SUPERCONDUCTING TECHNOLOGIES
FOR THE NEXT GENERATION OF ACCELERATORS
WORKSHOP

Fessia Paolo, David Smekens and the whole TE-MSC-MDT section

Insulation strategies and materials for incoming SC magnets

Outline

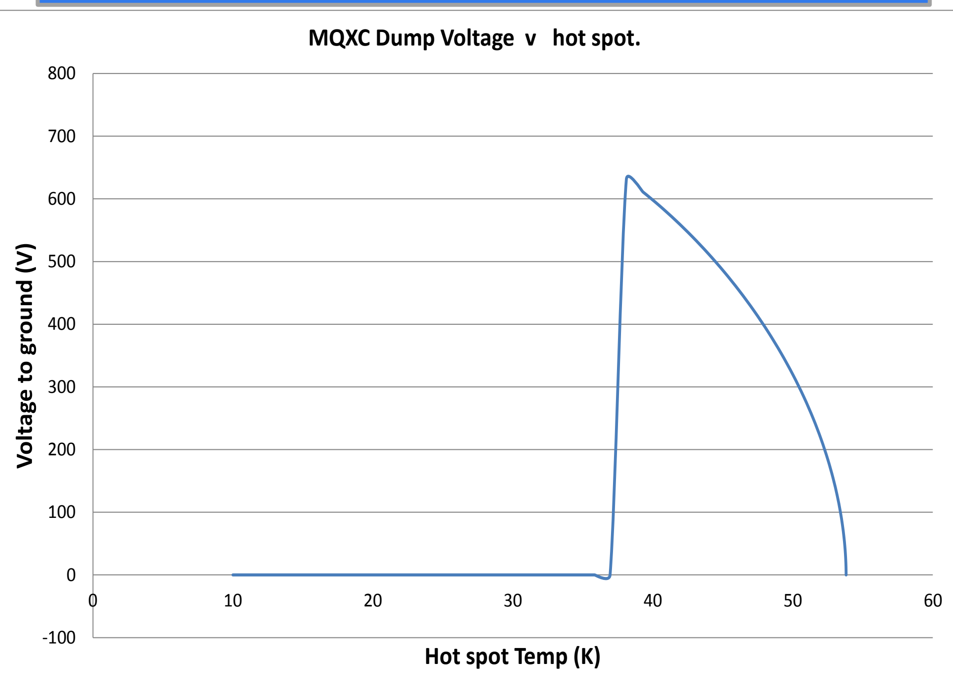
- Working conditions
- Ground Insulation
  - Voltages
  - Techniques
- Cable insulation
  - Nb-Ti
  - Nb_3Sn
- Quench heaters

Conditions of max voltage

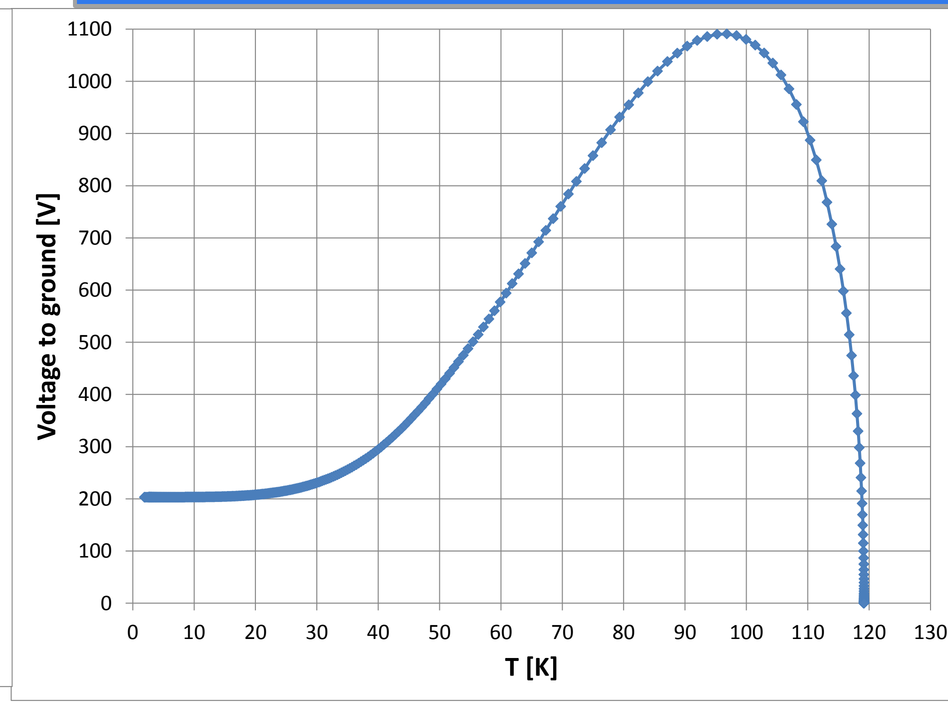
The maximum voltage is reached during the quench of the magnet that up to that point was in an He bath (hp. 1.9K).

We can assume that we need to be able to insulate the magnet in He gas at 75 K 1 bar (conservative)

