The MgB_2 Wire for the Superconducting Link HL-LHC Project

B. Bordini, A. Ballarino, J. Duvauchelle, J. Hurte,
P. Jacquot, K. Konstantopoulou, D. Richter

International Review of the conceptual Design of the Cold Powering system for the HL-LHC Superconducting Magnets – CERN – 03 July / 04 July 2017

Outline

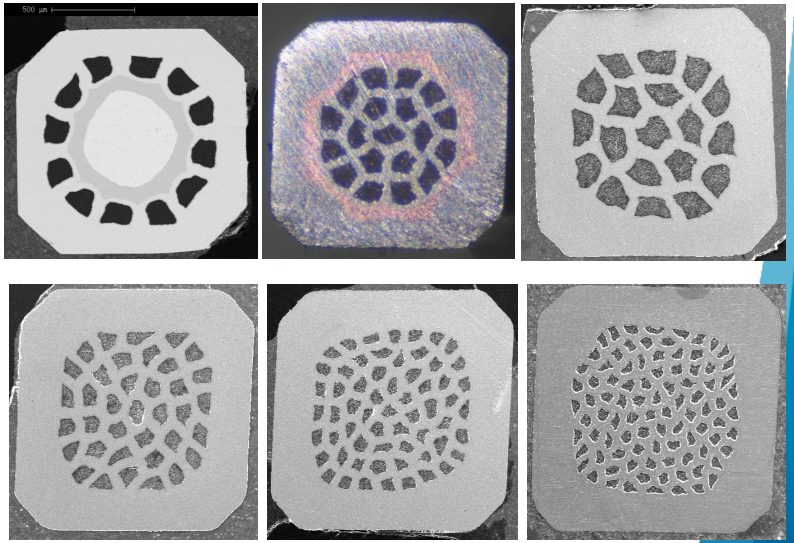
- Introduction
  - Development of the wire and main characteristics
- Technical Spec & Critical Current Performance
  - Main Parameters
  - Temperature dependence
- The first large procurement (80 km)
  - Measurement results from Columbus SPA and from CERN
- Status of the running contract and plans for next contracts
- Conclusions

Introduction

From Square to Round

- During the last years CERN has being collaborating with COLUMBUS for the development of a round MgB_2 wire suitable to the Superconducting Link Project

- Starting from their original square wires, COLUMBUS has manufactured several types of round wires, solving different type of issues



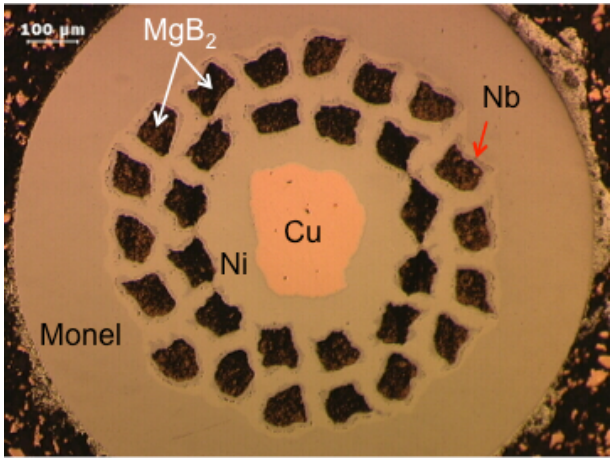
Introduction

Introducing the Nb barrier

- At the beginning of 2012, the state of the art MgB_2 wire for the superconducting link project was a 1.17 mm round wire composed of 30 MgB_2 filaments embedded in a Nickel matrix; a thin Niobum barrier was separating the MgB_2 from the Nickel.

- The wire had a copper core and an external Monel annulus around the Ni matrix.

