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MgB_2 round wires for the high power superconducting cable demonstrator in Best Paths project

Columbus Superconductors — M. Tropeano, G. Grasso

CERN — A.Ballarino, S.Giannelli, K. Konstantopoulou

Nexans — C.E. Bruzeck, G. Escamez

Rte, Nexans — F. Lesur

IASS Potsdam — A. Marian

BEST PATHS stands for "BEyond State-of-the-art Technologies for rePowering Ac corridors and multi-Terminal Hvdc Systems". It is co-funded by the European Commission under the Seventh Framework Programme for Research, Technological Development and Demonstration under the grant agreement no. 612748.

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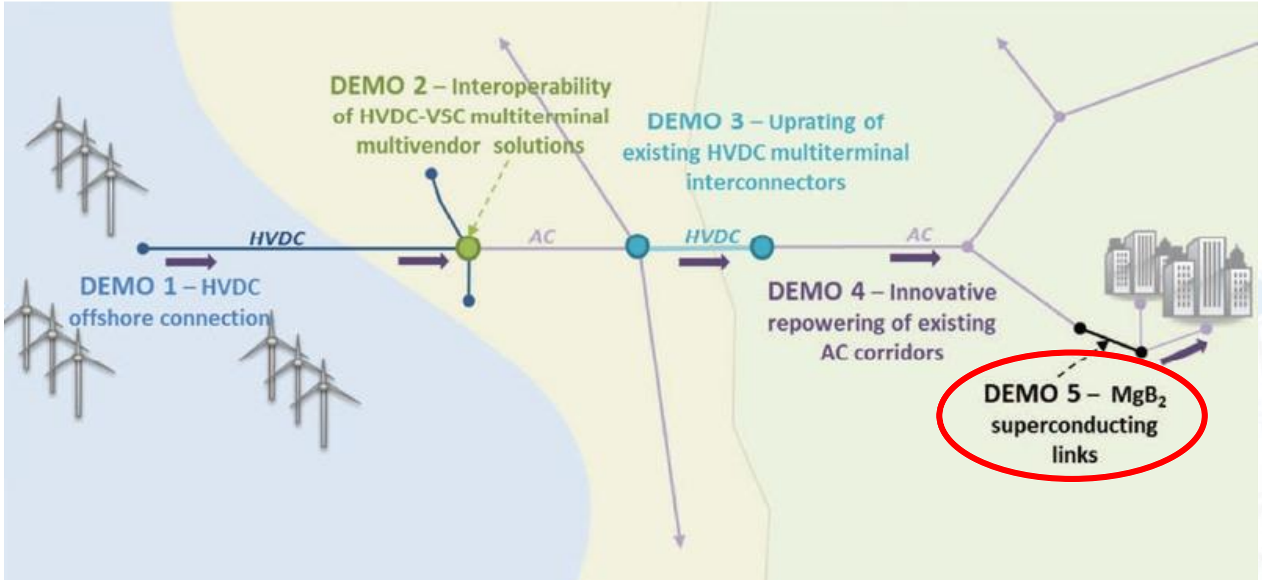
Best Paths Project: the largest project ever supported by the European Commission RDD Framework Programs within the field of power grids



A project to overcome the challenges of **integrating renewable energies**

October 2014
September 2018

Total budget (EC contribution: 57 %)
62.8 M€ = M$ 70.8 = 460 M¥

Demo 5 budget: 6.7 M€
EU contribution: 4 M€

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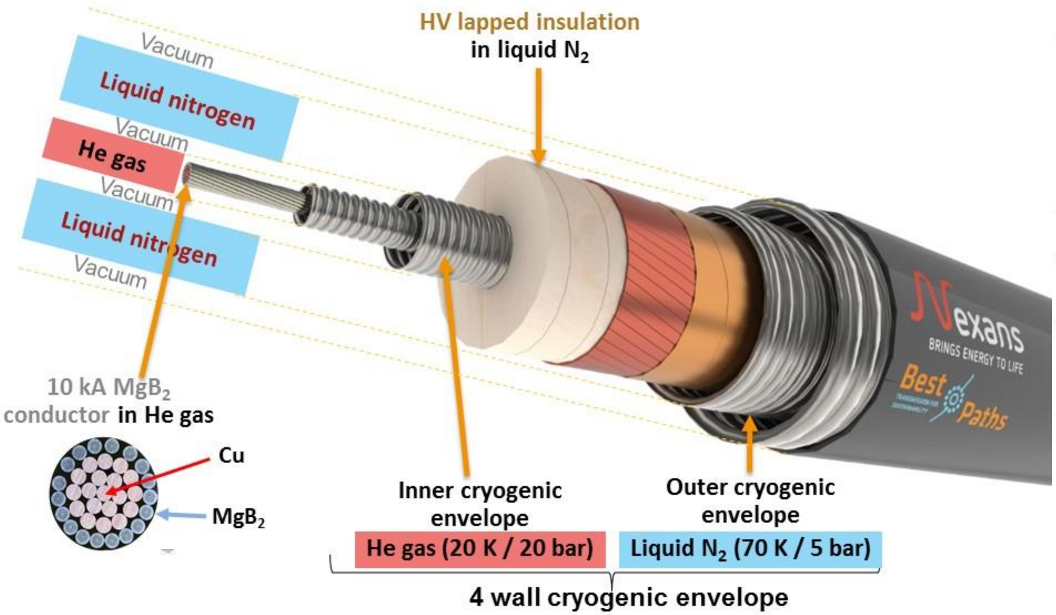
Objectives of DEMO 5

- Demonstrate full-scale 3 GW class HVDC superconducting cable system operating at 320 kV and 10 kA
- Validate the novel MgB_2 superconductor for high-power electricity transfer
- Provide guidance on technical aspects, economic viability, and environmental impact of this innovative technology



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10 project partners

Nexans
- Demo coordination
- Optimisation of MgB_2 wires and conductors
- Cable system
- Cryogenic machines
- Testing in He gas
- Integration into the grid

CERN
- Optimisation of MgB_2 wires and conductors
- Cable system
- Testing in He gas

Columbus Superconductors
- Manufacturing and optimisation of wires

IASS Potsdam
- Scientific coordination
- Dissemination

KIT Karlsruhe Institute of Technology
- Cable system
- Liquid hydrogen management

Technische Universität Dresden
- Cooling systems

ESPCI ParisTech
- Cable system
- Dielectric behaviour

Universidad Politécnica de Madrid
- Integration to the grid
- Reliability and maintenance