MQXC Nb-Ti 120 mm bore quad voltage increase



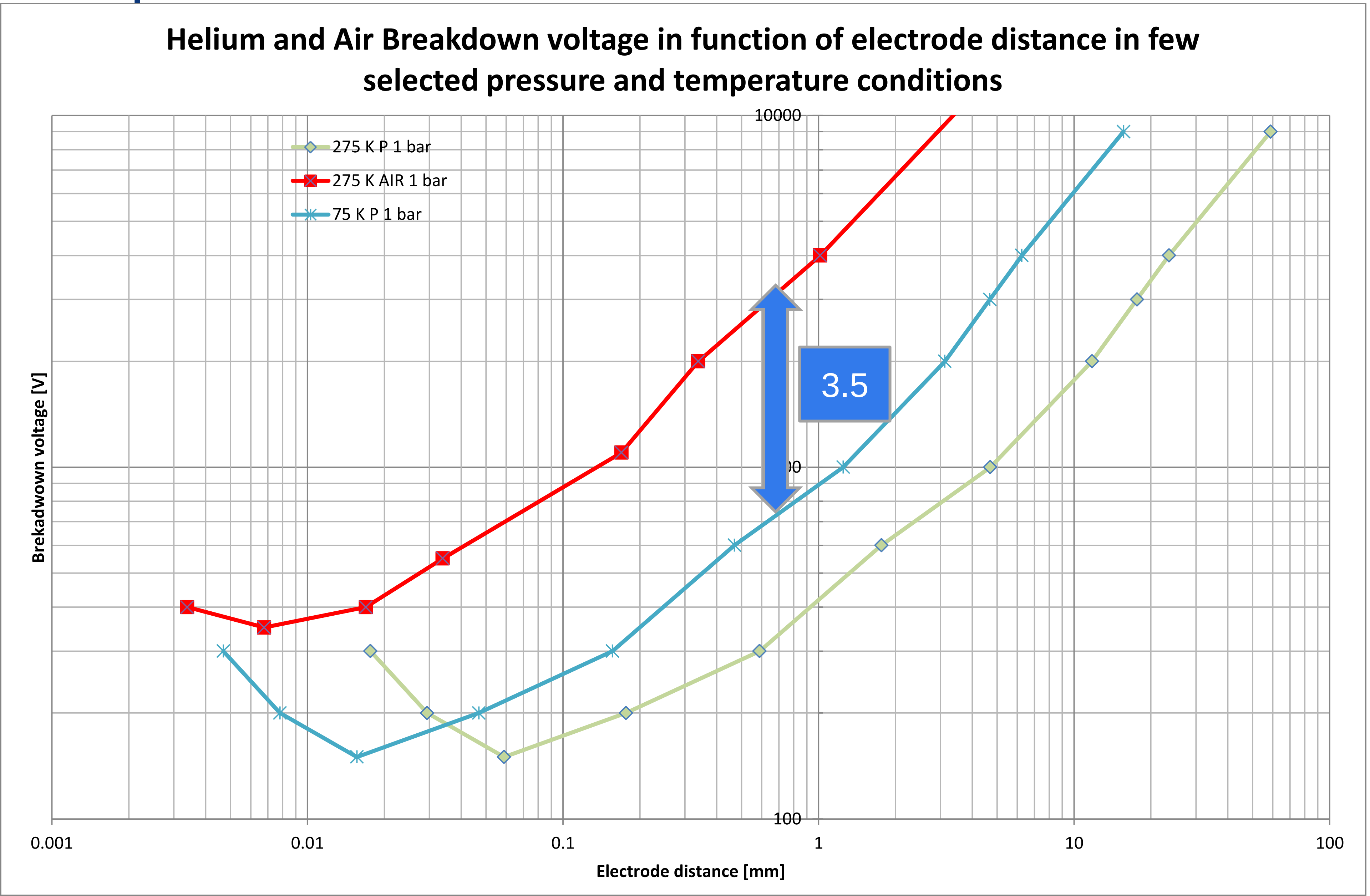
MQXF Nb_3Sn 150 mm bore quad voltage increase



Courtesy G. Kirby

Courtesy E. Todesco

Environment dielectric in function of temperature and pressure



GROUND INSULATION

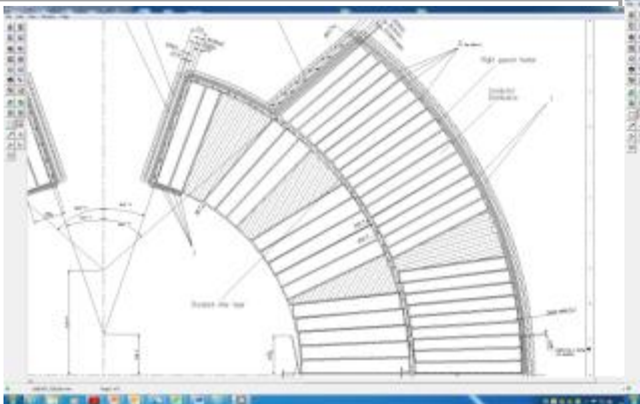
Vq	• Starting point: quench voltage	1000 V
Vmaxr	• Maximum reference voltage: assumed to be Vq plus 450 V+150 V (difference voltage between circuits/and or extraction voltage)	1600 V
Vtql	• Voltage for test qualification in liquid helium =1.2 Vmaxr	1920 V
Vtqgas	• Voltage for test qualification in He gas = 0.5 X Vtql	960 V
Vtfdel	• Voltage in air equivalent to Vtqgas: Vtfdel = 3 X Vtqgas	2880 V
ΔVcryo, ΔVcold	• Difference in voltage between 1st and last test during cold test and cryostating =0.1 X Vmaxr	160 V
Vtaf	• voltage for final assembly test= Vtfdel+ ΔVcryo+ ΔVcold	3200 V
Vtai	• Voltage for initial assembly test= Vtaf+ 0.2 X Vmaxr	3520 V

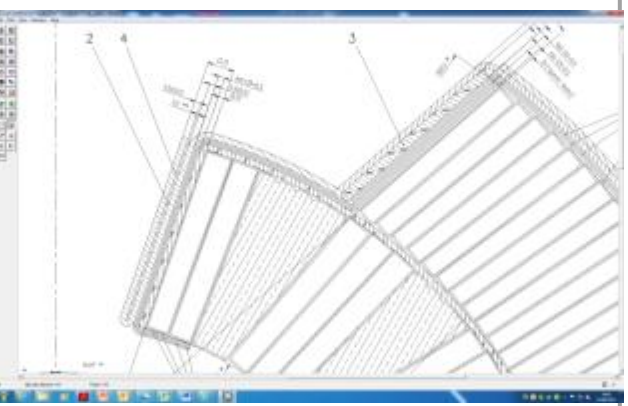
Vds
3X1600 V+500 V= 5300 V
Vds air= 3.5X Vds= 18550 V

Examples the ground insulation of the MQXC

Few Magnet examples I

LHC MB





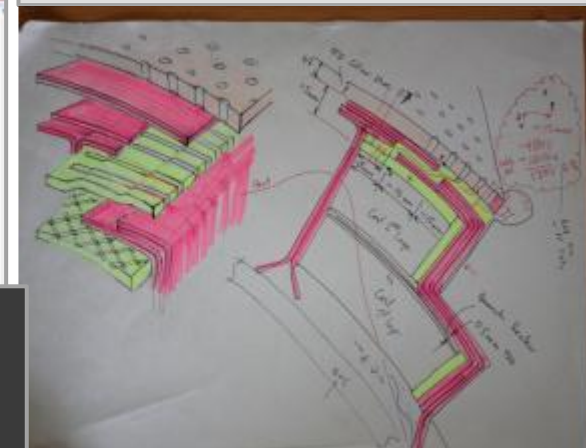
Material:
Polyimide foils 0.125 mm thick
Number of foils:
4
Minimum number of foils continuous: 2
Minimum overlap 7 mm
Creep path >> 7 mm

