Baseline Conductor Specification

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1st Review of the EuroCirCol WP 5

Outline

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Introduction

HiLumi Wire Technical Specs

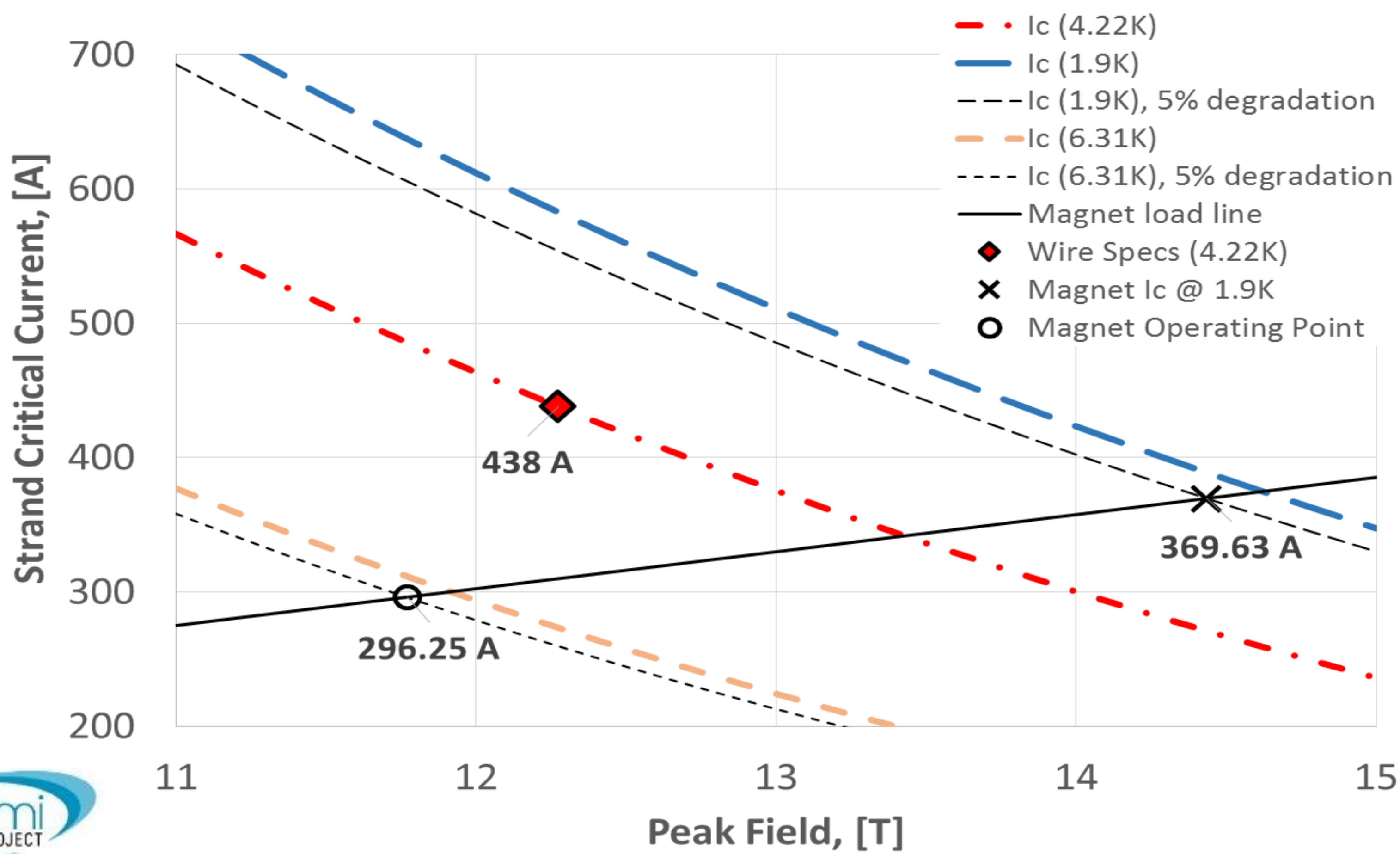
	11 T Dipole	MQXF Quadrupole
Wire diameter Φ	0.700 ± 0.003 mm	0.850 ± 0.003 mm
Nominal sub-element diameter	< 50 μm	< 55 μm
Copper to non-copper ratio	1.15 ± 0.1	1.2 ± 0.1
Wire twist pitch	14 ± 2 mm	19 ± 3 mm
Wire twist direction	Right-handed screw	Right-handed screw
Minimum critical current @ 4.22K, 12T	438 A	632 A
Minimum critical current @ 4.22K, 15T	/	331 A
RRR (after full heat treatment)	> 150	> 150
n-value @ 4.22K, 12T	> 30	> 30

