MgB_2 CONDUCTORS FOR FUTURE DETECTOR MAGNETS

RICCARDO MUSENICH

INFN
Istituto Nazionale di Fisica Nucleare

SUPERCONDUCTING MAGNETS FOR PARTICLE DETECTORS

Main characteristics:

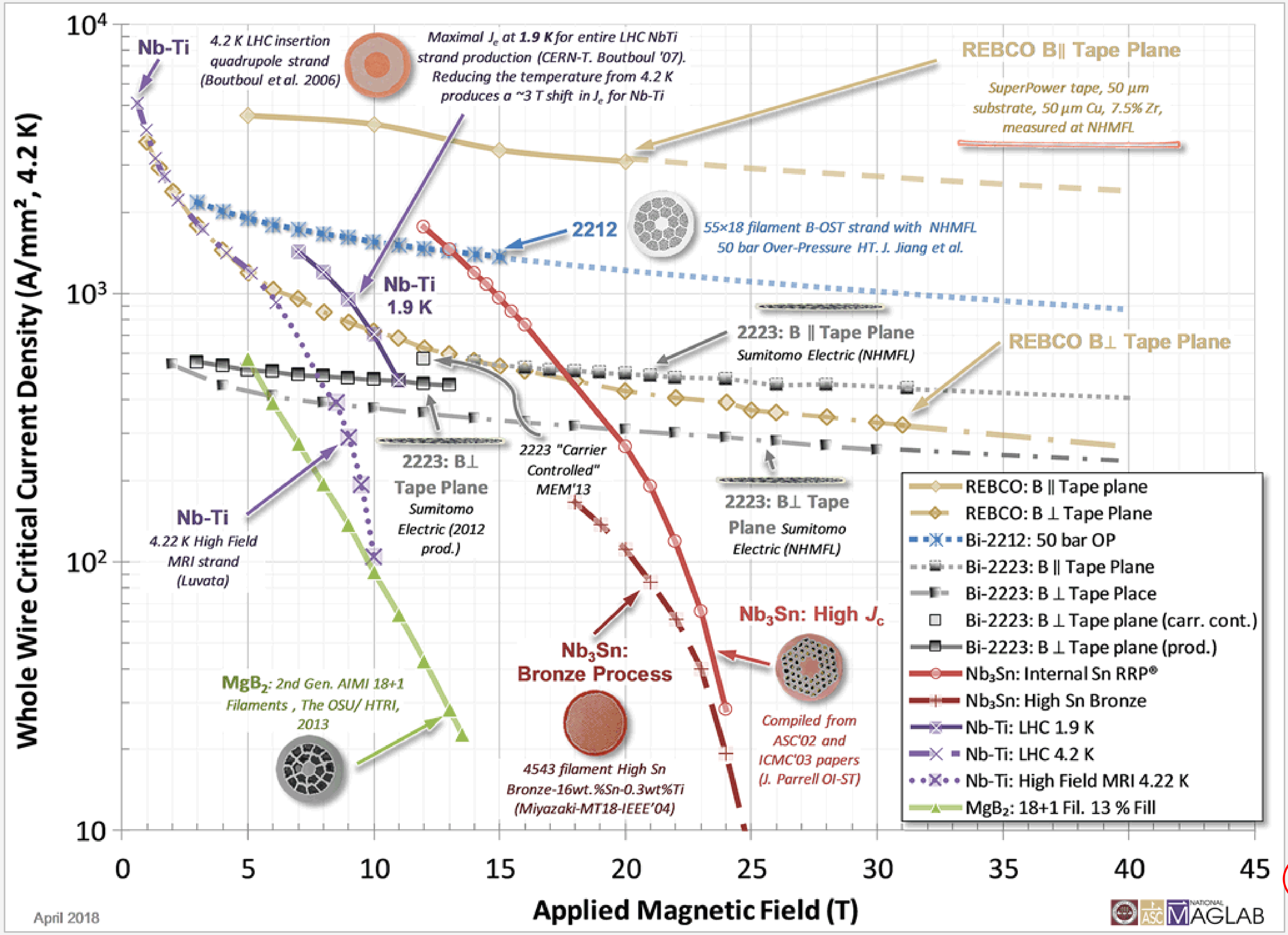
- Large volume
- Moderate magnetic field (0.5 to 4 T)
- Transparency to particles is often required
- Generally, solenoidal or toroidal shape

At present, only Al stabilised NbTi conductors are used for detector magnets.

