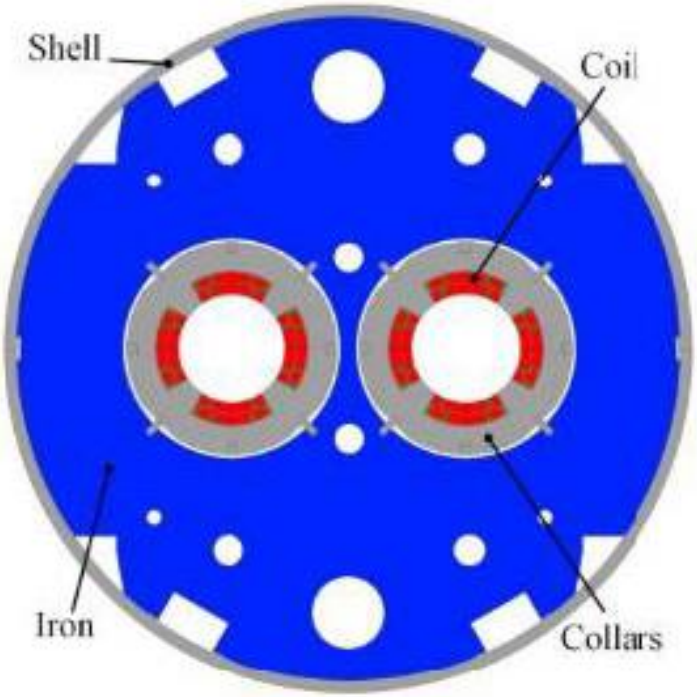


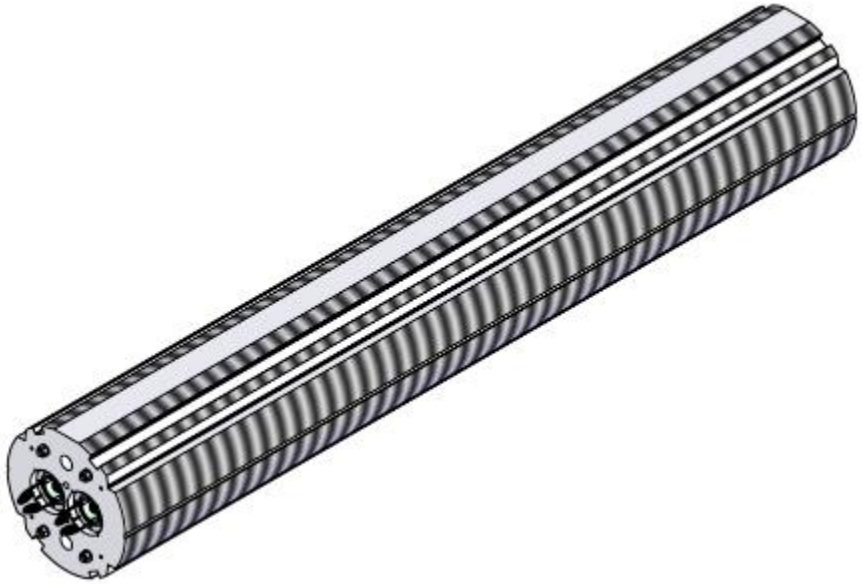


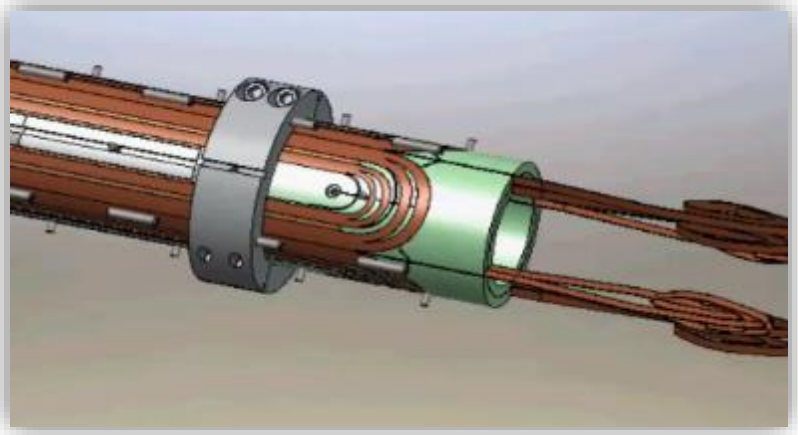


QUACO Quadrupole R&D for CERN Hilumi

Double aperture quadrupoles ID 90 mm – Gradient 120 T/m (peak field 6,1 T)
Length 4 meters – NbTi – 1,9K – 4596 A -
2020