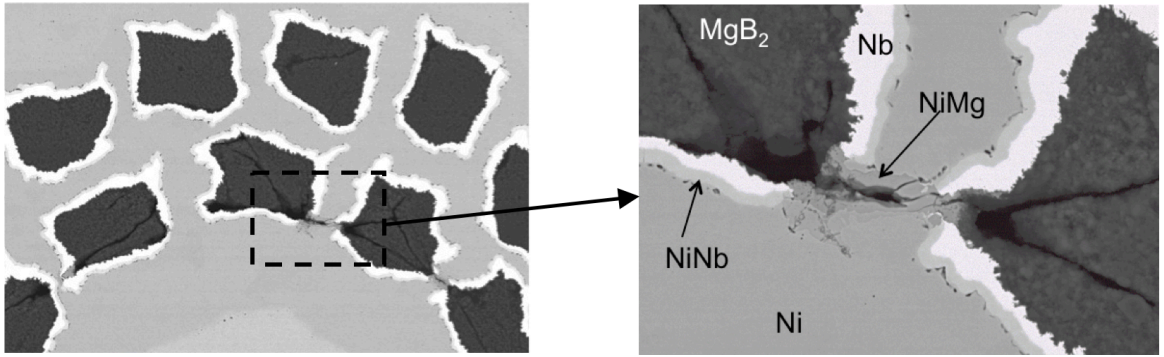
- Relatively large J_e (550 A/mm^2 at 4.3 K,1 T) but significantly non-homogeneous along the wire length (30%)



Introduction

Cracks in the Nb barrier and in the MgB_2

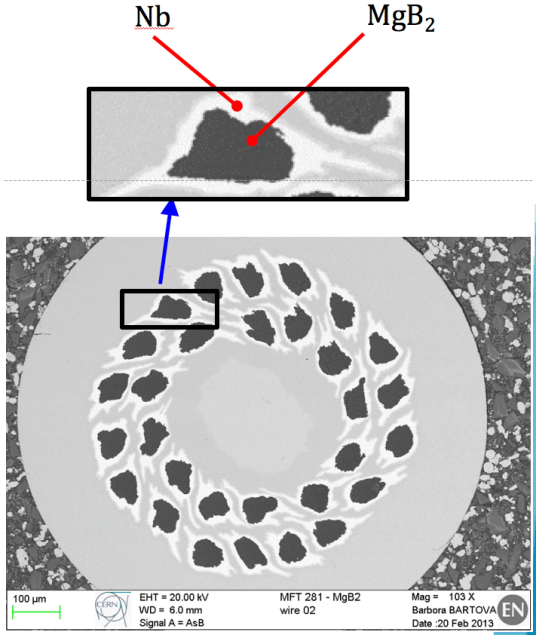
- Non-homogeneity was due to cracks on the MgB_2 filaments
- Cracks were associated to a failure of the Nb barrier
- The barrier failure allows the formation of NiMg, a very brittle compound that favors the formation of cracks.



Introduction

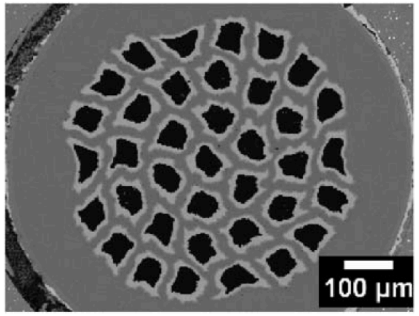
Doubling the Nb barrier Thickness

- The problem of non-homogeneity was solved by doubling the thickness of the Nb barrier
- The diameter of the wire was reduced to 1 mm
- This wire could also tolerate at room temperature a bending radius of 100 mm
- However, the critical current performance of this wire were still not sufficient