$$J_c(4.22\ K,\ \mathbf{12}\ T) \approx \mathbf{2450\ A/mm^2}$$

$$J_c(4.22\ K,\ \mathbf{15}\ T) \approx \mathbf{1280\ A/mm^2}$$

Introduction

11 T Wire Technical Specs & Magnet Margin



4.4 K Temperature Margin; 20 % Margin on the Load-Line;

I_c margin about 105%

EuroCirCol Baseline Conductor

J_c (T, B) scaling

Scaling Law

$$J_c = \frac{C}{B} \cdot b^{0.5}(1-b)^2 \qquad b = \frac{B}{B_{c2}}$$

$$C = C_0 \left[(B_{c2})(1-t^2) \right]^{\alpha}$$

$$B_{c2} = B_{c20}\left[1 - t^{1.52}\right] \qquad t = \frac{T}{T_{c0}}$$

Parameters

J_c(16 T, 4.22 K) = 1500 A/mm^2

B_{c2}(4.22 K) = 25.5 T

T_{c0} = 16 K

α = 0.96

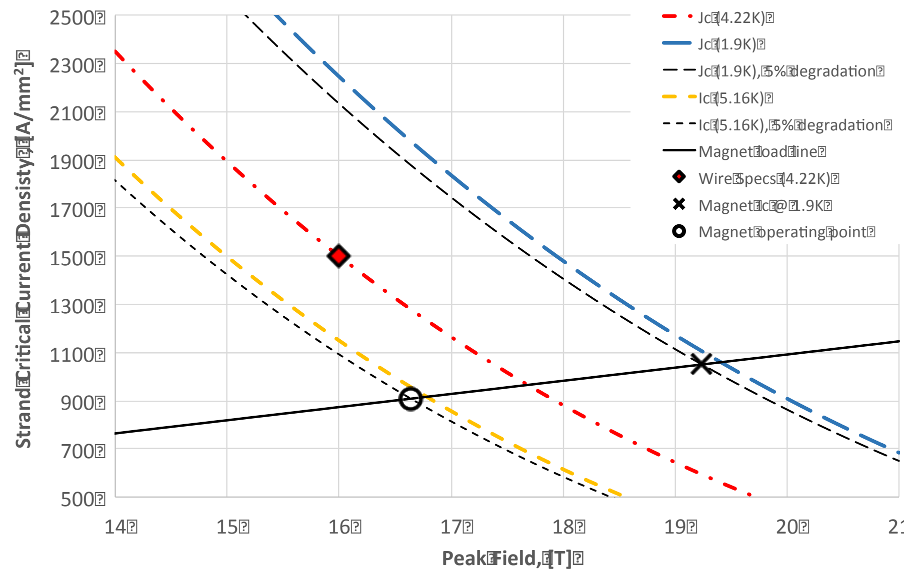
- Fresca2 RRP wire (1 mm – 132/169)
  - J_c(15.2 T, 4.22 K)= 1557 A/mm^2 (RMS 67 A/mm^2)
  - B_{c2}(4.22 K) = 25 T

J_c(16 T, 4.22 K) = 1280 A/mm^2

EuroCirCol Baseline Conductor

Conductor Performance and Magnet Margins 1/2

- By assuming:
  - B_{bore} 16 T;
  - B_{peak}/B_{bore}=1.04
  - B_{bore} ultimate 18.5 T