NbTi is ductile, relatively cheap and robust (J_C is not affected by mechanical stress).
Al ensures high heat capacity per unit length and low resistance path for current.

However, fabrication of conductors requires cabling and co-extrusion.
Co-extrusion is an expensive and delicindustrial process.
Very few firms have the expertise to perform co-extrusion.

Would it make sense to use other superconductors ?



https://nationalmaglab.org/magnet-development/applied-superconductivity-center

Other technical superconductors

REBCO (tape) $T_c = 92\ K$

BiSCCO 2223 (tape – Ag matrix) $T_c = 108\ K$

BiSCCO 2212 (Ag matrix) $T_c = 96\ K$

Nb_3Sn $T_c = 18\ K$

MgB_2 $T_c = 39\ K$

MgB_2 is more expensive than NbTi but much cheaper respect to REBCO and BiSCCO

In situ: wires are prepared by powder-in-tube method using the precursors. MgB_2 is then obtained inside the wire by suitable heat treatment (about 700°C for a few tens of minutes)

Ex situ: wires are prepared by powder-in-tube method directly using MgB_2 powders.

MgB_2 has low reversibility field B_{irr} (if $B \geq B_{irr}$ then $J_c = 0$)

Pure MgB_2: $B_{irr} \approx 12\ T$

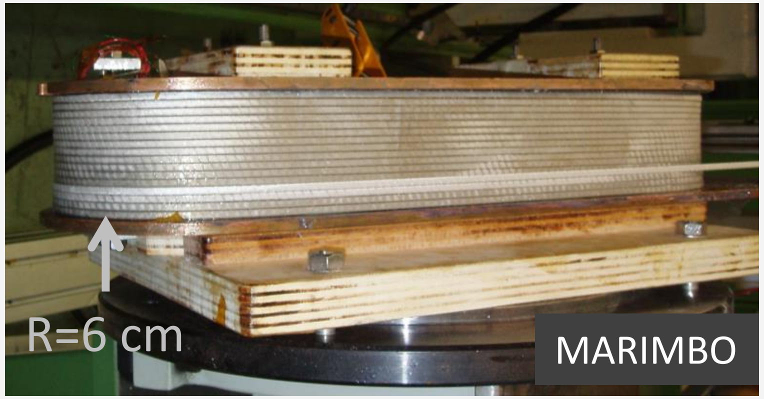
Doping increases B_{irr}

But detector magnets must not generate high magnetic field

Generally $B < 4\ T$

Like all technical superconductors except NbTi, MgB_2 is brittle:
for a given MgB_2 composite conductor, a critical bending radius does exist (order of few cm for a 0.65 mm thick tape).

Not an issue for large magnets!



Winding of a racetrack coil with ex-situ MgB_2 tape

MgB_2 would allow operating the magnet at $T > 10\ K$ ($T_c = 39\ K$)