MgB_2	10.4 %
Monel 400	44.6 %
Ni	26.8 %
Nb	13 %
Cu	5.2 %

Introduction
Increasing the J_e

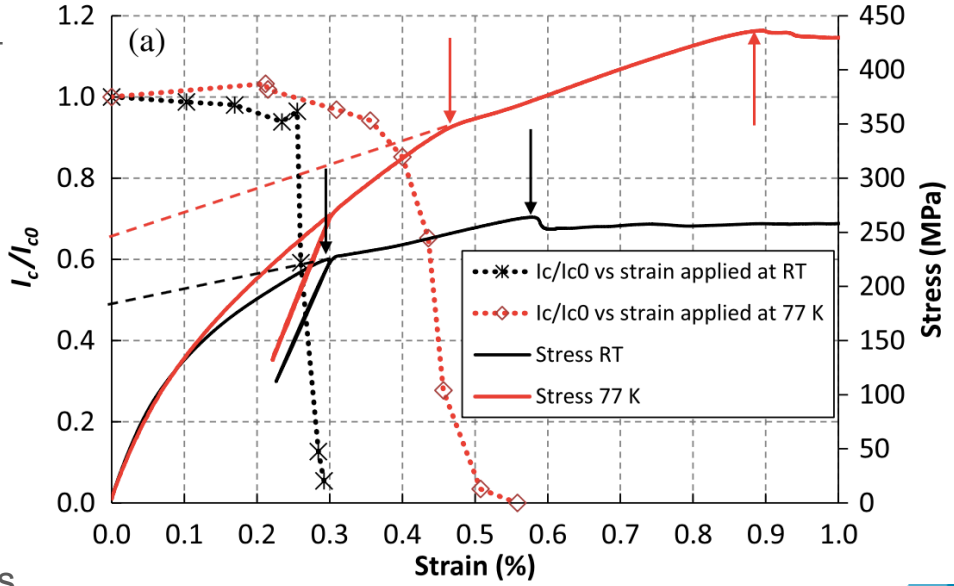


- The following steps were to :
  - increase the number of filaments (from 30 to 37) by removing the central Cu core,
  - reduce the Monel fraction of and the strand diameter from 1 mm to 0.85 mm
- In June 2013: J_e equal to 750 A/mm^2 at 4.3 K,1 T
- To further improve J_e, CERN and Columbus decided to use higher quality boron (from 95 % to 99 % purity) for producing the MgB_2 powder
  - This sole change significantly increased the current performance, the J_e increased from 750 A/mm^2 to 1150 A/mm^2 at 4.3 K, 1 T

Introduction

Electro-Mechanical Performance not Sufficient

- Permanent I_c degradation of 5% $\varepsilon_{crit-RT} \approx 0.25\%$ and $\varepsilon_{crit-77K} \approx 0.35\%$,
- Two characteristic changes of the slope of the RT and 77 K stress–strain curves
  - The first at about 0.28% and 0.47% at RT and 77 K, respectively.
  - These strain values are close to the strain values which cause a nearly complete I_c degradation.
  - Strong filament damage when strain exceeds 0.28% and 0.47% at RT and 77 K, respectively.



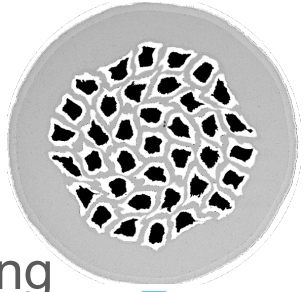
Courtesy of P. Alknes

P. Alknes, M. Hagner, R. Bjoerstad, C. Scheuerlein, B. Bordini, M. Sugano, J. Hudspeth, and A. Ballarino
IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 26, NO. 3, APRIL 2016

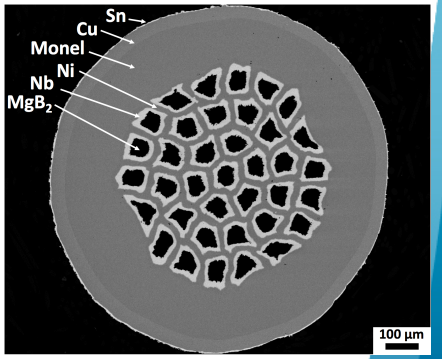
Introduction
Final Layout

- In order to improve the electro-mechanical performance of the wire, Columbus increased the Monel fraction maintaining the same layout of the superconducting filaments
  - the diameter was increased from 0.85 mm to 1 mm

From 0.85 mm



To 1 mm



Diameter	Filaments	Filament size	MgB_2	Nb	Ni	Nb-Ni	Monel	Cu
1.0 mm	37	55 µm	10%	8%	14%	4%	48%	16%