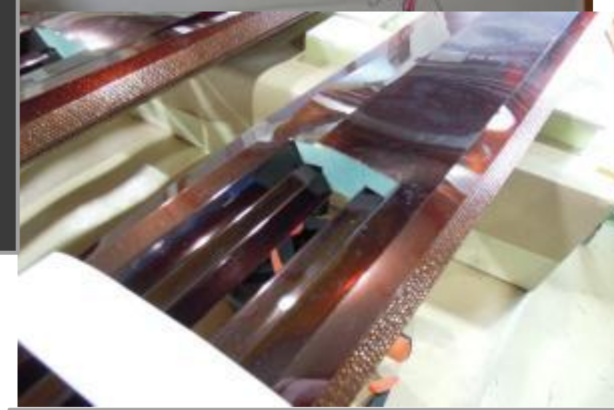
MQ

4-5 layer Polyimide 0.125 mm each
minimum overlap 10 mm
Creep path >> 12 mm

Material:
Polyimide foils 0.125 mm thick
Number of foils:
4
Minimum number of foils continuous: 2
Minimum overlap 10 mm
Creep path >> 10 mm

MQXC

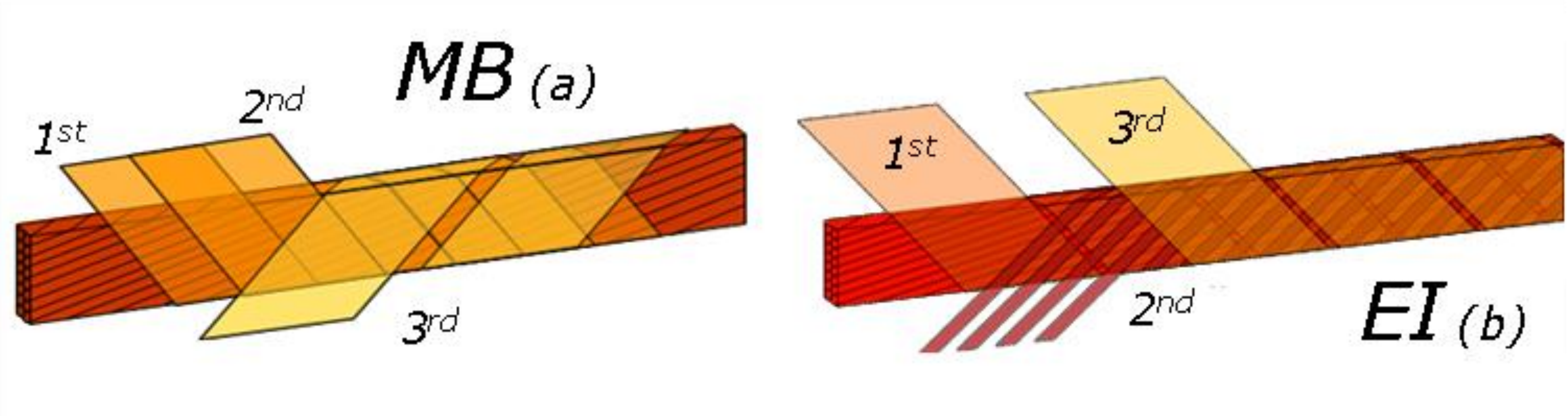




Material:
Polyimide foils 0.125 mm thick
Number of foils:
4
Minimum number of foils continuous: 2
Minimum overlap 10 mm
Creep path >> 10 mm

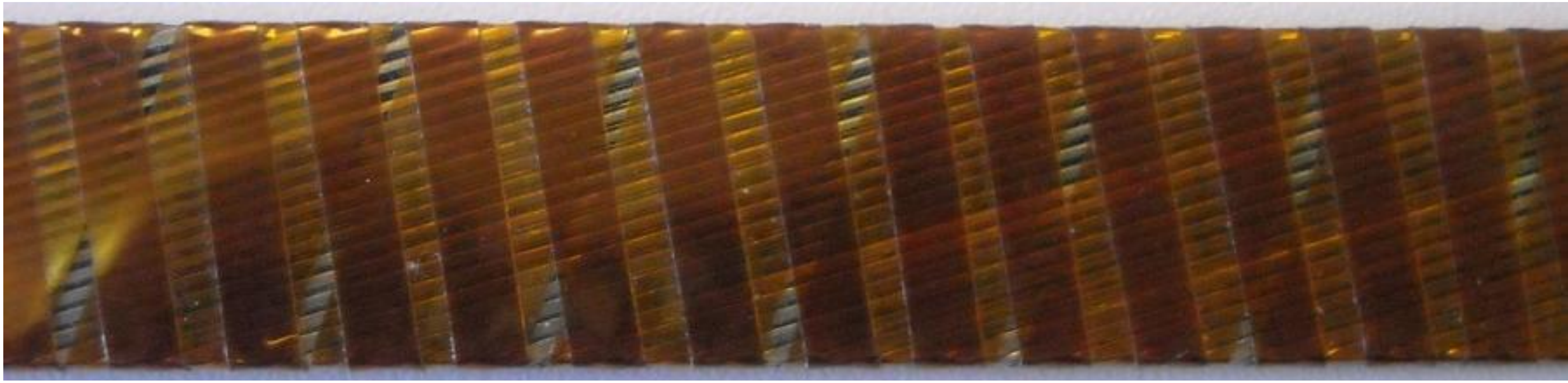
INTER-TURN

The Nb-Ti insulation schemes (polyimide based)