More efficient cryogenics

Higher COP

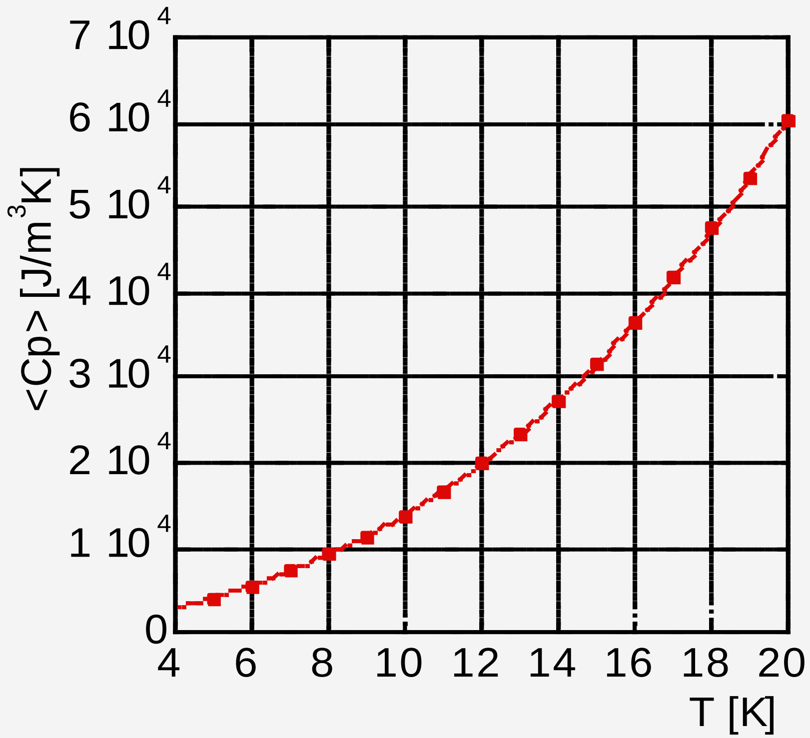
Better conduction cooling

$$\frac{K_{Al6061}@12\ K}{K_{Al6061}@4.2\ K} \approx 3$$

Higher energy density margin

$$\Delta e_{max} = \int_{T_{op}}^{T_{max}} c_{cond}\, dT$$

$$c_{cond} \propto \left(\frac{T}{\theta_D}\right)^3$$



Aluminium matrix is not necessary for stabilization.
It can be necessary/useful for quench protection.

First proposals about MgB_2 conductors coupled with Aluminium were related to space applications due to low weight requirement

P. Spillantini,
Superconducting magnets and mission strategies for protection from ionizing radiation in interplanetary manned missions and interplanetary habitats
Acta Astronautica, 68 (9–10), 2011, 1430-1439

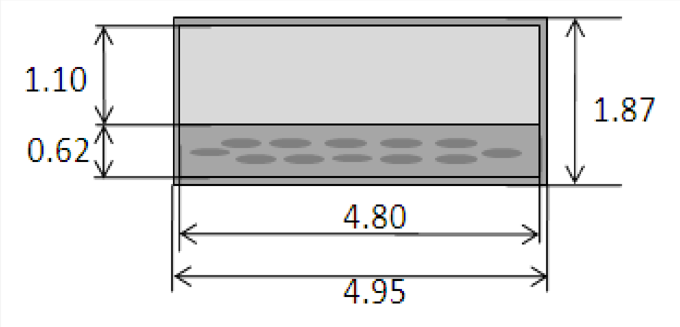
R. Battiston, W. J. Burger, V. Calvelli, V. I. Datskov, S. Farinon, and R. Musenich
Superconducting Magnets for Astroparticle Shielding in Interplanetary Manned Missions
IEEE Trans. on Appl. Supercond., 23 (3), 2013, 4101604

SR2S
Space Radiation Superconducting Shield

EU FP7 project to study superconducting shields to protect astronauts from space radiation

Conductor: Titanium clad MgB_2 tape + Aluminium strip

Ti/MgB_2 ratio 2.7/1.
75 µm thick insulation.
Total conductor cross section: 9.25 mm^2.
Average mass density : 3000 kg/m^3.

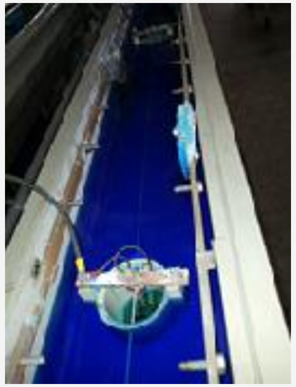


R. Musenich et al., “Ti–MgB2 Conductor for Superconducting Space Magnets”, IEEE Trans on Appl. Supercond26 (4), 2016

Development of SR2S conductor prototype

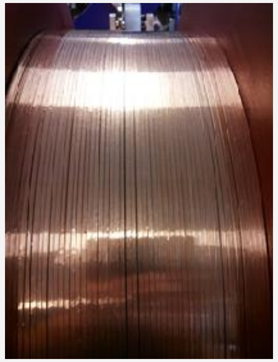
INFN Istituto Nazionale di Fisica Nucleare — ~~Columbus Superconductors~~ → now ASG Superconductors