Courtesy of P. Alknes

Technical Spec & Critical Current Performance

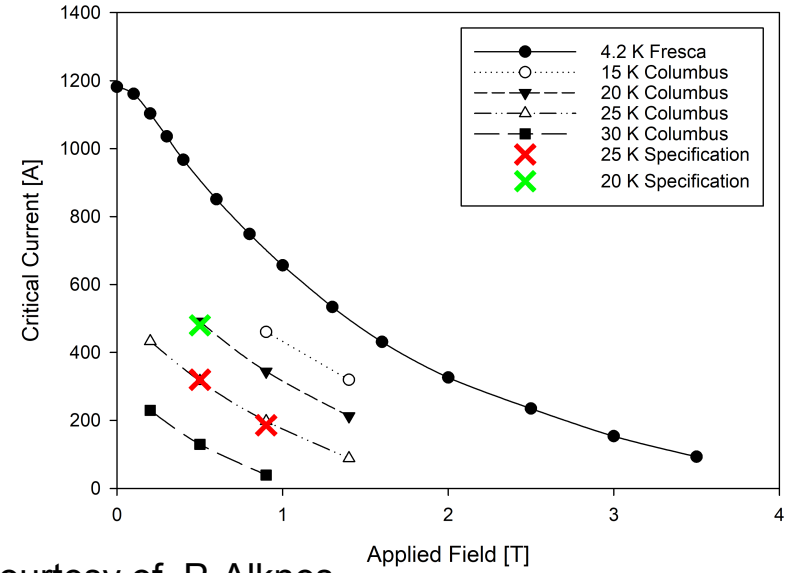
Main Parameters

Wire diameter Φ	0.995 ± 0.02 mm
Nominal sub-element diameter	≤ 60 μm
Copper Fraction	≥ 12 %
Wire twist pitch	100 mm
Minimum Piece Length	500 m
Minimum critical current @ 25 K, 0.9T	≥ 186 A
Minimum critical current @ 25K, 0.5T	≥ 320 A
Minimum critical current @ 20K, 0.5T	≥ 480 A
Minimum bending Radius	≤ 100 mm
Copper RRR	≥ 100

Technical Spec & Critical Current Performance

Pre-Production Billet (V1937)

- Before starting the industrial production, Columbus shipped to CERN 100 m of wire from a pre-production billet (V1937)
- Measurements done at Columbus and CERN showed that this wire met the specifications of the Link Project



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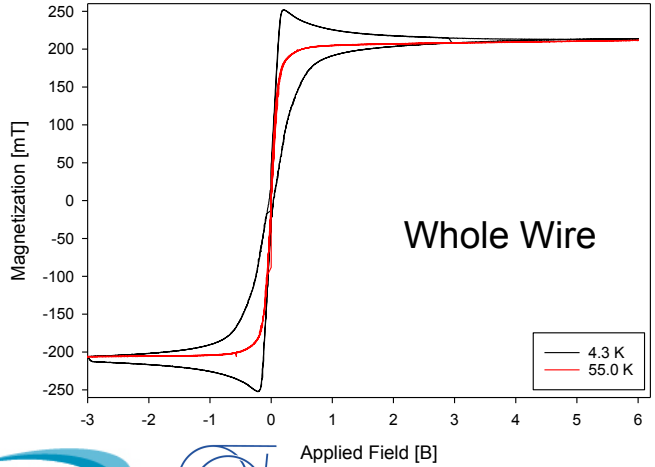
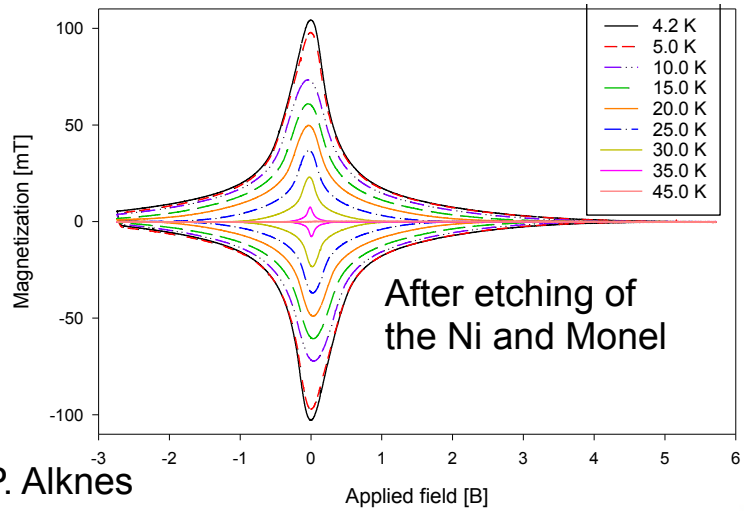
Technical Spec & Critical Current Performance

Temperature Dependence 1/2

- The temperature dependence was estimated via magnetization measurements carried out at CERN