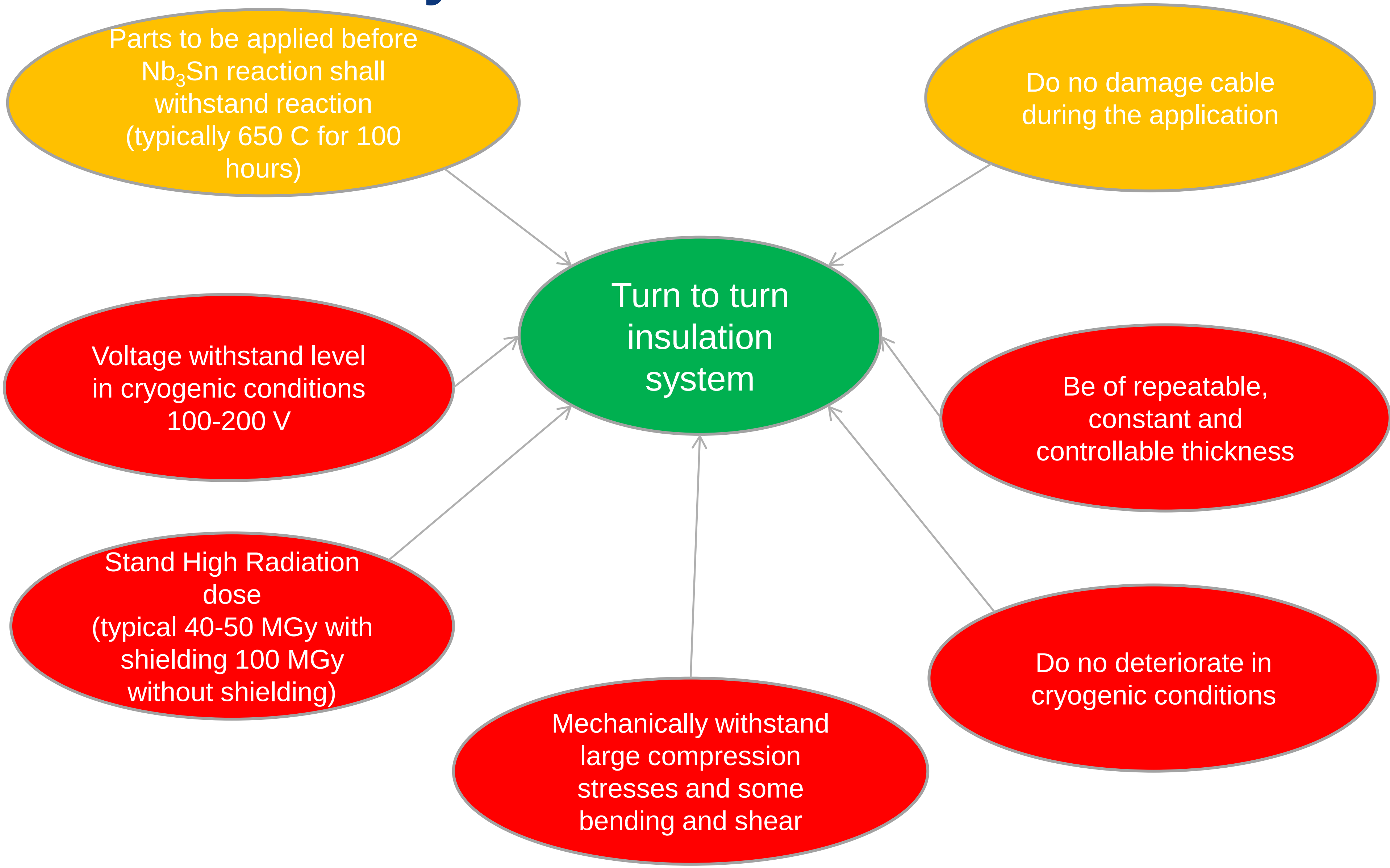


Insulation type	1st layer	2nd layer	3rd layer
MB	11 mm wide, no gap, 50 μm thick	11 mm wide, no gap, 50 μm thick 50% overlap 1st layer	9 mm wide, 2 mm gap, 69 μm thick, cross wrapped
MQ	11 mm wide, no gap, 50 μm thick	11 mm wide, no gap, 37.5 μm thick 50% overlap 1st layer	9 mm wide, 2 mm gap, 55 μm thick, cross wrapped
EI3	9 mm wide, no gap, 50 μm thick	3 mm wide, 1.5 mm gap, 50 μm thick cross wrapped	9 mm wide, 1 mm gap, 69 μm thick, 50% overlap 1st layer
EI4	9 mm wide, no gap, 50 μm thick	3 mm wide, 1.5 mm gap, 75 μm thick cross wrapped	9 mm wide, 1 mm gap, 69 μm thick, 50% overlap 1st layer