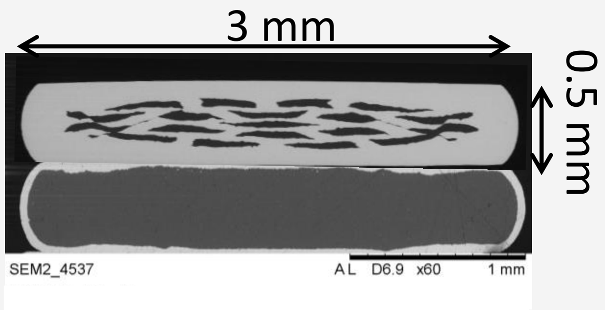
360 m Ti-MgB_2



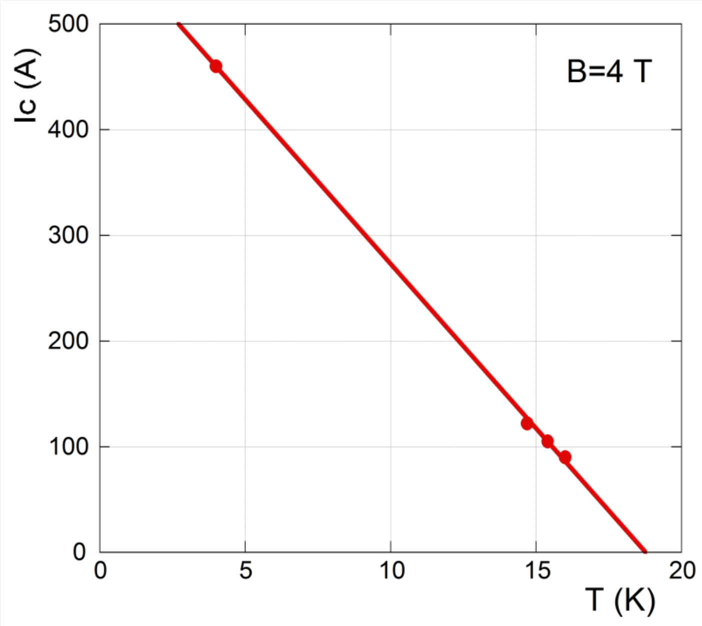
Ti-MgB_2 tape during copper plating

copper plated Ti-MgB_2 tape





Cu-Ti-MgB_2 tape

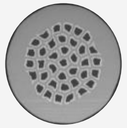


Problems occurred during aluminium tape soldering due to different thermal contractions.
Due to tight schedule and limited funds, no further attempts were made to solder the aluminum tape.