RSE Ricerca Sistema Energetico
- Cable system

Rte
- Integration into the grid
- Socio-economical impact

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Columbus Plant

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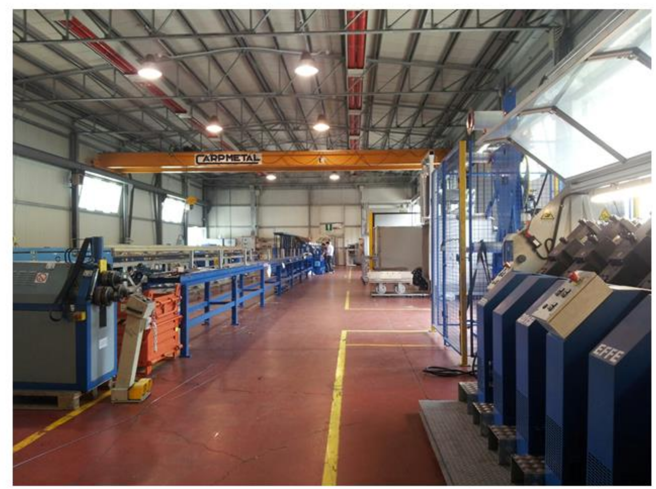
Columbus Plant

- The actual plant is fully operational for **MgB_2 wire production** with about 35 employees
- **MgB_2 chemical synthesis** also fully implemented
- Wire unit length today up to **2- 4 Km in a single piece –length**
- It will be possible up to **10 Km** with the full scale up of the process
- Columbus **MgB_2 tape production for MRI** has exceeded **500 Km** of fully tested and qualified wires
- Columbus **MgB_2 round wires production for cable** has exceeded **100 Km** of fully tested and qualified wires (end 2015-2016)



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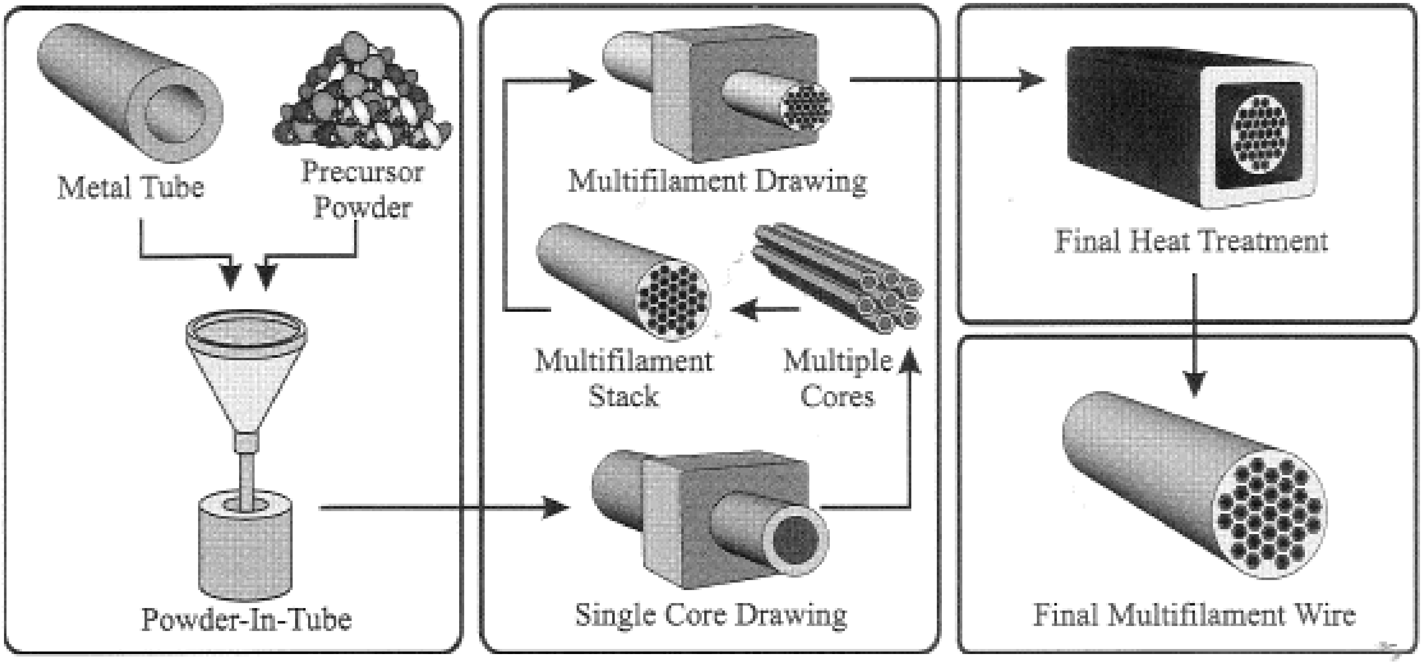
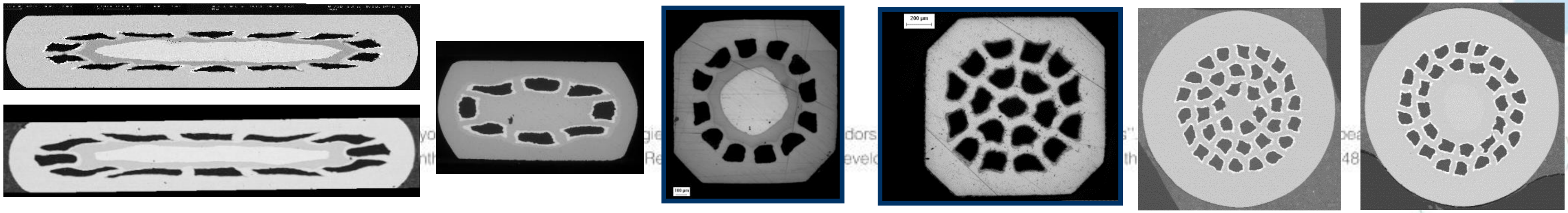
Columbus PIT manufacturing process



Conductors configuration:
different shape, aspect ratio, number of filaments, materials

Home made MgB_2 powders
Precursor quality, doping synthesis temperature, granulometry



Clean synthesis of powders

Multistep rolling machine

High power straigth drawing machine

- 39 new machines
- 15 existing machines will be still used over 21,
- 10 main upgrades to the technical infrastructures
- 1 new 2 floors buildiing
- 2.280m^2 of covered workshop area
- 20 direct production units

20 meter long
in-line furnace

Multistep drawing machine

4 meter furnace
for annealing HT

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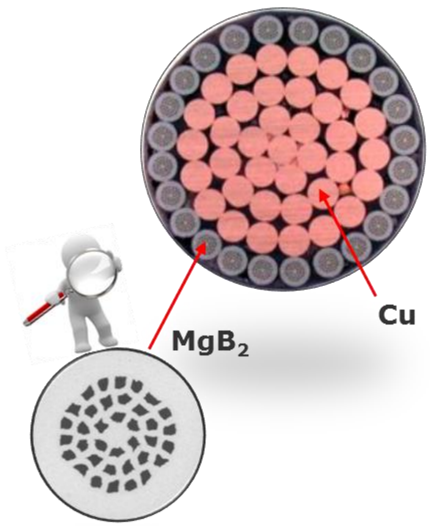
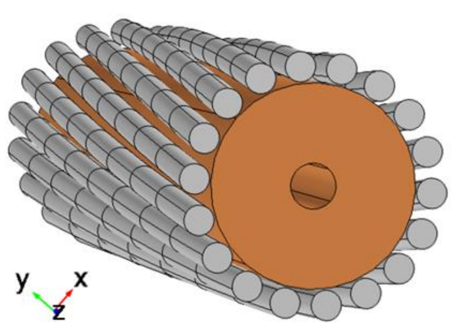
Commission under the Seventh Framework Programme for Research, Technological Development and Demonstration under the grant agre[illegible]