New enhanced scheme



Specifications the Nb_3Sn inter-turn insulation system



MQXF preliminary coil stresses evaluation

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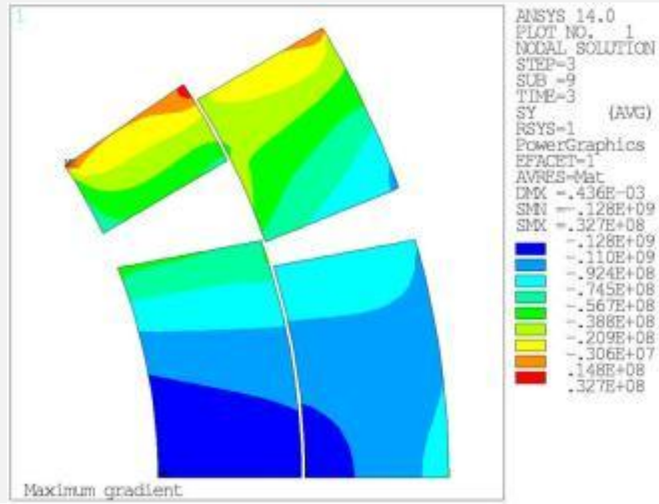
<tr><td>Azimuthal</td><td>
</td><td>
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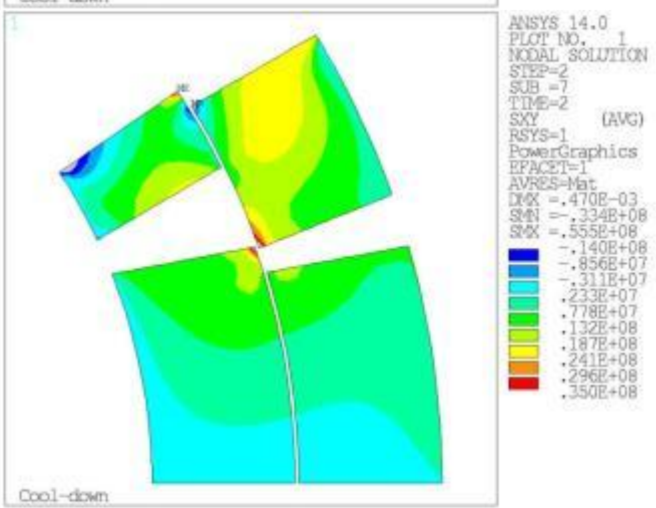
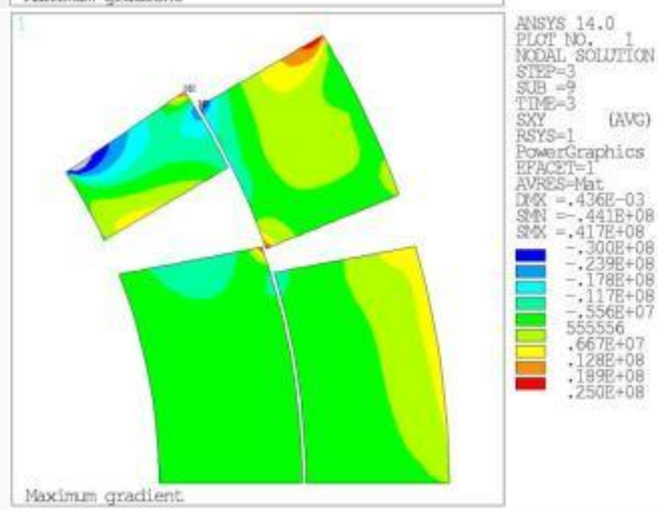
<tr><td>Shear</td><td>
</td><td>
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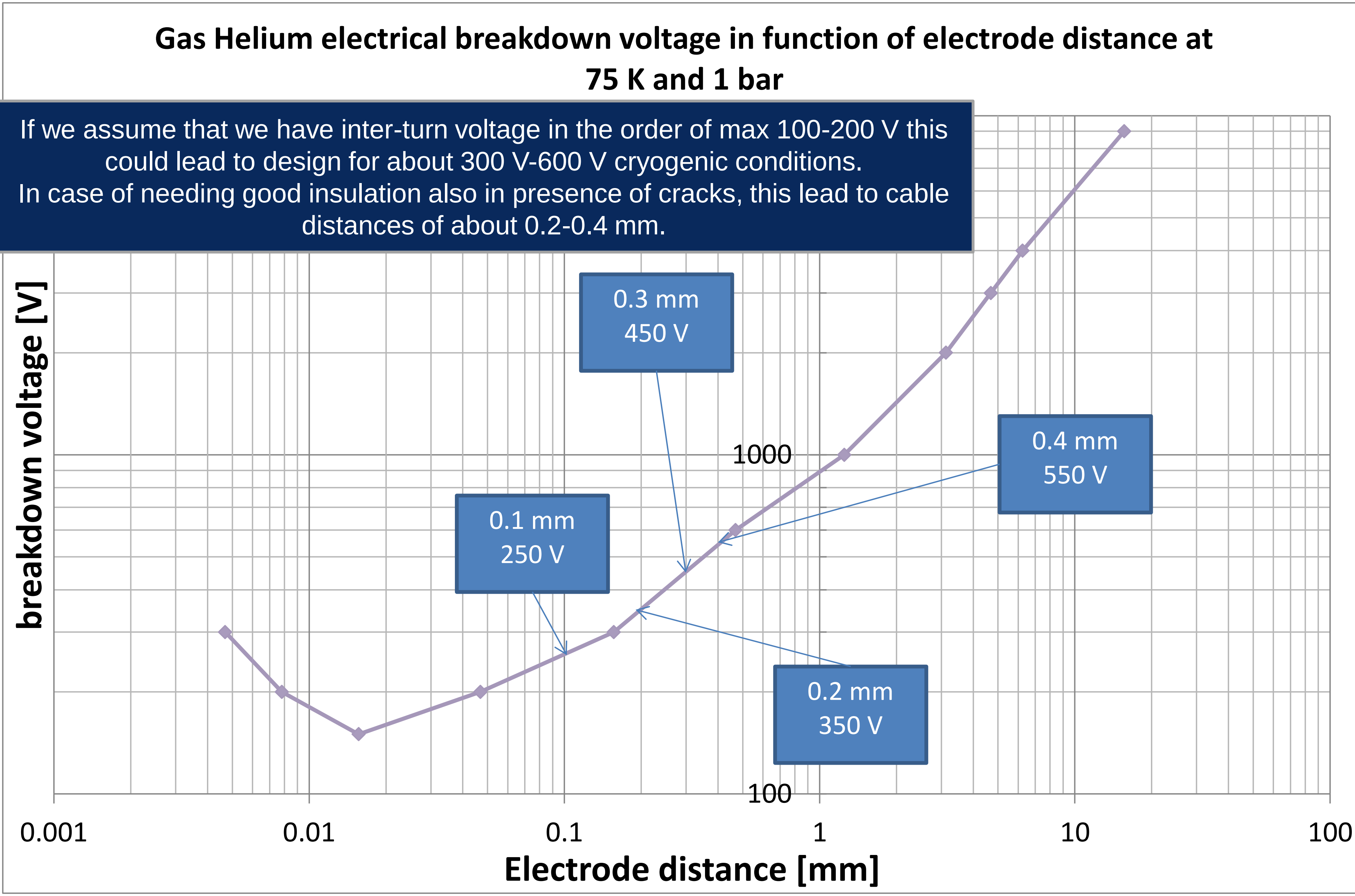
Nb_3Sn Turn to turn insulation Possible Approaches

Standard approach	Insulator based approach	Reinforced approach
• "Thick" fiber cable protection • Resin impregnation to provide the dielectric	• Add a thin thermal resistant insulator (MICA) that provides the dielectric • Impregnation is "only" structural	• Add a thin thermal resistant thin insulator (MICA) the provides the dielectric to "thick" fiber cable protection • Insure that the fiber+ impregnation is redundant in terms of insulation
• Better to get fibers that do not present carbon deposition after reaction • Local resins bubble could lead to local shorts if the fiber is not thick enough or damaged	• Impregnation provides second level of defense in case of 1st insulator breaks, but it is not necessarily dimensioned in terms of distance to keep all the inter-turn in case of fiber squeezing • Relaxed specification on the fiber	• Better to get fibers that do not present carbon deposition after reaction • Impregnation provides second level of defense in case of 1st insulator breaks, but it is not necessarily dimensioned in terms of distance to keep all the inter-turn in case of fiber squeezing • Absence of carbon will reassure also about the bonding impregnation to fiber • Main issue real estate, but would be possible to limit this application to the insulation between turn and metal posts (winding post and end spacers?)