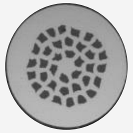
ASG SUPERCONDUCTORS

Present status of ex-situ MgB_2 conductors

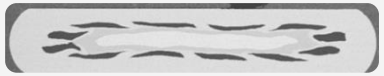
Wire 1



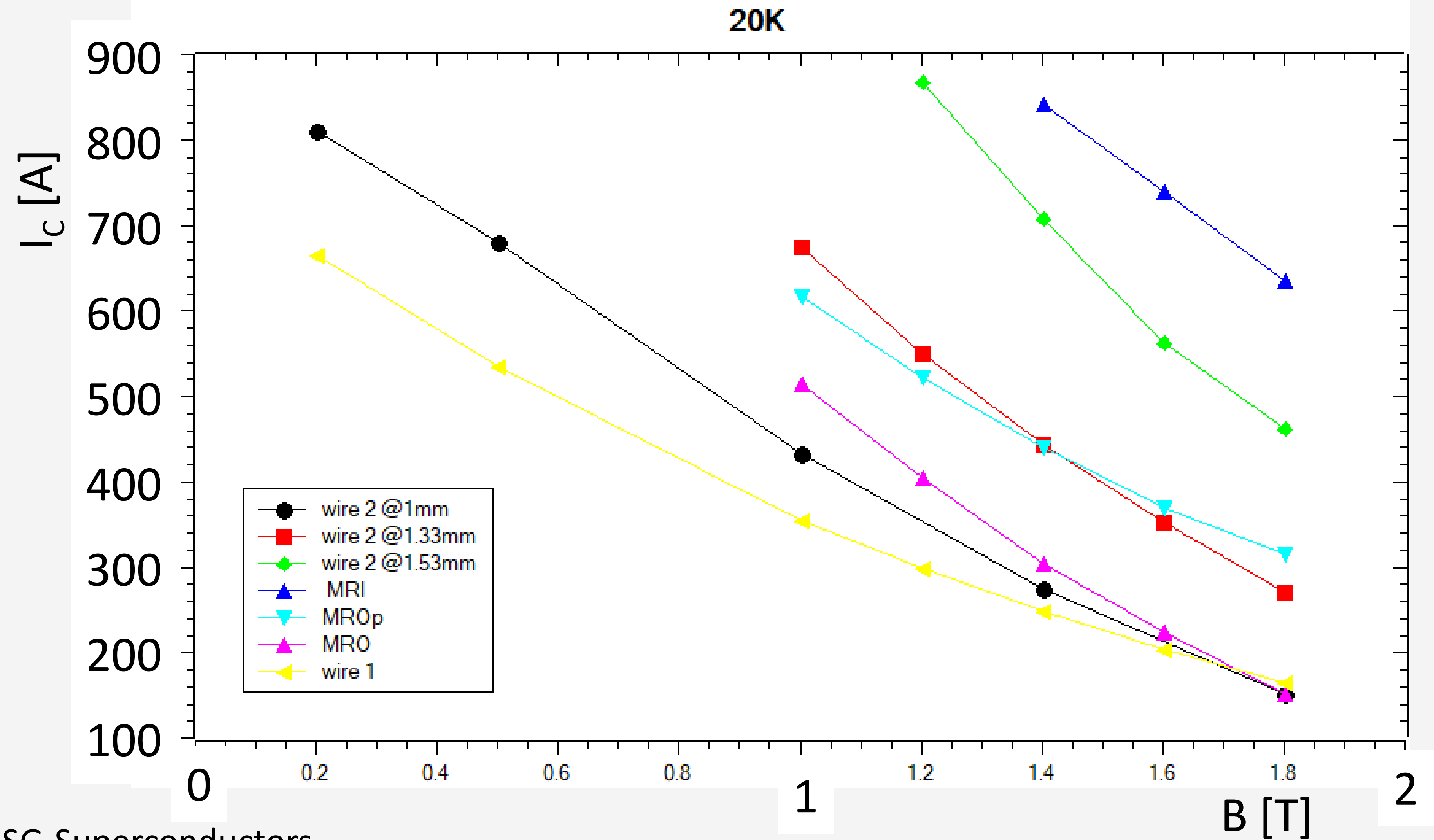
Wire 2



MRO/MRO+



MRI (1,53 mm)