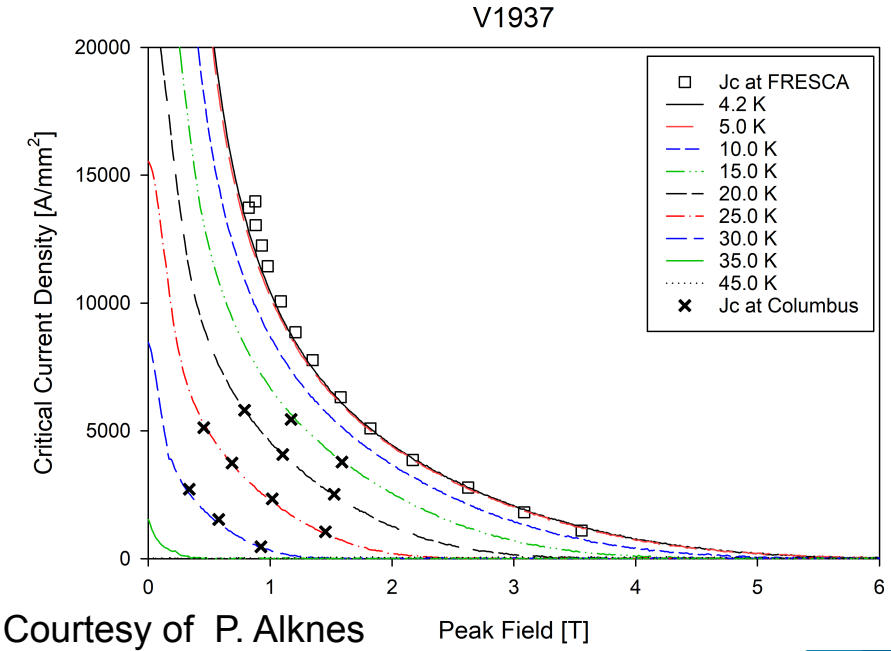


Courtesy of P. Alknes

Technical Spec & Critical Current Performance

Temperature Dependence 2/2

- The critical current density was estimated by normalizing the magnetization measurements results with the transport current results obtained in FRESCA
- The estimation is consistent with the transport measurements performed by Columbus SPA