Gas Helium electrical breakdown voltage in function of electrode distance at 75 K and 1 bar
If we assume that we have inter-turn voltage in the order of max 100-200 V this could lead to design for about 300 V-600 V cryogenic conditions.
In case of needing good insulation also in presence of cracks, this lead to cable distances of about 0.2-0.4 mm.
breakdown voltage [V]
0.3 mm
450 V
0.4 mm
550 V
0.1 mm
250 V
0.2 mm
350 V
1000
100
0.001
0.01
0.1
1
10
100
Electrode distance [mm]

Standard and reinforced approach Material considerations

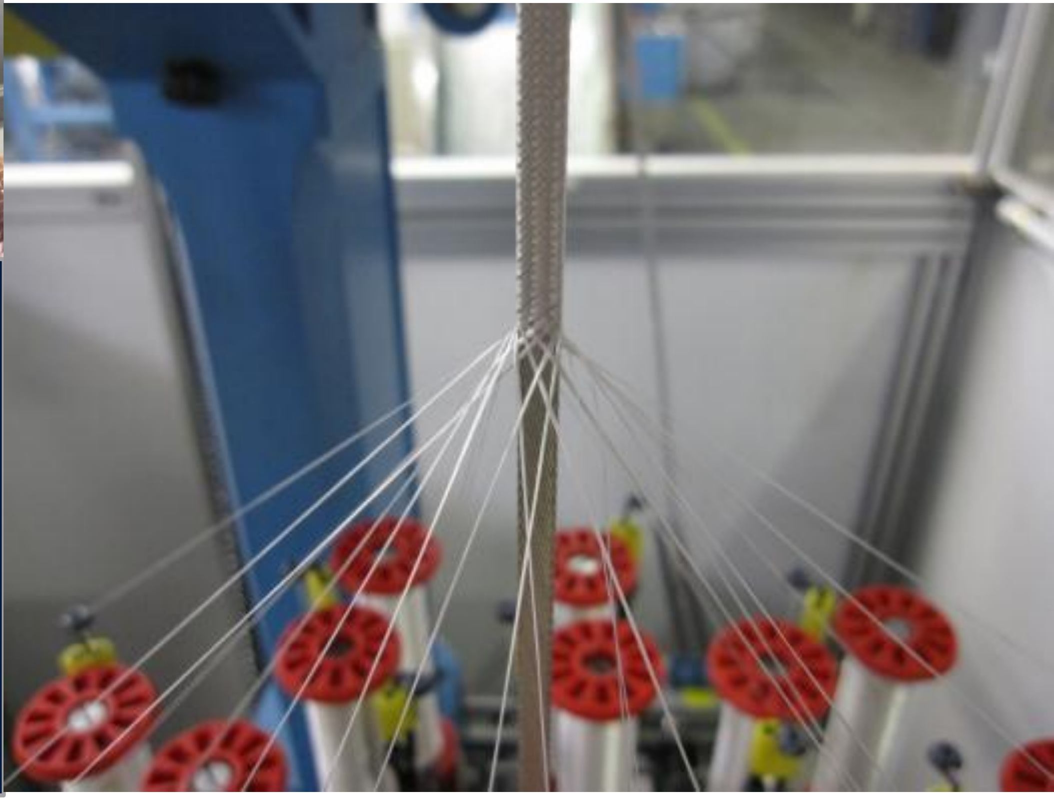
Possible cable insulation processes evaluated at CERN

1. Tape
    1. Problems in finding in Europe adequate tape quality for geometry and presence of polyester guiding wires on the edges. No S2 tape found on the Europe market
    2. Problems to achieve good overlapping
2. Sock type sleeve
    1. Very good results
    2. Problem to find European source
    3. Limited to cable of about 100 m
3. Direct cable braiding
    1. See following slides

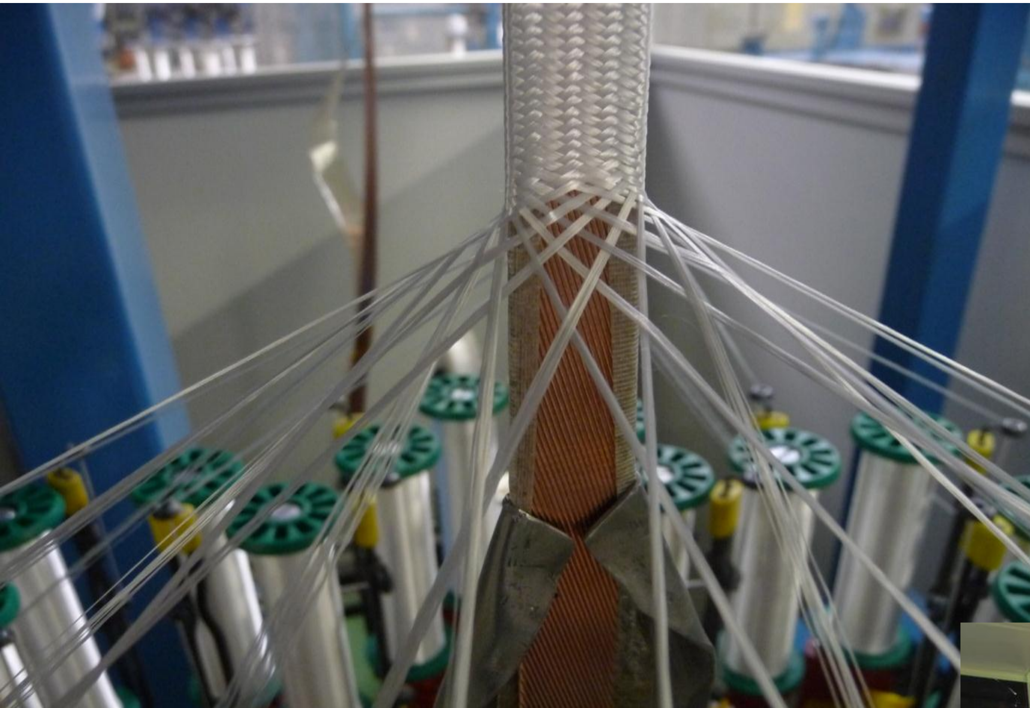
Direct braiding on cable

We have insulated
- 10 mm wide cable
- 15 mm wide cable
- 21 mm wide cable

Very promising under all point of view. Only issue, and experienced by us: educate the company to increase Q.C., awareness to avoid and identify possible cable damages that could occur during the braiding