Courtesy of Tiziana Spina, ASG-Superconductors

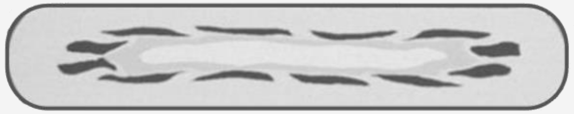
ASG SUPERCONDUCTORS

Wire 1

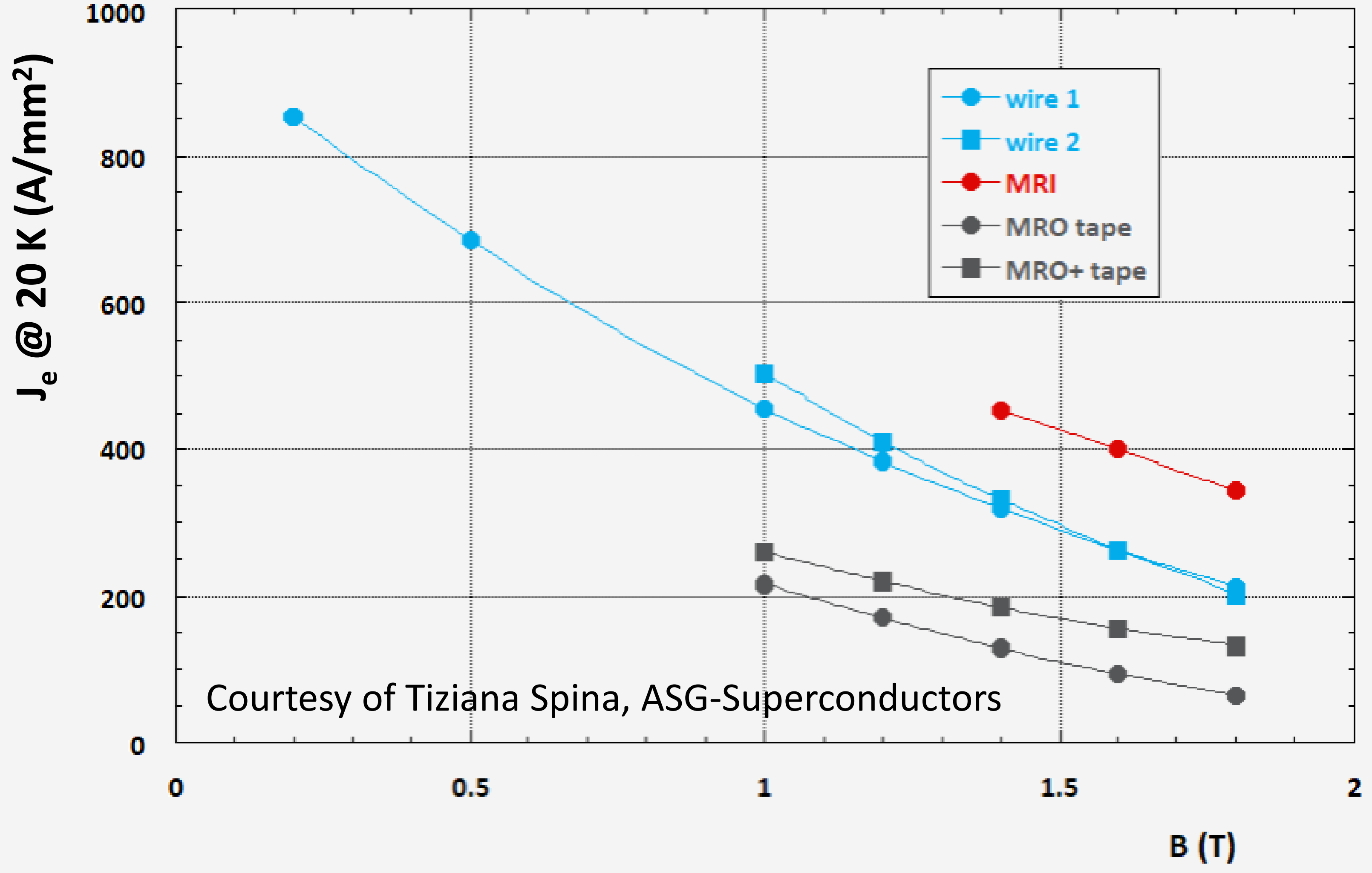
Wire 2

MRI

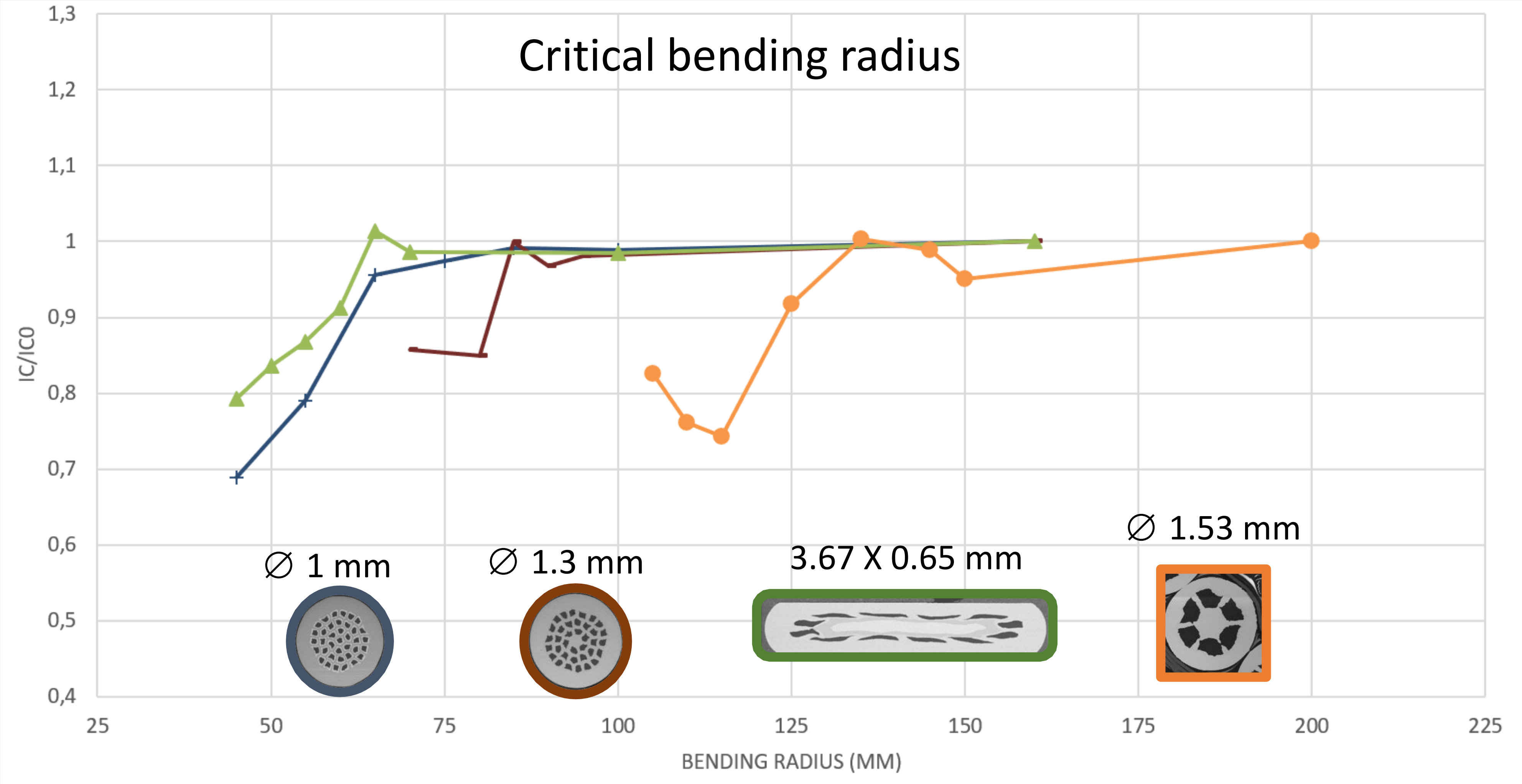
MRO/MRO+



Present status of ex-situ MgB_2 conductors



$$J_e(15K, 2T) \approx 400 - 600 \ {}^{A}/_{mm^2}$$



Courtesy of Tiziana Spina, ASG-Superconductors

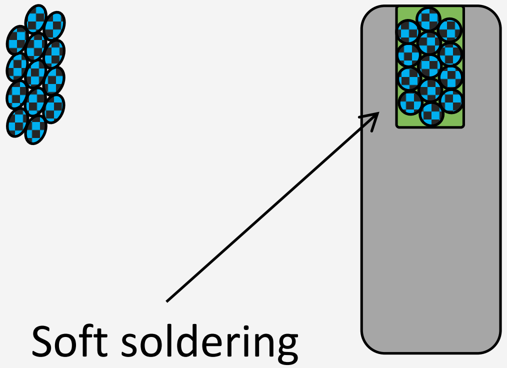
In MgB_2 magnets operating at $T > 10\ K$ stability is due to the high specific heat