Defining the cable layout





The most suitable wire for cabling activities is

- **a round wire** with the smallest possible diameter (i.e. below or close to 1.5 mm)

The wire must have **good mechanical properties** to enable cabling operations.
An important parameter for cabling is the **critical bending radius** to prevent deterioration

- during handling or introducing the right **twist**

Operating requirements

Nominal operating requirements of the cable

- Operating 10kA DC current

Actual operating requirements

- Controlled quench for 35kA 100ms
- DC+AC ripples
  - Ripples at 50hz, 1% of amplitude
  - Power inversion

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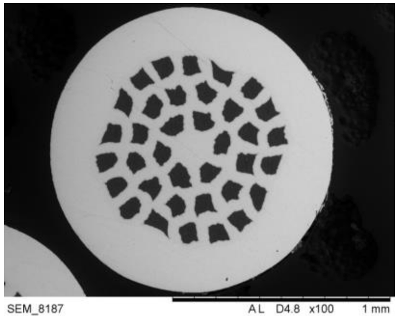
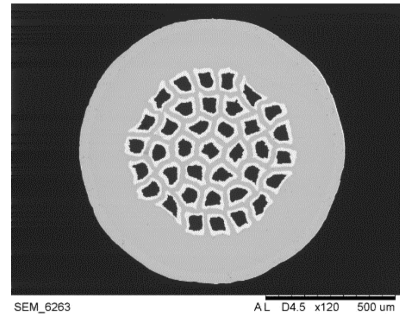
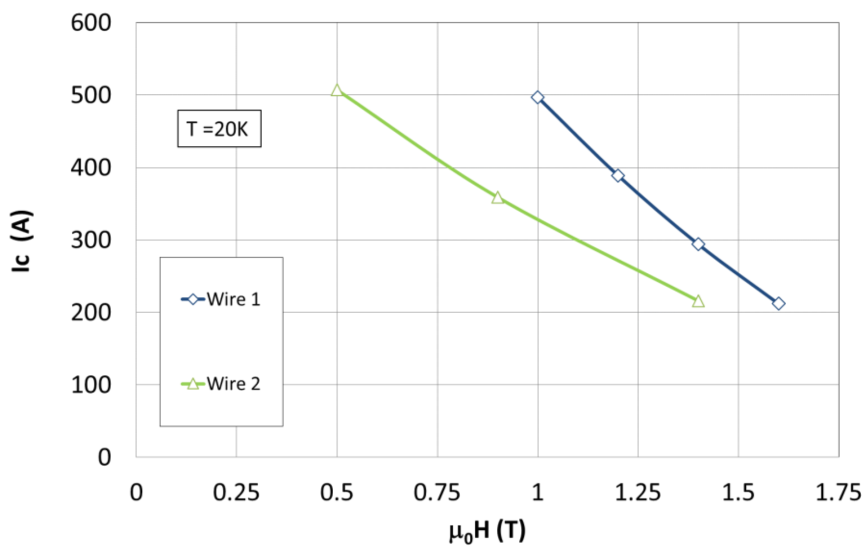
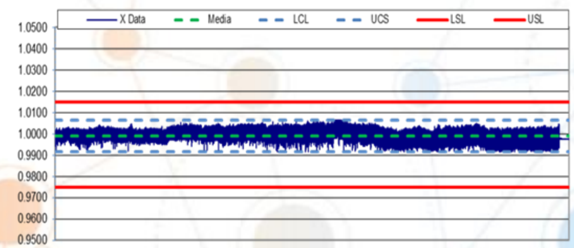


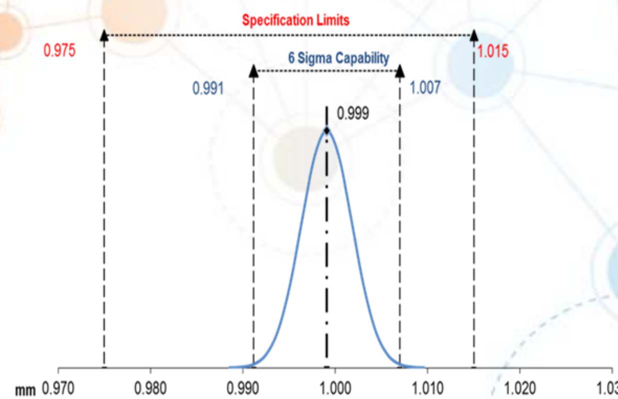
Wire type-1
diameter: 1.33mm
36 filaments
Materials: Monel, Ni
FF: 17%



Wire type-2
diameter: 0.99mm
37 filaments
Materials: Monel, Ni, Nb
FF: 11.5%







Type 2 is the result of a CERN-Columbus collaboration started in 2008

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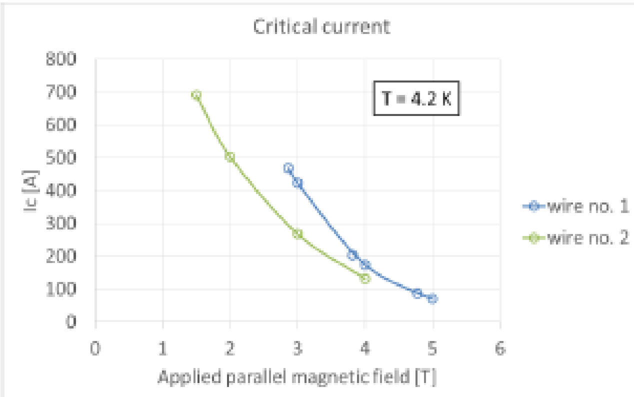
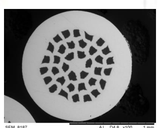
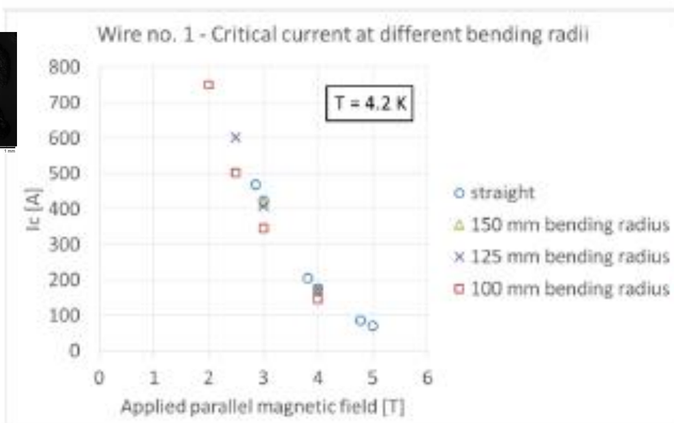
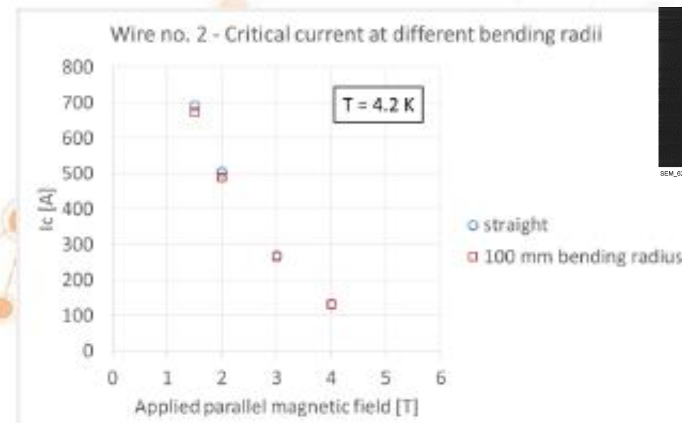
Samples have been characterized at CERN