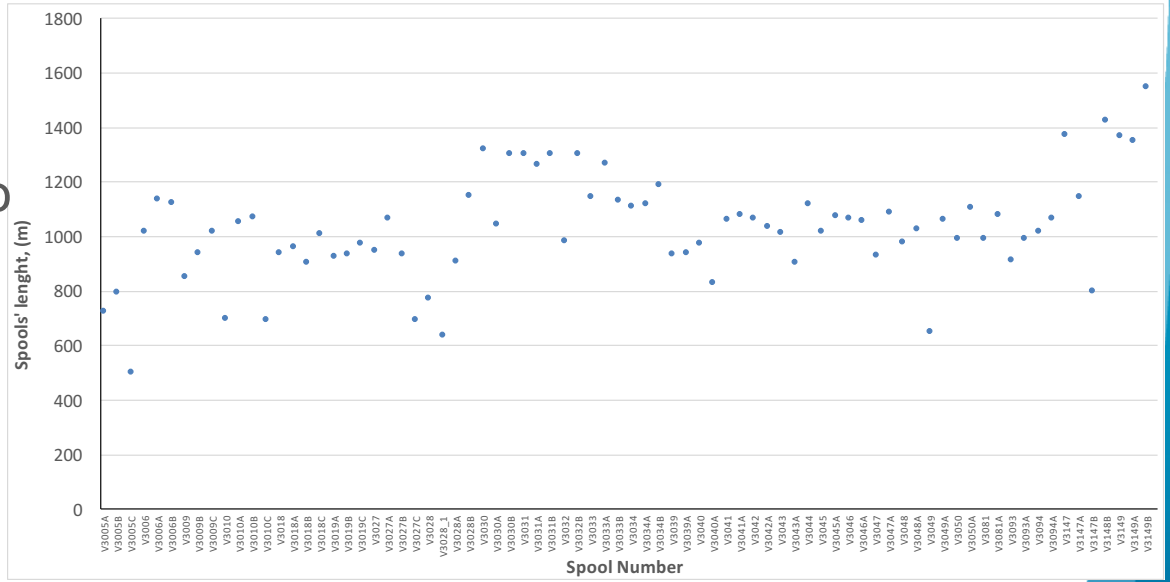


Courtesy of P. Alknes

The first Large Procurement

Quantities and Timing

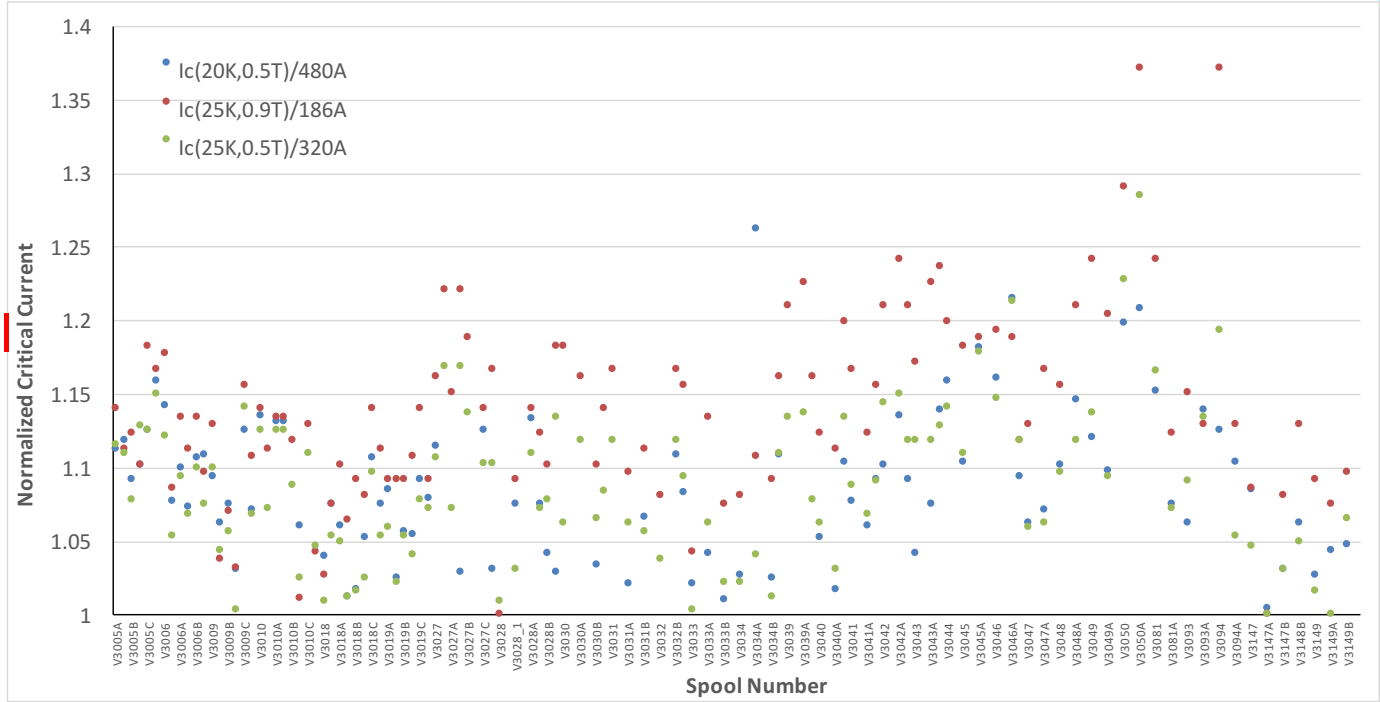
- Between September 2015 and June 2016, Columbus SPA successfully shipped to CERN 80 km of MgB_2 wire
- The material was produced from 31 billets and in total CERN received 78 spools