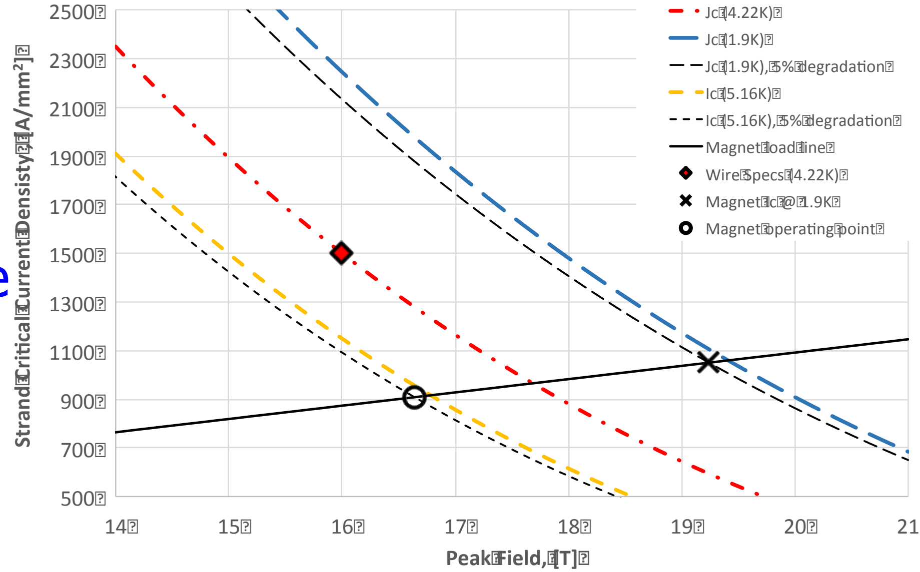
- Magnet Margins:
  - 15.6 % on the load line – lower than Hi-Lumi
  - 3.3 K – significantly lower than Hi-Lumi (especially considering the enthalpy margin)
  - Current margin @ operating point 106.7 % - similar to HiLumi

All the three magnet margins have an impact on the final magnet performance; changing one conductor parameter has not necessarily the same impact on the three margins (example next slide)

EuroCirCol Baseline Conductor

Conductor Performance and Magnet Margins 2/2

- By assuming:
  - same magnet design (load line & operating point as previous slide)
  - same conductor specification but the B_{c2}(4.22 K), from 25.5 T to 23 T