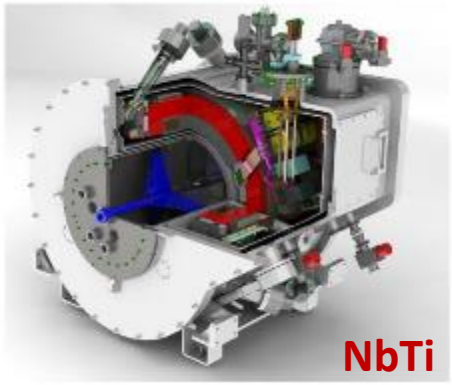




SIGMAPHI SUPERCONDUCTING MAGNETS

NbTi

2017 cea



NbTi

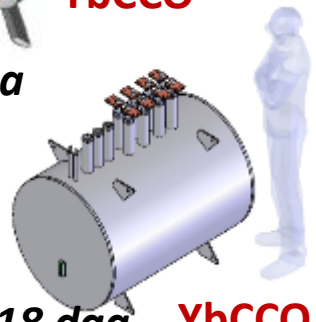
2017 pmb

YbCCO

2018 dga

NbTi

2016 jlab



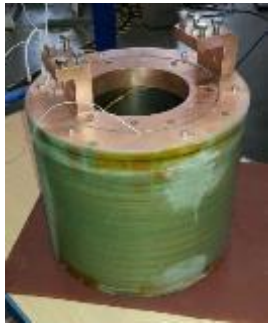
2018 dga

YbCCO

2016 jlab

NbTi

2015 cea

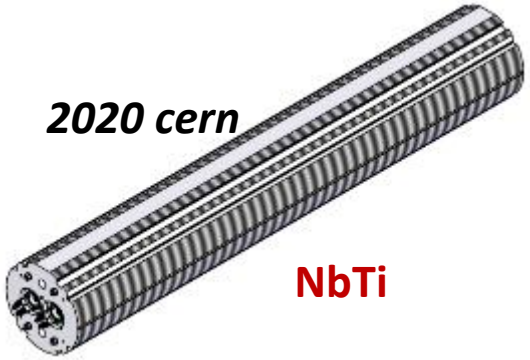


MgB2

2001 cern

NbTi

2020 cern



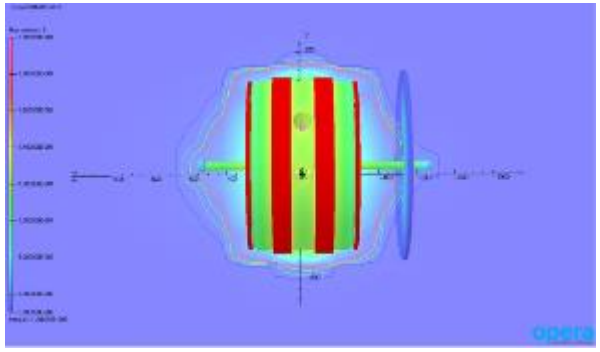
NbTi

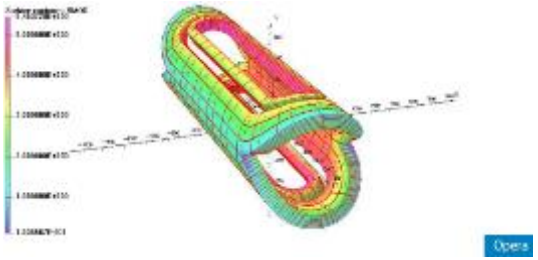
Our means

- Design and test
- Building and equipment
- Team

SIGMAPHI SUPERCONDUCTING MAGNETS

MAGNETIC (Static, AC, Transient, Eddy currents, Inductances…)