Insulator based approach



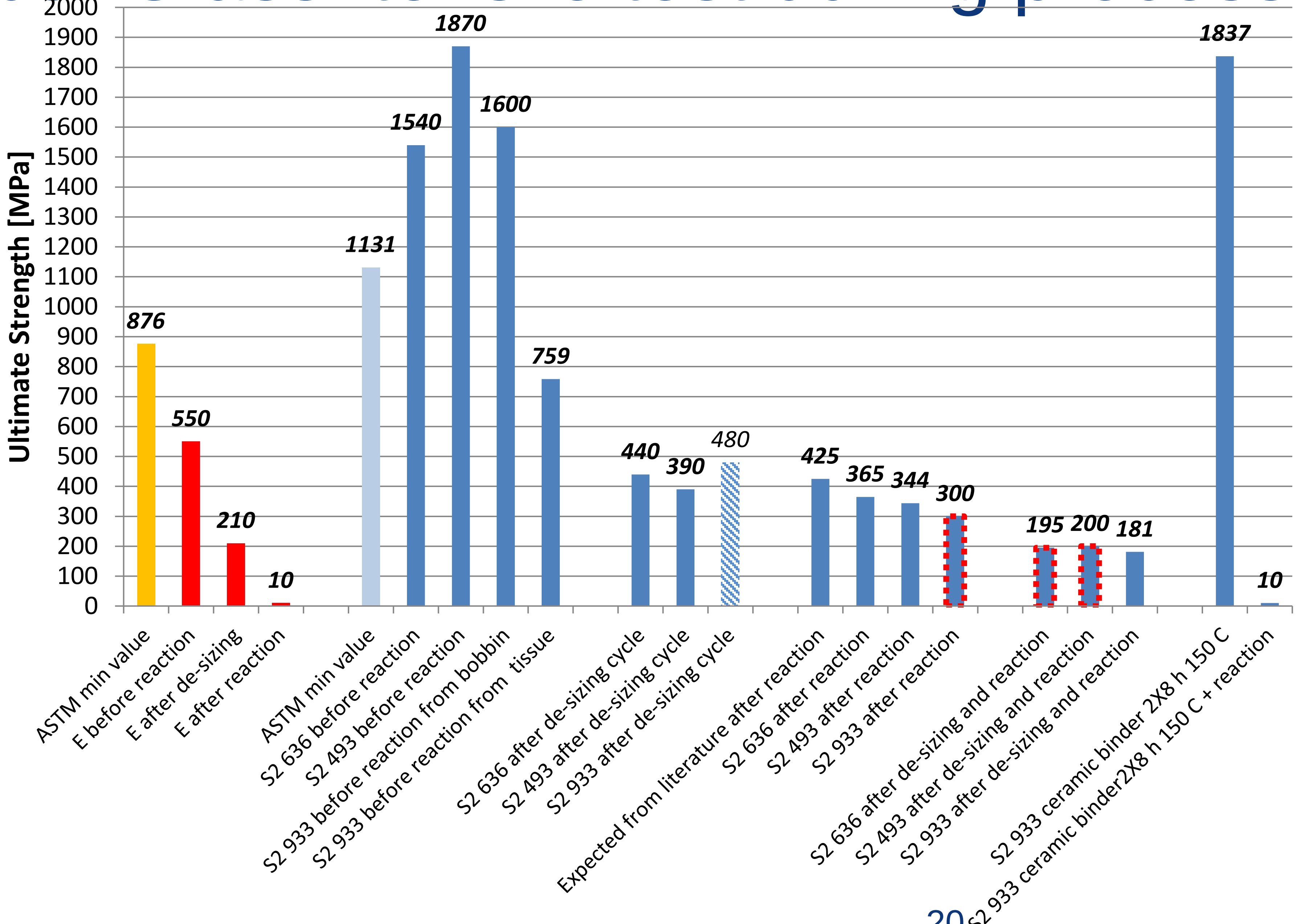
Braiding of 11 TEX plus MICA

Winding of copper coil 11 TEX+ MICA

Yarn for braiding

Use standard yarn with organic sizing for the braiding	Use standard yarn with organic sizing	Use special yarn with temperature stable sizing
	Thermally or chemically de- size	Braid
	Apply the palmitic acid or other sizing on the yarn	AGY 933 S2 glass
	Braid	
Easy, fast and cheap process	No carbon residuals	No carbon residuals
	Long, complex and costly operation	Easy and fast process
Carbon residuals after reaction	Probable deterioration of fibers during handling without sizing and thermal desizing	Average costs

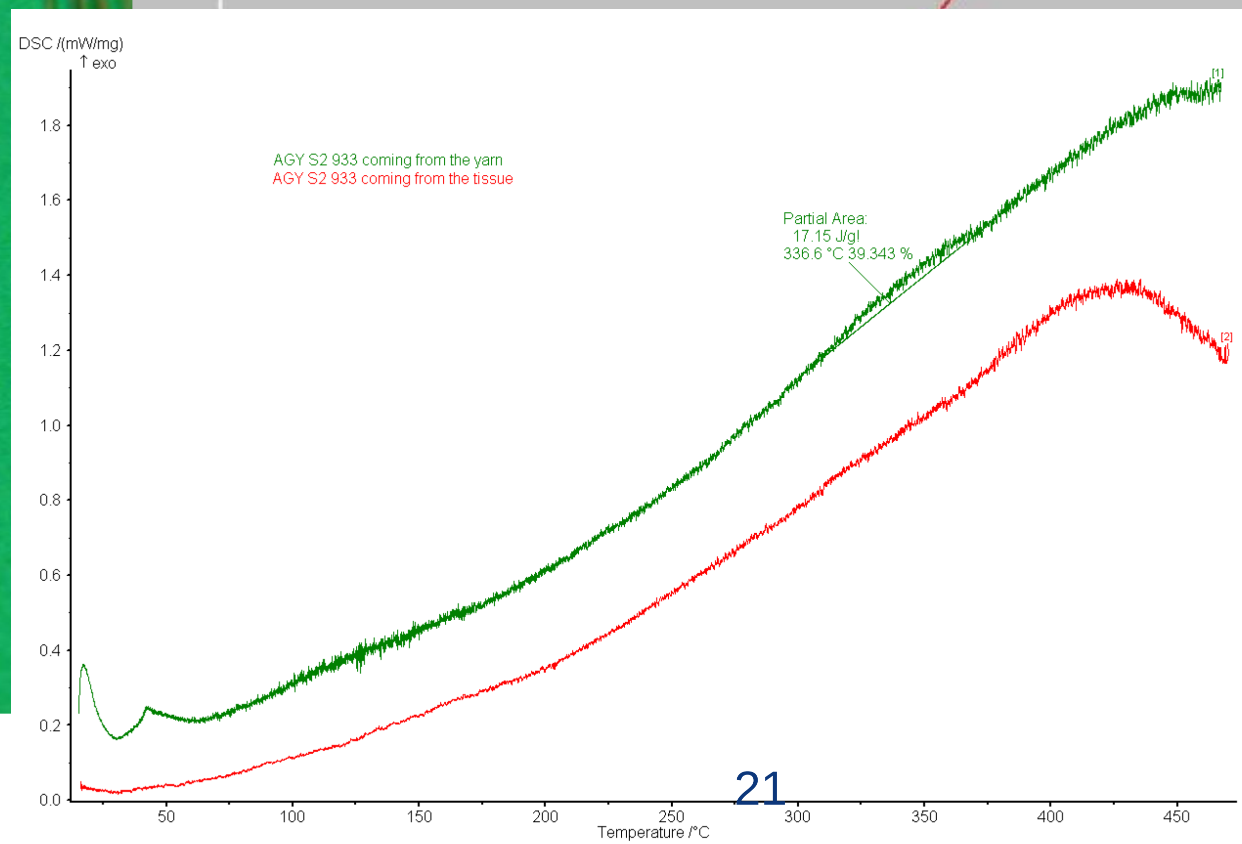
Fiber Glass: tensile test during process