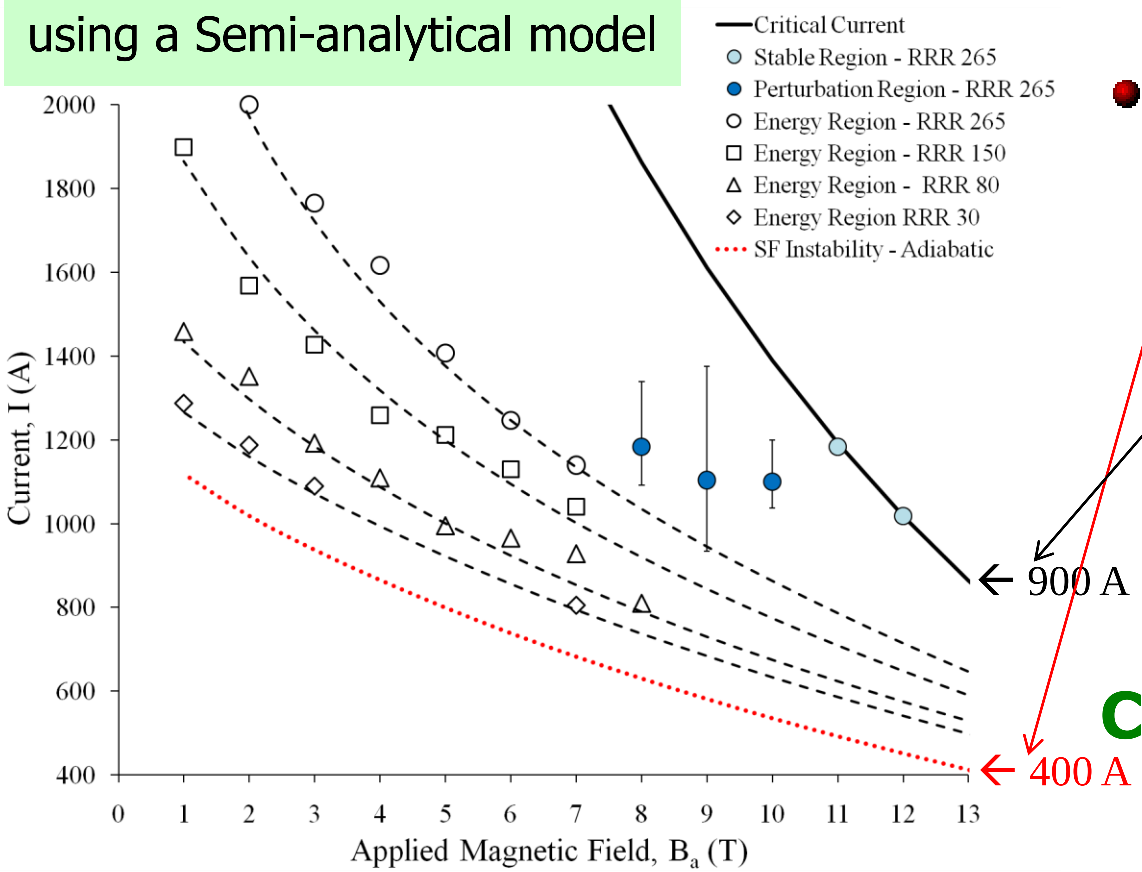


- Magnet Margins:
  - 13.7 % (instead of 15.6 %) on the load line ↓
  - 2.9 K (instead of 3.3 K) ↓
  - Current margin @ operating point 120.6 % (instead of 106.7 %) ↑

Instability @1.9 K and Magnet Margin
High Field Instability and Current Margin

- Because of magneto-thermal instabilities, small perturbations can produce premature quenches at high fields

Dashed Lines are Simulations using a Semi-analytical model



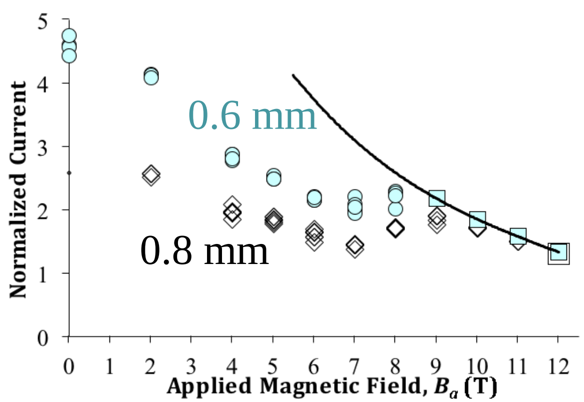
- A 13 T magnet using this wire with low RRR should have an operating current more than two times smaller than its critical current in order not to risk to be limited by instabilities