The first Large Procurement

Columbus QC measurements – I_c straight wire

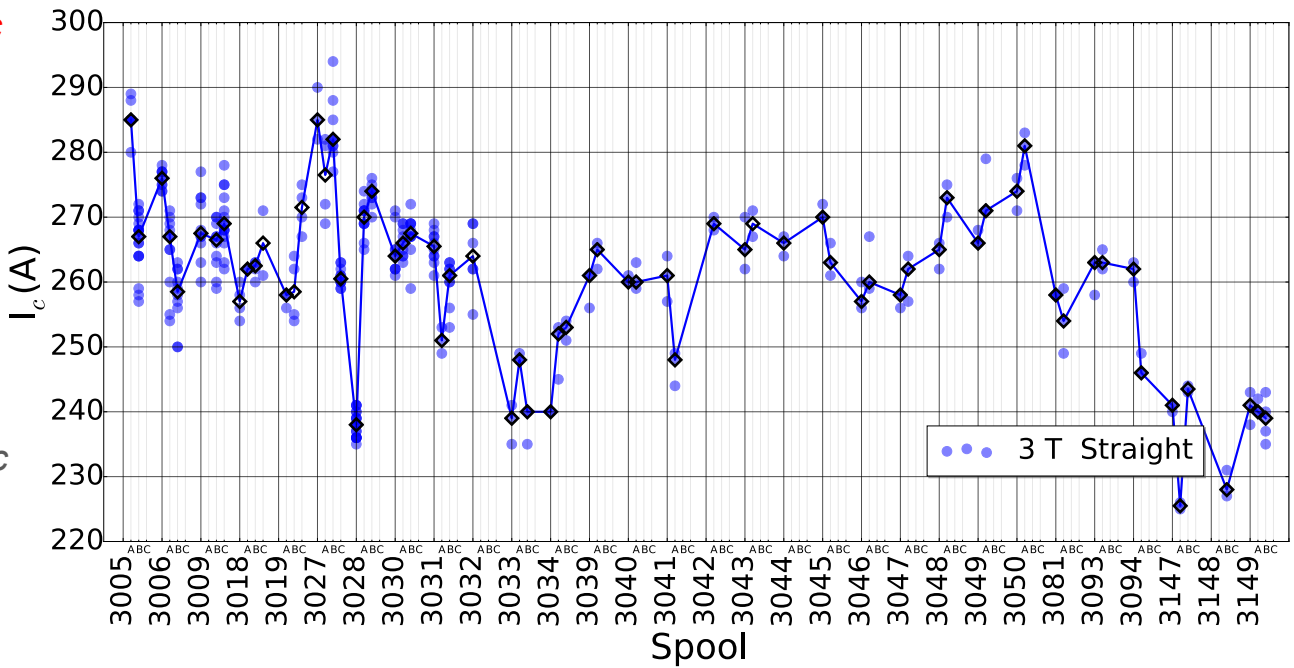
- Columbus performed one I_c measurement on each shipped spool



The first Large Procurement

CERN Verification Measurements - I_c straight wire

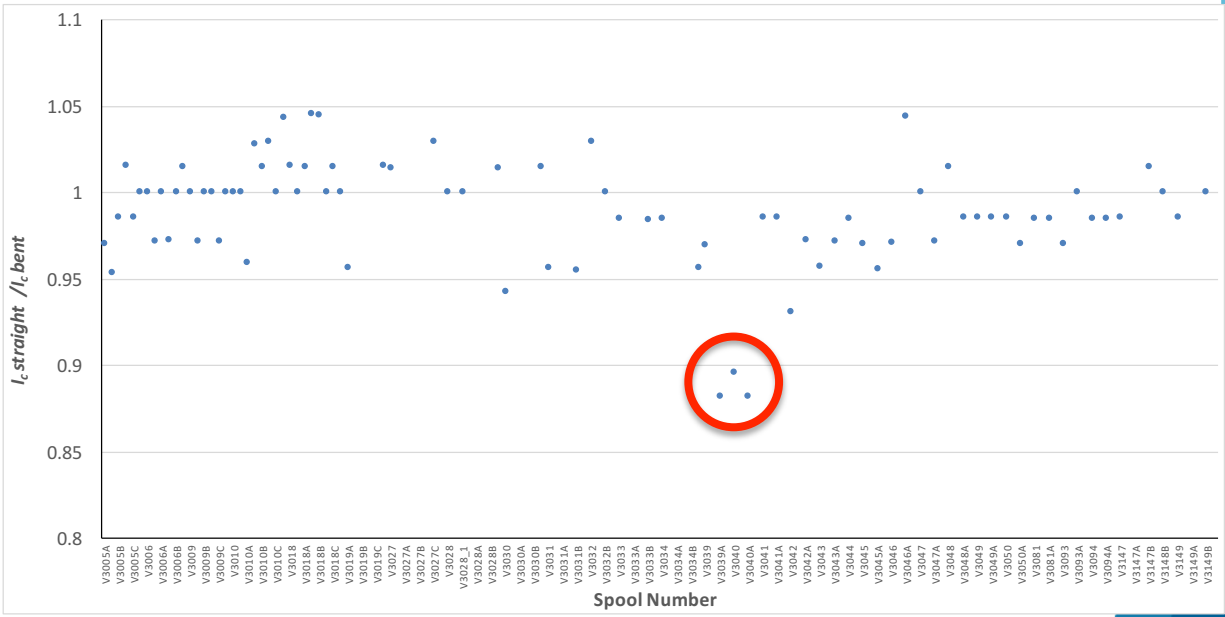
- Several verification I_c measurements (in parallel magnetic field) were done at CERN per each spool of wire
- The variation of the I_c was consistent with Columbus data