S2 933 temperature behavior

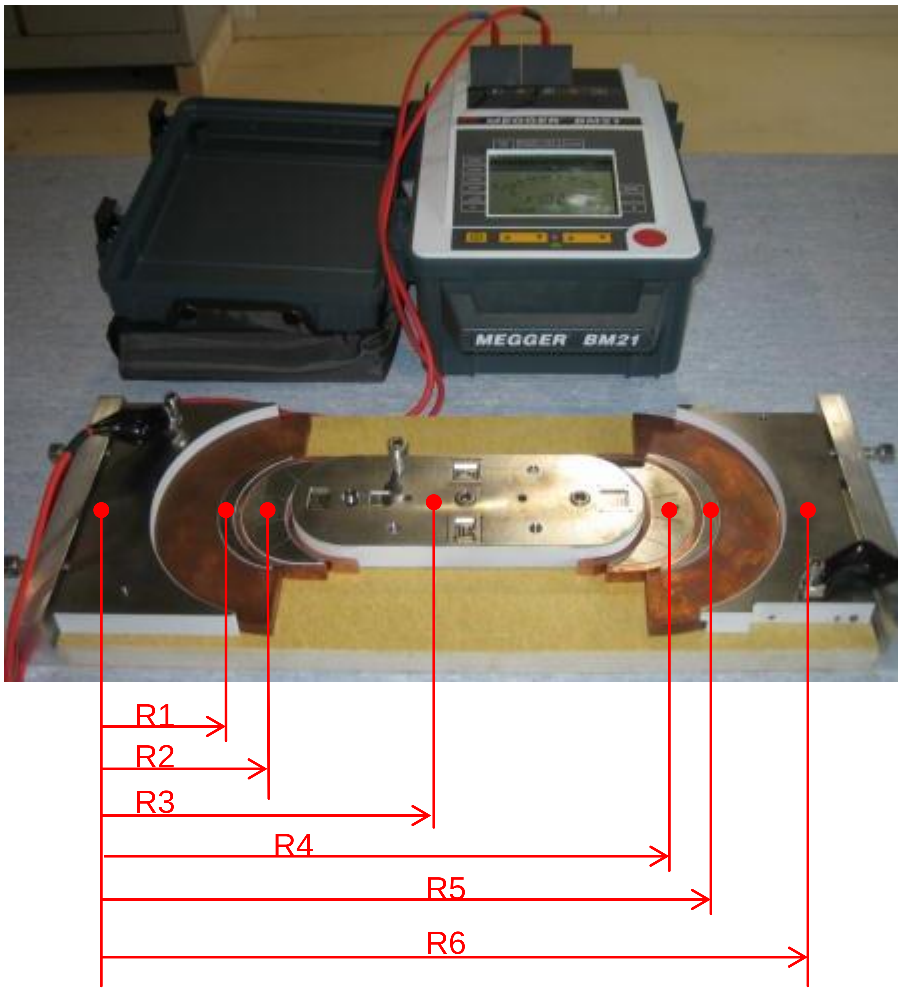
Glass fiber after 100 h

AGY S 2 493 **AGY S 2 933** **AGY S 2 63**



Metal component belonging to the coils

These parts (end spacer, winding posts) have to be strongly insulated to the coil and the insulation applied has to withstand reaction. Present practice is to overlap an insulation coating (Plasma Spray Al203) and add an extra protective cloth of fiber glass that will be later impregnated wit the coil



Central Post	Spacers set	R (GΩ) @ 1000 V (R1 to R6)	R (GΩ) @ 2500 V (R1 to R6)
Central post 1	1	73	52
Central post 1	2	73	52
Central post 2	1	73	52
Central post 2	2	73	52
Central Post 1 after Thermal cycle @ 650 ^{0}C	1	73	52
Central Post 1 after Thermal cycle @ 77 K	1	73	52

QUENCH HEATERS

Quench Heaters

Provide very efficient thermal transfer to the coil
(typical thickness 0.125 mm or less)

In cryogenic condition withstand V=1.2 (Vq+900 V)

Requirement for Q.H. insulation to coil

Be robust and allow shaping to follow the coil geometry

	Vq	Vq	Vq	Vq
	250 V	350 V	500 V	1000 V
$V_{mic\text{-}c}$	1380	1500	1680	2000
$V_{mic\text{-}w}$	455	495	554	660
$V_{QH\text{-}coil}$	1366	1485	1663	1980
$V_{tfQHdel}$	1366	1485	1663	1980
ΔV_{cryo}, ΔV_{cold}	90	90	90	90
V_{tQHaf}	1546	1665	1843	2160
V_{tQHai}	1726	1845	2023	2340

Other issues to remind

- A Nb_3Sn impregnated coil has a limited thermal conduction and limited electrical insulation: this leads to problems install effective and electrical safe quench heaters to protect magnets.
- Quench heaters at the Outer Radius might not be sufficient, as the heat does not immediately penetrate the coil. Inside the bore and inside the inter-layer of the coil, QHs are very technologically challenging.
- Instrumentation (voltage taps) are also difficult to install as the have to go through the insulation (either VTs installed before reaction, and survive the reaction and potting ; or installed after impregnation by digging into the epoxy to reach the bare conductor). All instrumentation circuit should be tested with the magnet and wire have sufficient voltage insulation rating

Questions ?