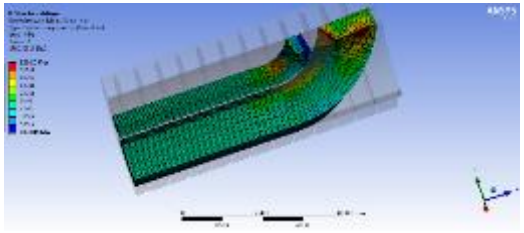


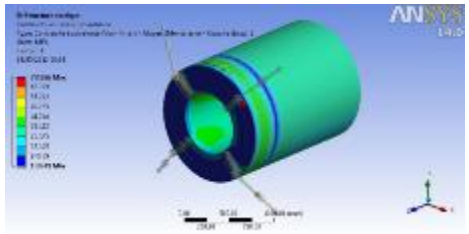


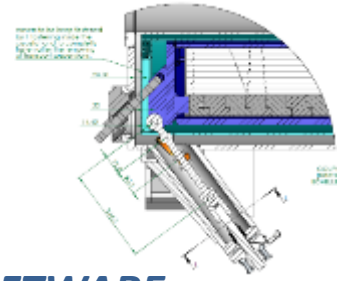
DESIGN & ENGINEERING

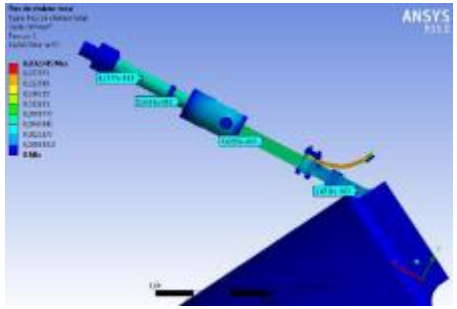
TESTING EQUIPMENT

STRESS(magnetic,forces,pressure,thermal,multiphysic…)

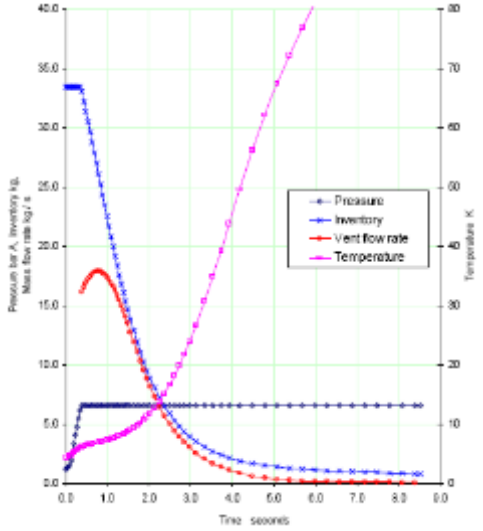








CRYOGENIC & QUENCH



SOFTWARE:

Mechanical : Solidworks

FEA: Ansys, Tosca, Elektra, Quench, Tempo

SIGMAPHI SUPERCONDUCTING MAGNETS

Dedicated workshop and equipment

SIGMAPHI SUPERCONDUCTING MAGNETS

A skilled and commited team, working with a high team spirit
(2 PhD, 5 high level engineer, 8 workers)

Why making SC magnets development

Decision is a combination of feeling, strategy and opportunity

- 15 years ago, strategy was more ‘’educated feelings’’, we had a sense of where to go
  - increase the technical content of our produits
  - Look for the fonction beyond the produit; in the case of a magnet, be able to propose any technical solution deviating particles
- But we had no action plan, no opportunity for SC magnet, we also feared that it was too difficult and did nothing for years

Opportunity showed up in 2008 with IBA RFQ for SC cyclotron coil

- We had 0 knowledge, 0 equipment, 0 process
- But it was in our mind to do something in SC magnets
- IBA proposed to reimburse proposal cost if technical proposal was fine
- Our key people were willing to go for it

We jumped on this, decided to find top level experts to help us making this proposal

And built a ‘’dream team’’ mixing

- top experts

  Martin Wilson   Charles Monroe

- dedicated Sigmaphi ressources keen to learn:

  William Beeckman   Frederick Forest

  physicist technical director

They started to work on this proposal

A major difficulty was to make a cost evaluation, with a high risk of loosing a significant amount of money (our total annual sales were 6 M€ !)