The first Large Procurement

Columbus QC measurements – I_c bent wire

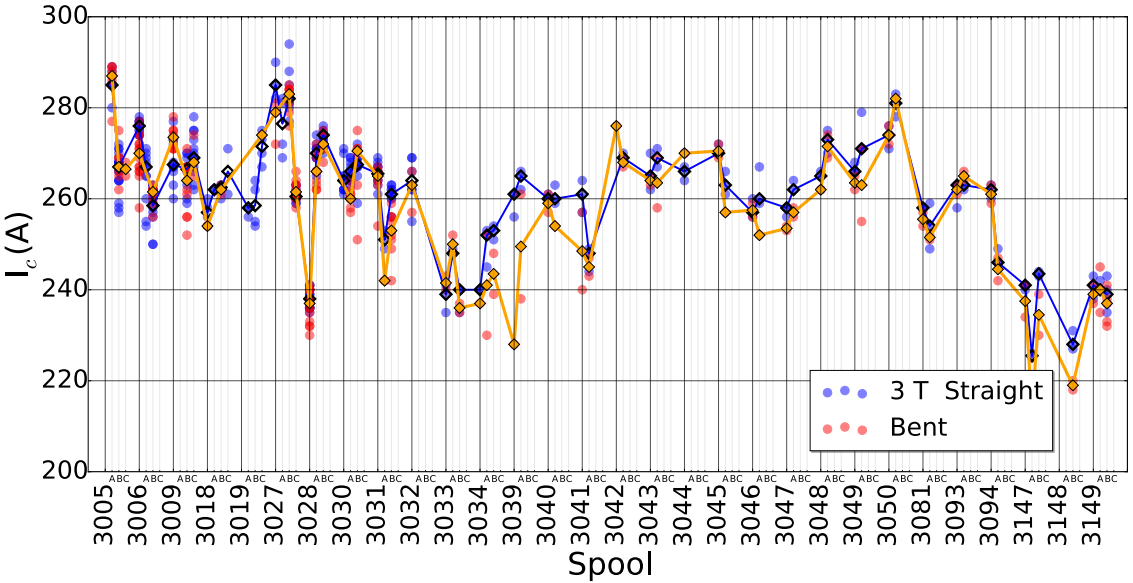
- Measurements of straight and bent (100 mm radius) performed at 4.2 K and 2 T
- Limited resolution: a difference of 5% cannot be attributed to the bending
- Only three spools were identified as critical



The first Large Procurement

CERN Verification Measurements - I_c bent wire

- CERN also performed measurements of bent (100 mm radius) samples at 4.2 K in parallel field – more than 90 % of the material completely fulfils the specifications
- Higher resolution (2%)
- Confirmed that billet 3039 had up to 10% degradation
- Other 4-5 spools presented a limited degradation (<5%)



Status of the Running Contract

- From the beginning of the year CERN already received 156 km out of the 200 km of wire ordered for manufacturing the prototype link
- Verification measurements carried out at CERN identified a non conformity in the first 100 km received
  - Large degradation (more than 10 %) after bending (100 mm radius) was observed in most of the the spools (in some case degradation up to 40 %) – only 13 km completely conform to specs
- Correction actions have been taken and the first measurements (70 on 14 spools) of the last shipment (35 spools, about 56 km) do not present degradation after bending

Plans for Next Contracts

- For the Link project additional 1200 km of wire are needed
- CERN Financial Committee has already approved an order for 200 km
  - The contract is expected to be placed by September 2017
- The remaining 1000 km are planned to be ordered by march 2018

Conclusions

- In collaboration with CERN, COLUMBUS SPA has developed a wire that fulfills the electro-mechanical performance required for the Superconducting Link Project
- The performance of the first large procurement (80 km of wire) demonstrated that the production can be industrialized without affecting the quality of the wire
- From the beginning of the year CERN already received 156 km out of the 200 km of wire ordered for manufacturing the prototype link
  - Verification measurements carried out at CERN identified a non conformity in the first 100 km received; correction actions have been taken and the first measurements of the last shipment (about 56 km) do not present the non conformity
- CERN is planning to place an additional order for 200 km of wire by September this year. The contract for the remaining 1000 km, which fulfils the needs of the project, is expected to be signed by march 2018

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HL-LHC PROJECT

Thanks For Your Attention !

CERN