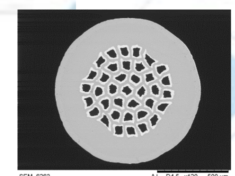


Trend has been confirmed also at 4.2K
Critical bending radius has been evaluated









- No/negligible degradation down to 125 mm bending radius
- 15-20% I_c degradation at 100 mm bending radius

- No/negligible degradation down to 100 mm bending radius

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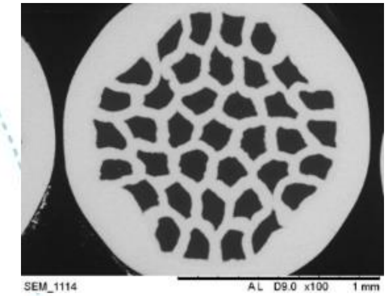
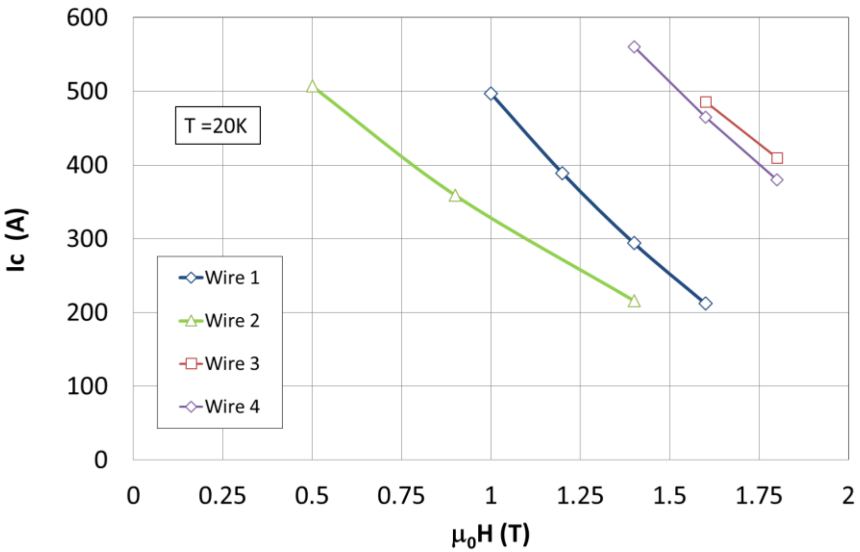
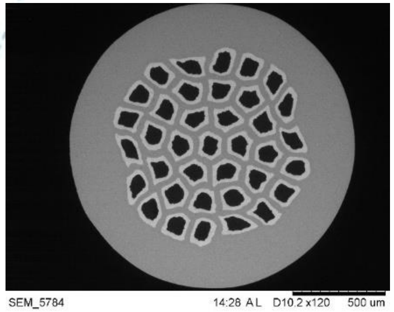
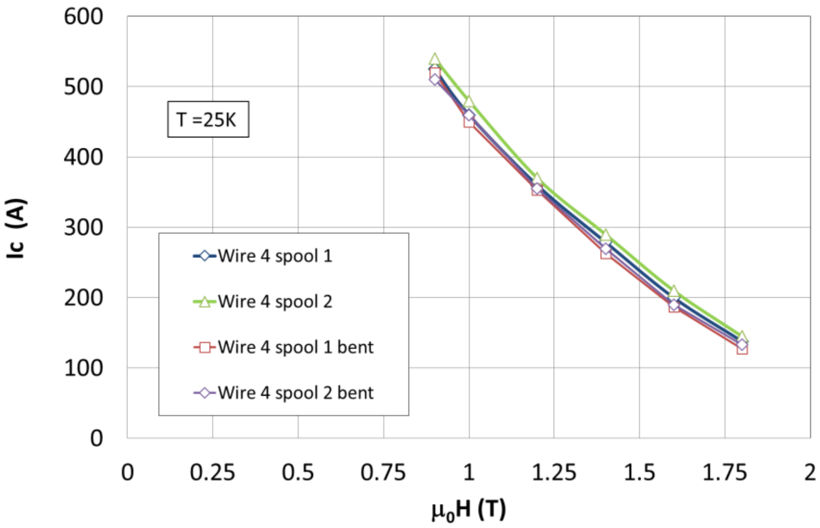


Wire 3
diameter: 1.5 mm
37 filaments
Materials: Monel, Ni
FF: 30%





Wire 4
diameter: 1.5 mm
37 filaments
Materials: Monel, Ni, Nb
FF: 12%



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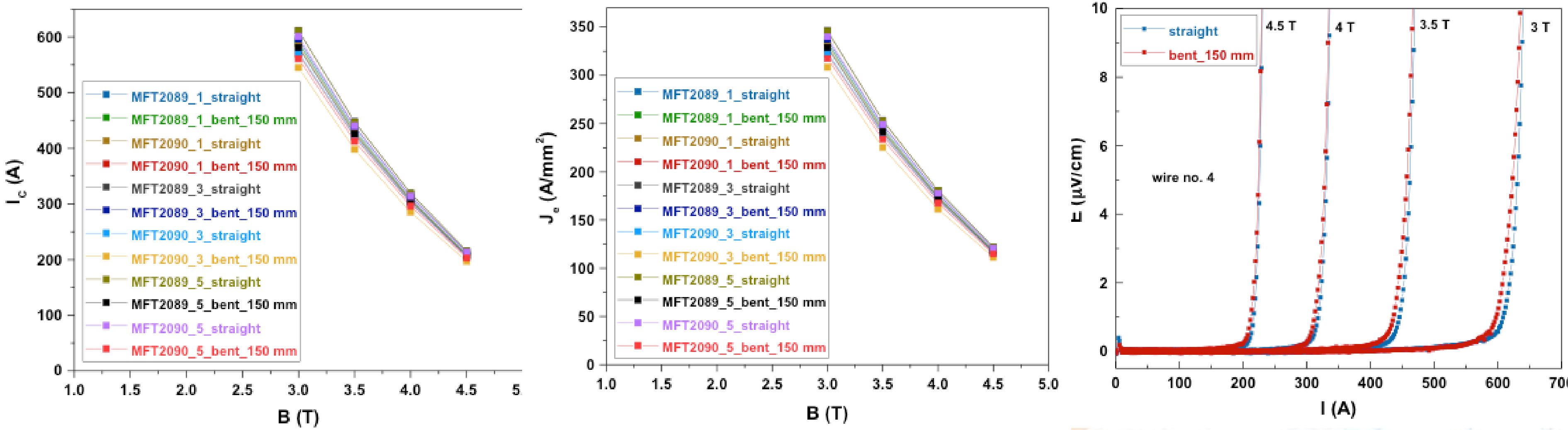
Measurements performed at CERN on 1.5mm wire