- Risk assessment
  - Need first to have a good technical work, just enough ‘’belt and braces’’
- Risk mitigation
  - Securing potential additional funding from French Innovation agencies
- Decision process
  - In a small family owned company
    - Fast decision process, easier to make long term decisions (ex China)
    - but you are alone at the end

- It moves from the brain to the heart

  Do you **believe** that you must do it; do you love this, is it good for your business ?

  - SC magnets ‘’shine’’ technically
  - It can only develop for future accelerators
  - Competition exists, but no major player controlling the market (unlike MRI)
  - It is a noble activity, saving energy, good for the planet
  - A lot of potential medical applications

- Entrepreneurship requires a high risk acceptance ! Loosing money is acceptable for good reasons , with the limitation of not endangering the company

After all, we made a very comprehensive and convincing proposal

We had a letter of intent from IBA

This was the real start of our SC magnet activity

- we soon realized that we would spend a lot more money in design, and could find additional financing for innovation

- IBA unfortunately stopped the project 1 year later (but it might revive !)

- The JLAB enquiry came 1 year later,
- We were still under the dynamics of the IBA teamwork, and had already learnt a lot
- same recipe, same conclusion
- But this time, we had to design, and manufacture…

- And we kept moving ahead

Challenges

- Every project brought its challenges,
  - From JLAB, we had to learn every process, with many unknown/unforeseen technical challenges
  - New people to train
  - Exceeded budgets

- The 2 most difficult and most important challenges were
  - To change culture from manufacturing products which can be repaired to products which cannot
  - To have a good assessment of the risk level and of mitigation possibilities

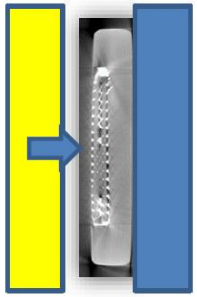
Our answers

- People
  - Set up dedicated workshop and management
  - Allocate/recruit rare people
  - get them trained and trained again, capitalize know how
  - get them commited, make them grow (learn from mistakes)
  - Trust them

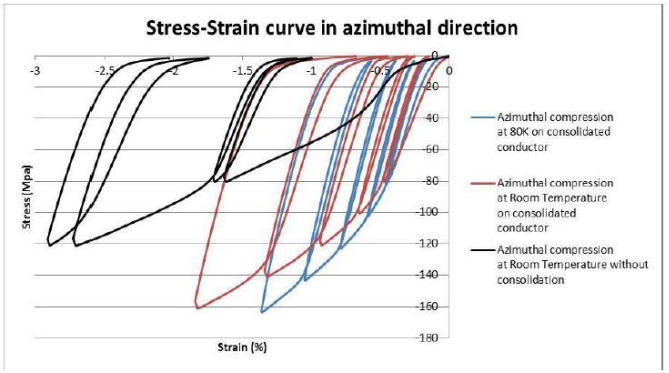
- No choice, once started, success is the only possible conclusion
- Be transparent with our customers when there is a difficulty, and try to solve it together; both learn
- Be flexible with budgets when in development phase, but find additional financing

- A good example of difficulty and collaboration to resolve it

Conductor consolidation



Conductor mechanical strength improved from 50 Mpa (20°C) to 100 Mpa (à 20°C) by mechanical hardenning
Special pressing machine designed and built to process 22 km of conductor
On line thickness control , cleaning and photography
Mechanical testing at room temperature, 77K and 4K to validate the process



Benefits

- For Sigmaphi
  - Working on highly demanding products drives all Sigmaphi Magnet activity and organization
  - It is a growth factor in our markets, and offers opportunities in other markets
  - It is another occasion to develop synergies between Sigmaphi Magnets and Sigmaphi Electronics
  - It enabled to develop a strong link with CEA Saclay team

- For our stakeholders
  - It has been a very nice opportunity to enlarge employees skills, responsabilities, and personal dimension (according to Sigmaphi Identity: create economical and human wealth)

- David moved to SC workshop manager, and is now Manufacturign Deputy Manager
- Leopold was winding technician, is now SC workshop magnet manager
- Raphael started as a PhD student shared between Saclay and Sigmaphi, and is now Project Manager at Sigmaphi