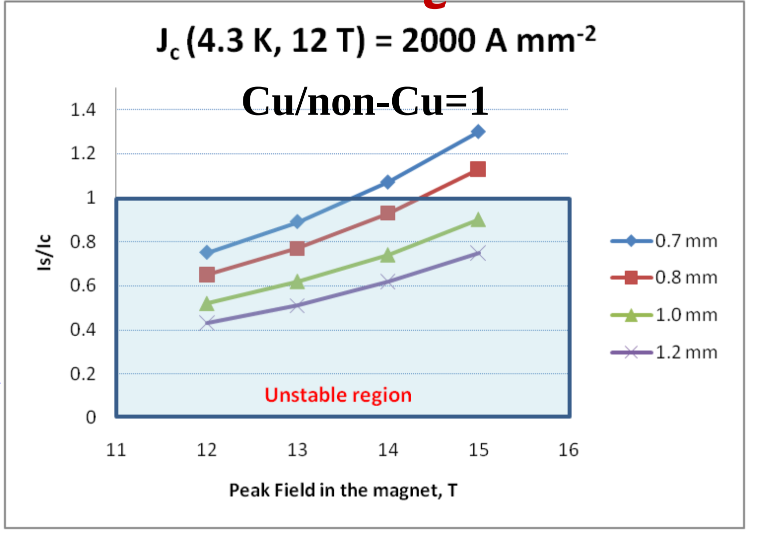
Current Margin > 100%

Instability @1.9 K and Magnet Margin
Effect of the Strand Diameter and J_e

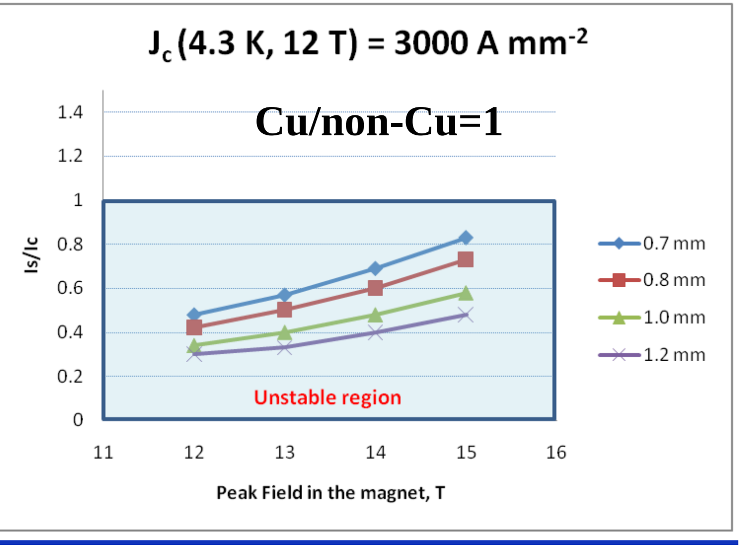
- The current margin of the magnet has to be larger the larger is
  - The strand diameters
  - The Engineering Critical Current Density

RRR	J_c @ 4.2 K, 12 T [A/mm²]	Strand diam. [mm]	Cu/ non-Cu
290	2978	**0.8**	0.927
270	2842	**0.6**	





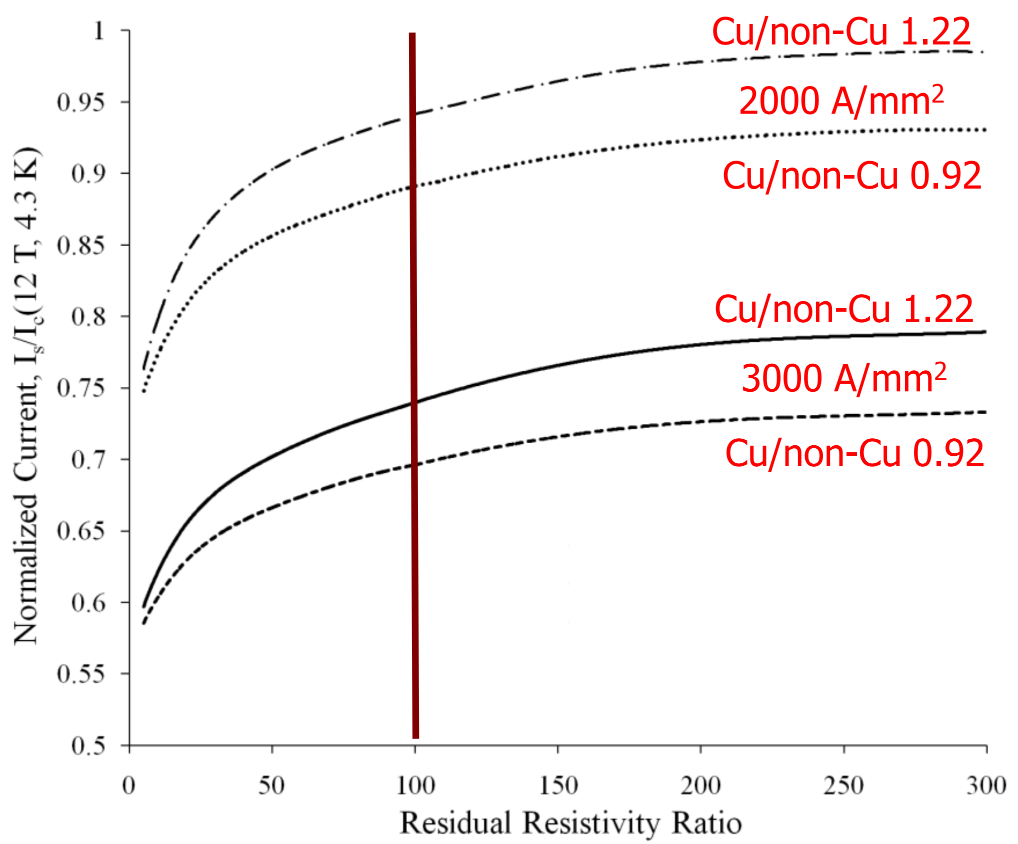
Adiabatic Calculation



Instability @1.9 K and Magnet Margin

Effect of Cu/non-Cu and RRR

- A larger current margin has also to be envisaged in the case of a smaller Cu fraction and smaller RRR



Ratio between the quench current and (12 T, 4.3 K) as a function of RRR in the case of high field instability at 12 T and 4.3 K for different strands.