No I_c degradation measured for bending at high field

Negligible at low field (high current)



- Measurements at 4.2 K performed on straight and bent samples from last **long-length production run**
- The magnetic field was applied **parallel** to the longitudinal axis of the wire

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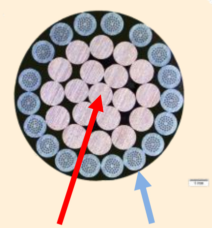
Cable design, manufacturing and test

- Cable manufactured by Nexans on industrial cabling machines
- Measurements of extracted wires performed after cabling after bending on 0,8 m diameter drum by Columbus SPA show no degradation
- Validation by electrical characterization of cable prototypes at CERN: Measurements of the critical current of 2 meter long prototype cable tested in liquid (at 4.3 K)

Design # 1

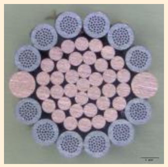
18 MgB_2 wires
I_c = 14000 A
I_{op}/I_c = 0.72
D= 9.6 mm



Cu **MgB_2**

Design # 2

12 MgB_2 +2 Cu wires
I_c = 13700 A
I_{op}/I_c = 0.73
D= 8,6 mm



Cu **MgB_2**

Benefits of Design #2 versus design #1:

1. Higher critical current density
2. Less MgB_2 wires to handle
3. MgB_2 wire stronger
4. Higher strain resistance
5. Increase of 16% of the hydraulic diameter for the Best Paths demonstrator

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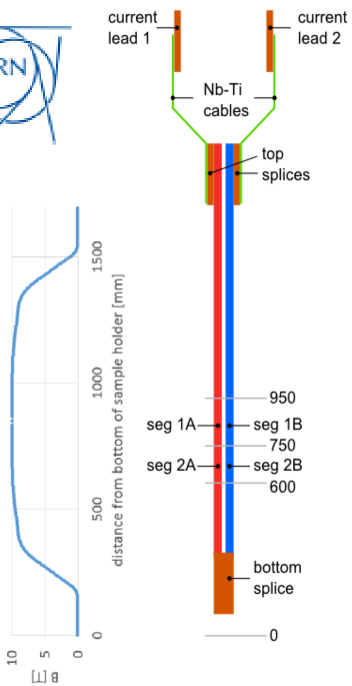
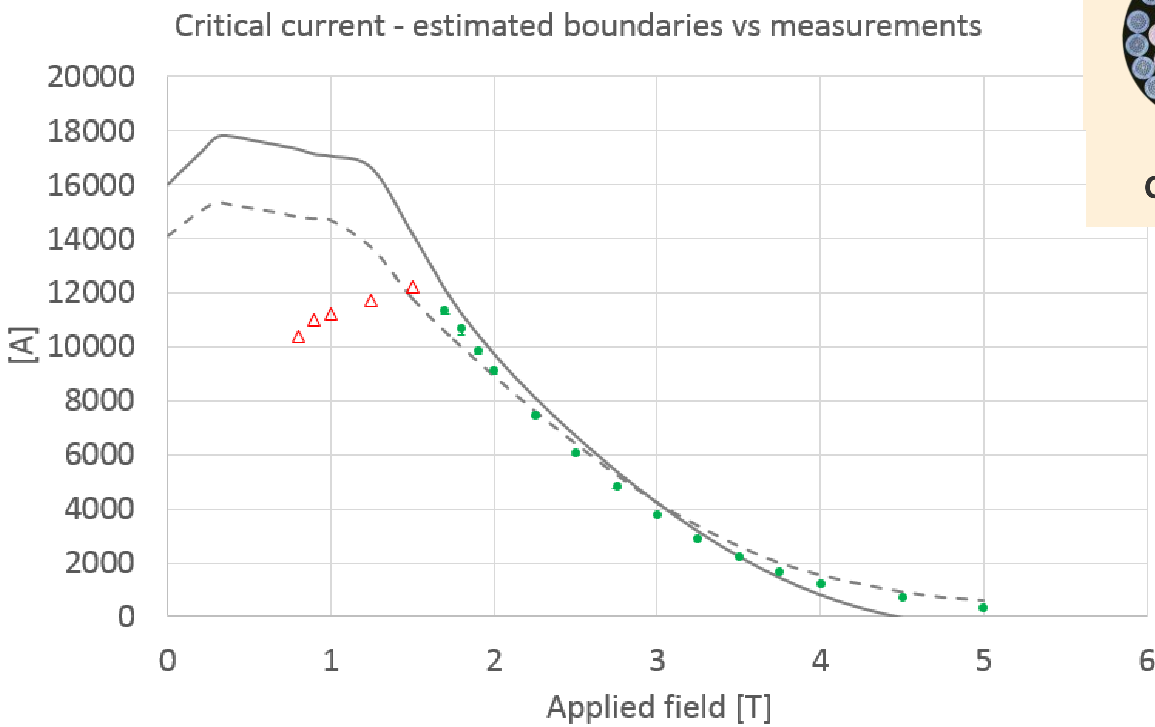
Test results at CERN Fresca Test Station