And many others, thanks to them

- For our suppliers
  - We helped several suppliers to develop their skills (example: spacers machining, or vacuum vessel manufacturing)

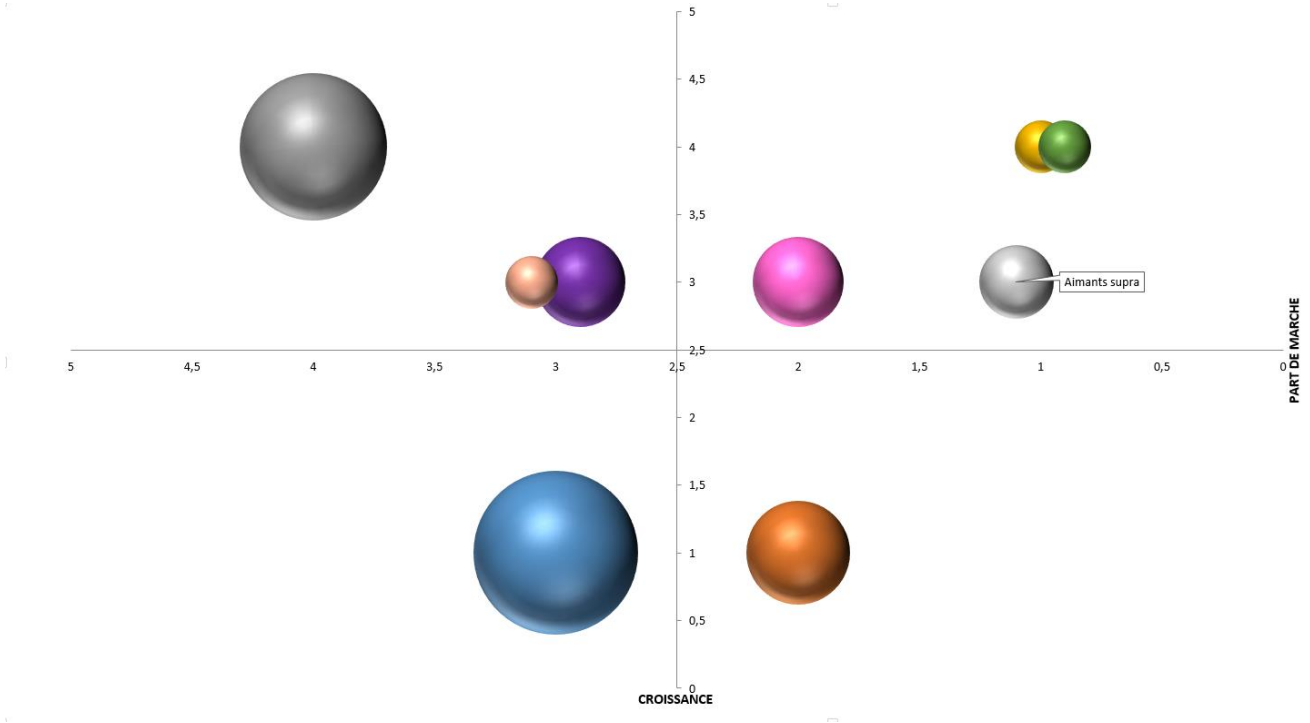
- For the world of education
  - We regularly make visits for schools, and this helps (we hope) to attract more interest for careers in technical and scientific field
  - We developed relationship with local university to make conductor characterization
- More generally, communicating locally about our SC Magnet activity helps giving a better image of industry

- More generally, we are proud of contributing to
  - Minimizing energy consumption
  - Through our Lotus project (cyclotron small thanks to SC coils) to the capacity to bring isotope production possible in remote areas
- This proudness is important for our employees

Conclusions

- We spent time, effort, € in developing SC magnets since 2008
- We developed a reasonably knowledgeable team, with equipments and processes
- We are more (better ?) organized and have a strategic plan Group-SC strategy-Eucas 2017

Group strategic approach



Upper right corner: dilemna, invest or leave

We evaluated our strengths and weaknesses and our capacity to change category, and decided to take necessary steps to increase our market share

Thank you for your attention