Aluminium in parallel is for protection:

- Good bonding between cable and aluminium is not necessary (no co-extrusion)
- High purity aluminium is not necessary

In principle, it is possible to use conductors obtained by cabling MgB_2 wires and aluminium wires

Limited deformation is possible before heat treatment to obtain an almost flat cable



A remarkable example of MgB_2 wire cabling: the LHC superconducting links

A. Ballarino, Supercond. Sci. Technol. 27 (2014) 044024

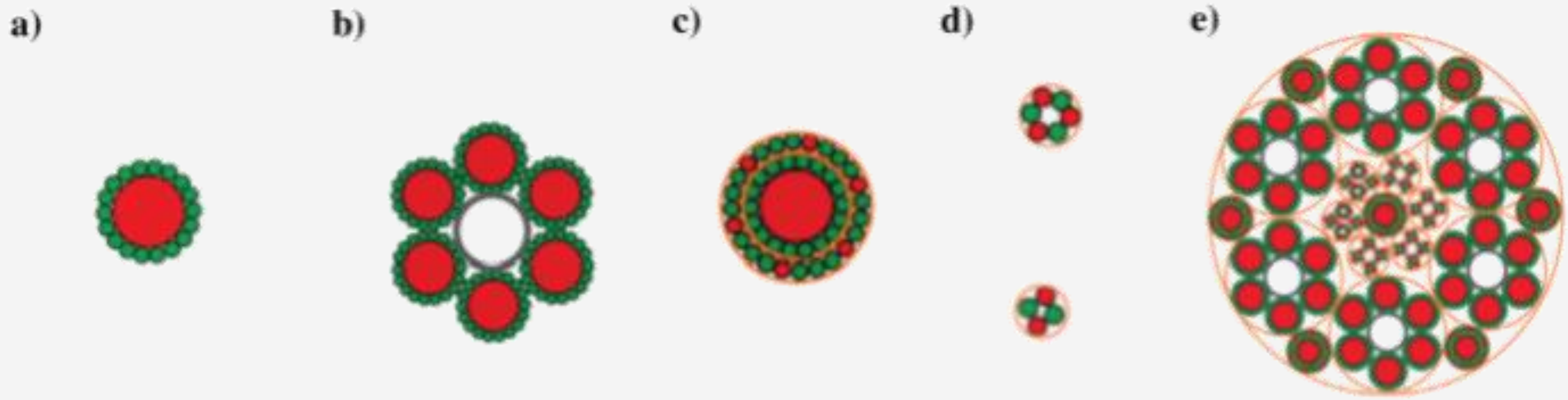


Figure 5. Cables made with MgB_2 round wire. (a) Sub-unit of 20 kA cable, $\Phi \sim 6.5$ mm ; (b) 20 kA cable, $\Phi \sim 19.5$ mm; (c) concentric 2×3 kA cable, $\Phi \sim 8.5$ mm; (d) 0.4 kA cable (top) and 0.12 kA cable (bottom), $\Phi < 3$ mm ; (e) 165 kA cable assembly for LHC P1 and P5 (6×20 kA, 7×2×3 kA, 4×0.4 kA, 18×0.12 kA), $\Phi \sim 65$ mm.

Summary

MgB_2 could be an excellent candidate to replace NbTi in detector magnets

Detector magnets based on MgB_2 conductors can be operated at $T > 10K$

Consequences of higher operative temperature are:

- higher stability (aluminium is required for protection, not as stabiliser)
- higher thermal conductivity (better indirect cooling)
- higher refrigerator COP

R&D is necessary to develop suitable conductors.

Detector magnet design should be rethought based on MgB_2 conductor features (as an example, the quench issue of MgB_2 detector magnets could be faced via controlled insulation technique.)