18 strands cable with Wire 1- 1.33mm tested





18 MgB_2 wires
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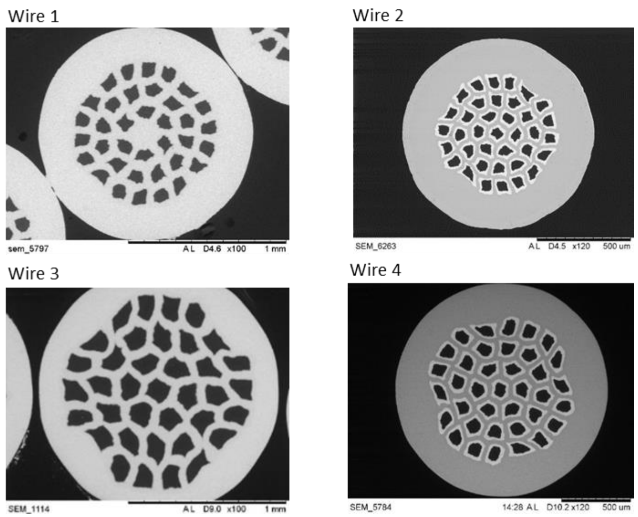
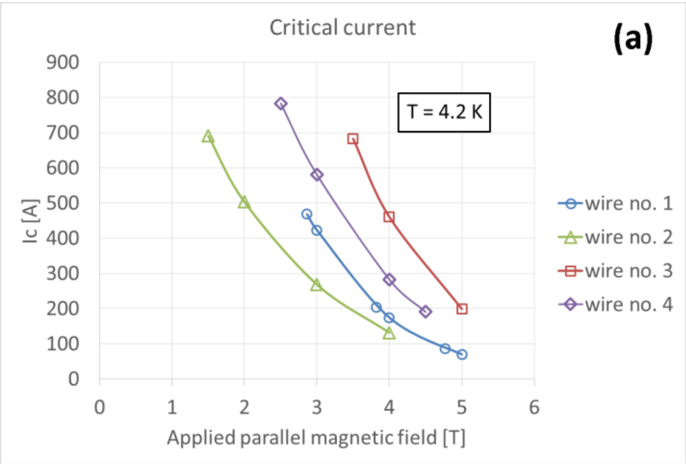
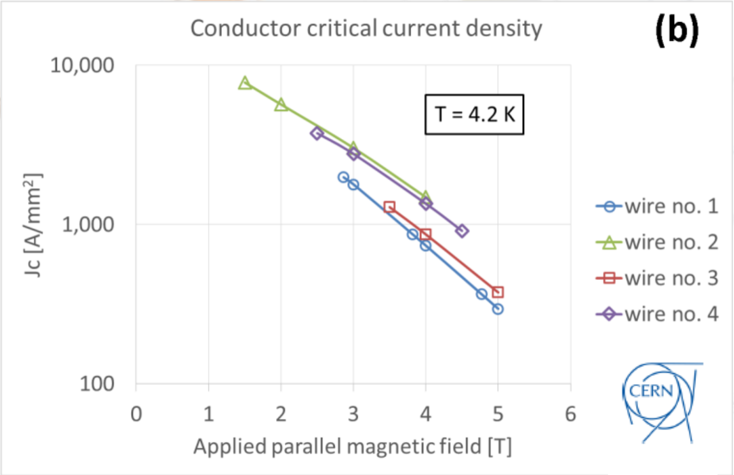
The wires proposed give enough flexibility to design the cable following different approach



PROPERTIES	Wire 1	Wire 2	Wire 3	Wire 4
Diameter (mm)	1.3	1	1.5	1.5
Materials	Monel Nickel	Monel Nickel Nb	Monel Nickel	Monel Nickel Nb
MgB2 fraction	17%	12%	30%	12%
Critical current at 20K, 1T	500A	300A	>650A	>650A
Critical current at 4.2K, 3T	280	400	>700	600
Critcal bending radius	125	100	200	150





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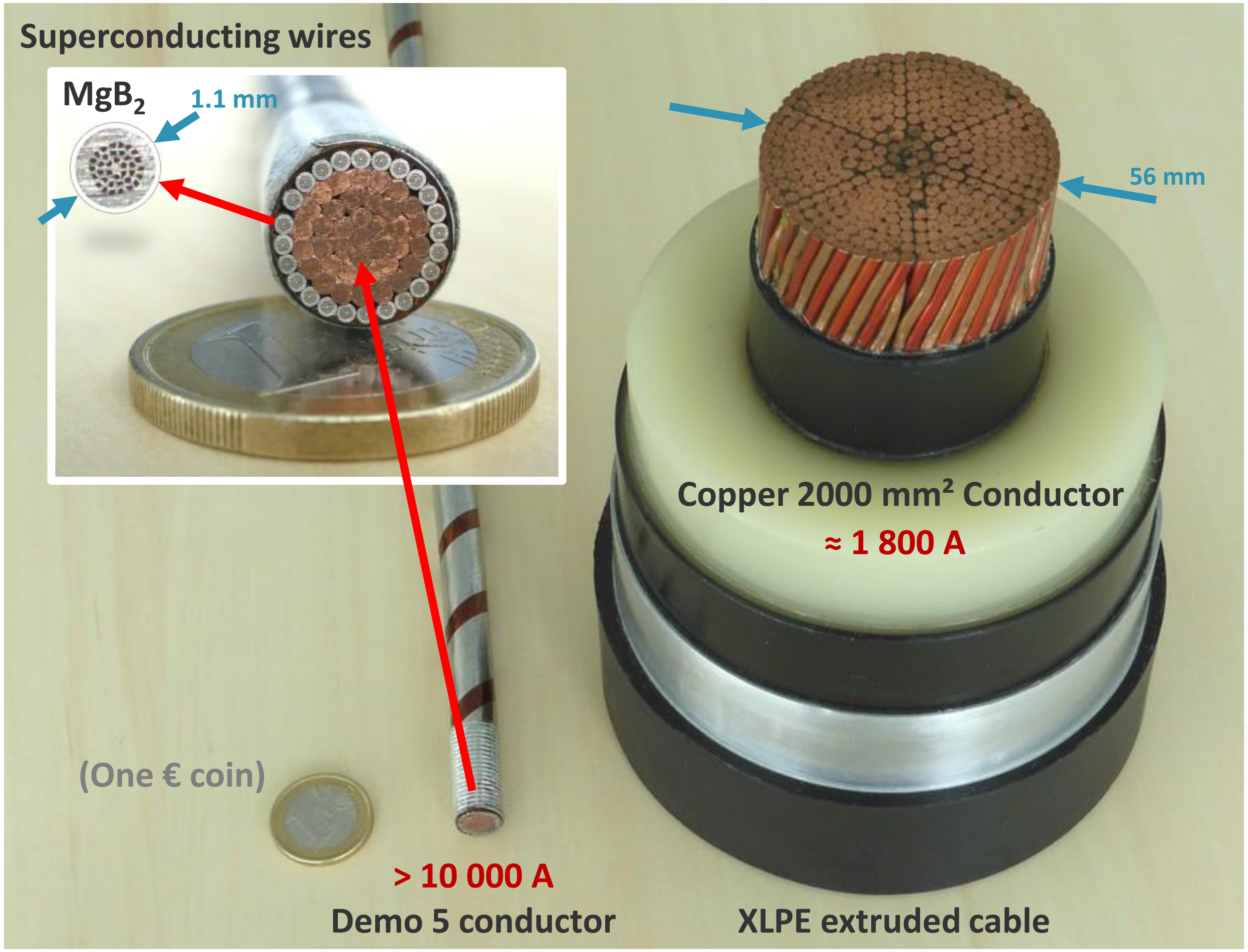

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Conclusion- Next steps

Four round wires have been optimized and proposed for the cabling activities within Best Paths

Different layouts provide enough flexibility to design the cable according to

Wires production is finished as well as cabling activities

A short length cable prototypes (Design #1) has been tested at CERN facilities (FRESCA test station)
A long length cable (Design #2) will be tested at CERN and Nexans facilities within the end of the project

Aging of commercial MgB2 wires in Hydrogen

Wilfried Goldaker et al

3-D Numerical Modelling of AC losses in MgB_2 wires for the 10 kA demonstrator of BEST PATHS

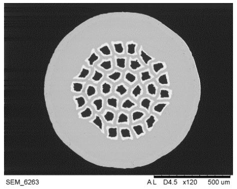
Guillaume Escamez et al.