Layout of the EuroCirCol Baseline conductor
Wire Diameter and non-Cu Fraction 1/2

- In order to build a Nb_3Sn magnet operating at 16 T and with a relatively large inductance (to limit the voltage within the magnet), magnet designer are naturally directed (by electromagnetic calculations) towards large:
  - strand diameters
  - superconductor Fraction in the wire

  (In the high Field Region)

- On the other hand increasing two much these two parameters has a negative impact on the magnet performance
  - ↑ Diameters and non-Cu fraction → ↓ lower magnet stability (we need a larger current margin)
  - ↑ non-Cu fraction → ↑ conductor degradation
  - ↑ non-Cu fraction → ↓ billet yield (more breakages during wire production)

Layout of the EuroCirCol Baseline conductor
Wire Diameter and non-Cu Fraction 2/2

- Taking into account the pros and cons presented in the previous slide the larger wire diameter and Non-Cu fraction for EuroCirCol were set respectively equal to 1.1 mm and to 50%
- These maximum values for the diameter and Non-Cu are challenging :
  - 1 mm is the largest diameter used for building Nb_3Sn accelerator magnets in the last 15 years
  - the non-Cu fraction of the HL-LHC 11 T (0.7 mm wire) is 46.5%; of the HL-LHC MQXF (0.85 mm wire) is 45.5 %; of the FRESCA2 (1 mm wire) is 44.5 %
- Regarding the minimum wire diameter, it was set equal to 0.7 mm because:
  - the interest of magnet designer towards smaller wire diameters is not much
  - Wire manufacturers still have a good billet yield with this diameter

Layout of the EuroCirCol Baseline conductor

Cable Constrains

- For the cable the following constraint were set
  - Maximum number of strand equal to 40
  - Maximum Compaction *C* of the cable thin edge larger than 0.14 ($c = 1 - h/2d$; where *h* is the cable thin edge thickness and *d* the wire diameter)
- The maximum number of strands was mainly fixed because of the present limitation of the CERN cabling machine and the impossibility of an upgrade in a relatively short term
- The compaction factor was set in order to guarantee a degradation of the critical current due to cabling lower than 5%

EuroCirCol Main Conductor Study

- In the development of a 16 T Nb_3Sn magnet one of the main issue is the large transversal stress applied on the conductor (significantly larger than 150 MPa)

- In the framework of EuroCirCol, we intend to investigate the effect of transverse pressure on Nb_3Sn Rutherford Cables
  - Correlate the wire measurements under transversal pressure carried out at UniGe with cable measurements
    1. Sub-cable (18-1mm-wires) measured at CERN and Twente for benchmarking
    2. Full size cable (40 wire) measured at Twente
  - Verify the compatibility of high J_e with large transversal pressure on the conductor

Conclusions

- A scaling law for the J_c of the EuroCirCol Conductor was defined
  - The field and temperature dependence is based on state of the art conductor
  - In the calculation of the magnet margin we have to consider the possibility that some of the reference parameters (B_{c2}?, p and q?) might change once the final wire will be developed
- The J_c (4.2 K, B_p=16 T) was set equal to 1500 A/mm^2
  - This value is about 20% larger than the average value obtained for the RRP FRESCA2 conductor; nevertheless to guarantee an efficient wire production the conductor performance has to be improved of at least 35 %
  - J_c (1.9 K, B_p=16 T) about 2200 A/mm^2
- In order to meet as much as possible the needs of magnet designers, wire diameters up to 1.1 mm and non-Cu fraction up to 50 % were considered; larger values were evaluated to risky because of: magnet stability, conductor degradation due to cabling, reduced billet yield
- In the framework of EuroCirCol we intend to investigate the effect of transverse pressure on Nb_3Sn Rutherford Cables

Thank You For Your Attention !

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