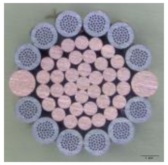
Development of MgB_2 cable conductor for very high power HVDC transmission within Best Paths project

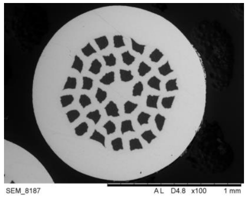
Christian-Eric Bruzek, et al.

Update on the high-power MgB_2 DC superconducting cable project within BEST PATHS

Christian Eric Bruzek, et al







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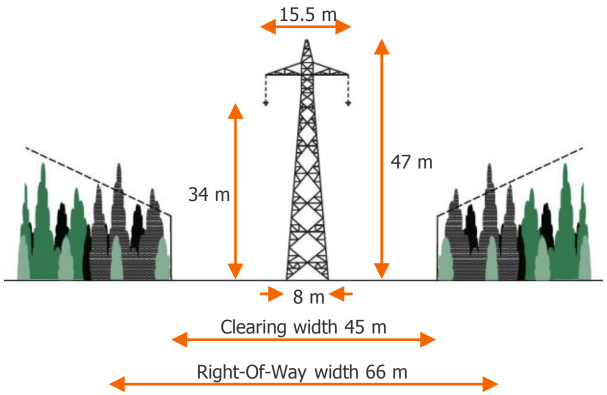
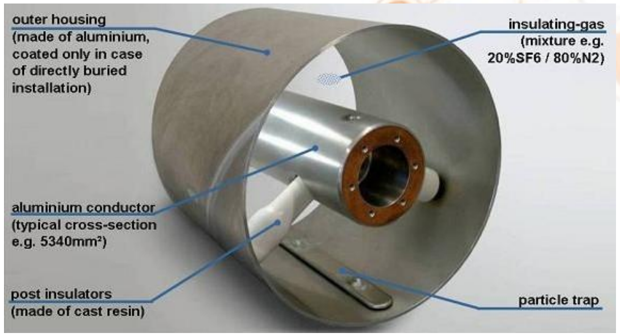
An alternative way to transmit bulk power 3-5 GW

Nelson River DC line (Canada)
1600+1800 MVA (+2000 under construction)





Raesfeld (380 kV AC, Germany)
2x 1800 MW

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Reduced space for cable installation and substations

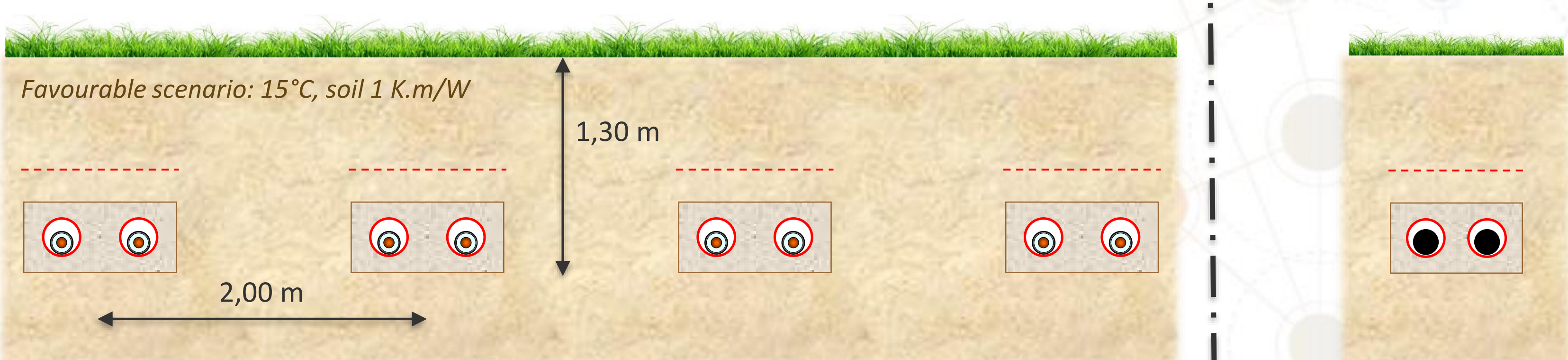
Significant reduction of right-of-way corridors and of excavation work

No thermal dependence to the environment

Example: 6.4 GW DC power link with XLPE cables

Foot print = 7 m

Foot print = 0.8 m



Resistive cables (8 x 400 kV - 2 kA)

Our Best Paths Demo 5

(2 x 320 kV - 10 kA)

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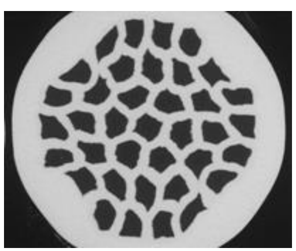
Main objectives of the superconducting demonstrator

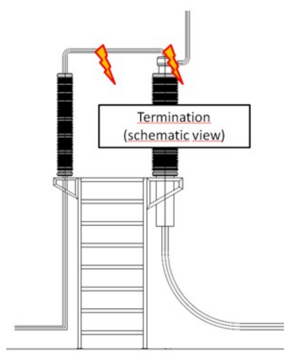
10 partners involved in the project

- Demonstrate full-scale **3 GW** class HVDC superconducting cable system operating at 320 kV and 10 kA
- Validate the novel **MgB_2** superconductor for high-power electricity transfer
- Provide information for technical aspects, economic viability, and environmental impact of this innovative technology

Process development to manufacture a large quantity of high performance MgB_2 wires at low cost

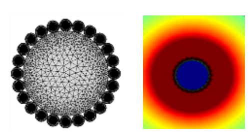


Cable and termination development + manufacturing processes



Validation of cable operations with laboratory experiments performed in He gas at variable temperature

Operating demonstration of a full scale cable system transferring up to 3.2 GW



System integration pathways for HDVC applications

Investigation in the availability of the cable system

Preparation of the possible use of H_2 liquid for long length power links

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Two approach:

1. Control quenching during the fault: « a fault tollerant » approach

- Design the cable for the 10kA operating condition and Ic 13-15KA and accept a global resistive transition

- Smaller overall dimension and amount of SC wires
- Need to evaluate the impact of cable heating on cryogenics enviroment, recovery time, ect etc

2. No quench during the fault « a fault transparent » appraocah

- Design the cable for 35kA (Ic of 42kA)

- Bigger overall dimension, larger number strands
- No additional load on the GRID
- Need to carefully evaluate AC losses and thermal margin during transient

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Demonstrator technical specification and testing strategy

Characteristics	
Structure	Monopole
Power	3.2 GW
Voltage	320 kV
Current	10 kA
Length	~ 20 m
Cooling media	Liq N_2 for the electrical insulation He gas for MgB_2 conductor
Losses of the demonstrator	< 50 W He gas (~20 K)
Fault current	35 kA during 100 ms
AC Ripples on 10 kA DC current	< 1% amplitude 50 Hz
Change of power flow direction	100 MW/s up to 10 GW/s

- Test of operating conditions on the demonstrator
- But use only modeling to check the cable behavior during faults and polarity changes

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Best Paths

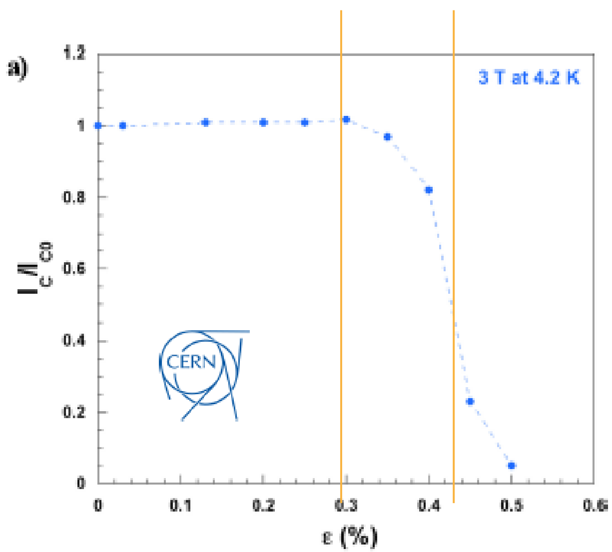
Transmission for sustainability

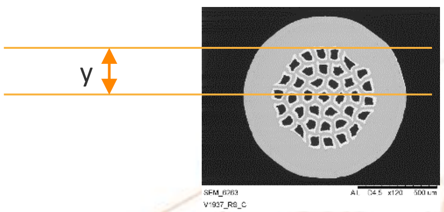
Columbus Superconductors

Electro-mechanical characterization of MgB_2 wires for the Superconducting Link Project at CERN

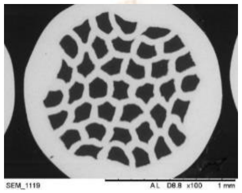
K Konstantopoulou[1,2], A Ballarino[1], A Gharib[1], A Stimac[1], M Garcia Gonzalez[1], A T Perez Fontenla[1] and M Sugano[3]

[1] European Organization for Nuclear Research (CERN), Switzerland
[2] Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), Spain
[3] High Energy Accelerator Research Organization (KEK), Japan





1mm diameter
y=0.3mm
R=100mm strain 0.3
No degradation



1.5mm diameter
y=0.65mm
R=150mm strain 0.43
40% Ic degradation

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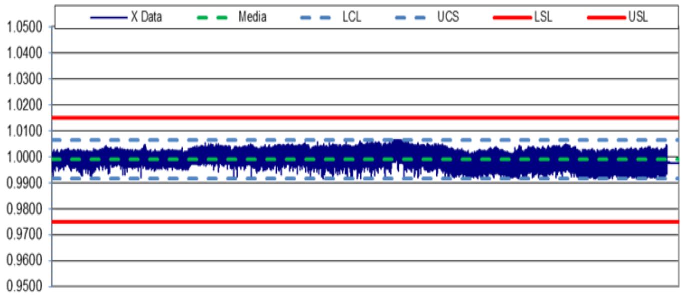
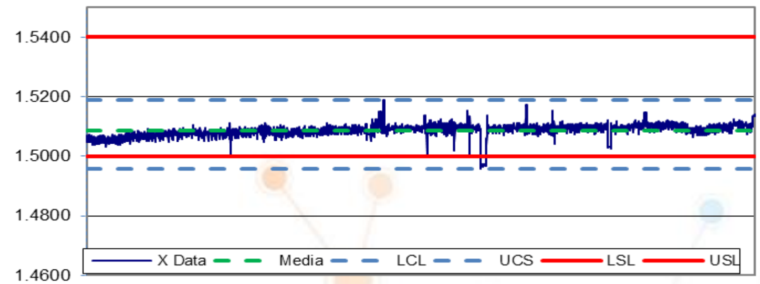
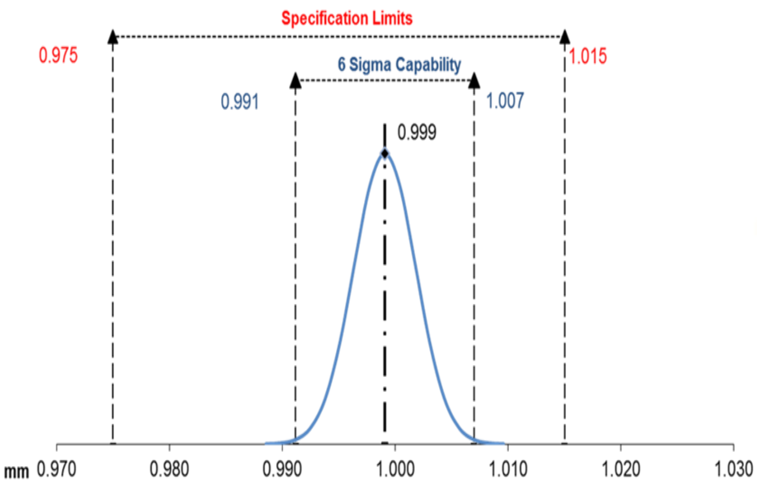
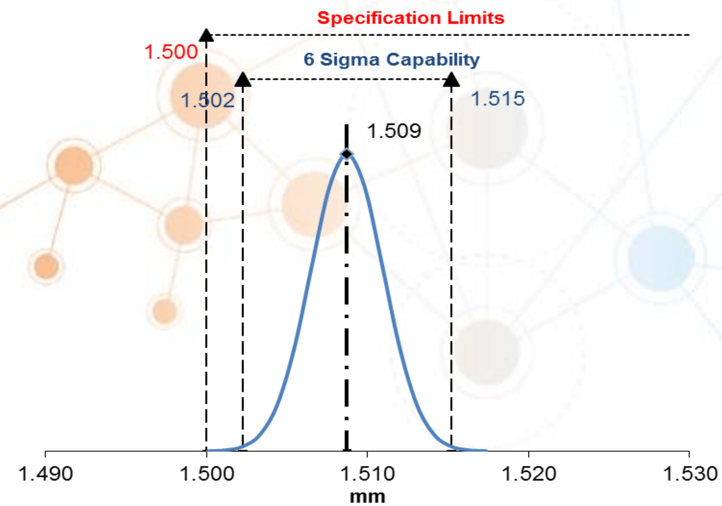
Best Paths
Transmission for sustainability









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